EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is responsible for the disposition of transuranic (TRU) waste generated through atomic energy defense activities. Approximately 62,000 cubic meters have been generated and are currently stored at government defense installations across the country. The Waste Isolation Pilot Plant (WIPP), located near Carlsbad, New Mexico, has been sited and constructed to meet the criteria established by the scientific and regulatory community for the safe disposal of TRU waste. The DOE has demonstrated that the WIPP facility can be operated and closed in a manner that complies with federal standards found in Title 40 of the Code of Federal Regulations, Part 191 (40 CFR Part 191), titled *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste*. The DOE will place only TRU waste from atomic energy defense activities in the WIPP.

In 1992, the U.S. Congress passed the WIPP Land Withdrawal Act (LWA) which, among other things, mandated that the U.S. Environmental Protection Agency (EPA) certify the DOE's compliance with 40 CFR Part 191, Subparts B and C. The EPA issued the criteria that it intends to use for certification as 40 CFR Part 194, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations* (61 FR 5224). This application, titled *Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant,* is the DOE submittal to the EPA, requesting certification. This application has been developed to be fully responsive to the requirements of 40 CFR Part 191, the criteria in 40 CFR Part 194, and the guidance in the *Compliance Application Guidance for 40 CFR Part 194*, EPA 402-R-95-014.

This application represents the culmination of over 20 years of scientific and engineering work specifically dedicated to TRU waste isolation at the WIPP. Throughout this work, the DOE and its predecessor agencies have ensured an ongoing technical oversight of the project through the services of the Environmental Evaluation Group (EEG), the National Academy of Sciences (NAS), and the New Mexico Governor's Consultation Task Force on Radioactive Waste. Frequent consultations with these organizations have served to identify important issues and their timely resolution. In addition, the DOE has involved the public in the decision-making process at key points throughout the compliance demonstration process.

The focal point of this application is the discussion of compliance with the quantitative standards in 40 CFR §§ 191.13, 191.15, 191.24, and the qualitative requirements of 40 CFR § 191.14. As a background to understanding the compliance discussions, the DOE has included extensive discussions of the geology, hydrology, and climate, the engineered facility, and the waste. In addition, this application includes two quality-related discussions. One is a description of the DOE Quality Assurance Program as it was applied to this application, and the other is the results of independent peer reviews of important portions of the WIPP compliance program.

This application references over 600 publications that support the demonstration of compliance. Expansions of these references are provided in order to assist the reviewer with additional detail within the context of the original publication. In addition, there are over 50

appendices that directly support the application. Many of these appendices were prepared to further explain the complex issues and processes associated with the demonstration of compliance, to provide background data and information, or to describe operational and postoperational compliance activities.

The DOE uses conceptual models of the WIPP disposal system to simulate the complex interactions between the natural environment, the engineered system, and the waste. All three of these aspects are important inputs to the conceptual models of the WIPP disposal system. Consequently, extensive descriptions are included in the application. Natural characteristics favorable to the isolation of TRU waste were emphasized by the DOE from the outset of the repository selection process, and the WIPP site was selected as the location that best met the siting criteria. This application summarizes these natural characteristics with emphasis on those properties that are inputs to the conceptual models.

As the DOE's knowledge of the site and its characteristics increased, so did the understanding of potential adverse characteristics. Two of these characteristics, deformation of the Castile and dissolution, have received extensive study. The results of these studies are summarized in this application. Based on the results of the studies, neither poses a significant threat to the disposal system.

The hydrology of the disposal system is another topic that has been the result of extensive field and laboratory study. This work is summarized and has resulted in the selection of a three-dimensional groundwater basin model for flow in the rocks above the Salado Formation and the development of a Darcy flow model for the Salado. A discussion of alternative conceptual models that were evaluated and rejected during the development process is also included.

Natural resources in the vicinity of the WIPP site are discussed because they have been identified by the EPA as having the potential to impact disposal system performance. These resources consist primarily of oil, natural gas, and potash. The information in the application provides the basis for incorporating these natural resources and their possible development as human-initiated events into the conceptual model of disposal system performance. These potential human-initiated events dominate total release calculated in performance assessment.

The application provides an overview of the engineered facility. The focus is on those aspects that contribute to the long-term performance of the disposal system, including the mined repository, the shaft seals, the panel closures, the borehole plugs, and the backfill. Each of these engineered features contributes to the isolation of radionuclides and is included in the final performance assessment. These engineered features have been selected to complement the natural ability of the repository to isolate radionuclides.

The manner in which the engineered features will limit releases of radionuclides is an important consideration that the DOE has included in the application. The shaft seals are designed to prevent the movement of radionuclides toward the accessible environment

through the shafts; panel closures prevent the movement of radionuclides toward the accessible environment by limiting the magnitude of releases that can occur during certain human intrusion events; backfill substantially delays the movement of radionuclides toward the accessible environment by limiting, through chemical means, the amount of actinides that can be dissolved in brines that enter the repository; and borehole plugs eliminate penetrations from the surface into the Salado so that circulating groundwaters cannot reach the salt and cause dissolution or provide release pathways.

The wastes to be managed and disposed of at the facility are described. The waste description includes the definition, sources, types, components, and characteristics of TRU waste planned for emplacement in the repository. There are two aspects to the process of identifying the waste and specifying appropriate waste characterization programs. The first is the determination of those waste properties that are important to repository performance, and the second is preparing an estimate of the inventory of those properties that can reasonably be expected to be placed into the disposal system. The first aspect came about through the iterative manner in which the DOE conducted preliminary performance assessments leading to the identification of important waste characteristics and the waste components that affect those characteristics. Eleven such components were initially identified by the DOE. The DOE assembled a baseline inventory referred to as the Transuranic Waste Baseline Inventory Report (TWBIR), which contained, among other information, projections of quantities of the 11 waste components expected to be important to performance. This baseline includes estimates of 570 stored or to-be-generated waste streams. Each of these streams is described in terms of expected volumes and the 11 components (such as radionuclide inventories, volume of corrodible metals, and organics). Waste-related input parameters were developed from the TWBIR. Because these parameters result in a complementary cumulative distribution function (CCDF) that complies with the disposal standards, they are acceptable repository limits that will be used as the basis for waste acceptance.

Waste characterization is also described in the application. This is the activity that the waste generator/shipper will have to accomplish prior to shipping waste to the WIPP.

Quality Assurance (QA) programs and plans for each of the activities completed in support of this compliance demonstration are described. The chapter on QA establishes that the DOE has had a QA program consistent with the requirements of the American Society of Mechanical Engineers-Nuclear Quality Assurance-1 (ASME-NQA-1) for many years at the WIPP facility and that the current DOE Carlsbad Area Office (CAO) Quality Assurance Program Document (QAPD) mandates, in addition to NQA-1, the ASME NQA-2a-1990 addenda to NQA-2-1989, Part 2.7, and the ASME NQA-3-1989. All WIPP project participants who perform work that affects quality are required to have QA programs that conform to the requirements of the CAO QAPD.

The performance assessment methodology and the process for identifying potential future conditions that could affect the repository are discussed. Once these possible futures are identified, they are screened on the basis of probability, consequence, or regulatory criteria to

identify those that must be retained for analysis. The resulting set of future conditions is organized into sequences of events referred to as scenarios and are incorporated into the modeling scheme. The DOE has identified six scenarios that include all the reasonable expected future natural and human-initiated processes. These are grouped as the undisturbed scenario, in which only natural processes and events act on the disposal system, and the disturbed scenarios, which include drilling, mining, and combinations of drilling and mining.

The undisturbed scenario couples natural processes such as creep closure and fluid flow with waste-induced processes such as gas generation caused by corrosion and microbial degradation of organic materials. These processes are simulated for 10,000 years into the future using numerical techniques implemented through computer codes. The modeling shows, as discussed in Chapter 6.0, that the behavior of the undisturbed disposal system will result in extremely effective isolation of the radioactive waste. Concrete, clay, and asphalt components of the shaft seal system will provide an immediate and effective barrier to fluid flow through the shafts, isolating the repository until salt creep has consolidated the compacted crushed salt components that will permanently seal the shafts. A disturbed rock zone (DRZ) will form around both the shafts and the repository excavations. The DRZ in these halite layers will heal over time, and, therefore, will not provide a ready pathway for fluid flow. Gas generation by corrosion and microbial degradation is expected to occur and will result in elevated pressures within the repository. These pressures will not significantly exceed lithostatic because fracturing within the more brittle anhydrite layers will occur and provide a pathway for gas to leave the repository. Fracturing is expected to enhance gas and brine migration from the repository, but gas transport will not contribute to the release of actinides from the disposal system. Brine flowing out of the waste disposal region through anhydrite layers may transport actinides as dissolved and colloidal species, but the quantity of actinides that may reach the accessible environment boundary during undisturbed performance through the interbeds is insignificant with regard to the compliance demonstration. The performance assessment results show that no migration of radionuclides occurs vertically through the Salado or through the shaft seal system.

Performance assessment is required by regulation to consider disturbed case scenarios that include intrusions into the repository by inadvertent and intermittent drilling for resources. The probability of these intrusions is based on a future drilling rate of 46.8 boreholes per square kilometer per 10,000 years. This rate is based on consideration of the past record of drilling events in the Delaware Basin. Results of the performance assessment indicate that human intrusion provides the only mechanism for significant releases of radionuclides from the disposal system. These releases may occur by five mechanisms: (1) cuttings, (2) cavings, (3) spallings, (4) direct brine releases, and (5) long-term brine releases. Because each of these release mechanisms would result in releases to both the surface and subsurface environments, migration pathways through the permeable layers of rock above the Salado are important in performance assessment. These are modeled based on extensive field data sets collected by the DOE. Major emphasis is placed in the Culebra Member of the Rustler Formation because this is by far the most transmissive geologic layer in the disposal system.

The DOE models multiple types of human intrusion scenarios in the performance assessment. These include both single intrusion events and combinations of multiple boreholes. Two different types of boreholes are considered: (1) those that penetrate a pressurized brine reservoir in the underlying Castile Formation and (2) those that do not. While the presence of a brine reservoir under the repository is speculative, it cannot be completely ruled out based on available information. The primary consequence of penetrating a brine reservoir is the introduction of an additional source of brine beyond that which is expected to flow into the repository from the Salado.

The DOE uses the Monte Carlo technique to perform probabilistic analysis. Key to this analysis is the specification of variables used to represent the disposal system over the regulatory time period. Fifty-seven different disposal system parameters are represented by ranges of values, with each value in the range assigned a probability. The range for any value is referred to as its uncertainty. The full range of uncertainty is included in the analysis by implementing random, stratified, and Latin hypercube sampling techniques.

Families of CCDFs and mean CCDFs for each of three replicate sets of calculations (each replicate consisting of 100 samples) are shown in Section 6.5. All 300 individual CCDFs lie below and to the left of the quantitative release limits specified in 40 CFR § 191.13(a). The overall mean CCDF determined from the three replicates also lies entirely below and to the left of the limits specified in 40 CFR § 191.13(a). Thus, the WIPP has demonstrated compliance with the containment requirements of 40 CFR Part 191.

The DOE's implementation of each of the six assurance requirements contained in 40 CFR Part 191 is discussed. Assurance requirements were mandated by the EPA to ensure that steps are taken to reduce the impacts of the uncertainties associated with making numerical predictions of events and processes 10,000 years into the future. According to the EPA, these assurance requirements are considered an essential complement to the containment requirements, which, when implemented, should ensure that the level of protection desired by the EPA is achieved. In this regard, the DOE describes its plans for active institutional controls, passive institutional controls, multiple barriers, and monitoring. In addition, the DOE addresses the resource disincentive requirements of 40 CFR § 191.14 and waste removal.

The DOE describes its compliance with the individual and groundwater protection requirements in 40 CFR Part 191. Nine of the 300 performance assessment realizations resulted in very small releases to the accessible environment laterally through marker beds. These releases are evaluated for compliance with the individual protection and groundwater protection standards and are shown to comply using an extremely conservative bounding analysis along with the additional assumption of the existence of an underground source of drinking water immediately adjacent to the controlled area. Under these conditions, the bounding doses are well below the EPA standards.

Finally, the DOE summarizes the results of peer reviews relevant to this application. The certification criteria mandated that the DOE perform peer reviews of the conceptual models, the waste characteristics analysis, and the engineered barrier study. In addition, the DOE conducted four other peer reviews, including reviews of the passive institutional controls, engineered systems data qualification, waste form and disposal room data qualification, and the natural barriers data qualification. Each of these is discussed along with the findings and recommendations of the peer panels and the DOE responses to these findings. The DOE has also documented other reviews that have been conducted for the WIPP, including major oversight activities by the EEG and the NAS. These are summarized, and supporting documentation is provided in Appendix PEER.

This application also contains supporting material included in the appendices. Four criteria were used by the DOE in deciding whether information should be included as an appendix. The criteria are (1) the information is in existing technical reports or design documents that are heavily referenced in the application, (2) the information is routinely updated by the DOE as the result of internal document review or reporting procedures and the latest version of the information is inserted just prior to submittal of the application, (3) the information is an output that is specified in the 40 CFR Part 194 certification criteria and the output is lengthy, and (4) the information is required to support several chapters and is voluminous in nature. The DOE believes that the information in the appendices is needed to make the application complete; therefore, the appendices are considered by the DOE to be an integral part of the application.

The DOE has prepared this application to be fully responsive to 40 CFR Parts 191 and 194 and the associated requirements of the LWA, and demonstrates the DOE's compliance with the final disposal standards in 40 CFR Part 191. In addition, the DOE has addressed the criteria in the EPA's compliance application guidance document. Comments or questions regarding this application should be directed to the U.S. Department of Energy, Carlsbad Area Office, PO Box 3090, Carlsbad, NM 88221, (505) 234-7300. Correspondence should be marked to the attention of the Assistant Manager, Office of Regulatory Compliance.

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is responsible for the disposition of transuranic (TRU) waste generated through national defense-related activities. Approximately 62,000 cubic meters of these wastes have been generated and are currently stored at government defense installations across the country. The Waste Isolation Pilot Plant (WIPP), located near Carlsbad, New Mexico, has been sited and constructed to meet the criteria established by the scientific and regulatory community for the safe disposal of TRU wastes. This Compliance Certification Application provides the DOE's demonstration of compliance for the WIPP with the long-term disposal regulations set forth in Title 40 of the Code of Federal Regulations (CFR) Part 191, Subparts B and C (U.S. Environmental Protection Agency [EPA] 1993). The information provided in this application has been structured in accordance with the criteria for certification issued by the EPA in February 1996 as 40 CFR Part 194, titled *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule.*

In this application, the DOE documents how the favorable geological, hydrological, physical, chemical, and environmental characteristics of the site, along with engineered features of the facility, contribute to a reasonable expectation that compliance will be achieved for the 10,000-year regulatory period. Calculations provided in this application demonstrate that even under the stringent conditions dictated by the disposal standards and the certification criteria, the WIPP complies with the quantitative release limits, individual exposure standards, and groundwater protection standards. In addition, this application documents the measures that the DOE has taken, or intends to take at the time of facility closure, to provide further assurance that the quantitative limits will be met.

The activities that have led up to the preparation of this application began over 20 years ago with the selection of a site that best met the numerous siting criteria established for safe disposal of TRU waste. At that time, the DOE and its predecessor agencies sought a disposal location with certain favorable characteristics that were anticipated as desirable for long-term waste isolation. The WIPP site best met these criteria. For example, the site has favorable geological characteristics in that

- the host rock formation behaves plastically, thereby creeping closed to encapsulate buried waste;
- the effects of dissolution at the site were minimal and predictable;
- deformation of the rocks within the disposal system is low;
- excavation of the repository is relatively easy;
- future resource development is predictable and minimal; and
- the repository host rock is relatively uncomplicated lithologically and structurally.

Hydrologically, the site exhibits

- a host rock formation that contains little groundwater and transmits it poorly;
- a location where the effects of groundwater flow are minimal and predictable;
- an area where future groundwater use is low and where there are no permanent surface waters;
- an area where future groundwater use is unlikely; and
- a repository host rock that will not likely be affected by anticipated possible long-term climate changes within 10,000 years.

Finally, when selected, the WIPP site

- maximized the use of federal lands while avoiding existing drill holes, avoiding known oil and gas trends and minimizing the impacts on potash deposits;
- avoided natural areas, endangered species and critical habitats;
- has a climate that minimizes hydrological impacts; and
- is in a seismically stable area.

All of these favorable factors contribute to the demonstration of compliance and more than compensate for less favorable features such as nearby hydrocarbon production and potash mining. Furthermore, the favorable characteristics allow the WIPP to accommodate a broad spectrum of TRU waste characteristics, thereby allowing the DOE to meet its mandated mission of disposal of the nation's TRU waste inventory.

The efforts to prepare this final documentation of compliance began in 1992, when Congress passed the WIPP Land Withdrawal Act (LWA), in which it established several mandates. First, Congress required that the DOE demonstrate compliance to the final disposal standards codified in 40 CFR Part 191, Subparts B and C, prior to opening the WIPP for the disposal of TRU waste (EPA 1985, 1993). Second, Congress mandated that the DOE submit an application to the EPA seeking certification of the DOE's compliance demonstration. To facilitate the certification process, Congress mandated that the EPA issue certification criteria to judge the adequacy of the DOE's application. The EPA met this obligation in February 1996 with the issuance of 40 CFR Part 194. Following the issuance of 40 CFR Part 194, the EPA issued guidance for implementation. This guidance is the *Compliance Application Guidance for 40 CFR Part 194* (EPA 1996b).

The DOE has been working on its demonstration of compliance since the initial publication of the disposal standards in 1985. Initial work was aimed at identifying appropriate conceptual models for the features, events, and processes (FEPs) that could reasonably be expected to affect the disposal system.[1] The effect of the LWA was to focus the DOE's activities to meet specific criteria that the EPA has established for certification of compliance. This application is the result of those efforts and demonstrates that the WIPP meets the disposal standards of 40 CFR Part 191, Subparts B and C, under the conditions imposed by the standards and in accordance with the certification criteria.

The information presented in this application is the culmination of over 20 years of scientific work specifically dedicated to TRU waste isolation in the WIPP. Throughout this process, the DOE and its predecessor agencies have ensured that qualified individuals were available to address the technical questions surrounding the long-term performance of the disposal system. These experts have included members of the federal and state government agencies, several national laboratories, academia, and industry. In addition, the DOE has ensured ongoing technical oversight of the project through the services of the Environmental Evaluation Group (EEG), the National Academy of Sciences (NAS), and the New Mexico Governor's Consultation Task Force on Radioactive Waste. Frequent consultation with these organizations has served to identify important issues and their timely resolution. In addition, the DOE has involved the public in the decision-making process at key points throughout the compliance demonstration process. The DOE has maintained a documented Quality Assurance Program to ensure that objective evidence exists to support the quality of the work that has been performed for this assessment.

This chapter provides an overview of the application, including a summary of the regulatory basis for the application, a discussion of the DOE's purpose for the WIPP, a summary of the site selection process, a summary of the approach taken in this application to demonstrate long-term performance, and a summary of the contents of the remaining chapters.

1.1 Applicable Regulations

Several federal and state of New Mexico regulations apply specifically to the DOE's activities to open and operate the WIPP for the disposal of TRU waste. Compliance with these regulations is summarized in Appendix BECR. However, two of these regulations are the specific subject of this application. These are 40 CFR Part 191, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes,*[2] and 40 CFR Part 194, *Criteria for the Certification and*

[1] The EPA defines the disposal system as any combination of engineered and natural barriers that isolate spent nuclear fuel or radioactive waste after disposal (40 CFR § 191.12).

[2] The DOE uses the following convention in referencing regulations: General references are expressed as 40 CFR Part 191 or 40 CFR Part 191, Subpart B. Specific references to requirements within the regulations are shown as 40 CFR § 191.14(b). In addition, reference is made to the supplementary information provided in the preamble of the regulation. *Federal Register* citations for these references are shown as follows: 61 FR 5224.

Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule.

1.1.1 40 CFR Part 191

The EPA is responsible for developing environmental standards for the protection of the public and the environment from radioactivity. The statutory authority for establishing and implementing the regulatory standards applicable to the operation, closure, and long-term performance of the WIPP facility are found in the Atomic Energy Act of 1954, Reorganization Plan Number 3 of 1970, and in the Nuclear Waste Policy Act of 1982. The regulations affecting the radioactive waste disposal operations that will occur at the WIPP are found in 40 CFR Part 191.

Since the mid-1970s, the EPA has been developing guidance and standards for the management and disposal of radioactive waste. The EPA's final rule, 40 CFR Part 191, was first published on September 19, 1985. This standard was vacated and remanded to the EPA by a Federal Court of Appeals in 1987. The LWA of 1992 reinstated the 1985 disposal standard except for the aspects of the standard that were specifically questioned by the court (that is, 40 CFR § 191.15, Individual Protection Requirements, and 40 CFR § 191.16, Ground Water Protection Requirements). On December 20, 1993, the EPA promulgated, effective January 19, 1994, final disposal standards that corrected deficiencies associated with the individual and groundwater protection requirements.

40 CFR Part 191 Subparts B and C establish standards and measures of performance for the following aspects of a disposal system:

- isolation of radionuclides sufficient to meet the containment requirements of the disposal system.
- protection of individuals from radiation exposures for a period of 10,000 years,
- protection of groundwater from radioactive contamination for 10,000 years, and

To demonstrate that a disposal system will comply with 40 CFR Part 191, the DOE must show a reasonable expectation that each performance measure will be satisfied.

In addition to numeric standards, the qualitative assurance standards set out in 40 CFR § 191.14 were promulgated in order to provide the confidence needed for long-term compliance with the containment requirements in 40 CFR § 191.13. They include (1) active and passive institutional controls to preclude or mitigate the potential for human disturbance of the repository for an extended period of time, (2) the concept of multiple (natural and engineered) barriers, and (3) other measures taken to enhance confidence in the disposal system performance.

The DOE has demonstrated that the WIPP complies with the disposal standards in 40 CFR Part 191. This demonstration is documented in this application. The location in this application of compliance demonstrations for each of the requirements in 40 CFR Part 191 is shown under the Regulatory Cross Reference tab in this application. The final complementary cumulative distribution function (CCDF), which is the measure of compliance for containment, is shown in Figure 1-1. Based on this CCDF, the DOE has a reasonable expectation that the disposal system will perform in compliance with the containment requirements of 40 CFR Part 191.

1.1.2 40 CFR Part 194

As mentioned above, the EPA was mandated by the LWA to issue criteria for evaluating the DOE's compliance demonstration. The EPA met this mandate on February 9, 1996 with the publication of 40 CFR Part 194. In the summary of the rule, the EPA states that by this rule it is

> promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. (61 FR 5224)

The EPA states that "[w]ith today's rulemaking, the Agency establishes criteria by which to judge whether the WIPP is in compliance with the 'disposal regulations' and sets forth procedural requirements for this determination." To this end, the rule contains four subparts.

- Subpart A establishes provisions related to the structure of the 40 CFR Part 194, including purpose, scope and applicability; definitions; substitution of alternative provisions for those promulgated in the final rule; and procedures that shall be followed in communications and written reports submitted by the Secretary of Energy to the Administrator of the EPA.

- Subpart B sets forth requirements for the format and content of compliance applications.

- Subpart C establishes the requirements that apply to the performance assessments and compliance assessments that will be used to demonstrate compliance with the numerical requirements of the disposal regulations.

- Subpart D establishes procedures that the EPA will use to involve the public in the decisions on certification and recertification and requires the EPA to publish notices of its actions in the *Federal Register*.

The DOE has met all of the criteria established by the EPA in 40 CFR Part 194. The documentation for demonstrating compliance as defined in the criteria in 40 CFR Part 194 are contained in this application. A crosswalk relating the criteria to the various sections of the application can be found under the Regulatory Cross Reference tab in this application. The location of the principal information required by the certification criteria is shown in Table 1-1.

1.1.3 Other Regulations

In addition to 40 CFR Part 191, one other regulation applies to the WIPP during the period following closure of the facility. This is a regulation issued pursuant to the Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act (RCRA). The RCRA regulates the hazardous waste component of TRU waste.[3] The DOE has implemented compliance programs for the RCRA that complement the disposal standards. Details of the RCRA compliance program can be found in Appendix BECR.

1.2 Project Background

The DOE began the development of the WIPP facility by selecting a site. The DOE evaluated several alternative sites, and the present site was selected as the best alternative based on considerable existing geotechnical information and confirmed by extensive research and testing. Based upon the properties of the site, the DOE designed the repository and prepared safety analyses. Subsequent research has expanded the understanding of the geologic, hydrologic, geochemical, and mechanical properties of the host rock and surrounding strata of the site. This siting phase ended with the publication of a Final Environmental Impact Statement (FEIS) in 1980 (DOE 1980), which evaluated alternatives for the safe, long-term isolation of TRU waste. The Record of Decision concluded that the phased development of the WIPP facility was the preferred alternative of those considered (DOE 1981).

The site and preliminary design validation phase followed the siting phase. During this phase, the DOE constructed two shafts, excavated an underground testing area, and investigated various geologic, hydrologic, and other geotechnical features, further expanding the knowledge of the site's characteristics. In addition, the DOE evaluated methods for assessing the long-term performance of the WIPP facility. A series of geologic and hydrologic studies began in 1984 under an agreement between the DOE and the state of New Mexico. These studies were completed and site characterization ended.

The construction phase followed the site and preliminary design validation phase, during which the DOE built surface structures for receiving waste and mined underground excavations, including one panel for waste emplacement and numerous areas for in-situ experiments. The DOE's decision to initiate operations was reached after all prerequisites for

[3] TRU waste that also contains hazardous waste contaminants as defined by the RCRA is referred to as TRU mixed waste.

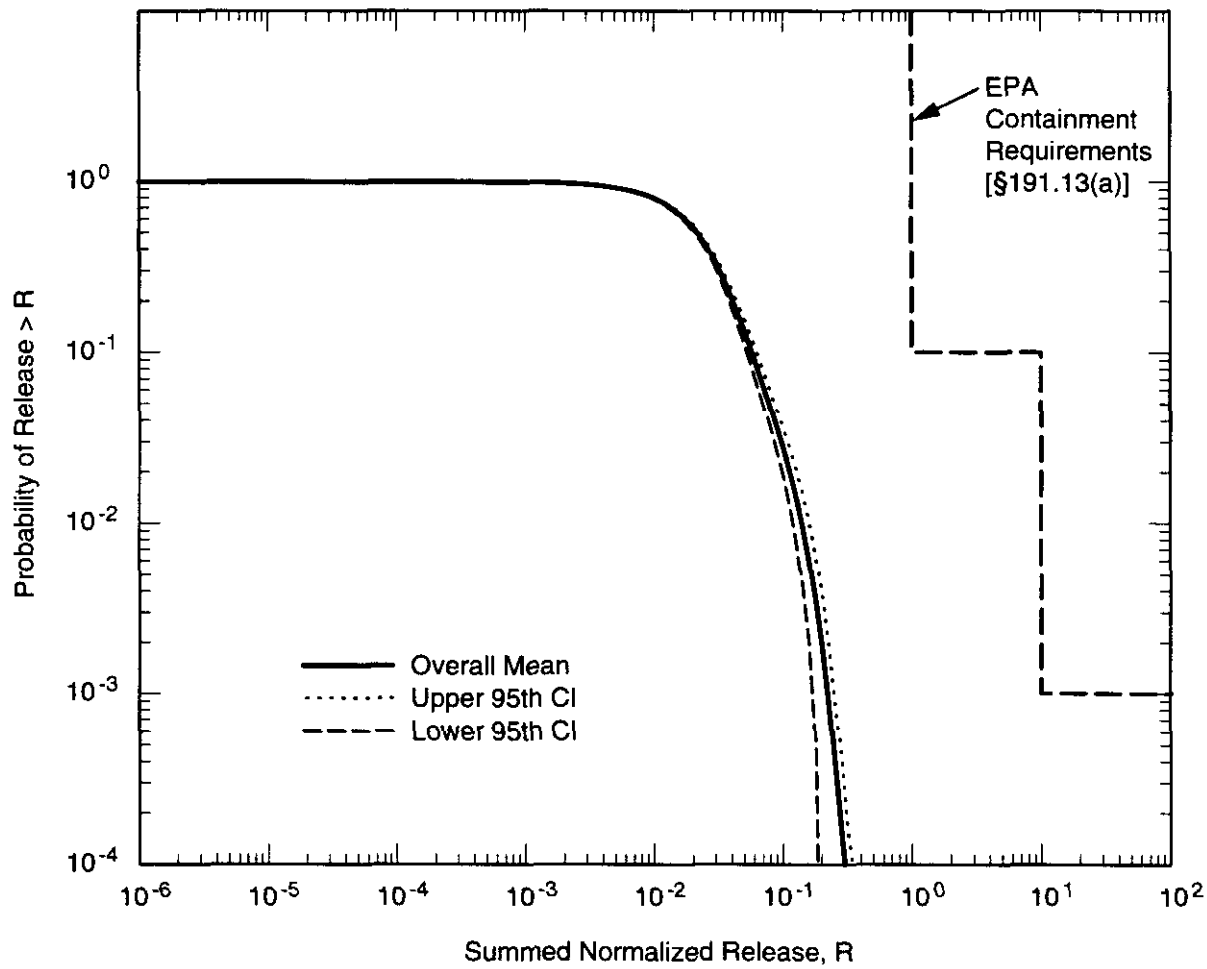

Note: This figure is reproduced from Figure 6-39.

CCA-143-3

Figure 1-1. Final WIPP CCDF

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Table 1-1. Analyses and Studies Mandated by the Certification Criteria and Their Location in this Application

40 CFR Part 194	Criterion	Location in This Application
§ 194.23 Models and Computer Codes	(c) Documentation of all models and computer codes included as part of any compliance application performance assessment calculation shall be provided. Such documentation shall include but shall not be limited to (1) Descriptions of the theoretical backgrounds of each model and the method of analysis or assessment; (2) General descriptions of the models; discussions of the limits of applicability of each model; detailed instructions for executing the computer codes, including hardware and software requirements, input and output formats with explanations of each input and output variable and parameter (for example, parameter name and units); listings of input and output files from a sample computer run; and reports on code verification, benchmarking, validation, and quality assurance (QA) procedures; (3) Detailed descriptions of the structure of computer codes and complete listings of the source codes; (4) Detailed descriptions of data collection procedures, sources of data, data reduction and analysis, and code input parameter development; (5) Any necessary licenses; and (6) An explanation of the manner in which models and computer codes incorporate the effects of parameter correlation.	Chapter 4.0 Sections 5.3.18 and 5.3.20 Chapter 6.0 Appendix BRAGFLO Appendix CCDFGF Appendix CUTTINGS Appendix GENII Appendix MASS Appendix NUTS Appendix PANEL Appendix PAR Appendix SECOFL2D Appendix SECOTP2D Numerous support codes as discussed in Appendix CODELINK GRASP_INV (in Appendix TFIELD) FMT (in Appendix SOTERM) NONLIN (in Appendix SOTERM) SANTOS (in Appendix PORSURF)
§ 194.24 Waste Characterization	(b) The Department shall submit in the compliance certification application the results of an analysis which substantiates (1) That all waste characteristics influencing containment of waste in the disposal system have been identified and assessed for their impact on disposal system performance. . . (2) That all waste components influencing the waste characteristics identified in paragraph (b)(1) of this section have been identified and assessed for their impact on disposal system performance. . . (3) Any decision to exclude consideration of any waste characteristic or waste component because such characteristic or component is not expected to significantly influence the containment of the waste in the disposal system.	Section 4.2 Appendix WCA Appendix SOTERM

Table 1-1. Analyses and Studies Mandated by the Certification Criteria and Their Location in this Application (Continued)

40 CFR Part 194	Criterion	Location in This Application
§ 194.24 Waste Characterization	(c) For each waste component identified and assessed pursuant to paragraph (b) of this section, the Department shall specify the limiting value (expressed as an upper or lower limit of mass, volume, curies, concentration), and the associated uncertainty (that is, margin of error) for each limiting value, of the total inventory of such waste proposed for disposal in the disposal system.	Section 4.2 Appendix WCL
§ 194.27 Peer Review	(a) Any compliance application shall include documentation of peer review that has been conducted, in a manner required by this section, for (1) Conceptual models selected and developed by the Department; (2) Waste characterization analyses as required in § 194.24(b); and (3) Engineered barrier evaluation as required in § 194.44.	Chapter 9.0 Appendix PEER
§ 194.27 Peer Review	(c) Any compliance application shall (1) Include information that demonstrates that peer review processes required in paragraph (a), and conducted prior to the implementation of the promulgation of this part, were conducted in accordance with an alternate process substantially equivalent in effect to NUREG-1297 and approved by the Administrator or the Administrator's authorized representative; and (2) Document any peer review processes conducted in addition to those required pursuant to paragraph (a) of this section. Such documentation shall include formal requests, from the Department to outside review groups or individuals, to review or comment on any information used to support compliance applications, and the responses from such groups or individuals.	Chapter 9.0 Appendix PEER
§ 194.34 Results of Performance Assessments	(e) Any compliance application shall display the full range of CCDFs generated.	Section 6.5.2 Appendix SA
§ 194.41 Active Institutional Controls	(a) Any compliance application shall include detailed descriptions of proposed active institutional controls, the controls' location, and the period of time the controls are proposed to remain active. Assumptions pertaining to active institutional controls and their effectiveness in terms of preventing or reducing radionuclide releases shall be supported by such descriptions.	Section 7.1 Appendix AIC

Table 1-1. Analyses and Studies Mandated by the Certification Criteria and Their Location in this Application (Continued)

40 CFR Part 194	Criterion	Location in This Application
§ 194.42 Monitoring	(a) The Department shall conduct an analysis of the effects of disposal system parameters on the containment of waste in the disposal system and shall include the results of such analysis in any compliance application. The results of the analysis shall be used in developing plans for pre-closure and post-closure monitoring required pursuant to paragraphs (c) and (d) of this section.	Section 7.2 Appendix MON
§ 194.43 Passive Institutional Controls	(a) Any compliance application shall include detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system.	Section 7.3 Appendix PIC
§ 194.43 Passive Institutional Controls	(c) The Administrator may allow the Department to assume passive institutional control credit, in the form of reduced likelihood of human intrusion, if the Department demonstrates in the compliance application that such credit is justified because the passive institutional controls are expected to endure and be understood by potential intruders for the time period approved by the Administrator.	Section 7.3 Appendix EPIC
§ 194.44 Engineered Barriers	(b) In selecting any engineered barrier(s) for the disposal system, the Department shall evaluate the benefit and detriment of engineered barrier alternatives, including but not limited to cementation, shredding, supercompaction, incineration, vitrification, improved waste canisters, grout and bentonite backfill, melting of metals, alternative configurations of waste placements in the disposal system, and alternative disposal system dimensions. The results of this evaluation shall be included in any compliance application and shall be used to justify the selection and rejection of each engineered barrier evaluated.	Section 3.3 Section 7.4 Appendix EBS
§ 194.45 Consideration of the Presence of Resources	Any compliance application shall include information that demonstrates that the favorable characteristics of the disposal system compensate for the presence of resources in the vicinity of the disposal system and the likelihood of the disposal system being disturbed as a result of the presence of those resources. If performance assessments predict that the disposal system meets the containment requirements of § 191.13 of this chapter, then the Agency will assume that the requirements of this section and § 191.14(e) of this chapter have been fulfilled.	Section 7.5 Appendix IRD

Table 1-1. Analyses and Studies Mandated by the Certification Criteria and Their Location in this Application (Continued)

40 CFR Part 194	Criterion	Location in This Application
§ 194.46 Removal of Waste	Any compliance application shall include documentation which demonstrates that removal of waste from the disposal system is feasible for a reasonable period of time after disposal. Such documentation shall include an analysis of the technological feasibility of mining the sealed disposal system, given technology levels at the time a compliance application is prepared.	Section 7.6 Appendix WRAC

ending construction were met and documented. These documents used the data collected since 1980 to evaluate the potential short-term and long-term impacts of the WIPP facility.

Once the DOE demonstrates compliance with applicable federal and state laws and regulations and obtains required approvals to begin operations, the WIPP facility will proceed through three additional phases: an operations phase, a decommissioning phase, and a postdecommissioning phase. During the operations phase, which the DOE assumes for the purposes of this application to last 25 years, the DOE will receive, handle, and emplace TRU and TRU mixed waste in the repository. The operations phase will end when the design capacity of the repository is reached.

The decommissioning phase will follow the operations phase. The repository will be prepared for permanent closure during this phase. Surface facilities will be decontaminated and decommissioned, underground excavations will be closed, and shaft seals will be emplaced. The decommissioning phase is expected to last 10 years.

Active and passive institutional controls will be implemented following the operations phase. Active institutional controls include activities such as control of access to the site, maintenance, clean-up, and monitoring. Such controls will be implemented consistent with applicable regulations and permit conditions. Only the first 100 years of active institutional controls have been included in the assessment of the disposal system's performance consistent with 40 CFR Part 191 and 40 CFR Part 194. Passive institutional controls include notification devices such as permanent markers and archives. These controls have been designed to reduce the likelihood of inadvertent human intrusion to the extent practicable.

1.3 Site Selection Process

In 1957, the NAS National Research Council recognized salt as a medium well suited for radioactive waste disposal. Salt has relatively high thermal conductivity (which serves to conduct heat away from waste rapidly) and has favorable plastic (creep) properties, which allow significant deformation without fracturing. The existence of large salt deposits

demonstrates isolation from circulating groundwaters for long periods of geologic time. Similarly, the depositional nature and preservation of large intact salt deposits demonstrate that the region has been stable for long periods of time.

The site selection process for the WIPP began in 1973 with a review of information on potential disposal media. This work focused on salt beds and salt domes. The tentative selection criteria used in the initial stage of the process emphasized radiation and mine safety, hydrologic isolation, and ease of construction. In addition to salt lithological factors, the criteria specified the following conditions: 1,000 to 2,500 feet (305 to 762 meters) depth to salt, 200 feet (61 meters) minimum of salt thickness, lateral extent of salt sufficient to protect against dissolution, favorable tectonics (low historical seismicity and no salt-flow structures nearby), minimal groundwater, low resource potential, minimum number of existing boreholes, low population density, and maximum use of federal lands. The U.S. Geological Survey (USGS) and the Oak Ridge National Laboratory (ORNL) selected eastern New Mexico as the area that best satisfied the tentative selection criteria from the bedded salt regions surveyed.

During the second stage of the selection process, two of the three locations in this region were determined to be inadequate: the Clovis-Portales site because shallow salt formations had a significant clay content and the purer salt formations were too deep, and the Mescalero Plains area because of extensive oil field development. After shifting the potential site twice (in order to avoid borehole penetrations of the salt within 2 miles (3.2 kilometers) of the repository border), ORNL selected a site in the Delaware Basin for extensive characterization.

In the final stage of the process, eight areas in the Delaware Basin in Eddy and Lea counties were evaluated. Exploratory drilling at the first site recommended for characterization indicated unsuitable geology (see Chapter 2.0), and in 1975 the USGS and SNL reexamined the Delaware Basin for a more favorable location. This reexamination led to the selection of the Los Medaños site. Selection criteria considered at this stage of the process included:

1. The site should be at least 6 miles (10 kilometers) from the Capitan Limestone to avoid any possible deformation hazard related to the nearness of this reef structure.

2. To minimize potential conflicts with exploration of mineral resources, the central 4 square miles (10 square kilometers) of the repository itself should not be in the known Potash District, and as little as possible of the surrounding buffer zone should be in the district.

3. No part of the central area should be less than 1 mile (1.6 kilometers) away from holes drilled through the Castile Formation (hereafter referred to as the Castile) into underlying rocks in order to avoid dissolution by water flowing upward through an inadequately plugged borehole.

4. Known oil and gas stratigraphic trends should be avoided.

5. The nearest dissolution front in the Salado Formation (hereafter referred to as the Salado) should be at least 1 mile (1.6 kilometers) from the site.

6. The bedding of geological strata should be as nearly flat as can be determined by surface geophysical investigations to ensure mine safety and ease of construction and to avoid the need for numerous exploratory holes that could pose a subsequent risk to the integrity of the repository.

7. Salt of high purity should be available at depths between 1,000 and 3,000 feet (305 and 914 meters) to ensure mine safety and ease of construction. In addition, a salt thickness of 200 feet (61 meters) or more is preferred to confine thermal and mechanical effects to the salt.

8. The use of state and private land should be minimized, especially in the central area, to simplify land acquisition and to avoid any relocation of residents.

The FEIS provided the basis for making the final decision regarding siting the WIPP facility at the Los Medaños site. This decision weighed the numerous advantages of the location and its suitability against potentially adverse environmental impacts. The WIPP site (Figure 1-2) was selected as the best of the alternatives. The specific horizon in the bedded salt was selected because of its desirable stratigraphic features. The stratigraphy is continuous throughout a large geographic area and major clay seams and interbeds of anhydrite or polyhalite are absent from the repository horizon. The facility has been constructed at a horizon such that operational and rock-support problems are minimized. Subsequent validation and construction activities have confirmed that the site's features are suitable for the long-term isolation of TRU waste. The DOE has concluded, based on the demonstration in this application, that these favorable features offset any enhanced risk of human intrusion associated with resources in the vicinity.

1.4 Program for Evaluating Long-Term Performance

When ORNL scientists recommended siting criteria for selecting a waste disposal location in salt, they had a general understanding of how a salt disposal system should perform, given the nature of the waste to be managed. Siting criteria emphasized stratigraphic factors to take full advantage of thermal and creep properties of salt; purity to minimize the presence of complicating or unfavorable properties; isolation from aquifers to minimize impacts of circulating groundwaters; tectonic stability to ensure long-term isolation of waste; minimizing the presence of existing boreholes that could become conduits for release or dissolution; and minimizing resource activity that could disrupt the disposal system. This understanding was, in a broad sense, a conceptual model that linked waste isolation to key features and processes that describe or affect the disposal system (ORNL 1973).

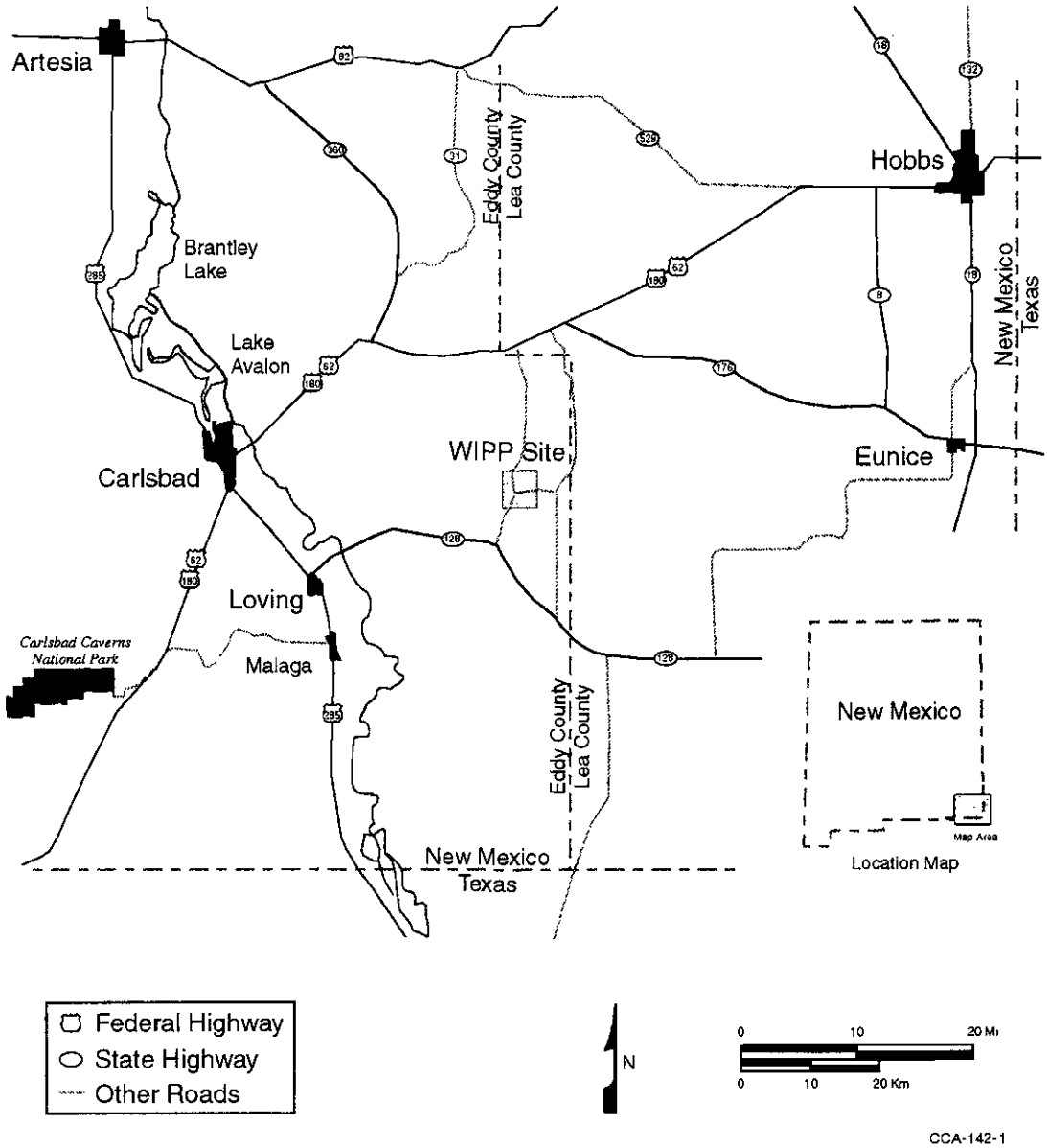

Figure 1-2. WIPP Site Location in Southeastern New Mexico

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As site selection and site characterization proceeded, emphasis was placed on obtaining additional information on those features, events, and processes (FEPs) that define disposal system performance. For this application, about 240 FEPs that could operate on the WIPP disposal system were identified and addressed by the DOE (see Appendix SCR). This information led to (1) the development of detailed conceptual models of various disposal system components such as salt creep, salt hydrology, groundwater hydrology, and waste degradation, as well as investigations to determine regional processes such as tectonism; and (2) scenarios of disposal system performance to be addressed by the modeling. The development of conceptual models led to the identification of detailed laboratory and field experimental and investigation programs to answer questions about parameter values and uncertainty. Ultimately, the interaction between the various components of the disposal system was modeled to produce estimates of expected disposal system performance. Appendix MASS contains a historical discussion of the evolutionary process that led to the conceptual model of the disposal system that is used in this application.

To evaluate the long-term performance of the disposal system, the DOE uses a technique developed especially for predicting the behavior of geologic repositories over the thousands of years required for waste isolation. This technique is performance assessment. Performance assessment is a multidisciplinary, iterative, analytical process that begins by using available information that characterizes the waste and the disposal system (the design of the repository, the repository seals, and the natural barriers provided by the host rock and the surrounding formations). The DOE uses performance assessment to estimate the releases of radionuclides, based on the probabilities of relevant FEPs occurring. Sensitivity analyses are used by the DOE to determine which characteristics of the disposal system exert the greatest effect on performance. The results of sensitivity analyses are provided in this application in Appendix SA. The results of performance assessment are used by the DOE in the 40 CFR Part 191 compliance program to assess disposal system behavior and possible environmental releases.

The DOE's methodology for performance assessment uses relevant information about the disposal system and the waste to simulate performance over the regulatory time periods. This process is schematically represented by the flow diagram in Figure 1-3, which shows how information describing the disposal system is used by the DOE to develop scenarios, scenario probabilities, and the consequence models used to estimate performance. The WIPP performance assessment method has been reviewed by the NAS, the EEG, and experts in and outside the United States. Initially, the DOE used the process in Figure 1-3 with a feedback line from the Uncertainty Analysis block to the System Description block. In this way, the DOE used performance assessment to identify important parameters and the programs needed to better define the parameters and to obtain relevant information.

Uncertainty and how it is handled in the analysis plays a major role in the formulation of a performance assessment strategy. The EPA anticipates that uncertainty in long-term predictions will be inevitable and substantial (see 40 CFR § 191.13[b]). Because of this, the EPA applies a reasonableness test to the outcome of performance assessments. In other

words, the EPA examines the record placed before it to determine if there is a reasonable expectation that compliance will be achieved.

The DOE has addressed uncertainty associated with the WIPP disposal system through careful site, facility, and waste characterization. Uncertainty remaining after these characterizations is incorporated into the performance assessment through the use of reasonable assumptions about models and parameter values.

In general, the DOE has not attempted to bias the performance assessment toward a conservative outcome, and the mean CCDF represents a best estimate of the expected, and in the case of human intrusion, prescribed performance of the disposal system. However, where realistic approaches to incorporating uncertainty are unavailable or impractical, and where the impact of the uncertainty on performance is small, the DOE has chosen to simplify the analysis by implementing conservative assumptions.[4] The conservatism in the analysis is reviewed in Section 6.5.4 and discussed in Appendix MASS (Table MASS-1), and leads to the conclusion that the conservatism does not significantly affect the location of the mean CCDF in Figure 1-1.

The format of this application is tied to the process discussed in Section 6.1 and depicted in Figure 1-3. Basic input information is included in the next four chapters. Then the subsequent chapters use the input information to predict compliance. Each is discussed in the following section.

1.5 Compliance Certification Application Synopsis

This document contains all of the information necessary for the EPA to complete its review and issue a certification of compliance. The DOE has provided links between the chapters to assist in locating data, parameters, models, and assumptions. The DOE used documented guidance provided by the EPA to assist in preparing this application. In many cases, the DOE has included information in the form of appendices. Four criteria were used by the DOE in deciding which information should be included as an appendix. These are as follows:

- The information is in existing technical reports or design documents that are heavily referenced in the application. An example is the Geological Characterization Report (Powers et al. 1978), which is Appendix GCR.

- The information is updated regularly and the latest version of the information is inserted just prior to submittal of the application. Examples are the Annual Site Environmental Report (Appendix SER) and the TRU Waste Baseline Inventory Report (Appendix BIR).

[4] Conservative assumptions are defined by the DOE as assumptions that result in the overestimation, rather than the underestimation, of any phenomenon that could contribute to the release of radionuclides from the disposal system.

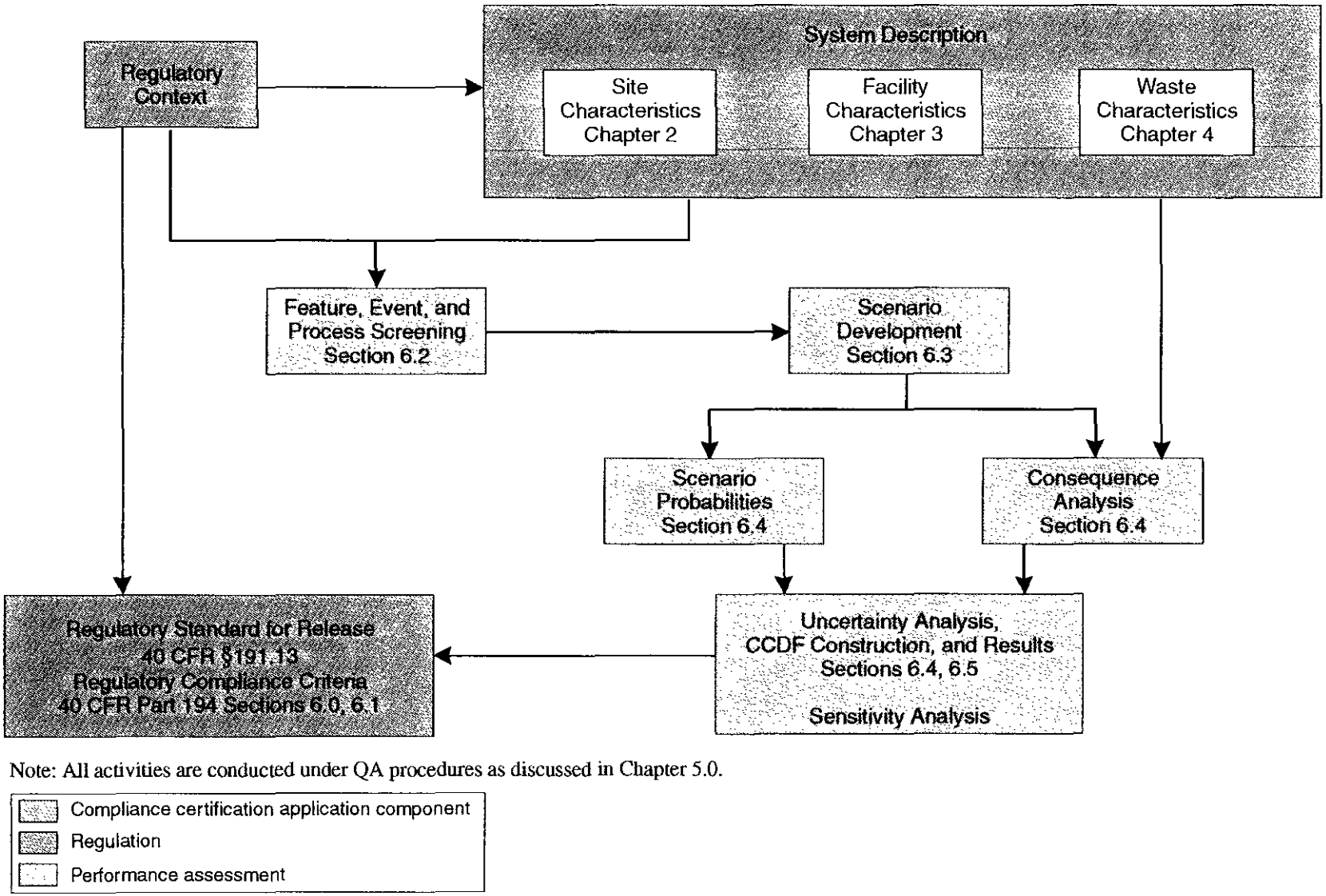

Figure 1-3. Methodology for Performance Assessment of the WIPP

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- The information is an output that is specified in the 40 CFR Part 194 certification criteria and the output is lengthy. Examples are the engineered barriers study (Appendix EBS), the waste characterization analysis (Appendix WCA), the input values and selected intermediate results for each individual calculation of compliance (Appendix IRES), and the computer code manuals (such as Appendix BRAGFLO).

- The information is required to support several chapters and is voluminous in nature. An example is Appendix PAR, which includes parameters based on site characteristics identified in Chapter 2.0, facility design features identified in Chapter 3.0, and the waste parameters identified in Chapter 4.0, in a format that can be used in the numerical models in Chapter 6.0.

The information in the appendices is needed to make the application complete; therefore, the appendices are to be treated as integral parts of the application.

The application contains references to published work that was used in preparing the demonstration of compliance. Ten copies of these references have been provided to the EPA along with the application. However, in order to enhance the readability of the application, expanded references have been provided with each chapter in this application. These are accumulated in Appendix XRE. Expanded references are intended to put referenced statements into context. This is done by providing actual excerpts from the source document in the vicinity of the referenced text. In cases where the text references a document generally (that is, no particular page or section is called out), no expansion is provided. In addition, no expansion is provided for copyrighted materials for which permission to reproduce the text could not be obtained.

Bibliographies are provided for most chapters to provide listings of further information that may be of interest to a reviewer. Bibliographic entries many times are of interest because they discuss alternative models or methodologies that are relevant to the process of assessing disposal system performance. The DOE used several criteria in deciding what entries were to be included in the bibliography. These are as follows:

- Documents were of historical interest and not necessarily WIPP specific. Examples are older geological works cited in Chapter 2.0, such as Shumard (1858), Crandall (1929), and Dunham (1972). Perusal of these documents will provide the reader with general background information on the area around the WIPP.

- Documents are generally well-known technical references (textbooks) that provide the basic understanding that the DOE assumes a technical reader has when reviewing this application. An example is the classic textbook, *Dynamics of Fluids in Porous Media,* by Jacob Bear.

- Reports that provide interim results of testing programs and experimental activities. Generally, such reports are not able to draw final conclusions in support of WIPP

conceptual models, yet the interim results may be of interest to understanding the development of the experimental or testing programs, or, some of the information in these reports has been superseded by more recent information. For example, earlier work by Brinster on the geohydrologic model of the region has been updated by the more recent work cited as references in this application.

- Project documents that reflect compliance activities associated with other regulations that, while not directly relevant to the application, are useful in understanding other aspects of the WIPP program and how the DOE has implemented regulations in a complementary fashion. Examples are the RCRA permit application and the No-Migration Variance Petition.

- Documents that are not available or for some reason cannot be obtained in sufficient numbers to comply with the certification criterion regarding the submittal of references.

- Any other document that the DOE believes would be of interest and benefit to the reader.

Chapter 2.0 describes the site and surrounding area as it existed prior to construction of the WIPP repository. Geological descriptions include both regional and local geology including structure, subsurface geology, geomorphology, geologic stability, soils, and topography. This chapter's purpose is to (1) explain the characteristics of the site, (2) describe background environmental quality, and (3) discuss features of the site that are important for inclusion in a quantitative performance assessment. The DOE has used the information in Chapter 2.0 to develop and screen FEPs (see Appendix SCR) and to develop conceptual, mathematical, and computational models to evaluate the efficacy of the natural and engineered barriers in meeting the environmental performance standards (see Section 6.4). Numerical values have been derived for key characteristics of the natural system. Information that supports these characteristics is discussed in Chapter 2.0; however, the specific values used in the performance assessment are presented in Appendix PAR.

Chapter 2.0 is supported by several appendices. These include basic site characterization reports such as Appendices GCR, HYDRO, SUM, DEF, CLI, RBP, SER, and FAC. A summary of these appendices and their role in this application is presented in Table 1-2. Other appendices were prepared specifically for this application. These include Appendices DEL, SCR, TFIELD, and BH. These are also discussed in Table 1-2.

Chapter 3.0 provides technical information about those engineered systems at the WIPP that are important in meeting the disposal standards of 40 CFR Part 191. Descriptions relevant to long-term containment are provided for underground waste disposal and support facilities, and engineered barriers. The DOE provided for independent review of the design and construction prior to allowing the WIPP facility to start up. The purpose of the review is to ensure that the needed systems and procedures are in place and that there are no errors in the

Table 1-2. Appendices That Support Chapter 2.0 and Their Relevance

Appendix	Relevance to Chapter 2.0
BH	Numerous boreholes have been drilled around the WIPP site for characterization purposes and for monitoring. These include holes for geological, hydrological, potash and soil investigations. Information and data from many of these holes were used in the preparation of Chapter 2.0. A compendium of these holes, along with summary physical and geological information is provided in Appendix BH. In addition, reference tables for non-WIPP holes (such as oil wells) that have been used in both site and regional studies by various investigators are provided in Appendix BH.
CLI	Appendix CLI is a technical study that was performed to determine climate change in the recent past as summarized in Chapter 2.0.
DEF	The DOE conducted numerous investigations to resolve the issues surrounding deformation of the evaporites and dissolution of salt. This appendix summarizes those investigations and the conclusions reached as the result. This supplements the summary information in Chapter 2.0.
DEL	The DOE has compiled information regarding drilling in the Delaware Basin. This appendix includes a summary of current drilling practices and current well plugging practices, presents an inventory of deep and shallow wells, and proposes assumptions for the inadvertent human intrusion scenarios in the performance assessment. This appendix supplements the resource discussions in Chapter 2.0.
EMP	The WIPP Environmental Monitoring Plan (EMP) is included in Appendix EMP. It describes the ongoing environmental sampling activities at the WIPP. Results are reported annually. The EMP encompasses all possible environmental pathways along which humans may be exposed to radionuclides. Media sampled include groundwater, surface water, soil, air, airborne particulate, penetrating radiation, vegetation and other biota. The EMP is relevant to the background environmental conditions discussed in Chapter 2.0.
FAC	The WIPP shafts provided an excellent opportunity to study the sediments and evaporites at the WIPP site. This report provides in-depth interpretations of the geological evidence in the shafts and proposes depositional theories for the rocks of the site region. This report is the source of some of the detailed lithological information in Chapter 2.0.
GCR	Much of Chapter 2.0 was prepared based on the 1978 Geological Characterization Report prepared by Sandia National Laboratories (SNL) as a summary of the investigations performed for the WIPP. It includes a summary of work performed in the area by numerous other scientists as well as specific studies funded by the federal government specifically for selecting a radioactive waste disposal facility site. The basic geological features such as stratigraphy, lithology, geomorphology, physiography are established in this report. Discussions of regional features such as dissolution and deformation are included; however, conclusions regarding many of these features are reserved for later studies (see, for example, Appendices SUM and DEF).
HYDRO	The USGS performed investigations and offered interpretations of the hydrological regime in the region around the WIPP site. Much of the subsequent hydrological testing and modeling are the results of the initial observations reported in Appendix HYDRO. Significant portions of the hydrological data in Chapter 2.0 are derived from this report.

Table 1-2. Appendices That Support Chapter 2.0 and Their Relevance (Continued)

Appendix	Relevance to Chapter 2.0
RBP	The first three years of environmental sampling that were conducted at the WIPP site were designed to compile the radiological baseline described in Chapter 2.0 against which future sampling will be compared. These comparisons will allow the DOE to identify instances where the environmental conditions are deteriorating. The DOE investigates all deteriorating environmental conditions to determine if WIPP activities are the cause. Mitigative actions can be taken based on ongoing observations to ensure no irreparable damage results from WIPP activities.
SCR	The natural FEPs that have been identified for the WIPP site region and are discussed in Chapter 2.0 are screened for inclusion in the performance analysis. Appendix SCR documents the screening process and decisions.
SER	The DOE reports environmental conditions at the WIPP and in the vicinity as far away as Hobbs and Carlsbad in an annual site environmental report. The most current report, summarizing environmental measurements made during 1995, is included as Appendix SER to augment the summary background environmental conditions in Chapter 2.0.
SUM	Following the final selection of the site in 1980 and a review by the NAS and the EEG, numerous additional studies were identified to resolve specific site-related issues. These included regional studies, site studies, and underground tests. These were, for the most part, to a point of completion in 1988 that the DOE could prepare a summary of the findings and offer revised interpretations of geological relationships. These results were definitive in developing conceptual models for the FEPs that were expected to act on the WIPP disposal system. This report is the source of some of the detailed information in Chapter 2.0.
TFIELD	As discussed in Chapter 2.0, the hydrological transmissivity of the Culebra is highly variable. Numerous measurements have been made to characterize this parameter. These data have been processed geostatistically to produce an array of transmissivity fields for use in the transport calculations that are part of the performance assessment. The process for generating these fields and the results themselves are included in this appendix.
USDW	The criteria in 40 CFR Part 194 mandate a map showing the location of any underground source of drinking water within the vicinity of the controlled area as discussed in Chapter 8.0. This appendix includes an analysis of the available groundwater information and concludes, based on limited information, that there are three possible underground sources of drinking water near the WIPP controlled area. One is in the Dewey Lake Redbeds, another is in the Santa Rosa Formation, and the other is in the Culebra Member of the Rustler Formation.

design, construction, or operation of the facility. In addition, details are provided for engineered features that significantly impede the movement of radionuclides to the accessible environment. These include shaft and borehole seals, panel closures, and backfill. This chapter is supported by Appendices SEAL, PCS, BACK, BECR, QAPD, and SCR. Table 1-3 summarizes these appendices as they relate to Chapter 3.0.

Table 1-3. Appendices That Support Chapter 3.0 and Their Relevance

Appendix	Relevance to Chapter 3.0
BACK	A backfill consisting of magnesium oxide (MgO) has been defined for the WIPP facility. Its configuration is defined in Chapter 3.0. This appendix contains background information on its purpose and distribution.
BECR	The Biennial Environmental Compliance Report is required by the WIPP LWA. It summarizes the DOE's compliance with applicable environmental protection standards.
EBS	The DOE performed a study of engineered barriers in accordance with the criteria in 40 CFR Part 194. The final report of this study is contained in this appendix. This study was peer reviewed and those results are summarized in Chapter 9.0 and Appendix PEER. This supports the concept of multiple barriers in Section 7.4.
DVR	The Design Validation Report discusses the analysis used in the design of the disposal system.
PCS	Chapter 3.0 discusses the closure of filled waste panels. This appendix contains the design of the Panel Closure System that will be used to close waste panels after they are filled. This closure contains conventional cement and block components to ensure that ventilation air will not enter a closed panel, thereby limiting the amount of volatile organic compounds that may be in the mine air at any given time.
QAPD	The Carlsbad Area Office (CAO) Quality Assurance Program Document (QAPD) defines the QA requirements that are applicable to WIPP quality affecting activities. DOE contractors, specifically Westinghouse Electric Corporation and SNL, have prepared QAPDs that are tiered to the CAO's QAPD. All three are provided in this appendix. Of particular relevance to Chapter 3.0 are those portions that define design and construction activities and maintenance and configuration management of facilities. In addition, the QA standards imposed for operations are included.
SCR	The repository-induced FEPs that have been identified for the WIPP site region and discussed in Chapter 3.0 are screened for inclusion in the performance analysis. Appendix SCR documents the screening process and decisions that are relevant to Chapter 3.0.
SEAL	The final design for repository seals is described in Chapter 3.0. This appendix provides the details of the design, including component descriptions, performance predictions, and materials selections.

Chapter 4.0 describes the wastes to be managed and disposed of at the facility. The waste description includes the definition, sources, types, components, and characteristics of TRU waste planned for emplacement in the repository. The description identifies those physical, chemical, and radiological characteristics of the waste that may singly or in combination affect the ability of the WIPP disposal system to meet the environmental performance standards in 40 CFR Part 191. The DOE has performed an analysis of the waste to determine those components of the waste that are important to the performance of the disposal system. The analysis is detailed in Appendix WCA and Appendix SOTERM. Waste components summarized in Chapter 4.0 are used as input into the performance assessment to determine acceptable ranges for waste components. The acceptable ranges for waste components for waste to be placed in the WIPP facility are contained in Appendix WCL. These were

determined based on the waste parameter values that were used in the performance assessment for this application. These waste ranges will be imposed on the waste generators as limits through the waste acceptance process as criteria in the WIPP Waste Acceptance Criteria document. In addition to Appendices WCA and WCL, Chapter 4.0 is supported by other appendices. These include Appendices SCR, BIR, WAP, and SA. Table 1-4 summarizes the role of each appendix relative to Chapter 4.0.

Table 1-4. Appendices That Support Chapter 4.0 and Their Relevance

Appendix	Relevance to Chapter 4.0
BIR	The DOE has assembled a database of waste information that serves to define the waste-related parameter values for the performance assessment. These data are tabulated in Chapter 4.0. This database covers existing waste and estimates of future waste. The most recent version of this database is in this appendix.
SA	The final step in the performance assessment process is to perform a sensitivity analysis. This is included in this appendix.
SCR	The waste-induced FEPs that have been identified for the TRU waste to be sent to the WIPP are screened for inclusion in the performance analysis. Appendix SCR documents the screening process and decisions that are relevant to Chapter 4.0.
SOTERM	This appendix describes the actinide source term for the WIPP performance calculations. The quantities of radionuclides are based on data summarized in Chapter 4.0.
WAP	The DOE has prepared a comprehensive plan for determining the physical and chemical characteristics of the waste as required by the RCRA. This plan (referred to as the Waste Analysis Plan or WAP) specifies acceptable sampling and analysis techniques and establishes data quality objectives for characterization. In addition, it defines the methodology for collecting and using acceptable knowledge in the characterization process.
WCA	The certification criteria state that the DOE shall perform an analysis of the TRU waste to determine the components that are important to disposal system performance. This analysis, which supports the description of waste components in Chapter 4.0, is presented in this appendix.
WCL	In calculating the performance of the disposal system, the DOE has to set bounding values for the waste components. Within these values, the analyses are valid, and the WIPP can be reasonably expected to comply with the disposal standards. These bounds are presented in this appendix.

Chapter 5.0 describes QA programs and plans for activities described in this application. The certification criteria in 40 CFR Part 194 place significant emphasis on QA. This is appropriate since an adequate QA program can instill a significant amount of confidence in measured data and in complex computational models. The chapter provides the information requested by the EPA in 40 CFR § 194.22. It establishes that the DOE has had a QA program consistent with the requirements of the American Society of Mechanical Engineers (ASME)-Nuclear Quality Assurance(NQA)-1 for many years at the WIPP facility and that the current CAO QAPD mandates, in addition to NQA-1, the ASME NQA-2a-1990 addenda to

NQA-2-1989, Part 2.7, and ASME NQA-3-1989. All WIPP participants who perform work that affects quality are required to have QA programs that meet requirements of the CAO QAPD. Chapter 5.0 documents that the data used in the performance assessment meet the QA requirements established by the EPA.

Chapter 5.0 is supported with Appendix AUD and Appendix QAPD. These are summarized in Table 1-5. In addition, all QA records (including many technical documents) related to this application are available for inspection in records facilities in Carlsbad, Albuquerque, and at other WIPP participant sites. Access to these records can be arranged through the CAO.

Table 1-5. Appendices That Support Chapter 5.0 and Their Relevance

Appendix	Relevance to Chapter 5.0
AUD	The CAO QAPD requires that the WIPP participants undergo independent QA assessments (audits and surveillances) to ensure compliance to the requirements of NQA-1, NQA-2, Part 2.7, and NQA-3. This appendix documents audits and surveillances conducted recently that were not included in Chapter 5.0 directly.
QAPD	The CAO QAPD defines the QA requirements that are applicable to WIPP quality affecting activities. DOE contractors, specifically Westinghouse Electric Corporation and SNL, have prepared QAPDs that are tiered to the CAO's QAPD. All three are provided in this appendix. The QAPDs are an integral part of the Quality Assurance Program described in Chapter 5.0.

Chapter 6.0 details compliance with the containment requirements of 40 CFR § 191.13. Included is a description of the overall system performance assessment methodology used to evaluate the performance of the WIPP disposal system; a comprehensive list of FEPs that might affect the disposal system performance, the screening methodology applied to that list, and the result of the screening process; a summary of the development of the scenarios that were used in the performance assessment; details of the conceptual and computational models used in the performance assessment, the overall flow of information in the performance assessment, and the construction of the performance measure for comparison to the disposal standards; and the results of the performance assessment along with a discussion of the reliability of those results.

Chapter 6.0 is supported by numerous appendices including Appendices BRAGFLO, CCDFGF, CODELINK, CUTTINGS, NUTS, PANEL, PORSURF, SECOFL2D, SECOTP2D, and TFIELD, all of which describe major numerical codes used in the analysis. Performance assessment parameters are in Appendix PAR. Modeling assumptions used in the construction of the conceptual models and the implementation of the mathematical models are in Appendix MASS. Justification for the source term used in the analysis is in Appendix SOTERM. In addition, Appendices SCR, SEAL, CLI, DEL, IRES, EPIC, and SA support Chapter 6.0. Each is discussed in Table 1-6.

Table 1-6. Appendices That Support Chapter 6.0 and Their Relevance

Appendix	Relevance to Chapter 6.0
BRAGFLO	BRAGFLO estimates brine and gas flow everywhere within the controlled area and beyond from the Castile to the surface. Conceptual models implemented in BRAGFLO are discussed in Section 6.4. BRAGFLO couples the flow of brine and gas to other important repository processes such as creep closure and gas generation. The resulting brine-phase, transient flow fields are used by NUTS to simulate radionuclide transport in these flow fields.
CCDFGF	CCDFGF is used to calculate and present statistical performance assessment results. CCDFGF scales BRAGFLO and SECOTP2D results to match radionuclide outputs calculated by NUTS and PANEL. It combines all the calculated release data to simulate many different repository histories, generating random sequences of future events, calculating the probabilities associated with those random sequences, and preparing the data required to produce the CCDF plots that summarize the WIPP's predicted performance as presented in Section 6.5.
CLI	Appendix CLI is a technical study that was performed to determine climate changes in the recent past as a means of anticipating further changes in the next 10,000 years. Climate variation is modeled as described in Section 6.4.9 and Appendix MASS.
CODELINK	This appendix presents overviews of and backgrounds for (1) the principal codes, and (2) the principal code-linkage sequences that support the 1996 performance assessment as reported in Chapter 6.0. Detailed user's manuals, one for each performance assessment code, have been compiled and archived as part of the QA procedure for the performance assessment, and functional descriptions of each modeling code are included elsewhere as appendices.
CUTTINGS	This appendix describes the CUTTINGS_S code. This code estimates the direct removal of radionuclides from the repository as the result of penetration by a borehole inadvertently drilled into the disposal system at some time in the future. The word direct refers to the fact that CUTTINGS_S releases to the surface occur at the time of drilling. The conceptual models for direct release are discussed in Section 6.4.7.
DEL	The DOE has compiled information regarding drilling in the Delaware Basin. This appendix includes a summary of current drilling practices, current well-plugging practices, presents an inventory of deep and shallow wells, and proposes assumptions for the inadvertent human intrusion scenarios in the performance assessment. These data are used in the performance assessment. Section 6.4 contains the conceptual model of drilling.
EPIC	This appendix provides the DOE's rationale for taking credit for 700 years of institutional controls in the calculation of the performance of the disposal system in Chapter 6.0. This means that the likelihood of an inadvertent intrusion during this period of time is significantly diminished by active and passive institutional controls.
IRES	This appendix contains intermediate results calculated during the performance assessment including Latin hypercube sampling (LHS) output for each of the three replicates, time dependent shaft-seal permeabilities used in BRAGFLO, and actinide concentrations as discussed in Chapter 6.0.

Table 1-6. Appendices That Support Chapter 6.0 and Their Relevance (Continued)

Appendix	Relevance to Chapter 6.0
MASS	Numerous modeling assumptions are used to simplify the calculations when such simplifications are justified. This appendix discusses the major modeling assumptions that are used in the WIPP performance assessment and attaches appropriate supportive information. Numerous references to Appendix MASS occur in Chapter 6.0. The appendix also discusses some alternative approaches that were considered by the DOE in developing the conceptual model.
NUTS	NUTS is a radioisotope transport code that is used for the analysis in Chapter 6.0. Its principal capabilities are (1) to decay the inventory, using Bateman's equations, and (2) to transport radionuclide through porous or fractured media. NUTS is capable of resolving and tracking many individual radioisotopes.
PANEL	PANEL is a radionuclide mobilization and decay code that is used for the analysis in Chapter 6.0. Its principal functions are (1) to decay the inventory, using Bateman's equations, and (2) to use the decayed inventory together with the repository brine volume and outflow rate, and the dissolved and colloidal actinide source terms, to estimate the quantity of all modeled radionuclides that are transported up the intrusion borehole.
PAR	Specific parameters are identified in Section 6.4 as necessary to describe the geological system, the hydrological system, engineered systems, and the waste for the purposes of numerical modeling. The parameter values, listed as either ranges or constants, are included in Appendix PAR. Parameter values in Appendix PAR go directly into the performance assessment.
PORSURF	Creep closure of the excavation and the presence of either brine or gas in the waste disposal region both influence the time-dependent changes in void volume in the waste disposal region. In order to vary them in a calculationally efficient manner, a porosity surface is generated. This surface is used by the BRAGFLO code to indirectly couple mechanical closure of the excavation and gas generation to the two-phase fluid flow calculations. This appendix discusses how the porosity surface is generated.
SA	The final step in a Monte Carlo study is sensitivity analysis, which provides information about the sensitivity of the modeling system to uncertainty in specific input parameters. Appendix SA is the sensitivity analysis for the performance assessment described in Chapter 6.0.
SCR	FEPs that have been identified for the WIPP site region are screened for inclusion in the performance analysis. Appendix SCR documents the screening process and decisions. Those that are retained (not screened out) are included in the conceptual models of repository performance as described in Chapter 6.0.
SEAL	The final design for repository seals is described in Chapter 3.0. This appendix provides the details of the design, including component descriptions, performance predictions, and materials selections. Seal parameters are an input to Chapter 6.0. The seal conceptual model is discussed in Section 6.4.4.
SECOFL2D	The SECOFL2D code calculates a groundwater flow field. The two-dimensional groundwater flow is governed by Darcy's Law. Different hydrological transmissivities are specified in the code for every node throughout the region because they vary from node to node. Direct measurements of Culebra transmissivities exist at a number of locations throughout the WIPP region. The DOE used those data to generate an ensemble of fields that define transmissivity values at each node in the computational domain.

Table 1-6. Appendices That Support Chapter 6.0 and Their Relevance (Continued)

Appendix	Relevance to Chapter 6.0
SECOTP2D	For each flow field, SECOTP2D (1) combines the flow results with material and transport parameters that affect radionuclide transport in the Culebra, (2) calculates the concentration of radionuclides everywhere in the local domain as a function of time, and (3) calculates the integrated discharge across user-defined boundaries. The conceptual model implemented by SECOTP2D for the performance assessment is discussed in Section 6.4.6.2.
SOTERM	This appendix describes the actinide source term for the WIPP performance calculations in Chapter 6.0. The source term is defined by the sum of dissolved actinide species and mobile colloidal actinide species. Appendix SOTERM establishes the mobile concentration of actinides that may be released from the repository in brine.
TFIELD	GRASP-INV is used outside of the performance assessment. It generates a field of transmissivities in the Culebra for a regional scale for each of the *n* input vectors. The conceptual model implemented by these codes for the performance assessment is described in Section 6.4.6.2.

Chapter 7.0 describes the DOE's implementation of each of the assurance requirements contained in 40 CFR Part 191. Each of the six sections in this chapter describes one of the six assurance measures required by the disposal standards. In this chapter and associated appendices, the DOE describes its plans for active institutional controls, passive institutional controls, multiple barriers, and monitoring. In addition, the chapter addresses the resource disincentive requirements of 40 CFR § 191.14 and waste removal. Chapter 7.0 is supported with numerous appendices that contain analyses needed for certification. Appendix MON describes the rationale for the monitoring program and addresses the criterion for an analysis of sensitive disposal system parameters to identify candidates for monitoring. Appendix WRAC includes a waste removal feasibility study mandated by the certification criteria. Similarly, Appendix EBS includes the mandated engineered barrier study. Other supporting appendices include Appendices AIC, BACK, D&D, DMP, EMP, EPIC, GTMP, LMP, GWMP, PIC, SA, SMP, and VCMP. Each is summarized in Table 1-7.

Chapter 8.0 describes the DOE's compliance with the individual and groundwater protection requirements in 40 CFR Part 191. Some combinations of sampled parameter values resulted in extremely small releases to the accessible environment within the marker beds in the Salado under undisturbed conditions. These releases are evaluated for compliance to the individual protection and groundwater protection standards and are shown to comply.

Chapter 8.0 is supported by Appendix USDW, which fulfills the criterion to identify underground sources of drinking water in the vicinity of the controlled area, as well as by Appendices GENII and SCR. These are summarized in Table 1-8.

Chapter 9.0 summarizes the results of peer reviews relevant to this application. The certification criteria mandated that the DOE perform peer reviews of the conceptual models,

Table 1-7. Appendices That Support Chapter 7.0 and Their Relevance

Appendix	Relevance to Chapter 7.0
AIC	This appendix includes the DOE's plans for active institutional controls that will be used immediately following facility closure. The appendix provides the rationale for the design and the details of the various measures that the DOE intends to take for active institutional control. Active institutional controls are summarized in Section 7.1.
BACK	A backfill consisting of MgO has been defined for the WIPP facility as an engineered barrier. It substantially delays the movement of radionuclides by limiting their solubility. Its configuration is defined in Chapter 3.0. This appendix contains background information on its purpose and distribution. Backfill fulfills the requirement for implementing the concept of multiple barriers in Section 7.4.
DMP	This appendix contains the Delaware Basin drilling activity surveillance program as described in Section 7.2. This program will focus on those drilling activities whose changes over time may impact the disposal system. These may include drilling rates, drill diameters, and borehole plugging practices.
D&D	The DOE has prepared an initial decommissing and decontamination (D&D) plan for the facility. This plan is in this appendix. A final plan will be prepared just prior to final closure and will reflect the condition of the facility at the time of closure. Documents and regulations applicable to D&D are included in this appendix. This activity precedes active institutional controls as discussed in Section 7.1.
EBS	The DOE performed a study of engineered barriers in accordance with the criteria in 40 CFR Part 194. The final report of this study is contained in this appendix. This study was peer reviewed and those results are summarized in Chapter 9 and Appendix PEER. This supports the concept of multiple barriers in Section 7.4.
EMP	The WIPP EMP is included in Appendix EMP. It describes the ongoing environmental sampling activities at the WIPP site. Results are reported annually. The EMP encompasses all possible environmental pathways along which humans may be exposed to radionuclides. Media sampled include groundwater, surface water, soil, air, airborne particulate, penetrating radiation, vegetation and other biota. The EMP is one monitoring activity that the DOE has committed to continue until after final facility closure. This supports monitoring discussions in Section 7.2.
EPIC	This appendix provides the DOE's rationale for taking credit for 700 years of passive institutional controls in the calculation of the performance of the disposal system. This means that the likelihood of an inadvertent intrusion during this period of time is significantly diminished by active and passive institutional controls. This appendix supports the discussion of passive institutional controls in Section 7.3.
GTMP	This appendix contains the geotechnical surveillance program that the DOE currently operates at the WIPP site and plans to continue to operate as part of the preclosure monitoring system as discussed in Section 7.2. The program will focus on observations of excavation effects such as creep closure and stresses that are useful in detecting deviations in expectations for near-term disturbed rock zone development.

Table 1-7. Appendices That Support Chapter 7.0 and Their Relevance (Continued)

Appendix	Relevance to Chapter 7.0
GWMP	This appendix contains the groundwater surveillance program that the DOE currently operates at the WIPP site and plans to continue to operate as part of the pre- and postclosure monitoring system as discussed in Section 7.2. The program will focus on those characteristics of the Culebra, Magenta Member of the Rustler, and Dewey Lake whose changes over time may be diagnostic of changes in the disposal system. These include water salinity and water levels.
IRD	This appendix supports the discussion in Section 7.5 and documents that the DOE considered natural resources and their impact during site selection and characterization. This discussion, along with the analysis of disposal system performance in Chapter 6.0, shows that the favorable features of the WIPP compensate for any increased risk from the presence of resources.
MON	The DOE has conducted an analysis of the significant performance assessment parameters to determine which, if any, are candidates for monitoring. This analysis is included in this appendix along with the details of how the DOE has selected the parameters that will be subject to monitoring and the rationale for the monitoring methods that are planned as discussed in Section 7.2.
PIC	This appendix contains the DOE's design for passive institutional controls as discussed in Section 7.3. This involves a defense in depth approach that includes monuments, markers, records and archives in addition to continued federal control of the land. The details of the designs and messages to be used are provided.
SA	The final step in the Monte Carlo process is to perform a sensitivity analysis. This is included in this appendix. The sensitivity analysis is used in the process of identifying those parameters that are candidates for monitoring as discussed in Section 7.2.
SMP	This appendix contains the subsidence surveillance program that the DOE plans to operate as the postclosure monitoring system as discussed in Section 7.2. This program monitors subsidence. Subsidence predictions will be compared to actual measurements to investigate any potential deviations that may indicate a change in repository performance.
VCMP	This appendix describes the volatile organic compound confirmatory monitoring plan that will be used to evaluate the efficacy of panel closures. The DOE believes that these measurements may provide information regarding the gas generation process and creep closure processes in closed panels as discussed in Section 7.2.
WRAC	This appendix contains a feasibility study for the removal of most of the waste from the disposal system at some time in the future as discussed in Section 7.6. Conventional mining techniques, coupled with remote-handled (RH) technology, are discussed to show that, even with today's technology, such removal would be possible at any time after facility closure.

the waste characteristics analysis, and the engineered barrier study. In addition, the DOE conducted four other peer reviews. Each of these is discussed along with the findings and recommendations of the peer panels and how the DOE has responded to these findings. Appendix PEER provides details of WIPP peer review activities. Table 1-9 summarizes this appendix.

Table 1-8. Appendices That Support Chapter 8.0 and Their Relevance

Appendix	Relevance to Chapter 8.0
GENII	This appendix contains the code manuals for the numerical codes used to calculate the doses to human receptors as the result of releases to the accessible environment.
SCR	FEPs that have been identified for the WIPP site region are screened for inclusion in the analysis of undisturbed performance. Appendix SCR documents the screening process and decisions. Those FEPs that are determined to be relevant are discussed in Chapter 6.0 in terms of their implementation into the conceptual model. The undisturbed performance analysis in Chapter 6.0 supports Chapter 8.0.
USDW	The criteria in 40 CFR Part 194 mandate a map showing the location of any underground source of drinking water within the vicinity of the controlled area as discussed in Chapter 8.0. This appendix includes an analysis of the available groundwater information and concludes, based on limited information, that there are three possible underground sources of drinking water near the WIPP controlled area. One is in the Dewey Lake, another is in the Santa Rosa, and the other is in the Culebra.

Table 1-9. Appendices That Support Chapter 9.0 and Their Relevance

Appendix	Relevance to Chapter 9.0
PEER	This appendix includes the details of the peer reviews that are discussed in Chapter 9.0. Included are the results of the peer panels deliberations, comments, and DOE responses.

1.6 Statement for the Purposes of 40 CFR Part 194, Subpart A

The DOE has not proposed any alternate provisions to the criteria in 40 CFR Part 194. The Secretary of the DOE has designated the CAO Manager as the appropriate contact with regard to matters associated with this application and applications for recertification. Should any changes occur that significantly affect the assertions and demonstrations in this application, the DOE will inform the EPA in a timely manner and in accordance with the criteria in 40 CFR § 194.4(b)(3).

The major participants in the WIPP program include the DOE, the Scientific Advisor, the WIPP Management and Operating Contractor, and the Management and Operating Contractors at eight major TRU waste generator and storage sites. Access to any site can be gained through the appropriate DOE CAO contact as shown in Table 1-10. The DOE CAO requests that all contact with the generator and storage sites be initiated through the CAO because the DOE has given the CAO management responsibility for all aspects of the TRU waste disposal program.

Table 1-10. Major WIPP Participants and Points of Contact

Name	Location	Point of Contact
DOE Carlsbad Area Office	Carlsbad, NM	Manager, CAO (505) 234-7300
Sandia National Laboratories	Carlsbad, NM	Assistant Manager, Office of Regulatory Compliance (505) 234-7486
Westinghouse Electric Corp.	Carlsbad, NM	Manager, National TRU Program (NTP) (505) 234-7456
Richland Hanford Site	Richland, WA	Manager, NTP (505) 234-7456
Idaho National Engineering Laboratory	Idaho Falls, ID	Manager, NTP (505) 234-7456
Lawrence Livermore National Laboratory	Livermore, CA	Manager, NTP (505) 234-7456
Los Alamos National Laboratory	Los Alamos, NM	Manager, NTP (505) 234-7456
Nevada Test Site	Las Vegas, NV	Manager, NTP (505) 234-7456
Oak Ridge National Laboratory	Oak Ridge, TN	Manager, NTP (505) 234-7456
Rocky Flats Environmental Technology Site	Golden, CO	Manager, NTP (505) 234-7456
Savannah River Site	Aiken, SC	Manager, NTP (505) 234-7456

1.7 Documentation Incorporated by Reference

In accordance with the provisions of 40 CFR § 194.13, the DOE has incorporated the computer code documentation specified in 40 CFR § 194.23 and data records supporting the parameters listed in Appendix PAR into this application by reference. This documentation consists of numerous quality assurance records packages that are filed in the Sandia WIPP Central Files (SWCF). A list of the packages incorporated by reference is provided in Appendix CODELINK and in references to data packages found throughout Appendix PAR. Incorporation by reference is used for the information in these records packages because of their large volume. The DOE will provide copies of the information extracted from QA records, which are incorporated by reference, upon request. In addition, 40 CFR § 194.14(g) requests information regarding the collection of radiological baseline data. This information has been reported by the DOE in the annual site environmental reports for calendar years 1985, 1986, 1987, 1988, and 1989. These reports are also incorporated into this application by reference. The specific titles of these reports are listed in Appendix RBP. Ten copies of these reports are being provided to the EPA. The DOE is also providing the EPA with copies of scientific and technical literature references and other materials used as sources of additional information that supports this application. These are listed as references at the end of each chapter. Ten copies of these materials are provided, as available, to facilitate the EPA's review of the application.

REFERENCES

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026, Vols. 1 and 2. Office of Environmental Restoration and Waste Management, Washington, D.C. WPO 38835, WPO 38838, and WPO 38839.

DOE (U.S. Department of Energy). 1981. Waste Isolation Pilot Plant: Record of Decision. *Federal Register*, Vol. 46, No. 18, p. 9162, January 28, 1981. Office of Environmental Restoration and Waste Management, Washington D.C.

EPA (U.S. Environmental Protection Agency). 1985. "40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes: Final Rule." *Federal Register*, Vol. 50, No. 182, pp. 38066–38089, September 19, 1985. Office of Radiation Programs, Washington, D.C. WPO 39132.

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. *Federal Register*, Vol. 58, no. 242, pp. 66398 – 66416, December 20, 1993. Office of Radiation and Indoor Air, Washington D.C. WPO 39133.

EPA (U.S. Environmental Protection Agency). 1996a. *40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. Federal Register,* Vol. 61, No. 28, pp. 5224 – 5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C. In NWM Library as KF70.A35.C751 1996 (Reference).

EPA (U.S. Environmental Protection Agency). 1996b. *Compliance Application Guidance for 40 CFR Part 194.* EPA 402-R-95-014, March 29, 1996. Office of Radiation and Indoor Air, Washington, D.C. WPO 39159.

ORNL (Oak Ridge National Laboratory). 1973. Site Selection Factors for the Bedded Salt Pilot Plant, ORNL-TM-4219, Oak Ridge National Laboratory, Oak Ridge, TN.

Powers, D.W., Lambert, S.J., Shaffer, S.E., Hill, L.R., and Weart, W.D., eds. 1978. *Geological Characterization Report for the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND78-1596, Vols. I and II. Sandia National Laboratories, Albuquerque, NM. (This document is included as Appendix GCR.)

BIBLIOGRAPHY

NAS-NRC (National Academy of Sciences–National Research Council). 1957. *Disposal of Radioactive Wastes on Land.* Publication 519. National Academy of Sciences, Washington, D.C.

U.S. Congress. 1992. *Waste Isolation Pilot Plant Land Withdrawal Act.* Public Law 102-579, 106 Stat. 4777, October 1992. 102nd Congress, Washington, D.C. WPO 39015.

2.0 SITE CHARACTERIZATION

The U.S. Department of Energy (DOE) uses the performance assessment methodology described in Section 6.1 to demonstrate that the Waste Isolation Pilot Plant (WIPP) disposal system will meet the environmental performance standards of Title 40 of the Code of Federal Regulations (CFR) Part 191 Subparts B and C. In order to effectively use performance assessment, three inputs are necessary: What can happen to the disposal system? What are the chances of it happening? And what are the consequences if it happens? The answers to these questions are derived from many sources, including field studies, laboratory evaluations, experiments, and, in the case of some features not amenable to direct characterization, professional judgment. The information used in performance assessment is described in terms of features of the disposal system that can be used to describe its isolation capability, events that can affect the disposal system, and processes that are reasonably expected to act on the disposal system.

The DOE selected the Los Medaños region and present site for the WIPP based on certain defined siting criteria. The site selection process, which was focused on sites that contained certain favorable features while other unfavorable features were excluded, was applied by the DOE with the intent of finding the area that best met the siting criteria. The siting process is discussed in this application in Appendix GCR. See Table 1-2 in Chapter 1.0 for a list of appendices that provide additional information supporting this chapter.

Conceptual models of the WIPP disposal system simulate the interaction between the natural environment (described in this chapter), the engineered structures (described in Chapter 3.0) and the waste (described in Chapter 4.0). One starting point in developing conceptual models of the WIPP disposal system is an understanding of the natural characteristics of the site and of the region around the site. Site characterization and model development is an interactive process that the DOE has used for many years. Basic site information leads to initial models. Initial model sensitivity studies indicate the need for more detailed information. More site characterization then leads to improved models. In addition, an assessment of the impacts of uncertainty inherent in the parameters used to numerically simulate geological features and processes has also led the DOE to conduct more in-depth investigations of the natural system. These investigations generally proceeded until uncertainty was sufficiently reduced or to the point where no further information could be reasonably obtained.

The discussion of conceptual models and initial and boundary conditions is in Section 6.4 and Appendix MASS (Sections MASS.2 and MASS.4 through MASS.18). Conceptual models implement scenarios about the future. Scenario development is discussed in Section 6.3. Scenario development requires as inputs information about the natural features, events, and processes (FEPs) that can reasonably be expected to act on the disposal system. While the list of possible FEPs is derived independently of the disposal system, their screening (in Section 6.2 and Appendix SCR) is based on a basic understanding of the geology, hydrology, and climatology of the region and the site in particular. The screening methodology follows U.S. Environmental Protection Agency (EPA) criteria on the Scope of Performance Assessments (40 CFR § 191.32). This basic understanding is provided in this chapter and its associated appendices.

Table 2-1 shows the tie between the list of natural FEPs that were identified and screened for the WIPP and the sections of this chapter or Appendix SCR. Those FEPs that have been retained for inclusion in the modeling are shown in bold in Table 2-1. These generally receive a greater level of detail in the following discussions and are supported by additional discussion in Chapter 6.0, Appendix SCR, and Appendix MASS. In addition, parameter values that have been derived for these FEPs are included in Appendix PAR.

In this chapter, the DOE describes the WIPP site geology, hydrology, climatology, air quality, ecology, and cultural and natural resources. This chapter's purpose is to (1) explain characteristics of the site, (2) describe background environmental quality, and (3) discuss features of the site that might be important for inclusion in a quantitative performance assessment. The DOE has used this information to develop and screen FEPs and to develop conceptual, mathematical, and computational models to evaluate the efficacy of natural and engineered barriers in meeting environmental performance standards (Chapter 6.0). Results of these predictive models are used by the DOE to demonstrate that the DOE has a reasonable expectation that compliance with applicable regulations will be achieved. This chapter has been prepared to describe the site prior to excavating the repository. Excavation of the repository and its associated effects, such as the disturbed rock zone (DRZ), are discussed in Chapter 3.0.

The DOE located the WIPP site 26 miles (42 kilometers) east of Carlsbad, New Mexico, in Eddy County (Figure 2-1). Additional details related to the location of the WIPP site can be found in Section 2.1.4.2 (Figure 2-18) and in Figure 3-1 (see Chapter 3.0). The latitude of the WIPP site center is 32°22' 11" N and the longitude is 103°47' 30" W. The region surrounding the WIPP site has been studied for many years, and exploration of both potash and hydrocarbon deposits has provided extensive knowledge of the geology of the region. Two exploratory holes were drilled by the federal government in 1974 at a location northeast of the present site; that location was abandoned in 1975 as a possible repository site after U.S. Energy Research and Development Administration (ERDA)-6 borehole was drilled and unacceptable structure and pressurized brine were encountered. The results of these investigations are reported in Powers et al. (1978, 2 – 6; included in this document as Appendix GCR). During late 1975 and early 1976, the ERDA identified the current site, and an initial exploratory hole (ERDA-9) was drilled. By the time an initial phase of site characterization was completed in August 1978, 47 holes had been or were being drilled for various hydrologic and geologic purposes. Geophysical techniques were applied to augment data collected from boreholes. Since 1978, the DOE has drilled additional holes to support hydrologic studies, geologic studies, and facility design. Geophysical logs, cores, basic data reports, geochemical sampling and testing, and hydrological testing and analyses are reported by the DOE and its scientific advisor, Sandia National Laboratories (SNL), in numerous public documents. Many of those documents form the basis for the DOE's assertions in this application. As necessary, specific references from these documents are cited to reinforce the statements being made.

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP Performance Assessment Scenario Screening

Features, Events, and Processes (FEPs)	Discussion
NATURAL FEPs	
Stratigraphy	
Stratigraphy	Section 2.1.3
Brine reservoirs	Section 2.2.1.2.2
Tectonics	
Changes in regional stress	Section 2.1.5.1
Regional tectonics	Section 2.1.5.1
Regional uplift and subsidence	Section 2.1.5.1
Structural FEPs	
Deformation	
Salt deformation	Section 2.1.6.1
Diapirism	Appendix SCR, Section SCR.1.1.3.1
Fracture development	
Formation of fractures	Section 2.1.5
Changes in fracture properties	Section 2.1.5
Fault movement	
Formation of new faults	Section 2.1.5
Fault movement	Section 2.1.5.4
Seismic activity	
Seismic activity	Section 2.6
Crustal processes	
Igneous activity	
Volcanic activity	Section 2.1.5.4
Magmatic activity	Appendix SCR, Section SCR.1.1.4.1.2
Metamorphic activity	
Metamorphism	Appendix SCR, Section SCR.1.1.4.2
Geochemical FEPs	
Dissolution	
Shallow dissolution	Section 2.1.6.2
Lateral dissolution	Section 2.1.6.2
Deep dissolution	Section 2.1.6.2
Solution chimneys	Section 2.1.6.2
Breccia pipes	Section 2.1.6.2
Collapse breccias	Section 2.1.6.2
Mineralization	
Fracture infills	Section 2.1.3.5.2
SUBSURFACE HYDROLOGICAL FEPs	
Groundwater characteristics	
Saturated groundwater flow	Section 2.2.1

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP Performance Assessment Scenario Screening (Continued)

Features, Events, and Processes (FEPs)	Discussion
Unsaturated groundwater flow	Section 2.2.1
Fracture flow	Section 2.2.1
Density effects on groundwater flow	Section 2.2.1
Effects of preferential pathways	Section 2.2.1
Changes in groundwater flow	
Thermal effects on groundwater flow	Appendix SCR, Section SCR.1.2.2.3
Saline water intrusion	Appendix SCR, Section SCR.1.2.2.1
Freshwater intrusion	Appendix SCR, Section SCR1.2.2.2
Hydrological effects of seismic activity	Appendix SCR, Section SCR.1.2.2.5
Natural gas intrusion	Appendix SCR, Section SCR.1.2.2.4
SUBSURFACE GEOCHEMICAL FEPs	
Groundwater geochemistry	Section 2.4.2.1
Groundwater geochemistry	
Changes in groundwater geochemistry	
Saline water intrusion	Appendix SCR, Section SCR.1.2.2.1
Freshwater intrusion	Appendix SCR, Section SCR.1.2.2.2
Changes in groundwater Eh	Appendix SCR, Section SCR.1.3.2
Changes in groundwater pH	Appendix SCR, Section SCR.1.3.2
Effects of dissolution	Appendix SCR, Section SCR.1.3.2
GEOMORPHOLOGICAL FEPs	
Physiography	
Physiography	Section 2.1.4
Meteorite impact	
Impact of a large meteorite	Appendix SCR, Section SCR.1.4.2
Denudation	
Weathering	
Mechanical weathering	Appendix SCR, Section SCR.1.4.3.1
Chemical weathering	Appendix SCR, Section SCR.1.4.3.1
Erosion	
Eolian erosion	Section 2.1.3.10
Fluvial erosion	Section 2.2.2

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP Performance Assessment Scenario Screening (Continued)

Features, Events, and Processes (FEPs)	Discussion
Mass wasting	Appendix SCR, Section SCR.1.4.3.2
Sedimentation	
Eolian deposition	Appendix SCR, Section SCR.1.4.3.3
Fluvial deposition	Appendix SCR, Section SCR.1.4.3.3
Lacustrine deposition	Appendix SCR, Section SCR.1.4.3.3
Mass wasting	Appendix SCR, Section SCR.1.4.3.3
Soil development	
Soil development	Section 2.1.3.10
SURFACE HYDROLOGICAL FEPs	
Fluvial	
Stream and river flow	Section 2.2.2
Lacustrine	
Surface water bodies	Section 2.2.2
Groundwater recharge and discharge	
Groundwater discharge	Section 2.2.1
Groundwater recharge	Section 2.2.1
Infiltration	Section 2.1.4.2
Changes in surface hydrology	
Changes in groundwater recharge and discharge	Section 2.2.1
Lake formation	Section 2.2.2
River flooding	Section 2.2.2
CLIMATIC FEPs	
Climate	
Precipitation (for example, rainfall)	Section 2.5.2.3
Temperature	Section 2.5.2.2
Climate change	
Meteorological	
Climate change	Section 2.5.1
Glaciation	
Glaciation	Section 2.5.1
Permafrost	Appendix SCR, Section SCR.1.6.2.2
MARINE FEPs	
Seas	
Seas and oceans	Appendix SCR, Section SCR.1.7.1

Table 2-1. Issues Related to the Natural Environment That Were Evaluated for the WIPP Performance Assessment Scenario Screening (Continued)

Features, Events, and Processes (FEPs)	Discussion
Estuaries	Appendix SCR, Section SCR.1.7.1
Marine sedimentology	
Coastal erosion	Appendix SCR, Section SCR.1.7.2
Marine sediment transport and deposition	Appendix SCR, Section SCR.1.7.2
Sea level changes	
Sea level changes	Appendix SCR, Section SCR.1.7.3
ECOLOGICAL FEPs	
Flora & fauna	
Plants	Section 2.4.1
Animals	Section 2.4.1
Microbes	Appendix SCR, Section SCR.1.8.1
Changes in flora & fauna	
Natural ecological development	Section 2.4.1

Biological studies of the site began in 1975 to gather information for the Environmental Impact Statement. Meteorological studies began in 1976, and economic studies were initiated in 1977. Baseline environmental data were initially reported in 1977 and are now updated annually by the DOE.

The DOE located the WIPP disposal horizon within a rock salt deposit known as the Salado Formation (hereafter referred to as the Salado) at a depth of 2,150 feet (650 meters) below the ground surface. The Salado is regionally extensive, includes continuous beds of salt without complicated structure, is deep with little potential for dissolution in the immediate vicinity of the WIPP, and is near enough to the surface to make access reasonable. Particular site selection criteria narrowed the choices when the present site was located during 1975 and 1976, as is discussed in Appendix GCR (2-10 to 2-27) and summarized by Weart (1983).

2.1 Geology

The DOE and its predecessor agencies determined at the outset of the geological disposal program that the geological characteristics of the disposal system are extremely important because the natural barriers provided by the geological units have a significant impact on the performance of the disposal system. Among the DOE's site selection criteria was the intent to maximize the beneficial impacts of the geology. This was accomplished when the DOE selected (1) a host formation that behaves plastically, thereby creeping closed to encapsulate buried waste, (2) a location where the effects of dissolution are minimal and predictable,

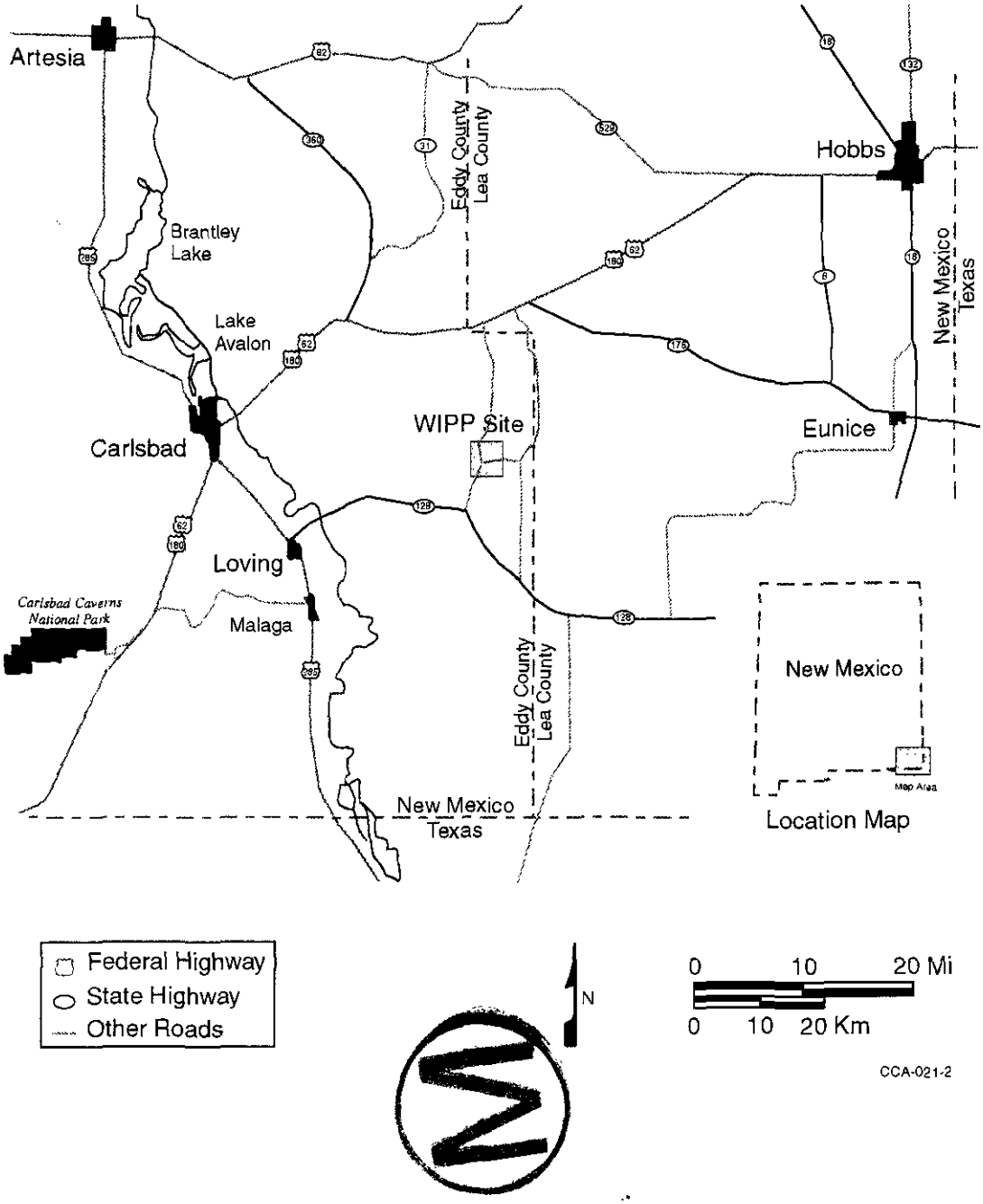

Figure 2-1. WIPP Site Location in Southeastern New Mexico

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(3) an area where deformation of the rocks is low, (4) an area where excavation is relatively easy, (5) an area where future resource development is predictable and minimal, and (6) a repository host rock that is relatively uncomplicated lithologically and structurally. Therefore, a thorough and accurate description of the WIPP facility's natural environmental setting is considered crucial by the DOE for a demonstration of compliance with the disposal standards and is an EPA certification criteria in 40 CFR § 191.14(a). The DOE is providing the detail necessary to assess the achievable degree of waste isolation. In this chapter, the DOE addresses environmental factors and long-term environmental changes that are important for assessing the waste isolation potential of the disposal system. The first of these environmental factors is geology.

Geological data have been collected from the WIPP site and surrounding area to evaluate the site's suitability as a radioactive waste repository. These data have been collected principally by the DOE, the DOE's predecessor agencies, the United States Geological Survey (USGS), the New Mexico Bureau of Mines and Mineral Resources (NMBMMR), and private organizations engaged in natural resource exploration and extraction. The DOE has analyzed the data and has determined that the data support the DOE's position that the WIPP site is suitable for the long-term isolation of radioactive waste. Many issues have been discussed, investigated, and resolved in order for the DOE to conclude that the site is suitable. The DOE discusses these issues in the following sections. Most of the data collected have been reported or summarized in Appendices GCR, SUM, HYDRO, and FAC. These appendices represent the majority of the site characterization results for the WIPP site which ended in 1988. A number of more focused geological and hydrological studies continued after this date. These latter studies, many of which were only recently concluded, provided detailed information needed to construct the conceptual models for disposal system performance that are discussed in Section 6.4. An example of these studies is the H-19 multiwell tracer test that was completed in early 1996. Results of this test have been incorporated into the discussions in this chapter and into the conceptual models described in Section 6.4.6. Model parameters derived from the results are displayed in Appendix PAR. A discussion of the test results is included in Appendix MASS (Section MASS.15).

2.1.1 Data Sources

The geology of southeastern New Mexico has been of great interest for more than a century. The Guadalupe Mountains have become a common visiting and research point for geologists because of the spectacular exposures of Permian-age reef rocks and related facies (see Shumard 1858, Crandall 1929, Newell et al. 1953, and Dunham 1972 in the bibliography). Because of intense interest in both hydrocarbon and potash resources in the region, a large volume of data exists as background information for the WIPP site, though some data are proprietary. Finally, there is the geological information developed directly and indirectly by studies sponsored by the DOE for the WIPP project; it ranges from raw data to interpretive reports.

Elements of the geology of southeastern New Mexico have been discussed or described in professional journals or technical documents from many different sources. These types of articles are an important source of information, and where there is consistency among the technical community, the information in these articles is referenced when subject material is relevant. Implicit rules of professional conduct for research and reporting have been assumed, as have journal and editorial review. Elements of the geology presented in such sources have been deemed critical to the WIPP and have been the subject of specific DOE-sponsored WIPP studies.

The geological data that the DOE has developed explicitly for the WIPP project have been produced over a 20-year period by different organizations and contractors using applicable national standards (Quality Assurance Program history is described in Section 5.2). During a rulemaking in 1988 related to the underground injection of hazardous wastes, the EPA addressed the use of older geological data in making a long-term demonstration of repository performance. In response to comments on a proposed rule regarding the permitting of underground injection wells, the EPA concluded that "[e]xcluding historical data or information which might have been gathered off-site by methods not consistent with certain prescribed procedures may be counterproductive." The EPA further stated that such data should be used as long as their limitations are accounted for. In the final rule, the EPA stipulated "that only measurements pertaining to the waste or that result from testing performed to gather data for the petition demonstration comply with prescribed procedures." Further, the EPA stated that "the concerns about the accuracy of geologic data are addressed more appropriately by requiring that the demonstration identify and account for the limits on data quality rather than by excluding data from consideration" (EPA 1988).

As site characterization activities progressed, the DOE, along with independent review groups such as the National Academy of Sciences (NAS), the Environmental Evaluation Group (EEG), and the state of New Mexico acting through the Governor's Radioactive Waste Consultation Task Force, identified natural FEPs that required additional detailed investigation. Because these investigations, in many cases, were to gather data that would either be used in developing conceptual models or in the prediction of disposal system performance, the quality assurance (QA) standards applied to these investigations were more stringent, thereby ensuring accuracy and repeatability to the extent possible for geologic investigations.

Geological data from site characterization have been developed by the DOE through a variety of WIPP-sponsored studies using drilling, mapping or other direct observation, geophysical techniques, and laboratory work. Most of the techniques and statistics of data acquisition will be incorporated by specific discussion. The processes used in deriving modeling parameters from field and laboratory data are discussed in records packages which support the conceptual models in Section 6.4 and the parameters in Appendix PAR. Pointers to these records packages are provided principally in Appendix PAR. Records packages are stored in the Sandia WIPP Central Files (SWCF) in Albuquerque. Access to review of these records packages can be obtained by contacting the person designated in Table 1-10. Borehole

investigations are a major source of geological data for the WIPP and surrounding area. Borehole studies provide raw data (for example, depth measurements, amount of core, geophysical logs) that support point data and interpreted data sets. These data sets are used in computing other analysis tools such as structure maps for selected stratigraphic horizons or isopachs (thicknesses) of selected stratigraphic intervals.

The borehole data sets that were used specifically for obtaining WIPP geologic information are included as reference information in Appendix BH. This appendix provides some summary information and is a pointer for data reports that contain more detailed results. A map of some borehole locations in the data set is provided in Figure 2-2. These boreholes are the ones used for most of the geological interpretations in this chapter. Other holes are not shown because they were not of sufficient depth, were not cored, or were not drilled for purposes of site characterization. A more comprehensive drillhole database of the entire Delaware Basin is addressed in Section 2.3.1.2 and is presented in Appendix DEL (Figure DEL-4). This database includes all drillholes used in evaluating human intrusion rates for the WIPP performance assessment.

2.1.2 Geologic History

In this section, the DOE summarizes the more important points of the area's geologic history within about 200 miles (320 kilometers) of the WIPP site, with emphasis on more recent or nearby events. Figure 2-3 shows the major elements of the area's geological history from the end of the Precambrian Period.

The geologic time scale that the DOE uses for WIPP is based on the compilation by Palmer (1983, 503 – 504) for *The Decade of North American Geology* (DNAG). There are several compiled sources of chronologic data related to different reference sections or methods (see, for example, Harland et al. 1989 and Salvador 1985 in the bibliography). Although most of these sources show generally similar ages for chronostratigraphic boundaries, there is no consensus on either reference boundaries or most-representative ages. The DNAG scale is accepted by the DOE as a standard that is useful and sufficient for WIPP purposes, as no known critical performance assessment parameters require more accurate or precise dates.

The geologic history in this region can be conveniently subdivided into three general phases:

- A Precambrian Period, represented by metamorphic and igneous rocks ranging in age from about 1.5 to 1.1 billion years.
- A period from about 1.1 to 0.6 billion years ago, from which no rocks are preserved. Erosion may have been the dominant process during much of this period.
- An interval from 0.6 billion years ago to the present represented by a more complex set of mainly sedimentary rocks and shorter periods of erosion and dissolution.

This latter phase is the main subject of the DOE's detailed discussion in this text.

Only a few boreholes in the WIPP region have bored deep enough to penetrate Precambrian crystalline rocks, and, therefore, relatively little petrological information is available. Foster (1974, Figure 3) extrapolated the elevation of the Precambrian surface under the area of WIPP as being between 14,500 feet (4.42 kilometers) and 15,000 feet (4.57 kilometers) below sea level; the site surface at WIPP is about 3,400 feet (1,036 meters) above sea level. Keesey (1976, Vol. II, Exhibit No. 2) projected a depth of about 18,200 feet (5,545 meters) from the surface to the top of Precambrian rocks in the vicinity of the WIPP. The depth projection is based on the geology of the nearby borehole in Section 15, T22S, R31E.

Precambrian rocks of several types crop out in the following locations: the Sacramento Mountains northwest of WIPP; around the Sierra Diablo and Baylor Mountains near Van Horn, Texas; west of the Guadalupe Mountains at Pump Station Hills; and in the Franklin Mountains near El Paso, Texas. East of the WIPP, a relatively large number of boreholes on the Central Basin Platform have penetrated the top of the Precambrian (Foster 1974, Figure 3). As summarized by Foster (1974, 10), Precambrian rocks in the area considered similar to those in the vicinity of the site range in age from about 1.14 to 1.35 billion years.

For about 500 million years (1.1 to 0.6 billion years ago), there is no certain rock record in the region around the WIPP. The most likely rock record for this period may be the Van Horn sandstone (McGowan and Groat 1971), but there is no conclusive evidence that it represents part of this time period (Appendix GCR, Section 3.3.1). The region is generally thought to have been subject to erosion for much of the period until the Bliss sandstone began to accumulate during the Cambrian.

2.1.3 Stratigraphy and Lithology in the Vicinity of the WIPP Site

The conceptual model of the disposal system uses information about the geometry of the various rock layers as a model input as described in Section 6.4.2.1. This means that stratigraphic information (thickness and lateral extent) provided in the following sections are important inputs. In addition, less important features such as the lithology and the presence geochemically significant minerals are provided to support screening arguments in Appendix SCR. Consequently, this discussion has focused on the general properties of the various rock units as determined from field studies. Specific parameters used in the modeling described in Sections 6.4.5 and 6.4.6 are summarized in Appendix PAR (Tables PAR-25 to PAR-32 and PAR-34 to PAR-36). Stratigraphy-related parameters are input as constants. Stratigraphic thicknesses of units considered in modeling are compiled in Appendix PAR (Table PAR-57).

This section describes the stratigraphy and lithology of the Paleozoic and younger rocks underlying the WIPP site and vicinity (Figure 2-4), emphasizing the units nearer the surface. After briefly describing pre-Permian rocks, the section provides detailed information on the Permian (Guadalupian) Bell Canyon Formation (hereafter referred to as the Bell Canyon)—the upper unit of the Delaware Mountain Group—because this is the uppermost

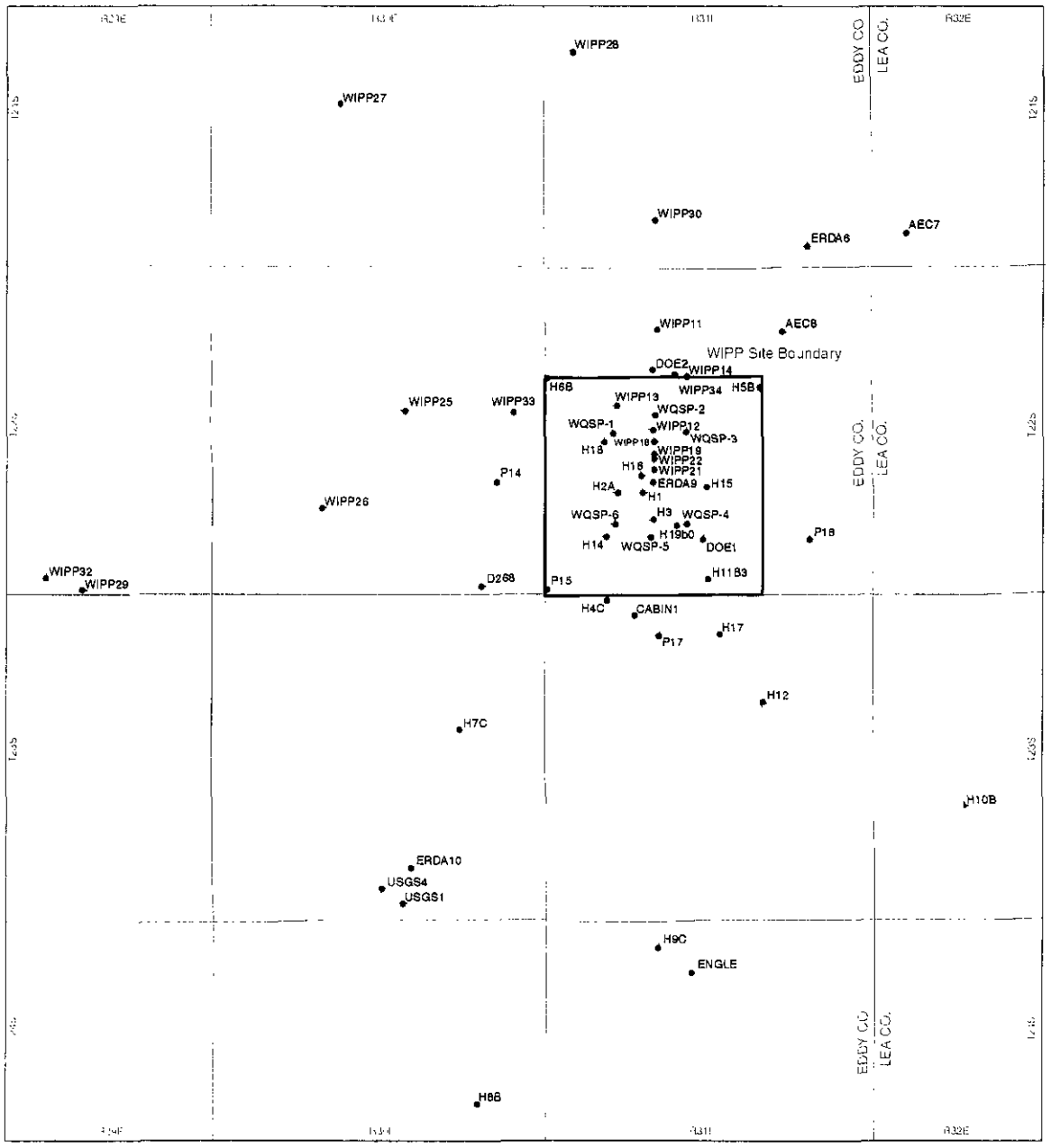

● Borehole Location

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Figure 2-2. WIPP Site and Vicinity Borehole Location Map (partial)

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ERA	PERIOD	EPOCH	YEARS DURATION	YEARS BEFORE PRESENT	MAJOR GEOLOGIC EVENTS - SOUTHEAST NEW MEXICO REGION
CENOZOIC	Quaternary	Holocene	10,000		Eolian and erosion/solution activity. Development of present landscape.
		Pleistocene	1,590,000	1,600,000	Continued deposition of Gatuña sediments.
	Tertiary	Pliocene	3,700,000		Deposition of Gatuña sediments. Formation of caliche caprock. Regional uplift and east-southeastward tilting; Basin-Range uplift of Sacramento and Guadalupe-Delaware Mountains.
		Miocene	18,400,000		
		Oligocene	12,900,000		Erosion dominant. No Early to Mid-Tertiary rocks present.
		Eocene	21,200,000		Laramide revolution. Uplift of Rocky Mountains. Mild tectonism and igneous activity to west and north.
		Paleocene	8,600,000	66,400,000	
MESOZOIC	Cretaceous		77,600,000	144,000,000	Submergence. Intermittent shallow seas. Thin limestone and clastics deposited.
	Jurassic		64,000,000	208,000,000	Emergent conditions. Erosion, formation of rolling terrain. Deposition of fluvial clastics.
	Triassic		37,000,000	245,000,000	Erosion. Broad flood plain develops.
PALEOZOIC	Permian		41,000,000	286,000,000	Deposition of evaporite sequence followed by continental redbeds. Sedimentation continuous in Delaware, Midland, Val Verde basins and shelf areas.
	Pennsylvanian		34,000,000	320,000,000	Massive deposition of clastics. Shelf, margin, basin pattern of deposition develops.
	Mississippian		40,000,000	360,000,000	Regional tectonic activity accelerates, folding up Central Basin platform. Matador arch, ancestral Rockies. Regional erosion. Deep, broad basins to east and west of platform develop.
	Devonian		48,000,000	408,000,000	Renewed submergence. Shallow sea retreats from New Mexico; erosion. Mild epeirogenic movements. Tobosa basin subsiding. Pedernal landmass and Texas Peninsula emergent until Middle Mississippian.
	Silurian		30,000,000	438,000,000	
	Ordovician		67,000,000	505,000,000	Marathon-Quachita geosyncline, to south, begins subsiding. Deepening of Tobosa basin area; shelf deposition of clastics, derived partly from ancestral Central Basin platform and carbonates.
	Cambrian		65,000,000	570,000,000	Clastic sedimentation - Bliss sandstone.
	PRECAMBRIAN				Erosion to a nearly level plain. Mountain building, igneous activity, metamorphism, erosional cycles.

Figure 2-3. Major Geologic Events - Southeast New Mexico Region

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System	Series	Group	Formation	Member
Recent	Recent		Surficial Deposits	
Quaternary	Pleistocene		Mescalero Caliche	
			Gatuña	
Tertiary	Mid-Pliocene		Ogallala	
Triassic		Dockum	Santa Rosa	
Permian	Ochoan		Dewey Lake	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				lower
			Salado	upper
				McNutt Potash
				lower
			Castile	
	Guadalupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

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Figure 2-4. Partial Site Geologic Column

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transmissive formation below the evaporites. The principal stratigraphic data are the chronologic sequence, age, and extent of rock units, including some of the nearby relevant facies changes. For deeper rocks, characteristics such as thickness and depth are summarized from published sources, and for shallower rocks, they are mainly based on data sets presented in Appendix BH (above the Bell Canyon). The lithologies of upper formations and some formation members are described. A comprehensive discussion of stratigraphy in the WIPP area is presented in this application in Appendix GCR. Detailed referencing to original investigations by the USGS and others is included.

2.1.3.1 General Stratigraphy and Lithology below the Bell Canyon

As stated previously, the Precambrian basement near the site is projected to be about 18,200 feet (5,545 meters) below the surface (Keesey 1976, Vol. II, Exhibit No. 2), consistent with information presented by Foster in 1974. Ages of similar rock suites in the region range from about 1.14 to 1.35 billion years.

A detailed discussion of the distribution of Precambrian rocks in southeastern New Mexico and Texas can be found in this application in Appendix GCR (Section 3.3.1). Figure 3.4-2 in Appendix GCR provides a structure contour map of the Precambrian.

The basal Paleozoic units overlying Precambrian rocks are clastic rocks commonly attributed either to the Cambrian Bliss sandstone or the Ellenberger Group (Foster 1974, 10), considered most likely to be Ordovician in age in this area. The Ordovician System comprises the Ellenberger, Simpson, and Montoya Groups in the northern Delaware Basin. Carbonates are predominant in these groups, with sandstones and shales common in the Simpson Group. Foster (1974, Figure 4) reported 975 feet (297 meters) of Ordovician-age rocks north of the site area and extrapolated a thicker section of about 1,300 feet (396 meters) at the present site (Foster 1974, Figure 5). Keesey (1976, Vol. II, Exhibit No. 2) projected a thickness of 1,200 feet (366 meters) for the Ordovician System within the site boundaries.

Silurian-Devonian rocks in the Delaware Basin are not stratigraphically well defined, and there are various notions for extending nomenclature into the basin. Common drilling practice is not to differentiate, though the Upper Devonian Woodford shale at the top of the sequence is frequently distinguished from the underlying dolomite and limestone (Foster 1974, 18). Foster (1974, Figure 6) showed a reference thickness of 1,260 and 160 feet (384 and 49 meters) for the carbonates and the Woodford shale, respectively; he estimated thickness of these units at the present WIPP site to be about 1,150 feet (351 meters) (Foster 1974, Figure 7) and 170 feet (52 meters) (Foster 1974, Figure 8), respectively. Keesey (1976, Vol. II, Exhibit No. 2) projected 1,250 feet (381 meters) of carbonate and showed 82 feet (25 meters) of the Woodford shale.

The Mississippian System in the northern Delaware Basin is commonly attributed to Mississippian limestone and the overlying Barnett shale (Foster 1974, 24), but the nomenclature is not consistently used. At the reference well used by Foster (1974, 25), the

limestone is 540 feet (165 meters) thick and the shale is 80 feet (24 meters); isopachs at the WIPP are 480 feet (146 meters) (Foster 1974, Figure 10) and less than 200 feet (61 meters). Keesey (1976, Vol. II, Exhibit No. 2) indicates 511 feet (156 meters) and 164 feet (50 meters), respectively, within the site boundaries.

The nomenclature of the Pennsylvanian System applied within the Delaware Basin is both varied and commonly inconsistent with accepted stratigraphic rules. Chronostratigraphic, or time-stratigraphic, names are applied from base to top to these lithologic units: the Morrow, Atoka, and Strawn (Foster 1974, 31). Foster (1974, Figure 13) extrapolated thicknesses of about 2,200 feet (671 meters) for the Pennsylvanian at the WIPP site. Keesey (1976, Vol. II, Exhibit No. 2) reports 2,088 feet (636 meters) for these units. The Pennsylvanian rocks in this area are mixed clastics and carbonates, with carbonates more abundant in the upper half of the sequence.

The Permian is the thickest system in the northern Delaware Basin, and it is divided into four series from the base to top: Wolfcampian, Leonardian, Guadalupian, and Ochoan. According to Keesey (1976, Vol. II, Exhibit No. 2), the three lower series total 8,684 feet (2,647 meters) near the site. Foster (1974, Figures 14, 16, and 18) indicates a total thickness for the lower three series of 7,665 feet (2,336 meters) for a reference well north of WIPP. Foster's isopach maps of these series (Foster 1974, Figures 15, 17, and 19) indicate about 8,500 feet (2,591 meters) for the WIPP site area. The Ochoan Series at the top of the Permian is considered in more detail later because the formations host and surround the WIPP repository horizon. Its thickness at DOE-2, about 2 miles (3.2 kilometers) north of the site center, is 3,938 feet (1,200 meters), according to Mercer et al. (1987, 23).

The Wolfcampian Series is also referred to as the Wolfcamp Formation (hereafter referred to as the Wolfcamp) in the Delaware Basin. In the site area, the lower part of the Wolfcamp is dominantly shale with carbonate and some sandstone, according to Foster (1974, Figure 14); carbonate increases to the north (Foster 1974, 36). Clastics increase to the east toward the margin of the Central Basin Platform. Keesey (1976, Vol. II, Exhibit No. 2) reports the Wolfcamp to be 1,493 feet (455 meters) thick at a well near the WIPP site.

The Leonardian Series is represented by the Bone Spring Limestone or Formation (hereafter referred to as the Bone Spring). According to Foster (1974, 35 – 36), the lower part of the formation is commonly interbedded carbonate, sandstone, and some shale, while the upper part is dominantly carbonate. Near the site the Bone Spring is 3,247 feet (990 meters) thick, according to Keesey (1976, Vol. II, Exhibit No. 2).

The Guadalupian Series is represented in the general area of the site by a number of formations exhibiting complex facies relationships (Figure 2-5). The Guadalupian Series is known in considerable detail west of the site from outcrops in the Guadalupe Mountains, where numerous outcrops and subsurface studies have been undertaken. (See, for example, P.B. King 1948, Newell et al. 1953, and Dunham 1972 in the bibliography.)

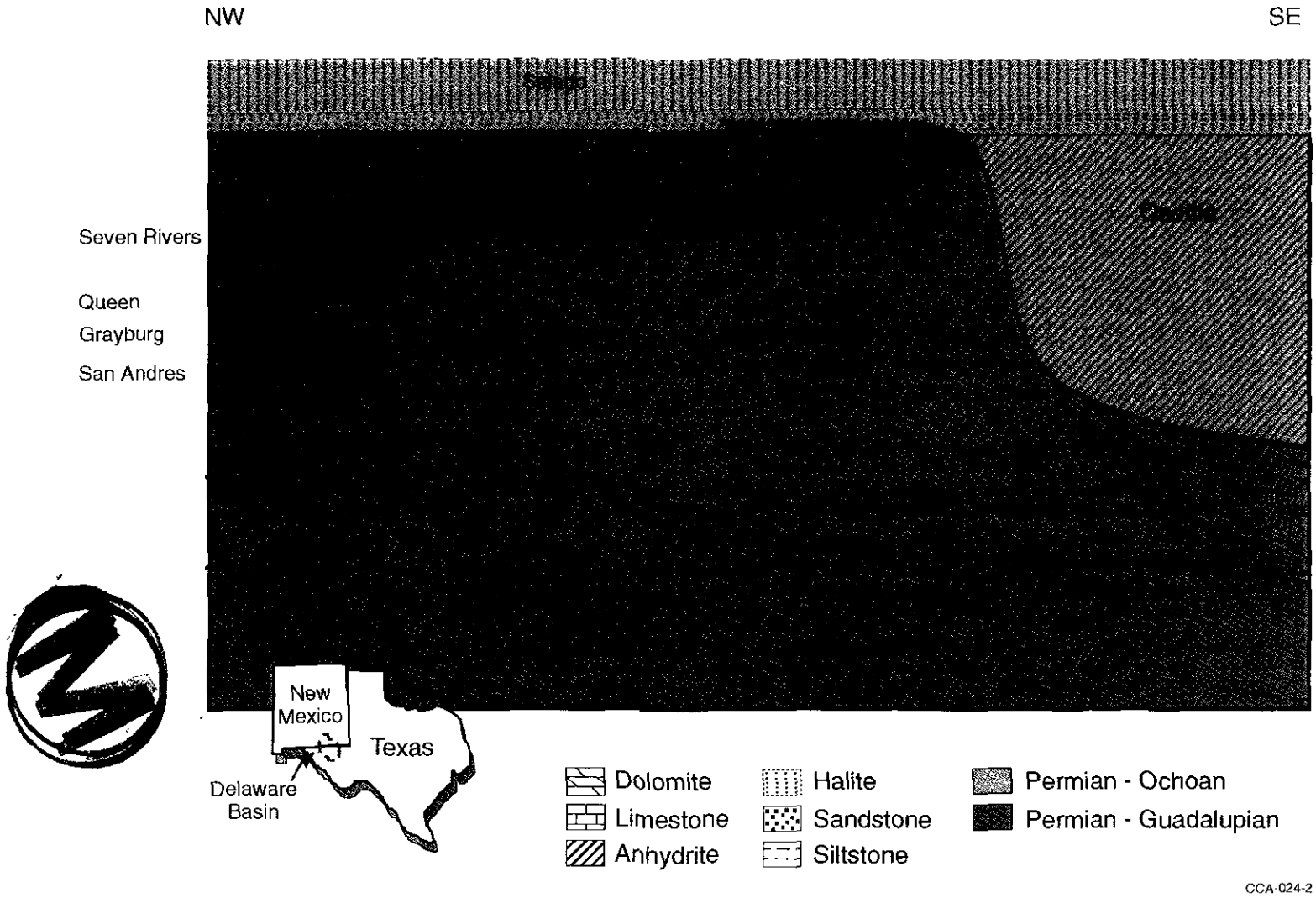

Figure 2-5. Schematic Cross Section from Delaware Basin (southeast) through Marginal Reef Rocks to Back-Reef Facies (based on King, P. B., 1948)

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Within the Delaware Basin, the Guadalupian Series, known as the Delaware Mountain Group, comprises three formations: Brushy Canyon, Cherry Canyon, and Bell Canyon, from base to top. These formations are dominated by submarine channel sandstones with interbedded limestone and some shale. The Lamar limestone generally tops the series, immediately underneath the Castile Formation (hereafter referred to as the Castile). Around the margin of the Delaware Basin, reefs developed when the Cherry Canyon and Bell Canyon were being deposited. These massive reef limestones, the Goat Seep and Capitan Limestones, are equivalent in time to the basin sandstone formations but were developed topographically much higher around the basin margin. A complex set of limestone-to-sandstone and evaporite beds was deposited further away from the basin, behind the reef limestones. The Capitan reef and back-reef limestones are well known because numerous caves, including the Carlsbad Caverns, are partially developed in these rocks.

2.1.3.2 The Bell Canyon

As will be discussed in Section 2.1.3.3, the Castile is a 1,400-to-1,600-foot- (427-to-487-meter-) thick layer of nearly impermeable anhydrites and halites that isolate the Salado from the deeper water-bearing rocks. This notwithstanding, the DOE is interested in the Bell Canyon because it is the first laterally continuous transmissive unit below the WIPP repository. The significance of this unit is related to the FEP in Table 2-1 for deep dissolution. In evaluating this FEP, the DOE considers the potential for groundwater to migrate from the Bell Canyon or lower units into the repository and cause dissolution. The following discussion summarizes the basic understanding of the Bell Canyon lithology. Dissolution is discussed in Section 2.1.6. Bell Canyon hydrology is presented in Section 2.2.1.2. A thorough discussion of dissolution is in Appendix DEF (Section DEF.3.1).

The Bell Canyon is known from outcrops on the west side of the Delaware Basin and from subsurface intercepts for oil and gas drilling. Several informal lithologic units are commonly named during such drilling. Mercer et al. (1987, 28) stated that DOE-2 penetrated the Lamar limestone, the Ramsey sand, the Ford shale, the Olds sand, and the Hays sand. This informal nomenclature is used for the Bell Canyon in some other WIPP reports.

The Clayton Williams Badger Federal borehole (Section 15, T22S, R31E) intercepted 961 feet (293 meters) of Bell Canyon, including the Lamar limestone, according to Keesey (1976, Vol. II, Exhibit No. 2). Reservoir sandstones of the Bell Canyon were deposited in channels that are straight to slightly sinuous. In their 1988 paper, Harms and Williamson proposed that density currents flowed from shelf regions, cutting channels and depositing the sands.

Within the basin, the Bell Canyon- (Lamar limestone-) Castile contact is distinctive on geophysical logs because of the contrast in low natural gamma of the basal Castile anhydrite compared to the underlying limestone. Density or acoustic logs are also distinctive because of the massive and uniform lithology of the anhydrite compared to the underlying beds. In cores, the transition is sharp, as described by Mercer et al. (1987, 312) for DOE-2. A structure contour map of the top of the Bell Canyon is shown in Figure 2-6. Also see Appendix MASS

(Section MASS.18, MASS Attachment 18-6, Figure 5.3-3). According to Powers et al. 1978 (Appendix GCR, 4 – 59) this structure does not reflect the structure of deeper formations, suggesting different deformation histories. The rootless character of at least some of the normal faulting in the lower Permian suggests these are shallow-seated features.

2.1.3.3 The Castile

The Castile is the lowermost lithostratigraphic unit of the Late Permian Ochoan Series (Figure 2-7) and is part of the thick layer of evaporites within the WIPP disposal system. It was originally named by Richardson (1904, 43) for outcrops in Culberson County, Texas. The Castile crops out along a lengthy area of the western side of the Delaware Basin. The two distinctive lithologic sequences now known as the Castile and the Salado were separated into the Upper and Lower Castile by Cartwright (1930). Lang in 1939 clarified the nomenclature by restricting the Castile to the lower unit and naming the upper unit the Salado. By defining an anhydrite resting on the marginal Capitan limestone as part of the Salado, Lang in 1939 effectively restricted the Castile to the Delaware Basin inside the reef rocks.

Through detailed studies of the Castile, Anderson et al. (1972) introduced an informal system of names that is widely used and included in many WIPP reports. The units are named from the base as anhydrite I (A1), halite I (H1), anhydrite II (A2), etc. The informal nomenclature varies through the basin from A3 up because of complexity of the depositional system. The Castile consists almost entirely of thick beds of two lithologies: (1) interlaminated carbonate and anhydrite and (2) high-purity halite.

In the eastern part of the Delaware basin, the Castile is commonly 1,400 to 1,600 feet (427 to 487 meters) thick (derived from Borns and Shaffer 1985, Figures 9, 11, 16). At DOE-2, the Castile is 989 feet (301 meters) thick. The Castile is thinner in the western part of the Delaware Basin, and it lacks halite units. Anderson et al. (1978 and Anderson 1978, Figures 1, 3, 4, 5) correlated geophysical logs throughout the WIPP region, interpreting thin zones equivalent to halite units as dissolution residues. Anderson et al. (1972, 81) further attributed the lack of halite in the basin to its removal by dissolution. A structure contour map of the top of the Castile is reported in Figure 4.4-6 of Appendix GCR based on seismic data gathered for site characterization. In addition, Borns et al. (1983) prepared a seismic time structure of the middle Castile for identifying deformation. This map is shown in Figure DEF-2.2 in Appendix DEF.

For borehole DOE-2, a primary objective was to ascertain whether a series of depressions in the Salado 2 miles (3.3 kilometers) north of the site was from dissolution in the Castile and related processes, as proposed by Davies in his doctoral thesis (1984, 175). Studies have suggested that these depressions were not from dissolution but from halokinesis in the Castile (see, for example, Borns 1987). Robinson and Powers (1987, 22 and 78) interpreted one deformed zone in the Castile as partly caused by synsedimentary, gravity-driven, clastic deposition and suggested that the extent of dissolution may have been overestimated by previous workers. No Castile dissolution is known to be present in the immediate vicinity of

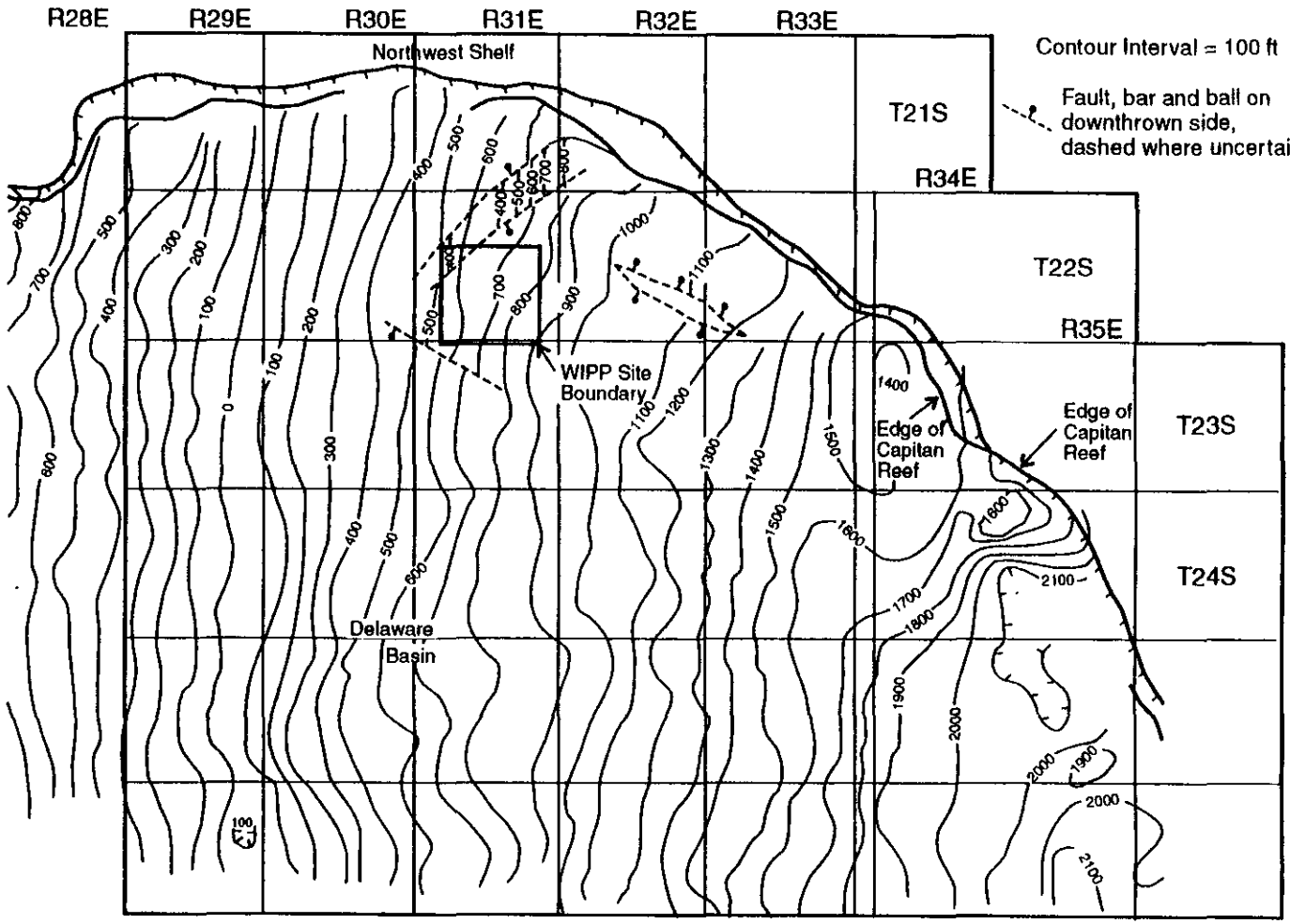

Modified from Borns et al., 1983, Figure 2-3

Figure 2-6. Structure Contour Map of Top of Bell Canyon

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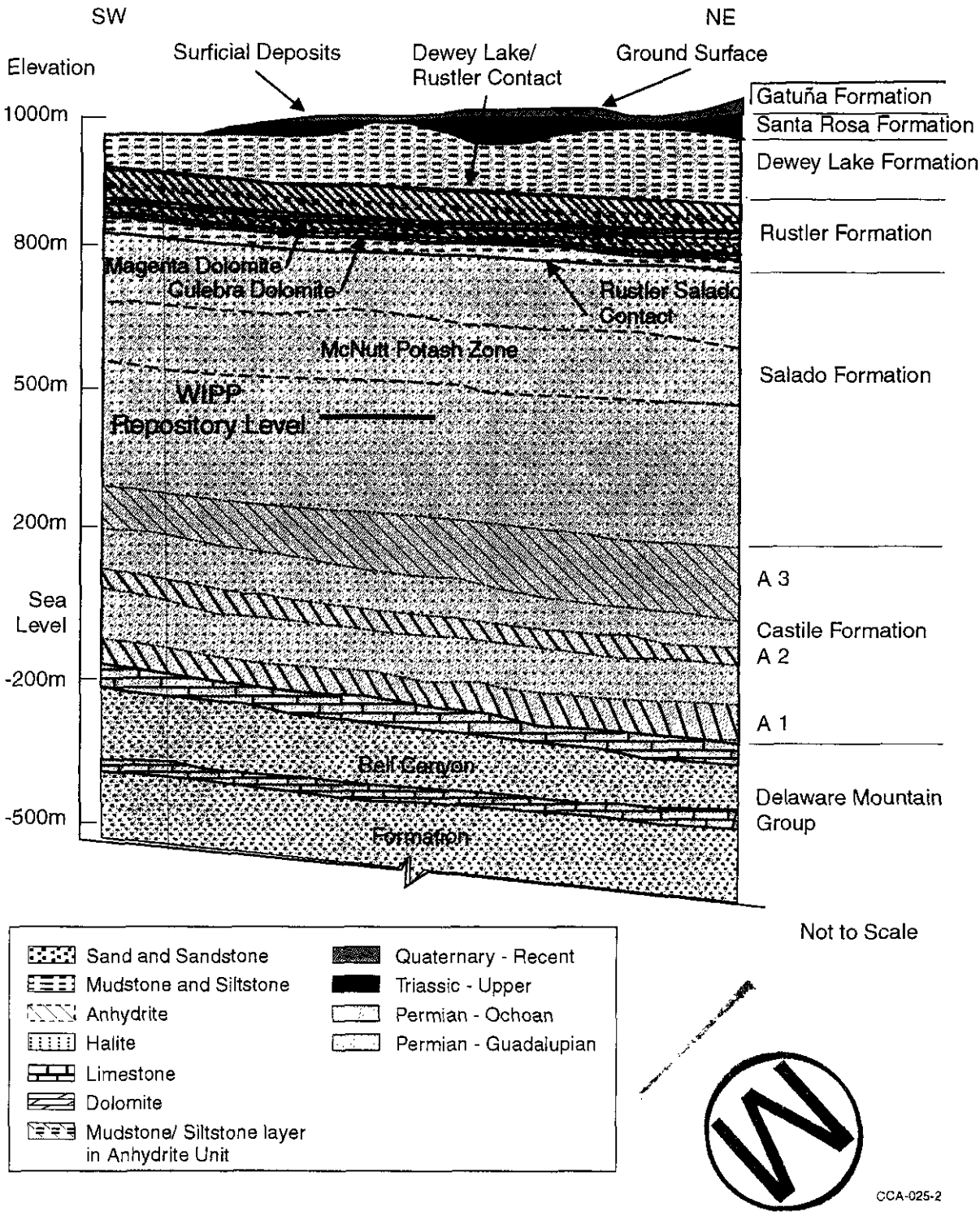

Figure 2-7. Generalized Stratigraphic Cross Section above Bell Canyon Formation at WIPP Site

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the WIPP site. The process of dissolution and the resulting features are discussed later in this chapter. See Appendix DEF (Section DEF.3) for a more in-depth discussion of the study of dissolution in the Castile.

In Culberson County, Texas, the Castile hosts major native sulfur deposits. The outcrops of Castile on the Gypsum Plain south of White's City, New Mexico, have been explored for native sulfur without success, and there is no reported indication of native sulfur anywhere in the vicinity of the WIPP.

In part of the area around the WIPP, the Castile has been significantly deformed and there are pressurized brines associated with the deformed areas; borehole ERDA-6 encountered both deformation and pressurized brine. WIPP-12, 1 mile (1.6 kilometers) north of the site center, revealed lesser Castile structure, but it also encountered a zone of pressurized brine within the Castile. Castile deformation is described and discussed in Section 2.1.5 and in Appendix DEF, which detail structural features. Pressurized brine is described in Section 2.2.1, which details the area's hydrology.

Where they exist, Castile brine reservoirs in the northern Delaware Basin are believed to be fractured systems, with high-angle fractures spaced widely enough that a borehole can penetrate through a volume of rock containing a brine reservoir without intersecting any fractures and therefore not produce brine. They occur in the upper portion of the Castile (Popielak et al. 1983). Appreciable volumes of brine have been produced from several reservoirs in the Delaware Basin, but there is little direct information on the areal extent of the reservoirs or the interconnection between them. The presence of a pressurized brine pocket is treated in the conceptual model of WIPP as discussed in Section 6.4.8.

The Castile continues to be an object of research interest unrelated to the WIPP program as an example of evaporites supposedly deposited in deep water. Anderson (1993, 12 – 13) discusses alternatives and contradictory evidence. Although these discussions and a resolution might eventually affect some concepts of Castile deposition and dissolution, this issue is largely of academic interest and bears no impact on the suitability of the Los Medaños region for the WIPP site. Additional discussion of Castile deformation and the associated WIPP studies appears in Section 2.1.6.1 and Appendix DEF. The Castile is included in the conceptual model as described in Section 6.4.8. As shown in Appendix PAR in Table PAR-49, no stratigraphic or lithologic parameters are of importance for this unit. Important hydrological parameters are discussed subsequently.

2.1.3.4 The Salado

The Salado is of interest because it contains the repository horizon and provides the primary natural barrier for the long-term containment of radionuclides. The following section provides basic information regarding the genesis and lithology of the Salado. Subsequent sections discuss Salado deformation, Salado dissolution, and Salado hydrology. Appendix GCR provides detailed information about the Salado from early site characterization studies.

The Salado is dominated by halite, in contrast to the underlying Castile. The Salado extends well beyond the Delaware Basin, and Lowenstein (1988, 592) has termed the Salado a saline giant.

While the Fletcher Anhydrite Member, which is deposited on the Capitan reef rocks, is defined by Lang (1939; 1942) as the base of the Salado, some investigators consider that the Fletcher Anhydrite Member may interfinger with anhydrites normally considered part of the Castile. The Castile-Salado contact is not uniform across the basin, and whether it is conformable is unresolved. Around the WIPP site, the Castile-Salado contact is commonly placed at the top of a thick anhydrite informally designated A3; the overlying halite is called the infra-Cowden salt and is included within the Salado. Bodine (1978, 28 – 29) suggests that the clay mineralogy of the infra-Cowden in ERDA-9 cores changes at about 15 feet (4.6 meters) above the lowermost Salado and that the lowermost clays are more like Castile clays. At the WIPP site, the DOE recognizes the top of the thick A3 anhydrite as the local contact for differentiating the Salado from the Castile and notes that the distinction is related only to nomenclature and has no relevance to the performance of the WIPP disposal system.

The Salado in the northern Delaware Basin is broadly divided into three informal members. The middle member is known locally as the McNutt Potash Zone (hereafter referred to as McNutt) or member, and it includes 11 defined potash zones, 10 of which are of economic significance in the Carlsbad Potash District. The lower and upper members remain unnamed. The WIPP repository level is located below the McNutt in the lower member. Figure 2-8 shows details of the Salado stratigraphy near the excavated regions. Elements of this stratigraphy are important to the conceptual model. The conceptual model for the Salado is discussed in Section 6.4.5. The thicknesses used in the model are given in Appendix PAR (Table PAR-57).

Within the Delaware Basin, a system is used for numbering the more significant sulfate beds within the Salado, designating these beds as marker beds (MBs) from MB100 (near the top of the formation) to MB144 (near the base). The system is generally used within the Carlsbad Potash District as well as at and around the WIPP site. The repository is located between MB139 and MB138.

In the central and eastern part of the Delaware Basin, the Salado is at its thickest, ranging up to about 2,000 feet (about 600 meters) thick and consisting mainly of interbeds of sulfate minerals and halite, with halite dominating. The thinnest portions of the Salado consist of a brecciated residue of insoluble material a few tens-of-feet thick, which is exposed in parts of the western Delaware Basin. The common sulfate minerals are anhydrite ($CaSO_4$), gypsum ($CaSO_4 \bullet 2H_2O$) near the surface, and polyhalite ($K_2SO_4 \bullet MgSO_4 \bullet 2CaSO_4 \bullet 2H_2O$). They form interbeds and are also found along halite grain boundaries. Isopach maps of various intervals of the Salado above the repository horizon have been provided to assist in understanding regional structure. These are Figures 4.3-4 to 4.3-7 in Appendix GCR. A structure contour map of the Salado can be found in Appendix GCR (Figure 4.4-10).

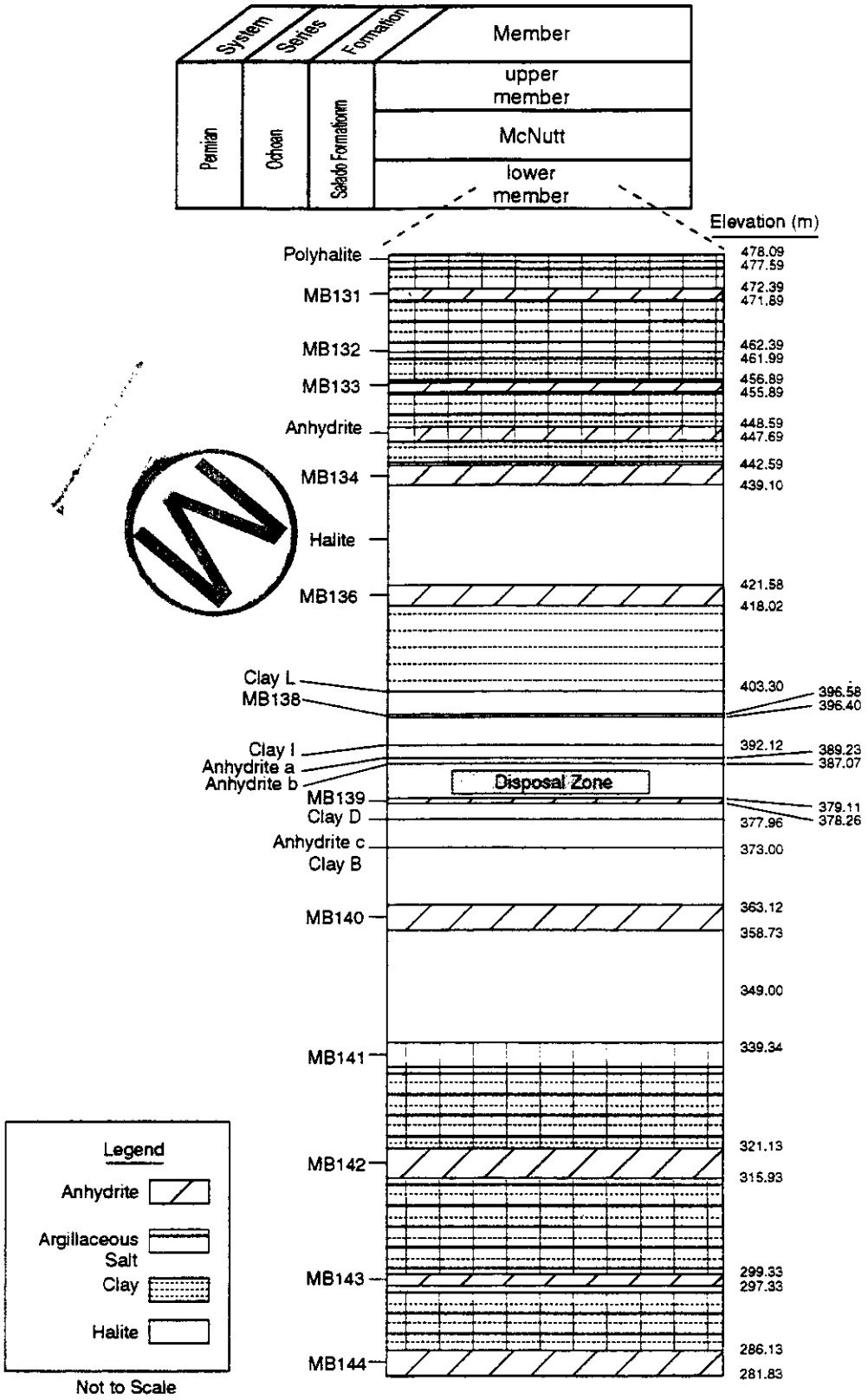

Figure 2-8. Salado Stratigraphy

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In the vicinity of the repository, authigenic quartz (SiO_2) and magnesite ($MgCO_3$) are also present as accessory minerals. Interbeds in the salt are predominantly anhydrite with seams of clay. The clays within the Salado are enriched in magnesium and depleted in aluminum (Bodine 1978, 1). The magnesium enrichment probably reflects the intimate contact of the clays with brines derived from evaporating sea water, which are relatively high in magnesium.

Powers et al. (Appendix GCR, Chapter 7) studied the geochemistry of the rocks in the vicinity of the disposal system. A partial list of minerals found in the Delaware Basin evaporites, together with their chemical formulas, is given in Table 2-2. The table also indicates the relative abundances of the minerals in the evaporite rocks of the Castile, Salado, and Rustler. Minerals found either only at depth, removed from influence of weathering, or only near the surface, as weathering products, are also identified.

Table 2-2. Chemical Formulas, Distributions, and Relative Abundances of Minerals in the Castile, Salado, and Rustler Formations

Mineral	Formula	Occurrence and Abundance
Amesite	$(Mg_4Al_2)(Si_2Al_2)O_{10}(OH)_8$	S, R
Anhydrite	$CaSO_4$	CCC, SSS, RRR (rarely near surface)
Calcite	$CaCO_3$	S, RR
Carnallite	$KMgCl_3 \bullet 6H_2O$	SS
Chlorite	$(Mg,Al,Fe)_{12}(Si,Al)_8O_{20}(OH)_{16}$	S, R
Corrensite	mixed-layer chlorite and smectite	S, R
Dolomite	$CaMg(CO_3)_2$	RR
Feldspar	$(K,Na,Ca)(Si,Al)_4O_8$	C, S, R
Glauberite	$Na_2Ca(SO_4)_2$	C, S (never near surface)
Gypsum	$CaSO_4 \bullet 2H_2O$	CCC (only near surface), S, RRR
Halite	$NaCl$	CCC, SSS, RRR (rarely near surface)
Illite	$K_{1-1.5}Al_4[Si_{7-6.5}Al_{1-1.5}O_{20}](OH)_4$	S, R
Kainite	$KMgClSO_4 \bullet 3H_2O$	SS
Kieserite	$MgSO_4 \bullet H_2O$	SS
Langbeinite	$K_2Mg_2(SO_4)_3$	S
Magnesite	$MgCO_3$	C, S, R
Polyhalite	$K_2Ca_2Mg(SO_4)_4 \bullet 2H_2O$	SS, R (never near surface)
Pyrite	FeS_2	C, S, R
Quartz	SiO_2	C, S, R
Serpentine	$Mg_3Si_2O_5(OH)_4$	S, R
Smectite	$(Ca_{1/2},Na)_{0.7}(Al,Mg,Fe)_4(Si,Al)_8O_{20}(OH)_4 \bullet nH_2O$	S, R
Sylvite	KCl	SS

Legend:

C = Castile
S = Salado
R = Rustler
3 letters = abundant
2 letters = common
1 letter = rare or accessory

Although the most common Delaware Basin evaporite mineral is halite, the presence of less soluble interbeds (dominantly anhydrite, polyhalite, and claystone) and more soluble admixtures (for example, sylvite, glauberite, kainite) has resulted in chemical and physical properties of the bulk Salado that are significantly different from those of pure halite layers contained within it. In particular, the McNutt, between MB116 and MB126, is locally explored and mined for potassium-bearing minerals of economic interest. Under differential stress, interbeds (anhydrite, polyhalite, magnesite, dolomite) may fracture while, under the same stress regime, pure halite would undergo plastic deformation. Fracturing of relatively brittle beds, for example, has locally enhanced the permeability, allowing otherwise nonporous rock to carry groundwater. Some soluble minerals incorporated in the rock salt can be radiometrically dated, and their dates indicate the time of their formation. The survival of such minerals is significant, in that such dating is impossible in pure halite or anhydrite.

Liquids were collected from fluid inclusions and from seeps and boreholes within the WIPP drifts. Analysis of these samples indicated that there is compositional variability in the fluids that shows the effects of various phase transformations on brine composition. The fluid inclusions belong to a different chemical population than do the fluids emanating from the walls. It was concluded that much of the brine is completely immobilized within the salt and that the free liquid emanating from the walls is present as a fluid film along intergranular boundaries, mainly in clays and in fractures in anhydrites. Additional information can be found in Appendix GCR (Sections 7.5 and 7.6).

Early investigators of the Salado recognized a repetitious vertical succession or cycle of beds in the Salado: clay - anhydrite - polyhalite - halite and minor polyhalite - halite. Later investigators described the cyclical units as clay - magnesite - anhydrite or polyhalite or glauberite - halite - argillaceous halite capped by mudstone. Lowenstein (1988, 592 – 608) defined a depositional cycle (Type I) consisting of (1) basal mixed siliciclastic and carbonate (magnesite) mudstone, (2) laminated to massive anhydrite or polyhalite, (3) halite, and (4) halite with mud. Lowenstein also recognized repetitious sequences of halite and halite with mud as incomplete Type I cycles and termed them Type II cycles. Lowenstein (1988, 592 – 608) interpreted the Type I cycles as having formed in a shallowing upward, desiccating basin beginning with a perennial lake or lagoon of marine origin and evaporating to saline lagoon and salt pan environments. Type II cycles are differentiated because they do not exhibit features of prolonged subaqueous deposition and also have more siliciclastic influx than do Type I cycles.

From detailed mapping of the Salado in the air intake shaft (AIS) at WIPP, Holt and Powers (1990a) constructed a more detailed sedimentological analysis of Salado depositional cycles, similar in broad aspects to the Type I cycle of Lowenstein. Argillaceous halites and halitic mudstone at the top of many depositional cycles were interpreted by Holt and Powers (1990a, 3 – 26) in terms of modern features such as those at Devil's Golf Course at Death Valley National Monument, California. The evaporative basin was desiccated, and varying amounts of insoluble residues had collected on the surface through surficial dissolution, eolian sedimentation, and some clastic sedimentation from temporary flooding caused from

surrounding areas. The surface developed local relief that could be mapped in some cycles, while the action of continuing desiccation and exposure increasingly concentrated insoluble residues. Flooding, most commonly from marine sources, reset the sedimentary cycle by depositing a sulfate bed.

The details available from the shaft demonstrated the important role of syndepositional water level to water table changes that created solution pits and pipes within the halitic beds while they were at the surface. Holt and Powers (1990a, Appendix F) concluded that passive halite cements filled the pits and pipes, as well as less dramatic voids, as the water table rose. Early diagenetic to synsedimentary cements filled the porosity early and rather completely with commonly clear and coarsely crystalline halite, reducing the porosity to a very small volume according to Casas and Lowenstein (1989).

Although Holt and Powers (1990a) found no evidence for postdepositional halite dissolution in the AIS, dissolution of the upper Salado halite has occurred west of the WIPP. Effects of dissolution are visible in Nash Draw and at other localities where gypsum karst has formed, where units above the Salado such as the Rustler Formation (hereafter referred to as the Rustler), Dewey Lake Redbeds (hereafter referred to as the Dewey Lake), and post-Permian rocks have subsided. Dissolution studies are summarized in Appendix DEF (Section DEF.3).

Within Nash Draw, Robinson and Lang (1938, 87 – 88) recognized a zone equivalent to the upper Salado but lacking halite. Test wells in southern Nash Draw produced brine from this interval, and it has become known as the brine aquifer. Robinson and Lang considered this zone a residuum from dissolution of Salado halite (see Section 2.1.6.2.1). Jones et al. (1960) remarked that the residuum should be considered part of the Salado, though in geophysical logs it may resemble the Lower Rustler. The approximate eastern limit of the residuum and brine aquifer lies near Livingston Ridge (the eastward margin of Nash Draw) and is marked by a thickening of the Salado (see Section 2.1.6.2.2).

At the center of the site, Holt and Powers (1984, 4 – 9) in their 1984 report recognized clasts of fossil fragments and mapped channeling in siltstones and mudstones above the halite; they considered these beds to be a normal part of the transition from the shallow evaporative lagoons and desiccated salt pans of the Salado to the saline lagoon of the Lower Rustler. Although some Salado halite dissolution at the WIPP may have occurred prior to deposition of the Rustler clastics, this process was quite different from the subsurface removal of salt from the Salado in more recent time that caused the residuum and associated brine aquifer in Nash Draw. Where the Salado halite is buried at depths greater than about 1,000 feet (approximately 300 meters), physical evidence for large-scale dissolution (for example, postdepositional accumulation of insoluble residues, brecciation from differential collapse, and mass removal) is not observed.

Geochronological investigations provide a means to confirm the physical evidence indicating that little or no rock-water interactions have occurred in the Salado at the WIPP since the Late Permian Period. Radiometric techniques provide a means of determining the approximate

time of the latest episode of regional recrystallization of evaporite minerals, which can be inferred to be the approximate time of the latest episode of freely circulating groundwater. Radiometric dates for minerals of the Salado are available from mines and boreholes in the vicinity of the WIPP (Register and Brookins 1980, 39 – 42; Brookins 1980, 29 – 31; Brookins et al. 1980, 635 – 637; Brookins 1981; and Brookins and Lambert 1987, 771 – 780). The distribution of dates shows that rubidium-strontium (Rb-Sr) isochron determinations on evaporite minerals, largely sylvite (214 ± 14 million years ago), are in good agreement with potassium-argon (K-Ar) determinations on pure polyhalites (198 to 216 million years ago). (Potassium-argon ages for sylvite are significantly younger than Rb-Sr ages for the same rocks because of the loss of radiogenic argon. Radiogenic strontium, as a solid, is less mobile than argon and therefore the Rb-Sr isochron method is preferred for sylvite.) Clay minerals have both Rb-Sr and K-Ar ages significantly older (390 ± 77 million years [Register 1981]) than the evaporite minerals, presumably reflecting the detrital origin of the clays.

One significantly younger recrystallization event has been identified in evaporites in the WIPP region and has been shown to be a contact phenomenon associated with the emplacement of an Oligocene igneous dike (see Section 2.1.5.4). Polyhalite near the dike yields a radiometric age of 21 million years, compared to the 32- to 34-million-year age determined for the dike (Brookins 1980, 29 – 31; and Calzia and Hiss 1978, 44) (this number was recalculated to 34.8 ± 0.8 million years [Appendix GCR, 3-80]). This exception notwithstanding, the results of radiometric determinations argue for the absence of pervasive recrystallization of the evaporites in the Salado in the last 200 million years. This conclusion is supported by the number of replicate determinations, the wide distribution of similarly dated minerals throughout the Delaware Basin, and the concordance of dates obtained by various radiometric methods.

The Salado is of primary importance to the containment of waste. Because it is the principal natural barrier, many of the properties of the Salado have been characterized by the DOE, and numerical codes are used by the DOE to simulate the natural processes within the Salado that affect the disposal system performance.

Two conceptual models of the Salado are used in the performance assessment. One models the creep closure properties of the Salado and the other, the hydrological properties. The creep closure of the Salado is discussed in Appendix PORSURF. This model uses key parameters derived from both in-situ measurements and laboratory testing on Salado core samples. Summaries of these parameters are in Appendix PORSURF (PORSURF Attachment 1, Table 2).

The second conceptual model is titled the Salado conceptual model and is discussed in Section 6.4.5. This model divides the Salado into two lithologic units: impure halite and Salado interbeds. The impure halite in this conceptual model is characterized entirely by its hydrological parameters as shown in Table 6-14. The interbeds are characterized by both hydrological parameters in Table 6-15 and fracture properties in Table 6-17. This latter information is needed since the model in Section 6.4.5.2 incorporates the possibility of

interbed fracturing should pressures in the repository become high enough. The modeling assumptions surrounding the fracturing model are discussed in Appendix MASS (Section MASS.13.3).

2.1.3.5 The Rustler

The Rustler is the youngest evaporite-bearing formation in the Delaware Basin. It was originally named by Richardson in 1904 for outcrops in the Rustler Hills of Culberson County, Texas. Adams (1944, 1614) first used the names Culebra Member and Magenta Member to describe the two carbonates in the formation, indicating that Lang favored the names, although Lang did not use these names to subdivide the Rustler in his 1942 publication. Vine (1963, B1) extensively described the Rustler in Nash Draw and proposed the four formal names and one informal term that are still used for the stratigraphic subdivisions of the Rustler. These are as follows (from the base): unnamed lower member, Culebra Dolomite Member, Tamarisk Member, Magenta Dolomite Member, and Forty-niner Member (Figure 2-9). Though it has been suggested by some investigators that the unnamed lower member might be named the Los Medaños Member, this nomenclature has not been formalized and is not adopted here.

Two studies of the Rustler since Vine's 1963 work contribute important information about the stratigraphy, sedimentology, and regional relationships while examining more local details as well. Eager (1983) published a report on relationships of the Rustler observed in the southern Delaware Basin as part of sulfur exploration in the area. Holt and Powers (1988, Section 5.0), reproduced in this application as Appendix FAC, reported the details of sedimentologic and stratigraphic studies of WIPP shafts and cores as well as of geophysical logs from about 600 boreholes in southeastern New Mexico. Their work resulted in the more detailed subdivisions of the Rustler indicated in the right-hand column of Figure 2-9.

The Rustler is regionally extensive; a similar unit in the Texas Panhandle is also called the Rustler. Within the area around WIPP, evaporite units of the Rustler are interbedded with significant siliciclastic beds and the carbonates. Both the Magenta and the Culebra extend regionally beyond areas of direct interest to the WIPP. In the general area of the WIPP, both the Tamarisk and the Forty-niner have similar lithologies: lower and upper sulfate beds and a middle unit that varies principally from mudstone to halite from west to east (Figure 2-9).

In a general sense, halite in the unnamed lower member broadly persists to the west of the WIPP site, and halite is found east of the center of the WIPP in the Tamarisk and the Forty-niner (Figure 2-10).

Two different explanations have been used to account for the halite distribution. An implicit assumption in many documents is that halite was originally deposited relatively uniformly in the noncarbonate members across southeastern New Mexico, including the WIPP site. The modern distribution resulted from dissolution of Rustler halite to the west of the site. As shown in Appendix FAC, sedimentary features and textures within WIPP shafts and cores led

Holt and Powers to propose an alternative interpretation of depositional facies for the mudstone-halite units: halite was dissolved syndepositionally from mudflat facies, especially to the west, and was redeposited in a halite pan to the east. As discussed in Section 2.2.1.4.1.2, regional Culebra transmissivity shows about six orders of magnitude variation across the area around the site and about three orders of magnitude across the site itself. Although some investigators have called attention to the correlation between the distribution of halite in the Rustler and variations in Culebra transmissivity and have attributed the variation to fracturing resulting from postdepositional dissolution of Rustler halite (see, for example, Snyder 1985, 10; and Appendix DEF, Section DEF-3.2), Holt and Powers' work in Appendix FAC largely rules out this explanation. Variations in transmissivity of the Culebra (Beauheim and Holt 1990) have also been correlated qualitatively to the thickness of overburden above the Culebra (see discussion in Section 2.1.5.2), the amount of dissolution of the upper Salado, and the distribution of gypsum fillings in fractures in the Culebra. The DOE believes that variations in Culebra transmissivity are primarily caused by the relative abundance of open fractures in the unit, which may be related to each of these factors. As discussed in Section 6.4.6.2 and Appendix TFIELD, uncertainty in spatial variability in the transmissivity of the Culebra has been incorporated in the performance assessment.

In the region around the WIPP, the Rustler reaches a maximum thickness of more than 500 feet (152 meters) (Figure 2-11), while it is about 300 to 350 feet (91 to 107 meters) thick within most of the WIPP site. Much of the difference in Rustler thickness can be attributed to variations in the amount of halite contained in the formation. Variation in Tamarisk thickness accounts for a larger part of thickness changes than do variations in either the unnamed lower member or the Forty-niner. Details of the Rustler thickness can be found in Appendix GCR (4-39 to 4-42 and Figure 4.3-8; see also Appendix FAC).

Much project-specific information about the Rustler is contained in Appendix FAC. The WIPP shafts were a crucial element in Holt and Powers' 1988 study, exposing features not previously reported. Cores were available from several WIPP boreholes, and their lithologies were matched to geophysical log signatures to extend the interpretation throughout a larger area in southeastern New Mexico. These data are included in Appendix II to Appendix FAC.

2.1.3.5.1 Unnamed Lower Member

The unnamed lower member rests on the Salado with apparent conformity at the WIPP site. It consists of significant proportions of bedded and burrowed siliciclastic sedimentary rocks with cross-bedding and fossil remains. These beds record the transition from strongly evaporative environments of the Salado to saline lagoonal environments. The upper part of the unnamed lower member includes halitic and sulfatic beds within clastics. Holt and Powers (Appendix FAC, 6 – 8) interpret these as facies changes within a saline playa environment and not dissolution residues from postdepositional dissolution.

According to Holt and Powers (Appendix FAC, Figure 4-4), the unnamed lower member ranges in thickness from about 96 to 126 feet (29 to 38 meters) within the site boundaries.

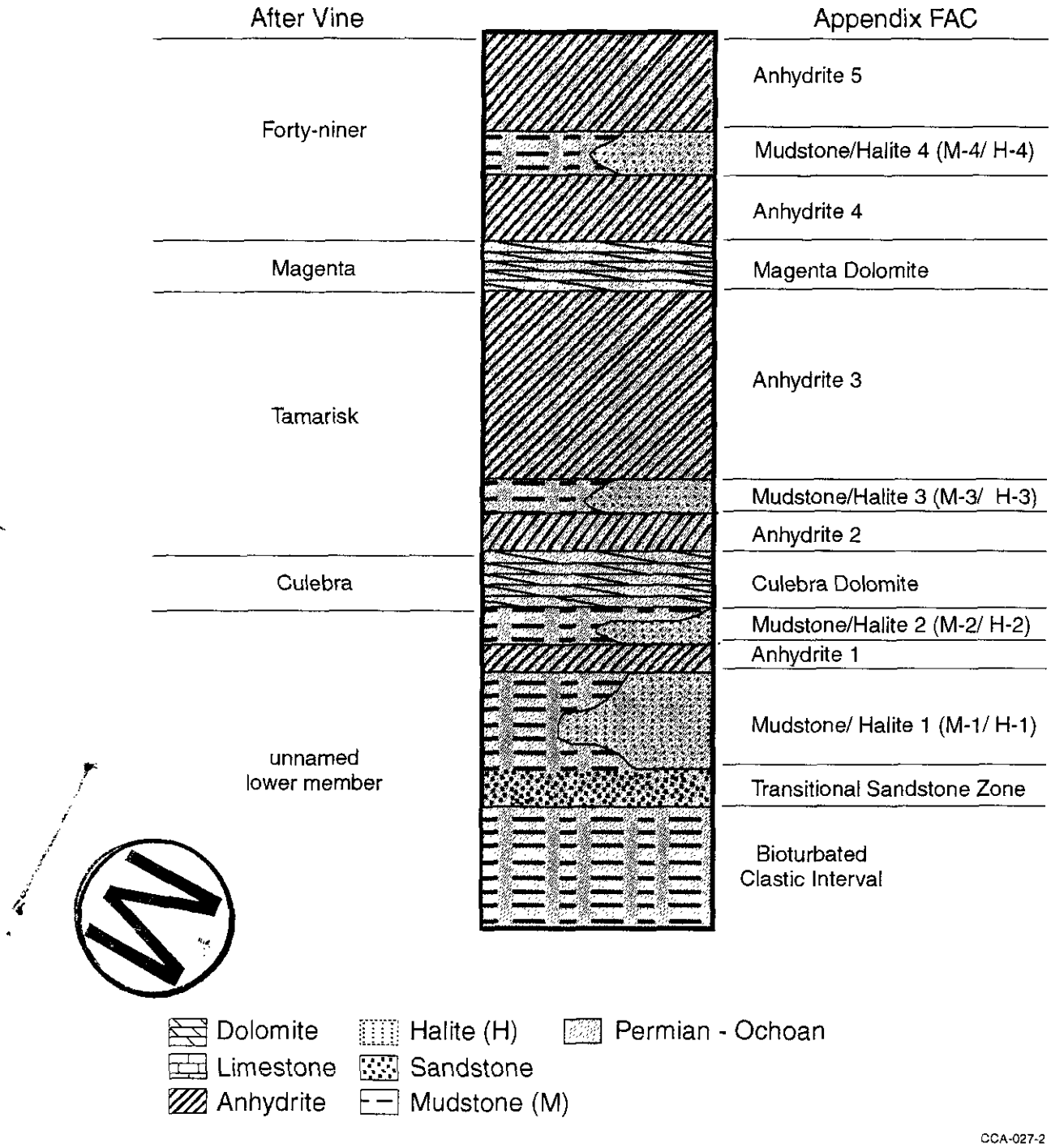

Figure 2-9. Rustler Stratigraphy (From Appendix FAC, Figure 3.2)

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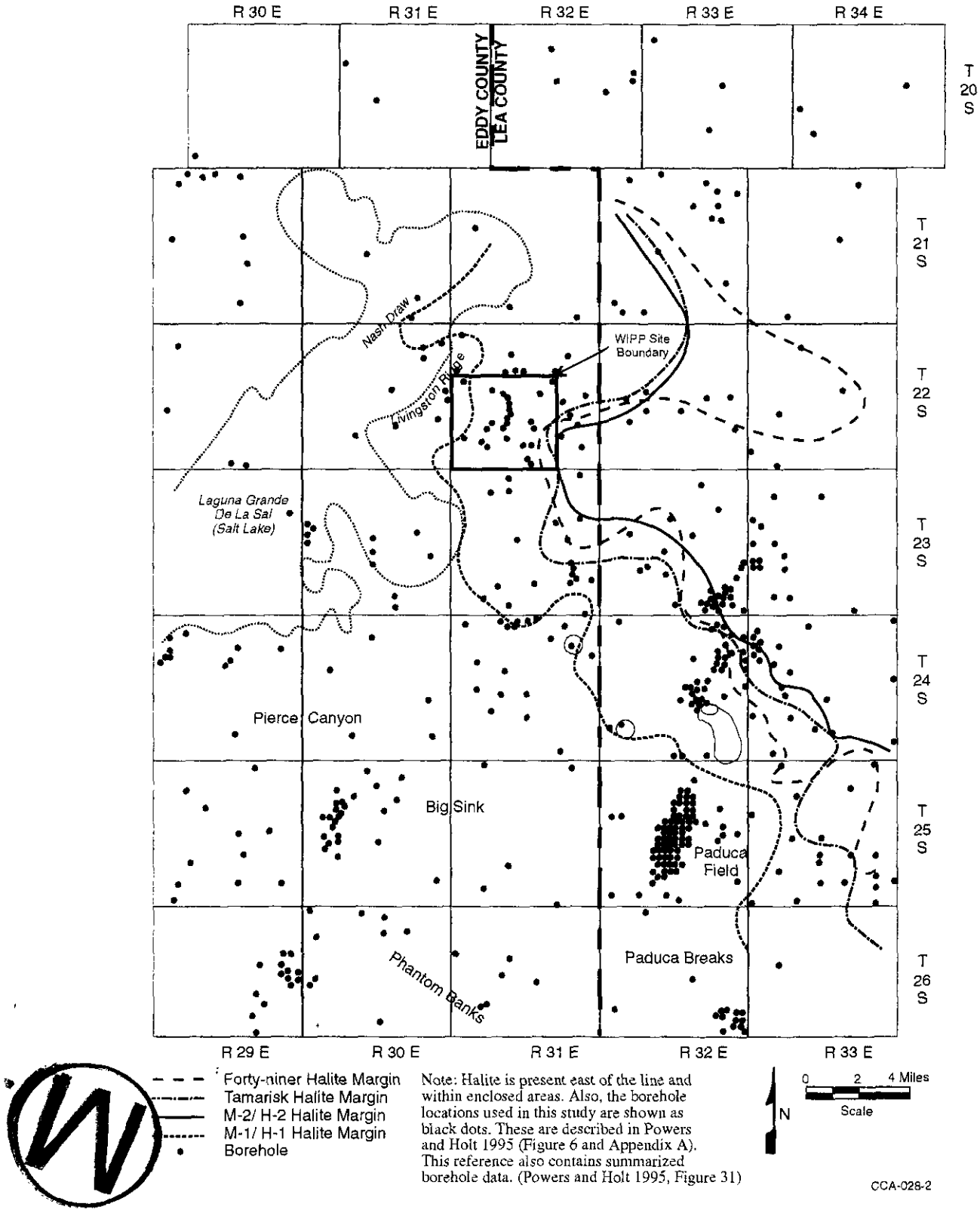

Figure 2-10. Halite Margins in the Rustler

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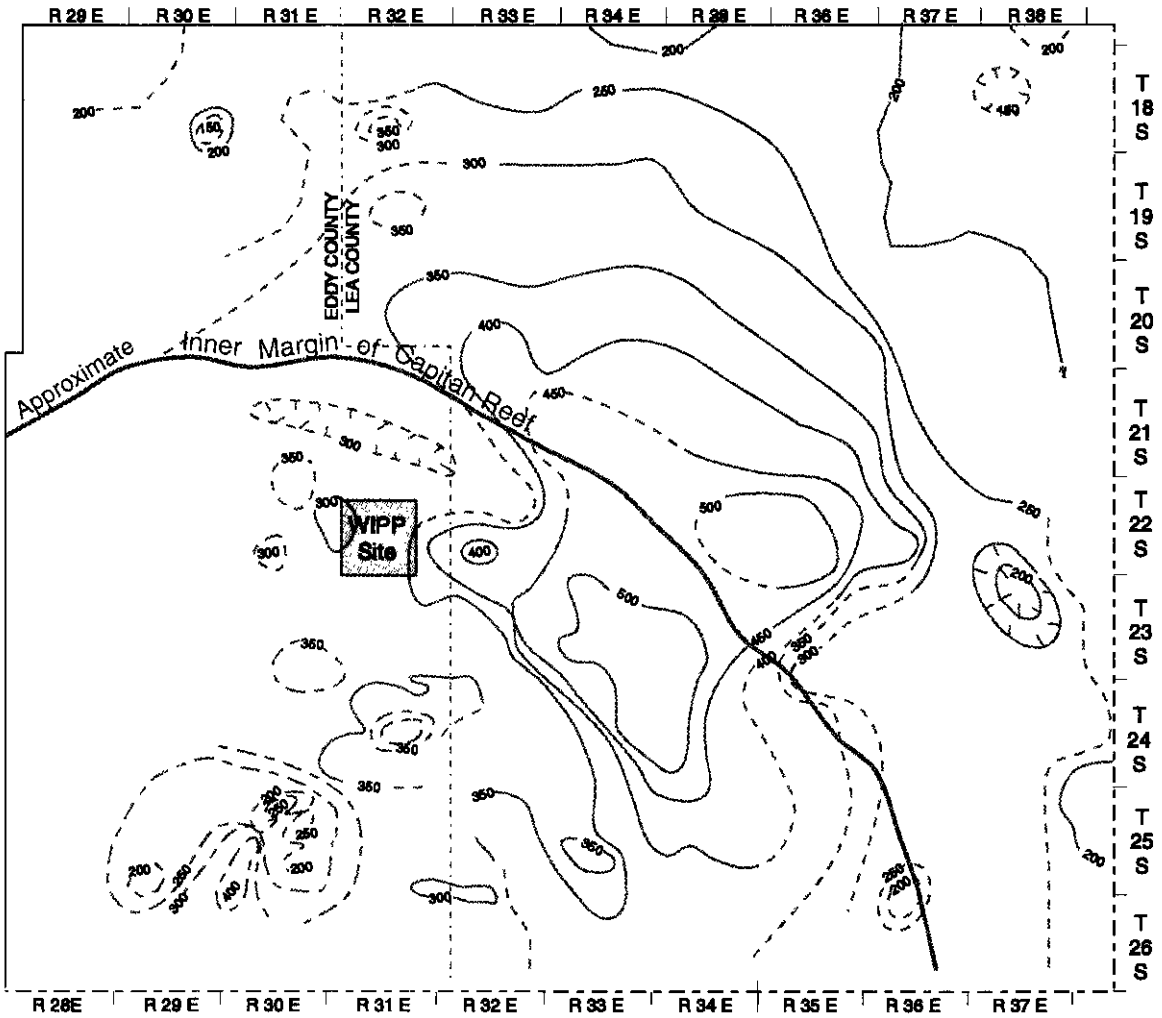

Contour Interval = 50 feet

Source: Powers and Holt (1990)

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Figure 2-11. Isopach Map of the Entire Rustler

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The maximum thickness recorded during that study was 208 feet (63 meters) southeast of the WIPP site. An isopach of the unnamed lower member is shown as Figure 4-7 in Appendix FAC.

Halite is present in the MI/HI unit of the unnamed lower member west of most of the site area (see Figure 2-10 for an illustration of the halite margins). Cross sections based on geophysical log interpretations by Holt and Powers (Appendix FAC) show that the unit is thicker to the east where the halite is more abundant.

The unnamed lower member is incorporated into the conceptual model as described in Section 6.4.6.1. Model parameters are in Appendix PAR (Table PAR-31).

2.1.3.5.2 The Culebra

The Culebra rests with apparent conformity on the unnamed lower member, though the underlying unit ranges from claystone to its lateral halitic equivalent in the site area. West of the WIPP site, in Nash Draw, the Culebra is disrupted from dissolution of underlying halite. Holt and Powers (Appendix FAC, Section 8.9.3) principally attribute this to dissolution of Salado halite, while Snyder (1985, 6) indicates that salt was dissolved postdepositionally from the unnamed lower member. These alternative interpretations offer differing explanations of how the existing Rustler hydrologic system developed and might continue to develop. Culebra hydrology and its significance to disposal system performance are discussed in detail in Section 2.2.1.4.1.2.

The Culebra was described by Robinson and Lang (1938, 83) as a dolomite 35 feet (11 meters) in thickness. The Culebra is generally brown, finely crystalline, locally argillaceous and arenaceous dolomite with rare to abundant vugs with variable gypsum and anhydrite filling; Adams (1944, 1614) noted that oölites are present in some outcrops as well. Holt and Powers (Appendix FAC, 5 – 11) describe the Culebra features in detail, noting that most of the Culebra is microlaminated to thinly laminated, while some zones display no depositional fabric. Holt and Powers (1984) described an upper interval of the Culebra consisting of medium brown, microlaminated carbonate that thickens up to 2 feet (.6 meters) in the vicinity of dome structures and is of probable algal origin. This is underlain by a .25-to-1-inch- (.64-to-2.56-centimeter-) thick bed of cohesive black claystone. Because of the unique organic composition of this thin layer, Holt and Powers did not include it in the Culebra for thickness computations, and this will be factored into discussions of Culebra thickness. Based on core descriptions from the WIPP project, Holt and Powers (Appendix FAC) concluded that there is very little variation of depositional sedimentary features throughout the Culebra.

Vugs are an important part of Culebra porosity. They are commonly zoned parallel to bedding. In outcrop, vugs are commonly empty. In the subsurface, vugs range from open to partially filled or filled with anhydrite, gypsum, or clay (Holt and Powers 1990a, 3-18 to 3-20). Lowenstein (1987, 19 – 20) noted similar features. Holt and Powers (Appendix FAC)

attributed vugs partly to syndepositional growth as nodules and partly as later replacive textures. Lowenstein (1987, 29 – 31) also described textures related to later replacement and alteration of sulfates. Vug or pore fillings vary across the WIPP site and contribute to the porosity structure of the Culebra. As pointed out by Holt and Powers (see Appendix FAC, Section 8.8), natural fractures filled with gypsum are common east of the WIPP site center and in a smaller area west of the site center (Figure 2-12). Section 2.1.5.2 discusses Culebra fracture mechanisms. Additional discussion of Culebra fractures and their role in groundwater flow and transport is in Section 2.2.1.4.1.1 and Appendix MASS (Sections MASS.14.2 and MASS.15).

Sewards et al. (1991, IX-1) report that the Culebra is primarily dolomite with some quartz and clay. Clay minerals include corrensite, illite, serpentine, and chlorite. Clay occurs in bulk rock and on fracture surfaces. Even though these clays occur, the conceptual model discussed in Section 6.4.6.2.1 takes no credit for their presence.

In the WIPP area, the Culebra varies in thickness. Depending on the area considered and the horizons chosen for the upper and lower boundaries of the Culebra, different data sources provide varying estimates (Table 2-3). Holt and Powers (Appendix FAC, 4-4) considered the organic-rich layer at the Culebra-Tamarisk contact separately from the Culebra in interpreting geophysical logs.

Table 2-3. Culebra Thickness Data Sets

	Data Set Location								
	T22S, R31E			T21-23S, R30-32E			Entire Set		
Source	**n**	**ave**	**std dev**	**n**	**ave**	**std dev**	**n**	**ave**	**std dev**
Richey (1989)	7	7.5 m	1.04 m	115	7.9 m	1.45 m	633	7.7 m	1.65 m
Appendix FAC	35	6.4 m	0.59 m	122	7.0 m	1.26 m	508	6.5 m	1.89 m
LaVenue et al. (1988)							78	7.7 m	
Source	**WIPP Potash Drillholes**								
Jones (1978)				21	7.5 m	0.70 m			
Appendix FAC				21	6.3 m	0.50 m			

Legend:

n number of boreholes or data points
ave average or mean
std dev standard deviation
m meters

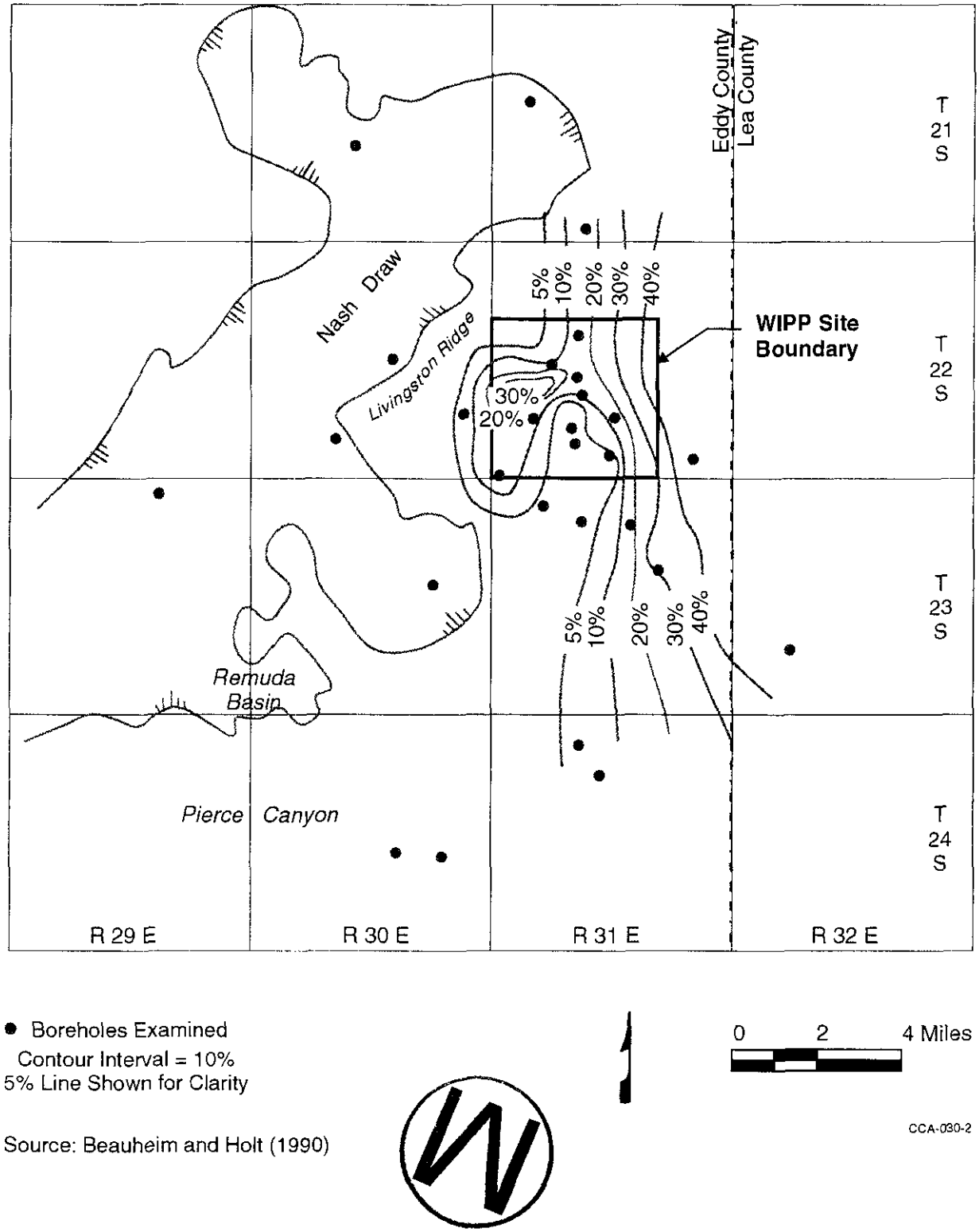

Figure 2-12. Percentage of Natural Fractures in the Culebra Filled with Gypsum

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Comparing data sets, Holt and Powers (Appendix FAC) typically interpret the Culebra as being about 3 feet (about 1 meter) thinner than do other interpretations. In general, this reflects the difference between including or excluding the unit at the Culebra-Tamarisk contact. Holt and Powers isopach of the Culebra is shown as Figure 4.8 in Appendix FAC.

LaVenue et al. (1988, Table B.1) calculated a mean thickness of 25 feet (7.7 meters) for the Culebra within their model domain based on thicknesses measured in 78 boreholes. Mercer (1983, reproduced here as Appendix HYDRO) reported a data set similar to that of LaVenue et al (Table 1 of Appendix HYDRO). The borehole database for the region of interest is provided in Appendix BH.

The treatment of the Culebra in the conceptual model is discussed in Section 6.4.6.2 and associated parameter values in Table 6-18. A more thorough discussion of Culebra features, such as fractures, is provided in Appendix MASS (Section MASS.15).

2.1.3.5.3 <u>The Tamarisk</u>

Vine (1963, B14) named the Tamarisk for outcrops near Tamarisk Flat in Nash Draw. Outcrops of the Tamarisk are distorted, and subsurface information was used to establish member characteristics. Vine reported two sulfate units separated by a siltstone, about 5 feet (1.5 meters) thick, interpreted by Jones et al. in 1960 as a dissolution residue.

The Tamarisk is generally conformable with the underlying Culebra. The transition is marked by an organic-rich unit interpreted as being present over most of southeastern New Mexico. The Tamarisk around the WIPP site consists of lower and upper sulfate units separated by a unit that varies from mudstone (generally to the west) to mainly halite (to the east). Near the center of the WIPP site, the lower anhydrite was partially eroded during deposition of the middle mudstone unit, as observed in the WIPP waste-handling and exhaust shafts. The lower anhydrite was completely eroded at WIPP-19. Before shaft exposures were available, the lack of the Lower Tamarisk anhydrite at WIPP-19 was interpreted as the result of dissolution and the mudstone was considered a cave filling.

Jones interprets halite to be present east of the center of the WIPP site based on geophysical logs and drill cuttings. Based mainly on cores and cuttings records from the WIPP potash drilling program, Snyder prepared a map in 1985 showing the halitic areas of each of the noncarbonate members of the Rustler (Snyder 1985, Figure 4). A very similar map based on geophysical log characteristics was prepared by Holt and Powers (1988).

Holt and Powers (Appendix FAC) describe the mudstones and halitic facies in the middle of the Tamarisk and postulate that the unit formed in a salt-pan-to-mudflat system. Holt and Powers cited sedimentary features and the lateral relationships as evidence of syndepositional dissolution of halite in the marginal mudflat areas. In contrast, other investigators interpreted

the lateral decrease in thickness and absence of halite to the west as evidence of postdepositional dissolution (see, for example, Jones et al. 1960, Jones 1978, and Snyder 1985).

The Tamarisk thickness varies greatly in southeastern New Mexico, principally as a function of the thickness of halite in the middle unit. Within T22S, R31E, the thickness ranges from 84 to 184 feet (26 to 56 meters) for the entire Tamarisk and from 6 to 110 feet (2 to 34 meters) for the interval of mudstone-halite between lower and upper anhydrites (Appendix FAC, Figures 4-9 and 4-11). Expanded geophysical logs with corresponding lithology illustrate some of the lateral relationships for this interval (Figure 2-13).

The Tamarisk is modeled as discussed in Section 6.4.6.3. Tamarisk parameter values are given in Appendix PAR (Table PAR-29).

2.1.3.5.4 *The Magenta*

Adams (1944, 1614) attributes the name Magenta Member to Lang, based on a feature named Magenta Point north of Laguna Grande de la Sal. According to Holt and Powers (Appendix FAC), the Magenta is a gypsiferous dolomite with abundant primary sedimentary structures and well-developed algal features. It does not vary greatly in sedimentary features across the site area.

Holt and Powers (Appendix FAC, 5-22) reported that the Magenta varies from 23 to 28 feet (7.0 to 8.5 meters) around the WIPP site. Additional detail on the Magenta can be found in Section 4.3.2 of Appendix GCR and in Sections 4.1.4, 4.2.4, and 5.4 of Appendix FAC. Holt and Powers did not prepare a regional Magenta isopach.

The Magenta is included in the conceptual model as discussed in Section 6.4.6.4. Modeling values are in Table 6-22.

2.1.3.5.5 *The Forty-niner*

Vine (1963) named the Forty-niner for outcrops at Forty-niner Ridge in eastern Nash Draw, but the unit is poorly exposed there. In the subsurface around the WIPP, the Forty-niner consists of basal and upper sulfates separated by a mudstone. It is conformable with the underlying Magenta. As with other members of the Rustler, geophysical log characteristics can be correlated with core and shaft descriptions to extend geological inferences across a large area.

The Forty-niner varies from 43 to 77 feet (13 to 23 meters) thick within T22S, R31E. East and southeast of the WIPP, the Forty-niner exceeds 80 feet (24 meters), and some of the geophysical logs from this area indicate that halite is present in the beds between the sulfates. A regional isopach map of the Forty-niner is in Appendix FAC (Figures 4-13).

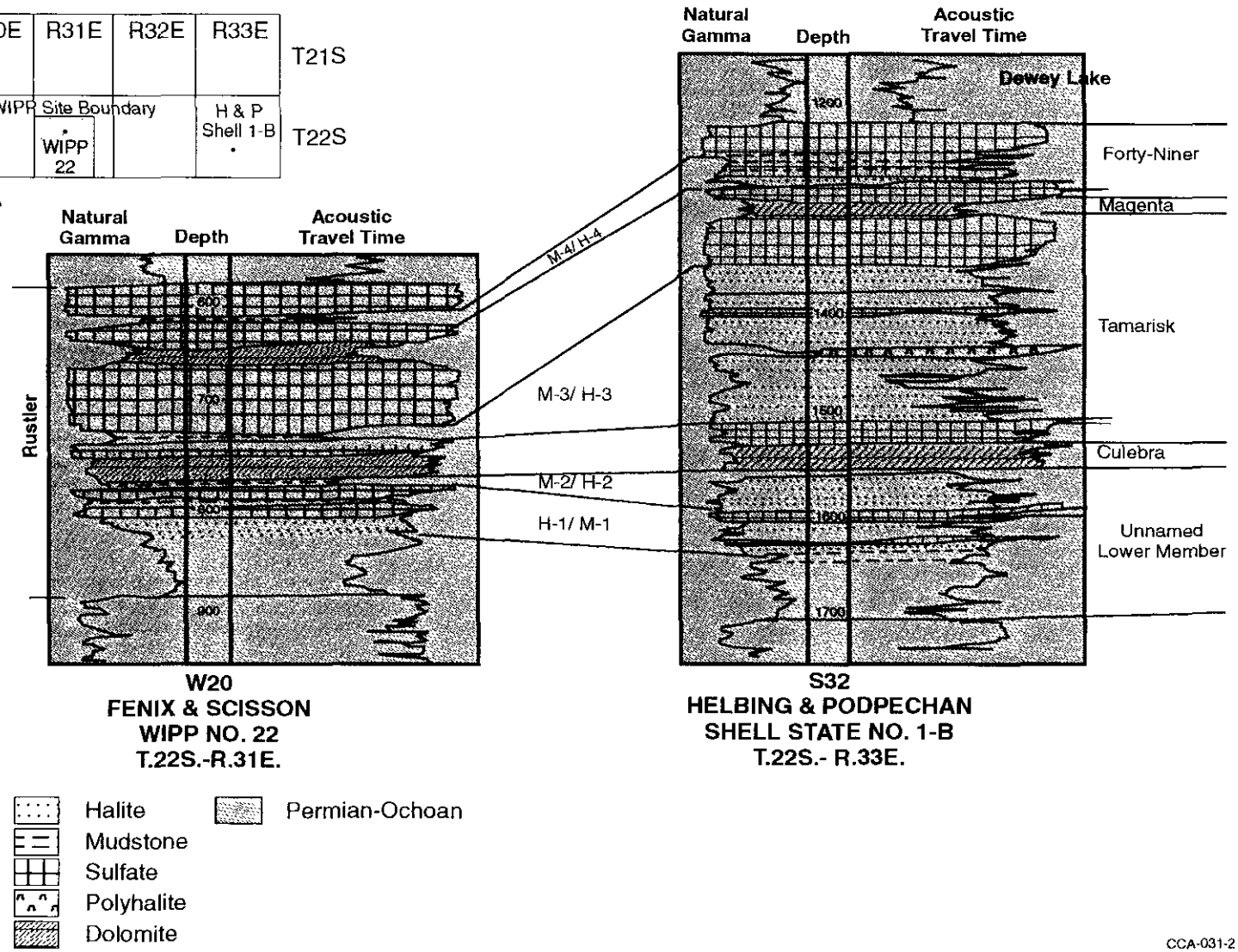

Figure 2-13. Log Character of the Rustler Emphasizing Mudstone-Halite Lateral Relationships

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Within the waste-handling shaft, the Forty-niner mudstone displayed sedimentary features and bedding relationships indicating sedimentary transport. The mudstone has commonly been interpreted as a residue from the dissolution of halitic beds because it is thinner where there is no halite. These beds are not known to have been described in detail prior to mapping in the waste-handling shaft at WIPP, and the features found there led Holt and Powers (Appendix FAC) to reexamine the available evidence for, and interpretations of, dissolution of halite in Rustler units.

The inclusion of the Forty-niner in the conceptual model is discussed in Section 6.4.6.5.

2.1.3.6 Dewey Lake Redbeds

The nomenclature for rocks included in the Dewey Lake was introduced during the 1960s to clarify relationships between these rocks assigned to the Upper Permian and the Cenozoic Gatuña Formation (hereafter referred to as the Gatuña).

There are three main sources of data about the Dewey Lake in the area around WIPP. Miller reported the petrology of the unit in 1955 and 1966. Schiel (1988) described outcrops in the Nash Draw areas and interpreted geophysical logs of the unit in southeastern New Mexico and west Texas to infer the depositional environments and stratigraphic relationships in 1988 and 1994. Holt and Powers (1990a) were able to describe the Dewey Lake in detail at the AIS for WIPP in 1990, confirming much of Schiel's information and adding data regarding the Lower Dewey Lake.

The Dewey Lake overlies the Rustler conformably, though local examples of the contact (for example, the AIS described by Holt and Powers in 1990a) show minor disruption by dissolution of some of the upper Rustler sulfate. The formation is predominantly reddish-brown fine sandstone to siltstone or silty claystone with greenish-gray reduction spots. Thin bedding, ripple cross-bedding, and larger channeling are common features in outcrops, and additional soft sediment deformation features and early fracturing from the lower part of the formation are described by Holt and Powers. Schiel (1988, 143; 1994, 9) attributed the Dewey Lake to deposition on "a large, arid fluvial plain subject to ephemeral flood events."

There is little direct faunal or radiometric evidence of the age of the Dewey Lake. It is assigned to the Ochoan Series of Late Permian age, and it is regionally correlated with units of similar lithology and stratigraphic position. Schiel (1988, 1994) reviewed the limited radiometric data from lithologically similar rocks (Quartermaster Formation) and concluded that much of the unit could be Early Triassic in age.

Near the center of the WIPP site, Holt and Powers (1990a, Figure 5) mapped 498 feet (152 meters) of the Dewey Lake (Figure 2-14). The formation is thicker to the east (Schiel 1994, Figure 2) of the WIPP site, in part because western areas were eroded before the overlying Triassic rocks were deposited.

The Dewey Lake contains fractures, which are filled with minerals to varying degrees. Both cements and fracture fillings have been examined and used to infer groundwater infiltration. Holt and Powers (1990a, 3-10) described the Dewey Lake as cemented by carbonate above 164.5 feet (50 meters) in the AIS; some fractures in the lower part of this interval were also filled with carbonate, and the entire interval surface was commonly moist. Below this point, the cement is harder, the shaft is dry, and fractures are filled with gypsum. Holt and Powers (1990a, 3 – 11, Figure 16) suggested that the cement change might be related to infiltration of meteoric water. They also determined that some of the gypsum-filled fractures are syndepositional. Dewey Lake fractures include horizontal to subvertical trends, some of which were mapped in detail (Holt and Powers 1986, Figures 6, 7, and 8).

Lambert (in Siegel et al. 1991, 5 – 65) analyzed the deuterium/hydrogen (D/H) ratios of gypsum in the Rustler and gypsum veins in the Dewey Lake. He suggests that none of the gypsum formed from evaporitic fluid such as Permian seawater but that the D/H ratios all show influence of meteoric water. Furthermore, Lambert (in Siegel et al. 1991, 5 – 66) infers that the gypsum D/H ratio is not consistent with modern meteoric water; it may, however, be consistent with older meteoric fluids. There is no obvious correlation with depth to indicate infiltration. Strontium isotope ratios ($^{87}Sr/^{86}Sr$) indicate no intermixing or homogenization of fluids between the Rustler and the Dewey Lake, but there may have been lateral movement of water within the Dewey Lake (Siegel et al. 1991, 5 – 54). Dewey Lake carbonate-vein material shows a broader range of strontium ratios than does surface caliche, and the ratios barely overlap.

The treatment of the Dewey Lake in the conceptual model can be found in Section 6.4.6.6. Dewey Lake parameter values are in Table 6-23.

2.1.3.7 The Santa Rosa

There have been different approaches to the nomenclature of rocks of Triassic age in southeastern New Mexico. Bachman generally described the units in 1974 as "Triassic, undivided" or as the Dockum Group, without dividing it. Vine in 1963 used "Santa Rosa Sandstone," and Santa Rosa has become common usage. Lucas and Anderson (1993a, b) import other formation names that are unlikely to be useful for WIPP.

The Santa Rosa has been called disconformable over the Dewey Lake by Vine (1963, B25). These rocks have more variegated hues than the underlying uniformly colored Dewey Lake. Coarse-grained rocks, including conglomerates, are common, and the formation includes a variety of cross-bedding and sedimentary features (Lucas and Anderson 1993a, 231 – 235).

Within the WIPP site boundary, the Santa Rosa is relatively thin to absent (Figure 2-15). At the AIS, Holt and Powers (1990a, Figure 5) attributed about 2 feet (0.6 meter) of rock to the Santa Rosa. The Santa Rosa is a maximum of 255 feet (78 meters) thick in potash holes drilled for WIPP east of the site boundary. The Santa Rosa is thicker to the east.

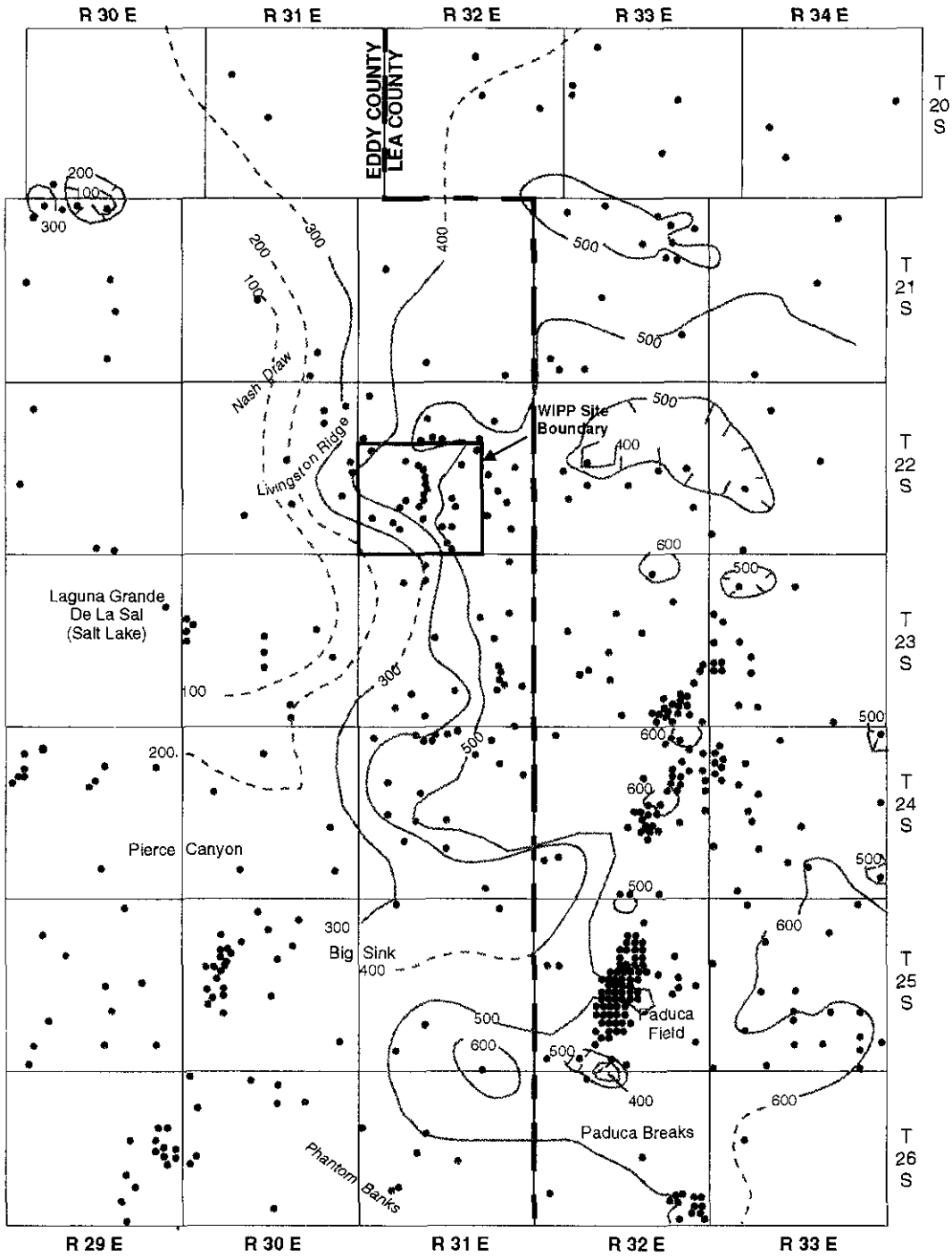

● Boreholes

Contour Interval = 100 feet

Note: The borehole locations used in this study are shown as shaded dots. These are described in Powers and Holt 1995 (Figure 6 and Appendix A). This reference also contains summarized borehole data. (Powers and Holt 1995, Figure 26)

N

0 2 4 Miles
Scale

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Figure 2-14. Isopach of the Dewey Lake

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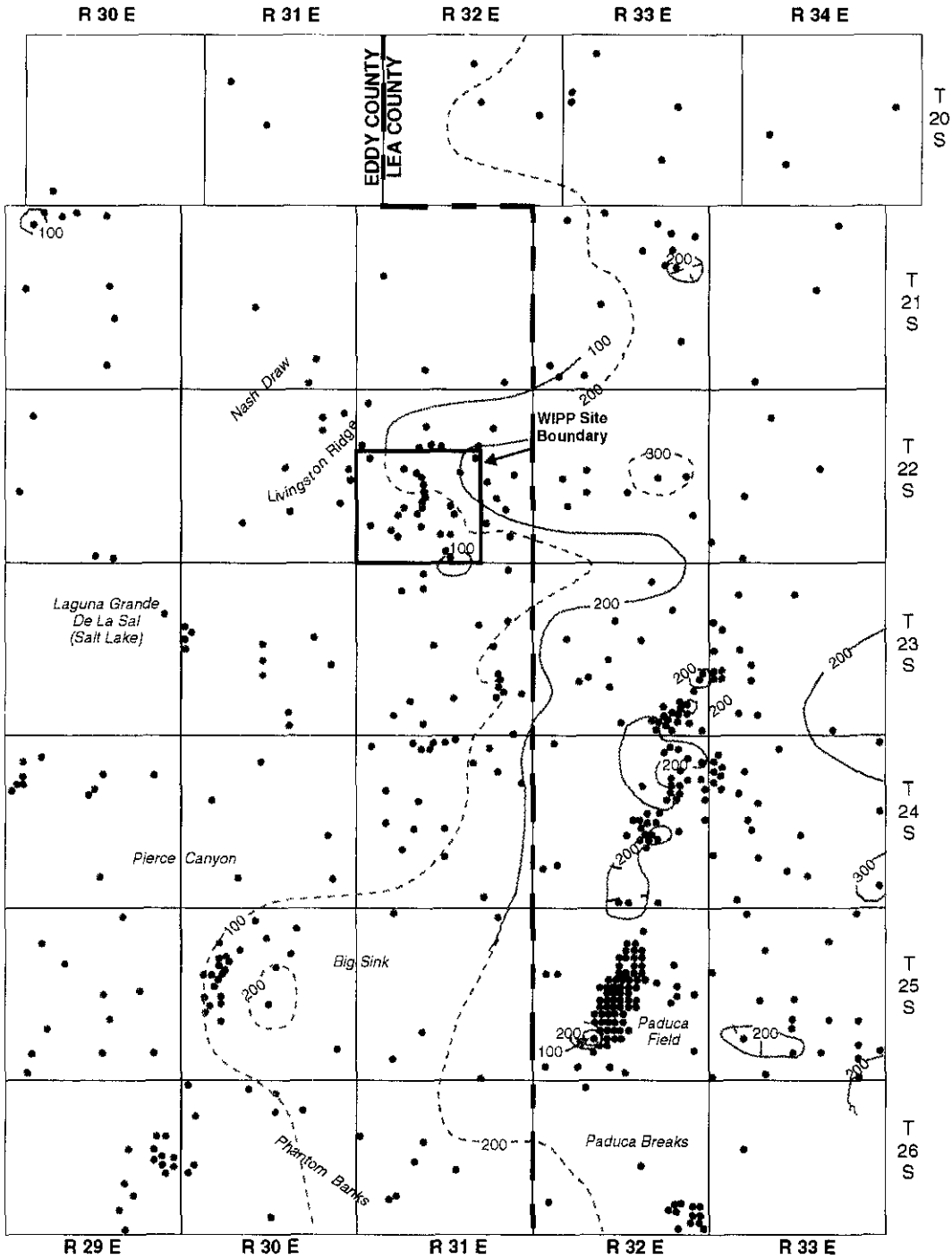

● Boreholes

Contour Interval = 100 feet

Note: The borehole locations used in this study are shown as shaded dots. These are described in Powers and Holt 1995 (Figure 6 and Appendix A). This reference also contains summarized borehole data. (Powers and Holt 1995, Figure 27)

N

0 2 4 Miles
Scale

CCA-033-2

Figure 2-15. Isopach of the Santa Rosa

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The Santa Rosa and younger rocks are modeled in the WIPP performance assessment as a single region as discussed in Section 6.4.6.7. The model parameters for this supra-Dewey Lake region are given in Table 6-24.

2.1.3.8 The Gatuña Formation

Lang (in Robinson and Lang 1938, 84) named the Gatuña for outcrops in the vicinity of Gatuña Canyon in the Clayton Basin. Rocks now attributed to the Gatuña in Pierce Canyon were once included in the Pierce Canyon Formation with rocks now assigned to the Dewey Lake. The formation has been mapped from the Santa Rosa, New Mexico, area south to the vicinity of Pecos, Texas. It is unconformable with underlying units.

Vine in 1963 and Bachman in 1974 provided some limited description of the Gatuña. The most comprehensive study of the Gatuña is based on WIPP investigations and landfill studies for the City of Carlsbad and Eddy County (Powers and Holt 1993). Much of the formation is colored light reddish-brown. It is broadly similar to the Dewey Lake and the Santa Rosa, though the older units have more intense hues. The formation is highly variable, ranging from coarse conglomerates to claystones with some highly gypsiferous sections. Sedimentary structures are abundant. Analysis of lithofacies indicates that the formation is dominantly fluvial in origin with areas of low-energy deposits and evaporitic minerals.

The thickness of the Gatuña is not very consistent regionally, as shown in Figure 2-16. Thicknesses range up to about 300 feet (91 meters) at Pierce Canyon, with thicker areas generally subparallel to the Pecos River. To the east, the Gatuña is thin or absent. Holt and Powers in (1990a) reported about 9 feet (2.7 meters) of undisturbed Gatuña in the AIS at WIPP.

The Gatuña has been considered Pleistocene in age based on a volcanic glass in the Upper Gatuña along the eastern margin of Nash Draw that has been identified as the Lava Creek B ash, dated at 0.6 million years by Izett and Wilcox (1982). This upper-limit age is corroborated by the age determinations from the Mescalero caliche (hereafter referred to as the Mescalero) that overlies the Gatuña (see Section 2.1.3.9). An additional volcanic ash from the Gatuña in Texas yields consistent K-Ar and geochemical data, indicating that it is about 13 million years old at that location (Powers and Holt 1993, 271). Thus, the Gatuña ranges in age over a period of time that may be greater than that spanned by the Ogallala Formation (hereafter referred to as the Ogallala) on the High Plains east of WIPP.

2.1.3.9 Mescalero Caliche

The Mescalero caliche is an informal stratigraphic unit apparently first differentiated by Bachman in 1974, though Bachman (1973, 17, 27) described the caliche on the Mescalero Plain. He differentiated the Mescalero from the older, widespread Ogallala caliche or caprock on the basis of textures, noting that breccia and pisolitic textures are much more common in the Ogallala caliche. The Mescalero has been noted over significant areas in the Pecos

drainage, including the WIPP area, and it has been formed over a variety of substrates. Bachman (1973) described the Mescalero as a two-part unit: (1) an upper dense laminar caprock and (2) a basal, earthy-to-firm, nodular calcareous deposit. Machette (1985, 5) classified the Mescalero as having Stage V morphologies of a calcic soil (the more mature Ogallala caprock that occurs east of the WIPP site reaches Stage VI).

Bachman (1976, Figure 8) provided structure contours on the Mescalero caliche for a large area of southeastern New Mexico, including the WIPP site. From the contours and Bachman's discussion of the Mescalero as a soil, it is clear that the Mescalero is expected to be continuous over large areas. Explicit WIPP data are limited mainly to boreholes, though some borehole reports do not mention the Mescalero. The unit may be as much as 10 feet (3 meters) thick.

The Mescalero overlies the Gatuña and was interpreted by Bachman (1976) on basic stratigraphic grounds as having accumulated during the early-to-middle Pleistocene. Samples of the Mescalero from the vicinity of the WIPP were studied using uranium-trend methods. Based on early written communication from Rosholt, Bachman (1985, 20) reports that the basal Mescalero began to form about 510,000 years ago and the upper part began to form about 410,000 years ago; these ages are commonly cited in WIPP literature. The samples are interpreted by Rosholt and McKinney (1980, Table 5) in the formal report as indicating ages of 570,000 ± 110,000 years for the lower part of the Mescalero and 420,000 ± 60,000 years for the upper part.

According to Bachman (1985, 19), where the Mescalero is flat-lying and not breached by erosion, it is an indicator of stability or integrity of the land surface over the last 500,000 years. An additional discussion of the Mescalero caliche can be found in Appendix GCR (Section 4.2.2).

2.1.3.10 Surficial Sediments

Soils of the region have developed mainly from Quaternary and Permian parent material. Parent material from the Quaternary System is represented by alluvial deposits of major streams, dune sand, and other surface deposits. These are mostly loamy and sandy sediments containing some coarse fragments. Parent material from the Permian System is represented by limestone, dolomite, and gypsum bedrock. Soils of the region have developed in a semiarid, continental climate with abundant sunshine, low relative humidity, erratic and low rainfall, and a wide variation in daily and seasonal temperatures. Subsoil colors are normally light brown to reddish brown but are often mixed with lime accumulations (caliche) that result from limited, erratic rainfall and insufficient leaching.

A soil association is a landscape with a distinctive pattern of soil types (series). It normally consists of one or more major soils and at least one minor soil. There are three soil associations within 5 miles (8.3 kilometers) of the WIPP site: the Kermit-Berino, the Simona-Pajarito, and the Pyote-Maljamar-Kermit. Of these three associations, only the Kermit-Berino

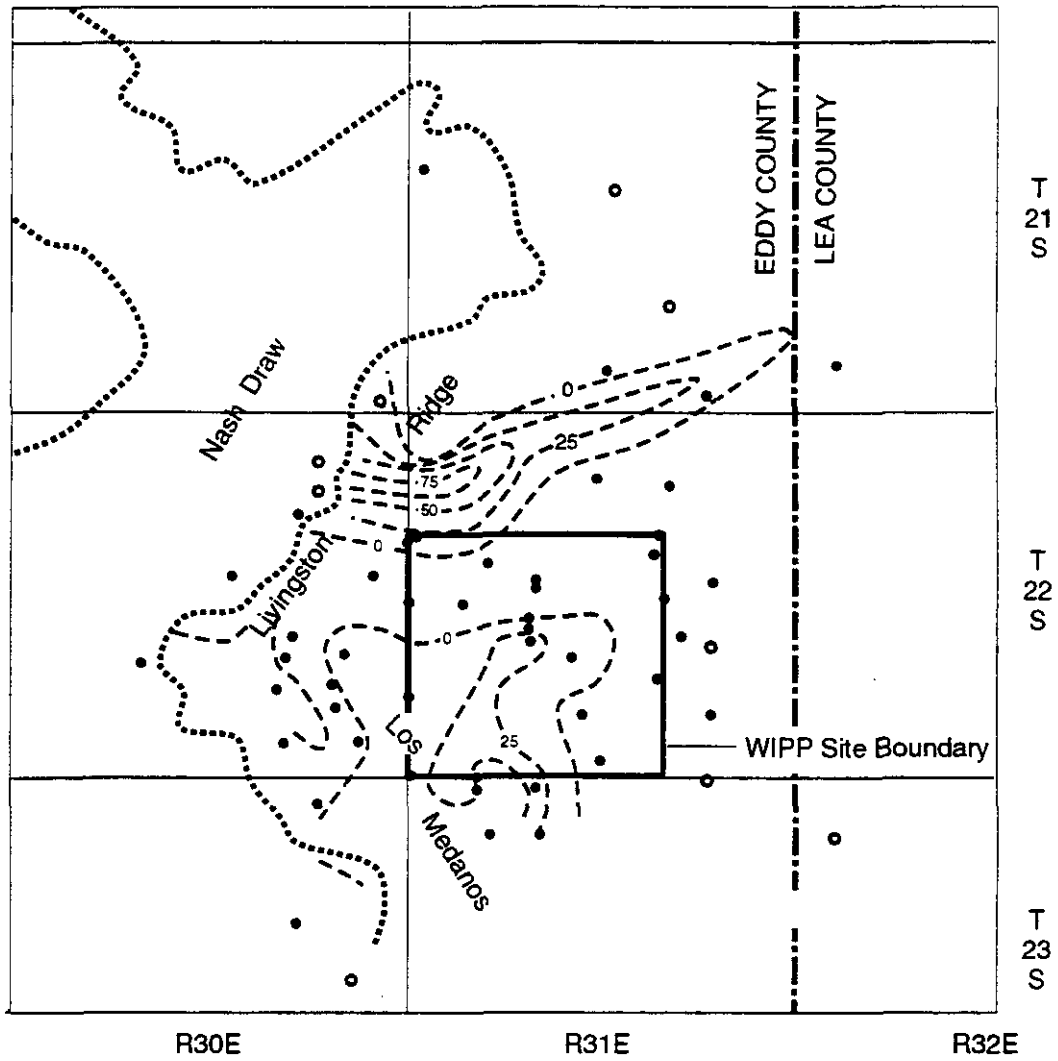

Modified from Mercer, J. W., 1983, Figure 1a

- o Test Hole for Oil and Gas
- • Test Hole for Basic Data or Potash

Contour Interval = 25 feet

N

0 2 4
Miles

CCA-071-2

Figure 2-16. Isopach of the Gatuña

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soil series has been mapped across the WIPP site by Chugg et al. (1952, Sheet No. 113). These are sandy soils developed on eolian material. The Kermit-Berino soils include active dune areas. The Berino soil has a sandy A horizon; the B horizons include more argillaceous material and weak-to-moderate soil structures. A and B horizons are described as noncalcareous, and the underlying C horizon is commonly caliche. Bachman (1980, 44) interpreted the Berino soil as a paleosol that is a remnant B horizon of the underlying Mescalero. Rosholt and McKinney (1980, Table 5) applied uranium-trend methods to samples of the Berino soil from the WIPP site area. They interpreted the age of formation of the Berino soil as 330,000 ± 75,000 years.

Generally, the Berino Series, which covers about 50 percent of the site, consists of deep, noncalcareous, yellow-red to red sandy soils that developed from wind-worked material of mixed origin. These soils are described as undulating to hummocky and gently sloping (0 to 3 percent slopes). The soils are the most extensive of the deep, sandy soils in the Eddy County area. Berino soils are subject to continuing wind and water erosion. If the vegetative cover is seriously depleted, the water-erosion potential is slight, but the wind-erosion potential is very high. These soils are particularly sensitive to wind erosion in the months of March, April, and May, when rainfall is minimal and winds are highest. These soil characteristics are a consideration for the design of long-term passive controls such as monuments and markers (see Appendix PIC, Section III).

The Kermit Series consists of deep, light-colored, noncalcareous, excessively drained loose sands, typically yellowish-red fine sand. The surface is undulating to billowy (from 0 to 3 percent slopes) and consists mostly of stabilized sand dunes. Kermit soils are slightly to moderately eroded. Permeability is very high, and, if vegetative cover is removed, the water-erosion potential is slight, but the wind-erosion potential is very high.

Surface soils appear to play a role in the infiltration of precipitation. Mercer (Appendix HYDRO) points out that where surface deposits are thickest, they may contain localized perched zones of groundwater. A more thorough discussion of this topic can be found in Appendix HYDRO.

2.1.3.11 Summary

The stratigraphy and lithology at the WIPP site has been summarized from the lowermost pre-Cambrian units to the surface soils. While these are important for an understanding of the site and its stability, not all of these units are important to the performance of the disposal system. As a result, the DOE has developed a conceptual model that describes the lithology as thirteen discrete model regions ranging from the Castile to a region that generally includes units above the Dewey Lake. In this model, emphasis is placed on the Castile, the Salado, the five members of the Rustler, the Dewey Lake, and the supra-Dewey Lake units. The Salado is divided into five stratigraphic units to capture the variations in properties near the horizon of the repository (see Section 6.4.2.1). The identification and definition of the appropriate

modeling units is based on the identification of FEPs that can impact the performance of the disposal system. Details of the conceptual model can be found in Section 6.4.2.

2.1.4 Physiography and Geomorphology

In this section, the DOE presents a discussion of the physiography and geomorphology of the WIPP site and surrounding area. This information is taken from DOE 1980 (7-21 to 7-23). Geomorphology and physiography are determined by the DOE to be features that are potentially important to disposal system performance. They are included in the consequence analysis through consideration of the topography and its influence on the regional water table. (See discussion of regional water table characteristics in Section 2.2.1.) Consequently, topographic information is presented in this section. In addition, several geomorphological processes have been screened out on the basis of either low consequence or low probability, as discussed in Appendix SCR. These include weathering, erosion, sedimentation, and soil development. Information is presented in this section to support this screening. In order to perform this screening, such factors as slopes, proximity to watercourses, dissection, and historic and existing processes are important. These are presented in this section in terms of the regional and local physiographic and geomorphological characteristics. Tectonic processes that may alter the physiography of the region or site area are discussed in Section 2.1.5. In addition, Section 2.1.6 presents more specific details on nontectonic processes identified during site characterization as having the potential for affecting the repository over the longer term and as requiring detailed investigation. These include halite deformation and dissolution.

2.1.4.1 Regional Physiography and Geomorphology

The WIPP site is in the Pecos Valley section of the southern Great Plains physiographic province (Figure 2-17), a broad, highland belt sloping gently eastward from the Rocky Mountains and the Basin and Range Province to the Central Lowlands Province. The Pecos Valley section itself is dominated by the Pecos River Valley, a long north-south trough that is from 5 to 30 miles (8.3 to 50 kilometers) wide and as much as 1,000 feet (305 meters) deep in the north. The Pecos River System has evolved from the south, cutting headward through the Ogallala sediments and becoming entrenched some time after the Middle Pleistocene. It receives almost all the surface and subsurface drainage of the region; most of its tributaries are intermittent because of the semiarid climate. The surface locally has a karst terrain containing sinkholes, dolines, and solution-subsidence troughs from both surface erosion and subsurface dissolution. The valley has an uneven rock- and alluvium-covered floor with widespread solution-subsidence features, the result of dissolution in the underlying Upper Permian rocks. The terrain varies from plains and lowlands to rugged canyonlands, and contains such erosional features as scarps, cuestas, terraces, and mesas. The surface slopes gently eastward, reflecting the underlying rock strata. Elevations vary from more than 6,000 feet (1,829 meters) in the northwest to about 2,000 feet (610 meters) in the south.

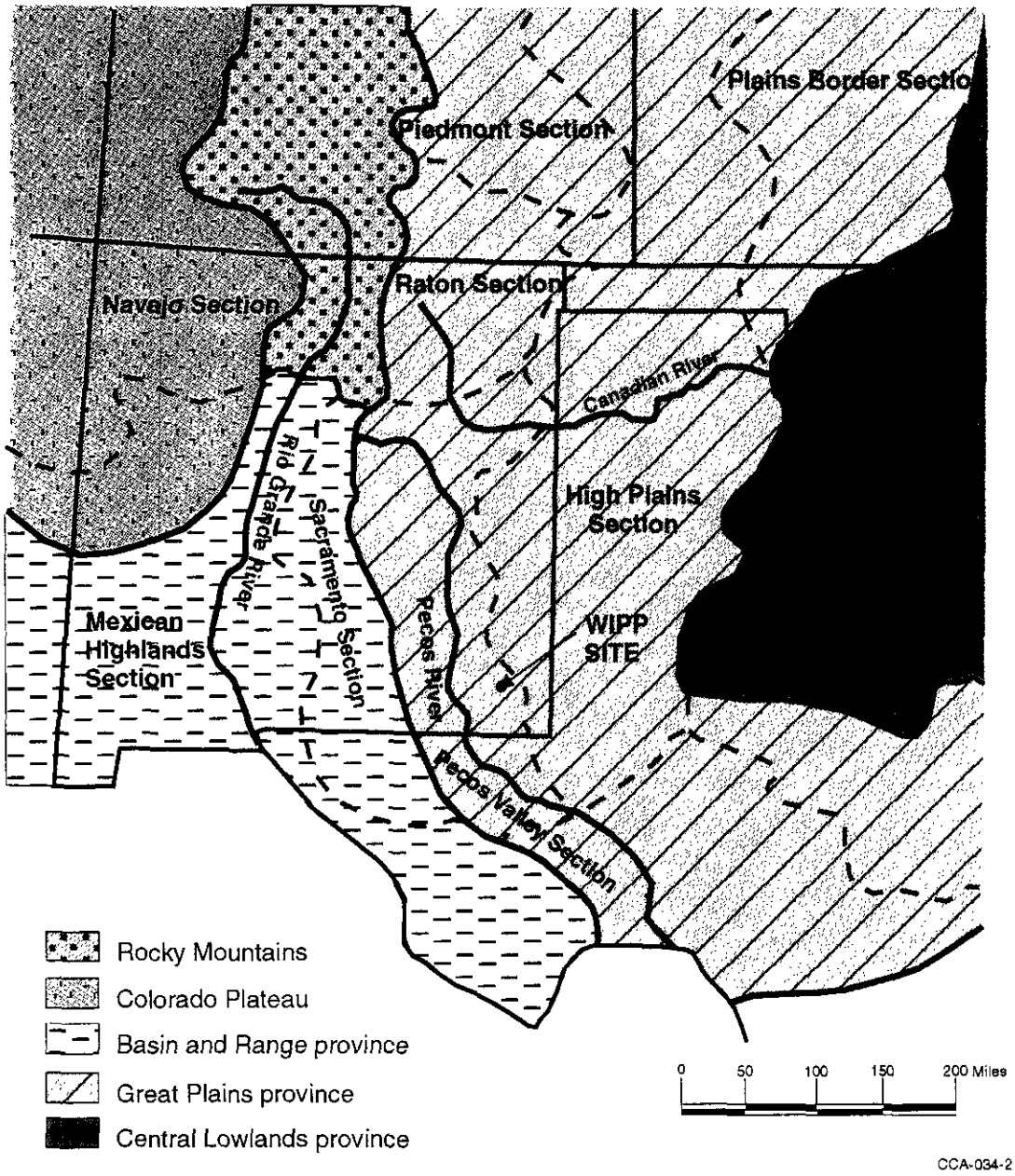

Figure 2-17. Physiographic Provinces and Sections

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The Pecos Valley section is bordered on the east by the virtually uneroded plain of the Llano Estacado. The Llano Estacado is part of the High Plains section of the Great Plains physiographic province and is a poorly drained eastward-sloping surface covered by gravels, wind-blown sand, and caliche that has developed since early-to-middle Pleistocene time. Few and minor topographic features are present in the High Plains section, formed when more than 500 feet (152 meters) of Tertiary silts, gravels, and sands were laid down in alluvial fans by streams draining the Rocky Mountains. In many areas, the nearly flat surface is cemented by a hard caliche layer.

To the west of the Pecos Valley section are the Sacramento Mountains and the Guadalupe Mountains, part of the Sacramento section of the Basin and Range Province. The Capitan escarpment along the southeastern side of the Guadalupe Mountains marks the boundary between the Basin and Range and the Great Plains provinces. The Sacramento section has large basinal areas and a series of intervening mountain ranges (DOE 1980).

2.1.4.2 Site Physiography and Geomorphology

The land surface in the area of the WIPP site is a semiarid, wind-blown plain sloping gently to the west and southwest, and is hummocky with sand ridges and dunes. A hard caliche layer (Mescalero rocks) is typically present beneath the sand blanket and on the surface of the underlying Gatuña. Figure 2-18 is a topographic map of the area. Detailed topographic maps are attached at the end of this volume. Elevations at the site range from 3,570 feet (1,088 meters) in the east to 3,250 feet (990 meters) in the west. The average east-to-west slope is 50 feet per mile (9.4 meters per kilometer).

Livingston Ridge is the most prominent physiographic feature near the site. It is a west-facing escarpment that has about 75 feet (23 meters) of topographic relief and marks the eastern edge of Nash Draw, the drainage course nearest to the site (see Figure 2-1). Nash Draw is a shallow 5-mile-wide (8-kilometer-wide) basin, 200 to 300 feet (61 to 91 meters) deep and open to the southwest. It was caused, at least in part, by subsurface dissolution and the accompanying subsidence of overlying sediments. Livingston Ridge is the approximate boundary between terrain that has undergone erosion and/or solution collapse to the west and terrain that has been little affected to the east.

About 15 miles (24 kilometers) east of the site is the southeast-trending San Simon Swale, a depression caused, at least in part, by subsurface dissolution. Between San Simon Swale and the site is a broad, low mesa named the Divide. Lying about 6 miles (9.7 kilometers) east of the site and about 100 feet (30 meters) above the surrounding terrain, it is a boundary between southwest drainage toward Nash Draw and southeast drainage toward San Simon Swale. The Divide is capped by the Ogallala and the overlying caliche, upon which have formed small, elongated depressions similar to those in the adjacent High Plains section to the east.

Surface drainage is intermittent; the nearest perennial stream is the Pecos River, 12 miles (19 kilometers) southwest of the WIPP site boundary. The site's location near a natural divide

protects it from flooding and serious erosion caused by heavy runoff. Should the climate become more humid, any perennial streams should follow the present basins, and Nash Draw and San Simon Swale would be the most eroded, leaving the area of the Divide relatively intact.

2.1.5 Tectonic Setting and Site Structural Features

The DOE has screened out, on the basis of either probability or consequence or both, all tectonic, magmatic, and structural related processes. The screening discussions can be found in Appendix SCR. The information needed for this screening is included here and covers regional tectonic processes such as subsidence and uplift and basin tilting, magmatic processes such as igneous intrusion and events such as volcanism, and structural processes such as faulting and loading and unloading of the rocks because of long-term sedimentation or erosion. Discussions of structural events, such as earthquakes, are considered to the extent that they may create new faults or activate old faults. The seismicity of the area is considered in Section 2.6 for the purposes of determining seismic design parameters for the facility.

2.1.5.1 Tectonics

The processes and features included in this section are those more traditionally considered part of tectonics, processes that develop the broad-scale features of the earth. Salt dissolution is a different process that can develop some features resembling those of tectonics.

Most broad-scale structural elements of the area around the WIPP developed during the Late Paleozoic (Appendix GCR, 3-58 to 3-77). There is little historical or geological evidence of significant tectonic activity in the vicinity, and the level of stress in the region is low. The entire region tilted slightly during the Tertiary, and activity related to Basin and Range tectonics formed major structures southwest of the area. Seismic activity is specifically addressed in a separate section.

Broad subsidence began in the area as early as the Ordovician, developing a sag called the Tobosa Basin. By Late Pennsylvanian to Early Permian time, the Central Basin Platform developed (Figure 2-19), separating the Tobosa Basin into two parts: the Delaware Basin to the west and the Midland Basin to the east. The Permian Basin refers to the collective set of depositional basins in the area during the Permian Period. Southwest of the Delaware Basin, the Diablo Platform began developing either in the Late Pennsylvanian or Early Permian. The Marathon Uplift and Ouachita tectonic belt limited the southern extent of the Delaware Basin.

According to Brokaw et al. (1972, 30), pre-Ochoan sedimentary rocks in the Delaware Basin show evidence of gentle downwarping during deposition, while Ochoan and younger rocks do not. A relatively uniform eastward tilt, generally from about 75 to 100 feet per mile (14 to

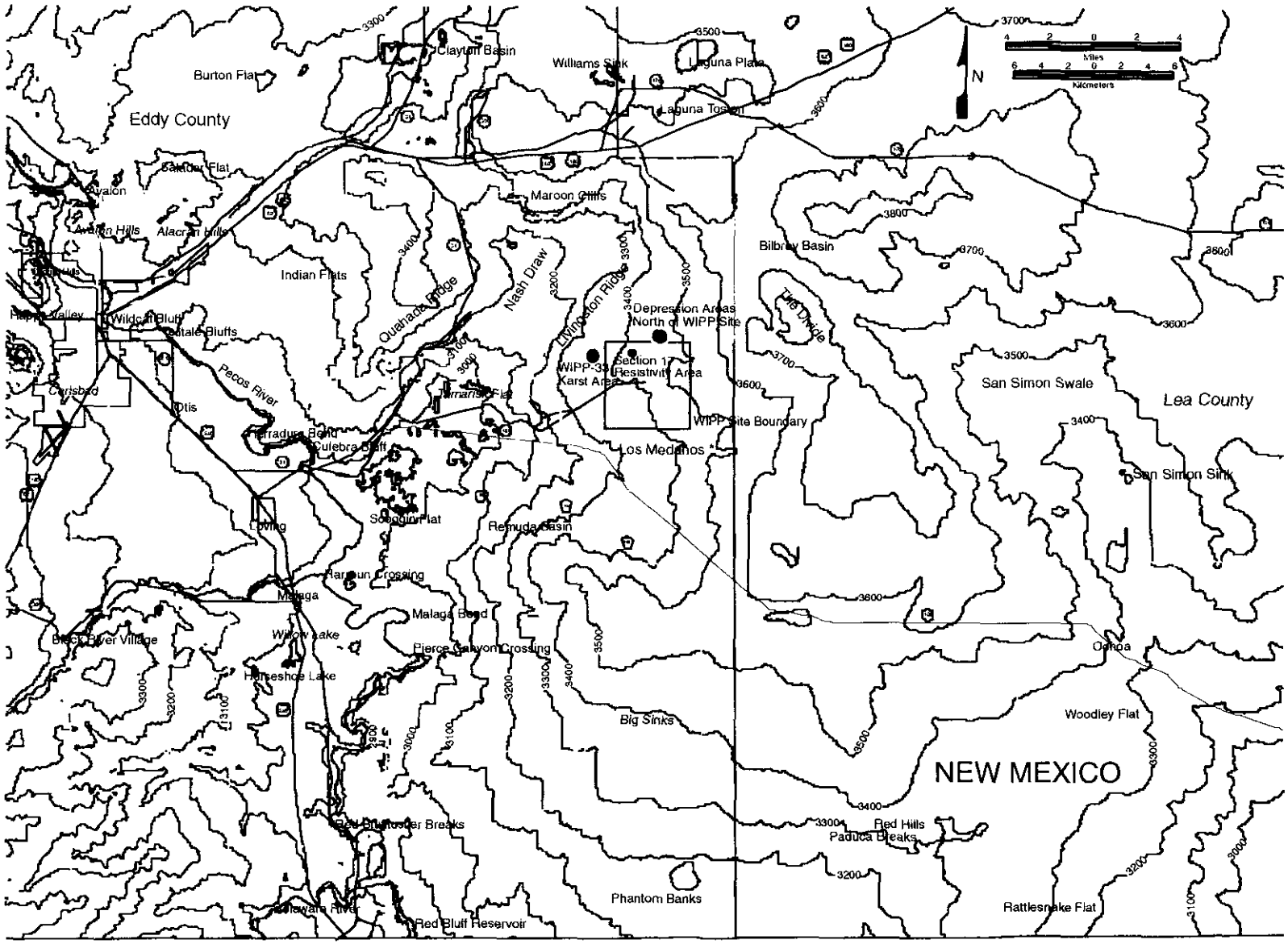

Contour Interval = 100 feet

Note: Full size map of this figure is in a pocket at the end of this volume.

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Figure 2-18. Topographic Map of Area Around the WIPP Site

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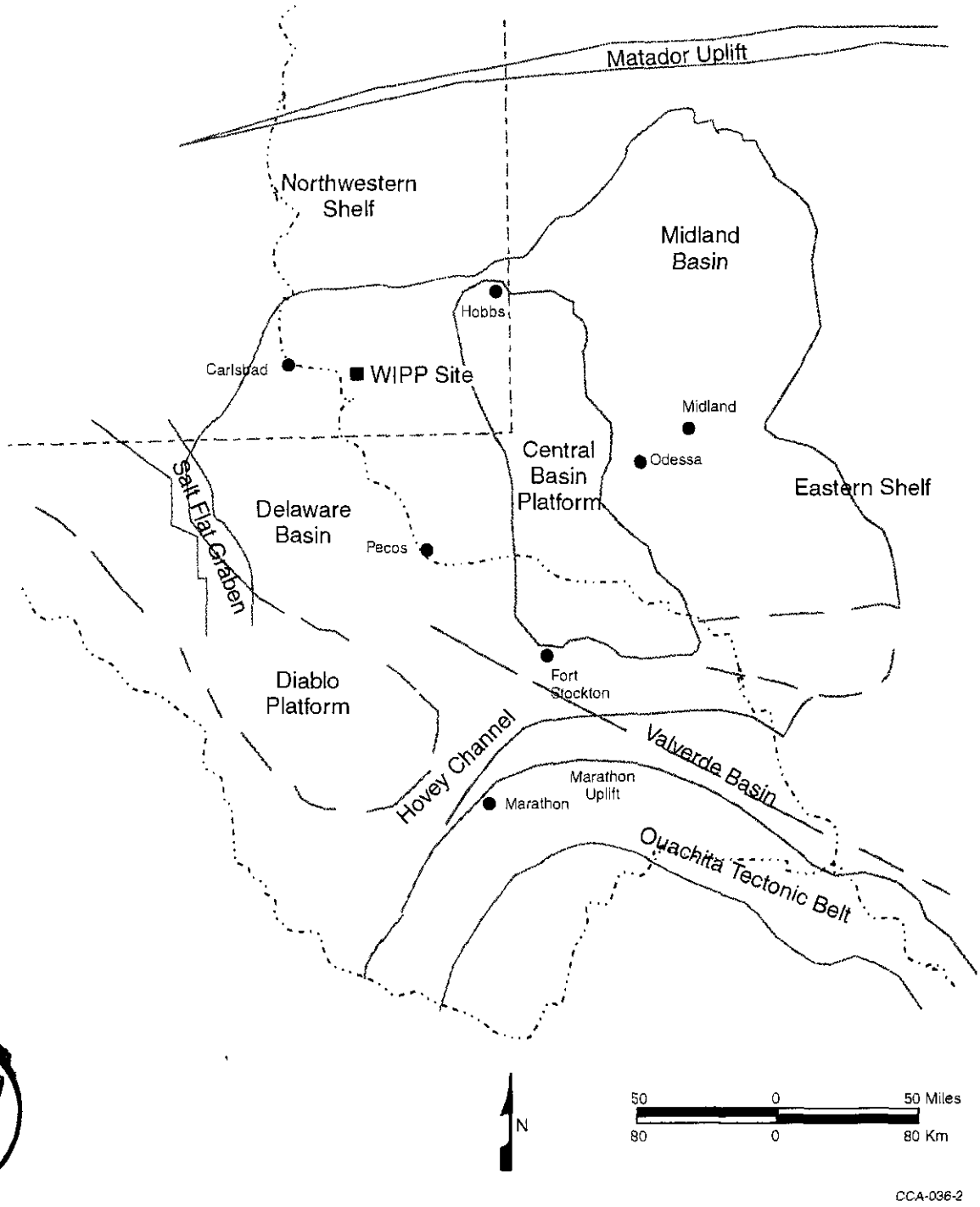

Figure 2-19. Structural Provinces of the Permian Basin Region

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19 meters per kilometer), has been superimposed on the sedimentary sequence.[1] P.B. King (1948, 108 and 121) generally attributes the uplift of the Guadalupe and Delaware mountains along the west side of the Delaware Basin to the later Cenozoic, though he also notes that some faults along the west margin of the Guadalupe Mountains have displaced Quaternary gravels.

P.B. King (1948, 144) also infers the uplift from the Pliocene-age deposits of the Llano Estacado. Subsequent studies of the Ogallala of the Llano Estacado show that it varies in age from Miocene (about 12 million years before present) to Pliocene (Hawley 1993). This is the most likely range for uplift of the Guadalupe Mountains and broad tilting to the east of the Delaware Basin sequence.

Analysis of the present regional stress field indicates that the Delaware Basin lies within the Southern Great Plains stress province. This province is a transition zone between the extensional stress regime to the west and the region of compressive stress to the east. An interpretation by Zoback and Zoback (1991, 350) of the available data indicates that the level of stress in the Southern Great Plains stress province is low. Changes to the tectonic setting, such as the development of subduction zones and a consequent change in the driving forces, would take much longer than 10,000 years to occur.

To the west of the Southern Great Plains province is the Basin and Range province, or Cordilleran Extension province, where according to Zoback and Zoback (1991, 348 – 351) normal faulting is the characteristic style of deformation. The eastern boundary of the Basin and Range province is marked by the Rio Grande Rift. Sanford et al. (1991, 230) note that, as a geological structure, the Rift extends beyond the relatively narrow geomorphological feature seen at the surface, with a magnetic anomaly at least 300 miles (500 kilometers) wide. On this basis, the Rio Grande Rift can be regarded as a system of axial grabens along a major north-south trending structural uplift (a continuation of the Southern Rocky Mountains). The magnetic anomaly extends beneath the Southern Great Plains stress province, and regional-scale uplift of about 3,300 feet (1,000 meters) over the past 10 million years also extends into eastern New Mexico.

To the east of the Southern Great Plains province is the large Mid-Plate province that encompasses central and eastern regions of the conterminous United States and the Atlantic basin west of the Mid-Atlantic Ridge. The Mid-Plate province is characterized by low levels of paleo- and historic seismicity. Where Quaternary faulting has occurred, it is generally strike-slip and appears to be associated with the reactivation of older structural elements.

Zoback et al. (1991) report no stress measurements from the Delaware Basin. The stress field in the Southern Great Plains stress province has been defined from borehole measurements in west Texas and from volcanic lineaments in northern New Mexico. These measurements

[1] Local dip of the Salado has been determined by mapping in the WIPP underground excavations. This dip is modeled as one degree to the south as discussed in Section 6.4.2.1.

were interpreted by Zoback and Zoback (1991, 353) to indicate that the least principal horizontal stress is oriented north-northeast and south-southwest and that most of the province is characterized by an extensional stress regime.

There is an abrupt change between the orientation of the least principal horizontal stress in the Southern Great Plains and the west-northwest orientation of the least principal horizontal stress characteristic of the Rio Grande Rift. In addition to the geological indications of a transition zone as described above, Zoback and Zoback (1980, 6134) point out that there is also evidence for a sharp boundary between these two provinces. This is reinforced by the change in crustal thickness from about 24 miles (40 kilometers) beneath the Colorado Plateau to about 30 miles (50 kilometers) or more beneath the Southern Great Plains east of the Rio Grande Rift. The base of the crust within the Rio Grande Rift is poorly defined but is shallower than that of the Colorado Plateau (Thompson and Zoback 1979, 152). There is also markedly lower heat flow in the Southern Great Plains (typically < 60 mWm^{-2}) reported by Blackwell et al. (1991, 428) compared with that in the Rio Grande Rift (typically > 80 mWm^{-2}) reported by Reiter et al. (1991, 463).

On the eastern boundary of the Southern Great Plains province, there is only a small rotation in the direction of the least principal horizontal stress. There is, however, a change from an extensional, normal faulting regime to a compressive, strike-slip faulting regime in the Mid-Plate province. According to Zoback and Zoback (1980, 6134), the available data indicate that this change is not abrupt and that the Southern Great Plains province can be viewed as a marginal part of the Mid-Plate province.

2.1.5.2 Loading and Unloading

Loading and unloading during the geological history since deposition is considered an influence on the hydrology of the Permian units because of its possible effect on the development of fractures.

The sedimentary loading, depth of total burial, and erosion events combine in a complex history reconstructed here from regional geological trends and local data. The history is presented in Figure 2-20 with several alternatives, depending on the inferences that are drawn, ranging from minimal to upper-bound estimates (Powers and Holt 1995, Section 5.3). Borns (1987) also made a generalized estimate of loading that is similar. The estimates are made with a reference point and depth to the Culebra at the AIS.

Given the maximum local thickness of the Dewey Lake, the maximum load at the end of the Permian was no more than approximately 787 feet (240 meters). Given the present depth to the Culebra from the top of the Dewey Lake in the AIS, approximately 115 feet (35 meters) of Dewey Lake might have been eroded during the Early Triassic before additional sediments were deposited. The Triassic thickness at the AIS is approximately 26 feet (8 meters). Northeast of the WIPP site (T21S, R33E), Triassic rocks (Dockum Group) have a maximum local thickness of approximately 1,233 feet (373 meters). This thickness is a reasonable

estimate of the maximum thickness also attained at the WIPP site prior to the Jurassic Period. At the end of the Triassic, the total thickness at the WIPP site may have then attained approximately 1,863 feet (586 meters) in two similar loading stages of a few million years each, over a period of approximately 50 million years.

The Jurassic outcrops nearest to the WIPP site are in the Malone Mountains of west Texas. There is no evidence that Jurassic rocks were deposited at or in the vicinity of the WIPP site. As a consequence, the Jurassic is considered a time of erosion or nondeposition at the site, though erosion is most likely.

Widespread erosion during the Jurassic obviously cannot be broadly inferred for the area or there would not be thick Triassic rocks still preserved. Triassic rocks of this thickness are preserved nearby, indicating either pre-Jurassic tilting or that erosion did not occur until later (but still after tilting to preserve the Triassic rocks near the WIPP site). It is also possible that the immediate site area had little Triassic deposition or erosion, but very limited Triassic deposition (that is, 26 feet [8 meters]) at the WIPP site seems unlikely.

Lang (1947) reported fossils from Lower Cretaceous rocks in the Black River Valley southwest of the WIPP site. Bachman (1980, 28) also reported similar patches of probable Cretaceous rocks near Carlsbad and south of White's City. From these reports, it is likely that some Cretaceous rocks were deposited at the WIPP site. Approximately 70 miles (110 kilometers) south-southwest of the WIPP site, significant Cretaceous outcrops of both Early and Late Cretaceous age have a total maximum thickness of approximately 1,000 feet (300 meters). Southeast of the WIPP, the nearest Cretaceous outcrops are thinner and represent only the Lower Cretaceous. Based on outcrops, a maximum thickness of 1,000 feet (300 meters) of Cretaceous rocks could be estimated for the WIPP site. Compared to the estimate of Triassic rock thickness, it is less likely that Cretaceous rocks were this thick at the site. The uppermost lines of Figure 2-20 summarize the assumptions of maximum thickness of these units.

A more likely alternative is that virtually no Cretaceous rocks were deposited, followed by erosion of remaining Triassic rocks during the Late Cretaceous to the Late Cenozoic. Such erosion may also have taken place over an even longer period, beginning with the Jurassic Period. Ewing (1993) favors Early Cretaceous uplift and erosion for the Trans-Pecos Texas area, but he does not analyze later uplift and erosional patterns.

In the general vicinity of the WIPP site, there are outcrops of Cenozoic rock from the Late Miocene (Gatuña and Ogallala Formations). There is little reason to infer any significant Early Cenozoic sediment accumulation at the WIPP site. Erosion is the main process inferred to have occurred during this period and an average erosion rate of approximately 10 meters per million years is sufficient during the Cenozoic to erode the maximum inferred Triassic and Cretaceous thickness prior to Gatuña and Ogallala deposition. Significant thicknesses of Cretaceous rocks may not have been deposited, however, and average erosion rates could have been lower.

Maximum-known Gatuña thickness in the area around the WIPP is approximately 330 feet (100 meters); at the WIPP site the Gatuña is very thin to absent. Ogallala deposits are known from the Divide east of the WIPP site, as well as from the High Plains further east and north. On the High Plains northeast of the WIPP, the upper Ogallala surface slopes to the southeast at a rate of approximately 20 feet per mile (4 meters per kilometer). A straight projection of the 4,100-foot (1,250-meter) contour line from this High Plains surface intersects the site area, which is at an elevation slightly above 3,400 feet (1,036 meters). This difference in elevation of 700 feet (213 meters) represents one estimate, probably near an upper bound, of possible unloading subsequent to deposition of the Ogallala Formation.

Alternatively, the loading and unloading of the Ogallala could have been closer to 330 feet (100 meters). In any case, it would have occurred as a short-lived pulse over a few million years at most.

While the above inferences about greater unit thicknesses and probable occurrence are permissible, a realistic assessment suggests a more modest loading and unloading history (Powers and Holt 1995). It is likely that the Dewey Lake accumulated to near local maximum thickness of approximately 787 feet (240 meters) before being slightly eroded prior to the deposition of Triassic rocks. It also is most probable that the Triassic rocks accumulated at the site to near local maximum thickness. In two similar cycles of rapid loading, the Culebra was buried to a depth of approximately 2,132 feet (650 meters) by the end of the Triassic.

It also seems unlikely that a significant thickness of Cretaceous rock accumulated at the WIPP site. Erosion probably began during the Jurassic, slowed or stopped during the Early Cretaceous as the area was nearer or at base level, and then accelerated during the Cenozoic, especially in response to uplift as Basin and Range tectonics encroached on the area and the basin was tilted more. Erosional beveling of Dewey Lake and Santa Rosa suggest considerable erosion since tilting in the mid-Cenozoic. Erosion rates for this shorter period could have been relatively high, resulting in the greatest stress relief on the Culebra and surrounding units. Some filling occurred during the Late Cenozoic as the uplifted areas to the west formed an apron of Ogallala sediment across much of the area, but it is not clear how much Gatuña or Ogallala sediment was deposited in the site area. From general reconstruction of Gatuña history in the area (Powers and Holt 1993, 281), the DOE infers that Gatuña or Ogallala deposits likely were not much thicker at the WIPP site than they are now. The loading and unloading spike (Figure 2-20) representing Ogallala thickness probably did not occur. Cutting and headward erosion by the Pecos River has created local relief and unloading by erosion.

At the WIPP site, this history is little complicated by dissolution, though locally (for example, Nash Draw) the effects of erosion and dissolution are more significant. The underlying evaporites have responded to foundering of anhydrite in less dense halite beds. These have caused local uplift of the Culebra (as at ERDA 6) but little change in the overburden at the WIPP. Areas east of the WIPP site are likely to have histories similar to that of the site. West

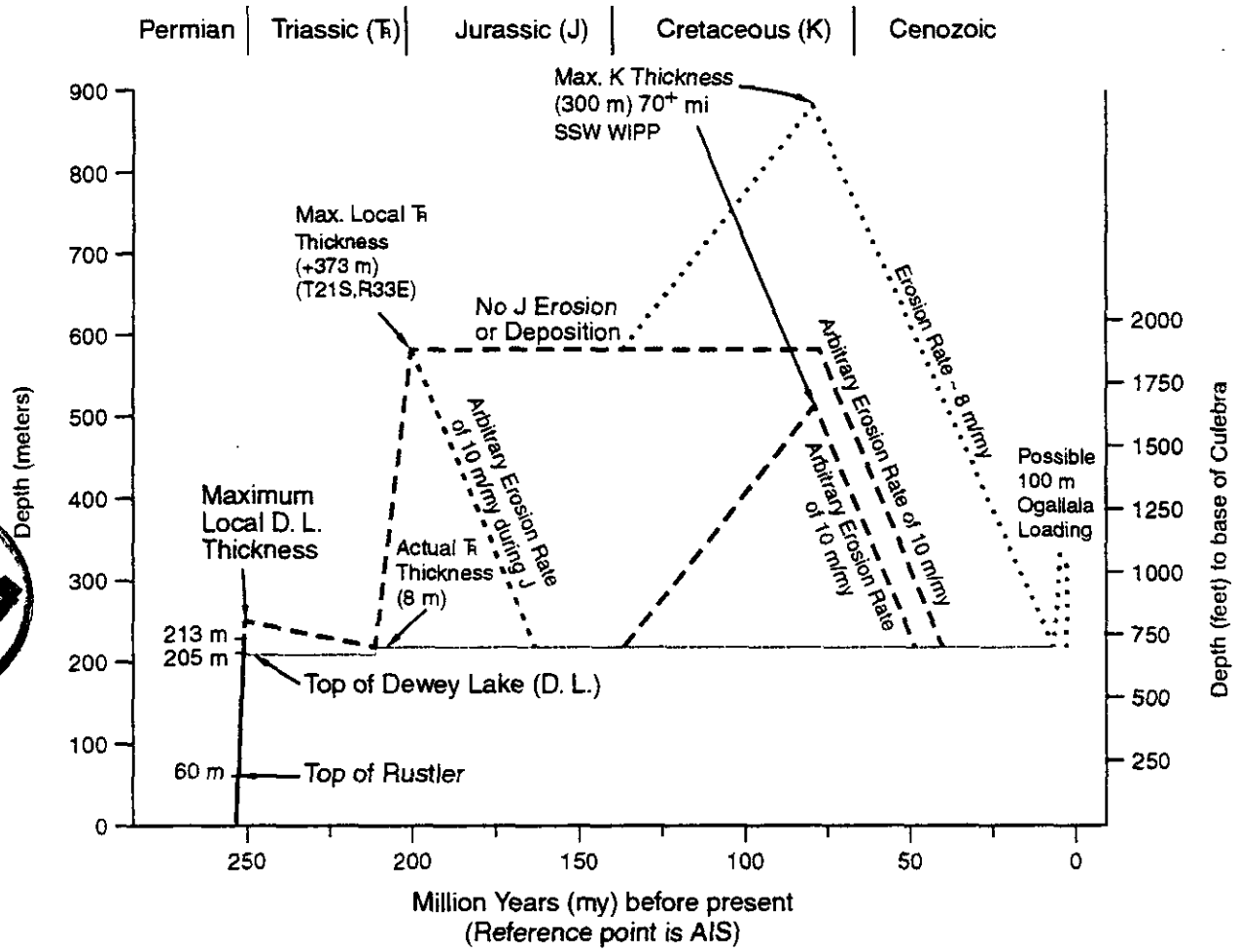

Note: The estimates are made with a reference point and depth to the base of the Culebra at the AIS. Source: Powers and Holt 1995, Figure 34.

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Figure 2-20. Loading and Unloading History Estimated to the Base of the Culebra

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of the site, the final unloading is more complicated by dissolution and additional erosion leading to exposure of the Culebra along stretches of the Pecos River Valley.

2.1.5.3 Faulting

Fault zones are well known along the Central Basin Platform, east of WIPP, from extensive drilling for oil and gas, as reported by Hills (1984). Holt and Powers performed a more recent analysis in 1988 (Appendix FAC, 4-14) of geophysical logs from oil and gas wells to examine the regional geology for the Rustler. This analysis showed that faults along the margin of the Central Basin Platform displaced Rustler rocks of at least Late Permian age. The overlying Dewey Lake shows marked thinning along the same trend, according to Schiel (1988, Figure 21), but the structure contours of the top of the Dewey Lake are not clearly offset. Schiel concluded that the fault was probably reactivated during the Dewey Lake's deposition, but movement ceased at least by the time the Santa Rosa was deposited. No surface displacement or fault has been reported along this trend.

Muehlberger et al. (1978) have mapped Quaternary fault scarps along the Salt Basin graben west of both the Guadalupe and Delaware mountains. These are the nearest known Quaternary faults of tectonic origin to the WIPP. Kelley in 1971 inferred the Carlsbad and Barrera faults along the eastern escarpment of the Guadalupe Mountains based mainly on vegetative lineaments. Hayes and Bachman reexamined the field evidence for these faults in 1979 and concluded that they were nonexistent. Figure 2-21 illustrates major regional structures, including faults.

On a national basis, Howard et al. (1971, sheets 1 and 2) assessed the location and potential for activity of young faults. For the region around the WIPP site, Howard et al. (1971, sheet 1) located faults along the western escarpment of the Delaware and Guadalupe mountain trend. These faults were judged to be Late Quaternary (approximately the last 500,000 years) or older.

In summary, there are no known Quaternary or Holocene faults of tectonic origin that offset rocks at the surface nearer to the site than the western escarpment of the Guadalupe Mountains. A significant part of the tilt of basin rocks is attributed to a mid-Miocene to Pliocene uplift trend along the Guadalupe-Sacramento Mountains that is inferred on the basis of High Plains sediments of the Ogallala.

2.1.5.4 Igneous Activity

Within the Delaware Basin, only one feature of igneous origin is known to have formed since the Precambrian. An igneous lamprophyre dike or series of dikes occurs along a linear trace about 75 miles (120 kilometers) long from the Yeso Hills south of White's City to the northeast of the WIPP site (Elliot Geophysical Company 1976). At its closest, the dike trend passes about 8 miles (13 kilometers) northwest of the WIPP site center, as shown in

Figure 2-22. Evidence for the extent of the dike includes outcroppings at Yeso Hills, subsurface intercepts in boreholes and mines, and airborne magnetic responses.

An early radiometric determination for the dike by Urry (1936) yielded an age of 30 ± 1.5 million years. More recent work on dike samples by Calzia and Hiss (1978) is consistent with early work, indicating an age of 34.8 ± 0.8 million years.[2] Work by Brookins (1980) on polyhalite samples in contact with the dike indicated an age of about 21.4 million years.

Volcanic ashes found in the Gatuña (Section 2.1.3.8) were airborne from distant sources and do not represent volcanic activity at the WIPP site.

2.1.6 Nontectonic Processes and Features

Nontectonic processes and features, which include evaporite deformation and dissolution of strata, are known to be active in the Delaware Basin. These processes are of interest because they represent mechanisms that are potentially disruptive to the repository in the long term. Both processes have been investigated extensively. The conclusions from these investigations are summarized in this section.

Halite in evaporite sequences is relatively plastic, which can lead to the process of deformation; it is also highly soluble, which can lead to the process of dissolution. Both processes (deformation and dissolution) can produce structural features similar to those produced by tectonic processes. The features developed by dissolution and deformation can be distinguished from similar-looking tectonic features where the underlying units do not reflect the same feature as do the evaporites. As an example, the evaporite deformation commonly does not affect the underlying Bell Canyon. Beds underlying areas of dissolved salt are not affected, but overlying units to the surface may be affected. The deformation in the Castile and Salado also tends to die out in overlying units, and the Rustler or the Dewey Lake may show little, if any, effects from deformed evaporites.

2.1.6.1 Evaporite Deformation

The most recent review of evaporite deformation in the northern Delaware Basin and original work to evaluate deformation is summarized here. More detail is provided in Appendix DEF.

2.1.6.1.1 Basic WIPP History of Deformation Investigations

The Castile has been known for many years to be deformed in parts of the Delaware Basin, especially along the northern margin. Jones et al. in 1973 clearly showed the Castile to be thicker from the northwestern to northern part of the basin margin, just inside the Capitan reef (hereafter referred to as the Capitan). A dissertation by Snider (1966, Figures 11 and 14)

[2] Calzia and Hiss (1978, 44) reported 32.2 to 33.9 million years. However, Powers et al. 1978 (Appendix GCR, 3-80) reported a recalculated value of 34.8 ± 0.8 million years based on a change in measured decay constant.

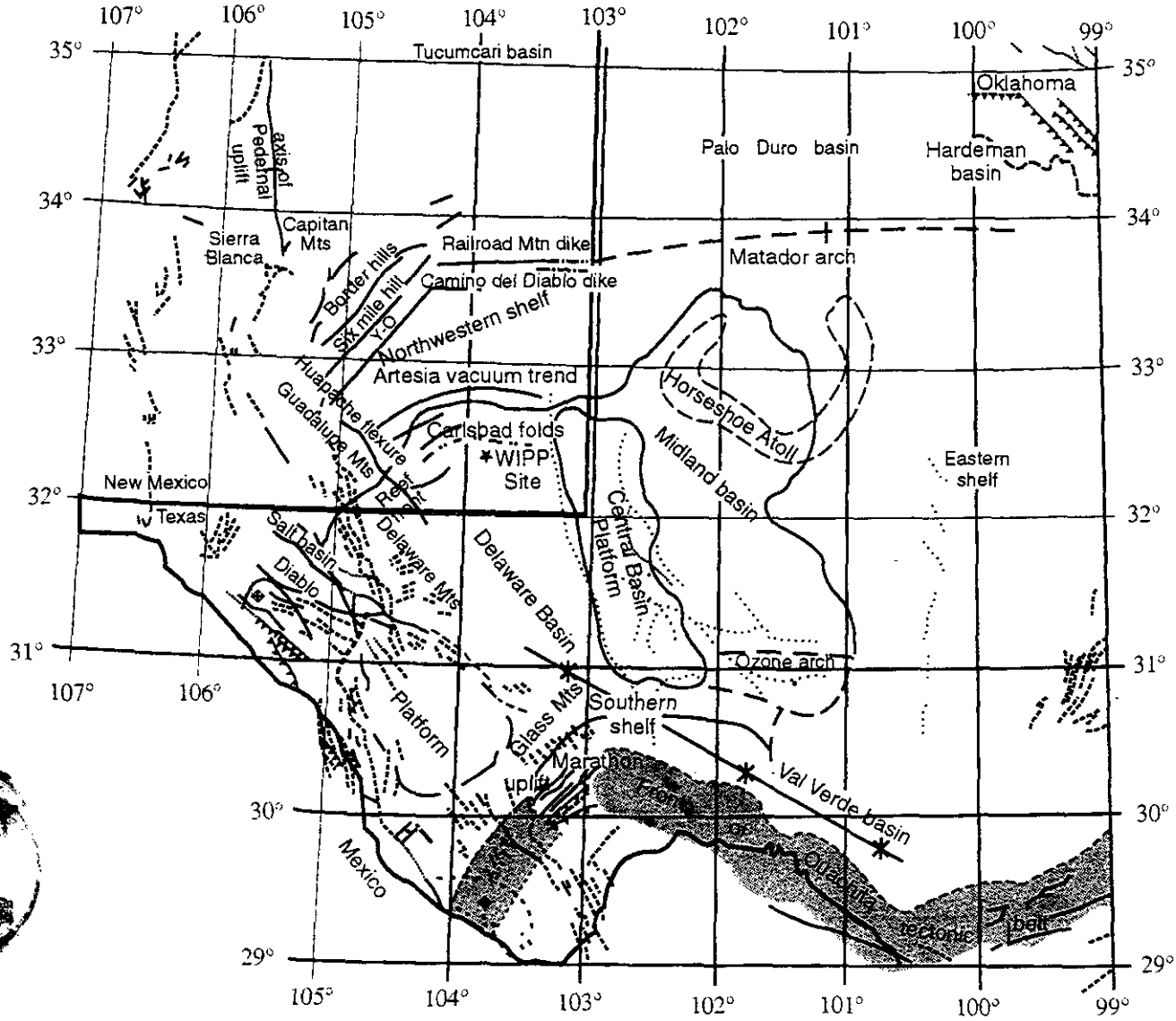

Figure 2-21. Regional Structures

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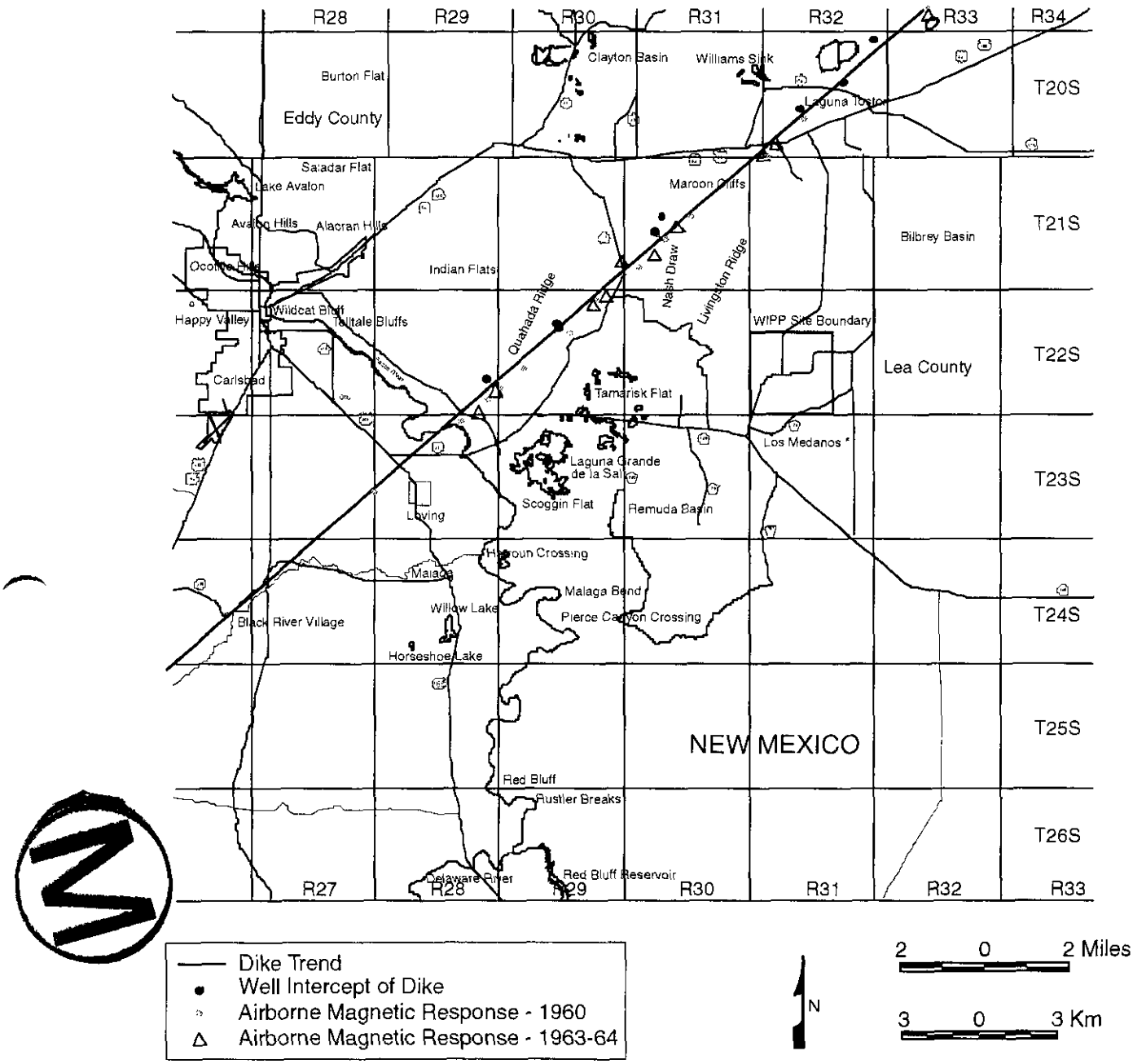

Source: Elliot (1976)

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Figure 2-22. Igneous Dike in the Vicinity of the WIPP Site

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and a paper by Anderson et al. (1972, Figure 10) also presented maps showing some evidence of thicker sections of Castile next to the Capitan. ERDA-6 was drilled during 1975 as part of the program to characterize an initial site for WIPP. The borehole penetrated increasingly deformed beds through the Salado into the Castile, and, at 2,711 feet (826 meters) depth, the borehole began to produce pressurized brine and gas. Anderson and Powers (1978, 79) and Jones (1981a) interpreted beds to have been displaced structurally by as much as 950 feet (289.5 meters). Some of the lower beds may have pierced overlying beds. The beds were considered too structurally deformed to mine reasonably along single horizons for a repository. Therefore, the site was abandoned in 1975, and the current site was located in 1976 (Appendix GCR). The deformed beds around ERDA-6 were considered part of a deformed zone within about 6 miles (10 kilometers) of the inner margin of the Capitan reef. As a consequence, the preliminary selection criteria were revised to prohibit locating a new site within 6 miles (10 kilometers) of the Capitan Reef margin.

General criteria for the present site for the WIPP appeared to be met based on initial data from drilling (ERDA-9) and geophysical surveys. Beginning in 1977, the new site was more intensively characterized through geophysical surveys, including seismic reflection and drilling. Extensive seismic reflection work revealed good reflector quality in the southern part of the site and poor-quality or disturbed reflectors in a sector of the northern part of the site (see Figure DEF-2.2 in Appendix DEF). The area of disturbed reflectors became known as the disturbed zone, the area of anomalous seismic reflectors, or the zone of anomalous seismic reflection data. (The disturbed zone based on poor Castile seismic reflectors is completely different from the DRZ that describes the deformation around mined underground openings at the WIPP.)

Powers et al., in Appendix GCR (Figures 4.4, 4.5, and 4.6), generally shows the disturbed zone beginning about 1 mile (1.6 kilometers) north of the WIPP site center. Borns et al., in 1983, included two areas south of the WIPP site as showing the same features of the disturbed zone. Neill et al., also in 1983, summarized the limits of the disturbed zone based on differing interpretations and included the area less than 1 mile (1.6 kilometers) north of the site center, where the dip in the Castile begins to steepen. WIPP-11 was drilled in early 1978 about 3 miles (5 kilometers) north of the site center over part of the disturbed zone where proprietary petroleum company data had also indicated significant seismic anomalies. The borehole encountered highly deformed beds within the Castile and altered thicknesses of halite units, but no pressurized brine and gas were found.

Less than 1 mile (1.6 kilometers) north of the site center, seismic data indicated possible faulting of the upper Salado and the lower Rustler over the area of steepening Castile dips. Four boreholes (WIPP-18, -19, -21, -22) were drilled into the upper Salado and demonstrated neither faulting nor significant deformation of the Rustler-Salado contact. Lateral changes in the seismic velocity of the upper sections contributed to the interpretation of a possible fault and thus complicate interpretations of deeper structure.

WIPP-12 was located about 1 mile (1.6 kilometers) north of the center of the site and drilled during 1978 to a depth of 2,785 feet (850 meters) in the upper Castile to determine the significance of structure on possible repository horizons. The top of the Castile was encountered at an elevation about 160 feet (49 meters) above the same contact in ERDA-9 at the site center.

WIPP-12 was deepened during late 1981 to a depth of 3,925 feet (1,200 meters) to test for possible brine and gas in the deformed Castile. The probability of encountering brine and gas was considered low because ERDA-6 and other known brine reservoirs in the Castile occurred in areas with greater deformation. During drilling, fractured anhydrite in the upper Castile (lower A3) began to yield pressurized brine and gas. The borehole was deepened to the basal anhydrite (A1) of the Castile. Subsequent reservoir testing (Popielak et al. 1983) was conducted to estimate reservoir properties (see Section 2.2.1.2.2 and Section 6.4.8).

As a consequence of discovering pressurized brine and gas in WIPP-12, the EEG recommended that the design of the facility be changed and that proposed waste disposal areas in the north be moved or reoriented to the south. After additional drilling of DOE-1, the DOE concluded that the design change had advantages, and the disposal facilities were placed south of the site center.

A microgravity survey of the site was designed to delineate further the structure within the disturbed zone, based on the large density differences between halite and anhydrite. The gravity survey was unsuccessful in yielding any improved resolution of the Castile structure.

DOE-2 was the last WIPP borehole to examine structure within the Castile. Potash drillhole data suggested a low point in Salado units about 2 miles (3.3 kilometers) north of the site center. It was proposed by Davies (1984, 175) that the Salado low might indicate deeper dissolution of Castile halite, somewhat similar to the dissolution causing breccia pipes (see Section 2.1.6.2 on evaporite dissolution). The borehole demonstrated considerable Castile deformation, but there was no indication that halite had been removed by dissolution (Mercer et al. 1987; Borns 1987).

2.1.6.1.2 Extent of the Disturbed Zone at the Site

Nearby surface drilling, shafts, and underground drilling during early excavations at WIPP showed that the repository horizon varies modestly from the regional structure over the central part of the site; north of the site center, the beds dip gently to the south. Borns in 1987 suggested that the south dip is probably related to the dip on the underlying Castile.

The upper surface of MB139, under the repository horizon, exhibited local relief in the exploratory salt-handling shaft. Jarolimek et al. (1983a, 4 – 6) interpreted the relief as mainly caused by syndepositional growth of gypsum at the water-sediment interface to form mounds and by subsequent partial crushing. Jarolimek et al. concluded that the MB relief was not caused by deformation because the base of the MB showed no comparable relief. Based on

concerns of the EEG, MB139 was reevaluated. Borns (1985) found less relief on the upper surface of the MB in the areas they examined; he also concluded that depositional processes were responsible for the relief. In both cases, deformation is not thought to have caused the relief on MB139.

2.1.6.1.3 Deformation Mechanisms

In analyzing Castile structure in the northern Delaware Basin, Borns et al. (1983, 3) proposed five processes as the principal hypotheses to explain the structure: gravity foundering, dissolution, gravity sliding, gypsum dehydration, and depositional processes. Gravity foundering is the most comprehensive and best-accepted hypothesis of the five. It is based on the fact that anhydrite is much more dense (about 2.9 grams per cubic centimeter) than halite (about 2.15 grams per cubic centimeter), and anhydrite beds therefore have a potential for sinking into underlying halite. Regardless of which mechanism caused the disturbed zone, the important consideration is the long-term future effects. To evaluate this, Borns et al. postulated that both gravity-driven deformation mechanisms could be ongoing. The strain rates from such deformation are such that deformation would progress over the next 250,000 years and that such deformation would not directly jeopardize the disposal system.

2.1.6.1.4 Timing of Deformation of the Disturbed Zone at the Site

Jones (1981a, 18) estimated that deformation of the Castile and overlying rocks took place before the Ogallala Formation was deposited, as he believes the unit is undeformed. Anderson and Powers (1978, 79) inferred that data from ERDA-6 indicate that the Castile was deformed after the basin was tilted. Though these lines of evidence could be consistent with mid-Miocene deformation, there are other interpretations consistent with older deformation (Madsen and Raup 1988). There is no known evidence of surface deformation or other features to indicate recent deformation.

2.1.6.2 Evaporite Dissolution

Because evaporites are much more soluble than most other rocks, project investigators have considered it important to understand the dissolution processes and rates that occur within the site being considered for long-term isolation. These dissolution processes and rates constitute the limiting factor in any evaluation of the site. Over the course of the WIPP project, extensive resources have been committed to identify and study a variety of features in southeastern New Mexico interpreted to have been caused by dissolution. The subsurface distribution of halite for various units has been mapped. Several different kinds of surface features have been attributed to dissolution of salt or karst formation. The processes proposed or identified include point-source (brecciation), deep dissolution, shallow dissolution, and karst. These are each discussed in more detail in Appendix DEF (Section DEF.3). Screening arguments relative to dissolution are presented in Appendix SCR (including dissolution

associated with abandoned boreholes in Sections SCR.1.2.1 and SCR.3.3.1). These arguments are based principally on the observed rates and processes in the region. These are described below.

2.1.6.2.1 Brief History of Project Studies

Well before the WIPP project, several geologists recognized that dissolution is an important process in southeastern New Mexico and that it contributed to the subsurface distribution of halite and to the surficial features. Early studies include those by Lee (1925), Maley and Huffington (1953), and Olive (1957) (in the Bibliography). Robinson and Lang (1938, 100) identified an area under Nash Draw where brine occurred at about the stratigraphic position of the upper Salado–basal Rustler and considered that salt had been dissolved to produce a dissolution residue. Vine (1963, B38 and B40) mapped Nash Draw and surrounding areas. Vine reported surficial domal structures, later called breccia pipes and identified as deep-seated dissolution and collapse features.

As the USGS and Oak Ridge National Laboratory (ORNL) began to survey southeastern New Mexico as an area in which to locate a repository site in salt, Brokaw et al. in 1972 prepared a summary of the geology that included solution and subsidence as significant processes in creating the features of southeastern New Mexico. Brokaw et al. also recognized a solution residue at the top of the salt in the Salado in the Nash Draw area, and the unit commonly became known as the brine aquifer because it yielded brine. Brokaw et al. also interpreted the east–west decrease in thickness of the Rustler to be a consequence of removal by dissolution of halite and other soluble minerals.

During the early 1970s, the basic ideas about shallow dissolution of salt (generally from higher stratigraphic units and within a few hundred feet of the surface) were set out in a series of reports by Bachman, Jones, and collaborators, as discussed in the following sections. Piper (1973, 1974) independently evaluated the geological survey data for ORNL. Claiborne and Gera (1974) concluded that salt was being dissolved too slowly from the near-surface units to affect a repository for several million years, at least.

By 1978, shallower drilling around the WIPP site to evaluate potash resources was interpreted by Jones (1978, 9), and he felt that the Rustler included "dissolution debris, convergence of beds, and structural evidence for subsidence." Halite in the Rustler has been reevaluated by the DOE, but there are only minor differences in inferred distributions among the various investigators. These investigators do have different explanations about how this distribution occurred (see Section 2.1.3.5 on Rustler stratigraphy): (1) through extensive dissolution of the Rustler's halite after the Rustler was deposited or (2) through syndepositional dissolution of halite from saline mud flat environments during Rustler deposition.

Anderson (1978) and Anderson et al. (1978) reevaluated halite distribution in deeper units, especially the Castile and Salado formations. He identified local anomalies proposed as features developed after deep dissolution of halite by water flowing upward from the

underlying Bell Canyon. Anderson mapped geophysical log signatures of the Castile and interpreted lateral thinning and change from halite to non-halite lithology as evidence of lateral dissolution of deeper units (part of deep dissolution), and he proposed that deep dissolution might threaten the WIPP site. In response to Anderson's developing concepts, ERDA-10 was drilled south of the WIPP area during the latter part of 1977. ERDA-10 intercepted a stratigraphic sequence without evidence of solution residues in the upper Castile.

A set of annular or ring fractures is evident in the surface around San Simon Sink, about 18 miles (30 kilometers) east of the WIPP site. Nicholson and Clebsch (1961, 14) suggested that San Simon Sink developed as a result of deep-seated collapse. WIPP-15 was drilled at about the center of the sink to a depth of 811 feet (245 meters) to obtain samples for paleoclimatic data and stratigraphic data to interpret collapse. Anderson (1978) and Bachman (1980) both interpret San Simon Sink as dissolution and collapse features, and the annular fractures are not considered evidence of tectonic activity.

Following the work by Anderson, Bachman (1980, 1981) mapped surficial features in the Pecos Valley, especially at Nash Draw, and differentiated between those surface features in the basin that were formed by karst and those that were formed by deep collapse features over the Capitan Reef. WIPP-32, WIPP-33, and two boreholes over the Capitan reef were eventually drilled. Their data, which demonstrated the concepts proposed by Bachman, are documented in Snyder and Gard (1982, 65).

A final program concerning dissolution and karst was initiated following a microgravity survey of a portion of the site during 1980. Based on localized low-gravity anomalies, Barrows et al. in 1983 interpreted several areas within the site as locations of karst. WIPP-14 was drilled during 1981 at a low-gravity anomaly. It revealed normal stratigraphy through the zones proposed to be affected by karst. As a followup, in 1985 Bachman also reexamined surface features around the WIPP and concluded that there was no evidence for active karst within the WIPP site. The nearest karst feature is northwest of the site boundaries at WIPP-33.

2.1.6.2.2 Extent of Dissolution

The margins of halite within the anhydrite and claystone members of the Rustler have been mapped by different methods, the findings of which were consolidated by Beauheim (in 1987a, 131 – 134). There are few differences in interpretation, despite the different methods used (Figure 2-10). Lower members of the Rustler are halitic west of the site, and higher members generally show halite only further east. Snyder interprets these margins as a consequence of post-depositional dissolution of halite. Holt and Powers (Appendix FAC, 6-29) report and interpret sedimentary structures within the Rustler mudstone equivalent to halite beds, indicating that most halite was removed during the depositional process and redeposited in a salt pan in the eastern part of the depositional basin.

Upper intervals of the Salado thin dramatically west and south of the WIPP site (Figure 2-23) compared to deeper Salado intervals. There are no cores for further consideration of possible depositional variations. As a consequence, this zone of thinning is interpreted by the DOE as the edge of dissolution of the upper Salado.

2.1.6.2.3 Timing of Dissolution

The dissolution of Ochoan evaporites through the near-surface processes of weathering and groundwater recharge has been studied extensively (Anderson 1981, Lambert 1983a, Lambert 1983b, Bachman 1984, and see also Appendix FAC). The work of Lambert (1983a) was specifically mandated by the agreement between the DOE and the state of New Mexico to evaluate in detail the conceptual models of evaporite dissolution proposed by Anderson (1981). There was no clear consensus among investigators on the volume of rock salt removed. Hence, estimates of the instantaneous rate of dissolution vary significantly. Dissolution may have taken place as early as the Ochoan, during or shortly after deposition. For the Delaware Basin as a whole, Anderson (1981) proposed that up to 40 percent of the rock salt in the Castile and Salado formations was dissolved during the past 600,000 years. Lambert (1983b, 292) suggested that in many places the variations in salt-bed thicknesses inferred from borehole geophysical logs that were the basis for Anderson's calculation were depositional in origin, compensated by thickening of adjacent nonhalite beds, and were not associated with the characteristic dissolution residues. Borns and Shaffer (1985, 44 – 45) also suggested in 1985 a depositional origin for many apparent structural features attributed to dissolution.

Snyder (1985, 8), as well as earlier workers (for example, Vine 1963, Lambert 1983b, and Bachman 1984), attributes the variations in thickness in the Rustler, which crops out in Nash Draw, to postdepositional evaporite dissolution. Holt and Powers (Appendix FAC, 9-2) have challenged this view and attribute the east-to-west thinning of salt beds in the Rustler to depositional facies variability rather than postdepositional dissolution. Bachman (1974, 1976, and 1980) envisioned several episodes of dissolution since the Triassic, each dominated by greater degrees of evaporite exhumation and a wetter climate, interspersed with episodes of evaporite burial and/or a drier climate. Evidence for dissolution after deposition of the Salado and before deposition of the Rustler along the western part of the Basin was cited by Adams (1944, 1612). Others have argued that the evaporites in the Delaware Basin were above sea level and therefore potentially subject to dissolution, during the Triassic, Jurassic, Tertiary, and Quaternary periods. Because of discontinuous deposition, not all of these times are separable in the geological record of southeastern New Mexico. Bachman (1980) contends that dissolution was episodic during the past 225 million years as a function of regional base level, climate, and overburden.

There have been several attempts to estimate the rates of shallow dissolution in the basin. Bachman provided initial estimates of dissolution rates in 1974 based on a reconstruction of Nash Draw relationships, including the observation that portions of the Gatuña were deposited over areas of active dissolution and subsidence of the underlying evaporites. Though these

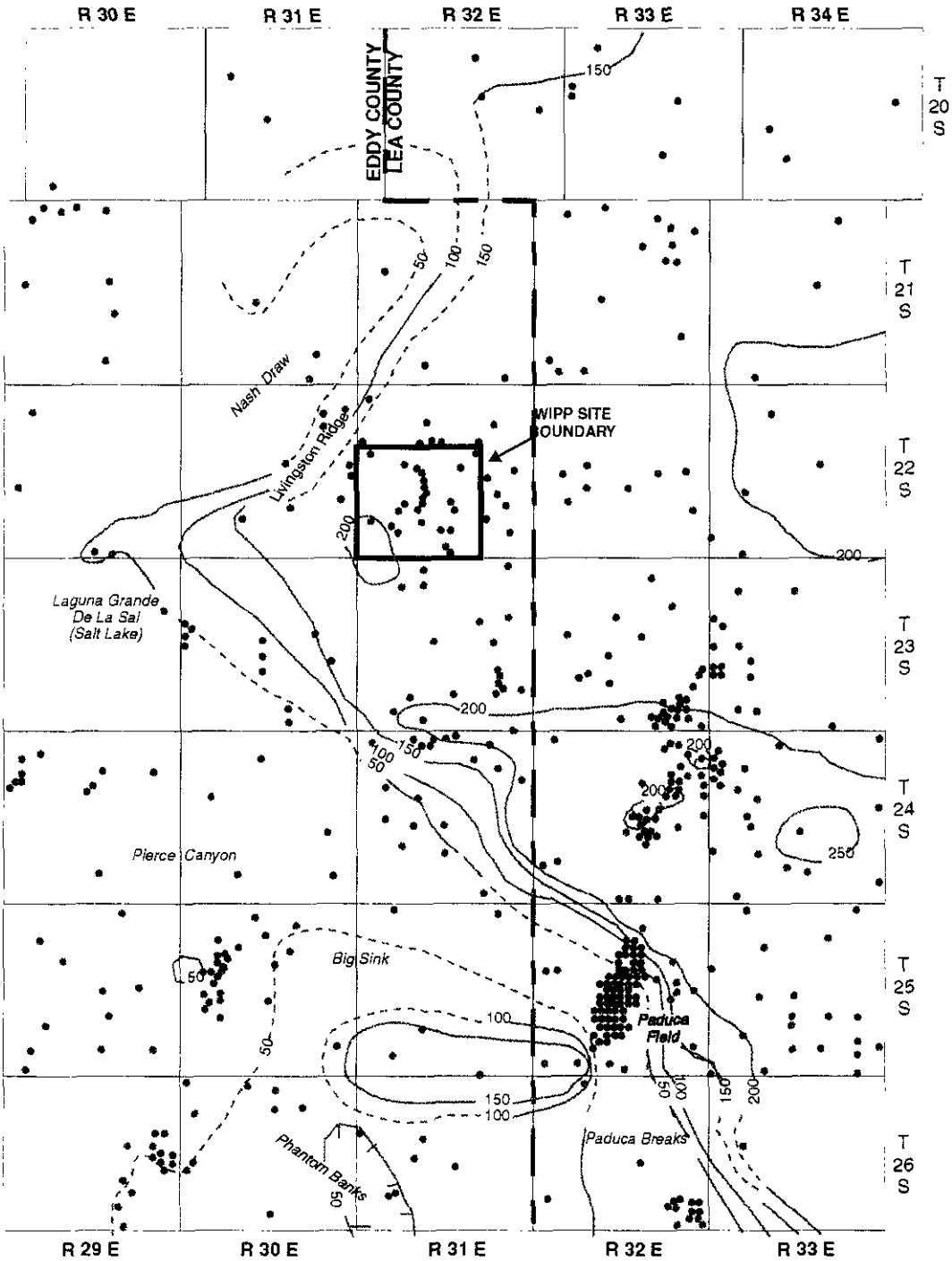

● Borehole

Contour Interval = 50 Feet

Note: The borehole locations used in this study are shown as shaded dots. These are described in Powers and Holt 1995 (Figure 6 and Appendix A). This reference also contains summarized borehole data (Powers and Holt 1995, Figure 15).

N

0 2 4 Miles
Scale

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Figure 2-23. Isopach from the Base of MB103 to the Top of the Salado

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rates indicate no hazard to the WIPP related to Nash Draw dissolution, Bachman (1980, 85) later reconsidered the Nash Draw relationships and concluded that pre-Cenozoic dissolution had also contributed to salt removal. Thus, the initial estimated rates were too high.

With regards to deep dissolution, Anderson concluded in 1978 that the integrity of the WIPP to isolate radioactive waste would not be jeopardized by dissolution within about 1 million years. Anderson and Kirkland (1980, 66 – 69) expanded on the concept of brine density flow proposed by Anderson in 1978 as a means of dissolving evaporites at a point by circulating water from the underlying Bell Canyon. Wood et al. (1982, 100) examined the mechanism and concluded that, while it was physically feasible, it would not be effective enough in removing salt to threaten the ability of the WIPP to isolate transuranic (TRU) waste.

2.1.6.2.4 Features Related to Dissolution

Bachman (1980, 97) separated breccia pipes, formed over the Capitan reef by dissolution and collapse of a cylindrical mass of rock, from evaporite karst features that appear similar to breccia pipes. There are surficial karst features, including sinks and caves, in large areas of the basin. Nash Draw is the result of combined dissolution and erosion. Within the site boundaries, there are no known surficial features caused by dissolution or karst.

The subsurface structure of the Culebra is shown in Figure 2-24. South of the WIPP site between Pierce Canyon and Paduca Breaks there is a relationship between this structure and dissolution. Salt has been removed from the underlying Salado to create a general anticline from near Laguna Grande de la Sal to the southeast of the WIPP site. Beds generally dip to the east, and salt removed to the west created the other limb of the structure. Units below the evaporites apparently do not show the same structure.

2.2 Surface Water and Groundwater Hydrology

The DOE has determined that the hydrological characteristics of the disposal system are important because contaminant transport via fluid flow has a potential to impact the performance of the disposal system. In addition, the EPA has provided numerous criteria related to groundwater in 40 CFR § 194.14(a). At the WIPP site, one of the DOE's selection criteria was to choose a location that would minimize this impact. This was accomplished when the DOE selected (1) a host formation that contains little groundwater and transmits it poorly, (2) a location where the effects of groundwater flow are minimal and predictable, (3) an area where groundwater use is low, (4) an area where there are no permanent surface waters, (5) an area where future groundwater use is unlikely, and (6) a repository host rock that will not likely be affected by anticipated possible long-term climate changes within 10,000 years.

The following discussion summarizes the characteristics of the groundwater and surface water at and around the WIPP site. This summary is based on data collection programs that were initiated with the WIPP program and that continue to some extent today. The purpose of these

programs was to provide information sufficient for the development and use of predictive models of the groundwater movement at the WIPP site.

For a comprehensive understanding of the impact of groundwater and surface water on the disposal system, the following factors have been evaluated:

Groundwater

- Horizontal and vertical flow fluxes and velocities
- Hydraulic interconnectivity between rock units
- Hydraulic parameters (porosity, etc.)
- General groundwater use
- Chemistry (including, but not limited to, salinity, mineralization, age, Eh, and pH).

Surface Water

- Regional precipitation and evapotranspiration rates
- Location and size of surface-water bodies
- Water volume, flow rate, and direction
- Drainage network
- Hydraulic connection with groundwater
- Soil hydraulic properties (infiltration)
- General water chemistry and use.

Changes to the hydrological system due to human activity are evaluated in Chapter 6.0.

The specifics of groundwater modeling are found in Section 6.4.6 and Appendix MASS (Section MASS.14.2). The hydrological system is divided into four segments for the discussion in this chapter. These are (1) the rock units below the Salado, which may impact the disturbed (human intrusion) performance of the disposal system; (2) the Salado, which mostly addresses the undisturbed performance of the disposal system; (3) the rock units above the Salado, which essentially impact only the disturbed (human intrusion) performance of the disposal system; and (4) the surface waters. The groundwater regime is discussed in Section 2.2.1, and the surface-water regime in Section 2.2.2.

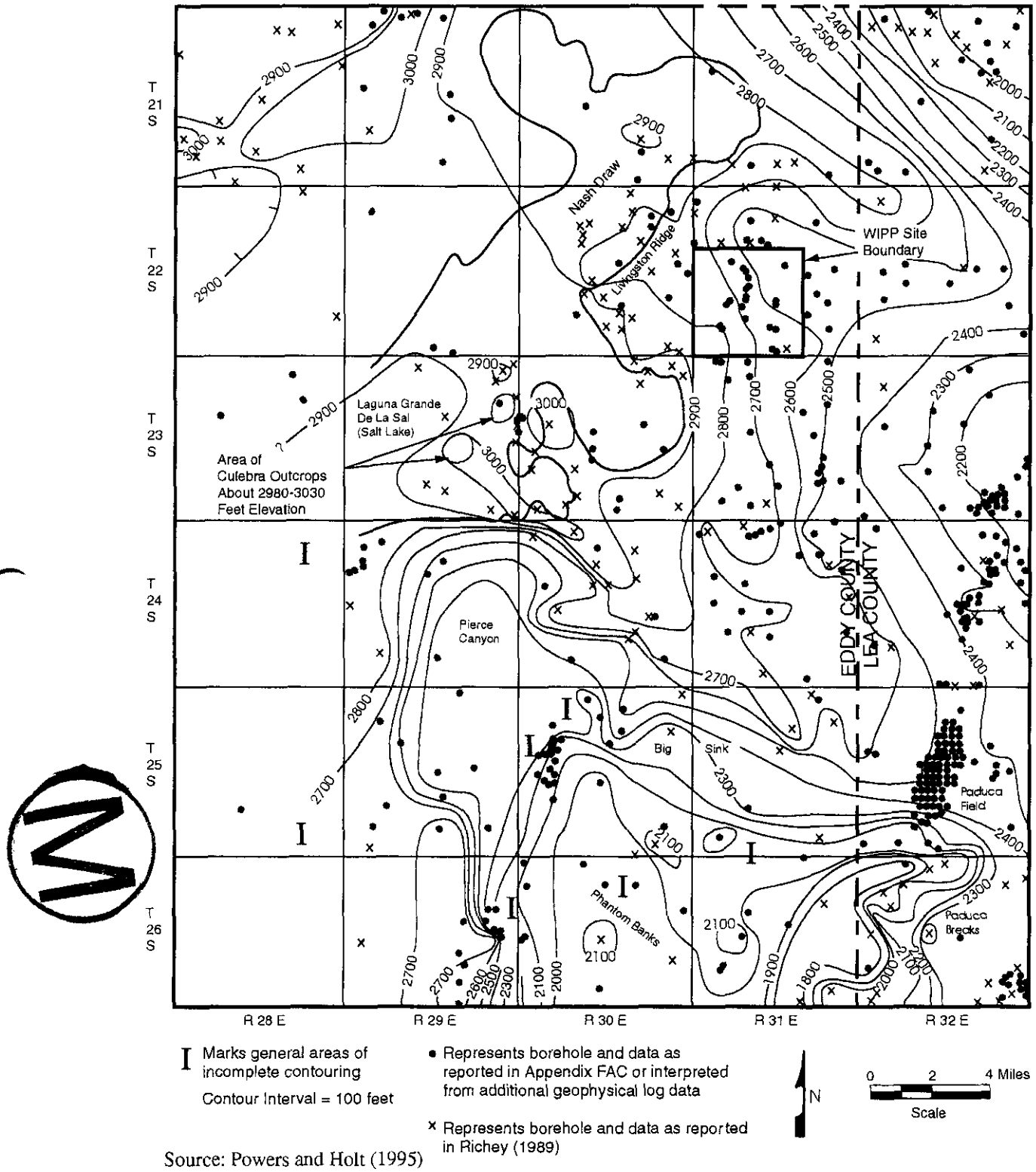

Source: Powers and Holt (1995)

Figure 2-24. Structure Contour Map of Culebra Dolomite Base

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The WIPP site lies within the Pecos River drainage area (Figure 2-25, see also Section 2.2.2, Figure 2-36). As discussed in the Final Environmental Impact Statement (FEIS) (DOE 1980, Section 7.1.1), the climate is semiarid, with a mean annual precipitation of about 13 inches (0.33 meter), a mean annual runoff of 0.1 to 0.2 inch (2.5 to 5 millimeters), and a mean annual pan evaporation of more than 100 inches (2.5 meters). Runoff is practically nonexistent and the WIPP does not have a well defined drainage pattern. The general movement of runoff can be inferred from the topography in Figure 2-25. Only one stream flow gaging station has been operated in the vicinity. This is at the location shown as Hill Tank in Figure 2-25. Observations at Hill Tank are discussed in Section 2.2.2.

Additional information about climatic conditions at the WIPP is given in Section 2.5.2. Brackish water with total dissolved solids (TDS) concentrations of more than 3,000 parts per million is common in the shallow wells near the WIPP site. Surface waters typically have high TDS concentrations, particularly of chloride, sulfate, sodium, magnesium, and calcium. Additional information about water quality is given in Section 2.4.2.

2.2.1 Groundwater Hydrology

At the WIPP site, the DOE obtains groundwater hydrologic data from conventional and special-purpose test configurations in multiple surface boreholes. (Figure 2-2 is a map of borehole locations.) Geophysical logging of the boreholes has provided hydrologic information on the rock strata intercepted. Pressure measurements, fluid samples, and ranges of rock permeability have been obtained for selected formations through the use of standard and modified drill-stem tests. Slug injection or withdrawal tests and other flow-rate tests have provided data to aid in the estimation of transmissivity and storage. The hydraulic heads of groundwaters within many water-bearing zones in the region have been mapped from measured depths to water in the boreholes.

Rock units that are shown in the conceptual models in Section 6.4 to be important to disposal system performance from a hydrological standpoint are the Castile, the Salado, the Rustler, and the Dewey Lake (Figures 2-26 and 2-27). However, other units which are discussed due to their significance in screening hydrological processes or because they are less important to the conceptual model includes the Bell Canyon, the Capitan, the Rustler-Salado contact zone, and the Supra-Dewey Lake units. These will also be discussed because they are features of the groundwater flow system of the WIPP region.

The Bell Canyon is of interest to the DOE because it is the first regionally continuous water-bearing unit beneath the WIPP. The halite and anhydrite layers of the Castile provide a hydrologic barrier between the Salado and the underlying Bell Canyon. The Castile is of interest to performance assessment because it contains isolated high-permeability zones containing pressurized brine. As discussed in Section 2.1.6.1, several such zones of pressurized brine have been intercepted by boreholes near the WIPP site, and one or more may exist at the WIPP site.

The Salado comprises low-permeability beds of variable composition. The low permeability of the Salado provides a hydrologic barrier in all directions between the repository and the accessible environment or more transmissive beds.

The Rustler contains two laterally transmissive members. The Culebra is the first laterally continuous unit located above the WIPP underground facility to display hydraulic conductivity sufficient to warrant concern about lateral contaminant transport. It is also the most transmissive unit above the Salado at the WIPP site. Therefore, except for a breach directly to the surface, the Culebra provides the most direct pathway between the WIPP underground and the accessible environment. The hydrology and fluid geochemistry of the Culebra are complex and, as a result, have received a great deal of study (see, for example, LaVenue et al. 1988, 1990; Haug et al. 1987; and Siegel et al. 1991 in the bibliography). The Magenta, although more transmissive than the anhydrite and claystone members of the Rustler, has lower transmissivity than the Culebra, and is unfractured at the WIPP.

There was no inflow of water from the Dewey Lake into the WIPP shafts after they were completed and prior to their lining, indicating unsaturated conditions or low transmissivity. Flow from a fractured zone has been observed at Water Quality Sampling Program (WQSP)-6a. The Santa Rosa is shallow and unsaturated at the site, and the only flow through it is infiltration, which likely occurs at low rates because of the evaporative climate.

In conclusion, at the WIPP site, the DOE recognizes the Salado as the most significant nontransmissive unit and the Culebra and the Magenta as the most significant transmissive units. Other units are considered to have less important roles. The DOE's sampling and analysis of non-Salado groundwater has focused on the Culebra and Magenta, and their hydrologic background, presented here, is more detailed than for other non-Salado rock units. Table 2-4 provides an overview of the hydrologic characteristics of the Rustler rock units at the WIPP site and the Rustler-Salado contact zone in Nash Draw. In developing this position on modeling the hydrology of the WIPP, the DOE considered several modeling approaches. These are summarized in Appendix MASS (Section MASS.14.1 generally and Section MASS.15.1 for the Culebra). The DOE's conceptual models for hydrology are in Sections 6.4.5 and 6.4.6.

2.2.1.1 Conceptual Models of Groundwater Flow

The DOE addresses issues related to groundwater flow and radionuclide transport within the context of a conceptual model of how the natural hydrologic system works on a large scale. The conceptual model of regional flow around the WIPP that is presented here is based on widely accepted concepts of regional groundwater flow in groundwater basins (see, for example, Hubbert 1940, Tóth 1963, and Freeze and Witherspoon 1967 in the bibliography).

See Appendix MASS (Sections MASS.14.1 and MASS.14.2) for a summary of the DOE's activities leading to the acceptance of the groundwater basin model as a reasonable representation of groundwater flow in the region.

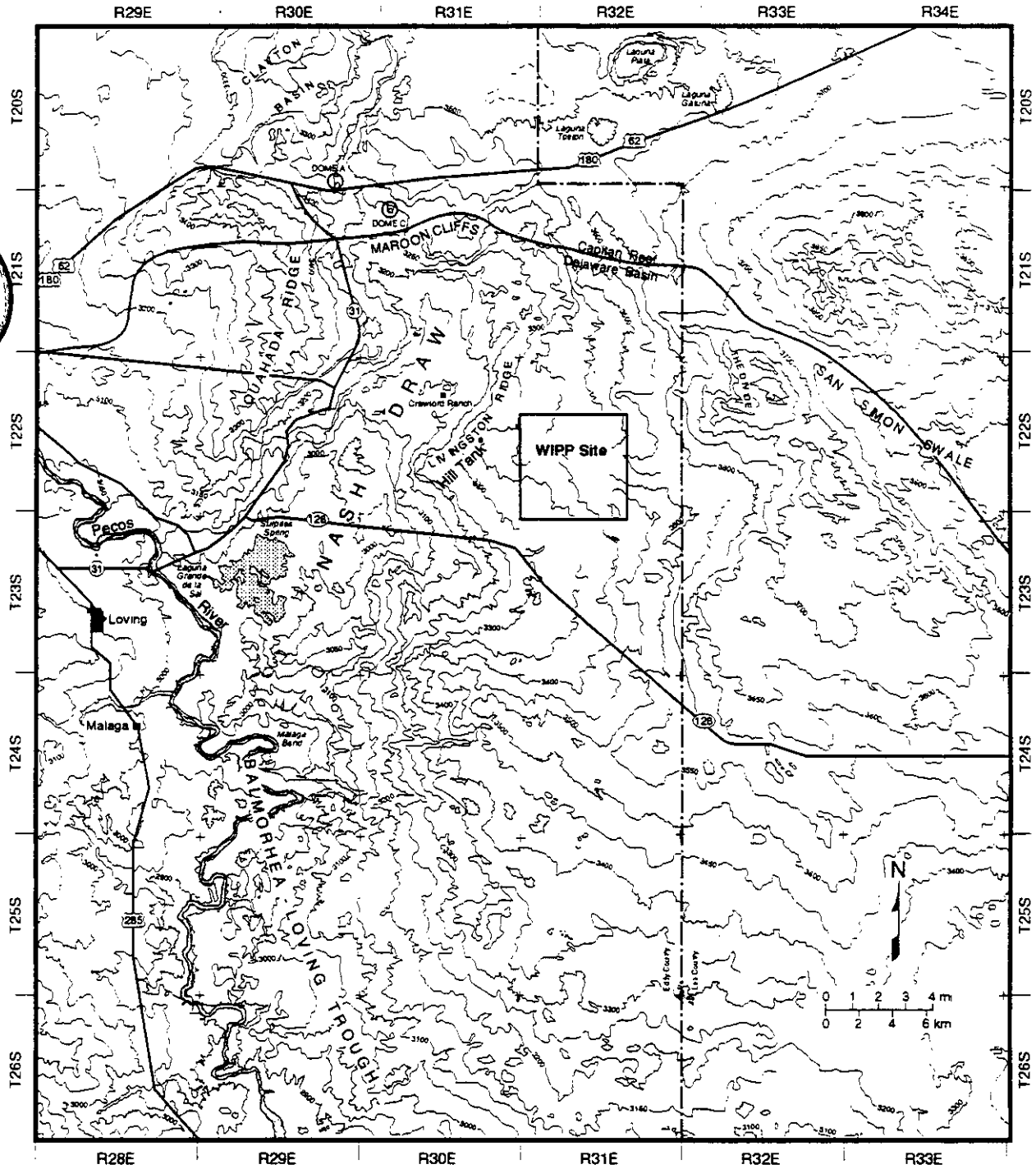

Note: WIPP Site and Vicinity, Eddy County, New Mexico; Drainage towards Pecos River.
Full-size map is in a pocket at the end of this volume.

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Figure 2-25. Drainage Pattern in the Vicinity of the WIPP Facility

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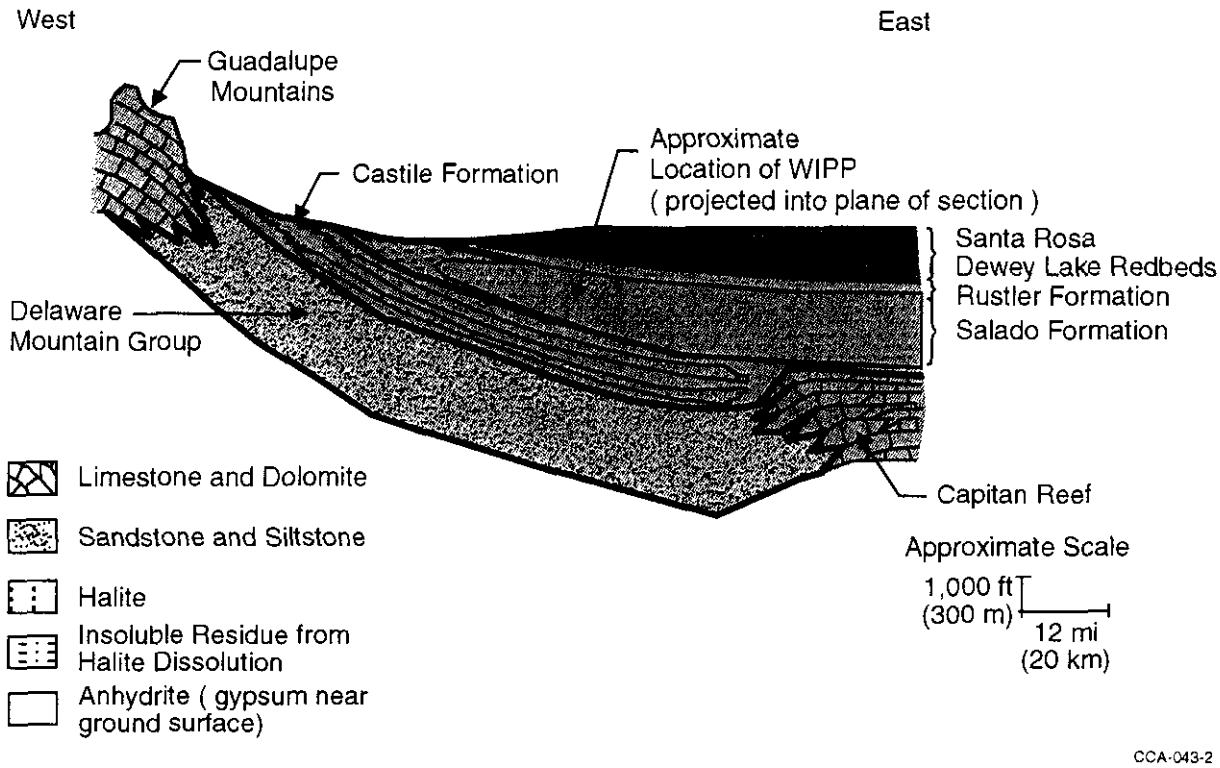

Figure 2-26. Schematic West-East Cross Section through the North Delaware Basin

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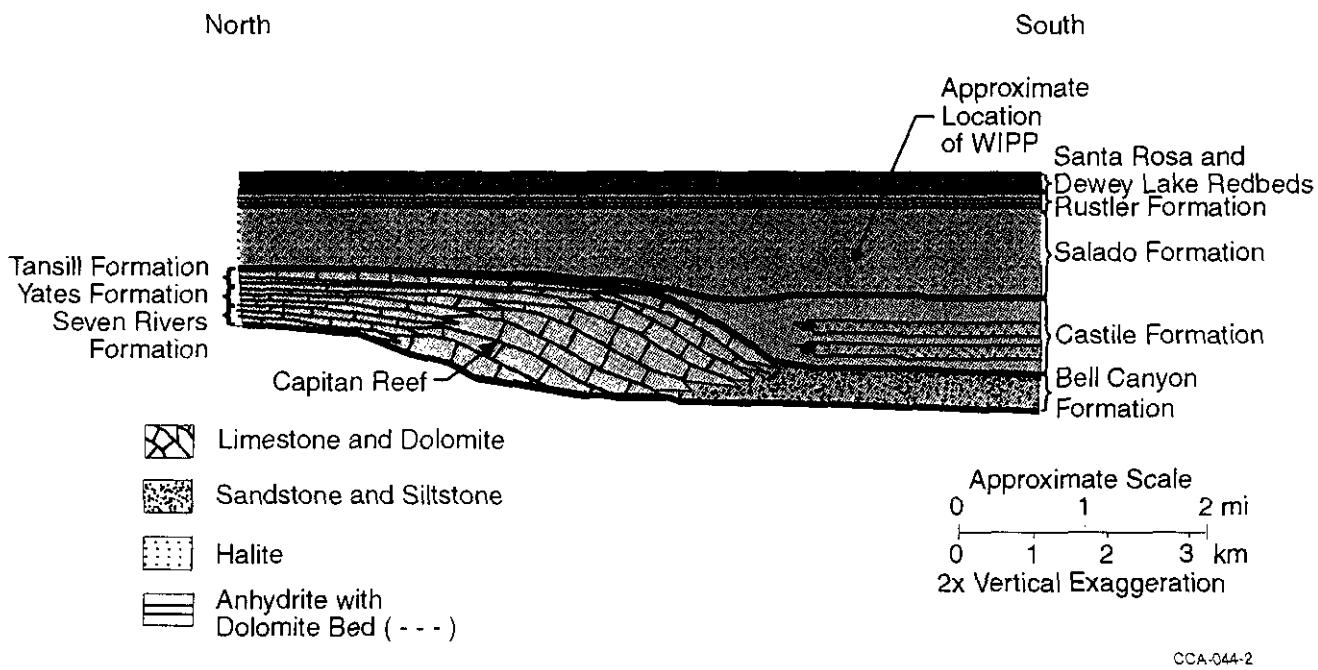

Figure 2-27. Schematic North-South Cross Section through the North Delaware Basin

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Table 2-4. Hydrologic Characteristics of the Rustler at the WIPP and in Nash Draw

Member	Thickness (meters) max	Thickness (meters) min	Transmissivity (square meters per second) max	Transmissivity (square meters per second) min	Porosity max	Porosity min
Forty-niner	23	13	8×10^{-8}	3×10^{-9}	—	—
Magenta	8.5	7	4×10^{-4}	1×10^{-9}	0.25	0.03
Tamarisk	56	26	2.7×10^{-11}	—	—	—
Culebra	11.6	4	1×10^{-3}	1×10^{-9}	0.30	0.03
unnamed lower	38	29	2.9×10^{-10}	2.2×10^{-13}	—	—
Rustler-Salado Contact Zone in Nash Draw	18	3	8.6×10^{-6}	3.2×10^{-11}	0.33	0.15

An idealized groundwater basin is a three-dimensional closed hydrologic unit bounded on the bottom by an impermeable rock unit (units with much smaller permeability than the units above), on the top by the ground surface, and on the sides by groundwater divides. The water table is the upper boundary of the region of saturated liquid flow. All rocks in the basin are expected to have finite permeability; in other words, hydraulic continuity exists throughout the basin. This means that the potential for liquid flow from any unit to any other units exists, although the existence of any particular flow path is dependent on a number of conditions related to gradients and permeabilities. All recharge to the basin is by infiltration of precipitation to the water table and all discharge from the basin is by flow across the water table to the land surface.

Differences in elevation of the water table across an idealized basin provide the driving force for groundwater flow. The pattern of groundwater flow depends on the lateral extent of the basin, the shape of the water table, and the heterogeneity of the permeability of the rocks in the basin. Water flows along gradients of hydraulic head from regions of high head to regions of low head. The highest and lowest heads in the basin occur at the water table at its highest and lowest points, respectively. Therefore, groundwater flows from the elevated regions of the water table, downward across confining layers (layers with relatively small permeability), then laterally along more conductive layers, and finally upward to exit the basin in regions where the water table (and by association, the land surface) is at low elevations. Recharge is necessary to maintain relief on the water table, without which flow does not occur.

Groundwater divides are boundaries across which it is assumed that no groundwater flow occurs. In general, these are located in areas where groundwater flow is dominantly downward (recharge areas) or where groundwater flow is upward (discharge areas). Topography and surface-water drainage patterns provide clues to the location of groundwater divides. Ridges between creeks and valleys may serve as recharge-type divides, and rivers, lakes, or topographic depressions may serve as discharge-type divides.

In the groundwater basin model, rocks can be classified into hydrostratigraphic units. A hydrostratigraphic unit is a continuous region of rock across which hydraulic properties are similar or vary within described or stated limits. The definition of hydrostratigraphic units is a practical exercise to separate rock regions with similar hydrologic characteristics from rock regions with dissimilar hydrologic characteristics. Although hydrostratigraphic units often are defined to be similar to stratigraphic units, this need not be the case. Hydrostratigraphic unit boundaries can reflect changes in hydraulic properties related to differences in composition, fracturing, dissolution, or a variety of other factors that may not be reflected in the definition of stratigraphic formations.

Confining layers in a groundwater basin model can be characterized as allowing vertical flow only. The amount of vertical flow occurring in a confining layer generally decreases in relation to the depth of the layer. Flow in conductive units is more complicated. In general, flow will be lateral through conductive units. The magnitude (in other words, volume flux) of lateral flow is related to the thickness, conductivity, and gradient present in the unit. Gradients generally decrease in deeper units. The direction of flow is generally related to the distance the unit is from the land surface. Near the land surface, flow directions are influenced primarily by the local slope of the land surface. In deeper conductive units, flow directions are generally oriented parallel to the direction between the highest and lowest points in a groundwater basin. Thus, flow rates, volumes, and directions in conductive units in a groundwater basin are generally not expected to be the same.

In the WIPP region, the Salado provides an extremely low-permeability layer that forms the base for a regional groundwater-flow basin in the overlying rocks of the Rustler, Dewey Lake, and Santa Rosa. The Castile and Salado together form their own groundwater system, and they separate flow in units above them from that in units below. Because of the plastic nature of halite and the resulting low permeability, fluid pressures in the evaporites are more related to lithostatic stress than to the shape of the water table in the overlying units, and regionally neither vertical nor horizontal flow will occur as a result of natural pressure gradients in time scales relevant to the disposal system. (On a repository scale, however, the excavations themselves create pressure gradients that may induce flow near the excavated region.) Consistent with the recognition of the Salado as the base of the groundwater basin of primary interest, the following discussion is divided into three sections: hydrology of units below the Salado, hydrology of the Salado, and hydrology of the units above the Salado. The DOE has implemented the groundwater basin model in the conceptual model for groundwater flow within the rocks above the Salado. The details of the model are discussed in Section 6.4.6. Key modeling assumptions associated with the implementation are provided in Appendix MASS (Section MASS.14.2).

2.2.1.2 Units Below the Salado

Units of interest to the WIPP project below the Salado are the Bell Canyon and the Castile. These units have quite different hydrologic characteristics. Because of its potential to contain

brine reservoirs below the repository, the hydrology of the Castile is regarded as having the most potential of all units below the Salado to impact the performance of the disposal system.

2.2.1.2.1 *Hydrology of the Bell Canyon Formation*

The Bell Canyon is considered for the purposes of regional groundwater flow to form a single hydrostratigraphic unit about 1,000 feet (300 meters) thick. Tests at five boreholes (Atomic Energy Commission [AEC]-7, AEC-8, ERDA-10, DOE-2, and Cabin Baby) (Appendix HYDRO, 29 – 31; Beauheim et al. 1983, 4-9 to 4-12; Beauheim 1986, 61 – 71) indicate a range of hydraulic conductivities for the Bell Canyon from 5×10^{-2} feet per day to 1×10^{-6} feet per day (1.7×10^{-7} to 3.5×10^{-12} meters per second). The pressure measured in the Bell Canyon at the DOE-2 and Cabin Baby boreholes ranges from 12.6 to 13.3 megapascals. Fluid flow in the Bell Canyon is markedly influenced by the presence of the extremely low-permeability Castile and Salado above it, which effectively isolate it from interaction with overlying units except where the Castile is absent because of erosion or nondeposition, such as in the Guadalupe Mountains, or where the Capitan reef is the overlying unit (Figures 2-26 and 2-27). Because of the isolating nature of the Castile and Salado, fluid flow directions in the Bell Canyon are sensitive only to gradients established over very long distances. At the WIPP, the brines in the Bell Canyon flow northeasterly under an estimated hydraulic gradient of 25 to 40 feet per mile (4.7 to 7.6 meters per kilometer) and discharge into the Capitan aquifer. Velocities are on the order of tenths of feet per year, and groundwater yields from wells in the Bell Canyon are 0.6 to 1.5 gallons (2.3 to 5.8 liters) per minute. The fact that flow directions in the Bell Canyon under the WIPP are inferred to be almost opposite to the flow directions in units above the Salado (see Section 2.2.1.4) is not of concern because, as discussed above, the presence of the Castile and Salado makes the flow in the Bell Canyon sensitive to gradients established over long distances, whereas flow in the units above the Salado is sensitive to gradients established by more local variations in water table elevation.

2.2.1.2.2 *Castile Hydrology*

As described in Section 2.1.3, the Castile is dominated by low-permeability anhydrite and halite zones. However, fracturing in the upper anhydrite has generated isolated regions with much greater permeability than the surrounding intact anhydrite. These regions are located in the area of structural deformation, as discussed in Section 2.1.6.1.1. The higher-permeability regions of the Castile contain brine at pressures greater than hydrostatic and have been referred to as brine reservoirs (see Figure 2-28). The fluid pressure measured by Popielak et al. in 1983 in the WIPP-12 borehole (12.7 megapascals) is greater than the nominal hydrostatic pressure for a column of equivalent brine at that depth (11.1 megapascals). Therefore, under open-hole conditions, brine could flow upward to the surface through a borehole.

Results of hydraulic tests performed in the ERDA-6 and WIPP-12 boreholes suggest that the extent of the highly permeable portions of the Castile is limited. As discussed in Section

permeability microfractures; about 5 percent of the overall brine volume is stored in large open fractures. The volumes of the ERDA-6 and WIPP-12 brine reservoirs were estimated by Popielak et al. in 1983 to be 3.5×10^6 cubic feet (100,000 cubic meters) and 9.5×10^7 cubic feet (2,700,000 cubic meters), respectively. The conceptual model of the Castile brine region is discussed in Section 6.4.8. The model uses parameter values derived from the ERDA-6 and WIPP-12 tests for quantifying some reservoir characteristics. The derivation of some model parameters in Appendix PAR (Tables PAR-49 and PAR-50) from the data discussed here is given in Appendix MASS (Section MASS.18).

A geophysical survey using time-domain electromagnetic (TDEM) methods was completed over the WIPP-12 brine reservoir and the waste disposal panels (The Earth Technology Corporation 1988). The TDEM measurements detected a conductor interpreted to be the WIPP-12 brine reservoir and also indicated that similar brine occurrences may be present within the Castile under a portion of the waste disposal panels. In a recent geostatistical analysis, Powers et al. (1996) used 354 drill holes and 27 Castile brine occurrences to establish that there is an 8 percent probability of a hole drilled into the waste panel region encountering brine in the Castile. This analysis is included in the application as Attachment 18-6 in Appendix MASS.

The origin of brine in the Castile has been investigated geochemically. Popielak et al. (1983, 2) concluded that the ratios of major and minor element concentrations in the brines indicate that these fluids originated from ancient seawater and that no evidence exist for fluid contribution from present meteoric waters. The Castile brine chemistries from the ERDA-6 and WIPP-12 reservoirs are distinctly different from each other and from local groundwaters. These geochemical data indicate that brine in reservoirs has not mixed to any significant extent with other waters and has not circulated. The brines are saturated, or nearly so, with respect to halite and, consequently, have little potential to dissolve halite. The chemical composition of Castile brine is given in Table 2-5. Its use as a parameter model in the conceptual model of repository performance is discussed in Appendix SOTERM (Section SOTERM.2.2.1).

2.2.1.3 Hydrology of the Salado

As described in Section 2.1.3, the Salado consists mainly of halite and anhydrite. A considerable amount of information about the hydraulic properties of these rocks has been collected through field and laboratory experiments. Appendices HYDRO (41 – 42) and Appendix PAR summarize this information.

Hydraulic testing in the Salado in boreholes in the WIPP underground provided quantitative estimates of the hydraulic properties controlling brine flow through the Salado (Beauheim et al. 1991; Beauheim et al. 1993; Domski et al. 1996). The stratigraphic intervals tested include both pure and impure halite. Tests influence rock as far as 33 feet (10 meters) distant from the test zone and therefore provide results that are not significantly influenced by disturbances

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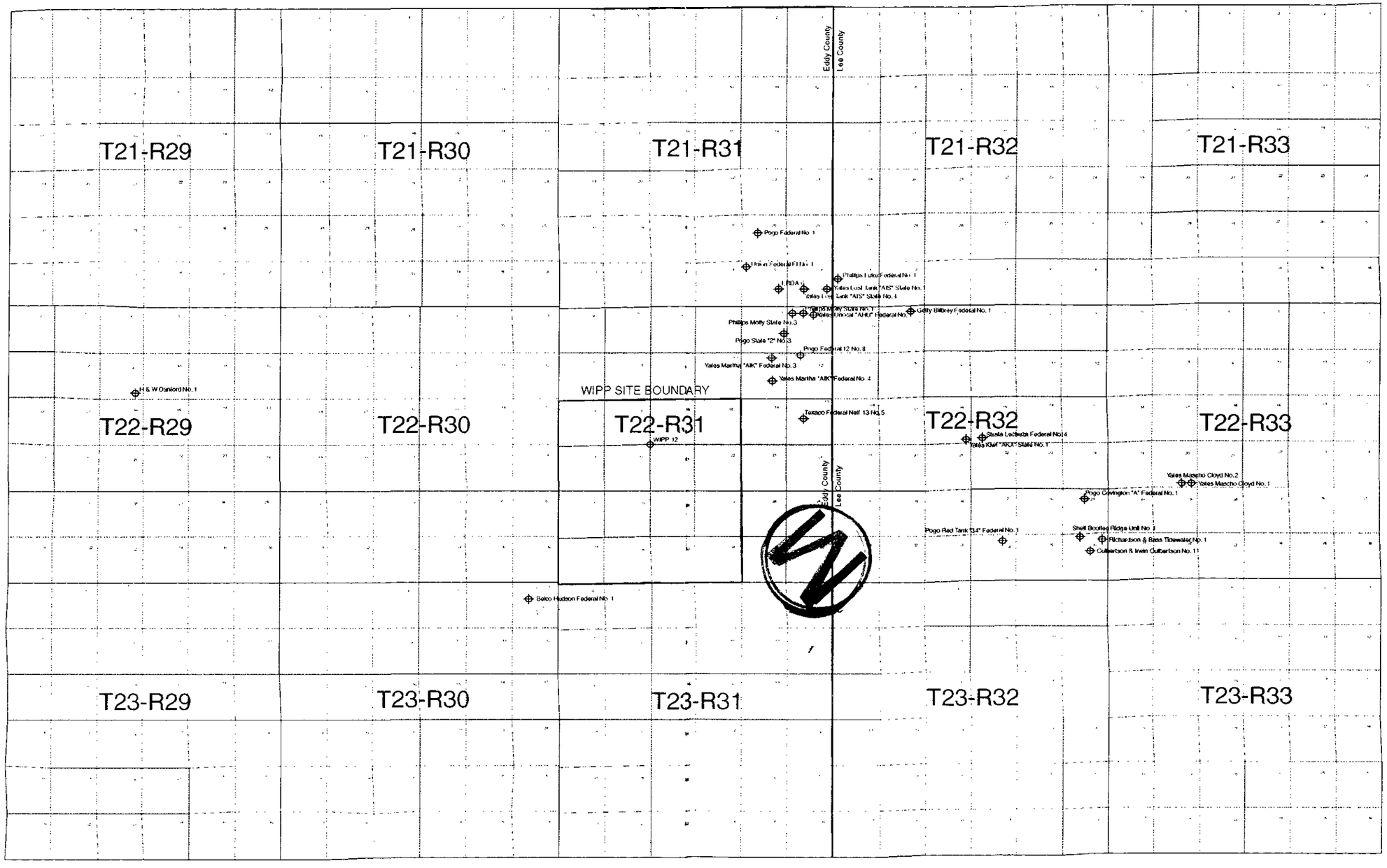

Note: Full-sized map of this figure is in a pocket at the end of this volume.

◆ Castile Brine Well Locations

Figure 2-28. Recent Occurrences of Pressurized Brine in the Castile

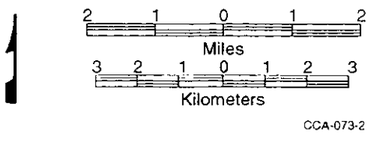

Table 2-5. WIPP Salado and Castile Brine Compositions

	Salado Brine Average (n between 82 and 96)		Castile ERDA-6	Castile WIPP-12
Specific Gravity	1.22	± 0.01	1.216	1.215
pH	6.1		6.17	7.06
Sodium	79,100	± 2,100	112,000	138,000
Potassium	15,900	± 800	3,800	2,900
Calcium	282	± 38	490	350
Magnesium	22,700	± 1,400	450	1,600
Boron	1,450	± 120	680	990
Lithium	nd		240	280
Silicon	1.6	± 0.7	21	27
Strontium	1.6	± 0.6	18	19
Ammonium	148	± 16	1,119	476
Nitrate	0.8	(median)	2,746	2,436
Chloride	193,000	± 4,000	170,000	178,000
Sulfate	17,000	± 900	16,000	18,000
Bromide	1,500	± 60	880	510
Iodide	14.8	± 3.1	28	24
Alkalinity (as HCO_3^- equivalent)[1]	883	± 123	2,600	2,700
Total Organic Carbon	54	± 50	nd	nd
Total Dissolved Solids	374,000	± 13,000	330,000	328,000

[1] Alkalinity measured to an endpoint pH of 2.5 and expressed as equivalent bicarbonate.

Legend:

nd not determined

Note: All determinands reported in units of milligrams per liter, except for pH and Specific Gravity. Only determinands with a concentration in excess of 10 milligrams per liter in at least one of the brines are shown. Data taken from DOE (1994, Table 3-3) and Popeliak et al. (1983, Table C.2).

associated with the tests themselves. Because tests close to the repository are within the DRZ that surrounds the excavated regions (see Section 3.2), results of the tests farthest from the repository are most representative of undisturbed conditions.

Twenty-two hydraulic tests have been performed in impure halite, and two in pure halite. Interpreted permeabilities using a Darcy-flow model vary from 1×10^{-23} to 4×10^{-18} square meters for impure halite intervals. Interpreted formation pore pressures vary from 0.3 to 9.7 megapascals for impure halite, with the lower pressures believed to show effects of the DRZ. Tests in pure halite show no observable response, indicating either extremely low permeability ($<10^{-23}$ square meters), or no flow whatsoever, even though appreciable pressures are applied to the test interval.

Fourteen hydraulic tests have been performed in anhydrite. Interpreted permeabilities using a Darcy-flow model vary from 2×10^{-20} to 7×10^{-18} square meters for anhydrite intervals. Interpreted formation pore pressures vary from atmospheric to 12.5 megapascals for anhydrite intervals (Beauheim et al. 1993, 139). Lower values are caused by depressurization near the excavation.

The properties of anhydrite interbeds have also been investigated in the laboratory. Tests were performed on three groups of core samples from MB139 as part of the Salado Two-Phase Flow Laboratory Program. The laboratory experiments provided porosity, intrinsic permeability, and capillary pressure data. Analysis of capillary pressure test results indicate a threshold pressure of less than 1 megapascal. Both laboratory and field data were used to establish hydraulic parameters for the Salado for performance assessment as summarized in Appendix PAR (Tables PAR-6 and PAR-7).

Fluid pressure above hydrostatic is a hydrologic characteristic of the Salado (and the Castile) that plays a potentially important role in the repository behavior. It is difficult to accurately measure natural pressures in these formations because the boreholes or repository excavations required to access the rocks decrease the stress in the region measured. Stress released instantaneously decreases fluid pressure in the pores of the rock, so measured pressures must be considered as a lower bound of the natural pressures. Stress effects related to test location and the difficulty of making long-duration tests in lower-permeability rocks result in higher pore pressures observed to date in anhydrites. The highest observed pore pressure in halite-rich units, near Room Q, is on the order of 9 megapascals, whereas the highest pore pressures observed in anhydrite are 12.5 megapascals (Beauheim et al. 1993, 139). Far-field pore pressures in halite-rich and anhydrite beds in the Salado at the repository level are expected to be similar because the anhydrites are too thin and of too low permeabilities to have liquid pressures much different than those of the surrounding salt. For comparison, the hydrostatic pressure for a column of brine at the depth of the repository is about 7 megapascals, and the lithostatic pressure calculated from density measurements in ERDA-9 is about 15 megapascals.

Fluid pressure in sedimentary basins that are much higher or much lower than hydrostatic are referred to as abnormal pressures by the petroleum industry, where they have received considerable attention. In the case of the Delaware Basin evaporites, the high pressures are almost certainly maintained because of the large compressibility and plastic nature of the halite and, to a lesser extent, the anhydrite. The lithostatic pressure at a particular horizon must be supported by a combination of the stress felt by both the rock matrix and the pore fluid. In highly deformable rocks, the portion of the stress that must be borne by the fluid exceeds hydrostatic pressure but cannot exceed lithostatic pressure.

Brine content within the Salado is estimated at 1 to 2 percent by weight, although the thin clay seams have been observed by Deal et al. (1993, 4-3) to contain up to 25 percent brine by volume. Where sufficient permeability exists, this brine will move towards areas of lower hydraulic potential, such as a borehole or mined section of the Salado.

Observation of the response of pore fluids in the Salado to changes in pressure boundary conditions at walls in the repository, in boreholes without packers, in packer-sealed boreholes, or in laboratory experiments is complicated by low permeability and low porosity. Qualitative data on brine flow to underground workings and exploratory boreholes have been collected routinely since 1985 under the Brine Sampling and Evaluation Program (BSEP) and have been documented in a series of reports (Deal and Case 1987; Deal et al. 1987, 1989, 1991a, 1991b, and 1993). These and other investigations are discussed in Appendix SUM (Section 3.3.1.3). A discussion of alternative conceptual models for Salado fluid flow is given in Appendix MASS (Section MASS.7). Additional data on brine inflow are available from the Large-Scale Brine Inflow Test (Room Q). Flow has been observed to move to walls in the repository, to boreholes without packers, and to packer-sealed boreholes. These qualitative and relatively short-term observations suggest that brine flow in the fractured DRZ is a complex process. In some locations, evidence for flow is no longer observed where it once was; in others, flow has begun where it once was not observed. In many cases, observations and experiments must last for months or years to obtain useful results.

For performance assessment modeling, brine flow is a calculated term dependent on local hydraulic gradients and properties of the Salado units. Data on pore pressure and permeability of halite and anhydrite layers are available from the Room Q test and other borehole tests, and these data form the basis for the quantification of the material properties used in the performance assessment. See Section 6.4.3.2 for a description of the repository fluid flow model.

Because brine is an important factor in repository performance, several studies of its chemistry have been conducted. Initial investigations were reported in Powers et al. (Appendix GCR, Section 7.5) and were continued once access to the underground was established. The most comprehensive data were developed by the Brine Sampling and Evaluation Program (Deal and Case 1987; Deal et al. 1987, 1989, 1991a, 1991b, 1993). Results are summarized in Table 2-5. Appendix SOTERM discusses the role of brine chemistry in the conceptual model for actinide dissolution. The conceptual model is described in Section 6.4.3.5.

2.2.1.4 Units Above the Salado

In evaluating groundwater flow above the Salado, the DOE considers the Rustler, Dewey Lake, Santa Rosa, and overlying units to form a groundwater basin with boundaries coinciding with selected groundwater divides as discussed in Section 2.2.1.1. The model boundary follows Nash Draw and the Pecos River valley to the west and south and the San Simon Swale to the east (Figure 2-29). The boundary continues up drainages and dissects topographic highs along its northern part. These boundaries represent groundwater divides whose positions remain fixed over the past several thousand years and 10,000 years into the future. For reasons described in Section 2.2.1.2.1, the lower boundary of the groundwater basin is the upper surface of the Salado.

Nash Draw and the Pecos River are areas where discharge to the surface occurs. Hunter in 1985 described discharge at Surprise Spring and into saline lakes in Nash Draw. She reported groundwater discharge into the Pecos River between Avalon Dam north of Carlsbad and a point south of Malaga Bend as approximately 32.5 cubic feet per second (0.92 cubic meter per second), mostly in the region near Malaga Bend.

Within this groundwater basin, hydrostratigraphic units with relatively high permeability are called conductive units, and those with relatively low permeability are called confining layers. The confining layers consist of halite and anhydrite and are perhaps five orders of magnitude less permeable than conductive units.

In a groundwater basin, the position of the water table moves up and down in response to changes in recharge. The amount of recharge is generally a very small fraction of the amount of rainfall; this condition is expected for the WIPP. Modeling of recharge changes within the groundwater basin as a function of climate variation is discussed in Section 6.4.9. The water table would stabilize at a particular position if the pattern of recharge remained constant for a long time. The equilibrated position depends, in part, on the distribution of hydraulic conductivity in all hydrostratigraphic units in the groundwater basin. However, the position of the water table depends mainly on the topography and geometry of the groundwater basin and the hydraulic conductivity of the uppermost strata. The position of the water table can adjust slowly to changes in recharge. Consequently, the water table can be at a position that is very much different from its equilibrium position at any given time. Generally, the water table drops very slowly in response to decreasing recharge but might rise rapidly in times of increasing recharge.

The asymmetry of response occurs because the rate at which the water table drops is limited by the rate at which water flows through the entire basin. In contrast, the rate at which the water table rises depends mainly on the recharge rate and the porosity of the uppermost strata. From groundwater basin modeling, the head distribution in the groundwater basin appears to equilibrate rapidly with the position of the water table.

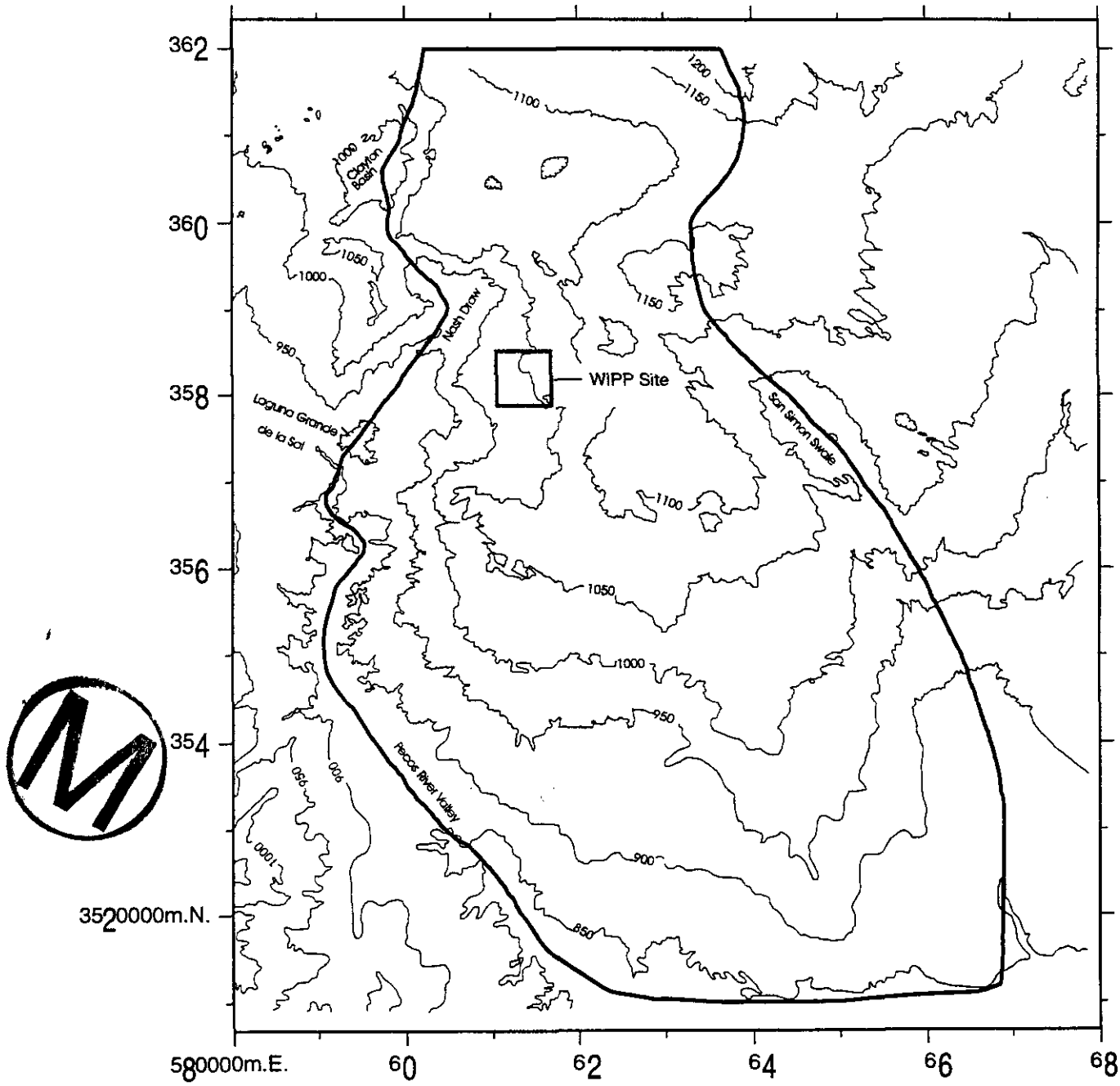

Note: Contour level for elevation above mean sea level is 50 meters

N 0 20 m

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Figure 2-29. Outline of the Groundwater Basin Model Domain on a Topographic Map

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The groundwater basin conceptual model (Corbet and Knupp 1996) described above has been implemented in a numerical model as described in Section 6.4.6.2 and Appendix MASS (Section MASS.14.2). This model has been used to simulate the interactive nature of flow through conductive layers and confining units for a variety of possible rock properties and climate futures. Thus, this model has allowed insight into the magnitude of flow through various units. The DOE has used this insight as a basis for model simplifications used in performance assessment that are described here and in Chapter 6.0.

One conclusion from the regional groundwater basin modeling is pertinent here. In general, vertical leakage through confining layers is directed downward over all of the controlled area. This downward leakage uniformly over the WIPP site is the result of a well-developed discharge area, Nash Draw and the Pecos River, along the western and southern boundaries of the groundwater basin. This area acts as a drain for the laterally conductive units in the groundwater basin, causing most vertical leakage in the groundwater basin to occur in a downward direction. This conclusion is important in performance assessment simplifications related to the relative importance of lateral flow in the Magenta versus the Culebra, which will be discussed later in this chapter and in Section 6.4.6.

2.2.1.4.1 Hydrology of the Rustler Formation

The Rustler is of particular importance for WIPP because it contains the most transmissive units above the repository. Fluid flow in the Rustler is characterized by very slow rates of vertical leakage through confining layers and faster lateral flow in conductive units. To illustrate this point, regional modeling with the groundwater basin model indicates that lateral specific discharges in the Culebra, for example, are perhaps two to three orders of magnitude greater than the vertical specific discharges across the top of the Culebra.

2.2.1.4.1.1 Unnamed Lower Member

The unnamed lower member makes up a single hydrostratigraphic unit in WIPP models of the Rustler, although its composition varies somewhat. Overall, it acts as a confining layer. The basal interval of the unnamed lower member, approximately 64 feet (19.5 meters) thick, is composed of siltstone, mudstone, and claystone and contains the water-producing zones of the lowermost Rustler. Transmissivities of 2.7×10^{-4} square feet per day (2.9×10^{-10} square meters per second) and 2.2×10^{-4} square feet per day (2.4×10^{-10} square meters per second) were reported by Beauheim (1987a, 50) from tests at well H-16 that included this interval. The porosity of the unnamed lower member was measured in 1995 as part of testing at the H-19 hydropad. Two claystone samples had effective porosities of 26.8 and 27.3 percent. One anhydrite sample had an effective porosity of 0.2 percent. The transmissivity values correspond to hydraulic conductivities of 4.2×10^{-6} feet per day (1.5×10^{-11} meters per second) and 3.4×10^{-6} feet per day (1.2×10^{-11} meters per second). Hydraulic conductivity in the lower portion of the unnamed lower member is believed by the DOE to increase to the west in and near Nash Draw, where dissolution at the underlying Rustler-Salado contact has caused subsidence and fracturing of the sandstone and siltstone.

The remainder of the unnamed lower member contains mudstones, anhydrite, and variable amounts of halite. The hydraulic conductivity of these lithologies is extremely low; tests of mudstones and claystones in the waste-handling shaft gave hydraulic conductivity values varying from 2×10^{-9} feet per day (6×10^{-15} meters per second) to 3×10^{-8} feet per day (1×10^{-13} meters per second) according to Saulnier and Avis (1988, 6 – 11). It is for this reason the unnamed lower member is treated as a single hydrostratigraphic unit that overall acts as a confining unit. The conceptual model incorporating the unnamed lower member is discussed in Section 6.4.6.1. Important hydrologic model properties of the unnamed lower member are discussed in Section 6.4.6.1 and are summarized in Appendix PAR (Table PAR-31).

2.2.1.4.1.2 The Culebra

The Culebra is of interest because it is the most transmissive unit at the WIPP site, and hydrologic research has been concentrated on the unit for over a decade. Although it is relatively thin, it is an entire hydrostratigraphic unit in the WIPP hydrological conceptual model, and it is the most important conductive unit in this model. Implementation of the Culebra in the conceptual model is discussed in detail in Section 6.4.6.2. Model discussions cover groundwater flow and transport characteristics of the Culebra. These are supported by parameter values in Table 6-18, 6-19, 6-20, and 6-21. Additional background for the Culebra model is in Appendix MASS (Sections MASS.14 and MASS.15).

The two primary types of field tests that are being used to characterize the flow and transport characteristics of the Culebra are hydraulic tests and tracer tests.

The hydraulic testing consists of pumping, injection, and slug testing of wells across the study area (for example, Beauheim 1987a, 3). The most detailed hydraulic test data exist for the WIPP hydropads (for example, H-19). The hydropads generally comprise a network of three or more wells located within a few tens of meters of each other. Long-term pumping tests have been conducted at hydropads H-3, H-11, and H-19 and at well WIPP-13 (Beauheim 1987b, 1987c, 1989; Beauheim et al. 1995). These pumping tests provided transient pressure data at the hydropad and over a much larger area. Tests often included use of automated data-acquisition systems, providing high-resolution (in both space and time) data sets. In addition to long-term pumping tests, slug tests and short-term pumping tests have been conducted at individual wells to provide pressure data that can be used to interpret the transmissivity at that well (Beauheim 1987a). (Additional short-term pumping tests have been conducted in the WQSP wells [Stensrud 1995]). Detailed cross-hole hydraulic testing has recently been conducted at the H-19 hydropad (Kloska et al. 1995).

The hydraulic tests are designed to yield pressure data for the interpretation of such characteristics as transmissivity, permeability, and storativity. The pressure data from long-term pumping tests and the interpreted transmissivity values for individual wells are used for the generation of transmissivity fields in performance assessment flow modeling (see Appendix TFIELD, Section TFIELD.2). Some of the hydraulic test data and interpretations

are also important for the interpretation of transport characteristics. For instance, the permeability values interpreted from the hydraulic tests at a given hydropad are needed for interpretations of tracer test data at that hydropad.

To evaluate transport properties of the Culebra, a series of tracer tests has been conducted at six locations (the H-2, H-3, H-4, H-6, H-11, and H-19 hydropads) near the WIPP site. Tests at the first five of these locations consisted of two-well dipole tests and/or multiwell convergent flow tests and are described in detail in Jones et al. (1992). Tracer tests at the H-19 hydropad and additional tracer tests performed at the H-11 hydropad are described in Beauheim et al. (1995). The more recent tracer test program consisted of single-well injection-withdrawal tests and multi-well convergent flow tests. Unique features of this testing program include the single-well test at both H-19 and H-11, the injection of tracers into six wells during the H-19 convergent-flow test, the injection of tracer into upper and lower zones of the Culebra at the H-19 hydropad, repeated injections under different convergent-flow pumping rates, and the use of tracers with different free-water diffusion coefficients. The recent tracer tests were specifically designed to evaluate the importance of heterogeneity (both horizontal and vertical) and diffusion on transport processes.

The Culebra is a fractured dolomite with nonuniform properties both horizontally and vertically. Examination of core and shaft exposures has revealed that there are multiple scales of porosity within the Culebra including fractures ranging from microscale to potentially large, vuggy zones, and interparticle and intercrystalline porosity. Porosity measurements made on core samples give porosity measurements ranging from 0.03 to 0.30 (Kelley and Saulnier 1990). This large range in porosity for small samples is expected given the variety of porosity types within the Culebra. However, the effective porosity for flow and transport at larger scales will have a smaller range due to the effects of spatial averaging. The core measurements indicate that the Culebra has significant quantities of connected porosity.

Flow in the Culebra occurs within fractures, within vugs where they are connected by fractures, and to some extent within interparticle porosity where the porosity (and permeability) is high, such as chalky lenses. At any given location, flow will occur in response to hydraulic gradients in all places that are permeable. When the permeability contrast between different scales of connected porosity is large, the total porosity can effectively be conceptualized by dividing the system into advective porosity (often referred to as fracture porosity) and diffusive porosity (often referred to as matrix porosity). The advective porosity can be defined as the portion of the porosity where flow is the dominant process (for example fractures and to some extent vugs connected by fractures and interparticle porosity). Diffusive porosity can be defined as the portion of the porosity where diffusion is the dominant process (for example, intercrystalline porosity and to some extent microfractures, vugs and portions of the interparticle porosity.)

For the Culebra in the vicinity of the WIPP site, defining advective porosity is not a simple matter. In some regions the permeability of the fractures is inferred to be significantly larger than the permeability of the other porosity types, thus advective porosity can be

conceptualized as predominantly fracture porosity (low porosity). In some regions, there appear to be no high permeability fractures. This may be due to a lack of large fractures or may be the result of gypsum fillings in a portion of the porosity. Where permeability contrasts between porosity types are small, the advective porosity can be conceptualized as a combination of fractures, vugs connected by fractures and permeable portions of the interparticle porosity. In each case, the diffusive porosity can be conceptualized as the porosity where advection is not dominant.

The major physical transport processes that affect actinide transport through the Culebra include advection (through fractures and other permeable porosity), diffusion from the advective porosity into the rest of the connected porosity (diffusive porosity) and dispersive spreading due to heterogeneity. Diffusion can be an important process for effectively retarding solutes by transferring mass from the porosity where advection (flow) is the dominant process into other portions of the rock. Diffusion into stagnant portions of the rock also provides access to additional surface area for sorption. A further discussion of transport of actinides in the Culebra as either dissolved species or as colloids is given in Section 6.4.6.2. Parameter values determined from tests of the Culebra are given in Appendix PAR and are described in Section 6.4.6.2.2. A summary of input values to the conceptual model are in Tables 6-20 and 6-21.

Fluid flow in the Culebra is dominantly lateral and southward except in discharge areas along the west or south boundaries of the basin. Where transmissive fractures exist, flow is dominated by fractures but may also occur in vugs connected by microfractures and interparticle porosity. Regions where flow is dominantly through vugs connected by microfractures and interparticle porosity have been inferred from pumping tests and tracer tests. Flow in the Culebra may be concentrated along zones that are thinner than the total thickness of the Culebra. In general, the upper portion of the Culebra is massive dolomite with a few fractures and vugs, and appears to have low permeability. The lower portion of the Culebra appears to have many more vuggy and fractured zones and to have a significantly higher permeability.

There is strong evidence that the permeability of the Culebra varies spatially and varies sufficiently that it cannot be characterized with a uniform value or range over the region of interest to the WIPP. The transmissivity of the Culebra varies spatially over six orders of magnitude from east to west in the vicinity of the WIPP (Figure 2-30). Over the site, Culebra transmissivity varies over three to four orders of magnitude. Appendix TFIELD (Section TFIELD.2) contains the data used to develop Figure 2-30, which shows variation in transmissivity in the Culebra in the WIPP region. Appendix MASS (Section MASS.15, including MASS Attachment 15-6) provides modeling rationale. The discussion in Appendix TFIELD addresses how data collected over a number of years were correlated for the generations of transmissivity fields. Transmissivities are from about 1×10^{-3} square feet per day (1×10^{-9} square meters per second) at well P-18 east of the WIPP site to about 1×10^{3}

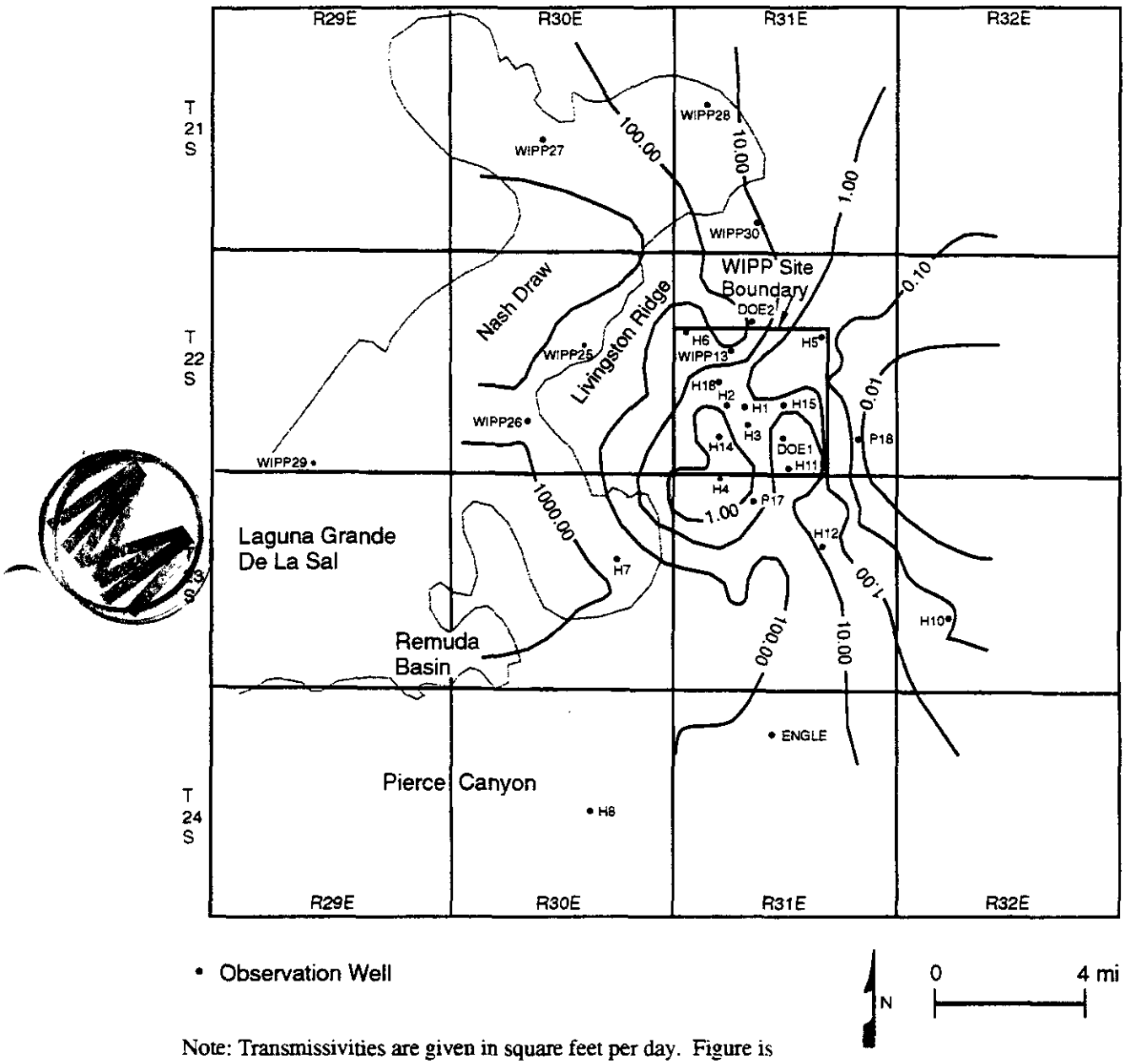

Note: Transmissivities are given in square feet per day. Figure is modified from Cauffman et al. 1990 (Figure 5.22a). See Appendix TFIELD for details of the performance assessment implementation.

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Figure 2-30. Transmissivities of the Culebra

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square feet per day (1×10^{-3} square meters per second) at well H-7 in Nash Draw (see Figure 2-2 for the locations of these wells and see Figure 4-8 in Appendix FAC for a Culebra isopach map).

Transmissivity variations in the Culebra are believed to be controlled by the relative abundance of open fractures rather than by primary (that is, depositional) features of the unit. Lateral variations in depositional environments were small within the mapped region, and primary features of the Culebra show little map-scale spatial variability, according to Holt and Powers (Appendix FAC). Direct measurements of the density of open fractures are not available from core samples because of incomplete recovery and fracturing during drilling, but observation of the relatively unfractured exposures in the WIPP shafts suggests that the density of open fractures in the Culebra decreases to the east. Qualitative correlations have been noted between transmissivity and several geologic features possibly related to open-fracture density, including (1) the distribution of overburden above the Culebra, (2) the distribution of halite in other members of the Rustler, (3) the dissolution of halite in the upper portion of the Salado, and (4) the distribution of gypsum fillings in fractures in the Culebra (see Section 2.1.3.5.2 and Figure 2-12).

Geochemical and radioisotope characteristics of the Culebra have been studied. There is considerable variation in groundwater geochemistry in the Culebra. The variation has been described in terms of different hydrogeochemical facies that can be mapped in the Culebra (see Section 2.4.2). A halite-rich hydrogeochemical facies exists in the region of the WIPP site and to the east, approximately corresponding to the regions in which halite exists in units above and below the Culebra (Figure 2-10), and in which a large portion of the Culebra fractures are gypsum filled (Figure 2-12). An anhydrite-rich hydrogeochemical facies exists west and south of the WIPP site, where there is relatively less halite in adjacent strata and where there are fewer gypsum-filled fractures. Radiogenic isotopic signatures suggest that the age of the groundwater in the Culebra is on the order of 10,000 years or more (see, for example, Lambert 1987, Lambert and Carter 1987, and Lambert and Harvey 1987 in the bibliography).

The radiogenic ages of the Culebra groundwater and the geochemical differences provide information potentially relevant to the groundwater flow directions and groundwater interaction with other units and are important constraints on conceptual models of groundwater flow. Previous conceptual models of the Culebra (see for example, Chapman 1986, Chapman 1988, LaVenue et al. 1990, and Siegel et al. 1991 in the bibliography) have not been able to consistently relate the hydrogeochemical facies, radiogenic ages, and flow constraints (that is, transmissivity, boundary conditions, etc.) in the Culebra.

The groundwater basin modeling that has been conducted, although it did not model solute transport processes, provides flow fields that can be used to develop the following concepts that help explain the observed hydrogeochemical facies and radiogenic ages. The groundwater basin model combines and tests three fundamental processes: (1) it calculates vertical leakage, which may carry solutes into the Culebra; (2) it calculates lateral fluxes in the

Culebra (directions as well as rates); and (3) it calculates a range of possible effects of climate change. The presence of the halite-rich groundwater facies is explained by vertical leakage of solutes into the Culebra from the overlying halite-containing Tamarisk by advective or diffusive processes. Because lateral flow rates here are low, even slow rates of solute transport into the Culebra can result in high solute concentration. Vertical leakage occurs slowly over the entire model region, and thus the age of groundwater in the Culebra is old, consistent with radiogenic information. Lateral fluxes within the anhydrite zone are larger because of higher transmissivity, and where the halite and anhydrite facies regions converge, the halite facies signature is lost by dilution with relatively large quantities of anhydrite facies groundwater. Response of groundwater flow in the Culebra as the result of increasing recharge is modeled through the variation in climate. This is discussed in Section 6.4.9.

Groundwater levels in the Culebra in the WIPP region have been measured continuously for several decades. Water-level rises have been observed in the WIPP region and are attributed to three causes as discussed below. The extent of water-level rise observed at a particular well depends on several factors, but the proximity of the observation point to the cause of the water-level rise appears to be a primary factor.

In the vicinity of the WIPP site, water-level rises are unquestionably caused by recovery from drainage into the shafts. Drainage into shafts has been reduced by a number of grouting programs over the years, most recently in 1993 around the AIS. Northwest of the site, in and near Nash Draw, water levels appear to fluctuate in response to effluent discharge from potash mines. Correlation of water-level fluctuation with potash mine discharge cannot be proven because sufficient data on the timing and volumes of discharge are not available. Head distribution in the Culebra (Figure 2-31) is consistent with groundwater basin modeling results (discussed in Section 6.4.6 and Appendix MASS, Section MASS.14.2) indicating that the generalized direction of groundwater flow is north to south . However, caution should be used when making assumptions based on groundwater-level data alone. Studies in the Culebra have shown that fluid density variations in the Culebra can affect flow direction (Davies 1989, 35). The fractured nature of the Culebra, coupled with variable fluid densities, can also cause localized flow patterns to differ from general flow patterns. Water-level rises in the vicinity of the H-9 hydropad, about 6.5 miles (10.46 kilometers) south of the site, are not thought to be caused by either WIPP activities or potash mining discharge. They remain unexplained. The DOE continues to monitor groundwater levels throughout the region, but only water level changes at or near the site have the potential to affect performance. The DOE has implemented water level changes in its conceptual model through variations in climate as discussed in Section 6.4.9. These variations bring the water level to the surface for some calculations. This modeling simplification bounds the possible effects of anomalous water level changes regardless of their origin.

Inferences about vertical flow directions in the Culebra have been made from well data collected by the DOE. Beauheim (1987a) reported flow directions towards the Culebra from both the unnamed lower member and the Magenta over the WIPP site, indicating that the Culebra acts as a drain for the units around it. This indication is consistent with results of

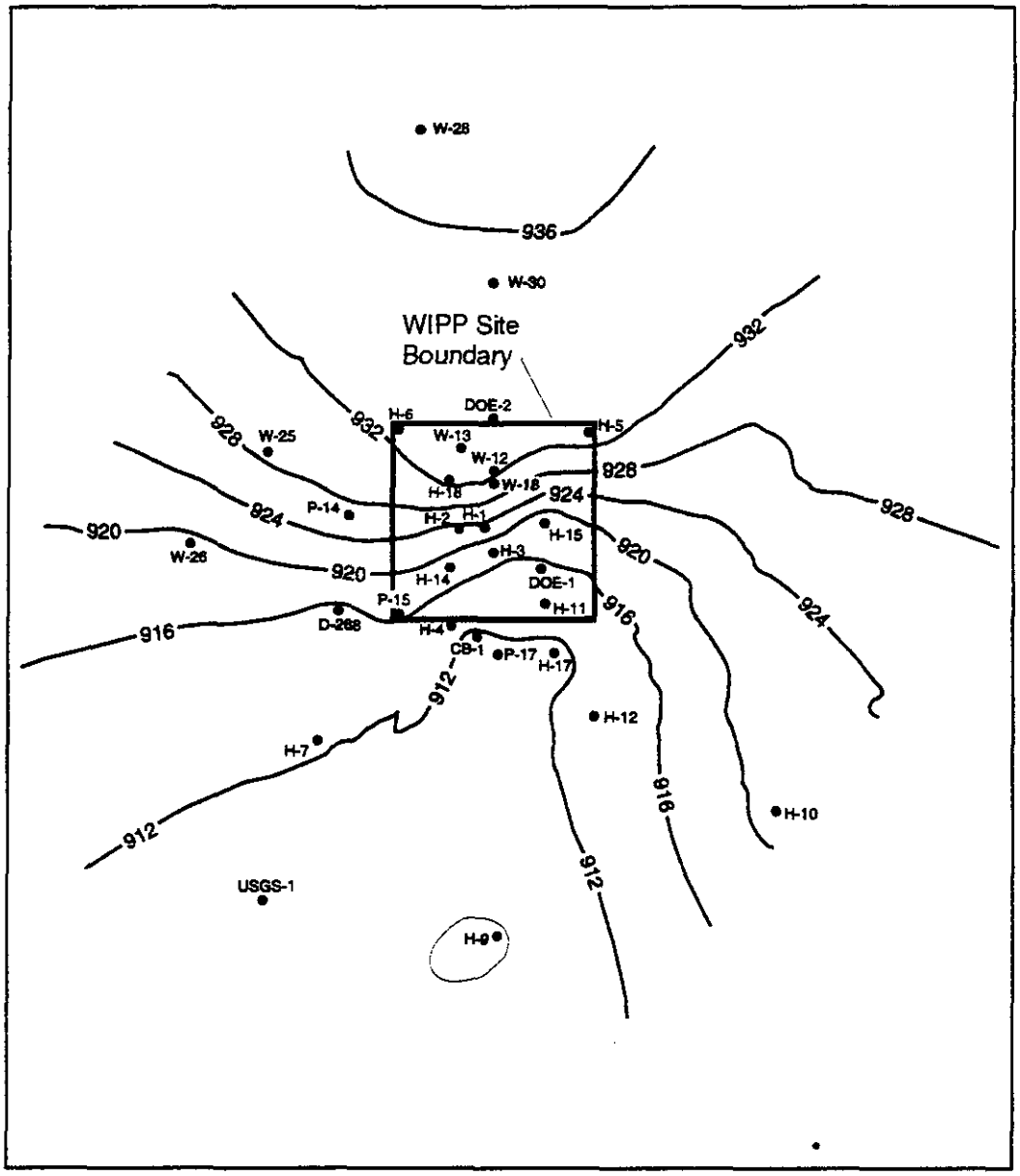

• Observation Well
Heads in meters
Contour Interval:4m

N

0 1 2 3 4 mi
0 2 4 6 km

Note: Elevations in meters above the mean sea level adjusted to equivalent freshwater values.

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Figure 2-31. Hydraulic Heads in the Culebra

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groundwater basin modeling. A more detailed discussion of Culebra flow and transport can be found in Appendices MASS (Sections MASS.14 and MASS.15) and TFIELD.

2.2.1.4.1.3 The Tamarisk

The Tamarisk acts as a confining layer in the groundwater basin model. Attempts were made in two wells, H-14 and H-16, to test a 7.9-foot (2.4-meter) sequence of the Tamarisk that consists of claystone, mudstone, and siltstone overlain and underlain by anhydrite. Permeability was too low to measure in either well within the time allowed for testing; consequently, Beauheim (1987a, 108 – 110) estimated the transmissivity of the claystone sequence to be one or more orders of magnitude less than that of the tested interval in the unnamed lower member (that is, less than approximately 2.5×10^{-5} square feet per day [2.7×10^{-11} square meters per second]). The porosity of the Tamarisk was measured in 1995 as part of testing at the H-19 hydropad. Two claystone samples had an effective porosity of 21.3 to 21.7 percent. Five anhydrite samples had effective porosities of 0.2 to 1.0 percent.

The Tamarisk is incorporated into the conceptual model as discussed in Section 6.4.6.3. The role of the Tamarisk in the groundwater basin model is in Appendix MASS (Section MASS.14.1). Tamarisk hydrological model parameters are in Appendix PAR (Table PAR-29).

2.2.1.4.1.4 The Magenta

The Magenta is a conductive hydrostratigraphic unit about 26 feet (7.9 meters) thick at the WIPP. The Magenta is saturated except near outcrops along Nash Draw, and hydraulic data are available from 15 wells. According to Mercer (Appendix HYDRO, 65), transmissivity ranges over five orders of magnitude from 4×10^{-3} to 3.75×10^{2} square feet per day (1×10^{-9} to 4×10^{-4} square meters per second). The porosity of the Magenta was measured in 1995 as part of testing at the H-19 hydropad. Four samples had effective porosities ranging from 2.7 to 25.2 percent.

The hydraulic transmissivities of the Magenta, based on sparse data, show a decrease in conductivity from west to east, with slight indentations of the contours north and south of the WIPP that correspond to the topographic expression of Nash Draw. In most locations, the hydraulic conductivity of the Magenta is one to two orders of magnitude less than that of the Culebra. The Magenta does not have hydraulically significant fractures in the vicinity of the WIPP. Treatment of the Magenta in the model is discussed in Section 6.4.6.4 with modeling parameters in Table 6-22.

The hydraulic gradient across the site varies from 16 to 20 feet per mile (3 to 4 meters per kilometer) on the eastern side, steepening to about 32 feet per mile (6 meters per kilometer) along the western side near Nash Draw (Figure 2-32).

Regional modeling using the groundwater basin model indicates that leakage occurs into the Magenta from the overlying Forty-niner and out of the Magenta downwards into the Tamarisk. Regional modeling also indicates that flow directions in the Magenta are dominantly westward, similar to the slope of the land surface in the immediate area of the WIPP. This flow direction is different than the dominant flow direction in the next underlying conductive unit, the Culebra. This difference is consistent with the groundwater basin conceptual model, in that flow in shallower units is expected to be more sensitive to local topography.

Inferences about vertical flow directions in the Magenta have been made from well data collected by the DOE. Beauheim (1987a, 137) reported flow directions downwards out of the Magenta over the WIPP site, consistent with results of groundwater basin modeling. However, Beauheim (1987a, 139) concluded that flow directions between the Forty-niner and Magenta would be upward in the three boreholes from which reliable pressure data are available for the Forty-niner (H-3, H-14, and H-16), which is not consistent with the results of groundwater modeling. This inconsistency may be the result of local heterogeneity in rock properties that affect flow on a scale that cannot be duplicated in regional modeling.

As is the case for the Culebra, groundwater elevations in the Magenta have changed over the period of observation. The pattern of changes is similar to that observed for the Culebra, and is attributed to the same causes (see Section 2.2.1.4.1.2).

2.2.1.4.1.5 The Forty-niner

The Forty-niner is a confining hydrostratigraphic layer about 66 feet (20 meters) thick throughout the WIPP area and consists of low-permeability anhydrite and siltstone. Tests by Beauheim (1987a, 119 – 123 and Table 5-2) in H-14 and H-16 yielded transmissivities of about 3×10^{-2} to 7×10^{-2} square feet per day (3×10^{-8} to 8×10^{-8} square meters per second) and 5×10^{-3} to 6×10^{-3} square feet per day (3×10^{-9} to 6×10^{-9} square meters per second), respectively. The porosity of the Forty-niner was measured as part of testing at the H-19 hydropad. Three claystone samples had effective porosities ranging from 9.1 to 24.0 percent. Four anhydrite samples had effective porosities ranging from 0.0 to 0.4 percent. Model consideration of the Forty-niner is in Section 6.4.6.5. Modeling parameters are in Appendix PAR (Table PAR-27).

2.2.1.4.2 Hydrology of the Dewey Lake and the Santa Rosa

The Dewey Lake and the Santa Rosa, and surficial soils, overlie the Rustler and are the uppermost hydrostratigraphic units considered by the DOE. The Dewey Lake and overlying rocks are more permeable than the anhydrites at the top of the Rustler. Consequently, basin modeling indicates that most (probably more than 70 percent) of the water that recharges the groundwater basin (that is, percolates into the Dewey Lake from surface water) flows only in the rocks above the Rustler. As modeled, the rest leaks vertically through the upper anhydrites of the Rustler and into the Magenta or continues downward to the Culebra. More

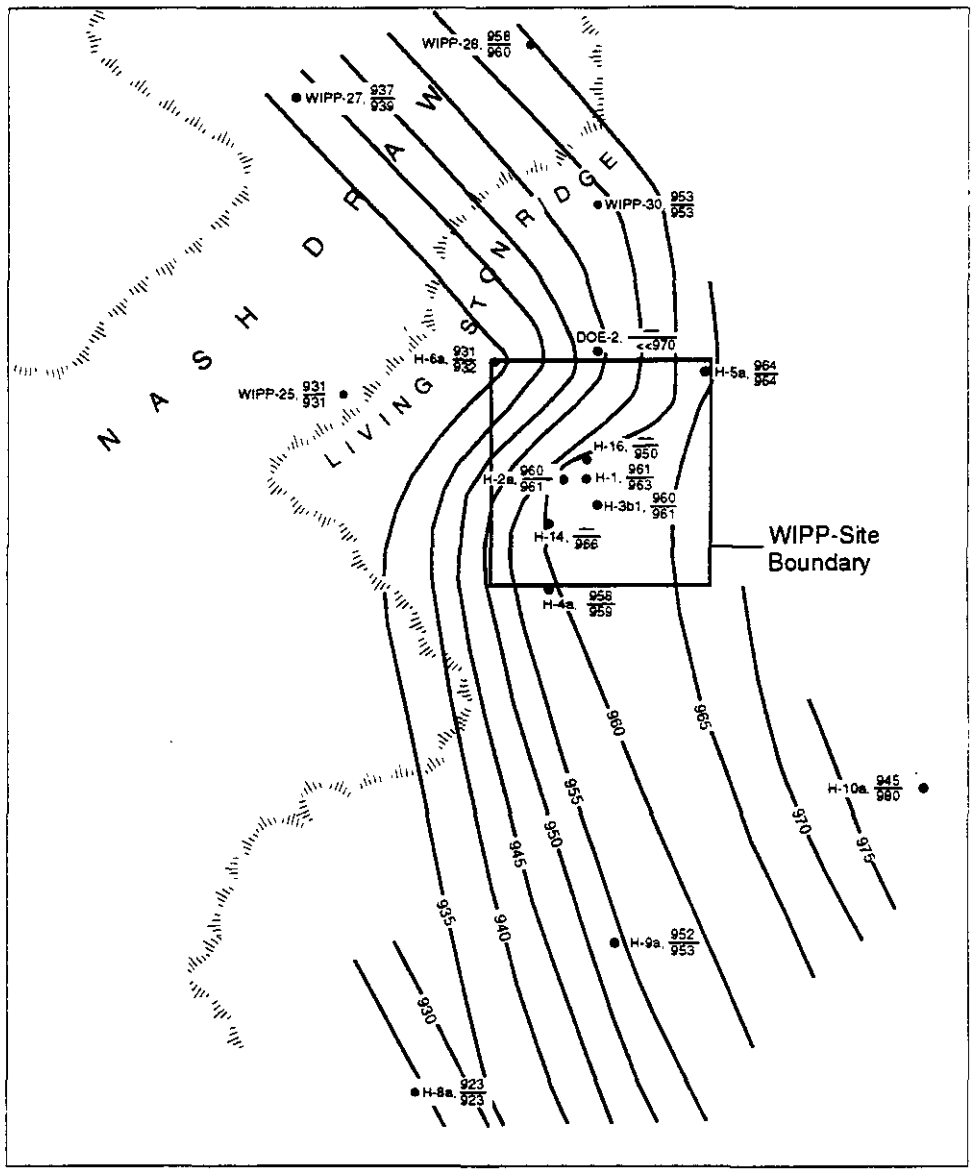

Legend

Well Tested

Measured Water-Level Elevation, m amsl

H-2a, 960/961

Estimated Freshwater-Head Elevation, m amsl

950 Freshwater-Head Elevation Contour

Contour Interval = 5 meters

N

0 4 Miles

Scale 6 Km

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Figure 2-32. Hydraulic Heads in the Magenta

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flow occurs into the Rustler units at times of greater recharge. Even though it carries most of the modeled recharge, lateral flow in the Dewey Lake is slow because of its low permeability in most areas.

2.2.1.4.2.1 The Dewey Lake

The Dewey Lake contains a productive zone of saturation, probably under water-table conditions, in the southwestern to south-central portion of the WIPP site and south of the site. Several wells operated by the J.C. Mills Ranch south of the WIPP site produce sufficient quantities of water from the Dewey Lake to supply livestock. Short-term production rates of 25 to 30 gallons per minute (5.7 to 6.8 cubic meters per hour) were observed in boreholes P-9 (Jones 1978, Vol. 1., 167 and 168), WQSP-6, and WQSP-6a (see Appendix USDW). The productive zone is typically found in the middle of the Dewey Lake, 180 to 265 feet (55 to 81 meters) below ground surface and appears to derive much of its transmissivity from open fractures. Where present, the saturated zone may be perched or simply underlain by less transmissive rock. Fractures below the productive zone tend to be completely filled with gypsum. Open fractures and/or moist (but not fully saturated) conditions have been observed at similar depths north of the zone of saturation, at the H-1, H-2, and H-3 boreholes (Appendix HYDRO, 69). The Dewey Lake has not produced water within the WIPP shafts or in boreholes in the immediate vicinity of the panels. For modeling purposes, the hydraulic conductivity of the Dewey Lake, assuming saturation, is estimated to be 3×10^{-3} feet per day (10^{-8} meters per second), corresponding to the hydraulic conductivity of fine-grained sandstone and siltstone (Davies 1989, 110). The porosity of the Dewey Lake was measured as part of testing at the H-19 hydropad. Four samples taken above the gypsum-sealed region had measured effective porosities of 14.9 to 24.8 percent. Four samples taken from within the gypsum-sealed region had porosities from 3.5 to 11.6 percent.

The Dewey Lake is the uppermost important layer in the hydrological model. Its treatment is discussed in Section 6.4.6.6 and Appendix MASS (Section MASS.14.2). Model parameters are in Table 6-23.

The DOE has estimated the position of the water table in the southern half of the WIPP site from an analysis of drillers' logs from three potash exploration boreholes and five hydraulic test holes. These logs record the elevation of the first moist cuttings recovered during drilling. Assuming that the first recovery of moist cuttings indicates a minimum elevation of the water table, an estimate of the water table elevation can be made, and the estimated water table surface can be contoured. This method indicates that the elevation of the water table over the WIPP waste panels may be about 3,215 feet (980 meters) above sea level, as shown in Figure 2-33. Changes in this water table in the future, due to wetter conditions, are part of the conceptual model discussed in Sections 6.4.6 and 6.4.9.

2.2.1.4.2.2 The Santa Rosa

The Santa Rosa ranges from 0 to about 300 feet (0 to 91 meters) thick and is present over the eastern half of the WIPP site. It is absent over the western portion of the site. It crops out northeast of Nash Draw. The Santa Rosa near the WIPP site may have a saturated thickness of limited extent. It has a porosity of about 13 percent and a specific capacity of 0.14 to 0.20 gallons per minute per foot (0.029 to 0.041 liters per second per meter) of drawdown, where it yields water in the WIPP region.

2.2.1.5 Hydrology of Other Groundwater Zones of Regional Importance

The groundwater regimes in the Capitan Limestone, which is generally regarded as the northern boundary of the Delaware Basin, and Nash Draw have been evaluated by the DOE as part of the WIPP project because of their importance in some processes, notably dissolution features, that the DOE has determined to be of low probability at the WIPP site.

2.2.1.5.1 The Capitan Limestone

The Capitan, which outcrops in the southern end of the Guadalupe Mountains, is a massive limestone unit that grades basinward into recemented, partly dolomitized reef breccia and shelfward into bedded carbonates and evaporites. A deeply incised submarine canyon near the Eddy-Lea county line has been identified (Hiss 1976). This canyon is filled with sediments of lower permeability than the Capitan and, according to Hiss (1975, 199) restricts fluid flow. The hydraulic conductivity of the Capitan ranges from 1 to 25 feet per day (3×10^{-6} to 9×10^{-5} meters per second) in southern Lea County and is 5 feet per day (1.7×10^{-5} meters per second) east of the Pecos River at Carlsbad (Appendix HYDRO, 34). Hiss (1975, 199) reported in 1975 that average transmissivities around the northern and eastern margins of the Delaware Basin are 10,000 square feet per day (0.01 square meters per second) in thick sections and 500 square feet per day (5.4×10^{-4} square meters per second) in incised submarine canyons. Water table conditions are found in the Capitan aquifer southwest of the Pecos River at Carlsbad; however, artesian conditions exist to the north and east. The hydraulic gradient to the southeast of the submarine canyon near the Eddy-Lea county line has been affected by large oil field withdrawals. The Capitan limestone is recharged by percolation through the northern shelf aquifers, by flow from the south and west from underlying basin aquifers (see information on the Bell Canyon, Section 2.2.1.2.1), and by direct infiltration at its outcrop in the Guadalupe Mountains. The Capitan is important in the regional hydrology because breccia pipes in the Salado have formed over it, most likely in response to the effects of dissolution by groundwater flowing in the Castile along the base of the Salado. See Appendix DEF (Section DEF.3.1) for a more thorough discussion of breccia pipe formation.

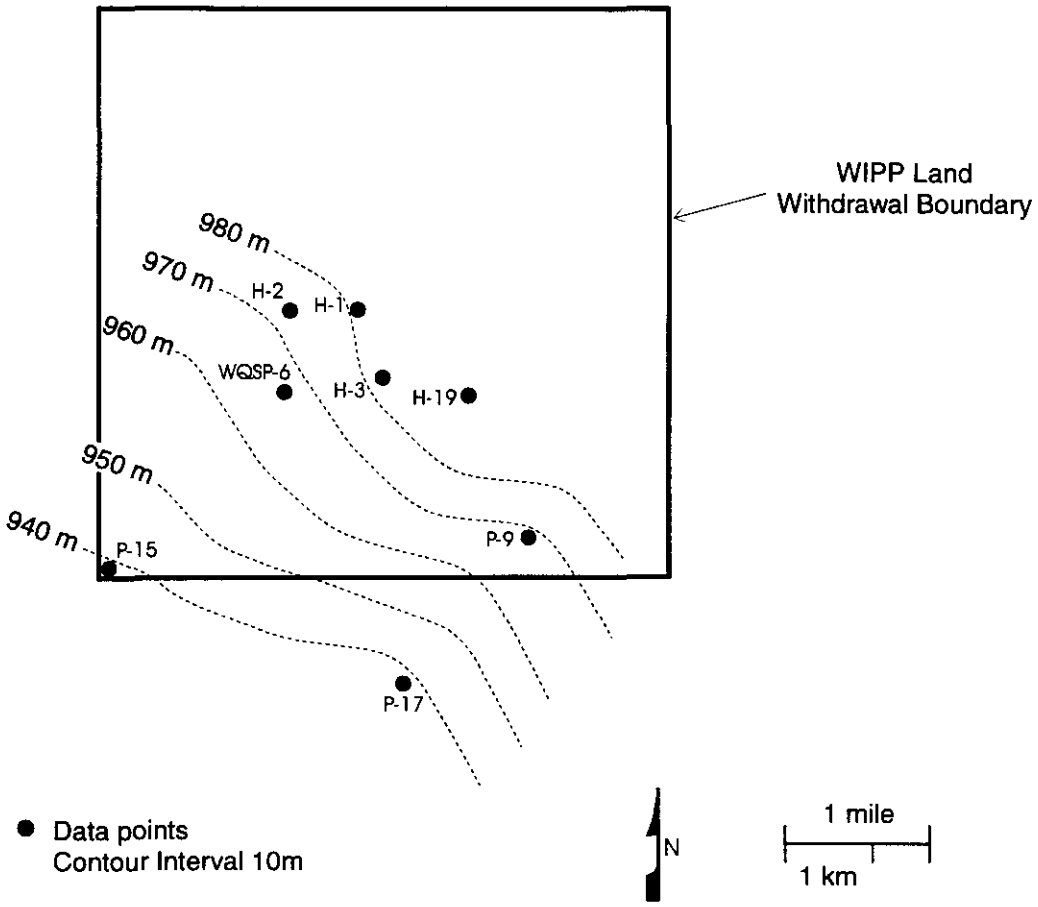

Note: Meters Above Mean Sea Level

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Figure 2-33. Interpreted Water Table Surface

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2.2.1.5.2 Hydrology of the Rustler-Salado Contact Zone in Nash Draw

As discussed in Sections 2.1.3.4 and 2.1.6.2.1, in Nash Draw the contact between the Rustler and the Salado is an unstructured residuum of gypsum, clay, and sandstone created by the dissolution of halite and has been known as the brine aquifer, Rustler-Salado residuum, and residuum. The residuum is absent under the WIPP site. It is clear that dissolution in Nash Draw occurred after deposition of the Rustler (see Appendix DEF, Section DEF.3.2, for a discussion of lateral dissolution of the Rustler-Salado contact). As described previously, the topographic low formed by Nash Draw is a groundwater divide in the groundwater basin conceptual model of the units above the Salado. The brine aquifer is shown in Figure 2-34.

Robinson and Lang described the brine aquifer (Section 2.1.3.4) in 1938 and suggested that the structural conditions that caused the development of Nash Draw might control the occurrence of the brine; thus, the brine aquifer boundary may coincide with the topographic surface expression of Nash Draw, as shown in Figure 2-29. Their studies show brine concentrated along a strip from 2 to 8 miles (3.3 to 13 kilometers) wide and about 26 miles (43 kilometers) long. Data from the test holes that Robinson and Lang drilled indicate that the residuum (containing the brine) ranges in thickness from 10.5 to 60 feet (3 to 18 meters) and averages about 24 feet (7 meters).

In 1954, hydraulic properties were determined by Hale et al., primarily for the area between Malaga Bend on the Pecos River and Laguna Grande de la Sal. They calculated a transmissivity value of 8,000 square feet per day (8.6×10^{-3} square meters per second) and estimated the potentiometric gradient to be 1.4 feet per mile (0.27 meter per kilometer). In this area, the Rustler-Salado residuum apparently is part of a continuous hydrologic system, as evidenced by the coincident fluctuation of water levels in the test holes (as far away as Laguna Grande de la Sal) with pumping rates in irrigation wells along the Pecos River.

In the northern half of Nash Draw, the approximate outline of the brine aquifer as described by Robinson and Lang in 1938 has been supported by drilling associated with the WIPP hydrogeologic studies. These studies also indicate that the main differences in areal extent occur along the eastern side where the boundary is very irregular and, in places (test holes P-14 and H-07), extends farther east than previously indicated by Robinson and Lang.

Other differences from the earlier studies include the variability in thickness of residuum present in test holes WIPP-25 through WIPP-29. These holes indicate thicknesses ranging from 11 feet (3.3 meters) in WIPP-25 to 108 feet (33 meters) in WIPP-29 in Nash Draw, compared to 8 feet (2.4 meters) in test hole P-14, east of Nash Draw. The specific geohydrologic mechanism that has caused dissolution to be greater in one area than in another is not apparent, although a general increase in chloride concentration in water from the north to the south may indicate the effects of movement down the natural hydraulic gradient in Nash Draw.

The average hydraulic gradient within the residuum in Nash Draw is about 10 feet per mile (1.9 meters per kilometer); in contrast, the average gradient at the WIPP site is 39 feet per mile (7.4 meters per kilometer) (Appendix HYDRO, 50). This difference reflects the changes in transmissivity, which are as much as five orders of magnitude greater in Nash Draw. The transmissivity determined from aquifer tests in test holes completed in the Rustler-Salado contact residuum of Nash Draw ranges from 2×10^{-4} square feet per day (2.1×10^{-10} square meters per second) at WIPP-27 to 8 square feet per day (8.6×10^{-6} square meters per second) at WIPP-29. This is in contrast to the WIPP site proper, where transmissivities range from 3×10^{-5} square feet per day (3.2×10^{-11} square meters per second) at test holes P-18 and H-5c to 5×10^{-2} square feet per day (5.4×10^{-8} square meters per second) at test hole P-14 (Appendix HYDRO, 50). Locations and estimated hydraulic heads of these wells are illustrated in Figure 2-35.

Hale et al. (1954) believed the Rustler-Salado contact residuum discharges to the alluvium near Malaga Bend on the Pecos River. Because the confining beds in this area are probably fractured because of dissolution and collapse of the evaporites, the brine (under artesian head) moves up through these fractures into the overlying alluvium and then discharges into the Pecos River.

According to Mercer (Appendix HYDRO, 55), water in the Rustler-Salado contact residuum in Nash Draw contains the largest concentrations of dissolved solids in the WIPP area, ranging from 41,500 milligrams per liter in borehole H-1 to 412,000 milligrams per liter in borehole H-5c. These waters are classified as brines. The dissolved mineral constituents in the brine consist mostly of sulfates and chlorides of calcium, magnesium, sodium, and potassium; the major constituents are sodium and chloride. Concentrations of the other major ions vary according to the spatial location of the sample, are probably directly related to the interaction of the brine and the host rocks, and reflect residence time within the rocks. Residence time of the brine depends upon the transmissivity of the rock. For example, the presence of large concentrations of potassium and magnesium in water is correlated with minimal permeability and a relatively undeveloped flow system.

2.2.2 Surface-Water Hydrology

The WIPP site is in the Pecos River basin, which contains about 50 percent of the drainage area of the Rio Grande Water Resources Region. The Pecos River headwaters are northeast of Santa Fe, and the river flows to the south through eastern New Mexico and western Texas to the Rio Grande. The Pecos River has an overall length of about 500 miles (805 kilometers), a maximum basin width of about 130 miles (209 kilometers), and a drainage area of about 44,535 square miles (115,301 square kilometers). (About 20,500 square miles [53,075 square kilometers] contained within the basin have no external surface drainage and their surface waters do not contribute to Pecos River flows.) Figure 2-36 shows the Pecos River drainage area.

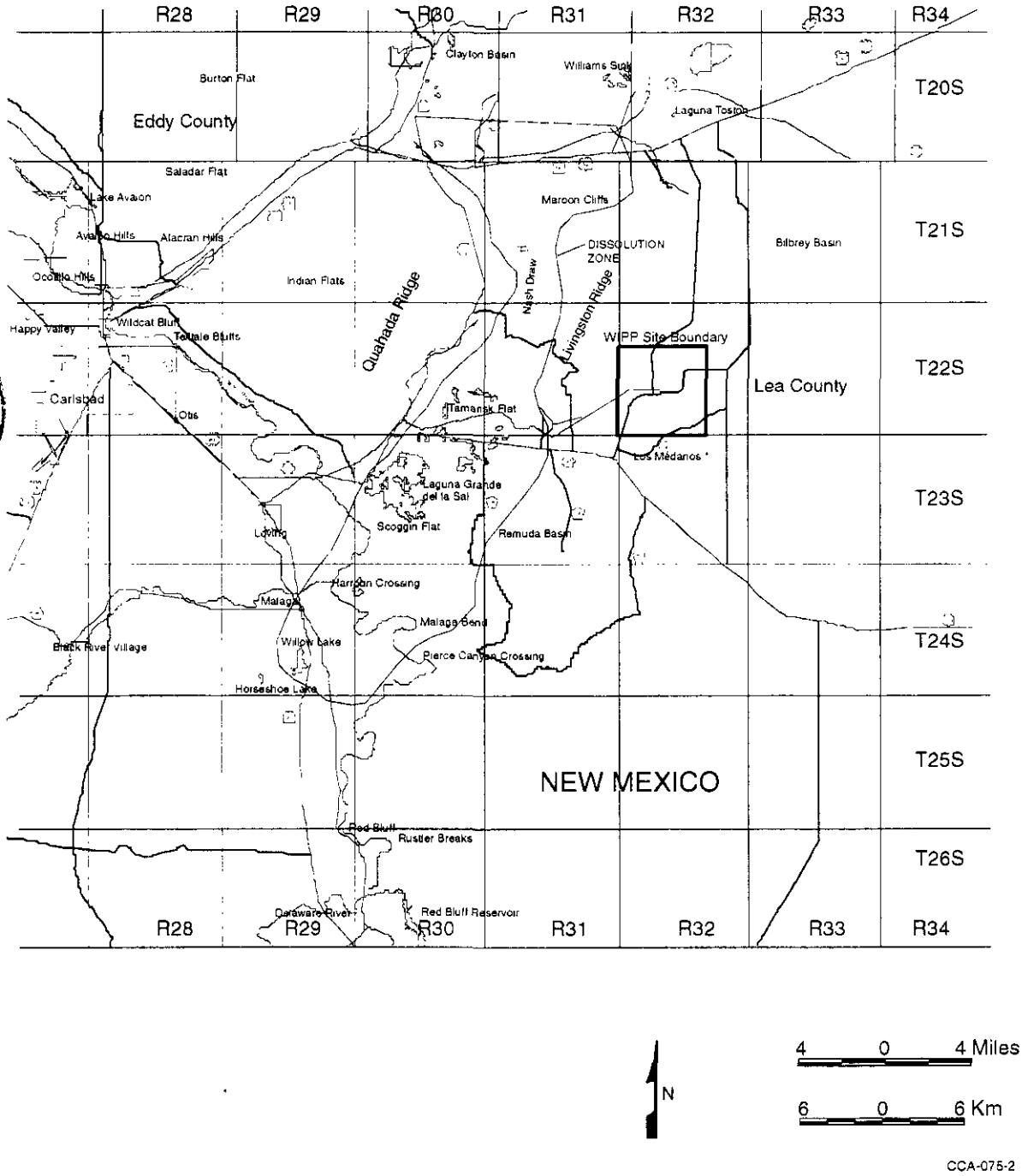

Figure 2-34. Brine Aquifer in the Nash Draw (Redrawn from Appendix HYDRO, Figure 14)

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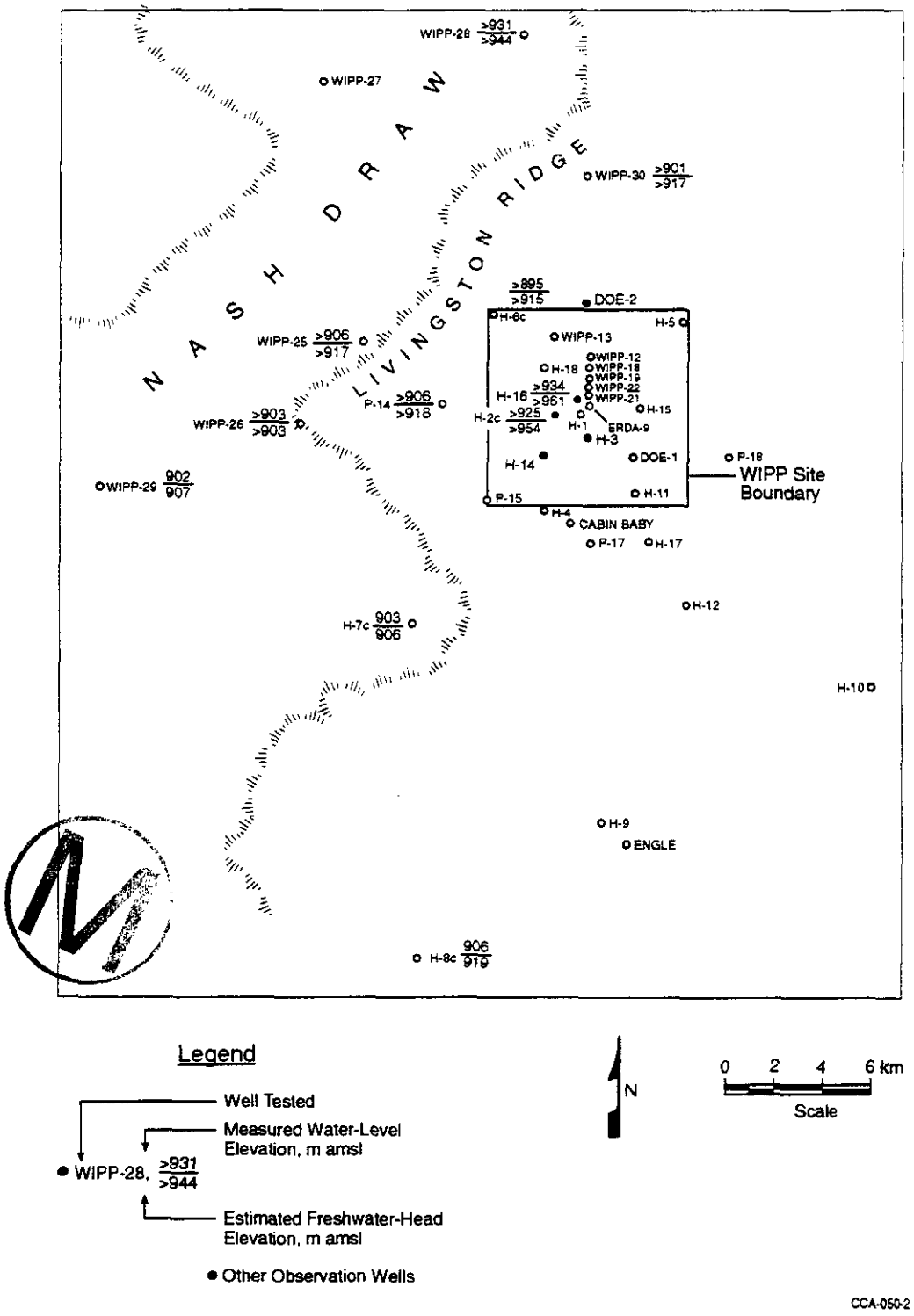

Figure 2-35. Measured Water Levels of the Unnamed Lower Member and Rustler-Salado Contact Zone

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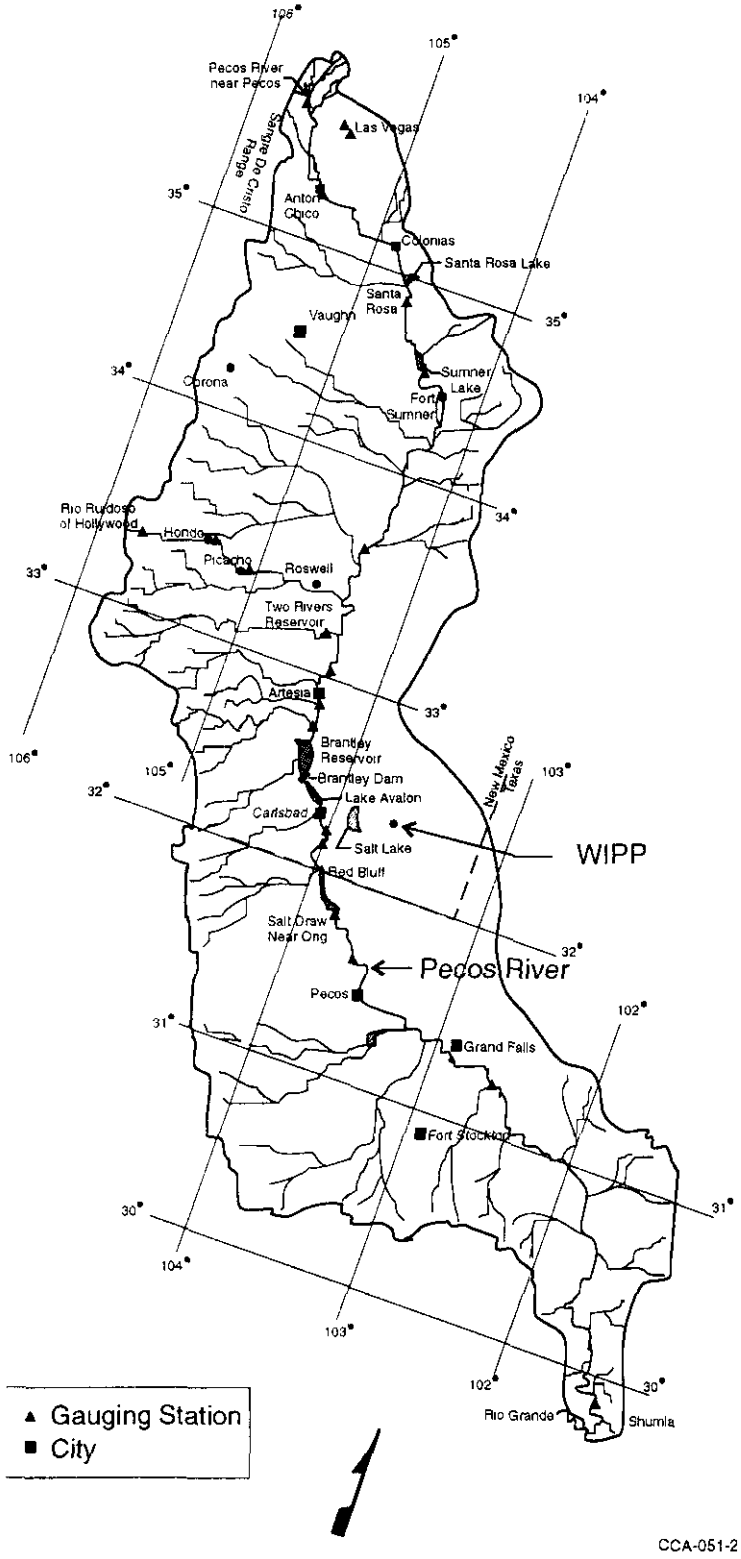

Figure 2-36. Location of Reservoirs and Gauging Stations in the Pecos River Drainage Area

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The Pecos River generally flows year-round, except in the reach below Anton Chico and between Fort Sumner and Roswell, where the low flows percolate into the stream bed. The main stem of the Pecos River and its major tributaries have low flows, and the tributary streams are frequently dry. About 75 percent of the total annual precipitation and 60 percent of the annual flow result from intense local thunderstorms between April and September.

There are no perennial streams at the WIPP site. At its nearest point, the Pecos River is about 12 miles (19 kilometers) southwest of the WIPP site boundary. A few small creeks and draws are the only westward flowing tributaries of the Pecos River within 20 miles (32 kilometers) north or south of the site. Nash Draw, the largest surface drainage feature east of the Pecos River in the WIPP region, is a closed depression and does not provide surface flow into the Pecos. The Black River (drainage area: 400 square miles [1,035 square kilometers]) joins the Pecos from the west about 16 miles (25 kilometers) southwest of the site. The Delaware River (drainage area: 700 square miles [1,812 square kilometers]) and a number of small creeks and draws also join the Pecos River along this reach. The flow in the Pecos River below Fort Sumner is regulated by storage in Sumner Lake, Brantley Reservoir, Lake Avalon, and several other smaller irrigation dams.

Five major reservoirs are located on the Pecos River: Santa Rosa Lake, Sumner Lake, Brantley Reservoir, Lake Avalon, and the Red Bluff Reservoir, the last located just over the border in Texas (Figure 2-36). The storage capacities of these reservoirs and the Two Rivers Reservoir in the Pecos River Basin are shown in Table 2-6.

Table 2-6. Capacities of Reservoirs in the Pecos River Drainage

Reservoir	River	Total Storage Capacity[a] (acre-feet)	Use[b]
Santa Rosa	Pecos	282,000	FC
Sumner	Pecos	122,100	IR, R
Brantley	Pecos	42,000	IR, R, FC
Avalon	Pecos	5,000	IR
Red Bluff	Pecos	310,000	IR, P
Two Rivers	Rio Hondo	167,900	FC

[a] Capacity below the lowest uncontrolled outlet or spillway.
[b] **Legend:**
FC flood control
IR irrigation
R recreation
P hydroelectric

With regard to surface drainage onto and off of the WIPP site, there are no major natural lakes or ponds within 5 miles (8 kilometers) of the site. Laguna Gatuña, Laguna Tonto, Laguna Plata, and Laguna Toston are playas more than 10 miles (16 kilometers) north and are at elevations of 3,450 feet (1,050 meters) or higher. Thus, surface runoff from the site (elevation 3,310 feet [1,010 meters] above sea level) would not flow toward any of them. To the northwest, west and southwest, Red Lake, Lindsey Lake, and Laguna Grande de la Sal are more than 5 miles (8 kilometers) from the site, at elevations of 3,000 to 3,300 feet (914 to 1,006 meters). A low-flow investigation has been initiated by the USGS within the Hill Tank Draw drainage area, the most prominent drainage feature near the WIPP site. The drainage area is about 4 square miles (10.3 square kilometers), with an average channel slope of 1 to 100, and the drainage is westward into Nash Draw. Two years of observations showed only four flow events. The USGS estimates that the flow rate for these events was under 2 cubic feet per second (0.057 cubic meters per second) (DOE 1980, 7 – 74).

As discussed in Section 2.5.2.3, the mean annual precipitation in the region is 13 inches (0.33 meter), and the mean annual runoff is 0.1 to 0.2 inches (2.5 to 5 millimeters). The maximum recorded 24-hour precipitation at Carlsbad was 5.12 inches (130 millimeters) in August 1916. The predicted maximum 6-hour, 100-year precipitation event for the site is 3.6 inches (91 millimeters) and is most likely to occur during the summer. The maximum recorded daily snowfall at Carlsbad was 10 inches (254 millimeters) in December 1923.

The maximum recorded flood on the Pecos River occurred near the town of Malaga, New Mexico, on August 23, 1966, with a discharge of 120,000 cubic feet (3,396 cubic meters) per second and a stage elevation of about 2,938 feet (895 meters) above mean sea level. The minimum surface elevation at the WIPP is over 300 feet above the elevation of this maximum historic flood (DOE 1980, § 7.4.1).

As discussed in the FEIS (DOE 1980, 7 – 71), more than 90 percent of the mean annual precipitation at the site is lost by evapotranspiration. On a mean monthly basis, evapotranspiration at the site greatly exceeds the available rainfall; however, intense local thunderstorms may produce runoff and percolation.

Water quality in the Pecos River basin is affected by mineral pollution from natural sources and from irrigation return flows (see Section 2.4.2.2 for discussion of surface-water quality). At Santa Rosa, New Mexico, the average suspended-sediment discharge of the river is about 1,650 tons per day (1,497 metric tons per day). Large amounts of chlorides from Salt Creek and Bitter Creek enter the river near Roswell. River inflow in the Hagerman area contributes increased amounts of calcium, magnesium, and sulfate; and waters entering the river near Lake Arthur are high in chloride. Below Brantley Reservoir, springs flowing into the river are usually submerged and difficult to sample; springs that could be sampled had TDS concentrations of 3,350 to 4,000 milligrams per liter. Concentrated brine entering at Malaga Bend adds an estimated 370 tons per day (64 metric tons per day) of chloride to the Pecos River (Appendix GCR, 6-7).

2.3 Resources

At the outset of the repository program, the DOE understood the importance of resources in the vicinity of a disposal system. Several of the siting criteria emphasized avoidance of resources that would impact the performance of the disposal system. In this regard, the DOE selected a site that (1) maximized the use of federal lands, (2) avoided known oil and gas trends, (3) minimized the impacts on potash deposits, and (4) avoided existing drill holes. While the DOE could not meet all these criteria totally, this application shows that the favorable characteristics of the location compensate for any increased risks due to the presence of resources. Consequently, the DOE has prepared this section to discuss resources that may exist at or beneath the WIPP site. The topic of resources is used to broadly define both economic (mineral and nonmineral) and cultural resources associated with the WIPP site. These resources are important because they (1) provide evidence of past uses of the area and (2) indicate potential future use of the area with the possibility that such use could lead to disruption of the closed repository. Because of the depth of the disposal horizon, it is believed that only the mineral resources are of significance in predicting the long-term performance of the disposal system. However, the nonmineral and cultural resources are presented for completeness because they are included in the FEP screening discussions in Chapter 6 and Appendix SCR. Information needed to make screening decisions includes natural resource distributions, including potable groundwaters, the distribution of drillholes, mines, excavations, and other man-made features that exploit these resources, the distribution of drillholes and excavation used for disposal or injection purposes, activities that significantly alter the land surface, agricultural activities that may affect the disposal system, archaeological resources requiring deep excavation to exploit, and technological changes that may alter local demographics. This information is presented here or is referenced.

With respect to minerals or hydrocarbons, reserves are the portion of resources that are economic at today's market prices and with existing technology. For hydrocarbons, proved (proven) reserves are an estimated quantity that engineering and geologic data analysis demonstrates, with reasonable certainty, is recoverable in the future from discovered oil and gas pools. Probable resources (extensions) consist of oil and gas in pools that have been discovered but not yet developed by drilling. Their presence and distribution can generally be surmised with a high degree of confidence. Probable resources (new pools) consist of oil and gas surmised to exist in undiscovered pools within existing fields. (Definitions are from NMBMMR 1995, V-2 and V-3.)

Mineral resource discussions are focused principally on hydrocarbons and potassium salts, both of which have long histories of development in the region. Development of either resource potentially could be disruptive to the disposal system. The information regarding the mineral resources concentrates on the following factors:

- number, location, depth, and present state of development, including penetrations through the disposal horizon;

- type of resource;
- accessibility, quality, and demand; and
- mineral ownership in the area.

The specific impacts of resource development are discussed in Section 6.4.6.2.3, where scenarios related to mineral development are included for evaluation of disposal system performance. This discussion uses information presented in Appendices DEL and MASS as indicated in the following text. The discussion of cultural and economic resources is focused on describing past and present land uses unrelated to the development of minerals. The archaeological record supports the observation that changes in land use are principally associated with climate and the availability of forage for wild and domestic animals. In no case does it appear that past or present land use has had an impact on the subsurface beyond the development of shallow groundwater wells to water livestock.

2.3.1 Extractable Resources

The geologic studies of the WIPP site included the investigation of potential natural resources to evaluate the impact of denying access to these resources and other consequences of their occurrence. Studies were completed in support of the FEIS to ensure knowledge of natural resources, and the impacts of denying access were included in the decision-making process for WIPP. Of the natural resources expected to occur beneath the site, five are of practical concern: the two potassium salts sylvite and langbeinite, which occur in the McNutt; and the three hydrocarbons, crude oil, natural gas, and distillate liquids associated with natural gas, all three of which occur elsewhere in strata below the Castile. Other mineral resources beneath the site are caliche, salt, gypsum, and lithium; enormous deposits of these minerals near the site and elsewhere in the country are more than adequate (and more economically attractive) to meet future requirements for these materials. In 1995, the NMBMMR performed a reevaluation of the mineral resources at and within 1 mile (1.6 kilometers) around the WIPP site. The following discussion is based in part on information from NMBMMR (1995).

2.3.1.1 Potash Resources at the WIPP Site

Throughout the Carlsbad Potash District, commercial quantities of potassium salts are restricted to the middle portion of the Salado, locally called the McNutt. A total of 11 zones (or distinct ore layers) have been recognized in the McNutt. Horizon Number 1 is at the base, and Number 11 is at the top. The 11th ore zone is not mined.

The USGS uses three standard grades—low, lease, and high—to quantify the potash resources at the site. The USGS assumes that the lease and high grades comprise reserves because some lease-grade ore is mined in the Carlsbad Potash District. Most of the potash that is mined,

however, is better typified as high-grade. Even the high-grade resources may not be reserves, however, if properties such as high clay content make processing uneconomical. The analysis in the 1995 NMBMMR report distinguishes between lease-grade ore and economically mineable ore.

The NMBMMR 1995 study contains a comprehensive summary of all previous potash resource evaluations. Griswold (NMBMMR 1995, Chapter VII) used 40 existing boreholes drilled on and around the WIPP site to perform a reevaluation of potash resources. He selected holes that were drilled using brine so that the dissolution of potassium salts was inhibited. The conclusion reached by Griswold is that only the 4th and 10th ore zones contain economic potash reserves. The quantities are summarized in Table 2-7.

Table 2-7. Current Estimates of Potash Resources at the WIPP Site

		Recoverable Ore (10^6 tons)	
Mining Unit	**Product**	**Within the WIPP site**	**One-Mile Strip Adjacent to the WIPP site**
4th Ore Zone	Langbeinite	40.5 @ 6.99 percent*	126.0 @ 7.30 percent
10th Ore Zone	Sylvite	52.3 @ 13.99 percent	105.0 @ 14.96 percent

Source: NMBMMR 1995, Chapter VII.

* For example, read as 40.5×10^6 tons of ore at a grade of 6.99 percent or higher.

Within the Carlsbad Known Potash Leasing Area, exploration holes have been drilled to evaluate the grade of the various ore zones. These are included in the drillhole database in Appendix DEL. None of the economically minable reserves identified by the NMBMMR lie directly above the waste panels. The known potash leases within the Delaware Basin are shown in Figure 2-37 and are detailed in Appendix DEL (Figure DEL-8). From information in this figure and other data which is provided in Appendix MASS (Attachment 15-5), the DOE evaluates the extent of future mining outside the land withdrawal area. The extent of possible future mining within the controlled area is shown in Figure 2-38. The DOE also addresses this subject with respect to performance assessment in Section 6.4.6.2.3.

2.3.1.2 Hydrocarbon Resources at the WIPP Site

In 1974, Foster of the NMBMMR conducted a hydrocarbon resource study in southeastern New Mexico under contract to the ORNL. The study included an area of 1,512 square miles (3,914 square kilometers). At the time of that study, the proposed repository site was about 5 miles (8 kilometers) northeast of the current site. The 1974 NMBMMR evaluation included a more detailed study of a four-township area centered on the old site; the present site is in the southwest quadrant of that area. The 1974 NMBMMR hydrocarbon resources study (Foster

1974) is presented in more detail in the FEIS (DOE 1980, § 9.2.3.5). The reader is referred to the FEIS or the original study for additional information.

The resource evaluation was based both on the known reserves of crude oil and natural gas in the region and on the probability of discovering new reservoirs in areas where past unsuccessful drilling was either too widely spread or too shallow to have allowed discovery. Potentially productive zones were considered in the evaluation; therefore, the findings may be used for estimating the total hydrocarbon resources at the site. A fundamental assumption in the study was that the WIPP area has the same potential for containing hydrocarbons as the larger region studied for which exploration data are available. Whether such resources actually exist can be satisfactorily established only by drilling at spacings close enough to give a high probability of discovery.

The NMBMMR 1995 mineral resource reevaluation contains a comprehensive summary of all previous evaluations. Broadhead et al. (NMBMMR 1995, Chapter XI) provided a reassessment of hydrocarbon resources within the WIPP site boundary and within the first mile adjacent to the boundary. Calculations were made for resources that are extensions of known, currently productive oil and gas resources that are thought to extend beneath the study area with reasonable certainty (called probable resources in the report). Qualitative estimates are also made concerning the likelihood that oil and gas may be present in undiscovered pools and fields in the area (referred to as possible resources). Possible resources were not quantified in the study. The results of the study are shown in Tables 2-8 and 2-9.

The DOE has compiled statistics on the historical development of hydrocarbon resources in the Delaware Basin and has included them in Appendix DEL. For these purposes, the Delaware Basin is described as the surface and subsurface features that lie inside the boundary formed to the north, east, and west by the innermost edge of the Capitan Reef and formed to the south by a straight line drawn from the southeastern point of the Davis Mountains to the southwestern point of the Glass Mountains (see Figure 2-39).

Several important modeling parameters result from the study of hydrocarbon resources and the history of their exploitation. These include parameters related to the number of human intrusions, the size of boreholes, the operational histories of such holes, the plugging of these holes, and the use of such holes for other purposes, such as liquid disposal. Each of these topics is discussed in detail in Appendices DEL and Appendix MASS (Section Appendix MASS.16) and is addressed in Sections 6.4.7 and 6.4.12. The distribution of existing boreholes is shown in Figure DEL-4 for the entire Delaware Basin and Figure DEL-6 for the vicinity of the WIPP site. In addition, Appendix DEL includes an assessment of current drilling and plugging practices in the Delaware Basin. Appendix DEL also discusses the regulatory constraints placed on the use of wells for injection.

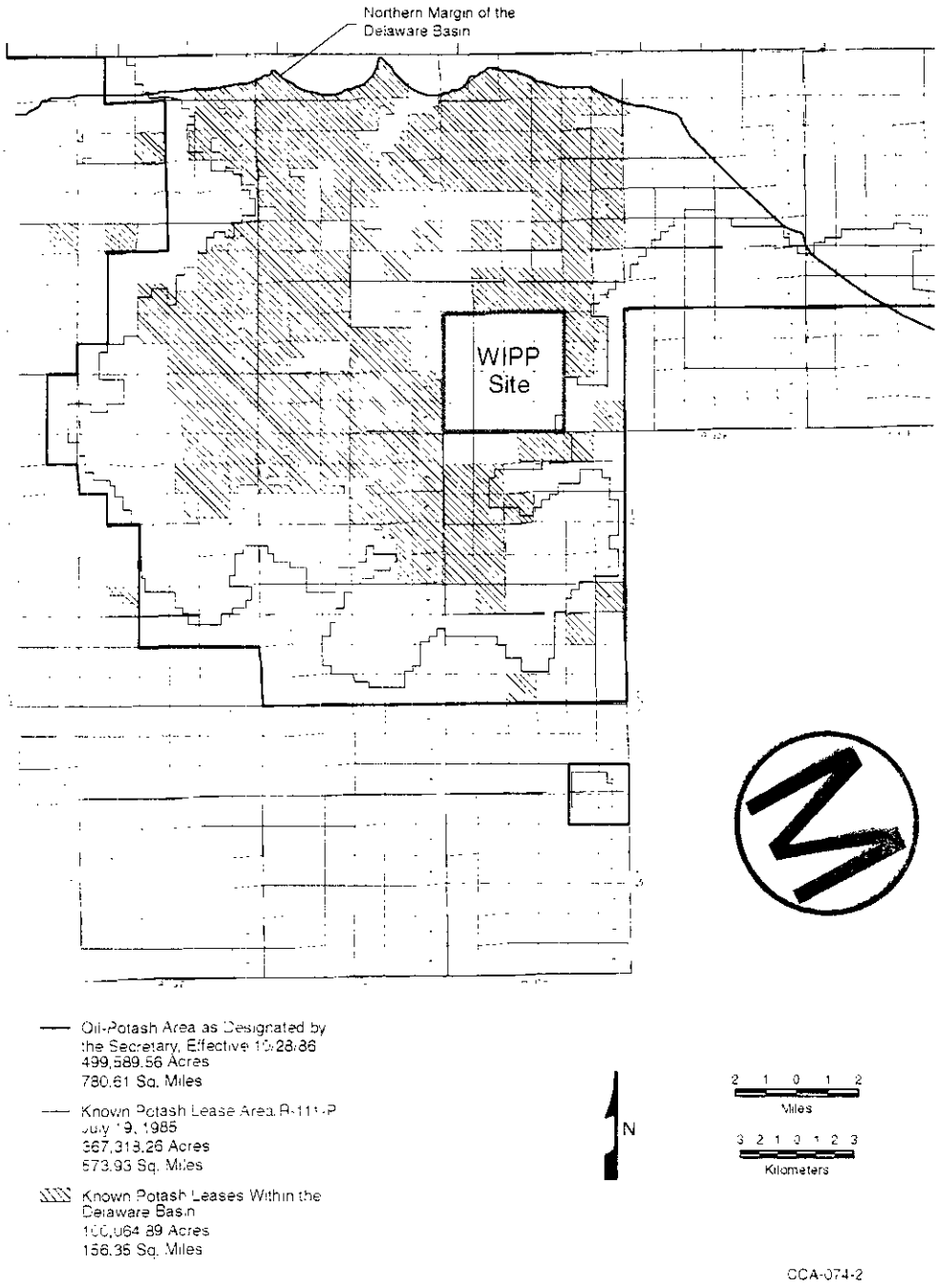

Figure 2-37. Known Potash Leases Within the Delaware Basin

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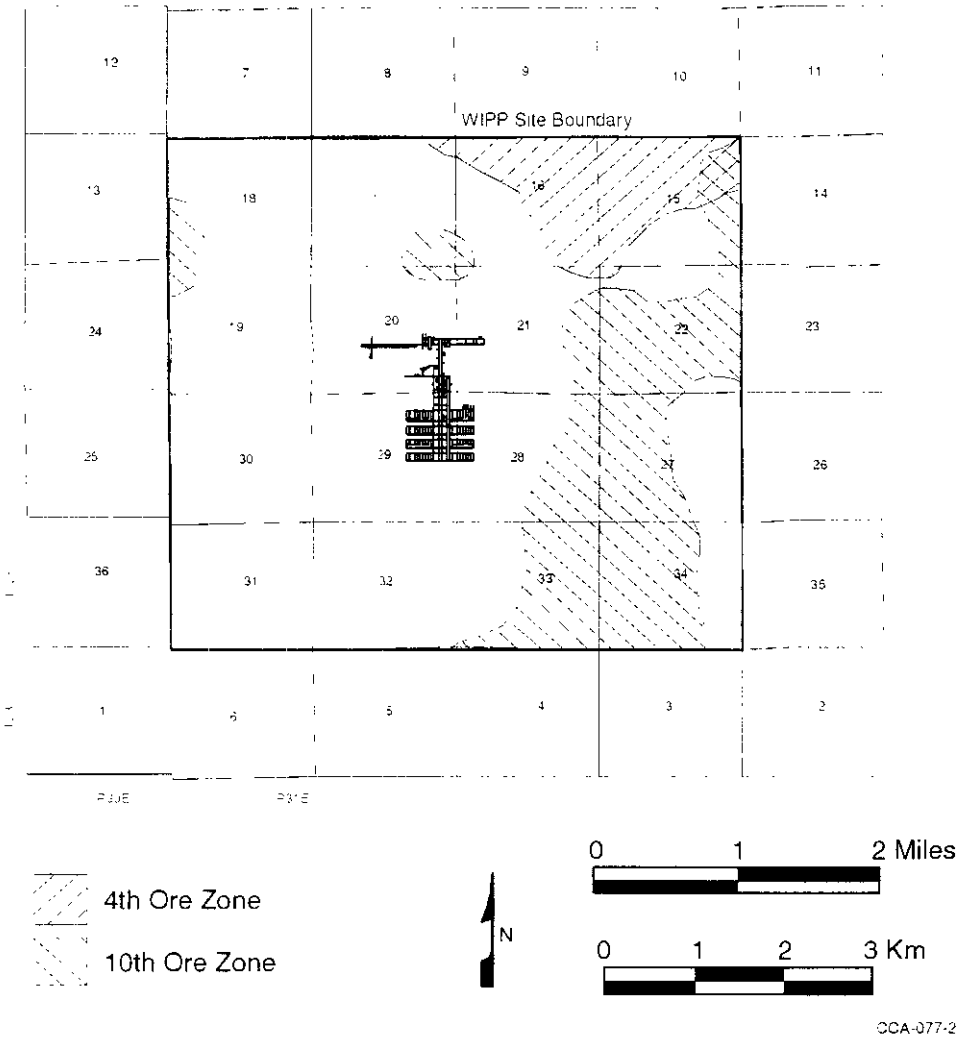

Figure 2-38. Extent of Economically Mineable Reserves Inside the Site Boundary (Based on NMBMMR Report)

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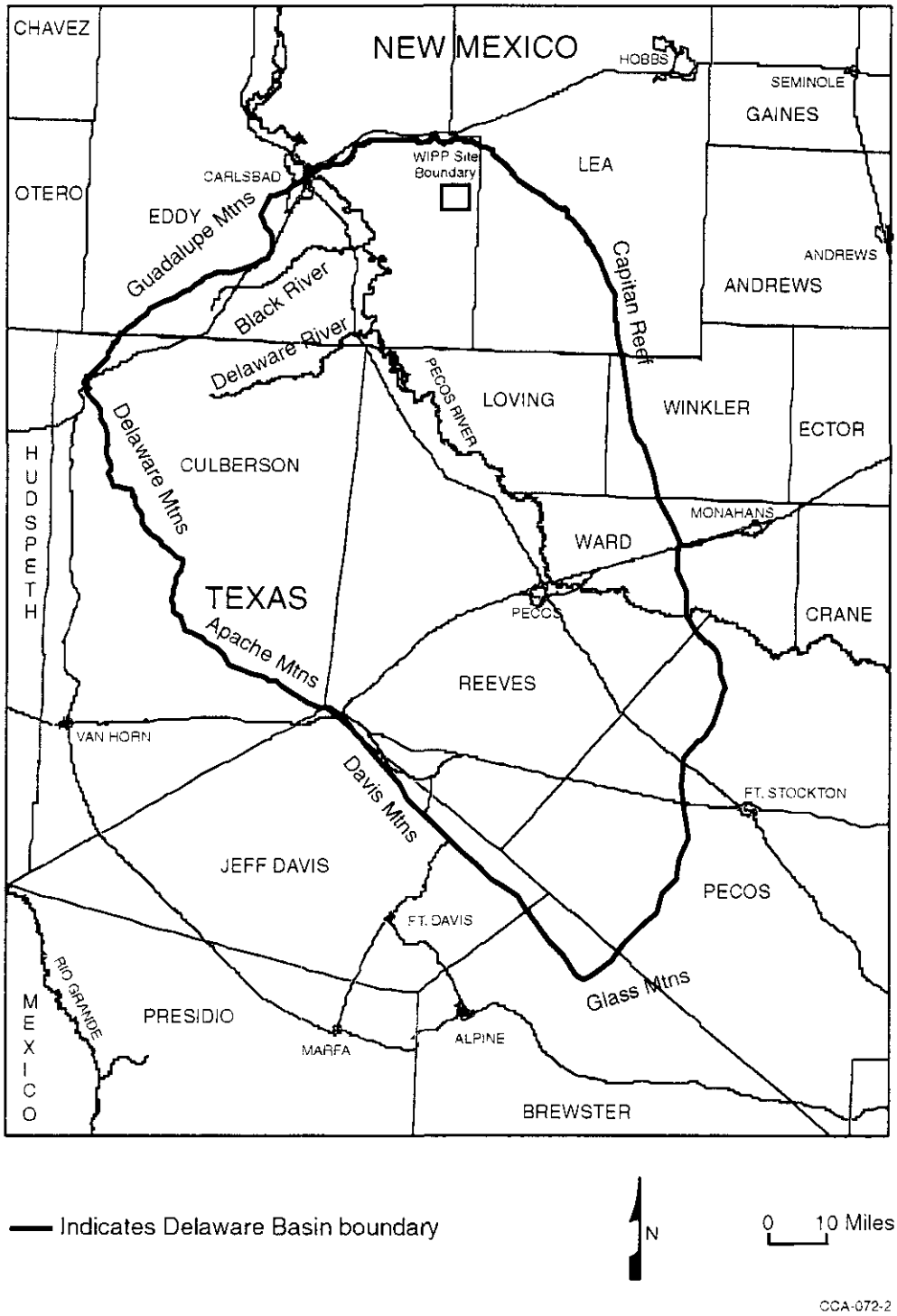

Figure 2-39. Delaware Basin Boundary

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Table 2-8. In-Place Oil within Study Area

Formation	Within WIPP site (10^6 bbl[a])	One-mile strip adjacent to the WIPP site (10^6 bbl)	Total (10^6 bbl)
Delaware	10.33	20.8	31.13
Bone Spring	0.44	0.8	1.25
Strawn	0.4	0.4	0.8
Atoka	1.1	0.1	0.2
Total	**12.3**	**22.9**	**35.3**

Source: NMBMMR 1995, Chapter XI.

[a] bbl = barrel = 42 gallons

Table 2-9. In-Place Gas within Study Area

Formation	Gas Reserves (Mcf)[a] Within WIPP Site	One-mile strip adjacent to the WIPP
Delaware	18,176	32,873
Bone Springs	956	1,749
Strawn	9,600	9,875
Atoka	123,336	94,410
Morrow	32,000	28,780

Source: NMBMMR 1995, Chapter XI.

[a] Mcf = thousand cubic feet

2.3.1.3 Other Resources

While the focus of studies at the WIPP has been on potash and hydrocarbon, other resources are known to occur within the Delaware Basin and are considered in the screening. For example, sulfur is produced in the vicinity of Orla, Texas. Sulfur wells are included in Appendix DEL; however, no sulfur resources have been identified in the vicinity of the WIPP; therefore, there are no projected impacts. Another resource that is extensively produced is groundwater. Potable water occurs in numerous places within the Delaware Basin. Several communities rely solely on groundwater sources for drinking water. Appendix DEL includes

a distribution of groundwater wells in the Delaware Basin. All such wells in the vicinity of the WIPP are shallow, generally no deeper than the Culebra. An evaluation of underground sources of drinking water in the vicinity of the disposal system is presented in Appendix USDW. Figure USDW-4 shows the distribution of groundwater wells in the vicinity of the disposal system. Sand, gravel, and caliche are produced in numerous areas within the Delaware Basin. In all cases, these are surface quarries that are generally shallow (tens of feet). No impact to the disposal system is expected from these activities.

2.3.2 Cultural and Economic Resources

The demographics, land use, and history and archaeology of the WIPP site and its environs are characterized in the sections that follow.

2.3.2.1 Demographics

The WIPP facility is located 26 miles (42 kilometers) east of Carlsbad in Eddy County in southeastern New Mexico and includes an area of 10,240 acres (16 square miles, or approximately 41 square kilometers). The facility is located in a sparsely populated area with fewer than 30 permanent residents living within a 10-mile (16-kilometer) radius of the facility. The area surrounding the facility is used primarily for grazing, potash mining, and hydrocarbon production. No resource development that would affect WIPP facility operations or the long-term integrity of the facility is allowed within the 10,240 acres that have been set aside for the WIPP project.

The permanent residence nearest to the WIPP site boundary is the J.C. Mills Ranch, which is 1.2 miles (2 kilometers) to the south. The community nearest to the WIPP site is the town of Loving, New Mexico, 18 miles (29 kilometers) west-southwest of the site center. The population of Loving decreased from 1,355 in 1980 to 1,243 in 1990. The nearest population center is the city of Carlsbad, New Mexico, 26 miles (42 kilometers) west of the site. The population of Carlsbad has decreased from 25,496 in 1980 to 24,896 in 1990. Hobbs, New Mexico, 36 miles (58 kilometers) to the east of the site had a 1980 population of 29,153 and a 1990 population of 29,115. Eunice, New Mexico, 40 miles (64 kilometers) east of the site, had a 1980 population of 2,970 and a 1990 population of 2,731. Jal, New Mexico, 45 miles (72 kilometers) southeast of the site, had a population of 2,575 in 1980 and of 2,153 in 1990.

The WIPP site is located in Eddy County near the border to Lea County, New Mexico. The Eddy County population increased from 47,855 in 1980 to 48,605 in 1990. The Lea County population decreased from 55,993 in 1980 to 55,765 in 1990. Population figures are taken from the 1980 and 1990 censuses (U.S. Department of Commerce 1980, 1990).

2.3.2.2 Land Use

At present, land within 10 miles (16 kilometers) of the site is used for potash mining operations, active oil and gas wells and activities associated with hydrocarbon production, and grazing.

The WIPP Land Withdrawal Act (LWA) (U.S. Congress 1992) withdrew certain public lands from the jurisdiction of the Bureau of Land Management (BLM). The law provides for the transfer of the WIPP site lands from the U.S. Department of the Interior (DOI) to the DOE and effectively withdraws the lands, subject to existing rights, from entry, sale, or disposition; appropriation under mining laws; and operation of the mineral and geothermal leasing laws. The LWA directed the Secretary of Energy to produce a management plan to provide for grazing, hunting and trapping, wildlife habitat, mining, and the disposal of salt and tailings.

Between 1978 and 1988, the DOE acquired all active potash and hydrocarbon leases within the WIPP site boundary. These were acquired either through outright purchase or through condemnation. In one condemnation proceeding, the court awarded the DOE the surface and top 6,000 feet (1.82 kilometers) of Section 31 and allowed the leaseholder to retain the subsurface below 6,000 feet (1.82 kilometers). This was allowed because analysis showed that wells developed within this lease below the 6,000-foot (1.82-kilometer) limit would be too far away from the waste panels to be of consequence to the WIPP (see, for example, Brausch et al. 1982). This is corroborated by the results of performance assessment discussed in Section 6.2.5.1 and Appendix SCR (Section SCR.3.3.1). Consequently, as the result of the DOE's acquisition activities, there are no producing hydrocarbon wells within the volumetric boundary defined by the land withdrawal (T22S, R31E, S15-22, 27-34). One active well, referred to as James Ranch 13, was drilled in 1982 to tap gas resources beneath Section 31. This well was initiated in Section 6, outside the WIPP site boundary. The well enters Section 31 below a depth of 6,000 feet (1.82 kilometers) beneath ground level. Except for the leases in Section 31, the LWA prohibits all drilling into the controlled area unless such drilling is in support of the WIPP.

Grazing leases have been issued for all land sections immediately surrounding the WIPP facility. Grazing within the WIPP site lands occurs within the authorization of the Taylor Grazing Act of 1934, the Federal Land Policy and Management Act (FLPMA), the Public Rangelands Improvement Act of 1978, and the Bankhead-Jones Farm Tenant Act of 1973.

The responsibilities of the DOE include supervision of ancillary activities associated with grazing (for example, wildlife access to livestock water development); tracking of water developments inside WIPP lands to ensure that they are configured according to the regulatory requirements; and ongoing coordination with respective allottees. Administration of grazing rights is in cooperation with the BLM according to the memorandum of understanding (MOU) and the coinciding Statement of Work through guidance established in the East Roswell Grazing Environmental Impact Statement. The WIPP site is composed of two grazing allotments administered by the BLM: the Livingston Ridge (No. 77027) and the Antelope Ridge (No. 77032).

2.3.2.3 History and Archaeology

From about 10,000 B.C. to the late 1800s, the WIPP site and surrounding region were inhabited by nomadic aboriginal hunters and gatherers who subsisted on various wild plants and animals. From about A.D. 600 onward, as trade networks were established with Puebloan peoples to the west, domesticated plant foods and materials were acquired in exchange for dried meat, hides, and other products from the Pecos Valley and Plains. In the late 1500s, the Spanish Conquistadors encountered Jumano and Apachean peoples in the region who practiced hunting and gathering and engaged in trade with Puebloans. After the Jumanos abandoned the southern Plains region, the Comanches became the major population of the area. Neighboring populations with whom the Comanches maintained relationships ranging from mutual trade to open warfare included the Lipan, or Southern Plains Apache, several Puebloan Groups, Spaniards, and the Mescalero Apaches.

The best documented indigenous culture in the WIPP region is that of the Mescalero Apaches, who lived west of the Pecos. The lifestyle of the Mescalero Apaches represents a transition between the full sedentism of the Pueblos and the nomadic hunting and gathering of the Jumanos. In 1763, the San Saba expedition encountered and camped with a group of Mescaleros in Los Medaños. Expedition records indicate the presence of both Lipan and Mescalero Apaches in the region.

A peace accord reached between the Comanches and the Spaniards in 1786 resulted in two historically important economic developments: (1) organized buffalo hunting by Hispanic and Puebloan ciboleros and (2) renewal and expansion of the earlier extensive trade networks by Comancheros. These events placed eastern New Mexico in a position to receive a wide array of both physical and ideological input from the Plains culture area to the east and north and from Spanish-dominated regions to the west and south. Comanchero trade began to mesh with the Southwest American trade influence in the early nineteenth century. However, by the late 1860s the importance of Comanchero trade was cut short by Texan influence.

The first cattle trail in the area was established along the Pecos River in 1866 by Charles Goodnight and Oliver Loving. By 1868, Texan John Chisum dominated much of the area by controlling key springs along the river. Overgrazing, drought, and dropping beef prices led to the demise of open-range cattle ranching by the late 1880s.

Following the demise of open-range livestock production, ranching developed using fenced grazing areas and production of hay crops for winter use. Herd grazing patterns were influenced by the availability of water supplies as well as by the storage of summer grasses for winter feeding.

The town of Carlsbad was founded as Eddy in 1889 as a health spa. In addition to ranching, the twentieth century brought the development of the potash, oil, and gas industries that have increased the population eightfold in the last 50 years.

Although technological change has altered some of the aspects, ranching remains an important economic activity in the WIPP region. This relationship between people and the land is still an important issue in the area. Ranch-related sites dating to the 1940s and 1950s are common in parts of the WIPP area. These will be considered historical properties within the next several years, and thus will be treated as such under current law.

The National Historic Preservation Act (NHPA; 16 USC Part 470 et seq.) was enacted to protect the nation's cultural resources in conjunction with the states, local governments, Indian tribes, and private organizations and individuals. The policy of the federal government includes (1) providing leadership in preserving the prehistoric and historic resources of the nation; (2) administering federally owned, administered, or controlled prehistoric resources for the benefit of present and future generations; (3) contributing to the preservation of nonfederally owned prehistoric and historic resources; and (4) assisting state and local governments and the national trust for historic preservation in expanding and accelerating their historic preservation programs and activities. The act also established the National Register of Historic Places (National Register). At the state level, the State Historic Preservation Officer (SHPO) coordinates the state's participation in implementing the NHPA. The NHPA has been amended by two acts: the Archeological and Historic Preservation Act (16 USC Part 469 et seq.) and the Archeological Resource Protection Act (16 USC Part 470aa et seq.).

To protect and preserve cultural resources found within the WIPP site boundary, the WIPP submitted a mitigation plan to the New Mexico SHPO describing the steps to either avoid or excavate archaeological sites. A site was defined as a place used and occupied by prehistoric people. In May 1980, the SHPO made a determination of "no adverse effect from WIPP facility activities" on cultural resources. The Advisory Council on Historic Preservation concurred that the WIPP Mitigation Plan is appropriate to protect cultural resources.

Known historical sites (more than 50 years old) in southeastern New Mexico consist primarily of early twentieth century homesteads that failed or isolated features from late nineteenth century and early twentieth century cattle or sheep ranching and military activities. To date, no Spanish or Mexican sites have been identified. Historic components are rare but are occasionally noted in the WIPP area. These include features and debris related to ranching.

Since 1976, cultural resource investigations have recorded 98 archaeological sites and numerous isolated artifacts within the 16-square-mile (41-square-kilometer) area enclosed by the WIPP site. In the central 4-square-mile (10.4-square-kilometer) area, 33 sites were determined to be eligible for inclusion on the National Register as archaeological districts. Investigations since 1980 have recorded an additional 14 individual sites outside the central 4-square-mile (10.4-square-kilometer) area that are considered eligible for inclusion on the National Register. The following major cultural resource investigations to date are broken out in the list that follows. Additional information can be found in the bibliography.

1977. The first survey of the area was conducted for SNL by Nielson of the Agency for Conservation Archaeology (ACA). This survey resulted in the location of 33 sites and 64 isolated artifacts.

1979. MacLennan and Schermer of ACA conducted another survey to determine access roads and a railroad right-of-way for Bechtel, Inc. The survey encountered two sites and 12 isolated artifacts.

1980. Schermer conducted another survey to relocate the sites originally recorded by Nielson. This survey redescribed 28 of the original 33 sites.

1981. Hicks (1981a, b) directed the excavation of nine sites in the WIPP core area.

1982. Bradley (Lord and Reynolds 1985) recorded one site and four isolated artifacts in an archaeological survey for a proposed water pipeline.

1985. Lord and Reynolds examined three sites within the WIPP core area that consisted of two plant-collecting and processing sites and one base camp used between 1000 B.C. and A.D. 1400. The artifacts recovered from the excavations are in the Laboratory of Anthropology at the Museum of New Mexico in Santa Fe.

1987. Mariah Associates, Inc., identified 40 sites and 75 isolates in an inventory of 2,460 acres in 15 quarter-section units surrounding the WIPP site. In this investigation, 19 of the sites were located within the WIPP site's boundary. Sites encountered in this investigation tended to lack evident or intact features. Of the 40 new sites defined, 14 were considered eligible for inclusion in the National Register, 24 were identified as having insufficient data to determine eligibility, and two were determined to be ineligible for inclusion. The eligible and potentially eligible sites have been mapped and are avoided by the DOE in its current activities at the WIPP site.

1988–1992. Several archaeological clearance reports have been prepared for seismic testing lines on public lands in Eddy County, New Mexico.

All archaeological sites are surface or near-surface sites, and no reasons exist (either geological or archeological) to suspect that deep drilling would uncover or investigate archaeological sites.

The Delaware Basin has been used in the past for an isolated nuclear test. This test, Project Gnome, took place in 1961 at a location approximately 8 miles (13 kilometers) southwest of the WIPP. The primary objective of Project Gnome was to study the effects of an underground nuclear explosion in salt. The Gnome experiment involved the detonation of a 3.1-kiloton nuclear device at a depth of 1,200 feet (361 meters) in the bedded salt of the Salado (Rawson et al. 1965). The explosion created a cavity of approximately 1,000,000 cubic feet (28,000 cubic meters) and caused surface displacements over an area of about a

1,200-foot (360-meter) radius. Fracturing and faulting caused measurable changes in rock permeability and porosity at distances up to approximately 330 feet (100 meters) from the cavity. No earth tremors were reported at distances over 25 miles (40 kilometers) from the explosion. Project Gnome was decommissioned in 1979.

2.4 Background Environmental Conditions

One of the criteria established for the selection of a repository site was that the impacts on the ecology from constructions and operations be minimal. Consequently, as the DOE assessed the geological and hydrological characteristics of the site, they also assessed the ecological characteristics. The result was a demonstration, documented in the FEIS, that the ecological impacts are minimal and within acceptable bounds. The FEIS concluded that adverse impacts on the ecology were expected to be slight for the following reasons:

(1) No natural areas proposed for protection are present on or near the site,

(2) No endangered species of plants or animals are known to inhabit the site or the vicinity of the site; nor are any critical habitats known to exist on or near the site,

(3) Water requirements for the site are low,

(4) The land contains soil types and vegetation associations that are common throughout the region, and

(5) Access in the form of dirt roads is already available throughout the area; therefore, recreational use of the area is not likely to increase significantly.

The results of the DOE's assessment of background environmental conditions are provided in this application as part of the complete description of the WIPP and its vicinity. Background environmental conditions form the baseline for determining if releases to the environment have occurred during the operational period or during any postoperational monitoring period (Wolfe et al. 1977). For this reason, the EPA considers these are important criteria for certification as stated in 40 CFR § 194.14(g). The DOE routinely collects environmental information at and around the WIPP site in accordance with the WIPP Environmental Monitoring Plan (see Appendix EMP). The EMP satisfies the criteria of 40 CFR § 194.14(g) in that it provides programmatic specifications for implementing and operating the WIPP environmental monitoring program. Appendix EMP includes a description of sampling locations, sampling frequencies, sample management practices, and where appropriate, analytical procedures. Specific field procedures are maintained at the WIPP site in a separate Environmental Monitoring Procedures Manual. Emphasis is placed on ecological conditions, water quality, and air quality and includes the following:

Ecological Conditions

- Vegetation
- Mammals
- Reptiles and amphibians
- Birds
- Arthropods
- Aquatic ecology
- Endangered species.

Quality of Environmental Media

- Surface water
- Groundwater
- Air.

2.4.1 Terrestrial and Aquatic Ecology

The vegetation, mammals, reptiles and amphibians, birds, arthropods, aquatic ecology, and endangered species of the WIPP site and its environs are characterized in the sections that follow. Much of the information in this section was reported in the FEIS (DOE 1980). Where this information has been updated with more recent data, this update is noted.

2.4.1.1 Vegetation

The WIPP site is in an area characterized by stabilized sand dunes. The vegetation is dominated by shinnery oak, mesquite, sand sage, dune yucca, smallhead snakeweed, three-awn, and numerous species of forbs and perennial grasses. The dominant shrubs are deep-rooted species with extensive root systems. The shrubs not only stabilize the dune sand but serve as food, shelter, and nesting sites for many species of wildlife inhabiting the area.

The vegetation in the vicinity of the WIPP site is not a climax vegetation, at least in part because of past grazing management. The composition of the plant life at the site is heterogeneous because of variations in terrain and in the type and depth of soil. Shrubs are conspicuous members of all plant communities. The site lies within a region of transition

between the northern extension of the Chihuahuan Desert (desert grassland) and the southern Great Plains (short grass prairie); it shares the floral characteristics of both.

Grazing, primarily by domestic livestock, and fire control are largely responsible for the shrub-dominated seral communities of much of southeastern New Mexico. A gradual retrogression from the tall- and mid-grass-dominated vegetation of 100 years ago has occurred throughout the region. The cessation of grazing would presumably not alter the domination by shrubs, but it would result in an increase in grasses. Experimental exclosures have been established to study site-specific patterns of succession in the absence of grazing, but long-term results are not yet available.

The semiarid climate makes water a limiting factor in the entire region. The amount and timing of rainfall greatly influence plant productivity and, therefore, the food supply for wildlife and livestock. The seeds of desert plants are often opportunistic: they may lie dormant through long periods of drought to germinate in the occasional year of favorable rainfall. Significant fluctuations in the abundance and distribution of plants and wildlife are typical of this region. Several examples of such fluctuations have been documented in the area within 5 miles (8.3 kilometers) of the center of the WIPP site, which has been intensively studied.

Two introduced species of significance in the region are the Russian thistle, or tumbleweed, a common invader in disturbed areas, and the Tamarisk, or salt cedar, which has proliferated along drainage ways.

Several distinct biological zones occur on or near the site: the mesa, the central dunes complex, the creosote-bush flats, the Livingston Ridge escarpment, and the Tobosa Flats in Nash Draw west of the ridge. A low, broad mesa named the Divide lies on the eastern edge of the study area and supports a typical desert-grassland vegetation. The dominant shrub and subshrub are mesquite and snakeweed, respectively. The most abundant grasses are black grama, bush muhly, ring muhly, and fluffgrass. Cacti, especially varieties of prickly pear, are present.

Where the ground slopes down from the Divide to the central dune plains, the soil becomes deep and sandy. Shrubs like shinnery oak, mesquite, sand sagebrush, snakeweed, and dune yucca are dominant. In some places, all of these species are present; in others, one or more are either missing or very low in density. These differences appear to be caused by localized variations in the type and depth of soil. Thus, a number of closely related but distinct plant associations form a patchwork complex, or mosaic, across the stabilized dunes in the central area. Hummocky, partially stabilized sand dunes occur, and large, active dunes are also present. The former consist of islands of vegetation, primarily mesquite, separated by expanses of bare sand. The mesquite-anchored soil is less susceptible to erosion, mainly by wind, than is the bare sand. The result is a series of valley-like depressions, or blowouts, between vegetated hummocks. Active dunes running east to west are found 10 miles (16 kilometers) south and east of the site.

To the west and southwest, the soil changes again, becoming more dense and shallow (less than 10 inches [254 millimeters] to caliche) than in the dune area. The composition of the plant life is radically altered, and creosote bushes become dominant. Toward Livingston Ridge to the west and northwest, creosote bushes gradually give way to an acacia-dominated association at the top of the escarpment. The western face of the ridge drops sharply to a valley floor (flats) that is densely populated with tobosa grass, which is rare elsewhere in the study area.

2.4.1.2 Mammals

The most conspicuous wild mammals at the site are the black-tailed jack rabbit and the desert cottontail. Common small mammals found at the WIPP site include the Ord's kangaroo rat, the Plains pocket mouse, and the northern grasshopper mouse. Big-game species, such as the mule deer and the pronghorn antelope, and carnivores, such as the coyote, are present in small numbers.

2.4.1.3 Reptiles and Amphibians

Commonly observed reptiles in the study area are the side-blotched lizard, the western box turtle, the western whiptail lizard, and several species of snakes, including the bullsnake, the prairie rattlesnake, the western diamondback rattlesnake, the coachwhip, the western hognose, and the glossy snake. Of these, only the side-blotched lizard is found in all habitats. The others are mainly restricted to one or two associations within the central dunes area, although the western whiptail lizard and the western diamondback rattlesnake are found in areas dominated by creosote bush as well. The yellow mud turtle is found only in the limited number of aquatic habitats in the study area (that is, dirt stock ponds and metal stock tanks), but it is common in these locales.

Amphibians are similarly restricted by the availability of aquatic habitat. Stock-watering ponds and tanks may be frequented by tiger salamanders and occasional frogs and toads. Fish are sometimes stocked in the ponds and tanks.

2.4.1.4 Birds

Numerous birds inhabit the area either as transients or year-long residents. Loggerhead shrikes, pyrrhuloxias, and black-throated sparrows are examples of common residents. Migrating or breeding waterfowl species do not frequently occur in the area. Some raptors (for example, Harris hawks) are residents. The density of large avian predators' nests has been documented as among the highest recorded in the scientific literature.

2.4.1.5 Arthropods

About 1,000 species of insects have been collected in the study area. Of special interest are subterranean termites. Vast colonies of these organisms are located across the study area; they are detritivores and play an important part in the recycling of nutrients in the study area.

2.4.1.6 Aquatic Ecology

Aquatic habitats within a 5-mile (8-kilometer) radius of the WIPP site are limited. Stock-watering ponds and tanks constitute the only permanent surface waters. Ephemeral surface-water puddles form after heavy thunderstorms. At greater distances, seasonally wet, shallow lakes (playas) and permanent salt lakes are found.

Laguna Grande de la Sal is a large, permanent salt lake at the south end of Nash Draw. Natural brine springs, effluent brine from nearby potash refineries, and surface and subsurface runoff discharge into the lake. One of the natural brine springs at the northern margin of the lake has been found to support a small population of the Pecos River pupfish. This species is among the species recognized as threatened by the state of New Mexico. The spring, now called Surprise Spring, is about 11 miles (18 kilometers) west-southwest of the WIPP site.

Several marine organisms are present in the Lower Pecos River and in the Red Bluff Reservoir. They include small, shelled protozoans (Foraminifera), a Gulf Coast shrimp, an estuarine oligochaete and a dragonfly, and several species of marine algae. These species have presumably been introduced. Salt-tolerant species of insects, oligochaetes, and nematodes and unusual algal assemblages characterize this stretch of the river. The combination of high salinity, elevated concentrations of heavy metals, and salt-tolerant and marine fauna makes the Lower Pecos River a unique system (DOE 1980, § 7.1.3.).

2.4.1.7 Endangered Species

The DOE consulted with the U.S. Fish and Wildlife Service (FWS) in 1979 to determine the presence of threatened and endangered species at the WIPP site. At that time the FWS listed the Lee pincushion cactus, the black-footed ferret, the American peregrine falcon, the bald eagle, and the Pecos gambusia as threatened or endangered and as occurring or having the potential to occur on lands within or outlying the WIPP site. In 1989, the FWS advised the DOE that the list of species provided in 1979 is still valid, with the exception of the black-footed ferret. The DOE believes that the actions described in the 1990 *Final Supplement Environmental Impact Statement* (SEIS, in the bibliography) will have no impact on any threatened or endangered species because these activities do not involve any ground disturbance that was not already evaluated in the FEIS. In addition, there is no critical habitat for terrestrial species identified as endangered by either the FWS or the New Mexico Department of Game and Fish (NMDG&F) at the site area.

Also in 1989, the DOE consulted with the NMDG&F regarding the endangered species listed by the state in the vicinity of the WIPP site. The NMDG&F currently lists (based on NMDG&F Regulation 657, dated January 9, 1988) seven birds and one reptile that are in one of two endangerment categories and that occur or are likely to occur at the site. The NMDG&F agreed in 1989 that the proposed WIPP activities would probably not have appreciable impacts on endangered species listed by the state in the area. *A Handbook of Rare and Endemic Plants of New Mexico*, published by the University of New Mexico (UNM) (UNM 1984), lists the plants in New Mexico classified as threatened, endangered, or sensitive, and includes 20 species, representing 14 families, that are found in Eddy County and could occur at or near the WIPP site.

2.4.2 Water Quality

In this section, the DOE presents a discussion of the quality of groundwater and surface water in the WIPP area.

2.4.2.1 Groundwater Quality

Based on the major solute compositions described in Siegel et al. (1991, Section 2.3.2.1), four hydrochemical facies are delineated for the Culebra, as shown in Figure 2-40.

Zone A. A sodium chloride brine (approximately 3.0 molar) with a magnesium/calcium (Mg/Ca) mole ration between 1.2 and 2.0 exists here. This water is found in the eastern third of the WIPP site. The zone is roughly coincident with the region of low transmissivity described by LaVenue et al. (1988, 6-1). On the western side of the zone, halite in the Rustler has been found only in the unnamed lower member. In the eastern portion of the zone, halite has been observed throughout the Rustler.

Zone B. A dilute anhydrite-rich water (ionic strength < 0.1 molar) occurs in the southern part of the site. The Mg/Ca mole ratios are uniformly low (0.0 to 0.5). This zone is coincident with a high-transmissivity region, and halite is not found in the Rustler in this zone.

Zone C. Waters of variable composition with low to moderate ionic strength (0.3 to 1.6 molar) occur in the western part of the WIPP site and along the eastern side of Nash Draw. Mg/Ca mole ratios range from 0.3 to 1.2. This zone is coincident with a region of variable transmissivity. In the eastern part of this zone, halite is present in the lower member of the Rustler. Halite is not observed in the formation on the western side of the zone. The most halite-rich water is found in the eastern edge of the zone, close to core locations where halite is observed in the Tamarisk Member.

Zone D. A fourth zone can be defined based on inferred contamination related to potash refining operations in the area. Waters from these wells have anomalously high solute concentrations (3 to 7 molar) and potassium/sodium (K/Na) weight ratios (0.2) compared to waters from other zones (K/Na = 0.01 to 0.09). In the extreme southwestern part of this zone,

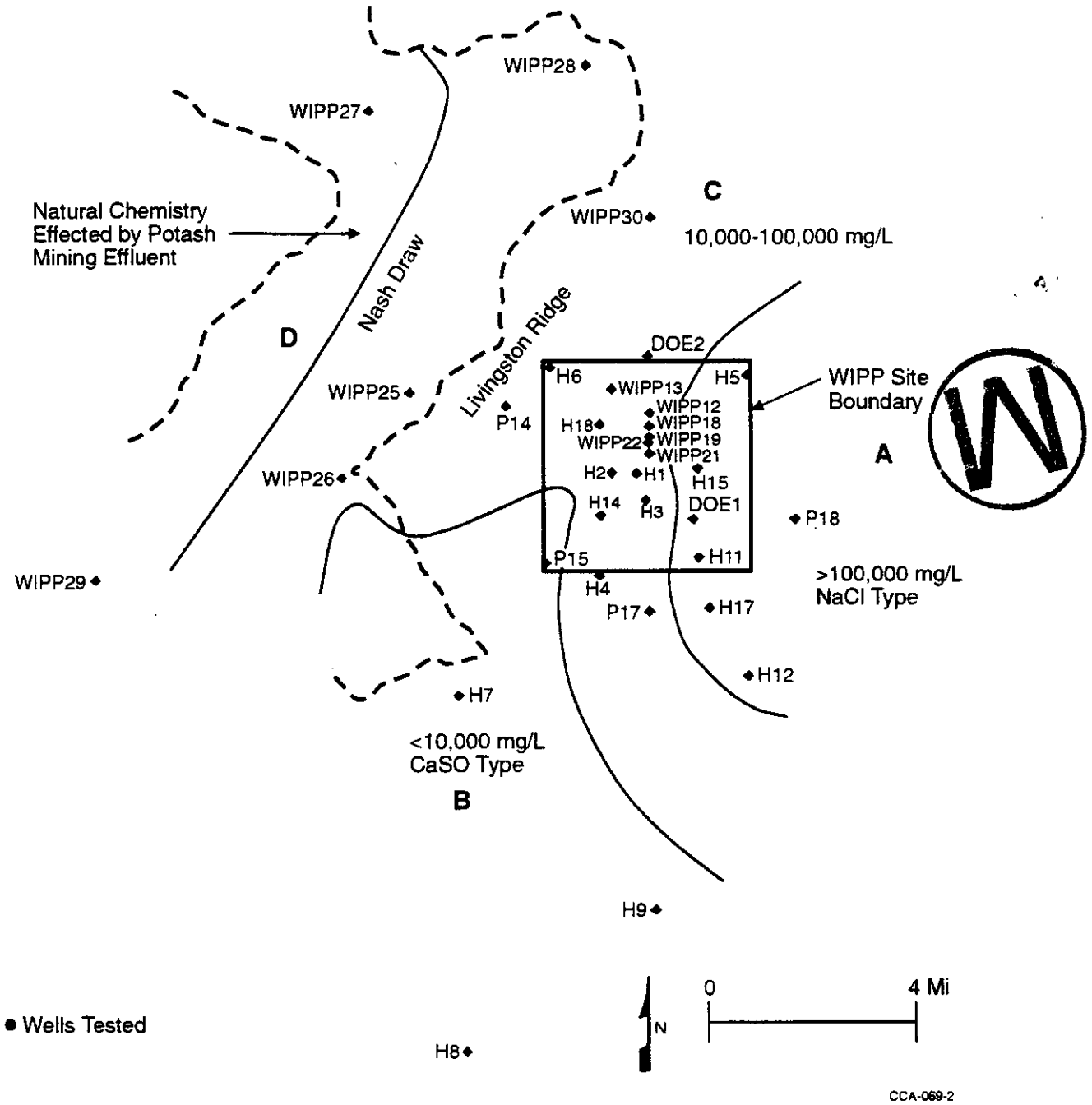

Figure 2-40. Hydrochemical Zones of the Culebra

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the composition of the Culebra well water has changed over the course of a seven-year monitoring period. The Mg/Ca mole ratio at WIPP-29 is anomalously high, ranging from 10 to 30 during the monitoring period (Siegel et al. 1991, Figure 2-19).

This zonation is consistent with that described by Ramey in 1985, who defined three zones. The fourth zone (D) was added by Siegel et al. in 1991 to account for the local potash contamination.

Together, the variations in solutes and the distribution of halite in the Rustler exhibit a mutual interdependence. Concentrations of solutes are lowest where Rustler halite is less abundant, consistent with the hypothesis that solutes in Rustler groundwaters are derived locally by dissolution of minerals (for example, halite, gypsum, and dolomite) in adjacent strata.

The TDS in the Magenta groundwater ranges in concentration from 3,240 to 222,000 milligrams per liter (Siegel et al. 1991, Table 4-6). This water is considered saline to briny. The transmissivity in areas of lower TDS concentrations is very low, thus greatly decreasing its usability, and the Magenta is not considered as a water supply. In general, the chemistry of Magenta water is variable. Groundwater types range from a predominantly sodium chloride type to a calcium-magnesium-sodium-sulfate type chemistry. The water chemistry may indicate a general overall increase in TDS concentrations to the south and southwest, away from the WIPP site, and a potential change to a predominantly sodium chloride water in that area.

In the WIPP area, the water quality of the Magenta is better than that of the Culebra. However, water from the Magenta is not used anywhere in the vicinity of the WIPP. The DOE has performed an analysis to determine whether there are underground source of drinking water (USDWs) in the vicinity of the WIPP. This analysis has resulted in a conclusion that there could be three USDWs as defined by 40 CFR Part 191 exist in the area, as given in Appendix USDW. The impact of the WIPP on USDWs is discussed in Chapter 8.0.

2.4.2.2 Surface-Water Quality

The Pecos River is the nearest permanent surface water source to the WIPP site. Natural brine springs, representing outfalls of the brine aquifers in the Rustler, feed the Pecos River at Malaga Bend, southwest of the site. This natural saline inflow adds approximately 370 tons of chloride per day to the Pecos River (Appendix GCR, 6-7). Return flow from irrigated areas above Malaga Bend further contributes to the salinity. The concentrations of potassium, mercury, nickel, silver, selenium, zinc, lead, manganese, cadmium, and barium also show significant elevations at Malaga Bend but tend to decrease downstream. The metals presumably are rapidly adsorbed onto the river sediments. Natural levels of certain heavy metals in the Pecos River below Malaga Bend exceed the water quality standards of the World

Health Organization, the EPA, and the state of New Mexico. For example, the maximum level for lead is 50 parts per billion, and levels of up to 400 parts per billion have been measured in the Pecos River.

As it flows into Texas south of Carlsbad, the Pecos River is a major source of dissolved salt in the west Texas portion of the Rio Grande Basin. Natural discharge of highly saline groundwater into the Pecos River in New Mexico keeps TDS levels in the water in and above the Red Bluff Reservoir very high. The TDS levels in this interval exceed 7,500 milligrams per liter 50 percent of the time and, during low flows, can exceed 15,000 milligrams per liter. Additional inflow from saline water-bearing aquifers below the Red Bluff Reservoir, irrigation return flows, and runoff from oil fields continues to degrade water quality between the reservoir and northern Pecos County in Texas. Annual discharge-weighted average TDS concentrations exceed 15,000 milligrams per liter. Water use is varied in the southwest Texas portion of the Pecos River drainage basin. For the most part, water use is restricted to irrigation, mineral production and refining, and livestock. In many instances, surface-water supplies are supplemented by groundwaters that are being depleted and are increasing in salinity.

2.4.3 Air Quality

Measurements of selected air pollutants at the WIPP site began in 1976 and were reported by the DOE in the FEIS. Since the preparation of that document, a more extensive air quality monitoring program has been established. Seven classes of atmospheric gases regulated by the EPA have been monitored at the WIPP site between August 27, 1986, and October 30, 1994. These gases are carbon monoxide (CO), hydrogen sulfide (H_2S), ozone (O_3), nitrogen oxides (NO, NO_2, NO_x), and sulfur dioxide (SO_2). The total suspended particulates (TSPs) are monitored in conjunction with the air-monitoring programs of the WIPP. The results of the monitoring program are detailed in the annual reports for the WIPP Environmental Monitoring Program (see Appendix SER; Westinghouse 1991b, 1992, 1993, 1994, 1995 in the Bibliography).

2.4.4 Environmental Radioactivity

The background radiation conditions in the vicinity of the WIPP site are influenced by natural sources of radiation, fallout from nuclear tests, and one local research project (Project Gnome). Prior to the WIPP project, long-term radiological monitoring programs were established in southeastern New Mexico to determine the widespread impacts of nuclear tests at the Nevada Test Site and to evaluate the effects of Project Gnome. As discussed in Section 2.3.2.3, Project Gnome resulted in the underground detonation of a nuclear device on December 10, 1961, at a site approximately 8 miles (13 kilometers) southwest of the WIPP site.

The WIPP Radiological Baseline Program (RBP), which included the Radiological Environmental Surveillance Program, was initiated in July 1985 to describe background levels

of radiation and radionuclides in the WIPP environment prior to the underground emplacement of radioactive waste. The RBP consisted of five subprograms: (1) atmospheric baseline; (2) ambient radiation (measuring gamma radiation); (3) terrestrial baseline (sampling soils); (4) hydrologic baseline (sampling surface water and bottom sediments and groundwater); and (5) biotic baseline (analyzing radiological parameters in key organisms along potential radionuclide migration pathways). The RBP has been succeeded by the Environmental Monitoring Plan (EMP). The final report on the RBP is included as Appendix RBP. This report summarizes the statistical approach used to analyze the RBP data. In addition, the RBP discusses how values below detection limits are handled. The sampling locations for the RBP are the same as those reported on Figures 5-2 through 5-7 in Appendix EMP. This appendix discusses the statistical analyses used to support data.

2.4.4.1 Atmospheric Radiation Baseline

Historically, most gross alpha activity in airborne particulates has shown little variation and is within the range of from 1×10^{-15} to 3×10^{-15} microcuries per milliliter, which is equivalent to 3.7×10^{-11} to 11×10^{-11} becquerels per milliliter. Mean gross beta activity in airborne particulates fluctuates but is typically within the range of from 1×10^{-14} to 4×10^{-14} microcuries per milliliter (3.7×10^{-10} to 15×10^{-10} becquerels per milliliter). A peak of 3.5×10^{-13} microcuries per milliliter (1.2×10^{-8} becquerels per milliliter) in mean gross beta activity occurred in May 1986 and has been attributed to atmospheric fallout from the Chernobyl incident in the former Soviet Union. The average level of gamma radiation in the environment is approximately 7.5 microroentgens per hour, or approximately 66 millirem per year.

For 1995, the mean gross alpha concentrations show limited fluctuation throughout the year and range from 2.0×10^{-15} to 2.6×10^{-14} microcuries per milliliter (7.5×10^{-11} to 9.6×10^{-10} becquerels per milliliter). These fluctuations appeared to be consistent among all sampling locations. The mean gross beta concentrations fluctuate throughout the year within the range of 2.4×10^{-14} to 4.0×10^{-14} microcuries per milliliter (8.9×10^{-10} to 1.5×10^{-9} becquerels per milliliter). Individual gross alpha and beta concentrations reported for each location are documented in Appendix SER.

2.4.4.2 Ambient Radiation Baseline

Using the average rate of 7.5 microroentgens per hour, the estimated annual dose is approximately 66 millirem. The fluctuations noted are primarily due to calibration of the system and meteorological events such as the high-intensity thunderstorms that frequent this area in late summer. A seasonal rise in ambient radiation has been observed in the first and fourth quarters each year. It is speculated that this fluctuation may be due to variations in the emission and dispersion of radon-222 from the soil around the WIPP site. These variations can be caused by meteorological conditions, such as inversions, which would slow the dispersion of the radon and its progeny.

2.4.4.3 Terrestrial Baseline

Data were collected as part of the RBP at the WIPP in December 1985 and July 1987. Soil samples were collected and analyzed from a total of 37 locations within a 50-mile (80-kilometer) radius of the WIPP (see Table 2-10). The soil samples were analyzed for 19 radionuclides: ^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, two isotopes of radium, three isotopes of thorium, four isotopes of uranium, ^{237}Np, four isotopes of plutonium (^{239}Pu and ^{240}Pu were measured together), ^{241}Am, and ^{244}Cm. Four isotopes (^{40}K, ^{234}U, ^{235}U, and ^{238}U) exhibited significant differences among the three geographic groups, with samples from the outer sites having significantly higher levels of radioactivity than those from the 5-mile (8-kilometer) ring sites (that is, 16 sampling sites in a ring around the WIPP with a 5-mile [8-kilometer] radius). For ^{234}U, ^{235}U, and ^{238}U, the 5-mile (8-kilometer) ring sites also showed higher levels than the WIPP sites. The isotopes ^{137}Cs, ^{226}Ra, ^{228}Th, and ^{230}Th exhibited differences between the outer sites and the other two groups, which were indistinguishable. Again, the outer sites had significantly higher levels of radioactivity than the other two groups. Measured mean values for ^{40}K, ^{137}Cs, ^{226}Ra, the three thorium isotopes, and the three uranium isotopes were above detection limits, as shown in Table 2-10. The mean values for ^{60}Co, ^{90}Sr, ^{228}Ra, ^{233}U, ^{237}Np, the plutonium isotopes, ^{241}Am, and ^{244}Cm fell below detection limits.

2.4.4.4 Hydrologic Radioactivity

The hydrologic radioactivity monitoring program is designed to establish characteristic radioactivity levels in surface-water bodies, bottom sediments, and groundwater.

2.4.4.4.1 Surface Water and Sediment Background Radiation Levels

Samples of both surface water and groundwater were collected for the RBP. These samples were analyzed for 19 radionuclides (^{3}H, ^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, two isotopes of radium, three isotopes of thorium, four isotopes of uranium, ^{237}Np, and four isotopes of plutonium [^{239}Pu and ^{240}Pu were measured together]). The resulting data from the sampling of surface water and groundwater were analyzed independently.

2.4.4.4.1.1 Surface Water

Samples of surface water were collected from 12 locations over the course of the RBP. Sampling locations were divided into three groups for an initial analysis of geographic variability. Stock tanks represented the largest group, with five locations; they are located closest to WIPP. Stock tanks in this area are typically man-made earthen catchment basins with no surface outflow. The Pecos River represents the next major surface-water group. Four sampling locations were used along the Pecos River, from a northern (upriver) point near the town of Artesia to a southern (downriver) point near the town of Malaga, New Mexico. The third group, called Laguna Grande de la Sal, represents water from a series of playa lakes at the lower end of Nash Draw.

Table 2-10. Ranges of Mean Values Measured for Radioactive Isotopes In Soils at WIPP Site, 5 Miles from WIPP, and beyond 5 Miles from WIPP

	Range of Mean Values[a]	
Isotope	µCi/g	Bq/g
^{40}K	4.9 to 9.3 × 10^{-6}	1.8 to 3.4 × 10^{-1}
^{60}Co	-	0
^{90}Sr	-	0
^{137}Cs	1.3 to 2.2 × 10^{-7}	4.7 to 8.1 × 10^{-3}
^{226}Ra	2.6 to 5.4 × 10^{-7}	9.6 to 20 × 10^{-3}
^{228}Ra	-	[b]
^{228}Th	2.1 to 4.9 × 10^{-7}	7.8 to 18 × 10^{-3}
^{230}Th	2.5 to 52 × 10^{-7}	9.1 to 19 × 10^{-3}
^{232}Th	3.0 × 10^{-7}	1.1 × 10^{-2}
^{233}U	-	[b]
^{234}U	1.5 to 3.3 × 10^{-7}	5.4 to 12 × 10^{-3}
^{235}U	4.4 to 17 × 10^{-9}	1.6 to 6.3 × 10^{-4}
^{238}U	1.6 to 3.0 × 10^{-7}	5.7 to 11 × 10^{-3}
^{237}Np	-	[b]
^{238}Pu	-	[b]
$^{239/240}Pu$	-	[b]
^{241}Pu	-	[b]
^{241}Am	-	[b]
^{244}Cm	-	[b]

Source: Appendix RBP, Table 4-1.

[a] The ranges of mean values are expressed in terms of microcuries per gram of soil and becquerels per gram of soil.
[b] Below minimum detection limit of 3.7 × 10^{-3} becquerels per gram.

The sample mean radioactivity levels for most radionuclides were below their respective detection limits. Peak levels of ^{40}K from Laguna Grande de la Sal were 2.7 × 10^{-5} microcuries per gram (1.0 becquerels per gram), whereas the mean level at all other sampling locations was less than 2.7 × 10^{-7} microcuries per gram (0.01 becquerels per gram). All four isotopes of uranium exhibited significant differences among the three geographic groups. For all four isotopes, radionuclide levels in the tanks were at least one order of magnitude lower than levels found in the Pecos River and Laguna Grande de la Sal. Similar to ^{40}K, levels of uranium were highest in Laguna Grande de la Sal. Only ^{60}Co, ^{137}Cs, ^{228}Ra, ^{234}U, and ^{238}U were found to be above detection limits. (See Appendix RBP, Table 5-1 for details.)

2.4.4.4.1.2 Sediments

Sediments were collected for the WIPP RBP from six locations: Hill Tank, Indian Tank, Noye Tank, Laguna Grande de la Sal, and two sites along the Pecos River. These samples were analyzed for 18 radionuclides (tritium, ^{3}H, was not analyzed in the sediments).

In all five cases where differences were found among location groups, the stock tanks had higher concentrations of radionuclides, possibly indicating an accumulation effect from the closed nature of the tanks. Laguna Grande de la Sal sediments contained significantly higher concentrations of ^{234}U than did the stock tanks and the Pecos River, which were indistinguishable.

2.4.4.4.2 Groundwater Radiological Characterization

Groundwater samples were collected from 37 wells: 23 completed by the DOE in the Culebra, four completed by the DOE in the Magenta, and 10 privately owned in various units. The samples were analyzed for the same 19 radionuclides as the surface-water samples. Elevated levels of ^{40}K were found in the Magenta and private wells, and in the Culebra (2.0×10^{-7} to 5.4×10^{-7} microcuries per gram, or 7.3×10^{-3} to 20×10^{-3} becquerels per gram, respectively). The increased levels of ^{40}K can be attributed to the generally high levels of dissolved solids in groundwater in these formations. Only ^{60}Co, ^{137}Cs, ^{234}U, ^{238}U, and ^{226}Ra, which were found to have a distinct geographic pattern in the Culebra, were found above detection limits, as shown in Table 2-11. Means from individual wells show that levels of ^{226}Ra increase in concentration from west to east. Means of radionuclide concentrations from wells around the WIPP site are shown in Table 2-11.

Groundwater samples were collected in accordance with the EMP (Appendix EMP) and the Groundwater Monitoring Plan (Appendix GWMP) (Westinghouse 1991a). The primary objective of the WQSP is to obtain representative and repeatable groundwater quality data from selected wells under rigorous field and laboratory procedures and protocols. At each well site, the well is pumped and the groundwater serially analyzed for specific field parameters. Once the field parameters have stabilized, denoting a chemical steady-state with respect to these parameters, a final groundwater sample is collected for analysis of radionuclides.

2.4.4.5 Biotic Baseline

This subprogram characterizes background radioactivity levels in key organisms along possible food-chain pathways to man. Vegetation, rabbits, quail, beef, and fish are sampled, and palatable tissues are analyzed for concentrations of transuranics and common naturally occurring radionuclides. Because of the small sample sizes in this program, no attempt has been made to interpret these data. The results are presented in Appendix RBP (Section 7).

Table 2-11. Mean Values Measured for Radionuclides in Water Wells around the WIPP Site

Isotope	Mean Value (10^{-4} becquerels per gram)*
^{3}H	Below <MDL (56)
^{40}K	73 to 200
^{60}Co	12
^{90}Sr	<MDL (7.4)
^{137}Cs	7.2
^{226}Ra	6.9 to 52
^{228}Ra	9.6
^{228}Th	<MDL (3.7)
^{230}Th	<MDL (0.37)
^{232}Th	<MDL (0.37)
^{233}U	<MDL (0.37)
^{234}U	2.6
^{235}U	<MDL (N/S)
^{238}U	0.72
^{237}Np	<MDL (0.37)
^{238}Pu	<MDL (0.11)
$^{239/240}Pu$	<MDL (0.74)
^{241}Pu	<MDL (37)

Source: Appendix RBP, Table 5-4

* Units are becquerels per gram of sample.

Legend:

<MDL Less than the minimum detection level (MDL is shown in parentheses)
N/S MDL not specified

2.5 Climate and Meteorological Conditions

The DOE did not consider climate directly in its site selection process although criteria such as low population density and large tracts of federally owned land tend to favor arid and semi-arid areas in the western United States. The semiarid climate around the WIPP is beneficial since it is a direct cause of the lack of a near surface water table and the minimization of radiation exposure pathways that involve surface or groundwater. Data used to interpret paleoclimates in the American Southwest come from a variety of sources and indicate alternating arid and subarid to subhumid climates throughout the Pleistocene. The information in this section was taken from Swift 1992, included in this application as Appendix CLI, and references therein.

2.5.1 Historic Climatic Conditions

Prior to 18,000 years ago, radiometric dates are relatively scarce, and the record is incomplete. From 18,000 years ago to the present, however, the climatic record is relatively well constrained by floral, faunal, and lacustrine data. These data span the transition from the last full-glacial maximum to the present interglacial period; given the global consistency of glacial fluctuations described below, they can be taken to be broadly representative of extremes for the entire Pleistocene.

Early and middle Pleistocene paleoclimatic data for the southwestern United States are incomplete and permit neither continuous reconstructions of paleoclimates nor direct correlations between climate and glaciation prior to the last glacial maximum, which occurred 22,000 to 18,000 years ago. Stratigraphic and soil data from several locations, however, indicate that cyclical alternation of wetter and drier climates in the Southwest had begun by the Early Pleistocene. Fluvial gravels in the Gatuña exposed in the Pecos River Valley of eastern New Mexico suggest wetter conditions 1.4 million years ago and again 600,000 years ago. The Mescalero caliche, exposed locally over much of southeastern New Mexico, suggests drier conditions 510,000 years ago, and loosely dated spring deposits in Nash Draw west of the WIPP imply wetter conditions occurring again later in the Pleistocene. The Blackwater Draw Formation of the southern High Plains of eastern New Mexico and western Texas, correlating in time to both the Gatuña Formation and the Mescalero caliche, contains alternating soil and eolian sand horizons that show at least six climatic cycles beginning more than 1.4 million years ago and continuing to the present.

Data used to construct the more detailed climatic record for the latest Pleistocene and Holocene come from six independent lines of evidence dated using carbon-14 techniques: plant communities preserved in packrat middens throughout the Southwest, including sites in Eddy and Otero counties, New Mexico; pollen assemblages from lacustrine deposits in western New Mexico and other locations in the Southwest; gastropod assemblages from western Texas; ostracod assemblages from western New Mexico; paleolake levels throughout the Southwest; and faunal remains from caves in southern New Mexico.

Prior to the last glacial maximum 22,000 to 18,000 years ago, evidence from faunal assemblages in caves in southern New Mexico, including the presence of species such as the desert tortoise that are now restricted to warmer climates, suggests hot summers and mild, dry winters. Lacustrine evidence confirms the interpretation of a relatively dry climate prior to and during the glacial advance. Permanent water did not appear in what was later to become a major lake in the Estancia Valley in central New Mexico until some time before 24,000 years ago, and water depths in lakes at higher elevations in the San Agustin Plains in western New Mexico did not reach a maximum until sometime between 22,000 and 19,000 years ago. Ample floral and lacustrine evidence documents cooler, wetter conditions in the Southwest during the glacial peak. These changes were not caused by the immediate proximity of glacial ice. None of the Pleistocene continental glaciations advanced farther southwest than northeastern Kansas, and the most recent, late-Wisconsinan ice sheet reached its limit in

South Dakota, approximately 750 miles (1,200 kilometers) from WIPP. Discontinuous alpine glaciers formed at the highest elevations throughout the Rocky Mountains, but these isolated ice masses were symptoms, rather than causes, of cooler and wetter conditions and had little influence on regional climate at lower elevations. The closest such glacier to WIPP was on the northeast face of Sierra Blanca Peak in the Sacramento Mountains, approximately 135 miles (220 kilometers) to the northwest.

Global climate models indicate that the dominant glacial effect in the Southwest was the disruption and southward displacement of the westerly jet stream by the physical mass of the ice sheet to the north. At the glacial peak, major Pacific storm systems followed the jet stream across New Mexico and the southern Rocky Mountains, and winters were wetter and longer than either at the present or during the previous interglacial period.

Gastropod assemblages at Lubbock Lake in western Texas suggest mean annual temperatures 5 degrees Celsius below present values. Both floral and faunal evidence indicate that annual precipitation throughout the region was 1.6 to 2.0 times greater than today's values. Floral evidence also suggests that winters may have continued to be relatively mild, perhaps because the glacial mass blocked the southward movement of arctic air. Summers at the glacial maximum were cooler and drier than at present, without a strongly developed monsoon.

The jet stream shifted northward following the gradual retreat of the ice sheet after 18,000 years ago, and the climate responded accordingly. By approximately 11,000 years ago, conditions were significantly warmer and drier than previously, although still dominated by winter storms and still wetter than today. Major decreases in total precipitation and the shift toward the modern monsoonal climate did not occur until the ice sheet had retreated into northeastern Canada in the early Holocene.

By middle Holocene time, the climate was similar to that of the present, with hot, monsoon-dominated summers and cold, dry winters. The pattern has persisted to the present, but not without significant local variations. Soil studies show that the southern High Plains were drier from 6,500 to 4,500 years ago than before or since. Gastropod data from Lubbock Lake indicate the driest conditions from 7,000 to 5,000 years ago (precipitation, 0.89 times present values; mean annual temperature, 2.5 degrees Celsius higher than present values), with a cooler and wetter period 1,000 years ago (precipitation, 1.45 times present values; mean annual temperature, 2.5 degrees Celsius lower than present). Plant assemblages from southwestern Arizona suggest steadily decreasing precipitation from the middle Holocene to the present, except for a brief wet period approximately 990 years ago. Stratigraphic work at Lake Cochise (the present Willcox playa in southeast Arizona) shows two mid-Holocene lake stands, one near or before 5,400 years ago and one between or before 3,000 to 4,000 years ago; however, both were relatively short-lived, and neither reached the maximum depths of the Late Pleistocene high stand that existed before 14,000 years ago.

Inferred historical precipitation indicates that during the Holocene, wet periods were relatively drier and shorter in duration than those of the late Pleistocene. Historical records over the last

several hundred years indicate numerous lower-intensity climatic fluctuations, some too short in duration to affect floral and faunal circulation. Sunspot cycles and the related change in the amount of energy emitted by the sun have been linked to historical climatic changes elsewhere in the world, but the validity of the correlation is uncertain. Correlations have also been proposed between volcanic activity and climatic change. In general, however, causes for past short-term changes are unknown.

The climatic record presented here should be interpreted with caution because its resolution and accuracy are limited by the nature of the data used to construct it. Floral and faunal assemblages change gradually and show only a limited response to climatic fluctuations that occur at frequencies that are higher than the typical life span of the organisms in question. For long-lived species such as trees, resolution may be limited to hundreds or even thousands of years. Sedimentation in lakes and playas has the potential to record higher-frequency fluctuations, including single-storm events, but only under a limited range of circumstances. Once water levels reach a spill point, for example, lakes show only a limited response to further increases in precipitation.

With these observations in mind, three significant conclusions can be drawn from the climatic record of the American Southwest. First, maximum precipitation in the past coincided with the maximum advance of the North American ice sheet. Minimum precipitation occurred after the ice sheet had retreated to its present limits. Second, past maximum long-term average precipitation levels were roughly twice the present levels. Minimum levels may have been 90 percent of the present levels. Third, short-term fluctuations in precipitation have occurred during the present relatively dry, interglacial period, but they have not exceeded the upper limits of the glacial maximum.

Too little is known about the relatively short-term behavior of global circulation patterns to accurately predict precipitation levels over the next 10,000 years. The long-term stability of patterns of glaciation and deglaciation, however, do permit the conclusion that future climatic extremes are unlikely to exceed those of the late Pleistocene. Furthermore, the periodicity of glacial events suggests that a return to full-glacial conditions is highly unlikely within the next 10,000 years.

2.5.2 Recent Climatic Conditions

Recent climatic conditions are provided to allow for the assessment of impacts of these factors on the disposal unit and the site. Data are taken from the WIPP environmental monitoring reports (see Westinghouse 1991a, b, 1992, 1993, 1994, 1995 in the Bibliography).

2.5.2.1 General Climatic Conditions

The climate of the region is semiarid, with generally mild temperatures, low precipitation and humidity, and a high evaporation rate. Winds are mostly from the southeast and moderate. In late winter and spring, there are strong west winds and dust storms. During the winter, the

weather is often dominated by a high-pressure system situated in the central portion of the western United States and a low-pressure system located in north-central Mexico. During the summer, the region is affected by a low-pressure system normally situated over Arizona.

2.5.2.2 Temperature Summary

Temperatures are moderate throughout the year, although seasonal changes are distinct. The mean annual temperature in southeastern New Mexico is 63 degrees Fahrenheit. In the winter (December through February), nighttime lows average near 23 degrees Fahrenheit, and maxima average in the 50s. The lowest recorded temperature at the nearest Class-A weather station in Roswell was -29 degrees Fahrenheit in February 1905. In the summer (June through August), the daytime temperature exceeds 90°F approximately 75 percent of the time. The National Weather Service recently documented 122 degrees Fahrenheit at the WIPP site as the record high temperature for New Mexico. This temperature was recorded on June 27, 1994. Table 2-12 shows the annual average, maximum, and minimum temperatures from 1990 through 1994. Temperature data for 1995 are summarized in Appendix SER.

Table 2-12. Annual Average, Maximum, and Minimum Temperatures

	Annual Average Temperature		Maximum Temperature		Minimum Temperature	
Year	**(°C)**	**(°F)**	**(°C)**	**(°F)**	**(°C)**	**(°F)**
1990	17.8	64	46.1	115	-13.9	7
1991	17.2	63	42.8	109	-7.8	18
1992	17.2	63	42.8	109	-10	14
1993	17.8	64	42.8	109	-18.9	-2
1994	17.8	64	50	122	-14.4	6
Average	17.6	63.6	44.9	112.8	-13	8.6

Source: WIPP Annual Site Environmental Report for Calendar Years 1990 through 1994.

2.5.2.3 Precipitation Summary

Precipitation is light and unevenly distributed throughout the year, averaging 13 inches (33 centimeters) per year for the past 5 years. Winter is the season of least precipitation, averaging less than 0.6 inches (1.5 centimeters) of rainfall per month. Snow averages about 5 inches (13 centimeters) per year at the site and seldom remains on the ground for more than a day. Approximately half the annual precipitation comes from frequent thunderstorms in June through September. Rains are usually brief but occasionally intense when moisture from the Gulf of Mexico spreads over the region. Monthly average, maximum, and minimum

precipitations recorded at the WIPP site from 1990 through 1994 are summarized in Figure 2-41. Precipitation data for 1995 are summarized in Appendix SER.

2.5.2.4 Wind Speed and Wind Direction Summary

The frequencies of wind speeds and directions are depicted by windroses in Figures 2-42 through 2-45 for the WIPP site and Figure 2-46 for Carlsbad, New Mexico. In general, the predominant wind direction at the WIPP site is from the southeast, and the predominant wind directions in Carlsbad are from the south, southeast, and west. Wind data for 1995 are summarized in Appendix SER.

2.6 Seismology

The DOE used tectonic activity as a siting criterion. The intent was to avoid tectonic conditions such as faulting and igneous activity that would jeopardize waste isolation over the long term and to avoid areas where earthquake size and frequency could impact facility design and operations. The WIPP site met both aspects of this criterion fully. Long-term tectonic activity is discussed in Section 2.1.5. The favorable results of the seismic (earthquake) studies are discussed here. The purpose of the seismic studies is to build a basis from which to predict ground motions that the WIPP repository may be subjected to in the near and distant future. The concern about seismic effects in the near future, during the operational period, pertains mainly to the design requirements for surface and underground structures for providing containment during seismic events. The concern about effects occurring over the long term, after the repository has been decommissioned and sealed, pertains more to relative motions (faulting) within the repository and possible effects of faulting on the integrity of the salt beds and/or shaft seals.

In this discussion, the magnitudes are reported in terms of the Richter scale, and all intensities are based on the modified Mercalli intensity scale. Most of the magnitudes were determined by the New Mexico Institute of Mining and Technology or are described in Appendix GCR and references therein.

2.6.1 Seismic History

Seismic data are presented in two time frames, before and after the time when seismographic data for the region became available. The earthquake record in southern New Mexico dates back only to 1923, and seismic instruments have been in place in the state since 1961. Various records have been examined to determine the seismic history of the area within 180 miles (288 kilometers) of the site. With the exception of a weak shock in 1926 at Hope, New Mexico (approximately 40 miles [64 kilometers] northwest of Carlsbad), and shocks in 1936 and 1949 felt at Carlsbad, all known shocks in the region before 1961 occurred to the west and southwest of the site more than 100 miles (160 kilometers) away.

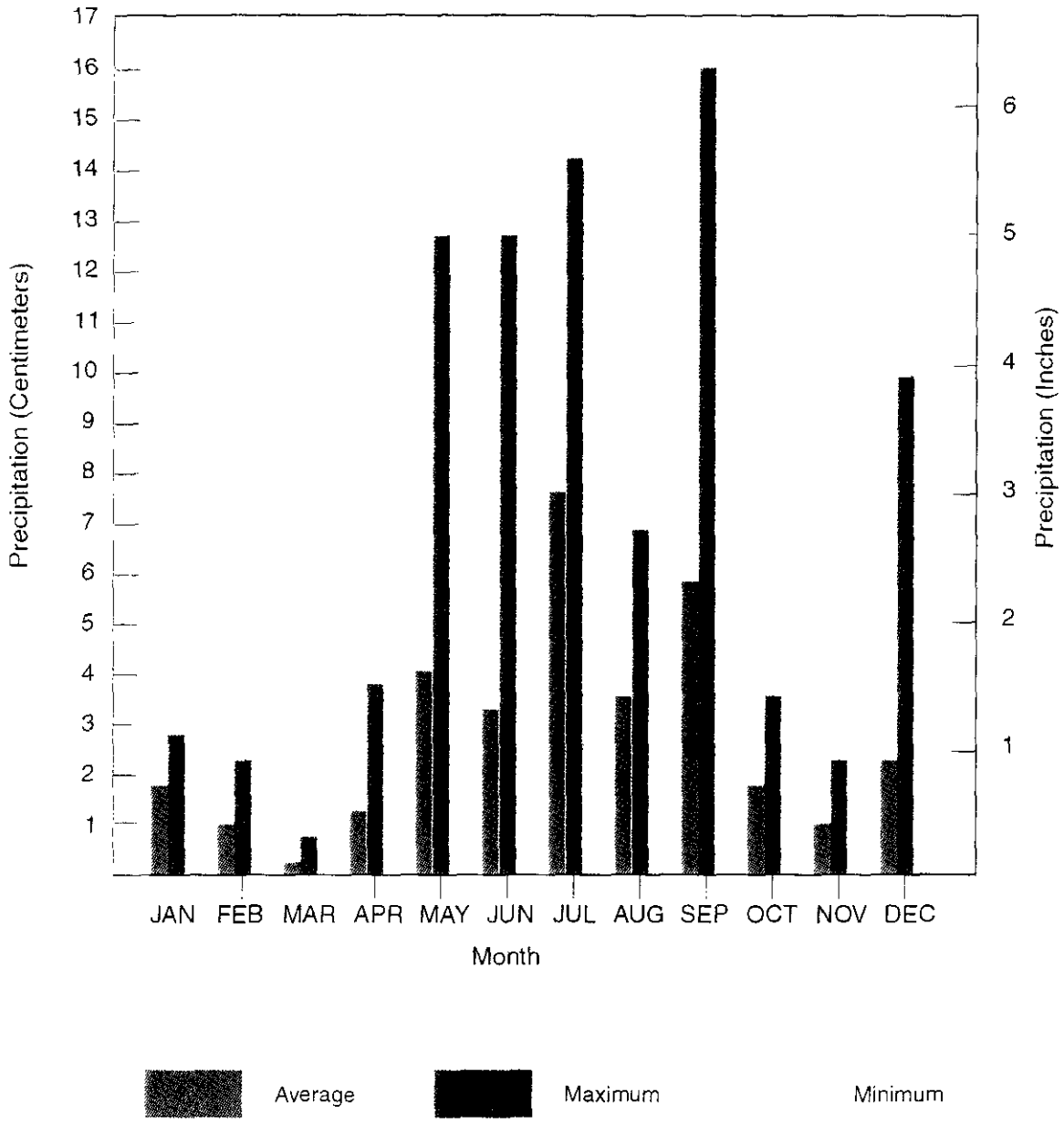

Figure 2-41. Monthly Precipitation for the WIPP Site from 1990 through 1994

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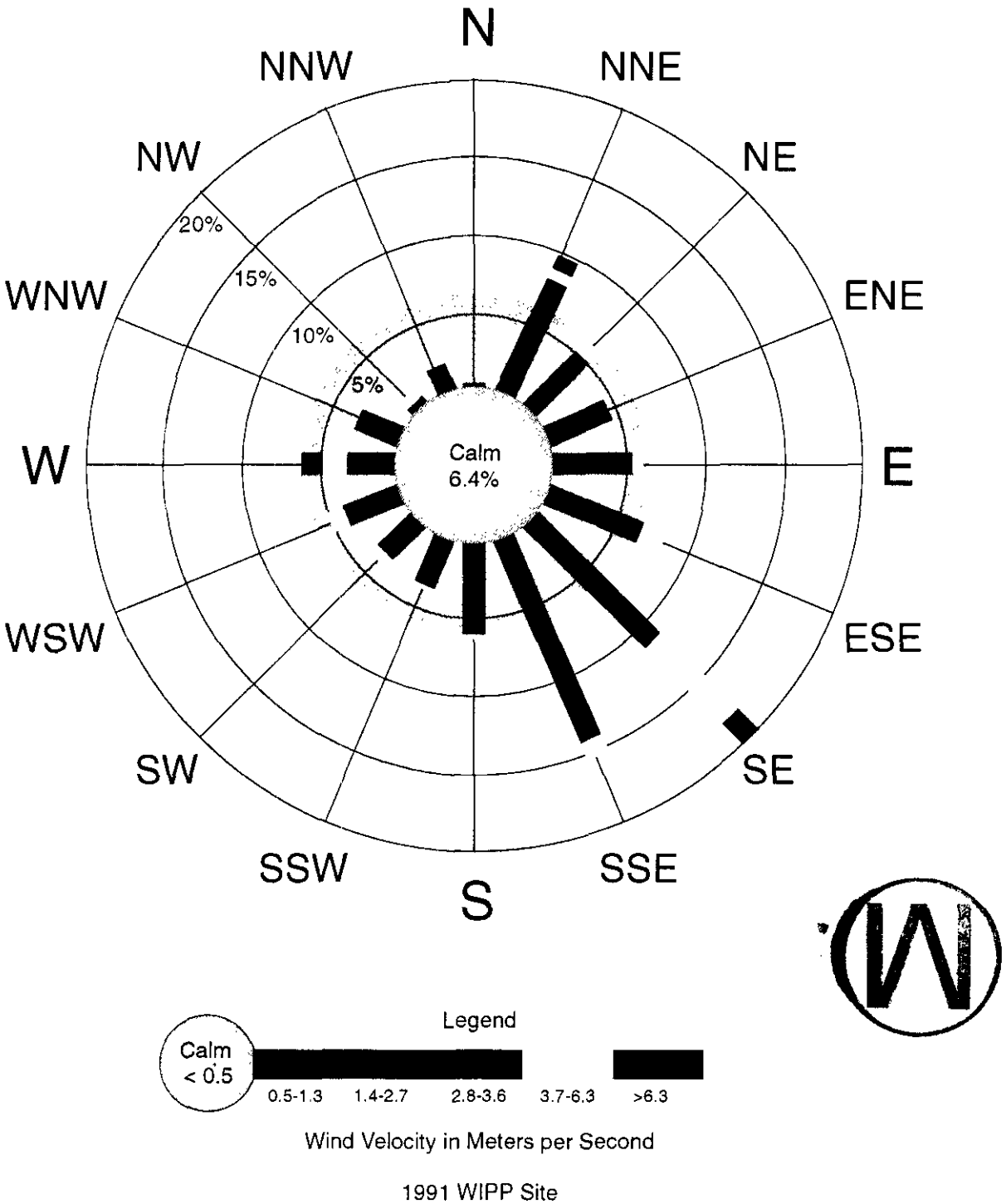

Figure 2-42. 1991 Annual Windrose - WIPP Site

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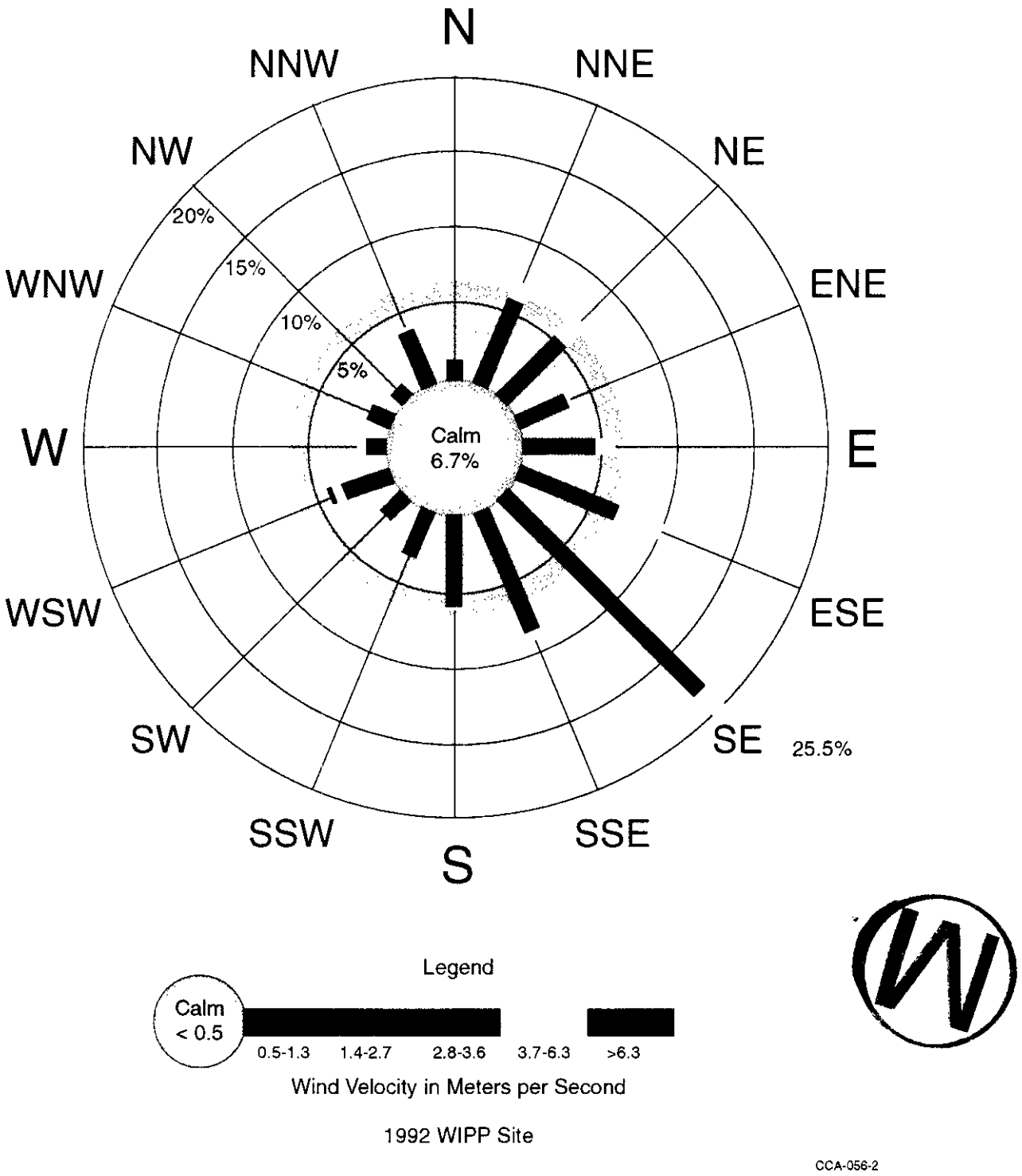

Figure 2-43. 1992 Annual Windrose - WIPP Site

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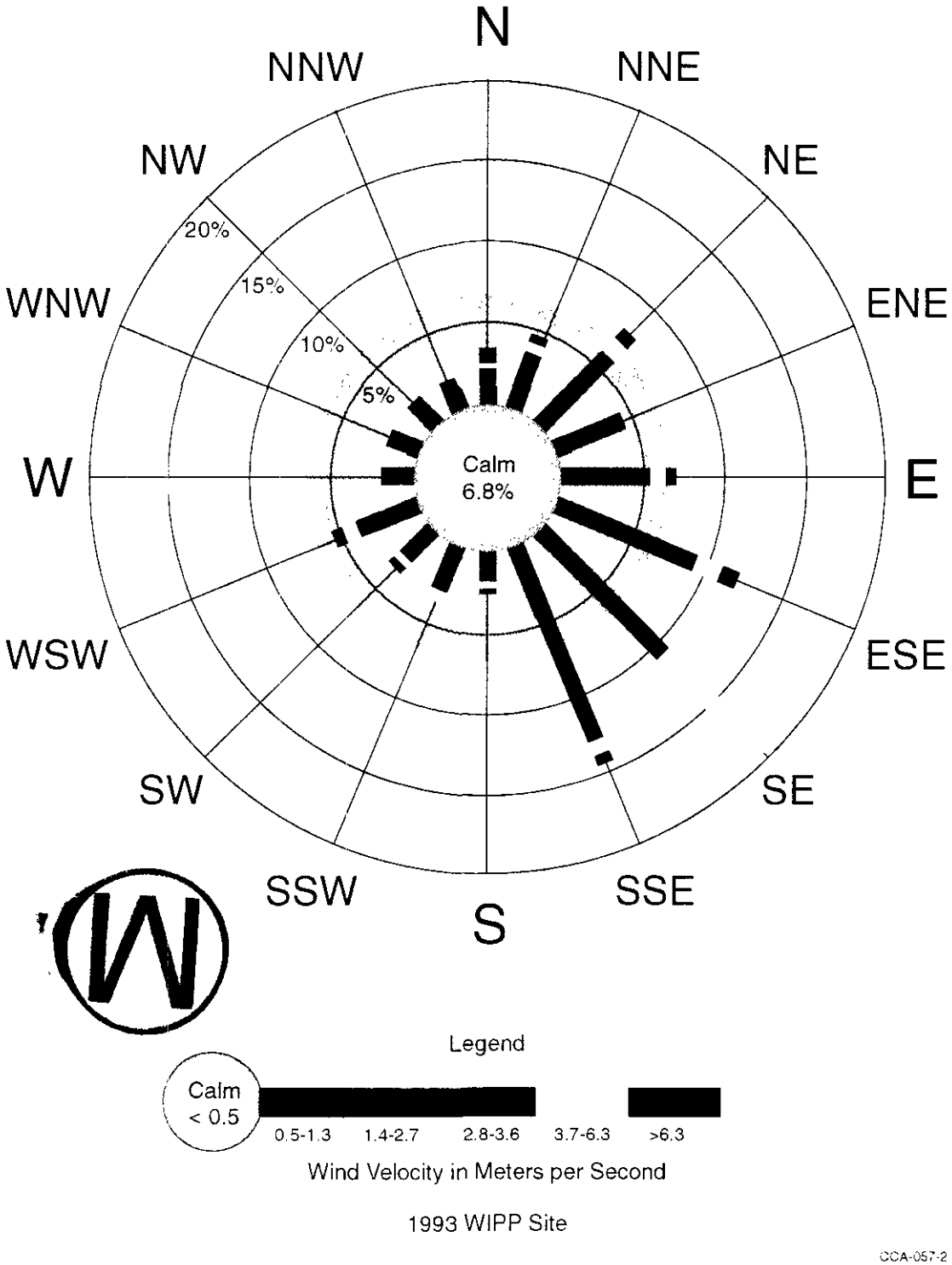

Figure 2-44. 1993 Annual Windrose - WIPP Site

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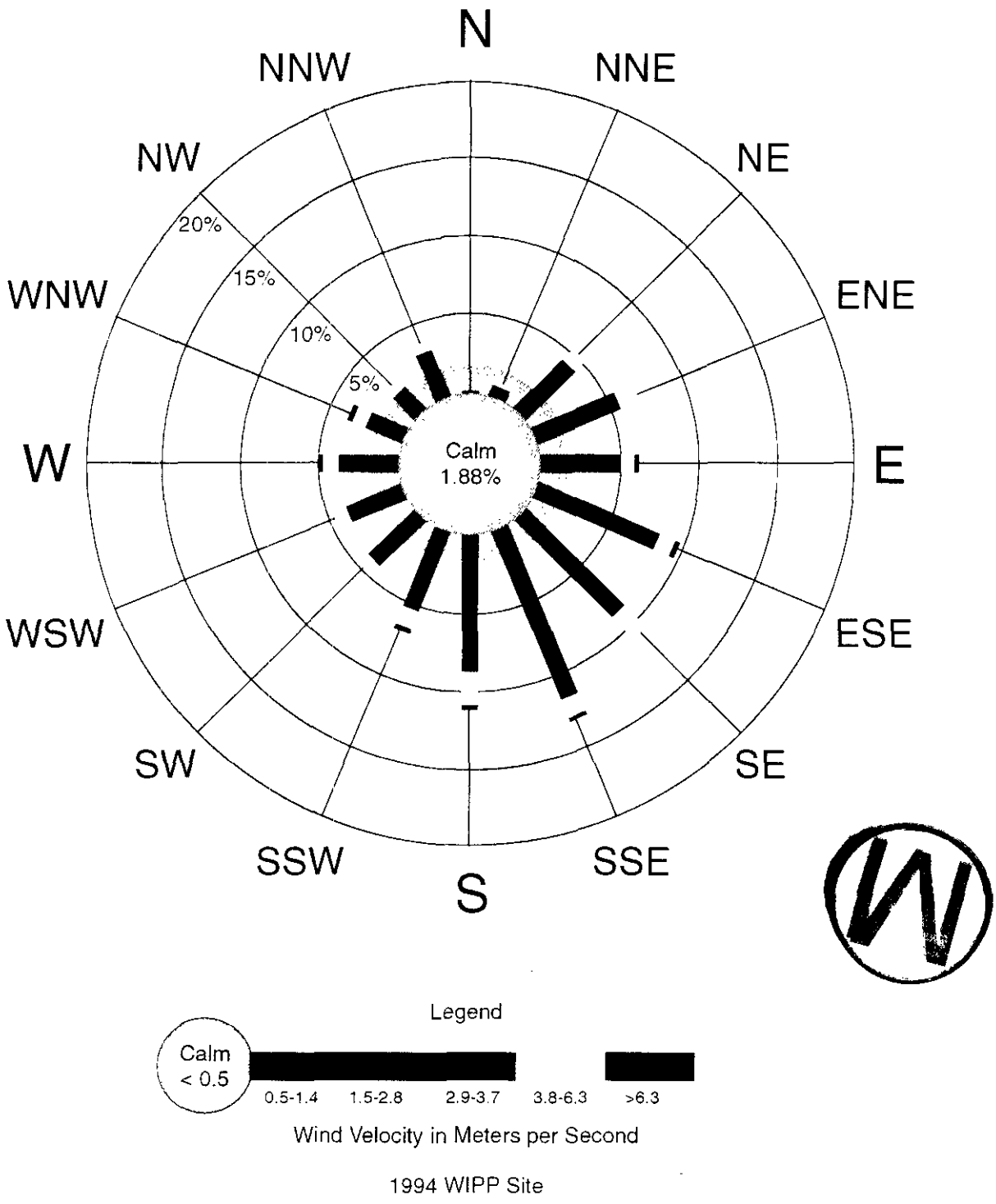

Figure 2-45. 1994 Annual Windrose - WIPP Site

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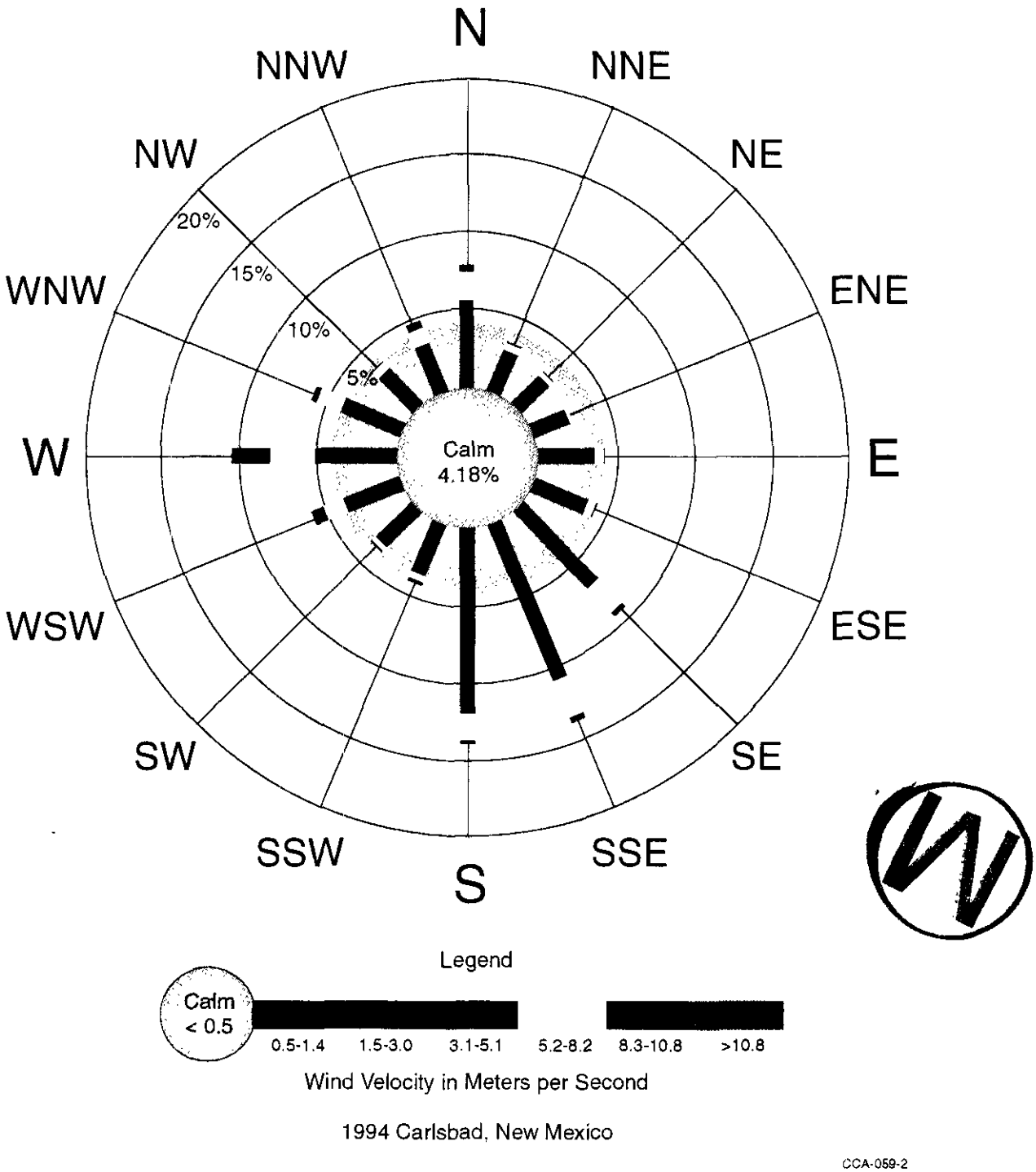

Figure 2-46. 1994 Annual Windrose - Carlsbad, NM

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The strongest earthquake on record occurring within 180 miles (288 kilometers) of the site was the Valentine, Texas, earthquake of August 16, 1931. It has been estimated to have been of magnitude 6.4 on the Richter scale (Modified Mercalli Intensity of VIII). The Valentine earthquake was 130 miles (208 kilometers) south-southwest of the site. Its Modified Mercalli Intensity at the site is estimated to have been V; this is believed to be the highest intensity felt at the site in this century.

In 1887, a major earthquake occurred in northeast Sonora, Mexico. Although about 335 miles (536 kilometers) west-southwest of the site, it is indicative of the size of earthquakes possible in the eastern portion of the Basin and Range Province, west of the province containing the site. Its magnitude was estimated to have been 7.8 (VIII to IX in Modified Mercalli Intensity). It was felt over an area of 0.5 million square miles (1.3 million square kilometers) (as far as Santa Fe to the north and Mexico City to the south); fault displacements near the epicenter were as large as 26 feet (18 meters).

Since 1961, instrumental coverage has become comprehensive enough to locate most of the moderately strong earthquakes (local magnitude >3.5) in the region. Instrumentally determined shocks that occurred within 180 miles (288 kilometers) of the site between 1961 and 1994 are shown in Figure 2-47. The distribution of these earthquakes may be biased by the fact that seismic stations were more numerous and were in operation for longer periods north and west of the site. Pre-1961 earthquakes can be found in Appendix GCR (Figure 5.2-1).

Except for the activity southeast of the site, the distribution of epicenters since 1961 differs little from that of shocks before that time. There are two clusters, one associated with the Rio Grande Rift on the Texas-Chihuahua border and another associated with the Central Basin Platform in Texas near the southeastern corner of New Mexico. The latter activity was not reported before 1964. It is not clear from the record whether earthquakes were occurring in the Central Basin Platform before 1964, although local historical societies and newspapers tend to confirm their absence before that time.

A station operating for 10 months at Fort Stockton, Texas, indicated many small shocks from the Central Basin Platform. Activity was observed at the time the station opened on June 21, 1964. This activity may be related to the underground injection of water for oil recovery. In the Ward–Estes North oilfield, operated by the Gulf Oil Corporation, the cumulative total of water injected up to 1970 was over 1 billion barrels. Accounting for 42 percent of the water injected in Ward and Winkler counties, Texas, the quantity is three times the total injected in all the oil fields of southeastern New Mexico during the same period. The nearest oil fields in the Delaware Basin, where secondary recovery might be attempted in the future, are adjacent to the WIPP site boundary in the Delaware Mountain Group.

The most recent earthquakes to be felt at the WIPP site occurred in January 1992 and April 1995 and are referred to as the Rattlesnake Canyon and Marathon, Texas earthquakes,

respectively. The Rattlesnake earthquake occurred 60 miles (100 kilometers) east-southeast of the WIPP site. The earthquake was assigned a magnitude of 5.0. This event had no effect on any of the structures at the WIPP as documented by post-event inspections by the WIPP staff and the New Mexico Environment Department. This event was within the parameters used to develop the seismic risk assessment of the WIPP facility for the purpose of construction and operation. The Rattlesnake Canyon event likely was tectonic in origin based on the 12 ± 2-kilometer depth.

The April 14, 1995, earthquake near Marathon, Texas, was located 150 miles (240 kilometers) south of the WIPP site. The USGS estimated that moment magnitude for this event was 5.7. At a distance of 149 miles (240 kilometers), an event of magnitude 5.7 would produce a maximum acceleration at the WIPP site of less than 0.01 g.

The Marathon earthquake should not be considered an unanticipated event. The shock occurred in the Basin and Range Province, a seismotectonic province with evidence for 24 Quarternary faults in West Texas and adjacent parts of Mexico. Two of these faults had recent surface-faulting events in the Holocene. Strong earthquakes have occurred within the West Texas part of the Basin and Range Province, most notably the $M_W = 6.4$ (Richter) Valentine, Texas earthquake on August 15, 1931.

The WIPP site is located within the Great Plains seismotectonic province, a region that has no evidence of Quarternary faulting, even above major buried structures such as the Central Basin Platform. Because the Great Plains seismotectonic province is geologically distinct from the Basin and Range Province and lacks evidence for recent faulting, the maximum possible or credible earthquake for this region would be substantially smaller than that for the Basin and Range Province of West Texas.

2.6.2 Seismic Risk

Procedures exist that allow for formal determination of earthquake probabilistic design parameters. In typical seismic risk analyses of this kind, the region of study is divided into seismic source areas within which future events are considered equally likely to occur at any location. For each seismic source area, the rate of occurrence of events above a chosen threshold level is estimated using the observed frequency of historical events. The sizes of successive events in each source are assumed to be independent and exponentially distributed; the slope of the log number versus frequency relationship is estimated from the relative frequency of different sizes of events observed in the historical data. This slope, often termed the b value, is determined either for each seismic source individually or for all sources in the region jointly. Finally, the maximum possible size of events for each source is determined using judgement and the historical record. Thus, all assumptions underlying a measure of earthquake risk derived from this type of analysis are explicit, and a wide range of assumptions may be employed in the analysis procedure.

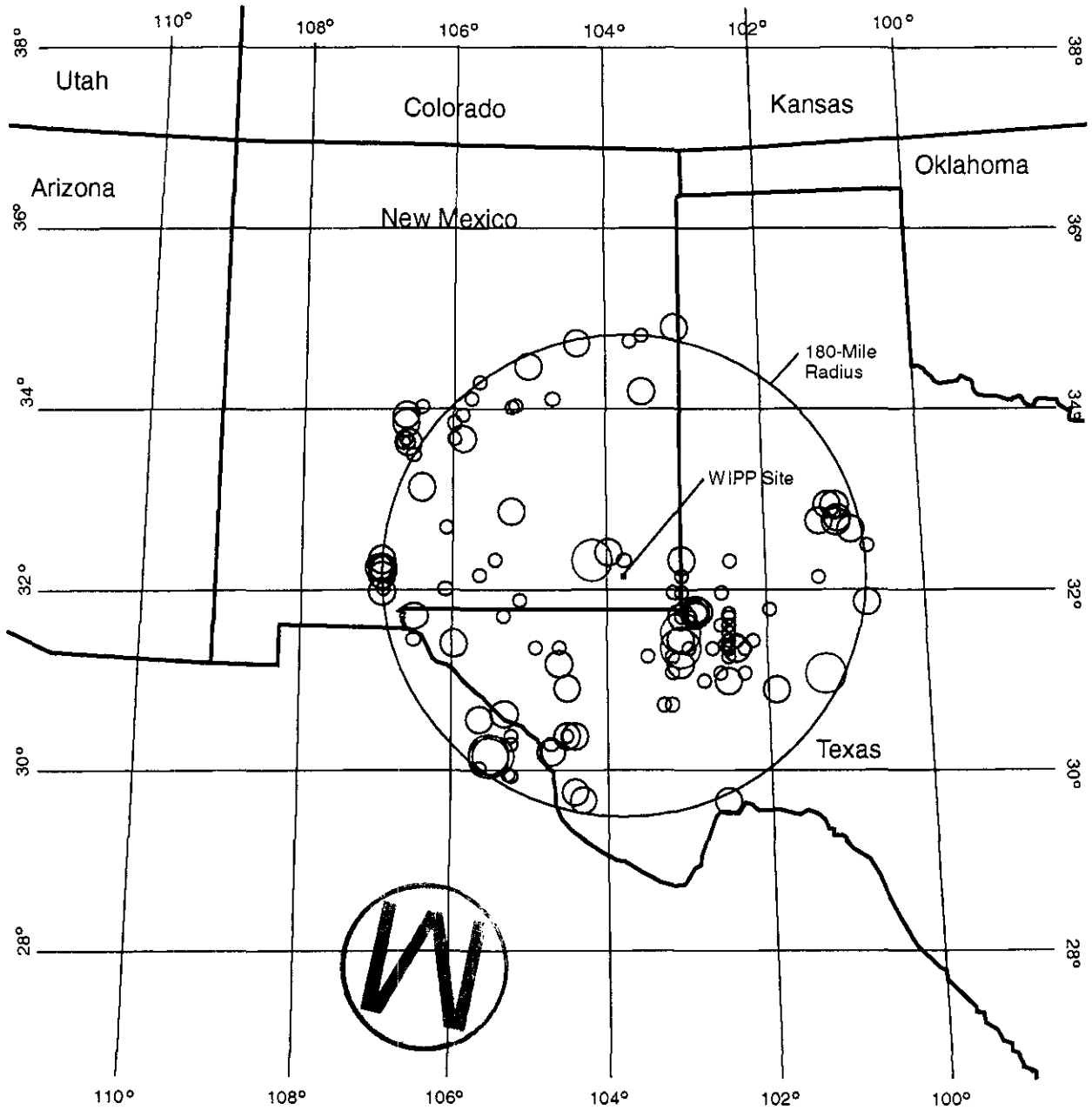

Magnitude
>3.5
2.5-3.5
<2.5

Note: Locations of earthquakes within 180 mi. of the WIPP Site. Epicenters were determined instrumentally and cover the period from 1961 through 1994. For drafting clarity no earthquake with a magnitude less than 2.0 is shown. In areas where crowding occurs some epicenters are slightly offset for drafting convenience.

N

50 0 50 100 Miles
Scale

CCA-060-2

Figure 2-47. Regional Earthquake Epicenters Occurring between 1961 and 1994

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In this section, the particular earthquake risk parameter calculated is peak acceleration expressed as a function of annual probability of being exceeded at the WIPP site. The particular analysis procedure applied to the calculation of this probabilistic peak acceleration is taken from a computer program written by McGuire in 1976. In that program, the seismic source zones are modeled geometrically as quadrilaterals of arbitrary shape. Contributions to site earthquake risk from individual source zones are integrated into the probability distribution of acceleration, and the average annual probability of exceedence then follows directly.

In the analysis, the principal input parameters are as follows: site region acceleration attenuation, source zone geometry, recurrence statistics, and maximum magnitudes. Based on these parameters, several curves showing probabilistic peak acceleration are developed, and the conclusions that may be drawn from these curves are considered. The data treated in this way are used to arrive at a general statement of risk from vibratory ground motion at the site during its active phase of development and use.

2.6.2.1 Acceleration Attenuation

The first input parameters considered have to do with acceleration attenuation in the site region as a function of earthquake magnitude and hypocentral distance. The risk analysis used in this study employs an attenuation law of the form

$$a = b_1 \exp(b_2 M_L) R - b_3 ,$$

where a is acceleration in centimeters per second squared, M_L is Richter local magnitude, and R is the distance in kilometers. The particular formula used in this study is based on a central United States model developed by Nuttli (1973). The formula coefficients $b_1 = 17$, $b_2 = 0.92$, and $b_3 = 1.0$ were selected. A justification for this assumption can be found in Section 5.3.2 of Appendix GCR.

2.6.2.2 Seismic Source Zones

Geologic, tectonic, and seismic evidence indicates that three seismic source zones may be used to adequately characterize the region. These are well approximated by the Basin and Range subregion, the Permian Basin subregion exclusive of the Central Basin Platform, and the Central Basin Platform itself. Specific boundaries are taken from a 1976 study by Algermissen and Perkins of earthquake risks throughout the United States. Additional details on this study are in Appendix GCR (Section 5.3.2).

Site region seismic source zones are shown in Figure 2-48. Superposed on these zones are the earthquake epicenters of Figure 2-47. The zonation presented generally conforms with historical seismicity. The source zonation of Figure 2-48 has no explicit analog to the Permian Basin subregion exclusive of the Central Basin Platform. This is considered part of the broad background region.

For the purposes of this study, some minor modifications of the Algermissen and Perkins source zones were made. Geologic and tectonic evidence suggests that the physiographic boundary between the Basin and Range and Great Plains provinces provides a good and conservative approximation of the source zones (Appendix GCR). In addition, information from the Kermit seismic array (Appendix to Rogers and Malkiel 1979) indicates that the geometry used to model the limits of the Central Basin Platform source zone may be modified somewhat from the original analogous Algermissen and Perkins zone. These modifications are shown in Figure 2-49 and constitute the preferred model for the WIPP site region seismic source zones in this study. This model is preferred because it more completely considers geologic and tectonic information, as well as seismic data, and because it results in a more realistic development of risks at the WIPP facility.

With regard to earthquake focal depth, there is little doubt that the focal depths of earthquakes in the WIPP facility region should be considered shallow. Early instrumental locations were achieved using an arc intersection method employing travel-time-distance curves calculated from a given crustal model, and the assumption of focal depths of 3.1 miles (5 kilometers), 6.2 miles (10 kilometers), or, for later calculations, 5 miles (8 kilometers). Good epicentral locations could generally be obtained under these assumptions. For conservatism, a focal depth of 3.1 miles (5 kilometers) is used in all source zones of this study including that of the site. For smaller hypocentral distances, the form of the attenuation law adopted here severely exaggerates the importance of small, close shocks in the estimation of probabilistic acceleration at the WIPP site. Additional discussion is included in this application in Chapter 5 of Appendix GCR.

2.6.2.3 Source Zone Recurrence Formulas and Maximum Magnitudes

The risk calculation procedure used in this study requires that earthquake recurrence rates for each seismic source zone be specified. This is done formally by computing the constants a and b in the equation

$$\log N = a - bM ,$$

where N is the number of earthquakes of magnitude greater than or equal to M within a specified area occurring during a specified period.

For the WIPP facility region, three formulas of this type are needed: one for the province west and southwest of the site (the Basin and Range subregion or Rio Grande rift source zone), another for the province of the WIPP facility exclusive of the Central Basin Platform (the Permian Basin subregion or background source zone), and a final one for the Central Basin Platform. In practice, the difficulties in finding meaningful recurrence formulas for such small areas in a region of low historical earthquake activity are formidable.

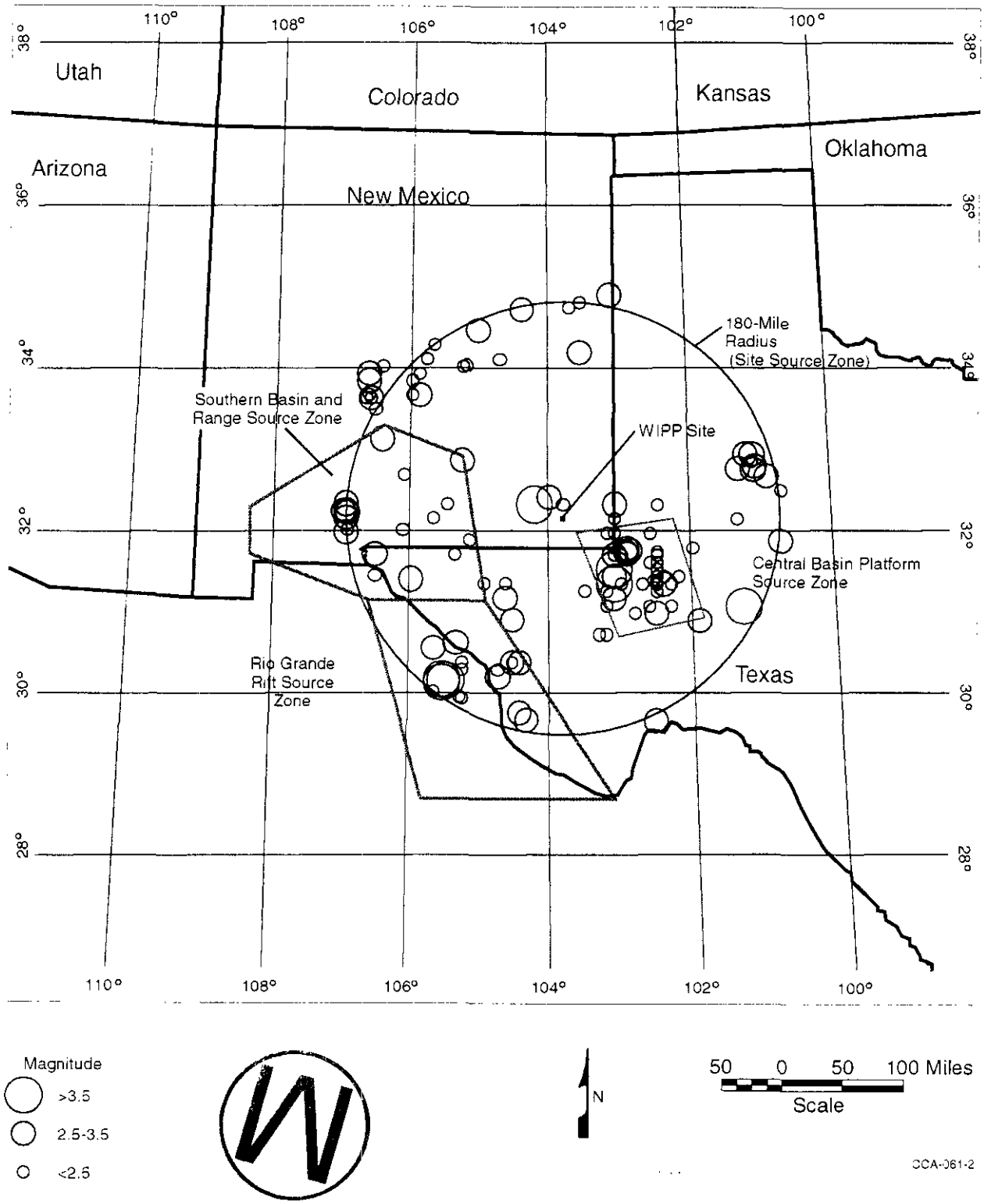

Figure 2-48. Seismic Source Zones

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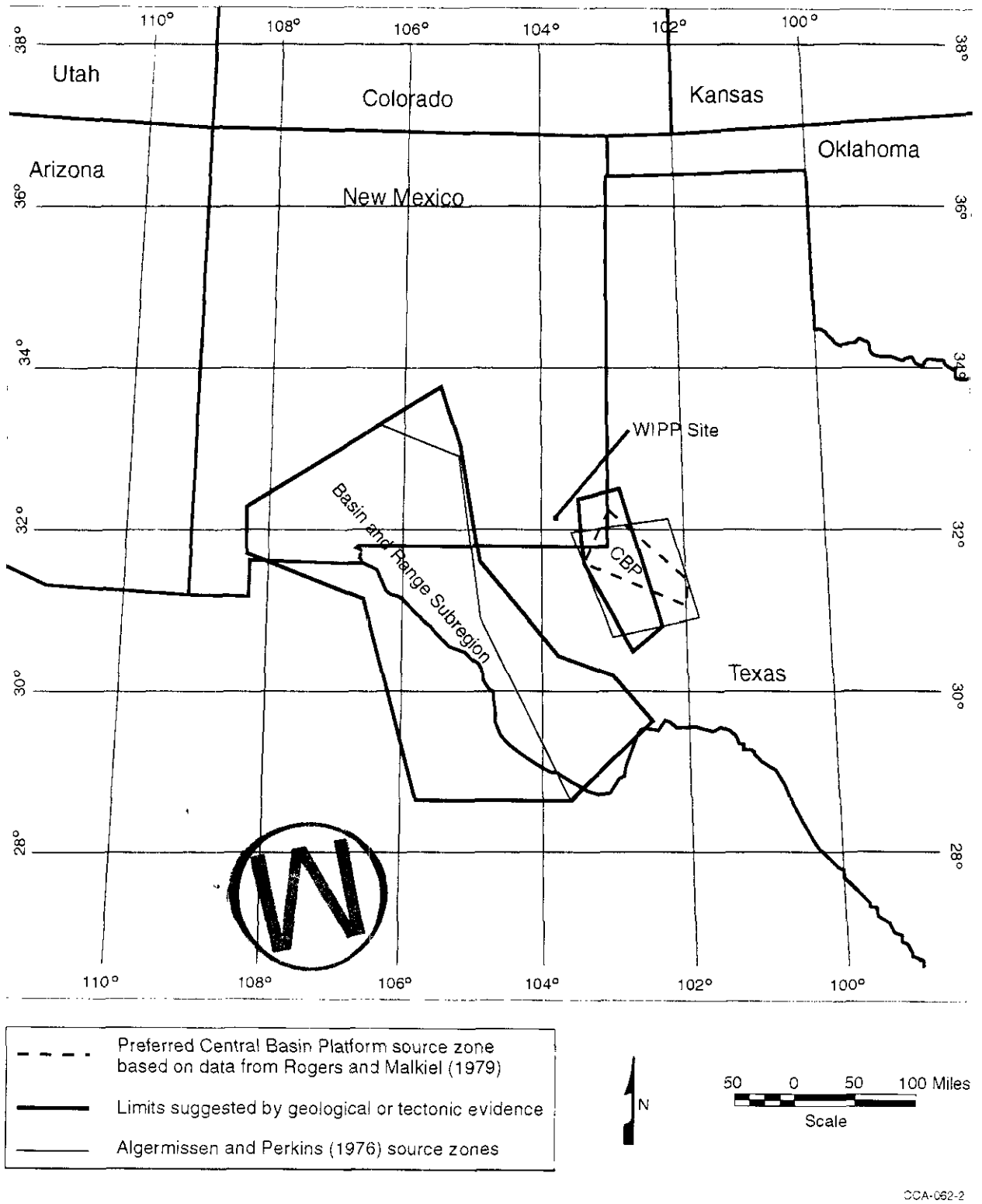

Figure 2-49. Alternate Source Geometries

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The formulas have been determined to be

- $\log N = 2.43 - M_{CORR}$ Site source zone (background)
- $\log N = 3.25 - M_{CORR}$ Basin and Range subregion
- $\log N = 3.19 - 0.9\ M_{CORR}$ Central Basin Platform

The rationale for their development and the relationship used to determine M_{CORR} can be found in Appendix GCR (Section 5.3).

2.6.2.4 Design Basis Earthquake

The term Design Basis Earthquake (DBE) is used for the design of surface confinement structures and components at the WIPP facility. As used here, the DBE is equivalent to the design earthquake used in Regulatory Guide 3.24 (National Regulatory Commission [NRC] 1974). That is, in view of the limited consequences of seismic events in excess of those used as the basis, the DBE is such that it produces ground motion at the WIPP facility with a recurrence interval of 1,000 years. In practice, the DBE is defined in terms of the 1,000-year acceleration and design response spectra.

The generation of curves expressing probability of occurrence or risk as a function of peak WIPP facility ground acceleration is discussed in detail in Appendix GCR (Section 5.3) for a number of possible characterizations of WIPP facility region source zones and source zone earthquake parameters. The most conservative (and the least conservative) risk curves are shown in Figure 2-50.

From this figure, the most conservative calculated estimate of the 1,000-year acceleration at the WIPP facility is approximately 0.075 g.[3] The geologic and seismic assumptions leading to this 1,000-year peak acceleration include the consideration of a Richter magnitude 5.5 earthquake at the site, a 6.0 magnitude earthquake on the Central Basin Platform, and a 7.8 magnitude earthquake in the Basin and Range subregion. These values, especially the first two, are considered quite conservative, as are the other parameters used in the 0.075-g derivation. For additional conservatism, a peak design acceleration of 0.1 g is selected for the WIPP facility DBE. The design response spectra for vertical and horizontal motions are taken from Regulatory Guide 1.60 (NRC 1973) with the high-frequency asymptote scaled to this 0.1-g peak acceleration value.

This DBE and the risk analysis that serves an important role in its definition are directly applicable to surface confinement structures and components at the WIPP facility.

[3] g = acceleration due to gravity.

Underground structures and components are not subject to DBE design requirements because according to Pratt et al. (1979), mine experience and studies on earthquake damage to underground facilities show that tunnels are not damaged at sites having peak surface accelerations below 0.2 g.

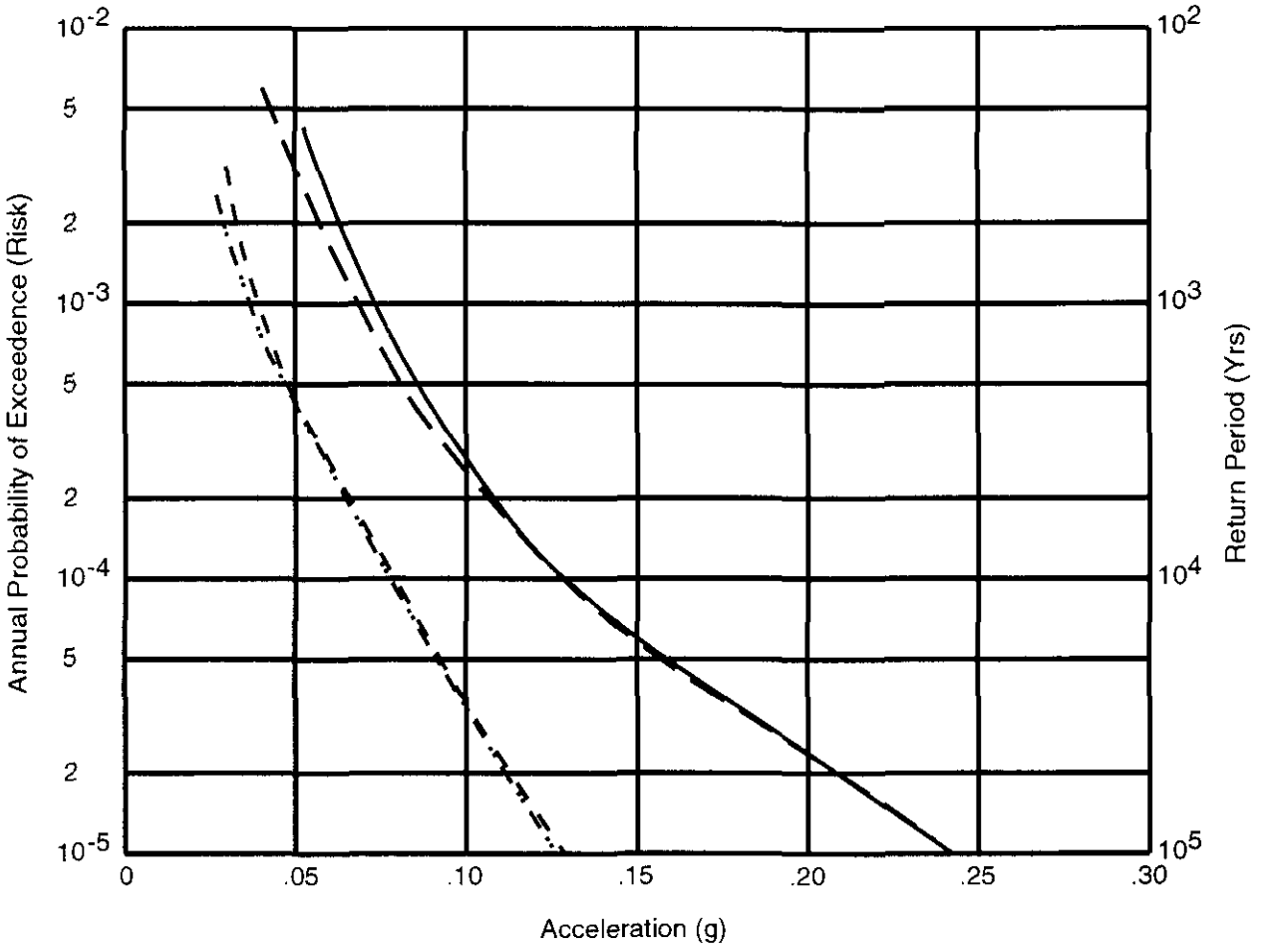

Curve 1	— · · — · · — · ·	Risk from site source zone assuming a maximum magnitude of 4.5.
Curve 2	— — — —	Risk from site and Central Basin Platform source zones assuming maximum magnitudes of 4.5 and 5.0, respectively.
Curve 3	— — —	Risk from the site source zone assuming a maximum magnitude of 5.0.
Curve 4	————	Risk from the site and Central Basin Platform source zones assuming a maximum magnitude of 5.0 for both.

Note: Risk curves generated by using worst and best case assumption from the parameter variation considered for site region source zones. See Appendix GCR, Figure 5.3-7 for further details.

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Figure 2-50. Total WIPP Facility Risk Curve Extrema

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REFERENCES

Adams, J.E. 1944. "Upper Permian Ochoa Series of the Delaware Basin, West Texas and Southeastern New Mexico." *American Association of Petroleum Geologists Bulletin*, Vol. 28, No. 11, 1596-1625. WPO 37940.

Algermissen, S.T., and Perkins, D.M. 1976. *A Probabilistic Estimate of Maximum Ground Acceleration in the Contiguous United States.* Open-file Report 76-416, pp. 1 – 45. U.S. Geological Survey.

Anderson, R.Y. 1978. *Deep Dissolution of Salt, Northern Delaware Basin, New Mexico.* Report to Sandia National Laboratories, Albuquerque, NM. WPO 29527 – WPO 29530.

Anderson, R.Y., and Kirkland, D.W. 1980. Dissolution of Salt Deposits by Brine Density Flow. *Geology*, Vol. 8, No. 2, pp. 66 – 69.

Anderson, R.Y. 1981. "Deep-Seated Salt Dissolution in the Delaware Basin, Texas and New Mexico." In *Environmental Geology and Hydrology in New Mexico,* S.G. Wells and W. Lambert, eds., Special Publication No. 10, pp. 133 – 145. New Mexico Geological Society.

Anderson, R.Y. 1993. "The Castile as a 'Nonmarine' Evaporite." In *Carlsbad Region, New Mexico and Texas, New Mexico Geological Society, Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993*, D.W. Love et al., eds., pp. 12 – 13. New Mexico Geological Society, Socorro, NM.

Anderson, R.Y., Dean, W.E., Jr., Kirkland, D.W., and Snider, H. I. 1972. "Permian Castile Varved Evaporite Sequence, West Texas and New Mexico." *Geological Society of America Bulletin*, Vol. 83, No. 1, pp. 59 – 85.

Anderson, R.Y., and Powers, D.W. 1978. "Salt Anticlines in the Castile-Salado Evaporite Sequence, Northern Delaware Basin, New Mexico." In *Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas*, G.S. Austin, ed., Circular 159. pp. 79 – 83. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Anderson, R.Y., Kietzke, K.K., and Rhodes, D.J. 1978. "Development of Dissolution Breccias, Northern Delaware Basin, New Mexico and Texas." In *Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas*, G.S. Austin, ed., Circular 159. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Bachman, G.O. 1973. *Surficial Features and Late Cenozoic History in Southeastern New Mexico.* Open-File Report 4339-8. U.S. Geological Survey, Reston, VA.

Bachman, G.O. 1974. *Geologic Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico.* Open-File Report 74-194. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1976. "Cenozoic Deposits of Southeastern New Mexico and an Outline of the History of Evaporite Dissolution." *Journal of Research*, Vol. 4, No. 2, pp. 135 – 149. U.S. Geological Survey.

Bachman, G.O. 1980. *Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico.* Open-File Report 80-1099. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1981. *Geology of Nash Draw, Eddy County, New Mexico.* Open-File Report 81-31. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1984. *Regional Geology of Ochoan Evaporites, Northern Part of Delaware Basin.* Circular 184, pp. 1 – 22. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Bachman, G.O. 1985. *Assessment of Near-Surface Dissolution at and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND84-7178. Sandia National Laboratories, Albuquerque, NM. WPO 24609.

Barrows, L.J., Shaffer, S.E., Miller, W.B., and Fett, J.D. 1983. *Waste Isolation Pilot Plant (WIPP) Site Gravity Survey and Interpretation.* SAND82-2922. Sandia National Laboratories, Albuquerque, NM.

Beauheim, R.L., Hassinger, B.W., and Kleiber, J.A. 1983. *Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* WTSD-TME-020. United States Department of Energy, Albuquerque, NM.

Beauheim, R.L. 1986. *Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-1364. Sandia National Laboratories, Albuquerque, NM. WPO 27656.

Beauheim, R.L. 1987a. *Interpretations of Single-Well Hydraulic Tests Conducted at and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983–1987.* SAND87-0039. Sandia National Laboratories, Albuquerque, NM. WPO 27679.

Beauheim, R.L. 1987b. *Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-2311. Sandia National Laboratories, Albuquerque, NM.

Beauheim, R.L. 1987c. *Interpretation of the WIPP-13 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site.* SAND87-2456. Sandia National Laboratories, Albuquerque, NM.

Beauheim, R.L. 1989. *Interpretation of H-14b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site.* SAND89-0536. Sandia National Laboratories, Albuquerque, NM.

Beauheim, R.L., and Holt, R.M. 1990. "Hydrogeology of the WIPP Site." In *Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, Geologic Society of America 1990 Annual Meeting Field Trip #14 Guidebook*, pp. 131 – 179. Dallas Geologic Society, Dallas, TX. WPO 29378.

Beauheim, R.L., Roberts, R.M., Dale, T.F., Fort, M.D., and Stensrud, W.A. 1993. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report.* SAND92-0533. Sandia National Laboratories, Albuquerque, NM. WPO 23378.

Beauheim, R.L., Saulnier, Jr., G.J., and Avis, J.D. 1991. *Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report.* SAND90-0083. Sandia National Laboratories, Albuquerque, NM.

Beauheim, R.L., Meigs, L.C., Saulnier, G.J., and Stensrud, W.A. 1995. *Culebra Transport Program Test Plan: Tracer Testing of the Culebra Dolomite Member of the Rustler Formation at the H-19 and H-11 Hydropads on the WIPP Site.* On file in the Sandia WIPP Central Files.

Blackwell, D.D., Steele, J.L., and Carter, L.S. 1991. "Heat-Flow Patterns of the North American Continent; A Discussion of the Geothermal Map of North America." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 423 – 436. Geological Society of America, Boulder, CO.

Bodine, Jr., M.W. 1978. "Clay-Mineral Assemblages from Drill Core of Ochoan Evaporites, Eddy County, New Mexico." In *Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas*, G.S. Austin, ed., Circular 159. pp. 21 – 31. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Borns, D.J. 1987. *The Geologic Structures Observed in Drillhole DOE-2 and Their Possible Origins: Waste Isolation Pilot Plant.* SAND86-1495. Sandia National Laboratories, Albuquerque, NM.

Borns, D.J., Barrows, L.J., Powers, D.W., and Snyder, R.P. 1983. *Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site.* SAND82-1069. Sandia National Laboratories, Albuquerque, NM. WPO 27532.

Borns, D.J. 1985. *Marker Bed 139: A study of Drillcore from a Systematic Array.* SAND85-0023. Sandia National Laboratories, Albuquerque, NM. WPO 24529.

Borns, D.J., and Shaffer, S.E. 1985. *Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin.* SAND83-1798. Sandia National Laboratories, Albuquerque, NM. WPO 24511.

Brausch, L.M., Kuhn, A.K., and Register, J.K. 1982. *Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME 3156. Albuquerque, NM: U.S. Department of Energy, Waste Isolation Pilot Plant. WPO 39094.

Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hays, W.H. 1972. *Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico.* Open-File Report 4339-1. U.S. Geological Survey, Denver, CO.

Brookins, D.G. 1980. "Polyhalite K-Ar Radiometric Ages from Southeastern New Mexico." In *Isochron/West*, No. 29, pp. 29 – 31.

Brookins, D.G. 1981. "Geochronologic Studies Near the WIPP Site, Southeastern New Mexico." In *Environmental Geology and Hydrology in New Mexico*, S.G. Wells, and W. Lambert, ed., Special Publication 10, pp. 147 – 152. New Mexico Geological Society.

Brookins, D.G., and Lambert, S.J. 1987. "Radiometric Dating of Ochoan (Permian) Evaporites, WIPP Site, Delaware Basin, New Mexico, USA." *Scientific Basis for Nuclear Waste Management X, Materials Research Society Symposia Proceedings, Boston, MA, December 1-4, 1986*, J.K. Bates and W.B. Seefeldt, eds., Vol. 84, pp. 771 – 780, Materials Research Society, Pittsburgh, PA.

Brookins, D.G., Register, J.K, Jr., and Krueger, H.W. 1980. "Potassium-Argon Dating of Polyhalite in New Mexico." *Geochimica et Cosmochimica Acta*, Vol. 44, No. 5, pp. 635 – 637.

Calzia, J.P., and Hiss, W.L. 1978. "Igneous Rocks in Northern Delaware Basin, New Mexico, and Texas." In *Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas*, G.S. Austin, ed., Circular 159, pp. 39 – 45. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Cartwright, Jr., L.D. 1930. Transverse Section of Permian Basin, West Texas and Southeastern New Mexico. *American Association of Petroleum Geologists Bulletin*, Vol. 14.

Casas, E., and Lowenstein, T.K. 1989. Diagenesis of Saline Pan Halite: Comparison of Petrographic Features of Modern, Quaternary and Permian Halites. *Journal of Sedimentary Petrology*, Vol. 59.

Chugg, J.C., Anderson, G.W., Kink, D.L., and Jones, L.H. 1971. *Soil Survey of Eddy Area, New Mexico.* Prepared by the U.S. Soil Conservation Service in cooperation with New Mexico Agricultural Experiment Station. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

Claiborne, H.C., and Gera, F. 1974. *Potential Containment Failure Mechanisms and Their Consequences at a Radioactive Waste Repository in Bedded Salt in New Mexico.* ORNL-TM 4639. Oak Ridge National Laboratories, Oak Ridge, TN.

Corbet, T.F. and Knupp, P.M. 1996. *The Role of Regional Groundwater Flow in the Hydrogeology of the Culebra Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND96-2133. Sandia National Laboratories: Albuquerque, NM.

Davies, P.B. 1984. "Deep-Seated Dissolution and Subsidence in Bedded Salt Deposits." Ph.D. Thesis. Stanford University, Palo Alto, CA.

Davies, P.B. 1989. *Variable-Density Ground-Water Flow and Paleohydrology in the Waste Isolation Pilot Plant (WIPP) Region, Southeastern New Mexico.* Open-File Report 88-490. U.S. Geological Survey, Albuquerque, NM. WPO 38854.

Deal, D.E., and Case, J.B. 1987. *Brine Sampling and Evaluation Program Phase I Report.* DOE-WIPP 87-008. Westinghouse Electric Corporation, Carlsbad, NM.

Deal, D.E., Case, J.B., Deshler, R.M., Drez, P.E., Myers, J., and Tyburski, J.R. 1987. *Brine Sampling and Evaluation Program Phase II Report.* DOE-WIPP-87-010. Westinghouse Electric Corporation, Carlsbad, NM.

Deal, D.E., Abitz, R.J., Belski, D.S., Case, J.B., Crawley, M.E., Deshler, R.M., Drez, P.E., Givens, C.A., King, R.B., Lauctes, B.A., Myers, J., Niou, S., Pietz, J.M., Roggenthen, W.M., Tyburski, J.R., and Wallace, M.G. 1989. *Brine Sampling and Evaluation Program, 1988 Report.* DOE-WIPP-89-015. Carlsbad, NM: Westinghouse Electric Corporation.

Deal, D.E., Abitz, R.J., Belski, D.S., Clark, J.B., Crawley, M.E., and Martin, M.L. 1991a. *Brine Sampling and Evaluation Program, 1989 Report.* DOE-WIPP-91-009. Carlsbad, NM: Westinghouse Electric Corporation.

Deal, D.E., Abitz, R.J., Myers, J. Case, J.B., Martin, M.L., Roggenthen, W.M., and Belski, D.S. 1991b. *Brine Sampling and Evaluation Program, 1990 Report.* DOE-WIPP-91-036. Prepared for U.S. Department of Energy by IT Corporation and Westinghouse Electric Corporation. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026, Vols. 1 and 2. Office of Environmental Restoration and Waste Management, Washington, D.C.

Deal, D.E., Abitz, R.J., Myers, J., Martin, M.L., Milligan, D.J., Sobocinski, R.W., Lipponer, P.P.J., and Belski, D.S. 1993. *Brine Sampling and Evaluation Program, 1991 Report.* DOE-WIPP-93-026. Carlsbad, NM: Westinghouse Electric Corporation.

DOE (U.S. Department of Energy). 1995. *Brine Sampling and Evaluation Program, 1992 - 1993 Report and Summary of BSEP Data Since 1982.* DOE-WIPP-94-011. Carlsbad, NM: Westinghouse Electric Corporation.

Domski, P.S., Upton, D.T., and Beauheim, R.L. 1996. *Hydraulic Testing Around Room Q: Evaluation of the Effects of Mining on the Hydraulic Properties of Salado Evaporites.* SAND96-0435. Sandia National Laboratories, Albuquerque, NM. WPO 37380.

Eager, G.P. 1983. Core from the Lower Dewey Lake, Rustler, and Upper Salado Formation, Culberson County, Texas. In *Permian Basin Cores*, R.L. Shaw and B.J. Pollen, eds., P.B.S.-S.E.P.M. Core Workshop No. 2, pp. 273–283. Permian Basin Section, Society of Economic Paleontologists and Mineralogists, Midland, TX.

Earth Technology Corporation. 1988. *Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site.* SAND87-7144. Albuquerque, NM: Sandia National Laboratories.

Elliot Geophysical Company. 1976. *A Preliminary Geophysical Study of a Trachyte Dike in Close Proximity to the Proposed Los Medaños Nuclear Waste Disposal Site, Eddy and Lea Counties, New Mexico.* Elliot Geophysical Company, Tucson, AZ.

EPA (U.S. Environmental Protection Agency). 1988. "40 CFR Parts 124, 144, 146, and 148 Underground Insertion Control Program: Hazardous Waste Disposal Injection Restrictions; Amendments to Technical Requirements for Class 1 Hazardous Waste Injection Wells, and Additional Monitoring Requirements Applicable to All Class 1 Wells." *Federal Register*, Vol. 53, 28188, July 26, 1988.

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. *Federal Register*, Vol. 58, No. 242, pp. 66398 – 66416, December 20, 1993. Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

EPA (U.S. Environmental Protection Agency). 1996. *40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. Federal Register*, Vol. 61, No. 28,

pp. 5224 – 5245, February 9, 1996. Office of Air and Radiation, Washington, D.C. In NWM Library as KF70.A35.C751. 1996 (Reference).

Foster, R.W. 1974. *Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste.* BNL/SUB-44231/1. Ridge National Laboratory, Oak Ridge, TN. Available fro NTIS. NTIS Accession number: ORNL/SUB-4423-1.

Hale, W.E., Hughes, L.S., and Cox, E.R. 1954. *Possible Improvement of Quality of Water of the Pecos River by Diversion of Brine at Malaga Bend, Eddy County, NM.* Pecos River Commission New Mexico and Texas, in cooperation with United States Department of the Interior, Geological Survey, Water Resources Division, Carlsbad, NM.

Hawley, J.W. 1993. "The Ogallala and Gatuña Formations in the Southeastern New Mexico Region, a Progress Report." In *Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society, Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993*, D.W. Love et al., eds., pp. 261 – 269. New Mexico Geological Society, Socorro, NM.

Hayes, P.T., and Bachman, G.O. 1979. *Examination and Reevaluation of Evidence for the Barrera Fault, Guadalupe Mountains, New Mexico.* Open-File Report 79-1520. U.S. Geological Survey, Denver, CO.

Hills, J.M. 1984. Sedimentation, Tectonism, and Hydrocarbon Generation in Delaware Basin, West Texas and Southeastern New Mexico. *American Association of Petroleum Geologists Bulletin*, Vol. 68.

Hiss, W.L. 1975. "Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas." PhD dissertation. University of Colorado, Department of Geological Sciences, Boulder, CO.

Hiss, W.L. 1976. *Structure of the Premium Guadalupian Capitan Aquifer, Southeast New Mexico and West Texas.* Resource Map. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Holt, R.M., and Powers, D.W. 1984. *Geotechnical Activities in the Waste Handling Shaft Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico.* WTSD-TME-038. U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1986. *Geotechnical Activities in the Exhaust Shaft.* DOE-WIPP-86-008. U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP 88-004. U.S. Department of Energy, Carlsbad, NM. (This document is included as Appendix GCR.)

Holt, R.M., and Powers, D.W. 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant.* DOE/WIPP 90-051. U.S. Department of Energy, Carlsbad, NM.

Howard, K.A., Aaron, J.M., Brabb, E.E., Brock, M.R., Gower, H.D., Hunt, S.J., Milton, D.J., Muehlberger, W.R., Nakata, J.K., Plafker, G., Prowell, D.C., Wallace, R.E., and Witkind, I.J. 1971 [reprinted 1991]. *Preliminary Map of Young Faults in the United States as a Guide to Possible Fault Activity.* Miscellaneous Field Studies Map MF-916, 1:5,000,000. 4 maps on 2 sheets. U.S. Geological Survey, Denver, CO.

Hunter, R.L. 1985. *A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area.* SAND84-2233. Sandia National Laboratories, Albuquerque, NM.

Izett, G.A., and Wilcox, R.E. 1982. *Map Showing Localities and Inferred Distribution of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds in the Western United States and Southern Canada.* Misc. Investigations Map I-1325, scale 1:4,000,000. U.S. Geological Survey.

Jarolimek, L., Timmer, M.J., and McKinney, R.F. 1983. *Geotechnical Activities in the Exploratory Shaft—Selection of the Facility Interval, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME 3178. U.S. Department of Energy, Albuquerque, NM.

Jones, C.L., Bowles, C.G., and Bell, K.G. 1960. *Experimental Drillhole Logging in Potash Deposits of the Carlsbad District, New Mexico.* Open-File Report. U.S. Geological Survey, Denver, CO.

Jones, C.L., Cooley, M.E., and Bachman, G.O. 1973. *Salt Deposits of Los Medaños Area, Eddy and Lea Counties, New Mexico.* Open-File Report 4339-7. U.S. Geological Survey, Denver, CO.

Jones, C.L. 1978. *Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico.* Open-File Report 78-592. Vols. 1 and 2. U.S. Geological Survey, Denver, CO.

Jones, C.L. 1981. *Geologic Data for Borehole ERDA-6, Eddy County, New Mexico.* Open-File Report 81-468. U.S. Geological Survey, Denver, CO.

Jones, T.L., Kelley, V.A., Pickens, J.T., Upton, D.T., Beauheim, R.L., and Davies, P.B. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site.* SAND92-1579. Sandia National Laboratories, Albuquerque, NM.

Keesey, J. J. 1976. *Hydrocarbon Evaluation, Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico.* SAND71-7033. Vols. I and II. Sipes, Williamson, and Aycock, Midland, TX.

Kelley, V.A. 1971. *Geology of the Pecos Country, Southeastern New Mexico.* Memoir 24. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Kelley, V.A., and Saulnier, Jr., G.J. 1990. *Core Analyses for Selected Samples from the Culebra Dolomite at the Waste Isolation Pilot Plant Site.* SAND90-7011. Sandia National Laboratories, Albuquerque, NM.

King, P.B. 1948. *Geology of the Southern Guadalupe Mountains, Texas.* Professional Paper 215. U.S. Geological Survey, Washington, D.C.

Kloska, M.B., Saulnier, Jr., G.J., and Beauheim, R.L. 1995. *Culebra Transport Program Test Plan: Hydraulic Characterization of the Culebra Dolomite Member of the Rustler Formation at the H-19 Hydropad on the WIPP Site.* On file in the Sandia WIPP Central Files.

Lambert, S.J. 1983a. *Dissolution of Evaporites in and around the Delaware Basin, Southeastern New Mexico and West Texas.* SAND82-0461. Sandia National Laboratories, Albuquerque, NM.

Lambert, S.J. 1983b. "Evaporite Dissolution Relevant to the WIPP Site, Northern Delaware Basin, Southeastern New Mexico." In *Scientific Basis for Nuclear Waste Management VI, Materials Research Society Symposia Proceedings, Boston, MA, November 1-4, 1982,* SAND82-1416C. D.G. Brookins, ed., pp. 291 – 298. Elsevier Science Publishing Company, New York, NY.

Lambert, S.J. 1987. *Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and other Nuclides to the Groundwater Hydrology of the Rustler Formation, Southeastern New Mexico.* SAND86-1054. Sandia National Laboratories, Albuquerque, NM.

Lambert, S.J., and Carter, J.A. 1987. *Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico. I. Principles and Preliminary Results.* SAND87-0388. Sandia National Laboratories, Albuquerque, NM.

Lambert, S.J., and Harvey, D.M. 1987. *Stable-Isotope Geochemistry of Groundwaters in the Delaware Basin of Southeastern New Mexico.* SAND87-0138. Sandia National Laboratories, Albuquerque, NM.

Lang, W.B. 1939. Salado Formation of the Permian Basin. *American Association of Petroleum Geologists Bulletin,* Vol. 23, pp. 1569 – 1572.

Lang, W.B. 1942. Basal Beds of Salado Formation in Fletcher Potash Core Test near Carlsbad, New Mexico. *American Association of Petroleum Geologists Bulletin*, Vol. 26.

LaVenue, A.M., Haug, A., and Kelley, V.A. 1988. *Numerical Simulation of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Second Interim Report.* SAND88-7002. Sandia National Laboratories, Albuquerque, NM. WPO 28558.

Lord, K.J., and Reynolds, W.E., eds. 1985. *Archaeological Investigations of Three Sites within the WIPP Core Area.* Prepared for the U.S. Army Corps of Engineers (COE), Albuquerque District in NM. Eddy County, NM, Chambers Consultants and Planner, Albuquerque, NM.

Lowenstein, T.K. 1987. *Post Burial Alternation of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico: Textural Stratigraphic and Chemical Evidence.* EEG-36, New Mexico Health and Environment Department, Santa Fe, New Mexico.

Lowenstein, T.K. 1988. "Origin of Depositional Cycles in a Permian Saline Giant: The Salado (McNutt Zone) Evaporites of New Mexico and Texas." *Geological Society of America Bulletin*, Vol. 100, No. 4, pp. 20 – 21, 592 – 608.

Lucas, S.G., and Anderson, O.J. 1993a. "Triassic Stratigraphy in Southeastern New Mexico and Southwestern Texas." In *Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society, Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993.* D.W. Love et al., eds., pp. 231 – 235. New Mexico Geological Society, Socorro, NM.

Lucas, S.G., and Anderson, O.J. 1993b. "Stratigraphy of the Permian-Triassic Boundary in Southeastern New Mexico and West Texas." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

Machette, M.N. 1985. "Calcic Soils of the Southwestern United States." In *Soils and Quaternary Geology of the Southwestern United States*, D.L. Weide and M.L. Faber, eds., Special Paper Vol. 203, pp. 1 – 21. Geological Society of America, Denver, CO.

Madsen, B.M., and Raup, O.B. 1988. Characteristics of the Boundary between the Castile and Salado Formations near the Western Edge of the Delaware Basin, Southeastern New Mexico. *New Mexico Geology*, Vol. 10, No. 1.

McGowen, J.H., and Groat, C.G. 1971. *Van Horn Sandstone, West Texas: An Alluvial Fan Model for Mineral Exploration.* Report of Investigations No. 72. Bureau of Economic Geology, Austin, TX.

McGuire, R.K. 1976. *FORTRAN Computer Program for Seismic Risk Analysis.* Open-File Report No. 76-67, pp. 1 – 68. U.S. Geological Survey.

Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area, Southeastern New Mexico.* Water Resources Investigation Report 83-4016. U.S. Geological Survey, Albuquerque, NM. (This document is included as Appendix HYDRO.)

Mercer, J.W., Beauheim, R.L., Snyder, R.P., and Fairer, G.M. 1987. *Basic Data Report for Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-0611. Sandia National Laboratories, Albuquerque, NM. WPO 27646.

Miller, D.N. 1955. *Petrology of the Pierce Canyon Formation, Delaware Basin, Texas and New Mexico* [Ph.D. Dissertation]. University of Texas, Austin.

Miller, D.N. 1966. Petrology of Pierce Canyon Redbeds, Delaware Basin, Texas and New Mexico. *American Association of Petroleum Geologists Bulletin*, Vol. 80.

Muehlberger, W.R., Belcher, R.C., and Goetz, L.K. 1978. Quaternary Faulting on Trans-Pecos, Texas. *Geology*, Vol. 6, No. 6, pp. 337 – 340.

Nicholson, Jr., A., and Clebsch, Jr., A. 1961. *Geology and Ground-Water Conditions in Southern Lea County, New Mexico.* Ground-Water Report 6. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. *Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site.* Vols. 1 to 4.

NRC (U.S. Nuclear Regulatory Commission). 1973. Design Spectra for Seismic Design of Nuclear Power Plants, Revision 1. *Regulatory Guide* 1.60, December 1973.

Nuttli, O.W. 1973. Design Earthquakes for the Central United States. Miscellaneous Paper S-73-1, pp. 1 – 45. U.S. Army Waterways Experiment Station, Vicksburg, MS.

Palmer, A.R. 1983. "The Decade of North American Geology 1983 Geologic Time Scale." *Geology*, Vol. 11, No. 9, pp. 503 – 504.

Piper, A.M. 1973. *Subrosion in and about the Four-Township Study Area near Carlsbad, New Mexico.* Report to Oak Ridge National Laboratories, Oak Ridge, TN.

Piper, A.M. 1974. *The Four-Township Study Area near Carlsbad, New Mexico: Vulnerability to Future Subrosion.* Report to Oak Ridge National Laboratories, Oak Ridge, TN.

Popielak, R.S., Beauheim, R.L., Black, S.B., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP), Project*

Southeastern New Mexico. TME-3153. Vols. 1 and 2. Westinghouse Electric Corporation, Carlsbad, NM.

Powers, D.W., Lambert, S.J., Shaffer, S.E., Hill, L.R., and Weart, W.D., eds. 1978. *Geological Characterization Report for the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND78-1596, Vols. I and II. Sandia National Laboratories, Albuquerque, NM. (This document is included as Appendix GCR.)

Powers, D.W., and Holt, R.M. 1995. *Regional Geological Processes Affecting Rustler Hydrogeology.* Prepared for U.S. Department of Energy by IT Corporation, Albuquerque, NM.

Powers, D.W., and Holt, R.M. 1993. "The Upper Cenozoic Gatuña Formation of Southeastern New Mexico." In *Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society, Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993,* D.W. Love et al., eds., pp. 271–282. New Mexico Geological Society, Roswell, NM.

Powers, D.W., Sigda, J.M., and Holt, R.M. 1996. "Probability of Intercepting a Pressurized Brine Reservoir Under the WIPP." Unpublished report, July 10, 1996. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

Pratt, H.R., Stephenson, D.E., Zandt, G., Bouchon, M., and Hustrulik, W.A. 1979. Earthquake Damage to Underground Facilities. *Proceedings of the 1979 RETC,* Vol. 1. AIME, Littleton, CO.

Ramey, D.S. 1985. *Chemistry of Rustler Fluids.* EEG-31. New Mexico Environmental Evaluation Group, Santa Fe, NM.

Rawson, D., Boardman, C., and Jaffe-Chazan, N. 1965. *The Environment Created by a Nuclear Explosion in Salt.* PNE-107F. U.S. Atomic Energy Commission Plowshare Program, Project Gnome, Carlsbad, NM.

Register, J.K. 1981. *Rubidium-Strontium and Related Studies of the Salado Formation, Southeastern New Mexico.* SAND81-7072. Sandia National Laboratories, Albuquerque, NM.

Register, J.K., and Brookins, D.G. 1980. "Rb-Sr Isochron Age of Evaporite Minerals from the Salado Formation (Late Permian), Southeastern New Mexico." *Isochron/West,* No. 29, pp. 39 – 42.

Reiter, M., Barroll, M.W., and Minier, J. 1991. "An Overview of Heat Flow in Southwestern United States and Northern Chihuahua, Mexico." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 457 – 466. Geological Society of America, Boulder, CO.

Richardson, G.B. 1904. "Report of a Reconnaissance of Trans-Pecos Texas, North of the Texas and Pacific Railway." *Texas University Bulletin 23*. Var Boeckmann-Jones Company, Austin, TX.

Richter, C.F. 1958. *Elementary Seismology*. W.H. Freeman & Co., San Francisco, CA.

Robinson, T.W., and Lang, W.B. 1938. "Geology and Ground-Water Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal, New Mexico, with Special Reference to the Salt Content of the River Water." *Twelfth and Thirteenth Biennial Reports of the State Engineer of New Mexico for the 23rd, 24th, 25th, and 26th Fiscal Years, July 1, 1934 to July 30, 1938.* State Engineer, Santa Fe, NM. WPO 37942.

Robinson, J.Q., and Powers, D.W. 1987. "A Clastic Deposit within the Lower Castile Formation, Western Delaware Basin, New Mexico." In *Geology of the Western Delaware Basin, West Texas and Southeastern New Mexico,* D.W. Powers, and W.C. James, eds., El Paso Geological Society Guidebook 18, pp. 66 – 79. El Paso Geological Society, El Paso, TX.

Rogers, A.M., and Malkiel, A. 1979. A Study of Earthquakes in the Permian Basin of Texas–New Mexico. *Bulletin of the Seismological Society of America*, Vol. 69, pp. 843 – 865.

Rosholt, J.N., and McKinney, C.R. 1980. *Uranium Series Disequilibrium Investigations Related to the WIPP Site, New Mexico (USA), Part II. Uranium Trend Dating of Surficial Deposits and Gypsum Spring Deposit Near WIPP Site, New Mexico.* Open-File Report 80-879. U.S. Geological Survey, Denver, CO.

Sanford, A.R., Jaksha, L.H., and Cash, D.J. 1991. "Seismicity of the Rio Grand Rift in New Mexico." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 229 – 244. Geological Society of America, Boulder, CO.

Saulnier, Jr., G.J., and Avis, J.D. 1988. *Interpretation of Hydraulic Tests Conducted in the Waste-Handling Shaft at the Waste Isolation Pilot Plant (WIPP) Site.* SAND88-7001. Sandia National Laboratories, Albuquerque, NM. WPO 24164.

Schiel, K.A. 1988. "The Dewey Lake Formation: End Stage Deposit of a Peripheral Foreland Basin." Master's thesis. University of Texas at El Paso, El Paso, TX.

Schiel, K.A. 1994. "A New Look at the Age, Depositional Environment and Paleogeographic Setting of the Dewey Lake Formation (Late Permian)." *West Texas Geological Society Bulletin*, Vol. 33, No. 9, pp. 5 – 13. WPO 20465.

Sewards, T., Williams, M.L., and Keil, K. 1991. *Mineralogy of the Culebra Dolomite Member of the Rustler Formation.* SAND90-7008. Sandia National Laboratories, Albuquerque, NM. WPO 23879.

Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Sandia National Laboratories, Albuquerque, NM. WPO 25624.

Snider, H.I. 1966. "Stratigraphy and Associated Tectonics of the Upper Permian Castile-Salado-Rustler Evaporite Complex, Delaware Basin, West Texas and Southeast New Mexico." Ph.D. dissertation. University of New Mexico, Albuquerque, NM.

Snyder, R.P. 1985. *Dissolution of Halite and Gypsum, and Hydration of Anhydrite to Gypsum, Rustler Formation, in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* Open-File Report 85-229. U.S. Geological Survey, Denver, CO.

Snyder, R.P., Gard, Jr., L.M., and Mercer, J.W. 1982. *Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, with Section on Drill-Stem Tests.* Open-File Report 82-968. U.S. Geological Survey, Denver, CO.

Stensrud, W.A. 1995. *Culebra Transport Program Test Plan: Hydraulic Tests at Wells WQSP-1, WQSP-2, WQSP-3, WQSP-4, WQSP-5, WQSP-6 and WQSP-6a at the Waste Isolation Pilot Plant (WIPP) Site.* On file in the Sandia WIPP Central Files.

Swift, P.N. 1992. *Long-Term Climate Variability at the Waste Isolation Pilot Plant, Southeastern New Mexico, USA.* SAND91-7055. Sandia National Laboratories, Albuquerque, NM. (This document is included as Appendix CLI.)

Thompson, G.A. and Zoback, M.L. 1979. Regional Geophysics of the Colorado Plateau. *Tectonophysics,* Vol. 61, Nos. 1 – 3, pp. 149 – 181.

UNM (University of New Mexico). 1984. *A Handbook of Rare and Endemic Plants of New Mexico.* New Mexico Native Plants Protection Advisory Committee, eds. University of New Mexico Press, Albuquerque, NM.

U.S. Congress. 1992. *Waste Isolation Pilot Plant Land Withdrawal Act.* Public Law 102-579, October 1992. 102nd Congress, Washington, D.C.

U.S. Department of Commerce. 1980. *Census of Population, General Population Characteristics of New Mexico.* Bureau of the Census.

U.S. Department of Commerce. 1990. *Census of Population, General Population Characteristics of New Mexico.* Bureau of the Census.

Vine, J.D. 1963. "Surface Geology of the Nash Draw Quadrangle, Eddy County, New Mexico." *U.S. Geological Survey Bulletin 1141-B.* U.S. Government Printing Office, Washington, DC. WPO 29558.

Weart, W.D. 1983. *Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability.* SAND83-0450. Albuquerque, NM: Sandia National Laboratories.

Westinghouse Electric Corporation. 1991a. *Waste Isolation Pilot Plant Groundwater Monitoring Program Plan and Procedures Manual.* WP02-1. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1991b. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1990.* DOE/WIPP 91-008. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1992. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1991.* DOE/WIPP 92-007. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1993. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1992.* DOE/WIPP 93-017. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1994. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1993.* DOE/WIPP 94-2003. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1995. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1994.* DOE/WIPP 95-Draft-2094. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Wolfe, H.G., et al., eds. 1977. *An Environmental Baseline Study of the Los Medaños Waste Isolation Pilot Plant (WIPP) Project Area of New Mexico: A Progress Report.* SAND77-7017. Sandia National Laboratories, Albuquerque, NM.

Wood, B.J., Snow, R.E., Cosler, D.J., and Haji-Djafari, S. 1982. *Delaware Mountain Group (DMG) Hydrology—Salt Removal Potential, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME 3166. U.S. Department of Energy, Albuquerque, NM.

Zoback, M.L., and Zoback, M.D. 1980. "State of Stress in the Conterminous United States." *Journal of Geophysical Research,* Vol. 85, No. B11, pp. 6113 – 6156.

Zoback, M.L., Zoback, M.D., Adams, J., Bell, S., Suter, M., Suarez, G., Estabrook, C., and Magee, M. 1991. *Stress Map of North America.* Continent Scale Map CSM-5, Scale 1:5,000,000. Geological Society of America, Boulder, CO.

Zoback, M.D., and Zoback, M.L. 1991. "Tectonic Stress Field of North America and Relative Plate Motions." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 339 – 366. Geological Society of America, Boulder, CO.

BIBLIOGRAPHY

AIM (Agricultural and Industrial Minerals, Inc.). 1979. *Resource Study for the [WIPP], Eddy County, NM.* AIM, Inc., San Carlos, CA.

Anderson, R.Y. 1982. "Deformation-Dissolution Potential of Bedded Salt, Waste Isolation Pilot Plant Site, Delaware Basin, New Mexico." In *Scientific Basis for Nuclear Waste Management, Materials Research Society Proceedings,* V. W. Lutze, ed., Vol. 11. Elsevier Science Publishing Co., New York.

Anderson, R.Y. 1993. "The Castile as a 'Nonmarine' Evaporite." In *Geology of the Carlsbad Region, New Mexico and Texas,* D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

Anderson, R.Y., Dean, W.E., Kirkland, Jr., D.W., and Snider, H. I. 1972. Permian Castile Varved Evaporite Sequence, West Texas and New Mexico. *Geological Society of America Bulletin,* Vol. 83, No. 1, pp. 59 – 85.

Anderson, R.Y., and Kirkland, D.W. 1980. Dissolution of Salt Deposits by Brine Density Flow. *Geology,* Vol. 8, No. 2, pp. 66 – 69.

Anderson, R.Y., and Powers, D.W. 1978. "Salt Anticlines in the Castile-Salado Evaporite Sequence, Northern Delaware Basin, New Mexico." In *Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas,* G.S. Austin, ed., Circular 159. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Bachman, G.O. 1973. *Surficial Features and Late Cenozoic History in Southeastern New Mexico.* Open-File Report 4339-8. U.S. Geological Survey, Reston, VA.

Bachman, G.O. 1985. *Assessment of Near-Surface Dissolution at and near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND84-7178. Sandia National Laboratories, Albuquerque, NM.

Bachman, G.O., and Johnson, R.B. 1973. *Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico.* Open-File Report 4339-4. U.S. Geological Survey, Denver, CO.

Bachman, G.O., and Machette, M. N. 1977. *Calcic Soils and Calcretes in the Southwestern United States.* Open-File Report 77-794. U.S. Geological Survey.

Balazs, E.I. 1978 [undated]. *Report on First-Order Leveling Survey for Sandia Laboratories Waste Isolation Pilot Plant (WIPP) Project.* Report to Sandia National Laboratories, Albuquerque, NM. National Geodetic Survey, Rockville, MD.

Balazs, E.I. 1982. *Vertical Movement in the Los Medaños and Nash Draw Areas, New Mexico, as Indicated by 1977 and 1981 Leveling Surveys.* NOAA Technical Memorandum NOS NGS 37, National Geodetic Survey, Rockville, MD.

Barker, J.M., and Austin, G.S. 1993. "Economic Geology of the Carlsbad Potash District, New Mexico, in Carlsbad Region, New Mexico and West Texas." In *Geology of the Carlsbad Region, New Mexico and Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 283 – 291. New Mexico Geological Society, Socorro, NM.

Barrows, L.J., and Fett, J.D. 1985. A High-Precision Gravity Survey in the Delaware Basin of Southeastern New Mexico. *Geophysics*, Vol. 50, No. 5, pp. 825 – 833.

Beauheim, R.L. 1986. *Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-1364. Sandia National Laboratories, Albuquerque, NM.

Beauheim, R.L., and Holt, R.M. 1990. "Hydrology of the WIPP Site." In *Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico,* Geologic Society of America 1990 Annual Meeting Field Trip #14 Guidebook, pp. 131 – 179. Dallas Geologic Society, Dallas, TX.

Beauheim, R.L., Roberts, R.M., Dale, T.F., Fort, M.D., and Stensrud, W.A. 1993. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report.* SAND92-0533. Sandia National Laboratories, Albuquerque, NM.

Bertram-Howery, S.G., and Hunter, R.L. 1989. *Plans for Evaluation of the Waste Isolation Pilot Plant Compliance with EPA Standards for Radioactive Waste Management and Disposal.* SAND88-2871. Sandia National Laboratories, Albuquerque, NM.

Blaney, H.F., and Hanson, E.G. 1965. *Consumptive Use and Water Requirements in New Mexico.* Technical Report 32. New Mexico State Engineer's Office.

Blackwell, D.D., Steele, J.L., and Carter, L.S. 1991. "Heat-Flow Patterns of the North American Continent; A Discussion of the Geothermal Map of North America." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 423 – 436. Geological Society of America, Boulder, CO.

Bodine, Jr., M.W. 1978. "Clay-Mineral Assemblages from Drill Core of Ochoan Evaporites, Eddy County, New Mexico." In *Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas*, G.S. Austin, ed., Circular 159. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Borns, D.J., and Shaffer, S.E. 1985. *Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin.* SAND83-1798. Sandia National Laboratories, Albuquerque, NM.

Borns, D.J., and Stormont, J.C. 1987. *Delineation of the Disturbed Rock Zone around Excavations in Salt, Waste Isolation Pilot Plant (WIPP), SE New Mexico: Abstracts with Programs.* 1987 Annual Meeting and Exposition of the Geological Society of America, Vol. 19, No. 7. Geological Society of America, Phoenix, AZ.

Brinster, K.F. 1991. *Preliminary Geohydrologic Conceptual Model of the Los Medaños Region near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment.* SAND89-7147 and addendum. Sandia National Laboratories, Albuquerque, NM.

Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hays, W.H. 1972. *Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico.* Open-File Report 4339-1. U.S. Geological Survey, Denver, CO.

Brookins, D.G. 1980. Polyhalite K-Ar Radiometric Ages From Southeastern New Mexico. In *Isochron/West* pp. 29 – 31.

Brookins, D.G., and Lambert, S.J. 1987. *Radiometric Dating of Ochoan (Permian) Evaporites, WIPP site, Delaware Basin, New Mexico, USA.* Materials Research Society, ed., Vol. 84, pp. 771 – 780.

Brookins, D.G., Lambert, S.J., and Ward, D.B. 1990. *Authigenic Clay Minerals in the Rustler Formation, WIPP Site Area, New Mexico.* SAND89-1405. Sandia National Laboratories, Albuquerque, NM.

Brookins, D.G., Register, J.K., and Krueger, H. 1980. Potassium-Argon Dating of Polyhalite in Southeast New Mexico. *Geochimica et Cosmochimica Acta*, Vol. 44, pp. 635 – 637.

Cauffman, T.L., LaVenue, A.M., and McCord, J.P. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume II: Data Base.* SAND89-7068/2. Sandia National Laboratories, Albuquerque, NM.

Chapman, J.B. 1986. *Stable Isotopes in the Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area.* EEG-35, DOE/AL/10752-35. Environmental Evaluation Group, Santa Fe, NM.

Chapman, J.B. 1988. *Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern NM.* EEG-39. Environmental Evaluation Group, Santa Fe, NM.

Chaturvedi, L., ed. 1987. *The Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler as It Relates to the WIPP Project.* EEG-34, DOE/AL/10752-34. Environmental Evaluation Group, Santa Fe, NM.

Chugg, J.C., Anderson, G.W., Kink, D.L., and Jones, L.H. 1952. *Soil Survey of Eddy Area, New Mexico.* U.S. Department of Agriculture.

Cornell, C.A. 1968. Engineering Seismic Risk Analysis. Seismological Society of America Bulletin. Vol. 58, pp. 1583 – 1606.

Cornell, C.A. 1971. "Probabilistic Analysis of Damage to Structures Under Seismic Load." In *Dynamic Waves in Civil Engineering*, D.A. Howell, I.P. Haigh, and C. Taylor, eds., pp. 473 – 488.

Cornell, C.A., and Merz, H.A. 1975. Seismic Risk Analysis of Boston. *Journal of the Structural Engineering American Society of Civil Engineering*, Vol. 10, pp. 2027 – 2043.

Cornell, C.A., and Vanmarke, E.H. 1969. "The Major Influences on Seismic Risk." In *Fourth World Conference on Earthquake Engineering*, Vol. I, pp. 69 – 83. Santiago, Chile.

Crandall, K.H. 1929. Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas. *American Association of Petroleum Geologists Bulletin*, Vol. 13.

Crawford, J.E., and Wallace, C.S. 1993. "Geology and Mineralization of the Culberson Sulfur Deposit." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Guidebook, pp. 301 – 316. New Mexico Geological Society, Socorro, NM.

Crawley, M.E. 1988. *Hydrostatic Pressure and Fluid-Density Distribution of the Culebra Dolomite Member of the Rustler Formation near the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP 88-030. U.S. Department of Energy, Carlsbad, NM.

Dalrymple, G.B. and Lanphere, M.A. 1969. *Potassium-Argon Dating.* W.H. Freeman and Company.

Davies, P.B. 1984. *Deep-Seated Dissolution and Subsidence in Bedded Salt Deposits* [Ph.D. Thesis]. Stanford University, Palo Alto, CA.

DOE (U.S. Department of Energy). 1989. *Draft Supplement Environmental Impact Statement Waste Isolation Pilot Plant.* DOE/EIS-0026-DS. U.S. Department of Energy, Washington, D.C.

DOE (U.S. Department of Energy). 1983. *Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing.* WTSD-TME-020. United States Department of Energy, Albuquerque, NM.

DOE (U.S. Department of Energy). 1990. *Final Supplement, Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-FS. Office of Environmental Restoration and Waste Management, Washington, D.C.

DOE (U.S. Department of Energy). 1993. *Waste Isolation Pilot Plant Land Management Plan.* DOE/WIPP 93-004. U.S. Department of Energy, Carlsbad Area Office Carlsbad, NM.

DOE (U.S. Department of Energy). 1994. *Format and Content Guide for Title 40 CFR 191 and Title 40 CFR 268.6 Compliance Reports.* DOE/CAO-94-2004. Carlsbad, NM.

DOE (U.S. Department of Energy). 1994. *Waste Isolation Pilot Plant Environmental Monitoring Plan.* DOE/WIPP 94-024. U.S. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy) and state of New Mexico. 1981. *Consultation and Cooperation Agreement.* Appendix A to the Stipulated Agreement Resolving Civil Action, 81-0363JB, state of New Mexico vs. United States Department of Energy, United States District Court, Albuquerque, NM.

Doser, D.I., Baker, M.R., Luo, M., Marroquin, P., Ballesteros, L., Kingwell, J., Diaz, H.L., and Kaip, G. Undated. *The Not So Simple Relationship between Seismicity and Oil Production in the Permian Basin, West Texas.* Department of Geological Sciences, University of Texas at El Paso, El Paso, Texas.

Dunham, R.J. 1972. *Capitan Reef, New Mexico and Texas: Facts and Questions to Aid Interpretation and Group Discussion.* Publication 72-14, p. 297. Permian Basin Section, Society of Economic Paleontologists and Mineralogists.

EPA (U.S. Environmental Protection Agency). 1990. "Background Document for the U. S. Environmental Protection Agency's Proposed Decision on the No Migration Variance for U.S. Department of Energy's Waste Isolation Pilot Plant," U.S. Environmental Protection Agency, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1990. Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant. *Federal Register,* Vol. 55, No. 220, p. 47700, November 14, 1990. Office of Solid Waste and Emergency Response, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1992. *"No Migration" Variances to the Hazardous Waste Land Disposal Prohibitions: A Guidance Manual for Petitioners* [Draft]. EPA530-R-92-023. Office of Solid Waste, Washington, D.C.

Esteva, L. and Rosenblueth, E. 1964. Espectros de Temblores a Distancias Moderas y Grandes. *Bol. Soc. Mex. Ing. Sism,* Vol. 2, pp. 1 – 18.

Evernden, J.F. 1967. Magnitude Determination at Regional and Near-Regional Distances in the United States. *Seismological Society of America Bulletin*, Vol. 57, pp. 591 – 639.

Ewing, T.E. 1993. "Erosional Margins and Patterns of Subsidence in the Lake Paleozoic West Texas Basin and Adjoining Basins of West Texas and New Mexico," *New Mexico Geological Society Guidebook, 44th Field Conference, Carlsbad Region New Mexico and West Texas*, D.W. Lowe et al., eds., pp. 155 – 166.

Ferrall, C.C., and Gibbons, J.F. 1980. *Core Study of Rustler Formation over the WIPP Site.* SAND79-7110. Sandia National Laboratories, Albuquerque, NM.

Foster, R.W. 1974. *Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste.* Open-File Report, Contract No. AF(40-1)-4423. Oak Ridge National Laboratory, Oak Ridge, TN.

Freeze, R.A., and Witherspoon, P.A. 1967. "Theoretical Analysis of Regional Groundwater Flow: 2. Effect of Water-Table Configuration and Subsurface Permeability Variation," *Water Resources Research.* Vol. 3, No. 2, pp. 623 – 634.

FWS (U.S. Fish and Wildlife Services). 1989. Letter from John C. Peterson, Field Supervisor, Albuquerque, NM, to Jack B. Tillman, Project Manager, U.S. DOE–Carlsbad, May 25, 1989.

Galley, J.E. 1958. "Oil and Geology in the Permian Basin of Texas and New Mexico." In *Habitat of Oil—A Symposium*, L. G. Weeks, ed.

Garber, R.A., Grover, G.A., and Harris, P.M. 1989. "Geology of the Capitan Shelf Margin—Subsurface Data from the Northern Delaware Basin." In *Subsurface and Outcrop Examination of the Capitan Shelf Margin, Northern Delaware Basin*, P.M. Harris and G.A Grover, eds., Core Workshop No. 13, p. 3-269. Society of Economic Paleontologists and Mineralogists (SEPM).

Griswold, G.B. 1977. *Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, New Mexico.* SAND77-0946. Sandia National Laboratories, Albuquerque, NM.

Guilinger, J.R. 1993. "The Geology and Development of the Phillips Ranch Sulfur Deposit." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 21 – 23. New Mexico Geological Society, Socorro, NM.

Gutenberg, B. and Richter, C.F. 1942. Earthquakes Magnitude, Intensity, Energy and Accelerations. *Seismological Society of America Bulletin.* Vol. 32, pp. 163 – 191.

Harding, S.T., Carver, D., Henrisey, R.F., Dart, R.L., and Langer, C.J. 1978. The Scurry County, Texas, Earthquake Series of 1977–1978: Induced Seismicity? *Earthquake Notes*, Vol. 49, no. 3.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G., and Smith, D.G. 1989. *A Geologic Time Scale 1989.* Cambridge Earth Science Series. Cambridge University Press.

Harms, J.C., and Williamson, C.R. 1988. Deep-Water Density Current Deposits of Delaware Mountain Group (Permian), Delaware Basin, Texas and New Mexico. *American Association of Petroleum Geologists Bulletin*, Vol. 72.

Haug, A., Kelley, V.A., LaVenue, A.M., and Pickens, J. F. 1987. *Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report.* SAND86-7167. Sandia National Laboratories, Albuquerque, NM.

Hawley, J.W. 1993. "The Ogallala and Gatuña Formations in the Southeastern New Mexico Region, a Progress Report." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

Hendrickson, G.E., and Jones, R. S. 1952. Geology and Ground-Water Resources of Eddy County, New Mexico. *Ground-Water Report*, Vol. 3, p. 169. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Hern, J.L., Powers, D.W., and Barrows, L.J. 1979. *Seismic Reflection Data Report Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND79-0264, Vols. 1 and 2. Sandia National Laboratories, Albuquerque, NM.

Hicks, P.A. 1981. *Mitigative Collection and Testing of Five Archaeological Sites on the Waste Isolation Pilot Project near Carlsbad, New Mexico for Westinghouse, Inc.* Agency for Conservation Archaeology, Eastern New Mexico University, Portales, NM.

Hicks, P.A. 1981. *Mitigation of Four Archaeological Sites on the Waste Isolation Pilot Project near Carlsbad, New Mexico for Westinghouse, Inc.* Agency for Conservation Archeology, Eastern New Mexico University, Portales, NM.

Hills, J.M., and Kottlowski, F.E. 1983. *Southwest/Southwest Mid-Continent Region.* Correlation Chart Series. American Association of Petroleum Geologists.

Holt, R.M. 1993. *Sedimentary Textures, Structures, and Lithofacies in the Salado Formation: A Guide for Recognition, Classification, and Interpretation.* DOE/WIPP 93-056. U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1986. *Geotechnical Activities in the Exhaust Shaft.* DOE-WIPP-86-008. U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1988. *Facies Variability and Post-Depositional Alteration within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP 88-004. U.S. Department of Energy, Carlsbad, NM. (This document is included as Appendix FAC.)

Holt, R.M., and Powers, D.W. 1990. "Halite Sequences within the Late Permian Salado Formation in the Vicinity of the Waste Isolation Pilot Plant." In *Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico*, D. Powers et al., eds., Field Trip #14. Geological Society of America, Dallas, TX.

Holt, R.M., and Powers, D.W. 1993. "Summary of Delaware Basin End-Stage Deposits." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 90–92. New Mexico Geological Society, Socorro, NM.

Howard, K.A., Aaron, J.M., Brabb, E.E., Brock, M.R., Gower, H.D., Hunt, S.J., Milton, D.J., Muehlberger, W.R., Nakata, J.K., Plafker, G., Prowell, D.C., Wallace, R.E., and Witkind, I.J. 1971 [reprinted 1991]. *Preliminary Map of Young Faults in the United States as a Guide to Possible Fault Activity: Miscellaneous Field Studies Map MF-916, 1:5,000,000.* 2 sheets. U.S. Geological Survey.

Hubbert, M.K. 1940. "The Theory of Ground-Water Motion," *The Journal of Geology.* Vol. 48, no. 8, pt. 1., pp. 785 – 944.

Jarolimek, L., Timmer, M.J., and McKinney, R.F. 1983. *Geotechnical Activities in the Exploratory Shaft—Selection of the Facility Interval, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME 3178. U.S. Department of Energy, Albuquerque, NM.

Jarolimek, L., Timmer, M.J., and Powers, D.W. 1983. *Correlation of Drillhole and Shaft Logs, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME 3179. U.S. Department of Energy, Albuquerque, NM.

John, C.B., Cheeseman, R.J., Lorenz, J.C., and Milligate, M.L. 1978. *Potash Ore Reserves in the Proposed [WIPP] Plant Area.* Open-File Report for Eddy County, Southeastern NM. U.S. Geological Survey.

Johnson, K.S. 1978. "Stratigraphy and Mineral Resources of Guadalupian and Ochoan Rocks in the Texas Panhandle and Western Oklahoma." In *Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas*, G.S. Austin, ed., Circular 159, pp. 57 – 62. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Jones, C.L. 1954. *The Occurrence and Distribution of Potassium Minerals in Southeastern New Mexico.* Guidebook to Southeastern New Mexico. New Mexico Geographical Society, Albuquerque, NM.

Jones, C.L. 1978. *Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico.* Open-File Report 78-592. Vols. 1 and 2. U.S. Geological Survey, Denver, CO.

Jones, C.L. 1981. *Geologic Data for Borehole ERDA-9, Eddy County, New Mexico.* Open-File Report 81-469. U.S. Geological Survey, Denver, CO.

Keesey, J. J. 1976. *Hydrocarbon Evaluation, Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico.* Vols. I and II. Sipes, Williamson and Aycock, Midland, TX.

Keesey, J.J. 1977. *Hydrocarbon Evaluation, Waste Isolation Pilot Plant Site Area to State and Federal Royalty Interests.* Eddy County, NM.

Kelley, V.A., and Pickens, J.F. 1986. *Interpretation of the Convergent-Flow Tracer Tests Conducted in the Culebra Dolomite at the H-3 and H-4 Hydropads at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-7161. Sandia National Laboratories, Albuquerque, NM.

Kenney, J.W., Downes, P.S., Gray, D.H., and Ballard, S.C. 1995. *Radionuclide Baseline In Soil Near Project Gnome and the Waste Isolation Pilot Plant.* EEG-58. Environmental Evaluation Group, Albuquerque, NM.

King, P.B. 1948. *Geology of the Southern Guadalupe Mountains, Texas.* Professional Paper 215. U.S. Geological Survey, Washington, D.C.

King, R.H. 1947. Sedimentation in Permian Castile Sea. *American Association of Petroleum Geologists Bulletin*, Vol. 31, pp. 470 – 477.

Klemmick, G.F. 1993. "Geology of the Pokorny Sulfur Deposit, Culberson County, Texas." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 18 – 19. New Mexico Geological Society, Socorro, NM.

Kunkler, J.L. 1980. *Evaluation of the Malaga Bend Salinity Alleviation Project.* Open-File Report 80-1111. U.S. Geological Survey, Denver, CO.

Lambert, S.J., and Carter, J.A. 1984. "Uranium-Isotope Disequilibrium in Brine Reservoirs of the Castile Formation." In *Principles and Methods, Northern Delaware Basin, Southeastern New Mexico*. SAND83-0144. Sandia National Laboratories, Albuquerque, NM.

Lang, W.B. 1935. Upper Permian Formation of Delaware Basin of Texas and New Mexico. *American Association of Petroleum Geologists Bulletin*, Vol. 19, pp. 262 – 276.

Lang, W.B. 1947. "Occurrence of Comanche Rocks in Black River Valley, New Mexico," *American Association of Petroleum Geologists Bulletin*, Vol. 31, pp. 1472 – 1478.

Lappin, A.R., Hunter, R.L., Garber, D.P., Davies, P.B., Beauheim, R.L., Borns, D.J., Brush, L.H., Butcher, B.M. Cauffman, T., Chu, M.S.Y., Gomez, L.S., Guzowski, R.V., Iuzzolino, H.J., Kelley, V., Lambert, S.J., Marietta, M.G., Mercer, J.W., Nowak, E.J., Pickens, J.F., Rechard, R.P., Reeves, M., Robinson, K.L., and Siegel, M.D., eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico: March 1989.* SAND89-0462. Sandia National Laboratories, Albuquerque, NM.

LaVenue, A.M., Cauffman, T.L., and Pickens, J.F. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume 1: Model Calibration* SAND89-7068/1. Sandia National Laboratories, Albuquerque, NM.

LaVenue, A.M., Haug, A., and Kelley, V.A. 1988. *Numerical Simulation of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Second Interim Report.* SAND88-7002. Sandia National Laboratories, Albuquerque, NM.

Lee, W.T. 1925. "Erosion by Solution and Fill." In *Contributions to Geography in the United States: USGS Bulletin,* 760-C.

Leslie, A., Kendall, A., and Harwood, G. 1993. "The Castile Formation: A Continuing Paradox." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

Long, G.J., and Associates, Inc. 1976. *Interpretation of Geophysical Data, Los Medaños and Vicinity, Lea and Eddy Counties, New Mexico.* Report to Sandia National Laboratories.

Lowenstein, T.K. 1987. *Postal Burial Alternation of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico.* EEG-36, New Mexico Health and Environment Department, Santa Fe, New Mexico.

Lowenstein, T.K. 1988. Origin of Depositional Cycles in a Permian "Saline Giant": The Salado (McNutt Zone) Evaporites of New Mexico and Texas. *Geological Society of America Bulletin*, Vol. 100, No. 4, pp. 592 – 608.

Lucas, S.G., and Anderson, O.J. 1993. "Triassic Stratigraphy in Southeastern New Mexico and Southwestern Texas." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

Machette, M.N. 1985. "Calcic Soils of the Southwestern United States." In *Soils and Quaternary Geology of the Southwestern United States*, D.L. Weide, and M.L. Faber, eds., Special Paper Vol. 203, pp. 1 – 21. Geological Society of America, Denver, CO.

MacLennan, R.B., and Schermer, S.C. 1979. *An Archaeological Survey for the Waste Isolation Pilot Project: Access Roads and Railroad Right-of-Way.* Agency for Conservation Archaeology Report 79-23. Eastern New Mexico University, Portales, NM.

Maley, V.C., and Huffington, R.M. 1953. Cenozoic Fill and Evaporate Solution in the Delaware Basin, Texas and New Mexico. *Geological Society of America Bulletin*, Vol. 64.

Mariah Associates, Inc. 1987. *Report of Class II Survey and Testing of Cultural Resources at the WIPP Site at Carlsbad, NM.* Prepared for the U.S. Corps of Engineers, Albuquerque District in NM.

McTigue, D.F. 1993. *Permeability and Hydraulic Diffusivity of Waste Isolation Pilot Plant Repository Salt Inferred from Small-Scale Brine Inflow Experiments.* SAND92-1911. Sandia National Laboratories, Albuquerque, NM.

Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area, Southeastern New Mexico.* Water Resources Investigation Report 83-4016. U.S. Geological Survey, Albuquerque, NM. (This document is included as Appendix HYDRO.)

Mercer, J.W. 1987. *Compilation of Hydrologic Data From Drilling the Salado and Castile Formations Near the Waste Isolation Pilot Plant (WIPP) Site in Southeastern New Mexico.* SAND86-0954. Sandia National Laboratories, Albuquerque, NM.

Mercer, J.W., Beauheim, R.L., Snyder, R.P., and Fairer, G.M. 1987. *Basic Data Report for Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-0611. Sandia National Laboratories, Albuquerque, NM.

Mercer, J.W. and Orr, B.R. 1977. *Review and Analysis of Hydrogeologic Condition Near the Site of a Potential Nuclear-Waste Repository, Eddy and Lea Counties, New Mexico.* USGS Open-File Report 77-123. U.S. Geological Survey, Albuquerque, NM.

Mercer, J.W., and Orr, B.R. 1979. *Interim Data Report on Geohydrology of Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico.* Water Resources Investigations 79-98. U.S. Geological Survey, Albuquerque, NM.

Merz, H.A., and Cornell, C.A. 1973. Seismic Risk Analysis Based on a Quadratic Magnitude-Frequency Law. *Seismological Society of America Bulletin.* Vol. 63, pp. 1999 – 2006.

Meyer, R.F. 1966. *Geology of Pennsylvania and Wolfcampian Rocks in Southeast New Mexico.* Memoir 17. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Mitchell, B.J. 1973. Radiation and Attenuation of Rayleigh Waves from the Southeastern Missouri Earthquake of October 21, 1965. *Journal of Geophysical Research.* Vol. 78, pp. 886 – 889.

NAS-NRC (National Academy of Science–National Research Council). 1957. *Disposal of Radioactive Wastes on Land.* Publication 519. National Academy of Sciences, Washington, D.C.

Neill, R.H., Channell, J.K., Chaturvedi, L., Little, M.S., Rehfeldt, K., and Spiegler, P. 1983. *Evaluation of the Suitability of the WIPP Site.* EEG-23. Environmental Evaluation Group, Santa Fe, NM.

Newell, N.D., et al. 1953. *The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico—A Study in Paleoecology.* W.H. Freeman and Co., San Francisco.

Nicholson, Jr., A., and Clebsch, Jr., A. 1961. *Geology and Ground-Water Conditions in Southern Lea County, New Mexico.* Ground-Water Report 6. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Nielson, J. 1977. *An Archaeological Reconnaissance of a Proposed Site for the Waste Isolation Pilot Plant (WIPP).* Sandia National Laboratories, Albuquerque, NM.

NRC (U.S. Nuclear Regualtory Commission). 1974. Guidance on the License Application, Siting, Design, and Plant Protection for an Independent Spent Fuel Storage Installation. *Regulatory Guide* 3.24, December 1974.

Nuttli, O.W. 1973. The Mississippi Valley Earthquakes of 1811 and 1812—Intensities, Ground Motion and Magnitudes. *Seismological Society of America Bulletin.* Vol. 63, pp. 227 – 248.

Nuttli, O.W. 1973. Seismic Wave Attenuation and Magnitude Relations for Eastern North America. *Journal Geophysical Research*, Vol. 78, pp. 876 – 885.

Olive, W.W. 1957. Solution-Subsidence Troughs, Castile Formation of Gypsum Plain, Texas and New Mexico. *Geological Society of America Bulletin*, Vol. 68.

Orphal, D.L., and Lahoud, J.A. 1974. Prediction of Peak Ground Motion from Earthquakes. *Seismological Society of America Bulletin*, Vol. 64, pp. 1563 – 1574.

Palmer, A.R. 1983. The Decade of North American Geology 1983 Geologic Time Scale. *Geology*, Vol. 11, pp. 503 – 504.

Powers, D.W. 1995. *Tracing Early Breccia Pipe Studies, Waste Isolation Pilot Plant, Southeastern New Mexico: A Study of the Documentation Available and Decision-Making during the Early Years of WIPP*. SAND94-0991. Sandia National Laboratories, Albuquerque, New Mexico.

Powers, D.W., and Holt, R.M. 1993. "The Upper Cenozoic Gatuña Formation of Southeastern New Mexico." In *Geology of the Carlsbad Region, New Mexico and West Texas*, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 271 – 282. New Mexico Geological Society, Socorro, NM.

Powers, D.W., and Holt, R.M. 1995. "Regional Geological Processes Affecting Rustler Hydrogeology," Westinghouse Electric Corporation, Carlsbad, NM.

Powers, D.W., and LeMone, D.V. 1987. *A Summary of Ochoan Stratigraphy, Western Delaware Basin.* Guidebook 18, pp. 63 – 68. El Paso Geological Society.

Powers, D.W., and Martin, M.L. 1993. *A Select Bibliography with Abstracts of Reports Related to Waste Isolation Pilot Plant (WIPP) Geotechnical Studies (1972–1990).* SAND92-7277. Sandia National Laboratories, Albuquerque, NM.

Powers, D.W. and Holt, R. 1990. *Sedimentology of the Rustler Formation Near the Waste Isolation Pilot Plant (WIPP) Site.* pp. 77–106. GSA Field Trip #14. Geological Society of America 1990 Annual Meeting. October 29–November 1, 1990. Dallas, TX.

Register, J.K., and Brookins, D.G. 1980. Rb-Sr Isochron Age of Evaporite Minerals from the Salado Formation (Late Permian), Southeastern New Mexico. In *Isochron/West, 29,* pp. 39 – 42.

Reilinger, R., Brown, L., and Powers, D. 1980. New Evidence for Tectonic Uplift in the Diablo Plateau Region, West Texas. *Geophysical Research Letters*, Vol. 7, No. 3.

Reiter, M., Barroll, M.W., and Minier, J. 1991. "An Overview of Heat Flow in Southwestern United States and Northern Chihuahua, Mexico." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 457–466. Geological Society of America, Boulder, CO.

Richey, S.F. 1989. *Geologic and Hydrologic Data for the Rustler Formation Near the Waste Isolation Pilot Plant, Southeastern New Mexico.* Open-File Report 89-32. U.S. Geological Survey, Albuquerque, NM.

Robinson, T.W., and Lang, W.B. 1938. *Geology and Ground-Water Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal, New Mexico, with Special Reference to the Salt Content of the River Water.* Twelfth and Thirteenth Biennial Reports of the State Engineer of New Mexico for the 23rd, 24th, 25th, and 26th Fiscal Years, July 1, 1934 to July 30, 1938. State Engineer, Santa Fe, NM.

Salvador, A. 1985. Chronostratigraphic and Geochronometric Scales in Colorado SUNA Stratigraphic Correlation Charts of the United States. *American Association of Petroleum Geologists Bulletin*, Vol. 69.

Sandia National Laboratories. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 3: Model Parameters.* SAND92-0700/3. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1982. *Basic Data Report for Drillhole WIPP 12 (Waste Isolation Pilot Plant—WIPP).* SAND82-2336. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1982. *Basic Data Report for Drillhole WIPP 14 (Waste Isolation Pilot Plant—WIPP).* SAND82-1783. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1983. *Basic Data Report for Drillhole ERDA 10 (Waste Isolation Pilot Plant—WIPP).* SAND79-0271. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and UNM (University of New Mexico). 1981. *Basic Data Report for Drillhole WIPP 15 (Waste Isolation Pilot Plant—WIPP).* SAND79-0274. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and USGS (U.S. Geological Survey). 1979. *Basic Data Report for Drillhole WIPP 13 (Waste Isolation Pilot Plant—WIPP).* SAND79-0273. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and USGS (U.S. Geological Survey). 1980. *Basic Data Report for Drillhole WIPP 18 (Waste Isolation Pilot Plant—WIPP).* SAND79-0275. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and USGS (U.S. Geological Survey). 1980. *Basic Data Report for Drillhole WIPP 32 (Waste Isolation Pilot Plant—WIPP).* SAND80-1102. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and USGS (U.S. Geological Survey). 1981. *Basic Data Report for Drillhole WIPP 33 (Waste Isolation Pilot Plant—WIPP).* SAND80-2011. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and USGS (U.S. Geological Survey). 1982. *Basic Data Report for Drillhole WIPP 11 (Waste Isolation Pilot Plant—WIPP).* SAND79-0272. Sandia National Laboratories, Albuquerque, NM.

Sandford, A., Sandford, S., Wallace, T., Barrows, L., Sheldon, J., Ward, R., Johansen, S., and Merritt, L. 1980. *Seismicity in the Area of the Waste Isolation Pilot Plant (WIPP).* Report by the New Mexico Institute of Mining and Technology to Sandia National Laboratories. SAND80-7096. Sandia National Laboratories, Albuquerque, NM.

Sandford, A.R, and Toppozada, T.R. 1974. *Seismicity of Proposed Radioactive Waste Isolation Disposal Site in Southeastern New Mexico.* New Mexico Bureau of Mines and Mineral Resources, Circular 143, pp. 1 – 15.

Sandford, A.R, Toppozada, T.R., Ward, R.M., and Wallace, T.C. 1976. The Seismicity of New Mexico 1962 through 1972. *Geological Society of America Abstracts with Programs,* Vol. 8, p. 625.

Sanford, A.R., Jaksha, L.H., and Cash, D.J. 1991. "Seismicity of the Rio Grand Rift in New Mexico." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 229 – 244.

Saulnier, Jr., G.J., and Avis, J.D. 1988. *Interpretation of Hydraulic Tests Conducted in the Waste-Handling Shaft at the Waste Isolation Pilot Plant (WIPP) Site.* SAND88-7001. Sandia National Laboratories, Albuquerque, NM.

Saulnier, Jr., G.J., Domski, P.S., Palmer, J.B., Roberts, R.M., and Stensrud, W.A. 1991. *WIPP Salado Hydrology Program Data Report #1.* SAND90-7000. Sandia National Laboratories, Albuquerque, NM.

Schaller, W.T., and Henderson, E.P. 1932. Mineralogy of Drill Cores from the Potash Field of New Mexico and Texas. *U.S. Geological Survey Bulletin,* Vol. 833.

Schermer, S.C. 1980. *A Report on the Archaeological Site Locations in the WIPP Core Area with Mitigation Recommendations for Bechtel National, Inc.* Report 80-176. Agency for Conservation Archaeology, Eastern New Mexico University, Portales, NM.

Schiel, K.A. 1988. *The Dewey Lake Formation: End Stage Deposit of a Peripheral Foreland Basin* [M.S. thesis]. University of Texas at El Paso, El Paso, TX.

Schiel, K.A. 1994. A New Look at the Age, Depositional Environment and Paleogeographic Setting of the Dewey Lake Formation (Late Permian). *West Texas Geological Society Bulletin*, Vol. 33, No. 9, pp. 5 – 13.

Seed, H.B., Idriss, I.M., and Kiefer, R.W. 1976. *Characteristics of Rock Motions during Earthquakes*. Report No. 68-5. Earthquake Engineering Research Center.

Schnabel, P.B., and Seed, H.B. 1973. Accelerations in Rock for Earthquakes in the Western United States. *Seismological Society of America Bulletin*, Vol. 63, pp. 501 – 516.

Sewards, T., Glenn, R., and Keil, K. 1991. *Mineralogy of the Rustler Formation in the WIPP-19 Core*. SAND87-7036. Sandia National Laboratories, Albuquerque, NM.

Shah, H.C., Mortgat, C.P., Kiremidjian, A., and Zsutty, T.C. 1975. A Study of Seismic Risk for Nicaragua. Report 11. Department of Civil Engineering, Stanford University, Palo Alto, CA.

Shumard, G.G. 1858. "Observations on the Geological Formation of the Country between the Rio Pecos and the Rio Grande, in New Mexico, Near the Line of the 32nd Parallel, Being an Abstract of Portion of the Geological Report of the Expedition Under Capt. John Pope, Corps of Topographical Engineers, U.S. Army, in the Year 1855." In *St. Louis Academy of Sciences Transactions*, Vol. 1.

Siegel, M.D., Lambert, S.J., and Robinson, K.L. eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico*. SAND88-0196. Sandia National Laboratories, Albuquerque, NM.

Siemers, W.T., Hawley, J.W., Rautman, C., and Austin, G. 1978. *Evaluation of the Mineral Potential (Excluding Hydrocarbons, Potash, and Water) of the Waste Isolation Pilot Plant Site, Eddy County, New Mexico*. Open-File Report 87. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Snider, H.I. 1966. *Stratigraphy and Associated Tectonics of the Upper Permian Castile-Salado-Rustler Evaporite Complex, Delaware Basin, West Texas and Southeast New Mexico* [Ph.D. dissertation]. University of New Mexico, Albuquerque.

Snyder, R.P. 1985. *Dissolution of Halite and Gypsum, and Hydration of Anhydrite to Gypsum, Rustler Formation, in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico*. Open-File Report 85-229. U.S. Geological Survey, Denver, CO.

Snyder, R.P., and Gard, Jr., L.M. 1982. *Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, with Section on Drill-Stem Tests.* Open-File Report 82-968. U.S. Geological Survey, Denver, CO.

Stensrud, W.A., Dale, T.F., Domski, P.S., Palmer, J.B., Roberts, R. M., Fort, M.D., and Saulnier, Jr., G.J. 1992. *Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2.* SAND92-7072. Sandia National Laboratories, Albuquerque, NM.

Thompson, G.A. and Zoback, M.L. 1979. Regional Geophysics of the Colorado Plateau. *Tectonophysics,* Vol. 61, Nos. 1–3, pp. 149 – 181.

Tóth, J., 1963. "A Theoretical Analysis of Groundwater Flow in Small Drainage Basins," *Journal of Geophysical Research.* Vol. 68, no. 16, pp. 4795 – 4812.

Urry, W.E. 1936. *Post-Keweenawan Timescale.* Exhibit 2, pp. 35 – 40. National Research Council, Report Committee on Measurement of Geologic Time 1935–36.

USBM (U.S. Bureau of Mines). 1977. *Valuation of Potash Occurrences within the [WIPP] Site in Southeastern New Mexico.* Prepared for the U.S. Energy Research and Development Administration.

Vail, P.R., Mitchum, Jr., R.M., Thompson, III, S. 1977. "Seismic Stratigraphy and Global Changes of Sea Level, Part 4: Global Cycles of Relative Changes of Sea Level," in *Seismic Stratigraphy Applications to Hydrocarbon Exploration*, C.E. Payton ed., AAPG Memoir 26, pp. 83-97, American Association of Petroleum Geologists.

Vine, J.D. 1963. Surface Geology of the Nash Draw Quadrangle, Eddy County, New Mexico. *U.S. Geological Survey Bulletin*, 1141-B.

Von Hake, C., and Cloud, W.K. 1968. United States Earthquakes 1966. Coast and Geodetic Survey. U.S. Department of Commerce, Washington, D.C.

Westinghouse Electric Corporation. 1990. *WIPP Final Safety Analysis Report.* WP 02-9, Rev. 0. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1991b. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1990.* DOE/WIPP 91-008. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1992. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1991.* DOE/WIPP 92-007. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1993. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1992.* DOE/WIPP 93-017. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1994. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1993.* DOE/WIPP 94-2003. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Westinghouse Electric Corporation. 1995. *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1994.* DOE/WIPP 95-Draft-2094. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Zoback, M.L., and Zoback, M.D. 1980. State of Stress in the Conterminous United States. *Journal of Geophysical Research,* Vol. 85, No. B11, pp. 6113 – 6156.

Zoback, M.D., and Zoback, M.L. 1991. "Tectonic Stress Field of North America and Relative Plate Motions." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 339 – 366. Geological Society of America, Boulder, CO.

3.0 FACILITY DESCRIPTION

Chapter 3.0 provides technical information about those engineered systems at the Waste Isolation Pilot Plant (WIPP) disposal system that are important to meeting the disposal standards of Title 40 of the Code of Federal Regulations (CFR) Part 191. The U.S. Department of Energy (DOE) has specified a facility design that facilitates the rapid encapsulation of emplaced waste by creep closure of salt, forming a nearly impermeable barrier around the waste. In addition, the DOE has taken a defense in depth approach in the design of engineered shaft sealing systems to ensure the shafts will not become pathways for radionuclide release. Shaft seals incorporate multiple engineered materials and compacted crushed salt which will effectively reduce the permeability of the shaft-seal system to values near those of unexcavated intact salt. The DOE also employs backfill to chemically condition any brine that may reach the waste in order to reduce radionuclide solubility. Finally, the DOE will close each panel of waste with a panel closure system to provide for operational protection of workers, the public and the environment from emplaced waste. In addition, the panel closure system provides a long-term benefit to the performance of the disposal system. The DOE's choices of engineered barriers complement the natural barriers at the site that were key to site selection. These engineered barriers are incorporated in the conceptual model used for disposal system performance assessment described in Section 6.4.

In this chapter, descriptions are provided for the shafts, the underground waste disposal region and support facilities, and the engineered barriers as these are the only engineered systems germane to long-term performance of the disposal system. Information on other aspects such as general facility operations, waste handling and emplacement process, repository mining, ground control and the use of roof bolts, ventilation, transportation, emergency preparedness, training and maintenance are covered, as appropriate, in other WIPP documents such as the Final Environmental Impact Statement (FEIS) (DOE 1980), Safety Analysis Report (SAR) (DOE 1995), and the hazardous waste facility permit application, and other documents that are available from the DOE.

The facility has been divided into four areas designated for protection of human health and the environment: (1) the property protection area, which is surrounded by a chain-link security fence that encloses approximately 34 acres (13.7 hectares) and provides security and protection for all major surface structures; (2) the exclusive use area, which is approximately 277 acres (112 hectares) restricted exclusively for the use of the DOE, its contractors, and subcontractors in support of the project and posted against trespass and use by the general public; (3) the off limits area, which consists of approximately 1,454 acres (5.9 square kilometers) posted and managed as off limits by the DOE; and (4) the WIPP land withdrawal area, the 16-section (41.4-square-kilometer) federal land area under jurisdiction of the DOE and bounded by the WIPP site boundary (see Figure 3-1). The WIPP land withdrawal area is the controlled area for purposes of demonstrating compliance to 40 CFR Part 191. The waste area of the repository lies within the bounds of the off limits area, and within the WIPP land withdrawal area.

The amount of waste to be received at the WIPP is governed by the Land Withdrawal Act, which sets the total volume for contact-handled (CH-) and remote-handled (RH-) transuranic

(TRU) waste combined at a maximum of 6.2 million cubic feet (175,600 cubic meters). 6.2 million cubic feet technically corresponds to 175,564 cubic meters (see page 4-2) but will be routinely represented in this application with four significant digits. The Land Withdrawal Act restricts RH-TRU waste to a maximum activity of 23 curies per liter and not to exceed a total of 5.1 million curies (U.S. Congress 1992) (see Chapter 4 for a description of the waste). There is a volume limit of 0.25 million cubic feet for RH-TRU waste (DOE 1980, 1 – 5). The waste disposal area of the WIPP facility consists of eight panels, each of which contains seven rooms, and the access drifts and crosscuts adjacent to the disposal panels. This latter region has been labeled Panels 9 and 10 for convenience as shown in Figure 3-2. At the end of the operational period, the DOE will begin the process of sealing the shafts, which is a part of final facility closure.

Table 3-1 delineates pertinent site features of the WIPP facility.

Table 3-1. WIPP Site Features

Facility Name	Waste Isolation Pilot Plant (WIPP)
U.S. Environmental Protection Agency (EPA) Identification Number	NM 4890139088
Location	26 miles east of Carlsbad, New Mexico
Latitude	32°22'11"N
Longitude	103°47'30"W
County	Eddy
Section	15-22 and 27-34
Township	22S
Range	31E
Land Withdrawal Area	16 square miles (41.4 square kilometers)
Property Protection Area	34 acres (13.7 hectares)
Depth to repository horizon	2,150 feet below grade level (655 meters)

3.1 General Facility Design

The DOE has designed the WIPP facility to accomplish four primary goals:

1. to receive, handle, and dispose of TRU waste and TRU-mixed waste (in this document, the term TRU waste is used to describe both TRU and TRU-mixed waste unless otherwise noted);

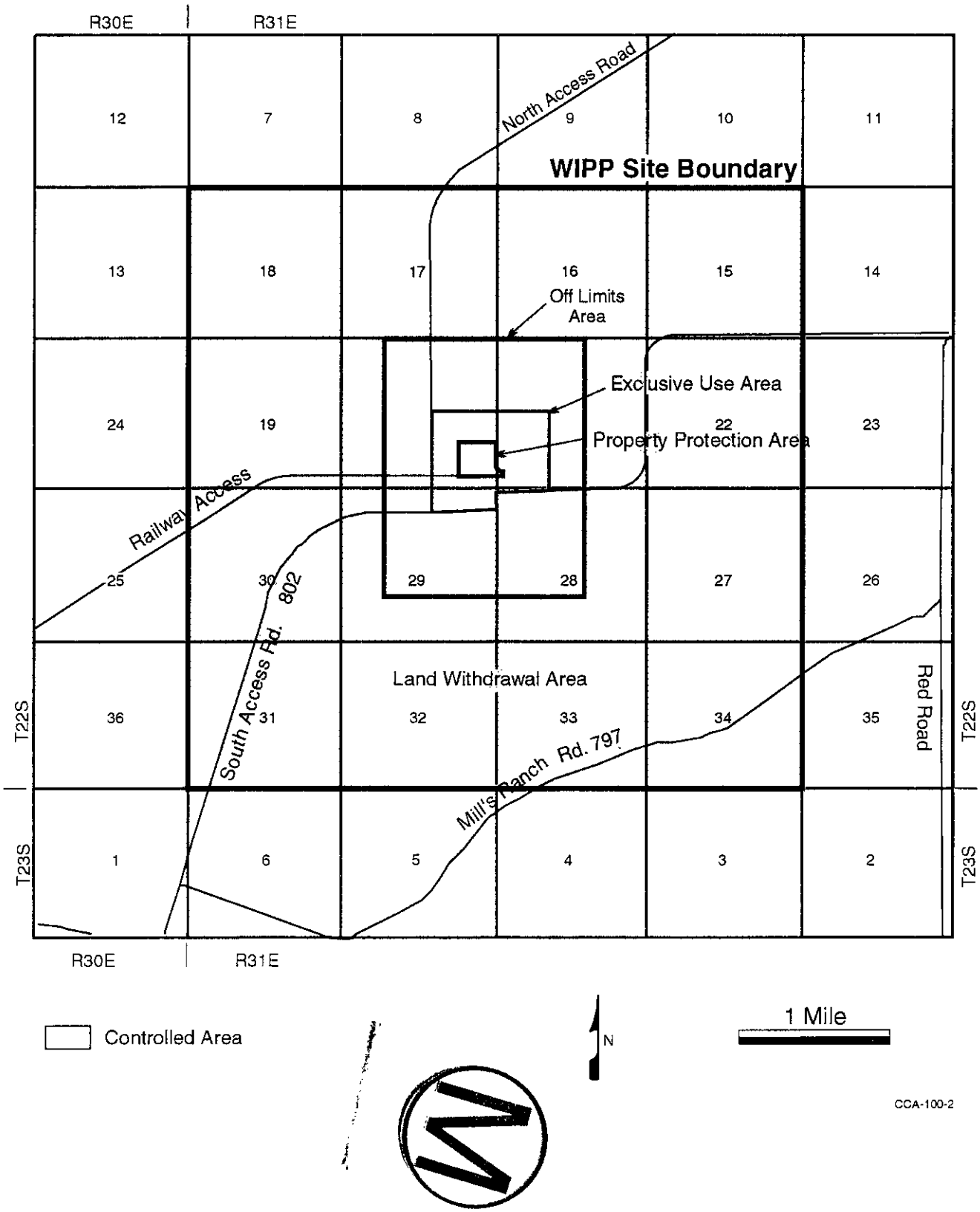

Figure 3-1. WIPP Property Sector Designators

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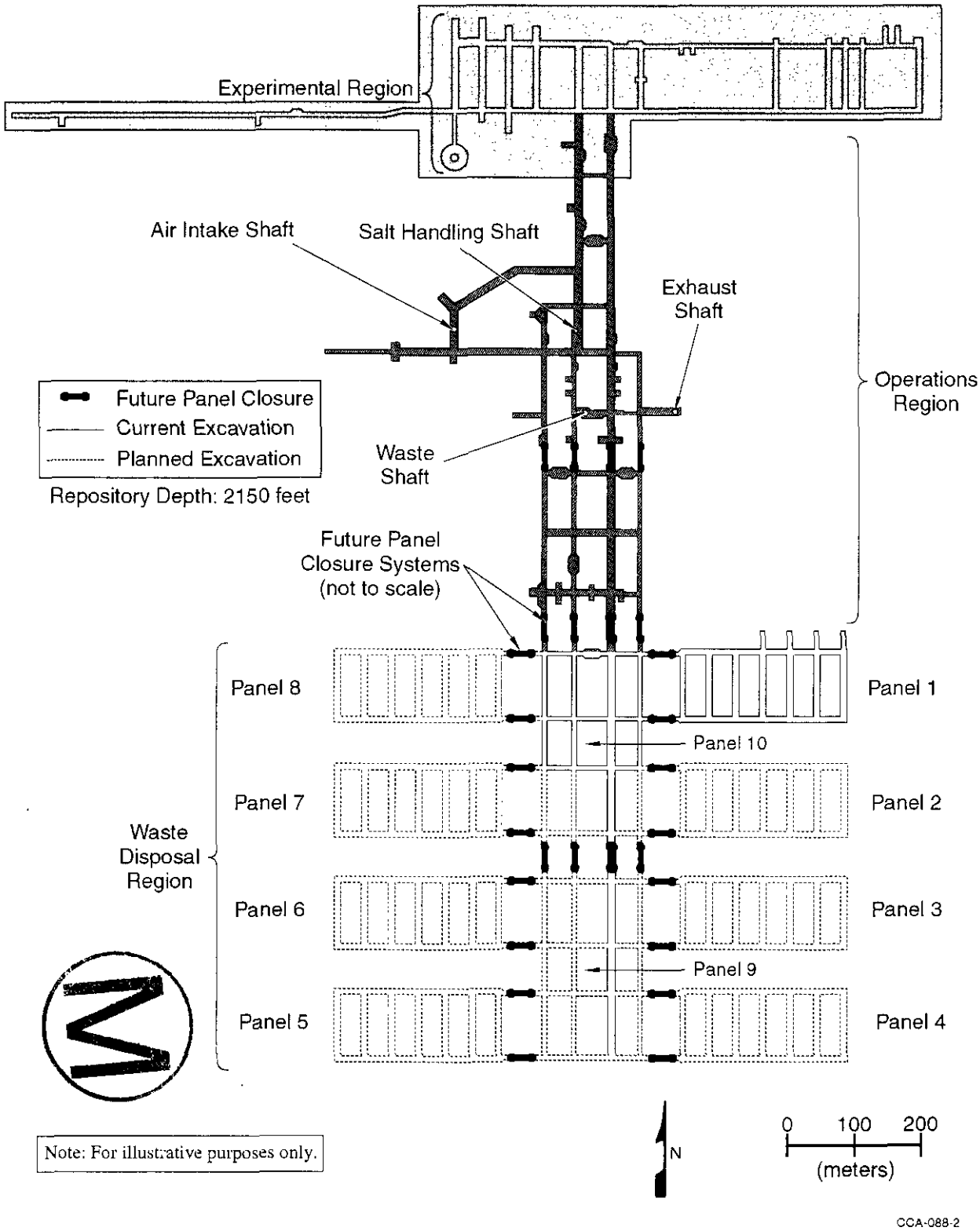

Figure 3-2. Plan View of WIPP Underground Facility and Panel Closure Systems

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2. to protect the health and safety of workers, the public, and the environment;

3. to comply with applicable radiation protection standards; and

4. to comply with other environmental statutes and regulations, and requirements of federal, state, and local agencies (as discussed in Appendix BECR).

The surface facilities at the WIPP accommodate the personnel, equipment, and support services required for the safe receipt and transfer of TRU waste from the surface to the underground. The surface structures are located within a perimeter security fence. This area is the property protection area on Figure 3-1. Access is controlled by security officers 24 hours a day. Four vertical shafts connect the surface facilities to the underground. The underground facilities include the

- waste disposal area,
- shaft pillar area, and
- associated support facilities.

Figure 3-3 provides a spatial view of the WIPP facility.

The DOE acquisition process that was used for the design and construction of the WIPP determined the steps and processes taken to assure that the WIPP was constructed consistent with applicable codes and standards. This process defined key activities and milestones that were applicable and specified such project management activities as initial and final design, independent review, acceptance testing, start-up, and quality assurance (QA). Additional detail is provided in the following sections.

3.1.1 DOE Facility Acquisition Process

Federal facility acquisition policies were applied to the design and construction of the WIPP facility. WIPP structures are designed to meet DOE design and QA requirements as documented in the Final Safety Analysis Report (DOE 1990b). Structures, systems and components are designed to meet the requirements applicable to Design Class II structures, systems, and components for nonreactor nuclear facilities. The design class designations are categorized in accordance with their importance relative to health and safety of the public and on-site personnel during plant operations.

3.1.2 Configuration Control

The DOE mandates that the configuration control of the WIPP facility be accomplished through written procedures and policies as set forth in DOE Orders and regulations. For example, the WIPP System Design Descriptions provide a framework for the configuration control. Any changes to the facility, and subsequently configuration documentation (design descriptions, as-built drawings, specifications, etc.), must be reviewed and approved by cognizant personnel. These documented reviews determine if the change will affect the ability of the facility to comply with applicable environmental, safety, and health requirements. The DOE must approve proposed changes that could affect the Safety Analysis Report and may elect to conduct an independent review of analyses supporting the change.

QA requirements applicable to WIPP facility design and configuration control activities are founded on the basic and supplemental requirements of the American Society of Mechanical Engineers' QA program requirements for nuclear facilities (American Society of Mechanical Engineers' NQA-1 1989). As discussed in Section 5.2, the DOE now implements these requirements through the CAO's QAPD, which is provided in Appendix QAPD. Design QA elements include (1) documentation, review, and approval of design inputs; (2) control of design analyses, design verification, and design changes; and (3) institution of design interface controls and records management practices. These and other applicable configuration management QA requirements are discussed in Section 5.1.6.

3.1.3 Surface Structures

WIPP surface structures accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of waste from the surface to the underground areas. These surface structures serve the operational functions of the WIPP and are not intended to serve long-term performance functions. The surface facilities are located in the Property Protection Area of approximately 34 acres (13.7 hectares) within the perimeter fence. The principal surface structure is the Waste Handling Building; other surface structures include the following:

- hoist houses,
- support building,
- guard and security building,
- office trailers,
- exhaust filter building,
- warehouse and shops,

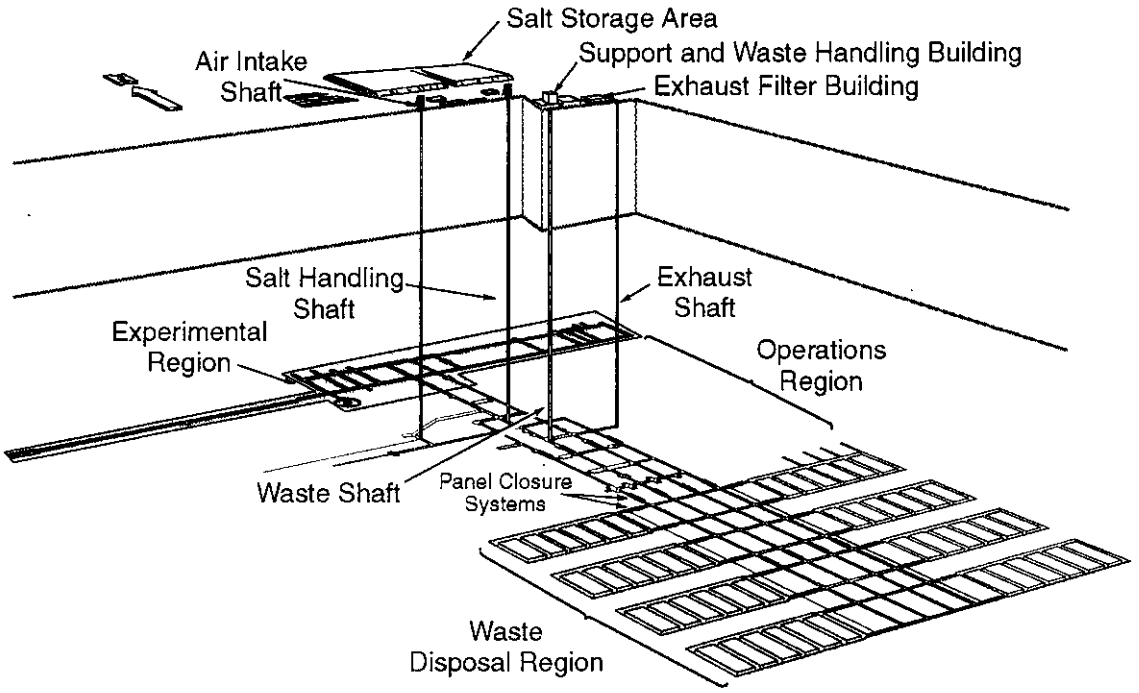

Note: For illustrative purposes only. Not to scale.

CCA-087-2

Figure 3-3. Spatial View of the WIPP Facility

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- water pump house,
- training building,
- engineering building,
- core storage building,
- safety and emergency services building.

In addition to these structures, the DOE has employed a system of berms and ditches to divert storm-water runoff away from the surface facilities. The WIPP facility drainage system is designed so that storm runoff caused by the probable maximum precipitation event will not flood the WIPP facility (DOE 1995).

The WIPP facility does not lie within a 100-year floodplain. There are no major surface-water bodies within five miles (8 kilometers) of the site, and the nearest river, the Pecos River, is approximately 12 miles (19 kilometers) away. The general ground elevation in the vicinity of the surface facilities (approximately 3,400 feet [1,036 meters] above mean sea level) is about 500 feet (152 meters) above the riverbed and 400 feet (122 meters) above the 100-year floodplain. Protection from flooding or ponding caused by probable maximum precipitation (PMP) events is provided by the diversion of water away from the WIPP facility by a system of peripheral interceptor diversions. Additionally, grade elevations of roads and surface facilities are designed so that storm water will not collect on the site under the most severe conditions.

Repository shafts are elevated at least 6 inches (15.2 centimeters) to prevent surface water from entering the shafts. The floor levels of all surface facilities are above the levels calculated for local flooding due to PMP events.

The mean annual precipitation in the region is about 12 inches (30 centimeters), and the mean annual runoff is 0.1 to 0.2 inch (0.25 to 0.50 centimeters). The maximum recorded 24-hour precipitation at Carlsbad was 5.12 inches (13 centimeters) in August 1916. The 6-hour, 100-year precipitation event for the site is 3.6 inches (9.1 centimeters) and is most likely to occur during the summer. The maximum daily snowfall at Carlsbad was 10 inches (76 centimeters) in December 1923.

The WIPP facility design includes four shafts: the waste shaft, the salt handling shaft, the exhaust shaft, and the air intake shaft (AIS). Each shaft includes a shaft collar, a shaft lining, and a shaft key section. The shaft and shaft liner design information is discussed in detail in the Site Characterization and Validations studies from 1983 to 1987. The shaft design features have not changed.

The reinforced concrete shaft collars extend from the surface to the top of the underlying consolidated sediments. Each collar serves both to retain adjacent unconsolidated sands and soils and to prevent surface runoff from entering the shaft. The shaft linings extend from the base of the collar to the top of the salt beds approximately 850 feet (259.1 meters) below the surface. The shaft lining serves to inhibit water seepage into the shafts from water-bearing formations, such as the Magenta and Culebra members of the Rustler. The liners are also designed to retain loose rock. The shaft liners are concrete except in the salt handling shaft, in which a steel shaft liner has been grouted in place.

The shaft key is a circular reinforced concrete section emplaced in each shaft below the liner in the base of the Rustler and extending about 100 feet (30.5 meters) below and into the Salado. The shaft key functions to resist lateral pressures and to contain the water seals.

Two separate water-seal rings are incorporated in each key. Performance of the seals is monitored by inspection of the bottom of the key for seepage. If groundwater is detected flowing past the upper ring, this condition is corrected by injecting chemical sealants or cement grouts to stop the leakage.

On the inside surface of each shaft, excluding the salt handling shaft, there are three water collection rings. The first is located just below the Magenta interval, the second just below the Culebra interval, and the last at the lowermost part of the key section. These collection rings function to collect any groundwater that may seep into the shaft through the liner. Therefore, flooding of the WIPP repository as a result of PMP events is not a credible event because of the site-runoff design.

Flood-control structures are inspected as part of a general facility inspection at least annually. During this inspection, the structures are checked to assure that there has been no wind or rain erosion or animal-caused damage that would cause the structures to fail. Further, the areas around the structures are inspected to ensure they are free of vegetation, debris, or other items that would impede the diversion of water. Experience with these structures has shown that annual structural inspection are adequate for the climate and soil conditions at the WIPP facility; however, inspections are also conducted after severe natural events, such as severe storms or earthquakes.

3.2 Repository Configuration

A preliminary design of the WIPP repository was presented in the FEIS (DOE 1980). Validation efforts for the WIPP repository preliminary design began in 1981 with the Site and Preliminary Design Validation (SPDV) program. The SPDV program was implemented to further characterize and validate the WIPP site geology and to provide preliminary validation of the underground excavation. The SPDV program involved the excavation of four full-sized disposal rooms, excavated 13 feet (4 meters) high, 33 feet (10 meters) wide, and 300 feet (91 meters) long, and separated by 100-foot (31-meter)-wide pillars. Data obtained from geologic field activities and geomechanical instrumentation were analyzed to determine the suitability

of the design criteria and design bases and to provide confirmation of the underground opening reference design. Analyses of these preliminary designs performed by the WIPP architect and engineer are included in Appendix DVR. These analyses considered expected creep closure rates in determining disposal room sizes. Information in Appendix DVR (Section DVR.6.4.2) meets the criterion specified in 40 CFR § 194.14(b)(2). Figures 12-21 and 12-22 in the Final Design Validation Report in Appendix DVR show the creep closure histories used for designing the disposal rooms. The specified size was selected to ensure no CH-TRU containers would breach due to creep closure while a panel is being filled with waste. A nominal five-year life is used for operational purposes for mining, emplacement, and closure with no risk of CH-TRU waste containers breaching. Remote-handled containers will not breach in this time period due to the canister wall thickness and the 2 to 4 inch (5.08 to 10.16 centimeter) creep tolerance in each RH-TRU emplacement hole.

The WIPP underground facilities are located on the repository horizon 2,150 feet (655 meters) beneath the surface (see Figure 3-2). In Chapter 2.0, Figure 2-8 shows a stratigraphic column which displays the repository and its position relative to mean sea level. These facilities include the waste disposal region, the operations region, an experimental region, and associated support facilities. The underground support facilities service and maintain underground equipment for mining and disposal operations, monitor for radioactive contamination, and allow limited decontamination of personnel and equipment.

Waste panels consist of seven rooms. Each room will have nominal dimensions of 300 feet (91 meters) long, 33 feet (10.1 meters) wide, and 13 feet (4.0 meters) high. Pillars between rooms are 100 feet (30 meters) thick. Eight waste panels will be separated from each other and the main entries by nominally 200-foot (61-meter) pillars. In addition to the eight panels, the main north-south and east-west access drifts in the waste regions are available for waste disposal. These have been designated Panels 9 and 10 for permitting and modeling purposes (see Figure 3-2). Section 6.4.2.1 describes the treatment of all waste panels in BRAGFLO. Additional information can also be found in Appendix MASS.5. Rockbolts, or related types of ground support, are used as necessary to maintain safe underground personnel access. In the panels, this will typically consist of localized bolting when needed. All panels will be closed using the panel closure system described in Section 3.3.2.

The underground is connected to the surface by four vertical shafts: the waste shaft, the salt handling shaft, the exhaust shaft, and the AIS. The waste shaft, salt handling shaft, and the air intake shaft have permanently installed hoists capable of moving personnel, equipment, and materials between the surface and the repository. All shafts will eventually be sealed using the seal design described in Section 3.3.1. A summary of information describing existing WIPP shafts is given in Table 4-2 of Appendix SEAL.

Mining of the shafts and underground passages within the repository gives rise to a disturbed rock zone (DRZ) that is important to repository performance. The DRZ forms as a consequence of unloading the rock in the vicinity of the excavation. Increased permeability is created by microfractures along grain boundaries and by bed separation along lateral seems.

The DRZ development begins immediately after excavation and continues as salt creeps into the opening. The DRZ surrounding the shafts is symmetrical and has been characterized and incorporated into the shaft seal design as discussed in Appendix SEAL. As shaft seal elements resist inward creep, the stress state becomes compressive and gives rise to fracture healing, and a return of the disturbed salt to its original extremely low permeability. The lateral DRZ along passages in the underground includes fracture in nonhalitic rock, such as anhydrite, and bed separation on clay seams. These zones will not naturally heal in a manner similar to healing of halite. Panel closure systems discussed in Section 3.3.2 will prevent further development of the DRZ in panel entries, thereby restricting flow from the panels to that existing in the DRZ at the time of panel closure construction.

3.3 Engineered Barriers

In addition to the natural barriers provided by the geology and hydrology of the disposal system, the DOE's design of the WIPP includes engineered barriers to significantly delay the migration of radionuclides to the accessible environment. These engineered barriers are integral parts of the disposal system as modeled in Section 6.4 and are included in the demonstration of compliance to the containment standards in Section 6.5. Because the WIPP uses the concept of multiple barriers, that is, both natural and engineered barriers, the requirements in 40 CFR § 191.14(d) are met. In addition, the incorporation of both engineered and natural barriers satisfies the criterion stated in 40 CFR § 194.44(a).

> Disposal systems shall incorporate engineered barrier(s) designed to prevent or substantially delay the movement of water or radionuclides toward the accessible environment.

The DOE has elected to incorporate four types of engineered barriers in the design of the disposal system:

(1) shaft seals,

(2) panel closures,

(3) backfill around the waste, and

(4) borehole plugs.

These four types of engineered barriers are described in the following sections.

Shaft seals and borehole plugs will limit migration of liquid and gases in the WIPP shafts and boreholes. Panel closures will limit the communication of brine and gases among waste disposal panels. Designs of shaft seals, borehole plugs, and panel closures use common engineering materials that possess low permeability, appropriate mechanical properties, and durability.

The DOE performed an Engineered Alternatives Cost/Benefit Study (see Appendix EBS) to examine the benefits and detriments associated with an array of engineered barrier alternatives. This study, in combination with past sensitivity and other analyses, was used to make a decision about an additional engineered barrier, a chemical backfill that will improve performance of the WIPP. The DOE has chosen an MgO backfill to buffer the chemical composition of brine that may enter the repository over the 10,000-year regulatory period. The principal beneficial performance characteristic resulting from this backfill is a reduction in actinide solubility in brine. Specific performance information on backfill is presented in Section 6.4.3.

3.3.1 Shaft Seals

The purpose of the shaft seal system is to limit fluid flow within four existing shafts after the WIPP is decommissioned. Such a seal system will not be implemented for several decades, but in order to establish performance requirements now that can be achieved at a later date, a shaft seal system has been designed possessing excellent durability, performance, and constructability using existing technology. The design approach is conservative, with redundant functional elements and various common materials. Because this design is not the only possible combination of materials and construction strategies that would adequately limit fluid flow within the shafts, future developments may change the design.

Material specifications and construction techniques for the shaft seal system are given in Appendix SEAL in Chapter 5 (Materials Specification) and Chapter 6 (Construction Techniques). Chapter 5 of Appendix SEAL also provides the rationale and quantification methods used to develop parameter distribution functions. Appendix SEAL also has Appendices A and B, which are materials specification and construction techniques, respectively. Appendix PAR provides a complete summary of parameters used as inputs to the performance assessment codes.

The presently envisaged shaft seal system is described in this section, including the configuration of material, seal material specifications, construction methods, rock mechanics analyses, and fluid flow evaluations.

The shaft seal design package in Appendix SEAL thoroughly explores function and performance of the WIPP shaft seal system and provides well-documented assurance that such a shaft seal system can be constructed using available materials and methods. Sections of Appendix SEAL provide hydrologic and structural calculations, material specifications and properties, construction methods, and engineering drawings. Documentation of material properties and their satisfactory application in the site-specific environment for regulatory time periods aid in assuring that the WIPP shaft seal system will meet performance expectations. Documentation of the analyses conducted and the results can be referenced in Appendix SEAL (Chapter 2.4 of Appendix A, and in Appendix SEAL, Chapter 3.1.2 of Appendix D).

3.3.1.1 Site Setting

The geologic setting and groundwater hydrology in the proximity of the WIPP site are presented in Sections 2.1 and 2.2. These sections describe low brine-flow quantities and low hydrologic gradients, both very positive features with regard to sealing shafts or boreholes. As noted in Section 2.2, one of DOE's site selection criteria was a favorable geologic setting that minimizes fluid flow as a transport mechanism. Although these positive hydrologic attributes are documented, the shaft seal design concentrates on further mitigating fluid transport. For the purposes of the hydrologic sealing evaluation, the lithologies have been divided into the Rustler (and overlying strata) and the Salado. The fluid transport phenomena of seal materials within Salado lithologies are the primary design concerns.

3.3.1.2 Design Objectives

Design objectives for the shaft seal system address the need for the WIPP to comply with system requirements and to follow accepted engineering practices using demonstrated technology. Shaft seal design objectives are summarized as follows:

- limit radionuclides from reaching regulatory boundaries,
- restrict groundwater flow through the sealing system,
- use engineered materials possessing good long-term stability,
- protect against structural failure of system components,
- minimize subsidence and prevent accidental entry, and
- use available construction methods and materials.

Details of the design respond to these qualitative design objectives and present an implementation approach. The shaft seal system design was completed under the QA program described in Chapter 5.0 and includes review by independent, qualified experts. Reviewers examined the complete design including conceptual, mathematical, and numerical models, and computer codes. The design reduces uncertainty associated with any particular element by using multiple sealing system components constructed from different materials. The shaft seal system design review is documented in Appendix SEAL (Chapter 1.4).

3.3.1.3 Design Description

A schematic of the shaft seal system as configured for the AIS is shown in Figure 3-4. Slight differences in seal element geometry occur within the four shafts owing to different shaft diameters or stratigraphic variations.

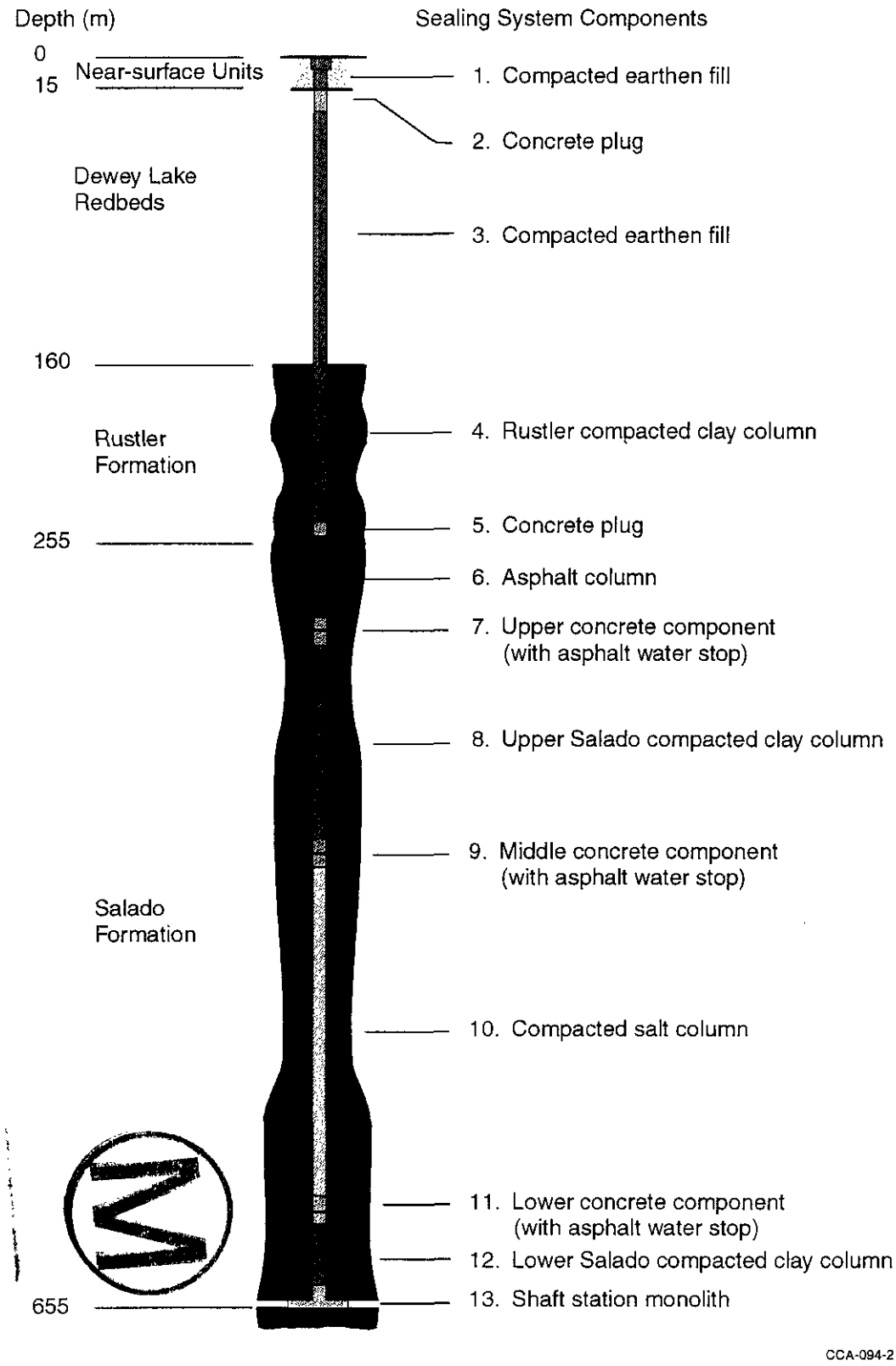

Figure 3-4. Proposed Seal Design for the WIPP AIS

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The shaft seal system has 13 elements that fill the shaft with engineered materials possessing high density and low permeability. Components of the seal system within the Salado provide the primary barrier by limiting fluid transport along the shaft during the 10,000-year regulatory period. Components of the seal system within the Rustler limit commingling of groundwater between water-bearing members. Components of the seal system overlying the Rustler fill the shaft with common materials of high density, consistent with good engineering practices. A brief description of the general shaft seal system is given in this section. The detailed design drawings for each shaft seal system are provided in Appendix SEAL (Appendix E).

3.3.1.3.1 *Shaft Station Monolith*

At the bottom of each shaft, a salt-saturated concrete monolith (Component #13) is placed to fill the station excavations. All concrete is placed using a slick line from the surface. The salt-saturated concrete is called Salado mass concrete (SMC) because it has been tailored to match site conditions. The salt-handling shaft and the waste-handling shaft have sumps that will also be filled with SMC as part of the monolith. Geometries of the monolith for the four shafts vary slightly because of the differing diameters and station configurations.

3.3.1.3.2 *Clay Columns*

A commercial well-sealing-grade sodium bentonite clay is used for Components #12 and #8 in the Salado and Component #4 in the Rustler. Construction specifications for these three seal components call for placement of compressed blocks to achieve design requirements. These clay columns effectively limit groundwater movement from the time they are placed and provide an effective barrier to fluid migration throughout the 10,000-year regulatory period. Lengths vary for each shaft based on individual stratigraphy. The lower Salado compacted clay column ranges from 93 to 107 feet (28 to 33 meters) thick, the upper Salado compacted clay column ranges from 335 to 345 feet (102 to 105 meters) thick, and the Rustler compacted clay column ranges from 234 to 235 feet (71 meters) thick in the four shafts. Locations of the Salado compacted clay columns were selected to limit brine migration and the potential for gas migration into the consolidating compacted salt column (Component #10). The lower Salado compacted clay column stiffness is sufficient to promote early healing of fractures in the surrounding rock salt, thus removing the shaft DRZ as a pathway for gases or brines (Appendix SEAL, Section 7.4.3). Handling of the DRZ is addressed in Appendix SEAL (Chapter 5 of Appendix D, Tables D-18 through D-21).

The Rustler groundwater compacted clay column (Component #4) limits groundwater communication between the Magenta and the Culebra. The Culebra accounts for most of the Rustler groundwater movement of significance in the vicinity of the WIPP site. Members above the Magenta (the Forty-niner), between the Magenta and Culebra (the Tamarisk), and below the Culebra (the unnamed lower member) are aquitards in the vicinity of the WIPP

shafts. Existing shaft lining is removed from the water-bearing zones for a distance of 10 feet (3 meters) into each of the aquitards to allow the clay to contact the native rock and thus seal the shaft wall interface at these locations.

3.3.1.3.3 Concrete-Asphalt Water Stop Components

The upper (#7), middle (#9), and lower (#11) concrete components in the Salado are composed of three elements: an upper concrete plug, a central asphalt water stop, and a lower concrete plug. Concrete fills irregularities in the shaft wall, while use of the SMC assures good bonding with salt. Salt creep against the rigid concrete components establishes a compressive stress state and promotes early healing of the shaft DRZ surrounding the concrete plugs. Healing of the DRZ is addressed in Appendix SEAL (Chapter 5 of Appendix D, Tables D-18 through D-21). The asphalt water stop intersects the shaft cross section and the shaft DRZ. Like the shaft station monolith, SMC is placed using a slick line while asphalt is placed using a heated slick line.

Concrete Components #7, #9, and #11 have an overall design length of 50 feet (15 meters). The concrete plugs on either side of the asphalt are identical. They fill the shaft cross section and have a design length of 23 feet (7 meters). The plugs are keyed into the surrounding rock. An asphalt water stop is located between concrete plugs. In all cases, a kerf extending one shaft radius beyond the shaft wall is cut into the surrounding salt. The kerf is 1 foot (0.3 meters) thick at its tip, 2 feet (0.6 meters) thick at the shaft wall, and 4 feet (1.2 meters) thick across the shaft. The kerf, which cuts through the existing shaft DRZ, results in the formation of a new DRZ along its perimeter, but at these depths within the Salado, the new DRZ will heal shortly after construction (see Appendix SEAL, Chapter 5 of Appendix D, Tables D-18 through D-21), and thereafter the water stop will provide a low permeability barrier to brine or gas migration (Appendix SEAL, Section 4.3.1).

3.3.1.3.4 Compacted Salt Column

Each shaft seal includes a length of compacted salt (Component #10) that varies from 559 to 563 feet (170 to 172 meters) in the four shafts. Each compacted salt column is constructed of crushed Salado salt with about 1.5-weight-percent water added during construction. Demonstrations have shown that mine-run WIPP salt can be dynamically compacted to a density equivalent to approximately 90 percent of the average density of intact Salado salt. The remaining void space is effectively removed through consolidation caused by creep closure. The location of the compacted salt column near the bottom of the shaft assures the fastest achievable consolidation of the compacted salt column after closure of the repository. Salt creep increases rapidly with depth; therefore, at any given time, creep closure of the shaft is greater with depth. The salt column offers limited resistance to brine migration immediately after placement but becomes less permeable as density increases. Analyses indicate that the salt column becomes an effective long-term barrier in less than 100 years (Appendix SEAL, Section 7.4.2).

3.3.1.3.5 Asphalt Column

An asphalt-aggregate mixture is specified for the asphalt column (Component #6), which bridges the Rustler and Salado contact. Length of the asphalt column ranges from 138 to 143 feet (42 to 44 meters) in the four shafts. The asphalt column is located above the upper concrete and asphalt component (#7) and extends approximately 16 feet (5 meters) above the Rustler and Salado contact. Existing shaft linings and keys are removed from 20 feet (6 meters) above the top of the asphalt column to just below the lowest chemical seal ring. The asphalt column provides an essentially impermeable seal for the shaft cross section and along the shaft wall interface.

3.3.1.3.6 Concrete Plugs

A 20-foot (6-meter)-long concrete plug (Component #5) is located just above the asphalt column. The concrete plug, constructed of SMC, is placed directly on top of the asphalt column and keyed into the surrounding rock. The plug permits work to begin on the overlying clay column before the asphalt has completely cooled and allows the option of constructing the overlying clay column using dynamic compaction, although the present design calls for construction using compressed clay blocks. Another concrete plug (Component #2) is located near the surface extending 40 feet (12 meters) downward from the top of the Dewey Lake. It is placed inside the existing shaft lining; the shaft liner will be removed as necessary.

In all lining removal areas, the shaft is grouted before removal of the shaft lining to assure structural stability of the shaft wall. The grout curtain begins 10 feet (3 meters) above the lining removal areas and extends 10 feet (3 meters) below the lining removal areas. Grouting is used to stabilize the shaft walls and thus provide safer working conditions; it is not considered a flow barrier within the sealing system.

3.3.1.3.7 Earthen Fill

Approximately 500 feet (160 meters) of the upper shaft is filled with compacted earthen fill. These components (#3 and #1) use locally available fill. Component #3 is dynamically compacted (the same method used to construct the salt column) to a density approaching that of the surrounding materials. The length of this column varies from 447 to 486 feet (136 to 148 meters) in the four shafts. The uppermost earthen fill (Component #1) extends from the shaft collar through surface deposits downward to the top of the Dewey Lake. Fill near the surface is compacted with a sheepsfoot roller or vibratory plate compactor. The length of this column varies from 40 to 92 feet (12 to 28 meters) in the four shafts.

3.3.1.4 Materials

The shafts will be filled with dense materials possessing low permeability and/or other desirable attributes. The other desirable attributes include strength, ease of construction, longevity, and cost. These attributes are described in Appendix SEAL (Appendix A). Seal

materials include concrete, clay, asphalt, compacted salt, cementitious grout, and earthen fill. Other materials include cementitious grout and earthen fill. Concrete, clay and asphalt are common construction materials, used extensively in hydrologic applications. Concrete is the most common structural material being proposed for the WIPP shaft seal system, and its use and specification have a long history. Clay is often specified as a construction material and bentonitic clay is often specified as a low permeability liner for hazardous waste sites. Asphalt is a widely used paving and waterproofing material used in the mining industry as a seal filler between a concrete liner and the surrounding rock. Compacted and reconsolidated crushed-salt are uniquely applied as seal components. Specifications are provided for all seal materials in Appendix SEAL (Section 5 and Appendix A). Each material is described in the appendix in terms of its

- functions,
- material characteristics,
- construction,
- performance requirements,
- verification methods, and
- references.

Both natural processes and engineered barriers combine to form the shaft seal system. The shaft seal system contains functional redundancy and uses different materials to reduce uncertainty in performance. Materials specifications are used to develop probability distributions and input parameters for performance assessment calculations. Input to performance assessment calculations and treatment of shaft seal elements within performance assessment models are summarized in Section 6.4.4.

3.3.1.5 Structural Analysis

The shaft seal system has been evaluated with regard to structural issues. Mechanical, thermal, physical, and hydrological features of the system are included in a broad suite of structural calculations. Conventional structural mechanics applications normally calculate the loads on system elements and compare the loads to failure criteria. Several such conventional calculations have been performed and show the seal elements to exist in a favorable, compressive stress state, which is low in comparison to the strength of the seal materials. Thermal analyses have been performed to examine the effects of concrete heat of hydration and heat transfer for asphalt elements. Physical coupling between shaft DRZ and fluid flow and between the density and permeability of the consolidating compacted salt column is evaluated within the scope of structural calculations. Creation of a fracture zone around the shaft, its increased transmissivity relative to unfractured rock, and its healing characteristics

are analyzed. Similarly, time-dependent density and permeability are calculated for the reconsolidating salt column.

Structural calculations conducted as part of the design study generally address one or more of the following concerns: (1) stability of the component, (2) influences of the component on hydrological properties of the seal and surrounding rock, or (3) construction methods. Stability calculations address

- potential for thermal cracking of concrete seals,
- structural stability of seal components under loads resulting from creep of surrounding salt, other seal components through gravity or clay swelling, dynamic compaction, and potential repository-generated gas pressures,
- shaft closure-induced consolidation of compacted salt column, and
- impact of pore pressures on consolidation of compacted salt column.

Structural calculations used to define input conditions to the hydrological calculations include

- spatial extent of the shaft DRZ within the Salado surrounding the shafts as a function of depth, time, and seal material moduli,
- fracturing and shaft DRZ development within Salado interbeds, and
- compacted salt fractional density as a function of depth and time.

Construction analyses examine

- emplacement and structural performance of asphalt water stops and
- potential benefits of backfilling shaft stations.

Details of the structural analyses are provided in Appendix SEAL (Section 7). Calculations pertaining to bulleted items use computational models to demonstrate structural performance of the shaft seal elements.

3.3.1.5.1 DRZ Behavior

The development and subsequent healing of a DRZ in the rock mass surrounding the WIPP shafts are significant concerns in the shaft seal design. It is well known that a DRZ develops in the rock adjacent to the shaft immediately after excavation. After closure of the shaft this fractured zone is initially a major flow path regardless of the material placed within the shaft because the materials selected as seal components possess very low intrinsic permeabilities

and the intact Salado halite is essentially impermeable. Additional discussed is provided in Appendix SEAL (Chapter 5 of Appendix D). Knowledge of DRZ behavior allows the design to increase confidence in the overall shaft seal system. For example, low permeability components (termed water stops) are included in the design to intersect the DRZ surrounding the shaft. These water stops are placed to alter the flow direction either inward toward the shaft seal or outward toward intact salt. Structural calculations evaluate performance of the water stops in terms of (1) intersecting the DRZ around the shaft, (2) inducing a new DRZ because of special excavation, and (3) promoting healing of the DRZ.

The DRZ behavior is evaluated for all of the various materials placed in the shaft because DRZ creation and healing depend on the stress state. A DRZ within salt, the major lithology in the Salado, continues to develop creep without a supportive element that would serve as a load-bearing member. Within the formations above the Salado, the DRZ is assumed to be time-invariant because the behavior of the rock masses encountered there is predominantly elastic. The temporal and spatial extent of the DRZ along the entire shaft length is addressed in the shaft seal system. Rigid seal components in the shaft provide a restraint to salt creep closure, thereby inducing healing stress states in the salt.

3.3.1.5.2 Compacted Salt Behavior

Creep-driven consolidation of the compacted salt column is an important long-term consideration of the shaft seal system. This behavior has been examined in detail, with three material models selected to describe the phenomenon (see Appendix SEAL, Appendix D, Chapter 3.1.2). Results of tests on WIPP salt were used to evaluate constitutive models for reconsolidating salt (see Appendix SEAL, Appendix D, Chapter 4.2). Coupled with finite element models for the surrounding geologic setting, the models for reconsolidating salt provide estimates of effective permeability of the salt component of the shaft seal system. As an example, structural calculations determine fractional density of the crushed-salt seal as a function of time and depth and use results of laboratory tests to determine permeability. Based on these calculations, a desirable fractional density (hence, permeability) is achieved over a substantial length of the compacted salt seal within several decades of placement.

3.3.1.6 Hydrologic Evaluations

The ability of the shaft seal system to satisfy design guidance is determined by the performance of the actual seal components within the physical setting in which they are constructed. The guidance used in seal system design is documented in Appendix SEAL (Chapter 3). The important elements of the physical setting are hydraulic gradients of the region, properties of the lithologic units surrounding a given seal component, and potential gas generation within the repository. Hydrologic evaluation focuses on processes that could result in fluid flow through the shaft seal system and the ability of the seal system to limit any such flow. If the carrier fluids are limited, transport of radiological or hazardous constituents will be similarly limited.

The physical processes that could impact seal system performance are presented in detail in Appendix SEAL (Chapter 8). These processes have been incorporated into four models, which are used to evaluate the design. Briefly, these models evaluate

(1) downward migration of groundwater from the Rustler,

(2) gas migration and reconsolidation of the compacted salt seal component,

(3) upward migration of brines from the repository, and

(4) flow between water-bearing zones in the Rustler.

3.3.1.6.1 Downward Migration of Rustler Groundwater

The shaft seal system is designed to limit groundwater flowing into and through the shaft sealing system. The principal source of groundwater to the seal system is the Culebra. The Magenta is a less significant groundwater source. No significant sources of brine or water exist within the Salado; however, brine seepage has been noted at a number of the marker beds and is included in the models. Downward migration of Rustler groundwater is limited to ensure liquid saturation of the Salado salt column does not impact the consolidation process and to limit quantities of brine reaching the repository horizon. Because the limitation of liquid flow into the salt column necessarily limits liquid flow to the repository, the volumetric flux of liquid into and through the salt column was selected as the design performance measure for this model.

At steady-state, the flow rate is most dependent on the permeability of the system. Potential flow paths within the seal system consist of the seal material, an interface with the surrounding rock, and the host rock DRZ. Low permeability is specified of the engineered materials and construction methods ensure a tight interface; thus, the flow path most likely to impact performance is the shaft DRZ. Fluid flow analyses conducted are provided in Appendix SEAL (Appendix C). Rock mechanics calculations predict that the DRZ in the Salado will not be vertically continuous because of intermittent layers of stiff anhydrites (marker beds). Concrete and asphalt water stops are included in the design as a means to mitigate DRZ impacts. Effects of marker beds and asphalt water stops on limitation of downward migration are explicitly simulated through permeability variation of the layers of Salado shaft DRZ. Initial, upper, and lateral boundary conditions of the hydrologic model are consistent with field measurements of the physical system. At the base of the shaft a constant, atmospheric pressure is assumed. The hydrologic model predicts a maximum cumulative flow of less than 353 cubic feet (10 cubic meters) through the sealed shafts during the first 200 years following closure.

3.3.1.6.2 *Gas and Brine Migration*

A multiphase flow model of the lower seal system evaluates the performance of components extending from the middle asphalt-concrete water stop (located at the top of the salt column) to the repository horizon for 200 years following closure. The 200-year period was selected arbitrarily; however, this ensures that the calculations are continued well beyond the time required for salt component consolidation (see Appendix SEAL, Appendix C). During this time period, the principal fluid sources to the salt column consist of gas (potentially generated by the waste) and lateral brine migration within the Salado. The predicted downward migration of Rustler groundwater (discussed above) is included in this analysis. Performance measures for the model are the volume of gas that migrates through the seal components to the middle asphalt-concrete component and the time-dependent permeability of the crushed-salt component. These performance measures address the need to limit fluid flow upward from the repository and to predict the performance of the salt component.

In the physical setting, pore fluids can create pore pressure and reduce the rate of the compacted salt column reconsolidation. Calculations demonstrate that repository gas pressure will not impact reconsolidation. The fluid flow analyses conducted to support seal system design efforts can be reviewed in Appendix SEAL (Appendix C). As a result, the salt column achieves its long-term effective permeability at 100 years following seal construction.

3.3.1.6.3 *Upward Migration of Brine*

Fluid pressure of the Salado is higher than fluid pressure in the Rustler so that upward migration of brines could occur through an inadequately sealed shaft. Results from modeling (discussed above) demonstrate that the crushed-salt seal will reconsolidate to a very low permeability within 100 years following repository closure (see Appendix SEAL, Appendix C). Structural results reported in Appendix SEAL (Section 7.4) show that the DRZ surrounding the compacted clay and compacted components will completely heal within the first several decades (see Appendix SEAL, Appendix D, Table D-20). As a result, upward brine flux at the Rustler and Salado contact in the sealed AIS is approximately 35 cubic feet (1 cubic meter) over the 10,000-year regulatory period. This brine originates in the marker beds; no brine from the repository migrates up the shaft.

3.3.1.6.4 *Intra-Rustler Flow*

Based on estimated undisturbed and measured disturbed head differences between the various members of the Rustler (see Table C-2 of Appendix C of Appendix SEAL), nonhydrostatic conditions exist within the Rustler. Therefore, the potential exists for vertical flow within water-bearing strata within the Rustler. The dolomitic members of the Rustler have the greatest potential to produce significant interflow within the Rustler in response to nonhydrostatic conditions. The relatively low undisturbed permeabilities of the mudstone and

anhydrite units separating the Culebra and the Magenta naturally limit crossflow. However, the construction and subsequent closure of the shaft could provide a vertical conduit connecting water-bearing units.

The primary motivation for limiting formation crossflow within the Rustler is to prevent mixing of formation waters within the Rustler. In the vicinity of the shafts, the potential for fluid migration between the two most transmissive units is from the Magenta unit with the lower total dissolved solids to the Culebra unit with the higher dissolved solids. This calculation shows that the potential flow rate between the Culebra and the Magenta is expected to be of such a limited quantity that (1) it will not affect either the hydraulic or chemical regime within the Culebra or the Magenta and (2) it will not be detrimental to the seal system itself. The fluid flow analysis conducted for the purposes of seal system design is included in Appendix SEAL (Appendix C).

3.3.2 Panel Closure System

Panel closures have been included for the purpose of Resource Conservation and Recovery Act (RCRA) disposal unit closure and to prevent potentially unacceptable levels of volatile organic compound release during waste management operations. The panel closure system was not designed or intended to support long-term repository performance. The panel closures do, however, provide a solid within the drifts which prevent the preexisting DRZ from increasing in permeability after closure system installation. The DRZ permeability value and the supporting rationale are provided in Appendix PAR. Additional information is provided in Appendix MASS (MASS Attachment 7-1). A panel closure system will be emplaced in the panel access drifts, in accordance with the design (see Appendix PCS) in the WIPP facility closure plan prepared for the RCRA permit application. The panel closure system has been designed according to a number of operational objectives set out by the DOE, the main elements of which are

1. the panel closure system shall restrict flow from the panels,

2. the panel closure system should perform its intended functions under loads generated by creep closure, and in general under the most severe ground conditions expected in the waste disposal area during the operational phase,

3. the panel closure system should be capable of containing and continuing to perform its intended function under conditions of a postulated methane explosion,

4. the panel closure system should be constructed of materials that are compatible with its emplacement environment and function,

5. engineering design of the panel closure system should include structural analyses using WIPP specific data, and should address such issues as the thermal cracking of concrete, and

6. the panel closure system should be designed and constructed using conventional mining practices, with full consideration of shaft and underground access and services. It should be constructed to generally accepted national design and construction standards, with a QA and quality control program used to verify material properties and construction practices.

The design of this closure system, as described in Appendix PCS, includes a number of detailed engineering studies that analyze operational requirements and structural and material requirements. As a result of these analyses, a composite panel closure system was designed, consisting of a rigid concrete component, emplaced with or without removal of the DRZ, and either an explosion-isolation wall or a construction-isolation wall. The various options for the closure designs are shown in Figures 3-5. The excavation configurations for these closure designs are shown in Figure 3-6. These designs allow for components to be added or removed, or their shapes to be adjusted. Decisions about the shape of the rigid concrete component will depend on the particular ground conditions at the time of installation and the time when installation occurs relative to final facility closure. The concrete for the component is chosen to be compatible with the environment. Contact grouting around the concrete component is carried out as needed. The material for the isolation walls is concrete construction block.

Figures 3-5 and 3-6 show a diagram of the panel closure design and installation envelopes. Appendix PCS provides the detailed design and the design analysis for the panel closure system. The panel closure design is such that components can be added or removed or their shapes adjusted depending on the particular ground conditions at the time of installation. For example, in Figure 3-5, Option A represents the likely closure of panels less than 20 years old at the time of final facility closure and whose entries are sufficiently intact such that DRZ removal is not needed. These would likely include Panels 6 through 8. Option B represents the preferred option for panels that will be closed for more than 20 years prior to final facility closure and whose entries are reasonably intact at time of closure. These will likely be Panels 2 through 5. Option C may be desirable for panels whose entries require DRZ removal and whose closure precedes final facility closure by less than 20 years. This is the likely configuration of the closure for Panels 9 and 10. Finally, Option D may be appropriate for panels whose entires require significant removal of the DRZ and whose closure will precede final facility closure by more than 20 years. Panel 1 is the most likely candidate for this type of closure.

The 20-year limit in the design selection process is based on what the DOE believes to be conservative analytical results that indicate methane, being generated by waste degradation at the rate of 0.1 mole per drum per year, will not reach flammable concentrations for at least 20 years. As part of the decision-making process on design selection, an investigation of the DRZ would precede the selection of the concrete component and the specification of the amount of excavation that is needed. These investigations could be done using geophysical methods (such as ground penetrating radar) or drillholes. Drillholes can be investigated using video cameras or scratchers.

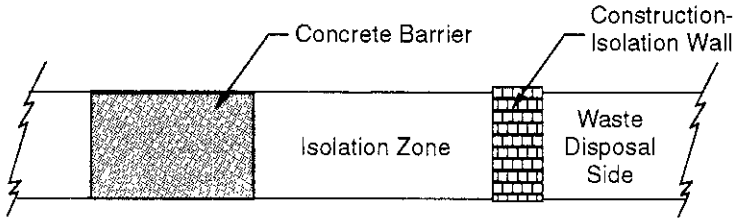

Option A. Construction-Isolation Wall and
Concrete Barrier without the DRZ Removed

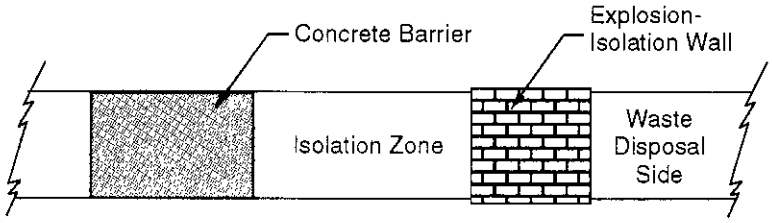

Option B. Explosion-Isolation Wall and
Concrete Barrier without the DRZ Removed

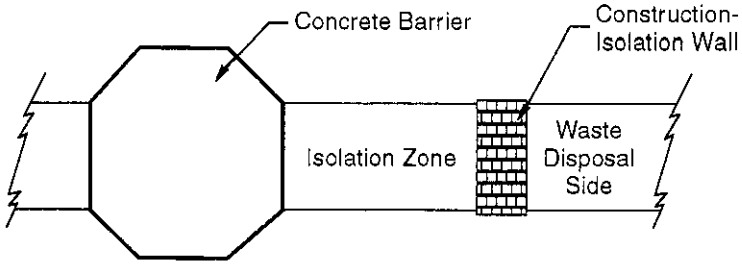

Option C. Construction-Isolation Wall and
Concrete Barrier with DRZ Removed

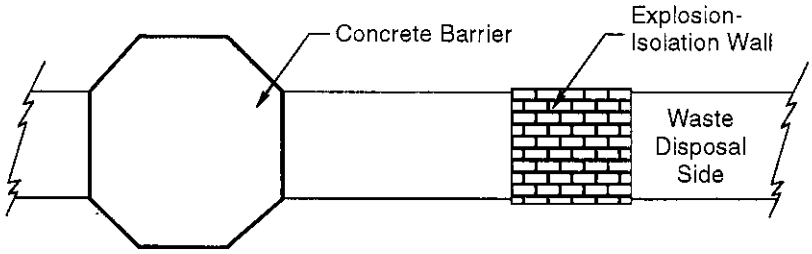

Option D. Explosion-Isolation Wall and
Concrete Barrier with DRZ Removed

CCA-090-2

Figure 3-5. Panel Closure Design

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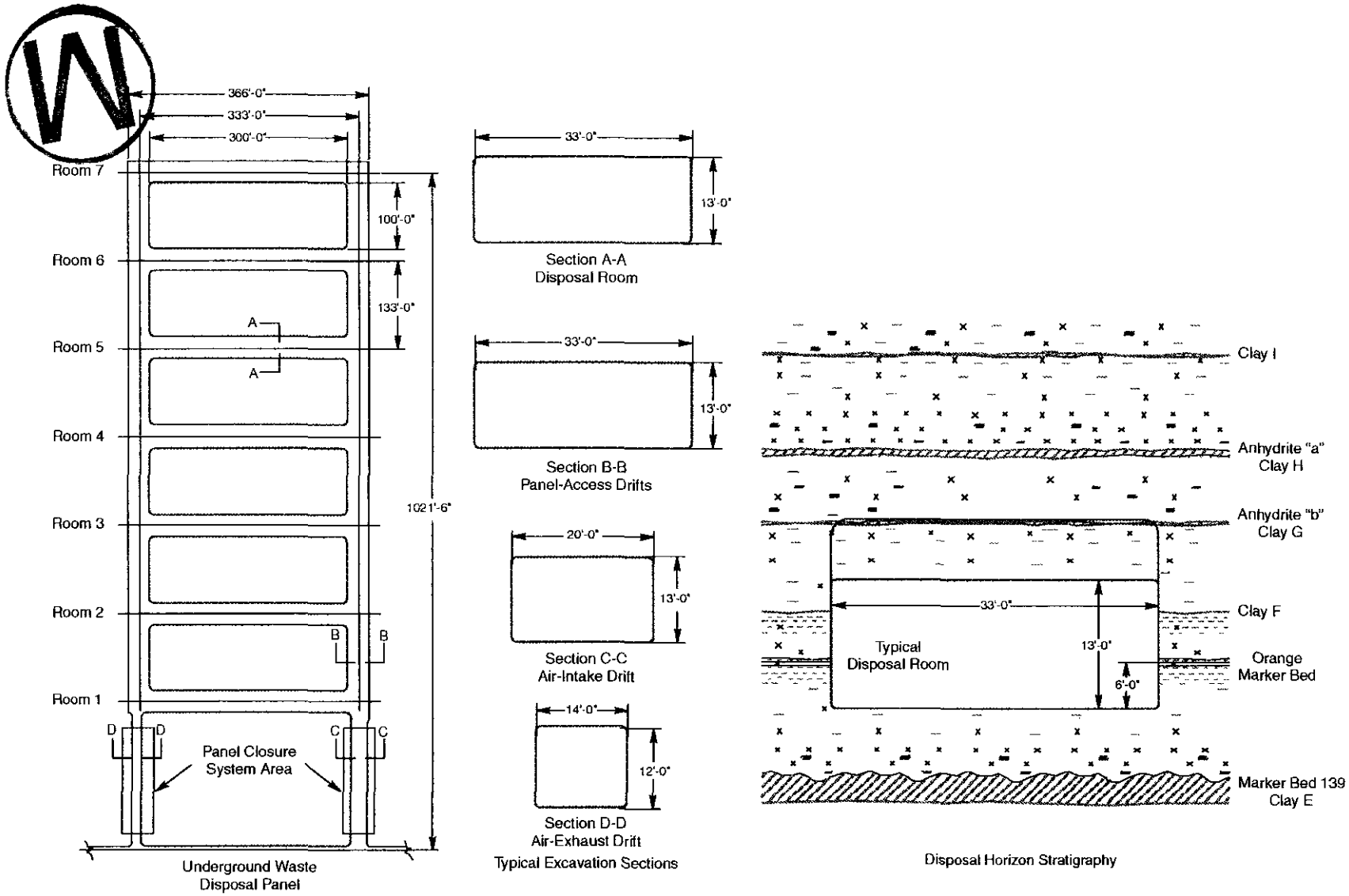

Note: Figure is not to scale. All dimensions shown are nominal.

Figure 3-6. Location of Panel Closure System

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The DOE will evaluate these criteria at the time a panel closure is needed and will select the proper closure design. If a design different from those listed above is identified, the appropriate permit modification will be sought.

Although the design of this closure system was based on its need to protect public health and the environment during the operations period, the use of these systems coupled with any other material placed in the panel entries will also influence fluid connections between panels during the postclosure phase. Flow of fluids into or out of the panels will be controlled by the permeability of the panel closure and the surrounding DRZ. Consideration of the current panel closure designs indicated that they will maintain their structural integrity for the regulatory period. Concrete degradation may occur by interaction with brine flowing through the plug or with brines flowing along the plug and salt interface or through the DRZ.

Calculations show that insufficient brine transport is available to begin degradation processes (Appendix MASS, MASS Attachment 7-1). The concrete element of the closure system will continue to provide resistance to inward deformation of the surrounding salt and will thereby prohibit growth of the DRZ from its initial state. Therefore, the concrete components are not expected to degrade to a condition that is more permeable than the DRZ in the regulatory period of 10,000 years. Although the panel closures are neither intended nor designed for long-term regulatory compliance, they provide a solid within the drifts that prevents the existing DRZ from increasing in permeability after panel closure. Development of the value for DRZ permeability is given in Appendix PAR. Additional information specific to the DRZ can be reviewed in the following records packages in the Sandia WIPP Central Files: WPOs 32905, 32906, and 32907.

3.3.3 Backfill

The DOE has concluded that it is desirable to add MgO to the repository to improve performance of the disposal system (see Appendix BACK). This additive will be protected in sacks until the sacks are broken during creep closure of the room. The MgO backfill will be purchased prepackaged in the proper containers for emplacement in the underground. Purchasing prepackaged backfill eliminates handling and placement problems associated with bulk materials, such as dust creation. In addition, prepackaged materials will be easier to emplace, thus reducing potential worker exposure to radiation.

The MgO backfill will be purchased and received in two different containers: (1) a supersack holding several thousand pounds, and (2) a mini sack holding 25 pounds (11.3 kilograms). Quality assurance requirements, such as material quality, will be addressed through the procurement quality requirements in Section 2.3 of the Westinghouse Waste Isolation Division (WID) Quality Assurance Program Description (see Appendix QAPD). MgO is available from several suppliers in a range of grain sizes and purities. Typical purities range from 93 percent MgO for baked dolomite to 98 percent for MgO extracted from brines. Chemical grade product (100 percent MgO) is also available. MgO is available in a variety of milled and screened grain sizes ranging from a powder (minus 325 mesh) to granular (0.5 inch

by 6 mesh). The filled containers will be shipped by road or rail and will be delivered underground using current shaft and material handling procedures and processes.

The mini sack will be 34 inches (86.4 centimeters) long, 6 inches (15 centimeters) in diameter and will be fabricated of a single layer of polyethylene or other suitable material. It will have an integral handle and hook attached into the sack closure. Six sacks will be manually placed in the external voids of each seven-pack unit just before the seven-pack is positioned on the waste stack. The mini sack will be lifted up behind the shrink wrap around the top of the seven-pack, slid into place, and held there by the 4-inch (10-centimeter) hole in the lower slip sheet (see Figure 3-7). Once the sacks are in place, the seven-pack will be positioned on the waste stack in the normal manner. A similar process will be used for standard waste boxes (SWB) except that the sacks will be hung from the lift clips on these units as shown in Figure 3-7.

Super sacks, which may be up to 4,000 pounds (1,814 kilograms) will be handled and placed using normal waste handling techniques. Once each row of waste units is in place, a layer of super sacks will be placed on top of them as shown in Figure 3-8. The super sack will be of multiwall construction with a vapor and moisture barrier. The super sack will have an integral slip sheet or base attachment so that it can be handled and placed in a manner that is identical to how waste units are emplaced. Typically, the space above a stack of containers will be 36 to 48 inches (90 to 122 centimeters), of which about 18 inches (45 centimeters) will contain the backfill material.

Finally, mini sacks will be manually stacked on the floor in the space between the waste stack and ribside. These sacks can be placed horizontally or vertically as may be convenient and loading rates up to 100 pounds per linear foot (148.8 kilograms per linear meter) can be achieved simply and quickly.

Quality control will be provided within waste handling operating procedure to record that the correct number of sacks are placed and that the condition of the sacks is acceptable.

There are about 3,700 linear feet (1,128 linear meters) of waste stack in a panel. The stated configuration provides about 4,000 pounds per linear foot (5,952 kilograms per linear meter) of waste stack or about 7,400 short tons (6,712 metric tons) per panel. About 10,836 waste disposal units (that is, seven-packs of drums and SWBs) will be placed in a panel and at six 25-pound (11.3-kilogram) mini sacks per unit, this will provide about 800 short tons (726 metric tons) per panel. Finally, material stacked along the ribside at 100 pounds per linear foot (148.8 kilograms per linear meter) of rib will provide about 360 short tons (327 metric tons) per panel. This gives a total of about 8,560 short tons (7,764 metric tons) per panel or approximately 85,600 short tons (77,640 metric tons) for the repository.

Backfill placed in this manner is protected until exposed when sacks are broken during creep closure of the room and compaction of the backfill and waste. Backfill in sacks use existing

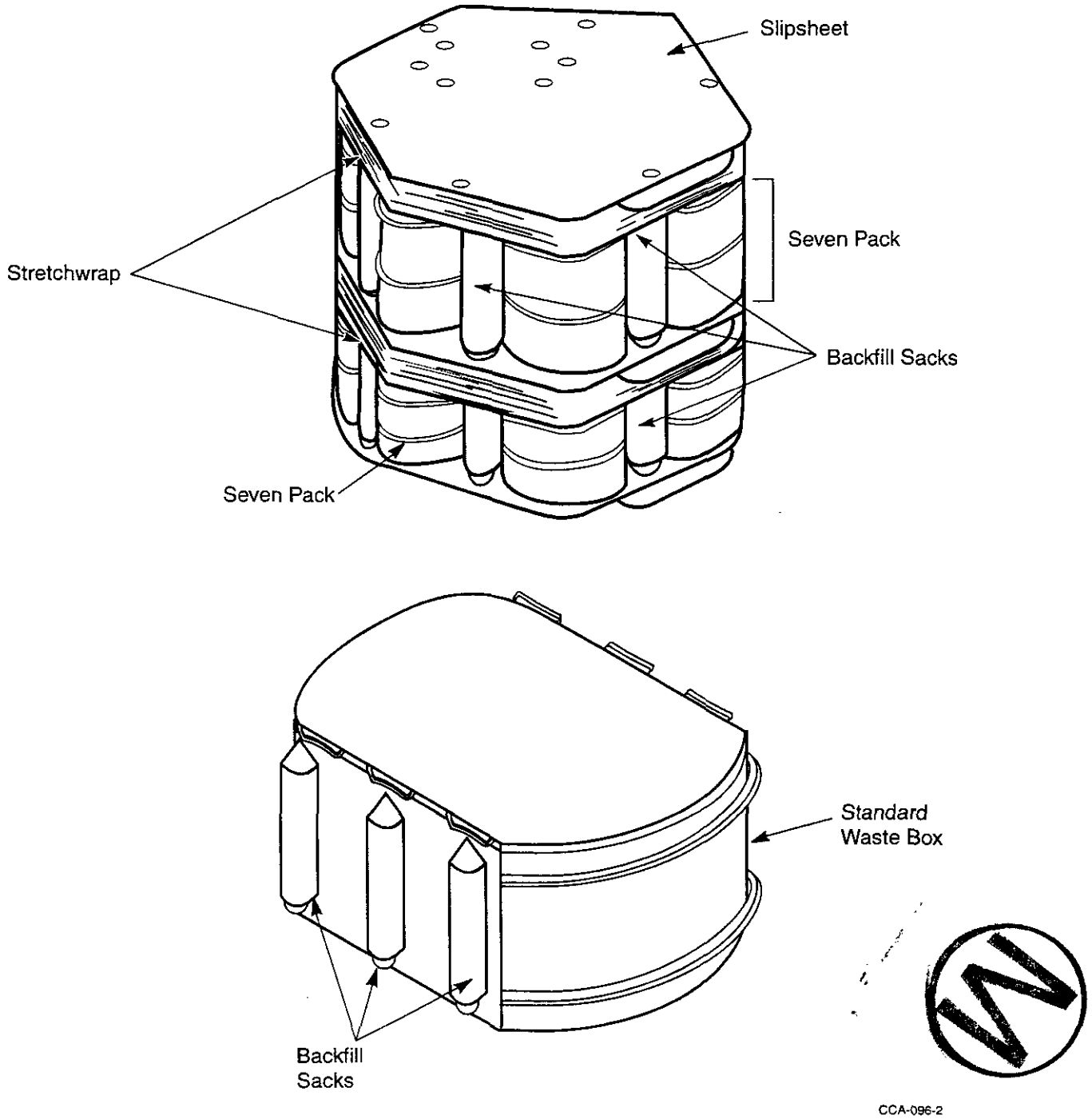

Figure 3-7. Backfill Sacks Used with Seven-Pack and SWB

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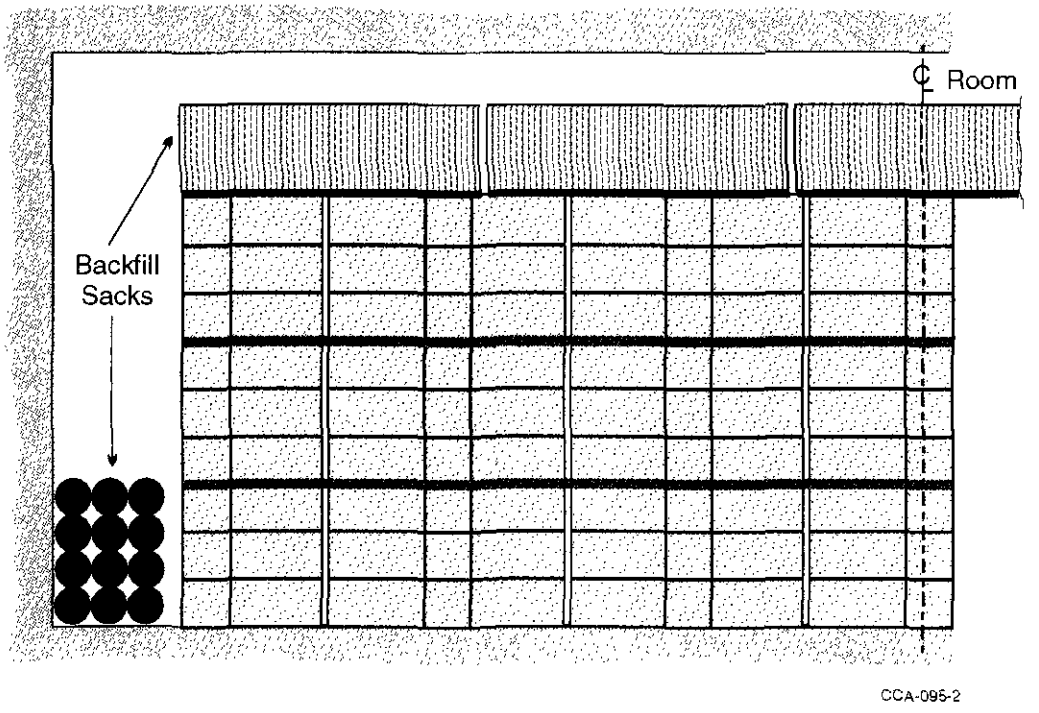

Figure 3-8. Room Cross Section Showing the Position of Backfill Sacks

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techniques and equipment and eliminates operational problems such as dust creation and introducing additional equipment and operations into waste handling areas. There are no mine operational considerations (for example, ventilation flow and control) when backfill is placed in this manner. Backfill performance and disposal system impacts are discussed in more detail in Section 6.4.3. Appendix BACK provides the rationale for the use of MgO as a backfill. Appendix SOTERM (Section SOTERM.2.2) contains information regarding the chemical effects of MgO in the disposal room. The commercially available code EQ3/EQ6 was used in the determination of chemical effects.

3.3.4 Borehole Plugs

Figure 3-9 identifies existing unplugged boreholes that lie within the controlled area. Of these boreholes, four are deep boreholes that exceed the depth of the repository, and the remainder are shallow boreholes that do not reach the repository horizon.

To mitigate the potential for migration of contaminants toward the accessible environment, the DOE has specified that borehole plugs be designed to limit the volume of water that could be introduced to the repository from the overlying water-bearing zones and to limit the volume of contaminated brine released from the repository to the accessible environment.

Grout-plugging procedures are routinely performed in standard oil-field operations; however, quantitative measurements of plug performance are rarely obtained. The Bell Canyon Test reported by Christensen and Peterson (1981, 25) was a field test demonstration of the use of cementitious plugging materials and modification of existing industrial emplacement techniques to suit repository plugging requirements. The test was performed in an 8 inch (20 centimeter) well bore near the top of the Bell Canyon. The test bore intercepted an aquifer at a depth of 4,495 feet (1,370 meters) with a shut in pressure of 1,800 pounds per square inch (12.4 megapascals). A 6 foot (2 meter) grout plug was emplaced above the aquifer and tested by unloading the hole (that is, removing fluids) above the plug to allow the full pressure in the aquifer to bear on the plug. This plug was observed to reduce the flow by five orders of magnitude, to 0.2 gallons per day (0.6 liters per day).

Cement emplacement technology was found to be generally adequate to satisfy repository plugging requirements. Christensen and Peterson (1981) also report

> that grouts can be effective in sealing boreholes, if proper care is exercised in matching physical properties of the local rock with grout mixtures.

A significant amount of research has been completed by the DOE to optimize concrete mixtures for the conditions expected in the Salado. The results of this research have been used to design the shaft sealing system as discussed in Appendix SEAL. (Concrete is discussed in Appendix A of Appendix SEAL, Section A2.1.) Consequently, the DOE has identified materials that will provide suitable plugs for boreholes. In addition, appropriate national standards such as the American Petroleum Institute Specification 10 and American Society for Testing Materials specification Volume 04.02 are available to assure the quality of

borehole plugging material and installation. Section 2.1.4 of the CAO QAPD (Appendix QAPD) provides the quality assurance requirements for the control of special processes such as plugging.

As a result of the Christensen and Peterson (1981) report and subsequent evaluations of plugging materials, the DOE concluded that boreholes within the controlled area, which were previously plugged in accordance with the appropriate state and federal regulations in effect at the time plugging, will mitigate the potential for migration of fluids beyond the repository horizon. Shallow unplugged boreholes within the controlled area will be plugged in accordance with the current state or federal regulations using materials shown to be compatible with the underground environment. Deep unplugged boreholes within the controlled area, shown in Figure 3-9 as WIPP 13, WIPP 12, ERDA 9, and DOE 1, will be plugged according to the state of New Mexico, Oil Conservation Division, Order R-111-P. The governing regulations for plugging and/or abandonment of boreholes are summarized in Table 3-2. These solid cement plugs will go through the salt section and any water-bearing horizon to prevent liquids or gases from entering the hole above or below the salt section. The boreholes not being used for monitoring will be plugged at decommissioning.

Figure 3-10 depicts a typical deep borehole plugged to the requirements of Order R-111-P. This order specifies, among other things, that the cements be mixed with salt-saturated fluids made with salts from the horizon being plugged (see Appendix DEL, Section DEL.6.2.4).

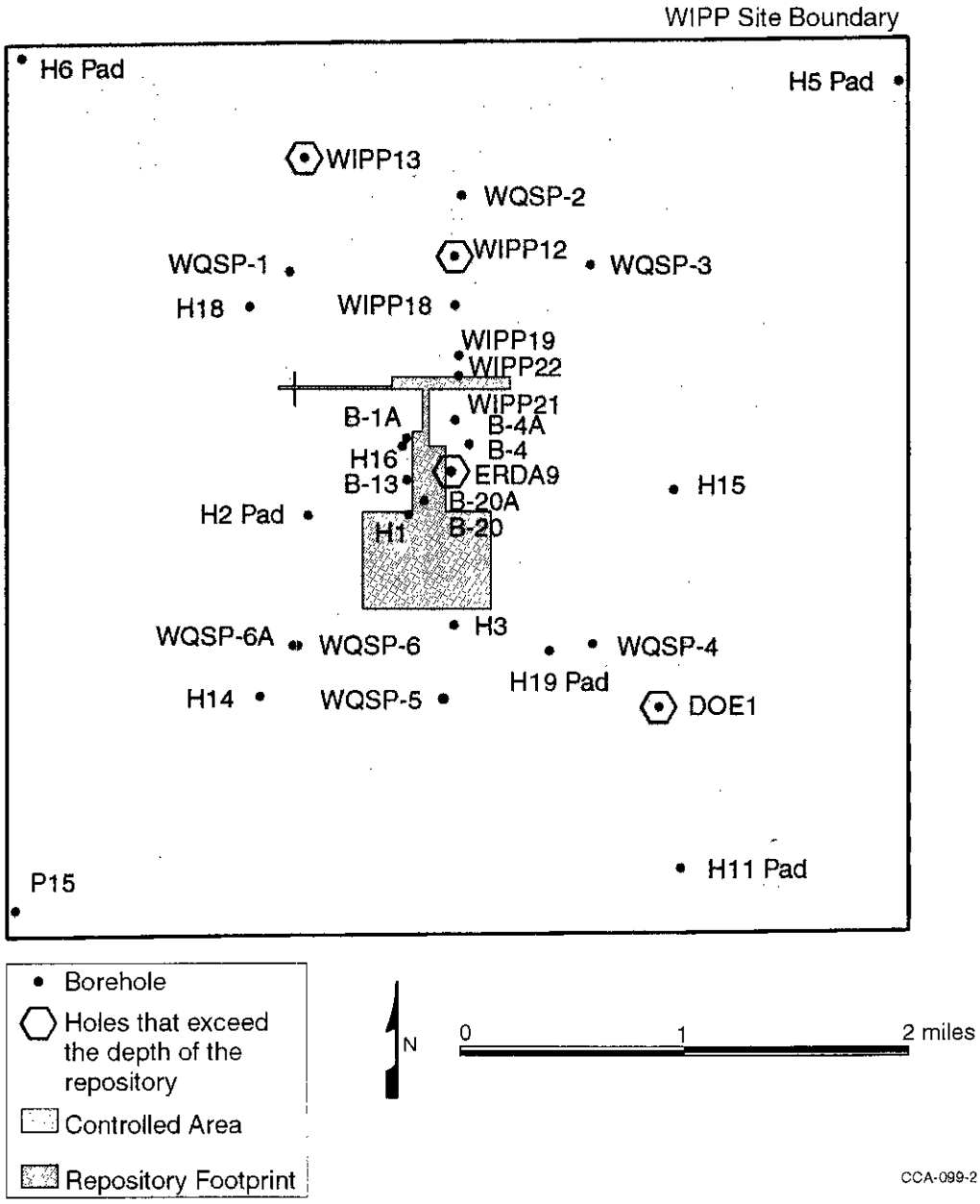

Figure 3-9. Approximate Locations of Unplugged Boreholes

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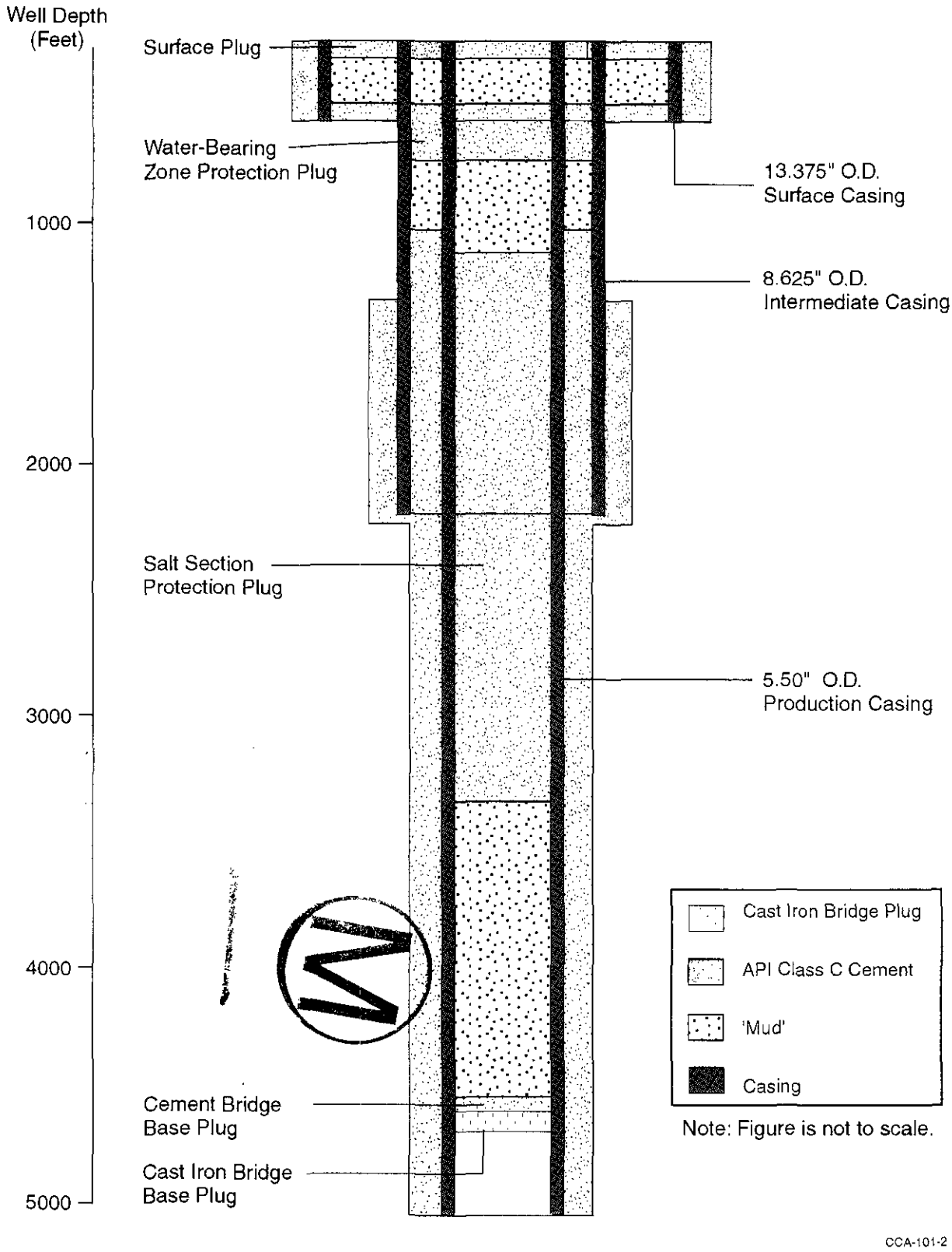

Figure 3-10. Typical Deep Borehole Plugged to Requirements of Order R-111-P

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Table 3-2. Governing Regulations for Borehole Abandonment

Federal or State Land	Type of Well or Borehole	Governing Regulation	Summary of Requirements
Both	Groundwater Wells	State of New Mexico (1995) Rules and Regulations Governing Drilling of Wells and Appropriation and Use of Groundwater in New Mexico, Article 4-14	Any specific plugging requirements and provisions made by the state engineer shall be set forth in the permit.
Federal	Oil and Gas Wells	43 CFR Part 3160, § 3162.3-4 (DOI, 1995a)	The operator shall promptly plug and abandon, in accordance with a plan first approved in writing or prescribed by the authorized officer.
Federal	Potash	43 CFR Part 3590, § 3593.1 (DOI, 1995b)	(b) Surface boreholes for development or holes for prospecting shall be abandoned to the satisfaction of the authorizing officer by cementing and/or casing or by other methods approved in advance by the authorized officer. The holes shall also be abandoned in a manner to protect the surface and not endanger any present or future underground operation, any deposit of oil, gas, or other mineral substances, or any aquifer.
State	Potash	State of New Mexico (1995), Rules and Regulations Governing Drilling of Wells and Appropriation and Use of Groundwater, Article 4-20.2	In the event that the test or exploratory well is to be abandoned, the state engineer shall be notified. Such well shall be plugged in accordance with Article 4-19.1 so that the fluids will be permanently confined to the specific strata in which they were originally encountered.
State	Oil and Gas Well Outside the Oil-Potash Area	State of New Mexico, Oil Conservation Division (1991), Rule 202 (eff. 3-1-91)	B. Plugging (1) Prior to abandonment, the well shall be plugged in a manner to permanently confine all oil, gas, and water in the separate strata where they were originally found. This can be accomplished by using mud-laden fluid, cement, and plugs singly or in combination as approved by the Division on the notice of intention to plug. (2) The exact location of plugged and abandoned wells shall be marked by the operator with a steel marker not less than four inches (4") in diameter, set in cement, and extending at least four feet (4') above mean ground level. The metal of the marker shall be permanently engraved, welded, or stamped with the operator name, lease name, and well number and location, including unit letter, section, township, and range.
State	Oil and Gas Wells Inside the Oil-Potash Area	State of New Mexico, Oil Conservation Division (1988), Order No. R-111-P (eff. 4-21-88)	F. Plugging and Abandonment of Wells (1) All existing and future wells that are drilled within the potash area shall be plugged in accordance with the general rules established by the Division. A solid cement plug shall be provided through the salt section and any water-bearing horizon to prevent liquids or gases from entering the hole above or below the salt selection. It shall have suitable proportions—but no greater than three (3) percent of calcium chloride by weight—of cement considered to be the desired mixture when possible.

REFERENCES

ASME (American Society of Mechanical Engineers). 1989. *Quality Assurance Program Requirements for Nuclear Facilities.* ASME NQA-1-1989, September 15, 1989. The American Society of Mechanical Engineers, New York, NY.

Christensen, C.L., and Peterson, E.W. 1981. "Field-Test Programs of Borehole Plugs in Southeastern New Mexico." In *The Technology of High-Level Nuclear Waste Disposal Advantages in the Science and Engineering of the Management of High-Level Nuclear Wastes,* P.L. Hofman and J.J. Breslin, eds., SAND79-1634C, DOE/TIC-4621, Vol. 1, pp. 354 – 369. Technical Information Center of the U.S. Department of Energy, Oak Ridge, TN.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026, Vol. 1 and 2. U.S. Department of Energy, Washington, D.C.

DOE (U.S. Department of Energy). 1990a. *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-FS. US Department of Energy, Office of Environmental Restoration and Waste Management, Washington, D.C. Available from NTIS as DE90005774.

DOE (U.S. Department of Energy). 1990b. *Final Safety Analysis Report.* WP 02-9, Rev. 0. May 1990. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995. *Safety and Analysis Report.* DOE/WIPP-95-2065, Rev. 0, November 30, 1995. Carlsbad Area Office, Carlsbad, NM.

DOI (Department of the Interior). 1995a. 43 CFR Part 3160, Onshore Oil and Gas Operations, Federal and Indian Oil and Gas Leases Drilling Operations. Subpart 3162, Requirements for Operating Rights, Owners and Operators. Subpart 3162.3-4, Well Abandonment. 43 CFR Chapter 2. October 9, 1995. 53 *Federal Register* 22 847, June 17, 1988. Bureau of Land Management, Washington, D.C.

DOI (Department of the Interior). 1995b. 43 CFR Part 3593, Boreholes and Samples. Subpart 3593.1, Core and Testhole Cores, Samples, Cuttings. 43 CFR Chapter 2. October 9, 1995. 53 *Federal Register* 22 847, June 17, 1988. Bureau of Land Management, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. *Federal Register*, Vol. 58, No. 242, pp. 66398 – 66416, December 20, 1993. Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

EPA (U.S. Environmental Protection Agency). 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. *Federal Register*, Vol. 61, No. 28, pp. 5224 – 5245, February 9, 1996. Office of Air and Radiation, Washington, D.C. In NWM Library as KF70.A35.C751 1996 (Reference).

State of New Mexico, Oil Conservation Division, Energy, Minerals, and Natural Resources Department. 1988. Order R-111-P, Potash Areas of Eddy and Lea Counties, NM. Case 9316, Revision to Order R-111-P. April 21, 1988. Santa Fe, NM.

State of New Mexico, Oil Conservation Division, Energy, Minerals, and Natural Resources Department. 1991. Rule 202, Plugging and Permanent Abandonment. March 1, 1991. Santa Fe, NM.

State of New Mexico, State Engineer's Office. 1995. Article 4, Well Drillers' Licensing-Construction, Repair and Plugging of Wells: Articles 4-14, Shallow Wells Construction Repair Plugging, and 4-20.2, Abandonment-Plugging. Santa Fe, NM.

U.S. Congress. 1992. *Waste Isolation Pilot Plant Land Withdrawal Act.* Public Law 102-579, October 1992. 102nd Congress, Washington, D.C.

BIBLIOGRAPHY

Beauheim, R.L., Saulnier, Jr., G.J., and Avis, J.D. 1991. *Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report.* SAND90-0083. Sandia National Laboratories, Albuquerque, NM.

Bechtel National. 1986. *Quarterly Geotechnical Field Data Report.* DOE/WIPP-221. U.S. Department of Energy, Carlsbad, NM.

Borns, D.J. 1985. *Marker Bed 139: A Study of Drillcore from a Systematic Array.* SAND85-0023. Sandia National Laboratories, Albuquerque, NM.

Borns, D.J., and Stormont, J.C. 1988. *An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone.* SAND87-1375. Sandia National Laboratories, Albuquerque, NM.

Borns, D.J., and Stormont J.C. 1989. The Delineation of the Disturbed Rock Zone Surrounding Excavations in Salt. *Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Proceedings of the 30th U.S. Symposium on Rock Mechanics*, June 19 – 22, 1989, A.W. Khair, ed., SAND88-2230c, pp. 353 – 360. A.A. Balkema, Brookfield, VT.

Chan, K.S., Bodner, S.R., Fossum, A.F., and Munson, D.E. 1992. A Constitutive Model for Inelastic Flow and Damage Evolution in Solids Under Triaxial Compression. *Mechanics of Materials*, SAND92-0546J, Vol.14, No.1, pp.1 – 14.

COE (U.S. Army Corps of Engineers). 1985. *Federal Engineering Operating Procedures for Construction of the Waste Isolation Pilot Plant.*

DOE (U.S. Department of Energy). 1986. *Waste Isolation Pilot Plant Design Validation Final Report.* DOE/WIPP 86-010. U.S. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy). 1988. *Geotechnical Field Data Report and Analysis Report.* DOE/WIPP 87-017. U.S. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995. "Waste Isolation Pilot Plant Seal System Design Report," DOE/WIPP-95-3117. Carlsbad, NM.

DOE (U.S. Department of Energy). 1995. *Conceptual Design for Operational Phase Panel Closure Systems.* DOE-WIPP-95-2057, U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1996. *U.S. Department of Energy Carlsbad Area Office Quality Assurance Program Description.* CAO-94-1012, Rev. 1, April 1996. U.S. Department of Energy, Carlsbad, NM. (This document is included as Appendix QAPD.)

ERDA (Energy Research and Development Administration). 1976. *Management Guideline and Project Executive Assistance, Construction Management Plan.*

Fernandez, J. A., Hinkebein, T.E., and Case, J.B. 1989. *Selected Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain.* SAND85-0598, Sandia National Laboratories, Albuquerque, NM.

Griswold, G.B. 1977. *Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, New Mexico.* SAND77-0946. Sandia National Laboratories, Albuquerque, NM.

Nowak, E.J., and McTigue, D.F. 1987. *Interim Results of Brine Transport Studies in the Waste Isolation Pilot Plant.* SAND87-0880. Sandia National Laboratories, Albuquerque, NM.

ORNL (Oak Ridge National Laboratory). 1973. *Site Selection Factors for the Embedded Salt Pilot Plant.* ORNL-TM-4219. Oak Ridge National Laboratory, Oak Ridge, TN.

Pfeifle, T.W., and Brodsky, N.S. 1991. *Swelling Pressure Water Uptake and Permeability of 70/30 Crushed Salt Bentonite.* SAND91-7070. Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 3: Model Parameters.* SAND92-0700/3. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

Stormont, J.C., Howard, C.L., and Daemen, J.J.K. 1991. *In Situ Measurements of Rock Salt Permeability Changes Due to a Nearby Excavation.* SAND90-3134. Sandia National Laboratories, Albuquerque, NM.

Stormont, J.C., Peterson, E.W., and Langus, P.L. 1987. *Summary and Observations about WIPP Facility Horizon Flow Measurements through 1986.* SAND87-0176. Sandia National Laboratories, Albuquerque, NM.

Stormont, J. C. 1991. "Gas Flow Measurements as Index Tests for the Disturbed Rock Zone," Memorandum to Distribution, Sandia National Laboratories, Albuquerque, NM.

Stormont, J. C. 1988. *Preliminary Seal Design Evaluation for the Waste Isolation Pilot Plant.* SAND87-3083, Sandia National Laboratories, Albuquerque, NM.

Westinghouse Electric Corporation. 1995. Conceptual Design for Operational Phase Panel Closure System. DOE/WIPP-Draft-2057. *Closure and Post Closure Plans.* Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

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4.0 WASTE DESCRIPTION

This chapter describes the type of waste that will be emplaced in the Waste Isolation Pilot Plant (WIPP) and provides an appraisal of the inventory of physical, chemical, and radionuclide components of the waste. This information supports the development of the performance assessment models that are used in predicting the long-term behavior of the repository. This chapter includes a waste description based on the inventories of existing and projected waste reported in the transuranic (TRU) Waste Baseline Inventory Report (TWBIR) (included in this application as Appendix BIR), a description of the projected waste inventory, waste limits derived from both the performance assessment and operational safety and health considerations, and methods of control to ensure compliance with the identified waste limits. In addition, this chapter provides a discussion of the applicable qualitative and quantitative waste characterization methodologies.

Title 40 of the Code of Federal Regulations (CFR) § 194.24(a) specifies that the U.S. Department of Energy (DOE) shall provide information pertaining to the chemical, radiological, and physical composition of the waste planned to be emplaced in the repository. Specifically, the criterion states

> Any compliance application shall describe the chemical, radiological and physical composition of all existing waste proposed for disposal in the disposal system. To the extent practicable, any compliance application shall also describe the chemical, radiological and physical composition of to-be-generated waste proposed for disposal in the disposal system. These descriptions shall include a list of waste components and their approximate quantities in the waste. The list may be derived from process knowledge, current non-destructive examination/assay, or other information and methods.

This waste description includes the definition, sources, types, components, and characteristics of TRU waste planned for emplacement in the WIPP. The description provided in this chapter, along with the waste characterization analysis in Appendix WCA,[1] identifies those physical, chemical, and/or radiological components of the waste that may singly or in combination affect the ability of the WIPP disposal system to meet the environmental performance standards contained in 40 CFR Part 191. This chapter is supported with several appendices. For example, waste related parameters used in performance assessment are discussed in Appendix PAR and Appendix WCA. Results of sensitivity analyses with respect to total releases used to generate the mean complementary cumulative distribution function (CCDF) in Section 6.5 are discussed in Appendix SA. The impact of waste components and characteristics on WIPP performance is discussed in Appendix WCA. Limits for waste components are discussed in Appendix WCL and summarized in this chapter. (See Table 1-4 in Chapter 1.0 for a list of appendices that provide additional information supporting this chapter.) This chapter also describes methods of control that will be employed by the DOE to ensure that only those wastes that are consistent with these descriptions are actually emplaced

[1] The waste characterization analysis detailed in Appendix WCA was peer reviewed per the criteria in 40 CFR § 194.27(a)(2). Results of this peer review are documented in Section 9.3.2 and in Appendix PEER.

in the repository. One such control is the WIPP Waste Information System (WWIS) (DOE 1995e, 1996b) database for controlling the receipt of and tracking the emplacement of waste (see Section 4.3.2).

Before the final performance assessment was designed, waste characterization analyses comprised of iterative preliminary performance assessments, related sensitivity analyses, and dedicated process studies for specific components and characteristics of the waste, were performed. A list of waste components and characteristics that were considered during these analyses, the list of and rationale for the ones retained for inclusion in the final performance assessment, and the ones not included are documented in Appendix WCA. Retained waste components are assigned fixed values in the final performance assessment (See Appendix PAR) based on information reported in the TWBIR, Revision 3 (Appendix BIR). Therefore, during the performance assessment, plausible combinations of fixed values for waste components are included in all performance assessment scenario analyses. Important imprecisely known waste characteristics are provided ranges and distributions (See Appendix SOTERM and Appendix PAR) from which values are drawn using a Latin hypercube sampling (LHS) technique that ensures that samples are taken from across the entire range of the distribution (See Section 6.1.5.2).

Since results demonstrate compliance with the quantitative containment requirements in 40 CFR § 191.13, the individual protection requirements in 40 CFR § 191.15, and the groundwater protection requirements in 40 CFR § 191.24, the fixed values used for waste components define a profile of waste suitable for disposal at WIPP. Following the final performance assessment, sensitivity analyses determined the contribution of uncertainty in individual input variables to the uncertainty in model predictions (that is, final releases). There are no waste characteristics that have a significant impact on the uncertainty about and the location of the mean CCDF reported in Figure 6-39 (See Appendix SA for a discussion of this uncertainty). Therefore, setting waste component limits is not based on performance assessment results but is based on ensuring the validity of repository conditions modelled by performance assessment (See Appendix WCL). In addition, the limits are repository-scale limits that should be met at the time of repository decommissioning. The process for demonstrating compliance with these limits is to track the waste-component quantity and the uncertainty associated with that quantity as waste is emplaced in the repository. For example, the curie content for plutonium and it's uncertainty (based on the fact that a large percentage of the waste has yet to be generated) can be accumulated as waste is emplaced throughout the operational phase. Then, at the time of decommissioning, when these repository limits apply, the total curie content for plutonium may be provided with a specified level of confidence, such as 95 percent, to demonstrate compliance with the waste component limits.

Figure 4-1 illustrates the information flow pertaining to the waste description and its relationship to other sections of this chapter as well as Chapter 6.0 and appendices to this application.

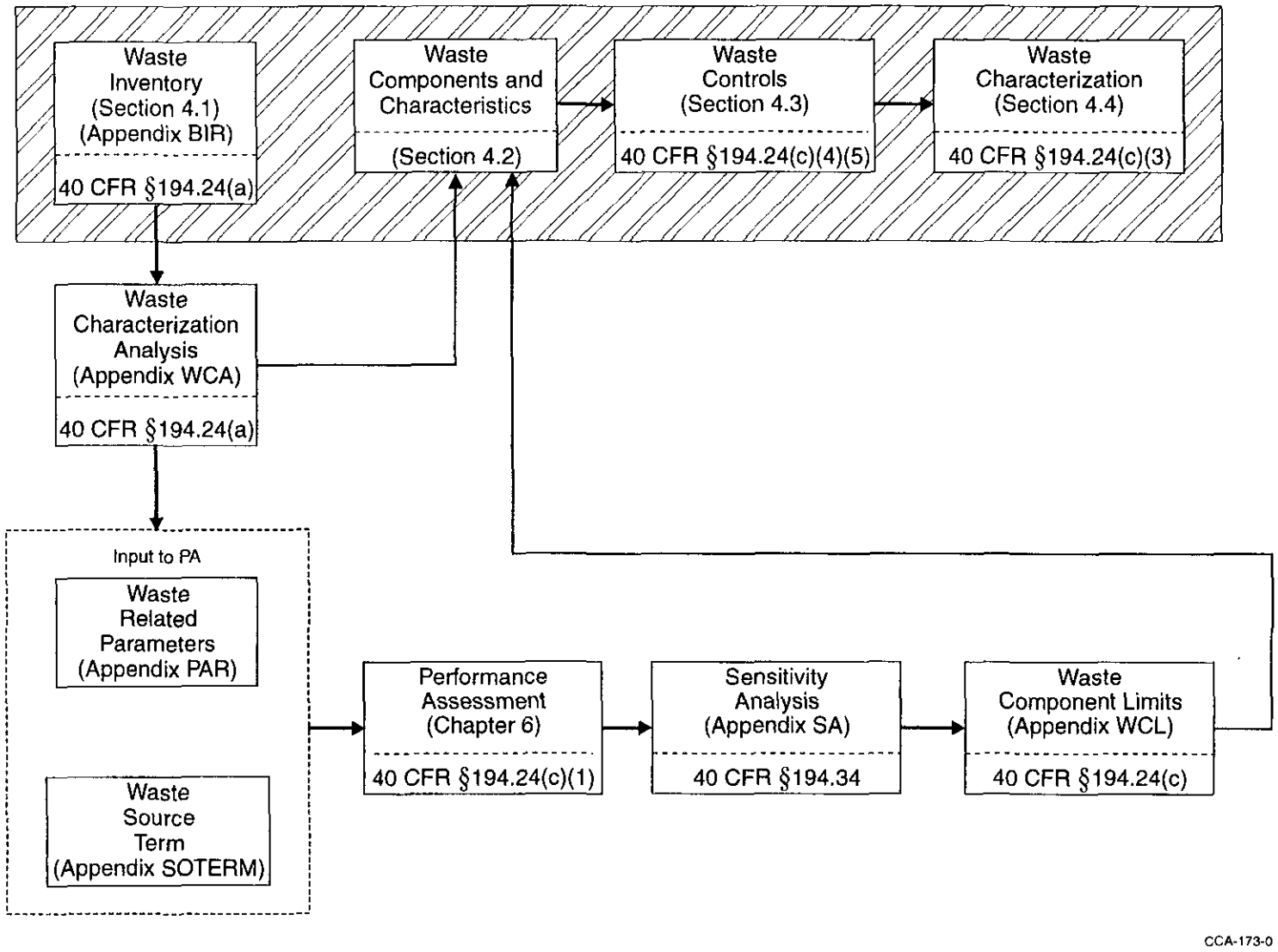

Figure 4-1. Waste Description Information Flow

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4.1 Waste Inventory

The waste inventory is defined as the quantity of waste that is anticipated to be emplaced in the WIPP. This inventory is generally characterized as the nonradionuclide inventory that consists of both physical and chemical waste constituents, generally expressed in units of density or concentration; and the radionuclide inventory, which is a tabulation, by specific isotope, of anticipated radionuclides in the waste expressed in units of curies.

The term TRU waste is defined (EPA 1993) as

> waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste, except for (1) High-level radioactive wastes; (2) wastes that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this part; or (3) wastes that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.

TRU isotopes have atomic numbers greater than uranium (92). In determining the alpha-activity concentration levels for waste classification, only the mass of the waste is used in the concentration calculation. The waste container, plus any added shielding and other packaging, is not included in the mass component of this determination.

Pre-1970 TRU waste that has been disposed of by generators in on-site, shallow landfill-type configurations is referred to as buried waste. In 1970, the U.S. Atomic Energy Commission concluded that TRU waste should have greater confinement from the environment. Thus, TRU waste generated since that date has been segregated from other waste types and placed in retrievable storage. Waste generated after the early 1970s, but before implementation of the DOE's TRU Waste Characterization Quality Assurance Program Plan (QAPP), is referred to as retrievably stored waste. Waste generated after a site's implementation of the QAPP is defined as newly generated TRU waste (DOE 1995b). Implementation of the QAPP occurs after the site's Quality Assurance Project Plans (QAPjPs) have been approved and implemented. Newly generated waste will be characterized in a similar manner to retrievably stored waste, but it will incorporate more real-time, as opposed to historical, acceptable knowledge. Approximately 65 percent of the waste to be disposed of at the WIPP is expected to be newly generated waste, as described in the TWBIR (Appendix BIR).

TRU waste is classified as either contact-handled (CH) or remote-handled (RH) based on the contact dose rate at the surface of the waste container. If the contact dose rate is less than or equal to 200 millirem per hour (2 milliSievert per hour), the waste is defined as CH-TRU (DOE 1988). If, on the other hand, the contact dose rate is greater than 200 millirem per hour (2 milliSievert per hour), the waste and its container are defined as RH-TRU (DOE 1988). Only RH-TRU waste less than or equal to 1000 rem per hour (10 Sievert per hour) is eligible for disposal at the WIPP (DOE 1996a). To meet the requirements as set forth in the WIPP Land Withdrawal Act (LWA) (U.S. Congress 1992b), the total combined volumes of CH-TRU and RH-TRU waste are not to exceed 6.2 million cubic feet (175,564 cubic meters). Moreover, the LWA also specifies that the emplaced RH-TRU waste is not to exceed a total activity of 5.1 million curies (~ 18.9×10^{16} Becquerel) and a total activity concentration of 23

curies per liter (averaged over the volume of the canister). No more than five percent of the emplaced RH-TRU waste may exhibit a dose rate in excess of 100 rem per hour (1 Sievert per hour).

The last category of waste to be defined is TRU mixed waste, that is, waste that contains both TRU radioactive components and hazardous components as defined in the New Mexico Administrative Code (see NMAC in the Bibliography). Hazardous components of TRU mixed waste to be managed at the WIPP facility are designated in Part A of the WIPP Resource Conservation and Recovery Act (RCRA) permit application. The Waste Analysis Plan (WAP) (see Appendix WAP) describes measures to ensure that the wastes received at the WIPP facility are within the scope of the Part A. As stated in Appendix WCA (Section WCA.4.1.3), only four of 60 organic compounds in the waste are expected to have an effect on actinide mobility. None of the four (acetate, citrate, oxalate, and ethylenediaminetetracetate [EDTA]) are listed in Part A of the WIPP RCRA permit application. Consequently, this component of TRU waste is omitted from further discussion in this chapter.

4.1.1 Sources of TRU Waste

The DOE's TRU waste, as described in this chapter, is derived primarily from plutonium fabrication and reprocessing, research and development (R&D), decontamination and decommissioning (D&D), and environmental restoration (ER) programs at various sites. Most TRU waste generated at the DOE sites results from specific processes and activities that are well defined and well controlled, enabling the DOE to characterize the waste on the basis of acceptable knowledge of the process, input raw materials, and output finished products. Some examples of these operations include

- Production of nuclear products. Production of nuclear products includes reactor operation, radionuclide separation and finishing, and weapons fabrication and manufacturing. The majority of the TRU waste was generated by weapons fabrication and radionuclide separation and finishing processes. More specifically, wastes typically consist of TRU-contaminated material derived from chemical processes, air and liquid filtration, casting, machining, cleaning, product quality sampling, analytical activities, and maintenance and refurbishment of equipment and facilities.

- Plutonium recovery. Plutonium recovery wastes are TRU-contaminated items and materials from the recovery of valuable plutonium, including contaminated molds, metals, glass, plastics, rags, salts used in electrorefining, precipitates, firebrick, soot, and filters.

- R&D. R&D projects include a variety of hot-cell or glove-box activities that often simulate full-scale operations described above, producing similar TRU wastes. Other types of R&D projects include metallurgical research, actinide separations, process demonstrations, and chemical and physical properties determinations.

- D&D. Facilities and equipment that are no longer needed or usable are decontaminated and decommissioned, resulting in TRU wastes consisting of scrap materials, cleaning agents, tools, piping, filters, plexiglas, gloveboxes, concrete rubble, asphalt, cinder blocks, and other building materials. This is expected to be the largest category by volume of TRU waste to be generated.

Operations carried out in glove boxes and hot cells generate both combustible and noncombustible wastes. Combustible waste contains mixtures of paper, plastics, rags, cloth clothing, and wood resulting from plutonium operations. Cloth and paper wipes are used to clean parts and glove boxes. Depending on the operations, damp combustibles are usually used and then wrung out, drained, or dried. Noncombustibles consist primarily of glass and metal. Much of this waste is laboratory equipment and glassware from R&D activities.

Filters are sometimes combinations of combustibles and non-combustibles and come from a variety of sources including high-efficiency particulate air (HEPA) filters , filter media, processed filter media, and prefilters. Prefilters and HEPA filters are used on all ventilation intake and exhaust systems associated with plutonium operations. Filter frames can be either wood, aluminum, or stainless steel; and the filter media may be paper, Fiberglass, Nomex, or similar material. Filter media are generated from splitting absolute dry box and HEPA filters apart from their frames in the plutonium process areas. Loose particulate materials that are dislodged from the filters are stabilized and packaged separately from the media. Filter media are packaged in plastic bottles or bags. Filter media may also be mixed with portland cement to neutralize any residual nitric acid.

Graphite waste is produced from molds that are broken, cleaned, or scraped in glove boxes to remove excess plutonium. Graphite is a uniform, well-defined material.

Benelex and Plexiglas are well-defined materials that are used as neutron shielding material and in glove-box construction. Benelex consists mainly of cellulose with residual amounts of the phenolic resin. Plexiglas is a polymethyl methacrylate polymer used for glove-box windows and is generated as waste during the change-out of the glove-box windows.

Inorganic process solids include residues from evaporator and other types of storage tanks, grit, firebrick fines, ash, salts, metal oxides, and filter sludge. This waste is typically solidified in portland- or gypsum-based cements.

Soil, asphalt, and sand contaminated from spills or generated from D&D activities may also be present in the waste.

To isolate the radiological and hazardous co-contaminants of these wastes from humans and the environment during handling and other life-cycle operations, a primary confinement barrier is used. Both CH-TRU and RH-TRU waste at the WIPP facility will be managed using payload containers that meet the requirements of the U.S. Department of Transportation (DOT) for Type A or equivalent containers (DOE 1995d). The term payload container in this

document refers to a drum, drum overpack, canister, standard waste box, or ten-drum overpack unit. Internal to these payload containers may be other secondary layers of confinement, including rigid plastic inner liners and multiple layers of plastic bagging. Each container is vented using one or more filters.

4.1.2 TRU Waste Generator and Storage Sites

The major generator and storage sites (see Figure 4-2) that are planning to ship their TRU waste to the WIPP for disposal include

- Richland Hanford Site (HANF)
- Idaho National Engineering Laboratory (INEL)
- Lawrence Livermore National Laboratory (LLNL)
- Los Alamos National Laboratory (LANL)
- Nevada Test Site (NTS)
- Oak Ridge National Laboratory (ORNL)
- Rocky Flats Environmental Technology Site (RFETS)
- Savannah River Site (SRS)

The INEL, LANL, and RFETS are expected to be among the first of the major generator and storage sites to begin shipping TRU waste to the WIPP. As the other major sites develop the prerequisite certification programs required for TRU waste disposal at the WIPP, they too will commence shipping waste to the WIPP. Effective implementation by the generator and storage sites of the DOE Carlsbad Area Office (CAO) Quality Assurance Program Document (QAPD) (see Appendix QAPD) is a prerequisite for granting TRU waste certification authority to the sites. A letter granting such authority will specify the date that the subject site effectively implemented their characterization and certification program. Any limitations imposed on the certification authority will be described in the letter.

In addition to the major generator and storage sites, there are currently numerous small-quantity sites (SQSs) planning to dispose TRU waste at the WIPP. Options to facilitate disposal of the SQS waste at the WIPP include either direct shipment to the WIPP after on-site characterization and certification or shipment to an interim site for performing waste consolidation, treatment, and/or characterization and certification in accordance with WIPP requirements. The current list of SQSs includes

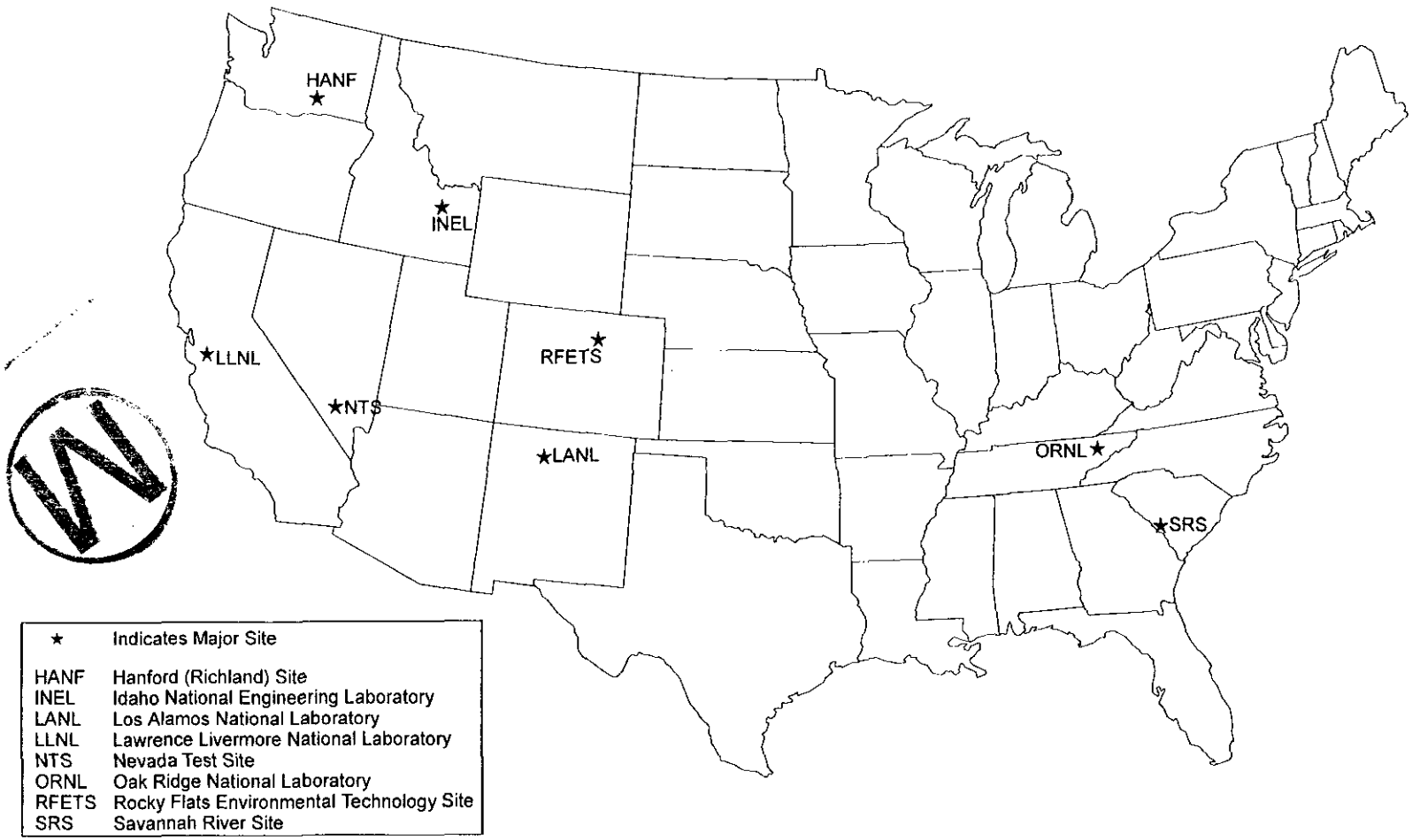

Note: Adapted from Figure 1-1, TWBIR Vol. 1.

Figure 4-2. U.S. DOE TRU Waste Generator and Storage Sites

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- Ames Laboratory
- Argonne National Laboratory - East
- Argonne National Laboratory - West
- Battelle Columbus Laboratories
- Bettis Atomic Power Laboratory
- Energy Technology Engineering Center
- General Electric Vallecitos Nuclear Center
- Massachusetts Institute of Technology
- Mound Plant
- National Institute of Standards and Technology
- Paducah Gaseous Diffusion Plant
- Pantex Plant
- Sandia National Laboratories/NM (SNL)
- Site A/Plot M (near Chicago, Illinois)
- Special Process Research Unit
- Teledyne Brown Engineering
- University of Missouri Research Reactor
- U.S. Army Material Command

As more SQSs are identified, they will be added to this list. Figure 4-2 shows the geographic locations of the major generator and storage sites.

4.1.3 TRU Waste Inventory

A summary of the quantity of stored and projected TRU waste and TRU waste components is contained in the TWBIR (see Appendix BIR). The TWBIR documents the total inventory of DOE TRU waste and includes both the TRU waste that is planned to be disposed at the WIPP

site and the TRU waste that will not be sent to WIPP. Only the WIPP portion of the TRU waste inventory is used in performance assessment calculations that support the development of this compliance application.

Although updates are made to the TWBIR based on new information received from ongoing waste identification and characterization activities at the generator and storage sites, the TWBIR is an inventory report and not a summary of TRU waste characterization data. For waste shipped to the WIPP, waste characterization data associated with each container is entered into the WWIS for tracking purposes. A description of the WWIS is given in Section 4.3.2.

In support of performance assessment, it was necessary for the DOE to roll-up waste information on a repository scale. To this end, the TWBIR describes a process for grouping individual waste streams with similar physical and chemical properties into waste profiles, based on the waste matrix code (WMC) assigned by the DOE TRU waste generator and storage sites. Waste profiles with similar WMCs are then combined across the DOE TRU waste system to provide estimated total volumes and total waste material parameters (WMPs). WMPs and waste components (as used in 40 CFR § 194.24) are synonymous. Individual waste streams are evaluated to estimate the occurrence and quantities of nonradioactive WMPs (for example, cellulosics, plastics, iron-base metal and alloys, etc.) and are identified in Appendix WCA as having either a significant or negligible effect on the performance of the WIPP repository. See Table 4-1 for a listing of these waste components and their associated characteristics.

4.1.3.1 Inventory Terminology

Stored Inventory – The part of the TRU inventory currently in retrievable storage at the time of the last data call for inventory information is known as stored inventory. Retrievably stored waste includes waste stored since approximately 1970 in buildings or in berms with earthen cover and does not include any waste that was disposed prior to 1970.

As-Generated Waste – The chemical and physical status of waste when it is generated. The as-generated term applies to both stored and future waste.

Projected Inventory – The part of the TRU inventory that has not been generated but is currently estimated to be generated at some time in the future by the TRU waste generator and storage sites, is known as projected inventory. The projected inventory is the same as the to-be-generated waste referred to in 40 CFR §194.24(a).

Scaling – The process of adjusting, if needed, the projected inventory to the design limit (disposal inventory) is called scaling. Scaling is needed in performance assessment to model the WIPP repository at full capacity (6.2 million cubic feet by statute).

Table 4-1. Waste Characteristics and Components That are Expected to Have Significant and Negligible Effects

Characteristic	Component	Effect on Performance
Characteristics and Components Expected to Have a Significant Effect		
radioactivity in curies of each isotope	radioactivity in curies of each isotope	used in calculation for normal release
TRU radioactivity at closure	α-emitting TRU radionuclides, $t_{1/2} > 20$ years	determines waste unit factor
solubility	radionuclides	actinide mobility
colloid formation	radionuclides, cellulose, soils, plastics, rubber	actinide mobility
redox state	radionuclides	actinide mobility
redox potential	ferrous metals	actinide oxidation state; actinide mobility
gas (H_2) generation	ferrous metals	increase in H_2 pressure
microbial substrate: CH_4 generation	cellulose	increase in gas pressure
microbial substrate: CH_4 generation	plastics, rubber	increase in gas pressure
particle diameter	solid waste components	spalling release
microbial nutrients: CH_4 generation	sulfates	increase in gas pressure
microbial nutrients: CH_4 generation	nitrates	increase in gas pressure
compressibility and shear strength	solid waste components	effect on creep closure, cuttings, caving, spalling
Characteristics and Components Expected to Have a Negligible Effect		
permeability	solid waste components	negligible effect on brine movement, gas storage
porosity	solid waste components	negligible effect on brine movement
microbial nutrients, CO_2 generation	sulfates	negligible: MgO reacts with CO_2
microbial nutrients, CO_2 generation	nitrates	negligible: MgO backfill reacts with CO_2
microbial substrate: CO_2 generation	cellulose	negligible: MgO backfill reacts with CO_2
microbial substrate: CO_2 generation	plastics, rubber	negligible: MgO backfill reacts with CO_2
gas generation	water in the waste	enhances initial gas generation

Based on the inventory identified in Revision 3 of the TWBIR, the scaling factor is calculated to be 2.05 (see Appendix BIR [Revision 3, 2-3]).

Stored Inventory + Projected Inventory (2.05) = Disposal Inventory

Disposal Inventory – The inventory volume defined for WIPP emplacement to be used for performance assessment calculations is the disposal inventory. The LWA defines the total amount of TRU waste allowed for disposal in the WIPP as 6.2 million cubic feet (175,564 cubic meters) (U.S. Congress 1992b). Consistent with 40 CFR § 194.24(g), this is the maximum quantity of TRU waste which will be emplaced in the repository. The WIPP limit of RH-TRU inventory is 250,000 cubic feet (7,079 cubic meters), as set by the Consultation and Cooperation Agreement between the DOE and the state of New Mexico (DOE and state of New Mexico 1981).

WMCs – Codes developed by DOE, in response to the Federal Facility Compliance Act (U.S. Congress 1992a), as a methodology to aid in categorizing mixed waste streams in the DOE system into a series of five-digit alphanumeric codes (for example, S5400; Heterogeneous Debris) that represent different physical and chemical matrices. Using guidance prepared by the DOE (DOE 1995f), the WMC is assigned by the TRU waste generator and storage sites for all mixed waste streams and some unmixed waste streams. The TWBIR has adopted this system to remain consistent with common terminology used by the DOE waste generator and storage sites. WMCs are verified with radiographic examination (using either real-time radiography [RTR] or an equivalent methodology) and/or visual examination.

Final Waste Form – The final waste form of a waste stream consists of a series of WMCs that are grouped together, which for performance assessment purposes have similar physical and chemical properties. The final waste form applies to both stored and projected inventory. Table 4-2 presents anticipated WMCs for TRU waste and indicates the final waste form typically assigned to each WMC for the TWBIR. There are 11 final waste forms used in the TWBIR. Each of the 11 final waste forms described in Table 4-2 identify a material property common to the numerous waste streams grouped under it.

Waste Stream Profile – This is a description of a CH-TRU or RH-TRU waste stream. Examples of information included in a waste stream profile are

- waste stream description;
- waste stream source description;
- currently used identification codes, including the DOE TRU waste site matrix description;
- final waste form assigned by the TRU waste generator and storage sites;

Table 4-2. WMCs and Their Anticipated Final Waste Form

Final Waste Form	WMCs
Solidified Inorganics	L1000, L1100, L1110, L1120, L1130, L1140, L1190, 1200, L1210, L1220, L1230, L1240, L1290, S3000, S3100, S3110, S3111, S3112, S3113, S3115, S3118, S3119, S3120, S3121, S3122, S3123, S3124, S3125, S3129, S3130, S3131, S3132, S3139, S3144, S3150, S3160, S3190, S3900, X6000, X6200, X6300, X6400, X6900, X7300, X7500, X7510, X7520, X7530, X7590, L9000, Z1110, Z1190
Salt	S3000, S3140, S3141, S3142, S3143, S3149, S3900, L9000
Solidified Organics	L2000, L2100, L2110, L2120, L2190, L2200, L2210, L2220, L2290, L2900, S3000, S3114, S3200, S3210, S3211, S3212, S3219, S3220, S3221, S3222, S3223, S3229, S3230, S3290, S3900, S5340, X6000, X6100, X6190, X6900, L9000, Z1110, Z1190
Soils	S4000, S4100, S4200, S4300, S4900
Uncategorized Metal (Metal Waste Other Than Lead and/or Cadmium)	S3116, S5000, S5100, S5110, S5111, S5119, S5190, X6200, X7000, X7290, X7400, X7430, X7490, X7520, Z1140, Z1190, Z2100
Lead and Cadmium Metal	S5000, S5100, S5110, S5112, S5113, S5119, S5190, X6220, X7000, X7200, X7210, X7211, X7212, X7219, X7220, X7290, X7400, X7410, X7420, X7490, Z2100
Inorganic Nonmetal	S3117, S3118, S3160, S5000, S5100, S5120, S5121, S5122, S5123, S5124, S5125, S5126, S5129, S5190, Z1120, Z1150, Z1190
Combustible	S5000, S5300, S5310, S5311, S5312, S5313, S5319, S5320, S5330, S5390, Z1130, Z1190, Z1200
Graphite	S5000, S5126
Heterogeneous	S5000, S5100, S5400, S5420, S5440, S5450, S5460, S5490, X7520, Z2900
Filter	S5000, S5410

Source: Adapted from TWBIR, Revision 3, Table 1-2.

Legend:

L Liquids
S Solids
X Specific Waste Forms
Z Final Waste Forms

- as-generated waste form volumes and final waste form volumes:

- estimated minimum, average, and maximum weights of waste components per cubic meter of final waste form volume (for example, iron-base metal and alloys, aluminum-base metal and alloys, cellulosics, etc.);

- identification of whether the waste is CH-TRU or RH-TRU;

- final waste form radionuclide inventory (activity in curies per cubic meter); and

- comments provided by the TRU waste generator and storage sites to further explain the data provided.

Site-Specific Waste Profile – This represents a final waste form at a particular DOE TRU waste generator and storage site. That is, one or more waste stream profiles at a particular DOE TRU waste site that have been placed in the same final waste form are summarized in the site-specific waste profile. Examples of information included in a site-specific waste profile are

- DOE TRU waste generator and storage site identification;

- final waste form that the profile represents;

- listing of the waste streams (represented by waste stream profiles provided by the TRU waste generator and storage sites) that are included in the site-specific waste profile, including the waste stream identification;

- final waste form volumes (both stored and currently projected); and

- summary of minimum, average, and maximum weights of WMPs per cubic meter of final waste form volume on a site basic (for example, iron-base metal and alloys, aluminum-base metal and alloys, cellulosics, etc.).

WIPP Waste Profile – The WIPP waste profile represents a summary of TRU wastes at all DOE TRU waste generator and storage sites that have an identical final waste form. Examples of information included in a WIPP waste profile are

- the final waste form that the profile represents;

- listing of the DOE TRU waste sites (represented by the same final waste form) that are included in the WIPP waste profile, including the name of the DOE TRU waste site;

- final waste form volumes of stored and currently projected waste for each site; and

- summary of minimum, volume-weighted average, and maximum weights of WMPs per cubic meter of final waste form volume on a WIPP basis (for example, iron-base metal and alloys, aluminum-base metal and alloys, cellulosics, etc.).

WMP – This is one or more of the nonradioactive TRU waste stream constituents. The 12 WMPs have been grouped by their chemical and physical properties as shown in the following list.

Inorganics

- Iron-based metals and alloys — includes iron and steel alloys in the waste and does not include the waste container materials.

- Aluminum-based metals and alloys.

- Other metal and alloys — includes all other metals found in the waste materials (for example, copper, lead, zirconium, tantalum, etc.). The lead portion of lead rubber gloves and aprons is also included in this category.

- Other inorganic materials — includes inorganic nonmetal waste materials such as concrete, glass, firebrick, ceramics, sand, and inorganic sorbents.

- Vitrified materials — includes waste that has been melted or fused at high temperatures with glass-forming additives such as soil or silica to form a homogeneous glass-like matrix.

Organics

- Cellulosics — includes those materials generally derived from high-polymer plant carbohydrates. Examples are paper, cardboard, kimwipes, wood, cellophane, cloth, etc..

- Rubber — includes natural or synthetic elastic latex materials. Examples are Hypalon, neoprene, surgical gloves, leaded-rubber gloves (rubber part only), etc..

- Plastics — includes generally synthetic materials, often derived from petroleum feedstock. Examples are polyethylene, polyvinylchloride, Lucite, Teflon, etc..

Solidified Materials

- Inorganic matrix — includes any homogenous materials consisting of sludge or aqueous-based liquids that are solidified with cement, Envirostone, or other solidification agents. Examples are wastewater treatment sludge, cemented aqueous liquids, inorganic particulates, etc..

- Organic matrix — includes cemented organic resins, solidified organic liquids, and sludges.

- Cement — includes the cement used in solidifying liquids, particulates, and sludges.

Soils

- Soils — generally consists of naturally occurring soils that have been contaminated with inorganic radioactive waste materials.

Although not considered to be a waste component, the associated packaging materials are also listed because they also provide input to the performance assessment calculations.

Packaging Materials

- Steel — weight of the steel component of the standard container. Any necessary overpacking is included in the weight of steel.

- Plastics — weight of any standard plastic secondary confinement within the container.

- Lead — weight of the lead shielding.

The estimated WMP information is expressed in units of kilograms per cubic meter of waste matrix. This unit facilitates scaling the material parameters to address various volumes for performance assessment calculations and sensitivity analysis.

4.1.3.2 Nonradionuclide Inventory Roll-up

The DOE uses the eleven final waste forms in the TWBIR as an intermediate step in determining the inventory of nonradioactive waste components. These final waste forms are a convenient way for the DOE to categorize waste for the purpose of waste management and waste characterization prior to shipment to the WIPP.

Waste streams at each TRU waste generator and storage site with similar WMCs are grouped together into one of the 11 final waste forms as shown in Table 4-2. An example of the methodology for grouping waste stream information is illustrated in Figure 4-3. The grouping of individual waste stream profiles into a site-specific waste profile is based on the similar physical and chemical properties of the waste streams. In the example in Figure 4-3, because of their similar properties for performance assessment modeling, concrete waste, glass waste, firebrick waste, and ceramic waste mainly influence the estimation of porosity and permeability in the waste panel region (see Figure 6-13) of the model. Therefore, the three streams within the DOE TRU Waste Site #1 and the two at DOE TRU Waste Site #2 can be

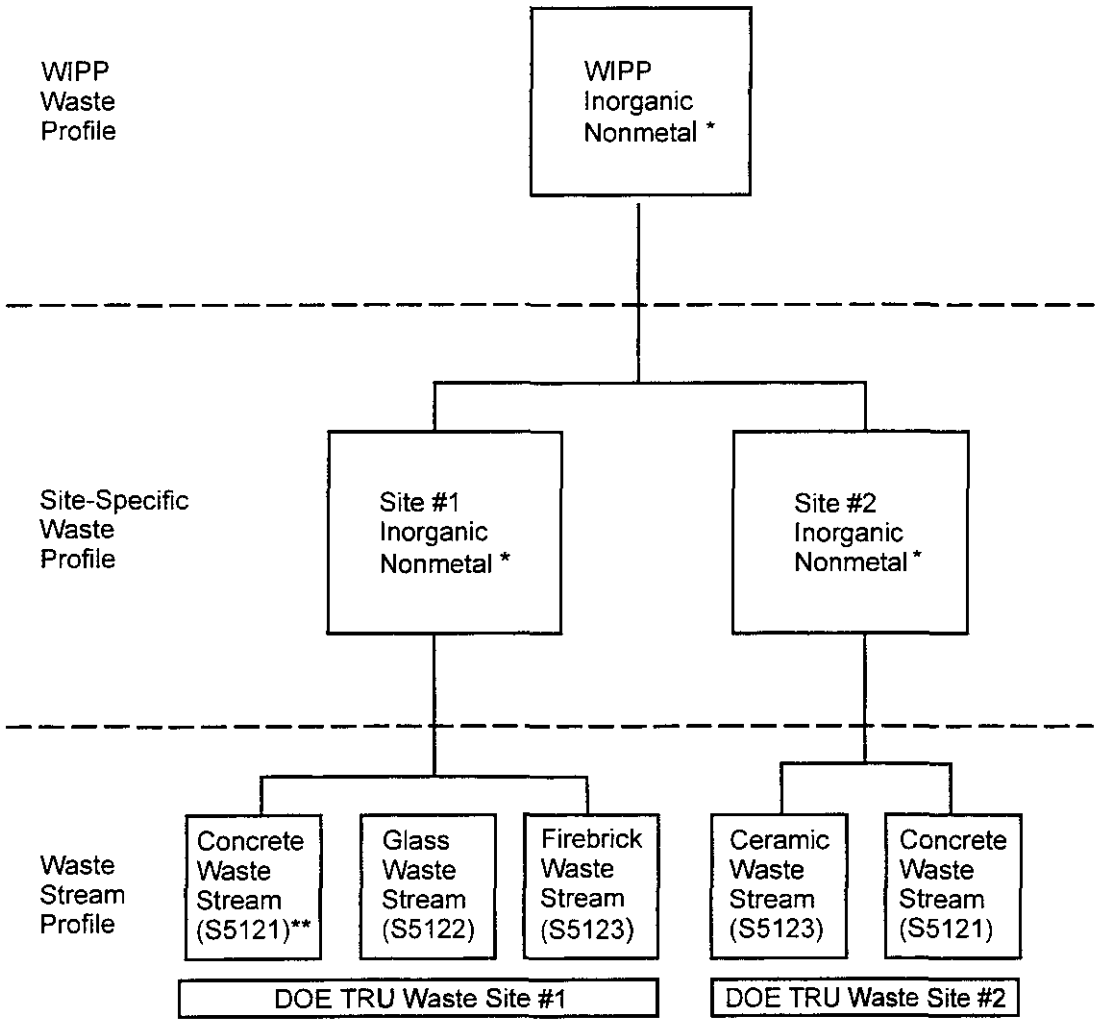

* See Table 4-2 for WMCs that can occur in each final waste form
** WMC

Note: Adapted from Figure 1-2, TWBIR, Revision 3.

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Figure 4-3. Schematic of Waste Stream Profile Methodology

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grouped together at each site based on similar physical and chemical properties and placed into the site-specific waste profile inorganic nonmetal waste, with the final waste form defined in Table 4-2.

For the DOE to consider disposal system performance at full capacity, it was necessary to scale the waste volumes in the TWBIR. This is because the TWBIR does not identify 6.2 million cubic feet (175,564 cubic meters) of existing or projected waste. The projected inventory in the TWBIR is scaled, if needed, to achieve a disposal limit equal to the design limit. For RH-TRU waste volume, the TWBIR has identified a sufficient quantity of retrievably stored waste, such that scaling is not required to meet the WIPP's RH-TRU waste disposal limit of 250,000 cubic feet (7,079 cubic meters). Estimates of the WIPP final waste-form volumes for CH-TRU and RH-TRU waste are provided in Table 4-3.

Table 4-3. Anticipated Nonradionuclide TRU Waste Inventory for the WIPP

Final Waste Forms	Stored Volumes (cubic meters)	Projected Volumes (cubic meters)	Anticipated Volumes (cubic meters)	WIPP Disposal Volumes (cubic meters)
CH Waste				
Combustible	5.8E+03	4.6E+03	1.0E+04	1.4E+04
Filter	2.2E+02	5.1E+02	7.3E+02	1.2E+03
Graphite	5.1E+02	4.8E+01	5.6E+02	6.0E+02
Heterogeneous	2.7E+04	1.3E+04	4.0E+04	5.1E+04
Inorganic Nonmetal	3.1E+03	9.4E+02	4.1E+03	4.9E+03
Lead and Cadmium Metal Waste	3.5E+01	3.3E+02	3.7E+02	6.6E+02
Salt Waste	2.1E+01	3.3E+02	3.5E+02	6.4E+02
Soils	4.1E+02	6.0E+03	6.4E+03	1.2E+04
Solidified Inorganics	9.6E+03	4.5E+03	1.4E+04	1.8E+04
Solidified Organics	9.1E+02	7.5E+01	9.8E+02	1.1E+03
Uncategorized Metal	1.1E+04	2.3E+04	3.4E+04	5.4E+04
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**	**1.6E+05**
RH Waste				
Combustible	3.6E+01	4.9E+01	8.5E+01	
Heterogeneous	2.3E+03	5.5E+03	7.8E+03	
Inorganic Non-Metal	4.6E+01	2.1E+01	6.8E+01	
Lead and Cadmium Metal Waste	7.1E+00	6.7E+01	7.4E+01	
Solidified Inorganics	1.1E+03	2.3E+02	1.3E+03	
Solidified Organics	3.6E+00	0.0E+00	3.6E+00	
Uncategorized Metal	1.2E+02	1.7E+04	1.8E+04	
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**	**7.1E+03**[1]
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**	**1.7E+05**

Source: Adapted from TWBIR, Revision 3, Table 2-1.

[1] WIPP is limited to 7,079 cubic meters of RH-TRU waste.

To establish the nonradioactive waste component inventory, the DOE accumulated WMP information in the TWBIR by final waste form. This accumulation is shown as a series of tables (Tables 3-1 through 3-18 in Appendix BIR) in the TWBIR. These are further summed to determine the total WIPP waste component disposal inventory for CH-TRU and RH-TRU waste and are given in Tables 4-4 and 4-5, respectively. It should be noted that MgO is not listed in these tables. Since MgO is not a component of the waste, it is not regarded as a WMP. A discussion of the MgO backfill is contained in Chapter 3.0, Appendix BACK, and Appendix SOTERM.

Table 4-4. WIPP CH-TRU WMP Disposal Inventory

Waste Components	Average (kilograms per cubic meter)
Iron Base Metal and Alloys	170
Aluminum Base Metal and Alloys	18
Other Metal and Alloys	67
Other Inorganic Materials	31
Vitrified	55
Cellulosics	54
Rubber	10
Plastics	34
Solidified Inorganic Material	54
Solidified Organic Material	5.6
Cement (Solidified)	50
Soils	44
Container Materials - kilograms per cubic meter	
Steel	139
Plastic and Liners	26

Source: Adapted from TWBIR, Revision 3, Table 2-2.

The DOE reports the average density for WMPs because these values are used to generate the waste-related inputs for performance assessment. Section 3.4 of the TWBIR recommends use of the average value, based on the methodology used to obtain and report data. Section 3.3 of the TWBIR provides a formula for determining the average WMP densities.

With regard to the inventory of chemical components of the waste (needed for scoping calculations to determine their importance on performance), this information was requested from the generator/storage sites by the DOE subsequent to the issuance of Revision 2 of the TWBIR. The information requested by the DOE was specific to solidified waste forms destined for disposal at the WIPP and included complexing agents, nitrates, sulfates, phosphates, and cement. A summary of this supplemental information can be found in Sections 3.3.1, 3.3.2, and 3.3.3 of the TWBIR, Revision 3. Additional information addressing the impact, limits, and characterization (or noncharacterization) of these chemical components

Table 4-5. WIPP RH-TRU WMP Disposal Inventory

Waste Components	Average (kilograms per cubic meter)
Iron Base Metal and Alloys	10
Aluminum Base Metal and Alloys	7.1
Other Metal and Alloys	250
Other Inorganic Materials	64
Vitrified	4.7
Cellulosics	17
Rubber	3.3
Plastics	15
Solidified Inorganic Material	22
Solidified Organic Material	.093
Cement (Solidified)	19
Soils	1
Container Materials - kilograms per cubic meter	
Steel	446
Plastic and Liners	3.1
Lead	465
Steel Plug	2145

Source: Adapted from TWBIR, Revision 3, Table 2-3.

is provided in Appendix WCA, Appendix WCL, Section 4.4, and Tables 4-1 and 4-13. The importance of these chemical components to performance assessment is assessed in Appendix WCA.

4.1.3.3 Radionuclide Inventory Roll-up

Estimates of the radionuclide inventory are included in the TWBIR. Generators derive these estimates based on acceptable knowledge including any quantitative results that may be available. The radioactive inventory of disposed waste will be determined quantitatively prior to shipment as discussed in Section 4.2.2.

The estimates of radioactivity provided by the generator and storage sites are for stored waste only. Assuming the radionuclide distribution for projected waste to be the same as the stored waste inventory, and taking the radionuclide distribution of the stored inventory to be uniform over the stored volume, it is possible to scale the activity of the stored radionuclide inventory to the full WIPP repository. This assumption is reasonable because no new waste forms or waste generating processes are anticipated for the future and radionuclide distributions for the DOE weapons program activities are well known. The WIPP disposal radionuclide inventory has been estimated on the basis of these assumptions by first calculating the activity per unit volume (that is, curies per cubic meter) of each radionuclide that is present in the stored waste at each site. This calculation is based on all radionuclide activities decayed to the end of 1995. Radioactive decay and build-up calculations are performed annually and reported in the

TWBIR using the commercially available code ORIGEN2 (Croff 1980). The levels of radioactivity reported include contributions from both parent and daughter decay products. The curies per cubic meter calculated for each radionuclides in the stored waste at each site are then multiplied by the volume of projected waste to estimate the total curies of each radionuclide in the projected waste. The curies for the stored and the projected waste for each individual radionuclide at all sites are then added to obtain the total curies for CH-TRU and RH-TRU waste. For CH-TRU waste, the total curies for each radionuclide is divided by the CH-TRU disposal inventory to obtain a curies per cubic meter concentration for each radionuclide on a repository level. For RH-TRU waste, the total decayed WIPP curies for each radionuclide is divided by the sum of the stored and actual projected RH-TRU waste volume to obtain a radionuclide concentration in curies per cubic meter.

The WIPP disposal radionuclide inventory to be used in this application for both CH-TRU and RH-TRU wastes is shown in Table 4-6. The table shows individual radionuclide activity in curies for both CH-TRU and RH-TRU waste. Based on the total curies shown in Table 4-6 and to the extent to which each radionuclide is regulated by 40 CFR § 191.13, approximately 99.9 percent of the regulated CH-TRU activity at repository closure is contributed by ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am. Approximately 99.4 percent of the regulated RH-TRU activity at repository closure is contributed by ^{137}Cs, ^{90}Sr, ^{239}Pu, ^{240}Pu, ^{241}Am, and ^{238}P (See Appendix WCA, Section WCA.8.2). The values presented in Table 4-6 are used as input to the performance assessment calculations. A more detailed examination of the programs prepared by the DOE to collect supplemental radiological data is provided in Section 4.4.

In addition to the inventory in Table 4-6, the DOE has determined the average radionuclide inventory for each of the 569 CH-TRU and one RH-TRU waste streams in the conceptual models (see Appendix BIR, Revision 3, Appendix B-2). The distribution of waste streams is randomly sampled in the performance assessment process to determine releases due to inadvertent human intrusion. This process is discussed in Section 6.4.12.4 and assumes that each container in the waste stream has the average radionuclide inventory for that stream.

4.2 Waste Components and Characteristics

This section of the application is provided to document compliance with the provisions of 40 CFR § 194.24(b) and describes, in summary fashion,

- those components or characteristics of the waste that are most important in terms of their impact on the performance of the WIPP disposal system and

- the limits imposed by the DOE on the significant components or characteristics of the waste to ensure that future emplaced waste will behave in a manner that is consistent with the inventory assumed for the performance calculations.

Table 4-6. Important Radionuclides Considered in Performance Assesment

Radionuclide	Inventory at Closure (Curies)	EPA Units at Closure	EPA Units at 10,000 years	Release Calculations (1)		
				Cuttings, Cavings, & Spall Release	Direct Brine Release	Culebra Release
Pu238	1.94E+06	5.63E+03	1.32E-22	x	x	(2)
Pu239	7.95E+05	2.31E+03	1.73E+03	x	x	x
Am241	4.88E+05	1.42E+03	1.55E-01	x	x	x
Pu240	2.14E+05	6.23E+02	2.16E+02	x	x	c
Cs137	9.31E+04	2.71E+01	0.00E+00	x	--	--
Sr90	8.73E+04	2.54E+01	0.00E+00	x	--	--
U233	1.95E+03	5.67E+00	5.44E+00	x	x	c
U234	7.51E+02	2.18E+00	4.09E+00	x	x	x
Th230	3.06E-01	8.88E-03	3.56E+00	--	x	x
Pu242	1.17E+03	3.40E+00	3.34E+00	--	x	c
Th229	9.97E+00	2.90E-02	3.40E+00	--	x	c
Np237	6.49E+01	1.89E-01	4.82E-01	--	x	--
Cm245	1.15E+02	3.33E-01	1.48E-01	--	x	--
Ra226	1.14E+01	3.32E-02	2.77E-01	--	--	--
Pb210	8.75E+00	2.54E-02	2.77E-01	--	x	--
U238	5.01E+01	1.46E-01	1.46E-01	--	x	--
U236	6.72E-01	1.95E-03	1.16E-01	--	x	--
Am243	3.25E+01	9.45E-02	3.69E-02	--	x	--
U235	1.75E+01	5.08E-02	7.06E-02	--	x	--
Cm243	2.07E+01	6.03E-02	0.00E+00	--	x	--
U232	1.79E+01	5.21E-02	0.00E+00	--	--	--
C14	1.28E+01	3.72E-02	1.11E-02	--	--	--

Table 4-6. Important Radionuclides Considered in Performance Assesment (Continued)

Radionuclide	Inventory at Closure (Curies)	EPA Units at Closure	EPA Units at 10,000 years	Release Calculations (1)		
				Cuttings, Cavings, & Spall Release	Direct Brine Release	Culebra Release
Th232	1.01E+00	2.92E-02	2.92E-02	--	x	--
Ac227	5.05E-01	1.47E-03	1.28E-02	--	--	--
Pa231	4.67E-01	1.36E-03	1.28E-02	--	--	--
Cm248	3.72E-02	1.08E-04	1.06E-04	--	x	--
Pu244	1.51E-06	4.40E-09	1.26E-08	--	x	--
Pu241	3.94E+05	(3)	(3)	x	x	--
Cm244	7.44E+03	(3)	(3)	x	x	--
Percent of EPA Units at closure included in calculation				99.96%	99.48%	43.45%
Percent of EPA Units at 10,000 years included in calculation				99.40%	99.98%	99.92%

(1) See Section 6.3 for a discussion of scenarios analysed by performance asessment and the release pathways.
(2) Pu238 was included in the Salado transport calculations but the release to the Culebra was too low to merit calculation of its transport within the Culebra. The EPA unit percent total at closure increases to 99.47% with Pu238 added; the percent at 10,000 years is unaffected.
(3) Pu241 and Cm244 are not regulated by 40 CFR Part 191 but are included because their daughters, Am241 and Pu240 respectively, are significant to performance.
x indicates an isotope included in calculation.
c indicates isotopes that are combined for transport with isotopes having similar chracteristics.

4.2.1 Identification and Qualification

The following text is responsive to the criterion at 40 CFR § 194.24(b).

The waste characteristics and components expected to be most significant to performance are the predominant radionuclides and their associated characteristics and components affecting actinide mobility. These are summarized in Table 4-7. The waste unit factor is the number of millions of curies of alpha-emitting TRU radionuclides with half-lives longer than 20 years (40 CFR Part 191, Appendix A). In the WIPP, 3.44 million curies of TRU waste will be in the repository at closure, so the waste unit factor is 3.44. The radionuclides that contribute to the waste unit factor are based on an analysis (see Appendix WCA.8.2) of the radionuclide

Table 4-7. Waste Characteristics and Components Expected to be Most Significant to Performance

Characteristic and Component	Reason for Significance
^{239}Pu, ^{240}Pu, ^{241}Am, ^{233}U, and ^{234}U	99 percent of EPA unit after 2,000 years
^{238}Pu	dominates EPA unit at early times
solubility of Pu and Am	large EPA unit; mobility depends on solubility
^{238}U	very low activity; dilutes higher-activity uranium isotopes for brine-based releases
iron	maintains reducing environment so that lower, less soluble oxidation states of actinides predominate
cellulose, plastic, rubber, nitrate, sulfate	microbial nutrients that are metabolized to methane and several other gases, increasing gas pressure; formation of colloids
humic materials, cellulose breakdown products	form humic colloids that sorb and transport actinides
nonferrous metals	prevent increase in actinide solubility by binding with ligands
waste shear strength	important to spalling and cavings

Source: Appendix WCA (Table WCA-12)

inventory in Revision 3 of the TWBIR (Appendix BIR) and are presented in Table 4-8 (decayed to the end of 2033). Waste characteristics and components with an insignificant impact of performance are summarized in Table 4-9.

4.2.2 Repository Limits

This following discussion is responsive to the criteria at 40 CFR § 194.24(c)(1) and 40 CFR § 194.24(c)(2).

Components are the controlling factors for the characteristics; therefore any limits imposed on the waste components necessarily serve to limit the waste characteristics. In the case where a characteristic is benign with respect to repository performance, no control of the corresponding component is necessary and no limits need be imposed on that component. Conversely, should repository performance be sensitive to a particular waste characteristic, then control of the corresponding component is mandated and limits are established to restrict the maximum or minimum amounts of that component allowed for disposal.

Table 4-10 shows the components expected to be potentially significant in as previously identified in Tables 4-1 and 4-7. Based on the performance assessment calculations and the rationale developed in Appendix WCL, Table 4-10 identifies the characteristics of the

Table 4-8. Radionuclides That Contribute to the Waste Unit Factor

Nuclide	Half-Life (years)	Inventory at Closure (curies)	Percent of Waste Unit
^{241}Am	432.7	4.88×10^{5}	1.42×10^{1}
^{243}Am	7370	3.25×10^{1}	9.45×10^{-4}
^{249}Cf	351	6.38×10^{-2}	1.85×10^{-6}
^{251}Cf	900	3.67×10^{-3}	1.07×10^{-7}
^{243}Cm	29.1	2.07×10^{1}	6.02×10^{-4}
^{245}Cm	8500	1.15×10^{2}	3.34×10^{-3}
^{246}Cm	4760	1.02×10^{-1}	2.97×10^{-6}
^{247}Cm	1.56×10^{7}	9.51×10^{-9}	2.76×10^{-13}
^{248}Cm*	3.48×10^{5}	3.72×10^{-2}	1.08×10^{-6}
^{237}Np	2.14×10^{6}	6.49×10^{1}	1.89×10^{-3}
^{238}Pu	87.7	1.94×10^{6}	5.64×10^{1}
^{239}Pu	2.41×10^{4}	7.95×10^{5}	2.31×10^{1}
^{240}Pu	6560	2.14×10^{5}	6.22
^{242}Pu	3.75×10^{5}	1.17×10^{3}	3.40×10^{-2}
^{244}Pu	8.0×10^{7}	1.51×10^{-6}	4.39×10^{-11}
TOTAL		3.44×10^{6}	

Modified (Inventory decayed to 2033) from Table WCA-5 (Appendix WCA)

* This number differs slightly from that in Appendix WCA (Section WCA.8.2) as a result of more recent information.

Table 4-9. Waste Characteristics and Components Expected to be Not Significant

Characteristics and Component	Reason for insignificant impact
radionuclides other than those in Table 4-7	EPA unit is negligible fraction of total, even with ingrowth
substances that may affect pH*	pH is buffered by MgO backfill
substances that produce CO_2*	CO_2 is removed by reaction with MgO backfill
intrinsic and mineral fragment colloids	fraction of actinides mobilized by these colloids is insignificant
organic ligands	removed by binding with Mg and nonferrous metal
heat generated by exothermic reactions	heats of formation are small and thermal mass of repository is large so that temperature rise is negligible
fluid in the waste	negligible compared to brine volume

Source: Appendix WCA (Table WCA-13)

* These components are significant for gas generation, but not for actinide solubility.

Table 4-10. Repository-Based Emplacement Limits Related to Performance Assessment

Waste Components	Associated Waste Characteristics	Components Requiring Quantification	Emplacement Limits
radionuclides	radioactivity at closure radioactivity after closure solubility colloid formation reduction-oxidation state	^{241}Am ^{238}Pu ^{239}Pu ^{240}Pu ^{242}Pu ^{233}U ^{234}U ^{238}U ^{90}Sr ^{137}Cs	none [a]
ferrous metals (iron)	reduction-oxidation potential H_2 has generation complexing with organic ligands	none	minimum = 2×10^7 kilograms (amount from containers) [b]
cellulose, plastics, rubber	gas generation humic colloids (see below) gas generation	sum of emplaced components	maximum = 2×10^7 kilograms[c]
sulfates	gas generation	none	none[d]
nitrates	gas generation	none	none[d]
solid components	particle size effective shear resistance to erosion tensile strength	none	none
free water emplaced with waste	gas generation	none	maximum = 1684 cubic meters for CH-TRU (limit of 1 percent total waste volume as set by the WAC) [e]
humic substances	radionuclide-bearing humic colloids	none	none
nonferrous metals (metals other than iron)	bind with organic ligands and prevent increased solubility	none	minimum = 2×10^3 kilograms[f]
organic ligands	solubility	none	none [d]

Source: Appendix WCL

[a] Inventory curie content will be tracked.

[b] Minimum set to ensure sufficient reactants for reducing radionuclides to lower and less soluble oxidation states. Average density for CH-TRU container steel of 139 kilograms per cubic meter multiplied by the design basis value of 168,485 cubic meters.

[c] Maximum set to ensure sufficient MgO backfill is available to react with CO_2 produced.

[d] For the current waste generation processes that are documented in the TWBIR.

[e] 1 percent of the design basis values for CH-TRU of 168,485 cubic meters.

[f] Minimum quantity for complexing with organic ligands (see Appendix SOTERM, Section SOTERM.5).

components for which assay prior to emplacement is required. Table 4-10 also lists any applicable repository-based emplacement limit for the components. Discussions of the rationale for the proposed assaying and emplacement limits for each component are in Appendix WCL. All of the components identified in Appendix WCA were found to be insignificant to disposal system performance. Therefore, it is not necessary to establish container-based emplacement limits for these components other than those already imposed through the Waste Acceptance Criteria (WAC) (see next section).

Table 4-11 is a supplement to Table 4-10; that is, it lists the repository limits imposed by the LWA (U.S. Congress 1992b). Collectively, Tables 4-10 and 4-11 define the WIPP repository-based emplacement limits on the waste.

Table 4-11. Repository-Based Emplacement Limits Imposed by the LWA

Waste Components	Emplacement Limits
Total Capacity (CH- and RH-TRU)	6.2 million cubic feet (175,564 cubic meters)
RH waste total curies	5.1 million curies (~18.9×10^{16} Becquerels)

4.2.3 Waste Container Limits

Waste limits have been established by the DOE as part of the WIPP's design development and by the WIPP LWA. Table 4-12 identifies waste container limits. The WAC is a compilation of criteria that restrict the physical, chemical, and radiological properties of the waste to mitigate conditions that will have adverse impacts on human health and the environment. The current WIPP WAC (DOE 1996a) does not contain restrictions associated with or driven by performance assessment results.

The WAC is founded on transportation requirements, disposal operations safety criteria as documented in the Safety Analysis Report (SAR) (DOE 1995d), regulatory compliance requirements and several other drivers (depicted in Figure 4-4) including the WAP, the Safety Analysis Report for Packaging (SARP), and this application. Only those wastes that meet established acceptance criteria and obtain waste stream profile approval from the CAO will be emplaced in the WIPP disposal system. Waste forms that do not meet these criteria will require treatment and/or repackaging prior to WIPP certification. Application of the WAC extends to both CH-TRU and RH-TRU waste proposed for disposal in the WIPP. The current WAC limits shown in Table 4-12 are on a waste container basis.

The WAC requires the generator to prepare a waste-certification program that lists the methods and techniques used to determine compliance with the WAC and the quality assurance (QA) and quality control criteria that are applied to the generator's waste certification program. Each participating site is responsible for developing and implementing

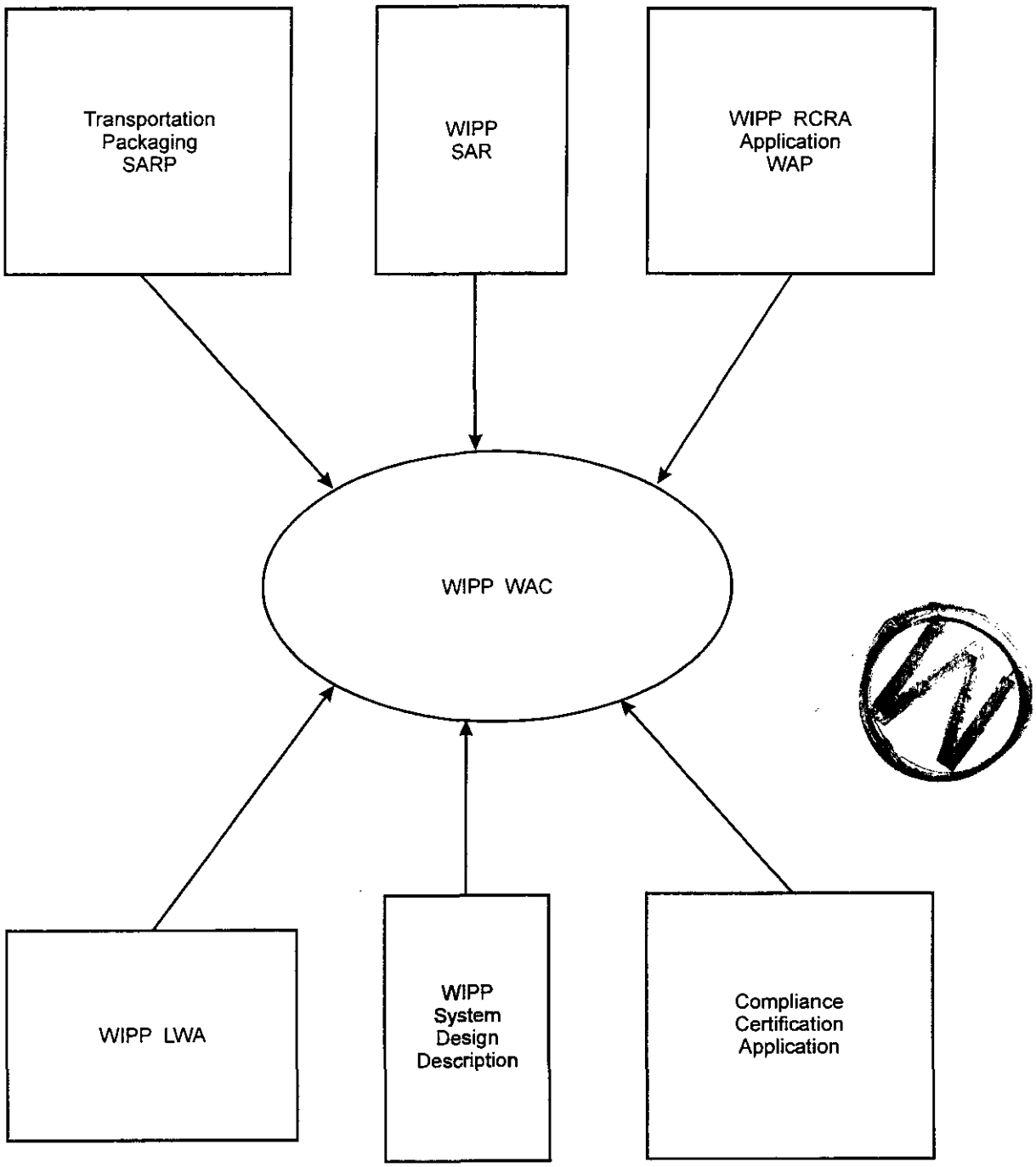

Note: Adapted from Figure 2-1, WAC Revision 5.

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Figure 4-4. Origins of the WAC

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Table 4-12. Container-Based Limits Imposed by the WAC

Waste Component or Characteristic	Limit
CH and RH waste criticality	<200 fissile gram equivalents (FGE) per 55 gallon drum <325 FGE per standard waste box (SWB)
CH and RH waste ^{239}Pu equivalent activity	Untreated Waste ≤80 plutonium equivalent curies (PE-Ci) per drum ≤130 PE-Ci per SWB ≤1800 PE-Ci per drum[1] Solidified/Vitrified Waste ≤1800 PE-Ci/55 gallon drum
CH and RH waste surface dose rate	≤200 mrem/hr (CH) ≤1000 rem/hr (RH)
RH waste thermal power	Report if 70.1 watts/cubic feet
RH waste curies per liter	≤23 curies/liter
Liquids or aqueous waste	No liquid wastes <2 liters total residual liquid per 55 gallon drum <8 liters total residual liquid per SWB <inch in the bottom of any container
Explosives	None
Compressed gases	None
Pyrophoric materials	<1% radionuclide pyrophorics No nonradionuclide pyrophorics
Polychlorinated Biphenyls	<50 ppm

[1] Overpacked in a SWB or ten-drum overpack.

site-specific TRU waste program documents (plans) that address all activities pertaining to TRU waste characterization, certification, packaging, and transportation of TRU waste to the WIPP. These plans include the TRU Waste Certification Plan and associated QA plan, the TRUPACT-II Authorized Methods for Payload Control and associated QA plans, and the TRU waste characterization QAPjP. Methods of compliance with each criterion and requirement are documented or specifically referenced and include procedural and administrative controls.

The DOE CAO Manager is responsible for granting and revoking authority to a site to certify TRU waste to the WAC. The CAO performs certification audits of the sites to assess the implementation of and compliance with the approved plans. On the basis of acceptable results of the certification audits, the DOE grants TRU waste certification authority and

transportation authority to the site. Continuing oversight of participating sites is provided by the DOE through periodic audits of TRU waste characterization, certification, and transportation activities.

A waste-stream profile form (contained in the WAP) is used by generator site personnel to notify the WIPP that a waste stream has been identified and characterized. The data described on this form are used by the WIPP as the basis for acceptance of the waste characterization process identified for each container belonging to this waste stream. The WAC establishes limits for the physical, radiological, and chemical characteristics of the waste in addition to specifications for the waste packaging.

Once the DOE has obtained necessary operating permits and certifications, appropriate changes to the WAC will be published to reflect new restrictions and conditions imposed by permits and certifications. These changes will be communicated to the generator and storage sites as a change to the WAC. Those retrievably stored or newly generated waste streams that do not meet the current disposal WAC, however, may require processing (including repackaging and/or treatment) until certification can be attained. Any such processing is the responsibility of the site proposing to ship the waste to the WIPP. TRU waste that has been characterized in accordance with prior revisions of the WAC and the QAPP may be reconciled with current requirements. This reconciliation is documented and filed at the site.

4.3 Waste Controls

This section describes those processes that ensure compliance with the limits for CH-TRU and RH-TRU waste to be emplaced in the WIPP disposal system.

4.3.1 Load Management

The following discussion is responsive to the criteria at 40 CFR § 194.24(d)(f).

Load management is the process of controlling the shipment and emplacement of TRU waste in order to achieve a predetermined (that is, nonrandom) distribution of waste within the disposal system. An important reason for considering the impact of spatial distribution of waste in the repository is because of the significance of human intrusion on long-term repository performance. As described in Section 6.4.12, drilling events are assumed to be random in time and space. The location of each intrusion borehole within the waste disposal region is sampled randomly. Each intrusion borehole that penetrates waste may encounter CH-TRU waste or RH-TRU waste. For calculating direct releases to the accessible environment, containers are assumed to be placed in the WIPP from the various 569 waste streams which comprise CH-TRU waste in a random manner. In calculating direct releases resulting from a drill bit penetrating containers, each of the three stacked containers can come from different waste streams and have different activity loading. As described in Section 6.5, direct release from cuttings and cavings are the most important releases in assessing compliance with the quantitative containment requirements in 40 CFR § 191.13(a).

The CCDFs presented in Section 6.5 are constructed by estimating cumulative radionuclide releases to the accessible environment for 10,000 different possible futures. The estimated release for each future includes the randomly sampled waste streams for each of the various intruding boreholes that comprise that sampled future. A sampling of 10,000 futures is large enough that the relatively low probability combination of three of the waste streams with higher activity loading occurring in a single drilling event is captured in the CCDFs presented in Section 6.5. As described in Section 6.5, the CCDF is not impacted by sampling uncertainty so the assumption of random emplacement of containers is not important to the location of the CCDF and a load management plan is not necessary to support performance assessment assumptions.

4.3.2 WIPP Waste Information System

The following discussion is responsive to the criteria at 40 CFR § 194.24(c)(4) and 40 CFR § 194.24(c)(5) and those at 40 CFR § 194.24(e).

The WWIS is a computerized data management system used by the WIPP to gather, store, and process information pertaining to TRU waste destined for or disposed at the WIPP. The system supports those organizations who have responsibility for managing TRU waste by collecting information into one source and providing data in a uniform format that has been verified or certified as being accurate. The WWIS is used to store all information pertaining to characterization, certification, and emplacement of waste at the WIPP. Information for this system is supplied by the generator sites of TRU waste and the WIPP facility. Figure 4-5 depicts the process and flow of data from the sites to the WWIS.

The WWIS uses the Oracle (Version 7) database management system that follows American National Standards Institute (ANSI) standard query language. The database management system resides on a Digital Equipment Corporation hardware platform and is compliant with the majority of existing computer hardware throughout the DOE complex. UNIX is the operating system and supports multiuser and multitasking environments. The WWIS shall be available seven days a week, 24 hours a day except for periodic maintenance and shall support the maximum number of simultaneous users determined by the database management system license agreement and the operating system license agreement. The network communication protocol of the WWIS is Transmission Control Protocol/Internet Protocol (TCP/IP). Other features that distinguish the WWIS from its predecessor include automatic limit, range, and QA checks; automatic report generation; and compliance with QA requirements for computer software for nuclear facility applications (American Society of Mechanical Engineers [ASME], Nuclear Quality Assurance [NQA]-1, NQA-2, Part 2.7, and NQA-3 [ASME 1989a, b, and c in the Bibliography]).

The following WWIS documentation has been identified as necessary and sufficient to document the software lifecycle:

- WWIS Evaluation & Recommendation – provides an evaluation of hardware and software configurations for the WWIS and recommends an approach for implementation.

- WWIS Software Quality Assurance Plan – identifies and defines the standards and methodologies required to ensure conformance to accepted quality standards during the development, maintenance, and operation of the WWIS. This plan ensures that products conform to established technical requirements.

- WWIS Software Verification and Validation Plan – describes the criteria for verification and validation activities for the requirements, design, testing, and all necessary documentation.

- WWIS Software Requirements Specification – defines the requirements essential to the WWIS based on the WWIS Functional and Operational Requirements Document. All requirements shall be internally consistent and verifiable through demonstration, analysis, or testing.

- WWIS Software Design Description – defines the major features of the WWIS including the operating environment, databases, tables, external and internal interfaces, overall structure, sizing, modeling, and system throughput.

- WWIS Software Configuration Management Plan – describes the methods used for identifying software configuration items, controlling and implementing changes, and recording and reporting change implementation status.

- WWIS Security Plan – details the information for handling the security needs of the system (data, software, and hardware). This plan also describes password and access control procedures.

The DOE has identified more than 130 data fields for inclusion in the WWIS. An alphabetical listing and description of these data fields is found in Appendix C13 of Appendix WAP. The majority of these data fields are considered pertinent to demonstrate compliance with TRU waste transportation and disposal requirements, those data fields identified as relevant to this application include the following:

- assay characterization method

- assay date

- disposal date

- nondestructive examination

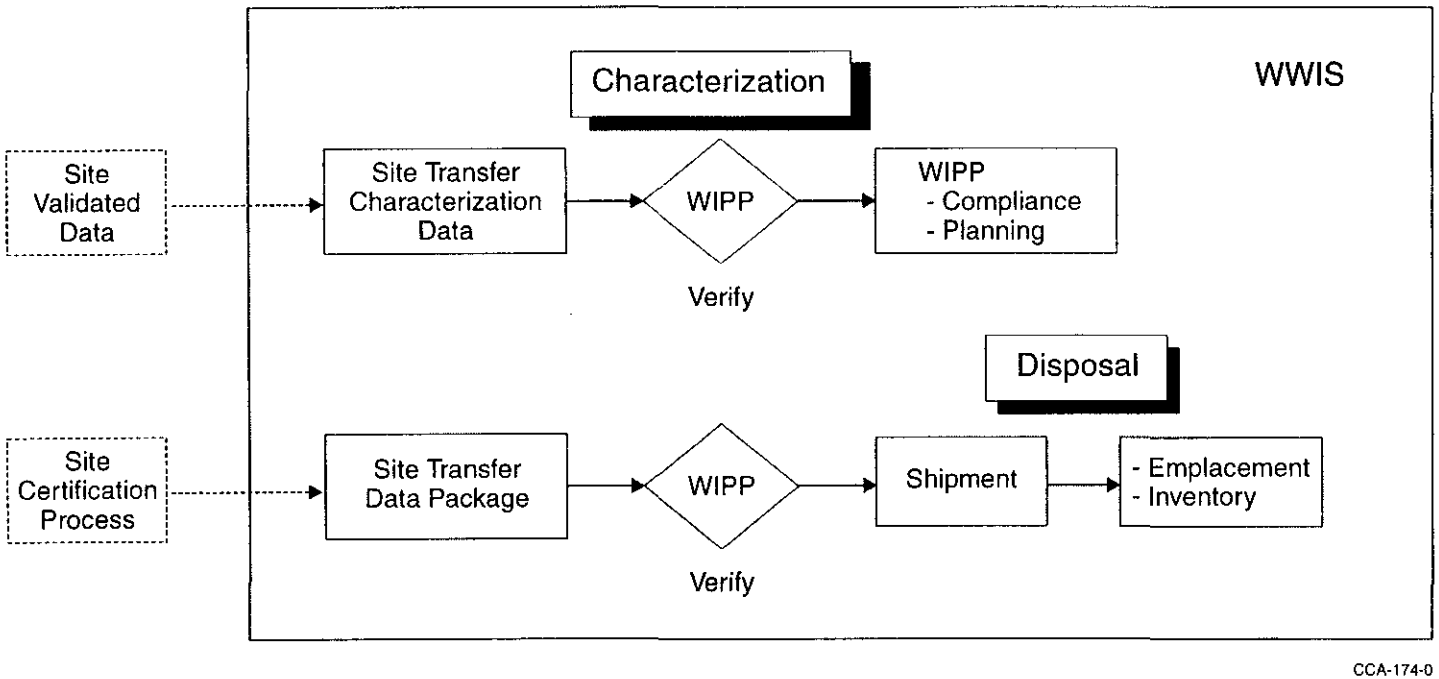

Figure 4-5. WIPP Waste Information System Process and Data Flow

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- ^{239}Pu fissile gram equivalent
- radionuclide activity
- radionuclide activity uncertainty
- radionuclide mass
- radionuclide mass uncertainty
- TRU alpha activity
- TRU alpha activity uncertainty
- verification data
- verification method
- visual examination of container
- WAC certification data
- WMPs
- WMC

To ensure compliance with the data requirements, personnel at the WIPP review the data package for completeness and adequacy before notifying the shipping site of acceptance. Thus, the WWIS becomes an integral part of the waste information screening process described in the WAP.

4.3.3 Quality Assurance

The implementation of a formal quality assurance program demonstrates the commitment of the DOE to perform all work activities and operations to the highest standards of quality. The DOE has established an effective QA program that complies with applicable sections of NQA-1, NQA-2 (Part 2.7), and NQA-3. The management controls defined by the various quality assurance plans and procedures ensure that all work is planned, documented, performed under controlled conditions, and periodically assessed to establish work item quality and process effectiveness and to promote improvement. The complexity, inherent risk, and significance of the work to the overall project and to public safety are key factors in determining applicable quality management requirements. Internal and external organizational interfaces and responsibilities are described in detail in Chapter 5.0.

The QA requirements for TRU waste characterization are contained in the DOE TRU Waste Characterization QAPP. The QAPP is applicable to all DOE TRU waste generator sites that anticipate characterizing TRU waste. Participating sites must follow acceptable analytical methods as specified in the Transuranic Waste Characterization Sampling and Analysis Methods manual (DOE 1995c). Included in the QAPP for each method is a description of the specific performance requirements. These are referred to as quality assurance objectives (QAOs). Should modifications to the approved test methods be necessary, whether for personnel protection from radiation or to implement an improved methodology, these modifications are to be fully documented and approved in accordance with the QAPP and the Sampling and Analysis Methods Manual.

The QAPjPs developed at each generator and storage site describe the characterization activities that are performed in conformance with the QA requirements specified in the QAPP. The DOE conducts annual certification audits, supplemented by surveillances to ensure that the sites comply with their approved site-specific QAPjPs. Figure 4-6 shows the quality assurance document hierarchy for waste characterization.

The QAOs for the nondestructive assay (NDA) of CH-TRU waste are listed in the QAPP and are intended to establish minimum performance requirements for the approved types of measurement systems. The QAOs include criteria for precision, accuracy, minimum detectable concentration, completeness, and total uncertainty. All measurements of activity for CH-TRU waste must have a precision bounded by the range of values in the QAOs established in the QAPP. Only those containers that can be assayed with a precision falling within these bounding values can be accepted for disposal at the WIPP.

Additional information regarding the quality assurance and quality controls used in ascertaining the waste description is given in Chapter 5.0.

4.3.3.1 Performance Demonstration Programs

The Performance Demonstration Program (PDP) plan for NDA for the TRU Waste Characterization Program (DOE 1995a) is designed to help ensure compliance with the QAOs identified in the TRU Waste Characterization QAPP for the WIPP. This plan, as well as the radioassay portion of the current revision of the QAPP, defines QAOs and measurement requirements for the characterization of alpha-emitting TRU isotopes associated with weapons-grade (WG) plutonium. WG plutonium is selected because of its predominance in an isotopic mixture within the TRU waste generated and retrievably stored across the DOE complex.

The CAO is the reviewing and approving authority for the PDP. All DOE facilities intending to dispose of their TRU waste at the WIPP must participate in the PDP and pass all individual tests within each PDP cycle. The CAO uses the PDP plan to assess, evaluate, and approve DOE facilities for waste measurement and characterization before the waste is shipped to the

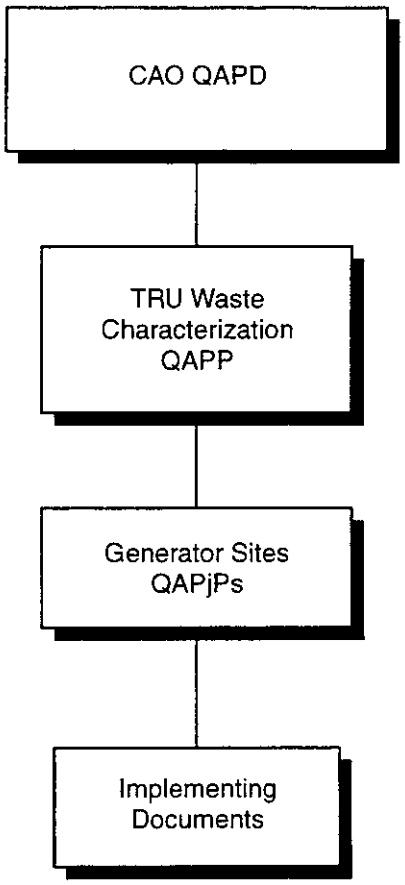

Figure 4-6. QA Document Hierarchy for Waste Characterization

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WIPP facility. This approval process also includes the evaluation of method performance data submitted by the measurement facility and the performance of QA audits.

The PDP plan describes the detailed elements that comprise the program, including the test materials and the analysis required. The PDP plan also identifies the criteria used for the evaluation of laboratory performance and the responsibilities of the program coordinator, the standard preparation team, and the participating laboratories. The radioactive source standards encompass the range of activities (masses) anticipated in actual waste characterization. The PDP sample standards address activity ranges relative to WIPP WAC limits, QAPP QAOs, and/or NDA method detection limits (DOE 1995a). The isotopes analyzed under this program plan include but are not limited to ^{238}Pu, ^{239}Pu, ^{240}Pu, and ^{241}Am.

In conjunction with the source standards, the 55-gallon drums used in the PDP also contain manufactured matrix inserts. These matrix inserts simulate waste matrix conditions and provide acceptable consistency in the sample preparation process at each measurement facility. For the first PDP cycle, the sample 55-gallon drums contain either no matrix material or a benign material.

Laboratory performance must be demonstrated by the successful analysis of blind samples by all participating measurement facilities on a semiannual basis. The blind samples (called PDP samples) are prepared twice during a calendar year at approximately six-month intervals. The PDP samples are analyzed using the methods the measurement facility anticipates using for the analysis of WIPP wastes. These methods must have been developed and approved within the specifications of the QAPP. Only the methods actually used in the PDP are considered acceptable to support the analysis of WIPP wastes. The data generated as a result of the performance demonstration indicate the appropriateness of the method used as well as the performance of the measurement facility. The program coordinator uses a set of standards that encompasses the range of WG material anticipated in actual WIPP waste.

The measurement facility analyzes the contents of each PDP sample using the procedures in the WIPP waste characterization program. The scoring system for the PDP is a pass-fail system. To pass a specific test, the measurement must fall within the specified QAOs of the QAPP. To pass the PDP cycle, the measurement must pass all individual tests. The scoring system of the PDP ensures that the QAOs are satisfied at the 95-percent confidence level.

Waste analyses may be performed only by measurement facilities that have demonstrated acceptable performance in the PDP. Measurement facility performance is used to assess general problems that may affect the facility's ability to analyze total alpha activity within a 55-gallon waste drum. Identified problems are resolved in accordance with the established QA program.

4.4 Waste Characterization

The process of waste characterization identifies the physical, chemical, and radiological properties of the waste using a variety of methodologies (DOE 1995c), including acceptable knowledge, headspace gas sampling and analysis, solid waste sampling and analysis, visual examination, NDA, and nondestructive examination (NDE). The measured waste properties obtained by the generator and storage sites are either on a waste container or waste stream basis and serve to demonstrate compliance with the limits imposed by transportation requirements (DOT) and operational safety requirements (DOE). In contrast, the waste component limits described in Appendix WCL are on a repository basis and serve as an upper bound for the accumulative waste inventory. As described in Section 4.3.2, the linkage between the collective waste inventory and the repository limits is provided by the WWIS.

Recognizing that the WAP establishes the TRU mixed-waste characterization requirements for DOE waste destined for the WIPP, it is necessary to understand the complementary role played by the radiological characterization of TRU waste. Figure 4-7 shows the requirements hierarchy governing the characterization of TRU waste for purposes of transportation, disposal, and long-term regulatory compliance. The implementation of waste characterization occurs on a waste-stream basis at the lowest tier of the diagram through the Standard Operating Procedures (SOPs). The next higher tier of Figure 4-7 includes the WAC, followed by progressively higher-tier requirements, including this application. The waste characterization requirements for compliance with the EPA's regulations pertaining to the identification of the disposed waste's hazardous and radiological components are implemented by the SOPs.

The WAP includes requirements for the determination of the physical and chemical properties of CH-TRU and RH-TRU mixed waste streams — specifically the identification and quantification of their hazardous components (see Appendix WAP). A combination of five waste characterization methodologies is employed by the WAP and includes acceptable knowledge, radiography, visual examination, headspace gas sampling and analysis, and solidified waste sampling and analysis. The capabilities and applicabilities of these five methodologies to TRU mixed waste are discussed in considerable detail in the WAP and the QAPP. Except for a brief overview of acceptable knowledge, radiography, and visual examination, a description of the five waste characterization methodologies will not be repeated in this document.

Radiological characterization of TRU waste is needed for compliance demonstrations to 40 CFR Parts 191 and 194. A quantitative determination of the radionuclides listed in Table 4-10 is driven by the need to demonstrate compliance with the release limits as specified in Appendix A to 40 CFR Part 191, Subpart B, and the RH-TRU waste curie limit established by the LWA (see Table 4-11).

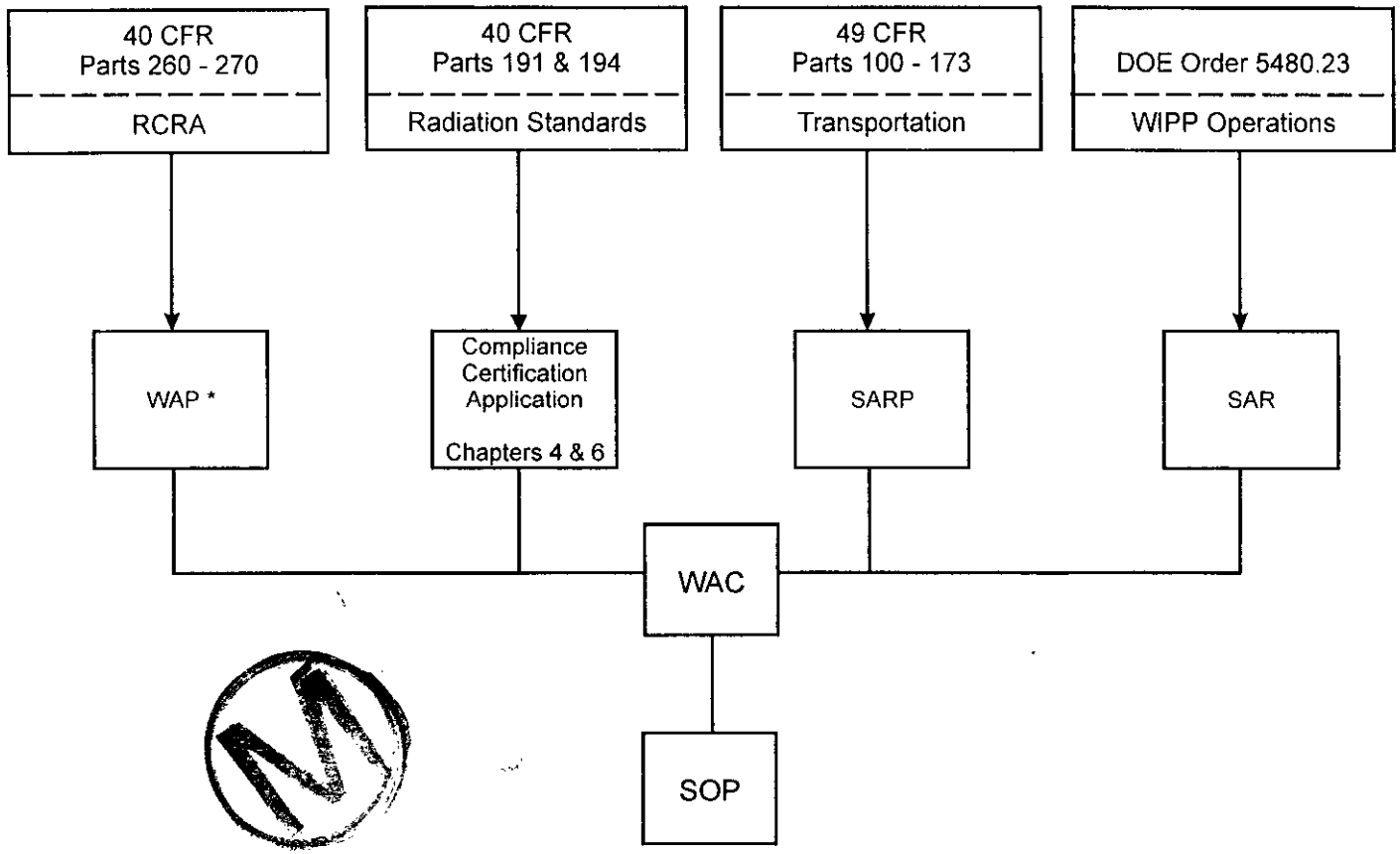

* Chapter C of Part B of the WIPP RCRA Permit Application

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Figure 4-7. Requirements Hierarchy of TRU Waste Characterization for Transportation and Disposal

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Collectively, those elements of the waste characterization program that support long-term regulatory compliance include the determination of the radionuclide inventory (for purposes of normalizing radionuclide releases as required for comparison with 40 CFR § 191.13[a]), the identification of the physical and chemical waste form inventories (if applicable), and the verification that no wastes are emplaced in the WIPP that exceed the disposal system's safety and/or performance limitations.

In a manner analogous to the WAP, the WIPP waste radioassay characterization program is conducted by generator and storage site personnel and is implemented in accordance with the requirements of the QAPP and the WAC. A description of the approved waste characterization methodologies and QAOs is provided in the QAPP.

Generator and storage sites may propose alternative characterization methodologies, either because of the availability of newer technologies offering enhanced performance or the modification of older technologies to facilitate meeting the QAOs. In these instances, method performance must be demonstrated and approved prior to its use in characterization TRU waste for disposal at the WIPP.

Implementation of the TRU waste characterization program at DOE sites requires that all waste characterization activities be conducted in accordance with approved documentation that describes the management, operations, and QA aspects of the program. Conformance with applicable regulatory, programmatic, and operational requirements is monitored by CAO audits and surveillances. Refer to Appendix QAPD and Sections 3.2.3 and 3.2.4 for a more detailed discussion of the CAO audit and surveillance program. The documentation requirements important to the implementation of the TRU Waste Characterization Program at each site are briefly discussed below.

- QA requirements. Implementation of individual site-specific waste certification and characterization programs must meet the QA requirements contained in the CAO QAPD, which are traceable to the applicable sections of ASME NQA-1 through NQA-3 (ASME 1989a, b, and c in the Bibliography). The QAPP describes the specific QAOs for the TRU Waste Characterization Program. The QAPP and its associated document, the TRU Waste Characterization Sampling and Analysis Methods Manual, delineate approved analytical methods for meeting regulatory requirements.

- QAPjPs. Generator sites prepare site-specific QAPjPs that describe waste characterization activities in support of the TRU waste characterization program. These documents, developed in accordance with the applicable requirements in the CAO QAPD and the QAPP, define QA management and program elements that provide for planning, implementation, and assessment of the TRU waste characterization data-collection activities.

- SOPs. The QAPP requires that each DOE site develop, implement, and control written SOPs that provide detailed descriptions of routine, standardized, or critical waste characterization activities. The SOPs serve as the basis for quality assessments of waste characterization activities at the site level because they provide detailed descriptions of required activities.

- PDPs. Analytical facilities characterizing waste for disposal at the WIPP must successfully participate in the applicable portions of the PDP. The PDP supports the determination of a facility's ability to meet the QA objectives identified in the QAPP. A more detailed description of the PDP can be found in Section 4.3.3.1.

As the generator sites complete the necessary program documentation, they commence waste characterization activities. Information derived from these activities is on a waste-stream basis and is used in preparing the site's waste-stream profile forms required for waste acceptance at the WIPP. The waste characterization data are electronically backed-up in databases at the generator sites and downloaded into the WWIS database (DOE 1996b). The WWIS is described in Section 4.3.2.

Generator and storage sites prepare documented and approved programs controlling their TRU waste characterization, certification (which includes characterization), and transportation processes. Site-specific TRU waste certification plans document how compliance with the WAC and QAPP are accomplished. Site certification shall be granted by the CAO manager contingent upon final approval of the following documentation:

1. TRU waste certification plan (including QA),

2. QAPjP(s),

3. TRU package transporter, Model 2 (TRUPACT II) Authorized Methods for Payload Compliance,

4. packaging QA plan, and

5. performance in applicable PDPs.

In addition to approval of this site-specific documentation, generator and storage sites must pass an initial site certification audit where adequate and effective implementation of these programs is assessed (see Sections 5.1.1 and 5.3.19).

Each TRU waste generator and storage site that is characterizing TRU waste to the requirements of the QAPP and the WAC is recertified by the CAO annually. A recertification consists of reviewing (if applicable)

1. site-specific program documents that are written and approved to the latest WAC,

2. program implementation as determined by a site certification audit,
3. reports from surveillances conducted during the past year,
4. performance in shipping TRU waste to the WIPP, and
5. performance in the PDPs.

To ensure that the DOE generator and storage sites comply with the WIPP TRU waste certification program, audits are conducted by the CAO. An initial audit is conducted at each generator site performing waste characterization activities prior to the formal acceptance of the waste-stream profile forms and/or any waste characterization data supplied by site personnel. This formal acceptance is referred to as site certification. Audits are performed at least annually thereafter, including the possibility of unannounced (not regularly scheduled) audits. These audits verify that the generator site has implemented a QA program for all certification activities. The accuracy of the physical waste description and the subsequent waste stream assignment are verified by a review of acceptable knowledge documentation, radiography data, and visual examination results (if applicable). Table 4-13 summarizes the characterization requirements and methods detailed in the WAC that support this application.

Table 4-13. Applicable CH- and RH-TRU Waste Component Characterization Methods

Waste Properties	Waste Components	Waste Characterization Methods
Nuclear	Radionuclides	NDA OR previous isotopic distribution from destructive radiochemistry OR previous radioassay data reconciled with WAC requirements
Physical	ferrous metals nonferrous metals cellulose plastics, rubber solid components free water humic substances	radiography with statistical selection for visual examination OR visual examination and documentation of container content at time of waste packaging for newly generated waste OR documentation and verification (random sampling) for newly generated waste
Chemical	sulfates nitrates organic ligands	No upper or lower limits apply to these chemicals; therefore no waste characterization methods are applied.

4.4.1 Qualitative Methodologies

The criteria at 40 CFR § 194.24(a) state that a description of the physical, chemical, and radiological composition of the TRU waste to be emplaced in the WIPP disposal system be provided. With regard to the waste's nonhazardous physical and chemical components (such as cellulosics), there are three qualitative methodologies, used either singularly or in combination, for verifying adherence to the compliance limits contained in Appendix WCL. These methodologies include acceptable knowledge, nonintrusive examination using penetrating radiation such as X-ray (referred to as either RTR, radiographic examination, radiometric examination, or NDE), and intrusive visual examination consisting of opening the container and recording the contents.

4.4.1.1 Acceptable Knowledge

The following discussion is responsive to the criteria at 40 CFR § 194.24(c)(3).

Acceptable knowledge is defined in the EPA Guidance Manual (EPA 1994) in the Bibliography. Acceptable knowledge includes information regarding the physical form of the waste, the base materials composing the waste, and the process that generates the waste. Waste characterization will be used to confirm acceptable knowledge information.

Consistency among DOE sites in using acceptable knowledge information to characterize TRU waste involves a three phase process: (1) compiling the minimum acceptable knowledge documentation in an auditable record, (2) confirming acceptable knowledge information, and (3) auditing acceptable knowledge records.

Appendix WAP, Figure C9-1 illustrates provides an overview of the process for assembling acceptable knowledge documentation into an auditable record. The first step is to assemble all of the mandatory acceptable knowledge information and any supplemental information regarding the materials and processes that generate a specific waste stream. DOE sites must ensure the following criteria are met in establishing acceptable knowledge records:

- Acceptable knowledge information must be compiled in an auditable record, including a road map for all applicable information.

- The overview of the facility and TRU waste management operations in the context of the facility's mission must be correlated to specific waste stream information.

- Correlations between waste streams, with regard to time of generation, waste generating processes, and site-specific facilities must be clearly described.

Acceptable knowledge documentation provides qualitative information that cannot be assessed according to specific data quality objectives that are used for analytical techniques. QAOs objectives for analytical results are described in terms of precision, accuracy,

completeness, comparability, and representativeness. Analytical results will be used to confirm the characterization of wastes based on acceptable knowledge.

To ensure that the acceptable knowledge process is consistently applied, sites must comply with the following data quality indicators for acceptable knowledge documentation.

- Precision – Precision is the agreement among a set of replicate measurements without assumption of the knowledge of a true value. The qualitative determinations, such as compiling and assessing acceptable knowledge documentation, do not lend themselves to statistical evaluations of precision.

- Accuracy – Accuracy is the degree of agreement between an observed sample result and the true value. The percentage of waste containers that require reassignment to a new WMC will be reported as a measure of acceptable knowledge accuracy.

- Completeness – Completeness is an assessment of the number of waste streams or number of samples collected to the number of samples determined to be useable through the data validation process. The acceptable knowledge record must contain 100 percent of the required information (see Section C9-3 in Appendix WAP). The useability of the acceptable knowledge information will be assessed for completeness during audits.

- Comparability – Data are considered comparable when one set of data can be compared to another set of data. Comparability is ensured through sites meeting the training requirements and complying with the minimum standards outlined for procedures that are used to implement the acceptable knowledge process.

- Representativeness – Representativeness expresses the degree to which sample data accurately and precisely represent characteristics of a population. Representativeness is a qualitative parameter that will be satisfied by ensuring that the process of obtaining, evaluating, and documenting acceptable knowledge information is performed in accordance with the minimum standards listed in Section C9-4 contained in Appendix WAP. Sites also must assess and document the limitations of the acceptable knowledge information.

The acceptable knowledge process and waste stream documentation must be evaluated through internal assessments by quality assurance organizations and assessments by auditors external to the organization (that is, the CAO).

The CAO will conduct an initial audit of each generator and storage site prior to certifying the site for shipment of TRU waste to the WIPP facility (see Figure C9-2 in Appendix WAP). This initial audit will establish an approved baseline that will be reassessed annually.

Audit plans will identify the scope of the audit, requirements to be assessed, participating personnel, activities to be audited, organizations to be notified, applicable documents, and schedule. Audits will be performed in accordance with written procedures and checklists. The audit checklists will include specific items associated with the compilation and evaluation of the required acceptable knowledge information.

Audit checklists must include all of the following elements for review during the audit:

- Documentation of the process used to compile, evaluate, and record acceptable knowledge is available and implemented;
- Personnel qualifications and training are documented;
- Required acceptable knowledge documentation has been compiled in an auditable record;
- A procedure exists for resolving inconsistencies in acceptable knowledge documentation;
- A procedure exists for confirming acceptable knowledge information; and
- Results of other audits of the TRU waste characterization programs at the site are available in site records.

Members of the audit team will be knowledgeable regarding the required acceptable knowledge information regarding the use of acceptable knowledge for waste characterization. Audit team members will be independent of all TRU waste management operations at the site being audited.

Auditors will evaluate documents associated with the evaluation of the acceptable knowledge documentation for at least one debris waste stream and one solidified waste stream during the audit. For these waste streams, auditors will review procedures and associated processes developed by the site for documenting the process of compiling acceptable knowledge documentation; correlating information to specific waste inventories; and identifying, resolving, and documenting discrepancies in acceptable knowledge records. The adequacy of acceptable knowledge procedures and processes will be assessed and any deficiencies in procedures documented in the audit report.

Auditors will review the acceptable knowledge documentation for selected waste streams for logic, completeness, and defensibility. The criteria that will be used by auditors to evaluate the logic and defensibility of the acceptable knowledge documentation include completeness and traceability of the information, consistency of application of information, clarity of presentation, degree of compliance with Appendix C9 of the WAP with regard to acceptable knowledge confirmation data, nonconformance procedures, and oversight procedures.

Auditors will evaluate compliance with written site procedures for developing the acceptable knowledge record. A completeness review will evaluate the availability of the minimum required TRU waste management and TRU waste stream information. Records will be reviewed for correlation to specific waste streams. Auditors will verify that sites include all required information. All deficiencies in the acceptable knowledge documentation will be included in the audit report.

Auditors will verify and document that sites use administrative controls and follow written procedures to make waste determinations for newly generated and retrievably stored wastes. Auditors will review procedures used by the sites to confirm acceptable knowledge information.

After the audit is complete, the CAO will provide the site with preliminary results at a close-out meeting. The CAO will prepare a final audit report that includes all observations and findings identified during the audit. Sites must respond to all audit findings and identify corrective actions. Audit results will be available at CAO for review by regulatory agencies, and copies will be provided upon request. If acceptable knowledge procedures do not exist, the minimum required information is not available, or significant findings of noncompliance are identified, the CAO will not grant the site waste characterization and certification authority for the subject waste. Waste stream characterization and certification authority may be revoked or suspended if there are significant findings during subsequent annual audits.

Prior to notifying a site that a waste stream can be shipped and accepted at the WIPP facility, the CAO will review the Waste Stream Profile Forms and associated data packages. Sites must provide all of the required data associated with waste steam characterization. The data packages will be evaluated as illustrated in Figure C9-2 in Appendix WAP. The CAO will review information provided by the sites to ensure that changes to waste codes are identified and justified. If data consistently indicates discrepancies with acceptable knowledge information, the CAO will require sites to increase sampling, reassess the materials and processes that generate the waste, and resubmit waste stream profile information. Until discrepancies are resolved, shipment of the waste stream to the WIPP will be prohibited.

4.4.1.2 Nondestructive Examination

NDE is a nondestructive qualitative technique that involves X-ray interrogation of waste containers to identify and verify the contents. NDE is used to verify the absence of prohibited items and to determine the appropriate methodologies to be used for waste characterization. NDE is not required for newly generated waste because controls exist to verify compatibility of the matrix material(s) and the absence of prohibited items prior to and during waste packaging.

A typical NDE system consists of an X-ray producing device, a container handling system, and an imaging detector. X-ray generators typically used in NDE produce X-rays ranging in energy from under 100 kiloelectron volts up to approximately 450 kiloelectron volts. If higher

energies are needed, either because of a high density waste matrix or the need to penetrate shielded payload containers, then the use of a linear accelerator becomes a viable approach for producing a pulsed X-ray beam with energies to 25 megaelectron volts and beyond.

The X-ray detector has the function of converting the radiation input signal into a corresponding optical or electronic output signal that ultimately is used to reconstruct an image of the payload container contents. An example of a system presently in use at many of the generator and storage sites is RTR, which gives the operator the opportunity to view events in progress (that is, in real time). In an RTR system, the imaging system typically utilizes a fluorescent screen and a low light television camera (since the light output of most screens is quite low). The resulting image is transferred to a remotely located television screen, and the operator conducts the examination by viewing the remote television screen.

Data acquired by NDE are documented as required by the QAPP. The QAOs for radiography, as listed in Section 10 of the QAPP, include precision, accuracy, completeness, and comparability. Since radiography, the primary methodology for performing NDE, is basically a qualitative determination, there is no specification for a method detection limit. The QAOs for NDE using radiography are summarized below.

Precision and Accuracy – The qualitative determinations made during radiography do not readily lend themselves to statistical evaluation of precision or accuracy. An estimate of precision and accuracy can be made, however, by comparing the results of NDE with the results of visual examination of a randomly selected statistical portion of waste containers.

Completeness – An audiotape or videotape of the radiography examination (or equivalent for other NDE methodologies) and a radiography data form, validated according to the requirements in Section 3.0 in the QAPP, must be obtained for 100 percent of the retrievably stored waste containers.

Comparability – The comparability of radiography data from different sites shall be enhanced by using standardized radiography procedures and operator qualifications in accordance with the requirements of the QAPP.

All activities required to achieve the radiography objectives must be described in site QAPjPs and SOPs. Retrievably stored containers will have this type of permanent record on file throughout the life of the WIPP project. As a quality control check on NDE, a statistically determined number of retrievably stored containers within the population subjected to NDE will be randomly selected and visually examined.

4.4.1.3 Visual Examination

The visual examination technique is used by the DOE to provide an acceptable level of confidence in NDE. There is no equivalent method in the EPA sampling and analysis guidance documents. A detailed procedure that meets the requirements of this method can be

found in the WIPP Waste Characterization Program Sampling and Analysis Methods Manual (DOE 1995c). Generator site personnel develop training programs that are based on waste form and waste management operations. These training programs are used to assess operator performance. The QAPjPs and supporting SOPs specify the training requirements and other activities required to achieve the visual examination objectives. The visual examination expert must be familiar with the waste generating processes that have taken place at that site and also with the types of waste being characterized at the site. For an explanation of the hypergeometric approach used in determining the number of containers to be statistically sampled by visual examination, see Appendix A of the QAPP (DOE 1995b).

4.4.2 Quantitative Methodologies

To minimize exposure, the quantitative methodology used to determine the radionuclide inventory of the waste is NDA. The nonintrusive methodology of NDA employs radiation detection techniques for determining the waste's isotopic content and activity. This is the preferred approach because of the safety hazards involved in opening waste containers having radioactive contaminants. Although the data generated by radioassay serve many functions including the calculation of the ^{239}Pu equivalent activity, the ^{239}Pu fissile gram equivalent, and the decay heat of waste containers, the purpose of these data relative to long-term regulatory compliance with 40 CFR Part 191 is to provide corroborative data relating to the radionuclide inventory reported in the TWBIR and furnish radionuclide information on a container basis to maintain a running inventory of TRU waste emplaced in the WIPP disposal system.

TRU nuclides emit both ionizing radiation (including alpha particles, beta particles, and gamma rays) and nonionizing radiation (neutrons). Based on detection of these emissions, several technologies have been developed to measure one or more of these radiations as they emerge from the waste container. Although most of the ionizing radiation (alpha and beta particles) are not able to penetrate the walls of the waste container, both gamma rays and neutrons can penetrate the waste matrix as well as the waste container to varying degrees. Combining gamma ray measurements, other advanced particle detection techniques specific to neutrons, and acceptable knowledge provides the precision and accuracy required by the QAOs contained in the QAPP. Mass spectroscopy and radiochemistry also provide the precision and accuracy to meet the QAO requirements in the QAPP.

Special techniques, instrumentation, and detectors have been developed to measure the gamma ray energies. Because there are many different gamma rays originating from any one radionuclide with each gamma ray having a unique energy and rate of occurrence characteristic of the radionuclide from which it originated, the resulting distribution or spectrum of gamma ray energies provides a fingerprint or signature of that particular radionuclide. In practice, with the application of appropriate correction factors and the utilization of acceptable knowledge, gamma ray and neutron NDA systems provide radioisotope inventory information about the waste without the need for opening the container.

All radioassay systems must be calibrated using a variety of matrix and source standards to simulate the various waste compositions, source distributions, and interferences common to the waste streams originating from a particular generator site. By applying the resulting correction factors to the measurements, an accurate assessment of the radionuclide inventory within the waste container is feasible. NDA methods appropriate to a particular waste stream profile are used in the radionuclide analysis.

4.4.2.1 Nondestructive Assay

A variety of NDA methodologies are effective in meeting the requirements of the QAPP. Table 9-2 of the QAPP identifies a number of such systems that are in use at various DOE and/or contractor testing facilities. These instruments can be classified as belonging to one or more of the four categories listed below:

- gamma ray measurements
  - low- and high-resolution spectroscopy using a sodium iodide and intrinsic germanium detector, respectfully,
  - transmission-corrected gamma ray measurement using a segmented gamma ray scanner, and
  - transmission-corrected gamma ray measurement using a computed tomographic gamma ray scanner.
- passive neutron measurements
  - passive neutron coincidence counter,
  - advanced matrix-corrected passive neutron counter (add-a-source), and
  - shielded neutron-assay probe totals counter.
- passive and active neutron measurements
  - americium-Lithium source-driven coincident counter,
  - californium delayed-neutron counter (shuffler),
  - neutron generator differential die-away counter, and
  - combined thermal and epithermal neutron counter.
- thermal neutron capture
  - californium delayed-neutron counter,
  - neutron generator differential die-away counter, and
  - combined thermal and epithermal neutron counter.

The list is neither complete nor limiting and is meant to illustrate the breadth of choice available. QAOs may be met with the listed systems or by modifications, functionally equivalent alternatives, multiple combinations, or hybrids of the systems.

For each of the radionuclide components identified in Table 4-10 as being significant to performance assessment and requiring assay, any of the above NDA methodologies, either singularly or in combination, may be used in determining the activity and corresponding uncertainty. In the case of 100-percent sampling, these measurements are performed on a waste container basis. For the case of less than 100-percent sampling, the reported values are on a waste stream basis. Upon receipt of the waste at the WIPP, the measured activity of these significant radionuclide components, plus their associated uncertainty, are accumulated by the WWIS in order to ensure that the volume and activity limits of the repository are not exceeded.

REFERENCES

Croff, A.B., 1980. *A User's Manual for the ORIGEN2 Code.* ORNL/TM-7175, Oak Ridge National Laboratory, July 1980.

DOE (U.S. Department of Energy). 1988. *Radioactive Waste Management*, Order 5820.2A. Washington, D.C.

DOE (U.S. Department of Energy). 1995a. *Performance Demonstration Program Plan for Nondestructive Assay for the TRU Waste Characterization Program*, Appendix A, Determining the Number of Containers to Visually Examine Using the Hypergeometric Distribution. DOE/CAO-94-1045, Revision 0, March 1995. Carlsbad, NM.

DOE (U.S. Department of Energy). 1995b. *Transuranic Waste Characterization Quality Assurance Program Plan.* DOE/CAO-94-1010, Revision 0, April 30, 1995. Carlsbad, NM.

DOE (U.S. Department of Energy). 1995c. *Transuranic Waste Characterization Sampling and Analysis Methods Manual.* DOE/WIPP-91-043, Revision 1, April 1996. Carlsbad, NM.

DOE (U.S. Department of Energy). 1995d. *Waste Isolation Pilot Plant Safety Analysis Report.* DOE/WIPP-95-2065, Revision 0, November 1995. Carlsbad, NM.

DOE (U.S. Department of Energy). 1995e. *WWIS Software Quality Assurance Plan.* CAO-95-1108. Version 0, May 1995. Carlsbad, NM.

DOE (U.S. Department of Energy). 1995f. *DOE Waste Treatability Group Guidance.* DOE/LLW-217, Revision 0, January 1995. Washington, D.C.

DOE (U.S. Department of Energy). 1996a. *Waste Acceptance Criteria for the Waste Isolation Pilot Plant.* DOE/WIPP-96-069, Revision 5, April 1996. Carlsbad, NM.

DOE (U.S. Department of Energy). 1996b. *WIPP Waste Information System Software Design Description*, CAO-96-1111, Revision 0, September 1996. Carlsbad, NM.

DOE (U.S. Department of Energy) and State of New Mexico. 1981. *Consultation and Cooperation Agreement.* Appendix A to the Stipulated Agreement Resolving Civil Action, 81-0363JB, State of New Mexico vs. United States Department of Energy, United States District Court, Albuquerque, NM.

U.S. Congress. 1992a. Federal Facility Compliance Act. Public Law 102-386.

U.S. Congress. 1992b. Waste Isolation Pilot Plant Land Withdrawal Act. Public Law 102-579, October 1992. 102nd Congress, Washington, D.C.

BIBLIOGRAPHY

ASME (American Society of Mechanical Engineers), 1989a. *Quality Assurance Program Requirements for Nuclear Facilities*. ASME NQA-1-1989.

ASME (American Society of Mechanical Engineers). 1989b. *Quality Assurance Requirements for Nuclear Facility Applications*. ASME NQA-2a-1990 Addenda, Part 2.7, to ASME NQA2-2-1989 edition.

ASME (American Society of Mechanical Engineers), 1989c. *Quality Assurance Program Requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories*. ASME NQA-3-1989, excluding Sections 2.1(b), 2.1(c), and 17.1.

EPA (U.S. Environmental Protection Agency). 1993. *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, 40 CFR 191, Final Rule*. 58 FR 66398.

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. *Federal Register*, Vol. 58, No. 242, pp. 66398 – 66416, December 20, 1993. Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

EPA (U.S. Environmental Protection Agency). 1994. *Waste Analysis at Facilities that Generate, Treat, Store, and Dispose of Hazardous Waste; A Guidance Manual*. EPA-530-R-94-024. Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. *Federal Register*, Vol. 61, No. 28, pp. 5224 – 5245, February 9, 1996. Office of Air and Radiation, Washington, D.C. In NWM Library as KF70.135.C751 1996 (Reference).

EPA (U.S. Environmental Protection Agency). 1996. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations, 40 CFR 194, final rule*. 61 FR 5224.

NMAC (New Mexico Administrative Code). NMAC. 20 NMAC 4.1, Subpart V, §264.13, and Subpart VIII, §268.35(d).

RCRA. 1976. *Resource, Conservation, and Recovery Act of 1976*. Public Law 94-580, 90 Stat. 2795.

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5.0 QUALITY ASSURANCE

In Title 40 of the Code of Federal Regulations (CFR) Part 194, the U.S. Environmental Protection Agency (EPA) describes the quality assurance (QA) requirements needed to comply with 40 CFR Part 191, which specifies environmental radiation protection standards for disposal of transuranic (TRU) waste. The mission of the U.S. Department of Energy (DOE) Carlsbad Area Office (CAO) is to protect human health and the environment by opening and operating the Waste Isolation Pilot Plant (WIPP) for safe disposal of TRU waste, and to establish an effective system for the management of TRU waste from its generation to its disposal. To help in fulfilling this mission and to ensure that the risks and environmental impacts are identified and minimized, and that safety, reliability, and performance are optimized, it is the policy of the DOE to establish, implement, and maintain an effective QA program that supports compliance with 40 CFR Part 194, other applicable federal, state, and local regulations, and DOE Orders and requirements.

The CAO Quality Assurance Program Document (QAPD) (included in this application as Appendix QAPD; see Table 1-5 in Chapter 1.0 for a list of appendices that provide additional information supporting this chapter) establishes and describes the QA program requirements that apply to programs and projects managed by the DOE. This program-wide requirements document establishes the controls applicable to all participants within the DOE management infrastructure. From the CAO QAPD, the principal participants (Sandia National Laboratories [SNL], Westinghouse Waste Isolation Division [WID], and the TRU waste generator and storage sites) develop and implement their management systems and controls to ensure that items, processes, and services meet or exceed applicable requirements.

The adequacy and effectiveness of implementation of these management systems and controls are verified through a program of audits and surveillances conducted by the DOE and the principal participants. This program of audits and surveillances assesses the adequacy and effectiveness of implementation of the individual QA programs. A comprehensive series of assessments has determined that the DOE, SNL, and WID QA programs are adequate and effectively implemented. The adequacy of WIPP QA programs is discussed in Section 5.3. The effective implementation of these QA programs is discussed in Section 5.4.

5.1 Applicability

QA program requirement sources include federal requirements, DOE Orders (primarily DOE Order 5700.6C), and national consensus standards. 40 CFR § 194.22, Quality Assurance, incorporates by reference the requirements of the following:

- American Society of Mechanical Engineers (ASME) Nuclear Quality Assurance (NQA) Standard, NQA-1-1989 edition, "Quality Assurance Program Requirements for Nuclear Facilities";

- ASME NQA-2a-1990 addenda to NQA-2-1989, Part 2.7, "Requirements of Computer Software for Nuclear Facility Applications"; and

- ASME NQA-3-1989 edition, "Quality Assurance Program Requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories" (excluding Section 2.1[b] and [c], and Section 17.1).

These NQA requirements form the basis of the CAO QAPD. Additionally, 40 CFR § 194.22 requires that QA programs be applied to the following eight items and activities:

- Waste characterization activities and assumptions,
- Environmental monitoring, monitoring of disposal system performance, and sampling and analysis activities,
- Field measurements of geological factors, groundwater, meteorologic, and topographic characteristics,
- Computations, computer codes, models, and methods to demonstrate compliance with 40 CFR Part 194,
- Procedures for implementation of expert judgment elicitation to support the applications for certification and recertification of compliance with 40 CFR Part 194,
- Design of the disposal system and actions taken to ensure compliance with design specifications,
- Collection of data and information to support compliance application(s), and
- Other systems, structures, components, and activities important to the containment of waste in the disposal system.

The objective of the CAO QAPD is to effectively satisfy QA requirements from a variety of sources through the application of management controls appropriate to the varied activities of the DOE and participants. The CAO QAPD establishes two primary categories of requirements, identified as general requirements and additional requirements.

The sections of the CAO QAPD that do not identify specific applications are general requirements that apply to all items, activities, and processes under the cognizance of the DOE. The requirements of the CAO QAPD sections identified as additional requirements apply to the eight key areas identified above.

Additionally, the use of a graded approach supports the proper implementation of QA program requirements for items and activities important to compliance with 40 CFR Parts 191 and 194. The graded approach, described in CAO QAPD Section 1.1.2.4 and in the CAO Management Procedure (MP) 1.2, Selection of Quality Levels and Grading of QA

Requirements, is the process by which the level of analysis, documentation, verification, and other controls necessary to comply with QA program requirements is determined.

The extent of management and QA controls applied to an item or activity varies as a function of the degree of confidence needed to achieve the desired quality. The grading process provides the flexibility to design and implement controls that best suit the facility or activity but is not intended to reduce or in any way degrade the full implementation of DOE implementing procedures requirements.

As discussed above, the DOE provides the overall QA program requirements for WIPP principal participants through the CAO QAPD. The CAO QAPD requirements are further supported and amplified by the next tier of QA program documents which include the DOE TRU Waste Characterization Quality Assurance Program Plan (TRU QAPP), the SNL Implementing Procedures, and the WID Quality Assurance Program Description. As generator sites initiate activities to ship waste, the DOE will perform audits and surveillances to qualify generator site QA programs. General QA program documents and implementing procedures are identified in Section 5.3.

In addition to identifying applicable QA requirements through QA program documents, the DOE, SNL, and WID conduct the following activities in support of the QA program:

- audits and surveillances (external and internal) to evaluate the adequacy and effectiveness of implementation of the applicable QA requirements.

- development and issuance of their own implementing documents, and the review and approval of lower-tier implementing documents.

40 CFR Part 194 stipulates that the DOE apply QA controls to eight areas. These quality affecting areas are discussed in detail in the following sections and are implemented in accordance with the QA program discussed in this chapter.

5.1.1 Waste Characterization Activities and Assumptions

The Transuranic Waste Baseline Inventory Report (TWBIR) (see Appendix BIR) is the inventory source document that provides the waste data used in the performance assessment and is presented in tabular form in Chapter 4.0. The TWBIR was prepared in compliance with the CAO QAPD and this activity was audited by the DOE QA Program on September 5 and 6, 1995. Quality assurance of the use of these waste data (by SNL) for performance assessment is addressed in Sections 5.1.4 and 5.1.7.

The Waste Acceptance Criteria (WAC) serve as the primary directive for ensuring that only waste that can be transported, handled, and disposed of in the WIPP are shipped and for ensuring that these wastes are certified by the generator and storage sites. The WAC was written and reviewed in compliance with the CAO QAPD. Each of the DOE source

documents for the WAC was written, reviewed, and approved in accordance with a DOE-approved QA program. The WAC requires generation and storage sites to enter waste characterization data into the WIPP Waste Information System (WWIS) prior to shipment.

The TRU QAPP describes the QA and quality control requirements for characterization of TRU waste coming to the WIPP. The TRU QAPP was written and reviewed in compliance with CAO QAPD requirements. The TRU QAPP includes both management and technical aspects of program implementation and the data-quality requirements that each DOE facility must meet in characterizing TRU wastes intended for disposal at the WIPP facility. The TRU QAPP also identifies the performance-based QA and quality control requirements with which each facility participating in the program must comply and the performance criteria for the preparation, review, and approval of site Quality Assurance Project Plans (QAPjPs).

The DOE verifies program implementation at participating sites through audits and assessments to ensure that WIPP waste characterization activities comply with applicable QAPjPs and standard operating procedures (SOPs).

Each generator and storage site submits a QAPjP for review and approval by the DOE/CAO. These QAPjPs identify QA and quality control provisions in response to the requirements in the TRU QAPP.

The Performance Demonstration Program evaluates the capability of generator and storage sites to perform TRU waste characterization within acceptable limits.

The following identifies the applicable quality-affecting activities, QA documents, and examples of subcontractors for the principal participants.

DOE Activities:

1. Prepare TWBIR

DOE QA Documents:

CAO QAPD	
MP 10.3	Audits
MP 3.1	Corrective Actions

SNL Activities:

Addressed in Sections 5.1.4 and 5.1.7.

WID Activities: None

WID QA Documents: None

Generator Site Activities:

1. Characterize TRU waste.

Generator Site QA Documents:

The following sites have Generator Site QAPjPs that have been approved by the DOE:

- Los Alamos National Laboratory
- Oak Ridge National Laboratory
- Lawrence Livermore National Laboratory
- Rocky Flats Environmental Technology Site
- Idaho National Engineering Laboratory
  - Site Project Office
  - Environmental Chemistry Laboratory
  - Radioactive Material Analytical Laboratory
  - Radioactive Waste Management Complex
  - Argonne National Laboratory-West

5.1.2 Environmental Monitoring, Monitoring of the Performance of the Disposal System, and Sampling and Analysis Activities

The monitoring plans required by 40 CFR § 194.42 detail the disposal system monitoring program that will be implemented during pre- and postclosure of the WIPP. This program will be implemented by the WID under the QA program described in this chapter.

SNL Activities: None.

WID Activities: Conduct performance monitoring.

WID Documents: Reference Appendices MON and EMP.

5.1.3 Field Measurements of Geological Factors, Groundwater, Meteorologic, and Topographic Characteristics

The current WIPP activities related to field measurements are conducted by the WID and include several areas. Measurements of geologic factors include surface subsidence measurements, which provide a baseline for evaluating long-term change in elevation, and an

ongoing program of underground monitoring to provide data on rock mass performance. Underground monitoring includes measurement of salt creep rates and local area fracturing. Seismic monitoring is also conducted to verify site characterization accuracy with regard to seismicity.

In 1989, the EPA reviewed and commented on much of the data collected by the DOE during the site selection and site characterization program. After this review by EPA geologists, hydrologists, and other scientists, the EPA reached conclusions regarding the adequacy of the DOE's site characterization program and the reasonableness of the site characterization activities. The EPA's independent reviews and conclusions regarding the adequacy of the data were supplemented by the independent reviews conducted by the National Academy of Sciences. Therefore, the DOE considers the adequacy of the QA programs and the data collected during site selection and site characterization to be satisfactory.

Topographic characteristics were characterized early in the site characterization phase of the WIPP project, and the QA of data from that period is addressed in detail in Section 5.4.2.2. The continuing subsidence measurements discussed above are the only current efforts in this area.

See Appendix EMP for QA controls applied to monitoring activities of groundwater well levels.

The following identifies the applicable quality-affecting activities, QA documents, and examples of subcontractors for the principal participants.

SNL Activities: None.

WID Activities:

1. Conduct geomechanical monitoring.

2. Conduct groundwater-level monitoring.

3. Conduct seismic monitoring.

WID QA Documents:

WP 07-1	WIPP Geotechnical Engineering Quality Assurance Program
WP 02-1	WIPP Groundwater Monitoring Quality Assurance Plan

Examples of WID Subcontractors:

Servco Industrial Division Corona, California
Servco Industrial Division Costa Mesa, California

Gage Lab Corp.
New Mexico Institute of Mining and Technology
Garwin Group

Generator Site Activities: None.

5.1.4 Computations, Computer Codes, Models, and Methods to Demonstrate Compliance

Computations and computer codes used to demonstrate compliance with 40 CFR Parts 191 and 194 are controlled as described in Section 5.3.20. Models and methods are controlled by the SNL Quality Assurance Procedures (QAPs) listed below. Software supporting compliance fall into one of three categories: (1) performance assessment scientific and engineering software (PA SES), which apply to the disposal system; (2) performance assessment nonscientific and engineering software (PA NON-SES), which apply to performing calculations; and (3) nonperformance assessment scientific and engineering software (NON-PA SES), which provide parameters used in the calculations. Table 5-1 lists the compliance software according to category.

SNL QAP 9-2, Quality Assurance Requirements for the Selection and Documentation of Parameter Values Used in WIPP Performance Assessment, establishes the method for the selection and documentation of parameter values used in compliance-level performance assessment modeling performed by SNL. This document applies to categories of parameters that are relied upon to make design, analytical, operational, or regulatory-compliance decisions affecting the WIPP. The four parameter categories that are used in current compliance calculations are

1. parameters derived from experimental data (measurements collected in the field and/or in a laboratory) or that are derived through a combination of experimental data and modeling (parameters that do not fall into categories 2 through 4);

2. parameters representing the inventory of the waste to be emplaced in the WIPP, as defined in the TWBIR;

3. parameters representing physical constants; and

4. parameters that are model configuration parameters or that are assigned based on assumed correlation of properties between similar materials.

A set of screening efforts, comprised of calculations and reasoned arguments, has been identified to help define and build confidence in assumptions, data sets, and conceptual and numerical models on which the performance assessment in this application is based. Assessing the effects of features, events, and processes (FEPs) on system performance is a primary component in conceptual model development. The results of screening efforts are

Table 5-1. Computer Software and Codes

PA SES[a,c]	PA NON-SES	NON-PA SES[a]
BRAGFLO	ALGEBRACDB	COLUMN
CCDFGF	BLOTCDB[b]	EPAUNI
CUTTINGS_S	CAMCON_LIB[b]	EQ3/6
BRAGFLO_DBR	CAMDAT_LIB[b]	FMT
GENII_A[b]	CAMSUPES_LIB[b]	GRASP-INV
NUTS	CCD2STEP	GTFM-PC
PANEL	CCDFSUM	NONLIN
SECOFL2D	GENMESH	ORIGEN2
SECOTP2D	GROPECDB[b]	SANTOS
	ICSET	SPECTROM-32
	LHS	SPECTROM-41
	LHS2STEP	SWIFTII
	MATSET	THEMM
	NUCPLOT[b]	TOUGH28W
	PCCSRC[b]	
	PLT_LIB[b]	
	POSTBRAG	
	POSTGENII[b]	
	POSTLHS	
	POSTSECOFL2D	
	POSTSECOTP2D	
	PREBRAG	
	PREGENII[b]	
	PRELHS	
	PRESECOFL2D	
	PRESECOTP2D	
	RELATE	
	SDBREAD_LIB[b]	
	SPLAT[b]	
	STEPWISE[b]	
	SUMMARIZE	

[a] PA SES codes model physical processes that describe the behavior of the repository system. NON-PA SES codes provide parameters for use in the performance assessment calculation. Most NON-PA SES codes provide their parameters to the performance assessment parameters database; however, GRASP-INV and SANTOS provide their outputs directly to the performance assessment codes, as described in Appendix CODELINK.

[b] PLT_LIB, CAMCON_LIB, CAMDAT_LIB, CAMSUPES_LIB, and SDBREAD_LIB are subroutine libraries used by the performance assessment codes. GROPECDB, PCCSRC, STEPWISE, PREGENII, GENII_A, POSTGENII, BLOTCDB, NUCPLOT, and SPLAT are codes that are used to postprocess compliance certification application calculation results, such as for sensitivity analysis, plotting, and humandose calculation.

[c] Appendix CODELINK describes all the codes except those in footnote b and NON-PA SES codes described in footnote a.

used to build upon and modify, when necessary, those conceptual and numerical models employed in past WIPP performance assessments.

FEP screening is phased. Phase I FEPs are those that could potentially affect conceptual and/or numerical models. Phase II FEPs are those that could impact parameter input to the numerical models. FEP screening analysis plans for Phase I and Phase II FEPs were developed and controlled in accordance with SNL QAP 9-1. A FEP screening analysis plan is used to develop the initial screening recommendation and is also used to reevaluate FEPs whenever changes in the regulatory standard occur or in light of new or revised laboratory and field data. Additionally the DOE and SNL have provided oversight of the FEPs screening process in the form of detailed audits and surveillances. See Section 5.3.18 for the location of applicable QA records.

Experimental data are acquired through the utilization of measuring and test equipment. Software is used to record instrumentation values. This data acquisition software (DAS) is controlled in accordance with SNL QAP 19-1 and the CAO QAPD. Additionally, software used for data reduction or for performing calculations and unit conversions is also controlled in accordance with the requirements of the CAO QAPD.

The WWIS is a computer database and reporting program that will track and tally the waste that comes to the WIPP. The WWIS computer program and system are being programmed and established in compliance with CAO QAPD and WID Quality Assurance Program Description requirements.

Software used to prepare, analyze, or verify WIPP facility designs are processed and controlled in accordance with the WID Quality Assurance Program Description.

A primary component of the waste characterization process is the nondestructive assay (NDA) process. NDA software is used to collect, measure, and interpret radioisotope emissions in order to define and characterize the waste. NDA software is controlled in accordance with the requirements of the CAO QAPD.

The following identifies the applicable quality-affecting activities, QA documents, and examples of subcontractors for the principal participants.

SNL Activities:

1. Develop performance assessment calculations and computer codes.

2. Develop conceptual models and numerical codes.

3. Develop and control DAS.

SNL QA Documents:

QAP 19-1	WIPP Computer Software Requirements
QAP 9-1	Quality Assurance Requirements for Conducting Analyses
QAP 9-2	Quality Assurance Requirements for the Selection and Documentation of Parameter Values Used In WIPP Performance Assessment
QAP 9-4	Quality Assurance Requirements for the Database Management of Parameter Values Used In WIPP Performance Assessment
QAP 9-5	Conducting and Documenting Routine Calculations

SNL Subcontractors:

Subcontractors that directly support performance assessment and conceptual model work follow the SNL QA program.

WID Activities: Develop and control WIPP site design and the WWIS software.

WID Documents:

WP 16-0	Software Management Plan
WP 16-117	WIPP Computer Software Quality Assurance

Generator Site Activities: Develop and control NDA software.

Generator Site Documents: Documents are site specific.

5.1.5 Expert Judgment Elicitation

No expert judgment activities have been identified.

SNL Activities: None.

WID Activities: None.

Generator Site Activities: None.

5.1.6 Design of the Disposal System and Actions Taken to Ensure Compliance with Design Specifications

5.1.6.1 WIPP Facility

Disposal system items and processes were designed using sound engineering practices, scientific principles, and applicable industry and government standards. System design descriptions, conceptual design reports, performance requirements, and regulatory requirements are included in new designs. Designs are initiated using a classification system that ensures that the proper level of design and QA requirements is employed to meet design and testing requirements.

NQA-1 Supplement 3S-1 requires that design verification be performed to verify the adequacy of design. Specifically,

> Design control measures shall be applied to verify the adequacy of design, such as by one or more of the following: the performance of design reviews, the use of alternate calculations, or the performance of qualification tests.

At the WIPP, initial design was done by Bechtel as the architectural and engineering contractor. Design verification was accomplished by a combination of Supplement 3S-1 methods.

5.1.6.2 Original Repository Design

After Bechtel turned systems over to the DOE, an extensive and comprehensive program of start-up testing was initiated by the DOE. The program tested systems and components against the requirements specified in design documents. This testing meets the requirements of Supplement 3S-1 for design verification. Start-up testing is currently described in WID Implementing Procedures WP 03-001 through WP 03-006 and has been controlled since its inception by appropriate predecessor procedures.

Brookhaven National Laboratory performed independent calculations of important design parameters (for example, structural steel stress calculations) using methods and engineering personnel independent of the original Bechtel design. This task was documented in a report commissioned by the Office of Environmental Safety and Health (EH-30) titled, "Waste Isolation Pilot Plant Safety Evaluation Report" dated August 1989, including two subsequent addenda, the last of which closed all action items, concluding the Brookhaven effort.

The combination of qualification testing and independent calculations meets the requirements of Supplement 3S-1 for design verification of the WIPP facility.

Design verification ensures compliance with identified requirements. The WID Quality Assurance Program Description (see Appendix QAPD) establishes actions and responsibilities to verify the adequacy of a design. Design controls specified in the WID Quality Assurance

Program Description are in place to track and verify the design process. These controls ensure that new designs and design changes are subject to specifications commensurate with the original design and verify that the design analyses are still valid. All changes are approved by technically qualified individuals. See Section 5.3.1.8 for the location of applicable QA records.

SNL Activities: None.

WID Activities: Design Configuration Control

WID Documents:

WP-09-9

Generator Site Activities: None.

5.1.6.3 Repository Sealing System

Design work for the repository sealing system was conducted under the SNL QA program. Two procedures are especially relevant to design work. QAP 3-1, Managing Design and Analysis Contracts, and QAP 3-2, Verification of Design Adequacy, applied to the development of the repository sealing system.

The repository sealing system design is summarized in Section 3.3.1 and Appendix SEAL. This report was extensively reviewed by DOE, SNL, WID, and CAO Technical Assistance Contractor personnel as well as independent design reviewers. All comments were resolved. Audits or surveillances were performed on each of the primary contractors. In all cases, QA requirements were properly identified and were effectively implemented. The DOE performed oversight activities to evaluate the adequacy and effectiveness of implementation of the SNL QA program as it relates to the SNL Sealing Systems Program. These oversight activities determined that the QA program was effectively implemented for the repository sealing system program, including the activities of the participating subcontractors. The DOE also determined that the procurement document process used to pass down QA requirements to subcontractors was adequate.

The following identifies the applicable quality-affecting activities, QA documents, and examples of subcontractors for the principal participants.

SNL Activities:

1. Evaluate sealing systems designs.

SNL QA Documents:

QAP 3-1	Managing Design and Analysis Contracts
QAP 3-2	Verification of Design Adequacy

Examples of SNL Subcontractors:

RE/SPEC, Inc.
Parsons-Brinkerhoff Energy Services, Inc.
Intera, Inc.

5.1.7 Collection of Data and Information to Support Compliance Application(s)

Data and information collected from experimental programs serve multiple purposes in the WIPP project: to collect data about the chemical or physical characteristics of the site; to collect data that allow estimation of the behavior of the wastes and system during the 10,000-year regulatory period; or to develop data to be used in testing alternative conceptual models and selecting the most appropriate model(s) of engineered system behavior for use in the performance assessment modeling process.

SNL Activities:

1. Collect scientific data in the following areas: rock mechanics, actinide source term, chemical transport, disposal room, gas generation, non-Salado flow and transport, Salado hydrology and transport.

SNL QA Documents:

QAP 20-1	Preparing, Reviewing, and Approving Test Plans
QAP 20-2	Preparing, Reviewing, and Approving Scientific Notebooks
QAP 20-3	Qualification of Existing Data
QAP 20-4	Preparing, Reviewing, and Approving Field Operations Plans
QAP 20-5	Preparing, Reviewing, and Approving Technology Development Descriptions
QAP 20-6	Preparing, Reviewing, and Approving Experimental Plans
QAP 2-1	Qualification and Certification of Personnel
QAP 4-1	WIPP Supplier Quality Assurance Program Requirements
QAP 5-2	Preparing, Reviewing, and Approving Drawings and Sketches
QAP 5-3	Preparing, Reviewing, and Approving Technical Operating Procedures
QAP 9-1	Quality Assurance Requirements for Conducting Analyses
QAP 13-1	Conducting and Documenting Sample Control
QAP 13-2	Chain-Of-Custody

Examples of SNL Subcontractors:

Baker Oil Tools
RE/SPEC, Inc.
Intera, Inc.
University of California
Core Laboratories, Inc.
University of New Mexico
University of Nevada Las Vegas
Northwestern University
Pacific Northwest Laboratory
Rust Geotech, Inc.
Argonne National Laboratory
Florida State University
Lovelace Inhalation Toxicology Research Institute

WID Activities: None.

Generator Site Activities: None.

5.1.8 Other Systems, Structures, Components, and Activities Important to the Containment of Waste in the Disposal System

At this time, the DOE has not identified any other systems, structures, components, or activities important to waste isolation in the disposal system that require controls to be applied as described in the CAO QAPD.

5.2 Program History

WIPP work has been performed under nuclear QA programs from 1977 to the present throughout several project phases. All DOE programs have been required to work under nuclear QA programs since the early 1980s. However, during the past 19 years, there have been changes in the scope, purpose, and regulatory responsibility for the WIPP. Changes in the state of development of the WIPP have resulted in corresponding changes in the QA program requirements. It is important to understand the evolution of the QA requirements applicable to the WIPP when assessing QA program adequacy.

From 1975, when the DOE first commenced site investigations, until late 1977, there were no DOE QA requirements imposed; no nuclear QA programs were applied to WIPP geotechnical data collection activities during this siting phase. Drilling and other related site activities were controlled by recognized industry drilling and geotechnical practices. Data collected during this phase were limited to seismic, geophysical, and hydrologic data derived from surface surveys and borehole cores and logs.

A QA program was established in late 1977 that was based on 10 CFR Part 50, Appendix B, which was applicable to engineering and construction activities that were important for the protection of public health and safety. By late 1978, DOE policy refinements had expanded the QA program to incorporate the requirements of American National Standards Institute (ANSI)/ASME N45.2 (the precursor to NQA-1) and had extended the applicability of the program to subsurface investigation activities and all earth science activities furnishing information on the possibility of radionuclide release into the biosphere.

Public Law 96-164, passed by Congress in late 1979, authorized the DOE to proceed with the WIPP construction project as a research & development (R&D) facility to demonstrate the safe disposal of the radioactive wastes resulting from U.S. defense activities exempted from regulation by the Nuclear Regulatory Commission (NRC). The WIPP QA program was revised to meet the DOE/Albuquerque Operations Manual (Chapter WIPP), which was equivalent to the requirements of ANSI/ASME NQA-1-1979.

Over the next 12 years (1980 to 1992), the WIPP QA program was revised to reflect the changes resulting from DOE and WIPP management reorganizations and the changes in upper-tier QA program documents NQA-1-1979 to NQA-1-1989 and DOE Orders 5700.6A, 5700.6B, and 5700.6C.

The following summarizes the QA program requirements in force during the various phases of the WIPP development.

1975-1977	Siting Phase. Recognized potash and petroleum industry drilling and geotechnical practices formed the basis of the QA effort.
1977-1980	Site and Characterization Phase. The earliest WIPP QA programs were based on the nuclear power plant QA requirements of 10 CFR Part 50, Appendix B, and ANSI/ASME N45.2 (the precursor to NQA-1). The ASME NQA-1 standards were issued in 1979 and began to be incorporated into the WIPP QA program.
1980-1983	Site and Preliminary Design Validation Phase. NQA-1 requirements, as suggested by DOE Order 5700.6A, were the basis for WIPP QA programs.
1983-1989	Construction Phase. NQA-1 continued to be recognized as the preferred standard for QA through DOE Order 5700.6B.
1989-1993	Test Phase. The WIPP QA programs began to incorporate program elements from DOE Order 5700.6C while retaining the requirements of NQA-1.

1994-Present Preoperational Phase. The current requirements are taken from 40 CFR Part 194, which incorporates the NQA requirements referenced in Section 5.1, DOE Order 5700.6C, and 10 CFR Subpart 830.120.

5.3 Adequacy

The adequacy of a QA program is measured by the extent to which QA requirements, both external and internal, are incorporated in QA program documents and in implementing procedures. An adequate QA program contains detailed instructions for each process or activity in a manner that provides traceability, replication, and accountability.

From May 1993 to March 1994, DOE Headquarters, Division of Waste Isolation Pilot Plant Program, Office of Environmental Management (EM-342), assessed the quality of the WIPP data acquisition process for performance assessment. The assessment was conducted to determine whether these data were collected under approved QA programs that met DOE requirements or whether acceptable alternative methods were used to ensure data quality in the absence of approved QA programs. The team concluded that the DOE needed to reevaluate all experimental program data used to support performance assessment.

The adequacy of the current DOE QA program is ensured by passing down requirements (see Section 5.3.5) to principal participants (SNL, WID, and the generator sites) with the directive that applicable requirements then be passed down to lower-tier organizations. The DOE QA Manager assesses the adequacy of QA program documents for the DOE and the principal participant organizations. The responsibility for oversight of QA program documents for lower-tier organizations and contractors is delegated to the principal organizations. Lower-tier organizations prepare, issue, and maintain QAPs or QAPjPs, as appropriate, for specific projects. Figure 5-1 illustrates the hierarchy of QA program documents for 40 CFR Parts 191 and 194 compliance activities, and Figure 5-2 illustrates the hierarchy of QA program documents for waste characterization activities.

Adequacy of QA program requirements are initially verified by the DOE through the review of lower-tier QA program documents prior to their implementation by the organizations. These document reviews focus on the proper transmission of requirements into lower-tier documents. These documents are not approved for use until their adequacy has been determined to be acceptable. Formal document review forms are used to document this process (see Section 5.3.18 for discussion of QA records).

The audits, surveillances, and management assessments conducted by DOE, SNL, WID, and the generator sites at the various organizational levels also assess the adequacy and effectiveness of those documents applicable to the assessed areas. Any inadequacies in QA program documents that are identified during audits or other assessments are documented and tracked until the condition has been corrected, verified, and closed (refer to Section 5.3.17).

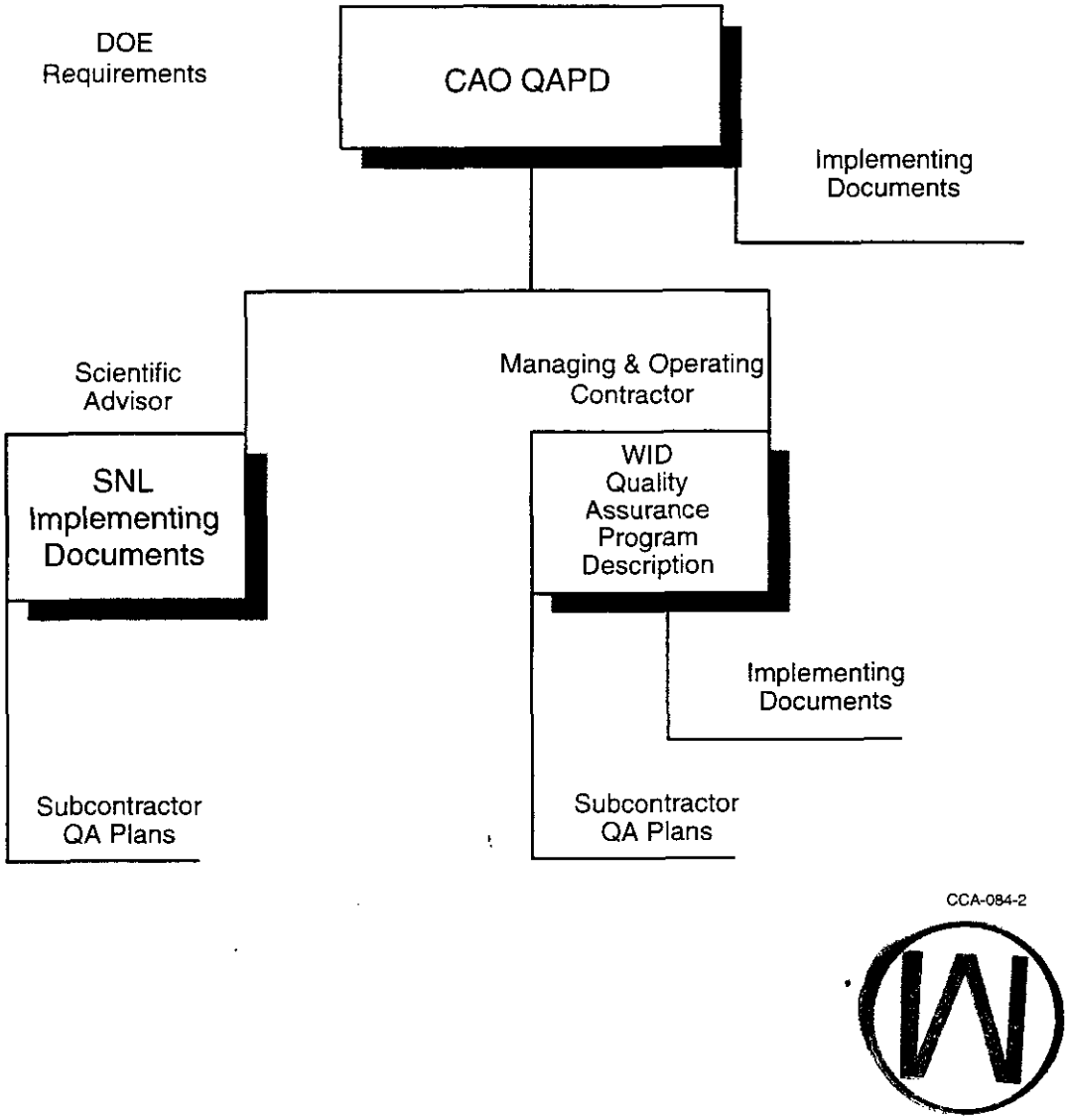

Figure 5-1. Document Hierarchy for 40 CFR Part 194 Compliance

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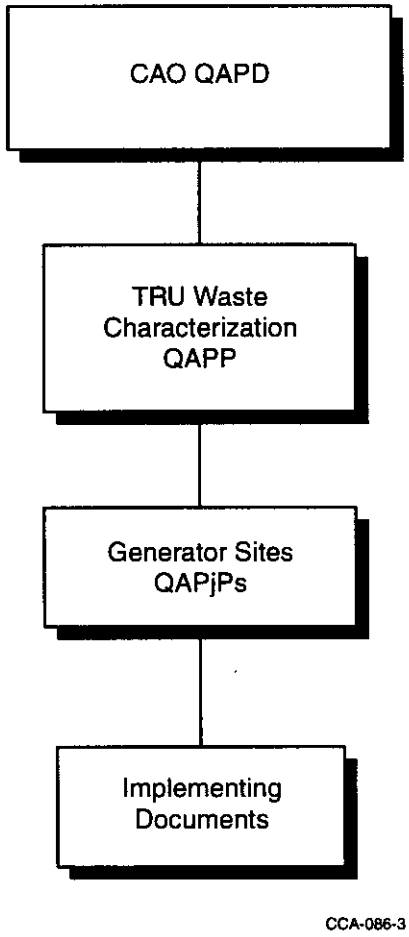

Figure 5-2. QA Document Hierarchy for Waste Characterization

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The DOE has also prepared matrices tracing the applicable NQA requirements referenced in Section 5.1 to the CAO QAPD. WID and SNL likewise are required to prepare and maintain matrices that identify all current and applicable documents that serve to implement the applicable CAO QAPD requirements. These matrices provide sufficient detail to identify documents that implement each applicable CAO QAPD requirement and are submitted to the DOE QA Manager for review. The matrices are required to be updated as implementation procedures are revised. The matrices are designated to demonstrate that the DOE, SNL, and WID QA programs are adequate and address all applicable requirements.

The DOE, SNL, and WID perform assessments that include the review of implementing documents for adequacy. These assessments verify that all appropriate upper-tier requirements have been addressed. These assessments (see Section 5.4) and the resulting corrective actions have determined that the DOE, SNL, and WID QA programs have adequately included upper-tier requirements. Ongoing audits and surveillances by these organizations ensure that QA programs continue to address the requirements adequately.

5.3.1 QA Program Description

The current CAO QAPD addresses QA requirements from multiple sources. The present DOE QA program is described in the CAO QAPD.

5.3.2 Organization and Interfaces

The DOE and WIPP organizational structures, primary interfaces, functional responsibilities, and levels of authority for activities affecting quality are described and documented in the CAO QAPD. The organizational interfaces are illustrated in Figure 5-3.

DOE Headquarters: Within the DOE headquarters, the Office of Environmental Management (EM-1) is responsible for the overall management of the DOE waste management programs. Responsibilities of the Office of Waste Management (EM-30) include establishing the DOE policy and issuing policy guidelines, setting the overall budget, and integrating TRU-waste activities with other waste-type activities.

CAO Manager: The CAO Manager reports directly to the DOE Assistant Secretary, Office of Environmental Management (EM-1), and has the responsibility for management of the WIPP, including the overall responsibility for the DOE QA program.

The DOE QA Manager has been delegated the authority for execution of the QA function by the CAO Manager. The DOE QA Manager has the authority and overall responsibility to independently assess the effective implementation of the DOE QA Program, within both the DOE organization and participant organizations. The DOE QA Manager reports through the Office of Program Support and Assurance for administrative matters. Participant QA

management has the authority and responsibility to independently assess the effective implementation of the DOE QA Program, within both the participant organization and lower-tier organizations.

Responsibilities of the WIPP principal participants are as follows:

- The DOE is responsible for WIPP QA program development, implementation, and assessment. The DOE reviews and approves the WIPP-related QA program documents of SNL, WID, and the TRU waste generator sites. The DOE performs QA audits and surveillances of these organizations to verify compliance to QA program requirements.

- The WID is responsible for establishing and implementing the QA program for the WIPP site operation and maintenance, for monitoring the site environment, and for receipt of waste.

- SNL is responsible for establishing and implementing QA programs for activities involved in the development, confirmation, and verification of models used to simulate long-term repository performance. SNL's QA program covers research, experiments, and tests to collect the data needed for input to the models.

- The TRU waste generator sites are responsible for establishing and implementing a QA program for TRU and TRU-mixed waste characterization and for the implementation of waste certification programs.

5.3.3 QA Program (Grading, QA Program Documents, Qualification and Training, and Management Assessment)

The CAO QAPD reflects the WIPP QA requirements, lists sources of program requirements and guidance, and describes the organizational interfaces and responsibilities. Independent assessors are responsible for measuring and evaluating the adequacy and effectiveness of implementation of the DOE QA program throughout the DOE and participant organizations.

5.3.3.1 Grading

The rigor of QA controls is commensurate with, but not limited to, the following criteria:

- function or end-use of the item,

- importance and end-use of the data generated,

- probability of failure,

- complexity or uniqueness of the design, fabrication, or implementation,

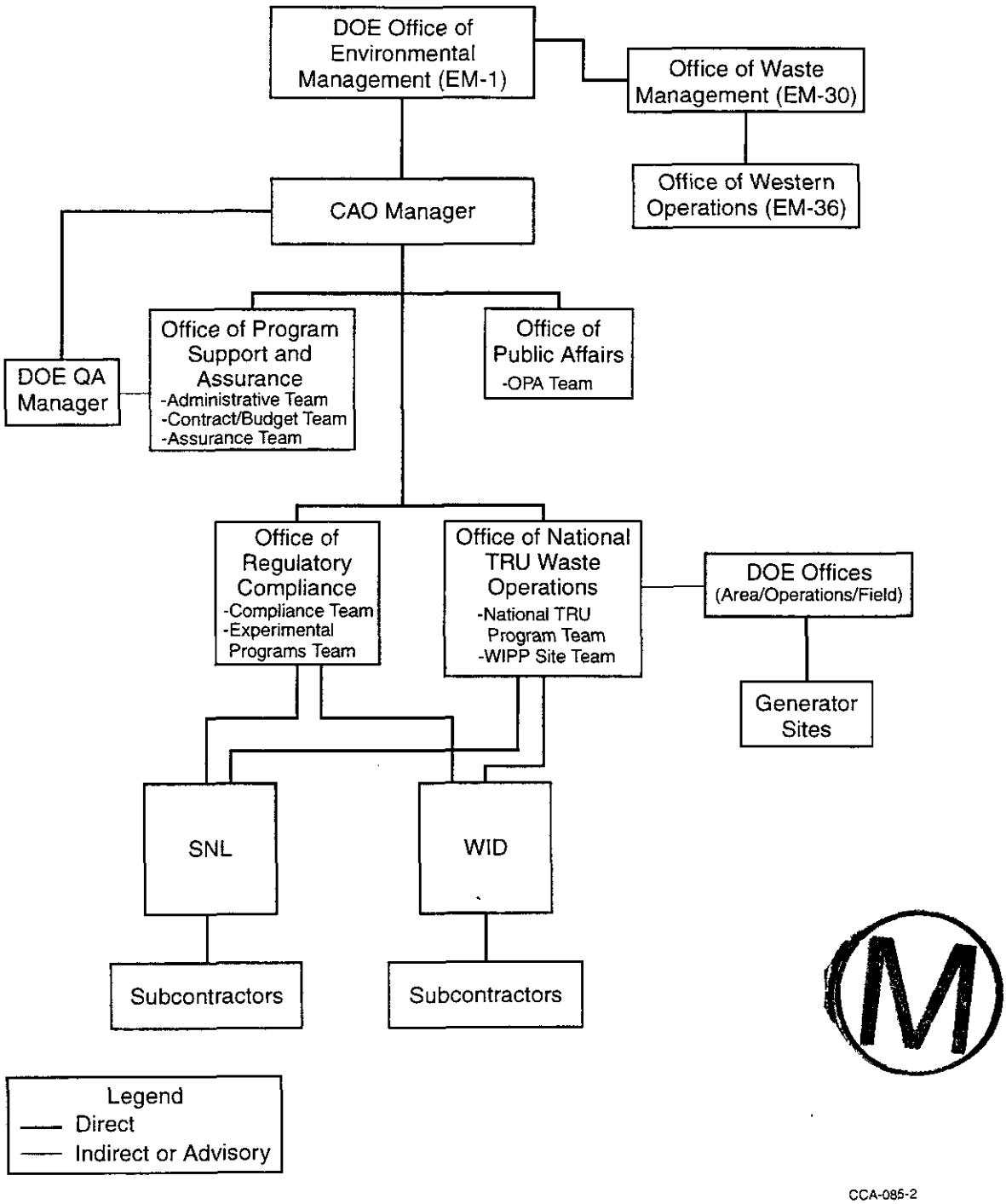

Figure 5-3. Organizational Interfaces

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- reproducibility of the results,
- history of the item or service quality,
- necessity for special controls or processes, and
- ability to demonstrate functional compliance with applicable regulations.

DOE Implementing Document:

MP 1.2	Selection of Quality Levels and Grading of QA Requirements

SNL Implementing Documents:

QAP 2-4	Preparing, Reviewing, and Approving Quality Assurance Project Plans
QAP 2-7	Preparing, Reviewing, and Approving Activity Authorizations

WID Implementing Document:

WP13-QA3501	Graded Approach

5.3.3.2 QA Program Documents

The DOE and principal participants implement the requirements of the CAO QAPD internally through QA program documents and implementing procedures prepared and maintained by their organizations (see the document hierarchy illustrated in Figures 5-1 and 5-2).

WID has issued and maintains a Quality Assurance Program Description (see Appendix QAPD), approved by the DOE, that incorporates the requirements of the CAO QAPD. SNL is currently working directly in accordance with the CAO QAPD requirements. The TRU QAPP has been prepared and is maintained by the DOE to supplement CAO QAPD requirements and prescribe program-specific QA and quality control provisions applicable to the waste generator sites for characterization of TRU waste.

Documents implementing the requirements of the DOE QA Program elements are

WIPP QA Program Documents:

CAO Quality Assurance Program Document
CAO TRU Waste Characterization Quality Assurance Program Plan
WID Quality Assurance Program Description
Generator/Storage Site Quality Assurance Project Plans

5.3.3.3 Qualification and Training

Personnel performing work are qualified and capable of performing their assigned tasks. Participants have established formal methods for the evaluation, selection, indoctrination, training, and qualification of personnel performing work that comply with the requirements of the CAO QAPD.

DOE QA Program Implementing Document:

MP 2.1	Training and Qualification

SNL QA Program Implementing Documents:

QAP 2-1	Qualification and Certification of Personnel
QAP 2-2	Orientation and Training Program
QAP 2-3	Qualification and Certification of Quality Assurance Audit Personnel

WID QA Program Implementing Documents:

Quality Assurance	
WP 13-QA.02	Quality and Regulatory Assurance Department Training Program
WP 14-TR	WIPP Technical Training Procedures Manual

5.3.3.4 Management Assessments

Management personnel of DOE participants perform assessments of the portions of the program for which they are responsible to assist in ensuring effective implementation of QA requirements.

DOE Implementing Document:

MP 9.1	Management Assessment

SNL Implementing Document:

QAP 2-8	Conducting and Documenting Management Assessments

WID Implementing Document:

MP 1.20	Assessments

5.3.4 Design Control

Design work, including changes, incorporates appropriate requirements such as general design criteria and design bases. Design interfaces are identified and controlled. The adequacy of design products is verified by individuals or groups independent from those who perform the work. Verification is completed prior to approval and implementation of the design. Control of design functions also extends to design reviews and qualification testing.

DOE Implementing Documents:

Not applicable.

SNL Implementing Documents:

QAP 3-1	Managing Design and Analysis Contracts
QAP 3-2	Verification of Design Adequacy

WID Implementing Documents:

WP 09-9	Configuration Management Plan
WP 09-CN3007	Engineering and Design Document Preparation and Change Control
WP 09-010	Design Development Testing
WP 09-CN3018	Design Verification
WP 09-CN3031	Engineering Calculations

5.3.5 Procurement Document Control

Procurement documents include the following, as applicable: scope of work; technical requirements, design bases, appropriate codes, standards, regulations, procedures, instructions, tests, inspections, hold points, and acceptance criteria; QA requirements; and documentation requirements.

The requirements of the CAO QAPD are transmitted from the DOE to its contractors. In addition, each contractor is required to transmit the appropriate CAO QAPD requirements to its subcontractors. Audits and surveillances are performed on quality-affecting vendors and subcontractors to verify that the requirements are being met.

Selected procurement documents are reviewed by knowledgeable and qualified technical and QA representatives and are approved by the appropriate management.

DOE Implementing Document:

MP 7.1	QA Requirements for Procurement of Goods and Services

SNL Implementing Document:

QAP 4-1	WIPP Supplier Quality Assurance Program Requirements

WID Implementing Document:

WP 13-QA3012	Supplier Evaluation/Qualification

5.3.6 Instructions, Procedures, and Drawings

Activities affecting quality are prescribed by and performed in accordance with the appropriate established, documented, and approved instructions, procedures, or drawings. Instructions, procedures, and drawings are developed, reviewed, and approved by technically competent personnel. They contain specific information appropriate to the work to be performed, including the following required elements:

- responsibilities,
- program requirements,
- description of the work,
- acceptance criteria,
- prerequisites, limits, precautions, process parameters, and environmental conditions,
- special qualifications and training requirements,
- verification and hold points,
- methods for demonstrating that the activity was performed as required, and
- identification and classification of QA records to be generated.

DOE Implementing Documents:

MP 4.1	Preparation and Maintenance of CAO Procedures
MP 4.4	Document Preparation and Control

SNL Implementing Documents:

QAP 5-1	Preparing, Reviewing, and Approving Quality Assurance Procedures and Abstracts
QAP 5-2	Preparing, Reviewing, and Approving Drawings and Sketches

QAP 5-3	Preparing, Reviewing, and Approving Technical Operating Procedures

WID Implementing Documents:

WP 15-PS.1	Management Control Procedures Writer's Guide
WP 15-PS.2	Technical Procedures Writer's Guide
WP 15-PS.3002	Review, Approval, and Cancellation of WID Procedures

5.3.7 Document Control

Documents affecting quality that specify requirements, prescribe processes, or establish designs important to compliance with 40 CFR Parts 191 and 194, such as instructions, procedures, drawings, test plans, and management plans, are controlled to ensure that correct documents are being employed. Prior to approval and issuance, controlled documents are reviewed by competent personnel using specified criteria for adequacy, correctness, and completeness. Review comments are formally resolved. Review comment documentation is maintained by the originating organization. Responsibilities for document preparation are specified, and the documents are controlled during the preparation, review, approval, issuance, use, and revision processes.

DOE Implementing Documents:

MP 4.2	Document Review
MP 4.4	Document Preparation and Control

SNL Implementing Documents:

QAP 6-1	Document Control System
QAP 6-2	Preparing, Reviewing, and Approving Technical Information Documents
QAP 6-3	Conducting and Documenting Reviews of Documents

WID Implementing Documents:

WP 15-PS3103	Document Distribution
WP 09-CN3022	Engineering Document Control and Distribution

5.3.8 Control of Purchased Items and Services

Controls are established to ensure that procured items and services meet applicable technical and QA requirements and performance specifications. Prospective suppliers are evaluated and selected on the basis of documented criteria. Procurement controls are in place to ensure that

approved suppliers continue to provide acceptable items and services. These procurement controls extend to the following areas:

- procurement planning,
- supplier selection and performance evaluation,
- proposal and bid evaluation,
- procurement documents,
- source verification and supplier certificate of conformance,
- receipt inspections and post-installation testing,
- control of supplier nonconformances, and
- commercial grade items.

DOE Implementing Documents:

MP 7.1	QA Requirements for Goods and Services

SNL Implementing Documents:

QAP 4-1	WIPP Supplier QA Program Requirements

WID Implementing Documents:

WP 15-609	Procurement Process
WP 13-QA10003	Quality Assurance Inspections

5.3.9 Identification and Control of Items

Items used in systems supporting compliance with 40 CFR Parts 191and 194 are identified and controlled. Processes have been established to identify, control, and maintain items from receipt through installation and end-use. Item identification ensures the appropriate traceability as specified in design documents, codes, standards, specifications, and implementing procedures. Identification is placed on the item or is located in documents traceable to the item. Acceptable methods and materials for characteristics and markings are prescribed, and the authority for applying and removing status characteristics and markings is specified.

WID Implementing Documents:

WP 15-PM3517	Stores Inventory Control

5.3.10 Control of Processes

Work processes that support compliance with 40 CFR Parts 191 and 194 are performed in accordance with established, approved, and documented technical standards and administrative controls. Work is planned, authorized, and accomplished under controlled conditions using approved instructions, procedures, drawings, or other appropriate means. Implementing procedures are developed, reviewed, and approved by technically competent personnel and contain information, including the following elements, appropriate for the work being performed:

- prerequisites, limits, precautions, process parameters, and conditions necessary for accomplishment of the process, including calibration requirements;
- special qualifications and training requirements; and
- acceptance criteria, including applicable codes and standards.

Personnel performing work are responsible for complying with appropriate instructions, which include or reference procedure, personnel, and equipment qualification requirements. Handling, storage, cleaning, shipping, and other means of preserving, transporting, and packaging of items are conducted in accordance with established work and inspection procedures, shipping instructions, or other specified documents.

DOE Implementing Documents: None

SNL Implementing Documents:

QAP 9-1	QA Requirements for Conducting Analyses
QAP 9-2	QA Requirements for the Selection and Documentation of Parameter Values Used in WIPP Performance Assessment
QAP 9-4	QA Requirements for the Database Management of Parameter Values Used in WIPP Performance Assessment
QAP 9-5	Conducting and Documenting Routine Calculations

WID Implementing Documents:

WP 13-QA10001	Liquid Penetrant Examination–Visible, Solvent–Removable Penetrant Technique
WP 13-QA10002	Visual Inspection
WP 13-QA10004	Magnetic Particle Examination

WP 13-QA10005	Penetrant Examination–Visible, Water–Washable Penetrant Technique

5.3.11 Inspection

Inspections determine acceptance or rejection of a process, product, or service. Inspection documentation for DOE participants includes the following:

- approved implementing procedures;
- identification of the items and processes to be inspected, the parameters or characteristics to be evaluated, the techniques to be used, the acceptance criteria, and any hold points;
- the acceptance of items and processes by qualified and authorized persons; and
- identification of any equipment to be used, including the equipment identification number and the calibration due date.

DOE Implementing Documents: None

SNL Implementing Documents: None

WID Implementing Documents:

QAI 2-5	Qualification and Certification of Inspection Personnel
WP 13-007	Hold Tag Issuance
WP 13-013	Inspection Points

5.3.12 Test Control

Tests determine the capability of an item to meet specified requirements by subjecting the item to a set of operating conditions. Tests included as part of scientific investigations are conducted in accordance with the QA methods described in Section 5.3.21. Test planning includes the following:

- procedures and related requirements documents used to control and perform the test (for example, test plans);
- identification of the item to be tested, test requirements, and acceptance criteria;
- identification of the measuring and test equipment (including the type, range, accuracy, and tolerance);

- test prerequisites and provisions to ensure that all test requirements and objectives have been met;

- any designated hold points; and

- recording methods used to collect and record the data.

In addition to the above, documentation of test results identifies the test date, the personnel performing the test, the data collected and the results of the tests, the actual measuring and test equipment used, the actions taken when unexpected results are obtained, and the persons evaluating the test results. A qualified person evaluates the results to ensure that all test requirements are met.

DOE Implementing Documents: None

SNL Implementing Documents: None

WID Implementing Documents:

WP 03-001	Preparation, Release, and Cancellation of Start-up Test Procedures

5.3.13 Control of Measuring and Test Equipment

The control system for monitoring, measuring, testing, and using data collection equipment prevents the use of suspect and out-of-tolerance equipment in activities that could affect quality. If such equipment is inadvertently used, the control system provides for segregation of the defective equipment and evaluation of the data obtained using the out-of-tolerance or defective equipment. In addition, the calibration system includes provisions for

- using documented procedures that describe the calibration system and the detailed calibration methods;

- using qualified calibration services that meet the requirements of the CAO QAPD;

- developing a schedule for the initial calibration of measuring and test equipment and for periodic recalibration to ensure acceptable reliability;

- documenting the results of the calibration;

- labeling and identifying all measuring and test equipment to provide information needed for recalibration and to ensure that adequate standards are traceable to the measuring and test equipment;

- identifying any needed precautions for handling, storing, and transporting equipment to prevent damage or out-of-tolerance conditions;

- providing the environment needed to calibrate the measuring and test equipment and to take measurements; and

- using calibration standards traceable to nationally recognized standards or physical constants. (When such standards do not exist, the bases for calibration are documented.)

DOE Implementing Documents: None

SNL Implementing Document:

QAP 12-2	WIPP Calibration Laboratory Quality Assurance Program

WID Implementing Document:

WP 10-AD0.1	Metrology Program

5.3.14 Handling, Storage, and Shipping

Items supporting compliance with 40 CFR Parts 191 and 194 are handled, stored, and shipped using approved and documented methods designed to prevent damage or loss and to minimize deterioration. Precautions taken include the following:

- preparing procedures that describe the methods to be applied, the proper controls, and the records to be generated;

- using and documenting special equipment and environments when required; and

- creating and maintaining markings and labeling that identify the item, any special environments required, and the need for any other special controls as necessary.

DOE Implementing Documents: None

SNL Implementing Documents: None

WID Implementing Documents:

WP 15-525	Preparation and Processing of Shipping Authorization
WP 15-PM3500	Equipment Held for Future Projects
WP 15-PM3517	Spares Inventory Control

5.3.15 Inspection, Test, and Operating Status

Authorized persons apply and remove status indicators on items, as appropriate. These status indicators help prevent inadvertent installation, use, or operation of items that have not passed the required inspections or tests. The specific status indicators, their use, and the authority to apply or remove them are delineated in applicable QA plans or implementing procedures. Status indicator processes include provisions for

- using and maintaining status indicators to indicate if an item has completed the required inspections or tests and to indicate the operating status of items;
- placing status indicators on the items or in documents traceable to the items;
- using tags, markings, labels, stamps, travelers, inspection and test records, or other appropriate means as status indicators; and
- using and maintaining a lockout/tagout system for setting and maintaining specific conditions.

DOE Implementing Documents: None

SNL Implementing Documents: None

WID Implementing Document:

WP 13-007	Hold Tag Issuances

5.3.16 Control of Nonconforming Items

Items that do not conform to specified requirements are controlled to prevent their installation, use, or operation prior to correction. Nonconforming items may be identified at any time by anyone, although they are identified primarily during inspections, tests, and operations.

When appropriate, further work on the item is halted by senior management until the appropriate actions have been taken and have been verified. The nonconformance control process is documented in applicable QA plans or implementing procedures. The process in place to control nonconforming items includes provisions for

- identifying nonconforming items, using methods that do not adversely affect the end-use of the item;
- segregating nonconforming items, when practical;
- assigning the responsibility to halt or control further work on the item;

- evaluating and dispositioning nonconforming items by authorized persons; and

- reexamination of the item to verify acceptability after the item has been reworked or repaired, and subsequent dispositioning of the item.

In addition, suppliers are required to identify items that do not meet the requirements of the procurement documents, to document the nonconforming condition and the proposed disposition, and to provide technical justification for the disposition. The purchaser evaluates and dispositions the supplier recommendations and verifies implementation of the disposition.

WID Implementing Document:

WP 13-007 Hold Tag Issuance

5.3.17 Corrective Action

All personnel are responsible for identifying conditions adverse to quality. Conditions adverse to quality are evaluated, the appropriate corrective action is defined and taken, and the completion and effectiveness of corrective action is verified. If a condition adverse to quality is determined to be significant, the root cause is determined and appropriate actions are taken to preclude recurrence. A significant condition adverse to quality is defined as a condition that, if not corrected, could have a serious effect on compliance with 40 CFR Parts 191 and 194.

When appropriate, further work on the item, activity, or process is halted by senior management until the appropriate actions have been taken and verified. The corrective action process for conditions adverse to quality is documented in appropriate QA plans and implementing procedures. The process used to identify and control conditions adverse to quality includes provisions for

- identifying and documenting conditions adverse to quality;

- assigning the responsibility to halt or control further work on the item, activity, or process;

- evaluating and dispositioning conditions adverse to quality by authorized persons;

- notifying management of the results of evaluations of significant conditions adverse to quality;

- preparing corrective action plans that include remedial actions, investigative actions, root cause determinations, expected completion dates, and responsible persons, as appropriate;

- evaluating the corrective action plans and verifying the completion and effectiveness of the corrective actions taken; and

- assigning unique numbers to each Correction Action Request generated, maintaining a log of the specific status of each request until it is finally closed, and regularly reporting and reviewing the status of all open corrective action requests.

Minor software problems are documented by software problem reports or other resolution mechanisms as discussed in Section 5.3.20. If a software problem is determined to be a condition adverse to quality, it is documented and resolved as described in this section.

DOE Implementing Document:

MP 3.1	Corrective Action

SNL Implementing Documents:

QAP 16-1	Trend Analysis Program
QAP 16-2	Conditions Adverse to Quality and Corrective Action
QAP 16-3	Root Cause Analysis

WID Implementing Documents:

WP 12-135	Root Cause Analysis Investigation Procedure
WP 13-QA3003	Corrective Actions Program
WP 13-QA.04	Quality and Regulatory Assurance Department Administrative Program

5.3.18 QA Records

Records generated under the QA program are specified, prepared, reviewed, approved, maintained, and disposed of in accordance with the CAO QAPD. The CAO QAPD provides reference for DOE participants in meeting QA records management requirements. Records provide evidence of the work quality and evidence that the QA program has been followed in work performance. The records management system is documented in appropriate QA plans and implementing procedures. The records management process includes provisions for

- identifying those documents that become QA records and identifying the organizations responsible for submitting the QA records to the records system;

- generating records that are legible, accurate, and complete;

- protecting documents that will become QA records during generation and use;

- authenticating the QA record;
- indexing QA records to ensure retrievability and to identify record retention times and the location of the record within the records system;
- classifying QA records as either lifetime, nonpermanent, or postclosure;
- designating the organization that receives and controls QA records;
- storing QA records, using methods and facilities that meet the requirements of the CAO QAPD; and
- correcting, replacing, restoring, and substituting records for any incorrect, lost, or damaged QA records in the QA records system.

The generation and retention of QA records are controlled by appropriate QA plans or records-related procedures. These records are maintained by the proper organization for approved disposition. DOE QA records are retained in the document services storage facility in Carlsbad, New Mexico. SNL QA records are retained in the SNL WIPP Central Files located in Albuquerque, New Mexico, and Carlsbad. WID QA records are retained in the WID WIPP Files located in Carlsbad. Generator site QA records are retained in NQA-1 storage facilities at each site.

DOE Implementing Document:

MP 4.5	Records Management

SNL Implementing Documents:

QAP 17-1	WIPP Quality Assurance Records Source Requirements
QAP 17-2	WIPP Quality Assurance Records Center Operations

WID Implementing Documents:

WP 15-PR	Records Management Plan
WP 15-PR3001	Generation, Storage, and Control of Active WIPP Records
WP 15-PR3002	Development and Implementation of Records Inventory and Disposition Schedule
WP 15-PR3003	Disposal of Nonpermanent Records
WP 15-PR3005	Records Transfer and Retrieval

5.3.19 Audits and Surveillances

Audits and surveillances verify that the various QA programs adequately reflect the requirements of the CAO QAPD and that they are being effectively implemented.

The DOE has designated specific meaning to the assessment terms adequacy, implementing, and effectiveness. Adequacy refers to the flowdown of requirements contained in upper-tier documents into implementing procedures. An adequate procedure is one that contains all appropriate upper-tier requirements. Implementation refers to the performance of the process steps identified in the procedures. An implemented procedure is one where all steps have been completed as identified within the procedure. Effectiveness refers to a process that produces the desired (specified) end product or end service. These terms are used to describe assessment activities throughout this chapter.

The management and control of audits and surveillances are documented in QA plans or implementing procedures. The audit and surveillance processes include provisions for

- scheduling audits and surveillances;
- using qualified, certified, and independent personnel;
- reporting results to the management of the audited or surveilled organization and to any other affected organizations;
- requiring a written response to any noted conditions adverse to quality; and
- ensuring that the audited or surveilled organization verifies that appropriate corrective actions have been taken and are effective.

DOE Implementing Documents:

MP 10.1	Qualification and Certification of Audit Personnel
MP 10.2	Surveillances
MP 10.3	Audits

SNL Implementing Documents:

QAP 18-1	Quality Assurance Audit Requirements
QAP 18-2	Quality Assurance Surveillance Requirements

WID Implementing Documents:

WP 13-QA1003	Quality Assurance Inspection
WP 13-QA3012	Supplier Evaluation/Qualification

5.3.20 Computer Software QA

Software quality assurance controls ensure that the software meets its intended use and is controlled. These controls apply to software that manipulates or produces data that are, in turn, used to process, gather, or generate information and whose output is relied upon to make design, analytical, operational, or compliance-related decisions affecting the performance of the waste isolation or waste characterization processes. The application of these requirements is prescribed in written plan(s), policies, procedures, or instructions.

Software QA controls include inventorying and classifying appropriate software. Plans are prepared at the start of the software life cycle to document the software basis and objectives of the software to meet its intended use.

The sponsoring organization for the software procurement and related services verifies the software's capability and the acceptability of the supporting documentation. Any software errors and failures are reported to the sponsoring organization for analysis and then forwarded to the supplier, if applicable.

Software not developed under a QA program meeting CAO QAPD requirements, including preexisting software, is evaluated, uniquely identified, and controlled in accordance with the requirements of CAO QAPD, Section 6.0. When accepted, the software is placed under configuration control prior to use. QA records (for software) are controlled and stored as described in Section 5.3.18.

Software controls use an iterative or sequential approach during the following phases:

- definition of requirements,
- design,
- implementation,
- testing, including verification and validation test,
- installation and checkout,
- operations and maintenance, including in-use tests, and
- retirement.

Verification and validation of the software, including a review of software activities, documentation, and tests is performed to ensure that the software adequately and correctly performs all intended functions and does not perform any unintended functions, in accordance with the requirements of the CAO QAPD. Software verification is performed during the

software development phases to verify that the requirements of the previous phase are fulfilled. Software validation is performed to ensure that the software satisfies requirements.

Controlled software is placed under configuration management to ensure that changes are controlled and that the appropriate version of the software is used. Configuration management includes the maintenance of unique identification, configuration change control, and configuration status accounting. When appropriate, access is controlled.

Software documentation that is generated and retained includes

- procurement documentation for procured software,
- software requirements documentation,
- design and implementation documentation,
- verification and validation documentation,
- any change documentation,
- user documentation, and
- any errors and disposition documentation.

For released versions, software problems are documented, evaluated, and, if appropriate, corrected. Evaluation of software problems includes the impact on previous use and any appropriate corrective action. Problems that significantly impact decisions based upon prior use or that require significant modification to the software are identified. Errors that qualify as a condition adverse to quality are controlled as described in Section 5.3.17.

DOE Implementing Documents: None

SNL Implementing Documents:

QAP 9-1	Quality Assurance Requirements for Conducting Analyses
QAP 9-5	Conducting and Documenting Routine Calculations
QAP 19-1	WIPP Computer Software Requirements

WID Implementing Documents:

WP 16-0	Software Management Plan
WP 16-117	WIPP Computer Software Quality Assurance

5.3.21 Scientific Investigations

Technical investigations and design-development data collection activities performed in support of this application are defined, controlled, verified, and documented. Process variables affecting scientific investigations are measured and controlled as described in Section 5.3.13. Planning for scientific investigations ensures that the appropriate information is collected and that outside factors are eliminated or their effects are minimized. Planning is coordinated with other organizations that provide input or use the results. Planning for scientific investigations includes provisions for

- identifying and appropriately controlling variables that affect interrelated scientific investigations;
- documenting the intended use of the data before collection;
- considering the compatibility of data processing with any conceptual or mathematical models used at each applicable stage;
- reviewing and approving the technical adequacy of procedures;
- reviewing and approving the documented development activities used to establish new methods or procedures;
- establishing acceptance criteria for the data quality evaluation;
- identifying known sources of error and uncertainty; and
- identifying input data that are suspect or whose quality is beyond the control of the performing organizations.

Scientific investigations are performed according to requirements documented in scientific notebooks or technical implementation documents or both. If no nationally recognized test standard exists, special test procedures are developed and used. Scientific notebooks contain the results of the investigations, and they are periodically reviewed by a qualified individual for completeness.

Methods used in the investigations are reviewed to ensure that they are technically sound and have been properly selected. Data collection and analysis are controlled by procedures that allow the processes to be replicated. Test media are characterized and controlled in accordance with test procedures.

Data are recorded, identified, and traceable to the scientific investigation from which they were generated. Data collection and analysis are critically reviewed and questions resolved

before the results are used or reported. Uncertainty limits are assigned to the data prior to their use. Data are controlled to

- prevent data loss and permit data retrievability;
- maintain data integrity and security;
- ensure error-free transfer, reduction, and change of expression or quantity of data; and
- prevent the use of erroneous, rejected, superseded, or otherwise unsuitable data.

Data used for compliance with 40 CFR Parts 191 and 194 that were not collected under a QA program meeting CAO QAPD requirements are qualified through one or a combination of five methods detailed in Section 5.4.2.1. If peer reviews are necessary, the DOE uses procedure Team Procedure (TP) 10.5 to conduct them.

DOE Implementing Document:

TP 10.5	CAO Office of Regulatory Compliance (ORC) Team Procedure for Peer Review

SNL Implementing Documents:

QAP 13-1	Conducting and Documenting Sample Control
QAP 13-2	Chain-Of-Custody
QAP 20-1	Preparing, Reviewing, and Approving Test Plans
QAP 20-2	Preparing, Reviewing, and Approving Scientific Notebooks
QAP 20-3	Qualification of Existing Data
QAP 20-4	Preparing, Reviewing, and Approving Field Operations Plans
QAP 20-5	Preparing, Reviewing, and Approving Technology Development Descriptions (TDDs)
QAP 20-6	Preparing, Reviewing, and Approving Experimental Plans

WID Implementing Documents: None

5.3.21.1 Data Quality Characteristics

40 CFR § 194.22(c) states that to the extent practicable, data used to support compliance will be assessed according to their accuracy, precision, representativeness, completeness, and comparability. The DOE believes that these data quality characteristics are applicable to tasks involving the quantification through sampling and analysis of specific constituents in an environmental medium. The DOE also believes that these requirements are intended to address activities such as the determination of the presence or absence of pollutants in waste streams. Waste characterization and environmental monitoring are examples of the types of

activities at the WIPP in which data quality characteristics apply. In these cases, the performance measurement is the concentration of the constituent of interest.

In performance assessments that address compliance with 40 CFR Part 191, Subpart B, the performance measure is cumulative release of radionuclides to the accessible environment over the next 10,000 years. This measure is estimated using mathematical models rather than being determined by direct measurement. The performance assessment process requires the use of mathematical models for the repository, which, in general, require that numbers (here called parameters) be assigned to geologic formation and waste properties. Since many of these parameters are not amenable to direct measurement, they must be treated as uncertain variables, rather than precisely determined quantities, and characterized by probability distributions.

Data are used to develop conceptual models for disposal system performance that are implemented as computational models in the performance assessment. Data are also used to support distributions for parameter values used in the computational models. Between the point of data collection and the final computational model, uncertainty is introduced (for example, experimental design, extrapolation of the experimental results to spatial or temporal scales, etc.). These parameter distributions may span several orders of magnitude, and many parameters derived from data measurements need be known only within orders of magnitude of their true value. Efforts to reduce the range do not necessarily improve model accuracy.

Uncertainty and sensitivity analyses respectively assess the uncertainty in system performance measures and identify modeling areas and parameters in which reductions in uncertainty can increase confidence. If the uncertainty of a parameter is of significant importance to the performance of the WIPP, more data could possibly be collected to reduce uncertainty.

It is often not practicable for the DOE to document the above data quality characteristics for the scientific investigation and characterization of natural systems. As an example, data accuracy would be very difficult to assess for geologic site characterization activities because reference or true values do not exist.

Instead of the above quality characteristics, other steps ensure that data are of adequate quality. Upper-tier quality requirements documents specifically define QA requirements for the collection of scientific and technical information. Section 5 of the CAO QAPD, Scientific Investigation Requirements, identifies the current requirements for data collection. For inclusion in compliance calculations, the data must be collected under an approved QA plan or be otherwise qualified (see Section 5.4.2.1).

In summary, it is not practicable to apply data quality characteristics to most scientific investigations used to support a performance assessment in which there is uncertainty in the conceptual models and the resultant ranges of parameters. Instead, controls established by the QA program provide the necessary quality.

5.4 Implementation

The DOE, SNL, and WID QA programs have been determined to be effectively implemented in accordance with adequate procedures that meet the CAO QAPD. Specific details are described in Sections 5.4.1, 5.4.2, and 5.4.3.

The DOE maintains and implements an assessment schedule to assess continuing DOE, SNL, WID, and generator site QA program adequacy, implementation, and effectiveness. The scheduling of assessments is a dynamic process that requires frequent changes to respond to DOE and participant needs. The DOE assessment schedule is issued quarterly with distribution to WIPP participants and stakeholders. The assessment schedule accommodates the routine, recurring, and any focused or special purpose assessments that are deemed appropriate by management. An example of a typical assessment schedule is illustrated in Table 5-2.

5.4.1 DOE QA Program Implementation

Controlling QA documents for the DOE audit, surveillance, and corrective action programs were revised, reissued, and implemented in October 1994. These included DOE Branch Procedure (BP) 10.3, *Audits*; BP 10.2, *Surveillances*; BP 10.1, *Qualification and Certification of QA Audit Personnel*; and BP 3.1, *Corrective Action*. Subsequently, assessment 95EM34-AS-01 conducted by DOE EM-34 in March 1995, characterized these four documents as a particularly commendable aspect of the QA program and did not identify any deficiencies in the DOE audit and surveillance activities conducted in accordance with these documents.

The most recent audit of DOE/CAO by EM-30 (96 EM36-AU-01) was conducted in July 1996. The audit team concluded that the DOE/CAO QA Program was adequate and effective, but not completely implemented. They cited nonimplementation of two DOE procedures MP 1.2, *Selection of Quality Levels and Applicable QA Requirements*, and MP 9.1, *Management Assessment*. These procedures are now fully implemented and the overall DOE QA Program is being effectively implemented.

In addition to the audits performed by the DOE Office of Environmental Management, the DOE has performed internal surveillances to supplement the audit program in determining adequacy, implementation, and effectiveness. These surveillances are summarized in Table 5-3.

5.4.2 SNL QA Program Implementation

In May 1996, the DOE conducted audit A-96-02 of SNL. In June 1996, the DOE conducted audit A-96-03 of SNL performance assessment and software activities. The SNL QA Program was determined to be marginally adequate and marginally implemented. Areas requiring improvement were identified on Corrective Action Reports (CARs). As a result of

Table 5-2. DOE/CAO Assessment Schedule (Sample)

APPROVED BY: EXAMPLE ONLY

DOE/CAO MANAGER DATE

Organization and Scope	DOE/CAO Team	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	Remarks and Schedule
WID/Environmental Procedural Implementation	Assurance/WIPP Site			●										Surveillance, S-96-22, Bennington April 17 - June 14, 1996
SNL/Performance Assessment Program (includes Performance Assessment Final Calcs, Software QA, FEPs, and Parameters)	Experimental Programs					●								Audit, A-96-03, Paedon June 17-21, 1996
WID/Emergency Management	WIPP Site					●								Surveillance, S-96-39, Galle June 24-26, 1996
WID/Quality Assurance Program	Assurance					●								Audit, A-96-05, Ziemba June 24-28, 1996
CAO/QAPD Implementation	All CAO						●							Audit, A-96-10, Himpler July 15-19, 1996
WID/Work Packages (Safety Issues)	Assurance/WIPP Site						●							Surveillance, S-96-47, Lilly July 15-19, 1996
ANL-West Gas Generation	Experimental Programs						●							Audit, A-96-06, Dunhour July 22-24, 1996
LANL/Waste Characterization and Certification	National TRU Programs							○						Surveillance, S-96-48, Gilkerson August 13-16, 1996
WID/Environmental Data Control	Assurance/WIPP Site							○						Surveillance, S-96-45, Bennington August, 1996

○ = Planned
● = Performed

Table 5-3. DOE Internal Surveillances

Organization and Activity	Number	Date
Compliance Team (QAPD)	CAO S-96-21	2/96
Experimental Programs Team (QAPD)	CAO S-96-25	3/96
WIPP Site Team (QAPD)	CAO S-96-27	4/96
Office of Regulatory Compliance (Peer Review)	CAO S-96-29	4/96
National TRU Program Team (QAPD)	CAO S-96-30	5/96
Administration, Contracts & Budgets, National Environment Policy Act Team (QAPD)	CAO S-96-31	5/96
Assurance Team (QAPD)	CAO S-96-28	5/96

actions taken by SNL to correct the deficiencies, the SNL QA Program has been determined to be adequate and is being effectively implemented. Table 5-4 summarizes the DOE audits conducted of the SNL QA Program.

The SNL external audit program was audited by the DOE in August 1995. The audit CAO A-95-07 (see Table 5-4) examined QA records concerning SNL audits performed back to May 1994. After the implementation of specific corrective actions, SNL subcontractor QA programs, audited by the SNL audit program back to May 1994, were determined to be adequate and effectively implemented.

A primary result of the qualification of the SNL QA audit and surveillance programs was the determination of which performance assessment data provided by SNL subcontractors were collected under an approved QA program and which data required additional qualification. Currently, SNL is working directly in accordance with the CAO QAPD requirements.

Table 5-4. DOE Audits of SNL

Activity	Number	Date
QA Records Management	CAO A-95-03B	7/95
External QA Audit Program	CAO A-95-07	8/95
Qualification of Existing Data	CAO A-95-05	9/95
QA Program	CAO-A-96-02	5/96
Performance Assessment and Software QA	CAO A-96-03	6/96

Previously, SNL worked in accordance with the SNL Quality Assurance Program Description, which was in accordance with the requirements of the CAO QAPD. Since the May 1994 date for qualification of the SNL assessment programs, two revisions of the SNL Quality Assurance Program Description were implemented.

Revision P of the SNL Quality Assurance Program Description was issued in October 1992. Revision R was released in July 1995. Although Revision P was determined to be inadequate to meet the requirements of the CAO QAPD, it was also determined that the inadequate areas did not adversely affect the qualification of SNL subcontractors or data collected under Revision P. Major requirement changes from Revision P to Revision R are discussed below.

- Resolution of QA Disputes. QAP 2-9 was added to address the requirements for the resolution of disputes. Previously, QA disputes were normally handled through the nonconformance reporting process, described in SNL Quality Assurance Program Description, Rev. P, Section 15.

- Stop Work Orders. QAP 2-5 was added to address the requirements for stopping work because of quality concerns. Previously, stopping work was considered a part of the process for completing a nonconformance report, described in SNL Quality Assurance Program Description, Rev. P, Section 15.

- Conditions Adverse to Quality and Corrective Action. QAP 16-2 was added to address the corrective action reporting process. Previously, corrective action documentation, resolution, and verification was documented on a nonconformance report, described in SNL Quality Assurance Program Description, Rev. P, Section 15.

- Scientific Investigation. Many of the requirements under scientific investigations were already in the program and implemented through various QAPs (for example, earlier revisions of QAP 6-1 included the requirements for writing, approving, revising, and issuing test plans, field operation plans, procedures, and other documents describing scientific investigations). QAP 20-2 was added to address scientific notebooks. QAP 20-3 was added to address the qualification of existing data (QED). Previously, existing data was qualified by the review of planning, implementing, and reporting documentation.

- Software. QAP 19-1 was revised to address the considerably different software requirements.

5.4.2.1 Data Qualification

An SNL audit Internal Audit [IA] 95-03 (see Table AUD-3 in Appendix AUD) was conducted in August 1995 to verify the adequacy and effective implementation of QA requirements. The scope of the audit included the 11 experimental areas of the program. The audit resulted in 14 findings in the areas of calibration, procedures, training, experimental planning, test records,

and equipment and data acquisition. All the resulting corrective actions have been completed and verified. Two positive observations were made: (1) efficient organization of data used in the demonstration of compliance and (2) noticeably strong commitment to quality by management and staff. The audit concluded that, with the exception of the Corrective Action Requests, there was evidence that SNL QA controls were in place and that they were adequate and effectively implemented.

Data can be qualified for use by one of five methods:

(1) data used in performance assessment were obtained under an approved QA program that implements the NQA requirements referenced in Section 5.1;

(2) existing data collected before the implementation of a qualified QA program are qualified by showing that the data were obtained under a QA program that is equivalent to one satisfying the NQA requirements referenced in Section 5.1;

(3) existing data are qualified by peer review conducted in a manner compatible with NUREG-1297, Peer Reviews for High-Level Nuclear Waste Repositories;

(4) corroborating data are collected; and

(5) confirmatory testing is performed.

For data qualified by implementation of a QA program meeting the requirements of 40 CFR Part 194 (Method 1), the supporting documents include the QA plan, audits and surveillances of the work that produced the data, and other objective evidence of QA implementation. If the audits show the program to be adequate and effectively implemented, then the data can be qualified back to the earliest date of the objective evidence reviewed during the audits. If audits identify significant deficiencies, then data whose quality is affected by those deficiencies are not qualified until impact assessments are completed and corrective actions have been implemented and verified.

For data collected prior to the DOE approval of the overall SNL QA program, another process was used to qualify data. A qualification date (T=0) is documented in summary reports that provide rationale and pointers to supporting information (see Section 5.4.2.3). For new and existing data (work completed prior to 1992), the QED process, as described in SNL QAP 20-3, was used to qualify the data to determine if the QA program in effect met the requirements of 40 CFR Part 194 (Method 2). The results of the QED process are documented in Statements of Condition.

Data collected by SNL and its subcontractors to support compliance were used if the data were

- collected after August 1, 1995 when SNL QA program was qualified by the DOE (Method 1),
- collected after the qualification of a subcontractor QA Program by SNL (Method 1),
- qualified by an Independent Review Team (IRT) (Method 2), or
- qualified by the Peer Review process (Method 3).

Data that did not fall into one of these four categories were not used in compliance.

5.4.2.2 Qualification of Existing Data (Methods 2 and 3)

Existing data are those data collected prior to the implementation of a QA program satisfying the requirements identified in 40 CFR § 194.22. Existing data, used as input to support computer codes and models, have been used to support the development of parameter values and distributions used in the performance assessment calculations. SNL QAP 9-2, Quality Assurance Requirements for the Selection and Documentation of Parameter Values Used in WIPP Performance Assessment, describes the process for selecting parameter values used in performance assessment. To ensure that data are used as intended, the scientific investigator and the performance assessment analyst must concur on Form 464 (WIPP Parameter Entry Form) that the proposed parameter is appropriate and the supporting documentation is sufficient. To qualify existing data to support the compliance application, a process following the guidelines of NUREG-1298 (NRC 1988) was developed.

The QED process, as described in SNL QAP 20-3, includes three major steps. The first step identifies the packages to be qualified by identifying those data packages that support the performance assessment calculations. The second step includes provisions for the evaluation of the QA requirements and technical status of the data packages by an IRT. If the QA requirements applicable to the data package are determined to be acceptable, the data are considered qualified. If the QA requirements are determined to be unacceptable, a third step is followed in which the data are qualified by peer review, confirmatory testing, or the use of corroborating data. Otherwise, the data are not used.

The experiments reviewed by the QED process have been diverse, including the thermal-structural interaction tests conducted underground in the WIPP, the gas generation tests conducted at other national laboratories, the surface and underground hydrologic testing in the vicinity of the WIPP, the laboratory testing of salt properties, and others. The previous work reviewed was performed from 1984 to 1992. Each data package corresponded to a test plan or other test control document. Table 5-5 identifies the 14 packages reviewed by the IRT and determined to have been collected under an equivalent QA program.

Peer reviews are performed when necessary to verify the technical adequacy of work done and to qualify data. The peer review process and peer reviews conducted to support data

Table 5-5. QED Data Packages Qualified by IRT (in accordance with SNL QAP 20-3)

Review Group	Data Package
Salado testing activities (two packages)	Salado in situ permeability
Creep and fracture tests	Clean and argillaceous salt
Salt compaction	Hydrostatic and shear consolidation
Corrosion	Steel
Microbial	Cellulosics, plastics, and rubbers
Borehole tests, two or more wells (six packages)	Drilling, drill stem and hydrologic testing, well development
Hydrogeologic characterization (two packages)	Permeability and water level measurements

qualification are described in Chapter 9.0, Peer Review. All data sets not qualified by IRT or collected under a qualified QA program were qualified by the peer review process.

The QA records packages generated as a result of the IRT process described in SNL QAP 20-3 contain the following documents:

- IRT Statement of Condition, composite checklist, recommendations for improvement, etc., and
- qualifications and training documentation of IRT members.

5.4.2.3 T=0 Process

The T=0 process implemented by SNL was used to determine the date when NQA controls were adequate and effectively implemented for subcontractor activities performed prior to the qualification of the current SNL QA program.

The process is documented in SNL procedure QAP 20-7, *Establishing T=0 for Internal and External Experiment Activity QA Programs*, and includes the following key elements:

1. The process evaluation was performed by a certified NQA-1 Lead Auditor. Results are documented in a memorandum.
2. The QA requirements identified for the work (as described in the Statement of Work), the subcontractor QA program plan, and other implementing documents, were reviewed.

3. The audit record, including audit responses and corrective actions, was reviewed to determine the requirements and objective evidence evaluated during the audit and the audit results.

4. The audit record and the associated documentary evidence were evaluated to determine when adequate controls on the work were effectively implemented. This evaluation included a review of any corrective actions and the associated responses as well as verifications of the corrective actions.

5. A determination was made of the date when adequate QA controls were applied to the work. Results of audits and surveillances were documented in a report that included the rationale and the identification of reviewed documentation.

This process provides a traceable basis for determining when adequate QA controls were applied to subcontractor activities. The results of this process are shown in Table 5-6 for SNL subcontractors supplying data to support performance assessment. Additionally, SNL conducts internal and external surveillances, the most recent of which are shown in Table 5-7. The five external surveillances in Table 5-7 supplemented and supported the findings of the SNL audits of its subcontractors. See Section 5.3.18 for discussion on control and location of associated QA records.

5.4.3 WID QA Program Implementation

The WID QA Program was determined to be adequate and effectively implemented based on DOE audit A-96-01 in December 1994. The most recent audit in June 1996, A-96-05, indicated that the WID QA Program was adequate, implemented, and marginally effective. As a result of actions taken by WID to correct the deficiencies, the WID QA Program has been determined to be adequate and effectively implemented. Tables 5-8 and 5-9 summarize the DOE audits and surveillances, respectively, of the WID QA Program.

As the WID conducts audits of internal or external organizations, an evaluation is made of past performance by that organization. In most cases, an organization's program had been in effect before a WID audit, therefore WID determines program adequacy to one year before the audit.

WID determines the adequacy of the implementation of QA requirements for both internal WID customers and external contractors. Internal determinations of adequacy of QA implementation are generally based on adherence to the WID QAPD requirements. The process includes a review of the contractor's QA program with regard to the applicable elements of the WID QAPD, nationally recognized codes and standards, and regulations. The WID has performed audits and surveillances to determine the dates when each of its supplier's and subcontractor's QA programs were considered adequate and effectively implemented. These dates and the basis for determination are shown in Table 5-10.

Table 5-6. T=0 for SNL Subcontractors

Subcontractor	First Qualification Date	First Qualification Basis
Lawrence Berkeley National Laboratory (LBNL) (AH-5592)	9/93	EA 94-07
University of Nevada Reno (AG-4915)	1/95	IA 95-01
Florida State University (AH-5590)	7/94	EA 95-02
Battelle (AF-3339)	12/93	EA 95-01
University of Nevada Las Vegas (AJ-8745)	4/95	EA 95-04
Stanford University (AG-4979)	11/94	EA 95-05
Lawrence Livermore National Laboratory (AG-4965 and AF-3341)	4/95	EA 95-13
RE/SPEC Inc. (AF-3334)	5/94	EA 95-06
RE/SPEC Inc. (AG-4911)	4/94	EA 95-06
Parsons-Brinkerhoff (AG-4909)	3/94	EA 95-10
INTERA Inc. (AG-4910)	7/94	EA 95-11
Core Laboratories (AF-3945, AI-3669)	5/93	EA 94-04
RE/SPEC Inc. (AA-2020)	6/94	EA 94-05

Table 5-7. Additional SNL Internal and External Surveillances

Activity	Assessment Number	Date
FEPs	SR 96-01	10/95
Los Alamos National Laboratory (external)	SR 96-02	12/95
Texas A & M (external)	SR 96-03	12/95
RE/SPEC (external)	SR 96-04	2/96
INTERA, Inc. (external)	SR 96-05	2/96
Dissolved Species Program	SR 96-06	3/96
Los Alamos National Laboratory (external)	SR 96-07	3/96
Software QA	SR 96-08	4/96
Training	SR 96-09	4/96
Small-Scale Seal Performance Test	SR 96-10	7/96

Table 5-8. DOE Audits of WID

Activity	Number	Date
QA Program	CAO A-95-01	12/94
QA Records Management	CAO A-95-03A	7/95
QA Program	CAO A-96-05	6/96

Table 5-9. DOE Surveillances of the WID Organization

Surveilled Organization	Number	Date
WID/Safety and Health Surveillance of Occupational Medical Program	S-95-07	4/95
WID/Environmental Compliance	S-95-08	5/95
WID/Environmental Compliance Program	S-95-17	10/95
WID/Equipment Safety	S-95-26	9/95
WID/Operation Maintenance	S-95-29	5/95
WID/Emergency Response/Training and Qualification	S-95-30	7/95
WID/Biennial Environmental Compliance Report Hazardous Waste Management for Generator	S-95-31	6/95
WID/Accident Analysis and Reporting Program	S-95-32	4/95
WID/Food Service Sanitation Program	S-95-32A	9/95
WID/Lockout-Tagout	S-95-33	9/95
WID/Hazardous Waste Satellite Accumulation Points	S-95-34	9/95
WID/MSDS Waste Characterization	S-96-02	11/95
WID/Mine Safety	S-96-06	12/95
WID/Spill Response and Control	S-96-12	2/96
WID/Hazard Communication	S-96-14	12/95
WID/Environmental Procedural Implementation	S-96-22	6/96
WID/Conduct of Operations	S-96-26	4/96
WID/Excavation and Trenching Safety	S-96-33	3/96
WID/Personal Protective Equipment	S-96-34	3/96
WID/Fall Protection	S-96-35	3/96
WID/Emergency Management	S-96-39	7/96
WID/Work Packages (Safety Issues)	S-96-47	7/96

Table 5-10. T=0 for WID Subcontractors

Contractor	Qualification: Data Prequalification Date for Audit	Qualification: Audit Number and Date of Qualification
Shortridge Instruments	June 1993	Audit E94-04A, 06/21/94
John Fluke Mfg.	June 1993	Audit E94-05A, 06/30/94
Kinemetrics, Inc.	July 1993	Audit E94-07A, 07/14/94
Hi-Q Environmental Products	July 1993	Audit E94-08S, 07/12/94
Pacific Northwest National Laboratory - Battelle	August 1993	Audit E94-09A, 08/03/94
Quanterra Corporation	August 1993	Audit E94-10S, 08/08/94
MKS Instruments, Inc.	August 1993	Audit E94-12S, 08/04/94
GE Rental	September 1993	Audit E94-14S, 09/15/94
Haliburton NUS Environmental	September 1993	Audit E94-16A, 09/19/94
Southern California Edison Energy Services	October 1993	Audit E94-17S, 10/26/94
IT Corp., Air Quality Services, Cincinnati, Ohio	October 1993	Audit E94-18A, 10/25/94
Benchmark Environmental	February 1994	Audit E95-001A, 02/23/95
Servco Industrial Division Corona, California	March 1994	Audit E95-002A, 03/01/95
Wyle Labs	April 1992	Audit E94-003S, 04/05/94
Merrick and Company	January 1994	Audit E95-004A, 03/07/95
Quantrad Sensor	April 1994	Audit E95-005A, 04/26/95
Servco Industrial Division Costa Mesa, California	March 1994	Audit E95-006A, 03/01/95
Colorado Allstate Transportation	April 1994	Audit E95-008S, 04/18/95
Nordberg, Inc.	May 1994	Audit E95-009A, 05/05/95
Lake Shore Mining Co.	May 1994	Audit E95-010A, 05/05/95
Instrument Services Lab	May 1994	Audit E95-012A, 05/12/95
Ross Analytical Services	May 1994	Audit E95-014A, 05/11/95
Gage Lab Corporation	May 1994	Audit E95-015A, 05/23/95
EG&G Ortec	May 1994	Audit E95-016A, 05/23/95
Eberline Instruments	September 1994	Audit E95-026A, 09/26/95
IT Corp. Albuquerque, New Mexico	November 1994	Audit E95-028A, 11/30/95

An established NQA-1-based auditing process is used to ensure the integrity of the WID program. Procedures are in place that specify the qualifications for the audit team and the lead auditor in particular. Audits are conducted according to approved WID procedures. Internal audits and surveillances of the WID QA program are identified in Appendix AUD. Corrective actions resulting from an audit require action plans that identify such items as the cause of the condition found to be adverse to quality, effect on other processes, method to prevent recurrence, and scheduled dates of completion of accepted corrective actions.

5.4.4 QA Program Implementation at Other Organizations

The DOE, WID, and SNL have performed numerous additional audits and surveillances, both internal and external to their organizations, in accordance with the same procedures used to directly support this application. Lists of these audits and surveillances are included in Appendix AUD.

REFERENCES

ASME (American Society of Mechanical Engineers). 1989a.. *Quality Assurance Program Requirements for Nuclear Facilities*. ASME NQA-1-1989. September 15, 1989. The American Society of Mechanical Engineers, New York, NY.

ASME (American Society of Mechanical Engineers). 1989b. "Part 2.7 Quality Assurance Requirements of Computer Software for Nuclear Facility Applications," *Quality Assurance Requirements for Nuclear Facility Applications*. ASME NQA-2a-1990, Part 2.7. May 31, 1990. ASME, New York, NY.

ASME (American Society of Mechanical Engineers). 1989c. *Quality Assurance Program Requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories*. ASME NQA-3-1989. March 23, 1990. American Society of Mechanical Engineers, New York, NY.

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. *Federal Register*, Vol. 58, No. 242, pp. 66398 – 66416, December 20, 1993. Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

EPA (U.S. Environmental Protection Agency). 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. *Federal Register*, Vol. 61, No 28, pp. 5224 – 5245, February 9, 1996. Office of Air and Radiation, Washington, D.C. In NWM Library as KF70.A35.C751 1996 (Reference).

NRC (U. S. Nuclear Regulatory Commission). 1988. *Qualification of Existing Data for High-Level Nuclear Waste Repositories*. NUREG-1298. February 1988.

BIBLIOGRAPHY

NRC (U. S. Nuclear Regulatory Commission). 1988a. *Peer Review for High-Level Nuclear Waste Repositories*. NUREG-1297. February 1988.

Knight, J.P. 1989. Memorandum. "Waste Isolation Pilot Plant Safety Evaluation Report," on EH-30 Safety Evaluation Report (SER) for the Waste Isolation Pilot Plant (WIPP) plus attachment.

6.0 CONTAINMENT REQUIREMENTS

6.0.1 Introduction

Because of the amount of material presented in Chapter 6.0 and its complexity, the U.S. Department of Energy (DOE) has provided an introductory summary of Chapter 6.0. Detailed discussions of the topics covered in this summary are found in the remainder of the chapter, which is organized as follows:

- Section 6.1 – the overall system performance assessment methodology used to evaluate compliance with the containment requirements.
- Section 6.2 – a comprehensive list of features, events, and processes (FEPs) that might affect disposal system performance, the screening methodology applied to that list, and the results of the screening process.
- Section 6.3 – development of the scenarios that are considered in the system-level consequence analysis.
- Section 6.4 – the conceptual and computational models used to perform the system-level consequence analysis (performance assessment), the overall flow of information in the performance assessment, the scenario probabilities, and the construction of a performance measure for comparison with the standard.
- Section 6.5 – the results of the performance assessment.

Additional information supporting this chapter is provided in appendices. See Table 1-6 in Chapter 1.0 for a list of these appendices.

6.0.2 Overview of Chapter 6.0

The DOE has determined that the Waste Isolation Pilot Plant (WIPP) is in compliance with the Containment Requirements of Title 40 Code of Federal Regulations (CFR) § 191.13. These requirements are stringent and state that the DOE must demonstrate a reasonable expectation that the probabilities of cumulative radionuclide releases from the disposal system during the 10,000 years following closure will fall below specified limits. The performance assessment analyses supporting this determination must be quantitative and must consider uncertainties caused by all significant processes and events that may affect the disposal system, including inadvertent human intrusion into the repository during the future. A quantitative performance assessment is conducted using a series of linked computer models in which uncertainties are addressed by a Monte Carlo procedure for the sampling of selected input parameters.

As required by regulation, results of the performance assessment are displayed as complementary cumulative distribution functions (CCDFs) that display the probability that cumulative radionuclide releases from the disposal system will exceed the values calculated

for each scenario considered in the analysis. These CCDFs are calculated using reasonable and, in some cases conservative, conceptual models that are based on the scientific understanding of the behavior of the disposal system. Parameters used in these models are derived from experimental data, field observations, and relevant technical literature. The overall mean CCDF lies entirely below and to the left of the specified limits, and the WIPP is therefore in compliance with the containment requirements of 40 CFR Part 191. Sensitivity analysis of results shows the location of the mean CCDF is dominated by releases of radionuclides that could occur directly at the ground surface during the inadvertent penetration of the repository by a future drilling operation. Releases of radionuclides to the accessible environment resulting from transport in groundwater through the shaft seal systems and the subsurface geology are negligible, with or without human intrusion, and make no contribution to the location of the mean CCDF. No releases whatsoever are predicted to occur at the ground surface in the absence of human intrusion. The natural and engineered barrier systems of the WIPP provide robust and effective containment of transuranic (TRU) waste even if the repository is penetrated by multiple borehole intrusions.

6.0.2.1 Conceptual Basis for the Performance Assessment

The foundations of the performance assessment lie in a thorough understanding of the disposal system and the possible future interactions among the repository, the waste, and the surrounding geology. This application is organized such that site characterization, facility design, and waste characterization are described separately in Chapters 2.0, 3.0, and 4.0. The DOE's confidence in the results of the performance assessment is based in part on the strength of the research done during site characterization, the robustness of the facility design, and the knowledge of the inventory. Quality assurance activities, described in Chapter 5.0, demonstrate that the information gathered during these activities is qualified to support the compliance decision.

Chapters 2.0, 3.0, and 4.0 provide the basic descriptions of the main components of the disposal system. The interactions of the repository and waste with the geologic system, and the response of the disposal system to possible future inadvertent human intrusion are described in Section 6.4.

6.0.2.2 Undisturbed Performance

An evaluation of undisturbed performance, which is defined by regulation (see 40 CFR § 191.15 and § 191.2) to exclude human intrusion and unlikely disruptive natural events, is required by regulation (see 40 CFR § 191.12). Evaluation of past and present natural geologic processes in the region indicate that none has the potential to breach the repository within 10,000 years. Behavior of the disposal system is dominated by the coupled processes of deformation of the rock surrounding the excavation, fluid flow, and waste degradation. Each of these processes can be described independently, but the extent to which each process occurs will be affected by the others.

Deformation of the rock immediately around the repository begins as soon as excavation creates a disturbance in the stress field. Stress relief results in some degree of brittle fracturing and the formation of a disturbed rock zone (DRZ) surrounding excavations in all deep mines. For the WIPP, the DRZ is characterized by an increase in permeability and a decrease in pore pressure, and may ultimately extend a few meters from the excavated region. Salt will also deform due to deviatoric stress by creep processes and move inward to fill voids. This process of salt creep will continue until deviatoric stress is dissipated and the system is once again at stress equilibrium.

The ability of salt to creep, thereby healing fractures and filling porosity, is one of the fundamental advantages of using it as a medium for geologic disposal of radioactive waste and is one of the reasons it was recommended for use by the National Academy of Sciences. For the WIPP, salt creep provides the basis for the design of the compacted crushed salt components of the shaft seal system that will compact to yield properties approaching those of the intact salt within 200 years. The salt creep will also cause the DRZ surrounding the shaft to heal rapidly around the concrete components of the seal system. In the absence of elevated pressure in the repository, salt creep would also eventually result in substantial compaction of the waste and the healing of the DRZ around the disposal region. Understanding the coupling of salt creep with fluid flow and waste degradation processes suggests that fluid pressure within the waste disposal region will be sufficient to maintain significant porosity within the disposal region throughout the performance period.

Characterization of the Salado Formation indicates that fluid flow does not occur on time scales of interest in the absence of an artificially imposed hydraulic gradient. This lack of fluid flow is the second fundamental reason for the choice of salt as a medium for geologic disposal of radioactive waste. Lack of fluid flow is a result of the extremely low permeability of the evaporite rocks that make up the Salado. Excavation of the repository has disturbed the natural hydraulic gradient and rock properties and has resulted in fluid flow. Small quantities of interstitial brine present in the Salado move toward regions of low hydraulic potential and brine seeps are observed in the underground. The slow flow of brine from halite into more permeable anhydrite marker beds and then through the DRZ into the repository is expected to continue as long as the hydraulic potential within the repository is below the hydraulic potential in the far field. The repository environment will also involve gas, and fluid flow there must be modeled as a two-phase process. Initially, the gas phase will consist primarily of air trapped at the time of closure, although other gases will form as a result of waste degradation. The gas phase pressure will rise due to creep closure, gas generation, and brine inflow, creating the potential for flow outward from the excavated region.

Consideration of waste degradation processes indicates that the role of the gas phase in fluid flow and the pressure history of the repository will be far more important than would be expected if the initial air were the only gas present. Degradation of waste can generate significant additional gas by two processes:

(1) the generation of hydrogen gas by anoxic corrosion of iron, iron alloys, and aluminum, and

(2) the generation of carbon dioxide and methane by anaerobic microbial degradation of waste containing cellulose, rubber, or plastic.

The coupling of these gas generation reactions to the processes of fluid flow and salt creep is complex. Gas generation will increase fluid pressure in the repository, thereby decreasing the hydraulic gradient and deviatoric stress between the far field and the excavated region and inhibiting the processes of brine inflow and salt creep. Anoxic corrosion will also consume brine as it breaks down water to oxidize iron and release hydrogen gas. Thus, corrosion has the potential to be a self-limiting process, in that as it consumes all water in contact with iron, it will cease. Microbial reactions are also considered to be dependent on the presence of water to occur, although their net effect is uncertain. It is assumed that microbial reactions will result in neither the consumption nor creation of water.

The total volume of gas that may be generated by corrosion and microbial degradation may be sufficient to result in repository pressures that approach lithostatic. Sustained pressures above lithostatic are not physically reasonable within the disposal system, and fracturing of the more brittle anhydrite layers is expected to occur if sufficient gas is present. The conceptual model implemented in the performance assessment causes permeability and porosity of the anhydrite marker beds to increase rapidly as pore pressure approaches and exceeds lithostatic. This conceptual model for pressure-dependent fracturing approximates the hydraulic effect of pressure-induced fracturing and allows gas and brine to move more freely within the marker beds at higher pressures.

Overall, the behavior of the undisturbed disposal system will result in extremely effective isolation of the radioactive waste. Concrete, clay, and asphalt components of the shaft seal system will provide an immediate and effective barrier to fluid flow through the shafts, isolating the repository until salt creep has consolidated the compacted crushed salt components that will permanently seal the shafts. Around the shafts, the DRZ in halite layers will heal rapidly because the presence of the solid material within the shafts will provide rigid resistance to creep. The DRZ around the shaft, therefore, will not provide a continuous pathway for fluid flow. The DRZ is not expected to heal completely around the disposal region or the operations and experimental regions, and pathways for fluid flow may exist indefinitely to the overlying and underlying anhydrite layers (Marker Beds [MB] 138 and 139 and anhydrites a and b). Some quantity of brine is expected to be present in the repository under most conditions and this brine may contain actinides (which dominate the radionuclide inventory and are therefore the elements of primary regulatory interest) mobilized as both dissolved and colloidal species. Gas generation by corrosion and microbial degradation is expected to occur and will result in elevated pressures within the repository. These pressures will not significantly exceed lithostatic, because fracturing within the more brittle anhydrite layers will occur and provide a pathway for gas to leave the repository. Fracturing is expected to enhance gas and brine migration from the repository, but gas transport will not contribute to the release of actinides from the disposal system. Brine flowing out of the waste disposal region through anhydrite layers may transport actinides as dissolved and colloidal species, but the quantity of actinides that may reach the accessible environment boundary during undisturbed performance through the interbeds is insignificant and has no effect on the

compliance determination. No migration of radionuclides whatsoever is expected to occur vertically through the Salado or through the shaft seal system.

6.0.2.3 Disturbed Performance

Performance assessment is required by regulation to consider scenarios that include intrusions into the repository by inadvertent and intermittent drilling for resources. The probability of these intrusions is based on a future drilling rate of 46.8 boreholes per square kilometer per 10,000 years. This rate is based on consideration of the past record of drilling events in the Delaware Basin consistent with regulatory criteria. Active institutional controls are assumed to be completely effective in preventing intrusion during the first 100 years after closure and passive institutional controls are assumed to be effective in reducing the drilling rate by two orders of magnitude for the 600 years that follow the 100 years of active control. Future drilling practices are assumed to be the same as current practice, also consistent with regulatory criteria. These practices include the type and rate of drilling, emplacement of casing in boreholes, and the procedures implemented when boreholes are plugged and abandoned.

Results of the performance assessment indicate that human intrusion provides the only mechanism for significant releases of radionuclides from the disposal system. These releases may occur by five mechanisms:

(1) cuttings, which include material intersected by the rotary drilling bit,

(2) cavings, which include material eroded from the borehole wall during drilling,

(3) spallings, which include solid material carried into the borehole during rapid depressurization of the waste-disposal region,

(4) direct brine releases, which include contaminated brine that may flow to the surface during drilling, and

(5) long-term brine releases, which include the contaminated brine that may flow through a borehole after it is abandoned.

The first four of these mechanisms operate immediately following the intrusion event and are collectively referred to as direct releases. The accessible environment boundary for these releases is the ground surface. The fifth mechanism, actinide transport by long-term groundwater flow, begins when concrete plugs are assumed to degrade in an abandoned borehole and may continue throughout the regulatory period. The accessible environment boundary for these releases may be the land surface or the lateral subsurface limit of the controlled area.

Repository conditions prior to intrusion will be the same as those described for undisturbed performance and all processes active in undisturbed performance will continue to occur

following intrusion. Because intrusion provides a pathway for radionuclides to reach the ground surface and to enter the geological units above the Salado, additional processes will occur that are less important in undisturbed performance. These processes include the mobilization of radionuclides as dissolved and colloidal species in repository brine and groundwater flow and actinide transport in the overlying units. Flow and transport in the Culebra Member of the Rustler Formation are of particular interest because this is the unit to which modeling indicates most flow from a borehole will occur.

6.0.2.3.1 Cuttings and Cavings

In a rotary drilling operation, the volume of material brought to the surface as cuttings is the cylinder defined by the thickness of the unit being drilled and the diameter of the drill bit. The quantity of radionuclides released as cuttings is therefore a function only of the activity of the intersected waste and the diameter of the intruding drill bit. Like all parameters that describe future drilling activities, the diameter of a drill bit that may intersect waste is speculative. The DOE uses a constant value of 12.25 inches (0.311 meters), consistent with bits used at the WIPP depth in the Delaware Basin today. The activity of the intersected waste may vary depending on the type of waste intersected, and the DOE considers random penetrations into remote-handled (RH)-TRU waste and each of the 569 different waste types identified for contact-handled (CH)-TRU waste.

The volume of particulate material eroded from the borehole wall and brought to the surface as cavings may be affected by the drill bit diameter, the effective shear resistance of the intruded material, the speed of the drill bit, the viscosity of the drilling fluid and the rate at which it is circulated in the borehole, and other properties related to the drilling process. The most important of these parameters, after drill bit diameter, is the effective shear resistance of the intruded material. In the absence of data describing the reasonable and realistic future properties of degraded waste and backfill, the DOE has used conservative parameter values based on the properties of fine-grained sediment. Other properties are assigned fixed values consistent with current practice. The quantity of radionuclides released as cavings depends on the volume of eroded material and its activity, which is treated in the same manner as the activity of the cuttings.

6.0.2.3.2 Spallings

Unlike releases from cuttings and cavings, which will occur with every borehole intrusion, spalling releases will occur only if pressure in the waste-disposal region exceeds the hydrostatic pressure in the borehole. At lower pressures, below about 8 megapascals, fluid in the waste-disposal region will not flow toward the borehole. At higher pressures, gas flow toward the borehole may be sufficiently rapid to entrain particulate waste. If spalling occurs, the volume of spalled material is affected by the physical properties of the waste, specifically its tensile strength and particle diameter. As is the case for the effective shear resistance for the waste, WIPP-specific experimental data are not available to support parameter values for the tensile strength and average particle diameter of degraded waste and backfill. The DOE

has based the parameter values used in the performance assessment on reasonable and conservative assumptions.

The quantity of radionuclides released as spalled material depends on the volume of spalled waste and its activity. Because spalling may occur at a greater distance from the borehole than cuttings and cavings, spalled waste is assumed to have the volume-averaged activity of CH-TRU waste rather than the sampled activities of individual waste streams. RH-TRU waste is isolated from the spallings process and does not contribute to the volume or activity of spalled material.

6.0.2.3.3 Direct Brine Flow

Radionuclides may be released to the accessible environment if repository brine enters the borehole during drilling and flows to the ground surface. The quantity of radionuclides released by direct brine flow depends on the volume of brine reaching the ground surface and the concentration of radionuclides contained in the brine. As is the case for spallings, direct releases of brine will not occur if repository pressure is below the hydrostatic pressure in the borehole. At higher repository pressures, if mobile brine is present in the repository, it will flow toward the borehole. If the volume of brine flowing from the repository into the borehole is small, it will not affect the drilling operation and flow may continue until the driller reaches the base of the evaporite section and installs casing in the borehole. This length of time is estimated to be 72 hours, consistent with current practice. Larger brine flows or large gas flows could cause the driller to lose control of the borehole and fluid flow, in this case, could continue until repository pressure drops or the hole is contained. The maximum length of time that such flow would be allowed to continue before the borehole would be controlled by the driller is 11 days, consistent with current drilling practice in the Delaware Basin.

6.0.2.3.4 Mobilization of Actinides in Repository Brine

Actinides may be mobilized in repository brine in two principal ways:

(1) as dissolved species, and

(2) as colloidal species.

The solubilities of actinides differ among the different oxidation states in which they may exist, with the more reduced forms (for example, Pu-III or Pu-IV rather than Pu-V or Pu-VI) being less soluble. Conditions within the repository will be reducing because of the large quantity of iron in the waste and containers and, in some cases, only the lower solubility oxidation states will be present. Solubilities also vary with pH. The DOE will therefore emplace magnesium oxide (MgO) in the waste disposal region with the waste to ensure conditions that favor minimum actinide solubility. Solubilities in the performance assessment are based on reducing conditions, MgO backfill, and the chemistry of brines that can be present in the waste disposal region.

The waste contains organic ligands that, under some circumstances, can enhance actinide concentrations in brine by forming soluble complexes containing actinide ions. However, these organic ligands also bond strongly to other metals, such as magnesium, that will be present in far larger quantities in repository brine. Because of this competition effect, organic ligands will not have a significant effect on overall actinide concentrations in brine.

Colloidal transport of actinides has been examined and four types have been determined to represent the possible behavior at the WIPP. These include microbes, humic substances, actinide intrinsic colloids, and mineral fragments. Concentrations of actinides mobilized as these colloidal forms are included in the estimates of total actinide concentrations used in the performance assessment.

6.0.2.3.5 Long-Term Brine Flow up an Intrusion Borehole

Long-term releases to the ground surface or into groundwater in the Rustler or overlying units may occur after the borehole has been plugged and abandoned. In keeping with regulatory criteria, borehole plugs are assumed to have the properties consistent with current practice in the basin. Thus, boreholes are assumed to have concrete plugs emplaced at various locations. Initially, concrete plugs will be effective in limiting fluid flow in the borehole. However, under most circumstances, these plugs cannot be expected to remain fully effective indefinitely. For the purposes of performance assessment, discontinuous borehole plugs above the repository are assumed to degrade 200 years after emplacement. From then on, the borehole is assumed to be filled with a silty-sand like material containing degraded concrete, corrosion products resulting from degradation of casing, and material that sloughs into the hole from the walls. Of six possible plugged borehole configurations in the Delaware Basin, three are considered either likely or found to adequately represent other possible configurations; one configuration (a two-plug configuration) is explicitly modeled.

If sufficient brine is available in the repository, and if pressure in the repository is higher than that in the overlying units, brine may flow up the borehole following degradation of the plugs. In principle, this brine could flow into any permeable unit or to the ground surface if repository pressure were high enough. For modeling purposes, brine is allowed to flow only into the higher permeability units and to the surface. Lower permeability anhydrite and mudstone layers in the Rustler are treated as if they were impermeable, to simplify the analysis while maximizing the amount of flow occurring into units where it has a potential to contribute to releases from the disposal system. Model results indicate that essentially all flow occurs into the Culebra, which has been recognized since the early stages of site characterization as the most transmissive unit above the repository and the most likely pathway for subsurface transport.

6.0.2.3.6 Groundwater Flow in the Culebra

Site characterization activities in the units above the Salado have focused on the Culebra. These activities have shown that the direction of groundwater flow in the Culebra varies somewhat regionally, but in the area that lies over the site, flow is southward. Regional

variation in groundwater flow direction in the Culebra is influenced by the regional variation in transmissivity observed and also by the shape of and distribution of rock types in the groundwater basin in which the WIPP is located. Site characterization activities have demonstrated that there is no evidence of karst groundwater systems in the controlled area, although groundwater flow in the Culebra is affected by the presence of fractures, fracture fillings, and vuggy pore features. A zone of relatively high transmissivity in the Culebra in the southeast portion of the controlled area has been identified as the most important flow path away from the waste disposal panels, based on analysis of regional groundwater pumping tests. Other laboratory and field activities have focused on the behavior of dissolved and colloidal actinides in the Culebra. These characterization and modeling activities conducted in the units above the Salado confirm that the Culebra is the most transmissive unit above the Salado. The Culebra is the unit into which actinides are likely to be introduced from long-term flow up an abandoned borehole.

Basin-scale regional modeling of three-dimensional groundwater flow in the units above the Salado demonstrates that it is appropriate, for the purposes of estimating radionuclide transport, to conceptualize the Culebra as a two-dimensional confined aquifer. As modeled in the performance assessment, the steady-state flow field within the Culebra is affected only by the initial head distribution and the spatial variability of the transmissivity of the unit. Field data for both transmissivity and head are available from many locations in the Culebra. Uncertainty in the flow field is incorporated in the analysis through the use of 100 different geostatistically-based transmissivity fields, each of which is consistent with available head and transmissivity data.

Groundwater flow in the Culebra is modeled as a steady-state process, but two mechanisms are considered in the performance assessment that could affect flow in the future. Potash mining in the McNutt Potash Zone (hereafter referred to as the McNutt) of the Salado, which occurs now in the Delaware Basin outside the controlled area and which may continue to occur in the future, has the potential to affect flow in the Culebra if subsidence over mined areas causes fracturing or other changes in rock properties. Climatic changes during the next 10,000 years may also affect groundwater flow by altering recharge to the Culebra.

Consistent with regulatory criteria, mining outside the controlled area is assumed to occur in the near future, and mining within the controlled area is assumed to occur with a probability of 1 in 100 per century (adjusted for the effectiveness of institutional controls during the first 700 years following closure). Consistent with regulatory guidance, the effects of mine subsidence are incorporated in the performance assessment by increasing the transmissivity of the Culebra over the areas identified as mineable by a factor sampled from a uniform distribution between 1 and 1000. Transmissivity fields used in the performance assessment are therefore adjusted and steady-state flow fields calculated accordingly, once for the case in which mining is assumed to occur only outside the controlled area and once for the case in which mining is assumed to occur both inside and outside the controlled area. Mining outside the controlled area is considered in both undisturbed and disturbed performance.

The extent to which climate will change during the next 10,000 years and the extent to which such change will affect groundwater flow in the Culebra are uncertain. Regional three-dimensional modeling of groundwater flow in the units above the Salado indicates that flow velocities in the Culebra may be increased by a factor of between 1 and 2.25 for reasonably possible future climates. This uncertainty is incorporated in the performance assessment by scaling the calculated steady-state specific discharge within the Culebra by a sampled parameter within this range.

6.0.2.3.7 Actinide Transport in the Culebra

Field tests have shown that the Culebra is best characterized as a double porosity medium for the purposes of estimating contaminant transport in groundwater. Groundwater flow and advective transport of dissolved species or colloidal particles occurs primarily in a small fraction of the total porosity of the rock and thus corresponds to the porosity of open and interconnected fractures and vugs. Diffusion and slower flow occur in the remainder of the porosity, which is associated with the low-permeability dolomite matrix. Transported species, including actinides if present, will diffuse into this porosity.

Diffusion out of the advective porosity into the dolomite matrix will retard actinide transport by two mechanisms. Physical retardation occurs simply because actinides that diffuse into the matrix are no longer transported with the flowing groundwater. Transport is interrupted until they diffuse back into the advective porosity. In situ tracer tests have been conducted to demonstrate this phenomenon. Chemical retardation also occurs within the matrix as actinides are sorbed onto dolomite grains. The relationship between sorbed and liquid concentrations is assumed to be linear, and the distribution coefficients (K_ds) that characterize the extent to which actinides will sorb on dolomite are based on experimental data.

Modeling indicates that physical and chemical retardation, as supported by field tests and laboratory experiments, will be extremely effective in reducing the transport of dissolved actinides in the Culebra. Experimental work has demonstrated that transport of colloidal actinides is not a significant mechanism in the Culebra. As a result, actinide transport through the Culebra to the subsurface boundary of the controlled area is not a significant pathway for releases from the WIPP. As discussed in Section 6.5.3, the location of the mean CCDF that demonstrates compliance with the containment requirements of 40 CFR § 191.13 is determined entirely by direct releases at the ground surface during drilling (cuttings, cavings, and spallings).

6.0.2.3.8 Intrusion Scenarios

Human intrusion scenarios evaluated in the performance assessment include both single intrusion events and combinations of multiple boreholes. Two different types of boreholes are considered:

(1) those that penetrate a pressurized brine reservoir in the underlying Castile Formation, and

(2) those that do not.

The presence of a brine reservoir under the repository is speculative, but cannot be ruled out by available information. A pressurized brine reservoir was encountered at the WIPP-12 borehole within the controlled area to the northwest of the disposal region and other pressurized brine reservoirs have been encountered elsewhere in the Delaware Basin that are associated with regions of deformation in the Castile. Based on a geostatistical analysis of the distribution of brine encounters in the region, the DOE has estimated that there is a 0.08 probability that any random borehole that penetrates waste in the WIPP will also penetrate an underlying brine reservoir. Properties are assigned to the hypothetical reservoir (for example, its pressure and volume) that are consistent with the available information from tests at WIPP-12 and other boreholes. These properties are also made consistent with the hypothetical reservoir's location under the waste disposal region.

The primary consequence of penetrating a pressurized reservoir will be to provide an additional source of brine beyond that which flows into the repository from the Salado. Direct releases at the ground surface resulting from the first intrusion into the repository will be unaffected by the presence of additional Castile brine even if it flows to the surface, because brine moving straight up a borehole will not mix significantly with waste. The presence of Castile brine has the potential to increase radionuclide releases significantly in two ways, however. First, the volume of contaminated brine that could flow to the surface may be greater for a second or subsequent intrusion into a repository that has already been connected to a Castile reservoir. Second, the volume of contaminated brine that may flow up an abandoned borehole after plugs have degraded may be greater for combinations of two or more boreholes that intrude the same panel if one of the boreholes penetrates a pressurized reservoir. Both processes are modeled in the performance assessment.

6.0.2.4 Compliance Demonstration Method

The DOE's approach to demonstrating compliance is the performance assessment methodology described in Section 6.1. The performance assessment process is based on a comprehensive consideration of the features, events, and processes that are relevant to disposal system performance. Those features, events, and processes that are shown by screening analyses to have the potential to affect performance are included in quantitative calculations using a system of linked computer models to describe the interaction of the repository with the natural system, both with and without human intrusion. Uncertainty is incorporated in the analysis through a Monte Carlo approach in which multiple simulations (or realizations) are completed using sampled values for 57 imprecisely known or naturally variable input parameters. Distribution functions are constructed that characterize the state of knowledge for these parameters, and each realization of the modeling system uses a different set of sampled input values. A sample size of 100 results in 100 different values of each parameter. Therefore, there are 100 different sets (vectors) of input parameter values. Quality assurance activities, described in Chapter 5.0, demonstrate that the parameters, software, and analysis used in the performance assessment were the result of a rigorous process conducted under controlled conditions.

Probabilities of scenarios composed of specific combinations of features, events, and processes are estimated based on regulatory criteria (applying to the probability of future human action) and the understanding of the natural and engineered systems. Cumulative radionuclide releases from the disposal system are calculated for each scenario considered and probabilities of the scenarios are summed for each realization of the modeling system to construct distributions of CCDFs. Sampling of the input parameters was performed in three separate replicates resulting in three independent distributions of CCDFs and allowing the construction of three independent mean CCDFs, each based on 100 individual CCDFs.

6.0.2.5 Results of the Performance Assessment

Section 6.5 addresses the Containment Requirements of 40 CFR Part 191 and the associated criteria of 40 CFR § 194.34. Section 6.5 presents distributions of CCDFs for each replication of the analysis, mean CCDFs, and an overall mean CCDF, together with the 95 percent confidence interval estimated from the distribution of the three independent means.

Families of CCDFs and mean CCDFs for each of the three replicates are also shown in Section 6.5. All 300 individual CCDFs lie below and to the left of the limits specified in 40 CFR § 191.13(a). The overall mean CCDF determined from the three replicates lies entirely below and to the left of the limits specified in 40 CFR § 191.13(a). Thus, the WIPP is in compliance with the containment requirements of 40 CFR Part 191. Comparison of the results of the three replicates indicates that the sample size of 100 in each replicate is sufficient to generate a stable distribution of outcomes. Within the region of regulatory interest (that is, at probabilities greater than $10^{-3}/10^{4}$ yr), the mean CCDFs from each replicate are essentially indistinguishable from the overall mean.

As discussed in Section 6.5, examination of the normalized releases resulting from cuttings and cavings, spallings, and direct brine release provides insight into the relative importance of each release mode in terms of its contribution to the location of the mean CCDF and the compliance determination. Releases from cuttings and cavings dominate the mean CCDF. Spallings make a small contribution. Direct brine releases are less important and have very little effect on the location of the mean. Subsurface releases resulting from groundwater transport are less than 10^{-6} EPA units and make no contribution to the location of the mean CCDF.

Uncertainties characterized in the natural system and the interaction of waste with the disposal system environment have little effect on the location of the mean CCDF, providing additional confidence in the compliance determination. The natural and engineered barrier systems of the WIPP provide robust and effective containment of TRU waste even if the repository is penetrated by multiple borehole intrusions.

6.1 Performance Assessment Methodology

The U.S. Environmental Protection Agency (EPA), in 40 CFR Part 191, specifies the generally applicable environmental standards for the protection of public health and the

environment for the disposal of TRU and high-level radioactive wastes. In this chapter, the DOE addresses compliance with the Containment Requirements of 40 CFR § 191.13 and the associated portions of 40 CFR Part 194.

The complete text of the 40 CFR § 191.13 Containment Requirements follows:

> (a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based on performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:
>
> (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and
>
> (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).
>
> (b) Performance assessments need not provide complete assurance that the requirements of § 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with § 191.13(a) will be achieved.

The term accessible environment is defined as "(1) The atmosphere; (2) land surfaces; (3) surface waters; (4) oceans; and (5) all of the lithosphere that is beyond the controlled area" (40 CFR § 191.12). Further, controlled area means "(1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location" (40 CFR § 191.12). The controlled area established by the Land Withdrawal Act is shown in Figure 3-1 (see Chapter 3.0). The release limits listed in Appendix A of 40 CFR Part 191 are reproduced as Table 6-1.

For a release to the accessible environment that involves a mix of radionuclides, the limits in Table 6-1 are used to determine a normalized release (*nR*) of radionuclides for comparison with the release limits

(1)

where

Q_i = cumulative release in curies (*Ci*) of radionuclide *i* into the accessible environment during the 10,000-year period following closure of the repository.
L_i = release limit in curies for radionuclide *i* given in Table 6-1.
C = amount of curies of TRU waste emplaced in the repository. (As described in Section 4.1, TRU wastes contain alpha-emitting transuranic radionuclides with half-lives greater than 20 years.)

Table 6-1. Release Limits for the Containment Requirements (EPA 1985, Appendix A, Table 1)

Radionuclide	Release Limit L_i per 1,000 MTHM[a] or Other Unit of Waste (curies)
Americium-241 or -243	100
Carbon-14	100
Cesium-135 or -137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, -239, -240, or -242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or -232	10
Tin-126	1,000
Uranium-233, -234, -235, -236, or -238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

[a] Metric tons of heavy metal exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (MWd/MTHM) and 40,000 MWd/MTHM.

As indicated in Note 1(e) to Table 1 in Appendix A of 40 CFR Part 191, the "other unit of waste" for TRU waste shall be "an amount of transuranic wastes containing 1 million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years."

Performance assessments are the basis for addressing the containment requirements. 40 CFR § 191.12 defines performance as follows:

> "Performance assessment" means an analysis that: (1) identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events.

The DOE's methodology for performance assessment uses information about the disposal system and the waste to evaluate performance in a regulatory context over the 10,000-year regulatory time period.

The general theory for conducting a performance assessment is presented in this section together with details specific to the performance assessment conducted for the WIPP. Figure 6-1 illustrates the general, high-level steps used by the DOE for this final performance assessment of the WIPP. In this figure, the sections of this chapter are indicated in which these steps are discussed in detail, and it shows several important features of the WIPP performance assessment. It indicates the points at which regulatory standards and guidance (40 CFR Part 191 and related documents) are most influential, and it shows that there can be an iterative process between site characterization and performance assessment that facilitates improvement in both characterization data and performance assessment. Through this process, the DOE has used early site characterization information and design specifications to develop preliminary performance assessments, from which sensitivity analyses were used to guide further characterization of important features of the site data collection on specific topics and to further develop the repository design.

Section 6.1 presents the basis for the methodology shown in Figure 6-1. Section 6.1.1 presents the conceptualization of risk, Section 6.1.2 discusses the characterization of uncertainty in risk, Section 6.1.3 discusses regulatory criteria for the quantification of risk, Section 6.1.4 discusses calculation of risk, and Section 6.1.5 discusses techniques for probabilistic analysis.

6.1.1 Conceptualization of Risk

Performance assessment of the WIPP is fundamentally concerned with the evaluation of risk, for which comparative measures are defined by regulatory standards. For comparison with these standards, the DOE uses a conceptualization for risk similar to that developed for risk assessments of nuclear power plants. This description provides a structure on which both the representation and calculation of risk can be based.

Kaplan and Garrick (1981, 11 – 12) have presented the representation of risk as a set of ordered triples. The DOE uses this representation and defines risk to be a set R of the form

$$R = [(S_i, pS_i, \mathbf{cS}_i), i = 1, ..., nS] , \quad (2)$$

where

S_i = a set of similar occurrences
pS_i = probability that an occurrence in set S_i will take place
$\mathbf{cS}_i$ = a vector of consequences associated with S_i
nS = number of sets selected for consideration

and the sets S_i have no occurrences in common (that is, the S_i are disjoint sets). This representation formally decomposes risk into what can happen (the S_i), how likely things are to happen (the pS_i), and the consequences of what can happen (the $\mathbf{cS}_i$). In the WIPP performance assessment, the S_i are scenarios, the pS_i are scenario probabilities, and the vector $\mathbf{cS}_i$ contains consequences associated with scenario S_i. Development of scenarios for the WIPP is discussed in Sections 6.1.2, 6.2, and 6.3. Scenario probabilities and consequence determination are discussed in Section 6.4.

As discussed in the following sections of this chapter, risk in the set R can be displayed using CCDFs, as required by the EPA. As stated in 40 CFR § 194.34(a),

> The results of performance assessments shall be assembled into "complementary, cumulative distribution functions" (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events.

In the context of Equation 2, CCDFs provide information about the consequences $\mathbf{cS}_i$ and the probabilities pS_i associated with the scenarios S_i. The probability that **cS** exceeds a specific consequence value x is determined by the CCDF F defined by

(3)

where the particular consequence result **cS** under consideration is ordered so that $\mathbf{cS}_i \leq \mathbf{cS}_{i+1}$ for i=1, …, nS-1, and i is the smallest integer such that $\mathbf{cS}_i > x$. The function F represents the probabilities that consequence values plotted on the abscissa will be exceeded. A diagrammatic example of an estimation of F is shown in Figure 6-2. The steps in the CCDF shown in Figure 6-2 result from the evaluation of F with a discrete number of possible occurrences (that is, futures) represented in the sets S_i. Unless the underlying processes are inherently disjoint, the use of more sets S_i will tend to reduce the size of these steps and, in the limit, will result in a smooth curve. To avoid a broken appearance, the DOE plots estimated CCDFs with vertical lines added at the discontinuities.

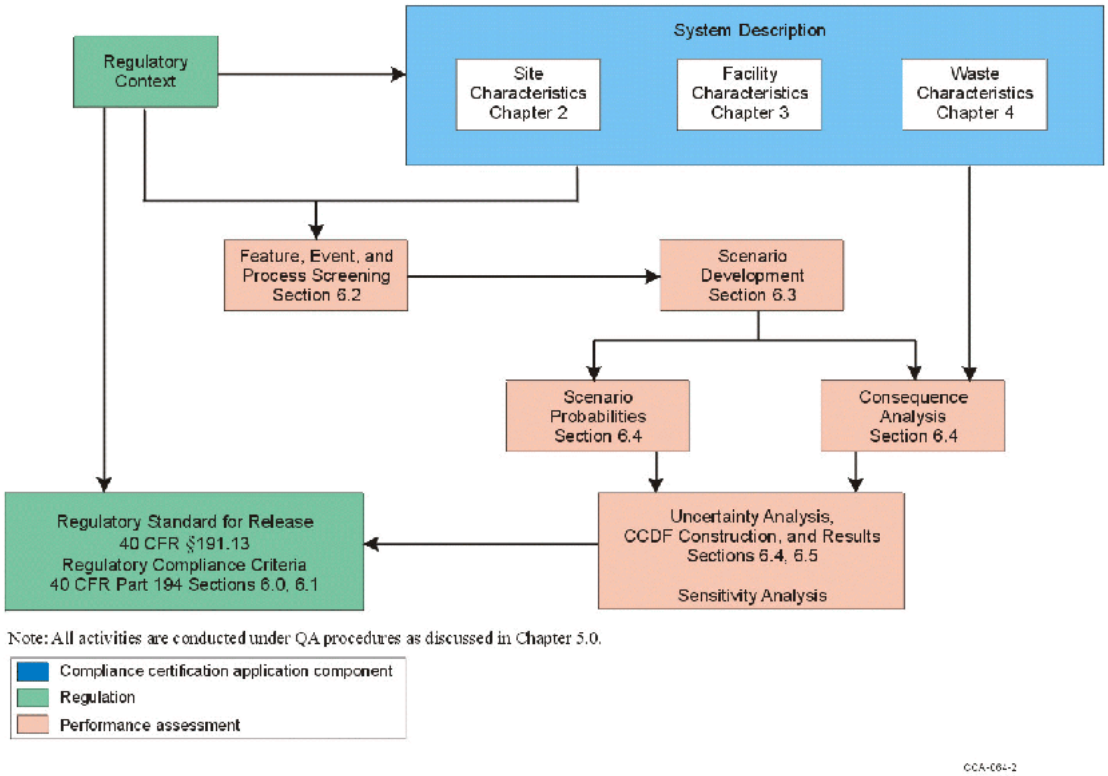

Figure 6-1. Methodology for Performance Assessment of the WIPP

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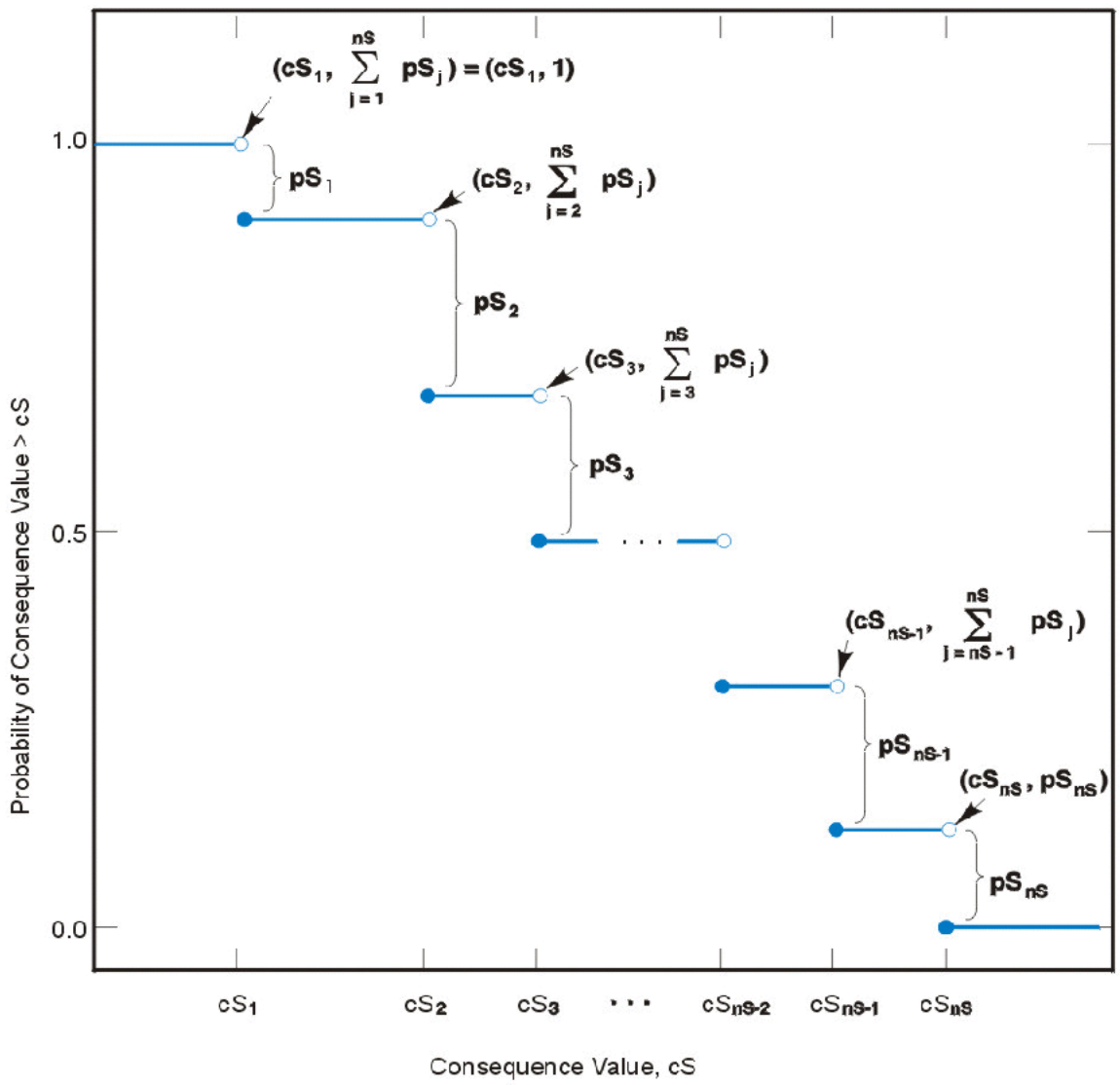

Note: The open and solid circles at the discontinuities indicate the points included on (solid circles) and excluded from (open circles) the CCDF.

CCA 006 2

Figure 6-2. Estimated CCDF For Consequence Results

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6.1.2 Characterization of Uncertainty in Risk

The DOE defines uncertainty in the analysis as either stochastic uncertainty or subjective uncertainty. Stochastic uncertainty derives from lack of knowledge about the future. Subjective uncertainty derives from lack of knowledge about quantities, properties, or attributes that are believed to have single or certain values. Stochastic uncertainty can be further subdivided into completeness, aggregation, and stochastic variation. Completeness refers to the extent that a performance assessment includes all possible occurrences for the system under consideration. In terms of the risk representation in Equation 2, completeness deals with whether all significant occurrences are included in the union of the sets S_i. The DOE addresses completeness in its development of scenarios, discussed here and in Sections 6.2 and 6.3. Aggregation refers to the division of the possible occurrences into the sets S_i. Resolution is lost if the S_i are defined too coarsely (for example, if nS is too small). Computational efficiency is affected if nS is too large. Aggregation gives rise to the steps in a single CCDF, as shown in Figure 6-2. The DOE addresses aggregation uncertainty in Sections 6.1.4 and 6.4.13. Stochastic variation is represented by the probabilities pS_i, which are functions of the many factors that affect the occurrence of the individual sets S_i. The DOE addresses stochastic variation in Sections 6.1.4 and 6.4.12.

Stochastic uncertainty can be characterized in performance assessment by evaluating the probability of future events (for example, by assuming that the occurrence of certain future events will be random in space and time), and by consideration of imprecisely known system properties directly associated with the future events. These imprecisely known system properties can be expressed as variables represented by the vector

$$\mathbf{x_{st}} = [x_{st,1}, x_{st,2}, \ldots, x_{st,nV(st)}] \,, \tag{4a}$$

where each $x_{st,j}$ [j = 1, 2, …, $nV(st)$] is an imprecisely known property required in the analysis, nV is the total number of such properties associated with stochastic uncertainty, and the subscript st denotes stochastic uncertainty.

Subjective uncertainty results from incomplete data or measurement uncertainty. These uncertainties are addressed in Section 6.4. Subjective quantities, properties, or attributes may be associated with stochastic uncertainties (events that might occur in the future).

Subjective uncertainty can be characterized in performance assessment by consideration of system properties that are imprecisely known. These imprecisely known system properties can be expressed as variables represented by vectors

$$\mathbf{x_{su}} = [x_{su,1}, x_{su,2}, \ldots, x_{su,nV(su)}] \,, \tag{4b}$$

where each $x_{su,j}$ [j = 1, 2, …, $nV(su)$] is an imprecisely known property required in the analysis, nV is the total number of such properties associated with subjective uncertainty, and the subscript su denotes subjective uncertainty.

If the analysis has been developed such that each x_j is a quantity for which the overall analysis requires a single value, the representation for risk in Equation 2 can be restated as a function of $\mathbf{x}_{\mathbf{st}}$ and $\mathbf{x}_{\mathbf{su}}$:

$$\mathrm{R}(\mathbf{x}_{\mathrm{su}}) = [S_i(\mathbf{x}_{\mathrm{su}}), pS_i(\mathbf{x}_{\mathrm{su}}), \mathbf{cS}_i(\mathbf{x}_{\mathrm{st,i}}, \mathbf{x}_{\mathrm{su}}), i = 1, ..., nS(\mathbf{x}_{\mathrm{st}}, \mathbf{x}_{\mathrm{su}})] \ , \tag{5}$$

where $x_{st,i}$ is included in S_i. Probability distributions are then assigned to the individual variables $x_{su,j}$ and $x_{st,j}$ as defined in Equation 4. These probability distributions are of the form

$$D_{st,1}, D_{st,2}, \ldots, D_{st,nV(st)} \ , \tag{6a}$$
$$D_{su,1}, D_{su,2}, \ldots, D_{su,nV(su)} \ , \tag{6b}$$

where the D_j's are the distributions developed for the variables x_j, $j = 1, 2,...nV$, and the subscripts *st* and *su* denote distributions associated with $\mathbf{x}_{\mathbf{st}}$ or $\mathbf{x}_{\mathbf{su}}$. The definition of these distributions may also be accompanied by the specification of correlations and various restrictions that further define the possible relations among the x_j. These distributions (along with specified correlations or restrictions) probabilistically specify what the appropriate input to use in the performance assessment calculations might be, given that the analysis is structured so that only one value can be used for each variable, x_j, under consideration for a particular calculation.

Monte Carlo techniques can be used to determine the uncertainty in $\mathrm{R}(\mathbf{x}_{\mathbf{su}})$ associated with both $\mathbf{x}_{\mathbf{st}}$ and $\mathbf{x}_{\mathbf{su}}$. The theory of this technique is similar for characterization of both stochastic and subjective uncertainty. This technique as applied to determining the risk $\mathrm{R}(\mathbf{x}_{\mathbf{su}})$ associated with $\mathbf{x}_{\mathbf{su}}$ is developed in the following paragraphs.

Once the distributions in Equation 6b have been developed, a sample

$$\mathbf{x}_k = (x_{k1}, x_{k2}, \ldots, x_{k,nV}), k = 1, \ldots, nK \tag{7}$$

is generated according to the specified distributions and restrictions where nK is the size of the sample. Performance assessment calculations are then performed for each sample element $\mathbf{x}_k$, which yields a sequence of risk results of the form

$$\mathrm{R}(\mathbf{x}_k) = \{[S_i(\mathbf{x}_k), pS_i(\mathbf{x}_k), \mathbf{cS}_i(\mathbf{x}_k)], i = 1, \ldots, nS(\mathbf{x}_k)\} \ . \tag{8}$$

Each set $\mathrm{R}(\mathbf{x}_k)$ is the result of one complete set of calculations performed with a set of inputs (that is, $\mathbf{x}_k$) obtained from the distributions assigned in Equation 6b. Further, associated with each risk result $\mathrm{R}(\mathbf{x}_k)$ in Equation 8 is a weight[1] that can be used in making probabilistic statements about the distribution of $\mathrm{R}(\mathbf{x})$.

[1] In random or Latin hypercube sampling (LHS), this weight is the reciprocal of the sample size (that is, $1/nK$) and can be used in estimating means, cumulative distribution functions, and other statistical properties. This weight is often referred to as the probability for each observation (that is, sample $\mathbf{x}_k$). However, this usage is not technically correct. If continuous distributions are involved, the actual probability of each observation is zero.

A single CCDF can be produced for each set $R(\mathbf{x}_k)$ of results shown in Equation 8, yielding a family of CCDFs of the form shown in Figure 6-3. The distribution of CCDFs in Figure 6-3 can be summarized with the mean and percentile curves shown in Figure 6-4. These curves result from connecting the mean and percentile values corresponding to individual consequence values on the abscissa of Figure 6-3. The percentile curves provide a probabilistic representation of the estimated exceedance probability given a fixed consequence value. For example, the probability is 0.8 that the exceedance probability for a particular normalized release is located between the 10 and 90 percentile curves.

To summarize, consideration of a family of CCDFs allows a distinction between stochastic uncertainty that controls the shape of a single CCDF and subjective uncertainty that results in a distribution of CCDFs. The stepwise shape of a single CCDF reflects aggregation of future events into similar groups. A family of CCDFs arises from imperfect knowledge of quantifiable properties, or, in other words, subjective uncertainty. The distribution arising from subjective uncertainty involves an infinite number of CCDFs; a family of CCDFs is a sample of finite size.

6.1.3 Regulatory Criteria for the Quantification of Risk

The representation for risk in Equation 2 provides a conceptual basis for the calculation of the CCDF for normalized releases specified in 40 CFR § 194.34(a). Further, this representation provides a structure that can be used for both the incorporation of uncertainties and the representation of the effects of uncertainties, as stated in 40 CFR § 194.34.

In 40 CFR § 194.34(b), the EPA states that "probability distributions for uncertain disposal system parameter values used in performance assessments shall be developed and documented in any compliance application." The treatment of uncertain parameter values in the performance assessment is discussed in Sections 6.1.4, 6.1.5, and 6.4. Further discussion of distributions assigned to uncertain parameter values is provided in Appendix PAR (Section PAR.2).

In 40 CFR § 194.34(c), the EPA states that documentation shall be provided of the computational techniques used to generate random samples. The sampling techniques used are discussed in Section 6.1.5.2. Sampled values are reproduced in tabular form in Appendix IRES (Section IRES.1).

In 40 CFR § 194.34(d), the EPA states that "the number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least a 0.95 probability." The CCDFs resulting from this performance assessment are provided in Section 6.5, together with a demonstration that the total number of CCDFs is sufficiently large.

In 40 CFR § 194.34(e), the EPA states that "any compliance application shall display the full range of CCDFs generated." The full range of CCDFs generated is displayed in Section 6.5.

In 40 CFR § 194.34(f), the EPA states that "any compliance application shall provide information which demonstrates that there is at least a 95 percent level of confidence that the mean of the population of CCDFs meets the containment requirements . . . ." Section 6.5 contains a display of the mean CCDF and evidence demonstrating level of confidence.

6.1.4 Calculation of Risk

The methodology presented in Sections 6.1.1 and 6.1.2 is based on the work of Kaplan and Garrick (1981) and is one way to estimate the effects of uncertain but characterizable futures. In Kaplan and Garrick's procedure, the possible futures are defined as literal entities (S_i), and each is associated with a probability of occurrence (pS_i) and a consequence of occurrence ($\mathbf{cS}_i$). Preliminary performance assessments of the WIPP have used this procedure (for example, see Sandia National Laboratories 1991; 1992-1993, Vol. 1, Section 4), but definition of the futures S_i as discrete entities resulted in a great number of possible futures to be defined. The method of analysis used in preliminary performance assessments was called importance sampling.

For this performance assessment, an alternative method for calculating futures has been used that is based on developing futures by direct probabilistic sampling of the possible events leading to uncertain futures rather than a priori definition of possible futures. This modification from the calculational techniques of previous preliminary performance assessments is consistent with the fundamental concepts of Kaplan and Garrick and does not alter the results of the analysis. Both techniques will lead to the same CCDF. Adoption of this new procedure was prompted by two practical considerations. First, it is difficult to define futures as literal entities as required by importance sampling and to develop probabilities for each one. Second, generation of the futures by probabilistic methods allows for greater resolution in a CCDF, for equal effort, than the importance sampling procedure used in preliminary performance assessments.

The concept of a scenario is important in this performance assessment. There is a universe of possible futures, which is the set of all possible occurrences within the 10,000-year regulatory time frame. For analysis, this universe is divided into subsets of occurrences—scenarios—that are defined practically to include similar future occurrences. It should be noted that scenarios would not necessarily have to be defined as subsets of similar future occurrences, but by defining a scenario as a subset of similar futures, the DOE gains a practical advantage

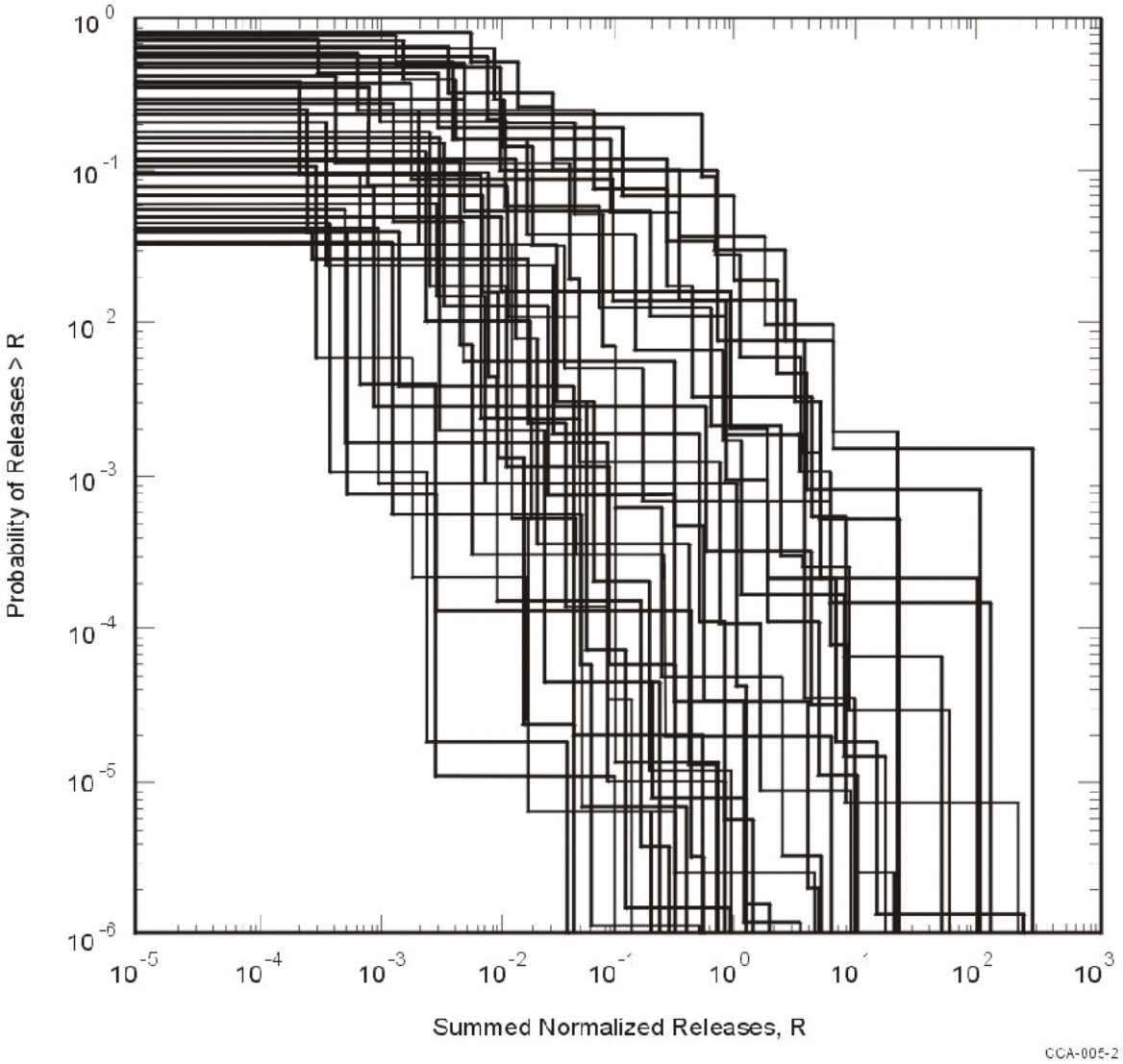

Figure 6-3. Example Distribution of a Family of CCDFs Obtained by Sampling Imprecisely Known Variables

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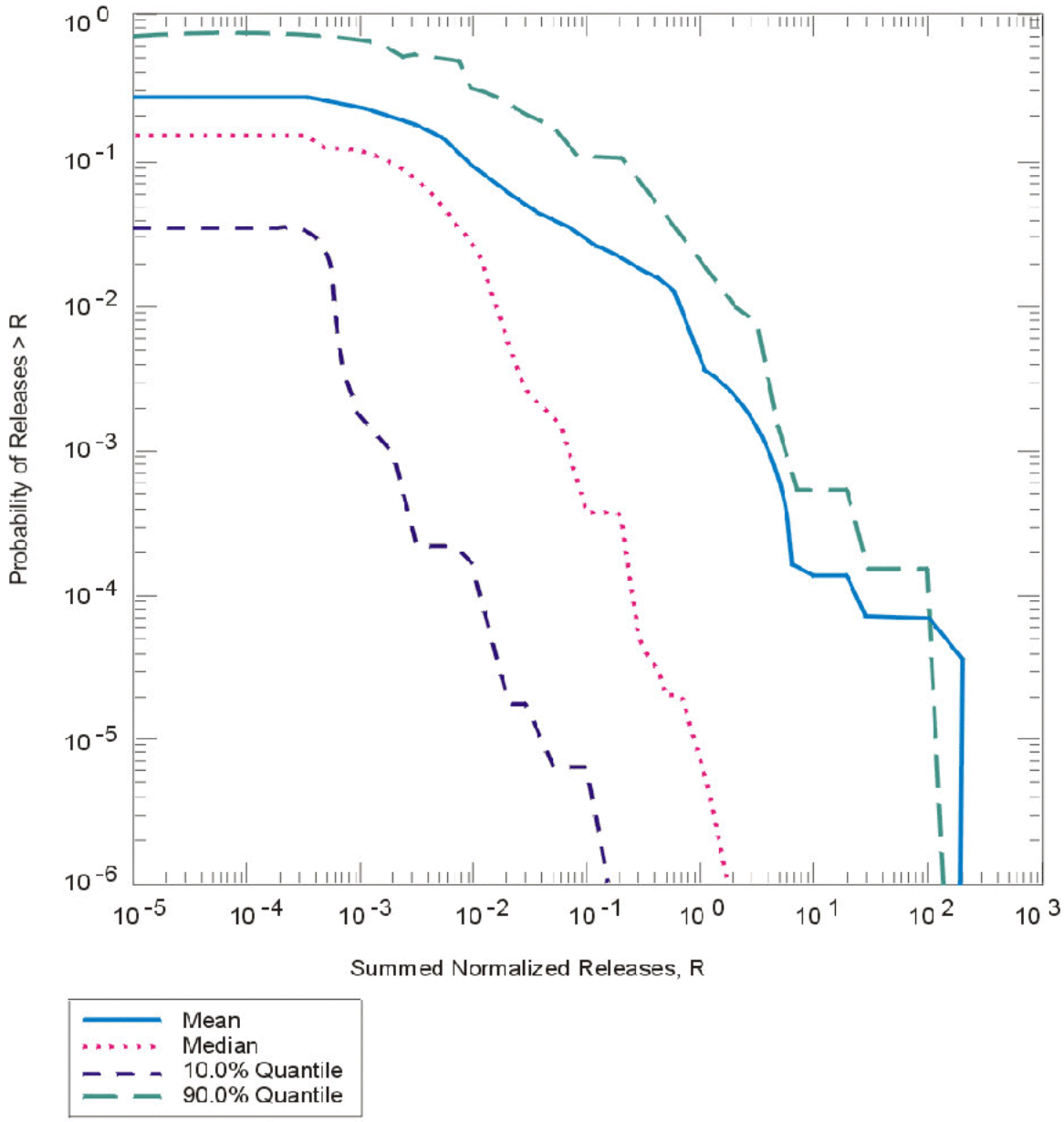

Note: The curves in this figure were obtained by calculating the mean and the indicated percentiles for each consequence value on the abscissa in Figure 6-3. The 90th-percentile curve crosses the mean curve because of highly skewed distributions for exceedance probability. This skew also results in the mean curve being above the median curve.

CCA-007-2

Figure 6-4. Example Summary Curves Derived from an Estimated Distribution of CCDFs

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because the consequences of futures falling within one scenario can be calculated with the same model configuration. Because the term scenario is defined simply as a subset of futures with similar occurrences, any size subset of similar futures can be called a scenario. In general, applying the term scenario for larger subsets of futures is useful in discussions of concepts; whereas, applying the term scenario for smaller subsets of futures is useful when constructing a CCDF.

The calculation of the probabilities and consequences of future occurrences begins with the determination of the sets S_i, which are the scenarios to be analyzed. Scenarios are determined through a formal process similar to that proposed by Cranwell et al. (1990, 5 – 10), and the process used in preliminary performance assessments for the WIPP. This process has four steps:

(1) FEPs (features, events, and processes) potentially relevant to the WIPP are identified and classified.

(2) Certain FEPs are eliminated according to well-defined screening criteria as not important or not relevant to the performance of the WIPP.

(3) Scenarios are formed from the remaining FEPs, in the context of regulatory performance criteria.

(4) Scenarios are specified for consequence analysis.

Through steps (1) and (2) of the scenario development process, the DOE identifies "all significant processes and events that may affect the disposal system" as required by 40 CFR § 191.13(a) and as further addressed in 40 CFR § 194.32. These steps are described in Section 6.2. The grouping of retained FEPs to form scenarios, and the specification of scenarios for consequence analysis, is presented in Section 6.3.

As discussed in Section 6.2, the DOE has developed a comprehensive initial list of FEPs for this performance assessment. This comprehensive initial list assures that the identification of significant processes and events is complete, that potential interactions between FEPs are not overlooked, and that responses to possible questions are available and well documented.

Once scenarios have been defined, a calculational methodology for evaluating their consequences must be developed. The calculational methodology must address stochastic uncertainty related to aggregation and stochastic variation, and subjective uncertainty because of, for example, measurement difficulties or incomplete data. The DOE uses a system of linked computer models to calculate scenario consequences cS_i. As discussed in Section 6.4, these computer models are based on conceptual models that describe the processes relevant to disposal system performance for the defined scenarios. These conceptual models are in turn based on site-specific experimental and observational data and the general scientific understanding of natural and engineered systems.

For practical purposes, the DOE separates the calculation of risk because of stochastic uncertainty, represented in an individual CCDF, from risk because of subjective uncertainty, which is represented by the family of CCDFs. This can be represented mathematically as a double integral of a function with the function representing the probability of exceedance associated with any particular consequence. The inner integral evaluates stochastic uncertainty, or the probability of exceedance associated with any particular consequence; the outer integral evaluates subjective uncertainty and leads to a distribution of exceedance probabilities for any given consequence value. Because of the complexity of this double integral for the WIPP, an analytical method for its solution is not available. Instead, the DOE approximates the solution of this double integral with a linked system of computer codes. In this computational framework, the performance assessment analysis can be thought of as a double sum, presented here in a stylized form for clarity,

(9)

Here, $F(x)$ is a procedure for estimating the normalized release to the accessible environment associated with each scenario that could occur at the WIPP site. The inner sum denoted with the subscript *st* is a probabilistic characterization of the uncertainty associated with parameters used to characterize stochastic uncertainty (the $\mathbf{x_{st}}$ and D_{st} in equations 4a and 6a, respectively). It is the evaluation of $F(x)$ through the inner sum that develops an individual CCDF, as shown in Figure 6-2. The outer sum denoted with the subscript *su* is a probabilistic characterization of the uncertainty associated with parameters used to characterize subjective uncertainty (the $\mathbf{x_{su}}$ and D_{su} in Equations 4b and 6b, respectively). It is the combined evaluation in the outer sum of the inner sum with $F(x)$ that develops the family of CCDFs, as shown in Figure 6-3.

A separate probabilistic analysis is required to evaluate each sum. Associated with each analysis are parameter distributions representing uncertainty (the D_{st} and D_{su} of Equations 6a and 6b). For example, associated with the inner sum may be uncertainty in the number and time of intrusion boreholes. The outer sum includes a probabilistic characterization of site properties, such as the permeability of specific rock types.

For the methodology adopted by the DOE for the evaluation of stochastic uncertainty in the inner sum, consequence calculations are required for model configurations with a set of fixed values for subjective parameters $\mathbf{x_{su}}$ taken from their distributions D_{su}, as well as for defined sequences and times of events associated with scenarios. These calculations are referred to in Section 6.4.11 and later sections as deterministic calculations (or deterministic futures). For the evaluation of stochastic uncertainty and construction of a CCDF, the consequences of futures generated probabilistically by random sampling (probabilistic futures) are evaluated in the context of these deterministic futures. This process is discussed in detail in Sections 6.4.12 and 6.4.13.

In certain cases, it may not be obvious whether a particular uncertainty should be classified as subjective or stochastic. For example, whether currently observed geologic properties persist

through time could be thought of as either subjective or stochastic uncertainty. For the WIPP, the DOE treats uncertainty associated with significant future human actions as stochastic (for example, drilling for natural resources), and uncertainty in disposal system properties that are subject to ongoing physical processes as subjective (for example, climate change or gas generation). In particular, the DOE's formal separation of the evaluation of stochastic uncertainty from subjective uncertainty into different probabilistic analyses allows clear understanding as to how any particular uncertainty is incorporated.

Once the scenarios have been determined and their consequences calculated using the appropriate conceptual and computational models, scenario probabilities must be determined for a CCDF to be constructed. This process is described in Section 6.4.12. CCDF construction is also described in Section 6.4.13.

6.1.5 Techniques for Probabilistic Analysis

Once scenarios have been defined, conceptual models defined, and the computational modeling system developed, the DOE uses probabilistic techniques to evaluate the double sum presented above. Monte Carlo analysis is the general name for the technique used for probabilistic analysis of the WIPP. Monte Carlo analyses can involve five steps: (1) selection of the variables to be examined and the ranges and distributions for their possible values, (2) generation of the samples to be analyzed, (3) propagation of the samples through the analysis, (4) uncertainty analysis, and (5) sensitivity analysis. These steps are described briefly in the following sections.

Within the general framework of Monte Carlo analysis, performance assessment uses two methods for generating the samples propagated through the model system. One method is used for the assessment of stochastic uncertainty, and another method is used for the characterization of subjective uncertainty. Each of these methods utilizes the five steps summarized in the preceding paragraph but differs in methodology in Steps 2 through 5.

6.1.5.1 Selection of Variables and Their Ranges and Distributions

Monte Carlo analyses use a probabilistic procedure for the selection of model input. Therefore, the first step in a Monte Carlo analysis is the selection of uncertain variables and the assignment of ranges and distributions that characterize them. These variables are typically input parameters to computer models, and the impact of the assigned ranges and distributions can be great; for a given set of conceptual and mathematical models, performance assessment results are largely controlled by the choice of input. Results of uncertainty and sensitivity analyses, in particular, strongly reflect the characterization of uncertainty in the input data.

Information about the ranges and distributions of possible values can be drawn from a variety of sources, including field data, laboratory data, and literature. In instances where sufficient data are not available, the documented solicitation of experts may be used. A review process leads from the available data to the construction of the distribution functions used in the

performance assessment to characterize uncertainty in input parameters. In part, this review process addresses the scaling of data collected at experimental scales of observation to the development of the parameter ranges applied to scales of interest in the disposal system. Because of the nature of the available data and the type of analysis, this review process unavoidably involves some judgment of the investigators and analysts involved. For this performance assessment, a discussion of parameter ranges developed by this process is provided in Appendix PAR (Sections PAR.1, PAR.2, and PAR.3). The QA procedures associated with this review process are identified in Section 5.1.4 and Appendix PAR (Section PAR.1).

The outcome of the review process is a cumulative distribution function (CDF) *D(x)* of the form shown in Figure 6-5 for each independent variable of interest. For a particular variable x_j, the function D is defined such that

$$prob(x < x_j \leq x+\Delta x) = D(x+\Delta x) - D(x) \ . \qquad (10)$$

That is, $D(x+\Delta x) - D(x)$ is equal to the probability that the appropriate value to use for x_j in the particular analysis under consideration falls between x and $x+\Delta x$.

6.1.5.2 Generation of the Sample

Various techniques are available for generating samples from the assigned distribution functions for the variables, including random sampling, stratified sampling, and Latin hypercube sampling (LHS). The DOE's performance assessment for WIPP uses random sampling and LHS.

Random sampling of the occurrence of possible future events is used to generate the possible futures (probabilistic futures) that comprise a CCDF. This sampling is used to select values of uncertain parameters associated with future human activities, or in other words, it is used to incorporate stochastic uncertainty into the WIPP performance assessment. This sampling is used for parameters evaluated in the inner sum of the double sum and included in the parameter set $\mathbf{x_{st}}$ with associated distributions D_{st}, as shown in Equations 4a and 6a, respectively. Generation of the futures comprising a CCDF by random sampling, rather than importance or stratified sampling as used in previous preliminary performance assessments, largely eliminates errors from aggregation.

LHS, in which the full range of each variable is subdivided into intervals of equal probability and samples are drawn from each interval, is used to select values of uncertain parameters associated with the physical system being simulated. In other words, LHS incorporates subjective uncertainty into the WIPP performance assessment. This sampling is used for

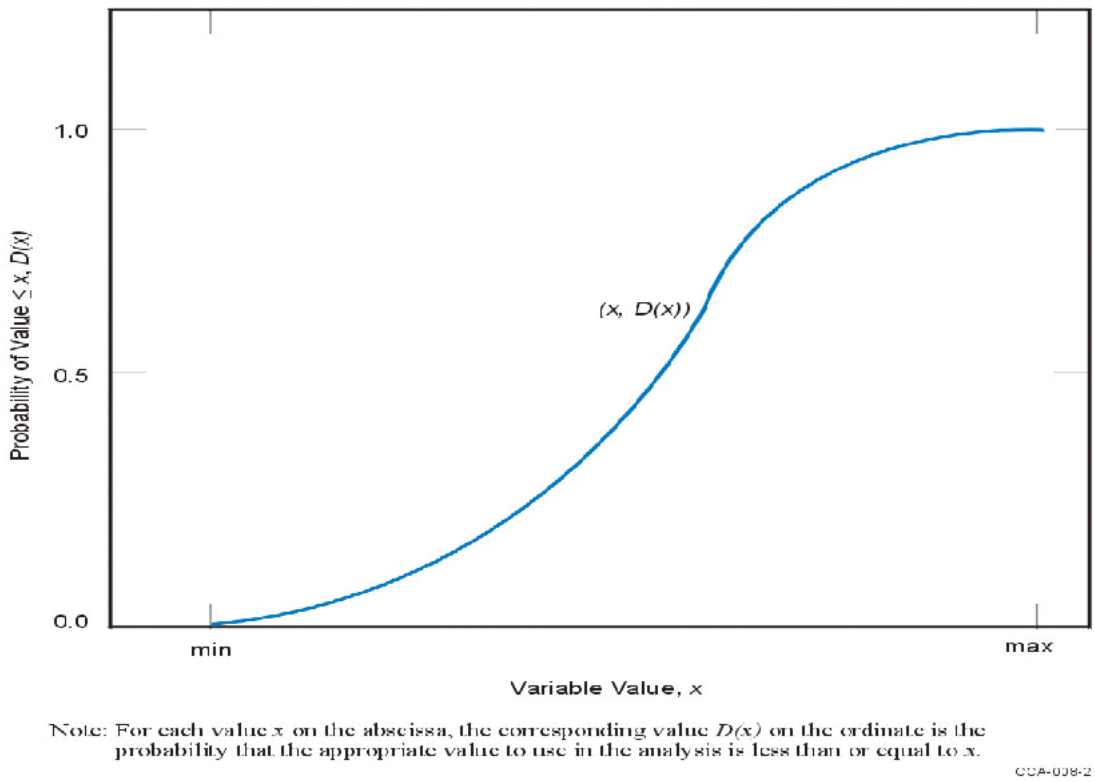

Figure 6-5. Distribution Function for an Imprecisely Known Variable

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parameters that are evaluated in the outer sum of the double sum and are included in the parameter set $\mathbf{x}_{su}$ with associated distributions D_{su}, as shown in Equations 4b and 6b, respectively. The restricted pairing technique of Iman and Conover (1982, 314 – 319) is used to prevent spurious correlations within the sample.

6.1.5.3 Propagation of the Sample through the Analysis

The next step is the propagation of the sample through the analysis. Each element of the sample is supplied to the model system as input, and the corresponding model system predictions are saved for use in later uncertainty and sensitivity studies. The Software Configuration Management System (SCMS) has been developed to facilitate the complex calculations performed by the model system and to store the input and output files from each program.

6.1.5.4 Uncertainty Analysis

Uncertainty analyses evaluate uncertainty in performance estimates that results from uncertainty about imprecisely known input parameters. Once a sample has been generated and propagated through the modeling system, uncertainty in the outcome can be interpreted directly from the display of the results. For the WIPP performance assessment, stochastic uncertainty is represented by the shape of the individual CCDFs displayed in Section 6.5. Subjective uncertainty is represented by the family of CCDFs displayed in Section 6.5.

6.1.5.5 Sensitivity Analysis

Sensitivity analyses determine the contribution of individual input variables to the uncertainty in model predictions. This is the final step in a probabilistic study. Sensitivity analyses can identify those parameters for which reductions in uncertainty (that is, narrowing of the range of values from which the sample used in the Monte Carlo analysis is drawn) have the greatest potential to increase confidence in the estimate of the disposal system's performance. However, because results of these analyses are inherently conditional on the models, data distributions, and techniques used to generate them, the analyses cannot provide insight to the correctness of the conceptual models and data distributions used. Qualitative judgment about the modeling system must be used with sensitivity analyses to set priorities for performance assessment data acquisition and model development. Sensitivity analyses conducted as part of the WIPP performance assessment are described in Appendix SA.

6.2 Identification and Screening of Features, Events, and Processes

The EPA has provided criteria concerning the scope of performance assessments in 40 CFR § 194.32. In particular, criteria relating to the identification of potential processes and events that may affect the performance of the disposal system are provided in 40 CFR § 194.32(e), which states that

> Any compliance application(s) shall include information which:

> (1) Identifies all potential processes, events or sequences and combinations of processes and events that may occur during the regulatory time frame and may affect the disposal system;
>
> (2) Identifies the processes, events or sequences and combinations of processes and events included in performance assessments; and
>
> (3) Documents why any processes, events or sequences and combinations of processes and events identified pursuant to paragraph (e)(1) of this section were not included in performance assessment results provided in any compliance application.

This section and Appendix SCR fulfill these criteria by documenting DOE's identification, screening, and screening results of all potential processes and events consistent with the criteria specified in 40 CFR § 194.32(e).

As discussed in Section 6.1.4, the first two steps in scenario development involve the identification and screening of FEPs (features, events, and processes) potentially relevant to the performance of the disposal system. This section contains a discussion of the development of a comprehensive initial set of FEPs, the methodology and criteria used for screening, and a summary of the FEPs retained for scenario development. Detailed discussion of the basis for eliminating or retaining particular FEPs is provided in Appendix SCR. The formation of scenarios from retained FEPs is discussed in Section 6.3, and the specification of scenarios for consequence analysis is addressed in Section 6.4.12.

6.2.1 Identification of FEPs

The first step of the scenario development procedure is identification and classification of FEPs potentially relevant to the performance of the disposal system. Catalogs of FEPs have been developed in several national radioactive waste disposal programs as well as internationally. In constructing a comprehensive list of FEPs for the WIPP, the DOE drew on the work of these other radioactive waste disposal programs.

As a starting point, the DOE assembled a list of potentially relevant FEPs from the compilation developed by Stenhouse et al. (1993) for the Swedish Nuclear Power Inspectorate *Statens Kärnkraftinspektion* (SKI). The SKI list was based on a series of FEP lists developed for other disposal programs and is considered to be the best documented and most comprehensive starting point for the WIPP. For the SKI study, an initial raw FEP list was compiled based on nine different FEP identification studies (Table 6-2).

The compilers of the SKI list eliminated a number of FEPs as irrelevant to the particular disposal concept under consideration in Sweden; these FEPs were reinstated for the WIPP effort, and several FEPs on the SKI list were subdivided to facilitate screening for the WIPP. Finally, to ensure comprehensiveness, other FEPs specific to the WIPP were added based on review of key project documents and broad examination of the preliminary WIPP list by both project participants and stakeholders. The initial unedited list is contained in Attachment 1 of

Table 6-2. FEP Identification Studies Used in the SKI Study

Study	Country	Number of FEPS Identified
Atomic Energy of Canada Limited (AECL) study of disposal of spent fuel in crystalline rock (Goodwin et al. 1994)	Canada	275
SKI & Swedish Nuclear Fuel and Waste Management Company (SKB) study of disposal of spent fuel in crystalline rock (Andersson 1989)	Sweden	157
National Cooperative for the Storage of Radioactive Waste (NAGRA) Project Gewähr study (NAGRA 1985)	Switzerland	44
UK Department of the Environment Dry Run 3 study of deep disposal of low- and intermediate-level waste (L/ILW) (Thorne 1992)	United Kingdom	305
UK Department of Environment assessment of L/ILW disposal in volcanic rock at Sellafield (Miller and Chapman 1992)	United Kingdom	79
UK Nuclear Industry Radioactive Waste Executive (NIREX) study of the deep disposal of L/ILW (Hodgkinson and Sumerling 1989)	United Kingdom	131
SNL study of deep disposal of spent fuel (Cranwell et al. 1990)	United States	29
NEA Working Group on Systematic Approaches to Scenario Development (OECD 1992)	International	122
International Atomic Energy Agency (IAEA) Safety Series (IAEA 1981)	International	56

Appendix SCR. The initial unedited FEP list was restructured and revised to derive the comprehensive WIPP FEP list used in this application. The number of FEPs has been reduced to approximately 240 for this application to avoid the ambiguities caused by the use of a generic list. Restructuring the list for this application did not remove any substantive issues from the discussion. As discussed in more detail in Attachment 1 to Appendix SCR, the following steps have been used to derive the WIPP FEP list used in this application from the initial unedited list.

- References to subsystems have been eliminated because the SKI subsystem classification is not appropriate for the WIPP disposal concept. For example, in contrast to the Swedish disposal concept, canister integrity does not have a role in postoperational performance of the WIPP, and the terms near-field, far-field, and biosphere are not unequivocally defined for the WIPP site.

- Duplicate FEPs have been eliminated. Duplicate FEPs arose in the SKI list because individual FEPs could act in different subsystems. FEPs have a single entry in this application list whether they are applicable to several parts of the disposal system or to a single part only. For example, the FEP *Gas Effects: Disruption* appears in the seals,

backfill, waste, canister, and near-field subsystems in the initial FEP list. These FEPs are represented by the single FEP *Disruption Due to Gas Effects* for this application.

- FEPs that are not relevant to the WIPP design or inventory have been eliminated. Examples include FEPs related to high-level waste, copper canisters, and bentonite backfill.

- FEPs relating to engineering design changes have been eliminated because they are not relevant to a compliance application based on the DOE's design for the WIPP. Examples of such FEPs are *Design Modifications: Canister* and *Design Modification: Geometry*.

- FEPs relating to constructional, operational, and decommissioning errors have been eliminated. The DOE has administrative and quality control procedures to ensure that the facility will be constructed, operated, and decommissioned properly.

- Detailed FEPs relating to processes in the surface environment have been aggregated into a small number of generalized FEPs. For example, the SKI list includes the biosphere FEPs *Inhalation of Salt Particles, Smoking, Showers and Humidifiers*, *Inhalation and Biotic Material, Household Dust and Fumes, Deposition (wet and dry), Inhalation and Soils and Sediments, Inhalation and Gases and Vapors (indoor and outdoor)*, and *Suspension in Air*, which are represented by the FEP *Inhalation* in this application.

- FEPs relating to the containment of hazardous metals, volatile organic compounds (VOCs), and other chemicals that are not regulated by 40 CFR Part 191 are not included.

- A few FEPs have been renamed to be consistent with terms used to describe specific WIPP processes (for example, *Wicking*, *Brine Inflow*).

6.2.2 Criteria for Screening of FEPs and Categorization of Retained FEPs

The purpose of FEP screening is to identify those FEPs that should be accounted for in performance assessment calculations, and those FEPs that need not be considered further. The DOE's process of removing FEPs from consideration in performance assessment calculations involved the structured application of explicit screening criteria. The criteria used to screen out FEPs are explicit regulatory exclusions (SO-R), probability (SO-P), or consequence (SO-C). As discussed in Section 6.2.2.1, all three criteria are derived from regulatory requirements. FEPs not screened as SO-R, SO-P, or SO-C have been retained for inclusion in performance assessment calculations and are classified as undisturbed performance (UP) or disturbed performance (DP) FEPs. These screening criteria and FEP classifiers are discussed in this section, and FEP screening is discussed in Sections 6.2.3, 6.2.4, and 6.2.5.

6.2.2.1 Elimination of FEPs Based on Regulation (SO-R), Probability (SO-P), or Consequence (SO-C)

Regulation (SO-R). Specific FEP screening criteria are stated in 40 CFR Part 191 and 40 CFR Part 194. These screening criteria relating to the applicability of particular FEPs represent screening decisions made by the EPA. That is, in the process of developing and demonstrating the feasibility of the 40 CFR Part 191 standard and the 40 CFR Part 194 criteria, the EPA considered and made conclusions on the relevance, consequence, and/or probability of occurrence of particular FEPs and, in so doing, allowed for some FEPs to be eliminated from consideration. Section 6.2.5 describes the regulatory screening criteria that pertain to limitations on the type of human-initiated events and processes that need be analyzed.

Probability of occurrence of a FEP leading to significant release of radionuclides (SO-P). Low-probability events can be excluded on the basis of the criterion provided in 40 CFR § 194.32(d), which states that "performance assessments need not consider processes and events that have less than one chance in 10,000 of occurring over 10,000 years." In practice, for most FEPs screened out on the basis of low probability of occurrence, it has not been possible to estimate a meaningful quantitative probability. In the absence of quantitative probability estimates, a qualitative argument has been provided.

Potential consequences associated with the occurrence of the FEPs (SO-C). The DOE recognizes two uses for this criterion:

(1) FEPs can be eliminated from performance assessment calculations on the basis of insignificant consequence. Consequence can refer to effects on the repository or site or to radiological consequence. In particular, 40 CFR § 194.34(a) states that "The results of performance assessments shall be assembled into "complementary, cumulative distribution functions" (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all *significant* processes and events." (emphasis added). The DOE has omitted events and processes from performance assessment calculations where there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changed by such omissions.

(2) FEPs that are potentially beneficial to subsystem performance may be eliminated from performance assessment calculations if necessary to simplify the analysis. This argument may be used when there is uncertainty as to exactly how the FEP should be incorporated into assessment calculations or when incorporation would incur unreasonable difficulties.

In some cases the effects of the occurrence of a particular event or process, although not necessarily insignificant, can be shown to lie within the range of uncertainty of another FEP already accounted for in the performance assessment calculations. In such cases the event or

process may be considered to be included in performance assessment calculations implicitly, within the range of uncertainty associated with the included FEP.

The distinctions between the SO-R, SO-P, and SO-C screening classifications are summarized in Figure 6-6. Although some FEPs could be eliminated from performance assessment calculations on the basis of more than one criterion, the most practical screening criterion was used for classification. In particular, a regulatory screening classification was used in preference to a probability or consequence screening classification, as illustrated in Figure 6-6. FEPs that have not been screened out based on any one of the three criteria are included in the performance assessment.

6.2.2.2 Undisturbed Performance (UP) FEPs

FEPs classified as UP are accounted for in calculations of undisturbed performance of the disposal system. Undisturbed performance is defined in 40 CFR § 191.12 as "the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events." The UP FEPs are accounted for in the performance assessment calculations to evaluate compliance with the Containment Requirements in 40 CFR § 191.13.

6.2.2.3 Disturbed Performance (DP) FEPs

FEPs classified as DP are accounted for only in assessment calculations for disturbed performance. As described in Appendix SCR (Sections SCR.3.1.3.2 and SCR.4), the DP FEPs that remain following the screening process relate to the potential disruptive effects of future drilling and mining events in the controlled area. Consideration of both DP and UP FEPs is required to evaluate compliance with 40 CFR § 191.13.

In the following sections, FEPs are discussed under the categories Natural FEPs, Waste- and Repository-Induced FEPs, and Human-Initiated Events and Processes (EPs).

This also allows an evaluation of compliance with the individual dose criterion in 40 CFR § 191.15 and the groundwater protection requirements in 40 CFR § 191.24 (see Chapter 8.0).

6.2.3 Natural FEPs

This subsection briefly discusses natural FEPs that have the potential to affect long-term performance of the WIPP disposal system. These FEPs and their screening classifications are listed in Table 6-3; the DOE's detailed screening arguments for natural FEPs are contained in Appendix SCR (Section SCR.1). This screening of natural FEPs fulfills, in conjunction with the performance assessment calculations, the criterion of the Future States Assumptions in

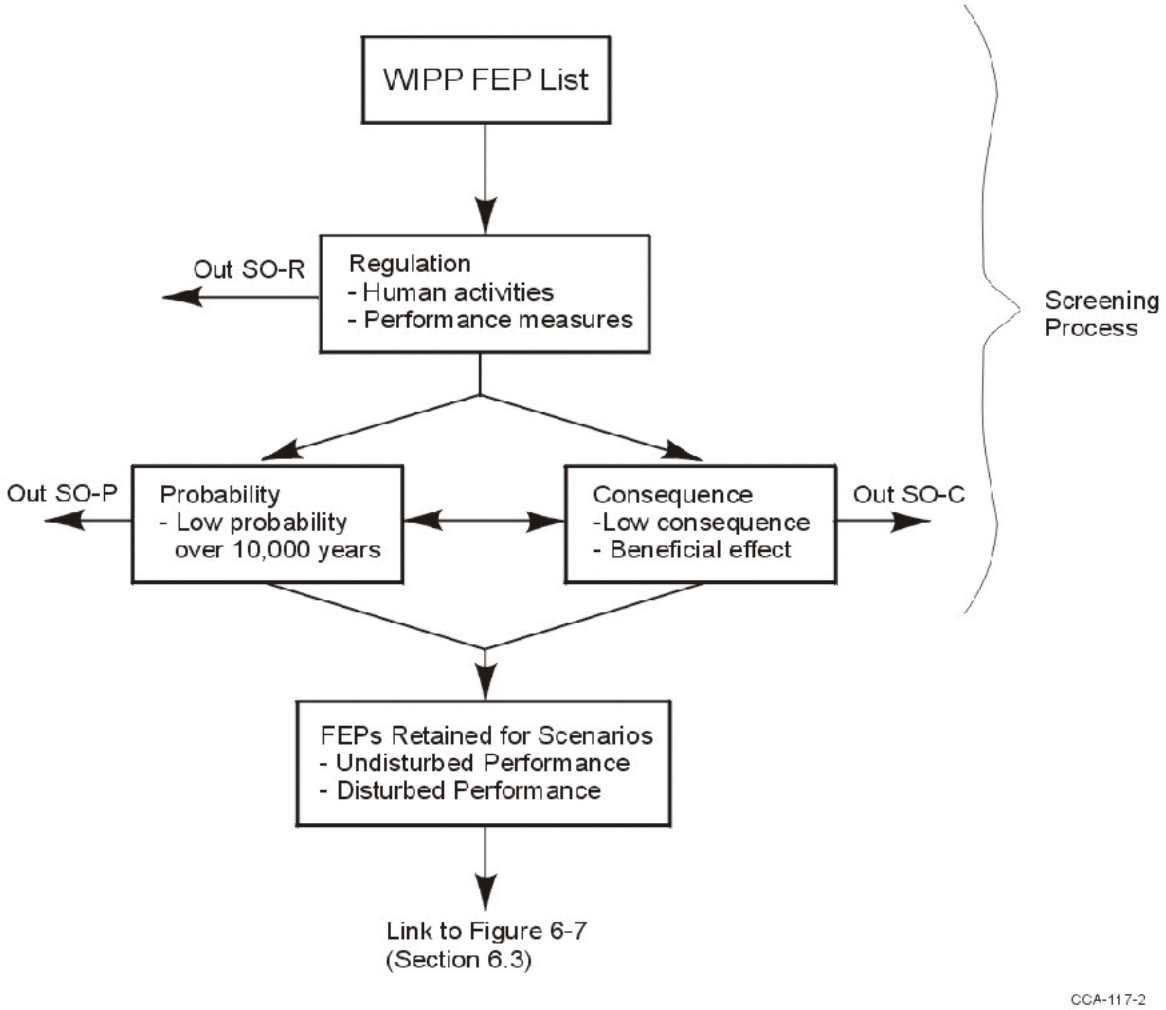

Figure 6-6. Screening Process Based on Screening Classifications

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Table 6-3. Natural FEPs and Their Screening Classifications

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
GEOLOGICAL FEPS			SCR.1.1
Stratigraphy			SCR.1.1.1
Stratigraphy	UP		
Brine reservoirs	DP		
Tectonics			SCR.1.1.2
Changes in regional stress	SO-C		
Regional tectonics	SO-C		
Regional uplift and subsidence	SO-C		
Structural FEPs			SCR.1.1.3
Deformation			SCR.1.1.3.1
Salt deformation	SO-P	UP near repository.	
Diapirism	SO-P		
Fracture development			SCR.1.1.3.2
Formation of fractures	SO-P	UP near repository.	
Changes in fracture properties	SO-C	UP near repository.	
Fault movement			SCR.1.1.3.3
Formation of new faults	SO-P		
Fault movement	SO-P		
Seismic activity			SCR.1.1.3.4
Seismic activity	UP		
Crustal processes			SCR.1.1.4
Igneous activity			SCR.1.1.4.1
Volcanic activity	SO-P		
Magmatic activity	SO-C		
Metamorphism			SCR.1.1.4.2
Metamorphic activity	SO-P		
Geochemical FEPs			SCR.1.1.5
Dissolution			SCR.1.1.5.1
Shallow dissolution	UP		
Lateral dissolution	SO-C		
Deep dissolution	SO-P		
Solution chimneys	SO-P		
Breccia pipes	SO-P		
Collapse breccias	SO-P		
Mineralization			SCR.1.1.5.2
Fracture infills	SO-C		
SUBSURFACE HYDROLOGICAL FEPS			SCR.1.2
Groundwater characteristics			SCR.1.2.1
Saturated groundwater flow	UP		
Unsaturated groundwater flow	UP	SO-C in Culebra.	
Fracture flow	UP		
Density effects on groundwater flow	SO-C		
Effects of preferential pathways	UP	UP in Salado and Culebra.	

Table 6-3. Natural FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Changes in groundwater flow			SCR.1.2.2
Thermal effects on groundwater flow	SO-C		
Saline intrusion	SO-P		
Freshwater intrusion	SO-P		
Hydrological response to earthquakes	SO-C		
Natural gas intrusion	SO-P		
SUBSURFACE GEOCHEMICAL FEPS			SCR.1.3
Groundwater geochemistry			SCR.1.3.1
Groundwater geochemistry	UP		
Changes in groundwater chemistry			SCR.1.3.2
Saline intrusion	SO-C		
Freshwater intrusion	SO-C		
Changes in groundwater Eh	SO-C		
Changes in groundwater pH	SO-C		
Effects of dissolution	SO-C		
GEOMORPHOLOGICAL FEPS			SCR.1.4
Physiography			SCR.1.4.1
Physiography	UP		
Meteorite impact			SCR.1.4.2
Impact of a large meteorite	SO-P		
Denudation			SCR.1.4.3
Weathering			SCR.1.4.3.1
Mechanical weathering	SO-C		
Chemical weathering	SO-C		
Erosion			SCR.1.4.3.2
Aeolian erosion	SO-C		
Fluvial erosion	SO-C		
Mass wasting	SO-C		
Sedimentation			SCR.1.4.3.3
Aeolian deposition	SO-C		
Fluvial deposition	SO-C		
Lacustrine deposition	SO-C		
Mass wasting	SO-C		
Soil development			SCR.1.4.4
Soil development	SO-C		
SURFACE HYDROLOGICAL FEPS			SCR.1.5
Fluvial			SCR.1.5.1
Stream and river flow	SO-C		
Lacustrine			SCR.1.5.2
Surface water bodies	SO-C		
Groundwater recharge and discharge			SCR.1.5.3
Groundwater discharge	UP		

Table 6-3. Natural FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Groundwater recharge	UP		
Infiltration	UP	UP for climate change effects.	
Changes in surface hydrology			SCR.1.5.4
Changes in groundwater recharge and discharge	UP		
Lake formation	SO-C		
River flooding	SO-C		
CLIMATIC FEPS			SCR.1.6
Climate			SCR.1.6.1
Precipitation (for example, rainfall)	UP		
Temperature	UP		
Climate change			SCR.1.6.2
Meteorological			SCR.1.6.2.1
Climate change	UP		
Glaciation			SCR.1.6.2.2
Glaciation	SO-P		
Permafrost	SO-P		
MARINE FEPS			SCR.1.7
Seas			SCR.1.7.1
Seas and oceans	SO-C		
Estuaries	SO-C		
Marine sedimentology			SCR.1.7.2
Coastal erosion	SO-C		
Marine sediment transport and deposition	SO-C		
Sea level changes			
Sea level changes	SO-C		SCR.1.7.3
ECOLOGICAL FEPS			SCR.1.8
Flora & fauna			SCR.1.8.1
Plants	SO-C		
Animals	SO-C		
Microbes	SO-C	UP for colloidal effects and gas generation	

Table 6-3. Natural FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Changes in flora & fauna			SCR.1.8.2
Natural ecological development	SO-C		

Legend:

UP FEPs accounted for in the assessment calculations for undisturbed performance for 40 CFR § 191.13 (as well as 40 CFR § 191.15 and Subpart C of 40 CFR Part 191).

DP FEPs accounted for (in addition to all UP FEPs) in the assessment calculations for disturbed performance for 40 CFR § 191.13.

SO-R FEPs eliminated from performance assessment calculations on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.

SO-C FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of consequence.

SO-P FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of low probability of occurrence.

40 CFR § 194.25(b) that the DOE shall "document in any compliance application, to the extent practicable, effects of potential future hydrogeologic, geologic and climatic conditions on the disposal system over the regulatory time frame."

Consistent with 40 CFR § 194.32(d), the DOE has screened out several natural FEPs from performance assessment calculations on the basis of a low probability of occurrence at or near the WIPP site. In particular, natural events for which there is no evidence indicating that they have occurred within the Delaware Basin have been screened on this basis. In this analysis, the probabilities of occurrence of these events are assumed to be zero. Quantitative, nonzero probabilities for such events, based on numbers of occurrences, cannot be ascribed without considering regions much larger than the Delaware Basin, thus neglecting established geological understanding of the events and processes that occur within particular geographical provinces. No disruptive natural FEPs are likely to occur during the regulatory time frame that could result in the creation of new pathways or significant alteration of existing pathways.

In considering the overall geological setting of the Delaware Basin, the DOE has eliminated many FEPs from performance assessment calculations on the basis of low consequence. Events and processes that have had little effect on the characteristics of the region in the past are expected to be of low consequence for the regulatory time period.

6.2.4 Waste- and Repository-Induced FEPs

The waste- and repository-induced FEPs are those that relate specifically to the waste material, waste containers, shaft seals, MgO backfill, panel closures, repository structures, and investigation boreholes. All FEPs related to radionuclide chemistry and radionuclide migration are included in this category. FEPs related to radionuclide transport resulting from future borehole intersections of the WIPP excavation are defined as waste- and repository-

induced FEPs. Waste- and repository-induced FEPs and their screening classification are listed in Table 6-4. The DOE's detailed screening discussions for these FEPs are contained in Appendix SCR (Section SCR.2).

The DOE has screened out many FEPs in this category on the basis of low consequence to the performance of the disposal system. For example, the DOE has shown that the heat generated by radioactive decay of the emplaced RH- and CH-TRU waste will not result in temperature increases sufficient to induce significant thermal convection, thermal stresses and strains, or thermally induced chemical perturbations within the disposal system (see Appendix SCR, Sections SCR.2.2.2 and SCR.2.5.7). Also, hydration of the emplaced concrete seals and chemical conditioner will be exothermic, but the DOE has shown that the heat generated will not have a significant effect on the performance of the disposal system (see Appendix SCR, Section SCR.2.5.7).

Other waste- and repository-induced FEPs have been eliminated from performance assessment calculations on the basis of beneficial effect to the performance of the disposal system, if necessary to simplify the analysis.

Waste- and repository-induced FEPs eliminated on the basis of low probability of occurrence over 10,000 years are generally those for which no mechanisms have been identified that could result in their occurrence within the disposal system. Such FEPs include explosions resulting from nuclear criticality, and the development of large-scale reduction-oxidation fronts.

6.2.5 Human-Initiated Events and Processes

Assessments of compliance with the Containment Requirements in 40 CFR § 191.13 require consideration of "all significant processes and events" including human-initiated EPs. These EPs and their screening classifications are listed in Table 6-5. The DOE's detailed screening arguments for human-initiated EPs are presented in Appendix SCR (Section SCR.3).

The scope of performance assessments is clarified with respect to human-initiated events and processes in 40 CFR § 194.32. At 40 CFR § 194.32(a) the EPA states that

> Performance assessments shall consider natural processes and events, mining, deep drilling, and shallow drilling that may affect the disposal system during the regulatory time frame.

Thus, performance assessments must include consideration of human-initiated EPs relating to mining and drilling activities that might take place during the regulatory time frame. In particular, performance assessments must consider the potential effects of such activities that might take place within the controlled area at a time when institutional controls cannot be assumed to completely eliminate the possibility of human intrusion.

Table 6-4. Waste- and Repository-Induced FEPs and Their Screening Classifications

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
WASTE AND REPOSITORY CHARACTERISTICS			SCR.2.1
Repository characteristics			SCR.2.1.1
Disposal geometry	UP		
Waste characteristics			SCR.2.1.2
Waste inventory	UP		
Heterogeneity of waste forms	DP		
Container characteristics			SCR.2.1.3
Container form	SO-C		
Container material inventory	UP		
Seal characteristics			SCR.2.1.4
Seal geometry	UP		
Seal physical properties	UP		
Seal chemical composition	SO-C	Beneficial SO-C	
Backfill characteristics			SCR.2.1.5
Backfill physical properties	SO-C		
Backfill chemical composition	UP		
Postclosure monitoring			SCR.2.1.6
Postclosure monitoring	SO-C		
RADIOLOGICAL FEPS			SCR.2.2
Radioactive decay			SCR.2.2.1
Radionuclide decay and ingrowth	UP		
Heat from radioactive decay			SCR.2.2.2
Heat from radioactive decay	SO-C		
Nuclear criticality			SCR.2.2.3
Nuclear criticality: heat	SO-P		
Radiological effects on material properties			SCR.2.2.4
Radiological effects on waste	SO-C		
Radiological effects on containers	SO-C		
Radiological effects on seals	SO-C		
GEOLOGICAL AND MECHANICAL FEPS			SCR.2.3
Excavation-induced fracturing			SCR.2.3.1
Disturbed rock zone	UP		
Excavation-induced changes in stress	UP		
Rock creep			SCR.2.3.2
Salt creep	UP		
Changes in the stress field	UP		
Roof falls			SCR.2.3.3
Roof falls	UP		
Subsidence			SCR.2.3.4
Subsidence	SO-C		
Large scale rock fracturing	SO-P		

Table 6-4. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Effects of fluid pressure changes			SCR.2.3.5
Disruption due to gas effects	UP		
Pressurization	UP		
Effects of explosions			SCR.2.3.6
Gas explosions	UP		
Nuclear explosions	SO-P		
Thermal effects			SCR.2.3.7
Thermal effects on material properties	SO-C		
Thermally-induced stress changes	SO-C		
Differing thermal expansion of repository components	SO-C		
Mechanical effects on material properties			SCR.2.3.8
Consolidation of waste	UP		
Movement of containers	SO-C		
Container integrity	SO-C	Beneficial SO-C	
Mechanical effects of backfill	SO-C		
Consolidation of seals	UP		
Mechanical degradation of seals	UP		
Investigation boreholes	SO-C		
Underground boreholes	UP		
SUBSURFACE HYDROLOGICAL AND FLUID DYNAMICAL FEPS			SCR.2.4
Repository-induced flow			SCR.2.4.1
Brine inflow	UP		
Wicking	UP		
Effects of gas generation			SCR.2.4.2
Fluid flow due to gas production	UP		
Thermal effects			SCR.2.4.3
Convection	SO-C		
GEOCHEMICAL AND CHEMICAL FEPS			SCR.2.5
Gas generation			SCR.2.5.1
Microbial gas generation			SCR.2.5.1.1
Degradation of organic material	UP		
Effects of temperature on microbial gas generation	UP		
Effects of pressure on microbial gas generation	SO-C		
Effects of radiation on microbial gas generation	SO-C		
Effects of biofilms on microbial gas generation	UP		

Table 6-4. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Corrosion			SCR.2.5.1.2
Gases from metal corrosion	UP		
Galvanic coupling	SO-P		
Chemical effects of corrosion	UP		
Radiolytic gas generation			SCR.2.5.1.3
Radiolysis of brine	SO-C		
Radiolysis of cellulose	SO-C		
Helium gas production	SO-C		
Radioactive gases	SO-C		
Chemical speciation			SCR.2.5.2
Speciation	UP	UP in disposal rooms and Culebra. SO-C elsewhere, and beneficial SO-C in cementitious seals.	
Kinetics of speciation	SO-C		
Precipitation and dissolution			SCR.2.5.3
Dissolution of waste	UP		
Precipitation	SO-C	Beneficial SO-C	
Kinetics of precipitation and dissolution	SO-C	Kinetics of waste dissolution is a beneficial SO-C	
Sorption			SCR.2.5.4
Actinide sorption	UP	UP in the Culebra and Dewey Lake. Beneficial SO-C elsewhere	
Kinetics of sorption	UP		
Changes in sorptive surfaces	UP		
Reduction-oxidation chemistry			SCR.2.5.5
Effect of metal corrosion	UP		
Reduction-oxidation fronts	SO-P		
Reduction-oxidation kinetics	UP		
Localized reducing zones	SO-C		
Organic complexation			SCR.2.5.6
Organic complexation	SO-C		
Organic ligands	SO-C		
Humic and fulvic acids	UP		
Kinetics of organic complexation	SO-C		
Exothermic reactions			SCR.2.5.7
Exothermic reactions	SO-C		
Concrete hydration	SO-C		
Chemical effects on material properties			SCR.2.5.8
Chemical degradation of seals	UP		
Chemical degradation of backfill	SO-C		

Table 6-4. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Microbial growth on concrete	UP		
CONTAMINANT TRANSPORT MODE FEPS			SCR.2.6
Solute transport			SCR.2.6.1
Solute transport	UP		
Colloid transport			SCR.2.6.2
Colloid transport	UP		
Colloid formation and stability	UP		
Colloid filtration	UP		
Colloid sorption	UP		
Particulate transport			SCR.2.6.3
Suspensions of particles	DP	SO-C for undisturbed conditions	
Rinse	SO-C		
Cuttings	DP	Repository intrusion only	
Cavings	DP	Repository intrusion only	
Spallings	DP	Repository intrusion only	
Microbial transport			SCR.2.6.4
Microbial transport	UP		
Biofilms	SO-C	Beneficial SO-C	
Gas transport			SCR.2.6.5
Transport of radioactive gases	SO-C		
CONTAMINANT TRANSPORT PROCESSES			SCR.2.7
Advection			SCR.2.7.1
Advection	UP		
Diffusion			SCR.2.7.2
Diffusion	UP		
Matrix diffusion	UP		
Thermochemical transport phenomena			SCR.2.7.3
Soret effect	SO-C		
Electrochemical transport phenomena			SCR.2.7.4
Electrochemical effects	SO-C		
Galvanic coupling	SO-P		
Electrophoresis	SO-C		
Physicochemical transport phenomena			SCR.2.7.5
Chemical gradients	SO-C		
Osmotic processes	SO-C	Beneficial SO-C	
Alpha recoil	SO-C		
Enhanced diffusion	SO-C		

Table 6-4. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
ECOLOGICAL FEPS			SCR.2.8
Plant, animal, and soil uptake			SCR.2.8.1
Plant uptake	SO-R	SO-C for 40 CFR § 191.15	
Animal uptake	SO-R		
Accumulation in soils	SO-C	Beneficial SO-C	
Human uptake			SCR.2.8.2
Ingestion	SO-R	SO-C for 40 CFR § 191.15	
Inhalation	SO-R	SO-C for 40 CFR § 191.15	
Irradiation	SO-R	SO-C for 40 CFR § 191.15	
Dermal sorption	SO-R	SO-C for 40 CFR § 191.15	
Injection	SO-R	SO-C for 40 CFR § 191.15	

Legend:

UP FEPs accounted for in the assessment calculations for undisturbed performance for 40 CFR § 191.13 (as well as 40 CFR § 191.15 and Subpart C of 40 CFR Part 191).

DP FEPs accounted for (in addition to all UP FEPs) in the assessment calculations for disturbed performance for 40 CFR § 191.13.

SO-R FEPs eliminated from performance assessment calculations on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.

SO-C FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of consequence.

SO-P FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of low probability of occurrence.

Further criteria concerning the scope of performance assessments are provided at 40 CFR § 194.32(c):

> Performance assessments shall include an analysis of the effects on the disposal system of any activities that occur in the vicinity of the disposal system prior to disposal and are expected to occur in the vicinity of the disposal system soon after disposal. Such activities shall include, but shall not be limited to, existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities.

Table 6-5. Human-Initiated EPs and Their Screening Classifications

Events and Processes (EPs)	Screening Classification Historical/ Ongoing/ Near Future	Future	Comments	Appendix SCR Section
GEOLOGICAL EPs				SCR.3.2
Drilling			DP for boreholes that penetrate the waste and boreholes that penetrate Castile brine underlying the waste disposal region. SO-C for other future drilling.	SCR.3.2.1
Oil and gas exploration	SO-C	DP		
Potash exploration	SO-C	DP		
Water resources exploration	SO-C	SO-C		
Oil and gas exploitation	SO-C	DP		
Groundwater exploitation	SO-C	SO-C		
Archeological investigations	SO-R	SO-R		
Geothermal	SO-R	SO-R		
Other resources	SO-C	DP		
Enhanced oil and gas recovery	SO-C	DP		
Liquid waste disposal	SO-R	SO-R		
Hydrocarbon storage	SO-R	SO-R		
Deliberate drilling intrusion	SO-R	SO-R		
Excavation activities				SCR.3.2.2
Potash mining	UP	DP	UP for mining outside the controlled area. DP for mining inside the controlled area.	
Other resources	SO-C	SO-R		
Tunneling	SO-R	SO-R		
Construction of underground facilities (for example storage, disposal, accommodation)	SO-R	SO-R		
Archeological excavations	SO-C	SO-R		
Deliberate mining intrusion	SO-R	SO-R		
Subsurface explosions				SCR.3.2.3
Resource recovery				SCR.3.2.3.1
Explosions for resource recovery	SO-C	SO-R		
Underground nuclear device testing				SCR.3.2.3.2
Underground nuclear device testing	SO-C	SO-R		

Table 6-5. Human-Initiated EPs and Their Screening Classifications (Continued)

Events and Processes (EPs)	Screening Classification Historical/ Ongoing/ Near Future	Future	Comments	Appendix SCR Section
SUBSURFACE HYDROLOGICAL AND GEOCHEMICAL EPs				SCR.3.3
Borehole fluid flow				SCR.3.3.1
Drilling-induced flow				SCR.3.3.1.1
Drilling fluid flow	SO-C	DP	DP for boreholes that penetrate the waste. SO-C for other future drilling.	
Drilling fluid loss	SO-C	DP	DP for boreholes that penetrate the waste, SO-C for other future drilling	
Blowouts	SO-C	DP	DP for boreholes that penetrate the waste and boreholes that penetrate Castile brine underlying the waste disposal region. SO-C for other future drilling.	
Drilling-induced geochemical changes	UP	DP	SO-C for units other than the Culebra.	
Fluid extraction				SCR.3.3.1.2
Oil and gas extraction	SO-C	SO-R		
Groundwater extraction	SO-C	SO-R		
Fluid injection				SCR.3.3.1.3
Liquid waste disposal	SO-C	SO-R		
Enhanced oil and gas production	SO-C	SO-R		
Hydrocarbon storage	SO-C	SO-R		
Fluid-injection induced geochemical changes	UP	SO-R	SO-C for units other than the Culebra	
Flow through abandoned boreholes			Classification distinguishes the time when drilling occurs.	SCR.3.3.1.4
Natural borehole fluid flow	SO-C	DP	DP for boreholes that penetrate Castile brine underlying the waste disposal region. SO-C for other future boreholes.	
Waste-induced borehole flow	SO-R	DP	DP for boreholes that penetrate the waste. SO-C for other future boreholes.	

Table 6-5. Human-Initiated EPs and Their Screening Classifications (Continued)

Events and Processes (EPs)	Screening Classification Historical/ Ongoing/ Near Future	Future	Comments	Appendix SCR Section
Flow through undetected boreholes	SO-P	NA		
Borehole-induced solution and subsidence	SO-C	SO-C		
Borehole-induced mineralization	SO-C	SO-C		
Borehole-induced geochemical changes	UP	DP	SO-C for units other than the Culebra	
Excavation-induced flow			Classification distinguishes the time when excavation occurs.	SCR.3.3.2
Changes in groundwater flow due to mining	UP	DP	UP for mining outside the controlled area. DP for mining inside the controlled area.	
Changes in geochemistry due to mining	SO-C	SO-R		
Explosion-induced flow				SCR.3.3.3
Changes in groundwater flow due to explosions	SO-C	SO-R		
GEOMORPHOLOGICAL EPs				SCR.3.4
Land use and disturbances				SCR.3.4.1
Land use changes	SO-R	SO-R		
Surface disruptions	SO-C	SO-R		
SURFACE HYDROLOGICAL EPs				SCR.3.5
Water control and use				SCR.3.5.1
Damming of streams or rivers	SO-C	SO-R		
Reservoirs	SO-C	SO-R		
Irrigation	SO-C	SO-R		
Lake usage	SO-R	SO-R		
Altered soil or surface water chemistry by human activities	SO-C	SO-R		
CLIMATIC EPs				SCR.3.6
Anthropogenic climate change				SCR.3.6.1
Greenhouse gas effects	SO-R	SO-R		
Acid rain	SO-R	SO-R		
Damage to the ozone layer	SO-R	SO-R		

Table 6-5. Human-Initiated EPs and Their Screening Classifications (Continued)

Events and Processes (EPs)	Screening Classification Historical/ Ongoing/ Near Future	Future	Comments	Appendix SCR Section
MARINE EPs				SCR.3.7
Marine activities				SCR.3.7.1
Coastal water use	SO-R	SO-R		
Sea water use	SO-R	SO-R		
Estuarine water use	SO-R	SO-R		
ECOLOGICAL EPs				SCR.3.8
Agricultural activities				SCR.3.8.1
Arable farming	SO-C	SO-R		
Ranching	SO-C	SO-R		
Fish farming	SO-R	SO-R		
Social and technological developments				SCR.3.8.2
Demographic change and urban development	SO-R	SO-R		
Loss of records	NA	DP		

Legend:

UP FEPs accounted for in the assessment calculations for undisturbed performance for 40 CFR § 191.13 (as well as 40 CFR § 191.15 and Subpart C of 40 CFR Part 191).

DP FEPs accounted for (in addition to all UP FEPs) in the assessment calculations for disturbed performance for 40 CFR § 191.13.

SO-R FEPs eliminated from performance assessment calculations on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.

SO-C FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of consequence.

SO-P FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of low probability of occurrence.

NA FEPs not applicable to the particular category.

Performance assessments must include consideration of all human-initiated EPs relating to activities that have taken place or are reasonably expected to take place outside the controlled area in the near future.

In order to implement the criteria in 40 CFR § 194.32, relating to the scope of performance assessments, the DOE has divided human activities into three categories. Distinctions are made between (1) human activities that are currently taking place and those that took place prior to the time of the compliance application, (2) human activities that might be initiated in the near future after submission of the compliance application, and (3) human activities that might be initiated after repository closure. The first two categories of EPs are considered

under undisturbed performance, and EPs in the third category lead to disturbed performance conditions.

(1) Historical and current human activities include resource extraction activities that have historically taken place and are currently taking place outside the controlled area. These activities are of potential significance insofar as they could affect the geological, hydrological, or geochemical characteristics of the disposal system or groundwater flow pathways outside the disposal system. Current human activities taking place within the controlled area are essentially those associated with development of the WIPP repository. Historical activities include existing boreholes.

(2) Near-future human activities include resource extraction activities that may be expected to occur outside the controlled area based on existing plans and leases. Thus, the near future includes the expected lives of existing mines and oil and gas fields, and the expected lives of new mines and oil and gas fields that the DOE expects will be developed based on existing plans and leases. These activities are of potential significance insofar as they could affect the geological, hydrological, or geochemical characteristics of the disposal system or groundwater flow pathways outside the disposal system. The only human activities that are expected to occur within the controlled area in the near future are those associated with development of the WIPP repository. The DOE assumes that any activity that is expected to be initiated in the near future, based on existing plans and leases, will be initiated prior to repository closure. Activities initiated prior to repository closure are assumed to continue until their completion.

(3) Future human activities include activities that might be initiated within or outside the controlled area after repository closure. This includes drilling and mining for resources within the disposal system at a time when institutional controls cannot be assumed to completely eliminate the possibility of such activities. Future human activities could influence the transport of contaminants within and outside the disposal system by directly removing waste from the disposal system or altering the geological, hydrological, or geochemical characteristics of the disposal system.

In order to satisfy the criteria in 40 CFR § 194.32, performance assessments must consider the potential effects of historical, current, near-future, and future human activities on the performance of the disposal system. The criterion in 40 CFR § 194.25(a) concerned with predictions of the future states of society requires that performance assessments and compliance assessments "shall assume that the characteristics of the future remain what they are at the time the compliance application is prepared." This criterion has been applied to eliminate the following human-initiated EPs from performance assessment calculations:

- drilling associated with geothermal energy production, liquid waste disposal, hydrocarbon storage, and archeological investigations (Appendix SCR, Sections SCR.3.2.1.1 and SCR.3.2.1.2),

- excavation activities associated with tunneling and construction of underground facilities (for example, storage, disposal, and accommodation) (Appendix SCR, Sections SCR.3.2.2.1 and SCR.3.2.2.2),

- changes in land use (Appendix SCR, Section SCR.3.4.1.2),

- anthropogenic climate change (Appendix SCR, Section SCR.3.6.1),

- changes in agricultural practices (Appendix SCR, Section SCR.3.8.1.2),

- demographic change, urban developments, and technological developments (Appendix SCR, Section SCR.3.8.2).

As discussed in Chapter 8.0, compliance assessments (to determine compliance with 40 CFR § 191.15 and Subpart C of 40 CFR Part 191) need consider the undisturbed performance of the disposal system.

6.2.5.1 Historical, Current, and Near-Future Human Activities

The observational data obtained as part of WIPP site characterization reflect any effects of historical and current human activities in the vicinity of the WIPP, such as groundwater extraction and oil and gas production. As discussed in Appendix SCR (Section SCR.3), historic and current human activities are modeled or found to be of low consequence to long-term performance.

Historical, current, and near-future human activities could affect WIPP site characteristics subsequent to the submission of this application, and could influence the performance of the disposal system. The hydrogeological impacts of historical, current and near-future potash mining outside the controlled area are accounted for in calculations of the undisturbed performance of the disposal system. Near-future potash mining is assumed to continue for the expected economic life of each mine. The potential consequences to the performance of the disposal system of other human-initiated EPs expected to occur in the Delaware Basin in the near future are discussed in Appendix SCR (Section SCR.3), which describes how these EPs are eliminated on the basis of low consequence.

6.2.5.2 Future Human Activities

Performance assessments (but not compliance assessments, as discussed in Chapter 8.0) must consider the effects of future human activities on the performance of the disposal system. The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a), which limits the scope of consideration of future human actions in performance assessments to mining and drilling.

Criteria concerning future mining: The EPA provides additional criteria concerning the type of future mining that should be considered by the DOE in 40 CFR § 194.32(b):

> Assessments of mining effects may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system from excavation mining for natural resources. Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame. Performance assessments shall assume that mineral deposits of those resources, similar in quality and type to those resources currently extracted from the Delaware Basin, will be completely removed from the controlled area during the century in which such mining is randomly calculated to occur. Complete removal of such mineral resources shall be assumed to occur only once during the regulatory time frame.

Thus, consideration of future mining may be limited to mining within the controlled area at the locations of resources that are similar in quality and type to those currently extracted from the Delaware Basin. Potash is the only resource that has been identified within the controlled area in quality similar to that currently mined from underground deposits elsewhere in the Delaware Basin. Within the controlled area, the McNutt of the Salado provides the only potash of appropriate quality. The hydrogeological impacts of future potash mining within the controlled area are accounted for in calculations of the disturbed performance of the disposal system. Consistent with 40 CFR § 194.32(b), all economically recoverable resources in the vicinity of the disposal system (outside the controlled area) are assumed to be extracted in the near future.

Criteria concerning future drilling: With respect to consideration of future drilling, in the preamble to 40 CFR Part 194, the EPA "reasoned that while the resources drilled for today may not be the same as those drilled for in the future, the present rates at which these boreholes are drilled can nonetheless provide an estimate of the future rate at which boreholes will be drilled." Criteria concerning the consideration of future deep and shallow drilling[2] in performance assessments are provided in 40 CFR § 194.33. These criteria require that, to calculate future drilling rates, the DOE should examine the historical rate of drilling for resources in the Delaware Basin. Historical drilling for purposes other than resource exploration and recovery (such as WIPP site investigation) need not be considered in determining future drilling rates.

In particular, in calculating the frequency of future deep drilling, 40 CFR § 194.33(b)(3)(i) states that the DOE should

> Identify deep drilling that has occurred for each resource in the Delaware Basin over the past 100 years prior to the time at which a compliance application is prepared.

Oil and gas are the only known resources below 2,150 feet (655 meters) that have been exploited over the past 100 years in the Delaware Basin. However, some potash and sulfur exploration boreholes have been drilled in the Delaware Basin to depths in excess of 2,150 feet (655 meters) below the surface relative to where the drilling occurred. Thus, consistent with 40 CFR § 194.33(b)(3)(i), the DOE has used the historical record of deep

[2] The EPA has defined two types of drilling in 40 CFR § 194.2: deep drilling is defined as "drilling events in the Delaware Basin that reach or exceed a depth of 2,150 feet below the surface relative to where such drilling occurred"; shallow drilling is defined as "drilling events in the Delaware Basin that do not reach a depth of 2,150 feet below the surface relative to where such drilling occurred."

drilling associated with oil, gas, potash and sulfur exploration, and oil and gas exploitation in the Delaware Basin in calculations to determine the rate of deep drilling within the controlled area and throughout the basin in the future, as discussed in Appendix DEL, Section DEL.7.4 (see also Table DEL-6). Deep drilling may occur within the controlled area after the end of the period of active institutional control (100 years after disposal).

In calculating the frequency of future shallow drilling, 40 CFR § 194.33(b)(4)(i) states that the DOE should

> Identify shallow drilling that has occurred for each resource in the Delaware Basin over the past 100 years prior to the time at which a compliance application is prepared.

An additional criterion with respect to the calculation of future shallow drilling rates is provided in 40 CFR § 194.33(b)(4)(iii):

> In considering the historical rate of all shallow drilling, the Department may, if justified, consider only the historical rate of shallow drilling for resources of similar type and quality to those in the controlled area.

As an example of the use of the criterion in 40 CFR § 194.33(b)(4)(iii) the EPA states in the preamble to 40 CFR Part 194 that "if only non-potable water can be found within the controlled area, then the rate of drilling for water may be set equal to the historical rate of drilling for non-potable water in the Delaware Basin over the past 100 years." Thus, the DOE may limit the rate of future shallow drilling based on a determination of the potential resources in the controlled area. Shallow drilling associated with water, potash, sulfur, oil, and gas extraction has taken place in the Delaware Basin over the past 100 years. However, of these resources, only water and potash are present at shallow depths (less than 2,150 feet [655 meters] below the surface) within the controlled area. Thus, consistent with 40 CFR § 194.33(b)(4), the DOE has used the historical record of shallow drilling associated with water and potash extraction in the Delaware Basin in calculations to determine the rate of shallow drilling within the controlled area, as discussed in Appendix DEL (Sections DEL.7.2 and DEL.7.4).

The EPA also provides a criterion in 40 CFR § 194.33(d) concerning the use of future boreholes subsequent to drilling:

> With respect to future drilling events, performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole.

Thus, performance assessments need not consider the effects of techniques used for resource extraction and recovery, that would occur subsequent to the drilling of a borehole in the future.

The EPA provides an additional criterion that limits the severity of human intrusion scenarios that must be considered in performance assessments. In 40 CFR § 194.33(b)(1) the EPA states that

> Inadvertent and intermittent intrusion by drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario.

Thus, human intrusion scenarios involving deliberate intrusion need not be considered in performance assessments.

Screening of future human-initiated EPs: Future human-initiated EPs accounted for in performance assessment calculations for the WIPP are those associated with mining and deep drilling within the controlled area at a time when institutional controls cannot be assumed to eliminate completely the possibility of such activities. All other future human-initiated EPs, if not eliminated from performance assessment calculations based on regulation, have been eliminated based on low consequence or low probability. For example, the effects of future shallow drilling within the controlled area have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. These screening decisions are listed in Table 6-5 and are discussed in Appendix SCR (Section SCR.3).

6.3 Scenario Development and Selection

This section addresses the formation of scenarios from FEPs that have been retained for performance assessment calculations, and introduces the specification of scenarios for consequence analysis. Specification of probabilities associated with scenarios is discussed in Section 6.4.12.

Logic diagrams are used to illustrate the formation of scenarios for consequence analysis from combinations of FEPs that remain after FEP screening (Cranwell et al. 1990) (Figure 6-7). Each scenario shown in Figure 6-7 is defined by a combination of occurrence and nonoccurrence of all potentially disruptive EPs. Disruptive EPs are defined as those EPs that result in the creation of new pathways, or significant alteration of existing pathways, for fluid flow and, potentially, radionuclide transport within the disposal system. Each of these scenarios also contains a set of features and nondisruptive EPs that remain after FEP screening. As shown in Figure 6-7, undisturbed performance and disturbed performance scenarios are considered in consequence modeling for the WIPP performance assessment. The undisturbed performance scenario, as discussed in Chapter 8.0, is used for compliance assessments. Important aspects of undisturbed and disturbed performance are summarized in this section.

6.3.1 Undisturbed Performance

Undisturbed performance is defined in 40 CFR § 191.12 to mean “the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.” Consideration of only undisturbed performance is required for compliance assessments with respect to the Individual and Groundwater Protection Requirements (40 CFR § 191.15 and 40 CFR § 191.24) (see Chapter 8.0). Undisturbed performance is also

considered, together with disturbed performance, for performance assessments with respect to the Containment Requirements (40 CFR § 191.13).

No potentially disruptive natural EPs are likely to occur during the regulatory time frame (Section 6.2.3 and Appendix SCR, Section SCR.1). Therefore, all naturally occurring EPs retained for scenario construction are nondisruptive and are considered as part of undisturbed performance. The only natural features and waste- and repository-induced FEPs retained after screening that are not included in the undisturbed performance scenario but are included in disturbed performance are those directly associated with the potential effects of future deep drilling within the controlled area. These drilling-related FEPs are discussed in Section 6.3.2. Potash mining outside the controlled area does not constitute a disruption of the disposal system by human intrusion and is included in the undisturbed performance scenario. In total, 67 undisturbed performance FEPs have been identified (Section 6.2.3). These FEPs have been assigned a screening designator UP in tables in Section 6.2.3 and Appendix SCR and are listed separately in Table 6-6. Table 6-6 also contains references to text in Section 6.4 that describes the conceptual models that account for the undisturbed performance FEPs.

Among the most significant FEPs that will affect the undisturbed performance within the disposal system are excavation-induced fracturing, gas generation, salt creep, and MgO backfill in the disposal rooms:

- The excavation of the repository and the consequent changes in the stress field in the rock surrounding the excavated opening will result in the creation of a DRZ immediately adjacent to excavated openings. The DRZ will exhibit mechanical and hydrological properties different than those of the intact rock.

- Organic material in the waste may degrade because of microbial activity, and brine will corrode metals in the waste and waste containers, with concomitant generation of gases. Gas generation may result in pressures sufficient to both maintain or develop fractures and change the fluid flow pattern around the waste disposal region.

- At the repository depth, salt creep will tend to heal fractures and reduce the permeability of the DRZ and the crushed salt component of the long-term shaft seals to near that of the host rock salt.

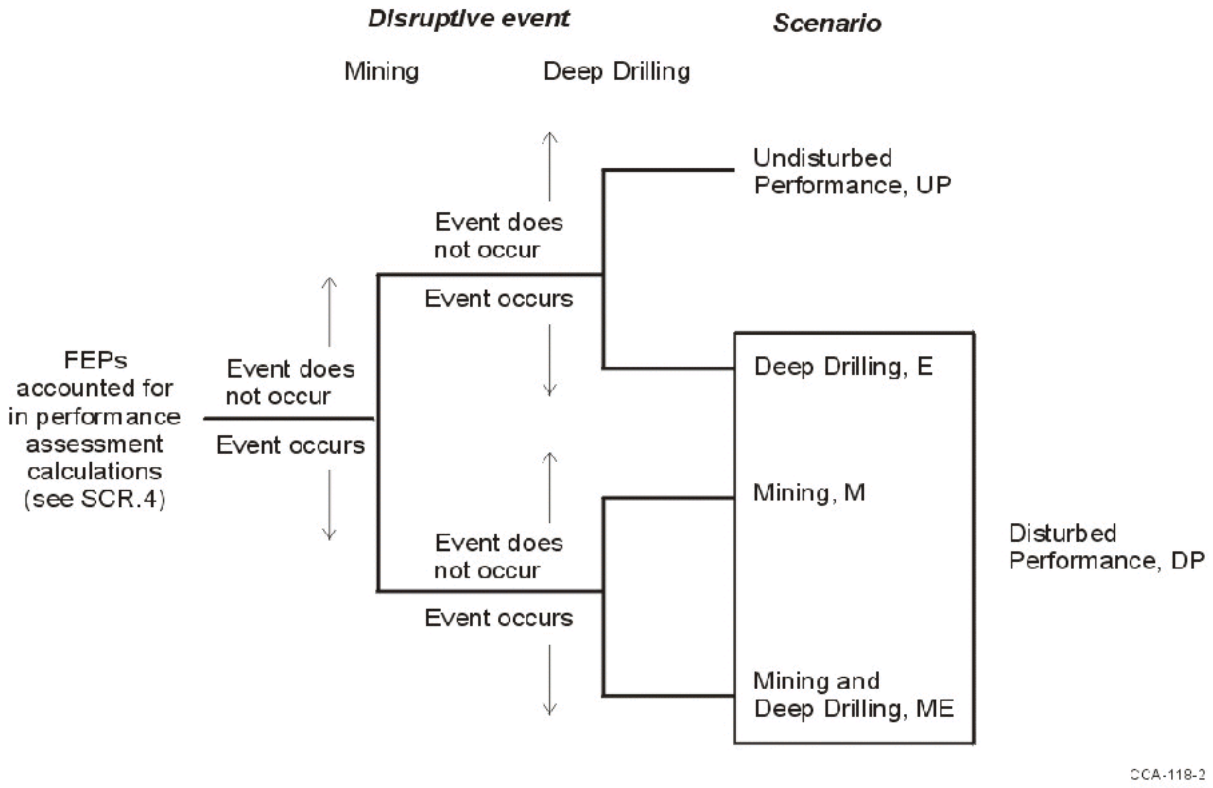

Figure 6-7. Logic Diagram for Scenario Analysis

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Table 6-6. Undisturbed Performance (UP) FEPs

Undisturbed Performance Features, Events, and Processes (FEPs)	Chapter Section
NATURAL FEPs	
Geological	
Stratigraphy	
Stratigraphy	6.4.2
Structural effects	
Seismic activity	
Seismic activity	6.4.5.3
Geochemical	
Dissolution	
Shallow dissolution	6.4.6.2
Subsurface hydrological	
Groundwater characteristics	
Saturated groundwater flow	6.4.5 6.4.6
Unsaturated groundwater flow	6.4.6
Fracture flow	6.4.6.2
Effects of preferential pathways	6.4.6.2
Subsurface geochemical	
Groundwater geochemistry	
Groundwater geochemistry	6.4.3.4 6.4.6.2
Geomorphological	
Physiography	
Physiography	6.4.2
Surface hydrological	
Groundwater recharge and discharge	
Groundwater discharge	6.4.10.2
Groundwater recharge	6.4.10.2
Infiltration	6.4.10.2
Changes in surface hydrology	
Changes in groundwater recharge and discharge	6.4.9
Climatic	
Climate	
Precipitation (for example, rainfall)	6.4.9
Temperature	6.4.9
Climate change	
Meteorological	
Climate change	6.4.9
WASTE- AND REPOSITORY-INDUCED FEPs	
Waste and repository characteristics	
Repository characteristics	
Disposal geometry	6.4.2.1
Waste characteristics	
Waste inventory	6.4.3.3

Table 6-6. Undisturbed Performance (UP) FEPs (Continued)

Undisturbed Performance Features, Events, and Processes (FEPs)	Chapter Section
Container characteristics	
Container material inventory	6.4.3.3
Seal characteristics	
Seal geometry	6.4.3
Seal physical properties	6.4.4
Backfill characteristics	
Backfill chemical composition	6.4.3.4
Radiological	
Radioactive decay	
Radionuclide decay and ingrowth	6.4.5.4.2 6.4.12.4
Geological and Mechanical	
Excavation-induced fracturing	
DRZ	6.4.5.3
Excavation-induced changes in stress	6.4.3.1
Rock creep	
Salt creep	6.4.3.1
Changes in the stress field	6.4.3.1
Roof falls	
Roof falls	6.4.5.3
Effects of fluid pressure changes	
Disruption due to gas effects	6.4.5.2
Pressurization	6.4.5.2
Effects of explosions	
Gas explosions	6.4.5.3
Mechanical effects on material properties	
Consolidation of waste	6.4.3.1
Consolidation of seals	6.4.4
Mechanical degradation of seals	6.4.4
Underground boreholes	6.4.5.3
Subsurface hydrological and fluid dynamics	
Repository-induced flow	
Brine inflow	6.4.3.2
Wicking	6.4.3.2
Effects of gas generation	
Fluid flow due to gas production	6.4.3.2
Geochemical and chemical	
Gas generation	
Microbial gas generation	
Degradation of organic material	6.4.3.3
Effects of temperature on microbial gas generation	6.4.3.3
Effects of biofilms on microbial gas generation	6.4.3.3
Corrosion	
Gases from metal corrosion	6.4.3.3
Chemical effects of corrosion	6.4.3.3

Table 6-6. Undisturbed Performance (UP) FEPs (Continued)

Undisturbed Performance Features, Events, and Processes (FEPs)	Chapter Section
Chemical speciation	
Speciation	6.4.3.4 6.4.3.5
Precipitation and dissolution	
Dissolution of waste	6.4.3.5
Sorption	
Actinide sorption	6.4.3.6 6.4.6.2.1
Kinetics of sorption	6.4.6.2.1
Changes in sorptive surfaces	6.4.6.2.1
Reduction-oxidation chemistry	
Effect of metal corrosion	6.4.3.5
Reduction-oxidation kinetics	6.4.3.5
Organic complexation	
Humic and fulvic acids	6.4.3.6 6.4.6.2.2
Chemical effects on material properties	
Chemical degradation of seals	6.4.4
Microbial growth on concrete	6.4.4
Contaminant transport mode	
Solute transport	
Solute transport	6.4.5.4 6.4.6.2.1
Colloid transport	
Colloid transport	6.4.6.2.2
Colloid formation and stability	6.4.3.6
Colloid filtration	6.4.6.2.2
Colloid sorption	6.4.6.2.2
Microbial transport	
Microbial transport	6.4.6.2.2
Contaminant transport processes	
Advection	
Advection	6.4.5.4 6.4.6.2
Diffusion	
Diffusion	6.4.5.4 6.4.6.2
Matrix diffusion	6.4.6.2
HUMAN-INITIATED EPs	
Geological	
Excavation activities	
Potash mining outside controlled area	6.4.6.2.3 6.4.12.8 6.4.13.8

Table 6-6. Undisturbed Performance (UP) FEPs (Continued)

Undisturbed Performance Features, Events, and Processes (FEPs)	Chapter Section
Subsurface hydrological and geochemical	
Borehole fluid flow	
Drilling-induced flow	
Drilling induced geochemical changes	6.4.6.2
Fluid injection	
Fluid injection-induced geochemical changes	6.4.6.2
Flow through abandoned boreholes	
Borehole-induced geochemical changes	6.4.6.2
Excavation-induced flow	
Changes in groundwater flow due to mining	6.4.6.2.3 6.4.12.8 6.4.13.8

- The MgO backfill emplaced in the disposal rooms will react with carbon dioxide and maintain mildly alkaline conditions. Corrosion of metals in the waste and waste containers will maintain reducing conditions. These effects will control radionuclide solubility.

Radionuclides can become mobile as a result of waste dissolution and colloid generation following brine flow into the disposal rooms. Colloids may be generated from the waste (humics, mineral fragments, and actinide intrinsic colloids) or from other sources (humics, mineral fragments, and microbes).

Conceptually, there are several pathways for radionuclide transport within the undisturbed disposal system that may result in releases to the accessible environment (Figure 6-8). Contaminated brine may migrate away from the waste-disposal panels if pressure within the panels is elevated by the generation of gas from corrosion or microbial degradation. Radionuclide transport may occur laterally, through the anhydrite interbeds toward the subsurface boundary of the accessible environment in the Salado, or through access drifts or anhydrite interbeds (primarily MB139) to the base of the shafts. In the latter case, if the pressure gradient between the panels and overlying strata is sufficient, then contaminated brine may migrate up the shafts. As a result, radionuclides may be transported directly to the ground surface, or they may be transported laterally away from the shafts, through permeable strata such as the Culebra, toward the subsurface boundary of the accessible environment. These conceptual pathways are shown in Figure 6-8.

The modeling system described in Section 6.4 includes potential radionuclide transport along other pathways, such as migration through Salado halite. However, the natural properties of the undisturbed system make radionuclide transport to the accessible environment via these other pathways unlikely.

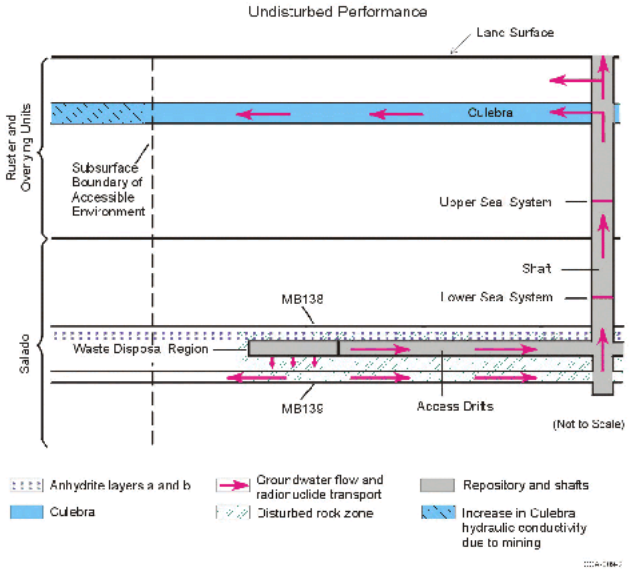

Figure 6-8. Conceptual Release Pathways for the Undisturbed Performance Scenario

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6.3.2 Disturbed Performance

Assessments for compliance with 40 CFR § 191.13 need to consider the potential effects of future disruptive natural and human-initiated EPs on the performance of the disposal system. As discussed in Section 6.2.3, no potentially disruptive natural EPs are considered to be sufficiently likely to require inclusion in analyses of either undisturbed or disturbed performance. The only future human-initiated EPs retained after FEP screening are those associated with mining and deep drilling (but not the subsequent use of a borehole) within the controlled area at a time when institutional controls cannot be assumed to eliminate the possibility of such activities (Sections 6.2.5.2 and 6.4.12.1). In total, 21 disturbed performance FEPs associated with future mining and deep drilling have been identified. These FEPs have been assigned a screening designator DP in tables in Section 6.2 and Appendix SCR and are listed separately in Table 6-7. Table 6-7 also contains references to text in Section 6.4 that describes the conceptual models which account for the disturbed performance FEPs.

For evaluation of the consequences of disturbed performance the DOE has defined the mining scenario, M, the deep drilling scenario, E, and a mining and drilling scenario, ME. These scenarios are described in the following sections.

6.3.2.1 The Disturbed Performance Mining Scenario (M)

The disturbed performance mining scenario, M, involves future mining within the controlled area.

Consistent with the criteria stated by the EPA in 40 CFR § 194.32 (b), for performance assessment calculations, the effects of potential future mining within the controlled area are limited to changes in hydraulic conductivity of the Culebra that result from subsidence (as described in Section 6.4.6.2.3).

Radionuclide transport may be affected in the M scenario if a head gradient between the waste-disposal panels and the Culebra causes brine contaminated with radionuclides to move from the waste-disposal panels to the base of the shafts and up the shafts to the Culebra. The changes in the Culebra transmissivity field may affect the rate and direction of radionuclide transport within the Culebra. Features of the M scenario are illustrated in Figure 6-9. The three disturbed performance FEPs labeled M in Table 6-7 relate to the occurrence and effects of future mining. The modeling system used for the M scenario is similar to that developed for the undisturbed performance scenario, but with a modified Culebra transmissivity field within the controlled area to account for the effects of mining.

Table 6-7. Disturbed Performance (DP) FEPs

Disturbed Performance Features, Events, and Processes (FEPs)	Scenario	Chapter Section
ALL UNDISTURBED PERFORMANCE (UP) FEPS		
NATURAL FEPs		
Geological		
Stratigraphy		
Brine reservoirs	E1	6.4.8 6.4.12.6
WASTE- AND REPOSITORY-INDUCED FEPs		
Waste and repository characteristics		
Waste characteristics		
Heterogeneity of waste forms	E1, E2	6.4.12.4
Contaminant transport mode		
Particulate transport		
Suspensions of particles	E1, E2	6.4.7.1
Cuttings	E1, E2	6.4.7.1
Cavings	E1, E2	6.4.7.1
Spallings	E1, E2	6.4.7.1 6.4.13.7
HUMAN-INITIATED EPs		
Geological		
Drilling		
Oil and gas exploration	E1, E2	6.4.7 6.4.12.2
Potash exploration	E1, E2	6.4.7 6.4.12.2
Oil and gas exploitation	E1, E2	6.4.7 6.4.12.2
Other resources	E1, E2	6.4.7 6.4.12.2
Enhanced oil and gas recovery	E1, E2	6.4.7 6.4.12.2
Excavation activities		
Potash mining	M	6.4.6.2.3 6.4.12.8 6.4.13.8
Subsurface hydrological and geochemical		
Borehole fluid flow		
Drilling-induced flow		
Drilling fluid flow	E1, E2	6.4.7.1
Drilling fluid loss	E2	6.4.7.1.1
Blowouts	E1, E2	6.4.7.1.1
Drilling-induced geochemical changes	E1, E2	6.4.6.2
Flow through abandoned boreholes		

Table 6-7. Disturbed Performance (DP) FEPs (Continued)

Disturbed Performance Features, Events, and Processes (FEPs)	Scenario	Chapter Section
Natural borehole fluid flow	E1, E2	6.4.7.2 6.4.12.7 6.4.13
Waste-induced borehole flow	E1, E2	6.4.7.2 6.4.12.7 6.4.13
Borehole-induced geochemical changes	E1, E2	6.4.6.2
Excavation-induced flow		
Changes to groundwater flow due to mining	M	6.4.6.2.3 6.4.12.8 6.4.13.8
Ecological		
Social and technological developments		
Loss of records	M, E1, E2	6.4.7 6.4.12.1

Legend:

M Mining within the controlled area.
E1 Deep drilling that intersects the waste disposal region and a brine reservoir in the Castile.
E2 Deep drilling that intersects a waste disposal panel.

6.3.2.2 The Disturbed Performance Deep Drilling Scenario (E)

The disturbed performance deep drilling scenario, E, involves at least one deep drilling event that intersects the waste disposal region. The EPA provides criteria concerning analysis of the consequences of future drilling events in performance assessments in 40 CFR § 194.33(c):

> Performance assessments shall document that in analyzing the consequences of drilling events, the Department assumed that:
> (1) Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared. Such future drilling practices shall include, but shall not be limited to: the types and amounts of drilling fluids; borehole depths, diameters, and seals; and the fraction of such boreholes that are sealed by humans; and
> (2) Natural processes will degrade or otherwise affect the capability of boreholes to transmit fluids over the regulatory time frame.

Consistent with these criteria, there are several pathways for radionuclides to reach the accessible environment in the E scenario. During the period before any deep drilling intersects the waste, potential release pathways are identical to those in the undisturbed performance scenario.

If a borehole intersects the waste in the disposal rooms, releases to the accessible environment may occur as material entrained in the circulating drilling fluid is brought to the surface, as discussed further in Section 6.4.7.1. Particulate waste brought to the surface may include cuttings, cavings, and spallings. Cuttings are the materials cut by the drill bit as it passes through waste. Cavings are the materials eroded by the drilling fluid in the annulus around the

drill bit. Spallings are the materials that may be forced into the circulating drilling fluid if there is sufficient pressure in the waste disposal panels. During drilling, contaminated brine may flow up the borehole and reach the surface, depending on fluid pressure within the waste disposal panels.

When abandoned, the borehole is assumed to be plugged in a manner consistent with current practice in the Delaware Basin (see Section 6.4.7.2; Appendix DEL, Sections DEL.5 and DEL.6; and Appendix MASS, Section MASS.16.3 and MASS Attachment 16-1). An abandoned intrusion borehole with degraded casing and/or plugs may provide a pathway for fluid flow and contaminant transport from the intersected waste panel to the ground surface if the fluid pressure within the panel is sufficiently greater than hydrostatic. Additionally, if brine flows through the borehole to overlying units, such as the Culebra, it may carry dissolved and colloidal actinides that can be transported laterally to the accessible environment by natural groundwater flow in the overlying units.

Alternatively, the units intersected by an intrusion borehole may provide sources for brine flow to a waste panel during or after drilling. For example, in the northern Delaware Basin, the Castile, which underlies the Salado, contains isolated volumes of brine at fluid pressures greater than hydrostatic (as discussed in Section 2.2.1.2.2). The WIPP-12 penetration of one of these reservoirs provided data on one brine reservoir within the controlled area. The location and properties of brine reservoirs cannot be reliably predicted; thus, the possibility of a deep borehole penetrating both a waste panel and a brine reservoir is accounted for in consequence analysis of the WIPP, as discussed in Section 6.4.8. Such a borehole could provide a connection for brine flow from the Castile to the waste panel, thus increasing fluid pressure and brine volume in the waste panel.

Also, a borehole that is drilled through a disposal room pillar, but does not intersect waste, could penetrate the brine reservoir underlying the waste disposal region. Such an event would, to some extent, depressurize the brine reservoir, and thus would affect the consequences of any subsequent intersections of the reservoir. The possibility for boreholes that do not penetrate the waste to depressurize a brine reservoir underlying the waste disposal region is accounted for in the consequence analysis of the WIPP.

The DOE has distinguished two types of deep drilling events by whether or not the borehole intersects a Castile brine reservoir. A borehole that intersects a waste disposal panel and penetrates a Castile brine reservoir has been designated an E1 event. The 18 disturbed performance FEPs labeled E1 in Table 6-7 relate to the occurrence and effects of an E1 drilling event. A borehole that intersects a waste panel but does not penetrate a Castile brine reservoir has been designated an E2 event. The 18 disturbed performance FEPs labeled E2 in Table 6-7 relate to the occurrence and effects of an E2 drilling event.

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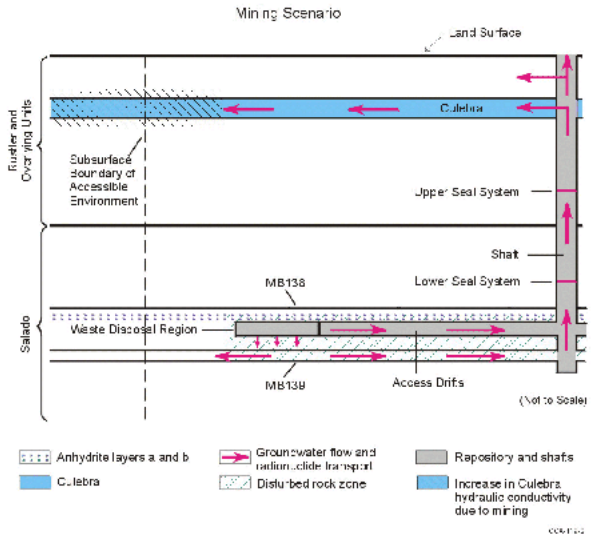

Figure 6-9. Conceptual Release Pathways for the Disturbed Performance Mining Scenario

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In order to evaluate the consequences of future deep drilling, the DOE has divided the E scenario into three drilling subscenarios, E1, E2 and E1E2, distinguished by the number of E1 and E2 drilling events that are probabilistically assumed to occur in the regulatory time frame. These subscenarios are described in order of increasing complexity in the following sections.

6.3.2.2.1 The E2 Scenario

The E2 scenario is the simplest scenario for inadvertent human intrusion into a waste disposal panel. In this scenario, a panel is penetrated by a drill bit; cuttings, cavings, spallings, and brine flow releases may occur; and brine flow may occur in the borehole after it is plugged and abandoned. Sources for brine that may contribute to long-term flow up the abandoned borehole are the Salado or, under certain conditions, the units above the Salado. An E2 scenario may involve more than one E2 drilling event. Features of the E2 scenario are illustrated in Figure 6-10. A modeling system has been developed to evaluate the consequences of an E2 scenario during which single or multiple E2 events occur.

6.3.2.2.2 The E1 Scenario

Any scenario with one inadvertent penetration of a waste panel that also penetrates a Castile brine reservoir is called E1. Features of this scenario are illustrated in Figure 6-11.

Sources of brine in the E1 scenario are the brine reservoir, the Salado and, under certain conditions, the units above the Salado. However, the brine reservoir is conceptually the dominant source of brine in this scenario. The model configuration developed for the E1 scenario is used to evaluate the consequences of futures that have only one E1 event. A future during which more than one E1 event occurs is described as an E1E2 scenario.

6.3.2.2.3 The E1E2 Scenario

The E1E2 scenario is defined as all futures that have multiple penetrations of a waste panel of which at least one intrusion is an E1 type. One case of this scenario, with a single E1 event and a single E2 event penetrating the same panel, is illustrated in Figure 6-12. However, the E1E2 scenario can include many possible combinations of intrusion times, locations, and types of event (E1 or E2). The sources of brine in this scenario are those listed for the E1 scenario, and multiple E1-type sources may be present. The E1E2 scenario potentially has a flow path not present in the E1 or E2 scenarios: flow from an E1 borehole through the waste to another borehole. This flow path has the potential to (1) bring large quantities of brine in direct contact with waste and (2) provide a less restrictive path for this brine to flow to the units above the Salado (via multiple boreholes) compared to either the E1 or E2 individual scenarios. It is both the presence of brine reservoirs and the potential for flow through the waste to other boreholes that make this scenario different in terms of potential consequences from combinations of E2 boreholes. The extent to which flow occurs between boreholes, as estimated by modeling, determines whether combinations of E1 and E2 boreholes at specific locations in the repository should be treated as E1E2 scenarios or as independent E1 and E2 scenarios in the consequence analysis. Because of the number of possible combinations of

drilling events, the modeling configuration for the E1E2 scenario differs in significant ways from the model configuration used for evaluating E1 and E2 scenarios. This configuration is described in Section 6.4.13.5.

6.3.2.3 The Disturbed Performance Mining and Deep Drilling Scenario (ME)

Mining in the WIPP site (the M scenario) and deep drilling (the E scenario) may both occur in the future. The DOE calls a future in which both of these events occur the ME scenario. The occurrence of both mining and deep drilling do not create processes in addition to those already described separately for the M and E scenarios. For example, the occurrence of mining does not influence any of the interactions between deep boreholes and the repository or brine reservoirs. As well, the occurrence of drilling does not impact the effects of mining on Culebra hydrogeology. The difference between the M and E scenarios considered separately and the ME scenario is that the combination of borehole transport to the Culebra (E) and a transmissivity field impacted by mining (M) may result in more rapid transport of actinides to the accessible environment. For example, because the M scenario does not include drilling the only pathway for actinides to reach the Culebra is up the sealed shafts. For clarity in describing computational results, the ME scenario has been subdivided according to the types of deep drilling subscenarios into the ME1 scenario (M and E1), the ME2 scenario (M and E2), and the ME1E2 scenario (M and E1E2).

The system used for modeling flow and transport in the Culebra for the ME scenario is similar to that used for the E scenario. However, in the ME scenario the Culebra transmissivity field is modified to account for the effects of mining within the controlled area.

6.3.3 Scenarios Retained for Consequence Analysis

These scenarios described in Sections 6.3.1 and 6.3.2 have been retained for consequence analysis to determine compliance with the Containment Requirements in 40 CFR § 191.13. The modeling systems used to evaluate the consequences of these undisturbed and disturbed performance scenarios are discussed in Section 6.4. For consequence analysis, the scenarios and subscenarios described in this section are further subdivided into scenarios, S_i. The S_i scenarios are distinguished by, for example, the time of occurrence of disruptive events. The S_i scenarios are generated, and their probabilities determined, by probabilistic sampling of selected processes and events (see Sections 6.1.5.2 and 6.4.12).

6.4 Calculation of Scenario Consequences

Scenario consequence, cS_i, is the third element of the ordered triples shown in Equation 2 in Section 6.1.1. Estimation of cS_i requires quantitative modeling; performance assessment uses a linked system of individual computer codes. This section discusses the conceptual and computational models and some parameter values used to estimate the consequence of the

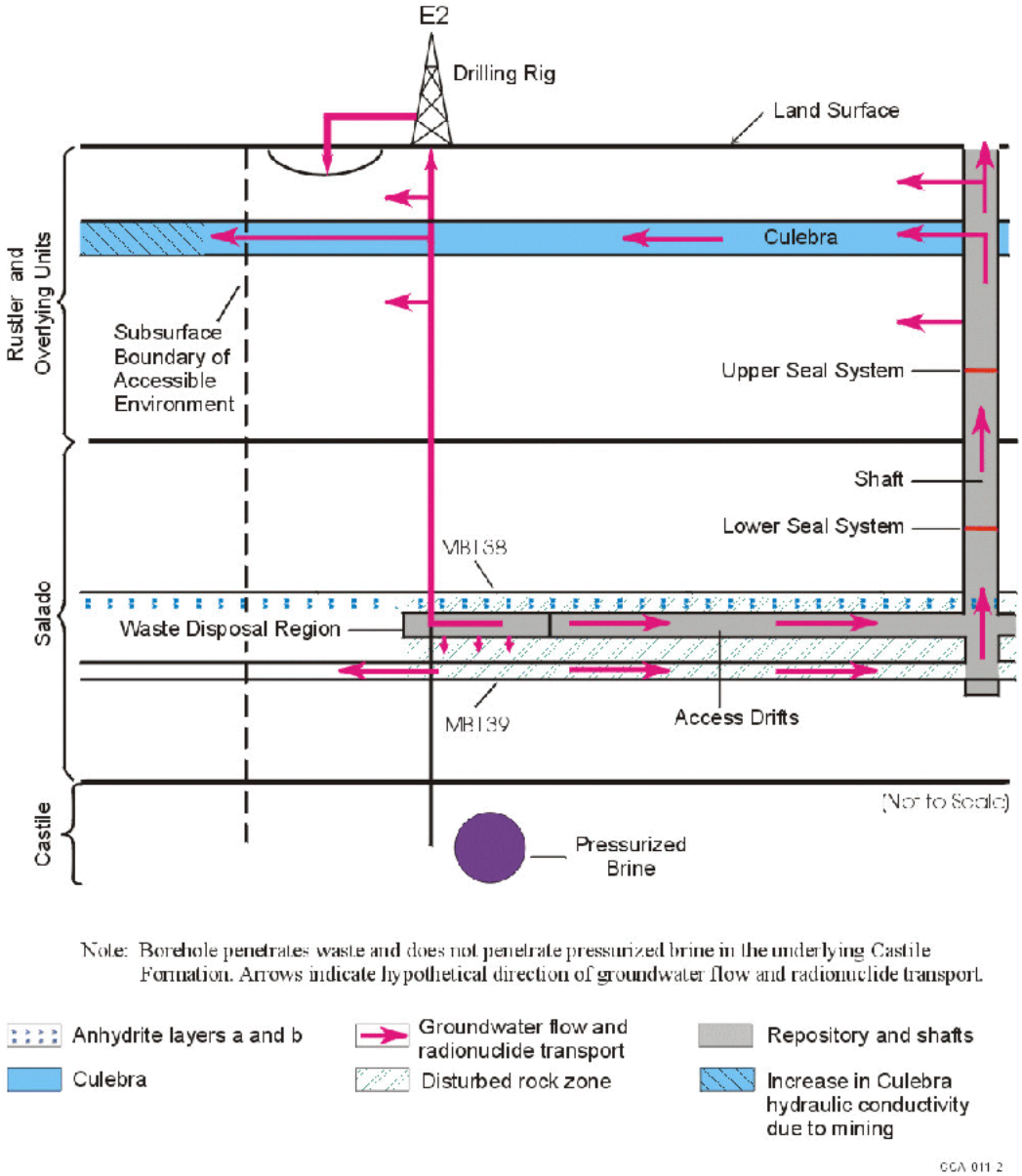

Figure 6-10. Conceptual Release Pathways for the Disturbed Performance Deep Drilling E2 Scenario

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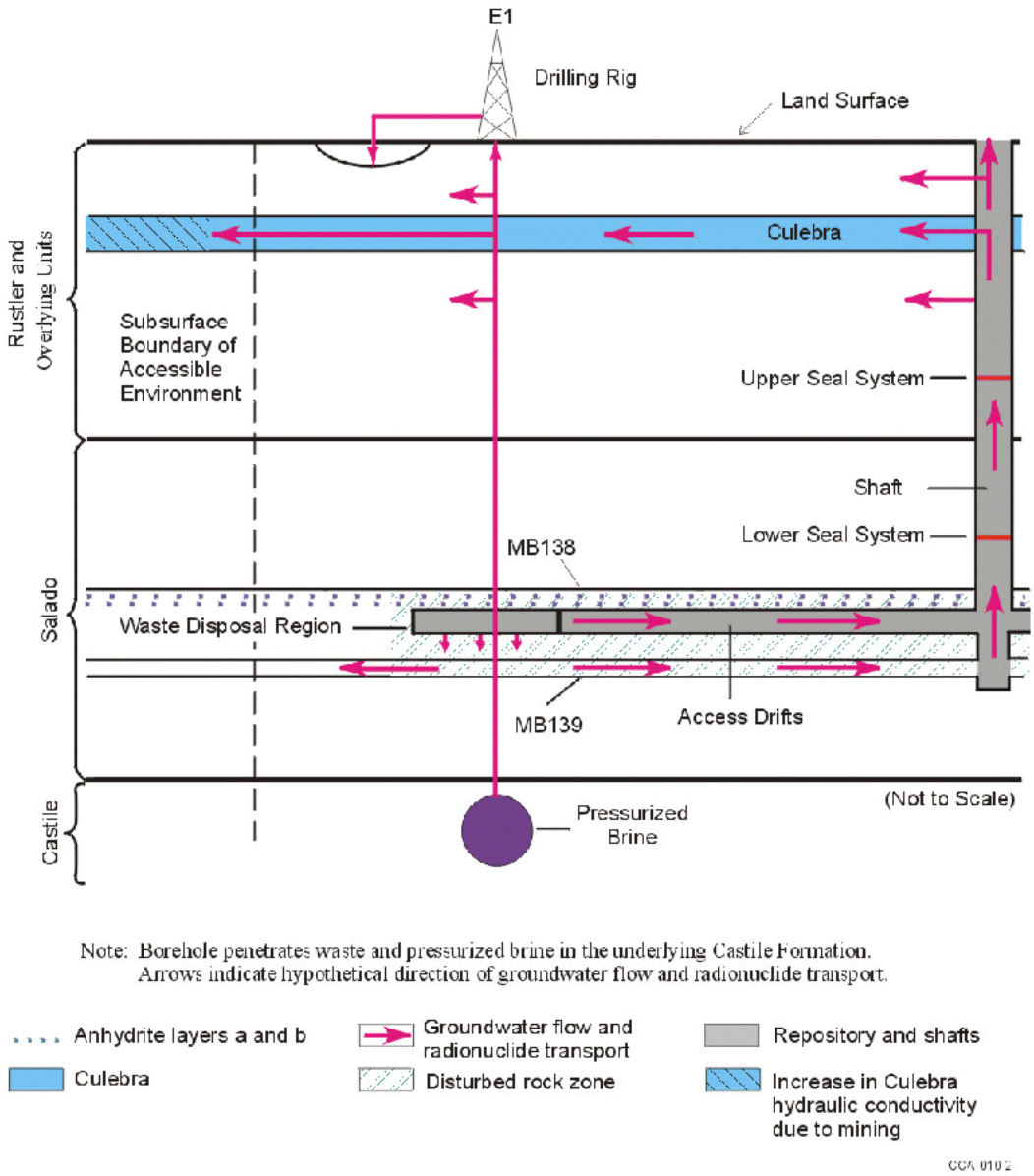

Figure 6-11. Conceptual Release Pathways for the Disturbed Performance Deep Drilling Scenario E1

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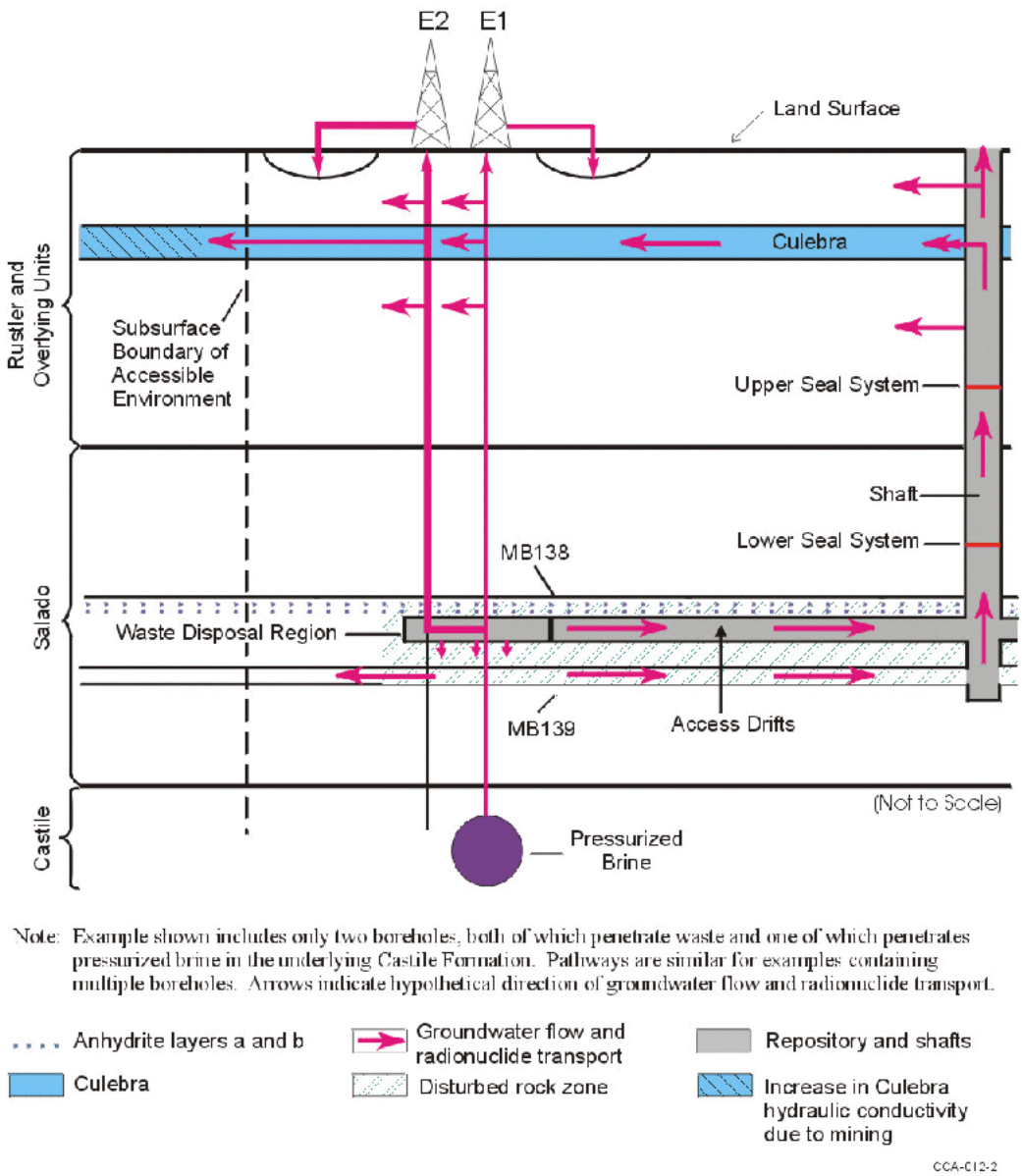

Figure 6-12. Conceptual Release Pathways for the Disturbed Performance Deep Drilling Scenario E1E2

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scenarios described in Section 6.3. Additional discussion of conceptual models and modeling assumptions is provided in Appendix MASS. Additional descriptions of sampled parameter values are included in Appendix PAR (Parameters 1 to 57).

6.4.1 Types of Models

A single modeling system was used to represent the disposal system and calculate the CCDFs presented in Section 6.5. The modeling system, however, can be conveniently described in terms of various submodels with each describing a part of the overall system. This section is organized to provide, for each submodel defined, an integrated, summary description of the conceptual model, mathematical model, numerical model, computational model, experimental data, and model parameters used. These terms are described below.

The models used in the WIPP performance assessment, as in other complex analyses, exist at four different levels:

(1) **Conceptual models** are a set of qualitative assumptions used to describe a system or subsystem for a given purpose. At a minimum, these assumptions concern the geometry and dimensionality of the system, initial and boundary conditions, time dependence, and the nature of the relevant physical and chemical processes. The assumptions should be consistent with one another and with existing information within the context of the given purpose.

(2) **Mathematical models** are developed to represent the processes at the site. The conceptual models provide the context within which these mathematical models must operate and define the processes they must characterize. The mathematical models are predictive in the sense that, once provided with the known or assumed properties of the system and possible perturbations to the system, they predict the response of the system. The processes represented by these mathematical models include fluid flow, mechanical deformation, radionuclide transport in groundwater, and removal of waste through intruding boreholes.

(3) **Numerical models** are developed to provide approximations of mathematical model solutions because most mathematical models do not have closed-form solutions.

(4) The complexity of the system requires the use of computer codes to solve the numerical models. The implementation of the numerical model in the computer code with specific initial and boundary conditions and parameter values is generally referred to as the **computational model**.

Data are descriptors of the physical system being considered, normally obtained by experiment or observation. Parameters are values necessary in mathematical, numerical, or computational models. The distinction between data and parameters can be subtle. Parameters are distinct from data, however, for three reasons. First, data may be evaluated, statistically or otherwise, to generate parameters for a model to account for uncertainty in

data. Second, some parameters have no relation to the physical system, such as the parameters in a numerical model specified to determine when an iterative solution scheme has converged. Third, many model parameters are applied at a different scale than one that can be directly observed or measured in the physical system. The distinction between data and parameter values is described further in Appendix PAR, where the derivations of distributions for specific parameters are given. The interpretation and the scaling of experimental and field data are discussed in Appendix PAR for individual and sampled parameters, as appropriate.

6.4.2 Model Geometries

Although the specific geometries used in performance assessment models are developed after the conceptual and mathematical models are defined, they are introduced here because they provide a useful framework for presenting the full discussion of the modeling system. Performance assessment represents the three-dimensional geometry of the disposal system (repository, shafts, and controlled area) using two primary two-dimensional simplifications. In the first two-dimensional geometry, processes that act on the entire disposal system occur within the repository and are simulated in the BRAGFLO (BRine And Gas FLOw) computer code using a geometry that approximates a north-south vertical cross section through the disposal system and some surrounding rock. This geometry is used to simulate processes in the disposal system, such as two-phase flow and movement of actinides, as well as processes acting only within the repository, such as creep closure of disposal rooms and gas generation. In the second two-dimensional geometry, groundwater flow and actinide transport in the Culebra, which provides a potential pathway for lateral transport of actinides to the accessible environment, are simulated in the SECOFL2D and SECOTP2D computer codes using a two-dimensional horizontal geometry that treats the Culebra as a single layer. These two geometries are discussed in the following sections. Additional geometries used to simulate system behavior during drilling intrusions are discussed in Sections 6.4.7 and 6.4.13. Performance assessment codes and the flow of numerical information through the performance assessment are described in Section 6.4.11 and referenced appendices.

6.4.2.1 Disposal System Geometry

A single disposal system geometry is used in the BRAGFLO computational model (see Appendix BRAGFLO) with four different maps of material properties: one for undisturbed conditions; one for the E1 intrusion event, in which a borehole penetrates the panel and a Castile brine reservoir; one for the E2 intrusion event, in which a borehole penetrates the repository but not a Castile brine reservoir; and one for the E1E2 intrusion event, in which at least one E1 borehole and one other borehole penetrate a disposal panel (see Section 6.4.13.5). The geometry and material maps used in BRAGFLO are similar; each is a model for fluid flow calculations that represents the three-dimensional physical system in a two-dimensional plane that cuts vertically through the repository and surrounding strata. Side views of the vertical cross section and two of the material maps are presented in Figures 6-13 and 6-14. In these figures, the boundaries of grid blocks discretized in the model (see

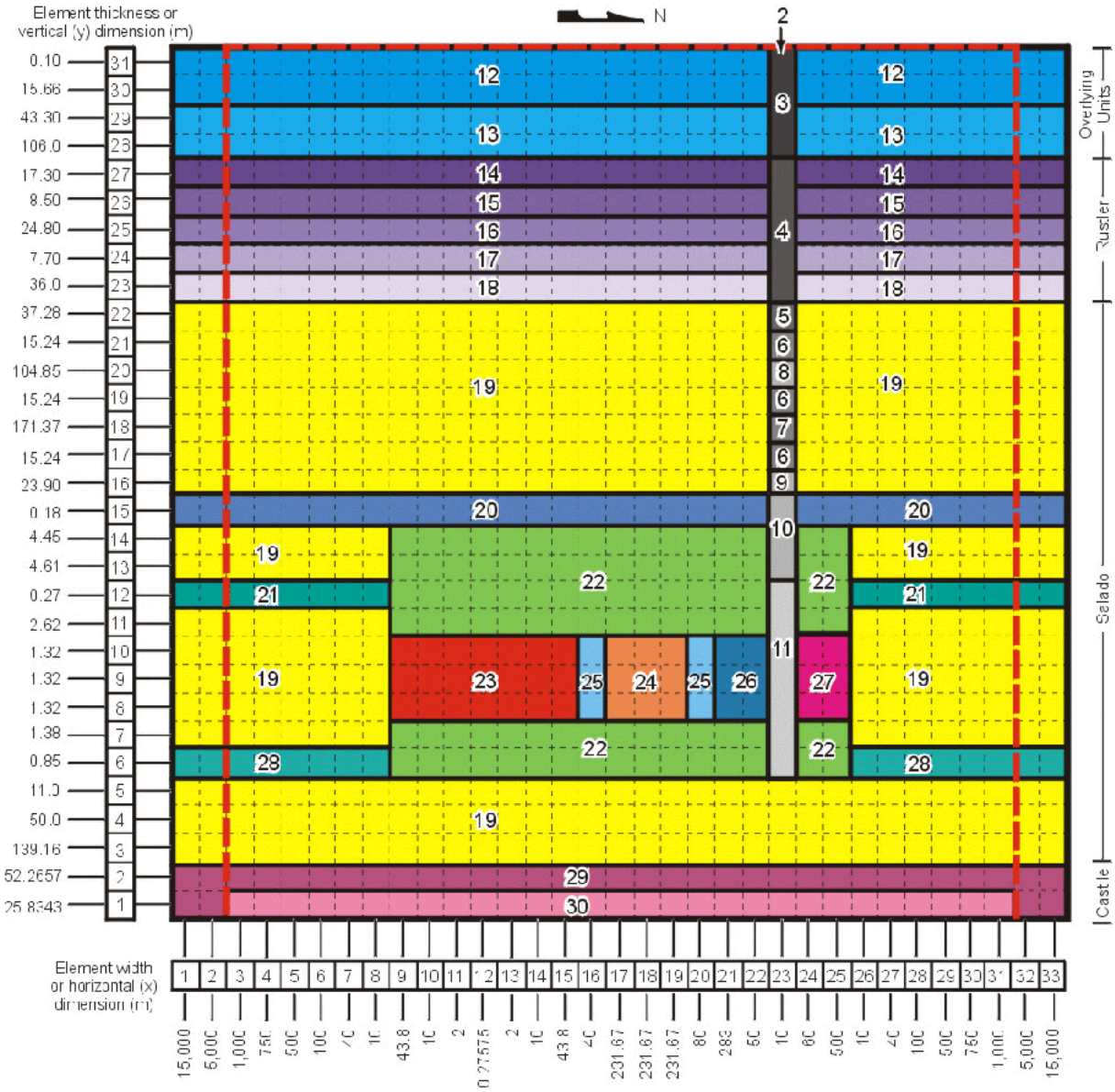

2. Shaft
3. Earth fill
4. Rustler compacted clay column
5. Asphalt
6. Concrete
7. Crushed salt (compacted salt column)
8. Upper Salado compacted clay column
9. Lower Salado compacted clay column
10. Lower clay component
11. Concrete monolith
12. Units above the Dewey Lake
13. Dewey Lake
14. Forty-niner
15. Magenta
16. Tamarisk
17. Culebra
18. Unnamed lower member
19. Impure halite
20. MB138
21. Anhydrite layer a and b
22. Disturbed rock zone
23. Waste panel
24. Rest of repository
25. Panel closures
26. Operation region
27. Experimental area
28. MB139
29. Castile
30. Brine reservoir

Boundary of accessible environment

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Figure 6-13. A Side View of the BRAGFLO Elements and Material Regions Used for Simulation of Undisturbed Performance

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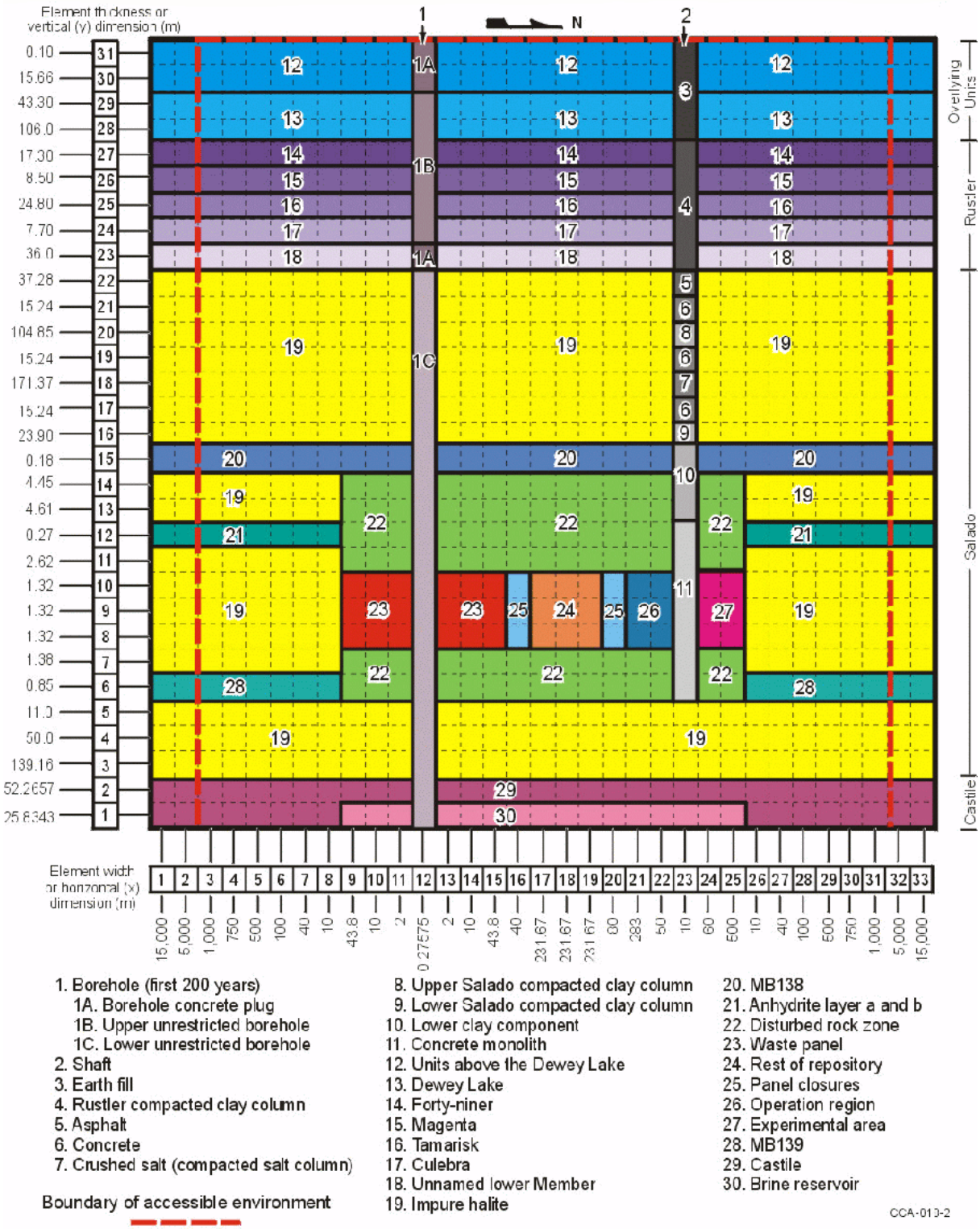

Figure 6-14. A Side View of the BRAGFLO Elements and Material Regions Used to Simulate the E1 Event (For E2 Event, the Borehole Extends Only Between the Surface and the Base of the Repository)

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Appendix BRAGFLO, Section 4.5, for details of the finite-difference method) are shown with dashed lines; each grid block is associated with material properties representing an important feature of the disposal system. These associations between grid blocks and material properties are shown by color and number in the figures. The two figures differ in that the material property map used for E1 intrusion events (Figure 6-14) includes a material region representing the borehole (Region 1) that is not present in the undisturbed case. The borehole region vertically transects other material regions and connects the single panel (Region 23) with the Castile brine reservoir (Region 30), marker beds, overlying units, and the surface. The E2 intrusion event material regions are similar to those of E1, except that the modeled borehole region does not extend below the repository and therefore does not contact a brine reservoir. Additionally, the extent of the Castile brine reservoir is different from undisturbed to disturbed performance. This difference has no impact on results because no natural FEPs are retained that can create a pathway from the Castile to the repository.

Figures 6-13 and 6-14 show the relationship among material regions in the model and how connections are made within the finite-difference scheme. However, by illustrating equidimensional grid blocks, the volumetric relationship between grid blocks is greatly distorted. To show the volumetric relationship among nodal blocks and between the repository and host formations, a scaled side view of the vertical cross section used in BRAGFLO is shown in Figure 6-15. An undistorted 1:1 vertical:horizontal scale side view is in the upper left corner of Figure 6-15; at this scale, important model features are not resolvable. Therefore, two other views are provided in which the vertical scale has been exaggerated 50:1 to show model features. Notice that the modeling system extends more than 15 miles (25 kilometers) to the north and 14 miles (22.5 kilometers) to the south from the borehole, which intersects the approximate center of the waste disposal region and includes the uppermost 2,990 feet (911 meters) of rock at the WIPP site. Colors in Figure 6-15 are consistent with colors for material regions in Figures 6-13 and 6-14.

Effects of flow in the third (out-of-plane) dimension are approximated with a two-dimensional element configuration that simulates convergent or divergent flow to the north and south, centered on the repository, in intact rocks laterally away from the repository. A top-down (plan) view of the model is shown in Figure 6-16 and illustrates the discretization adopted to simulate convergent or divergent flow. Colors in Figure 6-16 are consistent with colors for material regions in Figures 6-13 through 6-15 at the repository depth (node rows 8, 9, and 10). In this text, the term width corresponds to the x (lateral) dimension of nodes, thickness refers to the y (vertical) dimension, and depth refers to the z (out-of-plane) dimension. The effects of the grid assumptions on fluid flow processes in the Salado are discussed in Appendix MASS (Section MASS.4 and MASS Attachment 4-1).

Based on observations in the existing excavations, the DOE approximates the regionally variable dip in the Salado by incorporating a 1-degree dip to the south in the BRAGFLO computational mesh. This dip is not indicated in Figures 6-13, 6-14, and 6-15.

The BRAGFLO definition of hydrostratigraphic units follows formation and member divisions. Inside the Salado, however, further subdivision of hydrostratigraphy has been made

based on the observed differences in permeability between anhydrite-rich interbeds and halite-rich intervals. This further subdivision has been made only at elevations near the repository horizon because only in this region are such distinctions important. The models and assumptions used to represent the various regions of material properties shown in Figures 6-13 and 6-14 are discussed beginning in Section 6.4.3 and in Appendices MASS and PAR. The thickness of hydrostatigraphic units used in BRAGFLO are tabulated in Appendix PAR (Table PAR-57).

6.4.2.2 Culebra Geometry

Although the BRAGFLO model contains a discretization of the Culebra and calculates flow there, the DOE uses a more detailed representation of this unit to estimate potential radionuclide releases to the accessible environment resulting from lateral subsurface transport. The conceptual model for flow and transport in this geometry is discussed in Section 6.4.6.2. The boundary and initial conditions applied to this geometry are discussed in Section 6.4.10.2. SECOFL2D and SECOTP2D are the computer codes used to simulate groundwater flow and radionuclide transport in the Culebra. The manner in which this geometry is linked to the BRAGFLO geometry described in the preceding section is discussed in Sections 6.4.6.2, 6.4.11, and Appendix CODELINK (Section CODELINK.6). The grids used for modeling the Culebra are discussed in Section 6.4.6.2.

6.4.3 The Repository

The repository, as shown in Figure 3-2 (see Chapter 3.0), is represented by Regions 23 to 27 in Figures 6-13 and 6-14. These regions include a waste disposal panel (Region 23), panel closures (Region 25), the panels and access drifts in the rest of the waste disposal region (Region 24), the operations region (Region 26), and the experimental region at the north end of the repository (Region 27). The shaft (Region 2, which is further subdivided into Regions 3 through 11) intersects the repository between the operations region and the experimental region. The shaft is discussed in detail in Section 6.4.4. For human-intrusion events, the borehole (Region 1) intersects the waste disposal region in the panel. In two-dimensional fluid flow codes, a grid block's length, volume, and cross-sectional area of faces connected to other grid blocks are important model features. For each region of the repository depicted, the BRAGFLO model geometry preserves the true excavated volume. Lateral dimensions have been determined to preserve volume and retain important cross-sectional areas and distances between defined regions, as discussed below. These simplifications are conservative with respect to fluid contact with waste, which is a critical factor in determining the quantity of actinides mobilized in the aqueous phase. The simplifications are conservative because (1) all pillars have been removed from the modeled panel, resulting in homogeneous waste regions through which fluid can flow directly; and (2) the panels in the rest of the repository have neither pillars nor closures, resulting in a large homogeneous region that is assigned an average

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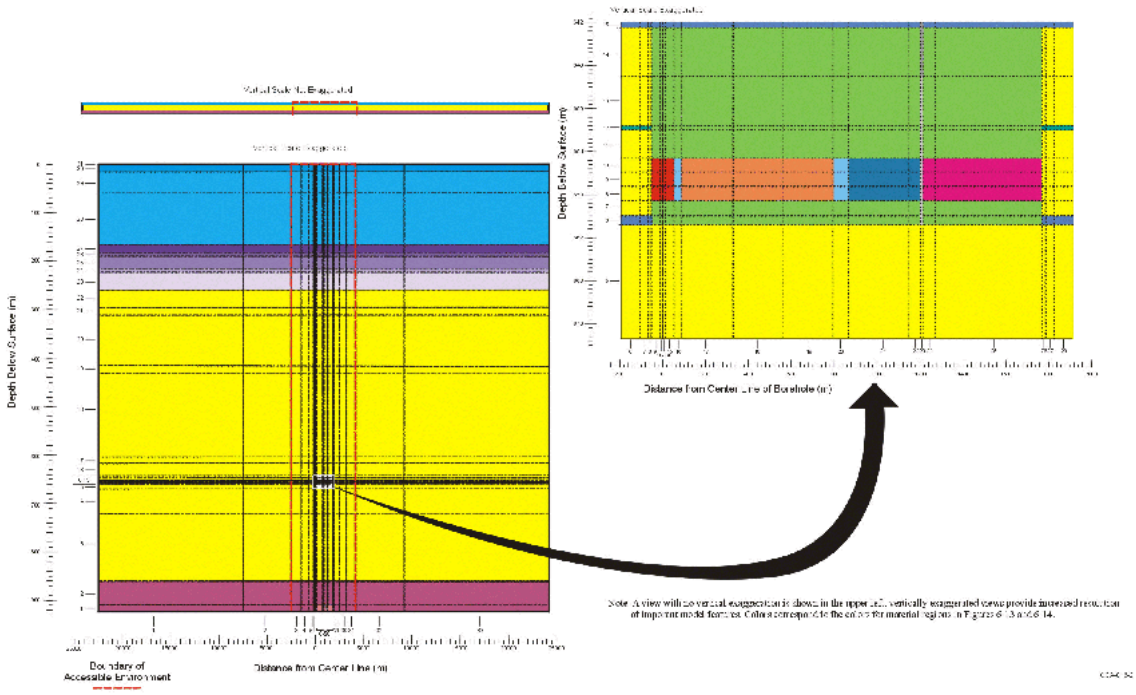

Figure 6-15. A Side View of the BRAGFLO Geometry Drawn to Scale Used for this Performance Assessment

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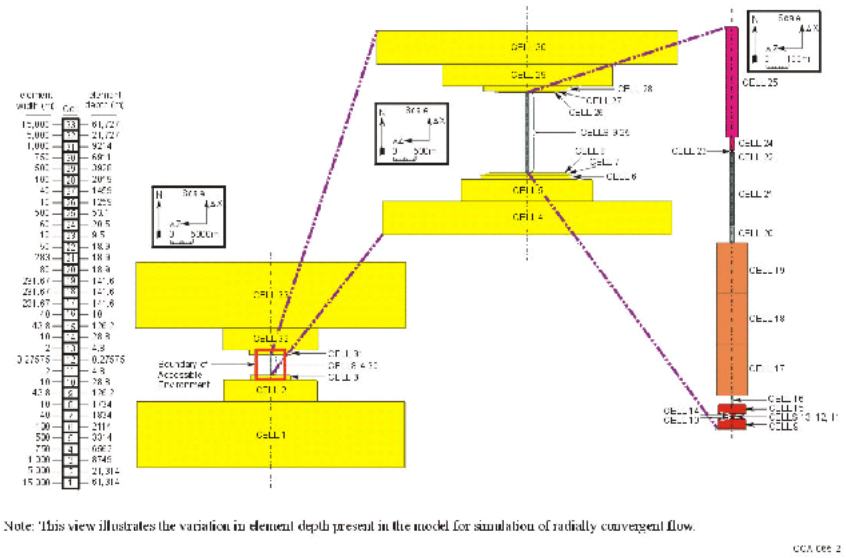

Figure 6-16. A Top-Down View of a Row of Elements in BRAGFLO Used for Undisturbed Performance

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permeability within the range of experimentally determined permeabilities (see Section 6.4.3.2 and Appendix MASS, Section MASS.5).

The single panel that is represented individually (Region 23) is discretized to simulate radial flow to and from the borehole that intersects it. The true distance from the south end of the waste disposal region to the waste handling shaft is preserved in the model as the distance from the south end of the modeled panel to the modeled single shaft. In BRAGFLO, the single panel region is the southernmost portion of the repository. It occupies this position because separate modeling activities indicate that slightly larger releases may result from a panel in this position than from alternative placements (see Vaughn et al. 1995).

The panel closure between the panel and the rest of the repository has a cross-sectional area equal to the cross-sectional area of the drifts between panels. The length and total volume of modeled panel closures is consistent with their design. The panel closure between the rest of the repository and the operations region has a cross-sectional area equal to the cross-sectional area of the drifts between the north end of the waste disposal region and the operations region. Because there are two closures between the waste disposal region and the shafts in the operations region, the modeled panel closures between the rest of the repository and the operations region have a length and volume consistent with two panel closures.

A number of submodels have been defined within the repository region and are described in this section. The submodels that have been defined for repository processes are Creep Closure (6.4.3.1), Repository Fluid Flow (6.4.3.2), Gas Generation (6.4.3.3), Chemical Conditions in the Repository (6.4.3.4), Dissolved Actinide Source Term (6.4.3.5), and Source Term for Colloidal Actinides (6.4.3.6).

6.4.3.1 Creep Closure

Salt creep occurs naturally in the Salado halite in response to deviatoric stress. Inward creep of rock and the repository response is a process generally referred to as creep closure. Creep closure of excavated regions begins immediately because of excavation-induced deviatoric stress. If the rooms were empty, closure would proceed to the point where the void volume created by the excavation would be eliminated as the surrounding formation returns to a uniform stress state. In the waste disposal region, waste consolidation will continue until loading in the surrounding rock is uniform, at which point salt creep ceases. The amount of waste consolidation that occurs and the time it takes to consolidate are governed by properties of the waste (waste strength, modulus, etc.), properties of the surrounding rock, the dimensions and location of the room, and the quantities of fluids present in the room.

Fluids that could affect closure are brine that may enter the repository from the Salado or an intrusion borehole, air present in the repository when it is sealed, and gas produced by reactions occurring during waste degradation. Closure and consolidation can be slowed by fluid pressure in the repository. This can be quantified according to the principle of effective stress:

$$\sigma_T = \sigma_e + p \,, \tag{11}$$

where σ_T is the stress caused by the weight of the overburden (an essentially constant value), p is the pressure of the repository pore fluid, and σ_e is the stress that is applied to the waste matrix. In this formulation, the waste is considered a skeleton structure containing pore fluids. As the pore pressure increases, an increasing amount of overburden stress is supported by pore fluid pressure, P, and less overburden stress is supported by the strength of the waste matrix. Waste consolidation will cease when the sum of the stresses felt by the waste matrix and fluid pressure reaches lithostatic pressure. If gas and brine quantities in the repository stabilize, creep closure will act to establish a constant pressure and pore volume.

In summary, creep closure of waste disposal areas will cause their volume to decrease as the Salado deforms to consolidate and encapsulate the waste, changing waste porosity and permeability. Resistance to creep closure will be caused by waste strength and fluid pressure.

Three major material-response models are required for closure analyses. The first model describes how the halite creeps as a function of time and stress. The second model describes the state of consolidation of the waste as a function of applied stress. A third constitutive model is used to model inelastic behavior of anhydrite marker beds (see Appendix PORSURF, PORSURF Attachment 1).

Halite deformation is predicted using a multimechanism deformation steady-state creep model with work hardening and recovery transient response. For the conditions of the WIPP, creep mechanisms are governed by the temperature and shear stress at a given location in the surroundings at any time. Although WIPP conditions are expected to be nearly isothermal at the ambient natural underground temperature, several of the mechanisms can be active at the same time because of the large range of stress states that occur around underground rooms and shafts. The focus of the mechanistic part of the model is definition of steady-state creep strain, with transient creep strain described through a multiplier on the steady-state rate, thus accommodating both transient changes in stress loading and unloading.

The volumetric plasticity model is the mathematical model for room closure and waste consolidation. The experimental data used in this model are summarized and interpreted in Butcher et al. (1991, 65 – 76) and Luker et al. (1991).

The volumetric plasticity model, multimechanism deformation model, and the inelastic constitutive model for anhydrite were numerically implemented in the SANTOS computer code to calculate the closure of disposal rooms for performance assessment (Appendix PORSURF, PORSURF Attachment 1). SANTOS is described in Appendix PORSURF (Section PORSURF.3).

As a boundary condition, SANTOS requires estimates of the fluid pressure and hence the quantity of gas present in a disposal room. These estimates are obtained using the average stoichiometry model of gas generation (Section 6.4.3.3) with different rates of gas generation that reflect different assumptions about the quantity of brine that might be available in a waste

disposal room. The different rates of gas generation used in SANTOS bound the possible conditions for gas content in the repository. With the volumetric plasticity model and the fluid pressure boundary condition, SANTOS calculates the pore volume of the disposal room through time.

In performance assessment, the time-dependent effects on volume of creep closure calculated by SANTOS are linked to the fluid-flow code BRAGFLO by a porosity surface, which is a look-up table relating porosity (void volume) to (1) time after sealing and (2) gas pressure. At the beginning of a time step, BRAGFLO evaluates the pressure of a cell in the waste disposal regions; the pressure is sensitive to brine and gas flow and the previous pore volume of the cell. The code then consults the porosity surface to find the void volume of the cell appropriate for a given time and pressure. The void volume in the cell is iteratively adjusted during a time step for consistency with gas generation, fluid movement, and repository pressure. Additional details about the porosity surface method are included in Appendix BRAGFLO (Section 4.11) and Appendix PORSURF (Sections PORSURF.1, PORSURF.2, and PORSURF Attachments 1 through 6). The porosity surface method of incorporating the dynamic effect of creep closure in performance assessment has been compared to more complex techniques that are computationally impractical in a performance assessment (Freeze et al. 1995). In these comparisons, the porosity surface method was found to be a reasonable representation of behavior observed in more complex models.

The operations area and experimental area (Regions 26 and 27 in Figures 6-13 and 6-14, respectively) are modeled as unfilled after closure in this performance assessment. These regions are expected to close in less than 200 years and do not require a porosity surface, in contrast to the region containing waste (Vaughn et al. 1995).

6.4.3.2 Repository Fluid Flow

Fluid flow modeling within the repository is concerned with (1) fluid flow and distribution in the waste, (2) fluid flow to and from the Salado and shafts, and (3) fluid flow between the repository and intrusion boreholes. These are important in assessing gas generation rates (Section 6.4.3.3), repository pressure, and the mobility of radionuclides in the disposal system. Additional discussion of this topic is provided in Appendix MASS (Section MASS.7).

Disposal region fluid flow is affected by the geometrical association of pillars, rooms, drifts, panel closures, possible borehole locations, the time-dependent properties of waste areas resulting from creep closure, flow interactions with other parts of the disposal system, and reactions that generate gas. As described in Section 6.4.3.1, creep closure changes disposal region porosity. Depending on material properties and conditions, brine may flow into the disposal region by moving down shafts and through the DRZ or operations region, or during disturbed conditions, through a borehole. Brine contained in the Salado may flow to the waste disposal region because of pressure gradients created by the excavation. Brine flow into the repository may be reduced as repository pressure increases, and brine may be expelled from the repository if pressure in the repository exceeds brine pressure in the immediately surrounding rock or borehole. Gas may be generated as waste decomposes, causing a

pressure increase. Gas may flow away from the waste into lower pressure areas, which may include disturbed areas surrounding the repository, the interbeds, the shafts, or an intrusion borehole. Gas flow into intact, halite-rich rock is not expected because of the expected high threshold pressure of halite (see Section 6.4.5.1).

Fluid flow in the disposal system is conceptualized using principles of multiphase flow, except for Culebra flow and transport modeling. In multiphase flow, a residual brine saturation (S_{br}), is defined, which is the minimum saturation at which the brine phase has a nonzero relative permeability; below this saturation brine is immobile. In accordance with two-phase flow theory, the residual gas saturation (S_{gr}) in the disposal system corresponds to the gas saturation necessary to create an incipient gas-phase relative permeability; below this saturation waste-generated gas is immobile. The multiphase flow techniques adopted by the DOE are described in Appendix BRAGFLO (Section 4.8).

The intrinsic permeability of waste at a given time can influence repository system performance by affecting the flow rate of gas or brine through the waste. Tests reported by Luker et al. (1991, 693 – 702) on simulated waste have shown material permeabilities from about 10^{-12} to 10^{-16} square meters on waste compacted under a lithostatic load. Performance assessment assigns a permeability of the waste as a constant at 1.7×10^{-13} square meters (Table 6-8). This permeability value is representative of the average value of compacted waste. Use of a constant value rather than a variable has been found acceptable (Vaughn et al. 1995).

Because two-phase relationships have not been measured for waste, performance assessment determines a range of possible two-phase conditions for the repository by applying the LHS technique to parameters within the Brooks-Corey two-phase equations. These and other parameters in the disposal room and repository flow model are shown in Tables 6-8 and 6-9. Details about the two-phase equations and parameters used in performance assessment are included in Appendix BRAGFLO (Sections 4.8 and 4.9) and Appendix PAR (Parameters 6 and 7).

Material properties in the waste are assumed to be homogeneous and are distributed in the BRAGFLO model in cells whose volumes are much larger than an individual waste container. Two processes that may occur on scales smaller than the cell volumes in BRAGFLO are wicking (the retention of brine in a capillary fringe) and puddling (the capture of brine in isolated pockets of waste caused by waste heterogeneity). Wicking is accounted for in the gas generation model (Section 6.4.3.3). Vaughn et al. (1995) found that puddling can be neglected.

Table 6-8. Repository[a] and Panel Closures Parameter Values

Parameter (units)	Maximum	Minimum	Median or Constant
Permeability, k (square meters) - Waste Region	-	-	1.70×10^{-13}
Permeability, k (square meters) - Operations and Experimental Regions	-	-	10^{-11}
Permeability (square meters) - Panel Closures	-	-	10^{-15}
Initial Effective Porosity (percent) - Waste Region	-	-	84.8
Effective Porosity (percent) - Operations and Experimental Regions	-	-	18.0
Effective Porosity (percent) - Panel Closures	-	-	7.5
Threshold Pressure, P_t (pascals) - Repository[a]	-	-	0
Threshold Pressure, P_t (pascals) - Panel Closures[b]	-	-	8.67×10^{4}
Residual Brine Saturation, S_{br} (unitless) - Repository	0.552	0	0.276
Residual Brine Saturation, S_{br} (unitless) - Operations and Experimental Regions	-	-	0
Residual Brine Saturation, S_{br} (unitless) - Panel Closures	-	-	0.20
Residual Gas Saturation, S_{gr} (unitless) - Repository	0.15	0	0.075
Residual Gas Saturation, S_{gr} (unitless) - Operations and Experimental Regions	-	-	0
Residual Gas Saturation, S_{gr} (unitless) - Panel Closures	-	-	0.20
Pore Distribution Parameter, λ (unitless) - Repository	-	-	2.89
Pore Distribution Parameter, λ (unitless) - Operations and Experimental Regions	-	-	0.7
Pore Distribution Parameter, λ (unitless) - Panel Closures	-	-	0.94
Maximum Capillary Pressure (pascals) - Repository and Panel Closures	-	-	10^{8}
Pore Compressibility (1/pascals) - Repository[c]	-	-	0
Pore Compressibility (1/pascals) - Panel Closures	-	-	2.64×10^{-9}

[a] Unless specifically listed, Repository refers to operations, experimental, and waste regions.
[b] Threshold pressure (P_t) determined from the relationship: $P_t = PCT_A \cdot k^{PCT_EXP}$ where PCT_A and PCT_EXP are constants and k is the permeability.
[c] Accounted for in porosity surface.

Table 6-9. BRAGFLO Fluid Properties

Parameter (units)	Value
Reference Temperature (kelvin)[a]	300.15
Liquid Density (kilograms per cubic meter)[a,b] at	
• Atmospheric Pressure	1,220.0
• 8 megapascals	1,223.0
• 15 megapascals	1,225.7
Liquid Viscosity (pascals * seconds)[b]	2.1×10^{-3}
Liquid Compressibility (1/pascals)[b]	3.1×10^{-10}
Gas Density (kilograms per cubic meter)[a,b] at:	
• Atmospheric Pressure	0.0818
• 8 megapascals	6.17
• 15 megapascals	11.1
Gas Viscosity (pascals * seconds)[b]	8.93×10^{-6}

[a] These values applied to fluids in all material regions in BRAGFLO.
[b] See Appendix BRAGFLO (Section 4.4) for equations of state.

The experimental and operations regions (Regions 26 and 27 in Figures 6-13 and 6-14) are represented in performance assessment with a porosity of 18.0 percent and a permeability of 10^{-11} square meters as a conservative upper bound. For postoperational performance, the panel closures (Region 25 in Figures 6-13 and 6-14) are represented with a porosity of 7.5 percent and a permeability of 10^{-15} square meters, as discussed in Appendix MASS (MASS Attachment 7-1).

6.4.3.3 Gas Generation

Gas will be produced in the repository because of a variety of chemical reactions, primarily those occurring between brine, metals, microbes, cellulosics and similar materials, plastics, and rubber materials, and via liberation of dissolved gases to the gas phase. The dominant processes are anoxic corrosion of metals in the waste containers and the waste and microbial degradation of cellulosics, plastics, and rubbers in the waste. Anoxic corrosion reactions will occur between brine and steel, aluminum, and aluminum alloys, producing H_2. Microbial degradation of cellulosics may produce a variety of gases; however, for the waste inventory and expected conditions, CO_2 and CH_4 (methane) are expected to be the dominant gases for the process. Radiolysis has been demonstrated by laboratory experiment and model calculations to be insignificant (see Appendix MASS, Section MASS.8; Appendix SCR, Section SCR.2.5.1.3).

Gas generation will affect repository pressure, which is important in other submodels of the disposal system, such as those calculating creep closure (Section 6.4.3.1), interbed fracturing (Section 6.4.5.2), two-phase flow (Section 6.4.3.2), and the radionuclide release associated

with spallings during an inadvertent drilling intrusion (Section 6.4.7). Thus, gas generation must be estimated in performance assessment.

Performance assessment uses the average stoichiometry model to estimate gas generation occurring in the waste disposal region. This model was developed for WIPP performance assessment based on gas generation experiments performed for the WIPP (see Appendix MASS, Section MASS.8 and MASS Attachment 8-2). The average stoichiometry model accounts for the formation of gas by anoxic corrosion of steels and microbial degradation of cellulosics, including plastics and rubbers. For the purpose of calculating repository pressure and gas flow, the density and viscosity of the generated gas are assumed to be those of H_2. In the average stoichiometry model, gas is assumed to be generated at a rate dependent on the availability of brine in the computational cell. Gas can be generated by anoxic corrosion in all realizations, and is assumed to be generated by microbial degradation in half of the realizations. The average stoichiometry model is based on experimental data on the rates of corrosion and microbial degradation under inundated and humid conditions. These data were used to develop ranges of possible gas-generation rates, as shown in Table 6-10. In BRAGFLO, a gas-generation rate is determined from the rates listed in Table 6-10 by a linear interpolation method that combines humid and inundated rates based on the effective liquid saturation (Appendix BRAGFLO, Section 4.13). The effective liquid saturation in a computational cell in BRAGFLO for the purpose of gas generation is the computed liquid saturation in that cell, plus an adjustment to account for uncertainty in the capillary rise (wicking) characteristics of the waste. Refer to Appendices PAR (Parameter 8) and BRAGFLO (Sections 4.13 and 7.2.9) for details on the treatment of wicking in the gas generation model.

Anoxic corrosion is represented by a generic equation given in Appendix BRAGFLO (Section 4.13). This equation accounts for corrosion only of the steel content in the repository by the reaction expected to dominate. Because the total quantity of aluminum and aluminum alloys is a small compared to the quantity of iron base metals, corrosion of aluminum is omitted for simplicity. The steel content of the repository is depleted separately in each computational cell (that is, a cell-by-cell basis), and gas generation can continue in cells, depending on parameter values, until all steel in a cell is consumed. Brine in cells is consumed as gas generation proceeds. If a cell has a brine saturation equal to zero, it cannot produce gas by anoxic corrosion.

It is assumed that there is no passivation of anoxic corrosion of steel by CO_2 and H_2S produced by microbial degradation because microbial gas generation is too slow and also because CO_2 will be removed from the gaseous phase by reaction with MgO backfill. Details of the equations and parameter values are given in Appendix BRAGFLO (Section 4.13), Appendix PAR (Parameter 1), and Appendix MASS (Section MASS.8).

Microbial degradation occurs in only half of the realizations because of uncertainties in viability of the microbial colonies (Appendix MASS, Section MASS.8 and MASS Attachment 8-2). Like anoxic corrosion, microbial degradation is represented by a generic

Table 6-10. Average-Stoichiometry Gas Generation Model Parameter Values

Parameter (units)	Maximum	Minimum	Median or Constant
Inundated Corrosion Rate for Steel without CO_2 Present (meters per second)	1.59×10^{-14}	0	7.94×10^{-15}
Humid Corrosion Rate for Steel	-	-	0
Probability of Microbial Degradation of Plastics and Rubbers in the Waste in the Event of Significant Microbial Gas Generation (see figure PAR-1) where 0 represents corrosion and no significant microbial gas generation. 1 represents cellulosic degradation only, and 2 represents cellulosic, plastic, and rubber degradation	2	0	2
Rate for Microbial Degradation Under Humid Conditions (mole per kilogram∗ second)	1.27×10^{-9}	0	6.34×10^{-10}
Rate for Microbial Degradation under Brine-Inundated Conditions (mole per kilogram∗ second)	9.51×10^{-9}	3.17×10^{-10}	4.92×10^{-9}
Factor β for Microbial Reaction Rates (unitless)	1.0	0	0.5
Anoxic Corrosion Stoichiometric Factor X (unitless)	-	-	1.0
Average Density of Cellulosics in CH Waste (kilograms per cubic meter)	-	-	54.0
Average Density of Cellulosics in RH Waste (kilograms per cubic meter)	-	-	17.0
Average Density of Iron-Based Materials in CH Waste (kilograms per cubic meter)	-	-	170.0
Average Density of Iron-Based Materials in RH Waste (kilograms per cubic meter)	-	-	100.0
Average Density of Plastics in CH Waste (kilograms per cubic meter)	-	-	34.0
Average Density of Plastics in RH Waste (kilograms per cubic meter)	-	-	15.0
Average Density of Rubber in CH Waste (kilograms per cubic meter)	-	-	10.0
Average Density of Rubber in RH Waste (kilograms per cubic meter)	-	-	3.3
Bulk Density of Iron Containers, CH Waste (kilograms per cubic meter)	-	-	139.0
Bulk Density of Iron Containers, RH Waste (kilograms per cubic meter)	-	-	2.59×10^{3}

Table 6-10. Average-Stoichiometry Gas Generation Model Parameter Values (Continued)

Parameter (units)	Maximum	Minimum	Median or Constant
Bulk Density of Plastic Liners, CH Waste (kilograms per cubic meter)	-	-	26.0
Bulk Density of Plastic Liners, RH Waste (kilograms per cubic meter)	-	-	3.1
BIR Total Volume of CH Waste (cubic meters)	-	-	1.69×10^5
BIR Total Volume of RH Waste (cubic meters)	-	-	7.08×10^3
Wicking Saturation (unitless)	1.0	0	0.5

equation, given along with other details in Appendix BRAGFLO (Section 4.13). The cellulose inventory is depleted on a cell-by-cell basis. Depending on parameter values, gas generation by microbial degradation can continue until all cellulosics in the cell are degraded. Reaction with MgO added to the repository consumes CO_2 (see Section 6.4.3.4 and Appendix SOTERM, Section SOTERM.2.2.2). Thus, the net quantity of gas developed by microbial degradation is correlated with constituents of the waste disposal region. Details are provided in Appendix BRAGFLO (Section 4.13). It is assumed that the microbial degradation process neither produces nor consumes water, but its rate is dependent on the amount of liquid present in a computational cell.

Microbial degradation may consume plastic and rubber materials in the repository. The DOE assumes that in half of those simulations in which microbial degradation of cellulosics occurs, microbial degradation also acts on plastic and rubber materials in the waste disposal region. As with cellulosics, these materials are depleted on a cell-by-cell basis. Parameter values for the average stoichiometry model are summarized in Table 6-10 and detailed in Appendix PAR (Parameters 1 through 5).

6.4.3.4 Chemical Conditions in the Repository

The chemical conditions in the repository determine actinide solubility, a property demonstrated in past analyses as important to disposal system performance. In scenarios that have the potential to result in releases to the accessible environment, the DOE has determined that chemical conditions in the repository can be modeled as constant in performance assessment. This use of constant conditions is based on an assumption of equilibrium for most processes between the brine in the repository (determined by the scenario being considered), waste, MgO backfill, and abundant minerals. Some exceptions to the equilibrium assumption are present in some performance assessment models and are discussed where appropriate. In addition to the following discussion, information supporting this position is presented in Appendix SOTERM.

Brine and waste within the WIPP repository are modeled as a uniform mixture of dissolved and solid-state species. Thermodynamic equilibrium is assumed for dissolved actinide

concentrations, but oxidation-reduction reactions between the actinides and other waste components are not assumed to proceed to equilibrium. Although materials in the waste will actually dissolve at different rates, the presumption of homogeneity and solubility equilibrium, along with assumed disequilibrium reduction-oxidation conditions, yields the largest reasonable concentration of aqueous actinides in the repository. No chemical microenvironments that influence the overall chemical environment are expected to persist, nor is supersaturation expected during the 10,000-year regulatory period. The average temperature of the WIPP is expected to increase by less than 6°C as a result of radioactive decay and exothermic reactions, such as MgO hydration and carbonization, and the effect of this small increase is assumed negligible (see Appendix WCA, Section WCA.5.3, and Appendix SCR, Sections SCR.2.2.2 and SCR.2.5.7).

Brine composition in the repository can vary depending on the sequence of future human events. Calculating mixing of brine from different sources is not amenable to performance assessment. The DOE has made the reasonable simplification that in the undisturbed performance and E2 scenarios, which do not include penetration of a Castile brine reservoir, all brine in the repository will have the composition of Salado brine (see Appendix SOTERM, Section SOTERM.2.2.1). In these scenarios, there is no process that could introduce Castile brine into the repository. For the E1 and E1E2 scenarios, which include penetration of a brine reservoir in the Castile, brine in the repository is assumed to have the composition of Castile brine at all times. Even though some Salado brine may enter the repository in these scenarios, it is reasonable to assume that Castile brine is the dominant portion of brine because the quantity of brine that can flow from a reservoir through a borehole and into the repository is substantial compared to the quantity of brine entering from the Salado.

The chemical environment in the repository after closure is expected to be reducing (that is, lowered oxidation states are expected to be favored). Any gaseous or dissolved oxygen present in the repository will be consumed quickly either by aerobic microbes or by oxic corrosion after repository closure. Moreover, the repository will contain large amounts of iron, and anoxic corrosion has been shown to produce considerable quantities of hydrogen gas and Fe^{2+} under expected repository conditions (see Appendix MASS, MASS Attachment 8-3). Despite the overall reducing conditions, however, a condition of reduction-oxidation disequilibrium is assumed in that reduction-oxidation reactions between dissolved actinides in possible oxidation states are assumed to not occur.

Based on experimental data reported in Appendix SOTERM (Sections SOTERM.2.2.2, SOTERM.3.4, and SOTERM.3.6), the DOE has determined that alkaline conditions in the repository favor lower actinide solubility. As discussed in Section 3.3.3 and Appendix BACK, MgO will be emplaced in the repository with the waste, in order to ensure alkaline conditions in the repository. MgO emplaced with the waste will react with the CO_2 that forms, creating magnesium carbonate minerals such as $MgCO_3$. The fugacity of CO_2 will be low and controlled by equilibrium considerations, rather than controlled by its rate of production by microbial degradation, because the DOE will emplace enough MgO with sufficient surface area to ensure CO_2 uptake will exceed the CO_2 production rate. Thus, by adding MgO to the repository, the DOE not only maintains alkaline conditions but also minimizes a property of

the repository, its CO_2 fugacity, that would be expected to vary with time and potentially complicate the estimation of actinide solubilities in performance assessment.

MgO reacts with brine to form $Mg(OH)_2$. $Mg(OH)_2$ will react with CO_2 produced by the microbial degradation of cellulosics by reactions such as

$$Mg(OH)_2 + CO_2 = MgCO_3 + H_2O \ . \tag{12}$$

There is a small amount of other alkaline components in the waste, such as $Ca(OH)_2$, contained in the cementitious waste. Their effect will be minimal because they will be consumed by reactions with $MgCl_2$ in the Salado brine and microbially generated CO_2. Details of those buffering reactions are described in Appendix SOTERM (Section SOTERM.2.2.2).

Because the processes that might cause time-dependent changes in important chemical conditions in the repository have been eliminated by the addition of MgO and by the assumptions made regarding brine composition, performance assessment uses constant chemical conditions. The chemical conditions in the repository, including the pmH (the $-\log_{10}$ of the molality of the hydrogen ion), are assumed to be controlled by equilibrium between minerals (that is, MgO, Salado halite, and anhydrite present in interbeds), brine present, and waste. In Salado brine, the pmH in this system will be about 9.4. In Castile brine, the pmH in this system will be about 9.9. In both systems, the carbon dioxide fugacity will be low and will be determined by the equilibrium system (see Appendix SOTERM, Section SOTERM.2.2.2, for a detailed discussion).

The waste contains chemical compounds, known as organic ligands, that can enhance the concentration of actinide ions by forming soluble complexes of these ions. The ligands of concern in the repository are acetate, citrate, oxalate, and ethylenediaminetetraacetate (EDTA) because they are soluble in brine and are known to be present in the waste (see WCA Section 8.11). However, these organic ligands also bond strongly to other metal species known to be in the repository system. The DOE assumes that because of this competition effect, the organic ligands will have no significant impact on the repository performance (see Appendix SOTERM, Section SOTERM.5, and Appendix SCR, Section SCR.2.5.6, for discussion).

6.4.3.5 Dissolved Actinide Source Term

Analysis reported in Appendix WCA (Section WCA.3) has demonstrated that the mobility in brine of the following actinides may be significant in the performance assessment of the WIPP: Th, U, Np, Pu, Cm, and Am. Although commonly referred to as actinides in the waste inventory, these substances are almost always present in the waste as solid actinide oxides or solid actinide salts, and if they dissolve in the WIPP brines, they will dissolve as complex ions. Additional discussion of actinide solubility modeling and the oxidation state distribution of the actinides is presented in Appendix SOTERM (Sections SOTERM.3 and SOTERM.4, respectively).

Actinides may be mobilized either by dissolution in brine as aqueous species, by bioaccumulation or sorption onto colloidal particles, or by condensation into colloidal forms as actinide-intrinsic colloids that could be carried by brine (see Section 6.4.3.6 for a discussion of colloidal actinides). The dissolved actinide source term model calculates the dissolved concentration of each actinide in solution by applying the modeled solubility for the particular oxidation state, as determined by the oxidation state distribution for that actinide, at the repository conditions presented in Section 6.4.3.4. Several oxidation states are not stable in the chemically reducing conditions described in Section 6.4.3.4. The unstable oxidation states are Np(VI), Pu(V), Pu(VI), and Am(V), as described in Appendix SOTERM (Section SOTERM.4).

Thorium will exist only in the IV oxidation state (see Appendix SOTERM, Section SOTERM.4.1). Am and Cm will exist in only the III oxidation state (see Appendix SOTERM, Sections SOTERM.4.4 and SOTERM.4.5). For the remaining actinides, Pu, U, and Np, it is uncertain whether repository conditions will favor the lower or higher of the remaining oxidation states (see Appendix SOTERM, Sections SOTERM.4.2, SOTERM.4.3, and SOTERM.4.6). The DOE has captured the range of possible behavior by assuming that in half the realizations, conditions within the repository are extremely reducing and the solubility of all three of these actinides will be adequately represented by the solubility of their lower oxidation states. In the other half of the realizations, the solubilities of these actinides are well represented by the solubilities of the higher of the possible oxidation states. The factors controlling the aqueous actinide concentration in a possible oxidation state are equilibrium with anhydrite, halite, MgO, and brine.

The solubility of the actinides as a function of equilibrium between anhydrite, halite, MgO, and brine is calculated outside of the performance assessment using FMT, a computer code for calculating actinide concentration limits based on thermodynamic parameters. The parameters for FMT are derived both from experimental investigations specifically designed to provide parameter values for this model and from the published literature. FMT and its application are described in Appendix SOTERM (Section SOTERM.3.5). Table 6-11 presents a summary of solubility parameter values for each actinide oxidation state consistent with the assumptions regarding chemical conditions stated in this section and Section 6.4.3.4. These values are documented in Table 6-11 and in Appendix PAR (Parameters 36 through 45 and Table PAR-39). Details of the generation of Table 6-11 are given in Appendix SOTERM (Section SOTERM.3).

Actinide concentration may not be equal to the values sampled in LHS. This condition could arise when there are not sufficient actinides in the solid phase in a particular cell, when combined with the dissolved actinides that may have been transported into that cell from an

Table 6-11. Summary of Dissolved Actinide Solubilities (moles per liter) in Castile and Salado Brines[a]

Actinides	Brine	Maximum	Minimum	Median[b] or Constant
Am(III), Pu(III), Cm(III)	Salado	1.46×10^{-5}	5.82×10^{-9}	4.73×10^{-7}
Pu(IV), Th(IV), U(IV)	Salado	1.11×10^{-4}	4.40×10^{-8}	3.58×10^{-6}
Np(IV)	Salado	-	-	4.40×10^{-6}
Np(V)	Salado	-	-	2.30×10^{-6}
U(VI)	Salado	2.19×10^{-4}	8.70×10^{-8}	7.07×10^{-6}
Am(III), Pu(III), Cm(III)	Castile	1.64×10^{-6}	6.52×10^{-10}	5.30×10^{-8}
Pu(IV)	Castile	1.51×10^{-7}	6.00×10^{-11}	4.88×10^{-9}
Th(IV)	Castile	-	-	6.00×10^{-9}
U(IV)	Castile	-	-	6.00×10^{-9}
Np(IV)	Castile	-	-	6.00×10^{-9}
Np(V)	Castile	-	-	2.20×10^{-6}
U(VI)	Castile	2.21×10^{-4}	8.80×10^{-8}	7.15×10^{-6}

[a] Inorganic chemistry controlled by the $Mg(OH)_2$ - $MgCO_3$ pair.
[b] Appendix SOTERM (Sections SOTERM.3.6 and SOTERM.7.2) discusses the relationship of this distribution to the modeled solubility.

adjacent cell, to achieve the concentration value as determined by LHS sampling. This situation is referred to as inventory limited.

The actinide inventory is depleted on a cell-by-cell basis by the computer code NUTS (NUclide Transport Systems) for the undisturbed, E1, and E2 scenarios. The treatment of the E1E2 scenario is described in Section 6.4.13.5. In a computational cell, the processes affecting actinide dissolved concentration are dissolution of solid actinide compounds, advection of dissolved actinides by brine flow from neighboring cells and interaction with colloidal particles (see Section 6.4.3.6). NUTS dissolves each actinide until the maximum concentration determined by the actinide source term algorithms is obtained or an inventory limit is reached. In the repository, the transfer of actinides between solid phase and solution is tracked to preserve mass balance of the actinide inventory. Outside the repository, the model does not precipitate actinides into the solid phase, thereby giving a conservative measure of mobile actinide quantities (see Appendix SCR, Section SCR.2.5.3.2).

6.4.3.6 Source Term for Colloidal Actinides

Colloidal actinides are discussed in greater detail in Appendix SOTERM (Section SOTERM.6). Colloidal particles form in the repository by a variety of processes, including waste degradation, microbial activity, rock decomposition, and chemical condensation. These particles may also be carried into the repository by liquids moving from the Salado or through boreholes. Because of the presence of soils, nutrients, and cellulosic substrates for microbial

action in WIPP waste (see Appendix BIR), humic substances and microbes will be present in disposal room brines, or may form in situ. Actinide-intrinsic colloids may form in the disposal rooms from condensation of dissolved actinides. Mineral fragments, as well as humic substances and microbes, may provide surfaces on which dissolved actinides may sorb.

Four types of colloidal particles are believed to cover the range of possible behavior of all colloid types (see Appendix SOTERM, Section SOTERM.6.1.2). The four particle types considered in performance assessment are microbes, humic and fulvic acids (humic substances), actinide-intrinsic (intrinsic), and mineral fragments. The concentration of actinides carried by each colloidal particle type depends on many of the same chemical conditions that govern the concentration of dissolved actinides.

Actinide concentrations associated with humic substances and microbes are linked to dissolved actinide concentrations through proportionality constants based on experimental results. For humic substances, actinide complexation constants from WIPP-specific experiments or from published literature are coupled with experimentally determined site-binding densities and solubilities of different types of humic substances in WIPP brines. For microbes, actinide uptake was experimentally determined through experiments with WIPP-relevant bacteria cultures. Actinide concentrations associated with mineral fragment-type colloidal particles are estimated based on results from experiments designed to determine mobile concentrations in brines, coupled with site-binding densities of mineral substrates. For the Pu(IV)-polymer, actinide concentrations are determined through solubility experiments conducted from over- and undersaturation over a range of pmH values. Intrinsic colloids of other actinides were determined to be of negligible importance and are eliminated from performance assessment calculations. For more discussion on this topic refer to Appendix SOTERM (Section SOTERM.6.3.2.2).

Actinides associated with microbes and humics are related to the concentration of dissolved actinides in the repository through proportionality constants determined from interpretation of WIPP-relevant experiments and the literature (Appendix SOTERM, Sections SOTERM.6.3.3 and SOTERM.6.3.4). The proportionality-constant relationship is not based rigorously on thermodynamic equilibrium but is simply an empirical relationship. The concentration of actinides associated with the Pu(IV)-polymer is a constant value determined from experimental results at the pmH conditions dictated by the presence of MgO backfill. Likewise, the concentration of actinides associated with mineral colloids is also a constant value, not linked to the concentration of dissolved actinides. Actinides associated with humics and microbes represent most of the colloidal actinide source term. Consequently, the colloidal actinide source term is closely related to the dissolved actinide source term. As discussed in Section 6.4.6.2, however, the source terms are considered separately for transport in the Culebra.

For performance assessment, the concentration of each actinide element on each colloidal particle type during a realization is a fixed value. The concentration parameters are summarized in Table 6-12. Actual values of actinide concentration on colloidal particles are constrained by inventory limits.

Table 6-12. Colloid Concentration Factors

	Concen-tration on Mineral Fragments[a]	Concen-tration as Intrinsic Colloid[a]	Proportion Sorbed on Microbes[b]	Maximum Sorbed on Microbes[c]	Proportion Sorbed on Humics[b]		Maximum Sorbed on Humics[a]
					Salado	Castile	
Th(IV)	2.6×10^{-8}	0.0	3.1	0.0019	6.3	6.3	1.1×10^{-5}
U(IV)	2.6×10^{-8}	0.0	0.0021	0.0021	6.3	6.3	1.1×10^{-5}
U(VI)	2.6×10^{-8}	0.0	0.0021	0.0023	0.12	0.51	1.1×10^{-5}
Np(IV)	2.6×10^{-8}	0.0	12.0	0.0027	6.3	6.3	1.1×10^{-5}
Np(V)	2.6×10^{-8}	0.0	12.0	0.0027	9.1×10^{-4}	7.4×10^{-3}	1.1×10^{-5}
Pu(III)	2.6×10^{-8}	0.0	0.3	6.8×10^{-5}	0.19	1.37[d]	1.1×10^{-5}
Pu(IV)	2.6×10^{-8}	1.0×10^{-9}	0.3	6.8×10^{-5}	6.3	6.3	1.1×10^{-5}
Am(III)	2.6×10^{-8}	0.0	3.6	NA	0.19	1.37[d]	1.1×10^{-5}

[a] In units of moles colloidal actinide per liter
[b] In units of moles colloidal actinide per mole dissolved actinide
[c] In units of moles total mobile actinide per liter
[d] A cumulative distribution from 0.065 to 1.60 with a mean value of 1.1 was used.
NOTE: The colloidal source term is added to the dissolved source term to arrive at a total source term. Mineral fragments were provided with distributions, but the maximum was used as described in Appendix SOTERM (Section SOTERM.7.1.3). Humic proportionality constants for III, IV, and V were provided with distributions, but only the Castile Am(III) and Pu(III) were sampled.

The concentrations of colloidal actinides indicated in this section are assumed to be concentrations of actinides mobilized on colloidal particles. The indicated concentrations will be entrained in moving brine. For conservatism, it is assumed that no actinides sorb onto colloidal particles that are not mobile in the repository. Thus all actinides in the repository will be present in the solid phase, dissolved in the aqueous phase, or as colloidal actinides suspended in the aqueous phase.

When actinide inventory in a model cell is sufficient, the concentration of colloidal actinides will be at the values indicated in Table 6-12. The total concentration of an actinide in solution and suspension is limited by the amount of solid available to dissolve from the inventory. This condition is called inventory-limited when it occurs.

Colloid concentrations are calculated by the source term procedure described in Appendix SOTERM (Sections SOTERM.7.1.4 and SOTERM.7.2). Processes affecting the transport of colloids in the Culebra are addressed in Section 6.4.6.2.2.

6.4.4 Shafts and Shaft Seals

The four shafts connecting the repository to the surface are represented in performance assessment with a single shaft, represented by Regions 2 through 11 on Figures 6-13 and 6-14. This single shaft has a cross section and volume equal to the total cross section and volume of the four real shafts it represents and is separated from the waste disposal regions in the model by the true north-south distance from the waste to the nearest shaft (the Waste Shaft). Upon closure of the repository, the shafts will be sealed as described in Section 3.3.1. The seal system is represented in performance assessment by discretizing 11 model regions in the shaft. These regions are as follows: an earthen fill region above the Rustler; a compacted clay column in the Rustler; an asphalt region at the top of the Salado; three concrete sections within the Salado; an upper Salado compacted clay column; a thick section of compacted crushed salt; a lower Salado compacted clay column separated into upper and lower segments; and a concrete monolith at the repository horizon (see Appendix SEAL, Section 4 and Appendix A). The concrete components in the Salado represent the concrete asphalt waterstops in the seal system design. Seal material parameter values used in the performance assessment are provided in Table 6-13.

Conceptually, the shafts are assumed to be surrounded by a DRZ in the Salado. Within the bedded halite, the DRZ begins to form immediately after excavation and develops progressively as a function of unloading as the formation creeps toward the excavated area. From a sealing perspective, the most important characteristic of the DRZ is the higher permeability that results from dilatant deformation and the increased pore volume.

The properties of the DRZ are known to vary with the type of adjacent material, time, and depth. When the shaft seals are emplaced, back pressures will progressively develop over time as the surrounding salt creeps inward. The back pressure applied by the seal material will progressively reduce the magnitude of the stress differential, which is the source for the DRZ microfracturing mechanism. The back pressure also results in a higher mean stress, which induces healing of the DRZ. The shaft DRZ permeability will, over time, approach that of the intact halite. Also, since the creep rate of the salt surrounding the shafts depends on depth, the back pressures supplied by the seal materials will result in DRZ healing at rates that increase with depth. The relative stiffness of the seal material is a factor, as well.

In the performance assessment model, the radial extent of the DRZ around the shaft seal materials is an input parameter obtained by numerical model calculations and is corroborated by field data (see Appendix SEAL, Section 8 and SEAL Appendix C). The permeability of the DRZ around the shaft versus distance is assumed to follow a log linear relationship. Permeability of the DRZ at the shaft wall is based on experimental data collected in the air intake shaft (Dale and Hurtado 1996) and Room M (Van Pelt 1995). More information on how the DRZ is incorporated into the shaft parameters is contained in Appendix PAR (Parameter 12).

Table 6-13. Shaft Materials Parameter Values

Parameter (units)	Maximum	Minimum	Median or Constant
ALL SHAFT MATERIALS			
Residual Brine Saturation, S_{br} (unitless)	0.6	0	0.2
Residual Gas Saturation, S_{gr} (unitless)	0.4	0	0.2
Pore Distribution, λ (unitless)	8.10	0.11	0.94
Maximum Capillary Pressure (pascals)[a]	-	-	10^8
Threshold Pressure, P_t (pascals)	-	-	0
CLAY SHAFT MATERIALS			
Permeability (square meters) - Rustler Compacted Clay[b]	5×10^{-18}	1.0×10^{-21}	5×10^{-19}
Permeability (square meters) - Upper Salado Compacted Clay[b]	5×10^{-18}	1.0×10^{-21}	5×10^{-19}
Permeability (square meters) - Lower Salado Compacted Clay[b]	5×10^{-18}	1.0×10^{-21}	5×10^{-19}
Permeability (square meters) - Bottom Clay[b]	5×10^{-18}	1.0×10^{-21}	5×10^{-19}
Thickness (meters) - Rustler Compacted Clay	-	-	94.3
Thickness (meters) - Upper Salado Compacted Clay	-	-	104.85
Thickness (meters) - Lower Salado Compacted Clay	-	-	23.9
Thickness (meters) - Bottom Clay	-	-	9.24
Effective Porosity (percent) - All Clays	-	-	24.0
Pore-Volume Compressibility (1/pascals) - Rustler Compacted Clay	-	-	1.96×10^{-9}
Pore-Volume Compressibility (1/pascals) - Upper Salado Compacted Clay	-	-	1.81×10^{-9}
Pore-Volume Compressibility (1/pascals) - Lower Salado Compacted Clay and Bottom Clay	-	-	1.59×10^{-9}
SALT SHAFT MATERIAL			
Permeability (square meters) - Salt[b]	2×10^{-18}	1×10^{-23}	5.4×10^{-21}
Thickness (meters) - Salt	-	-	171.37
Effective Porosity (percent) - Salt	-	-	5.0
Pore-Volume Compressibility (1/pascals) - Salt	-	-	1.60×10^{-9}
CONCRETE SHAFT MATERIALS			
Permeability (square meters) - Concrete (T < 400 years)	1×10^{-17}	1×10^{-23}	1.78×10^{-19}
Permeability (square meters) - Concrete (T > 400 years) and Concrete Monolith	-	-	1×10^{-14}
Thickness (meters) - Concrete	-	-	45.72
Thickness (meters) - Concrete Monolith	-	-	9.08
Effective Porosity (percent)	-	-	5.00
Threshold Pressure P_t (pascals) - All Concrete[a]	-	-	0
Pore-Volume Compressibility (1/pascals) - All Concrete	-	-	2.64×10^{-9}

Table 6-13. Shaft Materials Parameter Values (Continued)

Parameter (units)	Maximum	Minimum	Median or Constant
ASPHALT SHAFT MATERIAL			
Permeability (square meters) - (T = 0 - 10,000 years)	10^{-18}	10^{-21}	10^{-20}
Thickness (meters)	-	-	37.28
Effective Porosity (percent)	-	-	1.00
Pore-Volume Compressibility (1/pascals)	-	-	2.97×10^{-8}
EARTHEN FILL MATERIAL ABOVE RUSTLER			
Permeability (square meters) (T = 0 - 10,000 years)	-	-	1×10^{-14}
Thickness (meters)	-	-	165.06
Effective Porosity (percent)	-	-	32.0
Pore-Volume Compressibility (1/pascals)	-	-	3.1×10^{-8}

[a] Capillary pressure for all shaft materials is set to 0.
[b] These values represent the permeabilities of the seal material without the surrounding DRZ incorporated. See Appendix IRES, Section IRES.2, for time-dependent values.

The DRZ surrounding the shaft is not represented explicitly in the BRAGFLO mesh (Figures 6-13 to 6-15). Rather, the mesh has been simplified to represent only the cross-sectional area of the four WIPP shafts, and the permeability values for the various seal components at different times have been adjusted to account for the presence of the shaft DRZ. This adjustment, which yields effective permeabilities, can be done because in Darcy flow the flux through a porous medium is a linear function of the product of the permeability of the medium and the cross-sectional area across which flow occurs. Thus, the flux that would occur through a shaft and its surrounding DRZ can be modeled equivalently using the shaft cross-sectional area with a higher seal component permeability. Equations for the derivation of the effective permeabilities are given in Appendix PAR (Parameter 12) and Appendix IRES (Section IRES.2). The permeabilities of shaft components are calculated in the SCMS (see Section 6.4.11) from LHS parameter values according to these equations. Appendix IRES (Section IRES.2) shows calculated shaft component effective permeabilities.

6.4.5 The Salado

The Salado is the principal natural barrier to fluid flow between the waste disposal panels and the accessible environment. Fluid flow in natural conditions in the Salado is discussed in Section 2.2.1.3. Excavation of the repository has altered natural pressure gradients in the Salado, creating the potential for fluid flow into the excavation. Fluid flow, gas generation, and volume changes from creep closure cause changes in pressure gradients through time. Salt creep, as well as possible fracturing from high repository pressure, alters the permeability and other flow properties of the rock near the repository. Depending on pressure gradients

developed and altered material properties, gas and brine flow may be enhanced in affected portions of the Salado.

For performance assessment, the DOE conceptualizes the Salado as a porous medium composed of several rock types arranged in layers, through which flow occurs according to Darcy's law. Two rock types, impure halite and anhydrite, are used to represent the intact Salado. Once sampled, model parameters for all layers are uniform and constant, with two exceptions, porosity and permeability. Conceptually, this assumption of constant properties is based on observations of compositional and structural regularity in layers exposed by the repository and on the inference that there is little variation in large-scale averages of rock or flow properties across the disposal system. For several meters above and below the repository, a DRZ has increased permeability compared to intact rock and offers little resistance to flow between anhydrite interbeds and the repository. In all rock units, porosity can vary from initial values due to compressibility, depending on pressure changes in a computational grid block. As discussed in Section 6.4.5.2, a model has been implemented in interbeds to simulate the effects of fracturing caused by high repository pressure as pore pressure approaches or exceeds lithostatic.

Specific information about the three submodels used to represent impure halite, Salado interbeds, and the DRZ is presented in the following sections.

6.4.5.1 Impure Halite

The DOE uses a single porous medium with spatially constant rock and hydrologic properties (Region 19 in Figures 6-13 and 6-14) in performance assessment to represent intact, halite-rich layers in the Salado and minor interbeds contained within those layers that are not explicitly represented. A comparison has been made between the simplified stratigraphy used in the performance assessment model and a model with a more detailed stratigraphy in the vicinity of the repository; this comparison supports use of the stratigraphic representation used for performance assessment. This model comparison is described in Christian-Frear and Webb (1996).

Gas may not be able to flow through intact, halite-rich strata of the Salado under realistic conditions for the repository. Gas flow in liquid-saturated rock depends on the gas pressure required to overcome capillary resistance to initial gas penetration and development of interconnected gas pathways that allow gas flow (threshold pressure). While the permeability of halite is known to be low, its threshold pressure has never been measured. An empirical relationship between threshold pressure and permeability in non-WIPP rocks (Davies 1991, 17 – 19) suggests that threshold pressure will be sufficiently high that gas will not be able to flow through the halite-rich strata of the Salado under any conditions foreseeable for the WIPP (see Appendix MASS, Section MASS.13.1). Values used by the DOE for halite threshold pressure are consistent for generic material of low permeability and prevent the flow of gas into the impure halite regions (Table 6-14). This is a conservative assumption because gas flow in halite would decrease the pressure in the repository and the driving force available for flow elsewhere. Table 6-14 shows various parameter values used in modeling the Salado

impure halite. Additional information on parameter values is contained in Appendix PAR (Parameters 17 through 19 and Table PAR-32).

Table 6-14. Salado Impure Halite Parameter Values

Parameter (units)[a]	Maximum	Minimum	Median or Constant
Permeability (square meters)	10^{-21}	10^{-24}	3.16×10^{-23}
Effective Porosity (percent)	3.0	0.10	1.0
Threshold Pressure, P_t (pascals)[b]	1.13×10^{8}	1.03×10^{7}	3.41×10^{7}
Residual Brine Saturation, S_{br} (unitless)	-	-	0.3
Residual Gas Saturation, S_{gr} (unitless)	-	-	0.2
Pore Distribution Parameter, λ (unitless)	-	-	0.7
Maximum Capillary Pressure (pascals)	-	-	10^{8}
Rock Compressibility (1/pascals)[c]	1.92×10^{-10}	2.94×10^{-12}	9.75×10^{-11}

[a] See Table 6-9 for fluid properties.
[b] Threshold pressure (P_t) determined from the relationship: $P_t = PCT_A \cdot k^{PCT_EXP}$ where PCT_A and PCT_EXP are constants and k is the permeability.
[c] Pore compressibility = Rock compressibility/effective porosity.

6.4.5.2 Salado Interbeds

Three distinct anhydrite interbeds are modeled in BRAGFLO, representing MB138 (Region 20 in Figures 6-13 and 6-14), anhydrite layers a and b (Region 21), and MB139 (Region 28). The three intact interbeds have the same set of model parameters, and the parameters are initially spatially constant. Porosity and permeability can vary spatially during a simulation depending on the extent of interbed fracturing. The interbeds differ only in position and thickness.

The three interbeds explicitly represented in the BRAGFLO model are included because they exist in the disturbed region around the repository within which fluid is expected to be able to flow with relative ease compared to the surrounding formation. MB139 and anhydrite layers a and b are present within the DRZ that forms around excavations. MB138 is included along with a thick DRZ because of uncertainty in the extent and properties of the DRZ and the associated long-term isolation of MB138 from the repository.

In BRAGFLO, brine flows between the Salado and the repository in response to fluid potential gradients that may form over time. Because of the low permeability of the impure halite and relatively small surface area involved, direct brine flow between the impure halite and the repository is relatively small. The interbeds included in the BRAGFLO model of the Salado (Regions 20, 21, and 28), however, can serve as conduits for brine flow between the impure halite and the repository. Conceptually, brine flows laterally along higher permeability interbeds towards or away from the repository and vertically between the interbeds and the

lower permeability halite. Because the interbeds have a very large contact area with adjacent halite-rich rock, even a very small flux from the halite into the interbeds (for brine inflow) or to the halite from the interbeds (for brine outflow) can accumulate into a significant quantity of brine. In this manner, halite serves as a source or sink for brine in the repository. It is expected that, because of density differences between gas and brine and their stratification within the repository, brine outflow will be dominantly in MB139, and gas outflow will occur in anhydrite a and b or MB138. However, the model does not preclude other flow patterns.

Interbeds contain natural fractures that may be partially healed. If high pressure is developed in an interbed, its preexisting fractures may dilate or new fractures may form, altering its porosity and permeability. Pressure-dependent changes in permeability are supported by experiments conducted in the WIPP underground and in the laboratory (Beauheim et al. 1993). Accordingly, the DOE has implemented in BRAGFLO a porous-media model of interbed dilation and fracturing that causes the porosity and permeability of a computational cell in an interbed to increase as its pore pressure rises above a threshold value. Model details are presented in Appendix BRAGFLO (Section 4.10) and Appendix MASS (Section MASS.13.3). To the extent that it occurs, dilation or fracturing of interbeds is expected to increase the transmissivity of interbed intervals. The threshold pressure of dilated or fractured interbeds is expected to be low because apertures of the fractures increase; thus, fluid is expected to be able to flow outward readily if adequate pressure is available to dilate the interbeds.

The model used to simulate the effects of interbed dilation or fracturing is explained in detail in Appendix BRAGFLO (Section 4.10). In summary, it assigns a fracture initiation pressure above the initial pressure at which local fracturing takes place, and changes in permeability and porosity occur above this pressure. Below this fracture initiation pressure, an interbed has the permeability and compressibility assigned by LHS and representative of intact rock. Below the fracture initiation pressure, the initial sampled porosity is modified slightly with pressure caused by compressibility. Above the fracture initiation pressure, the local compressibility of the interbed is assumed to increase linearly with pressure. This greatly increases the rate at which porosity increases with increasing pore pressure. Additionally, permeability increases by a power function of the ratio of altered porosity to initial porosity. For numerical reasons (that is, to prevent unbounded changes in parameter values that would create numerical instabilities in codes), a pressure is specified above which porosity and permeability change no further.

Parameters associated with the interbeds are shown in Table 6-15. Table 6-16 lists parameters used in the model of interbed dilation and fracture. Additional information about interbed parameters is included in Appendix PAR (Table PAR-36 and Parameters 20 through 25).

Table 6-15. Parameter Values for Salado Anhydrite Interbeds a and b, and MB138 and MB139

Parameter (units)[a]	Maximum	Minimum	Median or Constant
Permeability (square meters)	7.94×10^{-18}	10^{-21}	1.29×10^{-19}
Effective Porosity (percent)	-	-	1.1
Threshold Pressure, P_t (pascals)[b]	5.28×10^{6}	2.32×10^{5}	9.74×10^{5}
Residual Brine Saturation, S_{br} (unitless)	0.174	0.007846	0.084
Residual Gas Saturation, S_{gr} (unitless)	0.197	0.014	0.077
Pore Distribution Parameter, λ (unitless)	0.842	0.491	0.644
Maximum Capillary Pressure (pascals)	-	-	10^{8}
Rock Compressibility (1/pascals)[c]	2.75×10^{-10}	1.09×10^{-11}	8.26×10^{-11}
Brine Far-Field Pore Pressure at elevation of MB139 and shaft intersection (pascals)	13.9×10^{6}	11.0×10^{6}	12.5×10^{6}

[a] See Table 6-9 for fluid properties.
[b] Threshold pressure (P_t) determined from the relationship: $P_t = PCT_A \cdot k^{PCT_EXP}$ where PCT_A and PCT_EXP are constants and k is the permeability.
[c] Pore compressibility = Rock compressibility/effective porosity.

Table 6-16. Fracture Parameter Values for Salado Anhydrite Interbeds a and b, and MB138 and MB139

Parameter (units)	Constant
Fracture Initiation Pressure at MB139, base of shaft (pascals)	12.7×10^{6}
Increment to give Full Fracture Porosity (percent), MB139 and MB138[a]	3.9
Increment to give Full Fracture Porosity (percent), Anhydrite a and b[a]	23.9
Full Fracture Permeability (square meters)	10^{-9}
Increment above Fracture Initiation Pressure to Obtain Full Fracture Pressure (pascals)[a]	3.8×10^{6}

[a] A fitting parameter to yield desired dilation over a variation in pressure.

6.4.5.3 DRZ

In the DRZ (Region 22 in Figures 6-13 and 6-14) near the repository, permeability and porosity are expected to generally increase in both halite and interbeds. These increases are due to a variety of processes. Creep closure and stress-field alterations as the result of the excavation are the dominant causes, similar to the processes discussed for the formation of the DRZ around the shaft (see Section 6.4.4). The increases in permeability and porosity in interbeds are not expected to be completely reversible with creep closure of the disposal rooms. The increase in DRZ permeability increases the ability of fluid to flow from interbeds to the waste disposal region. The increase in DRZ porosity provides a volume in which some

fluid could be retained so that it does not contact waste, or slows actinide movement. Performance assessment approximates the effects of the DRZ conservatively with respect to brine flow to the repository (see Appendix MASS, Section MASS.13.4). In the model, the permeability of this region is increased relative to intact Salado rock for the duration of a realization. The porosity of the modeled DRZ is increased by a fixed value of 0.0029 (0.29 percent) above the sampled intact Salado impure halite. The modeled DRZ extends above and below the repository from the base of MB138 to MB139. The performance assessment treatment of the DRZ creates a permanent high-permeability region that does not significantly impede flow between the repository and affected interbeds. Table 6-17 shows parameter values used in the performance assessment representation of the DRZ.

Table 6-17. DRZ Parameter Values

Parameter (units)[a]	Maximum	Minimum	Median or Constant
Permeability (square meters)	-	-	10^{-15}
Effective Porosity (percent)[b]	-	-	1.29
Threshold Pressure, P_t (pascals)	-	-	0
Residual Brine Saturation, S_{br} (unitless)	-	-	0
Residual Gas Saturation, S_{gr} (unitless)	-	-	0
Pore Distribution Parameter, λ (unitless)	-	-	0.7
Maximum Capillary Pressure (pascals)	-	-	10^{8}
Rock Compressibility (1/pascals)[c]	-	-	7.41×10^{-10}

[a] See Table 6-9 for fluid properties.
[b] The DRZ effective porosity value for each realization is equivalent to the sampled value for the Salado halite plus 0.0029 (0.0029 is the difference between the medians for the DRZ and the halite).
[c] Pore compressibility = rock compressibility/effective porosity.

6.4.5.4 Actinide Transport in the Salado

Actinide transport in the Salado is considered by the DOE to be a possible mechanism for release to the accessible environment. As in other areas of the disposal system, actinides in the Salado may be transported as dissolved species or as colloidal particles. Actinide transport is affected by a variety of processes that may occur along the flow path.

The DOE uses the NUTS code (see Appendix NUTS) to model the migration of radionuclides in the repository and surrounding formations. NUTS models radionuclide transport within all regions for which BRAGFLO computes brine and gas flow, and uses as input for each realization the corresponding BRAGFLO velocity field, pressures, porosities, saturations, and other model parameters including, for example, the geometrical grid, residual saturation, material map, and compressibility.

NUTS is used in two ways in the performance assessment. First, the code is used in a computationally fast tracer mode to identify those BRAGFLO realizations for which it is not necessary to do full transport calculations because contaminated brine never reaches the top of the salt or the accessible environment within the Salado. Such realizations have no potential to contribute to the total integrated release of radionuclides from the disposal system. If the tracer calculation indicates a possibility of consequential release, a computationally slow calculation of the full transport of each radionuclide is performed.

6.4.5.4.1 NUTS Tracer Calculations

All BRAGFLO realizations are evaluated using NUTS in a tracer mode to identify those realizations for which there is no possibility of radionuclides reaching the accessible environment. The tracer simulations consider an infinitely soluble, nondecaying, nondispersive, and nonsorbing species as a tracer element. The tracer is given a unit concentration in all waste disposal areas of 1 kilogram per cubic meter. If this tracer does not reach the selected boundaries (the top of the Salado and the land withdrawal boundary within the Salado) in a cumulative mass greater than or equal to 10^{-7} kilograms within 10,000 years, then it is assumed that there is no consequential release to these boundaries. If a cumulative mass greater than or equal to 10^{-7} kilograms does reach the selected boundaries within 10,000 years, a complete transport analysis is conducted. The value of 10^{-7} kilograms is selected because, regardless of the isotopic composition of the release, it corresponds to a normalized release less than 10^{-6} EPA units, which is the smallest release displayed in CCDF construction. The largest normalized release corresponding to 10^{-7} kilograms would occur if the release were entirely ^{241}Am and would be 9.98×10^{-7} EPA units.

6.4.5.4.2 NUTS Transport Calculations

For those BRAGFLO realizations with greater than 10^{-7} kilograms reaching the boundaries in the tracer calculations, NUTS models the transport of five different species of radionuclides (^{241}Am, ^{239}Pu, ^{238}Pu, ^{234}U, and ^{230}Th). These radionuclides represent a lumping of a larger number of radionuclides, as discussed in Appendix WCA (Sections WCA.3 and WCA.8.3). For decay purposes, radionuclides have been lumped together based on similarities to simplify the calculations, as discussed in Appendix WCA. For transport purposes, solubilities are lumped to represent both dissolved and colloidal forms. These lumpings simplify and expedite calculations.

NUTS models radionuclide transport by advection (see Appendix MASS, Section MASS.13.5). NUTS disregards sorptive and other retarding effects throughout the entire flow region. Physically, some degree of retardation must occur at some locations within the repository and the geologic media, and the disregard of retardation processes is therefore conservative. NUTS also disregards reaction-rate aspects of dissolution and colloid formation processes, and mobilization is assumed to occur instantaneously. Neither molecular nor mechanical dispersion is modeled in NUTS. These processes are assumed to be insignificant in comparison to advection, as discussed further in Appendix MASS (Section MASS.13.5).

Colloidal actinides are subject to retardation by chemical interaction between colloids and solid surfaces and by clogging of small pore throats (that is, sieving). It is expected that there will be some interaction of colloids with solid surfaces in the anhydrite interbeds. As well, because of the low permeability of intact interbeds, it is expected that pore apertures are small and some sieving will occur. However, colloidal particles, if not retarded, are transported slightly more rapidly than the average velocity of the bulk liquid flow. Because the effects on transport of slightly increased average pore velocity and retarding interactions with solid surfaces and sieving are offsetting, the DOE assumes residual effects of these opposing processes will be either small or beneficial and does not incorporate them in modeling of the transport of actinides in the Salado interbeds.

If brine that has been in the repository moves into interbeds, it is likely that mineral precipitation reactions will occur. Precipitated minerals may contain actinides as trace constituents. The beneficial effects of the possible mineral co-precipitation process are neglected in performance assessment. Furthermore, colloidal-sized precipitates will behave like mineral-fragment colloids, which are destabilized by brines, quickly agglomerate and settle by gravity. The beneficial consequence of colloid precipitation is disregarded in performance assessment also.

Additional processes that may impact transport in Salado interbeds are related to fractures, channeling, and viscous fingering. Interbeds contain natural fractures. Because of the low permeability of unfractured anhydrite, it is expected that most fluid flow occurring in interbeds will occur in fractures. Even though some properties of naturally fractured interbeds are characterized by in-situ tests (see Section 2.2.1.3), other uncertainty exists in the characteristics of the fracture network that may be created if gas pressure in the repository becomes high. The performance assessment modeling system accounts for the possible effects on porosity and permeability of fracturing through the implementation of a fracturing model (see Section 6.4.5.2). It is considered that the processes and effects associated with fracture dilation or fracture propagation that are not already captured by the performance assessment fracture model will be negligible (see Appendix MASS, Section MASS.13.3 and MASS Attachment 13.2). Of those processes not already incorporated, channeling is considered to have the greatest potential effect.

Channeling is the movement of fluid through the larger aperture portions of a fracture network (that is, areas of local high permeability). It could locally enhance actinide transport. However, it is assumed that the effects of channeled flow in existing or altered fractures will be negligible on the scale of the disposal system. The DOE believes this assumption to be reasonable because processes that act to limit the effectiveness of channels or disperse actinides in them are likely to occur. First, if gas is present in the fracture network, it will be present as the nonwetting phase and will occupy the portions of the fracture network with relatively large apertures, where the highest permeabilities will exist locally. The presence of gas thus removes the most rapid transport pathways from the contaminated brine and decreases the impact of channeling. Second, brine penetrating the Salado from the repository is likely to be completely miscible with in-situ brine. Because of miscibility, diffusion or other

local mixing processes will probably broaden fingers (reduce concentration gradients) until the propagating fingers are indistinguishable from the advancing front.

It is expected that gas will penetrate the liquid-saturated interbeds as a fingered front rather than as a uniform front. Fingers form because of the difference in viscosity between the invading fluid (gas) and the resident fluid (liquid brine), and because of channeling effects. This process does not affect actinide transport, however, because actinides of interest are transported only in the liquid phase, and the liquid phase will not displace gas in the relatively high-permeability regions because of capillary effects.

6.4.6 Units Above the Salado

The geology and hydrology of units above the Salado are discussed in Sections 2.1.3 and 2.2.1.4, respectively. In this section, the assumptions, simplifications, and models used in performance assessment modeling of these units are described. Because it is unlikely that these units will be impacted by undisturbed performance, modeling of these units is performed mainly because regulations require consideration of the effects of inadvertent human intrusions. See Appendix MASS (Section MASS.14) for additional discussion on the units above the Salado.

The principal purpose of BRAGFLO calculations for units above the Salado is to determine the quantity of brine entering each unit from an intrusion borehole or the shaft. It is unrealistic to assume that all flow up an intrusion borehole enters the Culebra. Accordingly, BRAGFLO parameters are specified such that brine flow from the intrusion borehole is possible not only into the Culebra but also into the Magenta, Dewey Lake, and overlying units (as well as to the ground surface), depending on whether liquid rises above the Culebra in the intrusion borehole. Some of the assumptions regarding the properties of the units above the Salado are made specifically because they allow model simplification and are conservative with respect to actinide transport in the Culebra (that is, tend to cause overestimates of release).

Consistent with accepted stratigraphic conventions for the area, discussed in Section 2.1.3, the units above the Salado are subdivided into seven layers in performance assessment; these are, in order of lower-to-higher, the unnamed lower member, the Culebra, the Tamarisk, the Magenta, the Forty-niner, the Dewey Lake, and the units above the Dewey Lake. The conceptual model for each of these layers is described sequentially in the following sections.

A fundamental assumption in the conceptual model used in performance assessment for modeling actinide transport to the accessible environment in units above the Salado is that lateral actinide transport through rock formations is possible within the next 10,000 years only in the Culebra. This assumption is appropriate for several reasons relating to the properties of the other rock units and the groundwater basin conceptual model, which are discussed in following sections.

Section 2.2.1.4 describes the hydrology of the units above the Salado in terms of the groundwater basin conceptual model. Insight into the processes occurring in the groundwater basin obtained by modeling and other lines of evidence indicates that significant simplification of the hydrologic models in the units above the Salado is possible to obtain reasonable estimates of actinide transport (see Corbet and Knupp 1996; Appendix MASS, Section MASS.14.2). Therefore, the DOE calculates actinide transport in the units above the Salado with a two-dimensional conceptual and mathematical model. The models used for actinide transport in the units above the Salado are a simplified implementation of the groundwater basin conceptual model. The mathematical model is implemented in the computer codes SECOFL2D and SECOTP2D.

6.4.6.1 Unnamed Lower Member

The unnamed lower member of the Rustler (Region 18 in Figures 6-13 and 6-14) rests above the Salado. Its transmissivity has been measured (see Section 2.2.1.4.1.1) and was found to be low, which is consistent with expectations based on its anhydrite, gypsum, halite, clay, and siltstone composition (see Section 2.1.3.5.1). In performance assessment, this member is treated as impermeable, which prevents liquid flow and actinides from entering this unit. The DOE assumes that because of the low permeability of the unnamed lower member, any brine entering it adjacent to an intrusion borehole would be contained well within the site boundary for more than 10,000 years. Therefore, this treatment is conservative, regarding estimated releases into the Culebra, because allowing flow from a borehole or shaft into the unnamed lower member would, if anything, decrease flow into the Culebra. This would have a tendency to reduce the release of actinides from the Culebra to the accessible environment. In performance assessment, the thickness of the unnamed lower member is 118 feet (36 meters), and its permeability is zero.

6.4.6.2 The Culebra

The Culebra is represented in BRAGFLO as Region 17 in Figures 6-13 and 6-14. The model geometries for Culebra flow calculations and transport calculations are discussed in this section. Boundary and initial conditions for this geometry are discussed in Section 6.4.10.2. Supplementing the discussion in this section are additional details about the Culebra modeling provided in Section 6.4.13 and Appendices SECOFL2D, SECOTP2D, MASS (Section MASS.15), and TFIELD (Sections TFIELD.2.2 and TFIELD.4).

Conceptually, radionuclides might be introduced into the Culebra through brine flow up the sealed shafts. However, the chief source of actinides in the Culebra is modeled as long-term releases from a borehole that intersects the repository. If radionuclides are introduced into the Culebra, they may be transported from the point of introduction by groundwater flowing naturally through the Culebra.

The Culebra is conceptualized as a horizontal, confined aquifer. For fluid flow, it is conceptualized as a heterogeneous porous medium which is represented by variations in transmissivity. A heterogeneous velocity field is used for transport calculations, but all other rock properties are conceptualized as constant (homogeneous) across the model area. The Culebra is conceptualized as having two types of porosity; a portion of the porosity is associated with high-permeability features where transport occurs by advection, and the rest of the porosity is associated with low-permeability features where flow does not occur and retardation occurs by physical processes (diffusion) and chemical processes (sorption). This type of conceptual model is commonly referred to as double-porosity. In this conceptual model, transport and retardation of colloidal particles is also considered. In this section, the principal topic will be fluid flow in the Culebra. The transport and retardation of dissolved actinides will be discussed principally in Section 6.4.6.2.1. The transport and retardation of colloidal particles will be discussed principally in Section 6.4.6.2.2.

In the Culebra conceptual model used in performance assessment, the spatial distribution of transmissivity in the Culebra is important. Other potentially important processes acting on Culebra flow and transport are climate change (Section 6.4.9 and Appendix MASS, Section MASS.17) and the effects of subsidence caused by potash mining in the McNutt (Section 6.4.6.2.3 and Appendix MASS, Section MASS.15.4).

The SECOFL2D code uses two-dimensional horizontal grids to simulate groundwater flow. A regional grid approximately 14 miles by 19 miles (22 kilometers by 30 kilometers) with spatially varying transmissivity (Figure 6-17) is used to determine the flow fields in the WIPP region resulting from hydraulic head distributions that are controlled by distant topographic and hydrologic features (that is, boundary conditions). Because this grid is used to define the boundary conditions for the flow and transport calculations, it is discussed in detail in Section 6.4.10.2, together with the specification of initial and boundary conditions. For transport in the region of interest within the disposal system, a local grid 4 miles by 4 miles (7 kilometers by 7 kilometers) with finer discretization is used in both SECOFL2D and SECOTP2D (Figure 6-18). Boundary heads and fluxes for the local grid are obtained by interpolation from the regional flow field. The grid for the local domain contains 75 columns and 65 rows, resulting in 4,875 grid blocks.

Boundaries of the local domain were chosen to capture important flow paths and facilitate the computation of integrated release to the accessible environment. Because past analyses have indicated that transport in the Culebra will occur within a region that lies from southeast of the repository to west of the repository, the local domain extends slightly beyond the southern and western boundaries of the controlled area. Because it is not needed, a strip in the northern portion of the controlled area has been omitted from the local domain to ease the computational burden.

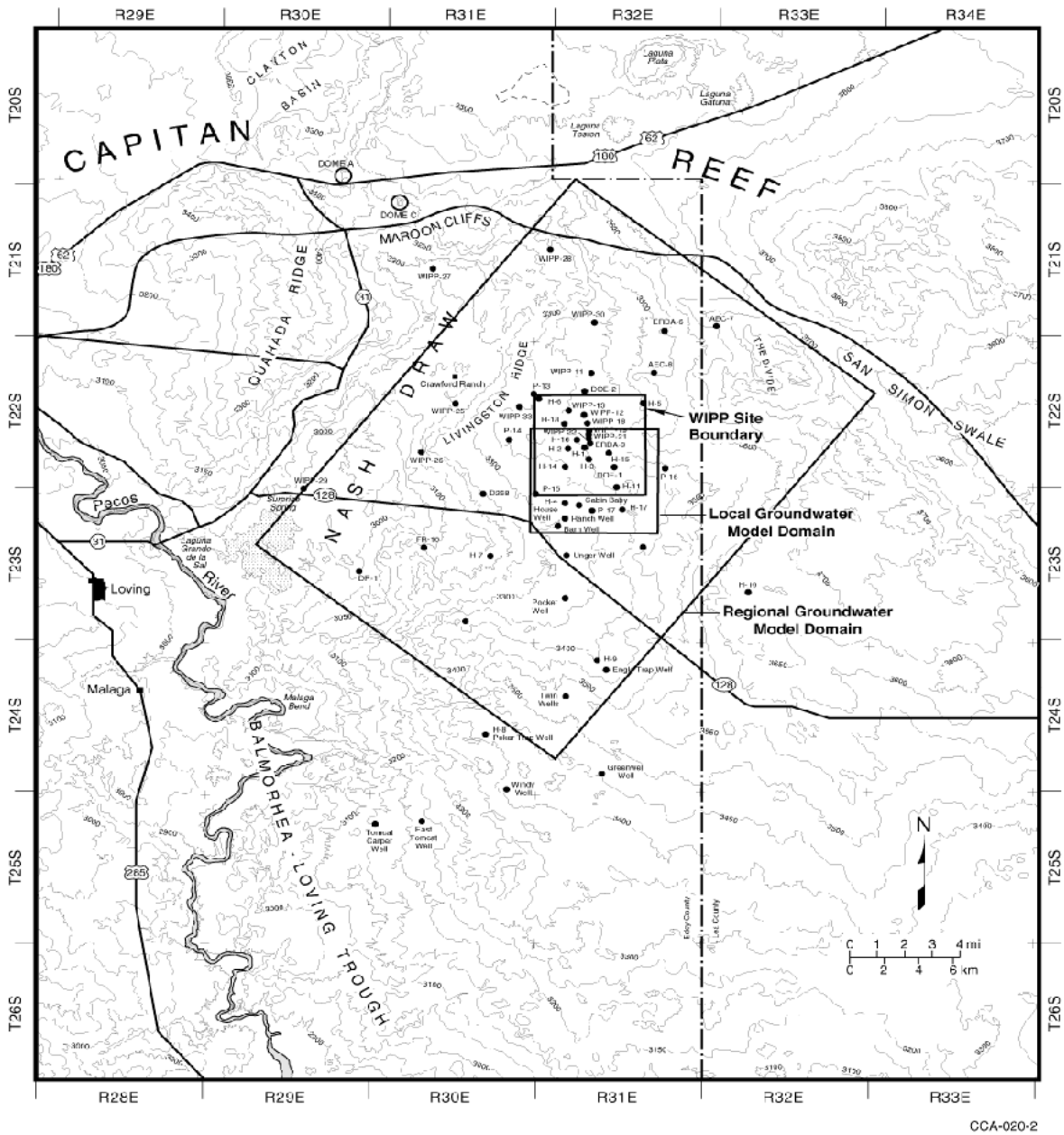

Figure 6-17. The Regional and Local Domains Used in the Horizontal Groundwater Model of the Culebra

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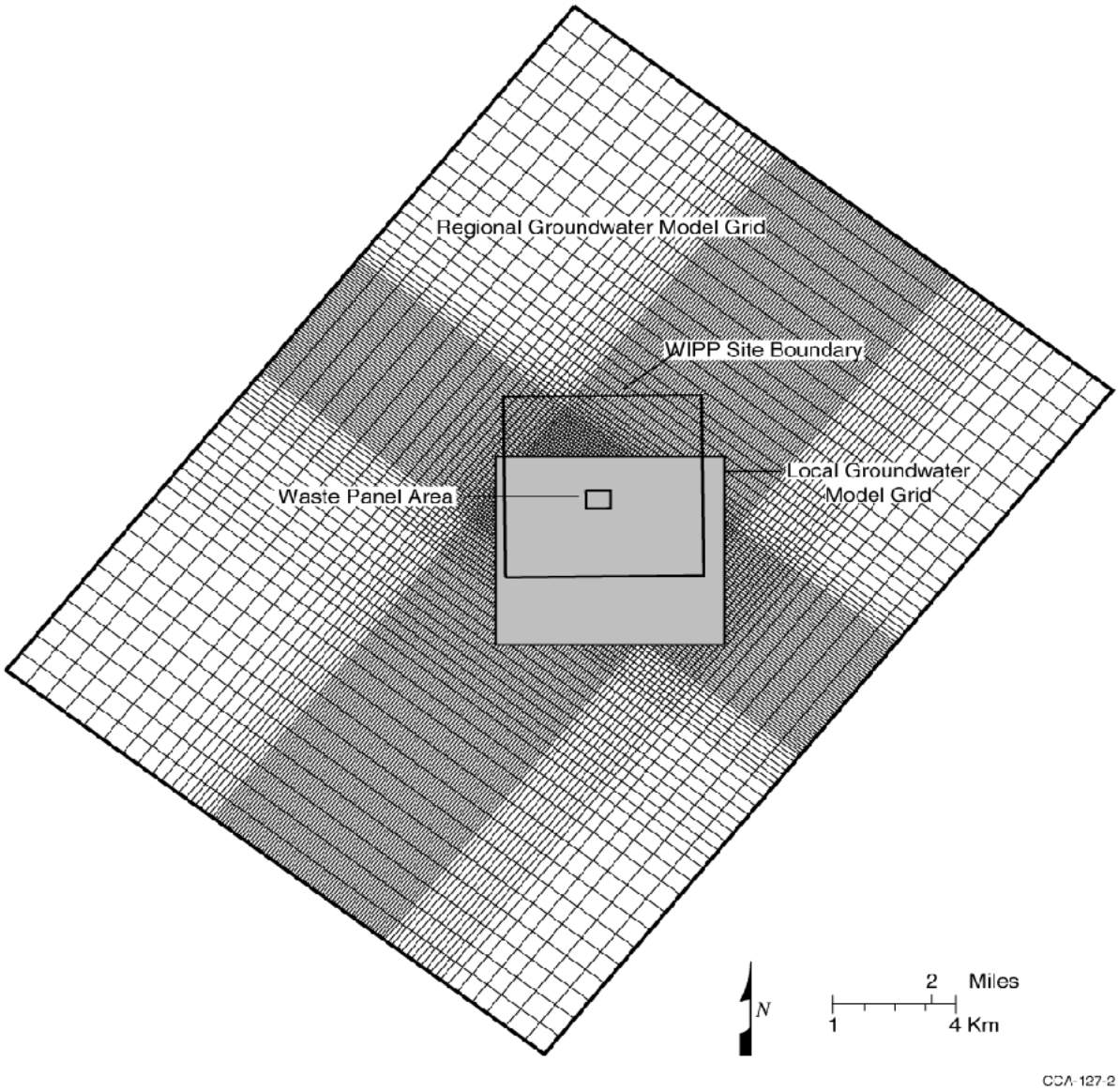

Figure 6-18. The Discretization Used in Modeling Groundwater Flow in the Culebra

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Flow directions and transmissivities in the Culebra vary significantly from location to location to a considerable distance from the site boundary. Consequently, the effects of flow in the region around the WIPP site are considered important in the conceptual model. The boundaries to the flow model are discussed in Section 6.4.10.2; the grid itself is shown in Figure 6-18.

The conceptual model for the Culebra assumes that fluid fluxes and directions in the future will be the same as they are projected to be at repository closure, unless future mining within the site occurs, in which case changes to fluid flow are calculated. A steady-state flow field is used to represent this assumption. Conditions assumed at site closure are the subsidence effects of mining in the near future outside the site boundary, climate change, and a reasonable estimate of the hydraulic conditions that existed prior to disturbances to the Culebra caused by site characterization activities (see Appendix MASS, Sections MASS.15.4 and MASS.14.2, and Appendix TFIELD, Section TFIELD.2.2).

The factors controlling fluid flow in the Culebra are conceptualized to be the hydraulic gradient, transmissivity distribution, and porosity. The hydraulic gradient and transmissivities used in performance assessment are coupled because they are calibrated to observed conditions by a process described in Appendix TFIELD (Section TFIELD.3). Flow fields are calculated with the code SECOFL2D using an assumption of homogeneous porosity in the Culebra. This single value is the total porosity for the Culebra, including both advective and diffusive porosity, as discussed below. Use of a single porosity for the flow calculation does not introduce inconsistency with transport calculations because (1) steady-state flow fields are used so flux through the system is not dependent on porosity, and (2) the velocity of liquid for transport is calculated based on a double-porosity model implemented in the code SECOTP2D. Thus, the important factors for flow calculations are the hydraulic gradient and transmissivity variation.

Because BRAGFLO models a vertical section of the disposal system, the spatial distribution of transmissivity cannot be represented in the BRAGFLO grid. The source term of actinides in the Culebra is calculated in part from BRAGFLO flow fields, so parameters for the Culebra are required in BRAGFLO. Specifically, a single value of Culebra permeability representative for the Culebra in the area immediately over the waste-emplacement panels is input to partition fluid flow among the stratigraphic units along the human-intrusion borehole.

BRAGFLO calculates gas flow and brine flow that may occur up a borehole (see Section 6.4.7). The SECO codes model flow of the liquid phase only. The possible effects of gas on Culebra flow are not modeled in the SECO codes. This simplification is reasonable because after gas pressure is relieved by flow to the surface during drilling, little gas will remain in the repository. This gas will move up the borehole at low rates and tend to move directly to the top of the liquid-saturated section of the borehole, bypassing the Culebra. Any gas that does enter the Culebra will tend to displace brine from fractures and reduce the potential for actinide transport. Based on previous modeling (Lappin et al. 1989, Appendix E.1.5.1), the effect of the mass of brine being injected into the Culebra on the natural flow in the Culebra is negligible. Parameter values used in BRAGFLO to describe the Culebra are shown in

Table 6-18. Parameter values used in SECOFL2D are shown in Table 6-19. See Appendix PAR (Table PAR-30) and relevant Culebra parameter sheets, for additional information.

Table 6-18. Culebra Parameter Values for the BRAGFLO Model

Parameter (units)[a]	Value
Permeability (square meters)	2.1×10^{-14}
Effective Porosity (percent)	15.1
Rock Compressibility (1/pascals)[b]	10^{-10}
Threshold Pressure, P_t (pascals)[c]	1.5×10^{4}
Residual Brine Saturation, S_{br} (unitless)	0.084
Residual Gas Saturation, S_{gr} (unitless)	0.077
Pore Distribution Parameter, λ (unitless)	0.644
Maximum Capillary Pressure (pascals)	10^{8}
Thickness (meters)	7.70
Initial Pressure (pascals)	8.22×10^{5}

[a] See Table 6-9 for fluid properties in BRAGFLO.
[b] Pore compressibility = rock compressibility/effective porosity.
[c] Threshold pressure (p_t) determined from relationship: $P_t = PCT_A \cdot k^{PCT_EXP}$, where PCT_A and PCT_EXP are constants and k is the permeability.

Table 6-19. SECO Fluid Properties

Parameter (units)	Value
Liquid Density (kilograms per cubic meter)	1,000
Liquid Compressibility (1/pascals)	4.4×10^{-10}

Three different thicknesses of the Culebra have been assumed in performance assessment modeling. BRAGFLO uses a thickness of 25.3 feet (7.7 meters), representative of the Culebra over the waste disposal panels. For calibrating transmissivity fields (see Appendix TFIELD, Section 4.4.1) and calculating flow in the Culebra with SECOFL2D, a thickness of 25.4 feet (7.75 meters) is assumed, consistent with an average thickness over the area modeled. For transport calculations using the code SECOTP2D, a thickness of 13 feet (4 meters) is assumed, consistent with observations of the thickness of the Culebra active in transport, which are discussed in Section 6.4.6.2.1. Use of different thicknesses does not introduce inconsistencies in the modeling, however, because the transmissivities used in these codes are consistent, and it is this parameter that governs the total flux of fluid through the Culebra. Furthermore, the fluid flux used in the SECOTP2D model is the same as that calculated by SECOFL2D, ensuring consistency.

The spatial variation in transmissivity observed in the Culebra is incorporated by assigning different transmissivity values to every computational cell in the model. Because there is uncertainty in the estimated value of Culebra transmissivity in areas where measurements have not been made, a large set of transmissivity fields is developed. Each transmissivity field is a statistical representation of the natural variation in transmissivity that honors measured data according to certain criteria. For a set of transmissivity fields generated with identical constraints, each field is equally likely to represent actual conditions. Monte Carlo simulations using a large number of equally-likely transmissivity fields is a statistically sound method of characterizing the uncertainty associated with transmissivity in the Culebra. For details of the generation and use of transmissivity fields, refer to Appendix TFIELD (Section TFIELD.4.1).

Regional flow directions and fluxes are calculated with the regional domain, as described earlier and shown in Figures 6-17 and 6-18. For increased resolution of transport processes in the region where transport is important, a finer grid is used. Consistency between the flow calculated in the regional domain and flow in the local domain is important, and is assured by interpolation of the boundary conditions and transmissivity field properties of the regional domain onto the local domain. This process of calculating two flow fields with domains of different extent and different resolution is implemented for practical reasons only. It is a method of incorporating regional effects in finely discretized local flow fields that has relatively low computational burden, compared to other possible methods. Additional discussion of this process is provided in Section 6.4.10.2.

In summary, flow in the Culebra is calculated with the code SECOFL2D, using a conceptual model of a horizontal confined aquifer, regional flow effects, uniform porous media, steady state, and transmissivity variation. In addition, the effects of subsidence caused by potash mining in the McNutt are incorporated during the flow calculation, as discussed in Section 6.4.6.2.3.

6.4.6.2.1 Transport of Dissolved Actinides in the Culebra

Actinides may be introduced into the Culebra by brine flowing up a borehole or by brine flowing up the shaft. Three principal processes have been demonstrated to occur naturally that affect the transport and retardation of dissolved actinides. Dissolved actinides will be carried by advection in the natural flow of Culebra groundwater. Dissolved actinides will diffuse into the matrix. Dissolved actinides will sorb to varying extents onto the different minerals lining pore walls or fractures. It is possible that dissolved actinides may participate as trace constituents in reactions between water and rock and be bound up in newly formed minerals, but this phenomenon is not included in the conceptual model. These processes are complicated to characterize because of known stratigraphic variation in the Culebra and expected heterogeneity in solution chemistry along the possible flow paths from the injection point to the accessible environment.

The basic stratigraphy of the Culebra is continuous across the WIPP site (Appendix FAC, Section FAC.4.1.2), and it contains layers with significantly different properties (Holt and

Powers 1984, 1986, 1990, and Appendix FAC, Section FAC.5.2). Hydraulically, there appear to be two distinct layers in the Culebra. Mercer and Orr (1979) report the result of a tracer and temperature survey that suggests there is not significant flow in the upper 14 feet (4.3 meters) of the Culebra. Culebra hydraulic testing at well H-14 indicates generally low permeabilities but a slightly higher permeability in the upper portion (Beauheim 1987). In descriptions from the air intake shaft, Holt and Powers (1990) noted that most of the fluid produced came out of the lower portion of the Culebra. Hydraulic tests at the H-19 hydropad indicate that the permeability of the upper portion of the Culebra is significantly lower than the permeability of the lower portion. Consistent with hydraulic indicators, tracer tests conducted at H-19 confirmed that the upper portion of the Culebra makes no significant contribution to the transport of dissolved species, although it may act to retard solute transport by diffusion into it. The Culebra at the WIPP site is conceptualized as having very low permeability in the upper approximately 9.8 feet (3 meters), and variable permeability in the lower portion, which can be lower than the upper portion in regions where the Culebra as a whole is relatively impermeable. Thus, the bulk of the data indicates that the majority of the flow and transport takes place in the lower portions of the Culebra. Accordingly, for flow and transport calculations, an effective thickness of the Culebra of 13.1 feet (4 meters) is assumed.

There is considerable variability in the structure and size of porous features in the Culebra, including fractures (of a variety of dimensions and interconnectedness), vugs, interparticle and intercrystalline porosity. The principal flow occurs within those features with the high permeability, and slower flow and diffusion are primary processes in the lower permeability features. Tracer test interpretations indicate that at some locations flow occurs predominantly through fractures (advective porosity is low) and at other locations slower transport indicates that flow is occurring in other permeable features such as vugs connected by microfractures, and possibly interparticle porosity (higher advective porosity). Tracer test interpretations also indicate that matrix diffusion is an important process in high-permeability regions of the Culebra. In other words at least two scales of porosity are needed to reasonably represent the transport processes in the Culebra (that is, a double-porosity model). At some locations of low permeability, fractures may be absent or filled with gypsum. An alternative conceptual model for transport at these locations is uniform single porosity with a high porosity. To simplify calculations, the uniform single porosity model was not implemented; the double porosity model implemented results in faster transport.

In SECOTP2D, advective porosity represents the porous features in which flow occurs. Advective porosity values are low, which is representative of flow in fractures. Diffusive porosity represents those porous features in which no flow is assumed to occur and diffusion and sorption occur. Diffusive porosities are large relative to advective porosity, representative of the vugs, interparticle, and intercrystalline porosity of the bulk rock.

The processes that occur in the advective porosity portion of the Culebra are advection (flow), dispersion (spreading caused by heterogeneity), diffusion within the advective porosity, and diffusion into the diffusive porosity. Important factors in this conceptual model are the velocities of fluid in the advective porosity, free-water diffusion coefficients, and

dispersion coefficients. The most important factor is the fluid velocity. Free-water tracer diffusion coefficients are specified for actinides. Dispersive spreading at the scale of disposal-system modeling is dominated by the effects of heterogeneities explicitly incorporated in the transmissivity fields input to SECOFL2D. This eliminates the need to account for larger-scale features by specifying a dispersion coefficient for SECO modeling larger than those observed at the hydropad-test scale.

Fluid velocity in SECOTP2D is coupled to the results of the fluid flow modeling conducted with SECOFL2D on the local domain (see the preceding section). Fluid flow directions and volumetric fluxes in SECOTP2D are calculated in SECOFL2D. The flow velocities in the transport calculation are determined using the fluxes from the fluid flow calculation, the Culebra thickness specified for the transport calculation, and the advective porosity specified for the transport calculation. Because a different transmissivity field is used and the values of several important parameters are sampled, each realization uses a different velocity field. Retardation is conceptualized to be a function of physical effects of diffusion into diffusive porosity, and sorption. Diffusion is parameterized by the diffusive porosity (which can essentially be thought of as a reservoir for diffusion) tortuosity, matrix block length and free-water diffusion coefficient. Tortuosity represents the tortuous structure of the porosity within the matrix; it acts to slow the diffusion process. The matrix block length is a conceptual construct representing the ratio of the surface area between advective and diffusive porosity to the volume of diffusive porosity features; physical retardation increases as the matrix block length decreases. Physical retardation also increases if tortuosity or the free-water diffusion coefficient of diffusive porosity are larger. See Appendix MASS (Section MASS.15.2 and MASS Attachment 15-6) and Appendix SECOTP2D (Section 2, Governing Equations) for more details.

Chemical retardation of dissolved actinides is conceptualized to occur by sorption onto dolomite grains exposed in diffusive porosity because of the large amount of dolomite present in the Culebra. Chemical retardation increases if diffusive porosity is smaller because there is a larger volume of rock for sorption. Although clay minerals are present and would sorb actinides in the Culebra, their effects are not included in the conceptual model or parameter values specified. Effective properties for the rock matrix, which is assumed to be homogeneous, and solution chemistry are assumed and are incorporated directly in specification of the parameters for the retardation model (see Appendix MASS, Section MASS.15.2, and Appendix PAR, Parameters 49 through 57).

The DOE uses a linear isotherm model to represent the retardation that occurs as dissolved actinides are sorbed onto dolomite. This model uses a single parameter K_d to express a linear relationship between sorbed concentration and liquid concentration. The K_ds used in performance assessment have been determined from experimental data and are conservatively chosen such that the model predictions of sorption are less than or equal to actual sorption expected along the possible flow paths in the Culebra should a release occur (Appendix MASS, Section MASS.15.2 and MASS Attachment 15-1). Other important parameters in the linear isotherm model are the diffusive porosity and the grain density of the Culebra because these determine the mass of dolomite available on which sorption can occur. Consistent with

the assumption of homogeneous rock properties in the conceptual model, K_ds and grain densities are selected and then applied to the entire transport domain and are held constant for an entire realization. See Appendices SECOTP2D (Section 7, User Interactions, Input and Output Files) and PAR (Parameters 49 through 57) for details of parameter definitions and values.

Selection of the parameter values required by the SECOTP2D model for physical retardation and chemical retardation is performed in LHS according to the CDFs described in Appendix PAR. Important parameter values are summarized in Tables 6-20 and 6-21.

In summary, the conceptual model for dissolved actinide transport includes the following: transport in advective porosity, physical retardation (diffusion) into diffusive porosity, chemical retardation (sorption) in diffusive porosity, homogeneous rock properties, and a linear isotherm to describe the sorption process. Some of the more important parameters are advective porosity, diffusive porosity, tortuosity, matrix block length, molecular diffusion coefficients, K_d, and the grain density of dolomite in the Culebra.

6.4.6.2.2 Transport of Colloidal Actinides in the Culebra

Colloidal particles are subject to many of the same processes that affect dissolved actinides, but because of their size several additional processes affect them. There are three process differences. Colloidal particles in general are preferentially carried in the center of pore throats by faster-moving fluid, which could cause slightly increased rates of transport compared to dissolved species. Colloidal particles can be filtered from flowing groundwater when they encounter small-aperture features in the pore network. Finally, colloidal particles may undergo different sorption processes than dissolved species.

The primary distinction in the transport behavior of the different colloidal particles is whether particles diffuse into the matrix from fractures. This is controlled by the difference between the size of colloidal particles and the mean pore-throat diameters in the diffusive porosity of the Culebra. Colloidal particles that are smaller than the pore throats can diffuse into the diffusive porosity. Actinide intrinsic colloids and humic materials are small enough for this to occur. The conceptual model for these particles includes the processes of advection, diffusion, and dispersion in the advective porosity, diffusion into diffusive porosity, and sorption of actinides in diffusive porosity. This model is analogous to the model specified for dissolved actinides, although the parameter values are different. The conceptual model assumes that other retardation processes (for example, filtration) will not occur for actinide-intrinsic colloids and humic materials.

In contrast, colloidal particles that are larger than pore throats will be excluded from the matrix and will remain in advective porosity. Microbes and mineral fragments are

Table 6-20. Matrix Distribution Coefficients (K_ds) and Molecular Diffusion Coefficients for Dissolved Actinides in the Culebra

Actinide	K_d (cubic meters per kilogram) Maximum	Minimum	Median	Molecular Diffusion Coefficients (square meters per second)[a] Constant
U(IV)	20.0	0.90	10.0	1.53×10^{-10}
U(VI)	0.030	3.0×10^{-5}	0.015	4.26×10^{-10}
Th(IV)	20.0	0.90	10.0	1.53×10^{-10}
Pu(III)	0.50	0.02	0.26	3.00×10^{-10}
Pu(IV)	20.0	0.90	10.0	1.53×10^{-10}
Am(III)	0.50	0.02	0.26	3.00×10^{-10}

[a] See Appendix MASS, MASS Attachment 15-3

Table 6-21. Culebra Actinides Flow and Transport Parameters Required for SECO Codes

Parameter (units)	Maximum	Minimum	Median or Constant
Advective Porosity (percent)	1.0	0.01	0.10
Diffusive Porosity (percent)	25.0	10.0	16.0
Half Matrix Block Length (meters)	0.50	0.05	0.275
Longitudinal Dispersivity, α_L (meters)	-	-	0
Transverse Dispersivity, α_T (meters)	-	-	0
Grain Density (cubic kilograms per cubic meter)	-	-	2.82
Effective Thickness (meters)	-	-	4.0
Fracture Tortuosity (unitless)	-	-	1.0
Diffusive Tortuosity (unitless)	-	-	0.11

conceptualized as being larger than the mean pore-throat diameter in Culebra diffusive porosity. The conceptual model for these particles includes the processes of advection in advective porosity and filtration by small-aperture features that occur within the advective porosity. See Appendix MASS (Section MASS.15.3 and MASS Attachment 15-9) for additional discussion.

Experiments have demonstrated that mineral fragments and microbes are attenuated so effectively by the advective porosity in the Culebra that it was deemed unnecessary to include those colloids in performance assessment calculations. Under the neutral to slightly basic geochemical conditions expected in the Culebra, humic substances were found to not influence the sorption behavior of dissolved actinides. Therefore, actinides associated with

humic substances were treated as dissolved species in the performance assessment calculations. The only actinide-intrinsic colloid found to exist in significant concentrations was the Pu(IV)-polymer. At the WIPP, the total amount of Pu(IV)-polymer introduced to the Culebra was found to be insignificant with respect to the EPA normalized release limit and so was not included in transport calculations. See Appendix SOTERM (Section SOTERM.6) and Appendix MASS (Section MASS.15.3.1) for details. See Appendix MASS (Section MASS.15.3.3) for alternative modeling approaches considered.

Indigenous microbes, humics, and mineral fragment colloids in the Culebra may react with actinides introduced to the Culebra in dissolved form to create new colloidal actinides. Newly formed actinide-bearing microbial and mineral colloids, however, will be attenuated similarly to colloidal actinides introduced from the repository. Therefore, disregarding the impact of newly formed microbial and mineral fragment colloidal actinides is conservative. Experimental results indicate that humics do not interact with dissolved actinides under Culebra geochemical conditions. Consequently, the quantity of newly formed humic actinides will be insignificant.

6.4.6.2.3 Subsidence Due to Potash Mining

Subsidence effects caused by potash mining are included in this performance assessment because of specific criteria in the EPA's 40 CFR Part 194. For incorporating the effects of subsidence caused by mining, the DOE uses the conceptual model provided by the EPA in 40 CFR Part 194 and supporting documents.

The EPA's conceptual model for mining is introduced in 40 CFR § 194.32 (b) and (c) and clarified in the Preamble and Background Information. 40 CFR § 194.32 (b) and (c) state

> (b) Assessments of mining effects may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system from excavation mining for natural resources. Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame. Performance assessments shall assume that the mineral deposits of those resources, similar in quality and type to those resources currently extracted from the Delaware Basin, will be completely removed from the controlled area during the century in which such mining is randomly calculated to occur. Complete removal of such minerals resources shall be assumed to occur only once during the regulatory time frame.
>
> (c) Performance assessments shall include an analysis of the effects on the disposal system of any activities that occur in the vicinity of the disposal system prior to disposal and are reasonably expected to occur in the vicinity of the disposal system soon after disposal. Such activities shall include, but shall not be limited to, existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities.

40 CFR § 194.32 (b) and (c) state what gets mined, when it gets mined, and the effects of mining on the disposal system—a conceptual model. Within the disposal system, mineral resources similar in quality and type to those currently being mined outside the disposal system may be mined at an uncertain time in the future. Outside the disposal system, mineral

resources reasonably expected to be mined in the near future should be assumed to be mined. These effects are included in analyses of both disturbed and undisturbed performance. Inside the disposal system, whether and when a mining event occurs after the active institutional control period is determined by a probabilistic model. Outside the disposal system, what is reasonably expected to be mined is assumed to be mined by the end of WIPP disposal operations. With respect to consequence analysis, mining affects only the hydraulic conductivity of the units of the disposal system.

The DOE has identified areas that are assumed to be mined in a manner consistent with the conceptual model and other guidance presented by the EPA in 40 CFR Part 194. The only natural resource being mined currently near WIPP is potash in the McNutt, and it is the only mineral considered for future mining. Appendix MASS (Sections MASS.15.4 and MASS Attachment 15-4) provides a description of the method used to determine the extent of mining in the McNutt both inside and outside the disposal system. This description also presents additional relevant discussion by the EPA on the extent of mining. The extent of mining outside the disposal system used in this performance assessment is shown in Figure 6-19. It is based on the map of existing leases presented in Chapter 2.0 (Figure 2-37), setbacks from existing boreholes, and the presence of ore in the lease (see Appendix MASS, Section MASS.15.4 and MASS Attachment 15-5). Inside the disposal system, a region that could be mined in the future is specified based exclusively on the quality and type of ore present. This region was presented in Figure 2-38 (see Chapter 2.0) and is reproduced here for convenience as Figure 6-20.

The EPA clarifies its conceptual model on the effects of mining on hydraulic conductivity of the units of the disposal system in the Preamble to 40 CFR Part 194 (EPA 1996a, 61 FR 5229). The EPA states

> Some natural resources in the vicinity of WIPP can be extracted by mining. These natural resources lie within the geologic formations found at shallower depths than the tunnels and shafts of the repository and do not lie vertically above the repository. Were mining of these resources to occur, this could alter the hydrologic properties of overlying formations—including the most transmissive layer in the disposal system, the Culebra dolomite—so as to either increase or decrease groundwater travel times to the accessible environment. For the purposes of modeling these hydrologic properties, this change can be well represented by making corresponding changes in the values for the hydraulic conductivity. The Agency has conducted a review of the data and scientific literature discussing the effects mining can induce in the hydrologic properties of a formation. Based on its review of available information, the Agency expects that mining can, in some instances, increase the hydraulic conductivity of overlying formations by as much as a factor of 1,000, although smaller and even negligible changes can also be expected to occur. Thus, the final rule requires DOE to consider the effects of mining in performance assessments. In order to consider the effects of mining in performance assessments, the DOE may use the location-specific values of hydraulic conductivity, established for the different spatial locations within the Culebra dolomite, and treat them as sampled parameters varying between unchanged and increased 1,000-fold relative to the value that would exist in the absence of mining.

This section adds four important clarifying concepts. First, the EPA has concluded that there are no minerals vertically above the repository similar in quality and type to those currently

being extracted elsewhere in the Delaware Basin. Second, the EPA does not draw conclusions about whether mining will increase or decrease groundwater travel times to the accessible environment. Third, it may be assumed that the important effects of change in hydraulic conductivity occur only in the Culebra. Fourth, the spatially variant hydraulic conductivities established in the Culebra by the DOE may be multiplied, where they are impacted by mining, by a factor from 1 to 1,000. The DOE has applied the EPA's guidance regarding hydraulic conductivity to the transmissivity at locations in the Culebra.

In using the EPA's conceptual model for mining, the DOE makes assumptions with respect to two topics in order to formulate the mathematical model. The angle of draw is a parameter necessary to translate the area mined in the McNutt to the area affected in the Culebra. In its Background Information Document for 40 CFR Part 194, the EPA discusses the possible range in the value of angle of draw (EPA 1996b, 9-36). The DOE has examined the Background Information for 40 CFR Part 194 (see EPA 1996b, 9-47) and concluded that an angle of draw of 45° is the value most consistent with the EPA's discussions and calculations. Second, the Agency does not specify a distribution to the multiplicative factor. As discussed in Appendix PAR (Parameter 34), the DOE has assigned a uniform distribution to this variable. As discussed in the introduction to Appendix PAR, a uniform distribution is appropriate when only lower and upper bounds of the range are known.

Applying the angle of draw to the mined areas presented in Figures 6-19 and 6-20 makes the area impacted in the Culebra larger than the area actually mined in the McNutt. The area in the Culebra impacted by mining is shown in Figure 6-21, for outside the controlled area, and in Figure 6-22, for inside and outside the controlled area. These figures are plotted on the regional domain of the SECOFL2D model, which is used to calculate the effects of subsidence caused by mining on flow directions and rates in performance assessment.

The effects of mining outside the disposal system are included in the undisturbed performance scenario, and, therefore, the effects of this mining are included in all scenarios. In other words, all calculations of transport in the Culebra include the effects of mining outside the controlled area. This is the undisturbed mining case because mining within the controlled area has not occurred.

These effects are incorporated by multiplying location-specific values in the transmissivity field in the area labeled "Impacted by Mining" in Figure 6-21 by a factor (mining multiplier) between 1 and 1,000 that is randomly sampled in LHS. The same factor is applied to all affected nodal blocks. In every vector of the LHS, the steady-state flow fields used in the 10,000-year transport simulation incorporate this change to the transmissivity field. These simulations, followed by a transport simulation as discussed in preceding sections, develop reference conditions for the transport of actinides in the Culebra in the undisturbed mining case.

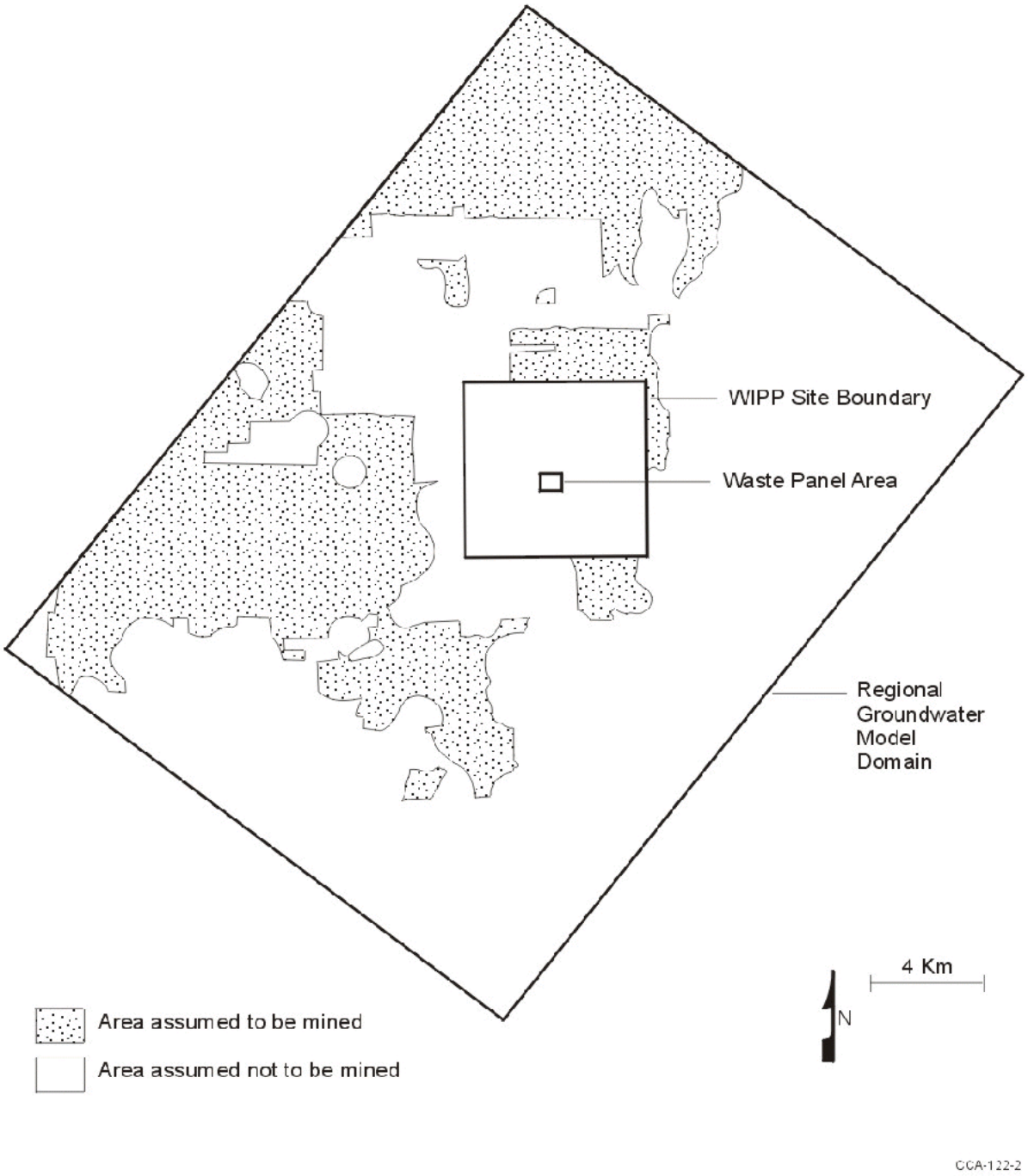

Figure 6-19. Extent of Mining in the McNutt in Undisturbed Performance within SECOFL2D Regional Model Domain

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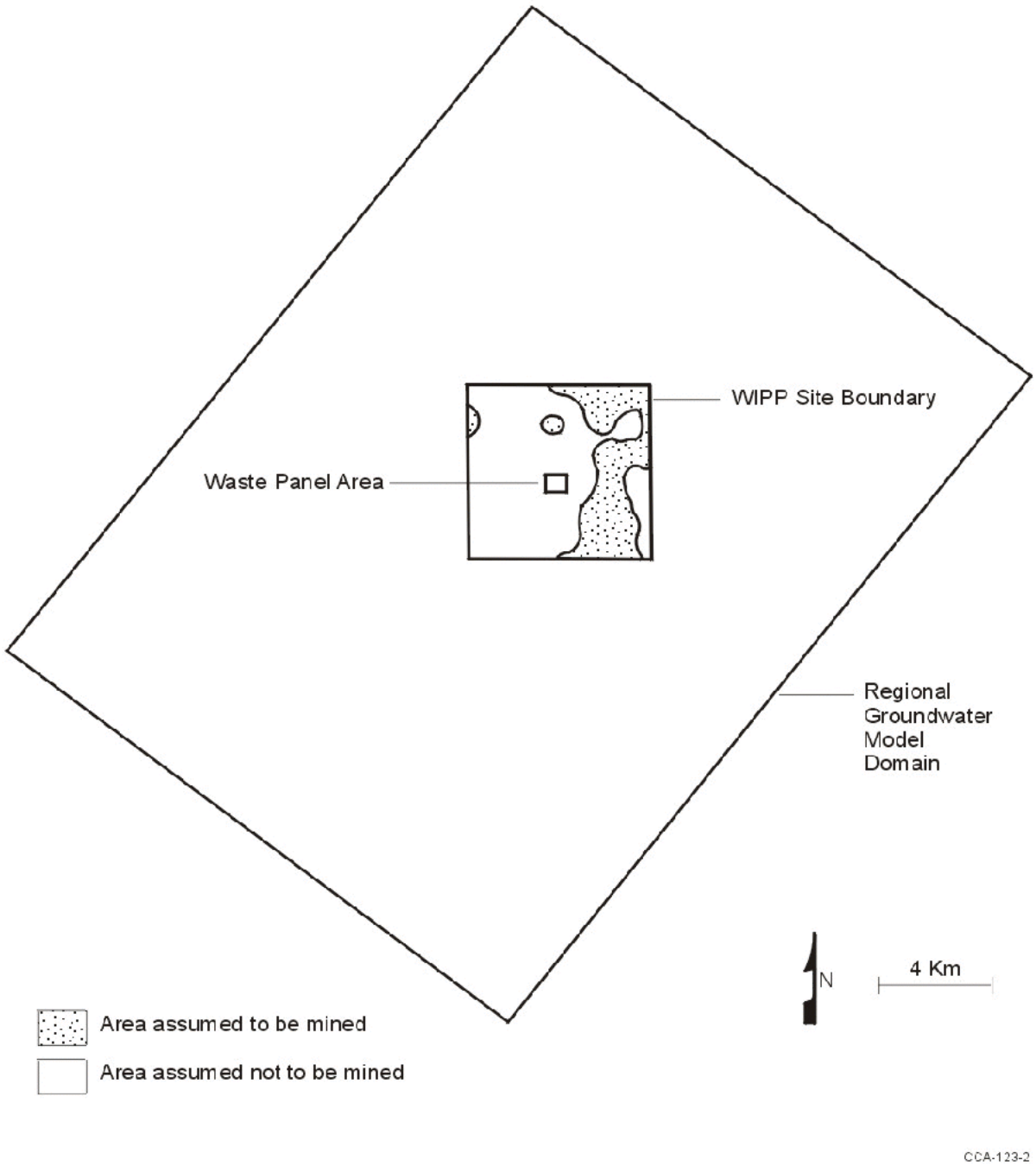

Figure 6-20. Extent of Future Mining in the McNutt within the Controlled Area Considered in Disturbed Performance

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Figure 6-21. Extent of Impacted Area in the Culebra from Mining in the McNutt Outside the Controlled Area for Undisturbed Performance

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Figure 6-22. Extent of Impacted Area in the Culebra for Disturbed Performance if Mining In the McNutt Occurs in the Future Within the Controlled Area

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If mining occurs within the controlled area, an area of the Culebra inside and outside the disposal system is affected. This is the disturbed mining case. To evaluate the impact of disturbed mining, a second simulation of Culebra flow directions and rates is executed on the regional and local domains. In this second simulation, the affected location-specific values in the transmissivity field within the controlled area are multiplied by the same mining multiplier used for the undisturbed mining case outside the controlled area. These simulations, followed by a transport simulation as discussed in preceding sections, develop reference conditions (see Section 6.4.11) for the transport of actinides following mining inside the controlled area.

The implementation of the EPA's probability model for future mining is presented in Section 6.4.12.8. A discussion of how the reference simulations for the undisturbed and disturbed mining cases are used in CCDF construction is presented in Section 6.4.13.

6.4.6.3 The Tamarisk

The Tamarisk (Region 16 in Figures 6-13 and 6-14) rests between the more transmissive Culebra and Magenta. An in-situ hydraulic test determined that the transmissivity of the Tamarisk is lower than the transmissivity of the unnamed lower member (see Section 2.2.1.4.1.3). This low transmissivity is consistent with expectations because of its anhydrite, gypsum, and clay composition (see Section 2.1.3.5.3). In performance assessment, this member is treated as impermeable. This may cause an increase in flow through the adjacent Culebra and Magenta. This treatment is considered conservative in that allowing flow from the intrusion borehole or shaft into the Tamarisk would, if anything, decrease flow into the Culebra, which would tend to reduce the consequence of radionuclide release to the Rustler. In performance assessment, the thickness of the Tamarisk is assumed to be 81.4 feet (24.8 meters) and its permeability is effectively zero (Appendix PAR, Table PAR-29).

6.4.6.4 The Magenta

The Magenta is described in Sections 2.1.3.5.4 and 2.2.1.4.1.4 and is shown as Region 15 in Figures 6-13 and 6-14. Transport of actinides through the Magenta to the accessible environment is not modeled. The assumption that no releases will occur from the Magenta is based on the hydraulic test results from wells on the WIPP site (Beauheim 1987, 110 – 118) that indicate that the Magenta is a porous medium with no hydraulically significant fractures (in contrast to the Culebra) and that its conductivity is lower than that of the Culebra. Early numerical simulations of flow and transport in the Magenta suggested much slower transport than in the Culebra (Barr et al. 1983, 26 – 27). Therefore, no radionuclides entering the Magenta will reach the accessible environment boundary within the 10,000-year time frame. Accordingly, the BRAGFLO model geometry reasonably approximates the effects of Magenta flow. The Magenta permeability is chosen conservatively as the lowest of measured values near the center of the WIPP site, in order to yield a lower reasonable amount of brine (and radionuclide) storage within the Magenta, while continuing to yield an upper bounding flow into the Culebra. The volumes of brine and radionuclides calculated to be stored in the Magenta are tracked and documented, however. Magenta parameter values are summarized in Table 6-22 and are described in more detail in Appendix PAR (Table PAR-28).

Table 6-22. Model Parameter Values for the Magenta

Parameter (units)	Value
Permeability (square meters)	6.31×10^{-16}
Effective Porosity (percent)	13.8
Rock Compressibility (1/pascals)[a]	2.64×10^{-10}
Threshold Pressure, P_t (pascals)[b]	5.06×10^{5}
Residual Brine Saturation, S_{br} (unitless)	0.084
Residual Gas Saturation, S_{gr} (unitless)	0.077
Pore Distribution Parameter, λ (unitless)	0.644
Maximum Capillary Pressure	10^{8}
Thickness (meters)	8.5
Initial Pressure (pascals)	9.17×10^{5}

[a] Pore compressibility = rock compressibility/effective porosity.
[b] Threshold Pressure (P_t) determined from the relationship: $PCT_A \cdot k^{PCT_EXP}$, where PCT_A and PCT_EXP are constants and k is the permeability.

6.4.6.5 The Forty-niner

In evaluations of radionuclide transport, flow in the Forty-niner is considered insignificant because of its low transmissivity (see Section 2.2.1.4.1.5). As with the Tamarisk and unnamed lower members, the Forty-niner is assigned a permeability of effectively zero in performance assessment (Appendix PAR, Table PAR-27). This treatment is considered conservative in that allowing flow from the intrusion borehole or shaft into the Forty-niner would, if anything, decrease flow into the Culebra, which would tend to reduce the consequence of radionuclide release to the Rustler. Its modeled thickness is 56.8 feet (17.3 meters). It is shown as Region 14 in Figures 6-13 and 6-14.

6.4.6.6 Dewey Lake

Release of actinides to the accessible environment from transport in the Dewey Lake is assumed not to occur even if contaminated brine reaches the unit because the sorptive capacity of this unit appears large. This assumption is based on an analysis (Wallace et al. 1995) that demonstrated that the potential sorption capacity of the Dewey Lake is sufficient to prevent releases for 10,000 years. This analysis consisted of (1) a literature review of sorptive capacity of redbeds and (2) an estimate of the minimum sorption required to prevent release of actinides that enter the Dewey Lake to the accessible environment in 10,000 years. Comparison of the sorption values for the Dewey Lake analogues established by literature review with the minimum sorption required to prevent release indicates that the likely sorptive capacity of the Dewey Lake is orders of magnitude greater than would likely be required to prevent release. Therefore, the DOE assumes that chemical retardation occurring in the Dewey Lake will prevent release within 10,000 years of any actinides that might enter it. Geological and hydrological information on the Dewey Lake is presented in Sections 2.1.3.6

and 2.2.1.4.2, respectively. Dewey Lake parameter values are summarized in Table 6-23 (see also Appendix PAR, Table PAR-26). The Dewey Lake is shown as Region 13 in Figures 6-13 and 6-14.

Table 6-23. Dewey Lake Parameters for the BRAGFLO Model

Parameter (units)	Value
Permeability (square meters)	5.01×10^{-17}
Effective Porosity (percent)	14.3
Rock Compressibility (1/pascals)[a]	10^{-8}
Threshold Pressure, P_t (pascals)[b]	0
Residual Brine Saturation, S_{br} (unitless)	0.084
Residual Gas Saturation, S_{gr} (unitless)	0.077
Pore Distribution Parameter, λ (unitless)	0.644
Maximum Capillary Pressure (pascals)	10^8
Thickness (meters)	149.3
Initial Pressure (below water table at 980 meters, 43.3 meters below top of formation) (pascals)	hydrostatic
Initial Pressure, 20 percent liquid saturation above water table (atmospheres)	1

[a] Pore compressibility = rock compressibility/effective porosity.
[b] Threshold Pressure (P_t) determined from the relationship: $PCT_A \cdot k^{PCT_EXP}$, where PCT_A and PCT_EXP are constants and k is the permeability.

6.4.6.7 Supra-Dewey Lake Units

The units overlying the Dewey Lake are discussed in Sections 2.1.3.7 through 2.1.3.10 and are shown as Region 12 in Figures 6-13 and 6-14. Because these units are thin and predominantly unsaturated at the WIPP site, brine that might enter from the borehole (assuming brine can reach this elevation) is assumed to flow downward to the Dewey Lake, where any actinides will be sorbed. These units are included in BRAGFLO, however, and the possibility of actinide transport into them from a borehole is considered in the performance assessment. Actinide transport within the Supra-Dewey Lake units is not modeled, and it is assumed that there can be no actinide release to the accessible environment through these units. For performance assessment, the units overlying the Dewey Lake are represented as a single hydrostratigraphic unit whose parameters are shown in Table 6-24.

Table 6-24. Supra-Dewey Lake Unit Parameters for the BRAGFLO Model

Parameter (units)	Value
Permeability (square meters)	10^{-10}
Effective Porosity (percent)	17.5
Rock Compressibility (1/pascals)[a]	5.71×10^{-8}
Threshold Pressure, P_t (pascals)[b]	0
Residual Brine Saturation, S_{br} (unitless)	0.084
Residual Gas Saturation, S_{gr} (unitless)	0.077
Pore Distribution Parameter, λ (unitless)	0.644
Maximum Capillary Pressure (pascals)	10^8
Thickness (meters)	15.76
Initial Pressure, 8.36 percent liquid saturation (atmospheres)	1

[a] Pore compressibility = rock compressibility/effective porosity.
[b] Threshold Pressure (P_t) determined from the relationship: $PCT_A \cdot k^{PCT_EXP}$, where PCT_A and PCT_EXP are constants and k is the permeability.

6.4.7 The Intrusion Borehole

In accordance with the requirements of 40 CFR § 194.33(b)(1), the DOE models consequences of inadvertent and intermittent intrusion into the repository during drilling for natural resources as the most severe human intrusion scenario that may affect long-term performance of the disposal system. This section discusses the conceptual models used for drilling (particulate release during drilling, direct brine release during drilling, and long-term brine flow) and provides references to appropriate discussions of numerical modeling codes.

This section does not address the likelihood that inadvertent human intrusion will occur. As discussed in Chapter 7.3.4, the DOE believes passive institutional controls will be effective in reducing the likelihood of intrusion (see Appendix EPIC); however, regulatory guidance requires consideration of a nonzero probability of intrusion (40 CFR § 194.43[c]). The DOE's treatment of the probability of inadvertent human intrusion is discussed in Section 6.4.12.

Human intrusion scenarios require simulating penetration of an intrusion borehole into the waste disposal region. There are two effects associated with drilling: releases from the drilling itself and possible releases because of the long-term effects on fluid flow in the disposal system after the borehole casing and plugs have degraded. Both types of releases are estimated for two different types of intrusions: those that intersect pressurized brine in the Castile (E1 events, see Section 6.3.2.2.2), and those that do not (E2 events, see Section 6.3.2.2.1).

6.4.7.1 Releases During Drilling

Consistent with the criterion of 40 CFR § 194.33(c)(1), releases that may occur during and immediately following the drilling event are modeled under the assumption that future drilling practices will be the same as those of the present (see Appendix DEL, Sections DEL.5 and DEL.6, for a complete description of present drilling practices). Figure 6-23 shows a schematic representation of a standard rotary drilling operation inadvertently penetrating the repository. A drill bit is attached to the bottom of a string of steel pipe, the lowest segments of which are reinforced collars. The drill bit, collars, and pipe are collectively referred to as the drill string. As the drill string rotates, liquid, referred to as drilling mud, is pumped down the interior of the pipe and out through the bit. The drilling fluid cools and lubricates the bit and then returns to the surface outside the pipe in the annulus between the pipe and the borehole wall. During its return flow, the mud carries the cuttings to the surface where they settle out in a mud pit. The mud is typically a water-based brine that is weighted with additives to maintain a hydrostatic pressure in the borehole equal to or greater than the normally anticipated fluid pressures in the formations being drilled. Salt-saturated brines are generally used in evaporites to prevent dissolution of the formation. Steel casing is installed in boreholes before entering the salt section to protect the near-surface units from contamination with fluids from deeper units and, after drilling through the salt section, to prevent hole closure on the drill string and subsequent in-hole hardware.

If a rotary drill bit penetrates the waste, radionuclides may be brought to the surface by four means. First, some quantity of cuttings, which contain material intersected by the drill bit, will be brought to the surface. Second, cavings, which contain material eroded from the borehole wall by the circulating drill fluid, may also be brought to the surface by the circulating drilling mud. Third, releases of radionuclides may occur if the repository contains fluids at pressures higher than the pressure exerted by the drilling fluid. Spalling of waste material into the borehole may occur if high-pressure gas flows into the borehole. Brine as well as gas may enter the borehole from the repository if the driller is unable to control the pressure within the well or if the driller chooses not to control the pressure. The brine may flow to the surface, and if it has been in contact with waste, it may contain dissolved or suspended radionuclides.

Releases of particulate waste material (that is, cuttings, cavings, and spallings) are modeled using the CUTTINGS_S code as described in Section 6.4.11 and Appendix CUTTINGS. Appendix MASS (Section MASS.16.1) discusses the conceptual basis for the model. As discussed in Section 6.4.12.4, cuttings and cavings are calculated separately for CH-TRU and RH-TRU waste, with distinct waste streams considered. Spallings are calculated as homogeneous waste obtained by averaging over all CH-TRU waste. For all releases during drilling, appropriate corrections are made for radioactive decay. Releases of dissolved or suspended radionuclides contained in brine are modeled using the BRAGFLO and PANEL codes as described in the next section. Casing is assumed to be intact through the Rustler and overlying units during drilling, and there is assumed to be no communication between the borehole and those units. For all direct releases, actinides that enter the borehole are conservatively assumed to reach the surface.

6.4.7.1.1 Direct Brine Release During Drilling

Direct brine release refers to the possibility that brine containing actinides may flow from the waste panels up a borehole to the surface during drilling (Appendix MASS, Section MASS.16.2). It is conceptualized that direct brine release to the surface will not occur every time a borehole penetrates the waste panels but rather that it can occur only when two conditions are met. The first condition is the presence of mobile brine in the waste panels. Because of brine consumption by corrosion and low initial saturation, it is possible for liquid saturations below the residual saturation to exist in the repository, in which case direct brine release cannot occur. The second condition is the pressure in the waste panels must be greater than the pressure at the base of the column of drilling mud. Drillers in the Delaware Basin use a salt-saturated mud with a specific gravity of about 1.23 while drilling through the Salado. This corresponds to a pressure of approximately 8 megapascals at the repository horizon (see Appendix MASS, Section MASS.16.2, and MASS Attachment 16-2). If fluid in the waste panels is below this pressure, no direct brine release during drilling can occur because liquid flow in the repository will be away from the borehole.

In the conceptual model, resolution of the details of flow near the borehole is considered important, as the changing physical conditions over the short duration of this flow can significantly impact estimates of the total volume released. It is not assumed that a direct brine release would be noticed by the driller (EPA 1996a, 61 FR 5230). Also important to the conceptual model is how long direct brine release occurs. There are several ways in which the direct brine release could be stopped. A driller might detect higher flow rate to the mud pit and take action to mitigate consequences. Alternatively, direct brine release will stop when the driller cases the hole after reaching the base of the salt section. As discussed in Appendix MASS (MASS Attachment 16-2) and Appendix DEL (Section 7.5), the DOE assumes that for low volumes of fluid flow, the borehole will be controlled and cased within 72 hours after the penetration of the repository. In all cases, all fluid flow to the surface during drilling is assumed to cease within 11 days after penetration of the repository.

In the conceptual model for direct brine release, several other assumptions are made that relate to other conceptual models. The processes of direct solids release from cuttings, cavings, spall, and direct brine release are treated separately, although the direct brine release model does account for the effects of solids removal (spall) on fluid flow near the well bore. Direct brine release will affect the pressure and saturation in the repository. However, it is assumed that these effects are negligible over the long-term because of their transient and local nature, and they are not accounted for in long-term (10,000-year) BRAGFLO disposal system calculations. This assumption simplifies modeling because it allows detailed consideration of direct brine release over a short time period, without having to couple the results of these calculations back into the disposal system simulations.

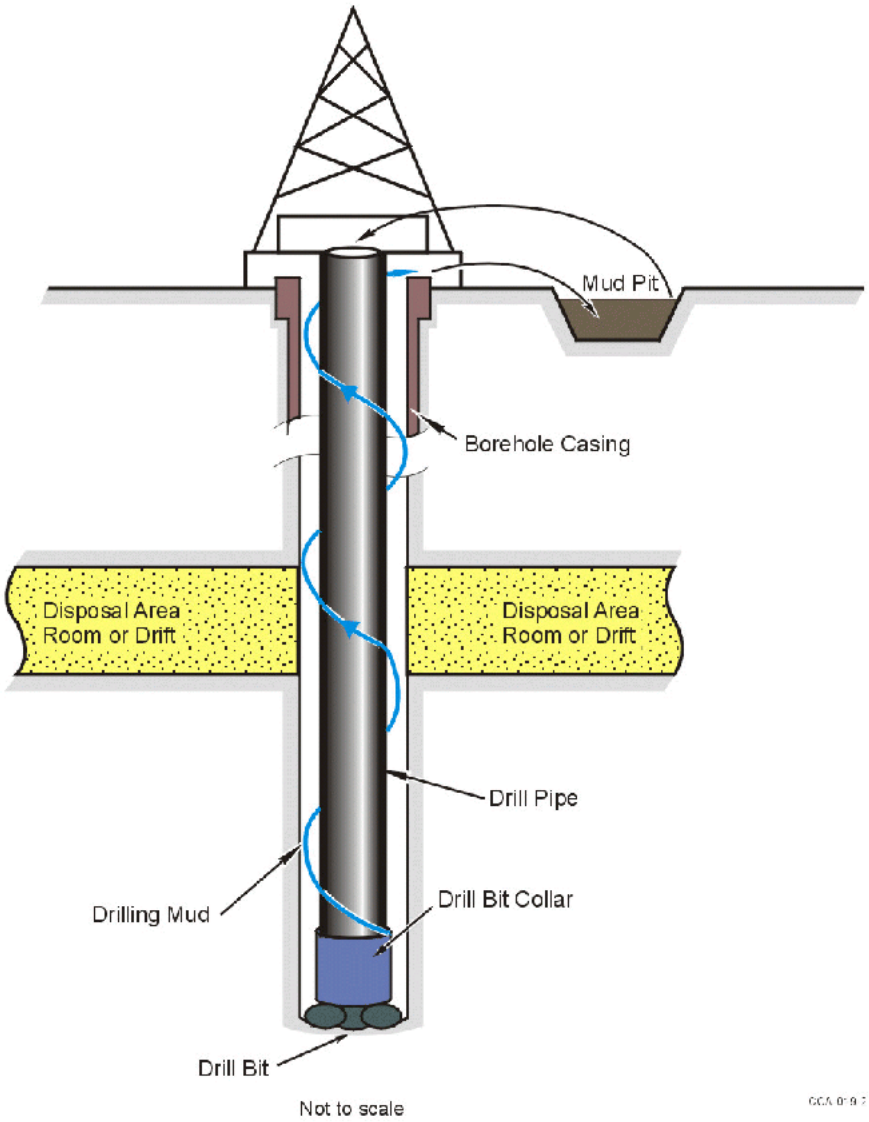

Figure 6-23. Schematic Representation of a Rotary Drilling Operation Penetrating the Repository

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The area over which fluid flow can occur during direct brine release is assumed to be the rooms and drifts of waste panels, the DRZ, room pillars, and panel closures. Because local-scale, short-duration flow is important, the geometry of the waste panels is considered important and is represented in the model. It is assumed that the flow interactions with the Salado other than the DRZ are not important during direct brine release. For this model, pillars are arbitrarily assumed to have the properties of the DRZ rather than intact halite, although in reality their properties are probably like a DRZ at their edge and like intact halite in their core. Since the DRZ permeability is greater than the permeability of intact halite, this assumption is conservative. A two-dimensional geometry is used parallel to the repository horizon, with a 1° dip from north to south. The geometry of the grid used is shown in Figure 6-24.

The BRAGFLO code is used to calculate direct brine release, and the mathematical and computational model is called the BRAGFLO direct brine release (BRAGFLO_DBR) model (Appendix MASS, Section MASS.16.2 and MASS Attachment 16-2). The initial and boundary conditions for this model are derived from the corresponding BRAGFLO disposal system simulation through several codes, including CUTTINGS_S. Some of the parameters derived from the BRAGFLO disposal system model are permeabilities, porosities, two-phase flow properties, and the height of the waste region. Initial saturations and pressures in the BRAGFLO direct brine release model are mapped from the BRAGFLO disposal system model. Other parameters used in the BRAGFLO direct brine release models are consistent with those used in the BRAGFLO disposal system model (Appendix MASS, Section MASS.16.2 and MASS Attachment 16-2, 3 – 5).

It is possible that a direct brine release could occur from a panel that is connected by a previously-drilled, abandoned borehole to a brine reservoir in the Castile. If this were to happen, flow directly between the two boreholes, analogous to the E1E2 scenario for long-term performance, may affect the estimate of the total brine released. The direct brine release for this possibility is calculated by BRAGFLO_DBR by placing a constant-pressure, flowing injection well as a boundary condition in the model. The locations used for these boreholes are shown in Figure 6-24. It is assumed that a direct brine release from a panel that has a previously-drilled, abandoned borehole of the E2 type is not affected by the presence of the other borehole. Thus, reference direct brine release conditions are calculated for previously unintruded and E2-intruded panels, and for previously-intruded E1 panels. Details about the properties assigned to the flowing-well boundary condition are discussed in Appendix MASS (Section MASS.16.2 and MASS Attachment 16-2, Appendix A). Details about how the consequences of direct brine releases from other possible combinations of boreholes are accounted for in the CCDF are discussed in Section 6.4.13.

A borehole could penetrate the repository anywhere. For simplification, the BRAGFLO direct brine release model assumes that calculation of direct brine release from several defined locations provides meaningful reference results for the possible variation in release because of location. The locations of boreholes from which representative results are calculated are indicated in Figure 6-24. In construction of a CCDF (see Section 6.4.13), the direct brine release associated with a borehole whose position is randomly selected is

correlated with the reference release most consistent with the geometry near the location of the random borehole.

Accurate representation of the flow into the borehole is considered important in the BRAGFLO direct brine release model. Accordingly, a number of mathematical methods that are not used to calculate long-term releases are applied to the conditions in the borehole for calculation of direct brine releases. The methods used appear in Appendix MASS (Section MASS.16.2 and MASS Attachment 16-2).

6.4.7.2 Long-Term Releases Following Drilling

Long-term releases to the ground surface or into groundwater in the Rustler or overlying units may occur after the hole has been plugged and abandoned (Appendix MASS, Section MASS.16.3). As required by regulation, the plugging and abandonment of future boreholes are assumed to be "consistent with practices in the Delaware Basin at the time a compliance application is prepared" [40 CFR § 194.33(c)(1)]. Detailed examination of current practice in the Delaware Basin indicates that all boreholes abandoned recently are plugged to meet state and federal regulatory requirements protecting groundwater and natural resources (see Appendix DEL, Sections DEL.5.5 and DEL.6; Appendix MASS, Section MASS.16.3 and MASS Attachment 16-3). These plugs will be effective in preventing flow in abandoned boreholes for some period of time after emplacement. However, some plugs may fail and radionuclides may be transported in brine flowing up the borehole.

Borehole plug configurations used today in the Delaware Basin vary based on the local stratigraphy encountered in the hole, its total depth, and the types of fluids present. All holes are plugged with some combination of solid concrete plugs isolating different fluid-bearing horizons from each other and from the ground surface. As discussed in detail in Appendix MASS (Section MASS.16.3 and MASS Attachment 16-1) and Appendix DEL (DEL Attachment 7), six different plug configurations are identified that are potentially relevant to future borehole abandonment practice at the WIPP. As discussed in Appendix MASS (Section MASS.16.3.3 and MASS Attachment 16-3, Section 2.0), these six plug configurations can be approximated for performance assessment by three conceptual plugging patterns. The three plugging configurations addressed in the performance assessment are described in the following section. Probabilities of occurrence for each of these three plugging configurations are discussed in Section 6.4.12.7. Parameters used to describe the borehole and its plugs are summarized in Table 6-25.

6.4.7.2.1 Continuous Concrete Plug through the Salado and Castile

In this configuration, a continuous concrete plug is assumed to exist throughout the Salado and Castile (Appendix MASS, Section MASS.16.3 and MASS Attachment 16-3, Figure 1). Such a plug could be installed in keeping with current regulatory requirements of the New Mexico Oil Conservation Division Order R-111-P (State of New Mexico 1988, 10), which is applicable within the potash leasing area that includes the WIPP site. The purpose of the

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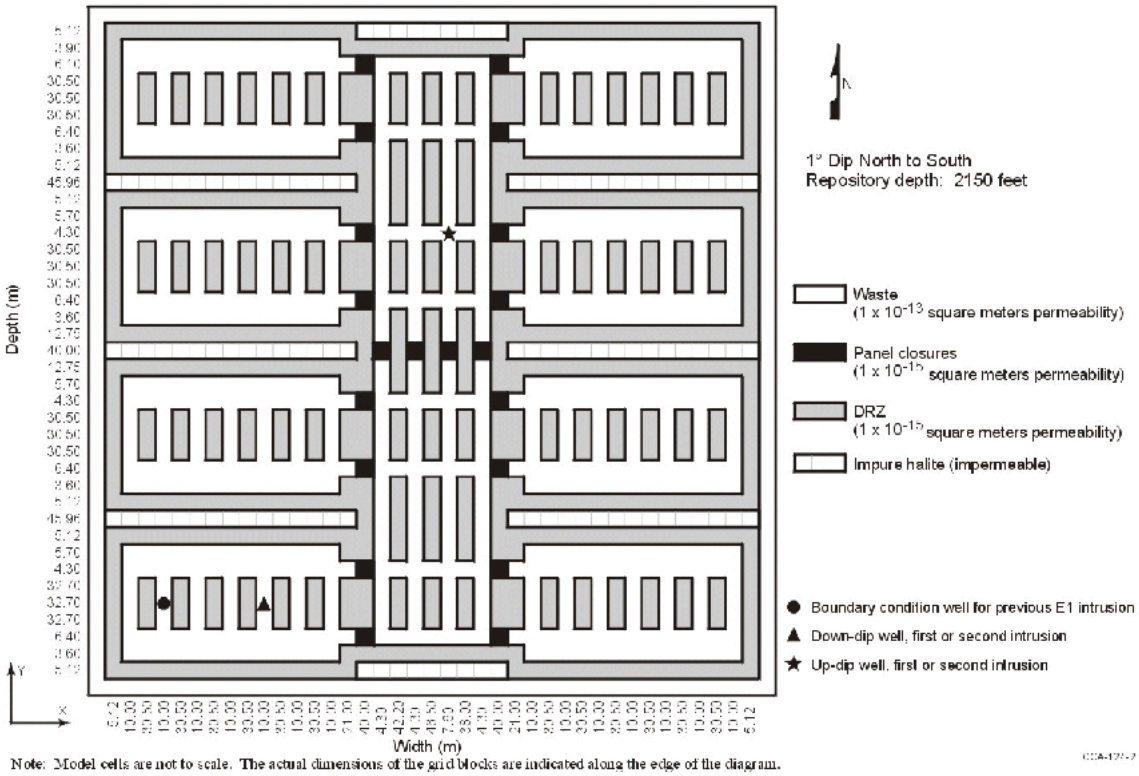

Note: Model cells are not to scale. The actual dimensions of the grid blocks are indicated along the edge of the diagram.

Figure 6-24. Repository-Scale Horizontal BRAGFLO Mesh Used for Direct Brine Release Calculations

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Table 6-25. Intrusion Borehole Properties for the BRAGFLO and CUTTINGS_S Models

Parameter (units)	Maximum	Minimum	Median or Constant[a]
Permeability of open hole (0 to 200 years) (square meters)	—	—	10^{-9}
Permeability of concrete plugs (0 to 200 years in Rustler and at surface) (square meters)[b]	—	—	5×10^{-17}
Permeability of borehole fill material (>200 years) (square meters)[b]	1×10^{-11}	1×10^{-14}	3.16×10^{-13}
Permeability of lower borehole fill material (>1,200 years) (square meters)[b]	1×10^{-12}	1×10^{-15}	3.16×10^{-14}
Effective Porosity (percent)	—	—	0.32
Pore Compressibility (1/pascals)	—	—	0
Diameter (meters)	—	—	0.311
Threshold Pressure, P_t (pascals)	—	—	0
Pore Distribution Parameter, λ (unitless)	—	—	0.94
Residual Brine Saturation, S_{br} (unitless)	—	—	0
Residual Gas Saturation, S_{gr} (unitless)	—	—	0
Effective Shear Resistance to Erosion (pascals)	0.05	10.0	5.03
Waste Particle Diameter (meters)	4×10^{-5}	0.20	2.83×10^{-3}

[a] Parameters with no maximum and minimum values are treated as constants in the performance assessment.
[b] Borehole permeabilities are for the two-plug case. Continuous three-plug case is treated as undisturbed performance.

continuous plug is to protect potash mining operations from possible hydrocarbon contamination. A continuous concrete plug is also used to approximate flow in boreholes in which numerous concrete plugs are found throughout the salt section. Examples of such plugging configurations currently used in the Delaware Basin are described in Appendix MASS (Section MASS.16.3, and MASS Attachments 16-1 and 16-3).

Because concrete within a continuous plug will be physically confined and will have very little brine flow through it, degradation will be minimal and limited to the upper and lower ends of the plug (see Appendix MASS, Section MASS.16.3.3 and MASS Attachment 16-3, Appendix C). For performance assessment, the permeability of the continuous concrete plug is 5×10^{-17} square meters. Because of the small cross-sectional area and low permeability of the potential pathway, long-term releases through a continuous concrete plug are not calculated explicitly for the performance assessment, and are assumed to be zero.

6.4.7.2.2 <u>The Two-Plug Configuration</u>

In the two-plug configuration, two concrete plugs are assumed to have a significant effect on long-term flow in the borehole (Appendix MASS, Section MASS.16.3 and MASS Attachment 16-3, Figure 2). The lower plug of interest is assumed to be located somewhere between the hypothetical Castile brine reservoir and underlying formations. A second plug is located within the lower portion of the Rustler, immediately above the Salado. Additional plugs that have little effect on long-term flow are also assumed to be present deeper in the hole and at the land surface.

In E1-type intrusions with two plugs, the brine reservoir and the repository are assumed to be in direct communication through an open cased hole immediately following drilling. The plugs are located in the borehole Region 1A of the BRAGFLO mesh in Figure 6-14 in Rows 30 and 31 (the surface plug) and Row 23 (the lower unnamed member). The plugs located below the brine reservoir are not modeled explicitly. Plugs are assigned initial permeabilities of 5×10^{-17} square meters, consistent with the expected properties of intact concrete (see Appendix MASS, Section MASS.16.3.2 and MASS Attachment 16-3, Appendix C.3.1.2 [C-4]). The open segments of borehole between the plugs are assigned an initial permeability of 10^{-9} square meters. Steel casing above the Salado is assumed to begin to degrade within decades after abandonment and is assumed to have failed completely after 200 years. The concrete plugs above the Salado are also assumed to fail after 200 years, as a result of chemical degradation where they are in contact with brine. The plug below the Castile brine reservoir is in a less aggressive chemical environment, and its properties remain constant in performance assessment.

After the upper plugs and casing have failed, the borehole is assumed to be filled by a silty-sand-like material containing degraded concrete, corrosion products, and material that sloughs into the hole from the walls. Thus, beginning 200 years after the time of intrusion, the entire borehole region in the BRAGFLO model, including the sections previously modeled as concrete plugs, is assigned a permeability corresponding to silty sand. This permeability is sampled from a log-uniform distribution from 10^{-11} square meters to 10^{-14} square meters.

One thousand years after the plug at the base of the Rustler has failed, or 1,200 years after the time of intrusion, permeability of the borehole region below the waste-disposal panel in the BRAGFLO model used for E1-type intrusions is decreased from its sampled value by one order of magnitude. For the remainder of the 10,000-year period, the borehole is modeled with its sampled permeability value above the repository and the adjusted value below. Conceptually, the decrease in permeability below the panel corresponds to compaction of the silty-sand-like material by partial creep closure of the lower portion of the borehole. As discussed in Appendix MASS (Section MASS.16 and MASS Attachment 16-3, Appendix D), creep closure of boreholes is not expected to be significant above the repository horizon but will be effective at greater depths because of the greater lithostatic stress. Nowhere in the borehole is creep closure assumed to close the hole completely in the regulatory time frame, but closure will be sufficient at depths below the repository to reduce the permeability of the material filling the hole.

6.4.7.2.3 <u>The Three-Plug Configuration</u>

In the three-plug configuration, three concrete plugs are assumed to have an effect on long-term flow in the borehole (Appendix MASS, Section MASS.16.3 and MASS Attachment 16-3, Figure 3). Two of the plugs are identical to those modeled in the two-plug configuration. The third plug is located within the Castile above the brine reservoir and below the waste-disposal panel. This plug is assumed to behave in the same manner as the lower plug in the two-plug configuration: that is, its properties remain unchanged in performance assessment. Otherwise, all portions of the borehole in the three-plug configuration are assumed to have the same material properties as the corresponding regions in the two-plug configuration, with adjustments to borehole-fill permeability occurring 1,000 years after failure of the overlying plug (Appendix MASS, Section MASS.16.3 and MASS Attachment 16-3, Section 5.3).

Because the three-plug configuration isolates the repository from the brine reservoir for the time period during which the middle plug remains effective and because the portion of the borehole above the middle plug will already be filled with silty-sand-like material before failure of the middle plug occurs, the DOE has chosen not to model this configuration explicitly in the BRAGFLO calculations. Boreholes in which the three-plug configuration is emplaced are assumed to result in long-term releases comparable to those calculated for E2 intrusions, regardless of whether they penetrate a Castile brine reservoir. Consequences of E1-type intrusions with the three-plug configuration are assumed for the purposes of CCDF construction to be identical to the consequences of E2 intrusions occurring at the same time.

6.4.8 Castile Brine Reservoir

As discussed in Section 2.2.1.2.2, high-pressure Castile brine has been encountered in several WIPP-area boreholes, including the WIPP-12 borehole within the controlled area and the U.S. Energy Research and Development Administration (ERDA)-6 borehole northeast of the site.

The E1 and E1E2 scenarios include penetration by a borehole of the repository and a brine reservoir in the Castile. The properties of the borehole are discussed in Section 6.4.7.

For performance assessment, the Castile is conceptualized as unimportant because of its expected low permeability (based on similarities to the Salado), unless a borehole penetrates both the repository and a brine reservoir in the Castile. Two regions are specified in the Castile horizon in the disposal system geometry: the Castile (Region 29 in Figure 6-13) and a reservoir (Region 30 in Figure 6-13). The Castile region is assigned an extremely low permeability, which prevents it from participating in fluid flow processes, consistent with the concept that it is unimportant.

It is not known whether a brine reservoir actually exists below the repository. Because of this fact, the conceptual model for the brine reservoirs is somewhat different from those for known major properties of the natural barrier system, such as stratigraphy. The principal difference is that a reasonable treatment of the uncertainty of the occurrence of brine reservoirs requires that assumptions be made about their spatial distribution and probability of intersection (Appendix MASS, Section MASS.18.1 and MASS Attachment 18-6). These properties are treated as stochastic uncertainty in performance assessment modeling (that is,

they are related to whether a brine reservoir exists and whether a brine reservoir intersection occurs; see Section 6.1.2). These assumptions are discussed in Section 6.4.12.

In addition to the stochastic uncertainty in the location and probability of intersecting reservoirs, there is also uncertainty in the properties of reservoirs if they are intersected (Appendix MASS, Section MASS.18 and MASS Attachments 18-2 and 18-3). This is treated as subjective uncertainty (that is, it is related to the question, If a brine reservoir is assumed to be penetrated, how does it behave?; see Section 6.1.2) and is incorporated in the BRAGFLO calculations of disposal system performance. The conceptual model for the behavior of the hypothetical brine reservoir is discussed here.

Where they exist, Castile brine reservoirs in the northern Delaware Basin are believed to be fractured systems, with high-angle fractures spaced widely enough that a borehole can penetrate through a volume of rock containing a brine reservoir without intersecting any fractures and therefore not produce brine. They occur in the upper portion of the Castile (Popielak et al. 1983, G-2). Appreciable volumes of brine have been produced from several reservoirs in the Delaware Basin, but there is little direct information on the areal extent of the reservoirs or the interconnection between them. The WIPP-12 data indicate that fractures in the network have a variety of apertures and permeabilities, and they deplete at different rates. Brine occurrences in the Castile behave as reservoirs—that is, they are bounded systems—rather than as aquifers such as groundwater in the Culebra and Magenta. The properties that need to be specified for brine reservoirs are pressure, permeability, compressibility, total brine volume, and porosity.

Brine reservoir pressure in this performance assessment is based on measured pressure in anhydrites in the Castile and Salado. The values used in this performance assessment are shown in Table 6-26. These values are determined by analysis of pressures observed in brine produced from anhydrites in the Salado and Castile, corrected for the difference in depth between the observation location and WIPP-12. The analysis is documented in Appendix MASS (Section MASS.18 and MASS Attachments 18-1 and 18-2) and Appendix PAR (Parameter 27).

The permeability of brine reservoirs is based on analysis of brine reservoirs tested by the DOE in drillholes ERDA-6 and WIPP-12 (Popielak et al. 1983, Sections H-3.4.3 and H-3.4.4). Values used in this performance assessment are shown in Table 6-26. The derivation of these values from the referenced study is documented in Appendix PAR (Parameter 28).

Table 6-26. Parameter Values Used for Brine Reservoirs in the BRAGFLO Calculations

Parameter (units)	Maximum	Minimum	Median or Constant[a]
Permeability (square meters)	1.58×10^{-10}	2.0×10^{-15}	1.58×10^{-12}
Effective Porosity (percent)	-	-	0.87
Rock Compressibility (1/pascals)[b]	10^{-8}	5.0×10^{-12}	10^{-10}
Initial Pressure (pascals)	1.70×10^{7}	1.11×10^{7}	1.27×10^{7}
Threshold Pressure, P_t (pascals)[c]	4.59×10^{-6}	2.28×10^{-4}	4.6×10^{-5}
Pore Distribution Parameter, λ	-	-	0.70
Residual Brine Saturation, S_{br} (unitless)	-	-	0.20
Residual Gas Saturation, S_{gr} (unitless)	-	-	0.20
Maximum Capillary Pressure (pascals)	-	-	10^{8}
Brine Volume (cubic meters)	160,000	32,000	80,000[d]

[a] Parameters with no maximum and minimum values are treated as constants in the performance assessment.
[b] Pore compressibility = rock compressibility/effective porosity.
[c] Threshold Pressure (P_t) determined from the relationship: $PCT_A \cdot k^{PCT_EXP}$, where PCT_A and PCT_EXP are constants and k is the permeability.
[d] There is equal probability of a brine volume less than 80,000 or greater than 80,000 cubic meters. However, 80,000 cubic meters is not a brine reservoir volume allowed in the model. See Appendix PAR.

The compressibility of brine reservoirs is based on analysis (Appendix MASS and MASS Attachment 18-2) of data collected from the WIPP-12 brine reservoir (Popielak et al. 1983, G-33). Values used in this performance assessment are shown in Table 6-26. The derivation of these values is documented in Appendix PAR (Parameter 29). The range for Castile brine reservoir compressibility used in BRAGFLO is broad. This range was selected in an attempt to ensure that all possible values are encompassed. Because the volume of brine that could be produced from a reservoir depends heavily upon the compressibility assumed, the brine volumes generated by the model reasonably bound those that would be produced from a Castile brine reservoir that could exist directly below the waste panels.

The brine reservoir volume is based on WIPP-12 observations and consideration of the effects of drilling 46.8 boreholes per square kilometer in the next 10,000 years in the vicinity of the site. The interconnectivity, or extent, of a fractured reservoir is uncertain. Analysis of WIPP-12 data has led to estimates of the effective radius of reservoirs from several hundred meters to several kilometers (Appendix MASS, Section MASS.18.1 and MASS Attachment 18-3), where the effective radius is the area over which the fractured network of a single reservoir extends. Reservoirs interpreted as smaller have effective radii on the order of several hundred meters—in other words, dimensions somewhat smaller than the waste panel. This interpretation is generally supported by geophysical survey data (see Section 6.4.12.6 and Appendix MASS, Section MASS.18.1 and MASS Attachment 18-5). Reservoirs interpreted as large have effective radii much larger than the waste panel dimensions, or even the site dimensions. The DOE assumes that reservoirs that may exist under the waste panels have

limited extent and interconnectivity, with brine volumes consistent with the lower values estimated from the WIPP-12 encounter. The basis for this assumption is discussed in the following paragraphs.

Consistent with regulatory criteria in 40 CFR § 194.33(b)(3) regarding the rate of drilling used in performance assessment, the DOE assumes that 46.8 deep boreholes may be drilled per square kilometer in the next 10,000 years. This drilling rate implies nearly 40-acre spacing of boreholes in the vicinity of the WIPP in 1,000 years, and nearly 5-acre spacing of boreholes at the end of 10,000 years. Even with limited probability of intersecting a brine reservoir (Section 6.4.12.6), there should be approximately one intersection per 480 acres in 1,000 years, and approximately one intersection per 48 acres in 10,000 years. Every time a reservoir of abnormally pressurized brine is penetrated, its pressure is partially depleted. Abnormally pressurized brine is defined as exhibiting pressure that exceeds the anticipated hydrostatic pressure for that depth. If reservoirs are well interconnected, they will be penetrated and partially depleted many times during 10,000 years until penetrating a reservoir no longer produces flow. If reservoirs are poorly interconnected, regions of pristine reservoirs could persist, although these would have lower producible brine volumes because of their limited extent.

There is an area in which potential brine reservoirs cannot be penetrated and depleted for some time—under the waste panels while passive institutional controls are effective. The passive institutional controls shield a region of the Castile from exploratory drilling. If brine reservoirs are well interconnected, the sheltered region could be depleted by the effects of multiple penetrations occurring in unprotected areas. If brine reservoirs are poorly interconnected, they could persevere under pristine conditions under the panels. The DOE considers that there are two reasonable conceptual models consistent with the drilling rate for the future condition of brine reservoirs in the WIPP region: (1) they are interconnected over large areas and penetrated and partially depleted many times; and (2) they are interconnected over small areas and not affected by the penetrations that occur outside but near the waste-area footprint. The DOE assumes that brine reservoirs potentially under the waste panels are poorly interconnected hydraulically (with extents similar to the lower estimates from WIPP-12), not much affected by penetrations occurring outside but near the waste-area footprint, and can persevere with pristine conditions until penetrated by a borehole drilled within the panel area. The DOE considers a pristine-condition, smaller reservoir to have potentially greater consequences than a depleted large reservoir.

The distribution of brine volumes assumed in performance assessment for determining the consequence of first penetration of a brine reservoir has five values: 32,000, 64,000, 96,000, 128,000, and 160,000 cubic meters (see Appendix MASS, Section MASS.18 and MASS Attachment 18-3). The smallest volume, 32,000 cubic meters, is the minimum volume from an analysis of WIPP-12 data (see Appendix MASS, MASS Attachment 18-3). Because this WIPP-12 reservoir volume represents an estimated effective area of about one-third of the waste panel area and because a reservoir larger than the minimum WIPP-12 volume could reasonably exist under the waste panels, the DOE also considers larger reservoir volumes in performance assessment. In BRAGFLO, the brine volume is placed in a region of rock of

constant dimensions. The porosity of the constant rock volume is set such that it contains pore volume equal to the reservoir brine volume. The porosity used for the largest reservoir is shown in Table 6-26. Porosities for smaller reservoirs are adjusted to yield the appropriate volume.

The BRAGFLO calculations develop reference system behavior for possible future events. BRAGFLO calculations of the E1 scenario are executed for every vector. In the calculations, it is assumed that a brine reservoir exists beneath the waste panels, and it is assigned properties from LHS. Because there is a probability associated with the occurrence of a brine reservoir, there may be no penetration of a brine reservoir in a randomly determined sequence of future events. In this case, the BRAGFLO reference-condition results for a brine reservoir penetration are not used. The probability assigned to penetrating a brine reservoir is discussed in Section 6.4.12.6 and Appendix MASS (Section MASS.18 and MASS Attachment 18-6).

6.4.9 Climate Change

The present climate at the WIPP and the geologic record of past climate change in southeastern New Mexico are discussed in Section 2.5 and Appendix CLI. Although meaningful quantitative predictions of future climate for the next 10,000 years are not feasible for the WIPP (or any location), effects of reasonably possible climate changes on disposal system performance must be considered. For the WIPP, uncertainty about these effects is incorporated in the performance assessment by considering the effects of various possible future climates on groundwater flow and potential radionuclide transport in groundwater. Direct effects of climate change that do not involve groundwater flow do not affect the long-term performance of the WIPP because of its depth below the land surface. Examples of such direct effects are changes in wind patterns, thermal effects related to changes in surface temperature, and near-future impacts on surface facilities. Long-term effects of climate change on the near-surface portions of the shaft seal system (see Section 6.4.4) are not incorporated in the analysis because BRAGFLO modeling conducted for this performance assessment indicates that system performance is unaffected by the behavior of the upper portion of the shaft seal system. Additional aspects of climate change screened out from the performance assessment, including glaciation at the site and possible future anthropogenic changes, are discussed in Appendix SCR (Sections SCR.1.6.2 and SCR.3.6.1).

The effects of postulated climate change on groundwater flow have been evaluated outside of the performance assessment calculations using a regional three-dimensional groundwater basin model based on the concept of basin hydrology introduced in Section 2.2.1.1. For the purposes of the regional analysis, climate-related factors that might affect groundwater flow, such as precipitation, temperature, and evapotranspiration, are treated through a single model parameter, potential recharge, which controls the rate at which water is added to the model at the water table. As described in Appendix MASS (Section MASS.17 and MASS Attachment 17-1), changes in this parameter allow simulation of regional groundwater flow under a range of different future states in which the climate may be wetter, the water table may be higher, and groundwater velocity in all units may increase. These and other simulations discussed in Appendix MASS (Section MASS.15 and MASS Attachment 15-7), show that the regional,

three-dimensional effects of climate change can be reasonably approximated in performance assessment through direct scaling of specific discharge in the two-dimensional, steady-state groundwater velocity field for the Culebra. The velocity field is calculated using SECOFL2D, as described in Section 6.4.6.2 and Appendix CODELINK (Section CODELINK.6.4). Radionuclide transport in the Culebra is then calculated by SECOTP2D using the scaled velocity fields.

Scaling of the two-dimensional velocity field is done using the Climate Index (Table 6-27), which is a dimensionless factor by which the specific discharge in each grid block of the SECOFL2D domain is multiplied. As summarized in Appendix PAR (Parameter 48), the Climate Index is a sampled parameter in the performance assessment, with a bimodal distribution ranging from 1.00 to 1.25 and from 1.50 to 2.25. A single value of the Climate Index is chosen in LHS for each sample element and held constant throughout the 10,000-year SECOFL2D simulation. Each realization of disposal system performance thus represents a different approximation of future climate. Those realizations in which the sampled value is close to its maximum of 2.25 represent the most extreme changes in groundwater flow that may result from climatic change.

Table 6-27. Climate Change Properties for the SECOFL2D Model

Parameter (units)	Maximum	Minimum	Median
Climate Index (dimensionless)	2.25	1.00	1.17

Sampled values close to the minimum of 1.00 represent climatic changes that have little effect on groundwater-flow velocities. Because all sampled values of the Climate Index are greater than 1.00, climate change as implemented in the performance assessment can only increase the rate of groundwater flow.

The distribution assigned to the Climate Index parameter is based on the results of three-dimensional basin modeling that considers future changes in the temporal pattern of potential recharge (see Appendix MASS, Section MASS.17 and MASS Attachment 17-1, Section F). Potential recharge is defined for the purposes of the regional modeling to be the maximum rate at which water can be added at the water table. Recharge itself is a model result and ranges from zero to the potential recharge. For those areas where the water table is at the ground surface and modeling indicates that water is discharging to the land surface through a seepage face, the potential recharge does not enter the model and has no effect on groundwater flow. In areas where the water table is below the land surface, potential recharge becomes actual recharge and tends to cause the elevation of the water table to rise. If potential recharge is zero, the water table in an idealized basin will tend to fall until it is a horizontal plane with an elevation equal to the lowest topographic point in the basin. Sufficiently large values of potential recharge will cause the water table to rise to the land surface everywhere. Smaller nonzero values result in solutions with water tables that are at the land surface at topographic low points (discharge areas) and at some distance below the

land surface at topographic highs (recharge areas). Changes in potential recharge cause the elevation of the water table to rise or fall. In the three-dimensional modeling of the WIPP region, potential recharge was assumed to be spatially invariant across the regional model domain and is assumed to change through time in response to changes in climate.

Both steady-state and transient three-dimensional regional analyses have been executed with values of potential recharge varied such that the elevation of the water table ranged from approximately its present position to at or near the land surface. The latter condition provides an upper bound for regional groundwater-flow velocities during future wetter climates. For all simulations examining the effects of climate change, recharge is assumed to be greater at some time in the future than it is at present. Present recharge is assumed to be the same as its minimum value during the Holocene. The dominant effects on climate change during the next 10,000 years are assumed to be natural rather than anthropogenic. This assumption is consistent with regulatory guidance provided by the EPA indicating that consideration of the effects of climate change should be limited to natural processes (EPA 1996a, 61 FR 5227).

Because of uncertainty about recharge rates during future wet periods and the timing of these periods, transient analyses use two fundamentally different patterns for the change in potential recharge. The first pattern for future potential recharge used in the analysis corresponds to a continuation of the inferred climate patterns of the Holocene (see Section 2.5.1 and Appendix CLI, Section 3), with wetter peaks occurring 500, 2,000, 4,000, 6,000, 8,000, and 10,000 years in the future. Potential recharge is assumed to increase and decrease linearly during the wet periods 500 years before and after the peaks, and the wet periods are each separated by 1,000 years of a drier climate like that of the present. Several different values were examined for the maximum potential recharge imposed at the wet peaks, with the largest value chosen to provide a steady-state solution with the water at, or close to, the land surface throughout the model domain. As discussed in Appendix MASS (Section MASS.17 and MASS Attachment 17-1, Section F), a continuation of the Holocene climatic variability is considered likely during the next 10,000 years, and this function is assigned a relatively high probability of occurrence (0.75). This recharge function and its probability of occurrence are reflected in the lower portion of the bimodal distribution assigned to the Climate Index parameter.

The second recharge pattern considered in the analysis assumes that potential recharge will increase from its present value to a specified larger value 500 years in the future and that potential recharge will then remain constant throughout the rest of the 10,000-year simulation. As with the Holocene pattern, several different values were examined, with the largest being sufficient to result in a steady-state solution with the water table at, or close to, the land surface throughout the model domain. Conceptually, this pattern corresponds to a future in which the climate either becomes continuously wetter or the frequency of wetter periods becomes sufficiently large that the hydrologic response is indistinguishable from that of a continuously wetter climate. Step-increase recharge functions were used to simulate the effects of major disruptions of the Holocene climate, analogous to those that might occur during the next 10,000 years in a transition from the present warm interglacial climate to the early stages of a future glacial climate. As discussed in Appendix MASS (Section MASS.17), such disruptions to the Holocene climate are considered unlikely, and the step function is

assigned a relatively low probability of occurrence (0.25). This recharge pattern and its probability of occurrence are represented by the upper portion of the bimodal distribution assigned to the Climate Index parameter.

As reported in Appendix MASS (Section MASS.17 and MASS Attachment 17-1, Section E), 17 transient and 54 steady-state, regional three-dimensional groundwater-flow simulations were run to examine effects of climate change. Simulations considered both potential recharge functions with varying peak recharge rates and different sets of assumptions about regional rock properties. Total specific discharge into and out of the Culebra within a model region approximately corresponding to the controlled area was calculated for each simulation. Values for the Climate Index parameter were determined by comparing the total lateral specific discharge calculated for each simulation. The largest observed increase in flow for those simulations using realistic values of rock properties was a factor of 2.1. Although some simulations produced a slight reduction in flow, Climate Index parameter values less than 1.0 are not considered in the performance assessment. Changes in flow direction in the Culebra were also noted in some three-dimensional simulations, with a shift in flow toward the west corresponding to a regional increase in the elevation of the water table. These potential changes in flow direction are not incorporated in the two-dimensional flow and transport modeling to simplify the computational process. This treatment is conservative with respect to radionuclide transport because the most rapid transport possible under any climate conditions will be through the most conductive portion of the Culebra south and east of the repository. Any shift of the flow direction away from this high conductivity zone would result in slower transport through less permeable rock. Restricting the effects of climate change to a uniform linear scaling of specific discharge in the SECOFL2D model is, therefore, a conservative assumption.

6.4.10 Initial and Boundary Conditions for Disposal System Modeling

The solution of many mathematical models used in performance assessment requires specification of a starting point, called initial conditions, and specification of how the region modeled (that is, volume) interacts with the regions not modeled, called boundary conditions. Initial values are required for all of the parameters appearing in a computer code. In practice, however, the term initial conditions refers to the values assigned to the primary variables used to describe the system, examples of which may be pressure, composition, and saturation. The term boundary conditions refers to the specification of primary variables that control the interaction of the modeled region with the regions excluded from the model. In many studies, applied boundary conditions are static in time, although computer codes that implement time-dependent boundary conditions are not uncommon. A common practice in modeling groundwater flow is to place boundaries of the modeled system somewhat distant from the region in which model results are of interest. This is done to help ensure that uncertainty in the natural boundaries of the system does not unduly influence model results in the region of interest. The DOE adopts this practice in its application of BRAGFLO and SECOFL2D to the WIPP.

The following sections describe the initial and boundary conditions specified for the major codes used in this performance assessment. Initial values of parameters not discussed in the following sections are set equal to the values assigned from the performance assessment database or LHS sampling that are discussed elsewhere in Section 6.4.

6.4.10.1 Disposal System Flow and Transport Modeling (BRAGFLO and NUTS)

In BRAGFLO, initial conditions for the simulation of the regulatory period are consistent with the following: (1) there are no gradients for flow in the far-field Salado; (2) Salado far-field pore pressures are elevated above hydrostatic from the surface but below lithostatic; and (3) near the repository, excavation and waste emplacement results in partial drainage of the DRZ and subsequent evaporation of drained brine into mine air, and then removal from the modeled system by air exchanged to the surface. The term far-field used above refers to the region that is not influenced by the drainage of the DRZ mentioned in (3). For units above the Salado, initial pressures are set to be consistent with observed pore pressures or normal hydrostatic gradients.

Estimating the effects of drainage of the DRZ that occurs during the operational period, (3) above, is not simple. For each vector sampled in LHS, the DOE estimates this by using BRAGFLO to simulate a period of time representing disposal operations. This calculation is called the start-up simulation and covers five years from t = −5 years to t = 0 years, corresponding to the amount of time a typical panel is expected to be open during disposal operations. Most of the initial parameters used during the regulatory period simulation (t = 0 to t = 10,000 years) are also assigned for the start-up simulations, with some exceptions that are described below.

The initial pressures in the Salado for the start-up simulation are calculated based on a sampled pressure at the elevation of MB139 at the shaft and adjusted throughout the Salado and the DRZ to account for changes in hydraulic head due to elevation change. This parameter is discussed in Appendix PAR (Parameter 26). This adjustment assumes hydrostatic equilibrium. The DRZ permeability is set at 10^{-17} square meters for the start-up simulation. Based on observed changes in the DRZ, the DRZ porosity is adjusted upwards 0.0029 (0.29 percent) from the sampled value for intact impure halite. Initial pressure for the start-up simulation in the excavated regions is set to atmospheric. The shaft exists and is modeled as unfilled with the same physical properties as the excavation.

For the start-up simulation, an initial water-table surface is specified within the Dewey Lake at an elevation of 3,215 feet (980 meters) above mean sea level. This elevation is consistent with observations discussed in Section 2.2.1.4.2.1. Above the water table, pressure is maintained at one atmosphere, 0.101 megapascals; liquid saturations in these computational cells are held constant at residual liquid saturation (Section 6.4.6.6, Table 6-23). Below the water table initial liquid saturations in all regions except the repository and shaft are 100 percent. Pressures are set consistent with a hydrostatic gradient below the water table within the Dewey Lake, as well as in the Rustler except for the Magenta and Culebra. An initial pressure for the Culebra is set at 0.822 megapascals, based on fluid level and fluid density

data collected at H-1, H-2B, H-3, H-4B, H-5B, H-6B, P-14, P-15, and P-17. An initial pressure of 0.917 megapascals is specified for the Magenta, calculated from fluid level and fluid density data from H-1, H-2A, H-3, H-4A, H-5A, and H-6A (Dotson 1996). Even though the natural properties of the units above the Salado vary considerably over the domain modeled by BRAGFLO, the BRAGFLO initial condition of constant pressure and constant properties for each layer is considered reasonable because the purpose of the BRAGFLO calculation with respect to these units is to calculate the long-term flux of brine from the borehole or shaft to each unit, or to the surface. For this purpose, the pressure and properties at the borehole or shaft are important, but details of regional hydraulic head and unit properties are not.

For the start-up simulation, permeabilities of all units above the Salado are set to zero so that flow cannot occur from these units into the shaft. This modeling assumption is adopted as a simple method of accounting for the existence of effective liners in the shafts during disposal operations.

For the start-up simulation, no-flow boundary conditions are assigned in the BRAGFLO model of the disposal system along all of the exterior boundaries of the computational mesh except at the far field boundaries of the Culebra and Magenta and the top of the model (that is, the surface of the ground). These boundaries are 20 kilometers from the edge of the land withdrawal area boundary, as discussed in Section 6.4.2.1. The ground surface is maintained at atmospheric pressure. The boundaries of the Culebra and Magenta are maintained at pressures of 0.822 megapascals and 0.917 megapascals, respectively, corresponding to the initial pressure conditions used in the Culebra and Magenta. The pressure in the Castile brine reservoir is set at its sampled value for the start-up simulation.

During the start-up simulation, fluid flow calculated by BRAGFLO from the Salado and the DRZ into the excavated region simulates the effect of drainage into the repository during the operational period. Following the completion of the start-up simulations, specification of initial conditions occurs for the regulatory period simulation. Boundary conditions for the regulatory period simulation are the same as those for the start-up simulation.

The regulatory period simulation begins with conditions specified consistent with the sealing of the repository by construction of shaft seals. Certain properties assigned for the start-up simulation are changed to make model conditions consistent with the emplacement of waste and completion of sealing. The liquid saturation in the waste-disposal region of the repository is set at 0.015, which is a conservative value (Butcher 1996), and other areas of the excavation are assigned zero liquid saturation (100 percent gas saturation), regardless of the quantity of brine that may have flowed into the excavation during the start-up simulations. This is consistent with the observed ability of circulating mine air to remove any inflowing brine by evaporation. The entire repository is assigned an initial pressure of one atmosphere. Pressures and saturations in model regions representing rock remain as they were calculated to be at the end of the start-up simulation. Permeabilities of the units above the Salado are reset to the values specified for them as discussed in Section 6.4.6. The shaft is assigned properties for shaft seal materials discussed in Section 6.4.4. The pressure in the shaft is set to

one atmosphere, and the liquid saturation of shaft materials is set to 1.0 except in asphalt, where liquid saturation is 0 percent. Waste is emplaced in the waste-disposal regions at a density of 1.63×10^2 kilograms per cubic meters for ferrous metals and 6.52×10^1 kilograms per cubic meters for biodegradable materials, and other waste properties are assigned as discussed in Section 6.4.3.2. Panel closure properties discussed in Section 6.4.3.2 are assigned to the panel closure regions. Permeability in the DRZ is raised to 10^{-15} square meters; this value remains constant for the regulatory period simulation. Corrosion and biodegradation reactions that produce gas are modeled to begin at the start of the regulatory period simulation, and their rates depend on the sampled parameter values for the gas generation model (see Section 6.4.3.3) and the availability of brine. Modeling of creep consolidation through the use of the porosity surface also begins at this time (see Section 6.4.3.1).

6.4.10.2 Culebra Flow and Transport Modeling (SECOFL2D, SECOTP2D)

Groundwater flow in the Culebra is computed at both a regional and local scale. Regional-scale simulations are performed over a large domain using a computational grid that is coarser than the grid used for the local scale. The regional domain covers only a portion of the natural hydrologic system. A correct flow field can be calculated for any arbitrary part of a more extensive system if the transmissivity distribution and the values of hydraulic head assigned at the boundaries are representative of observed conditions. There is therefore considerable flexibility in choosing the locations of boundaries for the regional SECOFL2D model. Several factors were considered in selecting these boundaries. One side of the rectangular domain was aligned along a natural hydrologic feature, the axis of Nash Draw. The size of the model domain was selected such that the domain does not extend a great distance beyond the region of concentrated transmissivity and hydraulic-head data but was large enough that the imposed boundary conditions would not have a large influence on the solution in the region of interest. The results of the regional-scale simulations are used to interpolate boundary conditions at the local scale. This modeling approach allows the use of high resolution computational grids in the region of interest for computing radionuclide transport and the incorporation of a flow field representing a larger area.

The regional domain is approximately 13.67 miles by 18.64 miles (22 kilometers by 30 kilometers) and is aligned with the axis of Nash Draw along a portion of the western boundary (see Figure 6-17 in Section 6.4.6.2). Nash Draw is a highly conductive region that behaves hydraulically as a groundwater divide (see Section 2.2.1.1). Therefore, that portion of the western boundary oriented along Nash Draw is represented by a no-flow boundary. The remaining regional boundary conditions are positioned to align with topographic highs or other geologic features such as the San Simon Swale on the southeast boundary. Because of uncertainty in boundary heads, the boundaries are positioned a large distance from the local problem domain (see Figure 6-18 in Section 6.4.6.2). This is done to reduce the influence of these boundary conditions on the solution in the region of interest. Because boundary head values can be easily estimated numerically during the calibration of transmissivity fields from existing well data, Dirichlet (constant head) boundary conditions are used on these boundaries (see also the discussion in Section 6.4.6.2).

Boundary conditions of the local domain are Dirichlet (constant-head) and derived by interpolating the solution of the regional domain. Because these boundary conditions are set by interpolation and because the simulations are steady state, Dirichlet and Neuman (specified flux) boundary conditions will provide essentially identical results, and specification of the type of boundary condition is not important.

An initial estimate of the undisturbed head distribution is required to analyze transient well data needed to generate the transmissivity fields (see Section 6.4.6.2 and Appendix TFIELD, Section TFIELD.2.2.4). These data were obtained from hydrographs of the WIPP boreholes measured prior to the excavation of the first shaft. The hydrographs depict hydraulic heads for up to 5 years preceding shaft excavations. The transmissivity-field calibration process develops a set of boundary heads for the regional domain that are consistent with hydrograph observations and the transmissivity field generated.

Initial conditions are not required for the Culebra flow calculations because these are steady state. Initial actinide concentrations in the transport simulations are assumed to be zero.

6.4.10.3 Initial and Boundary Conditions for Other Computational Models

In addition to BRAGFLO, SECOFL2D, and SECOTP2D, several other codes are used in performance assessment that require initial and boundary conditions. In general, these codes are strongly coupled to BRAGFLO, analogous to the manner in which SECOTP2D is coupled to SECOFL2D. These additional codes are NUTS, PANEL, the BRAGFLO direct brine release model (BRAGFLO_DBR), and CUTTINGS_S.

NUTS transports radionuclides through the BRAGFLO domain based on fluid flow characteristics as calculated by BRAGFLO and, therefore, does not need explicit definition of flow boundary conditions. As actinide transport is not of concern until the repository contains waste and is sealed, a start-up simulation is not executed with NUTS. Boundary conditions for advective transport are consistent with the boundary conditions assumed for fluid flow. Molecular transport boundary conditions for NUTS simulations consist of no diffusion or dispersion in the normal direction across far-field boundaries. Initial actinide concentrations are zero in all regions except the waste. Actinide concentrations in brine in the waste regions are assigned as discussed in Section 6.4.3.5 (Table 6-11).

PANEL is used to estimate the transport of radionuclides from the repository to the Culebra for the E1E2 scenario. PANEL assumes homogeneous mixing within a panel of the waste disposal region for determination of a source term for radionuclides. PANEL is strongly coupled to BRAGFLO, in that the flux of liquid up the borehole out of the separate panel in BRAGFLO is provided as the flux of liquid leaving the mixing volume in PANEL. Liquid leaving the mixing cell in PANEL is assumed to arrive at the Culebra, thereby maximizing the source of actinides to the Culebra.

Models for direct release to the surface are also strongly coupled to BRAGFLO. CUTTINGS_S (cuttings, cavings, and spall) and BRAGFLO_DBR acquire fluid pressure, fluid

saturation, and other necessary quantities from the appropriate BRAGFLO disposal system model simulation. It is assumed in the direct release models that radionuclides, once entrained in drilling fluid, remain in the drillhole until they reach the surface. In other words, there is no interaction between drilling fluid and the formations between the repository and the surface. Boundary conditions in the direct brine release model are no-flow except for the sources and sinks of brine through borehole nodes and at the surface.

6.4.11 Numerical Codes Used in Performance Assessment

To evaluate scenario consequences for both undisturbed and disturbed performance, the DOE uses many computer codes to simulate relevant features of the disposal system. The flow of information and primary roles of the codes used are discussed in this section; detailed discussion of the individual codes is reserved for appendices, which are referenced as appropriate. Parameter values and disposal system conditions must be passed between codes several times in an assessment.

The codes are executed under the requirements of the SCMS, which creates and maintains a complete record of the input data and results of each calculation, together with the exact codes used to create those results. For this application, performance assessment codes used in conjunction with LHS or random sampling were executed under the SCMS.

The major computer codes and the flow of information among them are illustrated in Figure 6-25. As discussed in Section 6.1.4 and indicated in Figure 6-25, some of these codes are used to calculate reference conditions for deterministic futures associated with the parameters in $\mathbf{x}_{su}$ (Equation 4b [Section 6.1.2]) and their associated uncertainty characterized by distributions D_{su} (Equation 6b [Section 6.1.2]). The results of these codes are then used in the construction of the consequences of probabilistic futures. There are three major steps in evaluating scenario consequences for deterministic futures: (1) preparation of input from submodels executed independent of LHS (for example, SANTOS, GRASP-INV), (2) LHS of the variables $\mathbf{x}_{su}$ in the performance assessment parameter database, and (3) execution of the sampling-dependent performance assessment codes (those within the deterministic futures box indicated by dashed lines in Figure 6-25).

Some performance assessment codes are used to calculate probabilistic futures, that is, future events that occur randomly in time and space, and uncertainty in associated parameters in $\mathbf{x}_{st}$ (Equation 4a [Section 6.1.2]) and their uncertainty characterized by distributions in D_{su} (Equation 6a [Section 6.1.2]). There are two major steps in evaluating scenario consequences for probabilistic futures: (1) random sampling of the parameter database, and (2) execution of the codes.

Figure 6-25 indicates only those codes that perform the bulk of the computational effort related to simulating the significant physical processes occurring within the disposal system. In addition to these codes, a variety of additional codes are used in this performance assessment. These additional codes are used for the transfer of data between codes,

preparation of input files, model output processing, and similar tasks. These codes are also executed within the SCMS.

Because these additional codes are not expressly used for simulation of physical processes, they have been omitted for clarity from discussion here and on Figure 6-25. A comprehensive description of the coupling of codes used in this performance assessment is provided in Appendix CODELINK (see Table CODELINK-1).

Figure 6-26 shows an alternative method of visualizing how the various performance assessment codes relate to each other and to the estimation of scenario consequences. This figure represents a vertical cross section of the disposal system, associating the major codes with the particular components of the system each code simulates. As shown in the figure, BRAGFLO, SANTOS, NUTS, and PANEL address the Salado. GRASP-INV, SECOFL2D, and SECOTP2D address the Culebra. CUTTINGS_S, BRAGFLO_DBR, and PANEL address the immediate consequences of inadvertent human intrusion through one or more exploratory boreholes. Combined, Figures 6-25 and 6-26 illustrate the flow of information through major performance assessment codes and the relationship between the codes and the physical system being simulated.

The parameter database is the initial element in the performance assessment process. The database includes the parameters used in performance assessment codes that pertain to the technical aspects of disposal system performance. Parameters pertaining only to the execution of the codes (for example, convergence criteria for Newton-Raphson numerical solvers) are generally not included in the database but are recorded in input files and are traceable through the SCMS. The parameters in the database fall into two categories: those that are assigned fixed values, and those that are uncertain and are therefore assigned a range of values according to a CDF.

Vectors (sets) of parameter values are created from the uncertain variables in the database by LHS of each variable for the set of simulations comprising a performance assessment of the system. In this performance assessment, 57 parameters are sampled using LHS, and 100 vectors are assembled in each replicate (see Section 6.5). The values assigned to each sampled parameter in each of the vectors in this performance assessment are included in Appendix IRES (Section IRES.1). Each of the fixed parameter values from the database and a vector of sampled parameter values are combined to form a realization (a set of input parameters). Each realization is then propagated through the performance assessment codes within the dashed lines in Figure 6-25.

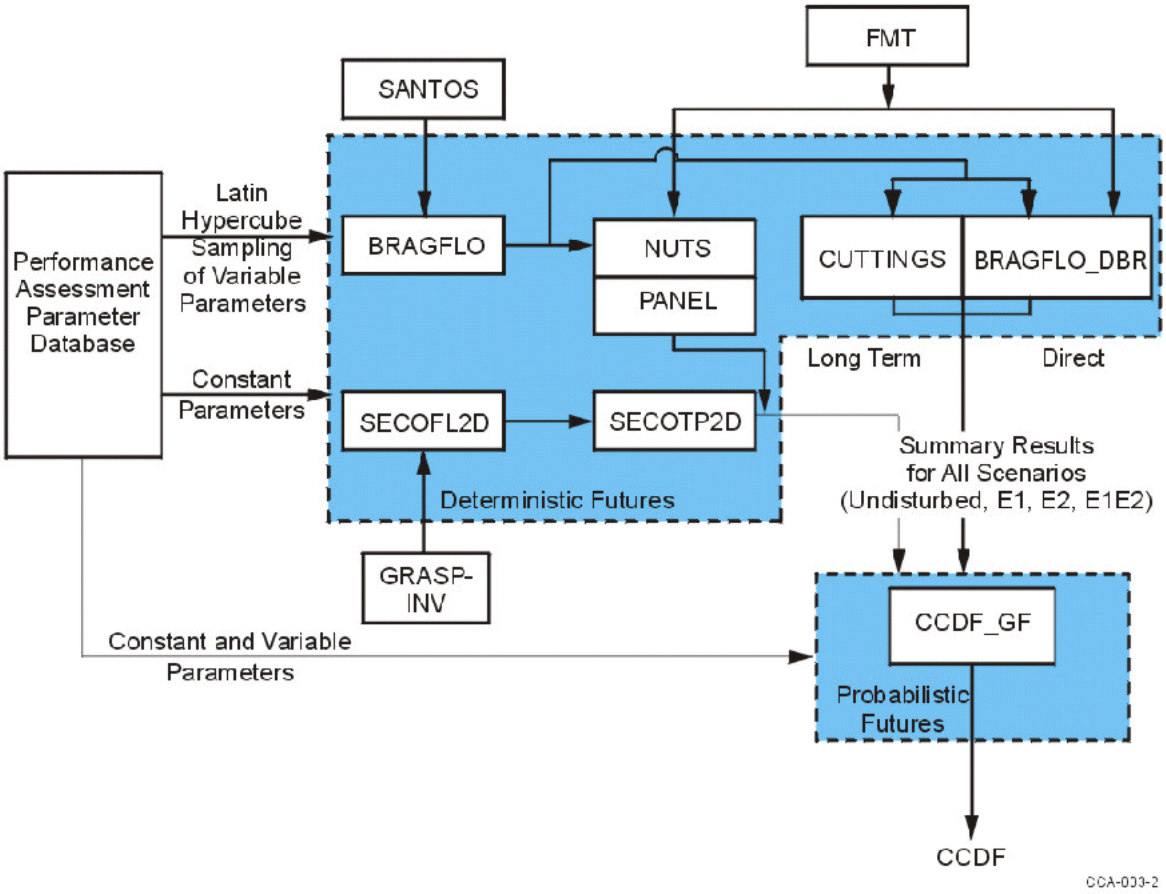

Figure 6-25. Major Codes, Code Linkages, and Flow of Numerical Information in WIPP Performance Assessment

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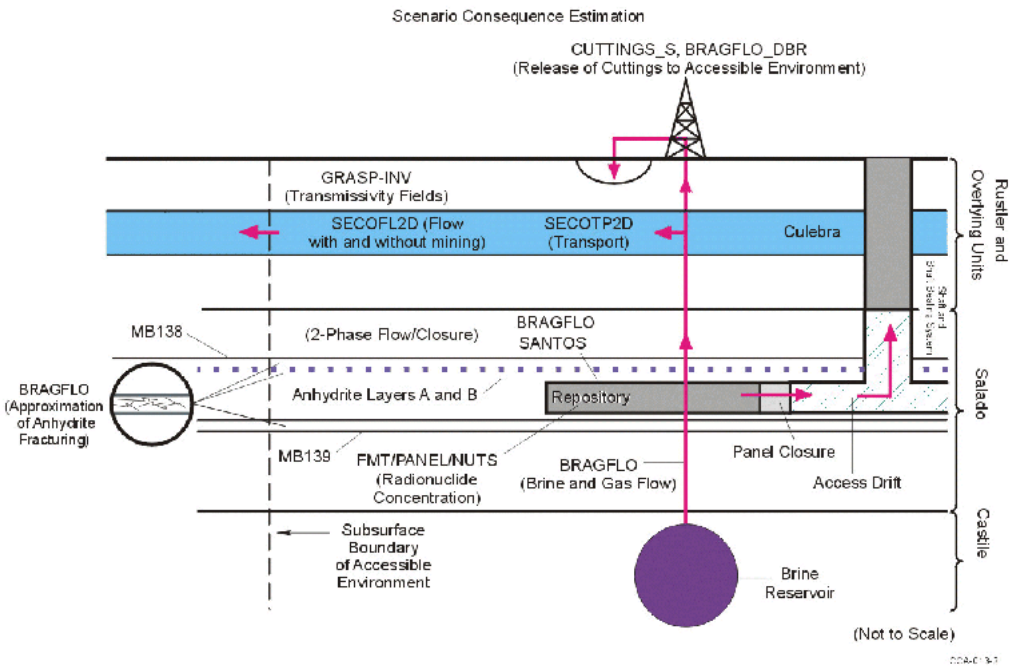

Figure 6-26. Schematic Side View of the Disposal System Associating Performance Assessment Codes with the Components of the Disposal System Each Code Simulates

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The assessment of each realization requires that the codes shown in Figure 6-25 for deterministic futures be executed under four code sequence configurations, one each for the undisturbed performance scenario, the E1 scenario, the E2 scenario, and the E1E2 scenario.

Each intrusion scenario may occur with or without mining. The techniques used for each scenario are described in Section 6.4.13.

As shown in Figure 6-25, information for some of the major codes comes from the following additional sources: the SANTOS, GRASP-INV, and FMT codes. The SANTOS code develops the porosity surface describing porosity as a function of time and pressure; this information is used in the BRAGFLO code (see Appendices BRAGFLO, Section 4.11, and PORSURF, Section PORSURF.1). GRASP-INV calculates numerous possible and equally likely Culebra transmissivity fields; these transmissivity fields are used in the SECOFL2D code (see Appendix TFIELD, Section TFIELD.4, and Appendix CODELINK, Section CODELINK.6.4). FMT is used to calculate solubility parameters that were entered into the parameter database. These parameters, as well as sampled solubility distribution parameters, were used to calculate solubilities for the performance assessment. Actinide solubility in the repository is used by the codes NUTS and PANEL.

The performance assessment codes are executed sequentially. Following LHS, BRAGFLO is the first major code executed. Notice that the code BRAGFLO is listed twice in this sequence. BRAGFLO is used in two applications for performance assessment. In the first application, BRAGFLO calculates the overall movement of gas and brine in the repository and from the Castile to the surface; this movement forms the basis for estimating radionuclide releases to the accessible environment (Appendix BRAGFLO, Sections 4.1 through 4.9). BRAGFLO also contains subsystem models for estimating gas generation in the repository, disposal room closure and consolidation, and interbed fracturing (Appendix BRAGFLO, Sections 4.10 through 4.13). BRAGFLO does not calculate the movement of radionuclides. The second application of BRAGFLO is discussed below.

NUTS calculates the overall movement and decay of radionuclides in the repository and disposal system. NUTS uses the same geometry as BRAGFLO, the brine and gas flow fields calculated by BRAGFLO, and the radionuclide source concentrations (solubilities) in the repository defined by the actinide source term models. In simulations of the E1 scenario, NUTS also tracks brine originating in the Castile brine reservoir, including the fraction of Castile brine that has flowed out from the borehole and into the waste in the repository. See Appendix NUTS (Section 4) for additional information on the use of NUTS in performance assessment. PANEL calculates actinide source term to the Culebra for the E1E2 scenario, as discussed in Section 6.4.13.5. PANEL is described in detail in Appendix PANEL.

In all scenarios, the quantity of brine flowing up the shafts or a degraded exploratory borehole to the Culebra is calculated by BRAGFLO, and the concentration of radionuclides in that brine, calculated by NUTS or PANEL, is used to determine the quantity of radionuclides released to the Culebra.

CUTTINGS_S and BRAGFLO_DBR are used to evaluate the immediate consequences of inadvertent human intrusion through exploratory drilling. Solid material and brine may be transported to the surface in the drilling fluid. After pressure in the repository is relieved through the first borehole, subsequent boreholes may release less material to the surface. CUTTINGS_S calculates the quantity of solid material transported to the accessible environment at the surface during the drilling activities. This material includes material removed directly from the borehole (cuttings), together with cavings and spallings. The code is discussed in Appendix CUTTINGS. BRAGFLO_DBR is used to calculate the quantity of brine transported up the borehole to the surface.

SECOFL2D and SECOTP2D together calculate the detailed movement of radionuclides in the Culebra that occurs if radionuclides are introduced by flow up the shafts or through a degraded exploratory borehole. SECOFL2D calculates regional Culebra flow fields using an assumption that flow occurs in a single-porosity medium. SECOFL2D uses the transmissivity fields calculated by GRASP-INV (one field in each simulation). SECOTP2D calculates radionuclide transport in a double-porosity medium, accounting for advection in fractures, matrix diffusion, retardation, and decay, as described in Section 6.4.6.2. SECOFL2D is discussed in Appendix SECOFL2D; SECOTP2D is discussed in Appendix SECOTP2D. The NUTS and PANEL codes calculate the actinide source term to the Culebra.

The computer code CCDFGF is used to (1) determine random sequences of future events that may occur over the next 10,000 years at the WIPP site; (2) estimate the radionuclide releases resulting for these random sequences of future events, using the results of the calculations described thus far in Section 6.4; and (3) construct a CCDF for each realization. The manner in which CCDFGF determines random sequences of future events is the subject of Section 6.4.12. The estimation of consequences and construction of a CCDF for these sequences of future events is the subject of Section 6.4.13.

6.4.12 Sequences of Future Events

For this application, sequences of future events that may occur are determined using a random sampling procedure described in Appendix CCDFGF (Section 3.2). A general description of the technique is presented in this section.

The incorporation of stochastic uncertainty in the performance assessment is based on repeatedly generating independent sequences of events that may occur at the WIPP over the next 10,000 years. Each 10,000-year sequence is generated by randomly sampling six parameters that characterize stochastic uncertainty about future events repeatedly. These parameters include (1) the interval of time between drilling intrusions (which yields both the number and time of intrusions), (2) the location of each drilling intrusion, (3) the activity of the waste penetrated by each drilling intrusion, (4) the plug configuration in the intrusion borehole, (5) the penetration of a Castile brine reservoir, and (6) the occurrence of mining. Probability distribution functions are assigned to each of these six parameters and are discussed in the following sections. Random sampling from these distributions is used to generate 10,000 equally likely, independent futures for the WIPP for each realization

executed and CCDF constructed. The computer code CCDFGF (Appendix CCDFGF, Section 3.2) is used to randomly sample sequences of future events, construct consequences of these sequences, and assemble CCDFs. As described in Section 6.4.13, normalized integrated radionuclide releases to the accessible environment are estimated for each history using the consequence modeling system.

The probability assigned to the occurrence of certain events in the future at the WIPP site is affected by regulatory guidance and by actions taken by the DOE to deter activities detrimental to WIPP performance. Active and passive institutional controls are discussed extensively in Chapter 7.0. A summary of their use in performance assessment begins the discussion in this section.

6.4.12.1 Active and Passive Institutional Controls in Performance Assessment

Active institutional controls and passive institutional controls will be implemented at the WIPP site to deter human activity that may be detrimental to the performance of the repository. Active institutional controls and passive institutional controls are described in detail in Chapter 7.0 and in appendices referenced in Chapter 7.0. In this section, the impact of active institutional controls and passive institutional controls to performance assessment is described.

Active institutional controls will be implemented at the WIPP after final facility closure to control access to the site and to ensure that activities detrimental to the performance of the disposal system do not occur within the controlled area. The active institutional controls will preclude human intrusion in the disposal system. A limitation for considering the effectiveness of active institutional controls in performance assessment is established in 40 CFR Part 191. That limitation is 100 years. Because of the nature of the system of active institutional controls to be implemented and regulatory restrictions, it is assumed in performance assessment that there can be no inadvertent human intrusions or mining in the controlled area for 100 years following repository closure.

Passive institutional controls have a function in deterring inadvertent human intrusion into the disposal system in performance assessment. While only minimal assumptions were made about future society for the purposes of designing the passive institutional controls to comply with the Assurance Requirements, more detailed assumptions are made in order to quantify the effectiveness of passive institutional controls for performance assessment. The preamble to 40 CFR Part 194 limits any credit for passive institutional controls in deterring human intrusion to 700 years after disposal (EPA 1996a, 61 FR 5231). This suggested time limit is important in quantifying the effectiveness of passive institutional controls for performance assessment purposes. Because active institutional controls are effective for the first 100 years, passive institutional controls are effective for the period of time from 100 to 700 years, or a duration of 600 years.

The effectiveness of passive institutional controls is implemented in performance assessment by reducing the rate of human intrusion and mining by a factor that estimates the

effectiveness of passive institutional controls. As discussed in Appendix EPIC, passive institutional controls are assumed to be 0.99 effective, meaning that the rate of deep drilling and mining for the 600-year duration of passive institutional controls is a factor of 0.01 times the respective rates for the uncontrolled period following 700 years. Because passive institutional controls are designed to protect the controlled area, this reduction factor is applied to the entire controlled area.

6.4.12.2 Number and Time of Drilling Intrusions

The number of drilling intrusions associated with each 10,000-year history is based on 40 CFR § 194.33(b)(2) and § 194.33(b)(3):

> In performance assessments, drilling shall be assumed to occur in the Delaware Basin at random intervals in time and space during the regulatory time frame. [40 CFR 194.33(b)(2)]
>
> The frequency of deep drilling shall be calculated in the following manner:
> (i) Identify deep drilling that has occurred for each resource in the Delaware Basin over the past 100 years prior to the time at which a compliance application is prepared.
> (ii) The total rate of deep drilling shall be the sum of the rates of deep drilling for each resource. [40 CFR 194.33(b)(3)]

The DOE's implementation of these criteria is described in this and the following sections.

Mathematically, events that are random in time can be described as following a Poisson process that can be written in a simple form as

(13)

where $p[E_n(\Delta t)]$ is the probability (p) that some number (n, an integer) of events (E) will occur in a time interval (Δt) given a rate constant λ with units of events per time.

Inadvertent human intrusions may occur at any time between 100 years and 10,000 years after the decommissioning of the facility. Both the number and time of intrusions are determined sequentially by sampling from a CDF derived from the Poisson model that probabilistically describes the time period that elapses between an intrusion at a fixed time and the next intrusion. The time interval to the next intrusion following an intrusion may vary from 0 years to greater than 9,900 years, with a probability determined by the rate constant λ. The rate constant is derived from the drilling rate established for the Delaware Basin and the area of the waste disposal region, 0.049 square miles (0.126 square kilometers). The drilling rate used in this analysis was 46.8 boreholes per square kilometer per 10,000 years. As discussed in Appendix DEL (Section DEL.7.4), this rate is based on a review of past and present drilling activity in the Delaware Basin. The rate constant λ is assigned different values for three time periods. While active institutional controls are effective, it is equal to zero, and while passive institutional controls are effective, it is two orders of magnitude lower than during the uncontrolled period (700 to 10,000 years).

The CDF for intrusion times while passive institutional controls are effective is called the passive institutional controls CDF. The CDF for intrusion times after passive institutional controls may no longer be considered effective is called the post-passive institutional controls CDF. Sequences of future deep drilling events are constructed as follows. The passive institutional controls CDF is sampled to determine whether an intrusion occurs while passive institutional controls are effective. If the sampled time is greater than 600 years, zero intrusions occur before 700 years. If the time is less than 600 years, the passive institutional controls CDF is sampled again to determine whether a second intrusion occurs in the interval between the time of the first intrusion and 700 years. This procedure continues until a time of intrusion greater than 700 years is determined.

Intrusions times after 700 years are determined by sampling the post-passive institutional controls CDF. If the sampled time is greater than 9300 years (700 + 9,300 = 10,000), no intrusions occur between 700 and 10,000 years. If the sampled time is less than 9,300 years, an intrusion occurs at 700 years plus the sampled time. The post-passive institutional controls CDF is sampled iteratively to determine whether intrusions occur in the time interval between the last intrusion and 10,000 years, until an intrusion is determined to occur after 10,000 years.

Evaluation of the Poisson process for a specified rate constant and time interval yields the probability of occurrence of specified numbers of intrusions. Using a different rate constant for 100 years of active institutional controls, 600 years of passive institutional controls, and 9300 years of uncontrolled activity, the most likely number of intrusions into the waste disposal region during 10,000 years is five, occurring with a probability of 0.1715. Zero intrusions occur with a probability of 0.0041. The largest number of intrusions that occur with a probability greater than 10^{-3} per 10,000 years (and which therefore can contribute to releases for comparison with the quantitative release limits) is 14, occurring with a probability of 0.0011. Probabilities for other numbers of intrusions within 10,000 years are given in Table 6-28. These probabilities are shown as a histogram in Figure 6-27.

6.4.12.3 Location of Intrusion Boreholes

Drilling events are assumed to be random in time and space, and the location of each intrusion borehole within the waste disposal region is sampled randomly. This is done in the analysis by discretizing a plan view of the area within the passive institutional control berms (see Appendix PIC, Section VIII) into 144 separate regions, and requiring each intruding borehole to penetrate one, and only one, region (Figure 6-28). The probability of intersecting each location is equal to 1/144 (about 0.00694), and slight variations in the size of regions are disregarded as unimportant.

Table 6-28. Probabilities of Different Numbers of Intrusions into the Waste Disposal Region (for 100 years of active institutional control, 600 years of passive institutional control, and 9,300 years of uncontrolled activity)

Number of Intrusions	Probability of Occurrence
0	0.0041
1	0.0227
2	0.0622
3	0.1138
4	0.1562
5	0.1715
6	0.1570
7	0.1231
8	0.0845
9	0.0516
10	0.0283
11	0.0141
12	0.0065
13	0.0027
14	0.0011
15	0.0004

Each of the 144 regions contains both excavated and unexcavated areas at the repository horizon. A borehole penetration of a region has an approximately 20 percent chance of intruding excavations and approximately 80 percent chance of passing through unexcavated Salado. The berm area and the proportion of excavated to unexcavated regions at the repository horizon are important in the Castile brine reservoir model, as discussed in 6.4.12.6.

Boreholes that penetrate excavations may penetrate CH-TRU waste, RH-TRU waste, or panel closures that contain no waste. For long-term releases and direct brine releases, all penetrations into excavations are treated as if CH-TRU waste is penetrated, and the RH-TRU waste inventory is averaged into the CH-TRU waste inventory for source-term determination. For cuttings and cavings direct releases, there is an approximately 12 percent chance that RH-TRU waste canisters are penetrated and an 88 percent chance that CH-TRU waste is penetrated, corresponding to the relative plan-view areas of each waste type. For cuttings and cavings direct releases, the small area of the panel closures is treated as CH-TRU waste and is included in the CH-TRU waste probability. Because of the low permeability of the region surrounding each RH-TRU waste canister, intrusions into RH-TRU waste are assumed to not produce spallings releases. Intrusions resulting in spallings releases are treated as CH-TRU waste for the source term determination.

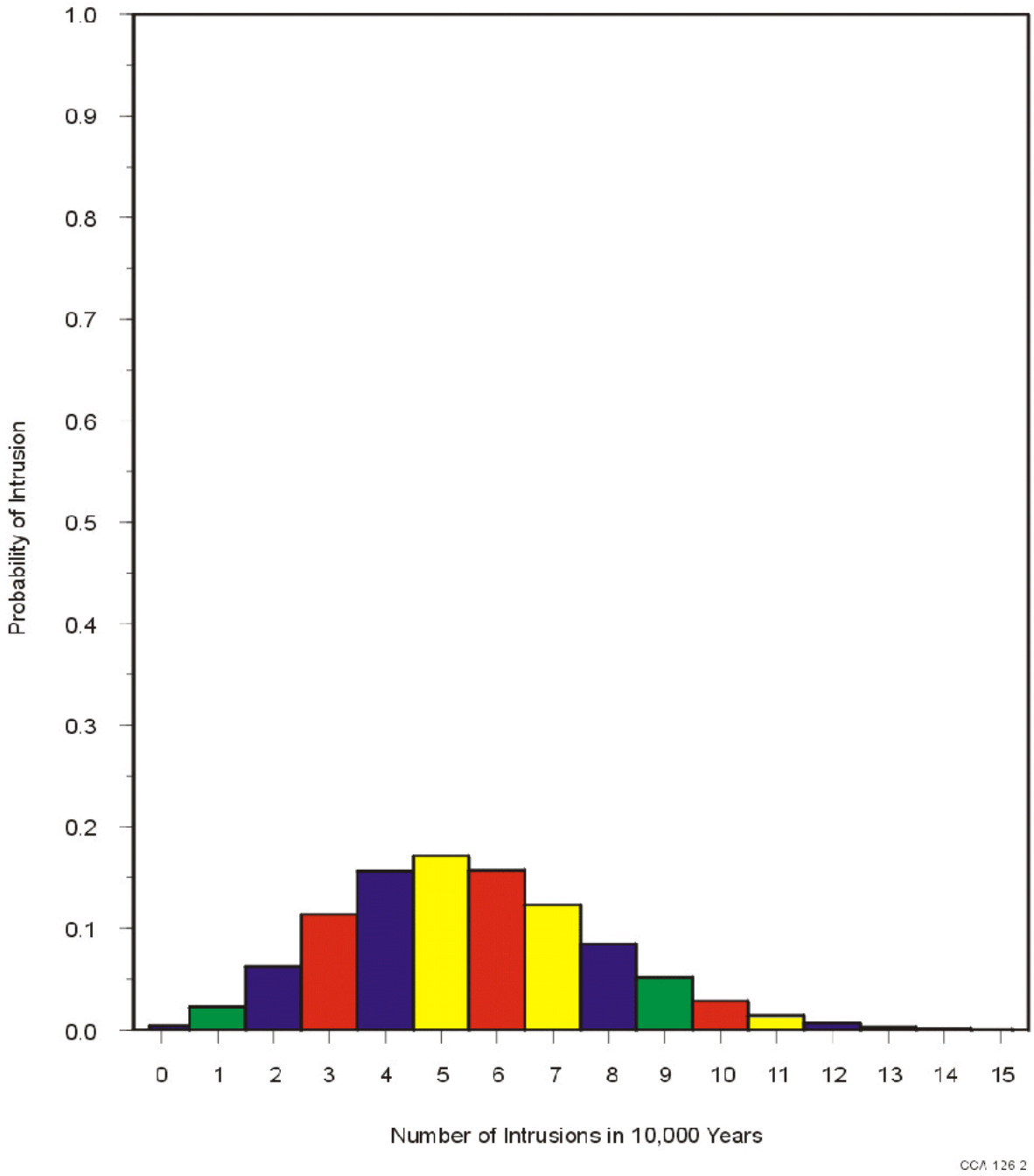

Figure 6-27. Probability of Intrusions in 10,000 Years with Active Institutional Control for 100 Years Followed by 600 Years of Passive Institutional Control

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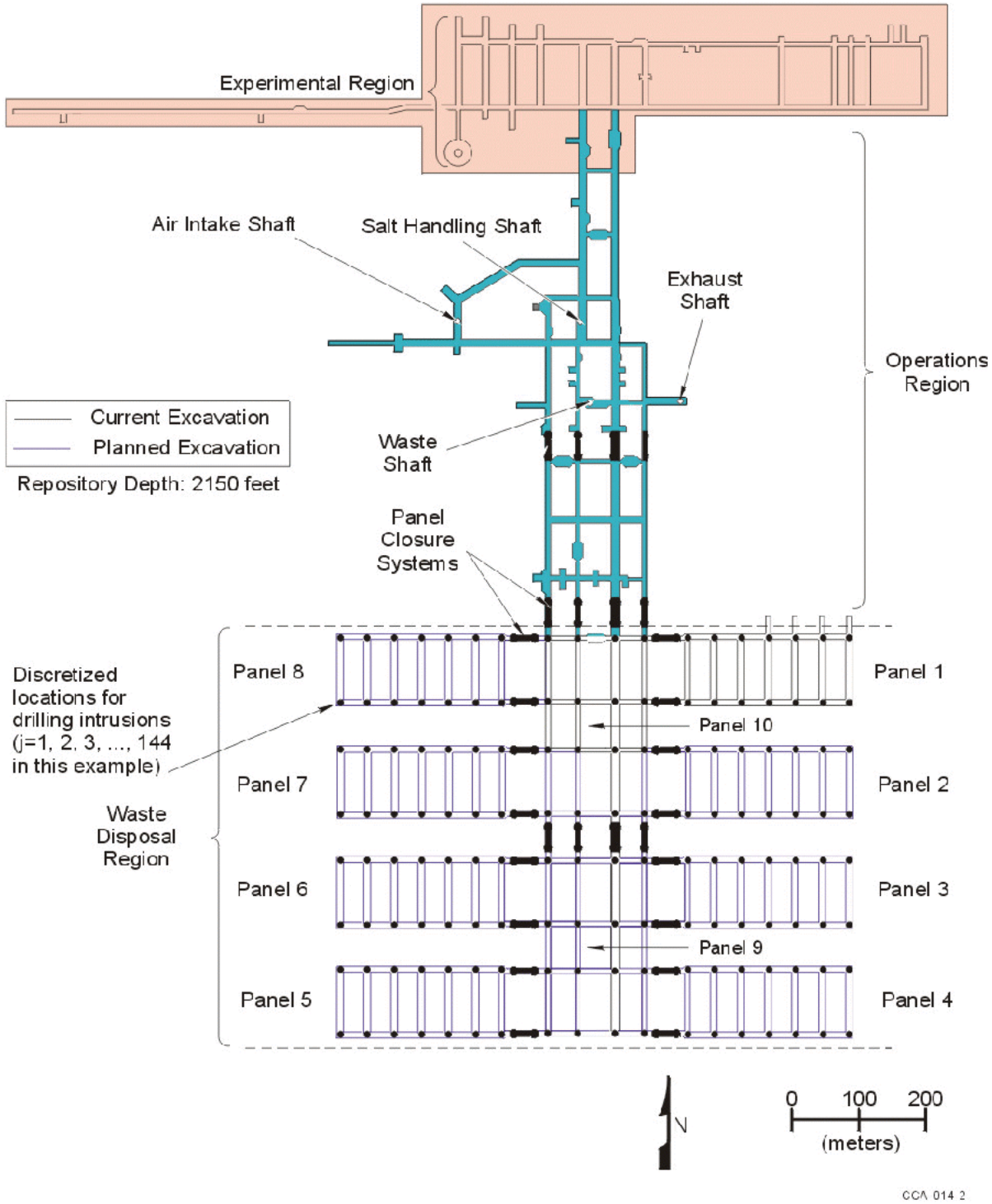

Figure 6-28. Discretized Locations for Random Intrusion by an Exploratory Borehole

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6.4.12.4 Activity of the Intersected Waste

Containers of waste shipped to the WIPP will contain quantities of radionuclides that will vary from container to container. Radioactivity may vary by several orders of magnitude from those waste containers with the largest quantities of radionuclides to those with the smallest.

Information about waste radioactivity has been compiled at several different levels (Figure 6-29). The waste-stream level includes information about waste activities from different processes at the generator sites that create TRU waste. At this level, a separate waste stream characteristic is maintained for RH-TRU. In total, there are approximately 970 CH- and RH-TRU waste streams, of which 569 are CH-TRU. Because the RH-TRU is approximately 1 percent (actually 1.5 percent) of the total EPA units (not activity) of CH-TRU waste, all the RH-TRU waste was grouped (binned) together into one equivalent or average (WIPP-scale) RH-TRU waste stream. It is assumed that variability in this small fraction is negligible. The waste-generator site level includes information integrated over the scale of a generator site. There are 21 generator sites identified for the WIPP. The WIPP-scale level includes integrated information about all waste destined for the WIPP, including CH- and RH-TRU. Data are present for existing waste and estimates have been made for future (to-be-generated) waste. The integration of waste data with the performance assessment is illustrated in Figure 6-30. This information is compiled for the WIPP from the Transuranic Waste Baseline Inventory Database (TWBID), an electronic version of information present in the Transuranic Waste Baseline Inventory Report (TWBIR), Rev. 3. (see Appendix BIR).

For calculation of radionuclide releases from groundwater transport (including direct brine release) and from spallings, spatial variability in the activity in the waste is assumed to have no significant impact. Concentrations of radionuclides mobilized in repository brine and quantities transported to the ground surface in spallings are assumed to be derived from a sufficiently large volume of waste that container-scale variability can be neglected. For long-term releases and direct brine releases, releases are calculated using WIPP-scale data assuming homogeneous accessibility of RH- and CH-TRU waste activities by liquid in the repository. As discussed previously, spallings releases are not calculated for RH-TRU waste; consequently, for spallings releases, activities are determined assuming homogeneous accessibility for only CH-TRU waste.

Direct releases caused by the mechanisms of cuttings and cavings access discrete and relatively small portions of the waste, and estimates of the quantity of radioactivity released to the accessible environment from these mechanisms may be sensitive to variability in activity loading. The radioactivity of cuttings and cavings releases is calculated using data from the waste-stream level in the following manner.

Containers are assumed to be placed in the WIPP from the various waste streams in a random manner. Because waste containers are to be stacked three-high for disposal, a drill bit is assumed to penetrate three containers. The direct-release consequence resulting from a drill

bit hitting the edges of containers and generating releases from more than three containers is assumed to be similar to the consequence of penetrating three containers only. Each of the three containers penetrated by the drill bit can come from different waste streams and have different activities associated with them. The waste streams penetrated are randomly sampled according to the relative quantity of waste in each waste stream. Figure 6-31 shows the discretized activities, expressed as the EPA normalized release density, of the 569 CH-TRU waste streams as a CDF, and the decay of the waste stream activities through time. Waste stream activities are maintained in performance assessment at 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years. Activities for cuttings and cavings releases at other times are interpolated from these values.

The code CUTTINGS_S calculates the volume of repository material brought to the surface by the mechanisms of cuttings and cavings. Of the volume of repository removed, approximately 40 percent is waste material, the rest is void space, backfill, and drum packing material. It is assumed that one-third of the waste material released comes from each of three containers assumed to be intersected. The activity of the release to the surface during drilling by cuttings and cavings is determined as the sum of the products of one-third the release volume times the three waste stream activities randomly sampled to be intersected. If random sampling determines that the borehole penetrates RH-TRU waste, 100 percent of the material removed is assumed to be waste and the activity of the release is equal to the volume calculated by CUTTINGS_S times the activity of RH-TRU waste.

6.4.12.5 Diameter of the Intrusion Borehole

Historical Delaware Basin drilling records were reviewed to determine the diameter of a typical intrusion borehole. In performance assessment, the borehole diameter parameter value is held constant for all future drilling and is equal to 12.25 inches (0.311 meter). Appendix DEL (DEL Attachment 1) discusses typical drill stem and drill collar diameters used to drill oil and gas wells in the Delaware Basin. Appendix DEL (Section DEL.6.1.2.2) illustrates a generalized circular cross section of a well plugged according to current practice (see Appendix DEL, DEL Attachment 7).

6.4.12.6 Probability of Intersecting a Brine Reservoir

As mentioned in Section 6.4.8, there is uncertainty about the existence of brine reservoirs and uncertainty in the probability of intersecting a brine reservoir with a deep borehole. The DOE has examined available data and concluded that there is no reasonable basis to eliminate the possibility of a brine reservoir existing under the site. Therefore, the DOE assumes that a brine reservoir may exist under the waste panels. The DOE has determined that there is a reasonable basis for determining the probability of intersecting a brine reservoir and has pursued three types of investigation relevant to this issue: geophysical methods, geological structure analysis, and geostatistical correlation.

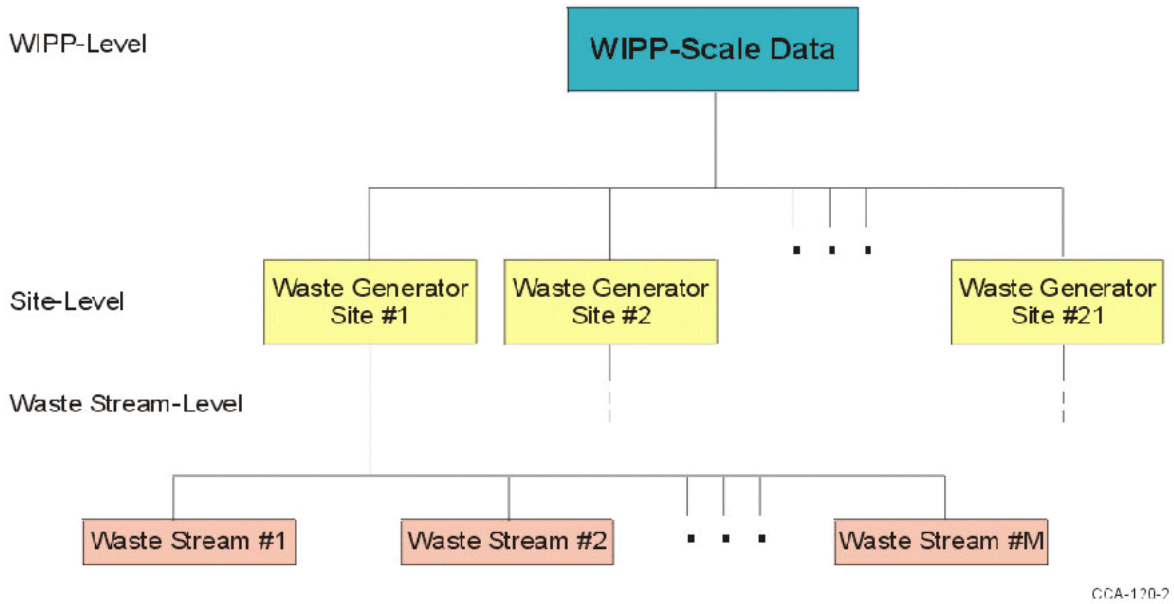

Figure 6-29. Levels of Information Available in the TWBID

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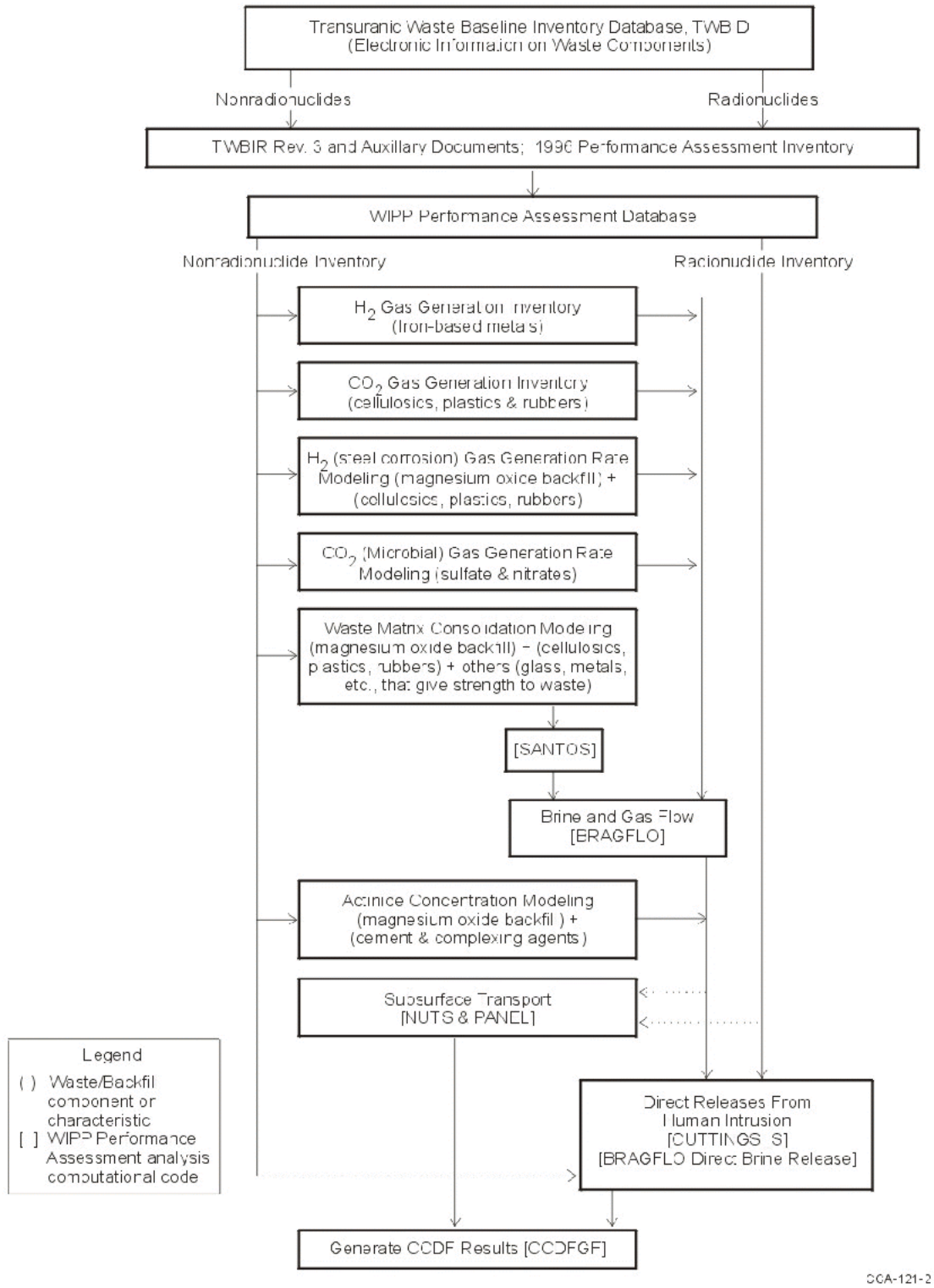

Figure 6-30. Flowchart Showing Integration of TWBID Data in Performance Assessment Calculations

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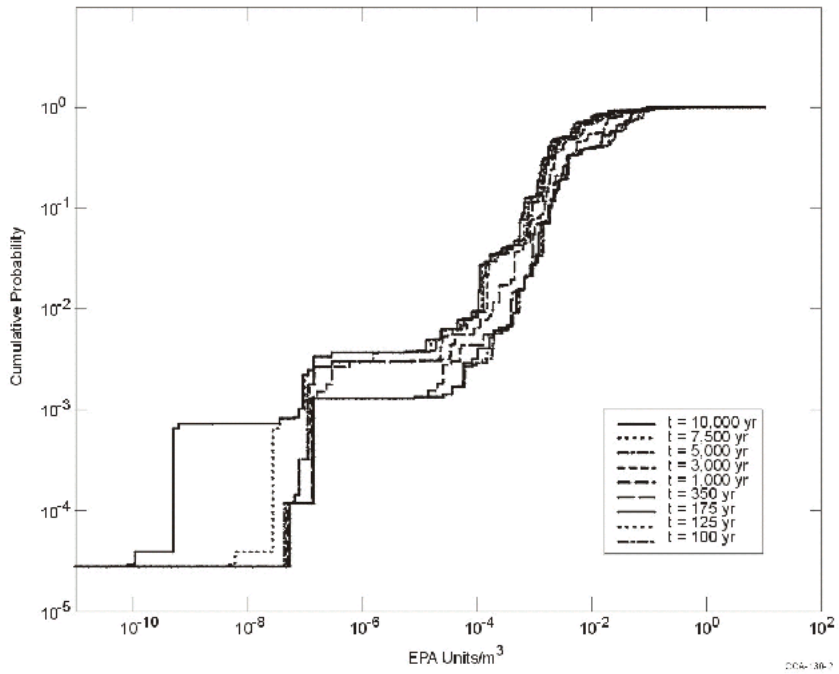

Figure 6-31. Cumulative Distribution Function for Waste Stream EPA Units/Volume

Figure 6-31. Cumulative Distribution Function for Waste Stream EPA Units/Volume

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In 1987, the DOE conducted a series of 38 time-domain electromagnetic (TDEM) soundings at the WIPP site (Earth Technology Corporation 1988; Appendix MASS, Section MASS.18.1 and MASS Attachment 18-5). Thirty-six of these soundings were executed over a 1-by-2-kilometer area, with the north-central nine soundings located directly over the waste panels. The electromagnetic data collected by the measurements indicate differences in electrical resistivity, which can be interpreted as occurring in the Castile. Regions of relatively low resistivity in the Castile are presumed to be so because of a greater abundance of interconnected brine compared to higher-resistivity regions. A sounding executed near the brine reservoir penetrated at WIPP-12 provides an independent calibration on the interpretation of the data. The study indicates the presence of electrically conductive regions below the waste panels at the WIPP. However, because of the inherent coarse resolution of the method, the data do not support the development of a unique map of the extent of conductors in the Castile. A recent interpretation of the data included in Appendix MASS (Section MASS.18.1 and MASS Attachment 18-5) suggests that between 10 percent and 55 percent of the waste panel area may be underlain by relatively conductive units, interpreted to be one or several brine reservoirs. The TDEM data do support a limited probability of intersecting brine. Because of the spatial resolution provided by TDEM data, however, the data do not support distinguishing boundaries between reservoir and nonreservoir areas. Thus, the DOE assumes that one reservoir exists below the waste panels.

The geological structure of selected units within the Castile and Salado has been mapped recently to examine more closely the relationship between identified brine intercepts and evaporite deformation. This study is described in Appendix MASS (Section MASS.18.1 and MASS Attachment 18-6). After ERDA-6 encountered brine in steeply dipping beds, studies indicated that many of the other observed brine encounters in the Delaware Basin are associated with structural deformation in the Castile. The study of structure reaffirms the concept that much of the Castile underlying the present WIPP site is generally undeformed. The DOE does not use the results of the structural study in quantifying the existence or probability of intersecting a brine reservoir.

The geostatistical study discussed in Appendix MASS (Section MASS.18 and included as MASS Attachment 18-6), was conducted using existing borehole data to estimate the probability of drilling into a fractured reservoir in areas overlain by WIPP underground workings. The database consists of boreholes in the general area of the WIPP where Castile brine has been encountered as well as a much larger number of boreholes in which brine is not reported to have been encountered. The study used geostatistical methods to estimate the probabilities that a randomly placed borehole would encounter pressurized brine in the Castile. These methods do not require assumptions about the distribution of brine reservoirs but are based on the empirical evidence available. Based on geostatistical analysis, the DOE uses a 0.08 probability that any deep borehole drilled within the waste panel penetrates the brine reservoir that is assumed to exist below the waste panels.

The DOE assumes that there is one reservoir under the quadrilateral area enclosing the waste panels with a constant probability of any deep borehole penetrating it. The location of boreholes in this area is sampled. They may lie over repository excavations, or over rock in

pillar cores or between panels. The brine reservoir under the waste panels can be depleted during the 10,000-year regulatory period by boreholes drilled anywhere within this area. Boreholes that are randomly located over rock have the same probability of intersecting the brine reservoir as boreholes located over excavations. Boreholes located over the excavations are assumed to penetrate waste, and the consequences are modeled as described throughout Section 6.4. Boreholes located over the intact rock in this area are assumed to have no consequences on the disposal system other than that they can contribute to the depletion of reservoirs, as discussed below.

Long-term depletion of pressure and the production of brine from a reservoir that may exist under the repository occurs only for the two-plug configuration boreholes. Long-term depletion does not occur during the 10,000-year regulatory period for the solid-concrete plug boreholes or three-plug configuration borehole.

BRAGFLO calculates the long-term depletion of pressure and production of brine from the reservoir for only one two-plug configuration borehole. For estimating the consequences of possible sequences of future events, the DOE assumes how the reservoir responds to additional penetrations. Subsequent penetrations are assumed to behave identically to the first until the reservoir is assumed to be completely depleted and cannot produce more brine (see Appendix MASS, Section MASS.18 and MASS Attachment 18-3). The DOE assumes the 32,000-cubic-meter reservoir is depleted after two penetrations; the 64,000-cubic-meter reservoir after four penetrations; the 96,000-cubic-meter reservoir after six penetrations; the 128,000-cubic-meter reservoir after eight penetrations; and the 160,000-cubic-meter reservoir after 10 penetrations. Because it is assumed for modeling simplicity that penetrations before depletion behave identically to the first penetration, it is possible for a reservoir to cumulatively produce more brine with multiple intrusions than it is assumed to contain for the first intrusion.

6.4.12.7 Plug Configuration in the Abandoned Intrusion Borehole

As stated in Section 6.4.7, three different plug configurations can be used to represent possible future configurations of plugged and abandoned intrusion boreholes. Based on a survey of current practice (see Appendix MASS, Section MASS.16.3 and MASS Attachment 16-1), the two-plug configuration borehole is considered most likely and is assigned a probability of 0.68. The three-plug configuration is considered less likely and is assigned a probability of 0.30. The continuous concrete plug is considered least likely and is assigned a probability of 0.02.

6.4.12.8 Probability of Mining Occurring within the Land Withdrawal Area

The EPA has specified the probability of mining in the future. In 40 CFR § 194.32 (b), the EPA states, “Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame.”

Also in 40 CFR § 194.32(b), the EPA limits the occurrence of mining to a maximum of once per 10,000 years. The DOE has interpreted this probability model as a Poisson model with a probability of mining of 10^{-4} per year (Appendix CCDFGF, Section 3). During the period that passive institutional controls are effective, the probability of mining is 10^{-6} per year. The occurrence of mining is sampled from a CDF of the time until mining in a manner similar to the procedure described for the time between drilling intrusions, except that multiple mining events cannot occur.

6.4.13 Construction of a Single CCDF

Construction of a single CCDF requires combining the results of numerical simulations performed for a given set of values of subjective parameters (that is, those determined by LHS) with the probabilistic futures determined by random sampling of stochastic parameters (that is, those associated with intermittent drilling) (see Appendix CCDFGF, Section 2). Because of the variety of sequences of events represented in a single CCDF and the impossibility of modeling the details of each future separately, building a CCDF necessarily involves methods for the construction of consequences for any probabilistic future from a limited number of calculations for deterministic, idealized futures. Although this methodology is conceptually straightforward, the details of the process are highly dependent on model and system-specific considerations (see Appendix CCDFGF, Section 4). Accordingly, insight gained from previous, preliminary performance assessments as well as analysis of early results for this performance assessment are used to help configure the methodology used for CCDF construction.

Depending on the scenario into which probabilistic futures are classified, different techniques are used for estimating their consequences. The deterministically determined undisturbed performance scenario consequences require no special techniques for application to probabilistic futures. For E1, E2, and E1E2 scenarios, the CCDF construction methodology is primarily based on the principle of scaling, with some simplifying assumptions made for the E2 scenario. Scaling is the estimation of consequences of probabilistic futures based on consequence estimates from deterministic futures. The use of scaling and the building of a CCDF with it is discussed in this section. Note that all of the discussions in Section 6.4.13 are for one vector of values for those parameters included in the subjective uncertainty analysis. In other words, this section addresses only stochastic variation resulting from uncertainty in the sequence of future events that may occur at the WIPP (see Section 6.1.2).

6.4.13.1 Constructing Consequences of the Undisturbed Performance Scenario

All probabilistic futures in which drilling intrusion and mining within the controlled area do not occur are included in the undisturbed performance scenario. Because there is no stochastic uncertainty for this scenario, all futures within a single LHS vector of undisturbed performance have the same releases to the accessible environment. The following major codes are used to estimate the consequences of undisturbed performance: BRAGFLO, NUTS, and, if actinides reach the Culebra, SECOFL2D and SECOTP2D. To illustrate the flow of information for the undisturbed performance scenario, these codes and the connections

between them are highlighted on the diagram of performance assessment codes in Figure 6-32. For undisturbed performance, no special techniques are required to modify the results of the deterministic calculation to fit probabilistic futures. Therefore, for a single consequence for undisturbed performance, BRAGFLO is executed once and NUTS is executed once. These calculations determine the release to the accessible environment because of transport in the Salado or up the shaft to the surface. If any actinides reach the Culebra following these calculations, SECOFL2D and SECOTP2D are executed to determine whether actinides released to the Culebra reach the lateral accessible environment. This information is sufficient to construct consequences for all probabilistic futures that have no intrusion events. This information is also used as the basis for evaluations of compliance with 40 CFR § 191.15 and 40 CFR § 191.24, described in Chapter 8.0.

6.4.13.2 Scaling Methodology for Disturbed Performance Scenarios

Although 10,000 probabilistic futures are generated for the construction of a CCDF, the major codes used in performance assessment are executed many fewer times. The results of the fewer calculations are used in part to construct the consequences of all of the probabilistic futures comprising a CCDF in a process called scaling.

The scaling methodology is simple in concept. First, several simulations are performed with a code to develop a reference behavior for a particular event or process. Each simulation has a defined event occurring at a different time. Then, a large set of futures is developed probabilistically by random sampling. The behavior of the particular event or process in each of the probabilistically sampled futures is estimated by scaling from the results of the limited number of deterministic calculations. This scaling is generally simple linear interpolation. For events or processes involving radionuclides, however, scaling becomes more complicated as it incorporates the effects of radioactive decay and ingrowth. Because scaling is generally less intensive computationally than is solving matrix equations of the type encountered in many performance assessment codes, scaling is an efficient way to develop multiple probabilistic consequence estimates from a limited number of deterministic calculations. Without scaling, fewer futures would be possible, and resolution in the CCDF would be reduced.

For an example of the application of scaling, assume that the process of interest is release of actinides to the surface during drilling. It is impossible to explicitly model the infinite possibilities present in a probabilistic conceptualization of the future. Thus, scaling is used. To develop a reference behavior for scaling, the CUTTINGS_S code is executed several times with different intrusion times. A probabilistic method is then used to develop a large number of possible, different future intrusion times. To estimate the release to the surface in probabilistic futures, scaling is used in which release at the times in the deterministic calculations closest to the probabilistic time of interest are used as reference points for scaling or interpolation.

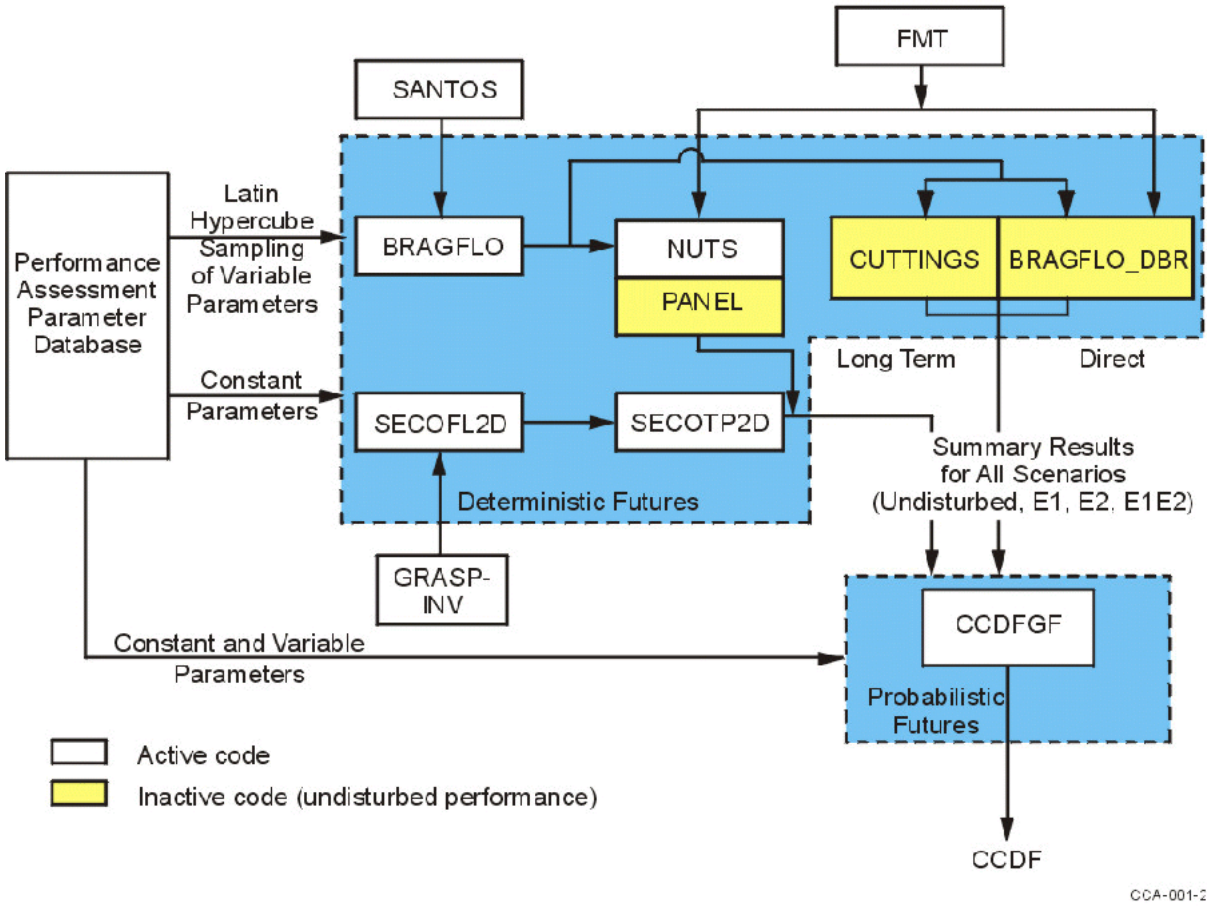

Figure 6-32. Code Configuration for the Undisturbed Performance Scenario

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Scaling is used for all futures with intrusion boreholes. The times when various codes are executed to develop reference behavior, and how this reference behavior is used by other codes, is the subject of the next two sections. In presenting complete descriptions of the process for each scenario, there will be some duplication of discussion.

6.4.13.3 Estimating Long-Term Releases from the E1 Scenario

The E1 scenario is defined as a single penetration of a panel by a borehole that also intersects a brine reservoir. The code configuration with which the long-term consequences of E1 scenarios are estimated is illustrated in Figure 6-33. For the E1 scenario, BRAGFLO is executed twice more for each CCDF (assuming the undisturbed performance run has already been executed), with the E1-type intrusion occurring at 350 years and 1,000 years. These three BRAGFLO calculations form the foundation for transport modeling that is used for scaling consequences to probabilistic futures.

Consistent with the BRAGFLO intrusion times, NUTS is executed with intrusions occurring at 350 and 1,000 years. These calculations form the basis for (1) estimating releases to the accessible environment via Salado interbeds or to the surface and (2) forming the actinide source term to the SECOTP2D code for Culebra transport. For computational efficiency, an intermediate scaling step is conducted prior to calculating the releases associated with probabilistic futures. In this intermediate step, NUTS reference conditions for Culebra releases by an intrusion at 100 years are calculated by using borehole flow from the 350-year intrusion, and NUTS reference conditions for intrusions at 3,000, 5,000, 7,000, and 9,000 years are calculated by using borehole flow from the 1,000-year calculation. Thus, for the scaling of consequences of E1 intrusions in probabilistic futures, reference conditions calculated by NUTS are available for 100, 350, 1,000, 3,000, 5,000, 7,000, and 9,000 years postclosure.

Consistent with the BRAGFLO intrusion times, reference behavior for actinide transport in the Culebra is calculated by SECOTP2D for the E1 intrusion occurring at 350 and 1,000 years. Because the equations governing actinide transport and retardation in SECOTP2D are linear, scaling releases to probabilistic E1 penetrations occurring at other times is easily accomplished.

6.4.13.4 Estimating Long-Term Releases from the E2 Scenario

The E2 scenario includes all futures with one or more exploratory borehole penetrations of a panel, none of which hits a brine reservoir. Estimation of long-term releases from the E2 scenario is slightly more complex than the consequences of the E1 scenario because the E2 scenario includes the possibility of multiple E2-type intrusions. The same codes used in the construction of the E1 scenario consequences are used for construction of the E2 scenario consequences. These are indicated in Figure 6-33.

As is done for the E1 scenario, BRAGFLO is executed twice more for each CCDF (assuming the undisturbed performance run has already been executed), with the E2-type intrusion

occurring at 350 years and 1,000 years. These three BRAGFLO calculations form the foundation for transport modeling that is used for scaling consequences to probabilistic futures.

NUTS is executed with intrusions occurring at 350 and 1,000 years, consistent with the BRAGFLO times of intrusion. These calculations form the basis for (1) estimating releases to the accessible environment via Salado interbeds or to the surface and (2) forming the actinide source term to the SECOTP2D code for Culebra transport. For computational efficiency, an intermediate scaling step is conducted prior to calculating the releases associated with probabilistic futures. In this intermediate step, NUTS reference conditions for Culebra release by an intrusion at 100 years is estimated by scaling borehole flow from the 350-year intrusion, and NUTS reference conditions for intrusions at 3,000, 5,000, 7,000, and 9,000 years are estimated by scaling from the 1,000-year calculation. Thus, for the scaling of consequences of E2 intrusions in probabilistic futures, reference conditions from calculations by NUTS are available for 100, 350, 1,000, 3,000, 5,000, 7,000, and 9,000 years.

Consistent with the BRAGFLO intrusion times, reference behavior for actinide transport in the Culebra is calculated by SECOTP2D for the E2 intrusion occurring at 350 and 1,000 years. Because the equations governing actinide transport and retardation in SECOTP2D are linear, scaling releases to probabilistic E2 penetrations occurring at other times is easily accomplished. For futures with two or more E2-type intrusions (and no E1-type intrusions), a simplifying assumption is made. The additional increment to the source term to the Culebra for the second and subsequent intrusions is assumed to be zero. This is considered reasonable because in the E2 scenario the flux of brine to the Culebra is limited by the rate of flow from the Salado to the waste panels rather than by borehole properties. For second and subsequent E2 scenarios, only the direct releases to the surface are therefore considered in CCDF construction.

6.4.13.5 Estimating Long-Term Releases from the E1E2 Scenario

The E1E2 scenario is defined as multiple boreholes intersecting a single waste panel, at least one of which is an E1 penetration of a brine reservoir (Section 6.3.2.2.3). The DOE uses both scaling and simplification to develop the consequences of this scenario. Similar to the E1 and E2 scenarios, BRAGFLO and related computer codes are executed with a deterministic sequence of future events to develop reference behavior for the E1E2 consequences (see Figure 6-34). Scaling is used to estimate the consequences for events occurring at different times than those used in the BRAGFLO calculations. Simplifying assumptions are used to develop the consequences of E1E2 occurrences in different waste panels or the consequences of a different sequence of future events leading to the E1E2 scenario than assumed in the deterministic BRAGFLO calculation.

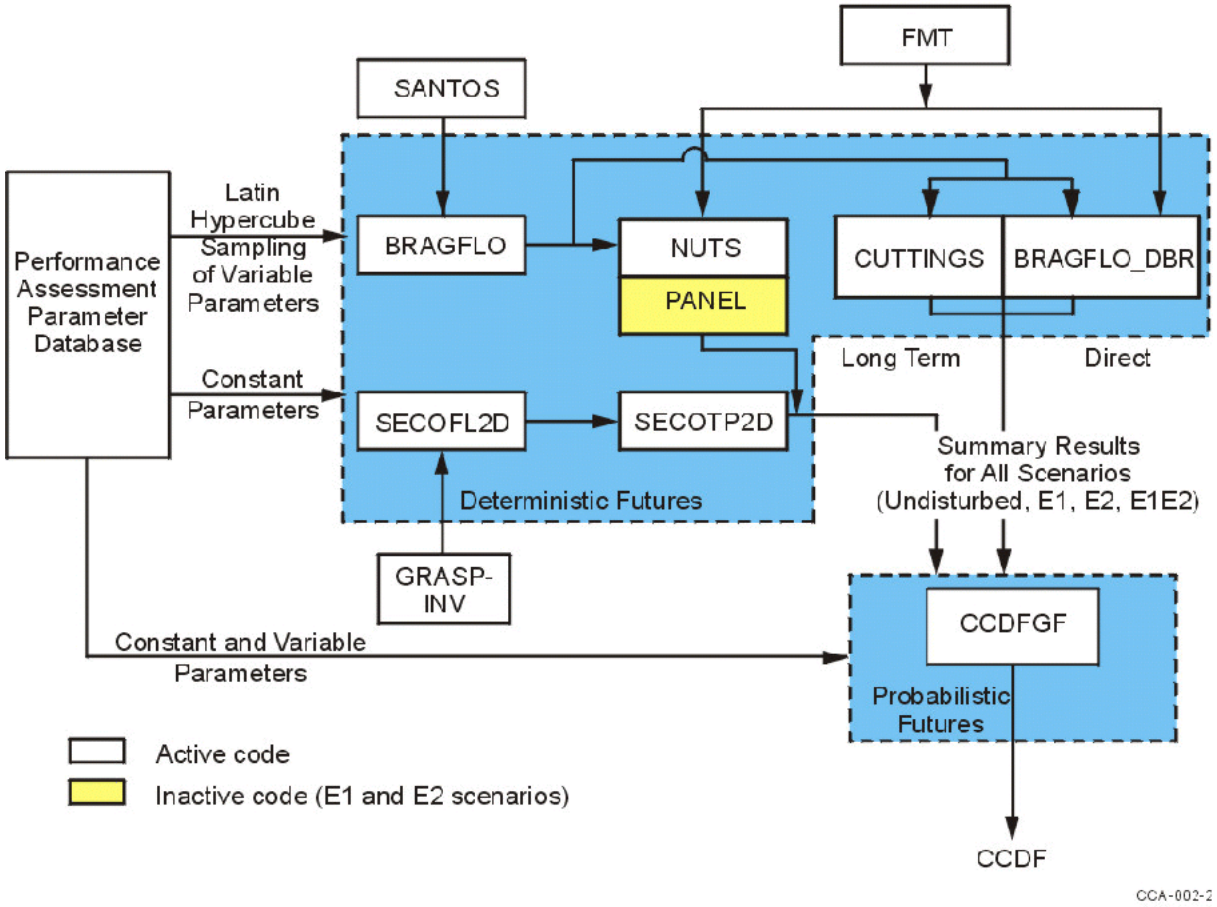

Figure 6-33. Code Configuration for Disturbed Performance Scenarios E1 and E2

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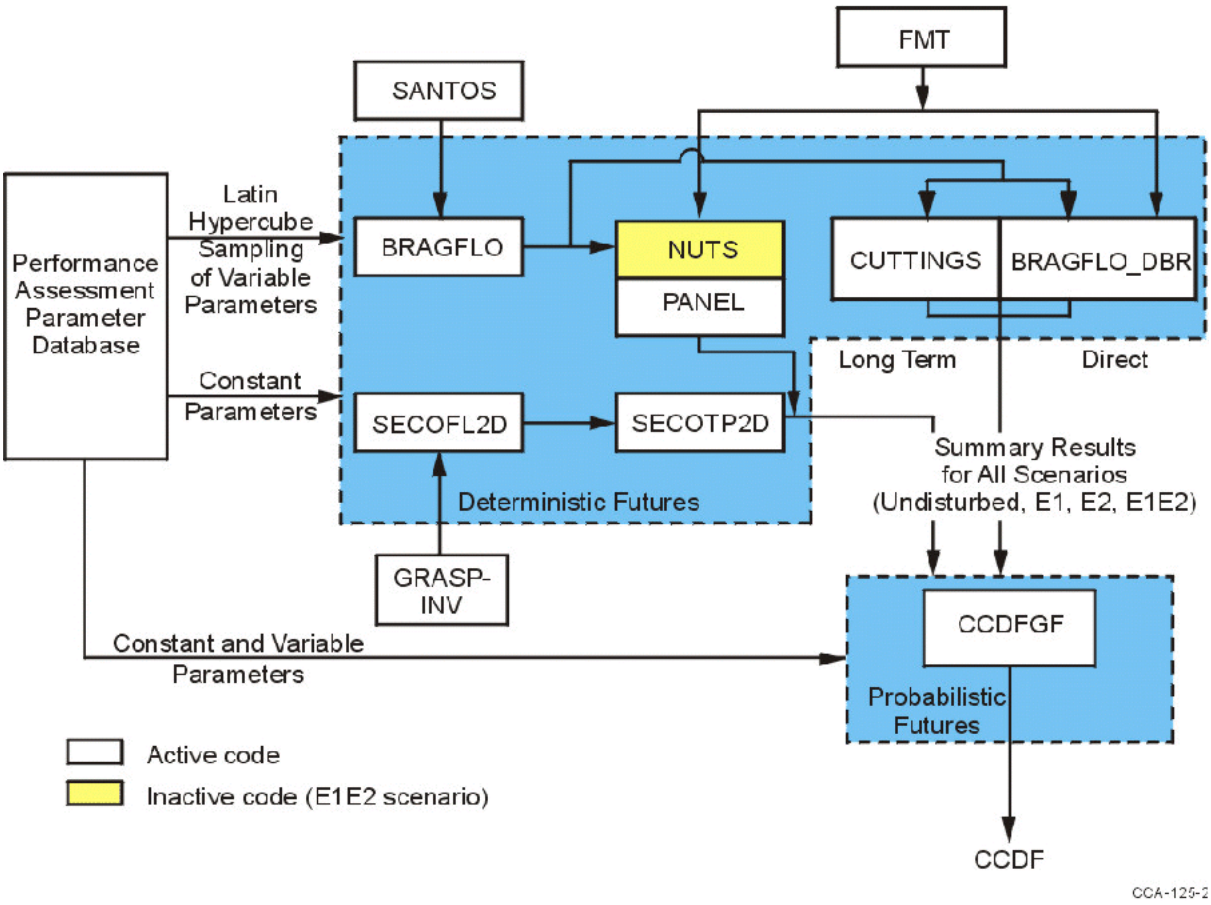

Figure 6-34. Code Configuration for Disturbed Performance Scenario E1E2

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Reference behavior for brine flow to the Culebra in the E1E2 scenario is predicted by the BRAGFLO disposal system model. This is the same model used to predict brine flow to the Culebra for the E1 and E2 scenarios. The geometry of the grid used is the same as that depicted in Figures 6-13 through 6-16; however, different assumptions are used about the borehole development through time. Even though the E1E2 scenario includes at least two boreholes intersecting the panel, the model used included only one borehole column. As will be described, the assumptions used about the manner in which brine mixes in the intruded panel are such that two boreholes are not needed to represent flow through the waste. The assumptions about the development of the borehole are related to the most likely (that is, most probable) sequence of events that gives rise to the E1E2 scenario.

Ninety-two percent of all deep boreholes are the E2 type (see Section 6.4.12.6). Therefore, it is most probable that the first borehole into any panel is an E2 borehole. In a BRAGFLO calculation after 1,000 years of undisturbed performance, the properties of the column of elements in BRAGFLO representing the borehole are changed. The changed properties represent the E2 borehole after the Rustler plug has degraded and silty sand fills the borehole. The period during which the plug is effective is not modeled to develop reference behavior for the E1E2 Culebra releases because relatively little happens in the disposal system during the time that the Rustler plug is effective. Reference conditions are developed with the E1 intrusion that follows the initial E2 intrusion occurring after the 200 years that it takes Rustler plugs to degrade because it is more probable that a subsequent E1 intrusion occurs after the Rustler plug has degraded. It is assumed that the E1 intrusion occurs 1,000 years after the E2 borehole becomes filled with silty sand, at a simulation time of 2,000 years. At 2,000 years, the properties of the section of the borehole below the repository horizon are changed to represent an open borehole (the E1 intrusion), allowing flow between the Castile brine reservoir and the repository. After another 200 years, the lower section is assumed to become filled with silty sand; after another 1,000 years, the permeability of the lower section is decreased one order of magnitude because of salt creep. These changes are documented in Table 6-29.

Table 6-29. Changes in BRAGFLO Borehole Properties in Developing Reference Behavior for the E1E2 Scenario

Time (years)	Borehole Portion	Properties
0-1,000	All	Undisturbed conditions
1,000-2,000	Above waste panel	Silty sand
	Below waste panel	Undisturbed conditions
2,000-2,200	Above waste panel	Silty sand
	Below waste panel	Open borehole between panel and Castile
2,200-3,200	Above waste panel	Silty sand
	Below waste panel	Silty sand
3,200-10,000	Above waste panel	Silty sand
	Below waste panel	Silty sand, permeability decreased 1 order of magnitude

Thus, above the waste panel, the E1E2 borehole evolves as an E2 borehole from 1,000 years to 10,000 years. Below the waste panel, the borehole evolves as an E1 borehole from 2,000 to 10,000 years. At 2,200 years, there will be two boreholes above the waste panels with silty-sand properties. The assumption about upper borehole permeability most consistent with the assumption made for this scenario of complete mixing in the panel (discussed below) is that the upper portion of the E1 borehole is relatively impermeable and all flow that might occur through it is diverted to the E2 borehole. Therefore, the permeability of the upper borehole remains that of the E2 borehole at 2,200 years.

The concentration of actinides in liquid moving up the borehole assumes homogeneous mixing within the panel and is calculated with the code PANEL. PANEL is a mixing-cell model that sums BRAGFLO fluxes into the waste panel from the boreholes and Salado as inputs to the cell and subtracts the flow up the borehole as a depletion from the model. Brine moving up the borehole is assumed to be at its greatest possible actinide concentration according to the dissolved and colloidal actinide source term models (Sections 6.4.3.5 and 6.4.3.6). In PANEL calculations, all actinides that enter the borehole are conservatively assumed to reach the Culebra.

Random sampling of future events can produce different timing of borehole penetrations. From the time the E2 borehole penetrates until the E1 borehole penetrates, the consequences are determined as they are in the E2 scenario. When the E1 is drilled, completing the E1E2 configuration, the consequences are assumed to be similar to the consequences modeled after the E1 penetration for the reference calculation, accounting for radionuclide decay and ingrowth.

Random sampling of future events can also produce a different sequence of borehole types. In a randomly sampled future with many E2 intrusions into a waste panel prior to the E1, the consequences are determined as they are for the E2 scenario until the E1 occurs, at which time the E1E2 consequences are used. In a randomly sampled future with the sequence E1 then E2, the consequences are assumed to be similar to an E1 event until the E2 is drilled, whereupon the consequences are assumed to be similar to the E1E2 event following the E1 drilling. In a randomly sampled future with two E1 boreholes, the consequences are assumed to be similar to an E1 borehole until the second E1 is drilled, at which time the consequences are assumed to be similar to the E1E2 behavior.

For computational simplicity, the E1E2 calculations are scaled to E1 intrusions following a prior E2 intrusion occurring at 100, 350, 3,000, 5,000, 7,000, and 9,000 years, similar to the treatment of the E1 and E2 reference conditions.

6.4.13.6 Multiple Scenario Occurrences

For long-term brine flow into the Culebra, scenario occurrences are effectively defined at the panel scale for this performance assessment. It was recognized in preliminary analysis of BRAGFLO results for this analysis that liquid flow between the separate panel and the rest of the repository is slow enough that the panel is effectively independent from the rest of the

repository. Gas flow does occur, and for this reason calculations of direct release to the surface are performed at the repository scale. For long-term brine flow to the Culebra, it is considered more reasonable, based on BRAGFLO results, to assume independent panel behavior in developing the CCDF rather than an interconnected repository.

It is very important to distinguish between model results and model assumptions on this point. For disposal system performance, the DOE is not assuming that panel closures isolate panels from one another. Rather, the DOE has assigned reasonable properties to the panel closures as input to the BRAGFLO calculations and has found that the assignment of these reasonable properties results in limited liquid flow through them. Because simplification and scaling must be used to develop CCDFs, the DOE has to assume either that the repository is well interconnected or that the panels behave fairly independently. Based on model results for this analysis, the DOE has established that it is more reasonable in constructing a CCDF to assume that brine does not flow between panels. This is a simplification of results of the detailed modeling conducted in BRAGFLO, necessary for CCDF construction. It is not an assumption used in developing conceptual models of disposal system performance. This assumption does affect how scenario consequences are developed.

There are 10 panels in the repository and the possibility of many intrusions. If panels behave independently as they are assumed to in developing consequences of long-term brine flow in the CCDF, it is possible for different configurations of boreholes (scenarios) to occur in different panels. For example, an E1E2 type situation might occur in one panel, an E2 situation in a different panel, and an E1 situation in a third panel. In this example, there are essentially three scenario types occurring. For long-term release, the repository behaves as 10 small modules (each comprising one panel), and a different borehole scenario can develop in each of those 10 modules. Long-term releases in CCDF construction are based on the premise that releases from each of these modules are independent and that the cumulative release from the repository is equal to the sum of the cumulative releases from the different modules.

6.4.13.7 Estimating Releases During Drilling for All Scenarios

The reference behavior for cuttings and cavings from the first intrusion into a pressurized repository, regardless of whether it is an E1 or E2 intrusion, is established by calculations performed in the CUTTINGS_S code. Cavings releases are also dependent on the effective shear resistance to erosion (Appendix PAR, Parameter 33). The effects of radioactive decay are captured by calculating reference behavior for cuttings and cavings by the CUTTINGS_S code at 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years.

Spall and direct brine releases during drilling are also dependent on pressure conditions in the repository, and reference releases are calculated by CUTTINGS_S for spall and by BRAGFLO_DBR at 100, 350, 1,000, 3000, 5,000, and 10,000 years for intrusions into up-dip and down-dip (that is, northern and southern) panels. Spall releases are also dependent on the waste particle diameter (Appendix PAR, Parameter 32).

Radionuclide releases from the processes in the CUTTINGS_S code and direct brine release for intrusions occurring at intermediate times are scaled from the closest calculated releases, correcting for radioactive decay (see Section 6.4.12.3 and Figure 6-28). The cuttings and cavings portion of the CUTTINGS_S releases are further adjusted to account for the distribution of CH- and RH-TRU waste streams (see Sections 6.4.12.3 and 6.4.12.4). The processes of spallings and direct brine release are assumed to involve a large enough volume of waste that it is reasonable to use homogeneous waste with average activity to estimate releases.

For multiple-intrusion scenarios, the pressure in the repository at the time of the second and subsequent intrusions may be quite different from the pressure at the time of the first intrusion. This is expected because of the assumptions of relatively permeable boreholes adopted in performance assessment. Therefore, estimates of drilling releases to the accessible environment need to be formed for penetrations of a previously intruded repository. The reference behavior for these releases for subsequent intrusions is calculated by the CUTTINGS_S code from BRAGFLO histories with E1- and E2-type intrusions at 350 and 1,000 years. Repository conditions from the calculations of the effects of a subsequent E1-type penetration are used in consequence analysis for both E1- and E2-type intrusions that follow an E1 intrusion. Conditions from the subsequent E2 calculations are used for intrusions that follow E2 intrusions only. E1 conditions are used for multiple combinations of boreholes that include at least one E1 intrusion, based on the assumption that repository conditions will be dominated by Castile brine if any borehole connects to a brine reservoir. For futures in which more than two E2-type intrusions occur (and no E1-type intrusions occur), third and subsequent spall and direct brine releases are assumed to be the same as for the second release.

For both E1 and E2 conditions following a 350-year intrusion, spall and direct brine release calculations are performed at 550, 750, 2,000, 4,000, and 10,000 years. For the 1,000-year E1 and E2 intrusions, spall and direct brine release calculations are performed at 1,200, 1,400, 3,000, 5,000, and 10,000 years. Because the subsequent intrusion may penetrate either a previously-intruded panel or an unintruded panel, these calculations are done twice, once with initial conditions drawn from the previously-intruded panel in BRAGFLO, and once with conditions drawn from the BRAGFLO subsequent intrusion of the waste-disposal region. As is done for the first intrusion into a previously undisturbed repository, radionuclide releases from spall and direct brine release for intrusions occurring at intermediate times are scaled from the closest calculated releases, correcting for radioactive decay.

After flow through the repository has occurred for some time, such as may occur in an E1E2 scenario, portions of the repository may be depleted of actinides. In the estimate of releases during drilling, however, the possibility is not accounted for that random drilling might penetrate portions of the repository that have been depleted of actinides as a consequence of processes initiated by previous drilling. This is conservative because it tends to overestimate releases during drilling.

6.4.13.8 Estimating Releases in the Culebra and the Impact of the Mining Scenario

Ten thousand-year SECOFL2D and SECOTP2D calculations are performed with Culebra transmissivity fields reflecting undisturbed performance (no future mining within the land withdrawal area) and disturbed performance (see Section 6.4.6.2.3). These calculations are performed with a unit source term of one kilogram of the actinide species of interest at 100 years. Because transport as modeled is a linear process, scaling is used to estimate the consequences of time-variable concentrations and different times of intrusion (see Appendix CCDFGF, Section 4.9). As well, mining may occur at random times in the future. The effect of mining on releases in the Culebra is determined in the following manner.

Boreholes intersecting the repository may provide a source of actinides to the Culebra with concentrations that vary through time. Until mining occurs, the transport behavior of actinides from these borehole sources is estimated by scaling the results of the undisturbed performance Culebra transport calculations. All actinides introduced into the Culebra by the time of mining are transported exclusively in the undisturbed performance flow fields. In other words, actinides in transit in the Culebra when mining occurs are assumed to be not affected by it and continue to be transported in the undisturbed flow field. Once mining occurs (it is assumed to occur instantaneously), the transport behavior of all actinides subsequently introduced into the Culebra is estimated by scaling the results of the disturbed performance flow fields.

6.4.13.9 Final Construction of a Single CCDF

After consequences for all of the sampled probabilistic futures have been estimated by the methodologies presented in the preceding sections, the information necessary to plot the CCDF associated with the probabilistic futures and the particular LHS vector is available.

The sequences of future events used in this performance assessment were generated by random sampling. Thus, each sampled future is assigned an equal weight of occurrence for the construction of a CCDF. Each sequence of future events is assigned a weight of 1/10,000 of occurrence because 10,000 futures are used for each CCDF. Before plotting, an additional step is performed in which the weights of futures with similar consequences are summed. The first step in the plotting process is to order the grouped futures according to normalized release, as discussed in Section 6.1.1, from lowest normalized release to highest. Following this ordering, the CCDF can be plotted by summing, for a given value of EPA normalized release, the probabilities of all futures whose normalized release exceeds the given value, where the probabilities are assumed to be equal to the weights. Because the releases **cS** have been ordered so that $cS_i \leq cS_{i+1}$ for i=1 …, nS-1, the probability that **cS** exceeds a specific consequence value x is determined by the summation routine (duplicated from Section 6.1.1)

(14)

where i is the smallest integer such that $cS_i > x$. This completes an analysis of stochastic uncertainty for a particular vector of variable values from the LHS sampling.

6.4.14 CCDF Family

The process of CCDF construction described in Section 6.4.13 is repeated once for each vector of values of subjectively uncertain variables created by LHS. This process yields a family of CCDFs such as those presented in Section 6.5. This family of CCDFs provides a complete display of both stochastic and subjective uncertainty, as discussed in Section 6.1.2.

6.5 Performance Assessment Results

This section contains results of the performance assessment and demonstrates that the WIPP complies with the quantitative containment requirements in 40 CFR § 191.13(a). See Section 6.1 for a discussion of the containment requirements. Criteria for presenting the results of performance assessments are provided by the EPA in 40 CFR § 194.34, and are discussed in Section 6.1.3. These criteria are also summarized here for clarity.

Additional detail about the results of the performance assessment is contained in Appendix SA, which describes sensitivity analyses conducted as the final step in the Monte Carlo analysis. These sensitivity analyses indicate the relative importance of each of the sampled parameters in terms of their contribution to uncertainty in the estimate of disposal system performance. Analyses also examine the sensitivity of intermediate performance measures to the sampled parameters. Examples of such intermediate performance measures include the quantity of radionuclides released to the accessible environment by any one mechanism (for example, cuttings or direct brine releases), and other model results that describe conditions of interest such as disposal region pressure.

6.5.1 Demonstrating Convergence of the Mean CCDF

As discussed in Sections 6.4.13 and 6.4.14, individual CCDFs for the WIPP are constructed by estimating cumulative radionuclide releases to the accessible environment for 10,000 different possible futures. Each CCDF is calculated for a single LHS vector of input parameters and is conditional on the occurrence of that particular combination of parameter values. Multiple realizations of the performance assessment calculations yield a family of CCDFs in which each individual CCDF is generated from a different LHS vector. Families of CCDFs calculated for the WIPP performance assessment are based on 100 LHS vectors drawn from distributions of values for 57 imprecisely known parameters. As discussed in Section 6.1.2, mean and percentile CCDFs are constructed from families and provide summary measures of disposal system performance.

Criteria provided by the EPA in 40 CFR Part 194.34 address the statistical interpretation of CCDFs:

> The number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least a 0.95 probability. Values of cumulative release shall be calculated according to Note 6 of Table 1, Appendix A of Part 191 of this chapter. (40 CFR § 194.34(d))
>
> Any compliance application shall provide information which demonstrates that there is at least a 95 percent level of statistical confidence that the mean of the population of CCDFs meets the containment requirements of § 191.13 of this chapter. (40 CFR § 194.34(f))

Information provided by the EPA in the Background Information Document for 40 CFR Part 194 clarifies the intent of these criteria.

> In 40 CFR part 194, EPA decided that the statistical portion of the determination of compliance with 40 CFR part 191 will be based on the sample mean. The LHS sample sizes should be demonstrated operationally (approximately 300 when 50 variables are considered) to improve (reduce the size of) the confidence interval for the estimated mean. The underlying principle is to show convergence of the mean. (EPA 1996b, 8-41)

The DOE has chosen to demonstrate convergence of the mean and to address the associated criteria of 40 CFR Part 194 using an operational approach of multiple replication as proposed by Iman (1982). The complete set of performance assessment calculations was repeated three times with all aspects of the analysis identical except for the random seed used to initiate the LHS procedure. Thus, performance assessment results are available for three replicates, each based on an independent set of 100 LHS vectors drawn from identical CCDFs for imprecisely known parameters and propagated through an identical modeling system. This technique of multiple replication allows evaluation of the adequacy of the sample size chosen in the Monte Carlo analysis and provides a suitable measure of confidence in the estimate of the mean CCDF used to demonstrate compliance with 40 CFR § 191.13(a).

6.5.2 Complementary Cumulative Distribution Functions for the WIPP

Families of CCDFs for each of the three replicates are shown in Figures 6-35, 6-36, and 6-37. Each figure contains 100 CCDFs. These figures address the criterion stated in 40 CFR § 194.34(e):

> Any compliance application shall display the full range of CCDFs generated.

Figures 6-35 through 6-37 show that all 300 CCDFs lie below and to the left of the limits specified in 40 CFR § 191.13(a). They also show qualitatively that the three replicates yield very similar results. Quantitative verification of the similarity of the three replicates is demonstrated in Figure 6-38, which shows the mean CCDFs calculated for each of the three replicates, together with an overall mean CCDF that is the arithmetic mean of the three individual mean CCDFs. Figure 6-38 demonstrates two key points. First, the overall mean CCDF lies entirely below and to the left of the limits specified in 40 CFR § 191.13(a). Thus, the WIPP is in compliance with the containment requirements of 40 CFR Part 191. Second, the sample size of 100 in each replicate is sufficient to generate a stable distribution of outcomes. Within the region of regulatory interest (that is, at probabilities greater than

$10^{-3}/10^{4}$ yr), the mean CCDFs from each replicate are essentially indistinguishable from the overall mean at the resolution of the figure. Figure 6-39 provides quantitative confirmation of the sufficiency of the sample size, by displaying the overall mean together with the 0.95 confidence interval of the Student's t-distribution estimated from the individual means of the three independent replicates (Iman 1982), as shown in Figure 3-38.

Figure 6-40 provides additional summary information about the distributions of CCDFs resulting from the three replicates. This figure shows CCDFs representing the mean, median, and 10th and 90th percentile CCDFs from each replicate, together with the overall mean. Note that for each type of CCDF (for example, the 10th percentile), curves from each replicate overlie closely. This provides quantitative verification of the qualitative observation that distributions from each replicate appear similar. Note also that the mean CCDFs lie to the right of the 90th percentile CCDFs at probabilities less than approximately $10^{-2}/10^{4}$ yr. This is a result of the strongly skewed distribution, with the location of the mean being dominated by the relatively small number of CCDFs associated with the largest normalized releases.

6.5.3 Release Modes Contributing to the Total Radionuclide Release

Radionuclide releases to the accessible environment can be grouped into four categories according to their mode of release:

(1) cuttings and cavings releases,

(2) spallings releases,

(3) releases resulting from the direct release of brine at the surface during drilling, and

(4) releases in the subsurface following transport in groundwater.

Each of these four modes has the potential to contribute to the total quantity of radionuclides released from the repository, and therefore each has the potential to affect the position of the mean CCDF.

Figure 6-41 provides a display of the relative contribution of each mode to the total release. Releases for each of the three replicates are similar, and results are shown for replicate 1 only for simplicity. Mean CCDFs are shown for the total normalized release (this curve is also shown in Figure 6-40 and is the mean of the family shown in Figure 6-35) and for the normalized releases resulting from cuttings and cavings, spallings, and direct brine release. The mean CCDF for subsurface releases resulting from groundwater transport is not shown because those releases were less than 10^{-6} EPA units and the CCDF cannot be shown at the scale of this figure. Releases from cuttings and cavings are shown to be the most important contributors to the location of mean CCDF, with spallings also making a small contribution. Direct brine releases are less important, and have very little effect on the location of the mean

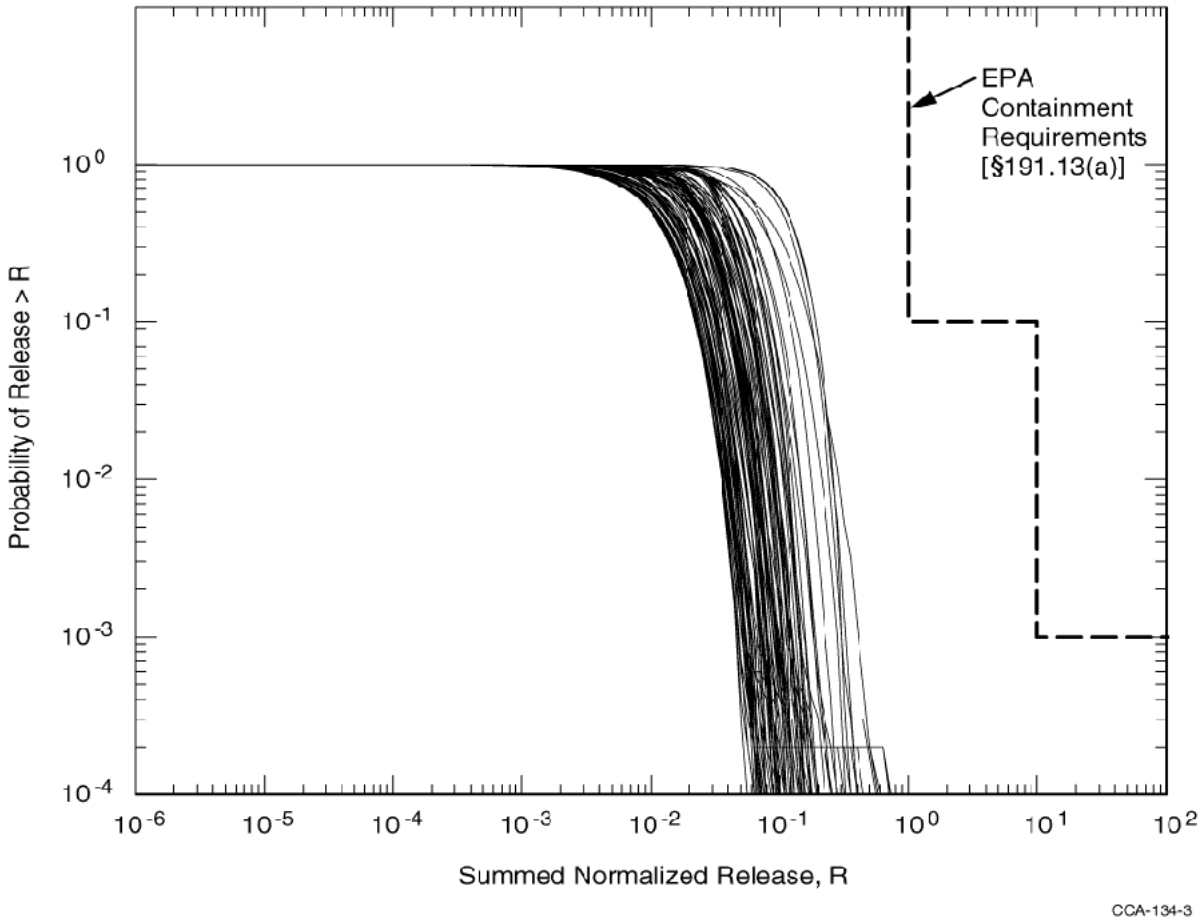

Figure 6-35. Distribution of CCDFs for Normalized Radionuclide Releases to the Accessible Environment from the WIPP, Replicate 1

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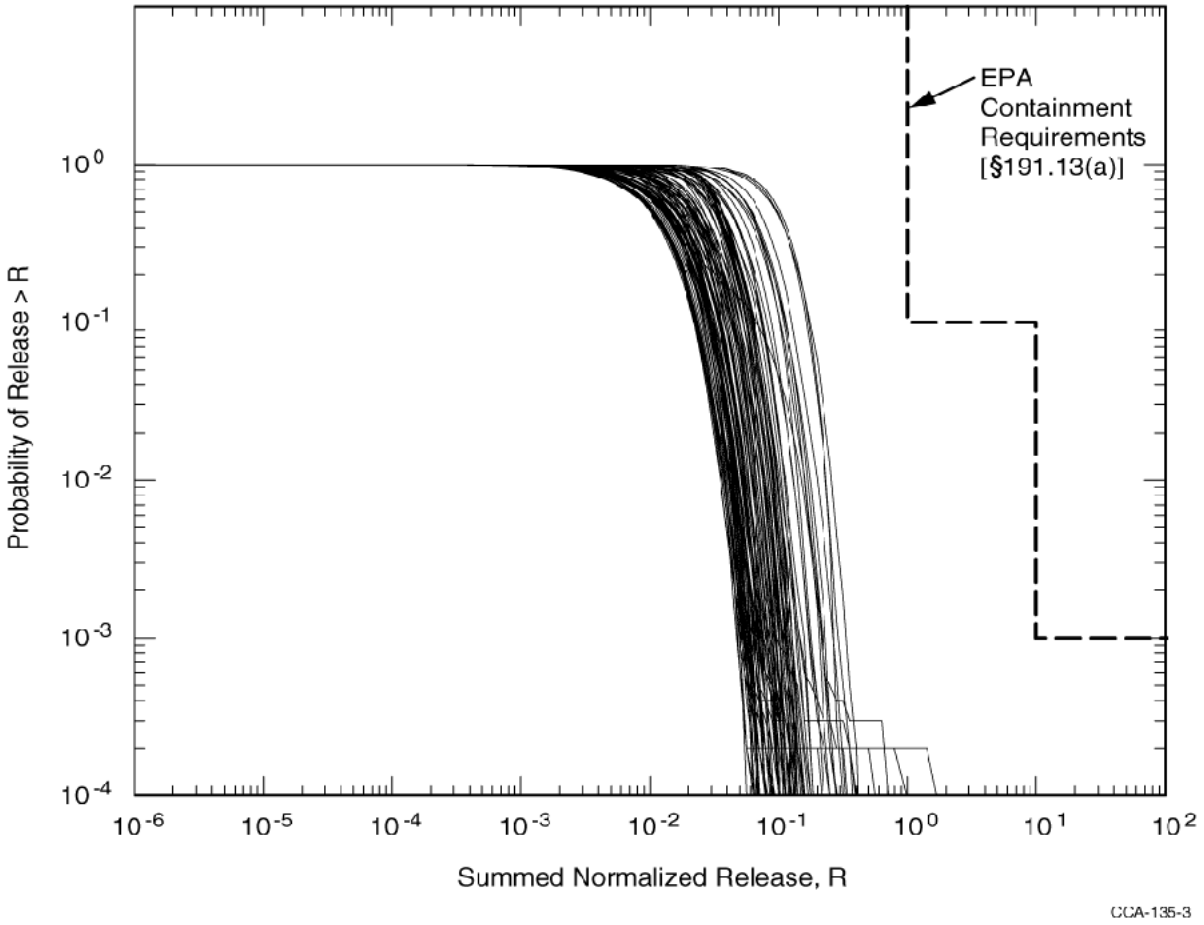

Figure 6-36. Distribution of CCDFs for Normalized Radionuclide Releases to the Accessible Environment from the WIPP, Replicate 2

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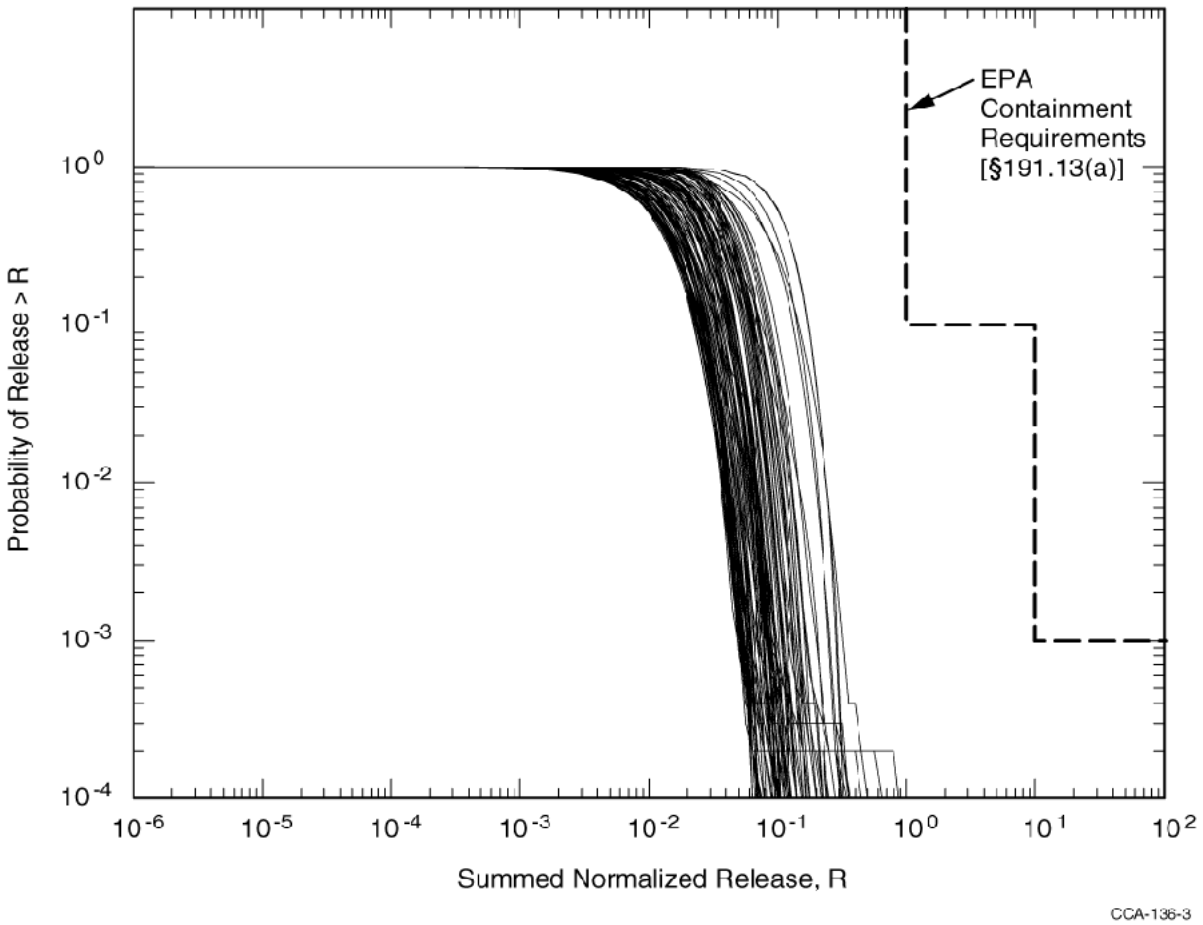

Figure 6-37. Distribution of CCDFs for Normalized Radionuclide Releases to the Accessible Environment from the WIPP, Replicate 3

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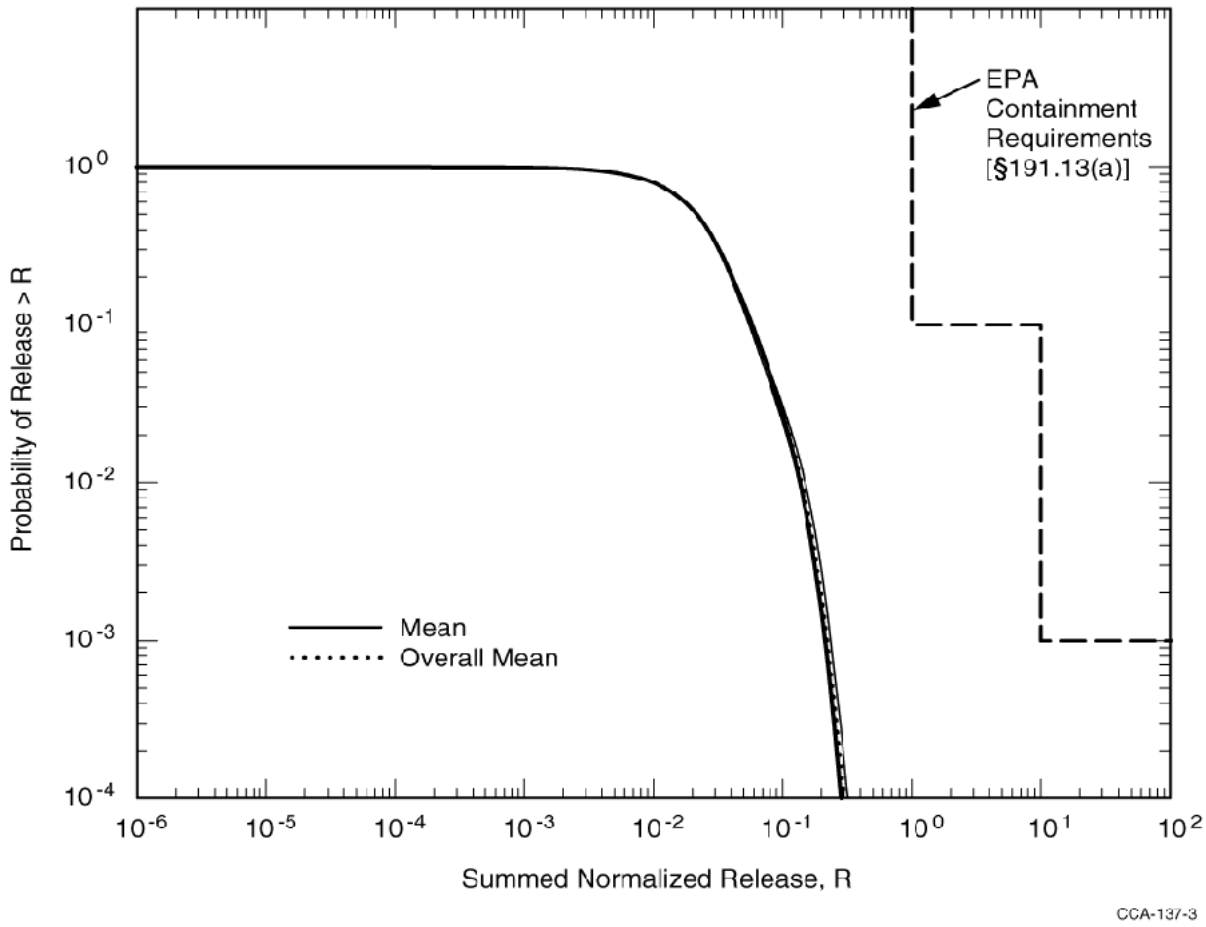

Note: Four CCDFs are shown, including three individual mean CCDFs calculated for each of the three distributions of CCDFs calculated for the three replicates and shown in Figures 6-35, 6-36, 6-37, and an overall mean CCDF that is the arithmetic mean of the three individual mean CCDFs.

Figure 6-38. Mean CCDFs for Normalized Radionuclide Releases to the Accessible Environment

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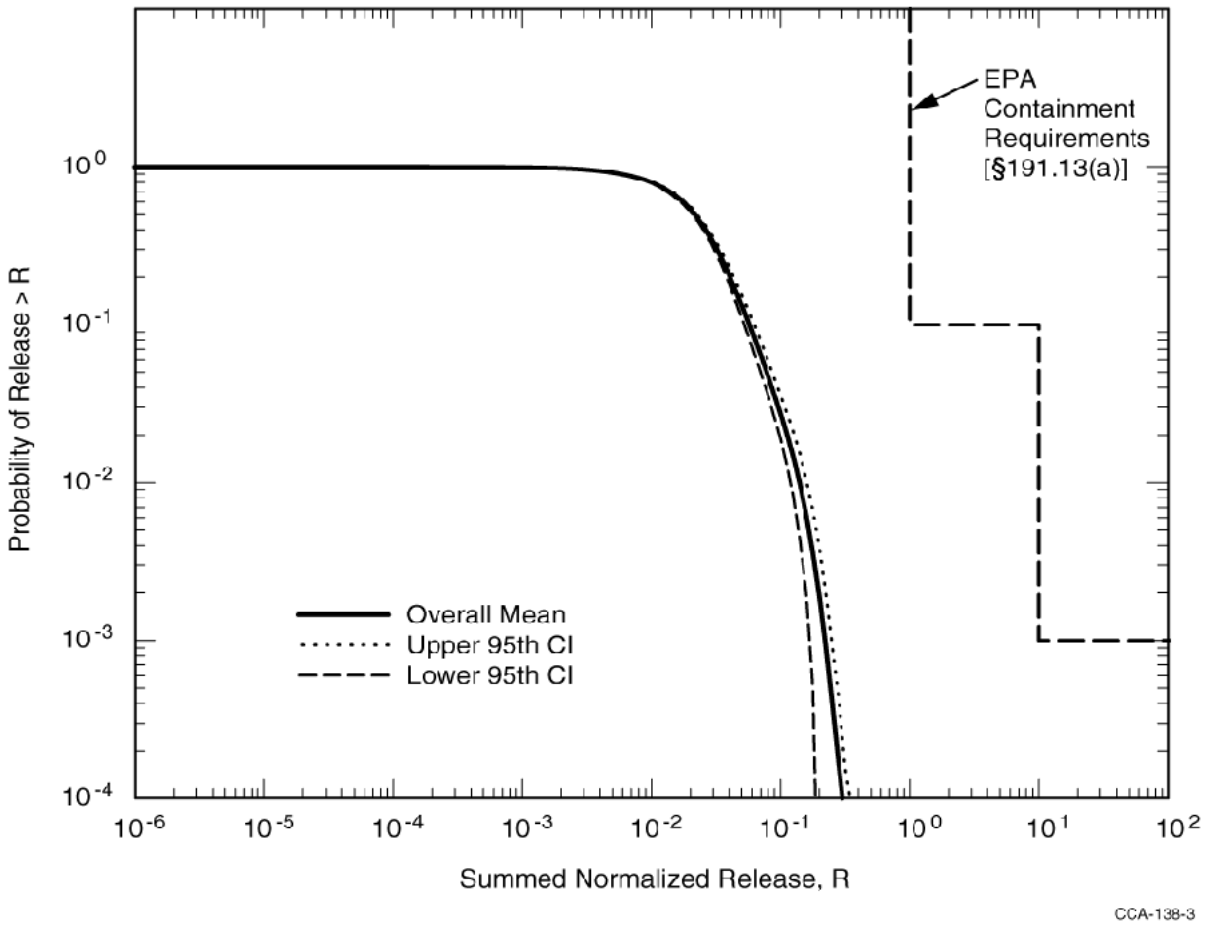

Note: The overall mean CCDF shown in Figure 6-38 is repeated together with the 0.95 confidence interval of the Student-t distribution estimated from the three individual mean CCDFs.

Figure 6-39. Confidence Levels for the Mean CCDF

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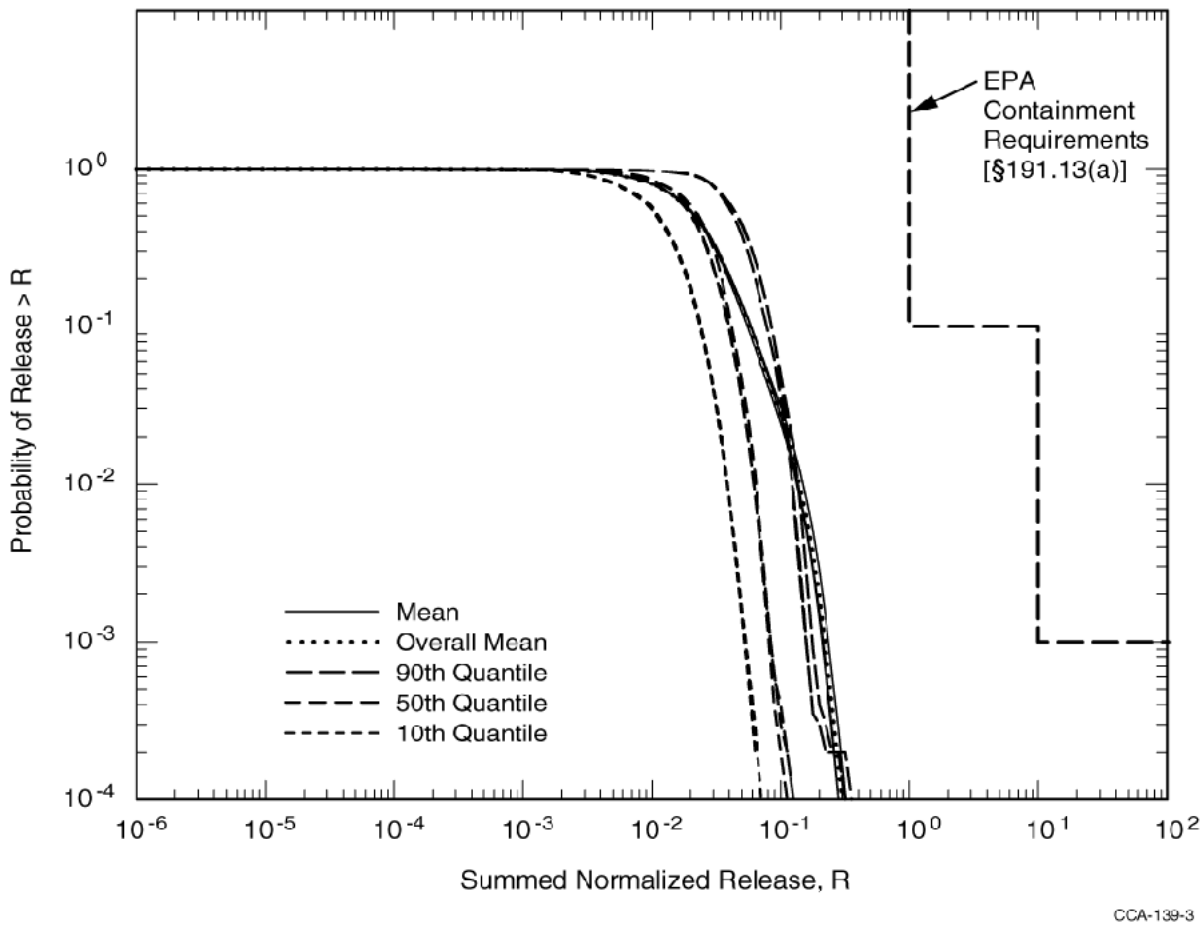

Note: Mean, median, and 10th and 90th percentile CCDFs are shown together with the overall mean. These CCDFs are based on the distributions of CCDFs shown in Figures 6-35, 6-36, and 6-37.

Figure 6-40. Summary CCDFs for Replicates 1, 2, and 3

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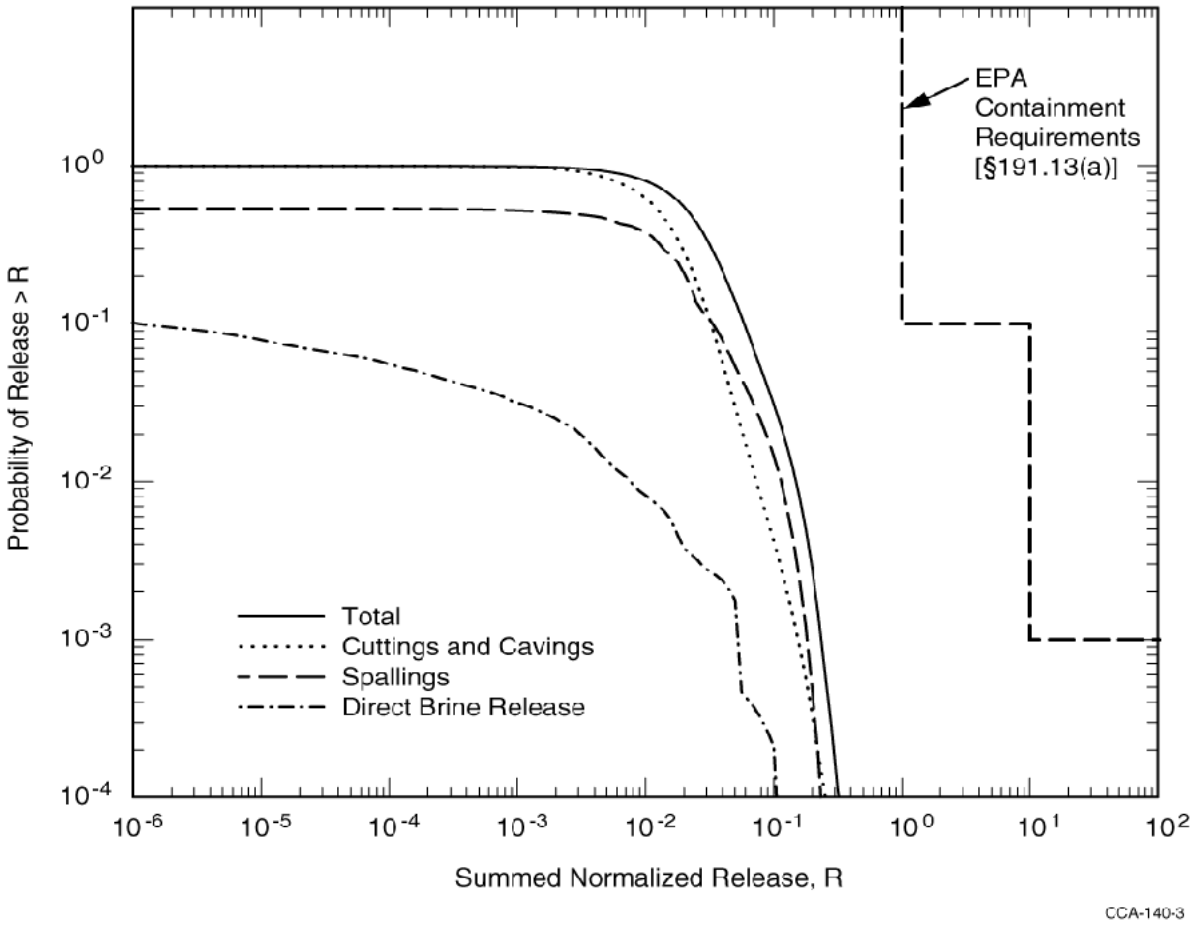

Note: Mean CCDFs are shown for the total normalized release (this curve is also shown in Figure 6-40 and is the mean of the family shown in Figure 6-35) and for the normalized releases resulting from cuttings and cavings, spallings, and direct brine release. The mean CCDF for subsurface releases resulting from groundwater transport is not shown because those releases were less then 10-6 EPA units and the CCDF cannot be shown at the scale of this figure.

Figure 6-41. Mean CCDFs for Specific Release Modes, Replicate 1

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CCDF. Subsurface groundwater releases are not important, and have essentially no effect on the mean CCDF. See Appendix SA for additional discussion of the relative importance of the release modes.

6.5.4 Uncertainty and the Role of Conservatism in the Compliance Demonstration

As defined in 40 CFR § 191.12, performance assessments must "estimate the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant events and processes."

Site characterization, repository design, and waste characterization activities, as described in Chapters 2.0, 3.0, and 4.0, respectively, have removed much uncertainty from the analysis. Uncertainties remain, however, about how best to characterize some aspects of the disposal system and how best to model the complex interactions between the waste and its surrounding environment. These remaining uncertainties have been incorporated in the performance assessment to the extent practicable through the use of reasonable and realistic assumptions about models and parameter values.

In general, the DOE has not attempted to bias the performance assessment toward a conservative outcome, and the mean CCDF represents a reasonable estimate of the expected and, in the case of future human activities including intrusion, prescribed, performance of the disposal system. However, where realistic approaches to incorporating uncertainty are unavailable or impractical and where the impact of the uncertainty on performance is small, the DOE has chosen to simplify the analysis by implementing reasonable and conservative assumptions. These conservative assumptions are reviewed here, not because they bias the location of the mean CCDF, but rather because an understanding of their effects contributes qualitatively to the "reasonable expectation, on the basis of the record before the implementing agency, that compliance with [§] 191.13(a) will be achieved," as required by 40 CFR § 191.13(b).

As noted in Section 6.2 and Appendix SCR, in some cases processes have been omitted from the modeling system for simplicity because the only possible effects of including them would be beneficial to system performance. Examples include the decision to model radionuclide dissolution as an equilibrium process (assuming instantaneous leaching and dissolution), and the decision not to model sorption of radionuclides in the Salado or in the seal system.

In other cases, the DOE has made conservative decisions during the design of the conceptual and computational models, as listed in Table 6-30. Some conservative assumptions listed in this table are mentioned below. For example, within the repository portion of the BRAGFLO model, fluid flow in a single panel is treated as if all rooms were a single void (that is, pillars are omitted). This treatment allows brine flow to and from an intrusion borehole to contact more waste than it would if it followed a more realistic flow path between rooms. The effect is conservative with respect to brine flow up a plugged and abandoned borehole. Similarly,

Table 6-30. Conservative Model and Parameter Assumptions Used in Performance Assessment (from Appendix MASS, Table MASS-1)

Conservative Assumption	Code	Cross-Reference
Long-term flow up plugged and abandoned boreholes is modeled as if all intrusions occur into a down-dip (southern) panel.	BRAGFLO	Section 6.4.3
Pillars and individual drifts in rooms, and panel closures in the nine lumped panels, are not modeled for long-term performance, and containers provide no barrier to fluid flow.	BRAGFLO	Section 6.4.3, Appendix MASS, Section MASS.5
Panel closures are modeled with the same permeability as the surrounding DRZ.	BRAGFLO	Sections 6.4.3.2 and 6.4.5.3 MASS Attachment 7-1
Brine in the repository will contain a uniform mixture of dissolved and solid-state species. No microenvironments that influence the overall chemical conditions will persist.	NUTS PANEL	Section 6.4.3.4 Appendix SOTERM, Section SOTERM.2.2
Radionuclide dissolution to solubility limits is instantaneous.	NUTS PANEL	Sections 6.4.3.5 and 6.4.3.4 (Appendix SOTERM, Section SOTERM.3.3, SCR.2.5.3.1)
Radionuclides are not retarded by shaft seals.	NUTS	Section 6.4.4 Section SCR.2.5.4.2
Shaft concrete components are modeled as if they degrade 400 years after emplacement.	BRAGFLO	Section 6.4.4 Appendix PAR, Table PAR-19
The permeability of the DRZ is constant and higher than intact Salado.	BRAGFLO	Section 6.4.5.3 Appendix MASS, Section MASS.13.4
The unnamed lower member, Tamarisk, and Forty-niner are assumed to be impermeable.	BRAGFLO SECOFL2D	Sections 6.4.6.1, 6.4.6.3, and 6.4.6.5 Appendix MASS, Section MASS.14
Sorption on clays present in the Culebra is not modeled.	SECOFL2D	Section 6.4.6.2.1 Appendix MASS, Section MASS.15.2
Particle waste shear based on properties of marine clays, considered a worst case.	CUTTINGS_S	Section 6.4.7.1 Appendix PAR, Parameter 33
The concentration of actinides in liquid moving up the borehole in the E1E2 scenario assumes homogeneous mixing within the panel.	CCDFGF PANEL	Section 6.4.13.5

Table 6-30. Conservative Model and Parameter Assumptions Used in Performance Assessment (from Appendix MASS, Table MASS-1) (Continued)

Conservative Assumption	Code	Cross-Reference
For all direct releases to the surface and the E1E2 source term to the Culebra, any actinides that enter the borehole are assumed to reach the surface or Culebra.	CUTTINGS_S BRAGFLO_DBR PANEL CCDFGF	Section 6.4.7.1 Section 6.4.13.5
Retardation is assumed to not occur in the Salado.	NUTS CCDFGF	Section 6.4.5.4.2
Depletion of actinides in parts of the repository that have been penetrated by boreholes is not accounted for in calculating the releases from subsequent intrusions at such locations.	CUTTINGS_S	Section 6.4.13.7
Hydraulically-significant fractures are assumed to be present everywhere in the Culebra.	SECOTP2D	Section 6.4.6.2.1

the DOE has chosen to model fluid flow through plugged and abandoned boreholes as if all intrusions occurred into a down-dip (that is, southern) panel. As modeled, downdip panels tend to have more brine in them than up-dip panels and this assumption therefore may result in overestimating the amount of brine present in intruded panels. Radionuclide dissolution to solubility limits is modeled as instantaneous. The DRZ around the panel closures is assumed not to heal and panel closures are assumed to be no more effective than the surrounding DRZ, tending to overestimate the amount of fluid flow between panels. For E1E2 scenarios, complete mixing is assumed within the intruded panel, and all brine that flows out of the panel and up the borehole is assumed to have been in contact with waste.

Within the shaft seal system, concrete components are modeled as if they degrade 400 years after emplacement, underestimating their potential to limit fluid flow over the long-term. For direct releases and E1E2 releases to the Culebra, processes of actinide transport and retardation are not modeled within the intrusion borehole and all actinides that enter the borehole are assumed to be transported to the surface or into an overlying transmissive unit. Within the Culebra (which modeling indicates will be the only transmissive unit that will receive long-term flow from the borehole), hydraulically significant fractures are assumed for modeling simplicity to be present everywhere, even though test data indicate that the portions of the Culebra above the waste disposal region behave as an unfractured, single porosity matrix.

These conservative assumptions have not significantly affected the location of the mean CCDF, which, as shown in Section 6.5.3, is dominated by cuttings and cavings releases that are, with one exception, independent of the conservative simplifications described here. As discussed in Appendix SA (Section SA.1), the parameter making the largest contribution to uncertainty in the location of the mean CCDF is the effective shear resistance of the waste,

which affects the quantity of waste eroded from the borehole wall and transported to the surface as cavings. In the absence of data describing the reasonable and realistic future properties of degraded waste and backfill, effective shear resistance of the waste is a parameter for which the DOE has selected a conservative distribution (see Appendix PAR, Parameter 33).

6.5.5 Summary of the Demonstration of Compliance with the Containment Requirements

The WIPP is in compliance with the containment requirements of 40 CFR § 191.13(a), as shown by Figures 6-35 through 6-39. Figures 6-38 and 6-39 demonstrate that the sample size of 100 chosen for this analysis is sufficient to provide the level of statistical confidence specified in 40 CFR § 194.34.

Additional confidence in the compliance determination comes from examination of Figure 6-41, which shows that the location of the mean CCDF depends almost entirely on the relatively simple processes that contribute to cuttings and cavings releases resulting from inadvertent human intrusion by drilling. Uncertainties related to the characterization of the natural system and the interaction of waste with the disposal system environment have little effect on long-term performance. The natural and engineered barrier systems, as described in Chapters 2.0 and 3.0, provide robust and effective containment of TRU waste even if the repository is penetrated by multiple borehole intrusions.

REFERENCES

Andersson, J., Ed. 1989. *The Joint SKI/SKB Scenario Development Project*. SKB Technical Report 89-35, Authors: J. Andersson, T. Carlsson, T. Eng, F. Kautsky, E. Söderman, and S. Wingefors. Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.

Barr, G.E., Miller, W.B., and Gonzalez, D.D. 1983. *Interim Report on the Modeling of the Regional Hydraulics of the Rustler Formation.* SAND83-0391. Sandia National Laboratories, Albuquerque, NM, pp. 26 – 27. WPO 27557.

Beauheim, R.L. 1987. *Interpretations of Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983 – 1987*. SAND87-0039. Sandia National Laboratories, Albuquerque, NM, pp. 110 – 118. WPO 27679.

Beauheim, R.L., Wawerisk, W.R., and Roberts, R.M. 1993. "Coupled Permeability and Hydrofracture Tests to Assess the Waste-Containment Properties of Fractured Anhydrite." *Journal of Rock Mechanics*, Vol. 30, No. 7, pp. 1159 – 1163.

Butcher, B.M. 1996. Memo to M.S. Tierney, RE: QAP 9-1 Documentation of the Initial Waste Water Content for the CCA, January 29, 1996. WPO 30925.

Butcher, B.M., Thompson, T.W., VanBuskirk, R.G., and Patti, N.C. 1991. *Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste*. SAND90-1206. Sandia National Laboratories, Albuquerque, NM. WPO 23968.

Christian-Frear, G.L., and Webb, S.W. 1996. *The Effect of Explicit Representation of the Stratigraphy on Brine and Gas Flow at the Waste Isolation Pilot Plant*. SAND94-3173. Sandia National Laboratories, Albuquerque, NM.

Corbet, T.F. and Knupp, P.M. 1996. *The Role of Regional Groundwater Flow in the Hydrogeology of the Culebra Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND96-2133. Albuquerque, NM: Sandia National Laboratories.

Cranwell, R.M., Guzowski, R.V., Campbell, J.E., and Ortiz, N.R. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste: Scenario Selection Procedure.* NUREG/CR-1667, SAND80-1429. Sandia National Laboratories, Albuquerque, NM. WPO 26750.

Dale, T., and Hurtado, L.D. 1996. "WIPP Air-Intake Shaft Disturbed-Rock Zone Study," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17–18, 1996.* SAND96-1327C. Albuquerque, NM: Sandia National Laboratories.

Davies, P.B. 1991. *Evaluation of the Role of Threshold Pressure in Controlling Flow of Waste-Generated Gas into Bedded Salt at the Waste Isolation Pilot Plant.* SAND90-3246. Sandia National Laboratories, Albuquerque, NM, pp. 17 – 19. WPO 26169.

Dotson, L.J. 1996. *Non-Salado Initial Pressure*. Sandia National Laboratories, NM. WPO 30713.

Earth Technology Corporation. 1988. *Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site.* SAND87-7144. Albuquerque, NM: Sandia National Laboratories.

EPA (U.S. Environmental Protection Agency). 1985. "40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule." *Federal Register,* Vol. 50, No. 182, pp. 38066 – 38089, September 19, 1985. Office of Radiation and Air, Washington, D.C. WPO 39132.

EPA (U.S. Environmental Protection Agency). 1993. "40 CFR Part 191: Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule." *Federal Register,* Vol. 48, No. 242, pp. 66398 – 66416, December 20, 1993. Office of Radiation and Air, Washington, D.C. WPO 39133.

EPA (U.S. Environmental Protection Agency). 1996a. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule." *Federal Register*, Vol. 61, No. 28, pp. 5224 – 5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C. In NWM Library as KF70.A35.C751 1996 (Reference)

EPA (U.S. Environmental Protection Agency). 1996b. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document for 40 CFR Part 194.* EPA 402-R-96-002. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, DC.

Freeze, G.A., Larson, K.W., and Davies, P.B. 1995. *A Summary of Methods for Approximating Salt Creep and Disposal Room Closure in Numerical Models of Multiphase Flow.* SAND94-0251. Sandia National Laboratories, Albuquerque, NM. WPO 29557.

Goodwin, B.W., Stephens, M.E., Davison, C.C., Johnson, L.H., and Zach, R. 1994. *Scenario Analysis for the Postclosure Assessment of the Canadian Concept for Nuclear Fuel Waste Disposal*. AECL-10969, COG-94-247. Whiteshell Laboratories, Pinawa, Manitoba, Canada.

Hodgkinson, D.P. and Sumerling, T.J. 1989. "A Review of Approaches to Scenario Analysis for Repository Safety Assessment." In *Proceedings of the IAEA/CEC/NEA (OECD)*

Symposium on Safety Assessment of Radioactive Waste Repositories (Paris, 1989). OECD/NEA, Paris, France. pp. 333 – 350.

Holt, R.M., and Powers, D.W. 1984. *Geotechnical Activities in the Waste Handling Shaft Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico*. WTSD-TME-038. U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1986. *Geotechnical Activities in the Exhaust Shaft*. DOE/WIPP-86-008. U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant.* DOE/WIPP 90-051. Westinghouse Electric Corporation, Carlsbad, NM.

IAEA (International Atomic Energy Agency). 1981. *Safety Assessment for the Underground Disposal of Radioactive Wastes*. IAEA Safety Series No. 56, Vienna, Austria.

Iman, R.L., 1982. "Statistical Methods for Including Uncertainties Associated with the Geologic Isolation of Radioactive Waste Which Allow for a Comparison with Licensing Criteria," *Proceedings of the Symposium on Uncertainties Associated with the Regulation of the Geologic Disposal of High-Level Radioactive Waste*, *Gatlinsburg, Tennessee, March 9-13, 1981*, ed. D.C. Kocher. NUREG/CP-0022, CONF810372. Oak Ridge National Laboratory, Oak Ridge, Tennessee, 145-157. Available from NTIS. Order #: DE82008883.

Iman, R.L., and Conover, W.J. 1982. A Distribution-Free Approach to Inducing Rank Correlation Among Input Variables. *Communications in Statistics*: *Simulation and Computation*, Vol. B11, No. 3, pp. 311 – 334.

Kaplan, S., and Garrick, B.J. 1981. On the Quantitative Definition of Risk. *Risk Analysis*, Vol. 1, No. 1, pp. 11 – 27.

Lappin, A.R., Hunter, R.L., Garber, D.P., Davies, P.B., Beauheim, R.L., Borns, D.J., Brush, L.H., Butcher, B.M., Cauffman, T., Chu, M.S.Y., Gomez, L.S., Guzowski, R.V., Iuzzolino, H.J., Kelley, V., Lambert, S.J., Marietta, M.G., Mercer, J.W., Nowak, E.J., Pickens, J., Rechard, R.P., Reeves, M., Robinson, K.L., and Siegel, M.D., eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico: March 1989.* SAND89-0462. Sandia National Laboratories, Albuquerque, NM. WPO 24125.

Luker, R.S., Thompson, T.W., and Butcher, B.M. 1991. "Compaction and Permeability of Simulated Waste." In *Rock Mechanics as a Multidisciplinary Science: Proceedings of the 32nd U.S. Symposium, University of Oklahoma, Norman, OK, July 10-12, 1991*, J.C. Roegiers, ed. SAND90-2368C, pp. 694 – 702. A.A. Balkema, Brookfield, VT. WPO 38847.

Mercer, J.W., and Orr, B.R. 1979. *Interim Data Report on Geohydrology of Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico*. Water Resources Investigations 79-98. U.S. Geological Survey, Albuquerque, NM.

Miller, W.M. and Chapman, N.A., Ed. 1992. *Identification of Relevant Processes, System Concept Group Report,* UKDOE/HMIP Report TR-ZI-11, London, England.

NAGRA. 1985. *Nuclear Waste Management in Switzerland: Feasibility Studies and Safety Analyses (Project Gewahr, 1985)*. NAGRA Project Report NGB 85-09 (English Summary), Wettingen, Switzerland.

OECD Nuclear Energy Agency. 1992. *Systematic Approaches to Scenario Development.* Organisation for Economic Co-Operation and Development, Paris, France. NWM Library, NNA.920610.0027.

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. *Brine Reservoirs in the Castile Formation Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico.* TME-3153, Vols. 1 and 2. Westinghouse Electric Corp, Carlsbad, NM.

Sandia National Laboratories. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume. 1: Methodology and Results.* SAND91-0893/1. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM. WPO 26404.

Sandia National Laboratories. 1992-1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992.* SAND92-0700, Vols. 1 – 5. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM. Vol. 1 - WPO 20762, Vol. 2 - WPO 20805, Vol. 3 - WPO 23529, Vol. 4 - WPO 20958, Vol. 5 - WPO 20929.

State of New Mexico, Oil Conservation Division, Energy, Minerals, and Natural Resources Department. 1988. "Application of the Oil Conservation Division Upon It's Own Motion to Revise Order R-111. As Amended. Pertaining to the Potash Areas of Eddy and Lea Counties, New Mexico." Case 9316, Revision to Order R-111-P, April 21, 1988. Santa Fe, NM. On file in the NWM Library as KFN2581.

Stenhouse, M.J., Chapman, N.A., and Sumerling, T.J. 1993. *SITE-94 Scenario Development FEP Audit List Preparation: Methodology and Presentation*. SKI Technical Report 93:27. Swedish Nuclear Power Inspectorate, Stockholm. Available from NTIS as DE 94621513.

Thorne, M.C. 1992. *Dry Run 3 - A Trial Assessment of Underground Disposal of Radioactive Wastes Based on Probabilistic Risk Analysis - Volume 8: Uncertainty and Bias Audit.* United Kingdom Department of Environment Report DOE/HMIP/RR/92.040, London, England.

Van Pelt, R.S. November 20, 1995. "Permeability Estimates of MGFT08 and MGFT09." SNL Technical Memorandum to M.K. Knowles. Contained in SWCF Record Package, "Small-Scale Seals Performance Test: Series A Post-Mortem," WPO 39631.

Vaughn, P., Bean, J., Garner, J., Lord, M., MacKinnon, R., McArthur, D., Schreiber, J., and Shinta, A.. 1995. FEPs Screening Analysis DR2, DR3, DR6, DR7, and S6. Record package submitted to SWCF-A:1.1.6.3:PA:QA:TSK:DR2, DR3, DR6, DR7, and S6. Sandia National Laboratories, Albuquerque, NM. WPO 38152.

Wallace, M.G., Beauheim, R., Stockman, C., Martell, M.A., Brinster, K., Wilmot, R., and Corbet, T. 1995. FEPs Screening Analysis, NS-1: Dewey Lake Data Collection and Compilation. Record package submitted to SWCF-A:1.1.6.3:PA:QA:TSK:NS1. Sandia National Laboratories, Albuquerque, NM. WPO 30650.

Wang, Y., and Brush, L.H. January 26, 1996. "Estimates of Gas Generation Parameters for the Long-Term WIPP Performance Assessment." WPO 31943.

BIBLIOGRAPHY

Adams, J.E. 1944. Upper Permian Ochoa Series of Delaware Basin, West Texas and Southeastern New Mexico. *American Association of Petroleum Geologists Bulletin,* Vol. 28, No. 11, pp. 1596 – 1625. WPO 37940.

Anderson, R.Y. 1978. *Deep Dissolution of Salt, Northern Delaware Basin, New Mexico.* Sandia National Laboratories, Albuquerque, NM. WPO 29527 - WPO 29530.

Anderson, R.Y., and Kirkland, D.W. 1980. Dissolution of Salt Deposits by Brine Density Flow. *Geology*, Vol. 8, No. 2, pp. 66 – 69.

Anderson, R.Y., Dean, Jr., W.E., Kirkland, D.W., and Snider, H.I. 1972. Permian Castile Varved Evaporite Sequence, West Texas and New Mexico. *Geological Society of America Bulletin*, Vol. 83, No. 1, pp. 59 – 85.

Argüello, J.G., Molecke, M.A., and Beraun, R. 1989. "3D Thermal Stress Analysis of WIPP T RH TRU Experiments." *Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Proceedings of the 30th U.S. Rock Mechanics Symposium, West Virginia University, Morgantown, WV, June 19-22, 1989*, A.W. Khair, Ed. SAND88-2734C, pp. 681 – 688. A.A. Balkema, Brookfield, VT. WPO 25724.

Bachman, G.O. 1973. *Surficial Features and Late Cenozoic History in Southeastern New Mexico*. Open-File Report 4339-8. U.S. Geological Survey, Reston, VA.

Bachman, G.O. 1974. *Geologic Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico*. Open-File Report 74-194. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1976. Cenozoic Deposits of Southeastern New Mexico and an Outline of the History of Evaporite Dissolution. *Journal of Research*, Vol. 4, No. 2, pp. 135 – 149. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1980. *Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico.* Open-File Report 80-1099. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1981. *Geology of Nash Draw, Eddy County, New Mexico*. Open-File Report 81-31. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1984. *Regional Geology of Ochoan Evaporites, Northern Part of Delaware Basin*. Circular 184, pp. 1 – 22. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Bachman, G.O. 1985. *Assessment of Near-Surface Dissolution at and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND84-7178. Sandia National Laboratories, Albuquerque, NM. WPO 24609.

Bachman, G.O. 1987. *Karst in Evaporites in Southeastern New Mexico.* SAND86-7078. Sandia National Laboratories, Albuquerque, NM. WPO 24006.

Bachman, G.O., Johnson, R.B., and Swenson, F.A. 1973. *Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico.* Open-File Report 4339-4. U.S. Geological Survey, Denver, CO.

Baes, C.F., Jr., and Mesmer, R.E. 1976. *The Hydrolysis of Cations.* John Wiley & Sons, New York, NY.

Barker, D.S. 1977. Northern Trans-Pecos Magmatic Province: Introduction and Comparison with the Kenya Rift. *Geological Society of America Bulletin*, Vol. 88, No. 10, pp. 1421 – 1427.

Bear, J. 1988. *Dynamics of Fluids in Porous Media*. Dover Publications, Inc., New York, NY. NNA. 911127.0046.

Bear, J., and Verruijt, A. 1987. *Modeling Groundwater Flow and Pollution.* D. Reidel Publishing Company, Boston, MA. NNA. 900212.0003.

Bear, J., Tsang, C.F., and de Marsily, G. 1993. *Flow and Contaminant Transport in Fractured Rock*. Academic Press, Inc., San Diego, CA.

Beauheim, R.L. 1986. *Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-1364. Sandia National Laboratories, Albuquerque, NM. WPO 27656.

Beauheim, R.L. 1987. *Interpretation of WIPP-13 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site.* SAND87-2456. Sandia National Laboratories, Albuquerque, NM. WPO 28512.

Beauheim, R.L. 1987. *Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-2311. Sandia National Laboratories, Albuquerque, NM. WPO 28468.

Beauheim, R.L., and Holt, R.M. 1990. "Hydrogeology of the WIPP Site." In *Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico.* Field Trip #14 Guidebook, Geologic Society of America 1990 Annual Meeting, Dallas, TX, October 19 - November 1, 1990, pp. 131 – 179. D.W. Powers, R.M. Holt, R.L. Beauheim, and N. Rempe, leaders. SAND90-2035J. Dallas Geologic Society, Dallas, TX. WPO 29377.

Beauheim, R.L., Hassinger, B.W., and Klaiber, J.A. 1983. *Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* WTSD-TME-020. U.S. Department of Energy, Albuquerque, NM.

Beauheim, R.L., Dale, T.F., and Pickens, J.F. 1991. *Interpretations of Single-Well Hydraulic Tests of the Rustler Formation Conducted in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, 1988-1989.* SAND89-0869. Sandia National Laboratories, Albuquerque, NM. WPO 25862.

Beauheim, R.L., Saulnier, Jr., G.J., and Avis, J.D. 1991. *Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report*. SAND90-0083. Sandia National Laboratories, Albuquerque, NM. WPO 26003.

Bechtel National. 1985. *Quarterly Geotechnical Field Data Report*. DOE/WIPP-221. U.S. Department of Energy, Carlsbad, NM.

Bell, J.T., Coleman, C.F., Costanzo, D.A., and Biggers, R.E. 1973. Plutonium Polymerization–III. The Nitrate Precipitation of Pu(IV) Polymer. *Journal of Inorganic and Nuclear Chemistry*, Vol. 35, No. 2, pp. 629 – 632.

Bell, J.T., Costanzo, D.A., and Biggers, R.E. 1973. Plutonium Polymerization–II. Kinetics of the Plutonium Polymerization. *Journal of Inorganic and Nuclear Chemistry*, Vol. 35, No. 2, pp. 623 – 628.

Bellin, A., Salandin, P., and Rinaldo, A. 1992. Simulation of Dispersion in Heterogeneous Porous Formations: Statistics, First-Order Theories, Convergence of Computations. *Water Resources Research*, Vol. 28, No. 9, pp. 2211 – 2228.

Berger, A. 1988. Milankovitch Theory and Climate. *Reviews of Geophysics*, Vol. 26, No. 4, pp. 624 – 657.

Bertram-Howery, S.G., and Hunter, R.L. Eds. 1989. *Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant*. SAND89-0178. Sandia National Laboratories, Albuquerque, NM. WPO 24103.

Bertram-Howery, S.G., Marietta, M.G., Rechard, R.P., Swift, P.N., Anderson, D.R., Baker, B.L., Bean, Jr., J.E., Beyeler, W., Brinster, K.F., Guzowski, R.V., Helton, J.C., McCurley, R.D., Rudeen, D.K., Schreiber, J.D., and Vaughn, P. 1990. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990.* SAND90-2347. Sandia National Laboratories, Albuquerque, NM. WPO 27796.

Bird, R.B., Stewart, W.E., and Lightfoot, E.N. 1960. *Transport Phenomena*. John Wiley & Sons, New York, NY. NNA. 900919.0195.

Borns, D.J. 1985. *Marker Bed 139: Study of Drillcore From A Systematic Array.* SAND85-0023. Sandia National Laboratories, Albuquerque, NM. WPO 24529.

Borns, D.J., and Shaffer, S.E. 1985. *Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin*. SAND83-1798. Sandia National Laboratories, Albuquerque, NM. WPO 24511.

Borns, D.J., and Stormont, J.C. 1988. *An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone.* SAND87-1375. Sandia National Laboratories, Albuquerque, NM. WPO 24694.

Borns, D.J., and Stormont, J.C. 1989. "The Delineation of the Disturbed Rock Zone Surrounding Excavations in Salt." In *Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Proceedings of the 30th U.S. Symposium, Morgantown, WV, June 19-22, 1989*, A.W. Khair, ed., pp. 353 – 360. SAND88-2230C. A.A. Balkema, Brookfield, VT. WPO 29974.

Borns, D.J., Pfeifer, M.C., Andersen, H.T., and Skokan, C.K. 1990. "Electrical Methods to Delineate Fluid Flow In Situ in Bedded Salt." In *Society of Exploration Geophysicists Workshop on Permeability, Fluid Pressure and Pressure Seals in the Crust, Denver, CO, August 5-8, 1990*. SAND90-1685A. Sandia National Laboratories, Albuquerque, NM. WPO 28590.

Bredehoeft, J.D., Riley, F.S., and Roeloffs, E.A. 1987. Earthquakes and Groundwater. *Earthquakes and Volcanoes*, Vol. 19, No. 4, pp. 138 – 146.

Brush, L.H., and Anderson, D.R. 1989. "Appendix E: Estimates of Gas Production Rates, Potentials, and Periods, and Dissolved Radionuclide Concentrations for the WIPP Supplemental Environmental Impact Statement." In *Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance With EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant*. M.G. Marietta, S.G. Bertram-Howery, D.R. Anderson, K.F. Brinster, R.V. Guzowski, H. Iuzzolino, and R.P. Rechard, eds. SAND89-2027. Sandia National Laboratories, Albuquerque, NM. pp. E-1 through E-14. In Appendix E of WPO 25952.

Buddemeier, R.W., and Hunt, J.R. 1988. Transport of Colloidal Contaminants in Groundwater: Radionuclide Migration at the Nevada Test Site. *Applied Geochemistry*, Vol. 3, No. 5, pp. 535 – 548.

Burton, P.L., Adams, J.W., and Engwall, C. 1993. "History of the Washington Ranch, Eddy County, New Mexico." In *Carlsbad Region, New Mexico and West Texas.* D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.W. Austin, and J.M. Barker, eds. Forty-Fourth Annual Conference, October 6–9, 1993, pp. 65 – 67. New Mexico Geological Society, Roswell, NM.

Cauffmann, T.L., LaVenue, A.M., and McCord, J.P. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume II: Data Base*. SAND89-7068/2. Sandia National Laboratories, Albuquerque, NM. WPO 10551.

Chapman, J.B. 1986. *Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area*. EEG-35, DOE/AL/10752-35. Environmental Evaluation Group, Santa Fe, NM.

Chappell, J., and Shackleton, N.J. 1986. Oxygen Isotopes and Sea Level. *Nature*, Vol. 324, No. 6093, pp. 137 – 140.

Chaturvedi, L. 1993. "WIPP-Related Geological Issues." In *Carlsbad Region, New Mexico and West Texas*, D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.S. Austin, and J.M. Barker, eds. Forty-Fourth Annual Field Conference, October 6–9, 1993, pp. 331 – 338. New Mexico Geological Society, Roswell, NM.

Choppin, G.R. 1988. Humics and Radionuclide Migration. *Radiochimica Acta*, Vols. 44/45, Pt. 1, pp. 23 – 28.

Chugg, J.C., Anderson, G.W., King, D.L., and Jones, L.H. 1952. *Soil Survey of Eddy Area, New Mexico*. U.S. Department of Agriculture, Washington, D.C.

Coats, K.H. 1989. "Implicit Compositional Simulation of Single-Porosity and Dual-Porosity Reservoirs." In *Proceedings, Tenth SPE Symposium on Reservoir Simulation, Houston, TX, February 6–8, 1989*. SPE 18427, pp. 239 – 275. Society of Petroleum Engineers, Richardson, TX.

Cooper, J.B., and Glanzman, V.M. 1971. *Geohydrology of Project Gnome Site, Eddy County, New Mexico*. United States Geological Survey Professional Paper 712-A. U.S. Geological Survey, Washington, D.C.

Corbet, T.F., and Wallace, M.G. 1993. "Post-Pleistocene Patterns of Shallow Groundwater Flow in the Delaware Basin, Southeastern New Mexico and West Texas." In *Carlsbad Region, New Mexico and West Texas*, D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.S. Austin, and J.M. Barker, eds. Forty-Fourth Annual Field Conference, October 6–9, 1993, SAND93-1318J, pp. 321 – 351. New Mexico Geological Society, Roswell, NM. WPO 28643.

Cranwell, R.M., Campbell, J.E., Helton, J.C., Iman, R.L., Longsine, D.E., Ortiz, N.R., Runkle, G.E., and Shortencarier, M.J. 1987. *Risk Methodology for Geologic Disposal of Radioactive Waste: Final Report*. NUREG/CR-2452, SAND81-2573. Sandia National Laboratories, Albuquerque, NM. WPO 28296.

Davies, P.B. 1983. "Assessing the Potential for Deep-Seated Salt Dissolution and the Subsidence at the Waste Isolation Pilot Plant (WIPP)." In *State of New Mexico*

Environmental Evaluation Group Conference, WIPP Site Suitability for Radioactive Waste Disposal, Carlsbad, NM, May 12–13, 1983. (Copy on file at the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM as WPO 29533.)

Davies, P.B. 1989. *Variable-Density Ground-Water Flow and Paleohydrology in the Waste Isolation Pilot Plant (WIPP) Region, Southeastern New Mexico*. Open-File Report 88-490. U.S. Geological Survey, Albuquerque, NM. WPO 38854.

Dearlove, J.P.L., Longworth, G., Ivanovich, M., Kim, J.I., Delakowitz, B., and Zeh, P. 1990. "Organic Colloid Transport of Radionuclides at Gorleben, West Germany." In *Proceedings of the Symposium on Waste Management, Tucson, AZ, February 25–March 1, 1990.* R.G. Post, ed., Vol. 2, pp. 565 – 569. University of Arizona, Tucson, AZ.

Doctor, P.G., Liebetrau, A.M., Eslinger, P.W., Reimus, P.W., Elwood, D.M., Strenge, D.L., Engel, D.W., Tanner, J.E., and Freshley, M.D. 1992. *An Example Postclosure Risk Assessment Using the Potential Yucca Mountain Site.* PNL-8081. Pacific Northwest Laboratory, Richland, WA. NNA. 930414.0031.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026, Vols. 1 and 2. U.S. Department of Energy, Washington, D.C. WPO 38835, WPO 38838 - WPO 38839.

DOE (U.S. Department of Energy). 1990. *Final Safety Analysis Report*. WP 02-9, Rev. 0, May 1990. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

DOE (U.S. Department of Energy). 1990. *WIPP Test Phase Plan: Performance Assessment.* DOE/WIPP-89-011, Rev. 0. U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U.S. Department of Energy). 1991. *Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force.* DOE/WIPP 91-007, Rev. 0. Vols. 1 and 2. Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U.S. Department of Energy). 1991. *Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics.* DOE/RW-0006, Rev. 7. Oak Ridge National Laboratory, Oak Ridge, TN. HQX. 910711.0004.

DOE (U.S. Department of Energy). 1994. *Compliance Status Report for the Waste Isolation Pilot Plant*. DOE/WIPP 94-019, Rev. 0. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1994. *Experimental Program Plan for the Waste Isolation Pilot Plant*. DOE/WIPP 94-008, Rev. 0. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1994. *Compliance Status Report for the Waste Isolation Pilot Plant*. DOE/WIPP 94-019, Rev. 0. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995. *U.S. Department of Energy Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report*. DOE/CAO-94-1005, Rev. 1, Vols. 1-2. WIPP Technical Assistance Contractor for U.S. Department of Energy, Carlsbad, NM.

Dowding, C.H., and Rozen, A. 1978. Damage to Rock Tunnels from Earthquake Shaking. *Journal of the Geotechnical Engineering Division, American Society of Civil Engineers*, Vol. 104, No. GT2, pp. 175 – 191.

Eager, G.P. 1983. Cores from the Lower Dewey Lake, Rustler, and Upper Salado Formation, Culberson County, Texas. *Permian Basin Cores*. R.L. Shaw and B.J. Pollan, eds. P.B.S.-S.E.P.M. Core Workshop, Vol. 2, pp. 273 – 283. Permian Basin Section, Society of Economic Paleontologists and Mineralogists, Midland, TX.

EPA (U.S. Environmental Protection Agency). 1996. *40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule*. *Response to Comments Document for 40 CFR Part 194*. EPA 402-R-96-001. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

Francis, A.J., and Gillow, J.B. 1994. *Effects of Microbial Processes on Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions*. SAND93-7036. Sandia National Laboratories, Albuquerque, NM. WPO 26555.

Freeland, M.H. 1982. *Basic Data Report for Borehole DOE-1, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico*. TME 3159. U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM.

Freeze, R.A., and Cherry, J.A. 1979. *Groundwater*. Prentice-Hall, Englewood Cliffs, NJ. NNA. 870406.0444.

Galson, D.A., Hicks, T.W., Wilmot, R.D., and Swift, P.N. 1995. *Systems Prioritization Method—Iteration 2 Baseline Position Paper: Scenario Development for Long-Term Performance Assessments of the WIPP*. Sandia National Laboratories, Albuquerque, NM. WPO 28726.

Gonzales, M.M. 1989. *Compilation and Comparison of Test-Hole Location Surveys in the Vicinity of the Waste Isolation Pilot Plant Site*. SAND88-1065. Sandia National Laboratories, Albuquerque, NM. WPO 24121.

Griswold, G.B. 1977. *Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM*. SAND77-0946. Sandia National Laboratories, Albuquerque, NM. WPO 28125.

Hays, J.D., Imbrie, J., and Shackleton, N.J. 1976. Variations in the Earth's Orbit: Pacemaker of the Ice Ages. *Science*, Vol. 194, No. 4270, pp. 1121 – 1132. HQS.880517.2140.

Helton, J.C., Garner, J.W., McCurley, R.D., and Rudeen, D.K. 1991. *Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant.* SAND90-7103. Sandia National Laboratories, Albuquerque, NM. WPO 23803.

Helton, J.C., Garner, J.W., Rechard, R.P., Rudeen, D.K., and Swift, P.N. 1992. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 4: Uncertainty and Sensitivity Analysis Results*. SAND91-0893/4. Sandia National Laboratories, Albuquerque, NM. WPO 26423.

Helton, J.C., Marietta, M.G., and Rechard, R.P. 1993. *Conceptual Structure of Performance Assessments Conducted for the Waste Isolation Pilot Plant*. SAND92-2285. Sandia National Laboratories, Albuquerque, NM. WPO 27834.

Hiemenz, P.C. 1986. *Principles of Colloid and Surface Chemistry*. 2nd ed. Marcel Dekker, Inc., New York, NY.

Hill, A.C., and Thomas, G.W. 1985. "A New Approach for Simulating Complex Fractured Reservoirs." In *Proceedings, Eighth SPE Symposium on Reservoir Simulation, Dallas, TX, February 10-13, 1985*, L.C. Young, ed. SPE 13537, pp. 429 – 440. Society of Petroleum Engineers of AIME, Richardson, TX.

Hills, J.M., and Kottlowski, F.E. 1983. *Southwest/Southwest Mid-Continent Region: Correlation of Stratigraphic Units of North America (COSUNA) Project*. Correlation Chart Series 1983. AAPG Bookstore, Tulsa, OK.

Holcomb, D.J. 1988. "Cross-Hole Measurements of Velocity and Attenuation to Detect a Disturbed Zone in Salt at the Waste Isolation Pilot Plant." In *Key Questions in Rock Mechanics: Proceedings of the 29th U.S. Symposium, University of Minnesota, Minneapolis, MN, June 13-15, 1988*, P.A. Cundall, R.L. Sterling, and A.M. Starfield, eds. SAND87-3016C, pp. 633 – 640. A.A. Balkema, Brookfield, VT. WPO 29992.

Hora, S.C. 1992. "Appendix A: Probabilities of Human Intrusion into the WIPP, Methodology for the 1992 Preliminary Comparison." In *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters.* SAND92-0700/3. Sandia National Laboratories, Albuquerque, NM. In Appendix A of WPO 23529, pp. A-69 through A-99.

Hora, S.C., von Winterfeldt, D., and Trauth, K.M. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Sandia National Laboratories, Albuquerque, NM. WPO 26161.

Houghton, J.T., Jenkins, G.J., and Ephraums, J.J. 1990. *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, New York, NY.

Howard, C.L., Jensen, A.L., Jones, R.L., and Peterson, T.P. 1993. *Room Q Data Report: Test Borehole Data from April 1989 through November 1991*. SAND92-1172. Sandia National Laboratories, Albuquerque, NM. WPO 23548.

Hunter, R.L. 1985. *A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area*. SAND84-2233. Sandia National Laboratories, Albuquerque, NM. WPO 27628.

Hunter, R.L., Cranwell, R.M., and Chu, M.S.Y. 1986. *Assessing Compliance with the EPA High-Level Waste Standard: An Overview.* SAND86-0121, NUREG/CR-4510. Sandia National Laboratories, Albuquerque, NM. WPO 28435.

IAEA (International Atomic Energy Agency). 1989. *Evaluating the Reliability of Predictions Made Using Environmental Transfer Models*. Safety Series Report No. 100. International Atomic Energy Agency, Vienna.

Imbrie, J. 1985. A Theoretical Framework for the Pleistocene Ice Ages. *Journal of the Geological Society*, Vol. 142, Pt. 3, pp. 417 – 432.

Imbrie, J., and Imbrie, J.Z. 1980. Modeling the Climatic Response to Orbital Variations. *Science*, Vol. 207, No. 4434, pp. 943 – 953.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., and Shackleton, J.J. 1984. "The Orbital Theory of Pleistocene Climate: Support from a Revised Chronology of the Marine $\delta^{18}O$ Record." In *Milankovitch and Climate, Understanding the Response to Astronomical Forcing, Proceedings of the NATO Advanced Research Workshop on Milankovitch and Climate, Palisades, NY, November 30-December 4, 1982,* A. Berger, J. Imbrie, J. Hays, G. Kukla, and B. Saltzman, eds., Pt. 1, pp. 269 – 305. D. Reidel, Boston, MA.

Imbrie, J., McIntyre, A., and Mix, A. 1989. Oceanic Response to Orbital Forcing in the Late Quaternary: Observational and Experimental Strategies. *Climate and Geo-sciences*, A. Berger, S. Schneider, and J.C. Duplessy, eds., pp. 121 – 164. Kluwer, Boston, MA.

Izett, G.A., and Wilcox, R.E. 1982. *Map Showing Localities and Inferred Distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds in the Western United States and Southern Canada*. Misc. Investigations Map I-1325, Scale 1:4,000,000. U.S. Geological Survey.

Jones, C.L. 1978. *Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico*. Open-File Report 78-592, Vols. 1 and 2. U.S. Geological Survey, Denver, CO.

Jones, T.L., Kelley, V.A., Pickens, J.F., Upton, D.T., Beauheim, R.L., and Davies, P.B. 1992. *Integration of the Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site.* SAND92-1579. Sandia National Laboratories, Albuquerque, NM. WPO 23504.

Jung, Y., Ibrahim, A., and Borns, D.J. 1991. Mapping Fracture Zones in Salt; High-Resolution, Cross-Gallery Seismic Tomography. *Geophysics: The Leading Edge of Exploration*, Vol. 10, No. 4, pp. 37 – 39.

Kazemi, H., Merrill, Jr., L.S., Porterfield, K.L., and Zeman, P.R. 1976. Numerical Simulation of Water-Oil Flow in Naturally Fractured Reservoirs. *Society of Petroleum Engineers Journal*, Vol. 16, No. 6, pp. 317 – 326.

Kelley, V.A., and Saulnier, Jr., G.J. 1990. *Core Analyses for Selected Samples from the Culebra Dolomite at the Waste Isolation Pilot Plant Site*. SAND90-7011. Sandia National Laboratories, Albuquerque, NM, pp. 4-10. WPO 28629.

Kim, J.I. 1991. Actinide Colloid Generation in Groundwater. *Radiochimica Acta*, Vol. 52/53, Pt. 1, pp. 71 – 81.

Lambert, S.J. 1983. *Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas.* SAND82-0461. Sandia National Laboratories, Albuquerque, NM. WPO 27520.

Lambert, S.J. 1987. "Stable-Isotope Studies of Groundwaters in Southeastern New Mexico." In *The Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler Formation as it Relates to the WIPP Project*, L. Chaturvedi, ed. SAND85-1978C, EEG-34, pp. 36 – 57. Environmental Evaluation Group, Santa Fe, NM. WPO 28418.

Lenhardt, W.A. 1988. "Damage Studies at a Deep Level African Gold Mine." In *Rockbursts & Seismicity In Mines, Proceedings of the Second International Symposium, Minneapolis, MN, June 8-10, 1988,* C. Fairhurst, ed., 1990, pp. 391 – 393. A.A. Balkema, Brookfield, VT.

Lieser, K.H., Gleitsmann, B., and Steinkopff, T. 1986. Sorption of Trace Elements or Radionuclides in Natural Systems Containing Groundwater and Sediments. *Radiochimica Acta*, Vol. 40, No. 1, pp. 33 – 37.

Lieser, K.H., Gleitsmann, B., Peschke, S., and Steinkopff, T. 1986. Colloid Formation and Sorption of Radionuclides in Natural Systems. *Radiochimica Acta*, Vol. 40, No. 1, pp. 39 – 47.

Lieser, K.H., Ament, A., Hill, R., Singh, R.N., Stingl, U., and Thybusch, B. 1990. Colloids in Groundwater and Their Influence on Migration of Trace Elements and Radionuclides. *Radiochimica Acta*, Vol. 49, No. 2, pp. 83 – 100.

Litvak, B.L. 1986. "Simulation and Characterization of Naturally Fractured Reservoirs." In *Reservoir Characterization Technical Conference, Dallas, TX, April 29-May 1, 1985*, L.W. Lake and H.B. Carroll, Jr., eds., pp. 561 – 584. Academic Press, Orlando, FL.

Lowenstein, T.K. 1987. *Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico: Textural, Stratigraphic and Chemical Evidence*. EEG-36, DOE/AL/10752-36. Environmental Evaluation Group, Santa Fe, NM.

Lowenstein, T.K. 1988. Origin of Depositional Cycles in a Permian "Saline Giant": The Salado (McNutt Zone) Evaporites of New Mexico and Texas. *Geological Society of America Bulletin*, Vol. 100, No. 4, pp. 592 – 608.

Lyklema, J. 1978. Surface Chemistry of Colloids in Connection with Stability. *The Scientific Basis of Flocculation*, K.J. Ives, ed., pp. 3 – 36. Sijthoff and Noordhoff, Dordrecht.

Lyon, M.L. 1989. *Annual Water Quality Data Report for the Waste Isolation Pilot Plant*. DOE/WIPP 89-001. Westinghouse Electric Corporation, Carlsbad, NM.

Machette, M.N. 1985. "Calcic Soils of the Southwestern United States." In *Soils and Quaternary Geology of the Southwestern United States,* D.L. Weide and M.L. Faber, eds. Special Paper Vol. 203, pp. 1 – 21. Geological Society of America, Denver, CO.

Maiti, T.C., Smith, M.R., and Laul, J.C. 1989. Colloid Formation Study of U, Th, Ra, Pb, Po, Sr, Rb, and Cs in Briny (High Ionic Strength) Groundwaters: Analog Study for Waste Disposal. *Nuclear Technology*, Vol. 84, No. 1, pp. 82 – 87.

Mansure, A., and Reiter, M. 1977. *An Accurate Equilibrium Temperature Log in AEC No. 8, A Drill Test in the Vicinity of the Proposed Carlsbad Disposal Site*. Open File Report 80. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM. WPO 21200.

Marietta, M.G., Bertram-Howery, S.G., Anderson, D.R., Brinster, K.F., Guzowski, R.V., Izzulino, H., and Rechard, R.P. 1989. *Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant.* SAND89-2027. Sandia National Laboratories, Albuquerque, NM. WPO 25952.

McGrath, E.J., and Irving, D.C. 1975. *Techniques for Efficient Monte Carlo Simulation. Volume III. Variance Reduction*. ORNL-RSIC-38, Vol. 3. Oak Ridge National Laboratory, Oak Ridge, TN.

McGrath, E.J., and Irving, D.C. 1975. *Techniques for Efficient Monte Carlo Simulation. Volume II. Random Number Generation for Selected Probability Distributions.* ORNL-RSIC-38, Vol. 2. Oak Ridge National Laboratory, Oak Ridge, TN.

McGrath, E.J., Basin, S.L., Burton, R.W., Irving, D.C., and Jaquette, S.C. 1975. *Techniques for Efficient Monte Carlo Simulation*. *Volume I. Selecting Probability Distribution*s. ORNL-RSIC-38, Vol. 1. Oak Ridge National Laboratory, Oak Ridge, TN.

McKay, M.D., Beckman, R.J., and Conover, W.J. 1979. A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code. *Technometrics*, Vol. 21, No. 2, pp. 239 – 245.

Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area, Southeastern New Mexico*. Water Resources Investigations Report 83-4016. U.S. Geological Survey, Albuquerque, NM. (This document is included as Appendix HYDRO.)

Mercer, J.W., and Snyder, R.P. 1990. *Basic Data Report for Drillholes at the H-11 Complex (Waste Isolation Pilot Plant—WIPP)*. SAND89-0200. Sandia National Laboratories, Albuquerque, NM. WPO 27705.

Mercer, J.W., Beauheim, R.L., Snyder, R.P., and Fairer, G.M. 1987. *Basic Data Report for Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site*. SAND86-0611. Sandia National Laboratories, Albuquerque, NM. WPO 27646.

Mitchell, J.F.B. 1989. The "Greenhouse" Effect and Climate Change. *Reviews of Geophysics*, Vol. 27, No. 1, pp. 115 – 139.

Molecke, M.A., Argüello, J.G., and Beraún, R. 1993. *Waste Isolation Pilot Plant Simulated RH TRU Waste Experiments: Data and Interpretation Report*. SAND88-1314. Sandia National Laboratories, Albuquerque, NM. WPO 24906.

Muehlberger, W.R., Belcher, R.C., and Goetz, L.K. 1978. Quaternary Faulting on Trans-Pecos, Texas. *Geology*, Vol. 6, No. 6, pp. 337 – 340.

Myers, J., Drez, P., and James, P. 1991. "Chapter 6: The Redox State and the Occurrence and Influence of Organics in the Culebra." In *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico*. M.D. Siegel, S.J. Lambert, and K.L. Robinson, eds. SAND88-0196. Sandia National Laboratories, Albuquerque, NM. In WPO 25624 (Chapter 6) pp. 6-1 throgh 6-35.

Nicholson, Jr., A., and Clebsch, Jr., A. 1961. *Geology and Ground-Water Conditions in Southern Lea County, New Mexico.* Ground-Water Report 6. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Nowak, E.J., Tillerson, J.R., and Torres, T.M. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant.* SAND90-0355. Sandia National Laboratories, Albuquerque, NM. WPO 23981.

OECD Nuclear Energy Agency. 1995. *Future Human Actions at Disposal Sites, A Report of the NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites*. Organisation for Economic Co-Operation and Development, Paris, France.

Parry, G.W. 1988. On the Meaning of Probability in Probabilistic Safety Assessment. *Reliability Engineering and System Safety*, Vol. 23, No. 4, pp. 309 – 314.

Paté-Cornell, M.E. 1986. Probability and Uncertainty in Nuclear Safety Decisions. *Nuclear Engineering and Design*, Vol. 93, No. 2-3, pp. 319 – 327.

Pfeifer, M.C., Borns, D.J., Skokan, C.K., Andersen, H.T., and Starrett, J.M. 1989. "Geophysical Methods to Monitor the Development of the Disturbed Rock Zone Around Underground Excavations in Bedded Salt." In *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, Golden, CO, March 13–16, 1989*. SAND89-7055A, Vol. 2, pp. 400 – 411. WPO 29630.

Powers, D.W., and Holt, R.M. 1990. "Sedimentology of the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) Site." In *Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico.* Field Trip #14 Guidebook, Geological Society of America 1990 Annual Meeting, October 29–November 1, 1990, pp. 79 – 106. Dallas Geological Society, Dallas, TX.

Powers, D.W., and Holt, R.M. 1993. "The Upper Cenozoic Gatuna Formation of Southeastern New Mexico." In *Carlsbad Region, New Mexico and West Texas,* D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.S. Austin, and J.M. Barker, eds. Forty-Fourth Annual Field Conference, October 6–9, 1993, pp. 271 – 282. New Mexico Geological Society, Socorro, NM.

Powers, D.W., Lambert, S.J., Shaffer, S-E., Hill, L.R., and Weart, W.D., eds. 1978. *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico*. SAND78-1596, Volumes I and II. Sandia National Laboratories, Albuquerque, NM. (This document is included as Appendix GCR.) Vol. 1 - WPO 5448, Vol. 2 - WPO 26829 - WPO 26830.

Rechard, R.P. 1989. *Review and Discussion of Code Linkage and Data Flow in Nuclear Waste Compliance Assessments.* SAND87-2833. Sandia National Laboratories, Albuquerque, NM. WPO 25675.

Rechard, R.P., ed. 1992. *User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller Version 3.0.* SAND90-1983. Sandia National Laboratories, Albuquerque, NM. WPO 25628.

Richey, S.F. 1987. *Water-Level Data from Wells in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico*. Open-File Report 87-120. United States Geological Survey, Albuquerque, NM.

Robinson, J.Q., and Powers, D.W. 1987. "A Clastic Deposit Within the Lower Castile Formation, Western Delaware Basin, New Mexico." In *Geology of the Western Delaware Basin, West Texas and Southeastern New Mexico*, D.W. Powers and W.C. James, eds. El Paso Geological Society Guidebook 18, pp. 69 – 79. El Paso Geological Society, El Paso, TX. WPO 37942.

Robinson, T.W., and Lang, W.B. 1938. *Geology and Groundwater Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal, New Mexico, with Special Reference to the Salt Content of the River Water*. Twelfth and Thirteenth Biennial Reports of the State Engineer of New Mexico for the 23rd, 24th, 25th, and 26th Fiscal Years, July 1, 1935 to July 30, 1938. State Engineer, Santa Fe, NM. WPO 37942.

Rosholt, J.N., and McKinney, C.R. 1980. *Uranium Series Disequilibrium Investigations Related to the WIPP Site, New Mexico (USA). Part II. Uranium Trend Dating of Surficial Deposits and Gypsum Spring Deposits Near WIPP Site, New Mexico*. Open-File Report 80-879. U.S. Geological Survey, Denver, CO.

Sandia National Laboratories. 1992. *Long-Term Gas and Brine Migration at the Waste Isolation Pilot Plant: Preliminary Sensitivity Analyses for Post-Closure 40 CFR 268 (RCRA), May 1992*. SAND92-1933. Sandia National Laboratories, WIPP Performance Assessment Department, Albuquerque, NM. WPO 23513.

Saulnier, Jr., G.J. 1987. *Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-11 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site*. SAND87-7124. Sandia National Laboratories, Albuquerque, NM. WPO 28520.

Saulnier, Jr., G.J., Domski, P.S., Palmer, J.B., Roberts, R.M., Stensrud, W.A., and Jensen, A.L. 1991. *WIPP Salado Hydrology Program Data Report #1*. SAND90-7000. Sandia National Laboratories, Albuquerque, NM. WPO 25746.

Schiel, K.A. 1988. *The Dewey Lake Formation; End Stage Deposit of a Peripheral Foreland Basin*. [M.S. thesis.] University of Texas at El Paso, El Paso, TX.

Schlesinger, M.E., and Mitchell, J.F.B. 1987. Climate Model Simulations of the Equilibrium Climatic Response to Increased Carbon Dioxide. *Reviews of Geophysics*, Vol. 25, No. 4, pp. 760 – 798.

Sewards, T., Glenn, R., and Keil, K. 1991. *Mineralogy of the Rustler Formation in the WIPP-19 Core*. SAND87-7036. Sandia National Laboratories, Albuquerque, NM. WPO 24140.

Shinta, A.A., and Kazemi, H. 1993. "Tracer Transport in Characterization of Dual-Porosity Reservoirs." In *Reservoir Engineering Proceedings, SPE Annual Technical Conference and Exhibition, Houston, TX, October 3-6, 1993*. SPE 26636, pp. 285 – 299. Society of Petroleum Engineers, Richardson, TX.

Silva, M. 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP*. EEG-55, DOE/AL/58309-55. Environmental Evaluation Group, Albuquerque, NM. WPO 9607.

Slezak, S., and Lappin, A. 1990. "Potential for and Possible Impacts of Generation of Flammable and/or Detonable Gas Mixtures during the WIPP Transportation, Test, and Operational Phases." In Memorandum to D. Mercer and C. Fredrickson, January 5, 1990. Sandia National Laboratories, Albuquerque, NM. WPO 21224.

Snyder, R.P., Gard, Jr., L.M, and Mercer, J.W. 1982. *Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site*. Open-File Report 82-968. U.S. Geological Survey, Denver, CO.

Stensrud, W.A., Bame, M.A., Lantz, K.D., Cauffman, T.L., Palmer, J.B., and Saulnier, Jr., G.J. 1988. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #6*. SAND87-7166. Sandia National Laboratories, Albuquerque, NM. WPO 29674.

Stensrud, W.A., Dale, T.F., Domski, P.S., Palmer, J.B., Roberts, R.M., Fort, M.D., Saulnier, Jr., G.J., and Jensen, A.L. 1992. *Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2*. SAND92-7072. Sandia National Laboratories, Albuquerque, NM. WPO 26432.

Stone, C.M., Krieg, R.D., and Beisinger, Z.E. 1985. *SANCHO, A Finite Element Computer Program for the Quasistatic, Large Deformation, Inelastic Response of Two-Dimensional Solids.* SAND84-2618. Sandia National Laboratories, Albuquerque, NM. WPO 24658.

Stormont, J.C. 1990. Discontinuous Behavior Near Excavations in a Bedded Salt Formation. *International Journal of Mining and Geological Engineering*, SAND89-2403J, Vol. 8, No. 1, pp. 35 – 56. WPO 29472.

Stormont, J.C., Peterson, E.W., and Lagus, P.L. 1987. *Summary of and Observations About WIPP Facility Horizon Flow Measurements Through 1986.* SAND87-0176. Sandia National Laboratories, Albuquerque, NM. WPO 27053.

Stormont, J.C., Howard, C.L., and Daemen, J.J.K. 1991. *In Situ Measurements of Rock Salt Permeability Changes Due to Nearby Excavation*. SAND90-3134. Sandia National Laboratories, Albuquerque, NM. WPO 26166.

Swift, P.N. 1992. *Long-Term Climate Variability at the Waste Isolation Pilot Plant, Southeastern New Mexico, USA*. SAND91-7055. Sandia National Laboratories, Albuquerque, NM. WPO 27093.

Telander, M.R., and Westerman, R.E. 1993. *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Progress Report for the Period November 1989 through December 1992*. SAND92-7347. Sandia National Laboratories, Albuquerque, NM. pp. 6-14 to 6-27. WPO 23456.

Thorne, B.J., and Rudeen, D.K. 1980. *Regional Effects of TRU Repository Heat.* SAND80-7161. Sandia National Laboratories, Albuquerque, NM. WPO 10281.

Tierney, M.S. 1993. "PA Methodology Overview." In *Initial Performance Assessment of the Disposal of Spent Nuclear Fuel and High-Level Waste Stored at Idaho National Engineering Laboratory. Volume 1: Methodology and Results.* R.P. Rechard, ed. SAND93-2330/1. Sandia National Laboratories, Albuquerque, NM. 3-1 through 3-28. Chapter 3 of WPO 26694.

Tiller, C.L., and O'Melia, C.R. 1993. "Natural Organic Matter and Colloidal Stability: Models and Measurements." In *Colloids in the Aquatic Environment. Colloids and Surfaces A: Physicochemical and Engineering Aspects*, T.F. Tadros and J. Gregory, eds., pp. 89 – 102. Elsevier Applied Science, London.

Tipping, E. 1993. "Modelling Ion Binding by Humic Acids." In *Colloids in the Aquatic Environment. Colloids and Surfaces A: Physicochemical and Engineering Aspects*, T.F. Tadros and J. Gregory, eds., pp. 117 – 131. Elsevier Applied Science, London.

Toth, L.M., Friedman, H.A., and Osborne, M.M. 1981. Polymerization of Pu(IV) in Aqueous Nitric Acid Solutions. *Journal of Inorganic and Nuclear Chemistry*, Vol. 43, No. 11, pp. 2929 – 2934.

Van der Lee, J., de Marsily, G., and Ledoux, E. 1993. "Are Colloids Important for Transport Rate Assessment of Radionuclides? A Microscopic Modeling Approach," In *High Level Radioactive Waste Management, Proceedings of the Fourth Annual International Conference, Las Vegas, NV, April 26-30, 1993*, pp. 646 – 652. American Society of Civil Engineers, New York, NY.

Van Sambeek, L.L., Luo, D.D., Lin, M.S., Ostrowski, W., and Oyenuga, D. 1993. *Seal Design Alternatives Study*. SAND92-7340. Sandia National Laboratories, Albuquerque, NM. WPO 23445.

Vesely, W.E., and Rasmuson, D.M. 1984. Uncertainties in Nuclear Probabilistic Risk Analyses. *Risk Analysis*, Vol. 4, No. 4, pp. 313 – 322.

Vilks, P. 1994. *The Role of Colloids and Suspended Particles in Radionuclide Transport in the Canadian Concept for Nuclear Fuel Waste Disposal.* AECL-10280. Whiteshell Laboratories, Atomic Energy of Canada, Ltd., Pinawa, Manitoba. Yucca Mt. #: MOL. 19950202.0067.

Vine, J.D. 1963. Surface Geology of the Nash Draw Quadrangle, Eddy County, New Mexico. *U. S. Geological Survey Bulletin*, 1141-B. WPO 39558.

Vlassopoulos, D., Wood, S.A., and Mucci, A. 1990. Gold Speciation in Natural Waters: II. The Importance of Organic Complexing—Experiments with Some Simple Model Ligands. *Geochimica et Cosmochimica Acta,* Vol. 54, No. 6, pp. 1575 – 1586.

Wallner, M. 1981. "Critical Examination of Conditions for Ductile Fracture in Rock Salt." In *Proceedings of the Workshop on Near-Field Phenomena in Geologic Repositories for Radioactive Waste, Seattle, WA, August 31–September 3, 1981*, pp. 243 – 253. Organisation for Economic Co-Operation and Development, Paris, France.

Warrick, R., and Oerlemans, J. 1990. "Sea Level Rise." In *Climate Change: The IPCC Scientific Assessment*, J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds., pp. 257 – 281. Intergovernmental Panel on Climate Change, Sweden.

Washington, W.M., and Meehl, G.A. 1984. Seasonal Cycle Experiment on the Climate Sensitivity Due to a Doubling of CO_2 with an Atmospheric General Circulation Model Coupled to a Simple Mixed-Layer Ocean Model. *Journal of Geophysical Research,* Vol. 89, No. D6, pp. 9475 – 9503.

Weatherby, J.R., Brown, W.T., and Butcher, B.M. 1991. "The Closure of WIPP Disposal Rooms Filled with Various Waste and Backfill Combinations." In *Rock Mechanics as a Multidisciplinary Science*, *Proceedings of the 32nd U.S. Symposium, University of Oklahoma, Norman, OK, July 10-12, 1991*, J.C. Roegiers, ed. SAND90-2399C, pp. 919 – 928. A.A. Balkema, Brookfield, VT. WPO 28617.

Westinghouse Electric Corporation. 1994. *Backfill Engineering Analysis Report, Waste Isolation Pilot Plant.* Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM. WPO 37909.

Wilson, C.A., and Mitchell, J.F.B. 1987. A Doubled CO_2 Climate Sensitivity Experiment with a Global Climate Model Including a Simple Ocean. *Journal of Geophysical Research*, Vol. 92, No. D11, pp. 13,315 – 13,343.

Wolery, T.J. 1992. *EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0).* UCRL-MA-110662, Pt. 3. Lawrence Livermore National Laboratory, Livermore, CA.

Wolery, T.J., and Daveler, S.A. 1992. *EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0)*. UCRL-MA-110662-Pt.4. Lawrence Livermore National Laboratory, Livermore, CA.

Wood, B.J., Snow, R.E., Cosler, D.J., and Haji-Djafari, S. 1982. *Delaware Mountain Group (DMG) Hydrology—Salt Removal Potential, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico*. TME 3166. U.S. Department of Energy, Albuquerque, NM.

Zoback, M.D., and Zoback, M.L. 1981. State of Stress and Intraplate Earthquakes in the United States. *Science*, Vol. 213, No. 4203, pp. 96 – 104.

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7.0 ASSURANCE REQUIREMENTS

In the Preamble to Title 40 of the Code of Federal Regulations (CFR) Part 191 (EPA 1985) (50 FR 30879), the U.S. Environmental Protection Agency (EPA) points out that

> There are too many uncertainties in projecting the behavior of natural and engineered components for many thousands of years—and too many opportunities for mistakes or poor judgments in such calculations—for the numerical requirements on overall system performance in Subpart B to be the sole basis to determine the acceptability of disposal systems for these very hazardous wastes.

In view of this, the EPA developed assurance requirements (40 CFR § 191.14) to ensure that implementing agencies act cautiously and take steps to reduce the impacts of these uncertainties. According to the EPA, these assurance requirements are considered an essential complement to the containment requirements, which, when implemented, should ensure that the level of protection desired by the EPA is achieved. Contained in 40 CFR § 191.14 are these six separate assurance requirements:

- active institutional controls,
- monitoring,
- passive institutional controls,
- use of different types of barriers,
- resource disincentives, and
- waste removal.

Figure 7-1 provides a timeline illustrating the implementation of these assurance requirements. Waste removal is not included in Figure 7-1 because it is not a planned activity. Waste removal is discussed in Appendix WRAC. See Table 1-7 in Chapter 1.0 for a list of appendices that provide additional information supporting this chapter.

The provisions of 40 CFR Part 194 (EPA 1996a) contain detailed criteria that the U.S. Department of Energy (DOE) is to use in implementing the assurance requirements contained in 40 CFR Part 191. The following sections detail the DOE's compliance with the assurance requirements of 40 CFR Part 191 and the associated certification criteria in 40 CFR Part 194. In addition to addressing the six assurance requirements stated above, the DOE used some conservative assumptions in the performance assessment that provide additional assurance. Use of conservative assumptions in the performance assessment is discussed in Section 6.5.4.

7.1 Active Institutional Controls

Active institutional controls and passive institutional controls satisfy two roles:

(1) they meet assurance requirements per 40 CFR Parts 191 and 194, and

(2) they contribute to performance assessment per 40 CFR Part 194.

Once the facility at the Waste Isolation Pilot Plant (WIPP) is decommissioned and decontaminated (D&D), positive actions (active institutional controls) will be taken to ensure site access control. Active institutional control begins after final facility closure. The EPA has specified that no more than 100 years of active institutional controls can be assumed in predictions of long-term performance. The DOE interprets this requirement to mean that control programs should be implemented as long as such controls are useful and practical, but credit for active institutional controls cannot be considered in the performance assessment beyond 100 years from the final closure of the repository. Therefore, performance assessment does not consider credit for active institutional controls beyond 100 years.

The EPA defines active institutional controls as "(1) controlling access to a disposal site by any means other than passive institutional controls, (2) performing maintenance operations or remedial actions at the site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance" (40 CFR § 191.12). Active institutional controls to be used by the DOE include facility guarding, evaluation of land use in the area, postoperational monitoring, land reclamation, and maintenance of fences and buildings. In addition, active institutional controls are integrated with the D&D activities that are described in Appendix D&D.

7.1.1 Requirements for Active Institutional Controls

In prescribing active institutional controls, the EPA has specified that "active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal" (40 CFR § 191.14[a]). The EPA addresses the effectiveness of these controls and the length of the time for which such controls should be considered effective for the performance assessment.

Section 194.41(a) specifies that "any compliance application shall include detailed descriptions of proposed active institutional controls, the controls' location, and the period of time the controls are proposed to remain active." Section 194.41(a) also states that any assumptions pertaining to the effectiveness of active controls in preventing inadvertent human intrusion should be supported by such descriptions. This section provides support for the assumptions pertaining to the active institutional controls program for the WIPP facility. Prior to decommissioning of the facility and full implementation of the active controls program, the DOE will reevaluate the proposed active controls program and make any changes necessary as indicated by experience and evaluation of data. The design of the DOE's active controls program is described in Appendix AIC.

For the purposes of this application, the DOE will begin the active controls period within sixty days of completion of final facility closure. This start point will be simultaneous with the

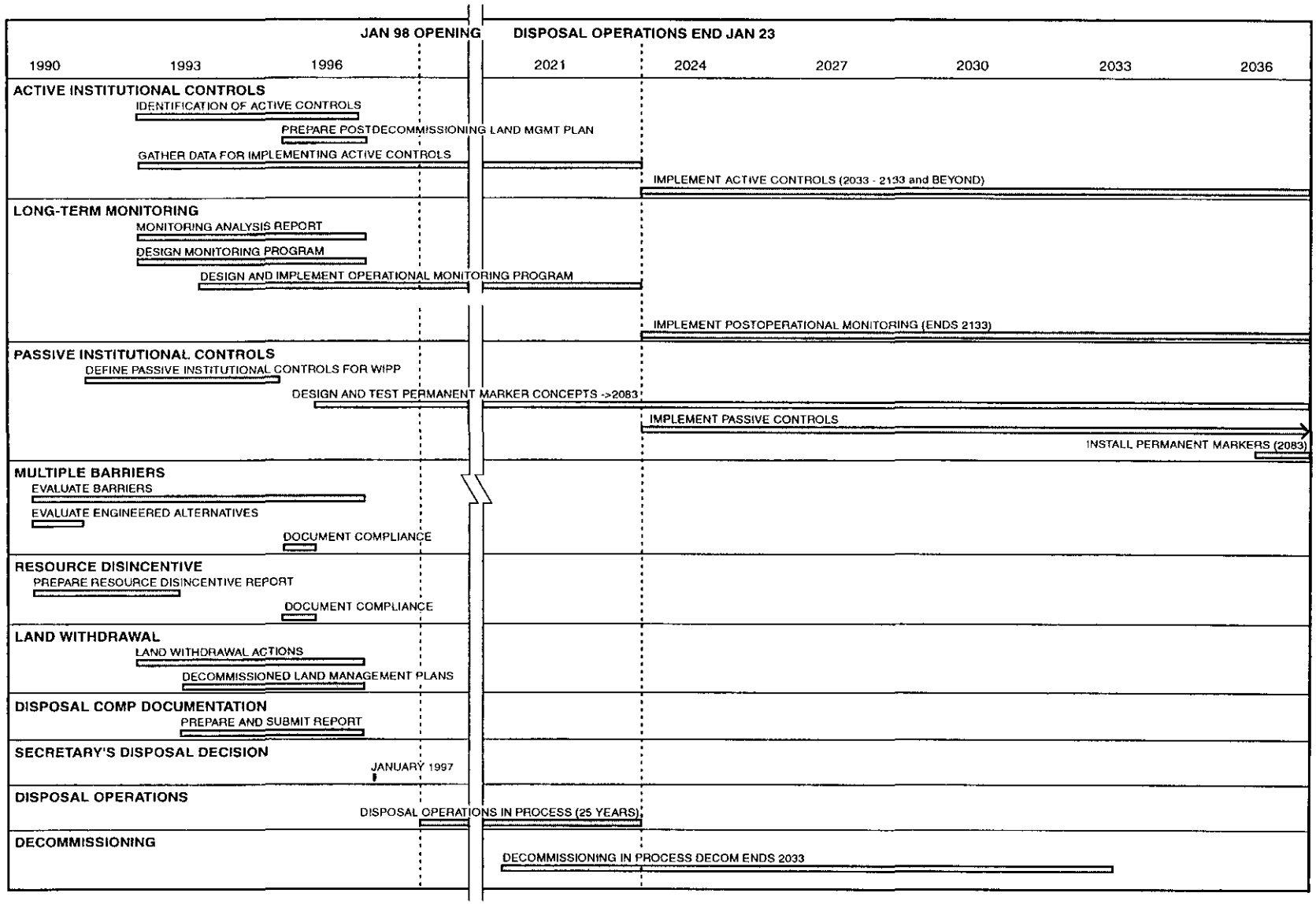

Figure 7-1. Implementation Timeline

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initiation of the postclosure care period mandated under the closure plan submitted to the New Mexico Environment Department (NMED) with the hazardous waste facility permit application.

7.1.2 Objectives for Active Institutional Controls

The primary goal of DOE's active institutional controls program is to prevent unauthorized use of the WIPP site. Because of the massive body of rock that separates the waste from the accessible environment, there are not many activities that pose a threat to the WIPP disposal system. The threats that are severe enough or likely enough to consider are addressed in Appendix SCR and in the conceptual models description located in Section 6.4. The DOE has identified four objectives for the design of the active controls program: (1) eliminating those site features that would cause future populations to develop the WIPP site (see Section 7.1.3.1), (2) identifying allowed and disallowed activities, (3) identifying and minimizing the impacts of the intentional user, and (4) controlling allowed activities and preventing unallowed activities. In addition, the DOE will install and protect monitoring equipment and any test facilities established for evaluating the long-term marker system.

In order to design an active controls program around these four objectives, the DOE has assumed the following:

- site restoration will be to as near the original condition as practicable,
- future authorized site uses will not be significantly different than they are now, as described in Appendix LMP, and
- a threat of future unauthorized use exists.

Restoration of the WIPP site includes any activities associated with demobilization following D&D. In addition, as part of the active institutional controls program, the DOE will implement monitoring systems suitable for assessing disposal system performance. The objectives of the active institutional controls program, the monitoring program, and the decommissioning plan overlap; therefore, the DOE believes it is both prudent and within the EPA's intent to conduct these programs simultaneously. This provides for a more comprehensive understanding of the multitude of activities that will be taking place during the active controls period.

7.1.3 Implementation of the Active Institutional Controls Program

The first step in the process of implementing the active institutional controls program was to identify measures needed to satisfy the active institutional controls requirements. Certain characteristics of active institutional controls measures have been identified, such as minimizing features that would attract future development of the site, warning of potential

hazards through signage, implementing the measures for at least 100 years, addressing the standards, and preventing development. These characteristics were used to develop conceptual designs for active institutional controls.

Some active institutional controls were obvious at the outset, including site access control, site remedial actions, site maintenance, and site monitoring. Information and specifications useful in implementing these and possibly other controls have been gathered (see Appendix LMP). A detailed explanation of the resulting active institutional controls is provided in Appendix AIC (Section 2). The design will be reviewed periodically and updated as appropriate during WIPP's operations phase. Ongoing review and evaluation will ensure that the active institutional controls implemented are appropriate for the conditions that may exist at that time. The DOE will review the design prior to implementation and the recertification process will be used as a vehicle for modification to include any future enhancements. Any recertification will be accomplished in accordance with the requirements of the Land Withdrawal Act (LWA) and the provisions of 40 CFR Part 194.

The final operational activity at the repository will be closing the waste disposal area and sealing the shafts. All surface structures, except for the concrete hot cell structure (Appendix AIC), and a sufficient quantity of salt tailings to support construction of the permanent marker berm (Appendix PIC) will be removed and the site regraded and revegetated to as near its original condition as practicable. In addition, those structures erected during the disposal phase, as part of the permanent marker testing program (Section 7.3.3.2), will also remain in place after decommissioning. These will include a section of the berm, the salt filled trench that will serve as the berm base, and at least one monument marker used in long-term materials testing for the permanent marker system.

In order to determine the active controls that would be beneficial, the DOE analyzed the types of land uses anticipated and, based on that analysis, developed a design plan for active institutional controls. The following two sections summarize the analysis and the design plan.

7.1.3.1 Analysis of Activities

The purpose of the analysis of activities is to determine the types of disturbances that may be associated with each activity, the depth of such disturbances, and the need for any mitigation of these activities. These activities are supported with screening decisions in Appendix SCR. This section addresses the following activities:

- ranching,
- farming,
- hunting,
- scientific activities,

- utilities and transportation,
- groundwater pumping,
- surface excavation,
- potash exploration,
- hydrocarbon exploration,
- construction, and
- hostile and illegal activities.

Table 7-1 indicates the active institutional controls that will be applied to prevent unauthorized activities.

7.1.3.1.1 Ranching

Description of the Activity: Ranching involves the management of herds of cattle on the public lands surrounding and including the WIPP. These activities are regulated on federal lands such as the WIPP under a permitting process administered by the Bureau of Land Management (BLM). There is little surface-disturbing activity associated with ranching except for the construction of fences, the construction and operation of watering facilities, and the occasional drilling of groundwater wells. Currently, only the 277 acres within the Exclusive Use Area are not used for ranching. In the future, barbed wire enclosures will be constructed to provide security for monitoring facilities, test areas, and construction areas. Eventually, the entire surface is expected to be released for ranching activities. Only those activities associated with groundwater use could have any impact on the disposal system. These are discussed in Section 7.1.3.1.6. Figure 7-2 depicts the current grazing allotments on the WIPP site.

Goal of Active Controls: Active controls will ensure that grazing leases are administered consistently and in compliance with applicable regulations. Fencing will be needed to protect government property. In addition, areas will be fenced as needed to prevent cattle from disturbing reclaimed areas until vegetation has been reestablished.

7.1.3.1.2 Farming

Description of the Activity: Farming includes soil preparation, planting, irrigation, and harvesting. Significant quantities of water are needed to support crops in the Delaware Basin. Crops grown in the farming area nearest to the WIPP include cotton, alfalfa, peppers, and pecans. Small quantities of other crops are also grown. Farming using irrigation would require access to large amounts of fresh water, either through the diversion of surface water or

Table 7-1. Effectiveness of Active Controls Activities

Activities / Active Institutional Control	Ranching	Farming	Hunting	Scientific Activities	Utilities and Trans-portation	Ground-water Pumping	Excav-ation	Potash Explor-ation	Hydro-carbon Explor-ation	Construc-tion	Hostile and Illegal Activities
Land Management Plan	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	
Fence	▨	▨	▨				▨			▨	▨
Roadway				▨	▨	▨					
Signs		▨	▨		▨		▨	▨	▨	▨	▨
Contract for Inspec-tion and Maintenance	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Security Surveillance	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Testing				▨	▨						
Disposal System Monitoring				▨		▨					
Permanent Marker System Installation				▨							
Response	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Reporting	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

▨ indicates component addressed by active controls

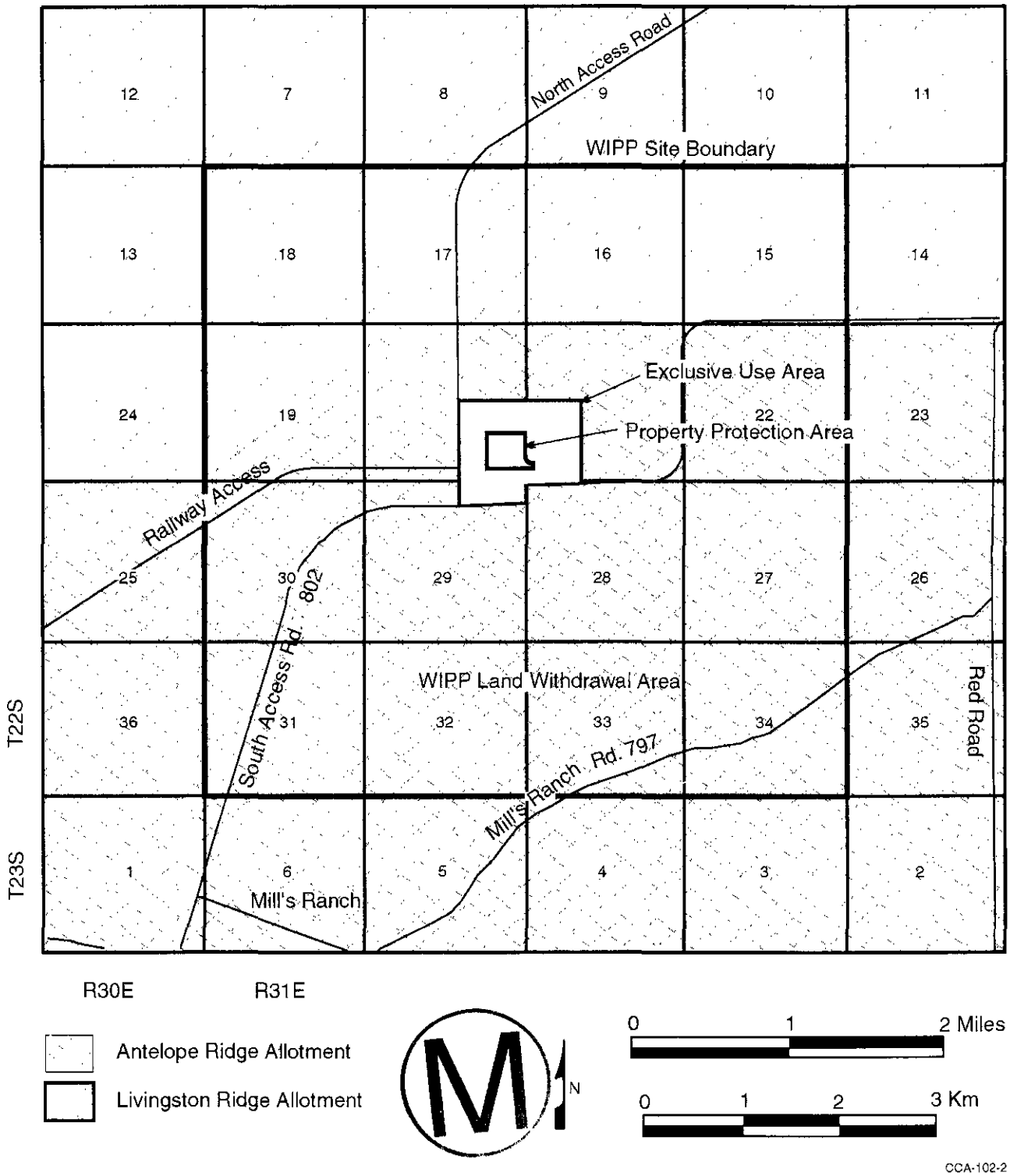

Figure 7-2. Grazing Allotments on the WIPP Site as of October 1996

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the construction of groundwater wells. There is currently no known farming near the WIPP because of the lack of good quality water and the poor soil composition. Farming, therefore, is screened out of the performance assessment on the basis that any impacts are of low consequence to the disposal system (see Appendix SCR, Section SCR.3.8.1).

Goal of Active Controls: While farming is unlikely, the land management plan, fence, signs, and other measures will prevent farming activities from disturbing test areas or affecting monitoring locations.

7.1.3.1.3 Hunting

Description of the Activity: Currently, hunting occurs outside the WIPP Off Limits Area. The prohibition from hunting is mandated by DOE policy. Unless the restrictions are lifted, hunting will continue to be prohibited in this 1,454-acre (590-hectare) area. The restriction has been placed to provide protection for facilities and personnel working at the WIPP. Game animals in the vicinity include deer, small mammals, and birds. There are no hunting activities that are anticipated to impact the disposal system. Figure 7-3 depicts the area within the WIPP site boundary where hunting is allowed.

Goal of Active Controls: Protection of facilities and personnel engaged in monitoring, reclamation, and testing activities will be needed throughout the active controls period. Local and state hunting laws and restrictions will apply.

7.1.3.1.4 Scientific Activities

Description of the Activity: Scientific activities can include both those conducted by the DOE for the WIPP and those conducted by outside organizations. Types of activities include archeological investigations, wildlife studies, vegetation studies, grazing studies, geomorphic studies, passive marker testing, passive marker construction, hydrologic studies, disposal system monitoring, and others. Prolonged studies of vegetation, geomorphic features, or grazing impacts may require the construction of fenced enclosures. Some may involve the placement of monitoring or other types of equipment or monuments that need to be protected from vandalism.

Goal of Active Controls: In the case of scientific studies, active controls will ensure that scientific activities can proceed undisturbed without impacting the disposal system. Specific needs for protection may be identified with each study proposed for the area.

7.1.3.1.5 Utilities and Transportation

Description of the Activity: Currently, the WIPP site is traversed by several pipelines (natural gas), buried telephone lines, power lines, a highway, and a railroad. Future transportation needs are expected to remain the same. Construction and maintenance of utilities and transportation facilities involve significant surface-disturbing activities.

However, they are confined to the upper several meters of soil and will not impact the disposal system. Currently, the construction of utilities and transportation facilities are controlled by a permitting process administered by the DOE for the WIPP and the BLM for other federal lands. The BLM ensures that operators remain within designated rights-of-way and that they comply with applicable environmental protection regulations. Figure 7-4 depicts the current rights-of-way that have been granted for utilities or transportation on the WIPP site.

Goal of Active Controls: Active controls will ensure that utility and transportation activities are conducted in a manner that is consistent with permits and that locations are selected to avoid conflicts with permanent markers. Measures, such as fences, may be needed to provide mutual protection for personnel, livestock, and rights-of-way uses.

7.1.3.1.6 Groundwater Pumping

Description of the Activity: Groundwater wells are drilled for several uses near the WIPP. The most common use within the controlled area is in support of the WIPP groundwater monitoring program. These wells generally target waters in the Dewey Lake Redbeds and the Santa Rosa Formation. Before a groundwater well can be drilled, a permit must be obtained and the State Engineer must be notified of the final well configuration and its use (see Appendix USDW). Wells are abandoned in accordance with state regulations that govern the plugging of such wells (see Section 3.3.4). Groundwater well drilling unrelated to the DOE is prohibited by the LWA within the WIPP site boundary. Figure 7-5 shows the location of groundwater wells within the WIPP site boundary.

Goal of Active Controls: The active controls program will ensure that the prohibition on drilling groundwater wells and fluid injection within the WIPP site boundary is enforced and that those wells that currently exist, or that are drilled to support future WIPP activities, are plugged and abandoned in accordance with applicable regulations.

7.1.3.1.7 Surface Excavation

Description of the Activity: Both sand and caliche are mined locally for use in construction. Mining for sand and caliche is always limited to surface quarries. To mine these materials on public lands, a permit must be obtained from the DOE or the BLM. The permit limits the quantity that can be removed and specifies appropriate environmental protections, including reclamation. Sand or caliche removal will have no impact on the disposal system (Appendix SCR, Section SCR.3.4.1).

Many surface quarries within the WIPP site boundary have been remediated, which included recontouring the surface and planting vegetation. Others will be remediated either during the operational phase or as part of postdecommissioning land management. The development of surface quarries unrelated to the DOE is prohibited by the LWA. Figure 7-6 shows the location of surface quarries within the WIPP site boundary.

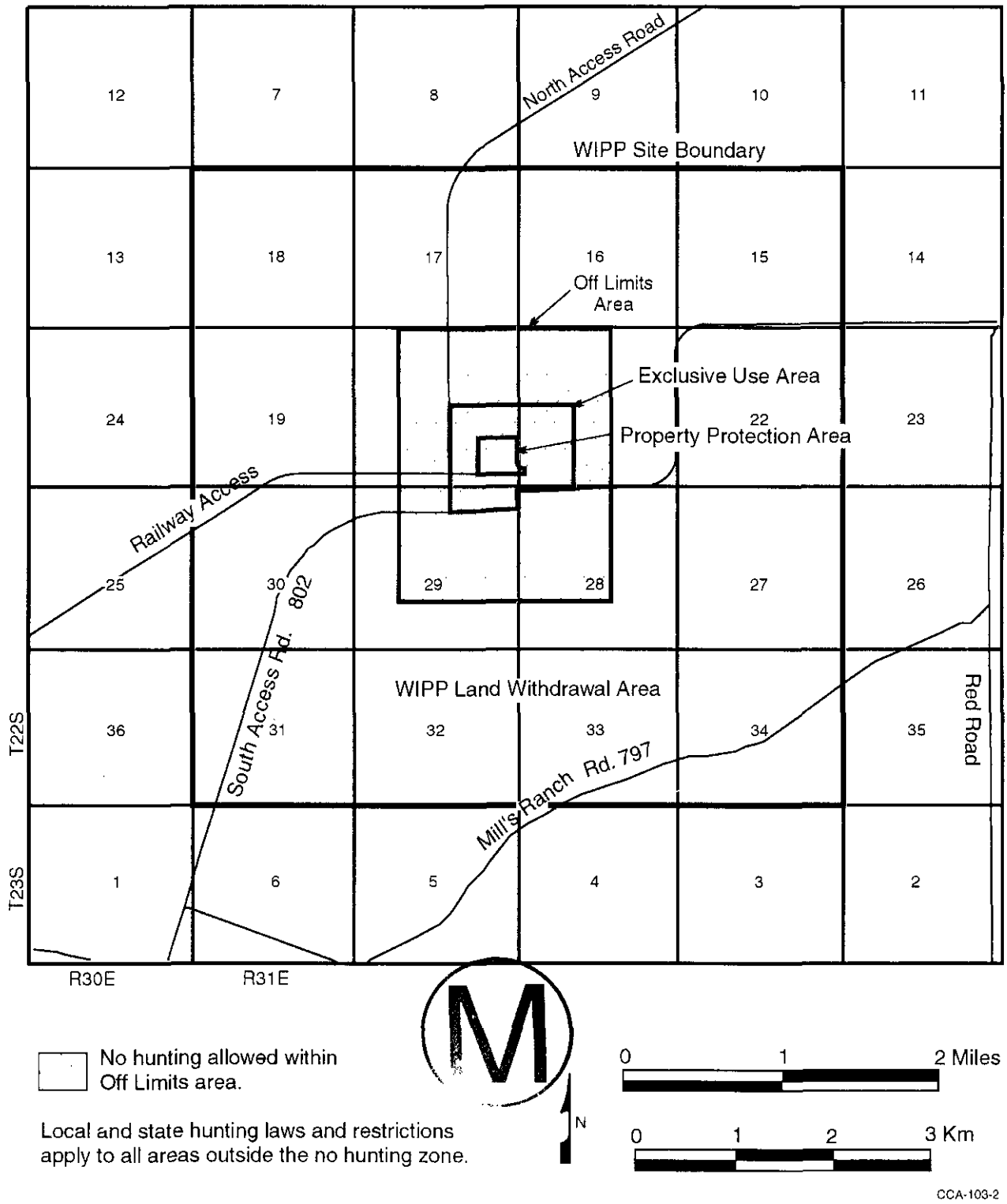

Figure 7-3. Area Where Hunting is Permitted Within the WIPP Site Boundary

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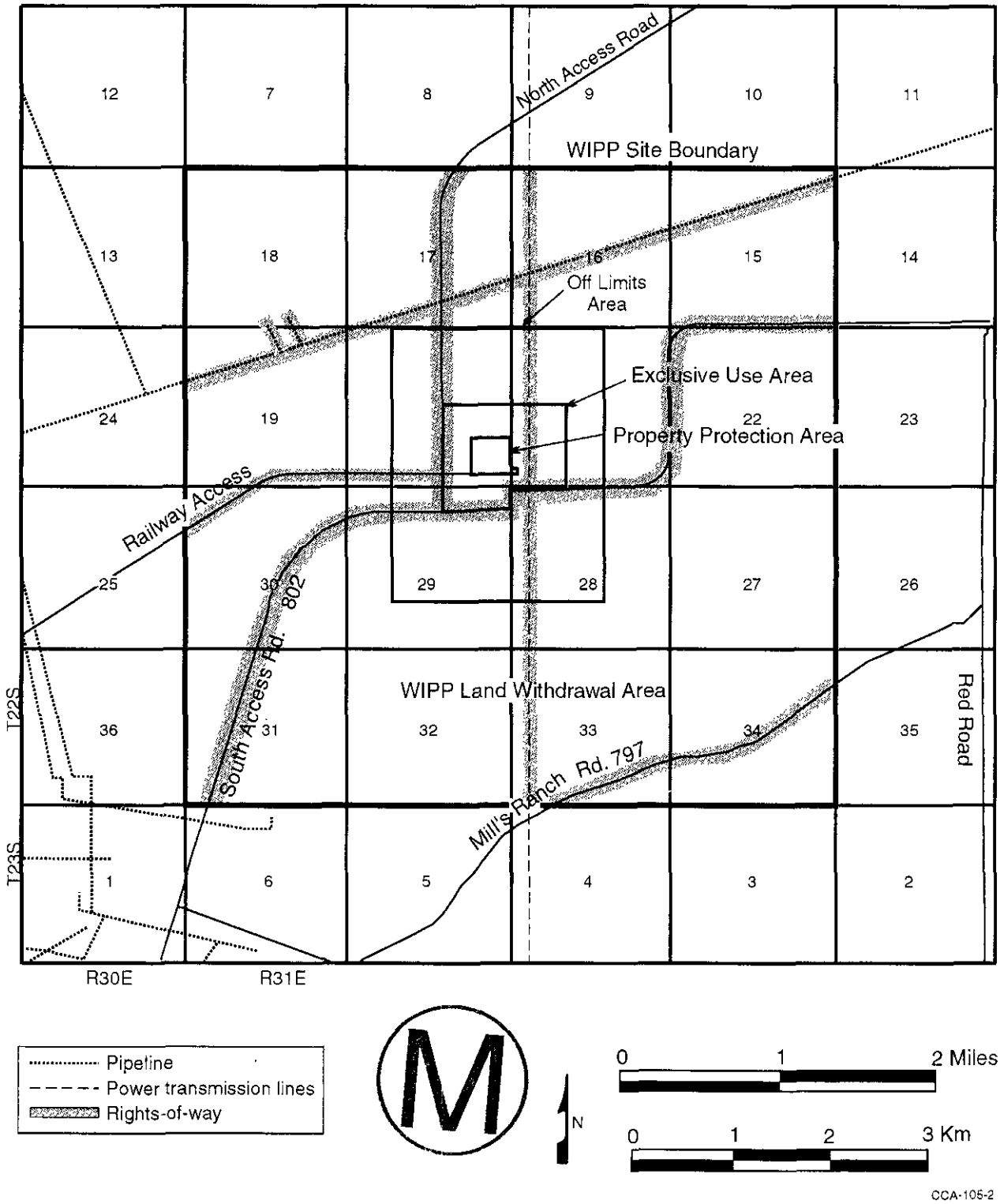

Figure 7-4. Location of Rights-of-Way Within the WIPP Site Boundary as of October 1996

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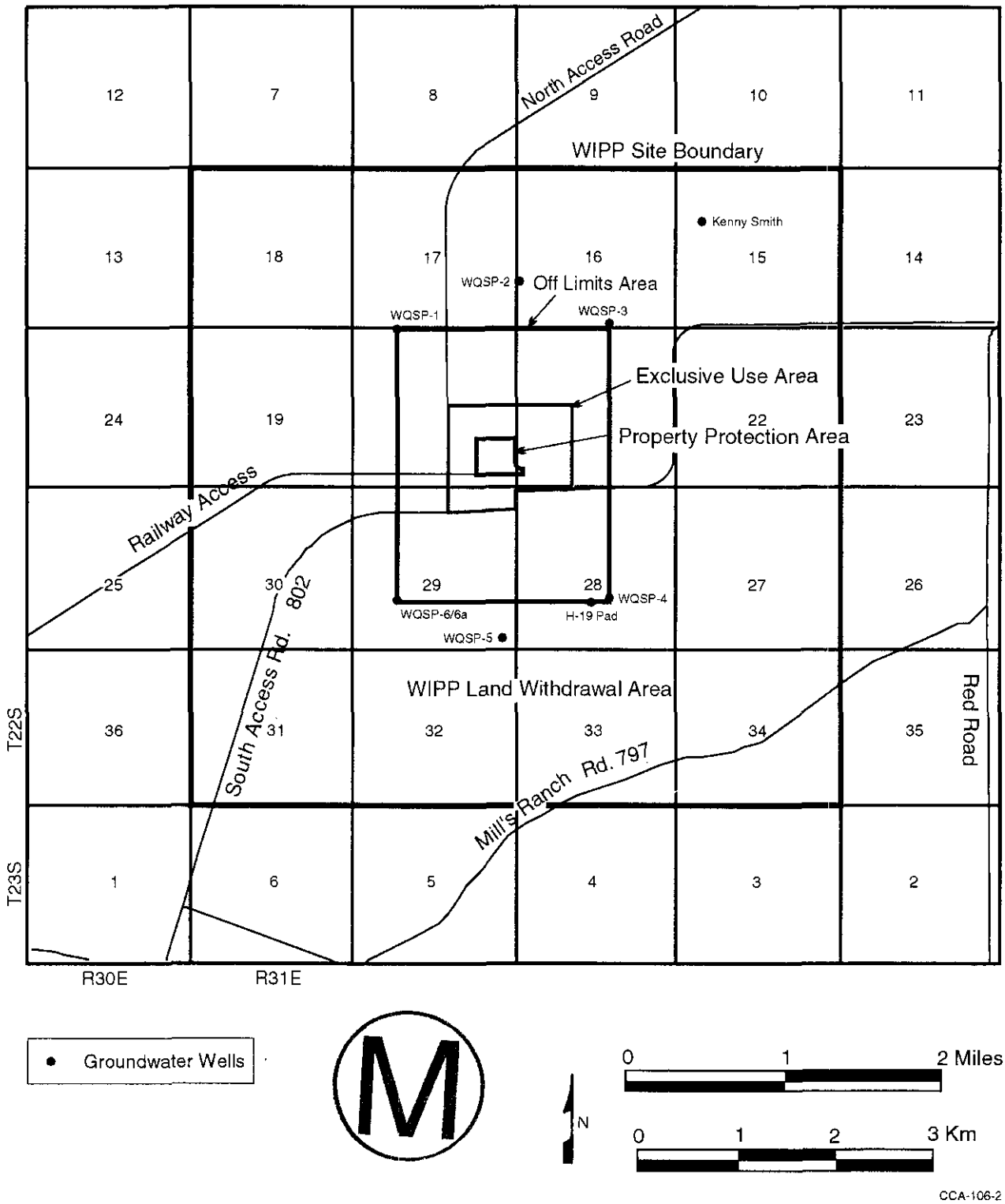

Figure 7-5. Location of Groundwater Wells Within the WIPP Site Boundary as of October 1996

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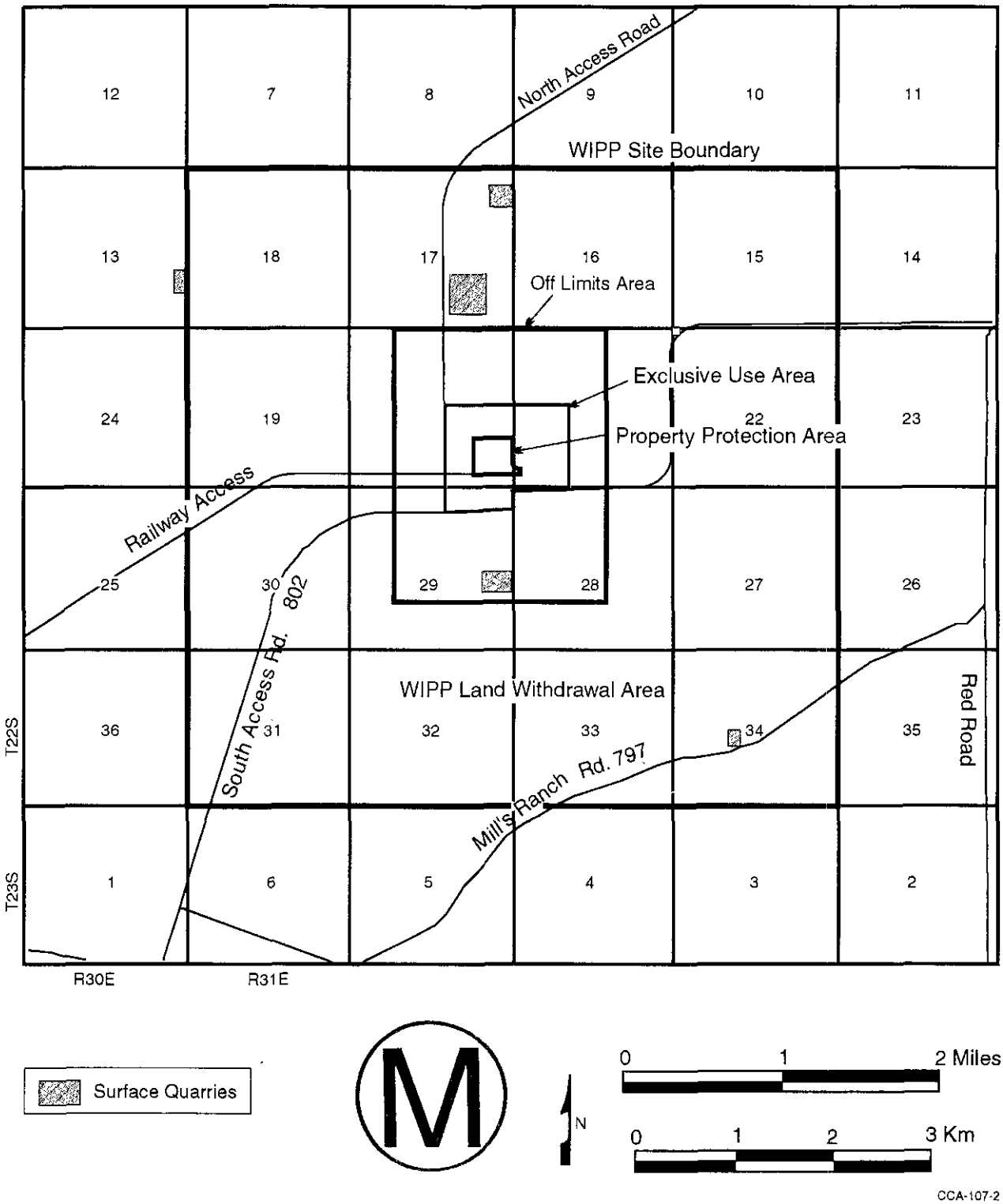

Figure 7-6. Location of Surface Quarries Within the WIPP Site Boundary as of October 1996

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Goal of Active Controls: The objective of the DOE with respect to surface excavation is to ensure that the development of mineral leases does not affect the integrity of the disposal system. In accordance with the LWA requirement that no surface or subsurface mining unrelated to the DOE may be conducted within the boundaries of the land withdrawal area, the DOE and the state of New Mexico have entered into a memorandum of understanding (MOU). This MOU dictates that the state will forward any mining and reclamation plans to the DOE for review and comment in determining issuance of such permits within one mile of the withdrawal area boundary. In addition to the commitments in the MOU, the DOE will conduct perimeter surveillance and evaluate potential encroachment of ancillary activities associated with mines.

7.1.3.1.8 Potash Exploration and Extraction

Description of the Activity: Potash mineralization is known to exist beneath the WIPP site (see Section 2.3.1.1). The extent of mineralization is generally determined through the drilling of core holes and the examination and analysis of rock cores. Sufficient core holes have already been drilled within the WIPP site boundary to characterize the resident mineralization. Future drilling, however, is prohibited by the LWA. Holes drilled for the exploration of potash must be closed in accordance with state or federal regulations, depending on the location of the potash lease (see Appendix DEL, Section DEL.5.5). The closure of potash holes within the WIPP site boundary is discussed in Section 3.3.4.

Extraction of potash in the Delaware Basin is accomplished through the use of conventional underground mining technologies. Development of resources within the WIPP site boundary would require that a mine be built in the vicinity or that an existing mine be expanded to include the WIPP. Potash mining is conducted in accordance with the rules and regulations of the BLM on federal lands and the state of New Mexico on state lands. The impacts of mining are evaluated in the performance assessment in accordance with the requirements of 40 CFR § 194.32(b) and are discussed in Section 6.4. Figure 7-7 shows a map of the distribution of potash exploration holes and the extent of currently economically minable reserves.

Goal of Active Controls: The active controls program will ensure that mineral leasing and development within the WIPP site boundary are prevented and that existing or near future mines do not encroach on the site.

7.1.3.1.9 Hydrocarbon Exploration

Description of the Activity: Hydrocarbon resources are assumed to exist below the WIPP site. The amount of these resources and their locations are projected from information that the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) report compiled and interpreted for the DOE in 1995. (See Section 2.3 for a discussion of this report.) Exploration companies use surface-based geophysical techniques to determine likely locations for hydrocarbon accumulations and then investigate the prospect using deep drilling. Both the

geophysical and the drilling activities have historically occurred on the WIPP site, but further drilling is prohibited by the LWA. Figure 7-8 shows the location of hydrocarbon wells within the WIPP site boundary.

Goal of Active Controls: The active controls program will ensure that the prohibition on the drilling of hydrocarbon wells is enforced. In addition, the BLM and the state of New Mexico will administer permits to perform geophysical investigations.

7.1.3.1.10 Construction

Description of Activity: The construction of a permanent building typically involves activities that disturb the surface only to a depth of a few meters, with the exception of the drilling of a groundwater well. Construction is currently prohibited by the DOE for public protection reasons during disposal operations. Because the WIPP site is federally owned, only federal facilities can be built there and any construction will require federal permits. After the conclusion of operations and during the active institutional controls period, construction will not be allowed within the areas reserved for the permanent marker system.

Goal of Active Controls: Controls will ensure that construction does not occur within the WIPP site boundary prior to the end of the active institutional controls period and that no construction will interfere with the goals of the passive controls system.

7.1.3.1.11 Hostile and Illegal Activities

Description of Activity: Activities in this category include vandalism, sabotage, theft, and artifact hunting. All of these activities are prohibited by federal and state law. None is expected to have an impact on the disposal system, although they could impact monitoring efforts, the construction and preservation of permanent markers, the integrity of fences and test areas, and other authorized uses.

Goal of Active Controls: Active controls will prevent the occurrence of hostile and illegal activities to the extent practicable within the WIPP site boundary. Controls may include access control and other security measures.

7.1.3.2 Active Controls Design Features

Based on these possible land uses, the DOE has specified the following design features for the active controls system. Additional detail is presented in Appendix AIC (Section 1).

- Signage will be established to control access to the WIPP site. A fence will be erected along the perimeter of the repository surface footprint. The fence will have gates placed approximately midway along each of the four sides.

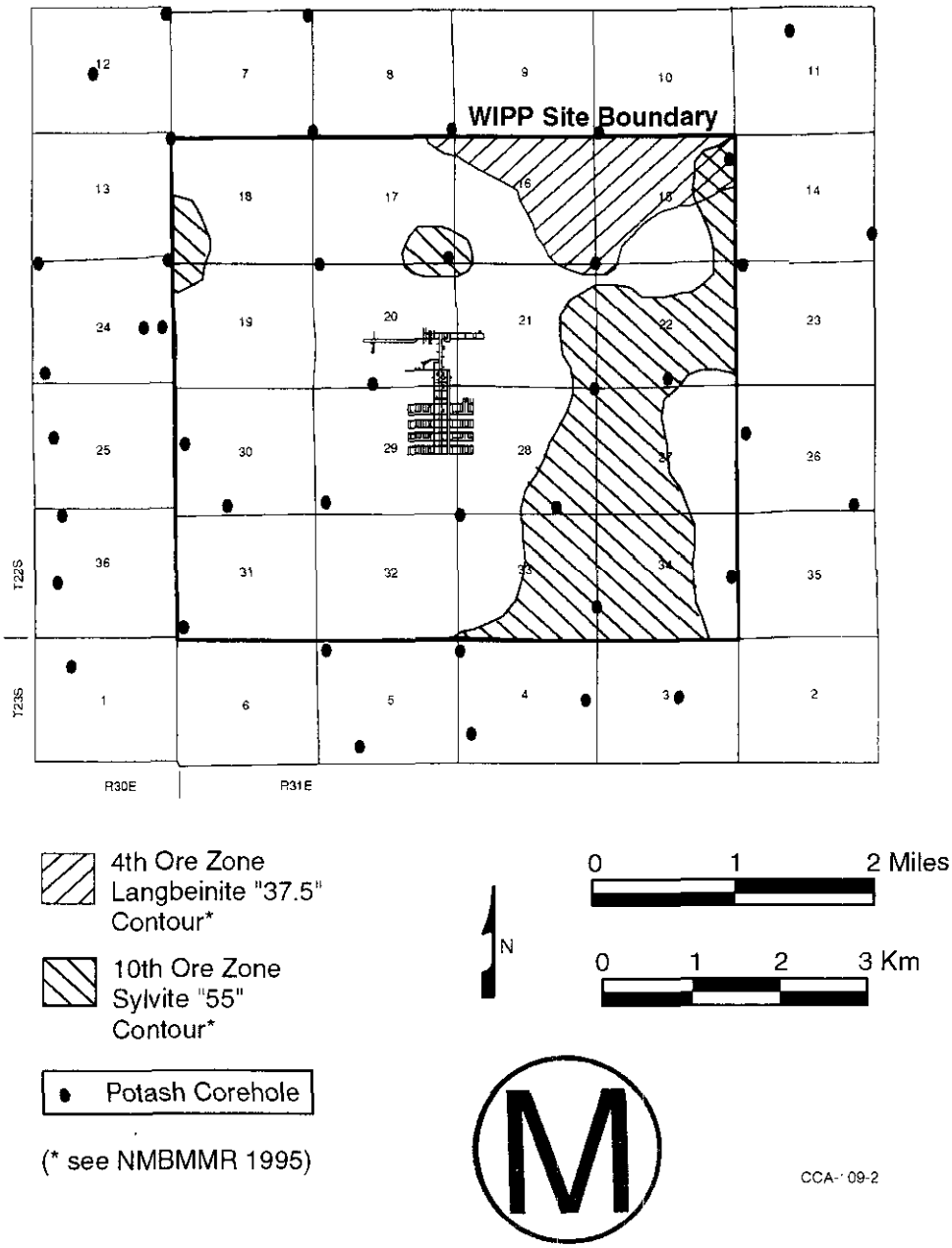

Figure 7-7. Location of Potash Exploration Holes and Economically Mineable Potash Within the WIPP Site Boundary as of October 1996

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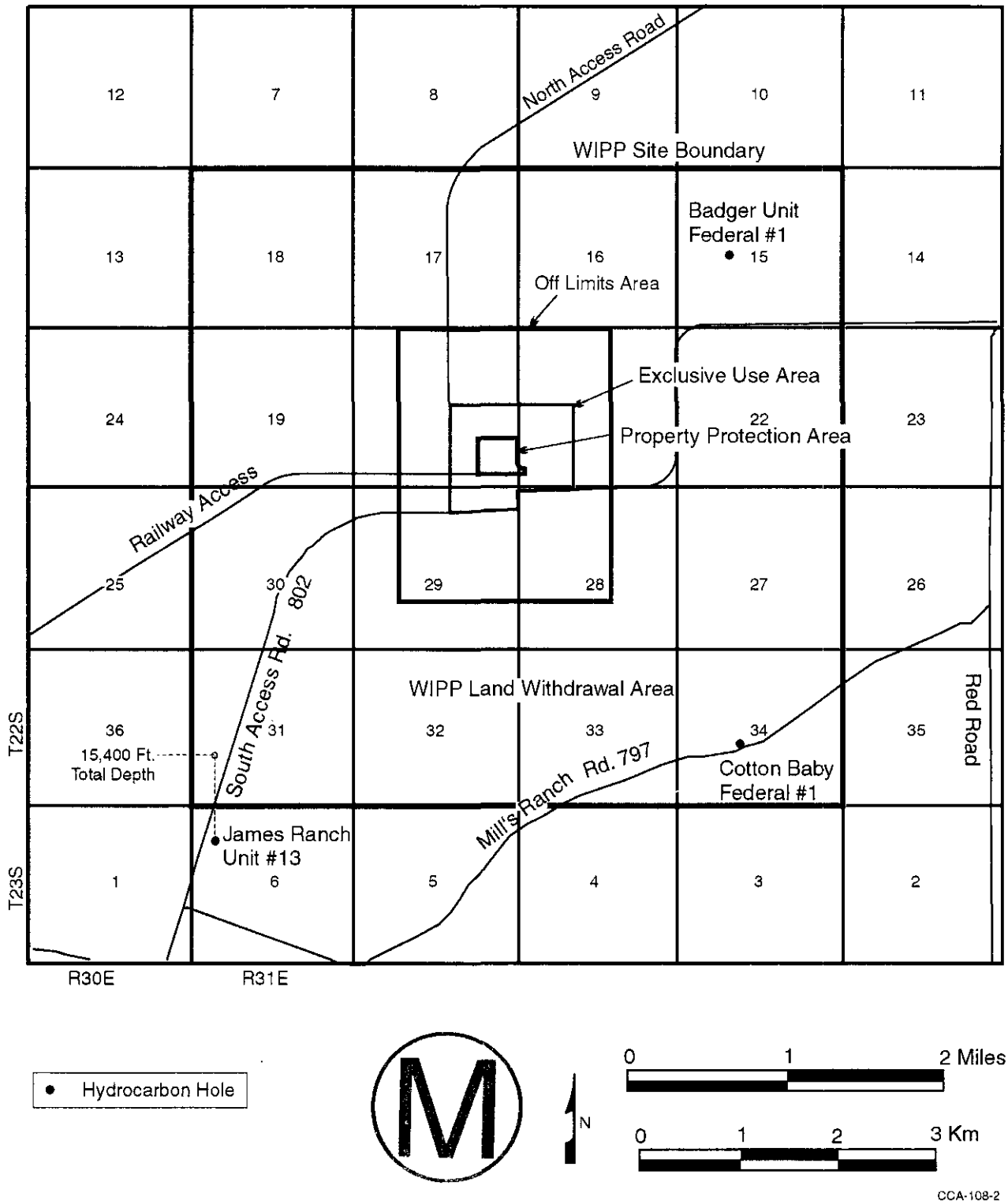

Figure 7-8. Hydrocarbon Holes Located Within the WIPP Site Boundary as of October 1996

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- Roadways will be constructed as needed to provide easy visual inspection and ready vehicle access to any point around the fenced perimeter and to facilitate maintenance of the fence line. These roadways will connect to the paved south access road.

- The fence line and the WIPP site perimeter will be posted with signs having as a minimum a legend reading "Danger—Unauthorized Personnel Keep Out" and a warning against entering the area without specific permission of the DOE. Signs prohibiting hunting will also be posted as appropriate. In addition, the DOE will include the area in the local one-call system.

- Periodic inspection and necessary corrective maintenance will be conducted on the fence line, associated warning signs, and the roadways.

- Routine periodic patrols and surveillance of the WIPP site by personnel trained in security surveillance and investigation will be established and maintained.

- A process will be developed and implemented for monitoring and controlling the long-term testing of the permanent marker system.

- Upon installation of the permanent marker system, the active institutional controls program will be revised as deemed appropriate.

- Guidelines will be developed for identifying and implementing the appropriate corrective measures to address any abnormal conditions identified during periodic surveillance and inspections.

- Reports of activities associated with the postdisposal active access controls will be prepared in accordance with regulatory requirements for submittal to the appropriate regulatory and legislative authority.

7.1.3.3 Description of Active Institutional Controls Features

Most of the active institutional controls measures, such as long-term site monitoring and site remedial actions, will be implemented simultaneously with facility closure and D&D. It may be possible, however, to implement some measures earlier. For example, salt disposal may begin prior to final facility closure. Reclamation and restoration of unused disturbed surface areas have already begun. Guarding and maintenance activities, which are in place, could evolve into an appropriate type of postclosure activity.

During the disposal phase, the DOE will manage and store waste in a manner that limits the public's exposure to radiation to the standards of 40 CFR Part 191, Subpart A. Subsequent to disposal and after shafts are backfilled and sealed, radioactive releases to the accessible environment, exposures to humans, and concentrations in groundwater cannot exceed the standards of 40 CFR Part 191, Subparts B and C. The periods of active and passive

institutional controls begin when the disposal phase ends, and according to the EPA, run concurrently for at least 100 years. Also per the EPA, after 100 years, credit for active controls must end, but credit for passive controls may continue for up to 700 years after final facility closure.

The active controls program design described above is implemented through the following components. Additional detail is provided in Appendix AIC (Section 2):

- Signage that indicates the areal extent of the WIPP and a fence that restricts access to the repository footprint, respectively, and includes the area in which the passive markers will be constructed. This area (shown in Figure 7-9) is referred to as the repository footprint and represents the surface projection of all areas underground that contain waste. Note that additional fencing may be needed for remote locations that are used for disposal system monitoring. Such fences will meet the same construction specifications as those for the perimeter footprint.

- A 16-foot (4.9 meter) wide roadway around the perimeter of the WIPP site boundary. Roads to remote sites will also be constructed and maintained as needed.

- Surveillance that includes drive-by patrolling two or three times per week. This frequency will be sufficient to detect and remove the most severe threats to the disposal system, such as drilling.

- Maintenance services for fences, gates, cattle guards, signs, and monitoring equipment.

- Site restoration activities in accordance with the postclosure land management plan.

- Agreements with the BLM to administer grazing and other permitted land uses consistent with the DOE's postclosure land management plan.

- Monitoring of the disposal system.

- Construction of a permanent marker system.

7.1.4 Effectiveness of the Active Institutional Controls Program

Performance assessment for the WIPP assumes that the active institutional controls program will be 100 percent effective in preventing human intrusion into the repository for the 100 years immediately following disposal. The DOE believes that this assumption is supported by the proposed design features alone (that is, fencing, postings, perimeter inspections, surveillance, and mitigation measures) and the defense-in-depth nature of the features and resulting controls. The DOE believes that taking 100 percent credit for 100 years of active

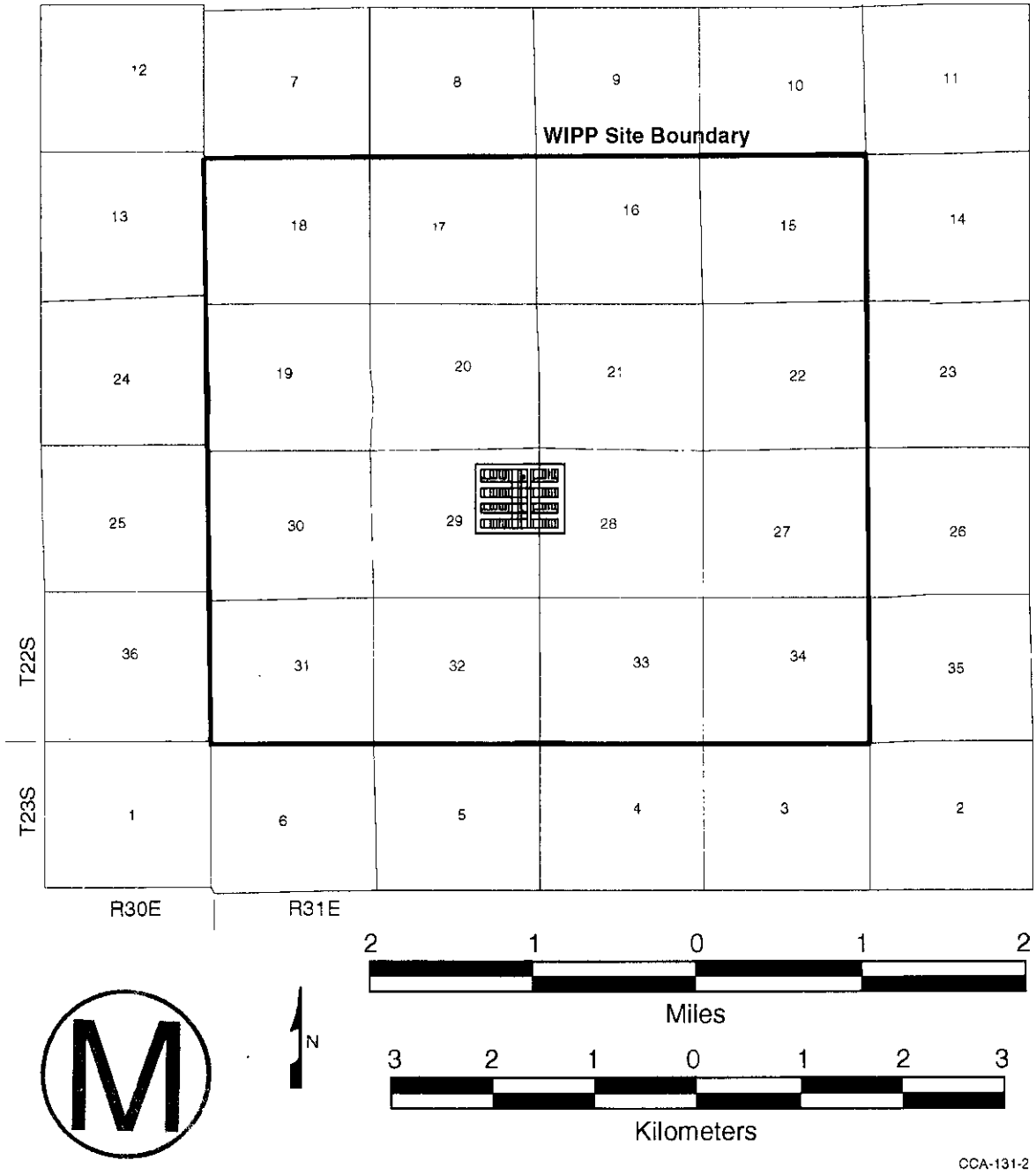

Figure 7-9. Planned Repository Footprint

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controls is justified by the repetitive and redundant nature of the active controls that will be implemented at the WIPP site. The DOE is committed to retaining active control over the site for as long as is practicable, but at least for 100 years.

Governments have successfully controlled and protected facilities of national importance for hundreds of years. The U.S. Government has existed and effectively maintained many facilities under its control for over 200 years. The DOE and its predecessor agencies have successfully maintained (preventing intrusion) several major facilities for over 50 years. Therefore, the DOE believes there is a reasonable expectation that active institutional controls will be effective for at least the assumed 100-year institutional control period, and are likely to be effective for substantially longer periods.

7.2 Monitoring

The requirements for disposal system monitoring are stated in 40 CFR § 191.14(b). In order to certify the DOE's compliance with these requirements, the EPA has established certification criteria that the DOE must satisfy in its application for certification. These criteria are stated in 40 CFR § 194.42. The requirements and the criteria form the basis for the DOE's monitoring program. Appendix MON, Pre-Closure and Post-Closure (Long-Term) Monitoring Plan, describes the details of the DOE's monitoring program.

The criteria provided in 40 CFR § 194.42(a) state

> The Department shall conduct an analysis of the effects of disposal system parameters on the containment of waste in the disposal system and shall include the results of such analysis in any compliance application. The results of the analysis shall be used in developing plans for preclosure and postclosure monitoring required pursuant to paragraphs (c) and (d) of this section. The disposal system parameters analyzed shall include, at a minimum:
>
> (1) Properties of backfilled material, including porosity, permeability, and degree of compaction and reconsolidation;
>
> (2) Stresses and extent of deformation of the surrounding roof, walls, and floor of the waste disposal room;
>
> (3) Initiation or displacement of major brittle deformation features in the roof or surrounding rock;
>
> (4) Ground water flow and other effects of human intrusion in the vicinity of the disposal system;
>
> (5) Brine quantity, flux, composition, and spatial distribution;
>
> (6) Gas quantity and composition; and
>
> (7) Temperature distribution.

Attachment 1 (MONPAR) to Appendix MON is an "Analysis of the Effects of Disposal System Parameters on Waste Containment" that the DOE has used to base decisions regarding disposal system monitoring. 40 CFR § 194.42 dictates the manner in which the stated analysis will be used in deriving the monitoring program, including the specification that the program consider preclosure monitoring as an integral component of meeting the monitoring requirements.

MONPAR's scope of analyzed parameters exceeds the minimum parameters identified in 40 CFR § 194.42(a). The following is a summary of the results of the analysis with respect to those parameters identified in 40 CFR § 194.42(a).

(1) *Properties of backfilled material, including porosity, permeability, and degree of compaction and reconsolidation;*

Backfill Material Properties. The mechanical and hydrologic properties of the backfill are not significant to the performance assessment. Therefore, they will not be monitored during the preclosure or postclosure periods.

See Appendix MON (Attachment 1, MONPAR, Section MONPAR.3.5) for additional detail regarding DOE's analysis of backfill.

(2) *Stresses and extent of deformation of the surrounding roof, walls, and floor of the waste disposal system; and*

(3) *Initiation or displacement of major brittle deformation features in the roof or surrounding rock;*

Stress and Extent of Deformation. Creep closure of the repository will occur, and is included within compliance assessment and performance assessment models as a control on waste consolidation and other time-dependent disposal room conditions. The individual creep closure parameters are not significant to performance assessment. Sufficient data have been collected for the purposes of verifying the underlying rock mechanics models. The numerical models of the repository used in performance assessment are based upon assumptions about long-term behavior that are not applicable to behavior during the operational period. Further monitoring of creep closure and stress would not provide information that is useful for calculating disposal system performance, nor would it lead to additional confidence in the performance assessment models.

The initiation or displacement of major brittle deformation features in the roof or surrounding rock, beyond that already accounted for in performance assessment calculations, is not significant to the containment of waste. The individual parameters that are used in modeling the mechanical behavior of brittle anhydrite interbeds are not significant to performance assessment. Monitoring mechanical behavior of the

interbeds would not provide information that is useful for calculating system performance, nor would it lead to additional confidence in the performance assessment models.

Monitoring of creep closure and mechanical behavior will be conducted during preclosure monitoring to provide information that is relevant to repository operations.

See Appendix MON (Attachment 1, MONPAR, Sections MONPAR.3.1 and MONPAR.3.2) for additional detail regarding DOE's analysis of creep closure and deformation features.

(4) *Ground water flow and other effects of human intrusion in the vicinity of the disposal system;*

Drilling Intrusions. Intrusion into the repository through drilling may occur during the regulatory time period. In accordance with regulatory requirements, such intrusions are modeled to occur randomly in time and space. Drilling leads to direct releases during the drilling itself and possible long-term releases due to effects on fluid flow in the disposal system. The drilling rate (boreholes per square kilometer per 10,000 years) is significant to repository performance. The DOE uses a drilling rate in performance assessment that is based on historical rates in the Delaware Basin.

The DOE will monitor the drilling activity in the Delaware Basin during the preclosure and postclosure periods and will use the results in performance calculations performed in support of recertification.

Borehole Properties. The properties of a borehole change over time, and are incorporated into performance assessment. The properties are established to be "consistent with practices in the Delaware Basin at the time a compliance application is prepared" (40 CFR § 194.33[c][1]). These parameters are significant to compliance. The current practices will be monitored and changes will be incorporated into the performance assessment models of borehole properties in future calculations in support of recertification.

Groundwater Flow. Historical, current, and near-future human activities in the vicinity of the repository could affect groundwater flow in the Culebra prior to closure of the repository, as well as subsequent to repository closure. The significance of these human activities depends on the extent and magnitude of the induced hydrological, geochemical, and mechanical disturbance. Changes in groundwater in the Culebra are moderately significant to performance. Such changes are incorporated into performance assessment as described in Appendix MON (Attachment 1, MONPAR, Sections MONPAR.4.4 and MONPAR.4.5). Changes in brine flow in the Salado as a result of any current or near-future human activities in the vicinity of the repository are not anticipated, and therefore are not significant to performance assessment.

The DOE will monitor water levels and groundwater flow direction in the Culebra during the operational period. Monitoring of groundwater flow conditions in the Salado could create additional pathways for radionuclide transport, and would potentially jeopardize long-term performance of the disposal system; thus the DOE will not perform such monitoring.

See Appendix MON (Attachment 1, MONPAR, Sections MONPAR.4.1, MONPAR.4.3, and MONPAR.4.4) for additional detail regarding DOE's analysis of drilling intrusions, borehole properties, and groundwater flow in the vicinity of the repository.

(5) *Brine quantity, flux, composition, and spatial distribution;*

Salado Hydrology. Hydrologic properties (quantity, flux, and spatial distribution) of the intact Salado Formation are incorporated into performance assessment through use of parameters that are consistent with extensive experimental observations. Variations in these parameters have a moderate effect on system performance assessment. There is no indication that properties of the intact (far-field) Salado will change during the regulatory period; thus, they will not be monitored during the operational period nor during the postclosure period. Composition of Salado brines has been well established through investigations. Brine composition is significant and is incorporated into performance assessment calculations. Based on the extensive experimental evidence collected, there is no indication that Salado brine composition will change over the regulatory period; thus it will not be routinely monitored during the operational period nor during the postclosure period.

The presence of a disturbed rock zone (DRZ) surrounding the repository has also been incorporated into performance assessment calculations. The properties of the DRZ have been well characterized; they include altered hydrologic properties that are expected to enhance near-field fluid flow both to and from the repository. The initial conditions and enhanced fluid flow are moderately significant to disposal system performance. In an effort to simplify the calculations, the effects are maximized by the conceptual model and altered properties of the DRZ. This treatment is believed to be a conservative choice with respect to the ultimate impact on predicted release. Monitoring the DRZ hydrologic properties would not provide relevant information or verify assumptions used in performance assessment; therefore they will not be monitored during the operational period nor during the postclosure period.

Mechanical and hydrologic properties of the disposal room are incorporated into performance assessment as they affect gas generation and fluid flow into and out of the repository. These properties and parameters are moderately significant to disposal system performance. Additional properties are significant in the event of intrusion into the repository; these are discussed in Appendix MON (Attachment 1, MONPAR, Section MONPAR.4.2). The conceptual model of disposal room behavior is based on

extensive experimental data that support a number of assumptions about long-term behavior that will not be applicable during the preclosure period. The closed disposal room will not achieve the expected long-term properties predicted in performance assessment during the operational or active control periods. Therefore, monitoring the mechanical and hydrologic properties would not provide relevant information or verify assumptions used in performance assessment. Thus the disposal room properties will not be monitored during the operational period nor during the postclosure period.

See Appendix MON (Attachment 1, MONPAR, Sections MONPAR.2.1, MONPAR.2.2, MONPAR.3.3, and MONPAR.3.4) for additional detail regarding DOE's analysis of these parameters.

Culebra Hydrology. Hydrologic properties (quantity, flux, and spatial distribution) of the undisturbed Culebra Member of the Rustler Formation exhibit spatial variability and are incorporated into performance assessment through both fixed values and parametric ranges that are consistent with experimental observations to date. Variations in some of the parameters are significant to overall disposal system performance. The hydrologic properties of the undisturbed Culebra are not expected to change during the regulatory period, thus they will not be monitored during the operational period nor during the postclosure period. Culebra groundwater is less saline than Salado and Castile brines. The Culebra groundwater is spatially variable, and its composition has been well established through investigations. Groundwater composition is incorporated into performance assessment calculations; however it is not significant to performance. Based on extensive experimental evidence, there is no indication that Culebra groundwater composition will change over the regulatory period; however, monitoring will provide information that is relevant to a comprehensive environmental monitoring program.

See Appendix MON (Attachment 1, MONPAR, Sections MONPAR.2.3 and MONPAR.2.4) for additional detail regarding DOE's analysis of these parameters.

Castile Hydrology. The Castile Formation underlying the WIPP may contain reservoirs of pressurized brine. This is incorporated into performance assessment through use of input parameters that address hydrologic properties and the probability that a reservoir will be encountered during an intrusion event. The hydrologic properties are significant to disposal system performance in such an intrusion event. The Castile is not significant to system performance except for the brine reservoirs. There is no indication that the properties of the undisturbed reservoirs will change over the regulatory period although the assumption is made in the modeling that intrusions into brine reservoirs lead to their eventual depletion. It is not possible to completely define the location and extent of brine reservoirs without jeopardizing the integrity of the disposal system. Composition of brines from two Castile brine reservoirs is moderately significant and is incorporated into performance assessment calculations. There is no evidence to suggest that the brine composition will change over the

regulatory period. It is not possible to further investigate composition of any brine that may be present below the repository without jeopardizing the integrity of the disposal system. Therefore no further investigations or monitoring will be performed during the preclosure period nor during the postclosure period. However, monitoring of drilling activity in the Delaware Basin for instances of encountering pressurized brine reservoirs in the Castile will be a part of the preclosure and postclosure monitoring programs.

See Appendix MON (Attachment 1, MONPAR, Sections MONPAR.2.5 and MONPAR.2.6) for additional detail regarding DOE's analysis of the Castile hydrology parameters.

(6) *Gas quantity and composition;*

Gas Quantity and Composition. Gas generated in the repository may retard creep closure, may fracture the anhydrite interbeds in the DRZ (enhancing fluid flow), and may enhance direct releases (Appendix MON, Section MONPAR.4.2) These effects are moderately significant and are accounted for in performance assessment. Gas composition (carbon dioxide concentration) and the corrosion rate of metals are controlled chemically by the backfill and are not significant. Gas generation is moderately significant to system performance. The conceptual model of gas generation processes is based on experimental data and incorporates a number of assumptions about long-term behavior that will not be applicable during the operational period (such as anoxic conditions). Monitoring the quantity and composition of gas generated in the closed panels would not provide information that is useful for calculating system performance, nor would it lead to additional confidence in the performance assessment models.

However, in accordance with requirements under RCRA regulations, gas sampling and analysis will be conducted as described in Appendices MON and VCMP, Confirmatory Monitoring Plan.

See Appendix MON (Attachment 1, MONPAR, Section MONPAR.3.6) for additional detail regarding DOE's analysis of gas generation.

(7) *Temperature distribution.*

Temperature Distribution. Natural geological thermal gradients have been well characterized and are not significant: they will not affect repository performance, either directly by affecting the containers and repository chemistry, or indirectly by altering fluid flow through the Salado or the Culebra. Similarly waste-induced and repository-induced thermal gradients in the repository are not significant: they will not affect repository performance, either directly by affecting the containers and repository chemistry, or indirectly by altering fluid flow through the Salado or the Culebra.

Therefore natural thermal gradients, waste-induced thermal gradients, and repository-induced thermal gradients will not be monitored during the preclosure period nor during the postclosure period.

See Appendix MON (Attachment 1, MONPAR, Sections MONPAR.2.7 and MONPAR.3.8) for additional detail regarding DOE's analysis of natural temperature distribution.

The criteria state that the DOE is to base decisions regarding disposal system monitoring on "an analysis of the effects of disposal system parameters on the containment of waste in the disposal system and shall include the results of such analysis in any compliance application." The rule goes on to dictate the manner in which the stated analysis will be used in deriving the monitoring program, including the specification that the program consider preclosure monitoring as an integral component of meeting the monitoring requirements.

The DOE has completed the analysis and has designed a monitoring program (including both preclosure and postclosure monitoring techniques) that meets the requirements of 40 CFR § 191.14(b). The program is documented in a manner that addresses the certification criteria of 40 CFR § 194.42, and is described in this section. This monitoring program is described in this section. More detailed information is provided in Appendix MON.

Additional parametric areas of analysis included in MONPAR (Attachment 1 of Appendix MON) are:

- repository chemical conditions,
- shaft seal system,
- radionuclide transport and retardation,
- direct releases, and
- mining.

Table 7-2 is a list of the specific disposal system parameters discussed in MONPAR.

7.2.1 Monitoring Program Requirements

Requirements for monitoring of a disposal system[1] are included in the final disposal regulations as follows:

[1] Disposal system means "any combination of engineered and natural barriers that isolate...radioactive waste after disposal" (40 CFR § 191.12).

Table 7-2. Potentially Significant Disposal System Parameters

NATURAL PARAMETERS	
Impure halite effective porosity	Culebra diffusional porosity
Impure halite permeability	Culebra longitudinal dispersivity
Impure halite pore compressibility	Climate change index
Impure halite far-field pore pressure	Culebra groundwater quantity
Anhydrite permeability	Culebra groundwater flux
Anhydrite pore compressibility	Culebra groundwater spatial distribution
Anhydrite two-phase flow model choice	Culebra groundwater composition
Salado pore shape	Castile brine volume in reservoir
Salado residual brine saturation	Castile brine reservoir volume selection index
Salado residual gas saturation	Castile brine reservoir pressure
Salado brine quantity	Castile brine reservoir permeability
Salado brine flux	Castile brine reservoir rock compressibility
Salado brine spatial distribution	Castile brine composition
Salado brine composition	Castile brine flux
Culebra transmissivity	Castile brine spatial distribution
Culebra advective porosity	Natural temperature distribution
Culebra fracture spacing	

WASTE AND REPOSITORY PARAMETERS	
Closure rates and stresses	Probability factor for types of microbial degradation
Extent of deformation	Gas quantity
Initiation of brittle deformation	Gas composition
Displacement of major deformation features	Choice of oxidation state distribution
DRZ permeability	Solubility of nine radionuclides in Salado brine
DRZ effective porosity	Solubility of nine radionuclides in Castile brine
DRZ brine flux	Humic colloid concentration in Salado brine
DRZ brine quantity	Humic colloid concentration in Castile brine
Waste area residual gas saturation	Clay shaft seal member permeability
Waste area residual brine saturation	Concrete shaft seal member permeability
Brine wicking	Asphalt shaft seal member permeability
Waste area permeability	Shaft DRZ permeability
Backfill porosity	Crushed salt seal component permeability (permeability selection index)
Backfill permeability	
Degree of backfill compaction	Seal residual gas saturation
Backfill reconsolidation	Seal residual brine saturation
Inundated steel corrosion rate with CO_2	Seal pore shape
Inundated steel corrosion rate without CO_2	Waste- and repository-induced temperature distribution
Inundated microbial degradation rate	Salado K_ds for dissolved radionuclides
Humid microbial degradation rate	Culebra K_ds for six dissolved radionuclides
β-factor for microbial degradation process	Salado K_ds for colloidal radionuclides

HUMAN INITIATED PARAMETERS	
Drilling rate	Borehole permeability
Waste particle diameter	Borehole plugging pattern (probability index)
Effective shear resistance to erosion	Change in Salado brine flow
Gravity correction factor for spalling	Change in Culebra groundwater flow
Strength correction factor for spalling	Probability that mining will occur
Time between intrusions	Mining index for adjusting Culebra transmissivity
Borehole location	Waste activity
Probability of encountering a Castile brine reservoir	Waste tensile strength
Borehole diameter	

> Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring (§ 191.14[b]).

Within this context, monitoring becomes one of several activities to be implemented at the WIPP facility during the active institutional controls period. Monitoring the WIPP disposal system is designed to address significant concerns associated with the performance of the isolation system. The EPA points out that monitoring approaches to address significant concerns should be limited to those that can provide meaningful data in a relatively short period of time (50 FR 38081).

In addition, the EPA points out that monitoring must not become a reason to relax the degree of care with which the compliance determination is made. Finally, the EPA specifies that monitoring must not jeopardize the integrity of the disposal system (50 FR 38081).

The DOE has addressed the need for monitoring the disposal system during both the preclosure period and the postclosure period in its application for a hazardous waste facility operating permit (see Appendix MON). In its Pre-Closure and Post-Closure (Long-Term) Monitoring Plan (Appendix MON), the DOE incorporates three monitoring programs that will be used to ensure compliance with the hazardous waste regulations of RCRA as implemented by the NMED. These programs include (1) a confirmatory volatile organic compound (VOC) monitoring program to demonstrate that the numerical predictions of VOC releases are reasonable, (2) a groundwater monitoring program to verify knowledge regarding the characteristics of groundwater flow, including periodic testing for releases from the repository, and (3) a geomechanical monitoring program to support decisions regarding operations and maintenance of underground openings. Only the groundwater program is expected to extend into the 30-year RCRA postclosure period. The EPA has established, as a certification criterion, that the monitoring programs in this application must be complementary with the RCRA programs that the DOE will be required to implement.

7.2.2 Monitoring Program Design

The requirements in 40 CFR § 191.14(b) and the criteria in 40 CFR § 194.42 can be translated into five screening criteria for selecting monitoring parameters and for developing monitoring plans. The monitoring plan should

- address significant disposal system parameters,
- address important disposal system concerns,
- obtain meaningful data in a short time period (50 FR 38081),
- preserve disposal system integrity, and

- be complementary with RCRA programs.

Each of these screening criteria is discussed below.

7.2.2.1 Significant Disposal System Parameters

In the certification criteria, the EPA states that

> The Department shall conduct an analysis of the effects of disposal system parameters on the containment of waste in the disposal system and shall include the results of such analysis in any compliance application. The results of the analysis shall be used in developing plans for preclosure and postclosure monitoring required pursuant to paragraphs (c) and (d) of this section (40 CFR § 194.42[a]).

The EPA also states that to the extent practicable, preclosure monitoring shall be conducted of significant disposal system parameter(s) as identified by the analysis conducted pursuant to paragraph (a) of this section (40 CFR § 194.42[c]). Though not explicitly stated in the criteria, it is appropriate that the same requirement hold for postclosure monitoring. The EPA defines significant parameters as follows: "A disposal system parameter shall be considered significant if it affects the system's ability to contain waste or the ability to verify predictions about the future performance of the disposal system" (40 CFR § 194.42[c]).

The terms significant, important, and sensitive have been used in the WIPP program to describe parameters with variability that impact the outcome of performance assessment. While these terms are for the most part interchangeable, the term significant is used in this discussion to maintain consistency with the terminology in the 40 CFR Part 194 criteria.

The DOE has conducted the requisite study of parameters that are inputs to the performance assessment. MONPAR (Attachment 1 of Appendix MON) provides a description of the methodology and results of that study. The DOE has implemented the criteria for significance in Appendix MON.

Verification of parameters used in the system performance analysis may occur in one or both of the following ways:

- measurement of physical or chemical conditions to see if they remain consistent with expected conditions or within the range of conditions incorporated into the assumptions and models, and

- measurement of physical and chemical processes that are currently based on professional judgment or regulatory guidance because data are not available.

The DOE considered the major processes and models described in Section 6.4 and the regulations and developed an initial list of potentially significant parameters as discussed in

Attachment 1 to Appendix MON (MONPAR). Parameters were screened for inclusion in the list based on the following criteria:

- the parameter represents one or more important aspects of a chemical or physical process or model,
- the parameter represents subjective uncertainty (such as spatial variabililty in a physical property or process),
- the parameter represents stochastic uncertainty (such as drilling rate), and
- the parameter proved to be moderately to highly sensitive in terms of modeling results in previous preliminary performance assessments.

The parameters identified through this screening process are summarized in Table 7-2 and discussed in MONPAR (Attachment 1 of Appendix MON).

The parameters identified in Table 7-2 are assigned high, medium, and low significance values. Those parameters that would significantly affect a release are assigned a HIGH level. Parameters that influence a release are assigned a MEDIUM value. Parameters that are not significant (represent spatial variability or an uncertainty in a given value) are assigned a LOW value. Those that were determined as having a high significance are shown in Table 7-3.

7.2.2.2 Important Disposal System Concern

This criterion is closely tied with the first in that, in the final analysis, the most significant parameters are related to important disposal system concerns. However, the DOE has included this category as a separate criterion to identify any other parameters that, while they are not significant in performance assessment, do describe important disposal system features. For example, the creep properties of the Salado can be considered an important feature of the disposal system, although the parameter analysis identified them as having a minor effect on the outcome of the analysis. Creep properties are identified in Appendix MON (Attachment 1, MONPAR) because they can provide a body of information that allows the DOE to evaluate its conceptual model of Salado creep closure.

In order to select these parameters for further evaluation, the DOE divided the disposal system into five major components: Salado and repository physical properties, Salado and repository hydrological properties, non-Salado hydrological properties, waste properties, and engineered barrier properties. Based on this division, the DOE revisited the list of potentially significant parameters and determined those parameters that were related to a measurable property of the disposal system. Those parameters are shown in Table 7-4.

Table 7-3. Disposal System Parameters Determined to be of Highest Significance to Disposal System Performance

Parameter	Significance to Containment	Significance to Verification
NATURAL PARAMETERS		
Salado anhydrite permeability	HIGH	HIGH
Salado brine composition	HIGH	HIGH
Culebra fracture spacing	HIGH	HIGH
Castile brine reservoir volume selection index	HIGH	HIGH
Castile brine reservoir pressure	HIGH	HIGH
Castile brine reservoir permeability	HIGH	HIGH
Castile brine reservoir rock compressibility	HIGH	HIGH
Castile brine reservoir volume selection index	HIGH	HIGH
Castile brine flux	HIGH	HIGH
Castile brine spatial distribution	HIGH	HIGH
Castile brine composition	HIGH	HIGH
WASTE AND REPOSITORY PARAMETERS		
Inundated steel corrosion rate without CO_2	HIGH	HIGH
Choice of oxidation state distribution	HIGH	HIGH
Solubility of nine radionuclides in Salado brine	HIGH	HIGH
Solubility of nine radionuclides in Castile brine	HIGH	HIGH
Humic colloid concentration in Salado brine	HIGH	HIGH
Humic colloid concentration in Castile brine	HIGH	HIGH
Culebra K_ds for dissolved radionuclides	HIGH	HIGH
Crushed salt seal component permeability (permeability selection index)	HIGH	HIGH
HUMAN INITIATED PARAMETERS		
Drilling rate	HIGH	HIGH
Waste particle diameter	HIGH	HIGH
Borehole permeability	HIGH	HIGH
Borehole plugging pattern (probability index)	HIGH	HIGH
Time between intrusions	HIGH	HIGH
Borehole location	HIGH	HIGH
Probability of encountering Castile brine reservoir	HIGH	HIGH
Waste activity	HIGH	HIGH
Effective shear resistance to erosion	HIGH	HIGH

Table 7-4. Parameters Related to Measurable Disposal System Properties

Parameter	Significance to Containment	Significance to Verification
SALADO PHYSICAL PARAMETERS		
Creep closure and stresses	LOW	LOW
Extent of deformation	LOW	LOW
Initiation of brittle deformation	LOW	LOW
Displacement of major deformation features	LOW	LOW
Natural temperature distribution	LOW	LOW
SALADO HYDROLOGICAL PARAMETERS		
Impure halite pore compressibility	LOW	LOW
Impure halite far-field pore pressure	MEDIUM	MEDIUM
Salado pore shape	MEDIUM	MEDIUM
Impure halite effective porosity	MEDIUM	MEDIUM
Impure halite permeability	MEDIUM	MEDIUM
Anhydrite permeability	HIGH	HIGH
Anhydrite pore compressibility	MEDIUM	MEDIUM
Salado residual brine saturation	MEDIUM	MEDIUM
Salado residual gas saturation	MEDIUM	MEDIUM
Salado brine quantity	LOW	LOW
Salado brine flux	MEDIUM	MEDIUM
Salado brine spatial distribution	LOW	LOW
Salado brine composition	HIGH	HIGH
Salado K_ds for dissolved radionuclides	LOW	LOW
Salado K_ds for colloidal radionuclides	LOW	LOW
Salado change in groundwater brine	LOW	LOW
Natural temperature distribution	LOW	LOW
DRZ permeability	MEDIUM	MEDIUM
DRZ effective porosity	MEDIUM	MEDIUM
DRZ brine flux	MEDIUM	MEDIUM
DRZ brine quantity and spatial distribution	LOW	LOW

Table 7-4. Parameters Related to Significant Disposal System Properties (Continued)

Parameter	Significance to Containment	Significance to Verification
NON-SALADO HYDROLOGICAL PROPERTIES		
Culebra transmissivity	MEDIUM	MEDIUM
Culebra advective porosity	MEDIUM	MEDIUM
Culebra fracture spacing	HIGH	HIGH
Culebra diffusional porosity	MEDIUM	MEDIUM
Culebra longitudinal dispersivity	LOW	LOW
Culebra groundwater quantity	LOW	LOW
Culebra groundwater flux	MEDIUM	MEDIUM
Culebra groundwater spatial distribution	LOW	LOW
Culebra groundwater composition	LOW	LOW
Castile brine reservoir pressure	HIGH	HIGH
Castile brine reservoir permeability	HIGH	HIGH
Castile brine reservoir rock compressibility	HIGH	HIGH
Castile brine reservoir brine volume	HIGH	HIGH
Castile brine flux	HIGH	HIGH
Castile brine spatial distribution	HIGH	HIGH
Castile brine composition	MEDIUM	MEDIUM
Natural temperature distribution	LOW	LOW
Culebra K_ds for six dissolved radionuclides	HIGH	HIGH
Culebra K_ds for humic and actinide-intrinsic colloidal radionuclides	MEDIUM	MEDIUM
Drilling rate	HIGH	HIGH
Effective decay constant for microbes	MEDIUM	MEDIUM
Culebra change in groundwater flow	MEDIUM	MEDIUM
WASTE RELATED PARAMETERS		
Waste area residual gas saturation	MEDIUM	MEDIUM
Waste area residual brine saturation	MEDIUM	MEDIUM
Waste area permeability	MEDIUM	MEDIUM
Brine wicking	MEDIUM	MEDIUM
Inundated steel corrosion rate with CO_2	LOW	LOW

Table 7-4. Parameters Related to Significant Disposal System Properties (Continued)

Parameter	Significance to Containment	Significance to Verification
Inundated steel corrosion rate without CO_2	MEDIUM	MEDIUM
Inundated microbial degradation rate	LOW	LOW
Humid microbial degradation rate	LOW	LOW
Gas quantity	MEDIUM	MEDIUM
Gas composition	LOW	LOW
Choice of oxidation state distribution	HIGH	HIGH
Solubility of nine radionuclides in Salado brine	HIGH	HIGH
Solubility of nine radionuclides in Castile brine	HIGH	HIGH
Humic colloid concentrations in Salado brine	HIGH	HIGH
Humic colloid concentrations in Castile brine	HIGH	HIGH
Waste particle diameter	HIGH	HIGH
Effective shear resistance to erosion	MEDIUM	MEDIUM
Waste activity	HIGH	HIGH
Waste tensile strength	MEDIUM	MEDIUM
Gravity factor for spalling	MEDIUM	MEDIUM
Strength factor for spalling	LOW	LOW
ENGINEERED BARRIER PROPERTIES		
Shaft DRZ permeability	MEDIUM	MEDIUM
Backfill porosity	LOW	LOW
Backfill permeability	LOW	LOW
Degree of backfill compaction	LOW	LOW
Backfill reconsolidation	LOW	LOW
Clay seal member permeability	MEDIUM	MEDIUM
Concrete seal member permeability	MEDIUM	MEDIUM
Asphalt seal member permeability	MEDIUM	MEDIUM
Seal residual gas saturation	LOW	LOW
Seal residual brine saturation	LOW	LOW
Seal pore shape	LOW	LOW
Long-term borehole permeability	HIGH	HIGH

7.2.2.3 Meaningful Data in a Relatively Short Time

The amount of time available for the DOE to obtain data regarding important disposal system parameters is approximately 150 years. This assumes a 50-year preclosure period and 100 years of active institutional controls. However, the DOE will continue monitoring programs for as long as needed if meaningful data are collected or are expected.

In screening parameters using this criterion, the DOE applied two qualifications. First, parameters had to be amenable to measurement within the disposal system and, second, parameter changes expected to occur within the first 150 years and affecting long-term disposal system performance had to be predictable. For example, parameters such as the shape of pore spaces cannot be reasonably measured and, therefore, would not become candidates for a monitoring program. Likewise, changes in parameters such as the actual brine concentration within the Salado are likely to be rapid initially and not necessarily diagnostic of the steady state that will exist over most of the regulatory time period.

The results of the screening of the parameters in Tables 7-3 and 7-4 are given in Table 7-5.

Table 7-5. Listing of Parameters That Can Produce Meaningful Data During Monitoring Period

Parameter	Comment
SALADO PHYSICAL PARAMETERS	
Creep closure and stresses	Can be measured during operations
Extent of deformation	Can be measured during operations
Initiation of brittle deformation	Can be measured during operations
Displacement of deformation features	Can be observed during operations
SALADO HYDROLOGICAL PARAMETERS	
Salado brine composition	Can be measured during operations
NON-SALADO HYDROLOGICAL PROPERTIES	
Culebra groundwater composition	Can be measured for entire period
Castile brine reservoir location	Can be observed for entire period
Drilling rate	Can be observed for entire period
Culebra change in groundwater flow	Can be observed for entire period
WASTE RELATED PARAMETERS	
Waste activity	Can be calculated using measurements made during waste characterization

In some cases, the parameter is indicated as a measurable parameter, meaning that it can either be directly monitored or be deduced from a monitoring program. Other parameters are indicated as observed. This means that the parameter represents an event that occurs at unspecified intervals or changes too slowly or too intermittently to be a viable monitoring candidate. For example, displacements of deformation features occur intermittently and can be observed only when they occur, even though other processes leading up to displacement (such as creep) can be monitored.

7.2.2.4 Preservation of Disposal System Integrity

Disposal system integrity could be compromised by drill holes, conduits, or other entries that are left in place to allow access to monitoring equipment. The requirement to avoid such conditions leads to the conclusion that the only viable monitoring systems are those that can be operated directly during operations, those that can transmit information without cabling (telemetry), and those that can be used to evaluate parameters using remote sensing techniques. Each is discussed briefly below. Table 7-6 shows the final screening of parameters in order to determine those that are candidates for a monitoring program. Table 7-7 identifies those parameters included in the preclosure and postclosure monitoring programs. The differences in Tables 7-6 and 7-7 are explained as follows. The presence of a DRZ surrounding the repository has been incorporated into performance assessment calculations. The properties of the DRZ have been characterized; they include altered hydrologic properties that are expected to enhance near-field fluid flow both to and from the repository. The initial conditions and enhanced fluid flow are considered moderately significant to disposal system performance. In an effort to simplify the calculations, the effects are maximized by the conceptual model and altered properties of the DRZ. This is believed to be a conservative choice with respect to the ultimate impact on predicted release.

Monitoring the DRZ hydrologic properties would not provide relevant information or verify assumptions used in performance assessment; therefore they will not be monitored during the operational period nor during the postclosure period. For more detail regarding DRZ-related parameters, see Appendix MON (Attachment 1, Section MONPAR.3.3).

Composition of Salado brines has been established through investigations. Brine composition is significant and is incorporated into performance assessment calculations. Based on the extensive experimental evidence collected, there is no indication that Salado brine composition will change over the regulatory period; thus it will not be routinely monitored during the operational period nor during the postclosure period. For more detail regarding Salado brine composition see Appendix MON (Attachment 1, Section MONPAR.2.2).

7.2.2.4.1 Evaluation of Monitored Parameters

The preclosure and postclosure parameters identified in Table 7-7 will be evaluated as a part of the plan described in Appendix MON. Significant deviations in expected values of any of these parameters from those ranges of values in the performance assessment models will be

Table 7-6. Parameters That Can Be Measured Without Violating Repository Integrity

Parameter	Comment
SALADO PHYSICAL PARAMETERS	
Creep closure	Direct measurement in open areas of the repository
Extent of deformation	Direct measurement in open areas of the repository
Initiation of brittle deformation	Direct measurement in open areas of the repository
Displacement of deformation features	Directly observed from other open areas of the repository
NON-SALADO HYDROLOGICAL PROPERTIES	
Culebra groundwater composition	Can be measured using existing or additional groundwater surveillance wells
Probability of encountering a Castile brine reservoir	Can be developed based on observations of drilling activity in Delaware Basin
Drilling rate	Can be developed based on observations of drilling activity in Delaware Basin
Culebra change in groundwater flow	Can be determined using existing or additional groundwater surveillance wells
WASTE RELATED PARAMETERS	
Waste activity	Limited to observations during waste characterization activities

Table 7-7. Preclosure and Postclosure Monitored Parameters

Monitored Parameter	Preclosure	Postclosure
Culebra groundwater composition	X	X
Culebra change in groundwater flow	X	X
Probability of encountering a Castile brine reservoir	X	X
Drilling rate	X	X
Subsidence measurements	X	X
Waste activity	X	
Creep closure and stresses	X	
Extent of deformation	X	
Initiation of brittle deformation	X	
Displacement of deformation features	X	

evaluated. Where applicable, any new information will be incorporated into the performance assessment conducted for recertification. Parameter values outside of expected ranges will also prompt the evaluation of models and their modification, where appropriate, for use in recertification performance assessment activity.

Culebra groundwater composition, Culebra changes in groundwater flow, Castile brine reservoir encounters, Castile brine reservoir pressure, and drilling rate parameters will be evaluated for substantiation that they remain within the range of values assumed in model development and performance assessment. Should there be a significant change outside the assumed range of values used in the performance assessment models, the DOE will evaluate and, where appropriate, modify models for incorporation into the next performance assessment recertification.

In the unlikely event that subsidence values fall significantly outside the range of values predicted and experienced elsewhere in the Delaware Basin, additional evaluation of the potential effects of such deviations will be conducted. If the evaluation requires changes to models used in the performance assessment, these changes will be made and the revised models incorporated into the recertification performance assessment.

The waste activity (see Appendix WCL for a detailed discussion) will be monitored to ensure compliance with the requirements of the LWA and that the values are within the range of values used in performance assessment models. Any significant deviation from expected values will be addressed by the DOE in a timely fashion to avoid any violation of the compliance certification.

Creep closure and stresses, extent of deformation, initiation of brittle deformation, and displacement of deformation features are all parameters that reflect on the geomechanical nature of the repository. Evaluation of these parameters influence the operational aspects of safe operation of the repository. However, should any of these parameters exhibit properties that are significantly outside the experience and expectations of the information baselines developed to date, the DOE will evaluate the impact on the design of the repository and the design of the shaft seal system.

The EPA will be notified of any deviation that the DOE evaluates as significant with respect to complying with the regulations or the certification of the WIPP as a safe repository.

7.2.2.4.2 Direct Measurement

Direct measurement includes current programs such as the underground geomechanical monitoring program and the groundwater surveillance program. In such cases, the monitoring equipment can be inspected, calibrated, and used with high reliability. Malfunctioning equipment can be easily repaired or replaced. Power requirements are met with portable power units such as rechargeable batteries or generators. In some cases, analog measurements can be made mechanically and recorded in notebooks. In other cases, digital logging

equipment is available to record large quantities of data and information. Direct measurement allows for changing the measurement parameters as environmental conditions change. Replicate samples can be taken easily if needed. Unusual conditions can be investigated to provide unambiguous interpretation of data.

7.2.2.4.3 Telemetry Systems

In the early 1970s to the mid 1980s, the U.S. Bureau of Mines and the Mine Safety and Health Administration demonstrated that reliable communications can be established between underground mines and the surface for the purpose of locating and rescuing trapped miners (see Powell 1976; Murphy and Parkinson 1978, 42). Low frequency radio equipment was demonstrated in numerous mine environments and at many depths. The systems evaluated used low-duty cycle transmitters connected to loop antennae powered by miners' cap lamp batteries. Although through-the-earth transmission of signals is feasible, any system that uses this type of telemetry must deal with the following design problems.

First, because the purpose of the telemetry is to obviate the need for cabling to the surface, all power must be self-contained. For the WIPP, this will require extending battery or portable generators beyond the tens of years that can now be achieved for low-duty cycle systems. Second, issues regarding durability must be addressed since the environmental conditions will be severe. Components will have to withstand the brine and gas environments that are predicted, as well as the effects of creep closure and repressurization. Third, reliability will have to be addressed since failed sensors cannot be replaced nor can calibrations be performed or adjustments made. Finally, in addition to the equipment issues, there are concerns about interpreting results in an environment where interference, such as background electromagnetic noise, can only be, at best, poorly characterized. While these issues and concerns can be addressed with technology development programs, it is doubtful that the high cost is justifiable for the limited amount of data that may be obtained from such systems.

7.2.2.4.4 Remote Sensing Systems

The use of remote techniques to determine the characteristics of the earth have been well established. Generally classified as geophysical measurements, these systems look for variations in a parameter within the earth in order to determine geological relationships. Typical parameters that are measured remotely are resistivity, acoustic velocity, magnetism, density, temperature, moisture content, radioactivity, and radiometry (infrared). The general conclusion is that the changes in the repository are too small (in scale), too far from the surface, and too slow to be detectable using remote techniques.

7.2.2.5 Complementary With RCRA Programs

The RCRA, as implemented by both the EPA Office of Solid Waste (OSW) and the NMED, requires that the owner and operator of a hazardous waste management facility prevent releases of hazardous constituents that are harmful to human health and the environment.

Where feasible, credible release pathways must be monitored to demonstrate that no releases above regulatory limits are occurring. In some cases, if monitoring is not feasible or if releases can be shown to be either not measurable or inconsequential, monitoring is not needed.

To satisfy these monitoring requirements, the DOE plans to implement the following programs:

- geomechanical monitoring program,
- VOC confirmatory monitoring program, and
- groundwater surveillance program.

Based on the approach the DOE has taken to monitoring program implementation, the criterion of compatibility with the RCRA program is met.

7.2.3 Monitoring Program Description

Based on the parameter screening described above and the analysis in Appendix MON, the DOE has selected a monitoring program with the following components:

- preclosure monitoring
  - geomechanical monitoring parameters are (25 years or until closure):

    Creep closure and stresses,
    Extent of deformation,
    Initiation of brittle deformation, and
    Displacement of deformation features.

  - VOC confirmatory monitoring parameters are (a minimum of 6 months after closure of first panel):

    1,1-Dichloroethylene,
    Carbon tetrachloride,
    Methylene chloride,
    Chloroform,
    1,1,2,2-Tetrachloroethane,
    1,1,1-Trichloroethane,
    Chlorobenzene,
    1,2-Dichloroethane, and
    Toluene.

- Waste Characterization monitoring parameters (25 years or until last waste shipment is made):

  Waste activity

- preclosure and postclosure monitoring parameters are (30 years after closure and as required by RCRA):[2]
  - groundwater surveillance:

    Culebra brine composition,
    Culebra change in groundwater flow direction, and
    Culebra well water level.

  - observation of drilling activities (100 years after closure):[2]

    Castile brine reservoir encounter,
    Castile brine reservoir pressure, and
    drilling rate.

- postclosure monitoring parameter (100 years after closure):[2]

  - subsidence monitoring.

Each of these programs is described in the following sections. Individual program plans are included in Appendices VCMP, GWMP, SMP and DMP.

7.2.3.1 Geomechanical Monitoring Program

The geomechanical monitoring program at the WIPP facility is an integral part of the DOE's ground control program (see Figure 7-10). Disposal rooms, drifts, and operational area excavations will be monitored to provide confirmation of structural integrity. Geomechanical data on the performance of the repository shafts and excavated areas are currently collected as part of the geotechnical field monitoring program. The results of the geotechnical investigations are reported annually. The report describes monitoring programs and geomechanical data collected during the previous year.

The instrumentation in Table 7-8 is available for use in support of the geomechanical program. The minimum instrumentation for the unexcavated disposal areas designated as Panels 2 through 8 is one borehole extensometer installed in the roof at the center of each disposal room. The roof extensometers will monitor the dilation of the immediate salt roof beam and possible bed separations along clay seams. Additional instrumentation may be

[2] Or until the DOE can demonstrate to the EPA that there are no significant concerns to be addressed by further monitoring.

Table 7-8. Instrumentation Used in Support of the Geomechanical Monitoring System

Instrument Type	Features	Parameter Measured	Range
Borehole extensometer	The extensometer provides for monitoring the deformation parallel to the borehole axis. Units suitable for up to five measurement anchors in addition to the reference head.	Cumulative deformation	0-2 inches
Borehole television camera	Closed circuit television may be used for monitoring areas otherwise inaccessible, such as boreholes or shafts.	Video image	n/a
Convergence points and tape extensometers	Mechanically anchored eyebolts to which a portable tape extensometer is attached.	Cumulative deformation	2-50 feet
Convergence meters	Includes wire and sonic meters. Mounted on rigid plates anchored to the rock surface.	Cumulative deformation	2-50 feet
Inclinometers	Both vertical and horizontal inclinometers are used. Traversing type of system in which a probe is moved periodically through casing located in the borehole whose inclination is being measured.	Cumulative deformation	0-30 degrees
Rock bolt load cells	Spool type units suitable for use with rock bolts. Tensile stress is inferred from strain gauges mounted on the surface of the spool.	Load	0-300 kips
Earth pressure cells	Installed between concrete keys and rock. Preferred type is a hydraulic pressure plate connected to a vibrating wire transmitter.	Lithostatic pressure	0-1,000 pounds per square inch
Piezometer pressure transducers	Located in shafts and of robust design and construction. Periodic checks on operability required.	Fluid pressure	0-500 pounds per square inch
Strain gauges	Installed within the concrete shaft key. Suitably sealed for the environment. Two types used—surface mounted and embedded.	Cumulative deformation	0-3,000 microinches per inch (embedded) 0-2,500 microinches per inch (surface)

installed as conditions warrant. Panel 1 has already been excavated and is heavily instrumented, as shown in Figure 7-10.

Polling of the geomechanical instrumentation will be performed at least once every month. This frequency may be increased to accommodate any changes that may develop. The results from the remotely read instrumentation will be evaluated after each scheduled polling. Documentation of the results will be provided annually in the Geotechnical Analysis Report.

The instrumentation system provides for data maintenance, retrieval, and presentation. The instrumentation system cognizant engineer first retrieves the data from the instrumentation system and verifies their accuracy by assuring the measurements were taken in accordance with applicable instructions and procedures. Next, the cognizant engineer reviews the data after each polling to assess the performance of the instrument and the excavation. Data that look anomalous are detected during this polling and are investigated to determine the cause (for example, instrumentation problem, error in recording, or changing rock conditions). The data are then processed to calculate various parameters such as the change between successive readings and deformation rates. The results of this assessment are reported to the ground control cognizant engineer and operations personnel. The stability of an open panel excavation is generally determined by the rock deformation rate. Unexpected deformation rates are investigated by Geotechnical Engineering to determine if remediation is needed.

The evaluation of the performance of the excavation is also performed by Geotechnical Engineering. These evaluations will provide an estimate of the stand-up time of the excavation. If the trend is toward adverse (unstable) conditions, then the results of these assessments are reported to the operations manager to determine appropriate operational responses.

Roof conditions are assessed from observation boreholes and extensometer measurements. Measurements of room closure, rock displacements, and observations of fracture development in the immediate roof beam are used to evaluate the performance of a panel. A summary of the Panel 1 monitoring program was presented to the members of the Geotechnical Experts Panel in 1991, who concurred that the monitoring was adequate to determine deterioration within the rooms and could provide early warning of deteriorating conditions.

The assessment and evaluation of the condition of WIPP excavations is an iterative, continuous process using the data from the monitoring programs. Criteria for corrective action are continually reevaluated and reassessed based on total performance to date. Actions taken are based on these analyses and on planned utilization of the excavation. Because WIPP excavations are in a natural geologic medium, there is inherent variability from point to point. The principle adopted is to anticipate potential ground control requirements and implement them in a timely manner rather than to wait until a need arises.

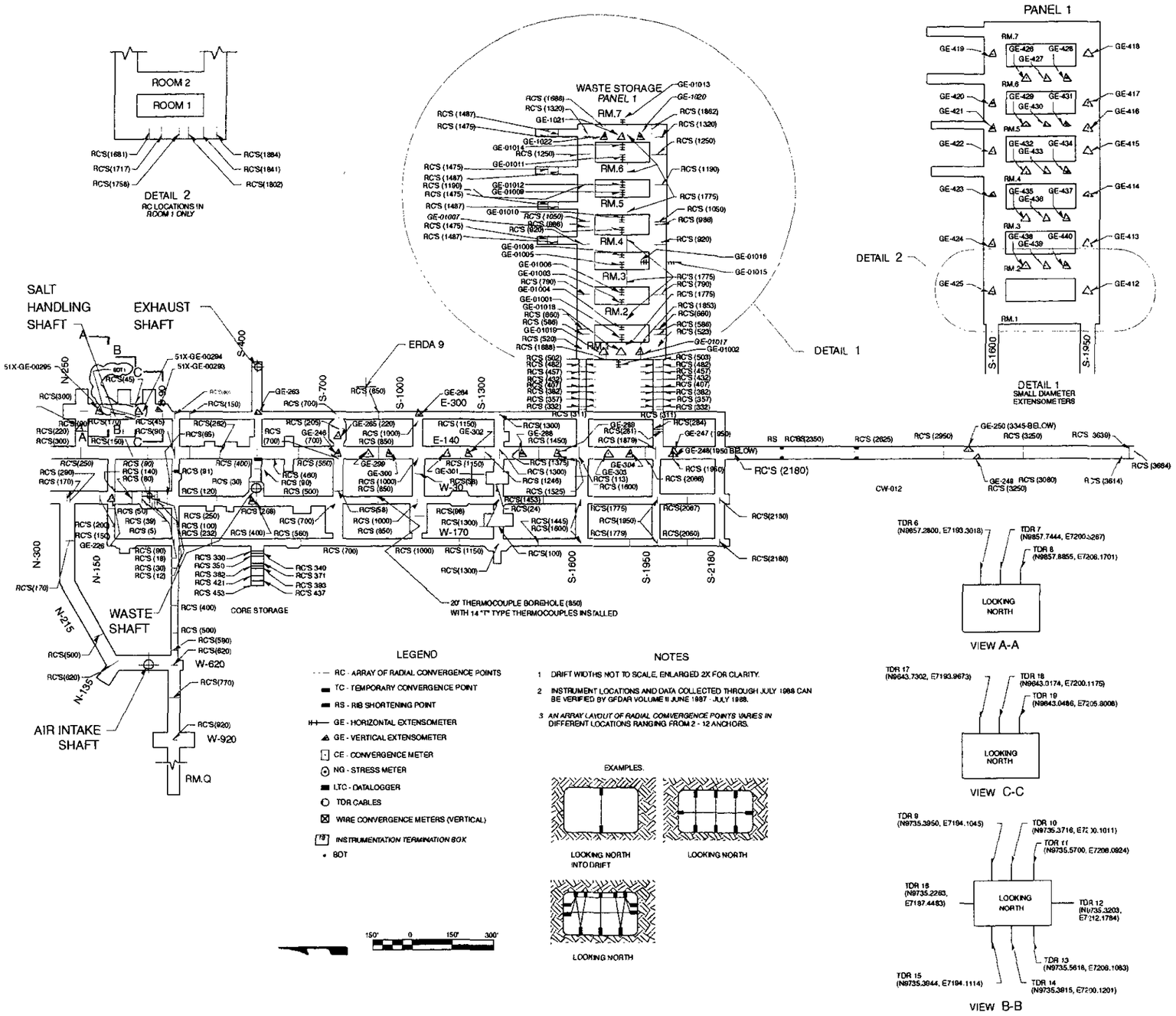

Figure 7-10. Layout and Instrumentation of Geomechanical Monitoring System as of January 1996

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Both creep closure of the excavation and the development of the DRZ are included in the conceptual model of disposal system performance. Creep closure is discussed in Section 6.4.3.1 and Appendix PORSURF. The numerical model for predicting creep closure has been developed based on both theoretical considerations and observations. The goal of monitoring is to detect any substantial and detrimental deviations from the expected behavior of Salado halite and to determine the significance of such deviations. Data are analyzed after each round of measurements and results are distributed for use in making ground control decisions. A compilation of data (current and previous) is published annually in the Geotechnical Field Data and Analysis Report. This compilation is useful determining long-term trends in the behavior of underground openings and can be a diagnostic tool for determining substantial and detrimental deviations for expected performance.

The DRZ is modeled as discussed in Section 6.4.5.3. It is assumed that the DRZ maintains its permeability throughout the model period as shown in Table 6-17. Marker bed (MB) 138 and 139 are modeled to be separate geological units with permeabilities lower than those in the DRZ as shown in Table 6-16. Substantial and detrimental deviations from these expectations may impact repository performance. Consequently, as discussed in Section 4.3 of Appendix GTMP, observations of excavation effects, along with the other geotechnical measurements will be useful to detect deviations in expectations for near-term DRZ development.

7.2.3.2 VOC Confirmatory Monitoring Program

As documented in the WIPP Safety Analysis Report (SAR) (DOE 1990, 6.1-34), airborne emission is the only credible contaminant release pathway from the WIPP facility during disposal operations. The panel closure design basis requires this pathway to be controlled during operations and the final facility closure requires that it be eliminated. The panel closure design is described in Appendix PCS. Final facility shaft sealing is described in Appendix SEAL. In order to determine the effectiveness of panel closures, the DOE has targeted the measurement of VOC emissions as diagnostic of repository processes that may be underway within closed panels. The DOE has prepared a VOC confirmatory monitoring plan. The plan has been prepared so that the DOE can show that the assumptions and predictions used to demonstrate compliance to the environmental performance standards are valid. Verification is demonstrated when observed emissions are equal to or less than those predicted. The VOC Confirmatory Monitoring Plan (VCMP) is provided in Appendix VCMP. The VCMP includes monitoring design, sampling and analysis procedures, and quality assurance objectives.

In its application to the NMED for a hazardous waste facility operating permit, the DOE demonstrated compliance with the environmental performance standards of 20 NMAC 4.1, Subpart V, § 264.601(c). Appendix VCMP describes a sampling and analysis program to confirm the theoretical calculations. The monitoring program is capable of quantifying VOC concentrations in the ambient mine air at the WIPP. The VCMP addresses the following information requirements:

- rationale for the design of the monitoring program, based on possible pathways, operations, engineered and natural barriers, and monitoring locations optimized for detection, and

- descriptions of the specific elements of the monitoring program, including the type of monitoring, the location of stations, the frequency of sampling, the target analytes, the schedule for implementation, the equipment used, the sampling and analytical techniques, and the data recording and reporting procedures.

While the quantification of VOCs is not of direct relevance to this application, the rate of VOC emission is of direct interest because it is a function of two inter-related repository properties. These are the extent of deformation (creep closure) and gas-producing processes. Both gas generation and creep closure will lead to the pressurization of the closed panel during operations. This pressurization will become the driving force for VOC emissions through and around the closure system. Abnormally high rates of pressurization may indicate a substantial and detrimental deviation from expected conditions requiring further investigation.

The DOE will collect air samples upstream and down stream of Panel 1 beginning just prior to waste emplacement and proceeding until at least six months following completion of panel closure. The DOE will continue monitoring until the criteria for terminating monitoring are met. These criteria are established in Appendix VCMP (Section 3.4). DOE's waste characterization program requires 100 percent measurement of headspace gases. This information will be available to the DOE through the WIPP Waste Information System (WWIS), which is described in Chapter 4.0.

7.2.3.3 Groundwater Surveillance Program

In the development of the WIPP monitoring programs, potential pathways for release of hazardous constituents to the environment were evaluated. This evaluation indicated no credible release pathway via surface water. The DOE has prepared a groundwater monitoring plan (GMP), as presented in Appendix GWMP. The appendix describes the basis for the GMP, the organization of the program, the quality assurance for the GMP, and the sampling program description. Sampling locations are shown in Figure 7-11. Sampling frequency will be annual. Analytes of interest for groundwater sampling and other sampling programs[3] are defined in Table 7-9. Analysis of samples is performed by a commercial laboratory that participates in the EPA contract laboratory program. Methods are specified in procurement documents and are selected to be consistent with EPA recommended procedures in SW 846 (EPA 1988). For the GMP, the principal goal of data analyses is the comparison of a data point or data set to equivalent data collected at another location and time (such as preoperational baseline data or data collected at a control location), or to a fixed standard.

[3] Discussion of other sampling programs is provided in Appendix EMP.

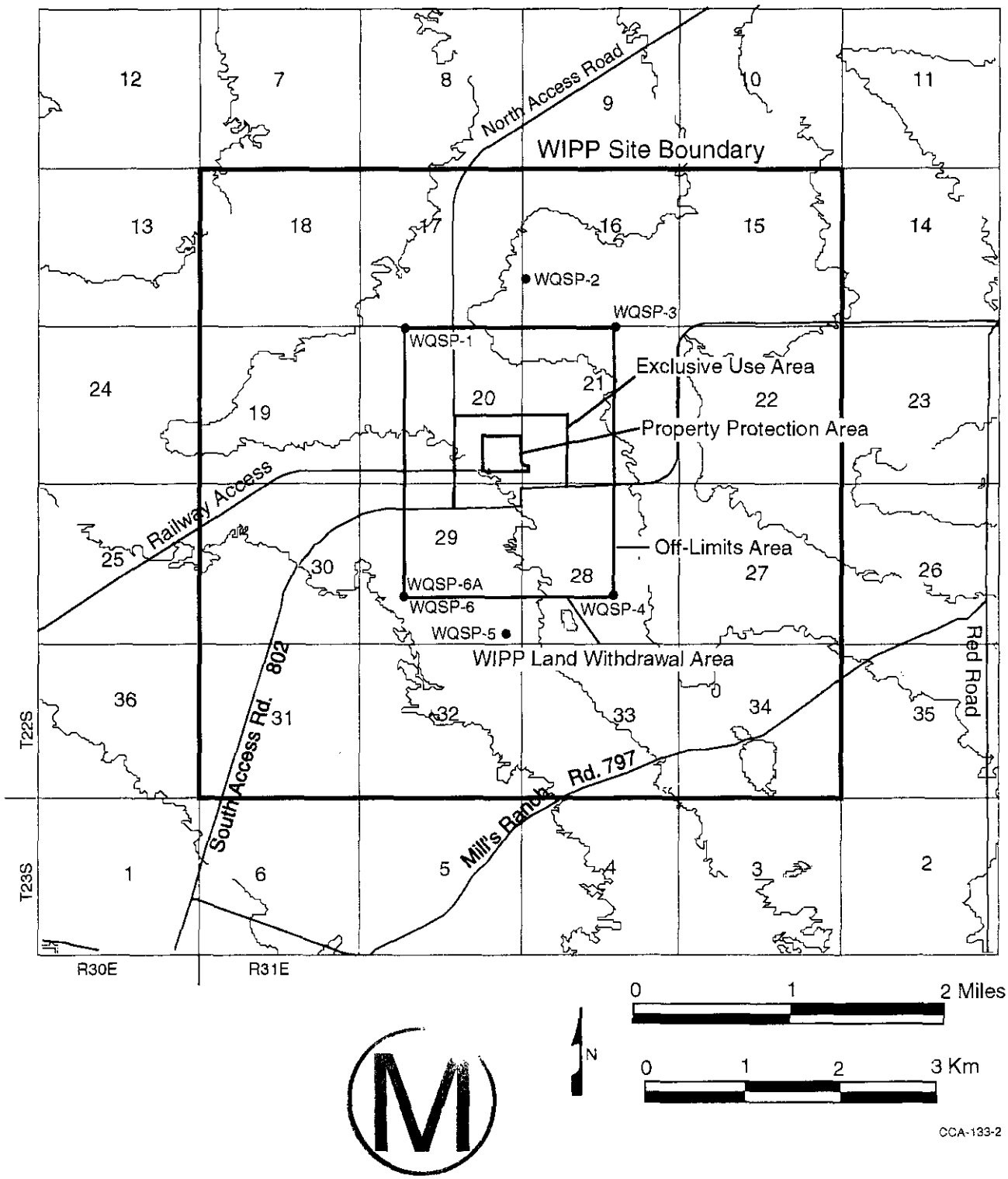

Figure 7-11. Location of the New Water Quality Sampling Wells

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Table 7-9. Typical Environmental Surveillance Analysis Schedule

Type of Sample	Analysis
Liquid influent	Radionuclides
Liquid effluent	Specific radionuclides, chemical constituents
Airborne effluent	Gross β, specific radionuclides
Meteorology	Temperature, wind speed, wind direction, precipitation, dewpoint, barometric pressure
Air quality	Total suspended particulates
Vegetation radionuclides	Specific radionuclides
Beef radioanalysis	Specific radionuclides
Game bird radioanalysis	Specific radionuclides
Rabbit radioanalysis	Specific radionuclides
Fish radioanalysis	Specific radionuclides
Deer radioanalysis	Specific radionuclides
Soil radioanalysis	Specific radionuclides
Surface-water radioanalysis	Specific radionuclides
Groundwater analysis	Specific radionuclides, chemical constituents[a]
Sediments radioanalysis	Specific radionuclides
Aerial photography	Area of land disturbed
Wildlife survey	Bird and small mammal population densities

Legend:

Specific radionuclides = ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{233}U, ^{241}Am, ^{243}Am, ^{244}Cm, ^{232}Th, ^{237}Np, ^{226}Ra, ^{137}Cs, ^{90}Sr, ^{60}Co, U_{nat}, and Th_{nat}.

Chemical constituents = chloride; iron; manganese; phenols; sodium; sulfate; pH; specific conductance; total organic carbon; total organic halogen; specified RCRA constituents; antimony; arsenic; barium; beryllium; cadmium; chromium; fluoride; lead; mercury; nickel; nitrate; selenium; silver; thallium zinc; endrin; methoxychlor; toxaphene; 2,4-D; 2,4,5-TP silvex; radium; turbidity; coliform bacteria. Additional analytes may be specified in the WIPP facility hazardous waste permit.

[a] For the purposes of establishing baseline values in wells Water Quality Sampling Program (WQSP) 1-6 and 6a, the analyses will include all 40 CFR 264 Appendix IX constituents.

Comparisons between data sets are performed using standard statistical tests. The selection of the specific test is dependent upon the relative power of the test and the degree to which the underlying requirements of the test are met. In addition to tests comparing data from distinct locations and times, trend analyses are performed on time series where sufficient data exist.

Citation of the source of the test method or the software used to perform the tests will be made when results are reported. Data and subsequent calculated values are reported in the annual site environmental report.

The two parameters of interest from the groundwater surveillance program are the composition of the Culebra groundwater and water levels. Significant and persistent changes in the composition of the Culebra groundwater will be investigated and impacts to the modeling assumptions for long-term performance in Section 6.4.6.2 will be evaluated. Large and rapid water-level fluctuations may be diagnostic of nearby human activity such as potash mining and fluid injection and withdrawal. Water-level changes within the groundwater modeling domain in Section 6.4.6.2 that cannot be explained either based on observed trends or on past experience will be investigated and assessed relative to the assumptions made in the regional groundwater flow model.

7.2.3.4 Observation of Drilling Activities

In preparing this application, the DOE developed a database of drilling activity within the Delaware Basin. In addition, the DOE has an ongoing program of field checking each well that is drilled within one mile of the WIPP site boundary. Field checking includes verifying the location as listed on the Application for Permission to Drill (APD), monitoring drilling and completion activities, and noting abandonment and plugging. Both the maintenance of the database and the field observation program will be continued throughout the operational period to develop additional statistics on the following parameters:

- drilling rates,
- drilling practices,
- Castile brine reservoirs encountered,
- Castile brine characteristics (where available), and
- plugging practices.

Data collected will be addressed as appropriate in the recertification process. Any analyses that indicate that parameter values are changing will be studied to evaluate the impact of the changes.

Significant changes in drilling practices, such as borehole diameters, plug and abandonment practices, mining techniques, Castile brine occurrence, and injection well use will be evaluated for potential impacts on disposal system performance. Any significant deviations noted will be reported to the EPA.

7.2.3.5 Subsidence Monitoring

Subsidence monitoring is accomplished with a Class I leveling survey. The surveys will be performed every ten years during the operational phase and thereafter.

The leveling survey procedures ensure that the data are documented and validated. The data will be included in the baseline database. A procedure will be developed to implement the monitoring program.

The monitoring program includes the following:

- management of the disposal phase monitoring program,
- maintenance of monitoring procedures and quality assurance/quality control documents,
- performance of all necessary field work,
- maintenance of the subsidence network,
- maintenance (and revision as necessary) of the monitoring schedule,
- maintenance and storage of baseline database,
- review of data and evaluation of performance,
- eventual decommissioning of the disposal system monitoring program, and
- archiving of monitoring data.

Subsidence predictions exist of the WIPP. These will be reevaluated at the time of closure. Subsidence measurements will be used to compare actual subsidence with predictions. Significant deviations between expected subsidence and actual subsidence will be investigated to determine if a substantial and detrimental deviation in the expected performance of the repository is indicated.

7.2.4 Reporting

The results of the DOE's monitoring program will be submitted annually. The report will include the results from the previous year, plus any cumulative information that is useful in interpreting the data. The annual report will contain a summary assessment of results to ensure that the performance of the repository can be evaluated on a continuous and consistent basis. Other reports, such as those stipulated in 40 CFR § 194.4 (b)(3), will be issued when necessary.

7.3 Passive Institutional Controls

Passive institutional controls, as opposed to active institutional controls, are controls that once established, can be expected to remain effective with no on-site human support. The DOE will implement passive institutional controls that involve multiple types and multiple levels of passive controls to make human intrusion into the disposal site unlikely. To accomplish this, the DOE intends to use several types of monuments and markers, land ownership, and written notations in land records in numerous locations (see Section XVI of Appendix PIC). Written documentation will include information on the location, design, and disposal contents and hazards, as well as stipulations on allowable land uses. Components of the passive controls system will be instituted at the site and at remote locations (see Appendix PIC).

As technology advances, this design concept will be revisited over the operational lifetime of the WIPP. If the DOE believes the design can be enhanced, changes will be proposed during the recertification process for EPA approval. The program described in Appendix PIC will fulfill the requirements of 40 CFR Part 191 and satisfy the certification criteria of 40 CFR Part 194.

7.3.1 Requirements for Passive Institutional Controls

The EPA has specified that "[d]isposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable" (40 CFR § 191.14[c]). The EPA then goes on to define passive institutional controls to mean "(1) permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system" (40 CFR § 191.12[e]). The DOE has interpreted this regulatory language to mandate the development and implementation of a system of passive institutional controls consistent with those components listed in the EPA's definition in order to protect the integrity of the disposal system for as long as practicable after disposal.

Guidance is provided by the EPA in 40 CFR § 194.43 on what subject areas must be addressed in order to demonstrate compliance with the regulation. Three subject areas must be addressed: (a) detailed descriptions of the passive institutional controls must be provided, (b) the period of time that the passive institutional controls are expected to endure and be understood must be estimated, and (c) credit for the passive institutional controls in reducing the likelihood of inadvertent human intrusion in performance assessments must be justified for the proposed time period. Additional guidance is provided in EPA (1996b) indicating what documentation is required in the compliance application to address 40 CFR § 194.43(a), the need for rationales to explain the estimates of how long the passive institutional controls are expected to endure and be understood in 40 CFR § 194.43(b), and the limitations of effectiveness and duration of the effectiveness of the passive institutional controls in performance assessment to address 40 CFR § 194.43(c).

7.3.2 Objectives for Passive Institutional Controls

As prescribed by the standards, the objectives of DOE's passive institutional controls for the WIPP are to convey the following:

- location,
- facility design,
- content, and
- hazard.

The passive institutional controls program described within this application will be effective in accomplishing these objectives (see Appendix EPIC, Section EPIC.6).

7.3.3 Implementation of the Passive Institutional Controls Program

The DOE began addressing the issue of passive institutional controls in the context of the assurance requirements by convening two panels of experts to identify what future societies might be like (Hora et al. 1991). The panels were convened so that the appropriate types of messages, the contents of the messages, and the types of media for transmitting the messages can be selected and to identify design concepts for the system of markers at the repository footprint (Trauth et al. 1993), which is one of the passive institutional controls. The work of the two panels was completed prior to promulgation of 40 CFR Part 194. To address the issues of the passive institutional controls in addition to the markers at the repository footprint and to incorporate the concept of practicable into the design, the DOE developed a conceptual design, which is included as Appendix PIC. With the promulgation of 40 CFR Part 194, the EPA provided guidance on how credit for the passive institutional controls deterring inadvertent human intrusion can be obtained for use in performance assessment. To address the issue of credit for passive institutional controls, the DOE has produced Appendix EPIC.

The timing and duration of the implementation of passive institutional controls is depicted in Figure 7-12.

7.3.3.1 Definition of Passive Institutional Design Appropriate for the WIPP

In deciding which passive institutional controls are appropriate for the WIPP, the DOE was guided by the regulatory language in 40 CFR § 191.14(c) that states that the controls should be practicable. The DOE is expected to address the components of the passive institutional controls listed in the definition of 40 CFR § 191.12(e). The components of the passive institutional controls for the WIPP consist of (1) monuments that define the boundary of the withdrawal area, (2) markers at the footprint of the repository that consist of monuments that identify the outer boundary of the subsurface facility, a berm surrounding the repository

footprint, an information center on the surface at the center of the repository footprint, a buried room halfway between the information center and the berm, a buried room halfway between the berm and the hot cell, and randomly spaced buried markers distributed across the repository footprint, (3) sets of records distributed to national and international archives, (4) sets of records distributed to records centers locally, nationally, and internationally (both those of a general nature and those specializing in land and resource use), (5) government control and land-use restrictions, and (6) other means of communication, such as encyclopedias, dictionaries, textbooks, and various maps and road atlases. Appendix PIC contains a detailed description of the designs of each of these components.

Trauth et al. (1993) examined a variety of configurations and materials in concluding that a system comprised of natural materials incorporating massive structures with messages provided in an enduring configuration offered the best system for permanently marking the site. The permanent marker system incorporates these concepts and thus is the best system of passive institutional controls for permanently marking the repository. The use of archives and national publications as described in Appendix PIC is the most extensive means of widespread distribution of the WIPP information. Use of radio or television is transient and will not provide the long-term societal memory.

7.3.3.1.1 *Markers*

Two groups of experts, the Futures Panel and the Markers Panel, were established to examine the issues involved with designing an effective system of permanent markers. Hora et al. (1991) incorporates judgments of the Futures Panel and discusses the underlying physical and societal factors that would influence society and the likely modes of human intrusion at the WIPP site.

The Hora et al. report was an important reference and source of information for the preparation of Trauth et al. (1993). Trauth et al. (1993) reports the results of the Markers Panel, which considered various concepts of marking the site and conveying to future generations information regarding the presence of dangerous waste material and the potential consequence of intrusion into the waste repository. Appendix PIC (Section I) is a modification of the ideas developed by this panel.

Appendix PIC sets forth the permanent markers system for the WIPP facility. This system involves the use of surface monuments, small subsurface warning markers, buried rooms, and large earthen structures marking the WIPP repository footprint on the surface. Appendix EPIC (Section EPIC.6) indicates the period of time during which passive institutional controls will be effective.

The surface monuments are large monuments erected on the surface at both the repository footprint and the controlled area boundaries. To facilitate fabrication and shipping of the monuments, each monument will consist of two separate stones connected by a tendon joint. The large monuments will be engraved with Level II and III messages and Level IV

pictographs as described in Appendix PIC (Section IV).[4] Figures 7-12 and 7-13 provide the dimensional characteristics of the large monuments. The monuments intended for marking the controlled area boundaries will differ from the monuments marking the repository footprint. Each footprint monument will be inscribed with the Level II and III messages in seven languages, the six official United Nations languages (English, French, Spanish, Chinese, Russian, and Arabic), and Navajo. The controlled area boundary monuments will be inscribed with warning messages. Trauth et al. (1993, Appendix F) discusses in some detail the selection of these languages by the Markers Panel.

The monuments will be quarried from granite and shipped by rail to the WIPP site. Each monument base will be soundly founded by excavating into the near-surface caliche. After emplacing the base monument, the excavation will be backfilled and the upper monument will be placed over the base tendon.

The small warning marker is shown in Figure 7-14. The Level II messages placed on the small subsurface warning markers will be in the seven languages previously listed. However, each marker will have the message in only one of the seven languages. Warning markers will be placed throughout the repository footprint and within the berm. The warning markers will be made of a diversity of durable materials, such as granite, aluminum oxide, and fired clay, thus improving the likelihood that at least some of the markers will endure for thousands of years.

The small buried warning markers will be randomly spaced in locations and at depths to provide a reasonable expectation of discovery by any organized exploration effort, but to discourage organized efforts at collecting the markers. The current petroleum industry practice in the Delaware Basin is to remove surface soil down to the caliche layer over an area

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[4] Five levels of messages will be used in the permanent marker system.

- Level I conveys the message that the site is man-made. The message itself is in the physical form of the marker system and the effort expended in constructing it.
- Level II conveys the message that something dangerous is buried here and that no digging or drilling should be conducted. This message is carried in seven languages uniformly distributed among the subsurface warning markers. Each marker has the message in a single language. The Level II message is also engraved on each monument in seven languages.
- Level III conveys basic information that tells what, why, when, where, who, and how. This message is carried by the monument markers.
- Level IV conveys complex information in seven languages and is stored in the permanent structures buried underground and the information center on the surface.
- Level V is archival and involves storing more complete rulemaking records than the messages provided at the WIPP site. These records are not stored at the site, but will be located in various public access facilities at the local, state, federal, and international levels.

sufficiently large to set up a drilling rig and dig a mud pit. Nominally, this area is 50,000 square feet (4,648 square meters). By placing the small warning markers above the caliche at intervals of a few feet, several of the warning markers should be unearthed during any soil clearing operation.

The inclusion of a berm in Figure 7-15 in the permanent marker design is based upon the following criteria (see Appendix PIC, Section VII, for more detail).

- The surface footprint of the repository should be essentially outlined by some enduring structure.
- The structure should be sufficiently massive to provide reasonable expectation that it will endure for thousands of years.
- The structure's profile should minimize the likelihood that it can become buried by shifting sands or that characteristics of the profile may lead to fabrication stresses affecting the ability of the structure to retain its configuration.
- The structure should be constructable without the need for sophisticated equipment or processes.
- The construction materials should be reasonably available to the WIPP site and have little intrinsic value.
- The cost should not be disproportionately high for the advantages that the alternative provides.
- To the extent practicable, the nature of the structure should lend itself to testing over a period of two to five decades.

The berm is proposed to encompass the repository footprint. Figure 7-15 also depicts the berm cross section.

To provide a distinctive magnetic signature for the berm, large permanent magnets buried at intervals in the berm will be used. These magnets will produce a detectable signal with current airborne detection equipment. The magnetic signal's geometric form will provide strong indication that it could only have been humanly engineered. This magnetic signature should motivate any organization capable of magnetic surveying to further investigate this anomaly prior to initiating drilling activities.

Similarly, to provide a distinctive radar-reflective signature unique from the surrounding terrain, trihedrals fabricated from metal will be buried in the berm. Bellus and Eckeman (1994) provide a description of the trihedrals.

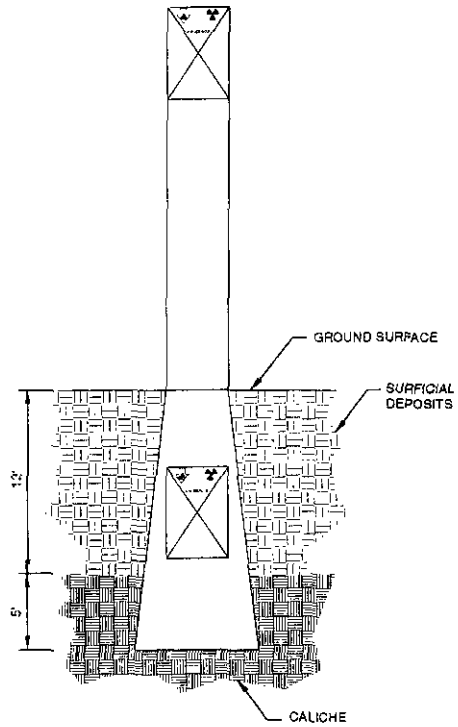

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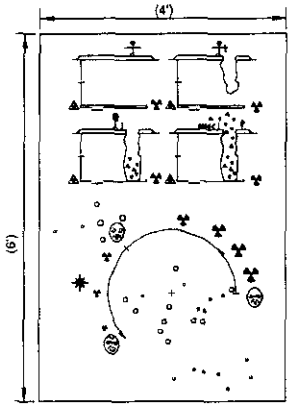

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NOTE 6

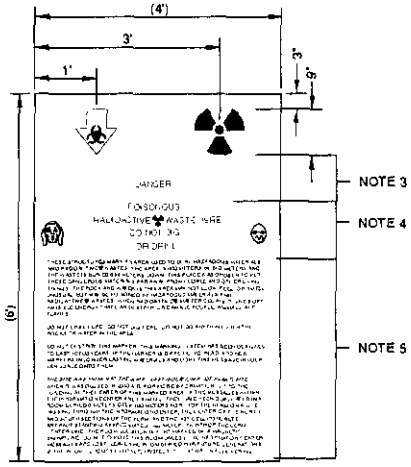

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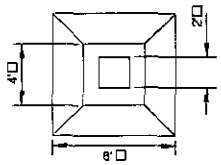

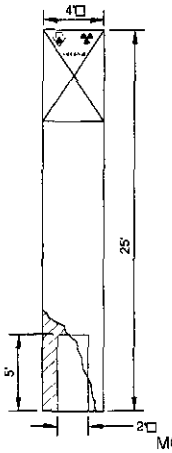

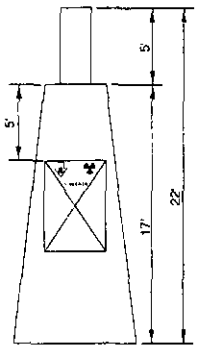

MONUMENT FABRICATION

NOTES:

1. MONUMENT TO BE HEWN FROM TWO SOLID PIECES OF GRANITE.
2. *MESSAGE TO BE CARVED INTO STONE FACE AND GENERAL LOCATIONS* AS SHOWN ON DRAWING. THE MESSAGE WILL APPEAR SEVEN TIMES ON THE MONUMENT, ONCE IN EACH LANGUAGE LISTED BELOW. THE MESSAGE WILL APPEAR AT THE TOP OF THE MONUMENT ON THREE FACES, LEAVING ONE BLANK FACE. IT WILL APPEAR ON FOUR SURFACES AT THE BOTTOM.
   A. ENGLISH
   B. SPANISH
   C. RUSSIAN
   D. FRENCH
   E. CHINESE
   F. ARABIC
   G. NAVAJO
3. THE LEVEL I MESSAGE WILL BE IN 3" HIGH LETTERS WITH A 3" SPACE ABOVE AND A 3" SPACE BELOW.
4. THE LEVEL II MESSAGE WILL BE IN 1 1/2" HIGH LETTERS WITH A 1" SPACE BETWEEN LINES AND A 2" SPACE BELOW THE BOTTOM LINE OF THE MESSAGE.
5. THE LEVEL III MESSAGE WILL BE IN 1" HIGH LETTERS WITH A 5/8" SPACE BETWEEN THE LINES. THERE WILL BE A 1 1/2" SPACE BETWEEN THE PARAGRAPHS OF THE MESSAGE.
6. THE DIAGRAM INSCRIPTION WILL APPEAR ON THE BLANK FACE ON THE TOP OF THE MONUMENT. THE DIAGRAM DESCRIBES THE HAZARDS OF DIGGING HERE AND HOW LONG THAT HAZARD WILL EXIST.

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Figure 7-12. Repository Footprint Perimeter Monument Configuration

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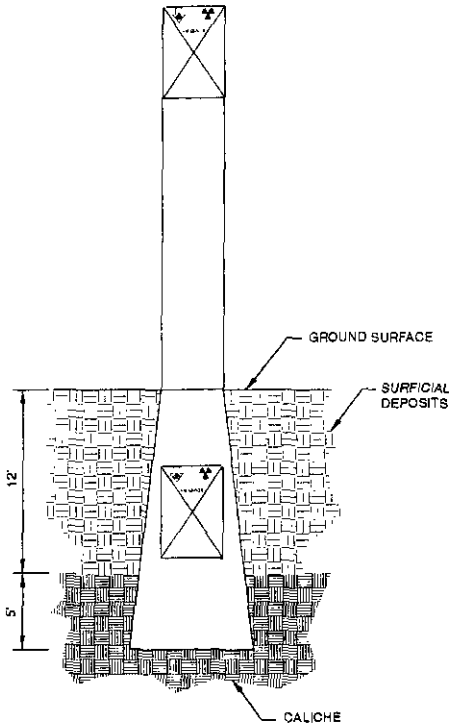

MONUMENT EMPLACEMENT

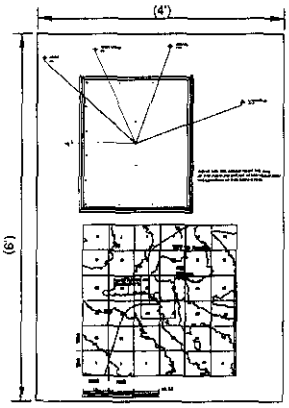

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NOTE 6

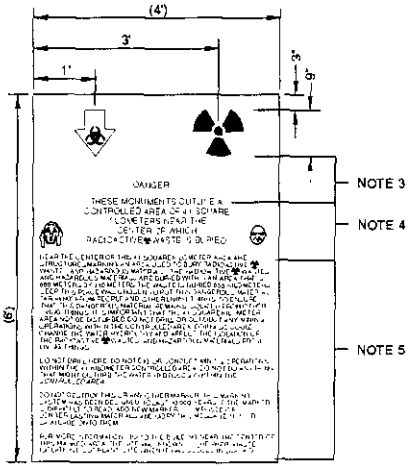

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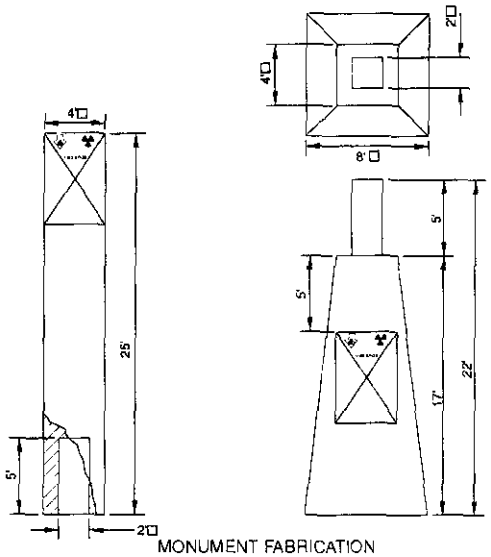

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3. THE LEVEL I MESSAGE WILL BE IN 3" HIGH LETTERS WITH A 3" SPACE ABOVE AND A 3" SPACE BELOW.
4. THE LEVEL II MESSAGE WILL BE IN 1 1/2" HIGH LETTERS WITH A 1" SPACE BETWEEN LINES AND A 2" SPACE BELOW THE BOTTOM LINE OF THE MESSAGE
5. THE LEVEL III MESSAGE WILL BE IN 1" HIGH LETTERS WITH A 5/8" SPACE BETWEEN THE LINES. THERE WILL BE A 1 1/2" SPACE BETWEEN THE PARAGRAPHS OF THE MESSAGE.
6. THE DIAGRAM INSCRIPTION WILL APPEAR ON THE BLANK FACE ON THE TOP OF THE MONUMENT. THE DIAGRAM DESCRIBES THE LOCATION OF THE BERM AND THE LOCATION OF THE INFORMATION CENTER BY USING THE STARS.

CCA-113-2

Figure 7-13. Controlled Area Perimeter Monument Configuration

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Diameter of Disk is 23 cm. (9 in.)
Not to Scale

CCA-114-2

Figure 7-14. Small Buried Warning Marker

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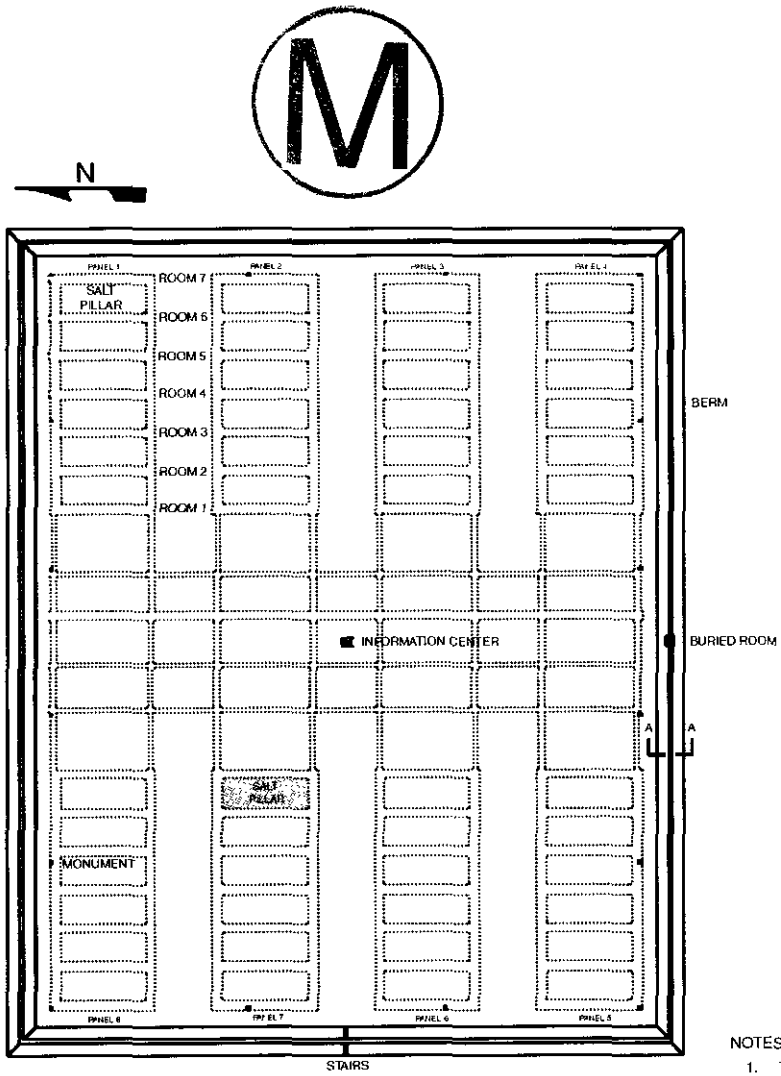

BERM LOCATION

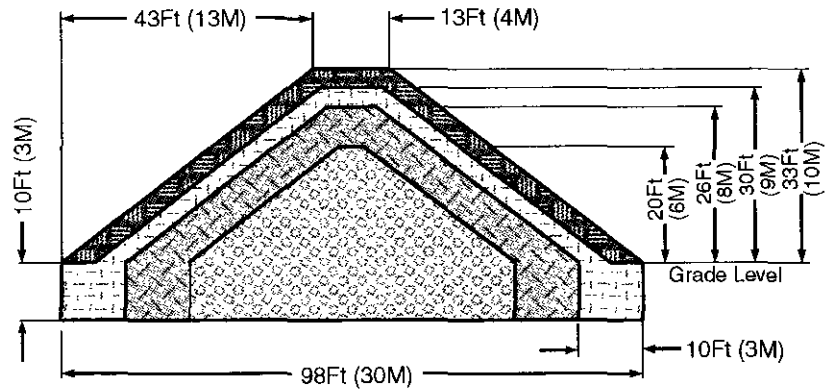

BERM CROSS SECTION

BERM CONSTRUCTION PROFILE
NOT TO SCALE

SALT

CALICHE

RIPRAP

SOIL/RIPRAP

NOTES:

1. THE DISPOSAL AREA PERIMETER MEASURES 629M BY 776M
2. THE INNER PERIMETER OF THE BERM MEASURES 660M BY 814M.
3. THE OUTER PERIMETER OF THE BERM MEASURES 720M BY 874M.
4. PANELS, ROOMS, AND SALT PILLARS REFER TO THE REPOSITORY FOOTPRINT SHOWN AS DOTTED LINES...

CCA-115-2

Figure 7-15. Berm Construction

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Another aspect of the marker system includes on-site buried storage rooms containing the Level IV message and associated diagrams. These rooms will be designed to endure for a similar time period as the permanent marker system and will be buried (see Appendix PIC). The design characteristics contributing to this longevity will be the material and environmental conditions associated with construction and location. The rooms will be made of granite with a minimum number of joints. Individual walls, the floors, and the roofs will comprise single granite slabs joined only at the edges. The configuration minimizes the risk of failure caused by chemical interactions between the construction material and the environment. The message texts contained within the buried storage rooms will be engraved on the walls. To provide redundancy, additional granite slabs engraved with the message text and the diagrams will be held in place against the interior walls. Although some damage could be inflicted by vandals, the granite composition of the message-carrying materials will provide the greatest opportunity for preventing complete destruction of the information contained within the buried rooms.

In addition to the buried storage rooms, an information center, as described in Appendix PIC (Section VII), will be located on the surface providing access to the same information that is contained in the buried rooms. Details regarding the location of one of the buried storage rooms and identical information will be contained in the information center.

7.3.3.1.2 *Records*

A significant part of the overall system will be the archiving of important information at sites remote to the repository. The archived material will include information that defines the location, design, content, and hazards associated with the WIPP. The amount of information will be more extensive than that available within the permanent marker system at the repository location. Information will be preserved using practicable materials and techniques at record centers and archives throughout the world. Appendix EPIC (Section EPIC.6) provides justification for a period of time that materials placed in archives and records centers are expected to endure and be understood.

Specific documents in the archived information portfolio will include the following. The specific requirements of 40 CFR § 194.43(2)(a) applicable to each document are indicated in parentheses.

- detailed maps describing the exact location of the repository (i),
- the Safety Analysis Report (i – iv),
- the Final Environmental Impact Statement (FEIS) for WIPP and the supplement(s) to the FEIS (i – iv),
- the RCRA Permit (i – v),

- the Compliance Certification Application (i – v),

- environmental and ecological background data collected during the preoperational phase of WIPP and summaries of data collected during the disposal and decommissioning phases of WIPP (iv),

- records of the waste container contents and disposal locations within the WIPP repository (iii),

- drawings defining the construction and configuration of the repository and shafts (ii),

- drawings, procedures, and design reports describing how the waste was emplaced, and how the repository was decommissioned, closed and sealed (v), and

- design information for the passive institutional controls (ii).

The National Archives will be one organization responsible for the permanent storage of this information. As discussed in Appendix PIC, the information will also be distributed to appropriate organizations such as the following for long-term safekeeping:

- federal and state government agencies,

- federal, state, tribal, and local archives and libraries,

- local and state and record repositories (for example, the Eddy County Clerk New Mexico)

- national archives and libraries of nations that possess nuclear weapons and nuclear energy or produce natural gas and oil resources, and

- professional and technical societies.

The archival and record centers identified in Appendix PIC as planned recipients of information were selected based upon one or more of the following criteria:

- *representing an international location in a nation which had citizens engaged in the oil* and gas exploration and exploitation industry,

- representing an international location in a nation which had the potential to generate radioactive waste,

- representing a local governmental organization frequented by individuals engaged in the oil and gas exploration and exploitation industry,

- representing a National Archival location,
- representing a Regional Library, or
- is a public funded location.

The DOE intends to submit WIPP records to over 100 archives nationally and internationally as identified in Appendix PIC. The initial submittal of these records will occur after closure and decommissioning of the WIPP. Since this time frame is decades into the future and thus significant changes will occur to some or all of the archives as well as some of the governments, the DOE has not attempted to identify the practices employed by each archive and repository for maintaining records and making them accessible to the public. However, the National Archive-Rocky Mountain Region practices are described and are representative of the National Archives and its regional facilities. The state of New Mexico Archive and the Canadian National Archive were also contacted and their practices are similar to those employed by the U.S. National Archives. There are also international standards for the organization and operation of archives that enable the world's archives to function similarly in many aspects of the practices governing maintenance of records and access to the records by members of the public.

To ensure the proper storage and retrievability of archived material, the DOE archivist will develop a filing code system specifically for the WIPP material. This system will be a part of the overall document submittal the DOE will provide to the various archival locations. In the development of the filing code system and communications with worldwide archives, it is expected that differing cultural issues will be addressed in order that the DOE gain acceptance of the information from as many archives as possible.

To reduce the possibility that future archivists may destroy the provided documents, each volume containing documents will be labeled with a warning that the intent of providing the archived material is to ensure its preservation for the 10,000-year regulatory time frame stipulated in the U.S. Government's regulations controlling the disposal of transuranic waste. It is recognized that the federal government may incur some long-term financial obligations to the archival locations to ensure retention. Within two years following the distribution of archival material and at least every 15 years thereafter during the active institutional controls period, the DOE will conduct audits of selected archival locations to verify retention and retrievability of the historical documents.

As an example of how an archive will handle archived information, the National Archive will use the indexing system provided by the DOE in organizing the WIPP material submitted for archiving and public use. Upon receipt of the material in boxes, the archive staff will examine the documents; remove staples, paper clips, rubber bands, and other miscellaneous materials that may damage or are otherwise incompatible with the records over an extended period of time; enclose any damaged material in individual protective covers; place the records in acid-free boxes; and store those boxes in an environmentally controlled vault. The individual

boxes are labeled with coded alpha-numeric designations that tie the contents back to the agency submitting the documents, the year in which the documents were received, and the general content of the documents. Finding aids, content indices, or significant word lists are developed to aid researchers in identifying the material desired. The coded number will also provide information relative to whether or not the documents may be destroyed after a given amount of time. Many government documents are scheduled to be destroyed after 30 years. Other documents are preserved indefinitely.

Title 36 CFR Part 1254, Availability of Records and Donated Historical Materials, regulates the manner in which archival material within the National Archive system is made available to members of the public. In general, researchers must register each day that they enter a research facility and may be required to provide identification. The researcher must sign for the documents received and again may be required to show identification. The researcher is not permitted to leave the room without notifying the room attendant and placing all documents in their proper containers. Documents must be returned to the research room attendant prior to the room closing. Documents may not be used where there is food, drink, or the presence of ink. Only pencils may be used in the room containing original documents. If the researcher requires copies of documents, the appropriate document must be marked with a paper tab provided by the archive. No paper clips or rubber bands may be used on the documents. The room attendant will provide the copying services for the researcher. Documents must be maintained in order by the researcher, however if the documents become disordered, the room attendant must perform the re-ordering function and not the researcher. Upon exiting a research room, the researcher must present for examination any article that could contain documents.

In addition to the national and state archives, Indian tribes and pueblos (for example, Navajo, Mescalero Apache, and Zuni) were contacted to determine the extent of any archival activity. Only the Zuni were establishing a limited internal archive. Other groups forward archive worthy materials to federal storage facilities. The DOE will continue to work with key nations, tribes, and pueblos to establish pertinent agreements and to ensure that appropriate WIPP records are distributed for archiving and reference purposes.

Finally, the International Atomic Energy Agency (IAEA), with the DOE as a current participatory through the agency of its Scientific Advisor, is developing a procedure for the archiving of records pertinent to the disposal of radioactive waste in deep geological repositories. The procedure, published in final draft May 31, 1996, is titled *Maintenance of Records for Deep Geological Repositories*. The DOE embraces this effort and intends to continue to pursue final publication of this comprehensive document with the IAEA.

7.3.3.2 Implementation of Programs to Collect Information

Prior to implementing the passive institutional controls, a testing program will determine whether the specific messages proposed can be expected to convey the intended warnings and information across cultures and whether the proposed media for transmitting the messages

will endure to the degree anticipated in the development of the conceptual model. The testing to be conducted will address the refinement of the messages, diagrams, and the method of presentation. As recommended in Trauth et al. (1993), the translated versions of the message text should be evaluated by presentations to groups indigenous to the countries whose language is represented in the message. This process should provide input into how comprehensible the messages are and provide information regarding any idiom changes that may be necessary in the translated versions. When considering that the messages were developed by educated individuals residing in the U.S., it is prudent that the effectiveness of the messages to convey their intended content to a broader cross-section of individuals be thoroughly tested. The testing therefore should include cross-cultural groups in evaluating the effectiveness of conveying the intended messages through diagrams and pictures as well as script. The DOE will continue to develop and review the details of a testing program to ensure that a comprehensive effort is made to test the final written and pictograph message comprehensibility. For those components that include either large volumes of various materials (for example, the berm) or the movement of heavy objects (for example, the sections of granite in the monuments), procedures will be tested for transporting the material and constructing the specified designs. The testing programs are described in Appendix PIC. See Appendix EPIC for a discussion of the durability of materials to be used to construct passive institutional controls.

7.3.3.3 Passive Institutional Controls Timelines

The DOE has prepared a tentative schedule of the implementation of the passive controls program. The schedule is shown in Figure 7-16. The following is provided as a brief expansion of the timelines provided in Figure 7-16.

- 1996-2083 Design and Test Permanent Marker Concepts and Materials. During this period the testing and monitoring described in Appendix PIC related to the permanent marker components, materials, and communication concepts are conducted.

  - 1998 – 2005 Construct Test Berm. During this period, the DOE will install test monuments, buried test markers, and construct a section of berm for testing. The berm section will include magnets and radar reflectors for testing.

  - 2005 – 2083 Monitor Performance of Test Markers and Test Berm. During this period, the DOE will monitor the performance of the test structures to develop information for use in the final design.

  - 2018 – 2023 Test Message Comprehension. The DOE will gain operational experience for any information that may affect the composition of the intended messages, both narrative and pictogram, and then conduct testing for comprehension by populations indigenous to the countries represented by the languages used in the messages.

- 2083 – 2090 Final Design. During this period, the DOE will complete the final design of the permanent marker system.

- 2090 – 2093 Construct Permanent Marker System. During the period, the permanent marker system will be constructed including installation of messages.

• 1999-2093 Implement Information Collection and Establish Archival and Record Center Agreements. During this period the actions required to implement record keeping and record storage aspects of passive institutional controls are conducted. Individual actions and associated timelines are:

- 2003 Establish Filing System. The DOE will establish the filing system under which the record center and archival information will be assembled. Completion of the system by 2003 will support the information collection program.

- 2003 – 2033 Collect Operational Information. Collect the information relative to WIPP operation, including decommissioning, which will be included in the promulgated documentation.

- 2033 – 2090 Collect Active Control Period Information and Marker Configuration. Collect the information relative to WIPP active controls and the results of testing of the permanent marker system components and communication concepts.

- 2023 – 2034 Establish Agreements with Recipients. During this period the DOE will communicate with the planned document recipients to develop general agreements with respect to language translation, scope of translated material, format in which the material will be provided, and any financial support required to achieve acceptance by each recipient. Beginning about 2023 when most of the documentation should have been developed, this effort should start. The DOE expects two to three years to establish the agreements and another five to eight years for translation with completion about the time that decommissioning and decontamination are finished. This provides for the incorporation of information related to decommissioning and decontamination.

- 2033 – 2034 Develop Summary Document. The DOE will develop the WIPP summary document to be provided for ease of public access and understanding of the WIPP.

- 2035 Promulgate Information Accumulated Through WIPP Closure and Decommissioning. The DOE will make a distribution of documents accumulated through the final closure, decontamination, and decommissioning of the WIPP.

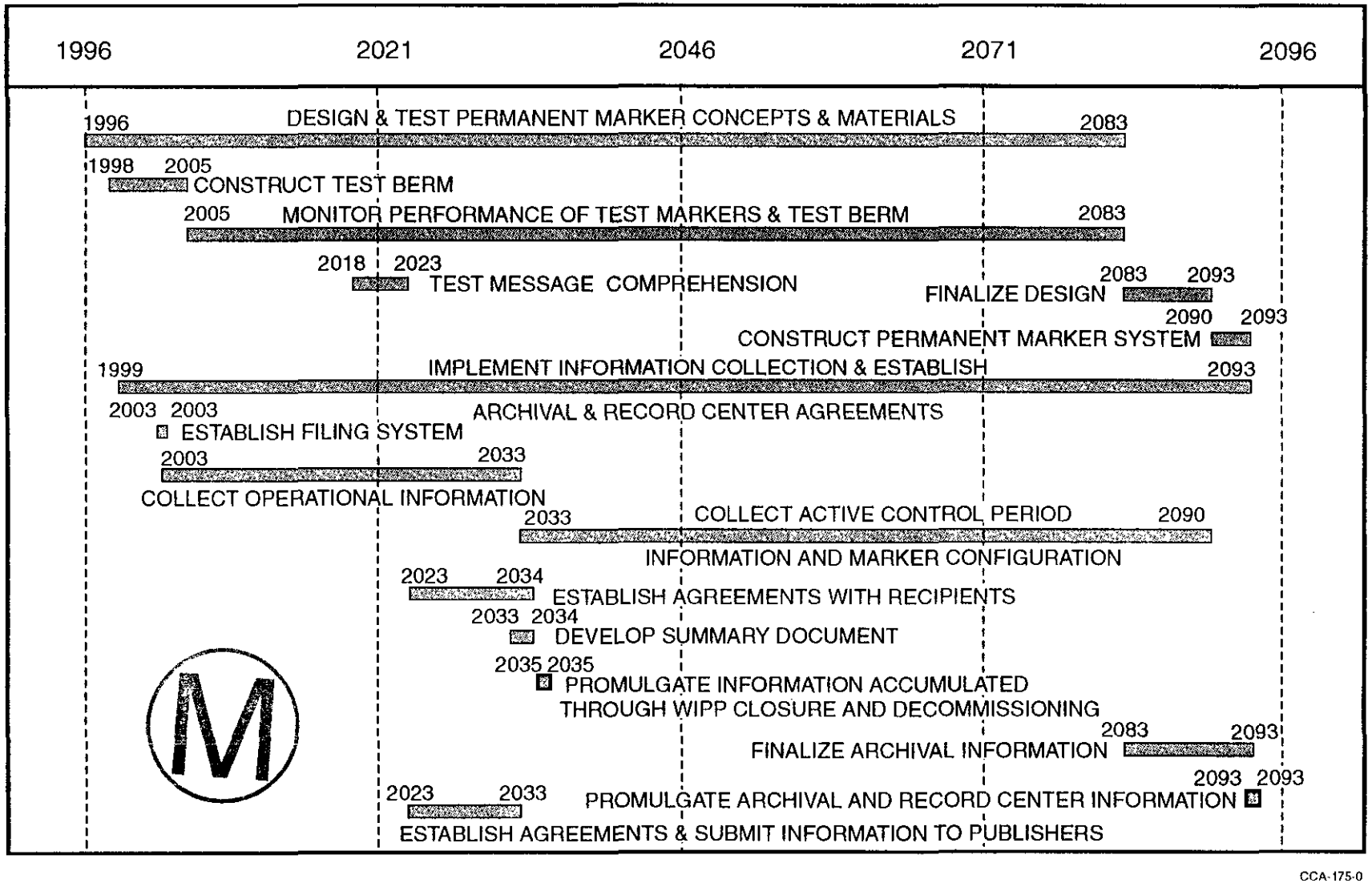

Figure 7-16. Passive Institutional Controls Timeline

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- 2023 – 2033 Establish Agreements and Submit Information to Publishers. During this period, the DOE will establish agreements with map makers and text publishers including financial support and provide hazard, history, and location information to be included on maps and various text materials.

- 2083-2093 Finalize Archival Information. During this period, the DOE will develop the final additions to the planned submittal, which include information describing the WIPP history during the first 50 to 60 years following closure and the final configuration of the permanent marker system.

- 2093 Promulgate Archival & Records Center Information. The DOE will make the distribution of the final portion of the archived information nationally and internationally.

7.3.4 Effectiveness of Passive Controls in Reducing the Rate of Human Intrusion

The EPA raises the issue of the expected ability of the passive institutional controls to convey information to future societies in two areas. In the context of the assurance requirement in which no assumptions can be made to limit the uncertainty of the future states of societies, the EPA states

> Any compliance application shall include the period of time passive institutional controls are expected to endure and be understood. (40 CFR § 194.43[b])

In the context of credit for passive institutional controls in deterring inadvertent human intrusion for use in performance assessments, the EPA goes on to state that

> The Administrator may allow the Department to assume passive institutional controls credit, in the form of reduced likelihood of human intrusion, if the Department demonstrates in the compliance application that such credit is justified because the passive institutional controls are expected to endure and be understood by potential intruders for the time period approved by the Administrator. Such credit, or a smaller credit as determined by the Administrator, cannot be used for more than several hundred years and may decrease over time. In no case, however, shall passive institutional controls be assumed to eliminate the likelihood of human intrusion entirely (40 CFR § 194.43 [c]).

To limit the speculation about the state of future society, the EPA has provided additional guidance by stating that "EPA expects that the DOE will establish a framework of assumptions for passive institutional controls that is a prudent extrapolation of the future state assumptions established in § 194.25" (EPA 1996b, 61) and by providing for the existence of certain societal "common denominators" based on "patterns of human behavior that may be detected throughout history and around the world" (EPA 1996b, 61).

Section 7.3.4.1 addresses the issue of how long the passive institutional controls are expected to endure and be understood in the context of the Assurance Requirement (40 CFR § 194.43[b]), and Section 7.3.4.2 addresses the issues of how long these controls are expected

to endure and be understood and the resulting credit in deterring inadvertent human intrusion in performance assessment calculations (40 CFR § 194.43[c]).

7.3.4.1 Expected Effectiveness

The passive institutional controls in the Conceptual Design Report (DOE 1994) were developed from the recommendations of the Markers Panel convened in 1991, modifying them for reasons such as constructability or resource requirements. The Markers Panel developed fundamental principles of long-term communication making only the most minimal assumptions about what future societies would be like (for example, they will be human beings similar to what we are today). No assumptions were made about what languages they might be speaking or how technologically sophisticated they might be. Because no assumptions were made about language or technology, the Markers Panel developed strategies that attempt to communicate with individuals in a variety of means and in a systems approach whereby the various components reinforce and supplement the other messages.

Without assumptions about technological sophistication, messages will be provided in various levels of complexity, ranging from the most basic marker of human construction rather than a natural phenomenon, to the entire written record of information about the repository and its certification. Because it is not known what languages will be spoken in the future, the markers will include non-linguistic means of communication, such as pictures of humans, star charts, and the periodic table of the elements. In this way, the design of the markers responds to the EPA's requirement for the "most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location" (40 CFR § 191.14[c]). While the Markers Panel focused its efforts on the repository footprint, based on the 40 CFR Part 191 definition of human intrusion, the entire withdrawal area will be identified by on-site passive institutional controls to satisfy criteria in 40 CFR § 194.43. Because of the requirement for records and archives, plans have been made to place materials within the existing governmental and scientific systems of recordkeeping.

In addressing the issue of credit for passive institutional controls in performance assessment calculations, the DOE examined historical analogues for the controls components (see Appendix EPIC, Chapter 5). Certain design characteristics of these historical analogues have survived destruction from both societal turmoil and natural processes. By designing the passive institutional controls to mimic and enhance these design characteristics, the DOE believes that the passive institutional controls for the WIPP will be capable of surviving at least as long as the historical analogues. Based on the characteristics of the markers, these components have the capability of lasting in excess of several thousand years. This conclusion is consistent with the conclusions of both teams of the Markers Panel whose estimates were based on basically the same design characteristics for the markers and on a wide variety of future states of society. The multiple copies of the records in the records centers and archives, the selection of highly durable materials (that is, archival paper and carbon-black ink), and the fact that the records will have value in the economic and health

areas suggest that at least some copies of the records have a high probability of surviving for many hundreds to thousands of years.

The Markers Panel concluded that the messages proposed have a high probability (greater than 0.70) of being understood by all potential levels of technology for at least 2,000 years (Team A estimated at least 5,000 years). Although the Markers Panel considered only the messages on the markers, the same information, both text and pictographs, will be included in the records in records centers and archives. As a result, the DOE concludes that these records will be interpretable for as long as the documents survive.

7.3.4.2 Credit Taken in Performance Assessment Calculations

In addition to their use for compliance with the assurance requirements, the passive institutional controls have a separate function in deterring human intrusion into the disposal system for performance assessment calculations. While only minimal assumptions were made about future society for the purposes of designing the passive institutional controls, more detailed assumptions need to be made to provide actual numbers for performance assessment calculations. The Preamble to 40 CFR Part 194 limits any credit for passive institutional controls in deterring inadvertent human intrusion to 700 years after disposal. This shorter time period is an important factor in the development of numbers to evaluate the effectiveness of passive institutional controls for performance assessment. The effectiveness of passive institutional controls is further described in Appendix EPIC.

Active institutional controls will be implemented at the WIPP after closure to control access to the site and will ensure that only those activities allowed by the LWA take place at the site. The existence of active institutional controls will preclude human intrusion in the withdrawal area, although there is a regulatory prohibition against taking credit for the effectiveness of active institutional controls in performance assessment calculations beyond 100 years after disposal. Because of the nature of the system of active institutional controls, the effectiveness of the active institutional controls would be the controlling factor for performance assessment calculations up to 100 years. Thus, the effectiveness of passive institutional controls for use in performance assessment is focused on the time period from year 100 to year 700 after disposal. See Appendix EPIC for discussion and analysis.

The Markers Panel developed its recommendations for the longevity of marker materials and configuration based, in part, on historical analogues. When the passive institutional controls task force (PTF) assessed the effectiveness of the passive institutional controls, as described in Appendix PIC, additional historical analogues were considered, and a one-to-one comparison was developed between individual passive institutional controls components and individual historical analogues. This one-to-one comparison allowed the PTF to identify general periods of time for endurance for each passive institutional control. At the same time, the PTF identified potential failure mechanisms of the markers components, the records and archives system, and governmental control components. Because the passive institutional controls were designed to address failure mechanisms based on historical analogues that endured and

those for which there is a record of failure, the PTF believes that physical failure of the passive institutional controls components over the entire withdrawal area will not occur in the time frame of interest for performance assessment. This belief is supported by the fact that no failure mode applies to all passive institutional controls and failure of the marker system requires failure of all components of the marker system.

After physical durability was evaluated, the PTF studied the ability of messages to be understood. Building upon assumptions listed by the EPA in the Compliance Application Guidance as common denominators of human behavior, the PTF developed a list of assumptions about how future societies would operate, focusing on potential intrusions to explore for and exploit natural resources. One of the PTF's assumptions is that English will be understandable to the resource exploration and exploitation community for at least 1,000 years. This assumption is made based on (1) 1,000-year-old English literature can be understood by scholars today, (2) English is a world language with a concomitant inertia against radical and rapid change, and (3) the valuable nature of the resources in the area means that resource-seeking individuals and corporations will make the effort to decipher past records dealing with resource availability. The PTF believes that for the time frame of interest for performance assessment, the ability of potential drillers to interpret past records is virtually certain.

Other assumptions made by the PTF are discussed in Appendix EPIC. The PTF provides the basis for assumptions relating to basic human attributes, government, language, natural resources, and estimating passive institutional controls effectiveness. The PTF established this framework of assumptions through a "prudent extrapolation" of the future state (that is, present-day) assumptions established in 40 CFR § 194.25.

The failure mode that remained after these PTF evaluations were performed was human error either in obtaining and documenting a lease or a permit to drill, or in actually setting up a drill rig and drilling a borehole in the wrong location. When a search of the New Mexico portion of the Delaware Basin resource records did not yield any documentation of wells drilled in the wrong location, the PTF queried individuals who had many years of experience with drilling in both the Delaware Basin and the encompassing Permian Basin. These individuals were able to provide five instances of wells drilled in the wrong location, although none was in the Delaware Basin. Based on 429,000 wells drilled in the area in question, these five instances resulted in a failure rate of 0.00001 for the Permian Basin and 0.00 for the Delaware Basin. There may be other wells drilled in the wrong location that were not identified in the recent search. In addition, there may be additional failure modes that were not identified in the passive institutional controls effectiveness report. Because of these possibilities, the PTF increased the calculated failure rate by three orders of magnitude to 0.01 to provide a bounding value for performance assessment calculations.

A one percent failure rate would mean that out of every 100 permit requests, one involved an unlawful permit, or one involved a location error on the permit itself, or the drillers set up in the wrong location (that is, in the wrong lease). Such a high failure rate, however, would be

widely known within the drilling community and the failure rate would have caused the implementation of stronger controls over drilling.

Thus, for performance assessment calculations, the passive institutional controls are considered to be 0.99 (that is, 1 to 0.01) effective in deterring inadvertent human intrusion over the entire withdrawal area.

7.4 Multiple Barriers

The WIPP facility has incorporated multiple natural and engineered barriers, including plugs, seals, and backfill into its design. As a part of the DOE's program to evaluate multiple barriers, an Engineered Alternatives Task Force (EATF) evaluated optional additional engineering measures for the WIPP facility. The findings of the task force are summarized in the *Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives* (DOE 1991). A more recent study, the Engineered Alternatives Cost/Benefit Study, updated the 1991 EATF activity and augmented it with more in-depth and comprehensive analyses of the relative benefits and detriments of the alternatives. Benefits and detriments at the waste generation and storage sites were evaluated in this study as well as those at the WIPP. (This study is included as Appendix EBS.)

Beyond the requirements contained in 40 CFR § 191.14(d) relating to multiple barriers, 40 CFR § 194.44 has imposed certification criteria upon the DOE with regard to engineered barriers. The following sections provide a discussion of the manner in which the DOE has complied with the multiple barrier requirement of 40 CFR § 191.14(d) and an overview of the manner in which the engineered barrier criteria of 40 CFR § 194.44 have been met. A detailed discussion of the cost and benefit analysis dictated in 40 CFR § 194.44 is provided in Appendix EBS.

7.4.1 Requirements for Multiple Barriers

By requiring the use of both natural and engineered barrier types as the assurance requirement, the EPA intends to ensure that the impacts of the failure of any single barrier type will be minimized.

In the LWA, Congress mandated that the Secretary will use both natural and engineered barriers. Waste form modifications may be used at the WIPP to isolate waste after disposal to the extent necessary to comply with the final disposal regulations. Therefore, the disposal system design involving the Salado as a natural barrier and the shaft seals as engineered barriers complies with this assurance requirement as indicated by the compliant complementary cumulative distribution functions (CCDFs) shown in Section 6.5.

7.4.2 Objectives for Multiple Barriers

The primary objective for the implementation and the use of multiple barriers at the WIPP facility is to help guard against unexpectedly poor performance from one type of barrier. This is accomplished by a design that includes multiple types of barriers.

7.4.3 Implementation of Multiple Barriers

The baseline design for the WIPP facility includes the concept of multiple barriers for isolation and containment of waste. Barriers that are part of the design include natural barriers (for example, hydrological, geological, and geochemical conditions) and engineered barriers (for example, borehole plugs, shaft seals, panel closures, and backfill). The effectiveness of these barriers is modeled in the performance assessment to demonstrate the ability of the disposal system to meet EPA standards.

Section 194.44(a) provides a criterion for certification for the analysis of the costs and benefits of various engineered barrier options. The text in the following subsections describes the DOE program that meets the engineered barrier requirements.

7.4.3.1 Engineered Alternatives Cost and Benefit Study

To fulfill the benefit and detriment evaluation criterion contained in 40 CFR § 194.44(b), the DOE published *Engineered Alternatives Cost/Benefit Study; Final Report* (DOE 1995) (see Appendix EBS). The EPA's criterion for this cost and benefit study is as follows:

> In selecting any engineered barrier(s) for the disposal system, the Department shall evaluate the benefit and detriment of engineered barrier alternatives, including but not limited to: cementation, shredding, supercompaction, incineration, vitrification, improved waste canisters, grout and bentonite backfill, melting of metals, alternative configurations of waste placements in the disposal system, and alternative disposal system dimensions. The results of this evaluation shall be included in any compliance application and shall be used to justify the selection and rejection of each engineered barrier evaluated. (40 CFR § 194.44[b])

The primary purpose of this cost and benefit study was to provide the DOE with information for use in selection or rejection of additional engineered barriers to provide assurance in the performance calculations. The current facility baseline, as represented in performance assessment, provides sufficient multiple barriers to obtain compliance with the requirements of 40 CFR § 191.14(d) as described in Sections 6.4.4 (Shaft Seal Engineered Barriers), 6.4.5 (The Salado Formation Natural Barrier), and 6.5 (Performance Assessment Results).

The approach used in the study was to screen potential engineered alternatives compiled from previous studies, the ten technologies specified in 40 CFR § 194.44(b), and input elicited from stakeholders. The screening process used a working group composed of technical professionals from various related fields to compare the proposed engineered alternatives to the established definition of an engineered alternative and then to determine if those

alternatives that meet the definition also meet regulatory and technological feasibility criteria. The outputs of the screening process were

- a list of engineered alternatives that did not meet the definition or screening criteria, along with the justification for their rejection, and
- a list of engineered alternatives retained for further consideration.

The screening process evaluated 111 proposed engineered alternatives and screened out all but 54 (see Appendix EBS, Section 2.2.2). The 54 alternatives retained were then subjected to a DOE management-level assessment to determine the set of alternatives that would be retained for full analysis through the study. The basis for this assessment was to:

- develop a set of alternatives that address important WIPP performance issues, such as reducing the solubility of actinides in brine and improving the strength of the waste,
- analyze those alternatives that have high technical feasibility (that is, those alternatives that have been subjected to bench-scale testing at the least), and
- assess those alternatives that have a high likelihood of being permitted in a reasonable amount of time.

This assessment resulted in the selection of 18 alternatives for full analysis through the study. The screening process, including this DOE management-level assessment, was included in the scope of an independent peer review done on the study to address the requirements of 40 CFR § 194.27(a)(3). The peer review panel concluded that the entire screening process was reasonable and acceptable. Details of the peer review are found in Appendix PEER (Section 3.2).

The 18 alternatives finally selected for further study consisted of nine basic alternatives and nine variations. The 18 alternatives were compared to the criteria in 40 CFR § 194.44(c):

> (i) The ability of the engineered barrier to prevent or substantially delay the movement of water or waste toward the accessible environment;
> (ii) The impact on worker exposure to radiation both during and after incorporation of engineered barriers;
> (iii) The increased ease or difficulty of removing the waste from the disposal system;
> (iv) The increased or reduced risk of transporting the waste to the disposal system;
> (v) The increased or reduced uncertainty in compliance assessment;
> (vi) Public comments requesting specific engineered barriers;
> (vii) The increased or reduced total system costs;
> (viii) The impact, if any, on other waste disposal programs from the incorporation of engineered barriers (for example, the extent to which the incorporation of engineered barriers affects the volume of waste);
> (ix) The effects on mitigating the consequences of human intrusion. (40 CFR § 194.44[c][1])

In addition to the criteria listed above, Appendix EBS includes analyses that evaluated

- existing waste that is already packaged,
- existing waste that is not yet packaged,
- existing waste that is in need of repackaging, and
- to-be-generated waste.

All 18 alternatives met the intent of these criteria. This process is further described in Section 2 and Appendix O of Appendix EBS. The variations originated in the screening process, details of which can be found in Sections 2.2 and 2.3.1 of Appendix EBS.

For comparison, the baseline was considered to be the WIPP facility with no additional engineered barriers beyond shaft seals and panel closures. The 18 final engineered alternatives, along with a brief description of each, are listed below.

- **Supercompact Organics and Inorganics.** Solid organic and inorganic wastes are sorted to remove items that cannot be compacted. Sorted waste is precompacted in 35-gallon (132.6-liter) drums and then supercompacted. Usually, the contents of four supercompacted drums are placed in a 55-gallon (208-liter) drum. Sludges are not processed.

- **Shred and Compact Organics and Inorganics.** Solid organics and inorganics are shredded and compacted in 55-gallon (208-liter) drums using a mechanical shredder and a low-pressure compactor. Sludges are not processed.

- **Plasma Processing of All Wastes.** All wastes are processed through a mechanical shredder and the input waste stream is controlled to ensure a suitable metal to nonmetal ratio. The waste is processed through a plasma arc centrifugal treatment system and placed into 55-gallon (208-liter) drums.

- **Sand Plus Clay Backfill.** A mixture of medium-grained sand and granulated clay is used as backfill. The mixture is placed around the waste stack and between the drums filling the void space between drums and unmined host salt in waste emplacement panels. A 50-percent void space is assumed.

- **Salt-Aggregate (Grout) Backfill.** A salt-aggregate grout mixture is used as backfill to fill the void spaces between drums and unmined host salt in waste emplacement panels. This backfill consists of a cementitious-based, salt-aggregate grout with crushed salt aggregate and is pumped around the waste stack and between the drums filling the void spaces. A 20-percent void space is assumed.

- **Cementitious Grout Backfill.** A cementitious grout backfill consisting of ordinary Portland cement, sand, and fresh water is pumped around the waste stack and between the drums filling the void space. A 20-percent void space is assumed.

- **Supercompact Organics and Inorganics, Salt-Aggregate and Grout Backfill.** Monolayer of 2,000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.6 meters) wide, and 300 feet (91.4 meters) long.

- **Supercompact Organics and Inorganics, Clay-Based Backfill.** Monolayer of 2,000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.6 meters) wide, and 300 feet (91.44 meters) long.

- **Supercompact Organics and Inorganics, Sand and Clay Backfill.** Monolayer of 2,000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.6 meters) wide, and 300 feet (91.44) meters long.

- **Supercompact Organics and Inorganics, CaO Backfill.** Monolayer of 2,000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long.

- **Salt Backfill with CaO.** A backfill of commercially available granulated lime and crushed salt is placed around the waste stacks and between the drums filling the void space. A 50-percent void space is assumed.

- **Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, No Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Sand and Clay Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A mixture of medium-grained sand and granulated clay is used as backfill. The mixture is placed around the waste stack and between the drums filling

the void space between drums and unmined host salt in waste emplacement panels. A 50-percent void space is assumed.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Cementitious Grout Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A cementitious grout backfill consisting of ordinary Portland cement, sand, and fresh water is pumped around the waste stack and between the drums filling the void space. A 20-percent void space is assumed.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Salt Aggregate Grout Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A salt-aggregate grout mixture is used as backfill to fill the void spaces between drums and unmined host salt in waste emplacement panels. This backfill consists of a cementitious-based, salt-aggregate grout with crushed salt aggregate and is pumped around the waste stack and between the drums filling the void spaces. A 20-percent void space is assumed.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Clay-Based Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A backfill consisting of commercially available pelletized clay is placed around the waste stack and between the drums, filling the void space. A 50-percent void space is assumed.

- **Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, CaO and Salt Backfill.** This alternative includes two processes to treat the waste. The first is an enhanced cementation process of previously solidified

and as-generated sludge. Existing sludges are fed into a mechanical crusher and shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly-generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums. A backfill of commercially available granulated lime and crushed salt is placed around the waste stacks and between the drums filling the void space. A 50-percent void space is assumed.

- **Clay-Based Backfill.** A backfill consisting of commercially available pelletized clay is placed around the waste stack and between the drums, filling the void space. A 50-percent void space is assumed.

The product from the evaluation of each factor was integrated into a quantifiable result called a performance vector. This vector expresses the performance of each engineered alternative relative to the baseline. The results of the factor analyses are presented in detail in Appendix EBS (Section 5.4).

The Engineered Alternatives Cost/Benefit Study (Appendix EBS) was useful to the DOE as it identified engineered barriers that could be used to improve long-term repository performance. Specifically, the advantages of a backfill that chemically altered the pH of brine in the disposal room were identified in Appendix EBS (Section 3.1) as providing significant benefit in reducing the quantity of mobile actinides. Alkaline earth oxides (such as calcium oxide [CaO]) are known to readily react with water to form hydroxides. These hydroxides are free to react with carbonic acid that may form in the disposal room. The reaction buffers the brines to a pH that reduces the amount of actinide in solution. After further analysis, which is documented in Appendix BACK and discussed in Appendix SOTERM, the DOE selected magnesium oxide (MgO) as the backfill material that provided the desired long-term benefit while minimizing the operational impacts associated with the more caustic CaO. The beneficial effects of MgO backfill are now included in the WIPP performance assessment calculation. Relevant discussions can be found in Sections 3.3.3 and 6.4.3.4.

7.4.3.2 Incorporation into Repository Design

In its guidance to implementation of the certification criteria in 40 CFR § 194.44(d), the EPA requested that the DOE describe how engineered barriers are incorporated into the repository. The purpose of this section is to identify the location of these descriptions and the location of the analysis that evaluates the performance of the engineered barriers.

Shaft seals delay the movements of radionuclides toward the accessible environment through the shafts. These shaft seals are described in detail in Appendix SEAL and are summarized in Section 3.3.1. Analysis of the effectiveness of shaft seals is included in Appendix SEAL (Section 8) and Section 6.4.4. Panel closures prevent the movement of radionuclides toward the accessible environment by limiting the magnitude of releases that can occur during certain

human intrusion events. The design of panel closures is described in Appendix PCS, summarized in Section 3.3.2, and their role in the repository model is discussed in Section 6.4.3. Backfill substantially delays the movement of radionuclides toward the accessible environment by limiting, through chemical means, the amount of actinides that can be dissolved in brines that enter the repository. The placement of backfill is described in Section 3.3.3, and its design and functions are described in Appendix SOTERM. Actinide mobility is discussed in Section 6.4.3. Borehole plugs are used to limit the volume of water that could be introduced to the repository from overlying water-bearing zones and to limit the volume of contaminated brine that could be released to the accessible environment. Borehole plug design is addressed in Section 3.3.4. In addition, parameter values selected to implement the various engineered components into the performance assessment model are described in Appendix PAR. Borehole plugs, as described in Section 3.3.4, are also included to mitigate the potential for contaminant migration.

7.5 Resource Characteristics Evaluations

The EPA discourages the location of repositories in areas in which valuable natural resources are present, through the assurance requirements in 40 CFR § 191.14(e). This assurance requirement states that

> Places where there has been mining for resources, or where there is a reasonable expectation of *exploration for scarce or easily accessible resources, or where there is a significant* concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future (40 CFR § 191.14[e]).

The purpose of the requirement is to provide assurance that site selection actions further reduce the likelihood of future intrusion into the repository by giving preference to those sites without currently recognized resources.

In promulgating 40 CFR Part 194, the EPA provided for a clear manner in which to assess compliance with this requirement, stating that

> If performance assessments predict that the disposal system meets the containment requirements of § 191.13 of this chapter, then the Agency will assume that the requirements of this section and § 191.14(e) of this chapter have been fulfilled (40 CFR § 194.45).

Section 6.5 demonstrates compliance with 40 CFR § 191.13, including resource considerations, and hence compliance with 40 CFR § 194.14(e). The EPA further provides, in its guidance to 40 CFR Part 194, that the DOE

- document that the effects of mining and drilling over the regulatory time frame have been incorporated into performance assessments according to the requirements of § 194.32, § 194.33, and § 194.43;

- document that performance assessments incorporate the effects on the disposal system of any activities that occur in the vicinity of the disposal system or are expected to occur in the vicinity of the disposal system soon after disposal, according to the requirements of § 194.32; and

- document whether the results of performance assessments demonstrate compliance with the containment requirements of § 191.13.

The DOE has satisfied the EPA guidance concerning resource evaluation. This information is documented in Chapter 6.0. The DOE has satisfied the EPA criteria concerning resource evaluation. This information is documented in Section 6.5.2. The mean CCDFs in Figure 6-38 incorporates both the effects of mining inside the controlled area (see Section 6.4.6.2.3 for a description of the mining conceptual model) and the effects of intermittent and inadvertent drilling (see Section 6.4.7 for a discussion of the drilling conceptual model). In addition, the impacts of resource development outside the controlled area were considered in the development of disposal system conceptual models.

7.5.1 Resource Considerations Prior to 40 CFR Parts 191 and 194

The WIPP site selection occurred prior to promulgation of 40 CFR Parts 191 and 194. Resource considerations were included in the site selection process for the WIPP and are documented in the WIPP FEIS (DOE 1980) and Appendices GCR and IRD. The objective of the program for demonstrating compliance with the resource considerations requirement is to document the rationale used in the decision-making process.

7.5.2 Implementation of Resource Considerations

Resource considerations were included in the site selection process for the WIPP and are documented in the WIPP FEIS (DOE 1980, Section 7.3.7). The FEIS describes a four-step decision-making process that was applied to siting the repository. This process is summarized below:

- Step 1 - Bedded salt was selected as the most promising geologic medium, and geographic regions that contain extensive bedded salt formations were identified. This was accomplished by gathering and evaluating existing information concerning rock types and their geographic distribution. Desirable criteria were identified and the most favorable regions were identified.

- Step 2 - A literature review was performed to narrow the number of regions identified in Step 1. Once a region was selected, candidate sites within the region were chosen. Selection criteria were used to compare the sites. Those sites that satisfied the most

criteria were selected for further evaluation. Resource-conflict considerations were applied on a broad scale at this stage of the process.

- Step 3 - The candidate sites identified in Step 2 were subjected to further investigations covering geology, hydrology, archaeology, demography, and biological resources. The results of all the site evaluations were compared, and the site that best met the selection criteria was selected for additional site characterization. At this stage, the types and quantities of natural resources present at the site were considered in detail.

- Step 4 - In this final step, a detailed system analysis was performed. This analysis addressed the specific geologic environment, the waste forms, the disposal facility design, and the potential failure modes with respect to radiation safety and environmental impact.

Based upon the above process, the DOE concluded that the favorable characteristics of the WIPP site (good hydrological characteristics, salt medium, moderate depth, salt thickness, low population density, lack of significant economic conflicts, and others) uniquely qualified it for a repository for defense waste. These characteristics also compensate for any increased likelihood of future disturbance. Appendix IRD provides further analysis of compliance with the resource disincentive requirement. Section 2.3.1 provides a summary of known and inferred resources in the vicinity of the WIPP. Appendix DEL contains resource-development-related information used in the conceptual model of disposal system performance.

7.6 Waste Removal

Removal of the waste any time after emplacement is possible. Because the repository was initially mined to provide access to the repository rooms, access to the waste can be accomplished using similar mining technologies. Location and removal are also possible using similar equipment modified to operate remotely. A remote retrieval demonstration was conducted at the WIPP in April 1992.

7.6.1 Requirements for Waste Removal

With the promulgation of 40 CFR Part 194, and in particular 40 CFR § 194.46, the EPA specifies the criteria for demonstrating compliance with this requirement. Specifically, the EPA mandates that "any compliance application shall include documentation which demonstrates that removal of waste is feasible for a reasonable period of time after disposal." The EPA states that this documentation should "include an analysis of the technological feasibility of mining the sealed disposal system, given technology levels at the time a compliance application is prepared."

In promulgating its disposal regulations, the EPA stated that "any current concept for a mined geologic repository meets this requirement without any additional procedures or design features" (EPA 1985, 50 FR 38082).

Because the WIPP facility is a mined repository, no additional actions other than documentation to meet this assurance requirement are necessary. The rationale for this assurance requirement is to preclude use of some disposal technologies that would not allow future generations to recover the wastes should they decide to do so. According to the EPA, recovery need not be easy or inexpensive but only possible (EPA 1985). Appendix WRAC describes a feasible system for waste removal using available mining technologies.

7.6.2 Implementation of Waste Removal

After determining the existing repository condition, the mining and waste removal operations will be designed to minimize the amount of contamination and exposure to allow limited human access for assessments, equipment retrieval, and repairs. Any radiological work will be performed using standard industry practices and approved procedures.

Radiological sampling activities will be planned and implemented so that recovered wastes can be handled. Packaging the removed waste and any decontamination of containers can be accomplished with standard automation techniques. Plans and procedures will ensure that the amount of additional contaminated material produced during the actual waste removal is minimized.

The removal concept is composed of the following five phases.

Phase 1 — Planning and permitting.
Phase 2 — Initial above ground setup and shaft sinking.
Phase 3 — Underground excavation and facility setup of underground ventilation, radiation control, packaging areas, decontamination areas, maintenance, remote control center, and personnel support rooms.
Phase 4 — Waste location and removal operations, including mining waste removal, packaging, package surveying and decontamination, transportation to surface, staging for off-site transportation, and off-site transportation.
Phase 5 — Closure and D&D of the facility.

Each of the five phases is summarized below and described in detail in Appendix WRAC (Section 5).

7.6.2.1 Planning and Permitting

A decision to remove waste will initiate the planning and permitting phase. Permitting requirements will be based on governing regulations at the time removal is authorized. The planning and permitting program will identify all permits and research the available

technologies at that time to determine available removal techniques and the condition of the repository. After initial research is completed, a plan will be drafted to itemize and schedule all removal activities.

7.6.2.2 Initial Above Ground Setup and Shaft Sinking

Above ground support buildings will house the exhaust fans and filters, administration, operations and maintenance facilities, control center waste staging and decontamination areas, the warehouse (containers), and others as deemed necessary.

7.6.2.3 Underground Excavation and Facility Setup

After the shafts are completed, drifts will be run and ventilation paths will be established using air control regulators. Support rooms will be excavated for maintenance, control rooms, and packaging areas. Air locks will be constructed to provide the necessary level of control and separation. All equipment required for removal, packaging, and related support equipment will be installed.

Excavation will be in two stages. Initial excavation will not contact waste but will mine support rooms and haulage drifts that provide ventilation and access to the waste. The second stage will remove the waste.

7.6.2.4 Waste Location and Removal Operations

The waste removal will be performed in separate operations. The waste will be removed by mining the area where the waste was emplaced. The mined waste will be transported to the packaging areas. The waste can be removed many ways using standard equipment. Appendix WRAC (Sections 6 and 7) contains a brief description and feasibility of using various mining techniques for waste removal. An appropriate level of radiological controls will be used depending upon the radioactivity of the mined waste.

7.6.2.5 Closure and D&D of the Facility

After waste is removed from the repository, the facility will be decommissioned according to the current regulations at that time.

REFERENCES

Bellus, P.A., and Eckerman, J. 1994. *Airborne or Spaceborne Surveillance Radar Detection of WIPP Site*. Westinghouse Electric Corporation, 10950, Minnetonka, MN.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026. Vols. 1 and 2. Assistant Secretary for Defense Programs. Washington, D.C. WPO 38835, WPO 38838, WPO 38839.

DOE (U.S. Department of Energy). 1990. *Final Safety Analysis Report*. WP 02-9, Rev. 0, May 1990. Westinghouse Electric Corporation, Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U.S. Department of Energy). 1991. *Draft Report: Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force*. DOE/WIPP 91-007, Rev. 0. Westinghouse Electric Corporation, Carlsbad, NM.

DOE (U.S. Department of Energy). 1994. *Permanent Marker Conceptual Design Report* Draft. Rev. 2, November 1994. U.S. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995. *Engineered Alternatives Cost/Benefit Study; Final Report*. DOE/WIPP 95-2135. U.S. Department of Energy, Carlsbad, NM. Included in this application as Appendix EBS.

EPA (U.S. Environmental Protection Agency). 1985. "40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule." *Federal Register*, Vol. 50, No. 182, pp. 38066 – 38089, September 19, 1985. Office of Radiation and Air, Washington, D.C. WPO 39132.

EPA (U.S. Environmental Protection Agency). 1988. Test Methods for Evaluating Solid Waste. Volume 1A through 1C and Volume 2. Field Manual Physical Chemical Methods (3rd Edition). Report EPA/SW-846, September 1988, National Technical Information Service, Springfield, VA.

EPA (U.S. Environmental Protection Agency). 1996a. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule." *Federal Register*, Vol. 61, No. 28, pp. 5224 – 5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1996b. *Compliance Application Guidance for 40 CFR Part 194*. EPA 402-R-95-014, March 29, 1996. Office of Radiation and Indoor Air, Washington, D.C. WPO 39159.

Hora, S.C., von Winterfeldt, D., and Trauth, K.M. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Sandia National Laboratories, Albuquerque, NM.

Murphy, J.N., and Parkinson, H.F. 1978. "Underground Mine Communications," Proceedings of the IEEE, Vol. 66, No. 1, pp. 26 – 50.

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. *Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site.* Vol. I, Ch. I-III, December 22, 1994.

Powell, J.A. 1976. *An Electromagnetic System for Detecting and Locating Trapped Miners,* U.S. Bureau of Mines Report of Investigations, RI 8159, U.S.B.M, Pittsburgh, PA.
Murphy, John N. and H.F. Parkinson. 1978. *Underground Mine Communications,* Proceedings of the IEEE, Vol. 66, No. 1, January 1978.

Trauth, K.M., Hora, S.C., and Guzowski, R.V. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Sandia National Laboratories, Albuquerque, NM. WPO 23389.

BIBLIOGRAPHY

DOE (U.S. Department of Energy). 1990. *Radionuclide Emission Data Package for the Waste Isolation Pilot Plant.* U.S. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy). 1992. *Statistical Summary of the Radiological Baseline Program for the Waste Isolation Pilot Plant.* DOE/WIPP 92-037. U.S. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy). 1993. *Waste Isolation Pilot Plant Land Management Plan.* DOE/WIPP 93-004. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1994. *WIPP Active Access Controls After Disposal Design Concept Description* (Draft). Rev. 1, December 1994. U.S. Department of Energy, Carlsbad, NM.

U.S. Congress. 1992. Waste Isolation Pilot Plant Land Withdrawal Act. Public Law 102-579.

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8.0 INDIVIDUAL AND GROUNDWATER PROTECTION REQUIREMENTS

The quantitative release limits set forth in the Containment Requirements provisions of Title 40 of the Code of Federal Regulations (CFR) § 191.13 are one of three long-term numerical performance requirements contained in 40 CFR Part 191. The Waste Isolation Pilot Plant (WIPP) must also comply with two other numerical performance standards that are contained in the individual (40 CFR § 191.15) and groundwater (40 CFR Part 191, Subpart C) protection requirements. This section describes the U.S. Department of Energy's (DOE's) demonstration of compliance for the WIPP with both the individual and groundwater protection requirements.

In performing the compliance assessment, the DOE applied a bounding-analysis approach using unrealistic assumptions that result in the over estimation of potential doses and contaminant concentrations. To provide added assurance, the DOE assumed the presence of an underground source of drinking water (USDW) in close proximity to the WIPP land withdrawal area boundary, even though available data indicate that none currently exists near the boundary. Using this very conservative approach, the calculated maximum potential dose to an individual would be about one-thirtieth of the individual protection standard. Concentrations of contamination in the hypothetical USDW would be less than half of the U.S. Environmental Protection Agency (EPA) groundwater protection limits and potential doses to a receptor who drinks from the hypothetical USDW would be an order of magnitude less.

This conservative approach also assumes that all contaminants reaching the accessible environment are directly available to a receptor. The analysis bounds any potential impacts of underground interconnections among bodies of surface water, groundwater, and any USDW. (See Table 1-8 in Chapter 1.0 for a list of appendices that provide additional information supporting this chapter.)

8.1 Individual Protection Requirements

The individual protection requirements are contained in 40 CFR § 191.15 of the long-term disposal regulations. 40 CFR § 191.15(a) requires that

> Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts).

Undisturbed performance (UP) is defined in 40 CFR Part 191 to mean "the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events" (40 CFR § 191.12). Section 6.3.1 provides a description of UP, the conceptual models associated with UP, and the screening of features, events, and processes (FEPs) that are important to UP.

The method used to evaluate compliance with the individual protection requirements is related to that developed for assessing compliance with the containment requirements. If the evaluation of the UP scenario considered for the containment requirements shows contaminants will reach the accessible environment, the resulting dose to exposed individuals must be calculated and compared to the 15-millirem annual committed effective dose specified in 40 CFR § 191.15.

Further guidance on the implementation of the individual protection requirements is found in 40 CFR Part 194. 40 CFR § 194.51 states that

> Compliance assessments that analyze compliance with § 191.15 of this chapter shall assume that an individual resides at the single geographic point on the surface of the accessible environment where that individual would be expected to receive the highest dose from radionuclide releases from the disposal system.

40 CFR § 194.52 states that

> In compliance assessment that analyze compliance with § 191.15 of this chapter, all potential exposure pathways from the disposal system to individuals shall be considered. Compliance assessments with part 191, subpart C and § 191.15 of this chapter shall assume that individuals consume 2 liters per day of drinking water from any underground sources of drinking water in the accessible environment.

In addition, 40 CFR § 194.25(a) provides criteria related to the assumptions that should be made when undertaking dose calculations

> Unless otherwise specified in this part or in the disposal regulations, performance assessments and compliance assessments conducted pursuant to the provisions of this part to demonstrate compliance with § 191.13, § 191.15 and part 191, subpart C shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions.

8.1.1 Compliance Assessment of UP

40 CFR § 194.52 specifies that compliance assessments consider "all potential pathways from the disposal system to individuals." The DOE has considered the following potential pathways for groundwater flow and radionuclide transport:

- existing boreholes as required by 40 CFR § 194.55(b)(1); and
- potential boreholes including those that may be used for fluid injection as required by 40 CFR § 194.32(c) and 40 CFR § 194.54(b)(2).

After considering all of these, the DOE has found that contaminated brine may migrate away from the waste-disposal panels if pressure within the panels is elevated by the generation of gas from corrosion or microbial degradation. Two credible pathways by which radionuclides could reach the accessible environment have been identified:

1. radionuclide transport may occur laterally, through the anhydrite interbeds toward the subsurface boundary of the accessible environment in the Salado Formation (hereafter referred to as the Salado), or;

2. transport may occur through access drifts or anhydrite interbeds (primarily Marker Bed [MB] 139) to the base of the shafts. In this case, if the pressure gradient between the panels and overlying strata is sufficient, then contaminated brine may migrate up the shafts. As a result, radionuclides may be transported directly to the ground surface, or they may be transported laterally away from the shafts, through permeable strata such as the Culebra, toward the subsurface boundary of the accessible environment.

These conceptual release pathways for UP are illustrated in Figure 6-8. The modeling system described in Section 6.4 does not preclude potential radionuclide transport along other pathways, such as migration through Salado halite. However, the natural properties of the undisturbed system make radionuclide transport to the accessible environment via these other pathways unlikely.

Although both pathways are possible, the performance assessment modeling indicates that under undisturbed conditions, only the first is a potential pathway during the 10,000-year period of interest specified in the regulation.

The DOE has used the modeling system applied to the performance assessment, as described in Chapter 6.0, to make this determination. Scenario screening for the UP is described in Appendix SCR. As specified by 40 CFR § 194.54(b)(2), Appendix SCR identifies activities that may occur in the vicinity of the disposal system prior to or soon after disposal and documents which of these are included in the compliance assessment calculations. Table SCR-4 in Appendix SCR identifies FEPs included in the UP modeling. Appendix SCR also identifies FEPs that were considered but are not included in the modeling evaluation and the reasons for their elimination.

As specified by 40 CFR § 194.55(a), uncertainty in the performance of the compliance assessment is documented in Section 6.1.2. Probability distributions for uncertain disposal system parameter values used in the compliance assessment were developed and are documented in Appendix PAR. Section 8.1.5 identifies sampled parameters used in the compliance assessment.

Three hundred realizations of the modeling system were generated to evaluate UP. These 300 realizations are comprised of three sets of 100 realizations each, generated using the Latin hypercube sampling (LHS) method. Of the 300 realizations, none show any radionuclides reaching the top of the Salado through the sealed shafts.

Nine of the 300 realizations show concentrations of radionuclides greater than zero reaching the accessible environment through the anhydrite interbeds. All of the remaining 291 realizations show that no radionuclides reach the accessible environment during 10,000 years

through the anhydrite interbeds. A receptor in the accessible environment could not come in contact with the anhydrite interbeds located at a depth greater than 2,000 feet (606 meters). Table 8-1 shows the maximum concentrations of radionuclides calculated by the modeling evaluation as reaching the accessible environment in the nine nonzero realizations. The full range of estimated values for radionuclide concentrations is from zero to the values shown in Table 8-1. The maximum concentration values shown in Table 8-1 occur 10,000 years after the time of decommissioning.

8.1.2 Dose Calculation

As quoted earlier, 40 CFR Part 194 states that doses must be estimated for an individual who resides at the location in the accessible environment where that individual would be expected to receive the highest exposure from radionuclide releases from the disposal system (40 CFR § 194.51). Also as stated earlier, all potential pathways for exposure associated with the UP of the repository must be assessed (40 CFR § 194.52).

8.1.2.1 Transport Pathway

To perform the required dose calculation, it is necessary to specify possible pathways for the transport of the contaminants from the anhydrite interbeds to a receptor. The specified pathway is an abandoned deep borehole which intersects the contaminant plume in the accessible environment. Consistent with assumptions described in Section 6.4.7.2 and the information provided in Appendix DEL, the hole is assumed to have the permeability of an uncased hole filled with silty sand after the degradation of a borehole plug in the Rustler Formation (hereafter referred to as the Rustler). A pressure gradient is assumed to exist because of the pressures in the anhydrite resulting from gas generation in the repository. The pressures are assumed to be sufficient to force contaminants up the abandoned hole to the Culebra Formation or the Dewey Lake Redbeds (hereafter referred to as the Culebra and the Dewey Lake, respectively). The contaminants would then be available to a receptor through a well used to supply drinking water. This conceptual transport pathway is shown in Figure 8-1.

This is the only credible pathway that the DOE has been able to identify. As such, no inhalation or direct radiation exposures are anticipated.

As specified in 40 CFR § 194.54(b), this pathway considers the presence of an existing borehole. As discussed in Section 6.2.5.1, the influence of other existing boreholes has been evaluated in the FEPs screening for UP.

8.1.2.2 Bounding Analysis

As stated earlier, uncertainty in the calculation of radionuclide concentrations in the anhydrite interbeds is described in Section 6.1.2. Additional uncertainty is involved in the calculation of doses resulting from the specified exposure pathway. Given this uncertainty, the DOE has elected to perform a bounding analysis using assumptions that do not represent reality, but that

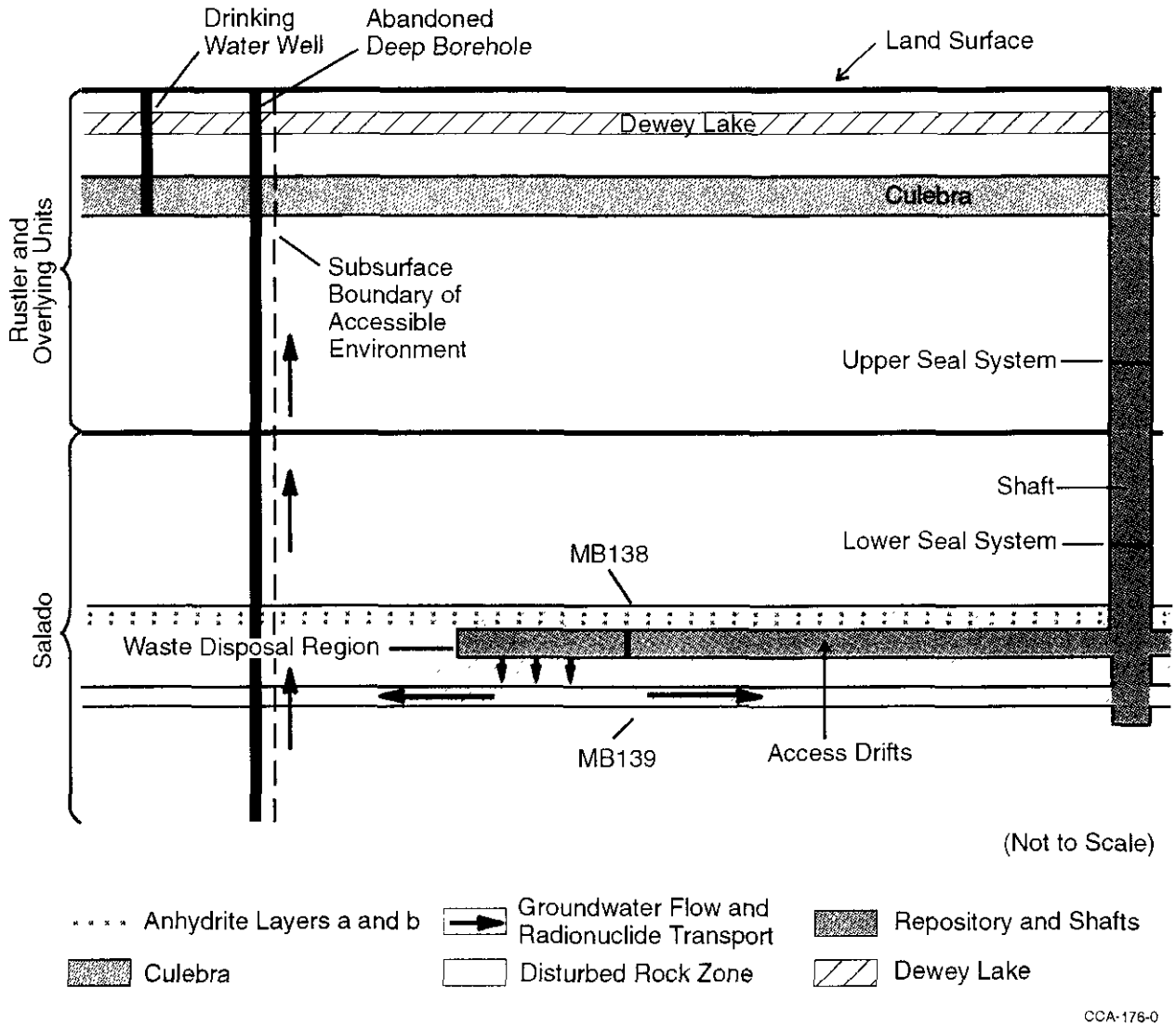

Figure 8-1. Conceptual Transport Pathway

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Table 8-1. Maximum Concentrations of Radionuclides Within the Salado Interbeds at the Disposal System Boundary

Realization No.	Vector No.[1]	Maximum Concentration (curies/liter)				
		^{241}Am	^{239}Pu	^{238}Pu	^{234}U	^{230}Th
1	Replicate 1 Vector 46	1.36×10^{-17}	4.33×10^{-12}	N[2]	5.82×10^{-13}	2.10×10^{-14}
2	Replicate 2 Vector 16	N	5.13×10^{-14}	N	6.77×10^{-15}	1.89×10^{-17}
3	Replicate 2 Vector 25	N	1.35×10^{-15}	N	1.65×10^{-16}	7.00×10^{-18}
4	Replicate 2 Vector 33	1.32×10^{-17}	7.18×10^{-14}	N	9.76×10^{-15}	9.36×10^{-16}
5	Replicate 2 Vector 81	N	6.23×10^{-18}	N	N	N
6	Replicate 2 Vector 90	N	5.20×10^{-16}	N	7.40×10^{-17}	N
7	Replicate 3 Vector 3	3.50×10^{-18}	3.08×10^{-13}	N	4.32×10^{-14}	1.07×10^{-16}
8	Replicate 3 Vector 60	5.98×10^{-17}	7.41×10^{-14}	N	9.09×10^{-15}	2.30×10^{-15}
9	Replicate 3 Vector 64	5.42×10^{-17}	5.85×10^{-12}	N	7.61×10^{-13}	4.68×10^{-15}
10-300	-	N	N	N	N	N

[1] Parameter values applied to each vector may be found in Appendix IRES (Tables IRES-2, IRES-3, and IRES-4).

[2] Values less than 10^{-18} curies per liter are considered to be negligible relative to the other values and are not reported.

would result instead in a bounding estimate that is much greater than any reasonably expected dose to a receptor. If this unrealistic yet bounding analysis results in calculated doses to the receptor that are below the regulatory limit, compliance with the standard is demonstrated.

The bounding analysis used for this assessment is based on the following factors and assumptions:

1. No specific transport mechanism is postulated. Instead, all of the contaminants reaching the accessible environment within the anhydrite interbeds during the year of maximum releases (that is, year 10,000) are assumed to be available to a receptor.

2. Brine derived from the anhydrite interbeds has total dissolved solids (TDS) concentrations of about 324,000 parts per million; this represents a concentration that could not be consumed by humans. For the bounding analysis, the calculation includes the dilution of this brine by a factor of 32.4 to a TDS concentration of 10,000 parts per million, which is the upper limit for potable water.

3. The resulting annual committed effective dose is calculated based on a 50-year dose commitment. A 50-year dose commitment is selected because this period is specified in Appendix B of 40 CFR Part 191 and because it is the duration for which published external dose-rate conversion factors are readily available in the literature (DOE 1988).

4. The individual receptor is assumed to drink two liters of water each day (as specified in 40 CFR § 194.52) for one year (in accordance with the specification of an annual committed effective dose in Appendix B of 40 CFR Part 191).

40 CFR § 194.51 states that DOE shall assume that an individual resides at the single geographic point where that individual would receive the highest dose. With the bounding analysis, the DOE complies with the intent of this criterion but the specific location of the receptor is not identified because all of the contaminants reaching the accessible environment within the anhydrite interbeds during the year of maximum releases are assumed to be directly available to the receptor, regardless of the location of the receptor. The well from which the receptor drinks is assumed to be located such that the contaminants reaching the anhydrite interbeds are delivered directly to the well.

The bounding analysis dose calculation was performed using the GENII-A code. Appendix GENII describes the modeling method. GENII-A incorporates dose-calculation guidance provided in Appendix B of 40 CFR Part 191.

8.1.3 Dose Calculation Results

The maximum doses calculated to result from the releases listed in Table 8-1, after applying the factors and assumptions listed above, are shown in Table 8-2. By definition, the bounding doses are greater than any realistic doses that could be delivered to a receptor. The calculated bounding doses are well below the regulatory standard, which is an annual committed effective dose of 15 millirems. The full range of estimated radiation doses is from zero to some value less than the bounding values shown in Table 8-2.

8.1.4 Statistical Assessment

EPA criterion 40 CFR § 194.55(d) specifies that the "number of estimates generated pursuant to paragraph (c) of this section shall be large enough such that the maximum estimates of doses and concentrations generated exceed the 99th percentile of the population of estimates with at least a 0.95 probability." The probability that an individual estimate is below the 99th

Table 8-2. Calculated Maximum Annual Committed Effective Doses

Realization No.	Vector No.[1]	Maximum Annual Committed Effective Dose (millirems)
1	Replicate 1 Vector 46	3.4×10^{-1}
2	Replicate 2 Vector 16	4.3×10^{-3}
3	Replicate 2 Vector 25	1.1×10^{-4}
4	Replicate 2 Vector 33	5.8×10^{-3}
5	Replicate 2 Vector 81	5.1×10^{-7}
6	Replicate 2 Vector 90	4.3×10^{-5}
7	Replicate 3 Vector 3	2.5×10^{-2}
8	Replicate 3 Vector 60	6.2×10^{-3}
9	Replicate 3 Vector 64	4.7×10^{-1}
10-300	-	N[2]

[1] Parameter values applied to each vector may be found in Appendix IRES (Tables IRES-2, IRES-3, and IRES-4).

[2] Doses derived from Table 8-1 concentration values of less than 10^{-18} curies are considered to be negligible and are not reported.

percentile is by definition 0.99. This means that only 1 in 100 estimates would have a value exceeding the 99th percentile, or conversely, the estimate would 99 times out of 100 have a value below the 99th percentile. Additionally, it follows that for two independent events, the probability that both estimates have a value below the 99th percentile is equal to the product (0.99)(0.99), or $(0.99)^2$, and that for n events, the probability that all estimates have a value below the 99th percentile is equal to $(0.99)^n$. To ensure a value exceeds the 99th percentile with a specified probability, the compliment ($1 - 0.99^n$) is used to calculate the number of estimates required.

The probability specified by 40 CFR § 194.55(d) is 0.95, or 95-percent confidence, that the maximum estimates of doses and concentrations generated exceed the 99th percentile of the

population of estimates. Therefore, the following equation can be solved for n, and the number of estimates required is

$$1 - 0.99^n = 0.95 \text{ or } n\log(0.99) = \log(0.05), \text{ which implies } n > 298 \qquad (1)$$

The solution requires n to be greater than 298 and was used to determine that 300 realizations of the modeling system is a sufficient number to meet the confidence level specified in 40 CFR § 194.55(d).

The 300 realizations of the modeling system (as described in Section 8.1.1) report concentrations of radionuclides reaching the accessible environment within the Salado anhydrite interbeds and not doses to a receptor, as specified by 40 CFR § 194.55(d). Nevertheless, the maximum possible resulting dose to an individual is 4.7×10^{-1} millirems, as reported in Table 8-2. All other potential doses resulting from the 300 realizations of the modeling system are below this value.

EPA criterion 40 CFR § 194.55(f) specifies that DOE shall

> document that there is at least a 95 percent level of statistical confidence that the mean and the median of the range of estimated radiation doses and the range of estimated radionuclide concentrations meet the requirements of § 191.15 and part 191, subpart C of this chapter, respectively.

Because the DOE has developed a bounding analysis, it is not meaningful to calculate and present mean and median dose values. Instead, the bounding analysis provides 100-percent confidence that all potential doses will be below the 4.7×10^{-1} millirem value.

8.1.5 Parameter Values

Appendix PAR provides tables listing the parameters used in the performance assessment and compliance assessment modeling program. As provided by 40 CFR § 194.55(b), Appendix PAR also identifies the probability distributions for these parameters, their units, the models and codes in which the parameters are used, the functional form of the probability distributions used for the sampled parameters, and associated input data. Of the listed parameters, the Appendix PAR tables listed in Table 8-3 identify parameters used in the compliance assessment.

8.1.6 Summary of Compliance with the Individual Protection Standard

In performing the compliance assessment, the DOE applied a bounding-analysis approach using unrealistic assumptions that result in the over estimation of potential doses and contaminant concentrations. This conservative approach assumes that all contaminants reaching the accessible environment are directly available to a receptor. Using this very conservative approach, the calculated maximum potential dose to an individual would be about one-thirtieth of the individual protection standard.

Table 8-3. Parameter Values Listed in Appendix PAR

Title	Table
Earthen Fill Shaft Material Parameters	PAR-16
Rustler Compacted Clay Shaft Material Parameters	PAR-17
Asphalt Shaft Material Parameters	PAR-18
Concrete Shaft Material Parameters	PAR-19
Compacted Salt Shaft Material Parameter	PAR-20
Upper Clay Shaft Material Parameters	PAR-21
Lower Clay Shaft Material Parameters	PAR-22
Bottom Clay Shaft Material Parameters	PAR-23
Concrete Monolith Shaft Material Parameters	PAR-24
Santa Rosa Formation Parameters	PAR-25
Dewey Lake Formation Parameters	PAR-26
Forty-Niner Member of the Rustler Formation Parameters	PAR-27
Magenta Member of the Rustler Formation Parameters	PAR-28
Tamarisk Member of the Rustler Formation Parameters	PAR-29
Culebra Member of the Rustler Formation Parameters	PAR-30
Unnamed Lower Member of the Rustler Formation Parameters	PAR-31
Salado Formation Intact Halite Parameters	PAR-32
Salado Formation Brine Parameters	PAR-33
Salado Formation Marker Bed 138 Parameters	PAR-34
Salado Formation Marker Bed 139 Parameters	PAR-35
Salado Formation anhydrite Beds a and b, Intact and Fractured Parameters	PAR-36
Disturbed Rock Zone Parameters	PAR-37
Waste Area and Waste Material Parameters	PAR-38
Waste Chemistry Parameters	PAR-39
Radionuclide Parameters	PAR-40
Isotope Inventory	PAR-41
Waste Container Parameters	PAR-42
Stoichiometric Gas Generation Model Parameters	PAR-43
Repository (Outside of Panel Region) Parameters	PAR-44
Predisposal Cavities (Waste Area) Parameters	PAR-45
Panel Closure Parameters	PAR-46
Operations Region Parameters	PAR-47
Experimental Area Parameters	PAR-48
Reference Constants	PAR-52
Listing of Parameters Used in BRAGFLO which Differ from the WIPP 1996 CCA Parameter Database	PAR-54
Listing of Parameters Used in PANEL which Differ from the WIPP 1996 CCA Parameter Database	PAR-55

8.2 Groundwater Protection Requirements

The groundwater protection requirements are contained in Subpart C of 40 CFR Part 191. In particular 40 CFR § 191.24(a)(1) requires that

> *General.* Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that 10,000 years of undisturbed performance after disposal shall not cause the levels of radioactivity in any underground source of drinking water, in the accessible environment, to exceed the limits specified in 40 CFR Part 141 as they exist on January 19, 1994.

EPA rule 40 CFR Part 141 specifies the National Primary Drinking Water Standards. The levels of radioactivity (and dose equivalent in the case of 40 CFR § 141.16[a]) specified in 40 CFR Part 141, as of January 19, 1994 were

1. combined ^{226}Ra and ^{228}Ra (40 CFR § 141.15[a]): 5 picocuries per liter;

2. gross alpha particle activity, including ^{226}Ra but excluding radon and uranium (40 CFR § 141.15[b]): 15 picocuries per liter;

3. annual dose equivalent to the total body or any internal organ from the average annual concentration of beta particle and photon radioactivity from man-made radionuclides (40 CFR § 141.16[a]): 4 millirem per year.

In addition, Section 194.53 applies to DOE's consideration of USDWs. The criterion specifies that

> In compliance assessments that analyze compliance with part 191, subpart C of this chapter, all underground sources of drinking water in the accessible environment that are expected to be affected by the disposal system over the regulatory time frame shall be considered. In determining whether underground sources of drinking water are expected to be affected by the disposal system, underground interconnections among bodies of surface water, groundwater, and underground sources of drinking water shall be considered.

To assess compliance with these provisions of the regulations, it is first necessary to identify any USDW that may be located near the WIPP. DOE's evaluation of whether any USDW is located near the WIPP is provided as Appendix USDW and is summarized in Section 8.2.2.

8.2.1 Criteria for USDW Determination

In performing the evaluation of the presence of any USDW, it is necessary to establish criteria to be applied to water quality and quantity data from wells in the vicinity of the WIPP. The criteria must be based on the regulatory definition of a USDW, as provided in 40 CFR § 191.22. A USDW is defined in 40 CFR § 191.22 to mean an aquifer or its portion that

> (1) Supplies any public water system; or
> (2) Contains a sufficient quantity of groundwater to supply a public water system; and

(i) Currently supplies drinking water for human consumption; or
(ii) Contains fewer than 10,000 milligrams of total dissolved solids per liter.

"Public water system" means a system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals. Such term includes:

(1) Any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system; and
(2) Any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system.

"Total dissolved solids" means the total dissolved (filterable) solids in water as determined by use of the method specified in 40 CFR Part 136.

Criteria based on these definitions were developed by the DOE and are applied to the assessment of the presence of any USDW near the WIPP. These criteria are defined in the following subsections.

8.2.1.1 Groundwater Quantity

Two subcriteria have been identified by the DOE and applied to the groundwater quantity definition:

1. An aquifer or its portion must be capable of producing water at an adequate rate.

2. An aquifer or its portion must be capable of producing water for a sufficient duration.

Water-consumption information was evaluated by the DOE to define the first subcriterion (the ability to produce at an adequate rate). The value to be applied is determined by obtaining the following information:

1. The rate, over a 24-hour period, at which water is consumed by 15 service connections.

2. The rate, over a 24-hour period, at which water is consumed by 25 individuals.

To be conservative in the definition of a USDW, the lower of these two values is assigned by the DOE to the first subcriterion. Based on calculations presented in Appendix USDW, a quantity of five gallons per minute is assigned as the first subcriterion.

The definition of the second quantity subcriterion (the acceptable production duration from a well) is more subjective. Because the creation of a public water supply system involves considerable capital expense, it is reasonable to assume that such a water system would not be constructed unless the water source would continue to be available for some time, at least long enough to recover the capital expense. The Rural Utility Service of the U.S. Department of Agriculture provides loans for funding new rural water supply systems. The loan periods are

generally 40 years in duration. Based on this, a duration of 40 years is applied by the DOE to the second quantity subcriterion.

8.2.1.2 Groundwater Quality

A criterion of 10,000 milligrams per liter of TDS is specified in 40 CFR § 191.22. Any aquifer or its portion producing water having TDS concentrations below this level is determined to be producing water that meets the quality criterion for a USDW. Any aquifer or its portion producing water having TDS concentrations at or above this level is determined to be producing water that does not meet the quality criterion and the regulatory definition of a USDW.

8.2.2 Comparison with USDW Determination Criteria

Current conditions and available hydrogeologic data were reviewed by the DOE to assess the presence of USDWs near the WIPP. This assessment compares current conditions and available data to the groundwater quantity and quality criteria described above. The results of this comparison are summarized below and provided in detail in Appendix USDW.

Five geologic units within the vicinity of the WIPP could potentially meet the definition of a USDW under Subpart C of 40 CFR Part 191. These include

- the Capitan Aquifer of the Guadalupian reef complex,
- the Culebra,
- the Magenta Dolomite Member of the Rustler Formation,
- the Dewey Lake,and
- the Santa Rosa Sandstone of the Dockum Group (hereafter referred to as the Santa Rosa).

Investigations conducted in the vicinity of the WIPP to characterize the hydrology of these formations are described in Appendix USDW. Important sources of relevant information are identified and findings or conclusions related to the presence of USDWs are provided. Based on this work, the DOE has concluded that USDWs are present in the Culebra, and, because of inconclusive groundwater production data, possible USDWs are present in the Dewey Lake and the Santa Rosa. USDWs in the Culebra are located at WIPP water quality sampling program (WQSP) wells, H-07b1, H-08b, and H-09b about 3, 9, and 6.5 miles (4.8, 14.5, and 10.5 kilometers) to the south/southwest of the controlled area boundary, respectively. Possible USDWs may occur in the Dewey Lake, about 1 mile (1.6 kilometers) south of the controlled area boundary, and the Santa Rosa, 7.7 to 9 miles (12.4 to 14.5 kilometers) to the east of the controlled area boundary, where private wells (used predominantly for supplying

water to livestock) have generated no available groundwater production data to assess their potential to yield a sufficient quantity to meet 40 CFR § 191.22 requirements. In the absence of such data, and to be conservative, these wells are designated as being located in possible USDWs.

8.2.3 Comparison with the National Primary Drinking Water Standards

To provide additional assurance of the safety of the WIPP, the DOE has prepared a bounding assessment of the concentrations of contaminants that could occur in a nearby USDW. Bounding doses that could be received by drinking from the USDW are also calculated. As was done to assess compliance with the individual protection standard, the analysis is bounding; the results do not represent reality but rather illustrate the maximum yet unrealistic concentrations of contaminants in a hypothetical USDW and the maximum yet unrealistic resulting doses. As was the case with the dose calculations, maximum concentrations were summed to develop concentrations for comparison with the National Primary Drinking Water Standards. The conclusions of this work, provided in the following subsections, are presented to illustrate that the consequences of the undisturbed repository are negligible, even when unrealistic assumptions are applied to the performance evaluation. The results of the bounding analysis support the position that additional characterization of groundwater near the WIPP to make a more definitive USDW determination is not warranted.

8.2.3.1 Transport Pathway

Section 8.1.2.1 describes the transport pathway assumed for the bounding analysis performed for the evaluation of compliance with the individual protection standard. This same transport pathway is assessed for the evaluation of compliance with the groundwater protection standard.

This pathway assumes that a USDW is located such that the maximum possible concentration of radionuclides could be realized in the USDW and the maximum possible dose to an individual who drinks from the USDW could be delivered to the individual. As such, the analysis bounds the 40 CFR § 194.53 criterion that specifies that DOE must consider underground interconnections among bodies of surface water, groundwater, and USDWs.

8.2.3.2 Combined ^{226}Ra and ^{228}Ra

The modeling system employed to simulate the performance of the undisturbed repository tracks the transport of the radionuclides of greatest importance to releases to the accessible environment (see Appendix WCA). These radionuclides of interest, listed in Table 8-1, are ^{241}Am, ^{239}Pu, ^{238}Pu, ^{234}U, and ^{230}Th. They do not include ^{226}Ra or ^{228}Ra because these radionuclides are not a prevalent component of the projected inventory of the repository. However, an analysis of ^{226}Ra and ^{228}Ra is required to evaluate compliance with the groundwater protection standard.

To perform the bounding analysis, the results of a tracer exercise of the NUTS code were used to scale the anticipated releases of ^{226}Ra and ^{228}Ra. The tracer exercise shows that an initial concentration of radionuclides in the repository of 1 kilogram per cubic meter results in a concentration at the accessible environment boundary of 2.5×10^{-7} kilograms per cubic meter. By applying this scaling factor determined by the tracer exercise to the quantity of ^{226}Ra and ^{228}Ra projected to be emplaced in the repository, it is determined that the maximum concentration of these radionuclides in the accessible environment is 2 picocuries per liter, which is below the 40 CFR § 141.15(a) standard of 5 picocuries per liter.

This concentration is calculated by transporting the passive tracer in the flow field generated using the BRAGFLO code for Realization 1, shown in Table 8-2. The calculation uses the mass and activity loads for ^{226}Ra and ^{228}Ra in the radionuclide inventory at decommissioning and at 10,000 years. These values are provided in Table 8-4. The ORIGEN 2 code is used to calculate the activity loads at 10,000 years; these loads are 94.98 curies of ^{226}Ra in CH and RH waste and 1.01 curies of ^{228}Ra in CH and RH waste. The calculated concentration is based on the volume of brine, 441,375 cubic feet (12,500 cubic meters), projected to flow across the accessible environment boundary at 10,000 years in the BRAGFLO flow field.

Table 8-4. Total Inventory and Mass Loading of ^{226}Ra and ^{228}Ra

Radionuclide	Waste Type	Total Inventory at Decommissioning [1] (curies)	Total Inventory at 10,000 Years [2] (curies)	Mass Loading [1] (kilograms)
^{226}Ra	CH	1.16×10^{1}	9.21×10^{1}	1.17×10^{-2}
^{226}Ra	RH	3.58×10^{-5}	2.88×10^{0}	3.62×10^{-8}
^{228}Ra	CH	7.47×10^{-1}	9.14×10^{-1}	3.19×10^{-6}
^{228}Ra	RH	7.77×10^{-2}	9.26×10^{-2}	3.32×10^{-7}

[1] Values for activity at decommissioning are from Table 4 of Appendix WCA, Attachment WCA.8.2. Values for mass loading at decommissioning are from Table 6 of Appendix WCA, Attachment WCA.8.2.

[2] Values for activity at 10,000 years are from Table 5.4-10 of Sanchez et al. 1996, *EPAUNI: Estimating Probability Distribution of EPA Unit Loading in the WIPP Repository for Performance Assessment Calculations*, in SWCF-A:1.2.07.1.1:WA; QA: EPAUNI, WPO No. 39259.

The total concentration (CH and RH) of either ^{226}Ra or ^{228}Ra at 10,000 years at the accessible environment boundary is calculated accordingly:

1. Calculate the total mass load at 10,000 years by multiplying the total mass load at decommissioning by the ratio of activity loadings at 10,000 years and decommissioning, respectively.

2. Calculate the total mass concentration at the accessible environment boundary by dividing by the value of brine from the BRAGFLO simulation and multiplying by the scaling factor.

3. Convert to total concentration of activity at the accessible environment boundary by multiplying by the ratio of activity loading to mass loading at decommissioning.

The 2 picocuries per liter maximum concentration occurs in the anhydrite interbeds within the Salado and not in a zone that could realistically be expected to be a source of drinking water.

8.2.3.3 Gross Alpha Particle Activity Including ^{226}Ra But Excluding Radon and Uranium

Compliance with the 40 CFR § 141.15(b) standard was assessed by summing the maximum concentration values provided in Table 8-1 for ^{241}Am, ^{239}Pu, ^{238}Pu, and ^{230}Th and adding the value for ^{226}Ra obtained to perform the 40 CFR § 141.15(a) assessment. The value obtained by this method is 7.81 picocuries per liter, which is below the 40 CFR § 141.15(b) standard of 15 picocuries per liter. This concentration occurs in the anhydrite interbeds within the Salado and not in a zone that could realistically be expected to be a source of drinking water.

8.2.3.4 Annual Dose Equivalent to the Total Body or Any Internal Organ from the Average Annual Concentration of Beta Particle and Photon Radioactivity from Man-Made Radionuclides

To assess compliance with the 40 CFR § 141.16(a) standard, an annual dose equivalent of 4 millirem per year, the transport of the following radionuclides was evaluated: ^{239}Pu, ^{238}Pu, ^{234}U, and ^{230}Th. The maximum annual committed effective dose from any of these radionuclides is 0.47 millirems, which is the value reported in Table 8-2 for transport through MB139 and is an order-of-magnitude below the regulatory standard. The 0.47 millirem value includes alpha particle radioactivity, as well as beta particle and photon radioactivity. Thus, the value is very conservative in that the 4 millirem annual dose equivalent limit is only for beta particle and photon radioactivity.

8.3 Compliance Summary

In performing the compliance assessment, the DOE applied a bounding-analysis approach using unrealistic assumptions that result in the over estimation of potential doses and contaminant concentrations. To provide added assurance, the DOE assumed the presence of a USDW in close proximity to the WIPP Land Withdrawal Area boundary, even though available data indicate that none currently exists near the boundary. Using this very conservative approach, the calculated maximum potential dose to an individual would be about one-thirtieth of the individual protection standard. The maximum concentrations of contamination in the hypothetical USDW would be less than half of the EPA groundwater protection limits and the maximum potential dose to a receptor who drinks from the hypothetical USDW would be an order of magnitude less.

This conservative approach also assumes that all contaminants reaching the accessible environment are directly available to a receptor. The analysis bounds any potential impacts of underground interconnections among bodies of surface water, groundwater, and underground sources of drinking water.

REFERENCES

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. *Federal Register*, Vol. 58, No. 242, pp. 66398 – 66416, December 20, 1993. Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

EPA (U.S. Environmental Protection Agency). 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. *Federal Register*, Vol. 61, No. 28, pp. 5224 – 5245, February 9, 1996. Office of Air and Radiation, Washington, D.C. In NWM Library as KF70.A35.C751 1996 (Reference).

BIBLIOGRAPHY

U.S. Department of Energy (DOE). 1988. *Internal Dose-Rate Conversion Factors for Calculation of Dose to the Public*. DOE/EH-0071. DOE Office of Environmental Guidance and Compliance, Washington, D.C.

9.0 PEER REVIEW

This chapter describes the regulatory basis for the conduct of peer reviews and summarizes relevant peer reviews that have been performed at the Waste Isolation Pilot Plant (WIPP). Key elements of the U.S. Department of Energy (DOE) Carlsbad Area Office (CAO) peer review program (for example, the review process, reports, and selection criteria and training for review panel members) are discussed. Three categories of peer reviews are reported in this chapter: (1) those conducted after the promulgation of Title 40 of the Code of Federal Regulations (CFR) Part 194 (U.S. Environmental Protection Agency [EPA] 1996a); (2) those conducted earlier; and (3) future or ongoing peer reviews.

In support of this application, seven peer reviews were initiated subsequent to the promulgation of 40 CFR Part 194. Per the criteria of 40 CFR § 194.27, they were conducted in a manner that is compatible with NUREG-1297 (Nuclear Regulatory Commission [NRC] 1988). The subjects of these reviews include: conceptual models; waste characterization analysis; engineered alternatives cost/benefit study (EACBS); engineered systems data qualification; waste form and disposal room data qualification; natural barriers data qualification; and passive institutional controls. These reviews are summarized in this chapter in the following sections:

- 9.3.1 – Conceptual Models Peer Review
- 9.3.2 – Waste Characterization Analysis Peer Review
- 9.3.3 – Engineered Alternatives Cost/Benefit Study Peer Review
- 9.3.4 – Engineered Systems Data Qualification Peer Review
- 9.3.5 – Natural Barriers Data Qualification Peer Review
- 9.3.6 – Waste Form and Disposal Room Data Qualification Peer Review
- 9.3.7 – Passive Institutional Controls Peer Review

The applicable peer review plans, complete peer review reports, and selected supporting documentation are provided in Appendix PEER. This chapter also presents the DOE responses to the findings and recommendations of the peer reviews. Additional documentation is available in project record packages in the CAO Record Center, which is located in Carlsbad, New Mexico.

Peer reviews that occurred prior to the promulgation of 40 CFR Part 194 were not necessarily conducted in accordance with NUREG-1297 guidelines. Therefore, candidate reviews were evaluated against specific criteria to determine whether they were appropriate for inclusion in this application. The selected historical reviews are summarized in the following sections:

- 9.4.1 – National Academy of Sciences WIPP Panel Reviews (12 reports)
- 9.4.2 – Performance Assessment Peer Review Panel
- 9.4.3 – Shaft Seal Design Independent Review
- 9.4.4 – Engineered Alternatives Task Force Report Peer Review
- 9.4.5 – Blue Ribbon Panel Peer Review
- 9.4.6 – Advisory Committee on Nuclear Facility Safety Review (two reports)
- 9.4.7 – Performance Assessment Review Team

- 9.4.8 – INTRAVAL
- 9.4.9 – WIPP Conceptual Model Uncertainty Group Review
- 9.4.10 – Environmental Evaluation Group Reviews (15 reports)
- 9.4.11 – Fracture Expert Group Review
- 9.4.12 – Fanghänel Review
- 9.4.13 – Independent Technical Review of the Bin and Alcove Test Programs
- 9.4.14 – Performance Assessment Reviews
- 9.4.15 – Technical Support Group Reviews (two reports)
- 9.4.16 – National Environmental Policy Act Reviews

The full reports from these reviews and selected supporting material are provided in Appendix PEER.

9.1 Regulatory Requirements

The certification criteria in 40 CFR Part 194 prescribes the use of peer reviews to support certain areas of the compliance evaluation. Compliance criteria in 40 CFR § 194.27 state that peer review at the WIPP be performed for several specific aspects of the program and that they be performed in a manner compatible with NUREG-1297. NUREG-1297 provides guidance on the definition of peer reviews, the areas for which a peer review is appropriate, the acceptability of peers, and the conduct and documentation of peer reviews. 40 CFR Part 194 states that *"The specific requirements in NUREG-1297 that discuss for which activities peer review should be conducted do not apply, nor do they supersede the requirements of the final rule."* (61 *Federal Register* [FR] 5228) Specific sections of 40 CFR Part 194 and NUREG-1297 provide the regulatory basis for this chapter.

The certification criteria state that any application for certification shall include documentation for the following peer reviews that are to be conducted: conceptual models used in the performance assessment; waste characterization analysis; and, engineered barrier evaluation (40 CFR § 194.27[a]). Section 194.27(b) states that these peer reviews, if conducted subsequent to the promulgation of 40 CFR Part 194, be conducted in a manner that is compatible with NUREG-1297. Section 194.27(c)(2) also states that this application include documentation of any peer review processes conducted in addition to those of 40 CFR § 194.27(a).

NUREG-1297 defines peer review as *"a documented, critical review performed by peers who are independent of the work being reviewed."* NUREG-1297 also states that a *"peer review is an in-depth critique of the assumptions, calculations, extrapolations, alternate interpretations, methodology, and acceptance criteria employed, and of conclusions drawn from the original work."*

The 40 CFR Part 194 Background Information Document (EPA 1996b) states that peer reviews can be used as part of *"a comprehensive quality assurance program"* to give *"confidence that work completed, underway, or planned was, is, or will be properly*

performed." The Background Information Document also notes that *"additional peer review is also necessary to establish the validity of procedures, methods, or interpretations which may not be addressed by a quality assurance program . . . ASME-NQA-3-1989 . . . includes peer review among those activities affecting quality associated with the collection of scientific and technical information, when other established methods cannot be used to establish the adequacy of information."*

NUREG-1297 states that for a repository,

> *"peer reviews should be used as a management tool to achieve confidence in the validity of certain technical and programmatic judgments. The intent of a peer review is to pass judgment on the technical adequacy of the work or data submitted for review, to identify aspects of the work on which technical consensus exists, to identify aspects on which technical consensus does not exist, and to identify aspects of the reviewed work which the reviewers believe to be incorrect or which need amplification. A peer review provides assurance in cases where scientific uncertainties and ambiguities exist but in which technical and programmatic judgments and decisions still must be made."*

9.2 Peer Review Process

NUREG-1297 suggests that procedures be developed to *"implement the NUREG-1297 guidance"* and to *"provide methods for initiating a peer review."* These procedures, for any given peer review, *"should require a planning document that describes the work to be reviewed, the size and spectrum of the peer review group, and the suggested method and schedule to arrive at a peer review report."*

WIPP-specific plans and procedures ensure that peer reviews performed subsequent to promulgation of 40 CFR Part 194 were conducted in accordance with the criteria of 40 CFR Part 194 and compatible with NUREG-1297. The most pertinent of the plans and procedures are discussed briefly below.

A Peer Review Management Plan (PRMP) (DOE 1996a) was developed and approved by the CAO to describe the management processes used to control the planning, implementation, and documentation of these reviews. The PRMP defines the management approach, resources, schedule, and technical requirements for using peer reviews to confirm and/or verify the adequacy of data and/or information utilized to support the WIPP application.

CAO Team Procedure (TP) 10.5, Peer Review (DOE 1996b), implements the requirements of NUREG-1297. TP 10.5 prescribes the responsibilities, requirements, and methodologies to be incorporated in the performance of peer reviews conducted by the CAO pursuant to the criteria of 40 CFR § 194.27. The procedure provides the criteria for determining the size and composition of the review panel and for selecting individual peer review panel members, and outlines the orientation and training to be provided for the panelists. TP 10.5 also describes

the actual peer review process, provides criteria for development of peer review plans and report preparation, and defines the responsibilities of individuals involved in the process.

Specific peer review plans were developed for each peer review at the WIPP. These plans documented the planning process for the peer reviews and were prepared and approved prior to performing the particular review (see Section 9.2.1).

As discussed more completely in Chapter 5.0, the Quality Assurance Program Document (QAPD) (DOE 1996c) establishes the minimum requirements for the WIPP quality assurance (QA) program. It provides guidance for development and implementation of QA programs for all aspects of the WIPP project. In particular, the QAPD provides general requirements for training, document control, and QA records management.

9.2.1 Peer Review Plan

TP 10.5 requires that the Peer Review Manager ensure that a peer review plan is prepared and approved prior to the performance of each peer review. Specific plans are approved by the CAO Assistant Manager for the Office of Regulatory Compliance.

The plan documents the planning of the peer review. It provides the scope of the peer review, a description of the work to be reviewed, the intended use of the work, the size and composition of the peer review panel, and methods for conducting peer reviews

40 CFR § 194.27(b) specifies that peer reviews performed subsequent to the promulgation of 40 CFR Part 194 be conducted in a manner compatible with NUREG-1297. NUREG-1297 states that

> *"The peer review process may vary from case to case, and should be determined by the chairperson of the peer review group, consistent with the guidance provided in this GTP* (Generic Technical Position). *In meetings and/or correspondence, the peer review group should evaluate and report on: (a) validity of assumptions; (b) alternate interpretations; (c) uncertainty of results and consequences if wrong; (d) appropriateness and limitations of methodology and procedures; (e) adequacy of application; (f) accuracy of calculations; (g) validity of conclusions; (h) adequacy of requirements and criteria. Furthermore, full and frank discussions between the peer reviewers and the performers of the work are encouraged."*

The WIPP peer review process consists of an in-depth analysis and evaluation of documented assumptions, calculations, extrapolations, alternate interpretations, methodology, and acceptance criteria employed, and of conclusions drawn in the original work. TP 10.5 specifically incorporates the above NUREG-1297 requirements into the WIPP peer review process.

9.2.2 Size and Composition of Peer Review Panels

NUREG-1297 states that

> *"The number of peers comprising a peer group should vary with the complexity of the work to be reviewed, its importance to establishing that safety or waste isolation performance goals are met, the number of technical disciplines involved, the degree to which uncertainties in the data or technical approach exist, and the extent to which differing viewpoints are strongly held within the applicable technical and scientific community concerning the issues under review. The collective technical expertise and qualifications of peer group members should span the technical issues and areas involved in the work to be reviewed, including any differing bodies of scientific thought. Technical areas more central to the work to be reviewed should receive proportionally more representation on the peer review group."*

The NUREG-1297 guidance also states that

> *"The peer review group should represent major schools of scientific thought. The potential for technical or organizational partiality should be minimized by selecting peers to provide a balanced review group."*

The size and composition of peer review panels established after the promulgation 40 CFR Part 194 were determined by a selection committee consisting of the Peer Review Manager and two members selected by the Peer Review Manager.

Peer review panel size and composition was determined by a selection committee consisting of the Peer Review Manager and two members selected by the Peer Review Manager. These individuals were picked because of their familiarity with the peer review process, the WIPP project, their impartiality, and their knowledge of potentially qualified peer reviewers.

Technical requirements for each peer review panel were established by the Peer Review Manager and provided to the selection committee, which then developed a list of potentially qualified personnel. Once a panel member was officially selected and had agreed to serve, the selection committee members documented the rationale for the selection of that peer review panel member on a "Peer Review Panel Selection, Size and Composition Justification/ Decision Form," which is maintained as a QA record.

The number of members selected for a particular panel depended on the amount and complexity of the work to be reviewed, its importance for establishing that safety or waste isolation performance goals are met, the number of technical disciplines involved, the degree to which uncertainties in the data or technical approach exist, and the extent to which differing viewpoints are strongly held within the applicable technical and scientific community concerning the issues under review. The panel members were selected based on their collective technical expertise and qualifications so that they spanned the technical issues and

areas involved in the work to be reviewed, including differing bodies of scientific thought. The technical areas more central to the work to be reviewed received proportionally more representation on the peer review panel. To the extent practical, the panels represented the major schools of scientific thought pertinent to the subject being reviewed. The selection committee strived to eliminate the potential for technical or organizational partiality by selecting peer reviewers that provided a balanced panel.

The strategy for staffing the panels was to use a combination of individuals knowledgeable of the WIPP with other individuals that had little or no knowledge of the WIPP. All of the individuals had to meet the strict independence requirements. To ensure that the data review panels had knowledge of the related conceptual models, two members of the Conceptual Models Peer Review Panel were assigned to the Natural Barriers Data Qualification Peer Review Panel and two others were assigned to the Engineered Systems Data Qualification Peer Review Panel. In addition, one individual from the Waste Form and Disposal Room Data Qualification Peer Review Panel was assigned to the Waste Characterization Analysis Review Panel to ensure the latter panel was provided with timely and in-depth knowledge of chemistry data pertinent to the waste.

9.2.3 Technical Qualifications of Panel Members

NUREG-1297 states that

> *"The technical qualifications of the peer reviewers, in their review areas, should be at least equivalent to that needed for the original work under review and should be the primary consideration in the selection of peer reviewers. Each peer reviewer should have recognized and verifiable technical credentials in the technical area he or she has been selected to cover. The technical qualifications of each peer, and hence of the peer review group as a whole, should relate to the importance of the subject matter to be reviewed."*

TP 10.5 specifies that the acceptability of any peer review panel member be based on the above NUREG-1297 requirements. The Peer Review Manager is required to ensure that education and pertinent experience information is verified and documented prior to the start of the peer review process. This documentation is also maintained as QA records.

9.2.4 Independence of Panel Members

NUREG-1297 states that

> *"Members of the peer review group should be independent of the original work to be reviewed. Independence in this case means that the peer, a) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed."*

> *"Because of DOE's pervasive effort in the waste management area, the lack or unavailability of other technical expertise in certain areas, and the possibility of reducing the technical qualifications of the reviewers in order that total independence is maintained, it may not be possible to exclude all DOE or DOE contractor personnel from participating in a peer review. In those cases where total independence cannot be met, a documented rationale as to why someone of equivalent technical qualifications and greater independence was not selected should be placed in the peer review report."*

NUREG-1297 allows both the work under review and the peer review of that work to be funded by DOE. It also provides the caveat that the

> *"independence criteria is not meant to exclude eminent scientists or engineers upon whose earlier work certain of the work under review is based so long as a general scientific consensus has been reached regarding the validity of their earlier work."*

TP 10.5 provides that the above NUREG-1297 requirements be used in selecting panel members. Each peer review panel member is required to document his or her independence. These documents are reviewed and approved by the Peer Review Manager and maintained as QA records.

9.2.5 Training of Peer Review Panel Members

TP 10.5 requires that the Peer Review Manager ensure that all peer review panel members receive adequate training prior to beginning a peer review. Training consists of reading assignments and, if deemed necessary by the Peer Review Manager or the Peer Review Panel Coordinator, briefings and classroom training. Assigned reading includes 40 CFR Parts 191 (EPA 1993) and 194, NUREG-1297, the CAO QAPD, TP 10.5, and the applicable Peer Review Plans.

TP 10.5 further requires that all panel members receive an orientation prior to the start of the peer review process. The orientation includes information on the peer review process, administrative requirements, the applicable Peer Review Plan, a summary of the technical subject matter, and an overview of TP 10.5. Panel member training and orientation are documented and this documentation is maintained as a QA record.

9.2.6 Peer Review Panel Report

NUREG-1297 states that

> *"A written report documenting the results of the peer review should be issued. It is usually prepared under the direction of the chairperson of the peer review group, and is signed by each member individually. It should clearly state the work or issue that was peer reviewed and the conclusions reached by the peer review process . . . The*

report should include individual statements by peer review group members reflecting dissenting views or additional comments, as appropriate. The peer review report should contain a listing of the reviewers and any acceptability information (i.e., technical qualifications and independence) for each member of the peer group, including potential technical and/or organizational partiality."

TP 10.5 requires that a peer review report be prepared for each peer review. Each panel member is required to sign and date the report. The report describes the work or issue that was reviewed and the conclusions reached by the panel, and it provides individual statements by the members reflecting dissenting views or additional comments, as appropriate. Finally, the report lists the peer review panel members and provides technical qualifications and independence information for each member.

9.2.7 Quality Assurance Records Management

NUREG-1297 specifies that written

"minutes should be prepared of meetings, deliberations, and activities of the peer review process."

TP 10.5 requires that written minutes, including graphic or calculated materials used in panel meetings, be prepared for meetings, deliberations, daily caucuses, and other activities. These written minutes are maintained as QA records. TP 10.5 also requires that a QA records management system be developed and implemented to ensure that peer review documents are identified, assembled, and transferred on a timely basis and in an orderly manner to the appropriate records center.

9.2.8 Quality Assurance Oversight

Section V of NUREG-1297 states that

"As a minimum, the QA organization should provide surveillance of the peer review process to ensure that the procedures conform to the guidance of this GTP and that they are followed by the peer review group."

The QAPD establishes requirements for implementing the QA program for the WIPP peer review process. The QAPD requires that assessments be conducted to ensure that all aspects of the peer review conform to the guidance of NUREG-1297, TP 10.5, and the CAO QAPD. Audits of the peer review process have been performed in accordance with the requirements of the QAPD. Additional details regarding the WIPP QA program are provided in Chapter 5.0.

9.3 Peer Reviews Conducted After Promulgation of 40 CFR Part 194

Seven peer reviews were performed by the WIPP project to address issues deemed necessary by the CAO. These peer reviews included reviews of conceptual models, waste characterization analysis and an evaluation of the benefits and detriments of potential engineered barriers and alternatives as stated in 40 CFR § 194.27(a); data reviews of engineered systems, waste form and disposal room, and natural barriers as stated in 40 CFR § 194.22(b); and a passive institutional controls review. These peer reviews were conducted subsequent to the promulgation of 40 CFR Part 194 and were conducted in a manner consistent with the NUREG-1297 guidance, as implemented by TP 10.5 and the QAPD.

Specifically, the following peer reviews were conducted:

- an evaluation of the adequacy and reasonableness of the WIPP conceptual models;
- a review of the adequacy and completeness of the waste characterization analysis;
- an assessment of the validity of the assumptions and approach used to select or reject engineered alternatives, as delineated in the EACBS (DOE 1995b) for the WIPP;
- a data qualification review of parameters used to describe engineered systems;
- a data qualification review of parameters used to describe natural barriers;
- a data qualification review of parameters used to describe the waste form and disposal room; and,
- a determination of whether the passive institutional controls have a reasonable expectation of meeting their intended purpose.

These seven reviews are discussed, and the WIPP project response to the peer review panel's comments are provided, in the following sections. The general process used by the CAO to plan and conduct the seven peer reviews is described in Section 9.2. The complete peer review reports are provided in Appendix PEER. The reports were all consensus documents which were signed by all the members of the specific panel involved, that is, there were no dissenting views on any of the final reports for the seven subject reviews.

9.3.1 Conceptual Models Peer Review

40 CFR § 194.23(a)(3)(v) specifies that this application include documentation that the conceptual models have undergone peer review consistent with 40 CFR § 194.27. A Conceptual Model Peer Review (CMPR) Plan (see Appendix PEER) was developed and approved in accordance with the requirements of TP 10.5. The CMPR Plan describes the peer

review process used to ensure that the conceptual models used in the WIPP performance assessment reasonably represent possible future states of the disposal system.

In accordance with the provisions of TP 10.5, a peer review panel was selected and organized. The six-member panel was composed of the following individuals:

Charles R. Wilson (Chairman), Private Consultant
Florie A. Caporuscio, Informatics Corporation
John F. Gibbons II, Private Consultant
Eric B. Oswald, Private Consultant
Darrell D. Porter, Science Applications International Corporation
Glen L. Sjoblom, Private Consultant

Florie A. Caporuscio has a Ph.D. in Geology and has more than 10 years of applied pertinent experience, including having served as the Acting Section Chief, WIPP Technical Review, at EPA Headquarters' Office of Radiation and Indoor Air and as a Staff Geologist at EPA Region II. In addition to Dr. Caporuscio's highly relevant regulatory expertise, his pertinent technical qualifications include extensive expertise in site characterization, geochemistry, radionuclide transport in geological media, and related conceptual models.

John F. Gibbons II has a Ph.D. in Geomechanics and has more than 20 years of relevant experience, including having served as the Technical Director of Applied Research Associates for site characterization technology research and development activities augmented by involvement in numerous site characterizations. Dr. Gibbons' site characterization and technology research and development (R&D) experience is particularly pertinent for peer reviews involving geology, tectonics, hydrology, and related conceptual models.

Eric B. Oswald has a Ph.D. in Hydrology and Water Resources Administration and has more than 25 years of applied pertinent technical and regulatory experience. Dr. Oswald's technical qualifications include extensive surface and groundwater flow system analyses and control, contaminant transport, and related conceptual models.

Darrell D. Porter has a Ph.D. in Mineral Engineering and has more than 34 years of experience in earth sciences programs with emphasis on rock mechanics. Dr. Porter's pertinent technical qualifications include extensive involvement in site characterization, regulatory compliance, quality assurance, and technical review activities in support of deep geologic repository development.

Glen L. Sjoblom has a M.Sc. in Chemical Engineering and has more than 26 years of experience in environmental radiation protection including having served as the Director of Radiation Programs at the EPA during the development and promulgation of 40 CFR Part 191. Mr. Sjoblom's extensive environmental radiation protection experience also includes serving as Special Assistant to the Director of the Office of Inspection and Enforcement and Deputy Director of the Division of Industrial and Regulatory Medical

Nuclear Safety at the NRC. Mr. Sjoblom's pertinent technical qualifications include chemistry, waste characterization, deterministic and stochastic risk and safety analysis, and environmental protection activities in support of deep geologic repository development.

Charles R. Wilson has a Ph.D. in Civil Engineering-Groundwater and has more than 26 years of relevant experience in earth sciences programs. Dr. Wilson's pertinent technical qualifications include lead roles in the geology, hydrology, geochemistry, and geotechnical engineering disciplines on teams involved in site characterization, model development, and modeling of: landfills; water resources; groundwater flow systems; contaminant and radionuclide transport; and nuclear waste repositories in the United States and abroad.

Additional details regarding the technical qualifications and independence of the panel members are provided in the final peer review report (see Appendix PEER). Each panel member's background was carefully reviewed to ensure his strong qualifications, and to verify his independence from other WIPP work, and to confirm the absence of conflicts of interest.

The peer review was conducted from April through August 1996. After orientation and training, the panel was provided draft conceptual model descriptions and other relevant information and was briefed by WIPP project staff. Panel members also had access to the Sandia National Laboratories (SNL) Nuclear Waste Management Program Library and to reports of prior peer reviews.

The objective of the review was to determine the adequacy and reasonableness of 24 conceptual models representing features, events, and processes involved in assessing the long-term performance of WIPP. As stated in the CMPR report:

> *"A conceptual model is a statement of how important features, events, and processes such as fluid flow, chemical processes, or intrusion scenarios are to be represented in performance assessment. To be used in performance assessment, the conceptual model must be successfully translated into analytical statements and mathematical analogs. The Panel reviewed in detail the twenty four conceptual models against criteria of the EPA....The Panel also made an assessment of the information used and whether the conceptual model is adequate for implementation in an overall performance assessment model."*

Per the criteria of 40 CFR Part 194, the peer review was conducted in a manner compatible with the provisions of NUREG-1297. The eight adequacy criteria from NUREG-1297 were used as a basis for review of each model (see Section 9.2.1).

The CMPR Report was issued in July 1996 (a copy of the CMPR Report is provided in Appendix PEER). The panel initially concluded that 13 of the models were adequate for implementation and that the remaining 11 models were not adequate for use in performance assessment. The DOE provided additional information in response to the panel's concerns, and the panel subsequently determined that the responses for six of those 11 models

reasonably addressed their concerns. In addition, the panel concluded that some of the responses (multiple concerns were identified for some models) relating to three additional models also reasonably addressed its concerns. Finally, the panel concluded that responses regarding three models did not reasonably address its concerns; however, one of these models was determined to have no consequence to performance assessment. The DOE's justification for using these unresolved models is discussed in the following Sections of this application.

The 24 models reviewed by the panel are listed in Table 9-1. Also provided are the panel's conclusions about the adequacy of the models and whether the panel believed that the DOE's responses reasonably addressed its concerns about those models that it determined to be inadequate.

Section 9.3.1.1 provides a brief description of the panel's discussion on the models it deemed adequate. Section 9.3.1.2 provides a brief description of the panel's discussion on the models deemed inadequate; the DOE's responses to the panel's concerns; the panel's comments on those responses; and the DOE's technical position on those concerns wherein the panel concluded that the responses did not reasonably address its concerns.

9.3.1.1 Adequate Models

The following excerpts are from the CMPR Report. They address those thirteen models that the panel determined to be adequate:

Disposal System Geometry

> *The conceptual model for the disposal system geometry provides a suitable framework for modeling the important processes and their interactions in the disposal system. . .The concept that the spatial effects of processes and interactions can be represented in two dimensions is defensible. The simplification in the system representation and computational method to simulate the two dimensions are defensible and adequate for implementation. The basic grid framework for representing the material properties of the disposal system, adjacent DRZ [disturbed rock zone], geologic formations, and intrusion scenarios is adequate and the proposed use of a finite difference method to connect the nodes and generate flow fields is also defensible and adequate for implementation.*

Salado

> *Given that the conceptual model predicts that there will be enough brine to corrode the waste and that other assumptions appear conservative, making other impacts unlikely, the model is adequate for its intended use. . .The conclusions appear to be valid. Estimates of inflow volumes from the mechanisms proposed in the model appear to be reasonable. . .The model is adequate for implementation.*

Table 9-1. Adequacy of WIPP Conceptual Models

Model	Report Findings	DOE Response Reasonable?
Disposal System Geometry	Adequate	Not Applicable
Culebra Hydrogeology	Not Adequate [1]	Yes
Repository Fluid Flow	Not Adequate	Yes
Salado	Adequate	Not Applicable
Impure Halite	Adequate	Not Applicable
Salado Interbeds	Not Adequate	Yes
DRZ	Adequate	Not Applicable
Actinide Transport in the Salado	Adequate	Not Applicable
Units Above the Salado	Not Adequate [1]	No[1]
Transport of Dissolved Actinides in the Culebra	Adequate	Not Applicable
Transport of Colloidal Actinides in the Culebra	Not Adequate	No
Exploration Boreholes	Not Adequate	Partially[2]
Cuttings and Cavings	Adequate	Not Applicable
Spallings	Not Adequate	Yes
Direct Brine Release	Not Adequate	No
Castile and Brine Reservoir	Not Adequate	Partially[3]
Multiple Intrusions	Adequate	Not Applicable
Climate Change	Adequate	Not Applicable
Creep Closure	Adequate	Not Applicable
Shafts and Shaft Seals	Adequate	Not Applicable
Gas Generation	Not Adequate	Yes
Chemical Conditions	Not Adequate	Partially[4]
Dissolved Actinide Source Term	Adequate	Not Applicable
Colloidal Actinide Source Term	Adequate	Not Applicable

[1] Although the model was found to be inadequate, it was determined to have no consequence to performance assessment.
[2] The panel concluded that responses to three of their four concerns were reasonable.
[3] The panel concluded that responses to two of their three concerns were reasonable.
[4] The panel concluded that responses to two of their three concerns were reasonable.

Impure Halite

Although differences in the behavior of pure and impure halite, variable degrees of impurity, and complexities of stratigraphic distribution of zones of impurity exist, the modeling of all halite rocks in the Salado as impure halite is an acceptable model simplification. . .The model appears to be adequate for the same reasons that the overall Salado model is adequate. Brine inflow sufficient to corrode the waste and to

drive biogenic degradation is assumed. For error to be significant, brine inflow would have to be very large, which is unlikely. . .The conclusions drawn on the basis of the impure halite model are valid for PA purposes.

Disturbed Rock Zone

All observed considerations of analysis, study, and proposed engineered applications regarding the DRZ and its impacts on effective shaft sealing appear to be valid. The understandings developed of DRZ phenomena and data reveal it is critical to engineering waste containment overall because of its potential for negative impact on shaft seals permeability and integrity and fluid flow in the rooms and their seals. It appears that all considerations of this impact and the conclusions discussed here are sound and valid. . .The panel concludes that the present DRZ model is adequate to be implemented in performance calculations.

Actinide Transport in the Salado

It seems DOE has provided a very rational way to "lump" all the various solubilities of dissolved actinides and to describe how the four main types of colloids will be "lumped" for transport. Both of these source terms have complex properties that could have been negated by the "lumping" factor. . .These two philosophies of solubility "lumping" have been clearly explained for dissolved and colloidal actinide transport. . .by the principal investigator and by this means the implementation was determined to be adequate. . .this model is wholly adequate and reasonable for implementation.

Transport of Dissolved Actinides in the Culebra

It is concluded that a dual porosity model is adequate for dissolved actinide transport analyses if ranges of model parameters are chosen properly in light of uncertainties. . .The conclusion that the actinide transport in the Culebra can be adequately modeled in a dual porosity model, with advective transport in the main flow porosity, diffusion into and physical and chemical retardation in the rock matrix porosity, is valid. . .The conceptual model appears compatible with other models it intersects with directly.

Cuttings/Cavings

This model is fundamentally appropriate. It is based on straightforward analysis, concepts, and technology that is well developed and believed to be adequate for depicting that part of the consequences of a waste room penetration by a borehole drill that is covered by this model....The CUTTINGS_S model contains well thought out and evaluated mathematics based on researched and established fluid flow technology and science. . .This model is sufficiently developed and uncomplicated that

no serious concerns were found. It appears to be capable of accurately representing the waste that might be removed during a drilling intrusion and is fully adequate for implementation in support of the WIPP performance assessment.

Multiple Intrusions

The conceptual model for multiple intrusions is fundamentally sound and appropriately conservative, given the simplifications that are required to model a complex set of conditions in an efficient manner. . .The application of the conceptual model to the numerical model is adequate, again given the simplifications that are required to model a complex set of conditions in an efficient manner. . .The Multiple Intrusion conceptual model is adequate for implementation in performance assessment.

Climate Change

The climate change conceptual model represents a reasonable and defensible range of potential future climate extremes for incorporation into the performance assessment. The conceptual model includes a range of conditions, bounded by reasonably foreseeable future climates and their effects, that are adequate to represent impacts to groundwater flows in the Culebra Dolomite Member of the Rustler Formation. In addition to providing adequate representation of conditions for implementation, the background research and analysis supporting the formulation of the conceptual model for climate change provides adequate information for satisfying EPA guidance.

Creep Closure

The adequacy of the Creep Closure conceptual model is demonstrated by its predictiveness of room closure in existing WIPP excavations. The uncertainties inherent in the model must be assessed through the sensitivity of the porosity surface calculation. The model appears to be adequately predictive. . .The porosity surface calculation appears to address the complex issues of timing among processes and provides a means of choosing representative parameters for individual process with respect to uncertainty about process results and timing during dynamic process evolution.

Shafts and Shaft Seals

Comments concerning two issues from the preceding section are also applicable to the model's adequacy for implementation: 1) further analysis of the salt compaction data base, firmed up with additional data, is important to support parameter permeability values, and 2) an analysis has not been found to assure the shaft monolith does not create a shear zone at the shaft perimeter interface. Aside from these, the foregoing discussions outline an insightful piece of scientific and engineering work. The shafts

and seals program is well thought through and the areas of perceived concern have been addressed to various degrees of detail, each believed sufficiently adequate to support qualifying this model as adequate to proceed in supporting performance assessment.

Dissolved Actinide Source Term

The true unknowns are to be found in the assumptions that the chemistry rapidly approaches equilibrium and that the waste has uniform characteristics and inventory. These fundamental assumptions are a basis of the conceptual model and are most probably adequate and reasonable. . .This model has turned out to be a very strong representation of how actinides would dissolve in the two major brines (Salado and Castile) of the repository and is adequate to support performance assessment.

Colloidal Actinide Source Term

Since this model is inexorably linked to the solubility concentrations of the dissolved actinide source term, one may conclude that this model is valid contingent on the validity of the other model (which was determined to be valid, with minor caveats)... The Colloidal Actinide Source Term model is a reasonable, if somewhat overly conservative representation of how actinides would sorb onto colloids in the two major brines (Salado and Castile) available for the repository. This conceptual model is adequate to support performance assessment.

9.3.1.2 Inadequate Models

As indicated above, the CMPR panel initially determined that 11 of the models they reviewed were inadequate. The CMPR panel concerns (Peer Review Panel Concerns - presented in italics below), the DOE interpretation of the panel's concerns (Statement of Issue), the DOE response to the panel's concerns (Response to Issue), and the panel reaction to the interpretation and responses (Peer Reviewer Consideration of Response) are provided below. In those instances in which the panel determined the response did not reasonably address its concerns, the DOE developed additional information regarding its position (DOE Technical Position versus Panel Issue). In some instances, a response addresses more than one concern.

The DOE responses were provided to the panel as individual memoranda. For incorporation into this application, the responses have been edited to remove the memorandum format, consolidate references, replace first-person language, insert cross-references where appropriate, and correct typographical errors. Substantive technical content of the responses has not been changed.

9.3.1.2.1 *Peer Review Panel Concerns - Culebra Hydrogeology*

No conceptual model which explains the variability of hydrologic properties and processes in the Culebra at a scale which is useful in correlating those properties in the numerical hydrologic flow model was developed.

An extensive hydrologic testing database and an apparently adequate numerical flow model were developed as a substitute for performance assessment purposes.

Although the Culebra conceptual model was found to be inadequate to support numerical modeling, this inadequacy was inconsequential for performance assessment because an extensive hydrologic database was developed and serves as an adequate substitute to support numerical modeling.

Statement of Issues

The main concern is that a conceptual model that integrates geologic and geochemical data was not developed to help define the distribution of Culebra hydraulic properties for the SECOFL2D calculations. The panel notes that construction of such a conceptual model would require an extensive field and modeling program to characterize geological properties such as fracture distribution, aperture, and orientation as well as patterns of spatial variability of matrix permeability and porosity.

Response to Issues

The CMPR panel noted that although the Culebra Hydrogeology conceptual model was found to be inadequate, this inadequacy is inconsequential for performance assessment. The objective of this response is mainly to clarify a few of the issues discussed by the panel.

The DOE confirms that the main objective of the Culebra field program is to measure hydraulic and transport properties, and that the intent was always to take an empirical approach to delineating the distribution of these properties for performance assessment calculations. The DOE did, however, examine rock cores, outcrops, geophysical logs, and the shaft walls to get information about the geology of the Culebra. One use of this information was to develop a conceptual model of how geologic processes have affected the hydraulic properties of the Rustler Formation, including the Culebra. This conceptual model was not used to condition the Culebra transmissivity field for the performance assessment flow calculations (that is, in the region for which extensive hydraulic data were collected). This conceptual model was used to assign values of hydraulic conductivity in the regional three-dimensional flow model which covers a much larger area. In addition, this conceptual model was used as a basis for understanding retardation of contaminant transport in the Culebra.

The CMPR panel noted that there have been two conceptual models of regional flow, the confined model and the groundwater basin model. The DOE considers these two conceptual

models to be complementary. The groundwater basin model represents the DOE's conceptual understanding of the real regional hydrologic system and is used to evaluate long-term changes in patterns of groundwater flow. The confined model is a necessary and appropriate simplification for performance assessment modeling. It provides the capability to perform detailed calculations of flow and transport in the region for which the site characterization has provided an extensive database.

The panel noted that two schools of thought about dissolution of Rustler halite have been presented in the project literature. One school argues that halite in Rustler units has been dissolved in regions beyond the modern-day extent of halite. The second school argues that the modern-day limits of halite represent essentially the original depositional boundaries. These schools represent an evolution of understanding as more information became available. The DOE's position is that the second school (that little dissolution of Rustler halite has occurred in the vicinity of the WIPP) best represents the present understanding. This position is based mainly on detailed mapping of the Rustler in the air intake shaft and the detailed depositional facies model developed by Holt and Powers (1988).

The panel notes that the project has not developed a detailed conceptual model that integrates hydrogeological features, hydrogeochemical facies, and radiogenic ages. DOE agrees with this assessment; however, consideration of these issues has made important contributions to the DOE conceptual understanding of Culebra hydrogeology. For example, the concept that groundwater flow is still adjusting to a drying of the climate at the end of the Pleistocene originated in analysis of chemical and isotopic data.

Peer Reviewer Consideration of Response

The DOE understood the issues and provided a reasonable response.

9.3.1.2.2 Peer Review Panel Concerns - Repository Fluid Flow

9.3.1.2.2.1 First Peer Review Panel Concern

> *The conceptual model and its two-dimensional numerical implementation may unrealistically restrict brine movement within the repository to the anhydrite interbeds because of the shallow depths of the borehole and shaft model cells. These restrictions could result in underestimating brine migration in the interbeds toward the accessible environment.*

Statement of Issue

The language "shallow depths" in the above concern is misleading. The concern is that the geometry of the finite difference grid blocks about the borehole and shaft represents the lateral or areal cross-sectional area of these units. This is an appropriate grid geometry if the flow is convergent on these units. For the undisturbed case, the flow is never convergent on the

borehole. The shaft seal system is very effective in preventing fluid flow up the shaft; consequently, fluid flow is not generally convergent on the shaft area. These regions will present very small normal areas to flow in the lateral direction. For example, in an intrusion scenario, when flow is convergent on the borehole, the supporting flow from the north end of the repository and formations north of the shaft will experience a flow restriction due to the geometry about the shaft. This could restrict brine inflow to the repository region.

Response to Issue

The recommended screening decision for the FEP screening analysis S1: Verification of 2D-Radial Flaring Using 3D geometry, Sandia WIPP Central Files (SWCF)-A: 1.2.07.3: PA: QA: TSK:S1 states the following:

Comparison of outputs of calculations of the simplified two-dimensional (2-D) WIPP performance assessment grid and a corresponding three-dimensional (3-D) grid, based on the selected input data, showed that results were equivalent for the most part. Although the 3-D grid showed flow details which were not accurately represented with the 2-D grid, the computed releases to the accessible environment for both grids were nearly equivalent. This indicates that, based on the performance measures and the overall uncertainty, the current model being used for WIPP performance assessment is sufficient for estimates of calculated releases. Calculations using the 2-D grid are more computationally efficient, which is necessary for the large number of vectors.

The issue raised by the peer review panel is addressed by the FEP S1 calculation as discussed above. The FEP S1 calculation included both the shaft and a borehole in the geometry, and considered an intrusion at 1,000 years. As stated above, the computed releases to the accessible environment for the 2-D and 3-D grids were nearly equivalent. If the geometry affects flow enough to significantly change releases to the accessible environment, it would be reasonable to expect that the effect would have occurred in the FEP S1 calculation. Since no such effect was observed, it is reasonable to conclude that the effects of the geometry do not significantly impact releases to the accessible environment.

Peer Reviewer Consideration of Response

The DOE understood the issue and the response reasonably addressed the panel's concern.

9.3.1.2.2.2 Second Peer Review Panel Concern - Repository Fluid Flow

> *The conceptual model and its two-dimensional numerical implementation do not include the presence of the unplugged ERDA-9 borehole within the walls of the operations area. This borehole could provide a pathway for gas and possibly brine to the ground surface, and no description of the plugging plan for this hole was seen in the documentation provided by the Panel.*

Statement of Issue

The panel is concerned about two items: a) the potential for unplugged boreholes close to the repository acting as pathways for fluids to escape, and b) the lack of any plans to plug these boreholes.

Response to Issue

The panel's concern presumably arises because they were not aware of the project plans for borehole plugging. In fact, the project does plan to plug these boreholes using a continuous plug through the Salado. Such plugging has been evaluated by Thompson et al. (1996).

The plugging plans are addressed in Section 3.3.4 of this application, entitled Borehole Plugs. Section 3.3.4 states:

"Deep unplugged boreholes within the Land Withdrawal Area, shown in Figure 3-9 as WIPP 13, WIPP 12, U.S. Energy Research and Development Administration (ERDA) 9, and DOE 1, will be plugged according to the state of New Mexico, Oil Conservation Division, Order R-111-P. The governing regulations for plugging and/or abandonment of boreholes are summarized in Table 3-2. These solid cement plugs will go through the salt section and any water-bearing horizon to prevent liquids or gases from entering the hole above or below the salt section. The boreholes not being used for monitoring will be plugged at decommissioning. Figure 3-10 depicts a typical deep borehole plugged to the requirements of Order R-111-P."

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.2.3 Third Peer Review Panel Concern - Repository Fluid Flow

> *The sensitivity of model results to the selection of constant permeability values for the waste, panel seals, and repository DRZ has not been evaluated for the current performance assessment. Early time permeabilities may be significantly greater than the model parameter for each of these media, and could lead to underestimation of radionuclide releases.*

Statement of Issue

Consolidation of the waste, panel seals, and repository disturbed rock zone (DRZ) over time would result in lower permeabilities for these regions. How sensitive are the simulation results to the time-dependent nature of permeability within these regions?

Response to Issue

A distinct response is given for each material region.

Response for waste: The effect of dynamic permeability of the waste on system performance has been studied through calculation of preliminary conditional complementary cumulative distribution functions (CCDFs). The recommended screening decision for the FEP screening analysis DR-7: Permeability Varying With Porosity in Closure Regions, SWCF-A: 1.1.6.3:PA:QA:TSK: DR-7 states the following:

Based on the CCDFs, the inclusion of dynamic permeability with closure of the waste region, north-end, and hallways in BRAGFLO results in computed releases to the accessible environment that are essentially equivalent to the baseline case. In addition, dynamic permeability has an insignificant effect on waste room conditions relevant to releases due to blowout, cuttings, and spalling. As a result, the baseline model is conservative in its treatment of closure and dynamic permeability can be eliminated from consideration in the baseline performance assessment model.

Response for DRZ: The effect of dynamic permeability of the DRZ on system performance has been studied through calculation of preliminary conditional CCDFs. The recommended screening decision for the FEP screening analysis S-6: Dynamic Alteration of the DRZ/transition zone (TZ), SWCF-A: 1.1.6.3:PA:QA:TSK: S-6 states the following:

Based on the CCDFs, the inclusion of dynamic alteration of the DRZ/TZ in BRAGFLO results in computed releases to the accessible environment that are essentially equivalent to the baseline case. In addition, dynamic alteration of the DRZ/TZ has an insignificant effect on waste room conditions relevant to blowout cuttings, and spalling releases. Therefore, dynamic alteration of the DRZ/TZ need not be included in system level performance assessment calculations.

Response for panel seals: Because of the high permeability within the panel seals (10^{-15} square meters) the long-term flow should not be sensitive to variants in the seal permeability. The permeability of the panels is set to the same value as the surrounding DRZ. If the panel seal permeability is tighter, then flow between the waste regions will be diverted from the seals through the lower permeability DRZ. The resulting communication between waste regions should be similar. The flow via the panel seals is quantified by considering the compliance certification application run with the highest flow through the panel seal between the intruded panel and the rest of the repository. This was run R1_S3_V25 (replicate 1, scenario 3 (E1 intrusion at 1,000 years), run or vector 25). This run was repeated with a panel seal permeability of 10^{-17} square meters. Figure 9-1 shows a maximum cumulative brine flux across the three grid blocks representing the panel seal of approximately 180 cubic meter. The panel seal volume of 1,584 cubic meters and porosity 0.05 results in a panel seal pore volume of 79 cubic meters. The brine flux across the panel seal is approximately 3 panel seal pore volumes over the 10,000 years. This brine flux is not considered to be enough to degrade

the emplaced concrete plugs. This is consistent with the logic describing the behavior of the borehole plugs. Therefore, by using 10^{-15} square meters permeability for the panel seals, more communication among panels is being allowed, which will result in overestimating the amount of waste contacted by the brine.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.2.4 Fourth Peer Review Panel Concern - Repository Fluid Flow

> *The long-term performance of the panel closure seals has not been subjected to a detailed engineering evaluation of the type performed for the shaft seal. The role of the panel seals in restricting brine flow among the waste panels and into other parts of the repository is an important element of the conceptual model and its implementation in performance assessment.*

Statement of Issue

The panel is concerned about the lack of supporting evaluations presented to them for the panel seal permeability assumption of 10^{-15} square meters.

Response to Issue

The long-term panel seal response has now been evaluated, and is documented in a 1996 memorandum by Thompson and Hansen (a complete copy of the Thompson and Hansen memorandum is provided in Appendix PEER, Section PEER.2). Basically, this memorandum argues that:

1. The panel closures include a 29 foot length of concrete. This will have an initial permeability of at least 10^{-17} square meters.

2. Flow through panel closures will be almost exclusively through the DRZ, which is assumed to have a permeability of 10^{-15} square meters, by-passing the seals due to their much lower permeability.

3. Given maximum calculated cumulative brine flow, flow through seals will be of the order of 1 - 2 pore volumes.

4. Significant degradation of the concrete of the seals will require more than 100 pore volumes, so degradation is not expected.

5. Flow along interface with salt may (at most) extend the DRZ by the order of millimeters. This will be taken up by much faster salt creep.

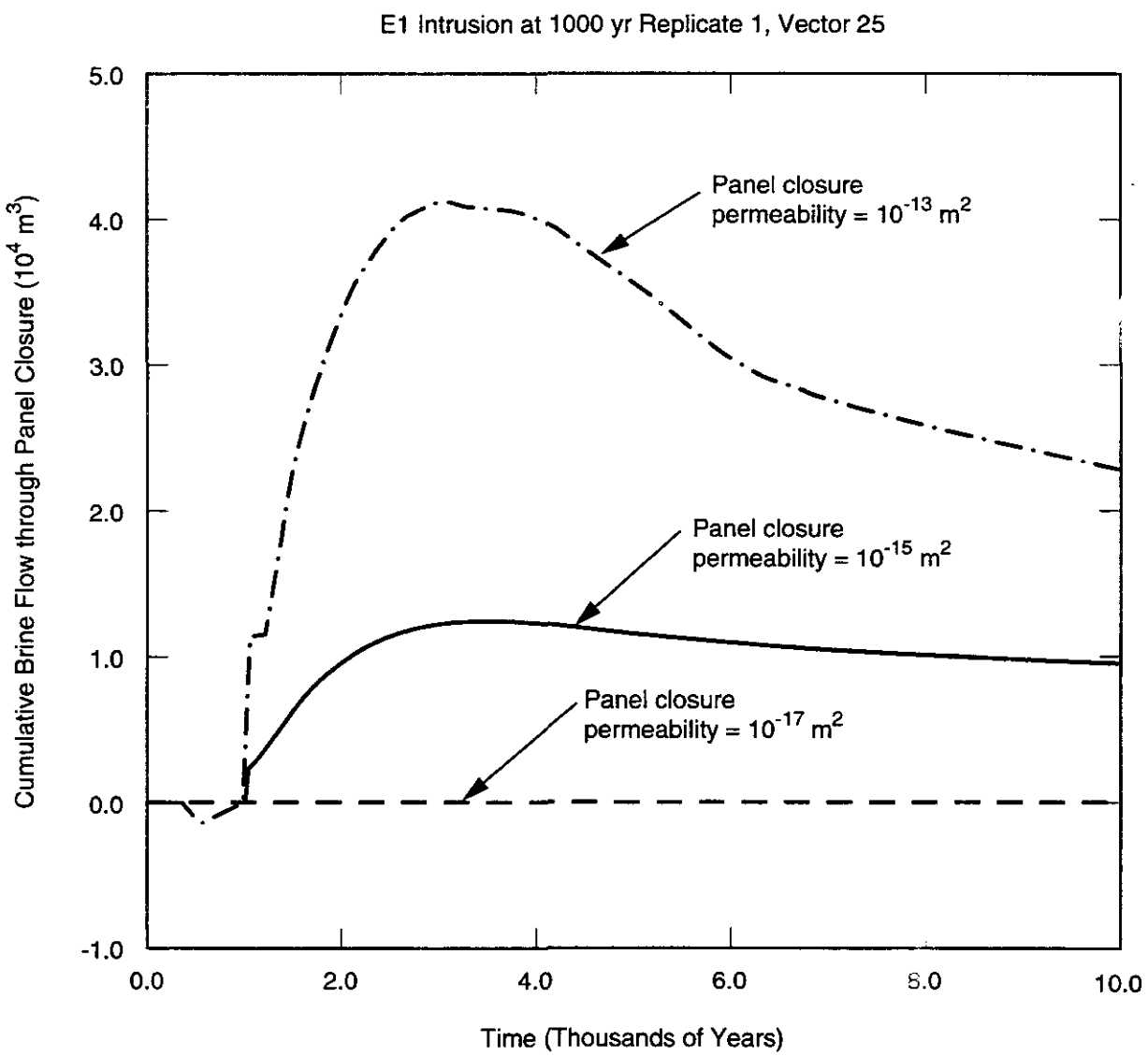

Figure 9-1. Cumulative Brine Flow through the Panel Closure between the Intruded Panel and the Rest of the Repository for Permeabilities of 10^{-15} to 10^{-17} m^2

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Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.3 Peer Review Panel Concern - Salado Interbeds

> *The conceptual model does not consider how the physical properties of the bounding clay seams affect model fracture propagation and permeability. Ignoring the characteristics of the clay seams may significantly overestimate the threshold pressure at which repository gases may be released.*

Statement of Issue

The CMPR report (Section 3.6.2.2, Validity of Model Assumptions) listed three assumptions of the interbed model that the panel felt had not been well documented. These were: (1) the description of the mechanism of vertical crack propagation; (2) no incorporation of continuous clay seams at the base of Marker Bed (MB) 138 and MB139; and (3) the fluid storage capacity of the interbeds. The report (Section 3.6.2.3, Evaluation of Alternatives) noted two items that did not appear to have been addressed: 1) "Is storage capacity of the anhydrite layers so small that brines would be forced to travel to the land withdrawal area boundary?" and 2) "What would the consequence be if the gas threshold pressure of the clay seams were very low (for example, 0.01 MPa)?" The report states (Section 3.6.2.6, Adequacy of Application): "At no time was the logic clearly presented whereby one could track the implementation of this conceptual model into the numerical code developed for this portion of BRAGFLO. Therefore, one must state that the discussion of how the anhydrite interbed conceptual model is applied into an overall performance modeling element was not adequate." The report (Section 3.6.2.7, Accuracy of Results) further states: "The implementation of the fracture modeling was not explained in sufficient detail in any document. The method of how the code represents the physical property is unknown and one can not judge its accuracy."

These concerns were reiterated in Section 3.6.2.9, Adequacy of Implementation, of the report, in which the panel asked for clarification of six points. These points are listed and addressed below. The panel also asked that the following question be addressed: "How do the physical properties of clay seams at the contact of the interbeds affect the fracture propagation and permeability of the model?"

Response to Issue

The clay seams would probably act as preexisting planes of weakness, helping to keep fracturing horizontal and confined to the interbeds. The expression used to calculate fracture permeability is not specific to anhydrite, and can be used equally well to calculate the permeability of fractured clay seams. In terms of threshold pressure, it should be noted that the field in situ threshold pressure tests were conducted with the clay seams contained within the test zones. Therefore, the interpreted threshold pressures are representative of the

combined anhydrite and clay units. The same is true for the in situ permeability tests — the clay seams were included in the test zones with the anhydrite beds during testing.

1. What is the mechanism for vertical crack propagation?

Fractures will propagate vertically if the least compressive stress is horizontal rather than vertical; that is, if the horizontal stress is less than the lithostatic load. Hydrofracture experiments conducted in MB139 and MB140 suggest that horizontal stresses may be slightly less than vertical stress in anhydrite interbeds. Thus, while subhorizontal partings and clay seams within the interbeds, which act as preexisting planes of weakness, may provide preferred fracture "guides", the potential also exists for the creation of vertical fractures providing local connections between horizontal fractures. Hydraulic fracturing experiments conducted in halite, in contrast, indicate isotropic stress conditions in the far-field with no preferred fracture orientation (Wawersik and Stone 1989).

2. What is [the] fluid storage capacity of the interbeds after dilation?

The full dilation of the interbeds for the performance assessment simulations would result in porosity changes as follows:

porosity at initial conditions = 0.011
porosity at full fracture pressure = 0.05 (MB138 and MB139)
porosity at full fracture pressure = 0.25 (MB a+b)

The potential storage is enhanced by

(0.05-0.011)/0.011 = 350 percent (MB138 and MB139)
(0.25-0.011)/0.011 = 2170 percent (MB a+b)

In order to realize these changes in storage, the pressure within the MB would have to reach full fracture pressure of 16.5 megapascals. These values are bounding in the sense that they represent end points on the mathematical functions. Simulation values would not be expected to reach these limiting values.

3. Enhanced porosity and permeability are presumed to mitigate each other in terms of gas migration responses. How can this happen when permeability is a power function (not linear) of porosity?

Both permeability and porosity increase with pressure. As pressure builds up in the MBs, the permeability effect will increase the fluid mobility. The higher gas mobility will move the gas further from the repository (in the direction of negative pressure gradient). The increase in porosity will provide more storage for the gas with resulting lower gas pressures and shorter gas migration distances. The DOE does not mean to imply that the two effects are essentially

equivalent and completely counteract each other. The quantitative difference between the two effects is determined by the specific fracture parameters used in the model.

4. What assumptions and limitations are made to represent the conceptual model by the mathematical code?

BRAGFLO allows for pressure-induced alterations to porosity by introducing a pressure-dependent pore compressibility. Pore compressibility is defined as the relative rate of change of porosity with respect to pressure:

$$c_f = \frac{1}{\phi}\frac{d\phi}{dp}$$

where:

c_f = pore compressibility [Pa^{-1}]
ϕ = porosity [-]
p = pressure [Pa]

For constant compressibility, porosity can be expressed as a function of pressure:

$$\phi = \phi_0 \exp\left[c_f(p-p_0)\right]$$

where:

ϕ_0 = porosity at reference pressure p_0

Below an initiation pressure, p_i, the compressibility is a constant intact value, C_i. For pressures above p_i, the compressibility increases linearly to a fully altered value, C_a, at the fully altered pressure, p_a. The porosity is then computed from the compressibility equation. For $p \le p_i$, the porosity is as given above. For $p_i < p \le p_a$:

$$\phi = \phi_0 \exp\left[C_i(p-p_0) + \frac{(C_a - C_i)(p - p_i)^2}{2(p_a - p_i)}\right]$$

and for $p > p_a$:

$$\phi = \phi_a$$

BRAGFLO is assigned values for p_i and p_a and the porosity at fully altered conditions, ϕ_a. From this information, the fully altered compressibility, C_a, is determined as:

$$C_a = C_i\left[1-2\frac{(P_a-P_o)}{P_a-P_i}\right] + \frac{2}{(P_a-P_i)}\ \ln\left(\frac{\phi_a}{\phi_o}\right) .$$

The fracture treatment further allows for changes in the fracture material permeability. The often-used parallel plate analogy for flow in fractured rock suggests the form:

$$\frac{k}{k_i} = \left[\frac{\phi}{\phi_i}\right]^n$$

where:

k = permeability of altered material
k_i = permeability of intact material
ϕ = porosity of altered material
ϕ_i = porosity of intact material at p_i
n = empirical parameter

The input data parameters that control the anhydrite fracturing were chosen deterministically so as to produce the appropriate pressure response as predicted by the linear elastic fracture mechanics model. Because the anhydrites have been found to have preexisting fractures that might easily be dilated, the pressure at which porosity and permeability changes are initiated is very close to the initial pressure within the anhydrite. The fracture initiation pressure (p_i) is assigned a value of 0.2 megapascals above the initial far-field brine pressure of 12.5 megapascals. The full fracture pressure (p_a) is specified to be 16.5 megapascals. A permeability of 10^{-9} square meters is given at full fracture conditions. The only parameter that is not uniform over the three modeled MBs is the full fracture porosity. The full fracture porosity in anhydrite a and b is 0.25, while in MB138 and MB139 the full fracture porosity is 0.05. From this information, the exponent, n, in the permeability formula is determined for the different MBs. Results from the performance assessment calculations using these parameters show that simulated repository pressures do not exceed the full fracture pressure of approximately 16.5 megapascals, a value slightly higher than lithostatic pressure.

5. Why is the full fracture porosity increment of 25 percent for anhydrite a and b so different from the 5 percent for MB138 and MB139?

Fracture dilation is assumed to be confined to a 10-centimeter thickness regardless of the thickness of the MB. Therefore, because 10 cm is a greater proportion of the total thickness of anhydrite a and b than of MB138 or MB139, the full fracture porosity increment is also greater. The Larson (1996) memorandum (see Appendix PEER, Section PEER.2) describes the expected fracture response for the MBs. The Lord (1996) memorandum (see Appendix PEER, Section PEER.2) describes the numerical study used to determine the fracture parameters that honor the desired fracture response.

6. What are the calculations that show that permeability increases by 10 orders of magnitude?

As suggested in Larson (1996; Appendix PEER), the full fracture permeability is used as a fitting parameter (end point on the curve) so that the appropriate response is obtained. A ten order of magnitude increase in permeability is unlikely to ever be achieved in the model.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.4 Peer Review Panel Concerns - Units Above the Salado

The conceptual models and the testing database are inadequate to exclude the Dewey Lakes Redbeds and the Magenta Dolomites as potential transport pathways for radionuclides in the event of an intrusion.

The analysis of brine flow in the intrusion scenarios limits the quantity of radionuclides reaching the region above the Culebra to such small amounts that transport in the Dewey Lakes and Magenta have negligible consequences.

The Units Above the Salado conceptual model was found to be inadequate to support the assumption that the Culebra is the only horizon above the Salado capable of significant radionuclide transport. This inadequacy was inconsequential for performance assessment because of modeling results indicating that long-term fluid flow in exploration boreholes above the Culebra was negligible because of relatively high permeability and low pressure in the Culebra.

Statement of Issue

None Provided

Response to Issues

Hydraulic testing of the Magenta has been performed at 16 locations, 10 of which are either on the WIPP site or within 700 feet of the site boundary. At four of these locations, DOE-2, H-3, H-6, and H-19, the Culebra has been found to be fractured and have a high transmissivity, whereas the Magenta has not. The Magenta has not been found to have a transmissivity greater than 0.3 square feet per day (3.0E-7 square meters per second) anywhere on the WIPP site. In addition to the locations where the Magenta has been tested, Magenta core has been recovered from six other locations on or near the WIPP site, B-25, H-11, H-15, WIPP-12, and WIPP-34. Magenta core recovery is typically 100 percent. The Magenta has also been examined in shaft exposures at the WIPP site. The only location on the WIPP site at which open fractures have been observed in the Magenta is WIPP-13. Filled fractures are only rarely observed at other locations. Based on the combined hydraulic test

results and core and shaft observations, the DOE is confident that the Magenta can be realistically modeled as a low transmissivity porous medium.

The test data support permeabilities within the Culebra significantly higher than the Magenta and Dewey Lake (2 to 3 orders of magnitude). This is due primarily to the fracture structure of the Culebra. Also, the Culebra is under pressured with respect to the Magenta and Dewey Lake. Therefore, any cross flow between the units will occur from the Magenta and Dewey Lake to the Culebra. As an example of the performance of the model on brine flow as communicated between the borehole and the upper units, the E1 (intrusion into the Castile brine reservoir) run with the highest borehole release was considered (replicate 1, scenario 2, run 23). For this run, the brine flow at the top of the Salado through the borehole was of the order 50,000 cubic meters, while the brine flow to the Culebra from all units above the Culebra was of the order 270,000 cubic meters. Further, it has been demonstrated from the NUTS that no nuclide transport occurs to any units above the Culebra.

The nonexistence of nuclide transport above the Culebra was demonstrated by the performance assessment simulations. Figure 9-2 shows the cumulative nuclide flux (in EPA units) up the borehole at a location above the Culebra and immediately below the Magenta. The figure includes all 100 NUTS runs from the first replicate of the E1 scenario. The E1 scenario is expected to have the highest borehole releases. This figure shows that the transport above the Culebra is zero uniformly over all 100 vectors

Peer Reviewer Consideration of Response

The DOE understood the issues; however, the panel concluded that the response did not reasonably address its concerns. The panel noted, however, that the inadequacy of the model is of no consequence to the performance assessment.

DOE Technical Position versus Panel Issues

As pointed out in the initial response, "Hydraulic testing of the Magenta has been performed at 16 locations, 10 of which are either on the WIPP site or within 700 feet of the site boundary. At four of these locations, DOE-2, H-3, H-6, and H-19, the Culebra has been found to be fractured and have a high transmissivity, whereas the Magenta has not. The Magenta has not been found to have a transmissivity greater than 0.3 square feet per day (3.0E-7 square meters per second) anywhere on the WIPP site."

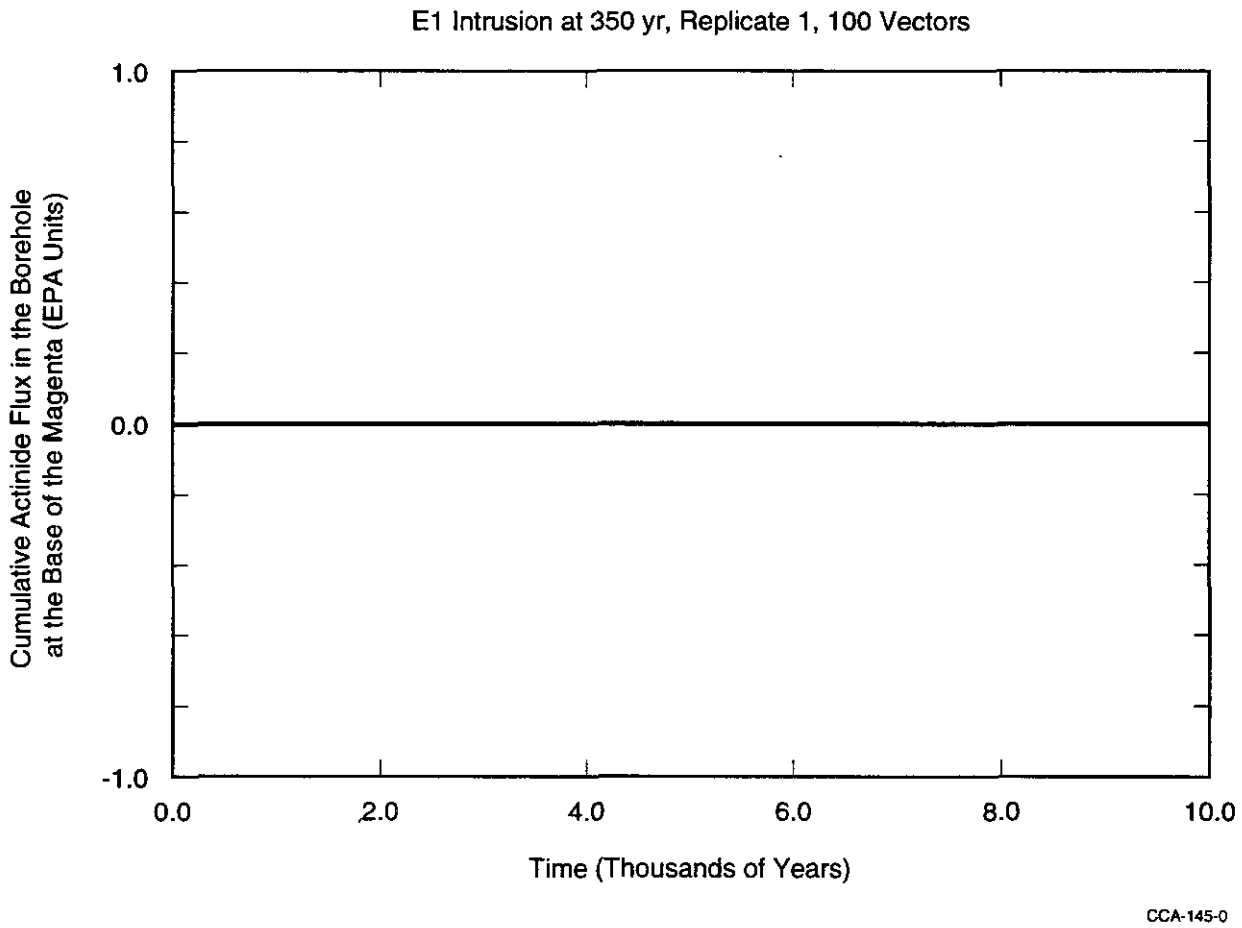

Figure 9-2. Actinide Transport to the Magenta, E1 Intrusion

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No reasonable amount of testing can "exclude the presence of fractured zones of high permeability similar to those in the Culebra." However, "based on the combined hydraulic test results and core and shaft observations, the DOE is confident that the Magenta can be realistically modeled as a low transmissivity porous medium."

In addition, as pointed out in the initial response, "The non-existence of nuclide transport above the Culebra was demonstrated by the performance assessment simulations." Therefore, as pointed out in the peer review comments, there are no performance assessment consequences to possible errors in the characterization of the Magenta or Dewey Lake.

9.3.1.2.5 Peer Review Panel Concerns - Transport of Colloidal Actinides in the Culebra

9.3.1.2.5.1 First Peer Review Panel Concern

> *The conceptual model does not adequately support the assumption that dissolved actinides will not interact with Culebra colloids. Ignoring this phenomenon could overestimate the travel time calculated for radionuclides to reach the accessible environment.*

Statement of Issue

The understanding of the panel appears to be that calculations addressing the transport of waste through the Culebra do not address the potential for waste mobilized in the repository to become sorbed onto colloids indigenous to the Culebra, and continue transport in the Culebra as a colloidal particle. Because transporting colloids may not experience as much chemical attenuation as is exerted by the Culebra minerals on dissolved materials, releases calculated in the CCDF may under-report actual releases.

Response to Issue

Four types of colloids have been identified and considered by the WIPP program. These colloids all fall within the traditional particle size definition of colloids. They have been distinguished based on their mode of production. The types are: (1) mineral fragments, (2) humics, (3) actinide intrinsics, and (4) microbial hosts. Formation and transport of waste by colloids generated in the Culebra was originally planned to be conducted using SECOTP2D. Experiments have shown that it is not necessary to calculate an explicit contribution to the release term from this transport mechanism. Actinides are not indigenous to the Culebra, so that type may be eliminated. Mineral fragments have been demonstrated to be unstable in WIPP brines. Mineral fragments present will agglomerate and settle out due to gravity. Humics and microbial hosts may persist in the Culebra, but column experiments containing crushed Culebra have shown that these colloids are effectively filtered out of the flow stream. As a result, colloidal transport in the Culebra will not contribute meaningfully to the CCDF and requires no explicit model.

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel concluded that the response did not reasonably address its concern.

DOE Technical Position versus Panel Issue

Two concerns were raised in this issue:

(1) The DOE's understanding of the CMPR panel's concern was that the project has demonstrated that mineral fragment colloids are destabilized in Castile and Salado environments, but the project has not evaluated the stability behavior of mineral fragment colloids in the Culebra. Specifically, the panel would like to understand how the experiments conducted apply to the geochemical conditions of the Culebra.

(2) Transport experiments with crushed-rock columns are not acceptable because when the rock is crushed, new mineral surfaces are exposed. Powder X-ray diffraction analysis to quantify clay mineral concentration has a minimum detection limit of 2 weight percent; changes in the rock composition due to crushing the rock may not be discernible.

The DOE positions on these concerns are as follows:

(1) The kinetic stability screening experiments were conducted with several WIPP-relevant brine simulants: Culebra H-17 brine simulant consisting primarily of NaCl, with an ionic strength of about 3 molal; a Salado-like brine simulant, consisting of NaCl but containing a significant concentration of Mg, with an ionic strength of about 8 molal; and NaCl solutions, ranging in concentration up to 5 molar. The screening experiments to verify the critical coagulation concentrations of the colloidal dispersion were conducted with sequential order-of-magnitude dilutions. Typically, the colloidal dispersions were destabilized at dilutions of 10^3 or 10^4. Because the experiments involved sequential dilutions, the question of which brine was used is not important. The main point is that mineral fragment colloids are destabilized by even very small concentrations of monovalent and particularly divalent cations. All groundwaters associated with the WIPP (that is, Castile Formation, Salado Formation, and Rustler Formation groundwaters within the land withdrawal area) have several orders-of-magnitude greater concentrations of cations than that required to destabilize mineral fragment colloids.

(2) The crushed-rock column flow experiments were used to determine physical retardation of colloidal particles (humic substances, mineral fragment colloids, and microbes). In the case of mineral colloids and microbes, some chemical retardation was observed, but was disregarded in development of performance assessment parameter values. The main phenomena causing physical retardation were entrapment of colloidal particles at pore throats smaller than the particles and bridging at pore throats larger than the size of individual particles. Crushed-rock column flow experiments were used to quantify the filtration term (γ), not a retardation term

(R). The presence of clay minerals in the rock is not a critical issue in these experiments, because colloid-rock interaction was physical rather than chemical.

9.3.1.2.5.2 Second Peer Review Panel Concern - Transport of Colloidal Actinides in the Culebra

The experimental K_Ds determined for this model are not fully defensible. Such values may overestimate the retardation of actinides in the Culebra.

Statement of Issue

The understanding of the panel appears to be that the distribution coefficients (K_d) used by performance assessment for colloidal transport in the Culebra is the same as that used for dissolved materials. (In fact, only humic K_ds are assigned the same values.) The basis for the identical K_ds is the result obtained from sorption competition experiments conducted using the batch method. In competition experiments, dissolved material is exposed to a known sorbent, that is, dolomite and allowed to "equilibrate." A competing material (for example, a colloid) is then added to the equilibrated batch, and the change in dispersion composition is monitored. Highly sorptive colloids might be expected to increase the apparent concentration of actinides in the liquid by competing effectively with the substrate material, and essentially shifting the actinide distribution from the immobile dolomite to the mobile dispersion (solution plus colloids). The interaction of dissolved material with two different substrates (for example, a dolomite substrate versus a colloidal particle) is normally expected to produce different results. The anticipated complexing behavior of actinides with humics (under certain conditions) might reflect a strong chemical affinity between the two substances and in turn be reflected in preferential partitioning of actinides toward humic colloids. Without additional explanation, the reliability of the experimental results and the conservatism of associated calculations are questioned.

Response to Issue

Three sets of K_d partitioning experiments were conducted in support of the WIPP Colloid Research Program:

(1) Actinide uptake experiments were conducted to determine bioaccumulation of Th, U, Np, Pu, and Am by microbes (BNL, Los Alamos National Laboratory [LANL]);

(2) Complexation experiments were conducted with U and Am on humic substances (Florida State University); and

(3) Batch competition experiments were conducted with Th, U, Np, Pu, and Am with crushed Culebra rock in the presence and absence of humic substances (LANL).

Those experiments provided part of the basis for determining the extent of interactions between humic actinides and microbial actinides in the Culebra. Flow experiments with crushed rock and intact cores, as well as information in published literature, provided critical complementary information. The following paragraphs elaborate on concerns regarding how retardation parameters were developed for humic substances and microbes.

The purpose of the batch competition experiments with humic substances (3) was to determine whether the presence of humic substances decide K_d values. The batch K_d values measured in the presence of humic substances were, within experimental and analytical error, identical to values measured in the absence of humic substances. The most reasonable explanation is that at the pH value of the dolomite-mediated system (nominally 7.5 under WIPP-relevant pCO_2 conditions), humic substances do not effectively complex with actinides, probably because the actinide ions have undergone hydrolysis reactions and the reactive ligands on the humic substances are not sufficiently strong to compete with the hydrolysis reactions. Intact core column flow tests were used to confirm the results of the humic batch competition experiments.

It is important to note that the results of the batch competition experiments (3) suggest that the mobile humic actinide source term is probably overly conservative. As described in Appendix SOTERM the humic-actinide complexation experiments (2) were conducted under conditions leading to optimal uptake of U and Am by humics, because when those experiments were conducted, the anticipated pH of the repository spanned a wide range (Papenguth and Behl 1996, Figure 5). The addition of MgO backfill now constrains pH in the repository to about 9.3. Unfortunately, whereas it is generally accepted that actinide complexation by humics will decrease as conditions change from acidic to basic (for example, pH 9.3), no strong experimental or literature basis could be developed to predict humic actinide concentrations under the more basic pH conditions. The humic actinide source term, therefore, reflects complexation which would be expected at much more acidic conditions, and is probably quite conservative.

The CMPR report (Section 3.11) raised a concern about the lack of addition of nutrients in the microbe experiments and also actinide reduction. Note that no batch competition experiments, involving microbes, rock, and dissolved actinides, were conducted with microbes. In the microbial bioaccumulation experiments (1) that were conducted, phosphate was added as a nutrient. During each experiment, microbe population was initially low, and then increased through early to late log phase, and stationary phase (steady state population). In other words, microbes were cultured in the presence of actinides, a condition which most closely simulates what would occur at the WIPP. Proportionality constants (like K_d, but not thermodynamically based) to describe the mobile microbial actinide source term were determined at stationary phase conditions, resulting in the highest (and most conservative) value. Microbial-mediated reduction of actinides may have occurred in those experiments. However, in the experiments, the concentrations of dissolved actinides and bioaccumulated actinides were measured from filtrates and filter retentates collected at the same point in time. A decrease in actinide concentration due to reduction would be reflected in that measurement.

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel concluded that the response did not reasonably address their concern.

DOE Technical Position versus Panel Issue

The panel was concerned with the following:

Crushed-rock column experiments were equilibrated with dissolved actinides, followed by introduction of humic substances to the column. Quantitative results would not be achieved using that technique because of kinetic inhibition of humics stripping sorbed actinides from the crushed rock. Because of the sequence of additions, time was allowed for hydrolysis of dissolved actinides to occur. The hydrolyzed actinides would have a decreased affinity for humics. Experiments with crushed dolomite are not acceptable because clay minerals would be exposed during the crushing process. Those exposed clay minerals would sorb dissolved actinides strongly, thereby reducing the potential uptake of dissolved actinides by humic substances.

The DOE position regarding that concern is as follows:

Crushed-rock column flow experiments were not conducted with actinides. In the batch sorption experiments with crushed rock, the rock was not preequilibrated with dissolved actinides. The following tests were conducted:

- complexation experiments with dissolved actinides and humic substances;
- batch sorption experiments in which humic substances and dissolved actinides were added to crushed rock equilibrated with brine;
- crushed-rock column flow tests conducted with humic substances and crushed rock, in the absence of dissolved actinides;
- intact-core column flow experiments in which Pu and Am were injected as a spike followed by elution of a large amount of humic substances and in which U and humic substances were injected simultaneously as a long step.

Regarding the panel's apparent concern on the sequences of additions, the batch sorption experiments were equilibrium experiments. Reactions such as hydrolysis, dissolved actinide sorption, and humic-actinide complexation may have different rates, but only one equilibrium can be reached in the system; the sequence of additions is inconsequential. Also, the duration of the static experiments is short relative to the time available for water-rock interactions in the Culebra transport path. Even more time would be allowed for hydrolysis reactions (which are essentially instantaneous anyway) in the actual transport situation.

Regarding the possible production of clay minerals during the crushing procedure, the microcrystalline nature of the Culebra inhibits that concentration process. Most of the surfaces in crushed rock particles are pristine because of the microcrystalline nature of the Culebra. The individual grains in the Culebra are on the order of 2 microns in size. The crushed particles are several hundred microns in diameter. Consequently, in a crushed rock particle, the total surface area is dominated by interparticle surface area, not the newly formed intraparticle surface area. In addition, the rock used was relatively poor in clay mineral concentration compared to other portions of the Culebra.

9.3.1.2.5.3 Third Peer Review Panel Concern - Transport of Colloidal Actinides in the Culebra

Recent experimental work to support assumptions and data for this model has not yet been published and were not available for Panel review.

Statement of Issue

The panel would have benefited from having a referencable document during development of their positions, instead of having to rely on limited verbal discussion.

Response to Issue

Information provided to the peer review was cut off effective June 7, 1996. The referenced information referred to in the peer review was under development at the time of the review and was verbally provided to the panel. It has subsequently been documented and corroborates the verbal presentations made to the panel.

Peer Reviewer Consideration of Response

Insofar as this issue was not based on a technical issue, the panel was not requested to review the response.

9.3.1.2.6 Peer Review Panel Concern - Exploration Boreholes

9.3.1.2.6.1 First Peer Review Panel Concern

The potential for releases or changes in repository conditions from borehole penetrations in the operations and experimental areas of the repository does not appear to have been evaluated. Radionuclides that may have migrated into those areas through the panel closures by diffusion or other transport mechanisms could be released to the ground surface, and gas pressures could be relieved by such boreholes. Also, brine could migrate into those areas from a borehole and then into the waste panels.

Statement of Issue

The CMPR panel concern is clearly stated. Both El- and E2-type intrusions could occur into the experimental and operations regions. E2 boreholes, which do not encounter pressurized brine in the Castile, could bring radionuclides to the surface as direct releases, if any are present in the region intersected. E2 boreholes could also provide a pathway for long-term fluid flow and radionuclide transport. El boreholes, which do encounter pressurized brine in the Castile, could result in similar consequences, and also have the potential to provide a pathway for Castile brine to reach the waste disposal region without the occurrence of a direct intrusion into the waste.

Response to Issue

The peer review panel is correct in its observation that the processes noted could occur. Justification for not modeling these processes explicitly in the performance assessment follows.

Direct releases from an intrusion into the experimental and operations regions. Direct releases from both E1 and E2 intrusions into the experimental and operations regions are not modeled explicitly because waste will not be emplaced in these regions. Releases of particulate waste (that is, cuttings, cavings, and spallings) will therefore not occur. Radionuclides could potentially be transported in brine into these regions, and contaminated brine contained in the pore space of the rock could be brought to the surface during drilling. However, the northern portions of the repository are separated from the waste disposal regions by panel closures that will greatly reduce brine flow. All waste will be separated from the northern regions by at least one set of panel closures (see Figure 3-2, Chapter 3.0), and all except the waste that will be emplaced in the north-central drift region (equivalent panel 10 in Figure 3-2) will be separated from the southern portion of the operations region by two or more sets of panel closures and from the remainder of the northern regions by three or more sets of panel closures.

BRAGFLO performance assessment calculations indicate that the panel closures will be effective in reducing brine flow. Figure 9-3 is a plot of net brine flow across the panel closure that separates the intruded panel from the rest of the waste disposal region. Results are shown for 100 realizations (replicate 1) of an El intrusion at 1,000 years. These flows represent brine leaving a panel closure separating a southern, down-dip panel from the rest of the repository. They are presumably greater than the flows that might be expected into the southern portion of the operations region following an E1 intrusion into equivalent panel 10, because some flow out of equivalent panel 10 would occur downdip rather than updip into the operations region. Flows into other portions of the northern region or for intrusions elsewhere in the waste region would be smaller.

As shown in Figure 9-3, flow across the panel closure is minor prior to intrusion. Following an El intrusion, net flow occurs away from the intruded panel. The largest flow is

approximately 14,000 cubic meters, and more typical flows are approximately 3,000 cubic meters. This volume of brine will occupy some portion of the 65,000 cubic meters of total pore volume (359,000 cubic meters excavated volume at an assumed 18 percent porosity after consolidation) in the northern regions, and will be diluted by any inflow of uncontaminated brine into the region from the DRZ and MB. Releases resulting from cuttings and cavings will be limited to the actinides contained in the brine that may be present in the pore space of the solid material brought up the borehole, and will be insignificant. Direct releases resulting from brine flow up the borehole or from brine that may be contained in the pore volume of spalled material are not anticipated from the northern region because intrusions into the waste disposal region that could cause brine flow into the northern region will also depressurize the repository and remove the potential for spalling and blowout from subsequent intrusions. Blowouts may occur from the northern region if it is the first portion of the repository penetrated; however, there is no reason to anticipate that significant quantities of radionuclides will be present in the northern region under undisturbed conditions.

Long-term releases from an E2 intrusion in the experimental and operations regions. Figure 9-4 shows the net brine flow through the panel closure separating the southern, down-dip panel from the rest of the repository following an E2 intrusion at 1,000 years (100 realizations, replicate 1). Two types of behavior can be observed. In most realizations, net flow is away from the borehole, as in the E1 scenario. For these realizations, an E2 borehole in the northern region would not provide a pathway for radionuclide transport to the accessible environment. In other realizations, net flow following intrusion is toward the borehole, and with flow volumes ranging from zero to less than 3,000 cubic meters. E2 boreholes in the southern portion of the operations region, where they are separated from the nearest waste by only a single set of panel closures, do have the potential to provide a pathway for radionuclide release if they display this type of behavior. As can be seen in Figure 3-2, this southern portion of the operations region is a small area. Including E2 intrusions into this area in the performance assessment could at most increase the total number of E2 intrusions contributing to the flow of contaminated brine into the Culebra by less than 10 percent. Radionuclide transport into the Culebra would increase by even less, because only a small portion of brine flowing up an E2 borehole in the operations region would be contaminated brine that flowed northward from the waste disposal region. Given the effectiveness of retardation processes within the Culebra, small changes in the amount of radionuclides reaching the Culebra would have no effect on the CCDF. E2 intrusions into the remainder of the northern region, north of the second set of panel closures, are anticipated to have smaller volumes of contaminated brine reaching them, and will also have no effect on the CCDF.

Long-term releases from an E1 intrusion in the experimental and operations regions. Figure 9-3 demonstrates that net flow through a panel closure following an E1 intrusion into a southern down-dip panel is away from the borehole in most realizations. An E1 intrusion in the northern region would, in most realizations, result in a net flow of uncontaminated brine through the panel closures to the south, and would not provide a pathway for radionuclide transport to the accessible environment. For those realizations showing a net flow toward the borehole, effects will be similar to those of an E2 borehole displaying the same behavior.

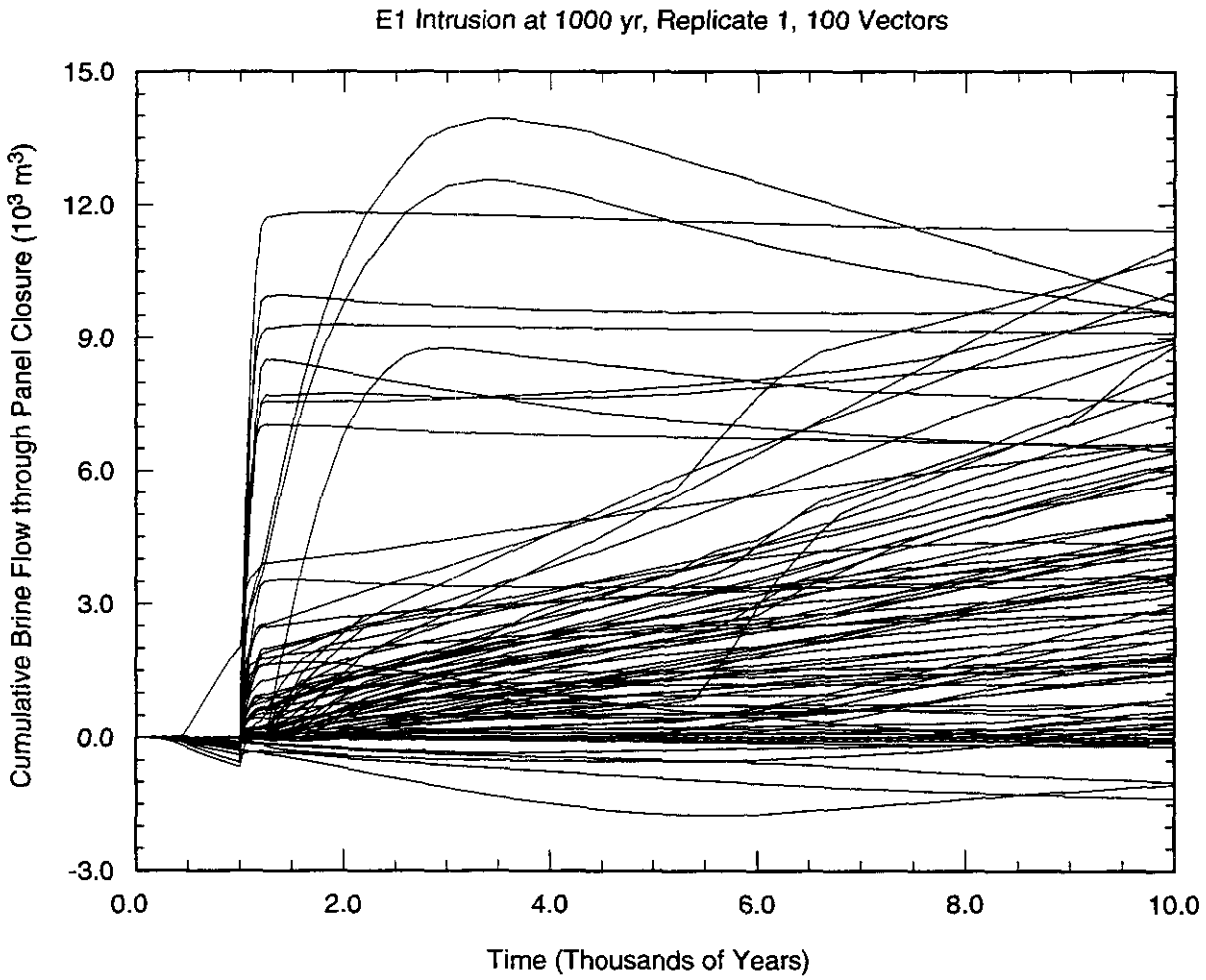

Figure 9-3. Cumulative Brine Flow through the Panel Closure between the Intruded Panel and the Rest of the Repository

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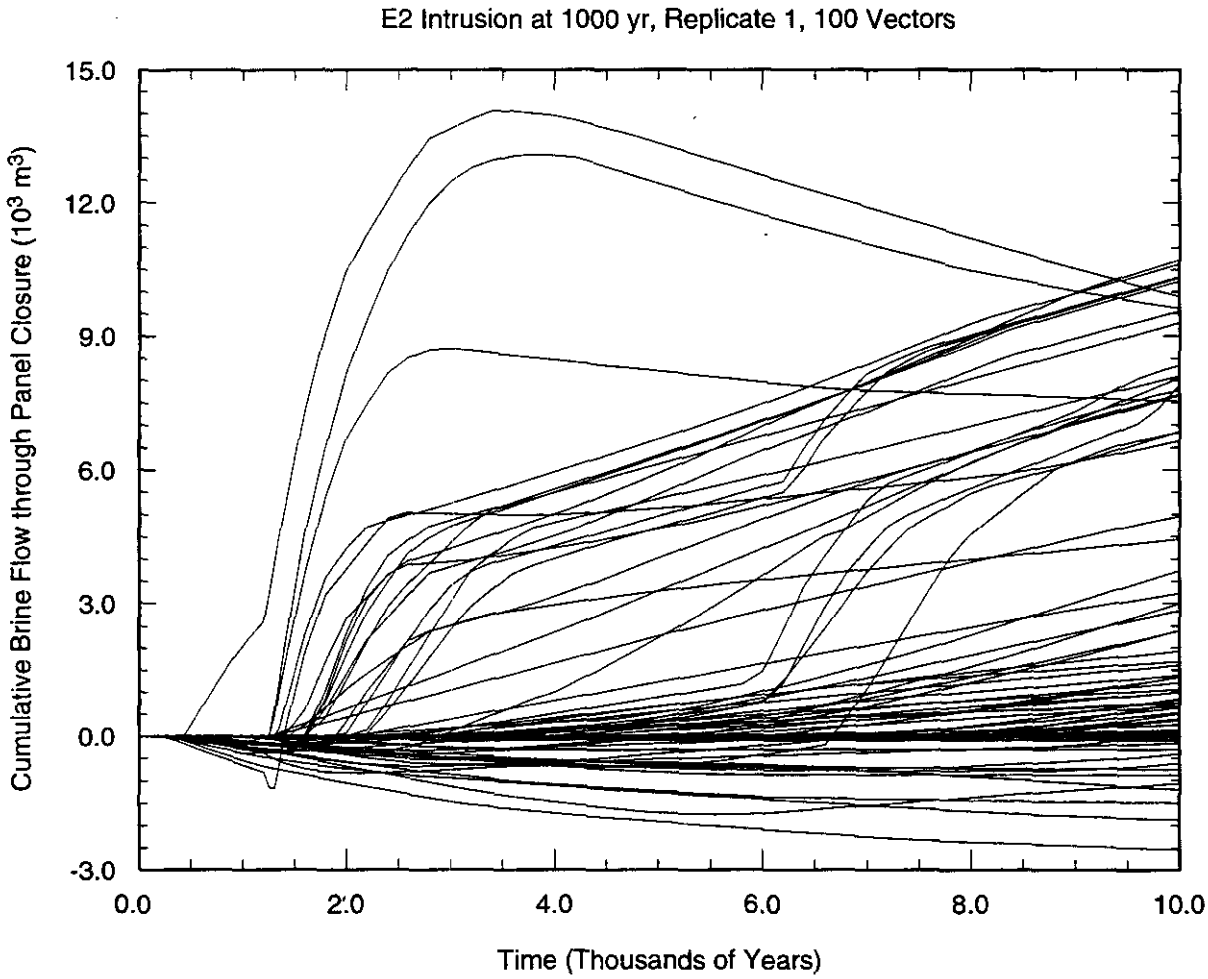

Figure 9-4. Cumulative Brine Flow through the Panel Closure between the Intruded Panel and the Rest of the Repository

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Other effects on brine and gas flow of intrusions into the experimental and operations regions. The permeability of the panel closures is not expected to be small enough to prevent gas flow and pressure equilibration throughout the repository, and intrusions into the northern regions therefore have the potential to decrease repository pressure by allowing gas flow up the borehole. This effect is not accounted for in the performance assessment calculations. Overall, consequences of including this phenomenon would be beneficial to disposal system performance, because it would reduce the likelihood of spalling and blowout releases occurring from intrusions into the waste disposal region.

If large brine flows occurred southward from the northern region following an E1 intrusion, they would raise brine saturation within the repository and could lead to increased gas generation. Large brine flows could also contribute to increased releases from subsequent intrusions into the waste disposal region. However, the permeability of the panel closures is expected to be small enough to prevent large brine flows from the northern region into the waste disposal region. Figure 9-3 shows brine flows that are representative of the volumes that might flow into the waste disposal region following an E1 intrusion in the southern portion of the operations region. Disposal system performance is not expected to be sensitive to changes of this order of magnitude in the amount of brine present in the waste disposal region. Brine flows southward from E1 intrusions into the northern portions of the operations and experimental regions will be less because of the presence of an additional set of panel closures.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.6.2 Second Peer Review Panel Concern - Exploration Boreholes

> *The assumption that shorter (40 m) borehole plugs beneath the repository horizon will not significantly degrade during the 10,000-year regulatory time frame has not been adequately supported. For the two- and three-plug configurations, degradation of these plugs could result in creation of a low permeability pathway for fluid migration between the Bell Canyon and the repository. For the three-plug configuration, degradation could result in increased fluid migration from a Castile brine reservoir to the repository.*

Statement of Issue

The panel has noted that the technical report containing predictions of borehole plug performance life describes a service life range of from 500 to 50,000 years, with a best estimate of around 5,000 years, while the performance assessment calculations take the life of intermediate plugs to be 10,000 years. The panel also notes that the 5,000 year predictions of plug performance life rely on reactions that produce $Fe(OH)_2$ to control corrosion. In addition, the panel notes that other reactions (such as magnetite production) could be the

operative corrosion control at greater depths, and that such changes in corrosion reaction could lead to collapse and failure of intermediate plugs in a manner similar to that predicted for shallow plugs. The result could be an effective flow path between the repository and both the Castile brine reservoir and/or the Bell Canyon aquifer.

Response to Issue

The report "Inadvertent Intrusion Borehole Permeability" (see Appendix MASS, Attachment 16-3) contains predictions of performance lives of deep (>1,000 feet) borehole plugs that range from 500 to 5,000 years. The predictions are driven by an understanding of the concrete degradation mechanisms and are sensitive to the porosity of the concrete plug. At shallow depths, plug life is controlled by casing corrosion, and the corrosion reaction is assumed to be controlled by $Fe(OH)_2$. This reaction was endorsed elsewhere by the panel when they considered corrosion in the disposal rooms. It is the most often cited corrosion reaction for iron-based alloys, and is reported from experiments on steel and is thermodynamically favored under the mildly reducing conditions expected at and above the Culebra and within a steel casing filled with oxygenated water.

Under mildly reducing or oxidizing conditions, such as may be expected at shallower depths, the corrosion mechanism operating on steel is uniform, general corrosion. Such a mechanism is expected to degrade the entire casing wall and leave a noncoherent residuum that lacks strength. As a result, corrosion to depths below a concrete plug is expected to remove physical support from the plug leading to total failure of the shallow plugs.

At greater depths, conditions are expected to be chemically more reducing and higher in alkalinity. At higher confining pressures (for example, 45 to 70 atmospheres; or approximately 1,000 to 1,500 feet deep), hydrogen gas is not mobile. Thus, at depths below the repository, corrosion of iron and equilibration with deep geochemical environments produces reducing conditions. The pH associated with natural systems is in the range 7 to 9. Under reducing, alkaline conditions, corrosion proceeds more slowly than predicted for shallower depths. More importantly, the corrosion mechanism associated with magnetite and carbonate production changes from the uniform, generalized model applied at shallower depths to one of localized, pitting corrosion. The resulting corroded casing is expected to remain largely intact but resemble a partial lattice-work of open penetrations and substantially intact pipe. As a result, the casing will continue to provide physical support to the concrete elements of the borehole plug, and failure of the plug will be associated with the concrete degradation process.

The concrete degradation process depends on the flow of brine through the plugs, and is most sensitive to the initial permeability and effective porosity of the concrete. At the expected permeabilities of the plug, and the maximum potential pressure gradients, the concrete will not degrade for between 500 and 50,000 years; this variation is a result of possible variations in the concrete properties.

The panel correctly notes that the 10,000 year performance assumed in performance assessment calculations differs from the 5,000 years (mid-range) prediction reported by Thompson et al. (1996). The performance assessment assumption was made to simplify CCDF calculations because the CCDF is not sensitive to the difference. In fact, the CCDF is sensitive only to the relationship that the lower plug lasts significantly longer than the shallow plug. This will always be the case, because of the different casing corrosion rates and mechanisms at the different depths, and because of the lower concrete permeability which can be expected at greater depth. This is expected because of the beneficial effect of the greater pressure of water on the initial permeability.

The BRAGFLO calculations begin with the assumption in both the two- and three-plug configurations that drilling into a brine reservoir initially connects the brine reservoir, the repository, and the Culebra.

In the two-plug configuration, the connection between the reservoir and the repository remains perfect for about 200 years, until the shallow plug fails and the borehole becomes filled with debris. During this time period, the repository may or may not become saturated by flow up from the reservoir, accompanied by drainage in from the Salado seeps and down from units in the Rustler. BRAGFLO shows that the major contributor to repository saturation can be the Castile reservoir, but that other sources also play a role. In some realizations, flow down the borehole dominates. The net result for most realizations is a saturation of intruded waste panels by brine of mixed compositions that is pressurized to the extent that gas generation allows.

In the three-plug configuration, the connection between the repository and the reservoir lasts several days, and then it is shut off by casing of the borehole, and eventually by placement of the intermediate plug. BRAGFLO shows that only a small portion of the repository becomes filled in this interval. For the first 200 years, or so, formation waters from the Salado are all that drain into the repository. After about 200 years, the shallow plug fails and water drains down from the Rustler sources, through the debris, saturating the repository. Gas generation in the repository generally rises due to the increased availability of moisture.

Ultimately, the intermediate plug fails; however, the permeability of the connection between the Castile brine reservoir and the repository is lower than between the Rustler and the repository. It can be inferred from BRAGFLO that the resistance of the creep consolidated debris, 10^{-12} to 10^{-15} square meters, opposes flow from the reservoir efficiently enough that flow into the repository occurs from both above and below the repository simultaneously. In addition, the brine reservoir is limited in terms of the volume of water it can provide, while the Rustler sources are assumed to be infinite. The result is that the preferred flow path for water into the repository is down the borehole into the repository. The net result is a repository saturated with mixed brines and pressurized to the extent allowed by generated gas.

The minor difference between a 5,000 and 10,000 year performance life in the intermediate plug of a three-plug configuration is minimal and does not warrant separate performance assessment calculations.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.6.3 Third Peer Review Panel Concern - Exploration Boreholes

> *The possibility that an effect on the repository could result from Castile brine encountered in an E1 borehole that is assigned a three-plug configuration does not appear to have been considered in the conceptual model. Castile brine could enter the repository during drilling before the borehole is cased and result in increased rates of corrosion, waste degradation, and gas production.*

Statement of Issues (Note: For the purpose of this response, the above exploration borehole concern has been combined with the first direct brine release concern regarding the transport of radionuclides with the discharge of brine [see Section 9.3.1.2.8.1].)

It has been hypothesized that potential interactions between the Castile reservoir, in which brine could flow into the intruded panel, or in which contaminants are removed from the waste panel during drilling, may exist, and that these pathways are not accounted for in the WIPP performance assessment. This discussion will show that these situations are accounted for within the assumptions contained in the current performance assessment conceptual models.

Response to Issues (Note: For the purpose of this response, the above exploration borehole concern has been combined with the first direct brine release concern regarding the transport of radionuclides with the discharge of brine [see Section 9.3.1.2.8.1].)

Figure 9-5 illustrates the problem. The drill bit first passes through the waste panel, at which time one of two events may occur: the wellbore experiences a "blowout", or brine flow from the panel into the wellbore (resulting in releases to the surface), or the well experiences "lost circulation", in which the drilling mud flows out of the wellbore and into the panel. The first event requires that the pressure differential be toward the wellbore (that is, $P_{panel} > P_{wf\ Panel}$). $P_{wf\ Panel}$ is the initial flowing wellbore pressure at the drill bit, which is equivalent to the pressure exerted by the column of drilling mud from the surface to the WIPP horizon. Current drillers in the area use a 1.23 specific-gravity-brine saturated mud, which will exert a pressure of approximately 8×10^6 pascals at the repository. When this pressure is exceeded in the panel, direct releases are accounted for in the Spall model for solids (within the CUTTINGS_S code), and the direct brine release model for dissolved radionuclides (Q_{BO} in Figure 9-5).

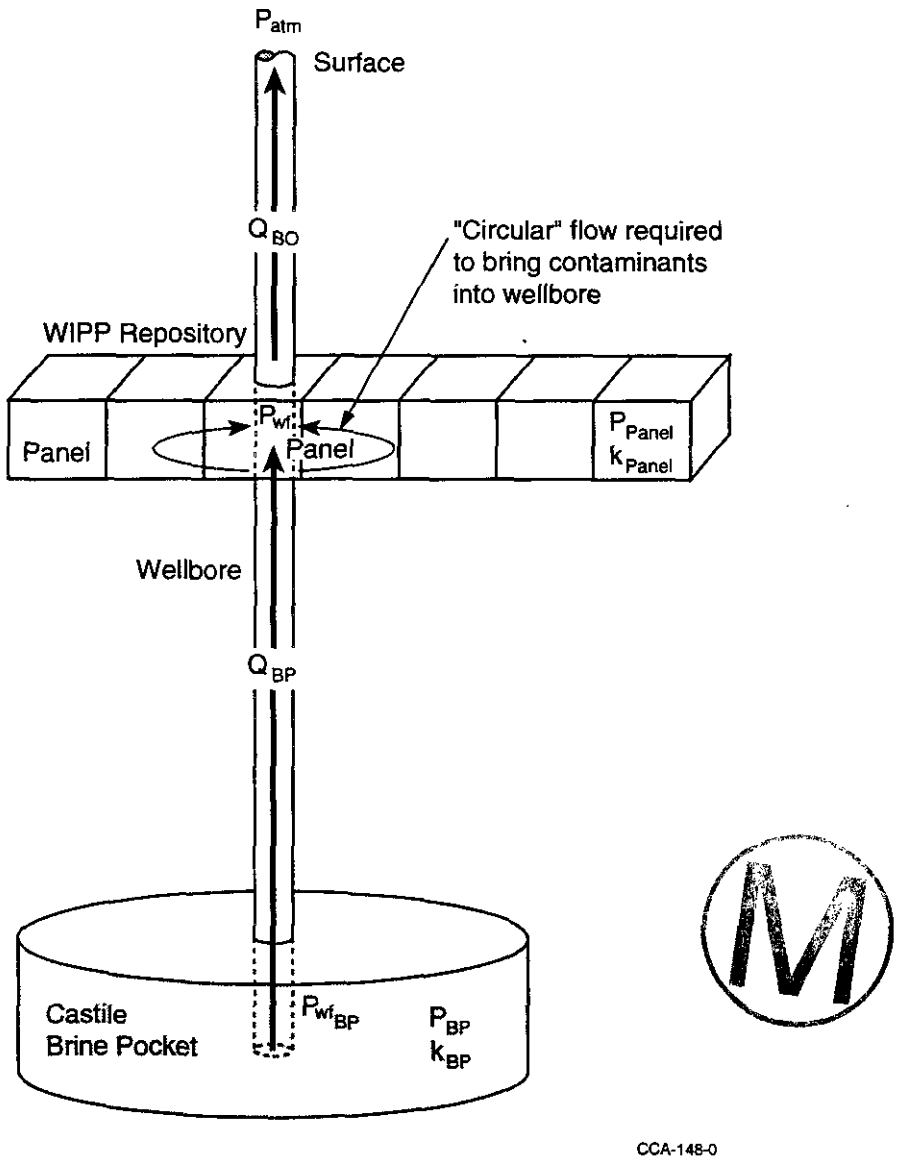

Figure 9-5. Sketch Showing Necessary Flow Path for Castile Brine To Carry Contaminants from Intruded Panel to Surface

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The second event (lost circulation) occurs if $P_{panel} < P_{wf\ Panel}$, which could result in drilling mud entering the panel during the drilling process. If the drilling mud loss into the panel is severe, current practice is to "plug" the "thief zone" (waste panel) by pumping high viscosity lost circulation material (LCM) into the thief zone until drilling mud circulation is restored. If the drilling mud loss to the panel is only a small "trickle" and the driller is able to maintain adequate circulation to the surface, he will most likely continue drilling to the next casing point, which is below the Castile.

It is important to mention the time duration of these events. Should the first event occur (the "blowout"), the direct brine release model assumes a minimum flow period of three days, which is the estimated time to continue drilling and case through the Castile. This minimum time period assumes brine "seeps" into the wellbore while drilling, and that there is little or no associated gas flow into the wellbore from the panel. The resulting increase in brine volume in the drilling mud will be treated as current drillers treat Castile brine pocket encounters, that is, to continue drilling and case the hole at the base of the Castile, at which time the cemented-in casing will stop all flow to or from the panel and brine pocket. If there is significant high-rate gas flow associated with the brine "blowout" from the panel, the direct brine release model assumes an uncontrolled flow of brine and gas which lasts for a maximum of 11 days. This is the assumed time duration to control the blowout. By "controlling" the well, current practice (and government regulations) require that the unexpected pressure be contained before drilling can continue. This can be done several ways, the most likely being to "weight up" or increase the drilling mud weight with additives and circulating until the hydrostatic pressure of the drilling mud in the wellbore exceeds the panel pressure. This will allow the driller to stop flow from the panel, at which point the blowout interval (panel) will be plugged by injecting cement, or setting casing, before drilling continues with the higher weight drilling mud. The "lost circulation" event, in which drilling mud flows into the panel, would last the length of time to case through the Castile for the "trickle" case (three days), to several hours, which is the time it would take to mix and pump the LCM plug(s) for the severe lost circulation case. In this case, the amount of drilling mud lost to the panel would be no more than several hundred cubic meters, which is the volume of the drilling mud pits (1,000 to 2,000 oil field barrels), should the driller pump the pits completely dry prior to circulating the LCM plug. This volume is significantly less (and therefore bounded) by the amount of brine available to flow from the Castile to the panel for the two-plug abandoned E1 borehole, as modeled by BRAGFLO.

If it is now assumed that drilling continues, and the drill bit penetrates a high pressure brine pocket in the Castile (E1 scenario), it is now possible for Castile brine to flow up the borehole and interact with the previously intruded waste panel on its way to the surface ($Q_{BP} = Q_{BO}$ in Figure 9-5). The flow into or out of the panel is still governed by the pressure differential between the panel (P_{panel}) and the borehole ($P_{wf\ panel}$). Assuming Castile brine has the same specific gravity as the drilling mud, $P_{wf\ panel}$ would be the same as it was for the initial penetration into the panel. This is because the pressures down the length of the open borehole are governed by the outlet pressure (atmospheric), which is the same for the drilling mud flows and Castile brine flows. Therefore, the high brine pocket pressure (P_{BP}) has no effect

on flow into or out of the panel, other than increasing Castile brine flow up the borehole past the panel. If anything, pressures in the borehole due to Castile brine flows could only increase as a result of higher frictional forces. As previously mentioned, Castile brine pocket encounters cause little concern to present-day drillers, and flows are stopped once the hole is cased (maximum three day flow duration). The effects of this transient Castile brine flow into the waste panel on corrosion, waste degradation, and gas production will be minimal and are in any case bounded by the higher-probability 2 plug scenarios for long term release. In order for Castile brine to carry contaminated brine from the panel to the surface, it would have to flow through the plug previously set to control the aforementioned blowout or lost circulation events, into the panel, then back into the wellbore. This "circular" flow can happen only if conditions change enough during the three-day flow period to cause the pressure differentials to reverse, that is, go from $P_{panel} < P_{wf\ Panel}$ to $P_{panel} > P_{wf\ Panel}$. As long as the borehole is filled with brine, $P_{wf\ panel}$ will remain unchanged. Therefore P_{panel} would have to increase. This can only be accomplished through an increase in pressures via gas generation through corrosion and/or biodegradation. These processes take many years to generate significant gas volumes, and therefore are of no concern during the three-day time frame of active drilling through the Castile.

The possibility of Castile brine entering the waste panel and removing contaminants is accounted for in the compliance certification application calculations, through the treatment of abandoned boreholes. The two-plug scenario, which is the highest probability plugging scenario, assumes 200 years of open, relatively isolated flow between the Castile and the intruded panel. During this time significant volumes of Castile brine can enter the panel, pick up dissolved radionuclides, and simultaneously increase the panel pressure via gas generation. Once the abandoned borehole assumes the permeability of silty sand, brine can leave the panel and flow to the accessible environment through the surrounding geology.

In conclusion, the likelihood of Castile brine carrying contaminated brine from the intruded (E1) panel to the surface during active drilling is highly unlikely, assuming present-day drilling practices. In addition, the pressure differentials in the panel and wellbore required to achieve this type of flow could not occur in the short time frame of active drilling.

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel concluded that the response did not reasonably address its concern.

DOE Technical Position versus Panel Issue (Note: For the purpose of this response, the above exploration borehole concern has been combined with the first direct brine release concern regarding the transport of radionuclides with the discharge of brine [see Section 9.3.1.2.8.1].)

As pointed out in the initial response, according to pipe flow dynamics, "the pressures down the length of the open borehole are governed by the outlet pressure (atmospheric), which is the same for the drilling mud flows and Castile brine flows. Therefore, the high brine pocket

pressure has no effect on flow into or out of the panel, other than increasing Castile brine flow up the borehole past the panel."

It should be noted that, as pointed out in the original response, the sequence of events is that the borehole intersects the repository before it intersects the brine reservoir.

Case 1. If there is significant flow from the borehole to the repository, this would be a source of circulation loss to the driller. Therefore, the aperture from the borehole to the repository would be plugged by the driller before the borehole intersects a Castile brine reservoir. "In this case, the amount of drilling mud lost to the panel would be no more than several hundred cubic meters, which is the volume of the drilling mud pits (1,000 to 2,000 oil field barrels), should the driller pump the pits completely dry prior to circulating the LCM plug. This volume is significantly less (and therefore bounded) by the amount of brine available to flow from the Castile to the panel for the two-plug abandoned E1 borehole, as modeled by BRAGFLO."

Case 2. If the flow from the borehole to the repository is too small for the driller to notice, it will be less than a few gallons a minute. In this case, Castile brine may flow from the borehole into the repository after the borehole intersects the brine reservoir "and flows are stopped once the hole is cased (maximum three day flow duration)." In this case, "The effects of this transient Castile brine flow into the waste panel on corrosion, waste degradation, and gas production will be minimal and are in any case bounded by the higher-probability 2-plug scenarios for long term release."

9.3.1.2.6.4 Fourth Peer Review Panel Concern - Exploration Boreholes

> *The sensitivity of the performance assessment to the simplified approach taken to determine reference conditions for BRAGFLO output does not appear to have been evaluated for the current model configuration. If reference conditions are not provided at sufficiently frequent time intervals, the modeling results may be erroneous.*

Statement of Issue

The panel accepts the necessity for using reference conditions, and acknowledges that the validity of the approach had been shown in earlier performance assessments. The concern is that the validity in the current performance assessment has not been demonstrated, particularly when only two release values (at 350 and 1,000 years) have been used.

Response to Issue

The panel is correct that formal sensitivities of the performance assessment to the assumed conditions have not been evaluated as yet. However, the calculations use more detailed results than releases calculated at 350 and 1,000 years, as indicated in the review comments:

Cuttings

Volume of material removed is independent of intrusion time. However, concentration in each of the 570 waste streams (that is, 569 for contact-handled [CH] waste and one for remote-handled [RH] waste) is time dependent. For each waste stream, concentration is calculated at 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years. Then, linear interpolation is used to estimate waste concentration at the time of a specific drilling intrusion.

Spallings

Volume of material removed is dependent on time of intrusion and whether or not the intrusion has been preceded by a prior intrusion. Calculations were performed for (1) initial intrusion into an upper waste panel at 100, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years, (2) initial intrusion into a lower waste panel at 100, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years, (3) initial E1 intrusion at 350 years followed by a second intrusion into the same waste panel at 500, 750, 2,000, 4,000, and 10,000, (4) same as (3) but second intrusion into different waste panel, (5) initial E1 intrusion at 1,000 years followed by a second intrusion into the same waste panel at 1,200, 1,400, 3,000, 5,000, and 10,000 years, (6) same as (4) but second intrusion into different waste panel, and (7) same as (3), (4), (5), and (6) but for initial E2 intrusion. For initial intrusions, one-dimensional linear interpolation used to estimate volume of release; for second and subsequent intrusions, two-dimensional linear interpolation used to estimate volume of release concentration in repository calculated at 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years. Then, linear interpolation used to estimate waste concentration at the time of a specific drilling intrusion.

Blowout

Computational structure and associated times are the same as for spallings.

Release to Culebra

BRAGFLO calculations were performed for E1 and E2 intrusions at 350 and 1,000 years and an E2 E1 intrusion (with the E2 intrusion at 800 years and the E1 intrusion at 2,000 years). Pressure and saturation conditions in repository depend primarily on time since a drilling intrusion rather than the actual time of the intrusion. The BRAGFLO results for E1 and E2 intrusions at 350 years were used to support NUTS calculations for intrusions at 100 and 350 years. The BRAGFLO results for E1 and E2 intrusions at 1,000 years were used to support NUTS calculations for intrusions at 1,000, 3,000, 5,000, 7,000, and 9,000 years. Further, the BRAGFLO results for an E2 E1 intrusion were used to support PANEL calculations for E1 E2-type intrusions at 100, 350, 1,000, 2,000, 4,000, 6,000 and 9,000 years. Then, two-dimensional interpolation was used to estimate releases for intrusions at other times.

Transport in the Culebra

Calculations were performed for unit releases into the Culebra. The results of these calculations were then used to construct releases to the accessible environment for arbitrary time-dependent releases into the Culebra.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.7 Peer Review Panel Concern - Spallings

9.3.1.2.7.1 First Peer Review Panel Concern

> *The conceptual model for channel flow of gases toward an exploratory borehole appears to be valid but has not been adequately evaluated. Spallings is a potentially important mechanism for direct waste release to the ground surface.*

Statement of Issue

The panel considers the spall model development to be on an appropriate path, but is concerned that the channel flow scenario needs additional validation.

Response to Issue

The concept of channeling is primarily based on results of laboratory experiments conducted on graded silica sands of low moisture content (Lenke et al. 1996). At the completion of each test, plaster casts were made of the void space remaining after achieving a steady gas flow state and when no additional material was being removed. The plaster filled the large primary channels near the borehole. Castings of the void volume revealed a blowout void volume characterized by a series of partial thin shells or lenses stacked at increasing distances from the borehole. The shells provided narrow pathways or channels for the passage of gas toward the borehole. A few tests also showed radial channeling in the form of conical tubular extensions extending radially from the center.

Quantitative predictions of the solids produced by channel flow made by the model are compared to laboratory experiments to define values for "effectiveness factors." These factors are needed to calibrate the model to actual observed experimental releases.

The channel pattern is postulated to grow from a region adjacent to the borehole radially outward as the result of the eroding effects of flowing gas within weakened planes or "fractures". The weakened planes are either preexisting resulting from small local variations in initial porosity and permeability (as certainly would be the case for actual waste) or are

caused by tensile and/or shear failures within the matrix resulting from local pressure gradients near the borehole.

The concept of channeling is also supported by the process used for open-hole well completions for methane production from coal seams (Mavor and Logan 1994). Open-hole cavity completion refers to the process of fracturing the coal adjacent to the wellbore through a series of controlled blowouts. The fracturing occurs in the coal due to the large gas pressure gradients that arise in the coal adjacent to the wellbore from the sudden drop in borehole gas pressure. The fracturing process increases methane gas production from the well by providing additional gas pathways or channels.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.7.2 Second Peer Review Panel Concern - Spallings

> *The conceptual model for waste erosion by flowing gases has not been adequately defined. The model describing the source(s) of waste erosion resistance and the parameter(s) characterizing that resistance have not been adequately evaluated. Errors in this conceptual model could lead to over estimating or under estimating the volume of waste released in the spallings process.*

Statement of Issue

The panel considers the spall model development to be on an appropriate path but is concerned that additional information is needed on the parameters.

Response to Issue

The concept of a fluid (liquid or gas) flowing adjacent to a stationary surface and generating a shear stress acting on that surface is well known. The pressure drop that occurs along the flow direction within pipes is based on such a phenomenon. For surface materials that have a resistance to erosion that is equal to this shear load, some of the surface material can be expected to erode and be carried along with the flowing fluid. For turbulent flow the fluid shear stress is dependent on the roughness of the surface (particle diameter), a typical dimension (for example, diameter of flow field), and the viscosity, density, and velocity of the fluid (Streeter 1958, 182). The resistance to erosion is a parameter that describes at what shear stress the surface erodes. Such a number must be related to the force required to dislodge a single particle of the surface into the fluid stream. This force can be reasonably assumed to be related to its bond to the surface (tensile strength and weight).

For spall, a model based on first principles was derived that related the forces acting on a particle projecting from the channel wall to the force required to dislodge that particle. The

forces acting on the particle were based on the drag forces generated by the flowing gas which, as above, are a function of a dimension (particle diameter), and the viscosity, density, and velocity of the fluid. An empirical coefficient of drag is also necessary which is analogous to the friction factor mentioned above. The experimentally determined effectiveness factors calibrate the model to actual observed experimental releases.

Particle bonding to the surface of the flow channels is assumed to be primarily related to the macroscopic tensile strength of the degraded waste. The value of 1 pound per square inch chosen for cementation strength for the decomposed waste for the performance assessment calculations can be reasonably expected to be conservative, that is, lower than those data values found for many weak materials that are naturally occurring or that have been manufactured. Data to support this value can be found in the literature for the strengths of soils, laboratory produced mixtures of salt and clay, and mixtures of various materials with MgO (Berglund et al. 1996; Appendix PEER, Section PEER.2).

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.7.3 Third Peer Review Panel Concern - Spallings

> *The waste has not been adequately characterized and the understanding of its physical properties in its decayed state has not been adequately developed to support the Spallings model. An adequate understanding of waste erosion processes requires an adequate understanding of the properties of the waste.*

Statement of Issue

The panel's concern is mainly with the strength assumed for the decomposed waste, since this is a controlling parameter for spall releases. In this regard, the concerns are more with the "understanding of its physical properties in its decayed state" than with characterization of the waste.

Response to Issue

A value of 1 pound per square inch (6,895 pascals) was chosen to represent the tensile strength of decomposed waste for the purpose of computing spall releases resulting from a drillbit intrusion into a pressurized waste panel. Such spall releases occur only if the gas pressure exceeds the hydrostatic drilling mud pressure of approximately 8 megapascals. A chemical reaction between the waste and brine from the surroundings is necessary to generate the gas to raise the waste pore pressure to these levels. Without brine inflow, little gas will be generated and waste decomposition will be negligible. Thus, the phenomenon of spall requires both brine inflow and waste decomposition.

The future state of decomposed waste is both time dependent and unknowable. Therefore, a decomposed state is bounded by an assumption of graded granular materials. This is consistent with the granular nature of decomposed geologic materials and corresponds to an end state of the decomposition process. Such materials lack significant composite strength from the interleaving of components and is the state found to be most troublesome in oil production where sand is produced from poorly consolidated sand layers. The value of 1 pound per square inch chosen for cementation strength for the decomposed waste can be reasonably expected to be conservative, that is, lower than those data values found for many weak materials that are naturally occurring or that have been manufactured. Data to support this value can be found in the literature for the strengths of soils, laboratory-produced mixtures of salt and clay, and mixtures of various materials with MgO; the latter added as a backfill material to the waste (Berglund et al. 1996; Appendix PEER).

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.8 Peer Panel Concern - Direct Brine Release

9.3.1.2.8.1 *First Peer Review Panel Concern*

> *The basis for the assumption that radionuclides do not accompany the direct discharge of Castile brine has not been adequately supported. This assumption could lead to underestimating radionuclide releases.*

Statement of Issue

This issue is addressed in Section 9.3.1.2.6.3 (Third Peer Review Panel Concern - Exploration Boreholes).

Response to Issue

This issue is addressed in Section 9.3.1.2.6.3 (Third Peer Review Panel Concern - Exploration Boreholes).

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel determined that the response did not reasonably address their concern.

DOE Technical Position versus Panel Issue

As pointed out in the initial response, according to pipe flow dynamics, "the pressures down the length of the open borehole are governed by the outlet pressure (atmospheric), which is the

same for the drilling mud flows and Castile brine flows. Therefore, the high brine pocket pressure has no effect on flow into or out of the panel, other than increasing Castile brine flow up the borehole past the panel."

As pointed out in the original response, "In order for Castile brine to carry contaminated brine from the panel to the surface, it would have to flow...into the panel, then back into the wellbore. This circular flow can happen only if conditions change enough during the three day flow period to cause the pressure differentials to reverse, that is, go from $P_{panel} < P_{wf\ Panel}$ to $P_{panel} > P_{wf\ Panel}$. As long as the borehole is filled with brine, $P_{wf\ panel}$ will remain unchanged. Therefore P_{panel} would have to increase. This can only be accomplished through an increase in pressures via gas generation through corrosion and/or biodegradation. These processes take many years to generate significant gas volumes, and therefore are of no concern during the three-day time frame of active drilling through the Castile."

9.3.1.2.8.1 Second Review Panel Concern - Direct Brine Release

> *Radionuclide transport through entrainment of brine and waste solids in rapid, two-phase liquid/gas releases during inadvertent borehole intrusions does not appear to have been evaluated. This transport mechanism may be an important component of the conceptual model.*

Statement of Issue

The possibility of solids (spall) releases as a result of the higher erosional forces of simultaneous brine and gas flows through the waste panel is not accounted for.

Response to Issue

Entrainment of contaminated brine in rapidly flowing gas is included in the direct brine release model used in performance assessment. Basically the brine and gas flow to the wellbore is computed by BRAGFLO. These are used with a Poettman-Carpenter well-bore model to iteratively determine a bottom-hole flowing pressure, which in turn is used to determine the direct brine releases appropriate for the particular conditions (including multiphase flow). The "gas-lift" effect is accounted for in the two-phase well-bore flow model in the determination of the flowing well boundary condition.

Solid entrainment is not explicitly included in this model, however the releases due to this mechanism are expected to be no more than that already accounted for in the cuttings, cavings, and spallings model.

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel concluded that the response did not reasonably address their concern.

DOE Technical Position versus Panel Issue

A simple modeling approach that accounts for the major influences of two-phase flow on solids releases is to increase the spall model gas density to correspond to the combined density of brine and hydrogen. The density contribution from the added brine is dependent on the liquid/gas ratio for the particular vector and is strongly correlated with the gas flow rate (Figure 9-6). For large liquid/gas ratios (large "gas" densities) the borehole flow rate is very small, while for small liquid/gas ratios (small "gas" densities) the borehole flow rate under standard conditions is large, approaching 20 cubic meters per second. Figure 9-6 shows this trend for all of the 699 downdip intrusions for which brine was released in the 1996 performance assessment as computed by BRAGFLO.

The spall model assumes that blowout gases flow up the borehole annulus and satisfy isothermal compressible flow equations in a long channel. The model also assumes that the bottom hole pressure is equal to the repository gas pressure and consequently the flow rate tends to be constant at 4.37 cubic meters per second at repository conditions. However, it is clear from Figure 9-6 that the flow rate is not constant when the effects of entrained brine are included. The competing effects of density and flow rate on spall releases can be determined by correcting the values of Figure 9-6 to repository conditions and by computing a release factor which would multiply the spall model releases. The release factor is proportional to [(borehole flow rate)("gas" density)$^{1/2}$]. Figure 9-7 shows this release factor for the 699 down-dip intrusions. The net effect of increased "gas" density and decreased borehole flow velocity decreases spall releases to less than 1/10 of the spall model.

9.3.1.2.8.2 Third Peer Review Panel Concern - Direct Brine Release

> *Releases resulting from flow into an exploration borehole intersecting a disturbed rock zone in the wall of a waste panel do not appear to have been evaluated. Large, open fractures in the walls could significantly increase the local halite permeability, allowing gas and brine to migrate through the borehole to the ground surface.*

Statement of issue

At issue is the potential for additional direct brine releases to occur due to the higher permeability of the DRZ.

Response to Issue

Inclusion of drilling intrusions into the DRZ is not expected to increase direct brine releases for the following reasons:

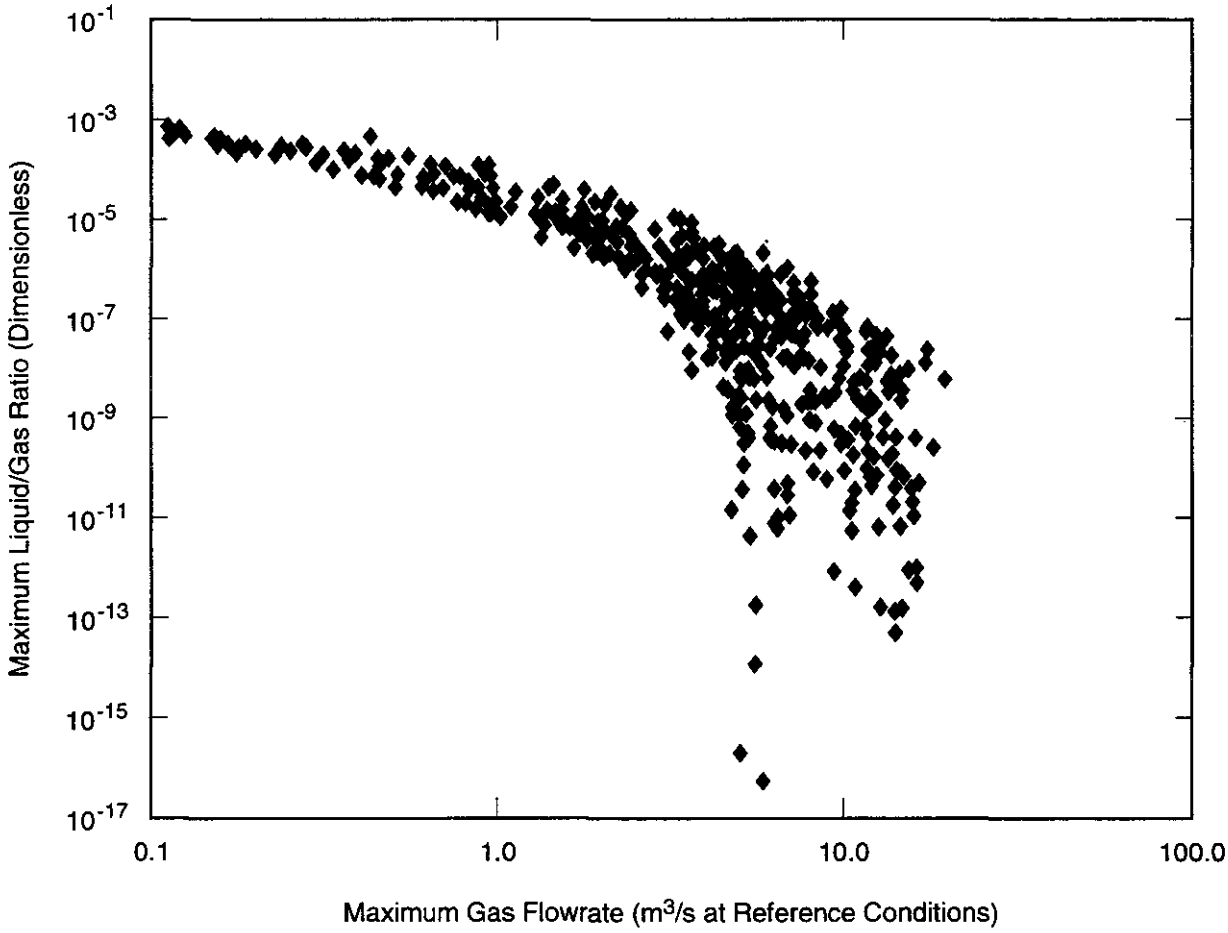

Figure 9-6. Maximum Liquid/gas Ratio versus Maximum Gas Flowrate (All Intrusions that Resulted in Direct Brine Release)

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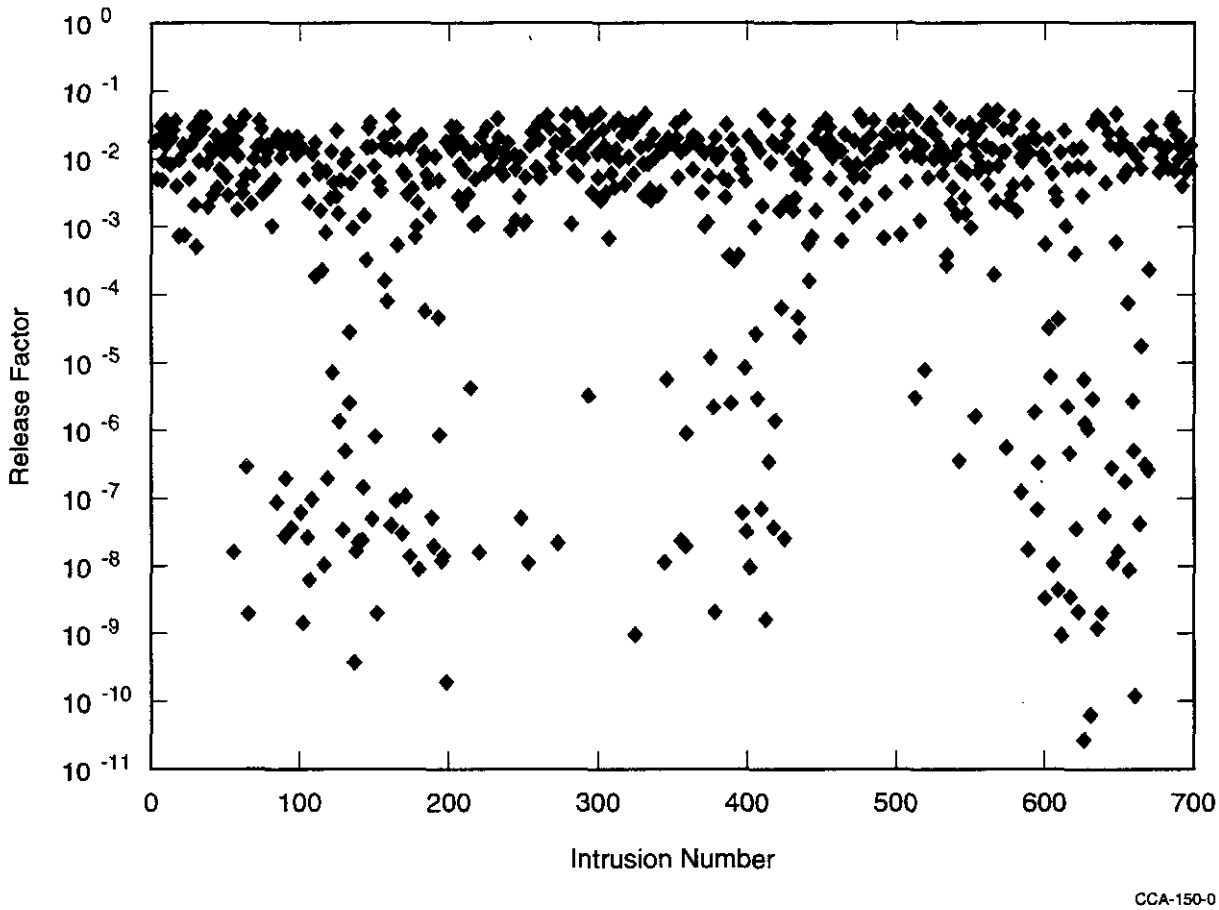

Figure 9-7. Multiplier by which Spall Releases Would Be Reduced if Effects of Two-phase Flow on Solids Were Included in Performance Assessment Modeling (All Intrusions That Resulted in Direct Brine Release)

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- The permeability of the DRZ (approximately 10^{-15} square meters) is lower than the permeability of the waste (approximately 10^{-13} square meters), which would substantially reduce the flow into the borehole compared to an intrusion directly into the waste.

- The area of the DRZ around the waste panels is probably small compared to the area of the waste panels, so including that area will not substantially increase the probability of an intrusion.

- The first intrusion has the largest release, with subsequent intrusions having little or no release. Since virtually all realizations have at least one intrusion, small increases in the probability of intrusion will not change the total direct brine releases.

- Inclusion of the DRZ (and the operations and experimental regions) would increase the area where intrusions:

  - result in little release (because of the lower permeability of the DRZ compared to the waste and the absence of waste from the operations and experimental regions) and

  - reduce pressure in the repository and thus reduce the potential for direct brine releases from subsequent intrusions.

Hence, neglecting these intrusions is reasonable.

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel concluded that the response did not reasonably address their concern.

DOE Technical Position versus Panel Issue

The current response includes those processes that are believed to be important for releases and discusses why the particular combination of circumstances identified by the peer panel is not believed to contribute significantly to releases. In fact, it shows that the current treatment is conservative compared to a treatment including DRZ penetrations because the DRZ penetrations could vent high gas pressures without cutting, cavings, and spallings releases, and with minimal direct brine releases.

9.3.1.2.9 Peer Review Panel Concerns - Castile and Brine Reservoir

9.3.1.2.9.1 First and Second Peer Review Panel Concerns

The basis for excluding larger, potentially depressurized brine reservoirs from performance assessment has not been adequately supported. Larger reservoirs may have greater brine flow volumes and may result in greater radionuclide releases.

The basis for the concept of reservoir depletion through previous borehole penetrations has not been adequately supported. Non-depleted reservoirs may have greater brine flow volumes and may result in greater radionuclide releases.

Statement of Issues

The panel is concerned that (a) larger brine reservoirs are not included in the performance assessment calculations and (b) the depletion of reservoirs in not well supported.

Response to Issues

The Anderson et al. (1996) memorandum demonstrates that the brine flow up a borehole is not sensitive to the reservoir size and that the effects of depletion are included in the uncertainty in the size of the brine pocket.

In Figure 9-8, the results of brine flow up a borehole that penetrates a brine pocket are plotted against the sampled initial brine pocket volume from the performance assessment calculations. The borehole flow is cumulative over the 10,000-year calculational period. This figure suggests that initial brine pocket volume is not an important variable for predicting borehole flow given the other uncertainties describing brine pockets included in the performance assessment calculations.

In Figure 9-9, the results of cumulative brine flow up a borehole that penetrates a brine pocket are again displayed, this time against the sampled values of brine pocket pore compressibility. The strong correlation observed indicates this parameter dominates the uncertainty in borehole flow upon penetration of the brine pocket.

The lack of sensitivity of cumulative brine flow up a borehole that intersects a brine pocket to initial brine pocket volume suggests that other uncertainties dominate the system. Furthermore, this lack of sensitivity allows for some flexibility in the rigor applied to determining and justifying the range in brine pocket volumes considered in the performance assessment calculation.

The analysis by Stoelzel et al. (1996) (see Appendix PEER) justifies the range of the initial brine pocket brine volumes (32,000 to 160,000 cubic meters) used in the performance

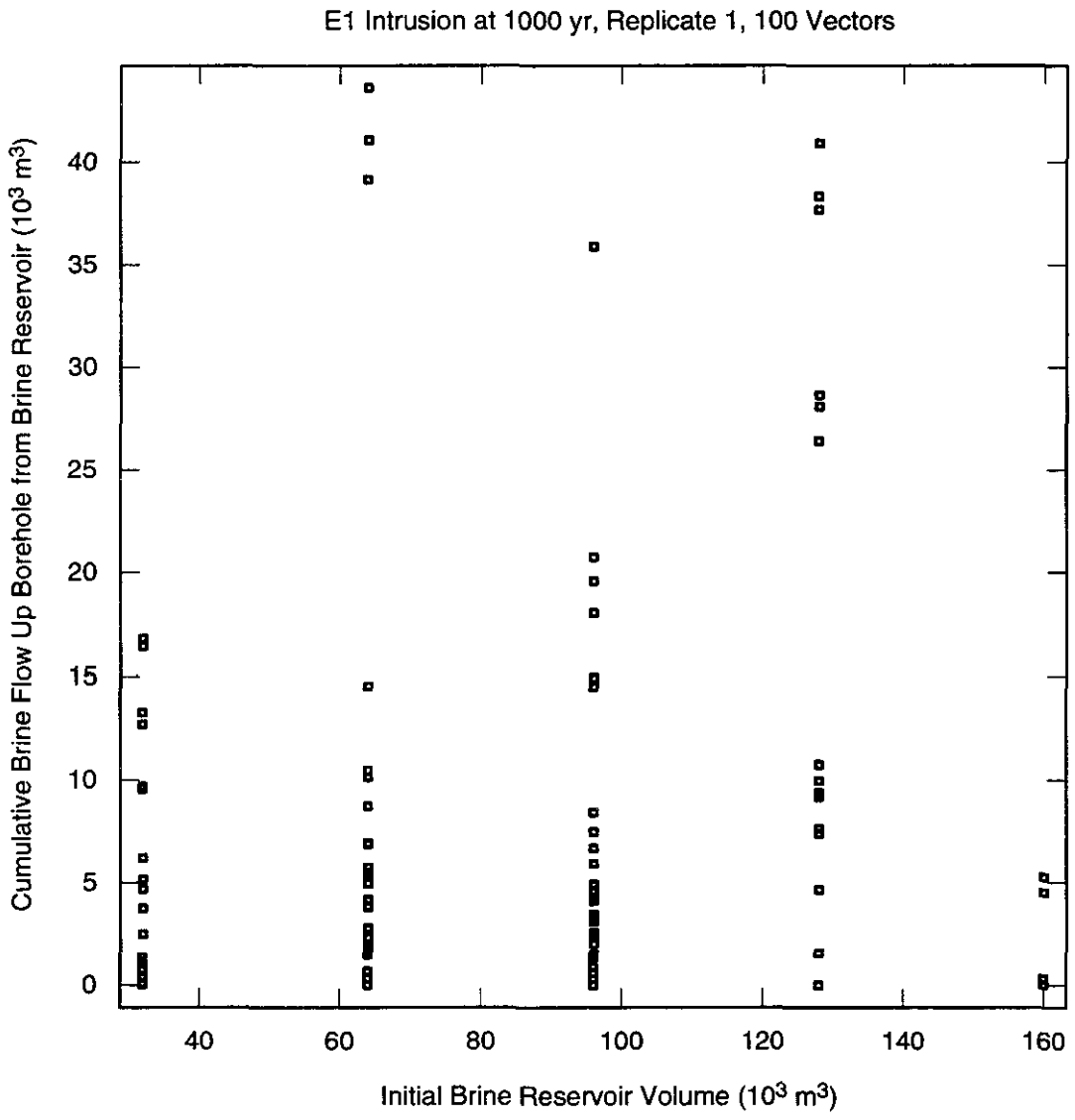

Figure 9-8. Scatterplot Showing Lack of Correlation Between Brine Flow from the Castile Brine Reservoir and the Sampled Value for Brine Reservoir Volume

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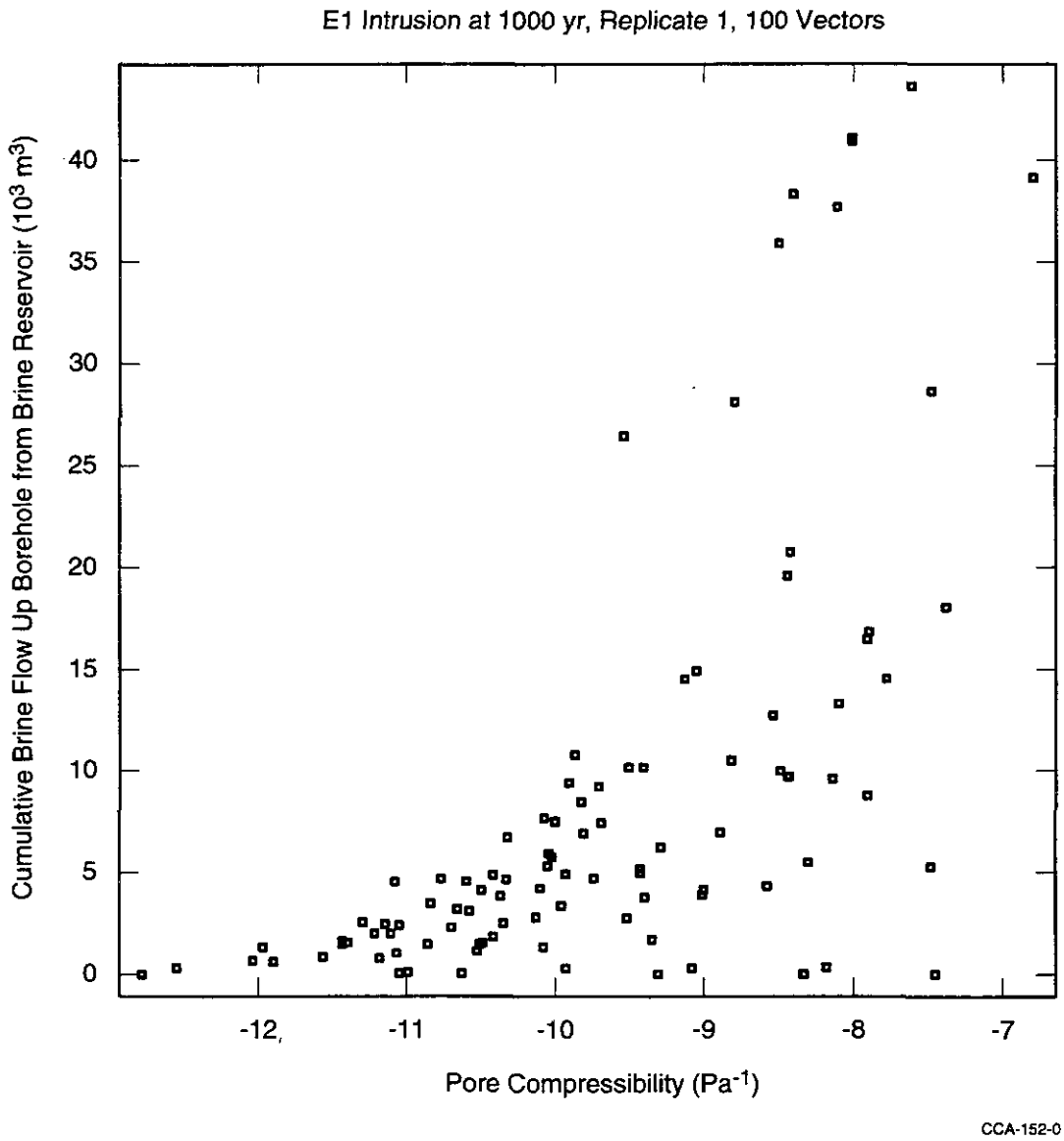

Figure 9-9. Scatterplot Showing Correlation between Brine Flow from the Castile Brine Reservoir and the Reservoir Pore Compressibility

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assessment calculation. This range is obtained from consideration of WIPP-12 data and an evaluation of depletion of the brine pocket due to penetrations that do not intersect waste.

Peer Reviewer Consideration of Response

The DOE understood the issues and provided a reasonable response.

9.3.1.2.9.2 Third Peer Review Panel Concern - Castile and Brine Reservoir

> *The expected probability of encountering pressurized brine beneath the waste panels has not been adequately supported, nor has the basis for apparently ignoring the quantitative value of site-specific geophysical data been presented. Unrealistically low probabilities of encountering brine may result in underestimating radionuclide releases.*

Statement of Issue

There are several parts to the panel concern that should be separated for a clear response:

1) the probability of encountering brine under the waste panels has not been adequately supported.

2) site-specific geophysical data are apparently being ignored without presenting the basis for ignoring it.

3) unrealistically low probabilities may result in underestimating radionuclide releases.

Response to Issue

1) In the overall context of the peer review report, this item refers to the discussion of geostatistical analyses, not the various methods of estimating probabilities based on the geophysical data (Item 2 below).

The work on estimating conditional probabilities of encountering brine in a drillhole under the waste panels was in progress during the panel deliberations, and a report was not yet prepared for the panel to review. The work in progress was presented orally to one member of the conceptual models panel before the panel completed its work. A draft report was prepared June 18, 1996 for internal review. A final report, dated July 10, 1996, has been submitted and will be reviewed by the project. The report is titled "Probability of Encountering Pressurized Brine under the WIPP" (Powers et al. 1996) and is included in Appendix MASS as Attachment 18-6.

The main points of the work can be summarized briefly. Maps of geological structure and thickness of Castile and related intervals were prepared incorporating data from many new drillholes in the vicinity of the WIPP, and the maps were interpreted as showing the relationship between brine occurrences and deformation of the Castile. The Castile under the waste panels is thought to be generally undeformed; there are no drillholes, however, in the Castile at the waste panel that would prove this to be true. An indicator function was developed for reports and non-reports of brine for 354 drillholes in a study area around WIPP, and a series of variograms were developed to show the spatial structure from these drillholes. An anisotropic model fit was used to provide parameters for ordinary kriging of the data for these drillholes. The area-weighted average estimated conditional probability was 0.08, based on computational nodes in the location of the waste panel. Nodal probabilities increase significantly north toward WIPP-12, reaching nodal values of about 0.37 in parts of the experimental area. The relationship between reported brine occurrences and thickness of certain intervals indicates that the thickness of the intervals under the waste panel area is less than the same interval in any known brine encounter. These different approaches indicate a low probability for encountering brine in a drillhole penetrating the Castile under the waste panels.

The panel discussed the validity of the geostatistical approach and the CMPR report (see Appendix PEER, 170 – 171) stated two principal objections to this approach:

a) lack of data in the vicinity of the WIPP.

b) an implicit assumption that geologic conditions at the WIPP would be similar to those in areas where brine encounters and drilling are more abundant.

Data on the Castile from drillholes near the WIPP site are limited for analyzing brine occurrences compared to some other areas. The main contributors to the geostatistical analysis at the site are WIPP-12 and DOE-1. WIPP-13, DOE-2, and commercial drillholes at greater distances contribute far less to the analysis. The strength of the analysis is that it uses the large database available to develop the spatial structure, and it honors the data at each drillhole location.

There is no assumption about underlying causes or distribution of brine occurrences. There is an assumption that the spatial information, developed from all drillholes in the study area, applies at the WIPP. Based on geological data developed independently of the geostatistical approach, Powers et al. (1996; Appendix MASS) concluded that there is a strong association of brine occurrences and Castile deformation, as indicated by thickness and structure data. As noted before, geologic data from the Castile at the site are limited. It might also be concluded that brine is not necessarily associated with structure, based on the assumption that geophysical data (Time-Domain Electromagnetic [TDEM] survey, see 2 below) indicate pressurized brine in the Castile under the waste panel location, where there is believed to be little, if any, Castile structure.

The effects on estimated conditional probabilities can be tested by assigning brine encounters or "nonencounters" in hypothetical drillhole locations around the immediate site area. The effects will differ greatly depending on the drillhole location and assignment as "an encounter" or "nonencounter".

The geostatistical approach is the most practical way to estimate the conditional probability that a future drillhole will encounter brine under the waste panel.

The geostatistical study was conducted independently of the geophysical data. The review of the geostatistical work in progress included that fact and may have contributed to the impression that the geophysical work was not being considered, at least quantitatively.

2) The geophysical data (particularly TDEM) that have been obtained represent the only significant site specific data over the waste panel. The TDEM work shows that there are very significant low resistivity anomalies that, under some of the waste panel area and adjacent to other areas, are consistent with depths of the middle to lower Castile. At this time, no other good explanation than brine has been proposed, and there has been no work that suggests the TDEM data are invalid. The method has been checked by tests near WIPP-12 that indicate low resistivity at depths approximately equivalent to the brine encounter in WIPP-12. DOE-1 did not encounter brine, and tests of TDEM near there did not indicate low resistivity within the Castile.

Most of the brine encounters that have been reported can be assigned to the lower half of the upper anhydrite (A3) or upper part of H2. Nonetheless, at least one encounter (see Table 4.2-2 in the report by Powers et al. 1996; Appendix MASS) was reported at a depth equivalent to the lower halite; another encounter was reported for a lengthy zone ranging from upper to lower anhydrite; and two encounters are from the uppermost anhydrite, but the unit may be A2. Thus, the geophysical data cannot be invalidated though the resistivity zones are interpreted to be at a depth equivalent to the basal anhydrite and lower halite of the Castile.

The interpreted depths to conductive units have been examined to estimate the area under the waste panels that might be underlain by Castile brine. Depending on the assumptions, the area ranges between about 10 percent and 55 percent. All analyses implicitly assume a uniform areal extent (similar to assuming porous medium), though the general concepts of brine reservoirs are of fractured rocks. In addition, various contouring ideas assume some small-scale structure (less than 250 meters), though a variogram of depth to conductor does not indicate any structure in ranges from 250 meters (smallest separation distance) to 500 meters separations or lag distances.

The TDEM data are the most specific indicators of possible locations where Castile brine might underlie the area of the waste panel.

3) Releases calculated are related to the probability of intercepting a brine reservoir within the area underlain by the waste panels. It may be more difficult to determine what an

"unrealistically low probability" may be when there are different ways of examining whether a drillhole is likely to intercept brine or whether brine underlies part of the waste panel.

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel concluded that the response did not reasonably address its concern.

DOE Technical Position versus Panel Issue

The current response provides a substantial geostatistical basis for the probability of encountering pressurized Castile brine. It extracts the maximum amount of information from the available direct data on exploration boreholes encountering Castile brine reservoirs. The indirect data (TDEM) used previously lack substantiated correlation with the probability of encountering Castile brine reservoirs but is consistent with the calculated probability from the direct data.

9.3.1.2.10 Peer Review Panel Concern - Gas Generation

9.3.1.2.10.1 First Peer Review Panel Concern

> *The conceptual model does not consider aluminum in the waste, steel in the rock bolts and netting, radiolysis of water by undissolved alpha emitters, and radiolysis of plastics and cellulosics as sources of additional hydrogen, oxygen, and other gases. Ignoring gases generated by these effects could result in underestimating the gas pressure in the repository."*

Statement of Issue

Corrosion. Anoxic corrosion of Al and Al-base metals in the transuranic (TRU) waste to be emplaced in the WIPP, and steel in the rock bolts, netting, etc., used for construction and maintenance of the repository will produce H_2 in addition to that predicted by the average-stoichiometry gas-generation model in the multi-phase flow code Brine and Gas Flow (BRAGFLO). For the calculations to support this application, the DOE considered the steel in waste containers (drums and boxes), steels and other Fe-base metals in the CH-TRU waste, and Fe-base metals associated with RH-TRU waste. However, the DOE did not consider the rock bolts and netting in the repository, nor Al and Al-base alloys in the waste. The DOE has assumed that the quantities of these metals are small relative to those included in the current and previous performance assessment calculations, and that the quantities of H_2 that would be produced by anoxic corrosion of these metals are small relative to that predicted by the current and previous performance assessment calculations. However, the DOE has not calculated the quantities of H_2 that would be produced by including them.

Radiolysis. Radiolysis of brine by solid-phase (crystalline or amorphous) actinides in the waste will produce H_2 and O_2 in addition to that predicted for dissolved actinides. Although a significant fraction of the energy associated with α-emissions from actinide-bearing solids could be absorbed by these solids, some of this energy could also be absorbed by any brine present. The DOE has calculated the maximum quantities of H_2 and O_2 that could be produced by brine radiolysis from dissolved Pu and concluded that the rate of gas production from brine radiolysis will be insignificant relative to that from anoxic corrosion and microbial activity (see Appendix SCR, Section 2.5.1.3.1). However, this analysis did not include Pu in solids.

Furthermore, the DOE has concluded, based on the results of laboratory studies summarized by Molecke (1979), that radiolysis of combustibles (cellulosics, plastics, and rubbers) will be insignificant relative to brine radiolysis (see Appendix SCR, Section SCR.2.5.1.3.2)) and, hence, insignificant relative to anoxic corrosion and microbial activity. However, the CMPR panel disagreed with this position, perhaps because compaction of the waste due to room closure may increase the radiolytic gas production rate by increasing the density of the waste and the extent to which particles interact with it.

Response to Issue

If added to the calculation for hydrogen production, the quantity of aluminum in the inventory would add about 4 percent to the corrodible metals in the repository. The quantity of netting and rock bolt iron represents a similarly small amount. No consequence to repository performance results from adding these additional metal quantities. The quantities themselves are small, and might increase the total moles of gas production by 10 percent to 15 percent. There is a fundamental, self-limiting relationship between gas pressure and corrosion. Prior to human intrusion, water initially drains into the repository from Salado sources, such as the DRZ and MBs. In inundated areas, metal corrodes and produces hydrogen, which exerts a backpressure on flow. In all realizations calculated by BRAGFLO, gas pressures rise high enough to prevent panel saturation. Importantly, this pressure is reached before all the metal in the panel is consumed by corrosion. In summary, prior to human intrusion, gas production is limited by the availability of water; hence addition of aluminum plus rock bolt plus netting inventory does not add significantly to the amount of corrosion gas that will be generated (Al will cause a small but indeterminate increase). The WIPP is in a location where drilling frequency is comparatively high. In 10,000 years, the repository will be intruded approximately six times. Boreholes connecting the repository to the surface are calculated to have a permeability of about 10^{-11} to 10^{-14} square meters for most of their lives. As a result, after human intrusion there may well be available water to drive corrosion, but there will also be release paths that vent elevated pressure. For most of the repository history, the principal effect of hydrogen will be to impose reducing chemical environments on waste dissolution. Accordingly, neglecting the small amounts of metal inventory or potential increases from radiolysis results in a slight conservatism. A detailed discussion of hydrogen generation is provided below.

Details of Hydrogen Generation in the WIPP Repository

Corrosion. The quantity of Al and Al-base metals in the TRU waste that will be emplaced in the WIPP is insignificant relative to that of the steel in waste containers and Fe-base metals in the CH and RH waste. According to the current version of the Baseline Inventory Report (BIR), the total, molar quantity of Al and Al-base metals is about 4 percent of the total quantity of Fe-base metals (DOE 1995a). Although the BIR does not estimate the quantity of Fe-base metals in rock bolts, netting, etc., the quantity of other Fe-base metals is probably insignificant relative to that included in the BIR.

Nevertheless, the DOE has concluded that inclusion of Al and Al-base metals and other sources of Fe-base metals would have no deleterious effect on the long-term performance of the repository. BRAGFLO calculations carried out to support this application have shown that, in the absence of human intrusion, anoxic corrosion of Fe-base metals was limited in all of the realizations (vectors) by the quantity of brine present in the repository, not the quantity of Fe-base metals. In other words, corrosion was brine-limited, not inventory-limited, over the entire range of system uncertainty. Figure 9-10 shows that, under undisturbed conditions, corrosion never consumed all of the Fe-base metals during the 10,000-year period of performance of the repository. Figure 9-11 shows the quantities of H_2 produced by anoxic corrosion in the undisturbed scenario. On a repository-wide basis, corrosion at most consumed only 60 percent of the inventory in 10,000 years. Therefore, including corrosion of Al-base metals, or increasing the quantity of Fe-base metals in the inventory would have no effect on the gas content of the repository after 10,000 years; it would only increase the quantity of uncorroded metals present after 10,000 years.

These BRAGFLO calculations also show that, in the event of human intrusion, anoxic corrosion is not necessarily brine limited, at least in the vicinity of the intrusion borehole. Therefore, corrosion can continue to consume brine and produce H_2. Figure 9-12 shows that, after intrusion of a brine reservoir at 1,000 years, corrosion consumed all of the Fe-base metals in the intruded panel in some of the realizations. However, Figure 9-13 shows that corrosion was inventory-limited only in the intruded panel. Nevertheless, including corrosion of Al-base metals, or increasing the quantity of Fe-base metals in the inventory would increase the quantity of H_2 produced in the intruded panel in those vectors in which corrosion was inventory-limited.

In the event of human intrusion, BRAGFLO predicts that the pressure of the surrounding Salado Formation will exceed that of WIPP disposal rooms, and brine inflow and corrosion will resume. However, gas will escape preferentially up the borehole because of the buoyancy of the gas and the relatively high permeability of the borehole. Therefore, additional gas production will not increase the pressure of the repository significantly under these conditions. Figure 9-14 shows the pressure in the intruded panel; Figures 9-15 and 9-16 show the volume of gas produced by corrosion and the volume of gas flowing up the borehole at the top of the DRZ above this panel. Comparison of these figures and those for the undisturbed scenario imply that as much as 25 to 50 percent more gas was produced as a result of human intrusion.

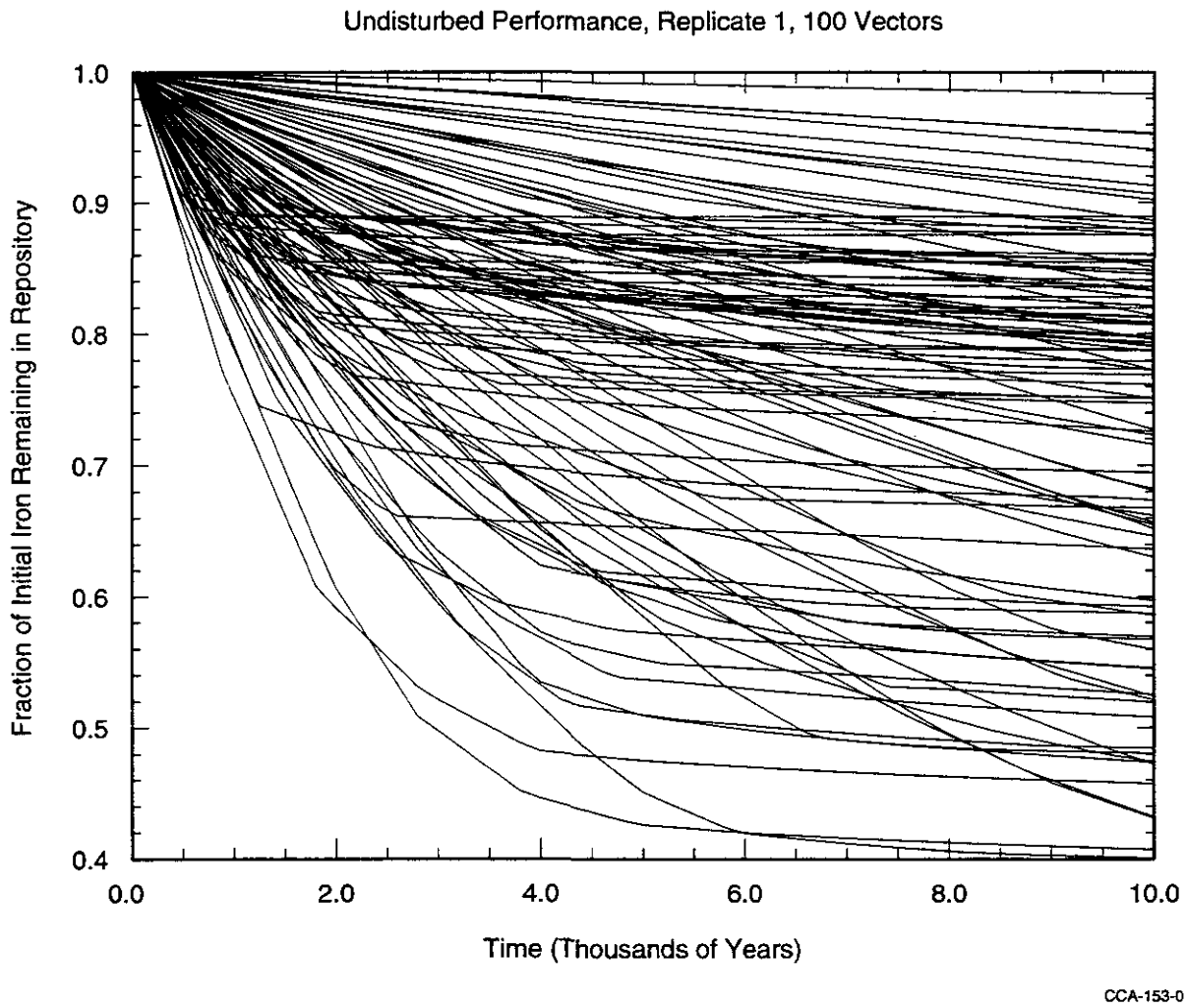

Figure 9-10. Fraction of Initial Iron Remaining in Repository, Undisturbed Performance

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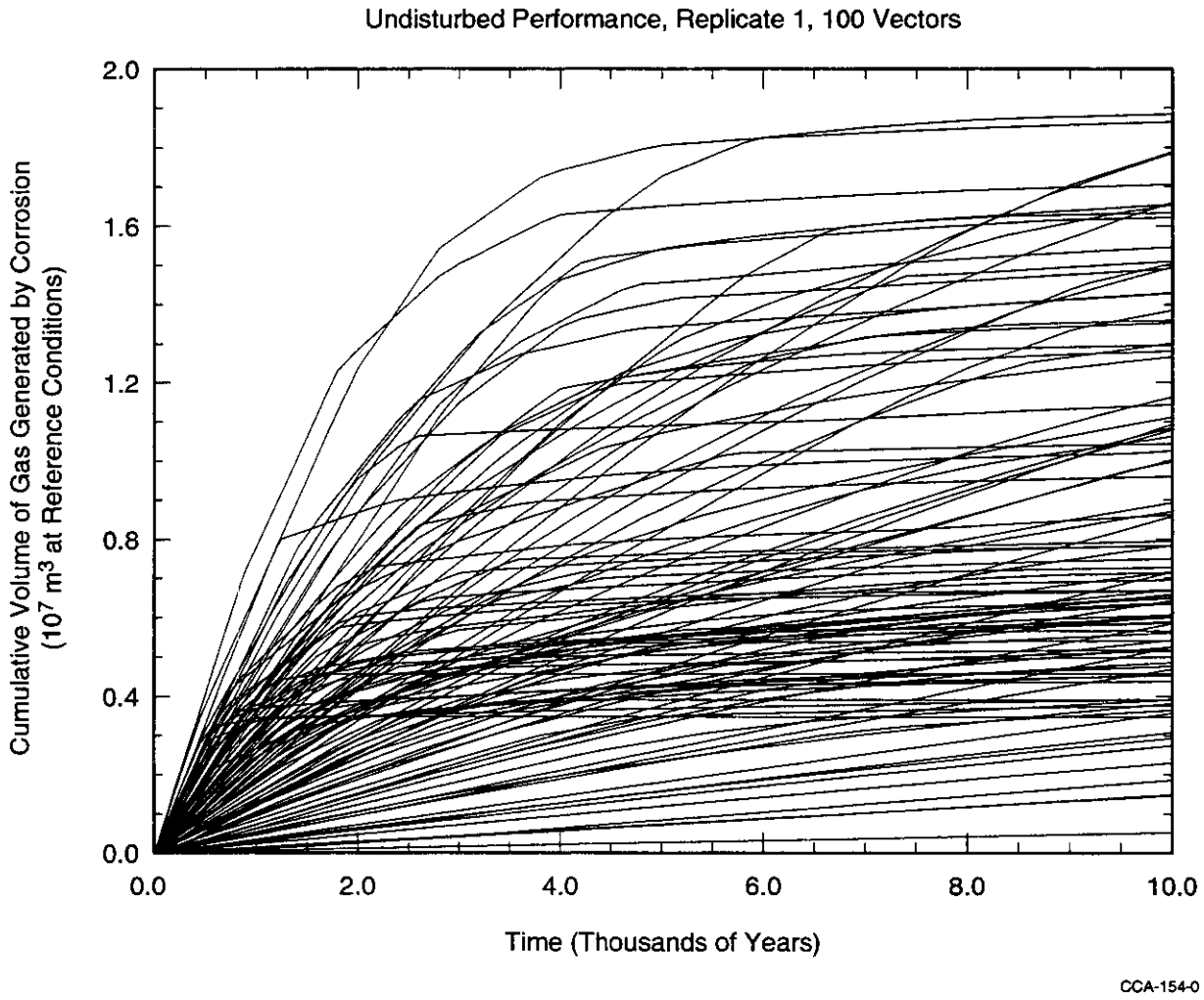

Figure 9-11. Total Gas Volume Generated by Corrosion of Iron, Undisturbed Performance

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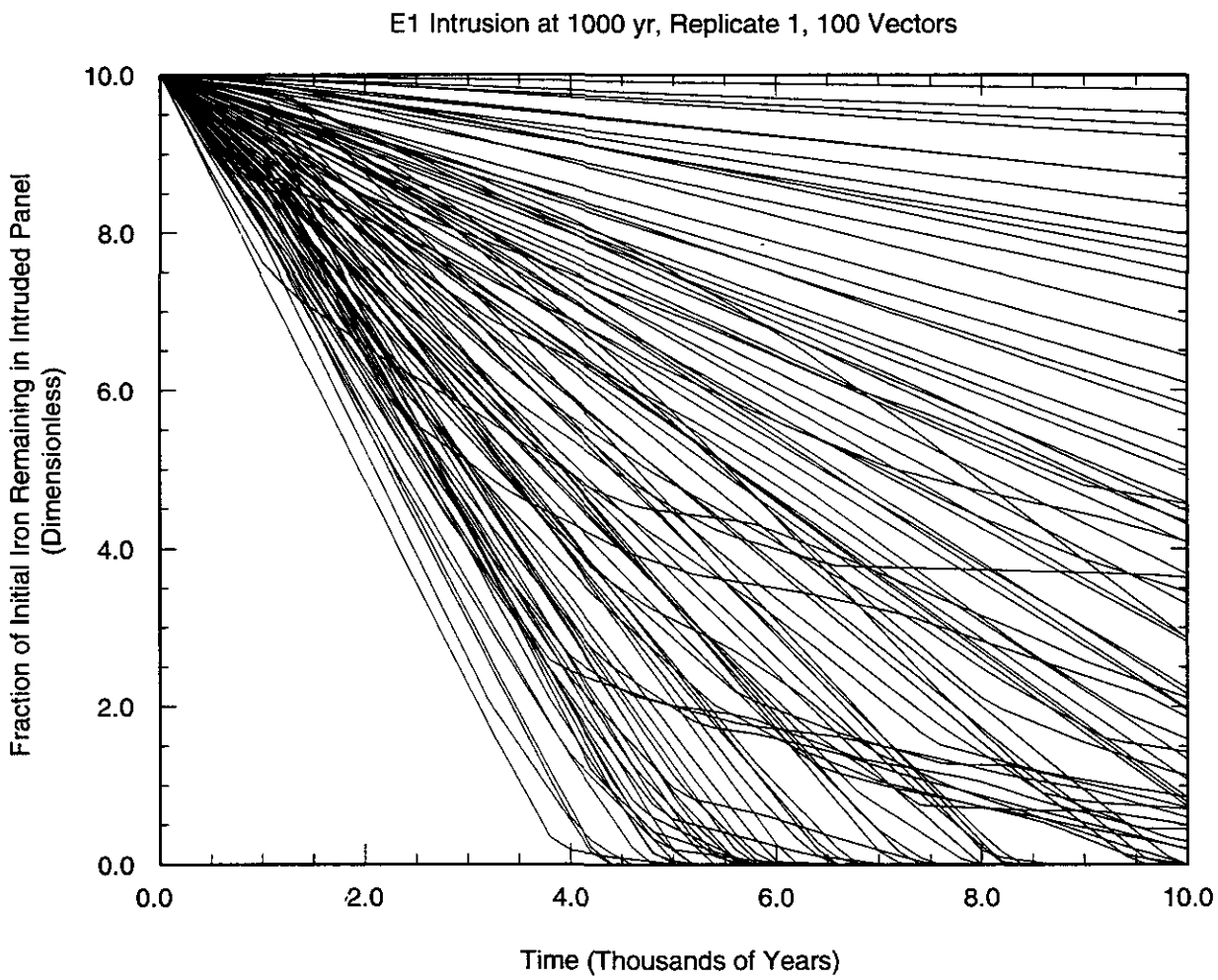

Figure 9-12. Fraction of Initial Iron Remaining in Intruded Panel, E1 Intrusion at 1000 Years

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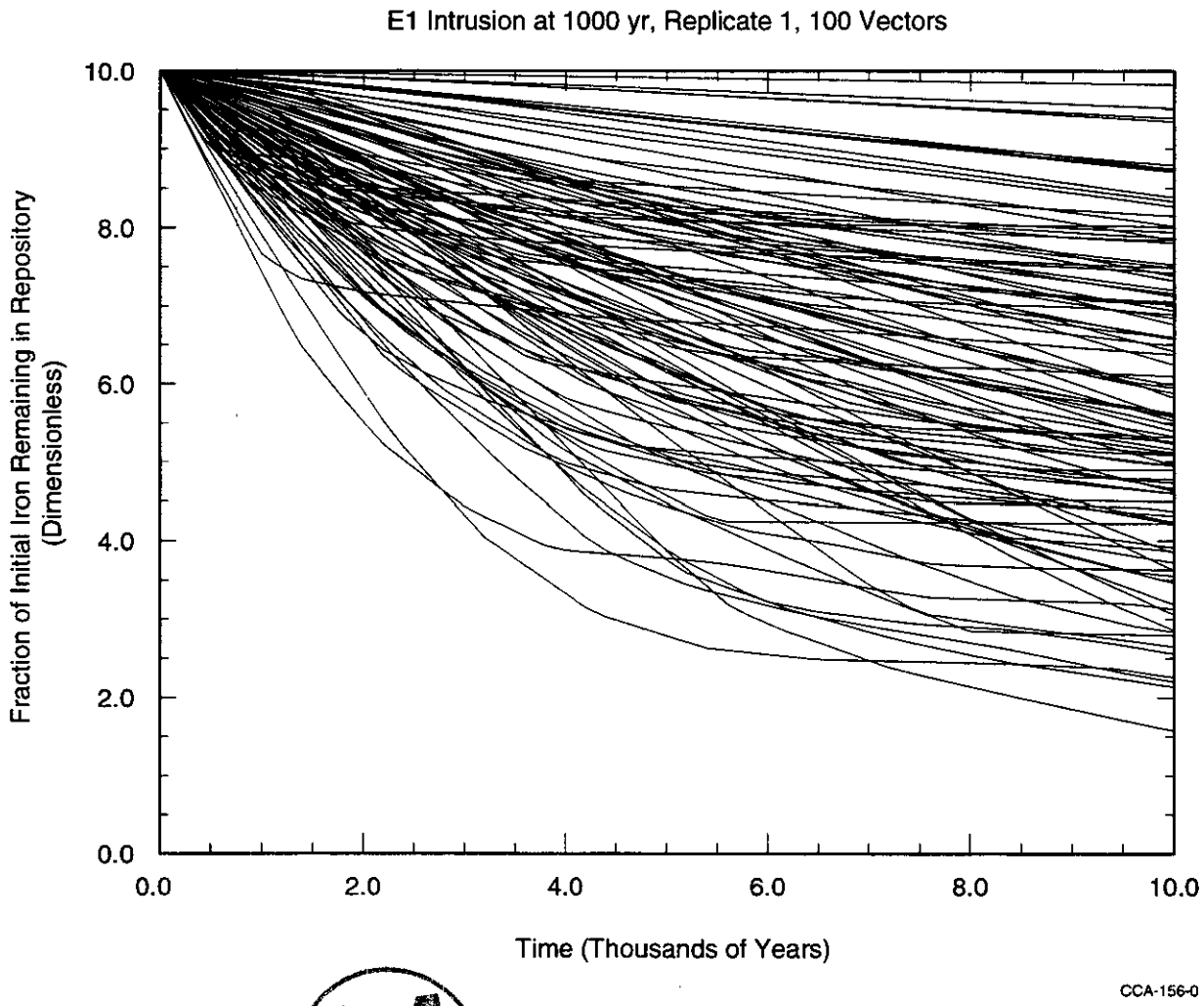

Figure 9-13. Fraction of Initial Iron Remaining in Repository, E1 Intrusion at 1000 Years

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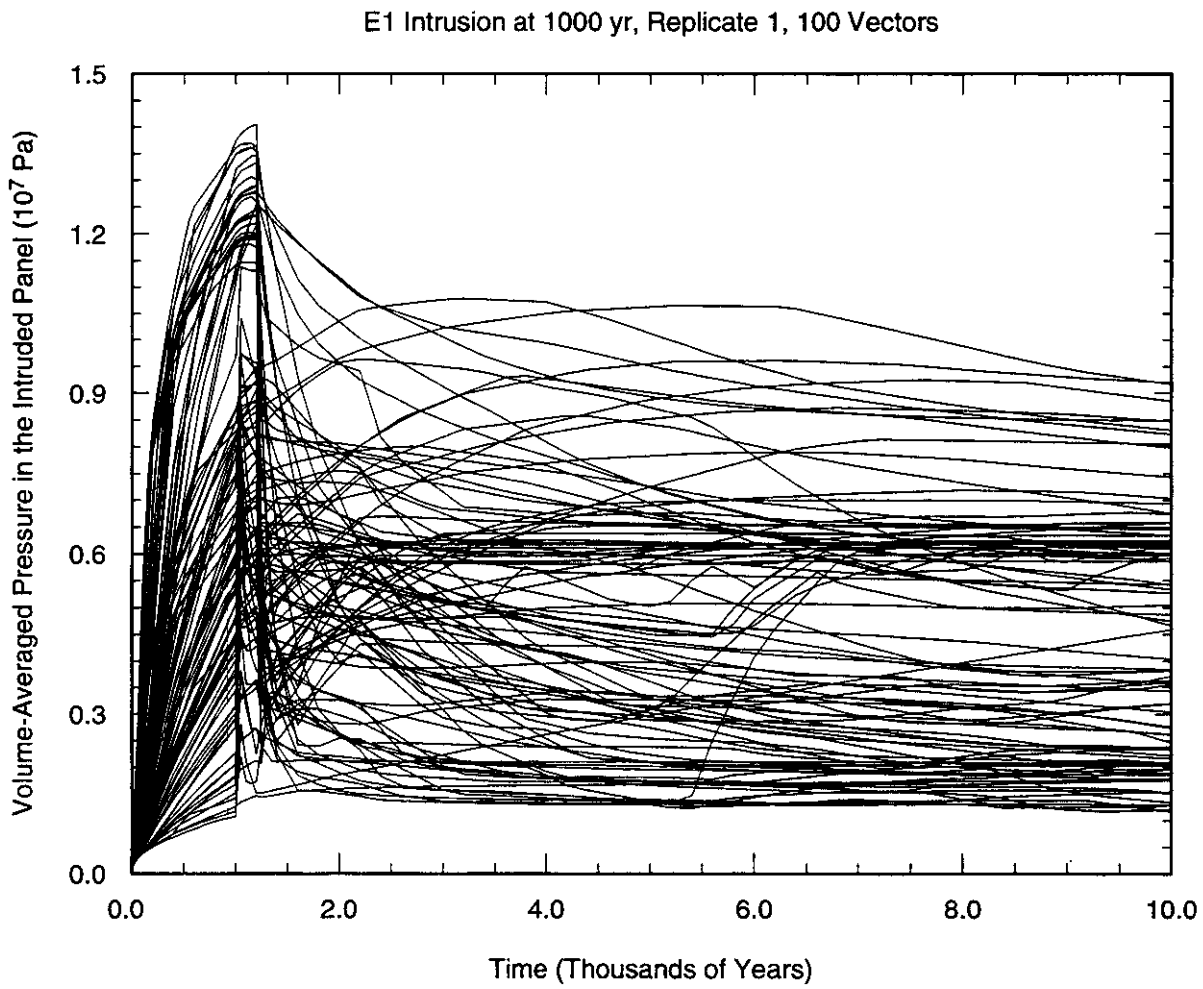

Figure 9-14. Volume Averaged Pressure in the Intruded Panel, E1 Intrusion at 1000 Years

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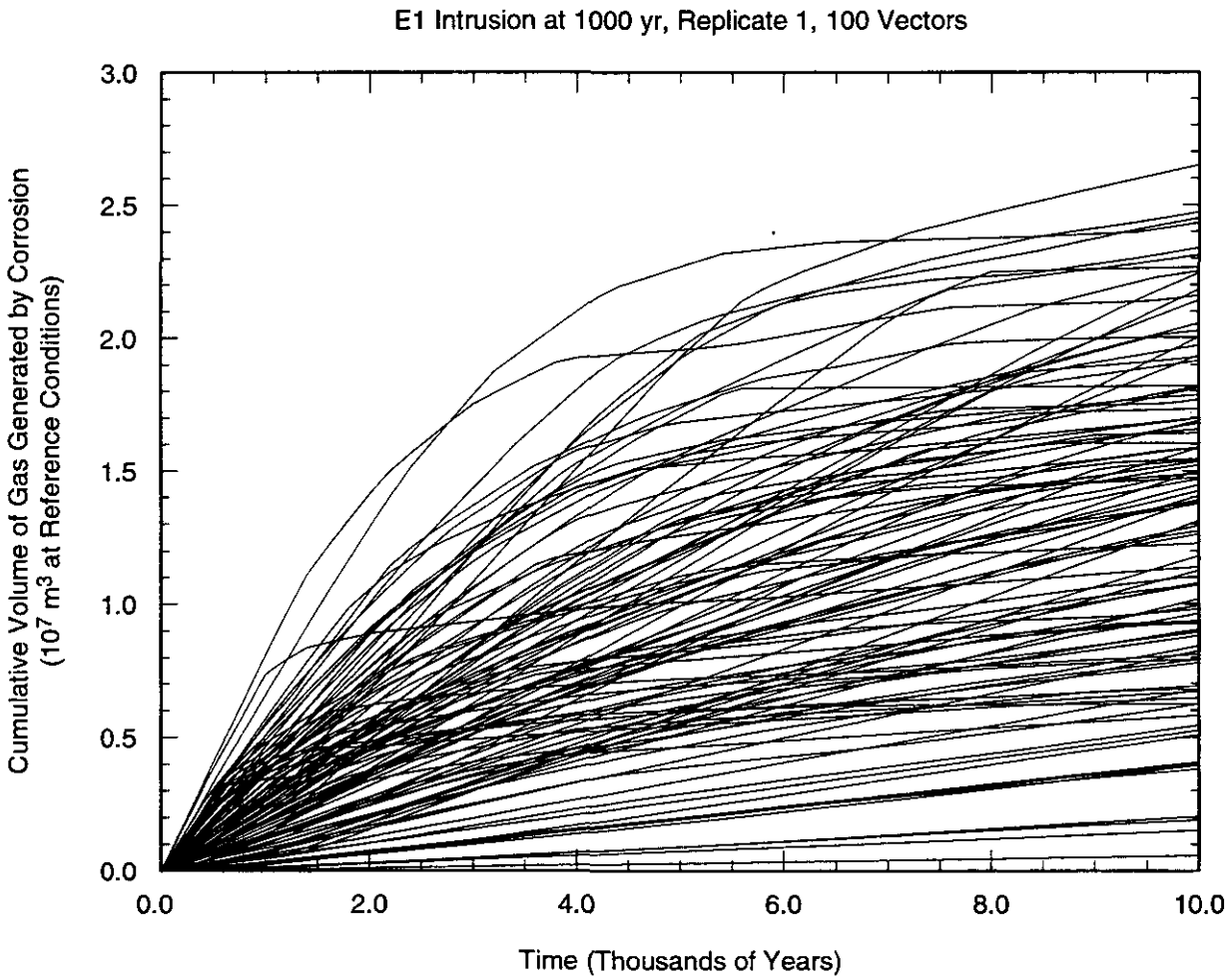

Figure 9-15. Cumulative Volume of Gas Generated by Corrosion of Iron, E1 Intrusion at 1000 Years

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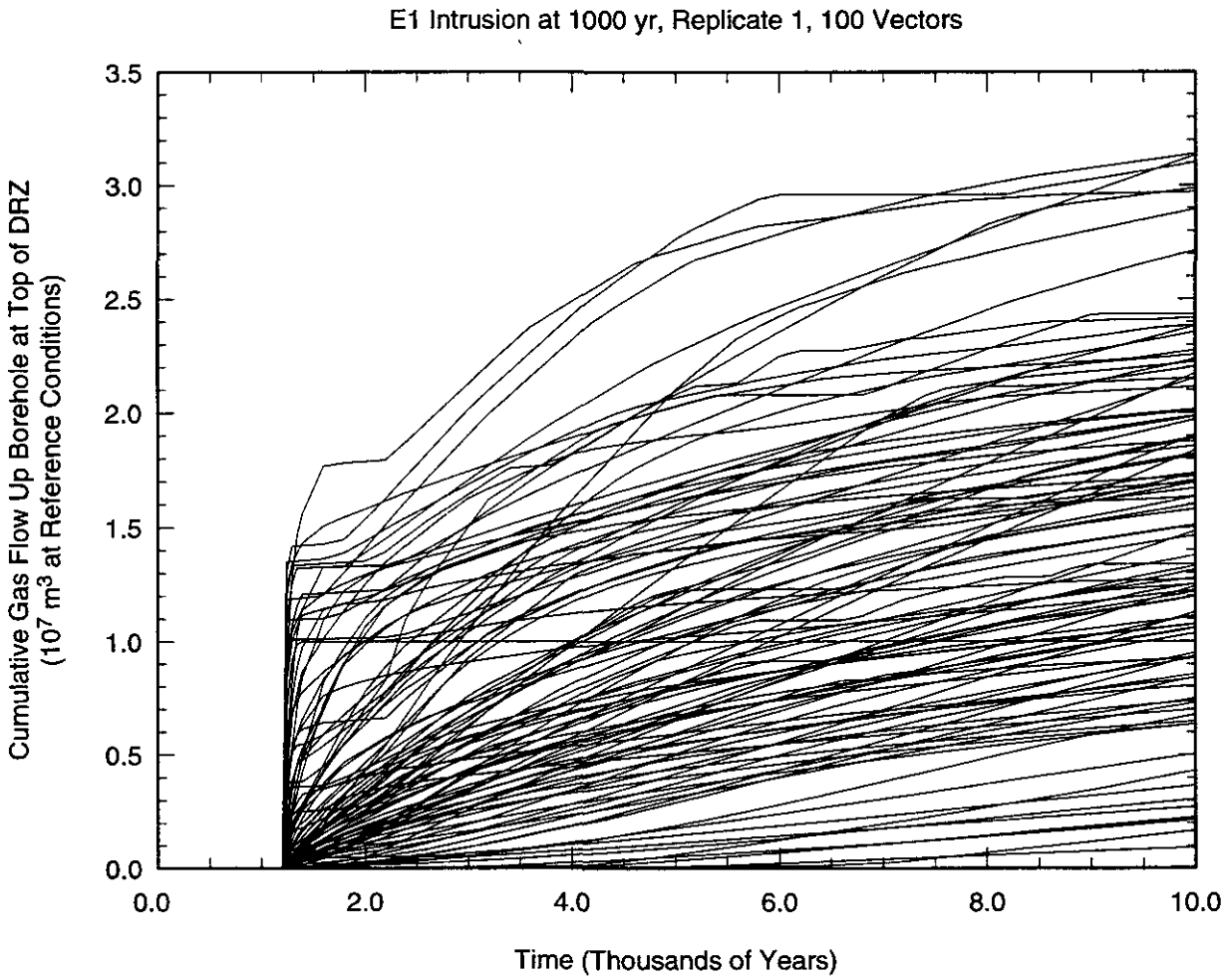

Figure 9-16. Cumulative Gas Flow Up the Borehole at the Top of the DRZ, E1 Intrusion at 1000 Years

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However, Figure 9-14 shows that this increase did not raise repository pressure significantly. In fact, the repository pressure remained well below the far-field pore pressure. This is because gas escaped up the borehole as fast as it was produced.

Furthermore, increased anoxic corrosion caused by human intrusion can affect repository performance beneficially by: (1) increasing the quantity of brine consumed, thus reducing the quantity that can flow up the borehole; (2) increasing the extent of gas interference with the flow of brine, thus decreasing the permeability of the borehole to brine.

Radiolysis. Predictions of gas production from radiolysis of brine by solid-phase actinides and radiolysis of combustibles would be subject to several uncertainties: (1) the particle-size distribution of actinide-bearing solids and, hence, the relative extent to which energy associated with α emissions from these solids will be absorbed by the solids, any brine present, and combustibles; (2) the extent to which actinide-bearing solids contact combustibles at the time of waste emplacement; and (3) the effects of room closure and long-term chemical reactions on the extent to which actinide-bearing solids contact combustibles.

Instead of attempting to predict the quantity of gas that will be produced from radiolysis of brine by solid-phase actinides and radiolysis of combustibles, the maximum quantity of gas that could be produced by these processes has been estimated and the effects of this gas on the long-term performance of the WIPP have been assessed. Although this estimate is probably much greater than the actual quantity of gas that will actually be produced by these processes, it would nevertheless have no significant effect on repository performance.

To estimate the maximum quantity of gas that could be produced from radiolysis of brine by actinide-bearing solids and radiolysis of combustibles, it was first assumed that all of the brine that will be consumed by corrosion would instead be consumed by radiolysis. The average-stoichiometry gas-generation model in BRAGFLO uses the following anoxic-corrosion reaction:

$$Fe + ((4 + 2x)/3)H_2O \Leftrightarrow xFe(OH)_2 + ((1 - x)/3)Fe_3O_4 + ((4 - x)/3)H_2. \quad (1)$$

However, Wang and Brush (1996a) specified a value of 1 for the stoichiometry factor x. Therefore, Reaction 1 reduces to:

$$Fe + 2H_2O \Leftrightarrow Fe(OH)_2 + H_2. \quad (2)$$

Brush (1995) gave the following reaction for α radiolysis of brine:

$$2H_2O \Leftrightarrow 2H_2 + O_2. \quad (3)$$

Because anoxic corrosion produces 0.5 mole of gas per mole of H_2O consumed and brine radiolysis produces 1.5 moles of gas per mole of H_2O consumed, the assumption that all of

the brine that will be consumed by corrosion would instead be consumed by radiolysis increases the predicted quantity of gas by a factor of three.

It was then assumed that all of the combustibles that could be consumed by microbial activity would instead be consumed by radiolysis. The average-stoichiometry model uses the following, generalized microbial reaction:

$$CH_2O + \text{unknowns} + \text{microorganisms} \Rightarrow y\text{gas} + \text{unknowns}. \quad (4)$$

However, to compute the stoichiometry factor "y" for the performance assessment calculations to support this application, Wang and Brush (1996a, 1996b) used the following reactions for microbial activity:

$$C_6H_{10}O_5 + 4.8H^+ + 4.8NO_3^- \Rightarrow 7.4H_2O + 6CO_2 + 2.4N_2; \quad (5)$$

$$C_6H_{10}O_5 + 6H^+ + 3SO_4^{2-} \Rightarrow 5H_2O + 6CO_2 + 3H_2S; \quad (6)$$

$$C_6H_{10}O_5 \Rightarrow 3CH_4 + 3CO_2. \quad (7)$$

In these reactions, $C_6H_{10}O_5$ represents the substrate (cellulosics and, perhaps, plastics and rubbers). Although all three of these microbial reactions could occur in the repository, Reaction 7 (methanogenesis) will be much more significant than Reactions 5 (denitrification) and 6 (SO_4^{2-} reduction) because the quantities of cellulosics, plastics, and rubbers (the potential microbial substrates) in WIPP disposal rooms will be much greater than the quantities of NO^{3-} and SO_4^{2-} (the potential electron acceptors for microbial denitrification and SO_4^{2-} reduction, respectively). In the absence of radiolysis of combustibles, Reaction 7 will consume greater than 90 percent of these potential microbial substrates. This reaction produces one mole of gas per mole of organic C consumed but, because the MgO backfill will consume all of the CO_2, the net yield will be 0.5 mole of gas per mole of organic C consumed. Radiolysis of combustibles produces a variety of gases, the composition of which depends upon the composition of the material and the conditions under which it is irradiated. To estimate the quantity of gas that could be produced, the DOE has assumed that all of the combustibles in the repository will be consumed by radiolysis and that the gases produced will not include CO_2. The first assumption is highly conservative because it is highly unlikely that the entire surface area of the combustibles will be exposed to α radiation for a significant portion of the 10,000-year period of performance of the repository. Furthermore, even if this occurred, the range of α particles in combustibles such as plastics is generally a few tens of microns. This is significantly less than the thickness of these materials, typically several mils to several tens of mils in the case of plastic drum liners (Brush 1990). The second assumption is also conservative because radiolysis of combustibles produces CO_2, among other gases (see, for example, Molecke 1979). It has also been assumed that radiolysis will produce one mole of gas per mole of organic C consumed, an assumption which may or may not be conservative. Because microbial activity (in the presence of MgO) produces 0.5 mole of gas per mole of organic C consumed and radiolysis of combustibles produces 1.0 mole of gas per

mole of organic C consumed, the assumption that all of the combustibles would be consumed by radiolysis increases the predicted quantity of gas by a factor of two.

The assumptions that all of the brine that will be consumed by corrosion would instead be consumed by radiolysis and that all of the combustibles that could be consumed by microbial activity would instead be consumed by radiolysis would at most increase the quantity of gas produced in a given realization by a factor of two to three. The actual factor by which the quantity of gas produced would increase depends on the relative amounts of gas produced by corrosion and microbial activity. If radiolysis consumed some, but not all, of the brine and some, but not all, of the combustibles, the increase could be significantly less than a factor of two to three.

In any case, the DOE has concluded that increasing the quantity of gas by a factor of two or three would not affect the long-term performance of the repository deleteriously. BRAGFLO calculations conducted for the this application have shown that, in the absence of human intrusion, the repository pressure increased to values equal to or slightly greater than lithostatic pressure in several realizations even without radiolysis (see Figure 9-17). The pressure did not exceed 16.5 megapascals in these calculations because BRAGFLO includes a model to simulate fracturing in the anhydritic interbeds above and below the repository (Anhydrites A and B, MB138, and MB139). If the repository pressure exceeds 12.7 megapascals, the fracture model generates additional voids in and increases the permeability of these interbeds, thus limiting the pressure to 16.5 megapascals. Increasing the quantity of gas produced by a factor of two to three would increase the number of vectors in which lithostatic pressure is attained, but not the maximum pressure.

Figure 9-18 shows the cumulative mass of contaminated brine (brine that has been in the waste-disposal area) as a function of time. After 10,000 years, the largest quantity of contaminated brine in all the interbeds is only about 2,000 kilograms (1.6 cubic meters), even with a repository pressure of 16.5 megapascals. The reason that so little brine flowed out of the repository under undisturbed conditions is that brine was consumed rapidly by corrosion, not low pressure. Any additional brine that flowed in was in most cases rapidly consumed. This maintained the brine content of the repository at levels low enough to prevent additional brine outflow despite the pressure gradient. In view of these results, it is highly unlikely that increasing the quantity of gas produced by a factor of two to three would increase brine outflow enough to be of regulatory concern.

In the event of human intrusion, increased gas production will not increase direct release of brine nor spallings to the surface, nor the long-term release of dissolved radionuclides. Figures 9-19 and 9-20 show that direct releases to the surface during drilling occurred only in those realizations in which the repository pressure was greater than 8 megapascals. However, at pressures above 8 megapascals, there was no correlation between the pressure and the size of the release. Furthermore, Figures 9-21 and 9-22 show that, for the E1 and E2 human-intrusion scenarios, there was no correlation between the quantity of gas produced and the pressure. This is because gas escaped up the borehole as fast as it was produced (see above).

Therefore, increasing the quantity of gas produced by a factor of two to three would not increase direct releases. Similarly, increasing the quantity of gas would not increase long-term dissolved releases because of gas escape up the borehole. In fact, in the event of multiple intrusions, venting decreased the pressure to values at or close to hydrostatic pressure as the brine content of the repository increased (see Figure 9-23).

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.1.2.10.2 Second Peer Review Panel Concern - Gas Generation

> *An adequate basis has not been presented for the assumption of complete and rapid carbon dioxide removal by magnesium oxide in the waste panels. The chemical conditions in the repository would significantly change if the magnesium oxide did not function as planned, and could result in higher radionuclide releases than the model would estimate.*

Statement of Issues (Note: For the purpose of this response, the above gas generation concern has been combined with the chemical conditions concerns regarding the assessment of phase equilibria and the reaction of the MgO backfill with the CO_2 generated by microbial action [see Section 9.3.1.2.11.2.1].)

The panel understands that in theory MgO (periclase) and $Mg(OH)_2$ (brucite) react with CO_2 to create carbonate phases such as $MgCO_3$ (magnesite). The carbonate equilibria impose a pH control on the brines resident in the waste panels. The panel questions whether or not the buffering phases will form fast enough that no excess CO_2 will remain. In addition, the panel recognizes that equilibrium thermodynamic codes have performed calculations of the phases and compositions that will be stable in the WIPP repository. The panel questions whether or not the codes were sufficiently complete to account for all possible Mg-containing carbonate phases that might occur either through absolute stability or metastable stability. The panel's concern is that the actual phase assemblage may impose geochemical conditions that differ from those calculated, and that the actual conditions might result in different solubilities and mobilities for mobilized waste components.

Response to Issues (Note: For the purpose of this response, the above gas generation concern has been combined with the chemical conditions concerns regarding the assessment of phase equilibria and the reaction of the MgO backfill with the CO_2 generated by microbial action [see Section 9.3.1.2.11.2.1].)

The ability of MgO to perform as expected is dependent on the following requirements:

1) The MgO will interact with any brine which may enter the repository and participate in transport.

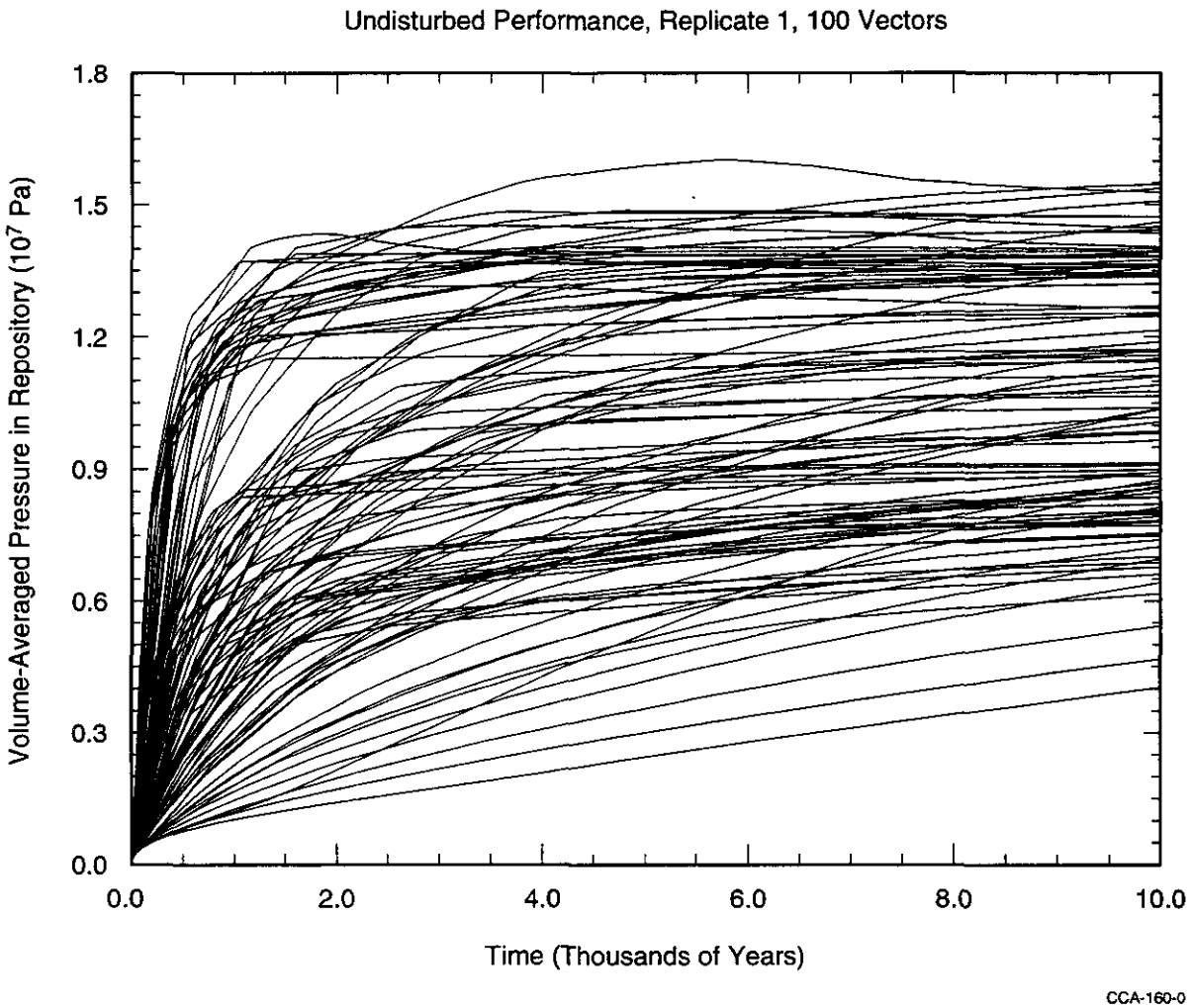

Figure 9-17. Volume-Averaged Pressure in the Repository, Undisturbed Performance

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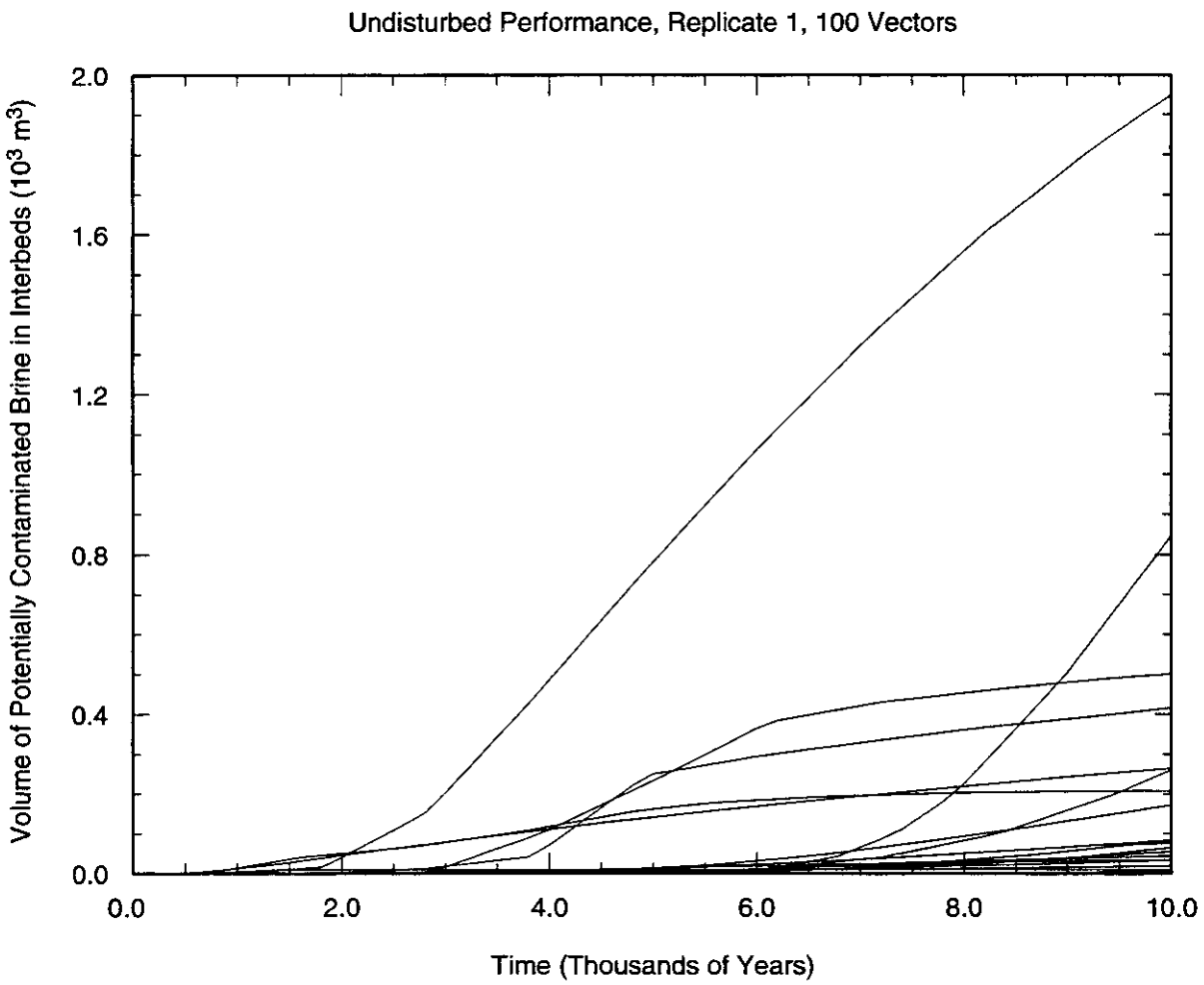

Figure 9-18. Volume of Brine in Anhydrite Interbeds That Has Previously Been in Contact with Waste, Undisturbed Performance

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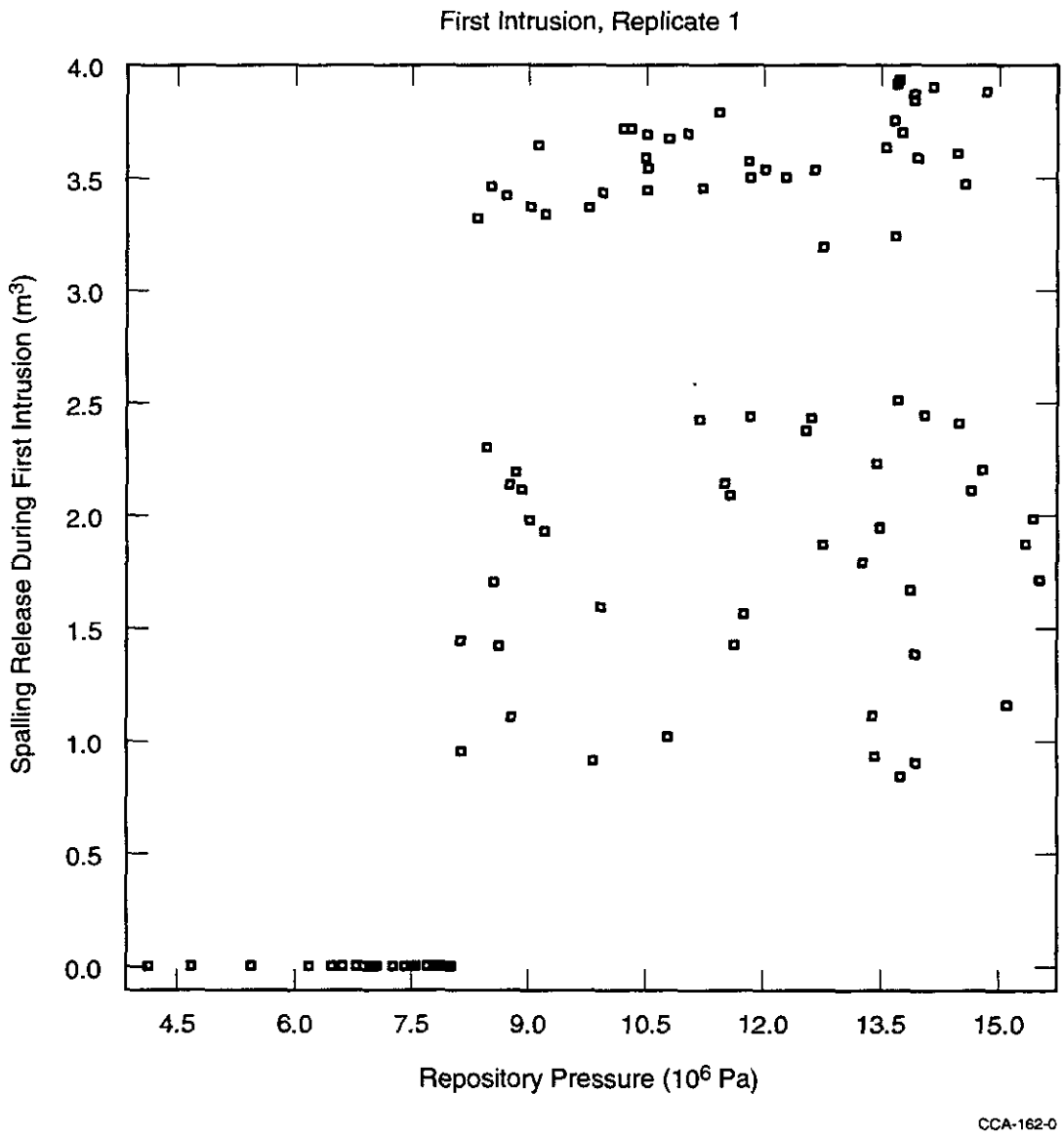

Figure 9-19. Scatterplot Showing Relationship of Spalling Releases to Repository Pressure, First Intrusion into the Repository

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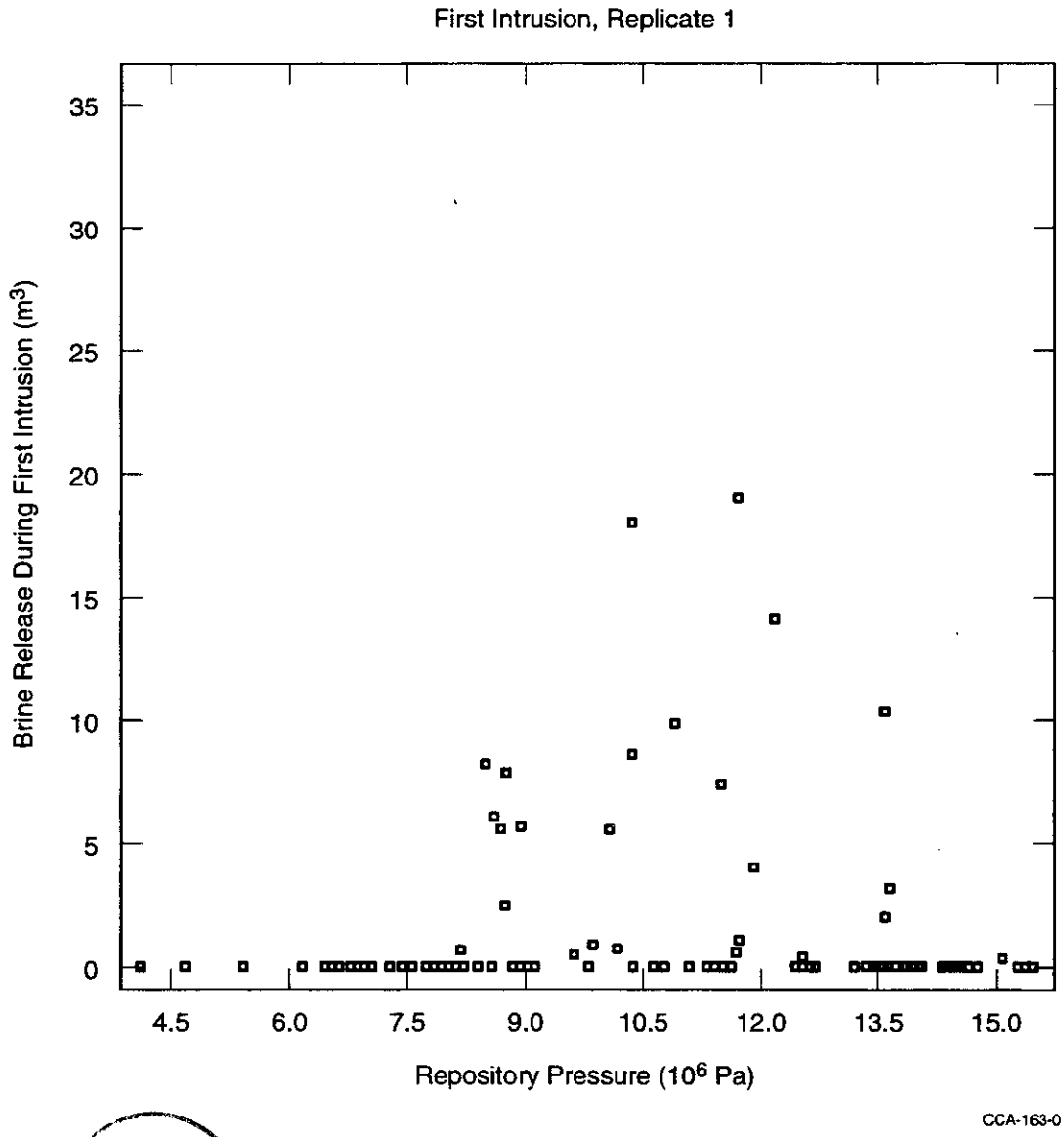

Figure 9-20. Scatterplot Showing Relationship of Direct Brine Releases to Repository Pressure, First Intrusion into the Repository

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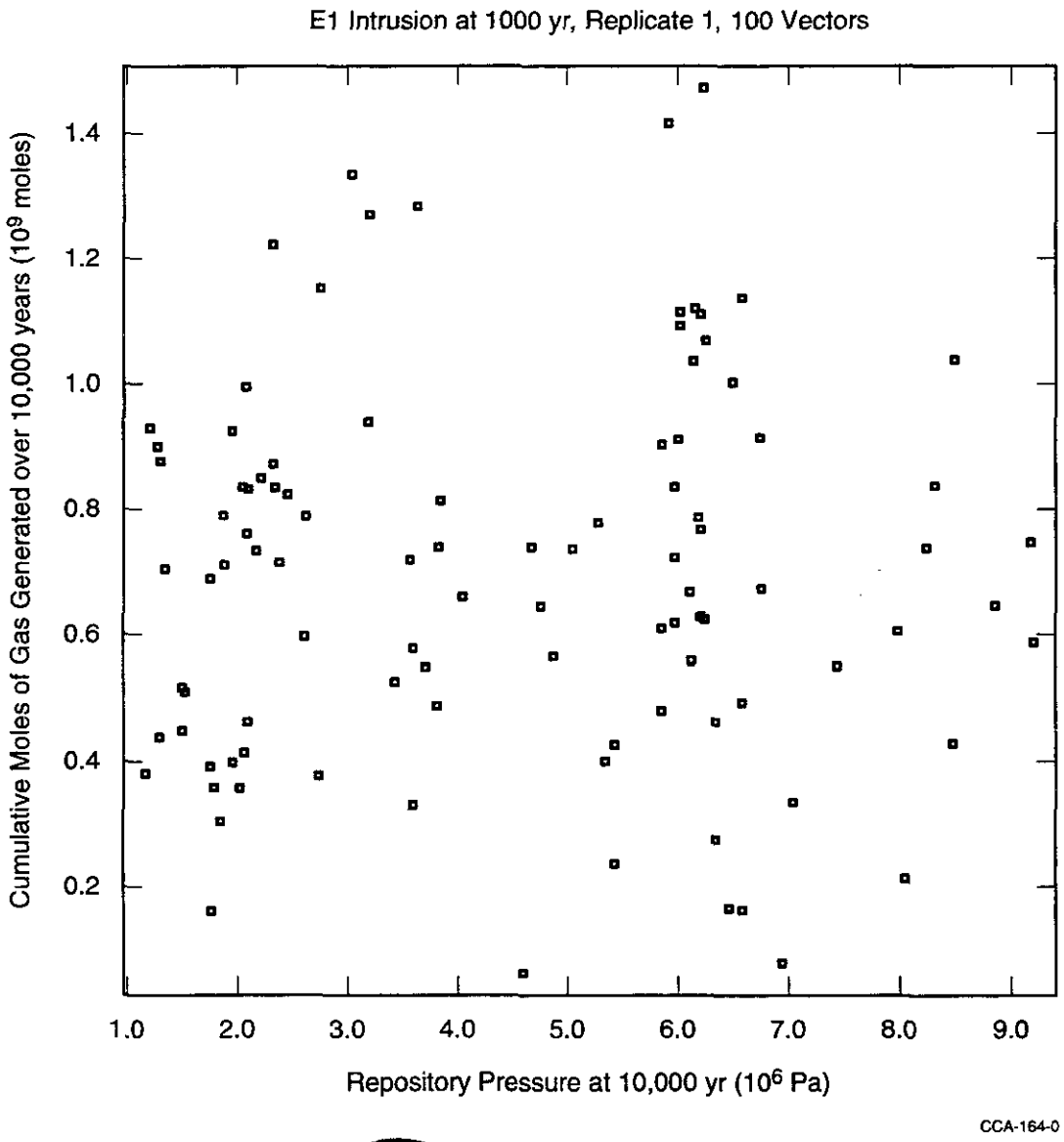

Figure 9-21. Scatterplot Showing Relationship of Total Moles of Gas Generated to Final Repository Pressure (E1 Intrusion at 1000 years)

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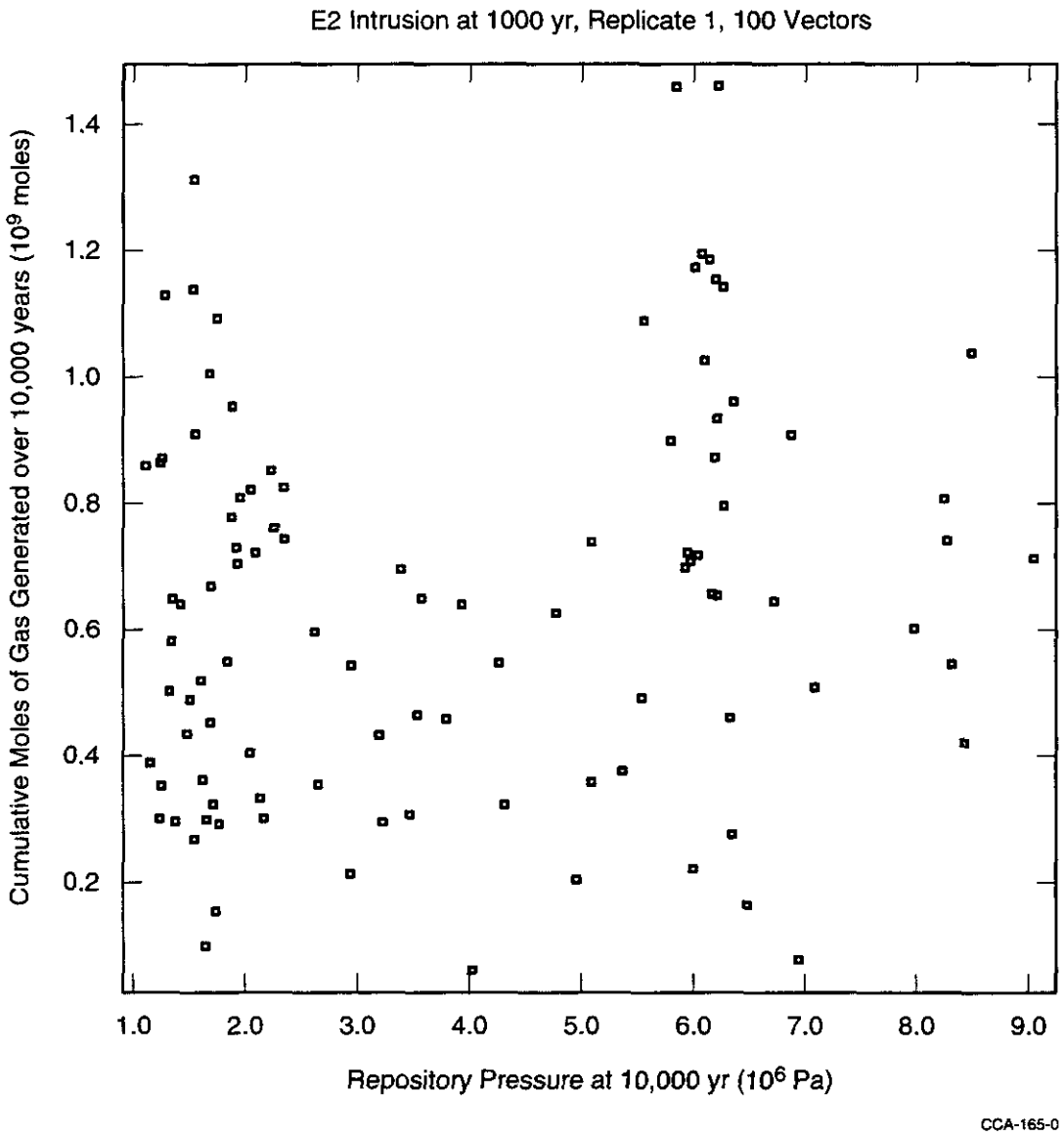

Figure 9-22. Scatterplot Showing Relationship of Total Moles of Gas Generated to Final Repository Pressure (E2 Intrusion at 1000 years)

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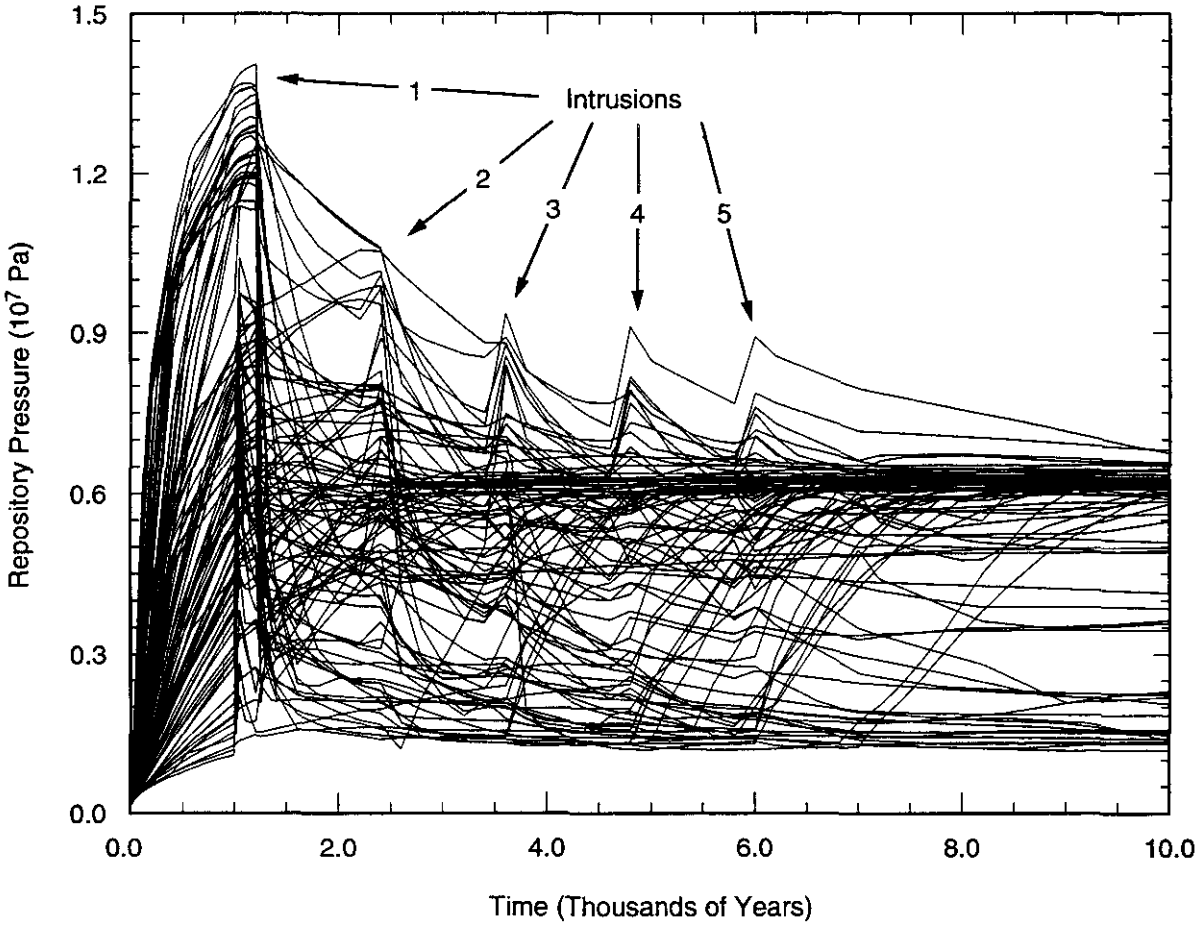

Figure 9-23. The Effect of Multiple Intrusions on Repository Pressure

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2) There is at least a stoichiometric amount of MgO available with respect to the maximum quantity of CO_2 that may be generated.

3) The rate of reaction of MgO and/or $Mg(OH)_2$ with CO_2 is equal to or greater than the maximum CO_2 generation rate.

4) Stable magnesium carbonate containing phases will exist under anticipated repository conditions. (This addresses in particular, Concern 3 above.)

The first requirement above is satisfied by the emplacement strategy being pursued. The MgO backfill will be placed in intimate contact with the waste via bags on top of the waste stack, bags within the seven packs, and bags along the ribs of the repository. Additionally, as room closure progresses, the waste and backfill will be further mixed via compression and consolidation of the waste and rupture of the waste drums and packaging. The mean residence time of brine in the repository is a few hundred years. Over this time scale, the brine chemistry will be significantly homogenized over an approximately 1 meter spatial scale (the approximate height of the waste after compression and compaction by room closure) by diffusion. Thus, there are no flow paths which can bypass the backfill.

The second requirement is being satisfied by the specification for the amount of backfill to be emplaced. Even if all of the cellulosics, rubbers, and plastics were to be converted to CO_2, the specification for the amount of MgO backfill to be emplaced is at least a two-fold excess of MgO above the stoichiometrically required amount.

The third requirement is addressed through an understanding of the chemical processes which will occur in the repository. The MgO backfill is expected to react with any brine or humidity in the air entering the repository via the following reaction:

$$MgO + H_2O \leftrightarrow Mg(OH)_2$$

This reaction is based on thermodynamic principles, the fact that MgO is commonly used as a desiccant, and the well known deliquescent behavior of alkaline earth oxides which react with water to form the alkaline earth hydroxides.

Any CO_2 which may be generated in the repository can react with either the MgO or $Mg(OH)_2$ via the following equations:

$$MgO + CO_2 \leftrightarrow MgCO_3$$

or

$$Mg(OH)_2 + CO_2 \leftrightarrow MgCO_3 + H_2O$$

Both of these reactions are thermodynamically favorable. Therefore, the issue comes down to the rate at which the reaction(s) may occur. Assuming that reaction rates in solution are relatively fast when compared to the geologic time scale, the rate limiting factor is the rate at which magnesium ions leave the surface of the MgO. The rate at which MgO dissolves has been previously studied (see Terry 1983, 315 – 344). Extending the cited values to the pH range expected in an MgO backfilled repository provides an average rate of MgO dissolution of 1.5×10^{-12} moles per square centimeter per second. The total quantity of cellulosics, rubbers, and plastics which are anticipated to be placed in the repository is 2.7×10^{7} kilograms (166 kilograms per cubic meter average cellulosics, rubbers, and plastics loading in a 1.6×10^{5} cubic meters total waste volume) (DOE 1995a). The maximum rate of CO_2 generation is 9.51×10^{-9} moles CO_2/kg/sec (see Appendix PAR). Thus, the maximum CO_2 generation rate for the entire repository is 0.2 moles CO_2/sec.

Given the maximum rate of CO_2 generation and the maximum rate of MgO dissolution (as a function of surface area), the theoretical minimum particle size which will have sufficient surface area to ensure reaction with the CO_2 as it is generated can be calculated. First, the minimum surface area per gram (that is, specific surface area) is calculated by dividing the total surface area required by the total number of grams of MgO emplaced. The total surface area required is given by:

$$(2.6 \times 10^{-1} \text{ moles } CO_2 \text{ generated/sec}) \times (1 \text{ mole MgO/1mole } CO_2) \times (1/1.5 \times 10^{-12} \text{ moles MgO/cm}^2\text{/sec}) = 1.76 \times 10^{11} \text{ cm}^2 \text{ MgO}$$

The total number of grams of MgO emplaced is given by:

$$(83{,}150 \text{ tons MgO}) \times (2000 \text{ lbs/ton}) \times (453\text{g/lb}) = 7.5 \times 10^{10} \text{ g MgO}$$

Thus, the minimum required surface area per gram of MgO is:

$$(1.76 \times 10^{11} \text{ cm}^2 \text{ MgO}) / (7.5 \times 10^{10} \text{ g MgO}) = 2.3 \text{ cm}^2\text{/g MgO}$$

Assuming a spherical particle, the surface area is $= 4\pi r^2$. Using "P_m" for the mass of a particle, the density can be expressed as:

$$\text{density} = P_m / (4/3\pi r^3)$$

Rearranging for the mass of a particle provides:

$$P_m = (4/3\pi r^3)(\text{density}) \quad \text{(eq. A)}$$

The specific surface area per gram may be expressed as:

$$\text{specific surface area} = 4\pi r^2 / P_m \qquad \text{(eq. B)}$$

Now, dividing equation A by equation B gives:

$$P_m /(\text{specific surface area}) = [(4/3\pi r^3)(\text{density})] / [4\pi r^2/ P_m]$$

Solving for "r" provides the maximum particle radius which can accommodate the maximum CO_2 generation rate

$$[P_m /(\text{ specific surface area})] [4\pi r^2/ P_m] = [(4/3\pi r^3)(\text{density})]$$

$$[4\pi r^2/(\text{ specific surface area})] = [(4/3\pi r^3)(\text{density})]$$

$$[1/(\text{ specific surface area})] = [(r/3)(\text{density})]$$

$$r = 3/[(\text{ specific surface area})(\text{density})]$$

Utilizing a crystalline density of 3.53 g/cm^3 provides

$$r = 3/[(2.3\ \text{cm}^2/\ \text{g})(3.53\ \text{g/cm}^3)]$$

or

$r = 0.37$ cm

Therefore, as long as the particles of the MgO backfill are no greater than 0.37 centimeter radius (or 0.74 centimeter in diameter), there will be sufficient surface area for the MgO dissolution to maintain pace with the maximum CO_2 generation. This minimum surface area is conservative in that it assumes only the exterior surface is available for reaction and a crystalline material is used. In reality, the particles of MgO will be amorphous and thus will have a much higher effective surface area as there will be some porosity (possibly of the order of 50 percent) to the particles.

The fourth and final requirement states that magnesium carbonate containing phases will be formed and will be stable under expected repository conditions. To demonstrate this, multiple thermodynamic modeling codes (for example, FMT [Novak 1995], EQ3/6 [Wolery 1992; Wolery and Daveler 1992], Geochemist's Workbench [Bethke 1994]) have been utilized. These modeling codes take into consideration many potential mineral phases (for example, 50 mineral phases were considered within the EQ3/6 simulation) and utilize a Gibbs free energy minimization method to predict the most stable phase for a given set of conditions. In each case, the modeling simulation predicts that magnesite and brucite will be formed within the system and that these phases are thermodynamically stable regardless of whether a Salado or Castile brine composition is used. If the formation of magnesite is suppressed within the calculations, other magnesium carbonate containing phases form which provide approximately the same chemical conditions as when magnesite is allowed to form.

Since the chemical conditions must be maintained over the repository life-time, the long-term stability of the mineral phase must also be considered. The most compelling arguments for the long-term stability of any mineral phase involve natural analogues. In this case, the most compelling case for a natural analog is the natural occurrence of magnesite in the Salado formation itself (Stein 1985). Therefore, the DOE maintains that magnesium carbonate containing phases will be stable under anticipated repository conditions.

For simulations of the equilibrium conditions which are expected in the WIPP repository, the Harvie, Møller, and Weare database (Harvie et al. 1984) was used which contains the approximately fifty mineral phases listed in Table 9-2. This database is not unique to EQ3/6 (Wolery 1992; Wolery and Daveler 1992), but is used by most codes seeking to model high ionic strength solutions. The Harvie, Møller, Weare database has been shown to be appropriate for systems similar to WIPP (Felmy and Weare 1986) and is well accepted within the scientific community. Since the Harvie, Møller, Weare database and the codes which utilize it are based on equilibrium thermodynamics, a kinetically unfavorable transition is not automatically accounted for as appropriately noted by the CMPR panel. To simulate such effects, the formation of the more thermodynamically stable, yet potentially kinetically unfavorable phase is suppressed and the system allowed to re-establish equilibrium. These studies were performed for the WIPP system with MgO backfill. What was found was that, upon suppression of the two potentially kinetically unfavorable phases (that is, magnesite and dolomite), other magnesium carbonate containing phases (for example, hydromagnesite) are formed which yield approximately the same chemical conditions as when these phases are enabled. Therefore, the DOE analysis did take into consideration the possibility of kinetically unfavorable phases and found no significant impact.

In the MgO backfilled WIPP system, there will always be a brucite phase formed due to the large excess of MgO being added to the system. This brucite phase establishes one dimension of the phase diagram for the system as shown in Figure 9-24. The formation of magnesite in the repository will yield the conditions as shown at the intersection of the brucite and magnesite lines, corresponding to a log fCO_2 of approximately -6.4. If the formation of magnesite does not occur, as simulated by its suppression, the conditions in the repository will correspond to those along the brucite line where it intersects with the next magnesium carbonate containing phase, in this case hydromagnesite, yielding a log fCO_2 of approximately -5.6. This small difference in fCO_2, if indeed it occurs, is not sufficient to cause significant changes in the actinide solubility.

The formation of metastable carbonate phases and their ability to freeze the reaction progress is the subject of much uncertainty and speculation. The formation of magnesite at low temperatures, for example, is subject to some question due to kinetic effects (Peterson et al. 1966; Christ and Hostetler 1970). However, low temperature authigenic magnesite is found in hypersaline environments (Graf et al. 1961; Von der Borch 1965; Christ and Hostetler 1970), which are similar to the expected repository environment. Sayles and Fyfe (1973) have

Table 9-2. Harvie, Møller, Weare Database

Name	Formula
Anhydrite	$CaSO_4$
Aphthitalite (Glaserite)	$NaK_3(SO_4)_2$
Antarcticite	$CaCl_2 \cdot 6H_2O$
Aragonite	$CaCO_3$
Arcanite	K_2SO_4
Bischofite	$MgCl_2 \cdot 6H_2O$
Bloedite	$Na_2Mg(SO_4)_2 \cdot 4H_2O$
Brucite	$Mg(OH)_2$
Burkeite	$Na_6CO_3(SO_4)_2$
Calcite	$CaCO_3$
Calcium Chloride Tetrahydrate	$CaCl_2 \cdot 4H_2O$
Calcium Oxychloride A	$Ca_4Cl_2(OH)_4 \cdot 13H_2O$
Calcium Oxychloride B	$Ca_2Cl_2(OH)_2 \cdot H_2O$
Carnallite	$KMgCl_3 \cdot 6H_2O$
Dolomite	$CaMg(CO_3)_2$
Epsomite	$MgSO_4 \cdot 7H_2O$
Gaylussite	$CaNa_2(CO_3)_2 \cdot 5H_2O$
Glauberite	$Na_2Ca(SO_4)_2$
Gypsum	$CaSO_4 \cdot 2H_2O$
Halite	$NaCl$
Hexahydrite	$MgSO_4 \cdot 6H_2O$
Hydromagnesite*	$Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$
Kainite	$KMgClSO_4 \cdot 3H_2O$
Kalicinite	$KHCO_3$
Kieserite	$MgSO_4 \cdot H_2O$
Labile Salt	$Na_4Ca(SO_4)_3 \cdot 2H_2O$
Leonite	$K_2Mg(SO_4)_2 \cdot 4H_2O$
Magnesite	$MgCO_3$
Magnesium Oxychloride	$Mg_2Cl(OH)_3 \cdot 4H_2O$
Mercallite	$KHSO_4$
Mirabilite	$Na_2SO_4 \cdot 10H_2O$
Misenite	$K_8H_6(SO_4)_7$
Nahcolite	$NaHCO_3$
Natron	$Na_2CO_3 \cdot 10H_2O$
Nesquehonite	$MgCO_3 \cdot 3H_2O$
Picromerite (Schoenite)	$K_2Mg(SO_4)_2 \cdot 6H_2O$
Pirssonite	$Na_2Ca(CO_3)_2 \cdot 2H_2O$
Polyhalite	$K_2MgCa_2(SO_4)_4 \cdot 2H_2O$
Portlandite	$Ca(OH)_2$
Potassium Carbonate	$K_2CO_3 \cdot 3/2\ H_2O$

Table 9-2. Harvie, Møller, Weare Database (Continued)

Name	Formula
Potassium Sesquicarbonate	$K_8H_4(CO_3)_6 \cdot 3H_2O$
Potassium Sodium Carbonate	$KNaCO_3 \cdot 6H_2O$
Potassium Trona	$K_2NaH(CO_3)_2 \cdot 2H_2O$
Sesquipotassium Sulfate	$K_3H(SO_4)_2$
Sesquisodium Sulfate	$Na_3H(SO_4)_2$
Sodium Carbonate Heptahydrate	$Na_2CO_3 \cdot 7H_2O$
Sylvite	KCl
Syngenite	$K_2Ca(SO_4)_2 \cdot H_2O$
Tachyhydrite	$Mg_2CaCl_6 \cdot 12H_2O$
Thenardite	Na_2SO_4
Thermonatrite	$Na_2CO_3 \cdot H_2O$
Trona	$Na_3H(CO_3)_2 \cdot 2H_2O$

* Hydromagnesite is not part of the original HMW database, but was added to account for the possibility of its presence as a metastable phase. Other, potentially more favorable magnesium carbonate phases (for example, artinite) could have been added but hydromagnesite was chosen due to it being the commonly cited precursor to magnesite in natural systems.

studied the kinetics of formation of magnesite and have shown that high ionic strength solutions, such as those in the expected repository environment, catalyze the formation of magnesite.

It is therefore the DOE's position that magnesite will be formed in the WIPP repository given the strong thermodynamic driver, the long regulatory period of interest, and the demonstrated catalytic effect of high ionic strength solutions. Even if magnesite were to be kinetically inhibited, other magnesium carbonate containing phases such as hydromagnesite, whose formation is not known to be kinetically hindered, will form and control the chemical environment.

Peer Reviewer Consideration of Response

The DOE understood the issue and the response reasonably addressed this gas generation concern.

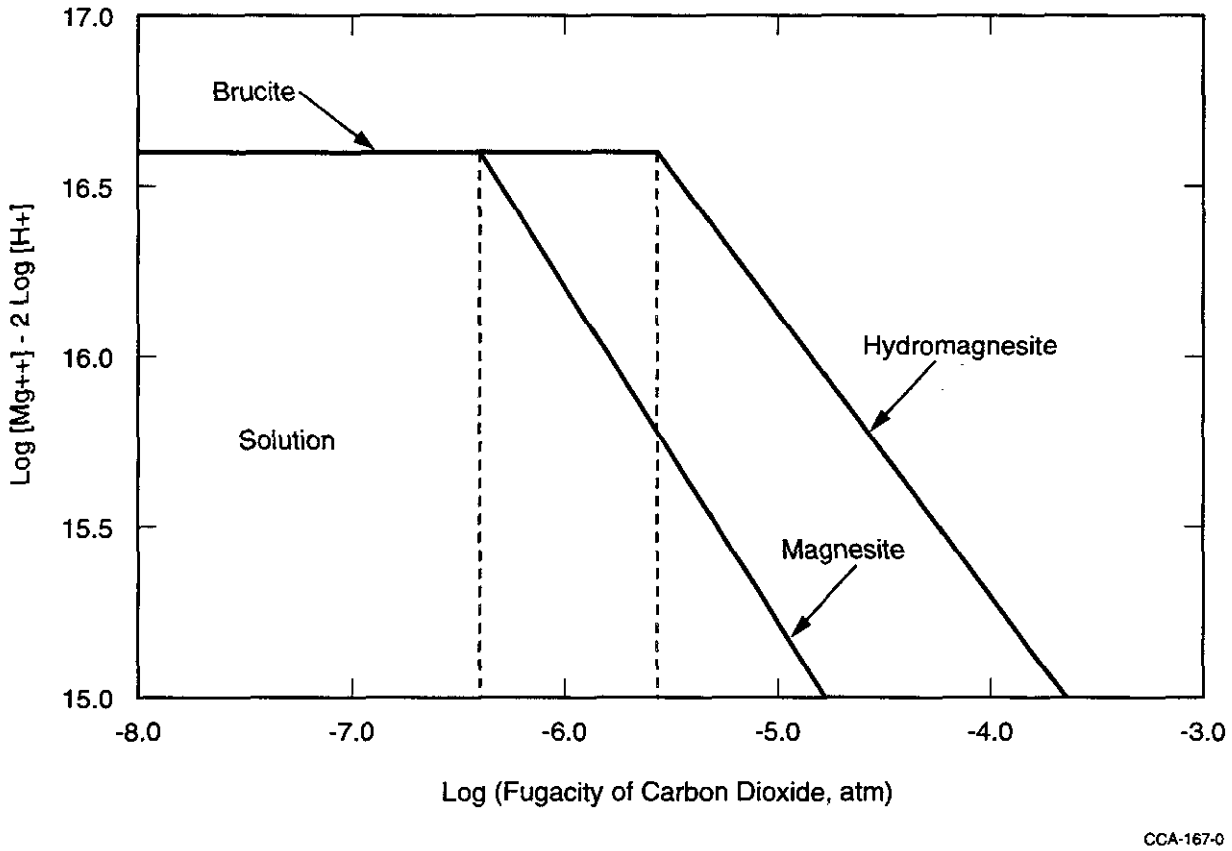

Figure 9-24. Phase Diagram for the MgO - CO_2 System

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9.3.1.2.10.3 Third Peer Review Panel Concern - Gas Generation

> *An adequate basis has not been presented for ignoring the effects of heat generation from corrosion and microbial actions. Higher ambient repository temperatures could increase the rates of chemical reactions, fluid flow, and halite creep.*

Statement of Issues (Note: For the purpose of this response, the above gas generation concern has been combined with the chemical conditions concern regarding the combined temperature increase and its effect on repository conditions [see Section 9.3.1.2.11.1].)

The net effect of potential temperature increases in the repository has not been adequately described and accounted for.

Response to Issues (Note: For the purpose of this response, the above gas generation concern has been combined with the chemical conditions concern regarding the combined temperature increase and its effect on repository conditions [see Section 9.3.1.2.11.1].)

There are several reactions which could potentially contribute heat to the repository system. These reactions include:

$$MgO + H_2O \rightarrow Mg(OH)_2 \qquad \text{Rxn. 1}$$

$$Mg(OH)_2 + CO_2 \rightarrow MgCO_3 + H_2O \qquad \text{Rxn. 2}$$

$$Fe + H_2O \rightarrow Fe(OH)_2 + H_2 \qquad \text{Rxn. 3}$$

$$C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2 \qquad \text{Rxn. 4}$$

$$Al + H_2O \rightarrow Al(OH)_3 + 1.5H_2O \qquad \text{Rxn. 5}$$

Evaluation of the ability of each of these reactions to produce heat while conservatively accounting for the repository's ability to dissipate the resulting heat generated has provided the following maximum temperature increases (Wang 1996b):

Reaction Number	Maximum Temperature Increase (K)
1	5
2	0.8
3	2
4	1
5	7

In the worst case, a temperature increase of 7 K could be experienced. However, these temperature extremes will not persist, if they are ever reached at all. Since all but Reaction 2 consume brine, they will be competing with each other for any brine that may enter the repository, an effect which will therefore temper the heat increase which could be predicted based on the most exothermic reaction alone. It should also be noted that all of the above reactions consume brine for the maximum temperature increases noted to be realized, all of the brine entering the repository would be consumed by the reactions; thus, no brine would be available for transport of actinides out of the repository region. To evaluate the worst case possible, for the maximum temperature increase to be realized from the corrosion of aluminum, all of the aluminum would have to be corroded within 2.5 years, after which the heat would be dissipated very rapidly. Therefore, if such a condition were to be created, it would be transitory on the repository time scale and its influence inconsequential.

The effect of small temperature increases arising from exothermic reactions has previously been screened out of the performance assessment on the basis of low consequence to factors such as creep closure, seal performance, transport, etc. (see Appendix SCR, Section SCR.2.5.7). The effect of heat generated by radiolysis has been considered as part of the repository conditions (Brush 1990) and utilized in the specification of experimental parameters, thus yielding data consistent with the anticipated conditions. Additionally, the small temperature increases cited above for exothermic reactions are insignificant to the thermodynamic modeling of solubility. For example, a temperature increase of 7 K (the maximum temperature increase possible) would result in an approximately 3 percent change in the free energy of formation of any species contained within the model. This is well within the model parameter bounds.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

DOE Technical Position versus Panel Issue

Further consideration of the DOE's response to the panel has resulted in a revision of the DOE technical position. Text of the revised DOE response to the peer panel (Wang 1996 [located as attachment to Bennett et al. memorandum]) and a supporting memorandum by Bennett et al. (1996) are provided in Appendix PEER. Text provided above ("Response to Issues") is consistent with the original response to the panel. However, as noted by Bennett et al. (1996), anoxic corrosion of iron was incorrectly described as an exothermic reaction. It should properly be identified as an endothermic reaction. As reported by Bennett et al. (1996), the maximum temperature rise possible in the repository should be 5 or 6 K, depending on whether MgO hydration or aluminum corrosion is the dominant reaction consuming brine.

9.3.1.2.11 Peer Review Panel Concern - Chemical Conditions

9.3.1.2.11.1 First Peer Review Panel Concern

The combined temperature increase (due to radioactive decay and exothermic reactions) and its effect on repository conditions has not been adequately addressed. Significantly higher repository temperatures could accelerate chemical reactions, fluid flow, and halite creep rates.

Statement of Issue

This concern is addressed in Section 9.3.1.2.10.3 (Third Peer Review Panel Concern - Gas Generation).

Response to Issue

This concern is addressed in Section 9.3.1.2.10.3 (Third Peer Review Panel Concern - Gas Generation).

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

DOE Technical Position versus Panel Issue

This concern is addressed in Section 9.3.1.2.10.3 (Third Peer Review Panel Concern - Gas Generation).

Second and Third Peer Review Panel Concerns - Chemical Conditions

Phase equilibria have not been critically assessed within the chemical parameters of the conceptual model. A major element stable phase that was overlooked could significantly alter the chemical conditions of the repository and vary the actinide source terms.

The MgO backfill has not been demonstrated to be able to react completely with CO_2 generated by microbial action. If the MgO backfill did not react as planned, the pH buffering capability of the repository would be significantly compromised, and could result in underestimating the actinide source terms.

Statement of Issues

These issues are addressed in Section 9.3.1.2.10.2 (Second Peer Review Panel Concern - Gas Generation).

Response to Issues

These issues are addressed in Section 9.3.1.2.10.2 (Second Peer Review Panel Concern - Gas Generation).

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel determined that the DOE response did not reasonably address their phase-equilibria concern. The panel did conclude that the response reasonably addressed their concern regarding the MgO backfill/CO_2 concern.

DOE Technical Position versus Panel Issues

The DOE believes the phase-equilibria concern is adequately addressed in Section 9.3.1.2.10.2 (Second Peer Review Panel Concern - Gas Generation).

9.3.2 Waste Characterization Analysis Peer Review

40 CFR § 194.27(a)(2) states that a compliance application shall include documentation of peer review conducted for "*waste characterization analyses as required in §194.24(b).*" 40 CFR § 194.24 (b) states:

> *"The Department shall submit in the compliance certification application the results of an analysis which substantiates:*
>
> > *(1) That all waste characteristics influencing containment of waste in the disposal system have been identified and assessed for their impact on disposal system performance. The characteristics to be analyzed shall include, but shall not be limited to: solubility; formation of colloidal suspensions containing radionuclides; production of gas from the waste; shear strength; compactability; and other waste-related inputs into the computer models that are used in the performance assessment.*
> >
> > *(2) That all waste components influencing the waste characteristics identified in paragraph (b)(1) of this section have been identified and assessed for their impact on disposal system performance. The components to be analyzed shall include, but shall not be limited to: metals; cellulosics; chelating agents; water and other liquids; and activity in curies of each isotope of the radionuclides present.*
> >
> > *(3) Any decision to exclude consideration of any waste characteristic or waste component because such characteristic or component is not expected to significantly influence the containment of the waste in the disposal system."*

A Waste Characterization Peer Review (WCPR) Plan (see Appendix PEER) was prepared and approved in accordance with the requirements of TP 10.5. The DOE convened a four-member peer review panel, in accordance with the guidance of NUREG-1297, to perform the review. The panel members were:

Duane C. Hrncir (Panel Chairman), University of Texas, Dallas
Evaristo J. Bonano, Beta Corporation International
James F. Bresson, Informatics Corporation
Patricia J. Robinson, Energy, Inc.

Dr. Hrncir is an Associate Professor of Chemistry at the University of Texas at Dallas. He holds a Ph.D. in inorganic chemistry and has 24 years of experience in research involving the interactions of metals and organics with mineral surfaces and the controls these interactions have on speciation and transport in aquatic environments.

Dr. Bonano is President and Chief Executive Officer of Beta Corporation International in Albuquerque, NM. He holds a Ph.D. in Chemical Engineering. His areas of expertise include transport phenomena, waste management, risk and performance assessment, regulatory compliance, elicitation and use of expert judgments, decision analysis, and environmental management.

Mr. Bresson is a senior scientist with Informatics Corporation in Albuquerque, New Mexico. He holds the degree Masters of Public Health, with an emphasis in radiological and environmental health. He has more than 35 years experience as a health physicist working on radioactive waste management and was involved in development of the WIPP Waste Acceptance Criteria and the first WIPP Waste Certification Program.

Ms. Robinson is President and CEO of Energy, Inc. in Albuquerque, New Mexico. She has a B.S. in Chemical Engineering and a pending M.S. in Nuclear Engineering from the University of California at Berkeley. Her 18-year career has been focussed on the resolution of technical problems and issues related to the generation and management of high-level and low-level radioactive wastes for the nuclear power industry.

All panel members had substantial academic qualifications and expertise in one or more of the fields required for this peer review, and all were independent of the WIPP project. The panel's report (see Appendix PEER) provides additional information regarding the technical qualifications of the panel members. Documentation of the independence of the panel members is also provided in Appendix PEER.

The panel focused its efforts primarily on Appendix WCA, in accordance with the WCPR plan, but also reviewed numerous other documents attached to Appendix WCA by reference as well as an early draft of Appendix SOTERM, on which Appendix WCA depended for a substantial amount of data. The panel's report was published in August 1996 (a copy is provided in Appendix PEER).

In the Executive Summary/Conclusions, the report states that, overall:

> *"It is the opinion of the Panel that Appendix WCA (draft, dated July 26, 1996) meets its goal in some areas, is weak but defensible in others, and is inadequate in others."*

9.3.2.1 General Results

The following excerpts are from the WCPR report. They address those areas that the panel considered adequate.

- ***"Radionuclide Inventory and Release Limits**. The analysis performed in estimating the parameters needed to establish the radionuclide inventory and release limits for estimating the CCDF was very thorough and systematic. This is a solid piece of work.*

- ***Solubility**. The median values for actinide solubility are reasonable.....*

- ***Colloids.** The experiments dealing with colloids in the repository were well done.*

- ***Production of Gas**. Appendix WCA adequately identifies the major issues of gas generation in the waste.*

- ***Permeability**. There are experimental data to support the conclusions about permeability discussed in Appendix WCA. The Panel concurs with the conclusions.*

- ***Heat Generation**. The analyses presented in Appendix WCA concerning heat generation are well done. The conclusion that this characteristic will have a negligible effect on performance is justified.*

- ***Metals**. The assumption that low valent metals in the repository will maintain a reducing atmosphere in the repository is substantiated by experimental data.*

- ***Cellulosics**. Cellulosics will be microbially degraded to carbon dioxide and methane. They also may provide a source of humic colloids. Treatment of these issues by Appendix WCA has been discussed in the appropriate sections above.*

- ***Water and Other Liquids**. The Panel agrees with the findings in Appendix WCA. Water in the waste is not an issue in repository performance.*

- ***Exclusion of Waste**. (1) The analysis performed to support the exclusion of radionuclides is methodical, complete and well done. (2) The exclusion of hazardous wastes is justified."*

9.3.2.2 Waste Characterization Peer Review Panel Concerns

The WCPR panel concluded that several areas they examined were inadequate. The WCPR panel's concerns ("Peer Review Panel Concerns" -- presented in italics below), the DOE's interpretation of the panel's concerns ("Statement of Issue"), the DOE's response to the panel's concerns ("Response to Issue"), and the panel's reaction to the interpretation and responses ("Peer Reviewer Consideration of Response") are provided below. The panel concluded that the responses reasonably addressed their concerns, except for their issues on actinide solubility and production of gas. In those two instances, the DOE developed additional information ("DOE Technical Position versus Panel Issue") which provides the DOE's justification for using the unresolved analyses. In some instances, a single response addressed more than one concern.

The DOE responses were provided to the panel as individual memoranda. For incorporation into this application, the responses have been edited to remove the memorandum format, consolidate references, replace first-person text, insert cross-references where appropriate, and correct typographical errors. Substantive technical content of the response has not been changed.

9.3.2.2.1 Peer Review Panel Concern - Radionuclide Inventory and Release Limits

> *"Radionuclide Inventory and Release Limits. The analysis used to determine the heterogeneous source term for the intrusion scenario was not clearly presented in Appendix WCA, resulting in an inability to judge its validity and degree of conservation."*

Statement of Issue

None provided

Response to Issue

Information about waste radioactivity has been compiled at the waste-stream level from different processes at the generator sites that create TRU waste. Radioactivity loading for each radionuclide and the total waste volume are provided for each waste stream. For the compliance certification application calculations, 569 CH-TRU waste streams and one RH-TRU waste stream are used in the direct release scenario. While 569 represents the true numbers of CH-TRU waste streams, RH-TRU waste has been lumped into one waste stream. This is because the total activity of RH-TRU waste is about one-percent of the total activity of CH-TRU waste, and it is assumed that variability of activity level in this small fraction has negligible effects.

In a rotary drilling operation, the volume of material brought to the surface as cuttings is the cylinder defined by the thickness of the unit being drilled and the diameter of the drill bit. The

quantity of radionuclides released as cuttings is therefore a function only of the activity loading of the intersected waste and the diameter of the intruding drill bit.

In the compliance certification application calculations, containers are assumed to be emplaced in the disposal rooms from various waste streams in a random manner. Because waste containers are to be stacked three-high for disposal, a drill bit is assumed to penetrate three containers. Each of the three containers penetrated by the drill bit can come from different waste streams with different activities associated with them. The waste streams penetrated are randomly sampled with a probability distribution according to the relative quantity (volume) of each waste stream. Figure 9-25 shows the resulting cumulative probability distribution function of the radioactivity loading (in terms of EPA unit per cubic meter of waste) of the 569 CH waste streams through time. Waste stream activities are maintained in performance assessment calculations at 100, 125, 175, 350, 1,000, 3,000, 5,000, 7,500, and 10,000 years. Activities for cuttings calculations at other times are interpolated from these values.

Additional analysis is contained in the WIPP Performance Assessment Analysis Report for EPAUNI: Estimating Probability Distribution of EPA Unit Loading in the WIPP Repository for Performance Assessment Calculations (in the SWCF, Albuquerque, New Mexico).

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response

9.3.2.2.2 Peer Review Panel Concern - Solubility

9.3.2.2.2.1 First Peer Review Panel Concern

> *The median values for actinide solubility are reasonable, but the uncertainty ranges about the median are too low and inconsistent with earlier results from the expert judgment panel study.*

Statement of Issue

A discrepancy exists between what the previous expert judgment panel determined as a reasonable range for actinide solubilities in the WIPP and the range of uncertainty currently being applied by the Actinide Source Term Program in Performance Assessment.

Response to Issue

The peer review panel was provided an early version of Appendix SOTERM which mistakenly stated that the uncertainty associated with an FMT model predicted solubility is one order of magnitude or less. An analysis by Bynum et al. (1996) has establisned the

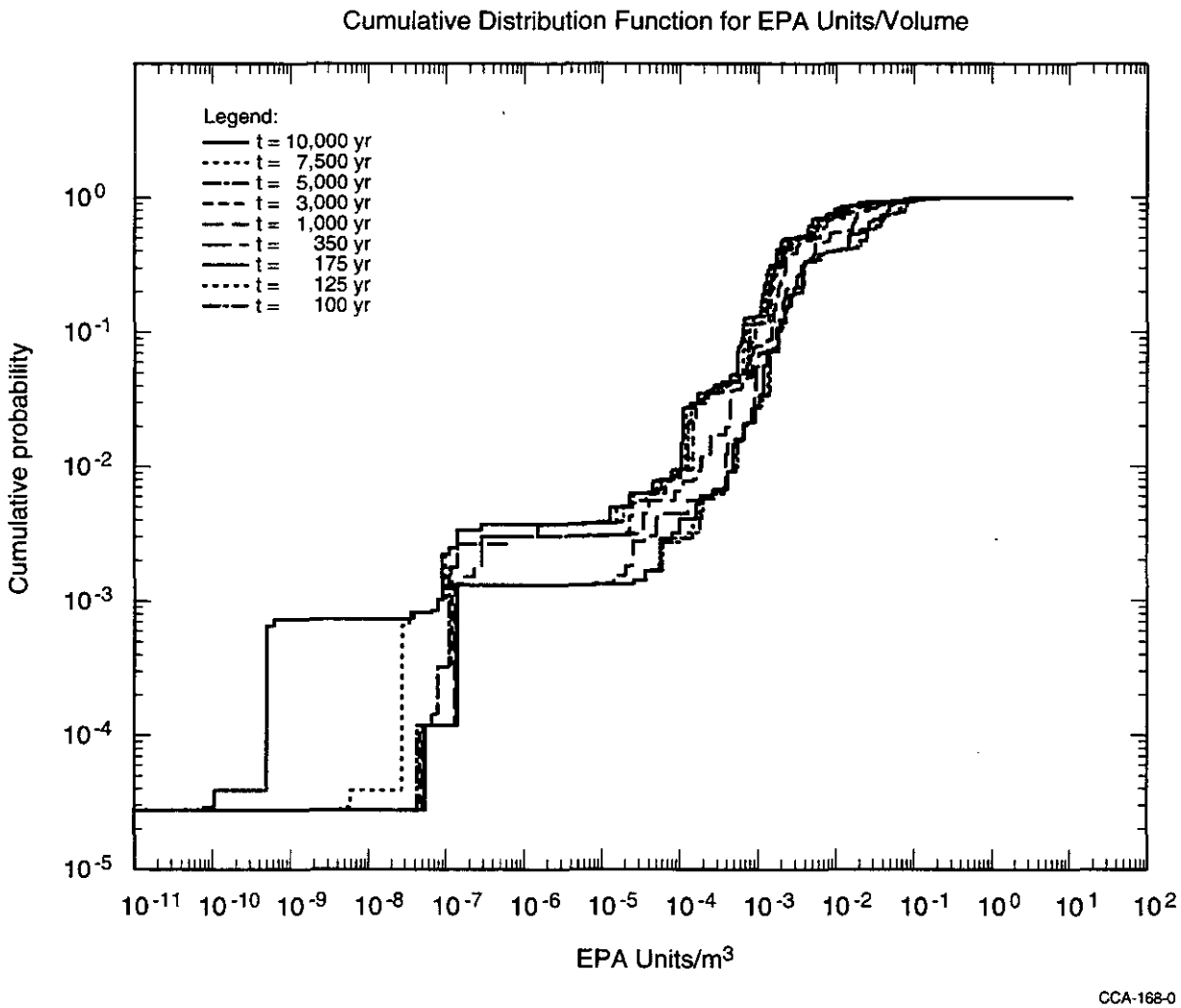

Figure 9-25. Cumulative Distribution Function (CDF) for CH-TRU EPA Units/Volume at Various Times

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uncertainty range to be from -2 to +1.4 orders of magnitude based on a comparison of approximately 150 data points of model predictions or curve fits to direct experimental observations. This error has been corrected in Appendix SOTERM and thus the model uncertainty range being used is approximately 3.4 orders of magnitude. While this is somewhat closer to the ranges of solubility utilized by the expert judgment panel, there still remains a significant difference.

There are two types of uncertainty which must be considered for an analysis of actinide solubility in the WIPP. The first of these centers around the ability to understand how accurately, given a set of chemical conditions, the dissolved species model (as implemented by FMT [Novak 1995]) can predict the actinide solubility. This is referred to as the model uncertainty. The second type of uncertainty, which will be called system uncertainty, involves how well the system is understood, and how the system effects impact the prediction of actinide solubility. In the WIPP repository, in the presence of MgO backfill, the chemical conditions are well understood and defined within a reasonably narrow range. Therefore, the system uncertainty is minimized, with the remaining system uncertainty (that is, oxidation state distribution and brine composition) being dealt with through sampling as described elsewhere. The model uncertainty, when combined with the system uncertainty yields a predicted range of plutonium concentrations of 6×10^{-11} to 1.1×10^{-4}, which is comparable to the range established by the expert judgement panel (2.5×10^{-17} to 5.5×10^{-4}), when discounting the values below the lower limit of detection for the common analytical technique for actinides, 10^{-9}.

The expert judgment panel study considered a wide range of chemical conditions, most of which are not pertinent to the current repository design. The expert judgment panel adopted the approach of selecting two solids, one yielding radionuclide concentrations at high values (a highly soluble solid) and one yielding radionuclide concentrations at low values (a sparingly soluble solid). This process allowed the expert judgment panel to consider conditions, and combinations of conditions, which are not possible within the WIPP. For example, the expert judgment panel considered low pH values and oxidizing conditions. This approach led to a very large system uncertainty (for example, is the repository oxidizing or reducing, is the repository acidic or basic, etc.).

Therefore, it is not appropriate to compare the model uncertainty established for the FMT predicted solubilities with the range of solubilities established by the expert judgment panel. The expert judgment panel did not undertake the defining of the uncertainty of a solubility prediction given a specific set of chemical conditions, and therefore provided no data appropriate for comparison to the model uncertainty utilized in the performance assessment calculations.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.2.2.2.2 Second Peer Review Panel Concern - Solubility

> *The issue of actinide solubility is not adequately addressed in Appendix WCA because the controlling assumption concerning MgO chemistry in the repository has no experimental data to support it.*

Statement of Issues (Note: For the purpose of this response, the above solubility concern has been combined with the first production-of-gas concern regarding the reaction of carbon dioxide with the MgO backfill [see Section 9.3.2.2.4.1].)

The WCPR panel, while recognizing that the fundamental chemistry behind the MgO backfill concept is sound, would feel more comfortable with the significant role that the MgO is playing in the repository, if that chemistry were confirmed with direct experimental observations at WIPP-like conditions.

Response to Issues (Note: For the purpose of this response, the above solubility concern has been combined with the first production of gas concern regarding the reaction of carbon dioxide with the MgO backfill [see Section 9.3.2.2.4.1].)

The arguments for the use of MgO are reasonable and conservative due to (a) the availability of experimental data on the chemical phenomena under a variety of conditions; (b) the soundness of the chemical arguments, which are summarized below; and (c) the conservatism built into the reaction rates and the repository loading of MgO.

The MgO backfill is expected to react with any brine or humidity in the air entering the repository via the following reaction:

$$MgO + H_2O \rightarrow Mg(OH)_2$$

This reaction is based on thermodynamic principles, the fact that MgO is commonly used as a desiccant, and the well known deliquescent behavior of alkaline earth oxides to react with water to form the alkaline earth hydroxides. This behavior is documented in the literature (Aldrich 1994; Terry 1983; Bates and Jackson 1987) and forms what the DOE feels to be a reasonable basis for expecting this reaction to proceed as indicated.

Any CO_2 which may be generated in the repository can react with either the MgO or $Mg(OH)_2$ via reactions such as:

$$MgO + CO_2 \rightarrow MgCO_3$$

or

$$Mg(OH)_2 + CO_2 \rightarrow MgCO_3 + H_2O$$

Both of these reactions are thermodynamically favorable and are known to occur (Budavari et al. 1989; DOI 1975). Therefore, the issue comes down to the rate at which the reaction(s) may occur. Since MgO is deliquescent, solid-gas reactions need not be considered and reactions always involve a liquid phase. Assuming that reaction rates in solution are relatively fast when compared to the geologic time scale, the rate limiting step is the magnesium ions leaving the surface of the MgO. The rate at which MgO dissolves has been previously studied (Terry 1983). Extending the cited values to the pH range expected in an MgO backfilled repository provides an average rate of MgO dissolution of 1.5×10^{-12} moles per square centimeter per second. The total quantity of cellulosics, rubbers, and plastics which are anticipated to be placed in the repository is 2.7×10^{7} kilograms (166 kilograms per cubic meter average cellulosics, rubbers, and plastics loading times 1.6×10^{5} cubic meters total waste volume) (DOE 1995a). The maximum rate of CO_2 generation is 9.51×10^{-9} moles CO_2/kg/sec (see Appendix PAR). Thus, the entire repository maximum CO_2 generation rate is 2.6×10^{-1}moles CO_2/sec.

Given the maximum rate of CO_2 generation and the maximum rate of MgO dissolution (as a function of surface area), we can calculate the theoretical minimum particle size which will have sufficient surface area to ensure reaction with the CO_2 as it is generated. First, the minimum surface area per gram (that is, specific surface area) is calculated by dividing the total surface area required by the total number of grams of MgO emplaced. The total surface area required is given by:

$$(2.6 \times 10^{-1} \text{ moles } CO_2 \text{ generated/sec}) \times (1 \text{ mole MgO/1mole } CO_2) \times (1/1.5 \times 10^{-12} \text{ moles MgO/cm}^2\text{/sec}) = 1.76 \times 10^{11} \text{ cm}^2 \text{ MgO}$$

The total number of grams of MgO emplaced is given by:

$$(83{,}150 \text{ tons MgO}) \times (2000 \text{ lbs/ton}) \times (453\text{g/lb}) = 7.5\text{xx } 10^{10} \text{ g MgO}$$

Thus, the minimum required surface area per gram of MgO is:

$$(1.76 \times 10^{11} \text{ cm}^2 \text{ MgO}) / (7.5 \times 10^{10} \text{ g MgO}) = 2.3 \text{ cm}^2\text{/g MgO}$$

Now, assuming a spherical particle, the surface area = $4\pi r^2$. Using "P_m" for the mass of a particle, we can express the density as:

$$\text{density} = P_m / (4/3\pi r^3)$$

Rearranging for the mass of a particle provides:

$$P_m = (4/3\pi r^3)(\text{density}) \qquad \text{(eq. A)}$$

The specific surface area per gram may be expressed as:

$$\text{specific surface area} = 4\pi r^2 / P_m \qquad \text{(eq. B)}$$

Now, dividing equation A by equation B gives:

$$P_m / (\text{specific surface area}) = [(4/3\pi r^3)(\text{density})] / [4\pi r^2 / P_m]$$

Solving for "r" provides the maximum particle radius which can accommodate the maximum CO_2 generation rate:

$$[P_m / (\text{specific surface area})]\,[4\pi r^2 / P_m] = [(4/3\pi r^3)(\text{density})]$$

$$[4\pi r^2 / (\text{specific surface area})] = [(4/3\pi r^3)(\text{density})]$$

$$[1/(\text{specific surface area})] = [(r/3)(\text{density})]$$

$$r = 3/[(\text{specific surface area})(\text{density})]$$

Utilizing a crystalline density of 3.53 g/cm^3 provides

$$r = 3/[(2.3\ \text{cm}^2/\text{g})(3.53\ \text{g/cm}^3)]$$

or

$$r = 0.37\ \text{cm}$$

Therefore, as long as the particles of the MgO backfill are no greater than 0.37 centimeter radius (or 0.74 centimeter in diameter), there will be sufficient surface area for the MgO dissolution to maintain pace with the maximum CO_2 generation. This minimum surface area is conservative in that it assumes only the exterior surface is available for reaction and a crystalline material is used. In reality, the particles of MgO will be amorphous and thus, will have a much higher effective surface area as there will be some porosity (possibly of the order of 50 percent) to the particles.

For the MgO backfill to function as designed it must be shown that magnesium carbonate containing phases will be formed and will be stable under expected repository conditions. To demonstrate this, multiple thermodynamic modeling codes (for example, FMT [Novak 1995], EQ3/6 [Wolery 1992; Wolery and Daveler 1992], Geochemist's Workbench [Bethke 1994]) have been utilized. These modeling codes take into consideration many potential mineral phases (see Table 9-2; see Section 9.3.1.2.10.2) and utilize a Gibbs free energy minimization method to predict the most stable phase given a set of conditions. The database for the brine components for these codes is well documented (Harvie et al. 1984; Harvie and Weare 1980; Pitzer 1991), and has been proven to be appropriate in conditions very similar to those expected in WIPP (Felmy and Waere 1986). In each case, the modeling simulation predicts that magnesite and brucite will be formed within the system and that these phases are

thermodynamically stable regardless of whether a Salado or Castile brine composition is used. By design of the system (that is, by utilizing a large excess of MgO), brucite will always be present in the system as long as water, in the form of brine in this case, has entered the repository and will thus set one dimension of the phase diagram. The formation of magnesite at low temperatures is however subject to some question due to kinetic effects (Peterson et al. 1966; Christ and Hostetler 1970). To address this potential issue the formation of magnesite was suppressed within the modeling calculations, and it was found that other magnesium carbonate containing phases form which provide approximately the same chemical conditions as when magnesite is allowed to form.

Figure 9-24 (see Section 9.3.1.2.10.2) presents an abbreviated phase diagram for the system. This phase diagram is abbreviated in that calcium containing phases are omitted since (1) the formation of dolomite is not kinetically favorable, and (2) the conditions will be dominated by the magnesium chemistry due to its extreme excess and the rapid consumption of any $Ca(OH)_2$ by relatively small quantities of CO_2 which may be generated. This phase diagram shows that under the worst case, hydromagnesite will form yielding an fCO_2 of approximately an order of magnitude greater than that found when magnesite is allowed to form. This possible increase of carbon dioxide fugacity is not sufficient to cause a significant increase in the actinide solubility.

Since the chemical conditions must be maintained over the repository life-time, the long-term stability of the mineral phase must also be considered. The most compelling arguments for the long-term stability of any mineral phase involve natural analogues. In this case, the most compelling case for a natural analog is the natural occurrence of magnesite in the Salado formation itself (Stein 1985).

Based on the above arguments and observations, the DOE maintains that magnesium oxide will function as an assurance measure in the postclosure repository, forming magnesium carbonate containing phases that will be stable under anticipated repository conditions. The combination of these magnesium carbonate containing phases and brucite will buffer the chemical conditions within the ranges utilized for the dissolved actinide solubility predictions, thus performing effectively as a chemical control.

Peer Reviewer Consideration of Response

The DOE understood the issues; however, the panel determined that the response did not reasonably address their concern.

DOE Technical Position versus Panel Issues (Note: For the purpose of this response, the above solubility concern has been combined with the first production of gas concern regarding the reaction of carbon dioxide with the MgO backfill [see Section 9.3.2.2.4.1].)

The arguments for the use of MgO are reasonable and conservative due to (a) the availability of experimental data on the chemical phenomena under a variety of conditions; (b) the

soundness of the chemical arguments, which are summarized in the response to WCA Concerns 3 and 5; and (c) the conservatism built into the reaction rates and the repository loading of MgO.

The DOE asserts that it has presented sufficient technical data to support its position that the implementation of a MgO backfill will control the repository chemical environment to a region of low actinide solubility through control of pH and CO_2. As the peer review panel notes, the conclusions regarding the impacts of magnesium oxide backfill are "based on sound chemistry." This sound chemistry is supported by geochemical modeling, which has been demonstrated by others to be adequate for systems similar to the WIPP. The panel did not dispute the adequacy of the basic chemistry or modeling but stated its desire to see further experimental confirmation.

9.3.2.2.3 Peer Review Panel Concern - Colloids

> *The uncertainty given for the colloid actinide source term is not adequate for purposes of PA calculations because the number of experiments performed does not generate meaningful statistical samples from which an uncertainty could be adequately calculated.*

Statement of Issue

The panel's concern pertains to the treatment of uncertainties associated with the six sets of parameters developed to quantify the mobile colloidal actinide source term. Two sets of parameters, CONCMIN and CONCINT, are sets of constant values describing concentrations of actinides associated with mineral fragment type colloids and with actinide intrinsic colloids, respectively. Two other sets of parameters, PROPHUM and PROPMIC, are proportionality constants describing the supplemental proportion of actinides, relative to the dissolved actinide source term, which are associated with humic substances and microbes, respectively. Two additional sets of parameters, CAPHUM and CAPMIC, are sets of values representing the maximum concentration of actinides associated with humic substances and microbes, respectively. Values within each parameter set are by actinide element or by actinide oxidation state.

Response to Issue

Parameter values for the six parameters listed above were developed from carefully planned experiments designed to provide reasonable bounding values. In all cases, the parameter values submitted to the WIPP Performance Assessment Department have measures of conservatism incorporated into them, and are essentially maximum values. The main source of uncertainty are due to our ability to quantify the exact nature of colloidal particles during the 10,000-year performance period of the WIPP. In comparison, uncertainty due to analytical and modeling error is negligible. The discussion which follows focuses on some of the major areas of conservatism leading to the development of maximum parameter values.

The two most important contributors to the mobile colloidal actinide source term are humic- and microbial actinides; actinide intrinsic colloids and mineral-fragment bound actinides have only a very small contribution. In spite of some speculation that humics and microbes will not be present in appreciable concentrations during the 10,000-year performance period, the project has bounded their effects by assuming that they are present for the duration. Microbes are present at their maximum ("stationary phase") concentrations established under optimal growth conditions. Humics are limited by their solubilities. It is quite possible that humics may not sustain that concentration because of slow kinetics of formation accompanied by rapid destabilization by brine constituents.

The microbe filtration experiments conducted at LANL and BNL provided the basis for the PROPMIC and CAPMIC parameter values. In those experiments, two WIPP-relevant microbe cultures were used: a pure microbe culture (WIPP-1A), and a mixed innoculum (BAB). The cultures had markedly different extents of bioaccumulation. In the WIPP system, it is more likely that a mixed culture will be present. For the PROPMIC values, the project elected to be conservative and use the values from the WIPP-1A culture. Experiments were conducted under optimal conditions for growth with ample nutrients. The CAPMIC term was determined directly for Th and U, but was determined by extrapolation for Np and Pu. In the latter case, an order-of-magnitude measure of conservatism was added to the extrapolated value to be safe. A CAPMIC term was not developed for Am. In the performance assessment calculations, the CAPMIC term was arbitrarily set at a high value so that CAPMIC for Am was never exceeded. (In fact, it turns out that CAPMIC was never exercised in the performance assessment calculations for any of the actinides.)

Because of the uncertainty in predicting which type of humic substance will be present in the repository environment, the project assumed an equal probability of occurrence of three representative types: *aliphatic humic acid, aromatic humic acid, and fulvic acid.* In cases where data were available for all three types, namely the III and VI oxidation states, a triangular distribution was defined. For oxidation states IV and V, information was not available for fulvic acids, the least powerful complexant, and parameter values were developed from the more strongly complexing humic acids. Consequently, PROPHUM values used for Th(IV), U(IV), Np(IV), Pu(IV), and Np(V) are conservative because they do not include the "diluting effect" of fulvic acids. In general, but particularly for PROPHUM constants for oxidation states III, V, and VI, actinide complexation was measured at very dilute actinide concentrations. As actinide concentrations increase, the extent of binding will decrease because of oligoelectrolyte effects. In other words, as pristine humics begin to complex actinides, they tend to fold in on themselves, decreasing the accessibility of sites for further complexation, and eventually leading to a compact form which is less likely to complex actinides and more likely to precipitate. The experimental approach itself leads to conservatism. Further, the estimated values for the III and the VI oxidation states (determined from experiments with Am and U, respectively) were conducted under relatively acidic conditions. The values reported to performance assessment were based on those conditions, despite the fact that under the higher pH conditions of the repository environment, hydrolysis will render those actinides much less reactive, thereby reducing the extent of complexation by

humics. For the IV oxidation state, the proportionality constant was developed from published information on Th(IV) behavior in sea water, which has a slightly basic pH. It is suspected, however, that under basic pH conditions, Th will be highly hydrolyzed, and will be present as species such as $Th(OH)_3^+$ or $Th(OH)_4^0$ or perhaps even $Th(OH)_5^-$. Under those conditions, "complexation" by humics will not occur by chemical reaction (that is, chemisorption), but instead by weak electrostatic effects (physisorption). The binding strength of the "complexes" is not likely to be very strong, and the extent of "complexation" will be less than that indicated by the parameter values provided to performance assessment.

The maximum value supplied to performance assessment for humic-actinide complexation, HUMCAP, was based on bounding calculations using site densities determined from titration experiments. Like the actinide complexation experiments described above, the site density titrations represent an ideal case. In reality, when the available binding sites on the humics are about 50 percent filled, the humic will tend to precipitate due to oligoelectrolyte effects (that is, charged sites will affect neighboring sites). A conservatism factor of two to four is also incorporated in the HUMCAP parameter, through the assumption that sorbing actinides have univalent charge (that is, one equivalent per mole).

A large number of experiments were conducted with the Pu(IV)-polymer, as a function of Pu(IV) saturation conditions (that is, from undersaturation and from oversaturation), pH conditions, ionic strengths, and time. For the Pu(IV) isotope used, and the analytical method used, the minimum detection limit was 1×10^{-9} M. Under MgO backfill conditions, the pH of the repository is anticipated to be about 9.3. Experiments on Pu(IV)-polymer concentration conducted as a function of pH show a very well-defined sympathetic trend in Pu(IV)-polymer concentration and hydrogen ion concentration (that is, concentration decreases with increasing pH). Under MgO-mediated pH conditions, the well-defined line drops below the minimum detection limit, and extrapolates to a value on the order of 10^{-10} M. The extrapolated value was *not* used in performance assessment calculations. Instead, the minimum analytical detection limit was used, 1×10^{-9} M. It is likely that some measure of conservatism stems from that approach.

The concentration of actinides associated with mineral fragment colloids was based on knowledge gained from approximately one-hundred individual experiments with different colloidal particles, pH conditions, and WIPP-relevant electrolytes. The final experiments used to develop performance assessment parameters were replicates of previous experiments using a substantially more sensitive analytical technique. The bounding approach used to estimate associated actinide concentrations assumes that all mineral fragment colloids present in the repository have fairly strong sorption (that is, 1 binding site per square nm of surface area). Most mineral fragment colloids will not sorb as strongly as iron corrosion products and clay minerals. Other colloidal particles present, for example disaggregated minerals associated with the rock and native groundwaters, will be sorbed less strongly. Consequently, the approach used provides a maximum, but reasonable, concentration of actinides associated with mineral colloids.

Perhaps the greatest conservatism results from disregarding attenuation of colloidal particles during transport through the waste itself or through the backfill material in intrusion boreholes. The project recognizes that work conducted over the past two decades in colloid geochemistry has demonstrated that filtration in the subsurface is not 100 percent efficient. Nevertheless, it is well-accepted that filtration in the subsurface through materials such as the borehole backfill material will result in attenuation of a substantial concentration of colloidal particles (and their associated actinides) over a relatively short transport distance.

In conclusion, the colloid source term parameter values are bounding values incorporating a significant degree of conservatism.

Peer Reviewer Consideration of Response

The DOE understood the issues and provided a reasonable response.

9.3.2.2.4 Peer Review Panel Concern - Production of Gas

9.3.2.2.4.1 First Peer Review Panel Concern

> *The issue of the reaction of carbon dioxide with the MgO backfill is not adequately resolved in Appendix WCA, because of a lack of experimental data which demonstrated that this chemistry occurs under conditions anticipated in the repository.*

Statement of Issue

This issue is addressed in Section 9.3.2.2.2.2 (Second Peer Review Panel Concern - Solubility).

Response to Issue

This issue is addressed in Section 9.3.2.2.2.2 (Second Peer Review Panel Concern - Solubility).

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel concluded that the response did not reasonably address their concern.

DOE Technical Position versus Panel Issue

This issue is addressed in Section 9.3.2.2.2.2 (Second Peer Review Panel Concern - Solubility).

9.3.2.2.4.2 Second and Third Peer Review Panel Concerns - Production of Gas

Appendix WCA does not adequately address the fate of microbially generated methane.

The treatment of gas generation in Appendix WCA is generally well done. However, the Appendix does not deal with the disposition of the generated methane. The gas will be produced on a mole per mole basis with carbon dioxide and yet there is no mention of its fate in the repository.

Statement of Issues

None provided.

Response to Issues

Methylation reactions of actinides are not expected to occur under WIPP repository conditions. Even if they were to occur, the products would not be stable in brine. Therefore, the only significant impact of methane generation is on repository gas pressure.

Microbially generated methane contributes to the total gas pressure generated in the WIPP repository. Because methane is produced by the microbial metabolic reaction (Wang and Brush 1996a),

$$C_6H_{10}O_5 \rightarrow 3CO_2 + 3CH_4$$

the rate of methane production by this reaction is about the same as the rate of cellulose degradation. Although methane can be produced by reaction of hydrogen with CO_2, Wang and Brush (1996a) neglect this pressure-reducing reaction in their calculations. In performance assessment, this rate is incorporated as part of the gas generation calculated by the code BRAGFLO. The parameters used by BRAGFLO to calculate gas generation are given in Table 6-9 (see Chapter 6.0).

For the purposes of calculating repository pressure and gas flow, the density and viscosity of any gas generated, including methane, are assumed to be those of hydrogen (see Section 6.4.3.4). The gas produced in the repository contains methane in half of the performance assessment realizations. The viscosity of hydrogen at 15 megapascals (lithostatic pressure), 6×10^{-6} ft-lb/sec, is less than half the viscosity of a gas mixture that contains 50 percent mole fraction hydrogen, 15×10^{-6} ft-lb/sec (see Appendix MASS; Section 3.2). At about half lithostatic pressure, the viscosity of a 50 percent mole fraction mixture is about 14.5×10^{-6} ft-lb/sec. Calculations of viscosity and compressibility of these mixtures were made using a National Institute of Standards and Technology (NIST) program entitled SUPERTRAPP (Vaughn 1996; Friend and Huber 1994). Viscosity has an inverse relationship to gas flow rate, and is proportional to the square of the repository pressure, so that assuming the viscosity of hydrogen for all generated gas yields a conservative result.

The compressibility factor of a gas is (Perry and Chilton 1973)

$$z = PV/RT \tag{31}$$

so that at constant temperature and a given pressure, the compressibility factor is inversely related to the gas density. The compressibility factor of hydrogen at 15 megapascals is 1.1, while that of 50 percent mole fraction hydrogen at 15 megapascals is 1.0 (Vaughn 1996). Like viscosity, compressibility is inversely related to gas flow rate, and is proportional to the square of the repository pressure. However, the difference between the compressibility of pure hydrogen and that of a 50 percent mixture is small, so that the effect of assuming the compressibility of hydrogen is minor.

Early in the regulatory period, there is likely to be relatively little hydrogen compared to methane. However, both the viscosity and density of methane are higher than those of hydrogen, so that predictions of gas flow and gas pressure would still be conservative.

Peer Reviewer Consideration of Response

The DOE understood the issues and provided a reasonable response.

9.3.2.2.5 Peer Review Panel Concern - Compressibility

Appendix WCA references studies describing the analysis of waste compressibility; however, it fails to provide any discussion of the results of these studies.

Statement of Issue

In Section WCA 5.2.1 (see Appendix WCA) laboratory tests on waste compaction are referenced (Butcher et al. 1991) and a waste compaction model is also referenced (Weatherby et al. 1991; Callahan 1993). However, Appendix WCA does not give any values for the compressibility, nor does it describe the model, thus making it difficult for the panel to review. The panel states that they concur that "this modeling combined with experimental data is an appropriate method" but also that they "do not have information to assess the reasonableness or accuracy of compactibility related parameters". They also lack "for example" a discussion "or references on the effect of compactibility on porosity."

They note that the basis for the compressibility is derived "from experiments and models which assume a distribution of metals, plastics, combustibles, cellulosics and sludges is representative." Although they accept that this distribution is uncertain, they conclude that the "assumptions made are considered appropriate and conservative."

Response to Issue

The values used for compressibility of the waste are based on a series of laboratory experiments carried out on simulated waste materials. These experiments consisted of a series of loading tests during which the materials representing various components of the waste were compacted uniaxially and deformation was measured as a function of applied load and time (some of the materials showed creep). The compaction curves for the individual materials were then combined as a volume weighted average, based on the expected proportions of the various materials in the waste. Two models were developed to represent this compaction, a nonlinear elastic model (Callahan 1993) and a volumetric plasticity (crushable foam) model (Weatherby et al. 1991). Due to certain physical consistency limitations of the nonlinear elasticity model, calculations for performance assessment use the volumetric plasticity model, which has been shown to reasonably represent the expected behavior of the waste, and has been checked against data for drum compaction described by Butcher et al. (1991).

Details of the crushable foam model are given in Labreche et al. (1993). The constitutive relationship for volumetric yield can be written as:

$$F_v = \sigma_m - f(\epsilon_v)$$

where:

σ_m = the mean applied stress;
ϵ_v = the volumetric strain; and,
$f(\epsilon_v)$ = describes the volumetric hardening by a set of pressure-volumetric strain relations (that is data pairs in tabular form).

Figure 9-26 illustrates this relationship.

The estimates for compaction described here are for as-received waste, with no correction for waste decomposition or corrosion with time. This is based on an assumption that the waste degrades before it reaches its fully compacted state. An analysis of the results for the compaction of limonite and magnetite (two possible corrosion products of iron) in Butcher et al. (1991), also indicated that the difference between reacted and unreacted compaction states at lithostatic pressure was too small to attempt to compensate for in closure calculations.

Clearly the porosity of the compacted waste will depend to some extent on the compressibility of the waste, although it will also depend on the generation of gas and the resulting pressure conditions. This is discussed further under the issue on porosity.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

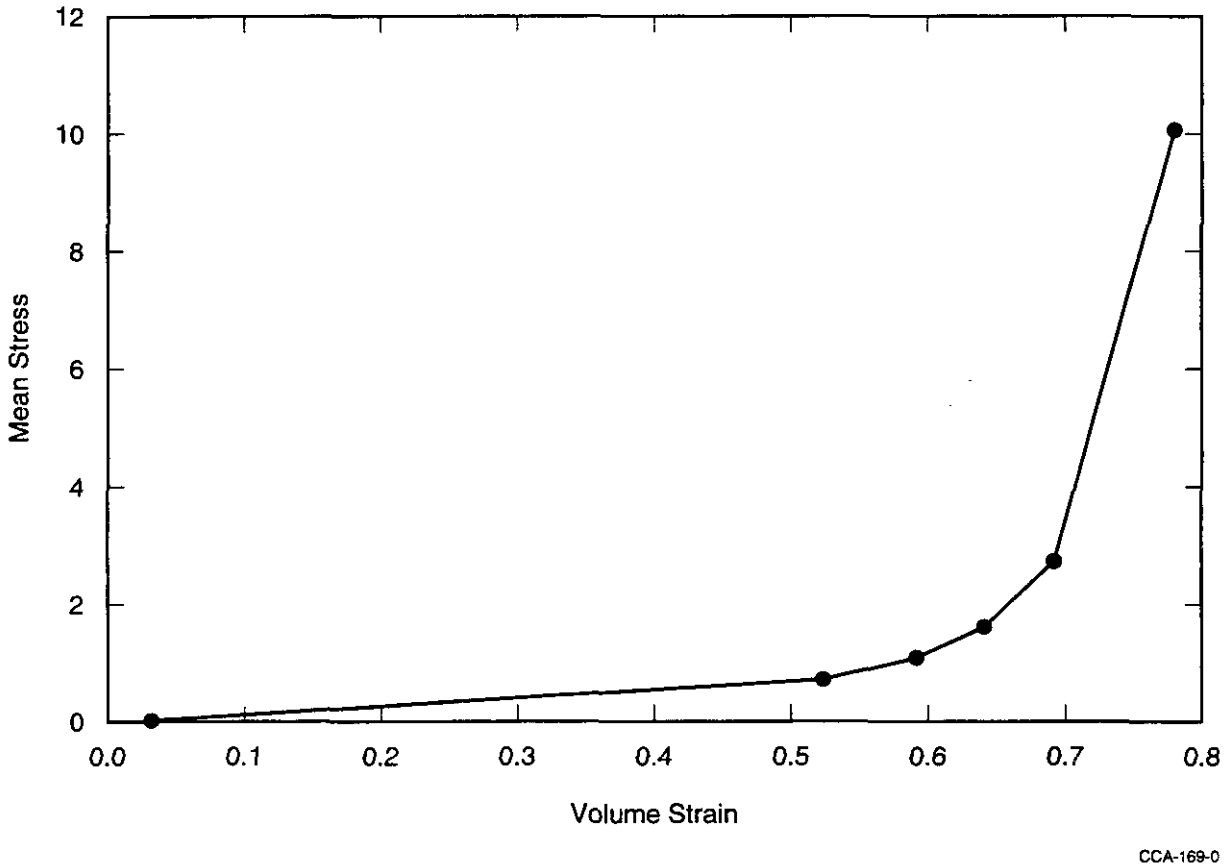

Figure 9-26. Relationship between Mean Applied Stress and Volume Strain, Volumetric Plasticity Model for Waste Compaction

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9.3.2.2.6 Peer Review Panel Concern - Strength

Appendix WCA references a study on waste strength, but fails to discuss the results of this study in the context of its impact on disposal system performance.

Statement of Issue

In Section WCA.5.2.2 (see Appendix WCA), a tensile strength of the waste of one-psi is argued by Berglund et al. (1996; Appendix PEER, Section PEER.2). The application of this is discussed in Appendix CUTTINGS, which is also referenced. However, Appendix WCA does not give any synopsis of these arguments, or the impact of the strength values, thus making it difficult for the panel to review. The panel states that the discussion of waste strength properties was "insufficient to assess reasonableness for inclusion in PA", and the panel "unanimously agreed that strength properties should be included for inclusion in PA".

Response to Issue

Waste strength influences the performance of the repository in two ways. First, during a drilling intrusion solid waste may be removed from the sides of a drillhole by erosion by the circulating drilling mud. In this case, the amount of material removed depends in part on the erosional strength of the waste, which is qualitatively related to the shear strength. Second, during a gas blowout event, material may be removed by "lofting" in the gas stream, a process known as spalling. In this case, the quantity of material removed is related to the tensile strength of the waste materials.

The values for the erosional strength of the waste were examined by Butcher (1994). In this memorandum, he argued that from a mechanical standpoint, the degraded waste would be similar to a clay-sand mixture. Based on literature values, he estimated that the strength of such a mixture would range between 0.1 and 1 pascal, with a median value of 1 pascal.

A value of 1 pound per square inch (6,895 pascals) has been chosen for the tensile strength of decomposed waste for the purpose of computing spall releases resulting from a drillbit intrusion into a pressurized waste panel. Such spall releases occur only if the gas pressure exceeds the hydrostatic drilling mud pressure of approximately 8 megapascals. A chemical reaction between the waste and brine from the surroundings is necessary to generate the gas to raise the waste pore pressure to these levels. Without brine inflow, little gas will be generated and waste decomposition will be negligible. Thus, the phenomenon of spall requires both brine inflow and waste decomposition.

The future state of decomposed waste is both time dependent and uncertain. Therefore, a decomposed state consisting of graded granular materials is assumed. This is consistent with the granular nature of decomposed geologic materials and corresponds to an end state of the decomposition process. Such materials lack significant composite strength from the interleaving of components and is the state found to be most troublesome in oil production

where sand is produced from poorly consolidated sand layers. The value of 1 pound per square inch chosen for cementation strength for the decomposed waste can be reasonably expected to be conservative, that is, lower than those data values found for many weak materials that are naturally occurring or that have been manufactured. Data to support this value can be found in the literature for the strengths of soils, laboratory produced mixtures of salt and clay, and mixtures of various materials with MgO; the latter added as a backfill material to the waste. The memorandum by Berglund et al. (1996; see Appendix PEER) discusses this in more detail.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.2.2.7 Peer Review Panel Concern - Porosity

> *There are conflicting statement in Appendix WCA concerning the importance of porosity to the performance of the repository. As a result, the Panel was unable to evaluate the treatment of this parameter.*

Statement of Issue

In Section WCA.5.2 (see Appendix WCA), the physical properties of the solid waste with "Expected Significant Effect on .... Performance" include ".... the porosity of the waste," while those with "Expected Negligible Effect on ... Performance" include "Porosity:....". The panel, understandably, were confused by this contradiction, and the lack of any discussion on this property.

Response to Issue

This apparent contradiction arises out of the lack of clarity in the use of the porosity in Tables WCA 2-1 and WCA 2-2, and in the text. As indicated in Table WCA 2-1, compressibility of the waste is important because of its effect on creep closure (the stiffer the waste the more closure will be delayed and reduced), as well as the resulting effect on strength. Time dependent porosity is important here in that it controls the amount of volume available for gas and brine, and thus effects the build-up of pressure.

The lack of clarity appears because Table WCA 2-2 indicates that "porosity" has negligible effect on performance. This is true in respect to the dependence of permeability of the waste on porosity. The system is relatively insensitive to permeability of the waste, because this permeability is much greater than either the panel closures or the DRZ, and in this sense only the system is insensitive to the porosity.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.2.2.8 Peer Review Panel Concern - Metals

> *The position taken in Appendix WCA concerning the uptake of organic ligands by the transition metals is not defensible due to lack of experimental data. It is not correct to apply results from experiments performed in low ionic strength solutions to WIPP brines."*

Statement of Issue (Note: For the purpose of this response, the above metals concern has been combined with the chelating agents concern regarding the reaction of transition metals with organic ligands [see Section 9.3.2.2.9].)

A sufficient case has not been made to give the panel an adequate degree of comfort with ignoring the effect of organic ligands.

Response to Issue (Note: For the purpose of this response, the above metals concern has been combined with the chelating agents concern regarding the reaction of transition metals with organic ligands [see Section 9.3.2.2.9].)

The panel was provided a version of Appendix SOTERM which contained an early version of the discussion of organic ligands and their effect on repository performance. The most recent text of Section 5 of Appendix SOTERM provides additional information to satisfy the panel's concerns. An excerpt of that text is provided below:

SOTERM.5 The Role of Organic Ligands

Organic ligands may be a component of the wastes to be disposed of in the WIPP. Because organic ligands may complex with actinides and increase dissolved actinide concentrations, the effect of organic liquids was evaluated. Organic ligands also complex strongly with multivalent metal cations. The multivalent metal cations thereby compete with the actinides, and an assessment of this effect was performed. The analysis, summarized here, demonstrates that organic ligands will not be available to complex the actinides and thus will not impact dissolved actinide concentrations in the WIPP.

A number of organic compounds are capable of forming strong complexes with actinide ions, thereby stabilizing the actinide in solution. In general, the reactions that take place for one-to-one complexes are:

$$An^{n+} + L^{m-} \rightarrow AnL^{(n+m)}, \qquad (5\text{-}1)$$

where An is a general symbol for any actinide, with charge n, and L is a general symbol for an organic ligand with charge m. The apparent stability constant for this reaction is

$$\beta = [AnL^{(n+m)}]/[An^{n+}][L^{m-}] . \quad (5\text{-}2)$$

The square brackets indicate concentration. This equilibrium constant is sometimes referred to as an association constant.

The Transuranic Waste Baseline Inventory Report (DOE 1996, Appendix B4) initially identified about 60 organic compounds among the non-radioactive constituents of TRU waste to be emplaced in the WIPP (Drez 1991; Brush 1990). Ten of these compounds have the potential to increase radionuclide solubility (Choppin 1988). Screening studies of these compounds have been conducted by Florida State University. Deprotonation and complexation experiments have been performed with five of these: acetate, citrate, oxalate, lactate, and EDTA. Four of these (acetate, citrate, oxalate, and EDTA) were identified in the waste inventory of the WIPP (DOE 1996, 3–12; Section WCA.8.11) as the only water-soluble organic ligands present in significant quantities. Lactate was not included because none was identified in the initial inventory, and estimating its concentration resulting from both production and consumption by microbes is not possible. These organic ligands are capable of significantly enhancing dissolved actinide concentrations, are potentially present in the repository, and are generally representative of any organic ligand that could be present in the WIPP.

Ligand concentrations in the repository were estimated using inventory amounts of ligands and a brine volume of 29,841 m^3, the smallest quantity of brine required to be in the repository which will support transport away from the repository (Larson 1996). As per BIR, Rev. 2, Page 3-1, a scaling factor of 2.05 was applied to all values. The results are listed in Table SOTERM-4.

Table SOTERM-4. Organic Ligand Concentrations in Inundated Repository

Organic Ligand	Inventory Amount (G)	Organic Concentration (molality)	Organic Concentration (scaled)
acetate	1.3×10^6	5.2×10^{-4}	1.1×10^{-3}
oxalate	1.6×10^6	2.3×10^{-4}	4.7×10^{-4}
citrate	1.4×10^8	3.6×10^{-3}	7.4×10^{-3}
EDTA	2.3×10^4	2.0×10^{-6}	4.2×10^{-6}

Apparent stability constants for organic ligand-actinide complexation and deprotonation constants for the organic acids were determined at Florida State University using potentiometric titration and a solvent extraction technique. The results of these studies are summarized in Table SOTERM-5.

Table SOTERM-5. Apparent Stability Constants for Organic Ligands and Actinides in NaCl Media

Organic Ligand	Actinide Ion	NaCl (molality)	$\log_{10}$ of Apparent Stability Constants $\log \beta_1$	$\log \beta_2$
Acetate	Am^{3+}	0.3 to 5	1.44 - 2.2	
	Th^{4+}	0.3 to 5	3.68 - 4.18	6.56 - 7.66
	NpO_2^+	0.3 to 5	1.05 - 1.8	
	UO_2^{2+}	0.3 to 4	2.23 - 3.09	5.12 - 5.72
Lactate	Am^{3+}	0.3 to 5	1.75 - 2.55	3.4 - 3.8
	Th^{4+}	0.3 to 5	3.83 - 4.28	6.43 - 7.23
	NpO_2^+	0.2 to 5	1.43- 1.95	
	UO_2^{2+}	0.3 to 5	2.45 - 2.73	
Oxalate	Am^{3+}	0.3 to 5	4.17 - 4.63	7.77 - 8.6
	Th^{4+}	0.3 to 5	7.04 - 7.47	13.42 - 13.95
	NpO_2^+	1.0 to 5.0	3.62 - 4.63	6.96 - 7.07
	UO_2^{2+}	0.3 to 5	5.82 - 6.7	
Citrate	Am^{3+}	0.3 to 5	4.84 - 5.9	
	Th^{4+}	0.1 to 5	9.31 - 10.18	17.33 - 19.12
	NpO_2^+	0.1 to 5	2.39 - 2.56	
	UO_2^{2+}	0.3 to 5	7.07 - 7.32	
EDTA	Am^{3+}	0.3 to 5	13.76 - 15.1	
	Th^{4+}	0.3 to 5	15.56 - 16.94	30.77 - 33.21
	NpO_2^+	0.3 to 5	5.45 - 6.7	
	UO_2^{2+}	0.3 to 4	10.75 - 12.16	10.77 - 12.12

Complexation constants for each organic-actinide binding reaction were determined using the Pitzer formalism. The NONLIN computer code was used to calculate Pitzer interaction parameters and standard chemical potentials (Moore 1996). The parameters were added to the existing FMT data base for inorganic compounds and equilibrium calculations were performed. In FMT modeling calculations including organic ligands, all four of the water-soluble organic ligands identified in the WIPP inventory were included together at the expected concentrations so that competition among complexing sites could be examined (Novak et al. 1996). Calculations were done separately for Salado and Castile brines, using the brine formulations given by Brush (1990, 17-28). Complexation constants for magnesium with the organic ligands were measured at Florida State University and the results are listed in Table SOTERM-6. These results were included in the calculations so that magnesium (backfill component) competition with the actinides for ligand complexation could be evaluated. The FMT output is the calculated equilibrium solubility of the actinide as a function of the repository conditions.

Table SOTERM-6. Apparent Stability Constants for Magnesium Complexation with Organic Ligands at High Ionic Strength

Organic Ligand	NaCl (Molality)	$\log_{10}$ of Apparent Stability Constant
acetate	5	0.690
oxalate	5	2.20
citrate	3	2.02
EDTA	5	6.66

As the iron and steel in the repository corrode, additional transition metal ions will dissolve. These ionic species include iron (Fe), nickel (Ni), chromium (Cr), vanadium (V), and manganese (Mn), because the steels used for the waste drums contain on average at least 0.001 weight percent of Ni, Cr, V, and Mn as minor constituents (NIST 1995). Because at least 1.9×10^9 moles of steels will be disposed of in the WIPP, there should be at least 1×10^4 moles of Ni, Cr, V, and Mn in the repository. There are also expected to be $> 6 \times 10^7$ moles of Pb. Additionally, these and other metals will be present in some of the waste forms; however, these additional quantities in the waste were not considered in this evaluation because insufficient data were available.

The complexation constants for the various metals cited above with the four representative organic ligands are listed in Table SOTERM-7. To assess the ability of these metals to complex with the organic ligands, competition calculations with EDTA (selected because it is the most strongly complexing of the four organic ligands under consideration) in low ionic strength NaCl solution saturated with iron hydroxide, nickel hydroxide and magnesium oxide (backfill) were performed. The calculations showed that under these conditions 99.8 percent of the EDTA was complexed by Ni, thus effectively rendering the EDTA unavailable for complexation with the actinides and rendering complexation of actinides by organic ligands inconsequential. Although these results are approximate because complexation constants for low ionic strength media were used, the fact that a single metal cation could bind more than 99 percent of the EDTA strongly suggests that the full range of metals that will be present will readily overwhelm the complexation sites of the organic ligands. Additionally, at higher ionic strength, iron and nickel have much higher solubility than in dilute solutions. Variation in ionic strength is not expected to change the complexation constants sufficiently to reduce this effect on the organics.

In addition to the calculations using the HYDRAQL code, simple scoping type equilibrium calculations were performed including several of the expected transition metals. The following equations were solved simultaneously:

Table SOTERM-7. Apparent Stability Constants for Organic Ligands with Metals (Martell and Smith 1982, 75, 284, 307, 328).

Organic Ligand	Metal	Ionic Strength (molality)	$\log_{10}$ of Apparent Stability Constant
EDTA	Fe^{2+}	0.1	14.3
	Ni^{2+}	0.1	13.6
	Cr^{2+}	0.1	18.4
	Mn^{2+}	0.1	13.9
	V^{2+}	0.1	12.7
	Cu^{2+}	0.1	18.9
	Pb^{2+}	0.1	18
Citrate	Fe^{2+}	0.1	4.4
	Ni^{2+}	0.1	5.4
	Mn^{2+}	0.1	4.15
	Cu^{2+}	0.1	5.9
	Pb^{2+}	0.1	4.08
Oxalate	Fe^{2+}	1.0	3.05
	Ni^{2+}	0.0	5.16
	Cr^{2+}	0.1	3.85
	Cu^{2+}	0.1	4.84
	Pb^{2+}	0.16	4.00
Acetate	Fe^{2+}	0	1.4
	Ni^{2+}	0	1.43
	Cr^{2+}	0.3	1.25
	Mn^{2+}	0.16	0.8
	Cu^{2+}	0	2.22
	Pb^{2+}	0.1	2.15

$$\beta_{Fe(II)} = [EDTA\text{-}Fe^{2-}] / [EDTA^{4-}][Fe^{2+}]$$

$$\beta_{Ni(II)} = [EDTA\text{-}Ni^{2-}] / [EDTA^{4-}][Ni^{2+}]$$

$$\beta_{Mg(II)} = [EDTA\text{-}Mg^{2-}] / [EDTA^{4-}][Mg^{2+}]$$

$$\beta_{Th(IV)} = [EDTA\text{-}Th] / [EDTA^{4-}][Th^{4+}]$$

along with mass balance equations for each metal. The nickel concentration of 3.65×10^{-4} used in the calculations was determined by taking the minimum number of moles of nickel expected in the repository, dividing by the available repository volume reported by Weiner (1996) and converting the value to molality. An approximation of 1×10^{-4} molal was chosen for the iron concentration. All other values for component concentrations and apparent stability constants are reported above. To approximate the effect of ionic strength on the apparent stability constants for nickel and iron the values used were an order of magnitude lower than those reported in Table WCA-10. These calculations do not include all possible

metal ions expected under repository conditions, for example calcium and chromium are not included. Therefore, these results are considered conservative. The results indicate more than 97 percent of the total EDTA is complexed by the transition metals. Thus the excess of nonradioactive metals present in the repository will overwhelm the complexation sites of the organic ligands and complexation of the organic ligands with actinides will be negligible.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.2.2.9 Peer Review Panel Concern - Chelating Agents

> *The position that transition metals will react with the organic ligands in the waste to render them unavailable for reaction with actinides should be justified with experiments done in high ionic strength brines."*

Statement of Issue

This issue is addressed in Section 9.3.2.2.8 (Peer Review Panel Concern - Metals).

Response to Issue

This issue is addressed in Section 9.3.2.2.8 (Peer Review Panel Concern - Metals).

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response.

9.3.3 Engineered Alternatives Cost/Benefit Study Peer Review

Per the criteria of 40 CFR § 194.27(a)(3), a compliance application shall include documentation of peer review that has been conducted for *"(e)ngineered barrier evaluation as required in §194.44."* 40 CFR § 194.44(b) states

> *"In selecting any engineered barrier(s) for the disposal system, the Department shall evaluate the benefit and detriment of engineered barrier alternatives, including but not limited to: Cementation, shredding, supercompaction, incineration, vitrification, improved waste canisters, grout and bentonite backfill, melting of metals, alternative configurations of waste placement in the disposal system, and alternative disposal system dimensions. The results of this evaluation shall be included in any compliance application and shall be used to justify the selection and rejection of each engineered barrier evaluated."*

In September 1989, the DOE established the Engineered Alternatives Task Force (EATF) to identify and screen potential engineered alternatives (EAs) with respect to both effectiveness

and feasibility of implementation in addressing concerns about gas generation and human intrusion. EAs are engineered barriers, waste modifications, facility modifications, process changes, or any other approach that enhances disposal system performance or reduces uncertainty in the predictions of disposal system performance.

The EATF, in turn, chartered an Engineered Alternatives Multi-disciplinary Panel that qualitatively screened an initial 64 alternatives to 36. The EATF then combined these candidates into 14 logically consistent and potentially actionable EAs. These 14 candidates, plus a base case, were evaluated with respect to relative effectiveness and feasibility in addressing gas generation and inadvertent human intrusion impacts. The EATF issued its final report in July 1991 (DOE 1991a). A subsequent peer review of the EATF Report is documented below (Section 9.4.4).

The DOE prepared the Engineered Alternatives Cost/Benefit Study (EACBS) Final Report (DOE 1995b, see Appendix EBS) in 1995. The EACBS Report includes a qualitative assessment of estimated costs, potential risks and benefits, and relative repository performance impacts resulting from the implementation of engineered alternatives.

The EACBS differs from the 1991 EATF in two fundamental ways. First, in the EACBS, EAs are assessed against eight factors specified in 40 CFR § 194.44(c)(1) that provide the data and information for use in selecting or rejecting an EA. The eight factors are:

- Long term repository performance
- Uncertainty in compliance assessment
- Impact on public and worker exposure
- Impact on waste removal
- Transportation risk
- Public confidence
- Impact on system cost and schedule
- Impact on other disposal systems

Second, the 1991 EATF study was aimed at identifying alternatives which, if needed, would improve disposal system performance to the point where compliance with quantifiable standards was achieved. The EACBS begins with the assumption that compliance is achieved and the comparison of alternatives is to assist future decision making should a need for additional EAs be identified.

An EACBS Peer Review Plan (see Appendix PEER) was developed and approved in accordance with the requirements of TP 10.5. The plan describes the peer review process used to ensure a sound technical basis for the selection or rejection of EAs should it be determined that additional engineered barriers are needed to satisfy the requirements of 40 CFR Part 191.

An independent peer review committee was assembled by the Waste-Management Education and Research Consortium (WERC) to provide the DOE with a review of the EACBS Final Report. The peer review was conducted in 1996, in a manner that was consistent with NUREG-1297 (NRC 1988) guidance and the requirements of TP 10.5 (DOE 1996b).

The purpose of the peer review of the EACBS was to assess the validity of the assumptions and the technical approach used in the EACBS and to evaluate the adequacy of the work. The peer review panel review focused on determining the reasonableness of the report's conclusions.

In accordance with the provisions of TP 10.5, a peer review panel was selected. The nine-member panel was composed of the following individuals:

Rohinton K. Bhada (Chairman), New Mexico State University
Catherine T. Aimone-Martin, New Mexico Institute of Mining and Technology
Arturo Duran, Environmental Consulting and Engineering
Douglass J. Kuhns, Lockheed-Martin Idaho Technologies Corporation
Cindy R. Lewis, Parsons Engineering Science, Inc.
James D. Navratil, Rust Federal Services
Jamal Rostami, Earth Mechanics Institute
Dennis M. Smith, Technical & Management Systems and Services, Inc.
Krishan K. Wahi, Geological Repository Assessment Methodologies, Inc.

Dr. Bhada has a Ph.D. in chemical engineering and an MBA in management. He is a registered professional engineer and was awarded the title of Diplomate of the American Association of Environmental Engineers. Dr. Bhada had 29 years of experience at the Babcock and Wilcox Company, where he worked primarily in the areas of pollution control and energy conversion, before he joined New Mexico State University in 1988.

Dr. Aimone-Martin has a Ph.D. in mineral resources engineering and management and civil (geotechnical) engineering. She is currently an Associate Professor and the Department Chair of the Mineral and Environmental Engineering Department at the New Mexico Institute of Mining and Technology where she has been since 1981.

Mr. Duran has an MS in chemical engineering and seven years of environmental experience as a private consultant and as a project manager with the EPA. Mr. Duran has worked as a project manager on more than 50 environmental projects including site investigations, feasibility studies, landfill closure, remedial design, construction and operation of groundwater and soil treatment systems and permitted RCRA treatment, storage and disposal facilities.

Ms. Lewis has a BS in chemical engineering and is a chemical engineer and risk assessment specialist for Parsons Engineering Science, Inc. She has provided guidance and technical

support for risk assessments conducted as part of environmental restoration efforts for the DOE and the Department of Defense.

Mr. Kuhns has an MS in safety science and is currently an advisory scientist and engineer for the Lockheed-Martin Idaho Technologies Corporation at the Idaho National Engineering Laboratory (INEL), which he joined in 1989. At INEL, Mr. Kuhns has held a number of positions in the environmental restoration/waste management arena.

Dr. Navratil has a Ph.D. in chemistry and is the Chief Scientist with Rust Federal Services. He has more than 25 years of extensive experience with radioactive, hazardous and mixed wastes, actinide chemistry and radionuclide solubilities.

Mr. Rostami has an MS in mining engineering and is currently a senior research associate at Earth Mechanics Institute. He has worked at various capacities in the Iranian Institute of Mineral Research and Application in the field of mineral processing.

Mr. Smith has an MS in environmental chemical hazard analysis and is currently president of Technical & Management Systems & Services Inc., an environmental management consulting firm. He has nearly 20 years of environmental science and engineering experience with 13 years in the hazardous waste industry. Mr Smith is a board certified industrial hygienist.

Dr. Wahi has a Ph.D. in mechanical engineering and is the President/Owner of Geological Repository Assessment Methodologies, Inc., which provides waste management and environmental restoration consulting and support services. He has 20 years of experience in nuclear waste management, specializing in geomechanics, numerical modeling, performance assessment of geological repositories and coupled processes.

Panel members have established academic qualifications, as well as substantial relevant experience, and are independent of the WIPP project. Additional information regarding the technical qualifications of the panel members is provided in the final peer review report (see Appendix PEER). A letter from the Peer Review Manager regarding the verification of independence for panel members is also presented in Appendix PEER (Additional information regarding the independence of the panelists is available in the CAO Record Center.) All technical disciplines needed to perform the review were represented.

After orientation and training as required by TP 10.5, the panel was briefed by the EACBS report authors and DOE staff. To review the large amount of information provided in the EACBS and supporting documentation, the peer panel divided itself into three subcommittees to address specific factors of the study. The subcommittees were formed on the basis of the expertise that was most appropriate for each set of factors. Eventually, all subcommittee findings were reviewed by the entire peer panel.

9.3.3.1 General Results

Following completion of its review, the panel prepared a final report on July 10, 1996. The results of the EACBS peer review evaluation are summarized in Table 9-3 and a copy of the complete report is provided in Appendix PEER. The following conclusions are presented in the final report:

- the information presented within the EACBS is of high quality,
- the approach taken is valid,
- the conclusions drawn are reasonable, and
- the analysis was conducted in accordance with 40 CFR § 194.44 criteria.

The EACBS panel report also identifies several findings/concerns/issues. The DOE developed a response to the issues identified in the panel report. The panel's concerns and the DOE responses are discussed in the following sections.

9.3.3.2 Engineered Alternatives Cost/Benefit Study Peer Review Panel Concerns

The DOE conducted an evaluation to assess the relative benefit and associated cost of various engineered alternatives (EAs) for the disposal system. The analytical methodology and final results of the Engineered Alternatives Cost Benefit Study (EACBS) were critically reviewed for technical merit, adequacy, and accuracy of results by a team of outside experts.

The EACBS panel expressed several concerns regarding the EACBS. The EACBS panel's concerns ("Peer Review Panel Concerns" -- presented in italics) and the DOE's response to the panel's concerns ("Response to Issue") are presented below. The panel members were asked to review the DOE responses and determine whether they agreed with the responses. The panel's reaction to the responses is provided below ("Peer Reviewer Consideration of Response"). In those instances where panel members disagreed, from a technical-based perspective, with the DOE response, the DOE developed additional information which describes the justification for its final technical position on the concern ("DOE Technical Position versus Panel Issue").

For incorporation into this application, the DOE responses were edited to insert cross-references where appropriate and correct typographical errors. Substantive technical content of the responses has not been changed.

The individual comments are listed first, followed by the response. Comments are arranged by topics that start with the engineered alternatives identification and screening process and are followed by the eight factors evaluated in the EACBS report. In several cases, the peer

Table 9-3. Summary of the Peer Review of the EACBS Evaluation Factors and Criteria

Engineered Alternatives Evaluation Factors	A. Adequacy of Requirements and Criteria	B. Validity of Assumptions	C. Alternative Interpretations	D. Uncertainty of Results and Consequences if Wrong	E. Appropriateness and Limitations of Methodology and Procedures	F. Adequacy of Application	G. Accuracy of Calculations	H. Validity of Conclusions
Evaluation of the EA Screening Process	Generally considered to be adequate, although some other potential EAs could have been added.	Evaluation was qualitative and was to assess assurance, not compliance. This assumption was prescribed by law and was therefore considered valid	None.	The screening process was conservative in nature and was thus more inclusive than exclusive.	The screening process was considered to be appropriate. A better description of the process would have enhanced the report.	The sequence of comparing, scoring, prioritizing, etc. was adequate to achieve the results.	The use of algorithms and professional judgement were deemed appropriate.	The final list of EAs selected for further analysis was reasonable.
1. Long Term Repository Performance	Adequate	Broad Level: Appropriate. Detailed Level: Intrusion scenarios assumed to occur at 5,000 years; and actinide solubility assumptions were conservative. Broad Level: Appropriate; Detailed Level: Uncertainty in creep parameters was not considered. Differences in creep closure estimates could affect the quantity and rates of release; early intrusion could result in significantly different releases; and EAs with plasma processing or clay backfill were not credited with enhanced Pu immobilization.	Different creep closure models or model coefficients may affect the relative benefits of EAs; and the effects of future mining nearby could have been considered as an additional human intrusion scenario.	Uncertainty will result due to the uncertainty of input parameters; however, no severe consequences if wrong; conservative parameter estimates were used.	Use of the DAM model to predict performance was appropriate; however, important advances in creep modeling were not used. Model did not (and cannot) consider stratigraphy (e.g., anhydrite layers) in the mechanical response calculations.	Compressive strengths of waste/backfill EAs is misleading; and intrusion before creep closure not adequately analyzed.	Creep rate calculations checked and qualitatively agree.	Effectiveness of some EAs may have been underestimated due to simultaneous consideration of pre-closure and post-closure risks.
2. Uncertainty in Compliance Assessment				Relative nature of analysis allows meaningful conclusions to be drawn. Discussion of uncertainty in the results does not fully reflect the uncertainty analysis that was in fact carried out.		Methods used are completely applicable for comparative screening process		

Table 9-3. Summary of the Peer Review of the EACBS Evaluation Factors and Criteria (Continued)

Engineered Alternatives Evaluation Factors	A. Adequacy of Requirements and Criteria	B. Validity of Assumptions	C. Alternative Interpretations	D. Uncertainty of Results and Consequences if Wrong	E. Appropriateness and Limitations of Methodology and Procedures	F. Adequacy of Application	G. Accuracy of Calculations	H. Validity of Conclusions
3. Worker and Public Risk	Adequate	Risk assumptions are conservative, conventional, and adequate for the work performed.	None.	Uncertainties err on the side of safety and risks are likely overstated.	Methodology did not account for risks inherent in current waste handling methods. For example, relative risks could have been different for these EAs having long development/processing time.	Methods are applicable for the comparative screening process.	Calculations are reasonable and consistent.	Risk conclusions for CH waste appear valid. Risk conclusions for RH waste are absent.
4. Impact on Waste Removal	200 year period for waste removal requires justification; different time frames have a major impact on the methods used for retrieval.	Assumed excavation technology is appropriate, but the data used in the calculations is not state-of-the-art. For long term retrieval, assumptions and methodology used for mining rate and time estimates are correct; quantitative studies are needed. Short-term retrieval method, rate, and schedule not addressed.	Alternative methods for recovery based on different time frames could have been performed.	Uncertainty associated with the compressive strength of the EAs is not critical to the relative comparison of EAs. The waste is removable with today's technology and the decisions made based on the EACBS are not irreversible.	Methodology was appropriate to estimate time required for long-term removal; however, some of the assumptions, data, and terminology were not suitable for the application.	Time of waste removal was not adequately addressed.	Overall, calculations could not be checked for accuracy; there is no reference to machine type, specifications, and utilization.	Although the quantitative results of the analysis can not be directly used for assessment of the EAs, the general conclusions based on a qualitative comparison with the baseline are valid and acceptable for long-term removal. Consideration of short-term removal could change the results.

Table 9-3. Summary of the Peer Review of the EACBS Evaluation Factors and Criteria (Continued)

Engineered Alternatives Evaluation Factors	A. Adequacy of Requirements and Criteria	B. Validity of Assumptions	C. Alternative Interpretations	D. Uncertainty of Results and Consequences if Wrong	E. Appropriateness and Limitations of Methodology and Procedures	F. Adequacy of Application	G. Accuracy of Calculations	H. Validity of Conclusions
5. Transportation Risk	Adequate	Risk analysis assumes 20 year active life, yet the WIPP operational window is for 33 to 35 years. Transportation is by truck only, no explanation why rail is not evaluated. Overall, however, risk assumptions are conservative, reasonable and well within contemporary transportation risk analysis.	There is no reasonable alternative interpretation.	Population densities will be different if the period of transportation and disposal is greater than 20 years. An added risk could occur for those EAs which have a longer time frame.	The methodologies were considered to be generally appropriate. Limitations include addressing only CH waste, a "bounding" accident not being evaluated, and lack of justification for selected values. The limitations should not compromise the EA evaluation so long as the 20 versus 35 year issue is recognized.	Methods used are applicable for comparative screening process	Calculations appear to be reasonable and consistent with the methodology.	The conclusions drawn for purposes of a qualitative comparison of the transportation risks of the various EAs appears valid.
6. Public Confidence in the Performance of the Disposal System	Adequate	Assumptions regarding the public's concerns as to content, categorization, timeliness, and affected in-state population are reasonable. Although out of state populations were not addressed, this is not considered to be a major deficiency.	Slightly different interpretations are possible, but would not affect the conclusions of the study.	Uncertainty is low regarding the public's position on the EAs and slight misinterpretations are not considered serious.	The methodology used to assess public confidence was appropriate. A limitation is the lack of opportunity for out of state public comment.	Application of the methodology was considered proper.	Categorization of public comments was checked and determined to be relatively accurate with only minor discrepancies.	The conclusions appear appropriate.
7. System Cost and Schedule	Adequate	Cost and schedule assumptions are considered to be valid with uncertainty of approximately 30 percent associated with the uncertainty of the waste inventories.	A few alternate interpretations may originate from the guidance documents. However, they would have little effect on the study's results.	The estimated costs and schedules were reasonable.	The methodology for cost and schedule evaluation is considered appropriate.	Methodologies were appropriately applied.	Spot checks determined that calculations were performed according to accepted methods and procedures.	In general, the conclusions are valid.

Table 9-3. Summary of the Peer Review of the EACBS Evaluation Factors and Criteria (Continued)

Engineered Alternatives Evaluation Factors	A. Adequacy of Requirements and Criteria	B. Validity of Assumptions	C. Alternative Interpretations	D. Uncertainty of Results and Consequences if Wrong	E. Appropriateness and Limitations of Methodology and Procedures	F. Adequacy of Application	G. Accuracy of Calculations	H. Validity of Conclusions
8. Impact on Other Disposal Systems	Adequate	The assumptions of waste type and volume have uncertainties associated with them that may impact other disposal systems. The assumptions used appear reasonable.	The uncertainties associated with waste volume can be interpreted in different ways. Some interpretations will result in higher volumes while others will result in lower volumes.	Uncertainty of results are +10% to -25% based on waste volume uncertainty. No serious negative consequences should occur because of this uncertainty.	Procedures used are technically defensible. A limitation of the methodology is the reliance on the accuracy of waste volume.	The techniques used were adequate to meet the intended goal.	The basis of calculations was not provided in the EACBS; however, using reasonable assumptions, data spot checks were found to be accurate.	The conclusions reached are valid and support the end use of the report.

review panel recommended clarification changes to the text of the EACBS report. The DOE has determined after a review of the peer review panel comments, that no revision of this report is necessary at this time. However, the DOE will ensure that these recommendations are kept in mind when discussions of the EACBS are included in regulatory documents.

9.3.3.2.1 Peer Review Panel Concerns - Results of the Engineered Alternatives Identification/Screening Process

In general, the peer panel members thought that the identification/screening process was adequate. However, members felt that the EACBS report was not clear on the description of the screening process and expressed difficulty in understanding the steps and criteria involved. Only after presentations were made by and interactive discussions were held with those involved in the actual EACBS identification/screening process did the members come to a mutual understanding of how the process was carried out. Among the comments made by the panel are the following:

9.3.3.2.1.1 First Peer Review Panel Concern - Results of the Engineered Alternatives Identification/Screening Process

> *"Clarification is needed in the text of the report on the steps involved in the identification/screening process, including steps that occurred after the Engineered Alternatives Task Force performed their initial evaluation. Better define what is meant by "screening," "optimization," and "prioritization." Clearly state the criteria used for each stage of the process."*

Response to Issue

The DOE understands the confusion surrounding these terms, particularly in light of the multiplicity of the agencies and organizations that have expressed interest in how EAs should be applied to the WIPP. In this application, the DOE has attempted to use these terms in a fashion that is consistent with the EPA's usage in 40 CFR Part 194 and the CAG (EPA 1996c). The three processes are documented in the EACBS. The specifics of the screening process and original prioritization are found in Appendix D. The optimization process is briefly described in Appendix D, however this process included management decisions not defined in the report.

Peer Reviewer Consideration of Response

Four panel members commented on the DOE response to this concern. Two members agreed with the response and one disagreed. The fourth panelist, although agreeing that the information in the response was adequate, believed that this information should be provided in the main part of the EACBS.

DOE Technical Position versus Panel Issue

The DOE has clarified the process in Section 7.4.3.1 of this application, which includes a description of the DOE Management Assessment used to determine the final 18 EA used in the analysis.

9.3.3.2.1.2 Second Peer Review Panel Concern - Results of the Engineered Alternatives Identification/Screening Process

> *"Some concern was expressed that the screening process was conducted independent of a consideration of the eight factors used in evaluating the EAs. If the screening process and evaluation of EAs according to the eight factors had been iterative, the list of EAs analyzed as well as the results of both the screening process and the evaluation of the EAs may have been different. However, this would probably be an endless process of iterations and not justified because of cost and time involved."*

Response to Issue

In an effort to ensure a reasonable menu of alternatives for potential selection of engineered barriers, the DOE elected to separate the screening process from the actual factor analyses. The key screening criteria for selecting EAs for detailed factor analysis was therefore the impact on improving long-term performance, with additional concern given to technological and regulatory feasibility of implementation. The selected alternatives were then evaluated with respect to the eight factors. Factors such as waste retrieval or public perception were not considered in the selection criteria because these factors are not related to compliance with 40 CFR Part 191.

Peer Reviewer Consideration of Response

Three panel members commented on the response. One panelist agreed with the response as written and one other disagreed. The third commenter agreed with the response but believed that the DOE should make a stronger case that the EACBS considered the breadth of plausible alternatives.

DOE Technical Position versus Panel Issue

The DOE developed the screening process that used a qualitative assessment of the potential benefits on the WIPP disposal system. Good engineering practices were used in this assessment. A pure quantitative rating could not be justified because it would require a complete analysis of each EA by all eight factors. The intent of the screening process was to identify EAs with the highest potential to benefit the disposal system and further analyze their impacts within the multifactor analysis.

9.3.3.2.1.3 Third Peer Review Panel Concern - Results of the Engineered Alternatives Identification/Screening Process

"Remote-handled waste was not considered. This issue may have implications to the compliance application."

Response to Issue

The inventory of remote-handled (RH) waste was combined with the contact-handled (CH) waste and was not considered separately in the EACBS. RH-TRU waste constitutes a maximum of five percent of the inventory by volume. This material is practically identical to CH-TRU waste except that it is contaminated with short-lived beta-gamma emitters as well as the long-lived actinides present in CH-TRU waste. There is therefore no need to consider RH-TRU waste separately from a long-term performance stand-point. There may have been some differences in the treatment costs for the RH fraction because of the possible need for a greater degree of shielding, and there may have been additional worker risks involved because of the presence of penetrating radiation. The Engineered Alternatives Screening Working Group concluded therefore, that the limited volume of RH did not justify separate consideration of this small fraction of the inventory.

Peer Reviewer Consideration of Response

The only panel member who commented on the response agreed in part with the response; however, the panelist suggested that, for completeness, a factor approach be used that could weigh the risk and cost of handling RH-TRU waste into each engineered alternative under evaluation.

DOE Technical Position versus Panel Issue

Because the inventory of RH-TRU wastes is a small percentage of the total WIPP waste inventory, is limited by the land withdrawal area, and will decay to CH-TRU waste levels in a relatively short time period, the DOE believes that RH-TRU wastes need not be considered separately in the EACBS.

9.3.3.2.2 Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

These factors focused primarily on the analyses performed with the Design Analysis Model (DAM) computer simulation program. This program was used to predict the future performance of the repository with different engineered alternatives given three different human intrusion scenarios. Values for several parameters are required as input to the model. Many input parameters were treated as being uncertain; that is, ranges and distributions were assigned to such parameters. Other parameters were given constant (single point) values. The panel members checked many of these parameters, as well as quality assurance documentation

for the computer simulation itself. No major discrepancies or errors were noted. It was noted by the panel members that much of the information used in the model was selected to be consistent with the performance assessment being conducted by SNL. The DAM was chosen to determine relative repository performance because it parallels SNL's performance assessment work in a less complex manner allowing various changes to the inputs to be run quickly on a PC format.

9.3.3.2.2.1 First Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

> *"The simplifying assumptions used in the model are valid given that the results are to be used in a relative, not absolute, manner. Actual calculated releases of radionuclides, although not absolute, are acceptable for comparison purposes."*

Response to Issue

The DOE agrees. The relative approach was designed to produce a ranking of the alternatives in a cost-effective manner without the need to apply a full performance assessment to each EA.

Peer Reviewer Consideration of Response

The only panelist who commented on this response agreed with the DOE response.

9.3.3.2.2.2 Second Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

> *"Creep closure modeling did not consider uncertainty in creep parameters nor did it incorporate important advances in creep modeling. Different time periods for closure would have likely resulted which may have changed the relative ratings of the EAs, but the conclusions will probably not change."*

Response to Issue

The DOE agrees with this statement. The creep algorithm in the DAM uses the Chabannes Equation as a functional form, but the values of the creep constants employed in the equation are based on a multivariate regression of many years of creep closure data obtained from extensiometer and closure measurements from the actual rooms and drifts excavated at the WIPP repository horizon. This semi-empirical approach has been benchmarked against the SANCHO code (a precursor to the SANTOS code; see Appendix PORSURF) and was shown to produce comparable results. The DOE maintains that the use of the Chabannes Equation, coupled with closure constants based on empirical observations, produces results that are adequate for implementation in the DAM, which was used for relative comparisons only.

Peer Reviewer Consideration of Response

Two panel members commented on this response: one agreed with the response and the other did not.

DOE Technical Position versus Panel Issue

The DOE maintains that the use of the Chabannes Equation, coupled with closure constants based on empirical observations, produces results that are adequate for implementation in the DAM, which was used for relative comparisons only. The time variations were investigated and the conclusions are discussed in Section 3.1.3.1 of the EA report.

9.3.3.2.2.3 Third Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

> *"The EACBS report assessed the effect of human intrusion at 5000 years as well as additional simulations for the baseline and nine selected alternatives at 200, 2000, and 7000 years. This assessment concluded that the Measures of Relative Effectiveness (MREs) are insensitive to the time of intrusion once the physical properties (density and permeability) of the composite material in the room reaches a steady-state condition. This occurs some time between 200 and 2000 years. One exception is the MREs at 200 years which differ by several percent from the MREs at later years because the composite material in the rooms at 200 years is still in the process of consolidating from creep closure, and this consolidation occurs at different rates for each alternative. Consolidation of the composite material is complete by 2000 years, so the MREs remain constant thereafter. Had the analysis included radionuclide transport within the Culebra, it is likely that the results would have shown a stronger sensitivity to the time of intrusion (e.g., within a few hundred years)."*

Response to Issue

The DOE agrees that results become insensitive to the time of intrusion at a point somewhere between 200 and 2,000 years after facility closure. However, there are two factors that strongly support the DOE's approach. First, the complexity that would be required in the calculation scheme to model the brine-gas-creep closure interactions and produce higher resolution are not justified to resolve minimal percentage point differences in MRE's. Secondly, characteristics of specific EAs that affect releases due to intrusions are, for the most part, insensitive to the state of consolidation in the repository; therefore, simplifying the analysis by "skipping" the 200 to 2,000 year interval does not result in a loss of the important information that is necessary to make reasonable comparisons of the alternatives.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.2.4 Fourth Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

> *"The uncertainty analysis in the EACBS report focused on uncertainty associated with input parameters. Uncertainty associated with the model itself and with the future state of the disposal system were not considered."*

Response to Issue

The DOE agrees. Uncertainties in the conceptual model and alternative future states of the disposal system were outside the scope of the EACBS. These types of uncertainties are, of course, incorporated in the final performance assessment calculations in the application, as they are important to a reasonable prediction of repository performance, but not necessary for reasonable selections among EAs.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.2.5 Fifth Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

> *"Because the study focuses on potential benefits of EAs beyond the baseline design, consequences of reaching a wrong conclusion are not expected to be severe."*

Response to Issue

The DOE agrees. The consequences of reaching a wrong conclusion are actually non-existent because before an alternative is implemented, it will be incorporated into performance assessment.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.2.6 Sixth Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

> *"Lack of a user's manual for the DAM code makes it difficult to independently verify calculations in the EACBS report."*

Response to Issue

Unfortunately, the DAM was prepared prior to the conduct of EACBS. DAM was an existing tool selected for use in the EACBS. The code is fully documented, checked, and has been verified in calculation briefs. The code documentation is on file and was reviewed by a subcommittee of the peer review panel.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.2.7 Seventh Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

> *"The comparative, unweighted approach used for evaluating alternatives results leads to an inevitable trade-off between long-term performance and short-term risk. The DOE can avoid this pitfall by separately evaluating the merits of each EA in the post-closure phase only. Specifically, by comparing only the first two columns of results in Figure E-4 (of the EACBS report), one can more clearly see the long-term benefits offered by each EA."*

Response to Issue

While the DOE agrees with this observation, the objective of the EACBS was to compile and present information on the eight factors for each of the EAs to support decisions regarding the selection of an EA. Assigning such weighing factors or discussing trade-offs between long-term performance versus short-term risks was a process that was appropriately left to the DOE decision maker and was beyond the scope of the EACBS.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.2.8 Eighth Peer Review Concern - Evaluation of Factors 1 and 2: Impacts on Long-Term Repository Performance and Uncertainty in Compliance Assessment

> *"The effectiveness of EAs with clay backfill or vitrification treatment was underestimated because the enhanced immobilization of actinides within these matrices was not assumed."*

Response to Issue

The DOE agrees. With respect to clay backfill, it was stated in Section 3.1.1 of the EACBS report (Appendix EBS) that, although clay minerals have a well known affinity to adsorb

actinides, the lack of data under saturated brine conditions makes it difficult to take credit for this process in a defensible way. This approach is consistent with the performance assessment methodology which also concluded that data to quantify actinide sorption on the various substrates under WIPP-specific physicochemical conditions are not available, and their acquisition is not practicable. Therefore, predicting sorption under WIPP-specific conditions is not feasible. It was also explained in the EACBS report that the net effect of not considering this process is to minimize the predicted effectiveness of EAs that involve the addition of clay to the drums or backfill.

Peer Reviewer Consideration of Response

Two panel members commented on this response: one agreed with the DOE response and the other did not.

DOE Technical Position versus Panel Issue

The DOE maintains its position that there are not enough data available under WIPP-specific conditions to take credit for this process in a defensible way.

9.3.3.2.3 Peer Review Panel Concern - Evaluation of Factor 3: Impact of Engineered Alternatives on Worker and Public Risk

9.3.3.2.3.1 First Peer Review Panel Concern - Evaluation of Factor 3: Impact of Engineered Alternatives on Worker and Public Risk

> *"An evaluation of the risks associated with the processing of remote-handled (RH) waste is absent. It would be helpful to include a discussion of the possible relative comparison between the risk associated with CH and RH wastes. For example, one can draw conclusions based on radionuclide difference, radionuclide mobility, potential for release, transport mechanisms, and exposure scenarios associated with both waste processing and long-term performance."*

Response to Issue

The inventory of RH-TRU waste was combined with the CH-TRU waste and was not considered separately in the EACBS. RH-TRU waste is limited by statute to comprise no more than five percent, by volume, of the total WIPP waste inventory. This material is practically identical to CH-TRU waste except that it is contaminated with short-lived beta-gamma emitters as well as the long-lived actinides present in CH-TRU waste. These beta-gamma emitters will rapidly decay during the 100-year postclosure period during active institutional control. Therefore, there is no need to consider RH-TRU waste separately from a long-term performance stand-point.

Peer Reviewer Consideration of Response

The only panel member who commented on this response partially agreed with the DOE response. That panelist made the same comment as was expressed for the RH concern discussed in Section 9.3.3.2.1.3.

DOE Technical Position versus Panel Issue

Because the inventory of RH-TRU wastes is a small percentage of the total WIPP waste inventory, is limited by the land withdrawal area, and will decay to CH-TRU waste levels in a relatively short time period, the DOE believes that RH wastes need not be considered separately in the EACBS.

9.3.3.2.3.2 Second Peer Review Panel Concern - Evaluation of Factor 3: Impact of Engineered Alternatives on Worker and Public Risk

> *"Many of the assumptions used in assessing worker and public risk appear to be borrowed from the Environmental Management Programmatic Environmental Impact Statement (EMPEIS). While these assumptions may be valid, additional discussion of them in the text of the EACBS would provide further clarification."*

Response to Issue

Many of the assumptions and initial analysis parameter values were, as the panel has noted, taken from the Environmental Management Programmatic Environmental Impact Statement. The reason this consistency was important was to keep the EACBS risk analysis consistent with important aspects of other related DOE risk evaluations nationwide. The entire suite of WIPP National Environmental Policy Act (NEPA) documents is available for review in several locations. The DOE did not see the need to discuss these assumptions in any greater detail within the EACBS.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.3.3 Third Peer Review Panel Concern - Evaluation of Factor 3: Impact of Engineered Alternatives on Worker and Public Risk

> *"Additional risks posed by allowing the waste to remain above ground for longer time periods necessitated by some of the EAs were not evaluated. This could underestimate risks associated with those EAs."*

Response to Issue

The purpose of the EACBS study was to determine relative risks from various TRU waste processing and disposal alternatives, and did not directly include waste storage impacts as noted. It is true that in some cases waste would be stored above ground for a longer time period for some of the EAs, particularly when a given treatment process has not yet been fully developed for TRU waste. However, ultimately, a long-term disposal decision would be needed. The scope of the EACBS was to look at alternatives to support the disposal decision. It is assumed that the waste containers would be stored for an additional time period that was within the expected lifetime of the container, and therefore no repackaging related risks would be included. It is further assumed that workers will continue to limit their exposure to stored waste containers in accordance with the as low as reasonably achievable policy. Therefore, the loss of resolution did not affect the DOE decisions in important ways.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.4 Peer Review Panel Concern - Evaluation of Factor 4: Waste Removal Impact

The evaluation of Factor 4 was conducted in the context of 40 CFR § 194.44, assuming that the removal of the emplaced waste and backfill (after the regulatory closure) is possible. The factor considers the impact of EAs on waste removal after 200 years with no justification. The methodology used and the conclusions made based on a qualitative comparison using the volume and the time required for removal are acceptable. However, the following comments were made with respect to this factor:

9.3.3.2.4.1 First Peer Review Panel Concern - Evaluation of Factor 4: Waste Removal Impact

> *"Short-term removal of the waste and backfill (from regulatory closure of the repository to geological closure of the rooms) was not considered. Had the short term removal scenarios been considered, the results of relative comparison may be different."*

Response to Issue

The DOE agrees with this statement. However, waste removal should not significantly influence the selection of an EA since the regulations clearly state that no additional actions are needed for mined geologic repositories to meet removal requirements. Therefore, an arbitrary point in time at 200 years after facility closure was chosen for convenience to evaluate the differences between the EAs with respect to the relative ease attributed to waste removal. It was beyond the scope of the EACBS to evaluate these differences as a function of time. A separate report has been prepared to demonstrate that it is technically feasible to

remove the waste should a future generation decide to do so. It is included as Appendix WRAC (Waste Removal After Closure).

Peer Reviewer Consideration of Response

Two panel members commented on the DOE response: one agreed with the DOE response and one did not.

DOE Technical Position versus Panel Issue

The DOE recognizes that the EPA requires an assessment of the feasibility of removing wastes from the repository after closure, and that these effects should be considered when selecting an engineered barrier alternative. The DOE has conducted this required assessment and has concluded that, using current technology for mining (a provision of 40 CFR § 194.25[a]), wastes of any form can be retrieved from the underground. This does not imply that removal of wastes would be simple or without risk. If fact, the level of risk and the cost are the uncertain variables in the various scenarios (that is, waste in degraded steel drums versus vitrified waste forms). Undoubtedly, a substantial level of radiological controls will be required to protect workers, and the process would span many years. Because of the effective design, construction, and management of the WIPP facility, combined with the demonstration of compliance with the long-term performance standards of 40 CFR 191 (see Section 6.5), the DOE does not believe that removal of wastes will be necessary. Therefore, this factor was not given special attention when selecting the current suite of engineered barriers.

9.3.3.2.4.2 Second Peer Review Panel Concern - Evaluation of Factor 4: Waste Removal Impact

> *"If waste removal had been one of the evaluation criteria, different alternatives may have reached the detailed evaluation stage (e.g., the EAs which passed through each screening process may have included one or more additional alternatives than the EAs contained in the final list)."*

Response to Issue

As stated above, the DOE chose not to emphasize removal in order to be consistent with the disposal standards. The standards require only that removal be possible, not easy, inexpensive, or free of risk. Therefore, the DOE believed it was best to ensure that there was no selection bias introduced based on removal.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.4.3 Third and Fourth Peer Review Panel Concerns - Evaluation of Factor 4: Waste Removal Impact

"The results of implementing any of the EAs would not be irreversible and waste could be removed after disposal, using current technology.

The assumptions and conclusions should be used for comparative purposes only. Some assumptions used for quantitative calculations were inappropriate for the circumstances but serve the purpose for a comparative study."

Response to Issues

These statements are correct. The goal for the study was indeed to produce relative results for comparison purposes only. Particular assumptions such as the use of current technology (continuous mining techniques) to remove the waste 200 years from final facility closure are consistent with EPA guidance for future state assumptions applicable to similar processes such as future drilling.

Peer Reviewer Consideration of Response

Two panel members commented on the above response. One panelist agreed with the DOE response, while the other believed that a study of the relative impacts of EAs on waste removal was within the scope of the EACBS.

DOE Technical Position versus Panel Issue

As stated previously, the DOE agrees that the Factor 4 analysis can be used only for comparative purposes. The specifics as to which technology should be used are not important. As the commenter noted, they serve the purpose for a comparative study.

9.3.3.2.5 Peer Review Panel Concern - Evaluation of Factor 5: Impact of Engineered Alternatives on Transportation Risk

9.3.3.2.5.1 First Peer Review Panel Concern - Evaluation of Factor 5: Impact of Engineered Alternatives on Transportation Risk

"The "worst-case" accident considered in the reference document for the EACBS (the Final Supplemental Environmental Impact Statement) appears to have been eliminated from consideration in the EACBS with no justification. RADTRAN accounts for accident severity categories within its code. Therefore, modeling of an additional worst-case accident would not provide substantive additional information."

Response to Issue

The "worst-case" accident scenario and analysis was required for NEPA documentation at the time the Final Environmental Impact Statement (FEIS) was prepared. Such an analysis is no longer required. Consequently, a worst case analysis was not performed as part of the EACBS. As noted, such a bounding approach would not have provided important additional information for the purpose of the EACBS.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.5.2 Second Peer Review Panel Concern - Evaluation of Factor 5: Impact of Engineered Alternatives on Transportation Risk

> *"For chemical hazards, risks are calculated solely on a consideration of wasteform characteristics. Transportation-related aspects of the scenario (e.g., mileage, population, density) were not included; an accidental release was simply assumed. The full range of transportation impacts cannot, therefore, be evaluated."*

Response to Issue

In general, transportation routes, population density, and highway mileage traveled during transport are basically constants in the relative comparison of exposure risk among the different waste forms generated by the different EAs. For this reason, the calculation of the full range of impacts would not change the outcome of the analysis in important ways. It was therefore not included in the EACBS.

Peer Reviewer Consideration of Response

Two panel members commented on the above DOE response. One agreed with the DOE response and the other did not.

DOE Technical Position versus Panel Issue

Transportation routes, population density, and highway mileage are the same for each alternative when considered in the same processing scenario. For example, transportation routes are the same for all alternatives in the decentralized scenario. The same is true for the centralized scenario as well as the regionalized scenarios. All waste must follow the same routes, through the same towns, for the same number of miles within each scenario. Therefore, the exclusion of chemical risk assessments for transportation scenarios does not affect the overall results of the EACBS.

9.3.3.2.5.3 Third Peer Review Panel Concern - Evaluation of Factor 5: Impact of Engineered Alternatives on Transportation Risk

> *"The analysis in the EACBS relies heavily on previous work done in the WIPP Final Environmental Impact Statement (FEIS) and the Final Supplemental Environmental Impact Statement (FSEIS). However, methods used in the previous reports varied; information was not provided in the EACBS to indicate which methods came from original documents and what the justification was for using the methods selected in the EACBS."*

Response to Issue

The FEIS (DOE 1980a) was issued in 1980, and the Final Supplement Environmental Impact Statement (FSEIS) (DOE 1990a) was issued in 1990. The DOE methodology for evaluating transportation risk has not significantly varied or changed over the past 14 years. There has, however, been some degree of refinement to the methodology, numerical models, and assumptions used to estimate transportation risk. Transportation risks will be updated for the baseline case in the Disposal Phase Supplement Environmental Impact Statement (SEIS). Transportation risk methodologies were derived from these NEPA analyses sources. This was done to ensure important consistencies between risk evaluation methods were preserved. The method justifications can be reviewed in the NEPA documentation. Including these justifications in the EACBS is not believed to be important considering the purpose of the study.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.5.4 Fourth Peer Review Panel Concern - Evaluation of Factor 5: Impact of Engineered Alternatives on Transportation Risk

> *"The risk analysis assumes a 20-year life for transportation and disposal of waste; however, the operational window for WIPP is approximately 35 years. Additional population densities might affect the impact analysis of alternatives that require treatment and greater than 20 years to complete transportation and disposal. The panel members do not feel that the apparent discontinuity in this assumption is limiting to the assessment of transportation-related risks."*

Response to Issue

The DOE agrees. The transportation risk as presented is not time dependent. As calculated, the risk is based on the total number of shipments to WIPP, thus the total risk posed by the waste does not change appreciably with respect to time. The annual risk could change if the number of shipments per unit time varies, but the annual risk calculations were not needed,

and were therefore not included in the analysis for the EACBS. Population densities, as noted, could change over time (35 years), but such change would affect all alternatives equally, thus the EACBS conclusions would still be valid and accurate.

Peer Reviewer Consideration of Response

The only panel member who commented on this response agreed with the DOE response.

9.3.3.2.6 Evaluation of Factor 6: Impact of Engineered Alternatives on Public Confidence

The peer review panel did not find any particular areas of concern with the public confidence evaluation, and felt that the methods used and conclusions reached were appropriate and reasonable. There are no specific comments or areas of concern in need of response.

9.3.3.2.7 Evaluation of Factor 7: Total System Cost and Schedule Estimates

The peer review panel found no significant flaws in the cost and schedule analysis. The panel agreed that the development of cost and schedule estimates was reasonable, appropriate, and defensible. There were no specific comments or areas of concern in need of response for this factor.

9.3.3.2.8 Peer Review Panel Concern - Evaluation of Factor 8: Impact on Other Waste Disposal Programs

The peer review panel concluded that the analysis for impacts to other waste disposal programs was conducted using the best available information. However, they felt that the evaluation should be updated as more recent and accurate data become available to ensure adequate facilities and resources are available for disposal. The following comments were offered:

9.3.3.2.8.1 First Peer Review Panel Concern - Evaluation of Factor 8: Impact on Other Waste Disposal Programs

> *"Except for plasma arc, all other EAs that included treatment are assumed to result in waste volumes similar to cementation processes used at Rocky Flats (an increase of 75 percent). An additional 30 percent of secondary waste is anticipated to be generated, resulting in a total of 2.275 drums from the treatment of a single drum."*

Response to Issue

The first sentence is correct: except for plasma arc, all other EAs that include treatment are assumed to result in secondary waste volumes similar to cementation processes at Rocky Flats (0.75 drums of secondary waste generated per drum of waste treated). However, additional secondary waste is generated in the waste characterization step that precedes treatment, which

is the same for the baseline and all EAs. Thirty percent of stored waste and ten percent of projected waste passes through the waste characterization step; for this waste, 0.75 drums of secondary waste will be generated per drum of waste characterized. The total secondary waste generated will not be as high as the 2.275 drums per input drum, as stated, but will be on the order of 0.975 drums per input drum for stored waste and 0.825 drums per input drum for projected waste (stored waste: 0.75 drums per input drum generated from treatment plus 0.75×30 percent generated from characterization = 0.75 + 0.225 = 0.975).

The peer review subcommittee apparently misinterpreted the term "secondary waste." Secondary waste includes wastes generated indirectly as a result of processing TRU waste, (for example, waste from processing related glovebox operations), and does not include waste volume increases or decreases directly related to the treatment operation. These wastes are considered "primary wastes." A cementation treatment process would generate more primary waste than, say, supercompaction, but the secondary wastes were assumed to be generated at the same rate regardless of the treatment process. This is valid because the majority of the secondary wastes result from processing related to glovebox operations for TRU waste and are not process-specific. For example, secondary wastes include leaded glovebox gloves, glovebox and plenum filters, line and non-line combustibles, protective equipment (PE), and empty glass and plastic containers. It was also assumed that the characterization step generates secondary wastes at the same rate as cementation and the other treatment processes because it would be conducted in a glovebox.

Peer Reviewer Consideration of Response

The two panel members who commented on this response agreed with the DOE response.

9.3.3.2.8.2 Second Peer Review Panel Concern - Evaluation of Factor 8: Impact on Other Waste Disposal Programs

> *"The EACBS report for this factor is difficult to follow at times and could benefit from clarification and the use of examples to show how waste volume estimates were made."*

Response to Issue

The DOE appreciates the feedback. There will be a clear explanation of waste volume estimating processes in Section 4.1.3 of this application.

Peer Reviewer Consideration of Response

The two panel members who commented on this response agreed with the DOE response.

9.3.3.2.8.3 Third Peer Review Panel Concern - Evaluation of Factor 8: Impact on Other Waste Disposal Programs

"It is not clear by reading the EACBS report how the volumes of waste destined for WIPP are factored into the report. A best estimate of waste to be disposed should be provided for WIPP operations personnel."

Response to Issue

The methods used to estimate waste volumes and the incorporation of these estimates into the EA study was not important. The DOE will include a clear description of these methods in the compliance certification application where they are much more important. (This information is presented in Chapter 4.0 and Appendix BIR.) Disposal estimates will be gathered annually by the DOE and reported in the BIR. This mechanism will ensure that the operations personnel are provided with the most current inventory estimates.

Peer Reviewer Consideration of Response

The two panel members who commented on this response agreed with the DOE response.

9.3.3.2.8.4 Fourth Peer Review Panel Concern - Evaluation of Factor 8: Impact on Other Waste Disposal Programs

"Percentages of secondary waste generated vary widely with respect to the type of EA implemented. However, the report uses 50-percent figure for both low-level and low-level mixed secondary waste. The use of the actual average percentages would provide a more accurate estimate of waste volumes generated."

Response to Issue

The 50-percent figure was a simplifying assumption that was made in the absence of real data. This assumption is also conservative; making the waste type unimportant.

Peer Reviewer Consideration of Response

The two panel members who commented on this response agreed with the DOE response.

9.3.3.2.8.5 Fifth Peer Review Panel Concern - Evaluation of Factor 8: Impact on Other Waste Disposal Programs

"The actual waste that may be generated by implementing an EA may be as much as 10 percent higher or 25 percent lower than the estimated volumes after treatment, which are provided in the EACBS. This uncertainty is acceptable at this time, as no

definitive information is available to provide a more accurate estimate. These estimates should be revisited and revised as more information becomes available."

Response to Issue

The DOE agrees and has plans to identify any significant, new waste inventory information as it becomes available. The reevaluations will focus on validation of the decisions made based on the EACBS and will be based on the most current BIR information.

Peer Reviewer Consideration of Response

The two panel members who commented on this response agreed with the DOE response.

9.3.3.2.8.6 Sixth Peer Review Panel Concern - Evaluation of Factor 8: Impact on Other Waste Disposal Programs

"The report could benefit by a discussion of other possible impacts on the different DOE disposal systems, not just waste generation."

Response to Issue

The analyses, as performed in the EACBS, were designed to meet the general criteria of 40 CFR Part 194, to address the additional waste generation associated with waste treatment and the implementation of EAs. Such other possible impacts were not believed to be important to the decisions made based on the EACBS. Such impacts are appropriately captured in the EMPEIS where their impacts are more important.

Peer Reviewer Consideration of Response

The only panelist who commented on the above response believed that, although the panel did not identify significant items needing to be addressed, the EACBS should discuss other possible impacts for completeness.

DOE Technical Position versus Panel Issue

The DOE maintains that its original response adequately addresses the issue.

9.3.4 Engineered Systems Data Qualification Peer Review

An Engineered Systems Peer Review (ESPR) Plan (see Appendix PEER) was developed and approved in accordance with the requirements of TP 10.5. The plan describes the peer review process used to ensure that the data used in the models describing engineered systems for rock mechanics and shaft/borehole seals in the performance assessment are qualified for use in the demonstration of compliance.

The DOE used an Independent Review Team (IRT) to carefully review the existing data that was necessary to support the performance assessment. Much of the existing data were qualified because the IRT determined that the quality assurance program in place at the time of its collection was equivalent to American Society of Mechanical Engineers (ASME) nuclear quality assurance (NQA) requirements. It was determined however, that some data used to describe engineered systems could not be qualified in that manner.

40 CFR § 194.22(b) states that:

> *"Any compliance application shall include information which demonstrates that data and information collected prior to the implementation of the quality assurance program required pursuant to paragraph (a)(1) of this section have been qualified in accordance with an alternate methodology, approved by the administrator or the administrator's authorized representative, that employs one or more of the following methods: peer review, conducted in a manner that is compatible with NUREG-1297...."*

The purpose of the ESPR was to seek qualification of scientific data by systematically reviewing parameters and subsystems used in the models describing engineered systems. The conceptual models used in the performance assessment of the engineered systems include components of

- disposal room geometry,
- creep closure,
- repository fluid flow,
- shafts and shaft seals, and
- DRZ.

The review was conducted by four panel members. The panel members and their affiliation were

Dermot Ross-Brown (Chairman), Independent Consultant
John Gibbons, Independent Consultant
Darrell Porter, Science Applications International Corporation
John Schatz, Independent Consultant

Dr. Ross-Brown has a Ph.D. in rock mechanics and more than 30 years experience as a mining/civil engineer. He has been heavily involved in nuclear waste disposal since 1975, including planned repositories in salt, granite and tuff.

Dr. Gibbons has over 25 years of experience consulting to the nuclear industry. He has been involved in several research and field studies of the behavior and geology of bedded salt deposits since 1965. Since 1976, Dr. Gibbons has also been a principal investigator for

hydrogeology in many low-level nuclear waste and uranium mine and mill tailings projects in the southwestern United States.

Dr. Porter has 34 years of experience in rock mechanics. During the past 13 years, he has supported the U.S. Geological Survey in its site characterization program for the Yucca Mountain project.

Dr. Schatz has 29 years of experience in rock properties testing and analysis, including nuclear waste-related activities at the national laboratories and in commercial industry. Dr. Schatz has been involved in IRT panels, which reviewed the existing WIPP data and its associated QA program.

The panel members have well established academic and professional credentials and were independent of the WIPP performance assessment activities. Additional information concerning the panel member qualifications is provided in the peer review report (see Appendix PEER). Documentation of panel member independence also presented in Appendix PEER. All of the technical disciplines needed to perform this task were represented on the panel.

Prior to beginning their review, the panel members received administrative orientation and training on the ESPR Plan, 40 CFR Parts 191 and 194, the QAPD, NUREG-1297 and TP 10.5. The panel reviewed information packages provided by SNL for each parameter. In addition, technical reports and documents obtained from the SNL waste management library and records center were used to supplement the information in the parameter packages provided. Both formal and informal technical discussions were held with SNL principal investigators to more fully understand the concepts, parameter derivation, and application in the performance assessment.

The panel performed an in-depth critique of assumptions, alternate interpretations, methodology and acceptance criteria employed, and of conclusions in the original work. According to the "Description of Work Performed" in their final report, the panel members considered:

- sources of the parameters and data, for example, professional judgment, published source material, field tests, laboratory experiments, etc.;
- appropriateness of the parameters and data for their intended use; and
- assumptions, calculations, extrapolations interpretations, methods, appropriateness, validity, sensitivities, and conclusions pertinent to the parameters and data used as input to the WIPP Performance Assessment.

The data that were considered by the panel supported the models describing engineered systems and were used to derive parameter values that are incorporated into the models. In some instances, parameters were consolidated into parameter groups.

Fourteen parameters (several of which were actually groups of closely related parameters) were evaluated by the panel. The panel qualified seven of the parameters and two of the parameter groups (properties of halite and anhydrite, and data on final porosity surface). In the panel's opinion, minor changes should be made to two of the parameters (pore volume compressibility of Salado mass concrete (SMC) and permeability of consolidated waste), and further analysis by SNL is needed on two other of the parameter groups (permeability of crushed salt and the strength of the waste for spalling ("blowout") releases. The panel concurred with SNL's general treatment of the remaining parameter (general treatment of the DRZ). Table 9-4 lists the parameters reviewed by the panel and summarizes the panel's conclusions regarding their adequacy.

Table 9-4. Summary of Qualification Status of Parameters, as a result of the Engineered Systems Peer Review

Subsystem	Parameter Name	Qualification Status of Parameters
Shaft/shaft Seal	Porosity of SMC	Qualified
	Pore Volume Compressibility of SMC	Minor change to value suggested*
	Bulk Modulus of Crushed Salt	Qualified
	Permeability of Crushed Salt	Requires further analysis by SNL*
	Permeability of SMC	Qualified
	Permeability of Compacted Clay	Qualified
Disposal Room/ Rock Mechanics	Initial Density of Waste	Qualified
	Mechanical Properties of Waste	Qualified
	Initial Water Content of Waste	Qualified
	Permeability of Consolidated Waste	Minor change to value suggested*
	Strength of Waste for "Blowout"	Insufficient data to qualify*
	Properties of Halite and Anhydrite	Qualified, based on limited review**
	Data on Final Porosity Surface	Qualified, based on limited review**
DRZ	Characterization of DRZ	Concepts qualified

* The panel subsequently determined, on the basis of additional input from the DOE, that the DOE responses had reasonably addressed their concerns.

** The panel chose to consider these parameters from an overview approach, however, the panel was able to qualify these parameters.

Initially, the ESPR panel failed to qualify four of the parameters (or parameter groups) which they reviewed. Where appropriate, the DOE interpreted the ESPR panel's concern and in all four cases developed a WIPP project response. The ESPR panel's concerns (in italics), the DOE's interpretations of the panel's concerns ("Statement of Issue"), where appropriate, and

their responses ("Response to Issue") are provided below. The panel then reviewed the response to determine whether the DOE understood the issue and provided a reasonable response ("Peer Reviewer Consideration of Response").

The DOE responses were provided to the panel as individual memoranda. For incorporation into this application, the responses have been edited to remove the memorandum format, consolidate references, replace first-person text, insert cross-references where appropriate and correct typographical errors. Substantive technical content of the responses has not been changed.

Based on the additional information the DOE provided in response to the panel's concerns, the panel subsequently concluded that the DOE had reasonably addressed their concerns for all the parameters and parameter groups. The data used to derive the parameters and parameter groups that were reviewed by the ESPR panel were therefore qualified per 40 CFR § 194.22(b).

At the completion of the review, the panel prepared a documented summary of its work and an evaluation of the selected parameters reviewed by the panel. A copy of the Engineered Systems Data Qualification Peer Review Report, dated July 1996, is provided in Appendix PEER. The following provides the initial evaluation of each parameter (or parameter group) that was qualified by the peer review as quoted from the "Executive Summary" of the ESPR Report:

- *"Porosity of Salado Mass Concrete (SMC). The panel is able to qualify the value of 5%. However, this value is not a unique property of SMC; rather, it is a property that needs to be controlled in the field during the mixing and placing of the concrete".*

- *"Bulk Modulus of Crushed Salt. The panel was able to qualify the values for this parameter (ranging from 5.74 to 20.67 GPa) at five different time intervals during the consolidation process."*

- *"Permeability of SMC. The panel concurs with the selected values for this parameter. Up to 400 years, this is a triangular distribution with a best estimate of 1.78×10^{-19} m^2. After 400 years, the SMC is assumed to deteriorate and acquire the permeability of a dense soil with a best estimate value of 1×10^{-14} m^2."*

- *"Permeability of Compacted Clay. The panel is able to qualify the value of 5×10^{-19} m^2 for the bentonite seals. The validity of this number depends to a large extent on how the bentonite is emplaced during construction and its consistency, particularly with regard to density."*

- *"Initial Density of Waste. The panel concurs with the average value of 559.5 kg/m^3 that is in use for the current inventory when used as input to room porosity calculations."*

- *"Mechanical Properties of Waste. The panel is able to qualify five elastic-plastic constants for the waste, together with a pressure-relative density table for the waste during the consolidations process. These values are appropriate for use in disposal room closure calculations."*

- *"Initial Water Content of Waste. The panel is able to qualify the value of 1.5%, which represents the initial waste container saturation by volume."*

- *"Properties of Halite and Anhydrite. The panel is able to qualify these parameter values for use in mechanical response models used for room closure predictions."*

- *"Data on Final Porosity Surface. The porosity surface is a valid method of describing disposal room closure as an input to BRAGFLO. The panel is able to qualify the final porosity surface as defined in WPO#35697."*

- *"Characterization of Disturbed Rock Zone. The panel concurs with the engineering concepts regarding the DRZ and its impacts on effective shaft sealing. The panel was not asked, however, to qualify any parameter values."*

9.3.4.1 Peer Review Panel Concern - Pore Volume Compressibility of SMC

There was little data in the data package to enable this value to be calculated. The panel was able to find some new data that Sandia should consider in deriving a modified value for this parameter.

Statement of Issue

There were little data in the data package to enable this value to be calculated. The Panel was able to find some new data which the DOE should consider in deriving a modified value for this parameter.

Response to Issue

A slightly different value for compressibility of SMC was derived by the panel. The panel concurred with the calculational methods. Their calculation yielded a value of 0.9 GPa^{-1} as compared to a value of 1.2 GPa^{-1} from Form 464 prepared by SNL for performance assessment calculations. The reason for the discrepancy is twofold: the DOE provided the panel with the most recent data (Pfeifle et al., 1996), which was not available at the time the probability distribution function (PDF) was developed. They interpreted values for Poisson's Ratio slightly differently based on this newest data. The panel further calculated a range of values, and the value of 1.2 GPa^{-1} is on the high end of their range. The difference between the panel's value and the one provided to performance assessment is approximately 33 percent, around the range of uncertainty of the value for porosity.

Performance assessment calculations have shown that model performance measures are insensitive to the storage capacity of the seals (WIPP Performance Assessment Department 1992). Porosity and rock compressibility are both used in the development of the rock storage parameter. Although there is some uncertainty in these parameters, the purposes of performance assessment are adequately met through provision of engineering values for these parameters. Consequently this parameter will not be changed at this time. A revisit to the existing data will be made before the next set of performance assessment calculations.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response. Therefore, the data included in this package are qualified per 40 CFR § 194.22(b).

9.3.4.2 Peer Review Panel Concern - Permeability of Crushed Salt

> *Based on current data, the Form 464 values may be too low, but new data being analyzed by SNL may establish the validity of these values or lead to a modification of them. The panel was unable to form a conclusion until this analysis is completed.*

Statement of Issue

The ESPR panel has suggested that the permeability versus fractional density data be reviewed, and consideration given to development of two trend lines as a means to interpret the permeability versus fractional density of the compacted crushed salt shaft seal component, and that more data and analysis is necessary in order to justify the interpretation taken in development of the PDFs.

Response to Issue

The PDF (best estimate and upper and lower bounds) on the Form 464 for the permeability of crushed salt is appropriate, because the range of values incorporated into the PDF take into account virtually all of the data obtained, and any reasonable extrapolation thereof. To justify this point, first an explanation will be given as to why the interpretation of the permeability versus density function, given in Figure 9-27, was selected as opposed to the interpretation suggested as a possibility by the peer review panel, given in Figure 9-28. Then, further justification will be given for the selection of the interpretation given in Figure 9-27.

The panel raised the issue that since the data fall into what, at a first glance, appear to follow two trends, why not draw a line through each? This interpretation was not taken because conditions which fell outside the range of scientific expectation were not included in the development of the permeability versus fractional density relationship for crushed salt, and consequently not in the development of the PDF for the permeability of crushed salt. The following discussion explains this interpretation in more detail.

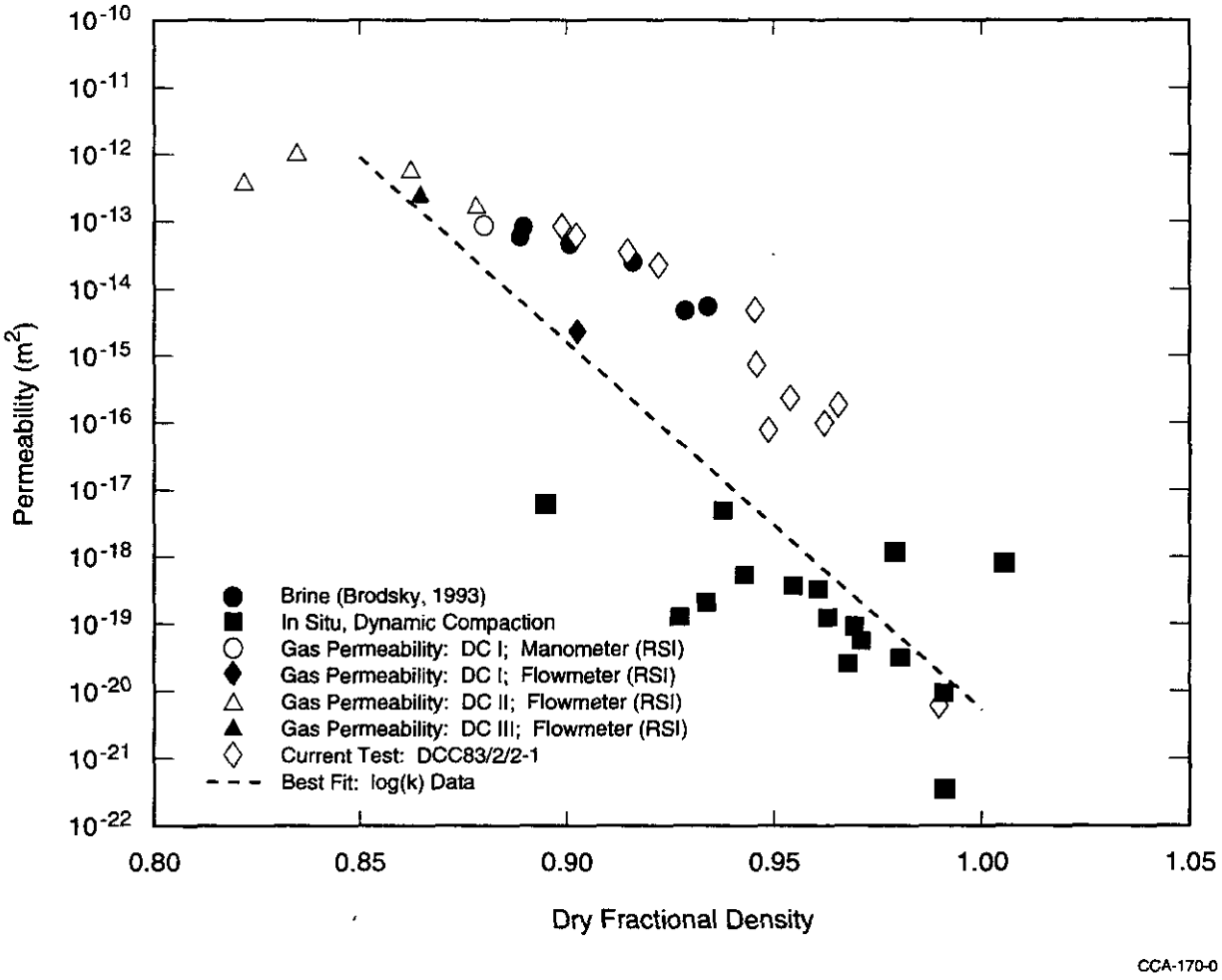

Figure 9-27. Permeability versus Fractional Density for WIPP Crushed Salt

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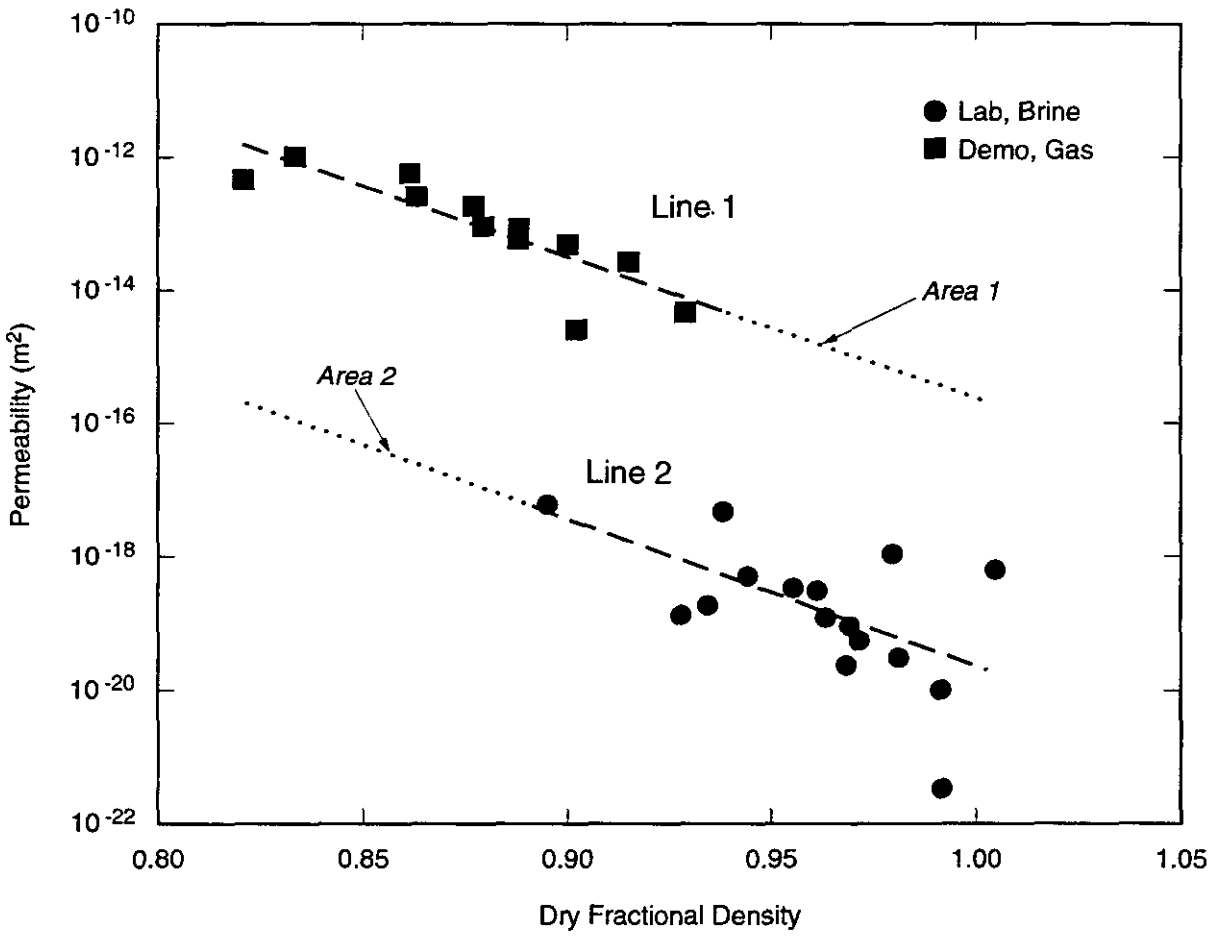

Figure 9-28. Crushed Salt Permeability Data with Two Power-Law Trend Lines Representing Brine Permeabilities on Lab-Prepared Samples and Gas Permeabilities on Field Demonstration Samples

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The objectives of PDF development is to provide an engineering approximation for the properties of the seal materials for use within the WIPP Performance Assessment conceptual models. As such, these properties need not incorporate behaviors which fall outside the range of reasonable expectation. The data given in Figure 9-27 are a result of: (1) gas permeability measurements performed on dynamically-compacted crushed salt (data at low densities, Hansen and Ahrens 1996); and (2) brine permeability measurements performed on loose mine-run salt consolidated under conditions of hydrostatic and shear consolidation stresses (data at high densities, Brodsky 1994). If the permeability function was developed solely on the basis of the dynamically-compacted specimens, as shown in Line 1 in Figure 9-28, estimates of the salt column permeability at intact densities would be on the order of 10^{-15} square meters, instead of 10^{-21} square meters, which is generally considered reasonable for intact salt. This interpretation is not defensible, due to the extrapolation shown as Area 1 in Figure 9-28. In addition, Line 1 in Figure 9-28 is not considered applicable to the material used in the shaft seal components because the dynamically compacted specimens used in these tests were dry (significantly more so than will be the crushed salt seal material). Laboratory experiments have demonstrated that the dry consolidation process will not continue, even at high confining pressures, beyond a fractional density of about 0.95, making Area 1 in Figure 9-28 physically unattainable. To achieve fractional densities higher than 0.95 requires the addition of small quantities of brine.

When brine is added to a consolidating crushed salt component, the deformation process more closely resembles the process that occurred in the Brodsky tests (high density data on Figure 9-27). Since the use of Line 1 alone would result in predictions considered indefensible, it was not used alone to develop the ranges for the PDF. Figure 9-29 depicts the 5 percent and 95 percent predictor lines for the salt permeability which were used in the development. Because extrapolation of this data to intact densities is not reasonable, the proposed extrapolation (Area 1 of Figure 9-28) was not included in the range of values used in development of the PDF. Similarly, if the PDF was developed solely on the basis of the Brodsky tests (Line 2 in Figure 9-28), the initial permeability of the salt column would be approximately 100 times less than that expected on the basis of full-scale experiments. Using this line alone would not yield a defensible result, and therefore this line alone was not used to develop the ranges for the PDF. The same rationale for exclusion of Area 1 on Figure 9-28 led to exclusion of Area 2 on Figure 9-28; hence, it was not included in the range of values for the PDF. The panel also asked that since the data appear so dissimilar, why draw a line through them? The explanation is that the data from the dynamically compacted specimens with fractional densities of about 0.90 are representative of conditions expected for early times after seal emplacement and the Brodsky data for fractional densities greater than about 0.95 are representative of conditions expected for the long term. Therefore, lacking any data to the contrary, a best fit line was drawn through these data. The basis for these expectations, and why the single line is actually a more accurate interpretation of the permeability versus fractional density function than the data may indicate are presented in the following paragraphs.

The properties of the dynamically compacted specimens will closely approximate those present in the WIPP compacted salt columns immediately following seal system construction, that is, low density and relatively high permeability. Permeability tests were performed on several specimens recovered from the large-scale dynamically compacted crushed salt experiments to establish this initial high permeability. Permeability estimates derived from Brodsky's experiments are considered representative of the intrinsic permeability of the compacted crushed salt at high fractional densities, that is, long term. These laboratory tests entailed hydrostatic and shear consolidation of partially to fully saturated mine-run salt, followed by brine flow testing. This procedure emulates conditions expected in the WIPP shafts within several decades of construction of the compacted salt columns. Since the data sets closely approximate the conditions at the WIPP at both initial emplacement times (low densities) and long term (high densities), both data sets are applicable and were included in the analysis of the permeability versus fractional density for the crushed salt seal material. Therefore, virtually all the data from these two tests were included in the ranges used in development of the PDF, as can be seen in Figure 9-29.

The range used to establish PDF bounds (5 percent and 95 percent predictor lines on Figure 9-28) covers nearly six orders of magnitude at a given fractional density, and is quite conservative. A question arises as to how the permeability transitions from the initially high values measured for dynamically compacted crushed salt to the low values reported for mine-run salt. Data were obtained in this transition region by performing permeability tests on dynamically compacted crushed salt specimens that were further consolidated under high hydrostatic stress. Unfortunately, these specimens were quite dry. The field test chamber for the dynamic compaction demonstration was heated, and the test required over 3 months to complete. Initial moisture was unavoidably lost and cores extracted from the test chamber may have lost additional moisture during transport and sample preparation. It is known that the initial moisture content of the compacted salt mass was considerably higher than that of test specimens. The materials specification for the WIPP shaft seal call for a moisture content of 1.5 percent by weight for the actual crushed salt seal component.

The consolidation data acquired for the dynamically compacted specimens indicate that the crushed salt material consolidates more slowly or requires greater pressure than anticipated to achieve higher densities. Optical and scanning microscopy of deformed and undeformed samples of crushed salt was performed to document the deformational processes that produce consolidation (void space reduction) and provide an explanation for these apparently anomalous data.

As observed through microscopy, consolidation is dominated by pressure solution and redeposition, a mechanism of mass movement facilitated by the presence of moisture on grain boundaries. As shown by Holcomb and Shields (1987), dry salt aggregate does not effectively consolidate. Because the dynamically compacted specimens were dry, the effective process of void space reduction-pressure solution/redeposition was not active during consolidation, but is expected to be very active in the WIPP seal components. Further, the consolidation was accomplished by crystal plasticity which is not effective in filling minute void spaces on grain

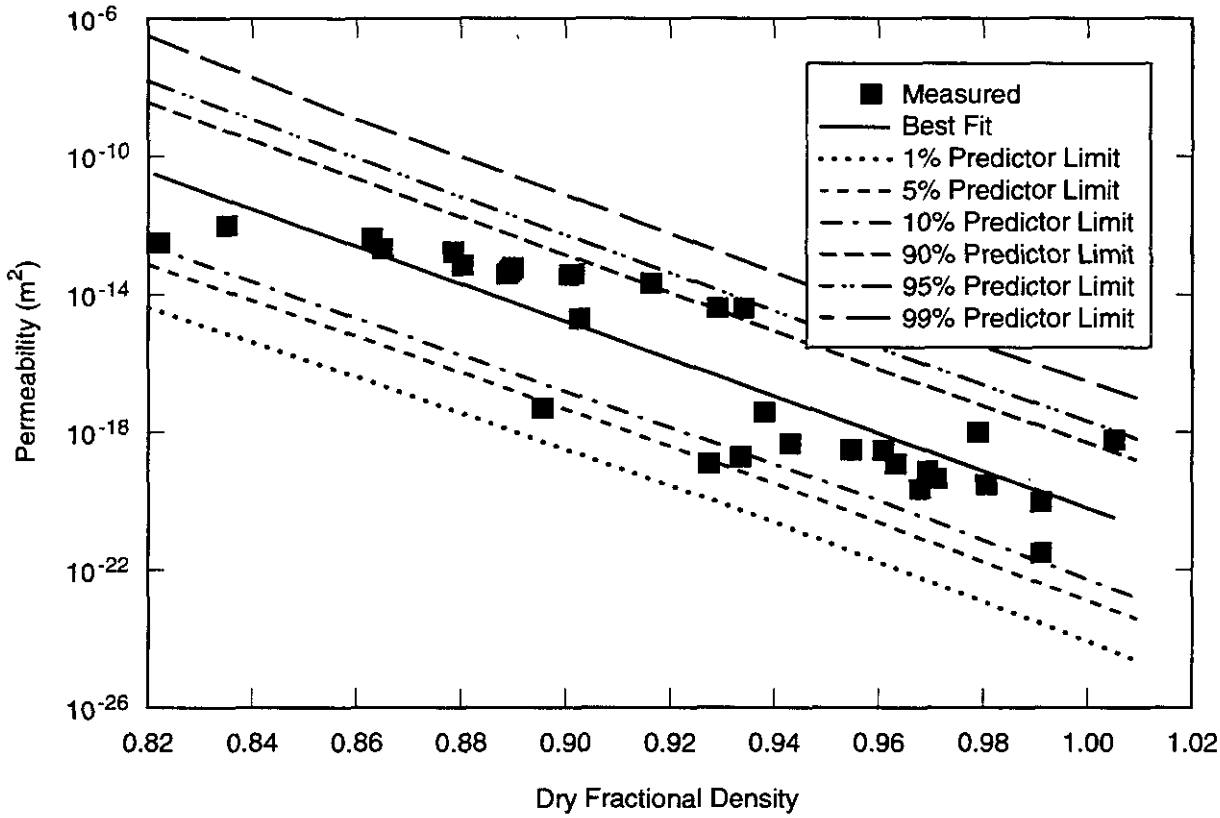

Figure 9-29. Measured and Predicted Permeability versus Fractional Density for the Compacted Crushed Salt Columns

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boundaries. Therefore, at equivalent densities, dry consolidated salt would remain more permeable than wet-deformed salt. The consolidation process expected in the shaft is fluid-aided pressure solution. The placed shaft seal salt will not dry in a manner similar to the large-scale compaction test, will retain moisture, and will consolidate readily to low permeability.

More recent experiments conducted on dry compacted specimens (Stuhrenberg and Zhang 1995) further substantiate that moisture content and particle size significantly impact the initial permeability and consolidation processes of crushed salt. At moisture contents similar to those of the dynamically compacted specimens, comparable permeabilities to the dynamically compacted specimens were measured. They also showed that permeability decreased as the maximum particle size decreased. It can be argued that the "extreme particle size distribution" present in the WIPP dynamically-compacted seals will produce a favorable result in the consolidation process. The presence of fine particles mixed throughout the compacted mass is likely to result in rapid localized consolidation due to the higher surface area attributable to these particles. As this process continues, the connected porosity, and hence, permeability of the composite mass will reduce at rates greater than those predicted by WIPP experiments. This hypothesis is further substantiated by Stuhrenberg and Zhang's result that compaction of specimens having smaller grain sizes have lower permeabilities than specimens composed of larger particles. Therefore, the permeability measurements made on dynamically compacted crushed salt specimens having densities in the range of 0.90 to 0.95 do not represent expected in situ conditions.

An additional argument for the conservatism inherent in the PDF development can be derived by examining the testing method. Testing of the dynamically-compacted specimens utilized nitrogen gas as the permeant fluid. In general, gas permeability measurements are performed at different fluid pressure gradients so that the measured permeability values can be corrected for Klinkenberg effects. However, flow rates through the dynamically-compacted specimens were quite high, requiring the use of rotameter flow meters to measure gas flow rates. These meters are calibrated for a single fluid pressure; hence flow measurements were made using a single fluid pressure gradient and the Klinkenberg correction could not be applied to these test results. This correction would reduce the permeability calculated from the gas flow rates measured during test conduct. Therefore, results presented for dynamically compacted specimens can be considered maximum estimates of the compacted salt permeability. Also, additional analysis of the data has led to the conclusion that brine saturation of the dynamically-compacted specimens was sufficiently low, such that relative permeability effects were inactive. These relative permeability effects would provide estimates of permeability that are lower than intrinsic values. It can be concluded that the permeability estimates derived for the dynamically-compacted specimens are maximum values.

In conclusion, it is the DOE's position that the PDF given in Form 464 for the permeability of crushed salt is a good approximation. The permeability versus density function given in Figure 9-27, and used in the development of the PDF for the permeability of crushed salt represent the best possible interpretation of existing data. The development of this function

incorporates both engineering judgement and test results, and is considered defensible in light of the arguments presented in the preceding paragraphs. The DOE recognizes that uncertainty exists, and that uncertainty was incorporated into the development of the PDF. In addition, the DOE continues to pursue experimental work to reduce uncertainty.

Finally, the salt column is not expected to fulfill a sealing function until it has achieved a relatively low permeability. The seal system design recognizes this, and includes multiple, redundant components which will be functional during and after the consolidation period. The redundancy in the design alleviates concerns regarding the time span required to complete the consolidation process.

Peer Reviewer Consideration of Issue

The DOE understood the issue and provided a reasonable response. Therefore, the data included in this package are qualified per 40 CFR § 194.22(b).

9.3.4.3 Peer Review Panel Concern - Permeability of Consolidated Waste

Based on a review of the data and discussions with Sandia, Sandia has calculated a new value of 2.4×10^{-13} m^2.

Statement of Issue

A change in the value of the average waste porosity from 1.7×10^{-13} m^2 to 2.4×10^{-13} m^2 based on a recalculation by the DOE is recommended. This change represents a factor of 1.4 increase in permeability.

Response to Issue

The DOE's calculation is based on a reasonable but highly conservative interpretation of the experimental data in terms of the ranges of permeabilities for the respective waste components. Slight modifications of these assumptions are also considered to be equally defensible, however, and are expected to increase or decrease the permeability value by similar factors. In addition, the data and assumptions are far too limited to discriminate between changes of this magnitude. The 2.4×10^{-13} square meter value is therefore as reasonable as the 1.7×10^{-13} square meter value.

The principal effect on performance assessment of this recommended change is to increase brine releases during a human intrusion in direct proportion to the increase in permeability. Such an increase would not significantly affect the final CCDFs, assuming that radionuclide solubility values remain unchanged.

It is concluded that the work involved in a sensitivity study to determine changes in assuming the new waste permeability value is not warranted because the change does not have any effect on the final performance outcome.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response. Therefore, the data included in this package are qualified in accordance with 40 CFR § 194.22(b).

9.3.4.4 Peer Review Panel Concern - Strength of Waste for "Blowout" (Spalling)

> *There is little data to support any value for this parameter, and the panel's opinion is that further analysis be undertaken by Sandia.*

Statement of Issue

There is no established scientific school of experience nor any database available to draw from for determining the mechanisms that this parameter (1.0 pound per square inch of waste strength) supports. Furthermore, because of the uncertainty of waste conditions at the time of intrusion, it requires an assumption that the standard waste composition and condition will be a granular material of a density approximating unconsolidated lightly cemented sand of unknown porosity and low moisture. The only data in the literature is for clays (and it is sparse) which approximates these conditions for strength properties (Lenke et al. 1996). Therefore, at this stage of process development and lack of defining conditions, it is not possible to ascertain if the value of 1.0 pound per square inch is adequate as a tensile strength.

Response to Issue

A value of 1.0 pound per square inch (6,895 pascals) was chosen to represent the tensile strength of decomposed waste for the purpose of computing blowout spall releases resulting from a drillbit intrusion into a pressurized waste panel. Such spall releases occur only if the gas pressure exceeds the hydrostatic drilling mud pressure of approximately 8 megapascals. A chemical reaction between the waste and brine from the surroundings is necessary to generate the gas to raise the waste pore pressure to these levels. Without brine inflow, little gas will be generated and waste decomposition will be negligible. Thus the phenomenon of blowout spall requires both brine inflow and waste decomposition.

The future state of decomposed waste is both time dependent and unknowable. Therefore a decomposed state consisting of graded granular materials is assumed. This is consistent with the granular nature of decomposed geologic materials and corresponds to an end state of the decomposition process. Such materials lack significant composite strength from the interleaving of components and is the salt found to be most troublesome in oil production where sand is produced form poorly consolidated sand layers. The value of 1 pound per square inch was chosen for cementation strength for the decomposed waste can be reasonably

expected to be conservative, that is, lower than those data values found for many weak materials that are naturally occurring or that have been manufactured. Data to support this value can be found in the literature for the strengths of soils, laboratory produced mixtures of salt and clay, and mixtures of various materials with MgO; the latter added as backfill material to the waste. A discussion of these data sources follows.

Soil Data. Tensile strengths for several compacted, cohesive soils, for example, Vicksburg buckshot clay (CH), Vicksburg lean clay (CL), and a sandy clay (SC) mixture from De Gray dam were measured using hollow cylinder tests and indirect tensile tests in Al-Hussaini (1981). The samples were prepared to optimum water content, compacted, and then tested. Results for the hollow cylinder tests are shown in Table 9-5. All exceed 1 psi by factors of approximately 3 to 8 times. Similar results were obtained from the indirect tensile tests.

Table 9-5. Hollow Cylinder Tests

Material Type	Tensile Strength (pounds per square inch)
CL-1	2.95
CL-2	3.90
CL-3	3.93
CH-1	7.93
CH-2	7.41
CH-3	7.99
SC-1	5.90
SC-2	5.38
SC-3	4.49
CH-4	6.46
CH-5	6.12
CH-6	6.52

Direct tensile tests on simulated waste materials were also conducted by Berglund and Lenke (1995, 13-14). Various mixtures of partially saturated silica sand and kaolin clay were used to represent the waste. The clay represented a natural material that was chosen to be a close surrogate to partially decomposed cellulosics and plastics. The sand represented the particulate structure expected of magnetite or other products of the iron corrosion reaction. The mixture was 85 percent sand and 15 percent clay, a ratio similar to the ratio of decomposition products anticipated for some waste conditions. The tensile strength measured in these experiments was 2.9 ± 1.4 pounds per square inch. A second indirect method of

measuring tensile strength in the Berglund and Lenke study implied an even higher tensile strength value of 4.3 ± 1 pounds per square inch.

The tensile strength of the above materials (Al-Hussaini 1981, Berglund and Lenke 1995) occurred in the absence of any additional cementation process which would tend to increase these measured tensile strengths.

Salt Mixture Data. Some brine is expected to exist within the waste panels after closure of the facility. The most likely source is brine of Permian age that was trapped in the Salado at the time of evaporite deposition. Limited brine occurrences in the WIPP underground have been extensively sampled and analyzed, and the composition of Salado brine is well understood. These brines contain approximately pounds (374 grams) of dissolved constituents per (liter) and are in chemical equilibrium with halite (NaCl), anhydrite ($CaSO_4$), and magnesite ($MgCO_3$).

The removal of even a small amount of water from this brine by evaporation or chemical reaction will result in the precipitation of salts which will act as a cementation agent. One such chemical reaction that is anticipated to occur is the anoxic corrosion of iron and ferrous alloys, which constitute a significant percentage of the waste inventory in the form of steel drums and boxes, contaminated tools and sheet metal, etc.

The reaction of brine with metal will consume H_2O and generate hydrogen and some corrosion product. A typical anoxic reaction might be

$$Fe + 2\,H_2O \Rightarrow Fe(OH)_2 + H_2$$

Consumption of H_2O by corrosion reactions will cause the mass of dissolved solids in the brine to precipitate as a series of evaporite minerals in close proximity to the surface of the corroding metals, forming encrustations which will tend to cement the waste. Simulation of the removal of H_2O from one kg of Salado brine using the EQ6 code (Wolery and Daveler 1992) yielded (534 grams) of precipitates (anhydrite, bischofite, carnallite, halite, kieserite, and magnesite). The mass is greater than the mass of dissolved solids because of the hydrous nature of some of the precipitates.

Evidence for this process in the WIPP underground was seen at the close of heated brine inflow experiments performed by the DOE a number of years ago. In these experiments, a metal canister containing an electrical heater was placed in a vertical hole excavated in the floor of a room in the northern experimental area. The top of the hole was sealed, and anhydrous nitrogen was circulated within the annulus between the canister and the hole. Small amounts of brine flowed toward the hole in response to the pressure and temperature gradients surrounding the heated hole, and evaporated as it approached the canister. The nitrogen acted as a carrier gas for water vapor and was allowed to exit the hole where it flowed into an apparatus where the water vapor was extracted and quantified.

It was found at the close of the experiment that the canister has become firmly cemented in the hole by the precipitation of salts from the evaporating brine within the annulus. A work-over rig had to be employed to extract the canister from the hole. The removal of water from brine by any process, be it evaporation or corrosion reactions, will produce the same cementation effect by the precipitation of minerals at the site of water removal. This cementation will act to increase the strength of the waste.

A number of strength tests were done for consolidated crushed WIPP salt and mixtures of WIPP salt and bentonite (70 and 30 percent, respectively) (Finley 1996). Finley's memorandum presents estimates of tensile strengths of clay/salt mixtures based on experimental observations of unconfined compressive strengths and the extended Griffith criterion for tensile failure (Jaeger and Cook 1976). These estimates are for 30/70 percent bentonite/salt mixtures at fractional densities of 0.83 to 0.88. Finley estimates tensile strengths between 10 and 100 pounds per square inch.

An average container of waste in a WIPP waste panel, upon creep closure and subsequent brine saturation, will consist of approximately 1,350 kilograms of waste solids (assumed average solid density of the waste was taken as 2,700 kilograms per cubic meter and 188 kilograms of precipitated salt (based on dissolved salt solids of 374 gram per liter cited above) per cubic meter of repository. These numbers are based on a typical closure porosity of 0.5 (final room height of 1.2 meters). The gravimetric ratio of salt precipitate to solid waste for these conditions is 0.14. This is a factor of 5 less than the ratio cited by Finley. Using this factor, it is not unreasonable to expect tensile strengths between 2 and 20 pounds per square inch.

Effects of MgO on Strength. An additional process affecting the strength of the waste/backfill composite material is the chemical interactions that will occur between Salado brine and the MgO backfill. This interaction is simulated using the EQ3/6 code (Wolery 1992; and Wolery and Daveler 1992) with the Pitzer activity coefficient option and Harvie-Moller-Weare database. Five moles of MgO were reacted with one kilogram of Salado brine in a series of small steps. The dissolution of the five moles (202 grams) of MgO into the brine resulted in the precipitation of a total of 507 grams of minerals and the incorporation of 20 percent of the original kg of brine as water of hydration within the precipitates. These precipitates include Mg-oxychloride (63 percent by mass) and brucite (31 percent by mass), with minor amounts of anhydrite, halite, and magnesite. Similar results were found by Wang (1996a).

The two dominant precipitates (Mg-oxychloride and brucite) are the key phases in Sorel cement. In fact, Sorel cement is commercially prepared by mixing a magnesium-chloride brine (quite similar to Salado brine) with MgO. Sorel cement is known to have uniaxial compressive strengths in the range of 7,000 to 10,000 pounds per square inch (Sax and Lewis 1987). This range is equivalent to tensile strengths of from 490 to 700 pounds per square inch (Dunham 1966). Thus, the use of an MgO backfill will result in the cementation and strengthening of the waste and backfill composite material as long as sufficient brine is available for the chemical reactions to occur.

Conclusions. While tests to actually measure the binding forces between particles of simulated waste have not been performed, there are data available from several independent sources that suggest that the selection of 1 psi is well below the actual value of tensile strength that can be reasonably expected for decomposed waste. The tensile data presented for several soils without chemically generated salt precipitates exceed 1 pound per square inch by factors generally greater than 3. Estimated tensile strengths of consolidated halite-bentonite mixtures exceed 1 pound per square inch by factors of ten or more. The role of precipitated salts from anoxic reactions of brine with waste metals is expected to be similar though perhaps not as intense. MgO is added to the waste as a backfill material in large volumes. The reaction of MgO plus brine are the principal components of Sorel cement which attains high compressive strengths and predicted tensile strengths of 490 to 700 pounds per square inch.

Peer Reviewer Consideration of Response

The DOE understood the issue and provided a reasonable response. Therefore, the data included in this package are qualified per 40 CFR § 194.22(b).

9.3.5 Natural Barriers Data Qualification Peer Review

The DOE used an IRT to carefully review the existing data that was necessary to support the performance assessment. Much of the existing data was qualified because the IRT determined that the quality assurance program in place at the time of its collection was equivalent to ASME NQA requirements. It was determined however, that some data used to describe natural barrier subsystems could not be qualified in that manner.

40 CFR § 194.22(b) states that

"Any compliance application shall include information which demonstrates that data and information collected prior to the implementation of the quality assurance program required pursuant to paragraph (a)(1) of this section have been qualified in accordance with an alternate methodology, approved by the administrator or the administrator's authorized representative, that employs one or more of the following methods: peer review, conducted in a manner that is compatible with NUREG-1297...."

A Natural Barriers Peer Review (NBPR) Plan (see Appendix PEER) was developed and approved in accordance with the requirements of TP 10.5. The purpose of the plan was to describe the NBPR process. The NBPR panel evaluated existing data and information that form the basis of the parameter values used in the mathematical expression of conceptual models for the natural barriers subsystems in the WIPP. The parameters selected for evaluation were those that had not previously been fully qualified for use in performance assessment.

The conceptual models used in the performance assessment of the natural barriers subsystem include components of: (1) Disposal System Geometry; (2) Culebra Model Geometry; (3)

Repository Fluid Flow; (4) Salado; (5) Impure Halite; (6) Salado Interbeds; (7) DRZ; (8) Actinide Transport (Salado); (9) Units Above the Salado; (10) Dissolved Actinides (Culebra); (11) Colloidal Actinides (Culebra); (12) Exploration Boreholes; (13) Cuttings and Cavings; (14) Spallings; (15) Direct Brine Release; (16) Castile and Brine Reservoir; (17) Multiple Intrusions; and, (18) Climate Changes.

A peer review panel, consisting of the following six members, was convened to undertake the work:

Darrel E. Dunn (Chairman), Independent Consultant
Florie Caporuscio, LANL
Paul L. Cloke, Independent Consultant
David A. Sommers, Independent Consultant
Charles Wilson, Independent Consultant
Chuan-Mian Zhang, Woodward-Clyde Federal Services

Dr. Dunn is an independent consultant with 38 years of experience in hydrogeology. He has a Ph.D. in geology and is a registered geologist in Wyoming. Dr. Dunn has taught advanced hydrogeology courses at Montana State University and the University of Toledo. He has been involved in finite-difference modeling of groundwater and vadose zones since 1967 and has been heavily involved in nuclear waste disposal since 1988.

Dr. Caporuscio has a M.S. in geology/chemistry and a Ph.D. in geology. He is a geochemist with 12 years of experience in high-level and TRU radioactive waste disposal. His primary work has involved the characterization of ash flow tuffs and their alteration products, and the technical analysis of bedded salt deposits. He has also worked in the fields of low-level radioactive and mixed-waste contamination, remediation, and disposal.

Dr. Cloke has 42 years of post-Ph.D. experience in geological science. Much of his experience has dealt with geochemistry and economic geology, but for the past eleven years has focused on problems in the disposal of nuclear wastes. He worked in the performance assessment departments for the former DOE Salt Repository Project and the Yucca Mountain Site Characterization Project. During the past two to three years, he has had significant interaction with the European nuclear waste programs in Germany, Switzerland, Sweden Spain, and Great Britain, as well as the Canadian and Japanese programs.

Dr. Sommers has a Ph.D. in geology and over 30 years of experience as a professional hydrogeologist, with registration in several states and certification by the European Federation of Geologists. He served on the NRC/National Academy of Sciences (NAS) Committee on Ground Water Resources and Coal Mining and is frequently retained as a technical expert to support litigation and provide expert testimony. Dr. Sommers has been involved in nuclear-related projects since 1971. Since 1995, Dr. Sommers has been an independent reviewer for the WIPP IRT.

Dr. Wilson has a Ph.D. in hydrology and is an independent consultant. He has acted as manager for a broad range of projects involving hydrogeology and geotechnical engineering, water resources planning, and environmental contamination. These projects have involved such topics as designing and conducting large-scale hydrologic tests in very low permeability, fractured rock; development of a national water resources planning agency for the Republic of the Philippines; and design of a sitewide groundwater monitoring system for DOE's INEL.

Dr. Zhang has a Ph.D. in civil engineering and has more than 10 years experience in surface water and groundwater hydrology, including contaminant transport, groundwater and watershed modeling, water resources management, statistical applications in hydrology and soil and water quality assessment and geochemical analysis. Recent work has been heavily involved in Rocky Flats.

The panel members all have well established credentials and were independent of the WIPP performance assessment activities. Additional information concerning the technical qualifications of the panel members is presented in the peer review panel report (see Appendix PEER). Documentation of the independence of the panel members is also provided in Appendix PEER.

Upon completion of the orientation and training required by TP 10.5, the panel was provided 32 parameter packages for their review. In addition, technical reports and documents were obtained by the panel from the SNL waste management library and records center to supplement the information in the parameter packages. Both formal and informal technical discussions were held with SNL principal investigators to assist the panel members to more fully understand the concepts and parameter derivation and application in the performance assessment.

The NBPR panel evaluated 142 parameters against the eight review criteria cited in NUREG-1297 (NRC 1988). The parameters were organized into 32 parameter packages, some of which contained more than one parameter. The parameter packages were grouped into three subsystems, Salado, Castile, and Units Above the Salado, to facilitate the review process.

In some subsystems, individual parameter values were evaluated and a determination made of their adequacy as used in the WIPP performance assessment program. In others, sets of parameters were evaluated to determine their collective contribution to a combined parameter value. The panel performed an in-depth critique of assumptions, alternate interpretations, methodology and acceptance criteria employed, and of the conclusions drawn in the original work. In evaluating the existing unqualified data, the peer review panel members considered the following:

- The source of the parameters and data (for example, professional judgment, published source material, field tests, laboratory experiments, etc.);

- The appropriateness of the parameters and data for their intended use; and,

- The assumptions, calculations, extrapolations, interpretations, methods, appropriateness, validity, sensitivities, and conclusions pertinent to the parameters and data used as input to the WIPP performance assessment.

At the conclusion of its review, the panel developed a final report (August 1996). A copy of the NBPR Report is provided in Appendix PEER.

Table 9-6 provides a listing of the 32 parameter packages, the appropriate subsystem, the number of parameters in the specific packages, and the qualification status of each as determined by the peer review panel. The panel concluded that 31 of the parameter packages were fully qualified. Therefore, the data supporting those parameters are qualified per 40 CFR § 194.22(b). As discussed below, the panel had a concern about one of the 21 data packages for the Culebra transmissivity parameter.

The NBPR panel's concern (in italics), the DOE's interpretation of the panel's concern ("Statement of Issue"), and the DOE response ("Response to Issue") are provided below. The panel then reviewed the response to determine whether the DOE understood the issue and provided a reasonable response ("Peer Reviewer Consideration of Response"). The justification for the DOE's continued use of the Well P-18 transmissivity value is also provided ("DOE Technical Position versus Panel Issue").

The DOE response was provided to the panel as an individual memorandum. For incorporation into this application, the response has been edited to remove the memorandum format, consolidate references, replace first-person text, insert cross-references where appropriate, and correct typographical errors. Substantive technical content of the responses has not been changed.

<u>Peer Review Panel Concern: Well P-18 Transmissivity Value</u>

The panel concluded in the NBPR Report that it was in general agreement with the parameter values chosen for the performance assessment models, except that

> *"The interpretation of the data from well P-18 is inadequate for its intended use as input to GRASP-INV for the development of transmissivity fields."*

Additional detail regarding the above issue is provided in the NBPR Report, which states

> *"<u>Well P-18</u> - the transmissivity value of 7.0 x 10^{-5} ft^2/day for well P-18, as reported in the Draft Culebra Transmissivity Database (July 1, 1996), represents a value obtained from interpretation of late time match parameters (after 600 hours since test inception) rather than early time data using semi-log slug test type curves on the semi-log plot of H/H_0 vs elapsed time (SAND87-0039, p.99). Use of the late time semi-log*

Table 9-6. Summary of Parameters Reviewed and Qualification Status

Parameter Package	Subsystem	Number of Parameters	Qualification of Parameter
DRZ Compressibility	Salado	2	Adequate
Undisturbed Halite Pore Pressure		1	Adequate
Undisturbed Halite Compressibility		1	Adequate
Effective Halite Porosity		1	Adequate
Undisturbed Halite Permeability		3	Adequate
Undisturbed Anhydrite Pressure		2	Adequate
Undisturbed Anhydrite Rock Compressibility		3	Adequate
Brine Salt Mass Fraction		1	Adequate
Brine Viscosity		1	Adequate
Brine Density		1	Adequate
Brine Compressibility		1	Adequate
Castile Brine Reservoir Rock Compressibility	Castile	1	Adequate
Castile Brine Reservoir Porosity		1	Adequate
Castile Brine Reservoir Pressure		1	Adequate
Castile Brine Reservoir Permeability		3	Adequate
Castile Brine Reservoir Volume		1	Adequate
Non-Salado Effective Porosity	Units Above the Salado	6	Adequate
Non-Salado Pressure		4	Adequate
Non-Salado Permeability		6	Adequate
Culebra Permeability		3	Adequate
Climate Index		1	Adequate
Culebra Transmissivity Data		100 Values	Adequate[1]
Culebra Thickness		1	Adequate
Culebra Storativity		1	Adequate
Culebra Fluid Density		32 Values	Adequate
Culebra Steady-State Freshwater Heads		31 Values	Adequate
Culebra Dolomite Grain Density		1	Adequate
Effective Culebra Thickness		1	Adequate
Advective Porosity		1	Adequate
Half Matrix Block Length		1	Adequate
Diffusive (Matrix) Porosity		1	Adequate
Diffusive (Matrix) Tortuosity		1	Adequate

[1] One of the 21 data packages for the Culebra Transmissivity parameter was deemed inadequate.

curve match for the transmissivity value seems questionable in this case, as the late time data do not represent the aquifer characteristics in the vicinity of the well, before boundary effects. Use of the late time data, after boundary effects, appear inappropriate since the theory presented by Cooper, et al. (1967) does not include boundary affects. Further, the early time (first 600 hours) interpreted transmissivity value of 4.3 x 10^{-3} ft^2/day (SAND87-0039, p.99) is in fairly close agreement with the 1.0 x 10^{-3} ft^2/day value provided by the interpretation of a preceding bailing test by the USGS (Mercer 1983)."

Statement of Issue

The DOE believes that the issue can be considered in two steps: a) is the choice of a P-18 transmissivity based on short-term data (less than 600 hours) or on the basis of long-term data (more than 600 hours) most appropriate?; and b) given the implementation of point transmissivity values into the regional T-field, is the difference between the two interpreted values (essentially two orders of magnitude) likely to be significant to WIPP regulatory compliance? These two lines of questioning are considered separately below.

Response to Issue

1. Concerning Specific Interpretation of the Culebra Transmissivity at P-18:

By way of introduction, it should be noted that the Culebra becomes progressively less transmissive from the west, where it is near land surface in Nash Draw, to the east, where its depth of burial increases. P-18 is the easternmost well in the Culebra in the immediate vicinity of the repository area. It was originally drilled to log the underlying Salado Formation, and was later perforated at the Culebra Dolomite. Other wells constructed in a similar fashion (for example, DOE-2, P-14) initially showed poor connection with the Culebra prior to acidization.

Specifically concerning P-18, the DOE agrees with the panel's comments to the effect that: a) the DOE specifically chose to use the long-term data from the rising-head slug test at H-19; b) that in doing so, the DOE specifically chose to use the interpretation from the time frame *after* boundary effects became evident; c) therefore, the theoretical basis for the interpretation used, that is, assumption of a homogeneous aquifer, no longer strictly applies; and d) the cause for the relatively sharp change (decrease) in recovery rate at approximately 600 hours remains unclear.

As summarized on page 100 of Beauheim (1987b), the DOE's preferred interpretation of this test is that: a) early-time data (less than 600 hours) reflect both a local or near-well zone of *relatively* high-permeability (perhaps generated by drilling activities) and the presence of a positive skin (poor connection between well and country rock) *immediately* adjacent to the well; and b) the long-term data (greater than 600 hours) most closely represent country-rock values outside the induced zone of increased permeability near the well. In summary, the transmissivity estimate from the early-time data, 4.3×10^{-3} square feet per day, is probably unrealistically high, but is reliably a maximum value. The estimate from the late-time data, 7×10^{-5} square feet per day, is probably more representative of the Culebra in the vicinity of P-18, but cannot be interpreted as a minimum value.

It is recognized however, that in the absence of additional data in the vicinity of hole P-18 (for example, a new well), it cannot be demonstrated objectively that the submitted transmissivity value is, in fact, representative of the rock mass in the vicinity. The question remains: Is the difference between the two transmissivity values (4.3×10^{-3} square feet per day versus

7×10^{-5} square feet per day) significant for purposes of WIPP regulatory compliance? The DOE's position is that the appropriate transmissivity value was selected, but that the P-18 data point does not substantially influence the critical potential migration pathways through the Culebra.

2. Concerning Issues of Implementation and Regulatory Impact

Ultimately it is not the transmissivity of a specific well *per se* that is important, but its impact on potential migration times from the Culebra overlying the repository to the WIPP boundary. There are several potential consequences resulting from mis-specification of a point value for Culebra transmissivity, such as that at well P-18, including:

a. Misidentification of the correlation structure used in geostatistical treatment of point data to generate the overall Culebra transmissivity field would result in a somewhat different overall pattern of simulated heterogeneity.

b. Changes in simulated transmissivity fields in areas that would affect potential radionuclide migration from the repository would be the most important ramification.

With regard to a), general estimates of overall heterogeneity are not extremely sensitive to the correlation structure, even though the semivariogram can be sensitive to outlying data points, such as the specific transmissivity assigned at well P-18. With regard to b), assuming that the higher transmissivity (4.3×10^{-3} square feet per day) is actually correct for well P-18, the impact of having used a lower value (7×10^{-5} square feet per day) on travel times near the repository is judged to be minimal. This consideration must, however, be made under two settings, that is, both in the absence of potash mining and assuming that such mining takes place.

Consider first the case without potash mining. Several data points (DOE-1, H-3, H-11, and H-19) define a finger of high transmissivity in the Culebra that extends up to the area near the repository. Transmissivities at these wells range from 2 to 3 square feet per day (H-3 and H-19) to approximately 80 square feet per day (H-11). This zone is bounded on the east and west by wells with distinctly lower transmissivity, including P-18. In the absence of potash mining, flow within the Culebra is mainly through the high transmissivity zone.

A salient feature of conditional geostatistical simulation is that local data values are incorporated (with consideration of measurement uncertainty) in the field. Thus, even if transmissivity at P-18 were increased to 4.3×10^{-3} square feet per day, the value based on short-term data, the high-transmissivity feature defined by wells such as DOE-1, H-3, H-11, and H-19 would still exist and be clearly defined. Since local data are honored in geostatistical simulations, the flow rates and directions in the high transmissivity zone, and hence, radionuclide travel time to the accessible environment, would still be more or less the same as estimated with the lower transmissivity value.

In the case of potash mining, Culebra transmissivities in the affected areas are assumed to increase by *up to* three orders of magnitude. The general impact on Culebra fluid flow is to deflect flow from a southerly direction, where it is focused in and near the high-transmissivity zone, toward and through the relatively low transmissivity district lying to the *west*. The transmissivity at well P-18, which lies east of *both* the high transmissivity zone and the zone which must be assumed to be impacted by potash mining, should have even less impact in simulations including potash mining than on those in which mining is not included.

Finally, the simulated transmissivity value for the grid block nearest P-18 was examined for the 100 transmissivity fields generated using GRASP-INV. The simulated value ranged from 10^{-8} to 10^{-4} square meters per second. Because the semivariogram had a nugget effect (implying small-scale noise), and because of upscaling effects, the block-average transmissivity need not and generally will not be the same as the P-18 data point. Over half the time, the transmissivity was between -5.5 and -6.5 log (square meters per second), versus the input value of -10.124 (7.5×10^{-11} square meters per second). Thus, if the higher value suggested by the Panel (about -8 log [square meters per second]) were used and honored exactly, the value used in the modeling analysis would still be higher. Also, note that the span of values for the grid block nearest P-18 in the generated transmissivity-fields is 2 orders of magnitude larger than that considered for the test. Thus, it is the DOE's belief that the probabilistic approach adequately deals with the uncertainty in this area.

Peer Reviewer Consideration of Response

The DOE understood the issue; however, the panel gave a "qualified yes" to the reasonableness of the response. A "qualified yes" indicates that the panel was split over the reasonableness of the response; however, the panel was in agreement that the data value in question had no effect on the qualification of the parameter value (see the discussion below).

DOE Technical Position versus Panel Issue

The DOE's technical position is that the appropriate transmissivity value was selected; however, which ever transmissivity value is used (4.3×10^{-3} square feet per day or 7×10^{-5} square feet per day), the well P-18 data point does not substantially influence the critical migration pathways through the Culebra. This interpretation is supported by the panel in Table 1.1 of its report (Appendix PEER) where the Culebra Transmissivity Data were determined to be adequate.

9.3.6 Waste Form and Disposal Room Data Qualification Peer Review

A Waste Form and Disposal Room (WFDR) Peer Review Plan (see Appendix PEER) was developed and approved in accordance with the requirements of TP 10.5. The plan describes the process used to plan and perform the review. The purpose of the peer review was to ensure that the scientific data used in the models describing the waste form and the disposal room closure and chemistry are qualified for use in the WIPP performance assessment.

The DOE used IRTs to carefully review the existing data necessary to support the performance assessment. Many of the existing data were qualified because the quality assurance program in place at the time of its collection was determined to be equivalent in effect to ASME NQA requirements. However, some of the data needed to support the waste form and disposal room models were not qualified by the IRTs.

As stated previously, 40 CFR § 194.22(b) states that

> *"Any compliance application shall include information which demonstrates that data and information collected prior to the implementation of the quality assurance program required pursuant to paragraph (a)(1) of this section have been qualified in accordance with an alternate methodology, approved by the administrator or the administrator's authorized representative, that employs one or more of the following methods: peer review, conducted in a manner that is compatible with NUREG-1297...."*

A panel consisting of the following two members was selected to perform the review of the above data that had not been qualified by the IRTs:

> Duane C. Hrncir (Chairman), University of Texas at Dallas
> Robert D. Knecht, Colorado School of Mines

Dr. Hrncir is an associate professor of chemistry and former head of the chemistry programs at the University of Texas at Dallas. He has 24 years of experience in research involving the interactions of metals with organic molecules.

Dr. Knecht is a research professor at the Colorado School of Mines and holds a Ph.D. in chemical-petroleum refining engineering and a Ph.D. in metallurgical engineering. He has provided management and technical assistance to a variety of energy, minerals and waste industries and to government.

The panel members were both highly qualified to conduct this review and were independent of the WIPP performance assessment program. Additional information concerning the qualifications of the panel members is provided in the peer review panel report (see Appendix PEER). Documentation regarding the independence of the panel members is also provided in Appendix PEER.

The panel received administrative orientation and training on the peer review plan, 40 CFR Parts 191 and 194, NUREG-1297, the QAPD and TP 10.5. During the course of its work, the panel reviewed information packages provided by SNL for each parameter. In addition, technical reports, published literature, and internal documents were used to supplement the information in the parameter packages. Discussions were held with SNL staff in order to more fully understand the concepts and parameter derivation.

The panel members evaluated existing data and information that form the basis of the parameter values used in the mathematical expression of conceptual models for the waste form and disposal room subsystem. As discussed above, the parameters evaluated had not previously been fully qualified for use in performance assessment. The conceptual models used in the performance assessment of the waste form and disposal room subsystem include components of:

- Gas Generation;
- Chemical Conditions;
- Dissolved Actinide Source Term; and,
- Colloidal Actinide Source Term.

The WFDR peer review panel evaluated 26 parameters against the eight NUREG-1297 review criteria. The parameters were solubilities of the actinides from the repository wastes in brines from the Salado and Castile.

The panel compared each calculated solubility parameter to those published in the peer-reviewed literature, when such data were available. To make this comparison, the panel considered compatibility of solvents, solution pH, and the absence of potentially ligating carbonate. The latter criterion is an imposed condition controlling the disposal room chemistry. When literature values were not available, the panel considered experimental data obtained from several different laboratories. In using these data, the panel evaluated the experimental approach to ascertain that the methods used for data acquisition and interpretation were consistent with recognized standards.

When experimental data were not available for particular parameters, the panel examined the method of calculation used to derive the value. The experimental data used as input to the calculation were evaluated and the validity of the calculation result was critiqued relative to similar calculated values where experimental data were available.

The panel members carefully reviewed each of the 26 parameters submitted for peer review. Based on their review, the panel prepared a final report in July 1996. A copy of the final report is provided in Appendix PEER.

Table 9-7 provides a listing and status of the reviewed parameters. As shown in Table 9-7, the panel concluded that all 26 of the values were qualified for use in the WIPP Performance Assessment for actinide solubility under repository conditions. Therefore, the data supporting these parameters are qualified per 40 CFR § 194.22(b).

Table 9-7 Listing and Status of Reviewed Parameters

ID number	Species	Brine	Status
	A. Inorganic Chemistry Controlled by $Mg(OH)_2/MgCO_3$		
WP037105	Am(III)	Salado	Qualified
WP037106	Am(III)	Castile	Qualified
WP037109	Pu(III)	Salado	Qualified
WP037108	Pu(III)	Castile	Qualified
WP037129	General An(III)	Salado	Qualified
WP037125	General An(III)	Castile	Qualified
WP037110	Pu(IV)	Salado	Qualified
WP037111	Pu(IV)	Castile	Qualified
WP037115	Th(IV)	Salado	Qualified
WP037112	U(IV)	Salado	Qualified
WP037130	General An(IV)	Salado	Qualified
WP037126	General An(IV)	Castile	Qualified
WP037131	General An(V)	Salado	Qualified
WP037127	General An(V)	Castile	Qualified
WP037113	U(VI)	Salado	Qualified
WP037114	U(VI)	Castile	Qualified
WP037132	General An(VI)	Salado	Qualified
WP037128	General An(VI)	Castile	Qualified
	B. Organic Chemistry Controlled by $Mg(OH)_2/MgCO_3$		
WP037116	General An(III)	Salado	Qualified
WP037121	General An(III)	Castile	Qualified
WP037117	General An(IV)	Salado	Qualified
WP037122	General An(IV)	Castile	Qualified
WP037118	General An(V)	Salado	Qualified
WP037123	General An(V)	Castile	Qualified
WP037120	General An(VI)	Salado	Qualified
WP037124	General An(VI)	Castile	Qualified

9.3.7 Passive Institutional Controls Peer Review

40 CFR § 194.43 states that

> *"Any compliance application shall include detailed descriptions of the measure that will be employed to preserve knowledge about the location, design, and contents of the disposal system."*

A Passive Institutional Controls Peer Review Plan (see Appendix PEER) was developed and approved in accordance with the requirements of TP 10.5. The plan describes the peer review process used to ensure that the passive institutional controls proposed by the DOE at the WIPP will reasonably preserve the knowledge about the location, design, and contents of the WIPP disposal system and reduce the likelihood of inadvertent intrusion.

A three-member panel of experts was convened in May 1996 to conduct an independent peer review of the system of passive institutional controls designed by the DOE. The panel reviewed the findings of the Passive Institutional Controls Task Force (PTF), evaluating detailed descriptions of the measures that the DOE intends to employ to preserve knowledge about the location, design, and contents of the WIPP disposal system. The primary focus of the evaluation was to determine whether the passive institutional controls designed by the DOE are adequate and have a reasonable expectation of meeting their intended purpose of reducing the likelihood of inadvertent intrusion.

The panel members were:

Jessica Glicken (Chairman), Ecological Planning and Toxicology, Inc.
Elizabeth K. Hocking, Argonne National Laboratory
Paul R. La Pointe, Golder Associates

Dr. Glicken is a senior anthropologist with over 14 years of experience in communications, strategic and organizational development and management, and policy analysis. She develops communications strategies for both public and private sector clients.

Dr. Hocking is a legislative analyst and section manager with Argonne National Laboratory. She provides technical, legal, and programmatic analyses of current statutes, regulations, and judicial decisions affecting the DOE and the energy industry.

Dr. La Pointe is a mathematical geologist and senior project manager with a Ph.D. in mining engineering. He has more than 16 years of experience in the oil and gas industry and is currently responsible for management and technical direction of reservoir engineering and characterization projects for domestic and international petroleum companies.

The panel members were well qualified for this review and were independent of the WIPP performance assessment program. Additional information concerning the qualifications of the panel members is presented in the panel report (see in Appendix PEER). Documentation of the panel member's independence from the WIPP project is also provided in Appendix PEER.

After administrative orientation and training, the panel members familiarized themselves with regulations impacting radioactive waste disposal at the WIPP (40 CFR Parts 191 and 194) and requirements for the conduct of peer reviews (NUREG-1297 and TP 10.5). Following

briefings by members of the PTF and other WIPP project staff, panel members were provided two documents that formed the basis of their peer review:

> *Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments* (referred to as the Passive Institutional Controls Efficacy Report, see Appendix EPIC); and,
>
> *Passive Institutional Controls Conceptual Design Report* (referred to as the Conceptual Design Report (CDR), see Appendix PIC).

Supplemental information requested by the panel was also used in the evaluation.

The peer review panel evaluated the assumptions and results presented in the Passive Institutional Controls Efficacy Report. The panel's findings, as presented in their final report, dated July 1996, are provided below. A complete copy of the panel's report is provided in Appendix PEER.

The panel identified several concerns during their review. The panel's concerns ("Peer Review Panel Concerns" - presented in italics below), the DOE's interpretation of the panel's concerns ("Statement of Issue"), the DOE's response to the panel's concerns ("Response to Issue"), and the panel's reaction to the interpretation and responses ("Peer Reviewer Consideration of Response") are provided below. In those instances where the panel determined the response did not reasonably address their concerns, the DOE's justification for its position ("DOE Technical Position versus Panel Issue") is provided. In some instances, a response addresses more than one concern; in those situations, the "Panel Concerns" will not necessarily be presented in the same order as they appeared in the passive institutional controls peer review report. The issues/concerns are from the Executive Summary and Conclusions sections of the report.

The DOE responses were provided to the panel in a memorandum format. For incorporation into this application, the responses have been edited to remove the memorandum format, consolidate references, replace first-person text (for example, where appropriate "PTF" was replaced with "DOE"), insert cross-references where appropriate, and correct typographical errors. Substantive technical content of the responses has not been changed.

9.3.7.1 Peer Review Panel Concerns - Adequacy and Completeness of Assumptions

> *In general, the panel found that the PTF's interpretation of the regulations regarding passive institutional controls was adequate and reasonable given the indeterminate quality of some of the regulations. However, the panel expressed concern about the way in which the PTF's interpretations were applied. In many cases, the panel found the PTF's assumptions to be reasonable but unsupported and/or incomplete. In other*

cases, the panel determined that the PTF failed to discuss assumptions that were: 1) implicit in, and necessary to, the assumptions they presented, or 2) made by expert panels and incorporated into the overall design of the passive institutional controls (e.g., validity of archetypes as a communications vehicle).

Another area of concern dealt with the PTF's failure to develop and/or discuss the communications and activities process models that underlie the conceptual design of the controls. Such models would: 1) look at passive institutional controls as communications vehicles, and 2) assume a general pattern of activity that will lead to an inadvertent intrusion event.

The panel's assessment of the individual assumptions presented in the PICs Efficacy Report resulted in a general consensus by panel members as to the adequacy and reasonableness of the information contained in the document. However, panel members noted their concern about areas within the PICs Efficacy Report that may be in need of clarification or modification. These areas include:

Basic human attributes. Several assumptions regarding human characteristics are poorly supported or in need of other modifications. For example, explicit assumptions should be provided relating to human evolution and associated biological and sociocultural capabilities.

Government. The PTF does not adequately define "government" and offers poor support for the assertions made in the PICs Efficacy Report. Also, some of the assumptions made by the PTF are actually conclusions or second order assumptions.

Language. Assumptions made by the PTF should be supported by references. Also, assumptions regarding other aspects of communication are not captured.

Natural resources. The panel found these assumptions to be generally reasonable and consistent with the requirements.

Estimating the effectiveness of passive institutional controls. Four assumptions are made that require additional support. Furthermore, the panel believes that social institutions other than government should be considered as potential facilitators of passive institutional controls since there are strong and effective mechanisms of social control other than government.

Statement of Issues

a. General: Regulatory interpretations were generally adequate and reasonable.

b. General: The panel believes that some assumptions were reasonable but were unsupported or incomplete.

c. Basic Human Attributes: The panel believes that the DOE failed to discuss certain assumptions that were implicit in other assumptions that were presented.

d. Government: The panel believes that the DOE failed to discuss assumptions from the Markers Panel that were used in the Passive Institutional Controls Efficacy Report.

e. Language: The panel believes that the validity of archetypes as a communications vehicle was an assumption used in the passive institutional controls work.

f. Natural Resources: The panel believes that a general communications model must be described. The model discussed by the panel includes: (1) develop intention; (2) identify audience; (3) encode in language; (4) capture in media; (5) transmit; (6) receive; (7) decode; (8) understand; and (9) respond and is shown as Figure 3.2.2-1 of the panel report (see Appendix PEER).

g. Passive Institutional Controls Effectiveness: In the absence of a documented communications model for the operation of the passive institutional controls, the panel created a model that they believe represents how the DOE expects that the passive institutional controls would be encountered by a site investigator/potential intruder (the "general pattern of activity"). The DOE believes that the panel interpretation of the operation of the passive institutional controls system is that if the markers at the WIPP were not encountered prior to a potential intrusion, then the passive institutional controls system would fail to communicate and deter inadvertent intrusion. The DOE believes that the panel proposed the horizontal drilling as a potential failure mechanism that could circumvent the markers.

Response to Issues

a. The DOE agrees with the panel report.

b. EPA's Compliance Application Guidance (CAG; EPA 1996c) was the basic source of guidance used by the DOE.

The EPA establishes Future State Assumptions in 40 CFR § 194.25 by stating that performance assessment and compliance assessment shall assume that characteristics of the future remain what they are at the time the application is prepared, except for geology, hydrology, and climate. Specific topical areas to which the future-state assumptions apply are listed in the Supplementary Information. This direction is consistent with the guidance provided on drilling technologies and plugging practices and technologies in 40 CFR § 194.33, which are integral parts of performance assessment. No specific guidance is provided on 40 CFR Part 194 as to the role of future-state assumptions in estimating credit for

passive institutional controls in performance assessment (40 CFR § 194.43[c]), and assuming that the future-state assumptions apply to the passive institutional controls in the performance-assessment arena is not consistent with the guidance in the CAG (EPA 1996c). Separate guidance on how the DOE may obtain credit for passive institutional controls in performance assessment is provided in 40 CFR § 194.43 of the CAG, perhaps because the DOE is not required to propose a credit for passive institutional controls, and the EPA is not required to allow credit for the passive institutional controls. The DOE's approach, then, was to give equal weight to the CAG as to 40 CFR Part 194, as expressing the intent of the EPA.

In the CAG, the EPA states that credit for passive controls will be based on two aspects of the passive institutional controls: whether they are expected to endure for the time period proposed by the DOE (not to exceed 700 years after disposal) and whether they are expected to be understood by the potential intruder for the proposed time period. With respect to the first aspect, the EPA states that the period of time for which the markers (the EPA does not mention any of the other passive institutional controls in this discussion) are expected (but not required) to endure is likely to require a deterministic analysis tied into CAG 194.43(1)(a) (that is, markers designed, fabricated, and emplaced to be as permanent as practicable).

The second aspect will be evaluated with respect to "a prudent extrapolation of the future state assumptions established in 40 CFR § 194.25". In an example provided on what will and will not be accepted in the context of future-state assumptions, the EPA states that government regulations will remain in force but the exact form and content of the regulation cannot be identified with certainty. In continuing the guidance, the EPA does not require justification for the existence of government but does require justification why any assumptions made about the regulations are sound. The treatment of the existence of government in this example is consistent with the paragraph in the CAG following the example that discusses societal "common denominators".

Societal common denominators are described as "patterns of human behavior that may be detected throughout history and around the world." Nowhere in this paragraph are these common denominators described as "assumptions" nor is there any suggestion that the discussion of assumptions in the previous paragraph applies to common denominators. This approach by the EPA is consistent with the view that basic human characteristics (that is, societal common denominators) are facts and are not assumptions. In addition, nowhere in this paragraph does the EPA state nor imply that these common denominators need to be justified by the DOE. Based on the EPA's guidance, the DOE does not believe that providing a discussion or references to support the societal common denominators listed in the CAG is appropriate. It is important to emphasize that the period that is being considered for credit in performance assessment calculations ends 700 years after disposal.

In the Passive Institutional Controls Efficacy Report, the PTF listed the common denominators along with working assumptions derived both from the CAG and the DOE. This approach obviously caused confusion to the peer-review panel, especially with the expectation of justification of the societal common denominators.

In their review of the Passive Institutional Controls Efficacy Report, the panel approved of the DOE's approach in using the EPA's guidance with regard to the treatment of natural resources in performance assessment. Neither references nor additional discussion were requested to support EPA's guidance. The DOE used the same approach for the societal common denominators that the EPA had provided. The approach was to quote the EPA's language and accept it as part of the regulatory framework that had to be established in the context of performance assessment.

c. The EPA has identified societal common denominators as "facts" that the DOE is not required to justify. The DOE believes that the underlying human conditions upon which these common denominators are based also do not require justification or discussion.

d. The assumption that the DOE incorporated from the Markers Panel was that human beings will be essentially the same as they are today (not evolve into a different species). Because of the limitation to 700 years, the DOE believes it is so basic and reasonable that it was not discussed individually.

e. The conceptual design for the passive institutional controls does not incorporate the concept of archetypes due to the constraints of "practicable". Only Team A of the Markers Panel recommended the use of archetypes, and the use of Menacing Earthworks was the specific recommendation to the DOE for the large overall site design. That design was modified by the DOE to a "practicable" design that directly outlines the repository area and did not use archetypes. The stone monuments, by their very shape, are not consistent with archetypes because they are more honorific shapes.

f. Although no communications model was identified in the CDR for the passive institutional controls components, the DOE has identified the steps in Figure 3.2.2-1 of the panel report, and they are listed with PTF Interpretation 1.f. EPA regulations identified the intentions of the passive institutional controls, the Futures Panel identified the audience in the Assurance Requirement arena whereas the CAG identified the audience in the performance assessment arena, the Markers Panel identified the communications principles, and the DOE incorporated these principles into a conceptual design of the most permanent practicable. QA procedures that will assure that steps (3), (4), and (5) of the panel's general communications model take place: (3) the correct media are selected (for example, correct paper, correct quality of granite), (4) the correct messages are captured in the appropriate media (for example, the printer copies the correct messages on the correct paper, the engraver carves the correct messages at the correct locations in the granite monuments and walls), and (5) the completed passive institutional controls components will be transported to the correct locations (for example, the records get to the correct records centers and archives, the granite monuments are delivered and emplaced in the correct locations) are being developed by the DOE. The DOE dealt with the issues of how long the passive institutional controls would endure with their messages intact and whether the messages could be decoded (recognized) and understood in the 700 years of performance assessment concern. The response of future societies that have understood the messages was not a DOE concern.

The approach of the DOE as expressed in the Passive Institutional Controls Efficacy Report (Appendix EPIC) reviewed by the panel was to focus on EPA's two concerns of messages enduring and being understood (steps (5) through (8) of the panel's general communications model). Steps (3), (4), and (5) of the panel's general communications model were assumed to be completed because the DOE has committed to implementing the passive institutional controls as described in the CDR.

g. The process model developed by the panel (Figure 3.2.2-2 of their report) is incorrect when compared with the manner in which the DOE worked, because it does not recognize any deterrent components other than markers and does not indicate that any single deterrent component (for example, markers, records center, or archive) on its own could deter inadvertent human intrusion. As stated in the Passive Institutional Controls Efficacy Report, each of the deterrent components can convey sufficient information to deter a potential intruder, because a potential intruder would have the information to know that the Withdrawal needed to remain isolated and to understand the danger associated with intruding into the repository.

Section 4.3 of the Passive Institutional Controls Efficacy Report (Appendix EPIC) discusses a typical approach for resource site investigators to come upon knowledge of the WIPP (that is, starting with an initial investigation of the literature to identify potential resource areas). Such an investigation would reveal that there is an area within the Delaware Basin where drilling is prohibited. This typical approach is not the only one possible. A site investigator might examine the site first and be deterred by the messages on the markers. As such, the order of encounter does not matter, nor does it matter if more than one component is encountered by a potential intruder--each deterrent component contains sufficient information to deter inadvertent human intrusion.

Peer Reviewer Consideration of Response

The DOE understood all the issues except items "f" and "g," and provided a reasonable response for all of the items except item "b."

DOE Technical Position versus Panel Issues

b. The EPA developed the CAG (EPA 1996c) which provided the only guidance about how to treat passive institutional controls in performance assessment other than the limit on 700 years of credit. The DOE believes that the CAG (EPA 1996c) shows the EPA's intent and therefore the DOE must follow this guidance to develop credit for passive institutional controls in performance assessment.

9.3.7.2 Peer Review Panel Concerns - Systems Approach

Application of the systems approach. The panel found that the redundancy of the individual components was well-supported and explained, but that the sufficiency of the individual components to effectively deter inadvertent intrusion in the absence of any other component was unevenly supported. The panel noted the PTF's failure to discuss the "Gestaltic" nature of the system, in which the whole is more effective in deterring intrusion than the sum of its parts.

Consequences for Performance Assessment. The panel concluded that:...4) the systems nature of passive institutional [sic] was not appropriately considered when calculating the probabilities that individual components and/or the system will fail.

(Conclusion #2 from the report Conclusions Section) The effectiveness of the deterrence afforded by the passive institutional controls components is such that any component in isolation from all the other components effectively deters inadvertent intrusion. This conclusion ignores the systems nature of the passive institutional controls in that, despite all of the systems redundancy, some components do not have the same level of deterrent efficacy as others for every credible intrusion scenario.

Statement of Issues

a. The panel believes that the DOE needs to support the sufficiency of individual passive institutional controls components to deter inadvertent human intrusion through year 700.

b. The panel believes that the DOE used a systems approach in estimating the effectiveness of passive institutional controls and needs to support it.

Response to Issues

a. The passive institutional controls components as a deterrent can be viewed in several ways:

(i). Each component is an independent deterrent whose effectiveness is uninfluenced by other components. The effectiveness of the passive institutional controls set or system is as effective as the most effective component that will be encountered by the potential intruder. Failure of one or more components could either reduce or leave unchanged the total effectiveness, depending on the differences in effectiveness of the components and the particular component(s) that fail. The message on each deterrent component conveys sufficient information so that comprehension of the message on any single component precludes inadvertent human intrusion.

(ii). The effectiveness of each of the components is dependent on the effectiveness of all of the other components. The effectiveness of the passive institutional controls system is the

product of the effectiveness of each component in the system. Failure of any component to deter would mean that the entire passive institutional controls system fails.

(iii). The effectiveness of each component contributes to the effectiveness of the passive institutional controls system. The effectiveness of the passive institutional controls system is the sum of the component effectivenesses. Failure of one or more components would reduce the effectiveness of the passive institutional controls system.

(iv). The effectiveness of each component contributes to the effectiveness of the passive institutional controls system, but because of the Gestaltic nature of the system design, the effectiveness of the total passive institutional controls system is greater than the sum of the effectivenesses of the components. The effect of the failure of any component on the system effectiveness depends on the contribution of the component to the Gestalt.

The passive institutional controls for the WIPP are envisioned by the DOE to operate as alternative (i) for the purposes of performance assessment.

What has to be provided is a reasonable expectation that a component will survive and be able to be correctly interpreted.

> (A) Assumptions establish that because of the relatively short time period of concern here, the nature of drilling in going after resources of worth, and previous examples of reading 700 year-old English, that there is a reasonable expectation that any English text surviving (on paper, in stone, in other materials) for 700 years will be able to be read by the resource exploration/exploitation decision makers.
>
> (B) The other half of the rationale is whether there is a reasonable expectation that the physical form of the component (or a subset of the multiple copies of the component) will survive for 700 years.

All the components have (A) and if a component has (B), then a component is sufficient to correctly convey the correct information.

b. The passive institutional controls system for the WIPP consists of two types of components. Awareness triggers are one type of component and are intended to alert the potential intruder or site investigator that something anomalous is present at the WIPP site, and that more information should be obtained before proceeding with the intrusion activity. In the search for additional information, the potential intruder or site investigator will encounter one or more deterrent components, which are the other type of components. (No credit is claimed for awareness triggers in deterring inadvertent human intrusion for the performance assessment calculations.) Deterrent components are designed to convey a warning to the potential intruder or site investigator that the WIPP site contains hazardous materials and is not a suitable location for the intended intrusion activity. This distinction

between the goals of awareness triggers and deterrent components is in a sense layering of the components by having separate goals for each category or components.

No hierarchy of deterrent components is intended. Each deterrent component contains enough information to deter the potential intruder or site investigator. Different levels of messages associated with different components may imply layering within the deterrent components, but these different message levels are targeted at different audiences to address the Assurance Requirement rather than to address the credit for passive institutional controls in performance assessment. Level II, and perhaps Level III messages, are targeted at people in societies that are not drastically different from our own involved in the natural-resource industries that might be interested in locating or exploiting natural resources at the WIPP site. Levels III, IV, and V messages are designed to reestablish basic scientific concepts within societies in which these concepts have been lost or the social/technological/language changes have been so great that the connection between the text messages and the concepts have to be reestablished. In addition, these higher-level messages provide basic information about the characteristics of the WIPP site, the repository, and TRU waste.

The concept of the passive institutional controls as an integrated system refers to design characteristics that develop a wide variety of passive institutional controls components encompassing a variety of message levels and using a variety of media for conveying the messages.

A Gestalt is a system in which the whole cannot be determined by simply summing the parts within the whole. The Gestaltic nature of the passive institutional controls system refers to the DOE's belief that the effectiveness of the system cannot be determined by summing the estimated effectivenesses of the passive institutional controls components. The physical presence of the passive institutional controls components, the repetition of the warning over and over on different media and in different ways, the size of the markers, and the level of effort required to construct the markers and distribute the records will reinforce to the potential intruder the importance of the location, and thereby reinforce the importance of the messages and warnings to an extent that simply reading a single message is unlikely to convey.

The concept of Gestalt for passive institutional controls addresses the requirements of the Assurance Requirements because of the potential for discontinuities in society and information. A future society might need to recreate all the information about the WIPP. For performance assessment purposes, and with the assumptions developed, redundancy and self sufficient passive institutional controls are used.

The DOE did not attempt to estimate the contribution of the Gestaltic nature of the passive institutional controls system when estimating the effectiveness of the passive institutional controls for performance assessment, and thus underestimated the effectiveness of the passive institutional controls system. Given the short time frame for which credit may be given for

the passive institutional controls in performance assessment and the high levels of effectiveness of each component when considered independently in this time frame, the DOE decided not to include the concept of Gestalt and the likely accompanying controversies into the DOE estimates. For longer time frames in which substantially greater changes to society, technology, and language are likely to occur, the contribution of the Gestaltic nature of the passive institutional controls system is likely to be a larger contributor to estimates of passive institutional controls effectiveness in deterring inadvertent intrusions.

Peer Reviewer Consideration of Response

The DOE understood both issues and provided a reasonable response for item "b." The panel concluded that the DOE response for item "a" did not reasonably address their concern.

DOE Technical Position versus Panel Issue

(a) The DOE believes that any one of the components, in isolation, will be an effective deterrent. The panel's report indicates that all of the components need to be encountered for deterrence; this is at odds with the DOE's approach. The statement that "the system is only as strong as its weakest — not its strongest — component" is incorrect because if a potential intruder encounters more than one message, the most convincing message, that is, the stronger component, will be believed.

9.3.7.3 Peer Review Panel Concern - Uncertainty

Assessment of the durability and comprehensibility of individual components of the system. The panel examined descriptions of markers, archives, records centers, government control of land use, and other passive institutional controls. The panel concluded that the materials (e.g., granite) and plans for the storage and retention of records appear to be adequate, but that there is uncertainty attached to both the durability and comprehension of all passive institutional controls and that this uncertainty has not been taken into account by the PTF.

Consequences for performance assessment. The panel concluded that:...1) uncertainties relating to the failure of various passive institutional controls components were not addressed properly.

Overall Conclusion from the Executive Summary. *The overall conclusions presented by the panel regarding the passive institutional controls described and supported in the PICs Efficacy Report and the Conceptual Design Report suggest that:...(2) the level of uncertainty as it applies to the passive institutional controls is higher than 0.0.*

Concern #5 from the report Conclusions section. *The report concludes that the marker system is 100 percent reliable with no uncertainty, and that the*

> *records/archives/land-use controls are highly reliable with no uncertainty. The panel believes that there is uncertainty attached to comprehension of all the passive institutional controls and that the records centers and archives, as described in the documents under review, are highly likely to fail as communication events.*

Statement of Issues

a. The panel believes that the DOE has not considered the uncertainty in durability and comprehension.

b. The panel believes that the DOE needs to calculate failure rates and uncertainty for each passive institutional controls component.

c. The panel believes that the DOE used a failure rate of 0.0 for the markers, records centers, archives, and land use controls at the WIPP.

d. The panel believes that the DOE considered no uncertainty in the response of the passive institutional controls to failure mechanisms.

e. The panel believes there is uncertainty in the response of the passive institutional controls to failure mechanisms.

f. The panel believes that there is a low probability and high uncertainty about the ability of records centers and archives to effectively communicate because of inadequate explanation in the Passive Institutional Controls Efficacy Report. As indicated in the text of the panel's report, this probability could be increased and the uncertainty decreased by developing additional arguments.

Response to Issues

a. The DOE assessment of durability and correct interpretation was that the effectiveness was very high, but not perfect. Explanations started out with the use of the term "virtually" to indicate high but not perfect performance. Later in the report the language slipped and the use of "virtually" was inadvertently left out, although the conclusions section does make use of the term. Any consideration of the passive institutional controls effectiveness being absolutely perfect would be counter to the EPA's instructions which the DOE quoted:

> "although passive institutional controls should not be assumed to completely rule out the possibility of intrusion" (EPA 1985, 50 FR 38089a) .

b. The assessment of a failure rate is in and of itself an uncertain quantity. The DOE used the approach of identifying a bounding value to address the factors that may affect this

uncertainty. In addition, Budescu and Wallsten (1987) indicate that it does a disservice to decision makers to present material which suggests that there is more certainty about something than there really is:

> "It is argued that the decision-maker is poorly served when provided with forecasts that are more precise than is warranted by the available information."

Putting a number on a failure rate for each passive institutional controls component would be introducing speculation that does not add information for a decision maker to assess credit for passive institutional controls in performance assessment.

c. The initial treatment of the effectiveness of passive institutional controls based on design concepts from historical analogues was that they were highly effective, but not perfect (that is, not a failure rate of 0.0 as indicated by the panel), as indicated by the use of the term "virtually". The conclusions of the Passive Institutional Controls Efficacy Report state that:

> "Based on the above analyses, the passive institutional controls system will offer virtually complete effectiveness in deterring inadvertent human intrusions within the repository footprint for as long as the marker system components at this location are in place. The effectiveness of the passive institutional controls system in deterring inadvertent human intrusions within the Withdrawal outside the repository footprint will offer virtually complete effectiveness for the period from 100 years...after disposal to at least a couple of thousand years after disposal."

The term "virtually" has a meaning in common usage of "for all practicable purposes." In the context of the passive institutional controls performance for performance assessment for the 700 years when credit may be allowed, "virtually certain" indicates a high level of confidence while recognizing a possibility, no matter how remote, of an alternative conclusion.

d. The DOE realized the uncertainty in addressing the issue of failure mechanisms. The available information on the failure rate of the existing control system to prevent boreholes from being drilled where it is not lawful (analogous to an inadvertent human intrusion event where a borehole anywhere within the Withdrawal is not lawful) provided a failure rate for the land-use controls, without benefit of any markers, records centers, and archives, as will be the case for the WIPP. The failures observed in these cases were location errors within the correct claim.

The DOE believes it was appropriate to use information on recent failure rates because of EPA's own use of today's activities as a surrogate for future activities (for example, drilling activity), and because the EPA instructed the DOE to undertake a prudent extrapolation of current conditions for use in considering the effectiveness of passive institutional controls. A recent "failure rate" of 0.00001 for the Permian Basin, and a 0.0 recent "failure rate" for the Delaware Basin were thus calculated. Even with the added protection afforded by markers at

the WIPP along with the deterrent components of records centers and archives, the DOE realized that the uncertainties inherent in addressing the impact of failure mechanisms and decided to recommend a bounding approach. As stated on 6-11 (see Appendix EPIC), "For the sake of addressing the needs of PA and to account for unidentified possible failure mechanisms and sources of human error that could result in reduced effectiveness of the passive institutional controls system, the DOE recommends that the failure rate for performance assessment calculations (100 to 700 years after disposal) be increased to a bounding value of 0.01." The DOE believes that the increase in the surrogate failure rate for use in performance assessment by three orders of magnitude is sufficient to capture the uncertainties associated with failure mechanisms. The DOE saw this as representing additional failure mechanism not considered and simple human error. As a result, the DOE increased the failure rate for performance assessment calculations by 1,000 times. Additional investigations into failures in several other states and several Canadian provinces supported the bounding failure rate developed previously.

e. The DOE agrees that there is uncertainty in the effectiveness of the passive institutional controls for certain failure mechanisms, and believes that it was appropriate to address it through the use of bounding estimates of effectiveness.

f. The DOE believes that the design solutions implemented for the records centers and archives for retaining WIPP material apply lessons learned from known failures and make retention of sufficient material to correctly communicate the necessary information a highly likely event and disagree with the panel on this point in the absence of any more specific failure-mechanism concerns. The design solutions implemented range from having both records centers (easier access to potential intruders) and archives (greater preservation potential) retain the information to having multiple locations for storage of the information under multiple jurisdictions to having a truthful representation of the risks of intruding upon the disposal system transmitted to future generations.

In order to ensure that these design solutions are implemented, the DOE is developing QA procedures addressing the three implementation steps (encode in language, capture in media, and transmit) from the panel's general communications model (Figure 3.2.2-1 of their report). The DOE believes that these QA procedures will provide the documentation that the panel felt was necessary to indicate how correct information will get into the records centers and archives. This documentation will support the DOE conclusions as to the effectiveness of records centers and archives.

Peer Reviewer Consideration of Response

The DOE understood all of the issues; however, the panel concluded that the responses to items "a," "d," and "f" did not reasonably address their concerns.

DOE Technical Position versus Panel Response

a) The definition of "virtually" that the DOE proposed in the Passive Institutional Controls Efficacy Report is consistent with the standard dictionary definition. The passive institutional control's components are over-designed for the relatively short time period for which credit may be given for passive institutional controls in performance assessment and based on the EPA's guidance on a prudent extrapolation from today's conditions. This over-design means that in fact the passive institutional controls are expected to be virtually (that is, for all practical purposes) certain to deter inadvertent human intrusion.

d) The DOE has committed to implementing the passive institutional controls as described in the CDR and the QA procedures being developed will assure that the correct documents will get to the correct records centers and archives with which arrangements have been made to receive and implement the prearranged storage and retrieval system. The list in the CDR of records centers and archives is based on those facilities that currently exist and that bear some relationship to, for example, nuclear waste, resource development, land use, document preservation, and health issues. When the DOE is ready to implement the passive institutional controls, the list will be finalized and the appropriate arrangements will be made. Because the WIPP information will be integrated into natural resource-based information centers, certain state and federal agencies dealing with land use and resource exploitation will be required by law to accept and maintain these records.

f) The DOE's responsibilities include developing estimates of the effectiveness of passive institutional controls for performance assessment based on the components in the CDR to which the DOE has committed. The DOE is responsible for ensuring that the components are designed, constructed, and implemented correctly.

9.3.7.4 Peer Review Panel Concerns - Failure Scenarios

Assessment of Completeness of Failure Scenarios. The panel found that at least two failure scenarios were not discussed by the PTF: collateral damage due to war and inadvertent intrusion due to horizontal drilling.

Consequences for performance assessment. *The panel concluded that:...2) certain credible failure scenarios were not considered;"*

Concern #1 from the report Conclusion section. *This report concludes that the sole cause of failure is incorrect location of a drilling rig. The panel believes that there are other failure scenarios that have not been taken into account-- specifically, horizontal drilling, collateral damage due to war, and vandalism.*

Concern #4 from the report Conclusion section. *The report concludes that vandalism and souvenir hunting will be effectively defeated by the passive institutional controls*

design. The panel believes that this conclusion has not considered the historical destruction of similar types of monuments, markers, and constructions during periods of war or loss of active governmental control.

Statement of Issues

a. The panel believes that horizontal drilling would constitute an inadvertent human intrusion (only inadvertent human intrusion is to be considered in performance assessments).

b. The panel believes that the probability of collateral war damage sufficient to make the markers at the WIPP unable to communicate is high enough to be screened in for performance assessment purposes and should be addressed in the report.

c. The panel believes that the markers as currently designed cannot completely address vandalism and souvenir hunting for a period of 600 years (from year 100 to year 700 after closure). It is not clear whether this failure was seen as a failure of some pieces of a component or the entire component.

d. The panel believes that the efficacy of certain markers components against potential horizontal drilling is lower than for vertical drilling, for instance, because of its more remote origination location.

e. The panel believes that the DOE used a failure rate of 0.0 for the effectiveness of the passive institutional controls against vandalism and souvenir hunting.

Response to Issues

a. Horizontal drilling would be subject to the same regulations as vertical drilling, and as a result would be subject to the same procedures. Consistent with these procedures (including examining maps ands other awareness triggers), horizontal drilling would require the obtaining of ownership or resource rights, both at the drill site and along the length of the drill string. There would be the same prohibitions on and legal disincentives to drilling into the disposal system from outside the Withdrawal as drilling vertically into the disposal system. As a result of being subject to the same procedures, the failure rate for horizontal drilling can be assumed to be the same as the failure rate for vertical drilling.

b. The collateral effects of war were not addressed and need not be addressed, because they would be such a low probability event. Collateral effects might take out some parts of a component or some parts of several components, but would be unlikely to take out all of the markers at the site. It would take a very large bomb to destroy all of the markers to the point that pieces of text on monuments did not remain in pieces larger enough to read. The trinitite produced from a nuclear device would itself be a marker. In discussing the impact of war damage, that is, bomb damage on a repository, the EPA has stated that "Similar to the

question of sabotage is the question of damage to the repository through some act of war. The only credible act that could even fracture the rock down to about 500 meters would be the detonation of at least a ten-megaton or larger nuclear device. During a war, it is hardly likely that bombs would be aimed at a repository. Cities and strategic installations are far more attractive targets. In addition, the effects on the biosphere from a damaged repository would be insignificant compared with the other damage inflicted in such a conflict." The WIPP is not a strategic target and is many miles away from any strategic targets. The probability of a stray missile in the expanse of southeastern New Mexico away from strategic targets, of a capacity large enough to destroy all the markers, was below the regulatory cut-off for scenarios that had to be considered. In addition, to paraphrase the EPA, if a bomb that large did come, it would disturb the repository and that bomb would represent far greater impacts than the disruption of the repository itself. In addition, collateral effects of war at the WIPP would not destroy all of the records centers and archives containing WIPP information.

c. Vandalism was taken into account in the designs. The passive institutional controls components are not replicates of the historical analogues examined, but take the basic design concept from the historical analogue that enabled these structures to endure and enhances them to compensate for natural and human factors that will tend to destroy the components. Specific examples of design solutions incorporated to counteract the effects of vandalism include: (1) selection of granite for the monuments and other markers as a durable rock that will resist chipping away pieces and limit damage from bullets; (2) use of multiple copies of the individual monuments and markers so the system will continue to communicate even if one or more individual monuments or markers are damaged or removed; (3) use of right angles and relatively large, flat surfaces in the shape of the monuments to reduce the amount of material that can be chipped away by someone hammering on a monument, (4) use of the large size of the monuments and the berm to make these components difficult to destroy or remove, (5) inclusion of two copies of the Level IV messages on the granite walls in each of the buried rooms, (6) use of an irregular pattern of the spacing and depth of the small buried markers to make systematic collection of these markers difficult.

The DOE expects that the markers at the WIPP, with their multiplicity of copies will be able to withstand casual vandalism and souvenir hunting (for example, spray paint, bullet holes, chipping of edges) for the period for 100 to 700 years after closure so that a sufficient number of components or pieces of components will remain to communicate their intended messages.

The DOE believes that systematic vandalism (for example, the monuments and markers at the WIPP being caught in the middle of a tank fight, the target of a scorched earth policy of a retreating army, the target of rampaging renegade troops, the target of deliberate destruction by cults, or the development of new highly destructive technologies that can be owned by the general public) will be a low probability event at the WIPP during the years from 100 to 700 after closure. In addition, vandalism of this type is beyond the realm of a prudent extrapolation of today's societal conditions.

The DOE disagrees with the panel on the possible impacts of vandalism on the effectiveness of passive institutional controls in deterring inadvertent human intrusion. The DOE believes that the passive institutional controls to be implemented for the WIPP will be highly effective in the context of performance assessments because of all the design solutions incorporated to address potential vandalism and other potential failure mechanisms and the relatively short time frame of interest (from year 100 to year 700 after closure of the WIPP).

d. Horizontal drilling is required to go through the same site-evaluation procedures and permitting processes as vertical drilling. As a result, the passive institutional controls will be as effective in deterring inadvertent horizontal drilling into the Withdrawal as they will be in deterring inadvertent vertical drilling.

e. See Section 9.3.7.3, DOE Response c.

Peer Reviewer Consideration of Response

The DOE understood the issues and provided reasonable responses.

9.3.7.5 Peer Review Panel Concerns - Calculations

Evaluation of credit calculations. The panel's analysis suggested that the PTF's credit calculations may be incorrect or incomplete. For example, failure rates and the uncertainty surrounding failure rates should be calculated for each component.

Consequences for performance assessment. The panel concluded that:...3) adequate evidence for calculating failure probabilities of various components was not provided,...

Overall conclusions from the Executive Summary. *The overall conclusions presented by the panel regarding the passive institutional controls described and supported in the PICs Efficacy Report and the Conceptual Design Report suggest that: (1) the evidence provided in the reports does not adequately demonstrate that passive institutional controls will have a failure probability of 0.01 or less....*

Concern #3 from the Conclusions section of the report. The report describes historical analogs for the passive institutional controls in order to justify a 0.0 failure rate for durability. However, failure rates ascribed on the basis of historical analogs do not account for the fact that similar monuments or constructions have not survived.

Statement of Issues

a. The panel believes that it is appropriate and necessary to calculate failure probabilities for each component.

b. The panel believes that the DOE needs to provide additional evidence/calculations to support the assessed failure rate.

c. The panel believes that there is uncertainty associated with the passive institutional controls.

d. The panel believes the DOE used a failure rate of 0.0 for durability of the markers at the WIPP in the estimate of the effectiveness of passive institutional controls in deterring inadvertent human intrusion.

e. The panel believes that monuments similar to those designed for the WIPP have failed.

f. The panel believes that the failure of historical analogues means that the durability failure rate for the markers at the WIPP must be less than 0.0.

Response to Issues

a. The approach taken by the DOE was that there is so much redundancy in the passive institutional controls components that the probability that all elements of each component, and all components failing within the 700 year time frame of interest was so low, that the most productive course of action was to focus on the human errors within the process of resource development. The probability of passive institutional controls failure calculated incorporates not only the probability of mislocating a drill rig within a lease, but also the probability of someone trying to drill without proper authorization and the probability of setting up on the wrong lease (these were both zero for the knowledge base of the DOE's sources at the time of the DOE's first estimate). Realizing that there may be some additional failures that were not known by the DOE's sources, and realizing the uncertainties in the operation of failure mechanisms, the calculated failure rate was increased by orders of magnitude. The DOE does not believe that developing individual probabilities for each component would add information that would be of use to the EPA as the decision maker/regulator.

It is important to highlight at this point that the EPA guidance indicates that the effectiveness of the passive institutional controls in deterring inadvertent drilling can also apply to mining for the same time period. Because the societal common denominators, regulatory assumptions, and the DOE assumptions apply equally well to mining as to drilling, the DOE believes that the effectiveness of the passive institutional controls determined for drilling also applies to mining.

b. The DOE has contacted several additional government agencies to try to determine the historical rates at which oil and gas wells have been drilled on or into the wrong leases. These contacts resulted in the following information: (1) in Montana, over 1,200 wells have been drilled during the past six years with no instances of drilling on or into the wrong leases, (2) in Michigan, over 40,000 wells have been drilled since the current drilling regulations went into effect in 1927 with no instances of drilling on or into the wrong leases, (3) in Wyoming, over 60,000 wells have been drilled with perhaps two or three instances of drilling on or into the wrong leases, (4) in Manitoba, a total of 4,500 wells have been drilled for oil or gas with no instances of drilling on or into the wrong leases, and (5) in Alberta, the number of wells is in the range from 30,000 to 50,000 with perhaps 10 or 12 instances of drilling on or into the wrong leases. This new information supports the conclusions from earlier investigations of the Delaware and Permian Basins that drilling on or into the wrong leases is an extremely rare event.

Regulatory control over resource exploration and exploitation is just one of the deterrent components that the DOE will use to protect the WIPP from future human intrusion. The historical effectiveness of this one component in deterring drilling into the wrong leases has been extremely high, supporting the DOE's contention that the incorporation of additional deterrents will provide additional support to maintaining the effectiveness at extremely high levels. The DOE believes that the historical drilling information supports the conclusion that the proposed failure rate of the passive institutional controls for use in performance assessments of 0.01 is a bounding value that substantially underestimates by orders of magnitude the effectiveness of the deterrent components.

c. See Section 9.3.7.5, DOE Response a.

d. See Section 9.3.7.3, DOE Response c.

e. The DOE agrees that historical analogues have failed. The markers to be implemented for the WIPP are not merely replicates of historical analogues. Design solutions have incorporated elements shown to have endured, and the marker designs were modified to address possible failure mechanisms.

f. The DOE does believe that the failure rate is very close to 0.0, but is not 0.0. With the incorporation of design solutions, the markers should have greater durability than historical analogues, and thus the DOE disagrees with the panel.

Peer Reviewer Consideration of Response

The DOE understood all of the issues except item "f" and provided reasonable responses for all of the issues except items "a," "b," and "f."

DOE Technical Position versus Panel Issues

(a) As stated above, the passive institutional controls are over-designed. This over-design means that, in fact, the passive institutional controls are expected to be virtually (that is, for all practical purposes) certain to deter inadvertent human intrusion, and the only failure mechanism that could really impact effectiveness is human error. Oil field "failure rates" are a surrogate for human error in the resource development industry (this use of surrogates is consistent with the EPA's use of historical drilling rates as a surrogate for future drilling rates for other possible resources). Again, because of the over-design of the passive institutional controls in the performance assessment context, they are all highly effective. The DOE's approach was to assign a bounding value to the effectiveness of the passive institutional controls system in relation to human errors. In a practical sense, this bounding value can be considered to be a bounding value for each of the components.

(b) The DOE, or a successor agency, need only endure long enough to implement the passive institutional controls, not for the entire compliance period, nor even for the entire 700 years for which credit may be claimed for passive institutional controls in performance assessment. The controls are designed to be passive and need no maintenance by the DOE or a successor agency. Even if agencies are reorganized, the national interest is served by reassigning responsibility for nuclear waste management.

(f) The DOE addressed residual uncertainty by using a bounding value for the failure rate. Consultations with individuals involved in natural resource development in the regulatory arena confirmed that the 0.01 bounding failure rate to be used in performance assessment calculations grossly over-estimated the failure rate that would be expected under conditions similar to today. Note, this conclusion was for a single deterrent component, rather than the suite of components that the DOE has committed to implementing.

9.4 Peer Reviews Conducted Prior to Promulgation of 40 CFR Part 194

40 CFR Part 194 states that

> *"Additionally, this section requires compliance applications to include documentation of any peer review activities that DOE may have conducted apart from those required by this rule, including those activities which are similar to peer review, such as the reviews conducted by the WIPP Panel of the National Academy of Sciences."* (61 FR 5228)

and that

> *"Peer review which has been conducted prior to today's action must be documented in compliance applications."*

Over the course of the WIPP endeavor, the project has undergone extensive review. These historical reviews were conducted prior to the implementation of 40 CFR Part 194. They provide additional information to the peer reviews specifically stated in 40 CFR § 194.27(a). These reviews were evaluated against criteria developed from 40 CFR Parts 191 and 194 and NUREG-1297 to determine which ones were appropriate for incorporation in this application. The following criteria were used to screen the historical reviews:

1. Was the "peer review" relevant to this application?

   The purpose of this application is to demonstrate the WIPP's compliance with the disposal regulations found in 40 CFR Part 191. 40 CFR Part 194 provides significant detail concerning the necessary contents of the application. Reviews that cover subject matter pertinent to those contents are considered relevant to this application.

2. Was there a formal report by the reviewer?

   NUREG-1297 requires a peer review to be documented.

3. Was the review a "peer review" rather than a "technical review"?

   NUREG-1297 states that

   > *"A peer review is an in-depth critique of the assumptions, calculations, extrapolations, alternate interpretations, methodology, and acceptance criteria employed, and of conclusions drawn from the original work. Peer reviews confirm the adequacy of work. In contrast to peer review, the term "technical review," as used in this GTP, refers to a review to verify compliance to predetermined requirements; industry standards; or common scientific, engineering, and industry practice."*

4. Was the review a "peer review" rather than an "expert judgment"?

   As discussed above, a peer review confirms the adequacy of the work being reviewed. 40 CFR Part 194 states that

   > *"Typically, expert judgment is used to elicit two types of information: (1) Numerical values for parameters (variables) which are measurable only by experiments that cannot be conducted due to limitations of time, money and physical situation; and (2) essentially unknowable information, such as which features should be incorporated into passive institutional controls that will deter human intrusion into the repository."* (61 FR 5228)

5. Was the technical expertise of the reviewer at least that needed to perform the original work?

NUREG-1297 states that

"The technical qualifications of the peer reviewers, in their review area should be at least equivalent to that needed for the original work under review and should be the primary consideration in the selection of peer reviewers. Each peer reviewer should have recognized and verifiable technical credentials in the technical area he or she has been selected to cover. The technical qualifications of each peer, and hence of the peer review group as a whole, should relate to the importance of the subject matter to be reviewed."

6. Were the reviewers independent?

   a. Were they involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed?

   b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?

Regarding the reviewers independence, NUREG-1297 states:

"Members of the peer review group should be independent of the original work to be reviewed. Independence in this case means that the peer, a) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed."

"Because of DOE's pervasive effort in the waste management area, the lack or unavailability of other technical expertise in certain areas, and the possibility of reducing the technical qualifications of the reviewers in order that total independence is maintained, it may not be possible to exclude all DOE or DOE contractor personnel from participating in a peer review. In those cases where total independence cannot be met, a documented rationale as to why someone of equivalent technical qualifications and greater independence was not selected should be placed in the peer review report."

"The pervasive nature of DOE's effort in the waste management area also makes it necessary that both the work under review as well as the peer review of this work be allowed to be funded by DOE."

> *"The independence criteria is not meant to exclude eminent scientists or engineer upon whose earlier work certain of the work under review is based so long as a general scientific consensus has been reached regarding the validity of their earlier work."*

7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review" for incorporation into the historical review section of this application?

Interviews with former and current WIPP project personnel were conducted to identify past reviews that should be considered for inclusion in this application. Records of the historical reviews were obtained and evaluated against the above screening criteria to select the specific reviews to be documented in the application. The selected reviews are discussed below and copies of the reports are provided in Appendix PEER.

A "historical review" may provide an evaluation of completed work by the WIPP project, for example, the Engineered Alternatives Task Force Report (DOE 1991a) review. In most cases however, the reviews were sought by the project to seek guidance and an outside perspective as to appropriate "next steps." It should be remembered that most of these reviews were actually evaluating "work-in-progress." They focus on the status of ongoing work at a specific point in time to guide future emphasis and direction of the work and, by their very nature, tend to accentuate aspects of the work that need improvement. They have been very important to the WIPP project because they have consistently provided an understanding of deficiencies and contributed heavily in guiding the project's future direction and needs. The historical peer reviews provide an overall perspective of the evolution and growth of the project.

9.4.1 NAS WIPP Panel Reviews

The NRC (National Research Council) was established by the NAS in 1916. The Council operates in accordance with Academy general policies under the authority of the NAS congressional charter of 1863. The NRC has become a principal NAS operating agency for providing services to the government, the public, and the scientific and engineering communities.

In March 1978, the DOE requested the NRC:

> *"to review the scientific and technical criteria and guidelines for designing, constructing and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere."*

The NRC assigned the study to the Committee on Radioactive Waste Management under the Commission on Natural Resources. The Committee organized the Panel on the WIPP to:

"review the scientific and technical adequacy of the site-suitability criteria; the guidelines for the site confirmation studies; the design criteria for the repository, including the waste acceptance criteria, the design philosophy, and the operational philosophy; the criteria for determining the environmental safety of future planned operations, viewed from the perspective of the environmental conditions of the repository site; and the design criteria for the experimental testing program of the behavior of the waste-geologic medium interaction."

Panel members are independent of the WIPP project and are nationally recognized experts in their respective disciplines. The panel was selected so as to provide an appropriate balance of relevant technical disciplines. The scope of the panel's expertise is very broad and includes environmental engineering, geology, geochemistry, nuclear science & technology, nuclear engineering, materials science and mining engineering. The panel regularly makes use of other members of the NRC Board of Radioactive Waste Management and/or consultants as necessary to provide additional expertise. The members of the initial panel were:

Frank L. Parker (Chairman), Vanderbilt University
Konrad B. Krauskopf (Vice Chairman), Stanford University
Merril Eisenbud, New York University Medical Center
Fred M. Ernsberger, PPG Industries, Inc.
Peter T. Flawn, University of Texas, Austin
Roger Kasperson, Clark University
Richard R. Parizek, Pennsylvania State University
Thomas H. Pigford, University of California, Berkeley
D'Arcy A. Shock, Consultant
Roger W. Staehle, University of Minnesota
John W. Winchester, Florida State University
John T. Holloway, NRC Senior Staff Officer

Changes to the membership of this panel have occurred over time. However, a continuity of WIPP knowledge has been maintained because of a significant overlap of members. The current panel members are:

Charles Fairhurst (Chairman), University of Minnesota
Howard Adler, Oxyrase, Incorporated
John O. Blomeke, Consultant
Sue B. Clark, University of Georgia
Rodney C. Ewing, University of New Mexico
Fred Ernsberger, Consultant
B. John Garrick, PLG, Incorporated
Leonard F. Konikow, U.S. Geological Survey
Konrad B. Krauskopf, Stanford University

Della Roy, Pennsylvania State University
David A. Waite, CH_2M Hill
Chris G. Whipple, ICF Kaiser Engineers, Inc.
Thomas A. Zordan, ICF Kaiser Engineers, Inc.
Darleane C. Hoffman, Lawrence Berkeley Laboratory (BRWM Liason)
Thomas Kiess, National Research Council Staff Officer
Angela Taylor, National Research Council Project Assistant

Since 1978, the WIPP Panel has produced several reports reflecting their ongoing review effort. An evaluation of the NAS reviews against the previously described screening criteria is provided in Table 9-8. Summaries of the review reports are provided in the following sections.

9.4.1.1 Letter Report of May 1, 1979

The panel reviewed the WIPP Draft Site Characterization Report (DSCR) (Powers et al. 1978) which was subsequently published as the Geological Characterization Report (GCR) (Appendix GCR). The DSCR is a compilation of the known geotechnical information about the proposed site and the surrounding region.

A copy of the NAS Letter Report is provided in Appendix PEER. The panel summarized its review findings in their report as follows:

> *"In summary, the Panel views the DSCR as a progress report on a continuing program of geotechnical data collection and analysis, conducted under the constraint of no perturbation of the potential site. The Panel considers the report to be useful as a compendium of the information available to the authors on the character of the unperturbed geological formation at the Los Medanos site and the dynamics of the geochemical/hydrological system. On the basis of this available information, further investigation of the site is warranted. However, final decisions regarding repository site selection must take into account more information than is contained in this report. Most importantly, they must take into account the effect of the emplacement of the waste and the waste itself on the repository and its surroundings. These decisions must be based also on supplementary data acquisition and analyses such as those suggested above; the additional studies delineated in the document itself; crucial in-situ studies conducted throughout the construction phase; and additional definition of design objective, criteria for safe operation, and waste forms to be accommodated."*

In response to the NAS report, a considerable amount of additional geotechnical information regarding the WIPP site has been developed. In particular, the geology and hydrology of the area have undergone continuing study since the inception of the project. Numerous evaluations and tests have expanded the project's knowledge of the site and the waste, and their potential interaction.

Table 9-8. NAS WIPP Panel Reviews

1. *Is the "peer review" relevant to the CCA?*	*Yes - The Panel has dealt with many WIPP* issues and most are directly relevant to the CCA.
2. Was there a formal report prepared by the reviewer?	Yes - There have been a series of formal reports.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A *technical review verifies compliance to* predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - Most of the reviews have addressed the adequacy of PA, site selection, etc. activities at WIPP.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Yes - The reviews have all evaluated the adequacy of work prepared by the WIPP project or others.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - Panel members are nationally recognized experts in their respective fields.
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from *funding considerations to assure the work was* impartially reviewed?	Yes - The Panel was established by the National Research Council in the 1970's.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A - However, 40 CFR 194 (Supplementary Information re: §194.27) specifically indicates the NAS Panel reviews are appropriate for the CCA.

9.4.1.2 Letter Report of September 10, 1979

This report (see Appendix PEER) was prepared after the panel reviewed the findings of geological explorations through the following: briefings by SNL and the U.S. Geological Survey, study of both published and unpublished technical literature, site visits, examination of actual borehole cores and discussions with other experts in selected geotechnical areas. The panel recommended that *"an exploratory shaft be sunk at the site of one of the proposed access shafts to the depth of the proposed repository horizon"* and that *"drilling be done and tunnels developed in the salt as necessary to conduct the measurements and observations needed to resolve remaining site-specific geotechnical uncertainties and to ascertain the degree to which the site is suitable for the excavation of a repository."*

An exploratory shaft and tunnels were developed subsequent to this report. The information gained from this additional work was sufficient to allow the DOE to proceed with development of the WIPP repository and construction of supporting facilities.

9.4.1.3 Continuing Evaluation of the Carlsbad Site

This July 28, 1980 report (see Appendix PEER) reviewed the Carlsbad site in light of the President's decision to cancel the WIPP project. Two panel members, Drs. Cohen and Winchester, did not participate in the deliberations or the drafting of this report. The panel analyzed geological characterization efforts regarding the Carlsbad site, the WIPP Draft Environmental Impact Statement (DOE 1979), and defense waste characteristics. In its report, the panel concluded that:

> *"it is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements for evaluation of this site, as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. If so reoriented, the project could contribute by:*
>
> - *providing prototype experience in site qualification;*
> - *testing, in situ, performance assumptions about the geologic medium; and*
> - *developing techniques and information which will be required in the licensing process.*
>
> *If given this new mission, work should proceed on constructing the exploratory shaft, acquiring hands-on repository mining experience, conducting in-situ tests and measurements at various depths, verifying engineering design assumptions, and developing analyses for licensing review."*

As indicated above, the DOE proceeded with site characterization and qualification, construction of an exploratory shaft and underground workings, and with in-situ testing.

Subsequently, development of the repository and construction of the above-ground facilities was initiated. Thermal tests to simulate defense high level waste were performed, but extensive evaluation for a spent fuel and high level waste repository were not conducted because the Congressional Authorization in 1980 restricted the WIPP to defense TRU wastes. Specific responses to the panel's concerns were provided in an August 18, 1989 letter from Mr. Leo Duffy to Dr. Peter Myers (Duffy 1989; Appendix PEER, Section PEER.10).

9.4.1.4 Review of the Criteria for the Site Suitability, Design, Construction, and Operation of the Proposed Waste Isolation Pilot Plant (WIPP); Progress Report: July 1, 1978, to December 31, 1979

This September 1981 report (see Appendix PEER) recounts the panel's findings through the end of 1979. Several major program documents had been issued and examined by the panel, including the GCR (Powers et al. 1978), the Title I Design Report (Bechtel 1979, 1980) and the Draft Environmental Impact Statement (DEIS) (DOE 1979). The report is based on analysis of these and other documents, numerous technical briefings, extensive discussions with representatives of DOE and its contractors, and several field visits.

The panel specifically addressed several topics during its review, including site selection criteria, design of underground facilities, acceptance criteria for TRU waste, environmental effects, in-situ tests and experiments, and natural resources at the WIPP site.

Regarding the issue of site selection criteria, the panel stated in its report:

> *"In summary, study of the WIPP site and its environs has shown that the criteria for site selection were in considerable measure satisfied; the Panel thinks probable site suitability has been demonstrated sufficiently to justify the sinking of an exploratory shaft without delay . . . . ."*

Concerning the design of the underground facilities, the report recommends that a study be made to *"determine whether it is necessary to seal the excavations in such a way that their void space and permeability are very much less than is currently envisaged. Such a study is needed to show that the intrinsic properties of salt can be taken advantage of to effect safe isolation of radioactive waste by deep geologic disposal."*

Regarding waste acceptance criteria, the report discusses fire, gas generation, complexation, immobilization, package structure and solution rates. Specifically, the panel notes that the criteria primarily deal with operational aspects of the WIPP and that the only long term concern addressed is that of gas generation. The report stated that the inclusion of organic materials in WIPP wastes raises questions about fire in the short term and about gas generation and formation of organic complexes with radioactive materials in the long term.

The panel determined that a sequence of confirmatory underground in-situ tests and experiments would be needed after completion of extensive laboratory and field investigations and analyses. This testing would help resolve geotechnical uncertainties, evaluate the physical characteristics of the host media, corroborate the design of the repository, demonstrate the viability and effectiveness of underground techniques such as backfilling, and obtain measurements of initial rock response to excavation and waste emplacement. The panel noted concerns with regard to existing test plans.

Finally, the report discusses the impact of natural resources at the WIPP site. The panel concluded that the DEIS value provided for hydrocarbon resources were "greatly underestimated" and recommended updating the estimates. The panel determined that for potash resources however, the DEIS analysis appears "to provide adequate baseline information." The panel also concluded that the DEIS scenarios regarding the threat to the repository due to future exploration and exploitation of natural resources may fail to bound the maximum credible event. The panel states that *"(e)ither solution mining for table salt 100 years after closure of a high-level waste repository or mining of radioactive materials themselves, whether purposeful or not, could produce consequences greater than those indicated in the worst-case analysis"* of the DEIS and concluded that the significance of these factors should be carefully evaluated.

As noted in the report's preface, the WIPP project experienced major changes in direction and scope following the period covered by this report. The report notes that *"(m)any of the technical deficiencies that were perceived to exist at the end of 1979 have since been remedied by additional investigations and design changes."* The effects of these changes were considered by the panel as it continued its review of the criteria for site suitability, design, construction and operation of the WIPP. An interim report of the continuing review was developed in 1983 (see Section 9.4.1.5 below). The panel subsequently completed the review and provided its conclusions in 1984 (see Section 9.4.1.6 below).

9.4.1.5 Review of the Criteria for the Site Suitability, Design, Construction, and Operation of the Proposed Waste Isolation Pilot Plant (WIPP); Interim Report: July 1, 1978 to July 31, 1982

This 1983 report (see Appendix PEER) updates the panel's review of WIPP and recounts the panel's findings through the end of July 1982. During this period several major project documents had been issued by the DOE, including the GCR (Powers et al. 1978), the Title I Design Report (Bechtel 1979, 1980), the FEIS (DOE 1980a) and the Safety Analysis Report (DOE 1980b). The panel report is based on analysis of the contents of these and other documents, numerous technical briefings, extensive discussions with representatives of DOE and its contractors, comments by interested members of the public, and several WIPP visits. The panel composition was the same as noted above, except that Drs. Eisenbud, Flawn, James, Kasperson, Pigford, and Staehle did not participate.

The recommendations from the report that are relevant to this application were as follows:

- Evaluate the practical effects of resource extraction in Zone IV to assess whether such extraction poses significant threat to the safety and integrity of the repository.

- Implement plans for further field and analytical work to test the extent of deep strata-bound dissolution.

- Locate one or both of the remaining hydrologic test holes planned to be drilled in 1983 in lineaments or fracture traces if such features are revealed on satellite images or high altitude areal photographs. Test holes so located will help determine fracture concentrations.

- Keep the WIPP R&D program flexible to accommodate changes suggested by early WIPP results or other waste disposal technologies by other organizations.

- Supplement the tests on waste form, package, overpack, and backfill with above-ground laboratory tests.

- Measure the humidity of still air in equilibrium with the salt and the pH of the salt at the storage horizon (significant for evaluation of biological and chemical degradation processes).

- If relative humidity of the sealed enclosure at the repository is 60 percent or less, drop restrictions on permissible mass of organic materials per unit volume of waste from the gas generation criteria.

- If the humidity of the air is higher than 60 percent, evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment.

- Provide state-of-the-art equipment at the WIPP facility for nondestructive verification of compliance of the waste acceptance criteria.

- Define the waste acceptance criteria for the defense high-level waste to be used in the experimental program.

- Establish explicit mechanisms for the transfer of information from experiments and information gathered during construction and development to final design.

- Determine if displacement of salt in the far field occurring as a result of long-term closure of excavations significantly increases the permeability of the bulk of the salt.

- Determine if sealing the repository is sufficient to preclude unacceptable increases in hydrologic conductivity across the repository horizon.

- Continue hydrologic investigations and monitoring programs to resolve interpretations of potentiometric maps and to determine the rates and directions of groundwater flow within Rustler aquifers above and immediately adjacent to the site.

- Delineate the karst-type flow in the Rustler aquifer near Nash Draw.

Consequences of natural resources in Zone IV and the decision to relinquish Zone IV as a buffer zone are detailed in the Natural Resources Study (Brausch et al. 1982). Additional hydrologic exploration holes were drilled in the site area to evaluate issues such as deep-seated evaporite dissolution. Transmissivity within the Culebra has since been evaluated through multipad interference testing. The DOE has continued to resist verification of waste acceptance criteria compliance at the WIPP site because of increased risk to workers. Laboratory testing continued to address proposed backfill material properties and effectiveness. The relative humidity at the WIPP was determined to be greater than 60 percent. Additional WIPP evaluations concluded that karstic flow exists within Nash Draw but that it does not affect the Rustler dolomites that dominate flow in the site area. Defense high-level waste experimentation was deleted from the project in 1988.

A considerable amount of further testing and evaluation occurred at the WIPP after this report was written. The DOE provided formal responses on August 18, 1989 to the NAS recommendations. The panel subsequently completed this review and provided its conclusions in 1984 (see Section 9.4.1.6 below).

9.4.1.6 Review of the Scientific and Technical Criteria for the Waste Isolation Pilot Plant (WIPP)

This 1984 report (see Appendix PEER, Section PEER.9.6) updates the panel's review of the WIPP and recounts the panel's findings through December 31, 1983. The report is based on analysis of the contents of documents issued to that date, technical briefings, discussions with representatives of the DOE and its contractors, comments by interested members of the public, and a number of field visits. The panel members involved in this review were the same as those noted in Section 9.4.1.5 above.

Several recommendations, in addition to those provided in 1983 (see Section 9.4.1.5), were provided by the panel. The new recommendations from the report, which are relevant to this application, are presented below.

- Redesign certification procedures to simulate those used commercially in the purchasing of commodities.

- Consider relaxing the waste acceptance criterion relating to gas generation due to bacterial action.

- Use models to assess whether closure of the excavations and consequent encapsulation of the waste in salt are likely to occur, and to determine the period of time within which they may occur.

- The FSEIS (DOE 1990a) should be reissued to correspond with the present design.

- Calculate all dosages on the same basis (that is, if recommendations of ICRP-26 and ICRP-30 were used, rather than those of ICRP-2).

A considerable amount of additional laboratory and in-situ testing and analysis have occurred. An FSEIS (DOE 1990 in the Bibliography) was issued in January 1990 to update the information in the FEIS and an additional resource evaluation was conducted by the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) in 1995 (NMBMMR 1995 in the Bibliography). Waste acceptance criteria continued to evolve based on further testing and analysis. The FSEIS (DOE 1990), a RCRA permit application, and formal performance assessment documents (Bertram-Howery et al. 1990 in the Bibliography, and subsequent reports) have provided significant additional analyses of potential accidents, environmental effects, and long-term performance of the repository. A disposal phase SEIS (SEIS-II) is currently being developed.

9.4.1.7 Letter Report of April 1987 on Planned Sorbing-Tracer Field Tests

The WIPP panel considered the sorbing-tracer field test planned at WIPP and provided their comments in April 1987 (see Appendix PEER). The purpose of the planned test was to develop data regarding the K_d (distribution coefficient) values for predicting retardation of radionuclide movement in the Culebra aquifer. The test plans were described to the panel at its February 1986 and September 1986 meetings.

The panel was divided in its opinion as to whether the tests would yield useful results but agreed that the tests should be carried out because of WIPP commitments to the state of New Mexico and the desirability of obtaining in-situ K_d values. The panel's Letter Report provided the following six recommendations regarding the tests:

1. Calculate the probable rate of release to the accessible environment of the important radionuclides in TRU waste on the assumption of no retardation due to sorption.

2. Select drillholes for injection and recovery for which the history since drilling is well known, particularly with respect to the composition of the drilling fluid and any other fluid that has been subsequently added.

3. Recommend additional research in the study of Culebra hydrology in different parts of the WIPP site and autoradiographic study of Culebra specimens to determine what phases are active sorbents for TRU elements.

4. The panel strongly urges the use of radionuclides rather than analog elements as sorbing-tracers.

5. Conduct tests at more than one hydropad to obtain a statistically significant result and to give some sense of the possible variability of the geochemistry and characteristics of groundwater flow in the Culebra aquifer.

6. Conduct laboratory tests for determination of K_d, using chunks of dolomite from drill cores with their surfaces and fractures kept in a state as close as possible to natural conditions.

The DOE provided a formal response to the panel's recommendations on August 18, 1989 (see Appendix PEER). The recommended calculations were performed and documented in SAND87-7105 (Reeves et al. 1987) and estimates of additional properties were provided in SAND89-0462 (Lappin et al. 1989). The sorbing-tracer test itself was canceled because it was concluded that mechanistic understanding could be better gained by a combination of laboratory experiments and additional hydrologic work. Agreements were reached with the state of New Mexico to conduct laboratory and hydrological studies, including a multipad interference test. The DOE position on a sorbing-tracer test is that it would be conducted only if the above studies and performance assessment calculations indicated it was necessary to reduce uncertainties. To date, the DOE believes this test is not necessary.

9.4.1.8 Report of March 3, 1988 on Brine Accumulation in the WIPP Facility

The following discussion of the issue is summarized and/or excerpted from the subject report (see Appendix PEER).

When the underground WIPP repository has been sealed, the surrounding salt is expected to move by plastic flow into repository openings and ultimately to lock the waste in a solid mass of crystalline salt. In addition, brine is expected to accumulate slowly in these openings. The amount of brine accumulation is uncertain and different estimates of the amount have been proposed.

A group of local scientists, primarily composed of staff from the University of New Mexico, suggested that the amount of brine accumulation in the repository:

"may be large enough to entrain both backfill and waste in a mobile radioactive "slurry." Such a fluid would prevent consolidation of the salt and might move to the surface to release radioactive material in quantities exceeding EPA standards."

Scientists at the SNL believed that the amount of brine accumulation will be small, and calculations indicated that it will be absorbed by the backfill material to be placed in the rooms and tunnels. Therefore, SNL staff concluded that:

"no interference is expected on the basis of preliminary observations with the plastic flow of salt into disposal rooms and around the waste packages."

The NAS was asked to express an opinion as to how well existing data resolve these conflicting viewpoints. In response to the request, a review panel composed of members of the NAS Board on Radioactive Waste Management and the WIPP panel, supplemented by outside experts was established. The panel consisted of Drs. Parker, Krauskopf, Cohen, Ernsberger, and Shock from the WIPP panel in addition to the following individuals:

Samuel Basham, Battelle Memorial Institute
John O. Blomeke, Oak Ridge National Laboratory
John D. Bredehoeft, U.S. Geological Survey
E. William Colglazier, University of Tennessee
Rodney C. Ewing, University of New Mexico
Charles Fairhurst, University of Minnesota
John W. Healy, Consultant
George M. Hornberger, University of Virginia
Leonard Konikow, U.S. Geological Survey
William R. Muehlberger, University of Texas, Austin
Irwin Remson, Stanford University
Christopher G. Whipple, Electric Power Research Institute

These members provided additional expertise in engineering, civilian waste program, chemical engineering, hydrology, risk analysis, local and regional geology, rock mechanics, health physics, geochemistry, and energy economics. Dr. Krauskopf chaired the augmented panel during this review. The panel reviewed pertinent documents and convened a special meeting at which local scientists and representatives of SNL and the Environmental Evaluation Group (EEG) presented their views. The panel was assisted in its review by several members of the three invited consultants. The panel's report was presented to, and discussed with, the New Mexico Congressional delegation on March 3, 1988.

The panel concluded in its report that

> *"from its study of currently available evidence that the formation of an abundant mobile fluid in a repository at the WIPP site, as postulated by [the group of scientists], is very improbable."*

However, the panel recommended the following actions:

- Establish a comprehensive, systematic experimental program to reduce remaining uncertainties and to support a conservative performance assessment.
- Better define the planned experimental program for a 5-year period.
- Only when the experimental work has substantially reduced the uncertainties about brine accumulation should additional waste containers, other than those required by the experiments, be emplaced.
- Experiments should be designed to lessen uncertainties, not to verify preconceived ideas about probable results.
- Continually refine performance assessment calculations as experimental results are obtained to test the confidence of achieving compliance with EPA standards.
- Develop multiphase models (gas + liquid + solid) to describe the behavior of complex fluids that may form as brine enters the repository and gas is generated from the waste.
- Investigate the feasibility of possible technical "fixes" if the problem of fluids in the repository is determined by the recommended experiments to be serious.

The DOE provided specific responses to the foregoing recommendations on August 18, 1989 (see Appendix PEER). The performance assessment process is iterative and as new experimental results were acquired, the impacts on compliance with the EPA standards were reassessed. For example, as estimates were made of the impacts of brine inflow, additional in-situ permeability measurements were made and models of brine inflow were improved. The WIPP Performance Assessment efforts refocussed the experimental program to supply the needs of the performance assessment program. A management plan (Bertram-Howery and Hunter 1989) describing the performance assessment program was provided to the NAS in 1989.

9.4.1.9 Letter Report of December 1988 on Experiments of Room Closure Rates

The DOE requested the panel to review the data collected on room closure rates from laboratory tests and in-situ experiments. Measurements in underground test rooms at the WIPP site indicated room closure rates three to six times greater than the rate predicted by numerical computational codes used to model the deformational behavior of the rooms and associated pillars. The codes incorporate mechanical properties for the salt around the rooms identical to the properties derived from deformation behavior observed in laboratory creep tests on small core samples taken from the WIPP site.

The December 1988 report (see Appendix PEER) provides the panel's suggested design for an intermediate-scale experiment to better define the sources of the discrepancy between the predicted and observed salt creep rates. The panel recommended that a few (two to five) in-situ tests be conducted to observe closure rates around horizontal, circular excavations intermediate in scale (that is, 1 meter or so in diameter) between the above mentioned field and laboratory tests.

The Intermediate Scale Borehole Test was conducted to address the possible "scale-effect" between laboratory and large underground tests. The Intermediate Scale Borehole Test consisted of a 0.91-meter-diameter hole core-drilled completely through an existing 18-meter-thick pillar between two large rooms (which had been constructed about 6.7 years earlier). The hole was situated so that the pillar was essentially composed of pure salt. Closure gauges were used to provide hole deformation and creep rate data.

The Brine Inflow Test (Room Q), a 107-meter-long room with a 2.9-meter-diameter, also provided creep data on a different (cylindrical) room scale geometry. A multimechanism constitutive model of salt deformation was developed which incorporated both steady state and transient creep. Results indicated the model is scale- and shape-independent and behavior can be predicted accurately from first principles within the current model.

9.4.1.10 Review Comments on DOE Document DOE/WIPP 89-011: Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration

This July 19, 1989 report (see Appendix PEER) documents the WIPP panel's review of the subject document. A panel meeting was convened on June 6-8 at which DOE staff and its contractors made presentations and answered questions.

The panel members attending the meeting included Drs. Fairhurst, Blomeke, Bredehoeft, Cohen, Ernsberger, Ewing, Shock, Hornberger, and Whipple as noted above, plus the following consultants with expertise in risk assessment and transportation:

B. John Garrick, Garrick, Pickard and Lowe

Sherwood Chu, MRS Commission

Dr. Fairhurst served as chairman for the panel meeting. The recommendations and conclusions made by the panel in its report were as follows:

- Develop and publish within the next six months a short, integrated, overall systematic assessment of long-term safety of the WIPP repository.

- Define the combined effects of gas generation, room closure and sealing, brine inflow, and other effects on the potential for long-term build-up of gases in the repository to lithostatic pressure, with respect to the long-term isolation capability of the WIPP repository.

- Examine options for modifications to the waste as part of the resolution of the gas generation issue.

- The panel agrees that the bin-scale and room-scale experiments, involving approximately 0.5 percent by volume of the capacity of the WIPP, are warranted and should begin without delay.

- Collect and study data from laboratory tests (including tests at high ambient pressures), information from studies on gas generation from waste packages now stored at various sites, information on experience abroad, and engineering modifications to address the gas generation issue.

- The test plan should discuss the risks associated with transportation of TRU waste to the WIPP, relative to the transportation of other hazardous materials.

- Delay the demonstration of operational readiness until several important issues concerning underground emplacement of waste for permanent isolation at the WIPP have been resolved.

This report was updated by a subsequent letter report, dated April 1991, which is discussed below (see Section 9.4.1.11). The April 1991 report also summarizes the DOE responses to the recommendations in this 1989 report and the NAS reaction to those responses.

9.4.1.11 Letter Report of April 1991, Summary of Recommendations

This April 1991 report (see Appendix PEER) summarizes the views of the WIPP panel on the status of the DOE program to assess the WIPP's ability to isolate TRU waste and to demonstrate compliance with relevant regulations. This report reviewed the progress made in the WIPP program since the 1989 report, summarized the responses made by the DOE to the

earlier recommendations, provided an overview of the panel's views on the overall safety of the WIPP facility, and presented some new recommendations to address unresolved issues. The panel members included Drs. Fairhurst, Blomeke, Bredehoeft, Ernsberger, Ewing, Garrick, Konikow, and Whipple. Dr. Fairhurst served as chairman for the panel during this review. Two additional experts served on the panel during this review:

Howard Adler, ORAU Medical Sciences Division
Jeremiah O'Driscoll, Jody Incorporated

The specific recommendations made by the WIPP panel in its report were as follows:

- Continue detailed study of the effects of human intrusion on repository performance.

- Apply performance assessment procedures to the alternatives identified by the Engineered Alternatives Task Force to assess the merits of engineered modification of the waste form and/or the repository to address the issues of gas generation and human intrusion.

- Use performance assessment analysis for the long-term extrapolation of the repository behavior.

- Assess the various engineered alternatives in terms of total system risk; including worker exposure, transportation and other risks, to evaluate the impacts on the entire TRU waste management system.

- Develop a well-designed experimental program and schedule that are sufficiently flexible to permit performance assessment analysis of important scientific and technical issues.

- Determine whether reliable conservative estimates of field retardation coefficients can be developed for use in performance assessment. If retardation is essential for adequate isolation of untreated TRU waste under the human intrusion scenario, such studies could be crucial before a decision is made on the required level of waste treatment.

- Continue the full-scale Room Q experiments with minimal interruption, together with intermediate-scale (900-mm-diameter) borehole inflow tests, since these experiments may provide conclusive evidence concerning the permeability of the repository salt to resolve the brine inflow question. DOE should consider constructing another full-scale room for additional brine inflow studies, using the improved instrumentation, seals, and excavation equipment now available at the WIPP site.

- The panel is concerned that the bin experiments, which are designed to provide information about gas generation, are of such large scale and complexity that they might not yield significant gas generation data within an acceptable time frame. The DOE should ensure that the effort and the resources devoted to the bin experiments do not impede other important experiments that may help to reduce significantly uncertainties in the assessment of repository performance.

- The DOE should actively support vigorous international discussion of scientific and technical issues affecting repository safety, including gas generation. In addition, the DOE should encourage critical review of the WIPP program through broader publication of its research findings in referred scientific journals.

As indicated above, the underground bin and alcove tests have been canceled. Smaller scale tests, replacing the bin experiments, are being conducted at LANL and INEL using actual TRU waste. Other recommendations have been incorporated into the WIPP project. In particular, see Section 9.5 for a discussion of ongoing international review and cooperation.

9.4.1.12 Letter Report of June 1992

This June 1992 report (see Appendix PEER) addressed the experimental plan for the WIPP and was based principally on a review of various documents submitted to the panel and presentations by the DOE and its contractors before the panel over the preceding three years.

In addition to Drs. Fairhurst, Adler, Blomeke, Bredehoeft, Ernsberger, Ewing, Garrick, Konikow, O'Driscoll, and Whipple, the panel was composed of:

Ina B. Alterman, National Research Council Staff Officer
Ricky A. Payne, National Research Council Project Assistant

Dr. Fairhurst served as chairman for the panel. The panel reaffirmed its position that performance assessment is the appropriate basis for setting priorities in the research and testing program for the WIPP. The report states that it believed DOE is "making excellent progress with its ongoing performance assessment efforts." Several proposed studies are specifically considered by the panel and comments are provided. The "Major Conclusions" section of the panel report is provided below.

> *Current performance assessment (PA) studies by the Department of Energy (DOE) indicate a high probability that the Waste Isolation Pilot Plant (WIPP) would perform successfully as a transuranic (TRU) waste repository. For some time, however, the panel has been concerned that questions identified as most critical by PA, particularly solubility and retardation, were not being given adequate or timely attention. The highest priority should now be given to conducting those tests that can determine the validity of the critical*

> *assumptions used in the PA calculations, especially the recently initiated solubility and dual porosity flow studies, and the proposed investigations on retardation in the Culebra.*
>
> *The February 1992 DOE/WIPP report is a clear statement of the 15 critical information needs and associated experiments necessary to assess the long-term performance of the repository. However, the report fails to indicate how the results of the experimental program at all scales (laboratory, bin, alcove, and field tests) will be integrated to assess the long-term performance of the repository. DOE needs to articulate a convincing scientific rationale for the proposed test program in terms of the performance of WIPP as a TRU repository.*
>
> *The panel has not been convinced by the scientific rationale, as presented, for the underground gas generation tests. In particular, the plan to conduct a large number of expensive bin tests and to terminate the experiments after five years has no discernible scientific basis. The possibility that the underground bin tests, as currently planned without brine sampling, will contribute to advances in the understanding of the overall long-term performance of a repository at WIPP is small.*

As previously indicated, the bin and alcove tests have been deleted from the project. However, the necessary input to WIPP performance is based on determination of required process parameters and their use in a disposal room model. Real waste tests supplement this information and are used to verify model predictions.

An additional report is expected from the NAS WIPP panel during October 1996.

9.4.2 Performance Assessment Peer Review Panel

The Performance Assessment Peer Review Panel (PAPRP) was established in 1987 as a standing group under contract to the WIPP Performance Assessment Department at SNL. The PAPRP charter states that the purpose for establishment of the panel was as follows:

> *"An external Peer Review Panel has been established for significant PA documentation so that the DOE can be assured that the performance evaluation is well-conceived and being carried out with professional competence, and so that scientists and state officials can be assured that the DOE's conclusions as to the suitability of the WIPP as a repository are credible."*

An evaluation of the PAPRP reviews against the screening criteria is provided in Table 9-9. Panel members were selected on the basis of their professional stature within the university, scientific and/or engineering communities. The PAPRP membership provides expertise in environmental research, geology, nuclear engineering, hydrogeology and public policy

Table 9-9. Performance Assessment Peer Review Panel

1. Is the "peer review" relevant to the CCA?	Yes - The PAPRP evaluates SNL PA efforts.
2. Was there a formal report prepared by the reviewer?	Yes - Formal reports are developed.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - The PAPRP reviews the adequacy of the SNL performance assessment activities.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Yes - The PAPRP performs documented, in-depth, critical evaluations of PA reports and other documentation, addressing validity of basic assumptions, alternative approaches, methodology, uncertainty, supportability of conclusions, and consequences of incorrect assumptions or conclusions.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - All members of the PAPRP are recognized experts in their fields.
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	Yes - The PAPRP operates as a independent group under contract to the SNL PA Department. Uncensored comments by the panel are maintained in the SWCF.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

development. Members were chosen explicitly for their independence from performance assessment work undertaken by SNL. Panel members are

G. Ross Heath (Chairman), University of Washington
Robert J. Budnitz, Future Resources Associates, Inc., Berkeley, California
Thomas A. Cotton, JK Research Associates, Inc., Washington, D.C.
Peter A. Domenico, Texas A&M University (Until 1990)
C. John Mann, University of Illinois, Urbana
Thomas H. Pigford, University of California, Berkeley
Frank W. Schwartz, Ohio State University (Since 1990)

The PAPRP chairman is responsible for ensuring that members do not have a conflict of interest. If an apparent or potential conflict of interest exists, the chairman and the SNL Performance Assessment program manager will determine if a conflict does exist and how to resolve it.

Panel members are requested to address the following areas, as applicable, for each review:

1. Validity of basic assumptions and extrapolations,
2. Alternative interpretations or approaches,
3. Appropriateness, logic and limitations of methodology,
4. Uncertainty of results,
5. Supportability of the conclusions drawn,
6. Consequences of incorrect assumptions or conclusions, and
7. Other issues appropriate to the review subject.

Whenever possible, following its review of a particular issue, the PAPRP meets with the SNL staff member who is the task leader for the work being reviewed, the author(s) of the material under review, and other performance assessment participants for a workshop to discuss the comments. The PAPRP chairman leads the discussion of comments. Conclusions regarding each issue discussed are recorded in the workshop proceedings. Uncensored comments by the panel are maintained in the SWCF. The performance assessment task leader for the document being reviewed is responsible for obtaining responses from the document authors for all comments identified by the PAPRP as mandatory.

The panel chairman and the peer panel task leader (the SNL staff member assigned to work with the PAPRP) prepare a review report. The report contains all panel review comments and recommendations, including the panel member's rationale and references. Each comment is identified as mandatory or non-mandatory by the PAPRP member. A statement of potential impact is also presented if the results of the review are considered to have a significant impact on schedules. The final report also includes the panel announcement memorandum, the workshop minutes, and a cover page identifying the panel and approval signatures of panel

members. The panel meets as needed (more than 20 times since inception) to discuss issues and review performance assessment documentation. The major issues (and their resolution) raised by the PAPRP during its review of performance assessment documentation since 1987 are provided below as summarized in (Trauth 1995; see Appendix PEER, Section PEER.11).

"Issue 1: Need to display confidence bounds around the mean CCDF.

Resolution: Beginning in 1990, the WIPP PA has used a methodology that allows for construction of a family of CCDFs from which both a mean curve and selected percentile curves can be derived. This methodology is first discussed in detail in the 1990 PA, and is further discussed in Volumes 1 and 2 of the 1991 PA and Volume 2 of the 1992 PA. References for additional publications can be found in Volume 2 of the 1992 PA. Note that all CCDFs presented in WIPP PAs are conditional on the modeling and data assumptions used in the analyses.

Issue 2: Question on how best to construct scenarios from the events and processes that remain following the screening process.

Resolution: Since 1988, the WIPP PA has used a "logic diagram" procedure to construct all possible combinations of events. This procedure differs from the "event tree" approach used in reactor safety assessments and in earlier WIPP PAs in that order of occurrence is not considered, and a smaller number of scenarios can be considered while maintaining comprehensiveness. Documentation of this technique is available in the 1990 PA, in Volume 1 of the 1991 PA, in SAND89-7149, and in SAND90-1429.

Issue 3: Need to provide automated data flow between subsystem level computational models within the PA. This issue was raised internally and by the PAPRP in 1988 and 1989 as being the most computationally efficient approach as well as essential for QA.

Resolution: The PA Department began development of software in 1988 to automate linkages between major codes. See Appendix CODELINK for a discussion of the current implementation.

Issue 4: Need to provide a means to estimate the probability of human intrusion and to quantify the effectiveness of potential passive marker systems, other than by ad-hoc estimates of fixed probabilities. This issue is based on interpretations of regulatory guidance, and was raised internally by the PAPRP in 1990.

Resolution: Beginning in the 1990 PA, a Poisson model for intrusion probability (intrusions are random in time, with a maximum expected value equal to the EPA guidance of 30/km/10,000 yr), was substituted for previous ad hoc estimates of probability. Expert panels were convened to consider future societies and the degree to which passive markers would be effective in communicating with them. Results of the expert judgment were used in the 1992

PA. Documentation of the Poisson model is available in Volume 2 of the 1991 and 1992 PAs, and in references provided therein. The algorithm for deriving drilling rates from the expert judgment is described in a memorandum by Hora in Appendix A of Volume 3 of the 1992 PA.

Issue 5: Need to include effects of gas generation and 2-phase flow in PA modeling.

Resolution: PA developed the capability to model 2-phase flow in human intrusion scenarios in the fall of 1990, using the BRAGFLO code developed in-house. Gas generation reactions and their dependency on reactant (i.e., brine, iron, and cellulosic waste) availability were included in the code. Technical complexities related to the short time steps required to model rapid pressure drops during intrusion precluded the use of other 2-phase flow codes prior to the development of BRAGFLO. The use of BRAGFLO is first documented in the 1990 PA, and subsequently described in Volume 2 of the 1991 and 1992 PAs, as well as in Volume 4 of the 1992 PA and in SAND92-1933.

Issue 6: Need to display uncertainty in performance estimates resulting from alternative conceptual models for waste form properties and radionuclide transport in the Culebra.

Resolution: Beginning in 1990, the PA Department examined conceptual model uncertainty by performing ceteris paribus Monte Carlo analyses, in which vectors of input values were the same for each conceptual model except for the parameters used to describe the specific model change. This technique allows direct comparison of probabilistic outcomes from system-level models using alternative conceptual models for those cases in which the alternative models can be described by parameter variations within the existing conceptual models. For example, potential effects of waste-form modification were examined by repeating the Monte Carlo analyses using various fixed values for radionuclide solubility and waste-form porosity and hydraulic conductivity. Dual- and single-porosity transport models for the Culebra were compared by repeating dual-porosity simulations with matrix porosity set to zero.

Issue 7: Need to couple creep closure process with gas generation and 2-phase flow.

Resolution: The 1992 PA included the effects of creep closure for the first time. Computational complexity prevented a full coupling of the mechanistic creep model SANCHO with the 2-phase flow code BRAGFLO, and instead SANCHO output, in the form of waste/backfill porosity as a function of moles of gas generated, was used to define time and pressure-dependent waste/backfill porosity in BRAGFLO calculations. See Volume 4 of the 1992 PA for additional information.

Issue 8: Need to include effects of pressure-dependent fracturing of anhydrite interbeds in the Salado Formation.

Resolution: Beginning in the fall of 1993, PA calculations have used an approximation of pressure-dependent fracturing in which porosity and permeability of the anhydrite interbeds are varied as a function of pressure at pressures close to lithostatic. Additional data are needed to evaluate the adequacy of this approximation (or to develop another) and to justify the parameter distributions used.

Issue 9: Need to reexamine the event and process screening procedure used in scenario construction. The PAPRP and other reviewers have noted since 1991 that some of the evidence used in screening is out of date, some is incomplete, and some events have never been adequately analyzed.

Resolution: The PA Department has undertaken a major effort in reviewing the screening of features, events, and processes (FEPs) for inclusion in scenarios, some of which involves sample calculations. Supporting documentation for those FEPs screened from consideration on regulatory grounds (specifically excluded from consideration by 40 CFR Part 191 or its supporting documentation, or excluded because of low probability or low consequence as per 40 CFR Part 191) and technical ground are being developed, and will be maintained in the Sandia WIPP Central Files.

Issue 10: Need to confirm adequacy of two-dimensional modeling in the repository environment (BRAGFLO) and the Culebra (SECO) with three-dimensional modeling.

Resolution: The PA Department is addressing these two questions through the FEPs effort. FEP S1 "Verification of 2D-radial flaring using 3D geometry [room to room processes]" is being addressed by comparing 2D BRAGFLO calculations against 3D TOUGH28W and 3D BRAGFLO calculations, based on the same physical representation (i.e., model) of the WIPP site. TOUGH28W is a version of TOUGH2 with WIPP-specific features such as creep closure and pressure-induced anhydrite fracturing.

FEP NS9 "Justification of SECO 2D approximations" addresses the SECO issue and the current rationale and justification are documented in a Summary Memo of Record written by T. Corbet. This memo summarizes the use of three-dimensional simulations to evaluate the amount of flow across the upper and lower surfaces of the Culebra.

Issue 11: After reviewing the 1990 and 1991 PAs, the PAPRP requested a more complete and accessible presentation of the data used in the PA calculations.

Resolution: Volume 3 of the 1991 PA contains a first attempt at providing data tables. Further improvements were made for Volume 3 of the 1992 PA which contains data tables that include the new categories of "correlation," usage" (in mathematical and computational models) and "ranking in past sensitivity analyses."

9.4.3 Shaft Seal Design Independent Review

A review plan, titled Shaft Seal System Design for the Waste Isolation Pilot Plant (WIPP), was developed and approved on January 12, 1996 (Hansen 1996). The review plan governed the preliminary and final reviews of the WIPP shaft seal system.

Members of the review panel were selected on the basis of their respective knowledge, experience and independence from the WIPP shaft seal design effort. The group had expertise in computational geomechanics, rock mechanics, mining engineering, civil engineering, and the design and construction of underground seals and bulkheads. The panel for both the preliminary and final reviews consisted of a review team chairman and three reviewers:

R.E. Stinebaugh (Chairman), SNL
Dr. Malcolm Gray, Atomic Energy of Canada Limited Whiteshell Laboratories
Stephen Phillips, Phillips Mining
Dr. John Tinucci, Itasca Consulting Group

A evaluation of the shaft seal design reviews against the screening criteria used to determine whether this review should be addressed in this application is presented in Table 9-10. While it might appear that the independence of the review could be questioned because of Mr. Stinebaugh's affiliation with SNL, Mr. Stinebaugh's organizational independence from the WIPP project, and his actual role in the review process, established and preserved the independence of the review. Mr. Stinebaugh is a member of Organization 2165, which has no responsibility for the WIPP program. In his role as chairman, Mr. Stinebaugh served as a manager and facilitator for the review and coordinated the preparation of the final report. He was not a reviewer and did not prepare formal comments or a summary statement regarding the design of the shaft seal system as did the three reviewers, Drs. Gray and Tinucci and Mr. Phillips.

Shaft seal design activities were conducted under an approved quality assurance program. The review was conducted in accordance with the requirements of SNL QAP 3-2, entitled Verification of Design Adequacy, approved 7/31/95 (Quality Assurance Department 1995), and the provisions of the review plan. Panel members were trained in accordance with the provisions of QAP 3-2 prior to beginning the design review. A member of the SNL quality assurance staff (Organization 6860) briefed the panel at the onset of the review, monitored the review as it progressed, and inspected record-keeping activities. Records of panel training and other QA records concerning this review were maintained in accordance with SNL QA program requirements.

Table 9-10. Shaft Seal System Design Review

1. Is the "peer review" relevant to the CCA?	Yes - The seal system is directly relevant to PA.
2. Was there a formal report prepared by the reviewer?	Yes - The title of the report is "Final WIPP Shaft Seal System Design Review."
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - The review focussed on the adequacy of the shaft seal system that was developed by SNL National Laboratories.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Yes - The review evaluated the adequacy of the work of others (the design of the shaft seal system).
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - The reviewers were specifically chosen because of their expertise in seal design and related disciplines.
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	Yes - It may appear that the independence could be questioned because of the chairman's affiliation with SNL. However, his organizational independence from the WIPP project and his actual role in the review process (see text of Section 9.4.3 for additional discussion) preserved the independence of the review.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

In both reviews, the panel was asked to address the following questions:

1. Will the shaft seal system satisfy design guidance?

2. Are there elements of the design which will prevent the sealing system from meeting design requirements?

3. Can the design be successfully implemented?

A short summary of each of the reviews is provided below.

Review of the Preliminary Shaft Seal Design

The preliminary design review considered the adequacy of design concepts summarized in the report entitled Waste Isolation Pilot Plant Sealing System Design Report (DOE 1995d). The report includes descriptions of the WIPP setting, design guidance derived from the regulations, a description of the design, materials comprising the seal components, and preliminary evaluations of the shaft seal system.

The review of the Sealing System Design Report was initiated in January 1996 and completed in March 1996. Following their review of the Sealing System Design Report, Dr. Gray, Dr. Tinucci and Mr. Phillips prepared detailed comments. These comments were forwarded to the appropriate design staff and formal responses were prepared. The reviewers evaluated the responses and determined their responsiveness to the concern.

Subsequent to resolution of outstanding issues, the updated information was used to amend the documentation provided to the review panel for its final review (discussed below). At the conclusion of the final review, all of the reviewers, without exception, stated that the actions promised in the responses to the preliminary review comments had been completed.

Review of the Final Shaft Seal System Design

During April 1996, the panel was convened to review the Compliance Submittal Design package for the WIPP shaft sealing system (SNL WIPP Central File records package WPO: 36546). Panel input was subsequently incorporated into the final Compliance Submittal Design report (Repository Isolation Systems Department 1996). The review was based on documentation provided by SNL and briefings by the WIPP technical staff. The documentation included an enhanced annotated outline for the compliance shaft seal design report, detailed drawings, a material specifications framework, and topical summaries of structural and fluid flow calculations. Briefings provided the panel with additional information covering the design, laboratory and in-situ experimentation results, and analyses that were completed.

Following completion of the review, each panel member prepared specific comments regarding the design (see Appendix PEER). The WIPP staff prepared specific responses to the comments and met with the reviewers to resolve them. In some instances, the WIPP staff, in response to the reviewer comments, promised to make certain changes or additions to the design drawings, the documentation of the analyses, or the report test; in some of these cases, a reviewer conditionally accepted those responses but required a copy of the marked up document to remove the condition for full acceptance. The comments were formally tracked with comment resolution forms. In addition, conditionally accepted comments were formally closed by sending the text changes to the reviewer as evidence of the direct incorporation of his or her comments. Final comment closure was documented in the form of a letter from the reviewer stating full acceptance of the changes.

Each reviewer also prepared a summary statement (see Appendix PEER). The summary statements provided recognition or explanation of specific technical concerns in the final documentation, identified the need for future work prior to emplacement of the seals, provided suggestions for design and analysis enhancements or simplifications, and encouraged more detailed quantification of design guidance. Each of the reviewers provided "bottom-line" assessments. Excerpts from the summary statements are provided below:

Dr. Malcom Gray

> *"In summary and conclusion, I consider that when completed as stated immediately above, it is likely that the documents being developed will present a design that will meet the general requirement of shaft sealing systems that will mitigate against water and gas flows from the repository to the biosphere and that can be built using existing technologies or reasonable extrapolation therefrom."*

Mr. Stephen Phillips

> *"It is considered improbable that the seal design, as presented including the revisions recently discussed, can be significantly and practically improved within the limits of existing construction materials and technologies, except in some areas where optimization of materials and methods of emplacement can be achieved."*

Dr. John Tinucci

> *"The design that has been put forth presents one way of efficiently sealing shafts. Recognizing that other ways could also be made to work, the design presented here is similar to others suggested by the scientific community for sealing deep geologic nuclear waste repositories. The concepts presented have been developed from sound engineering judgment and sound analyses techniques. The anticipated performance of individual sealing components are within reasonable expectations based on currently available field and laboratory data, albeit limited. To address the wide scale of*

uncertainties, the design has been conservatively laid-out with redundant multiple-barrier components so that the overall seal system performance is not dependent on the functionality of an individual component. The design as it exists today is a conceptual design since it describes basic concepts and provides sufficient backup analyses to demonstrate that those concepts will reasonably satisfy the qualitative design guidelines."

9.4.4 Engineered Alternatives Task Force Report Peer Review

The Engineered Alternatives Task Force (EATF) was established by the DOE in 1989. The EATF was tasked to evaluate the effectiveness, feasibility, and risk of implementing alternative facility designs, backfills, and/or waste forms in improving the long-term performance of the WIPP disposal system. The purpose, methodology, assumptions, and conclusions of the EATF are documented in a report, titled "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force" (DOE 1991a). The author of the report, IT Corporation, convened a peer review panel to review a final draft version of the report during 1991. An evaluation of the EATF review against the screening criteria is provided in Table 9-11. The panel consisted of experts in chemical and nuclear engineering and geology. The members of the panel and their affiliations were as follows:

Dr. H. Eric Nutall, University of New Mexico and Nutall & Associates, Inc.
Dr. Douglas Brookings, University of New Mexico
Dr. Robert J. Budnitz, Future Resources Associates, Inc.
Donald E. Shaw, P.E., Engineering and Management Consultant

A formal comment resolution process was employed to ensure that the reviewers' comments were incorporated into the final version of the report. The comments of the panel can be grouped into three general topics: (1) quality of technical work; (2) utility of a single figure-of-merit; and, (3) use of relative versus absolute risk.

The comments made by the peer review panel (see Appendix PEER) and the WIPP project responses are discussed below.

Quality of technical work

One reviewer commented that:

"The complex technical risk analysis work, aimed at determining risk-reduction factors of the many different risk endpoints and for 16 different alternative scenarios, is of high quality and deserves commendation. The technical information buried in the back of the Attachments to this report can provide an excellent basis for decision-makers to understand the various risk issues, and make decisions about them. The

Table 9-11. Engineered Alternatives Task Force Report Review

1. Is the "peer review" relevant to the CCA?	Yes - The review was conducted on the 1991 EATF report which formed the basis for the subsequent Engineered Alternatives Cost/Benefit Study.
2. Was there a formal report prepared by the reviewer?	Yes - The "report" consists of review comment record forms that were used to formally document the comments, responses, and their dispositions.
3. Was the review a "peer review" rather than a "technical review"?	Yes - The purpose of the review was to determine the adequacy of the EATF report.
a. A peer review's purpose is to confirm the adequacy of the work being reviewed.	
b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	
4. Was the review a "peer review" rather than an "expert judgment"?	Yes - The review evaluated the adequacy of the EATF report.
a. A peer review confirms the adequacy of the work being reviewed.	
b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - The reviewers were nationally recognized experts in their respective fields.
6. Were the reviewers independent?	Yes - The reviewers were not involved in the preparation of the work and were free from funding considerations.
a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed?	
b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

choice of alternative scenarios, the assumptions made to limit the scope of the analysis, the risk endpoints identified, and the analysis methods used are all fully acceptable to me. I am particularly pleased with how the analysis of specific risk endpoints was accomplished in a way that focused on the key issues relevant to the alternative scenarios. This part of the report can be a gold mine for further study by experts, as well as of use to decision-makers if presented properly."

The future value of the work predicted by the reviewers was an accurate prediction because the methodology and models developed for the EATF formed the basis for the subsequent Engineered Alternatives Cost/Benefit Study (EACBS) (DOE 1995b; Appendix EBS) that was performed in 1995. The EACBS was recently the subject for another peer review panel (see Section 9.3.3)

Utility of a single figure-of-merit

The reviewers questioned the utility of a single figure-of-merit to express the aggregated risk elements. The EATF used a Multi-Attribute Utility Theory approach to combine the risk components for each alternative into a single value for alternative ranking purposes. These risk components included the routine and accidental risks from waste transportation and handling, exposure to radiation and hazardous constituents in the waste during treatment, cost, schedule, and benefits to future generations from a safer disposal system. One reviewer commented that:

"Although I admire the attempt to come up with a single figure-of-merit useful to decision-makers by which to judge the overall benefit/disbenefit of each of the various scenarios being studied, in my view the effort has not succeeded. The methodology did use established decision-theory methods to identify and calculate such a single figure-of-merit, and seems to break some new ground, but in my opinion, the single figure-of-merit identified is not sufficiently useful to decision-makers to justify the continuation of work along those lines. In fact, I believe that the use of a single figure-of-merit obscures rather than illuminates the situation. Decision-makers are in my opinion fully capable of dealing with multiple attributes presented separately, and of weighing them in their own ways for decision-making purposes--this goes on every day in the upper-management board rooms of large enterprises and agencies. But to make these judgements, decision-makers need the best available disaggregated information about the issues at hand, in this case, the best absolute numbers and uncertainties about the specific risk endpoints. I don't believe that high-level decision-makers generally use aggregated information very much or very well, and I don't believe that the aggregated information based on the single figure-of-merit developed in this report will be of much use."

The WIPP project believed that although dissaggregated information may be used by many decision makers in finance and industry, it was not sufficient for the EATF. A compromise

was reached in final version of the EATF report. That compromise consisted of providing both the aggregate and individual risk components. This allows a decision-maker the option to develop an independent figure-of-merit based on personal weighting factors and preferences.

Use of relative versus absolute risk

The EATF methodology involved the calculation of relative risk reduction factors rather than absolute risks for each alternative. These relative risk reduction factors were based on a risk of unity for the baseline case (defined as: no waste treatment; a crushed salt backfill; and, the current repository design). Risks for each engineered alternative were ratioed against the risk for the baseline case, yielding the risk reduction factor. The main advantage of this relative risk approach is that many parameters that affect absolute risk will cancel when calculating relative risk. Uncertainties in those parameter values do not translate into uncertainties in the relative factors. Some reviewers felt that the calculation of absolute rather than relative risks would have been more useful to decision-makers. For instance, one reviewer commented that:

> *"In my view, the approach of identifying and working with risk-reduction factors (RRFs) is a very useful intermediate step toward what is actually needed. Indeed, calculating RRFs is often simpler than calculating absolute magnitudes of risks for reasons cited well in the report. However, I believe that for decision-makers these RRFs cannot adequately substitute for knowing the actual magnitudes of the risks involved, except in special cases, such as when almost no changes occur (RRF near unity) or when absolute risk magnitudes and minuscule small for both the base-case scenario and the alternative scenarios."*

The WIPP project concluded that although absolute risks convey a greater amount of information for decision-makers than relative risks, the calculation of absolute risks were outside the scope of the EATF study and would have entailed a considerably greater effort than was warranted. For instance, calculating absolute long-term risks to future generations for each alternative would require performing a complete performance assessment for each alternative.

9.4.5 Blue Ribbon Panel Peer Review

The Secretary of Energy established the WIPP Blue Ribbon Panel (BRP) in August 1989. The panel was composed of the following five members:

Dr. Thomas Bahr
Robert W. Bishop, esq.
Dr. Arthur S. Kubo
Leonard C. Slosky

Newal Squyres

Dr. Bahr, a water quality management expert and the Director of the New Mexico Water Resource Research Institute, was nominated to the BRP by the Governor of New Mexico. Mr. Bishop, General Counsel and Corporate Secretary for the Nuclear Management Resources Council, and Dr. Kubo, a nuclear and civil engineer and a vice president of the BDM Corporation, were appointed to the BRP by the Secretary of Energy. Mr. Slosky, an environmental consultant, and Mr. Squyres, an attorney, were nominated by the Governors of Colorado and Idaho, respectively.

The panel members were each requested to provide an independent technical review of WIPP issues and individually report on the following:

1. The concept and timing of DOE's proposed WIPP Operations Demonstration.

2. Whether or not the Operations Demonstrations should be conducted in parallel with the performance assessment.

.3. An evaluation of DOE's validation plan for certification of TRU waste to meet the WIPP Waste Acceptance Criteria.

The panel conducted site visits at the WIPP facility and portions of INEL and the Rocky Flats Plant. The panel met with and/or were briefed by staff from the DOE and its contractors, the NAS Board of Radioactive Waste Management WIPP Panel, the Environmental Evaluation Group and the Environmental Protection Agency. The panel members were provided an extensive amount of documentation and were encouraged to address questions to the above groups. An evaluation of the BRP review against the screening criteria is provided in Table 9-12.

Following submission of its reports, the BRP was asked to continue its service by providing their observations and recommendations to the DOE in three areas: (1) continued review of DOE plans to characterize Rocky Flats Plant TRU and mixed waste; (2) assist DOE in developing a strategy for achieving compliance with RCRA and other environmental regulations at WIPP; and (3) evaluate the Final Test Plan and ancillary documents. Subsequently, the DOE expanded the BRP charge to include a management review of the WIPP project, review of the rationale and plans to characterize waste for the test phase and a review of plans for engineered alternatives relating to the waste form.

The BRP was also asked in late November 1989 to comment on questions submitted by members of the New Mexico Congressional Delegation. The questions were: (1) what is the rationale for conducting in-situ experiments at the WIPP rather than at existing waste generation and storage sites; (2) how much waste would need to be emplaced at the WIPP for the experiments; and, (3) what are the BRP's recommendations regarding DOE's proposed Operational Demonstration experiments?

Table 9-12. Blue Ribbon Panel Review

1. Is the "peer review" relevant to the CCA?	Yes - The reviews addressed waste certification and PA aspects.
2. Was there a formal report prepared by the reviewer?	Yes - Each panel member prepared an individual report.
3. Was the review a "peer review" rather than a "technical review"?	Yes - The panel reviewed the adequacy of work being done primarily at WIPP, Rocky Flats Plant and INEL.
a. A peer review's purpose is to confirm the adequacy of the work being reviewed.	
b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	
4. Was the review a "peer review" rather than an "expert judgment"?	Yes - The panel reviewed DOE plans and processes.
a. A peer review confirms the adequacy of the work being reviewed.	
b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - Panel members were specifically chosen by the governors and the Secretary of Energy because of their qualifications.
6. Were the reviewers independent?	Yes - The panel members were not otherwise associated with the WIPP project.
a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed?	
b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

The BRP provided individual responses to the congressional delegation and provided testimony to the Senate Committee on Energy and Natural Resources on April 26, 1990. The general observations of the panel were provided to the Senate by Dr. Bahr who stated the following:

"At this point Mr. Chairman, rather than going into my specific observations and recommendations and then having each of the panel members do the same, we decided in order to save time that I would very briefly summarize the general observations of the panel to date. The first and most significant observation in my opinion is that each member of the Blue Ribbon Panel has independently arrived at similar conclusions on each of the issues we were asked to evaluate. Also noteworthy is the high level of congruence of our findings with those of the Advisory Committee on Nuclear Facility Safety (Ahearne Committee). We have also participated in meeting with the WIPP Panel of the National Academy of Sciences and I can report that we also generally share the same views on those issues we have both looked into. Let me now highlight those items upon which members of the Blue Ribbon Panel seem to agree.

1. The deep bedded salt repository at the WIPP appears to be a safe site for long term isolation of transuranic waste; certainly safer than where this waste is presently stored. Radioactive releases over the long term for an undisturbed WIPP site will probably meet EPA standards (40 CFR 191 Subpart B). Meeting this standard having to consider human intrusion scenarios will be more difficult. Treating the waste so as to change the waste form and thereby force the repository environment to known conditions will significantly reduce present uncertainties. The most controllable variable in the design of the repository environment is the waste form.

2. In situ testing is important and necessary and should begin as soon as possible. Results of bin and alcove testing should significantly increase the confidence of long range predictions undertaken in the performance assessment. Individual members of the Blue Ribbon Panel agree that the quantity of waste emplaced for experimental purposes should not be limited such as to preclude justifiable experiments. A limit of approximately 1% of the WIPP waste capacity is reasonable. A limit of 0.5% may be too restrictive by precluding the opportunity to undertake important Phase III bin testing of different waste forms resulting from different engineered modifications.

3. Members of the Blue Ribbon Panel agree conceptually that the EPA suggestion of adding two filled rooms for monitoring purposes is worthy of further consideration by DOE. This approach, however, should be evaluated in the context of verifying facility performance and not considered as part of the test phase itself. We have not, however, been asked to evaluate EPA's suggestion.

4. On the subject of Operations Demonstration, our panel agrees that such an undertaking will provide valuable information because of the practical experience gained

in system-wide operations. We are in general agreement, however, that a full "ramping up" of an Operations Demonstration should be postponed until such time as the final waste form and repository configuration are determined and that there is a high level of certainty that the Subpart B standard can be met.

5. We also have general agreement that DOE had underestimated the complexity and level of effort required to comply with RCRA in managing its transuranic-mixed wastes.

Mr. Chairman, I have touched the high points and obviously skipped over many details. Other panel members may wish to elaborate on these and other items. In closing, there is one last item of strong agreement expressed by all panel members. We are very impressed by the responsiveness of DOE to our suggestions. Some examples include 1) The significant improvements that have been made in the DOE organization toward overall systems integration, both vertically and horizontally among the varied elements of transuranic and mixed-transuranic waste management; 2) The significant increase in effort being placed on evaluation of engineered alternatives and waste treatment; 3) The accelerated activity and seriousness with which DOE is now placing on dealing with RCRA and in particular on waste characterization issues; and finally 4) The decision by the Secretary to postpone the start up of the Operations Demonstration program."

The full text of the panel's testimony to the Senate and of the independent reports prepared by the individual panel members are provided in Appendix PEER. There have been significant changes as a result of the recommendations of the BRP and other reviews of the project. These changes are especially dramatic with regard to the performance assessment activities and review. All of the findings and recommendations from the BRP were resolved by the WIPP project to the extent that they were formally closed by the individual Blue Ribbon Panel members.

9.4.6 Advisory Committee on Nuclear Facility Safety Review

The Advisory Committee on Nuclear Facility Safety (ACNFS) was established by the DOE on November 13, 1987, on the recommendation of the NAS. The Committee was appointed by the Secretary of Energy to provide advice and recommendations on the safety of the DOE's nuclear production and utilization facilities. The facilities reviewed by the ACNFS included the WIPP site and the waste generator sites. An evaluation of the ACNFS review with the screening criteria is provided in Table 9-13.

The Committee was composed largely of recognized experts (from outside the DOE) in the field of nuclear energy. Specific expertise of the committee members included environmental chemistry, risk assessment, radioactive waste management, medicine, geology, geochemistry, biophysics, health physics, and environmental regulatory compliance. The ACNFS panel was composed of the following members:

Table 9-13. Advisory Committee on Nuclear Facility Safety

1. Is the "peer review" relevant to the CCA?	Yes - The review addressed long term performance, gas generation and engineered alternatives issues.
2. Was there a formal report prepared by the reviewer?	Yes - There was a formal report.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - Although much of the Committee's scope could be characterized as technical review, there were other issues, such as the adequacy of the WIPP programs to address gas generation, long term performance and waste characterization that would be better characterized as peer review.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Yes - The Committee reviewed DOE operations, processes and documentation.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - Committee members were recognized experts in the field of nuclear energy.
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	Yes - Committee members were from outside the DOE and were appointed by the Secretary of Energy under the Federal Advisory Committee Act.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

John Ahearne (Chairman), Sigma Xi
Jess Cleveland, U.S. Geological Survey
Floyd Culler, EPRI
Jacob Fabrikant, University of California, Berkeley
William Kastenberg, University of California, Los Angeles
Terry Lash, Consultant
Harold Lewis, University of California, Santa Barbara
James Martin, University of Michigan
Dana Powers, SNL
William Schull, University of Texas
Robert Seale, University of Arizona
C. Frederick Sears, Northeast Utilities
Gerald Tape, Associated Universities
Victoria Tschinkel, Landers and Parsons

The ACNFS visited WIPP in June 1989, at which time a subcommittee was formed to review safety issues in further detail. The WIPP subcommittee was chaired by Dr. Tape (Paul D. Rice, a consultant, chaired the subcommittee until October 1990). Members included Drs. Kastenberg, Lash, Martin and Seale. Special consultants to the subcommittee included

Konrad Krauskopf, Stanford University (until October 1990)
James Ling, Consultant (until October 1990)
Thomas Pestorius, Consultant
Thomas Pigford, University of California, Berkeley (until October 1990)
Bernard T. Resnick, Consultant
Frank Rowsome, Consultant (until October 1990)

The subcommittee subsequently revisited WIPP and other related facilities: SNL, INEL, and the Rocky Flats Plant. Areas of review included unresolved short-term technical and operational issues and long-term environmental performance. A report to the Secretary was issued by the ACNFS on December 11, 1989 (see Appendix PEER, Section PEER.15) and a final report was issued in November 1991 (see Appendix PEER for the WIPP chapter of the final report).

The 1989 report identified several recommendations to resolve issues related to both short-term operations and long-term performance of the repository. The final report, titled "Final Report on Department of Energy Nuclear Facilities" (Document PB92-119809), contained a section that dealt with its review of WIPP. This final report contained the following recommendations to *"increase the probability of successful compliance with EPA's proposed standards in a shorter period of time . . ."*:

- *Prepare a concise report in a timely manner comparing the expected performance of WIPP with the requirements in EPA's proposed standard (40 CFR 191). This report should specifically focus on those parameters that are currently significantly uncertain and set forth the actions including alternatives, necessary to reduce the uncertainties to acceptable levels for demonstrating regulatory compliance.*

- *Change current project priorities by putting more emphasis on the use of experts. At this time, panels of experts will provide more significant input to the demonstration of compliance with EPA standards than will the results of the Dry Bin Tests. The Bin Test Program should continue to be focused on reducing uncertainties in those parameters that are most important in determining compliance with EPA's proposed standards.*

- *Initially dispose only the contact handled TRU waste that will not pose a gas generation problem. Other TRU wastes can be safely stored above ground until it is determined whether they can be buried at WIPP in compliance with regulatory requirements or have to be treated so that disposal at WIPP is acceptable.*

- *Immediately begin development and implementation of engineered alternative, especially for newly generated waste. DOE should be a technological leader in waste management and this initiative should go forward even if it were not specifically required to demonstrate compliance with EPA's proposed standards.*

The WIPP project initiated and continued several activities to resolve the ACNFS concerns. Specific action plans were developed and these plans were implemented. In June 1990, the DOE prepared a concise report summarizing the current understanding of expected performance and the potential for demonstrating compliance with 40 CFR Part 191, Subpart B (Bertram-Howery and Swift 1990). Preliminary performance assessments in 1990, 1991, and 1992 identified significant uncertainties and provided guidance to the project. The experimental program was refocused to meet the needs of the compliance evaluation, and the underground bin and alcove tests were canceled. Chapter 4.0 and Appendices WCA and WCL address which wastes will be emplaced at WIPP. The subject of engineered alternatives was reviewed by two recent peer review panels (see Sections 9.3.3 and 9.4.4). The ACNFS recommendations were formally closed by the Advisory Committee.

9.4.7 Performance Assessment Review Team

The Performance Assessment Review Team (PART) was organized in 1992 by the Department of Energy's Director of Environmental Restoration and Waste Management WIPP Project Management Division (EM-342). The purpose of the PART review was *"to assess the adequacy of the WIPP PA program for meeting relevant regulatory standards for the disposal of radioactive and hazardous wastes, to identify any deficiencies in the program, and to make recommendations for improvements."* The team members were as follows:

Bryan Bower (Chairman), DOE/EM-342
Charles Voss (Deputy Chairman), Golder Associates, Inc.
James Russell, Texas A&M University
Neville Carter, Texas A&M University
Pamela Doctor, Pacific Northwest Laboratory
Charles Cole, Pacific Northwest Laboratory

The group was very knowledgeable of geologic repositories and included specific expertise in performance assessment methodology, brine migration, flow and transport modeling, creep and room closure, and site operations. The review team was not completely independent because the chairman of the review team was a staff member of DOE/EM-342, which had oversight responsibility for WIPP. Section 1.4.1 of the PART (the complete report is provided in Appendix PEER) report states that

> *"The Director of EM-342 and the PART chairperson selected the PART members on the basis of their knowledge of components and processes associated with salt repository and their independence from the WIPP Project. More specific criteria included (1) familiarity with geologic repositories; (2) PA expertise or knowledge of risk assessment techniques; (3) knowledge of RCRA and/or 40 CFR 191 requirements; and (4) no direct association with any of the PA activities for the WIPP."*

It should be noted that the report findings *"reflect the consensus of team members"* and that the final report was signed by all team members. It was included in this application because of its insight into the performance assessment effort at a pivotal time in the direction of performance assessment for the WIPP project. An evaluation of the PART review against the screening criteria is provided in Table 9-14.

The review was primarily conducted during the first half of 1993 and a final report was issued in February 1994. All PART activities were conducted and documented in accordance with EM-342's NQA-1 based QA program. The PART reviewed the pertinent performance assessment documents and activities, toured the WIPP site, and interviewed members of the project staff. The team concluded that

> *"The review team finds that the work on the WIPP has generally been perceptive, incisive and fundamentally sound. However, for compliance with current standards and regulations, substantial progress and improvements will be necessary in certain areas where additional investigations and documentation may be required; the PA department is fully aware of most of them. These areas include PA documentation, parameter evaluation, conceptual model justification, time-dependent behavior of natural and engineered barriers to fluid migration from the coupled disposal system, and a total system model."*

Table 9-14. Performance Assessment Review Team (PART) Independent Review of WIPP Performance Assessment

1. Is the "peer review" relevant to the CCA?	Yes - The review dealt directly with the PA.
2. Was there a formal report prepared by the reviewer?	Yes - The report is titled "Performance Assessment Team's Independent Review of WIPP Performance Assessment Activities (40 CFR 191 and 40 CFR 268.6) for EM-342. The report is dated February 1994.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - The review focussed on the adequacy of then current PA and RCRA activities at WIPP.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Yes - The review evaluated the adequacy of the work of others.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - Section 1.4.1 states "The Director of EM-342 and the PART Chairperson selected the PART members on the basis of their knowledge of components and processes associated with salt repository and their independence from the WIPP Project. More specific criteria included (1) familiarity with geologic repositories, especially salt; (2) PA expertise or knowledge of risk assessment techniques; (3) knowledge of RCRA and/or 40 CFR 191 requirements; and (4) no direct association with any of the PA activities for the WIPP."

Table 9-14. Performance Assessment Review Team (PART) Independent Review of WIPP Performance Assessment (Continued)

6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	No - The team chairman was a DOE EM-342 employee. EM-342 has oversight responsibility for WIPP. The remaining members were university staff and a professional consultant.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	Yes - Report findings reflect the consensus of team members and the final report was signed by all team members.

Considerable effort has been made to resolve the concerns identified in this review. The performance assessment process has changed significantly since the PART report to address issues identified in this report as well as to document the conformance with the requirements of 40 CFR Part 191 and criteria of 40 CFR Part 194. Finally, it should be noted that the PART final report was provided to the recent conceptual models peer review panel (see Section 9.3.1) for its consideration. The issue of engineered alternatives, as they relate to performance assessment, was specifically reviewed by recent peer review panels (see Section 9.3.3).

9.4.8 INTRAVAL

The INTRAVAL project was initiated in 1987 in Stockholm as an international effort to validate geosphere models for transport of radionuclides. The project was initiated by the Swedish Nuclear Power Inspectorate and was first formed as an ad-hoc group with representatives from eight organizations. INTRAVAL has since grown to include 24 "Parties" from 14 countries. The project is governed by a coordinating group which has one representative from each member of the group. Project organization, the objectives of the study, and the rules for publication of results are defined by an agreement between the group members. The INTRAVAL philosophy is to use results from laboratory and field experiments as well as natural analog studies in a systematic study of the model validation process. The goal is to evaluate conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste, with particular focus on the validity of model concepts.

A number of "test cases" have been studied at various locations around the world. These test cases include field tests, mining operations, natural analogs, and laboratory experiments. In

1990, two test cases from the WIPP site were included as part of the INTRAVAL investigations, and were designated as WIPP1 and WIPP2. An evaluation of the INTRAVAL project reviews against the screening criteria is provided in Table 9-15. These two test cases are discussed in INTRAVAL Progress Reports (numbers 5 through 10) (see Appendix PEER) and are briefly described below.

WIPP1

The WIPP1 test case was based on experiments performed to determine the rate of brine flow through WIPP bedded evaporites. The experiments were designed to provide a variety of data with which to determine whether Darcy's Law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case was also related to the ability of waste-generated gas to flow from the repository into the formation. Data from three types of experiments form the basis for the test case:

- small scale brine inflow experiments,
- pore pressure and permeability testing, and
- integrated, large scale experiment.

The following project teams analyzed the WIPP1 test case:

SNL, United States
Ecole Nationale Superieure des Mines de Paris (EdM), France
Commissariat a l'Energie Atomique/Institut de Protection et de Surete Nucleaire (CEA/IPSN), France
National Institute of Public Health and Environmental Hygiene (RIVM), The Netherlands

The general approach taken by the teams was to attempt to determine values of permeability and specific capacitance that would be consistent with other available data and would be able to provide reasonable simulations of all of the brine-inflow experiments performed in the Salado Formation. All of the teams concluded that the average permeability of the halite strata penetrated by the experimental boreholes was between approximately 10^{-22} and 10^{-21} m^2. Specific capacitance values ranging from about 10^{-10} to 10^{-12} were found to be consistent with the experimental data.

All of the project teams found that Darcy-flow models could replicate the experimental data in a consistent and reasonable manner. Discrepancies between the data and simulations were attributed to inadequate representation in the models of processes modifying the pore-pressure field and to physical processes, such as ongoing deformation of the rock around the excavations, occurring in the experiments themselves.

Table 9-15. INTRAVAL

1. Is the "peer review" relevant to the CCA?	Yes - Although not a review of the WIPP project specifically, INTRAVAL used WIPP site characterization data to validate models of groundwater flow.
2. Was there a formal report prepared by the reviewer?	Yes - Annual INTRAVAL reports and journal articles provide summaries of the findings.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - The two cases discussed provide independent evaluation of the validity of the conceptual models used for Salado brine inflow and Culebra groundwater flow at WIPP.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Yes - The two cases evaluated the validity of conceptual models for the WIPP site.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - Reviewers were internationally recognized experts in their respective fields. Many had extensive experience in radioactive waste disposal projects in other countries.
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	Yes - Reviewers were not involved in the WIPP project, were impartial, and were free from funding considerations.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

The conclusion from the test case is that Darcy-flow models could reliably predict brine flow to WIPP excavations, provided that the flow modeling is coupled with measurement and realistic modeling of the pore-pressure field around the excavations. Realistic modeling of the pore-pressure field would probably require coupling to a geomechanical model of the stress evolution around the repository.

WIPP2

The WIPP2 test case was based on flow and transport experiments in heterogeneous fractured sediments overlying the WIPP repository horizon. Geologic, hydrologic, geochemical, and isotope data had been collected to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involved the travel time within the Culebra from a location above the repository to the WIPP site boundary. Sixty wells into the Culebra dolomite at 41 locations had been completed to provide information on the hydraulic properties. Two pumping tests, each of two months' duration, and two convergent-flow tracer tests had been performed. Geochemical and isotope studies had also been conducted to obtain additional insight into the hydrologic behavior of the Culebra.

The test case was studied by the project teams from

U.K. Nirex Ltd. (AEA/NIREX), United Kingdom
Empresa Nacional de Residuos Radioactivos S. A. (UPV/ENRESA), Spain
Atomic Energy Control Board, Canada
Bundesanstalt fur Geowissenschaften und Rohstoffe (BGR), Germany
SNL, United States

The primary data used in the INTRAVAL studies were the hydrogeological properties of the Culebra dolomite. The Culebra dolomite is quite thin, approximately 8 meters thick, but extends for many kilometers and is highly fractured in some locations. A large number of hydraulic tests has been performed in the dolomite including transmissivity measurements, steady-state measurements of heads, and cross-hole tests. The modeling has mainly addressed the issues involved in treating the heterogeneity of the transmissivity of the Culebra dolomite. The effects of the varying salinity of the groundwater in the Culebra dolomite have also been analyzed. There are large variations in the transmissivities of the Culebra leading to uncertainties in quantities of importance in a repository performance assessment such as travel times. Therefore, there seems to be a generally agreed-upon approach to use stochastic models. The conceptual models include two- as well as three-dimensional descriptions of the Culebra dolomite. Continuum porous media as well as fracture network models have been studied.

The teams from AEA and UPV tackled this test case by using stochastic models. The AEA team applied the Turning Band algorithm for generation of realizations. The finite element groundwater and transport code NAMMU was used to solve the problem. The team examined

the uncertainties in the path-lines, travel time, head and Darcy velocity that resulted from the uncertainties in the parameters. Furthermore, the statistical behavior of the variogram estimators was studied using Monte-Carlo simulations. The team considered four different stochastic models, all isotropic, and concluded that if the correlation length was comparable to, or greater than, the size of the domain investigated it was not possible to determine the correlation length from the measured data. However, this did not have a significant impact on the uncertainties in quantities such as the travel time, provided that the model was conditioned on a reasonable number of transmissivity measurements. The team applied three different approaches to condition the head data. None of these approaches were found to be entirely satisfactory. Furthermore, the performed work gave some evidence that conditioning on head data is not as strong a constraint as conditioning on transmissivity data.

The UPV team used a sequential Gaussian simulation for the generation of realizations. The finite difference codes MODFLOW and MODPATH were used to compute the flow and particle paths. An optimization method was used to condition the head data. The team found that the anisotropic variogram gave best fits. The conditioning on the heads provided significant improvement, but some discrepancies were still remaining. Gaussian models imply lack of connectivity of regions with higher (or lower) than average transmissivity. Therefore, they might not take into account fast flow paths from the repository, which are responsible for the main radiological consequences. Furthermore, the modeling performed by the team indicated that variable density has a large impact on the results and should therefore be included.

The Atomic Energy Control Board team studied the effects of salinity on the groundwater flow. This was done by comparing the groundwater flow and the head data using three different salinity distributions. The problem was solved using the finite difference code SWIFT. The results indicated that there was not any strong evidence for a trend, the variations were consistent with the correlated spatial process. The match to the heads was not good even with conditioning. The calculations with different salinities indicated that the flow paths in the Culebra from the center of the site are relatively insensitive to the uncertainties in the salinity distribution.

The BGR team addressed issues relating to the choice of conceptual model. The AEA, UPV and Atomic Energy Control Board teams all considered two-dimensional areal models of the Culebra dolomite and assumed that the permeabilities of the units above and below are sufficiently small so that vertical flow can be neglected. The BGR team used a two-dimensional cross-section model to evaluate vertical leakage between members of the Rustler Formation. The team concluded that flow between the Culebra and the overlying Tamarisk Member and underlying unnamed lower member affects the Culebra flow field. The team also concluded that the present-day salinity distributions within the Culebra and Magenta are consistent with diffusional transport of salt from halite-bearing members of the Rustler to the dolomite members.

The SNL team has applied different conceptual models to study the importance of vertical flow between the Culebra dolomite and the overlying units. Calculations using the preliminary conceptual model indicated that leakage into the Culebra may be of importance.

The test case provided a very valuable focus for the development and study of stochastic models for the treatment of heterogeneity in hydrogeological properties. The applied stochastic models have proven to be valuable tools in assessing the effect of uncertainty due to heterogeneity on the performance of a repository. The test case also provided impetus for 3-D basin-scale modeling to evaluate the conditions under which the Culebra could be conservatively modeled as a 2-D confined aquifer for performance assessment purposes.

9.4.9 WIPP Conceptual Model Uncertainty Group Review

The WIPP Conceptual Model Uncertainty Group (CMUG) was an advisory group that was formed and operated in 1993 to provide guidance to SNL's WIPP Performance Assessment effort. An evaluation of the CMUG activities against the screening criteria is provided in Table 9-16. A report of their evaluation of the WIPP Performance Assessment was prepared September 27, 1993 (see Appendix PEER) and is summarized below.

The CMUG included expertise in hydrology, geology, geochemistry, risk assessment, and environmental modeling. All committee members were consultants who, at that time, worked outside the SNL community. The panel members were as follows:

Craig Bethke, University of Illinois
Rafael Bras, Massachusetts Institute of Technology
Jesus Carrera, Universidad Politechnica de Catluta
Neil Chapman, Intera Information Technologies Ltd.
Ghislain de Marsily, University Pierre et Marie Curie
Daniel Galson, Galson Sciences Ltd.
Steven Gorelick, Stanford University
Jane Long, Lawrence Berkeley Laboratory
Dennis McLaughlin (Chairman), Massachusetts Institute of Technology

The charter of the CMUG states

> *"The conceptual model uncertainty ... group is being formed to provide guidance to the WIPP PA program on how to account for uncertainty associated with conceptual models for the groundwater flow and radionuclide transport systems in the Rustler and other non-Salado formations."*

Table 9-16. Conceptual Model Uncertainty Group

1. Is the "peer review" relevant to the CCA?	Yes - The CMUG reviewed the 1992 conceptual models used for PA.
2. Was there a formal report prepared by the reviewer?	Yes - Meeting summaries were prepared.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - It was a review of the adequacy of the WIPP conceptual models.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Partially - Although the CMUG reviewed the existing PA models, its primary thrust was to recommend improvements in the models.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - Group members are internationally recognized experts in their respective fields.
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	Yes - The recommendations were provided from an independent and impartial perspective.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	Yes - The review conducted a detailed review of the WIPP conceptual models and provided extensive comment on those models.

The group is also asked to

> *"... help ... on the development of alternative conceptual models and treatment of conceptual model uncertainty ..."*

During its first two meetings in March and October of 1993, the CMUG focused on gaps, ambiguities, questionable assumptions, and simplifications which should be resolved before a final performance assessment is submitted. The CMUG's initial reaction was that the WIPP Performance Assessment has concentrated too much on simulation exercises and too little on identifying potential pathways and processes. They recommended that the performance assessment should devote more effort to understanding the origins and evolution of the non-Salado environment, particularly its geology, geochemistry, and hydrology. Specific concerns were provided in four areas: (1) regional hydrology, recharge, and the effects of climate change; (2) geologic history, evolution, and structure over a range of scales; (3) geochemical evolution and composition of groundwater; and (4) alternative transport pathways. These concerns are documented in the CMUG report which is provided in Appendix PEER.

Most of the recommendations provided by the CMUG have been implemented. In direct response to the CMUG recommendations, an in-house working group was formed in the spring of 1993 to re-evaluate conceptual models for use in performance assessment. That group contained representatives of both performance assessment and experimental activities, and made significant progress during the remainder of 1993 in redefining performance assessment conceptual models. The DOE performed a complete rescreening of all FEPs as part of the preparation of this application: CMUG concerns were addressed as part of this activity. Also, the CMUG reports were provided to the recent CMPR panel (see Section 9.3.1) for consideration in its assessment of the WIPP Performance Assessment conceptual models.

9.4.10 Environmental Evaluation Group Reviews

The EEG was established in 1978 as an independent technical advisory group to assist in the State review of the WIPP project. The EEG continues to be funded by the DOE through the New Mexico Institute of Mining and Technology.

Current and former staff members of the EEG, and their technical disciplines, include the following:

Robert Neill (Director), Radiological Hygienist
Lokesh Chaturvedi (Deputy Director), Engineering Geologist
Sally Ballard, Laboratory Scientist
William Bartlett, Health Physicist
James Channell, Environmental Engineer (previous staff member)
Jenny Chapman, Hydrogeologist (previous staff member)

Thomas Clemo, Geohydrologist
Stuart Faith, Consulting Geochemist (previous staff member)
Donald Gray, Environmental Specialist
Jim Kenney, Environmental Scientist/Supervisor
Lanny King, Assistant Environmental Technician
Betsy Kraus, Technical Editor/Librarian
William Lee, Senior Scientist
Marshall Little, Health Physicist (previous staff member)
Kenneth Rehfeldt, Hydrologist (previous staff member)
Matthew Silva, Chemical Engineer
Peter Spiegler, Radiological Health Analyst (previous staff member)
Ben Walker, Quality Assurance Specialist
Ruth Weiner, Senior Scientist (previous staff member)
Carla Wofsy, Mathematician (previous staff member)

The EEG conducts independent technical analyses of numerous aspects of the WIPP project. These analyses include assessments of reports issued by the DOE and its contractors as they relate to the potential health, safety and environmental impacts from the WIPP. The EEG also performs independent environmental monitoring of background radioactivity in air, water and soil, both on- and off-site.

The EEG has published 60 reports relating to numerous aspects of the WIPP project since 1978. An evaluation of the EEG reviews against the screening criteria is provided in Table 9-17. When evaluated against the screening criteria, it was determined that most of the reports (and associated work) involve issues outside the scope of the this application and/or appear to represent expert judgment or technical review. However, 15 of the reports appear to qualify as peer reviews, per NUREG-1297, and address issues relevant to the compliance certification application. Each of these reports is discussed below.

The issues and concerns raised by EEG have been continually evaluated by the WIPP project. A considerable amount of additional testing and analysis have been undertaken because of EEG's involvement; substantial changes have occurred in the WIPP project as a result.

9.4.10.1 EEG-2 (1978): Review Comments on the GCR, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, SAND78-1596, Volumes I and II

The GCR (Powers et al. 1978) was a two volume summary of the geological background and studies of the geology through preliminary screening to site selection and initial characterization of the WIPP site. The EEG report was a

Table 9-17. EEG Reports

1. Is the "peer review" relevant to the CCA?	Some of the reports address site characterization and other CCA issues.
2. Was there a formal report prepared by the reviewer?	Yes - EEG prepares and publishes formal reports.
3. Was the review a "peer review" rather than a "technical review"?	Some of the reports fit the NUREG-1297 definition of peer review.
a. A peer review's purpose is to confirm the adequacy of the work being reviewed.	
b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	
4. Was the review a "peer review" rather than an "expert judgment"?	Some of the reports review the adequacy of the work of others.
a. A peer review confirms the adequacy of the work being reviewed.	
b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - The EEG is recognized as an expert group.
6. Were the reviewers independent?	Yes - EEG was created to provide an independent technical review of WIPP.
a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed?	
b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	Only those reports which pass the above criteria will be incorporated into the CCA.

synthesis of comments by Mr. Neill, Dr. Channell, Ms. Wofsy, Lynn Gelhar (a part-time staff hydrologist), and numerous consultants. The EEG report (see Appendix PEER) identified the following issues as the principal concerns relating to the review of the GCR:

- Concerns regarding high-pressure brine reservoirs encountered in the Castile formation in ERDA No. 6 and in other wells near the site.

- Concerns regarding 'breccia pipes' in the area. EEG proposed that the pipes may be localized deep dissolution features originating in the lower portion of the evaporites and migrating upward and that such features could now exist or develop later beneath the proposed repository.

- Concerns regarding processes and rates of deep dissolution of salt near the site that could result in preferential removal of the repository salt horizon.

- Inadequate hydrological information regarding the aquifers above and below the evaporites to assess possible releases from the repository.

Extensive study of the geology and hydrology of the area in and around the WIPP has been conducted. In particular, WIPP-12 was drilled and deepened to investigate the occurrence of brine in the Castile (when brine was encountered in deepening WIPP-12, the repository layout was reoriented to make emplaced waste further away from the brine occurrence). A breccia pipe study was also undertaken and completed by the United States Geological Survey (USGS) (USGS 1982). In addition, deep dissolution of salt near the repository was specifically addressed in at least two ways: a) by a SAND report (Lambert 1983); and, b) by drilling and hydrologic testing of hole DOE-2, sited on a structural "depression" in the Salado, believed initially to be the result of deep-seated dissolution (This was found not to be the case [Borns 1987]).

Information regarding the increased understanding of these features and processes have been documented in numerous technical reports and is summarized in the WIPP FEIS (DOE 1980a), the WIPP FSEIS (DOE 1990a), and the RCRA Part B application. The EEG raised the same issues in its EEG-3 report (see Section 9.4.10.2).

9.4.10.2 EEG-3 (1979): Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U.S. Department of Energy

The Draft Environmental Impact Statement (DEIS) (DOE 1979) was prepared to satisfy the requirements of the NEPA regarding the analysis and documentation of the impacts associated with major federal actions. EEG-3 (see Appendix PEER) is a compilation of the EEG's comments on the DEIS. Document editors were Mr. Neill, Dr. Channell, Ms. Wofsy, and Moses Greenfield (a consultant). Topics addressed by the comments included health effects, transportation, waste acceptance criteria, site characterization, site selection criteria,

operational exposure, the experimental waste program, long-term radiation releases, retrievability and decommissioning. From the report summary, the comments and recommendations relevant to this application included the following:

- The WIPP should have to meet NRC license requirements.
- Estimate both health effects and potential radiation exposures.
- Develop waste acceptance criteria before a full evaluation of radiological consequences of operations and accidents can be completed.
- Include a more detailed analysis of the following geological and hydrological aspects of the area surrounding the WIPP site:
- Brine reservoirs (EEG noted that large high pressure reservoirs were encountered in seven wells within 9 miles of WIPP).
- Dissolution of lower and intermediate levels of the salt beds.
- Breccia pipes which EEG noted may be localized deep dissolution features.
- Uncertainties in groundwater flow rates and flow paths.
- Effect of impurities on the physical, hydrological, thermal, and strength characteristics of rock salt from the repository horizons.
- Formally request federal agencies and other experts to comment on the reasonableness and adequacy of the site selection criteria.
- Include the detailed sensitivity analysis being conducted by DOE.
- Waste retrieval should be examined in detail.
- Evaluate the feasibility of site control for more than 100 years.

As stated previously, the geology, hydrology, and geochemistry of the WIPP site have continued to be the focus of extensive experimentation by the DOE and the USGS and evaluation by the DOE and others such as the NAS. In particular, further studies on brine reservoirs, deep dissolution, and breccia pipes were conducted (see Section 9.4.10.8 for a listing of some of the relevant reports). Information regarding the increased understanding of the site has been summarized in the WIPP environmental impact statements, and the RCRA Part B application.

Chapter 15 of the FEIS (DOE 1980a) provided responses to the EEG comments received on the DEIS (DOE 1979). Section 7 of the FEIS was extensively revised to answer many of the geological/hydrological issues raised by the EEG. In addition, the FEIS discussions of waste retrieval and decommissioning were expanded (see Section 9.4.10.5 for the EEG's comments on the FEIS).

9.4.10.3 EEG-8 (1980): The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP

This report (see Appendix PEER), written by Ms. Wofsy, evaluates the assumptions used for modeling radionuclide transport in the DEIS (DOE 1979) and the WIPP Safety Analysis Report (SAR) (DOE 1980b). The report summary states that

> *"The radionuclide transport modeling is used to predict worst possible consequences of a WIPP repository breach event in which waste enters groundwater. The aim of this report is to determine whether plausible changes in the parameters used by DOE to describe the flow of groundwater near the WIPP site could result in: a) significantly faster radionuclide movement in groundwater; and b) significantly higher concentrations of radionuclides in Pecos River water and correspondingly higher radiation doses than predicted by DOE.*
>
> *The conclusion reached is that while plausible changes in hydrologic conditions and waste-rock interactions might result in a significant reduction in the time it takes for radionuclides to reach the Pecos River, the shorter travel times do not result in significant increases in the estimated concentrations of radionuclides in the Pecos River, nor in the radiation doses associated with the use of such water."*

A number of reviews and analyses by the DOE and others have consistently concluded that catastrophic breaches of the repository, such as assumed above, are very unlikely. However, in the event of such an occurrence the DOE does not disagree with the EEG-8 report's basic conclusion that there would not be significant increases in radionuclide concentrations, or associated radiation doses, in the Pecos River.

9.4.10.4 EEG-9 (1981): An Approach to Calculating Upper Bounds on Maximum Individual Doses from the Use of Contaminated Well Water Following a WIPP Repository Breach

The EEG reviewed the approach used in the FEIS (DOE 1980a) and the SAR (DOE 1980b) to calculate the potential radiological consequences of releases from the WIPP repository. This report (see Appendix PEER) was written by Dr. Spiegler and evaluates the postclosure radiation dose commitments associated with a possible breach event (the hydrological event considered is described as communication event no. 2 in the FEIS). This postulated release involves dissolution of the radionuclides in the repository by groundwater and their

subsequent transport through an aquifer to a well. The well is assumed to exist 3 miles downstream from the repository. The report states that

> *"The concentrations of uranium and plutonium isotopes at the well are based on the nuclear waste inventory presently proposed for WIPP and basic assumptions concerning the transport of waste as well as treatment to reduce the salinity of the water. The concentrations of U-233, Pu-239, and Pu-240.....would exceed current EPA drinking water limits. The concentrations of U-234, U-235, and U-236.....would be well below current EPA drinking water limits. The 50-year dose commitments from one year of drinking treated water contaminated with U-233 or Pu-239 and Pu-240 were found to be comparable to a one year dose from natural background. The 50-year dose commitments from one year of drinking milk would be no more than about 1/5 the dose obtained from ingestion of treated water.*
>
> *These doses are considered upper bounds because of several very conservative assumptions....."*

As stated above, DOE and others have consistently concluded that catastrophic breaches of the repository, such as are presented above, are very unlikely. However, in the event of such an occurrence the DOE believes that the basic conclusion of the EEG-9 report, that resulting exposures would be small, even when using very conservative assumptions, is correct. Analyses of events similar to the one above were provided in the 1990 Final Supplement Environmental Impact Statement (FSEIS) (DOE 1990a).

9.4.10.5 EEG-10 (1981): Radiological Health Review of the Final Environmental Impact Statement, (DOE/EIS-0026), Waste Isolation Pilot Plant, U.S. Department of Energy

The FEIS provided a review of the potential impacts of the proposed WIPP project. The EEG reviewed the FEIS to determine (a) the changes made to the DEIS; (b) the adequacy of the evaluation; (c) the thoroughness of the DOE's response to EEG's comments on the DEIS; and (d) other issues which EEG believed should be addressed more fully before beginning construction of the WIPP.

The EEG concluded in its report (see Appendix PEER) that DOE had *"incorporated and addressed the majority of the concerns and recommendations that the EEG provided to them in our (EEG-3) August 1979 review of the Draft Environmental Impact Statement on WIPP and the FEIS provides a generally satisfactory evaluation of the potential radiological impact."* There were, however, areas that EEG believed that had not been adequately treated by DOE. The report made the following recommendations:

- Discuss how a zone of possible instability in the area north and southwest of ERDA-9 would be further investigated. The EEG also requested further information on brine reservoirs and dissolution processes near the site.

- Provide the criteria for the high-level experimental wastes and the procedures to assure that Waste Acceptance Criteria will be met.

- Provide more detailed information on the future control of the mineral and hydrocarbon resources at or near the site, and of the hazard analyses that led to the conclusion that resources at the site can be safely extracted.

- Consider the consequences of other potential release scenarios which have been recommended by the EEG.

Geophysical (Time Domain Electromagnetic) surveys were conducted in the immediate vicinity of ERDA-9 to examine the WIPP area for Castile brine reservoirs (Earth Technology Corporation 1988). Additional boreholes were drilled which showed deep dissolution was absent (see Section 9.4.10.1 for additional discussion of brine reservoir and dissolution process studies).

The high-level experiments were canceled. Additional evaluation of the mineral and hydrocarbon resources and their control has occurred since the FEIS was developed. A New Mexico Bureau of Mines and Mineral Resources report (titled, Evaluation of Mineral Resources at the Waste Isolation Pilot Plant [WIPP] Site) in March 1995 (NMBMMR 1995) was the most recent review and reevaluation of the potential for mineral resources and their development. Analysis of other potential release scenarios have been developed and provided in the 1990 FSEIS (DOE 1990a).

9.4.10.6 EEG-11 (1982): Calculated Radiation Doses from Radionuclides Brought to the Surface If Future Drilling Intercepts the WIPP Repository and Pressurized Brine

This report (see Appendix PEER) questions assumptions relating to potential brine reservoirs in the FEIS (DOE 1980a) and other documents and discusses the consequences if pressurized brine were encountered by future drilling at WIPP. The postulated scenario assumes that an exploratory borehole connects the repository and an undiscovered pressurized brine reservoir below the repository and results in saturation of the waste storage area. A subsequent borehole is assumed to bring portions of this contaminated brine to the surface. Based on the calculated radiation doses obtained from this study, the report recommends

- A more detailed evaluation of the probability of this scenario occurring, and

- Consideration of maintaining active institutional controls of WIPP for about 600 years after closure unless the probability of occurrence can be shown to be less than estimated.

Section 5.4 of the 1990 FSEIS (DOE 1990a) evaluated several postclosure repository release scenarios. The SEIS analyses considered a suite of breach scenarios, including some involving disturbed repository scenarios similar to that postulated in EEG-11. Title 40 CFR Part 191 requires that performance assessment not consider contributions from active institutional controls for more than 100 years after disposal.

9.4.10.7 EEG-12 (1982): Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP

The report (see Appendix PEER) evaluates release scenarios provided in the 1980 FEIS (DOE 1980a). The report was written by Mr. Little and evaluates the DOE's position regarding the likelihood and consequences of hydrocarbon and mineral exploration and development in the area of the WIPP site. An analysis of the potential radiological consequences of solution mining of halite is also provided. In the report summary, the EEG concluded that:

- The radiological consequences of the mining of potash or extraction of hydrocarbons (mostly natural gas) are probably bounded by the hydrologic breach scenarios and that the resultant doses would not constitute a significant threat to public health.

- The risk from the solution mining of salt was believed to be small and it is unlikely that the small doses resulting from such mining breach event would produce any detectable biological effects.

Potential radiological consequences of potash mining have been explicitly incorporated into the compliance certification application transport calculations by inclusion of an increase of up to three orders of magnitude increase in Culebra transmissivity/conductivity over mined areas, as a direct consequence of potash mining. The DOE continues to believe that solution mining of halite in the WIPP area is not a credible scenario. The shortage of water in the area, the amount of impurities in the Salado salt, and the enormous quantity of salt available in other parts of the country decrease the likelihood of this scenario.

9.4.10.8 EEG-22 (1983): EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983; and EEG-23 (1983): Evaluation of the Suitability of the WIPP Site

The DOE provided the EEG several reports documenting the status of evaluation and analysis of geotechnical issues regarding the WIPP site.

"Interim Report: Dissolution of Evaporites in and Around the Delaware Basin" (Lambert 1983)
"Evaluation of Breccia Pipe in Southeastern New Mexico and their Relation to the WIPP Site" (USGS 1982)
"Brine Reservoirs in the Castile Formation, Southeastern New Mexico" (Popielak et al. 1983)
"Delaware Mountain Group Hydrology - Salt Removal Potential" (DOE 1982)
"Fracture Flow in the Rustler Formation: WIPP, Southeast New Mexico (Draft Interim Report)" (Gonzalez 1983)
"Interim Policy Statement on Resource Recovery at the WIPP Site" (DOE 1981)
"Simulated Waste Experiments Planned for the Waste Isolation Pilot Plant (WIPP)" (Matalucci 1982)

EEG-22 (see Appendix PEER) is a compilation of the written comments by EEG on each of these reports. EEG-23 (see Appendix PEER) discusses each of the above documents and makes recommendations concerning additional work needed for further site characterization. These recommendations were

"The following is a list of certain investigations currently in progress or planned by DOE and additional work which EEG recommends that the State should demand if the construction is allowed to proceed."

Continuing or Planned DOE Studies

1. Field tests to identify possible occurrence of brine under the repository.

2. Analyze draw-down data in test holes H-1, H-2 and H-3 caused by WIPP shaft excavations.

3. Publish results of solute transport modeling in the Rustler aquifers.

4. Analyze Rustler aquifer for environmental isotopes (C-14, Cl-36, U-234, U-238) to aid in understanding groundwater flow direction and velocity.

5. Drill planned additional wells for hydrologic testing, viz. H-11 and H-12. Evaluate the cores to determine the extent of fracturing and solution residues in the Rustler formation.

6. Conduct a water balance study for the WIPP site.

7. Study mechanics of salt removal from the Rustler formation near WIPP.

8. Drill a shallow auger-hole in the depression in the SW corner of Sec. 30, T22S, R31E in Zone III to determine if this depression is a doline.

9. Study MB139 to determine its origin and its effect on the repository and confirm it does not violate Section 13.2 of the DOE's site criteria and qualification factors.

Studies Recommended by EEG

1. Investigate the depression of the MBs in the lower part of the Salado formation, centered two miles north of the WIPP shafts.

2. Perform computer modeling of groundwater flow in the Rustler aquifers.

3. Conduct the following hydrology tests:
   a) A long duration pumping test at well H-3.
   b) Measure anisotropy of hydraulic conductivity at test pads H-1, H-2 and H-3.
   c) Perform convergence tracer tests at wells H-1, H-3 and H-4.
   d) Perform convergence tracer tests at well H-6 using sorbing tracers."

The EEG recommendations for additional studies at the WIPP formed a large part of the basis for modification of the Agreement for Consultation and Cooperation between the DOE and the state of New Mexico. Several specific studies addressing issues raised by the EEG were performed between 1983 and 1988. The results of these studies are documented in SAND88-0157 (Lappin 1988), and in detailed references in that summary report. Specifically:

1. Brine occurrence under the repository - see (Earth Technology Corp. 1988).

2. Culebra draw-downs due to shaft excavation - see (Beauheim 1987a) and (Haug et al. 1987).

3. Publish solute-transport modeling in Rustler aquifers - see (Kelley and Pickens 1986), the 1990 FSEIS (DOE 1990a), and the annual performance assessment reports (Bertram-Howery et al. 1990, and subsequent reports).

4. Use of environmental isotopes - see (Lambert and Carter 1984, 1987), (Lambert 1987) and (Lambert and Harvey 1987).

5. Drilling additional wells for hydrologic testing - see (Beauheim 1989) and (Jones et al. 1992).

6. Water-balance study - see (Hunter 1985).

7. Mechanisms of salt removal from the Rustler - see (Holt and Powers 1984, 1987) and (EEG-34 1987).

8. Auger depression in SW corner of section 30 - see (Bachman 1985) and (Bachman 1987).

9. MB139 - see (Borns 1985).

Regarding studies recommended by the EEG:

1. Hole DOE-2 was redrilled and tested to study the noted depression in the Salado north of the WIPP site (see above references).

2. Computer modeling of groundwater flow has been performed - see (Haug et al. 1987) and (LaVenue et al. 1988) and reference the continuing use of Culebra T-field.

3. Non-sorbing tracer tests have now been conducted at H-2, H-3, H-4, H-6, H-11 and H-19. Convergent-flow tests were conducted at H-3, H-4, H-66, H-11 and H-19. Modern single-well tests were conducted at H-11 and H-19.

The DOE position is that the combination of field-scale testing with non-sorbing-tracers, batch sorption tests in the laboratory, and core/column tests in the laboratory using both sorbing and non-sorbing tracers is adequate; that is, that a field-scale sorbing-tracer test is not necessary for WIPP to demonstrate adequate regulatory compliance.

In summary, the DOE implemented tests and studies to address all of the above recommendations.

9.4.10.9 EEG-29 (1985): Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project

The SAR defines the safety envelope for operation of the WIPP facility. The contents of Chapter 8 of the SAR (entitled "Long Term Waste Isolation Assessment") is relevant to this application. The EEG report (see Appendix PEER), prepared by Mr. Little, evaluated the WIPP SAR and its associated amendments and provided written comments and recommendations based on that review. EEG-29 provided two unresolved comments related to Chapter 8 of the SAR:

- Provide maximum TRU content for packages authorized for WIPP.

- Change the SAR to reflect the results of in progress hydrological studies.

The DOE revised the WIPP SAR and provided a draft to the EEG in 1989. The EEG comments on that draft were provided to the DOE in EEG-40 (see Section 9.4.10.10).

9.4.10.10 EEG-40 (1989): Review of the Final Safety Analysis Report (FSAR) (Draft), DOE Waste Isolation Pilot Plant

As stated above, the DOE revised the SAR and provided the EEG with a draft version for review and comment. The EEG review is documented in EEG-40 (see Appendix PEER) which identified the following issues, relevant to this application in its summary:

- Since the FSAR does not include the long-term risk assessment required by EPA in Part 191, a supplement to the FSAR must be developed prior to the disposal phase.

- The FSAR should specify in as much detail as possible the volumes, curies, and distribution within both CH-TRU and RH-TRU containers and the totals.

- The FSAR takes credit in Chapter 8 for a peer review panel providing assurance on suitability of WIPP as a repository. The panels do not provide credibility unless the EEG is involved.

- The FSAR should discuss when the decision on backfill will be made and the probable final backfill design during operation.

The purpose of the SAR is to document that a systematic analysis of the potential hazards associated with operating the WIPP has been performed, that potential consequences have been analyzed, and that reasonable measure have been taken to control or mitigate the hazards. The focus of the SAR is to address hazards for the design life of the WIPP. Performance Assessment is a probabilistic risk assessment tool designed to evaluate the long-term performance of the repository.

The WIPP SAR was again revised on November 30, 1995 (DOE 1995c). Section 5.4 of the SAR, "Long-Term Waste Isolation Assessment," discusses the performance assessment process and its role in demonstrating compliance with Parts 191 and 268. The SAR is updated annually and the 1996 update is scheduled to address the use of magnesium oxide as backfill. The results of performance assessment will be presented in this application rather than in the SAR.

Finally, the EEG did participate as an observer of the recent peer review panels that were organized to support development of this application.

9.4.10.11 EEG-41 (1989): Review of the Draft SEIS, DOE Waste Isolation Pilot Plant, April 1989

The DOE published and provided to the public the draft SEIS in 1989 (DOE 1989). The purpose of the SEIS was to update the environmental record established in the 1980 FEIS (DOE 1980a). The EEG reviewed the draft SEIS and provided their comments to the DOE as EEG-41 (see Appendix PEER). The report summary includes the following conclusions/recommendations regarding the SEIS:

- The draft does not adequately justify shipping up to 620,000 cubic feet of TRU waste to WIPP before demonstrating compliance with 40 CFR Part 191.

- Discuss the lack of progress in demonstrating compliance with 40 CFR Part 191.

- Preliminary performance assessment calculations indicate the repository may not meet the EPA standards under human intrusion scenarios. Address this issue and its impact on the proposed action.

- Quantify CH-TRU waste volumes associated with the various alternatives.

- Explain changes in the estimates of waste from the FEIS. EEG recommended (EEG-3) that estimates of the uncertainty of radionuclide inventories be included.

- The calculations of human exposure from the stock water well to beef pathway are incorrect. The correct doses will likely violate EPA standards.

- Address concerns expressed in this review of the SEIS. Issues identified by EEG in its review of the 1980 FEIS were rejected by DOE and have come to pass or have yet to be resolved. The unresolved issues include:

  - Evaluate high pressure gas generation from organic decomposition of the waste which could drive wastes to the surface or form explosive gas mixtures.

  - Estimate the total radioactivity expected to be emplaced at WIPP.

  - An effective control period of 400 years should be established.

  - Information was not adequate on large brine reservoirs.

  - Include estimates of the uncertainties of waste quantities.

- The Site and Preliminary Design Validation (SPDV) program is insufficient to determine the site's geological adequacy.

The DOE reviewed the public and agency comments, including those from the EEG, categorized them and prepared a comment-response document (Volume 3 of the FSEIS [DOE 1990a]) that presents synopses of the comments and the DOE's responses. The SEIS was revised extensively to accommodate the comments received on the draft.

As noted in the Volume 3 comment responses, the WIPP will demonstrate compliance with Part 191 prior to any decision to utilize the WIPP as a permanent waste repository (in fact, the purpose of this application is explicitly to demonstrate that compliance). Other sections of the SEIS, including Sections 3 and 5 and Appendix I were also extensively revised to clarify waste inventories, assess environmental consequences, and readdress release scenarios. It should also be noted that, as promised in the 1990 FSEIS, a disposal phase SEIS is currently in preparation.

9.4.10.12 EEG-50 (1992): Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards

This report (see Appendix PEER) was prepared by Drs. Silva and Channell. The report contends that DOE documentation, including the FEIS (DOE 1980a), the SAR, the Secretary's Decision Plan, and the Implementation of the Resource Disincentives (DOE 1991b) document, is inconsistent and/or inaccurate regarding the presence of two active oil and gas leases and a gas well within the WIPP site boundary.

The report suggests that this situation indicates a need to reexamine the assumption that active institutional control will be completely effective for 100 years after disposal and how much credit should be taken for passive institutional controls between 100 and 10,000 years. The EEG recommends that the DOE be required to publish specific plans on how it intends to maintain active institutional control. Finally, the EEG states that the DOE needs to describe in detail its passive institutional control system and show how it will provide a deterrence to inadvertent human intrusion after 100 years.

The DOE provided specific responses to the issues raised by the EEG report in July and November of 1992 (see Appendix PEER). The DOE's position is that the significant conclusions of EEG-50 relative to institutional controls are incorrect and that none of the documents discussed by the EEG as being inconsistent or inaccurate are a part of the institutional control process at the WIPP. The issue of passive institutional controls was reexamined by a recent peer review panel (see Section 9.3.7).

9.4.10.13 EEG-57 (1994): An Appraisal of the 1992 Preliminary Performance Assessment for the Waste Isolation Pilot Plant

The report (see Appendix PEER) documents the EEG review of the WIPP 1992 performance assessment. The evaluation was prepared by Drs. Lee, Chaturvedi, Silva, and Weiner, and Mr. Neill. A summary of the recommendations from the report were as follows:

- Apply fully coupled codes regarding gas generation, brine flow, and room closure.
- Perform more field and laboratory work regarding transmissivity fields in the Culebra.
- Abandon claiming credit for matrix diffusion and corrensite sorption.
- Show the full uncertainty band of CCDFs.
- Use experimental solubility values, when available, in performance assessment.
- Use only demonstrable retardation coefficients in performance assessment.
- Discard subjective probabilities for human intrusion used in the 1992 Performance Assessment.
- Provide EEG with relevant computer code documentation and access.
- Accelerate experimentation to quantify matrix diffusion and sorption.
- Include the deleterious effect of gas generation in future analysis.
- Show results with physical correlations in performance assessment or explain their absence.
- Accurately reflect the status of resource development near WIPP in performance assessment.
- Use the latest data regarding oil and gas production near WIPP in performance assessment.
- Include methane and radiolytic hydrogen generation in gas calculations.
- Validate gas generation model before incorporation into BRAGFLO.

- Evaluate the criticality issue before concluding its effects are negligible.

- Evaluate and incorporate subsidence effects into human intrusion scenarios.

- Include contaminated brine flow to the surface in human intrusion scenarios.

- Analyze brine-slurry release regarding undisturbed performance and in E2 scenario.

- Do not assume perfect plugging of abandoned oil and gas wells. For the human intrusion borehole, the range of degraded permeabilities should span sand and gravel.

- Performance assessment should include erosion of waste by helical turbulent flow and the effect of sediment erosion. Analyze of other relevant scenarios, such as the E1/E2 with brine slurry discharge to the surface.

- Include ^{135}Cs, ^{129}I and ^{99}Tc and other fission products in PAs.

- Show the basis for inventories used.

- Limit the sampling range to the error bands in experimental data in performance assessments.

- Analyze two-phase transport of volatile organic compounds (VOCs) through gas-fractured interbeds.

- Do not claim credit for corrensite sorption, unless the extent of corrensite or other clay minerals can be quantified along postulated flow paths.

- Do not model movement of VOC vapors as ideal gas flow in showing Part 268 compliance without experimental corroboration.

Specific responses have been provided to the EEG regarding the above comments in a series of transmittals from the DOE. Also, detailed responses to the EEG comments on Volumes 1 through 3 of the 1992 WIPP performance assessment are provided in Appendix PEER (see Appendix PEER documentation supporting Section 9.4.14).

It should be noted that the 1992 performance assessment was not intended to demonstrate compliance with 40 CFR Part 191. The concerns identified by the EEG have been addressed through: (1) the continued development of modeling capability; (2) continued site characterization and experimental data collection activities; and, (3) documentation, review, and quality assurance activities completed to support the demonstration of compliance with applicable regulations. The concerns related to code coupling, gas generation modeling, brine

flow to the surface, and waste erosion by helical flow were handled in the 1996 Performance Assessment through model capabilities developed since 1992. The concerns regarding radionuclide transport in the Culebra, solubility values, isotopes considered in transport, and gas-generation validation have been addressed in experimental and characterization programs. Finally, the concerns related to the use of transmissivity fields, CCDF reporting, human-intrusion probabilities, documentation of the values assigned to model parameters, development of scenarios, abandoned-borehole treatment, and inventory basis are addressed in quality-assurance procedures, IRT processes, documentation in the FEPs screening and scenario development process, and in the DOE's implementation of regulatory criteria in 40 CFR Part 191 and 40 CFR Part 194.

Several of the concerns stated by the EEG are not relevant to this application because they concern the transport of non-radioactive substances. The DOE has considered the comments provided by the EEG in preparing the compliance certification application and appropriate revisions were made. In addition, EEG-57 was provided to the recent conceptual models peer review panel for its consideration in evaluating the adequacy of the conceptual models used to describe the WIPP.

9.4.10.14 EEG-61 (1996): Review of the WIPP Draft Application to Show Compliance with EPA TRU Waste Disposal Standards

A draft compliance certification application (DCCA) was prepared by the DOE and provided to the EEG for review. The EEG report (see Appendix PEER) was prepared by Messrs. Neill, Kenney and Walker, and Drs. Chaturvedi, Lee, Clemo, Silva, and Bartlett. The following comments and recommendations were provided in the report:

- The DCCA cannot be considered to be an adequate draft document for demonstrating compliance with 40 CFR Part 191.
- The historical sections of the DCCA omit several significant details.
- Descriptions of alternative conceptual models for projected conditions and processes in the repository and along potential breach pathways, and the defense of the models selected are inadequate.
- Experiments to resolve the conceptual model for radionuclide retardation in the Culebra aquifer, suggested in 1979 by the EEG, should be conducted.
- A basic understanding of the hydrology of the site is yet to be attained.
- The DCCA does not improve on the 1992 WIPP Performance Assessment calculations regarding containment requirements. It does not adequately analyze several potentially

disruptive scenarios, establish the probabilities for potential breach scenarios, or provide the basis for calculating consequences.

- Performance-based waste acceptance criteria are mentioned, but not listed.

- There is a lack of commitment to demonstrate compliance with the assurance requirements and none of the 40 CFR § 191.14 elements are adequately addressed: plans for institutional controls have not been prepared; engineered barriers are not addressed appropriately; issues regarding presence of natural resources are not resolved; and, plans for waste retrieval have not been developed.

- Compliance with the individual and groundwater requirements is not adequately demonstrated.

- An analysis of compliance with the DOE orders, and reviews and approvals by the Office of Environment Safety and Health and the Defense Nuclear Facilities Safety Board should be included in the Biennial Environmental Compliance Report (Appendix BECR).

The EEG raises several concerns in its critique of the DCCA. These concerns are considered, generally, as requesting that thorough documentation be provided to support the modeling and assessment conducted. The EEG statement that the DCCA does not demonstrate compliance is accurate, and this document was not intended nor is it purported to be a compliance demonstration; rather, it provided a vehicle for the DOE to begin the process of assembling a complete compliance certification document. This application follows a structure similar to the DCCA, but it contains a through description of the methodology used in performance assessment, utilizes expanded modeling capabilities, expanded historical references, and a discussion of alternative conceptual and mathematical codes. Also, this application either contains or references a much larger body of information related to site characterization, repository design, waste characterization, scenario screening, and performance assessment conceptual and mathematical models and techniques. The EEG concerns regarding assurance requirements criteria in 40 CFR § 191.14 have been addressed in the context of 40 CFR Part 194; concerns regarding the criteria in 40 CFR § 191.15 and 40 CFR § 191.16 are addressed.

In summary, this application has been extensively revised. The DOE has carefully considered the comments provided by the EEG in preparing the application and appropriate revisions were made. In addition, EEG-61 was provided to the recent conceptual models peer review panel for its consideration in evaluating the adequacy of the conceptual models used to describe the WIPP.

9.4.11 Fracture Expert Group Review

SNL convened the Fracture Expert Group (FxG) during the spring of 1993. A summary report of the FxG meeting (see Appendix PEER) was prepared in March 1993.

As discussed in the meeting report, the charter of the group was to:

"*1. Review the current (as of 1993) BRAGFLO model assumptions for permeability and porosity as a function of pressure for their adequacy as first-order representations of the changes in the anhydrite beds adjacent to the waste disposal horizons due to pressurization of the formation.*

2. Recommend improvements in the characterization of changes in permeability and porosity in the anhydrite beds adjacent to the waste disposal horizons due to pressurization of the formation."

An evaluation of the FxG review against the screening criteria is provided in Table 9-18. Since the 19-member FxG contained SNL staff, SNL contractors, and external experts, it was not a truly independent review group. However, the group, and especially the 11 external experts, provided a valuable review of the issues and made several valuable recommendations which were, to a large extent, independent. The group included nationally and internationally recognized expertise in experimental mechanics, materials science, fracture and fluid mechanics, and computational fluid dynamics. The group members were as follows:

Pierre Bérest, Ecole Polytechnique, Palaiseau, France
Barry Butcher, SNL
Peter Davies, SNL
Chandrakant Desai, University of Arizona
Dick Ewing, Texas A&M University
Mert Fewell, SNL
Mel Friedman, Texas A&M University
Bezalel Haimson, University of Wisconsin
Samuel W. Key, RE/SPEC Inc.
Jane Long, Lawrence Berkeley Laboratory
Darrell Munson, SNL
Sia Nemat-Nasser, University of California-San Diego
Karsten Pruess, Lawrence Berkeley Laboratory
Thomas Russel, University of Colorado at Denver
Chin-Fu Tsang, Lawrence Berkeley Laboratory
Palmer Vaughn, Applied Physics Inc.
Wolfgang Wawersik, SNL

Table 9-18. Fracture Expert Group

1. Is the "peer review" relevant to the CCA?	Partially - Although the FxG reviewed the BRAGFLO conceptual model, its focus was primarily related to compliance with Part 268, rather than Part 191, requirements.
2. Was there a formal report prepared by the reviewer?	Yes - Meeting summaries were prepared.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - The FxG reviewed the adequacy of 1993 BRAGFLO model assumptions as they relate to repository pressurization.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Partially - The FxG's purpose was as much to recommend improvements in BRAGFLO as to evaluate its adequacy.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - Group members are recognized experts in their respective fields.
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	Partially - The 19-member FxG contained SNL staff, SNL contractors, and external experts so it was not a truly independent review group. However, the eleven external experts provided valuable review and recommendations from an independent and impartial perspective.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	Yes - The FxG provided valuable review of one of the conceptual models used in PA.

Stephen Webb, SNL
Teng-Fong Wong, State University of New York-Stonybrook

The meeting summary report concluded that "The proposed first-order model in BRAGFLO for representing changes in permeability and porosity due to pressure-induced changes in the anhydrite is an acceptable first approximation." The FxG report also made recommendations for additional studies to support an extended and improved second-order model in BRAGFLO for simulating the two-phase flow occurring in the altered anhydrite MBs (MB138 and MB139). These recommendations are summarized in the FxG report (Appendix PEER).

Recommendations by the FxG for additional studies of fracturing were driven by concerns regarding the gas-phase transport of VOCs away from the repository via pressure-induced fractures. Gas-phase transport is not a mechanism that could contribute to actinide releases from the disposal system. The DOE therefore concludes that the current performance assessment model used to approximate the effects of pressure-induced fracturing, which is a refinement of the model presented to the FxG, is adequate for use in estimating actinide releases from liquid-phase transport. The FxG meeting summaries were provided to the recent conceptual models peer review panel for consideration during its evaluation of the WIPP conceptual models.

9.4.12 Fanghänel Review - WIPP Thermodynamic Model for Trivalent Actinides

Dr. Thomas Fanghänel of the Institut für Nukleare Entsorgungstechnik, Forschungszentrum Karlsruhe, Germany, was contracted to perform an independent review of the thermodynamic models WIPP has developed to predict potential dissolved concentrations of actinides in WIPP brines. An evaluation of his review against the screening criteria is provided in Table 9-19.

He was tasked to provide an independent assessment of the methods used to estimate the dissolved concentrations of III, IV, and VI actinides. For the V actinides, he performed an independent assessment of the WIPP augmentation of his Np(V) thermodynamic model, as well as its use for estimating dissolved concentrations of V actinides in WIPP brines. He performed the review and submitted his final report, dated May 7, 1996. A copy of the full report is provided in Appendix PEER.

Dr. Fanghänel is an internationally recognized expert regarding the thermodynamic modeling of actinides and is completely independent of the WIPP project. His qualifications include extensive experience with the development and evaluation of thermodynamic models for actinides. He is first author of a journal publication documenting the Np(V) dissolved concentration model that serves as the basis for the WIPP +V actinide dissolved concentration model.

Table 9-19. Fanghänel Review of the WIPP Thermodynamic Model for Trivalent Actinides

1. Is the "peer review" relevant to the CCA?	Yes - The reviewer evaluated one of the models used in the WIPP PA.
2. Was there a formal report prepared by the reviewer?	Yes - A report was prepared.
3. Was the review a "peer review" rather than a "technical review"?	Yes - The work was a review of the WIPP thermodynamic model for predicting dissolved concentrations of trivalent actinides in WIPP brines.
a. A peer review's purpose is to confirm the adequacy of the work being reviewed.	
b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	
4. Was the review a "peer review" rather than an "expert judgment"?	Yes - The review evaluated the adequacy of the WIPP thermodynamic model for trivalent actinides.
a. A peer review confirms the adequacy of the work being reviewed.	
b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - Dr. Fanghanel is an internationally recognized expert.
6. Were the reviewers independent?	Yes - The reviewer is independent of the WIPP project.
a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed?	
b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

The following paragraphs are quoted from Dr. Fanghänel's report:

> "*For the WIPP thermodynamic model the ion interaction approach (Pitzer equations)* was chosen for modeling the excess properties of the aqueous solution (activity coefficient model). At present, the Pitzer approach is the most sophisticated semiempirical approach for the Gibbs excess energy of a concentrated electrolyte solution. It is widely used and a database with ion interaction parameters covering a large variety of different solution species is available.....
>
> *The WIPP model treats the interaction of AN(III) with Cl^- and SO_4^- as strong ion-ion interaction without invoking the formation of complex species. Within the composition range of the WIPP brines, this is a reasonable approach, which was demonstrated in several comparisons between model calculations and data...*
>
> *The applied assumptions for the development of the WIPP thermodynamic model are conservative and simplify the overall model. This is a prerequisite for calculating dissolved actinide concentrations in the very complex repository system.*
>
> *In general, the model represents the present state of the knowledge of aqueous solution thermodynamics. The chosen activity coefficient model and the applied data base are, with a few exceptions, suitable for calculating maximum trivalent actinide concentrations in WIPP brines.*
>
> *The model needs to be improved in some parts. This concerns in particular the hydrolysis equilibria of trivalent actinides which have to be introduced into the model. Moreover, the reviewer recommends that the model regarding the interaction of carbonate complexes in concentrated electrolyte solutions be refined."*

In accordance with Dr. Fanghanel's suggested improvement in the model concerning the hydrolysis equilibria of trivalent actinides, the recommended data have been incorporated into the CHEMDAT database. Regarding the second suggestion, carbonates are no longer considered to be significant to repository performance due to the implementation of magnesium oxide backfill.

9.4.13 Independent Technical Review of the Bin and Alcove Test Programs

The objective of this Independent Technical Review (ITR) team assessment of proposed TRU waste experiments at WIPP, as specified in the charter, was to:

> *"Review the need for, and technical validity of, the Bin and Alcove test programs, as defined in the Test Phase Plan, the Technical Needs Assessment Document, and individual test plans."*

The team consisted of nine technical personnel from the DOE, LANL, Lawrence Livermore National Laboratory (LLNL), and private consultants. The team members had a large amount of expertise and experience in mechanical, chemical and civil engineering, earth and environmental science, and geology. The team was composed of the following members:

- Stephan Brocoum (Team Leader), DOE, Office of Geologic Disposal
- Philip Thullen (ITR Team Leader), LANL
- Deborah Bennett (ITR Team Leader), LANL
- Richard Beddoes, Golder Associates
- Corale Brierley, Private Consultant
- Jan Docka, Roy F. Weston, Inc.
- Joseph Farmer, LLNL
- Ron Guimond, Ogden Environmental and Energy Services
- Stan Kosiewicz, LANL
- Abraham Lerman, Northwestern University
- John Shaler, Private Consultant
- Terry Steinborn, Applied Research Associates, Inc.
- Dave Swale, British Nuclear Fuels Limited

Although the independence of the ITR could be questioned because of the presence of a DOE staff member as Team Leader, Dr. Brocoum, as a Director in the Office of Geologic Disposal, had no responsibility or authority as regards the WIPP project. Further assurance of the independence of the team was provided by the credentials and professional stature of the team members and the direct oversight of the ITR review by the Technical Oversight Board (TOB). The independence and technical qualifications of the ITR members were verified by several parties prior to commencement of work. A summary evaluation of the ITR team against the screening criteria for peer reviews is shown in Table 9-20.

The team began it's review in July, 1993, and completed a final report (see Appendix PEER) in December of that year. The review process consisted of document review, formal presentations by the DOE and its contractors and other groups, and interviews with personnel. The team met several times to develop consensus on issues and recommendations and to prepare its report.

A TOB was chartered to review all aspects of the ITR team's activities. The TOB was composed of senior level individuals who have extensive experience in the development, execution, management and evaluation of large and technically involved projects. The TOB members included

- Dr. Colin Heath (Chairman), GC Management Associates
- Mr. Richard Baxter, Independent Consultant

Table 9-20. Independent Technical Review of the Bin and Alcove Test Programs at the WIPP

1. Is the "peer review" relevant to the CCA?	Yes - This review addresses waste characterization and gas generation issues.
2. Was there a formal report prepared by the reviewer?	Yes - There was a formal report.
3. Was the review a "peer review" rather than a "technical review"?	Yes - This review addressed the adequacy of plans for testing to be done for waste characterization and performance assessment.
a. A peer review's purpose is to confirm the adequacy of the work being reviewed.	
b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	
4. Was the review a "peer review" rather than an "expert judgment"?	Yes - This review addressed the adequacy of the work and made recommendations for changes.
a. A peer review confirms the adequacy of the work being reviewed.	
b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - The team members are recognized as experts in their respective disciplines.
6. Were the reviewers independent?	Yes - Although the Team Leader was a DOE staff member, he had no organizational responsibility for the WIPP project. Also, the professional stature of the ITR members and the oversight of the Technical Oversight Board served to ensure the independence of the ITR team review.
a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed?	
b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

Mr. William Hamilton, Independent Consultant
Dr. Mujid Kazimi, Massachusetts Institute of Technology
Mr. Dennis Lachel, Lachel and Associates, Inc.
Mr. John Maddox, Independent Consultant
Ms. Debra Marsh, Marsh Consulting Group, Ltd.

They provided a solid reference point of experience and ideas against which the ITR team tested its ideas regarding lines of inquiry, and the logic and validity of findings and conclusions. The results of the review were discussed with the TOB, and their guidance was used in preparation of the ITR report.

The following statements are excerpted from the "Executive Summary" of the ITR report.

"*Principal Assessment*

The review team concluded that: ***there is no scientific, regulatory, or operational imperative to perform the Bin or Alcove tests at WIPP with radioactive waste****. Other tests can and should be performed at WIPP and elsewhere to confirm information used for regulatory compliance demonstration and certification. This is an assessment of the technical justification for the tests, not of the ability of site personnel to perform the tests or of the repository to accept TRU waste.*

Path Forward Recommendation

Preparation and submission of compliance and permitting packages at the earliest possible date are the foundation of the recommended path forward. All other near term work elements should support these activities. All regulatory permits, approvals, and certification should be acquired before any in situ confirmatory or operational tests are performed in WIPP with radioactive waste.

A lack of clear guidance from cognizant regulators on specific requirements for regulatory compliance should be the only source of future delay in operating WIPP as a TRU waste repository. While most, although not all, of the relevant regulations exist, no clear statement of what constitutes acceptable submissions has been produced by the regulatory bodies....The ITR team believes that delay will be minimized by making the regulators part of the process through early submission of the regulatory packages.

Although all regulations do not exist and existing regulations may change, the ITR team believes that sufficient gas generation information is available to complete the performance assessments and other elements required to prepare and submit compliance and permitting packages within 18 months. The recommended conceptual

compliance and permitting process will allow the TRU waste disposal phase to begin in three years if specified milestones are met...

Bench-scale laboratory tests using simulated and/or actual waste should be continued or completed, and additional tests initiated if required. Results of bench-scale tests will not only explain individual gas generation mechanisms but also the synergistic effects of combined mechanisms....

..... These tests can be performed above ground, at WIPP or elsewhere, unencumbered by mine safety regulations.."

As recommended by the ITR, the bin and alcove tests were subsequently abandoned and the WIPP program was redirected to completing the regulatory compliance documentation on an accelerated schedule. Bench-scale laboratory tests using actual TRU wastes are being conducted at LANL and the INEL.

9.4.14 Performance Assessment Reviews

In 1989, SNL prepared a performance assessment methodology report (Marietta et al. 1989) which provided information on the performance assessment process that was being developed to demonstrate compliance with criteria under development for 40 CFR Part 191, Subpart B. Formal comments on the methodology report were provided to the DOE by the EPA and the New Mexico Environment Department (NMED). The DOE responses to the comments were subsequently provided in the 1990 Performance Assessment report.

The DOE, through SNL, published iterative performance assessment reports describing the WIPP disposal system beginning with the first performance assessment report in 1990 (Bertram-Howery et al. 1990), followed by subsequent iterations in 1991 and 1992. Each updated report constituted a substantial revision of the previous document based on new information, experiments and comments from interested individuals. With regard to comments from interested parties, a number of these reviews could be classified as peer reviews for the purposes of this application. An evaluation of these reviews against the screening criteria for peer reviews is provided in Table 9-21.

This section is grouped into four divisions: Section 9.4.14.1 addresses the review of the 1990 Performance Assessment report; Section 9.4.14.2 addresses 1991 Performance Assessment report reviews; Section 9.4.14.3 addresses reviews of the 1992 Performance Assessment report: and Section 9.4.14.4 summarizes the DOE's responses to the comments provided to the DOE as a result of those reviews. Only comments from the EPA, the New Mexico State Attorney General (AG), the NMED, and Intera, Inc. are discussed in this section. Comments from groups such as the NAS and the EEG are addressed in Sections 9.4.1 and 9.4.10, respectively.

Table 9-21. External Review of the WIPP Performance Assessment Reports

1. Is the "peer review" relevant to the CCA?	Yes - The reviews specifically focused on the PA reports.
2. Was there a formal report prepared by the reviewer?	Yes - The reviews evaluated the adequacy of the WIPP PA reports.
3. Was the review a "peer review" rather than a "technical review"?	Yes - The reviews addressed the adequacy of the PA reports.
a. A peer review's purpose is to confirm the adequacy of the work being reviewed.	
b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	
4. Was the review a "peer review" rather than an "expert judgment"?	Yes - The reviews were based on evaluations of the PA.
a. A peer review confirms the adequacy of the work being reviewed.	
b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - The reviewing organizations are recognized as experts in their respective disciplines.
6. Were the reviewers independent?	Yes - The reviewers were independent of the WIPP project.
a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed?	
b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	N/A

9.4.14.1 1990 Performance Assessment Report

The first performance assessment report (Bertram-Howery et al. 1990) was issued in December 1990. As noted above, the 1990 report provided responses to the EPA and NMED comments that had been received on the 1989 methodology document.

Several groups reviewed and commented on the 1990 report. In particular, several requests were made from the NMED and others for additional clarification of several aspects of the report. Specific responses to the comments provided by the various reviews were developed and subsequently documented in the 1991 Performance Assessment report.

9.4.14.2 1991 Performance Assessment Report

The second performance assessment report (WIPP Performance Assessment Division 1991) was issued in December 1991. The 1991 report included responses to comments that had been received from the reviews of the 1990 report.

Intera, Inc. was requested by the SNL WIPP Performance Assessment Division to review Volumes 1-4 of the 1991 WIPP Performance Assessment report (WIPP Performance Assessment Division 1991). Although the independence of the review could be questioned because it was contracted directly by the WIPP Performance Assessment Division, it is provided here for completeness; the results of the review were important in establishing the direction of performance assessment. The review's purpose, as stated in the Intera report (see Appendix PEER), was to consider

> *"technical questions pertaining to the performance assessment methodology and its application and results, as well as issues of organization, presentation and flow of information between the various sections, chapters and volumes."*

The review is contained in a March 1992 report (see Appendix PEER). The report summary states the following:

> *"Our major technical concerns are in the general area of treatment of uncertainty in the assessment, including in particular treatment of scenario uncertainty, data and parameter uncertainty, and model uncertainty...."*

> *"We have also suggested a possible modification to the methodology for generating CCDFs for human intrusion events, and have noted that the treatment of human intrusion, as a particular class of scenarios, is imbalanced in places..."*

> *"With regard to presentation and organization of the report, there is substantial room for improvement....In particular, the report is excessively long, and very much in need of a good summary of the order of 100 pages (or less). More attention needs to be paid*

to the relevance of the information presented to the final assessment results, and to the potential audience for the report. Excessive use of mathematics is made throughout the report, and figures are too few in number, are poorly explained or are too complex. In addition, relatively minor errors are rife, particularly in Volume 3."

The Intera comments were carefully considered by SNL during the preparation of the succeeding report. Accordingly, appropriate modifications were incorporated in the 1992 Performance Assessment report. Specific responses to the various third-party reviews were documented in the 1992 Performance Assessment report.

9.4.14.3 1992 Performance Assessment Report

The third performance assessment report (WIPP Performance Assessment Department 1992) was published in December of 1992. This report provided responses to comments that had been received on the 1991 Performance Assessment report. As with the earlier performance assessment reports, several groups reviewed, and provided comments on, the 1992 report. In particular, the EPA, the NMED, the EEG, and the AG provided comments to the DOE. Comments received from the EPA, NMED, and the AG are discussed below. Comments from the EEG are discussed in Section 9.4.10.13.

9.4.14.3.1 EPA Review of the 1992 Performance Assessment Report

The EPA's review of the 1992 iteration of performance assessment was provided in two separate transmittals. The first group of review comments addressed only Volumes 1 through 3. The second set of comments primarily addressed Volumes 4 and 5.

Review of Volumes 1 through 3

In January 1994, the EPA provided extensive comments on Volumes 1 through 3 of the 1992 iteration of the performance assessment. The EPA grouped its discussion of the issues into six primary categories: (1) format and content; (2) access to information; (3) regulatory issues; (4) use of expert panel elicitation and investigator judgement; (5) models; and (6) QA. The EPA comments and the DOE responses for each comment are provided in Appendix PEER.

Volumes 4 and 5

In October of 1994, the EPA provided final comments to the DOE on the 1992 iteration of performance assessment. Although the comments addressed the entire performance assessment, the primary focus was Volumes 4 and 5. The EPA grouped its comments into five primary categories: (1) scenarios, (2) BRAGFLO and SANCHO computer code relationships, (3) Culebra groundwater modeling, (4) inventory, and (5) institutional controls. The EPA comments and the DOE responses for each comment are provided in Appendix PEER.

9.4.14.3.2 New Mexico Attorney General Review of the 1992 Performance Assessment Report

The New Mexico Attorney General also provided comments on the 1992 Performance Assessment report. These comments are provided in Appendix PEER, together with the DOE responses.

As part of his review, the Attorney General contracted with Dr. Elisabeth Paté-Cornell. Dr. Paté-Cornell is a Professor of Industrial Engineering and Engineering Management at Stanford University and is currently president of the Society for Risk Analysis. She has written and lectured extensively on probabilistic risk assessment and has testified in Congress on proposed legislation on the subject. Dr. Paté-Cornell prepared a report for the Attorney General, entitled "Conservatism of the Performance Assessment and Decision Criteria for WIPP." The comments are provided in Appendix PEER with a cover letter documenting its transmittal from the AG to the DOE.

9.4.14.3.3 NMED Review of the 1992 Performance Assessment Report

The NMED also provided comments on the 1992 Performance Assessment report. The comments are provided in Appendix PEER together with the DOE responses. The NMED's comments were detailed but focused upon several issues relevant to screening scenarios and events for performance assessment. Within this context the NMED provided detailed comments on three primary issues:

- additional groundwater migration pathways: the Dewey Lake (Redbeds) Formations and Magenta Member of the Rustler;
- subsidence potential related to dissolution of evaporite units caused by downward percolation of meteoric or groundwater through inner or outer zones of boreholes; and,
- subsidence potential related to extraction of oil and gas adjacent to the facility boundary.

9.4.14.4 DOE Response to Comments on the 1990, 1991, and 1992 Performance Assessment Reports

In summary, the DOE responded to comments from interested groups and individuals by revision of subsequent performance assessment reports and by providing specific responses to those comments in the subsequent reports. Chapter 6.0 is the result of many years of work on performance assessment activities by the DOE. Performance assessment has undergone extensive revision as a result of input from groups such as the EPA, the NMED, the EEG, and the Attorney General.

9.4.15 Technical Support Group Reviews

During 1993, the Technical Support Group (TSG) was tasked by the DOE to provide recommendations on the following topics:

- Experimental Plan for Tracer Testing in the Culebra Dolomite
- Performance Assessment Parameters
- Large-Scale Seals Test Program.

Evaluation of the resulting reviews against the screening criteria developed for this application indicated that the first two appear to qualify as peer reviews (see Table 9-22). As regards the large-scale seals test program, it was determined that the review team was mostly comprised of subcontractors with a long working relationship with the WIPP project. The reviewers' independence could also be questioned for the other two reviews; however, the case for the review's independence was stronger. These reviews are included in this application for the sake of completeness and because they were significant in terms of the performance assessment program. The reports were provided to the appropriate recent peer review panels for consideration. A brief discussion of the selected reviews is presented below.

The members of the review teams included expertise in geochemistry, geomechanics, hydrology, physical chemistry, NEPA compliance, performance assessment, and waste management. The members involved in the reviews included the following:

Paul Drez (TSG Core Member), Independent Consultant
Paul Cloke, Science Applications International Corporation - Nevada
David Dennison, Advanced Sciences, Inc. - Denver
Darrel Dunn, Advanced Sciences, Inc. - Denver
John Kircher, Battelle
David Lechel, Independent Consultant
John Schatz, Independent Consultant
Jim Tollison, Independent Consultant
Rose Zeiler, Advanced Sciences, Inc. - Denver

9.4.15.1 Review of Experimental Plan for Tracer Testing in the Culebra Dolomite

The review team was asked to address whether additional experiments for fluid flow and transport characterization of the Culebra are necessary. Additionally, if these experiments were determined to be necessary, the team was asked to evaluate whether the planned Culebra Tracer Tests, as described in the proposed Test Plan, would provide the data necessary to establish whether the Culebra retards radionuclide transport sufficiently to demonstrate that the Culebra is an effective geologic barrier.

Table 9-22. Technical Support Group Reviews

1. Is the "peer review" relevant to the CCA?	Yes - The reviews involved aspects of site characterization and PA.
2. Was there a formal report prepared by the reviewer?	Yes - Reports were prepared.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - The reviews addressed the adequacy of WIPP plans and programs.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Yes - The reports addressed the adequacy of work prepared by the WIPP project.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Yes - The reviewers are recognized experts in their respective disciplines.
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	Partially - Although several of the reviewers were independent, some of the TSG members involved in the reports discussed in this section routinely participated in the WIPP Project over a period of several years as subcontractors to the DOE.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	Yes - The reports were significant in terms of their impact on the WIPP performance assessment program. The reports were also provided to the recent peer review panels.

The formal report that was prepared by the team as a result of the review is provided in Appendix PEER, together with the transmittal letter to the DOE.

The recommendations from the TSG report on tracer testing in the Culebra dolomite were considered in the planning of ongoing hydrological studies and testing performed at the WIPP site. In addition, the review resulted in enhanced communication between the Principal Investigators generating data and the performance assessment staff. The TSG report was provided to the recent conceptual models peer review panel for its consideration.

9.4.15.2 Performance Assessment Parameters

A copy of the report that resulted from the TSG review of the performance assessment parameters is provided in Appendix PEER. The purpose of the TSG review, as stated in the transmittal letter to the DOE, was to

> *"conduct a detailed review of many of the parameters that form the basis for the PA calculations for the WIPP Project. This effort emphasized the key 49 PA parameters that were sampled in the 1992 PA calculations, and, as time permitted, included a preliminary review of an additional 80 parameters. Data type, data quality, data interpretation, and source documentation were evaluated and each reviewer categorized the data based on their professional judgment. A database called PERFORM was developed to help in the management of the reviews."*

From the report's "Summary of Findings," the team concluded that

> *"Results of the TSG review of PA parameters indicate that improvement is needed in areas of Data Quality, Data Interpretation, and Source Documentation. It is the opinion of the TSG that this needs to be accomplished to ensure regulatory compliance.*

IRTs were subsequently formed to specifically review, and qualify where appropriate, existing data. As discussed in Chapter 5.0, the IRTs were successful in qualifying a large amount of the data that had been collected prior to establishment of a qualified QA program. Data which were not qualified by the IRTs were qualified by three of the recent peer review panels, as discussed in Sections 9.3.4, 9.3.5, and 9.3.6.

Performance assessment parameter values were developed and controlled in accordance with the SNL QAPD and QAPs. QAP 9-2 was developed and used to document the selection, development, and entry of parameter values used in the performance assessment. The performance assessment database is controlled and maintained using SNL QAP 9-4. This QAP establishes the process for ensuring that parameter values and their associated documentation are maintained in a traceable, retrievable, and controlled environment and allow for the reproducibility of results.

Once the requirements controlling the development of parameter values (QAP 9-1 or QAP 9-5) are fulfilled, the parameter/distribution development is documented or referenced on the applicable WIPP Parameter Entry Form (Form 464). Form 464 provides a traceable link to the qualification of those portions of the data packages that support the parameter development.

9.4.16 NEPA Reviews

The NEPA requires formal analysis, documentation and an appropriate level of review for proposed major federal actions involving potentially significant environmental impacts. NEPA documentation and the associated public review and comment periods have provided environmental input and opposing viewpoints from a variety of sources for the DOE decisions regarding development of the WIPP. An evaluation of the external NEPA reviews against the screening criteria is provided in Table 9-23.

NEPA documentation of the WIPP includes the 1980 FEIS (DOE 1980a) and the 1990 FSEIS (DOE 1990a). Another environmental impact statement, the Disposal Phase Supplemental Environmental Impact Statement (SEIS-II) is currently in preparation.

A Draft Environmental Impact Statement (DEIS) (DOE 1979) was prepared by the DOE and provided to the public for review in April 1979. The significance of impacts associated with the various alternatives were assessed. Comments on the DEIS were obtained during seven days of public hearings and a 141-day written-comment period. A total of 167 persons presented oral statements on the WIPP during the public hearings that were held in Santa Fe, Carlsbad, and Hobbs, New Mexico; Idaho Falls, Idaho; and, Odessa, Texas. Ninety-three letters, several longer than 50 pages, were received during the written-comments period. Commenters included: federal agencies such as the EPA, the NRC, the Department of the Interior, and the Department of Health, Education and Welfare; agencies from at least 26 states, including several New Mexico agencies; and, groups such as the EEG.

In response to the comments, the DEIS was extensively revised to prepare the FEIS, which was published in October 1980. Comments were grouped into 30 major issues, which were then discussed in Chapter 15 of the FEIS. Appendix P of the FEIS reproduced in full the comments received from various federal agencies and the cover letters from all official responses from the various states. Copies of all comments received, including transcripts of the public hearings, were placed in the DOE public reading rooms for WIPP. The DOE Record of Decision, published January 28, 1981, announced the DOE decision to proceed with the construction of surface and subsurface facilities in southeastern New Mexico.

Table 9-23. NEPA Documentation Reviews

1. Is the "peer review" relevant to the CCA?	Yes - NEPA documentation addresses long term performance, siting issues, mitigation, etc. which are directly CCA relevant.
2. Was there a formal report prepared by the reviewer?	Yes - The results of the public reviews were submitted to the DOE. The DOE formally compiled comments and responses.
3. Was the review a "peer review" rather than a "technical review"? a. A peer review's purpose is to confirm the adequacy of the work being reviewed. b. A technical review verifies compliance to predetermined requirements; industry standards; or common scientific, engineering and industry practice.	Yes - The reviews focussed on the adequacy of NEPA documentation prepared for the DOE.
4. Was the review a "peer review" rather than an "expert judgment"? a. A peer review confirms the adequacy of the work being reviewed. b. An expert judgment is used to elicit either numerical values for parameters (variables) or essentially unknowable information.	Yes - The review evaluated the adequacy of environmental documentation produced for the DOE.
5. Was the technical expertise of the reviewer at least that needed to perform the original work?	Mixed - The technical expertise of the reviewers varied widely, but included several public agencies and oversight groups (e.g., NRC, EEG).
6. Were the reviewers independent? a. Were the reviewers involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed? b. Did the reviewers have sufficient freedom from funding considerations to assure the work was impartially reviewed?	Mostly - Very few of the reviewers had any affiliation with the WIPP or DOE.
7. If the answer to any of the above questions is no, is there an overriding consideration which would still serve to qualify the review as an appropriate and acceptable "peer review"?	Yes - The public comments on the WIPP NEPA documents have, in aggregate, provided an extensive and thorough review of many issues, several of which are relevant to the CCA.

A draft SEIS (DOE 1989) was published and provided to the public in April 1989. During the 90-day comment period, the DOE held nine public hearings at locations in Colorado, Georgia, Idaho, New Mexico, Oregon, Texas, and Utah. In addition to the testimony of nearly 1,000 individuals who spoke at the hearings, the DOE received 1,275 written documents and two petitions with a combined total of approximately 2,200 signatures.

The DOE reviewed the comments, categorized them by issue, revised the draft SEIS as appropriate, and prepared a comment-response document (Volume 3 of the FSEIS) that presents synopses of the comments and the DOE's responses. Indices to the comments were provided in Volumes 4 and 5 of the FSEIS and served to help locate specific questions or statements and the DOE response. Volumes 6 through 13 of the FSEIS reproduce the public comments received on the draft SEIS and transcripts of oral testimony provided during the public hearings. The draft SEIS was extensively revised, as a result of the comments, in development of the FSEIS, which was published in January 1990. The Record of Decision, dated June 22, 1990, documented the DOE determination to proceed with the phased development of the WIPP. The Record of Decision included a commitment to prepare SEIS-II before deciding whether to proceed with the WIPP disposal phase.

Preparation of the SEIS-II has been initiated. Public scoping activities have included

- publishing a Notice of Intent in the Federal Register on August 23, 1995 and a notice reopening the comment period, published on October 13, 1995,

- a public comment period from August 23, 1995 to October 16, 1995, and

- public scoping meetings held in Carlsbad, Albuquerque, and Santa Fe, New Mexico, in Boise, Idaho, and two meetings in Denver, Colorado.

The Implementation Plan (DOE 1996d), published in May 1996, documents the results of the scoping process and provides guidance for preparing SEIS-II. The public will have another opportunity to provide formal input and opposing viewpoints on the WIPP project during the SEIS-II development.

9.5 Current International Reviews

The WIPP project is participating in two ongoing peer review efforts by the international community. Both reviews involve performance assessment activities and are being managed by the Organization for Economic Cooperation and Development Nuclear Energy Agency (NEA). Participation in these international review activities allows WIPP to benefit from the experience of the world's leading experts in nuclear waste disposal and to take into account the approaches followed by other countries toward the safe disposal of radioactive waste.

9.5.1 NEA/International Atomic Energy Agency (IAEA) Review

Agreement was reached on June 7, 1996 between the DOE, the NEA and the IAEA to organize an international peer review of the long-term safety analysis of the WIPP. The objective of the joint NEA/IAEA peer review will be to examine whether the postclosure assessment of the WIPP described in this application is appropriate, technically sound and in conformity with international standards and practices.

The peer review will be organized jointly by the NEA and the IAEA and will be managed by the NEA. The agencies will appoint a group of independent international experts in the various disciplines involved in long-term safety assessments, such as geology, geochemistry, material sciences, radiation and environmental protection, and nuclear safety. This expert group, which will conduct the review, will include representatives from nuclear regulatory bodies, radioactive waste management agencies, universities and research institutions.

The review will begin in October 1996 and be conducted over a six-month period. The review will be based on detailed documentation provided by the DOE, a site visit to the WIPP, and discussions with the specialists in the WIPP project. A report containing the international expert group's findings will be developed during the review period.

9.5.2 GEOTRAP

GEOTRAP is an NEA project whose main objective is to build confidence in predictive modeling of radionuclide transport in geologic, heterogeneous media. The project focuses on the exchange of information and in-depth discussions on present approaches to acquiring and evaluating field data, testing, and developing adequate defensible models for performance assessment. The WIPP project's involvement in this project ensures the serious evaluation of its data collection and transport modeling efforts by experts from the international community.

A series of workshops will be held to promote the interaction and collaboration among scientists working in the relevant disciplines and the experts who are responsible for safety assessment studies and for site characterization and evaluation. Public status reports will review and summarize the lessons learned and put them into perspective.

The project is projected to run for a period of three years (starting August 1996). The following five workshops have been planned to date:

1. Field Tracer Transport Experiments: Design, Modeling, Interpretation, and Role in Predicting Radionuclide Transport;

2. Basis for Modeling the Effect of Spatial Variability on Radionuclide Migration;

3. The Characterization of Water Conducting Features and their Representation in Models of Radionuclide Migration;

4. Approaches to Confidence Building in Site-Specific Models of Radionuclide Migration for the Purposes of Performance Assessment; and,

5. Geological Evidence and Theoretical Bases for Radionuclide Retention Processes in Heterogeneous Media.

REFERENCES

Aldrich Chemical Co., Inc. 1994. *Aldrich Catalog Handbook of Fine Chemicals, 1994-1995.* Milwaukee, WI: Aldrich Chemical Co.

Al-Hussaini, M. 1981. "Tensile Properties of Compacted Soils," *Laboratory Shear Strength of Soil.* Eds. R.N. Yong and F.C. Townsend. ASTM Special Technical Publication No. 740. American Society for Testing and Materials, Philadelphia, PA. pp. 207 – 225.

Altman, W.D., Donnelly, J.P., and Kennedy, J.E. 1988. *Peer Review for High-Level Nuclear Waste Repositories Generic Technical Position.* NUREG-1297. Division of High-Level Nuclear Waste Management, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, DC.

Anderson, R., Vaughn, P.L., Stoelzel, D., and O'Brien, D. 1996. "Justification of Brine Pocket Volume Uncertainty." Memorandum to Margaret Chu, July 22, 1996. Sandia National Laboratories, Albuquerque, NM.

Bachman, G.O. 1985. *Assessment of Near-Surface Dissolution At and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND84-7178. Sandia National Laboratories, Albuquerque, NM. WPO 24609.

Bachman, G.O. 1987. *Karst in Evaporites in Southeastern New Mexico.* SAND86-7078. Sandia National Laboratories, Albuquerque, NM. WPO 24006.

Bates, R.L., and Jackson, J.A., eds. 1987. *Glossary of Geology.* 3rd ed. American Geological Institute, Alexandria, VA.

Beauheim, R.L. 1987a. *Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-2311. Sandia National Laboratories, Albuquerque, NM. WPO 28468.

Beauheim, R.L. 1987b. *Interpretations of Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987.* SAND87-0039. Sandia National Laboratories, Albuquerque, NM. WPO 27679.

Beauheim, R.L. 1989. *Interpretation of H-11b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site.* SAND89-0536. Sandia National Laboratories, Albuquerque, NM. WPO 24154.

Bechtel National, Inc. 1979-1980. *Waste Isolation Pilot Plant Title I Design Report.* Bechtel National Inc., San Francisco, CA. (This 32 volume set is on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM as UN00597.)

Berglund, J.W., and Lenke, L.R. 1995. "One Dimensional Experiments of Gas Induced Spall." NMERI 1995/3. Prepared for Sandia National Laboratories. New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, NM. WPO 27589.

Bertram-Howery, S.G., and Hunter, R.L., eds. 1989. *Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant.* SAND89-0178. Sandia National Laboratories, Albuquerque, NM. WPO 24103.

Bertram-Howery, S.G., and Swift, P.N. 1990. *Status Report: Potential for Long-Term Isolation by the Waste Isolation Pilot Plant Disposal System.* SAND90-0616. Sandia National Laboratories, Albuquerque, NM. WPO 23865.

Bethke, C.M. 1994. "The Geochemist's Workbench - Version 2.0 - A User's Guide to Rxn, Act2, Tact, React, Gtplot." Unpublished code. University of Illinois at Champaign-Urbana, Hydrogeology Program, Urbana, IL.

Borns, D.J. 1985. *Marker Bed 139: A Study of Drillcore From A Systematic Array.* SAND85-0023. Sandia National Laboratories, Albuquerque, NM. WPO 24529.

Borns, D.J. 1987. *Rates of Evaporite Deformation: The Role of Pressure Solution.* SAND85-1599. Sandia National Laboratories, Albuquerque, NM. WPO 27640.

Brausch, L.M., Kuhn, A.K., and Register, J.K. 1982. *Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME 3156. U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM. WPO 39094.

Brodsky, N.S. 1994. *Hydrostatic and Shear Consolidation Tests With Permeability Measurements on Waste Isolation Pilot Plant Crushed Salt.* SAND93-7058. Sandia National Laboratories, Albuquerque, NM. WPO 10087.

Brush, L.H. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266. Sandia National Laboratories, Albuquerque, NM. WPO 26015.

Brush, L.H. 1995. "Systems Prioritization Method - Iteration 2 Baseline Position Paper: Gas Generation in the Waste Isolation Pilot Plant." Sandia National Laboratories, Albuquerque, NM. WPO 28740.

Budavari, S., O'Neil, M.J., Smith, A., and Heckelman, P.E., eds. 1989. *The Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals*. 11th ed. Merck & Co., Rathway, NJ.

Budescu, D.V., and Wallsten, T.S. 1987. "Subjective Estimation of Precise and Vague Uncertainties," *Judgmental Forecasting*. Eds. G. Wright and P. Ayton. John Wiley & Sons, Chichester; New York. p. 63. WPO 39635.

Butcher, B.M. 1994. "A Model for Cuttings Release Waste Properties." Memorandum, January 6, 1994. Sandia National Laboratories, Albuquerque, NM.

Butcher, B.M., Thompson, T.W., VanBuskirk, R.G., and Patti, N.C. 1991. *Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste*. SAND90-1206. Sandia National Laboratories, Albuquerque, NM. WPO 23968.

Bynum, R.V. 1996. Memo to M.S. Tierney and C. Stockman. "Update of Uncertainty Range and Distribution for Actinide Solubilities to be Used in CCA NUTS Calculation." WPO 35835.

Callahan, G.D. 1993. "Further Discussion of the TRU Waste Model," *A Summary of the Models Used for the Mechanical Reponse of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B*. SAND92-0427. B.M. Butcher and F.T. Mendenhall. Sandia National Laboratories, Albuquerque, NM. pp. A-27 through A-30. In Appendix A of WPO 23356.

Chaturvedi, L., ed. 1987. *The Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler Formation as it Relates to the WIPP Project*. EEG-34. Environmental Evaluation Group, Santa Fe, NM.

Christ, C.L., and Hostetler, P.B. 1970. "Studies in the System MgO-SiO_2-CO_2-H_2O. II. Activity-Product Constant of Magnesite," *American Journal of Science*. Vol. 268, no. 4, pp. 439-453.

DOE (U.S. Department of Energy). 1979. *Draft Environmental Impact Statement Waste Isolation Pilot Plant*. DOE/EIS-0026-D. U.S. Department of Energy, Washington, D.C.

DOE (U.S. Department of Energy). 1980a. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE-EIS-0026. U.S. Department of Energy, Assistant Secretary for Defense Programs, Washington, D.C. WPO 38835, WPO 38838 – WPO 38839.

DOE (U.S. Department of Energy). 1980b. *WIPP SAR: Waste Isolation Pilot Plant Safety Analysis Report*. U.S. Department of Energy, Washington, D.C.

DOE (U.S. Department of Energy). 1989. *Draft Supplement Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-DS. U.S. Department of Energy, Washington, D.C.

DOE (U.S. Department of Energy). 1991. *Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force.* DOE/WIPP 91-007, Revision 0. Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U.S. Department of Energy). 1993. *Implementation of the Resource Disincentive in 40 CFR Part 191.14(e) at the Waste Isolation Pilot Plant.* DOE/WIPP 91-029, Revision 1.0. Westinghouse WID for the United States Department of Energy, Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995a. *Transuranic Waste Baseline Inventory Report (Revision 2).* DOE/CAO-95-1121. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995b. *Engineered Alternatives Cost/Benefit Study Final Report.* DOE/WIPP 95-2135 Revision 0. Albuquerque, NM: IT Corp.; United States Department of Energy, Waste Isolation Pilot Plant, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995c. *Waste Isolation Pilot Plant Safety Analysis Report.* DOE/WIPP-95-2065, Rev. 0. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM. NTIS Order #: DE9006847.

DOE (U.S. Department of Energy). 1995d. *Waste Isolation Pilot Plant Sealing System Design Report.* DOE/WIPP-95-3117. Waste Isolation Pilot Plant, Carlsbad, NM. WPO 29062.

DOE (U.S. Department of Energy). 1996a. *CAO Management Plan, Peer Review.* CAO-96-1187. Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1996b. "CAO Team Procedure." TP 10.5, Rev. 0. Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1996c. *Quality Assurance Program Document.* CAO-94-1012, Revision 1. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1996d. *Waste Isolation Pilot Plant Disposal Phase Supplemental Environmental Impact Statement: Implementation Plan.* DOE/EIS-0026-S-2-IP Rev. 0. United States Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1996e. *Transuranic Waste Baseline Inventory Report (Revision 3)*. DOE/CAO-95-1121. U.S. Department of Energy, Carlsbad, NM.

DOI (U.S. Department of the Interior). Bureau of Mines. 1976. *Mineral Facts and Problems, 1975 Edition*. U.S. Bureau of Mines Bulletin 667 (BUMINES-B-667). Bureau of Mines, Washington, D.C. Available from NTIS as PB-266 089/2.

Drez, P. 1991. "Preliminary Nonradionuclide Inventory of CH-TRU Waste," *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 3: Reference Data*. WIPP Performance Assessment Division. Eds. R.P. Rechard, A.C. Peterson, J.D. Schreiber, H.J. Iuzzolino, M.S. Tierney, and J.S. Sandha. SAND91-0893/3. Sandia National Laboratories, Albuquerque, NM. pp. A-43 through A-53. In Appendix A of WPO 26015.

Dunham, C.W. 1966. *The Theory of Reinforced Concrete*. 4th ed. McGraw-Hill, New York, NY. p. 36.

Earth Technology Corporation. 1988. *Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site*. SAND87-7144. The Earth Technology Corporation, Golden, CO; Sandia National Laboratories, Albuquerque, NM. WPO 25668.

EPA (U.S. Environmental Protection Agency). 1985. "40 CFR Part 191: Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register*. Vol. 50, no. 182, pp. 38066 – 38089. WPO 39132.

EPA (U.S. Environmental Protection Agency). 1993. "40 CFR Part 191: Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register*. Vol. 58, no. 242, pp. 66398 – 66416. WPO 39133.

EPA (U.S. Environmental Protection Agency). 1996a. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule," *Federal Register*. Vol. 61, no. 28, pp. 5224-5225.

EPA (U.S. Environmental Protection Agency). 1996b. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations: Background Information Document for 40 CFR Part 194*. EPA 402-R-96-002. U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1996c. *Compliance Application Guidance for 40 CFR Part 194*. EPA 402-R-95-014. United States Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C. WPO 39159.

Felmy, A.R., and Weare, J.H. 1986. "The Prediction of Borate Mineral Equilibria in Natural Waters: Application to Searles Lake, California," *Geochimica et Cosmochimica Acta*. Vol. 50, no. 12, pp. 2771 – 2783. WPO 30421.

Finley, R.E. 1996. "Tensile Strength of Consolidated Crushed Salt." Memorandum to D.R. Anderson and M.S.Y. Chu, May 3, 1996. Sandia National Laboratories, Albuquerque, NM.

Friend, D.G., and Huber, M.L. 1994. "Thermophysical Property Standard Reference Data from NIST," *International Journal of Thermophysics*. Vol. 15, no. 6, pp. 1279-1288.

Gonzalez, D.D. 1983. *Groundwater Flow in the Rustler Formation, Waste Isolation Pilot Plant (WIPP), Southeast New Mexico (SENM): Interim Report)*. SAND82-1012. Sandia National Laboratories, Albuquerque, NM. WPO 27528.

Graf, D.L., Eardley, A.J., and Shimp, S.F. 1961. "A Preliminary Report on Magnesium Carbonate in Glacial Lake Bonneville," *Journal of Geology*. Vol. 69, no. 2, pp. 219-223.

Hansen, F.D. 1996. "Review Plan, Shaft Seal System Design for the Waste Isolation Pilot Plant." Sandia National Laboratories, Albuquerque, NM. Attachment in WPO 36546.

Hansen, F.D., and Ahrens, E.H. 1996. "Large-Scale Dynamic Compaction of Natural Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Canada, June 17-18, 1996*. SAND96-0792C. Sandia National Laboratories, Albuquerque, NM. WPO 39544.

Harvie, C.E., Møller, N., and Weare, J.H. 1980. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-SO_4-H_2O System from Zero to High Concentration at 25°C," *Geochimica et Cosmochimica Acta*. Vol. 44, no. 7, pp. 981-999. WPO 30423.

Harvie, C.E., Møller, N., and Weare, J.H. 1984. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O System to High Ionic Strengths at 25°C," *Geochimica et Cosmochimica Acta*. Vol. 48, no. 4, pp. 723-751. WPO 30422.

Haug, A., Kelley, V.A., LaVenue, A.M., and Pickens, J.F. 1987. *Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report*. SAND86-7167. Sandia National Laboratories, Albuquerque, NM. WPO 28486.

Holcomb, D.J., and Shields, M. 1987. *Hydrostatic Creep Consolidation of Crushed Salt with Added Water*. SAND87-1990. Sandia National Laboratories, Albuquerque, NM. WPO 26778.

Holt, R.M., and Powers, D.W. 1984. *Geotechnical Activities in the Waste Handling Shaft, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico*. WTSD-TME 038. U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad, NM.

Holt, R., and Powers, D. 1987. "Rustler Formation in the Waste Handling and Exhaust Shafts, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico," *The Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler Formation as it Relates to the WIPP Project*. EEG-34. Environmental Evaluation Group, Santa Fe, NM.

Holt, R., and Powers, D. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico*. DOE/WIPP 88-004. Westinghouse Electric Corporation, Carlsbad, NM.

Hunter, R.L. 1985. *A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area*. SAND84-2233. Sandia National Laboratories, Albuquerque, NM. WPO 27628.

Jaeger, J.C., and Cook, N.G.W. 1976. *Fundamentals of Rock Mechanics*. 2nd ed. Chapman and Hall, London; Halsted Press, New York, NY.

Jones, T.L., Kelley, V.A., Pickens, J.F., Upton, D.T., Beauheim, R.L., and Davies, P.B. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site*. SAND92-1579. Sandia National Laboratories, Albuquerque, NM. WPO 23504.

Kelley, V.A., and Pickens, J.F. 1986. *Interpretation of the Convergent-Flow Tracer Tests Conducted in the Culebra Dolomite at the H-3 and H-4 Hydropads at the Waste Isolation Pilot Plant (WIPP) Site*. SAND86-7161. Sandia National Laboratories, Albuquerque, NM. WPO 27674.

Labreche, D.A., Callahan, G.D., DeVries, K.L., and Osnes, J.D. 1993. *Comparison of Two Geomechanical Analysis Codes for WIPP Disposal Room Modeling: Sancho and Spectrom-12*. Topical Report RSI-0461. Albuquerque, NM; RE/SPEC Inc., Rapid City, SD. WPO 36821.

Lambert, S.J. 1983. *Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas*. SAND82-0461. Sandia National Laboratories, Albuquerque, NM. WPO 27520.

Lambert, S.J. 1987. *Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and Other Nuclides to the Groundwater Hydrology of the Rustler Formation, Southeastern New Mexico*. SAND86-1054. Sandia National Laboratories, Albuquerque, NM. WPO 24475.

Lambert, S.J., and Carter, J.A. 1984. *Uranium-Isotope Disequilibrium in Brine Reservoirs of the Castile Formation, Northern Delaware Basin, Southeastern New Mexico. I: Principles and Methods*. SAND83-0144. Sandia National Laboratories, Albuquerque, NM. WPO 28341.

Lambert, S.J., and Carter, J.A. 1987. *Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico. I: Principles and Preliminary Results*. SAND87-0388. Sandia National Laboratories, Albuquerque, NM. WPO 24453.

Lambert, S.J., and Harvey, D.M. 1987. *Stable-Isotope Geochemistry of Groundwaters in the Delaware Basin of Southeastern New Mexico*. SAND87-0138. Sandia National Laboratories, Albuquerque, NM. WPO 24150.

Lappin, A.R. 1988. *Summary of Site-Characterization Studies Conducted From 1983 Through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico*. SAND88-0157. Sandia National Laboratories, Albuquerque, NM. WPO 24945.

Lappin, A.R., Hunter, R.L., Garber, D.P., and Davies, P.B., eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989*. SAND89-0462. Sandia National Laboratories, Albuquerque, NM. WPO 24125.

LaVenue, A.M., Haug, A., and Kelley, V.A. 1988. *Numerical Simulation of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant WIPP Site: Second Interim Report*. SAND88-7002. Sandia National Laboratories, Albuquerque, NM. WPO 28558.

Lenke, L.R., Berglund, J.W., and Cole, R.A. 1996. "Blowout Experiments Using Fine Grained Silica Sands in an Axisymmetric Geometry." NMERI 1996/7/32250. New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, NM.

Marietta, M.G., Bertram-Howery, S.G., Anderson, D.R., Brinster, K.F., Guzowski, R.V., Iuzzolino, H., and Rechard, R.P. 1989. *Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant*. SAND89-2027. Sandia National Laboratories, Albuquerque, NM. WPO 25952.

Martell, A.E., and Smith, R.M. 1977. *Critical Stability Constants. Vol. 3: Other Organic Ligands*. Plenum Publishing Corp, New York, NY.

Matalucci, R.V. 1982. *Simulated-Waste Experiments Planned for the Waste Isolation Pilot Plant (WIPP)*. SAND82-0547. Sandia National Laboratories, Albuquerque, NM. WPO 24689.

Mavor, M.J., and Logan, T.L. 1994. "Recent Advances in Coal Gas-Well Openhole Well Completion Technology," *JPT, Journal of Petroleum Technology*. Vol. 46, no. 7, pp. 587 – 593.

Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area, Southeastern New Mexico*. Water Resources Investigations Report 83-4016. U.S. Geological Society, Albuquerque, NM. (This document is included as Appendix HYDRO).

Molecke, M.A. 1979. *Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation*. SAND79-1245. Sandia National Laboratories, Albuquerque, NM. WPO 26715.

NIST (National Institute of Standards and Technology). 1995. *NIST Standard Reference Materials Catalog, 1995-1996*. Standards Reference Materials Program, National Institute of Standards and Technology, Washington, D.C.

Novak, C.F. 1995. "The Waste Isolation Pilot Plant (WIPP) Actinide Source Term: Test Plan for the Conceptual Model and the Dissolved Concentration Submodel." SAND95-1895 (September 21, 1995 revision). Sandia National Laboratories, Albuquerque, NM. WPO 27860.

Novak, C.F., Moore, R.C., and Vann Bynum, R. 1996. "Prediction of Dissolved Concentrations for $^{+}$III, $^{+}$IV, $^{+}$V, and $^{+}$VI Actinides in Salado and Castile Brine." Memorandum. Sandia National Laboratories, Albuquerque, NM.

Papenguth, H.W., and Behl, Y.K. 1996. *Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant*. TP 96-01. Sandia National Laboratories, Albuquerque, NM. WPO 31337.

Perry, R.H., and Chilton, C.H. 1993. *Chemical Engineers' Handbook*. 5th ed. McGraw-Hill Book Company, New York, NY.

Peterson, M.N.A., von der Borch, C.C., and Bien, G.S. 1966. "Growth of Dolomite Crystals," *American Journal of Science*. Vol. 264, no. 4, pp. 257 – 272.

Pfeifle, T.W., Hansen, F.D., and Knowles, M.K. 1996. "Salt-Saturated Concrete Strength and Permeability," *4th Materials Engineering Conference, ASCE Materials Engineering Division, Washington, DC, November 11-18, 1996.* Sandia National Laboratories, Albuquerque, NM.

Pitzer, K.S. 1991. "Ion Interaction Approach: Theory and Data," *Activity Coefficients in Electrolyte Solutions*. 2nd ed. Ed. K.S. Pitzer. CRC Press, Boca Raton, FL. pp. 75 – 154.

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME 3153. U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM. (Available from NTIS as DE86004341/XAB.)

Powers, D.W., Lambert, S.J., Shaffer, S-E., Hill, L.R., and Weart, W.D., eds. 1978. *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND78-1596. Sandia National Laboratories, Albuquerque, NM. Vols. 1-2. WPO 5448 (Volume 1); WPO 26829 – WPO 26930 (Volume 2).

Powers, D.W., Sigda, J.M., and Holt, R.M. 1996. "Probability of Encountering Pressurized Brine Under the WIPP." (This document is included in Appendix MASS).

Quality Assurance Department. 1995. "Verification of Design Adequacy." Waste Isolation Pilot Plant Quality Assurance Procedure QAP 3-2, Revision 1 (July 31, 1995). Sandia National Laboratories, Albuquerque, NM. Filed in records package WPO 37178.

Reeves, M., Kelley, V.A., and Pickens, J.F. 1987. *Regional Double-Porosity Solute Transport in the Culebra Dolomite: An Analysis of Parameter Sensitivity and Importance at the Wste Isolation Pilot Plant (WIPP) Site.* SAND87-7105. Sandia National Laboratories, Albuquerque, NM. WPO 25714.

Repository Isolation Systems Department. 1996. *Waste Isolation Pilot Plant Shaft Sealing System Compliance Submittal Design Report.* SAND96-1326. Sandia National Laboratories, Albuquerque, NM.

Sax, N.I., and Lewis, R.J. 1987. *Hawley's Condensed Chemical Dictionary.* 11th ed. Van Nostrand Reinhold, New York, NY.

Sayles, F.L., and Fyfe, W.S. 1973. "The Crystallization of Magnesite from Aqueous Solution," *Geochimica et Cosmochimica Acta.* Vol. 37, no. 1, pp. 87 – 99.

Snyder, R.P., Gard, L.M., Jr., and Mercer, J.W. 1982. *Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site,*

With Section on Drill-Stem Tests, WIPP 31. Open-File Report 82-968. U.S. Geological Survey for the U.S. Department of Energy, Albuquerque Operations Office, Denver, CO.

Stein, C.L. 1985. *Mineralogy in the Waste Isolation Pilot Plant (WIPP) Facility Stratigraphic Horizon*. SAND85-0321. Sandia National Laboratories, Albuquerque, NM. WPO 27631.

Streeter, V.L. 1958. *Fluid Mechanics*. 2nd ed. McGraw-Hill, New York, NY.

Stührenberg, D., and Zhang, C.L. 1995. "Results of Experiments on the Compaction and Permeability Behavior of Crushed Salt," *Fifth International Conference on Radioactive Waste Management and Environmental Remediation -- ICEM '95: Proceedings. Volume 1: Cross-Cutting Issues and Management of High-Level Waste and Environmental Remediation, Berlin, Germany, September 3-9, 1995*. Eds. S. Slate and F. Feizollahi. American Society of Mechanical Engineers, New York, NY. p 797 – 801. ISBN: 0-7918-1219-7.

Thompson, T.W., Coons, W.E., Krumhansl, J.L., and Hansen, F.D. 1996. "Inadvertent Intrusion Borehole Permeability. Final Report." Filed as an attachment to WPO 39622, WPO 39624 and WPO 39626.

Vaughn, P.L. 1996. "Impacts of Using Only H_2 on Repository Flow and Pressure." May 21, 1996. Sandia National Laboratories, Albuquerque, NM.

Von der Borch, C. 1965. "The Distribution and Preliminary Geochemistry of Modern Carbonate Sediments of the Coorong Area, South Australia," *Geochimica et Cosmochimica Acta*. Vol. 29, pp. 781 – 799.

Wang, Y. 1996a. "Define Chemical Conditions for FMT Actinide Solubility Calculations." Memorandum to Malcolm Siegel, May 18, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 37038.

Wang, Y. 1996b. "Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment." Memorandum to R.V. Bynum and L.H. Brush, July 19, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 39871.

Wang, Y., and Brush, L. 1996a. "Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance Assessment." Memorandum to M.S. Tierney, January 26, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 31943.

Wang, Y., and Brush, L.H. 1996b. "Modify the Stoichiometric Factor y in BRAGFLO to Include the Effect of MgO Added to WIPP Repository as Backfill." Memorandum to M.S. Tierney, February 23, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 32286.

Watkins, D. 1996. "Estimate of Cement Content in the TRU Solidified Waste Forms Scheduled for Disposal in WIPP." Memorandum to Les Shephard, April 4, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 37064.

Wawersik, W.R., and Stone, C.M. 1989. "A Characterization of Pressure Records in Inelastic Rock Demonstrated by Hydraulic Fracturing Measurements in Salt," *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*. Vol. 26, no. 6, pp. 613-627. (This document was also released as SAND87-2569J, which is filed in the SWCF as WPO 24523.)

Weatherby, J.R., Brown, W.T., and Butcher, B.M. 1991. "The Closure of WIPP Disposal Rooms Filled with Various Waste and Backfill Combinations," *Rock Mechanics as a Multidisciplinary Science, Proceedings of the 32nd U.S. Symposium on Rock Mechanics, Norman, OK, July 10-12, 1991*. Ed. J-C. Roegiers. A.A. Balkema, Brookfield, VT. pp 919-928. (This document was also released as SAND90-2399C, which is filed in the SWCF as WPO 28617.)

Weiner, R.F. 1996. "Dissolved Ligand Concentrations." Memorandum to C.F. Novak, March 27, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 36163.

WIPP PA (Performance Assessment). 1991-1992. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991*. SAND91-0893. Sandia National Laboratories, Albuquerque, NM. Vols. 1-4.

WIPP PA (Performance Assessment. 1992-1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992*. SAND92-0700. Sandia National Laboratories, Albuquerque, NM. Vols. 1-5.

Wolery, T.J. 1992. *EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0)*. UCRL-MA-110662, Pt. 3. Lawrence Livermore National Laboratory, Livermore, CA.

Wolery, T.J., and Daveler, S.A. 1992. *EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0)*. UCRL-MA-110662, Pt. 4. Lawrence Livermore National Laboratory, Livermore, CA.

Wood, B.J., Snow, R.E., Cosler, D.J., and Haji-Djafari, S. 1982. *Delaware Mountain Group (DMG) Hydrology - Salt Removal Potential, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico*. TME 3166. U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM.

BIBLIOGRAPHY

Brush, L.H., 1995. *Systems Prioritization Method - Iteration 2 Baseline Position Paper: Gas Generation in the Waste Isolation Pilot Plant.* Sandia National Laboratories, Albuquerque, NM.

Bertram-Howery, S.G., Marietta, M.G., Rechard, R.P., Swift, P.N., Anderson, D.R., Baker, B.L., Bean, J.E., Jr., Beyeler, W., Brinster, K.F., Guzowski, R.V., Helton, J.C., McCurley, R.D., Rudeen, D.K., Schreiber, J.D., and Vaughn, P. 1990. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990.* SAND90-2347. Sandia National Laboratories, Albuquerque, NM. WPO 27796.

DOE (U.S. Department of Energy). 1980. *Waste Isolation Pilot Plant Safety Analysis Report*, Washington, D.C.

DOE (U.S. Department of Energy). 1990. *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-FS. U.S. Department of Energy, Office of Environmental Restoration and Waste Management, Washington, D.C. Vols. 1-13.

DOE (U.S. Department of Energy). 1991. *Resource Conservation and Recovery Act Part B Permit Application*, February 1991, DOE/WIPP91-005. Prepared for the Department of Energy by Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Holt, R.M.S., and D.W. Powers. 1988. *Facies Variability in Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP 88-004. U.S. Department of Energy, Carlsbad, New Mexico. (This document is included as Appendix FAC).

Martell, A.E., and R.M. Smith. 1982. *Critical Stability Constants, Volume 5: Other Organic Ligands.* Plenum Press. New York, NY.

Mavor, M.J., and T.L. Logan. 1994. *Recent Advances in Coal Gas-Well Openhole Well Completion Technology.* JPT, July 1994, pp. 587-593.

Mercer, J.W. 1983. Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico. USGS Water Resources Investigation Report 83-4016. (This document is included as Appendix HYDRO).

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. *Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site.* March 31, 1995. New Mexico Bureau of Mines and Mineral Resources for Westinghouse Electric Corporation, Socorro, NM. WPO 39149 – WPO 39150.

Quality Assurance Department. 1995. *Verification of Design Adequacy.* Quality Assurance Procedure (QAP) 3-2, Rev. 1, Sandia National Laboratories, Albuquerque, NM.

Wang, Y. 1996b. *Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment.* Unpublished memorandum to R. V. Bynum and L. H. Brush, July 19, 1996. Sandia National Laboratories, Albuquerque, NM.

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix AIC

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Active Institutional Controls

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ACRONYMS

CH	contact-handled
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
LWA	Land Withdrawal Act
RH	remote-handled
SWB	standard waste box
TRU	transuranic
WIPP	Waste Isolation Pilot Plant

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APPENDIX AIC

The containment requirements for a disposal system for transuranic (TRU) radioactive wastes are defined in Title 40 Code of Federal Regulations (CFR) § 191.13 (U.S. Environmental Protection Agency [EPA] 1993). 40 CFR § 191.14 is titled Assurance Requirements. With regard to the active institutional controls aspect of Assurance Requirements, 40 CFR § 191.14 states the following:

> To provide the confidence needed for long-term compliance with the requirements of §191.13, disposal of spent fuel or high-level or transuranic wastes shall be conducted in accordance with the following provisions... (a) Active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contribution from active institutional controls for more than 100 years after disposal...

40 CFR §191.12 states the following:

> Active institutional controls mean:
> 1) controlling access to a disposal site by any means other than passive institutional controls,
> 2) performing maintenance operations or remedial actions at a site,
> 3) controlling or cleaning up releases from a site, or
> 4) monitoring parameters related to disposal system performance.

Purpose: The purpose of this report is to describe the design of a system that the U.S. Department of Energy (DOE) intends to implement for compliance with the requirement to control access to the Waste Isolation Pilot Plant (WIPP) disposal site and implement maintenance and remedial actions pertaining to the site access controls. In addition, this report addresses the scheduling process for control of inspection, maintenance, and periodic reporting related to long-term monitoring. Long-term monitoring addresses the monitoring of disposal system performance, as required by 40 CFR § 191.14(b), and environmental monitoring, in accordance with the Consultation and Cooperation Agreement between the DOE and the state of New Mexico. A description of the long-term monitoring program is contained in Appendix MON of this application. The scheduling process will also address evaluation of testing activities related to the permanent marker system design contained within the passive institutional controls. A description of the passive institutional controls is contained in Appendix PIC of this application.

Implementation of active institutional controls at the WIPP will commence at disposal. 40 CFR § 191.02 defines disposal for waste in a mined geologic repository as occurring when all of the shafts to the repository are backfilled and sealed. The sealing of the shafts is also the point in time at which final facility closure is achieved, as defined in the hazardous waste facility permit application. Implementation of active institutional controls marks the transition from the operational limits imposed by Subpart A of 40 CFR Part 191 to the disposal limits of Subparts B and C of 40 CFR Part 191. The DOE intends to continue the imposition of active institutional controls until such time as it is determined that there are no

significant concerns to be addressed by continued implementation of the controls. The DOE will implement this system of active controls for a minimum of 100 years after disposal.

The WIPP Land Withdrawal Act (LWA) (U.S. Congress 1992), requires the development of a plan for WIPP decommissioning and a management plan for the withdrawal after decommissioning (LWA Section 13). The concepts for decommissioning activities, which include decontamination and site restoration, are described in Appendix D&D of this application. However, Appendix D&D is not meant to meet the LWA requirement for a final decommissioning plan. The LWA-required management plan and decommissioning plan will be available by October 1997.

The decontamination effort will be completed prior to sealing of the shafts to allow disposal of all derived waste (radioactive and/or hazardous waste derived from TRU/TRU-mixed waste received at the WIPP) into the repository. With the implementation of active institutional controls upon completion of sealing of the shafts, access control will be successful in preventing human intrusion into the repository and thus there will be no future inadvertent releases from the site and no application of the 40 CFR § 191.12 "controlling or cleaning up releases from a site" condition for active institutional controls. The DOE's restoration efforts will return the land disturbed by the WIPP activities to a stable ecological state that will assimilate with the surrounding undisturbed ecosystem. Necessary exceptions to returning the site to its full pre-WIPP condition include the construction associated with the permanent marker system (see Appendix PIC) and measurements associated with long-term monitoring (see Appendix MON). The Land Management Plan (see Appendix LMP) describes the management and use of the land withdrawal area after facility decommissioning.

Scope: The access controls description includes a means of controlling access to the site of the repository's surface footprint (the repository area projected to the surface) and maintenance, including corrective actions, for access control system components. Active control of access to the site will be exercised by the DOE or another federal government entity for as long as practicable or until such time as it is determined that there are no significant concerns to be addressed by continued imposition of the controls. In any event, active institutional controls will be in place for at least 100 years after final facility closure. Control of access will preclude the inadvertent intrusion into the disposed waste by deep drilling or mining for natural resources. This appendix also describes a process for scheduling activities related to the testing of elements of the permanent marker system and the scheduling of activities required to meet the needs of the long-term monitoring of the repository. Some of the activities supporting the monitoring programs will be initiated during the disposal phase to establish databases. These activities are planned to continue beyond disposal through the time after removal of the site structures and return of the land disturbed by the WIPP activities to a stable ecological state that will assimilate with the surrounding undisturbed ecosystem. Permanent marker testing and long-term monitoring requirements will be necessarily integrated with efforts toward returning the land to a stable ecological state.

Background: The WIPP was sited and designed as a research and development facility to demonstrate the safe disposal of radioactive wastes. The wastes are derived from DOE defense-related activities. Specifically, the mission of the WIPP project is to conduct research, demonstration, and siting studies relevant to the permanent disposal of TRU wastes. Some of these wastes will be contaminated with hazardous constituents, making them mixed wastes.

The LWA addresses the disposal phase of the WIPP project, the period following closure of the site, and the removal of the surface facilities. Other codified requirements addressing postclosure activities include

- 40 CFR § 264.117(a)(1), which requires that

  > Post-closure care for each hazardous waste management unit subject to the requirements of § 264.117 through 264.120 must begin after completion of closure of the unit and continue for 30 years after that date...

- 40 CFR § 264.601, which requires that

  > A miscellaneous unit must be...maintained and closed in a manner that will ensure protection of human health and the environment...

- and 40 CFR § 264.603, which requires that

  > A miscellaneous unit that is a disposal unit must be maintained in a manner that complies with § 264.601 during the postclosure care period.

The LWA set aside 10,240 acres (4,144 hectares) located in Eddy County, 26 miles (42 kilometers) east of Carlsbad, New Mexico, as the WIPP site. A 277-acre (112-hectare) portion within the 10,240 acres (4,144 hectares) is bounded by a barbed wire fence. This fenced area contains the surface facilities and the mined salt piles for the WIPP site. Figure AIC-1 is a cutaway illustrating the spatial relationship of the surface facilities and the underground repository. (See Chapter 3.0 of this application for a description of the WIPP site.)

Upon receipt of the necessary certifications and permits from the EPA and the New Mexico Environment Department, the DOE will begin disposal of contact-handled (CH) TRU waste in the WIPP. This activity is scheduled to begin in 1998, with subsequent emplacement of remote-handled (RH) TRU waste to begin at a later date. This waste emplacement and disposal phase will continue until the regulated capacity of the repository of 6,200,000 cubic feet (175,588 cubic meters) of TRU waste has been reached. For the purposes of this application, this is assumed to be 25 years. The waste will be shipped from 10 DOE facilities across the country in specially designed transportation containers certified by the Nuclear Regulatory Commission, TRUPACT-IIs for CH-TRU waste and shielded road casks for RH-TRU waste. The transportation routes from these facilities to the WIPP have been

predetermined. The CH-TRU waste will be packaged in 55-gallon (208-liter) steel drums and/or standard waste boxes (SWBs). An SWB is a steel container having a free volume of approximately 65 cubic feet (1.8 cubic meters). Figure AIC-2 shows the general arrangement of a seven-pack of drums and an SWB as received in the TRUPACT-II. The RH-TRU waste will be shipped in a shielded road cask containing a three-drum capacity canister.

Upon receipt and inspection of the waste containers in the waste handling building, the containers will be moved into the repository 2,150 feet (655 meters) below the surface. The containers will then be transported to a disposal room. (See Figure AIC-1 for room and panel arrangement.) The initial seven disposal rooms are in Panel 1. Panel 1 is the first of eight panels planned to be excavated. Special supports and ground control corrective actions have been implemented in Panel 1 to ensure its stability. Upon filling an entire panel, that panel will be closed to isolate it from the rest of the repository and the ventilation system. During the period of time it takes to fill a given panel, an additional panel will be excavated. Sequential excavation of Panels 2 through 8 will ensure that these individual panels remain stable during the entire time a panel is being filled with waste. Ground control maintenance and evaluation with appropriate corrective action will be required to ensure that Panels 9 and 10 (ventilation and access drifts in the repository) remain stable.

Decontamination of the WIPP facility will commence with a detailed radiation survey of the entire site. Radioactively contaminated areas and equipment will be evaluated and decontaminated in accordance with applicable requirements. Where decontamination efforts identify areas that are below radiological release criteria, as defined in the WIPP's *Radiological Control Manual* (Westinghouse Electric Corporation 1996), routine dismantling and salvaging practices will determine the disposition of the material or equipment involved. Material and equipment that do not meet radiological release criteria will be emplaced in the access entries (Panels 9 and/or 10). Upon completion of emplacement of the contaminated facility material, the entries will be closed and the repository shafts will be sealed. Final repository closure entails sealing the shafts leading to the repository. Figure AIC-3 illustrates the shaft sealing arrangement. Completion of waste disposal that includes shaft sealing will end disposal operations and initiate the period for implementation of active controls.

The DOE will remove the surface facilities and return the land disturbed by the WIPP activities to a stable ecological state that will assimilate with the surrounding undisturbed ecosystem. However, the ability to return the land to the pre-WIPP condition will be impacted by the following conditions:

- As part of the permanent marker system, the hot cell concrete structure, protected by a chain link fence, will remain as an artifact marking the WIPP site. The hot cell is a reinforced concrete structure measuring approximately 71 feet by 40 feet with 4.5-foot thick walls (21.6 meters by 12 meters with walls 1.4 meter thick). The hot cell foundation extends approximately 28 feet (8.5 meters) below grade and the roof is 61 feet (18.6 meters) above grade.

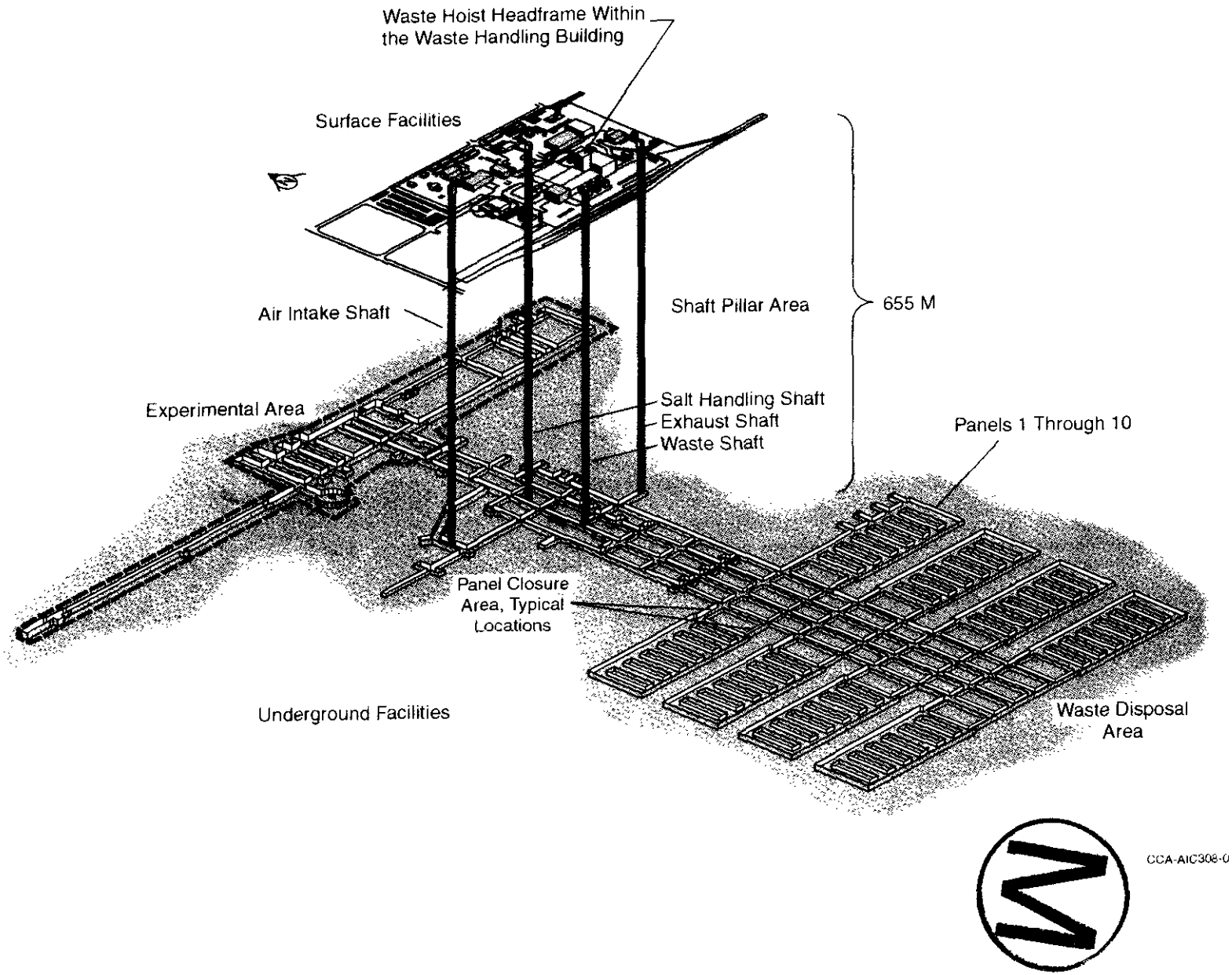

Figure AIC-1. Spatial View of WIPP Surface and Underground Facilities

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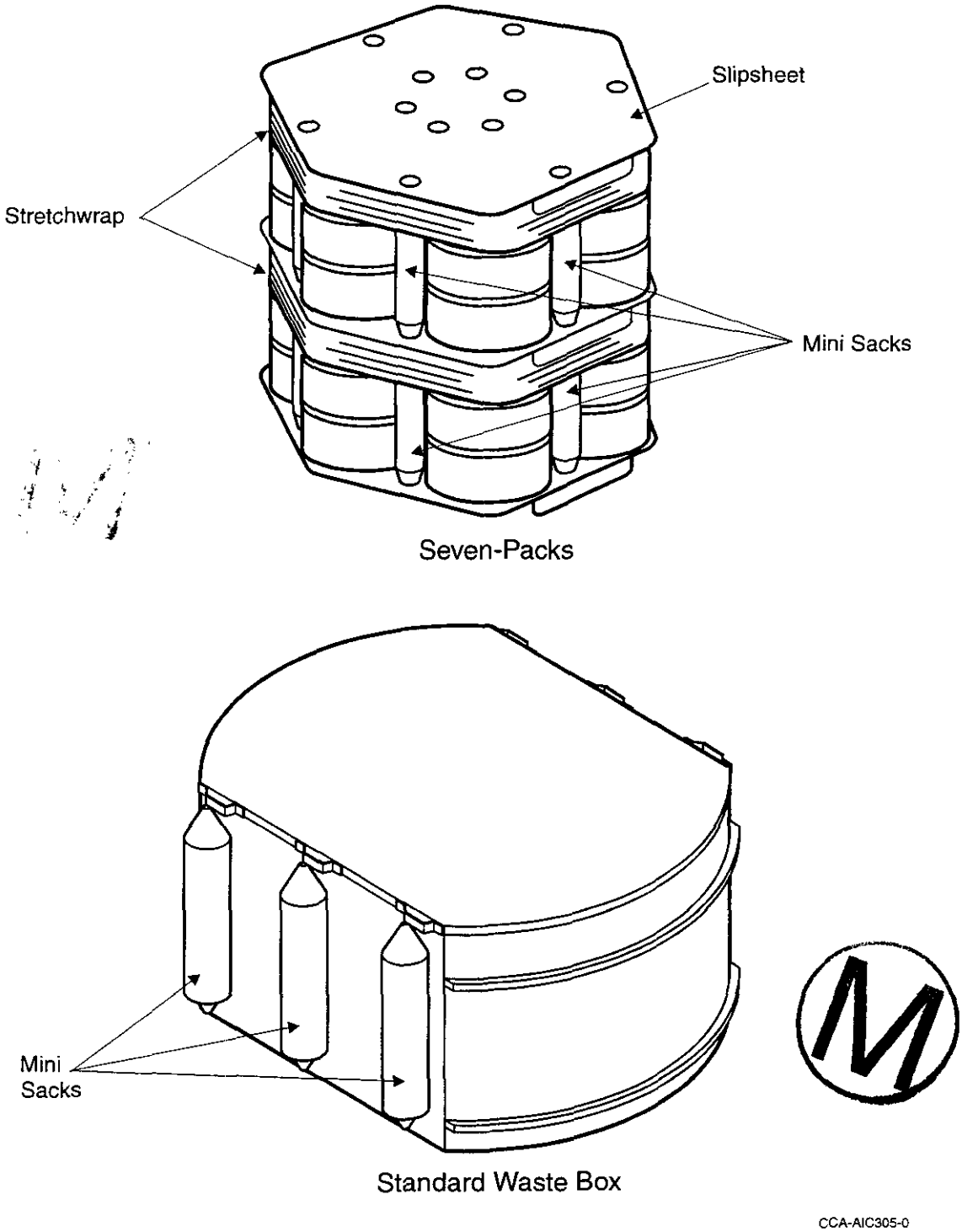

Figure AIC-2. Standard Waste Box and Seven-Pack Configuration

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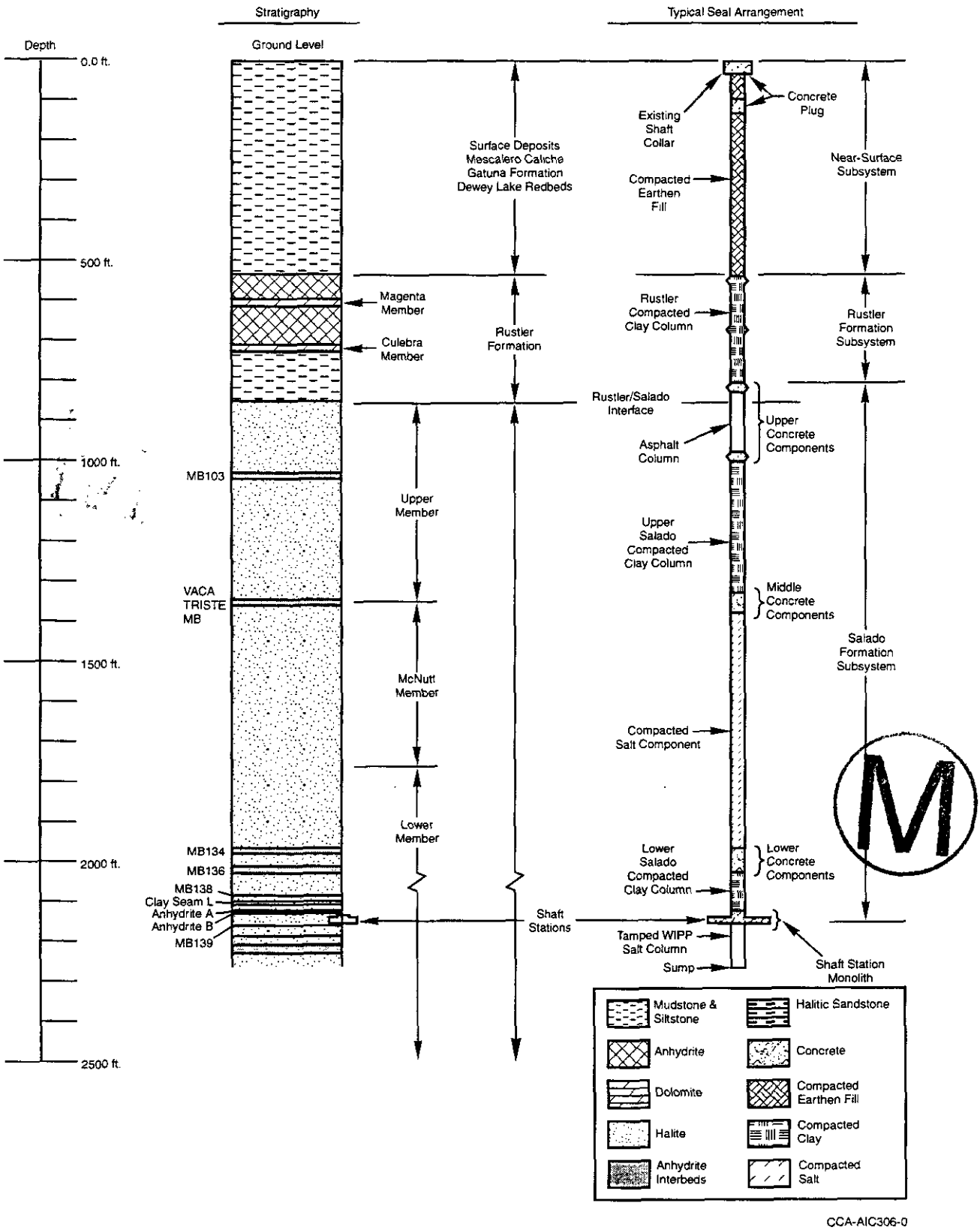

Figure AIC-3. Typical Shaft Sealing System

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- The test program supporting the permanent marker system will require the construction of a berm section, the erection of test monuments, and the emplacement of test markers, all of which impact the ability to return the land disturbed by the WIPP activities to a stable ecological state that will assimilate with the surrounding undisturbed ecosystem.

- A posted access barrier will be erected around the repository footprint, also affecting the return of the land disturbed by the WIPP activities to a stable ecological state.

- Elevation benchmarks to support the long-term monitoring program will be located within a grid network on the surface of the withdrawal area.

- A portion of the mined salt sufficient to support future construction of the berm component of the permanent marker system (see Appendix PIC) will remain on the surface.

- The water supply line to the site will be disconnected. At a future time, a water supply may have to be reestablished to support construction of the permanent marker system. This supply will also be disconnected when construction of the marker system is complete.

- The electrical supply to the site will be removed and isolated at the utility company's substation. Electricity will be required for the future construction of the permanent marker system.

Over the several decades following site restoration, activities supporting the long-term monitoring program and evaluation of the performance of the permanent marker system test program will require occasional access to the site surface area. Construction of the permanent marker system will be a significant effort that will again require the development of water, electrical, and transportation facilities at the site. Both railroad and trucking will be used to transport required materials to the site. This effort is scheduled to last several years.

Upon completion of the permanent marker system, the access control program for the site will be reevaluated and modified as required to address any changes necessitated by the effects of the permanent marker system. At the time that the permanent marker system construction effort is completed, the utilities and railroad spur supporting the site will be removed and the affected terrain returned to a stable ecological state that will assimilate with the surrounding undisturbed ecosystem.

AIC.1 Design Criteria

The access control design criteria applicable to the WIPP active institutional controls after disposal have been developed to meet the definition in 40 CFR § 191.12 for controlling access to the disposal site. In addition to active access controls, the criteria also address scheduling

processes to be implemented upon completion of shaft sealing activities. The decontamination, decommissioning, and restoration of the land is addressed in Appendix D&D of this application and will be described in detail in the *Plan for WIPP Decommissioning*. The *Passive Institutional Controls Conceptual Design Report* (Appendix PIC) addresses postdecommissioning testing activities conducted at the WIPP site. To a limited extent, the restoration of the land to its original condition will be impacted by the testing activities related to the permanent marker system and by the hot cell structure, which will not be removed but will remain as an artifact of the WIPP operating surface activity. The monitoring plan for the detection of substantial and detrimental deviations from expected performance of the disposal system is described in Appendix MON.

Although the LWA establishes a 10,240-acre (4,144-hectare) area for administrative control by the Secretary of Energy in conducting activities associated with the WIPP, the actual disposal area is only approximately 120 acres (48.5 hectares). Access is controlled to ensure that inadvertent intrusion into the disposal area does not occur. Deep or shallow drilling and mining activities are the scenarios requiring consideration as human intrusion events in performance assessment. Drilling techniques in the local area do not normally include slant drilling (see Appendix DEL). In those cases where slant drilling is used, deviation from vertical does not begin until a depth of approximately 4,000 feet (1,200 meters) is attained. This depth is well below the Salado Formation, which extends to approximately 2,800 feet (854 meters) below the surface in the vicinity of the repository. Salt formations do not typically support slant drilling because of the solubility and insufficient consolidation of the salt material (that is, its softness) (Rodriguez and Hughes 1994 and Rodriguez 1996, both in the Bibliography). These technical facts reasonably preclude slant drilling into the repository from outside the area immediately above the repository. In addition, as described in Appendix PIC, the withdrawal boundary is marked with warnings not to drill or conduct mining operations within the 16-square-mile (41-square-kilometer) controlled area. Therefore, it is reasonable not to extend a restrictive access control program to the entire 10,240 acres (4,144 hectares) with the accompanying cost increase and unnecessary resulting prohibition of such uses as grazing, hunting, and other public recreational activities.

The design features developed for the active access controls after disposal are the following:

1. A fence line will be established to control access to the repository footprint area on the surface. A standard four-strand (three barbed and one unbarbed, in accordance with the Bureau of Land Management specifications) wire fence will be erected along the perimeter of the repository surface footprint. To provide access to the repository footprint during construction of the berm (which may be built in multiple sections simultaneously), the fence will have gates placed approximately midway along each of the four sides. The western gate will be 20 feet (6 meters) wide. The remaining three gates will each be 16 feet (4.9 meters) wide. Additional fencing may be needed for remote locations that are used for disposal system monitoring. Such fences will meet the same construction specifications as the repository footprint perimeter fence.

2. Unpaved roadways 16 feet (4.9 meters) wide will be established along the perimeter of the barbed wire fence as well as along the WIPP site boundary. These roadways will be constructed so as to provide ready vehicle access to any point around the fenced perimeter and the site boundary. These roadways will facilitate inspection and maintenance of the fenceline and will allow visual observation of the repository footprint and the site boundary to the extent permitted by the lay of the land. These roadways will connect to the paved south access road. Roads to remote sites will also be constructed and maintained as needed.

3. The fence line will be posted with signs having, as a minimum a legend reading "Danger—Unauthorized Personnel Keep Out" (40 CFR § 264.14[c]) and warning against entering the area without specific permission of the federal government. The signs must be legible from a distance of at least 25 feet (7.6 meters). The size of the visual warning and the spacing of the warning signs will be sufficiently large and close to ensure that one or more of the signs can be seen from any approach prior to an individual actually making contact with the fence line. In no case will the spacing be greater than 300 feet (91.5 meters).

4. The federal government will ensure that periodic inspection and expedited corrective maintenance are conducted on the fence line, its associated warning signs, and the roadway.

5. The federal government will provide for routine periodic patrols and surveillance of the protected area by personnel trained in security surveillance and investigation.

6. A process will be implemented for monitoring and controlling the long-term testing requirements of the permanent marker system and implementing the periodic monitoring requirements of the long-term monitoring system.

7. The federal government will ensure that any necessary modifications to the active controls appropriate for access control and surveillance upon installation of the permanent marker system are provided.

8. The federal government will provide for actions to be taken to address abnormal conditions identified during periodic surveillance and inspections.

9. Reports addressing activities associated with the performance of the active access controls after disposal will be prepared periodically by the federal government for submittal to the appropriate regulatory and legislative authority.

The primary active attribute of access control consists of the routine surveillance patrols of the fence barrier and the repository footprint within that barrier. Periodic monitoring of the parameters associated with repository performance is a secondary active control feature. The

development of a schedule for these activities and implementation of that schedule serves as a tertiary active control. The details of the monitoring program are described in Appendix MON.

AIC.2 Access Controls

40 CFR § 191.12 defines active institutional controls to consist of four elements:

- controlling access to a disposal site by any means other than passive institutional controls,
- performing maintenance operations or remedial actions at a site,
- controlling or cleaning up releases from a site, and
- monitoring parameters related to disposal system performance.

The LWA has removed the WIPP site from public use as a site for mining and other types of mineral resource extraction. Since any type of exploration activity would require authorization, the issuance of approval to intrude upon the repository is precluded by the LWA. The existence of the LWA as law permits meeting the requirements of the first element above by implementing low technology barriers. These barriers include a posted fence and active surveillance at a frequency that denies sufficient time for an individual or organization to intrude into the repository undetected using today's drilling technology. As identified in the design criteria, maintenance and remedial actions at the WIPP site will be conducted by the federal government at the time of implementing the access controls for the site. Those maintenance operations and remedial actions associated with decommissioning and site restoration following final facility closure are discussed in Appendix D&D. The control or cleanup of releases from the site will be conducted as part of the operational program prior to sealing of the shafts. This is necessary to ensure that all radioactive derived waste is disposed of within the repository prior to shaft sealing. There is no credible scenario for the release of radioactive material during the active institutional controls period. Both preclosure and postclosure monitoring of disposal system performance are addressed in Appendix MON.

The federal government has the responsibility to maintain the access controls. Such responsibility includes the maintenance and corrective actions necessary to ensure that the fence and patrol requirements (surveillance) are met for as long as the federal government remains a viable controlling entity. Justification that such control will endure for at least 100 years is supported by the fact that the U.S. government has existed for over 200 years, and in that 200 years, its degree of control over activities affecting the common good has steadily increased. In addition, historical evidence supports that as the human population increases

and technology advances, the need to control the resulting complexities gives rise to society's acceptance of a governing system of laws, regulations, and oversight of activities affecting the common good.

AIC.2.1 Repository Footprint Fencing

Access to an area approximately 2,780 feet by 2,360 feet (875 meters by 720 meters) will be controlled by a four-strand barbed wire fence. A single gate will be included along each side of the fence for access. Around the perimeter of the fence, an unpaved roadway 16 feet (4.9 meters) wide will be cut to allow for patrolling of the perimeter. Figure AIC-4 is an illustration of the fence line in relation to the repository footprint. Patrolling of the perimeter is based upon the need to ensure that no mining or well drilling activity is inadvertently initiated that could threaten the integrity of the repository.

Fencing off an area larger than the disposal area footprint would not significantly reduce the risk of inadvertent intrusion but would interfere with cattle grazing established prior to the LWA. The LWA states that the Secretary of Energy can allow grazing to continue where it was established prior to enactment of the LWA. Based upon current drilling technologies, discussions with local well drilling organizations, and observation of well drilling activities in the WIPP vicinity, it typically requires at least two to three days for a driller to set up a deep drilling rig and commence actual drilling operations. Attaining the 2,150-foot (655-meter) depth that would approach the repository horizon takes at least another week to 10 days. Based upon current drilling practices (see Appendix DEL), patrolling the fenced area two to three times weekly would identify any potential drilling activity well before any breach of the repository could occur.

A scenario involving drilling at a location outside the disposal area surface footprint and inadvertently intruding into the disposal area is extremely unlikely. The most economical drilling practice is to drill vertically into the targeted formation. Local slant drilling is conducted only when the desired drill location is not available because of circumstances that the operator cannot overcome. When slant drilling practices are employed, the deviation from a vertical position directly below the drill rig does not commence until approximately 4,000 feet (1,200 meters) below the surface in the local area. Slant drilling within a salt formation is not practical because the salt is water soluble and insufficiently consolidated to support the technique for accurate control of the drill bit (Rodriguez 1996 in the Bibliography). According to the local office of the Bureau of Land Management, local operators and drillers, and oil field consultants, slant drilling in the local area does not begin until the drilling operator has reached a level below the evaporite formations. The lowest evaporite formation in the WIPP vicinity is the Castile Formation, which lies immediately below the Salado, which contains the WIPP repository.

Construction of access control systems using higher technology than described is not required or cost-effective. Likewise, continuous surveillance whether human or electronic is not required or practicable. The staffing levels required to achieve continuous human surveillance

become significant when weighed against the potential threat and alternatives for controlling access. Continuous electronic surveillance also has significant costs of procurement, installation, testing, and maintenance. Electronic systems would require significant maintenance, both operational and corrective, and probably would not relieve the need to make routine patrols to the site. This is especially true of alarmed electronic surveillance in a location populated by a variety of wild and domestic animals that might trigger numerous false alarms. Televised electronic surveillance that combines both human and electronic technology could be incorporated to deter inadvertent human intrusion; however, this method is extremely costly.

AIC.2.2 Surveillance Monitoring

The federal government (initially DOE and/or the Bureau of Land Management) will conduct periodic surveillance of the site and the repository footprint. Unpaved roadways around the WIPP site boundary and around the repository footprint will facilitate such surveillance. Contractual arrangements with a local organization such as the Eddy County Sheriff's Department would provide some distinct advantages. Among the advantages are the following:

- deputies are trained in patrol and surveillance activities,
- deputies are authorized to arrest members of the general public who are found to be violating trespassing laws,
- the liability associated with apprehension, attempted apprehension, or circumstances arising from attempts would remain with the Sheriff's Department, and
- the general area to be patrolled is already a part of the Sheriff's area of responsibility.

Surveillance will consist of drive-by patrolling around the fenced perimeter a minimum of two times per week. In the course of the patrol, particular note will be taken of the fence integrity. In addition, the locked condition of each gate will be checked to ensure that gate integrity is maintained and there is no evidence of tampering. Surveillance will also include visual observation of the entire enclosed area for any signs of human activity. Additionally, surveillance patrols will be conducted around the site boundary's perimeter for signs of unauthorized human activities. A routine summary of each month's surveillance activity will be prepared documenting the date and time of each patrol and any unusual circumstances that may have been observed. This surveillance routine will continue throughout the active controls period and for at least 100 years following the sealing of shafts.

Upon beginning construction of the permanent marker system, a routine presence at the site will once again be established and periodic surveillance will not be necessary. Once the permanent marker system is completed, the active controls program and access control measures will be reevaluated, and changes necessitated by construction of the permanent

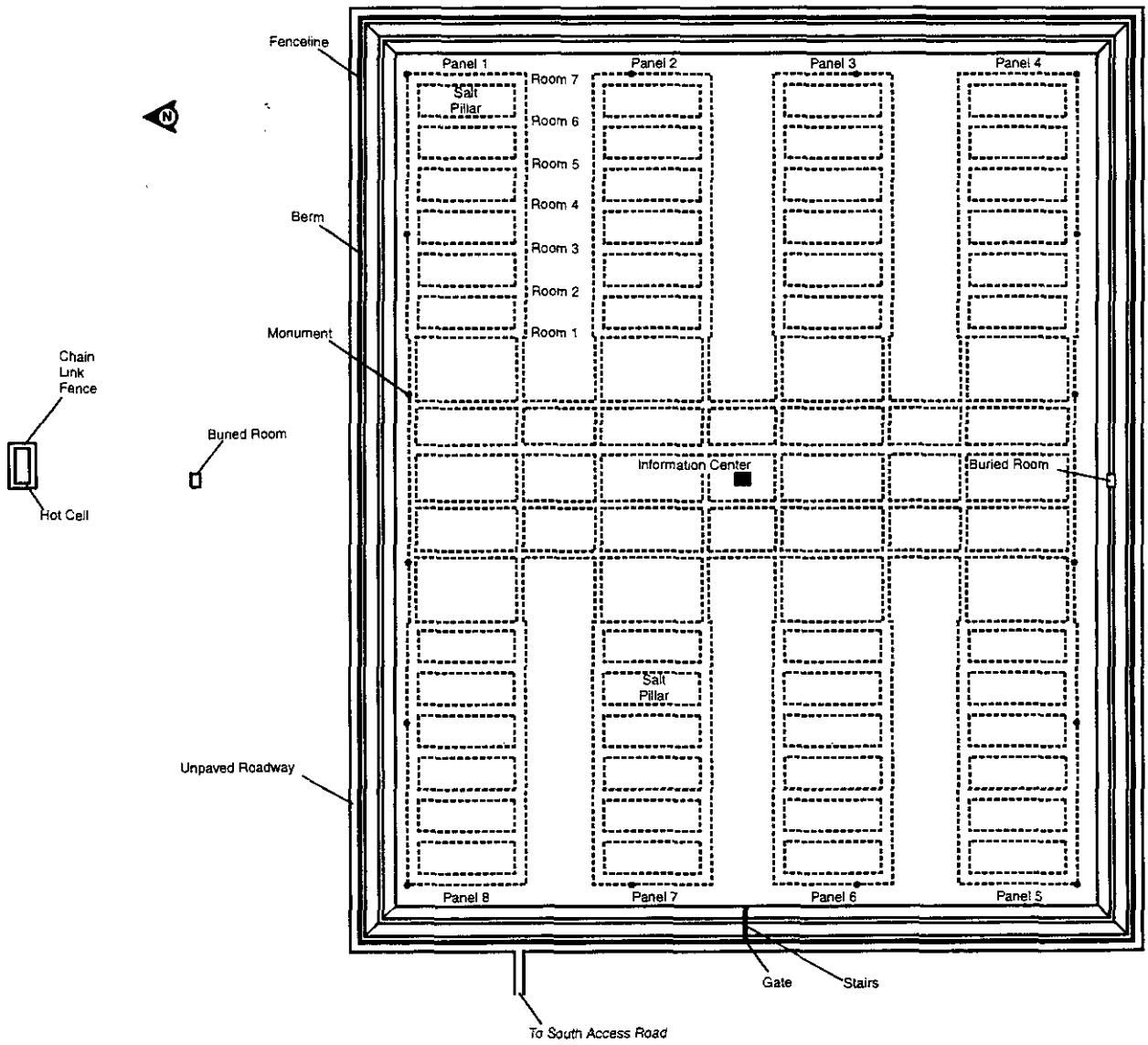

Figure AIC-4. Perimeter Fenceline and Roadway

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marker system will be made and implemented for the remainder of the active controls period. With construction of the permanent marker system, easy visual inspection will not be possible from the perimeter fence because the berm and monuments will restrict vision. However, this will not affect the ability of patrols to properly survey the repository footprint integrity. The berm profile and configuration would require an extensive dismantling effort to create an opening sufficient to permit entrance of drilling equipment. The routine patrols would detect this effort well before intrusion into the repository could occur.

AIC.2.3 Maintenance and Remedial Actions

Anticipated maintenance and remedial action issues during the active controls period are minimal and should encompass such issues as

- fence and road maintenance,
- correction of any damage that occurs due to vandalism,
- response to evidence of potential erection of drilling equipment, and
- response to unauthorized entry into prohibited areas.

The federal government (initially the DOE) will provide maintenance services when the need is identified during routine patrolling activity. Any observed vandalism or unauthorized entry will be investigated and action will be taken as the circumstances warrant.

AIC.2.4 Control and Clean-up of Releases

The *Plan for WIPP Decommissioning* (as required by the LWA) will describe how the DOE intends to decontaminate and dismantle the surface structures. The decontamination process and disposal of the derived radioactive waste will be completed prior to sealing the shafts and final facility closure. With the location of the WIPP repository at 2,150 feet (655 meters) below the surface and with panels closed and shafts sealed, the potential for releases of radioactive material following the sealing of the shafts is precluded. There will be no credible pathway for releases from the repository other than human intrusion. Routine patrols in accordance with access control requirements will preclude human intrusion into the repository.

AIC.2.5 Monitoring Disposal System Performance

Subsidence monitoring is one of three monitoring programs that are expected to be conducted throughout the active institutional controls period (see Appendix SMP). The other programs are groundwater surveillance and drilling practice observation (Appendices GWMP and DMP). If, upon analysis of monitoring data, disposal system performance deviates from what

is expected, other techniques also described in the long-term monitoring plan may be used to assist in acquiring more information regarding performance.

Performance assessment sensitivity analyses have identified important repository performance parameters (see Appendix MON). Those important parameters that lend themselves to current monitoring technologies without compromising the integrity of the disposal system were considered as candidates for preclosure and postclosure monitoring.

AIC.3 Periodic Activity Controls

With the advent of decommissioning the WIPP and returning the land disturbed by the WIPP activities to a stable ecological state that will assimilate with the surrounding undisturbed ecosystem, continuous occupancy of the site for operational and security purposes will cease. However, during the active controls period after disposal (at least 100 years) there will be an ongoing need to carry out periodic activities associated with the long-term monitoring program and evaluations of the performance of permanent marker system features under long-term testing. To ensure that these periodic activities are implemented and that their results are included in periodic reports to the appropriate regulatory and legislative authorities, the essential elements of the process for controlling these activities have been identified. The process will be managed from the appropriate DOE office. The essential elements of the process include the following:

- development of detailed individual activities supporting the long-term monitoring plan;
- development of detailed individual activities supporting the evaluation of performance of permanent marker system features;
- development of the individual steps and identification of responsible personnel required for the drafting, review, commenting, and approval of reports to the appropriate regulatory authority;
- development of the individual steps and identification of responsible organizations or personnel required for the drafting, review, commenting, and approval of reports to the appropriate legislative authority;
- identification of the requirements defined from the above actions in a detailed schedule covering a period of at least 10 years;
- review of the approved schedule at least quarterly during the first two years following completion of land restoration and implementation of active institutional controls; and

- semiannual reviews of the schedule including updating and progress reporting to the DOE to be documented until such time as the federal government ceases active control of the site.

For long-term repository performance monitoring, a detailed subsidence survey will be conducted upon completion of land restoration. That survey will include, at a minimum, the 54 elevation benchmarks currently monitored. Once every 10 years, an additional detailed subsidence survey will be taken and analyzed for indications of unexpected repository performance. The long-term monitoring plan describes in detail additional technologies to be used to further evaluate repository performance should any unanticipated subsidence data be developed. These additional technologies may include

- seismic reflection and refraction surveys,
- gravitational surveys,
- electromagnetic conductivity surveys,
- resistivity surveys, and
- ground-penetrating radar surveys.

Currently, none of these technologies is developed to the degree of providing irrefutable evidence of the condition of the sealed repository. However, over the next few decades while waste is being emplaced in the repository, the technologies will likely advance significantly. It is also possible that images available using today's technologies will improve to a point where resolution of images of the repository acquired from grade level will be of sufficient quality to make some assessments of repository performance. Updating the 10-year schedule every six months to one year will ensure that this infrequent requirement is not lost.

To optimize the final design of the permanent marker system, testing of various materials and berm configurations over a long period of time is a prudent and logical course of action. The detailed activities supporting the testing required to evaluate various aspects of the planned permanent marker system design will be included in the schedule managed during the active institutional controls period. Periodic reports will also be managed by the scheduling activity during the active controls period.

Because of the relatively simple technology utilized in providing access control to the repository footprint and the hot cell, the range of potential abnormal occurrences is quite limited. Primarily, the abnormal occurrences will involve damage to the fencelines or roadway through vandalism, weather effects, and aging of the materials. The federal government is responsible for corrective action to repair these effects. Considering the properties for which access control is being provided, there is no need to provide continuous

surveillance. However, arrangements will be made to increase vehicular patrols of the site to daily patrols until repairs are made, if the damage is of a suspicious nature. If not, no increase in patrol activity will be required.

Abnormal occurrences associated with the environmental monitoring activities will be investigated. As described above, the postdecommissioning environmental monitoring program will include both radiological and nonradiological monitoring for the first two years following land restoration and then only radiological monitoring thereafter. Because of the reduced activity to support the WIPP after disposal, it is probably more cost effective for the DOE to contract for the periodic sampling and analyses than to maintain a Carlsbad staff for that purpose. Within the contractual arrangements, immediate notification by the contractor to the DOE Albuquerque Operations Office in the event of an abnormal occurrence will be a requirement. Appropriate guidelines for action to mitigate the effects of abnormal occurrences related to environmental monitoring will include

- verification of analytical results,
- increased frequency of sampling and analyses,
- determination of cause,
- investigation of additional geographical and/or parameter monitoring areas that might be affected, and
- timely communication to the press regarding any potential adverse impacts and mitigating actions to be taken.

The action guidelines for abnormal occurrences associated with subsidence are the same as those proposed for the environmental monitoring program.

AIC.4 Quality Assurance

The quality assurance and quality control discipline will be applied to the procurement of materials for and the erection of the fencelines enclosing the repository footprint and the hot cell. In particular, quality control inspection of the placement and tensioning of the barbed wire and chain link fabric should be applied and utilized to provide reasonable assurance that the fencing structures will function over an extended period of years without significant maintenance.

Quality assurance and quality control will also be applied to the sampling and analyses supporting the environmental monitoring program and the long-term monitoring plan. DOE contractors collecting samples and laboratories conducting analyses should be qualified in

accordance with guidelines prescribed in the most current edition of the *Quality Assurance Program Document* (see Appendix QAPD of this application) at the time that the contracts are awarded.

REFERENCES

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste; Final Rule. *Federal Register*, Vol. 58, No. 242, pp. 66398-66416, December 20, 1993. Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

U.S. Congress. 1992. Waste Isolation Pilot Plant Land Withdrawal Act. Public Law 102-579, 106 Stat. 4777, October 1992. 102nd Congress, Washington, D.C. WPO 39015.

Westinghouse Electric Corporation (WEC). 1996. *WIPP Radiological Control Manual*, WP12-5. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

BIBLIOGRAPHY

Bechtold, S. L. 1995. *National Archives and Records Administration (NARA) Bulletin No. 95-7.* September 8, 1995.

DOE (U.S. Department of Energy). 1991. *Resource Conservation and Recovery Act Part B Permit Application*, DOE/WIPP 91-005. Prepared for the Department of Energy by Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995. *Conceptual Decontamination and Decommissioning Plan for the Waste Isolation Pilot Plant*, DOE/WIPP 95-2072. January 1995.

DOE (U.S. Department of Energy). 1995. *Permanent Marker Conceptual Design Report*, Draft. March 1995. U.S. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995. *Long-Term Monitoring Design Concept Description,* Draft. March 1995. U.S. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy). 1996. *Quality Assurance Program Document*, DOE/CA0-94-1012. Rev. 1. April 1996.

EPA (U.S. Environmental Protection Agency). 1985. 40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste; Final Rule. *Federal Register*, Vol. 50, No. 182, pp. 38066–38089, September 19, 1985. Office of Radiation and Air, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1994. 40 CFR Part 264: Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, Subpart X Miscellaneous Units. *Federal Register*, July 1, 1994. Washington, DC.

Jensen, M. 1993. *Conservation and Retrieval of Information - Elements of a Strategy to Inform Future Societies about Nuclear Waste Repositories.* Final Report of the Nordic Nuclear Safety Research Project KAN-1.3. August 1993.

Memorandum of Understanding Between the U.S. Department of Energy and the U.S. Department of Interior, July 19, 1994.

Rodriguez, R.J., telephone conference with Rodney Vogle, Vogle Horizontal Drilling, Inc. June 7, 1996.

Rodriguez, R.J. and Hughes, D. L. Meeting with Michael White, Santa Fe Energy Resources, Inc. June 29, 1994.

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix AUD

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Audits

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Audited Organization	Number	Date
Idaho National Engineering Laboratory & Argonne National Laboratory - West Transuranic Waste Characterization Activities	CAO A-95-02	8/95
Rocky Flats Environmental Technology Site Transuranic Waste Characterization Activities	CAO A-95-06	10/95

Table AUD-2. Carlsbad Area Office Surveillances of Other Organizations

Surveilled Organization	Number	Date
Los Alamos National Laboratory Transuranic Waste Solid Sample Analysis	CAO S-95-03	3/95
Argonne National Laboratory - West Sample Collection from Waste Sludge Drums	CAO S-95-04A	4/95
Los Alamos National Laboratory Heterogeneous Drum Scale Waste Characterization	CAO S-95-06	4/95
Oak Ridge National Laboratory Gunite Tank Transuranic Waste Sludge Sampling	CAO S-95-09	5/95
Los Alamos National Laboratory Actinide Source-Term Waste Test Program Sampling of Liter-Scale Containers	CAO S-95-15	6/95
Idaho National Engineering Laboratory Volatile Organic Compounds Transport Study	CAO S-95-12	6/95
Los Alamos National Laboratory Actinide Source-Term Test Program	CAO S-95-13	7/95
Idaho National Engineering Laboratory Packaging, Handling, and Transportation	CAO S-96-19	4/96
Los Alamos National Laboratory Sludge Coring and Chemical Analysis	CAO S-96-24	5/96
Los Alamos National Laboratory Waste Characterization Activities	CAO S-96-48	8/96

Table AUD-3. Internal Audits by Sandia National Laboratories

Activity	Number	Date
University of Nevada, Reno, Implementation of Quality Assurance Requirements from Statement of Work and Sandia National Laboratories Quality Assurance Program Description, Rev. P.	IA 95-01	1/95
Sandia National Laboratories WIPP Calibration Laboratory Quality Assurance Program 12-1 and Sandia National Laboratories Quality Assurance Program Description, Rev. P.	IA 95-02	5/95
Sandia National Laboratories WIPP Experimental Activities, Sandia National Laboratories Quality Assurance Program Description, Rev. P.	IA 95-03	8/95

Table AUD-4. Internal Audits by Waste Isolation Division

Activity	Number	Date
Hazardous Material Transportation	I96-01	1/96
Controller - Records Management Interfaces	I96-02	4/96
Groundwater Monitoring Program	I96-03	4/96
Hazardous Material Management Program	I95-01	3/95
Procedure and Document Control Process	I95-02	5/95
Procurement Services	I95-04	7/95
Emergency Management	I95-05	7/95
Environment, Safety & Health Volatile Organic Compounds Monitoring Program	I95-07	10/95
Human Resources Technical Training	I94-01	3/94
Environment Safety Health & Regulatory Compliance Environmental Monitoring	I94-02	2/94
Environment Safety Health & Regulatory Compliance Environmental Compliance & Support	I94-03	4/94
Environment Safety Health & Regulatory Compliance Industrial Safety, Fire Protection	I94-04	6/94
Controller Project Records Service	I94-05	6/94
Engineering Configuration Management	I94-06	7/94
Operations Work Control	I94-07	7/94
Environment Safety Health & Regulatory Compliance Emergency Management	I94-09	9/94
Controller Procurement Services	I93-01	3/93
Controller Information Resource Management	I93-02	8/93
Engineering/Configuration Control & Instruction, Procedure, & Drawings	I93-03	9/93
Underground Operations, Facility Operations, Experimental Operations	I93-04	12/93
WIPP Analytical Laboratory	I93-05	5/93
Packaging and Transportation	I93-06	7/93
Operations Metrology Lab Measurement & Testing Experiment/Measuring & Data Collection	I93-08	7/93
Controller, Procurement Services, Material Control, Stores Inventory Control	94-001	1/94
Stakeholder Relations, Emergency Operations Information Center	94-003	2/94
Underground Operations, Underground Work Area Ground Control Inspection	94-004	1/94
Environment Safety Health & Regulatory Compliance, Dosimetry and Analytical Technology, Volatile Organic Compounds Operational Procedures WP 12-EM3200 & 3205	94-010	3/94

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Activity	Number	Date
Operations, Work Control, Training of Subcontract Personnel	94-011	3/94
Environment Safety Health & Regulatory Compliance, Nuclear Safety and Assessment/Radiation Safety, Radioactive Material Control WP 12-HP3200	94-014	4/94
Environment Safety Health & Regulatory Compliance, Industrial Safety, Weekly Fire Pump Inspections WP 12-117	94-016	5/94
Environment Safety Health & Regulatory Compliance, Industrial Safety, Root Cause Analysis Investigation WP 12-135	94-018	5/94
Human Resources, Instructor Certification WP 14-TR3305	94-019	3/94
Engineering, Repository Engineering/Geotechnical Engineering, 1993 Geotechnical Analysis Report, DOE/WIPP 94-006	94-020	4/94
Controller, Information Resource Management/Document Services, Review, Approval, and Cancellation of Waste Isolation Division Procedures	94-023b	8/94
Quality and Regulatory Assurance, Quality Assessment/Inspection Services, Training and Qualification of Personnel	94-024	8/94
Controller, Procurement Services/Material Control, Stores Inventory Control WP 15-517	94-025	7/94
Human Resources, Technical Training, General Employee Training, Instructor Certification, Self-Assessment	94-026	8/94
Controller, Information Resources Management/Document Services, Procedure Change Process WP 15-PS3003 and Guidelines for Desk Top Instructions WP 15-PS3004	94-027	7/94
Operations, Work Control, Review and Control of Facility Inspections WP 10-010	94-028	7/94
Controller, Procurement Services, Material Control, Material Control and Inspection of the In-Town Warehouse Facility	94-031	9/94
Quality and Regulatory Assurance, Independent Assessment, Waste Characterization Records Management	93-001	1/93
Operations, Waste Handling, Training and Qualification	93-002	1/93
Operations, Work Control, Preventive and Corrective Maintenance	93-004	1/93
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Environment Safety Health & Regulatory Compliance, Nuclear Safety & Assessment, Radiation Safety, Operational Health Physics Survey of TRUPACT-II Receipt	93-008	2/93
Operations, Facility Operations, Qualification and Certification Records for Facility Operations Personnel	93-012	3/93

Table AUD-4. Internal Audits by Waste Isolation Division (Continued)

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Operations, Work Control, Preventive Maintenance Instructions and Validations	93-015	4/93
Environment Safety Health & Regulatory Compliance, Dosimetry and Analytical Technology, Acceptance Criteria for Volatile Organic Compounds Data Packages	93-016	4/93
Environment Safety Health & Regulatory Compliance, Industrial Safety, C Personnel Training and Qualification	93-017	5/93
Operations, Waste Handling, Overview of Waste Handling Exercise	93-022	6/93
Quality and Regulatory Assurance, Quality Assurance Record	93-026	6/93
Operation Waste Handling, Overview of Waste Handling Exercise	93-027	6/93
Controller, Information Resource Management, Control Document Locations	93-033	7/93
Operation, Waste Handling, Waste Characterization Records/Level V Verification Process	93-035	8/93
Operations, Environment Safety Health & Regulatory Compliance, Quality Assurance, Training of Support Personnel	93-044	8/93
Operations, Security, Interfaces Between Operations and Human Resources Relating to Waste Receipt	93-045	9/93
Operation, Work Control, Procedure Compliance and Loop Calibration	93-046	9/93
Environment Safety Health & Regulatory Compliance, Environmental Programs, Environmental Monitoring, Low-Volume Air Sampling WP 02-312	93-048	9/93
Controller, Information Resources Management, Surveillance Testing of the Waste Handling Building Sprinkler System	93-051	10/93
Controller, Information Resources Management, Procedure Compliance PM 711028	93-052	10/93
Operations, Mine Operations, Incorporation of Modifications	93-055	10/93
Engineering, Repository Engineering, Geomechanical Instrument Data Processing	93-056	11/93
Environment Safety Health & Regulatory Compliance, Environmental Programs/Industrial Safety, Environmental Incident Reporting	93-057	11/93
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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix BECR

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Biennial Environmental Compliance Report

DOE/WIPP 96-2171

Waste Isolation Pilot Plant Biennial Environmental Compliance Report

October 1996

United States Department of Energy
Carlsbad Area Office
Carlsbad, New Mexico

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ACRONYMS AND ABBREVIATIONS

AEA	Atomic Energy Act
AEC	Atomic Energy Commission
AHERA	Asbestos Hazard Emergency Response Act
AMR	Annual Mitigation Action Plan Report
AQCR	Air Quality Control Regulation
ASTM	American Society of Testing and Materials
BECR	Biennial Environmental Compliance Report
BLM	Bureau of Land Management
BMP	best management practice
BTU	British thermal unit
C of C	Certificate of Compliance
CAA	Clean Air Act
CAAA	Clean Air Act Amendments of 1990
CAM	continuous air monitor
CAO	Carlsbad Area Office
CAS	Chemical Abstract Service
CC	common conditions
CCDF	complementary, cumulative distribution function
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	chlorofluorocarbon
CFR	Code of Federal Regulations
CH	contact-handled
CMR	Central Monitoring Room
CWA	Clean Water Act
DCCA	Draft Compliance Certification Application
DMR	Discharge Monitoring Report
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DP	Discharge Plan
DWR	Drinking Water Regulations
EA	Environmental Assessment
ECAP	Environmental Compliance Assessment Program
EDE	effective dose equivalent
EEG	Environmental Evaluation Group
EHS	extremely hazardous substance
EIA	Environmental Impact Assessment; Environmental Improvement Act

EIB	Environmental Improvement Board
EID	Environmental Improvement Division
EIS	Environmental Impact Statement
EMA	Emergency Management Act
EMS	Emergency Management System
EMTF	Emergency Management Task Force
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
FAR	Federal Acquisition Regulation
FEIS	Final Environmental Impact Statement
FFCA	Federal Facility Compliance Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FIRST	Facility Inspection and Repair Service Team
FLPMA	Federal Land Policy and Management Act
FONSI	*Finding of No Significant Impact*
FR	*Federal Register*
FSAR	Final Safety Analysis Report
FSM	Facility Shift Manager
FWS	U.S. Fish and Wildlife Service
GET	General Employee Training
gpd	gallons per day
GR	general requirement
GSA	Government Service Administration
HAP	hazardous air pollutant
hbfc	hydrobromofluorocarbon
HCIA	Hazardous Chemicals Information Act
HMT	hazardous materials training
HMTA	Hazardous Materials Transportation Act
HMTUSA	Hazardous Materials Transportation Uniform Safety Act
HPD	Historic Preservation Division
HSWA	Hazardous and Solid Waste Amendments of 1984
HWA	Hazardous Waste Act
HWMR	Hazardous Waste Management Regulation
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICV	inner containment vessel
L	liter
LDR	land disposal restriction
LEPC	Local Emergency Planning Committee (or Coordinator)
LMIP	Land Management Implementation Plan

LMP	Land Management Plan
LWA	(Waste Isolation Pilot Plant) Land Withdrawal Act
MAP	Mitigation Action Plan
MCL	maximum contaminant level
MOU	Memorandum of Understanding
mg/L	milligrams per liter
mrem	millirem
MSDS	Material Safety Data Sheet
MVAC	motor vehicle air conditioner
NAAQS	National Ambient Air Quality Standard
NAR	North Access Road
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act
NESHAPS	National Emission Standards for Hazardous Air Pollutants
NHPA	National Historic Preservation Act
NMAAQS	New Mexico Ambient Air Quality Standard
NMAC	New Mexico Administrative Code
NMD	No-Migration Determination
NMDG&F	New Mexico Department of Game and Fish
NMED	New Mexico Environment Department
NMSA	New Mexico Statutes Annotated
NMVP	No-Migration Variance Petition
NOI	Notice of Intent
NOT	Notice of Termination
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NRCr	National Response Center
NSPS	New Service Performance Standards
NuPac	Nuclear Packaging Inc.
NWPA	Nuclear Waste Policy Act
OCA	outer containment assembly
OCV	outer containment vessel
ODS	ozone-depleting substance
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyl
PEIS	Programmatic Environmental Impact Statement
PL	Public Law
PM	particulate matter
ppm	parts per million
ppmw	parts per million by weight
PPP	Pollution Prevention Plan

PSD	Prevention of Significant Deterioration
PV	proposed variance
PWR	plant work request
QA	Quality Assurance
QAP	Quality Assurance Program
QAPD	Quality Assurance Program Description
QAPP	Quality Assurance Program Plan
QAPjP	Quality Assurance Project Plan
QC	Quality Control
Q&RA	Quality and Regulatory Assurance group
QSL	Qualified Supplier List
RCRA	Resource Conservation and Recovery Act
RH	remote-handled
ROD	Record of Decision
RQ	reportable quantity
RTR	real-time radiography
SAA	satellite accumulation area
SARA	Superfund Amendments and Reauthorization Act of 1986
SARP	Safety Analysis Report for Packaging
SDWA	Safe Drinking Water Act
SEIS	Supplement Environmental Impact Statement
SERC	State Emergency Response Commission
SHPO	State Historic Preservation Officer (or Office)
SIC	Standard Industrial Classification
SLO	State Land Office
SOP	standard operating procedure
SPCC	Spill Prevention, Control, and Countermeasures Plan
SPDV	Site and Preliminary Design Validation
SR	specific requirement
SS	standard stipulations
SWA	Solid Waste Act
SWB	standard waste box
SWDA	Solid Waste Disposal Act
SWMR	Solid Waste Management Regulation
SWMU	solid waste management unit
TAP	toxic air pollutant
TDOP	10-drum overpack
TDS	total dissolved solid
TLD	thermoluminescent dosimeter
TPQ	Threshold Planning Quantity
tpy	tons per year
TRANSCOM	Transportation Tracking and Communications System

TRAMPAC	TRUPACT-II Authorized Methods for Payload Control
TRI	Toxic Chemical Release Inventory
TRU	transuranic
TRUCON	TRUPACT-II content codes
TRUPACT-II	Transuranic Package Transporter Model II
TSCA	Toxic Substances Control Act
TSDF	treatment/storage/disposal facility
USFWS	U.S. Fish and Wildlife Service
UIC	underground injection control
UN	United Nations
USC	United States Code
USDW	underground storage of drinking water
UST	underground storage tank
USTR	Underground Storage Tank Regulation
VOC	volatile organic compound
WAC	Waste Acceptance Criteria
WID	Westinghouse Waste Isolation Division
WIPP	Waste Isolation Pilot Plant
WQA	New Mexico Water Quality Act
WQCC	Water Quality Control Commission

1.0 INTRODUCTION

This *Biennial Environmental Compliance Report* (BECR) addresses regulatory compliance at the Waste Isolation Pilot Plant (WIPP), a research and development facility designed to demonstrate the safe disposal of transuranic (TRU) radioactive waste. As required by the WIPP Land Withdrawal Act (LWA) (Public Law [PL] 102-579), the BECR documents WIPP's compliance with applicable federal laws implemented by the U.S. Environmental Protection Agency (EPA) and applicable New Mexico laws, regulations, and permit conditions.

The BECR also addresses compliance with some federal laws implemented by other United States agencies including the Council on Environmental Quality, Department of Energy (DOE), Nuclear Regulatory Commission, Department of Transportation, Department of Interior Bureau of Land Management and Fish and Wildlife Service, and the Advisory Council on Historic Preservation.

1.1 Background of the Waste Isolation Pilot Plant (WIPP)

The WIPP Project was authorized by the DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (PL 96-164). This legislation mandated that DOE provide a research and development facility to demonstrate the safe disposal of radioactive waste resulting from U.S. defense activities and programs. Initially, the WIPP mission was to include experimentation with high-level wastes, but subsequent legislation has restricted the radioactive waste to TRU waste. TRU waste is radioactive waste that contains alpha-emitting radionuclides of atomic number greater than 92 with half-lives longer than 20 years which are present in concentrations greater than 100 nanocuries per gram of waste. Most of this waste is generated from plutonium reprocessing and fabrication.

In January 1981, the DOE announced its decision to proceed with a phased development of the WIPP, to be located in Eddy County in southeastern New Mexico, 26 miles east of the city of Carlsbad. The decision called for the WIPP to be designed to accommodate approximately 6.2 million cubic feet of contact-handled (CH) TRU waste and 0.25 million cubic feet of remote-handled (RH) TRU waste. The WIPP LWA has limited the total WIPP capacity to 6.2 million cubic feet of transuranic waste.

After completing a site and preliminary design validation (SPDV) phase, the construction phase at the WIPP began in 1983. At present, surface and underground facilities to support waste handling and emplacement operations have been constructed. Of the nine surface buildings, the largest structure is the Waste Handling Building, which includes areas for the receipt, inventory, inspection, and transfer of waste to the underground. The WIPP underground facility, which is 2,150 feet below the land surface in a 2,000-foot-thick bedded salt formation, consists of four shafts, the waste disposal area, the experimental area (for repository safety and mine performance

studies), an equipment and maintenance facility, and connecting tunnels. Only a few waste disposal rooms have been mined at present because of the natural phenomenon of salt creep, which causes eventual room closure. Additional waste disposal rooms will be mined prior to permanent waste emplacement.

Originally, the construction phase was to have been followed by the pilot plant phase. Following the preparation of the Supplement Environmental Impact Statement (SEIS) in 1990, the DOE decided that the construction phase was to be followed by the test phase, during which tests with TRU waste would have been conducted underground at the WIPP. However, on October 21, 1993, the DOE announced its decision not to conduct TRU waste tests underground at the WIPP facility, but to conduct enhanced laboratory tests at existing DOE facilities elsewhere. Thus no TRU or TRU-mixed waste (radioactive waste with hazardous constituents) will be sent to WIPP until after the initiation of the disposal phase. The disposal phase will be followed by the decontamination and decommissioning phase.

More detailed information on the background of the WIPP project can be found in the DOE's *Final Environmental Impact Statement, Waste Isolation Pilot Plant* (FEIS; DOE, 1980); the DOE's 1981 Record of Decision (ROD) to the FEIS (DOE, 1981); the 1990 *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant* (SEIS; DOE, 1990a); and the 1990 ROD to the SEIS (DOE, 1990b).

A second supplemental environmental impact statement (SEIS-II) is presently being prepared to address information that has become available since 1990. Further information is also available in documents referenced by the SEIS-II.

1.2 Biennial Environmental Compliance Report under the WIPP Land Withdrawal Act

This BECR provides the documentation required by the 1992 LWA. The LWA specifies that :

> *The Secretary shall, not later than 2 years after the date of the enactment of this Act, and biennially thereafter, submit documentation of continued compliance with the laws, regulations and permit requirements described in paragraph (1) to the Administrator, and, with the law described in paragraph (1)(C), to the State [§ 9(a)(2)].*

Paragraph (1) requires that the WIPP comply with Subpart A of 40 *Code of Federal Regulations* (CFR) Part 191; the Clean Air Act; the Solid Waste Disposal Act (SWDA); the Safe Drinking Water Act; the Toxic Substances Control Act; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); "all other applicable Federal laws pertaining to public health and safety or the environment;" and "all regulations promulgated, and all permit requirements" under these laws.

1.3 Regulatory Requirements Hierarchy

The first step in documenting regulatory compliance is the identification of all applicable regulatory requirements. This section describes the interrelationships among laws, regulations, and permit conditions and identifies the origins of the detailed regulatory requirements discussed in this report.

1.3.1 Federal/State Laws

Laws result from legislative processes at either the federal, state, or local level. This report will summarize the purpose of each relevant law and discuss its applicability and importance to the WIPP.

1.3.2 Implementing Regulations

Once a law has been enacted, it must be implemented. Authority for implementation of each new act is usually assigned to a particular agency. That agency is responsible for developing regulations to implement the act. At the federal level, these regulations are first published in the *Federal Register* (FR) as "proposed" for comment from interested groups and individuals. The implementing agency must then respond appropriately to the comments and prepare the final regulations. These final regulations are again published in the *Federal Register*, along with a discussion of the comments, and are inserted into the appropriate part(s) of the Code of Federal Regulations (CFR).

New Mexico agencies use a similar process in the promulgation of regulations, with the proposed and final regulations published in the *New Mexico Register*. Many state environmental laws evolve from federal statutes, many of which allow that the state become authorized to administer and enforce its own regulatory program in lieu of the federal program as long as the state regulations are no less stringent than the federal requirements. In these cases, the state must send its "final" regulations to the governing agency, such as the EPA, for approval. The governing agency may approve all, part, or none of the final regulations. After agency approval, notification of the agency's authorization of the state program is published in the *Federal Register*.

Local laws or ordinances that apply to the WIPP are limited to those under the authority of the county commission. The only local laws or ordinances applicable to the facility are zoning ordinances. These do not affect the facility's ability to protect human health and the environment. Therefore, these laws and ordinances are not included in this report.

This report identifies specific requirements from federal/state implementing regulations that apply to the WIPP facility. In some cases where implementing regulations have not been promulgated or where a particular statute requirement is not covered by the implementing regulations, this report identifies specific requirements directly from the statute.

1.3.3 Permit Conditions

A number of federal/state implementing regulations include permit programs. Because many implementing regulations are couched in general terms, permits and permit programs allow the regulatory agency to regulate individual facilities and stipulate site-specific conditions that must be met by a specific facility to meet the statutory goals of protection of the public and the environment. Thus, permits are used to regulate discharges and activities (construction, modifications, and/or operations) of a facility. This report identifies site-specific permit conditions that apply to the WIPP.

1.4 Regulatory Compliance at the WIPP

The DOE and the Westinghouse Electric Corporation's Waste Isolation Division (WID), the Prime Contractor for the WIPP, are fully committed to conducting operations at the WIPP in a way that achieves and demonstrates compliance with applicable regulations and permit conditions. Both organizations have implemented plans and procedures to achieve and maintain compliance with the regulations and have established aggressive assessment programs to validate continued successful implementation of these activities.

In a number of areas throughout this document, it is noted that procedures and manuals are in place to guide and direct WIPP personnel in the performance of specific job tasks which have or could have a direct impact on the compliance status in a given situation. These procedures and manuals are in place to supplement personnel training, education, and qualifications and to promote the operation of the WIPP facility in a safe and environmentally sound manner. Because this is the intended purpose of these documents, they are continually evaluated and revised to ensure that they are effective and current with respect to both regulatory and operational changes. For this reason, specific procedures and manuals are not referenced in the body of this document.

In addition, a number of reports (especially those reports which are a result of regulatory requirements) are referenced throughout the document. Due to the continual update and revision requirements for reports of this nature, they are referenced only by the report title or by the citation that requires their submittal rather than by document numbers.

1.4.1 Organizational Structure

The organizational structure of the DOE Carlsbad Area Office (CAO) and WID reflect the importance of regulatory compliance at the WIPP and the commitment of both organizations to achieving and maintaining full compliance.

The CAO's organizational structure consists of the Area Manager, who oversees three major branches: the Office of Program Support and Assurance, the Office of

Regulatory Compliance, and the Office of National TRU Waste Operations. These branches function together to ensure that the WIPP's day-to-day and long-term environmental compliance programs remain exemplary. The Office of Program Support and Assurance interprets environment, safety, health, and quality assurance requirements applicable to WIPP. The Office of Regulatory Compliance develops the overall strategy and criteria to demonstrate and validate long-term compliance for the disposal of TRU waste. The Office of National TRU Waste Operations manages the day-to-day operation of the WIPP facility.

WID's commitment to compliance is also represented in their organizational structure, consisting of the General Manager, the Deputy General Manager, and eight department managers. The department manager of Environment, Safety, and Health reports directly to the General Manager and manages the WID's environmental compliance activities including document preparation, monitoring, analysis, and oversight. The department manager for Quality and Regulatory Assurance provides support to ensure that compliance activities are managed and performed in a manner consistent with WID's commitment to compliance.

1.4.2 Compliance Assurance

Compliance includes a wide range of activities, ranging from the preparation of plans, procedures, reports, or permit applications to hands-on actions such as record keeping, monitoring, sampling and analysis, performing assessments or audits, and housekeeping.

There are three programs to assess WIPP programs and activities that have an impact on the WIPP's environmental compliance status. These include the WID Environmental Compliance Assessment Program (ECAP), the WID Quality Assurance Programs, and the CAO Assurance Plan.

The ECAP provides a comprehensive system to appraise compliance with applicable environmental laws and regulations, and identifies environmentally sound corrective action measures for any findings or observations identified. The ECAP assessments are used to identify and eliminate deficiencies that could lead to the following unacceptable events:

- Permit violations
- Regulatory noncompliance
- Safety and health risks to WIPP site workers and/or the general public
- Spills, releases, or discharges of environmental pollutants

Complimenting the ECAP are the CAO and WID Quality Assurance Programs. Quality Assurance Program surveillances, audits, and assessments of WIPP activities are designed to verify compliance with quality assurance requirements and determine the adequacy and effectiveness of the activities. Elements of these oversight activities include:

- Monitoring work in progress
- Documenting compliance or non-compliance with established requirements and procedures
- Identifying actual and potential conditions adverse to quality
- Obtaining timely corrective action commitments from cognizant managers.
- Providing notification to responsible managers of the status and performance of work under assessment
- Verifying timely implementation of corrective actions.

1.5 Organization of and Reporting Period for the Report

The organization of and reporting period for the BECR are discussed in the following subsections.

1.5.1 Organization of the Report

This report organizes the pertinent regulatory requirements into 14 parts, each of which corresponds to a federal or state agency that is authorized to administer regulatory programs. Under each agency, separate chapters identify and discuss each law administered by the agency that is relevant to the WIPP facility. For example, the first part contains pertinent regulatory programs administered by the EPA. Within this part, ten chapters correspond to the ten environmental laws and sets of regulations that apply to the WIPP for which the EPA is responsible (Chapters 2 through 11).

Each of the following 37 chapters summarizes a law and its implementing regulations and briefly describes its applicability to the WIPP. For ease in identifying compliance status, summary tables in each chapter provide a synopsis of WIPP's compliance with each specific requirement and a cross-reference to the more detailed discussion in the text. Each section of the text summarizes a requirement and addresses its compliance status.

The WIPP is subject to oversight by a number of regulatory agencies. The scope of the BECR chapters includes the documentation of occasions in which the WIPP may have received a notice of violation by a regulatory agency.. Audits, appraisals, and

assessments conducted by regulatory agencies did not result in notices of violation during this reporting period.

Within the BECR summary tables the compliance status is identified as "achieved," "up to date," or "not applicable."

ACHIEVED Items with the status of "achieved" are requirements that have been met and do not require any further action. They are essentially "one-time" occurrences.

Example: As a generator of hazardous waste, WIPP must obtain an EPA ID number; this requirement has been achieved.

UP TO DATE Items with the status of "up to date" are requirements that require some type of ongoing activity to maintain compliance.

Example: The DOE must file a biennial hazardous waste report; these reports are up to date.

NOT APPLICABLE Items with the status of "not applicable" were evaluated and determined not to be applicable to the WIPP either during this reporting period or throughout the duration of the project.

Example: Since the WIPP disposes of its construction and demolition debris at a landfill located on DOE property and in accordance with the applicable regulations, the requirement for obtaining a permit is not applicable.

Following the list of references, Appendix A presents an index of the specific requirements discussed in the report by regulating agency. Appendix B indexes the specific requirements in terms of their technical subject areas (for example, waste management requirements, water quality requirements, historic preservation requirements).

1.5.2 Reporting Period

The first BECR, issued October 24, 1994, addressed the status of WIPP compliance programs and activities for the period from the congressional approval of the WIPP LWA on October 30, 1992 to March 31, 1994. This BECR addresses the compliance status of WIPP programs and activities for the reporting period beginning April 1, 1994, and ending on March 31, 1996.

2.0 RESOURCE CONSERVATION AND RECOVERY ACT AND SOLID WASTE DISPOSAL ACT

2.1 Summary of the Law

The Resource Conservation and Recovery Act (RCRA; 42 United States Code [USC] §§ 6901 et seq.) is a statute designed to provide "cradle-to-grave" control of hazardous waste by imposing management requirements on generators and transporters of hazardous wastes and on the owners and operators of treatment/storage/disposal facilities (TSDFs). RCRA applies primarily to active facilities; abandoned and inactive sites are regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund; see Chapter 3).

The legislative history of RCRA was initiated in 1965 when Congress enacted the Solid Waste Disposal Act (SWDA; PL 89-72; 42 USC §§ 3251 et seq.). This law dealt with solid waste disposal and gave the states the responsibility for developing solid waste management plans. In 1970, Congress passed the Resource Recovery Act (PL 91-12) to provide the EPA with funding for resource recovery programs. The Resource Conservation and Recovery Act of 1976 (PL 94-580) completely replaced the SWDA and incorporated the intent of the Resource Recovery Act. A number of minor amendments were added during the next few years. The Hazardous and Solid Waste Amendments of 1984 (HSWA; PL 98-616) reauthorized RCRA, expanded its scope significantly, and altered many of its provisions. The term "RCRA" will be used throughout this document to refer to the reauthorized law as amended.

There are two major objectives of RCRA. The first is to promote the protection of health and the environment and to conserve material and energy resources. This objective is to be accomplished through such means as ensuring that hazardous waste management practices are conducted so as to protect human health and the environment, minimizing the generation of hazardous waste, prohibiting open dumping on the land, and requiring existing open dumps to be converted to facilities that pose no danger to the environment or health. The second objective of RCRA is to set national policy to reduce or eliminate the generation of hazardous waste as expeditiously as possible and to ensure that any hazardous waste generated be treated, stored, or disposed of so as to minimize the present and future threat to human health and the environment.

The EPA implements RCRA primarily through the 40 CFR Part 260-280 series: 40 CFR Parts 260-270 consist of requirements and standards pertaining to solid waste, particularly hazardous waste; 40 CFR Parts 280-281 pertain to the management of underground storage tanks (USTs) containing petroleum products or hazardous chemicals.

Congress intended for the RCRA program to be implemented by the states. Consequently the EPA has defined a process through which states may apply for and

receive authorization to administer the RCRA program. New Mexico received authorization for the base RCRA program in January 1985 and for its mixed-waste program in July 1990. The EPA granted authorization for the HSWA program to the state of New Mexico in a notice that appeared in the *Federal Register* on October 17, 1995 (effective date: January 2, 1996). New Mexico administers its program through Chapters 4 and 5 of Title 20 of the New Mexico Administrative Code (20 NMAC 4.1, 4.2, and Chapter 5). By virtue of this authorization, New Mexico has primary authority for most aspects of the RCRA program.

The Federal Facility Compliance Act of 1992 (FFCA; 42 USC 6961) subjects the DOE to the requirements of federal RCRA or state hazardous waste programs. DOE is fulfilling the requirements of the FFCA for a federal inventory of sites handling mixed waste through the preparation of the Waste Management Programmatic Environmental Impact Statement (PEIS), in which the DOE sites managing mixed waste are discussed. Notice was made to the public regarding the availability of this document on September 22, 1995 (60 FR 49264). The individual generator/storage sites have prepared site-specific treatment plans to fulfill the requirement of site-specific plans under the FFCA. However, WIPP is not currently subject to the requirements for fees, inventory reporting, reporting the status of treatment capacity and technology (site treatment plans), or other FFCA requirements. Even though WIPP is subject to the Land Disposal Restrictions (LDRs) (and, as such, DOE has opted to request a variance from treatment standards prior to disposal), the WIPP will not treat mixed waste subject to the requirements of the FFCA during operation. It is possible that some "derived waste" will be generated at WIPP from the mixed waste from the generator sites (e.g., used personal protective equipment, swipes, and tools; i.e., any waste derived from contact with TRU mixed waste to be received at WIPP). As indicated in the WIPP RCRA Part B Permit Application for disposal, written procedures that direct normal operations at the facility will be implemented to minimize the possibility of generating new TRU mixed wastes. Any derived wastes that are generated will be contained in standard containers, the design of which has been approved by the Department of Transportation (DOT); this waste will be managed like the rest of the TRU/TRU mixed waste. Since there are no plans to treat mixed waste at WIPP, there is no need for a WIPP-specific treatment plan, and there are no requirements of the FFCA as currently written that apply to WIPP. Therefore, since the FFCA requirements are not applicable to WIPP, they are not addressed further in this report.

Table 2-1 is presented to assist the reader because of the complexity of the regulations and requirements under RCRA. This table shows the location of the RCRA-related requirements in this BECR by section and table numbers. The federal requirements are presented in this chapter; the state RCRA-related requirements are incorporated in Chapter 25, under the New Mexico Environment Department (NMED). The first BECR included the EPA's conditions and requirements from the conditional No-Migration Determination (NMD) issued for the test phase. Although DOE made the decision that no testing of radioactive waste would be conducted at WIPP, the conditions and requirements of the NMD have been implemented to the extent applicable to WIPP.

Therefore, this section is included in this revision of the BECR. It will be modified when the EPA issues a new no-migration determination for WIPP for the disposal phase. The conditions and requirements from the EPA's NMD are also included in this table.

TABLE 2-1. Index of Requirements Pertaining to RCRA in the BECR

Citation	Title	BECR Section
The Resource Conservation and Recovery Act (RCRA), 42 USC §§ 6901 et seq.		
RCRA, § 3016	Inventory of federal hazardous waste facilities	2.2.1
Regulations Implementing RCRA		
40 CFR Part 262 and 20 NMAC 4.1, Part III	Standards Applicable to Generators of Hazardous Waste	25.2.2
40 CFR Part 263; 20 NMAC 4.1, Part IV	Standards Applicable to Transporters of Hazardous Waste	25.2.3
40 CFR Part 264; 20 NMAC 4.1, Part V	Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities	Not applicable
40 CFR Part 265; 20 NMAC 4.1, Part VI	Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities	25.2.4
40 CFR Part 268	Land Disposal Restrictions	2.2.2
40 CFR Part 270; 20 NMAC 4.1, Part IX	EPA Administered Permit Programs: the Hazardous Waste Permit Program	25.2.5
Requirements for and Registration of Underground Storage Tanks (USTs)		
40 CFR Part 280; 20 NMAC 5.1-5.17	New Mexico underground storage tank regulations	25.2.6

Citation	Title	BECR Section
NMSA 74-6B-1 through 74-6B-14	New Mexico Ground Water Protection Act	25.2.2 and Chapter 28

RCRA provides direction for the management of solid and hazardous waste. It should be noted that waste defined as hazardous under RCRA (40 CFR Part 261, *Identification and Listing of Hazardous Waste*) does not include radionuclides. Thus, mixed waste, which consists of radioactive waste with hazardous constituents, is regulated under both the Atomic Energy Act (for the radionuclides) and RCRA (for the hazardous constituents).

Requirements and conditions related to the EPA's land-disposal restrictions are codified in 40 CFR Part 268 and are applicable to the WIPP facility. Under the 1984 HSWA, the land disposal of hazardous wastes not meeting EPA-imposed treatment standards is prohibited unless it can be demonstrated "to a reasonable degree of certainty" that there will be "no migration of hazardous constituents from the disposal unit . . . for as long as the wastes remain hazardous" (RCRA § 3004[d][1]). Section 40 CFR 268.6 allows for a variance from the land disposal restrictions when the applicant can make the required demonstration of no migration.

The DOE submitted a petition to EPA headquarters for a no-migration variance for the test phase in March 1989. On April 6, 1990, the EPA published the proposed variance for WIPP (EPA, 1990a). The EPA's decision to grant the final Conditional NMD was published on November 14, 1990 (EPA, 1990b). The DOE submitted a second petition for a variance addressing disposal in June 1996.

DOE has submitted a RCRA permit application to the NMED for the disposal phase at WIPP (see Chapter 25).

One section of RCRA governs the management of underground storage tanks (USTs). This portion of RCRA and the regulations specified under 40 CFR Parts 280 and 281 address USTs containing petroleum products or hazardous chemicals. (Requirements for tanks containing hazardous wastes are specified under Subpart J of 40 CFR Parts 264 and 265.) Requirements for UST management pertain to the design, construction, installation, and operation of USTs as well as notification and corrective action requirements in the event of a release and actions required for out-of-service USTs.

The NMED has been authorized by the EPA to regulate USTs. Therefore, the state UST requirements and the compliance status for each requirement are presented in Chapter 25 of this report.

2.2 Status of Compliance with the Regulatory Requirements

This section provides information on requirements of RCRA and of the EPA's regulations implementing this act. Each subsection contains a summary table with the requirement and the compliance status, and more detailed information is provided in the text.

2.2.1 Compliance with the Resource Conservation and Recovery Act

Nearly all of the requirements specified in RCRA are covered in more detail in the implementing regulations. The exception is § 3016 of the act, which requires each federal agency to provide a biennial inventory of its TSDFs (see Table 2-2). Also included in this table is a brief summary of the requirements of a new set of implementing regulations for the management of "universal waste" (40 CFR Part 273), which apply to three post-consumer use wastes. The universal waste regulations established management requirements for spent lead acid batteries, recalled and unused pesticides, and mercury-containing thermostats. These new regulations allow these items to be regulated as hazardous waste. There is no requirement to notify the EPA of universal waste handling activities (40 CFR 273.12) or to track shipments of universal waste (40 CFR 273.19) under this program. The state of New Mexico has not yet adopted these regulations. After the regulations have been adopted by the state, WIPP personnel will evaluate compliance alternatives. The universal waste regulations provide alternatives to managing three categories of waste; the regulations are not mandatory requirements. Until these regulations become part of the NMED regulations, WIPP will continue to manage its universal waste as required under the RCRA regulations, 40 CFR Part 262. Since all spent acid lead batteries generated at WIPP are sent to reclamation facilities, these batteries are essentially exempt from regulation under RCRA, as indicated in 40 CFR 266.80. The mercury-containing thermostats are currently sent to an EPA-approved TSDF.

Regulations have been promulgated with respect to organic emissions from containers, tanks, and surface impoundments. WIPP has been exempted from these because the wastes of concern are stored in DOT-approved containers that are less than 119 gallons in capacity. However, new regulations pertaining to organic emissions were published in the *Federal Register* on February 9, 1996, and may impact WIPP. Since the effective date of these new regulations falls outside the period of concern for this report, possible impacts to WIPP will be examined in the next BECR and will not be addressed here.

Other new regulations that do not currently apply to WIPP are the universal treatment standards and the treatment standards for organic toxicity characteristic wastes and newly listed wastes under the LDRs. When the EPA issues a variance determination in response to the submittal of the final No-Migration Variance Petition (NMVP) for disposal, no treatment of the wastes to be received from the generator sites will be necessary.

More detail about compliance with the biennial inventory and the universal waste management regulations is provided in Section 2.2.1.1 and Sections 2.2.1.2 through 2.2.1.9, respectively.

TABLE 2-2. The RCRA Requirements That Are Not Covered by Implementing Regulations and New Regulations Not Yet Implemented by the NMED - Compliance Status

Citation	Requirement	Compliance Status
RCRA Requirements That Are Not Covered by Implementing Regulations		
§ 3016	Inventory of federal hazardous waste facilities	**UP TO DATE** Report filed biennially in even-numbered years [Section 2.2.1.1]
New Regulations Not Yet Implemented by the NMED		
40 CFR Part 273, Subpart B	Standards for universal waste, small quantity handlers (general)	**NOT APPLICABLE** <5000 kg of universal waste at any time; no universal waste program at WIPP as yet [Section 2.2.1.2]
40 CFR 273.11	Prohibitions	**NOT APPLICABLE** No universal waste program at WIPP at present. Thermostats currently managed under 40 CFR Part 262 at WIPP; batteries managed under 40 CFR 266.80. [Section 2.2.1.3]
40 CFR 273.13	Waste management	**NOT APPLICABLE** No universal waste program at WIPP at present. Thermostats currently managed under 40 CFR Part 262 at WIPP; batteries managed under 40 CFR 266.80. [Section 2.2.1.4]

Citation	Requirement	Compliance Status
40 CFR 273.14	Labeling/marking	**NOT APPLICABLE** No universal waste program at WIPP at present. Thermostats currently managed under 40 CFR Part 262 at WIPP; batteries managed under 40 CFR 266.80. [Section 2.2.1.5]
40 CFR 273.15	Accumulation time limits	**NOT APPLICABLE** No universal waste program at WIPP at present. Thermostats currently managed under 40 CFR Part 262 at WIPP; batteries managed under 40 CFR 266.80. [Section 2.2.1.6]
40 CFR 273.16	Employee training	**NOT APPLICABLE** Should the WIPP opt to use the provision of the universal waste regulations, information will be made available to appropriate employees upon implement of universal waste program [Section 2.2.1.7]
40 CFR 273.17	Responses to releases	**NOT APPLICABLE** Thermostats currently managed under 40 CFR Part 262 at WIPP; batteries managed under 40 CFR 266.80. [Section 2.2.1.8]
40 CFR 273.18	Off-site shipments	**NOT APPLICABLE** Batteries sent for reclamation, thermostats sent to TSDF. [Section 2.2.1.9]

2.2.1.1 Inventory of Federal Hazardous Waste Facilities, § 3016

> *Each federal agency shall compile, publish, and submit to the EPA Administrator (and the state, if its hazardous waste program has been authorized by the EPA) an inventory of each site which the agency owns or operates at which hazardous waste is stored, treated, or disposed of at any time. The inventory shall be submitted every 2 years beginning January 31, 1986.*

The DOE files its hazardous waste inventory report (Form 0336-EPA-B1) for WIPP with the EPA and the NMED in even-numbered years as required by § 3016 of RCRA. DOE transmitted the latest report, the *1996 Inventory of Federal Hazardous Waste Activities at Currently Owned or Operated Federal Facilities--WIPP,* to the EPA before the due date.

2.2.1.2 Standards for Universal Waste, Small Quantity Handlers, 40 CFR Part 273, Subpart B

> *Small-quantity handlers are those who accumulate less than 5000 kg of universal waste at any one time.*

As indicated in Section 2.2.1, universal waste consists of spent lead acid batteries, pesticides, and mercury-containing thermostats. WIPP generates such batteries and thermostats. Since the quantity of universal waste present on site at any one time is believed to be less than 5000 kg, WIPP will probably be a small-quantity handler of these wastes. However, since the NMED has not yet codified these new regulations, WIPP is still managing lead acid batteries under the exemption described in 40 CFR 266.80 for batteries sent to a reclamation facility, and mercury-containing thermostats are being managed as hazardous waste.

2.2.1.3 Prohibitions, 40 CFR 273.11

> *Universal waste management is a recycling program. Universal waste is not to be disposed of or diluted or treated to render it less hazardous (except in the possible case of releases from universal waste).*

WIPP currently manages its spent acid lead batteries under the exemption specified under 40 CFR 266.80 and manages its waste mercury-containing thermostats as hazardous waste.

2.2.1.4 Waste Management, 40 CFR 273.13

> *Universal waste must be properly contained so as to prevent releases and must lack evidence of leakage, spillage, etc.*

Spent acid lead batteries and mercury-containing thermostats at WIPP are still managed under 40 CFR 266.80 and the hazardous waste regulations, respectively. After the universal waste regulations have been adopted by the state of New Mexico, WIPP personnel will determine whether it will be more feasible to continue to manage these wastes as is currently being done or to implement a universal waste program at WIPP.

2.2.1.5 Labeling/Marking, 40 CFR 273.14

> *Universal waste must be labeled or marked appropriately (e.g., universal waste--batteries).*

Spent lead acid batteries and waste mercury-containing thermostats are labeled as required under RCRA. If a universal waste program should be implemented at WIPP, the appropriate types of universal waste will be labeled as specific WID procedures and the universal waste requirements dictate.

2.2.1.6 Accumulation Time Limits, 40 CFR 273.15

> *A small-quantity universal waste handler may accumulate universal waste for up to 1 year from the date the waste was generated. A log or inventory should be used to show the date that each item of universal waste was placed in the universal waste collection container in a specific accumulation area.*

WIPP currently meets the accumulation time limits for hazardous waste for the spent lead acid batteries and waste mercury-containing thermostats generated on site.

2.2.1.7 Employee Training, 40 CFR 273.16

> *Employees who handle or are responsible for managing universal waste should be provided with the appropriate information needed with respect to proper handling and appropriate emergency procedures for the type of universal waste being managed at the facility.*

This requirement is currently inapplicable because the spent lead acid batteries and the waste mercury-containing thermostats at WIPP are managed under 40 CFR 266.80 and as fully regulated hazardous waste, respectively. When a universal waste program

is implemented at WIPP, the WIPP employees who work with these types of waste will receive the appropriate training.

2.2.1.8 Responses to Releases, 40 CFR 273.17

> *All releases of universal wastes and residues from such wastes must be contained immediately; any material resulting from the release must be assessed to determine if it is hazardous waste; if so, it must be managed in compliance with all applicable RCRA regulations.*

This requirement is not applicable because spent lead acid batteries and waste mercury-containing thermostats generated at WIPP are already being managed in compliance with applicable RCRA regulations. Should a decision be made in the future to adopt a universal waste program at WIPP, procedures will be put in place for responding appropriately to releases of hazardous wastes such as battery acid and mercury. Any such releases from spent batteries and/or waste thermostats will subsequently be sampled and analyzed to determine if the materials released are hazardous waste. If so, they will be handled as fully regulated hazardous waste.

2.2.1.9 Off-Site Shipments, 40 CFR 273.18

> *A small-quantity universal waste generator may send its universal waste only to another universal waste handler, a destination facility, or a foreign destination.*

Since WIPP has not yet implemented a universal waste program, the spent lead acid batteries are sent to a reclamation facility, and the waste mercury-containing thermostats are sent to an approved TSDF as required under 40 CFR 266.80 and 40 CFR Part 262, respectively.

2.2.2 Compliance with the Land Disposal Restrictions (LDRs), 40 CFR Part 268

This section is limited to those EPA regulations implementing RCRA that are directly applicable to the WIPP. Regulations implementing other portions of RCRA for which the state of New Mexico is authorized are found in Chapter 25.

The compliance status of WIPP with respect to each of the applicable land-disposal restrictions of 40 CFR Part 268 is summarized in Table 2-3. Detailed information is provided in the text.

TABLE 2-3. RCRA Land-Disposal Restrictions - Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 268.1	Purpose, scope, and applicability	**ACHIEVED** No-Migration Determination for the test phase (NMD); *WIPP No-Migration Variance Petition* (NMVP) for disposal [Section 2.2.2.1]
40 CFR 268.6(a)	Submittal of petitions to allow land disposal of a waste prohibited under Subpart C of 40 CFR Part 268	**ACHIEVED** NMVP for disposal submitted to the EPA [Section 2.2.2.2]
40 CFR 268.6(b)	Requirements of demonstration of no-migration in petition	**ACHIEVED** NMVP for disposal [Section 2.2.2.3]
40 CFR 268.6(c)	Contents of petition	**ACHIEVED** NMVP for disposal [Section 2.2.2.4]
40 CFR 268.6(d)	Submittal of petition to EPA Administrator	**ACHIEVED** NMVP for disposal [Section 2.2.2.5]
40 CFR 268.6(e)	Consistency of activities with those described in the petition and notification of EPA of changes in conditions at the unit and/or in the environment	**NOT APPLICABLE** WID procedure based on NMD inactivated [Section 2.2.2.6]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 268.6(f)	Activities required if hazardous constituents are found to have migrated from the repository	**NOT APPLICABLE** No waste emplaced at WIPP [Section 2.2.2.7]
40 CFR 268.6(g)	Certification in petition	**ACHIEVED** Final NMVP for disposal certification signature [Section 2.2.2.8]
40 CFR 268.6(h)	Additional information requested by Administrator	**UP TO DATE** Final NMVP for disposal [Section 2.2.2.9]
40 CFR 268.6(k)	Terms of variance	**UP TO DATE** NMD for test phase; up to November 14, 2000 [Section 2.2.2.10]
40 CFR 268.6(n)	Non-exemption of liquid hazardous wastes containing ≥ 500 ppm polychlorinated biphenyls (PCBs)	**UP TO DATE** Prohibition of PCBs > 50 ppm and of liquids by *WAC* [Section 2.2.2.11]
40 CFR 268.7	Waste analysis and record-keeping	**UP TO DATE** WID procedures [Section 2.2.2.12]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 268.8	Landfill and surface impoundment disposal restrictions	**UP TO DATE** WIPP-generated LDR waste treated prior to disposal at TSDF [Section 2.2.2.13]
40 CFR 268.9	Special rules regarding wastes that exhibit a characteristic	**UP TO DATE** Hazardous waste code for waste determined; no approved technologies for mixed waste [Section 2.2.2.14]
40 CFR 268.10-12	Identification of waste to be evaluated by August 8, 1988; by June 8, 1989; and by May 8, 1990	**NOT APPLICABLE** No treatment technology for mixed waste approved to meet treatment standard; NMD received for test phase [Section 2.2.2.15]
40 CFR 268.30	Waste-specific prohibitions—solvent wastes	**UP TO DATE** WIPP-generated solvent wastes treated prior to TSDF land disposal at TSDF, incinerated, or recycled [Section 2.2.2.16]
40 CFR 268.31	Waste-specific prohibitions—dioxin-containing wastes	**NOT APPLICABLE** No dioxins at WIPP; none expected from generator sites [Section 2.2.2.17]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 268.32	Waste-specific prohibitions—California-listed wastes	**UP TO DATE** WIPP-generated California-listed wastes treated prior to land disposal at TSDF, incinerated, or recycled [Section 2.2.2.18]
40 CFR 268.33	Waste prohibitions—first-third wastes	**UP TO DATE** WIPP-generated first-third wastes treated prior to land disposal at TSDF, incinerated, or recycled [Section 2.2.2.19]
40 CFR 268.34	Waste prohibitions—second-third wastes	**UP TO DATE** WIPP-generated second-third wastes treated prior to land disposal at TSDF, incinerated, or recycled [Section 2.2.2.20]
40 CFR 268.35	Waste prohibitions—third-third wastes	**UP TO DATE** WIPP-generated third-third wastes treated prior to land disposal at TSDF, incinerated, or recycled [Section 2.2.2.21]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 268.41	Treatment standards expressed as concentrations in waste extract	**UP TO DATE** WIPP treatment standards on notification/certification forms accompanying shipments of LDR wastes; no treatment at WIPP for site-generated hazardous wastes [Section 2.2.2.22]
40 CFR 268.42	Treatment standards expressed as specified technologies	**UP TO DATE** WIPP treatment standards on notification/certification forms accompanying shipments of LDR wastes; no treatment at WIPP for site-generated hazardous wastes [Section 2.2.2.23]
40 CFR 268.43	Treatment standards expressed as waste concentrations	**UP TO DATE** WIPP treatment standards on notification/certification forms accompanying shipments of LDR wastes; no treatment at WIPP of site-generated hazardous wastes [Section 2.2.2.24]
40 CFR 268.44	Variance from a treatment standard	**NOT APPLICABLE** No technologies approved for treatment of mixed waste [Section 2.2.2.25]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 268.50	Prohibitions on storage of restricted wastes	**UP TO DATE** Addressed in WID procedures and manuals [Section 2.2.2.26]

2.2.2.1 Purpose, Scope, and Applicability, 40 CFR 268.1

> *The hazardous wastes restricted from land disposal are specified in this section. Limited circumstances are described under which an otherwise prohibited waste may continue to be land disposed.*

The requirements of 40 CFR Part 268 apply to generators and to the owners and operators of hazardous waste TSDFs. Therefore, WIPP is subject to 40 CFR Part 268 both as a generator of hazardous waste and as a TSDF for mixed waste. WID procedures are in place for identifying and characterizing hazardous waste generated at the facility.

With respect to WIPP as a TSDF, restricted waste may be placed in a salt-bed formation when an exemption from the prohibition pursuant to a petition under 40 CFR 268.6 has been granted. WIPP obtained such an exemption for the test phase, during which TRU mixed waste was to have been tested at WIPP (i.e., the EPA's NMD dated November 14, 1990). In spite of DOE's decision not to conduct tests using TRU and TRU mixed waste at WIPP, the relevant conditions specified in the EPA's NMD are still being implemented and are discussed in this document (see Section 2.3 of this chapter). Conditions and requirements specified by the EPA under any new no-migration determination that may be issued for the disposal phase at WIPP, based on the new WIPP NMVP for disposal, will be discussed in later revisions of the BECR after the EPA issues a new NMD for disposal at WIPP.

2.2.2.2 Submittal of Petitions to Allow Land Disposal of Prohibited Waste, 40 CFR 268.6(a)

> *A petition may be submitted to the Administrator requesting land disposal of a waste that is prohibited under Subpart C of Part 268. The petition must demonstrate, with a reasonable degree of certainty, that there will be no migration of hazardous constituents from the unit as long as the wastes remain hazardous.*

The NMVP for the test phase was submitted to the EPA in March 1989, and a revised version was submitted in March 1990 (DOE, 1990f). The EPA granted the NMD for the test phase in November 1990 (EPA, 1990b). The DOE submitted the final NMVP for disposal to the EPA in June 1996. EPA approval in the form of a second no-migration determination must be obtained, and all conditions stipulated for receipt of waste must be met before TRU mixed waste may be received at WIPP.

2.2.2.3 Criteria for the Demonstration of No-Migration in Petition, 40 CFR 268.6(b)

> *A number of criteria for demonstrating no migration in the petition are specified.*

Since the NMVP and the NMD pertained only to the testing of TRU and TRU mixed waste at WIPP during the test phase, a new NMVP for disposal was submitted to the EPA in June 1996. One of the requirements that must be completed prior to the implementation of the disposal phase is the EPA's publication of a variance from the LDRs for this phase at WIPP.

All criteria specified in 40 CFR 268.6(b) are addressed in the WIPP NMVP for disposal and are being included in the final NMVP for disposal, which was sent to the EPA in June 1996.

2.2.2.4 Contents of Petition, 40 CFR 268.6(c)

> *Each petition must include a monitoring plan for the monitoring program required to verify continued compliance with the conditions of the variance; baseline monitoring prior to receipt of the prohibited waste; submittal of the monitoring data to the Administrator; retention of the data on site in the operating record; and the Administrator's approval of all sampling, testing, and analytical data as well as approval of all estimation and monitoring techniques and the quality assurance and quality control plan for the monitoring program.*

Compliance with this requirement has been addressed in the NMVP for disposal that was submitted to the EPA in June 1996. DOE continues to report monitoring results annually in compliance with an EPA/DOE agreement concerning the applicable conditions of the NMD, which had been issued by the EPA in November 1990 for the test phase.

2.2.2.5 Submittal of Petition to EPA Administrator, 40 CFR 268.6(d)

> *Each petition must be submitted to the EPA Administrator.*

In March 1989, the DOE submitted the NMVP for the test phase to the EPA. In response to requests for additional information from the EPA, the DOE submitted two addenda to the NMVP for the test phase, one on October 1, 1989, the other on January 22, 1990. For the convenience of reviewers and other readers of this document, the various portions of the petition and addenda were consolidated and reprinted as a single eight-volume document dated March 1990.

The EPA published its *Notice Proposing to Grant a Conditional Variance to the Department of Energy Waste Isolation Pilot Plant (WIPP) for Land Disposal Restrictions* in the *Federal Register* on April 6, 1990 (EPA, 1990a); the *Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP)* (the NMD) was published on November 14, 1990 (EPA, 1990b). This variance was for test phase activities only. The final NMVP for disposal was submitted to the EPA in June 1996.

2.2.2.6 Consistency of Activities with Those Described in the Petition and Notification of EPA of Changes in Conditions, 40 CFR 268.6(e)

> *After a petition has been approved, any changes in conditions at the unit or the environment around the unit that significantly depart from the conditions described in the variance and affect the potential for migration of hazardous constituents from the unit must be reported.*

A WID procedure was prepared and implemented for reviewing changes (either planned or unplanned) in conditions at WIPP and/or the surrounding environment that may significantly depart from conditions described in the NMVP and in the NMD issued by the EPA that may affect the demonstration of no migration of hazardous constituents beyond the unit boundary. This procedure was based upon the NMD for the test phase and therefore has been inactivated. A new procedure will be issued after a variance for the disposal phase is obtained.

2.2.2.7 Activities Required If Hazardous Constituents Migrate, 40 CFR Part 268.6(f)

> *If hazardous constituents are found to have migrated from the repository, receipt of prohibited waste at the unit must be suspended immediately, and the Administrator must be notified in writing within 10 days of the determination that a release occurred. Within 60 days of the receipt of the notification, the Administrator will determine whether the facility may continue receiving prohibited waste in the unit, whether the variance is to be revoked, and whether further examination of any migration is warranted under applicable provisions of 40 CFR Part 264 or 265.*

Any activities required if hazardous constituents are found to have migrated from the unit during the disposal phase will depend upon those conditions specified in any no-migration determination for disposal to be issued by the EPA. The activities required will be reflected in appropriate WID documents, which will include methods for informing the appropriate DOE and EPA personnel.

2.2.2.8 Certification in Petition, 40 CFR 268.6(g)

> *Each petition must include a signed certification statement indicating the completeness and accuracy of the information included.*

A signed certification accompanied the submittal of the final NMVP for disposal to the EPA (Chapter 10).

2.2.2.9 Additional Information Requested by the Administrator, 40 CFR 268.6(h)

> *The Administrator may request additional information to evaluate the demonstration.*

Additional information was requested by the EPA after the DOE submitted the original NMVP for the test phase in March 1989. The additional information was provided to the EPA on October 1, 1989. Additional requests for information from the EPA resulted in the preparation of a second addendum, which was submitted on January 22, 1990. (See also response in Section 2.2.2.5.)

2.2.2.10 Length of Variance, 40 CFR 268.6(k)

> *The term of a variance granted by the EPA will be no longer than the term of the RCRA permit or up to 10 years from the date of approval for an interim-status TSDF.*

The NMD for the test phase provided for a 10-year term for the variance (i.e., through November 14, 2000). Any NMD for disposal from the EPA will likewise specify the duration of the variance.

2.2.2.11 Non-exemption of Liquid Hazardous Wastes Containing PCBs, 40 CFR 268.6(n)

> *Liquid hazardous wastes containing $\geq$ 500 ppm of polychlorinated biphenyls (PCBs) are not eligible for an exemption under this section.*

The *Waste Acceptance Criteria for the Waste Isolation Pilot Plant* (WAC; DOE, 1996) document allows no liquid waste forms, only residual liquids that are not allowed to exceed 1 percent of the volume of the container, and prohibits PCBs in concentrations exceeding 50 ppm. Furthermore, there are no plans to accept PCBs or PCB-containing wastes equal to or above the WAC limit of 50 ppm at WIPP. The WIPP RCRA permit application for disposal that was submitted to the NMED also prohibits the acceptance of PCB- and PCB-containing waste in excess of 50 ppm at WIPP.

2.2.2.12 Waste Analysis and Record-keeping, 40 CFR 268.7

> *Waste analysis and record-keeping requirements include the retention of any notices and certifications from the generator site that the waste meets the treatment standards of Subpart D and the results of the testing of the waste or of an extract of the waste to ensure that the wastes are in compliance with the treatment standards. The testing must be performed in accordance with the facility's waste analysis plan.*

Although treatment standards exist for mixed waste, there is no approved technology for treating mixed waste. Therefore, no such notices and certifications are anticipated from the generator sites. The DOE has submitted the final variance petition for disposal at WIPP to the EPA. The final petition was sent to the EPA in June 1996. When the EPA grants a variance for the disposal phase, the DOE will be allowed to ship untreated TRU mixed waste to WIPP upon completion of all other predisposal-phase requirements.

Sampling and analysis will be conducted at the generator sites as addressed in the *Waste Analysis Plan* (DOE, 1996), the *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE, 1995), and the *Transuranic Waste Characterization Sampling and Analysis Methods Manual* (DOE, 1995). Sampling consists of visual examination, real-time radiography, and headspace gas sampling of the drums. Samples of homogeneous solids and soil/gravel wastes are analyzed for both organic and inorganic constituents. Acceptable knowledge will also be used as appropriate to supplement sampling and analysis.

As a generator of land-disposal restricted waste that is not related to the TRU mixed waste to be received, WIPP provides the appropriate notification and/or certification forms to the TSDF accepting the waste with each shipment. WID procedures provide guidance regarding compliance with the requirements for generators under this part. (See also Chapter 25 on compliance with 40 CFR 262.40.)

2.2.2.13 Landfill and Surface Impoundment Disposal Restrictions, 40 CFR 268.8

> *Specific disposal restrictions apply to landfills and surface impoundments. Generators must make a good faith effort to locate and contract with treatment and recovery facilities prior to disposing of hazardous waste in landfills and surface impoundments.*

As a generator, WIPP has provisions in place for shipping its hazardous waste to treatment and/or recovery facilities. The hazardous waste generated at WIPP is either recycled, incinerated, or treated at the TSDF to meet the LDR standards prior to being landfilled if appropriate. Surface impoundments are not used.

WIPP will not manage TRU mixed waste using surface impoundments or landfills. Thus, the disposal restrictions for landfills and surface impoundments do not apply to WIPP as a TSDF.

2.2.2.14 Special Rules Regarding Wastes Exhibiting a Characteristic, 40 CFR 268.9

> *Special rules have been promulgated regarding wastes that exhibit a characteristic. The generator of the waste must determine the EPA Hazardous Waste Number for the waste to ascertain the applicable treatment standard under Subpart D of 40 CFR Part 268.*

WIPP personnel determine the appropriate EPA hazardous waste code and the effective date of the applicable treatment standard for all hazardous waste generated at WIPP in accordance with WID procedures. This information is included on the manifest that is sent to the TSDF that will receive the waste.

Waste generated at WIPP will be handled in accordance with WID procedures. These procedures provide guidance regarding compliance with the generator requirements. (See also Chapter 25 on compliance with 40 CFR 262.40.)

The requirements of 40 CFR 268.9 are not applicable to WIPP as a TSDF. Although treatment standards now exist for mixed waste, there are no approved technologies for treating this type of waste. A variance from these requirements similar to the NMD for the test phase at WIPP will be needed for the disposal phase.

2.2.2.15 Identification of Waste to Be Evaluated, 40 CFR 268.10-12

> *Wastes to be evaluated for land-disposal prohibition and establishment of treatment standards were divided into three thirds. Mixed waste, which was to have been evaluated by May 8, 1990, was included in the "third third."*

Appropriate technology has not yet been approved to meet the treatment standards devised for mixed waste. Therefore, the emplacement of any mixed waste at WIPP will require a variance from the requirement for treatment prior to shipment to WIPP. The mixed wastes expected to be received at WIPP for disposal are listed in Part A of the RCRA permit application for the disposal phase. Revision 6 of the RCRA permit application for WIPP was submitted to the NMED on April 12, 1996, in response to the NMED's Notice of Deficiency (NOD) that was issued to WID. (See also Chapter 25.)

2.2.2.16 Waste-Specific Prohibitions--Solvent Wastes, 40 CFR 268.30

> *Solvent wastes are prohibited from land disposal unless they are treated in accordance with the treatment standards of Subpart D.*

WIPP-generated solvent wastes are either incinerated, recycled, or treated to meet the applicable treatment standards at the TSDF (i.e., Safety Kleen or Chemical Waste Management) prior to land disposal.

The final NMVP for disposal was submitted to the EPA in June 1996. When the EPA grants a variance from the treatment standards for the disposal phase, treatment of the TRU mixed wastes to be received from the generator sites will not be required. Since the WAC for WIPP prohibits liquid wastes (except for liquid residues), only minor amounts of solvent-containing wastes are anticipated from the generator sites.

2.2.2.17 Waste-Specific Prohibitions--Dioxin-Containing Wastes, 40 CFR 268.31

> *Dioxin-containing wastes are prohibited from land disposal unless they are treated in accordance with the treatment standards of Subpart D.*

No dioxin-containing wastes are generated at or will be managed at WIPP.

2.2.2.18 Waste-Specific Prohibitions--California-Listed Wastes, 40 CFR 268.32

> *California-listed wastes are prohibited from land disposal unless they are treated in accordance with the treatment standards of Subpart D.*

WIPP-generated, California-listed wastes are either recycled, incinerated, or treated to meet the applicable treatment standards at a contracted TSDF prior to land disposal.

2.2.2.19 Waste Prohibitions--First-Third Wastes, 40 CFR 268.33

> *First-third wastes are prohibited from land disposal unless they are treated in accordance with the treatment standards of Subpart D.*

WIPP-generated first-third wastes are either recycled, incinerated, or treated to meet the applicable treatment standards at a contracted TSDF prior to land disposal.

When the EPA grants a variance from the treatment standards for the disposal phase, treatment of the TRU mixed wastes to be received from the generator sites will not be required.

2.2.2.20 Waste Prohibitions--Second-Third Wastes, 40 CFR 268.34

> *Second-third wastes are prohibited from land disposal unless they are treated in accordance with the treatment standards of Subpart D.*

WIPP-generated second-third wastes are either recycled, incinerated, or treated to meet the applicable treatment standards at a contracted TSDF prior to land disposal.

When the EPA grants a variance from the treatment standards for the disposal phase, treatment of the TRU mixed wastes to be received from the generator sites will not be required.

2.2.2.21 Waste Prohibitions--Third-Third Wastes, 40 CFR 268.35

> *Third-third wastes are prohibited from land disposal unless they are treated in accordance with the treatment standards of Subpart D.*

WIPP-generated third-third wastes are either recycled, incinerated, or treated to meet the applicable treatment standards at a contracted TSDF prior to land disposal.

When the EPA grants a variance from the treatment standards for the disposal phase, treatment of the TRU mixed wastes to be received from the generator sites will not be required.

2.2.2.22 Treatment Standards Expressed as Concentrations in Waste Extract, 40 CFR 268.41

> *Treated waste must meet the treatment standards expressed as concentrations in waste extract for the waste to be land disposed.*

When the EPA grants a variance from the treatment standards for the disposal phase, treatment of the TRU mixed wastes to be received from the generator sites will not be required.

The hazardous wastes generated at WIPP that are subject to the land-disposal restrictions are not treated at WIPP but at the TSDFs to which they are sent. WIPP personnel identify all EPA hazardous waste codes that apply to the waste shipments as well as the applicable performance-based treatment standards for each code listed on the notification/certification form.

2.2.2.23 Treatment Standards Expressed as Specified Technologies, 40 CFR 268.42

> *Certain wastes must be treated with the technologies specified in this section for the wastes to be land disposed.*

When the EPA grants a variance from the treatment standards for the disposal phase, treatment of the TRU mixed wastes to be received from the generator sites will not be required.

Hazardous waste generated at WIPP that is subject to the LDRs is not treated at WIPP but at the TSDF to which it is sent.

2.2.2.24 Treatment Standards Expressed as Waste Concentrations, 40 CFR 268.43

> *The waste concentrations specified in this section may not be exceeded for wastes to be land disposed.*

When the EPA grants a variance from the treatment standards for the disposal phase, treatment of the TRU mixed wastes to be received from the generator sites will not be required.

Hazardous waste subject to the LDRs that is generated at WIPP is treated at the TSDF to which it is sent rather than being treated at WIPP. WIPP personnel identify all EPA hazardous waste codes that apply to the waste shipment(s) as well as the applicable performance-based treatment standards for each code listed on the notification/ certification form.

2.2.2.25 Variance from a Treatment Standard, 40 CFR 268.44

> *A variance from a treatment standard may be granted by the EPA.*

Although treatment standards now exist for mixed waste, no technology has been approved as yet for treating these kinds of wastes.

2.2.2.26 Prohibitions on Storage of Restricted Wastes, 40 CFR 268.50

A number of prohibitions and requirements relating to the storage of restricted wastes are specified in this section. They include storing accumulated hazardous/mixed waste for no longer than 1 year and prohibiting liquid hazardous/mixed wastes that contain PCBs at concentrations greater than or equal to 50 ppm unless the facility meets the requirements of 40 CFR 761.65(b) of the Toxic Substances Control Act (TSCA).

As a generator of hazardous waste, programs have been implemented at WIPP that demonstrate compliance with the storage prohibitions for restricted waste. WID procedure manuals contain the procedures by which waste is characterized, accumulated, stored, manifested, and transported off site for disposal.

This requirement does not apply to waste covered by a variance granted under 40 CFR 268.6. During the disposal phase, small amounts of TRU mixed waste may be generated at WIPP from managing the TRU waste shipped from the generator sites (i.e., "derived waste"). All such derived waste will be managed as TRU mixed waste. (See also Chapter 25.) At present, the DOE has no plans to accept PCB-containing waste at WIPP. Furthermore, the *WAC* (DOE, 1996) precludes the receipt of liquid waste forms, allowing only liquid residues that are less than 1 percent of the volume of the container.

2.3 Compliance with the Conditional NMD

On April 6, 1990, the EPA published its *Notice Proposing to Grant a Conditional Variance to the Department of Energy Waste Isolation Pilot Plant (WIPP) from Land Disposal Restrictions* in the *Federal Register* (EPA, 1990a). This was followed by the publication of the EPA's final *Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP)* in the *Federal Register* on November 14, 1990 (EPA, 1990b). The NMD specified eight conditions for placement of hazardous constituents at WIPP during the test phase. In addition, four general conditions were established. The NMD also stipulated that the conditions pertaining to the VOC monitoring program that were discussed in detail in the proposed variance published in April be adopted by reference and that compliance with these conditions is also mandatory.

The compliance status of each of these conditions was provided in the first version of the BECR. In spite of DOE's change in position regarding the decision not to conduct test phase activities at WIPP, they are still being implemented to the extent applicable to WIPP. Therefore, these conditions are still included in this revision of the BECR and are summarized in Table 2-4; the text provides more detailed information. Conditions 1 through 8 from the NMD are presented in Sections 2.3.1 through 2.3.10. The general

conditions from the NMD are discussed in Sections 2.3.11 through 2.3.14, and the specific conditions that pertain to the VOC monitoring program are contained in Sections 2.3.15 through 2.3.40.

A new NMVP for the disposal phase at WIPP was sent to the EPA in June 1996. When the EPA issues a new no-migration determination for disposal, the conditions will be incorporated in the appropriate revisions of the BECR.

TABLE 2-4. The Conditional No-Migration Determination and the Proposed Variance - Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
EPA's Conditional No-Migration Determination (NMD), *Federal Register*, November 14, 1990, pp. 47700-47721 (55 FR 47700)		
Condition 1, IV.B.1 and VI(1)	Only testing for the purpose of determining the long-term acceptability of WIPP to be performed during the test phase	**NOT APPLICABLE** DOE decision to discontinue test phase at WIPP [Section 2.3.1]
Condition 2, IV.B.2 and VI(2)	Wastes not to exceed 8,500 drums or 1 percent of repository's total capacity	**NOT APPLICABLE** DOE decision to discontinue test phase at WIPP [Section 2.3.2]
Condition 3, IV.B.3 and VI(3)	Retrieval of waste if noncompliance with 40 CFR 268.6	**NOT APPLICABLE** DOE decision to discontinue test phase at WIPP [Section 2.3.3]
Condition 4, IV.B.4 and VI(4)	Readily retrievable placement of waste	**NOT APPLICABLE** DOE decision to discontinue test phase at WIPP [Section 2.3.4]

CITATION	REQUIREMENT	COMPLIANCE STATUS
Condition 5, IV.B.5 and VI(5)	Installation of carbon adsorption device	**NOT APPLICABLE** *Removed because bin-*scale tests no longer planned for WIPP [Section 2.3.5]
Condition 6, IV.B.6 and VI(6)	Implementation of air monitoring plan for VOCs	**UP TO DATE** Draft Air Pathway Baseline Monitoring Plan (Draft APBMP); WID procedures (see *also Sections 2.3.15-*2.3.40) [Section 2.3.6]
Condition 7(a), IV.B.7(a) and VI(7)(a)	Waste analysis: flammable mixtures of gases	NOT APPLICABLE DOE decision to discontinue test phase at WIPP [Section 2.3.7]
Condition 7(b), IV.B.7(b) and VI(7)(b)	Waste analysis: comparison of analytical results with estimated compositions	**UP TO DATE** *Waste Analysis Plan*; WID procedure [Section 2.3.8]
Condition 7(c), IV.B.7(c) and VI(7)(c)	Waste analysis: maintenance of records	**UP TO DATE** Records maintained by WID [Section 2.3.9]
Condition 8, IV.B.8 and VI(8)	Annual report	**UP TO DATE** Annual reports submitted as required [Section 2.3.10]

General Conditions for Compliance with the NMD (EPA, 1990b)		
General condition (GC) 1, IV.B.1	Correlation between wastes received and those described in the NMVP	**NOT APPLICABLE** DOE decision to discontinue test phase at WIPP [Section 2.3.11]
GC 2, VI	Notification of EPA of changes in conditions	**UP TO DATE** Implementation of WID procedure for identification of relevant changes [Section 2.3.12]
GC 3, VI	Suspension of receipt of restricted wastes and notification of EPA in the event of migration of hazardous constituents from the repository	**NOT APPLICABLE** Implementation of WID procedures for identification of relevant changes [Section 2.3.13]
GC 4, VI	Term of petition approval	**NOT APPLICABLE** No term specified yet for disposal [Section 2.3.14]
Additional Requirements for Air Monitoring under the Proposed Variance (PV) Published in the *Federal Register* on April 6, 1990 (EPA, 1990a)		
PV 1, IV.K	Monitoring in the exhaust shaft	**UP TO DATE** Draft APBMP; monitoring implemented July 1991 [Section 2.3.15]

PV 2, IV.K	Monitoring of bin-scale experiment rooms	**UP TO DATE** Draft APBMP; monitoring implemented July 1991 [Section 2.3.16]
PV 3, IV.K	Monitoring of alcoves	**NOT APPLICABLE** DOE decision to discontinue test phase at WIPP [Section 2.3.17]
PV 4, IV.K.1	Measurement of the leakage rate of sealed alcoves	**NOT APPLICABLE** DOE decision to discontinue test phase at WIPP [Section 2.3.18]
PV 5, IV.K.1	Weekly collection of air samples	**UP TO DATE** Draft APBMP; weekly samples, 1991-1994; monthly samples, 1995-present [Section 2.3.19]
PV 6, IV.K.1	Weekly/monthly monitoring at the exhaust shaft and air intake locations	**UP TO DATE** Draft APBMP; weekly, then monthly, monitoring by exhaust shaft sampler [Section 2.3.20]
PV 7, IV.K.1	Monitoring frequency for the bin discharge system	**NOT APPLICABLE** DOE decision to discontinue test phase at WIPP [Section 2.3.21]

PV 8, IV.K.1	Increased monitoring frequency due to increased variability	**NOT APPLICABLE** Weekly monitoring, 1991-1994 [Section 2.3.22]
PV 9, IV.K.2	Routine quantification of any VOC	**UP TO DATE** Draft APBMP; VOC Monitoring Quality Assurance Project Plan (QAPjP) [Section 2.3.23]
PV 10, IV.K.2	Standard operating procedures to identify certain other VOCs	**ACHIEVED** Draft APBMP; VOC Monitoring QAPjP; WID procedure [Section 2.3.24]
PV 11, IV.K.3	Use of the average response factor for each target analyte	**ACHIEVED** Draft APBMP; VOC Monitoring QAPjP [Section 2.3.25]
PV 12, IV.K.4	Use of standard operating procedures to ensure the validity of the monitoring data	**ACHIEVED** VOC Monitoring QAPjP; WID manual and procedures [Section 2.3.26]
PV 13, IV.K.4	Recalibration of instruments	**UP TO DATE** VOC Monitoring QAPjP [Section 2.3.27]
PV 14, IV.K.4	Establishment and annual evaluation of the method limit of quantification for each target analyte	**UP TO DATE** Draft APBMP; VOC Monitoring QAPjP [Section 2.3.28]

PV 15, IV.K.4	Separate determination of the method limit of quantification for the bin, alcove, and exhaust shaft monitoring locations	**ACHIEVED** Draft APBMP; VOC Monitoring QAPjP Section 2.3.29]
PV 16, IV.K.4	Collection and analysis of recovery samples	**UP TO DATE** Draft APBMP; VOC Monitoring QAPjP [Section 2.3.30]
PV 17, IV.K.4	Collection and analysis of duplicate samples	**UP TO DATE** Draft APBMP; VOC Monitoring QAPjP; WID procedures [Section 2.3.31]
PV 18, IV.K.4	Validation of the completeness of the data	**UP TO DATE** VOC Monitoring QAPjP [Section 2.3.32]
PV 19, IV.K.4	Tracking and evaluation of accuracy, precision, and completeness of the data	**UP TO DATE** VOC Monitoring QAPjP [Section 2.3.33]
PV 20, IV.K.4	Performance of systems audits	**UP TO DATE** VOC Monitoring QAPjP [Section 2.3.34]
PV 21, IV.K.4	Corrective action required for improper conditions or practices	**ACHIEVED** VOC Monitoring QAPjP [Section 2.3.35]
PV 22, IV.K.4	Establishment of specific quality assurance objectives for data acceptability	**ACHIEVED** VOC Monitoring QAPjP [Section 2.3.36]

PV 23, IV.K.4	Corrective action required	**NOT APPLICABLE** VOC Monitoring QAPjP [Section 2.3.37]
PV 24, IV.K.5	Annual averaging of concentrations of targeted constituents	**ACHIEVED** Implementation of WID procedures; annual reports [Section 2.3.38]
PV 25, IV.K.5	Submittal of annual data summaries and summaries of data accuracy, precision, and completeness for each monitoring location	**ACHIEVED** Implementation of WID procedures; annual reports, VOC-1 [Section 2.3.39]
PV 26, IV.K.5	Maintenance of documentation on all aspects of quality assurance/quality control (QA/QC)	**ACHIEVED** Implementation of WID procedures [Section 2.3.40]

2.3.1 Condition 1, Testing Only of Long-Term Acceptablity of WIPP

Only testing for the purpose of determining WIPP's long-term acceptability is to be performed during the test phase.

Due to DOE's decision to discontinue plans for radioactive waste tests in the WIPP underground, this condition is no longer applicable.

2.3.2 Condition 2, Wastes Not to Exceed 8,500 Drums, or 1 Percent of the Repository's Total Capacity

Waste to be emplaced during the test phase at WIPP will not exceed 8,500 drums or 1 percent of repository's total capacity.

Due to DOE's decision to discontinue plans for radioactive waste tests in the WIPP underground, this condition is no longer applicable.

2.3.3 Condition 3, Retrieval of Waste in the Event of Noncompliance with 40 CFR 268.6

> *If the DOE cannot demonstrate compliance with the standards of 40 CFR 268.6, all wastes emplaced in WIPP must be removed.*

Due to DOE's decision to discontinue plans for radioactive waste tests in the WIPP underground, this condition is no longer applicable.

2.3.4 Condition 4, Readily Retrievable Placement of Waste

> *All wastes emplaced at WIPP during the test phase must be placed in a readily retrievable manner.*

Due to DOE's decision to discontinue plans for radioactive waste tests in the WIPP underground, this condition is no longer applicable.

2.3.5 Condition 5, Installation of a Carbon Adsorption Device

> *The DOE must install and operate a carbon adsorption device designed to achieve a control efficiency of 95 percent in the discharge system of the bin experiment rooms.*

Due to DOE's decision to discontinue plans for radioactive waste tests in the WIPP underground, this condition is no longer applicable.

2.3.6 Condition 6, Implementation of the Air Monitoring Plan for VOCs

> *The DOE must implement the air monitoring plan for VOCs described in Section IV.K of the proposed variance. (See also BECR Sections 2.3.15 through 2.3.40.) Requirements include weekly monitoring of the five targeted VOCs, QA/QC, collection of a matrix spike and a concurrent matrix duplicate to adjust for background VOC concentrations, ± 10-percent accuracy of the concentration data, a quarterly check on the calibration of the ventilation exhaust fans, and annual calibration. The five target compounds are carbon tetrachloride; methylene chloride; trichloroethylene; 1,1,1-trichloroethane; and 1,1,2-trichloro-1,2,2-trifluoro-ethane.*

The EPA required that the VOC program be implemented 30 days prior to the first receipt of TRU waste at WIPP. The VOC monitoring program described in the addendum to the NMVP was implemented at WIPP during July and August 1991.

Weekly monitoring was conducted at the VOC-1 location (i.e., at the exhaust shaft) from July 1991 and into November 1994; a semi-monthly monitoring schedule was implemented in November 1994 and continued until September 1995. Monthly sampling has been conducted from September 1995 through the present, with occasional monitoring being conducted at other locations. Records relating to VOC air monitoring are maintained in the WIPP operating record and will be retained for the term of the NMD (i.e., until November 14, 2000) or for 3 years, whichever is longer, as required by this condition.

The DOE has committed to a full dynamic calibration of the exhaust fans annually, with quarterly checks. The quarterly checks consist of a Pitot tube traverse, comparing the measured value from the reference method with that of the system being tested. If the system is outside tolerance, a full dynamic calibration will be performed. The quarterly checks are performed in accordance with WID preventive maintenance procedures.

The VOC monitoring plan designed for use during the test phase and its companion quality assurance project plan have been replaced by the draft *Air Pathway Baseline Monitoring Plan for Volatile Organic Compounds at the Waste Isolation Pilot Plant* (WID, 1996; referred to subsequently as the "Air Pathway Baseline Monitoring Plan"), which incorporates guidelines received from the EPA that resulted from DOE's decision to conduct no underground tests at WIPP involving radioactive wastes during the test phase. This document will continue to be used until the EPA issues a no-migration variance for disposal.

2.3.7 Condition 7(a), Waste Analysis: Flammable Mixtures of Gases

Three conditions were imposed relating to waste analysis. The first of these conditions is that the DOE ensure that each waste container emplaced underground at WIPP has no layer of confinement in containers that contain flammable mixtures of gases. This prohibition must be implemented by analytical testing of headspace gases from each drum/container. (The other two conditions relating to waste analysis are described in Sections 2.3.8 and 2.3.9.)

This condition from the NMD for the test phase was based upon the assumption that sealed containers of waste would be managed during the test phase at WIPP. During the disposal phase, however, all of the containers will be continuously vented, as reflected in the WIPP Waste Analysis Plan (Chapter C of the WIPP RCRA Permit Application, Revision 6). Therefore, this condition is no longer applicable.

2.3.8 Condition 7(b), Waste Analysis: Comparison of Analytical Results with Estimated Compositions

The second condition pertaining to waste analysis is that the DOE must analyze representative samples of the headspaces of containers and compare the results with the estimated compositions provided in the WIPP NMVP.

Due to DOE's decision to discontinue plans for conducting radioactive waste tests in the WIPP underground, the condition is not currently applicable.

2.3.9 Condition 7(c), Waste Analysis: Maintenance of Records

The third condition relating to waste analysis is that waste analysis records must be maintained for the term of the NMD or for 3 years after generation, whichever is longer. Records must also be maintained during the course of any enforcement action for which they are relevant.

Due to DOE's decision to discontinue plans to test radioactive mixed waste underground at WIPP during the test phase, this condition is no longer applicable.

2.3.10 Condition 8, Annual Report

The DOE must provide annual written reports to EPA Region VI on the status of DOE's performance assessment during the test phase.

The Office of Solid Waste at EPA headquarters and EPA's Region VI office have been provided with several annual written reports to date. Personnel from the EPA and WIPP have agreed that abbreviated reports be submitted under the NMD until the EPA's issuance of a no-migration variance for disposal. Therefore, the latest annual report, which was submitted to DOE in October 1995 and to the EPA in early November 1995, contained reference to the waste characterization data from the draft NMVP for disposal, a brief summary of DOE's experimental program for confirming parameters to be used in performance-assessment models, and a summary of the VOC monitoring data obtained since the submittal of the last VOC annual report in 1994.

2.3.11 General Condition (GC) 1, Correlation between the Wastes Emplaced by DOE at WIPP and DOE's Activities with Those Described in the NMVP

The wastes to be emplaced by the DOE at WIPP and the experiments and tests conducted during the test phase must be consistent with those described in the NMVP and in the DOE's performance assessment test plan.

Due to DOE's decision to discontinue plans for conducting tests on radioactive waste in the WIPP underground, this condition is no longer applicable.

2.3.12 General Condition 2, Notification of EPA of Changes in Conditions

> *The DOE must notify the EPA of "any changes in conditions at the unit and/or environment that significantly depart from the conditions described in the variance and affect the potential for migration of hazardous constituents from the unit..." If the change is planned, the EPA must be notified in writing 30 days before the change; if it is unplanned, the EPA must be notified within 10 days.*

Due to DOE's decision to discontinue plans for conducting tests on radioactive waste in the WIPP underground, this condition is no longer applicable.

2.3.13 General Condition 3, Suspension of Receipt of Restricted Wastes and Notification of EPA within 10 Days in the Event of Migration of Hazardous Constituents from the Repository

> *In the event of the migration of hazardous constituents from the repository, the DOE will suspend receipt of restricted wastes and will notify the EPA (Office of Solid Waste and EPA Region VI) within 10 days.*

Due to DOE's decision to discontinue plans for conducting tests on radioactive waste in the WIPP underground, this condition is no longer applicable.

2.3.14 General Condition 4, Term of Petition

> *The term of the petition approval specified in the NMD is 10 years (i.e., until November 14, 2000).*

The NMD pertains to the test phase only. Since the test phase will no longer involve the testing of TRU mixed waste at WIPP, the term specified is not directly applicable. When the EPA grants a variance determination in response to the submittal to the NMVP for disposal, it is likely that the term will also be for 10 years, subject to complying with any conditions set by the EPA and with other requirements.

2.3.15 Proposed Variance Condition (PV) 1, Monitoring in the Exhaust Shaft

> *Monitoring in the exhaust shaft must begin 30 days prior to the emplacement of any experimental wastes underground.*

This requirement was originally stipulated in Section 3.3 of the *VOC Monitoring Plan for the Bin-Scale Tests* and was met during July and August of 1991, when VOC monitoring was initiated at WIPP. Weekly monitoring in the exhaust shaft continued from July 1991 into November 1994; semi-monthly monitoring was performed beginning in November 1994 and continued until September 1995, when monthly monitoring was implemented, as described in the draft Air Pathway Baseline Monitoring Plan, which will continue to be used until the EPA issues a no-migration variance for disposal at WIPP.

It should be noted that this and the rest of the requirements in this section would have been applicable only to the performance of tests on TRU mixed waste at WIPP if they had been conducted. However, the DOE has chosen to maintain the programs necessary for compliance with a number of these requirements in accordance with a guidance letter received from the EPA regarding compliance with the 1990 NMD conditions.

2.3.16 Proposed Variance Condition 2, Monitoring of Bin-Scale Experiments

> *Monitoring of bin-scale experiment rooms must commence prior to emplacement of any bins containing TRU waste.*

Due to DOE's decision to discontinue plans to conduct tests on radioactive waste underground at WIPP during the test phase, this condition is no longer applicable because there are no longer any plans to conduct bin-scale tests at WIPP.

2.3.17 Proposed Variance Condition 3, Monitoring of Alcoves

> *Monitoring of alcoves must commence prior to initiation of alcove experiments, after alcoves are sealed, and prior to purging of alcove atmosphere.*

Due to DOE's decision to discontinue plans to conduct tests on TRU waste in the WIPP underground, this condition is no longer applicable.

2.3.18 Proposed Variance Condition 4, Leakage Rate of the Sealed Alcoves

> *The leakage rate of the sealed alcoves must be measured by means of injecting tracer gases into the atmosphere within each alcove and monitoring the tracer gas levels.*

Due to DOE's decision to discontinue plans to conduct tests on radioactive wastes in the WIPP underground, this condition is no longer applicable.

2.3.19 Proposed Variance Condition 5, Weekly Collection of Air Samples

> *Air samples must be collected at least weekly.*

A weekly schedule for collecting air samples for the subsequent analysis of VOCs was used at the exhaust shaft location at WIPP from July 1991 into November 1994, as indicated in Section 7.2.1 of the *VOC Monitoring Quality Assurance Project Plan* (WID, 1991a). Due to DOE's decision to discontinue plans to conduct tests on radioactive waste in the WIPP underground, the sample collection schedule was changed to a bi-monthly basis from November 1994, which continued until September 1995, when sampling was performed on a monthly basis, as described in the draft Air Pathway Baseline Monitoring Plan.

2.3.20 Proposed Variance Condition 6, Weekly Monitoring at the Exhaust Shaft and Air Intake Locations

> *Exhaust shaft and air intake locations must be monitored weekly.* A weekly schedule for collecting air samples for the subsequent analysis of VOCs was being used at the WIPP, as indicated in Section 7.2.1 of the *VOC Monitoring Quality Assurance Project Plan.*

Weekly collection of air samples was performed at the exhaust shaft from July 1991 into November 1994. Due to DOE's decision to discontinue plans to test radioactive waste in the WIPP underground, the sample collection schedule was changed to a semi-monthly basis in November 1994, which continued until September 1995, when sampling was performed on a monthly basis, as described in the draft Air Pathway Baseline Monitoring Plan.

2.3.21 Proposed Variance Condition 7, Monitoring Frequency

> *In no event shall the monitoring frequency for the bin discharge system be reduced to less than 20 percent of the minimum time required for the consumption of the total working capacity of the carbon adsorption system.*

This condition was reflected in Section 3.3.1 of the *VOC Monitoring Plan for the Bin-Scale Tests* and in Section 7.2.1 of the *VOC Monitoring Quality Assurance Project Plan.* Due to the DOE's decision to discontinue plans to conduct bin-scale tests for radioactive waste in the WIPP underground, this condition is no longer applicable.

2.3.22 Proposed Variance Condition 8, Increased Monitoring Due to Increased Variability

> *In the event that the results of weekly air monitoring exhibit increased variability, daily air sampling must be resumed if the calculated relative standard deviation in the preceding 4-week period at the monitoring locations exceeds 75 percent for any targeted constituent.*

Due to DOE's decision to discontinue plans for testing radioactive waste in the WIPP underground, this condition is no longer applicable.

2.3.23 Proposed Variance Condition 9, Routine Quantification of Any VOC

> *Any VOC must be targeted for routine quantification if the average estimated concentration at the point of sampling is 1 ppm or more during any 4-month period and the compound is detected in at least 10 percent of the samples collected from the gas discharge system from either the room containing bins or from 50 percent of the samples collected from any alcove.*

Section 3.2 of the draft Air Pathway Baseline Monitoring Plan indicates that 13 VOCs have been initially identified and that the presence of other compounds will be investigated. This requirement is also reflected in Section 9.4.2 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.24 Proposed Variance Condition 10, Standard Operating Procedures to Identify Certain Other VOCs

> *The DOE must implement standard operating procedures to provide positive identification of the following compounds: perchloroethylene (i.e., tetrachloroethylene), chloroform, bromoform, dichloroethane, dichloroethylene, toluene, and chlorobenzene.*

This requirement is reflected in Section 3.2 of the draft Air Pathway Baseline Monitoring Plan and in Sections 9.2.1.6 and 9.2.1.7 of the *VOC Monitoring Quality Assurance Project Plan.* To implement these plans, a standard operating procedure (SOP) is in place at the contract laboratory to provide positive identification of these non-targeted VOCs as well as the targeted compounds.

2.3.25 Proposed Variance Condition 11, Use of the Average Response Factor for Each Target Analyte

> *The average response factor for each target analyte, as determined by five-point instrument calibration, must be used for quantification in high-resolution gas chromatography.*

The generation of the relative response factor for each target compound is described in the draft Air Pathway Baseline Monitoring Plan. This requirement is also reflected in Sections 9.2.1.5 and 9.2.2.4 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.26 Proposed Variance Condition 12, Standard Operating Procedures to Ensure the Validity of Monitoring Data

> *Standard operating procedures must be adopted by the DOE to ensure the validity of the monitoring data.*

This requirement is reflected in Section 12.0 of the *VOC Monitoring Quality Assurance Project Plan.* A number of procedures have been issued to implement this requirement.

2.3.27 Proposed Variance Condition 13, Recalibration of Instruments

> *Consistent with EPA's Method 8240 of SW-846, instruments must be recalibrated by a full five-point calibration if the response factor from the calibration check differs by more than 25 percent of the average or expected response factor.*

This requirement is reflected in Section 4.5.4 of the draft Air Pathway Baseline Monitoring Plan and in Section 9.2.1.5 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.28 Proposed Variance Condition 14, Establishment and Annual Evaluation of the Method Limit of Quantification for Each Target Analyte

> *The method limit of quantification for each target analyte must be established prior to the initiation of the monitoring program and must be reevaluated annually thereafter in accordance with EPA/530-SW-90-021, "Quality Assurance and Quality Control," dated August 1990.*

This requirement is reflected in Section 9.3.2.6 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.29 Proposed Variance Condition 15, Separate Determination of the Method Limit of Quantification for the Bin, Alcove, and Exhaust Shaft Monitoring Locations

> *The method limit of quantification must be determined separately for the bin, alcove, and exhaust shaft monitoring locations.*

This requirement is reflected in Section 9.3.2.6 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.30 Proposed Variance Condition 16, Collection and Analysis of Recovery Samples

> *Recovery samples must be collected from audit cylinders and analyzed at a frequency of 10 percent at each monitoring location.*

This requirement is reflected in Section 9.3.1.4 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.31 Proposed Variance Condition 17, Collection and Analysis of Duplicate Samples

> *Duplicate samples must be collected and analyzed at a frequency of 10 percent in each monitoring location, including the exhaust shaft.*

This requirement is reflected in Section 9.3.1.3 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.32 Proposed Variance Condition 18, Validation of the Completeness of the Data

> *Data completeness must be evaluated by data validation audits at a frequency not less than 5 percent.*

This requirement is reflected in Sections 9.3.2.10 and 12.4 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.33 Proposed Variance Condition 19, Tracking and Evaluation of Accuracy, Precision, and Completeness

> *To ensure that any sampling analysis problems that may occur are detected and corrected, accuracy, precision, and completeness must be tracked and evaluated after every 10 quality control analyses.*

The evaluation and tracking of precision, accuracy, and completeness are discussed in Sections 5.11 through 5.1.3, respectively, in the draft Air Pathway Baseline Monitoring Plan. This requirement is also reflected in Section 9.3.2.9 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.34 Proposed Variance Condition 20, Performance of Systems Audits

> *Systems audits must be performed, not only prior to the initiation of the monitoring program, but also semi-annually thereafter to be consistent with good operating practice.*

This requirement is reflected in Section 12.3 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.35 Proposed Variance Condition 21, Corrective Action Required for Improper Conditions or Practices

> *Corrective action must be taken whenever a condition or practice is found that is outside systems specifications or SOPs or that could reasonably be expected to compromise the ability of the monitoring program to meet established quality assurance objectives for data acceptability.*

This requirement is reflected in Section 11.0 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.36 Proposed Variance Condition 22, Establishment of Specific Quality Assurance Objectives

> *Specific quality assurance objectives must be established for data acceptability for the WIPP air monitoring program consistent with method capability and good operating practice.*

This requirement is reflected in Section 5.1 of the draft Air Pathway Baseline Monitoring Plan and in Section 9.3.2 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.37 Proposed Variance Condition 23, Corrective Action Required

> *Corrective action must be taken whenever quality assurance objectives for data acceptability are not being met.*

This requirement is reflected in Section 11.0 of the *VOC Monitoring Quality Assurance Project Plan.*

2.3.38 Proposed Variance Condition 24, Annual Averaging of Concentrations of Targeted Constituents

> *To determine whether migration has occurred, concentrations of targeted constituents must be averaged over an annual time period.*

The VOC Operating Procedures Manual (WP 12-VC) includes all the operating procedures used to support the VOC monitoring program. In addition, the draft Air Pathway Baseline Monitoring Plan presents information about the program, and WP 12-7, the *VOC Monitoring Quality Assurance Project Plan*, presents information pertaining to quality assurance requirements. Average concentrations of the five targeted constituents were included as part of the annual reports issued to the EPA during this reporting period, including the report submitted by WID to the DOE in October 1995, as required by Condition 8 of the NMD. (See also Section 2.3.10.)

2.3.39 Proposed Variance Condition 25, Submittal of Annual Data Summaries and Summaries of Data Accuracy, Precision, and Completeness for Each Monitoring Location

> *Annual data summaries and summaries of data accuracy, precision, and completeness for each monitoring location, together with calculated concentrations at the exhaust shaft and documentation of the actual method limit of detection achieved for each targeted analyte, must be submitted to the EPA.*

The VOC Operating Procedures Manual (WP 12-VC) includes all the operating procedures used to support the VOC monitoring program. In addition, the draft Air Pathway Baseline Monitoring Plan presents information about the program, and WP 12-7, the *VOC Monitoring Quality Assurance Project Plan*, presents information pertaining to quality assurance requirements. Data summaries were provided to the EPA in the last annual report, which was submitted to DOE in October. In accordance with guidelines from the EPA, summaries of data accuracy, precision, and completeness were not required and were not included since this is baseline information, and a significant amount of baseline data have already been gathered in accordance with the draft Air Pathway Baseline Monitoring Plan.

2.3.40 Proposed Variance Condition 26, Maintenance of Documentation on All Aspects of QA/QC

Documentation on all aspects of QA/QC as described in EPA/530-SW-90-021 must be maintained at WIPP.

Auditable records pertaining to the VOC Monitoring Program have been examined and were found to be satisfactory. The EPA performed an unannounced audit during the reporting period in which such functions as chain of custody and QA parameters were examined. The findings were satisfactory.

3.0 COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT

3.1 Summary of the Law

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; 42 USC §§ 9601 et seq.), or "Superfund," and the Superfund Amendments and Reauthorization Act of 1986 (SARA) establish a comprehensive Federal strategy for responding to, and establishing liability for, releases of hazardous substances from a facility to the environment. The Emergency Planning and Community Right-to-Know Act (EPCRA) was enacted as a stand-alone portion under SARA. It is described in further detail in Chapter 4.

Any spills of reportable quantities of hazardous substances must be reported to the National Response Center (NRCr) under the provisions of § 103 of CERCLA, *Notices, Penalties,* and the implementing regulations in 40 CFR Part 302, *Designation, Reportable Quantities, and Notification.* Because the WIPP is not a CERCLA remediation site and is not expected to become one, most of the requirements of this act do not apply.

The WIPP is responsible to report and manage any release of hazardous substances as defined in § 101 of CERCLA, *Definitions*, in quantities equal to or greater than the reportable quantities outlined in § 102, *Reportable Quantities and Additional Designations*, and specified in 40 CFR Part 302. In the event of a release of a hazardous substance to the environment in an amount that meets or exceeds the reportable quantity for that substance, a notification of the release will be made to the appropriate agencies by WIPP personnel as required by § 103 of CERCLA.

Section 120(c) of CERCLA, *Federal Agency Hazardous Waste Compliance Docket*, establishes a docket that provides information regarding federal facilities that manage hazardous waste or from which hazardous substances may be or have been released. This is information to be submitted to the EPA by other federal agencies under § 103 of CERCLA or under §§ 3005, 3010, or 3016 of RCRA. Facilities listed under the docket must prepare a Preliminary Assessment and submit it to the EPA within 18 months of the date of publication in the *Federal Register.* If deemed necessary, a site inspection report is also due to the EPA within the same time frame.

Under 40 CFR Part 300, *National Oil and Hazardous Substances Pollution Contingency Plan* (NCP), the organizational structures and procedures are provided for preparing for and responding to discharges of oil and releases of hazardous substances, pollutants, and contaminants. The NCP is required by § 105 of CERCLA.

3.2 Compliance Status of the Regulatory Requirements

Table 3-1 summarizes each applicable requirement and its compliance status under CERCLA. The text provides more detail on the compliance status of each requirement.

TABLE 3-1. Comprehensive Environmental Response, Compensation, and Liability Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
§ 120, *Federal Facilities*, of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)		
CERCLA, § 120(d)	Assessment and evaluation	**UP TO DATE** Preliminary assessment submitted August 24, 1994, to EPA [Section 3.2.1]
40 CFR Part 300, *National Oil and Hazardous Substances Pollution Contingency Plan*		
40 CFR 300.215(b)	Emergency planning requirements	**ACHIEVED** WIPP representative on LEPC [Section 3.2.2]
40 CFR 300.215(e)	Material safety data sheet (MSDS) and inventory form	**UP TO DATE** List of hazardous chemicals; Emergency and Hazardous Chemical Inventory Report (Tier II Report) [Section 3.2.3]

40 CFR Part 302, *Designation, Reportable Quantities, and Notification*		
40 CFR 302.4	Designation of hazardous substances	**ACHIEVED** Spills of ethylene glycol identified as hazardous [Section 3.2.4]
40 CFR 302.5	Determination of reportable quantities (RQs)	**ACHIEVED** Spills of ethylene glycol that exceeded current RQ [Section 3.2.5]
40 CFR 302.6(a)	Notification requirements	**ACHIEVED** Ethylene glycol spills reported to NRCr [Section 3.2.6]
40 CFR 302.6(b)(1)	Release of mixtures or solutions	**ACHIEVED** RQ for mixture of hazardous constituents determined - see Section 3.2.5 [Section 3.2.7]
40 CFR 302.6(b)(2)	Notification of releases of radionuclides	**NOT APPLICABLE** Applicable upon receipt of TRU waste [Section 3.2.8]
40 CFR 302.6(d)	Notification of the release of heavy metals	**NOT APPLICABLE** No release of heavy metals at WIPP [Section 3.2.9]

3.2.1 Assessment and Evaluation of Federal Facilities, § 120 of CERCLA

> *A preliminary assessment and, if warranted, a site inspection must be submitted to the EPA by each Federal facility that is included on the docket of Federal facilities that manage hazardous waste or from which hazardous substances have been released. The preliminary assessment or preliminary assessment/site inspection for a facility must be submitted to the EPA within 18 months of the publication of the notice that includes the facility on the Federal Agency Hazardous Waste Compliance docket.*

On February 5, 1993, WIPP was included as a new facility in the additions made to the Federal Agency Hazardous Waste Compliance Docket in the *Federal Register* (58 *FR* 7298). A preliminary assessment for WIPP was submitted to the EPA August 24, 1994.

3.2.2 Emergency Planning Requirements, 40 CFR 300.215(b)

> *A facility is subject to emergency planning requirements if an extremely hazardous substance [as defined in 40 CFR Part 355] is present at the facility in an amount equal to or in excess of the threshold planning quantity established for the substance. A Governor may designate additional facilities that will also be subject to these planning requirements. Facility owners or operators should name a facility representative who will participate in the planning process as a facility Emergency Coordinator.*

WIPP is subject to the emergency planning requirements. A WIPP representative has been designated to serve on the Local Emergency Planning Committee (LEPC). The WIPP representative is part of the WID Emergency Management Section. Emergency Management is responsible for WIPP's emergency response and preparedness programs.

3.2.3 Material Safety Data Sheet and Inventory Form, 40 CFR 300.215(e)

> *Each facility required to prepare or have available a material safety data sheet (MSDS) will submit either an MSDS for each hazardous chemical or a list of hazardous chemicals to the appropriate State Emergency Response Commission (SERC), LEPC, and local fire department in accordance with 40 CFR Part 370.*

> *Each facility will also submit an inventory form to the SERC, LEPC, and local fire department. This inventory form must contain an estimate of the maximal amount of hazardous chemicals present at the facility during the preceding year, an estimate of the average daily amount of hazardous chemicals at the facility, and the location of those chemicals.*

In lieu of MSDSs, the WIPP submits a list of those hazardous chemicals which are present at WIPP in amounts that exceed their respective reportable quantities.

The requirement to submit the Emergency and Hazardous Chemical Inventory report to the SERC, LEPC, and local fire department has been met. These requirements are also discussed in Chapter 4.

3.2.4 Designation of Hazardous Substances, 40 CFR 302.4

> *Hazardous substances released to the environment must be identified.*

During this reporting period, there were two antifreeze spills at the WIPP facility which exceeded the RQ. The major ingredient of antifreeze is ethylene glycol (Chemical Abstract Service [CAS 107-21-1]). This substance is designated as a hazardous substance under § 302.4 of CERCLA.

3.2.5 Determination of Reportable Quantities, 40 CFR 302.5

> *Reportable quantities (RQs) are established for each substance listed in Table 302.4 or in Appendix B.*

Each of the spills was determined to have exceeded the RQ for ethylene glycol at that time; one pound. This determination was based upon the concentration of the ethylene glycol/water mixture, the data obtained from the MSDS, and the current RQ for the substance. The EPA raised the RQ for ethylene glycol from 1 pound to 5000 pounds on June 12, 1995.

3.2.6 Notification Requirements, 40 CFR 302.6(a)

> *Any release of a hazardous substance in a quantity equal to or exceeding the reportable quantity determined in 40 CFR 302.5 or in 40 CFR Part 117 in any 24-hour period shall immediately be reported to the NRCr at (800) 424-8802.*

The ethylene glycol spills were reported to the NRCr as required. (See also the *WIPP NPDES Storm Water Pollution Prevention Plan* [WID, 1993b]).

3.2.7 Releases of Mixtures or Solutions, 40 CFR 302.6(b)(1)

> *If a mixture or solution is released and the quantity of all hazardous constituents is known, notification is required when a quantity that meets or exceeds the RQ of any hazardous constituent has been released. If the quantity of one or more of the hazardous constituents is not known, notification is required when the total amount of the mixture or solution released equals or exceeds the RQ for the hazardous constituent with the lowest RQ.*

The determination of the RQs for hazardous constituents of a mixture was discussed in Section 3.2.5.

3.2.8 Notification of Releases of Radionuclides, 40 CFR 302.6(b)(2)

> *Radionuclides are subject to these notification requirements only under the following circumstances:*
>
> - *If the identity and quantity of each radionuclide in a released mixture or solution is known and the sum of the ratios (quantity released in curies/RQ for the radionuclide) for the radionuclides in the mixture or solution is equal to or greater than 1, or*
> - *If the quantity of each radionuclide in a released mixture or solution is known but the quantity released (in curies) of one or more of the radionuclides is unknown and the total quantity (in curies) of the mixture or solution is equal to or greater than the lowest RQ of any individual radionuclide in the mixture or solution, or*
> - *If the identity of one or more radionuclides in a released mixture or solution is unknown and the total quantity (in curies) released is equal to or greater than either 1 curie or the lowest RQ of any known individual radionuclide in the mixture or solution, whichever is lower.*

This requirement will become applicable when WIPP receives TRU waste.

3.2.9 Notification of the Release of Heavy Metals, 40 CFR 302.6(d)

> *Notification of the release of an RQ of solid particles of antimony, arsenic, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, or zinc is not required if the mean diameter released is larger than 100 micrometers except for releases of radionuclides.*

There have been no releases of heavy metals above an RQ from the WIPP facility to date.

4.0 EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT

4.1 Summary of the Law

Title III of the Superfund Amendments and Reauthorization Act (SARA), otherwise known as the Emergency Planning and Community-Right-to-Know Act of 1986 (EPCRA; 42 USC §§ 11001 et seq.), authorizes a nationwide program of emergency planning as protection against accidents involving extremely hazardous substances (EHSs). The act also requires a comprehensive body of information about hazardous substances to be submitted to various State and local groups. Under Subtitle A, *Emergency Planning and Notification*, facilities such as WIPP are required to make various notifications to the State Emergency Response Commission (SERC) and the Local Emergency Planning Committee (LEPC). These notifications include notification of applicability under EPCRA, designation of a facility Emergency Coordinator, and notification of extremely hazardous substance releases to the environment. Subtitle B, *Reporting Requirements*, requires the submittal of information such as inventories of specific hazardous chemicals used or stored within a facility to the SERC, LEPC, and the fire department that has jurisdiction over the facility. Within Subtitle B, the following sections outline specific reporting requirements: (1) Section 311, *Material Safety Data Sheets*, directs the submission of an MSDS for each hazardous chemical present or a list of hazardous chemicals present that require an MSDS; (2) Section 312, *Emergency and Hazardous Chemical Inventory Forms*, directs the annual submission of an inventory of hazardous chemicals present during the preceding year; and (3) Section 313, *Toxic Chemical Release Forms*, outlines requirements for facilities to submit a toxic chemical release report to the EPA and the resident state if toxic chemicals are used at that facility in excess of established threshold amounts.

The regulations under 40 CFR Part 355, *Emergency Planning and Notification*, established the list of EHSs, the threshold planning quantities, and facility notification responsibilities necessary for the development and implementation of State and local emergency response plans.

The regulations of 40 CFR Part 370, *Hazardous Chemical Reporting: Community Right-to-Know*, established reporting requirements that provide the public with vital information on the hazardous chemicals in their communities, with the intent of ensuring enhanced community awareness of chemical hazards and facilitating the development of state and local emergency response plans.

In 40 CFR Part 372, *Toxic Chemical Release Reporting: Community Right-to-Know*, requirements are established for the submission of information relating to the release of toxic chemicals under Section 313.

4.2 Compliance Status of the Regulatory Requirements

Table 4-1 summarizes the applicable requirements and their compliance status under EPCRA. The text provides more detail on the compliance status of each requirement.

TABLE 4-1. Emergency Planning and Community Right-to-Know Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR Part 355, *Emergency Planning Notification*		
40 CFR 355.30(a)-(b)	Emergency planning	**ACHIEVED** Notification submitted to SERC [Section 4.2.1]
40 CFR 355.30(c)	Facility Emergency Coordinator	**UP TO DATE** WIPP Emergency Coordinator on the LEPC [Section 4.2.2]
40 CFR 355.30(d)	Provision of information	**ACHIEVED** Information provided to LEPC as required [Section 4.2.3]
40 CFR 355.40	Releases of EHSs	**NOT APPLICABLE** No EHS releases [Section 4.2.4]
40 CFR Part 370, *Hazardous Chemical Reporting: Community Right-to-Know*		
40 CFR 370.21	Submission of MSDS or chemical list	**UP TO DATE** Revised list submitted in March 1995 and March 1996 [Section 4.2.5]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 370.25	Submission of hazardous chemical inventory form	**UP TO DATE** Inventory submitted in March 1995 and March 1996 [Section 4.2.6]
40 CFR Part 372, *Toxic Chemical Release Reporting: Community Right-to-Know*		
40 CFR 372.30	Submission of the Toxic Chemical Inventory Report	**NOT APPLICABLE** Toxic chemical inventory reporting not required due to certain exemptions [Section 4.2.7]

4.2.1 Emergency Planning, 40 CFR 355.30(a)-(b)

> *A facility must notify the SERC that it is subject to the emergency planning requirements if there are extremely hazardous substances equal to or in excess of the threshold planning requirements.*

DOE has notified the SERC that emergency planning requirements are applicable to the WIPP facility.

4.2.2 Facility Emergency Coordinator, 40 CFR 355.30(c)

> *The facility shall designate a facility representative who will participate in the local emergency planning process as a facility emergency response coordinator.*

WID has appointed a WIPP representative to the LEPC that began in 1994. The LEPC meets once a month.

4.2.3 Provision of Information, 40 CFR 355.30(d)

> *The facility will inform the LEPC of any changes occurring at the facility that may be relevant to emergency planning.*

WIPP provides information to the LEPC regarding changes at the facility which may be relevant to emergency planning.

4.2.4 Releases of Extremely Hazardous Substances, 40 CFR 355.40

> *For releases of extremely hazardous substances under SARA Title III (40 CFR Part 355, Appendix A), the owner or operator must notify the National Response Center of any area that is likely to be affected by the release.*

There have been no releases of extremely hazardous substances from the WIPP.

4.2.5 Submission of a Material Safety Data Sheet or List of Chemicals, 40 CFR 370.21

> *Facilities must submit either an MSDS for each hazardous chemical present at the facility according to established minimum threshold schedules or a list of the hazardous chemicals for which the MSDS is required.*

The WIPP submits a list of hazardous chemicals to the SERC, the LEPC, and the local fire department whenever additional hazardous substances are received at WIPP or if significant new information is received about an item for which a list was provided. In March 1995 and March 1996, a revised list of hazardous chemicals was submitted to the appropriate organizations. The listing was comprised of EHSs present in amounts equal to or greater than the threshold planning quantity (TPQ) or 500 pounds, whichever was less, and all substances classified as hazardous under the Occupational Safety and Health Act Hazard Communication Standard with site inventories equal to or greater than 10,000 pounds.

4.2.6 Submission of a Hazardous Chemical Inventory, 40 CFR 370.25

> *On or before March 1 of each year, facilities must submit an inventory form containing Tier I information on hazardous chemicals present during the preceding year, or Tier II information in lieu of Tier I, with respect to any specific hazardous chemical at the facility. This inventory must be submitted to the State Emergency Response Commission, the Local Emergency Planning Committee, and the local fire department.*

The WIPP submitted the Emergency and Hazardous Chemical Inventory Report (Tier II) on February 1, 1995, and January 16, 1996, to the SERC, LEPC, and local fire departments.

4.2.7 Submission of a Toxic Chemical Release Inventory Report, 40 CFR 372.30

> *For each toxic chemical on site in excess of the reporting threshold level, the owner or operator must submit a completed EPA Form R to the EPA and the State.*

During this reporting period, the WIPP was exempt from Section 313 reporting under 40 CFR 372.38, *Exemptions*. Products in excess of 10,000 pound threshold are either contained in enclosed systems or fall under the Motor Vehicle Use exemption.

5.0 ATOMIC ENERGY ACT AND THE ENVIRONMENTAL PROTECTION AGENCY (EPA)

5.1 Summary of the Law

The Atomic Energy Act of 1954, as amended (AEA; 42 USC §§ 2011 et seq.), initiated a national program for research, development, and use of atomic energy for both national defense and domestic civilian purposes. In § 161 of the AEA, the Atomic Energy Commission (succeeded by the DOE for national defense purposes) was authorized to prescribe regulations and Orders to:

> *[G]overn any activity authorized pursuant to [the AEA], including standards, and restrictions governing the design, location, and operation of facilities used in the conduct of such activity, in order to protect health and to minimize danger to life or property.*

The AEA authorized the DOE to develop policies, issue Orders, and promulgate regulations to address the environmental, safety, and health protection aspects of radioactive waste and nuclear materials. The AEA also authorized the U.S. Nuclear Regulatory Commission (NRC) to serve a similar function for civilian nuclear facilities.

Much of the waste to be emplaced at the WIPP is mixed (i.e., radioactive waste with hazardous constituents). This waste is subject to dual regulation: the radioactive constituents of the waste are regulated under the AEA, whereas the hazardous constituents are regulated under RCRA.

The authority of the EPA to establish standards for the protection of the public and the environment from radiation is derived from the AEA, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act (NWPA) (Public Law 97-425). The protection standards found in 40 CFR Part 191 apply to both spent nuclear fuel and high-level radioactive waste as defined by the NWPA, and to TRU waste, which contains more than 100 nanocuries per gram of waste of alpha-emitting TRU isotopes with half-lives greater than 20 years. The standards of 40 CFR Part 191 consist of three subparts: Subpart A; *Environmental Standards for Management and Storage,* Subpart B; *Environmental Standards for Disposal,* and Subpart C; *Environmental Standards for Ground-Water Protection.* Since § 9(a)(1)(A) of the Land Withdrawal Act (LWA) requires documentation of compliance with only Subpart A of 40 CFR Part 191 in the BECR, the section relating to this subpart is the only one addressed here.

Subpart A, *Standards for Management and Storage*, sets the operational term requirements limiting annual doses to members of the public from management and storage operations at disposal facilities that are operated by the DOE and are not regulated by either the NRC or by agreement states. The annual dose equivalent to

any member of the public in the general environment may not exceed 25 millirem (mrem) to the whole body and 75 mrem to any critical organ.

DOE has implementation authority for Subpart A of 40 CFR Part 191. However, since these regulations were promulgated by the EPA, they are discussed in this chapter rather than in Chapter 13, Atomic Energy Act and the U.S. Department of Energy. A discussion of compliance with the disposal-related portions of 40 CFR Part 191 (i.e., Subparts B and C) are not included in this BECR as indicated in the LWA (§ 9[a][1][A]).

5.2 Compliance Status with the Regulatory Requirements

The compliance status of each of the applicable requirements is summarized in Table 5-1. More detail is provided in the text under Section 5.2.1 for the environmental radiation protection disposal standards.

5.2.1 Radiation Protection Standards, 40 CFR Part 191

The requirements of Subpart A of 40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Waste,* do not currently apply to WIPP since no TRU waste has been received at this facility to date. Therefore, only the standard set for any member of the public is included in this revision of the BECR.

TABLE 5-1. Atomic Energy Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Waste*		
Subpart A, 40 CFR 191.03-191.04	Standard: Annual dose equivalent of 25 mrem to whole body and 75 mrem to any critical organ	**NOT APPLICABLE** Will become applicable when waste receipt begins [Sections 5.2.1.1 and 6.2.2]

5.2.1.1 Standard, Subpart A of 40 CFR 191.03-191.04

> *A standard of an annual dose equivalent of 25 mrem to the whole body and 75 mrem to any critical organ of any member of the public has been set for 40 CFR Part 191.*

In the Second Modification to the Agreement for Consultation and Cooperation (dated August 4, 1987), the DOE and the State of New Mexico agreed that the WIPP will comply with the standards of Subpart A upon the initial receipt of waste and thereafter.

However, since the only credible pathway for releases from the facility during operations is air, the applicable NESHAPs standard under 40 CFR Part 61, Subpart H (i.e., an annual effective dose equivalent of 10 mrem), is more restrictive. See also the report prepared by the S.M. Stoller Corporation, *Verification of the Station A Alpha CAM Alarm Set Point at the Waste Isolation Pilot Plant* (dated January 17, 1991) and the later report prepared by Stoller (dated November 2, 1992) that amended the 1991 report.

6.0 CLEAN AIR ACT

6.1 Summary of the Law

The Clean Air Act (CAA), as amended, establishes a national regulatory strategy and program to protect and enhance air quality in the United States. The CAA includes a number of standards, requirements, and permit programs to protect the quality of air in attainment areas (areas in which air pollutant emissions do not exceed the appropriate standards) and to improve it in nonattainment areas (areas that do not meet the national primary or secondary ambient air-quality standard for an air pollutant).

Congress enacted the Clean Air Act Amendments of 1990 (CAAA; PL 101-549) on November 15, 1990. The 11 titles in this public law are:

I. Provisions for Attainment and Maintenance of National Ambient Air Quality Standards
II. Provisions Relating to Mobile Sources
III. Hazardous Air Pollutants
IV. Acid Deposition Control
V. Permits
VI. Stratospheric Ozone Protection
VII. Provisions Relating to Enforcement
VIII. Miscellaneous Provisions
IX. Clean Air Research
X. Disadvantaged Business Concerns
XI. Clean Air Employment Transition Assistance

The 11 titles of the CAAA resulted in numerous changes to the CAA and other acts and established six titles in the CAA:

I. Air Pollution Prevention and Control
II. Emission Standards for Moving Sources
III. General Provisions
IV. Acid-Deposition Control (i.e., control of acid rain)
V. Operating Permits
VI. Stratospheric Ozone Protection

6.1.1 Title I, *Air Pollution Prevention and Control*

Title I of the CAA contains requirements and standards for a number of programs that govern air pollutant emissions from stationary sources. These include the National Ambient Air Quality Standards (NAAQSs), the New Source Performance Standards (NSPS), the National Emission Standards for Hazardous Air Pollutants (NESHAPs), the Prevention of Significant Deterioration (PSD) program, and requirements for nonattainment areas. Most of these programs are requirements for proposed new

construction or for modifications of existing sources. In addition, Titles VII and IX of the CAAA established provisions relating to enforcement and requirements for CAA-related research programs, respectively.

6.1.1.1 National Ambient Air Quality Standards (NAAQS)

This program was established by Title I of the CAA (and revised by Title I of the CAAA) for the six "criteria" pollutants: sulfur dioxide, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. These standards establish the maximum levels of each pollutant allowed in the air within a particular area. The federal NAAQSs are specified in 40 CFR 50.4 through 50.12, and the program is implemented under 40 CFR Part 51. The EPA has authorized the New Mexico Environment Department (NMED) to administer the NAAQS program. The federal NAAQSs have been superseded by the New Mexico Ambient Air Quality Standards (NMAAQSs) for the six criteria pollutants. Therefore, the two backup diesel electrical power-supply generators at WIPP are regulated under New Mexico regulations, and compliance with these regulations is discussed in Chapter 29 under the New Mexico Air Quality Act.

After consultation with the NMED Air Quality Bureau, a determination was made that the WIPP was required to obtain a permit under 20 New Mexico Administrative Code (NMAC) 2.72 for the operation of two back-up diesel electrical power-supply generators. A state permit is required when criteria pollutants exceed the state threshold levels of 10 pounds per hour or 25 tons per year (tpy). For compliance status with the state permit programs, see Chapter 29.

6.1.1.2 New Source Performance Standards (NSPS)

The NSPS program regulates emissions from operating facilities and specifies emission standards and test methods for analyzing the emissions. This program, which was initiated by § 111 of the CAA and is implemented by 40 CFR Part 60, *Standards of Performance for New Stationary Sources*, specifies standards of performance for air pollutant emissions from different types of facilities and equipment. Pollutants that are regulated under the NSPS include sulfur dioxide, nitrogen oxides, particulate matter, visible emissions (opacity), carbon monoxide, volatile organic compounds (VOCs), and lead. Since the EPA has authorized the NMED to administer the NSPS program, the NMED requirements supersede the federal requirements. Therefore, emissions from the backup generators at WIPP are regulated under the state program, which is discussed in Chapter 29.

6.1.1.3 National Emission Standards for Hazardous Air Pollutants (NESHAPs)

Hazardous air pollutant emissions are regulated under § 112 of the CAA (Title III of the CAAA) as implemented by 40 CFR Part 61, *National Emission Standards for Hazardous Air Pollutants (NESHAPs)*. Before the CAA was amended in 1990, Subpart A of NESHAPs listed only eight hazardous air pollutants (HAPs). These pollutants are

asbestos, benzene, beryllium, coke oven emissions, inorganic arsenic, mercury, radionuclides, and vinyl chloride. The CAAA (§ 301) added 181 HAPs, bringing the list of HAPs regulated under Subpart A to 189. De minimis levels for all the HAPs have been proposed under § 112(g) as referenced by the proposed rule *Hazardous Air Pollutants: Proposed Regulations Governing Constructed, Reconstructed or Modified Major Sources* dated April 1, 1994 (59 FR 15504).

In 1995, WID completed the *Air Emissions Inventory Report for Calendar Year 1994* (WID, 1995). This inventory report was developed to calculate maximum potential hourly and annual emissions of criteria pollutants, the regulated NESHAP pollutants, and the New Mexico toxic air pollutants (TAPs) specified under 20 NMAC 2.72 and 2.78. Emission estimates were used to determine if the WIPP is required to obtain air permits under state regulations.

Based on the inventory calculations, WIPP operations are significantly below the 10-tpy emission limit for any individual HAP or the 25-tpy limit for combined HAPs emissions established in Subpart A. Thus, the WIPP does not have any NESHAP Subpart A permitting or reporting requirement at this time. However, 40 CFR 61.09(a)(1) requires that the EPA be notified of WIPP's anticipated date of initial startup of the source no more than 60 days or less than 30 days before that date. This will be required because radionuclide emissions are regulated as HAPs under the NESHAPs program.

The inventory is updated annually to evaluate regulatory changes and to monitor the use of HAPs and TAPs at the site. The WIPP Chemical Inventory Database is used to evaluate chemical use at the site. Using chemical inventory data, WIPP personnel evaluate potential replacement chemicals and minimize the use of materials regulated under NESHAPs as much as possible.

With regard to radionuclide emissions at the WIPP, only Subpart H of NESHAPs applies due to the nature of wastes to be received at the WIPP. No radium-containing TRU wastes are currently identified for disposal at the WIPP. Subpart H of 40 CFR Part 61, *National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities*, pertains to non-radon radionuclide emissions from DOE facilities. The NESHAP for radionuclides is an effective dose equivalent (EDE) of 10 millirem (mrem) per year to any member of the public. A NESHAPs application must be filed if the anticipated EDE will exceed 1 percent of the standard. The DOE and the EPA have agreed that the WIPP will be regulated under NESHAPs through the disposal phase at the WIPP (see the final NESHAPs Memorandum of Understanding [MOU] between the EPA and the DOE, draft #6, dated May 16, 1995).

Analyses for the expected levels of radionuclide emissions were performed and reported in a data package submitted to the EPA (i.e., the NESHAPs data package). The emissions were calculated to be less than 1 percent of the allowable EDE of 10 mrem per year to any one member of the public. In the *Waste Isolation Pilot Plant*

Safety Analysis Report (SAR) (DOE, 1995), doses from radionuclide emissions anticipated from WIPP under normal operations were calculated to be undetectable. An emissions sampling system was installed to comply with NESHAPs and to meet periodic confirmatory measurement requirements. Emissions sampling test results will be used to verify compliance after receipt of TRU waste at WIPP.

6.1.1.4 Prevention of Significant Deterioration (PSD) Program

The PSD program, like many of the other programs under the CAA, is designed for proposed new construction or the modification of existing facilities. It pertains to any proposed new or modified facility to be located in an attainment area, particularly if the facility could impact the air quality in a national park, wilderness area, monument, seashore, or other areas of special national or regional natural, recreational, scenic, or historic value. Because the WIPP does not emit over 100 tpy of any criteria pollutant, the WIPP is not categorized as a major source, and the PSD program does not apply.

6.1.2 Title II, *Emission Standards for Mobile Sources*

Although most of the requirements under the CAA pertain to stationary sources, the requirements under Title II of the CAA and the CAAA pertain to mobile sources and establish standards for motor vehicles and fuel. Many of these requirements are aimed at automobile manufacturers and petroleum companies (e.g., Part A of Title II, *Motor Vehicle Emission and Fuel Standards*). Federal agency fleets are covered in § 248 of the CAA. Federal agencies that operate fleets in nonattainment areas for ozone and/or carbon monoxide are required to use clean-fuel vehicles and must use clean alternative fuels when operating in the nonattainment area. Indeed, DOE published its new Alternative Fuel Transportation Program (10 CFR Part 490) in the *Federal Register* on March 14, 1996. However, since it must be adopted only by federal agencies that operate a fleet with at least 20 light-duty vehicles in a metropolitan statistical area or a consolidated metropolitan statistical area with a 1980 population of at least 250,000 people, these new regulations do not apply to Carlsbad, which is the closest population center to WIPP. In addition, most of the requirements for federal agency fleets under Title II are not applicable to the WIPP because this facility is not located in a nonattainment area. However, a recent addition to the regulations (61 FR 3832, 40 CFR Part 80) makes the purchaser/consumer of gasoline products or his/her agent liable for using gasoline containing lead (i.e., more than 0.05 gram of lead per gallon) or lead additives for highway use after December 31, 1995. This new provision is now incorporated into this chapter (see Section 6.2.3.3). Regulations have also been promulgated for diesel fuel; however, they impact vehicles/equipment using diesel fuel that are used on highways and do not impact non-road vehicles and equipment. Therefore, they are not applicable to WIPP because the diesel fuel dispensed at this facility is used only in non-road vehicles and equipment, such as the backup diesel generators.

6.1.3 Title III, *General Provisions*

Title III of the CAA provides general provisions for the administration of the CAA and pertains to all titles. The provisions stipulated under Title III include administration, federal procurement, suits, audits, and air-quality monitoring and modeling. It does not add additional programs. Title III of the CAA (VIII of the CAAA) also requires that the EPA perform a comprehensive analysis of the impact of the CAAA.

6.1.4 Title IV, *Acid Deposition Control*

Title IV of both the CAA and the CAAA is aimed primarily at utilities and power plants that emit large quantities of sulfur dioxide and/or nitrogen oxides. It seeks to reduce emissions of sulfur dioxide and nitrogen oxides to decrease the acid-rain problem in the United States. It is not applicable to WIPP.

6.1.5 Title V, *Permits*

Most of the other permitting programs under the CAA are designed primarily for proposed new construction or the modification of existing facilities. Title V of both the CAA and the CAAA, as promulgated in 40 CFR Part 70, *State Operating Permit Programs*, identifies the operating permit requirements for major stationary sources. Those facilities required by the state or by the EPA to have an operating permit will be expected to submit an operating permit application, a compliance plan, and periodic compliance reports.

The EPA promulgated its interim final approval of the state of New Mexico operating permit program on November 18, 1994 (59 FR 59656), effective as of December 19, 1994. The state's program will be valid until November 18, 1996, unless it has been granted full final approval by the EPA by that time. The state's program was established in Air Quality Control Regulations 770, *Operating Permits,* and 771, *Operating Permit Emission Fees*; in the wake of the reformatting of the NMED regulations, these regulations are now available as 20 NMAC 2.70 and 2.71, respectively. The operating-permit program is now discussed in Chapter 29, the *New Mexico Air Quality Control Act.*

The federal program (40 CFR Part 70) regulates and requires permits for both area and major sources. At this time, emission limits for those area sources required to have an operating permit have not been established; therefore, the major-source emission thresholds are used to determine which facilities require operating permits for both area and major sources under 40 CFR Part 70 and 20 NMAC 2.70 and 2.71. The inventory was also used to determine if the WIPP is a major source as defined in 40 CFR Part 70 and 20 NMAC 2.71. A facility is considered a "major source" and is required to obtain an operating permit if the facility emits at least 100 tpy of criteria pollutants, 10 tpy of any single HAP, or 25 tpy of any combination of HAPs. Based on inventory emission

calculations, WIPP is not a major source and is not currently required to obtain a federal CAA operating permit . (See also Section 6.3.1).

6.1.6 Title VI, *Stratospheric Ozone Protection*

Title VI of both the CAA and the CAAA places restrictions on and phases out the use of ozone-depleting chemicals, particularly chlorofluorocarbons (CFCs). It is implemented by 40 CFR Part 82, *Protection of Stratospheric Ozone*. These regulations are designed to phase out the use of Class I and Class II substances. Class I substances are CFCs, halons, carbon tetrachloride, methyl chloroform, hydrobromofluorocarbons (HBFCs), and methyl bromide. Class II substances are hydrochlorofluorocarbons, which generally have a lower ozone-depleting potential than do CFCs. The production of most Class I substances was prohibited as of January 1, 1996 (methyl bromide will be prohibited as of January 1, 2001, as indicated in 58 FR 69235). Proposed legislation indicates that, effective January 1, 2010, the use of Class II substances will be prohibited unless the substance has been used, recovered, and recycled; is used and entirely consumed in producing other chemicals; or is used as a refrigerant in appliances manufactured prior to January 1, 2020 (58 FR 15014). By January 1, 2030, the manufacture of all Class II substances will also be prohibited (58 FR 65018).

Implementing regulations pertaining to labeling requirements and the use and disposal of Class I substances during the service, repair, or disposal of appliances and industrial process refrigeration have been published in the *Federal Register*. Recycling equipment registrations and training certifications have been received from all WIPP refrigerant recycling contractors. Effective February 16, 1993, the distribution or sale of any Class I substance identified as nonessential was implemented. Nonessential products include safety horns, wall-mounted alarms, CFC-containing cleaning fluids for electronic or photographic equipment, and CFC-containing aerosol products or other pressurized dispensers.

Most of the requirements pertaining to ozone-depleting substances (ODSs) such as CFCs are applicable primarily to manufacturers of the chemicals, products containing the chemicals, or products in which ODSs are used during the manufacturing process. However, these regulations are applicable to WIPP in that these products will no longer be available after the time specified in the regulations. Therefore, replacement products must be found. Any container in which Class I or Class II substances (including waste) will be transported must have a warning label as required by 40 CFR 82.106, *Warning Statement Requirements*. However, the *Waste Acceptance Criteria for the Waste Isolation Pilot Plant* (WAC; DOE, 1996) require that each generator site document that all aerosol cans included in the waste packages intended for WIPP have been punctured (because the WAC allows no pressurized containers to be transported in the TRUPACT-II containers) and that all such containers are empty. Therefore, wastes destined for the WIPP will not include containers with Class I or Class II substances, and the labeling requirements for Class I and Class II substances are not applicable to TRU wastes destined for WIPP.

6.2 Compliance Status with the Regulatory Requirements

Table 6-1 summarizes each applicable requirement and its compliance status under the CAA. Following the table, the text provides more detail on the compliance status of each requirement.

TABLE 6-1. Clean Air Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
Clean Air Act as amended, § 118, *Control of Pollution from Federal Facilities*		
§ 118	Control of pollution from federal facilities	See the rest of Chapter 6. See also Chapter 29. [Section 6.2.1]
Subpart H of 40 CFR Part 61, *National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities, and* § 112 of the *CAA*		
40 CFR 61.96	NESHAPs application for radionuclides	**ACHIEVED** *Radionuclide Emission Data Package for the WIPP* [Section 6.2.2.1]
40 CFR 61.93(a), (b)	EPA approval of any alternative methods for monitoring/sampling for radionuclide emissions and air flow rate that differ from those specified under NESHAPs	**NOT APPLICABLE** WIPP is not a major emitter and thus is not required to use a reference standard sampling method or obtain approval of an alternative sampling method [Section 6.2.2.2]
40 CFR 61.93(b) and Appendix B, Method 114, § 4.10	NESHAPs Quality Assurance Project Plan (QAPjP)	**ACHIEVED** NESHAPs QAPjP to be revised and submitted to EPA for approval [Section 6.2.2.3]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 61.09(a)(1)	EPA notification under NESHAPs, pre-startup	**UP TO DATE** Notifications: June 1991; update required before receipt of TRU waste [Section 6.2.2.4]
40 CFR 61.09(a)(2)	EPA notification under NESHAPs, post-startup	**NOT APPLICABLE** Will be required after receipt of TRU waste [Section 6.2.2.5]
40 CFR 61.94	NESHAPs annual report	**NOT APPLICABLE** Will be required prior to receipt of TRU waste at WIPP [Section 6.2.2.6]
40 CFR 61.95	Record-keeping requirements	**UP TO DATE** Will be required prior to receipt of TRU waste at WIPP. Records currently being kept. [Section 6.2.2.7]
CAA, § 112(r)(6)(K)	Risk management plan/hazard assessment, if applicable	**NOT APPLICABLE** Low levels of emissions and exemptions (air emissions inventory, Tier II report) [Section 6.2.2.8]
National Emission Standards for Hazardous Air Pollutants for Non-Radionuclides		
40 CFR Part 61, Subpart A	General NESHAPs requirements	See Chapter 29. (See also Section 6.2.2 for NESHAPs requirements for radionuclides for which the NMED is not authorized.)

40 CFR Part 70, *State Operating Permit Programs*, if applicable[1]		
40 CFR 70.3(a)(3)	Operating permit application from area sources under NESHAPs	**NOT APPLICABLE** No area-source thresholds established yet by the EPA or NMED. No definition of "major source" (or area-source thresholds) for radionuclide emissions by the EPA. [Section 6.2.3.1]
40 CFR Part 80, Mobile Sources, *Prohibition on Gasoline Containing Lead or Lead Additives for Highway Use*		
40 CFR 80.7	Reporting information about gasoline represented to be unleaded if requested by the EPA	**NOT APPLICABLE** Unleaded gasoline dispensed at WIPP [Section 6.2.3.2]
40 CFR 80.22	Prohibition against dispensing gasoline with lead or lead additives	**UP TO DATE** Unleaded gasoline dispensed at WIPP [Section 6.2.3.3]
40 CFR 80.23	Liability for violations	**NOT APPLICABLE** No instances are known of violations at WIPP [Section 6.2.3.4]
40 CFR Part 82, *Protection of Stratospheric Ozone*		

[1] Applicability of 40 CFR Part 70: "A state program with whole or partial approval under this part must provide for permitting of at least the following sources: ...(3) Any source, including an area source, subject to a standard or other requirement under section 112 of the Act..." (40 CFR 70.3[a]).

40 CFR 82.40	Restrictions on repairing and servicing motor vehicle air conditioners (MVACs)	**ACHIEVED** Off-site certified service technicians used on all Government Service Administration (GSA) vehicles [Section 6.2.4.1]
40 CFR 82.54(c) and 82.104(a)	Prohibition of nonessential Class I ozone-depleting substances (ODSs)	**UP TO DATE** Non-essential ODSs removed from purchase lists; substitute products being evaluated and used to replace ODSs [Section 6.2.4.2]
40 CFR 82.66	Ban on nonessential products containing Class I substances	**UP TO DATE** Substitute products [Section 6.2.4.3]
40 CFR 82.84	Federal procurement requirements	**NOT APPLICABLE** Substitute products [Section 6.2.4.4]
40 CFR 82.86	Reporting requirements	**NOT APPLICABLE** Substitute products [Section 6.2.4.5]
40 CFR Part 82, Subpart E	Labeling of products and containers containing Class I or Class II ODSs	**NOT APPLICABLE** Aerosol cans in waste packages punctured and containers drained to less than 1% residual liquid; label requirement not applicable [Section 6.2.4.6]
40 CFR 82.102	Applicability	**NOT APPLICABLE** Manufacturers; see also Section 6.2.4.6 [Section 6.2.4.7]

40 CFR 82.106	Required warning statements	**NOT APPLICABLE** Manufacturers; see also Section 6.2.4.6 [Section 6.2.4.8]
40 CFR 82.108 and 82.112	Placement of warning statement and prohibition of removal of the label bearing the warning statement	**NOT APPLICABLE** Manufacturers; see also Section 6.2.4.6 [Section 6.2.4.9]
40 CFR 82.122	Certification, record-keeping, and notice requirements	**UP TO DATE** Labels applied to containers as required [Section 6.2.4.10]
40 CFR 82.150	Service, maintenance, and repair of appliances using refrigerants	**ACHIEVED** EPA certification requirements met by contractors' recycling appliances at WIPP [Section 6.2.4.11]
40 CFR 82.154	Prohibitions	**ACHIEVED** Contractors responsible for management of appliances; no appliances sold at WIPP [Section 6.2.4.12]
40 CFR 82.156	Required practices	**UP TO DATE** Certified contractors and equipment; self-contained equipment; same-day repair of leaks [Section 6.2.4.13]

6.2.1 Control of Pollution from Federal Facilities, CAA § 118

Each department of the executive, legislative, and judicial branches of the federal government having jurisdiction over any property or facility or engaged in any activity resulting in or that may result in the discharge of air pollutants and each

> *employee thereof is subject to and must comply with all federal, state, interstate, and local requirements respecting the control and abatement of air pollution in the same manner and to the same extent as any nongovernmental entity.*

The DOE complies with all federal and state requirements pertaining to the release of air pollutants that apply to WIPP. Compliance with federal and state air-quality requirements are described in this chapter and in Chapter 29, respectively.

6.2.2 National Emission Standards for Hazardous Air Pollutants, 40 CFR 61, Subpart H

> *The NESHAP for radionuclides other than radon from DOE facilities is an effective dose equivalent (EDE) of 10 mrem/year to any member of the public.*

Subpart H, *National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities,* of 40 CFR Part 61 requires that facilities owned or operated by the DOE that emit any radionuclides other than radon-222 and radon-220 into the air are subject to this regulation.

Based on the final MOU between the EPA and DOE, WIPP is subject to the emissions standard that specifies that no member of the public may receive an EDE of 10 mrem/year in any year. In May 1994, modeling was performed for NESHAPs compliance using the CAP-88 code, which resulted in an estimated EDE of 4.04E-04 mrem/year. These calculated values are well below 1 percent of the regulatory limit of 10 mrem/year. In November 1995, DOE issued the *WIPP Safety Analysis Report* (SAR) (DOE, 1995). The SAR indicates that normal operations at WIPP are not expected to entail any releases of airborne radioactive materials, thus the EDE to the public would be undetectable. Since no source term exists at or is planned for WIPP that could cause normal operations to exceed the 1-percent emission limit, only confirmatory sampling will be required to comply with Subpart H.

6.2.2.1 NESHAPs Application for Radionuclides, 40 CFR 61.96

> *The submittal of a NESHAPs application is required prior to construction or modification of any DOE facility that will emit radionuclides to the air.*

An application under NESHAPs would ordinarily be required prior to receipt of radioactive waste at WIPP. However, if the estimated annual EDE is less than 1 percent of the standard, no application is required. Since the estimated EDE is well below this number, no application was required for compliance with Subpart H of NESHAPs at WIPP. Therefore, the application that had been prepared was converted

to a data package (*Radionuclide Emission Data Package for the Waste Isolation Pilot Plant*) in November 1990 and transmitted to the EPA for their information in February 1991 (WID, 1990). An application will be required only if confirmatory monitoring reveals that the emissions may have reached or exceeded 1 percent of the standard.

6.2.2.2 EPA Approval of Any Alternative Methods Used, 40 CFR 61.93(a),(b)

> *EPA approval is required for any alternative methods for monitoring/sampling for radionuclide emissions and air-flow rate that differ from those specified under NESHAPs.*

The WIPP employs a single-point, anisokinetic sampling technology for performing required periodic confirmatory measurements. The technology being used more accurately measures potential emissions in the WIPP mine atmosphere. This technology is not an EPA standard reference sampling method as defined in NESHAPs; however, since the DOE is not a major emitter, i.e., the WIPP's calculated emissions are less than 1 percent of the 10-mrem standard, the WIPP is not required to use a reference sampling method, and thus not required to obtain approval to use an alternative sampling method. This position is reflected in the May 1995 *Memorandum of Understanding Between the U.S. Environmental Protection Agency and the U.S. Department of Energy concerning The Clean Air Act Emission Standards for Radionuclides 40 CFR 61 Including Subparts H, I, Q, & T.* This regulatory citation does not apply to WIPP.

6.2.2.3 NESHAPs Quality Assurance Project Plan, 40 CFR 61.93(b) and Appendix B, Method 114, Section 4.10

> *A NESHAPs Quality Assurance Project Plan (QAPjP) is required for facilities subject to Subpart H of NESHAPs.*

The *Quality Assurance Project Plan for Sampling Emissions of Radionuclides to the Ambient Air at the Waste Isolation Pilot Plant* (NESHAPs QAPjP; DOE/WIPP 03-04), which was completed in 1993, will be revised before the end of the calendar year and will include a protocol for periodic confirmatory measurements. Since the NESHAPs QAPjP must be approved by the EPA and implemented at WIPP prior to the receipt of TRU waste, it will then be sent to the EPA with a request for approval.

6.2.2.4 NESHAPs Pre-Startup Notification, 40 CFR 61.09(a)(1)

> *The EPA will be notified of planned startup between 30 and 60 days prior to startup.*

On June 10 and June 26, 1991, DOE sent pre-startup notification letters to the EPA Administrator and the EPA Region VI office, respectively, to inform them of the pending

startup of WIPP, which was anticipated between July 17 and August 2, 1991. When startup was delayed, another letter of notification (not dated) was sent from DOE to the EPA Region VI office, indicating that the window for startup had shifted from August 30 to September 30, 1991. Again, startup was delayed. Because of the DOE's agreement to comply with NESHAPs requirements until closure of WIPP, notification of the EPA will be required prior to receipt of TRU waste at WIPP.

6.2.2.5 NESHAPs Post-Startup Notification, 40 CFR 61.09(a)(2)

> *The EPA will be notified of actual startup of WIPP within 15 days after that date.*

After the DOE opens WIPP for emplacement of radioactive waste, it will notify the EPA within 15 days after startup. Until that time, this requirement does not apply to WIPP.

6.2.2.6 NESHAPs Annual Report, 40 CFR 61.94

> *A NESHAPs annual report must be submitted by June 30th for facilities subject to Subpart H of NESHAPs.*

After DOE opens WIPP for the emplacement of radioactive waste, it will file a NESHAPs report by June 30 every year as long as the facility is subject to these regulations. If the WIPP were found not to be in compliance with the emission limits of 40 CFR 61.92, the WIPP would be required to commence reporting to the Administrator on a monthly basis. These requirements will no longer be applicable after closure of WIPP, when the radiation protection standards of Subpart B (40 CFR Part 191) will go into effect.

6.2.2.7 Record-keeping Requirements, 40 CFR 61.95

> *All facilities must maintain records documenting the source of input parameters, including the results of all measurements upon which they are based, the calculations and/or analytical methods used to derive values for input parameters, and the procedure used to determine effective dose equivalent. This documentation should be sufficient to allow an independent auditor to verify the accuracy of the determination made concerning the facility's compliance with the standard. These records must be kept at the site of the facility for at least 5 years and, upon request, be made available for inspection by the EPA Administrator or his/her authorized representative.*

Monitoring for airborne radioactive emissions has been performed at WIPP for years. Two emission monitoring stations sample exhaust from underground operations. All

applicable records are maintained on site for at least 5 years and are available for examination if requested by the EPA Administrator or an authorized representative. The results of the measurements, supporting calculations, analytical methods, and procedure used to determine effective dose equivalent are all included in the records.

6.2.2.8 Risk Management Plan/Hazard Assessment, CAA, § 112(r)

> *A risk management plan/hazard assessment must be prepared, if applicable.*

The list of regulated substances for accidental release prevention under § 112(r) of the CAA and the threshold quantities for these substances have been finalized in 40 CFR Part 68, *Chemical Accident Prevention Provisions* (59 FR 4478). However, the requirements for evaluating the need for and the preparation of a risk management plan were published separately as a proposed rule (Subpart B of 40 CFR Part 68) in October 1993 (*Risk Management Programs for Chemical Accidental Release Prevention*, 58 FR 54190). Since the requirements for risk management programs have not yet been finalized, they do not currently apply to WIPP. However, in order to take a proactive approach with Subpart B of 40 CFR Part 68 when these regulations became finalized, two documents were used to determine whether emissions from WIPP exceed the regulatory threshold level of any of the chemicals listed in the final rule. The two documents are the Air Emissions Inventory Report Calendar Year - 1994 for WIPP (WID, 1995) and the *WIPP Tier II Emergency and Hazardous Chemical Inventory Report* required under the Emergency Planning and Community Right-to-Know Act (EPCRA). It was found that, of the 162 substances and gases listed in the final rule, none meets or exceeds the final threshold levels. Sulfuric acid, which was included in the proposed list, is not included in the final list, and the final threshold quantity for sulfur dioxide (SO_2) is 5,000 pounds, which is considerably greater than the SO_2 emissions released as a combustion byproduct from the operation of the backup diesel generators and the emergency diesel fire pump. Therefore, WIPP is not currently required to develop a risk management plan to evaluate accidental releases from the site.

6.2.3 State Operating Permit Programs, 20 NMAC 2.70 and 2.71

The new requirements for operating permits include a provision that state programs must provide for permitting of "any source, including an area source (i.e., a source of the pollutant that is not a major source), subject to a standard or other requirement under § 112 of the [Clean Air] Act." (See Section 70.3[a][3], which is the section on NESHAPs.) Based on emission calculations in the 1994 inventory, emissions at the WIPP are below "major source" and NESHAP emission limits. Thus, the permitting and reporting requirements contained in 20 NMAC 2.70 and 2.71 are not applicable at this time. The inventory is updated annually to evaluate regulatory changes and to monitor the use of HAPs and TAPs (defined in 20 NMAC 2.72 and 2.78) at the site. The WIPP Chemical Inventory Database is used to evaluate chemical use at the site.

Using chemical inventory data, WIPP personnel evaluated potential replacement chemicals to minimize the use of materials regulated under the NESHAPs and TAP programs.

Since the state now has an operating permit program in place, most of the requirements for an operating-permit program are now discussed in Chapter 29. However, federal requirements for an operating permit program and those still under development are summarized here.

6.2.3.1 Operating Permit Application, 40 CFR 70.3(a)(3)

> *The state may require the submittal of operating permit applications from area sources under NESHAPs.*

Based on the 1994 WIPP inventory, HAP emissions from the facility are below current operating-permit threshold levels, and an operating permit is not required for WIPP. Submittal of an application is not applicable at this time. The state does not currently require the submittal of operating-permit applications from area sources under NESHAPs and is awaiting EPA's decision on emission thresholds from area sources that will trigger the need for an area source to submit such an application.

In addition, the EPA has not yet defined "major source" with respect to radionuclides. Until such a definition is provided, or until the EPA specifies the quantity of radionuclide emissions released from a facility that will trigger the need to submit an operating-permit application (as a major or an area source), no operating permit should be needed for WIPP based on radionuclide emissions alone.

6.2.3.2 Reporting Information about Gasoline Represented as Being Unleaded at the Request of the EPA, 40 CFR 80.7

> *If the Administrator, the Regional Administrator, or a delegate has reason to believe that a violation of the Clean Air Act or the regulations implementing with respect to the use of prohibited fuel (e.g., leaded) has occurred, he/she may require that any wholesale purchaser/consumer report information regarding receipt, transfer, delivery, or sale of gasoline represented to be unleaded and to allow the reproduction of such information at all reasonable times. The purchaser/consumer is also required to provide any other information to the EPA representative as requested to enable him/her to ensure that the purchaser/ consumer acted in compliance with the applicable provisions of the CAA and the implementing regulations.*

No known instances are known to have occurred in which the gasoline contained in one of the two underground storage tanks at WIPP has contained lead.

6.2.3.3 Prohibition against Dispensing Gasoline Containing Lead or Lead Additives, 40 CFR 80.22

> *After December 31, 1995, no person shall dispense or supply any gasoline produced with the use of lead additives or that contains more that 0.05 gram of lead per gallon, nor shall he/she supply or dispense gasoline represented to be unleaded unless it meets the criteria specified in 40 CFR 80.2(g) or allow gasoline other than unleaded to be dispensed into any motor vehicle that is equipped with a gasoline tank filler inlet designed for the introduction of unleaded gasoline.*

There are no known instances in which the gasoline dispensed at WIPP has contained lead in concentrations exceeding 0.05 gram per gallon.

6.2.3.4 Liability for Violations, 40 CFR 80.23

> *In any case in which a wholesale purchaser-consumer or his/her employee or agent introduces gasoline other than unleaded into a motor vehicle equipped with a gasoline tank filler inlet designed for the introduction of unleaded gasoline, only the wholesale purchaser-consumer shall be deemed in violation.*

There are no known instances in which a violation of these regulations has occurred at WIPP.

6.2.4 Protection of Stratospheric Ozone, 40 CFR Part 82

A number of requirements have been imposed that relate to CFCs and other ODSs. Most of these requirements pertain directly to manufacturers; however, because of the planned phaseout of these materials, the regulations will also impact users of these materials.

6.2.4.1 Restrictions on Repairing and Servicing Motor Vehicle Air Conditioners (MVACs), 40 CFR 82.40

> *Effective August 13, 1992, no person repairing or servicing motor vehicles for consideration may perform any service on a motor vehicle air conditioner (MVAC) involving the refrigerant for the air conditioner without using approved*

refrigerant recycling equipment and unless he/she has been properly trained and certified by a technician certification program approved by the Administrator.

No government vehicles are serviced, repaired, or maintained by WIPP employees.

All equipment owned or used by the vendors that service these vehicles has been approved, and all the service technicians who perform such work are certified to work on MVACs.

6.2.4.2 Prohibition of Nonessential Class I Ozone-Depleting Substances (ODSs), 40 CFR 82.54(c) and 82.104(a)

Nonessential Class I ODSs are being phased out and will no longer be sold or distributed in the United States as of January 17, 1994. The Class I ODSs currently consist of the chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform.

A list of the ODSs used at WIPP is included in the current WIPP emissions inventory. The major ODS used at WIPP is methyl chloroform (i.e., 1,1,1-trichloroethane). According to the estimated emissions from the 1993 and the 1994 HAPs inventories, use of this material at WIPP has decreased to approximately 4 percent of the usage in 1993 (based on estimated emissions of 0.67 lb/hr in 1993 vs. 0.027 lb/hr in 1994). As WIPP personnel continue to define the actual use of products containing ODSs, waste minimization personnel will continue to obtain substitute products to reduce ODS emissions from WIPP.

6.2.4.3 Ban on Nonessential Products Containing Class I Substances, 40 CFR 82.66

The following products that release a Class I substance were identified as being nonessential and are subject to the prohibitions specified under 40 CFR 82.64:

- *Personal safety horns;*
- *Wall-mounted alarms used in factories or other work areas;*
- *Any plastic flexible or packaging foam product which is manufactured with or contains a CFC;*
- *Any aerosol product or other pressurized dispenser that contains a CFC including but not limited to household, industrial, automotive, and pesticide uses except lubricants, coatings, or cleaning fluids for electrical or*

electronic equipment that contain no CFCs other than CFC-11, CFC-12, or CFC-113 for solvent purposes; and

- *Document preservation sprays that contain no other CFC than CFC-113.*

The deadlines set under 40 CFR 82.64 pertain to selling or distributing nonessential products. However, the items have been listed because no purchase of nonessential products may be made by government entities after October 24, 1994. An inventory of ODSs on site, dated June 1995, was reviewed. No personal safety horns, wall-mounted alarms, or plastic flexible or packaging foam was listed on the inventory list.

A number of aerosol products appears on the WIPP inventory of products used at the site. Substitute products are being investigated.

A number of cleaning fluids used at the site are listed on the inventory list. An inventory list dated October 26, 992, shows that substitute products are being identified and are replacing ODSs, and that the use of 1,1,1-trichloroethane (the ODS with the greatest use at WIPP) has been reduced to about 4 percent of the 1993 levels.

No document preservation sprays are used at WIPP.

6.2.4.4 Federal Procurement Requirements, 40 CFR 82.84

Each department, agency, and instrumentality of the United States shall conform its procurement regulations to the requirements and policies of Title VI of the CAA by October 24, 1994. Each such regulation shall provide, at a minimum, the following:

- *In place of Class I or Class II substances or of products made with or containing such substances, safe alternatives identified under 42 USC § 7671(k) (or products made with or containing such alternatives) shall be substituted to the maximum extent practicable.*

- *Consistent with the phaseout schedules for ODS, no purchase shall be made of Class II substances, or products containing Class II substances, for the purpose of any use prohibited under 42 USC § 7671(d)(c).*

- *All active or new contracts involving the performance of any service or activity subject to 42 USC § 7671(g) or 7671(h) or regulations promulgated thereunder include, or be modified to include, a condition requiring the contractor to ensure compliance with all requirements of those sections and regulations.*

- *No purchase shall be made of products whose sale is prohibited under 42 USC § 7671(h), except when they will be used by persons certified under § 609 to service vehicles, and no purchase shall be made of nonessential products as defined under 42 USC § 7671(i).*

- *Proper labeling under 42 USC § 7671(j) shall be a specification for the purchase of any product subject to that section.*

For agencies subject to the Federal Acquisition Regulation (FAR), 48 CFR Part 1, amendment of the FAR, consistent with this subpart, shall satisfy the requirement of this section.

A comparison of the inventory lists prepared to date (1993 and 1994) indicates that efforts are being made to identify substitute products to replace ODSs. In addition, proper labeling of ODSs is one of the criteria that must be met in the procurement of these materials. Furthermore, requests for the procurement of any new chemicals at WIPP are screened by personnel in one of the environment, safety, and/or health organizations before the chemicals are ordered to ensure that the applicable regulations are being met.

6.2.4.5 Reporting Requirements, 40 CFR 82.86

No later than 1 year after October 22, 1993, each agency, department, and instrumentality of the United States shall certify to the Office of Management and Budget (OMB) that its procurement regulations have been amended in accordance with this section.

Certification by the GSA that the FAR has been amended in accordance with this section shall constitute adequate certification for purposes of all agencies subject to the FAR.

The procurement regulations, which became effective on October 24, 1994, have been amended as required, and a report to that effect was made to the OMB. (See also the response to Section 6.2.4.4.)

6.2.4.6 Labeling of Products and Containers Containing Class I or Class II Ozone-Depleting Substances, 40 CFR Part 82, Subpart E

> *Warning statements are required on containers of and products containing or manufactured with certain ODSs.*

Federal procurement regulations require that proper labeling be a specification for the purchase of any product. WIPP requires that all chemicals purchased, including those containing an ODS be properly labeled.

6.2.4.7 Applicability, 40 CFR 82.102

> *These requirements apply to substances designated as Class I or Class II substances as of February 11, 1993, beginning on May 15, 1993. The requirements of this subpart apply to the following containers and products except those products manufactured prior to May 15, 1993, provided that the manufacturer submits documentation to the EPA upon request showing that the product was manufactured prior to that date. The requirements apply to:*
>
> - *All containers in which a Class I or Class II substance is stored or transported,*
> - *All products containing a Class I substance, or*
> - *All products directly manufactured with a process that uses a Class I substance, unless otherwise exempted.*
>
> *Beginning on January 1, 2015, or 1 year after any determination between May 15, 1993 and January 1, 2015, if suitable substitute products or manufacturing processes are found, the requirements of this subpart shall apply to the following:*
>
> - *All products containing a Class II substance or*
> - *All products manufactured with a process that uses a Class II substance*

Federal procurement regulations require that proper labeling shall be a specification for the purchase of any product. WIPP requires any chemical products including those containing ODSs be properly labeled as a prerequisite for purchase.

6.2.4.8 Required Warning Statements, 40 CFR 82.106

Unless otherwise exempted by this subpart, each container or product identified in § 82.102(a) or (b) shall bear the following warning statement, meeting the requirements of this subpart for placement and form:

"WARNING: Contains [or Manufactured with, if applicable]* [insert name of substance], *a substance which harms public health and environment by destroying ozone in the upper atmosphere."

Exemptions from the warning label requirement include:

- *Products in which trace quantities of a controlled substance remain as a residue or impurity*
- *Waste containing controlled substances or blends of controlled substances bound for discard*
- *Products that are manufactured using methyl chloroform or CFC-113 by persons who can demonstrate and certify a 95-percent reduction in overall usage from their 1990 calendar year usage of methyl chloroform or CFC-113 as solvents during a 12-month period ending within 60 days of such certification or during the most recently completed calendar year*
- *Products that are otherwise not subject to the requirements of this subpart that are being repaired, using a process that uses a controlled substance.*

Federal procurement regulations require that proper labeling be a specification for the purchase of any product. Proper labeling is now one of the specifications used in the purchase of products containing an ODS at WIPP.

6.2.4.9 Placement of Warning Statement and Prohibition on Removal of the Label Bearing the Warning Statement, 40 CFR 82.108 and 82.112

The warning statement shall be "clearly legible and conspicuous." The manner in which the label may be placed on the container is described. Removal of the label bearing the warning statement is prohibited. When purchasers of the product cannot view it at the time of purchase, the promotional printed material prepared for

> *display or distribution may contain the warning statement or the statement may be placed such that it is clearly legible and conspicuous at the time of product delivery so that the purchaser may return the product.*

The warning statement is primarily the responsibility of the manufacturer. The prohibition on removing the label bearing the warning statement applies primarily to the manufacturer and subsequent wholesalers. However, the purchaser also has the obligation to review products being ordered to avoid the procurement of all but essential ODS-containing materials. Furthermore, the purchaser is obliged to maintain the label on the container. It is WIPP policy that warning labels not be removed or tampered with. If a label is damaged, it is replaced.

6.2.4.10 Certification, Record-keeping, and Notice Requirements, 40 CFR 82.122

> *Procedures are provided for persons claiming an exemption under 40 CFR 82.106(b)(2) for seeking an exemption for containers containing a controlled substance in which trace quantities of that substance remain as a residue or impurity.*

These requirements no longer apply to WIPP. The only exemption from the labeling requirements here that could apply to WIPP pertains to waste containing ODSs, as described in 40 CFR 82.106(b)(3); no certification, record-keeping, or notice requirements are stipulated for use of this exemption from the labeling requirements. Therefore, unless the requirements change within the next 2-year period, this section will be omitted in subsequent revisions of the BECR.

6.2.4.11 Prohibitions, 40 CFR 82.124(a)(4)

> *On or after May 15, 1993, no person may modify, remove, or interfere with any warning statement required by this subpart, except as described in § 82.112.*

Every appliance and product containing CFCs should have a label from the manufacturer. It is WIPP policy that warning labels not be removed or tampered with. If a label is damaged, it is replaced.

6.2.4.12 Service, Maintenance, and Repair of Appliances Using Refrigerants, 40 CFR 82.150

> *This subpart applies to any person servicing, maintaining, or repairing appliances except for MVACs. This subpart also applies to persons disposing of appliances, including MVACs. In addition, this subpart applies to refrigerant*

reclaimers, appliance owners, and manufacturers of appliances and recycling and recovery equipment.

Although no WIPP employees service, maintain, or repair appliances, these regulations apply to WIPP because the facility owns appliances and is responsible for the disposal of appliances. WIPP policy is that appliances will be sold intact or refrigerants must be removed from all appliances by a certified recycling contractor.

6.2.4.13 Prohibitions Regarding Maintenance, Service, Repair, or Disposal of Appliances, 40 CFR 81.154

Prohibitions are specified for persons who maintain, service, repair, or dispose of appliances who may vent or otherwise release into the environment any Class I or Class II substance used as refrigerant in such equipment. De minimis releases associated with good faith attempts to recycle or recover refrigerants are not subject to this prohibition. No person may dispose of appliances except for small appliances, MVACs, and MVAC-like appliances unless the required practices described in 40 CFR 82.156 are observed and equipment that is certified for that type of appliance is used. Prohibitions are also specified regarding recycling or recovery equipment.

Prohibitions also exist for the sale of Class I or Class II substances consisting wholly or in part of used refrigerants.

It is a violation of this subpart to accept a signed statement pursuant to 40 CFR 82.156(f)(2) if the person knew or had reason to know that such a signed statement is false.

No WIPP employees service, repair, or maintain appliances on site. Before appliances are disposed of, refrigerant is evacuated by a contractor/technician. No WIPP employees perform work on regulated appliances, and no recycling or recovery equipment is owned by the facility. Only small appliances have been disposed of by WIPP personnel since the regulation took effect on July 13, 1993. All contractors have submitted a signed statement to the EPA that ensures compliance with and knowledge of applicable regulations and is included in the equipment certification form. Recycling and reclamation appliances containing refrigerants used at the WIPP are owned by certified contractors. Recycling and reclamation appliances containing refrigerants used at the WIPP are owned by certified contractors. No recycling or reclamation appliances have been altered since their certification.

No Class I or II substances are sold or distributed from WIPP.

The technician writes and signs all "Work Performed" narratives on the work order at WIPP. The technician is always accompanied by an electrician who is responsible for the verification of the "Work Performed" statements.

6.2.4.14 Required Practices, 40 CFR 82.156

> *Effective July 13, 1993, any person opening appliances other than MVACs must evacuate the refrigerant to a system receiver or to a recovery or recycling machine as specified. At least one piece of certified, self-contained recovery equipment must be available at his/her place of business.*
>
> *Leaks in appliances containing refrigerant must be repaired as specified.*

The contractors have indicated that this is done; Work Orders verify that this requirement is met. All recovery equipment owned/used by the contractors at WIPP is certified. All maintenance, service, and repair on applicable appliances is performed by one of the certified contractors, who have verified on the equipment certification form that they have complied with these regulations.

All equipment owned/used by the contractors at WIPP is self contained. All applicable requirements of this section are being met.

No leaks in the refrigeration units on site have been detected in this reporting period.

6.3 Compliance Status of Permit Conditions

Table 6-2 summarizes the applicable permits and the status of the permit conditions. Currently, only the permit for the backup diesel electrical power-supply generators and a permit for open burning are required for WIPP under the CAA; those permits are discussed in Chapter 29.

The requirement to have an operating permit will ultimately be extended to include area sources of HAPs as well as all major sources, where area sources are those sources that emit less than 10 tons/year of any single HAP or less than 25 tons/year of any combination of HAPs. (It should be noted that radioactive emissions are regulated as a HAP; however, no definition of a major source of radionuclide emissions has been promulgated by the EPA as yet.) The EPA must promulgate threshold limits to determine which area sources will be subject to the operating-permit requirements. To date, no such limits for HAPS emitted from area sources have been published by the EPA, even as a proposed rule. Since WIPP is an area source for several HAPs and could emit small quantities of radionuclides after TRU waste is accepted at the facility, it is possible that an operating permit may eventually be required for WIPP. However,

the need for such a permit is unlikely because of the low levels of HAPs emissions possible from this facility.

TABLE 6-2. Permits Required Under the Clean Air Act - Status of Compliance with Permit Conditions

CITATION	REQUIREMENTS	COMPLIANCE STATUS
§ 109	NAAQS permit	See Chapter 29
40 CFR Part 70	Operating permit conditions to be determined, if applicable	**NOT APPLICABLE** Threshold values for area sources requiring operating permits not yet established by EPA or NMED [See Section 6.3.1]

6.3.1 Applicability of Operating Permit Requirements, 40 CFR Part 70

The EPA has not yet defined "major source" with respect to radionuclide emissions, since neither the 10-tpy limit for a single HAP nor the 25-tpy limit for combined HAPs emissions are applicable to such emissions. The EPA and the state are required to establish a threshold value for area sources that emit HAPs in amounts that are less than the appropriate major source designation and that will be required to file an operating permit application. Those facilities that emit HAPs at rates that meet or exceed the threshold values will be regulated under the operating permit program; those area sources with emissions that are lower than the threshold values will not be required to file an operating permit application. Until the threshold values are promulgated, area sources are considered to be exempt from the operating permit requirements. Specific operating permit conditions for a given facility will be specified in the individual permit.

7.0 FEDERAL WATER POLLUTION CONTROL ACT OF 1972 ("CLEAN WATER ACT")

7.1 Summary of the Law

The Federal Water Pollution Control Act of 1972 (33 USC §§ 1251 et seq.) is usually referred to as the "Clean Water Act" (CWA). The major program under this act is the National Pollutant Discharge Elimination System (NPDES). This program, discussed in § 402 of the CWA, regulates the discharge of pollutants into navigable waters of the United States. The regulations implementing the NPDES that are relevant to the WIPP Project are found in 40 CFR Part 122, *EPA Administered Permit Programs: the National Pollutant Discharge Elimination System*, which contains definitions and basic application requirements, standard permit conditions, and monitoring and reporting requirements for the NPDES program. However, because there are no point-source discharges into navigable waters at WIPP, the facility is not required to obtain a standard NPDES permit.

In 1990, a NPDES storm water permit program was added to the CWA (§ 402[p]) to govern the discharge of pollutants into precipitation runoff. The EPA has determined that the NPDES storm water regulations found in 40 CFR 122.26 are applicable to WIPP because a potential exists for storm water runoff to contact regulated pollutants. The NPDES storm water permit program involves three types of permits: general, individual, and group. To obtain a permit, a facility submits either a Notice of Intent (NOI) for a general permit, an individual application for an individual permit, or an application as part of a group of applicants for a group permit. The EPA planned to cover most industrial discharges under general permits and issued the *Final NPDES General Permits for Storm Water Discharges Associated with Industrial Activity* in the *Federal Register* on September 9, 1992. These general permits cover facilities that discharge effluents associated with industrial activities in 11 states that do not have authorized NPDES programs, including New Mexico.

Of the other regulations that implement the NPDES program, only 40 CFR 122.21, *NPDES Permit Assessment for Sewage Sludge*, and 40 CFR Part 459, *Photographic Point Source Category*, could apply to WIPP. In order to meet the requirements of 40 CFR 122.21(c)(2), the DOE filed a NPDES sewage sludge information package with EPA Region VI, requesting a determination as to whether the facility will be required to obtain a NPDES sewage-sludge discharge permit. Based on the determination made by the Regional Director, the DOE may be required to submit an NOI to obtain a sludge-discharge permit. However, WIPP is exempt from regulation under 40 CFR Part 459 because photographic wastes are collected and transported off site to a licensed facility for disposal.

Another implementing regulation under the CWA applicable to the WIPP Project is 40 CFR Part 112, *Oil Pollution Prevention*, which includes criteria and guidelines for the

preparation and implementation of a facility's Spill Prevention, Control, and Countermeasures (SPCC) Plan.

7.2 Compliance Status of the Regulatory Requirements

Table 7-1 summarizes the regulatory requirements and their compliance status under the CWA. The text gives more detail on the compliance status for each requirement.

TABLE 7-1. Clean Water Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR Part 112, *Oil Pollution Prevention*		
40 CFR 112.3	Requirements for preparation and implementation of spill prevention, control, and countermeasures (SPCC) plans	**ACHIEVED** WIPP SPCC Plan [Section 7.2.1]
40 CFR 112.5	Amendment of SPCC plans by owners and operators	**UP TO DATE** WIPP SPCC Plan [Section 7.2.2]
40 CFR Part 122, *EPA-Administered Permit Programs: the National Pollutant Discharge Elimination System (NPDES)*		
40 CFR 122.1(b)(1)	1004[A]NPDES permits for the discharge of pollutants from any point source into waters of the United States	**NOT APPLICABLE** No NPDES permit required because of lack of process- or point-source discharges at WIPP [Section 7.2.3]
40 CFR 122.21(c)(2)	NPDES permit assessment for sewage sludge	**ACHIEVED** Information package submitted to the EPA for NPDES sewage-sludge permit determination by the deadline (February 19, 1994) [Section 7.2.4]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 122.26(a)	Requirement for a storm water discharge permit	**ACHIEVED** General permit obtained, # NMR00A021 [Section 7.2.5]
40 CFR 122.26(c)	Application requirement for storm water discharges associated with industrial activity	**NOT APPLICABLE** Requirement superseded by issuance of EPA's NPDES General Permits and filing of Notice of Intent for WIPP [Section 7.2.6]

7.2.1 SPCC Plan Requirements, 40 CFR 112.3

> *Requirements for the preparation and implementation of SPCC plans are specified under the "Oil Pollution Prevention" regulations of 40 CFR Part 112.*

The *WIPP Spill Prevention, Control, and Countermeasures Plan* was issued in November 1988.

7.2.2 Amendment of the SPCC Plan by the Owner/Operator, 40 CFR 112.5

> *Requirements for amending SPCC plans by the owners/operators of a facility are specified under the "Oil Pollution Prevention" regulations of 40 CFR Part 112.*

The WIPP SPCC Plan undergoes an annual review and is revised as needed to reflect changes in facility activities and emergency equipment (WID, 1993a).

7.2.3 NPDES Permit Requirement, 40 CFR 122.1(b)(1)

> *The NPDES program requires permits for the discharge of pollutants from any point source into waters of the United States.*

There are no point-source discharges into navigable water from WIPP. Therefore, the facility is not required to obtain a standard NPDES permit.

7.2.4 NPDES Permit Assessment, 40 CFR 122.21(c)(2)

> *Any "treatment works treating domestic sewage" commencing operations after the promulgation of an applicable standard for sewage sludge use or disposal shall submit an application to the director at least 180 days prior to the date proposed for commencing operations.*

The WIPP stabilization sewage lagoon began operating in June 1985. Sludge was disposed of in 1993 during the facility expansion. This expansion included the construction of two new lined evaporation ponds and the subsequent draining and lining of the primary evaporation pond. All sludges were removed from the primary evaporation pond prior to the installation of the synthetic liner. This was the first removal of sludge in the 9-year operation of the facility, and it is anticipated that sludge removal will be necessary approximately twice prior to final facility closure.

The sewage sludge permitting regulations were promulgated on February 19, 1993, and became effective on February 19, 1994 (i.e., the submittal of a sewage sludge application was due on the latter date). WID personnel worked closely with NMED and EPA personnel in complying with these new regulations and satisfied the applicable requirements. Therefore, the 180-day prenotification period is not applicable here.

Consultation with the NMED Surface Water Bureau and the EPA Region VI Water Management Division provided a determination for land disposal of the sewage sludges. Dried sludges were removed from the primary evaporation pond and mixed with top soils at a reclamation site near the construction landfill. Sludges were used as a soil additive to implement the best management practices (BMPs) identified in the *WIPP National Pollutant Discharge Elimination System (NPDES) Storm Water Pollution Prevention Plan* (WIPP PPP) (WID, 1993b).

7.2.5 Requirement for NPDES Permit for Storm Water Discharges, 40 CFR 122.26(a)

> *Storm water discharges are regulated by the EPA under the NPDES program. The EPA requires an NPDES permit for facilities that could discharge contaminated storm water runoff to waters of the United States.*

The WIPP site is regulated by NPDES Storm Water General Permit # NMR00A021.

Evaluation of NPDES storm water compliance options for the WIPP began in July 1991. On April 2, 1992, the EPA published the final *NPDES Application Deadlines, General Permit Requirements and Reporting Requirements for Storm Water Discharges Associated with Industrial Activity*, which established the new general permit rules for minimal sampling and analytical requirements. The EPA published the *Final NPDES*

General Permits for Storm Water Discharges Associated with Industrial Activity (hereafter referred to as the "NPDES General Permits") in the *Federal Register* on September 9, 1992. These general permits established NOI requirements, prohibitions, requirements to develop and implement storm water pollution prevention plans, and requirements to conduct site inspections for facilities with discharges that are authorized by the permit. In addition, these permits established monitoring requirements for certain classes of facilities.

This requirement is addressed in the WIPP Pollution Prevention Plan (PPP). No sampling was required for the submittal of the NPDES General Permits NOI.

The NPDES storm water rules require compliance sampling of discharges resulting from any storm event that is greater than 0.1 inch in magnitude. The WIPP uses BMPs such as retention basins designed to contain two consecutive 24-hour storm events, the covering of material storage areas, and the reclamation of disturbed sites to eliminate storm water contact with regulated pollutants. By design, it is anticipated that regulated discharges at WIPP will be required to complete compliance sampling only if a storm event results in a discharge from a retention basin. If sampling is required, it will be conducted as required by the NPDES General Permits.

7.2.6 Application Requirement for Storm Water Discharges Associated with Industrial Activity, 40 CFR 122.26(c)

> *The implementing regulations in Part 122 require the submittal of an application for a storm water NPDES permit.*

This requirement was superseded by the issuance of EPA's *Final NPDES General Permits for Storm Water Discharges Associated with Industrial Activity* (57 FR 41236, September 9, 1992), which replaces the requirement for the submittal of an application with the filing of an NOI for obtaining a general permit. The NOI for WIPP was submitted to the EPA on September 26, 1992 (see Section 7.3.1).

7.3 Compliance Status of Permit Conditions

Table 7-2 summarizes specific conditions and their compliance status under the EPA's *Final NPDES General Permits for Storm Water Discharges Associated with Industrial Activity*. These general permits were published in the *Federal Register* on September 9, 1992. All applicable requirements are specified in Part IV and Appendix B of the NPDES General Permits.

TABLE 7-2. NPDES General Permits - Summary of Permit Condition Compliance Status

CITATION	CONDITION	COMPLIANCE STATUS
CWA, *Final NPDES General Permits for Storm Water Discharges Associated with Industrial Activity* (57 FR 41236, September 9, 1992)		
IV(A); Appendix B, II(A)	Notice of Intent (NOI) to file for general permit	**ACHIEVED** Filed on September 26, 1992, with the EPA [Section 7.3.1]
IV(A)(4)	Notice of Termination (NOT)	**NOT APPLICABLE** Containment of storm water discharges not demonstrated [Section 7.3.2]
IV(B)(1); Appendix B, III(A)	Prohibition on non-storm water discharges	**ACHIEVED** Discharges: either exempt, non-regulated, or contained [Section 7.3.3]
IV(B)(2); Appendix B, III(B)	Releases of reportable quantities of hazardous substances and oil	**UP TO DATE** Two releases of ethylene glycol reported; no modification necessary to the WIPP PPP. [Section 7.3.4]
IV(C); Appendix B, Part IV	Storm water pollution prevention plan	**ACHIEVED** Identified in WIPP PPP [Section 7.3.5]
IV(C)(1); Appendix B, IV(D)(1)	Pollution prevention team	**ACHIEVED** Identified in WIPP PPP [Section 7.3.6]

CITATION	CONDITION	COMPLIANCE STATUS
IV(C)(2); Appendix B, IV(D)(2)	Identification of potential pollution sources	**ACHIEVED** Contained in WIPP PPP [Section 7.3.7]
IV(C)(2); Appendix B, IV(D)	Site assessments	**ACHIEVED** Summarized in WIPP PPP [Section 7.3.8]
IV(C)(3); Appendix B, IV(D)(3)	Measures and controls (including record-keeping and internal reporting)	**ACHIEVED** Identified in WIPP PPP [Section 7.3.9]
IV(C)(4); Appendix B, IV(D)(4)	Comprehensive site compliance evaluations	**UP TO DATE** Initial site inspection; WIPP PPP [Section 7.3.10]
IV(D)(1); Appendix B, IV(D)(7)	Requirements for storage, processing, and handling areas for EPCRA § 313 "water priority chemicals"	**NOT APPLICABLE** No reporting under § 313 of EPCRA required [Section 7.3.11]
IV(D)(2); Appendix B, IV(D)(8)	Enclosure or covering of outdoor salt piles	**NOT APPLICABLE** Runoff diverted to evaporation basins; no discharge to waters of the U.S. possible, WIPP PPP [Section 7.3.12]
IV(D)(3); Appendix B, IV(D)(5)	Notification to municipal large and medium separate storm water systems	**NOT APPLICABLE** Storm water not discharged through a large or medium separate system [Section 7.3.13]

CITATION	CONDITION	COMPLIANCE STATUS
IV(E); Appendix B, Part IV and XI(C)(vi)	Monitoring and reporting requirements	**NOT APPLICABLE** Required monitoring described in WIPP PPP [Section 7.3.14]
IV(G); Appendix B, IV(A)(1)	Deadline for plan preparation and compliance	**ACHIEVED** WIPP PPP issued March 31, 1993; implementation of BMP completed by October 1, 1993, compliance date [Section 7.3.15]

7.3.1 NOI to File for a General Permit, IV(A) and Appendix B, II(A)

In the EPA's NPDES General Permit, a provision was made that a facility should file an NOI to file for a general storm water discharge permit rather than submit a formal application for the permit.

The NOI to obtain a NPDES general storm water permit was submitted to the EPA on September 26, 1992. The EPA issued a general permit to WIPP on December 31, 1992 (# NMR00A021).

7.3.2 Notice of Termination (NOT), IV(A)(4)

A facility may submit an NOT if no storm water discharges will be released.

Although the WIPP has implemented BMPs that are designed to make WIPP a zero-discharge facility, this requirement currently is not applicable because the facility has the potential to discharge storm water that could contact regulated pollutants. If WIPP can demonstrate that the storm water discharges can be contained effectively, a NOT may be filed as specified under Condition IV(A)(4) of the NPDES General Permits. If the NOT is approved by the EPA, coverage of WIPP under the *NPDES General Permits for Storm Water Discharges Associated with Industrial Activity* will cease.

7.3.3 Prohibition on Non-Storm Water Discharges, IV(B)(1) and Appendix B, III(A)

The EPA prohibits the release of non-storm water discharges under the storm water discharge NPDES permit.

All condensate discharges are collected and disposed of as wastes in accordance with the applicable regulatory criteria.

7.3.4 Releases of Reportable Quantities of Hazardous Substances and Oil, IV(B)(2) and Appendix B, III(B)

Releases of reportable quantities of hazardous substances and oil must be reported.

Two spills (ethylene glycol) at WIPP over the RQ were reported to the National Response Center during this reporting period. Both spills were contained immediately and cleaned up in accordance with the WIPP spill response procedure.

The WIPP PPP (WID, 1993b) addresses the actions that must be taken in the event of a reportable spill, including notification of the National Response Center. If the notification to the National Response Center is made in reference to a release from BMPs (retention basins, etc.), the PPP must be modified within 14 days to provide a description of the release; the circumstances leading to, and the date of the release; measures to prevent recurrence and to respond to such releases; and notification of the EPA. The ethylene glycol spills were not released from the BMPs to waters of the United States.

7.3.5 Storm Water Pollution Prevention Plan, IV(C) and Appendix B, Part IV

Regulated facilities with a general permit must have prepared and implemented a storm water pollution prevention plan.

The WIPP PPP describes how the BMPs and other requirements of the NPDES storm water regulations are being implemented at the WIPP. Requirements addressed include the identification of a pollution prevention team, the potential pollution sources, and past spills and leaks.

7.3.6 Pollution Prevention Team, IV(C)(1) and Appendix B, IV(D)(1)

A pollution prevention team is required for permitted facilities. This team must be addressed in the facility's PPP.

The WIPP Pollution Prevention Team is composed of representatives from organizations within the DOE and WID who are knowledgeable about the facility and its operations and who will provide structure and direction to the storm water management program. The members of the Pollution Prevention Team and their functional area responsibilities are identified in the PPP.

7.3.7 Identification of Potential Pollution Sources, IV(C)(2) and Appendix B, IV(D)(2)

Potential sources of pollution must be identified at the permitted facility.

A site inspection was conducted to identify illicit connections into either the WIPP sewage system or into storm water diversion swales. The four-day site inspection focused on all surface facility operations, the status of existing BMPs, material handling practices, material storage areas, and storm water flow patterns and volumes. The inspection revealed seven areas that could contribute pollutants to storm water runoff. These seven areas are identified and discussed in the PPP.

Storm water flows were evaluated using NMED and EPA methodology. Because the NMED guidelines for calculating runoff coefficients are more stringent, they were chosen to calculate storm water runoff from the WIPP. Meetings were held with the EPA Region VI Storm Water Section and with the NMED Ground Water and Surface Water Bureaus to evaluate compliance alternatives.

As described in the PPP, three different material inventories were used to complete the materials inventory assessment: the WIPP Stores Stock Inventory, the MSDS Inventory, and the Hazardous Air Pollutants Inventory. Several site walkarounds were then conducted to examine material storage practice and to identify the operations and storage areas with the potential to come into contact with storm water.

Non-storm water discharges, described in the PPP, are discussed in Section 7.3.3 above. The existing monitoring data are also described in the PPP, and the locations of the data are specified. An identification of potential risks from discharges was not performed because all non-storm water discharges are either exempted, contained, or not regulated.

7.3.8 Site Assessments, IV(C)(2) and Appendix B, IV(D)

A site assessment for storm water discharge sources must be included in a facility's PPP.

A summary of the site assessment is provided in the PPP. This summary identifies the potential pollutant sources that require additional controls or BMPs to ensure compliance with the requirements. (See also Section 7.3.7 above.)

7.3.9 Measures and Controls, IV(C)(3) and Appendix B, IV(D)(3)

Measures and controls (including record-keeping and internal reporting) must be addressed in the PPP.

The measures and controls for discharges are described in the PPP. BMPs and implementation of these practices are specified for eight management areas, which include the seven areas identified in Section 7.3.7 and the solid waste management units (SWMUs) located in the rest of the 16-section withdrawal area. Included in the discussion are sections on good housekeeping, maintenance, and visual inspections; the WIPP SPCC Plan; management of runoff and of sediment and erosion controls; employee training; compliance reporting; annual site compliance evaluations; and record-keeping.

7.3.10 Comprehensive Site Compliance Evaluations, IV(C)(4) and Appendix B, IV(D)(4)

Comprehensive site compliance evaluations are mandatory for a permitted facility and must be discussed in the facility's PPP.

Comprehensive site inspections are discussed in the PPP. The initial internal site assessment is described, as is the periodic site compliance evaluation. The CWA Coordinator is responsible for conducting quarterly site compliance evaluations. The NPDES program, including site operation and materials management, is reviewed annually. In addition, the NPDES storm water permit program is evaluated periodically as part of the WIPP Environmental Compliance Assessment Program. The PPP will be reviewed quarterly to reflect changes in compliance strategy, regulations, team members, etc.

During the inspections, material handling and storage areas and other potential sources of pollution are visually inspected for evidence of actual or potential pollutant discharges. Guidelines for housekeeping, maintenance, and visual inspections are provided in a Westinghouse manual. WID personnel conduct self-assessments in accordance with a WIPP procedure, which outlines the requirements for evaluating good housekeeping practices and for making visual inspections. In addition, WID personnel conduct quarterly walkarounds to assess compliance with the storm water regulations at the site and develop corrective action plans to mitigate any issues that may arise from these assessments.

7.3.11 Requirements for Storage, Processing, and Handling Areas for EPCRA § 313 "Water Priority Chemicals," IV(D)(1) and Appendix B, IV(D)(7)

The EPA specifies requirements for storage, processing, and handling areas for EPCRA § 313 "water priority chemicals."

This section is not applicable because WIPP has not been required to submit a report under § 313 of EPCRA during this reporting period due to certain exemptions (see Chapter 4.0).

7.3.12 Enclosure or Covering of Outdoor Salt Piles, IV(D)(2) and Appendix B, IV(D)(8)

The EPA's NPDES General Permit requires that outdoor salt piles be enclosed or covered. This requirement applies only to storage pile runoff discharged to waters of the United States.

The outdoor salt piles at WIPP are situated on a compacted, caliche liner which eliminates potential discharge to waters of the United States. Any storm water runoff is diverted to the caliche-lined evaporation basin. Storm water that collects in the evaporation basin usually evaporates within 24 hours. Furthermore, the moisture contained in the mined salt quickly forms a hard crust over the surface of the pile, which reduces wind-borne particulates. As rain falls on the salt pile, this protective crust becomes thicker, which further reduces salt particulate discharges. Because no waters are diverted to waters of the United States, closure or enclosure of the salt piles is not required.

7.3.13 Notification to Municipal Large and Medium Separate Storm Water Systems, IV(D)(3) and Appendix B, IV(D)(5)

The NPDES General Permits require that the permitted facility notify the owners/operators of any municipal large and medium separate storm water systems that service the facility in the event of a discharge.

This requirement is not applicable at WIPP because storm water is not discharged through a large or medium separate storm water system.

7.3.14 Monitoring and Reporting Requirements, IV(E) and Appendix B, Part IV and XI (C)(vi)

Monitoring and reporting requirements required are described in the NPDES General Permits and differ for different types of facilities.

As discussed in the PPP, all regulated storm water discharges are or will be contained within retention basins or controlled by practices such as diversion berms, reclamation, or material covers. Therefore, the need for compliance sampling at WIPP is not anticipated.

As indicated by the PPP, a Discharge Monitoring Report (DMR) is required only if a discharge has occurred. In the event of a discharge, the DMR, along with sampling results, will be submitted to the EPA on the appropriate DMR form by October 28 of the appropriate year.

7.3.15 Compliance Deadlines, IV(G) and Appendix B, IV(A)(1)

> *The NPDES General Permits require that the permitted facility complete the development of the Pollution Prevention Plan by the regulatory deadline of April 1, 1993, and require compliance with the terms of the plan by October 1, 1993.*

As required by the NPDES General Permit for WIPP, the WIPP PPP was issued on March 31, 1993 (WID, 1993b). As described in Chapter 5 of the PPP, the implementation of BMPs such as retention basins, reclamation of disturbed sites in Zone 1, and the covering of material storage areas was completed by the regulatory deadline of October 1, 1993. The BMPs are inspected on a quarterly basis.

8.0 SAFE DRINKING WATER ACT

8.1 Summary of the Law

The Safe Drinking Water Act of 1974 (SDWA; 42 USC §§ 300f et seq.), as amended, provides the regulatory strategy for protecting public water supply systems and underground sources of drinking water. As defined in the implementing regulations in 40 CFR Part 141, *National Primary Drinking Water Regulations*, these are systems that provide water for human consumption and that have at least 15 connections or regularly serve at least 25 people.

The SDWA also protects underground sources of drinking water from underground injection of contaminated fluids. Underground injection, defined as "subsurface emplacements of fluids by well injections" in § 1421(d) of the SDWA, is governed by the Underground Injection Control (UIC) program described in Subpart C of 40 CFR Part 144.

The EPA delegated authority for ensuring compliance with the SDWA's National Primary Drinking Water Standards by approving the New Mexico Environment Drinking Water Regulations. These regulations now occupy Section 7.1 of Title 20 of the New Mexico Administrative Code (20 NMAC 7.0). (See Chapter 31, New Mexico Drinking Water Regulations.)

8.2 Compliance Status of the Regulatory Requirements

The WIPP LWA specifically requires compliance with the SDWA. The relevant requirements from the SDWA are summarized in Table 8-1, along with the compliance status of each. More detail is presented in the text.

The NMED has authority to administer the SDWA in New Mexico. The state compliance criteria and general operating requirements for the owners and operators of water-supply systems are described in 20 NMAC 7.1. These regulations and the compliance status at WIPP are covered in Chapter 31.

TABLE 8-1. Safe Drinking Water Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR Part 142, *National Primary Drinking Water Regulations Implementation*		
40 CFR 142.4	State program requirements	See Chapter 31, New Mexico Water Supply Regulations [Section 8.2.1]
40 CFR Part 144, *Underground Injection Control*		
40 CFR 144	UIC	**NOT APPLICABLE** *No TRU waste or other disposal* at WIPP using UIC [Section 8.2.2]

8.2.1 State Program Requirements, 40 CFR 142.4

All applicable requirements in this section are covered in the state program for the SDWA. (See Chapter 31, which addresses the New Mexico Water Supply Regulations.)

8.2.2 Underground Injection Control, 40 CFR 144

> *The EPA has established a number of requirements for facilities that dispose of wastes by means of underground injection.*

None of the hazardous waste currently generated at WIPP is injected underground, nor will TRU waste be disposed of by underground injection at WIPP. Therefore, the EPA's requirements for UIC do not apply to WIPP.

9.0 TOXIC SUBSTANCES CONTROL ACT

9.1 Summary of the Law

Prior to the passage of the Toxic Substances Control Act (TSCA; 15 USC §§ 2601 et seq.), significant gaps existed in the federal government's authority to test and regulate problem chemicals. The CAA, the CWA, and other laws deal with chemical substances only when they entered the environment as wastes (e.g., as emissions to the air or discharges into the water). In many cases, controls could not be easily fashioned or required without severe economic consequences. Other statutes, such as the Occupational Safety and Health Act and the Consumer Product Safety Act, deal only with one phase of the chemical's existence (worker exposure or direct consumer exposure) and have no authority to address environmental hazards. Whereas both of these statutes were needed, the life cycle of a chemical, from production to ultimate disposal, provides many opportunities for release to the environment, resulting in human exposure; and federal authority to deal with the overall cycle was fragmented. The TSCA legislation imposed on new toxic substances, which requires testing before the chemicals reach the production phase, helped to overcome this difficulty.

TSCA has two main features: it regulates (1) the production, use, distribution, and disposal of new, potentially toxic chemical substances, where necessary, and (2) potential hazards from toxic chemicals. TSCA requires that tests be conducted on new chemical substances before significant human or environmental exposure can occur.

The act applies primarily to commercial manufacturers, importers, and processors of toxic chemicals. The WIPP is not a manufacturer or a processor of chemical products; therefore, most of the provisions of TSCA do not apply. However, three sections of this act pertain to existing commercial toxic substances, rather than to the development of new chemicals. These sections deal with asbestos, indoor radon abatement, and polychlorinated biphenyls (PCBs).

9.1.1 Asbestos Hazard Emergency Response Act of 1986

Because of the potential for serious health hazards associated with asbestos, Congress amended TSCA in 1986 by adding Title II, *The Asbestos Hazard Emergency Response Act* (AHERA). AHERA requires the EPA to establish a comprehensive regulatory framework of inspection, management, planning, operations and maintenance activities, and appropriate abatement responses for controlling asbestos-containing materials in schools. Under AHERA, EPA promulgated its "AHERA-in-Schools Rule" on October 17, 1987. The 1988 AHERA amendments provided additional time for local educational agencies to submit asbestos management plans to the state governors and begin the implementation of these plans.

Under AHERA, the EPA was also required to conduct a study to determine the extent of danger to human health posed by asbestos in public and commercial buildings and the means to respond to such danger. This study has been submitted to Congress. At the present time, the EPA does not recommend a regulatory program modeled on AHERA for public and commercial buildings.

9.1.2 Indoor Radon Abatement

The Title III TSCA amendment, *Indoor Radon Abatement*, was added to address the national long-term goal "with respect to radon levels in buildings, that the air within the buildings in the United States should be as free of radon as the ambient air outside of buildings." One of the goal-driven requirements that Title III sets forth in § 309, *Study of Radon in Federal Buildings*, directs each Federal department or agency that owns a Federal building to conduct a study to determine the extent of radon contamination in such buildings. The WIPP has responded to this requirement.

9.1.3 Polychlorinated Biphenyls (PCBs)

Section 6(e) of TSCA, *Polychlorinated Biphenyls*, directed the EPA to phase out PCB manufacture and use according to a mandated timetable. This timetable directed the EPA to promulgate rules for the disposal and marking of PCBs within six months of the enactment of TSCA: by one year after the passage of this act, no one was allowed to manufacture, process, distribute, or use any PCB in the United States except in "a totally enclosed manner." Furthermore, unless the EPA did not find any unreasonable risk of injury to public health or the environment, no one was allowed to manufacture PCBs at all after two years, or to distribute them after two and one-half years after TSCA's passage.

The regulations in 40 CFR Part 761, *Environmental Protection Agency Regulations for Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions for Polychlorinated Biphenyls under the Toxic Substances Control Act*, implement the PCB provisions of TSCA. This part applies to all parties who manufacture, process, distribute in commerce, use, or dispose of PCBs or PCB items. The purpose of these regulations is to establish prohibitions of, and requirements for, the manufacture, processing, distribution in commerce, use, disposal, storage, and marking of PCBs and PCB items. DOE policy now prohibits the use of PCB items or equipment in DOE-installed equipment at facilities such as WIPP. However, prior to the enactment of TSCA prohibiting PCBs, these chemicals were used in fluids of electrical systems all over the country, including DOE sites. Therefore, surveys have been done at DOE sites to identify any PCB or PCB-containing equipment and to eliminate the fluids and equipment in accordance with EPA standards. Requirements for storage and disposal of PCBs have also been established under TSCA (e.g., see 40 CFR 761.60, *Disposal Requirements,* and 40 CFR 761.65, *Storage for Disposal*).

9.2 Compliance Status of the Regulatory Requirements

Table 9-1 summarizes the applicable regulatory requirements and their compliance status under TSCA. The text gives more detail on the compliance status of each requirement.

TABLE 9-1. Toxic Substances Control Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
Title II, *Asbestos Hazard Emergency Response Act*		
TSCA, §§ 201 et seq.	Hazards of friable asbestos-containing material	**ACHIEVED** Asbestos-containing material restricted at WIPP [Section 9.2.1]
Title III, *Indoor Radon Abatement*		
TSCA, § 309	Study of radon in federal buildings	**ACHIEVED** Study conducted [Section 9.2.2]
40 CFR Part 761, *EPA Regulations for Manufacturing Processing, Distribution in Commerce, and Use Prohibitions for Polychlorinated Biphenyls under the Toxic Substances Control Act*		
40 CFR 761.20	Prohibition of PCBs	**ACHIEVED** Survey and removal of PCB-contaminated equipment; PCBs prohibited at WIPP [Section 9.2.3]
40 CFR 761.60	Disposal requirements for PCBs	**NOT APPLICABLE** PCB-contaminated TRU waste above the regulatory threshold of 50 ppm prohibited from disposal at WIPP [Section 9.2.4]

9.2.1 Hazards of Friable Asbestos-Containing Materials, TSCA, §§ 201 et seq.

> *Because of the hazards to human health inherent in friable asbestos-containing materials, Congress specified a number of requirements pertaining to asbestos specified in Title II of TSCA.*

Asbestos is a restricted material at the WIPP. Therefore, in accordance with WIPP's Hazard Communication Program, asbestos-free insulating material must be used throughout the facility when insulation is being replaced or installed. The removal of any previously installed material that might contain asbestos requires the coordination of WID safety and compliance personnel.

9.2.2 Study of Radon in Federal Buildings, TSCA, § 309

> *Each Federal agency that owns a building must conduct a study of radon contamination in the building(s).*

The DOE conducted an indoor radon study in response to this requirement and submitted the findings in *Results of the U.S. Department of Energy Indoor Radon Study* (DOE, 1990e).

9.2.3 Prohibition of PCBs, 40 CFR 761.20

> *No person may use any PCB or any PCB item regardless of concentration in any way other than in a totally enclosed manner within the United States.*

The DOE has conducted surveys of electrical equipment, such as transformers, that could house PCB-containing fluids. Such a survey was conducted at WIPP. Any equipment containing PCBs was identified and has been replaced by non-PCB-containing equipment. All PCB-containing equipment identified was disposed of in accordance with the regulations described in Section 9.2.4.

9.2.4 Disposal Requirements for PCBs, 40 CFR 761.60

> *In most circumstances, PCBs must be incinerated as stipulated in 40 CFR 761.70 or placed in chemical-waste landfills that meet the requirements of 40 CFR 761.75 and that have been approved as a landfill for PCBs by the EPA.*

Any DOE equipment identified at WIPP that contained PCB fluids was decontaminated as described in the regulations and disposed of as required.

The WIPP WAC states that only those wastes identified in the RCRA Part A and Part B applications as acceptable for emplacement at WIPP may be shipped to WIPP. As indicated in Chapter K of the *WIPP RCRA Permit Application* (Rev. 6), there are currently no plans to ship PCB-contaminated wastes above the regulatory threshold of 50 ppm from the generator sites to WIPP.

10.0 FEDERAL INSECTICIDE, FUNGICIDE, AND RODENTICIDE ACT

10.1 Summary of the Law

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA; 7 USC §§ 136 et seq.) authorizes the EPA to regulate the registration, certification, use, storage, disposal, transportation, and recall of pesticides. Section 18 of FIFRA authorizes the EPA to exempt state and federal agencies from any provision of the act if emergency conditions requiring an exemption have been determined to exist, and the regulations of 40 CFR Part 166, *Exemption of Federal and State Agencies for Use of Pesticides under Emergency Conditions*, provide guidelines for urgent, nonroutine situations that require the use of pesticides and for which exemptions may be authorized. Sections 19(a) and 25(a) of FIFRA authorize the EPA to establish regulations and procedures regarding the disposal or storage of packages and containers of pesticides and the disposal or storage of excess amounts of such pesticides. The regulations of 40 CFR Part 165, *Regulations for the Acceptance of Certain Pesticides and Recommended Procedures for the Disposal and Storage of Pesticides and Pesticides Containers*, established procedures for the acceptance, disposal, or storage of packages and containers of pesticides and for the disposal or storage of excess amounts of such pesticides. The standards of FIFRA are considered mandatory for DOE facilities. All uses and applications of restricted-use pesticides at WIPP are conducted only by commercial pesticide applicators who are under contract with WID and are required to meet federal and state standards. (See also Chapter 38.)

10.2 Compliance Status of the Regulatory Requirements

The two major requirements of FIFRA and the compliance status of each are summarized in Table 10-1. More detail is provided in the text.

TABLE 10-1. Federal Insecticide, Fungicide and Rodenticide Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 152.15	Registration of pesticide products	**NOT APPLICABLE** Pesticide applications done by contractors; pesticides and contracts reviewed by WID safety and regulatory compliance personnel [Section 10.2.1]
40 CFR 165.8-.11	Recommended procedures for disposal or storage of pesticides	**UP TO DATE** General-use product stored at WIPP complies with storage instructions on label [Section 10.2.2]

10.2.1 Registration of Pesticide Products, 40 CFR 152.15

No person may distribute or sell any pesticide product that is not registered under FIFRA. The pesticide must be registered if the person who distributes or sells the substance knows that it will be used as a pesticide.

Restricted-use pesticides are neither stored at WIPP, nor are they applied by WIPP personnel. All applications of restricted-use pesticides are conducted according to existing contract(s) negotiated with pesticide applicators, and WID safety and regulatory compliance personnel review all pesticide application contracts before they are awarded. The DOE requires that any pesticide contractor be licensed with the state as a certified pesticide applicator and submit a list of pesticides used and their respective EPA numbers to WID prior to awarding the contract. The current agreement requires that the applicator perform scheduled quarterly applications and respond to unscheduled "special situations" such as occurrences of wasp swarming and ant infestation. Before an application is performed, the contractor submits information consisting of the application date, location, method of application, the generic pesticide name, and an MSDS for review by WID, which confirms that adequate protective equipment is available and that the pesticides to be used are not on the EPA restricted-

pesticide list. After the application, the contractor must submit such information to WID as the type and amount of pesticide used and the dilution factor.

CINCH, a general-use wasp and hornet killer used on site by WIPP personnel, is properly registered with the state of New Mexico.

10.2.2 Recommended Procedures for the Disposal or Storage of Packages and Containers of Pesticides, 40 CFR Part 165

Recommendations for the storage and disposal of pesticides are specified in 40 CFR 165.8 through 165.11.

WIPP currently makes a general-use wasp and hornet killer available to its personnel. The product is stored in the warehouse according to label instructions. Used, empty cans are discarded by WIPP personnel into satellite accumulation area containers and managed as hazardous waste.

Because WIPP personnel do not use, store, or dispose of restricted-use pesticides on site, the majority of these requirements are not applicable. All restricted-use pesticide applications are made by contractors, who are responsible for storing and disposing of pesticides off site.

The WIPP site is inspected annually by the New Mexico Department of Agriculture, Division of Agriculture and Environmental Services Bureau of Pesticide Management. The purpose of the inspection is to determine compliance with FIFRA, as amended and/or the New Mexico Pesticide Control Act. The inspection routinely includes an overview of the site warehouse, where consumer product pesticides are stored, and records pertaining to pesticides applied by the site pest control subcontractor. The site was inspected in March of 1995 and February of 1996. A Notice of Pesticide Inspection was generated following each inspection. No violations were noted.

All applications of restricted-use pesticides at WIPP are performed by commercial, state-licensed applicators. The DOE requires applicators under contract to comply with the requirements of the New Mexico Pesticide Control Act and the implementing regulations set forth by the New Mexico State University Board of Regents. More information on the state requirements is provided in Chapter 38.

11.0 NOISE CONTROL ACT OF 1972

11.1 Summary of the Law

In the Noise Control Act of 1972 (42 USC §§ 4901 et seq.), the EPA declared its policy of promoting an environment for all Americans that is free from noise jeopardizing public health or welfare. According to the act's policy clause in § 2(a)(3), the primary responsibility for noise control is vested in state and local governments. Federal regulation is deemed essential only for commercial noise sources requiring national uniformity of treatment (e.g., aircraft noise). However, federal agencies are directed to carry out the programs within their control in a manner that furthers the act's policy. Each agency having jurisdiction over any property or facility, or engaged in any activity resulting or which may result in the emission of noise, shall comply with federal, state, interstate, and local requirements regarding the control and abatement of environmental noise "to the fullest extent consistent with their authority." Facilities under the DOE are required to comply with the Occupational Safety and Health Administration (OSHA) regulations that address occupational noise exposure standards under 29 CFR Part 1910, *Occupational Safety and Health Standards.*

The regulations under 29 CFR 1910.95, *Occupational Noise Exposure*, define the permissible noise exposure levels to which employees may be subjected. The regulations also include requirements for the development and implementation of a monitoring program, the establishment and maintenance of an audiometric testing program, the measurement of noise, the provision of personal hearing-protection equipment when necessary, and the administration of a hearing conservation program.

11.2 Compliance Status of the Regulatory Requirement

Table 11-1 summarizes the applicable requirement and its compliance status. More information is provided in the text.

TABLE 11-1. Noise Control Act of 1972 - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
29 CFR 1910, *Occupational Safety and Health Standards*		
29 CFR 1910.95	Compliance with hearing protection standards	**ACHIEVED** Testing, controls, equipment, training, procedures, and contracted specialist in place; Hearing Conservation Program [Section 11.2.1]

11.2.1 Compliance with Hearing Protection Standards, 29 CFR 1910.95

> *Employers must take measures to protect the hearing of employees.*

The DOE administers a full program in accordance with the Noise Control Act and the implementing regulations. Program activities include the following: a hearing conservation program; an audiometric testing program; administrative and engineering controls (e.g., noise mufflers in the area of underground exhaust fans; posted signs); noise measurement (e.g., sound meters, dosimetry); and the provision of personal hearing-protection equipment (e.g., ear plugs, ear muffs). Furthermore, the DOE maintains a certified ear, nose, and throat specialist on contract, requires hearing protection training for WIPP employees, and has developed procedures such as the Hearing Conservation Program. The *WIPP Safety Manual* and the *Occupational Health Manual* and their implementing procedures address the requirements of and activities conducted under this program.

12.0 NATIONAL ENVIRONMENTAL POLICY ACT

12.1 Summary of the Law

The National Environmental Policy Act (NEPA; 42 USC §§ 4321 et seq.) establishes policy, sets goals, and provides means for carrying out the policy. Congress created the Council on Environmental Quality (CEQ) to administer the NEPA program. Within NEPA are "action-forcing" provisions to ensure that federal agencies act according to the letter and spirit of the act and NEPA requirements for identifying reasonable courses of action, along with the environmental consequences of all proposed actions, for all major Federal actions under consideration. The purpose of NEPA is not to generate paperwork but to foster action. The NEPA process is intended to help public officials make decisions based on understanding possible environmental consequences to actions and take the appropriate steps to protect, restore, and improve the environment. Because public involvement in the decision-making process is mandated, NEPA has often been referred to as a "public disclosure law."

The CEQ's regulations in 40 CFR Parts 1500 through 1508 implement § 102(2) of NEPA, informing Federal agencies about what they must do to comply with the procedures and to achieve the goals of NEPA. These regulations outline specific requirements for the early integration of the NEPA process, the preparation of environmental impact statements (EISs) or environmental assessments (EAs), public review and solicitation of comments on EISs, decisions with respect to an EIS or EA, and the implementation of the decisions.

12.2 Compliance Status of the Regulatory Requirements

Table 12-1 summarizes the regulatory requirements and their compliance status under NEPA. Additional information is provided in the text.

TABLE 12-1. National Environmental Policy Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR Parts 1500-1508	Provision of environmental information to public officials and private citizens; use as a decision-making tool; need for EISs, EAs, and categorical exclusions.	**UP TO DATE** 1980 Final Environmental Impact Statement (FEIS) issued. 1981 FEIS Record of Decision (ROD) issued. 1990 Final Supplement Environmental Impact Statement (SEIS) and SEIS ROD issued. 1995 Bureau of Land Management Environmental Assessment adopted by the DOE for the Sand Dunes to Ochoa Power Line Project. 1996, draft SEIS-II under preparation. Several categorical exclusions granted. [Section 12.2.1]

12.2.1 Provision of Environmental Information to Public Officials and Private Citizens, 40 CFR Parts 1500-1508.

> *Environmental information must be made available to the public before decisions are made and actions are taken and must include a detailed statement on environmental impacts of major Federal actions significantly affecting the quality of the human environment.*

Pursuant to the requirements of NEPA, the DOE published the *Final Environmental Impact Statement* (FEIS) for the WIPP in 1980 (DOE, 1980). The FEIS analyzed and compared the environmental impacts of various alternatives for demonstrating the safe disposal of TRU waste resulting from national defense activities. Based on the environmental analyses in the FEIS, the DOE published a Record of Decision (ROD) to the FEIS in 1981 to proceed with the phased development of the WIPP (DOE, 1981). This ROD noted that the FEIS would be supplemented as appropriate if new environmental data resulted from the SPDV program or from other WIPP activities.

Consistent with this commitment, the DOE prepared additional NEPA documentation to address changes in the proposed action and the development of new geologic and hydrologic information.

Changes addressed in the 1990 *Final Supplement Environmental Impact Statement* (SEIS) (DOE, 1990a) included alterations in the composition of the waste inventory, the transportation of waste to the WIPP, conducting a test phase at WIPP, and management of mixed waste (TRU waste with hazardous constituents). The DOE published a ROD to the SEIS in 1990 (DOE, 1990b). One of the commitments made in this second ROD was that the DOE will prepare another Supplemental Environmental Impact Statement (and ROD) prior to initiating the disposal phase at WIPP.

On August 23, 1995, the DOE issued a Notice of Intent (NOI) to prepare the WIPP's second SEIS for the disposal phase. Some of the information being analyzed in the SEIS-II includes the identification of additional generator sites, changes in known waste volume and form, acquisition of new data from the experimental program, and changes to the WAC.

On May 19, 1995, the DOE adopted an EA and a Finding of No Significant Impact issued by the Bureau of Land Management (BLM) which addressed potential impacts of the construction of the sand dunes to Ochoa Power Line Project and a new WIPP substation. The BLM prepared the EA since the construction of the power line took place on BLM-owned land.

Numerous categorical exclusions have been used at WIPP. WID maintains a procedure to direct the evaluation of potential environmental impacts associated with proposed WIPP projects and activities. The plan provides information regarding the screening of these activities to determine if additional NEPA documentation is required.

13.0 ATOMIC ENERGY ACT AND THE U.S. DEPARTMENT OF ENERGY

13.1 Summary of the Law

The Atomic Energy Act of 1954 as amended (AEA; 42 USC §§ 2011 et seq.) established a national program for research, development, and use of atomic energy for national defense and civilian purposes. Section 161 of the AEA authorized the Atomic Energy Commission (AEC) to establish rules, regulations, and orders to govern any activity regulated under the AEA to protect health and minimize hazards to life or property. Activities included standards and restrictions pertaining to the design, location, and operation of facilities.

The AEC has been succeeded by two organizations: DOE for national defense and the U.S. Nuclear Regulatory Commission (NRC) for domestic civilian purposes (see Chapter 15 for the compliance status of NRC-related requirements). Thus, the AEA gave the DOE its authority to develop policies, issue Orders, and promulgate regulations that address environmental, safety, and health protection aspects of radioactive waste and nuclear materials. The radioactive constituents of the transuranic[1] (TRU) waste to be shipped to WIPP are regulated under the AEA by a DOE system of Orders, notices, and directives which carries out the AEA mandate to implement effective and consistent programs to protect the public, the environment, and workers from adverse consequences from DOE operations. Thus, TRU waste is regulated under the AEA and, by extension, by DOE. Regulation of mixed waste (i.e., radioactive waste with hazardous constituents) is more complex. Radioactive wastes and constituents are excluded by statute from regulation under RCRA: in fact, RCRA specifically excludes "source, special nuclear, or by-product material as defined by the Atomic Energy Act of 1954, as amended" (§ 1004[27]) of RCRA; see also § 1006[a]). Therefore, TRU mixed waste is subject to dual regulation under the AEA and RCRA: the radioactive constituents are regulated under the AEA, whereas the hazardous constituents are regulated under RCRA. According to the EPA's policy statement that was published in the *Federal Register* on August 29, 1991 (56 FR 42730), "The hazardous waste components of mixed wastes are subject to RCRA management standards for hazardous wastes, whereas the regulation of the radionuclides (and their radiological hazards) are addressed under AEA authority."

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[1]The AEA defined "transuranic waste" as

> . . .material contaminated with elements that have an atomic number greater than 92, including neptunium, plutonium, americium, and curium, and that are in concentrations greater than 10 nanocuries per gram, or in such other concentrations as the Nuclear Regulatory Commission may prescribe to protect the public health and safety (AEA, § 11[ee]).

In 1982, TRU waste was redefined as having a half life greater than 20 years and a concentration greater than 100 nanocuries per gram of waste. Wastes with concentrations of radioactivity that are less than 100 nanocuries per gram of waste are classified as low-level waste.

13.2 Compliance Status with the Regulatory Requirements

As indicated in the previous section, the DOE has used a system of Orders, notices, and directives to implement its programs under the AEA and to ensure compliance with other statutes and regulations. These implementing documents are not considered to be at the same levels as are those in the Code of Federal Regulations. Those DOE Orders that are most relevant to the management of TRU waste under the AEA are listed and summarized in Table 13-1.

Table 13.1 Summary of the Major DOE Orders Relating to the Management of TRU Wastes under the Atomic Energy Act

DOE Order/ Notice Number	Title of Order and Previous Orders Incorporated[1]	Summary
N-441.1	*Radiological Protection for DOE Activities* Order 5480.11, *Radiation Protection for Occupational Workers* Order 5480.15, *DOE Laboratory Accreditation Program for Personnel Dosimetry* Notice 5400.13, *Sealed Radioactive Source Accountability* Notice 5480.11, *Extension of Radiological Control Manual*, Rev. 1	Establishes radiological protection program requirements that, combined with 10 CFR Part 835 and its associated implementation guidance, form the basis for a comprehensive program for protecting individuals from the hazards of ionizing radiation in controlled areas.
O-151.1	*Comprehensive Emergency Management System* Order 5500.1B, *Emergency Management System* Order 5500.2B, *Emergency Categories, Classes, and Notification and Reporting Requirements* Order 5500.3A, *Planning and Preparedness for Operational Emergencies* Order 5500.4A, *Public Affairs Policy and Planning Requirements for Emergencies* Order 5500.5A, *Public Affairs Policy*	Establishes the following: • Overall policy and requirements for the DOE Emergency Management System (EMS) • DOE emergency categories, classes, and notification and reporting requirements to facilitate the communication and reporting of emergency events. • Requirements for planning and preparedness for operational emergencies involving the DOE or requiring DOE assistance. • Requirements of the Emergency Readiness Assurance Program to ensure that the DOE EMS is ready to respond promptly, efficiently, and effectively to any emergency involving DOE facilities or requiring DOE assistance.

DOE Order/ Notice Number	Title of Order and Previous Orders Incorporated[1]	Summary
O-151.1 (Cont.)	*and Planning Requirements for a Fuel Supply Disruption Emergency* Order 5500.7B, *Emergency Operating Records Protection Program* Order 5500.8A, *Energy Emergency Planning and Management* Order 5500.9A, *Emergency Planning, Preparedness, and Response to Continuity of Government Emergencies* Order 5500.10, *Emergency Readiness Assurance Program*	
O-154.3	*Radiological Assistance Program* Order 5000.3A, *Occurrence Reporting and Processing of Operations Information* Order 5400.1, *General Environmental Protection Program* Order 5500.1B Order 5500.2B Order 5500.3A Order 5500.4A Order 5500.10 Order 5530.1A, *Accident Response Group* Order 5530.2, *Nuclear Emergency Search Team* Order 5530.4, *Aerial Measuring System* Order 5635.4, *Protection of Unclassified Controlled Nuclear Information* Order 5650.2B, *Identification of Classified Information*	Establishes DOE policy, procedures, authorities, and responsibilities for its Radiological Assistance Program (RAP).

DOE Order/ Notice Number	Title of Order and Previous Orders Incorporated[1]	Summary
O154.5	*Federal Radiological Monitoring and Assessment Center* Order 5000.3A Order 5400.1 Order 5500.1B Order 5500.2B Order 5500.3A Order 5500.4A Order 5500.10 Order 5530.1A Order 5530.2 Order 5530.3, *Radiological Assistance Program* Order 5530.4 Order 5635.4 Order 5650.2B	Establishes DOE policy, procedures, authorities, and requirements for the establishment of a Federal Radiological Monitoring and Assessment Center (FRMAC) as set forth in the *Federal Radiological Emergency Response Plan* (FRERP) described in 50 FR 46542.
O-231.1	*Environment, Safety, and Health Reporting* Order 5400.1 (portions) Order 5400.2A, *Environmental Compliance Issue Coordination* (portions) Order 5400.5, *Radiation Protection of the Public and the Environment* (portion) Order 5440.1E, *National Environmental Policy Act Compliance Program* (portions) Order 5480.3, *Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances and Hazardous Wastes* (portion) Order 5480.26, *Trending and Analysis of Operations Information Using Performance Indicators* (portion)	Ensures collection and reporting of information on environment, safety, and health that is required by law or regulation to be collected or that is essential for evaluating DOE operations and identifying opportunities for improvement needed for planning purposes within the DOE.

DOE Order/ Notice Number	Title of Order and Previous Orders Incorporated[1]	Summary
O-231.1 (Cont.)	Order 5483.1A, *Occupational Safety and Health Program for DOE Contractor Employees at Government-Owned Contractor-Operated Facilities* (portions) Order 5484.1, *Environmental Protection, Safety, and Health Protection Information Reporting Requirements* (portions) Order 5630.12A, *Safeguards and Security Inspection and Assessment Program* (portions) Order 5634.1B, *Facility Approvals, Security Surveys, and Nuclear Materials Surveys* (portion)	
O-231.2	*Environmental Protection, Safety and Health Protection Information Reporting Requirements* Order 5484.1	Establishes the requirements and procedures for the reporting of information having environment, safety, and health (ES&H) significance for DOE operations.
O-241.1	*Scientific and Technical Information Management* Order 1360.4B, *Scientific and Technical Computer Software* Order 1430.1C, *Management of Scientific and Technical Information* Order 1430.2B, *Scientific and Technical Information Management Program* Order 1430.3A, *Policy for the Dissemination of and Access to Departmental Unclassified Scientific and Technical Information*	Establishes DOE policy and requirements to ensure the integration of scientific and technical information management into applicable DOE programs and activities, including provisions for disseminating scientific and technical information to promote scientific progress and public understanding.
O-326.1	*Suitability, Position Sensitivity Designations, and Related Personnel Matters* Order 3735.1, *Dissemination of the Departmental Conduct of Employees Regulations* Order 3750.1, *Work Force Discipline* Order 5631.B, *Personnel Security Program*	Identifies the interrelationships among suitability, security, and access authorizations; establishes guidance and policy regarding position sensitivity designations, certain background investigations, and suitability determinations; and establishes the policies and procedures regarding waivers of preemployment investigations. Implements the section of the Atomic Energy Act [Section 145(b)] that describes access requirements.
O-416.1	*Quality Assurance* Order 5700.6B, *Quality Assurance*	Establishes QA requirements for the DOE.

DOE Order/ Notice Number	Title of Order and Previous Orders Incorporated[1]	Summary
O-421.3	*Nuclear Safety Analysis Reports* Order 5480.5, *Safety of Nuclear Facilities* (portions) Order 5480.6, *Safety of Department of Energy-Owned Reactors* (portions) Order 5481.1B, *Safety Analysis and Review Systems*	Establishes requirements for contractors responsible for the design, construction, operation, decontamination, or decommissioning of nuclear facilities to develop safety analyses that establish and evaluate the adequacy of the safety basis of the facilities.
O-435.1	*Radioactive Waste Management* Order 5820.2A, *Radioactive Waste Management*	Establishes policies, guidelines, and minimal requirements by which the DOE manages its radioactive and mixed waste and contaminated facilities.
O-440.1	*Worker Protection Management for DOE Federal and Contractor Employees* Order 3790.1B, *Federal Employee Occupational Safety and Health Program* (portions) Order 5480.b, *Environmental Protection, Safety, and Health Protection Standards* (portions) Order 5480.7A, *Fire Protection* Order 5480.8A, *Contractor Occupational Medical Program* Order 5480.9A, *Construction Project Safety and Health Management* Order 5480.10, *Contractor Industrial Hygiene Program* Order 5480.16A, *Firearms Safety* Order 5483.1A	Establishes the framework for an effective worker protection program that will reduce or prevent accidental losses, injuries, and illnesses by providing DOE federal and contractor workers with a safe and healthful workplace.
O-460.1	*Packaging and Transportation Safety* Order 1540.2, *Hazardous Material Packaging for Transport--Administrative Procedures* Order 5480.3	Establishes safety requirements for the proper packaging and transportation of DOE off-site shipments and on-site transfers of hazardous materials and for modal transport.

DOE Order/ Notice Number	Title of Order and Previous Orders Incorporated[1]	Summary
O-460.2	*Departmental Materials Transportation and Packaging Management* Order 1540.1A, *Materials Transportation and Traffic Management* Order 1540.2 Order 1540.3A, *Base Technology for Radioactive Material Transportation Packaging Systems*	Establishes DOE's policies and requirements to supplement rules, regulations, and other DOE Orders for material transportation and packaging operations.
P-450.1	*Environment, Safety and Health Policy for the Department of Energy Complex*	Lists DOE's guiding principles for protecting the worker and the environment.
5400.1	*General Environmental Protection Program*	Establishes environmental protection program requirements, authorities, and responsibilities for DOE operations for ensuring compliance with federal, state, and local environmental laws and regulations, Executive Orders, and internal DOE policies.
5400.3	*Hazardous and Radioactive Mixed Waste Program*	Establishes DOE hazardous and radioactive mixed waste policies and requirements and implements the requirements of RCRA within the framework of the environmental programs established under DOE Order 5400.1.
5400.5[2]	*Radiation Protection of the Public and the Environment*	Establishes standards and requirements for operations of the DOE and DOE contractors with respect to protecting members of the public and the environment against undue risk from radiation.
5480.4[3]	*Environmental Protection, Safety, and Health Protection Standards* Order 5480.1A, *Environmental Protection, Safety, and Health Protection Program for DOE Operations* (portion)	Specifies and provides requirements for the application of the mandatory ES&H standards applicable to all DOE and DOE contractor operations; provides a listing of reference ES&H standards; and identifies the sources of the mandatory and reference ES&H standards.

DOE Order/ Notice Number	Title of Order and Previous Orders Incorporated[1]	Summary
5480.5	*Safety of Nuclear Facilities*	Establishes a nuclear facility safety program requirements to ensure that: • Nuclear facilities are sited, designed, constructed, modified, operated, maintained, and decommissioned in accordance with generally uniform standards, guides, and codes that are consistent with those applied to comparable licensed nuclear facilities; • Radioactive and fissionable materials are managed in such a manner that the probability of an accident is acceptably low; • An ES&H program is established in accordance with the requirements stipulated in this Order; • ES&H matters are addressed comprehensively and receive an objective review, with all identifiable risks reduced to acceptably low levels, and management authorization of the operation is documented; • Consideration is given to all potential criticality hazards associated with fissionable material operations outside nuclear reactors; and • Government property and essential operations are protected from the effects of potential accidents.

[1] Titles of any previous DOE Order is provided only the first time it is cited.
[2] To be replaced by O-441.1, which has not yet been issued.
[3] To be replaced by O-440.3, which has not yet been issued.

In addition to the regulations that pertain to NEPA (see Chapter 14), the DOE has also issued other regulations in the 10 CFR series. On December 14, 1993, 10 CFR Part 835, *Occupational Radiation Protection*, was published in the *Federal Register*. These regulations became effective on January 13, 1994. A number of programs are in place at WIPP to meet the requirements of 10 CFR Part 835 prior to receipt of TRU waste. It should be noted that these regulations describe occupational exposure limits resulting from normal DOE activities for general DOE employees. These limits are an annual total effective dose equivalent of 5 rems (0.05 sievert), a dose equivalent of 15 rems (0.15 sievert) to the lens of the eye, 50 rems (0.5 sievert) from the sum of the deep dose equivalent for external exposures and the committed dose equivalents to any other organs and tissues, and a shallow dose equivalent of 50 rems (0.5 sievert) to the skin or to any extremity (10 CFR 835.202[a]). All such requirements and limits will become applicable at WIPP upon the receipt of radioactive waste at the facility.

Proposed DOE regulations entitled *Radiation Protection of the Public and the Environment* (10 CFR Part 834) were published in the *Federal Register* on

March 25, 1993. These regulations will become applicable to WIPP when they have been finalized and when waste has been received at the facility.

The DOE has promulgated a new set of regulations, 10 CFR Part 830 (*Nuclear Safety Management*), which was published in the *Federal Register* on April 5, 1994. Compliance with the relevant portions of these regulations is discussed in the following sections and is summarized in Table 13-2. At present, only Subpart A (*General Provisions*) of 10 CFR Part 830 has been issued. Subpart A deals with the scope of the regulations and QA. Other subparts will be issued in the future that will address design (Subpart B), operations (Subpart C), and material management (Subpart D).

TABLE 13.2 *Nuclear Safety Management* (10 CFR Part 830) - Summary of Regulatory Compliance Status

Citation	Requirement	Compliance Status
10 CFR 830.4(a)	Taking action(s) inconsistent with the requirements of 10 CFR Part 830	**UP TO DATE** No person known to have taken such action [Section 13.2.1]
10 CFR 830.4(b)	Implementation and compliance with requirements of 10 CFR Part 830	**UP TO DATE** *WID Quality Assurance Program Description* (QAPD), Rev. 15 [Section 13.2.2]
10 CFR 830.4(c)	Plan or program required by this part as the basis for determining compliance	**ACHIEVED** QAPD, Rev. 15 [Section 13.2.3]
10 CFR 830.6	Records to substantiate compliance	**UP TO DATE** QAPD, Rev. 15, Chapter 4 [Section 13.2.4]
10 CFR 830.7	Use of a graded approach	**UP TO DATE** QAPD, Rev. 15; Procedure WP 13-QA3501 [Section 13.2.5]

Citation	Requirement	Compliance Status
10 CFR 830.120(a)	Development and implementation of contractor's Quality Assurance Program (QAP) in accordance with 10 CFR 830.120(c) to be approved by DOE and conduct of work	**UP TO DATE** QAPD, Rev. 15; manuals, programs, and procedures; DOE approval of QAPD [Section 13.2.6]
10 CFR 830.120(b)	Application of the appropriate QA criteria in the QAP; original submittal of QAPD to DOE; annual submittal of substantive changes in QAP to DOE	**UP TO DATE** QAPD, Rev. 15; submittal to DOE and DOE approval; several submittals of substantive changes to DOE [Section 13.2.7]
10 CFR 830.120(c)	QA criteria to be included in the QAP	**UP TO DATE** QAPD, Rev. 15; other WID plans, procedures, and manuals (Attachment II) [Section 13.2.8]

13.2.1 Taking Action(s) Inconsistent with the Requirements of 10 CFR Part 830, 10 CFR 830.4(a)

> *No person shall take or cause to be taken any action inconsistent with the requirements of this part or any program, plan, schedule, or other process established by this part.*

No person is known to have taken action (or caused to take action) that is inconsistent with the requirements of 10 CFR Part 830 or with any of the program, plan, schedule, or other process established by these regulations.

13.2.2 Implementation and Compliance with Requirements of 10 CFR Part 830, 10 CFR 830.4(b)

> *The contractor responsible for the design, construction, operation, or decommissioning of the facility is responsible for implementing and complying with the requirements of this part.*

WID has implemented and is complying with the requirements of 10 CFR Part 830 in Revision 15 of the *WID Quality Assurance Program Description* (QAPD; WP 13-1), which was issued in January 1995. The manager of Quality and Regulatory Assurance is responsible for verifying effective implementation of the QAPD and for ensuring that an internal self assessment of the quality program is performed annually.

13.2.3 Plan or Program Required by This Part as the Basis for Determining Compliance, 10 CFR 830.4(c)

> *If a section of this part expressly requires a plan, program, or implementation plan (approved by DOE), the provisions of the plan or program will be the basis used to determine compliance with the relevant nuclear safety requirements in the section.*

This part specifies that a Quality Assurance Program (QAP) will be developed and implemented (10 CFR 830.120[a[]ii]-[iii]). This required QAP is described in the WID QAPD (Rev. 15). The provisions of this QAP provide the basis used to determine compliance with the relevant nuclear safety requirements in the section. The WID QAPD was approved by DOE in January 1995.

13.2.4 Records to Substantiate Compliance, 10 CFR 830.6

> *Complete and accurate records will be maintained as needed to substantiate compliance with the requirements of this part.*

WID personnel maintain complete and accurate records as necessary to substantiate compliance with the requirements of this part. Record keeping is described in more detail in Chapter 4 of the QAPD (Rev. 15).

13.2.5 Use of a Graded Approach, 10 CFR 830.7

> *Where indicated in a subpart, a graded approach will be utilized to comply with the requirements. When such an approach is applied, the bases for selecting an action shall be documented.*

According to 10 CFR 830.120(b)(1), the criteria of 10 CFR 830.120(c) shall be applied using a graded approach. (See also Section 1.3.2.8.) Risk factors and the graded approach to quality assurance (QA) are discussed in Section 1.5.1.2 of the QAPD (Rev. 15). Assignment of a specific quality code to an item or activity is commensurate with the associated risk classification; the resulting levels of control provide effective program management and incorporate due regard for the health and safety of the public and plant personnel, complexity, consequences of failure, environmental

impacts, cost, and the safe and reliable operation of WIPP and the TRU transport packaging program.

WID has also issued a procedure (WP 13-QA3501, *Graded Approach*) to implement the graded approach to the application of the criteria described in 10 CFR 830.120(c).

A graded approach of quality measures to software QA requirements is also described in the QAPD. The extent to which specific programmatic controls are implemented will be appropriate to the specific application and will also be sufficient to ensure the quality of the software for its intended use. Several criteria are described that are to be considered in the software evaluation process.

13.2.6 Development and Implementation of Contractor's QAP to Be Approved by DOE and Conduct of Work in Accordance with 10 CFR 830.120(a) and 10 CFR 830.120(c)

The contractor responsible for the DOE nuclear facility shall develop a Quality Assurance Program (QAP) and submit it to DOE for approval. After the QAP has been approved by DOE, the contractor must implement it and must conduct its work in accordance with the criteria described in 10 CFR 830.120(c).

WID developed a QAP as described in the QAPD (Rev. 15). Quality-related work is conducted in accordance with the criteria specified in 10 CFR 830.120(c) and described in the QAPD. Attachment 1 to the QAPD consists of a table, the WID Implementing Document Matrix, that shows how WID manuals, programs, and procedures implement the criteria specified in 10 CFR 830.120(c). DOE approved the QAPD in January 1995.

13.2.7 Application of the Appropriate QA Criteria in the QAP and Annual Submittal of Substantive Changes in the QAP to DOE, 10 CFR 830.120(b)

The contractor shall develop a QAP by applying the QA criteria described in 10 CFR 830.120(c) and indicating how the criteria will be satisfied. The contractor will use a graded approach in applying the criteria and shall use appropriate standards where applicable to develop and implement the QAP. Within 180 days after May 5, 1994, the contractor shall submit the current QAP to DOE, along with an implementation plan, for approval. Substantive changes made to the QAP over the previous year shall be submitted annually to DOE for review.

WID has developed a QAP as described in the QAPD (Rev. 15) using the criteria specified in 10 CFR 830.120(c) (see Section 1.3.2.8). The QAPD includes a discussion of how the criteria of paragraph (c) of 10 CFR 830.120 are met. The "graded approach" used was described in more detail in Section 13.2.5.

Attachment 1 to the QAPD consists of a table, the WID Implementing Document Matrix, that shows how WID manuals, programs, and procedures implement the criteria specified in 10 CFR 830.120.

The QAPD was submitted to DOE, and DOE approved it in January 1995. Several substantive changes have been made to the QAPD since that time; each time, the changes were submitted to and approved by DOE.

13.2.8 QA Criteria to Be Included in the QAP, 10 CFR 830.120(c)

> *A written quality assurance program (QAP) shall be developed. The QA criteria to be included in the QAP are specified and include the management program, personnel training and qualification, quality improvement, documents, and records. The QA criteria also must address performance (i.e., work processes, design, procurement, inspection, and acceptance testing) and assessment (i.e., management assessment and independent assessment.*

WID developed and implemented Revision 15 of the WID QAPD to comply with the requirement to prepare a written quality assurance program, which has recently been replaced with Revision 16. The management program is described in Subsection 1.1 of this document. As required, the organization structure, functional responsibilities and authorities, and interfaces are described in the QAPD and includes a description of planning considerations.

Personnel training and qualifications are described in Subsection 1.2. Subsection 1.3 pertains to quality improvement and includes a description of the requirements and responsibilities for ensuring that appropriate methods are used to enhance quality, to detect and prevent quality problems, and to take corrective actions when necessary when "conditions adverse to quality" have been detected.

Requirements pertaining to documents and records are described in Subsections 1.4 and 1.5 of the QAPD. The discussion in Subsection 1.4 addresses the preparation, review, and approval of documents. The discussion in Subsection 1.5 deals with the generation; classification; indexing; receipt; storage; preservation; disposition,; retrieval; and correction of information in quality records.

Section 2 of the QAPD encompasses the general area of performance QA requirements. Work processes are addressed in Subsection 2.1, including work,

implementing procedures; item identification and control; special processes; and handling, storage, and shipping. Subsection 2.2, *Design Control*, presents a discussion of the design control requirements, including design input, process, analyses, interfaces, verification, and change. Subsection 2.3, *Procurement*, describes the requirements pertaining to procurement planning, documents, evaluation of supplier performance, and commercial grade items. Subsection 2.4, *Inspection and Testing*, provides information pertaining to the requirements and responsibilities for the inspection of Quality Code 1, 2, and 3 items or activities affecting the quality of those items to verify conformance to specified criteria. This subsection also describes requirements and responsibilities for the control of measuring and test equipment.

Section 3, *Quality Assurance Assessment Requirements*, is comprised of two subsections: *Management Assessment* (Subsection 3.1) and *Independent Assessment* (Subsection 3.2). Subsection 3.1 describes how managers should assess their management processes and identify, correct, and track problems that impede achievement of the organization's objectives. Subsection 3.2 describes how independent assessments are planned and conducted to evaluate compliance with the applicable QA requirements and the implementing procedures, as well as to evaluate the effectiveness of the overall quality program.

Section 4, *Sample Control and Quality Assurance Requirements*, deals with sample control and identification; handling, storing, and shipping samples; disposition of nonconforming samples; and environmental data operation samples. Section 5 addresses QA requirements for scientific investigations, whereas Section 6 deals with requirements for software.

Attachment 1 to the QAPD consists of a table, "WID Quality Requirement Implementing Documents," that shows how WID manuals, programs, and procedures implement the criteria specified in 10 CFR 830.120.

This discussion of the organization of the QAPD is based on Revision 16 of this document. This new revision was approved by WID on December 1, 1995; CAO approval was obtained on April 24, 1996, with a May implementation date.

14.0 NATIONAL ENVIRONMENTAL POLICY ACT AND THE U.S. DEPARTMENT OF ENERGY

14.1 Summary of the Law

As discussed in Chapter 12, NEPA establishes policy, sets goals, and provides a process for carrying out the policy. The NEPA process requires the identification of reasonable courses of action, along with the environmental consequences of all proposed actions, for all major Federal actions under consideration. The NEPA process is intended to help public officials make decisions based on understanding possible environmental consequences of proposed actions and to take the appropriate steps to protect, restore, and improve the environment. The establishment of this national policy ensures that consideration is given to environmental values and factors in federal planning and decision making. The DOE's policy is to comply fully with the letter and spirit of NEPA.

The Council on Environmental Quality (CEQ) regulations in 40 CFR Parts 1500-1508 implement § 102(2) of NEPA and inform Federal agencies as to what they must do to comply with the procedures and achieve the goals of NEPA. These parts provide regulations applicable to and binding on all Federal agencies for implementing the procedural provisions of NEPA. The DOE adopted the CEQ regulations and established 10 CFR Part 1021, *National Environmental Policy Act Implementing Procedures*, to implement the procedural provisions of NEPA. By issuing its guidelines as regulations published in the CFR, the DOE ensures that its NEPA procedures are more accessible to the public.

The implementing procedures in 10 CFR Part 1021 detail requirements for the preparation and circulation of NEPA documents, including EISs, supplemental EISs, Records of Decision (RODs), Mitigation Action Plans (MAP), and Environmental Assessments (EAs). The DOE requires that a MAP be prepared for the implementation of any commitments made in an EIS/ROD or supplement for mitigation of environmental impacts associated with an action. A MAP is also required of any Finding of No Significant Impact (FONSI) to an EA that contains mitigative actions prior to initiating the proposed action.

Subpart D, *Typical Classes of Actions*, of this part lists typical types of actions that require NEPA documentation and those which are typically categorically excluded from the need to prepare an EIS or an EA. Classes of actions that the DOE has determined do not individually or cumulatively have a significant effect on the human environment are *categorical exclusions*. The classes of actions identified in Subpart D are: (1) *Categorical Exclusions Applicable to General Agency Actions*, such as routine administrative actions; (2) *Categorical Exclusions Applicable to Specific Agency Actions*, such as installation of data-processing equipment; (3) *Classes of Actions That Normally Require EAs but Not Necessarily EISs*, such as field demonstration projects

for wetlands mitigation; and (4) *Classes of Actions That Normally Require EISs*, such as the siting, construction, and operation of a facility, such as the WIPP, for the disposal of TRU waste.

14.2 Compliance Status of the Regulatory Requirements

Table 14-1 summarizes the regulatory requirements and their compliance status under the DOE's *National Environmental Policy Act Implementing Procedures* in 10 CFR Part 1021. Additional detail is presented in the text.

TABLE 14-1. DOE's National Environmental Policy Act Implementing Procedures, 10 CFR Part 1021 - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
10 CFR Part 1021, *Implementing Procedures*		
10 CFR Part 1021	Supplements and clarifies the requirements contained in 40 CFR Parts 1500-1508; adds requirement for MAPs; delineates specific categorical exclusions for use by the DOE.	**UP TO DATE** 1980 FEIS and 1981 FEIS ROD issued. 1990 SEIS and SEIS ROD issued. 1995 BLM EA adopted by the DOE for the Sand Dunes to Ochoa Power Line Project. 1996, draft SEIS-II under preparation. MAP issued in July 1991, with annual MAP reports submitted in July 1992, 1993, 1994, and 1995. Several categorical exclusions granted. [Section 14.2.1]

14.2.1 Implementing Procedures, 10 CFR Part 1021

> *DOE's regulations that implement NEPA (10 CFR Part 1021) supplement and clarify the requirements contained in 40 CFR Parts 1500-1508 (see also Chapter 12). The DOE regulations add a requirement for Mitigation Action Plans (MAPs) for EISs, supplemental EISs, and RODs. They also delineate specific categorical exclusions for DOE facilities.*

In 1980, the DOE published the FEIS (DOE, 1980) which analyzed and compared the environmental impacts of various alternatives for demonstrating the safe disposal of

TRU waste resulting from DOE national defense-related activities. The FEIS for the WIPP Project includes responses to the comments received in writing and at the public hearings, as is required.

Based on the environmental analyses presented in the FEIS, the DOE published a ROD in 1981 to proceed with the phased development of the WIPP. The ROD was published in the *Federal Register* on January 28, 1981 (DOE, 1981). A number of mitigative commitments were specified.

Since publication of the FEIS in 1980, new geological and hydrological information led to changes in the understanding of the hydrogeological characteristics of the WIPP site as they relate to the long-term performance of the underground waste repository. In addition, there have been changes in the information and assumptions used to analyze the environmental impacts in the FEIS. Consequently, the SEIS, which updated the environmental record established in 1980 by evaluating the environmental impacts associated with new information, new circumstances, and proposal modifications, was published in 1990 (DOE, 1990a).

Based on the analysis presented in the SEIS, the SEIS ROD accepted the proposed action to proceed with the phased WIPP development. The DOE published the SEIS ROD in the *Federal Register* on June 22, 1990 (DOE, 1990b). A number of mitigative commitments were specified in the ROD, including the commitment to prepare another supplemental EIS prior to the initiation of the disposal phase at WIPP.

On August 23, 1995, the DOE issued a NOI to prepare the WIPP's SEIS-II. Some of the information being analyzed in the SEIS-II include the identification of additional generator sites, changes in known waste volume and form, acquisition of new data from the experimental program, and changes to the WAC.

On May 19, 1995, the DOE adopted an EA and FONSI issued by the BLM which addressed potential impacts of the construction of the sand dunes to Ochoa Power Line Project and a new WIPP substation. The new 115 KV transmission line and WIPP substation were necessary to provide a redundant electrical power source to the WIPP. The BLM prepared the EA since the construction of the power line took place on BLM-owned land.

The DOE issued the *Mitigation Action Plan for the Records of Decision for the Waste Isolation Pilot Plant* (DOE, 1991e) on July 10, 1991. This document addresses the mitigative commitments stated in the RODs to the 1980 FEIS and the 1990 SEIS and discusses mitigative actions, organizations responsible for implementing these actions, and the status of each commitment. The Annual Mitigation Report (AMR) is prepared annually to track the status of each commitment that has not yet been closed. To date, AMRs have been issued in July 1992, July 1993, July 1994, and July 1995. The 1996 AMR is currently in preparation.

Numerous categorical exclusions have been used at WIPP in accordance with 10 CFR Part 1021. The WID maintains a procedure to direct the evaluation of potential environmental impacts associated with proposed WIPP projects and activities. The plan provides information regarding the screening of these activities to determine if additional NEPA documentation is required.

15.0 ATOMIC ENERGY ACT AND THE U.S. NUCLEAR REGULATORY COMMISSION

15.1 Summary of the Law

As discussed in Chapter 13, the Atomic Energy Act of 1954 as amended (AEA; 42 USC §§ 2011 et seq.) gives the U.S. Nuclear Regulatory Commission (NRC) its authority to develop policies, issue orders, and promulgate regulations that address environmental, safety, and health protection aspects of radioactive waste and nuclear materials in the civilian sector. Regulations promulgated by the NRC under the AEA appear in the first portion of Title 10 of the Code of Federal Regulations (CFR) and establish standards for the management of nuclear material and the protection of the public against radiation. Additional NRC requirements apply to the licensing, packaging, preparation, and transportation of radioactive materials.

15.2 Compliance Status of the Regulatory Requirements

Generally, the NRC does not have regulatory authority over the DOE. The only portion of the NRC's implementing regulations that applies to WIPP is 10 CFR Part 71, *Packaging and Transportation of Radioactive Material.* These regulations pertain to the NRC's certification of packaging such as the Transuranic Package Transporter Model II (TRUPACT-II) shipping container designed to transport contact-handled (CH) TRU wastes from the generator sites to WIPP. The current plans are to use the 72B cask to transport remote-handled (RH) TRU waste to WIPP. DOE plans to send a copy of the 72B cask Safety Analysis Report for Packaging (SARP) to the NRC during this calendar year to initiate the Certificate of Compliance (C of C) process for this cask.

It should be noted that the NRC revised 10 CFR Part 71 to make it more consistent with the regulations of the International Atomic Energy Agency (IAEA). The new rules, which appeared in the *Federal Register* on September 28, 1995 (60 FR 50248), do not impact WIPP's compliance status with the applicable requirements, nor will the impact certification requirements for either the TRUPACT-II container or the proposed 72B cask. Therefore, they are not addressed further in this document.

The compliance status of each of the applicable NRC regulatory requirements is summarized in Table 15-1. Details are provided in the text.

TABLE 15-1. Atomic Energy Act and the U. S. Nuclear Regulatory Commission (NRC) - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
10 CFR Part 71, *Packaging and Transportation of Radioactive Material*		
10 CFR 71.12	NRC-approved package	**ACHIEVED** *TRUPACT-II Certificate of Compliance (C of C, Rev. 7, dated 3/25/96) Section 14.* [Section 15.2.1]
10 CFR 71.31-71.39	Contents of application and package description, evaluation, and QA	**ACHIEVED** *TRUPACT-II Safety Analysis Report for Packaging (SARP)* [Section 15.2.2]
10 CFR 71.41	Demonstration of compliance	**ACHIEVED** TRUPACT-II SARP, Section 1.2 [Section 15.2.3]
10 CFR 71.43 and 71.45	Requirements for all packages	**ACHIEVED** TRUPACT-II SARP, Sections 2.4 and 2.5 [Section 15.2.4]
10 CFR 71.47	External radiation standards for all packages	**ACHIEVED** TRUPACT-II SARP, Section 5.0 [Section 15.2.5]
10 CFR 71.51	Additional requirements for Type B packages	**ACHIEVED** TRUPACT-II SARP, Section 4.0 [Section 15.2.6]

CITATION	REQUIREMENT	COMPLIANCE STATUS
10 CFR 71.55-71.61	Requirements for all fissile material packages	**ACHIEVED** TRUPACT-II SARP, Section 6.0 [Section 15.2.7]
10 CFR 71.63	Special requirements for plutonium shipments in excess of 20 Ci/shipment	**ACHIEVED** TRUPACT-II SARP, Section 1.2 and Appendix 1.3.7 [Section 15.2.8]
10 CFR 71.71	Tests under normal conditions of transport	**ACHIEVED** TRUPACT-II SARP, Section 2.6 [Section 15.2.9]
10 CFR 71.73	Tests under hypothetical accident conditions	**ACHIEVED** TRUPACT-II SARP, Section 2.7 [Section 15.2.10]
10 CFR 71.81	Compliance with general requirements (71.00-.6a), operating controls and procedures (71.81-.99), and QA requirements (71.101-.137)	**ACHIEVED** TRUPACT-II SARP, Sections 7.0, 8.0, and 9.0 [Section 15.2.11]
10 CFR 71.83	Assumptions as to unknown properties: assume credible values that will cause the maximum nuclear reactivity	**ACHIEVED** TRUPACT-II SARP, Appendix 1.3.7 [Section 15.2.12]
10 CFR 71.85	Preliminary determinations of integrity of packaging, pressure testing, and marking	**UP TO DATE** TRUPACT-II SARP, Section 8.1 [Section 15.2.13]

CITATION	REQUIREMENT	COMPLIANCE STATUS
10 CFR 71.87	Routine determinations prior to each shipment	**UP TO DATE** TRUPACT-II SARP, Section 7.0 [Section 15.2.14]
10 CFR 71.89	Any special opening instructions for the consignee	**UP TO DATE** TRUPACT-II SARP, Section 7.2 [Section 15.2.15]
10 CFR 71.91	Records to be kept at least 3 years after shipment	**UP TO DATE** WID record-keeping procedures in place for TRUPACT-II containers [Section 15.2.16]
10 CFR 71.93	Inspections and tests to be performed or allowed to be performed by the NRC	**UP TO DATE** NRC inspections during and after fabrication [Section 15.2.17]
10 CFR 71.95	Reports regarding (1) any decreased effectiveness of an authorized packaging during use and (2) details of any defects with safety significance	**UP TO DATE** Records maintained by TRUPACT-II Maintenance Engineer; no reports to date [Section 15.2.18]
10 CFR 71.97	Advance notification of shipment of nuclear waste as described	**UP TO DATE** TRANSCOM satellite tracking system for advance notification [Section 15.2.19]
10 CFR 71.101-71.137	NRC QA requirements	**ACHIEVED** NRC inspection of WID's QA program [Section 15.2.20]

15.2.1 General License, 10 CFR 71.12

A general license is issued to any licensee of the NRC to transport licensed material in a package for which a license, certificate of compliance, or other approval has been issued by the NRC.

A general license is not required for WIPP. However, each type of packaging to be used to transport either CH or RH TRU waste is required to have a C of C.

The TRUPACT-II container has been approved for use in transporting CH TRU waste under the general license provisions of 10 CFR 71.12 (C of C No. 9218, Revision 7, dated March 25, 1996, Section 14). The DOE is registered with the NRC as a user. The NRC's reissuance of Revision 7 of C of C No. 9218 confirms that the TRUPACT-II packaging design continues to meet the applicable requirements of 10 CFR 71.12. The TRUPACT-II C of C was reissued on March 30, 1995, and will expire on June 30, 1999.

15.2.2 Contents of Application and Package Description/Evaluation, 10 CFR 71.31-71.39

The required contents of an application are described. The application must include a package description/evaluation and description of the packaging and proposed contents as described in 10 CFR 71.33 and must demonstrate that the package meets the appropriate NRC standards. In addition, the quality assurance (QA) program for the design, fabrication, assembly, testing, maintenance, repair, modification, and use of the package must be described, along with established codes and standards. Any additional information requested by the NRC must be provided.

The SARP for the TRUPACT-II packaging describes the design, specifications, and safety evaluation in accordance with the NRC's requirements (DOE, 1989a). The NRC's reissuance of Revision 7 of C of C No. 9218 confirms that the TRUPACT-II is in compliance with all applicable requirements of 10 CFR 71.31-71.39.

15.2.3 Demonstration of Compliance, 10 CFR 71.41

The tests specified in 10 CFR 71.71 and 71.73 must be performed on the package to demonstrate compliance under normal conditions and hypothetical accident conditions, respectively.

Section 1.2 of the TRUPACT-II SARP describes the analysis and testing to demonstrate compliance with both normal and hypothetical accident conditions of

transport. The NRC's reissuance of C of C No. 9218 (Revision 7) confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.41.

15.2.4 Standards for All Packages, 10 CFR 71.43 and 71.45

> *Standards for all packages must be met. These include general standards such as size, seals and fastening devices, materials and construction of the package, valves, temperature, and prohibition of continuous venting during transport as well as lifting and tie-down standards.*

Sections 2.4 and 2.5 of the TRUPACT-II SARP describe the packaging features, including tie-downs. The NRC's reissuance of C of C No. 9218 (Rev. 7) confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.43 and 71.45.

15.2.5 External Radiation Standards for All Packages, 10 CFR 71.47

> *A package must be designed and prepared for shipment so that the radiation level at any external surface of the package does not exceed 200 millirem per hour and the transport index does not exceed 10.*

Section 5.0 of the TRUPACT-II SARP discusses the fact that the TRUPACT-II has no special shielding; the contents are limited to less than 200 millirem per hour at the surface of the payload containers. The NRC's reissuance of C of C No. 9218 (Rev. 7) confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.47.

15.2.6 Additional Requirements for Type B Packages, 10 CFR 71.51

> *Type B packages must be designed, constructed, and prepared for shipment so as to prevent loss or disposal of radioactive material, significant increase in external radiation levels, or substantial reduction in the effectiveness of the packaging (see also Section 15.2.1.9) during normal transport. In addition, release of krypton-85 may not exceed 10,000 curies in 1 week, release of other radioactive material may not exceed a total amount A_2 in 1 week, and no external radiation dose rate may exceed 1 rem per hour at 1 meter from the external surface of the package during hypothetical accident conditions. Compliance with these requirements must not be predicated upon the use of filters or of a mechanical cooling system.*

Section 4.0 of the TRUPACT-II SARP discusses containment design and an acceptance criterion (a leak rate of less than 1 x 10^{-7} standard cubic centimeters per second). The NRC's reissuance of C of C No. 9218 (Rev. 7) confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.51.

15.2.7 Requirements for All Fissile Material Packages, 10 CFR 71.55-71.61

> *All packages used to ship fissile material must be designed and constructed in accordance with 10 CFR 71.41 through 71.51. In addition, each package must be designed and constructed and its contents so limited that the contents will remain subcritical during normal and accident transportation conditions and that the packaging will remain effective during normal transportation conditions. Specific standards for Fissile Class I, II, and III packages are described in 10 CFR 71.57, 71.59, and 71.61, respectively. A Fissile Class I package must be designed and constructed and its contents so limited that (1) any number of undamaged packages would be subcritical in any arrangement and with optimal interspersed hydrogenous moderation and (2) 250 packages, if each were subjected to the tests specified in 10 CFR 71.73, would be subcritical if stacked together in any arrangement, closely reflected on all sides by water, and with optimal interspersed hydrogenous moderation.*

Section 6.0 of the TRUPACT-II SARP discusses criticality; the contents are controlled to limit the amount of fissile material that may be shipped. The TRUPACT-II is a Fissile Class I package. The NRC's reissuance of C of C No. 9218 (Rev. 7) confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.55-71.61.

15.2.8 Special Requirements for Plutonium Shipments, 10 CFR 71.63

> *Plutonium in excess of 20 curies per package must be shipped as a solid and must be packaged in a separate inner container placed within outer packaging that meets the requirements of 10 CFR 71.41 through 71.77. In addition, the restrictions limiting plutonium under normal and accident conditions must be met.*

Section 1.2 of the TRUPACT-II SARP describes the double containment feature of the TRUPACT-II; Appendix 1.3.7 of the TRUPACT-II SARP requires the contents to be in a nondispersable form. The NRC's reissuance of C of C No. 9218 (Rev. 7) confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.63.

15.2.9 Tests under Normal Conditions of Transport, 10 CFR 71.71

> *The behavior of each package design under tests and conditions simulating normal transportation conditions must be evaluated. The tests include thermal insulation for both heated and cold conditions, increased and reduced external pressure, vibration, water spray, free drop, corner drop, compressive loading, and penetration.*

Section 2.6 of the TRUPACT-II SARP describes the analyses and/or tests performed to demonstrate compliance with the normal conditions of transport. The NRC's reissuance of C of C No. 9218 (Rev. 7) confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.71.

15.2.10 Tests under Hypothetical Accident Conditions, 10 CFR 71.73

> *Evaluation of a package for hypothetical accident conditions is based upon the sequential application of tests in the order specified to determine their cumulative effect on a package or array of packages. Tests include free drop, puncture, thermal, and immersion as specified in 10 CFR 71.73.*

Section 2.7 of TRUPACT-II SARP describes the analyses and/or tests performed to demonstrate compliance with the hypothetical accident conditions of transport. The NRC's reissuance of Revision 7 of C of C No. 9218 confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.73.

15.2.11 Compliance with Operating Controls and Procedures, 10 CFR 71.81

> *A licensee who is subject to this part and who transports licensed material must comply with requirements of the general provisions (71.00-71.6a), operating controls and procedures (71.81-71.99), and quality assurance requirements (71.101-71.137).*

Sections 7.0, 8.0, and 9.0 of the TRUPACT-II SARP describe acceptance and maintenance, operating instructions, and QA. The NRC's reissuance of Revision 7 of C of C No. 9218 confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.81.

15.2.12 Assumptions Regarding Unknown Properties, 10 CFR 71.83

> *When the isotopic abundance, mass, concentration, degree of irradiation, degree of moderation, or other relevant property of fissile material in a package is not known, the*

> *fissile material will be packaged as if the unknown properties have credible values that will cause the maximum nuclear reactivity.*

Section 6.0 of the TRUPACT-II SARP assumes the worst case for the criticality assumptions; Appendix 1.3.7 limits the amount of fissile material that may be shipped in the TRUPACT-II packaging. The NRC's reissuance of Revision 7 of C of C No. 9218 confirms that the TRUPACT-II continues to meet the applicable requirements of 10 CFR 71.83.

15.2.13 Preliminary Determination of Integrity of Packaging, Pressure Testing, and Marking, 10 CFR 71.85

> *Prior to the first use of any packaging for shipment of licensed material, the licensee shall verify the structural integrity of the containment system by conducting a pressure test and shall mark the package appropriately as specified by 10 CFR 71.85.*

Prior to the first use of the TRUPACT-II packaging for the shipment of TRU waste, the integrity of the packaging will be ensured, pressure testing will be conducted as required, and the packagings will be marked with the TRUPACT-II model number, gross weight, and the package identification number assigned by the NRC. Section 8.1 of the TRUPACT-II SARP describes preliminary determinations.

15.2.14 Routine Determinations Prior to Each Shipment, 10 CFR 71.87

> *Prior to each shipment of licensed material, the licensee must ensure that the package and its contents satisfy the applicable requirements of this part and the license. These routine determinations include appropriateness and integrity of packaging; closure devices; liquid containment; pressure relief devices; loading and closure procedures; moderator/neutron absorbers, if appropriate; lift/tie-down devices; external radiation levels (on external surfaces of the package and around vehicle); and accessible package surface temperatures.*

Routine WID procedures and operating and maintenance instructions are in place to ensure that these requirements are met. Section 7.0 of the TRUPACT-II SARP describes routine determinations.

15.2.15 Special Opening Instructions, 10 CFR 71.89

> *Any special opening instructions must be sent or otherwise made available to the consignee prior to delivery of a package.*

WIPP personnel are also responsible for training personnel at the generator sites in these methods and performing assessments and audits to ensure that the WIPP-generated methods are being applied correctly at the generator sites.

15.2.16 Maintenance of Records, 10 CFR 71.91

> *A record of each shipment of licensed material must be kept at least 3 years after shipment. The records to be kept include identification of the packaging by model number, verification of integrity of the packaging, coolant information, type and quantity of licensed material, specific information regarding irradiated fissile material, date of shipment, any special controls, name and address of transferee and of recipient, and results of the determinations required by 10 CFR 71.87. Records demonstrating the quality of packaging must also be retained.*

Each WID procedure pertaining to the TRUPACT-II identifies the specific records required for retention. Retention times are also identified for each record. Records are retained at the working location and submitted to the WIPP Records Center for safe and retrievable storage.

15.2.17 NRC Inspections and Tests, 10 CFR 71.93

> *The licensee or certificate holder shall allow the NRC to inspect the licensed material, packaging, premises, and facilities in which the material or packaging is used, provided, constructed, listed, stored, or shipped; perform (and allow the NRC to perform) tests deemed necessary by the NRC; and notify the NRC at least 45 days prior to the fabrication of a package to be used to ship licensed material that exceeds the allowed heat load (5 kilowatts) or the maximal normal operating pressure (15 psi gauge).*

The DOE has allowed, and will continue to allow, the NRC to inspect and/or conduct tests, or will perform those tests deemed necessary by the NRC, on TRU waste transportation packages. The TRUPACT-II C of C requires DOE to meet Subpart G requirements (see Sections 15.2.11 through 15.2.19). Currently there are no

TRUPACT-II packages in production. At least 45 days prior to the resumption of construction, the DOE will notify the NRC as required by the TRUPACT-II C of C.

15.2.18 Reports Regarding Decreased Effectiveness or Defects with Safety Significance, 10 CFR 71.95

> *Within 30 days, the licensee will report the following to the NRC: (1) any instance in which there was decreased effectiveness of any authorized packaging during use and (2) details of any defects with safety significance in packaging after first use and the means used to prevent recurrence.*

The packaging maintenance program is defined and detailed in a WID procedure that addresses such topics as control of material, spare parts, and nonconformance reports. Maintenance records are maintained by the TRUPACT-II maintenance engineer. No conditions causing decreased effectiveness have occurred to date. An audit of the TRUPACT-II maintenance program, conducted in November 1995 by members of the WID Quality and Regulatory Assurance (Q&RA) Department, determined that all the programmatic requirements for maintaining the TRUPACT-II packagings were being met adequately.

15.2.19 Advance Notification of Shipment of Nuclear Waste, 10 CFR 71.97

> *Advance written notification of a shipment of nuclear waste will be provided to the governor of any state to be traversed by the shipment. Notification must be provided at least 7 days or 4 days before the beginning of the 7-day period during which departure of the shipment is expected if notification is by mail or by messenger, respectively. The information required by 10 CFR 71.97(d) will be provided. It should be noted that a revised list of governors' designees was published in the Federal Register on June 30, 1995 (60 FR 34306). The annually updated list will be published in the Federal Register every year around June 30.*

Advance notification to state officials will be made in writing and using the TRANSCOM satellite tracking system. Operations personnel and designated state officials will be notified regarding WIPP shipments and other selected high-visibility shipments. State officials designated for receipt of this information have been provided with the requisite TRANSCOM computer software and have been trained in its use. In addition, DOE will provide the officials with a year-long schedule of proposed shipments of TRU waste to WIPP, with updates every 6 months.

15.2.20 NRC Quality Assurance Requirements, 10 CFR 71.101-71.137

Subpart H of 10 CFR Part 71 (71.101-71.137) established the NRC quality assurance (QA) requirements for packagings. The QA requirements pertain to design, purchase, fabrication, handling, shipping, storage, cleaning, assembly, inspections, testing, operation, maintenance, repair, and modification of components of packaging that are important for safety. The requirements address the licensee's QA organization (71.103); QA program (71.105); package design control (71.107); procurement document control (71.109); instructions, procedures, and drawings (71.111); document control (71.113); control of purchased material, equipment, and services (71.115); identification and control of material parts and components (71.117); control of special processes (71.119); internal inspections (71.121); test control (71.123); control of measuring and test equipment (71.125); handling, storage, and shipping control (71.127); inspection test and operating status (71.129); non-conforming materials, parts, or components (71.131); corrective action (71.133); QA records (71.135); and audits (71.137).

The *WID QA Plan for Procurement, Use, Maintenance and Repair of TRUPACT-II* has addressed the 18 criteria specified within Annex 2 of the NRC's Regulatory Guide 7.10, promulgated by the Office of Nuclear Regulatory Research. The title of this document is *Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material*. The NRC has inspected the WID's QA program and found that it meets the requirements of 10 CFR 71, Subpart H.

Members of the WID Q&RA Department conducted an audit regarding the transportation, receipt, and maintenance of the TRUPACT-II packagings in November 1995. The overall audit results indicated that all the programmatic requirements in these three areas were being administered adequately.

15.3 Compliance Status of the Certificate of Compliance

The NRC has issued C of C No. 9218 to the DOE for the TRUPACT-II container and registered the DOE as a user. A number of conditions are specified in the C of C. The conditions from the latest revision of the C of C (Revision 7, dated March 25, 1995) are summarized in Table 15-2. Additional detail is presented in the text.

TABLE 15-2. The U. S. Nuclear Regulatory Commission's Certificate of Compliance for the TRUPACT-II Container - Compliance Status of Conditions and Restrictions

CITATION	CONDITION OR RESTRICTION	COMPLIANCE STATUS
	Description of TRUPACT-II	
C of C, p. 1, 5(2), para. 1	Overall specifications for the TRUPACT-II	**ACHIEVED** TRUPACT-II SARP, Section 1.2.1.1 and Appendix 1.3.2 [Section 15.3.1]
C of C, p. 1, 5(2), para. 1	Weight specifications	**ACHIEVED** TRUPACT-II SARP, Section 1.2.1.2 and Appendix 1.3.2 [Section 15.3.2]
C of C, p. 1, 5(2), para. 2	Outer containment assembly specifications	**ACHIEVED** TRUPACT-II SARP, Section 1.2.1.1 [Section 15.3.3]
C of C, p. 1, 5(2), para. 3, ICV	Inner containment vessel specifications	**ACHIEVED** TRUPACT-II SARP, Section 1.2.1.1.2 and Appendix 1.3.2 [Section 15.3.4]
	Packaging - Drawings	
C of C, p. 2, 5(a)(3), para. 1	Packaging construction	**ACHIEVED** TRUPACT-II SARP, Appendix 1.3.2 [Section 15.3.5]

CITATION	CONDITION OR RESTRICTION	COMPLIANCE STATUS
C of C, p. 2, 5(a)(3), para. 2	Positioning of contents within packaging	**ACHIEVED** TRUPACT-II SARP, Appendix 1.3.2 [Section 15.3.6]
Contents - Type and Form of Material		
C of C, p. 2, 5(b)(1)	Allowable materials	**UP TO DATE** TRUPACT-II SARP, Appendix 1.3.7, *TRUPACT-II Authorized Methods for Payload Control* (TRAMPAC); WAC [Section 15.3.7]
C of C, p. 2, 5(b)(1)	Explosives, corrosives, nonradioactive pyrophorics, and pressurized containers prohibited	**UP TO DATE** TRAMPAC; WAC [Section 15.3.8]
C of C, p. 2, 5(b)(1)	Radioactive pyrophorics not to exceed 1 percent by weight within a drum, standard waste box (SWB), or bin	**UP TO DATE** TRAMPAC; WAC [Section 15.3.9]
C of C, p. 2, 5(b)(1)	Free liquids not to exceed 1 percent by volume within a drum, SWB, or bin	**UP TO DATE** TRAMPAC; WAC [Section 15.3.10]
C of C, p. 2, 5(b)(1)	Flammable organics limited to 500 ppm in headspace of any drum, SWB, or bin	**UP TO DATE** TRAMPAC; WAC [Section 15.3.11]
Contents - Maximal Quantity of Material per Package		
C of C, p. 2, 5(b)(2), para. 1	Maximum allowable weight	**UP TO DATE** TRAMPAC; WAC [Section 15.3.12]

CITATION	CONDITION OR RESTRICTION	COMPLIANCE STATUS
C of C, p. 2, 5(b)(2), para. 2	Maximal number of payload containers per package and authorized packaging configurations	**UP TO DATE** TRAMPAC; WAC [Section 15.3.13]
C of C, p. 2, 5(b)(2), para. 3	Amount of allowable fissile material	**UP TO DATE** TRAMPAC; WAC [Section 15.3.14]
C of C, p. 2, 5(b)(2), para. 4	Allowable decay heat	**UP TO DATE** TRUPACT-II SARP, Section 1.2.3.33; TRUPACT-II Content Codes (TRUCON) [Section 15.3.15]
	Fissile Class	
C of C, p. 2, 5(c)	Fissile Class I	**UP TO DATE** TRUPACT-II SARP, Section 6.0 [Section 15.3.16]
C of C, p. 3, 6	Restrictions of form, properties, and other parameters	**UP TO DATE** TRAMPAC; WAC [Section 15.3.17]
C of C, p. 3, 7	Shipping category designations	**UP TO DATE** TRUCON [Section 15.3.18]
C of C, p. 3, 8	Labeling requirements	**UP TO DATE** TRAMPAC; WAC [Section 15.3.19]

CITATION	CONDITION OR RESTRICTION	COMPLIANCE STATUS
C of C, p. 3, 9	Preshipping venting or aspirating requirements	**UP TO DATE** TRAMPAC; WAC; TRUCON [Section 15.3.20]
C of C, p. 3, 10	Requirements of Subpart G of 10 CFR Part 71	**UP TO DATE** WID QA program [Section 15.3.21]
C of C, p. 3, 10(a)	Preparation of packages for shipment and operations	**UP TO DATE** TRUPACT-II SARP, Section 7.0 [Section 15.3.22]
C of C, p. 3, 10(b)	Testing and maintenance of packaging	**UP TO DATE** TRUPACT-II SARP, Section 8.0 [Section 15.3.23]
C of C, p. 3, 11	Contents of each package	**UP TO DATE** TRAMPAC; WAC [Section 15.3.24]
C of C, p. 3, 12	Leak testing	**UP TO DATE** TRUPACT-II SARP, Section 8.0 [Section 15.3.25]
C of C, p. 3, 13	Removal of free-standing water	**UP TO DATE** TRUPACT-II SARP, Section 7.0 [Section 15.3.26]
C of C, p. 3, 14	Approval of TRUPACT-II	**ACHIEVED** NRC's C of C No. 9218, Rev. 7 [Section 15.3.27]

CITATION	CONDITION OR RESTRICTION	COMPLIANCE STATUS
C of C, p. 3, 15	Expiration date: June 30, 1999	**UP TO DATE** Will submit application to the NRC for timely renewal prior to expiration [Section 15.3.28]

15.3.1 Overall Specifications for the TRUPACT-II, C of C, p. 1, 5(2), para. 1

> *The TRUPACT-II consists of an unvented, 1/4-inch-thick stainless steel inner containment vessel (ICV) positioned within an outer containment assembly (OCA).*
>
> *The OCA is an unvented 1/4-inch-thick stainless steel outer containment vessel (OCV) with a 10-inch-thick layer of polyurethane foam and a 1/4- to 3/8-inch-thick outer stainless steel shell.*
>
> *The package is a right circular cylinder with outside dimensions of about 94 inches in diameter and 122 inches in height.*

The TRUPACT-II packaging is composed of the ICV positioned within the OCA. As shown in the drawings in Appendix 1.3.2 of the TRUPACT-II SARP and discussed in Section 1.2.1.1 of that document, the ICV is unvented and is fabricated primarily of 1/4-inch Type 304 stainless steel. The OCA is also unvented and is bounded by a 1/4- to 3/8-inch-thick Type 304 stainless steel shell. Within the outer shell of the OCA is the OCV, which has a 3/16-inch-thick Type 304L stainless steel shell. Between the inner shell of the OCA and the outer shell of the OCV is a layer of polyurethane foam to provide insulation and absorb energy; this layer is up to 9-13/16 inches thick.

The configuration of the TRUPACT-II packaging is that of a right cylinder with domed heads. The OCA is 94-3/8 inches in diameter and 121-3/4 inches high (Section 1.2.1.1.1 of the TRUPACT-II SARP).

15.3.2 Overall Weight, C of C, p. 1, 5(2), para. 1

> *The package weighs no more than 19,250 lbs when loaded, with the maximal allowable contents of 7,265 lbs.*

According to Section 1.2.1.2 of the SARP, the maximum gross shipping weight of the TRUPACT-II package is 19,250 lbs. The maximal payload weight is 7,265 lbs.

15.3.3 Outer Containment Assembly of the TRUPACT-II, C of C, p. 1, 5(2), para. 2

The OCA has a domed lid that is secured to the OCA's cylindrical body with a locking-ring mechanism.

The OCV containment seal is provided by a butyl rubber O-ring (bore seal).

The OCV is equipped with a seal test port and a vent port.

As shown and described in Section 1.2.1.1 of the TRUPACT-II SARP, the OCA has a domed lid that is secured to the body of the OCA with a locking ring assembly. The containment O-ring is made of butyl rubber. The location of the OCV seal test port and the vent port are shown in Appendix 1.3.2 of the TRUPACT-II SARP (Sheet 2 of Drawing 2077-500 SNP).

15.3.4 Inner Containment Vessel of the TRUPACT-II, C of C, p. 1, 5(2), para. 3

The ICV is a right cylinder with two domed heads. The ICV is designed and constructed to the standards of the ASME Boiler and Pressure Vessel Code, Sections III and VIII, Division I. Its outside dimensions are approximately 73 inches in diameter and 98 inches high.

The lid is secured to the ICV body with a locking ring.

The containment seal is provided by a butyl rubber O-ring (bore seal).

The ICV is equipped with a seal test port and vent port. Honeycombed aluminum spacer sections are placed in the top and bottom domed heads of the ICV during shipping. The cavity available for the contents is a cylinder of approximately 73 inches in diameter and 75 inches in height.

The ICV is a right cylinder with domed heads. According to Section 1.2.1.1.2 of the TRUPACT-II SARP, the ICV has a maximal external diameter of 76-5/16 inches, a minimal external diameter of 73-1/8 inches, and an overall external length of 99 inches when the lid is installed on the body of the ICV. The lid is secured to the body with a locking ring. Two main O-rings are enclosed between the mating lid and body of the OCV: the upper main O-ring is made of butyl rubber and serves a containment function; the lower (test) seal is made of neoprene or ethylene propylene and allows a vacuum to be established on the exterior side of the containment O-ring for helium and pressure-rise leakage-rate testing.

The locations of the ICV seal test port and the vent port are shown in Appendix 1.3.2 of the TRUPACT-II SARP (Sheet 3 of Drawing 2077-500SNP). The upper and lower aluminum spacer assemblies are shown on Sheet 6 of this same set of drawings in Appendix 1.3.2 of the SARP.

A cylindrical cavity is available for the contents to be placed in the ICV. The dimensions of the cavity are a minimal and maximal diameter of 72-7/16 and 73-7/8 inches (Section 1.2.1.1.2 of the TRUPACT-II SARP) and a height of 74-5/8 inches (Appendix 1.3.2 of the SARP, Drawing 2077-500SNP, Sheet 2).

15.3.5 Drawings Showing Construction of TRUPACT-II, C of C, p. 2, 5(a)(3), para. 1

The packaging is constructed in accordance with Nuclear Packaging Inc. (NuPac) drawing # 2077-500SNP, Sheets 1-11 (Rev. K).

The 11 sheets of Drawing #2077-500SNP are included in the TRUPACT-II SARP. The TRUPACT-II packages are constructed in accordance with these drawings.

15.3.6 Drawings Showing Position of Contents in TRUPACT-II, C of C, p. 2, 5(a)(3), para. 2

The contents are positioned within the packaging in accordance with NuPac drawings # 2077-007SNP (Rev. C) and 2077-008 SNP, Sheets 1 and 2 (Rev. C).

NuPac Drawings 2077-007SNP (one sheet) and 2077-008SNP (two sheets) are included in Appendix 1.3.8 of the TRUPACT-II SARP. The drum assemblies or standard waste boxes (SWBs) are positioned within the package as shown in these drawings.

15.3.7 Physical Form of Allowable Material and Receptacles, C of C, p. 2, 5(b)(1)

Only dewatered, solid, or solidified TRU wastes are allowed. They must be packaged in 55-gallon drums, SWBs, or bins.

According to Section 3.2.1.2 of the *Waste Acceptance Criteria for the Waste Isolation Pilot Plant* (WAC) (DOE, 1996), standard 55-gallon metal drums, SWBs, 55-gallon drums overpacked in an SWB, and an experimental bin overpacked in an SWB are authorized for shipping CH TRU wastes in a TRUPACT-II packaging. The prohibition of free liquids is discussed in Section 15.3.10 of this BECR. (See also Section 5 of Appendix 1.3.7 to the TRUPACT-II SARP.)

15.3.8 Prohibition of Explosives, Corrosives, Nonradioactive Pyrophorics, and Pressurized Containers, C of C, p. 2, 5(b)(1)

> *Explosives, corrosives, nonradioactive pyrophorics, and pressurized containers are prohibited.*

Section 3.3.4 of the WAC prohibits the acceptance of explosives or pressurized canisters at WIPP. The WAC stipulates that any nonradioactive pyrophoric materials must be rendered safe by mixing them with chemically stable materials (e.g., concrete, glass) or by processing them to remove their hazardous properties; thus, they will be rendered nonpyrophoric prior to shipment to WIPP (Section 3.3.3). (See also Section 5 of Appendix 1.3.7 to the TRUPACT-II SARP.)

Corrosive wastes are prohibited on two counts. They are prohibited on the basis of the definition of corrosive waste used in the WAC (i.e., aqueous materials with a pH less than 2 or higher than 12.5[1]). Furthermore, since corrosive wastes are aqueous by definition, they are prohibited as free-standing liquids (see Section 15.3.10).

15.3.9 Restriction of Radioactive Pyrophorics, C of C, p. 2, 5(b)(1)

> *Radioactive pyrophorics must not exceed 1 percent by weight within a drum, SWB, or bin.*

Section 3.3.3 of the WAC restricts pyrophoric forms of radionuclides to 1 percent by weight of the waste in each waste container with the stipulation that such waste be dispersed in the waste. (See also Section 5 of Appendix 1.3.7 to the TRUPACT-II SARP.)

15.3.10 Restriction of Free Liquids, C of C, p. 2, 5(b)(1)

> *Free liquids must not exceed 1 percent by volume within a drum, SWB, or bin.*

Section 3.3.2 of the WAC stipulates that liquid waste will not be emplaced at WIPP and that the total liquid in a waste container will not equal or exceed 1 volume percent of the payload container. (See also Section 4 of Appendix 1.3.7 to the TRUPACT-II SARP.)

15.3.11 Restriction of Flammable Organics, C of C, p. 2, 5(b)(1)

> *Flammable organics are limited to 500 ppm in the headspace of any drum, SWB, or bin.*

[1] The WAC definition of corrosive wastes differs from that of RCRA since the latter includes aqueous materials with a pH of 2 or of 12.5 in its definition of corrosive waste under 40 CFR 261.22(a)(i).

Section 3.4.7.2 of the WAC limits the total concentration of potentially flammable volatile organic compounds (VOCs) to 500 ppm in the headspace of a waste package; this value includes error measurement.

15.3.12 Maximal Allowable Weight, C of C, p. 2, 5(b)(2), para. 1

Contents must not exceed 7,265 pounds including shoring and secondary containers, with no more than 1,000 lbs per 55-gallon drum and 4,000 lbs per SWB.

Section 3.4.1.2 of the WAC specifies the following weight limits for waste package assemblies transported in the TRUPACT-II package:

1,000 lbs per drum
1,450 lbs per drum overpacked in an SWB
4,000 lbs per SWB
7,265 lbs per TRUPACT-II payload
19,250 lbs per TRUPACT-II payload, including the weight of the TRUPACT-II packaging

15.3.13 Maximal Number of Payload Containers Per Package and Authorized Configurations, C of C, p. 2, 5(b)(2), para. 2

The maximal number of payload containers per package and authorized packaging configurations are:

14 55-gal drums
2 SWBs
2 SWBs, each containing one bin
2 SWBs, each containing four 55-gal drums
1 10-drum overpack (TDOP) containing ten 55-gal drums
1 TDOP containing one SWB
1 TDOP containing one bin within an SWB
1 TDOP containing four 55-gal drums within an SWB.

According to the WAC (Section 3.2.2.2), the authorized loading configurations for shipment in the TRUPACT-II package are standard 55-gallon metal drums in two seven-pack configurations or two SWBs. Up to four drums or one experimental bin may be overpacked in a SWB. If only one seven-pack or one SWB of waste is scheduled for shipment in the TRUPACT-II, a dunnage seven-pack or SWB must be added to the package for transport, as specified in Appendix 1.3.7 of the TRUPACT-II SARP. In addition, drums, SWBs, and experimental bins may be overpacked in a TDOP for shipment within the TRUPACT-II.

15.3.14 Amount of Allowable Fissile Material, C of C, p. 2, 5(b)(2), para. 3

Fissile material must not exceed 325 grams Pu-239 equivalent, with no more than 200 grams Pu-239 equivalent per 55-gal drum or 325 grams Pu-239 equivalent per SWB (for Pu-239 equivalent, see Appendix 1.3.7 of the TRUPACT-II SARP).

Section 3.4.2.1 of the WAC specifies that the fissile or fissionable radionuclide content of CH TRU waste packages will not exceed the following values, in Pu-239 fissile-gram equivalents:

- 200 grams per 55-gallon drum
- 5 grams per cubic foot in boxes, up to a 350-gram maximum

However, the TRUPACT-II package limit for the SWB cited in the WAC is less than 325 grams. Thus, the sum of the fissile equivalents of all waste packages in the entire payload of a quantity including two times the error may not exceed 325 grams. (See the calculation methods described in Appendix 1.3.7 of the TRUPACT-II SARP.)

15.3.15 Allowable Decay Heat, C of C, p. 2, 5(b)(2), para. 4

Decay heat must not exceed the values given in Tables 6.1 through 6.3 of the TRUPACT-II Content Codes (TRUCON) (DOE, 1989b).

According to Section 3.4.6.2 of the WAC, there are two thermal limits for decay heat: the total decay heat from radioactive decay of the radioisotopes within an individual payload container and the total decay heat from all payload containers in a TRUPACT-II package. The total decay heat limits per TRUPACT-II for each shipping category are presented in Table 1.2.3.3.3 of the TRUPACT-II SARP. In determining whether or not a waste package or group of waste packages meets the limits, the error must be added to the measured value. The design limit for the TRUPACT-II is 40 watts.

15.3.16 Fissile Class, C of C, p. 2, 5(c)

The C of C identifies the TRUPACT-II as a Fissile Class I package.

The C of C identified the TRUPACT-II as a Fissile Class I packaging. Therefore, the requirements specified in 10 CFR 71.57 must be met.

15.3.17 Restrictions of Form, Properties, and Other Parameters, C of C, p. 3, 6

The physical form, chemical properties, chemical compatibility, configuration of the payload containers and contents, isotopic inventory, fissile content, decay heat, weight and center of gravity, and radiation dose rate must be determined and limited in accordance with the TRUPACT-II Authorized Methods for Payload Control (TRAMPAC) (TRUPACT-II SARP, Appendix 1.3.7).

The methods for determining and controlling the physical form of the wastes are visual examination, real-time radiography (RTR), records and data-base information, and sampling (SARP, Appendix 1.3.7, Section 4). The chemical properties of the waste (SARP, Appendix 1.3.7, Section 5) are determined by the allowable chemical constituents within a given waste type and are restricted so that all the payload containers are safe for handling and transport. Chemical compatibility (SARP, Appendix 1.3.7, Section 6; see also SARP Appendix 2.10.12) within the waste and between the waste and the packaging ensures that no chemical process will occur that might pose a threat to the safe transport of the payload in the TRUPACT-II package. The configuration of the payload container and content is controlled as described in Section 8 of the SARP's Appendix 1.3.7; this section also describes specifications for filter vents and pre-shipping venting and aspiration requirements.

The isotopic inventory for each payload container and the fissile content are discussed in Section 9 of the TRAMPAC. Decay heat is discussed in Section 10 of the TRAMPAC.

The allowable weights for individual payload containers and for the total payload are presented in Section 11 of the TRAMPAC, along with methods of determining and controlling weight. The methods for determining the center of gravity of the loaded TRUPACT-II package are also described in this section for 55-gallon drums and for SWBs.

External radiation dose rates are presented in Section 12 of the TRAMPAC. These rates may not exceed 200 mrem per hour at the surface of the payload container and 10 mrem per hour at 2 meters. (See also Section 5.0 of the TRUPACT-II SARP.)

15.3.18 Shipping Category Designations, C of C, p. 3, 7

Each drum, SWB, or bin must be assigned a shipping category in accordance with Table 5 from TRUCON (Rev. 6) or tested for gas generation and must meet the acceptance criteria in accordance with Attachment 2.0 to Appendix 1.3.7 of the TRUPACT-II SARP.

Section 1.2.3.2 of the TRUPACT-II SARP discusses the payload shipping categories developed specifically for the TRUPACT-II package. The primary difference among the categories is their potential for gas generation and internal bagging configuration. For waste with an adequate margin of safety, an analytical prediction suffices. Wastes without such a margin of safety require testing as described in Section 1.23.3.12 and Attachment 2 to Appendix 1.3.7 of the TRUPACT-II SARP.

15.3.19 Labeling Requirements, C of C, p. 3, 8

> *Each drum, SWB, or bin must be labeled to indicate its shipping category. All drums, SWBs, or bins within a package must be of the same shipping category.*

As described in Section 3.4.8 of the WAC, each waste package will be labeled with the shipping category after all payload parameters have been verified. Furthermore, all waste packages within a single TRUPACT-II package must belong to the same shipping category (WAC, Section 3.6.1.2). (See also Section 13.1 of Appendix 1.3.7 to the TRUPACT-II SARP.)

15.3.20 Preshipment Venting or Aspirating Requirements, C of C, p. 3, 9

> *Each drum, SWB, bin, or TDOP must be equipped with filtered vents prior to shipment in accordance with Appendix 1.3.7 to the TRUPACT-II SARP; drums not equipped with filtered vents during storage must be aspirated before shipment; the minimal aspiration time may be determined from Tables 7.1 through 9.3 in TRUCON.*

Section 3.4.7.2 of the WAC stipulates that all payload containers, including any overpacks, must be vented with filters that meet the specifications described in the TRUPACT-II SARP. At least one filter will be used per drum, two per SWB, and at least nine per TDOP. Any rigid drum liners will be filtered or punctured. (See also Section 8.1 of Appendix 1.3.7 and Appendix 3.6.11 to the TRUPACT-II SARP.)

15.3.21 Requirements of Subpart G of 10 CFR Part 71, C of C, p. 3, 10

> *Compliance with the requirements of Subpart G of 10 CFR Part 71 is required.*

Subpart G invokes Subpart H, *Quality Assurance*. (See Section 15.2.20.)

15.3.22 Preparation of Packages for Shipment and Operations, C of C, p. 3, 10(a)

> *Each package must be prepared for shipment and operated in accordance with procedures described in Section 7, "Operating Procedures," of the TRUPACT-II SARP.*

Section 7 of the TRUPACT-II SARP contains procedures for loading and unloading the TRUPACT-II container and for preparing an empty packaging for transport. In addition, the payload assembly criteria are presented in Section 13 of Appendix 1.3.7 to the TRUPACT-II SARP.

15.3.23 Testing and Maintenance of Packages, C of C, p. 3, 10(b)

> *Each package must be tested and maintained in accordance with procedures described in Section 8, Acceptance Tests and Maintenance Program, of the TRUPACT-II SARP.*

The required acceptance tests and the maintenance program are included in Section 8 of the TRUPACT-II SARP. The acceptance tests are those tests that must be performed prior to the first use of the TRUPACT-II and that include visual inspection and structural, pressure, leakage, component, and thermal acceptance tests. (No shielding is provided in the TRUPACT-II container; therefore, shielding integrity tests are not appropriate.) The maintenance program consists of procedures and tests used to ensure the continuation of proper performance of the TRUPACT-II packaging. It comprises structural and pressure tests; leak tests and subsystems maintenance of fasteners; the ICV; the OCA; seal areas and grooves; and valves, rupture discs, and gaskets on the containment vessel. No shielding or thermal inspections or tests are necessary to ensure continued performance of the TRUPACT-II container.

Personnel from the WID Q&RA Department performed an audit between November 13 and November 30, 1995, on compliance with applicable regulations with respect to the training requirements and procedures relating to maintenance of the TRUPACT-II packagings. The audit team concluded that all the programmatic requirements for the maintenance of the TRUPACT-II packagings were being met.

15.3.24 Contents of Packages, C of C, p. 3, 11

> *The contents of each package must be in accordance with Appendix 7.4.1, "Payload Control Procedures," of the TRUPACT-II SARP.*

The payload control procedure appears in Appendix 7.4.3 and is summarized in Section 13 of Appendix 1.3.7 of the TRUPACT-II SARP. Section 3.6.1.2 of the WAC specifies that the payload control procedures provided in Section 7.4.3 of the TRUPACT-II SARP will be followed for shipping CH TRU waste in the TRUPACT-II package.

15.3.25 Leak Testing, C of C, p. 3, 12

> *Prior to each shipment, lid and vent port seals on inner and outer containment vessels must be leak tested to 1 x 10^{-7} standard cubic centimeter of helium per second in accordance with Section 7 of the TRUPACT-II SARP.*

The assembly verification leak test and other leak tests that must be performed on the TRUPACT-II package are described in Appendix 7.4.2 and Section 8 of the TRUPACT-II SARP. All such mandatory tests will be run on each package prior to shipment.

15.3.26 Removal of Free-Standing Water, C of C, p. 3, 13

> *All free-standing water must be removed from the ICV cavity and the OCV cavity before shipment.*

The operating procedures of Section 7 of the TRUPACT-II package include instructions for inspecting for free-standing water and removing it from the package (i.e., Sections 7.1.2.3.2, 7.1.2.3.3, and 7.1.2.3.6 through 7.1.2.3.9). These procedures must be used for loading the TRUPACT-II container.

15.3.27 Approval of the TRUPACT-II Packaging, C of C, p. 3, 14

> *The TRUPACT-II packaging must be approved for use under general license provisions of 10 CFR 71.12.*

See Section 15.2.1.

15.3.28 Expiration Date, C of C, p. 3, 15

> *The expiration date of this C of C is June 30, 1999.*

In order to use the TRUPACT-II packaging for shipping TRU waste, the C of C must be updated prior to its expiration date of June 30, 1999. This will be accomplished by submitting an application for timely renewal to the NRC.

16.0 HAZARDOUS MATERIALS TRANSPORTATION ACT

16.1 Summary of the Law

The Hazardous Materials Transportation Act (HMTA; 49 USC §§ 1801 et seq.), as amended, is the major transportation-related statute that affects the DOE. The objective of the HMTA is "to improve the regulatory and enforcement authority of the Secretary of Transportation to protect the Nation adequately against risks to life and property which are inherent in the transportation of hazardous materials in commerce." The HMTA provides for safe intra- and interstate transportation of hazardous materials (including nuclear materials).

The Hazardous Materials Transportation Uniform Safety Act (HMTUSA; PL 101-615) was enacted on November 16, 1990. This public law, which amends the HMTA, required the U.S. Department of Transportation (DOT) to set standards for designating routes for the transportation of hazardous materials that are required to be placarded, establish regulations on training standards for all hazardous materials transportation workers, issue safety permits to motor carriers for certain hazardous materials, and perform a railroad transportation safety study for certain highly radioactive materials. The DOT is also required to participate in international forums dealing with recommendations or legislation relating to mandatory standards and requirements pertaining to the transportation of hazardous materials, and to consult with interested agencies to facilitate consistency in international law with respect to hazardous materials transportation. In addition, HMTUSA requires registration and an annual registration fee for shippers and carriers of certain hazardous materials such as radioactive materials and establishes planning and training grants to the states for developing, improving, and implementing emergency plans.

In the Second Modification to the Agreement for Consultation and Cooperation, dated August 4, 1987, the DOE agreed to comply with all applicable DOT regulations and any applicable corresponding regulations of the U.S. Nuclear Regulatory Commission (NRC). The following regulations are applicable to WIPP.

Title 49 CFR Part 171, *General Information, Regulations, and Definitions*, sets forth the DOT requirements that are applicable to the transportation of hazardous materials and the packaging used in the transportation of those materials.

Title 49 CFR Part 172, *Hazardous Materials Table, Special Provisions, Hazardous Materials Communications Requirements and Emergency Response Information and Training Requirements*, lists and classifies the materials the DOT has designated as hazardous for the purpose of transportation and describes the communications regulations that apply when those materials are shipped.

In 49 CFR Part 173, *Shippers - General Requirements for Shipments and Packagings*, the DOT defines hazardous material classes for the purpose of transportation; establishes requirements in preparing materials for shipment; sets forth inspection, testing, and retesting responsibilities concerning containers built, repaired, or conditioned for use in the transportation of hazardous materials; sets forth requirements for transporting radioactive materials; classifies materials having more than one hazard; and describes criteria for instructing those responsible for preparing hazardous materials for shipment.

In 49 CFR Part 175, *Carriage by Aircraft*, the DOT prescribes additional requirements to those in Parts 171, 172, and 173 concerning the transportation of hazardous material by air.

In 49 CFR Part 177, *Carriage by Public Highway*, the DOT sets forth requirements to promote the uniform enforcement of law to minimize danger to life and property in the transportation of hazardous materials by public highway.

Title 49 CFR Part 178, *Specifications for Packagings*, describes manufacturing and testing specifications for packaging and containers used for the transportation of hazardous materials.

16.2 Compliance Status of the Regulatory Requirements

Table 16-1 summarizes the regulatory requirements and their compliance status under HMTA. The text gives more detail on the compliance status for each requirement.

TABLE 16-1. Hazardous Materials Transportation Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
49 CFR Part 171, *General Information, Regulations, and Definitions*		
49 CFR 171.2	General requirements	**UP TO DATE** Addressed in Transportation Plan and WID procedures [Section 16.2.1]
49 CFR 171.3	Transport of hazardous waste requiring manifests, labeling, and shipper/generator and transporter identification	**UP TO DATE** Addressed in Transportation Plan and WID procedures [Section 16.2.2]

CITATION	REQUIREMENT	COMPLIANCE STATUS
49 CFR 171.14	Transition of new requirements based on UN recommendations	**UP TO DATE** Addressed in Transportation Plan [Section 16.2.3]
49 CFR 171.15/16	Notice and report of hazardous material incidents	**UP TO DATE** Addressed in Transportation Plan [Section 16.2.4]
49 CFR Part 172, *Hazardous Materials Table, Special Provisions, Hazardous Materials Communication Requirements and Emergency Response Information Requirements*		
49 CFR 172.101	Hazardous materials table	**UP TO DATE** Addressed in WID procedure [Section 16.2.5]
Subpart C, 49 CFR 172.200-205	Shipping paper requirements	**UP TO DATE** Addressed in WID procedure [Section 16.2.6]
Subpart D, 49 CFR 172.300-.338	Marking of hazardous materials/substances for transport	**UP TO DATE** Addressed in WID procedure [Section 16.2.7]
Subpart E, 49 CFR 172.400-.450	Labeling of hazardous materials/substances for transport	**UP TO DATE** Addressed in WID procedure [Section 16.2.8]
Subpart F, 49 CFR 172.500-.560	Placarding of hazardous materials/substances for transport	**UP TO DATE** Addressed in WID procedure [Section 16.2.9]

CITATION	REQUIREMENT	COMPLIANCE STATUS
Subpart G, 49 CFR 172.600	Emergency response	**UP TO DATE** Addressed in WID procedure [Section 16.2.10]
Subpart H, 49 CFR 172.700-.704	Training requirements for the transportation of hazardous materials	**UP TO DATE** Addressed in Transportation Plan; training conducted and attended by appropriate personnel [Section 16.2.11]
49 CFR Part 173, *Shippers - General Requirements for Shipments and Packagings*		
Subpart A, 49 CFR 173.1-.12	General requirements for shipments and packagings	**UP TO DATE** Addressed in WID procedure [Section 16.2.12]
Subpart B, 49 CFR 173.21-.40	Preparation of hazardous materials for transport	**UP TO DATE** Addressed in WID procedure [Section 16.2.13]
Subpart C, 49 CFR 173.50-.63	Definitions, classification, and packaging of Class 1 materials	**NOT APPLICABLE** Class 1 materials were not packaged, or shipped from WIPP during reporting period [Section 16.2.14]
Subpart D, 49 CFR 173.115-.156	Classification, packing group assignments, and exceptions for hazardous materials other than Classes 1 and 7	**UP TO DATE** Addressed in WID procedures [Section 16.2.15]
Subpart E, 49 CFR 173.158-.230	Non-bulk packaging of hazardous materials other than Classes 1 and 7	**UP TO DATE** Addressed in WID procedure [Section 16.2.16]

CITATION	REQUIREMENT	COMPLIANCE STATUS
Subpart I, 49 CFR 173.401-.478	Transportation of radioactive materials (including empty packaging)	**UP TO DATE** Addressed in WID procedures [Section 16.2.17]
49 CFR Part 175, *Carriage by Aircraft*		
49 CFR 175	Transportation of hazardous material by aircraft	**UP TO DATE** Addressed in WID Procedure [Section 16.2.18]
49 CFR Part 177, *Carriage by Public Highway*		
49 CFR 177.800, .816, and 397 Subpart D	Training responsibilities and requirements for Class 7 material	**UP TO DATE** Training conducted and attended by appropriate personnel [Section 16.2.19]
49 CFR Part 178, *Specifications for Packagings*		
49 CFR 178	Packagings and containers used for transportation of hazardous materials	**UP TO DATE** C of C for TRUPACT-II packaging [Section 16.2.20]

16.2.1 General Requirements, 49 CFR 171.2

General requirements regarding the offering or acceptance of hazardous material for transportation in commerce are described. Material to be shipped must be properly classed, described, packaged, marked, labeled, and in condition for shipment.

General requirements for the shipment of hazardous material are addressed in the WID Transportation Plan and in WID procedures. The Transportation Plan identifies the organizations and positions responsible for ensuring compliance with the HMTA. The completion and certification of several worksheets (e.g., "Shipping Request," "Shipment

Worksheet for Ground Transportation," and "Shipment Worksheet for Air Transportation") ensures compliance through careful documentation of all required actions.

16.2.2 Hazardous Waste, 49 CFR 171.3

Requirements for the shipment of hazardous wastes include the preparation of manifests or other shipping papers, motor vehicle placarding, waste packaging, marking and labeling, and identification numbers for the generators and the transporters.

Manifests, marking and placarding, and other labeling requirements are addressed in WID procedures. Completion of step-by-step worksheets and checklists ensure the proper execution of these tasks in shipping hazardous wastes from WIPP to an off-site TSDF.

16.2.3 Transitional Provisions for Implementing Requirements Based on the United Nations (UN) Recommendations, 49 CFR 171.14

Provides an orderly transition to the new requirements incorporated as part of a comprehensive revision to this subchapter based on the UN Recommendations. Specified are requirements for new explosives, materials that are poisonous by inhalation, and infectious substances.

Prescribed methods are included in the WID procedures addressing the shipment of nonradioactive hazardous materials.

16.2.4 Immediate Notice of Certain Hazardous Materials Incidents and Detailed Hazardous Materials Incident Reports, 49 CFR 171.15-171.16

Section 171.15 specifies the requirements of immediate notification by each carrier who transports certain hazardous materials (including hazardous wastes) and is involved in a hazardous material incident during the course of transportation. Section 171.16 specifies the requirements for the submission of a written hazardous materials incident report by the carrier.

Requirements for transportation emergency notifications are specified in the Transportation Plan. This plan and WID procedures address reportable incident and reporting requirements, including the identification of organizations and other entities that receive reports. During this reporting period there were no hazardous materials incidents as defined in these regulations.

16.2.5 Table of Hazardous Materials, 49 CFR 172.101

> *The Hazardous Materials Table designates all materials listed as hazardous for the purpose of transporting those materials.*

These requirements are covered in a WID procedure that is directed to any "... material, including its mixtures and solutions that...is listed in Table 172.101 and/or in appendices to 49 CFR 172.101, *List of Hazardous Substances and Reportable Quantities.*"

16.2.6 Shipping Papers, Subpart C, 49 CFR 172.200-172.205

> *This subpart describes the requirements for the provision of shipping papers by persons who offer hazardous material for transportation. The shipping papers must include a description of the hazardous material and a shipper's certification. A "bill of lading" or "hazardous waste manifest" may be used depending on the commodity being shipped.*

Requirements concerning shipping papers, including manifests for hazardous waste and bills of lading for hazardous materials, are described in WID procedures. Each required record is identified and defined by forms attached to these procedures.

16.2.7 Marking, Subpart D, 49 CFR 172.300-172.338

> *Marking requirements for the transportation of hazardous materials or substances are described in this subpart.*

According to a WID procedure, the Transportation Engineer marks the shipment in accordance with either Subpart D of 49 CFR Part 172 or the International Air Transport Association (IATA) 7.1.

16.2.8 Labeling, Subpart E, 49 CFR 172.400-172.450

> *This subpart describes the requirements for the labeling of packages or containment devices by persons who offer hazardous material for transport.*

According to a WID procedure, the Transportation Engineer labels the shipment in accordance with either Subpart E of 49 CFR Part 172 or IATA 7.2.

16.2.9 Placarding, Subpart F, 49 CFR 172.500-172.560

This subpart describes the requirements for the placarding of hazardous material by persons who offer hazardous material for transport.

According to a WID procedure, the Transportation Engineer ensures that the vehicle that will transport hazardous materials or waste from WIPP is properly placarded, if necessary.

16.2.10 Emergency Response Information, Subpart F, 49 CFR 172.600

This subpart describes the requirements for the provision of emergency response information during transportation and at facilities where hazardous materials are loaded for transportation, stored incidental to transportation, or otherwise handled during any phase of transportation.

According to a WID procedure, the Transportation Engineer delivers the shipping papers and the *DOT Emergency Response Guides* for the particular shipment materials to the driver and releases the shipment. This plan specifies driver actions to be taken in the event of an incident during transportation.

On-site emergency response is addressed in the WID Waste Management Plan and WID procedures. The Transportation Engineer provides the CMR with copies of transportation documentation. The CMR is a 24-hour emergency contact for all shipments of hazardous waste or materials.

16.2.11 Training Requirements, Federal/State Relationship, and Applicability and Responsibility for Training and Testing, Subpart H, 49 CFR 172.700-.702 and 172.704

Prescribes minimal training requirements for the transportation of hazardous materials and specify requirements that Hazmat employers and employees as established by DOT must meet to ensure that their hazardous materials (hazmat) employees are trained in a systematic program. The following requirements are included: States may impose more stringent training requirements under certain conditions; the training curriculum must include general awareness and familiarization, hazardous material recognition and identification, function-specific topics, and safety and emergency response information; and current hazmat employee training records must be maintained and contain

specific training documentation including certification of training.

WIPP employees having job duties that require them to attend the Hazardous Material Transportation Course (HMT-102) have done so. Through the training programs, hazmat employees become familiar with the applicable hazardous material regulations, are able to recognize and identify hazardous materials, are knowledgeable of function-specific hazardous material regulations, and are knowledgeable of emergency response information and hazardous material communications requirements. The WIPP provides each hazmat employee with initial and recurrent training in accordance with established schedules. New employees, or employees who change job functions and are required to attend the training, must do so within 90 days. Until completion of their training, they may work under the direct supervision of another certified hazmat employee. The WIPP maintains records of current training, inclusive of the preceding two years. The training records are maintained in accordance with existing requirements

16.2.12 General Requirements for Shipments and Packagings, Subpart A, 49 CFR 173.1-173.12

This subpart includes the requirements for preparing hazardous materials for shipment by air, highway, rail, or water and definitions and classifications of hazardous materials for transportation purposes.

WID procedures encompass the requirements of these sections. WIPP shipments are evaluated and authorized by a WID Transportation Engineer to ensure these requirements are met.

16.2.13 Preparation of Hazardous Materials for Transportation, Subpart B, 49 CFR 173.21-173.40

This subpart describes the general requirements for the preparation of hazardous materials for transportation. The shipper's responsibilities are described and include the hazard classification and description of hazardous material and the determination that the packaging or container is an authorized packaging and that it has been manufactured, assembled, and marked properly.

According to WID procedures, the WID Hazardous Waste Operations Section is responsible for ensuring that materials are packaged, marked, and labeled in accordance with 49 CFR. Personnel packaging hazardous materials must be familiar with the packaging requirements for these materials, commensurate with the complexity of the packaging and the degree, nature, and quantity of hazard.

16.2.14 Definitions, Classification, and Packaging for Class 1 Materials, Subchapter C, 49 CFR 173.50-173.63

Definitions, classifications, and requirements for packaging of Class 1 materials (explosives) are described.

Class 1 materials were not packaged, or shipped from the WIPP; therefore, this section did not apply during this reporting period.

16.2.15 Definitions, Classification, Packaging Group Assignments, and Exceptions for Hazardous Materials other than Class 1 and Class 7, Subpart D, 49 CFR 173.115-173.156

Definitions, classifications, packing group assignments, and exceptions for hazardous materials, including flammable, non-flammable, poisonous and non-poisonous gases, flammable liquids and solids, and toxic material are specified.

WID procedures include worksheets for ground and air shipments. Actions required for the classification and packaging of hazardous materials other than Class 1 are included in these worksheets.

16.2.16 Non-Bulk Packaging Requirements for Hazardous Materials other than Class 1 and Class 7, Subpart E, 49 CFR 173.158-173.230

Non-bulk packaging requirements for hazardous materials other than Class 1 and Class 7 materials are described. Specific requirements are described in 49 CFR 173.158 through 173.198 for nitric acid; wet batteries; corrosive non-explosive smoke bombs; chemical kits; gallium; hydrogen fluoride; mercury; smokeless powder for small arms; aircraft hydraulic power unit fuel tanks; paint, paint-related material, adhesives, and ink; refrigerating machines; liquid pyrophoric materials; barium azide; nitrocellulose-based film; highway or rail fuses; lithium batteries and cells; matches; pyrophoric solids, metals, or alloys; white or yellow phosphorus; certain Group 1 poisonous materials; mixtures of bromoacetone, methyl bromide, chloropicrin, and methyl chloride or of chloropicrin and methyl chloride or of chloropicrin and compressed gas; hydrogen cyanide; infectious substances; and nickel carbonyl.

A WID procedure indicates that the Transportation Engineer classifies the shipment with the information provided in the shipping request by completing the shipment worksheet. If required, the requester and/or the Transportation Engineer obtain

additional information to classify the shipment properly. The Transportation Engineer determines the packaging requirements.

16.2.17 Radioactive Materials, Subpart I, 49 CFR 173.401-173.478

This subpart sets forth requirements for the transportation of radioactive materials by carriers and shippers and includes requirements for package design, package testing, empty radioactive materials packaging, and NRC-approved packages.

The WAC, SARP, and TRAMPAC programs control the generation, packaging, and shipment of radioactive waste to the WIPP. The procedures also show how packaging requirements are determined, including verification that the quantity and form of material to be shipped meet the requirements of the C of C and/or tested parameters of the intended package. More detail is specified in Chapter 15 under the NRC's regulations implementing transportation requirements under the Atomic Energy Act.

16.2.18 Carriage by Aircraft, 49 CFR Part 175

This part describes requirements that must be observed with respect to the transportation of hazardous materials in air craft. Included are provisions relating to unacceptable hazardous materials shipments; acceptance and inspection of shipments; discrepancy reports; notification of the pilot in command; shipping papers; keeping and replacement of labels; reporting hazardous materials incidents; quantity limitation; orientation, securing, and location of cargo containing hazardous materials; compatibility of packages; damaged shipments; and specific regulations applicable according to the classification of the material, including special limitations and requirements for Class 7 (i.e., radioactive) materials.

A WID procedure provides guidance for shipping hazardous materials by air. Hazardous materials shipped from WIPP are in accordance with the IATA, International Civil Aviation Organization (ICAO), and 49 CFR 171.11.

The transportation options studied in the Comparative Transportation Alternatives Study did not consider transportation of TRU wastes to WIPP by air.

16.2.19 Training Responsibilities and Requirements for Class 7 (Radioactive) Materials, 49 CFR 177.800, 177.816, and 397, Subpart D

These sections set forth requirements for training, including the following: a carrier may not transport or cause to be transported hazardous material by motor vehicle unless each of its hazmat employees has received the appropriate specialized training. Each of the carrier's hazmat driver's must have the appropriate State-issued commercial driver's license with the proper endorsement and must have in his/her immediate possession a certificate of training that includes a proper statement of authentication.

All transportation of radioactive or mixed waste will be by contract carrier. The carrier's employees have been properly trained, and their records include all certification information. The carrier's drivers all possess a commercial driver's license with a hazardous material endorsement, and each is trained and certified to transport highway route-controlled-quantity radioactive materials. Each driver has a properly authenticated training certificate in his or her possession.

16.2.20 Specifications for Packagings, 49 CFR Part 178

This part contains prescribed manufacturing and testing specifications and inspection requirements for packaging and for containers used for the transportation of hazardous materials.

WIPP quality assurance procedures define the methodology by which specified criteria are verified. The TRUPACT-II container has been developed to transport CH TRU waste to WIPP from the generator sites. The specifications for this packaging and conditions of the C of C granted by the NRC are described in more detail in Chapter 15. WID Transportation Engineers use a WID procedure worksheet to specify the performance-oriented packaging necessary to satisfy these requirements for each hazardous shipment from WIPP of hazardous materials.

17.0 MATERIALS ACT OF 1947

17.1 Summary of the Law

The Materials Act of 1947 (30 USC §§ 601 et seq.) establishes policy that directs the BLM to prescribe rules and regulations for the disposal of mineral material resources (including, but not limited to, sand, stone, gravel, pumice, cinders, and clay) on public lands under the BLM's jurisdiction at fair market value while ensuring that adequate measures are taken to protect the environment and to minimize damage to public health and safety during the authorized removal of such minerals. Under the act, no mineral material shall be disposed of if the Secretary of the Interior determines that the aggregate damage to public lands and resources would exceed the benefits to be derived from the proposed sale or free use of the material.

The policy of the Materials Act of 1947 is addressed in the 1992 LWA. In the LWA, the DOE was given statutory authority and responsibility for the management of the withdrawn land at WIPP consistent with the Materials Act of 1947 and other applicable laws such as the Federal Land Policy and Management Act and the Public Rangelands Improvement Act (see Chapters 18 and 19, respectively). Furthermore, the LWA directs the DOE to produce a WIPP land management plan to address the disposal of salt tailings subject to the Materials Act of 1947. The regulations in 43 CFR Part 3600, *Mineral Materials Disposal: General*, implement the Materials Act of 1947 and establish procedures for the disposal of mineral material resources.

17.2 Compliance Status of the Regulatory Requirement

Table 17-1 summarizes the single applicable requirement and its compliance status under the Materials Act of 1947. The text provides more detail on the compliance status of the requirement.

TABLE 17-1. Materials Act of 1947 - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
43 CFR Part 3600, *Mineral Materials Disposal: General*		
43 CFR 3601.1-3	Disposal of salt tailings	**UP TO DATE** Addressed in the *WIPP Land Management Plan* [Section 17.2.1]

17.2.1 Environmental Protection During Disposal of Mineral Material, 43 CFR 3601.1-3

> *Authorized land managers must take steps to prevent unnecessary or undue environmental degradation resulting from mineral material disposal operations.*

Salt from the underground mining operations at WIPP is brought to the surface and stored in the salt pile just north of the surface facilities. This salt storage pile has the capacity to store the two million tons of material projected to be excavated during the lifetime of the WIPP Project. There is also an inactive salt storage pile at WIPP. This salt pile is a result of the SPDV phase.

According to the planned actions addressed in the *WIPP Land Management Plan (LMP)*[1] (DOE, 1993c), salt tailings extracted from the withdrawal area that are not needed for backfill at WIPP will be disposed of in accordance with the requirements of §§ 2 and 3 of the Materials Act of 1947. These requirements specify that if the appraised value of the salt exceeds $1,000, disposal will be performed by the highest responsible qualified bidder by competitive bidding and publication of notice of the proposed disposal as described in § 2 of the Materials Act. If the appraised value of the salt is $1,000 or less, it may be disposed of at the discretion of the DOE. Any money received from the disposal of the salt will be disposed of in the same manner as money received from the sale of public lands (Materials Act, § 3).

1 The Land Management Plan (LMP) (DOE/WIPP 93-004) was reissued on January 31, 1996, to merge the Land Management Implementation Plan with the LMP.

18.0 FEDERAL LAND POLICY AND MANAGEMENT ACT

18.1 Summary of the Law

One of the objectives of the Federal Land Policy and Management Act (FLPMA; 43 USC §§ 1701-1782) is to ensure that

> *. . . public lands be managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values; that, where appropriate, will preserve and protect certain public lands in their natural condition; that will provide food and habitat for fish and wildlife and domestic animals; and that will provide for outdoor recreation and human occupancy and use.*

Title II under FLPMA, *Land Use Planning; Land Acquisition and Disposition*, directs the Secretary of the Interior to prepare and maintain an inventory of all public lands and to develop and maintain, with public involvement, land-use plans regardless of whether subject public lands have been classified as withdrawn, set aside, or otherwise designated. Under Title V, *Rights-of-Way*, the Secretary of the Interior is authorized to grant, issue, or renew rights-of-way over, upon, under, or through public lands.

The policy and commitment of the FLPMA are addressed in the 1992 LWA. The LWA gave the DOE statutory authority and responsibility for the management of the withdrawn land consistent with FLPMA and other applicable laws such as the Public Rangelands Improvement Act and the Taylor Grazing Act (see also Chapters 19 and 20, respectively). Furthermore, the LWA directed the DOE to produce a WIPP land-management plan to provide for grazing, hunting and trapping, wildlife habitat, the disposal of salt tailings, and mining, subject to the applicable implementing regulations of FLPMA.

A process was established in the implementing regulations of 43 CFR Part 1600, *Planning, Programming, Budgeting,* for the development, approval, maintenance, amendment, and revision of resource management plans for public lands administered by the BLM. This part states that the objective of resource management planning is to guide and control future management actions and the development of subsequent more detailed and limited scope plans for resources and uses consistent with the principles of Title II of FLPMA. The DOE must develop and maintain a land management plan consistent with the processes and requirements for resource management plans as described in these regulations.

Other regulations implementing FLPMA established procedures for the orderly and timely processing of applications, grants, permits, amendments, assignments, and terminations for rights-of-way and permits over, upon, under, or through public lands.

In particular, 43 CFR Part 2800, *Rights-of-Way, Principles and Procedures*, provides guidelines for the use of right-of-way and temporary-use permit areas and establishes requirements for the submission and processing of right-of-way grant/reservation and temporary-use permit applications. These regulations remain applicable to the WIPP because of the necessity to establish rights-of-way for the construction and phased operation of this facility.

18.2 Compliance Status of the Regulatory Requirements

Table 18-1 summarizes each applicable requirement and its compliance status under FLPMA. The text provides more detail on the compliance status of each requirement.

TABLE 18-1. Federal Land Policy and Management Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
43 CFR Part 1600, *Planning, Programming, Budgeting*		
43 CFR 1610.1	Resource management planning guidance	**ACHIEVED** *WIPP Land Management Plan* [Section 18.2.1]
43 CFR 1610.2	Public participation	**ACHIEVED** Public review of *WIPP Land Management Plan*, 30 days [Section 18.2.2]
43 CFR 1610.3-2	Consistency of management plan with applicable laws	**ACHIEVED** *WIPP Land Management Plan* [Section 18.2.3]
43 CFR Part 2800, *Rights-of-Way, Principles and Procedures*		

CITATION	REQUIREMENT	COMPLIANCE STATUS
43 CFR 2801.2(a)	Common terms and conditions of right-of-way reservations and temporary-use permits: • Compliance with regulations • Nondiscrimination • Repair of roads, fences, trails • Fire prevention and suppression	**ACHIEVED** Compliance status in BECR; nondiscrimination policy; repairs as needed; fire-fighting equipment, personnel, and agreement [Section 18.2.4]
43 CFR 2801.2(b)	Mandatory conditions for right-of-way reservations and temporary-use permits: • Restoration • Air- and water-quality standards • Scenic, cultural, and environmental values • Local inhabitants • State standards that are more stringent than the federal ones	**UP TO DATE** FEIS; LMP; SEIS and draft SEIS-II; no local inhabitants who rely on biota of the area for subsistence; operation and maintenance in accordance with reservations (see Section 18.3); and permit conditions met (see other chapters in BECR) [Section 18.2.5]
43 CFR 2802.2	Application requirements for a right-of-way reservation or temporary-use permit	**ACHIEVED** Several reservations and permits obtained (see Sections 18.3 and 35.3) [Section 18.2.6]

18.2.1 Resource Management Planning Guidance, 43 CFR 1610.1

> *Guidance in preparing resource management plans may be provided to the District and Area BLM Managers by the Director and State Director of the BLM.*

The LMP was prepared for the DOE by the WID with considerable input from the BLM. The plan parallels the general guidelines used in the development of the BLM's Area Resource-Management Plan.

18.2.2 Public Participation, 43 CFR 1610.2

> *The public shall be provided an opportunity to review and comment on land management plans.*

Public meetings were held in Carlsbad and Hobbs, New Mexico, and members of the public were given 30 days to review and comment on the LMP. A copy of the draft plan was also sent to the State Land Office, the Environmental Evaluation Group (EEG), and the NMED for their review. The comments obtained were incorporated, as appropriate, into the final document.

18.2.3 Consistency of Management Plans, 43 CFR 1610.3-2

> *Land-use plans shall be consistent with the purposes, policies, and programs of Federal laws and regulations that apply to public lands.*

As a requirement of the LWA, the LMP was developed for the withdrawal area consistent with FLPMA. The plan was drafted by the WID and DOE in consultation with the BLM and the state of New Mexico and was submitted to Congress in October 1993. The development of this plan parallels the general guidelines used in formulating the BLM's Area Resource-Management Plan.

18.2.4 Common Terms and Conditions of Right-of-Way Reservations and Temporary-Use Permits, 43 CFR 2801.2(a)

> *By accepting a right-of-way reservation or a temporary-use permit, the applicant agrees and consents to comply with the following terms and conditions in addition to those terms and conditions that are specified in the reservation(s) or permit(s). The common terms and conditions are:*

- *To comply with all applicable State and Federal laws and the implementing regulations to the extent practicable;*

- *To protect employees and applicants for employment who will be or are involved in the construction, operation, maintenance, and termination of the authorized use against discrimination because of race, creed, color, sex, or national origin and to ensure that all subcontracts include an identical provision;*

- *To rebuild and repair roads, fences, and established trails that may be destroyed or damaged by the construction, operation, or maintenance of the project and to build and maintain suitable crossings for existing roads and significant trails that intersect the project; and*

- *To prevent and suppress fires on or in the immediate vicinity of the right-of-way areas.*

Compliance with all applicable state and federal laws and their implementing regulations is discussed throughout this document. (See the specific regulations and the compliance status section of each for more detailed information.)

The DOE and its contractors have a nondiscrimination policy in effect for their employees and for hiring. In addition, contracts and subcontracts awarded by the DOE and by its contractors include such a nondiscrimination clause.

Any roads, fences, or established trails destroyed or damaged by the construction, operation, or maintenance of any of the structures for which WIPP has received a right-of-way reservation or temporary-use permit are repaired as required.

WIPP maintains fire-fighting equipment. Some WIPP emergency response personnel are trained in fire-fighting methods. WIPP also has an agreement with the Carlsbad Fire Department to provide fire-fighting service if necessary.

18.2.5 Conditions to be Incorporated within all Right-of-Way Reservations and Temporary-Use Permits, 43 CFR 2801.2(b)

All right-of-way reservations and temporary-use permits must contain requirements to ensure:

- *Restoration, revegetation, and curtailment of land erosion;*

- *Compliance with applicable air- and water-quality standards;*

- *Protection of scenic, aesthetic, cultural, and environmental values as well as Federal property and public health and safety;*

- *Protection of the interests of local inhabitants who rely on the fish, wildlife, and biota of the area for subsistence;*

- *Maintenance and operation of facilities on the prescribed location in a manner that is consistent with the reservation or permit; and*

- *Compliance with any State standards for public health and safety; environmental protection; and siting, construction, operation, and maintenance that are more stringent than the Federal standards.*

Each area that is the subject of a right-of-way reservation will be reclaimed and revegetated as described in the LMP.

Compliance with applicable air- and water-quality standards is discussed in Chapters 6 through 8, 29, and 30 of this report. (See these chapters for more specific information pertaining to the air- and water-quality standards.)

Protection of scenic, aesthetic, cultural, and environmental values was addressed in the FEIS and the SEIS. A second SEIS is being prepared to address disposal of TRU waste at WIPP; any changes in these values or in the potential impact of WIPP operations on these values will be addressed in this document.

The people who live in the vicinity of WIPP are ranchers. There are no local inhabitants who rely on fish, wildlife, or other biota of the area for subsistence. Therefore, this condition does not apply to WIPP.

Each "facility" (road, pipeline, railroad, etc.) is maintained and operated in accordance with the stipulations provided in the respective right-of-way reservation. (See Section 18.3 for more specific information.)

State standards or permit conditions imposed by the State are being met. For example, see Section 29.3 on the air-quality permit issued to WIPP by the NMED.

18.2.6 Requirements for Applications for Right-of-Way Reservations and Temporary-Use Permits, 43 CFR 2802.2

> *Parties seeking a right-of-way reservation or temporary-use permit involving the use of public lands shall file an application for the reservation or permit with either the Area Manager, the District Manager, or the State Director having jurisdiction over the affected public lands.*

To date, several right-of-way reservations and land-use permits have been granted to the DOE. The following are examples of WIPP reservations and permits.

Right-of-way Reservation No. NM 53809 for a water pipeline was granted on August 17, 1983, and is still active. There is no expiration date. (See Section 18.3.2.)

Right-of-way Reservation No. NM 55676 for the north access road at WIPP was granted on August 24, 1983, and is still active. There is no expiration date. (See Section 18.3.3.)

Right-of-way Reservation No. NM 55699 for the railroad spur at WIPP was granted on September 27, 1983, and is still active. There is no expiration date. (See Section 18.3.4.)

Right-of-way Reservation No. NM 63136 for dosimetry and aerosol sampling sites was granted on July 31, 1986, and is still active. There is no expiration date. (See Section 18.3.5.)

Right-of-way Reservation No. NM 65801 for seven subsidence monuments was granted on November 7, 1986, and is still active. There is no expiration date. (See Section 18.3.6.)

Right-of-way Reservation No. NM 82245 for the installation of a survey monument was granted on December 13, 1989, and is still active. The permit expires on December 13, 2019. (See Section 18.3.7.)

Right-of-way Reservation No. NM 77921 for an aerosol sampling site was granted on August 18, 1989, and is still active. The permit expires August 18, 2019. (See Section 18.3.8.)

Free-Use Caliche Permit No. NM-FU-91183 was renogotiated on June 13, 1995, and is extended to May 12, 1998. (See Section 18.3.9.)

A right-of-way permit for a high-volume air sampler has also been issued to WIPP. Because this permit was issued by the New Mexico Commissioner of Public Lands, it is discussed in more detail in Section 35.3.

18.3 Compliance Status of the Permit Conditions

Table 18-2 summarizes the conditions in the right-of-way reservations and the temporary-use permit awarded to WIPP by the BLM. The table also includes the compliance status. The text provides more detail on the compliance status of each reservation or permit condition.

TABLE 18-2. Federal Land Policy and Management Act - Summary of Permit Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
Common Conditions (CC) of Right-of-Way Reservations		
CC 1	Control and jurisdiction of DOE	**ACHIEVED** DOE jurisdiction and control [Section 18.3.1]
CC 2	Right of access and use	**ACHIEVED** DOE and BLM and authorized personnel [Section 18.3.1]
CC 3	Products or resources on lands within the right-of-way	**NOT APPLICABLE** Superseded by LWA [Section 18.3.1]
CC 4	Compliance with 43 CFR Part 2800	See Sections 18.2.4 through 18.2.6 [Section 18.3.1]
CC 5	BLM seeding requirements for BLM Roswell district	**UP TO DATE** Sites prioritized for reclamation and reseeding [Section 18.3.1]
Right-of-Way Reservation No. NM 53809, *Water Pipeline*		
Sec. 13; Standard Stipulations (SS) 1, 2, 5, 6, 8	Preconstruction and construction conditions	**ACHIEVED** Notification and construction activities [Section 18.3.2.1]
Sec. 13E	Water access for livestock	**ACHIEVED** Water tap on pipeline installed [Section 18.3.2.2]

CITATION	REQUIREMENT	COMPLIANCE STATUS
SS 3	Road construction	**ACHIEVED** Only essential roads; traffic confined to authorized right of way [Section 18.3.2.3]
SS 4	Posting of BLM number	**ACHIEVED** BLM No. NM 53809 posted [Section 18.3.2.4]
SS 7	Gates or cattleguards on public lands	**UP TO DATE** Gates and cattleguards on public lands not locked [Section 18.3.2.5]
Right-of-Way Reservation No. NM 55676, *North Access Road*		
SS 2	Polychlorinated biphenyls (PCBs)	**NOT APPLICABLE** All PCB-containing fluids and equipment removed from WIPP; no known PCB spills at WIPP [Section 18.3.3.1]
SS 3-5	Standard stipulations for the construction of overhead electric distribution lines	**ACHIEVED** All stipulations met [Section 18.3.3.2]
SS 6	Posting of BLM serial number	**ACHIEVED** BLM No. NM 55676 posted [Section 18.3.3.3]
Term/Condition (T/C) 7	Damage or injury to private property	**UP TO DATE** Personal responsibility of DOE and DOE contractor employees [Section 18.3.3.4]

CITATION	REQUIREMENT	COMPLIANCE STATUS
T/C 7 and 8	Actions required upon abandonment, relinquishment, or expiration of right-of-way reservation	**NOT APPLICABLE** Right-of-way reservation active [Section 18.3.3.5]
Amendment (April 22, 1988)	Fencing	**ACHIEVED** Fencing standards met [Section 18.3.3.6]
Right-of-Way Reservation No. NM 55699, *Access Railroad*		
SS 1-4, 7, 9, 11	Preconstruction and construction requirements for railroad spur	**ACHIEVED** Agreement among BLM, DOE, and Army Corps of Engineers [Section 18.3.4.1]
SS 5	Reseeding upon completion of construction	**ACHIEVED** BLM seeding requirements for Roswell district [Section 18.3.4.2]
SS 6	Abandonment of the site	**NOT APPLICABLE** Site not abandoned [Section 18.3.4.3]
SS 8	Responsibility for damage or injury to private property	See Section 18.3.3.4 [Section 18.3.4.4]
SS 10	Access to water for livestock	**ACHIEVED** Water taps and related equipment provided by DOE [Section 18.3.4.5]
SS 12	Removal of caliche and/or other mineral material	**ACHIEVED** Free-use caliche permit in effect (See Section 18.3.9) [Section 18.3.4.6]

CITATION	REQUIREMENT	COMPLIANCE STATUS
SS 13	Application for free-use permits	**ACHIEVED** Free-use permit application filed; permit granted by BLM (see also Section 18.3.9) [Section 18.3.4.7]
Amendment	Notification of BLM regarding the access road parallel to the railroad	**ACHIEVED** BLM notified [Section 18.3.4.8]
Right-of-Way Reservation No. NM 63136, *Dosimetry and Aerosol Sampling Sites*		
Attachment A	Establishment of dosimeter stations and air samplers	**ACHIEVED** Aerosol samplers installed; operated and maintained by WID personnel [Section 18.3.5.1]
Amendment	Air monitoring and data collection site	**ACHIEVED** Trailer, tower, and instruments installed as agreed [Section 18.3.5.2]
Right-of-Way Reservation No. NM 65801, *Seven Subsidence Monuments*		
Right-of-way reservation	No unique conditions	See Section 18.3.1 [Section 18.3.6]
Right-of-Way Reservation No. NM 82245 for Two Subsidence Monuments		
#1	Construction and maintenance of the monuments	**ACHIEVED** Installed as described in application [Section 18.3.7.1]
#3	Security and maintenance of the monuments	**UP TO DATE** DOE responsible for security; WID maintains monuments [Section 18.3.7.2]

CITATION	REQUIREMENT	COMPLIANCE STATUS
#5	Rehabilitation of the land	**NOT APPLICABLE** Right-of-way active [Section 18.3.7.3]
Right-of-Way Reservation No. NM 77921, *Aerosol Sampling Site*		
#1	Construction, operation, and maintenance	**ACHIEVED** Constructed, operated, and maintained as described in application [Section 18.3.8.1]
#3	Security and operation of aerosol sampling station	**UP TO DATE** DOE responsible for security; WID operates and maintains station [Section 18.3.8.2]
#5	Rehabilitation of the land occupied by the aerosol sampling station	**NOT APPLICABLE** See Section 18.3.7.3 [Section 18.3.8.3]
Letter from El Paso Natural Gas Company	Use of the abandoned concrete slab	**ACHIEVED** Discussions with El Paso Natural Gas Company personnel [Section 18.3.8.4]
Free-Use Permit No. NM-FU3-91183 for Use of Caliche		
Approval of request to mine 35,000 cubic yards of caliche	Withdrawal of caliche	**UP TO DATE** WIPP still removing allotted caliche [Section 18.3.9.1]
Attachment 2, Reclamation	Reclamation of caliche borrow pit	**NOT APPLICABLE** Withdrawal area to be recontoured to a slope of 3:1 [Section 18.3.9.2]

18.3.1 Common Conditions of the Right-of-Way Reservations

Several conditions are common to all the right-of-way reservations awarded to WIPP by the BLM. These common conditions are:

(1) That the subject of the reservation be under the control and jurisdiction of the DOE;

(2) That right of access and use is reserved to DOE personnel and those authorized by DOE and to BLM personnel and their authorized permittees, licensees, and leasees;

(3) That any products or resources on lands within the right-of-way remain under the jurisdiction of the issuing agency;

(4) That all applicable regulations under 43 CFR Part 2800 be followed; and

(5) That the BLM seeding requirements for the Roswell district be met.

The subjects of each of the right-of-way reservations are under the control and jurisdiction of the DOE. Right of access and use of these structures is reserved to the DOE and the BLM and their authorized personnel.

In October 1992, the WIPP LWA was passed. This legislation transferred WIPP lands from the DOI to the DOE. These lands were also withdrawn from all forms of entry, appropriation, and disposal under the public land laws, including the mineral leasing laws.

The applicable portions of 43 CFR Part 2800 and the compliance status of each are described in Sections 18.2.4 through 18.2.6. They are also summarized in Table 18-1.

Reclamation of disturbed areas is an ongoing project at WIPP and is performed as described in the LMP. Seeding is conducted in accordance with the requirements for the BLM Roswell district.

18.3.2 Right-of-Way Reservation No. NM 53809, Water Pipeline

The conditions specified for the water-pipeline right-of-way reservation are described in Section 18.3.2, along with the compliance status of each condition. Since the pipeline

was built approximately 10 years ago, the conditions required for its construction are not discussed individually.

The reservation was awarded on August 17, 1983, and extends to perpetuity.

18.3.2.1 Pre-Construction and Construction Conditions for the Water Pipeline, Section 13 and SS Nos. 1, 2, 5, 6, 8

Pre-construction notification and conditions for construction (e.g., minimization of blading and clearing of vegetation; protection of scenic values; permits; livestock barriers) were specified in the right-of-way reservation and in the Standard Stipulations for Pipeline and Underground Cable Rights of Way in the Roswell District, BLM.

All conditions were met when the water pipeline was constructed.

18.3.2.2 Livestock Water, Section 13.E

The DOE has agreed to provide water access (taps) off the waterline for livestock in the area. The DOE will also provide water meters and all necessary materials, equipment, and labor to install new water troughs in the four sections specified.

The DOE installed a water tap on the water pipeline for use by ranchers. The tap is located 0.6 mile south of the intersection of the DOE north access road (NAR) and Highway 62/180.

18.3.2.3 Road Construction, SS No. 3

Roads will not be constructed where terrain features allow vehicles to maneuver without the aid of such construction. All vehicular traffic and construction activities will be confined to the authorized right-of-way.

No roads have been constructed where the terrain allows vehicles to maneuver adequately. All traffic is confined to the authorized right-of-way.

18.3.2.4 Posting of the BLM Number Assigned to This Right-of-Way, SS No. 4

The grantee will post the BLM serial number assigned to this right-of-way in a conspicuous place where the right-of-way intersects existing roads or highways. If the right-of-way parallels existing roads, the BLM number will be posted

where the right-of-way first crosses the public lands and where it leaves the public lands.

The BLM number assigned to this right-of-way (i.e., NM 53809) is posted as required.

18.3.2.5 Gates or Cattleguards on Public Lands, SS No. 7

Gates or cattleguards on public lands will not be locked or closed to the public.

Gates and cattleguards on public lands are not locked and remain open to the public.

18.3.3 Right-of-Way Reservation No. NM 55676, North Access Road

The conditions specified for the NAR right-of-way reservation are described in this section, along with the compliance status of each condition. Since the road was built approximately 10 years ago, the conditions required for its construction are not discussed individually.

This reservation was awarded on August 24, 1983, and extends to perpetuity.

18.3.3.1 Polychlorinated Biphenyls (PCBs), SS No. 2

Any PCBs shall be used in a totally enclosed manner in accordance with the provisions of the Toxic Substances Control Act. Any release of PCBs in excess of the reportable quantity shall be reported as required under the Comprehensive Environmental Response, Compensation, and Liability Act, with a copy of any report required by the Federal or State agency being provided to the Authorized Officer within 5 working days of the occurrence of the spill or release.

As described in Chapter 9, all PCB-containing equipment and fluids have been removed from the WIPP site and have been disposed of in accordance with the regulations. No PCBs are allowed on site. No release or spill of PCBs or PCB-containing fluids is known to have ever occurred at WIPP. Therefore, these conditions do not apply at WIPP.

18.3.3.2 Standard Stipulations for the Construction of Overhead Electric Distribution Lines, SS Nos. 3-5

Upon DOE's request, BLM authorized the DOE to install an auxiliary electrical line and 10-13 poles along the right-of-way for the NAR. This authorization was accompanied by

standard stipulations for overhead electrical distribution lines in the Roswell District. The standard stipulations for the construction of power lines included a prohibition of clearing or blading of the right-of-way unless agreed to in writing by the Authorized Officer, construction of the power lines to ensure the safety of raptors, and minimization of damage to existing fences and other improvements on public lands.

All stipulations for the construction of power lines were met.

18.3.3.3 Posting of BLM Serial Number, SS No. 6

The BLM serial number assigned to this authorization (i.e., NM 55676) shall be posted in a permanent, conspicuous manner where the power line crosses roads and at all serviced facilities. Numbers must be at least 2 inches high and will be affixed to the pole nearest the road crossing and at the facilities served.

The BLM Serial Number (NM 55676) is posted as required.

18.3.3.4 Damage or Injury to Private Property, Term/Condition No. 7

The DOE and/or its authorized agents will be responsible for any damage or injury to private property, including livestock, and will financially reimburse the allottee for any such loss in accordance with applicable law.

In the event that the vehicle of an employee of the DOE or a DOE contractor injures or kills livestock within the WIPP's sixteen sections or causes other damage to private property, reimbursement will be made as appropriate, in accordance with applicable laws.

18.3.3.5 Actions Required Upon Abandonment, Relinquishment, or Expiration of Right-of-Way Reservation, Terms/Conditions, Nos. 7 and 8

Upon cancellation, relinquishment, or expiration of the reservation, the holder of the reservation will comply with those abandonment procedures prescribed by the BLM Authorized Officer. All surface structures (poles, lines, transformers, etc.) will be removed within 180 days of abandonment, relinquishment, or termination of use of the reservation or of the use of the serviced facility or facilities. This will not apply where the power line extends service to an active adjoining facility or facilities.

These conditions will be met upon termination of the reservation or abandonment of the site by the DOE.

18.3.3.6 Fencing, Amendment (April 22, 1988)

The DOE requested that it be allowed to install fencing on the east and west sides of the WIPP NAR for a distance of 12.125 miles to allow for a safe travel route when entering or leaving the site via Highway 62/180. The BLM allowed this installation, subject to the BLM fencing standards.

The BLM fencing standards were met in installing the fence along the NAR.

18.3.4 Right-of-Way Reservation No. NM 55699, Railroad

The conditions specified for the railroad right-of-way reservation are described in this section, and the compliance status of each condition is given. Since the railroad spur at WIPP was constructed a number of years ago, the conditions pertaining to the construction of the spur are not discussed individually.

This right-of-way reservation was awarded on September 27, 1983, and extends to perpetuity.

18.3.4.1 Preconstruction and Construction Requirements for the Railroad Spur, SS Nos. 1-4, 7-9, and 11

The preconstruction and construction conditions for the railroad spur were listed in the "Special Stipulation for WIPP Railroad Access." These conditions include preconstruction notification and a prework conference, notification of any anticipated changes, notification of grazing permittees or lessees prior to entering public lands on grazing allotments, barriers and fences for livestock, road or stock trail crossings, mitigation of cultural resources, and installation of fences.

Agreement was reached among members of the BLM, the DOE, and the Army Corps of Engineers with respect to the DOE's meeting all preconstruction and construction requirements.

18.3.4.2 Reseeding Upon Completion of Construction, SS No. 5

The right-of-way must be reseeded upon completion of railroad construction according to BLM seeding requirements for the Roswell District.

The right-of-way was reseeded upon completion of railroad construction in accordance with the BLM seeding requirements for the Roswell district.

18.3.4.3 Abandonment of the Site, SS No. 6

If the WIPP is abandoned for any reason, the railroad bed will be ripped and returned as much as possible to its original terrain. The area will be reseeded as discussed in Section 18.3.4.2.

If the site is abandoned, these actions will be conducted. Until such time, these conditions are not applicable.

18.3.4.4 Responsibility for Damage or Injury to Private Property, SS No. 8

See Section 18.3.3.4.

18.3.4.5 Access to Water for Livestock, SS No. 10

The DOE will provide a water tap and a livestock watering facility in one section, a livestock drinker and related pipeline in a second section, and a water pipeline to tie into an existing water tub in a third. This action is separate and apart from the railroad reservation and will be implemented after completion of the Cooperative Agreement among the DOE, the BLM, and the rancher.

Water taps and related equipment have been provided by the DOE. (See also Section 18.3.2.2.)

18.3.4.6 Removal of Caliche and/or other Mineral Material, SS No. 12

The grantee and its subcontractor will remove caliche and/or other mineral material from BLM-approved sites only. The DOE will submit a pit development and rehabilitation plan to the BLM for its approval before removing any caliche.

An application for a free-use caliche permit was submitted to the BLM by the DOE. The permit was awarded by the BLM. (See also Section 18.3.9.)

18.3.4.7 Application for Free-Use Permits, SS No. 13

The DOE will sign applications for BLM free-use permits for the borrowing of caliche, sand, gravel, and other construction materials in quantities that may be reasonably required for this project. WIPP contractors will be responsible for locating the source; obtaining, completing, and processing the applications; and complying with all BLM requirements.

The DOE submitted an application to the BLM for a free-use permit for caliche. The permit was granted by the BLM. (See also Section 18.3.9.)

18.3.4.8 Notification of the BLM Regarding the Access Road Parallel to the Railroad, Amendment

An access road parallel to the railroad was deemed necessary. Since the existing access road, constructed in conjunction with the railroad, is located within 75 feet of the railroad centerline (i.e., within the railroad right-of-way), no new right-of-way was required. However, notification to the BLM was needed.

The BLM was notified as specified.

18.3.5 Right-of-Way Reservation No. NM 63136, Dosimetry and Aerosol Sampling Sites

The conditions specified for the right-of-way reservation for the aerosol sampling site are described in this section, along with the compliance status of each condition. The reservation was awarded on July 31, 1986, and amended in August 1988. The reservation is to remain in effect for 25 years (i.e., until July 31, 2011).

18.3.5.1 Establishment of Dosimeter Stations and Air Samplers, Attachment A

The reservation allowed the installation of 21 thermoluminescent dosimeters (TLDs) and four aerosol sampling stations at 20 and two locations, respectively. The DOE and its operating contractor are technically and financially responsible for the installation, maintenance, and operation of these monitoring systems.

Air samplers have been installed. WID personnel operate and maintain the monitoring system. The environmental dosimetry program that used the TLDs was discontinued in 1990 on the basis of two studies performed: one internally; the other by University of Michigan personnel for the EEG. Both studies concluded that the environmental dosimetry program could be discontinued because it measures gamma or x-ray radiation rather than alpha radiation, such as that emitted by TRU material, and because it is much less sensitive than other sampling programs used at WIPP.

18.3.5.2 Air Monitoring and Data Collection Site, Amendment

Right-of-way reservation No. 63136 was modified to allow an air monitoring and data collection site.

An instrumentation trailer (8 feet by 16 feet), a 10-meter-tall meteorological tower, and various environmental monitoring instruments were installed as agreed to between the DOE and the BLM. The installation required clearing an area of vegetation, constructing a concrete foundation for the trailer and tower, burying instrumentation wires, and constructing an access road. The 0.25-acre area was enclosed by a chain-link security fence as specified in the request to amend the right-of-way reservation.

18.3.6 Right-of-Way Reservation for Subsidence Monuments, No. NM 65801

No unique conditions were specified for the right-of-way reservation for seven geological subsidence monuments. Therefore, only the common conditions described in Section 18.3.1 apply and have been met.

The right-of-way reservation was awarded on November 7, 1986. It is to be held in perpetuity.

18.3.7 Right-of-Way Reservation for Two Subsidence Monuments, No. NM 82245

The conditions of the right-of-way reservation for two subsidence monuments are described in this section, along with the compliance status of each condition.

The reservation was granted on December 13, 1989. It has a 30-year term and is renewable.

18.3.7.1 Construction and Maintenance of the Monuments, #1

The monuments will be constructed and maintained in accordance with the details specified in the application submitted on December 4, 1989.

Two concrete survey monuments were installed on the right-of-way. The monuments are approximately 18 inches in diameter and 36 inches deep. Installation of the monuments was performed as described in the application.

18.3.7.2 Security and Maintenance of the Monuments, #3

The DOE is responsible for the security and maintenance of the monuments.

The DOE is responsible for the security of the monuments. WID maintains the monuments.

18.3.7.3 Rehabilitation of the Land, #5

Upon cancellation or termination of this reservation, the DOE will rehabilitate the land. All structures, improvements, debris, etc., will be removed. All disturbed surfaces will be reseeded in accordance with BLM specifications using Seed Mixture 2.

Upon cancellation or termination of this right-of-way reservation, the DOE will ensure that the land is rehabilitated as specified. All structures, improvements, and debris will be removed and all disturbed surfaces reseeded with pure live seed (Seed Mixture 2) containing no weeds as specified in the *BLM Seeding Requirements in the Roswell District*. Until the reservation is canceled or terminated, these conditions are not applicable.

18.3.8 Right-of-Way Reservation for an Aerosol Sampling Site, No. NM 77921 (NM 77860)

The conditions for the right-of-way reservation for an aerosol sampling site are discussed in this section, along with the compliance status of each condition. Right-of-way reservation No. NM 77921 was granted on August 18, 1989. (It was originally granted as No. NM 77860, but the number had already been issued and was subsequently changed.) The reservation was made for a 30-year term and is renewable.

18.3.8.1 Construction, Operation, and Maintenance, #1

The facility will be constructed, operated, and maintained in accordance with the details specified in the application submitted on July 31, 1989.

The application (dated July 13, 1989) specified that a 6-foot metallic stand would be positioned on an existing concrete pad, an electrical hookup would be made to an

existing power line, and a chain-link security fence would be emplaced. It also indicated that the monitoring station would be used throughout the life of the project and would be operated throughout each year of the project. These conditions have been met.

18.3.8.2 Security and Operation of the Aerosol Sampling Station, #3

The DOE will be responsible for the security and day-to-day operation of the facility.

The DOE is responsible for the security of the aerosol sampling station. WID personnel operate and maintain the station.

18.3.8.3 Rehabilitation of the Land Occupied by the Aerosol Sampling Station, #5

The conditions specified (and the response to the conditions) specified are identical to those described in Section 18.3.7.3. See this section for specific information pertaining to rehabilitation of the land upon cancellation or termination of a right-of-way reservation.

18.3.8.4 Use of the Abandoned Concrete Slab

A concrete slab was present at the location of the right-of-way land. The slab had been owned by the El Paso Natural Gas Company. WID personnel requested the use of the slab for radiation monitoring. El Paso Natural Gas Company personnel stated that the slab could be used if their personnel in Jal, New Mexico, were notified prior to initiating construction and if the BLM gave its consent.

Discussions were held with personnel from the El Paso Natural Gas Company. No additional conditions were specified, and notifications were made as requested by El Paso Natural Gas.

The BLM's issuance of this right-of-way reservation consists of its tacit approval of use of the concrete slab.

18.3.9 Caliche Free-Use Permit, NM-FU3-91183

The conditions specified under this permit are discussed in this section, and the compliance status of each condition is given. The Caliche Free Use Permit was renegotiated June 13, 1995, and extended to May 12, 1998. Reclamation contingencies still apply.

18.3.9.1 Withdrawal of Caliche

Under this permit, WIPP is entitled to withdraw 35,000 cubic yards of caliche.

The WIPP has not yet finished withdrawing the allotted 35,000 cubic yards of caliche from the borrow pit as allowed by the permit. It is anticipated that this activity will have been completed by the time the permit expires on May 12, 1998.

18.3.9.2 Reclamation of the Caliche Borrow Pit

Upon completion of its withdrawal of caliche from the caliche borrow pit, the DOE will perform reclamation and other closure activities, including reseeding, as specified under the permit.

WIPP and BLM personnel have agreed that the only closure activity to be performed by the DOE is to recontour the slope of the withdrawal area to a 3:1 slope. The reason for the other conditions being canceled (e.g., reseeding the area) is that the pit is a community borrow pit; several other parties are removing caliche from the pit and will continue to do so past the expiration date of the WIPP caliche free-use permit.

19.0 PUBLIC RANGELANDS IMPROVEMENT ACT

19.1 Summary of the Law

Congress has recognized that vast segments of public rangelands produce less than their potential for livestock, wildlife habitat, recreation, forage, and water and soil conservation benefits. The 1978 Public Rangelands Improvement Act (43 USC §§ 1901 et seq.) was enacted to address the concerns that such rangelands could remain in such an unsatisfactory condition and that some areas could decline further under existing levels of management.

With the passage of this act, Congress reaffirmed a national policy and commitment to:

- Inventory and identify current public rangeland conditions and trends;
- Manage, maintain, and improve the condition of public rangelands so that they become as productive as is feasible; and
- Continue the policy of protecting wild free-roaming horses and burros while facilitating the removal and disposal of excess wild free-roaming horses and burros that pose a threat to themselves, their habitat, and other rangeland values.

This policy and commitment are echoed in other statutes that address public-land use and management. One such act, FLPMA, directs the Secretary of the Interior to prepare and maintain an inventory of all public lands and to develop and maintain land-use plans with public involvement regardless of whether the public lands have been classified as withdrawn, set aside, or otherwise designated (see Chapter 18). Another statute, the LWA, transferred jurisdiction over, and statutory authority and responsibility for, the management of the withdrawn lands at WIPP from the DOI to the DOE. Section 4 of the LWA, *Establishment of Management Responsibilities*, directs the DOE to conduct the management of grazing consistent with such laws as the Public Rangelands Improvement Act, the Taylor Grazing Act (Chapter 20), and other applicable laws such as Title IV, *Range Management,* of FLPMA (Chapter 18).

The implementing regulations under Subchapter D, *Range Management,* 43 CFR Part 4100, *Grazing Administration - Exclusive of Alaska*, provide uniform guidance for the administration of grazing on public lands. The objectives of these regulations include the following: orderly use, improvement, and development; enhancement of productivity by prevention of overgrazing and soil deterioration; and provision of inventory and categorization of public rangelands on the basis of range conditions and trends. The regulations specify that grazing on administered public lands must be managed in accordance with applicable land-use plans. These plans must set forth

program constraints and the general management practices needed to achieve the management objectives.

19.2 Compliance Status of the Regulatory Requirement

Table 19-1 summarizes the applicable requirement and its compliance status under the Public Rangelands Improvement Act. The text discusses the compliance status of the requirement in more detail.

TABLE 19-1. Public Rangelands Improvement Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
43 CFR Part 4100, *Grazing Administration - Exclusive of Alaska*		
43 CFR 4100.0-8	Land-use plan, including grazing management	**UP TO DATE** Authorized range-management activities ongoing per the LMP. [Section 19.2.1]

19.2.1 Management of Grazing Per Land-Use Plan, 43 CFR 4100.0-8

> *Grazing on administered public lands shall be managed under the principle of multiple use and sustained yield and must be in accordance with the applicable land-use plan.*

As addressed in the LMP, the DOE's intent is to continue current range-management practices with no immediate changes. Grazing will continue on the withdrawn lands as it has since the inception of the WIPP project. Range-management plans include (1) continued management of two affected grazing allotments under multiple-use management and sustained yield; (2) continued vegetative monitoring, which will include collecting data on actual livestock use, wildlife use, and degree of use of key forage species; and (3) continued monitoring studies to determine range condition and trends. In accordance with the LMP, the BLM will administer all range management activities.

20.0 TAYLOR GRAZING ACT

20.1 Summary of the Law

Although the United States does not and cannot hold property for private or personal purposes, it controls public lands under constitutional grant, acting through Congress. Control over public lands is in the hands of Congress; with this power, Congress may prohibit or fix the terms under which public lands may be used.

The Taylor Grazing Act of 1934 (43 USC §§ 315 et seq.) was enacted by Congress for the purpose of establishing a means for federal management of public lands used for grazing. The intent of Congress was to aid the livestock industry by defining grazing rights and to protect these rights by regulation. This act is intended to prohibit injury to public grazing lands from unregulated grazing and directs the orderly use of and improvement to public grazing lands by establishing grazing districts and a grazing permit system.

The LWA withdrew public lands and transferred jurisdiction over WIPP site lands from the DOI to the DOE. As a result of the LWA, the DOE was given statutory authority and responsibility for the management of the withdrawn land consistent with FLPMA (see Chapter 18) and other applicable laws such as the Taylor Grazing Act. Under the LWA, the DOE may allow grazing to continue where it was established before the enactment of the LWA, consistent with the applicable implementing regulations of the Taylor Grazing Act such as 43 CFR Part 4100, *Grazing Administration - Exclusive of Alaska*, although the BLM continues to administer the grazing-permit program and collects the grazing fee. The WIPP withdrawal area affects two grazing allotments (i.e., land designated and managed for the grazing of livestock).

The implementing regulations of 43 CFR Part 4100 provide uniform guidance for the administration of grazing on public lands, exclusive of Alaska. The objectives of these regulations are as follows: orderly use, improvement, and development of public grazing lands; enhancement of grazing land productivity by the prevention of overgrazing and soil deterioration; stabilization of the livestock industry dependent upon the public range; and provision of inventory and categorization of public rangelands on the basis of range conditions and trends. These objectives must be consistent with land-use plans, multiple use, sustained yield, environmental values, and other general objectives as stated by the Taylor Grazing Act.

20.2 Compliance Status of the Regulatory Requirements

Table 20-1 summarizes the two applicable regulatory requirements and their compliance status under the Taylor Grazing Act. The text gives more detail on the compliance status of each requirement.

TABLE 20-1. Taylor Grazing Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
43 CFR Part 4100, *Grazing Administration*		
43 CFR 4100.0-8	Management of grazing lands under principles of multiple use and sustained yield and in accordance with applicable land-use plans	**UP TO DATE** BLM authorized to administer ongoing grazing activities per the LMP [Section 20.2.1; see also Section 19.2.1]
43 CFR 4120.2	Preparation of allotment management plan	**ACHIEVED** BLM authorized to manage land use for two allotments [Section 20.2.2]

20.2.1 Management of Grazing Lands, 43 CFR 4100.0-8

> *Grazing on public lands shall be managed under the principles of multiple use and sustained yield in accordance with applicable land-use plans.*

In accordance with the LMP, the BLM will ensure that range management activities are carried out under the authority of the Taylor Grazing Act of 1934, FLPMA, (Chapter 18), and the Public Rangelands Improvement Act (Chapter 19). The principles of multiple use and sustained yield are basic to the management of these activities. The DOE's intent is to continue current management practices with no immediate changes in current operations. (See also Section 19.2.1.)

20.2.2 Allotment Management Plans, 43 CFR 4120.2

> *An allotment management plan shall be prepared in careful and considered consultation, cooperation, and coordination with BLM personnel, the landowners involved, the district grazing advisory board, and any other affected interests.*

The WIPP withdrawal area affects two grazing allotments administered by the BLM: the Livingston Ridge and Antelope Ridge. Portions of both allotments lie within the withdrawal area. No formal grazing system has been implemented for the Livingston

Ridge; however, a recent review by the BLM of actual-use data indicates that there is pasture rotation, with some pastures being rested for at least a portion of the growing season. The Antelope Ridge allotment is leased to a livestock rancher; in consultation with the BLM, an allotment management plan has been developed for this allotment. The plan includes a five-pasture rotation system, with some pastures being rested for full years and others receiving growing-season rest. WIPP is contained within an area of 300 acres within the Antelope Range allotment that is posted against trespass and fenced to prevent grazing. The 277-acre DOE Exclusive Use Area and 23 additional acres set aside for reclamation sites, storage yards, etc., are the only portions of the withdrawal area not currently used for livestock activity.

21.0 BALD AND GOLDEN EAGLE PROTECTION ACT

21.1 Summary of the Law

The Bald and Golden Eagle Protection Act (16 USC § 668-668d) makes it unlawful to take (i.e., capture, kill, or destroy), possess, molest, or disturb bald eagles (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*), alive or dead, their nests, or their eggs anywhere in the United States. A permit must be obtained from the DOI to relocate any nest that interferes with resource development or recovery operations. The Bald and Golden Eagle Protection Act is implemented by several parts under CFR Title 50, Subchapter B, *Taking, Possession, Transportation, Sale, Purchase, Barter, Exportation, and Importation of Wildlife and Plants*. These implementing regulations are found in 50 CFR Parts 13, 17, 21, and 22.

The regulations in 50 CFR Part 13, *General Permit Procedures,* provide uniform rules, conditions, and procedures for the application for, and the issuance, denial, suspension, revocation, and general administration of, all permits issued pursuant to 50 CFR Subchapter B. The provisions in this part are in addition to other regulations, such as the Migratory Bird Treaty Act (Chapter 22) and the Endangered Species Act (Chapter 23), and apply to all permits issued under these regulations, including 50 CFR Parts 17, 21, and 22.

The regulations of 50 CFR Part 17, *Endangered and Threatened Wildlife and Plants*, which also implement the Endangered Species Act and are discussed in Chapter 23, could apply to WIPP because of the potential for the presence of the endangered bald eagle. The regulations in this part outline permit requirements for activities involving endangered wildlife and identify those species of wildlife and plants recognized as endangered or threatened with extinction.

The purpose of the regulations in 50 CFR Part 21, *Migratory Bird Permits*, is to supplement the general permit regulations of Part 13 of Subchapter B with respect to permits for the taking, possession, transportation, sale, purchase, barter, importation, exportation, and banding or marking of migratory birds. Section 21.22 of 50 CFR Part 21 outlines the requirements and procedures for permitting the banding or marking of bald and golden eagles. The requirements under 50 CFR Part 21 are discussed in Chapter 22.

The purpose of the regulations in 50 CFR Part 22, *Eagle Permits*, is to govern the taking, possession, and transportation of bald and golden eagles for scientific, educational, and depredation-control purposes and for the religious purposes of Indian tribes. The import, export, purchase, sale, and or barter of bald or golden eagles, their parts, nests, or eggs are not permitted by any regulation of Subchapter B.

21.2 Compliance Status of the Regulatory Requirements

Table 21-1 summarizes some of the applicable requirements and their compliance status under the Bald and Golden Eagle Protection Act. The text provides more detail on the compliance status of these requirements.

TABLE 21-1. Bald and Golden Eagle Protection Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
50 CFR Part 13, *General Permit Procedures*		
50 CFR 13.11	Permit application procedures	**NOT APPLICABLE** Refer to 50 CFR 22.11 and 22.25 [Section 21.2.1]
50 CFR Part 22, *Eagle Permits*		
50 CFR 22.11	General permit requirements	**NOT APPLICABLE** Eagles not included on any general banding permits at WIPP [Section 21.2.2]
50 CFR 22.25	Permits to take golden eagle nests	**NOT APPLICABLE** No nesting eagles at WIPP [Section 21.2.3]

21.2.1 Permit Application Procedures, 50 CFR 13.11

> *Applicants must submit separate applications for each permit on prescribed forms and must follow prescribed forwarding instructions.*

At present, no bald or golden eagles are nesting on the WIPP site; however, individual eagles overwinter on WIPP lands. Overwintering eagles are provided considerations during determinations of all land-use actions. WIPP personnel will file an application for an eagle permit as required if the need for such a permit is perceived. Other permit requirements under 50 CFR Part 13, which would become applicable were a need to arise to disturb or relocate a bald or golden eagle, are discussed in Chapter 22.

21.2.2 General Permit Requirements, 50 CFR 22.11

> *No person shall take, possess, or transport any bald or golden eagle, living or dead, or the parts, nest, or eggs of such birds except as authorized under terms of a valid issued permit.*

WIPP personnel will apply for a permit and will comply with the permit conditions if such a permit is ever needed.

21.2.3 Permits to Take Golden Eagle Nests, 50 CFR 22.25

> *Persons desiring to take golden eagle nests during a resource-development or recovery operation must file a permit application in accordance with prescribed procedures. The nests may be taken only when they are inactive.*

At present, no golden eagles are nesting on the WIPP site. If it becomes necessary to move or remove a golden eagle nest, a permit application will be filed. All permit conditions will be met, and the nest(s) will be moved only when inactive.

22.0 MIGRATORY BIRD TREATY ACT

22.1 Summary of the Law

The Migratory Bird Treaty Act (16 USC §§ 703-712) is intended to protect birds that have common migratory flyways between the United States and Canada, Mexico, Japan, and Russia. The act stipulates that it is unlawful "at any time, by any means or in any manner, to pursue, hunt, take, capture, kill, or attempt to take, capture, or kill . . . any migratory bird, any part, nest, or eggs of any such bird" unless specifically authorized by the Secretary of the Interior by direction or through regulations permitting and governing these actions. Although WIPP is not located within a major migration corridor, there is the potential for migratory birds to be present on WIPP lands.

The regulations in 50 CFR Part 13, *General Permit Procedures,* provide uniform rules, conditions, and procedures for the application for and the issuance, denial, suspension, revocation, and general administration of all permits issued pursuant to 50 CFR Subchapter B, *Taking, Possession, Transportation, Sale, Purchase, Barter, Exportation, and Importation of Wildlife and Plants.* The provisions in this part are in addition to other regulations, including 50 CFR Parts 17, 21, and 22, and apply to all permits issued under these regulations.

The regulations of 50 CFR Part 17, *Endangered and Threatened Wildlife and Plants,* also implement the Migratory Bird Treaty Act and could apply to WIPP because of the potential for the presence of migratory endangered and threatened species of birds at the WIPP. These regulations, discussed in Chapter 23, outline the requirements for permits for activities involving endangered wildlife and identify those species of wildlife which are recognized as endangered or threatened with extinction.

Under the Migratory Bird Treaty Act, the DOE is required to consult annually with the U. S. Fish and Wildlife Service (FWS) with respect to impacts on migratory game birds[1] and crows resulting from the hunting activities permitted on WIPP lands. Hunting privileges for the public within the withdrawal area will continue, except for the areas that are posted against trespass. These hunting activities, whether conducted out of or within the withdrawal area, are subject to regulations implementing the Migratory Bird Treaty Act (i.e., 50 CFR Part 20, *Migratory Bird Hunting*[1]), which regulate the harvest of migratory birds by specifying the mode of harvest, hunting seasons, possession limits,

[1] Migratory game birds are migratory birds that belong to the following families: Anatidae (ducks, geese, brant, and swans); Columbidae (doves and pigeons); Gruidae (little brown cranes); Rallidae (rails, coots, and gallinules); and Scolopacidae (woodcock and snipe).

and so on. Furthermore, because certain migratory birds that have been federally recognized and listed as endangered or threatened, such as bald eagles and peregrine falcons, could be present on WIPP lands, the Bald and Golden Eagle Protection Act (Chapter 21) and the Endangered Species Act (Chapter 23) may also apply, along with their implementing regulations.

The regulations in 50 CFR Part 21, *Migratory Bird Permits*, supplement the general permit regulations of Part 13 of this subchapter with respect to permits for the taking, possession, transportation, sale, purchase, barter, importation, exportation, and banding or marking of migratory birds. The portion that is relevant to WIPP is § 21.22, which outlines the requirements and procedures for obtaining permits to band or mark birds. Part 21 also provides certain exceptions to the permit requirements for public, scientific, or educational institutions and establishes depredation orders that provide limited exceptions to the Migratory Bird Treaty Act.

The purpose of the regulations in 50 CFR 22, *Eagle Permits*, is to govern the taking, possession, and transportation of bald and golden eagles for scientific, educational, and depredation-control purposes and for the religious purposes of Indian tribes. Compliance with these regulations is discussed in Chapter 21.

22.2 Compliance Status of the Regulatory Requirements

The compliance status of each of the applicable regulatory requirements under the Migratory Bird Treaty Act is summarized in Table 22-1. More detail is provided in the text.

TABLE 22-1. Migratory Bird Treaty Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
50 CFR Part 13, *General Permit Procedures*		
50 CFR 13.11	Permit application procedures	**ACHIEVED** Application submitted to the U.S. Fish and Wildlife Service (FWS) [Section 22.2.1]
50 CFR 13.12	Information requirements for permit applications	**ACHIEVED** Prescribed information included in application [Section 22.2.2]

CITATION	REQUIREMENT	COMPLIANCE STATUS
50 CFR 13.44	Display of permit	**ACHIEVED** Permit displayed [Section 22.2.3]
50 CFR 13.45	Filing of reports	**ACHIEVED** Annual report submitted to FWS [Section 22.2.4]
50 CFR 13.46	Maintenance of records	**UP TO DATE** Maintained for at least 5 years [Section 22.2.5]
50 CFR 13.47	Inspection requirement	**NOT APPLICABLE** No inspections requested to date [Section 22.2.6]
50 CFR 13.48	Compliance with permit conditions	**UP TO DATE** All conditions met (See also Sections 22.2.12 and 22.3.1.) [Section 22.2.7]
50 CFR 13.50	Acceptance of liability	**UP TO DATE** No action required [Section 22.2.8]
50 CFR Part 20, *Migratory Bird Hunting*		
50 CFR Part 20, Subpart C	Compliance with applicable hunting regulations	**UP TO DATE** Hunting allowed in some areas in compliance with applicable regulations [Section 22.2.9]
50 CFR Part 21, *Migratory Bird Permits*		

CITATION	REQUIREMENT	COMPLIANCE STATUS
50 CFR 21.22(a)	Permit for banding or marking migratory birds	**ACHIEVED** Federal Permit 22478 for banding obtained [Section 22.2.10]
50 CFR 21.22(b)	Application procedures for banding or marking permits	**ACHIEVED** Prescribed information submitted to FWS [Section 22.2.11]
50 CFR 21.22(c)	Additional permit conditions	**UP TO DATE** Permit conditions met [Section 22.2.12]
50 CFR 21.22(d)	Term of permit	**UP TO DATE** Less than 3 years [Section 22.2.13]
50 CFR 21.27	Special-purpose permits	**NOT APPLICABLE** No action required [Section 22.2.14]
50 CFR 21.28	Falconry permits	**NOT APPLICABLE** No falconry activities anticipated at WIPP [Section 22.2.15]
50 CFR 21.41	Depredation permits	**NOT APPLICABLE** No need for a depredation permit anticipated for WIPP [Section 22.2.16]

22.2.1 Permit Application Procedures, 50 CFR 13.11

> *Applicants must submit a separate application on the prescribed form for each permit and must follow the prescribed forwarding instructions.*

The prescribed information has been submitted to the FWS.

22.2.2 Information Requirements for Permit Applications, 50 CFR 13.12

> *Applicants must provide current information such as organizational affiliation, reason(s) for the permit application, and certification of familiarity with 50 CFR Part 13.*

The prescribed permit applications and supporting information have been submitted to the FWS.

22.2.3 Display of Permit, 50 CFR 13.44

> *Any permit issued under 50 CFR Part 13 will be displayed for inspection upon the request of the Director, his/her agent, or any other person that relies upon the existence of the permit.*

The permits are permanently displayed on the door of the freezer in which tissue samples are held at WIPP.

22.2.4 Filing of Reports, 50 CFR 13.45

> *Recipients of a permit may be required to file reports of the activities conducted under the permit. Any such report must be filed by March 31 for the preceding calendar year ending December 31 or for any portion of the year during which the permit was in force.*

Annual reports are submitted to the FWS.

22.2.5 Maintenance of Records, 50 CFR 13.46

> *From the date of issuance of a permit, the recipient of the permit must maintain complete and accurate records of any taking, possession, transportation, sale, purchase, barter, exportation, or importation of plants obtained from the wild or wildlife covered under the permit. The records must be kept current and must include the names and addresses of any*

> *persons involved in the transfer of the plant or wildlife as well as the date of the transaction and any other appropriate information. The records must be legible or reproducible and written in English and must be maintained for 5 years from the date of expiration of the permit.*

All applicable records are held for at least five years from the date of expiration of the permit.

22.2.6 Inspection Requirement, 50 CFR 13.47

> *Any person holding a permit under this subpart shall allow the Director's agent to enter his/her premises at any reasonable hour to inspect any wildlife or plant held or to inspect, audit, or copy any permits, books, or records required under Subpart B.*

The Director's agent has not yet requested such an inspection. Should an inspection be requested, full cooperation will be given.

22.2.7 Compliance with Permit Conditions, 50 CFR 13.48

> *Any person holding a permit under this subpart or acting under the authority of the permittee must comply with all conditions of the permit and with all applicable laws and regulations governing the permitted activity.*

Conditions described in the permit have been met. See also Sections 22.2.12 and 22.3.1.

22.2.8 Acceptance of Liability, 50 CFR 13.50

> *Any person holding a permit under Subpart B assumes all liability and responsibility for the conduct of any activity conducted under the authority of the permit.*

The recipients of the permits under Subpart B at WIPP are fully aware of their liabilities and assume responsibility for their activities.

22.2.9 Compliance with Applicable Migratory Bird Hunting Regulations, 50 CFR 20, Subpart C

> *Hunters of migratory game birds and crows must comply with open-season requirements, including the avoidance of prohibited hunting methods.*

Hunting privileges for the public will continue within the withdrawal area, except in areas posted against trespass, in accordance with applicable hunting regulations.

22.2.10 Application for Banding or Marking Permit, 50 CFR 21.22(a)

Persons intending to capture migratory birds for banding or marking must have obtained a permit acquired in accordance with prescribed permit regulations.

A permit No. 22478 for banding at WIPP has been granted by the FWS. (See also Section 22.3.1.)

22.2.11 Application Procedures for Banding or Marking Permits, 50 CFR 21.22(b)

Information to be provided in banding or marking permit applications includes, but is not limited to, the State in which authorization is desired; the species to be banded or marked; and the name and address of the public, scientific, or educational institution that will be recipients of salvaged specimens.

This information was included in the application for the permit.

22.2.12 Additional Permit Conditions, 50 CFR 21.22(c)

In addition to the general permit conditions described in 50 CFR Part 13 (see Sections 22.2.1 through 22.2.8), the following conditions will be met:

- *Only official numbered leg bands issued by the Fish and Wildlife Service will be used to band migratory birds.*
- *All traps or nets used to capture migratory birds for banding or marking will have a tag attached with the name and address of the permittee and the permit number.*
- *The holder of a permit may salvage birds killed or found dead. All such dead birds salvaged under the authority of a banding or marking permit must be donated and transferred to a public, scientific, or educational institution at least every 6 months or*

within 60 days of the expiration or revocation of the permit unless a special permit that authorizes possession for a longer period of time has been issued.

- *The permittees must keep accurate records of their operations and must file reports as required.*

The additional permit conditions are met at WIPP.

22.2.13 Term of Permit, 50 CFR 21.22(d)

The term of a banding or marking permit shall not exceed 3 years from the date of issuance or renewal. The expiration date is designated on the permit unless the permit has been amended or revoked.

Permit No. 22478 does not exceed the three-year term. The permit was reissued to WID personnel on June 30, 1995, and will expire on June 30, 1997.

22.2.14 Special-Purpose Permits, 50 CFR 21.27

Permits may be issued for special-purpose activities related to migratory birds or their parts, nests, or eggs that are otherwise outside the scope of the standard permits of this part.

No special-purpose permits have been needed at WIPP to date. Should such a permit become necessary, all appropriate requirements will be met as specified under this section.

22.2.15 Falconry Permits, 50 CFR 21.28

A falconry permit is required before any person may take; possess; transport; sell; purchase; barter; or offer to sell, purchase, or barter raptors for falconry purposes.

No falconry activities are anticipated at WIPP. Therefore, this permit is not applicable.

22.2.16 Depredation Permits, 50 CFR 21.41

A depredation permit is required before any person may take, possess, or transport migratory birds for depredation control.

No need for a depredation permit to control migratory birds is anticipated at WIPP. Therefore, this permit does not apply.

22.3 Compliance Status of Permit Conditions

Table 22-2 summarizes the conditions imposed by the FWS for the permit issued. The text provides more detail on the compliance status of the permit conditions.

TABLE 22-2. Migratory Bird Treaty Act - Summary of Permit Compliance Status

CITATION	CONDITION	COMPLIANCE STATUS
Permit No. 22478	Authorization to capture and band or mark birds; excluded for waterfowl, eagles, and endangered or threatened species	**UP TO DATE** No waterfowl, eagles, or endangered species captured, banded, or marked at WIPP [Section 22.3.1]

22.3.1 Permit No. 22478

Permit No. 22478 authorizes the WID employee specified to capture and band or mark all species of birds except waterfowl, eagles, or endangered or threatened species.

Permit No. 22478 provides authority to capture and band or mark all species of birds except waterfowl, eagles, or endangered or threatened species. No waterfowl, eagles, or endangered or threatened species have been captured, marked, or banded at WIPP.

23.0 ENDANGERED SPECIES ACT

23.1 Summary of the Law

The Endangered Species Act (16 USC §§ 1531 et seq.) was enacted in 1973 to prevent the extinction of many species of animals and plants. This act provides strong measures to help alleviate the loss of species and their habitats and places restrictions on a wide range of activities involving endangered and threatened animals and plants to help ensure their continued survival. With limited exceptions, this act prohibits activities that could potentially impact these protected species unless authorized by a permit from the U.S. Fish and Wildlife Service (FWS). Under § 1536 of the act and the implementing regulations in 50 CFR Part 402, *Interagency Cooperation--Endangered Species Act, as Amended,* the EPA is prohibited from authorizing activities likely to jeopardize the continued existence of any threatened or endangered species or its critical habitat. A biological assessment and " formal consultation," followed by the issuance of a " biological opinion" by the FWS, may be required for any species that is determined to be in potential jeopardy.

The DOE consulted with the FWS in 1979 to determine the presence of threatened or endangered species at or near the WIPP site. At that time, the FWS listed the Lee Pincushion Cactus (*Coryphantha sneedi* var. *Leei*), the Black-Footed Ferret (*Mustela nigripes*), the American Peregrine Falcon (*Falco peregrinus anatum*), and the Bald Eagle (*Haliaeetus leucocephalus*) as threatened or endangered that could occur on lands within or outlying the WIPP site. However, no critical habitat for endangered species was identified at WIPP. In 1989, the DOE again consulted with the FWS to update the list of threatened and endangered species. The agency has advised the DOE that the list of species provided in 1979 is still valid.

During 1989, the DOE consulted with the New Mexico Department of Game and Fish (NMDG&F) regarding the state-listed endangered species in the vicinity of the WIPP. Based on NMDG&F Regulation 657, dated January 9, 1988, the NMDG&F listed seven birds and one reptile in one of two endangerment categories that occur or are likely to occur at the site.

During 1995, the FWS transmitted the April 24, 1995, updated list of threatened and endangered species (to include Notice of Review) for Eddy and Lea Counties, New Mexico. Inclusive were approximately 18 species that occur or are likely to occur on WIPP lands. Accordingly, the list was distributed to pertinent WIPP departments for consideration and incorporation into applicable documents. The DOE currently operates under the assumption that activities associated with the operation of the WIPP will have no impact on any threatened or endangered species. Considerations pertaining to protected species are implemented in accordance with this management plan, during the deliberation and administration of projects conducted on WIPP lands.

The regulations in 50 CFR Part 13, *General Permit Procedures,* provide uniform rules, conditions, and procedures for the application for and the issuance, denial, suspension, revocation, and general administration of all permits issued pursuant to 50 CFR Subchapter B, *Taking, Possession, Transportation, Sale, Purchase, Barter, Exportation, and Importation of Wildlife and Plants.* The provisions in this part are in addition to other regulations and apply to all permits issued under them, including 50 CFR Parts 17, 21, and 22.

The regulations of 50 CFR Part 17, *Endangered and Threatened Wildlife and Plants,* implement the Endangered Species Act as well as the Bald and Golden Eagle Protection Act (see Chapter 21) and could apply to WIPP because of the potential for the presence of the endangered animal and plant species identified above. The regulations in this part outline the requirements for permits for activities involving endangered wildlife and identify those species of wildlife and plants recognized as endangered or threatened with extinction.

Other federal regulations which implement the Endangered Species Act and which apply to the WIPP include the implementing regulations in 50 CFR Parts 21 and 22. The purpose of the regulations in 50 CFR Part 21, *Migratory Bird Permits*, is to supplement the general permit regulations of Part 13 of Subchapter B with respect to permits for the taking, possession, transportation, sale, purchase, barter, importation, exportation, and banding or marking of migratory birds, including those listed as threatened or endangered. Compliance with these regulations is discussed in Chapter 22.

The regulations in 50 CFR Part 22, *Eagle Permits*, govern the taking, possession, and transportation of the endangered bald eagle for scientific, educational, and depredation-control purposes and for the religious purposes of Indian tribes. Requirements under these regulations are discussed in Chapter 21.

23.2 Compliance Status of the Regulatory Requirements

Table 23-1 summarizes regulatory requirements and their compliance status under the Endangered Species Act. The text gives more detail on the compliance status of each requirement.

TABLE 23-1. Endangered Species Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
50 CFR Part 13, *General Permit Procedures*		
50 CFR 13.11	Permit application procedures	**NOT APPLICABLE** No work anticipated with endangered or threatened species [Section 23.2.1]
50 CFR Part 17, *Endangered and Threatened Wildlife and Plants*		
50 CFR 17.22, 17.32, 17.52, and 17.62	Application for permits for scientific purposes or for the enhancement of propagation or survival of endangered or threatened species	**NOT APPLICABLE** No work anticipated with endangered or threatened species [Section 23.2.2]
50 CFR Part 402, *Interagency Cooperation - Endangered Species Act, as Amended*		
50 CFR 402.12	Biological assessment to evaluate effects of proposed actions on designated species	**NOT APPLICABLE** Determination of no adverse impacts; see Section 23.2.4 [Section 23.2.3]
50 CFR 402.14	Formal consultation with the FWS to determine whether any action will affect listed species	**ACHIEVED** Determination of no adverse impacts [Section 23.2.4]

23.2.1 Permit Application Procedures, 50 CFR 13.11

> *Applicants must submit separate applications for each permit on prescribed forms and must follow prescribed forwarding instructions.*

No permit is required because activities involving endangered species are not conducted at WIPP. Other requirements related to permits under 50 CFR Part 13,

which would become applicable only if activities involving endangered species were initiated, are summarized and discussed in Chapter 22.

23.2.2 Application for Endangered or Threatened Species Permit, 50 CFR 17.22 (a)(1), 17.32, 17.52, and 17.62

> *Applicants for permits for using endangered or threatened species of wildlife or plants for scientific purposes, enhancement of propagation or survival, or for incidental taking must submit an application as prescribed.*

To date, taking endangered or threatened wildlife or plants for these purposes, which would require a permit from the FWS, has not been necessary. It is not expected that such a permit will be needed in the future.

23.2.3 Biological Assessment of Impacts on Recognized Species, 50 CFR 402.12

> *A biological assessment may be required to determine whether construction activities will jeopardize the continued existence of endangered species or the critical habitat of any such species.*

On May 29, 1980, the FWS determined that construction of the WIPP would have no adverse impacts on recognized endangered or threatened species. In addition, no critical habitat for terrestrial endangered species has been identified at the WIPP site. Consequently, no biological assessment has been required for the WIPP.

23.2.4 Formal Consultation with the FWS Regarding Impacts on Recognized Species, 50 CFR 402.14

> *Formal consultation with the FWS to determine whether construction activities will jeopardize the continued existence of endangered species or its critical habitat is required.*

On May 29, 1980, the FWS determined that construction of the WIPP would have no adverse impacts on recognized endangered or threatened species. In addition, no critical habitat for terrestrial endangered species has been identified at the WIPP site. Consequently, no formal consultation has been required for the WIPP.

24.0 NATIONAL HISTORIC PRESERVATION ACT

24.1 Summary of the Law

The National Historic Preservation Act (NHPA; 16 USC §§ 470 et seq.) was enacted to protect the nation's cultural resources in conjunction with the states, local governments, Indian tribes, and private organizations and individuals. The policy of the federal government includes (1) providing leadership in preserving the prehistoric and historic resources of the nation; (2) administering federally owned, administered, or controlled prehistoric resources for the benefit of present and future generations; (3) contributing to the preservation of nonfederally owned prehistoric and historic resources; and (4) assisting state and local governments and the National Trust for Historic Preservation in expanding and accelerating their historic preservation programs and activities. The act also established the National Register of Historic Places (" National Register"). At the state level, the State Historic Preservation Officer (SHPO) coordinates the state's participation in implementing the NHPA.

Section 106 of NHPA requires that a federal agency head who has jurisdiction over a federal, federally assisted, or federally licensed undertaking take into account the effects of the agency's undertaking on historic properties included in or eligible for the National Register. Furthermore, the " Section 106 process" requires that the federal agency head afford the Advisory Council on Historic Preservation (" the Council") a reasonable opportunity to comment on the undertaking prior to initiating the undertaking. Through the Section 106 process, the Council seeks to accommodate historic preservation concerns with the needs of federal undertakings. The Council encourages this accommodation through consultation among the federal agency, the SHPO, and other interested parties during the early stages of planning.

The NHPA has been amended by two acts. The Archaeological and Historic Preservation Act (16 USC §§ 469 et seq.) directs federal agencies to recover and preserve historic and archaeological data that would otherwise be lost as a result of federal construction or program activities. This statute applies to known cultural resources on WIPP lands or those which may be recorded in the future.

The other act amending the NHPA is the Archaeological Resources Protection Act (16 USC §§ 470aa et seq.). This statute sets forth the requirements for obtaining a permit from the DOI for the excavation or removal of archaeological resources from public or Indian lands. The act's implementing regulations in 43 CFR Part 7, *Protection of Archaeological Resources*, establish uniform definitions, standards, and procedures to be followed by all Federal land managers in providing protection for archaeological resources located on public lands. The statute and regulations apply to known cultural resources on WIPP lands or those that may be recorded in the future.

The NHPA's implementing regulations in 36 CFR Part 800, *Protection of Historic and Cultural Properties*, contain provisions for the development of a treatment plan by a federal agency that identifies historic properties likely to be discovered during the implementation of an undertaking and how they will be managed.

Since 1976, cultural resource investigations have recorded 60 archaeological sites and 91 isolated occurrences within the 16-square-mile, WIPP site boundary. The exact number of sites within the WIPP site boundary was confirmed with the completion of a comprehensive archaeological database created in July 1994. During the creation of the database some inconsistencies were discovered with regard to the number of archaeological sites, eligible and ineligible for inclusion in the National Register, reported to exist within the WIPP land withdrawal area. Some sites previously included as " WIPP archaeological sites" are located within the outer perimeters of WIPP's Control Zone IV. When the WIPP site was configured to the present 16-section square, much of Control Zone IV reverted to the management of the DOI. Therefore, the archaeological sites located in those areas are no longer the responsibility of the DOE.

Of the 60 archaeological sites, 33 sites recorded within the central 4-square-mile area were determined eligible for inclusion on the National Register as an archaeological district. Investigations since 1980 have recorded an additional 14 individual sites outside the central 4-square-mile area that are considered eligible for inclusion on the National Register. Of the 14 sites, six are within the WIPP's present 16-section configuration.

24.2 Compliance Status of the Regulatory Requirements

Table 24-1 summarizes the regulatory requirements and their compliance status under the NHPA. The text gives more detail on the compliance status of each requirement.

TABLE 24-1. National Historic Preservation Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
36 CFR Part 800, *Protection of Historic and Cultural Properties*		
36 CFR 800.5	Assessment of effects on historic properties	**ACHIEVED** Determination of No Adverse Effect obtained (May 1980) [Section 24.2.1]

CITATION	REQUIREMENT	COMPLIANCE STATUS
36 CFR 800.11	Development of plan for treatment of historic property	**ACHIEVED** *WIPP Mitigation Plan* submitted to State Historic Preservation Officer (SHPO) and to the Council; SHPO determined No Adverse Effect from WIPP activities in May 1980 [Section 24.2.2]
43 CFR Part 7, *Protection of Archaeological Resources*		
43 CFR 7.5	Application for permit to excavate and/or remove archaeological resources	**NOT APPLICABLE** No excavations or removal of *archaeological sites slated* [Section 24.2.3]

24.2.1 Assessment of Effects on Historic Properties, 36 CFR 800.5

In consultation with the SHPO, the Federal agency official with jurisdiction over an undertaking is responsible for assessing the effect of an undertaking on affected historic properties, obtaining the SHPO's concurrence when the effect is not considered adverse, and notifying and submitting summary documentation to the Council.

The DOE submitted documentation to the New Mexico SHPO describing excavation activities and the avoidance of any potential historical sites. A determination of No Adverse Effect from WIPP activities on historic properties was made by the SHPO in May 1980. This determination was applicable for the primary construction activities associated with the development of the WIPP. Similar documentation was submitted to the Council. Since the 1980 determination, the DOE has evaluated minor construction activities in previously undisturbed areas for potential impacts to cultural resources. New surface disturbing activities are evaluated by a licensed, permitted archaeologist and approval is obtained from the SHPO prior to allowing the action to proceed. Examples of activities approved during this reporting period include the construction of small access roads and new well pads for groundwater sampling wells.

24.2.2 Development of a Plan for the Treatment of Historical Property Discovered During a Federal Agency Undertaking, 36 CFR 800.11

After a determination by the Federal agency official presiding over an undertaking that the potential for the discovery of

> *historical property exists, the agency official may develop a plan for the treatment of such properties if discovered and include this plan in any documentation prepared to comply with 36 CFR 800.5.*

A mitigation plan describing excavation activities at WIPP and the avoidance of historical sites was submitted to the New Mexico SHPO. A determination of No Adverse Effect from WIPP activities on cultural resources was made by the SHPO in May 1980. A similar mitigation plan was submitted to the Council. The Council concurred that the *WIPP Mitigation Plan* is appropriate to protect cultural resources.

The LMP also outlines objectives and planned actions for the management of cultural resources within the withdrawal area.

24.2.3 Application for Permits and Information Collection, 43 CFR 7.5

> *Any person proposing to excavate and/or remove archaeological resources from public lands and to carry out activities associated with such excavation and/or removal shall apply for a permit for the proposed work and shall not begin the proposed work until a permit has been issued.*

Avoidance of known archaeological sites is the primary mitigation measure used at WIPP. During this reporting period no archaeological sites were excavated.

25.0 NEW MEXICO HAZARDOUS WASTE ACT

25.1 Summary of the Law

The purpose of the Hazardous Waste Act (HWA; §§ 74-4-1 through 74-4-14 NMSA 1978) is to help ensure the maintenance of the quality of New Mexico's environment; to confer optimal health, safety, comfort, and economic and social well being on its inhabitants; and to protect the proper utilization of its lands. The HWA established the program for hazardous waste management and control in the state of New Mexico. Since its initial enactment in 1977, it has been amended substantially several times to make its provisions more consistent with the 1980 and 1984 amendments to RCRA (see Chapter 2). The major provisions of the HWA were taken directly from Subtitles C (*Hazardous Waste Management*) and I (*Regulation of Underground Storage Tanks*) of RCRA.

On January 11, 1985, New Mexico received authorization from the EPA to administer the base federal hazardous waste program, effective January 25, 1985. Additional authorizations that expanded the scope of the initial authorization were granted by the EPA and became effective on April 10, 1990; July 25, 1990; December 4, 1992; September 23, 1994; and January 2, 1996.

The New Mexico Environmental Improvement Board (EIB) adopted amendments to the New Mexico Hazardous Waste Management Regulations in 1994 and 1995. The changes updated the regulations to be consistent with changes to the federal regulations.

On January 2, 1996, the EPA provided an additional Final Authorization of State Hazardous Waste Management Program Revisions in the State of New Mexico. With this authorization the state is provided regulatory authority to implement the 1984 Hazardous and Solid Waste Amendments. The EPA published this final authorization in accordance with the requirements of 40 CFR 271.21(B)(3). With this authorization the EPA determined that the revisions to the New Mexico hazardous waste program met the requirements of Section 3006(b) of RCRA by demonstrating that the state program was equivalent to and consistent with the federal program, and that the state program provided adequate enforcement authority to implement the revised Hazardous and Solid Waste Amendments (HSWA) authority under RCRA.

Section 74-4-4.E of the HWA allows the EIB to adopt federal hazardous waste management regulations by reference after public notice and public hearing. On January 11, 1991, New Mexico adopted the entire body of 40 CFR Parts 260 through 266 and Parts 268 through 270 of the EPA's regulations implementing Subtitle C with only a few substitutions and minor exceptions. Table 25-1 shows the correspondence

between the federal and state implementing regulations. On July 11, 1990, the EPA published its acceptance of New Mexico's revised hazardous waste program, effective July 25, 1990. This authorization allows New Mexico to regulate the hazardous constituents of mixed waste under the revised HWA. The only exception to this authorization are regulatory changes made by the EPA subsequent to the authorization. Therefore, this authorization allows the state to regulate the hazardous constituents of the mixed waste to be sent to the WIPP except for changes in the regulations that have been made by the EPA but have not yet received EPA's authorization in the state program.

On July 23, 1992, New Mexico submitted an application for additional program approvals. The EPA published an immediate final rule on October 5, 1992, in which the decision was made to grant final authorization to New Mexico for the additional program modifications. The final authorization became effective on December 4, 1992.

TABLE 25-1. Correspondence Between the Federal Regulations Implementing the Resource Conservation and Recovery Act (RCRA) and the State Regulations Implementing the New Mexico Hazardous Waste Act)

Implementing Regulations under RCRA	Hazardous Waste Management Regulations (HWMRs) under HWA/20 NMAC 4.1	Adoptions, Modifications, and Exceptions	BECR Sections
40 CFR Part 260	Section 101	Adopts Part 260 into Subpart I by reference	----
	Section 102	Modifies and adds several definitions; omits (from Subpart I) Sections 260.1(b)(6), 260.20 260.22, 260.30, 260.31, 260.32 and 260.33; the section also provides NMED's 24-hour emergency-response telephone number	----
40 CFR Part 261	Section 200	Adopts Part 261 into Subpart II by reference	----
40 CFR Part 262	Section 300	Adopts Part 262 into Subpart III by reference	Section 25.2.2
	Section 301	omits (from Subpart III) Sections 262.51-57	

Implementing Regulations under RCRA	Hazardous Waste Management Regulations (HWMRs) under HWA/20 NMAC 4.1	Adoptions, Modifications, and Exceptions	BECR Sections
40 CFR Part 263	Section 400 Section 401	Adopts Part 263 into Subpart IV by reference Omits (from Subpart IV) Section 263.20(e)	Section 25.2.3
40 CFR Part 264	Section 500 Section 501	Adopts Part 264 into Subpart V by reference Omits (from Subpart V) Sections 264.149, 264.150 and 264.301(1)	Not applicable
40 CFR Part 265	Section 600 Section 601	Adopts Part 265 into Subpart VI by reference Omits (from Subpart VI) Sections 265.149 and 265.150	Section 25.2.4
40 CFR Part 266	Section 700	Adopts Part 266 into Subpart VII by reference	Not applicable
40 CFR Part 268	Section 800	Adopts Part 268 into Subpart VIII by reference	Section 25.2.2.17
40 CFR Part 270	Section 900 Section 901	Adopts Part 270 into Subpart IX by reference. Several terms in Subpart I do not apply in Sections 270.5, 270.10(f)(2) & (3), 270.10 I (g)(1)(i), 270.11(a)(3), 270.32(c), 270.72(a)(5) and 270.72(b)(5) as adopted in Subpart IX. Adds New Mexico permitting procedures	Section 25.2.5

Implementing Regulations under RCRA	Hazardous Waste Management Regulations (HWMRs) under HWA/20 NMAC 4.1	Adoptions, Modifications, and Exceptions	BECR Sections
	Section 1101	Adopts Subpart X Requires compliance with applicable state and federal regulations,	Section 25.2.1
	Section 1102	Construction	
	Section 1103	Replaces Part 124 with Section 902 of the HWMRs	
	Section 1104	References Part 280. Required compliance with New Mexico's Underground Storage Tank Regulations	
	Section 1105	Severability	
	Section 1106	Effect of stay or invalidation of federal regulations incorporated by reference	
	Section 1107	Amendment of prior regulations	
	Section 1108	Saving clause	
	Section 1109	Materials incorporated by reference into the regulations may be viewed at the New Mexico Hazardous and Radioactive Materials Bureau	

The state's Hazardous Waste Management Regulations are applicable to the WIPP in three different areas. First, WIPP is a generator of hazardous waste and is thus required to comply with the RCRA requirements of 40 CFR Part 262 (20 New Mexico Administrative Code [NMAC] 4.1, Subpart III). As long as site generated hazardous wastes are sent to a permitted off-site TSD facility within 90 days, no permit is required for the accumulation and storage of hazardous wastes. Second, when WIPP receives waste from the generator sites, WIPP will be responsible for subcontracting the TRU

waste transporter. This activity will be regulated under the transporter requirements of 40 CFR Part 263 (Part IV of the HWMRs). Third, WIPP will be a disposal and storage facility for TRU mixed waste, which mandates that WIPP receive a RCRA operating permit. The permit for the disposal phase will be received from the NMED.

After New Mexico received authorization from the EPA to regulate mixed waste in July 1990, the NMED informed WIPP that the RCRA Part A permit application was due on January 22, 1991, with the Part B permit application due on February 28, 1991. WIPP submitted its Part A and Part B permit applications to the NMED and to Region VI of the EPA in January and February 1991. Since then, several revisions of the permit application have been submitted to the regulatory agencies to provide additional information required and to inform the agencies of changes.

The WIPP submitted a RCRA Part B permit application to the NMED in February 1991. The application was revised twice between 1991 and 1993 to detail the test phase. A draft permit was issued by the NMED in August 1993. In October l993, the DOE made a decision not to conduct tests with TRU and TRU mixed waste at the WIPP site. Instead, the DOE implemented an accelerated regulatory program, that focused on activities directly relevant to a demonstration of compliance with long-term disposal regulations. In September 1994 the NMED Secretary remanded the draft permit back to the Hazardous and Radioactive Materials Bureau for reconsideration based on DOE's changes.

In May l995, the DOE submitted a revised RCRA Part B permit application for the disposal of TRU and TRU mixed waste at the WIPP. A request for additional information was received from the NMED in November 1995. The requested information was submitted in phases throughout the months of December l995 and January 1996. The NMED issued an NOD in March 1996. The DOE responded with the final revision in April 1996.

The NMAC (20 NMAC 4.1) permitting procedures contained in Subpart IX, Section 901, and provisions contained in §§ 1101 through 1109 are not contained in the federal regulations and are additional requirements to those found in the federal regulations. Revisions that have changed since the hazardous waste regulations were codified include the requirements contained in § 1104, the provision that any reference to 40 CFR Part 280 is to be construed to mean compliance with the requirements of the New Mexico Underground Storage Tank Regulations (USTR). Furthermore, since the New Mexico USTRs differ from the federal regulations specified in 40 CFR Part 280, these state regulations are also discussed in detail in this chapter (see Section 25.2.7). The UST section includes the results of the environmental compliance assessment that was performed for the UST program at WIPP.

25.2 Compliance Status of Regulatory Requirements

There are two requirements contained in Subpart X of 20 NMAC 4.1 that do not have direct counterparts in the federal regulations. Section 25.2.1 discusses one requirement from the New Mexico regulations that is unique and is not in the federal regulation addressing state implementation programs. It also includes a discussion of the New Mexico USTR requirements and their compliance status at WIPP.

25.2.1 Compliance With the Hazardous Waste Regulatory Requirement

The New Mexico requirement pertaining to hazardous waste management that differs from the federal regulations is summarized in Table 25-2, along with a summary of WIPP's compliance status. Additional information is presented in the text.

TABLE 25-2. New Mexico Hazardous Waste Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
New Mexico Hazardous Waste Management Regulations (20 NMAC 4.1)		
20 NMAC 4.1 Subpart X, § 1101	Compliance with other regulations	**ACHIEVED** See other chapters in this report [Section 25.2.1.1]

25.2.1.1 Compliance With Other Regulations, 20 NMAC 4.1, § 1101

> *Compliance with the HWMRs does not relieve a person of the obligation to comply with other applicable state and federal regulations.*

Compliance with the other federal and state regulations that apply to WIPP is discussed in the other chapters of this BECR.

25.2.2 Compliance with Standards Applicable to Generators of Hazardous Waste (20 NMAC 4.1, Subpart III, § 300)

Table 25-3 summarizes the applicable regulatory requirements for hazardous waste generators under Subpart III of 20 NMAC 4.1, which corresponds to the federal implementing regulations of 40 CFR Part 262. Because New Mexico adopts the federal implementing regulations by reference, the citations given in this table are from the federal regulations (40 CFR Part 262). The compliance status of the WIPP to each

requirement of Subpart III is summarized in Table 25-3, and the text provides additional compliance status information.

TABLE 25-3. New Mexico Hazardous Waste Management Regulations (HWMRs) for Hazardous Waste Generators - Compliance Status

Citation	Requirement	Compliance Status
40 CFR 262.11 (20 NMAC 4.1, § 300)	Hazardous waste determination	**UP TO DATE** Addressed in WID procedures and plans [Section 25.2.2.1]
40 CFR 262.12 (20 NMAC 4.1, § 300)	EPA identification number	**ACHIEVED** NM 4890139088 [Section 25.2.2.2]
40 CFR 262.20 (20 NMAC 4.1, § 300)	General Requirements (manifest requirements)	**UP TO DATE** Addressed in WID plans and procedures [Section 25.2.2.3]
40 CFR 262.21 (20 NMAC 4.1, § 300)	Acquisition of manifests	**UP TO DATE** State-specific or uniform manifest used [Section 25.2.2.4]
40 CFR 262.22 (20 NMAC 4.1, § 300)	Number of copies	**UP TO DATE** Uniform manifest [Section 25.2.2.5]
40 CFR 262.23 (20 NMAC 4.1, § 300)	Use of the manifest	**UP TO DATE** Addressed in WID procedures and plans [Section 25.2.2.6]

Citation	Requirement	Compliance Status
40 CFR 262.30 (and 49 CFR Parts 173, 178, and 179) (20 NMAC 4.1, § 300)	DOT packaging requirements	**UP TO DATE** Addressed in WID procedures [Section 25.2.2.7]
40 CFR 262.31 (and 49 CFR Part 172) (20 NMAC 4.1, § 300)	Labeling requirements	**UP TO DATE** Addressed in WID procedures [Section 25.2.2.8]
40 CFR 262.32 (and 49 CFR Part 172) (20 NMAC 4.1, § 300)	Marking requirements	**UP TO DATE** Addressed in WID procedures [Section 25.2.2.9]
40 CFR 262.33 (and 49 CFR Part 172) (20 NMAC 4.1, § 300)	Placarding requirements	**UP TO DATE** Addressed in WID procedures [Section 25.2.2.10]
40 CFR 262.34(a) (20 NMAC 4.1, § 300)	Accumulation time	**ACHIEVED** Addressed in WID procedures and plans [Section 25.2.2.11]
40 CFR 262.34(a)(1)(i) (20 NMAC 4.1, § 300)	Compliance with Subpart I of 40 CFR Part 265 for waste placed in containers	**UP TO DATE** Addressed in WID procedures [Section 25.2.2.12]
40 CFR 262.34(a)(1)(ii) (20 NMAC 4.1, § 300)	Accumulation of hazardous wastes in tanks	**NOT APPLICABLE** Hazardous waste is not accumulated in tanks at WIPP [Section 25.2.2.13]

Citation	Requirement	Compliance Status
40 CFR 262.34(a)(1)(iii) (20 NMAC 4.1, § 300)	Compliance with Subpart W of 40 CFR Part 265 for wastes placed on drip pads	**NOT APPLICABLE** No drip pads are used at WIPP [Section 25.2.2.14]
40 CFR 262.34(a)(2) (20 NMAC 4.1, § 300)	Marking each container with the date of initial accumulation of waste	**UP TO DATE** Addressed in WID procedures and plans [Section 25.2.2.15]
40 CFR 262.34(a)(3) (20 NMAC 4.1, § 300)	Marking each container as hazardous waste	**UP TO DATE** Addressed in WID procedures and plans [Section 25.2.2.16]
40 CFR 262.34(a)(4) (20 NMAC 4.1, § 300)	Compliance with Subpart C of 40 CFR 265 for preparedness and prevention Compliance with Subpart D of 40 CFR Part 265 for contingency plans and emergency procedures Compliance with 40 CFR 265.16 regarding personnel training Compliance with 40 CFR 268.7(a)(4) regarding a waste analysis plan for prohibited waste under the land disposal restrictions (LDRs)	**UP TO DATE** *WIPP Contingency Plan* **UP TO DATE** *WIPP Contingency Plan* **UP TO DATE** Formal personnel training **NOT APPLICABLE** No treatment or land disposal at WIPP for WIPP-generated wastes [Section 25.2.2.17]
40 CFR 262.34(b) (20 NMAC 4.1, § 300)	Extension of the 90-day storage period due to unforeseen, temporary, and uncontrollable circumstances	**UP TO DATE** Procedures in place if an extension of time becomes necessary. [Section 25.2.2.18]

Citation	Requirement	Compliance Status
40 CFR 262.34(c)(1) (20 NMAC 4.1, § 300)	Restrictions and requirements for satellite accumulation areas (SAAs), including: • Limit of 55 gallons of hazardous or 1 quart of acutely hazardous waste (listed in 40 CFR 261.33 [e]) at or near point of generation	**UP TO DATE** WID procedures in place governing the management of SAAs at WIPP [Section 25.2.2.19]
40 CFR 262.34(c)(1)(i) (20 NMAC 4.1, § 300)	• Compliance with 40 CFR 265.171, *Condition of Containers* • Compliance with 40 CFR 265.172, *Compatibility of Waste with Container* • Compliance with 40 CFR 265.173(a) pertaining to keeping hazardous waste containers closed during storage	**UP TO DATE** Addressed in WID procedures and plans [Section 25.2.2.20]
40 CFR 262.34(c)(1)(ii) (20 NMAC 4.1, § 300)	Labeling of container as "hazardous waste"	**UP TO DATE** Addressed in WID procedures and plans [Section 25.2.2.21]
40 CFR 262.34(c)(2) (20 NMAC 4.1, § 300)	Management of waste exceeding the 55-gallon (hazardous) or 1-quart (acutely hazardous) waste limit, including required compliance within 3 days and marking container(s) containing the excess waste with the date on which excess waste began accumulating	**UP TO DATE** Addressed in WID procedures and plans [Section 25.2.2.22]
40 CFR 262.40 (20 NMAC 4.1, § 300)	Record-keeping requirements	**UP TO DATE** Addressed in WID procedures [Section 25.2.2.23]

Citation	Requirement	Compliance Status
40 CFR 262.41 (20 NMAC 4.1, § 300)	Generator-biennial report	**UP TO DATE** Biennial report submitted in February 1996 with revisions submitted in April 1996 [Section 25.2.2.24]
40 CFR 262.42 (20 NMAC 4.1, § 300)	Exception reporting if copy of manifest is not returned to the generator within the specified period of time	**UP TO DATE** No exception reporting required to date [Section 25.2.2.25]
40 CFR 262.43 (20 NMAC 4.1, § 300)	Additional reporting	**NOT APPLICABLE** No additional reports requested [Section 25.2.2.26]
40 CFR 262.44 (20 NMAC 4.1, § 300)	Special requirements for generators of between 100 and 1,000 kg/mo	**NOT APPLICABLE** WIPP produces in excess of 1,000 kg/mo [Section 25.2.2.27]

25.2.2.1 Hazardous Waste Determination, 40 CFR 262.11 (20 NMAC 4.1, § 300)

> *The generator of solid waste is required to determine whether the waste is hazardous as defined under 40 CFR Parts 260 and 261.*

Nonradioactive hazardous waste is currently generated from maintenance, construction, and laboratory operations at WIPP. This waste is characterized through process knowledge and/or waste sampling and analysis. Desktop instruction to meet these requirements have been implemented.

25.2.2.2 EPA Identification Number, 40 CFR 262.12 (20 NMAC 4.1, § 300)

> *An EPA identification number is required for each generator of hazardous waste.*

The DOE has obtained a generator identification number for the WIPP. The EPA identification number for the WIPP is *NM4890139088.*

25.2.2.3 Manifest Requirements, 40 CFR 262.20 (20 NMAC 4.1, § 300)

> *Compliance with the manifest requirements is mandatory for shipping hazardous waste off site. One of the requirements is that the generator have a waste minimization program in place.*

Nonradioactive hazardous waste generated at the WIPP is manifested prior to shipment to an off-site disposal facility. Records are maintained in the operating files for five years. Procedures are in place that address these requirements. The WID is responsible for implementing these procedures. A waste minimization program is in place.

25.2.2.4 Acquisition of Manifests, 40 CFR 262.21 (20 NMAC 4.1, § 300)

> *The generator must obtain a manifest from the appropriate source.*

The WIPP obtains a manifest from consignment states which require a manifest. If the consignment state does not require a specific manifest, a uniform hazardous waste manifest is used. The WIPP uses the current revision of EPA form 8700-22.

25.2.2.5 Number of Copies, 40 CFR 262.22 (20 NMAC 4.1, § 300)

> *The manifest shall consist of sufficient copies to provide two for the generator and one each for the transporter and owner or operator of the facility.*

The manifests used by WIPP contain the required number of copies to fulfill this requirement. The manifest form currently used contains six copies.

25.2.2.6 Use of the Manifest, 40 CFR 262.23 (20 NMAC 4.1, § 300)

> *The generator must sign the manifest certification by hand, obtain the handwritten signature of the initial transporter and date of acceptance on the manifest, and retain one copy. The generator must give the transporter the remaining copies of the manifest. Other requirements of this regulation pertain to shipments by water, rail, or to a designated facility in an authorized state which has not yet obtained authorization to regulate that particular waste as hazardous.*

WID procedures are in place that address compliance with applicable parts of this regulation. Hazardous waste generated at WIPP is sent to TSDFs in states with authorized hazardous-waste programs.

25.2.2.7 Packaging Requirements, 40 CFR 262.30 (20 NMAC 4.1, § 300)

> *EPA and DOT packaging requirements must be met before shipping hazardous waste off site.*

A WID procedure is in place that addresses these requirements. WID is responsible for proper packaging of all hazardous waste shipped from the site.

25.2.2.8 Labeling Requirements, 40 CFR 262.31 (20 NMAC 4.1, § 300)

> *EPA and DOT labeling requirements must be met before shipping hazardous waste off site.*

A WID procedure is in place that addresses these requirements.

25.2.2.9 Marking Requirements, 40 CFR 262.32 (20 NMAC 4.1, § 300)

> *EPA and DOT marking requirements must be met before shipping hazardous waste off site.*

A WID procedure is in place that addresses these requirements.

25.2.2.10 Placarding Requirements, 40 CFR 262.33 (20 NMAC 4.1, § 300)

> *EPA and DOT placarding requirements must be met before shipping hazardous waste off site.*

A WID procedure is in place that addresses these requirements.

25.2.2.11 Accumulation Time, 40 CFR 262.34(a) (20 NMAC 4.1, § 300)

> *Accumulation time for large quantity generators is limited to 90-day storage of hazardous wastes for a non-permitted facility.*

Waste is accumulated in containers in satellite accumulation areas (SAAs) and subsequently moved to the Hazardous Waste Staging Area at WIPP. At this point, the 90-day storage requirement comes into effect. WID procedures are in place that address this requirement for hazardous wastes generated at WIPP and shipped off site to an approved TSDF. Records that document compliance with the 90-day storage requirement are maintained at WIPP.

25.2.2.12 Compliance with Subpart I of 40 CFR Part 265, 40 CFR 262.34(a)(1)(i) (20 NMAC 4.1, § 300)

Compliance with Subpart I of 40 CFR Part 265 is required for waste placed in containers. The requirements of this subpart pertain to the condition of containers, compatibility of waste with the containers, closing containers during storage, inspections, the location of containers holding ignitable or reactive waste, and the segregation of incompatible wastes.

WID procedures that address compliance with Subpart I of 40 CFR Part 265 (See also Sections 25.2.4.54 through 25.2.4.59) are in place. These procedures provide for weekly inspections of containers and segregation of incompatible wastes. The hazardous waste storage area is located more than 50 feet from the WIPP property line for compliance with the requirements for ignitable or reactive waste (40 CFR 265.176).

25.2.2.13 Accumulation of Hazardous Wastes, 40 CFR 262.34(a)(1)(ii) (20 NMAC 4.1 § 300)

Except as provided in paragraphs (d), (e), and (f) of this section, a generator may accumulate hazardous waste on site for 90 days or less without a permit or without having interim status, provided that the waste is placed in tanks, and the generator complies with Subpart J of 40 CFR Part 265.0, except § 265.197(c) and § 265.200.

Hazardous waste is not accumulated in tank systems at WIPP; therefore, this regulation does not apply.

25.2.2.14 Compliance with Subpart W of 40 CFR Part 265, 40 CFR 262.34(a)(1)(iii) (20 NMAC 4.1, § 300)

Compliance with Subpart W of 40 CFR Part 265 for wastes placed on drip pads is required.

No drip pads are required at WIPP for hazardous waste accumulation. Therefore, these requirements do not apply.

25.2.2.15 Marking with Date of Initial Accumulation, 40 CFR 262.34(a)(2) (20 NMAC 4.1, § 300)

Each container of hazardous waste must be clearly marked with the date of accumulation of the waste, and the label must be visible for inspection.

The accumulation date is placed on the container when it enters the temporary storage area to await transport off site.

25.2.2.16 Marking as Hazardous Waste, 40 CFR 262.34(a)(3) (20 NMAC 4.1, § 300)

Each hazardous waste container in an SAA must be labeled or marked as hazardous waste.

Each hazardous waste container in each SAA is clearly labeled as hazardous waste as described in WID procedures. Weekly inspections are performed to verify proper labeling of containers.

25.2.2.17 Compliance with Emergency Response, Training, and Waste Analysis Plan Requirements, 40 CFR 262.34(a)(4) (20 NMAC 4.1, § 300)

Compliance with Subparts C (preparedness and prevention) and D (contingency plans and emergency procedures) of 40 CFR Part 265 and with Sections 40 CFR 265.16 (personnel training) and 268.7(a)(4) (waste analysis plan for prohibited waste under the land disposal restrictions) is required.

40 CFR Part 265, Subpart C, Preparedness and Prevention: WIPP is maintained and operated to minimize the possibility of fire, explosions, or any unplanned release of hazardous waste to the environment. Inspections of waste handling areas and equipment are conducted periodically in accordance with WID procedures. Any corrective actions needed are initiated via spill management procedures and action requests (ARs).

WID has prepared a contingency plan which provides a list of emergency equipment at WIPP, along with a description and statement of capabilities of the equipment and the cognizant organization responsible for ensuring that the equipment is available and operable.

The following communication and alarm systems are available at the WIPP site: two-way communication by the public address system and its intercom phones and paging channels, an intra-plant telephone system, mine phones, local and facility wide alarm systems, pagers and plectrons, and portable two-way radios. Inspection procedures are in place for the communication and alarm systems and the fire protection equipment. These procedures include provisions for testing and maintenance to ensure that equipment will be operable in an emergency. Spill control and decontamination equipment are inspected weekly, and the results are recorded on an inspection form. Adequate aisle space is provided in the hazardous waste storage area at WIPP to allow for potential emergency response activities.

The WIPP Emergency Management Section provides regional ambulance and emergency medical services. In addition, the DOE has established Memoranda of Understanding (MOU) with off-site emergency response agencies for fire fighting, medical assistance, and law enforcement. An example is the mutual aid agreement between Hobbs and the DOE that provides for mutual ambulance, medical, fire, rescue, and hazardous material response services. All outside agencies with which MOUs have been made have received copies of the *WIPP RCRA Contingency Plan* and the *WIPP Emergency Plan.*

40 CFR Part 265, Subpart D, Contingency Plan and Emergency Procedures: A contingency plan has been developed for the WIPP site and is maintained at all controlled document locations and has been provided to outside emergency response agencies. The purpose of the document is to define responsibilities, provide guidance for the coordination of activities, and minimize hazards to human health and the environment from fires, explosions, or any sudden or non-sudden release of hazardous waste or hazardous waste constituents. The *WIPP RCRA Contingency Plan* describes actions that must be taken in response to fires, explosions, or any unplanned sudden or non-sudden release of hazardous waste or hazardous waste constituents to air, soil, or water. It describes agreements with local authorities; lists names, addresses, and phone numbers of persons qualified to act as Emergency Coordinators; provides a list of emergency equipment at the facility; and includes an evacuation plan.

Copies of the *WIPP RCRA Contingency Plan* have been provided to all outside agencies with which WIPP has agreements for assistance in an emergency situation. A copy of the plan is maintained at WIPP controlled document locations. WID has the distribution list for the plan and is responsible for updating the controlled copies.

The plan will be reviewed and revised if necessary whenever applicable regulations are revised; if the plan fails in an emergency; if the facility changes in a way that materially increases the potential for fires, explosions, or releases of hazardous waste or hazardous waste constituents, or changes the response necessary in an emergency; or if the list of Emergency Coordinators or the list of emergency equipment changes.

The TRU mixed waste handling areas at the WIPP facility do not include tank storage or treatment of hazardous waste as defined and regulated by the regulations. At the WIPP facility, tanks are used to store water and petroleum fuels only. The petroleum tanks store diesel and unleaded gasoline. Underground storage tanks are subject to the New Mexico Underground Storage Tank Regulations.

A RCRA Emergency Coordinator is on site 24 hours a day, 7 days a week. The coordinator is responsible for coordinating all emergency response measures. The primary RCRA Emergency Coordinator is the on duty Facility Shift Manager (FSM). Emergency Coordinators are thoroughly familiar with the *WIPP RCRA Contingency Plan*. The plan has provisions that meet the emergency procedure requirements such as communication of an emergency situation to employees, notification of the

appropriate agency if assistance is needed, identification of hazardous materials, assessment of hazards, and notification of any incident that requires implementation of the *WIPP RCRA Contingency Plan*.

40 CFR 265.16, Personnel Training: Formal training at WIPP is conducted in accordance with a WID training procedures manual. Training includes General Employee Training (GET-19X), other classroom training, and on-the-job training. Training is conducted by certified instructors. Certification requirements are established in a WID procedure. The GET-19X course provides detailed training in such areas as communications, alarm systems, and emergency response. A WID procedure requires all personnel to attend GET-19X within 30 days of employment. WID employees must attend a refresher class annually. Other classroom training is offered for personnel in selected job categories that involve the management of hazardous waste, such as maintenance and waste operations. Annual refreshers are provided. Maintenance personnel are trained to provide repair and replacement services. Inspections are a part of job-specific training and emergency response personnel training. WIPP employees involved in managing site-generated, nonradioactive waste, or TRU mixed waste will receive the Hazardous Waste Worker course (HWW). This course provides job specific training required to safely receive, transfer, or handle waste at the facility. Review and update of the HWW topics are provided annually.

WID maintains a listing of all hazardous waste management job titles, the names of employees assigned by job title to hazardous waste management jobs, and job descriptions that identify RCRA-related duties. Records on active and inactive personnel are kept in accordance with WID documents.

40 CFR 268.7(1)(4), Waste Analysis for Treating Prohibited Wastes in Tanks or Containers: This requirement for a waste analysis plan for the treatment of wastes prohibited from land disposal in tanks or containers is not applicable to WIPP as WIPP-generated hazardous waste is neither treated nor land disposed at this facility.

25.2.2.18 Extension of Storage Period, 40 CFR 262.34(b) (20 NMAC 4.1, § 300)

> *The 90-day storage period may be extended due to unforeseen, temporary, and uncontrollable circumstances.*

WID procedures provide instruction for the shipment of hazardous waste off site prior to the 90-day deadline. An extension of the storage period was not required during this reporting period; however, procedures exist if a request for an extension is needed.

25.2.2.19 Restrictions and Requirements, 40 CFR 262.34(c)(1) (20 NMAC 4.1, § 300)

There are a number of restrictions and requirements for satellite accumulation areas. These include the limit of 55 gallons of hazardous or 1 quart of acutely hazardous waste (listed in 40 CFR 261.33[e])] and the requirement that the satellite accumulation area be located at or near the point of generation of the waste.

WID procedures are in place and weekly inspections are conducted to verify that the 55-gallon limit per SAA is not exceeded. None of the SAAs have a capacity that exceeds 55 gallons, and no acutely hazardous waste is generated at WIPP. The SAAs are located at or near the points of generation of the hazardous waste. In addition, WID procedures define the requirements for placing waste in an SAA. These procedures define the responsibilities of the waste generator.

25.2.2.20 Compliance with 40 CFR 265.171, 265.172, and 165.173(a), 40 CFR 262.34(c)(1)(i) (20 NMAC 4.1, § 300)

These requirements for hazardous waste generators from 40 CFR Part 265 pertain to the condition of the containers (265.171), compatibility of the waste with the container (265.172), and the necessity to keep the containers closed when not actually adding waste to or removing it from the containers (265.173[1]). In addition, a container holding hazardous waste must not be opened, handled, or stored in a manner that could rupture the container or cause it to leak.

WID procedures are in place to ensure that containers used to hold hazardous waste in SAAs are in good condition. If a container is found to be damaged, it is repaired, or the waste is removed and transferred to another container. All SAA inspection reports on file at WIPP indicate that the requirement for containers holding hazardous waste to be kept in good condition is met. Weekly inspections confirm that this requirement is being met. No special liners are used in the waste containers. Procedures are in place that address waste/container compatibility and the requirement that containers be closed except when waste is being added or removed. Inspections are conducted on a regular basis to ensure compliance with these regulations for containers.

A WID procedure addresses the requirement that containers not be opened, handled, or stored in a manner that could cause the container to rupture or leak by requiring that containers be inspected before and after transportation from the SAA to the staging area. (See also Sections 25.2.4.54 through 25.2.4.59).

25.2.2.21 Labeling of Container as "Hazardous Waste," 40 CFR 262.34(c)(1)(ii) (20 NMAC 4.1, § 300)

Labeling of each hazardous waste container as "hazardous waste" is required.

WID procedures are in place, and weekly inspections are conducted to verify that each container of hazardous waste is clearly labeled as hazardous waste.

25.2.2.22 Management of Waste, 40 CFR 262.34(c)(2) (20 NMAC 4.1, § 300)

If waste accumulates in one of the SAAs in excess of the 55-gallon or 1-quart limit, the container(s) containing the excess waste must be marked with the date on which excess waste began accumulating, and compliance with the 55-gallon or 1-quart limit must be restored within 3 days.

WID procedures that address the 55-gallon limit in the SAAs are in place. No acutely hazardous wastes are generated at WIPP. WID personnel verify that no SAA waste container is overfilled and that any waste stored at an SAA in excess of the 55-gallon limit is removed within three days in accordance with the regulations.

25.2.2.23 Record-keeping Requirements, 40 CFR 262.40 (20 NMAC 4.1, § 300)

Manifests, test results, waste analyses, and reports must be kept on site for at least three years.

WID procedures that address these requirements are in place. Required records are maintained by WID on site for a minimum of five years after which they may be retained onsite until closure or microfiched and stored indefinitely. Although 20 NMAC 4.1 § 300 requires that manifests and their associated records be maintained for only three years, WID procedures dictate that manifest records will be maintained onsite for five years. Waste analyses and reports supporting Land Disposal Restrictions (LDR) must be kept on file five years (40 CFR 268.7[a][7]). The five-year retention period is designed to assure that manifest and associated LDR records are kept together, and that LDR records are retained onsite the required five year period.

25.2.2.24 Generator-Biennial Report, 40 CFR 262.41 (20 NMAC 4.1, § 300)

Each generator of hazardous waste that ships the waste off site to an approved TSDF must file a report to the EPA by March 1 of every even-numbered year, including a description of the results of waste minimization efforts.

WID procedures have been prepared to respond to these requirements. The results of waste-minimization activities are included in the hazardous-waste generator biennial report. The most recent report was submitted in February 1996. Revisions to the report requested by NMED were submitted in April 1996.

25.2.2.25 Exception Reporting, 40 CFR 262.42 (20 NMAC 4.1, § 300)

> *Exception reporting is required if a copy of the manifest is not returned to the generator within 35 days of the date of acceptance of the hazardous waste by the transporter.*

A WID procedure addresses exception reporting. At this time, no exception reporting has been required.

25.2.2.26 Additional Reporting, 40 CFR 262.43 (20 NMAC 4.1, § 300)

> *The Administrator, as he or she deems necessary, may require generators to furnish additional reports concerning the quantities and disposition of wastes identified or listed in 40 CFR Part 261.0.*

No additional reports have been requested to date.

25.2.2.27 Special Requirements for Generators of Between 100 and 1,000 kg/mo, 40 CFR 262.44 (20 NMAC 4.1, § 300)

> *A generator of greater than 100 kilograms but less than 1000 kilograms of hazardous waste in a calendar month is subject to only ...record-keeping; ...exception reporting; and ...additional reporting*

The WIPP site is currently categorized as a large quantity generator (over 1,000 kilograms in any calendar month); therefore, this regulation is not applicable.

25.2.3 Compliance with Standards Applicable to Transporters of Hazardous Waste, 40 CFR Part 263 (20 NMAC 4.1, § 400)

The standards and requirements specified under 40 CFR Part 263 are currently not applicable to WIPP because of DOE's decision to eliminate testing of TRU mixed wastes at WIPP. However, the requirements will become applicable when the generator sites begin shipping TRU mixed wastes to WIPP because wastes will be transported via a trucking and/or rail company. The DOE and WID conduct assessments or audits to review WIPP compliance with requirements of applicable federal regulations, DOE Orders, and DOE Albuquerque Operations Office (AL) Directives that pertain to hazardous materials transportation activities. The DOE

conducted an assessment January 22-26, 1996, and WID conducted a quality assurance audit January 4-12, 1996.

A summary of the requirements for transporters of hazardous or mixed wastes and the compliance status of each requirement is described in Table 25-4. Additional information is provided in the text.

TABLE 25-4. New Mexico Hazardous Waste Management Regulations for Transporters of Hazardous/Mixed Waste, 40 CFR Part 263 - Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 263.10(a) (20 NMAC 4.1, § 400)	Compliance with DOT regulations	**UP TO DATE** CAST Transportation, Inc. Transportation Management Plan June 22, 1995 [Section 25.2.3.1]
40 CFR 263.11 (20 NMAC 4.1, § 400)	EPA identification number	**ACHIEVED** COD 980953269 [Section 25.2.3.2]
40 CFR 263.20-263.22 (20 NMAC 4.1, § 400)	Compliance with the manifest system and record-keeping	**UP TO DATE** CAST Transportation, Inc. Transportation Management Plan [Section 25.2.3.3]
40 CFR 263.30 (20 NMAC 4.1, § 400)	Immediate action after hazardous waste discharges	**NOT APPLICABLE** CAST Transportation, Inc. Standard Emergency Response on Comprehensive Contingency Plan [Section 25.2.3.4]
40 CFR 263.31 (20 NMAC 4.1, § 400)	Discharge cleanup	**NOT APPLICABLE** No actual waste has been emplaced at WIPP [Section 25.2.3.5]

25.2.3.1 Compliance with Department of Transportation (DOT) Regulations, 40 CFR 263.10(a) (20 NMAC 4.1, § 400)

Transporters of hazardous/mixed waste must comply with all applicable DOT regulations.

Cast Transportation, Inc. has been contracted to transport TRU waste to WIPP from the generator sites. The Cast Transportation Management Plan (dated June 22, 1995) incorporates the applicable DOT regulations from the Title 49 series of the Code of Federal Regulations.

Any transporter hired to ship TRU and TRU mixed waste from the generator sites to WIPP must comply with the DOT regulations.

25.2.3.2 EPA Identification Number, 40 CFR 263.11 (20 NMAC 4.1, § 400)

The transporter must have an EPA identification number from the EPA Administrator.

Cast Transportation Inc. has been contracted to transport TRU and TRU mixed waste from the generator sites to WIPP. Their EPA identification number is COD 980953269. Any transporter hired to ship TRU and TRU mixed waste to WIPP must have an EPA identification number.

25.2.3.3 Compliance with the Manifest System and with Record-keeping Requirements, 40 CFR 263.20-263.22 (20 NMAC 4.1, § 400)

The transporter must comply with all relevant manifest and record-keeping requirements.

The *Cast Transportation Management Plan* indicates that it will comply with requirements of the manifest system. Any transporter hired to ship TRU and TRU mixed waste to WIPP must comply with these requirements.

25.2.3.4 Immediate Action after Hazardous Waste Discharges, 40 CFR 263.30 (20 NMAC 4.1, § 400)

The transporter will take appropriate immediate action in the event of a discharge of hazardous waste (or hazardous constituents) during transportation.

The Cast Transportation Management Plan addresses actions that will be undertaken to protect human health and the environment. Any transporter that ships TRU and TRU mixed waste to WIPP must have these capabilities. To date, no waste has been shipped to WIPP and no waste discharges have occurred.

25.2.3.5 Discharge Cleanup, 40 CFR 263.31 (20 NMAC 4.1, § 400)

> *A transporter must clean up any hazardous waste discharge that occurs during transportation or must take any action(s) required by federal, state, or local officials to render the discharge nonhazardous to human health and the environment.*

In the event of a hazardous waste constituent discharge during transportation, cleanup activities will be undertaken, as required. Any transporter of TRU and TRU mixed waste to WIPP must be capable of ensuring adequate cleanup of any hazardous or mixed waste released to the environment during a transportation incident or accident. To date, no waste has been shipped to WIPP, and no waste discharges have occurred. (See also Section 25.2.3.4).

25.2.4 Compliance With the Regulatory Requirements for Interim-Status TSDFs, 40 CFR Part 265 (20 NMAC 4.1, §§ 600 and 601)

The WIPP is an interim-status facility. All applicable requirements for a TSDF are described in this section.

Table 25-5 summarizes each of the applicable requirements under 40 CFR Part 265 and provides the compliance status of each. The text that follows the table provides additional detail.

TABLE 25-5. NMACs for Interim-Status TSDFs, 40 CFR Part 265 - Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 265.10 (20 NMAC 4.1, § 600)	Applicability	See Section 25.2.4 and Sections 25.2.4.2 through 25.2.4.9
40 CFR 265.11 (20 NMAC 4.1, § 600)	EPA identification number	**ACHIEVED** NM4890139088 [Section 25.2.4.2]
40 CFR 265.12 (20 NMAC 4.1, § 600)	Required notices to off-site source(s)	**NOT APPLICABLE** None required to date [Section 25.2.4.3]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 265.13 (20 NMAC 4.1, § 600)	General waste analysis	**UP TO DATE** *WIPP Waste Analysis Plan; Transuranic Waste Characterization Sampling and Analysis Methods Manual; Transuranic Waste Characterization Quality Assurance Program Plan* [Section 25.2.4.4]
40 CFR 265.14 (20 NMAC 4.1, § 600)	Security	**ACHIEVED** Eight-foot-high chain-link fence, 24-hour surveillance system, and signs in Spanish and English posted at 50-foot intervals [Section 25.2.4.5]
40 CFR 265.15 (20 NMAC 4.1, § 600)	General inspection requirements	**UP TO DATE** Inspection procedures; inspection logs [Section 25.2.4.6]
40 CFR 265.16 (20 NMAC 4.1, § 600)	Personnel training	**UP TO DATE** Procedures, manuals, and employee records [Section 25.2.4.7]
40 CFR 265.17 (20 NMAC 4.1, § 600)	General requirements for ignitable, reactive, or incompatible wastes	**UP TO DATE** Part B permit application/*WIPP Waste Acceptance Criteria*; no incompatible wastes identified [Section 25.2.4.8]
40 CFR 265.18 (20 NMAC 4.1, § 600)	Location standards	**NOT APPLICABLE** Allows WIPP to be used as a TSDF [Section 25.2.4.9]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 265.31 (20 NMAC 4.1, § 600)	Maintenance and operation of facility	**UP TO DATE** *WIPP Waste Acceptance Criteria* and *WID Contingency Plan* [Section 25.2.4.10]
40 CFR 265.32 (20 NMAC 4.1, § 600)	Required equipment	**UP TO DATE** Addressed in WID procedures [Section 25.2.4.11]
40 CFR 265.33 (20 NMAC 4.1, § 600)	Testing and maintenance of equipment	**UP TO DATE** Addressed in WID procedures [Section 25.2.4.12]
40 CFR 265.34 (20 NMAC 4.1, § 600)	Access to communications or alarm system	**UP TO DATE** Public address system, intercom, phones, telephones, alarm systems, pagers and plectrons, portable two-way radios [Section 25.2.4.13]
40 CFR 265.35 (20 NMAC 4.1, § 600)	Required aisle space	**UP TO DATE** Procedures in place to ensure adequate aisle space when waste is brought to WIPP [Section 25.2.4.14]
40 CFR 265.37 (20 NMAC 4.1, § 600)	Arrangements with local authorities	**ACHIEVED** MOUs in place with local authorities [Section 25.2.4.15]
40 CFR 265.51 (20 NMAC 4.1, § 600)	Purpose and implementation of the contingency plan	**ACHIEVED** *WIPP Contingency Plan* in place [Section 25.2.4.16]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 265.52 (20 NMAC 4.1, § 600)	Content of the contingency plan	**ACHIEVED** *WIPP Contingency Plan* [Section 25.2.4.17]
40 CFR 265.53 (20 NMAC 4.1, § 600)	Copies of contingency plan	**ACHIEVED** Copy provided to each outside agency with an agreement to provide emergency assistance to WIPP [Section 25.2.4.18]
40 CFR 265.54 (20 NMAC 4.1, § 600)	Amendment of contingency plan	**UP TO DATE** *WIPP Contingency Plan* [Section 25.2.4.19]
40 CFR 265.55 (20 NMAC 4.1, § 600)	Emergency Coordinator	**ACHIEVED** Facility Shift Manager [Section 25.2.4.20]
40 CFR 265.56 (20 NMAC 4.1, § 600)	Emergency procedures	**UP TO DATE** *WIPP Contingency Plan* [Section 25.2.4.21]
40 CFR 265.71 (20 NMAC 4.1, § 600)	Use of manifest system	**NOT APPLICABLE** WID procedures; no shipments to date [Section 25.2.4.22]
40 CFR 265.72 (20 NMAC 4.1, § 600)	Manifest discrepancies	**NOT APPLICABLE** WID procedures; no shipments to date [Section 25.2.4.23]
40 CFR 265.73 (20 NMAC 4.1, § 600)	Operating record	**UP TO DATE** WID procedures [Section 25.2.4.24]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 265.74 (20 NMAC 4.1, § 600)	Availability, retention, and disposition of records	**UP TO DATE** WID procedures [Section 25.2.4.25]
40 CFR 265.75 (20 NMAC 4.1, § 600)	TSDF biennial report	**NOT APPLICABLE** Addressed in WID procedure [Section 25.2.4.26]
40 CFR 265.76 (20 NMAC 4.1, § 600)	Unmanifested waste report	**NOT APPLICABLE** No waste shipments to date [Section 25.2.4.27]
40 CFR 265.77 (20 NMAC 4.1, § 600)	Additional reports	**NOT APPLICABLE** No additional reporting to date [Section 25.2.4.28]
40 CFR 265.90 (20 NMAC 4.1, § 600)	Applicability of the ground-water monitoring system	**UP TO DATE** Ground-water monitoring plan [Section 25.2.4.29]
40 CFR 265.91 (20 NMAC 4.1, § 600)	Ground-water monitoring system	**UP TO DATE** Ground-water monitoring plan [Section 25.2.4.30]
40 CFR 265.92 (20 NMAC 4.1, § 600)	Sampling and analysis	**UP TO DATE** Ground-water monitoring plan [Section 25.2.4.31]
40 CFR 265.93 (20 NMAC 4.1, § 600)	Preparation, evaluation, and response	**UP TO DATE** Ground-water monitoring plan [Section 25.2.4.32]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 265.94 (20 NMAC 4.1, § 600)	Record-keeping and reporting	**UP TO DATE** Ground-water monitoring plan [Section 25.2.4.33]
40 CFR 265.110 (20 NMAC 4.1, § 600)	Applicability of the closure/post-closure requirements	**UP TO DATE** Disposal phase RCRA permit application [Section 25.2.4.34]
40 CFR 265.111 (20 NMAC 4.1, § 600)	Closure performance standard	**UP TO DATE** Disposal phase RCRA permit application [Section 25.2.4.35]
40 CFR 265.112 (20 NMAC 4.1, § 600)	Closure plan; amendment of plan	**UP TO DATE** Disposal phase RCRA permit application [Section 25.2.4.36]
40 CFR 265.113 (20 NMAC 4.1, § 600)	Time allowed for closure	**UP TO DATE** Disposal phase RCRA permit application [Section 25.2.4.37]
40 CFR 265.114 (20 NMAC 4.1, § 600)	Disposal or decontamination of equipment, structures, and soils	**UP TO DATE** Disposal phase RCRA permit application [Section 25.2.4.38]
40 CFR 265.115 (20 NMAC 4.1, § 600)	Certification of closure	**NOT APPLICABLE** Requirements will become applicable at the time of facility closure; addressed in WID procedures [Section 25.2.4.39]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 265.116 (20 NMAC 4.1, § 600)	Survey plat	**NOT APPLICABLE** Requirements will become applicable at the time of facility closure [Section 25.2.4.40]
40 CFR 265.117 (20 NMAC 4.1, § 600)	Postclosure care and use of property	**NOT APPLICABLE** Requirements will become applicable at the time of facility closure [Section 25.2.4.41]
40 CFR 265.118 (20 NMAC 4.1, § 600)	Postclosure plan; amendment of plan	**NOT APPLICABLE** Requirements will become applicable at the time of facility closure [Section 25.2.4.42]
40 CFR 265.119 (20 NMAC 4.1, § 600)	Postclosure notices	**NOT APPLICABLE** Requirement s will become applicable at the time of facility closure [Section 25.2.4.43]
40 CFR 265.120 (20 NMAC 4.1, § 600)	Certification of completion of postclosure care	**NOT APPLICABLE** Requirements may become applicable at the time of facility closure [Section 25.2.4.44]
40 CFR 265.142 (20 NMAC 4.1, § 600)	Cost estimate for closure	**NOT APPLICABLE** Exemption as federal facility [Section 25.2.4.45]

40 CFR 265.143 (20 NMAC 4.1, § 600)	Financial assurance for closure	**NOT APPLICABLE** Exemption as federal facility [Section 25.2.4.46]
40 CFR 265.144 (20 NMAC 4.1, § 600)	Cost estimate for postclosure care	**NOT APPLICABLE** Exemption as federal facility [Section 25.2.4.47]
40 CFR 265.145 (20 NMAC 4.1, § 600)	Financial assurance for postclosure care	**NOT APPLICABLE** Exemption as federal facility [Section 25.2.4.48]
40 CFR 265.146 (20 NMAC 4.1, § 600)	Use of a mechanism for financial assurance of both closure and postclosure care	**NOT APPLICABLE** Exemption as federal facility [Section 25.2.4.49]
40 CFR 265.147 (20 NMAC 4.1, § 600)	Liability requirements	**NOT APPLICABLE** Exemption as federal facility [Section 25.2.4.50]
40 CFR 265.148 (20 NMAC 4.1, § 600)	Incapacity of owners or operators, guarantors, or financial institutions	**NOT APPLICABLE** Exemption as federal facility [Section 25.2.4.51]
40 CFR 265.149 (20 NMAC 4.1, § 601(A))	Use of state-required mechanisms	**NOT APPLICABLE** Exemption as federal facility [Section 25.2.4.52]

40 CFR 265.150 (20 NMAC 4.1, § 601(B))	State assumption of responsibility	**NOT APPLICABLE** Omission from state regulations and exemption as federal facility [Section 25.2.4.53]
40 CFR 265.171 (20 NMAC 4.1, § 600)	Condition of containers	**UP TO DATE** Addressed in WID procedures [Section 25.2.4.54]
40 CFR 265.172 (20 NMAC 4.1, § 600)	Compatibility of waste with containers	**UP TO DATE** Addressed in WID procedures [Section 25.2.4.55]
40 CFR 265.173 (20 NMAC 4.1, § 600)	Management of containers	**UP TO DATE** Addressed in WID procedures; training [Section 25.2.4.56]
40 CFR 265.174 (20 NMAC 4.1, § 600)	Inspections	**UP TO DATE** Addressed in WID procedures [Section 25.2.4.57]
40 CFR 265.176 (20 NMAC 4.1, § 600)	Special requirements for ignitable or reactive waste	**UP TO DATE** RCRA part B permit application/*WIPP Waste Acceptance Criteria* [Section 25.2.4.58]
40 CFR 265.177 (20 NMAC 4.1, § 600)	Special requirements for incompatible wastes	**UP TO DATE** Addressed in WID procedures [Section 25.2.4.59]

40 CFR 265.190-265.445 (20 NMAC 4.1, § 600)	Tank systems; surface impoundments; waste piles; land treatment; incinerators; thermal treatment; chemical, physical, and biological treatment; underground injection; and drip pads	**NOT APPLICABLE** None of these used at WIPP [Section 25.2.4.60]
40 CFR 265.1032 (20 NMAC 4.1, § 600)	Standards (air emission) for process vents	**NOT APPLICABLE** No process vents at WIPP [Section 25.2.4.61]
40 CFR 265.1052-265.1062 (20 NMAC 4.1, § 600)	Air emission standards for equipment leaks	**NOT APPLICABLE** Listed equipment not in use at WIPP [Section 25.2.4.62]
40 CFR 265.1080 (20 NMAC 4.1, § 600)	Air emission standards for tanks, surface impoundment and containers	**NOT APPLICABLE** TRU or TRU mixed wastes exempted Containers used to store wastes are exempted [Section 25.2.4.63]

25.2.4.1 Applicability, 40 CFR 265.10 (20 NMAC 4.1 § 600)

> *The regulations in Subpart B apply to owners and operators of all hazardous waste facilities, except as § 265.1 provides otherwise.*

The portions of Subpart B applicable to the WIPP are identified in §§ 265.11 through 265.18 as discussed in Sections 25.2.4.2 through 25.2.4.9 below.

25.2.4.2 EPA Identification Number, 40 CFR 265.11 (20 NMAC 4.1, § 600)

> *Each TSDF must have an EPA identification number.*

The EPA identification number for WIPP is NM4890139088.

25.2.4.3 Required Notices, 40 CFR 265.12 (20 NMAC 4.1, § 600)

> *Notices required are notification of the Regional Administrator at least 4 weeks in advance of the date of arrival of waste from a foreign source and notification of a new owner or operator of the requirements under 40 CFR Parts 265 and 270.*

Waste destined for WIPP will originate at U.S. facilities; no foreign waste will be shipped to WIPP. Before transferring ownership or operation of the facility, the DOE and/or WID will notify the new owner or operator in writing of the requirements of this part and those of Part 270.

25.2.4.4 General Waste Analysis, 40 CFR 265.13 (20 NMAC 4.1, § 600)

> *A detailed chemical and physical analysis of a representative sample of the wastes is required before a TSDF may treat, store, or dispose of waste. The owner/operator of the TSDF must inspect and, if necessary, analyze the waste received to ensure that it matches the identity of the waste described in the accompanying manifest. The owner/operator must follow a written waste analysis plan to ensure compliance with these requirements.*

General waste analysis is addressed in the *WIPP Waste Analysis Plan* (DOE, 1996). Sampling and analysis are conducted in accordance with the *Transuranic Waste Characterization Sampling and Analysis Methods Manual* (DOE, /WIPP-91-043)). All activities are performed in accordance with the *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE, 1995y). Characterization methods consist of acceptable knowledge; visual examination (including weighing of individual items); radiography; headspace gas sampling and sampling of homogeneous waste forms.

25.2.4.5 Security, 40 CFR 265.14 (20 NMAC 4.1 § 600)

> *Security measures are required to prevent the possibility of unknowing and/or unauthorized entry by persons or livestock onto the active portion of the facility. A 24-hour surveillance system or barrier is required, and the facility must be posted.*

The WIPP is enclosed within an 8-foot-high, chain-link fence, and 24-hour surveillance is conducted by guards trained to prevent unauthorized entry onto the facility. Signs with the legend "Danger—Unauthorized Personnel Keep Out" in both Spanish and English are posted at 50-foot intervals. The perimeter fence, gates, and signs are inspected daily for evidence of tampering or structural damage in accordance with a WIPP procedure.

25.2.4.6 General Inspection Requirements, 40 CFR 265.15 (20 NMAC 4.1, § 600)

The owner/operator must inspect the facility for malfunctions, deterioration, operator errors, and discharges that cause actual or potential releases of hazardous constituents to the environment or a threat to human health. A written schedule must be developed and followed for inspecting all monitoring, safety, and emergency equipment; security devices; and operating/structural equipment needed to prevent, detect, or respond to environmental or human health hazards. The inspections must be recorded in an inspection log or summary and kept for at least three years.

The WID implements inspection procedures for all monitoring, safety, and emergency equipment; security devices; and operating and structural equipment. Written schedules that indicate the frequency of routine inspections have been developed. Inspections may be conducted more frequently than indicated but are not performed less frequently.

Each group develops procedures that outline the types of problems that will be examined during inspections of its equipment and systems and maintains its own inspection information. Completed inspection sheets include a signature, date, and time of inspection; observations made; and the date and nature of any repairs or other remedial actions. All log sheets are maintained in the operating record for at least three years.

25.2.4.7 Personnel Training, 40 CFR 265.16 (20 NMAC 4.1, § 600)

Personnel training must be provided to facility personnel within six months of their employment or new assignment; personnel must not work in unsupervised positions until the training has been completed. The training program must be designed to ensure that facility personnel can respond effectively to an emergency. The program must be directed by a person trained in hazardous waste management procedures. The job title for each position at the facility that is related to hazardous waste management, the name of the employee filling the position, a written description of the training required, and records that document that the training and/or job experience has been completed are also required. These records must be kept until closure for current personnel and for at least three years for former employees.

Formal training is conducted in accordance with a training manual. The training includes GET-19X for all WIPP employees, other classroom training, and on-the-job training. Training policy indicates that WIPP training will be conducted by certified instructors. Certification requirements are established in a WID procedure.

GET-19X provides detailed training in such areas as communications, alarm systems, and emergency response. A WID procedure requires all personnel to attend GET-19X within 30 days of employment. The GET-19X refresher class is required annually for all personnel. Other classroom training is offered for personnel in certain job categories. Annual refresher courses are provided. Maintenance personnel are trained to provide repair and replacement services. Inspections are a part of job-specific training and emergency response personnel training. WIPP employees involved in managing site-generated, nonradioactive waste, or TRU mixed waste receive the Hazardous Waste Worker course (HWW). This course provides job specific training required to safely receive, transfer or handle waste at the facility. Review and update of the HWW topics are provided annually.

WID maintains a listing of all hazardous waste management job titles, names of employees assigned by job title to hazardous waste management jobs, and job descriptions that identify RCRA duties. Records on active and inactive personnel are kept by the WIPP Technical Training Group.

25.2.4.8 General Requirements for Ignitable, Reactive, or Incompatible Wastes, 40 CFR 265.17 (20 NMAC 4.1, § 600)

> *Precautions must be taken to prevent accidental ignition or reaction of ignitable or reactive waste. Any mixture or commingling of incompatible wastes must be conducted so that it does not generate extreme heat or pressure, fire or explosion, violent reaction; does not produce uncontrolled toxic airborne materials; does not produce uncontrolled flammable fumes or gases; does not damage the structural integrity of the device or facility; or does not threaten human health or the environment.*

WIPP is precluded from accepting ignitable, corrosive, or reactive waste as specified in the Part B permit application and enumerated in the *Waste Acceptance Criteria.* In an analysis of the compatibility of the waste categories with each other and with waste containers, discussed in Chapter C of the permit application, no incompatibilities were identified.

No Smoking signs have been placed conspicuously at the Hazardous Waste Staging Area and at all SAAs where there could be a hazard from ignitable or reactive site generated wastes. A WID procedure requires a weekly inspection to verify that legible

No Smoking signs are posted near the SAAs. A WID procedure also prohibits storage of incompatible wastes within SAAs.

25.2.4.9 Location Standards, 40 CFR 265.18 (20 NMAC 4.1, § 600)

> *No hazardous waste may be emplaced in such structures as a salt-bed formation or an underground mine except at the DOE Waste Isolation Pilot Plant in New Mexico.*

WIPP is specifically identified in the regulation as the only facility of this type that may be used for the placement of hazardous waste.

25.2.4.10 Maintenance and Operation of Facility, 40 CFR 265.31 (20 NMAC 4.1, § 600)

> *Facilities must be maintained and operated to minimize the possibility of fire, explosions, or any unplanned release of hazardous constituents to air, soil, or surface water that could threaten human health or the environment.*

Section 1 of the *WID Contingency Plan* address this requirement. In addition, receipt of explosive or otherwise reactive waste, liquids, non-radioactive pyrophoric or other ignitable wastes, or compressed gases is prohibited at WIPP as a TSDF. Inspections of waste-handling areas and equipment are conducted as described by WID procedures. Corrective actions are initiated via Action Requests.

25.2.4.11 Required Equipment, 40 CFR 265.32 (20 NMAC 4.1, § 600)

> *All facilities must be equipped with an internal communications or alarm system for immediate emergency instruction; devices to summon external emergency assistance; fire extinguishers and fire-control, spill-control, and decontamination equipment; and water or foam equipment, sprinklers, or water-spray systems.*

WID has prepared a contingency plan which provides a list of emergency equipment at WIPP, along with a description and statement of capabilities of the equipment and the cognizant organization responsible for ensuring that the equipment is available and operable. Procedures for providing guidance to WIPP personnel for testing emergency equipment are in place.

25.2.4.12 Testing and Maintenance of Equipment, 40 CFR 265.33 (20 NMAC 4.1, § 600)

> *All facility communications or alarm systems and fire-control, spill-control, and decontamination equipment must be tested and maintained as needed to ensure its proper operation during an emergency.*

The WID maintains inspection procedures in place for communication and alarm systems and for fire protection equipment. These procedures include provisions for testing and maintenance to ensure that the equipment will be operable in an emergency. Spill control and decontamination equipment are inspected weekly and the results recorded on an inspection form.

25.2.4.13 Access to Communications or Alarm Systems, 40 CFR 265.34 (20 NMAC 4.1, § 600)

> *Immediate access to a communications or internal alarm system is required for all personnel involved when handling hazardous waste. If just one employee is ever on the premises during operations, he/she must have immediate access to a device (e.g., telephone) for summoning external emergency assistance.*

The following communication and alarm systems are available at the WIPP site: two-way communication by the public address system and its intercom phones and paging channels, an intra-plant telephone system, mine phones, local and facility-wide alarm systems, pagers and plectrons, and portable two-way radios. The WIPP RCRA Contingency Plan provides an inspection schedule for this equipment and describes the location of alarms, telephones, etc. There is more than one employee at the site at all times.

25.2.4.14 Required Aisle Space, 40 CFR 265.35 (20 NMAC 4.1, § 600)

> *Aisle space must be maintained to allow the unobstructed movement of personnel and of fire-protection, spill-control, and decontamination equipment to any area of facility operation unless aisle space is not needed for these purposes.*

No waste subject to this requirement is managed at WIPP at this time; however, a procedure is in place to address the areas of the WIPP where mixed waste containers will be maintained so that adequate aisle space will be provided for emergency response.

25.2.4.15 Arrangements with Local Authorities, 40 CFR 265.37 (20 NMAC 4.1, § 600)

> *Arrangements with local authorities must be made for the provision of emergency services if needed. Requirements include familiarizing the local authorities with the layout of the facility, properties of hazardous waste to be handled, possible evacuation routes, and other information needed for emergency responses.*

The RCRA Contingency Plan addresses this requirement. The DOE has established MOUs with appropriate off-site emergency response agencies for fire fighting, medical assistance, and law enforcement. Examples include an MOU with the Guadalupe Medical Center Emergency Radiological Treatment Center for the WIPP, which provides for the treatment of radiologically contaminated personnel, and a mutual aid agreement between Hobbs and the DOE, which provides for mutual ambulance, medical, fire, rescue, and hazardous material response services. Outside agencies with which MOUs have been made have received copies of the RCRA Contingency Plan and the *WIPP Emergency Plan* (WID, 1992). The WIPP provides regional fire and emergency services to residences and local businesses.

25.2.4.16 Purpose and Implementation of the Contingency Plan, 40 CFR 265.51 (20 NMAC 4.1, § 600)

> *Each owner/operator must have a contingency plan for his or her TSDF. The contingency plan must be designed to minimize hazards to human health or the environment from fires, explosions, or unplanned releases of hazardous constituents to the environment. The provisions of the plan must be carried out whenever a fire, explosion, or release of hazardous constituents could threaten human health or the environment.*

The RCRA Contingency Plan was developed for the WIPP. It is maintained at all controlled document locations. The purpose of the document is to define responsibilities; provide guidance for coordination of activities; and minimize hazards to human health and the environment from fires, explosions, or any unplanned release of hazardous waste or hazardous waste constituents.

25.2.4.17 Content of the Contingency Plan, 40 CFR 265.52 (20 NMAC 4.1, § 600)

> *The contingency plan must describe the actions to be taken by facility personnel in response to fires, explosions, or any unplanned releases of hazardous constituents to the environment. The plan must describe arrangements agreed*

> *to by local authorities and emergency response units and must list the current names, addresses, and phone numbers (work and home) of all Emergency Coordinators. All emergency equipment must be listed, along with the location, description, and capabilities of all equipment. An evacuation plan for facility personnel must be included.*

The RCRA Contingency Plan describes actions that must be taken in response to fires, explosions, or any unplanned or sudden or non-sudden release of hazardous waste or hazardous waste constituents to air, soil, or water, and describes agreements with local authorities. It also lists the names, addresses, and phone numbers of persons qualified to act as Emergency Coordinators, provides a list of emergency equipment at the facility, and includes an evacuation plan.

The RCRA Contingency Plan also describes the agreements between WIPP and local police and fire departments, hospitals, contractors, and state and local emergency response teams. An evacuation plan for WIPP personnel is also included in the RCRA Contingency Plan.

25.2.4.18 Copies of the Contingency Plan, 40 CFR 265.53 (20 NMAC 4.1, § 600)

> *Copies of the contingency plan and all revisions to the plan must be maintained at the facility and submitted to all local police and fire departments, hospitals, and state and local emergency response teams that may be called upon to provide emergency services.*

Copies of the RCRA Contingency Plan are maintained at WIPP. A copy of the plan is maintained at controlled document locations. WID maintains a distribution list for the plan and is responsible for updating the controlled copies. Copies of the RCRA Contingency Plan have been provided to all outside agencies with which WIPP has agreements for assistance in an emergency situation.

25.2.4.19 Amendment of Contingency Plan, 40 CFR 265.54 (20 NMAC 4.1, § 600)

> *The contingency plan must be reviewed and immediately revised, if necessary, whenever applicable regulations are revised; the plan fails in an emergency; the facility changes in a way that increases the potential for fire, explosions, or release of hazardous waste; or the list of Emergency Coordinators or emergency equipment changes.*

As described in the RCRA Contingency Plan, the plan will be reviewed and revised if necessary whenever applicable regulations are revised; the plan fails in an emergency; the facility changes in a way that materially increases the potential for fires, explosions,

or releases of hazardous waste or hazardous waste constituents or changes the response necessary in an emergency; the list of Emergency Coordinators changes; or the list of emergency equipment changes.

25.2.4.20 Emergency Coordinator, 40 CFR 265.55 (20 NMAC 4.1, § 600)

> *At least one employee (on the facility premises or on call) must be designated as the Emergency Coordinator, with the responsibility for coordinating all emergency response measures. The Emergency Coordinator must be familiar with the contingency plan, all operations and activities at the facility, the location and characteristics of waste handled, location of all facility records, and the facility layout. The Emergency Coordinator must have the authority to commit the resources needed to carry out the contingency plan.*

A RCRA Emergency Coordinator is on site at the WIPP facility 24 hours a day, 7 days a week, and is responsible for coordinating all emergency response measures. The primary RCRA Emergency Coordinator is the Facility Shift Manager (FSM). The FSM is the coordinator who will be on duty at the time of any incident that requires implementation of the RCRA Contingency Plan.

Persons qualified to act as the RCRA Emergency Coordinator are listed in the RCRA Contingency Plan. These employees have the requisite experience and authority to perform their role as Emergency Coordinator.

25.2.4.21 Emergency Procedures, 40 CFR 265.56 (20 NMAC 4.1, § 600)

> *In the event of an imminent or actual emergency situation, the Emergency Coordinator or designee must notify facility personnel via internal alarms or communications systems and must notify state or local agencies if their help is needed. A release, fire, or explosion mandates that the Emergency Coordinator obtain appropriate information, assess possible hazards, make any notifications required, prevent the spread or reoccurrence of the incident, monitor if necessary, recover waste, and record details regarding the incident in the facility's operating record. The owner or operator must note specific information about any incident that requires the contingency plan to be implemented. This information must be recorded in the facility's operating record. A written report must be submitted to the Regional EPA office and the NMED within 15 days of the incident. The state Emergency Response Commission (SERC) must be contacted rather than the NMED in the event of any spill*

> *incident that may endanger human health or the environment.*

WIPP Emergency Coordinators are thoroughly familiar with the RCRA Contingency Plan. The plan has provisions that meet the emergency procedure requirements such as communicating information about the emergency to employees, notifying appropriate agencies to obtain assistance, identifying hazardous materials, assessing hazards, and making the necessary notifications. The appropriate agencies include the Local Emergency Planning Committee (LEPC), the Carlsbad Police Department, the Carlsbad Fire Department, and the Eddy County Sheriff.

The FSM is responsible for coordinating the cleanup of spills. Disposal of the released material is the responsibility of WID.

All emergency equipment listed in the contingency plan is kept clean and fit for its intended use.

As described in the RCRA Contingency Plan, a daily log is maintained in the Central Monitoring Room (CMR) at WIPP. The FSM signs into the log before beginning his or her duty shift. All incidents, regardless of whether or not they activate the RCRA Contingency Plan, are recorded in the CMR log, along with routine maintenance activities.

The RCRA Contingency Plan addresses the requirement that the SERC be notified in the event of a spill that would endanger human health or the environment.

25.2.4.22 Use of Manifest System, 40 CFR 265.71 (20 NMAC 4.1, § 600)

> *If a facility receives hazardous constituents accompanied by a manifest, the owner or operator or designee must sign and date each copy of the manifest to certify receipt of the waste, note any significant discrepancies in the manifest, return at least one copy of the manifest to the transporter, send a copy of the manifest to the generator within 30 days, and retain a copy of the manifest for at least 3 years.*

A WID procedure provides guidance on the proper management and retention of hazardous waste manifests. Another WID procedure provides instructions for receiving, surveying, and inspecting TRUPACT-II containers at WIPP, which includes proper disposition of the hazardous waste. Further, generator sites are required to provide a manifest for shipments of TRU waste. This requirement will become applicable when the WIPP facility receives a waste shipment.

25.2.4.23 Manifest Discrepancies, 40 CFR 265.72 (20 NMAC 4.1, § 600)

> *Manifest discrepancies are differences between the quantity or type of hazardous waste designated in the manifest and that actually received. Upon discovering a significant discrepancy, the owner or operator must try to reconcile the discrepancy with the generator or transporter. If not resolved within 15 days, the owner or operator must notify the Regional Administrator.*

A WID procedure provides instruction and guidance for handling manifest discrepancies. The generator will be notified of all discrepancies, and the discrepancy will be recorded in the "remarks" section of the appropriate form. If the discrepancy cannot be resolved within 15 days, it will be reported in writing to the NMED. This requirement will become applicable when the WIPP facility receives a waste shipment.

25.2.4.24 Operating Record, 40 CFR 265.73 (20 NMAC 4.1, § 600)

> *The owner/operator must keep a written operating record at the facility. Information relating to the type and amount of hazardous waste, its location and quantity at each location, cross references to specific manifest documents and records and the results of waste analyses, summary reports and details of all incidents requiring implementation of the contingency plan, records and results of inspections, monitoring and analytical data and any corrective actions taken, and closure cost estimates must be included. In addition, records pertaining to an off-site treatment, land disposal, or storage facility must be kept in the operating record.*

A WID procedure establishes guidelines for maintaining the written operating record.

25.2.4.25 Availability, Retention, and Disposition of Records, 40 CFR 265.74 (20 NMAC 4.1, § 600)

> *All records required under this part, including plans, must be retained and made available for inspection by EPA designees. The retention period for all records required under this part is automatically extended during the course of any unresolved enforcement action or as requested by the Administrator. Records of waste disposal locations and quantities must be submitted to the appropriate agencies upon closure of the facility.*

This requirement is addressed in a WID procedure that establishes guidelines for maintaining a written operating record. The procedure includes provisions for furnishing all records upon request to the EPA and NMED, as well as provisions for submitting a copy of waste emplacement locations and quantities to appropriate state and federal regulators. In the event of an enforcement action, records will be retained for the duration of the action.

25.2.4.26 TSDF Biennial Report, 40 CFR 265.75 (20 NMAC 4.1, § 600)

> *The owner or operator of a TSDF must submit a copy of a biennial report to the Regional Administrator by March 1 of each even-numbered year using EPA Form 8700-13B.*

A WID procedure establishes guidelines for the preparation and submittal of a biennial report for a facility that operates as a generator and a TSD. The procedure indicates that all information needed to meet this requirement shall be provided, including a description and the quantity of each mixed waste received during the reporting year and the method and date of treatment, storage, or disposal at the facility. The Biennial Generator Report is submitted to the EPA Region VI on or before March 1st of even numbered years. The TSDF biennial report is not required until after TRU mixed waste is received at WIPP.

25.2.4.27 Unmanifested Waste Report, 40 CFR 265.76 (20 NMAC 4.1, § 600)

> *A report must be submitted to the Regional Administrator for any hazardous waste accepted for treatment, storage, or disposal that is not accompanied by a hazardous waste manifest.*

As stated in the part B permit application and enumerated in the *Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, a hazardous waste manifest shall be transmitted with each shipment of TRU mixed waste to WIPP. Therefore, no mixed waste will be accepted that is not accompanied by a hazardous waste manifest. No waste shipments have been received at WIPP to date.

25.2.4.28 Additional Reports, 40 CFR 265.77 (20 NMAC 4.1, § 600)

> *Additional reports required of the owner or operator of a TSDF by the Regional Administrator are reports relating to releases, fire, or explosions; ground-water contamination and monitoring data; facility closure; and air emissions under Subparts AA and BB of this part.*

Releases, fires, and explosions will be reported as specified in the WIPP RCRA Contingency Plan. Whenever it becomes necessary to partially close WIPP, the DOE will notify the NMED, in writing, at least 60 days prior to the date on which such partial or final closure will commence, as specified by WID procedure. Subparts AA and BB do not apply at WIPP; therefore no reporting is required at WIPP under these subparts.

25.2.4.29 Applicability of the Ground-Water Monitoring System, 40 CFR 265.90 (20 NMAC 4.1, § 600)

> *A ground-water monitoring system is required by the owner or operator of a surface impoundment, landfill, or land treatment facility used to manage hazardous waste. All or part of the ground-water monitoring requirements may be waived if the owner/operator can demonstrate a low potential for migration of hazardous constituents from the facility via the uppermost aquifer to water supply wells or to surface water. The demonstration, in writing, must be certified by a qualified geologist or geotechnical engineer.*

A ground-water monitoring waiver was prepared and is located at WIPP. This waiver contains the information to demonstrate that a very low potential for migration of hazardous waste or hazardous constituents from the WIPP site via ground water exists. A draft *No-Migration Variance Petition* was submitted to the EPA in May of 1995. The petition contained information for the operational phase at WIPP. The EPA has provided comments on the petition, but has made no formal decision. A final NMVP was submitted to the EPA in June 1996. The NMED has indicated that it is their policy to require the DOE to perform groundwater monitoring regardless of whether or not the WIPP is eligible for a federal groundwater monitoring waiver. Thus, the DOE has prepared a groundwater monitoring plan.

25.2.4.30 Ground-Water Monitoring System, 40 CFR 265.91 (20 NMAC 4.1, § 600)

> *The ground-water monitoring system required of landfills managing hazardous waste is described in detail.*

A ground-water monitoring waiver was prepared and is located at the WIPP facility. This waiver obviates the need for a ground-water monitoring system at WIPP. The NMED has indicated that it is their policy to require the DOE to perform groundwater monitoring regardless of whether or not the WIPP is eligible for a federal groundwater monitoring waiver. Thus, the DOE has prepared a groundwater monitoring plan.

25.2.4.31 Sampling and Analysis, 40 CFR 265.92 (20 NMAC 4.1, § 600)

> *Sampling and analytical requirements for the ground-water monitoring system are described in detail.*

A ground-water monitoring waiver was prepared and is located at WIPP. This waiver obviates the need for a ground-water monitoring system at WIPP. The NMED has indicated that it is their policy to require the DOE to perform groundwater monitoring regardless of whether or not the WIPP is eligible for a federal groundwater monitoring waiver. Thus, the DOE has prepared a groundwater monitoring plan.

25.2.4.32 Preparation, Evaluation, and Response, 40 CFR 265.93 (20 NMAC 4.1, § 600)

> *The owner or operator must prepare an outline of a ground-water quality assessment program, describing a more comprehensive ground-water monitoring program than that described in previous sections of this part.*

A ground-water monitoring waiver was prepared and is located at WIPP. This waiver obviates the need for the ground-water quality assessment program described in this section. The NMED has indicated that it is their policy to require the DOE to perform groundwater monitoring regardless of whether or not the WIPP is eligible for a federal groundwater monitoring waiver. Thus, the DOE has prepared a groundwater monitoring plan.

25.2.4.33 Record-keeping and Reporting, 40 CFR 265.94 (20 NMAC 4.1, § 600)

> *Record-keeping and reporting of the results of ground-water monitoring is required.*

A ground-water monitoring waiver was prepared and is located at WIPP. This waiver obviates the need for record-keeping and reporting the results of ground-water monitoring. The NMED has indicated that it is their policy to require the DOE to perform groundwater monitoring regardless of whether or not the WIPP is eligible for a federal groundwater monitoring waiver. Thus, the DOE has prepared a groundwater monitoring plan.

25.2.4.34 Applicability of the Closure/Postclosure Requirements, 40 CFR 265.110 (20 NMAC 4.1, § 600)

> *Closure and postclosure requirements apply to the owners and operators of all hazardous and mixed-waste management facilities.*

Plans for closure and postclosure are addressed in the disposal phase RCRA permit application.

25.2.4.35 Closure Performance Standard, 40 CFR 265.111 (20 NMAC 4.1, § 600)

> *A closure performance standard is required to minimize the need for further maintenance; to control, minimize, or eliminate the post-closure escape of hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to the environment; and to comply with the other closure requirements of this subpart.*

Closure will be deemed complete when all hazardous waste and hazardous waste residues have been removed from the units, all equipment and structures associated with the operation of the units have been decontaminated, and unit closure certification has been submitted to and approved by the NMED.

25.2.4.36 Closure Plan; Amendment of Plan, 40 CFR 265.112 (20 NMAC 4.1, § 600)

> *The owner/operator of a hazardous or mixed-waste management facility must have a written closure plan. The plan, approved by the Regional Administrator or designee, may be amended subject to the Regional Administrator's approval.*

WIPP has prepared a written closure plan to satisfy the RCRA closure requirements. The plan includes, but is not limited to, the following:

1. A description of how each hazardous waste management unit at the facility will be closed in accordance with the closure performance standard (see Section 25.2.4.34) and

2. A description of how final closure of the facility will be conducted.

Should it become necessary to amend the WIPP closure plan, the DOE will submit a written notification of, or request for, a permit modification describing any change in operation, facility design, or storage/disposal designs that affect the closure plan.

25.2.4.37 Time Allowed for Closure, 40 CFR 265.113 (20 NMAC 4.1, § 600)

> *Within 90 days after receipt of the final volume of hazardous mixed waste at a hazardous waste management unit or facility, the owner or operator must treat, remove, or dispose of all hazardous/mixed wastes on site in accordance with the approved closure plan. Partial or final closure activities must be complete in accordance with the*

approved closure plan within 180 days of receipt of the final volume of waste. An extension of time may be allowed if the owner/operator can demonstrate that the activities required will take longer than the allotted time period and has taken and will continue to take all steps necessary to prevent threats to human health and the environment from the unclosed but nonoperational facility.

The time allowed for closure is addressed in the disposal phase RCRA permit application.

25.2.4.38 Disposal or Decontamination of Equipment, Structures, and Soils, 40 CFR 265.114 (20 NMAC 4.1, § 600)

During the partial and final closure periods, all contaminated equipment, structures, and soils must be properly disposed of or decontaminated. By removing all hazardous constituents during closure, the owner/operator may become a mixed or hazardous waste generator and must handle all such waste in accordance with the requirements of 40 CFR Part 262.

The regulatory requirements for the disposal or decontamination of equipment, structures, and soils are addressed in WID procedures. This section is broken down into four subsections, which include the removal of hazardous waste residues; the decontamination of equipment, structures, and soils; personnel decontamination; and sampling and quality assurance.

25.2.4.39 Certification of Closure, 40 CFR 265.115 (20 NMAC 4.1, § 600)

Within 60 days of the completion of closure of each landfill unit and within 60 days of completion of final closure, the owner/operator must submit a certification that the hazardous or mixed waste unit has been closed in accordance with the specifications in the approved closure plan. The certification must be sent to the Regional Administrator by registered mail and must be signed by the owner/operator and by an independent registered professional engineer.

The DOE will submit the Certification of Closure to the Secretary of the NMED within 60 days of completion of closure activities.

25.2.4.40 Survey Plat, 40 CFR 265.116 (20 NMAC 4.1, § 600)

The owner/operator must submit a survey plat to the Regional Administrator and the authority with jurisdiction over local land use no later than the submittal of the certification of closure. The survey plat must indicate the location and dimensions of landfill cells or other hazardous waste disposal units with respect to permanently surveyed benchmarks. The plat must be prepared and certified by a professional land surveyor.

The survey plat will be submitted to the NMED following closure. The survey plat will indicate the location and dimensions of hazardous waste disposal units with respect to permanently surveyed benchmarks. The plat will be prepared and certified by a professional land surveyor and will contain a prominently displayed note that states the DOE's obligation to restrict disturbance of the hazardous waste disposal unit.

25.2.4.41 Postclosure Care and use of Property, 40 CFR 265.117 (20 NMAC 4.1, § 600)

Postclosure care for each hazardous/mixed-waste unit must begin after completion of closure and continue for 30 years after that date. All postclosure care must be performed in accordance with the postclosure plan for the facility.

Postclosure care and use of property will be performed in accordance with the Post Closure Plan.

25.2.4.42 Postclosure Plan; Amendment of Plan, 40 CFR 265.118 (20 NMAC 4.1, § 600)

The owner/operator of a hazardous or mixed-waste management facility must have a written postclosure plan. The plan, approved by the Regional Administrator or designee, may be amended subject to the Regional Administrator's approval.

A postclosure plan is contained in the WIPP permit application. The plan describes active controls, monitoring, and passive controls.

25.2.4.43 Postclosure Notices, 40 CFR 265.119 (20 NMAC 4.1, § 600)

A record of the type, location, and quantity of hazardous/mixed wastes disposed of within each unit must

be submitted to the Regional Administrator and the authority with jurisdiction over local land use no later than 60 days after submittal of the certification of closure. Within the same timeframe, the owner/operator must also record a notation in the deed to the facility that the facility has been used to manage hazardous/mixed wastes and that the record of type, location, and quantity of waste disposal has been filed; the owner/operator must also certify that this notation has been recorded as required.

The DOE will notify the NMED within 60 days after completion of closure, with a Registered Professional engineer's certification. The DOE will also assure that this notification is properly recorded in the deed to the facility.

25.2.4.44 Certification of Completion of Postclosure Care, 40 CFR 265.120 (20 NMAC 4.1, § 600)

Within 60 days of the completion of postclosure of each landfill unit and within 60 days of completion of final post-closure, the owner/operator must submit a certification that the hazardous or mixed-waste unit has been closed in accordance with the specifications in the approved postclosure plan. The certification must be sent to the Regional Administrator by registered mail and must be signed by the owner/operator and by an independent registered professional engineer.

The DOE will notify the NMED within 60 days after completion of closure, with a Registered professional engineer's certification.

25.2.4.45 Cost Estimate for Closure, 40 CFR 265.142 (20 NMAC 4.1, § 600)

The owner/operator must provide a detailed written estimate of the cost of closing the facility.

As a federal facility, WIPP is exempt from the requirement to provide cost estimates for closure actions.

25.2.4.46 Financial Assurance for Closure, 40 CFR 265.143 (20 NMAC 4.1, § 600)

The owner/operator of each facility must establish financial assurance for closure of the facility.

As a federal facility, WIPP is exempt from the requirement to provide financial assurance for closure actions.

25.2.4.47 Cost Estimate for Postclosure Care, 40 CFR 265.144 (20 NMAC 4.1, § 600)

> *The owner/operator of each TSDF must provide a detailed written cost estimate for postclosure monitoring and maintenance of the facility.*

As a federal facility, WIPP is exempt from the requirement to provide a cost estimate for postclosure care.

25.2.4.48 Financial Assurance for Postclosure Care, 40 CFR 265.145 (20 NMAC 4.1, § 600)

> *The owner/operator of a hazardous or mixed waste disposal unit must establish financial assurance for postclosure care of the disposal unit(s).*

As a federal facility, WIPP is exempt from the requirement to provide financial assurance for postclosure care.

25.2.4.49 Use of a Mechanism for Financial Assurance of Both Closure and Postclosure Care, 40 CFR 265.146 (20 NMAC 4.1, § 600)

> *The owner/operator may satisfy the requirements for financial assurance by using a mechanism such as a trust fund, security bond, letter of credit, etc.*

As a federal facility, WIPP is exempt from the requirement to provide mechanisms for financial assurance of both closure and postclosure care.

25.2.4.50 Liability Requirements, 40 CFR 265.147 (20 NMAC 4.1, § 600)

> *An owner/operator of a TSDF must demonstrate financial responsibility for bodily injury and property damage from accident occurrences arising from operations of the TSDF.*

As a federal facility, WIPP is exempt from the requirement to provide liability insurance.

25.2.4.51 Incapacity of Owners or Operators, Guarantors, or Financial Institutions, 40 CFR 265.148 (20 NMAC 4.1, § 600)

> *An owner/operator must notify the Regional Administrator by certified mail of the commencement of a bankruptcy proceeding that names him/her as a debtor within 10 days*

after commencement of the proceeding. In the event of bankruptcy of the guarantors or financial institutions, the owner/operator must establish financial assurance of liability coverage within 60 days after the event.

As a federal facility, WIPP is exempt from the requirement to provide financial status information.

25.2.4.52 Use of State-Required Mechanisms, 40 CFR 265.149 (20 NMAC 4.1, §601.A)

For a facility located in a state with financial assurance requirements but where the EPA administers the requirements of this subpart on closure and post-closure, an owner/operator may use state-required financial mechanisms to meet these requirements.

As a federal facility, WIPP is exempt from the requirement to provide financial status information.

25.2.4.53 State Assumption of Responsibility, 40 CFR 265.150 (20 NMAC 4.1, § 601.B)

If a state assumes responsibility for an owner/operator's compliance with the closure, post-closure, or liability requirements of this part, the owner/operator will be in compliance if the Regional Administrator determines that the state's assumption of responsibility is adequate.

As a federal facility, WIPP is exempt from the requirement to provide financial status information.

25.2.4.54 Condition of Containers, 40 CFR 265.171 (20 NMAC 4.1, § 600)

If a container holding hazardous or mixed waste is not in good condition or begins to leak, the waste within it must be transferred to a container that is in good condition, or the waste must be managed in another way that complies with the requirements in this part.

Containers must be in good condition (no visible deterioration) in accordance with WID procedures. The date and nature of repairs performed on a container or other remedial action is included in the Weekly Inspection Criteria Form or in the WIPP Waste Information System database and the operating record.

25.2.4.55 Compatibility of Waste With Containers, 40 CFR 265.172 (20 NMAC 4.1, § 600)

> *A container made of or lined with materials that will not react with and are compatible with the waste to be stored within it must be used.*

No special liners are placed in waste containers to hold hazardous wastes generated at WIPP, but measures are taken to ensure that the containers to be used are compatible with the waste generated. These measures are described in WID procedures.

A chemical compatibility analysis of the waste forms to be sent to WIPP as a TSDF and the container materials to be used was conducted. Each generator and storage site has produced a comprehensive list of all possible chemicals present in its waste. Low carbon steel and polyethylene were added to evaluate chemical compatibility between the waste materials and the container materials. Potential incompatibilities were analyzed using EPA-600/2-80-076, *A Method for Determining the Compatibility of Hazardous Waste*.

25.2.4.56 Management of Containers, 40 CFR 265.173 (20 NMAC 4.1, § 600)

> *A container holding hazardous or mixed waste must be kept closed during storage except when it is necessary to add or remove waste. Containers holding hazardous or mixed waste must not be opened, handled, or stored so as to rupture the container or cause it to leak.*

A WID procedure prohibits opening containers located in the SAAs at WIPP except to add or sample the WIPP-generated hazardous waste.

The requirement that hazardous waste containers not be opened, handled, or stored in a manner that would threaten the integrity of the containers is addressed in the WID procedure that requires that containers be inspected before and after transportation from the SAA to the Hazardous Waste Staging Area.

TRU mixed waste shipped to WIPP will be contained in sealed containers. WID procedures do not provide for accessing containers. None of the procedures directs or allows the removal of lids from the containers. Waste derived from decontamination of spills of TRU mixed waste will be collected in a container in the permitted Container Storage Unit in the Waste Handling Building. The container will remain closed except when adding derived waste.

The Hazardous Waste Regulations require that owners and operators of all hazardous waste facilities that store containers of hazardous waste must safely manage containers. All TRU mixed-waste-handling operators are thoroughly trained in the safe

use of TRU mixed waste handling and transport equipment to minimize the potential for rupture or leak of a container.

25.2.4.57 Inspections, 40 CFR 265.174 (20 NMAC 4.1, § 600)

> *Areas in which containers holding hazardous or mixed wastes are stored must be inspected at least weekly to ensure that there are no leaks or other signs of deterioration caused by corrosion or other factors.*

WID procedures are in place to ensure that the regulatory requirements for inspections are met. Inspections of containers holding hazardous waste are performed weekly, as described in WID procedures. All inspection report files are maintained by WID. TRU mixed waste containers to be emplaced in disposal rooms will not be inspected.

25.2.4.58 Special Requirements for Ignitable or Reactive Waste, 40 CFR 265.176 (20 NMAC 4.1, § 600)

> *Containers holding ignitable or reactive waste must be located at least 15 meters (50 feet) from the facility's property line.*

All storage containers holding hazardous waste are located more than 15 meters from the property line at WIPP.

As stated in the Part B permit application and enumerated in the *Waste Acceptance Criteria for the Waste Isolation Pilot Plant* (DOE, 1996) ignitable or reactive waste will not be accepted at the WIPP. It states that explosives, compressed gases, or non-radionuclide pyrophorics are not allowed. It also says that residual liquids and radionuclides in pyrophoric form are limited to less than 1 percent by volume and weight, respectively.

25.2.4.59 Special Requirements for Incompatible Wastes, 40 CFR 265.177 (20 NMAC 4.1, § 600)

> *Incompatible wastes must not be placed in the same container and must be segregated. Hazardous waste must not be placed in an unwashed container that previously held incompatible waste or material.*

A WID procedure prohibits the accumulation or storage of WIPP-generated hazardous wastes with materials that may be incompatible. The procedure includes a list of incompatible wastes that may be generated on site.

WID procedures prohibit placing hazardous waste in any unwashed container that previously held an incompatible material. WID procedures also specify that a storage container holding a hazardous waste that is incompatible with any waste or othermaterials stored nearby must be separated or protected from the other materials by means of a dike, berm, wall, or other barrier or device. WID procedures state that chemicals/materials must be compatible with any waste materials, container materials, and TRUPACT-II materials. A chemical compatibility analysis of the waste forms and container materials has been performed.

25.2.4.60 Tank Systems; Surface Impoundments; Waste Piles; Land Treatment; Landfills; Incinerators; Thermal Treatment; Chemical, Physical, and Biological Treatment; Underground Injection; and Drip Pads, 40 CFR 265.190-265.445 (20 NMAC 4.1, § 600)

Requirements are specified for tank systems; surface impoundments; waste piles; land treatment; incinerators; thermal treatment; chemical, physical, and biological treatment; underground injection; and drip pads.

None of these regulatory requirements is applicable to WIPP because none of these systems will be used at this facility.

25.2.4.61 Air Emission Standards for Process Vents, 40 CFR 265.1032 (20 NMAC 4.1, § 600)

Air emission standards have been set for TSDFs with process vents associated with distillation, fractionation, thin-film evaporation, solvent extraction, or air or steam stripping operations managing hazardous wastes with organic concentrations of at least 10 parts per million by weight (ppmw).

WIPP does not have process vents associated with distillation, fractionation, thin-film evaporation, solvent extraction, or air or steam stripping operations managing hazardous wastes with organic concentrations of at least 10 ppmw. Therefore, the requirements in Subpart AA of 40 CFR Part 265 (265.1032 through 265.1035) do not apply.

25.2.4.62 Air Emission Standards for Equipment Leaks, 40 CFR 265.1052-.1062 (20 NMAC 4.1, § 600)

Air emission standards have been promulgated for leaks from TSDF equipment that contains or contacts hazardous wastes with organic concentrations of at least 10 percent by weight.

The air emissions standards for equipment leaks do not apply at WIPP because the types of equipment listed, such as pumps in light liquid service and compressors, are not used at WIPP. Therefore, none of the standards and requirements of 40 CFR Part BB (265.1050 through 265.1064) pertains to WIPP.

25.2.4.63 Air Emission Standards for Tanks, Surface Impoundment, and Containers, 40 CFR 265.1080, (20 NMAC 4.1, § 600)

> *The owner or operator shall control air emissions from each waste management unit in accordance with standards specified in §265.1088 of this subpart, as applicable to the waste management unit, except as provided for in paragraph (c) of this section.*

The air emission standards for tanks, surface impoundments, and containers are not applicable to the WIPP. TRU or TRU mixed wastes are specifically exempted from these regulations by § 265.1080(b)(6). No site-generated wastes are stored or treated in tanks or surface impoundments, and the containers used to store wastes in the Hazardous Materials Storage Area are specifically exempted by § 265.1087 container standards. It should be noted that new federal regulations were published in the Federal Register on February 9, 1996; however, the effective date of the new regulations (June, 1996) falls outside the reporting period of this report.

25.2.5 Compliance with the Hazardous/Mixed Waste Permit Program, 40 CFR Part 270 (20 NMAC 4.1, §§ 900 and 901)

The requirements of 40 CFR Part 270 pertain to general RCRA permitting requirements for TSDFs and include provisions for submitting applications, standard permit conditions, and monitoring and reporting requirements. The compliance status of each applicable requirement is summarized in Table 25-6; detailed information is provided in the text.

TABLE 25-6. The New Mexico Hazardous/Mixed Waste Permit Program, 40 CFR Part 270 - Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 270.1 (20 NMAC 4.1, § 900)	Purpose and scope of the RCRA permit program regulations	**UP TO DATE** RCRA Part B permit application for the Waste Isolation Pilot Plant [Section 25.2.5.1]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 270.10 (20 NMAC 4.1, § 900)	General application requirements	**UP TO DATE** RCRA Part B permit application for the Waste Isolation Pilot Plant [Section 25.2.5.2]
40 CFR 270.11 (20 NMAC 4.1, § 900)	Signatories to permit applications and reports	**UP TO DATE** RCRA Part B permit application for the Waste Isolation Pilot Plant [Section 25.2.5.3]
40 CFR 270.13 (20 NMAC 4.1, § 900)	Contents of Part A of the permit application	**UP TO DATE** RCRA Part A permit application for the Waste Isolation Pilot Plant [Section 25.2.5.4]
40 CFR 270.14 (20 NMAC 4.1, §§ 900 and 901)	Contents of Part B: general requirements	**UP TO DATE** RCRA Part B permit application for the Waste Isolation Pilot Plant [Section 25.2.5.5]
40 CFR 270.15 (20 NMAC 4.1, § 900)	Specific Part B information requirements for containers	**UP TO DATE** RCRA Part B permit application for the Waste Isolation Pilot Plant, Chapters D and F [Section 25.2.5.6]
40 CFR 270.23 (20 NMAC 4.1, § 900)	Specific Part B information requirements for miscellaneous units	**UP TO DATE** RCRA Part B permit application for the Waste Isolation Pilot Plant, Chapter D [Section 25.2.5.7]

CITATION	REQUIREMENT	COMPLIANCE STATUS
40 CFR 270.30 (40 NMAC 4.1, § 900)	Conditions applicable to all permits	**NOT APPLICABLE** Will be applicable when a permit is issued [Section 25.2.5.8]
40 CFR 270.31 (20 NMAC 4.1, § 900)	Requirements for recording and reporting of monitoring results	**NOT APPLICABLE** Will be applicable when a permit is issued [Section 25.2.5.9]
40 CFR 270.42 (20 NMAC 4.1, §§ 900 and 901)	Permit modification at the request of the permittee	**NOT APPLICABLE** Will be applicable when a permit is issued [Section 25.2.5.10]
40 CFR 270.71 (20 NMAC 4.1, § 900)	Operation during interim status	**UP TO DATE** Interim status achieved by timely filing of Part A; compliance with interim-status requirements [Section 25.2.5.11]
40 CFR 270.72 (20 NMAC 4.1, § 900)	Changes during interim status	**UP TO DATE** WID procedure [Section 25.2.5.12]

25.2.5.1 Purpose and Scope of the RCRA Permit Program Regulations, 40 CFR 270.1(20 NMAC 4.1, § 900)

The purpose and scope of the RCRA permit program regulations are defined, and the regulations are summarized.

Prior to the receipt of TRU mixed waste, WIPP must retain interim status or be permitted as a mixed-waste facility. As required for an interim-status facility, the DOE submitted a RCRA permit application to the EPA and to the NMED for the disposal phase. The DOE has completed and submitted a revised permit application.

25.2.5.2 General Application Requirements, 40 CFR 270.10 (20 NMAC 4.1, § 900)

> *General application requirements include the requirement that an interim-status facility submit a RCRA Part A permit application within six months after the date of publication of regulations requiring its compliance with 40 CFR Part 265. Submittal of the Part B application is required at least six months from the date of request. The permit application must be considered complete before a permit may be issued, which includes providing all applicable information described in 40 CFR 270.13 through 270.29, using the appropriate application form. Records must be kept of all data used to complete permit applications (including updates) for at least three years from the date of signature on the application.*

On July 25, 1990, the NMED's predecessor agency, the New Mexico Environmental Improvement Division (EID) received the EPA's final authorization for the state's mixed-waste program. In a letter to DOE dated August 27, 1990, the EID required the submittal of Parts A and B of the *RCRA Permit Application for the Waste Isolation Pilot Plant* by January 22 and February 28, 1991, respectively. The DOE submitted the Part A portion of the application to the EID and to the Regional EPA office in Dallas, Texas, on January 22, 1991. The Part B portion was submitted to the EID and the EPA Regional Office on February 26 and February 27, 1991, respectively.

The RCRA permit application for the disposal phase was prepared to meet all applicable requirements specified in 40 CFR 270.13 through 270.29. The appropriate form was used for Part A; no form has been generated for Part B. Six major revisions of the application have been sent to the regulatory agencies, the latest being the April 1996 revision with minor revisions submitted in June 1996.

A record of all data used to complete the application for the disposal phase is being maintained at WIPP. It will be kept for at least three years from the date of the signature in the application.

25.2.5.3 Signatories to Permit Applications and Reports, 40 CFR 270.11 (20 NMAC 4.1, § 900)

> *Signatories to permit applications shall be by a senior executive officer with responsibility for overall operations for a federal agency and/or a responsible corporate officer for a corporation. Reports and plans required by permits (e.g., the annual waste minimization plan) and other information requested shall be signed by a duly authorized*

representative. Any person signing one of these documents is required to make the certification statement specified in 40 CFR 270.11(d). (See also Section 2.2.3.3).

The requirement calling for signatories to permit applications is met in Part A of the permit application.

25.2.5.4 Contents of Part A of the Permit Application, 40 CFR 270.13 (20 NMAC 4.1, § 900)

The contents required for Part A of the RCRA permit application include the activities mandating a RCRA permit, identification of the facility and operator, SIC codes, status of the facility, a scale drawing and photographs of the facility, description of processes to be used, a specification of the hazardous wastes/constituents and the estimated quantity of such wastes, a listing of all permits received or applied for and other environmental permits, a topographic map, and a brief description of the nature of the business.

Part A of the permit application contains all of the information required by 40 CFR 270.13. The permit application has been submitted to the NMED. The NMED issued a determination of administrative completeness on July 25, 1995. The NMED issued a formal Notice of Deficiency on March 14, 1996. DOE has submitted its response comments to the NMED with a final revision to the permit application on April 12, 1996, and is awaiting further action.

25.2.5.5 Contents of Part B: General Requirements, 40 CFR 270.14 (20 NMAC 4.1, §§ 900 and 901)

The general requirements for Part B of a RCRA permit application include a facility description, chemical and physical analyses of the hazardous waste to be handled, a copy of relevant plans (e.g., waste analysis plan; contingency plan; closure plan) security procedures and equipment, inspection schedule, procedures, structures, equipment to minimize hazards and releases, traffic patterns, geologic data, training program, ground-water monitoring information and data, and information regarding solid waste management units.

The Part B permit application has been submitted to the NMED. The NMED technical review resulted in a NOD, which DOE answered and submitted with a final revision of the permit application on April 12, 1996.

25.2.5.6 Specific Part B Information Requirements for Containers, 40 CFR 270.15 (20 NMAC 4.1, § 900)

> *Specific Part B information requirements for containers include a detailed description of the containment system; a demonstration to show that the wastes contain no free liquids; drawings or data showing ignitable, reactive or incompatible wastes; and procedures used for incompatible wastes.*

The requirement calling for specific container information is met in the permit application.

25.2.5.7 Specific Part B Information Requirements for Miscellaneous Units, 40 CFR 270.23 (20 NMAC 4.1, § 900)

> *Specific Part B information requirements for miscellaneous units include a detailed description of the unit; detailed hydrologic, geologic, and meteorological assessments and land-use maps for the region surrounding the site; information on potential exposure pathways to hazardous constituents and the potential magnitude and nature of such exposures; a report on the effectiveness of any treatment methodology proposed; and any additional information requested for evaluating the compliance of the unit with the environmental protection standards of 40 CFR 264.601.*

The requirement calling for specific miscellaneous unit information is met in the *RCRA Part B Permit Application for the Waste Isolation Pilot Plant.*

25.2.5.8 Conditions Applicable to all Permits, 40 CFR 270.30 (20 NMAC 4.1, § 900)

> *Conditions applicable to all permits are specified and include duty to comply, duty to reapply, minimization of releases, proper operation and maintenance, permit actions, property rights, duty to provide information, inspection and entry, monitoring and records, signatory requirements, and reporting requirements.*

This requirement will become applicable when a permit is issued by the NMED.

25.2.5.9 Requirements for Recording and Reporting of Monitoring Results, 40 CFR 270.31 (20 NMAC 4.1, § 900)

Requirements for recording and reporting monitoring results will be specified in the RCRA permit.

These requirements for recording and reporting monitoring results are met and discussed in the *RCRA Part B Permit Application for the Waste Isolation Pilot Plant.* These requirements will become applicable when a permit is issued by the NMED.

25.2.5.10 Permit Modification at the Request of the Permittee, 40 CFR 270.42 (20 NMAC 4.1, §§ 900 and 901)

After a RCRA permit has been finalized, the permittee may request that it be modified. Three classes of modifications are identified in Appendix I to 40 CFR 270.42. Class 1, the least significant of the permit modifications, covers minor modifications such as the correction of typographical errors; changes to conform with agency guidelines or regulations; or procedural changes that increase the frequency of monitoring, reporting, sampling, or maintenance activities. Class 1 modifications require notification of the Director within 7 days after the change has been made; all persons on the facility mailing list must be notified within 90 calendar days after the Director approves the request.

Class 2 modifications are more extensive and significant and apply to changes needed to allow timely response to common variations in the types and quantities of wastes managed, technological advancements, and changes in the regulations (e.g., changes in emergency procedures or removal of equipment from the emergency equipment list). They require that the permittee submit a modification request to the Director, announce a 60-day comment period, notify all persons on the facility mailing list, publish the notice in a major local newspaper of general circulation, and hold a public meeting.

Class 3 modifications are the most significant and potentially impactive and substantially alter the facility or its operation (e.g., extending the closure period or a final compliance date; creating a new landfill or other type of unit or increasing the capacity of a pre-existing one). The notification and other requirements are similar to those for Class 2 modifications.

Permit modification will not be applicable at WIPP until after a RCRA permit has been issued for this facility.

25.2.5.11 Operation During Interim Status, 40 CFR 270.71 (20 NMAC 4.1, § 900)

> *During interim status, the facility shall not treat, store, or dispose of hazardous waste or employ processes not specified or exceed the design capabilities described in Part A of the permit application. The facility will comply with all applicable standards described in 40 CFR Part 265.*

The WIPP has waste analysis and waste acceptance criteria in place to ensure that all waste managed at the facility is within the bounds specified in the Part A permit application. Further, the WIPP has programs and procedures in place that address compliance with the applicable interim-status standards of 40 CFR Part 265 (See Section 25.2.4).

25.2.5.12 Changes During Interim Status, 40 CFR 270.72 (20 NMAC 4.1, § 900)

> *Changes that may be made during interim status are treatment, storage, or disposal of new wastes; increases in the design capacity of processes used or changes in the processes used; changes in ownership or operational control; changes made in accordance with an interim-status corrective action order; or the addition of newly regulated units if and only if a revised Part A permit application is submitted and approved by the Director. Such changes may not be made if reconstruction of the facility results (i.e., the capital investment in the changes to the facility may not exceed 50 percent of the capital cost of a comparable, entirely new, hazardous waste management facility).*

Any changes to the disposal facility which require review and approval by NMED will be submitted to NMED for review and approval as required by the interim status provisions. Once a permit is issued, the DOE can propose modifications to the permit to the NMED for approval.

25.2.6 Compliance With the UST Regulatory Requirements under 20 NMAC, Chapter 5

This section of the report will examine the New Mexico UST requirements as they pertain to the WIPP. Compliance status is summarized in Table 25-7, and additional detail is provided in the text that follows the table.

TABLE 25-7. New Mexico Underground Storage Tank Regulations (20 NMAC, Chapter 5) - Compliance Status Summary

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.1, *General Provisions*		
20 NMAC 5.1, §101	Applicability	**UP TO DATE** Two USTs at WIPP, one for diesel fuel, the other for unleaded fuel [Section 25.2.6.1]
20 NMAC 5.2, *Registration of Tanks*		
20 NMAC 5.2, § 200	Existing tanks	**ACHIEVED** Two registered USTs [Section 25.2.6.2]
20 NMAC 5.2, § 201	Transfer of ownership	**NOT APPLICABLE** Original ownership [Section 25.2.6.3]
20 NMAC 5.2, § 202	New UST system	**ACHIEVED** Registration for two new USTs transmitted on June 18, 1992 [Section 25.2.6.4]
20 NMAC 5.2, § 203	Substantially modified UST systems	**NOT APPLICABLE** No system modifications made [Section 25.2.6.5]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.2, § 204	Notification of spill or release	**NOT APPLICABLE** No releases during this period and WID procedures in place [Section 25.2.6.6]
20 NMAC 5.2, § 205	Emergency repairs and tank replacement	**NOT APPLICABLE** No emergencies requiring repair or tank replacement [Section 25.2.6.7]
20 NMAC 5.2, § 206	Application forms	**ACHIEVED** Proper application forms used and submitted to the NMED [Section 25.2.6.8]
20 NMAC 5.2, § 207	Registration certificate	**ACHIEVED** Certificate displayed [Section 25.2.6.9]
	20 NMAC 5.3, *Annual Fee*	
20 NMAC 5.3, § 300	Payment of fee	**ACHIEVED** Fees paid annually by January 31 [Section 25.2.6.10]
20 NMAC 5.3, § 301	Amount of fee	**ACHIEVED** $200.00 paid per year ($100 per UST) [Section 25.2.6.11]
20 NMAC 5.3, § 302	Late payment penalties	**NOT APPLICABLE** No late payments made [Section 25.2.6.12]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.4, New and Upgraded *UST Systems: Design, Construction, and Installation*		
20 NMAC 5.4, § 400(a)	Performance standards to ensure that new UST systems tanks are properly designed and constructed	**ACHIEVED** ASTM and UL standards met by fiberglass-reinforced plastic tanks [Section 25.2.6.13]
20 NMAC 5.4, § 400(b)	Piping to be properly designed and constructed	**ACHIEVED** Fiberglass-reinforced plastic piping [Section 25.2.6.14]
20 NMAC 5.4, § 400(c)(1)(i)	Spill prevention equipment	**ACHIEVED** Spill catchment basin [Section 25.2.6.15]
20 NMAC 5.4, § 400(c)(1)(ii)	Overflow prevention equipment	**ACHIEVED** Model 310 extractor vent valve [Section 25.2.6.16]
20 NMAC 5.4, § 400(d)	Installation of tanks and piping	**ACHIEVED** Installer's oath on NMED tank registration form [Section 25.2.6.17]
20 NMAC 5.4, § 400(e)	Certificate of installation	**ACHIEVED** Certification of inspector; NMED UST Bureau representative present at installation of new UST systems [Section 25.2.6.18]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.4, § 401(a)	Upgrading of existing UST systems	**NOT APPLICABLE** Two new USTs installed on February 10, 1992 [Section 25.2.6.19]
20 NMAC 5.4, § 401(b)	Upgrading requirements for steel tanks	**NOT APPLICABLE** Single wall fiberglass-reinforced plastic tanks replaced with double-walled plastic tanks on February 10, 1992 [Section 25.2.6.20]
20 NMAC 5.4, § 401(c)	Upgrading requirements for metal piping	**NOT APPLICABLE** Metal piping replaced with fiberglass-reinforced plastic piping on February 10, 1992 [Section 25.2.6.21]
20 NMAC 5.4, § 401(d)	Spill and overfill protection equipment	**ACHIEVED** Current spill and overfill protection equipment meets 1998 deadline [Section 25.2.6.22]
20 NMAC 5.4, § 402	Certification of compliance with notification requirements	**ACHIEVED** Certification requirements met [Section 25.2.6.23]
20 NMAC 5.5, *General Operating Requirements*		
20 NMAC 5.5, § 500(a)	Spill and overfill control	**ACHIEVED** Addressed in WIPP procedure [Section 25.2.6.24]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.5, § 501(a)	Corrosion protection	**ACHIEVED** Rubber boots covering all metal fittings [Section 25.2.6.25]
20 NMAC 5.5, § 501(b)	Inspections of cathodic protection systems	**NOT APPLICABLE** No cathodic protection required [Section 25.2.6.26]
20 NMAC 5.5, § 501(c)	Inspections of impressed-current cathodic protection systems	**NOT APPLICABLE** No cathodic protection required for fiberglass-reinforced systems [Section 25.2.6.27]
20 NMAC 5.5, § 501(d)	Records of operation of the cathodic protection system	**NOT APPLICABLE** No cathodic protection required for fiberglass-plastic systems [Section 25.2.6.28]
20 NMAC 5.5, § 502	Compatibility	**ACHIEVED** Fiberglass-reinforced plastic system compatible with both diesel and unleaded fuel [Section 25.2.6.29]
20 NMAC 5.5, § 503(a)	Repairs allowed	**NOT APPLICABLE** No repairs performed on the UST system [Section 25.2.6.30]
20 NMAC 5.5, § 503(b)	Repairs to fiberglass-reinforced plastic tanks	**NOT APPLICABLE** No major repairs performed on the UST system [Section 25.2.6.31]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.5, § 503(c)	Replacement or repair of pipe sections and fittings	**NOT APPLICABLE** No repairs conducted on the pipes or fittings. [Section 25.2.6.32]
20 NMAC 5.5, § 503(d)	Tightness testing after repairs	**NOT APPLICABLE** No repairs conducted on the tanks or piping [Section 25.2.6.33]
20 NMAC 5.5, § 503(e)	Testing of any repaired cathodically protected UST system	**NOT APPLICABLE** No cathodic protection required [Section 25.2.6.34]
20 NMAC 5.5, § 503(f)	Records of all repairs	**UP TO DATE** Records of all repairs maintained for life of the UST system [Section 25.2.6.35]
20 NMAC 5.5, § 504(a)	Reporting requirements	**ACHIEVED** All required reports submitted [Section 25.2.6.36]
20 NMAC 5.5, § 504(b)	Record-keeping requirements	**ACHIEVED** All required records maintained [Section 25.2.6.37]
20 NMAC 5.5, § 504(c)	Availability and maintenance of records	**ACHIEVED** Records maintained at the site [Section 25.2.6.38]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.5, § 505(a)	Inspections, monitoring, and testing of USTs	**ACHIEVED** NMED personnel allowed to inspect, sample, and monitor the UST system [Section 25.2.6.39]
20 NMAC 5.5, § 505(c)	Inspections of UST installations, repairs or modifications, or removals or system closures	**ACHIEVED** NMED representative present at installation of new UST system [Section 25.2.6.40]
20 NMAC 5.6, *Release Detection*		
20 NMAC 5.6, § 600(a)	General requirements of all UST systems	**ACHIEVED** Interstitial monitoring system installed [Section 25.2.6.41]
20 NMAC 5.6, § 600(b)	Notification of releases	**ACHIEVED** No releases to date [Section 25.2.6.42]
20 NMAC 5.6, § 600(c)	Schedule for required release detection	**ACHIEVED** UST system designed so no release detection for piping is required; interstitial monitoring used for tanks [Section 25.2.6.43]
20 NMAC 5.6, § 600(d)	Failure to comply with release-detection requirements	**NOT APPLICABLE** Release-detection equipment used [Section 25.2.6.44]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.6, § 601(a)	Requirements for tanks of petroleum UST systems	**ACHIEVED** Interstitial monitoring used [Section 25.2.6.45]
20 NMAC 5.6, § 601(b)	Requirements for piping of petroleum UST systems	**ACHIEVED** See Sections 25.2.6.47 and 25.2.6.48 [Section 25.2.6.46]
20 NMAC 5.6, § 601(b)(1)	Requirements for pressurized piping	**NOT APPLICABLE** USTs under suction piping [Section 25.2.6.47]
20 NMAC 5.6, § 601(b)(2)	Requirements for suction piping	**ACHIEVED** Engineering drawings confirm compliance with this requirement [Section 25.2.6.48]
20 NMAC 5.6, § 602	Requirements for hazardous substance UST systems	**NOT APPLICABLE** No UST systems used for hazardous substances at the WIPP [Section 25.2.6.49]
20 NMAC 5.6, § 603	Methods of release detection for tanks	**ACHIEVED** Interstitial monitoring used [Section 25.2.6.50]
20 NMAC 5.6, § 603(a)	Inventory control	**ACHIEVED** Inventory control used as contingency method only [Section 25.2.6.51]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.6, § 603(b)	Manual tank gauging	**NOT APPLICABLE** Interstitial monitoring used [Section 25.2.6.52]
20 NMAC 5.6, § 603(c)	Tank tightness testing	**NOT APPLICABLE** Tank tightness testing not necessary when interstitial monitoring is used [Section 25.2.6.53]
20 NMAC 5.6, § 603(d)	Automatic tank gauging	**NOT APPLICABLE** Interstitial monitoring used [Section 25.2.6.54]
20 NMAC 5.6, § 603(e)	Vapor monitoring	**NOT APPLICABLE** Interstitial monitoring used [Section 25.2.6.55]
20 NMAC 5.6, § 603(f)	Ground-water monitoring	**NOT APPLICABLE** Interstitial monitoring used [Section 25.2.6.56]
20 NMAC 5.6, § 603(g)	Interstitial monitoring	**ACHIEVED** Release from any portion of the tank that regularly contains product detected by interstitial monitoring [Section 25.2.6.57]
20 NMAC 5.6, § 603(h)	*Other methods of detecting* releases	**NOT APPLICABLE** Interstitial monitoring used [Section 25.2.6.58]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.6, § 604	Methods of release detection for piping	**NOT APPLICABLE** Release detection for piping not required because of design [Section 25.2.6.59]
20 NMAC 5.6, § 605	Release detection record-keeping	**ACHIEVED** Required records maintained [Section 25.2.6.60]
20 NMAC 5.7, *Release Reporting, Investigation, and Confirmation*		
20 NMAC 5.7, § 700	Reporting of suspected releases	**NOT APPLICABLE** No releases to date [Section 25.2.6.61]
20 NMAC 5.7, § 701	Investigation of off-site impacts	**NOT APPLICABLE** Off-site-impact information not requested by NMED [Section 25.2.6.62]
20 NMAC 5.7, § 702	Release investigation and confirmation steps	**NOT APPLICABLE** No releases to date [Section 25.2.6.63]
20 NMAC 5.7, § 703(a)	Reporting and cleanup of spills and overfills exceeding 25 gallons (or an amount specified by NMED) or a hazardous substance *exceeding or equal to its* CERCLA reportable quantity	**NOT APPLICABLE** No spills or overfills [Section 25.2.6.64]
20 NMAC 5.7, § 703(b)	Reporting and cleanup of spills and overfills less than 25 gallons (or an amount specified by NMED) or a hazardous substance that is less than its reportable quantity	**ACHIEVED** Small spills and overfills properly controlled and cleaned up [Section 25.2.6.65]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.8, *Out-of-Service Systems and Closure*		
20 NMAC 5.8, § 800	Temporary closure	**NOT APPLICABLE** No temporary closure [Section 25.2.6.66]
20 NMAC 5.8, § 801(a)	Permanent closure and changes-in-service	**ACHIEVED** NMED notified before closure of old UST systems [Section 25.2.6.67]
20 NMAC 5.8, § 801(b)	Permanent closure of a tank	**ACHIEVED** Old UST system emptied, cleaned, and removed for permanent closure [Section 25.2.6.68]
20 NMAC 5.8, § 801(c)	Change in service	**NOT APPLICABLE** No change in service for UST systems [Section 25.2.6.69]
20 NMAC 5.8, § 802(a)	Assessing the site	**ACHIEVED** Site assessed prior to permanent closure of old UST systems; documentation maintained at WIPP [Section 25.2.6.70]
20 NMAC 5.8, § 802(b)	Corrective action	**UP TO DATE** UST area assessed before change in service; WID procedure in place [Section 25.2.6.71]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.8, § 803	Applicability to previously closed UST systems	**NOT APPLICABLE** No UST systems at WIPP closed before December 22, 1988 [Section 25.2.6.72]
20 NMAC 5.8, § 804	Closure records	**ACHIEVED** Tank closure; records maintained at the WIPP site [Section 25.2.6.73]
20 NMAC 5.9, *Financial Responsibility*		
20 NMAC 5.9, § 900	Applicability	**NOT APPLICABLE** Federal and state government entities exempt [Section 25.2.6.74]
20 NMAC 5.10, *Administrative Review*		
20 NMAC 5.10, § 1000	Informal review	**NOT APPLICABLE** Provision not invoked at WIPP [Section 25.2.6.75]
20 NMAC 5.10, § 1001	Review by Secretary	**NOT APPLICABLE** Provision not invoked at WIPP [Section 25.2.6.76]
Part I, *Miscellaneous*		
20 NMAC 5.1, § 108	Compliance with other regulations	See Chapters 2 - 24 and 25 - 38 for compliance with federal and state regulations, [Section 25.2.6.77]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.1, § 109	Construction	**NOT APPLICABLE** Construction of UST Regs [Section 25.2.6.78]
20 NMAC 5.1, § 110	Severability	**NOT APPLICABLE** No action required; pertains to regulations [Section 25.2.6.79]
20 NMAC 5.12, *Corrective Action for UST Systems Containing Petroleum*		
20 NMAC 5.12, § 1200(A)	Cleanup requirements for releases from petroleum UST systems	**NOT APPLICABLE** No releases with the UST system during this period [Section 25.2.6.80]
20 NMAC 5.12, §§ 1200(B)-1222	Additional corrective action requirements for petroleum UST systems	**NOT APPLICABLE** No corrective actions necessary for current UST system; WID procedures in place [Section 25.2.6.81]
20 NMAC 5.13, *Corrective Action for UST Systems Containing Other Regulated Substances*		
20 NMAC 5.13, §§ 1300-1320	Corrective action for hazardous substance UST systems	**NOT APPLICABLE** No hazardous substance USTs at WIPP [Section 25.2.6.82]
20 NMAC 5.14, *Certification of Tank Installers*		
20 NMAC 5.14, §§ 1400-1417	Certification of tank installers and repairers	**ACHIEVED** Required certification information maintained [Section 25.2.6.83]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 5.15, *Corrective Action Fund Allocation for State-Lead Sites*		
20 NMAC 5.15, § 1505	Priorities	**NOT APPLICABLE** Action taken by NMED [Section 25.2.6.84]
20 NMAC 5.15, § 1508	Minimum site assessment	**UP TO DATE** No UST releases to date [Section 25.2.6.85]
20 NMAC 5.16, *Certification of Contractors*		
20 NMAC 5.16	Certification requirements for firms performing work for which payment from the Corrective Action Fund will be sought	**NOT APPLICABLE** The Ground Water Protection Act prohibits expenditures from the Fund for corrective action at federally owned or operated sites [Section 25.2.6.86]
20 NMAC 5.17, *Corrective Action Fund Payment and Reimbursement*		
20 NMAC 5.17	Provisions for payments or reimbursements from the Corrective Action Fund	**NOT APPLICABLE** The Ground Water Protection Act prohibits expenditures from the Fund for corrective action at federally owned or operated sites [Section 25.2.6.87]

25.2.6.1 Applicability, 20 NMAC 5.1, § 103; 40 CFR 280.10

Any owner or operator of an UST that contains a hazardous substance or petroleum product must meet the standards set by the New Mexico Environmental Improvement Board (EIB) in the New Mexico Underground Storage Tank Regulations (USTRs).

The WIPP has two 8,000-gallon USTs. One contains unleaded gasoline, and the other contains diesel fuel.

25.2.6.2 Existing Tanks, 20 NMAC 5.2, § 200

> *The owner of any UST must register such tank or tanks with the Underground Storage Tank section of the NMED within three months after April 14, 1988, the effective date of this Part II as first adopted, except that any owner who has filed the form of notice entitled "Notification for Underground Storage Tanks," prescribed by the EPA and described in 40 CFR Part 280, is not required to register a tank for which a notice has been filed, provided that the information provided is still current.*
>
> *Registration becomes effective upon receipt of the first year's annual fee described in Sections 25.2.6.10 and 25.2.6.11. Registration must by renewed annually by payment of the annual fee until the permanent closure of the tank.*

Both USTs at WIPP are registered with the Underground Storage Tank Bureau of the NMED.

25.2.6.3 Transfer of Ownership, 20 NMAC 5.2, § 201

> *If ownership of the UST system changes, the new owner must re-register the tank with the division within 30 days of ownership transfer, using a form provided by the division.*

This section is not applicable since ownership of the tanks has not been transferred.

25.2.6.4 New UST System, 20 NMAC 5.2, § 202

> *The owner must notify the division in writing at least 30 days before any new tank or UST system is installed and must register any new tank or UST system with the division prior to placing it in service.*

Proper notification was provided to the NMED prior to the February 10, 1992, installation of the new UST system. The application for the new system was submitted on June 18, 1992, and the USTs were placed into service shortly thereafter.

25.2.6.5 Substantially Modified UST Systems, 20 NMAC 5.2, § 203

> *When an existing UST system is substantially modified or replaced, the owner must notify the division in writing of such modification or replacement at least 30 days prior to the modification or replacement. Emergency repairs or replacements made as described in Section 25.2.6.7 are exempt from these notification requirements.*

Proper notification was provided to the NMED prior to the February 10, 1992, installation of the new UST system. The application for the new system was submitted on June 18, 1992, and the USTs were placed into service shortly thereafter.

25.2.6.6 Notification of Spill or Release, 20 NMAC 5.2, § 204

> *Notice of any known or suspected release from a UST system, any spill, or any other emergency situation must be given to the NMED by telephone within 24 hours. The owner or operator making the report shall provide the information specified under Section 204(A).*
>
> *Written notice describing the spill, release, or suspected release and any investigation or follow-up action taken or to be taken must be mailed or delivered to the NMED within seven days of the incident. The written notice shall verify the prior oral notification as to each of the items of information listed in subsection A and provide any appropriate additions or corrections to the information contained in the prior oral notification.*

No releases have occurred during this reporting period. However, if this should occur, WID procedures discuss the requirements for the proper handling of spills and releases.

25.2.6.7 Emergency Repairs and Tank Replacement, 20 NMAC 5.2, § 205

> *Immediate repairs or replacement of an UST system may be made in the event an emergency situation presents a threat to the public health, provided notice is given to the NMED as described in Section 25.2.6.6.*

No such emergency repair or replacement of an UST system has been necessary at WIPP to date.

25.2.6.8 Application Forms, 20 NMAC 5.2, § 206

> *All USTs must be registered on application forms provided by the NMED unless the EPA form ("Notification for Underground Storage Tanks") has been submitted to the NMED and all information contained therein is still accurate. An application submitted by a municipal, state, or other public facility must be signed by either a principal executive officer, ranking elected official, or other duly authorized employee.*

The New Mexico UST registration form is used to register the USTs at WIPP. It has been submitted to the NMED.

25.2.6.9 Registration Certificate, 20 NMAC 5.2, § 207

> *Upon submittal of a complete registration application or the EPA form and payment of the annual fee, the NMED shall issue a validated registration certificate which is current and valid and must be displayed on the premises of the UST system at all times. In the event that any information provided on the registration form or the EPA form changes or is no longer accurate, the change must be reported to the NMED on the appropriate form within 30 days.*

The registration certificate from the NMED is displayed.

25.2.6.10 Payment of Fee, 20 NMAC 5.3, § 300

> *An annual per-tank fee shall be paid to the NMED no later than January 31 for each current calendar year or portion of a year that a tank is in use. A tank shall be deemed "in use" until notice is received by the NMED that the tank has been removed or otherwise permanently closed in a manner acceptable to the division.*
>
> *The annual fee for a new tank placed in service after January 31 for any calendar year after 1989 shall be paid within 30 days after the tank is placed in service. The annual fees shall be designated to the Hazardous Waste and Underground Storage Tank Fund.*

The annual fee per UST at WIPP is paid by January 31 for each calendar year. The fee for the replacement tanks accompanied the application that was transmitted to the NMED.

25.2.6.11 Amount of Fee, 20 NMAC 5.3, § 301

The annual fee for each UST is $100.00 per tank.

The annual fee paid for each UST at WIPP is $100, or $200 for both tanks.

25.2.6.12 Late Payment Penalties, 20 NMAC 5.3, § 302

In the event that the annual fee is not paid when due, a late fee of $5.00 or 5 percent of the unpaid fee, whichever is greater, and interest charges at the rate of 1.5 percent per month shall be imposed and shall accumulate until the annual fee and all accrued late fees and interest charges are paid.

No late payment penalties have been incurred.

25.2.6.13 Performance Standards for Tanks in New UST Systems, 20 NMAC 5.4 § 400(a); 40 CFR 280.20(a)

Each tank must be properly designed and constructed, and any portion underground must be protected from corrosion by a nationally recognized association or independent testing laboratory as specified. Each tank must be constructed of fiberglass-reinforced plastic; steel, with cathodic protection; or steel-fiberglass-reinforced-plastic composite. The tank may be constructed of metal without additional corrosion protection if the conditions apply as described in Section 400(a)(4) of 20 NMAC 5.4.

The tanks are designed and constructed of fiberglass-reinforced plastic in accordance with Underwriters Laboratories Standard 1316, *Standard for Glass-Fiber-Reinforced Plastic Underground Storage Tanks for Petroleum Products*, and with the American Society for Testing and Materials (ASTM) Standard D4021-86, *Standard Specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks.*

25.2.6.14 Design and Construction of Piping, 20 NMAC 5.4, § 400(b); 40 CFR 280.20(b)

The piping that routinely contains regulated substances and is in contact with the ground must be properly designed,

constructed, and protected from corrosion in accordance with a code of practice developed by a nationally recognized association or independent testing laboratory as specified. The piping is constructed of fiberglass-reinforced plastic; or steel, with cathodic protection; or metal without additional corrosion protection measures provided that the piping is installed at a non-corrosive site and records are maintained that demonstrate the noncorrosivity of the site for the remaining life of the piping. The piping construction and corrosion protection are determined by the implementing agency to be designed to prevent the release or threatened release of any stored regulated substance in a manner that is no less protective of human health and the environment.

The piping is constructed of fiberglass-reinforced plastic as designed by the Xerxes Corporation in accordance with the appropriated standards.

25.2.6.15 Spill Prevention Equipment, 20 NMAC 5.4, § 400(c)(1)(i); 40 CFR 280.20(c)(1)(i)

Owners and operators must use spill prevention equipment that will prevent the release of product to the environment when the transfer hose is detached from the fill pipe (for example, a spill catchment basin).

The WIPP's UST system uses a spill catchment basin.

25.2.6.16 Overflow Prevention Equipment, 20 NMAC 5.4, § 400(c)(1)(ii); 40 CFR 280.20(c)(1)(ii)

Overfill-prevention equipment must be used that will automatically shut off flow into the tank when the tank is no more than 95 percent full; alert the transfer operator when the tank is no more than 90 percent full by restricting the flow into the tank or triggering a high-level alarm; or restrict the flow 30 minutes prior to overfilling, alert the operator with a high-level alarm one minute before overfilling, or automatically shut off flow into the tank so that none of the fittings located on top of the tank is exposed to product due to overfilling. Owners and operators may use alternative equipment if it is determined by the implementing agency to be no less protective of human health and the environment than the equipment specified above or if the UST system is filled by transfers of no more than 25 gallons at one time.

The Model 310 extractor vent valve is used to automatically shut off the flow into the tank when the tank is no more than 95 percent full. This valve is a permanent part of the system.

25.2.6.17 Installation of Tanks and Piping, 20 NMAC 5.4, § 400(d); 40 CFR 280.20(d)

> *All tanks and piping must be properly installed in accordance with a code of practice developed by a nationally recognized association or independent testing laboratory and in accordance with the manufacturer's instructions.*

The installer (Cline Pump Co.) certified on the NMED application that the methods used to install the tanks and piping comply with the requirements. Cline Pump has supplied the WIPP with copies of qualified certification.

25.2.6.18 Certificate of Installation, 20 NMAC 5.4, § 400(e); 40 CFR 280.20(e)

> *All owners and operators must ensure that one or more of the specified methods of certification, testing, or inspection was used to demonstrate compliance with Section 25.2.6.17 by providing a certification of compliance on the UST notification form required by 20 NMAC 5.2. The allowable methods of certification for the installer are: certification by the tank and piping manufacturers; certification or licensing by the implementing agency; inspection and certification of the installation by a registered professional engineer with education and experience in UST system installation, inspection and approval by the implementing agency, or the presence of a representative from the UST Bureau of the NMED at the installation; completion of all work listed on the manufacturer's installation checklists; or compliance with another method for ensuring compliance with this section that is determined by the implementing agency to be no less protective of human health and the environment.*

Cline Pump Company is certified by the NMED. The installation of the new systems was inspected and approved by an NMED representative who was present during the installation.

25.2.6.19 Upgrading Existing UST Systems, 20 NMAC 5.4, § 401(a); 40 CFR 280.21(a)

All existing UST systems must be upgraded to meet the new performance standards (see Sections 25.2.6.13 through 25.2.6.18), the requirements described in Sections 25.2.6.20 through 25.2.6.22, or the closure requirements described in Sections 25.2.6.66 through 25.2.6.73 by December 22, 1998.

The UST system formerly used at the WIPP has been replaced. The new system meets the new performance standards (see Sections 25.2.6.13 through 25.2.6.18); therefore, upgrading is not appropriate at this time.

25.2.6.20 Tank Upgrading Requirements, 20 NMAC 5.4, § 401(b); 40 CFR 280.21(b)

Steel tanks must be upgraded to have an interior lining and/or cathodic protection.

The new tanks are constructed of fiberglass-reinforced plastic and are not constructed of steel (See Section 25.2.6.19).

25.2.6.21 Piping Upgrading Requirements, 20 NMAC 5.4, § 401(c); 40 CFR 280.21(c)

Metal piping that routinely contains regulated substances and is in contact with the ground must be cathodically protected.

The piping for the UST system at WIPP is made of double-walled fiberglass-reinforced plastic.

25.2.6.22 Spill and Overfill Prevention Equipment, 20 NMAC 5.4, § 401(d); 40 CFR 280.21(d)

To prevent spilling and overfilling associated with the transfer of product to the UST system, all existing UST systems must comply with the new UST system spill and overfill prevention equipment requirements specified in 20 NMAC 5.4, Section 400(c).

Spill and overfill prevention equipment has been incorporated into the new UST system as described in Sections 25.2.6.15 and 25.2.6.16.

25.2.6.23 Certificate of Compliance and Notification Requirements, 20 NMAC 5.4, §402; 40 CFR 280.22

In the registration application required by 20 NMAC 5.2, all owners and operators of new UST systems must certify compliance with the installation requirements of USTR Section 400(e), cathodic protection requirements for steel tanks and piping under Sections 400(a) and (b), financial responsibility under 20 NMAC 5.9, and release detection under Sections 601 and 602. The owners and operators must also ensure that the installer certifies that the methods used to install the tanks and piping comply with the requirements in Section 400(d).

The notification requirements pertain to the person who sells a tank intended to be used as an UST.

As outlined in the registration form, the certification requirements were met. The cathodic protection requirements are not applicable since neither the tank nor the piping is made of steel. The financial responsibility requirements are not applicable because WIPP is owned by the DOE. The notification requirements apply only to the person who sold the tank to be used as an UST and therefore do not apply to WIPP.

25.2.6.24 Spill and Overfill Control, 20 NMAC 5.5, § 500 (a); 40 CFR 280.30

Owners and operators must ensure that any releases due to spilling or overfilling do not occur, that the volume available in the tank is greater than the volume of product to be transferred to the tank before the transfer is made, and that the transfer operation is monitored constantly to prevent overfilling and spilling. Any spills or overfills must be reported, cleaned up, and investigated in accordance with 20 NMAC, Chapter 5, Sections 204 and 703.

The new tanks are equipped with spill and overfill protection equipment. WID procedures are in place that govern the transfer of product to the tanks and that specify requirements for reporting, cleaning up, and investigating spills or overfills.

25.2.6.25 Operation and Maintenance of Corrosion Protection, 20 NMAC 5.5, § 501(a); 40 CFR 280.31(a)

All corrosion protection systems must be operated and maintained to continuously provide corrosion protection to the metal components of that portion of the tank and piping

that routinely contain regulated substances and are in contact with the ground.

The corrosion protection consists of rubber boots around the metal fittings.

25.2.6.26 Inspections of Cathodic Protection System, 20 NMAC 5.5, § 501(b); 40 CFR 280.31(b)

All UST systems equipped with cathodic protection systems must be inspected for proper operation by a qualified cathodic protection tester in accordance with requirements regarding the frequency of inspections and specific inspection criteria.

Cathodic protection is required only for steel tanks and metal parts. The metal fittings in the UST system are protected by rubber boots. Therefore, cathodic protection is not required.

25.2.6.27 Inspections of Impressed-Current Cathodic Protection Systems, 20 NMAC 5.5, § 501(c); 40 CFR 280.31(c)

UST systems with impressed-current cathodic protection systems must be inspected every 60 days to ensure that the equipment is running properly.

No cathodic protection systems are required for fiberglass-reinforced plastic systems.

25.2.6.28 Records of Operation of the Cathodic Protection System, 20 NMAC 5.5, § 501(d); 40 CFR 280.31(d)

For UST systems using cathodic protection, records of the operation of the cathodic protection system must be maintained in accordance with 40 CFR 280.34 to demonstrate compliance with the performance standards in this section. These records must provide the results of inspections.

No cathodic protection is required for fiberglass-reinforced plastic UST systems. Therefore, this requirement does not apply.

25.2.6.29 Compatibility, 20 NMAC 5.5, § 502; 40 CFR 280.32

Owners and operators must use an UST system made of or lined with materials that are compatible with the substance stored in the UST system.

Fiberglass-reinforced plastic is compatible with unleaded and diesel fuel.

25.2.6.30 Repairs Allowed, 20 NMAC 5.5, § 503(a); 40 CFR 280.33(a)

Repairs to UST systems must be properly conducted in accordance with a code of practice developed by a nationally recognized association or an independent testing laboratory.

To date, no major repairs have been required.

25.2.6.31 Repairs to Fiberglass-Reinforced Plastic Tanks, 20 NMAC 5.5, § 503(b); 40 CFR 280.33(b)

Repairs to fiberglass-reinforced plastic tanks may be made by the manufacturer's authorized representatives or in accordance with a code of practice developed by a nationally recognized association or an independent testing laboratory.

To date, no major repairs have been required.

25.2.6.32 Repairs of Pipe Sections and Fittings, 20 NMAC 5.5, § 503(c); 40 CFR 280.33(c)

Metal pipe sections and fittings that have released product as a result of corrosion or other damage must be replaced. Fiberglass pipes and fittings may be repaired in accordance with the manufacturer's specifications.

No repairs have been conducted on the pipes or fittings.

25.2.6.33 Tightness Testing After Repairs, 20 NMAC 5.5, § 503(d); 40 CFR 280.33(d)

Repaired tanks and piping must be tightness tested in accordance with 20 NMAC 5.6, Sections 603(d) and 604(b) within 30 days after the date of the completion of the repair except as provided in this section.

No repairs have been conducted on the tanks or piping.

25.2.6.34 Testing of Repaired Cathodically Protected UST System, 20 NMAC 5.5, § 503(e); 40 CFR 280.33(e)

Within 6 months following the repair of any cathodically protected UST system, the cathodic protection system must be tested in accordance with 20 NMAC 5.5, Sections 501(b) and (c) to ensure that it is operating properly.

The current UST system does not require cathodic protection.

25.2.6.35 Records of all Repairs, 20 NMAC 5.5, § 503(f); 40 CFR 280.33(f)

UST system owners and operators must maintain records of each repair for the remaining operating life of the UST system to demonstrate compliance with the requirements of this section.

No repairs have been performed on the current system. However, when UST system repairs are necessary, the records will be maintained at WIPP for the life of the UST system.

25.2.6.36 Reporting, 20 NMAC 5.5, § 504(a); 40 CFR 280.34(a)

Owners and operators must submit the following information to the NMED: registration of all UST systems, including certification of installation for new UST systems (20 NMAC 5.2); reports of all releases (including suspected releases, spills, and overfills) and confirmed releases; corrective actions planned or taken; and a notification before permanent closure or change in service.

The information in this requirement has been submitted to the NMED. Spill, overfill, and release reporting requirements are addressed by WID procedures.

25.2.6.37 Record-keeping Requirements, 20 NMAC 5.5, § 504(b); 40 CFR 280.34(b)

Owners and operators must maintain the following information: a corrosion expert's analysis of site corrosion potential if corrosion protection equipment is not used, documentation of operation of corrosion protection equipment, documentation of UST system repairs, recent

compliance with release detection requirements, and the results of the site investigation required prior to permanent closure.

The rubber boots are considered adequate to meet the corrosion protection requirements since the tank and piping consist of fiberglass-reinforced plastic. Metal flex elbow fittings are contained within the rubber boots, which separate them from contact with the ground.

WID procedures specify the retention time for records of UST system repairs.

A WIPP procedure addresses the retention of monitoring results. Correspondence WD 93:00280 contains the tank closure form as an attachment.

25.2.6.38 Availability and Maintenance of Records, 20 NMAC 5.5, § 504(c); 40 CFR 280.34(c)

The applicable records must be kept either at the UST site and immediately available for inspections by the NMED or at a readily available alternative site and be provided to the NMED upon request.

The UST records are maintained at the WIPP site.

25.2.6.39 Inspections, Monitoring, and Testing of USTs, 20 NMAC 5.5, § 505(a)

Any owner or operator of an UST shall, upon the request of the director or authorized NMED representatives, furnish information relating to the UST(s), conduct monitoring or testing, and allow the NMED representative to have access to the USTs and to copy all records relating to such tanks at all reasonable times. NMED officers, employees, or representatives will be allowed to inspect the UST system(s) and obtain samples of its contents and to conduct monitoring or testing of the tanks and its associated equipment or the surrounding soils, air, surface water, or ground water.

NMED personnel are allowed to inspect the UST systems at any reasonable time. They are also allowed to sample the contents of the USTs. Monitoring or testing of the tanks and associated equipment and contents or the surrounding soils, air, or surface or ground water may also be performed.

25.2.6.40 Inspections of UST Installations, Repairs or Modifications, or Removals or System Closures, 20 NMAC 5.5, § 505(c)

> *The owner and operator must allow the Director or authorized NMED representatives to be present at and inspect all UST system installations, replacements, repairs, substantial modifications, installations of leak detection systems, and UST system closures. To ensure that the inspector has an opportunity to be present during the steps in these procedures which are important to the prevention of releases, the owner or operator must give the NMED oral notice of the dates on which critical junctures in the installation, repair, substantial modification, or closure of the UST system are to take place. Oral notice must be given at least 24 hours in advance of the commencement of the procedure. The inspector may require that critical junctures be performed from Monday through Friday during regular business hours.*

A representative of the NMED UST Bureau was present at the installation of the new UST systems on February 10, 1992.

25.2.6.41 General Requirements for all UST Systems, 20 NMAC 5.6, § 600(a); 40 CFR 280.40(a)

> *Owners and operators of new and existing UST systems must provide a method, or combination of methods, of release detection that can detect a release from any portion of the tank and the connected underground piping that routinely contains product; is installed, calibrated, operated, and maintained in accordance with the manufacturer's instructions, including routine maintenance and service checks for operability or running condition; meets the performance requirements; and must be capable of detecting the leak rate or quantity specified for that method in the corresponding section of the rule with a probability of detection (pd) of 0.95 and a probability of false alarm (pfa) of 0.05.*

The UST system uses interstitial monitoring to detect releases. There are sensors between the walls at the lowest end of the piping and tank. Interstitial monitoring is adequate because it can detect a release through the inner wall in any portion of the double-walled tank and/or piping that regularly contains product.

25.2.6.42 Notification of Releases, 20 NMAC 5.6, § 600(b); 40 CFR 280.40(b)

When a release detection method operated in accordance with the performance standards in 20 NMAC 5.6, Sections 603 and 604 indicates that a release may have occurred, owners and operators must notify the NMED in accordance with 20 NMAC 5.2, Section 204, and 20 NMAC 5.7.

No releases or suspected releases have occurred with the current UST system.

25.2.6.43 Schedule for Required Release Detection, 20 NMAC 5.6, § 600(c); 40 CFR 280.40(c)

Owners and operators of all UST systems must comply with the release-detection requirements of this part by December 22 of the year listed in the schedule in 40 CFR 280.40(c) e.

New UST systems were installed on February 10, 1992. The new systems meet the release-detection requirements of this part.

25.2.6.44 Failure to Comply with Release-Detection Requirements, 20 NMAC 5.6, § 600(d); 40 CFR 280.40(d)

Any existing UST system that cannot apply a release-detection method that complies with the requirements of this part must complete the closure procedures for the system by the date indicated in 20 NMAC 5.6, Section 600(c) (Section 25.2.6.43).

The new UST system at WIPP uses a release-detection method that complies with the requirements of this part. Therefore, Section USTR 600(d) does not apply to the WIPP UST systems.

25.2.6.45 Requirements for Tanks of Petroleum UST Systems, 20 NMAC 5.6, § 601(a); 40 CFR 280.41(a)

Tanks must be monitored at least every 30 days for releases using one of the methods listed in 20 NMAC 5.6, Sections 603(d)-(h) (see Sections 25.2.6.54 through 25.2.6.58) except that UST systems that meet the performance standards and the monthly inventory control requirements may use tank tightness testing at least every five years until December 22, 1998, or until 10 years after the tank is installed or upgraded, whichever is later; UST systems that do not meet the performance standards may use monthly

inventory controls and annual tank tightness testing until December 22, 1998, when the tank must be upgraded or permanently closed; and tanks with a capacity of 550 gallons or less may use weekly tank gauging.

The interstitial monitoring system meets the release-detection requirement. Should the interstitial system become inoperable, monthly inventory controls will be used. In this contingency situation, tank tightness testing will be performed every five years.

25.2.6.46 Requirements for Piping of Petroleum UST Systems, 20 NMAC 5.6, § 601(b); 40 CFR 280.41(b)

Underground piping that routinely contains regulated substances must be monitored for releases in a manner that meets the requirements for pressurized or suction piping.

See Section 25.2.6.48, which specifies the requirements for suction piping as used in the UST systems at WIPP.

25.2.6.47 Requirements for Pressurized Piping, 20 NMAC 5.6, § 601(b)(1); 40 CFR 280.41(b)(1)

Underground piping that conveys regulated substances under pressure must be equipped with an automatic line leak detector and have an annual line-tightness test or have monthly monitoring conducted.

This requirement is not applicable since the current UST system operates under suction piping.

25.2.6.48 Requirements for Suction Piping, 20 NMAC 5.6, § 601(b)(2); 40 CFR 280.41(b)(2)

Underground piping that conveys regulated substances under suction must either have a line tightness test conducted at least every 3 years in accordance with 20 NMAC 5.6, Section 604(b), or use a monthly monitoring method conducted in accordance with 20 NMAC 5.6, Section 604(c). No release detection is required for suction piping that is designed and constructed to meet the following standards: the below-grade piping operates at less than atmospheric pressure; the below-grade piping is sloped so that the contents of the pipe will drain back into the storage tank if the suction is released; only one check valve is included in each suction line; the check valve is located

directly below and as close as practical to the suction pump; and a method is provided that allows compliance with this section to be readily determined.

No release detection is required on the piping since the system was designed and constructed to meet each of the above requirements.

25.2.6.49 Requirements for Hazardous Substance UST Systems, 20 NMAC 5.6, § 602; 40 CFR 280.42

A number of release-detection requirements are specified for UST systems that contain hazardous substances.

WIPP has no UST systems that contain hazardous substances. Therefore, these requirements do not apply to this facility.

25.2.6.50 Methods of Release Detection for Tanks, 20 NMAC 5.6, § 603; 40 CFR 280.43

A number of requirements for the acceptable release-detection methods are specified. The release-detection methods described are: inventory control, manual tank gauging, tank-tightness testing, automatic tank gauging, vapor monitoring, ground-water monitoring, interstitial monitoring, and other methods.

WIPP uses interstitial monitoring (See Sections 25.2.6.51 through 25.2.6.59).

25.2.6.51 Inventory Control, 20 NMAC 5.6, § 603(a); 40 CFR 280.43(a)

Product inventory control (or another test of equivalent performance) must be conducted monthly to detect a release of at least 1.0 percent of flow-through plus 130 gallons on a monthly basis in the following manner: inventory volume measurements for regulated substance inputs, withdrawals, and the amount still remaining in the tank are recorded each operating day; the equipment used is capable of measuring the level of product over the full range of the tank's height to the nearest one-eighth of an inch; the regulated substance inputs are reconciled with delivery receipts by measurement of the tank inventory volume before and after delivery; deliveries are made through a drop tube that extends to within 1 foot of the tank bottom; product dispensing is metered and recorded within the local standards for meter calibration or an accuracy of 6

cubic inches for every five gallons of product withdrawn; and the measurement of any water level in the bottom of the tank is made to the nearest one-eighth of an inch at least once a month.

Inventory control is a "contingency" method used only if the interstitial monitoring system fails. There is a WIPP procedure addressing the requirements for using this method if this situation arises. Compliance with the requirement for a drop tube extending to within one foot of the tank bottom has been verified through discussions with the installing organization. The stick reading can measure to the nearest one-eighth of an inch.

25.2.6.52 Manual Tank Gauging, 20 NMAC 5.6, § 603(b); 40 CFR 280.43(b)

Manual tank gauging must meet the following requirements: tank liquid level measurements are taken at the beginning and ending of a period of at least 36 hours during which no liquid is added to or removed from the tank; level measurements are based on an average of two consecutive stick readings at both the beginning and ending of the period; the equipment used is capable of measuring the level of product over the full range of the tank's height to the nearest one-eighth of an inch; a leak is suspected and subject to the requirements of 20 NMAC 5.7 if the variation between beginning and ending measurements exceeds the weekly or monthly standards in the table provided.

This requirement is not applicable since the UST system uses interstitial monitoring as the primary method of release detection.

25.2.6.53 Tank Tightness Testing, 20 NMAC 5.6, § 603(c); 40 CFR 280.43(c)

Tank tightness testing (or another test of equivalent performance) must be capable of detecting a 0.1-gallon-per-hour leak rate from any portion of the tank that routinely contains product while accounting for the effects of thermal expansion or contraction of the product, vapor pockets, tank deformation, evaporation or condensation, and the location of the water table.

Tank tightness testing is not required for the current UST setup. If the interstitial monitoring method fails, tank tightness testing will be performed every five years as part of the inventory control method.

25.2.6.54 Automatic Tank Gauging, 20 NMAC 5.6, § 603(d); 40 CFR 280.43(d)

> *Equipment for automatic tank gauging that tests for the loss of product and conducts inventory control must meet the following requirements: the automatic product level monitor test can detect a 0.2-gallon-per-hour leak rate from any portion of the tank that routinely contains product, and inventory control (or another test of equivalent performance) is conducted in accordance with the requirements of 20 NMAC 5.6, Section 603(a).*

This method is not applicable for the current UST system (See Sections 25.2.6.51, 25.2.6.53, and 25.2.6.57).

25.2.6.55 Vapor Monitoring, 20 NMAC 5.6, § 603(e); 40 CFR 280.43(e)

> *Testing or monitoring for vapors within the soil gas of the excavation zone must meet the following requirements: the materials used as backfill are sufficiently porous (e.g., gravel, sand, crushed rock) to readily allow diffusion of vapors from releases into the excavation area; the stored regulated substance (e.g., gasoline), or a tracer compound placed in the tank system, is sufficiently volatile to result in a vapor level that is detectable by the monitoring devices located in the excavation zone in the event of a release from the tank; the measurement of vapors by the monitoring device is not rendered inoperative by the ground water, rainfall, soil moisture, or other known interferences so that a release could go undetected for more than 30 days; the level of background contamination in the excavation zone will not interfere with the method used to detect releases from the tank; the vapor monitors are designed and operated to detect any significant increase in concentration above background of the regulated substance stored in the tank system, a component or components of that substance, or a tracer compound placed in the tank system; in the UST excavation zone, the site is assessed to establish the number and positioning of monitoring wells that will detect releases within the excavation zone from any portion of the tank that routinely contains product; and monitoring wells are clearly marked and secured to avoid unauthorized access and tampering.*

This method is not applicable for the current UST system (See Sections 25.2.6.51, 25.2.6.53, and 25.2.6.57).

25.2.6.56 Ground-Water Monitoring, 20 NMAC 5.6, § 603(f); 40 CFR 280.43(f)

> *Testing or monitoring for liquids in the ground water must meet the following requirements: the regulated substance stored is immiscible in water and has a specific gravity of less than 1; ground water is never more than 20 feet from the ground surface, and the hydraulic conductivity of the soil(s) between the UST system and the monitoring wells or devices is not less than 0.01 cm/sec (e.g., the soil should consist of gravels, coarse to medium sands, coarse silts, or other permeable materials); the slotted portion of the monitoring well casing must be designed to prevent the migration of natural soils or filter pack into the well and to allow the entry of regulated substances on the water table into the well under both high and low ground-water conditions; monitoring wells shall be sealed from the ground surface to the top of the filter pack; monitoring wells or devices intercept the excavation zone or are as close to it as is technically feasible; the continuous monitoring devices or manual methods used can detect the presence of at least one-eighth of an inch of free product on top of the ground water in the monitoring wells; within and immediately below the UST system excavation zone, the site is assessed to ensure compliance with the first five requirements of this section and to establish the number and positioning of the monitoring wells or devices that will detect releases from any portion of the tank that routinely contains product; and monitoring wells are clearly marked and secured to avoid unauthorized access and tampering.*

The requirements of this section are not applicable to WIPP. The regulations require that tanks be monitored for releases using one of several methods. WIPP utilizes interstitial monitoring to meet the requirement (See Section 25.2.6.57).

25.2.6.57 Interstitial Monitoring, 20 NMAC 5.6, § 603(g); 40 CFR 280.43(g)

> *Interstitial monitoring between the UST system and a secondary barrier immediately around or beneath it may be used, but only if the system is designed, constructed, and installed to detect a leak from any portion of the tank that routinely contains product and also meets one of the following requirements: for double-walled UST systems, the sampling or testing method can detect a release through the inner wall in any portion of the tank that routinely contains product; for UST systems with a secondary barrier within the*

excavation zone, the sampling or testing method used can detect a release between the UST system and the secondary barrier; the secondary barrier around or beneath the UST system consists of artificially constructed material that is sufficiently thick and impermeable (at least 10^{-6} cm/sec for the regulated substance stored) to direct a release to the monitoring point and permit its detection; the barrier is compatible with the regulated substance stored so that a release from the UST system will not cause a deterioration of the barrier, allowing a release to pass through undetected; for cathodically protected tanks, the secondary barrier must be installed so that it does not interfere with the proper operation of the cathodic protection system; the ground water, soil moisture, or rainfall will not render the testing or sampling method used inoperative so that a release could go undetected for more than 30 days; the site is assessed to ensure that the secondary barrier is always above the ground water and is not located in a 25-year flood plain, unless the barrier and monitoring designs are for use under such conditions; monitoring wells are clearly marked and secured to avoid unauthorized access and tampering; and, for tanks with an internally fitted liner, an automated device can detect a release between the inner wall of the tank and the liner, and the liner is compatible with the substance stored.

The interstitial monitoring system is the primary method of release detection for the UST system. The as-built engineering drawings verify that this method can detect a release through the inner wall in any portion of the tank that routinely contains product.

25.2.6.58 Other Methods of Detecting Releases, 20 NMAC 5.6, § 603(h); 40 CFR 280.43(h)

Any other method may be used if it can detect a 0.2-gallon-per-hour leak rate or a release of 150 gallons within a month with a probability of detection of 0.95 and a probability of false alarm of 0.05, and it has been approved by the NMED.

The WIPP does not use any methods of release detection other than the ones described in Sections 25.2.6.51 and 25.2.6.57.

25.2.6.59 Methods of Release Detection of Piping, 20 NMAC 5.6, § 604; 40 CFR 280.44

Each method of release detection for piping used to meet the requirements of 20 NMAC 5.6, Section 601, must be conducted in accordance with specific requirements for automatic line leak detectors, line tightness testing, or applicable tank methods.

Since the system meets the requirements of 20 NMAC 5.6, Section 601(b)(2), line leak detectors are not required.

25.2.6.60 Release Detection Record-keeping, 20 NMAC 5.6, § 605; 40 CFR 280.45

All UST system owners and operators must maintain records in accordance with 20 NMAC 5.5, Section 504, that demonstrate compliance with all applicable requirements in 20 NMAC 5.6. All written performance claims pertaining to any release detection system used, and the manner in which these claims have been justified or tested by the equipment manufacturer or installer, must be maintained for five years, or for another reasonable period of time determined by the NMED, from the date of installation. The results of any sampling, testing, or monitoring must be maintained for at least 1 year, or for any reasonable period of time determined by the NMED, except that the results of tank tightness testing conducted in accordance with 20 NMAC 5.6, Section 603(c), must be retained until the next test is conducted. Written documentation of all calibration, maintenance, and repair of release-detection equipment permanently located on site must be maintained for at least one year after the servicing work has been completed or for any reasonable time period determined by the NMED. Any schedules of required calibration and maintenance provided by the release-detection equipment manufacturer must be retained for 5 years from the date of installation.

The WID purchasing group maintains the manufacturer's equipment and performance claims records. The Records Inventory and Disposition Schedule (RIDS) discusses the maintenance of these records. The RIDS adequately addresses the record retention requirements of this section. According to the manufacturer of the tanks, no calibration or maintenance is required for the current configuration. However, if modifications are made, these functions will need to be performed.

25.2.6.61 Reporting of Suspected Releases, 20 NMAC 5.7, § 700; 40 CFR 280.50

Owners and operators of UST systems must report suspected releases to the NMED within 24 hours and follow the procedures in 20 NMAC 5.7, Section 702, for any of the following conditions:

- *The discovery by owners and operators or others of released regulated substances at the UST site or in the surrounding area*
- *Unusual operating conditions*
- *Monitoring results from a release detection method that indicate that a release may have occurred unless the monitoring device is found to be defective and is immediately repaired and subsequent monitoring does not confirm the initial results or, in the case of inventory control, a second month of data does not confirm the initial result.*

No releases or suspected releases have occurred from the current UST system. A WIPP procedure outlines the required steps above should a suspected release occur.

25.2.6.62 Investigation of Off-Site Impacts, 20 NMAC 5.7, § 701; 40 CFR 280.51

When required by the NMED, owners and operators of UST systems must follow the procedures in 20 NMAC 5.7, Section 702, to determine if the UST system is the source of off-site impacts.

NMED has not requested off-site impact information.

25.2.6.63 Release Investigation and Confirmation Steps, 20 NMAC 5.7, § 702; 40 CFR 280.52

Unless corrective action is initiated in accordance with 20 NMAC 5.12 and 5.13, owners and operators must immediately investigate and confirm all suspected releases of regulated substances that require reporting under 20 NMAC 5.7, Section 700, within 7 days using a system test and/or a site check as described in more detail in this part of the regulations. If a leak in the UST system is found to exist,

the system must be repaired, replaced, or upgraded as needed.

WID procedures indicate the appropriate testing, investigating, reporting, and corrective action to be taken if a release of regulated substances is suspected. To date, there have been no leaks in the current UST system.

25.2.6.64 Reporting and Cleanup of Large Spills and Overfills, 20 NMAC 5.7, § 703(a); 40 CFR 280.53(a)

Owners and operators of UST systems must contain and immediately clean up a spill or overfill and report it to the NMED within 24 hours. Corrective action must be initiated in accordance with 20 NMAC 5.2, Section 204. If a spill or overfill of a petroleum product results in a release to the environment that exceeds 25 gallons [or a hazardous substance spill results in a release to the environment that equals or exceeds its reportable quantity under CERCLA (40 CFR Part 302), corrective action must be initiated in accordance with 20 NMAC 5.12 or 5.13.

There have been no large spills or overfills with the current UST setup. WID procedures address the requirements with respect to petroleum UST systems (i.e., as specified in 20 NMAC 5.12). No hazardous substances are contained in UST systems at WIPP; therefore, USTR Part XIII does not apply.

25.2.6.65 Reporting and Cleanup of Small Spills and Overfills, 20 NMAC 5.7, § 703(b); 40 CFR 280.53(b)

Owners and operators of UST systems must contain and immediately clean up a spill or overfill of a petroleum product that is less than 25 gallons and a spill or overfill of a hazardous substance that is less than the reportable quantity. If cleanup cannot be accomplished within 24 hours, owners and operators must immediately notify the implementing agency.

Small spills and overfills have been properly contained and cleaned up. WID procedures address this requirement with respect to petroleum UST systems. No UST systems are used to contain hazardous substances at WIPP.

25.2.6.66 Temporary Closure, 20 NMAC 5.8, § 800; 40 CFR 280.70

When an UST system is temporarily closed, owners and operators must continue operation and maintenance of

corrosion protection in accordance with 20 NMAC 5.5, Section 501, and any release detection in accordance with 20 NMAC 5.6, 5.7, 5.12, 5.13, and Section 204 of NMAC 5.2 must be complied with if a release is suspected or confirmed. However, release detection is not required as long as the UST system is empty. When an UST system is temporarily closed for three months or more, the vent lines must be left open and functioning, and all other lines, pumps, manways, and ancillary equipment must be capped and secured.

Documentation of the original tank closures was submitted to NMED. No temporary closure took place.

25.2.6.67 Permanent Closure and Changes in Service, 20 NMAC 5.8, § 801(a); 40 CFR 280.71(a)

At least 30 days before beginning either permanent closure or a change in service, owners and operators must notify the NMED unless such action is in response to corrective action.

The closure documentation for the old UST systems was submitted to the NMED within the 30-day requirement for beginning permanent closure.

25.2.6.68 Permanent Closure of a Tank, 20 NMAC 5.8, § 801(b); 40 CFR 280.71(b)

To permanently close a tank, the owners and operators must empty and clean it by removing all liquids and accumulated sludges. The tanks must be either removed from the ground or filled with an inert solid material.

The closure documentation for the old UST system is maintained at the WIPP site. These USTs were emptied, cleaned, and removed from the ground as required.

25.2.6.69 Change in Service, 20 NMAC 5.8, § 801(c); 40 CFR 280.71(c)

Before a change in service in which the use of a UST system is continued for the storage of a nonregulated substance, owners and operators must empty and clean the tank by removing all liquid and accumulated sludge and conduct a site assessment in accordance with 20 NMAC 5.8, Section 802.

There was no change in service for the old UST system.

25.2.6.70 Assessing the Site, 20 NMAC 5.8, § 802(a); 40 CFR 280.72(a)

> *Before permanent closure or a change in service is completed, owners and operators must measure for the presence of a release where contamination is most likely to be present at the UST site as required under this subsection.*

The UST site was assessed prior to permanent closure of the old UST system. The closure documentation for the old UST systems is maintained at the WIPP site.

25.2.6.71 Corrective Action, 20 NMAC 5.8, § 802(b); 40 CFR 280.72(b)

> *If contaminated soils, contaminated ground water, or free product as a liquid or vapor are discovered, owners and operators must begin corrective action in accordance with 20 NMAC 5.12 or 5.13.*

The WIPP has procedures in place which address the required actions to take if a release or suspected release is identified. See 25.2.6.80 for further information.

25.2.6.72 Applicability to Previously Closed UST Systems, 20 NMAC 5.8, § 803; 40 CFR 280.73

> *When directed by the NMED, the owner and operator of an UST system permanently closed before December 22, 1988, must assess the excavation zone and close the UST system if releases from the UST may pose a current or potential threat to human health and the environment.*

No UST systems at WIPP were permanently closed before December 22, 1988.

25.2.6.73 Closure Records, 20 NMAC 5.8, § 804; 40 CFR 280.74

> *Owners and operators must maintain records in accordance with 20 NMAC 5.5, Section 504, that demonstrate compliance with closure requirements under this part. The results of the excavation zone assessment required in 20 NMAC 5.8, Section 802 (Section 25.2.6.70), must be maintained for at least three years after completion of permanent closure or change in service.*

A tank closure for the old UST systems was submitted to NMED. The records are maintained at WIPP.

25.2.6.74 Applicability of Financial Responsibility, 20 NMAC 5.9, § 900; 40 CFR 280.90

> *State and federal government entities whose debts and liabilities are the debts and liabilities of a state or the United States are exempt from the requirements of 20 NMAC 5.9, "Financial Responsibility."*

As the owner of WIPP, the DOE is exempt from the financial responsibility requirements of this part.

25.2.6.75 Informal Review, 20 NMAC 5.10, § 1000

> *Any owner or operator of an UST who disagrees with a decision made by NMED personnel pursuant to the USTRs may have the decision reviewed by submitting a written request for informal review to the NMED. The request must be postmarked within 15 days of the date of the decision. The grounds for the petitioner's objection must be specified.*

This provision has not been invoked at WIPP.

25.2.6.76 Review by the Secretary on Written Memoranda, 20 NMAC 5.10, § 1001

> *Within 20 days after the NMED has made a determination under 20 NMAC 5.10, Section 1000, the petitioner may appeal the determination to the NMED Secretary by requesting a review on written memoranda in writing. The grounds for the objection to the determination must be specified. The request must be accompanied by all written information, documentation, and arguments that the petitioner wants the Secretary to consider.*

This provision has not been invoked at WIPP.

25.2.6.77 Compliance With Other Regulations, 20 NMAC 5.1, § 108

> *Compliance with the USTRs does not relieve a person of the obligation to comply with other applicable state and federal regulations.*

Compliance with the other applicable federal and state regulations is discussed elsewhere in this document (see Chapters 2 through 24 and 25 through 38, respectively).

25.2.6.78 Construction, 20 NMAC 5.1, § 109

> *The USTRs shall be liberally construed to effectuate the purpose of the New Mexico Hazardous Waste Act.*

The USTRs are liberally construed to effectuate the purpose of the New Mexico HWA with respect to the sections in this act that pertain to managing UST systems containing hazardous (i.e., regulated) substances.

25.2.6.79 Severability, 20 NMAC 5.1, § 110

> *If any part, section, or application of the USTRs is held invalid, the remainder (or its application to other situations or persons) shall not be affected.*

No action is required.

25.2.6.80 Cleanup Requirements for Releases from Petroleum UST Systems, 20 NMAC 5.12, § 1200(A)

> *All releases must be cleaned up through soil remediation, ground- and surface-water remediation, and any other appropriate procedures in a manner protective of health, public welfare, and the environment.*

No releases have occurred with the current UST system to date.

25.2.6.81 Additional Corrective Action Requirements for Petroleum UST Systems, 20 NMAC 5.12, §§ 1200(B)-1222

> *Additional corrective action requirements specify types of releases, notification and reporting requirements, types of actions required for remediation and reclamation involving specific releases, and provisions for monitoring.*

No releases have occurred during this reporting period. Consequently, these requirements are not applicable to WIPP, and no action is required. WID procedures are in place to address them, however, should corrective actions involving petroleum USTs become necessary in the future

25.2.6.82 Corrective Action for Hazardous Substance UST Systems, 20 NMAC 5.13, §§ 1300-1320

> *Requirements for corrective actions for hazardous substance UST systems are specified in this part of 20 NMAC Chapter 5.*

There are no hazardous substance UST systems at WIPP. Furthermore, it is very unlikely that such systems would be installed at this facility. Therefore, 20 NMAC 5.13 (Sections 1300-1320) do not apply to WIPP.

25.2.6.83 Certification Requirements for Tank Installers and Repairers, 20 NMAC 5.14, §§ 1400-1417

> *Certification by the NMED is required for all individuals and companies that install or repair UST systems in New Mexico. Certification is based on field experience, training, and a written and an on-site examination.*

Documentation of certification of the contractor that installed the new UST systems at WIPP is retained at the WIPP.

25.2.6.84 Priorities, 20 NMAC 5.15, § 1505

> *NMED priorities for corrective action at sites contaminated by releases of regulated substances from USTs are established in this section.*

If a release is detected from the UST systems at WIPP, the action to be taken by the NMED will depend on the extent and nature of the release.

See Section 25.2.6.85 for the requirements for a minimum site assessment.

25.2.6.85 Minimum Site Assessment, 20 NMAC 5.15, § 1508

> *Owners and operators are strictly liable for the NMED's costs of taking corrective action at a site unless the owner or operator has conducted a minimum site assessment as required by these regulations. To complete such an assessment, the owner and operator must report, investigate, and confirm the release pursuant to 20 NMAC 5.7 and determine the immediate extent, magnitude, and impact of contamination by conducting investigations and reporting to the NMED (20 NMAC 5.12, Sections 1203*

through 1206). The owner or operator shall include with the report of the on-site investigation a copy of any insurance policies which are in effect on the date of the report and any policies in existence at the time the release may have occurred. The NMED shall notify the owner or operator of any inadequacies in the report within 30 days of its receipt of the on-site investigation report. The owner or operator shall, within 15 days of such notice of inadequacy, modify the report and resubmit it to the NMED for review and written approval. If the modified report does not meet the requirements of 20 NMAC 5.12, Section 1205, the owner and operator shall be deemed not to have conducted a minimum site assessment.

If a minimum site assessment is deemed necessary, it will be prepared and submitted to meet the requirements specified. The transmittal of insurance policies is not required for a federal facility; therefore, the report would not be accompanied by a copy of such policies.

25.2.6.86 Certification of Contractors, 20 NMAC 5.16

Provisions are contained in 20 NMAC 5.16 for the qualification of firms performing corrective action on sites where payment or reimbursement from the Corrective Action Fund will be sought. It addresses education, experience, examination, continuing education and certification requirements for certified scientists.

This requirement is not applicable to WIPP. The Ground Water Protection Act prohibits expenditures from the Corrective Action Fund for federally owned and operated sites.

25.2.6.87 Corrective Action Fund Payment and Reimbursement, 20 NMAC 5.17

The regulation establishes procedures for the reimbursement or payment from the Corrective Action Fund for corrective actions.

This requirement is not applicable to WIPP. The Ground Water Protection Act prohibits expenditures from the Corrective Action Fund for federally owned and operated sites

26.0 NEW MEXICO SOLID WASTE ACT

26.1 Summary of the Law

With the enactment of the Solid Waste Act (SWA) in 1990, the New Mexico Legislature authorized and directed the establishment of a comprehensive and integrated solid waste management program at both the state and local levels. This legislation directs the planning and regulation of the reduction, storage, collection, transportation, and disposal of solid waste and authorizes the establishment of a system of permits for the construction, operation and, if applicable, closure and postclosure maintenance of solid waste facilities.

The SWA is implemented by the New Mexico Solid Waste Management Regulations (SWMRs). Since the last BECR was prepared, New Mexico's environmental regulations have been recodified under a new numbering system. The SWMRs are now contained within Section 9.1 of Title 20 of the New Mexico Administrative Code (NMAC). These regulations are applicable to WIPP because of infectious wastes generated at the facility. A construction landfill exists at the site but is exempt under § 108. C. of the SWMRs.

26.2 Compliance Status of the Regulatory Requirements

Table 26-1 summarizes the applicable requirements and their compliance status under the SWA. The text provides more detail on the compliance status of each requirement.

TABLE 26-1. New Mexico Solid Waste Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 9.1, § 106 A	Applicability of regulations	**UP TO DATE** Infectious waste [Section 26.2.1]
20 NMAC 9.1, § 106	General requirements	**NOT APPLICABLE** Construction Landfill covered by NMAC 9.1, §108.C exemption and infectious waste is disposed off-site [Section 26.2.2]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 9.1, § 107	Prohibited acts	**UP TO DATE** Wastes specified that are excluded from the landfill [Section 26.2.3]
20 NMAC 9.1, § 109	Record-keeping and annual reports	**NOT APPLICABLE** Construction Landfill covered by NMAC 9.1 ,§ 108.C exemption [Section 26.2.4]
20 NMAC 9.1, § 111	Entry by department; availability of records	**UP TO DATE** NMED may conduct inspections and review records [Section 26.2.5]
20 NMAC 9.1, §§ 201, 202, 209, 210	Permit application requirements	**NOT APPLICABLE** Landfill exempt Construction Landfill covered by NMAC 9.1, § 108.C exemption and infectious waste is disposed off-site [Section 26.2.6]
20 NMAC 9.1, [illegible]40[illegible], [illegible]03	Solid waste facility operation requirements	**NOT APPLICABLE** Construction Landfill covered by NMAC 9.1, § 108.C exemption [Section 26.2.7]
20 NMAC 9.1, Subpart V	Closure and postclosure requirements	**NOT APPLICABLE** Landfill exempt [Section 26.2.8]
20 NMAC 9.1, Subpart VI	Operator certification	**NOT APPLICABLE** Landfill exempt [Section 26.2.9]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 9.1, § 706(C)	Storage and containment requirements for infectious waste	**UP TO DATE** Storage and containment procedures established [Section 26.2.10]
20 NMAC 9.1, § 706(D)	Operational requirements for infectious waste treatment, storage, and disposal facilities	**ACHIEVED** Operational procedures established [Section 26.2.11]
20 NMAC 9.1, § 706(E)	Treatment and disposal of infectious waste	**ACHIEVED** Off-site incineration or steam sterilization used [Section 26.2.12]
20 NMAC 9.1, § 214.B	Requirements for infectious waste transporters	**NOT APPLICABLE** Transport by off-site contractor [Section 26.2.13]
20 NMAC 9.1, § 712	Manifest requirements (to accompany each load of infectious waste)	**UP TO DATE** Manifest provided [Section 26.2.14]

26.2.1 Applicability of Regulations, 20 NMAC 9.1, § 106.A

Subpart 106.A. specifies that all solid waste shall be processed or disposed of in accordance with the regulations.

A construction landfill is located on the WIPP site. The construction landfill is on property owned by DOE and receives nonhazardous material generated on the property from construction activities; no hazardous wastes or materials are allowed. The landfill is thus covered by the exemption found in § 108.C of the SWMRs. Infectious wastes are generated at the facility and meet the applicable requirements of § 706 of the SWMRs.

26.2.2 General Requirements for Processing and Disposal of Solid Waste, 20 NMAC 9.1, § 106

> *All solid waste must be processed or disposed of by means in accordance with Environmental Improvement Board regulations, including recycling, composting, transformation, or landfilling. Generators of solid waste must provide containers for the solid waste except for construction and demolition debris, yard refuse, and white goods.*

The construction landfill receives waste generated by construction activities at the site and is covered by the §108.C. exemption of the regulations. The requirements and rules of operation for the landfill are described in a WIPP procedure that provides guidelines for the operation of the construction landfill in a manner that is protective of human health and the environment and ensures compliance with applicable local, state, and federal laws and regulations. Infectious waste generated at the site is shipped off-site for disposal.

26.2.3 Prohibited Acts, 20 NMAC 9.1, § 107

> *Subpart 107 specifies prohibited acts including the following: disposal of solid waste in places other than a permitted solid waste facility; disposal of regulated waste such as special waste, hazardous waste, radioactive materials, and petroleum waste; disposal of bulk liquids; and disposal of any solid wastes that are known to be harmful to the environment or hazardous to public health or safety.*

The following wastes are excluded from the WIPP landfill:

- Radioactive materials
- Hazardous or other regulated materials, including petroleum products
- Liquids, or containers that contain liquids
- Any recyclable materials as determined by the WID

Construction debris that may be disposed of in the landfill is material generally considered to be non-water soluble and nonhazardous in nature and includes timers, pipes, excavation soil (if not contaminated with hazardous materials/wastes), concrete, packing materials, sheet metal, glass, and wood.

26.2.4 Record-keeping and Annual Reports, 20 NMAC 9.1, § 109

> *Operators of solid waste facilities shall make and maintain records during the active life of the facility. Operators shall submit annual reports to the Secretary of the New Mexico*

Environment Department (NMED) within 45 days after each anniversary date of any permit or other approval given.

The construction landfill is covered by the § 108.C exemption found in the SWMRs. Although the landfill is exempt from record-keeping requirements, records for the landfill are maintained. Records are found on the WID Construction Debris Disposal Form (WP Form 1633), which requires the name, company, date, description and estimated volume of debris, and signatures of the landfill user and of the landfill custodian. No permit is required (see Section 26.2.6). Therefore, an annual report is not necessary.

26.2.5 Entry by Department, Availability of Records, 20 NMAC 9.1, § 111

The Secretary or any authorized representative, employee or agent of the Department may enter any solid waste facility any reasonable times for the purpose of making an inspection.

The NMED will be provided access to the facility any time it wishes to conduct an inspection.

26.2.6 Permit Application Requirements, 20 NMAC 9.1, §§ 201, 202, 209, 210

Any person seeking a permit to construct, operate, or modify a solid waste facility must file an application.

Chapter 20 of NMAC 9.1, § 108.C provides an exemption for this site, because the regulations do not apply to disposal of construction and demolition debris if the material is generated on the property and the disposal of the solid waste does not violate any provision of the regulations. This landfill is exempted from permit application requirements because it receives construction debris only and because it is located at the same site where the construction debris is generated. Therefore, a permit is not required for this landfill.

26.2.7 Solid Waste Facility Operation, 20 NMAC 9.1, §§ 401, 403

A solid waste facility must be operated so that it does not cause a public nuisance or create a potential hazard to public health or welfare.

The landfill is covered by the § 108.C exemption contained in the SWMRs. In order to ensure compliance with the SWMRs, the construction landfill is operated according to WID procedures that ensure protection of public health and welfare.

26.2.8 Landfill Closure and Postclosure Requirements, 20 NMAC 9.1, Subpart V

Subpart V of 20 NMAC 9.1 specifies a number of landfill closure and postclosure requirements including the installation of a final cover, preparing and implementing a land-use plan, a schedule for completing all closure work, an approved postclosure care and monitoring plan, and annual reports.

This landfill is exempted from these requirements because it receives construction debris only and because it is located at the same site (i.e., WIPP) where the construction debris is generated. Therefore, closure and postclosure requirements are not applicable.

26.2.9 Operator Certification, 20 NMAC 9.1, Subpart VI

Subpart VI of 20 NMAC 9.1 provides requirements for operator certification: certification of operators is required as of January 31, 1994. The amount and type of personnel training and experience are specified for landfills and for other types of facilities.

This landfill is exempted from these requirements because it receives construction debris only and because it is located at the same site (i.e., WIPP) where the construction debris is generated. Therefore, operator certification is not required.

26.2.10 Storage and Containment of Infectious Waste, 20 NMAC 9.1, § 706(C)

Subpart 706(C) specifies infectious waste storage and containment requirements, including waste segregation; specifications for container integrity; container labeling and marking; and storage and containment area access, integrity, and marking.

The following practices are ongoing at WIPP:

- Access to the infectious waste collection and storage area is limited to trained medical personnel, who are vaccinated against hepatitis.
- Special containers are easily identifiable through the use of enclosed red-lined bio-hazard bags.
- All sharps are sealed in containers that are leak-proof, puncture-proof, and tamper-proof. These containers are then enclosed in plastic bio-hazard bags.

- All containment bags are clearly identifiable with red lining as specified by 29 CFR 1910.145(f)(4).
- No infectious waste containers are reused.
- Storage and containment areas are in an enclosed, clearly marked environment.
- No compaction or grinding devices are used to reduce the volume of infectious waste.

26.2.11 Infectious Waste Treatment, Storage, and Disposal Facilities, 20 NMAC 9.1, § 706(D)

Section 706(D) specifies operational requirements for infectious waste treatment, storage, and disposal facilities. Included is a requirement for the preparation and maintenance of a management plan that identifies the type of waste generated or handled; the segregation, packaging, labeling, collection, storage, and transportation procedures to be implemented; the treatment or disposal methods to be used; the transporter and disposal facility to be used; and the person responsible for the management of the infectious waste.

The WID Transportation Manual and the Occupational Health Manual address the operational requirements for infectious waste as specified in this part.

26.2.12 Treatment and Disposal of Infectious Waste, 20 NMAC 9.1, § 706(E)

Several methods are specified for the treatment and disposal of infectious waste. These methods include controlled incineration, heat sterilization, discharge to a sewage treatment system, and landfilling.

The method of treatment and disposal is incineration or steam sterilization at an off-site facility. Transportation is provided by an off-site subcontractor.

26.2.13 Infectious Waste Transporters, 20 NMAC 9.1, § 214(B)

Requirements for the transportation of infectious waste are specified in this section.

WIPP does not transport infectious waste. Transportation is accomplished by an off-site subcontractor.

26.2.14 Manifest Requirements, 20 NMAC 9.1, § 712

> *A manifest must accompany each shipment of infectious waste. Each manifest must include information on the waste generator, transporter, waste treatment facility, the type of waste, and any special instructions.*

Medical waste shipments are accompanied by a shipment manifest that includes the required information.

27.0 NEW MEXICO ENVIRONMENTAL IMPROVEMENT ACT

27.1 Summary of the Law

The enactment of the New Mexico Environmental Improvement Act (EIA; §§ 74-1-1 through 74-1-10 NMSA 1978) created the Environmental Improvement Board (EIB) to promulgate regulations and standards to protect health and safety and the environment. The EIA also created the EID, now known as the NMED. The act directs the NMED to assume responsibility for environmental management and protection to demonstrate that environmental policy provides optimal health, safety, social, and economic well-being for the people of New Mexico. In carrying out its responsibilities, the NMED is directed to maintain, develop, and enforce regulations and standards in areas including water supply, liquid waste, air quality, radiation control, health and safety, hazardous wastes, and underground storage tanks. As discussed in Chapters 25 through 31 of this report, many of these regulations and standards are applicable to WIPP. These include the Hazardous Waste Act and the implementing hazardous waste management and USTRs (Chapter 25), the Solid Waste Act (Chapter 26), the Ground Water Protection Act (Chapter 28), the Air Quality Control Act (Chapter 29), the Water Quality Act (Chapter 30), and Water Supply Regulations (Chapter 31).

27.2 Compliance Status of the Law

The DOE will continue to comply with all applicable New Mexico environmental regulations and standards as demonstrated in the following chapters.

28.0 NEW MEXICO GROUND WATER PROTECTION ACT

28.1 Summary of the Law

The Ground Water Protection Act (GWPA; § 74-6B NMSA 1978) was enacted in 1990 in response to the threat facing public health and safety and the environment from pollution of ground-water resources from leaking USTs. The purpose of this act includes the provision of substantive direction that allows the State of New Mexico to take corrective action at sites contaminated by leakage from USTs.

The GWPA is implemented by the regulations of the NMED, NMED-92-1, *Ground Water Protection Act Corrective Action Fund Regulations*. These regulations provide guidelines for the payment or reimbursal of the costs of a minimum site assessment and corrective action and specify the requirements for owners or operators of leaking USTs.

The GWPA is also implemented by the GWPA regulations, which are provided in the New Mexico USTR as Part XV. These regulations are discussed in Chapter 25. WIPP has installed two new UST systems that meet the new standards and requirements for USTs. Procedures are in place for routine operations regarding the tanks and for dealing with any spills or releases from the UST systems. Two sections in Chapter 25 (25.2.6.84 and 25.2.6.85) deal specifically with the applicable New Mexico GWPA regulations.

28.2 Compliance Status of the Regulatory Requirement

Table 28-1 summarizes the general regulatory requirement and its compliance status under the implementing regulation of the New Mexico Ground Water Protection Act. See also Sections 25.2.6.84 and 25.2.6.85 for the applicable portions of the Ground Water Protection Act Regulations.

TABLE 28-1. New Mexico Ground Water Protection Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
New Mexico Environment Department 92-1, *Ground Water Protection Act Corrective Action Fund Regulations*		
NMED 92-1	Reimbursement of costs from corrective actions for spills/releases from USTs	**NOT APPLICABLE** No spills or leaks from new UST systems [Section 28.2.1]

28.2.1 Corrective Action for Spills/Releases From USTs, NMED-92-1

> *The owners or operators of USTs that release a regulated substance must take appropriate corrective action. The NMED will reimburse certain costs associated with performing a minimum site assessment and other corrective actions taken for spills or releases from USTs.*

The WIPP will take appropriate corrective actions if a regulated substance is released from a UST.

29.0 NEW MEXICO AIR QUALITY CONTROL ACT

29.1 Summary of the Law

The New Mexico Air Quality Control Act (§§ 74-2-1 through 74-2-22 NMSA 1978), based primarily on the Clean Air Act (CAA; see Chapter 6), is not generally more stringent than the CAA except in areas of air pollution prevention that have not been preempted by the CAA and are not precluded by the limiting provisions of the Air Quality Control Act. The Air Quality Control Act was formerly implemented by the Air Quality Control Regulations (AQCRs) and is now implemented by Chapter 2 of Title 20 of the NMAC.

Under 40 CFR Part 70, operating permits are required for both area and major sources. The NMED will implement the federal requirements under 20 NMAC 2.70 and 2.71 which describe the fee structure for the operating permit program. At this time, emission limits for area sources have not been established, and major source emission thresholds are being used to determine which facilities require operating permits under 20 NMAC 2.70.

29.2 Compliance Status of the Regulatory Requirements

Table 29-1 summarizes the compliance status of the requirements in Chapter 2 of Title 20 of the NMAC that are potentially applicable to WIPP. The text provides more detail on the compliance status of each requirement. It should be noted that 20 NMAC 2.70 and 2.71 will deal with the state operating permit program and that the EPA has granted interim approval for the NMED's operating permit program. Therefore, a brief discussion of WIPP's compliance status with respect to 20 NMAC 2.70 is now included in this chapter.

TABLE 29-1. Air Quality Control Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENTS	COMPLIANCE STATUS
New Mexico Air Quality Control Regulations (AQCRs)		
	20 NMAC 2.60	**NOT APPLICABLE** Open-burning permit canceled in 1995 (see also Section 29.3.1) [Section 29.2.1]

CITATION	REQUIREMENTS	COMPLIANCE STATUS
20 NMAC 2.61	Regulations to control smoke and visible emissions	**ACHIEVED** Opacity testing found to be less than the 20 percent opacity limit [Section 29.2.2]
20 NMAC 2.18	Oil-burning equipment--particulate matter	**NOT APPLICABLE** Oil-burning equipment below rated heat capacity of regulated equipment [Section 29.2.3]
20 NMAC 2.34	Oil-burning equipment--nitrogen dioxide	**NOT APPLICABLE** Oil-burning equipment below rated heat capacity of regulated equipment [Section 29.2.4]
20 NMAC 2.75	Permit fees	**UP TO DATE** One-time fee sent with permit application in 1993 [Section 29.2.5]
20 NMAC 2.70 40 CFR 70.5(c)(8)	Compliance plan for 40 CFR Part 70 sources as part of operating permit application	**NOT APPLICABLE** Will be required if operating permit application is requested [Section 29.2.6]
20 NMAC 2.70 40 CFR 70.5(c)(8)(iv) and 70.6(a)(3)(iii)(A)	Semiannual operating permit reports and progress reports on compliance plan	**NOT APPLICABLE** Will be required if operating permit is needed [Section 29.2.7]
20 NMAC 2.72	Permits	**ACHIEVED** Application for permit for generators filed July 13, 1993; permit issued on December 7, 1993 (see Section 29.3.2) [Section 29.2.8]

CITATION	REQUIREMENTS	COMPLIANCE STATUS
20 NMAC 2.73	Annual emission inventory from permitted facility or if more than 1 ton of lead or 10 tons of particulates, SO_2, NO_2, CO, or VOCs are emitted from the facility in any calendar year	**UP TO DATE** No emissions inventory requested by the NMED [Section 29.2.9]
20 NMAC 2.80	Stack height requirements	**ACHIEVED** Stack height approved by state [Section 29.2.10]
20 NMAC 2.78	National Emission Standards for Hazardous Air Pollutants (NESHAPs) - radionuclides (40 CFR Part 61, Subpart H) NESHAPs - other HAPs (40 CFR Part 61, Subpart A)	**NOT APPLICABLE** Radionuclides (Subpart H): not present; EPA-regulated; see Chapter 6 Other HAPs (Subpart A): WID HAPs inventory: HAP emissions not present or significantly below regulatory limits [Section 29.2.11]
20 NMAC 2.7	Excess emissions during malfunction, startup, shutdown, or scheduled maintenance	**UP TO DATE** No problems detected during this reporting period [Section 29.2.12]
20 NMAC 2.8	Controlling emissions leaving New Mexico	**ACHIEVED** Emissions do not exceed NAAQS [Section 29.2.13]
20 NMAC 2.1	Sampling equipment	**UP TO DATE** Addressed in permit for diesel generators [Section 29.2.14]

29.2.1 Regulations to Control Open Burning, 20 NMAC 2.60

Open burning is allowed for the instruction and training of fire-fighting and -rescue personnel when a permit is obtained from the NMED.

The open-burning permit was canceled in October 1995 and will not be renewed. Firefighter live-fire training is no longer conducted at WIPP.

29.2.2 Regulations to Control Smoke and Visible Emissions, 20 NMAC 2.61

> *No person owning or operating stationary combustion equipment shall permit, cause, or allow visible emissions from stationary combustion equipment to equal or exceed an opacity of 20 percent. No emissions of smoke with an opacity greater than 30 percent shall be released into the open air for any period greater than 10 seconds from any diesel-powered vehicle operating below 8,000 feet mean sea level. Opacity emissions shall be determined using Method 9 described in Appendix A of 40 CFR Part 60 (minimum time period for taking opacity readings: 10 minutes).*

Opacity measurements are not required for the backup diesel generators because no opacity measurements are specifically required under the permit (see Section 29.3.2). However, opacity testing has been performed on the generators and was found to be less than the 20-percent opacity limit.

Other diesel equipment is present on site that does not require a permit under 20 NMAC 2.72 because this equipment represents such a small source of emissions. The inventory on the equipment was submitted to the NMED with the permit application for the backup generators. The emissions from this diesel equipment fall well below the permit thresholds; however, the equipment is scheduled for opacity testing. Method 9 will be used with at least 10-minute opacity readings.

29.2.3 Oil-Burning Equipment--Particulate Matter, 20 NMAC 2.18

> *Standards have been established for particulate-matter emissions from oil-burning equipment with a rated heat capacity exceeding 250 million British thermal units (BTUs) per hour.*

No oil-burning equipment at WIPP exceeds this rated heat capacity. The rated heat capacity of each of the generators is only 139.6 million BTUs per hour.

29.2.4 Oil-Burning Equipment-- Nitrogen Dioxide, 20 NMAC 2.34

> *Standards have been established for nitrogen dioxide emissions from oil-burning equipment with a rated heat capacity of 10^{12} BTUs per hour.*

No oil-burning equipment at WIPP exceeds this rated heat capacity. The rated heat capacity of each of the two generators is only 139.6 million BTUs per hour (i.e., 1.4×10^8 BTUs/hour).

29.2.5 Permit Fees, 20 NMAC 2.75

Permit fees must be paid with the submittal of a permit application.

The only permits required at WIPP under 20 NMAC 2 are for open burning and for the generators. (See also Sections 29.2.4, 29.3.1, and 29.3.2.) The permit fee for the diesel generators ($10,100) was submitted with the permit application in July 1993.

29.2.6 Compliance Plan, 20 NMAC 2.70

Submittal of a compliance plan is required as part of the operating permit application for 40 CFR Part 70 sources.

Based on the 1994 WIPP Inventory, HAP and other pollutant emissions from the facility are below current operating permit threshold levels; therefore, an operating permit is not required for WIPP. If a determination is made at a later date that an operating permit application is required for the facility, a compliance plan will be part of the application as specified.

29.2.7 Semiannual Operating Permit Reports and Progress Reports on the Compliance Plan, 20 NMAC 2.70

Semiannual operating permit reports and progress reports on the compliance plan will be filed, if applicable.

Based on the 1993 WIPP HAPs Inventory, HAP emissions from the facility are below current operating permit threshold levels, and an operating permit is not required for WIPP. The WIPP will be required to submit these reports if and when WIPP is considered to be subject to the operating permit program.

29.2.8 Permits, 20 NMAC 2.72

A permit is required for facilities that emit criteria pollutants or toxic air pollutants at rates that meet or exceed the threshold levels specified in 20 NMAC 2.72.

Preliminary calculations for the backup diesel generators indicated that the emissions anticipated from the generators would exceed the hourly thresholds for nitrogen dioxide that trigger the need for submitting a permit application under 20 NMAC 2.72. (Subsequent calculations have supported the need for a permit.) Therefore, the WIPP

submitted a permit application to the NMED for the diesel generators, which was received by the state on July 13, 1993. The WIPP received notification from the state on August 24, 1993, that modeling information was needed to complete the application. The information was submitted within the 10-day window specified by the state. The state has since concurred that the permit application is complete. The permit was issued by the NMED on December 7, 1993. (See Section 29.3.)

29.2.9 Annual Emission Inventory, 20 NMAC 2.73

An annual emission inventory is required annually for any stationary source permitted under 20 NMAC 2.72 (except for those sources that are permitted only for TAP emissions). Other sources that are required to file an annual emission inventory are those that must file a Notice of Intent under 20 NMAC 2.73 or that emit in excess of 1 ton of lead or 10 tons of total suspended particulates, particulate matter with an aerodynamic diameter of 10 μ or less (i.e., PM_{10}), sulfur dioxide, nitrogen dioxide, carbon monoxide, or volatile organic compounds (VOCs) in any calendar year including and subsequent to 1990.

Emission testing for the diesel generators was performed in February 1994 and reported to the NMED as part of the original permit package. There have been no further requirements or NMED requests for emission testing to date.

29.2.10 Stack Height Requirements, 20 NMAC 2.80

Stack height requirements must be met.

WIPP meets the requirement for stack height. The state has approved WIPP's calculations and modeling.

29.2.11 National Emission Standards for Hazardous Air Pollutants (NESHAPs), 20 NMAC 2.78

NESHAPs requirements must be met.

The state is authorized to administer the NESHAPs program except for radionuclide emissions. Therefore, the EPA regulates these emissions under Subpart H of 40 CFR Part 61 (see Chapter 6). The state is currently performing an inventory of HAP emissions within New Mexico, particularly of the 181 HAPs that were added to the list in the Clean Air Act Amendments of 1990. After the inventory has been completed, the state will begin the process of promulgating regulations to control these emissions. WIPP will be required to comply with these new regulations for any HAPs emitted from a major or an area source.

In 1995, the WIPP completed an emission inventory for chemicals used during 1994 (WID, 1995). The inventory included calculations of the maximal potential hourly and annual emissions of criteria pollutants, the chemicals regulated under the NESHAP program, and the New Mexico TAPs specified under 20 NMAC 2.78 and Part III of 20 NMAC 2.72. Based on the HAPs inventory calculations, WIPP operations are significantly below the 10-ton per year (tpy) emission limit for any individual HAP or the 25-tpy limit for combined HAPs emissions established in Subpart A of NESHAPs. Thus, the WIPP does not have any NESHAP Subpart A permitting or reporting requirement at this time.

29.2.12 Excess Emissions During Malfunction, Startup, Shutdown, or Scheduled Maintenance, 20 NMAC 2.7

Excess emissions during malfunction, startup, shutdown, or scheduled maintenance must be minimized.

Special attention is paid during startup, shutdown, scheduled maintenance, and any malfunction of the generators to ensure that emissions are minimized. The release of excess emissions is unlikely, however, because a redundant system is in place, and the second backup generator will be used to reduce potential emissions. If excess emissions occur, reporting will be performed as required by 20 NMAC 2.7. No problems have been detected during this reporting period.

29.2.13 Controlling Emissions Leaving New Mexico, 20 NMAC 2. 8

Emissions leaving New Mexico must not exceed the standards and regulations of the receiving state.

Emissions calculations and modeling that have been completed reveal that the emissions do not exceed the NAAQs.

29.2.14 Sampling Equipment, 20 NMAC 2.1

Sampling equipment on stacks or other openings through which emissions are released to the atmosphere will be used as required.

The sampling equipment required for measuring emissions from the WIPP backup diesel generators was specified by the state in § 3(b) of the permit. Sampling ports, safe sampling platforms, safe access to sampling platforms, and utilities for sampling and testing equipment have been provided. A 0.25-inch stainless steel sampling line adjacent to the sampling ports, which extends down to within 4 feet above ground level, has been installed as required by the permit. This sampling line provides access for future audits by the NMED (see Section 29.3.2).

29.3 Compliance Status of Permit Conditions

Only one permit issued under the NMAC is now in place at WIPP: the open-burning permit has been canceled. The permit for the backup diesel generators, which was issued to WIPP on December 7, 1993, is still in place. The permit conditions and the compliance status of each are summarized in Table 29-2. More detailed information is provided in the text.

TABLE 29-2. Air Quality Permits at WIPP - Summary of Regulatory Compliance Status

CONDITION	REQUIREMENTS	COMPLIANCE STATUS
Open-Burning Permit		
Conditions	Application and permit	**NOT APPLICABLE** Permit canceled [Section 29.3.1]
Air Quality Permit No. 310-M-2 for the Two Backup Diesel Generators		
Condition 1	Construction and operation	**UP TO DATE** Equipment installed and operated [Section 29.3.2.1]
Condition 2	Emission rates (NO_2, CO_2, SO_2, and particulate matter)	**UP TO DATE** Compliance tests [Section 29.3.2.2]
Conditions 3-4	Compliance test methods	**UP TO DATE** Completion of compliance tests and submittal of the final *Emission Sampling Report* to the NMED in March 1994 [Section 29.3.2.3]
Condition 5	Revisions and modifications	**NOT APPLICABLE** Revised permit application and NMED inspections [Section 29.3.2.4]

CONDITION	REQUIREMENTS	COMPLIANCE STATUS
Condition 6	Notification to subsequent owners	**NOT APPLICABLE** Notification to new owner/operator and to NMED [Section 29.3.2.5]
Condition 7	Right to access property and review records	**UP TO DATE** NMED request to inspect and/or to receive records [Section 29.3.2.6]
Condition 8	Posting of the permit	**ACHIEVED** Posting of permit [Section 29.3.2.7]
Condition 9	Record-keeping	**UP TO DATE** Records retained; WID procedure [Section 29.3.2.8]
Condition 10	Reporting	**UP TO DATE** Reports and notifications to NMED [Section 29.3.2.9]
Additional condition, p. 8	Permit cancellations	**NOT APPLICABLE** Submittal of new permit application [Section 29.3.2.10]
Additional condition, p. 8	Notice of intent and emission inventory	**UP TO DATE** See Section 29.2.7 [Section 29.3.2.11]

29.3.1 Conditions of Open-Burning Permit, Application and Permit

Open burning is allowed monthly for up to 1 year. Up to 500 gallons of propane, diesel, gasoline, wood products, and standard automotive vehicles are to be burned; plywood and tires are excluded. All burning must take place during

the time period of 3 hours after sunrise to 1 hour before sunset. The direction of the wind at the burning site must be such that the smoke is generally carried away from public roads and areas of human habitation. All burning must cease whenever an air stagnation advisory is issued for the area by the U.S. Weather Service. All material to be burned must be as dry as possible, and the amount of dirt on the material must be minimized. No natural or synthetic rubber or petroleum products shall be burned. All applicable restrictions, codes, and ordinances shall be met.

The open-burning permit was canceled in October 1995 and will not be renewed. Firefighter live-fire training is no longer performed at WIPP; therefore the permit is no longer needed. This section will not appear in subsequent revisions of the BECR.

29.3.2 Permit for Backup Diesel Generators, Permit No. 310-M-2

The conditions specified by Air Quality Permit No. 310-M-2 for the backup diesel generators at WIPP are described in this section.

29.3.2.1 Construction and Operation, Condition 1

The plant (i.e., the diesel generators) shall be constructed and operated as described in the permit application dated June 18, 1993, and with the air quality monitoring information that was submitted on September 22, 1993, unless modified by the conditions of this permit. The facility consists of two Caterpillar diesel generators with a rated capacity of 1500 horsepower. Only one Caterpillar diesel engine may operate at one time, and the sum of hours of operation for both engines shall not exceed 480 hours per year. Changes in plans, specifications, and other representations provided in the application documents shall not be made if they change the method of emissions control or in the character of the emissions or if they would increase the discharge of emissions. Any such proposed change must be submitted as a proposal revision or modification of the permit in accordance with the condition described in Section 29.3.2.4.

The equipment described in the permit application is being operated in accordance with the application and with the terms and conditions of the permit.

29.3.2.2 Emission Rates, Condition 2

The NMED has specified maximal emission rates for nitrogen oxide, carbon monoxide, sulfur dioxide, and particulate matter (see Table 29-3). The rates specified are in terms of pounds per hour and tons per year from each engine and from the facility (i.e., both engines).

The amounts of emissions were based upon calculations for the equipment installed. The equipment is operated and maintained in accordance with the manufacturer's specification.

TABLE 29-3. Allowable Emission Rates from the Diesel Generator Engines at WIPP

Pollutant	Allowable Emission Rates			
	Allowable Emission Rates from Each Diesel Engine		Total Allowable Rates from Both Diesel Engines	
	Pounds per Hour	Tons per Year	Pounds per Hour	Tons per Year
Nitrogen dioxide	46.3	5.6	46.3	11.2
Carbon monoxide	10.1	1.2	10.1	2.4
Sulfur dioxide	3.1	0.4	3.1	0.8
Particulate matter	3.3	0.4	3.3	0.8

29.3.2.3 Compliance Test Methods, Conditions 3-4

Initial compliance tests for all four pollutants described for Condition 2 (Section 29.3.2) are required for one of the diesel generators. Compliance tests may be reimposed if noncompliance is indicated or if the tests were technically unsatisfactory. The tests shall be conducted within 60 days after achieving the maximal production rate at which the generator will normally be operated. If the maximal production rate does not occur within 120 days of source startup, the tests must be conducted no later than 180 days after the initial startup of the source.

The tests shall be conducted in accordance with EPA Reference Methods 1-4, Method 5 (particulate matter), Method 6 (sulfur dioxide), Method 7(A-E) (nitrogen dioxide), and Method 10 (carbon monoxide) contained in 40 CFR Part 60, Appendix A, and with the requirements of

40 CFR 60.8(f). The oxygen in the stack gas shall be determined by using EPA Method 3.

The NMED shall be notified of the date and time of compliance testing at least 30 days before the planned test date so that the NMED may have an observer present during testing. The permittee will arrange a pretest meeting with the NMED at least 30 days prior to the anticipated test date and shall observe the pre-testing and testing procedures described in detail under this condition. These requirements include submitting a written test protocol to the NMED at least 1 week prior to the testing date for approval and providing appropriate equipment and access to the NMED observer for sampling. Several parameters (i.e., engine revolutions per minute, exhaust static pressure, exhaust manifold temperature, fuel consumption, and horsepower as indicated by kilowatt output) shall be monitored and recorded during the test and the results included with the test report. Flow straighteners shall be installed where necessary to prevent cyclonic flow in the stack. The tests shall be conducted at 90 percent of full load or greater and at additional loads as specified by NMED personnel at the test or pre-test meeting.

Two copies of the compliance test report must be submitted to the NMED within 30 days after completion of testing.

Compliance with these conditions was achieved and reported in the compliance test report, *Emission Sampling Report, Backup Diesel Generator*, that was submitted to the NMED Air Quality Bureau on March 6, 1994, and was approved on May 12, 1994.

29.3.2.4 Revisions and Modifications, Condition 5

Any future changes shall be preceded by the submittal of a permit application to the NMED in accordance with 20 NMAC 2.72. No modifications shall be made prior to the issuance of the revised permit.

There have been no revisions or modification to the equipment or its operation.

29.3.2.5 Notification to Subsequent Owners, Condition 6

If there is any change in control or ownership of the diesel generators, the permittee shall notify the succeeding owner

of the permit and its conditions and shall notify the NMED of the change in ownership within 15 days of the change.

There has been no change in ownership or control of the permitted equipment.

29.3.2.6 Right to Access Property and Review Records, Condition 7

The NMED will be given the right to enter the facility at all reasonable times to verify the terms and conditions of the permit. Upon receipt of a verbal or written request from any authorized representative of the NMED, the company will produce any records or information necessary to demonstrate that the terms and conditions of the permit are being met.

Upon request, NMED representatives will be allowed non-restricted entry to the site and will be provided with appropriate records and information. No NMED personnel requested entry to the site to verify the terms and conditions of the permit for the diesel generators within this reporting period.

29.3.2.7 Posting of the Permit, Condition 8

A copy of the permit will be posted and in view of the plant site at all times. It will be made available to NMED personnel for inspection upon request.

A copy of the permit is posted in the office of the Facility Shift Manager.

29.3.2.8 Record-keeping, Condition 9

DOE will maintain an operational log in which the date, time, and hours of operation will be recorded for each engine. The records will be maintained on site for at least 2 years from the time of recording and will be made available to NMED personnel upon request.

Completion and maintenance of operational logs are carried out as prescribed by WID procedure. Central Monitoring Room logs contain information about the diesel generators. The run times for the generators are recorded automatically by the Central Monitoring System. The records are maintained on site for at least 2 years.

29.3.2.9 Reporting, Condition 10

The permittee will notify the NMED in writing or provide the NMED with the following information:

- *The anticipated date of the initial startup of each new or modified emission source at least 30 days prior to that date*

- *The actual date of the initial startup of each new or modified source within 15 days after the startup date*

- *The date when each new or modified source reaches the maximal production rate at which it will operate within 15 days after that date*

- *Any change of operators within 15 days after the change*

- *Any necessary update or correction no more than 60 days after the operator knows or should have known of the condition necessitating the update or correction of the permit.*

Notice of the initial startup of each source was submitted to the Air Quality Bureau in December 1993. Subsequent reports will be filed as needed.

29.3.2.10 Permit Cancellations (Permit, p. 8)

> *The NMED will cancel the permit automatically if any source ceases operation for at least 5 years or if the construction or modification of a source is not initiated within 2 years from the date of issuance or if work on construction or modification is suspended for a total of 1 year.*

If the generator ceases operation for at least 5 years and is to be reactivated, a new permit application will be filed. The generators will not be operated until the permit has been issued.

29.3.2.11 Notice of Intent and Emission Inventory (Permit, p. 8)

> *Requirements related to Notice of Intent and emission inventory are contained in 20 NMAC 2.73.*

See Section 29.2.7, which pertains to compliance with 20 NMAC 2.73.

30.0 NEW MEXICO WATER QUALITY ACT

30.1 Summary of the Law

With the enactment of the New Mexico Water Quality Act (WQA; 74-6-1 through 74-6-17 NMSA 1978), a mechanism was provided at the state level to establish water-quality standards that are consistent with the CWA. The state act created the Water Quality Control Commission (WQCC) and directed the WQCC, as the state's water-pollution-control agency for all purposes of the CWA, to adopt a comprehensive water quality management program and water quality standards. The *New Mexico Water Quality Control Commission Regulations* include water-quality standards for ground and surface water and regulations regarding discharges to surface-water courses and ground water.

Pursuant to the regulations of § 3-109, *Director Approval, Disapproval, Modification, or Termination of Proposed Discharge Plans*, the Discharge Plan submitted by the DOE for the discharge of 23,000 gallons per day (gpd) of sewage effluent and up to 1,500 gpd of nonhazardous brine water from the WIPP was approved in 1992. On August 28, 1995, the WID submitted a request to the NMED requesting a minor amendment to DP-831 increasing the amount of nonhazardous brine for disposal to 2,000 gpd. On October 4, 1995, the NMED approved the amendment to the Discharge Plan. The increase was required, not because additional brine was being generated but because on days the observation wells were pumped, greater than 1,500 gallons were produced, necessitating that the brine be disposed of over two days' time.

The WQA was formerly implemented by WQCC 82-1. It is now implemented by Chapter 6 of Title 20 of the NMAC.

Title 20 NMAC 7.4 defines public water supply systems and public wastewater facilities. Under these definitions, and because of the size of the population served, the WIPP is classified as a Class 1 public wastewater facility and a Class 2 public water supply system. Since these systems require certified operators, the WIPP facility employs operators and supervisors certified to the requirements of Subpart II of this Part.

30.2 Compliance Status of the Regulatory Requirements

Table 30-1 summarizes the regulatory requirements and their compliance status under the New Mexico Water Quality Act. Following the table, the text gives more detail on the compliance status for each requirement.

TABLE 30-1. New Mexico Water Quality Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 6.2, *New Mexico Water Quality Control Commission Regulations*		
20 NMAC 6.2, § 1-201	NOI to discharge	**ACHIEVED** NOI filed as required [Section 30.2.1]
20 NMAC 6.2, § 1-202	Filing of plans and specifications--sewerage systems	**ACHIEVED** Submitted to NMED [Section 30.2.2]
20 NMAC 6.2, § 1-203	Notification of discharge--removal: requirements for notification, corrective action, and reporting in the event of an unauthorized discharge of oil or other water contaminant that could have adverse effects	**UP TO DATE** *RCRA Contingency Plan* [Section 30.2.3]
20 NMAC 6.2, § 2-101	General discharge limitations and sampling/analytical requirements	**UP TO DATE** Specified in NMED Discharge Plan approval [Section 30.2.4]
20 NMAC 6.2, § 3-104	Authorization only of effluent(s)/leachate(s) as specified in Discharge Plan	**UP TO DATE** Authorization granted [Section 30.2.5]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 6.2, § 3-106	Application for Discharge Plan approval	**ACHIEVED** Application sent to NMED [Section 30.2.6]
20 NMAC 6.2, § 3-107	Monitoring, reporting, and other requirements	**UP TO DATE** Monitoring reports filed [Section 30.2.7]
20 NMAC 6.2, § 3-108	Public notice and participation	**ACHIEVED** Public notice published [Section 30.2.8]
20 NMAC 6.2, § 3-109	Director approval, disapproval, modification, or termination of proposed Discharge Plans	**UP TO DATE** Discharge plan to be revised if necessary [Section 30.2.9]
20 NMAC 6.1	Water quality standards for interstate and intrastate streams in New Mexico	**NOT APPLICABLE** No streams affected by WIPP [Section 30.2.10]
20 NMAC 7.4	Utility Operator Certification	**UP TO DATE** Operators and supervisors undergo recertification and training every three years [Section 30.2.11]

30.2.1 Notice of Intent to Discharge, 20 NMAC 6.2, § 1-201

> *Any party intending to make a new water contaminant discharge or to alter the character or location of an existing water contaminant discharge, unless the discharge is being made or will be made into a community sewer system or subject to the Liquid Waste Disposal Regulations adopted by the New Mexico Environmental Improvement Board, shall file a notice with the Water Pollution Control Bureau of the New Mexico Environment Department (NMED).*

NOIs to discharge have been filed as required. The latest filing occurred on August 28, 1995.

30.2.2 Filing of Plans and Specifications - Sewerage Systems, 20 NMAC 6.2, § 1-202

> *Any party proposing to construct a sewerage system or proposing to modify any sewerage system in a manner that will change the quantity or quality of the discharge from the system substantially must file plans and specifications for the construction or modification with the Water Pollution Control Bureau of the NMED.*

Sewerage system plans and specifications were included in the transmittal of the Discharge Plan application to the NMED.

30.2.3 Notification of Discharge - Removal, 20 NMAC 6.2, § 1-203

> *Requirements for reporting, notifications, and corrective action with respect to any discharge from any facility of oil or other water contaminant, in such quantity as may with reasonable probability injure or be detrimental to human health, animal or plant life, or property, or unreasonably interfere with the public welfare or the use of property are specified.*

In the event of an unauthorized discharge of oil or other potentially harmful water contaminants, notification and reporting will be performed and corrective action taken according to WID procedures and the *RCRA Contingency Plan*. The discharge will be reported to the Chief of the Groundwater Bureau of the NMED within 24 hours. A written report will be submitted within seven days, as required under this regulation.

30.2.4 General Requirements, 20 NMAC 6.2, § 2-101

> *General discharge limitations and sampling/analytical requirements for the discharge of effluents to a watercourse must be met.*

These limitations and requirements are specified in the NMED's Discharge Plan Approval DP-831. The discharge limitations and the sampling/analytical requirements are met. Reports are submitted quarterly to the NMED.

30.2.5 Discharge Plan Required, 20 NMAC 6.2, § 3-104

> *No party shall cause or allow effluent or leachate to discharge so that it may move directly or indirectly into ground water unless the discharge meets the requirements of a discharge plan approved by the Director. When a plan has been approved, discharges must be consistent with the terms and conditions of the plan.*

The discharge of 2,000 gpd of nonhazardous brine water at WIPP is authorized by NMED Discharge Plan approval, DP-831.

30.2.6 Application for Discharge Plan Approval, 20 NMAC 6.2, § 3-106

> *Any party who intends to begin discharging any listed water contaminants or any toxic pollutant so that they may move directly or indirectly into ground water must submit a Discharge Plan as required.*

A Discharge Plan application was submitted to the NMED on November 14, 1991. The NMED approved the plan on January 16, 1992; it will expire on January 16, 1997.

30.2.7 Monitoring, Reporting, and other Requirements, 20 NMAC 6.2, § 3-107

> *Requirements include notification of the NMED of any facility expansion, production increase, or process modifications that would result in the discharge of water contaminants.*

Monitoring reports are filed quarterly according to the following schedule: January 16, April 16, July 16, and October 16.

30.2.8 Public Notice and Participation, 20 NMAC 6.2, § 3-108

> *Within 30 days of filing of a proposed discharge plan, or modification or renewal of an approved discharge plan, the*

NMED must ensure that the public and affected governmental agencies are notified.

The NMED made public notice of the Discharge Plan on December 15, 1991. No comments were received from the public.

30.2.9 Director Approval, Disapproval, Modification, or Termination of Proposed Discharge Plans, 20 NMAC 6.2, § 3-109

If the monitoring data submitted indicate that these regulations are being or may be violated or that the standards in 20 NMAC 6.2, § 3-102, "Standards for Ground Water of 10,000 mg/L TDS [total dissolved solid] Concentration or Less," are being or will be exceeded in ground water at any place of withdrawal for the present or reasonably foreseeable future due to the discharge, it may be necessary to modify the Discharge Plan.

If the monitoring data submitted indicate that the Discharge Plan conditions or the standards are being or will be exceeded, the plan may be revised.

Since the approval of discharge may not exceed seven years from the date of issuance of the Discharge Plan approval, it will be necessary to find an alternative means of disposal for the nonhazardous brine solution currently being discharged.

30.2.10 Water Quality Standards for Interstate and Intrastate Streams in New Mexico, 20 NMAC 6.1

The State has set a number of water-quality standards for interstate and intrastate streams in New Mexico.

The water-quality standards for interstate and intrastate streams in New Mexico do not apply to WIPP because there are no streams, either intermittent or permanent, that will be affected by WIPP.

30.2.11 Utility Operator Certification, 20 NMAC 7.4

The State requires that operators of public water supply systems and public wastewater facilities be certified to the educational and experience requirements of Subpart II of Part 4.

Under these regulations, the WIPP is considered a public water supply system, which is defined as a system for the provision to the public of piped water for human consumption or domestic purposes, and the system regularly serves an average of at

least 25 individuals at least 60 days of the year; it includes any water supply source and any treatment, storage, and distribution facilities. The WIPP is classified as a Class 2 public water supply system because of the population served, 501 to 5,000, and the treatment process being chlorination.

The WIPP is also considered a Class 1 public wastewater facility because of the population served and the treatment process being raw wastewater lagoons.

Since these systems at WIPP require certified operators, the WID's Facility Operations Section employs operators and supervisors certified to the section's requirements. All operators undergo recertification and training every three years; training and certification records are maintained by Facility Operations.

30.3 Compliance Status of the Permit Requirements

Table 30-2 summarizes the specific and general requirements from the Discharge Plan for WIPP and their compliance status. Additional information is provided in the text.

TABLE 30-2. New Mexico Water Quality Act - Summary of Compliance Status of Permit Requirements

CITATION	REQUIREMENT	COMPLIANCE STATUS
Approval DP-831, *New Mexico Discharge Plan for the WIPP*		
DP-831 Specific Requirement (SR) #1	Monitoring and quarterly reports	**UP TO DATE** Monitoring conducted and reports submitted quarterly [Section 30.3.1]
DP-831 SR #2	Submittal of water quality analysis with quarterly report	**UP TO DATE** Analysis submitted quarterly [Section 30.3.2]
DP-831 SR #3	Quarterly sampling of each evaporation lagoon	**UP TO DATE** Sampling and results reported quarterly [Section 30.3.3]

CITATION	REQUIREMENT	COMPLIANCE STATUS
DP-831 SR #4	Maintenance of berms protecting the lagoon system from precipitation runoff and run-on	**UP TO DATE** Performed quarterly [Section 30.3.4]
DP-831 SR #5	Completion of proposed evaporation ponds	**ACHIEVED** Completed July 16, 1993 [Section 30.3.5]
DP-831 General Requirement (GR)--*Record-keeping*	Records to be kept and made available to the NMED *upon request*	**UP TO DATE** *Information recorded and* available [Section 30.3.6]
DP-831 GR - Inspection and Entry	Allowing inspections, entry, sampling, and monitoring by NMED personnel	**UP TO DATE** Activities allowed on site [Section 30.3.7]
DP-831 GR - Duty to Provide Information	Providing information relevant to Discharge Plan/records required by Discharge Plan that has been requested by NMED	**UP TO DATE** No information requested to date [Section 30.3.8]
DP-831 GR - Spills, Leaks, and Other Unauthorized Discharges	Reporting and remediation of any spills, leaks, and any other unauthorized discharges	**UP TO DATE** Reports to be made if unauthorized discharges occur; no reporting required to date [Section 30.3.9]
DP-831 GR - Retention of Records	Retention of all monitoring information, Discharge Plan reports, and data used to complete the Discharge Plan application for at least five years	**UP TO DATE** Documentation being retained [Section 30.3.10]

CITATION	REQUIREMENT	COMPLIANCE STATUS
DP-831 GR - Modifications and/or Amendments	Notification of NMED of any modifications or additions to the wastewater disposal system; approval by NMED required prior to increasing the quantity or concentration of constituents in waste water above those approved in the plan	**UP TO DATE** Approval to be obtained as required [Section 30.3.11]

30.3.1 Requirements for Monitoring and Quarterly Reports, DP-831 Specific Requirement (SR) #1

The applicant shall monitor the quantity of brine water pumped into the evaporation ponds monthly and submit a quarterly report to the Ground Water Section's Office.

The monitoring required by the NMED Discharge Plan Approval DP-381 has been conducted as required. The results have been submitted in the quarterly Discharge Monitoring Reports required by the Discharge Plan, which are prepared in accordance with a WID procedure.

30.3.2 Requirement for Water Quality Analysis Submitted with Quarterly Report, DP-831 SR #2

A water quality analysis shall be submitted with the quarterly report mentioned above in SR #1.

Water quality analyses have been submitted with the quarterly reports.

30.3.3 Requirement that the Evaporation Lagoon be Sampled and the Results Reported, DP-831 SR #3

Each evaporation lagoon shall be sampled quarterly for total dissolved solids (TDS) and the results submitted in the quarterly report.

Each evaporation lagoon has been sampled quarterly, and the results provided in the quarterly reports.

30.3.4 Requirement for Berm Maintenance, DP-831 SR #4

> *Berms protecting the lagoon system shall be maintained to protect it from precipitation runoff and runon.*

Maintenance of the berms is performed quarterly.

30.3.5 Requirement for Completion of Proposed Evaporation Ponds, DP-831 SR #5

> *The applicant has 18 months from the date of approval to complete construction of the proposed evaporation ponds. The applicant can discharge brine waters into the existing salt pile evaporation pond until the new evaporation ponds are completed.*

The evaporation ponds were completed by July 16, 1993, as required.

30.3.6 General Requirement, *Record-keeping*, DP-831

> *The discharger must maintain a written record of ground-water and wastewater quality analyses at the facility. The information must be recorded and made available to the NMED upon request.*

Monitoring, reporting, and record-keeping requirements are met as specified in the Discharge Plan.

30.3.7 General Requirement, *Inspection and Entry*, DP-831

> *The discharger shall allow the NMED Secretary or her authorized representative, upon the presentation of credentials, to enter the discharger's facility during regular business hours or at other reasonable times under the conditions of this discharge plan.*

NMED personnel are allowed on site to conduct inspections, sampling, and monitoring during normal business hours.

30.3.8 General Requirement, *Duty to Provide Information*, DP-831

> *The discharger shall furnish to the NMED, within a reasonable time frame specified by the NMED, any relevant information which it may request to determine whether cause exists for modifying, terminating, and/or renewing this*

> *discharge plan or to determine compliance with this plan. The discharger shall furnish to the NMED, upon request, copies of records required to be kept by this Discharge Plan.*

No requests have been received from the NMED to provide information relevant to the Discharge Plan. Similarly, the NMED has not requested copies of the records to be maintained under the terms of the Discharge Plan.

30.3.9 General Requirement, *Spills, Leaks, and other Unauthorized Discharges*, DP-831

> *Any unauthorized discharges must be reported to the NMED and remediated as required. This requirement applies to all seeps, spills, and/or leaks discovered from the sewerage lagoons or that may directly or indirectly leave the boundaries of the WIPP site.*

Any spills, leaks, and other unauthorized discharges will be reported to NMED and remediated in accordance with WIPP procedures.

30.3.10 General Requirement, *Retention of Records*, DP-831

> *The discharger shall retain records of all monitoring information, including all calibration and maintenance records, copies of all reports required by this discharge plan, and records of all data used to complete the application for this discharge plan, for a period of at least 5 years from the date of the sample collection, measurement, report, or application.*

All monitoring information, analytical results, Discharge Plan reports, and data used to complete the Discharge Plan application will be retained for at least five years.

30.3.11 General Requirement, *Modifications and/or Amendments*, DP-831

> *The discharger must notify the NMED of any modifications or additions to the applicant's wastewater disposal system, including any increase in wastewater flow rate and wastewater storage and disposal management changes to the system as approved under this discharge plan. The discharger shall obtain the NMED's approval, as a discharge plan modification, prior to any increase in the quantity or concentration of constituents in the wastewater above those approved in this plan.*

If any modifications or additions to the wastewater disposal system are planned for WIPP that would increase the quantity and/or the concentration of constituents in the waste water above those approved in the discharge plan, the NMED will be notified. No work will be initiated until the NMED approves the modification or addition.

31.0 NEW MEXICO DRINKING WATER REGULATIONS

31.1 Summary of the Regulations

Like the SDWA, the New Mexico Drinking Water Regulations (DWRs), Section 7.1 of Title 20 of the New Mexico Administrative Code (NMAC), provide a regulatory strategy for protecting public water-supply systems within the state. This section identifies the various categories of water-supply systems and establish operating requirements for each system. It also establishes the maximum contaminant levels (MCLs) for water-supply systems and implement monitoring and analytical requirements for each system.

The DWRs were formerly implemented by the New Mexico Water Supply Regulations, Part III. They are now implemented by Chapter 7 of Title 20 of the NMAC.

31.2 Compliance Status of the Regulatory Requirements

The NMED notified the WIPP on September 9, 1992, that the WIPP water supply system is considered a public water supply and classified the system as a non-transient, non-community water supply for reporting and testing under the requirements of the SDWA. The DOE has corresponded with the NMED since the original letter of September 9, 1992, which identified the WIPP as a nontransient, noncommunity water supply system, to obtain a determination of the specific SDWA sampling requirements for the site. This direction was requested because the WIPP obtains raw water from the Double Eagle Water Line, which is owned and operated by the city of Carlsbad.

On March 11, 1994, the NMED Carlsbad Field Office provided specific direction on the type of SDWA sampling required for the WIPP water supply system. The letter references Part III, § 310, of the New Mexico DWRs, which states:

> *When a public water system supplies water to one or more other public water supply systems, the Department may modify the compliance sampling requirements imposed by the regulations to the extent that the interconnection of the systems justifies treating them as a single system for compliance sampling purposes.*

The NMED went on to determine that "since the Carlsbad Municipal Public Water Supply (WSS# 206-08) provides WIPP with its water and since Carlsbad already tests the various constituents at each Double Eagle wellfield source, WIPP is exempted from taking these samples." The NMED then determined that the WIPP is required to obtain point-of-use system samples, including lead, copper, and total coliform bacteria.

The specific requirements that are applicable to WIPP and the compliance status of each are summarized in Table 31-1. More detailed information is provided in the text.

TABLE 31-1. New Mexico Drinking Water Regulations (20 NMAC 7.1) - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 7.1, § 205(A)	MCLs for total coliform bacteria	**UP TO DATE** Monthly sampling below MCL [Section 31.2.1]
20 NMAC 7.1, § 208(I)	Cross connections	**UP TO DATE** Inspections, corrective actions [Section 31.2.2]
20 NMAC 7.1, § 301(E)	Certification of sampling personnel	**ACHIEVED** Certification of personnel involved with sampling [Section 31.2.3]
20 NMAC 7.1, § 302(A)	Compliance sampling of coliforms	**UP TO DATE** At least one sample of total coliform bacteria collected per month; WIPP Water Sampling Plan in WID procedure [Section 31.2.4]
20 NMAC 7.1, § 309	Laboratories	**ACHIEVED** Contracts with laboratories; QA/QC [Section 31.2.5]
20 NMAC 7.1, § 310	Sampling of consecutive public water-supply systems	**ACHIEVED** Modified sampling requirements [Section 31.2.6]
20 NMAC 7.1, § 401(A)	Reporting requirements	**UP TO DATE** Submittal of analytical reports [Section 31.2.7]

CITATION	REQUIREMENT	COMPLIANCE STATUS
20 NMAC 7.1, § 403(A)	Record maintenance	**UP TO DATE** Maintenance of analytical results as quality records [Section 31.2.8]

31.2.1 MCL for Total Coliform Bacteria, 20 NMAC 7.1, § 205(A)

> *The MCL for total coliform bacteria is based on the presence or absence of total coliforms in a sample rather than on coliform density. For a system that collects fewer than 40 samples per month, the system is in compliance with the total coliform MCL if no more than one sample collected during the month is total coliform positive.*

Analyses for total coliform bacteria (i.e., *Escherichia coli*) are performed at WIPP on a monthly basis. The laboratory submits the results to WIPP and to the NMED. To date, coliforms have remained below the MCL.

31.2.2 Cross Connections, 20 NMAC 7.1, § 208(I)

> *No physical connection between a public water supply and any water-supply source not regulated by the NMED is allowed unless the public water-supply system is protected by a backflow prevention device that has been reviewed by the NMED and is listed by an appropriate listing agency.*

WIPP has implemented a cross-connection control program. Inspections of the system's cross connections are complete. Corrective actions are being implemented as needed.

31.2.3 Certification of Sampling Personnel, 20 NMAC 7.1, § 301(E)

> *All persons who collect compliance samples for water-supply samples must possess a current Sampling Certificate issued by the Secretary of the NMED. Sampling Certificates are issued only to persons who have successfully completed an approved training course and have passed an examination that is administered periodically by the NMED. Sampling Certificates are valid for 3 years.*

All WIPP personnel involved with water-supply sampling to ensure compliance with the DWRs have completed the New Mexico water-sampling training course and have received Sampling Certificates.

31.2.4 Compliance Sampling of Coliforms, 20 NMAC 7.1, § 302(A)

> *Public water-supply systems must collect total coliform samples at sites that are representative of water throughout the distribution system according to their approved written sampling plan.*
>
> *The minimal number of samples required per month is based on the population served by the system. Only one sample per month is required by a water-supply system that serves an average daily population of 25 to 1,000.*

Samples are collected from sites that are representative of water throughout the distribution system. This technique is covered in the desktop instructions "Coliform Sampling of WIPP Drinking Water."

Fewer than 1,000 people are served by the water-supply system at WIPP. Therefore at least one sample is collected per month for total coliform bacteria analysis.

31.2.5 Laboratories, 20 NMAC 7.1, § 309

> *Compliance samples may be considered only if they have been analyzed by a laboratory that is acceptable to the NMED.*

Lead and copper samples are analyzed by the Scientific Laboratory Division of the NMED. In addition, WIPP has contracts in place with two off-site EPA-certified laboratories to complete all microbiological and inorganic analyses required by the NMED for WIPP. Both laboratories have undergone QA/QC review and approval. Each laboratory has an approved Quality Assurance Project Plan (QAPjP) in place and is listed on the WIPP Qualified Supplier List (QSL).

31.2.6 Sampling of Consecutive Public Water-Supply Systems, 20 NMAC 7.1, § 310

> *When a public water-supply system provides water to one or more other public water-supply systems, the NMED may modify the compliance sampling requirements imposed by these regulations. Any modified compliance sampling shall be conducted in accordance with the schedule specified by the NMED.*

The water-supply system at WIPP receives its water from the public water-supply system of the city of Carlsbad. Carlsbad is responsible for all well-source sampling. Therefore, the NMED has modified the compliance sampling requirements for WIPP and requires sampling only for lead, copper, and total coliform bacteria.

Per the requirements set forth in 20 NMAC 7.1, Subpart X, § 1001(c)(1), "the lead action level is exceeded if the concentration of lead in more than 10 percent of tap water samples collected during any monitoring period conducted in accordance with § 1007 is greater than 0.015 mg/L."

Per the requirements set forth in 20 NMAC 7.1, Subpart X, § 1001(c)(2), "the copper action level is exceeded if the concentration of copper in more than 10 percent of tap water samples collected during any monitoring period conducted in accordance with § 1007 is greater than 1.3 mg/L."

The schedule mandated by the NMED for sampling is presented in Table 31-2.

TABLE 31-2. Required Sampling at WIPP for Compliance with the Safe Drinking Water Act and the New Mexico Drinking Water Regulations

Contaminant	Frequency of Water-Supply Sampling
Lead and copper (for water systems for populations of 501 to 3,300)	Initial sampling required 20 sample sites for two 6-month periods beginning on July 1, 1993; requirements were reduced when action levels were met for two consecutive sampling periods (August 23, 1995). Sampling requirements will be reduced to 10 sample sites per year beginning July, 1996.
Total coliform bacteria	Once per month

31.2.7 Reporting Requirements, 20 NMAC 7.1, § 401(A)

> *Unless a shorter period is specified, the water supplier shall provide a copy of the results and data required to the appropriate NMED field office within 10 days after analysis.*

Analytical reports for lead and copper are submitted to the appropriate NMED field office within 10 days of their receipt by WID personnel and directly by the lab. The analytical laboratory that analyzes total coliform bacteria sends a copy of the results and data directly to WIPP and to the appropriate NMED field office.

31.2.8 Record Maintenance, 20 NMAC 7.1, § 403(A)

> *A water supplier shall retain the appropriate records on or near the premises of the public water-supply system. Records of bacteriological and chemical analyses shall be kept for at least 5 and 10 years, respectively. The information that must be retained includes the date, place, and time of sampling; the name of the person who collected the sample; identification of the sample; date of analysis and name of the laboratory and person who performed the analysis; the analytical method used; and the results of the analysis.*

All applicable records pertaining to the sampling and analysis and the analytical results are maintained as quality records by WID.

32.0 NEW MEXICO HAZARDOUS CHEMICALS INFORMATION ACT

32.1 Summary of the Law

The New Mexico Hazardous Chemicals Information Act (HCIA; §§ 74-4E-1 through 74-4E-9 NMSA 1978) was enacted to ensure that current information on the nature and location of hazardous chemicals is available to LEPCs, emergency responders, and the public as required by Title III. The HCIA created the SERC and directs facility owners or operators to notify the New Mexico Department of Public Safety under certain conditions, including the presence of extremely hazardous substances at or above a specified quantity at a facility and the release of any chemical substance that has occurred at or above reportable quantities determined by the state. The HCIA specifies reports to be submitted to the State, including toxic chemical release and hazardous material inventory reports.

32.2 Compliance Status of the Regulatory Requirements

Table 32-1 summarizes each applicable requirement and its compliance status under the HCIA. The text provides more detail on the compliance status of each requirement.

TABLE 32-1. Hazardous Chemicals Information Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
Hazardous Chemicals Information Act, §§ 74-4E-1 to 74-4E-9 NMSA 1978		
§ 74-4E-5(A)(1)	Notification to the state that an extremely hazardous substance, at or above a specified quantity, is present at a facility	**UP TO DATE** Notifications and revised listing submitted [Section 32.2.1]
§ 74-4E-5(A)(2)	Notice of release of chemical substance(s) when release is at or above the reportable quantity of the substance	**UP TO DATE** Notification of releases of ethylene glycol submitted [Section 32.2.2]
§ 74-4E-5(A)(3)	Submittal of an inventory form covering each hazardous material on or before March 1 of each year	**UP TO DATE** Chemical inventory submitted in March 1995 and 1996 [Section 32.2.3]

CITATION	REQUIREMENT	COMPLIANCE STATUS
§ 74-4E-5(A)(4)	Submittal of Toxic Chemical Release Inventory (TRI) forms to Public Safety Department for facilities employing at least 10 employees and with SIC code between 20-39 classification	**NOT APPLICABLE** TRI reporting not currently required due to certain exemptions [Section 32.2.4]

32.2.1 Notice of Extremely Hazardous Substance, § 74-4E-5(A)(1)

Facility owners or operators must notify the State safety department that an extremely hazardous substance, at or above the threshold planning quantity, is present at a facility.

The WIPP submits a list of hazardous chemicals to the SERC, the LEPC, and the local fire department whenever additional substances are received or if significant new information is received about an item for which a list was provided. In March 1995 and March 1996, a revised list of hazardous chemicals was submitted to these organizations. The listing comprised extremely hazardous substances present in amounts equal to or greater than the Threshold Planning Quantity (TPQ) or 500 pounds, whichever is less, and all substances classified as hazardous under the Occupational Safety and Health Act Hazard Communication Standard with site inventories equal to or greater than 10,000 pounds.

32.2.2 Notice of Release of Chemical Substance(s), § 74-4E-5(A)(2)

Facility owners or operators must notify the State safety department of the release of a chemical substance when the release is at or above the reportable quantity of the substance.

During this reporting period, there were two ethylene glycol spills at WIPP that exceeded the reportable quantity at the time of 1 pound. These were reported to the SERC and the LEPC. The reportable quantity for ethylene glycol was raised from 1 pound to 5,000 pounds on June 12, 1995.

32.2.3 Hazardous Material Inventory, § 74-4E-5(A)(3)

Facility owners or operators must submit to the State an inventory form containing Tier II information on or before March 1 of each year.

The WIPP submitted the Emergency and Hazardous Chemical Inventory Report (Tier II Report) on February 1, 1995, and January 16, 1996 to the SERC, the LEPC, and local fire departments.

32.2.4 Toxic Chemical Release Inventory, § 74-4E-5(A)(4)

> *Facility owners or operators employing at least 10 employees and with a SIC code between 20 and 39 must submit a toxic chemical release form on or before July 1 of each year to the State safety department.*

During this reporting period, the WIPP was exempt from submitting a Toxic Chemical Release Inventory report because of the use of toxic chemicals at WIPP and the exemptions described in 40 CFR 372.38, *Exemptions.*

33.0 NEW MEXICO EMERGENCY MANAGEMENT ACT

33.1 Summary of the Law

The New Mexico Emergency Management Act (EMA; §§ 74-4B-1 through 74-4B-14 NMSA 1978) was enacted to ensure the adequacy of hazardous material emergency management capabilities in the state to protect the health and safety of New Mexico citizens and the environment. The act delineates those state agencies that are responsible for responding to hazardous material accidents and providing control and management of such accidents. Furthermore, the act provides for the formulation of a comprehensive hazardous materials emergency management plan.

33.2 Compliance Status of the Regulatory Requirements

Table 33-1 summarizes each applicable requirement and its compliance status under the EMA. The text provides more detail on the compliance status of each requirement.

TABLE 33-1. New Mexico Emergency Management Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
Emergency Management Act, §§ 74-4B-1 - 74-4B-14 NMSA 1978		
§ 74-4B-2	Findings and purpose	**NOT APPLICABLE** State responsibilities [Section 33.2.1]
§ 74-4B-4	State responsibility for management of accidents; immunity from liability; cooperative agreements; private property	**NOT APPLICABLE** State responsibilities [Section 33.2.2]
§ 74-4B-5	State Police Emergency Response Officer; procedure for notification; cooperation with other State agencies and local governments	**UP TO DATE** WID procedures [Section 33.2.3]

CITATION	REQUIREMENT	COMPLIANCE STATUS
§ 74-4B-6	EMPT: powers and duties	**NOT APPLICABLE** State EMTF is no longer active [Section 33.2.4]
§ 74-4B-6.1	Creation and duties of the Hazardous Materials Emergency Response Administrator	**NOT APPLICABLE** State responsibilities [Section 33.2.5]
§ 74-4B-10	Responsibility for cleanup by owner, shipper, or carrier of the hazardous material	**UP TO DATE** WID procedures [Section 33.2.6]

33.2.1 Findings and Purpose, § 74-4B-2

The purpose of the EMA is to ensure that adequate hazardous materials emergency management capabilities exist in the State, delineate the State agencies that are responsible for responding to and controlling and managing a hazardous materials accident, and provide for the formulation of a comprehensive statewide hazardous materials emergency management plan.

These are state responsibilities. No action is required at WIPP by this subsection.

33.2.2 State Responsibility for Management of Accidents; Immunity from Liability; Cooperative Agreements; Private Property, § 74-4B-4

The State government has the primary responsibility for managing an accident. The EMA does not waive or alter immunity from liability. The State may enter into cooperative agreements with county and municipal governments for accident management. The State may enter into such agreements with the Federal government, Indian tribes and pueblos, and bordering States for assistance in managing accidents. When an accident has occurred or appears imminent, responsible State personnel or authorized persons are authorized to enter any buildings or premises to

determine whether emergency management procedures should be implemented.

These are state responsibilities. No action is required at WIPP under this subsection.

33.2.3 State Police Emergency Response Officer; Procedure for Notification; Cooperation of other State Agencies and Local Governments, § 74-4B-5

State Police Emergency Response Officers shall be designated, trained, and available to answer an emergency response call from the first responder. The responsibilities of these officers and of the State Police Emergency Response Center are described. Any driver of a vehicle carrying hazardous materials involved in an accident which may cause injury to persons or property or any owner, shipper, or carrier of hazardous materials involved in an accident who has knowledge of such accident or any owner or person in charge of any building, premises, or facility where such an accident occurs shall immediately notify the New Mexico State Police Division of the Public Safety Department by the quickest means of communication available.

Should an accident involving hazardous materials occur, the New Mexico State Police Division of the Public Safety Department will be notified by the driver, owner, shipper, or carrier of the waste as outlined in a WID procedure.

WIPP personnel will contact the SERC in the event of a spill that could endanger human health or the environment. The SERC will, in turn, contact the NMED if their assistance is needed.

33.2.4 Emergency Management Task Force: Powers and Duties, § 74-4B-6

The composition and responsibilities of the Emergency Management Task Force are described.

The state EMTF is no longer active. No action is required at WIPP under this subsection.

33.2.5 Creation and Duties of the Hazardous Materials Emergency Response Administrator, § 74-4B-6.1

The creation and responsibilities of the Hazardous Materials Emergency Response Administrator are described in this subsection.

These are state responsibilities. No action is required at WIPP under this subsection.

33.2.6 Clean-up, § 74-4B-10

> *Nothing in the EMA shall be construed to relieve hazardous materials owners, shippers, or carriers of their responsibilities and liability in the event of an accident. Such persons shall assist the State as requested in responding to an accident and are responsible for restoring the scene of the accident to the satisfaction of the State.*

An occurrence involving a TRUPACT-II container that is not within the confines of the WIPP does not fall under WID responsibility. The correct line of action for an on-site occurrence that can be cleaned up by site personnel is covered in a WID procedure. However, in the event of an on-site occurrence that is not handled by site personnel, a cleanup contractor will be obtained.

If an off-site occurrence takes place involving a TRUPACT-II container, the DOE will take responsibility for cleaning up the scene of the accident to the state's satisfaction.

34.0 NEW MEXICO PREHISTORIC AND HISTORIC SITES PRESERVATION ACT

34.1 Summary of the Law

The provisions of the Congressional National Historic Preservation Act (NHPA) are furthered by law in the state of New Mexico. The act currently in place is the New Mexico Prehistoric and Historic Sites Preservation Act (§§ 18-8-1 through 18-8-8 NMSA 1978). The purpose of this act is the acquisition, stabilization, restoration, or protection of significant prehistoric and historic sites by the state of New Mexico and corporations. This act is administered by the SHPO in consultation with the Cultural Properties Review Committee.

The Prehistoric and Historic Sites Preservation Act is implemented by Historic Preservation Division (HPD) Rule 89-2, which established procedures for acquiring, stabilizing, restoring, or protecting significant prehistoric and historic sites. Rule 89-2 also established procedures and guidelines to evaluate alternatives to programs and projects requiring the use of land from significant prehistoric and historic sites and to determine whether all possible planning has been implemented to preserve and protect such sites. Detailed requirements for a long-term management plan for any site acquired, stabilized, restored, or protected are included under this rule.

34.2 Compliance Status of the Regulatory Requirements

The WIPP is bound by the New Mexico statutes and regulations regarding cultural properties in accordance with edicts provided by the SHPO. WIPP personnel contract for archeological surveys and consult with the SHPO each time an action is proposed that would impact a previously undisturbed area. Detailed instructions for compliance with applicable cultural resource management requirements are contained in the LMP.

Prior to the issuance of the LWA, the BLM was responsible for archaeological resource management on the WIPP site and served as the DOE's liaison with the SHPO. Following the issuance of the LWA, the BLM continued to serve in this capacity until July 19, 1994, when the Memorandum of Understanding Between the U.S. Department of Energy and the U.S. Department of Interior was finalized. At that time, the WIPP began communicating directly with the SHPO regarding archaeological concerns.

The following describes SHPO approvals granted for surface disturbing activities during this reporting period. On July 15, 1994, the BLM, using provisions contained in their Memorandum of Agreement with the SHPO, processed and approved WIPP surface disturbing activities associated with the construction of six new well-pads. On September 7, 1994, the SHPO granted the DOE approval to construct a short access road, and on September 27, 1994, the SHPO granted the DOE approval to construct another well-pad.

On June 21, 1995, an investigation was conducted of a previously known site as several previously buried artifacts emerged at the surface. No regulatory actions were required following the investigation, since no surface-disturbing activities are planned for the area in question. During this reporting period no new archaeological sites were discovered, and stipulations for avoidance of previously known sites were observed during construction activities.

35.0 NEW MEXICO STATE IMPLEMENTATION OF THE FEDERAL LAND POLICY AND MANAGEMENT ACT

35.1 Summary of the Law

The FLPMA was enacted to ensure that public lands be managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values; that, where appropriate, will preserve and protect certain public lands in their natural condition; that will provide food and habitat for fish and wildlife and domestic animals; and that will provide for outdoor recreation and human occupancy and use." Under the FLPMA, the Secretary of the Interior is authorized to grant, issue, or renew rights-of-way over, upon, under, or through public lands.

The spirit and purpose of the congressional legislation to protect and preserve the quality of public lands is furthered by law in the state of New Mexico. In 1912, the New Mexico Legislature created the State Land Office (SLO) and directed that the Office's executive officer, the Commissioner of Public Lands (the Commissioner), execute jurisdiction over, and provide for the management, care, control, and disposition of, public lands owned and subsequently acquired by the state. The Commissioner was authorized to grant rights-of-way and easements over, upon, or across state lands for highways, power lines, mining, or other purposes. The Commissioner's authority related to rights-of-way and easements is currently promulgated in New Mexico Statute 19-7-57.

The regulation of right-of-way and easement grants is addressed in the SLO's Rule 10, *Relating to Easements and Rights-of-Way*, which outlines the requirements for applying for and maintaining a right-of-way grant.

35.2 Compliance Status of the Regulatory Requirements

Table 35-1 summarizes the applicable requirements under SLO Rule 10 and the compliance status of each requirement. The text provides more detail on the compliance status of the requirements.

TABLE 35-1. New Mexico Implementation of the Federal Land Policy and Management Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
State Land Office Rule No. 10, *Relating to Easements and Rights-of-Way*		
SLO Rule 10.006	Application requirements and fees	**ACHIEVED** Permit issued [Section 35.2.1]
SLO Rule 10.009	Conditions	**ACHIEVED** Right of way: 40 feet wide [Section 35.2.2]
SLO Rule 10.010	Damage bond	**NOT APPLICABLE** Requirement waived for government agencies [Section 35.2.3]
SLO Rule 10.011	Survey plat	**ACHIEVED** Plat included in application [Section 35.2.4]
SLO Rule 10.012	Construction reports for ruins, artifacts, or monuments found	**NOT APPLICABLE** No artifacts found on right-of-way [Section 35.2.5]
SLO Rule 10.013	Affidavit of completion	**ACHIEVED** Affidavit of completion submitted [Section 35.2.6]
SLO Rule 10.017	Renewal of right-of-way grants	**NOT APPLICABLE** Term of permit (35-years) currently deemed adequate [Section 35.2.7]

CITATION	REQUIREMENT	COMPLIANCE STATUS
SLO Rule 10.019	Reclamation and restoration	**NOT APPLICABLE** Right-of-way to be reclaimed and revegetated after use [Section 35.2.8]

35.2.1 Application Requirements and Fees, SLO Rule 10.006

> *Written application for right-of-way grants (reservations) shall be made upon the proper forms. The application shall be made under oath and be accompanied by the payment of appropriate fees. The application will contain a legal description of the lands to be crossed and a plat (see Section 35.2.4).*

The proper application form and the fees required were submitted as required. The application included the legal description of the lands to be crossed and a survey plat.

Permit No. RW-22789 was issued for a high-volume air sampler for the period of October 3, 1985, through October 3, 2020.

35.2.2 Conditions, SLO Rule 10.009

> *The minimum width of a right-of-way or easement granted under these rules shall be 30 feet.*

As described in the application and survey plat, the right-of-way covers a 40-foot-wide strip of land.

35.2.3 Damage Bond, SLO Rule 10.010

> *The applicant must file a bond with the Commissioner before the right-of-way may be issued. The bond must compensate the State or other appropriate party for any damage done to improvements or other property. The Commissioner may waive this requirement if the applicant is a governmental agency that is prohibited from posting a security bond, the applicant is not immune to suit or is otherwise required by law to pay such damages, or meets other conditions specified.*

The DOE is a governmental agency and as such a damage bond is not required.

35.2.4 Survey Plat, SLO Rule 10.011

> *Specific requirements for the survey plat are described in SLO Rule 10.011*

A survey plat was included in the application. The plat met all requirements specified in SLO Rule 10.011.

35.2.5 Construction Reports, SLO Rule 10.012

> *The holder of a right-of-way shall notify the Commissioner immediately in the event that any historic or prehistoric ruin, monument, or artifact of historical, archeological, or scientific value is discovered upon the right-of-way. The holder of the right-of-way shall refrain from further disturbing the area until the Commissioner has been notified and inspection and clearance have been performed by the proper authorities if deemed necessary by the Commissioner.*

No ruins, monuments, or artifacts of historical, archeological, or scientific value were discovered upon the right-of-way.

35.2.6 Affidavit of Completion, SLO Rule 10.013

> *Upon the completion of construction of any right-of-way, the applicant shall promptly file an affidavit of completion with the Commissioner. Failure to file such an affidavit in accordance with this section shall subject the right-of-way to cancellation in accordance with the provisions of these rules.*

The DOE submitted an Affidavit of Completion to the SLO certifying the completion of construction and the location of the high-volume air sampler.

35.2.7 Renewal of Right-of-Way Reservations, SLO Rule 10.017

> *An application may be submitted for a renewal of the reservation prior to the expiration date of any right-of-way.*

Permit No. RW-22789 (see Section 35.3) was granted for a term of 35 years. If the right-of-way will still be needed after the expiration date, an application will be submitted as required. However, it is likely that the 35-year period will be adequate.

35.2.8 Reclamation and Restoration, SLO Rule 10.019

> *Any person who enters upon State land to survey or construct a right-of-way shall take all steps necessary to preserve and protect the natural environmental conditions of the land, including reclaiming disturbed areas by leveling or terracing and revegetation. Revegetation shall include the establishment of suitable grasses and forbs. The grantee of any right-of-way shall consult with the Commissioner's designee regarding reclamation prior to undertaking same and shall abide by all directives of the designee.*

The DOE will ensure that all reclamation and revegetation activities requested by the Commissioner or by his/her designee will be performed. Until these activities have been initiated, these requirements do not apply to WIPP.

35.3 Compliance Status of the Permit Conditions

The Commissioner granted Right-of-Way Permit No. RW-22789 to WIPP for a high-volume air sampler. The term of the permit is 35 years (October 3, 1985, through October 3, 2020). Table 35-2 summarizes the applicable permit conditions and the compliance status of each condition. The text provides more detail on the compliance status of the permit conditions.

TABLE 35-2. State Land Office Right-of-Way Permit No. RW-22789 - Summary of Permit Compliance Status

CITATION	CONDITION	COMPLIANCE STATUS
Right-of-Way Permit No. RW-22789 for a High-Volume Air Sampler		
Term/Condition #3	Disposal of brush and other debris	**ACHIEVED** Appropriate disposal of brush and other debris [Section 35.3.1]
Term/Condition #4	Depth of pipelines	**NOT APPLICABLE** No pipelines on right-of-way [Section 35.3.2]

CITATION	CONDITION	COMPLIANCE STATUS
Term/Condition #5	Prevention of destruction or injury to improvements or livestock	**UP TO DATE** Care taken to avoid damage to improvements or livestock [Section 35.3.3]
Term/Condition #6	Purpose of right-of-way	**UP TO DATE** Used only for high-volume air sampler [Section 35.3.4]
Term/Condition #7	Existing rights	**NOT APPLICABLE** No other leases or rights-of-way known for area [Section 35.3.5]
Term/Condition #8	Leases for mineral resources	**NOT APPLICABLE** Affected land is outside the WIPP boundary; no action required by WIPP [Section 35.3.6]
Term/Condition #9	Compliance with all applicable regulations and requirements	**UP TO DATE** See entire BECR for compliance status [Section 35.3.7]
Term/Condition #10	Nonuse of the right-of-way	**UP TO DATE** Right-of-way used periodically [Section 35.3.8]

CITATION	CONDITION	COMPLIANCE STATUS
Term/Condition #13	Protection and preservation of natural environmental conditions	**UP TO DATE** Protection of land; best acceptable reclamation practices to be used [Section 35.3.9]
Term/Condition #14	Reclamation of all disturbed areas	**NOT APPLICABLE** Seed mixes of indigenous plants to be used for revegetation [Section 35.3.10]

35.3.1 Disposal of Brush and Other Debris, Term/Condition #3

> *In clearing the right-of-way, the grantee agrees to dispose of brush and other debris so as not to interfere with the movement of livestock of State grazing lessees.*

All brush and other debris were disposed of appropriately.

35.3.2 Depth of Pipelines, Term/Condition #4

> *All pipelines placed on the right-of-way lands under this permit must be buried at least 20 inches deep.*

This right-of-way was not obtained for a pipeline. Therefore, this condition is not applicable.

35.3.3 Prevention of Destruction or Injury to Improvements or Livestock, Term/Condition #5

> *The grantee agrees to carefully avoid causing destruction or injury to any improvements or livestock lawfully upon the premises, to close all gates immediately after passing through them, and to make prompt payment of all reasonable and just damages for any injury or destruction arising from constructing or maintaining the right-of-way.*

The DOE carefully avoids causing destruction or injury to any improvements or livestock that are lawfully upon the premises. Gates are closed as soon as possible.

35.3.4 Purpose of Right-of-Way, Term/Condition #6

> *The right-of-way granted is for the sole purpose of providing egress from and ingress to a high-volume air sampler. The right-of-way may not be used for any other purpose and may not be re-assigned by the grantee.*

The right-of-way granted under this permit is used only for accessing the high-volume air sampler.

35.3.5 Existing Rights, Term/Condition #7

> *The rights granted under Permit RW-22789 are subject to valid existing rights.*

No existing leases or rights-of-way of record are known.

35.3.6 Leases for Mineral Resources, Term/Condition #8

> *The Commissioner reserves the right to execute leases for oil and gas, coal and minerals; to sell or dispose of same; and to grant rights-of-way and easements related to such leasing.*

The land subject to the conditions of Permit RW-22789 (i.e., T 19 S, R 27 E, Section 13) is not part of the land that was withdrawn from the DOI and transferred to the DOE under the LWA (i.e., several sections under T 22 S, R 31 E). Therefore, this term remains applicable although no action is required by WIPP personnel.

35.3.7 Compliance with all Applicable Regulations and Requirements, Term/Condition #9

> *The grantee and its employees, agents, and contractors shall fully comply with all laws, regulations, and requirements of any governmental authority or agency in all matters that affect the premises and operations pertaining to such issues as conservation, sanitation, aesthetics, pollution, cultural properties, fire, or ecology.*

This entire BECR addresses compliance with all such laws, regulations, and requirements at WIPP.

35.3.8 NonUse of the Right-of-Way, Term/Condition #10

> *If the right-of-way granted is not used for a period that exceeds 1 year without the prior written permission of the Commissioner, the right-of-way will be considered abandoned. Non-use for shorter periods will require that the grantee prove that there was no intent to abandon the right-of-way.*

The right-of-way is used periodically to collect samples and to maintain the sampler.

35.3.9 Protection and Preservation of Natural Environmental Conditions, Term/Condition #13

> *The grantee agrees to preserve and protect the natural environmental conditions of the land encompassed in this permit and to take such reclamation or corrective actions necessary to protect the land from pollution, erosion, or other forms of environmental degradation.*

The land encompassed in this permit is being preserved and protected. In addition, a contemporary reclamation program and a corresponding long-range plan have been implemented at WIPP. When the right-of-way for the high-volume air sampler is to be reclaimed, WIPP personnel will use the best acceptable reclamation practices. (See also Section 35.3.10.)

35.3.10 Reclamation of All Disturbed Areas, Term/Condition #14

> *The grantee agrees to reclaim all disturbed areas by grading, leveling, or terracing and to landscape these areas at its own expense. Landscaping will include the planting of native grasses, shrubs, or other vegetation so as to return disturbed areas to their natural state and prevent erosion caused by water and/or wind.*

The seed mixes to be used to revegetate the area will reflect those species which are indigenous to the vicinity, with priority given to those species of plants that are conducive to soil stabilization and to the needs of livestock and wildlife. (See also Section 35.3.9.) This section is not applicable to WIPP during this reporting period.

36.0 NEW MEXICO STATE IMPLEMENTATION OF THE BALD AND GOLDEN EAGLE PROTECTION ACT

36.1 Summary of the Law

The Bald and Golden Eagle Protection Act makes it unlawful to take (i.e., capture, kill, or destroy), possess, molest, or disturb living or dead bald eagles (*Haliaeetus leucocephalus*) or golden eagles (*Aquila chrysaetos*), their parts, their nests, or their eggs anywhere in the United States. A permit must be obtained from the DOI to relocate any nest that interferes with resource development or recovery operations. In addition, a permit may be obtained that authorizes taking, possessing, or transporting eagles or their parts, nests, or eggs.

Chapter 17 of the New Mexico statutes establishes rules and regulations to protect raptors. In particular, § 17-2-14, *Hawks, vultures and owls, taking, possessing, trapping, destroying, maiming or selling prohibited; exception by permit; penalty,* authorizes the Director of the Department of Game and Fish to issue permits to allow any person to take, possess, trap, ensnare, or destroy any bird protected by this section. Permits may be granted for several purposes, including scientific purposes, in accordance with the law and the State Game Commission's regulations. In addition, §§ 17-2-37 through 17-2-46 of the Wildlife Conservation Act also further the purpose of the Bald and Golden Eagle Protection Act with respect to the bald eagle as an endangered species (see Chapter 37).

36.2 Compliance Status of the Regulatory Requirements

At present, no bald or golden eagles are nesting on the WIPP site; however, individual eagles are frequently observed overwintering in the area. Therefore, a permit regarding bald or golden eagles is not required. If it becomes necessary, a permit application will be submitted, and all applicable permit requirements will be met.

37.0 NEW MEXICO WILDLIFE CONSERVATION ACT, IMPLEMENTING THE ENDANGERED SPECIES ACT

37.1 Summary of the Law

The Endangered Species Act was enacted in 1973 to prevent the extinction of many species of animals and plants. The act provides strong measures to help alleviate the loss of species and their habitats. It places restrictions on a wide range of activities involving endangered and threatened animals and plants to help ensure their continued survival. With limited exceptions, the act prohibits activities using these protected species unless authorized by a permit from the FWS.

The intent of the Congressional endangered species legislation is furthered in the New Mexico's Wildlife Conservation Act, which was enacted in 1974. The current sections of the state's act reside in §§ 17-2-37 through 17-2-46 NMSA 1978. The act directs that endangered species of wildlife that are indigenous to New Mexico should be managed and maintained and, to the extent possible, their numbers enhanced within the carrying capacity of the habitat. The state is directed to assist in the management of endangered and threatened species of wildlife, including those which are federally listed.

Protection under the Wildlife Conservation Act extends to species, genera, and families that are listed in § 17-2-3, *Protected wildlife species and game fish defined*. Thus, protection under the Wildlife Conservation Act is extended to game birds such as all members of the family Phasianidae (quail, partridges, and pheasants) and game fish such as all members of the family Ictaluridae (catfish).

Section 17-2-41, *Endangered Species*, states that "except as otherwise provided in this act, it is unlawful to take, possess, transport, export, process, sell or offer for sale, or ship" any species or subspecies of wildlife that appears on the following lists: (1) wildlife indigenous to the state determined to be endangered within the state as set forth by regulations of the Game Commission of the State of New Mexico ("the Commission") and (2) the federal lists of endangered species as set forth in the Endangered Species Act to the extent that such lists are adopted by regulations of the Commission. In § 17-2-42, *Management Programs*, the Director of the State Department of Game and Fish is directed to perform the following: (1) establish programs deemed necessary by the Commission for the management of endangered species; (2) work with federal and state entities or with private individuals in the administration and management of programs for the management of endangered species; (3) authorize by permit the taking, possession, transportation, or shipment of species deemed to need management for purposes including scientific and educational; and (4) authorize by permit the removal, capture, and destruction of endangered species where necessary to prevent damage to property or to protect human health.

The intent of the congressional legislation protecting migratory game birds under the Migratory Bird Treaty Act is also addressed in Chapter 17 of the New Mexico statutes. In particular, § 17-2-3, *Protected wildlife species and game fish defined*, specifies that all of the migratory bird family Anatidae (waterfowl) is protected. The hunting, taking, capturing, killing, or possession or the attempt to hunt, take, capture, or kill species of this family is regulated by the Commission. In addition, the Wildlife Conservation Act also implements portions of the Migratory Bird Treaty Act with respect to migratory game birds that are recognized as endangered species.

The Commission's Regulation No. 564, *Governing the Removal, Capture or Destruction of Endangered Species*, was adopted in 1975. This regulation specifies that any person who does not possess a permit and who removes, captures, or destroys any wildlife species classified as endangered by Commission regulations, other than those listed in 50 CFR Part 17, *Endangered and Threatened Wildlife and Plants*, must report any such incident to the NMDG&F.

The Commission's Regulation No. 682, *Amending the Listing of Endangered Species and Subspecies of New Mexico*, lists endangered wildlife in the state. Amendment 1 to this regulation adopts the Federal list of endangered species specified in 50 CFR Part 17.

The amended listing of endangered wildlife of New Mexico, which was issued in November 1990, includes a number of endangered or threatened species that could be found at WIPP and were specified in the FEIS (DOE, 1980) or the SEIS (DOE, 1990a). These include three species of reptiles and five species of birds, which are listed in Table 37-1.

The Commission's Regulation No. 705, *Regulation for the Taking and Possession of Protected Wildlife for Scientific and Educational Purposes*, contains the requirements for obtaining and using state permits and authorizations for taking and possessing wildlife for scientific and educational purposes. Permits and authorizations are issued to individuals rather than to parties or organizations; however, a permittee may have qualified subpermittees. 'Protected wildlife"is defined as all wild species of mammals, birds, reptiles, amphibians, and fishes and endangered mollusks and crustaceans taken by a nonresident of New Mexico, or as pikas, marmots, and game, furbearing, and endangered mammals; all birds except rock doves, European starlings, and house sparrows; horned lizards if sacrificed, retained, and/or transported out of state; endangered reptiles; bullfrogs and endangered amphibians; game and endangered fishes; and endangered mollusks and crustaceans taken by a resident.

TABLE 37-1. Endangered and Threatened Species in the State of New Mexico that May Occur at WIPP

COMMON NAME	SCIENTIFIC NAME
Reptiles	
Western ribbon snake	*Thamnophis proximus*
(Dunes) sagebrush lizard	*Sceleroporus graciosus arenicolous*
Birds	
Aplomado falcon	*Falco femoralis*
Peregrine falcon (F)	*Falco peregrinus*
Bald eagle (F)	*Haliaeetus leucocephalus*
Baird's sparrow	*Ammodramus bairdii*
Varied bunting	*Passerina versicolor*

37.2 Compliance Status of the Regulatory Requirements

Table 37-2 summarizes each applicable requirement and its compliance status under the State of New Mexico's Wildlife Conservation Act. The text provides more detail on the compliance status of each requirement. It should be noted that a number of these requirements apply to WIPP because of the potential for the occurrence of recognized endangered or threatened species on WIPP lands.

TABLE 37-2. New Mexico Wildlife Conservation Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
State Game Commission Regulation No. 564, *Governing the Removal, Capture, or Destruction of Endangered Species*		
Regulation No. 564	Report of unpermitted removal, capture, or destruction of endangered species	**NOT APPLICABLE** No endangered species removed from, captured, or destroyed at WIPP [Section 37.2.1]
State Game Commission Regulation No. 682, *Amending the Listing of Endangered Species and Subspecies of New Mexico*		

CITATION	REQUIREMENT	COMPLIANCE STATUS
Regulation No. 682	Recognition of state-listed endangered wildlife	**ACHIEVED** Consultation with NMDG&F [Section 37.2.2]
State Game Commission Regulation No. 705, *Regulation for the Taking and Possession of Protected Wildlife for Scientific and Educational Purposes*		
Regulation No. 705, Chapter 2	Requirements for obtaining a permit	**ACHIEVED** Two permits obtained at WIPP (see Section 37.3) [Section 37.2.3]
Regulation 705, Chapter 5	Year-end reports	**UP TO DATE** Submitted annually by March 31 [Section 37.2.4]

37.2.1 Report of Unpermitted Removal, Capture, or Destruction of Endangered Species, Regulation No. 564

> *Persons without an authorized State permit who remove, capture, or destroy a State-listed endangered species must provide detailed information on such incident(s) to the State Game and Fish Department within 30 days.*

No incidents requiring reports have occurred. Several permits and authorizations have been issued for various activities involving the taking of wildlife that are neither endangered nor threatened. These permits and authorizations specify that endangered wildlife shall not be taken during these activities (see Section 37.3).

37.2.2 Recognition of State-Listed Endangered Wildlife, Regulation No. 682

> *The State-listed endangered species that could be present at WIPP and/or affected by WIPP activities must be identified.*

In 1989, the DOE consulted with the NMDG&F regarding the state-listed endangered species in the vicinity of the WIPP site. At that time, the department communicated to the DOE their opinion of which state-listed endangered species "occur or are likely to occur at the WIPP site." The species identified were listed in Regulation No. 657, dated January 9, 1988, and included the following species: Mississippi kite, bald

eagle, peregrine falcon, least tern, willow flycatcher, Bell's vireo, Baird's sparrow, and the sagebrush lizard. The NMDG&F subsequently concurred that proposed WIPP activities would probably have no significant impacts on state-listed species in the area. Regulation No. 682 was updated on November 30, 1990, with Amendment No. 1 issued on July 25, 1991. The list in the updated version of Regulation No. 682 does not include the Mississippi kite. WIPP received the most recent list (dated April 24, 1995) of threatened and endangered species delineated by county and currently uses this list when considering land-use proposals.

37.2.3 Permit Application and Requirements to Conduct Activities Authorized Under this Regulation, Chapter 2 of Regulation No. 705

> *A person must complete and submit a permit or authorization application; after receipt of the permit, permittees and subpermittees must comply with written permit requirements.*

To date, two permits for banding birds and taking protected birds (with specific methods for taking protected birds) have been issued. More detail on these permits is provided in Section 37.3.

37.2.4 Year-End Reports, Chapter 5 of Regulation No. 705

> *An annual report is generally required for permits issued by the Department of Game and Fish. The permits must be filed by March 31.*

Annual reports are submitted that describe the activities conducted under each permit issued by the NMDG&F.

37.3 Compliance Status of the Permit Conditions

Table 37-3 summarizes the conditions imposed by the NMDG&F for each of the two permits issued. The text provides more detail on the compliance status of each permit condition.

TABLE 37-3. New Mexico Wildlife Conservation Act - Summary of Permit Compliance Status

CITATION	CONDITION	COMPLIANCE STATUS
Permit No. 1961	• Authorization for live capture and banding of protected birds; excluded for waterfowl, eagles, resident gallinaceous species of gamebirds, and federally endangered or threatened species • Salvaged endangered or threatened species salvaged to be reported • Disposition of wildlife	**ACHIEVED** Only authorized birds captured and/or banded; no endangered or threatened species salvaged; disposition of wildlife as required under permit [Section 37.3.1]
Permit No. 1894	Live trapping; authorization for quail, catfish, and unprotected vertebrates; nonlethal methods for catfish; report for salvaging endangered or threatened vertebrates	**ACHIEVED** No gill nets used; no more than 50 catfish taken under permit; nonlethal methods used for catfish; no endangered or threatened vertebrates salvaged [Section 37.3.2]

37.3.1 Permit No. 1961

Permit No. 1961 authorizes the designated permittee and subpermittees to live-capture, band, and release all protected species of birds except for waterfowl, eagles, resident gallinaceous game birds, and endangered or threatened species. Salvage of any dead, injured, or otherwise incapacitated members of an endangered or threatened species must be reported to the NMDG&F within 14 days. The ultimate disposition of all protected wildlife that is not released is to the Carnegie Museum of Natural History, New Mexico State University, or the University of Arizona.

Permit No. 1961 was issued for the period of April 2, 1995, through March 31, 1996. No waterfowl, eagles, resident gallinaceous game birds, or endangered or threatened species have been live-captured, banded, or salvaged. The ultimate disposition of any protected species allowable under this permit resides in the Carnegie Museum of

Natural History, New Mexico State University, or the University of Arizona, as specified in the permit.

37.3.2 Permit No. 1894

> *Permit No. 1894 authorizes the permittee and subpermittees specified to use live traps, trotlines, and nets (except gill nets) to obtain specimens and to salvage dead, injured, or otherwise incapacitated vertebrates. The authorized WID personnel may take up to 30 specimens of quail, 50 channel/flathead catfish, and unprotected vertebrates as needed in Eddy and Lea counties. Nonlethal methods must be used to take the catfish. Any endangered or threatened species salvaged must be reported to the NMDG&F within 14 days. WIPP is the ultimate disposition location for all specimens retained under this permit.*

Permit No. 1894 was issued for the period of April 1, 1995, through March 31, 1996. No gill nets have been used to obtain specimens. The allowable number of specimens of 50 channel/flathead catfish has not been exceeded. Methods used to capture the catfish are not lethal to these fish or to other aquatic vertebrates. No endangered or threatened species have been salvaged.

38.0 NEW MEXICO PESTICIDE CONTROL ACT

38.1 Summary of the Law

The Pesticide Control Act (§§ 76-4-1 through 76-4-30 NMSA 1978) is administered and enforced by the New Mexico State Department of Agriculture under the direction of the Board of Regents of New Mexico State University, Las Cruces, New Mexico. This act provides for the registration, labeling, distribution, storage, transportation, application, use, and disposal of pesticides and pesticide-related devices. It also provides for the licensing of pesticide dealers, consultants, applicators, and operators of pesticide apparatus and imposes penalties to protect the environment and the public health and welfare.

The Pesticide Control Act is implemented by two regulatory orders of the Board of Regents of New Mexico State University. Regulatory Order No. 4, *Regulatory Orders of the Board of Regents of New Mexico State University* (dated September 16, 1978), describes state requirements for the storage of pesticides and the disposal of pesticide wastes. Regulatory Order No. 5, *Definitions, Licensing, Equipment Inspection, Record Keeping of Pesticides by Regulated Applicants* (dated November 2, 1979), describes requirements for licensing and for applying pesticides in New Mexico and applies to all activities involving the distribution and use of pesticides in the state.

38.2 Compliance Status of the Regulatory Requirements

The compliance status of each of the major requirements of the implementing regulations of the Pesticide Control Act is summarized in Table 38-1. Additional detail is provided in the text.

TABLE 38-1. New Mexico Pesticide Control Act - Summary of Regulatory Compliance Status

CITATION	REQUIREMENT	COMPLIANCE STATUS
New Mexico Pesticide Control Act, Regulatory Order No. 4, *Regulatory Order of the Board of Regents of New Mexico State University*		
Section 5	Storage of pesticides and disposal of pesticide wastes	**ACHIEVED** General-use wasp and hornet killer properly stored on site [Section 38.2.1; see also 10.2.2]

New Mexico Pesticide Control Act, Regulatory Order No. 5, *Definitions, Licensing, Equipment Inspections, Record Keeping of Pesticides by Regulated Applicators*		
Section 6	License classifications	**NOT APPLICABLE** Subcontractor: Categories 3A, 3B, 7A, 7B, 7D [Section 38.2.2]
Section 10	Protective equipment	**ACHIEVED** Contracts reviewed by WID personnel [Section 38.2.3]
Section 11	Application of pesticides	**UP TO DATE** Contracts reviewed by WID personnel [Section 38.2.4]

38.2.1 Storage of Pesticides and Disposal of Pesticide Wastes, Section 5 of Regulatory Order No. 4

Requirements for storing pesticides and for disposing of pesticide wastes and pesticide containers are described in Section 5 of Regulatory Order No. 4 to the New Mexico Pesticide Control Act.

All restricted-use pesticides are brought on site by the contractor who has been hired to apply them. Storage and disposal of restricted-use pesticides and their containers are the responsibility of the contractors who are licensed by the State and knowledgeable of applicable requirements (see also Section 10.2.2). Two general-use pesticides, CINCH Wasp and Hornet Killer® and RAID Wasp and Hornet Killer® are stored at WIPP. CINCH® and RAID® are properly stored in accordance with the product label. Used, empty aerosol cans are managed as hazardous waste.

38.2.2 License Classification, Section 6 of Regulatory Order No. 5

There are 17 categories of licenses granted by the State of New Mexico. Each one represents the type and scope of the specific certification examinations that must be taken by commercial, non-commercial, and public applicators and by pest-management consultants for their licenses.

The contractor who applies pesticides at WIPP is licensed under the following categories:

3A - Ornamental Pest Control
3B - Turf Pest Control
7A - Structural Pest Control
7B - Rodent Control
7D - Termite Control

38.2.3 Protective Equipment, Section 10 of Regulatory Order No. 5

> *All licensed certified applicators must make available properly decontaminated protective equipment which is in proper working order and must advise their employees of its use to meet the safety requirements of the pesticide labeling.*

All pesticide application contracts are reviewed and approved by WID before the contract is awarded. Provisions in the contract require that WID approve the use of all pesticides prior to application on site. In addition, the contractor is required to submit records of the date of application, specific location, application method, quantity applied, and weather conditions at time of application.

38.2.4 Application of Pesticides, Section 11 of Regulatory Order No. 5

> *A licensed certified applicator shall apply only those pesticides registered for use in New Mexico under his/her license application. Any person who applies pesticides must follow the directions, rates, and precautions that are stated on the approved label and labeling. Restricted-use pesticides shall be applied only by licensed certified applicators or persons under their direct supervision.*

WID reviews the application method and pesticide(s) to be used by the contractor before the application to ensure that the method is appropriate and that no pesticides on the EPA's restricted list will be used.

A copy of the contractor's current license is maintained by the WID.

39.0 REFERENCES

Anand, N.K., and A.R. McFarland, 1988. *Particle Penetration through CAM-Sampler Aerosol Transport Lines*, College Station, Texas, April.

Cooper, S.C., 1992. Letter report to G. Venable, Albuquerque, NM, November 2.

Dawn Enterprises, 1993. *Dawn Enterprises Management Plan*, Revision X, June 17.

IT Corporation, 1994. *Emission Sampling Report, Backup Diesel Generator*, March 24.

McFarland, A.R., C.A. Ortiz, M.E. Moore, R.E. DeOtte, Jr., and S. Somasundaram, 1989. *A Shrouded Aerosol Sampling Probe*, Environmental Science Technology, Vol. 23, No. 12, p. 1487.

Molecke, M.A. 1990. *Test Plan: WIPP In-Situ Alcove CH TRU Waste Tests*, Sandia National Laboratories, Albuquerque, NM.

Newton, G.J., K.J. Shenk, Y.F. Su, H-C Yeh, M.D. Hoover, and B.B. Boecker, 1987. *Aerosol Studies for Evaluation of 'Isokinetic' Sampling at the Waste Isolation Pilot Plant: Phase I, Measurement in the 14-ft Diameter Exhaust Shaft*, Lovelace Inhalation Toxicology Research Institute, Albuquerque, New Mexico, July 30.

S.M. Stoller Corporation, 1991. *Verification of the Station A Alpha CAM Alarm Set Point at the Waste Isolation Pilot Plant*, Albuquerque, NM, January 17.

Turner, W.D.; A.R. McFarland; M.G. Glass; C.A. Ortiz; D.L. O'Neal; S. Somasundaram; N.K. Anand; and R.E. DeOtte, Jr., 1988. *Tests of Model Waste Isolation Pilot Plant Site Exhaust Airflow Systems*, Lovelace Inhalation Toxicology Research Institute, Albuquerque, New Mexico, September.

U.S. Department of Energy, 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*, DOE/EIS-0026, 2 vols., October.

U.S. Department of Energy, 1981. *Record of Decision for the Final Environmental Impact Statement, Waste Isolation Pilot Plant, Federal Register* 46(18): 9162-9164, January 28.

U.S. Department of Energy, 1989a. *Safety Analysis Report for the TRUPACT-II Shipping Package*, March 3. Supplements dated May 26, June 27, June 30, August 3, and August 8, 1989; April 18, July 10, July 25, August 24, and December 20, 1990; April 11, April 29, and June 17, 1991; and September 24, 1992.

U.S. Department of Energy, 1989b. *TRUPACT-II List of Chemical Compounds in Each Content Code in TRUCON,* DOE/WIPP 89-004 (Rev. 6).

U.S. Department of Energy, 1990a. *Final Supplement, Environmental Impact Statement, Waste Isolation Pilot Plant*, DOE/EIS-0026-FS, 13 vols., January.

U.S. Department of Energy, 1990b. *Record of Decision for the Supplement Environmental Impact Statement, Waste Isolation Pilot Plant*, Federal Register 55(121): 25689-25692, June 22.

U.S. Department of Energy, 1990c. *WIPP Test Phase Plan: Performance Assessment*, DOE/WIPP 89-011, Rev. 0, April.

U.S. Department of Energy, 1995. *Waste Isolation Pilot Plant Safety Analysis Report*, DOE/WIPP-95-2065, Rev. 0, November.

U.S. Department of Energy, 1990e. *Results of the U.S. Department of Energy Indoor Radon Study*, DOE/ID/12584-75, 2 vols., August.

U.S. Department of Energy, 1990f. *Waste Isolation Pilot Plant No-Migration Variance Petition*, DOE/WIPP-89-003, March.

U.S. Department of Energy, 1996. *RCRA Part B Permit Application for the Waste Isolation Pilot Plant*, DOE/WIPP 91-005, Rev. 6

U.S. Department of Energy, 1995. *Waste Isolation Pilot Plant No-Migration Determination Annual Report for the Period September 1, 1994 through August 31, 1995*, DOE/WIPP 95-2141.

U.S. Department of Energy, 1991e. *Mitigation Action Plan for the Records of Decision for the Waste Isolation Pilot Plant, 1991*, DOE/WIPP 91-030, July 10.

U.S. Department of Energy, 1992c. *Waste Isolation Pilot Plant Emergency Plan*, WP-12-9, May.

U.S. Department of Energy, 1993a. *TRUPACT-II Transportation Management Plan*, DOE/ALWPIO 06-2, August 25.

U.S. Department of Energy, 1993c. *Waste Isolation Pilot Plant Land Management Plan*, DOE/WIPP 93-004, October.

U.S. Department of Energy, 1995. *Transuranic Waste Characterization Sampling and Analysis Methods Manual.*

U.S. Department of Energy, 1995. *Transuranic Waste Characterization Quality Assurance Program Plan.*

U.S. Department of Energy, 1996 *Waste Analysis Plan*, Chapter C from the RCRA Part B Permit Application, Rev. 6, April.

U.S. Department of Energy, 1996. *Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, DOE/WIPP-069, Rev. 5.

U.S. Environmental Protection Agency, 1990a. *Notice Proposing to Grant a Conditional Variance to the Department of Energy Waste Isolation Pilot Plant (WIPP) for Land Disposal Restrictions*, Federal Register 55(67): 13068-13094, April 6.

U.S. Environmental Protection Agency, 1990b. *Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP), Federal Register* 55(220): 47700-47721, November 14.

U.S. Environmental Protection Agency, 1992a. Letter from Don R. Clay, Assistant Administrator, Office of Solid Waste and Emergency Response, EPA, to Mr. Leo P. Duffy, Assistant Secretary, DOE, April 27.

U.S. Environmental Protection Agency, 1992b. *Final NPDES General Permits for Storm Water Discharges Associated with Industrial Activity, Federal Register* 57(175): 41236-41342, September 9.

U.S. Environmental Protection Agency, 1992c. *National Pollutant Discharge Elimination System Application Deadlines, General Permit Requirements and Reporting Requirements for Storm Water Discharges Associated with Industrial Activity, Federal Register* 57(64): 11394, April 2.

Westinghouse Electric Corporation Waste Isolation Division, 1990. *Radionuclide Emission Data Package for the Waste Isolation Pilot Plant*, November.

Westinghouse Electric Corporation Waste Isolation Division, 1991a. *VOC Monitoring Quality Assurance Project Plan*, WP 12-7.

Westinghouse Electric Corporation Waste Isolation Division, 1991c. *Waste Isolation Pilot Plant RCRA Compliance Manual*, WP 02-6 and 7, Rev. 0, December.

Westinghouse Electric Corporation Waste Isolation Division, 1992. *WIPP Emergency Plan and Procedures*, WP 12-9, Rev. 7, May.

Westinghouse Electric Corporation Waste Isolation Division, 1993a. *WIPP Spill Prevention, Control, and Countermeasures Plan*, Section 9 of WP 02-6 and 7, January 18 draft.

Westinghouse Electric Corporation Waste Isolation Division, 1993b. *WIPP National Pollutant Discharge Elimination System (NPDES) Storm Water Pollution Prevention Plan*, WP 02-14, April 1.

Westinghouse Electric Corporation Waste Isolation Division, 1995. *Air Emissions Inventory Report Calendar Year 1994 for WIPP.*

Westinghouse Electric Corporation Waste Isolation Division, 1993d. *Quality Assurance Project Plan for Sampling Emissions of Radionuclides to the Ambient Air at the Waste Isolation Pilot Plant*, September.

Westinghouse Electric Corporation Waste Isolation Division, 1996. *Air Pathway Baseline Monitoring Plan for Volatile Organic Compounds at the Waste Isolation Pilot Plant*, draft.

APPENDIX A
INDEX OF REQUIREMENTS BY AGENCY

Citation	Requirement	BECR Section
U.S. Environmental Protection Agency		
RCRA § 3016	Inventory of Federal hazardous waste facilities	2.2.1.1
CAA § 109	National Ambient Air Quality Standards (NAAQS)	6.3
CAA § 112(r)(6)(K)	Risk management plan/hazard assessment, if applicable	6.2.2.8
CAA § 118	Control of pollution from Federal facilities	6.2.1
TSCA Title II, §§ 201 et seq.	Hazards of friable asbestos-containing material	9.2.1
TSCA Title III, § 309	Study of radon in Federal buildings	9.2.2
CERCLA § 120(d)	Assessment and evaluation	3.2.1
29 CFR Part 1910	**Occupational Safety and Health Standards**	**11.1**
29 CFR 1910.95	Compliance with hearing protection standards	11.2.1
40 CFR Part 60	**Standards of Performance for New Stationary Sources**	**6.1**
40 CFR Part 61	**National Emission Standards for Hazardous Air Pollutants (NESHAPs)**	**6.1**
40 CFR 61.96	NESHAPs application for radionuclides	6.2.2.1
40 CFR 61.93(a),(b)	EPA approval of any alternative methods for monitoring/sampling for radionuclide emissions and air flow rate that differ from those specified under NESHAP	6.2.2.2
40 CFR 61.93(b) and Appendix B, Method 114, § 4.10	NESHAPs Quality Assurance Project Plan	6.2.2.3
40 CFR 61.09(a)(1)	EPA notification under NESHAPs, pre-startup	6.2.2.4

Citation	Requirement	BECR Section
40 CFR 61.09(a)(2)	EPA notification under NESHAPs, post-startup	6.2.2.5
40 CFR 61.94	NESHAPs annual report	6.2.2.6
40 CFR 61.95	Recordkeeping requirements	6.2.2.7
40 CFR Part 70	**State Operating Permit Programs, if applicable**	**6.1** **6.3.1**
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40 CFR 80.23	Liability for violations	6.2.3.4
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40 CFR 82.54(c), 82.104(a)	Prohibition of nonessential Class I ozone-depleting substances	6.2.4.2
40 CFR 82.66	Ban on nonessential products containing Class I substances	6.2.4.3
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Citation	Requirement	BECR Section
40 CFR 82.122	Certification, recordkeeping, and notice requirements	6.2.4.10
40 CFR 82.124(a)(4)	Prohibitions	6.2.4.11
40 CFR 82.150	Service, maintenance, and repair of appliances using refrigerants	6.2.4.12
40 CFR 82.154	Prohibitions regarding maintenance, service, repair, or disposal of appliances	6.2.4.13
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40 CFR 112.3	Requirements for preparation and implementation of spill prevention, control, and countermeasures (SPCC) plans	7.2.1
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40 CFR 122.1(b)(1)	NPDES permits for the discharge of pollutants from any point source into waters of the United States	7.2.3
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40 CFR Part 142	**National Primary Drinking Water Regulations Implementation**	**8.1**
40 CFR 142.4	State program requirements	8.2.1; see also Chapter 31
40 CFR Part 144	**Underground Injection Control Program**	**8.1**
40 CFR 144	Underground injection control	8.2.2
40 CFR Part 152	**Pesticide Registration and Classification Procedures**	**10.1**

Citation	Requirement	BECR Section
40 CFR 152.15	Registration of pesticide products	10.2.1
40 CFR Part 165	**Regulations for the Acceptance of Certain Pesticides and Recommended Procedures for the Disposal and Storage of Pesticides and Pesticides Containers**	**10.2**
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40 CFR Part 191	**Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Waste**	**5.1** **5.2.1**
40 CFR 191.03-191.04, Subpart A	Standard annual dose equivalent	5.2.1.1
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40 CFR 268.6(d)	Submittal of petition to EPA Administrator	2.2.2.5
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40 CFR 268.6(f)	Activities required if hazardous constituents are found to have migrated from the repository	2.2.2.7
40 CFR 268.6(g)	Certification in petition	2.2.2.8
40 CFR 268.6(h)	Additional information requested by Administrator	2.2.2.9
40 CFR 268.6(k)	Terms of variance	2.2.2.10

Citation	Requirement	BECR Section
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40 CFR 268.7	Waste analysis and recordkeeping	2.2.2.12
40 CFR 268.8	Landfill and surface impoundment disposal restrictions	2.2.2.13
40 CFR 268.9	Special rules regarding wastes that exhibit a characteristic	2.2.2.14
40 CFR 268.10-12	Identification of waste to be evaluated by August 8, 1988; by June 8, 1989; and by May 8, 1990	2.2.2.15
40 CFR 268.30	Waste-specific prohibitions--solvent wastes	2.2.2.16
40 CFR 268.31	Waste-specific prohibitions--dioxin-containing wastes	2.2.2.17
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Citation	Requirement	BECR Section
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40 CFR Part 300	**National Oil and Hazardous Substances Pollution Contingency Plan**	**3.1**
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40 CFR 302.4	Designation of hazardous substances	3.2.4
40 CFR 302.5	Determination of reportable quantities	3.2.5
40 CFR 302.6(a)	Notification requirements	3.2.6
40 CFR 302.6(b)(1)	Releases of mixture or solutions	3.2.7
40 CFR 302.6(b)(2)	Notification of releases of radionuclides	3.2.8
40 CFR 302.6(d)	Notification of the release of heavy metals	3.2.9
40 CFR Part 355	**Emergency Planning Notification**	**4.1**
40 CFR 355.30(a)-(b)	Emergency planning	4.2.1
40 CFR 355.30(c)	Facility Emergency Coordinator	4.2.2
40 CFR 355.30(d)	Provision of information	4.2.3
40 CFR 355.40	Releases of extremely hazardous substances	4.2.4
40 CFR Part 370	**Hazardous Chemical Reporting: Community Right-to-Know**	**4.1**
40 CFR 370.21	Submissions of MSDS or chemical list	4.2.5

Citation	Requirement	BECR Section
40 CFR 370.25	Submission of hazardous chemical inventory form	4.2.6
40 CFR Part 372	**Toxic Chemical Release Reporting: Community Right-to-Know**	**4.1**
40 CFR 372.30	Submission of the Toxic Chemical Inventory Report	4.2.7
40 CFR Part 761	**EPA Regulations for Manufacturing Processing, Distribution in Commerce, and Use Prohibitions for Polychlorinated Biphenyls under the Toxic Substances Control Act**	**9.1**
40 CFR 761.20	Prohibition of PCBs	9.2.3
40 CFR 761.60	Disposal requirements for PCBs	9.2.4
55 FR 47700	**Conditional No-Migration Determination (NMD)**	**2.3**
Condition 1, IV.B.1 and VI(1)	Testing of long-term acceptability of WIPP	2.3.1
Condition 2, IV.B.2 and VI(2)	Wastes not to exceed 8,500 drums or 1 percent of repository's total capacity	2.3.2
Condition 3, IV.B.3 and VI(3)	Retrieval of waste if noncompliance with 40 CFR 268.6	2.3.3
Condition 4, IV.B.4 and VI(4)	Readily retrievable placement of waste	2.3.4
Condition 5, IV.B.5 and VI(5)	Installation of carbon adsorption device	2.3.5
Condition 6, IV.B.6 and VI(6)	Implementation of air monitoring plan for VOCs	2.3.6
Condition 7(a), IV.B.7(a) and VI(7)(a)	Waste analysis: flammable mixtures of gases	2.3.7
Condition 7(b), IV.B.7(b) and VI(7)(b)	Waste analysis: comparison of analytical results with estimated compositions	2.3.8
Condition 7(c), IV.B.7(c) and VI(7)(c)	Waste analysis: maintenance of records	2.3.9
Condition 8, IV.B.8 and VI(8)	Annual report	2.3.10
55 FR 47700	**General Conditions for Compliance with the NMD**	**2.3**

Citation	Requirement	BECR Section
General condition (GC) 1, IV.B.1	Correlation between wastes received and those described in the No-Migration Variance Petition	2.3.11
GC 2, VI	Notification of EPA of changes in conditions	2.3.12
GC 3, VI	Suspension of receipt of restricted wastes and notification of EPA in the event of migration of hazardous constituents from the repository	2.3.13
GC 4, VI	Term of petition approved	2.3.14
55 FR 47700	**Additional Requirements for Air Monitoring under the Proposed Variance**	**2.3**
Proposed Variance (PV) 1, IV.K	Monitoring in the exhaust shaft	2.3.15
PV 2, IV.K	Monitoring of bin-scale experiment rooms	2.3.16
PV 3, IV.K	Monitoring of alcoves	2.3.17
PV 4, IV.K.1	Measurement of the leakage rate of sealed alcoves	2.3.18
PV 5, IV.K.1	Weekly collection of air samples	2.3.19
PV 6, IV.K.1	Weekly/monthly monitoring at the exhaust shaft and air intake locations	2.3.20
PV 7, IV.K.1	Monitoring frequency for the bin discharge system	2.3.21
PV 8, IV.K.1	Increased monitoring frequency due to increased variability	2.3.22
PV 9, IV.K.2	Routine quantification of any VOC	2.3.23
PV 10, IV.K.2	Standard operating procedures to identify certain other VOCs	2.3.24
PV 11, IV.K.3	Use of the average response factor for each target analyte	2.3.25
PV 12, IV.K.4	Use of standard operating procedures to ensure the validity of the monitoring data	2.3.26
PV 13, IV.K.4	Recalibration of instruments	2.3.27

Citation	Requirement	BECR Section
PV 14, IV.K.4	Establishment and annual evaluation of the method limit of quantification for each target analyte	2.3.28
PV 15, IV.K.4	Separate determination of the method limit of quantification for the bin, alcove, and exhaust shaft monitoring locations	2.3.29
PV 16, IV.K.4	Collection and analysis of recovery samples	2.3.30
PV 17, IV.K.4	Collection and analysis of duplicate samples	2.3.31
PV 18, IV.K.4	Validation of the completeness of the data	2.3.32
PV 19, IV.K.4	Tracking and evaluation of accuracy, precision, and completeness of the data	2.3.33
PV 20, IV.K.4	Performance of systems audits	2.3.34
PV 21, IV.K.4	Corrective action required for improper conditions or practices	2.3.35
PV 22, IV.K.4	Establishment of specific quality assurance objectives for data acceptability	2.3.36
PV 23, IV.K.4	Corrective action required	2.3.37
PV 24, IV.K.5	Annual averaging of concentrations of targeted constituents	2.3.38
PV 25, IV.K.5	Submittal of annual data summaries and summaries of data accuracy, precision, and completeness for each monitoring location	2.3.39
PV 26, IV.K.5	Maintenance of documentation on all aspects of QA/QC	2.3.40
57 FR 41236	**Final NPDES General Permits for Storm Water Discharges Associated with Industrial Activity**	**7.3**
IV(A); Appendix B, II(A)	Notice of Intent to file for general permit	7.3.1
IV(A)(4)	Notice of Termination	7.3.2
IV(B)(1); Appendix B, III(A)	Prohibition on non-storm water discharges	7.3.3
IV(B)(2); Appendix B, III(B)	Releases of reportable quantities of hazardous substances and oil	7.3.4

Citation	Requirement	BECR Section
IV(C); Appendix B, Part IV	Storm water pollution prevention plan	7.3.5
IV(C)(1); Appendix B, IV(D)(1)	Pollution prevention team	7.3.6
IV(C)(2); Appendix B, IV(D)(2)	Identification of potential pollution sources	7.3.7
IV(C)(2); Appendix B, IV(D)	Site assessments	7.3.8
IV(C)(3); Appendix B, IV(D)(3)	Measures and controls	7.3.9
IV(C)(4); Appendix B, IV(D)(4)	Comprehensive site compliance evaluations	7.3.10
IV(D)(1); Appendix B, IV(D)(7)	Requirements for storage, processing, and handling areas for EPCRA § 313 "water priority chemicals"	7.3.11
IV(D)(2); Appendix B, IB(D)(8)	Enclosure or covering of outdoor salt piles	7.3.12
IV(D)(3); Appendix B, IV(D)(5)	Notification to municipal large and medium separate storm water systems	7.3.13
IV(E); Appendix B, Part IV and XI(C)(vi)	Monitoring and reporting requirements	7.3.14
IV(G); Appendix B, IV (A)(1)	Deadline for plan preparation and compliance	7.3.15
Council On Environmental Quality		
40 CFR Parts 1500-1508	**Provision of environmental information to public officials and private citizens**	**12.2** **14.1**
U.S. Department of Energy		
10 CFR Part 830	**Nuclear Safety Management**	**13.2**
10 CFR 830.4(a)	Taking action(s) inconsistent with the requirements of 10 CFR Part 830	13.2.1
10 CFR 830.4(b)	Implementation and compliance with requirements of 10 CFR Part 830	13.2.2
10 CFR 830.4(c)	Plan or program required by this part as the basis for determining compliance	13.2.3

Citation	Requirement	BECR Section
10 CFR 830.6	Records to substantiate compliance	13.2.4
10 CFR 830.7	Use of a graded approach	13.2.5
10 CFR 830.120(a)	Development and implementation of contractor's Quality Assurance Program (QAP)	13.2.6
10 CFR 830.120(b)	Application of the appropriate quality assurance criteria in the QAP	13.2.7
10 CFR 830.120(c)	QA criteria to be included in the QAP	13.2.8
10 CFR Part 1021	**Implementing Procedures**	**14.2**
10 CFR Part 1021	Supplements and clarifies the requirements contained in 40 CFR Parts 1500-1508	14.2.1
U.S. Nuclear Regulatory Commission		
10 CFR Part 71	**Packaging and Transportation of Radioactive Material**	**15.1**
10 CFR 71.12	General license: NRC-approved package Note: The NRC issued the DOE a certificate of compliance for the TRUPACT-II instead of a license.	15.2.1
10 CFR 71.31-71.39	Contents of application and package description, evaluation, and QA	15.2.2
10 CFR 71.41	Demonstration of compliance	15.2.3
10 CFR 71.43 and 71.45	Requirements for all packages	15.2.4
10 CFR 71.47	External radiation standards for all packages	15.2.5
10 CFR 71.51	Additional requirements for Type B packages	15.2.6
10 CFR 71.55-71.61	Requirements for all fissile material packages	15.2.7
10 CFR 71.63	Special requirements for plutonium shipments in excess of 20 Ci/shipment	15.2.8
10 CFR 71.71	Tests under normal conditions of transport	15.2.9

Citation	Requirement	BECR Section
10 CFR 71.73	Tests under hypothetical accident conditions	15.2.10
10 CFR 71.81	Compliance with general requirements (71.00-6a), operating controls and procedures (71.81-71.99), and quality assurance requirements (71.101-71.137)	15.2.11
10 CFR 71.83	Assumptions as to unknown properties: assume credible values that will cause the maximum nuclear reactivity	15.2.12
10 CFR 71.85	Preliminary determinations of integrity of packaging, pressure testing, and marking	15.2.13
10 CFR 71.87	Routine determinations prior to each shipment	15.2.14
10 CFR 71.89	Any special opening instructions for the consignee	15.2.15
10 CFR 71.91	Records to be kept at least 3 years after shipment	15.2.16
10 CFR 71.93	Inspections and tests to be performed or allowed to be performed by the NRC	15.2.17
10 CFR 71.95	Reports regarding (1) any decreased effectiveness of an authorized packaging during use and (2) details of any defects with safety significance	15.2.18
10 CFR 71.97	Advance notification of shipment of nuclear waste as described	15.2.19
10 CFR 71.101-71.137	NRC quality assurance requirements	15.2.20
C of C	**Description of TRUPACT-II**	**15.3**
C of C, p. 1, 5(2), para. 1	Overall specifications for the TRUPACT-II	15.3.1
C of C, p. 1, 5(2), para. 1	Weight specifications	15.3.2
C of C, p. 1, 5(2), para. 2	Outer containment assembly specifications	15.3.3
C of C, p. 1, 5(2), para. 3, ICV	Inner containment vessel specifications	15.3.4
C of C	**Packaging - Drawings**	**15.3**
C of C, p. 2, 5(a)(3), para. 1	Packaging construction	15.3.5

Citation	Requirement	BECR Section
C of C, p. 2, 5(a)(3), para. 2	Positioning of contents within packaging	15.3.6
C of C	**Contents - Type and Form of Material**	**15.3**
C of C, p. 2, 5(b)(1)	Allowable materials	15.3.7
C of C, p. 2, 5(b)(1)	Explosives, corrosives, nonradioactive pyrophorics, and pressurized containers prohibited	15.3.8
C of C, p. 2, 5(b)(1)	Radioactive pyrophorics not to exceed 1 percent by weight within a drum, standard waste box (SWB), or bin	15.3.9
C of C, p. 2, 5(b)(1)	Free liquids not to exceed 1 percent by volume within a drum, SWB, or bin	15.3.10
C of C, p. 2, 5(b)(1)	Flammable organics limited to 500 ppm in headspace of any drum, SWB, or bin	15.3.11
C of C	**Contents - Maximal Quantity of Material per Package**	**15.3**
C of C, p. 2, 5(b)(2), para. 1	Maximum allowable weight	15.3.12
C of C, p. 2, 5(b)(2), para. 2	Maximal number of payload containers per package and authorized packaging configurations	15.3.13
C of C, p. 2, 5(b)(2), para. 3	Amount of allowable fissile material	15.3.14
C of C, p. 2, 5(b)(2), para. 4	Allowable decay heat	15.3.15
C of C	**Fissile Class**	**15.3**
C of C, p. 2, 5(c)	Fissile Class I	15.3.16
C of C, p. 3, 6	Restrictions of form, properties, and other parameters	15.3.17
C of C, p. 3, 7	Shipping category designations	15.3.18
C of C, p. 3, 8	Labeling requirements	15.3.19
C of C, p. 3, 9	Pre-shipping venting or aspirating requirements	15.3.20
C of C, p. 3, 10	Requirements of Subpart G of 10 CFR Part 71	15.3.21

Citation	Requirement	BECR Section
C of C, p. 3, 10(a)	Preparation of packages for shipment and operations	15.3.22
C of C, p. 3, 10(b)	Testing and maintenance of packaging	15.3.23
C of C, p. 3, 11	Contents of each package	15.3.24
C of C, p. 3, 12	Leak testing	15.3.25
C of C, p. 3, 13	Removal of free-standing water	15.3.26
C of C, p. 3, 14	Approval of TRUPACT-II	15.3.27
C of C, p. 3, 15	Expiration date: June 30, 1999	15.3.28
U.S. Department of Transportation		
49 CFR Part 171	General Information, Regulations, and Definitions	16.2.1 16.2.2 16.2.3 16.2.4
49 CFR Part 172	Hazardous Materials Table, Special Provisions, Hazardous Material Communication Requirements and Emergency Response Information Requirements	16.2.5 16.2.6 16.2.7 16.2.8 16.2.9 16.2.10 16.2.11
49 CFR Part 173	Shippers - General Requirements for Shipments and Packaging	16.2.12 16.2.13 16.2.14 16.2.15 16.2.16 16.2.17
49 CFR Part 175	Carriage by Aircraft	16.2.18
49 CFR Part 177	Carriage by Public Highway	16.2.19
49 CFR Part 178	Specifications for Packaging	16.2.20
U.S. Department of Interior		
43 CFR 3601.1-3	Protection of environment: disposal of salt tailings	17.2
43 CFR 1600	Planning, Programming, Budgeting	18.2

Citation	Requirement	BECR Section
43 CFR 1610.1	Resource management planning guidance	18.2.1
43 CFR 1610.2	Public participation	18.2.2
43 CFR 1610.3-2	Consistency of management plan with applicable laws	18.2.3
43 CFR Part 2800	Rights-of-Way, Principles and Procedures	18.2
43 CFR 2801.2(a)	Common terms and conditions of right-of-way reservations and temporary-use permits: • Compliance with regulations • Non-discrimination • Repair of roads, fences, trails • Fire prevention and suppression	18.2.4
43 CFR 2801.2(b)	Mandatory conditions for right-of-way reservations and temporary-use permits: • Restoration • Air- and water-quality standards • Scenic, cultural, and environmental values • Local inhabitants • State standards that are more stringent than the Federal ones	18.2.5
43 CFR 2802.2	Application requirements for a right-of-way reservation or temporary-use permit	18.2.6
CC 1	Common Conditions (CC) of Right-of-Way Reservations	18.3
CC 1	Control and jurisdiction of DOE	18.3.1
CC 2	Right of access and use	18.3.1
CC 3	Products or resources on lands within the right-of-way	18.3.1
CC 4	Compliance with 43 CFR Part 2800	18.3.1
CC 5	BLM seeding requirements for BLM Roswell District	18.3.1
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 53809, Water Pipeline**	**18.3**
Sec. 13; Standard Stipulations (SS) 1, 2, 5, 6, 8	Preconstruction and construction conditions	18.3.2.1

Citation	Requirement	BECR Section
Sec. 13E	Water access for livestock	18.3.2.2
SS 3	Road construction	18.3.2.3
SS 4	Posting of BLM number	18.3.2.4
SS 7	Gates or cattleguards on public lands	18.3.2.5
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 55676, North Access Road**	**18.3**
SS 2	Polychlorinated biphenyls (PCBs)	18.3.3.1
SS 3-5	SS for the construction of overhead electric distribution lines	18.3.3.2
SS 6	Posting of BLM serial number	18.3.3.3
Term/Condition (T/C) 7	Damage or injury to private property	18.3.3.4
T/C 7 and 8	Actions required upon abandonment, relinquishment, or expiration of right-of-way reservation	18.3.3.5
Amendment (April 22, 1988)	Fencing	18.3.3.6
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 55699, Access Railroad**	**18.3**
SS 1-4, 7, 9, 11	Preconstruction and construction requirements for railroad spur	18.3.4.1
SS 5	Reseeding upon completion of construction	18.3.4.2
SS 6	Abandonment of the site	18.3.4.3
SS 8	Responsibility for damage or injury to private property	18.3.4.4
SS 10	Access to water for livestock	18.3.4.5
SS 12	Removal of caliche and/or other mineral material	18.3.4.6
SS 13	Application for free-use permits	18.3.4.7
Amendment	Notification of BLM regarding the access road parallel to the railroad	18.3.4.8

Citation	Requirement	BECR Section
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 63136, Dosimetry and Aerosol Sampling Sites**	**18.3**
Attachment A	Establishment of dosimeter stations and air samplers	18.3.5.1
Amendment	Air monitoring and data collection site	18.3.5.2
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 65801, Seven Subsidence Monuments**	**18.3**
Right-of-way reservation	No unique conditions	18.3.6
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 82245 for Two Subsidence Monuments**	**18.3**
#1	Construction and maintenance of the monuments	18.3.7.1
#3	Security and maintenance of the monuments	18.3.7.2
#5	Rehabilitation of the land	18.3.7.3
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 77921, Aerosol Sampling Site**	**18.3**
#1	Construction, operation, and maintenance	18.3.8.1
#3	Security and operation of aerosol sampling station	18.3.8.2
#5	Rehabilitation of the land occupied by the aerosol sampling station	18.3.8.3
Letter from El Paso Natural Gas Company	Use of the abandoned concrete slab	18.3.8.4
Sec. 13; Standard Stipulations	**Free-Use Permit No. NM-FU3-91183 for Use of Caliche**	**18.3**
Approval of request to mine 35,000 cubic yards of caliche	Withdrawal of caliche	18.3.9.1
Attachment 2, Reclamation	Reclamation of caliche borrow pit	18.3.9.2
43 CFR Part 4100	**Grazing Administration - Exclusive of Alaska**	**19.2**

Citation	Requirement	BECR Section
43 CFR 4100.0-8	Land-use plan, including grazing management	19.2.1
43 CFR Part 4100	**Grazing Administration**	**20.2**
43 CFR 4100.0-8	Management of grazing lands under principles of multiple use and sustained yield and in accordance with applicable land-use plans	20.2.1
43 CFR 4120.2	Preparation of allotment management plan	20.2.2
50 CFR Part 13	**General Permit Procedures**	**21.2** **23.2**
50 CFR 13.11	Permit application procedures	21.2.1 22.2.1 23.2.1
50 CFR Part 22	**Eagle Permits**	**21.2**
50 CFR 22.11	General permit requirements	21.2.2
50 CFR 22.25	Permits to take golden eagle nests	21.2.3
50 CFR Part 13	**General Permit Procedures**	**22.2**
50 CFR 13.12	Information requirements for permit applications	22.2.2
50 CFR 13.44	Display of permit	22.2.3
50 CFR 13.45	Filing of reports	22.2.4
50 CFR 13.46	Maintenance of records	22.2.5
50 CFR 13.47	Inspection requirement	22.2.6
50 CFR 13.48	Compliance with permit conditions (see also Sections 22.2.12 and 22.3.1)	22.2.7
50 CFR 13.50	Acceptance of liability	22.2.8
50 CFR Part 20	**Migratory Bird Hunting**	**22.2**
50 CFR Part 20, Subpart C	Compliance with applicable hunting regulations	22.2.9
50 CFR Part 21	**Migratory Bird Permits**	**22.2**

Citation	Requirement	BECR Section
50 CFR 21.22(a)	Permit for banding or marking migratory birds	22.2.10
50 CFR 21.22(b)	Application procedures for banding or marking permits	22.2.11
50 CFR 21.22(c)	Additional permit conditions	22.2.12
50 CFR 21.22(d)	Term of permit	22.2.13
50 CFR 21.27	Special-purpose permits	22.2.14
50 CFR 21.28	Falconry permits	22.2.15
50 CFR 21.41	Depredation permits	22.2.16
Permit No. 22478	**Authorization to capture and band or mark birds**	**22.3**
50 CFR Part 17	**Endangered and Threatened Wildlife and Plants**	**23.2**
50 CFR 17.22, 17.32, 17.52, and 17.62	Application for permits for scientific purposes or for the enhancement of propagation or survival of endangered or threatened species	23.2.2
50 CFR Part 402	**Interagency Cooperation - Endangered Species Act, as Amended**	**23.2**
50 CFR 402.12	Biological assessment to evaluate effects of proposed actions on designated species	23.2.3
50 CFR 402.14	Formal consultation with the FWS to determine whether any action will affect listed species	23.2.4
Advisory Council on Historic Preservation		
36 CFR Part 800	**Protection of Historic and Cultural Properties**	**24.2**
36 CFR 800.5	Assessment of effects on historic properties	24.2.1
36 CFR 800.11	Development of plan for treatment of historic property	24.2.2
43 CFR Part 7	**Protection of Archaeological Resources**	**24.2**

Citation	Requirement	BECR Section
43 CFR 7.5	Application for permit to excavate and/or remove archaeological resources	24.2.3
New Mexico Environment Department		
40 CFR Part 262 (20 NMAC 4.1, § 301)	**Standards applicable to generators of hazardous waste**	**25.2.2**
40 CFR 262.11	Hazardous waste determination	25.2.2.1
40 CFR 262.12	EPA identification number	25.2.2.2
40 CFR 262.20	General requirements (manifest requirements)	25.2.2.3
40 CFR 262.21	Acquisition of manifests	25.2.2.4
40 CFR 262.22	Number of copies	25.2.2.5
40 CFR 262.23	Use of the manifest	25.2.2.6
40 CFR 262.30	DOT packaging requirements	25.2.2.7
40 CFR 262.31	Labeling requirements	25.2.2.8
40 CFR 262.32	Marking requirements	25.2.2.9
40 CFR 262.33	Placarding requirements	25.2.2.10
40 CFR 262.34(a)	90-day or less accumulation time	25.2.2.11
40 CFR 262.34(a)(1)(i)	Compliance with Subpart I of 40 CFR Part 265 for waste placed in containers	25.2.2.12
40 CFR 262.34(a)(1)(ii)	Accumulation of hazardous wastes in tanks	25.2.2.13
40 CFR 262.34(a)(1)(iii)	Compliance with Subpart W of 40 CFR Part 265 for wastes placed on drip pads	25.2.2.14
40 CFR 262.34(a)(2)	Marking each container with the date of initial accumulation of waste	25.2.2.15
40 CFR 262.34(a)(3)	Marking each container as hazardous waste	25.2.2.16
40 CFR 262.34(a)(4)	Compliance with Subparts C and D of 40 CFR 265, 40 CFR 265.16, and 40 CFR 268.7(a)(4) for preparedness/prevention, contingency plans/emergency procedures, training, and waste analysis plans	25.2.2.17

Citation	Requirement	BECR Section
40 CFR 262.34(b)	Extension of the 90-day storage period due to unforeseen, temporary, and uncontrollable circumstances	25.2.2.18
40 CFR 262.34(c)(1)(i)	Restrictions and requirements for satellite accumulation areas	25.2.2.19 25.2.2.20
40 CFR 262.34(c)(1)(ii)	Labeling of container as "hazardous waste"	25.2.2.21
40 CFR 262.34(c)(2)	Management of waste exceeding the 55-gallon or 1-quart limit	25.2.2.22
40 CFR 262.40	Recordkeeping requirements	25.2.2.23
40 CFR 262.41	Generator--biennial report	25.2.2.24
40 CFR 262.42	Exception reporting if copy of manifest is not returned to generator within the specified time period	25.2.2.25
40 CFR 262.43	Additional reporting	25.2.2.26
40 CFR 262.43	Special requirements for generators of between 100 and 1,000 kg/mo	25.2.2.27
40 CFR Part 263 (20 NMAC 4.1, § 400)	**Standards Applicable to Transporters of Hazardous Waste**	**25.2.3**
40 CFR 263.10(a)	Compliance with DOT regulations	25.2.3.1
40 CFR 263.11	EPA identification number	25.2.3.2
40 CFR 263.20 - 263.22	Compliance with the manifest system and recordkeeping	25.2.3.3
40 CFR 263.30	Immediate action after hazardous waste discharges	25.2.3.4
40 CFR 263.31	Discharge cleanup	25.2.3.5
40 CFR Part 265 (20 NMAC 4.1, § 601)	**Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities**	**25.2.4**
40 CFR 265.10	Applicability	25.2.4.1
40 CFR 265.11	EPA identification number	25.2.4.2
40 CFR 265.12	Required notices to the off-site source(s)	25.2.4.3

Citation	Requirement	BECR Section
40 CFR 265.13	General waste analysis	25.2.4.4
40 CFR 265.14	Security	25.2.4.5
40 CFR 265.15	General inspection requirements	25.2.4.6
40 CFR 265.16	Personnel training	25.2.4.7
40 CFR 265.17	General requirements for ignitable, reactive, or incompatible wastes	25.2.4.8
40 CFR 265.18	Location standards	25.2.4.9
40 CFR 265.31	Maintenance and operation of facility	25.2.4.10
40 CFR 265.32	Required equipment	25.2.4.11
40 CFR 265.33	Testing and maintenance of equipment	25.2.4.12
40 CFR 265.34	Access to communications or alarm system	25.2.4.13
40 CFR 265.35	Required aisle space	25.2.4.14
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CITATION	REQUIREMENT	BECR SECTION
40 CFR 80.22	Prohibition against dispensing gasoline with lead or lead additives	6.2.3.3
40 CFR 80.23	Liability for violations	6.2.3.4
40 CFR Part 82	**Protection of Stratospheric Ozone**	**6.1**
40 CFR 82.40	Restrictions on repairing and servicing motor vehicle air conditioners	6.2.4.1
40 CFR 82.54(c), 82.104(a)	Prohibition of nonessential Class I ozone-depleting substances	6.2.4.2
40 CFR 82.66	Ban on nonessential products containing Class I substances	6.2.4.3
40 CFR 82.84	Federal procurement requirements	6.2.4.4
40 CFR 82.86	Reporting requirements	6.2.4.5
40 CFR Part 82, Subpart E	Labeling of products and containers containing Class I or Class II ODSs	6.2.4.6
40 CFR 82.102	Applicability	6.2.4.7
40 CFR 82.106	Required warning statements	6.2.4.8
40 CFR 82.108, 82.112	Placement of warning statement and prohibition of removal of the label bearing the warning statement	6.2.4.9
40 CFR 82.122	Certification, recordkeeping, and notice requirements	6.2.4.10
40 CFR 82.124(a)(4)	Prohibitions	6.2.4.11
40 CFR 82.150	Service, maintenance, and repair of appliances using refrigerants	6.2.4.12
40 CFR 82.154	Prohibitions regarding maintenance, service, repair, or disposal of appliances	6.2.4.13
40 CFR 82.156	Required practices	6.2.4.14
20 NMAC 2	**New Mexico Air Quality Control Regulations**	**29.1**
20 NMAC 2.60	Regulations to control open burning	29.2.1
20 NMAC 2.61	Regulations to control smoke and visible emissions	29.2.2

CITATION	REQUIREMENT	BECR SECTION
20 NMAC 2.18	Oil-burning equipment -- particulate matter	29.2.3
20 NMAC 2.34	Oil-burning equipment -- nitrogen dioxide	29.2.4
20 NMAC 2.75	Permit fees	29.2.5
20 NMAC 2.70	Compliance Plan as part of operating permit application	29.2.6
20 NMAC 2.70	Semiannual operating permit reports and progress reports on Compliance Plan	29.2.7
20 NMAC 2.72	Permits	29.2.8
20 NMAC 2.73	Annual emission inventory	29.2.9
20 NMAC 2.80	Stack height requirements	29.2.10
20 NMAC 2.78	NESHAPs - radionuclides NESHAPs - other HAPs	29.2.11
20 NMAC 2.7	Excess emissions during malfunction, startup, shutdown, or scheduled maintenance	29.2.12
20 NMAC 2.8	Controlling emissions leaving New Mexico	29.2.13
20 NMAC 2.1	Sampling equipment	29.2.14
Air Quality Permit No. 310-M-2, Condition 1	**Construction and operation**	**29.3.2.1**
Condition 2	Emission rates	29.3.2.2
Conditions 3-4	Compliance test methods	29.3.2.3
Condition 5	Revisions and modifications	29.3.2.4
Condition 6	Notification to subsequent owners	29.3.2.5
Condition 7	Right to access property and review records	29.3.2.6
Condition 8	Posting of the permit	29.3.2.7
Condition 9	Recordkeeping	29.3.2.8
Condition 10	Reporting	29.3.2.9
Additional Condition, p. 8	Permit cancellations	29.3.2.10
Additional Condition, p. 8	Notice of intent and emission inventory	29.3.2.11

CITATION	REQUIREMENT	BECR SECTION
	Environmental Protection Legislation	
CERCLA § 120(d)	**Assessment and evaluation**	**3.2.1**
§§ 74-1-1 through 74-1-10	**New Mexico Environmental Improvement Act**	**27.1; see Chapters 25, 26 and 28-31**
10 CFR Part 1021	**Implementing Procedures**	**14.1**
29 CFR Part 1910	**Occupational Safety and Health Standards**	**11.1**
29 CFR 1910.95	Compliance with hearing protection standards	11.2.1
40 CFR Part 142	**National Primary Drinking Water Regulations Implementation**	**8.1**
40 CFR 142.4	State program requirements	8.2.1 Chapter 31
40 CFR Part 144	**Underground Injection Control Program**	**8.1**
40 CFR 144	Underground injection control	8.2.2
40 CFR Part 300	**National Oil and Hazardous Substances Pollution Contingency Plan**	**3.1**
40 CFR 300.215(b)	Emergency planning requirements	3.2.2
40 CFR 300.215(e)	Material safety data sheet and inventory form	3.2.3
40 CFR Part 302	**Designation, Reportable Quantities, and Notification**	**3.1**
40 CFR 302.4	Designation of hazardous substances	3.2.4
40 CFR 302.5	Determination of reportable quantities	3.2.5
40 CFR 302.6(a)	Notification requirements	3.2.6
40 CFR 302.6(b)(1)	Releases of mixture or solutions	3.2.7
40 CFR 302.6(b)(2)	Notification of releases of radionuclides	3.2.8
40 CFR 302.6(d)	Notification of the release of heavy metals	3.2.9
40 CFR Part 355	**Emergency Planning Notification**	**4.1**

CITATION	REQUIREMENT	BECR SECTION
40 CFR 355.30(a)-(b)	Emergency planning	4.2.1
40 CFR 355.30(c)	Facility Emergency Coordinator	4.2.2
40 CFR 355.30(d)	Provision of information	4.2.3
40 CFR 355.40	Releases of extremely hazardous substances	4.2.4
40 CFR Part 370	**Hazardous Chemical Reporting: Community Right-to-Know**	**4.1**
40 CFR 370.21	Submission of MSDS or chemical list	4.2.5
40 CFR 370.25	Submission of hazardous chemical inventory form	4.2.6
40 CFR Part 372	**Toxic Chemical Release Reporting: Community Right-to-Know**	**4.1**
40 CFR 372.30	Submission of the Toxic Chemical Inventory Report	4.2.7
40 CFR Parts 1500-1508	**Provision of Environmental Information to Public Officials and Private Citizens**	**12.2** **14.1**
§§ 74-4B-1 - 74-4B-14, NMSA 1978	**New Mexico Emergency Management Act**	**33.1**
§ 74-4B-2	Findings and purpose	33.2.1
§74-4B-4	State responsibility for management of accidents; immunity from liability; cooperative agreements; private property	33.2.2
§ 74-4B-5	State Police Emergency Response Officer; procedure for notification; cooperation with other State agencies and local governments	33.2.3
§ 74-4B-6	Emergency Management Task Force: powers and duties	33.2.4
§ 74-4B-6.1	Creation and duties of the Hazardous Materials Emergency Response Administrator	33.2.5
§ 74-4B-10	Responsibility for clean-up by owner, shipper, or carrier of the hazardous material	33.2.6

CITATION	REQUIREMENT	BECR SECTION
	Hazardous Substance Legislation	
TSCA, Title II	**Asbestos Hazard Emergency Response Act (AHERA)**	**9.1**
TSCA Title II, §§ 201 et seq.	Hazards of friable asbestos-containing material	9.2.1
TSCA, Title III	**Indoor Radon Abatement**	**9.1**
TSCA Title III, § 309	Study of radon in Federal buildings	9.2.2
40 CFR Part 152	**Pesticide Registration and Classification Procedures**	**10.1**
40 CFR 152.15	Registration of pesticide products	10.2.1
40 CFR Part 165	**Regulations for the Acceptance of Certain Pesticides and Recommended Procedures for the Disposal and Storage of Pesticides and Pesticides Containers**	**10.1**
40 CFR 165.8-.11	Recommended procedures for disposal or storage of pesticides	10.2.2
40 CFR Part 761	**EPA Regulations for Manufacturing Processing, Distribution in Commerce, and Use Prohibitions for Polychlorinated Biphenyls under the Toxic Substances Control Act**	**9.1**
40 CFR 761.20	Prohibition of PCBs	9.2.3
40 CFR 761.60	Disposal requirements for PCBs	9.2.4
HCIA § 74-4E	**New Mexico Hazardous Chemicals Information Act (HCIA)**	**32.1**
HCIA § 74-4E-5(A)(1)	Notification to the State that an extremely hazardous substance is present at a facility	32.2.1
HCIA § 74-4E-5(A)(2)	Notice of release of chemical substance(s) when release is at or above the reportable quantity of the substance	32.2.2
HCIA § 74-4E-5(A)(3)	Submittal of an inventory form covering each hazardous material	32.2.3

CITATION	REQUIREMENT	BECR SECTION
HCIA § 74-4E-5(A)(4)	Submittal of Toxic Chemical Release Inventory forms	32.2.4
Regulatory Order No. 4	**New Mexico Pesticide Control Act: Regulatory Order of the Board of Regents of New Mexico State University**	**38.1**
Section 5	Storage of pesticides and disposal of pesticide wastes	38.2.1 10.2.2
Regulatory Order No. 5	**New Mexico Pesticide Control Act: Definitions, Licensing, Equipment Inspections, Record Keeping of Pesticides by Regulated Applicators**	**38.1**
Section 6	License classifications	38.2.2
Section 10	Protective equipment	38.2.3
Section 11	Application of pesticides	38.2.4
Historic Preservation Legislation		
36 CFR Part 800	**Protection of Historic and Cultural Properties**	**24.2**
36 CFR 800.5	Assessment of effects on historic properties	24.2.1
36 CFR 800.11	Development of plan for treatment of historic property	24.2.2
43 CFR Part 7	**Protection of Archaeological Resources**	**24.2**
43 CFR 7.5	Application for permit to excavate and/or remove archaeological resources	24.2.3
§§ 18-8-1 through 18-8-8	**New Mexico Prehistoric and Historic Sites Preservation Act**	**34.1**
Land Management Legislation		
43 CFR Part 3600	**Mineral Materials Disposal: General**	**17.2**
43 CFR 3601.1-3	Protection of environment: disposal of salt tailings	17.2.1
43 CFR 1600	**Planning, Programming, Budgeting**	**18.2**

CITATION	REQUIREMENT	BECR SECTION
43 CFR 1610.1	Resource management planning guidance	18.2.1
43 CFR 1610.2	Public participation	18.2.2
43 CFR 1610.3-2	Consistency of management plan with applicable laws	18.2.3
43 CFR Part 2800	**Rights-of-Way, Principles and Procedures**	**18.2**
43 CFR 2801.2(a)	Common terms and conditions of right-of-way reservations and temporary-use permits: • Compliance with regulations • Non-discrimination • Repair of roads, fences, trails • Fire prevention and suppression	18.2.4
43 CFR 2801.2(b)	Mandatory conditions for right-of-way reservations and temporary-use permits: • Restoration • Air- and water-quality standards • Scenic, cultural, and environmental values • Local inhabitants • State standards that are more stringent than the Federal ones	18.2.5
43 CFR 2802.2	Application requirements for a right-of-way reservation or temporary-use permit	18.2.6
CC 1	**Common Conditions (CC) of Right-of-Way Reservations**	**18.3**
CC 1	Control and jurisdiction of DOE	18.3.1
CC 2	Right of access and use	18.3.1
CC 3	Products or resources on lands within the right-of-way	18.3.1
CC 4	Compliance with 43 CFR Part 2800	18.3.1
CC 5	BLM seeding requirements for BLM Roswell District	18.3.1
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 53809, Water Pipeline**	**18.3**

CITATION	REQUIREMENT	BECR SECTION
Sec. 13; Standard Stipulations (SS) 1, 2, 5, 6, 8	Preconstruction and construction conditions	18.3.2.1
Sec. 13E	Water access for livestock	18.3.2.2
SS 3	Road construction	18.3.2.3
SS 4	Posting of BLM number	18.3.2.4
SS 7	Gates or cattleguards on public lands	18.3.2.5
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 55676, North Access Road**	**18.3**
SS 2	Polychlorinated biphenyls (PCBs)	18.3.3.1
SS 3-5	SS for the construction of overhead electric distribution lines	18.3.3.2
SS 6	Posting of BLM serial number	18.3.3.3
Term/Condition (T/C) 7	Damage or injury to private property	18.3.3.4
T/C 7 and 8	Actions required upon abandonment, relinquishment, or expiration of right-of-way reservation	18.3.3.5
Amendment (April 22, 1988)	Fencing	18.3.3.6
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 55699, Access Railroad**	**18.3**
SS 1-4, 7, 9, 11	Preconstruction and construction requirements for railroad spur	18.3.4.1
SS 5	Reseeding upon completion of construction	18.3.4.2
SS 6	Abandonment of the site	18.3.4.3
SS 8	Responsibility for damage or injury to private property	18.3.4.4
SS 10	Access to water for livestock	18.3.4.5
SS 12	Removal of caliche and/or other mineral material	18.3.4.6
SS 13	Application for free-use permits	18.3.4.7
Amendment	Notification of BLM regarding the access road parallel to the railroad	18.3.4.8

CITATION	REQUIREMENT	BECR SECTION
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 63136, Dosimetry and Aerosol Sampling Sites**	**18.3**
Attachment A	Establishment of dosimeter stations and air samplers	18.3.5.1
Amendment	Air monitoring and data collection site	18.3.5.2
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 65801, Seven Subsidence Monuments**	**18.3**
Right-of-way reservation	No unique conditions	18.3.6
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 82245 for Two Subsidence Monuments**	**18.3**
#1	Construction and maintenance of the monuments	18.3.7.1
#3	Security and maintenance of the monuments	18.3.7.2
#5	Rehabilitation of the land	18.3.7.3
Sec. 13; Standard Stipulations	**Right-of-Way Reservation No. NM 77921, Aerosol Sampling Site**	**18.3**
#1	Construction, operation, and maintenance	18.3.8.1
#3	Security and operation of aerosol sampling station	18.3.8.2
#5	Rehabilitation of the land occupied by the aerosol sampling station	18.3.8.3
Letter from El Paso Natural Gas Company	Use of the abandoned concrete slab	18.3.8.4
Sec. 13; Standard Stipulations	**Free-Use Permit No. NM-FU3-91183 for Use of Caliche**	**18.3**
Approval of request to mine 35,000 cubic yards of caliche	Withdrawal of caliche	18.3.9.1
Attachment 2, Reclamation	Reclamation of caliche borrow pit	18.3.9.2
43 CFR Part 4100	**Grazing Administration - Exclusive of Alaska**	**19.2**

CITATION	REQUIREMENT	BECR SECTION
43 CFR 4100.0-8	Land-use plan, including grazing management	19.2.1
43 CFR Part 4100	**Grazing Administration**	**20.2**
43 CFR 4100.0-8	Management of grazing lands under principles of multiple use and sustained yield and in accordance with applicable land-use plans	20.2.1
43 CFR 4120.2	Preparation of allotment management plan	20.2.2
New Mexico State Land Office (SLO) Rule No. 10	**Relating to Easements and Rights-of-Way**	**35.1**
SLO Rule 10.006	Application requirements and fees	35.2.1
SLO Rule 10.009	Conditions	35.2.2
SLO Rule 10.010	Damage bond	35.2.3
SLO Rule 10.011	Survey plot	35.2.4
SLO Rule 10.012	Construction reports for ruins, artifacts, and monuments	35.2.5
SLO Rule 10.013	Affidavit of completion	35.2.6
SLO Rule 10.017	Renewal of right-of-way grants	35.2.7
SLO Rule 10.019	Reclamation and restoration	35.2.8
RW 22789	**Permit No. RW-22789 for a high- volume air sampler**	**35.3**
Term/condition (TC) #3	Disposal of brush and other debris	35.3.1
TC #4	Depth of pipelines	35.3.2
TC #5	Prevention of destruction or injury to improvements or livestock	35.3.3
TC #6	Purpose of right-of-way	35.3.4
TC #7	Existing rights	35.3.5
TC #8	Leases for mineral resources	35.3.6
TC #9	Compliance with all applicable regulations and requirements	35.3.7

CITATION	REQUIREMENT	BECR SECTION
TC #10	Non-use of the right-of-way	35.3.8
TC #13	Protection and preservation of natural environmental conditions	35.3.9
TC #14	Reclamation of all disturbed areas	35.3.10
	Radiation Protection Legislation	
10 CFR Part 71	**Packaging and Transportation of Radioactive Material**	**15.1**
10 CFR 71.12	General license: NRC-approved package	15.2.1
10 CFR 71.31-71.39	Contents of application and package description, evaluation, and QA	15.2.2
10 CFR 71.41	Demonstration of compliance	15.2.3
10 CFR 71.43 and 71.45	Requirements for all packages	15.2.4
10 CFR 71.47	External radiation standards for all packages	15.2.5
10 CFR 71.51	Additional requirements for Type B packages	15.2.6
10 CFR 71.55-71.61	Requirements for all fissile material packages	15.2.7
10 CFR 71.63	Special requirements for plutonium shipments in excess of 20 Ci/shipment	15.2.8
10 CFR 71.71	Tests under normal conditions of transport	15.2.9
10 CFR 71.73	Tests under hypothetical accident conditions	15.2.10
10 CFR 71.81	Compliance with general requirements (71.00-6a), operating controls and procedures (71.81-71.99), and quality assurance requirements (71.101-71.137)	15.2.11
10 CFR 71.83	Assumptions as to unknown properties: assume credible values that will cause the maximum nuclear reactivity	15.2.12
10 CFR 71.85	Preliminary determinations of integrity of packaging, pressure testing, and marking	15.2.13

CITATION	REQUIREMENT	BECR SECTION
10 CFR 71.87	Routine determinations prior to each shipment	15.2.14
10 CFR 71.89	Any special opening instructions for the consignee	15.2.15
10 CFR 71.91	Records to be kept at least 3 years after shipment	15.2.16
10 CFR 71.93	Inspections and tests to be performed or allowed to be performed by the NRC	15.2.17
10 CFR 71.95	Reports regarding (1) any decreased effectiveness of an authorized packaging during use and (2) details of any defects with safety significance	15.2.18
10 CFR 71.97	Advance notification of shipment of nuclear waste as described	15.2.19
10 CFR 71.101-71.137	NRC quality assurance requirements	15.2.20
C of C	**Description of TRUPACT-II**	**15.3**
C of C, p. 1, 5(2), para. 1	Overall specifications for the TRUPACT-II	15.3.1
C of C, p. 1, 5(2), para. 1	Weight specifications	15.3.2
C of C, p. 1, 5(2), para. 2	Outer containment assembly specifications	15.3.3
C of C, p. 1, 5(2), para. 3, ICV	Inner containment vessel specifications	15.3.4
C of C	**Packaging - Drawings**	**15.3**
C of C, p. 2, 5(a)(3), para. 1	Packaging construction	15.3.5
C of C, p. 2, 5(a)(3), para. 2	Positioning of contents within packaging	15.3.6
C of C	**Contents - Type and Form of Material**	**15.3**
C of C, p. 2, 5(b)(1)	Allowable materials	15.3.7
C of C, p. 2, 5(b)(1)	Explosives, corrosives, nonradioactive pyrophorics, and pressurized containers	15.3.8
C of C, p. 2, 5(b)(1)	Radioactive pyrophorics not to exceed 1 percent by weight within a drum, standard waste box (SWB), or bin	15.3.9
C of C, p. 2, 5(b)(1)	Free liquids not to exceed 1 percent by volume within a drum, SWB, or bin	15.3.10

CITATION	REQUIREMENT	BECR SECTION
C of C, p. 2, 5(b)(1)	Flammable organics limited to 500 ppm in headspace of any drum, SWB, or bin	15.3.11
C of C	**Contents - Maximal Quantity of Material per Package**	**15.3**
C of C, p. 2, 5(b)(2), para. 1	Maximum allowable weight	15.3.12
C of C, p. 2, 5(b)(2), para. 2	Maximal number of payload containers per package and authorized packaging configurations	15.3.13
C of C, p. 2, 5(b)(2), para. 3	Amount of allowable fissile material	15.3.14
C of C, p. 2, 5(b)(2), para. 4	Allowable decay heat	15.3.15
C of C	**Fissile Class**	**15.3**
C of C, p. 2, 5(c)	Fissile Class I	15.3.16
C of C, p. 3, 6	Restrictions of form, properties, and other parameters	15.3.17
C of C, p. 3, 7	Shipping category designations	15.3.18
C of C, p. 3, 8	Labeling requirements	15.3.19
C of C, p. 3, 9	Pre-shipping venting or aspirating requirements	15.3.20
C of C, p. 3, 10	Requirements pf Subpart G of 10 CFR Part 71	15.3.21
C of C, p. 3, 10(a)	Preparation of packages for shipment and operations	15.3.22
C of C, p. 3, 10(b)	Testing and maintenance of packaging	15.3.23
C of C, p. 3, 11	Contents of each package	15.3.24
C of C, p. 3, 12	Leak testing	15.3.25
C of C, p. 3, 13	Removal of free-standing water	15.3.26
C of C, p. 3, 14	Approval of TRUPACT-II	15.3.27
C of C, p. 3, 15	Expiration date: June 30, 1999	15.3.28
10 CFR Part 830	**Nuclear Safety Management**	**13.2**

CITATION	REQUIREMENT	BECR SECTION
10 CFR 830.4(a)	Taking action(s) inconsistent with requirements	13.2.1
10 CFR 830.4(b)	Implementation and compliance with requirements	13.2.2
10 CFR 830.4(c)	Plan or program required by this part as the basis for determining compliance	13.2.3
10 CFR 830.6	Records to substantiate compliance	13.2.4
10 CFR 830.7	Use of a graded approach	13.2.5
10 CFR 830.120(a)	Development and implementation of contractor's Quality Assurance Program (QAP)	13.2.6
10 CFR 830.120(b)	Application of the appropriate quality assurance (QA) criteria in the QAP	13.2.7
10 CFR 830.120(c)	QA criteria to be included in the QAP	13.2.8
40 CFR Part 191	**Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Waste**	**5.1** **5.2.1**
40 CFR 191.03-191.04, Subpart A	Standard annual dose equivalent	5.2.1.1
Plant and Animal Preservation Legislation		
50 CFR Part 13	**General Permit Procedures**	**21.2** **23.2**
50 CFR 13.11	Permit application procedures	21.2.1 22.2.1 23.2.1
50 CFR Part 22	**Eagle Permits**	**21.2**
50 CFR 22.11	General permit requirements	21.2.2
50 CFR 22.25	Permits to take golden eagle nests	21.2.3
50 CFR Part 13	**General Permit Procedures**	**22.2**
50 CFR 13.12	Information requirements for permit applications	22.2.2

CITATION	REQUIREMENT	BECR SECTION
50 CFR 13.44	Display of permit	22.2.3
50 CFR 13.45	Filing of reports	22.2.4
50 CFR 13.46	Maintenance of records	22.2.5
50 CFR 13.47	Inspection requirement	22.2.6
50 CFR 13.48	Compliance with permit conditions (see also Sections 22.2.12 and 22.3.1)	22.2.7
50 CFR 13.50	Acceptance of liability	22.2.8
50 CFR Part 20	**Migratory Bird Hunting**	**22.2**
50 CFR Part 20, Subpart C	Compliance with applicable hunting regulations	22.2.9
50 CFR Part 21	**Migratory Bird Permits**	**22.2**
50 CFR 21.22(a)	Permit for banding or marking migratory birds	22.2.10
50 CFR 21.22(b)	Application procedures for banding or marking permits	22.2.11
50 CFR 21.22(c)	Additional permit conditions	22.2.12
50 CFR 21.22(d)	Term of permit	22.2.13
50 CFR 21.27	Special-purpose permits	22.2.14
50 CFR 21.28	Falconry permits	22.2.15
50 CFR 21.41	Depredation permits	22.2.16
Permit No. 22478	**Authorization to capture and band or mark birds**	**22.3**
50 CFR Part 17	**Endangered and Threatened Wildlife and Plants**	**23.2**
50 CFR 17.22, 17.32, 17.52, and 17.62	Application for permits for scientific purposes or for the enhancement of propagation or survival of endangered or threatened species	23.2.2
50 CFR Part 402	**Interagency Cooperation - Endangered Species Act, as Amended**	**23.2**

CITATION	REQUIREMENT	BECR SECTION
50 CFR 402.12	Biological assessment to evaluate effects of proposed actions on designated species	23.2.3
50 CFR 402.14	Formal consultation with the FWS to determine whether any action will affect listed species	23.2.4
§ 17-2-14	**New Mexico State implementation of the Bald and Golden Eagle Protection Act**	**36.1**
§§ 17-2-37 through 17-2-46	**New Mexico Wildlife Conservation Act**	**36.1** **37.1**
Regulation No. 564	**State Game Commission Regulation, *Governing the Removal, Capture, or Destruction of Endangered Species***	**37.2**
Regulation No. 564	Report of unpermitted removal, capture, or destruction of endangered species	37.2.1
Regulation No. 682	**State Game Commission Regulation No. 682, *Amending the Listing of Endangered Species and Subspecies of New Mexico***	**37.2**
Regulation No. 682	Recognition of State-listed endangered wildlife	37.2.2
Regulation No. 705	**State Game Commission Regulation, *Regulation for the Taking and Possession of Protected Wildlife for Scientific and Educational Purposes***	**37.2**
Regulation No. 705, Chapter 2	Requirements for obtaining a permit	37.2.3
Regulation No. 705, Chapter 5	Year-end reports	37.2.4
NMDG&F permits	**New Mexico Department of Game and Fish Permits**	**37.3**
Permit No. 1961	Authorization for live capture and banding of protected birds, reporting of salvaged endangered or threatened wildlife, and disposition of wildlife	37.3.1
Permit No. 1894	Live trapping; authorization for quail, catfish, and unprotected species; nonlethal methods for catfish; report for salvaging endangered or threatened vertebrates	37.3.2

CITATION	REQUIREMENT	BECR SECTION
	Waste Management Legislation	
RCRA § 3016	**Inventory of Federal hazardous waste facilities**	**2.2.1.1**
20 NMAC 4.1, § 1101	**New Mexico Hazardous Waste Management Regulations**	**25.2.1.1**
40 CFR Part 262 (20 NMAC 4.1, § 301)	**Standards applicable to generators of hazardous waste**	**25.2.2**
40 CFR 262.11	Hazardous waste determination	25.2.2.1
40 CFR 262.12	EPA identification number	25.2.2.2
40 CFR 262.20	General requirements (manifest requirements)	25.2.2.3
40 CFR 262.21	Acquisition of manifests	25.2.2.4
40 CFR 262.22	Number of copies	25.2.2.5
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CITATION	REQUIREMENT	BECR SECTION
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CITATION	REQUIREMENT	BECR SECTION
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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix BH

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Borehole Data Report

DOE/WIPP 95-2092
Rev. 1

Waste Isolation Pilot Plant Borehole Data Report

July 1996

Prepared for:

United States Department of Energy
Carlsbad Area Office

Westinghouse Electric Corporation
Waste Isolation Division

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Introduction

INTRODUCTION

Data pertaining to the surface boreholes that have been used at the WIPP site for site characterization, hydrological testing and resource evaluation exists in numerous source documents. The WIPP Borehole Data Base was prepared to serve as a central document providing data on boreholes used in characterizing the site. This report contains a comprehensive data base on wells drilled in support of the WIPP and boreholes that are within the sixteen section Land Withdrawal Area. Basic data for other boreholes, which includes commercial petroleum and potash, has been copied from other existing reports and is provided in the following attachments:

- Attachment A, *Data for Drillholes in Holt and Powers (1988) including Additional Drillholes Interpreted by Powers*
- Attachment B, *Rustler Formation Stratigraphic Data from Richey (1989)*
- Attachment C, *Calculated Mineral Content of Selected Samples from Potassium-Bearing Intervals with Summation of Percent K_20 as Ore Mineral*

The data compiled from each borehole includes: the operator, permit number, location, elevation, total depth, type of well, driller, drilling record, hole size, well development and stratigraphic summary. There are seven groups of boreholes contained in this data base; they are as follows: Commercially Drilled Boreholes, Energy Department Wells, Geologic Exploration Boreholes, Hydrologic Test Boreholes, Potash Boreholes, Subsurface Exploration Boreholes, and Water Quality Sampling Program Boreholes.

There were numerous sources which contained borehole data. During the compilation of this data base, it was noted that in some cases the data found in one document was inconsistent with data in another document. In order to ensure consistency and accuracy in the data base, the same references were used for as many of the boreholes as possible. For example, all elevations and locations were taken from *Compilation and Comparison of Test-Hole Location Surveys in the Vicinity of the WIPP Site*. SAND 88-1065, Table 3-5. There are some sections where a data field is left blank. In this case, the information was either not applicable, or was unavailable.

Commercially Drilled Borehole Data Base

COMMERCIALLY DRILLED BOREHOLE DATA BASE

BOREHOLE: **BADGER-1**
OPERATOR: Clayton W. Williams, Jr.
PERMIT NO.: 14-08-0001-12400

LOCATION: 1980' FSL, 1980' FWL
Sec. 15, T 22 S, R 31 E

ELEVATION: 3475'
TOTAL DEPTH: 15225'
TYPE OF WELL: Gas Well
DRILLER:

DRILLING RECORD: **Date Started:** 06/28/73 **Date Completed:** 09/17/73

WELL DEVELOPMENT:

PLUGGING SCHEDULE

From: 14,275'
To: 14,075'
Int: 200'
Material: 65 sx Howco "H" cement

From: 12,940'
To: 12,840'
Int: 100'
Material: 35 sx Howco "H" cement

From: 12,100'
To: 11,900'
Int: 200'
Material: 65 sx Howco "H" cement

From: 4,300'
To: 4,200'
Int: 100'
Material: 35 sx Howco "H" cement

3,780': Set cast iron bridge plug in 9 5/8" casing
3,613': Cut off 9 5/8" casing and pulled

From: 3,668'
To: 3,568'
Int: 100'
Material: 100 sx Howco "C" cement

From: 850'
To: 750'
Int: 100'
Material: 100 sx Howco "C" cement

CASING RECORD

Diameter: 20
Grade:
Wt/Ft: 94
From: 804
To:
Cement: 1120 sx

Diameter: 13 3/8
Grade:
Wt/Ft: 68, 61
From: 4240
To:
Cement: 2920 sx

Diameter: 9 5/8
Grade:
Wt/Ft: 47, 43.5
From: 11,990
To:
Cement: 2000 sx

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
BADGER-1	Salado	1024
	Lamar Ls.	4217
	Deleware Sand	4273
	Cherry Canyon	5173
	Brushy Canyon	6220
	Bone Spring	8152
	Wolfcamp	11405
	Lower Strawn	12896
	Atoka	13152
	Morrow	13739
	Morrow Clastics	13942
	Barnett	14984
	Lower Mississippian Ls.	15195

COMMERCIALLY DRILLED BOREHOLE DATA BASE

BOREHOLE: **COTTON-1**
OPERATOR: Michael P. Grace
PERMIT NO.: Unknown

LOCATION: 1980' FSL, 1980' FWL
Sec. 34, T 22 S, R 31 E

ELEVATION: 3455'
TOTAL DEPTH: 6700'
TYPE OF WELL: Oil Well
DRILLER:

DRILLING RECORD: **Date Started:** 08/31/73 **Date Completed:** 12/15/75

WELL DEVELOPMENT:

PLUGGING SCHEDULE

From: 4,167'
To: 3,967'
Int: 200'
Material: Cement

From: 1,070'
To: 870'
Int: 200'
Material: Cement

3,980': 100' cement plug (top of 2 7/8" stub)

From: 4,424'
To: 4,400'
Int: 24'
Material:

From: 720'
To: 620'
Int: 100'
Material:

From: 20'
To: 0'
Int: 20'
Material:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 61
From: 680.76
To:
Cement: 70 sx Halliburton Lt. & 100 sx of Class "C" cement

Diameter: 2 7/8
Grade:
Wt/Ft: 6.5
From: 4634
To:
Cement: 325 sx with 3/4 of 1% CFR2
Cut off 2 7/8" casing at 3980'

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
COTTON-1	Rustler	655 (+2800)
	Salt	970 (+2485)
	Base Salt	4077 (-622)
	Lamar	4320 (-865)
	Deleware Sand	4380 (-925)
	Cherry Canyon	5916 (-2461)
	Brushy Canyon	6406 (-2951)
	Total Depth	6700

COMMERCIALLY DRILLED BOREHOLE DATA BASE

BOREHOLE:	**D-123**
OPERATOR:	Duval Sulphur & Potash Company
PERMIT NO.:	Potassium Prospecting Permit LC-066112
LOCATION:	2614' North and 277' West of Southeast Corner of Section 34, NE1/4 Section 34, Township 22 South, Range 31 East. NMPM
ELEVATION:	3432'
TOTAL DEPTH:	1880'
TYPE OF WELL:	Potash Core Test
DRILLER:	Weaver Drilling Company
DRILLING RECORD:	**Date Started:** 07/19/53 **Date Completed:** 08/07/53 Rotary Drill 6-1/4" Rockbit: 0-934' Corebit: 934-1880'

WELL DEVELOPMENT:

CASING RECORD

4" Casing: 934'
Recovered: 692'

PLUGGING SCHEDULE

Shot casing at 910' and 850'. Pulled 692' leaving 242' in hole. The following cement plugs were run:
1) 73 sacks of cement mixed with 3% CaCl^2 and brine at bottom of hole.
2) 45 sacks of cement mixed with fresh water bottomed at 880'.

The remainder of the hole was filled with cuttings, a four-foot marker post set, and the hole abandoned.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
D-123	Rustler Formation	670
	Top of Salt	988
	Top of USGS 124 Bed	1779

COMMERCIALLY DRILLED BOREHOLE DATA BASE

BOREHOLE: **I-374**
OPERATOR: International Minerals & Chemical Corp.
PERMIT NO.: Potassium Prospecting Permit NM-0359163

LOCATION: 424' North 45 degrees West from S1/4 Corner of Section 30, SW1/4 Section 30, Township 22 South, Range 31 East. NMPM

ELEVATION: 3340'
TOTAL DEPTH: 1538'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company

DRILLING RECORD: **Date Started:** 04/15/65 **Date Completed:** 04/27/65
Rotary Drill
6-1/4" Rockbit: 0-714'
3-7/8" Rockbit: 714-1149'
3-7/8" Corebit: 1149-1538'

WELL DEVELOPMENT:

CASING RECORD

4" Casing: 0-714'
Recovered: 0-437'

PLUGGING SCHEDULE

From: 1538'
To: 714'
Int: 824'
Material: Cement

From: 714'
To: 470'
Int: 244'
Material: Cement

From: 470'
To: 20'
Int: 450'
Material: Mud

From: 20'
To: 0'
Int: 20'
Material: Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
I-374	Rustler Formation	360
	Top of Salt	690
	Top of USGS 124 Bed	1399

COMMERCIALLY DRILLED BOREHOLE DATA BASE

BOREHOLE: **I-375**
OPERATOR: International Minerals & Chemical Corp.
PERMIT NO.: Potassium Prospecting Permit NM-0359161

LOCATION: 144' South 24 degrees East from Northwest Corner of Section 33, NW1/4 Section 33, Township 22 South, Range 31 East. NMPM

ELEVATION: 3390'
TOTAL DEPTH: 1746'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company

DRILLING RECORD: **Date Started:** 04/28/65 **Date Completed:** 05/13/65
Rotary Drill
6-1/4" Rockbit: 0-520'
3-7/8" Rockbit: 520-1300'
3-7/8" Corebit: 1300-1746'

WELL DEVELOPMENT:

CASING RECORD

4" Casing: 0-817'
Recovered: 0-129'

PLUGGING SCHEDULE

From: 1746'
To: 817'
Int: 929'
Material: Cement

From: 817'
To: 510'
Int: 307'
Material: Cement

From: 510'
To: 20'
Int: 490'
Material: Mud

From: 20'
To: 0'
Int: 20'
Material: Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
I-375	Rustler Formation	470
	Top of Salt	790
	Top of USGS 124 Bed	1602

BOREHOLE: **I-376**
OPERATOR: International Minerals & Chemical Corp.
PERMIT NO.: Potassium Prospecting Permit NM-0384583

LOCATION: 400' South 75 degrees East from Northwest Corner of Section 20, NW1/4 Section 20, Township 22 South, Range 31 East. NMPM

ELEVATION: 3410'
TOTAL DEPTH: 1702'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company

DRILLING RECORD: **Date Started:** 06/15/65 **Date Completed:** 06/23/65
Rotary Drill
6-1/4" Rockbit: 0-840'
3-7/8" Rockbit: 840-1328'
3-7/8" Corebit: 1328-1702'

WELL DEVELOPMENT:

CASING RECORD

4" Casing: 0-840'
Recovered: 0-840'

PLUGGING SCHEDULE

From: 1702'
To: 800'
Int: 902'
Material: Cement

From: 800'
To: 720'
Int: 80'
Material: Mud

From: 720'
To: 660'
Int: 60'
Material: Cement

From: 660'
To: 540'
Int: 120'
Material: Mud

From: 540'
To: 480'
Int: 60'
Material: Cement

From: 480'
To: 30'
Int: 450'
Material Mud

From. 30'
To: 0'
Int: 30'
Material: Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
I-376	Rustler Formation	500
	Top of Salt	840
	Top of USGS 124 Bed	1581

COMMERCIALLY DRILLED BOREHOLE DATA BASE

BOREHOLE: **I-377**
OPERATOR: International Minerals & Chemical Corp.
PERMIT NO.: Potassium Prospecting Permit NM-0384584

LOCATION: 105' South 48 degrees East from Northwest Corner of Section 22, NW1/4 Section 22, Township 22 South, Range 31 East. NMPM

ELEVATION: 3490'
TOTAL DEPTH: 1876'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Co.

DRILLING RECORD: **Date Started:** 06/26/65 **Date Completed:** 07/16/65
Rotary Drill
6-1/4" Rockbit: 0-996'
3-7/8" Rockbit: 996-1530'

WELL DEVELOPMENT:

CASING RECORD

4" Casing: 0-996'
Recovered: 0-996'

PLUGGING SCHEDULE

From: 1876'
To: 996'
Int: 880'
Material: Cement

From: 996'
To: 925'
Int: 71'
Material: Mud

From: 925'
To: 885'
Int: 40'
Material: Cement

From: 885'
To: 730'
Int: 155'
Material: Mud

From: 730'
To: 700'
Int: 30'
Material: Cement

From: 700'
To: 10'
Int: 690'
Material: Mud

From: 10'
To: 0'
Int: 10'
Material: Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
I-377	Rustler Formation	700
	Top of Salt	1014
	Top of USGS 124 Bed	1770

COMMERCIALLY DRILLED BOREHOLE DATA BASE

BOREHOLE: **I-456**
OPERATOR: International Minerals & Chemical Corp.
PERMIT NO.: Potassium Prospecting Permit NM-0384584

LOCATION: 300' from South Line and 2650' from East Line of Section 22, SW1/4 Section 22, Township 22 South, Range 31 East. NMPM

ELEVATION: 3520'
TOTAL DEPTH: 1975'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company

DRILLING RECORD: **Date Started:** 06/22/76 **Date Completed:** 07/07/76
Rotary Drill
6-1/4" Rockbit: 0-940'
3-7/8" Rockbit: 940-1580'
3-7/8" Corebit: 1580-1975'

WELL DEVELOPMENT:

CASING RECORD

4" Casing: Unknown
Recovered: All

PLUGGING SCHEDULE

From: 1975'
To: 0'
Int: 1975'
Material: Cement

COMMERCIALLY DRILLED BOREHOLE DATA BASE

BOREHOLE: **KSMITH**
OPERATOR: Mark Smith and Sons
PERMIT NO.:

LOCATION: 22.31.15.130a

ELEVATION: 3460'
TOTAL DEPTH: 167.3'
TYPE OF WELL:
DRILLER:

DRILLING RECORD: **Date Started:** **Date Completed:**
12"

WELL DEVELOPMENT:

Capped - Water Well

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
I-456	Rustler Formation	790
	Top of Salt	1080
	Top of USGS 124 Bed	1853

Energy Department
Wells Data Base

ENERGY DEPARTMENT WELLS DATA BASE

BOREHOLE: AEC-7
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1323

LOCATION: 2036.97' FNL, 2033.23' FEL
Sec. 31, T 21 S, R 32 E

ELEVATION: 3657.25' (Top of Casing)
TOTAL DEPTH: 4734'
TYPE OF WELL: Geological Exploration
DRILLER: Verna Drilling Company

DRILLING RECORD: **Date Started:** 03/20/74 **Date Completed:** 04/19/80

HOLE SIZE: 17 1/2": 0 to 40'
12 1/2": 40 to 1016'
7 7/8": 1016 to 4734'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade: H-40
Wt/Ft: 48
From: 0
To: 40
Cement:

Diameter: 8 5/8
Grade: H-40
Wt/Ft: 28
From: 0
To: 1016
Cement:

**********RECOMPLETION**********

1979, SNL deepened AEC-7 to 4720' to investigate the regional-formation-pressure distribution in the Bell Canyon Formation and to test borehole-plugging concepts. AEC-7 was completed open hole to 4455' and plugged with grout from 4455' to 4483'.

1980, the well was capped and remained unused until June 1988.

June 1988, AEC-7 was reentered by SNL and INTERA Technologies to reconfigure the well as a Culebra-dolomite observation well.

June 29, 1988, a Baker Service Tools inflatable, retrievable bridge plug was installed in AEC-7 at approximately 950'. After setting the bridge plug, 260 gallons of borehole fluid were air-lifted from the borehole. The Culebra dolomite interval in AEC-7 was shot-perforated at 4 shots/foot from 859' to 890'. Following perforation, a Baker Service Tools PIP was installed from 849' to 851' to prepare the well for bailing and/or swabbing to promote well development and hydrologic testing.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
AEC-7	Quaternary	
	Holocene-Eolian Sand	16.2-20.2
	Mescalero Caliche	20.2-24.2
	Triassic	
	Santa Rosa Sandstone	24.2-133.0
	Permian	
	Dewey Lake Red Beds	133.0-675.0
	Rustler Formation	675.0-1000.6
	Magenta Dolomite Member	733.5-767.0
	Culebra Dolomite Member	872.2-900.5
	Salado Formation	1000.6-3014.7
	Upper Member	1000.6-1505.1
	MB 101	1125.8
	MB 102	1158.5
	MB 103	1171.4-1186.5
	MB 104	1197.0
	MB 105	1211.5
	MB 106	1230.5
	MB 107	1269.0
	MB 108	1278.0
	MB 109	1303.8-1324.5
	MB 111	1378.0
	MB 112	1397.5
	MB 114	1450.5
	MB 116	1498.4
	McNutt Potash Zone	1505.1-1881.0
	Vaca Triste Sandstone	1505.1-1514.1
	MB 117	1578.9
	MB 118	1595.6
	MB 119	1619.8
	MB 121	1661.5
	MB 122	1668.5
	Union Anhydrite	1696.2-1705.0
	MB 123	1774.8-1781.2
	MB 124	1785.5-1795.5
	MB 126	1881.0
	Lower Member	1881.0-3104.7
	MB 128	1918.0
	MB 129	1943.9
	MB 131	2013.5
	MB 132	2039.0
	MB 133	2057.5
	MB 134	2097.0-2109.0
	MB 136	2161.0-2168.0
	MB 139	2267.5
	MB 140	2302.8-2314.2
	MB 141	2364.5
	MB 142	2400.2-2406.5
	MB 143	2453.0-2455.6
	Cowden Anhydrite	2520.0-2539.0

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
AEC-7	Castile Formation	3014.7-4535.3
	Anhydrite III	3014.7-3113.0
	Halite II	3113.0-3310.0
	Anhydrite II	3310.0-3506.9
	Halite II	3506.9-3588.2
	Anhydrite II	3588.2-4055.0
	Halite I	4055.0-4182.3
	Anhydrite I	4182.3-4535.5
	Bell Canyon Formation	4535.5-4731.9 (T.D.)
	Reef Talus	4535.5-4584.7
	Lamar Limestone	4584.7-4633.3
	Ramsey Sandstone	4633.3-4678.5
	Ford Shale	4678.5-4714.9
	Olds Sandstone	4714.9-4731.9

ENERGY DEPARTMENT WELLS DATA BASE

BOREHOLE: **AEC-8**
OPERATOR: Sandia National Labs
PERMIT NO.: Unkown

LOCATION: 935' FNL, 1979' FWL
Sec. 11, T 22 S, R 31 E

ELEVATION: 3532' (Top of Casing)
TOTAL DEPTH: 4922'
TYPE OF WELL: Geological Exploration
DRILLER: Sonora Drilling Company

DRILLING RECORD: **Date Started:** 06/28/76 **Date Completed:** 08/05/76

HOLE SIZE: 17 1/2": 0 to 42'
12 1/4": 42 to 886'
7 7/8": 886 to 4922'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 54.5
From: 0
To: 42
Cement:

Diameter: 8 5/8
Grade:
Wt/Ft: 28
From: 0
To: 885
Cement: 660 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 4919
Cement: 2481 Cu. Ft.

Completed logging. Ran 7 7/8" bit in the hole and conditioned mud to run casing. Corrected total depth to 4922'. Laid down drill pipe. Ran 123 joints (4933.72') of 5 1/2" O.D., 15.50#, J-55, range 3, ST&C casing in the hole and landed at 4918.77' (4907.22' GL). A Halliburton guide shoe was on bottom with a float shoe at 4859.52' GL. Centralizers were placed at 4905' GL, 4827' GL, 800' GL and 50' GL. 38 joints (1533.25') of casing were sand blasted for better bond from 2374' to 4907' KB.

Completed running casing. Cemented annulus using Halliburton with 1500 sacks (2085 cu ft) of 50-50 Pozmix "C" with 9.7 #/sk of salt and 2% bentonite followed by 300 sacks (396 cu ft) of Class "C" cement. Displaced cement with 117 barrels of water. Casing was reciprocated during displacement. After displacing 90 barrels approximately 2 barrels of cement circulated to the surface, circulation was lost at this point. Bumped plug with 2000 psi and held. Cement in place at 0220 hours. Ran Dresser Atlas temperature log, top of cement at 880'. Ran Sperry-Sun gyroscopic multishot survey in the hole on 25' stations and 100' stations out of the hole.

All depths are measured from Kelly Bushing 11.5' above ground level.

Currently used as a Bell Canyon Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
AEC-8	Quaternary: Holocene-Eolian Sand	9.0-29.0
	Mescalero Caliche	29.0-35.0
	Triassic	
	Santa Rosa Sandstone	35.0-177.4
	Permian	
	Dewey Lake Red Beds	177.4-668.0
	Rustler Formation	668.0-990.0
	Magenta Dolomite Mem	727.3-749.5
	Culebra Dolomite Mem	848.3-873.3
	Salado Formation	990.0-2979.6
	Upper Member	990.0-1469.3
	MB 101	1101.0-1116.5
	MB 102	1146.7
	MB 103	1157.7-1173.7
	MB 104	1184.4
	MB 105	1197.6
	MB 106	1215.3
	MB 107	1240.5
	MB 108	1261.3
	MB 109	1286.1-1304.7
	MB 111	1351.9
	MB 112	1370.4
	MB 113	1398.7
	MB 114	1418.2
	MB 115	1451.3
	MB 116	1462.5
	McNutt Potash Zone	1469.3-1826.5
	Vaca Triste Sands	1469.3-1484.1
	MB 117	1535.4
	MB 118	1557.0
	MB 119	1580.5
	MB 120	1603.2
	MB 121	1622.0
	MB 122	1628.6
	Union Anhydrite	1648.0-1657.9
	MB 123	1733.5
	MB 124	1746.8
	MB 126	1826.5
	Lower Member	1826.5-2979.6
	MB 127	1849.5
	MB 128	1861.5
	MB 129	1885.3
	MB 130	1894.7
	MB 131	1959.6
	MB 132	1989.0
	MB 133	2005.5
	MB 134	2047.9-2060.5
	MB 135	2076.0
	MB 136	2114.0-2128.3
	MB 137	2138.5

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
AEC-8	MB 138	2187.4
	MB 139	2247.8
	MB 140	2309.1-2316.5
	MB 141	2369.1
	MB 142	2411.8-2419.6
	MB 143	2465.2-2472.7
	MB 144	2498.8-2510.9
	Cowden Anhydrite	2539.5-2561.6
	Castile Formation	2979.6-4315.0
	Anhydrite III	2979.6-3290.0
	Halite II	3290.0-3555.0
	Anhydrite II	3555.0-3695.5
	Halite I	3695.5-4038.0
	Anhydrite I	4038.0-4315.0
	Bell Canyon Formation	4315.0-4918.0 (T.D.)
	Lamar Limestone	4344.5-4374.0
	Ramsey Sand	4374.0-4436.0
	Ford Shale	4436.0-?

ENERGY DEPARTMENT WELLS DATA BASE

BOREHOLE: **DOE-1**
OPERATOR: Westinghouse
PERMIT NO.: Unknown

LOCATION: 182.4' FSL, 607.8' FEL
Sec. 28, T 22 S, R 31 E

ELEVATION: 3465.22' (Top of Casing)
TOTAL DEPTH: 4057.3'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Salazar Bros. Drilling Co.

DRILLING RECORD: **Date Started:** 07/14/82 **Date Completed:** 07/28/82

HOLE SIZE: >20": 0 to 49'
14 3/4": 49 to 1122.5'
7 7/8": 1122.5 to 4053.3'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 3/4 O.D.
Grade:
Wt/Ft:
From: 0
To: 41
Cement: Set and cemented

Diameter: 10 3/4 O.D.
Grade: J-55
Wt/Ft: 40.5
From: 41
To: 1123
Cement: Set and cemented

Diameter: 7 7/8
Grade:
Wt/Ft:
From: 1126.2
To: 4057
Cement: Uncased

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
DOE-1	Quaternary	
	Eolian Sand	Not Described
	Gatuna Formation	Not Described
	Triassic	
	Santa Rosa Sandstone	46.0-133.0
	Permian	
	Dewey Lake Red Beds	133.0-667.5
	Rustler Formation	667.5-976.5
	Magenta Dolomite Member	722.0-745.0
	Culebra Dolomite Member	828.6-850.5
	Salado Formation	976.5-2936.5
	Upper Member	976.5-1486.0
	MB 101	1102.0
	MB 102	1138.5
	MB 103	1159.0-1169.0
	MB 105	1199.0
	MB 106	1216.0
	MB 107	1254.0
	MB 108	1263.0
	MB 109	1286.0-1309.5
	MB 111	1361.3
	MB 112	1379.8
	MB 113	1406.9
	MB 114	1429.3
	MB 115	1465.8
	MB 116	1477.6
	McNutt Potash Zone	1486.0-1880.3
	Vaca Triste Sandstone	1486.0-1489.8
	MB 117	1557.2
	MB 118	1582.6
	MB 119	1608.0
	MB 120	1632.0
	MB 121	1646.5
	MB 122	1656.0
	Union Anhydrite	1681.4-1694.0
	MB 123	1762.0-1769.9
	MB 124	1773.0-1783.8
	MB 126	1880.3
	Lower Member	1880.3-2936.5
	MB 127	1907.4
	MB 128	1919.7
	MB 129	1944.3
	MB 130	1956.7
	MB 131	2025.8
	MB 132	2056.6
	MB 133	2076.0
	MB 134	2117.0-2130.0
	MB 135	2149.4
	MB 136	2192.1-2197.1
	MB 137	2209.2

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
DOE-1	MB 138	2264.0
	MB 139	2323.7
	MB 140	2374.5-2389.0
	MB 141	2457.0
	MB 142	2497.0-2512.0
	MB 143	2563.5-2570.5
	MB 144	2606.0-2621.5
	Cowden Anhydrite	2647.8-2677.0
	Castile Formation	2936.5 (T.D.)
	Anhydrite III	2936.5-3374.8
	Halite II	3374.8-3600.0
	Anhydrite II	3600.0-3708.3
	Halite I	3708.3-4032.3
	Anhydrite I	4032.3-(T.D.)

ENERGY DEPARTMENT WELLS DATA BASE

BOREHOLE: **DOE-2**
OPERATOR: U.S. Department of Energy
PERMIT NO.: 0.08.1467 (State Engineers Office)

LOCATION: 704.07' FSL, 128.19' FEL
Sec. 8, T 22 S, R 31 E

ELEVATION: 3419.09' (Top of Casing)
TOTAL DEPTH: 4325'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Unkown

DRILLING RECORD: **Date Started:** 09/08/84 **Date Completed:** 09/18/84

HOLE SIZE: 12 1/4": 0 to 1009'
7 7/8": 1009 to 4325'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9.625
Grade: J-55
Wt/Ft: 36
From: 0
To: 1009
Cement:

Diameter: 13 3/8 O.D.
Grade: H-40
Wt/Ft: 48#
From: 0
To: 39
Cement: Cemented with 81 Cu. Ft.

**********RECOMPLETION**********

April 2, 1986, the Culebra-dolomite interval was perforated.

April 1, 1986, the PIP was released and removed from the well. During removal the 6 5/8" packer element was stripped off the packer mandrel (probably in the Salado Formation interval from 1400' to 1700').

April 2, 1986, the well was re-entered and a Baker 7 1/8" Inflatable Bridge Plug was set at 875'. Natural-gamma and casing-collar-locator geophysical logs were used to determine the location of the Culebra-dolomite. The 9 5/8" casing was shot-perforated from 822' to 848' with 1/2" bullets at 4 shots/foot.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
DOE-2	Quaternary	
	Holocene-Dune Sand	0-8
	Pleistocene-Mescalero Caliche	8-13
	Triassic	
	Santa Rosa Sandstone	13-133.3
	Permian	
	Dewey Lake Red Beds	133.3-639.1
	Rustler Formation	639.1-698.6
	Forty-Niner Member	698.6-722.4
	Magenta Dolomite Member	722.4-823.7
	Tamarisk Member	823.7-846.0
	Culebra Dolomite Member	846.0-960.9
	Unnamed Lower Member	
	Salado Formation	960.9-3082.8
	Upper Member	960.9-1448.7
	MB 101	1080.3-1084.2
	MB 102	1116.6-1117.7
	MB 103	1130.4-1143.5
	MB 104	1154.7-1155.1
	MB 105	1170.8-1171.8
	MB 106	Not Present
	MB 107	1228.0-1228.4
	MB 108	1237.5-1238.1
	MB 109	1260.0-1283.5
	MB 110	Not Present
	MB 111	1330.8-1331.0
	MB 112	1347.0-1349.2
	MB 113	1372.4-1372.9
	MB 114	1394.3-1394.8
	MB 115	1427.7-1430.6
	MB 116	1439.3-1441.4
	McNutt Potash Zone	1448.7-1827.4
	Vaca Triste Sandstone	1448.7-1456.1
	MB 117	1510.0-1511.9
	MB 118	1533.6-1534.7
	MB 119	1556.8-1557.9
	10th Ore Zone	1574.0-1580.0
	MB 120	1581.4-1581.8
	9th Ore Zone	1580-1584(EST.)
	MB 121	1598.5-1599.8
	MB 122	1606.6-1607.5
	8th Ore Zone	1611.1-1619.3
	Union Anhydrite	1630.1-1637.9
	MB 123	1716.5-1721.9
	MB 124	1728.8-1738.4
	4th Ore Zone	1746.0-1748.5
	3rd Ore Zone	1766-1774(EST.)
	2nd Ore Zone	1780-1782.5(EST.)
	MB 125	Not Present
	MB 126	1825.9-1827.4

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
DOE-2	Lower Member	1827.4-3082.8
	MB 127	1852.7-1853.8
	MB 128	1864.5-1865.5
	MB 129	1889.9-1891.9
	MB 130	1901.8-1902.0
	MB 131	1971.2-1971.7
	MB 132	1999.7-2001.2
	MB 133	2018.8-2021.7
	MB 134	2069.3-2081.0
	MB 135	2099.8-2100.5
	MB 136	2144.9-2157.3
	MB 137	Not Present
	MB 138	2203.1
	MB 139	2303.3-2306.3
	MB 140	2372.1-2388.0
	MB 141	2450.1-2454.5
	MB 142	2503.6-2517.9
	MB 143	2566.4-2571.6
	MB 144	2603.6-2615.7
	Cowden Anhydrite	2644.5-2669.5
	Castile Formation	3082.8-4071.4
	Anhydrite III	3082.8-3801.1
	Halite II	Not Present
	Anhydrite II	?
	Halite I	3801.1-3809.2
	Anhydrite I	3809.2-4071.4
	Delaware Mountain Group	
	Bell Canyon Formation	4071.4-4325+
	Lamar Limestone Member	4071.4-4103.4
	Ramsey Sand	4103.4-4174.0
	Ford Shale	4174.0-4182.8
	Olds Sand	4182.8-4218.2(?)
	Hays Sand	4218.2(?)-4248+

ENERGY DEPARTMENT WELLS DATA BASE

BOREHOLE: **ERDA-6**
OPERATOR: Sandia National Labs
PERMIT NO.: Unkown

LOCATION: 2152' FSL, 910' FEL
Sec. 35, T 21 S, R 31 E

ELEVATION: 3540.2' (Top of Casing)
TOTAL DEPTH: 2775'
TYPE OF WELL: Geologic Exploration
DRILLER: Boyles Bros. Drilling Company: 06/11/75 to 08/15/75 - Pan AM Dri

DRILLING RECORD: **Date Started:** *06/13/75* **Date Completed:** *09/23/75*

HOLE SIZE: 17 1/4": 0 to 30'
12 1/4": 30 to 883'
7 7/8": 883 to 2775'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 54.5
From: 0
To: 30
Cement: Ready Mix

Diameter: 8 5/8
Grade: K-55
Wt/Ft: 24
From: 0
To: 880
Cement: 575 SX

Plugged back 2773' to 2560' with 225 sacks of cement. Hole filled with brine.

Plugged and abandoned.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
ERDA-6	Quaternary	
	Holocene-Eolian Sand	0-9
	Mescalero Caliche	9-17
	Triassic	
	Santa Rosa Sandstone	17-72
	Permian	
	Dewey Lake Red Beds	72-538
	Rustler Formation	538-811
	Dissolution Residue	570-581
	Magenta Dolomite Member	598-623
	Dissolution Residue	696-707
	Culebra Dolomite Member	713-739
	Dissolution Residue	742-762
	Salado Formation	811-2396.5
	Upper Unit	811-1276.6
	MB 100	NR
	MB 101	923.5-929.9
	MB 102	956.8-958.2
	MB 103	970.3-984.3
	MB 104	992.1-992.4
	MB 105	NR
	MB 106	NR
	MB 107	1060.0-1060.9
	MB 108	1069.1-1069.9
	MB 109	1090.9-1113.5
	MB 110	NP
	MB 111	1161.5-1161.8
	MB 112	1178.9-1180.2
	MB 113	NP
	MB 114	1224.9-1226.9
	MB 115	1256.1-1257.2
	MB 116	1268.7-1271.4
	McNutt Potash Zone	1276.6-1612.9
	Vaca Triste Sandstone	1276.6-1287.3
	11th Ore Zone	1324.7-1329.8
	MB 117	1340.7-1342.7
		1346-1349.0
	MB 118	1359.0-1366.2
	MB 119	1378.4-1379.4
	10th Ore Zone	1386.1-1395.5
	MB 120	1401.0-1402.3
	9th Ore Zone	1403.2-1410.3
	MB 121	1413.3-1415.5
	MB 122	1422.3-1424.3
	8th Ore Zone	1424.9-1437.0
	Union Anhydrite	1444.6-1453.8
	7th Ore Zone	1464.0-1468.5
	6th Ore Zone	1479.7-1482.2
	5th Ore Zone	1487.8-1494.9
	MB 123	1517.7-1524.9

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
ERDA-6	MB 124	1529.4-1537.5
	4th Ore Zone	1541.9-1549.1
		1549.7-1553.0
	3rd Ore Zone	1555.5-1567.2
	2nd Ore Zone	1571.0-1574.3
	MB 125	NP
	1st Ore Zone	1587.0-1603.3
	MB 126	NP
	Lower Member	1612.9-2396.5
	MB 127	1635.0-1635.7
	MB 128	1647.7-1648.5
	MB 129	1670.0-1671.5
	MB 130	NP
	MB 131	1743.0-1743.7
	MB 132	1770.6-1771.4
	MB 133	1785.6-1789.2
	MB 134	1833.2-1843.4
	MB 135	1860.4-1861.5
	MB 136	1900.5-1910.5
	MB 137	NP
	MB 138	1967.5-1967.7
	MB 139	2019.5-2022.4
	MB 140	2060.4-2075.6
	MB 141	2124.5-2126.6
	MB 142	2163.8-2169.5
	MB 143	2212.7-2215.6
	MB 144	2237.0-2237.7
	Cowden Anhydrite	2269.5-2291.0
	Castile Formation	2400.5-2775.0
	Halite II	2400.5-2555.1
	Anhydrite II	55.1-2732.5 (Fault or Rupture Zone)
	Halite I	2732.5-2775.0
	Cowden Anhydrite	2540.0-2653.0
	Castile Formation	2836.0-2889.0

ENERGY DEPARTMENT WELLS DATA BASE

BOREHOLE: **ERDA-9**
OPERATOR: Sandia National Labs
PERMIT NO.: Unknown

LOCATION: 267.17' FSL, 176.74' FEL
Sec. 20, T 22 S, R 31 E

ELEVATION: 3410.10' (Top of Casing)
TOTAL DEPTH: 2886'
TYPE OF WELL: Geologic Exploration
DRILLER: Sonora Drilling Company

DRILLING RECORD: **Date Started:** 04/28/76 **Date Completed:** 06/26/76

HOLE SIZE: Excavated: 0 to 5'
20": 5 to 40'
15": 51 to 1049'
9 7/8": 1049 to 2886'

WELL DEVELOPMENT:

Diameter: 16
Grade:
Wt/Ft:
From: 0
To: 40
Cement: 95 Cu. Ft.

Diameter: 10 3/4
Grade: J-55
Wt/Ft: 40.5
From: 0
To: 1045
Cement: 1159 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 2883
Cement: Mud Pack

Ran Dresser Atlas caliper log. Ran 79 joints (2889.66') of 7" O.D., 23# casing with a Dowell swirl type shoe on bottom and a Dowell orifice fill collar on top of the bottom joint. Set casing at 2882.66' with centralizers at 2868', 2520', and 1030'. Rigged up Dowell and pumped in 140 barrels of Baroid casing pack mud. Cemented annulus with 10 barrels of water, 12 barrels of chemical wash, 12 barrels of oil base slurry ahead of 122 cu. ft. (115 sacks) of Class "H" cement + 3% calcium chloride. Seated plug with 1000 psi, plug holding. Cement in place at 1445 hours.

All depths are measured from Kelly Bushing 11.5' above ground level.

**********RECOMPLETION**********

October 1, 1986, cut the 7" casing in ERDA-9 at 980' with an explosive charge and removing the cut casing from the borehole. A 7" retrievable bridge plug was then installed inside 10 3/4" casing from 760.15' to 761.90' below top of wellhead.

October 4, 1986, ERDA-9 was flushed with 300 barrels of freshwater, washed twice with 150 barrels of freshwater mixed with 25 gallons of MilChem-MD (a degreaser), and rinsed with 300 barrels of freshwater to remove remnant oil-emulsion drilling fluid that

was left in the well after the original well completion.

October 20-21, 1996, the borehole fluid was bailed and pumped to a depth of 511'. The remaining fluid was left in the borehole to provide a fluid cushion for the perforation tool and to provide a post-perforation underpressure on the formation to help stimulate flow from the formation to the borehole.

October 22, 1986, the 10 3/4" casing in ERDA-9 was perforated across the Culebra-dolomite interval between 705.5' and 728.5' with 15/32" jet shots at 4 shots/foot.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
ERDA-9	Kelly Bushing (KB) to Land Surface (LS)	0-12.0
	Holocene Deposits	12.0-22.0
	Pleistocene Rocks	
	Mescalero Caliche	22.0-27.0
	Gatuna Formation	27.0-54.0
	Triassic	
	Santa Rosa Sandstone	54.0-63.0
	Permian	
	Dewey Lake Red Beds	63.0-550.0
	Rustler Formation	550.0-860.0
	Dissolution Residue	580.0-592.0
	Magenta Dolomite Member	608.0-632.0
	Dissolution Residue	691.0-710.0
	Culebra Dolomite Member	716.0-739.0
	Dissolution Residue	742.0-748.0
	Salado Formation	860.0-2836.0
	Upper Member	860.0-1362.0
	MB 100	939.0
	MB 101	984.0
	MB 102	1026.0
	MB 103	1040.0-1050.0
	MB 104	1061.0
	MB 105	1075.0
	MB 106	1093.0-1094.0
	MB 107	1132.0
	MB 108	1142.0
	MB 109	1165.0-1188.0
	MB 110	NP
	MB 111	1238.0
	MB 112	1256.0-1258.0
	MB 113	1282.0-1284.0
	MB 114	1306.0
	MB 115	1340.0-1344.0
	MB 116	1354.0-1356.0
	McNutt Potash Zone	1362.0-1742.0
	Vaca Triste Sands	1365.0-1367.0
	11th Ore Zone	1420.0-1422.0
	MB 117	1431.0-1433.0
	MB 118	1455.0-1463.0
	MB 119	1482.0
	10th Ore Zone	1487.0-1493.0
	MB 120	1501.0-1502.0
	9th Ore Zone	1507.0-1512.0
	MB 121	1515.0-1517.0
	MB 122	1524.0
	8th Ore Zone	1531.0-1542.0
	Union Anhydrite	1549.0-1557.0
	7th Ore Zone	1572.0-1576.0
	6th Ore Zone	1590.0-1593.0
	5th Ore Zone	1597.0-1603.0

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
ERDA-9	MB 123	1630.0-1637.0
	MB 124	1645.0-1653.0
	4th Ore Zone	1659.0-1669.0
	3rd Ore Zone	1676.0-1688.0
	2nd Ore Zone	1696.0-1698.0
	MB 125	NP
	1st Ore Zone	1712.0-1723.0
	MB 126	1742.0
	Lower Member	1742.0-2836.0
	MB 127	1768.0-1770.0
	MB 128	1778.0-1781.0
	MB 129	1803.0-1805.0
	MB 130	1815.0
	MB 131	1884.0
	MB 132	1914.0-1915.0
	MB 133	1933.0-1935.0
	MB 134	1976.0-1989.0
	MB 135	2006.0
	MB 136	2043.0-2058.0
	MB 137	2075.0
	MB 138	2120.0-2121.0
	MB 139	2177.0-2180.0
	MB 140	2241.0-2251.0
	MB 141	2320.0-2330.0
	MB 142	2377.0-2391.0
	MB 143	2450.0-2456.0
	MB 144	2493.0-2506.0
	Cowden Anhydrite	2540.0-2653.0
	Castile Formation	2836.0-2889.0

ENERGY DEPARTMENT WELLS DATA BASE

BOREHOLE: **ERDA-10**
OPERATOR: Sandia National Labs
PERMIT NO.: Unknown

LOCATION: 200' FNL, 2327' FEL
Sec. 34, T 23 S, R 30 E

ELEVATION: 3371.2' (Top of Casing)
TOTAL DEPTH: 4418.5'
TYPE OF WELL: Geologic Exploration
DRILLER: Corel Drilling Company

DRILLING RECORD: **Date Started:** 08/18/77 **Date Completed:** 10/14/77

HOLE SIZE: 18": 0 to 53'
12 1/4": 53 to 805'
7 7/8": 805 to 4431.5'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade: H-40
Wt/Ft: 48
From: 0
To: 50
Cement: 81 Cu. Ft.

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 805
Cement: 554 Cu. Ft.

Hole plugged to surface.
All depths are measured from Kelly Bushing 13' above ground level.

PLUGGING SCHEDULE

10/01/77 - Made trip with 7 7/8" bit and conditioned hole. Ran 2 3/8" O.D. tubing in the hole and plugged back hole using Dowell with 10 barrels of water ahead of 48 barrels of mud wash followed by 414 cu. ft. of class "C" cement with 2% calcuim chloride. Displace cement with 12.5 barrels of water. Cement in place at 1300 hours. Pulled tubing and waited on cement.

10/03/77 - Made trip with 7 7/8" bit and tagged cement at 3556', conditioned hole. Made up 7 13/16" core bit and cut core #32 from 3556' to 3595', recovered 10' of cement. Cut core #33 from 3595' to 3623', recovered 20' of cement. Cut core #34 from 3623' to 3630'.

10/04/77 - Completed core #34 from 3630' to 3673', recovered 27' of cement. Ran 2 7/8" O.D. tubing in the hole to 3673'. Cemented plug #2 using Dowell with 10 barrels of water ahead of 84 barrels of mud flush followed by 10 barrels of water ahead of 1040 cu. ft. of 70% class "C" cement and 30% Litepoz. Cement in place at 1140 hours. Pulled tubing to 2300' and curculated hole. Waited on cement. Laid down drill pipe.

10/05/77 - Waited on cement to 0900 hours. Tagged top of plug #2 at 2335' with tubing. Cemented plug #3 with 10 barrels of water 60 barrels of mud flush and 10 barrels of water, ahead of 1039 cu. ft. of cement slurry. Cement in place at 1420 hours. Pulled tubing to 803' and circulated out mud flush and cement. Waited on cement.

10/06/77 - Tagged top of plug #3 at 827'. Cemented plug #4 to surface with 10 barrels of water, 1000 gallons of mud flush and 10 barrels of water ahead of 417 cu. ft. of cement slurry. Cement in place at 0050 hours. Rigged down government furnished equipment and released rig at 1600 hours.

10/14/77 - Cement had dropped to 11.5' inside the 9 5/8" O.D. casing. Cemented to surface with 6 sacks of cement. Hole plugged 10/14/77.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
ERDA-10	Quaternary	
	Holocene-Eolian Sand	
	Mescalero Caliche	13.0-17.0
	Triassic	
	Gatuna Formation	17.0-164.0
	Permian	
	Dewey Lake Red Beds	164.0-378.0
	Rustler Formation	378.0-640.0
	Magenta Dolomite Member	378.0-379.0
	Culebra Dolomite Member	489.0-517.0
	Salado Formation	640.0-2350.0
	Upper Member	640.0-1078.0
	MB 101	696.0
	MB 102	743.0
	MB 103	775.0-783.5
	MB 104	794.5
	MB 105	807.0
	MB 106	817.0
	MB 107	829.0
	MB 108	852.5
	MB 109	879.5-904.5
	MB 111	960.0
	MB 112	978.0
	MB 113	1018.0
	MB 114	1035.0
	MB 115	1068.0
	MB 116	1076.0
	McNutt Postash Zone	1087.0-1521.5
	Vaca Triste Sands	1087.0-1092.5
	MB 117	1162.0
	MB 118	1189.0
	MB 119	1225.0
	MB 121	1264.0
	MB 122	1279.5
	Union Anhydrite	1310.0-1330.0
	MB 123	1380.5-1387.0
	MB 124	1399.5-1407.5
	MB 125	1482.5
	MB 126	1521.5
	Lower Member	1521.5-2350.0
	MB 128	1556.0
	MB 129	1590.0
	MB 130	1604.0
	MB 131	1674.5
	MB 132	1704.5
	MB 133	1722.0
	MB 134	1771.5-1781.0
	MB 135	1807.0
	MB 136	1855.0-1864.5
	MB 138	1930.0

Geologic Exploration Borehole Data Base

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-11**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.994 (State Engineer's Office)

LOCATION: 711.80' FNL, 294.08' FWL
Sec. 9, T 22 S, R 31 E

ELEVATION: 3426.07'
TOTAL DEPTH: 3580'
TYPE OF WELL: Geologic Exploration
DRILLER: Verna Drilling Company

DRILLING RECORD: **Date Started:** 02/06/78 **Date Completed:** 03/14/78

HOLE SIZE: Excavated: 0 to 5'
18": 5 to 40.4'
12 1/4": 40.4 to 985'
8 3/4": 985 to 3580'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade: H-40
Wt/Ft: 48
From: 0
To: 40
Cement: 81 Cu. Ft.

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 985
Cement: 656 Cu. Ft.

Hole plugged and abandoned by DOE/Sandia.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-11	MB 136-T	1978.5
	MB 136-B	1978.5-1986.0
	MB 138-T	1986-2025.0
	MB 138-B	2025-2027
	Anhydrite A	Not Encountered
	Anhydrite B	Not Encountered
	MB 139-T	2061.0
	MB 139-B	2061-2064
	MB 140-T	2064-2092
	MB 140-B	2092-2105

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-12**
OPERATOR: Westinghouse
PERMIT NO.: Unknown

LOCATION: 149.4' FSL, 80.4' FEL
Sec. 17, T 22 S, R 31 E

ELEVATION: 3472.06 (Top of Casing)
TOTAL DEPTH: 3927.5'
TYPE OF WELL: Geologic Exploration
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 11/17/78 **Date Completed:** 12/07/78

HOLE SIZE: 18": 0 to 38.6'
12 1/4": 38.6 to 1001.5'
7 7/8": 1001.5 to 3005'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: H-40
Wt/Ft: 32.3
From: 39
To: 1001.8
Cement: 475 Cu. Ft.

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 39
Cement: 475 Cu. Ft.

Diameter: 9 5/8
Grade: H-40
Wt/Ft: 32
From: 39
To: 1013
Cement: 475 Cu. Ft.

Hole loaded with brine based mud pending further tests. All depths are measured from Kelly Bushing 12.2 ft. above ground level.

**********RECOMPLETION**********

1981-1982, WIPP-12 was deepened through the Castile Formation to a total depth of 3927.5' using brine with a brine-gel clay additive as a drilling fluid (Black 1982). During the deepening, a pressurized brine reservoir was encountered in the Castile Formation at a depth of 3016'.

1983, the brine reservoir was sealed from the upper part of the borehole by installing a borehole plug from 2784' to 3000'. The borehole plug consisted of a bridge plug covered by 27' of sand and 189' of cement (D'Appolonia, 1983).

Well capped until August 1985, when drill-stem testing of the Castile and Salado Formations was performed by Sandia National Laboratories from August to September, 1985 (Beauheim, 1987a).

Following testing, a retrievable bridge plug was set in the casing below the Culebra-dolomite interval. The Culebra was then shot-perforated on October 14, 1985 from 815' to 840' and left open for Culebra groundwater level surveillance.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-12	Quaternary Deposits	
	Sand (Holocene-eolian)	0-16.2
	Mescalero Caliche	16.2-19.2
	Gatuna Formation	19.2-28.8
	Triassic Rocks	
	Santa Rosa Sandstone	28.8-167.0
	Permian Rocks	
	Dewey Lake Red Beds	167.0-640.0
	Rustler Formation	640.0-966.0
	Magenta Dolomite Member	703.9-727.0
	Culebra Dolomite Member	822.0-846.8
	Salado Formation	966.0-2737.5
	Upper Member	966.0-1444.0
	MB 101	1084.5
	MB 102	1116.0
	MB 103	1130.0-1141.0
	MB 104	1150.0
	MB 105	1167.6
	MB 106	1183.5
	MB 107	1223.5
	MB 108	1232.5
	MB 109	1254.0-1278.0
	MB 111	1324.0
	MB 112	1338.0-1342.0
	MB 113	1367.0
	MB 114	1389.0
	MB 115	1424.5
	MB 116	1436.0
	McNutt Member	1444.0-1798.0
	Vaca Triste Sandstone Member	1444.0-1447.0
	MB 117	1507.5
	MB 118	1531.0
	MB 119	1552.0-1556.5
	MB 120	1575.0
	MB 121	1588.0
	MB 122	1596.0
	Union Anhydrite	1617.0-1625.0
	MB 123	1695.0-1700.8
	MB 124	1708.0-1715.4
	MB 126	1798.0
	Lower Member	1798.0-2737.5
	MB 127	1825.0
	MB 128	1834.0
	MB 129	1856.0
	MB 130	1867.0
	MB 131	1928.0
	MB 132	1957.5

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-12	MB 133	1976.0
	MB 134	2015.0-2025.0
	MB 135	2040.0
	MB 136	2071.6-2083.1
	MB 138	2135.1
	MB 139	2184.9
	MB 140	2226.1-2238.1
	MB 141	2290.0-2296.0
	MB 142	2332.0-2344.0
	MB 143	2381.5-2387.6
	MB 144	2413.5-2423.9
	Cowden Anhydrite	2445.5-2471.0
	Castile Formation	2337.5-T.D.
	DEEPENED PORTION OF WIPP-12	
	Castile Formation	2776.0-T.D.
	Anhydrite III Member	2776.0-3053.9
	Halite II Member	3053.9-3281.8
	Anhydrite II Member	3281.8-3391.0
	Halite I Member	3391.0-3901.6
	Anhydrite I Member	3901.6-T.D.

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-13**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.09.1182 (State Engineer's Office)

LOCATION: 2565.68' FSL, 1730.59' FWL
Sec. 17, T 22 S, R 31 E

ELEVATION: 2565.68' (Top of Casing)
TOTAL DEPTH: 3856'
TYPE OF WELL: Geologic Exploration
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 07/26/78 **Date Completed:** 10/05/79

HOLE SIZE: 15": 0 to 66'
12 1/4": 66 to 846'
7 7/8": 846 to 3856'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 35.5
Cement: 108 Cu. Ft.

Diameter: 9 5/8
Grade:
Wt/Ft: 36
From: 0
To: 1023
Cement: 665 Cu. Ft.

Hole loaded with brine based mud pending further test and/or plugging. All depths are measured from Kelly Bushing 12.2 ft. above ground except cores between 570 and 878 ft. and Schlumberger logs which were measured from ground level.

**********RECOMPLETION**********

WIPP -13 was left filled with a brine-gel drilling fluid, capped, and left open hole through the Salado and Castile Formations until 1985.

July 1985, a valve and nipple apparatus was attached to the bull plug fitting of the WIPP-13 wellhead.

July 2 to October 4, 1995, measured pressure.

July 12, 1985, pressure was completely released by opening a valve on the wellhead.

July 30, 1985, closed valve.

October 4, 1985, the wellhead pressure was 404 psi immediately before opening the wellhead for workover activities associated with the casing perforation. A retrievable bridge plug was then set in the casing below the Culebra-dolomite interval.

October 26, 1985, the Culebra was shot perforated from 702' to 727' and left open for Culebra groundwater level surveillance.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-13	Quaternary Deposits	0-13
	Triassic Rocks	
	Santa Rosa Sandstone	13-66
	Permian Rocks	
	Dewey Lake Red Beds	66-517
	Rustler Formation	517-846
	Dissolution Residue	543-550
	Magenta Dolomite Member	565-583
	Dissolution Residue	679-686
	Culebra Dolomite Member	703-726
	Dissolution Residue	730-735
	Top of Highest Salt in Section	745
	Salado Formation	846-1025
	Upper Member	846-1025
	MB 101	967
	MB 102	1003
	MB 103	1018
	DEEPENED PORTION OF WIPP-13 (Distance below K.B.)	
	Permian Rocks	
	Salado Formation	858.0-2971.6
	Upper Member	858.0-1356.7
	MB 103	1030.0-1042.3
	MB 104	1069.8
	MB 105	1091.0
	MB 106	1111.0
	MB 107	1128.0
	MB 108	1136.1
	MB 109	1161.0-1185.0
	MB 111	1232.8
	MB 112	1250.0
	MB 113	1277.9
	MB 114	1300.9
	MB 115	1338.3
	MB 116	1350.0
	McNutt Member	1356.7-1730.4
	Vaca Triste Sandstone Member	1356.7-1359.0
	MB 117	1426.5
	MB 118	1451.5
	MB 119	1478.2
	MB 120	1497.0
	MB 121	1513.8
	MB 122	1522.0
	Union Anhydrite	1542.0-1550.0
	MB 123	1628.0
	MB 124	1644.7
	MB 126	1730.4
	Lower Member	1730.4-2971.6

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-13	MB 127	1757.8
	MB 128	1770.0
	MB 129	1794.0
	MB 130	1804.5
	MB 131	1873.6
	MB 132	1902.0
	MB 133	1924.0
	MB 134	1968.9-1980.6
	MB 135	1996.8
	MB 136	2033.0-2048.0
	MB 137	2063.0
	MB 138	2110.2
	MB 139	2168.3
	MB 140	2221.0-2232.9
	MB 141	2294.6
	MB 142	2341.5-2355.0
	MB 143	2409.0-2417.0
	MB 144	2460.4
	Cowden Anhydrite	2493.9-2521.6
	Castile Formation	2971.6-3861.6+ (T.D.)
	Anhydrite III	2971.6-3518.7
	Halite II	3518.7-3638.0
	Anhydrite II	3638.0-3727.5
	Halite I	3727.5-3821.0
	Anhydrite I	3821.0-3861.6+ (T.D.)

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-14**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1458 (State Engineer's Office)

LOCATION: 98.57' FSL, 2112.08' FEL
Sec. 9, T 22 S, R 31 E

ELEVATION: 3429' (G.L.)
TOTAL DEPTH: 1000'
TYPE OF WELL: Geologic Exploration
DRILLER: Boyles Brothers Drilling

DRILLING RECORD: **Date Started:** 05/02/81 **Date Completed:** 06/08/81

HOLE SIZE: 8 3/4": 0 to 110.4'
7 5/8": 110.4 to 111.4'
6 1/8": 111.4 to 1000'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7 5/8
Grade: J-55
Wt/Ft: 23
From: 0
To: 111
Cement: 2 sacks

Plugged and abandoned by DOE.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-14	Quaternary Rocks	
	Sand (Holocene-eolian)	0-15.4
	Triassic Rocks	
	Santa Rosa Sandstone	15.4-141.0
	Permian Rocks	
	Dewey Lake Red Beds	141.0-638.7
	Rustler Formation	638.7-951
	Magenta Dolomite Member	706.5-730.0
	Culebra Dolomite Member	817.2-836.2
	Salado Formation (Upper Member)	951.6

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-15**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.13.00 (State Engineer's Office)

LOCATION: 2426' FNL, 1973' FWL
Sec. 18, T 23 S, R 35 E

ELEVATION: 3269.34' (G.L.I)
TOTAL DEPTH: 810'
TYPE OF WELL: Geologic Exploration
DRILLER: Boyles Brothers Drilling

DRILLING RECORD: **Date Started:** 03/08/78 **Date Completed:** 04/04/78

HOLE SIZE: 4": 0 to 29'
3.975": 29' to 61.2'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7
Grade: J-55
Wt/Ft: 20
From: 0
To: 13
Cement: None

Diameter: 6 1/8
Grade: HW
Wt/Ft: 11.3
From: 13
To: 592
Cement: None

Diameter: 4
Grade: Core
Wt/Ft:
From: 592
To: 810
Cement: None

Diameter: 4 1/2
Grade: HW
Wt/Ft: 11.3
From: 0
To: 555
Cement: None

Hole loaded with mud and temporarily capped pending further testing and/or plugging. Hole was relinquished to land owner for use as water well to relieve liability for plugging.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-15	Quaternary Deposits	
	Clay	0-34
	Marl	34-99
	Sand	99-153.3
	Clay	153.3-226
	Sand	226-547.2
	Triassic Rocks	
	Chinle	547.2-790.5
	Santa Rosa Sandstone	790.5-812

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-16**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1290 (State Engineer's Office) 0.08.1182 (reentry)

LOCATION: 2356.6' FSL, 138.8' FWL
Sec. 5, T 21 S, R 30 E

ELEVATION: 3383.40' (Top of Casing)
TOTAL DEPTH: 1300'
TYPE OF WELL: Geologic Exploration
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 01/11/80 **Date Completed:** 02/08/80

HOLE SIZE: 18": 0 to 38'
6 3/4": 38 to 459'
3 3/4": 459 to 1300'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade: H-40
Wt/Ft: 48
From: 0
To: 38
Cement:

Diameter: 4 1/2
Grade: J-55
Wt/Ft: 10.5
From: 0
To: 459
Cement: None

Plugged and abandoned by DOE.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-16	Rubble?	0-1148
	Permian Rocks	
	Rustler Formation	1148-1300+
	Magenta Dolomite Member	1189-1199
	Culebra Dolomite Member	1153-1176
	Total Depth	1300

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-18**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1123 (State Engineer's Office)

LOCATION: 983.58' FNL, 11.85' FEL
Sec. 20, T 22 S, R 31 E

ELEVATION: 3458.7' (Top of Casing)
TOTAL DEPTH: 1060'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 03/14/78 **Date Completed:** 04/03/78

HOLE SIZE: 8 3/4": 0 to 16'
6 1/8": 16 to 1060'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7
Grade: Used
Wt/Ft: 20
From: 0
To: 16
Cement: None

Hole loaded with mud pending further testing and/or plugging.

**********RECOMPLETION**********

September-October, 1985, this well was recompleted as a hydrologic monitoring well for the Culebra-dolomite.

The recompletion activity of this well consisted of cleaning and reaming to a diameter of 7 7/8" using ten-pound per gallon salt-brine as a drilling fluid; fully cementing 5 1/2" casing to the top of the Salado Formation leaving a cement plug in the bottom of the casing; filling the casing with ten-pound per gallon salt-brine; and shot-perforating the Culebra-dolomite interval. The well is currently being used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-18	Quaternary Deposits	
	Holocene Deposits	0-5
	Mescalero Caliche	5-9
	Triassic Rocks	
	Santa Rosa Sandstone	9-138
	Permian Rocks	
	Dewey Lake Red Beds	138-613
	Rustler Formation	613-928
	Dissolution Residue	643-655
	Magenta Dolomite Member	672-696
	Dissolution Residue	757-769
	Culebra Dolomite Member	787-808
	Dissolution Residue	812-822
	Salt-bearing Interval	822-928
	Salado Formation	928-1060
	Upper Member	928-1060
	MB 101	1049
	Maximum Depth Recorded	1060

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-19**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1124 (State Engineer's Office)

LOCATION: 2286.5' FNL, 12.7' FEL
Sec. 20, T 22 S, R 31 E

ELEVATION: 3435.14' (Top of Casing)
TOTAL DEPTH: 1038'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Boyles Brothers Drilling

DRILLING RECORD: **Date Started:** 04/06/78 **Date Completed:** 05/08/78

HOLE SIZE: 8 3/4": 0 to 8'
6 1/8": 8 to 1038'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7
Grade: Used
Wt/Ft: 20
From: 0
To: 8
Cement: None

**********RECOMPLETION**********

September-October, 1985, this well was recompleted as a hydrologic monitoring well for the Culebra-dolomite.

The recompletion activity of this well consisted of cleaning and reaming to a diameter of 7 7/8" using ten-pound per gallon salt-brine as a drilling fluid; fully cementing 5 1/2" casing to the top of the Salado Formation leaving a cement plug in the bottom of the casing; filling the casing with ten-pound per gallon salt-brine; and shot-perforating the Culebra-dolomite interval. The well is currently being used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-19	Quaternary Deposits	
	Holocene Deposits	0-7
	Mescalero Caliche	7-14
	Triassic Rocks	
	Santa Rosa Sandstone	14-96
	Permian Rocks	
	Dewey Lake Red Beds	96-590
	Rustler Formation	590-895
	Dissolution Residue	619-629
	Magenta Dolomite Member	647-672
	Dissolution Residue	730-756
	Culebra Dolomite Member	756-779
	Dissolution Residue	781-795
	Salt-bearing Interval	795-895
	Salado Formation	895-1038.2
	Upper Member	895-1038.2
	MB 101	1010-1012
	Maximum Depth Recorded	1034

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-21**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1126 (State Engineer's Office)

LOCATION: 1450.6' FSL, 11.7' FEL
Sec. 20, T 22 S, R 31 E

ELEVATION: 3418.96' (Top of Casing)
TOTAL DEPTH: 1045'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Boyles Brothers Drilling

DRILLING RECORD: **Date Started:** 05/24/78 **Date Completed:** 05/26/78

HOLE SIZE: 8 3/4": 0 to 20'
6 1/8": 20 to 1045'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 20
Cement: Dirt

Hole loaded with brine mud pending further testing and/or plugging.

**********RECOMPLETION**********

September-October, 1985, this well was recompleted as a hydrologic monitoring well for the Culebra-dolomite.

The recompletion activity of this well consisted of cleaning and reaming to a diameter of 7 7/8" using ten-pound per gallon salt-brine as a drilling fluid; fully cementing 5 1/2" casing to the top of the Salado Formation leaving a cement plug in the bottom of the casing; filling the casing with fresh water; and shot-perforating the Culebra-dolomite interval. The well is currently being used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-21	Quaternary Deposits	
	Holocene Deposits	0-6
	Mescalero Caliche	6-12
	Gatuna Formation	12-39
	Triassic Rocks	
	Santa Rosa Sandstone	39-73
	Permian Rocks	
	Dewey Lake Red Beds	73-560
	Rustler Formation	560-868
	Dissolution Residue	588-601
	Magenta Dolomite Member	618-642
	Dissolution Residue	706-715
	Culebra Dolomite Member	729-753
	Dissolution Residue	755-759
	Salt-bearing Interval	770-868
	Salado Formation	868-1046
	Upper Member	868-1046
	MB 101	986-989
	MB 102	1025-1026
	MB 103	1039
	Maximum Depth Recorded	1046

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-22**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1127 (State Engineer's Office)

LOCATION: 2544.9' FSL, 10.82' FEL
Sec. 20, T 22 S, R 31 E

ELEVATION: 3428.12' (Top of Casing)
TOTAL DEPTH: 1450'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Boyles Brother Drilling

DRILLING RECORD: **Date Started:** 05/08/78 **Date Completed:** 05/24/78

HOLE SIZE: 8 3/4": 0 to 20'
6 1/8": 20 to 1450'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7
Grade: Used
Wt/Ft: 20
From: 0
To: 20
Cement: None

Hole loaded with mud pending further testing and/or plugging.

**********RECOMPLETION**********

September-October, 1985, this well was recompleted as a Culebra Groundwater Level Surveillance Well.

The recompletion activity of this well consisted of cleaning and reaming to a diameter of 7 7/8" using ten-pound per gallon salt-brine as a drilling fluid; fully cementing 5 1/2" casing to the top of the Salado Formation leaving a cement plug in the bottom of the casing; filling the casing with ten-pound per gallon salt-brine; and shot-perforating the Culebra-dolomite interval. The water level has been monitored since it was perforated.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-22	Quaternary Deposits	
	Holocene Deposits	0-6
	Mescalero Caliche	6-13
	Triassic Rocks	
	Santa Rosa Sandstone	13-81
	Permian	
	Dewey Lake Red Beds	81-574
	Rustler Formation	574-885
	Dissolution Residue	603-614
	Magenta Dolomite Member	630-654
	Dissolution Residue	717-728
	Culebra Dolomite Member	742-764
	Dissolution Residue	767-773
	Salt Interval	777-885
	Salado Formation	885-1450
	Upper Member	883-1363
	MB 101	1000-1003
	MB 102	1036-1037
	MB 103	1049-1063
	MB 104	1071-1072
	MB 105	1086-1087
	MB 106	1102-1103
	MB 107	1142-1143
	MB 108	1150-1151
	MB 109	1172-1196
	MB 111	1242-1243
	MB 112	1259-1261
	MB 113	1285-1286
	MB 114	1307-1308
	MB 115	1342-1344
	MB 116	1353-1355
	McNutt Potash Unit	1363-1450
	Vaca Triste Sandstone Member	1363-1367
	MB 117	1426-1427
	Maximum Depth Recorded	1448

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-25**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1172 (State Engineer's Office)

LOCATION: 1852.77' FSL, 2838.10' FEL Sec. 15, T 22 S, R 30 E

ELEVATION: 3214.39' (Top of Casing)
TOTAL DEPTH: 650'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Boyles Brothers Drilling

DRILLING RECORD: **Date Started:** 08/28/78 **Date Completed:** 09/12/78

HOLE SIZE: 8 3/4": 0 to 21'
7 7/8": 21 to 650'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 21
Cement:

Diameter: 5 1/2
Grade: K-55
Wt/Ft: 15.5
From: 0
To: 649
Cement: 269 Cu. Ft.

7" casing pulled. Culebra perforated from 445-475' with 120 holes spaced at 4 holes per foot. Magenta perforated from 300-330' with 120 holes spaced at 4 holes per foot. Rustler perforated from 579-608' with 116 holes spaced at 4 holes per foot. Top of PIP Packers set at 572.7' and 365.1'.

Currently used as a Culebra and Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-25	Pleistocene Deposits	0-17
	Permian Rocks	
	Dewey Lake Red Beds	17-232
	Rustler Formation	232-565
	Dissolution Residue	270-287
	Magenta Dolomite Member	302-328
	Dissolution Residue	415-424
	Culebra Dolomite Member	447-472
	Dissolution Residue	475-512
	Salado Formation	565-655 (T.D.)
	Upper Member	565-600
	Dissolution Residue	565-600
	MB 101	589
	MB 102	599
	Salt Interval	600-655
	MB 103	615
	MB 104	628
	MB 105	640
	Maximum Depth Recorded on Geophysical Logs	651

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-26**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1173 (State Engineer's Office)

LOCATION: 2232.27' FNL, 12.20' FEL
Sec. 29, T 22 S, R 30 E

ELEVATION: 3153.20' (Top of Casing)
TOTAL DEPTH: 503'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/28/78 **Date Completed:** 09/11/78

HOLE SIZE: 8 3/4": 0 to 268'
7 7/8": 268 to 503'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 268
Cement:

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 502
Cement: 510 Cu. Ft.

7" casing pulled. Culebra perforated from 185-210' with 100 holes spaced at 4 holes per foot. Magenta perforated from 70-100' wih 120 holes spaced at 4 holes per foot, and from 50-70' with 80 holes spaced at 4 holes per foot. Rustler perforated from 288-329' with 164 holes spaced at 4 holes per foot. Top of Pip Packers set at 269' and 139.1'.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-26	Holocene Deposits	0-10
	Permian Rocks	
	Rustler Formation	10-309
	Dissolution Residue	34-50
	Magenta Dolomite Member	70-99
	Dissolution Residue	152-174
	Culebra Dolomite Member	186-209
	Dissolution Residue	213-234
	Salado Formation	309-503
	Upper Member	309-503
	Dissolution Residue	309-320
	Salt Interval	320-503
	MB 101	387
	MB 102	423
	MB 103	460
	MB 104	469
	MB 105	481
	MB 106	495
	Maximum Depth Recorded	503

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-27**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1174 (State Engineer's Office)

LOCATION: 89.79' FNL, 1485.03' FWL
Sec. 21, T 21 S, R 30 E

ELEVATION: 3178.98' (Top of Casing)
TOTAL DEPTH: 592'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Boyles Brothers Drilling

DRILLING RECORD: **Date Started:** 09/12/78 **Date Completed:** 10/09/78

HOLE SIZE: 8 3/4": 0 to 200'
7 7/8": 200 to 592'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 588
Cement: 440 Cu. Ft.

Culebra perforated from 290-320' with 120 holes spaced at 4 holes per foot. Magenta perforated from 175-195' with 80 holes spaced at 4 holes per foot. Rustler perforated from 425-460' with 135 holes and from 483-513' with 120 holes spaced at 4 holes per foot. Top of PIP Packers set at 399.4' and 267.4'.

Currently used as a Culebra and Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-27	Quaternary Deposits	
	Holocene Deposits	0-74
	Mescalero Caliche	74-79
	Permian Rocks	
	Dewey Lake Red Beds	79-152
	Rustler Formation	152-421
	Dissolution Residue	152-193
	Magenta Dolomite Member	175-193
	Dissolution Residue	270-281
	Culebra Dolomite Member	292-318
	Dissolution Residue	321-421
	Salado Formation	421-592
	Upper Member	421-592
	Dissolution Residue	421-509
	MB 101	442-447
	MB 102	449-451
	MB 103	456-468
	MB 107-108	481-484
	MB 109	487-494
	Salt Interval	509-592
	MB 113	548-550
	Maximum Depth Recorded	592

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-28**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1175 (State Engineer's Office)

LOCATION: 98.72' FNL, 2400.99' FEL
Sec. 18, T 21 S, R 31 E

ELEVATION: 3349.21' (Top of Casing)
TOTAL DEPTH: 801'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/07/78 **Date Completed:** 08/28/78

HOLE SIZE: 12 1/4": 0 to 21.5'
8 3/4": 21.5 to 216'
7 7/8": 216 to 801'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 21
Cement: Ready Mix

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 223
Cement:

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 800
Cement: 314 Cu. Ft.

7" casing pulled. Culebra perforated from 420-446' with 104 holes spaced at 4 holes per foot. Magenta perforated from 285-310' with 100 holes spaced at 4 holes per foot. Rustler perforated from 549-589' with 160 holes spaced at 4 holes per foot. Top of PIP Packers set at 526.7' and 365.1'.

Currently used as a Rustler/Salado Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-28	Holocene Deposits	0-12
	Permian Rocks	
	Dewey Lake Red Beds	12-215
	Rustler Formation	215-531
	Magenta Dolomite Member	285-310
	Culebra Dolomite Member	420-446
	Salado Formation	531-801 (T.D)
	Upper Member	531-801
	Dissolution Residue	531-589
	MB 101	567
	MB 103	585
	Salt Interval	589-801
	MB 105	598
	MB 106	612
	MB 107	656
	MB 108	664
	MB 109	694
	MB 111	731
	MB 112	743
	MB 113	769
	MB 114	791
	Maximum Depth Recorded	802

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-29**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1176 (State Engineer's Office)

LOCATION: 406.62' FSL, 1827.54' FEL
Sec. 34, T 22 S, R 29 E

ELEVATION: 2978.26' (Top of Casing)
TOTAL DEPTH: 377'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 10/03/78 **Date Completed:** 10/10/78

HOLE SIZE: 8 3/4": 0 to 135'
7 7/8": 135 to 377'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 376
Cement: 135 Cu. Ft.

Top joint of 5 1/2" casing is 14 lb. Culebra perforated from 10-45' with 140 holes spaced at 4 holes per foot. Rustler perforated from 216-250' with 136 holes spaced at 4 holes per foot. Top of PIP Packers set at 203.7.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-29	Holocene Deposits	0-12
	Permian Rocks	
	Rustler Formation	12-143
	Culebra Dolomite Member	12-42
	Salado Formation	143-377 (T.D.)
	Upper Member	143-248
	Dissolution Residue	143-248
	MB 101	175
	MB 102	181
	MB 103	199
	MB 109	228
	McNutt Potash Zone	248-377 (T.D.)
	Dissolution Residue	248-251
	Vaca Triste Sandstone Member	248-251
	Salt Interval	251-377
	MB 117	319
	MB 118	346
	Maximum Depth Recorded	358

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-30**
OPERATOR: Sandia National Laboratories
PERMIT NO.: 0.08.1177 (State Engineer's Office)

LOCATION: 667.5' FNL, 177.41' FWL
Sec. 33, T 21 S, R 30 E

ELEVATION: 3429.05' (Top of Casing)
TOTAL DEPTH: 913'
TYPE OF WELL: Geologic Exploration/Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 09/08/78 **Date Completed:** 10/02/78

HOLE SIZE: 4.95": 0 to 913'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 246
Cement:

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 912
Cement: 463 Cu. Ft.

7" casing pulled. Culebra perforated from 631-654' with 92 holes spaced at 4 holes per foot. Magenta perforated from 510-540' with 120 holes spaced at 4 holes per foot. Rustler perforated from 731-753' with 88 holes spaced at 4 holes per foot. Top of PIP Packers set at 701.1' and 585.4'.

**********RECOMPLETION**********

March, July, September 1980, WIPP-30 was perforated across three intervals: the Rustler-Salado contact, from 731' to 753'; the interval from 631' to 654', which includes the Culebra-dolomite from 631' to 653'; and the interval from 510' to 540', which includes the Magenta-dolomite from 513' to 537'.

July and August, 1980, after perforation and testing, two retrievable bridge plugs were installed to prevent mixing of fluids between the Rustler-Salado contact, the Culebra-dolomite, and the Magenta-dolomite.

August 1983, the upper bridge plug in WIPP-30 was replaced with a 4 1/4" PIP installed on 2 3/8" tubing. The PIP was set at 570'.

October 1987, the PIP was removed from WIPP-30.

October 29, 1987, the casing was perforated with 15/32" bullets at 4 shots/foot over a 26' interval from 629' to 655' including the Culebra-dolomite interval from 631' to 653'.

Currently used as a Culebra and Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-30	Permian Rocks	
	Dewey Lake Red Beds	0-449
	Rustler Formation	449-748
	Magenta Dolomite Member	513-537
	Culebra Dolomite Member	631-653
	Salado Formation	748-912 (T.D.)
	Upper Member	748-912
	Salt Interval	748-912
	MB 101	862
	MB 102	894
	MB 103	In Bed at Total Depth
	Maximum Depth Recorded	908

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **WIPP-31**
OPERATOR: Sandia National Laboratories
PERMIT NO.: Unknown

LOCATION: 422.54' FSL, 1762.24' FWL
Sec. 35, T 20 S, R 30 E

ELEVATION: 3401.43' (Top of Casing)
TOTAL DEPTH: 1981.7'
TYPE OF WELL: Geologic Exploration
DRILLER: Chortes Drilling Company

DRILLING RECORD: **Date Started:** 07/18/80 **Date Completed:** 09/29/80

HOLE SIZE: 18": 0 to 40'
7 7/8": 40 to 810'

WELL DEVELOPMENT:

CASING RECORD

Diameter:
Grade: 6' x 6' CEL
Wt/Ft:
From: 0
To: 5
Cement: Dirt

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 3
To: 37
Cement: 81 Cu. Ft.

Diameter: 7 5/8
Grade: J-55
Wt/Ft: 26.4
From: 2.5
To: 808
Cement: 414 Cu. Ft.

Hole plugged and abandoned.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-31	Gatuna Formation	Not Present
	Santa Rosa Formation	0 (Breccia)
	Dewey Lake Redbeds	38 (Breccia)
	Rustler Formation	750 (Breccia)
	Magenta Dolomite Member	1981 (Breccia)
	Top of Salado Formation	Not Present
	Total Depth	1981

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**WIPP-32**
OPERATOR:	Sandia National Laboratories
PERMIT NO.:	SEO: 04/25/79; USGS: 10/15/79
LOCATION:	1673.22' FSL, 29.14' FEL Sec. 33, T 22 S, R 29 E
ELEVATION:	3023.26' (Top of Casing)
TOTAL DEPTH:	390'
TYPE OF WELL:	Geologic Exploration
DRILLER:	Pennsylvania Drilling Company
DRILLING RECORD:	**Date Started:** 08/07/79 **Date Completed:** 08/23/79
HOLE SIZE:	Excavated: 0 to 4' 6 3/4": 4 to 390'

WELL DEVELOPMENT:

CASING RECORD

No casing used.

Hole plugged to surface with 500 Cu. Ft. cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-32	Rustler Formation	0-166
	Magenta Dolomite Member	19-36
	Culebra Dolomite Member	61-90
	Top of Salado Formation	166-390
	Total Depth	390

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**WIPP-33**
OPERATOR:	Sandia National Laboratories
PERMIT NO.:	SEO: 04/25/79
LOCATION:	1762.48' FSL, 2426.65' FWL Sec. 13, T 22 S, R 30 E
ELEVATION:	3323.23' (Top of Casing)
TOTAL DEPTH:	840'
TYPE OF WELL:	Geologic Exploration
DRILLER:	Pennsylvania Drilling Company
DRILLING RECORD:	**Date Started:** 07/13/79 **Date Completed:** 07/26/79
HOLE SIZE:	Excavated: 0 to 5' 18": 5 to 38' 6 3/4": 38 to 840'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 38
Cement: 192 Cu. Ft.

Hole plugged and abandoned on 09/04/79.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-33	Surficial Deposits	0-40
	Dewey Lake Red Beds	40-398
	Rustler Formation	398-675
	Magenta Dolomite Member	449-468
	Culebra Dolomite Member	550-578
	Top of Salado Formation	657-840
	Total Depth	840

GEOLOGIC EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**WIPP-34**
OPERATOR:	Sandia National Laboratories
PERMIT NO.:	08.08.1291 (State Engineer's Office) 08.08.1195 (reentry)
LOCATION:	201.78' FSL, 1999.73' FWL Sec. 8, T 22 S, R 31 E
ELEVATION:	3433' (Top of Casing)
TOTAL DEPTH:	1820'
TYPE OF WELL:	Geologic Exploration
DRILLER:	Pennsylvania Drilling Company
DRILLING RECORD:	**Date Started:** 08/16/79 **Date Completed:** 09/04/79
HOLE SIZE:	Excavated: 0 to 5' 18": 5 to 38' 6 3/4": 38 to 1820'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement:

Plugged and abandoned 09/04/79.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WIPP-34	Quaternary Deposits	0-11
	Triassic Rocks	
	Santa Rosa Sandstone	11-154
	Permian Rocks	
	Dewey Lake Red Beds	154-657
	Rustler Formation	657-973
	Magenta Dolomite Member	716-741
	Culebra Dolomite Member	834-861
	Salado Formation	973-1820+
	Upper Unit	973-1437
	MB 101	1092
	MB 102	1122
	MB 103	1148
	MB 104	1158
	MB 105	1173
	MB 106	1191
	MB 107	1228
	MB 108	1237
	MB 109	1280
	MB 110	1317
	MB 111	1326
	MB 112	1344
	MB 113	1366
	MB 114	1396
	MB 115	1420
	MB 116	1430
	McNutt Potash Unit	1437-1751
	Vaca Triste Sandstone Member	1437-1442
	MB 117	1498
	MB 118	1520
	MB 119	1540
	MB 120	1560
	MB 121	1573
	MB 122	1580
	Union Anhydrite	1599-1607
	MB 123	1676
	MB 124	1690
	MB 125	---
	MB 126	1751
	Lower Unit	1751-1820+
	MB 127	1768
	MB 128	1775
	MB 129	1785

Hydrologic Test Borehole Data Base

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-1**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.979 (State Engineer's Office)

LOCATION: 623.2' FNL, 1083.1' FWL Sec. 29, T 22 S, R 31 E

ELEVATION: 3399.53' (Top of Casing)
TOTAL DEPTH: 856'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 05/20/76 **Date Completed:** 06/10/76

HOLE SIZE: 9 5/8": 0 to 856'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 1/8
Grade:
Wt/Ft: 40.5
From: 0
To: 48
Cement: 51 Cu. Ft.

Diameter: 7
Grade: K-55
Wt/Ft: 26
From: 0
To: 848
Cement: 192 Cu. Ft.

Perforated from 803 to 827' with 72 holes. 703 to 683' with 3 holes per foot. 683 to 675' with 3 holes per foot, 562 to 590' with 3 holes per foot. All depths are measured from Kelly Bushing 8' above ground level except DST's which are measured from ground level.

**********RECOMPLETION**********

January 1977, the casing in H-1 was perforated across the Rustler-Salado contact zone from 803' to 827' using 1/2" shots at 3 shots/foot.

March 1977, the casing across the Culebra-dolomite interval was perforated from 675' to 703' using 1/2" shots at 3 shots/foot.

April 1977, the casing across the Magenta-dolomite interval was perforated from 562' to 590' with 1/2" shots at 3 shots/foot.

Following hydrologic testing, an inflatable bridge plug was set in the casing at about 790' to isolate the Rustler-Salado contact, and PIP was set on 2 3/8" tubing at about 651'.

Currently used as a Culebra and Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-1	Holocene	
	Surficial Deposits	0-15
	Pleistocene	
	Gatuna Formation	15-35
	Ochoan	
	Dewey Lake Red Beds	35-502
	Rustler Formation	502-824
	Magenta Dolomite Member	563-589
	Culebra Dolomite Member	676-699
	Top of Salado	824
	Total Depth	856

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-2a**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.990 (State Engineer's Office)

LOCATION: 726.96' FNL, 1697.64', FWL
Sec. 29, T 22 S, R 31 E

ELEVATION: 3378.09' (Top of Casing)
TOTAL DEPTH: 672'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 02/14/77 **Date Completed:** 02/21/77

HOLE SIZE: 18": 0 to 33'
8 3/4": 33 to 513'
4 3/4": 513 to 672'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 3/4
Grade:
Wt/Ft:
From: 0
To: 33
Cement: 54 Cu. Ft.

Diameter: 6 5/8
Grade: J-55
Wt/Ft: 24
From: 0
To: 511
Cement: 260 Cu. Ft.

**********RECOMPLETION**********

April 1984, H-2a had degraded so much that it was necessary to reenter the hole, set casing to the top of the Culebra (4 1/2" OD, J-
9.5 lb/ft to 623') and place a screen assembly across the Culebra.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-2a	Holocene	
	Surficial Deposit	0-14
	Pleistocene	
	Gatuna Formation	14-38
	Ochoan	
	Dewey Lake Red Beds	38-457
	Rustler Formation	457-672 (T.D.)
	Forty-Niner Member	457-515
	Magenta Dolomite Member	515-543
	Tamarisk Member	543-623
	Culebra Dolomite Member	623-645
	Unnamed Part	645-672 (T.D.)
	Total Depth	672

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-2b1**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.990 (State Engineer's Office)

LOCATION: 695.57' FNL, 1660.57' FWL,
Sec. 29, T 22 S, R 31 E

ELEVATION: 3378.46 (Top of Casing)
TOTAL DEPTH: 661'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 02/07/77 **Date Completed:** 02/14/77

HOLE SIZE: 18": 0 to 33'
8 3/4": 33 to 609'
4 3/4": 609' to 661'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 3/4
Grade:
Wt/Ft:
From: 0
To: 33
Cement: 54 Cu. Ft.

Diameter: 6 5/8
Grade: J-55
Wt/Ft: 24
From: 0
To: 609
Cement: 282 Cu. Ft.

Perforated from 510 to 538' with 3 holes per foot.

**********RECOMPLETION**********

After coring and testing the Culebra interval, a retrievable bridge plug was set above the Culebra interval and the Mangenta interval was shot perforated and tested by bailing. After the initial construction-and-testing period, a PIP was installed and the well was used to monitor Magenta and Culebra water levels. The PIP separating the Culebra and Magenta had to be removed and replaced several times in 1987 and 1988 because of leaks and other technical problems.

April 1989, the PIP was replaced with a retrievable bridge plug set below the Magenta interval and H-2b1 was converted to a Magenta monitoring well for hydrologic testing and water-quality sampling.

April 20, 1989, a Baker Service Tools 4 1/4" PIP was set on 2 3/8" tubing above the Magenta interval to minimize wellbore volume and reduce test-zone volume. Testing was performed in the 2 3/8" tubing with BASKI 1 1/2" inflatable minipacker.

July 13, 1989, the PIP was removed and the well was returned to service as a Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-2b1	Holocene	
	Surficial Deposit	0-14
	Pleistocene	
	Gatuna Formation	14-38
	Ochoan	
	Dewey Lake Red Beds	38-457
	Rustler Formation	457-661
	Forty-Niner Member	457-515
	Magenta Dolomite Member	515-543
	Tamarisk Member	543-623
	Culebra Dolomite Member	623-645
	Unnamed Part	645-661
	Total Depth	661

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-2b2**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.990 (State Engineer's Office)

LOCATION: 700.6' FNL, 1690.8' FWL, Sec. 29, T 22 S, R 31 E

ELEVATION: 3378.31' (Top of Casing)
TOTAL DEPTH: 660'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 07/16/83 **Date Completed:** 05/03/84

HOLE SIZE: 18": 0 to 20'
7 7/8": 20 to 660'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9.625 O.D.
Grade: J-55
Wt/Ft: 36
From: 0
To: 20
Cement:

Diameter: 5.5 O.D.
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 620
Cement:

Note: Open 613-650'.

**********RECOMPLETION**********

April 1984, problems with hole instability necessitated the placement of a screen across the Culebra to maintain the hole in open condition. This was done on the first two days of May 1984.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-2b2	Holocene	
	Surficial Deposits	0-14
	Quaternary	
	Gatuna Formation	14-38
	Permian	
	Dewey Lake Red Beds	38-457
	Rustler Formation	457-660 (T.D.)
	Forty-Niner Member	457-515
	Magenta Dolomite Member	515-543
	Tamarisk Member	543-623
	Culebra Dolomite Member	623-645
	Unnamed Part	645-660 (T.D.)

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE:	**H-2c**
OPERATOR:	Sandia National Labs
PERMIT NO.:	0.08.990 (State Engineer's Office)
LOCATION:	637.15' FNL, 1708.62' FWL, Sec. 29, T 22 S, R 31 E
ELEVATION:	3378.41' (Top of Casing)
TOTAL DEPTH:	795'
TYPE OF WELL:	Hydrologic Test Hole
DRILLER:	Pennsylvania Drilling Company
DRILLING RECORD:	**Date Started:** 01/28/77 **Date Completed:** 02/05/77
HOLE SIZE:	18": 0 to 33' 8 3/4": 33 to 742' 4 3/4": 742 to 795'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 3/4
Grade:
Wt/Ft:
From: 0
To: 33
Cement: 54 Cu. Ft.

Diameter: 6 5/8
Grade: J-55
Wt/Ft: 24
From: 0
To: 742
Cement: 339 Cu. Ft.

Perforated from 618 to 655' with 3 holes per foot.

Currently used as a Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-2c	*Holocene*	
	Surficial Deposits	0-34
	Quaternary	
	Gatuna Formation	0-34
	Permian	
	Dewey Lake Red Beds	34-457
	Rustler Formation	
	Magenta Dolomite Member	515-540
	Culebra Dolomite Member	624-642
	Top of Rustler Salt	642
	Salado Formation	764-795 (T.D.)
	Maximum Depth	795

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE:	**H-3b1**
OPERATOR:	Sandia National Lab
PERMIT NO.:	0.08.991 (State Engineer's Office)
LOCATION:	2085.31' FSL, 138.10' FEL, Sec. 29, T 22 S, R 31 E
ELEVATION:	3390.64' (Top of Casing)
TOTAL DEPTH:	902'
TYPE OF WELL:	Hydrologic Test Hole
DRILLER:	Pennsylvania Drilling Company
DRILLING RECORD:	**Date Started:** 07/25/76 **Date Completed:** 08/12/76
HOLE SIZE:	13 3/4": 0 to 38' 8 3/4": 38 to 902'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 3/4
Grade:
Wt/Ft: 40.5
From: 0
To: 38
Cement: 54 Cu. Ft.

Diameter: 6 5/8
Grade: J-55
Wt/Ft: 24
From: 0
To: 891
Cement: 625 Sacks

Perforated from 813 to 837' with 72 holes, 683 to 703' with 3 holes per ft, 675 to 683' with 3 holes per ft, 562 to 590' with 3 holes per ft.

**********RECOMPLETION**********

1977, the Rustler/Salado contact and the Culebra-dolomite intervals, in that order, were each shot perforated, isolated, and bailed. The Culebra interval was also geophysically logged. After perforating and testing the Culebra interval, a retrievable PIP was set above the Culebra interval, and the Magenta interval was shot perforated, and tested by bailing. After testing the Magenta, tubing was reattached to the PIP and H-3b1 was used to monitor Magenta and Culebra water levels from 1977 to 1987.

1987, the PIP was replaced with a retrievable bridge plug set below the Magenta interval and H-3b1 was converted to a Magenta monitoring well for water-level monitoring and water-quality sampling.

July 14, 1989, a Baker Service Tools 4 1/4" PIP was set on 2 3/8" tubing above the Magenta interval to minimize wellbore volume and reduce test-zone volume. Testing was performed in the 2 3/8" tubing with a BASKI 1 1/2" inflatable minipacker.

After testing, the PIP was removed and the well was returned to service as a Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-3b1	Holocene	
	Surficial Deposits	0-4
	Quaternary	
	Gatuna Formation	4-22
	Permian	
	Dewey Lake Red Beds	22-502
	Rustler Formation	502-821
	Magenta Dolomite Member	559-584
	Culebra Dolomite Member	672-694
	Top of Rustler Salt	Not Given
	Salado Formation	821- T.D.
	Maximum Depth	902

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE:	**H-3b2**
OPERATOR:	Sandia National Labs
PERMIT NO.:	0.08.991 (State Engineer's Office)
LOCATION:	2122.15' FSL, 231.29' FEL, Sec. 29, T 22 S, R 31 E
ELEVATION:	3390.03' (Top of Casing)
TOTAL DEPTH:	725'
TYPE OF WELL:	Hydrologic Test Hole
DRILLER:	Pennsylvania Drilling Company
DRILLING RECORD:	**Date Started:** 10/25/83 **Date Completed:** 11/08/83
HOLE SIZE:	7 7/8": 0 to 673' 4 3/4": 673' to 725'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 5 1/2 O.D.
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 672.7
Cement:

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-3b2	Surficial Deposits	0-11
	Gatuna Formation	
	Dockum Group	11-65
	Dewey Lake Red Beds	65-565.7
	Rustler Formation	565.7-788.7
	Magenta Dolomite Member	564-590
	Culebra Dolomite Member	676-700
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	725

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-3b3**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.991 (State Engineer's Office)

LOCATION: 2022.35' FSL, 217.30' FEL,
Sec. 29, T 22 S, R 31 E

ELEVATION: 3388.67' (Top of Casing)
TOTAL DEPTH: 730'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 11/15/83 **Date Completed:** 12/16/83

HOLE SIZE: 7 7/8": 0 to 673'
4 3/4": 673' to 730'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 5.5
Grade: J-55
Wt/Ft: 15.5
From: .50
To: 670.5
Cement: Casing cemented in place

Currently used as a Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-3b3	*Surficial Deposits*	
	Gatuna Formation	
	Dockum Group	
	Dewey Lake Red Beds	
	Rustler Formation	
	Magenta Dolomite Member	563-586
	Culebra Dolomite Member	673-696
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Castile Formation	

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-3d (H-3b4)**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.991 (State Engineer's Office)

LOCATION: 2067.3' FSL, 164.3' FEL, Sec. 29, T 22 S, R 31 E

ELEVATION: 3390.01' (Top of Casing)
TOTAL DEPTH: 554'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 03/31/87 **Date Completed:** 04/22/87

HOLE SIZE:

WELL DEVELOPMENT:

CASING RECORD

Diameter: 8 5/8
Grade:
Wt/Ft:
From: 0
To: 39
Cement:

7 7/8" uncased borehole 33-559'.

Currently used as a Forty-niner and Dewey Lake Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-3d	Surficial Deposits	
	Gatuna Formation	
	Dockum Group	
	Dewey Lake Red Beds	420
	Rustler Formation	
	Forty-Niner Member	508-537
	Forty-Niner Claystone Member	537-547
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Castile Formation	

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-4a**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1153 (State Engineer's Office)

LOCATION: 545.89' FNL, 720.00' FWL,
Sec. 5, T 23 S, R 31 E

ELEVATION: 3333.29' (Top of Casing)
TOTAL DEPTH: 415'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 04/30/78 **Date Completed:** 05/23/78

HOLE SIZE: 18": 0 to 32'
7 7/8": 32 to 365'
4 3/4": 365 to 532'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 32
Cement: 63 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 364
Cement: 173 Cu. Ft.

Hole in standby condition for hydro tracer tests. 4 1/2" inflatable packer set at 485' on 1 1/2" galvanized pipe. 1 3/8" pump cylind set at 499' in the Culebra Dolomite. The hole is dual completion across the Magenta and Culebra Dolomites.

**********RECOMPLETION**********

Well deepened to 532' and recompleted. (SAND85-7206)

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-4a	Holocene	
	Surficial Deposits	0-13
	Pleistocene	
	Gatuna Formation	13-29
	Ochoan	
	Dewey Lake Red Beds	29-315
	Rustler Formation	315
	Magenta Dolomite Member	375-400
	Total Depth	415

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-4b**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1154 (State Engineer's Office)

LOCATION: 498.47' FNL, 632.54' FWL,
Sec. 5, T 23 S, R 31 E

ELEVATION: 3333.35 (Top of Casing)
TOTAL DEPTH: 529'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 04/30/78 **Date Completed:** 05/15/78

HOLE SIZE: 18": 0 to 33'
7 7/8": 33 to 477'
4 3/4": 477 to 529'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 33
Cement: 63 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 476
Cement: 269 Cu. Ft.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-4b	Surficial Deposits	0-13
	Gatuna Formation	13-29
	Dockum Group	NP
	Dewey Lake Red Beds	29-315
	Rustler Formation	315-T.D.
	Magenta Dolomite Member	377-402
	Culebra Dolomite Member	498-522
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	529

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-4c**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1152 (State Engineer's Office)

LOCATION: 446.36 FNL, 717.89 FWL, Sec. 5, T 23 S, R 31 E

ELEVATION: 3334.04' (Top of Casing)
TOTAL DEPTH: 661'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 04/30/78 **Date Completed:** 05/09/78

HOLE SIZE: 18": 0 to 33'
7 7/8": 33 to 610'
4 3/4": 610 to 661'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 33
Cement: 63 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 610
Cement: 270 Cu. Ft.

Bridge plug at 530'. Perforated from 494 to 520' with 104 holes spaced at 4 holes per foot. Hole in standby condition for hydro tracer tests.

**********RECOMPLETION**********

February 5, 1981, a 4 1/4" retrievable bridge plug was set in the casing at a depth of 530'. The casing was then shot perforated with 4 shots/foot from 494' to 520' to provide access to the Culebra dolomite. Mercer and others (1981) list the Culebra depths at H-4c as between 490' and 516' deep, and the gamma log used to select the perforation interval shows the Culebra from 489' to 515' deep. Therefore, the upper 4' to 5' of the Culebra dolomite are apparently not perforated at H-4c.

Currently used as a Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-4c	Surficial Deposits	0-13
	Gatuna Formation	13-29
	Dockum Group	NP
	Dewey Lake Red Beds	29-315
	Rustler Formation	315-626
	Magenta Dolomite Member	377-403
	Culebra Dolomite Member	490-516
	Salado Formation	626-661

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-5a**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1159 (State Engineer's Office)

LOCATION: 1091.98 FNL, 185.03 FEL, Sec. 15, T 22 S, R 31 E

ELEVATION: 3506.19 (Top of Casing)
TOTAL DEPTH: 824'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 05/22/78 **Date Completed:** 06/20/78

HOLE SIZE: 18": 0 to 38'
7 7/8": 38 to 775'
4 3/4": 775 to 930'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 774
Cement: 192 Cu. Ft.

Hole in standby condition for hydro tracer tests. 4 1/2" inflatable packer set at 895' on 1 1/2" galvanized pipe. 1 3/8" pump cylind set at 905' in the Culebra Dolomite. The hole is dual-completion across the Magenta and Culebra Dolomites.

**********RECOMPLETION**********

Well deepened to 930' and recompleted. (SAND85-7206)

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-5a	Surficial Deposits	0-8
	Gatuna Formation	Not Present
	Santa Rosa Formation	8-225
	Dewey Lake Redbeds	225-732
	Rustler Formation	732-
	Magenta Dolomite Member	783-810
	Culebra Dolomite Member	897-920
	Total Depth	824

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-5b**
OPERATOR: Sandia National Lab
PERMIT NO.: 0.08.1160 (State Engineer's Office)

LOCATION: 1008.30' FNL, 236.22' FEL,
Sec. 15, T 22 S, R 31 E

ELEVATION: 3506.04' (Top of Casing)
TOTAL DEPTH: 925'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 05/22/78 **Date Completed:** 06/13/78

HOLE SIZE: 18": 0 to 38'
7 7/8": 38 to 882'
4 3/4": 882 to 925'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 881
Cement: 336 Cu. Ft.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-5b	Surficial Deposits	0-8
	Gatuna Formation	NP
	Dockum Group	8-225
	Dewey Lake Red Beds	225-732
	Rustler Formation	732-T.D.
	Magenta Dolomite Member	785-805
	Culebra Dolomite Member	897-920
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Castile Formation	

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-5c**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1161 (State Engineer's Office)

LOCATION: 1005.55 FNL, 134.95 FEL, Sec. 15, T 22 S, R 31 E

ELEVATION: 3506.04' (Top of Casing)
TOTAL DEPTH: 1076'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 05/22/78 **Date Completed:** 06/03/78

HOLE SIZE: 18": 0 to 38'
7 7/8": 38 to 1025'
4 3/4": 1025 to 1076'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 1024
Cement: 416 Cu. Ft.

Bridge plug set at 935'. Perforated from 895' to 925' with 120 holes spaced at 4 holes per foot.

Currently used as a Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-5c	Surficial Deposits	0-8
	Gatuna Formation	NP
	Dockum Group	8-225
	Dewey Lake Red Beds	225-732
	Rustler Formation	732-1041
	Magenta Dolomite Member	788-812
	Culebra Dolomite Member	899-924
	Salado Formation	1041-T.D.
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	1076

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-6a**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1162 (State Engineer's Office)

LOCATION: 283.30' FNL, 274.34' FWL,
Sec. 18, T 22 S, R 31 E

ELEVATION: 3347.83' (Top of Casing)
TOTAL DEPTH: 525'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 03/05/78 **Date Completed:** 07/11/78

HOLE SIZE: 18": 0 to 38'
7 7/8": 38 to 475'
4 3/4": 475 to 637'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 475
Cement: 155 Cu. Ft.

Hole in standby condition for hydro tracer tests. 4 1/2" packer set at 594' on 1 1/2" galvanized pipe. 1 3/8" pump cylinder at 608' i the Culebra Dolomite. The hole is dual-completion across the Magenta and Culebra Dolomites.

**********RECOMPLETION**********

Well deepened to 637' and recompleted. (SAND 85-7206)

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-6a	Surficial Deposits	0-12
	Gatuna Formation	12-38
	Santa Rosa Formation	Not Present
	Dewey Lake Redbeds	225-732
	Rustler Formation	427
	Magenta Dolomite Member	429-511
	Total Depth	525

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-6b**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1163 (State Engineer's Office)

LOCATION: 196.34' FNL, 332.96' FWL, Sec 18, T 22 S, R 31 E

ELEVATION: 3348.25' (Top of Casing)
TOTAL DEPTH: 640'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 06/19/78 **Date Completed:** 07/05/78

HOLE SIZE: 18": 0 to 38'
7 7/8": 38 to 592'
4 3/4": 592 to 640'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 590
Cement: 210 Cu. Ft.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-6b	Surficial Deposits	0-12
	Gatuna Formation	12-38
	Dockum Group	NP
	Dewey Lake Red Beds	38-427
	Rustler Formation	427-T.D.
	Magenta Dolomite Member	492-511
	Culebra Dolomite Member	604-627
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	640

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-6c**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1164 (State Engineer's Office)

LOCATION: 281.06' FNL, 374.47' FWL,
Sec. 18, T 22 S, R 31 E

ELEVATION: 3348.52' (Top of Casing)
TOTAL DEPTH: 741'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 06/19/78 **Date Completed:** 06/26/78

HOLE SIZE: 18": 0 to 38'
7 7/8": 38 to 700'
4 3/4": 700 to 741'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: J-55
Wt/Ft: 36
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: +1.29
To: 699
Cement: 335 Cu. Ft.

Bridge plug set at 641'. Perforated from 604' to 631' with 108 holes spaced at 4 holes per foot.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-6c	Surficial Deposits	0-12
	Gatuna Formation	12-38
	Dockum Group	NP
	Dewey Lake Red Beds	38-427
	Rustler Formation	427-721
	Magenta Dolomite Member	490-514
	Culebra Dolomite Member	604-627
	Salado Formation	721-T.D.
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	741

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-7a**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08-1271 (State Engineer's Office)

LOCATION: 2495.04' FNL, 2492.35' FWL,
Sec. 14, T 23 S, R 30 E

ELEVATION: 3164' (Top of Casing)
TOTAL DEPTH: 154'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 09/18/79 **Date Completed:** 10/18/79

HOLE SIZE: 18"
9 7/8"
6 1/8"

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement: 81 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 23
From: 0
To: 109
Cement: 265 Cu. Ft.

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-7a	Surficial Deposits	0-5
	Santa Rosa Formation	Not Present
	Dewey Lake Redbeds	57-87
	Rustler Formation	87-283
	Magenta Dolomite Member	117-140
	Total Depth	154

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-7b1**
OPERATOR: Sandia National Lab
PERMIT NO.: 0.08-1272 (State Engineer's Office)

LOCATION: 2565.80' FNL, 2563.45' FWL,
Sec. 14, T 23 S, R 30 E

ELEVATION: 3164.17' (Top of Casing)
TOTAL DEPTH: 286'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 09/13/79 **Date Completed:** 09/18/79

HOLE SIZE: 18": 0 to 38'
9 1/2": 38 to 230'
6 1/8": 230' to 286'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement: 54 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 23
From: 0
To: 230
Cement: 270 Cu. Ft.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-7b1	Holocene	
	Surficial Deposits	0-5
	Pleistocene	
	Gatuna Formation	12-38
	Dockum Group	NP
	Dewey Lake Red Beds	57-87
	Rustler Formation	87-T.D.
	Magenta Dolomite Member	117-140
	Culebra Dolomite Member	237-283
	Salado Formation	
	Upper Member	
	Lower Member	
	Castile Formation	
	Total Depth	286

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-7b2**
OPERATOR: Sandia National Labs
PERMIT NO.: ---- (State Engineer's Office)

LOCATION: 2662.16' FNL, 2537.98' FWL,
Sec. 14, T 23 S, R 30 E

ELEVATION: 3164.40' (Top of Casing)
TOTAL DEPTH: 295'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/27/83 **Date Completed:** 09/02/83

HOLE SIZE: 8 3/4": 20 to 233'
6 1/8": 233 to 295'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 7/8
Grade:
Wt/Ft:
From: 0
To: 20
Cement: Casing set in cement

Diameter: 7
Grade: J-55
Wt/Ft: 20
From: 0
To: 230.19
Cement: Cemented in place

Hole was back filled with peu gravel from 295' to 268' and left open as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-7b2	Surficial Deposits	
	Gatuna Formation	57
	Dockum Group	NP
	Dewey Lake Red Beds	57-87
	Rustler Formation	87-T.D.
	Magenta Dolomite Member	117-140
	Culebra Dolomite Member	232-280
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	295

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: H-7c
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1273 (State Engineer's Office)

LOCATION: 2591.93' FNL, 2467.51' FWL,
Sec. 14, T 23 S, R 30 E

ELEVATION: 3164.13 (Top of Casing)
TOTAL DEPTH: 420'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 09/06/79 **Date Completed:** 11/02/79

HOLE SIZE: 9 7/8"

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement: 68 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 356
Cement: 706 Cu. Ft.

Slotted liner installed from 347' to 420'.

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-7c	Holocene	
	Unconsolidated Alluvium and Dune Sand	0-5
	Pleistocene	
	Gatuna Formation	5-57
	Permian	
	Dewey Lake Red Beds	57-87
	Rustler Formation	87-283
	Magenta Dolomite Member	117-140
	Culebra Dolomite Member	237-273.5
	Salado Formation	283-420
	Dissolution Residue	283-405
	Top of Salt Interval	405
	Total Depth	420

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-8a**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1274 (State Engineer's Office)

LOCATION: 1962.61' FNL, 1486.59' FEL,
Sec. 23, T 24 S, R 30 E

ELEVATION: 3432.99' (Top of Casing)
TOTAL DEPTH: 505'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 09/07/79 **Date Completed:** 09/18/79

HOLE SIZE: 9 7/8"

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement: 108 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 23
From: 0
To: 452
Cement: 393

Currently used as a Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-8a	Surficial Deposits	0-4 4-10 Mescalero
	Gatuna Formation	10-153
	Santa Rosa Formation	Not Present
	Dewey Lake Redbeds	153-399
	Rustler Formation	399-
	Magenta Dolomite Member	466-488
	Total Depth	505

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-8b**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1275 (State Engineer's Office)

LOCATION: 1994.76' FNL, 1405.41' FEL,
Sec. 23, T 24 S, R 30 E

ELEVATION: 3433.64' (Top of Casing)
TOTAL DEPTH: 624'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/06/79 **Date Completed:** 08/12/79

HOLE SIZE: 18": 0 to 38'
9 7/8": 38 to 575'
6 1/8": 575 to 624'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement: 108 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 20
From: 0
To: 574
Cement: 378 Cu. Ft.

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-8b	Surficial Deposits	0-10
	Gatuna Formation	10-153
	Dockum Group	NP
	Dewey Lake Red Beds	153-399
	Rustler Formation	399-T.D.
	Magenta Dolomite Member	466-490
	Culebra Dolomite Member	586-613
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	624

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-8c**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1276 (State Engineer's Office)

LOCATION: 2059.36' FNL, 1470.14' FEL,
Sec. 23, T 24 S, R 30 E

ELEVATION: 3432.90' (Top of Casing)
TOTAL DEPTH: 808'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 07/27/79 **Date Completed:** 08/06/79

HOLE SIZE: 9 7/8"

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement: 108 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 20
From: 0
To: 734
Cement: 314 Cu. Ft.

Currently used as a Rustler/Salado Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-8c	Holocene	
	Unconsolidated Alluvium and Eolian Sand	0-4
	Pleistocene Rocks	
	Mescalero Caliche	4-10
	Gatuna Formation	10-153
	Permian	
	Dewey Lake Red Beds	153-399
	Rustler Formation	399-733
	Magenta Dolomite Member	466-488
	Culebra Dolomite Member	588-614
	Salado Formation	733-
	Dissolution Residue	733-774
	MB 103	774-786
	Top of Salt Interval	798
	Total Depth	808

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-9a**
OPERATOR: Sandia National Lab
PERMIT NO.: 0.08.1277 (State Engineer's Office)

LOCATION: 2392.14' FNL, 138.92' FWL,
Sec. 4, T 24 S, R 31 E

ELEVATION: 3406.68' (Top of Casing)
TOTAL DEPTH: 692'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 07/09/79 **Date Completed:** 08/23/83

HOLE SIZE: 18": 0 to 40'
9 3/4": 40 to 512'
6 1/8": 512 to 645'
4 3/4": 645 to 692'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 20
From: 0
To: 570
Cement: 266 Cu. Ft.

Diameter: 4.5" O.D.
Grade: J-55
Wt/Ft: 9.5
From: 0
To: 643
Cement:

Hole in standby condition for testing.

**********RECOMPLETION**********

April 19, 1984, the plug was drilled out.

April 23, 1984, a screen and packer assembly was placed across the Culebra after washing the hole to 683'.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-9a	Holocene	
	Surficial Deposits	0-5
	Pleistocene	
	Gatuna Formation	5-25
	Ochoan	
	Dewey Lake Red Beds	25-455
	Rustler Formation	455-T.D.
	Forty-Niner Member	455-523
	Magenta Dolomite Member	523-554
	Tamarisk Member	554-647
	Culebra Dolomite Member	647-677
	Unnamed Part	677-T.D.
	Total Depth	692

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-9b**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1278 (State Engineer's Office)

LOCATION: 2391.04' FNL, 238.63' FWL,
Sec. 4, T 24 S, R 31 E

ELEVATION: 3406.86' (Top of Casing)
TOTAL DEPTH: 708'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/14/79 **Date Completed:** 08/28/79

HOLE SIZE: 18": 0 to 40'
9 3/4": 40 to 638'
6 1/8": 638 to 708'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade: K-55
Wt/Ft: 48
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 638
Cement: 295 Cu. Ft.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-9b	Surficial Deposits	0-5
	Gatuna Formation	5-25
	Dockum Group	NP
	Dewey Lake Red Beds	24-455
	Rustler Formation	455-T.D.
	Magenta Dolomite Member	523-554
	Culebra Dolomite Member	647-677
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	708

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-9c**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1279 (State Engineer's Office)

LOCATION: 2479.06' FNL, 188.02' FWL,
Sec. 4, T 24 S, R 31 E

ELEVATION: 3407.30' (Top of Casing)
TOTAL DEPTH: 816'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/01/79 **Date Completed:** 09/24/79

HOLE SIZE: 18": 0 to 40'
9 3/4": 40 to 785'
6 1/8": 785 to 816'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade: K-55
Wt/Ft: 48
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 20
From: 0
To: 783
Cement: 320 Cu. Ft.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-9c	Holocene	
	Eolian Sand and Caliche	0-5
	Pleistocene Rocks	
	Gatuna Formation	5-25
	Permian Rocks	
	Dewey Lake Redbeds	25-455
	Rustler Formation	455-791
	Dissolution Residue	484-501
	Magenta Dolomite Member	523-554
	Dissolution Residue	615-625
	Culebra Dolomite Member	647-677
	Dissolution Residue	692-712
	Salado Formation	791
	Top of Salt Interval	791
	Total Depth	816

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-10a**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1280 (State Engineer's Office)

LOCATION: 433.0' FSL, 2068.9' FEL, Sec. 20, T 23 S, R 32 E

ELEVATION: 3688.67' (Top of Casing)
TOTAL DEPTH: 1318'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/21/79 **Date Completed:** 08/26/79

HOLE SIZE: 9 7/8"

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade: K-55
Wt/Ft: 48
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 1243
Cement: 519 Cu. Ft.

Currently used as a Magenta Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-10a	Surficial Deposits	0-9
	Gatuna Formation	9-90
	Santa Rosa Formation	90-482 Chinle 482-658
	Dewey Lake Redbeds	658-1204
	Rustler Formation	1204-
	Magenta Dolomite Formation	1256-1280
	Total Depth	1318

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-10b**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1281 (State Engineer's Office)

LOCATION: 484.5' FSL, 1981.8' FEL, Sec. 20, T 23 S, R 32 E

ELEVATION: 3689.47' (Top of Casing)
TOTAL DEPTH: 1398'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 10/07/79 **Date Completed:** 10/13/79

HOLE SIZE: 9 7/8"

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade:
Wt/Ft: 48
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 1346
Cement: 480 Cu. Ft.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-10b	Surficial Deposits	do
	Gatuna Formation	do
	Santa Rosa Formation	do
	Dewey Lake Redbeds	do
	Rustler Formation	1204-
	Magenta Dolomite	1256-1280
	Culebra Dolomite	1360-1391
	Total Depth	1398

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-10c**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1282 (State Engineer's Office)

LOCATION: 384.5' FSL, 1981.8 FEL, Sec. 20, T 23 S, R 32 E

ELEVATION: 3687' (Top of Casing)
TOTAL DEPTH: 1550'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/11/79 **Date Completed:** 08/20/79

HOLE SIZE: 9 7/8"

WELL DEVELOPMENT:

CASING RECORD

Diameter: 13 3/8
Grade: K-55
Wt/Ft: 48
From: 0
To: 38
Cement: 72 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 20
From: 0
To: 1483
Cement: 627 Cu. Ft.

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-10c	Holocene	
	Unconsolidated Alluvium and Eolian Sand	0-5
	Pleistocene	
	Mescalero Caliche	5-9
	Gatuna Formation	9-90
	Triassic	
	Dockum Group	
	Chinle Formation	90-482
	Santa Rosa Sandstone	482-658
	Permian	
	Dewey Lake Red Beds	658-1204
	Rustler Formation	1204-1501
	Magenta Dolomite Member	1256-1280
	Culebra Dolomite Member	1360-1387
	Salado Formation	1501
	Top of Salt Interval	1501
	Total Depth	1538

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-11b1**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1462 (State Engineer's Office)

LOCATION: 173.91' FEL, 1510.69' FSL,
Sec. 33, T 22 S, R 31 E

ELEVATION: 3411' (Top of Casing)
TOTAL DEPTH: 785'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 08/03/83 **Date Completed:** 09/02/83

HOLE SIZE: 18": 0 to 35'
7 7/8": 35 to 733'
4 3/4": 733 to 785'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: H-40
Wt/Ft: 40
From: 0
To: 35
Cement: 27 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 732
Cement:

4 3/4" open hole from 732' to the total depth of 785'.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-11b1	Quaternary	deposits
	Holocene Deposits	0-12.5
	Upper Triassic Rocks	
	Dockum Group (undifferentiated)	12.5-63
	Upper Permian Rocks	
	Dewey Lake Redbeds	63-558
	Rustler Formation	
	Forty-niner Member	558-611
	Magenta Dolomite Member	611-638
	Tamarisk Member	638-730
	Culebra Dolomite Member	730-756
	Unnamed lower member	756-785+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-11b2**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1462 (State Engineer's Office)

LOCATION: 1436.3' FSL, 168.7' FEL, Sec. 33, T 22 S, R 31 E

ELEVATION: 3411.64' (Top of Casing)
TOTAL DEPTH: 776'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 10/01/83 **Date Completed:** 11/28/83

HOLE SIZE: 7 7/8": 35 to 734'
4 3/4": 734 to 776'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: H-40
Wt/Ft: 40
From: 0
To: 37
Cement:

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 733.4
Cement: Cemented

4 3/4" open hole from 733.39' to the total depth of 776'.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-11b2	Quaternary	deposits
	Holocene Deposits	0-11
	Upper Triassic Rocks	
	Dockum Group (undifferentiated)	11-62
	Upper Permian Rocks	
	Dewey Lake Redbeds	62-560
	Rustler Formation	
	Forty-niner Member	560-618
	Magenta Dolomite Member	618-644
	Tamarisk Member	644-733
	Culebra Dolomite Member	733-757
	Unnamed lower member	757-776+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-11b3**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1462 (State Engineer's Office)

LOCATION: 1501.7' FSL, 105.2' FEL, Sec. 33, T 22 S, R 31 E

ELEVATION: 3412.42' (Top of Casing)
TOTAL DEPTH: 788.7'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 12/01/83 **Date Completed:** 01/04/84

HOLE SIZE: 7 7/8": 35 to 734'
4 3/4": 734 to 789'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: H-30
Wt/Ft: 40
From: 0
To: 34
Cement: 27 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 55
From: 0
To: 733
Cement:

4 3/4" open hole from 733' to the total depth of 788.7'.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-11b3	Quaternary	deposits
	Holocene Deposits	0-11
	Upper Triassic Rocks	
	Dockum Group (undifferentiated)	11-65
	Upper Permian Rocks	
	Dewey Lake Redbeds	65-565.7
	Rustler Formation	565.7-788.7+
	Forty-niner Member	565.7-622.9
	Magenta Dolomite Member	622.9-648.8
	Tamarisk Member	648.8-740.2
	Culebra Dolomite Member	740.2-765.5
	Unnamed lower member	765.7-788.7+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-11b4**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1474 (State Engineer's Office)

LOCATION: 1514.7' FSL, 320.2' FEL, Sec. 33, T 22 S, R 31 E

ELEVATION: 3410.89' (Top of Casing)
TOTAL DEPTH: 765'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 02/23/88 **Date Completed:** 03/17/88

HOLE SIZE: 16": 0 to 27'
7 7/8": 27 to 714'
4 3/4": 714 to 765'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 8 5/8
Grade: H-40
Wt/Ft: 28
From: 0
To: 27
Cement: 18 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 714
Cement:

4 3/4 " open hole from 715' to total depth of 765'.

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-11b4	Quaternary	deposits
	Holocene	0-6
	Pleistocene	
	Mescalero Caliche	6-11
	Upper Triassic Rocks	
	Dockum Group (undifferentiated)	11-60
	Upper Permian Rocks	
	Dewey Lake Redbeds	60-554
	Rustler Formation	554-765.3+
	Forty-niner Member	554-614
	Magenta Dolomite Member	614-642
	Tamarisk Member	642-723.2
	Culebra Dolomite Member	723.2-746.1
	Unnamed Lower Member	746.1-765.3+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-12**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1463 (State Engineer's Office)

LOCATION: 23.1' FNL, 91.9' FEL,
Sec. 15, T 23 S, R 31 E

ELEVATION: 3427.19' (Top of Casing)
TOTAL DEPTH: 1001'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 10/03/83 **Date Completed:** 10/18/83

HOLE SIZE: 12": 0 to 41'
7 7/8": 41 to 820'
4 3/4": 820 to 1001'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 9 5/8
Grade: H-40
Wt/Ft: 36
From: 0
To: 37
Cement: 63 Cu. Ft.

Diameter: 5 1/2
Grade: J-55
Wt/Ft: 15.5
From: +1.45
To: 820
Cement:

4 3/4 " open hole from 820' to plugged back depth of 890'.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-12	Quaternary Deposits	0-10+
	Dockum Group	10+-70
	Dewey Lake Red Beds	70-622
	Rustler Formation	622-976
	Forty-Niner Member	622-678
	Magenta Dolomite Member	678-703
	Tamarisk Member	703-823
	Culebra Dolomite Member	823-850
	Unnamed Lower Member	850-976
	Salado Formation	976-T.D.
	Unnamed Upper Member	976-T.D.
	Total Depth	1001

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE:	**H-14**
OPERATOR:	Sandia National Labs
PERMIT NO.:	0.08.1469 (State Engineer's Office)
LOCATION:	372.2' FSL, 562.4' FWL, Sec. 29, T 22 S, R 31 E
ELEVATION:	3347.11' (Top of Casing)
TOTAL DEPTH:	589'
TYPE OF WELL:	Hydrologic Test Hole
DRILLER:	Pennsylvania Drilling Company
DRILLING RECORD:	**Date Started:** 09/25/86 **Date Completed:** 10/23/86
HOLE SIZE:	12 1/4": 0 to 39' 7 7/8": 39 to 533' 4 3/4": 533 to 589'

WELL DEVELOPMENT:

CASING RECORDS

Diameter: 8.625
Grade: H-40
Wt/Ft: 28
From: +1.6
To: 39
Cement: 27 cu. ft. of ready-mix grout

Diameter: 5.5
Grade: J-55
Wt/Ft: 15.5
From: 0
To: 532
Cement:

4 3/4" open hole from 532' to the total depth of 589'.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-14	Surficial Deposits	0-13
	Gatuna Formation	13-40
	Dockum Group	NP
	Dewey Lake Red Beds	40-360
	Rustler Formation	360-T.D.
	Magenta Dolomite Member	424-448
	Culebra Dolomite Member	545-572
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	589

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-15**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1470 (State Engineer's Office)

LOCATION: 88.7' FNL, 174.3' FEL, Sec. 28, T 22 S, R 31 E

ELEVATION: 3481.63' (Top of Casing)
TOTAL DEPTH: 900'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 10/24/86 **Date Completed:** 10/14/86

HOLE SIZE:
12 1/2": 0 to 39'
7 7/8": 39 to 854'
4 3/4": 854 to 900'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 8.625
Grade: H-40
Wt/Ft: 28
From: 0
To: 39
Cement: 27 cu. ft. of ready-mix grout

Diameter: 5.5
Grade: J-55
Wt/Ft: 15.5
From: +1.4
To: 853
Cement:

4 3/4" open hole from 853' to the total depth of 900'.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-15	Surficial Deposits	0-8
	Gatuna Formation	4-42
	Dockum Group	42-168
	Dewey Lake Red Beds	168-692
	Rustler Formation	692-T.D.
	Magenta Dolomite Member	748-773
	Culebra Dolomite Member	861-883
	Salado Formation	
	Upper Member	
	McNutt Member	
	Lower Member	
	Total Depth	900

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-16**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1471 (State Engineer's Office)

LOCATION: 1112.6 FSL, 1241.3 FEL, Sec. 20, T 22 S, R 31 E

ELEVATION: 3406.77' (Top of Casing)
TOTAL DEPTH: 850.9'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 07/13/87 **Date Completed:** 08/18/87

HOLE SIZE: 18": 0 to 36'
9 5/8": 36 to 469'
6 1/8": 469 to 850.9'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 3/4
Grade:
Wt/Ft: 40.5
From: 0
To: 36.5
Cement: 35 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 23
From: 0
To: 469
Cement:

6 1/8" inch open hole from 469' to total depth of 850.9'.

Currently used as a Dewey Lake and Unnamed Lower Member Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-16	Quaternary Deposits	
	Holocene	
	Drill pad material and unconsolidated sand	0-12
	Pleistocene rocks	
	Mescalero caliche	12-18
	Gatuna Formation	18-37
	Upper Triassic Rocks	
	Dockum Group (undifferentiated)	37-52
	Upper Permian Rocks	
	Dewey Lake Redbeds	52-531.9
	Rustler Formation	531.9-841.5
	Forty-niner Member	531.9-590.2
	Magenta Dolomite Member	590.2-615.6
	Tamarisk Member	615.6-702.5
	Culebra Dolomite Member	702.5-724.4
	Unnamed Lower Member	724.4-841.5
	Salado Formation	841.5-850.9+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-17**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1477 (State Engineer's Office)

LOCATION: 1465.5' FSL, 994.1' FWL, Sec. 3, T 23 S, R 31 E

ELEVATION: 3385.31' (Top of Casing)
TOTAL DEPTH: 880'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 09/21/87 **Date Completed:** 11/04/87

HOLE SIZE:
12 1/4": 0 to 38'
9 5/8": 38 to 692'
6 1/8": 692 to 870.3'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 3/4
Grade: H-40
Wt/Ft: 40.5
From: 0
To: 38
Cement: 35 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 692
Cement:

6 1/8" inch open hole from 693' to the plugged back depth of 773'.

The borehole was plugged back with cement grout to a total depth of 773' on 11/06/87.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-17	Quaternary Deposits	
	Holocene	0-15
	Pleistocene	
	Mescalero Caliche	15-21.5
	Upper Triassic	
	Dockum Group	21.5-55
	Upper Permian	
	Dewey Lake Red Beds	55-509
	Rustler Formation	509-855.7
	Forty-Niner Member	509-564
	Magenta Dolomite Member	564-590.8
	Tamarisk Member	590.8-705.8
	Culebra Dolomite Member	705.8-731.4
	Unnamed Lower Member	731.4-855.7
	Salado Formation	855.7-870.3+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-18**
OPERATOR: Sandia National Labs
PERMIT NO.: 0.08.1473 (State Engineer's Office)

LOCATION: 964.8' FNL, 445.6' FWL, Sec. 20, T 22 S, R 31 E

ELEVATION: 3414.21' (Top of Casing)
TOTAL DEPTH: 840'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Pennsylvania Drilling Company

DRILLING RECORD: **Date Started:** 09/29/87 **Date Completed:** 11/16/87

HOLE SIZE: 12 1/4": 0 to 38'
9 5/8": 38 to 673'
6 1/8": 673 to 830.5'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 10 3/4
Grade: H-40
Wt/Ft: 40.5
From: 0
To: 39
Cement: 37 Cu. Ft.

Diameter: 7
Grade: J-55
Wt/Ft: 23
From: 0
To: 673
Cement:

6 1/8" inch open hole from 673' to the plugged back depth of 766'.

The borehole was plugged back with cement grout to a total depth of 766' on 11/19/87.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-18	Quaternary Deposits	
	Holocene	
	Drill Pad Material & Unconsolidated Sand	0-5
	Pleistocene	
	Mescalero Caliche	5-8
	Upper Triassic	
	Dockum Group	8-20
	Upper Permian	
	Dewey Lake Red Beds	20-506.1
	Rustler Formation	506.1-820.9
	Forty-Niner Member	506.1-571.2
	Magenta Dolomite	571.2-594.2
	Tamarisk Member	594.2-688.6
	Culebra Dolomite Member	688.6-712.8
	Unnamed Lower Member	712.8-820.9
	Salado Formation	820.9-830.5+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H19b**
OPERATOR: US DOE/CAO
PERMIT NO.: C 2420

LOCATION: SE 1/4, SE 1/4, NE 1/4, SW 1/4, Sec. 28, T 22 S, R 31 E

ELEVATION: 3417.2' (Aluminum Cap)
TOTAL DEPTH: 787.7'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Water Development Corporation

DRILLING RECORD: **Date Started:** 03/28/95 **Date Completed:** 04/22/95

HOLE SIZE:
24": 0 to 38'
14 3/4": 38 to 731.9'
7 3/4": 731.9 to 778.7'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 20
Grade:
Wt/Ft: 53
From: 30
To: 38
Cement: 50 Cu. Ft.

Diameter: 9 5/8
Grade:
Wt/Ft: 5.7
From: 1.2
To: 731.9
Cement: 794 cu. ft.

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-19b	Holocene	0-28
	Dockum Group	28-53
	Dewey Lake Redbeds	53-567
	Rustler Formation	
	Forty-niner Member	567-628
	Magenta Dolomite Member	628-652
	Tamarisk Member	652-740.1
	Culebra Dolomite Member	740.1-764.4
	Unnamed Lower Member	764.4-778.7+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-19b2**
OPERATOR: US DOE/CAO
PERMIT NO.: C 2421

LOCATION: SE 1/4, SE 1/4, NE 1/4, SW 1/4, Sec 28, T 22 S, R 31 E

ELEVATION: 3417.1' (Aluminum Cap)
TOTAL DEPTH: 786'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Water Development Corporation

DRILLING RECORD: **Date Started:** 05/10/95 **Date Completed:** 05/20/95

HOLE SIZE:
18": 0 to 37'
12 1/4": 37 to 732.4'
5.88": 732.4 to 786'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 14
Grade:
Wt/Ft: 42
From: 0.3
To: 37
Cement: 35 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 5.7
From: +2
To: 732.4
Cement: 606 Cu. Ft.

Diameter: 5 1/2
Grade:
Wt/Ft: PVC Liner
From: 766
To: 780
Cement:

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-19b2	Holocene	0-28
	Dockum Group	28-58
	Dewey Lake Redbeds	58-567
	Rustler Formation	
	Forty-niner Member	567-628
	Magenta Dolomite Member	628-653
	Tamarisk Member	653-741.6
	Culebra Dolomite Member	741.6-765
	Unnamed Lower Member	765-786+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-19b3**
OPERATOR: US DOE/CAO
PERMIT NO.: C 2422

LOCATION: SE 1/4, SE 1/4, NE 1/4, SW 1/4, Sec 28, T 22 S, R 31 E

ELEVATION: 3417.2' (Aluminum Cap)
TOTAL DEPTH: 785'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Water Development Corporation

DRILLING RECORD: **Date Started:** 04/23/95 **Date Completed:** 05/09/95

HOLE SIZE: 18": 0 to 38'
12 1/4": 38 to 734'
5.88": 734 to785'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 14
Grade:
Wt/Ft: 42
From: +30
To: 38
Cement: 35 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 5.7
From: 1.7
To: 732
Cement: 606 Cu. Ft.

Diameter: 5 1/2
Grade:
Wt/Ft: PVC Liner
From: 762
To: 782
Cement:

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-19b3	Holocene	0-26
	Dockum Group	26-60
	Dewey Lake Redbeds	60-568
	Rustler Formation	
	Forty-niner Member	568-629
	Magenta Dolomite Member	629-654
	Tamarisk Member	654-740
	Culebra Dolomite Member	740-765
	Unnamed Lower Member	765-785+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-19b4**
OPERATOR: US DOE/CAO
PERMIT NO.: C 2423

LOCATION: SE 1/4, SE 1/4, Ne 1/4, SW 1/4, Sec 28, T 22 S, R 31 E

ELEVATION: 3416' (Aluminum Cap)
TOTAL DEPTH: 782'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Water Development Corporation

DRILLING RECORD: **Date Started:** 05/26/95 **Date Completed:** 06/05/95

HOLE SIZE:
18": 0 to 38'
12 1/4": 38 to 736.7'
5.88": 736.7 to782'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 14
Grade:
Wt/Ft: 42
From: 0
To: 38
Cement: 35 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 5.7
From: +2.6
To: 730.7
Cement: 606 Cu. Ft.

Diameter: 5 1/2
Grade:
Wt/Ft: PVC Liner
From: 762
To: 782
Cement:

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-19b4	Holocene	0-28
	Dockum Group	28-58
	Dewey Lake Redbeds	58-568
	Rustler Formation	
	Forty-niner Member	568-628
	Magenta Dolomite Member	628-653
	Tamarisk Member	653-738.5
	Culebra Dolomite Member	738.5-761.8
	Unnamed Lower Member	761.8-782+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-19b5**
OPERATOR: US DOE/CAO
PERMIT NO.: C 2424

LOCATION: SE 1/4, SE 1/4, Ne 1/4, SW 1/4, Sec 28, T 22 S, R 31 E

ELEVATION: 3417.1' (Aluminum Cap)
TOTAL DEPTH: 785.5'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Water Development Corporation

DRILLING RECORD: **Date Started:** 06/11/95 **Date Completed:** 08/27/95

HOLE SIZE:
18": 0 to 38'
12 1/4": 38 to 734'
5.88": 734 to 785.5'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 14
Grade:
Wt/Ft: 42
From: +30
To: 38
Cement: 35 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 5.7
From: +1.6
To: 730.7
Cement: 606 Cu. Ft.

Diameter: 5 1/2
Grade:
Wt/Ft: PVC Liner
From: 763
To: 783
Cement:

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-19b5	Holocene	0-29
	Dockum Group	29-58
	Dewey Lake Redbeds	58-565
	Rustler Formation	
	Forty-niner Member	565-623
	Magenta Dolomite Member	623-649
	Tamarisk Member	649-736.7
	Culebra Dolomite Member	736.7-761.2
	Unnamed Lower Member	761.2-785.5+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-19b6**
OPERATOR: US DOE/CAO
PERMIT NO.: C 2425

LOCATION: SE 1/4, SE 1/4, Ne 1/4, SW 1/4, Sec 28, T 22 S, R 31 E

ELEVATION: 3417.2' (Aluminum Cap)
TOTAL DEPTH: 788.1'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Water Development Corporation

DRILLING RECORD: **Date Started:** 07/10/95 **Date Completed:** 08/25/95

HOLE SIZE:
18": 0 to 39'
12 1/4": 39 to 733'
5.88": 733 to 788.1'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 14
Grade:
Wt/Ft: 42
From: +30
To: 39
Cement: 35 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 5.7
From: 1.9
To: 730.1
Cement: 606 Cu. Ft.

Diameter: 5 1/2
Grade:
Wt/Ft: PVC Liner
From: 766
To: 786
Cement:

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-19b6	Holocene	0-28
	Dockum Group	28-63
	Dewey Lake Redbeds	63-566
	Rustler Formation	
	Forty-niner Member	566-623
	Magenta Dolomite Member	623-649
	Tamarisk Member	649-739
	Culebra Dolomite Member	739-765
	Unnamed Lower Member	765-788.1+

HYDROLOGIC TEST BOREHOLE DATA BASE

BOREHOLE: **H-19b7**
OPERATOR: US DOE/CAO
PERMIT NO.: C2426

LOCATION: SE 1/4, SE 1/4, Ne 1/4, SW 1/4, Sec 28, T 22 S, R 31 E

ELEVATION: 3417.2' (Aluminum Cap)
TOTAL DEPTH: 785'
TYPE OF WELL: Hydrologic Test Hole
DRILLER: Water Development Corporation

DRILLING RECORD: **Date Started:** 07/26/95 **Date Completed:** 08/20/95

HOLE SIZE:
18": 0 to 38'
12 1/4": 38 to 734'
5.88": 734 to 785'

WELL DEVELOPMENT:

CASING RECORD

Diameter: 14
Grade:
Wt/Ft: 42
From: +10
To: 38
Cement: 35 Cu. Ft.

Diameter: 7
Grade:
Wt/Ft: 5.7
From: .8
To: 731
Cement: 606 Cu. Ft.

Diameter: 5 1/2
Grade:
Wt/Ft: PVC Liner
From: 764
To: 784
Cement:

Current status - Not in use.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
H-19b7	Holocene	0-28
	Dockum Group	28-60
	Dewey Lake Redbeds	60-567
	Rustler Formation	
	Forty-niner Member	567-627
	Magenta Dolomite Member	627-652
	Tamarisk Member	652-739.5
	Culebra Dolomite Member	739.5-764
	Unnamed Lower Member	764-785+

Potash Borehole Data Base

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-1**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 327' FSL, 551' FWL of Sec. 29, SW 1/4, T 22 S, R 31 E

ELEVATION: 3345'
TOTAL DEPTH: 1591'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 08/23/76 **Date Completed:** 09/02/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 32'
6 1/4": 32 to 794'
3 3/8": 794 to 1200'
3 1/4": 1200 to1591'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade: Used
Wt/Ft:
From: 0
To: 32
Cement: None

Diameter: 4 1/2
Grade: Used
Wt/Ft:
From: 0
To: 794
Cement: None

7" casing recovered. 203' of 4 1/2" casing left in hole between 591-794' below land surface.

PLUGGING SCHEDULE

From: 1591'
To: 0'
Int: 1591'
Material: 310 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-1	Holocene Deposits	0-10
	Pleistocene Rocks	
	Gatuna Formation	10-40
	Permian Rocks	
	Dewey Lake Red Beds	40-358
	Rustler Formation	358-677
	Magenta Dolomite Member	423-448
	Culebra Dolomite Member	538-565
	Salado Formation	677-1591
	Upper Member	677-1191
	McNutt Potash Zone	1191-1583
	Vaca Triste Sandstone Member	1191-1201
	11th Ore Zone	1246-1250
	MB 117	1259-1262
	MB 118	1282-1285
	MB 119	1307-1309
	10th Ore Zone	1319-1324
	MB 120	1334-1335
	9th Ore Zone	1338-1343
	MB 121	1347-1349
	MB 122	1356-1357
	8th Ore Zone	1361-1370
	Union Anhydrite	1381-1393
	7th Ore Zone	1400-1404
	6th Ore Zone	1414-1416
	5th Ore Zone	1419-1432
	MB 123	1462-1469
	MB 124	1477-1486
	4th Ore Zone	1490-1503
	3d Ore Zone	1511-1526
	2d Ore Zone	1533-1538
	1st Ore Zone	1554-1562
	MB 126	1582-1583
	Lower Member	1583-1587

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-2**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 125' FNL, 172' FEL of Sec. 28, NE1/4
Sec. 28, T 22 S, R 31 E

ELEVATION: 3478'
TOTAL DEPTH: 1895'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 08/25/76 **Date Completed:** 09/03/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE: 8 3/4": 0 to 20'
5 7/8": 20 to 1038'
3 15/16": 1038 to 1895'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade: Used
Wt/Ft:
From: 0
To: 20
Cement: None

Diameter: 4 1/2
Grade: HW
Wt/Ft:
From: 0
To: 1038
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1895'
To: 0'
Int: 1895'
Material: 274 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-2	Holocene Deposits	0-18
	Pleistocene Rocks	
	Gatuna Formation	18-38
	Triassic Rocks	
	Santa Rosa Sandstone	38-164
	Permian Rocks	
	Dewey Lake Red Beds	164-690
	Rustler Formation	690-1008
	Magenta Dolomite Member	748-773
	Culebra Dolomite Member	857-883
	Salado Formation	1008-1895
	Upper Member	1008-1506
	McNutt Potash Zone	1506-1883
	Vaca Triste Sandstone Member	1506-1512
	11th Ore Zone	1562-1565
	MB 117	1574-1576
	MB 118	1599-1601
	MB 119	1622-1626
	10th Ore Zone	1632-1639
	MB 120	1646-1647
	9th Ore Zone	1652-1656
	MB 121	1662-1663
	MB 122	1670-1671
	8th Ore Zone	1678-1687
	Union Anhydrite	1695-1705
	7th Ore Zone	1712-1719
	6th Ore Zone	1731-1733
	5th Ore Zone	1738-1745
	MB 123	1774-1781
	MB 124	1787-1795
	4th Ore Zone	1799-1809
	3d Ore Zone	1818-1832
	2d Ore Zone	1836-1840
	1st Ore Zone	1859-1870
	MB 126	1882-1883
	Lower Member	1883-1894

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-3**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 103' FSL, 3122' FEL of Sec. 20, SW1/4
Sec. 20, T 22 S, R 31 E

ELEVATION: 3382'
TOTAL DEPTH: 1676'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 08/26/76 **Date Completed:** 09/08/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE: 8 3/4": 0 to 30'
6 1/4": 30 to 826'
3 15/16": 826 to 1676'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade: Used
Wt/Ft:
From: 0
To: 30
Cement: None

Diameter: 4 1/2
Grade: Used
Wt/Ft:
From: 0
To: 826
Cement: None

7" casing recovered. 336' of 4 1/2" casing left in hole between 490-826' below land surface.

PLUGGING SCHEDULE

From: 1676'
To: 0'
Int: 1676'
Material: 302 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-3	Holocene Deposits	0-10
	Pleistocene rocks	
	Gatuna Formation	10-41
	Permian Rocks	
	Dewey Lake Red Beds	41-468
	Rustler Formation	468-786
	Magenta Dolomite Member	529-553
	Culebra Dolomite Member	642-665
	Salado Formation	786-1668
	Upper Member	786-1287
	McNutt Potash Zone	1287-1668
	Vaca Triste Sandstone Member	1287-1295
	11th Ore Zone	1346-1349
	MB 117	1357-1358
	MB 118	1375-1378
	MB 119	1405-1407
	10th Ore Zone	1415-1420
	MB 120	1428-1429
	9th Ore Zone	1434-1438
	MB 121	1443-1445
	MB 122	1452-1453
	8th Ore Zone	1458-1467
	Union Anhydrite	1473-1481
	7th Ore Zone	1494-1499
	6th Ore Zone	1509-1511
	5th Ore Zone	1515-1525
	MB 123	1555-1563
	MB 124	1571-1579
	4th Ore Zone	1585-1595
	3d Ore Zone	1599-1617
	2d Ore Zone	1623-1627
	1st Ore Zone	1645-1656
	MB 126	1667-1668

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-4**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 146' FSL, 1487' FEL of Sec. 28, SE1/4
Sec. 28, T 22 S, R 31 E

ELEVATION: 3441'
TOTAL DEPTH: 1857'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 08/27/76 **Date Completed:** 09/07/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE: 8 3/4": 0 to 23'
5 7/8": 23 to 958'
3 15/16": 958 to 1857'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 6 5/8
Grade: Used
Wt/Ft:
From: 0
To: 23
Cement: None

Diameter: 4 1/2
Grade: HW
Wt/Ft:
From: 0
To: 958
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1857'
To: 0'
Int: 1857'
Material: 360 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-4	Holocene Deposits	0-8
	Triassic Rocks	
	Santa Rosa Sandstone	8-99
	Permian Rocks	
	Dewey Lake Red Beds	99-609
	Rustler Formation	609-930
	Magenta Dolomite Member	662-686
	Culebra Dolomite Member	775-802
	Salado Formation	930-1857
	Upper Member	930-1446
	McNutt Potash Zone	1446-1853
	Vaca Triste Sandstone Member	1446-1452
	11th Ore Zone	1506-1509
	MB 117	1519-1521
	MB 118	1544-1547
	MB 119	1570-1572
	10th Ore Zone	1581-1589
	MB 120	1596-1597
	9th Ore Zone	1603-1607
	MB 121	1610-1612
	MB 122	1620-1621
	8th Ore Zone	1628-1637
	Union Anhydrite	1646-1659
	7th Ore Zone	1667-1671
	6th Ore Zone	1683-1686
	5th Ore Zone	1690-1700
	MB 123	1728-1735
	MB 124	1742-1752
	4th Ore Zone	1756-1768
	3d Ore Zone	1777-1792
	2d Ore Zone	1798-1803
	1st Ore Zone	1824-1835
	MB 126	1852-1853

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-5**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 202' FSL, 165' FEL of Sec. 17, SE1/4
Sec. 17, T 22 S, R 31 E

ELEVATION: 3472'
TOTAL DEPTH: 1830'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/10/76 **Date Completed:** 09/22/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 25'
6 1/4": 25 to 1000'
3 7/8": 1000 to 1420'
3 1/2": 1420 to 1830'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade: Used
Wt/Ft:
From: 0
To: 25
Cement: None

Diameter: 4 1/2
Grade:
Wt/Ft: 9.5
From: 0
To: 1003
Cement: None

7" casing recovered. 568' of 4 1/2" casing left in hole between 435-1003' below land surface.

PLUGGING SCHEDULE

From: 1830'
To: 0'
Int: 1830'
Material: 336 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-5	Holocene deposits	0-13
	Triassic Rocks	
	Santa Rosa Sandstone	13-146
	Permian Rocks	
	Dewey Lake Red Beds	146-623
	Rustler Formation	623-947
	Magenta Dolomite Member	686-711
	Culebra Dolomite Member	804-827
	Salado Formation	947-1830
	Upper Member	947-1429
	McNutt Potash Zone	1429-1785
	Vaca Triste Sandstone Member	1429-1436
	11th Ore Zone	1482-1486
	MB 117	1492-1494
	MB 118	1514-1517
	MB 119	1541-1543
	10th Ore Zone	1550-1556
	MB 120	1560-1561
	9th Ore Zone	1567-1571
	MB 121	1573-1575
	MB 122	1580-1582
	8th Ore Zone	1589-1595
	Union Anhydrite	1604-1611
	7th Ore Zone	1623-1628
	6th Ore Zone	1635-1638
	5th Ore Zone	1643-1659
	MB 123	1680-1687
	MB 124	1695-1705
	4th Ore Zone	1709-1717
	3d Ore Zone	1725-1737
	1st Ore Zone	1742-1746
	MB 126	1784-1785
	Lower Member	1785-1830
	MB 127	1810-1811
	MB 128	1821-1822

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-6**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 2767' FSL, 199' FWL of Sec. 30, NW1/4
Sec. 30, T 22 S, R 31 E

ELEVATION: 3354'
TOTAL DEPTH: 1573'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/03/76 **Date Completed:** 09/17/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 18'
5 7/8": 18 to 703'
3 15/16": 703 to 1573'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 6 5/8
Grade: Used
Wt/Ft:
From: 0
To: 18
Cement: None

Diameter: 4 1/2
Grade: HW
Wt/Ft:
From: 0
To: 775
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1573'
To: 0'
Int: 1573'
Material: 374 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-6	Holocene Deposits	0-8
	Pleistocene Rocks	
	Gatuna Formation	8-18
	Permian Rocks	
	Dewey Lake Red Beds	18-357
	Rustler Formation	357-659
	Magenta Dolomite Member	417-443
	Culebra Dolomite Member	537-560
	Salado Formation	659-1573
	Upper Member	659-1162
	McNutt Potash Zone	1162-1560
	Vaca Triste Sandstone Member	1162-1170
	11th Ore Zone	1218-1221
	MB 117	1231-1233
	MB 118	1252-1256
	MB 119	1279-1281
	10th Ore Zone	1291-1296
	MB 120	1307-1308
	9th Ore Zone	1313-1317
	MB 121	1324-1326
	MB 122	1332-1333
	8th Ore Zone	1338-1348
	Union Anhydrite	1357-1365
	7th Ore Zone	1378-1382
	6th Ore Zone	1394-1396
	5th Ore Zone	1400-1410
	MB 123	1436-1443
	MB 124	1453-1462
	4th Ore Zone	1468-1481
	3d Ore Zone	1489-1502
	2d Ore Zone	1509-1513
	1st Ore Zone	1533-1543
	MB 126	1559-1560

POTASH BOREHOLE DATA BASE

BOREHOLE: P-7
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 513' FNL, 396' FWL of Sec. 5, NW1/4
Sec. 5, T 23 S, R 31 E

ELEVATION: 3332'
TOTAL DEPTH: 1574'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/04/76 **Date Completed:** 09/22/76

Remarks: Encountered air pocket at 980' below land surface, and lost casing seat. Encountered several air pockets between 980-1264'. Lost mud at 1234'.

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 31'
6 1/4": 31 to 740'
3 7/8": 740 to 1574'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade: Used
Wt/Ft:
From: 0
To: 31
Cement: None

Diameter: 4 1/2
Grade: Used
Wt/Ft: 9.5
From: 0
To: 740
Cement: None

7" casing recovered. 210' of 4 1/2" casing left in hole between 530-740' below land surface.

PLUGGING SCHEDULE

From: 1574'
To: 0'
Int: 1574'
Material: 346 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-7	Holocene Deposits	0-11
	Pleistocene Rocks	
	Gatuna Formation	11-45
	Permian Rocks	
	Dewey Lake Red Beds	45-312
	Rustler Formation	312-630
	Magenta Dolomite Member	373-398
	Culebra Dolomite Member	496-522
	Salado Formation	630-1574
	Upper Member	630-1155
	McNutt Potash Zone	1155-1566
	Vaca Triste Sandstone Member	1155-1162
	11th Ore Zone	1215-1220
	MB 117	1228-1230
	MB 118	1252-1256
	MB 119	1277-1279
	10th Ore Zone	1291-1296
	MB 120	1307-1308
	9th Ore Zone	1312-1316
	MB 121	1326-1328
	MB 122	1330-1331
	8th Ore Zone	1335-1346
	Union Anhydrite	1358-1372
	7th Ore Zone	1377-1382
	6th Ore Zone	1391-1393
	5th Ore Zone	1398-1407
	MB 123	1433-1441
	MB 124	1448-1459
	4th Ore Zone	1467-1484
	3d Ore Zone	1492-1507
	2d Ore Zone	1513-1518
	1st Ore Zone	1537-1547
	MB 126	1565-1566

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-8**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 642' FNL, 96' FWL of Sec. 4, NW1/4
Sec. 4, T 23 S, R 31 E

ELEVATION: 3336'
TOTAL DEPTH: 1660'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/08/76 **Date Completed:** 09/15/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE: 6 3/4": 0 to 23'
5 7/8": 23 to 860'
3 15/16": 860 to 1660'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 6 5/8
Grade: Used
Wt/Ft:
From: 0
To: 23
Cement: None

Diameter: 4 1/2
Grade: HW
Wt/Ft:
From: 0
To: 860
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1660'
To: 0'
Int: 1660'
Material: 310 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-8	Holocene Deposits	0-9
	Pleistocene Rocks	
	Gatuna Formation	9-39
	Permian Rocks	
	Dewey Lake Red Beds	39-391
	Rustler Formation	391-715
	Magenta Dolomite Member	450-474
	Culebra Dolomite Member	563-585
	Salado Formation	715-1660
	Upper Member	715-1237
	McNutt Potash Zone	1237-1652
	Vaca Triste Sandstone Member	1237-1245
	11th Ore Zone	1297-1301
	MB 117	1308-1310
	MB 118	1333-1337
	MB 119	1360-1362
	10th Ore Zone	1373-1380
	MB 120	1389-1390
	9th Ore Zone	1395-1399
	MB 121	1405-1407
	MB 122	1413-1414
	8th Ore Zone	1421-1430
	Union Anhydrite	1440-1455
	7th Ore Zone	1461-1465
	6th Ore Zone	1472-1475
	5th Ore Zone	1481-1492
	MB 123	1517-1524
	MB 124	1537-1545
	4th Ore Zone	1554-1567
	3d Ore Zone	1577-1596
	2d Ore Zone	1601-1604
	1st Ore Zone	1624-1633
	MB 126	1661-1662

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-9**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 1493' FSL, 143' FEL of Sec. 33, SE1/4
Sec. 33, T 22 S, R 31 E

ELEVATION: 3409'
TOTAL DEPTH: 1796'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/16/76 **Date Completed:** 09/26/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 23'
5 7/8": 23 to 1023'
3 15/16": 1023 to 1796'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 8 5/8
Grade: Used
Wt/Ft:
From: 0
To: 23
Cement: None

Diameter: 4 1/2
Grade: HW
Wt/Ft:
From: 0
To: 1023
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1796'
To: 0'
Int: 1796'
Material: 410 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-9	*Holocene Deposit*	0-11
	Triassic Rocks	
	Santa Rosa Sandstone	11-66
	Permian Rocks	
	Dewey Lake Red Beds	66-562
	Rustler Formation	562-881
	Magenta Dolomite Member	617-644
	Culebra Dolomite Member	734-757
	Salado Formation	881-1796
	Upper Member	881-1401
	McNutt Potash Zone	1401-1796
	Vaca Triste Sandstone Member	1401-1410
	11th Ore Zone	1458-1462
	MB 117	1471-1473
	MB 118	1496-1499
	MB 119	1519-1521
	10th Ore Zone	1530-1538
	MB 120	1546-1547
	9th Ore Zone	1552-1555
	MB 121	1561-1563
	MB 122	1569-1570
	8th Ore Zone	1577-1585
	Union Anhydrite	1597-1608
	7th Ore Zone	1613-1618
	6th Ore Zone	1626-1629
	5th Ore Zone	1634-1643
	MB 123	1668-1676
	MB 124	1686-1695
	4th Ore Zone	1699-1714
	3d Ore Zone	1723-1738
	2d Ore Zone	1744-1748
	1st Ore Zone	1769-1778
	MB 126	1795-1796

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-10**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 2315' FNL, 339' FWL of Sec. 26, NW1/4
Sec. 26, T 22 S, R 31 E

ELEVATION: 3508'
TOTAL DEPTH: 2009'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/24/76 **Date Completed:** 10/17/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 31'
6 1/4": 31 to 1209'
3 7/8": 1209 to 2009'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade: Used
Wt/Ft:
From: 0
To: 31
Cement: None

Diameter: 4 1/2
Grade: Used
Wt/Ft: 9.5
From: 0
To: 1209
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 2009'
To: 0'
Int: 2009'
Material: 504 Cu. Ft of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-10	Holocene Deposits	0-8
	Triassic Rocks	
	Santa Rosa Sandstone	8-151
	Permian Rocks	
	Dewey Lake Red Beds	151-686
	Rustler Formation	686-1086
	Magenta Dolomite Member	757-781
	Culebra Dolomite Member	931-957
	Salado Formation	1086-2009
	Upper Member	1086-1594
	McNutt Potash Zone	1594-1983
	Vaca Triste Sandstone Member	1594-1603
	11th Ore Zone	1652-1655
	MB 117	1662-1664
	MB 118	1686-1688
	MB 119	1710-1712
	10th Ore Zone	1717-1725
	MB 120	1733-1734
	9th Ore Zone	1740-1744
	MB 121	1751-1753
	MB 122	1759-1760
	8th Ore Zone	1765-1775
	Union Anhydrite	1784-1798
	7th Ore Zone	1807-1811
	6th Ore Zone	1822-1825
	5th Ore Zone	1831-1841
	MB 123	1868-1875
	MB 124	1880-1888
	4th Ore Zone	1892-1905
	3d Ore Zone	1913-1929
	2d Ore Zone	1934-1938
	1st Ore Zone	1961-1969
	MB 126	1982-1983
	Lower Member	1983-2009
	MB 127	2005-2008

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-11**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 175' FNL and 177' FWL of Sec. 23, NW1/4
Sec. 23, T 22 S, R 31 E

ELEVATION: 3506'
TOTAL DEPTH: 1940'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/24/76 **Date Completed:** 10/18/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 25'
5 7/8": 25 to 1200'
3 7/8": 1200 to 1580'
3 1/2": 1580 to 1940'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade: Used
Wt/Ft:
From: 0
To: 25
Cement: None

Diameter: 4 1/2
Grade: Used
Wt/Ft: 9.5
From: 0
To: 1200
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1940'
To: 0'
Int: 1940'
Material: 490 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-11	Holocene Deposits	0-9
	Triassic Rocks	
	Santa Rosa Sandstone	9-224
	Permian Rocks	
	Dewey Lake Red Beds	224-745
	Rustler Formation	745-1058
	Magenta Dolomite Member	798-823
	Culebra Dolomite Member	912-938
	Salado Formation	1058-1942
	Upper Member	1058-1550
	McNutt Potash Zone	1550-1917
	Vaca Triste Sandstone Member	1550-1557
	11th Ore Zone	1604-1608
	MB 117	1616-1618
	MB 118	1640-1642
	MB 119	1664-1666
	10th Ore Zone	1674-1682
	MB 120	1687-1688
	9th Ore Zone	1693-1698
	MB 121	1702-1704
	MB 122	1711-1712
	8th Ore Zone	1717-1724
	Union Anhydrite	1735-1740
	7th Ore Zone	1754-1759
	6th Ore Zone	1767-1770
	5th Ore Zone	1775-1785
	MB 123	1811-1818
	MB 124	1824-1833
	4th Ore Zone	1837-1846
	3d Ore Zone	1853-1866
	2d Ore Zone	1871-1874
	1st Ore Zone	1890-1901
	MB 126	1916-1917
	Lower Member	1917-1942
	MB 127	1940-1941

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-12**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 167' FNL, 195' FEL of Sec. 24, NE1/4
Sec. 24, T 22 S, R 30 E

ELEVATION: 3376'
TOTAL DEPTH: 1598'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/17/76 **Date Completed:** 10/23/76

Remarks: Lost circulation at 742' and 813' below land.

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 30'
6 1/4": 30 to 801'
5 7/8": 801 to 827'
3 7/8": 827 to 1080'
3 1/2": 1080 to 1598'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade: Used
Wt/Ft:
From: 0
To: 30
Cement: None

Diameter: 4 1/2
Grade: Used
Wt/Ft: 9.5
From: 0
To: 827
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1598'
To: 0'
Int: 1598'
Material: 889 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-12	Holocene Deposits	0-8
	Permian Rocks	
	Dewey Lake Red Beds	8-461
	Rustler Formation	461-749
	Magenta Dolomite Member	519-543
	Culebra Dolomite Member	633-656
	Salado Formation	749-1598
	Upper Member	749-1226
	McNutt Potash Zone	1226-1597
	Vaca Triste Sandstone Member	1226-1233
	11th Ore Zone	1280-1284
	MB 117	1290-1292
	MB 118	1314-1317
	MB 119	1338-1340
	10th Ore Zone	1346-1353
	MB 120	1361-1362
	9th Ore Zone	1367-1370
	MB 121	1376-1378
	MB 122	1384-1385
	8th Ore Zone	1390-1398
	Union Anhydrite	1407-1417
	7th Ore Zone	1432-1436
	6th Ore Zone	1442-1445
	5th Ore Zone	1450-1459
	MB 123	1486-1492
	MB 124	1494-1509
	4th Ore Zone	1514-1523
	3d Ore Zone	1533-1546
	2d Ore Zone	1550-1555
	1st Ore Zone	1572-1582
	MB 126	1596-1597

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-13**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 125' FNL, 116' FWL of Sec. 18, NW1/4
Sec. 18, T 22 S, R 31 E

ELEVATION: 3345'
TOTAL DEPTH: 1576'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/17/76 **Date Completed:** 09/24/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE: 8 3/4": 0 to 18'
5 7/8": 18 to 785'
3 15/16": 785 to 1576'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 6 5/8
Grade: Used
Wt/Ft:
From: 0
To: 18
Cement: None

Diameter: 4
Grade: HW
Wt/Ft:
From: 0
To: 785
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1576'
To: 0'
Int: 1576'
Material: 338 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-13	Holocene Deposits	0-12
	Pleistocene Rocks	
	Gatuna Formation	12-38
	Permian Rocks	
	Dewey Lake Red Beds	38-427
	Rustler Formation	427-721
	Magenta Dolomite Member	490-514
	Culebra Dolomite Member	604-627
	Salado Formation	721-1573
	Upper Member	721-1201
	McNutt Potash Zone	1201-1547
	Vaca Triste Sandstone Member	1201-1208
	11th Ore Zone	1252-1255
	MB 117	1264-1265
	MB 118	1287-1289
	MB 119	1309-1311
	10th Ore Zone	1317-1323
	MB 120	1330-1331
	9th Ore Zone	1336-1340
	MB 121	1344-1346
	MB 122	1355-1356
	8th Ore Zone	1359-1368
	Union Anhydrite	1377-1382
	7th Ore Zone	1395-1400
	6th Ore Zone	1407-1410
	5th Ore Zone	1413-1423
	MB 123	1447-1453
	MB 124	1462-1471
	4th Ore Zone	1474-1483
	3d Ore Zone	1491-1501
	2d Ore Zone	1506-1510
	1st Ore Zone	1525-1533
	MB 126	1547-1548
	Lower Member	1548-1573
	MB 127	1572-1573

POTASH BOREHOLE DATA BASE

OREHOLE: **P-14**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 307' FSL, 615.8' FWL of Sec. 24, SW1/4
Sec. 24, T 22 S, R 30 E

ELEVATION: 3358'
TOTAL DEPTH: 1545'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/24/76 **Date Completed:** 10/04/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 20'
7 7/8": 20 to 776'
4": 776 to 1188'
3 15/16": 1188 to 1545'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 8 5/8
Grade: Used
Wt/Ft:
From: 0
To: 10
Cement: None

Diameter: 4 1/2
Grade: J-55
Wt/Ft: 9.5
From: 0
To: 775
Cement: 324 Cu. Ft.

McCullough 12 bullet carrier gun left in hole.
8 5/8" casing pulled.

PLUGGING SCHEDULE

From: 1545'
To: 775'
Int: 770'
Material: 122 Cu. Ft. of Cement

From: 775'
To: 0'
Int: 775'
Material:

Hole plugged from 1545-775' with cement and converted to hydrologic observation well in Rus Formation.

**********RECOMPLETION**********

January 21, 1977, P-14 was perforated across the Rustler-Salado contact from 676 to 700'. A PIP was installed between the Rustler-Salado contact and the Culebra-dolomite. The casing was then perforated across the Culebra-dolomite interval from 573 to 601' with 72 holes.

March 7, 1977, casing perforated from 676 to 700' with 72 holes.

February 2, 1989, the P-14 casing was reperforated across the Culebra dolomite interval from 573' to 601' with 15/32" bullets at 4 shots/foot.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-14	Holocene Deposits	0-10
	Pleistocene Rocks	
	Gatuna Formation	10-42
	Permian Rocks	
	Dewey Lake Red Beds	42-387
	Rustler Formation	387-687
	Magenta Dolomite Member	453-475
	Culebra Dolomite Member	573-595
	Salado Formation	687-1540
	Upper Member	687-1133
	McNutt Potash Zone	1133-1510
	Vaca Triste Sandstone Member	1133-1141
	11th Ore Zone	1186-1190
	MB 117	1199-1200
	MB 118	1225-1228
	MB 119	1251-1253
	10th Ore Zone	1257-1263
	MB 120	1273-1274
	9th Ore Zone	1277-1282
	MB 121	1287-1289
	MB 122	1297-1298
	8th Ore Zone	1302-1310
	Union Anhydrite	1319-1328
	7th Ore Zone	1342-1345
	6th Ore Zone	1352-1355
	5th Ore Zone	1361-1370
	MB 123	1394-1400
	MB 124	1410-1419
	4th Ore Zone	1423-1435
	3d Ore Zone	1443-1455
	2d Ore Zone	1461-1465
	1st Ore Zone	1482-1492
	MB 126	1509-1510
	Lower Member	1510-1540
	MB 127	1534-1536

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-15**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 410.8' FSL, 192.32' FWL of Sec. 21, SW1/4
Sec. 31, T 22 S, R 31 E

ELEVATION: 3309.7'
TOTAL DEPTH: 1465'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 10/04/76 **Date Completed:** 10/15/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 20'
7 7/8": 20 to 637'
4": 637 to 1038'
3 15/16": 1038 to 1465'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 8 5/8
Grade: Used
Wt/Ft:
From: 0
To: 20
Cement: None

Diameter: 4 1/2
Grade: J-55
Wt/Ft: 9.5
From: +1
To: 635
Cement: 266 Cu. Ft.

8 5/8" casing recovered. 210' of 4 1/2" casing left in hole between 530-740' below land surface.

PLUGGING SCHEDULE

From: 1465'
To: 620'
Int: 845'
Material: 108 Cu. Ft. of Cement

From: 620'
To: 0'
Int: 620'
Material:

Hole plugged from 1465'-620' with cement, and converted to hydrologic observation well in Rustler Formation.

**********RECOMPLETION**********

January 21, 1977, P-15 was re-entered and the casing was perforated across the Rustler-Salado contact from 532' to 556' with 1/2" shots at 3 shots/foot.

April 6, 1977, the casing in P-15 was perforated across the Culebra-dolomite interval from 410' to 438' with 1/2" shots at 3 shots/foot.

After hydrologic testing of both perforated intervals, a Lynes 3 1/2" PIP was set at a depth of 512'.

June 1985, the PIP was removed from P-15 and a Lynes 3 1/2" retrievable bridge plug was set at 441.36' to provide access to the Culebra-dolomite interval for water-level monitoring.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-15	Holocene Deposits	0-11
	Pleistocene Rocks	
	Gatuna Formation	11-32
	Permian Rocks	
	Dewey Lake Red Beds	32-231
	Rustler Formation	231-542
	Magenta Dolomite Member	294-321
	Culebra Dolomite Member	413-435
	Salado Formation	542-1465
	Upper Member	542-1057
	McNutt Potash Zone	1057-1453
	Vaca Triste Sandstone Member	1057-1065
	11th Ore Zone	1116-1119
	MB 117	1128-1130
	MB 118	1149-1152
	MB 119	1176-1178
	10th Ore Zone	1187-1195
	MB 120	1203-1204
	9th Ore Zone	1208-1212
	MB 121	1216-1218
	MB 122	1225-1226
	8th Ore Zone	1234-1244
	Union Anhydrite	1251-1263
	7th Ore Zone	1271-1275
	6th Ore Zone	1284-1288
	5th Ore Zone	1292-1301
	MB 123	1326-1333
	MB 124	1343-1353
	4th Ore Zone	1361-1376
	3d Ore Zone	1384-1397
	2d Ore Zone	1404-1408
	1st Ore Zone	1426-1436
	MB 126	1452-1453

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-16**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 951' FSL, 1629' FEL of Sec. 5, SW1/4
Sec. 5, T 23S, R 31E

ELEVATION: 3323'
TOTAL DEPTH: 1585'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 09/27/76 **Date Completed:** 10/06/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 23'
5 7/8": 23 to 770'
3 15/16": 770 to 1585

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 6 5/8
Grade: Used
Wt/Ft:
From: 0
To: 23
Cement: None

Diameter: 4
Grade: HW
Wt/Ft:
From: 0
To: 770
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1585'
To: 0'
Int: 1585'
Material: 353 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-16	Holocene Deposits	0-14
	Pleistocene Rocks	
	Gatuna Formation	14-32
	Permian Rocks	
	Dewey Lake Red Beds	32-316
	Rustler Formation	316-646
	Magenta Dolomite Member	376-401
	Culebra Dolomite Member	500-523
	Salado Formation	646-1587
	Upper Member	646-1174
	McNutt Potash Zone	1174-1585
	Vaca Triste Sandstone Member	1174-1182
	11th Ore Zone	1235-1237
	MB 117	1245-1247
	MB 118	1269-1273
	MB 119	1293-1295
	10th Ore Zone	1307-1313
	MB 120	1323-1324
	9th Ore Zone	1328-1331
	MB 121	1336-1338
	MB 122	1345-1346
	8th Ore Zone	1352-1365
	Union Anhydrite	1373-1390
	7th Ore Zone	1396-1400
	6th Ore Zone	1411-1412
	5th Ore Zone	1417-1425
	MB 123	1450-1456
	MB 124	1460-1470
	4th Ore Zone	1480-1501
	3d Ore Zone	1510-1526
	2d Ore Zone	1533-1536
	1st Ore Zone	1556-1568
	MB 126	1583-1585

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-17**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 1372.2' FSL, 401.9' FWL of Sec. 4, SW1/4
Sec. 4, T 23 S, R 31 E

ELEVATION: 3340'
TOTAL DEPTH: 1660'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 10/18/76 **Date Completed:** 10/28/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 20'
7 7/8": 20 to 755'
4": 755 to 1220'
3 15/16": 1220 to 1660'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 8 5/8
Grade: Used
Wt/Ft:
From: 0
To: 20
Cement: None

Diameter: 4 1/2
Grade: J-55
Wt/Ft: 9.5
From: +1
To: 751
Cement: 310 Cu. Ft.

8 5/8" casing recovered.

PLUGGING SCHEDULE

From: 1660'
To: 731'
Int: 929'
Material: 130 Cu. Ft. of Cement

From: 731'
To: 0'
Int: 731'
Material:

Hole plugged from 1660'-731 with cement and converted to hydrologic observation well in Rustler Formation.

**********RECOMPLETION**********

January 20, 1977, P-17 was bailed dry and perforated across the Rustler-Salado contact at 3 shots/foot from 702' to 726'

April 5, 1977, a 3 1/2" PIP was installed on tubing and set at 682.5'. The tubing was removed from the well and the casing was perforated across the Culebra-dolomite interval from 558' to 586'. The majority of the borehole fluid was removed by bailing and fluid levels were monitored until May 1977.

May 12, 1977, tubing was reattached to the PIP and the shear plug was overpressured and disengaged from the PIP tubing allowing the fluid levels in both the Rustler-Salado and the Culebra to be monitored. The Culebra was measured in the annulus between PIP's tubing and the perforated casing.

March 1983, the PIP was removed from P-17 due to suspected communication between the Rustler-Salado and Culebra due to leakage around the packer. A retrievable bridge plug was installed at 674' for water-level monitoring and future hydrologic testing of the Culebra.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-17	Holocene Deposits	0-14
	Pleistocene Rocks	
	Gatuna Formation	14-46
	Permian Rocks	
	Dewey Lake Red Beds	46-382
	Rustler Formation	382-715
	Magenta Dolomite Member	438-463
	Culebra Dolomite Member	558-583
	Salado Formation	715-1662
	Upper Member	715-1234
	McNutt Potash Zone	1234-1648
	Vaca Triste Sandstone Member	1234-1242
	11th Ore Zone	1294-1299
	MB 117	1306-1308
	MB 118	1330-1334
	MB 119	1358-1359
	10th Ore Zone	1368-1376
	MB 120	1387-1388
	9th Ore Zone	1391-1396
	MB 121	1402-1404
	MB 122	1410-1411
	8th Ore Zone	1418-1428
	Union Anhydrite	1438-1453
	7th Ore Zone	1456-1461
	6th Ore Zone	1471-1474
	5th Ore Zone	1478-1487
	MB 123	1513-1521
	MB 124	1527-1535
	4th Ore Zone	1544-1563
	3d Ore Zone	1573-1587
	2d Ore Zone	1594-1599
	1st Ore Zone	1619-1630
	MB 126	1647-1648

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-18**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 138.5' FSL, 732.7' FEL of Sec. 26, SE1/4
Sec. 26, T 22 S, R 31 E

ELEVATION: 3479'
TOTAL DEPTH: 1998'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 10/19/76 **Date Completed:** 11/06/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE: 8 3/4": 0 to 18'
7 7/8": 18 to 1139'
3 7/8": 1139 to 1998'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 8 5/8
Grade: Used
Wt/Ft:
From: 0
To: 18
Cement: None

Diameter: 4 1/2
Grade: J-55
Wt/Ft: 9.5
From: +1
To: 1138
Cement: 427 Cu. Ft.

8 3/4" casing recovered.

PLUGGING SCHEDULE

From: 1998'
To: 1125'
Int: 873'
Material: 130 Cu. Ft. of Cement

From: 1125'
To: 0'
Int: 1125'
Material:

Hole plugged from 1998-1125' with cement, and converted to hydrologic observation well in

Rustler Formation.

**********RECOMPLETION**********

January and April 1977, the casing was perforated across two intervals: the Rustler-Salado contact from 1076' to 1100'; and the interval from 912' to 940', which includes the Culebra dolomite from 909' to 938'. A PIP was set between the Rustler-Salado contact and the Culebra-dolomite perforated intervals to allow collection of water-level data for these two zones.

March 1983, the was removed and a retrievable bridge plug was set from 997' to 1002' to allow testing of the Culebra.

June 12, 1987, the 4 1/2" casing was reperforated across the Culebra dolomite interval from 909' to 938' with 15/32" bullets at 4 shots/foot to ensure a good hydraulic connection between the well and the Culebra dolomite.

After perforating the casing, a 3" PIP was installed on 2 3/8" tubing and set at a depth of 900'.

July 1 and 2, 1987, a BASKI 1.5" air-inflatable, sliding-end, feed-through minipacker with an attached pressure transducer was installed on 1/8" wireline at a depth of 824' to 826' and inflated.

August 19, 1987, minipacker removed from the well.

September 10, 1987, the minipacker with transducer was reinstalled and the packer inflated.

November 6, 1987, the minipacker was deflated and removed from the well and a Solinst electric water-level sounder was installed on the wellhead to monitor the fluid-level recovery to the slug-withdrawal test.

Currently used as a Culebra Groundwater Level Surveillance Well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-18	Holocene Deposits	0-9
	Triassic Rocks	
	Santa Rosa Sandstone	9-87
	Permian Rocks	
	Dewey Lake Red Beds	87-626
	Rustler Formation	626-1088
	Magenta Dolomite Member	704-730
	Culebra Dolomite Member	909-938
	Salado Formation	1088-2000
	Upper Member	1088-1604
	McNutt Potash Zone	1604-1987
	Vaca Triste Sandstone Member	1604-1614
	11th Ore Zone	1658-1662
	MB 117	1670-1672
	MB 118	1692-1694
	MB 119	1716-1718
	10th Ore Zone	1726-1734
	MB 120	1741-1742
	9th Ore Zone	1749-1752
	MB 121	1756-1758
	MB 122	1765-1766
	8th Ore Zone	1772-1783
	Union Anhydrite	1793-1808
	7th Ore Zone	1812-1817
	6th Ore Zone	1828-1830
	5th Ore Zone	1835-1844
	MB 123	1868-1875
	MB 124	1880-1889
	4th Ore Zone	1897-1910
	3d Ore Zone	1919-1933
	2d Ore Zone	1938-1942
	1st Ore Zone	1961-1972
	MB 126	1986-1987

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-19**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 1652' FSL, 2330' FWL of Sec. 23, SW1/4
Sec. 23, T 22 S, R 31 E

ELEVATION: 3546.3'
TOTAL DEPTH: 2000'
TYPE OF WELL: Potash Core Test
DRILLER: Pennsylvania Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 10/19/76 **Date Completed:** 11/04/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE:
8 3/4": 0 to 25'
6 1/4": 25 to 1228'
3 7/8": 1228 to 1635'
3 1/2": 1635 to 2000'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 7
Grade:
Wt/Ft:
From: 0
To: 25
Cement: None

Diameter: 4 1/2
Grade:
Wt/Ft:
From: 0
To: 1228
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 2000'
To: 0'
Int: 2000'
Material: 490 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-19	Holocene Deposits	0-8
	Triassic Rocks	
	Santa Rosa Sandstone	8-232
	Permian Rocks	
	Dewey Lake Red Beds	232-758
	Rustler Formation	758-1117
	Magenta Dolomite Member	814-839
	Culebra Dolomite Member	967-997
	Salado Formation	1117-2002
	Upper Member	1117-1621
	McNutt Potash Zone	1621-2011
	Vaca Triste Sandstone Member	1621-1628
	11th Ore Zone	1677-1681
	MB 117	1688-1690
	MB 118	1711-1713
	MB 119	1735-1737
	10th Ore Zone	1745-1753
	MB 120	1760-1761
	9th Ore Zone	1767-1771
	MB 121	1776-1778
	MB 122	1785-1786
	8th Ore Zone	1792-1801
	Union Anhydrite	1812-1822
	7th Ore Zone	1835-1840
	6th Ore Zone	1850-1854
	5th Ore Zone	1858-1872
	MB 123	1892-1901
	MB 124	1909-1917
	4th Ore Zone	1923-1933
	3d Ore Zone	1944-1955
	2d Ore Zone	1962-1967
	1st Ore Zone	1983-1994

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-20**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 794' FSL, 103' FEL of Sec. 14, SE1/4
Sec. 14, T 22 S, R 31 E

ELEVATION: 3552.9'
TOTAL DEPTH: 1995'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 10/06/76 **Date Completed:** 10/15/76

Remarks: Very weak air flow noted during logging operation on October 14, 1976. Air pocket escaped detection throughout coring operation.

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE: 8 3/4": 0 to 23'
5 7/8": 23 to 1195'
3 15/16": 1195 to 1995'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 6 5/8
Grade: Used
Wt/Ft:
From: 0
To: 23
Cement: None

Diameter: 4
Grade: HW
Wt/Ft:
From: 0
To: 1195
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1995'
To: 0'
Int: 1995'
Material: 442 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-20	Holocene Deposits	0-6
	Triassic Rocks	
	Santa Rosa Sandstone	6-261
	Permian Rocks	
	Dewey Lake Red Beds	261-780
	Rustler Formation	780-1103
	Magenta Dolomite Member	839-866
	Culebra Dolomite Member	953-979
	Salado Formation	1103-1996
	Upper Member	1103-1604
	McNutt Potash Zone	1604-1977
	Vaca Triste Sandstone Member	1604-1612
	11th Ore Zone	1658-1662
	MB 117	1671-1673
	MB 118	1696-1697
	MB 119	1720-1721
	10th Ore Zone	1728-1735
	MB 120	1742-1743
	9th Ore Zone	1747-1750
	MB 121	1756-1758
	MB 122	1764-1765
	8th Ore Zone	1771-1779
	Union Anhydrite	1789-1795
	7th Ore Zone	1807-1811
	6th Ore Zone	1821-1823
	5th Ore Zone	1828-1839
	MB 123	1866-1873
	MB 124	1880-1891
	4th Ore Zone	1893-1904
	3d Ore Zone	1911-1924
	2d Ore Zone	1928-1932
	1st Ore Zone	1947-1961
	MB 126	1975-1977
	Lower Member	1977-1996

POTASH BOREHOLE DATA BASE

BOREHOLE: **P-21**
OPERATOR: U.S. Department of Energy
PERMIT NO.: Unknown

LOCATION: 852' FNL, 150' FEL of Sec. 15, NE1/4
Sec. 15, T 22 S, R 31 E

ELEVATION: 3510'
TOTAL DEPTH: 1915'
TYPE OF WELL: Potash Core Test
DRILLER: Boyles Bros. Drilling Company (for Sandia Laboratories)

DRILLING RECORD: **Date Started:** 10/15/76 **Date Completed:** 10/27/76

Conventional Rotary Drilling procedures were used to bore to the top of the potash-bearing section, and consecutive cores, 2-1/4" in diameter, were taken through the full thickness of the potash-bearing section.

HOLE SIZE: 8 3/4": 0 to 23'
5 7/8": 23 to 1105'
3 15/16": 1105 to 1915'

WELL DEVELOPMENT: ***CASING RECORD***

Diameter: 6 5/8
Grade: Used
Wt/Ft:
From: 0
To: 23
Cement: None

Diameter: 4
Grade: HW
Wt/Ft:
From: 0
To: 1105
Cement: None

All casing recovered.

PLUGGING SCHEDULE

From: 1915'
To: 0'
Int: 1915'
Material: 425 Cu. Ft. of Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
P-21	Holocene Deposits	0-8
	Triassic Rocks	
	Santa Rosa Sandstone	8-225
	Permian Rocks	
	Dewey Lake Red Beds	225-734
	Rustler Formation	734-1043
	Magenta Dolomite Member	788-812
	Culebra Dolomite Member	899-924
	Salado Formation	1043-1918
	Upper Member	1043-1526
	McNutt Potash Zone	1526-1887
	Vaca Triste Sandstone Member	1526-1533
	11th Ore Zone	1579-1583
	MB 117	1591-1593
	MB 118	1615-1616
	MB 119	1637-1638
	10th Ore Zone	1647-1653
	MB 120	1659-1660
	9th Ore Zone	1665-1669
	MB 121	1676-1678
	MB 122	1685-1686
	8th Ore Zone	1690-1699
	Union Anhydrite	1707-1714
	7th Ore Zone	1727-1732
	6th Ore Zone	1740-1744
	5th Ore Zone	1748-1757
	MB 123	1781-1789
	MB 124	1796-1805
	4th Ore Zone	1811-1817
	3d Ore Zone	1824-1837
	2d Ore Zone	1841-1845
	1st Ore Zone	1859-1873
	MB 126	1886-1887
	Lower Member	1887-1918
	MB 127	1912-1913

Subsurface Exploration Borehole Data Base

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-1**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499833.57, E666341.70
ELEVATION:	3412.48'
TOTAL DEPTH:	58.2'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/29/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/27/78 **Date Completed:** 12/29/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drillin fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-1	Silty Sand, Sand	0-9.5
	Caliche	9.5-14.5
	Gatuna	14.5-38
	(Santa Rosa) Sandstone	38-58.2

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-1A**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499833.20, E666356.32
ELEVATION:	3412.48'
TOTAL DEPTH:	12.9'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/29/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/29/78 **Date Completed:** 12/29/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D, 3 1/4 inch I.D. hollow stem auger. Carbide inser teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-1A	Sand	0-11.2
	Caliche	11.2-12.9

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-2**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499835.35, E666841.60

ELEVATION: 3411.62'
TOTAL DEPTH: 33.9'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 11/22/78 **Date Completed:** 11/29/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D, 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-2	Sand	0-6.5
	Caliche	6.5-15.5
	Gatuna	15.5-23
	Siltstone	23-30.6
	Intercalated Sandstone and Soil	30.6-33.9

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-3**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499837.13, E667341.49
ELEVATION:	3415.33'
TOTAL DEPTH:	29'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/18/78 **Date Completed:** 12/18/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed wtih 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-3	Sand	0-7.8
	Caliche	7.8-14
	Gatuna	14-24.2
	Siltstone	24.2-25
	Sandstone	25-28
	Siltstone	28-29

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-4**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499838.91, E667841.39
ELEVATION:	3417.08'
TOTAL DEPTH:	38.8'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/18/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/17/78 **Date Completed:** 12/18/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and wither air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-4	Silty Sand	0-8.5
	Caliche	8.5-19
	Gatuna	19-37
	Claystone	37-38.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-4A**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499837.97, E667829.91
ELEVATION:	3417.08'
TOTAL DEPTH:	13.6'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/19/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/19/78 **Date Completed:** 12/19/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds of downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-4A	Silty Sand	0-11.5
	Caliche	11.5-13.6

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: B-5
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499840.69, E668341.29

ELEVATION: 3417.43'
TOTAL DEPTH: 32.3'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/17/78 **Date Completed:** 12/17/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-5	Silty Sand	0-8.2
	Caliche	8.2-17
	Gatuna	17-22.4
	Sandsone	22.4-26.9
	Intercalated Siltstone	26.9-32.3

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-6**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499842.47, E668841.15

ELEVATION: 3422.01'
TOTAL DEPTH: 26.3'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/17/78 **Date Completed:** 12/17/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-6	Silty Sand	0-3.5
	Caliche	3.5-10.1
	Gatuna	10.1-26.3

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-7**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499333.68, E666343.48

ELEVATION: 3404.19'
TOTAL DEPTH: 34.9'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 11/21/78 **Date Completed:** 11/21/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-7	Sand	0-5.5
	Caliche	5.5-20
	Gatuna	20-25
	Sandstone	25-27.5
	Santa Rosa	27.5-34.9

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-8**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499335.46, E666843.36

ELEVATION: 3408.55'
TOTAL DEPTH: 100'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/03/79 **Date Completed:** 01/03/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-8	Sand	0-7
	Caliche	7-12
	Gatuna	12-35.7
	Santa Rosa	35.7-40
	Dewey Lake	40-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-9**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499337.27, E667343.26
ELEVATION:	3410.47'
TOTAL DEPTH:	38.3
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/19/78 **Date Completed:** 12/19/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test corings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-9	Sand	0-8.1
	Caliche	8.1-18
	Gatuna	18-32.1
	Siltstone	32.1-36
	Sandstone	36-38.3

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-10**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499339.05, E6678434.11

ELEVATION: 3413'
TOTAL DEPTH: 32'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/19/78 **Date Completed:** 12/19/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-10	Sand	0-10.2
	Caliche	10.2-17
	Gatuna	17-26.5
	Siltstone	26.3-27
	Sandstone	27-32

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-11**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499340.83, E668343.05
ELEVATION:	3414.30'
TOTAL DEPTH:	30'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/15/78 **Date Completed:** 12/15/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-11	Sand	1.2-4.1
	Caliche	4.1-13.5
	Gatuna	13.5-30

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-12**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499342.61, E668842.93
ELEVATION:	3421.77'
TOTAL DEPTH:	41.5'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/01/78 **Date Completed:** 12/01/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-12	Sand	0-6
	Caliche	6-13
	Gatuna	13-20
	Sandstone	20-26
	Claystone	26-27
	Sandstone	27-31.5
	Claystone	31.5-33.5
	Sandstone	33.5-38.5
	Intercalated Sandstone	38.5-41.5

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-13**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498833.82, E666345.25
ELEVATION:	3403.91'
TOTAL DEPTH:	28.3'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/16/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/12/78 **Date Completed:** 12/16/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-13	Sand	0-7
	Caliche	7-12.5
	Gatuna	12.5-26
	Claystone	26-28.3

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-14**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498835.60, E666845.14

ELEVATION: 3406.57'
TOTAL DEPTH: 24.5'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/13/78 **Date Completed:** 12/13/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-14	Sand	0-4.8
	Caliche	4.8-9.9
	Gatuna	9.9-14
	Claystone	14-24.5

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-15**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498837.40, E667345.06

ELEVATION: 3408.64'
TOTAL DEPTH: 56.8'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 11/16/78 **Date Completed:** 11/17/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-15	Sand	0-9
	Caliche	9-13
	Silty Sand	13-26
	Gatuna	26-51.5
	Santa Rosa	51.5-55
	Shale	54.5-56.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-16**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498839.19, E667844.94
ELEVATION:	3411.21'
TOTAL DEPTH:	31'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/15/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/14/78 **Date Completed:** 12/15/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-16	Sand	0-7
	Caliche	7-15
	Gatuna	15-31

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-17**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498840.97, E668343.86

ELEVATION: 3413.26'
TOTAL DEPTH: 25.8'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/13/78 **Date Completed:** 12/13/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-17	Silty Sand	0-5.1
	Caliche	5.1-10.5
	Gatuna	10.5-25.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-18**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498842.75, E668844.75
ELEVATION:	3419.32'
TOTAL DEPTH:	33.3'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/15/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/14/78 **Date Completed:** 12/15/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-18	Sand	0-7.1
	Caliche	7.1-15
	Gatuna	15-33.3

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-19**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498333.94, E666347.03

ELEVATION: 3399.84'
TOTAL DEPTH: 38.8'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 11/30/78 **Date Completed:** 11/30/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-19	Sand	0-8.5
	Caliche	8.5-18.5
	Gatuna	18.5-21.1
	Sandstone	21.1-38.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-20**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498335.72, E666846.91
ELEVATION:	3403.53'
TOTAL DEPTH:	14'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/16/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/12/78 **Date Completed:** 12/16/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-20	Sand	0-10
	Caliche	10-14

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-20A**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498341.34, E666847.10
ELEVATION:	3403.53'
TOTAL DEPTH:	34.2'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 12/16/78
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/12/78 **Date Completed:** 12/16/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-20A	Sand	0-13.9
	Caliche	13.9-19
	Gatuna	19-34.2

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-21**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498337.50, E667346.75

ELEVATION: 3404.55'
TOTAL DEPTH: 40.4'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 11/17/78 **Date Completed:** 11/17/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-21	Sand	0-9.5
	Caliche	9.5-20
	Gatuna	20-32.5
	Sandstone	32.5-40.4

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-22**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498339.28, E667846.73

ELEVATION: 3406.85'
TOTAL DEPTH: 27.8'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/11/78 **Date Completed:** 12/11/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drillin fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-22	Sand	0-7.5
	Caliche	7.5-13
	Gatuna	13-27.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-23**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498341.06, E668346.63

ELEVATION: 3412.07'
TOTAL DEPTH: 40.5'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/06/78 **Date Completed:** 12/06/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drillin fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-23	Sand	0-6
	Caliche	6-14.3
	Gatuna	14.3-40.5

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-24**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498342.84, E668846.53
ELEVATION:	3417.87'
TOTAL DEPTH:	29.3'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 12/07/78 **Date Completed:** 12/07/78
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-24	Sand	0-5.5
	Caliche	5.5-12
	Gatuna	12-29.3

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-25**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499414.91, E666693.11

ELEVATION: 3408.19'
TOTAL DEPTH: 901.8'
TYPE OF WELL: Deep Exploratory Drilling
DRILLER: Gil's Drilling Co.

DRILLING RECORD: **Date Started:** 12/01/78 **Date Completed:** 01/18/79

WELL DEVELOPMENT: ***HOLE DIAMETER***

9 7/8" 0 to 22.4'
6 1/4" 22.4 to 908'

DRILLING EQUIPMENT

GD-2000 drill.

PLUGGING SCHEDULE

From: 909'
To: 750.4'
Interval: 158.6'
Material: Salt Grout

From: 750.4'
To: 466'
Interval: 284.4'
Material: Freshwater Grout

From: 466'
To: 20'
Interval: 446'
Material: Sand

From: 20'
To: Surface
Interval: 20'
Material: Cement

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-25	Sand	0-10
	Caliche	10-14
	Gatuna	14-34.7
	Santa Rosa	34.7-44.8
	Dewey Lake	44.8-533
	Rustler Formation	533-842.9
	Magenta Member	592.7-617
	Culebra Member	704.1-728
	Salado Formation	842.9-901.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-26**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499600.58, E666892.43
ELEVATION:	3410.19'
TOTAL DEPTH:	27.5'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 01/03/79 **Date Completed:** 01/03/79
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-26	Sand	0-5
	Caliche	5-11
	Gatuna	11-23
	Siltstone	23-27.5

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-27**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498982.08, E665854.70

ELEVATION: 3400.20'
TOTAL DEPTH: 25.8'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/11/79 **Date Completed:** 01/11/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-27	Sand	0-4
	Caliche	4-11
	Gatuna	11-22
	Sandstone	22-22.5
	Claystone	22.5-23
	Sandstone	23-24
	Intercalated Sandstone	24-25.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-28**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499295.02, E666718.53

ELEVATION: 3408.17'
TOTAL DEPTH: 27'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/04/79 **Date Completed:** 01/04/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-28	Sand	0-6
	Caliche	6-12
	Gatuna	12-21
	Sandstone	21-27

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-29**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499397.21, E667253.07

ELEVATION: 3410.87'
TOTAL DEPTH: 28.7'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** *12/30/78* **Date Completed:** *12/30/78*

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-29	Sand	0-13
	Gatuna	13-28.7

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-30**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499185.81, E666933.86

ELEVATION: 3408.75'
TOTAL DEPTH: 27.8'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/28/78 **Date Completed:** 12/28/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-30	Sand	0-7.5
	Caliche	7.5-11.5
	Gatuna	11.5-17.6
	Sandstone	17.6-27.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-31**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499206.60, E667143.76

ELEVATION: 3410.27
TOTAL DEPTH: 30.5'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/29//78 **Date Completed:** 12/29/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-31	Sand	0-7.8
	Caliche	7.8-13.4
	Gatuna	13.4-30.5

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-32**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499187.96, E667523.76

ELEVATION: 3410.89'
TOTAL DEPTH: 100'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/07/79 **Date Completed:** 01/07/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-32	Sand	0-12.5
	Caliche	12.5-19.5
	Gatuna	19.5-26.5
	Siltstone & Claystone	26.5-43
	Santa Rosa	43-53
	Dewey Lake	53-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-33**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498874.29, E666470.03

ELEVATION: 3404.05'
TOTAL DEPTH: 30.7'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 12/29/78 **Date Completed:** 12/29/78

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide curring faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-33	Sand	0-6.7
	Caliche	6.7-15.8
	Gatuna	15.8-19
	Sandstone	19-24
	Intercalated Siltstone & Mudstone	24-29.8
	Sandstone	29.8-30.7

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-34**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498205.49, E666762.36

ELEVATION: 3401.97'
TOTAL DEPTH: 100'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/09/79 **Date Completed:** 01/09/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-34	Sand	0-9.1
	Caliche	9.1-14.8
	Gatuna	14.8-40
	Siltstone & Claystone	40-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-35**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498326.97, E667196.82
ELEVATION:	3402.55'
TOTAL DEPTH:	32'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 01/05/79 **Date Completed:** 01/05/79
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-35	Sand	0-7
	Caliche	7-12
	Gatuna	12-23
	Sandstone	23-32

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-36**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499293.25, E669018.07

ELEVATION: 3422.03'
TOTAL DEPTH: 27.8'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/07/79 **Date Completed:** 01/07/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-36	Sand	0-5.9
	Caliche	5.9-13.2
	Gatuna	13.2-25
	Siltstone	25-27.8

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-37**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499297.91, E670352.77

ELEVATION: 3438.91'
TOTAL DEPTH: 27.5'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/09/79 **Date Completed:** 01/09/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-37	Sand	0-5.5
	Caliche	5.5-12.5
	Gatuna	12.5-20
	Siltstone	20-20.3
	Sandstone	20.3-27.5

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-37A**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499260.53, E669370.39
ELEVATION:	3426.68'
TOTAL DEPTH:	22.4'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 01/08/79 **Date Completed:** 01/08/79
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-37A	Sand	0-5.5
	Caliche	5.5-13.5
	Gatuna	13.5-22.4

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-38**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499155.65, E669683.42
ELEVATION:	3429.88'
TOTAL DEPTH:	50'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 1/23/79
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 01/11/79 **Date Completed:** 01/23/79
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-38	Sand	0-5.5
	Caliche	5.5-14
	Gatuna	14-20.5
	Sandstone	20.5-40.2
	Santa Rosa	40.2-43.7
	Dewey Lake	43.7-50

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-39**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499018.31, E669019.04

ELEVATION: 3422.08'
TOTAL DEPTH: 27.6'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/06/79 **Date Completed:** 01/07/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-39	Sand	0-7
	Caliche	7-13
	Gatuna	13-27.6

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-40**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499023.04, E670353.77

ELEVATION: 3438.48'
TOTAL DEPTH: 27.9'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/10/79 **Date Completed:** 01/10/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-40	Sand	0-7.6
	Caliche	7.6-13
	Gatuna	13-19
	Sandstone	19-27.9

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-41**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499335.51, E666858.36

ELEVATION: 3407.86'
TOTAL DEPTH: 100'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/05/79 **Date Completed:** 01/05/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-41	Sand	0-6
	Caliche	6-15
	Gatuna	15-42
	Santa Rosa	42-48
	Dewey Lake	48-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-42**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499335.57, E666873.35

ELEVATION: 3408.99'
TOTAL DEPTH: 100'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/06/79 **Date Completed:** 01/06/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-42	Sand	0-6
	Caliche	6-14
	Gatuna	14-42
	Santa Rosa	42-48
	Dewey Lake	48-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-43**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499202.96, E667523.70

ELEVATION: 3410.75'
TOTAL DEPTH: 100'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/06/79 **Date Completed:** 01/06/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-43	Sand	0-12
	Caliche	12-20
	Gatuna	20-43
	Santa Rosa	43-53
	Dewey Lake	53-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-44**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499172.96, E667523.82

ELEVATION: 3411.48'
TOTAL DEPTH: 100'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/08/79 **Date Completed:** 01/08/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-44	Sand	0-16
	Caliche	16-21
	Gatuna	21-38
	Santa Rosa	38-52
	Dewey Lake	52-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-45**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498205.44, E666747.36

ELEVATION: 3401.51'
TOTAL DEPTH: 100'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/10/79 **Date Completed:** 01/17/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-45	Sand	0-7.5
	Caliche	7.5-15.3
	Gatuna	15.3-31.3
	Dewey Lake	31.3-44.2
	Sandstone	44.2-44.7
	Siltstone	44.7-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-46**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498205.54, E666777.36
ELEVATION:	3401.98'
TOTAL DEPTH:	100'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 01/08/79 **Date Completed:** 01/08/79
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-46	Sand	0-8
	Caliche	8-13
	Gatuna	13-41
	Santa Rosa	41-48
	Dewey Lake	48-100

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: B-47
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N499206.77, E667193.82

ELEVATION: 3409.49'
TOTAL DEPTH: 17.5'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/25/79 **Date Completed:** 01/25/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-47	Sand	0-8.9
	Caliche	8.9-15
	Gatuna	15-17.5

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-48**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498839.26, E667854.93

ELEVATION: 3412.12'
TOTAL DEPTH: 15.7'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** *01/24/79* **Date Completed:** *01/24/79*

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-48	Sand	0-9
	Caliche	9-15.7

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-49**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498937.22, E667294.71

ELEVATION: 3409.07'
TOTAL DEPTH: 19.2'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/24/79 **Date Completed:** 01/24/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-49	Sand	0-8.5
	Caliche	8.5-10.5
	Silty Sand	10.5-15
	Gatuna	15-19.2

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-50**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N498487.09, E667236.23

ELEVATION: 3405.65'
TOTAL DEPTH: 23.7'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/26/79 **Date Completed:** 01/26/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-50	Sand	0-9.5
	Caliche	9.5-15
	Gatuna	15-23.7

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-51**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N498337.48, E667341.75
ELEVATION:	3404.74'
TOTAL DEPTH:	15.2'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 01/25/79 **Date Completed:** 01/25/79
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-51	Sand	0-7.5
	Caliche	7.5-14.5
	Gatuna	14.5-15.2

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-52**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N496981.21, E665461.91
ELEVATION:	3385.48'
TOTAL DEPTH:	30.0'
TYPE OF WELL:	Shallow Exploratory Drilling
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 01/26/79 **Date Completed:** 01/26/79
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-52	Sand	0-3.1
	Caliche	3.1-8.5
	Gatuna	8.5-19
	Dewey Lake	19-30

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-53**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: N496651.28, E665463.05

ELEVATION: 3386.65'
TOTAL DEPTH: 30.2'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 01/30/79 **Date Completed:** 01/30/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drillin fluid.

PLUGGING SCHEDULE

Grouted with cement.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-53	Sand	0-8.5
	Caliche	8.5-15.7
	Gatuna	15.7-23.7
	Dewey Lake	23.7-30.2

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE:	**B-54**
OPERATOR:	Sergent, Hauskins, & Beckwith
PERMIT NO.:	Unknown
LOCATION:	N499386.52, E666651.92
ELEVATION:	3408.60'
TOTAL DEPTH:	210'
TYPE OF WELL:	Shallow Exploratory Drilling Converted to Observation Well 02/14/79
DRILLER:	Sergent, Hauskins & Beckwith
DRILLING RECORD:	**Date Started:** 02/13/79 **Date Completed:** 02/14/79
WELL DEVELOPMENT:	***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-54	Sand	0-6
	Caliche	6-12
	Gatuna	12-25
	Santa Rosa	25-30
	Dewey Lake	30-210

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-301**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: North Access Road

ELEVATION: Not Recorded
TOTAL DEPTH: 39.7'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 02/08/79 **Date Completed:** 02/08/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-301	Sand	0-1
	Caliche	1-24
	Dewey Lake	24-39.7

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-302**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: North Access Road

ELEVATION: Not Recorded
TOTAL DEPTH: 39'
TYPE OF WELL: *Shallow Exploratory Drilling*
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 02/07/79 **Date Completed:** 02/07/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-302	Sand	0-10.4
	Caliche	10.4-23
	Dewey Lake	23-39.0

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-303**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: North Access Road

ELEVATION: Not Recorded
TOTAL DEPTH: 39.1'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 02/07/79 **Date Completed:** 02/07/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-303	Sand	0-15.5
	Caliche	15.5-18
	Dewey Lake	18-39.1

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-304**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: North Access Road

ELEVATION: Not Recorded
TOTAL DEPTH: 41.5'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: ***Date Started:*** *02/06/79* ***Date Completed:*** *02/06/79*

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-304	Sand	0-20.6
	Caliche	20.6-33
	Sand	33-41.5

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-305**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: North Access Road

ELEVATION: Not Recorded
TOTAL DEPTH: 41'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 02/06/79 **Date Completed:** 02/06/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-305	Sand	0-14.5
	Caliche	14.5-19.5
	Sand	19.5-25.5
	Caliche	25.5-33
	Sand	33-41

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-306**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: North Access Road

ELEVATION: Not Recorded
TOTAL DEPTH: 38'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 02/02/79 **Date Completed:** 02/02/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-306	Sand	0-7.3
	Caliche	7.3-18
	Santa Rosa	18-38

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-307**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: Railroad

ELEVATION: Not Recorded
TOTAL DEPTH: 40'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 02/01/79 **Date Completed:** 02/01/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-307	Caliche	0-5.6
	Sand	5.6-11.1
	Gatuna	11.1-17.1
	Dewey Lake	17.1-40

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-308**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: Railroad

ELEVATION: Not Recorded
TOTAL DEPTH: 39.9'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 02/01/79 **Date Completed:** 02/01/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-308	Caliche	0-10.5
	Gatuna	10.5-19.5
	Dewey Lake	19.5-39.9

SUBSURFACE EXPLORATION BOREHOLE DATA BASE

BOREHOLE: **B-309**
OPERATOR: Sergent, Hauskins, & Beckwith
PERMIT NO.: Unknown

LOCATION: South Access Road

ELEVATION: Not Recorded
TOTAL DEPTH: 39.4'
TYPE OF WELL: Shallow Exploratory Drilling
DRILLER: Sergent, Hauskins & Beckwith

DRILLING RECORD: **Date Started:** 02/02/79 **Date Completed:** 02/02/79

WELL DEVELOPMENT: ***DRILLING EQUIPMENT***

Truck-mounted CME-55 drill rigs powered with 6 cylinder Ford industrial engines were used in advancing test borings. The 6 cylinder engines are capable of delivering about 6,500 foot/pounds torque to the drill spindle. The spindle is advanced with twin hydraulic rams capable of exerting 12,000 pounds downward force. Drilling through soil or softer rock was performed with 6 1/2 inch O.D., 3 1/4 inch I.D. hollow stem auger. Carbide insert teeth were used on the auger bits. Core drilling in bedrock was performed using NX size core bits with either diamond or carbide cutting faces and either air or water for drilling fluid.

PLUGGING SCHEDULE

Backfilled with native drilled material.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
B-309	Sand	0-5.6
	Caliche	5.6-14
	Gatuna	14-19.8
	Santa Rosa	19.8-22
	Dewey Lake	22-39.4

Water Quality Sampling Program Data Base

WATER QUALITY SAMPLING PROGRAM DATA BASE

BOREHOLE: **WQSP-1**
OPERATOR: U.S. Dept. of Energy
PERMIT NO.: Unkown

LOCATION: 101' FNL, 1422' FWL,
Sec. 20, T 22 S, R 31 E

EVALUATION: 3419.2' above mean sea level
TOTAL DEPTH: 737'
TYPE OF WELL: Water Quality Sampling Program
DRILLER: West Texas Water Well Service

DRILLING RECORD: **Date Started:** 09/13/94 **Date Completed:** 09/16/94

HOLE SIZE: 4"

WELL DEVELOPMENT: ***CASING RECORD***

0 to 25': 10 3/4" wall surface casing
25 to 550': 5" wall blank fiberglass casing
1 to 550': Cement slurry mix
550 to 640': Bentonite seal
640 to 651': Sand pack
651 to 712': 8/16 Brady gravel
25' of 5" O.D. Fiberglass 0.020 slot screen
Centralizers located at bottom of screen, top of screen, and at 60' intervals to surface
10" of Blank 5" O.D. casing

Currently used as a hydrologic surveillance well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WQSP-1	Surficial Deposits/Santa Rosa	0-40
	Dewey Lake Redbeds	40-522
	Rustler Formation	522-689 partial
	Forty-niner Member	522-591
	Magenta Member	591-612
	Tamarisk Member	612-689?
	Culebra Member	NA
	Partial Lower Unnamed Member	NA
	Maximum Recorded Depth	689

WATER QUALITY SAMPLING PROGRAM DATA BASE

BOREHOLE: **WQSP-2**
OPERATOR: U.S. Dept. of Energy
PERMIT NO.: Unkown

LOCATION: 1646' FSL, 142' FWL,
Sec. 16, T 22 S, R 31 E

EVALUATION: 3463.9' above mean sea level
TOTAL DEPTH: 846'
TYPE OF WELL: Water Quality Sampling Program
DRILLER: West Texas Water Well Service

DRILLING RECORD: **Date Started:** 09/06/94 **Date Completed:** 09/10/94

HOLE SIZE: 4"

WELL DEVELOPMENT: ***CASING RECORD***

0 to 25': 10 3/4" wall surface casing
25 to 770': 5" wall blank fiberglass casing
1 to 770': Cement slurry mix
770 to 790': Bentonite seal
790 to 793': Sand pack
793 to 846': 8/16 Brady gravel
25' of 5" O.D. Fiberglass 0.020 slot screen
Centralizers located at bottom of screen, top of screen, and at 60' intervals to surface
10" of Blank 5" O.D. casing

Currently used as a hydrologic surveillance well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WQSP-2	Surficial Deposits/Santa Rosa	0-143
	Dewey Lake Redbeds	143-629
	Rustler Formation	629-844 partial
	Forty-niner Member	629-692
	Magenta Member	692-714
	Tamarisk Member	714-811
	Culebra Member	811-833
	Partial Lower Unnamed Member	833-844
	Maximum Recorded Depth	844

WATER QUALITY SAMPLING PROGRAM DATA BASE

BOREHOLE: WQSP-3
OPERATOR: U.S. Dept. of Energy
PERMIT NO.: Unkown

LOCATION: 96' FSL, 2162' FEL,
Sec. 16, T 22 S, R 31 E

EVALUATION: 3480.3' above mean sea level
TOTAL DEPTH: 879'
TYPE OF WELL: Water Quality Sampling Program
DRILLER: West Texas Water Well Service

DRILLING RECORD: **Date Started:** 10/20/94 **Date Completed:** 10/26/94

HOLE SIZE: 4"

WELL DEVELOPMENT: ***CASING RECORD***

0 to 25': 10 3/4" wall surface casing
25 to 797': 5" wall blank fiberglass casing
1 to 796': Cement slurry mix
797 to 827': Bentonite seal
827 to 830': Sand pack
830 to 880': 8/16 Brady gravel
25' of 5" O.D. Fiberglass 0.020 slot screen
Centralizers located at bottom of screen, top of screen, and at 60' intervals to surface
10" of Blank 5" O.D. casing

Currently used as a hydrologic surveillance well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WQSP-3	Surficial Deposits/Santa Rosa	0-156
	Dewey Lake Redbeds	156-669
	Rustler Formation	669-881 partial
	Forty-niner Member	669-727
	Magenta Member	727-749
	Tamarisk Member	749-848
	Culebra Member	848-871
	Partial Lower Unnamed Member	871-881 partial
	Maximum Recorded Depth	881

WATER QUALITY SAMPLING PROGRAM DATA BASE

BOREHOLE: **WQSP-4**
OPERATOR: U.S. Dept. of Energy
PERMIT NO.: Unkown

LOCATION: 1632' FSL, 2136' FEL,
Sec. 28, T 22 S, R 31 E

EVALUATION: 3433' above mean sea level
TOTAL DEPTH: 800'
TYPE OF WELL: Water Quality Sampling Program
DRILLER: West Texas Water Well Service

DRILLING RECORD: **Date Started:** 10/05/94 **Date Completed:** 10/07/94

HOLE SIZE: 4"

WELL DEVELOPMENT: ***CASING RECORD***

0 to 25': 10 3/4" wall surface casing
25 to 715': 5" wall blank fiberglass casing
1 to 715': Cement slurry mix
715 to 752': Bentonite seal
752 to 755': Sand pack
755 to 800': 8/16 Brady gravel
25' of 5" O.D. Fiberglass 0.020 slot screen
Centralizers located at bottom of screen, top of screen, and at 60' intervals to surface
10" of Blank 5" O.D. casing

Currently used as a hydrologic surveillance well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WQSP-4	Surficial Deposits/Santa Rosa	0-78
	Dewey Lake Redbeds	78-588
	Rustler Formation	588-802 partial
	Forty-niner Member	588-652
	Magenta Member	652-672
	Tamarisk Member	672-770
	Culebra Member	770-790
	Partial Lower Unnamed Member	790-802 partial
	Maximum Recorded Depth	802

WATER QUALITY SAMPLING PROGRAM DATA BASE

BOREHOLE: **WQSP-5**
OPERATOR: U.S. Dept. of Energy
PERMIT NO.: Unkown

LOCATION: 330' FSL, 340' FEL,
Sec. 29, T 22 S, R 31 E

EVALUATION: 3384.4' above mean sea level
TOTAL DEPTH: 681'
TYPE OF WELL: Water Quality Sampling Program
DRILLER: West Texas Water Well Service

DRILLING RECORD: **Date Started:** 10/12/94 **Date Completed:** 10/13/94

HOLE SIZE: 4"

WELL DEVELOPMENT: ***CASING RECORD***

0 to 25': 10 3/4" wall surface casing
25 to 616': 5" wall blank fiberglass casing
1 to 613': Cement slurry mix
613 to 623': Bentonite seal
623 to 626': Sand pack
626 to 681': 8/16 Brady gravel
25' of 5" O.D. Fiberglass 0.020 slot screen
Centralizers located at bottom of screen, top of screen, and at 60' intervals to surface
10" of Blank 5" O.D. casing

Currently used as a hydrologic surveillance well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WQSP-5	Surficial Deposits/Santa Rosa	0-25
	Dewey Lake Redbeds	25-475
	Rustler Formation	475-683 partial
	Forty-niner Member	475-530
	Magenta Member	530-554
	Tamarisk Member	554-648
	Culebra Member	648-669
	Partial Lower Unnamed Member	669-683
	Maximum Recorded Depth	683

WATER QUALITY SAMPLING PROGRAM DATA BASE

BOREHOLE: **WQSP-6**
OPERATOR: U.S. Dept. of Energy
PERMIT NO.: Unkown

LOCATION: 1626' FSL, 1461' FWL,
Sec. 29, T 22 S, R 31 E

EVALUATION: 3363.8' above mean sea level
TOTAL DEPTH: 617'
TYPE OF WELL: Water Quality Sampling Program
DRILLER: West Texas Water Well Service

DRILLING RECORD: **Date Started:** 09/22/94 **Date Completed:** 09/30/94

HOLE SIZE: 4"

WELL DEVELOPMENT: ***CASING RECORD***

0 to 25': 10 3/4" wall surface casing
25 to 560': 5" wall blank fiberglass casing
1 to 560': Cement slurry mix
560 to 570': Bentonite seal
567 to 570': Sand pack
626 to 681': 8/16 Brady gravel
25' of 5" O.D. Fiberglass 0.020 slot screen
Centralizers located at bottom of screen, top of screen, and at 60' intervals to surface
10" of Blank 5" O.D. casing

Currently used as a hydrologic surveillance well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WQSP-6	Surficial Deposits/Santa Rosa	0-68
	Dewey Lake Redbeds	68-409
	Rustler Formation	409-620
	Forty-niner Member	409-474
	Magenta Member	474-497
	Tamarisk Member	497-588
	Culebra Member	588-606
	Partial Lower Unnamed Member	606-620
	Maximum Recorded Depth	620

WATER QUALITY SAMPLING PROGRAM DATA BASE

BOREHOLE: **WQSP-6a**
OPERATOR: U.S. Dept. of Energy
PERMIT NO.: Unkown

LOCATION: 1653' FSL, 1395' FWL,
Sec. 29, T 22 S, R 31 E

EVALUATION: 3364.7' above mean sea level
TOTAL DEPTH: 225'
TYPE OF WELL: Water Quality Sampling Program
DRILLER: West Texas Water Well Service

DRILLING RECORD: **Date Started:** 10/28/94 **Date Completed:** 10/31/94

HOLE SIZE: 4"

WELL DEVELOPMENT: ***CASING RECORD***

0 to 25': 10 3/4" wall surface casing
25 to 152': 5" wall blank fiberglass casing
1 to 152': Cement slurry mix
152 to 172': Bentonite seal
172 to 175': Sand pack
175 to 225': 8/16 Brady gravel
25' of 5" O.D. Fiberglass 0.020 slot screen
Centralizers located at bottom of screen, top of screen, and at 60' intervals to surface
10" of Blank 5" O.D. casing

Currently used as a hydrologic surveillance well.

STRATIGRAPHIC SUMMARY

BOREHOLE	ROCK UNIT	DEPTH INTERVAL IN FEET
WQSP-6a	Surficial Deposits/Santa Rosa	0-35
	Dewey Lake Redbeds	35-220 partial

Bibliography

BIBLIOGRAPHY

Beauheim, R.L. Interpretations of Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987. SAND87-0039, Sandia National Laboratories, Albuquerque, New Mexico. December 1987.

Beauheim, R.L., et al. Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. WTSD-TME-020, U.S. Department of Energy, Albuquerque, New Mexico. December 1983.

Black, S.R. Basic Data Report Borehole WIPP-12 Deepening, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3148, U.S. Department of Energy, Albuquerque, New Mexico. 1982.

Cauffman, T.L., et al. Ground Water Flow Modeling of the Culebra Dolomite-Volume II:Data Base. SAND89-7068/2, INTERA Technologies, Inc., Austin, Texas. October 1990.

Dennehy, K.F. Results of Hydrologic Tests and Water-Chemistry Analysis, Wells H-6A, H-6B, and H-6C, at the Proposed Waste Isolation Pilot Plant Site, Southeastern New Mexico. U.S. Geological Survey Water-Resources Investigation Report 82-8. 1982.

Freeland, M.H. Basic Data Report for Borehole DOE-1, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3159, U.S. Department of Energy, Albuquerque, New Mexico. 1982.

Gonzalez, D.D. Hydrogeochemical Parameters of Fluid-Bearing Zones in the Rustler and Bell Canyon Formation. SAND83-0210. March 1983.

Gonzales, M.M. Compilation and Comparison of Test-Hole Location Surveys in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site. SAND88-1065, Sandia National Laboratories, Albuquerque, New Mexico. February 1989.

Griswold, G.B., and V.C. McWhirter. Interpretation of Wireline Geophysical Logs ERDA No. 9 Stratigraphic Test Borehole DOE WIPP Site, Eddy County, New Mexico. SAND80-7119, Telecote Corporation, Albuquerque, New Mexico. February 1981.

Hydro Geo Chem, Inc. WIPP Hydrology Program, Waste Isolation Pilot Plant, SENM, Hydrologic Data Report #1. SAND85-7206. Hydro Geo Chem, Inc., Tucson, Arizona. September 1985.

INTERA Technologies, Inc., and Hydro Geo Chem, Inc. WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #2. SAND85-7263, INTERA Technologies, Inc., Austin, Texas and Hydro Geo Chem, Inc., Tucson, Arizona. December 1985.

INTERA Technologies, Inc. WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #3. SAND86-7109, INTERA Technologies, Inc., Austin, Texas. June 1986.

Memo from Jery W. Mercer, January 22, 1991

Mercer, J.W., and B.R. Orr. Interim Data Report on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site Southeast New Mexico. USGSOFR-79-98, U.S. Geological Survey, Denver, Colorado. 1979.

Mercer, J.W., et al. Results of Hydrologic Tests and Water Chemistry Analyses, Wells H-4A, H-4B, H-4C at the Proposed Waste Isolation Pilot Plant Site, Southeastern New Mexico. U.S. Geological Survey Water-Resources Investigations 81-36, U.S. Geological Survey, Albuquerque, New Mexico. 1981.

Mercer, J.W. Basic Data Report for Drillholes at the H-11 Complex (Waste Isolation Pilot Plant-WIPP). SAND89-0200, Sandia National Laboratories, Albuquerque, New Mexico. May 1990.

Mercer, J.W., and R.P. Snyder. Basic Data Report for Drillhole H-12 (Waste Isolation Pilot Plant-WIPP). SAND89-0201, Sandia National Laboratories, Albuquerque, New Mexico. January 1990.

Mercer, J.W., and R.P. Snyder. Basic Data Report for Drillholes H-14 and H-15 (Waste Isolation Pilot Plant-WIPP). SAND89-0202, Sandia National Laboratories, Albuquerque, New Mexico. February 1990.

Mercer, J.W., and R.P. Snyder. Basic Data Report for Drillhole H-16 (Waste Isolation Pilot Plant-WIPP). SAND89-0203, Sandia National Laboratories, Albuquerque, New Mexico. January 1990.

Mercer, J.W., and R.P. Snyder. Basic Data Report for Drillholes H-17 and H-18 (Waste Isolation Pilot Plant-WIPP). SAND89-0204, Sandia National Laboratories, Albuquerque, New Mexico. February 1990.

Potash Mine or Bureau of Land Management (SUNDRY NOTICES AND REPORTS ON WELLS)

SAND 78-1596, August 1978, Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, Volume II

SAND 79-0267, Basic Data Report for Drillhole ERDA-6

SAND 79-0268, Basic Data Report for Drillhole AEC-7

SAND 79-0269, Basic Data Report for Drillhole AEC-8

SAND 79-0270, Basic Data Report for Drillhole ERDA-9

SAND 79-0271, Basic Data Report for Drillhole ERDA-10

SAND 85-7206, September 1985, WIPP Hydrology Program Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #1

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-18 (Waste Isolation Pilot Plant-WIPP). SAND79-0275, Sandia National Laboratories, Albuquerque, New Mexico. March 1980.

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-19 (Waste Isolation Pilot Plant-WIPP). SAND79-0276, Sandia National Laboratories, Albuquerque, New Mexico. March 1980.

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-21 (Waste Isolation Pilot Plant-WIPP). SAND79-0277, Sandia National Laboratories, Albuquerque, New Mexico. March 1980.

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-22 (Waste Isolation Pilot Plant-WIPP). SAND79-0278, Sandia National Laboratories, Albuquerque, New Mexico. March 1980.

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-26 (Waste Isolation Pilot Plant-WIPP). SAND79-0280, Sandia National Laboratories, Albuquerque, New Mexico. August 1979.

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-27 (Waste Isolation Pilot Plant-WIPP). SAND79-0281, Sandia National Laboratories, Albuquerque, New Mexico. October 1979.

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-28 (Waste Isolation Pilot Plant-WIPP). SAND79-0282, Sandia National Laboratories, Albuquerque, New Mexico. August 1979.

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-29 (Waste Isolation Pilot Plant-WIPP). SAND79-0283, Sandia National Laboratories, Albuquerque, New Mexico. September 1980.

Sandia National Laboratories, and U.S. Geological Survey. Basic Data Report for Drillhole WIPP-30 (Waste Isolation Pilot Plant-WIPP). SAND79-0284, Sandia National Laboratories, Albuquerque, New Mexico. April 1980.

Sandia National Laboratories, and D'Appolonia Consulting Engineers. Basic Data Report for Deepening of Drillhole WIPP-13 (Waste Isolation Pilot Plant-WIPP). SAND82-1880, Sandia National Laboratories, Albuquerque, New Mexico. October 1982.

Sandia National Laboratories, and D'Appolonia Consulting Engineers. Basic Data Report for Drillhole WIPP-14 (Waste Isolation Pilot Plant-WIPP). SAND82-1783, Sandia National Laboratories, Albuquerque, New Mexico. August 1982.

Sandia National Laboratories, and D'Appolonia Consulting Engineers. Basic Data Report for Drillhole WIPP-12 (Waste Isolation Pilot Plant-WIPP). SAND82-2336, Sandia National Laboratories, Albuquerque, New Mexico. October 1982.

Saulnier, G.J., et al. WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #4. SAND86-7166, INTERA Technologies Inc., Austin, Texas. February 1987.

Sergent, Hauskins & Beckwith, Volume I, Subsurface Exploration & Laboratory Testing, Plant Site, Waste Isolation Pilot Plant, Bechtel Job No. 12484

Seward P.D. Abridged Borehole Histories for the Waste Isolation Pilot Plant (WIPP) Studies. SAND82-0080, Sandia National Laboratories, Albuquerque, New Mexico. January 1982.

Stensrud, W.A. Reconfiguration of H-4c, H-5c, and H-6c. Communication to Dan Winstanley, Westinghouse Electric. August 1986.

Stensrud, W.A., et al. WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #5. SAND87-7125, INTERA Technologies Inc., Austin, Texas. October 1987.

Stensrud, W.A., et al. WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #6. SAND87-7166, INTERA Technologies Inc., Austin, Texas. May 1988.

Stensrud, W.A., et al. WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #7. SAND88-7014, INTERA Technologies Inc., Austin, Texas. November 1988.

Stensrud, W.A., et al. WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #8. SAND89-7056, INTERA Technologies Inc., Austin, Texas. April 1990.

TME-020, Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydraulic Testing

U.S. DOE/WIPP 89-006, February 1989, Well History for the Water Quality Sampling Program

U.S. DOI Geological Survey, Open-File Report 78-592

USGS OFR 81-469, Geologic Data for Borehole ERDA-9, Eddy County, New Mexico

USGS OFR 81-488, Geologic Data for Borehole ERDA-9, Eddy County, New Mexico

USGS WRI 82-4111, Geologic and Well-Construction Data for the H-9 Borehole Complex Near the Proposed WIPP Site, Southeastern New Mexico

Winstanley, D.J. and R.C. Carrasco. Annual Hydrologic Data Report, 1985-1986. DOE-WIPP 86-004, WIPP Project, Carlsbad, New Mexico. October 1986.

WIPP Central File 4542. WIPP-18, WIPP-19, WIPP-21, and WIPP-22, Field Engineering Summary, Volume II

Appendix A

APPENDIX A

DATA FOR DRILLHOLES IN HOLT AND POWERS (1988) INCLUDING ADDITIONAL DRILLHOLES INTERPRETED BY POWERS

APPENDIX A-1

LOCATIONS FOR RUSTLER FORMATION DATA POINTS

Rustler Formation Location Data

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name**	Revisions
1001	W04	18	29	4	1980n	1980w	Roach Drilling, Western Development Miller No. 1	
1002	T19	18	29	19	660s	1980e	Martin Yates III and S.P. Yates, Travis Fed. 2	
1003	L18	18	30	18	1650n	924w	Newmont Oil Co., Loco Hills 21-B-6	
1004	C25	18	30	25	990n	330e	Yates Petroleum Corp., Creek "AL" #1	
1005	G26	18	30	26	990s	330e	Hanson Oil Corp., Ginsberg Fed. No. 11	
1006	M27	18	30	27	990n	1651w	Texaco, Inc., L.R. Manning "B" NCT-1 Well #20	
1007	R28	18	30	28	330s	1491e	Texaco, Inc., L.R. Manning Fed. "B" (NCT_1) #4	
1008	MO2	18	31	2	330s	660w	W.S. Montgomery, Magnolia St. #1	
1009	S11	18	31	11	660s	660w	Hudson & Hudson Inc., Shugart B-1	
1010	M16	18	31	16	660s	1980e	M.R. Voltz, Magnolia St. #2	
1011	F22	18	31	22	660s	660w	Gulf Oil Corp., Fed. Littlefield #1	
1012	F28	18	31	28	1980n	660w	Gulf Oil Corp., Fed. Keohane et al "B" No. 1	
1013	K28	18	31	28	1980n	1980w	Gulf Oil Corp., Fed.-Keohane et al "B" #3	
1014	C31	18	31	31	1980n	1980e	Campana Petroleum Co., Pure Fed. #1	
1015	H31	18	31	31	330n	844w	Ray M. Hall, Pure-Fed. #1	
1016	M32	18	31	32	1980n	1980w	Chambers and Kennedy, Monterey St. #4	
1017	S32	18	31	32	1650n	2310e	Sunray Mid-Continent Oil Co., St. "Y" #1	
1018	P32	18	31	32	330n	330w	L.T. Pate, Monterrey St. #5	
1019	W33	18	31	33	330n	330w	V.S. Welch [indet] No. 2, Shugart No. 5-B	
1020	J04	18	32	4	1650n	990e	B.M. Jackson, Fed. No. 2	
1021	G16	18	32	16	1980n	1980w	Gulf Oil Corp., Lea St. "HS" #3	
1022	J20	18	32	20	2310s	990w	John M. Beard, Young Fed. #5	
1023	C28	18	32	28	1980n	660w	Texaco, Inc., Cotton Draw Unit No. 53	
1024	C10	18	33	10	1980n	660e	Carper Drilling Co., Corbin R #1	
1025	B12	18	33	12	660n	1980e	P.W. Miller Drilg. & Prod. Co., Brit. Am. St. #2	
1026	D13	18	33	13	1650s	2310w	J.I. O'Neill, Jr., Dorothy Swigart #1	
1027	S28	18	33	28	1980s	660e	Sunray Mid-Continent Oil Co., Fed. "E" #1	Rev loc ctr, NE1/4, SE1/4
1028	H30	18	33	30	1980s	1980w	Penzoil United Inc., Hudson "29" Fed. #3	
1029	N01	18	34	1	560n	760w	Texaco, Inc., St. of New Mexico "M" #5	
1030	L06	18	34	6	989n	330w	Phillips Petroleum Co., Lea No. 17	
1031	B07	18	34	7	660s	660e	Richardson & Bass, St. of New Mexico #1	
1032	S22	18	34	22	1980s	1980w	Continental Oil Co., St. V-22 #2	
1033	T22	18	34	22	330s	1980w	Continental Oil Co., St. V-22 #1	
1034	M33	18	34	33	330s	1980w	Tom Brown Drilling Co., Marathon St. #1	
1035	F03	18	35	3	2310s	330e	Phillips Petroleum Co., Santa Fe No. 114	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1036	V04	18	35	4	1980n	660w	Standard Oil Co. of Texas, Vac Edge Unit #2	
1037	F05	18	35	5	1650n	990e	Phillips Petroleum Co., Santa Fe No. 111	
1038	S05	18	35	5	1650n	2285e	Phillips Petroleum Co., Santa Fe No. 93	
1039	V05	18	35	5	990s	990e	Standard Oil Co. of Texas, Vac Edge Unit #19	
1040	W06	18	35	6	330s	913w	The Ohio Oil Co., St. Waren Account 2 #9	
1041	A07	18	35	7	330n	990e	Tidewater Oil Co., St. AN #1	
1042	C29	18	35	29	1980n	660w	Carper Drilling Co., Carper-Luthy No. 1	
1043	C01	18	36	1	1980s	1980e	Cactus Drilling Corp., Catron "B" No. 2	
1044	P11	18	36	11	1980s	1980w	John M. Kelly, St. PE #1	
1045	K11	18	36	11	660s	660e	John M. Kelly, St. J.J. #1	
1046	C12	18	36	12	660n	1980w	Cactus Drilling Co., Amerada St. #1	
1047	A14	18	37	14	1650s	2310w	Amerada Petroleum Corp., St. W.H. "B" #2	
1048	W31	18	37	31	1980n	660w	Amerada Petroleum Corp., St. WM "E" #3	
1049	A03	18	38	3	1980s	1980e	O.D. Alsabrook, Saunders #1	
1050	M19	18	38	19	2310s	1650e	Shell Oil Co., Shell et al McKinley A-19 #1	
1051	N06	19	29	6	1980s	1765w	Shamrock Drilling Co., Nix & Curtis #1	
1052	S21	19	29	21	2015n	1880e	Wayne J. Spears, Stout St. #1	
1053	U26	19	29	26	660n	660w	Wayne J. Spears, Union St. #1	Rev loc NW1/4, NW1/4
1054	P05	19	30	5	1980n	330w	Yates Petroleum Corp., Perkins "AD" #3	
1055	U06	19	31	6	330n	1650w	Texaco, Inc., USA Fed. #1	
1056	S13	19	31	13	660s	1980e	Phillips Petroleum Co., Simon "A" No. 1	
1057	S14	19	31	14	660s	660e	Phillips Petroleum Corp., Simon "A" #2	
1058	T21	19	31	21	1980s	660e	Texas Crude Oil Co., Tennessee-Fed. #1-21	
1059	E29	19	32	29	1980n	660e	El Paso Natural Gas Co., Southern Cal. Fed. #1	
1060	C12	19	34	12	660n	660w	Carper Drilling Co., U.S. Smelting St. #1	
1061	A14	19	35	14	660s	660w	Atlantic Refining Co., St. AU #1	
1062	S27	19	35	27	1980n	660e	Shell Oil Co., Allen ESt. A #1	
1063	C28	19	35	28	1980s	660w	Cabot Carbon Co., St. G #1	
1064	L33	19	35	33	1980n	660e	Gulf Oil Corp., Lea St. BG #8	
1065	P01	19	36	1	1980n	330e	Pan American Petroleum Corp., St. "B" #1	
1066	H11	19	36	11	660s	1980w	Humble Oil and Refining Co., New Mex. St. "AO" #1	
1067	S18	19	36	18	1980n	1980w	Tom Brown Drilling Co., Sunray-Bryan #1	
1068	A25	19	36	25	660n	1980w	Amerada Petroleum Corp., St. "T" No. 4	Rev loc NE1/4, NW1/4
1069	A32	19	37	32	1980s	1980e	Amerada Petroleum Corp., May Love Unit #1	
1070	F21	20	30	21			Amoco Prod., Fed. Gas Com No. 1-G	Log lacks loc data

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1071	L31	20	30	31	1980n	760e	Texas International Petrol. Corp., Lowe Fed. #1	
1072	B07	20	31	7	1650s	660e	Pan American Petroleum Corp., Big Eddy Unit #11	
1073	B21	20	31	21	660n	660w	Pennzoil United, Big Eddy Unit No. 12	
1074	F10	20	32	10	330n	990w	Shell Oil Co., Perry Fed. #1	
1075	H13	20	32	13	660s	1980w	Flag-Redfern Oil Co., Hanson St. #1	
1076	P15	20	32	15	1980s	1980w	Phillips Petroleum Co., Plata Deep Unit #1	
1077	L05	20	33	5	660s	1980w	Pan American Petroleum Corp., Little Eddy Unit #1	
1078	S14	20	33	14	2310s	990w	Carl Engwall, Sinclair Fed. #1	
1079	B18	20	33	18	660n	2080w	Randall F. Montgomery, Bass St. #1	
1080	S18	20	33	18	1650n	1650w	Randall F. Montgomery, Bass St. #2	
1081	F27	20	33	27	1980n	1650e	Amoco Prod. Co., API #30-025-26241, Fed."Y" Com #1	
1082	L13	20	34	13	1980s	1980e	Marathon Oil Co., Lea Unit #3	
1083	H20	20	34	20	2310n	1650w	Burk Royalty, Hanson Fed. B #2	
1084	F29	20	34	29	1980s	330e	Earl G. Colton, Fed. #1	
1085	B28	20	35	28	660n	660e	W.H. Black, Phillips St. No. 1	
1086	S02	20	36	2	660n	1980e	The Superior Oil Co., St. "A" No. 2	
1087	U30	20	36	30	660n	660w	Union Oil Co. of California, Sims St. 1-30	
1088	H01	20	37	1	990n	1650w	Humble Oil and Refining Co., N.M. St. "AG" No. 6	
1089	W27	20	38	27	660s	660w	Continental Oil Co., Warren Unit "BT" No. 26	
1090	P03	21	29	3	1980n	1980w	Pan American Petroleum Corp., Big Eddy Unit #18	
1091	N04	21	29	4	4620s	1980w	Union Oil Co. of California, Cowden Fed. #1	
1092	P05	21	29	5	1980n	660e	Meadco Properties, Ltd., Harris-Bell #1	
1093	M05	21	29	5	980n	1880w	Meadco Properties Ltd., Harris Bell #2	
1094	M06	21	29	6	3147n	660e	Meadco Properties Ltd., Harris "6" #1	
1095	B15	21	29	15	1980s	1980w	Perry R. Bass, Big Eddy Unit #61	
1096	P18	21	29	18	1980s	1980e	Pan American Petroleum Corp., Big Eddy Unit #16	
1097	B22	21	29	22	1980n	1980e	Perry R. Bass, Big Eddy Unit No. 40	
1098	E34	21	29	34	660n	1980w	Bass Enterprises Prod. Co., Big Eddy Unit No. 38	
1099	D21	21	30	21	90n	1485w	WIPP 27	
1100	P26	21	30	26	660s	1980w	Phillips Petroleum Co., James "D" 1	
1101	P35	21	30	35	1980s	660w	Phillips Petroleum Co., James "C" #1	
1102	D18	21	31	18	99n	2401e	WIPP 28	
1103	D33	21	31	33	668n	177w	WIPP 30	Ref El from SAND79-0284
1104	Q35	21	31	35	2152s	910e	ERDA 6	
1105	E01	21	32	1	3255n	1972e	Phillips Petroleum Co., ETZ Fed. #1	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1106	F01	21	32	1	660s	1980w	Kimball Production Co., Fed. #1	
1107	H02	21	32	2	660s	1980e	Phillips Petroleum Co., Hat Mesa "A" #1	
1108	P02	21	32	2	3300n	660w	Amini Oil Co., Pubco Fed. #1	
1109	N04	21	32	4	1683n	1650w	Amini Oil Co., New Mexico Fed. #1	
1110	S06	21	32	6	2189n	500e	Holly Energy, Inc., Salt Lake Deep No. 1	
1111	G10	21	32	10	1980n	1980e	The Superior Oil Co., Government "H" Com. #1	
1112	F11	21	32	11	660s	660e	Gackle Drilling Co., Fed. #1	Rev loc SE1/4, SE1/4
1113	H11	21	32	11	660s	1980w	Phillips Petroleum Co., Hat Mesa 2-#2	
1114	M11	21	32	11	1980n	1980e	Phillips Petroleum Co., Hat Mesa #1	
1115	S21	21	32	21	660n	660w	Skelly Oil Co., Salt Lake South Unit #1	
1116	G26	21	32	26	1980n	660e	Gulf Oil Corp., San Simon #1	
1117	H31	21	32	31	660n	1980w	Gulf Oil Corp., H.T. Mattern (NCT) #10	
1118	U31	21	32	31	2040n	2040e	Union Carbide Corp., AEC #7; also Fenix & Scisson, AEC #7	
1119	G32	21	32	32	1980n	1980e	Getty Oil Co., Getty "32" St. Com #1	
1120	S02	21	33	2	2310s	2310w	Charles Read, Sinclair St. #1	
1121	W01	21	35	1	660n	660e	Amerada Petroleum Corp., St. WE "F" #3	Surf El from log
1122	N04	21	35	4	1902n	660w	British American Oil Prod. Co., N.M. St. "F" #1	
1123	C16	21	35	16	660s	660e	Cosden Petroleum Co., Cosden Petr. St. D #1	
1124	R32	21	35	32	1650n	660e	Resler & Sheldon, Phillips "C" No. 2	
1125	C17	21	36	17	990n	1650w	Atlantic Refining Co., Coleman #1	
1126	A21	21	36	21	660s	1980w	Gulf Oil Corp., Arnott Ramsey "C" No. 5	Rev loc SE1/4, SW1/4; log elev
1127	H26	21	36	26	1980n	1980w	Humble Oil & Refining Co., N.M. St. "G" #14	
1128	A27	21	36	27	1980s	1980e	Gulf Oil Corp., Arnott Ramsey "C" No. 5; ?DUP 1126***	Rev loc SE1/4, SW1/4
1129	G27	21	36	27	650n	1980e	Gulf Oil Corp., W.A. Ramsey NCT A #42	
1130	R27	21	36	27	1980s	510e	Gulf Oil Corp., W.A. Ramsey (N.C.T.A.) #39	
1131	L31	21	36	31	1980n	1980e	Late Oil Co., Rector A #1	
1132	A33	21	36	33	1980s	1980e	Gulf Oil Corp., Arnett Ramsey NCT-D #12	
1133	R34	21	36	34	1980n	660w	Gulf Oil Corp., W.A. Ramsey NCT #38	
1134	C28	21	37	28	2085s	765e	Gulf Oil Corp., J.N. Carson (NCT) C#9	
1135	M31	21	37	31	1980n	660w	Gulf Oil Corp., N.T. Mattern (NCT) No. B-12	B#10 or B#12?, log unclear
1136	E06	22	29	6	660s	660e	William A. and Edward R. Hudson, Eddy Fed. #1	
1137	D33	22	29	33	1673s	29e	WIPP 32	
1138	D34	22	29	34	407s	1828e	WIPP 29	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1139	T01	22	30	1	990s	1980w	Troporo Oil and Gas Co., Cabana #1	
1140	M02	22	30	2	665s	2006e	Phillips Petroleum Co., James "A" #1	
1141	D11	22	30	11	1980n	1980e	Phillips Petroleum Co., James "E" #1	
1142	D13	22	30	13	1762s	2427w	WIPP 33	
1143	D15	22	30	15	1853s	2838e	WIPP 25	Rev loc, elev from SAND79-0279
1144	P24	22	30	24	312s	613w	P-14	
1145	O24	22	30	24	167n	195e	P-12	
1146	B27	22	30	27	660n	2003e	Richardson & Bass, Fed. Legg #1	
1147	D29	22	30	29	2232n	12e	WIPP 26	
1148	C06	22	31	6	1980n	660w	B. McKnight et al, Campana No. 1	
1149	Z08	22	31	8	698s	122e	Fenix & Scissons Inc., WIPP No. DOE-2	
1150	D09	22	31	9	712n	294w	WIPP 11	
1151	W09	22	31	9	202s	2000w	WIPP 34	
1152	I09	22	31	9	99s	2112e	WIPP 14	Ref elev typo revised
1153	A11	22	31	11	935n	1979w	AEC 8	
1154	P14	22	31	14	794s	103e	P-20	
1155	H15	22	31	15	1007n	134e	Fenix & Scisson, WIPP HYDRO H-5c	
1156	P15	22	31	15	852n	150e	P-21	
1157	B15	22	31	15	1980s	1980w	Clayton W. Williams Jr., Badger Unit Fed. No. 1	
1158	D17	22	31	17	2564s	1727w	Fenix & Scisson, WIPP #13	
1159	W17	22	31	17	175s	84e	Fenix & Scisson, Inc., WIPP No. 12	
1160	P17	22	31	17	202s	165e	P-5	
1161	P18	22	31	18	125n	116w	P-13	
1162	H18	22	31	18	281n	375w	Fenix and Scisson, Inc., WIPP H-6c	
1163	P20	22	31	20	103s	3122e	P-3	
1164	S20	22	31	20	4306s	50e	Fenix & Scisson, Inc., WIPP #18	
1165	W20	22	31	20	2547s	50e	Fenix & Scisson, Inc., WIPP #22	
1166	D20	22	31	20	1451s	10e	Fenix & Scisson, Inc., WIPP #21	
1167	I20	22	31	20	2986s	50e	Fenix & Scisson, Inc., WIPP #19	
1168	Q20	22	31	20	267s	177e	ERDA 9	
1169	P23	22	31	23	175n	177w	P-11	
1170	O23	22	31	23	1652s	2330w	P-19	
1171	W23	22	31	23	330s	330e	Texas Crude Oil Co., Wright-Fed. #1-23	
1172	O26	22	31	26	134s	797e	P-18	
1173	P26	22	31	26	2315n	339w	P-10	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1174	P28	22	31	28	146s	1487e	P-4	
1175	DOE1	22	31	28	182s	608e	DOE-1	
1176	O28	22	31	28	125n	172e	P-2	Rev loc from OFR78-592
1177	L29	22	31	29	623n	1083e	H-1	
1178	H29	22	31	29	372s	562w	Department of Energy, H-14	Elev from SAND89-0202; ?Cul
1179	R29	22	31	29	770n	3584e	ERDA, Hydrological H-2c	
1180	Y29	22	31	29	3200n	140e	Sandia National Laboratories, Hydrological No. 3	
1181	P29	22	31	29	327s	551w	P-1	
1182	P30	22	31	30	2767s	199w	P-6	
1183	P31	22	31	31	398s	184w	P-15	
1184	H33	22	31	33	1502s	105e	H-11	Rev for H11b3; SAND89-0200
1185	P33	22	31	33	1493s	143e	P-9	
1186	T13	22	32	13	660s	660e	Ray Smith Drilling Co., B&H Fed. 1	
1187	C14	22	32	14	660s	1980w	Carper Drilling Co., #2 Red Tank Unit	
1188	C17	22	32	17	1980s	1980e	Cleary Petroleum Corp., Fed. 1-17	
1189	T18	22	32	18	660s	660e	J.H. Trigg Co., Fed. Jennings 1-18	
1190	B19	22	32	19	660s	660e	Ralph Lowe, Bass Fed. #1	
1191	M20	22	32	20	1980n	1980e	R.J. Zonne, #1 Fed.	
1192	T22	22	32	22	1980n	660w	John M. Trigg Co., Fed. Red Tank Unit #1-22	
1193	A25	22	32	25	660n	1980w	Gulf Oil Co. -- U.S., Covington "A" Fed. #1	
1194	T36	22	32	36	660n	660e	Tidewater Oil Co., Richardson & Bass St. "AO" #1	
1195	H01	22	34	1	1980s	660e	Humble Oil and Refining Co., N.M. St. BS #1	
1196	N08	22	34	8	660s	1980e	Sunray Mid-Continent, New Mexico St. "AE" No. 1	Elev from Richey (1989); KB??
1197	H10	22	34	10	1980n	660e	Hudson & Hudson Personal, Allison Fed. No. 1	
1198	J01	22	35	1	660s	660w	British American Oil Prod. Co., Jalmat Deep #1	
1199	D03	22	35	3	660n	660w	Western Drilling Co., Donegan St. No. 1	
1200	A04	22	35	4	660s	660e	Ashmun & Hilliard No. 3 Ltd., Skelly St. #1-U	
1201	S05	22	35	5	660n	660e	Skelly Oil Co., St. "U" #1	
1202	H09	22	35	9	1980s	1980w	William A. & Edward R. Hudson, Humble St. #1	
1203	B11	22	35	11	660s	990w	British American Oil Prod. Co., Hall St. "F" #9	
1204	C20	22	35	20	1980n	660e	Carper Drilling Co., Carper Aztec No. 1	
1205	H22	22	35	22	1980s	1980e	Curtis Hankamer, Humble St. #1	
1206	A23	22	35	23	1980s	330e	Atlantic Refining Co., St. "AN" #1	
1207	G35	22	35	35	660s	660w	John M. Kelly, Gulf St. 1-A	
1208	L03	22	36	3	660n	660w	Gulf Oil Corp., Harry Leonard (NCT-D) No. 9	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1209	G03	22	36	3	1980n	1980w	Gulf Oil Corp., Harry Leonard NCT-D No. 10	
1210	J04	22	36	4	1980s	660e	Gulf Oil Corp., J.F. Janda NCT F#15	
1211	G09	22	36	9	1980s	660e	Sinclair Oil & Gas Co., St. 157 A #4	
1212	S09	22	36	9	660s	660e	Sinclair Oil & Gas Co., St. 157 A #3	
1213	W10	22	36	10	560s	660w	Western Natural Gas Co., Record #2	
1214	A17	22	36	17	1980n	1980w	Continental Oil Co., Arrowhead Deep Unit #1	
1215	C19	22	36	19	660n	330w	Cities Service Oil Co., Closson "B" #14	
1216	C23	22	36	23	660s	660w	Shell Oil, Christmas #A-2	Co. name uncertain
1217	A33	22	36	33	1980n	1830w	Atlantic Refining Co., J.L. Selby No. 2	
1218	M36	22	36	36	2310n	330w	The Ohio Oil Co., St. McDonald A/C 1-B #11	
1219	W15	22	37	15	1980s	660w	Amerada Petroleum Co., E.W. Walden No. 4	Rev loc NW1/4, SW1/4
1220	R16	22	37	16	2310s	1650e	E.P. Campbell, R.E. Cole #1	
1221	A36	22	37	36	1980s	1980e	Aztec Oil & Gas Co., St. BD 36 #1	
1222	W30	22	38	30	990s	330w	Western Oil Fields Inc., Gulf Drinkard #2	
1223	M02	23	28	2	1560s	330w	Neil H. Wills, Martin & Pardue #1	
1224	C11	23	28	11	2316s	2290w	Neil H. Wills, C.P. Pardue #1	
1225	P17	23	28	17	660n	2310e	Cities Service Co., Polk "A" #1	
1226	N12	23	29	12	1980s	1980w	Mesa Petroleum Co., Nash Unit #3	
1227	P13	23	29	13	2310s	330e	Mesa Petroleum, Nash Unit #5	
1228	M13	23	29	13	990n	330e	Mesa Petroleum Co., Nash Unit #4	
1229	U13	23	29	13	1980n	660e	Mesa Petroleum Co., Nash Unit #1	
1230	H14	23	30	14	2595n	2471w	Fenix & Scisson, Inc., WIPP H-7c	
1231	F16	23	30	16	1980s	1980e	Skelly Oil Co., Forty-Niner Rdige Unit #1	
1232	U18	23	30	18	1980n	330w	Mesa Petroleum Co., Nash Unit #6	
1233	S21?	23	30	21	1980n	1980e	Skelly Oil, Forty Niner Ridge Unit 2; ? DUP 1234	
1234	N21	23	30	21	1980n	1980e	Skelly Oil Co., Forty Niner Ridge Unit 2	
1235	S24	23	30	24	1980n	660w	Phillips Petroleum Co., Sandy Unit #1	
1236	Q34	23	30	34	200n	2327e	ERDA 10	Rev from BDR: SAND79-0271
1237	U34	23	30	34	2640n	2640w	Atomic Energy Commission, U.S.G.S. Test Hole #1	
1238	S02	23	31	2	660n	660e	Continental Oil Co., St. AA 2 No.1	
1239	O04	23	31	4	1351s	395w	P-17	Ref elev from OFR78-592
1240	P04	23	31	4	642n	96w	P-8	
1241	H05	23	31	5	447n	719w	Fenix & Scisson, WIPP No. H-4C	
1242	P05	23	31	5	513n	396w	P-7	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1243	C05	23	31	5	1990n	2017e	M.P. Grace Cabin Baby Fed. 1	Data from WTSD-TME-020
1244	O05	23	31	5	951s	1629w	P-16	
1245	B11	23	31	11	660s	660e	Max M. Wilson, Bauerdorf-Fed. #1	
1246	T14	23	31	14	1980s	1980w	Texas American Oil Corp., Todd Fed. "14" No. 1	
1247	H15	23	31	15	23n	92e	H-12	Rev from BDR; SAND90-0201
1248	A16	23	31	16	1980s	1980w	El Paso Natural Gas Co., Arco St. #1-16	
1249	P21	23	31	21	660s	660e	Patoil Corp., Muse Fed. #1	
1250	F23	23	31	23	1980s	1800e	Texas American Oil Corp., Todd Fed. 23 #3	
1251	T23	23	31	23	660s	1650e	Texas American Oil Corp., Todd "23" Fed. No. 1	
1252	T25	23	31	25	1980n	1970w	Skelly Oil Co., Todd 25 Fed. #1-Z	
1253	A26	23	31	26	1980n	1650e	Texas American Oil Corp., Todd Fed. #2	
1254	T26	23	31	26	1980n	1980e	Texas American Oil Corp., Todd Fed. "26" No. 1	
1255	B26	23	31	26	660n	1980e	Texas American Oil Corp., Todd Fed. #4	Rev elev from geophys log
1256	P27	23	31	27	1980s	660w	Patoil Corp., Wright-Fed. #1	
1257	M29	23	31	29	1980s	1980e	El Paso Natural Gas Co., Mobil-Fed. #1	
1258	L32	23	31	32	660n	660w	J.A. Leonard, Continental St. No. 1	
1259	W33	23	31	33	1980n	660w	Patoil Corp., Wright-Fed. #2	
1260	H36	23	31	36	660s	660w	Charles P. Miller, Pauley Harrison St. #1	sw1/4,sw1/4 converted
1261	K03	23	32	3	1980n	660e	O.B. Kiel, Jr., Fed. #1	
1262	M09	23	32	9	660s	1980e	McBee Oil Co., Continental Fed. #1-9	
1263	H11	23	32	11	1980n	1980e	Hill & Meeker & Ambass. Oil Corp., Matthews "11" #1	
1264	T15	23	32	15	1980n	1980e	John H. Trigg, Fed. Continental 1-15	
1265	F18	23	32	18	1980n	660e	Skelly Oil Co., Fed. Sand 18-1	
1266	K20	23	32	20	660s	1980e	Kirklin Drilling Co., Fed. Estill AF-1	Grnd elev from topo map
1267	H20	23	32	20	381s	1978e	Fenix & Scisson, Inc., WIPP No. H-10c	
1268	G21	23	32	21	660n	1980e	Curtis Hankamer, Gulf-Fed. "A-A" #1	
1269	H24	23	32	24	1650s	330e	H.L. Johnston, Sr., Conoco-Fields-Fed. #1	
1270	C24	23	32	24	660s	660e	Continental Oil Co., Fields Fed. No. 1	
1271	C25	23	32	25	990s	330w	Continental Oil Co., Fields No. 2	
1272	J25	23	32	25	990n	2310w	H.L. Johnston, Sr., Wehrli-Fed. #1	
1273	W26	23	32	26	330s	330e	John H. Trigg, Fed. "WL" #3-26	
1274	F26	23	32	26	1980s	330e	P.M. Drilling Co., Fed. James No. 4	
1275	P26	23	32	26	660s	1980w	P.M. Drilling Co., Fed. Field #1	Ref elev rev from log
1276	L26	23	32	26	330s	1650e	John H. Trigg Co., No. 4-26 Fed. WL	
1277	W28	23	32	28	660n	1980w	Max Wilson, Continental Fed. No. 1	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1278	H31	23	32	31	660s	660w	Curtis Hankamer, Hankamer No.1 Continental Fed.	
1279	C33	23	32	33	1980n	660e	Curtis Hankamer, Holder Fed. #1	
1280	P34	23	32	34	1980s	330e	The Pure Oil Co., Fed. "K" No. 1	
1281	Q35	23	32	35	1980s	1980e	PM Drilling Co., Fed. James No. 3	Ref elev rev from log
1282	A35	23	32	35	1650n	2310e	John H. Trigg, Fed. WL 1-35	
1283	T35	23	32	35	660n	660e	P.M. Drilling Co., Fed.-James No. 1	Ref elev rev from log
1284	M35	23	32	35	990n	2310w	P-M Drilling Co., Payne No. 2	
1285	J35	23	32	35	1650n	990e	John H. Trigg, Fed. "WL" No. 2-35	Ref elev rev from log
1286	F35	23	32	35	1980n	660w	P.M. Drilling Co., Payne Fed. No. 4	
1287	P35	23	32	35	2310n	2310w	P-M Drilling Co., Fed.-Payne No. 1	
1288	R35	23	32	35	660n	1980e	P.M. Drilling Co., Fed. James No. 2	
1289	D35	23	32	35	1980s	330w	P.M. Drilling Co., Fed. Payne No. 3	
1290	P36	23	32	36	330n	330w	Penroc Oil Corp., Triste St. #1	Ref elev rev from log
1291	B36	23	32	36	1980s	1980e	The Pure Oil Co., Brinninstool Deep Unit #1	
1292	G36	23	32	36	1980n	660w	David Fasken, Gulf St. #1	
1293	C04	23	33	4	660s	660e	Cabeen Exploration Corp., Continental Fed. #1-P	
1294	T06	23	33	6	330s	330e	William A. & Edward R. Hudson, Shell Fed. #1-6	
1295	H07	23	33	7	660s	660w	William A. & Edward R. Hudson, Fed. 7 Well #1	
1296	T17	23	33	17	660s	660w	P-M Oil Co., Texaco St. No. 1	
1297	S18	23	33	18	660s	660w	Helbing & Podpechan, #1 "A" Shell St.	
1298	T18	23	33	18	660n	1980e	Tenneco Oil Co., Skelly St. #1	
1299	M19	23	33	19	660s	1980w	Continental Oil Co., Marshall #3	
1300	B19	23	33	19	660s	660w	Continental Oil Co., I.J. Marshall 19-1	
1301	A19	23	33	19	1980s	625w	Continental Oil Co., Marshall #4	
1302	C19	23	33	19	1980s	1910w	Continental Oil Co., Marshall #19-2	
1303	A20	23	33	20	1980n	1980e	American Quasar, Brinninstool #1	
1304	C20	23	33	20	660s	660e	Continental Oil Co., Levick Fed. #1	
1305	K31	23	33	31	660n	660e	Kirklin Drilling Co., Lea St. #1	
1306	H32	23	33	32	660n	1980e	El Cinco Production Co., Ltd., Humble St. 1-32	
1307	B35	23	33	35	660s	660w	George L. Buckles Co., St. 1-35	
1308	B18	23	34	18	1980s	1980w	Continental Oil Co., Bell Lake #9	
1309	L19	23	34	19	1980n	1980w	Continental Oil Co., Bell Lake Unit #10	
1310	N22	23	34	22	1980n	1980e	Shell Oil Co., North Antelope Ridge Unit #1	
1311	S34	23	34	34	1980s	1650w	Shell Oil Co., Antelope Ridge Unit 34-1	
1312	E01	23	35	1	660n	660e	Kenwood Oil Co., Ehrman Fed. No. 1	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1313	M01	23	35	1	2310s	330w	Schermerhorn Oil Corp., Malco Fed. No. 1	
1314	G03	23	36	3	660n	660e	Albert Gackle, Sinclair St. #7	
1315	F17	23	36	17	1650n	990w	Continental Oil Co., Farney A-17 No. 3	
1316	S20	23	36	20	1980s	1980w	Sinclair Oil & Gas Co., Fed. 714 #4	
1317	H04	23	37	4	1980s	660w	Samedan Oil Corp., Hughes A-1 #6	
1318	K06	23	37	6	330n	330e	Ralph Lowe, King "B" #5	
1319	H09	23	37	9	1980s	1980w	Skelly Oil Co., Harrison B-10	
1320	T16	23	37	16	1980s	1980e	The Texas Co., #3 St. of New Mexico "BZ" NCT-8	
1321	O24	23	37	24	660s	660e	Earl M. Craig, Ohio St. #1	
1322	B31	23	37	31	1980s	660e	Texaco Inc., E.E. Blinberry A NCT 1-2	
1323	C05	24	29	5	1650s	660w	Chase Petroleum Co., Valley #1	
1324	E06	24	29	6	330s	2310e	El Capitan Oil Co., Fed. Reid No. 1	
1325	F07	24	29	7	2310s	2310e	Southern California Petrol. Corp., Fed. Reid #1	
1326	R07	24	29	7	2310n	2310e	Southern California Petrol. Corp., Fed. Reid #2	
1327	V07	24	29	7	990s	330w	Tennessee Production Comp., Valley Land Co. #2	
1328	T07	24	29	7	1650s	1650w	Tennessee Production Co., Valley Land #3	
1329	C09	24	29	9	770s	770e	Skelly Oil Co., Cedar Canyon #1	
1330	S09	24	29	9	660s	1980e	Skelly Oil Co., Cedar Canyon 9D #1	
1331	C10	24	29	10	2180n	1980w	Skelly Oil Co., Cedar Canyon #10-1	
1332	P27	24	29	27	660s	660w	Penzoil United Inc., Mobil-Fed. "27" #1	
1333	P04	24	30	4	660s	1980e	Perry R. Bass, Poker Lake Unit #54	
1334	P18	24	30	18	460n	660e	Perry R. Bass, Poker Lake Unit #45	
1335	H23	24	30	23	2062n	1466e	Fenix & Scisson, Inc., WIPP H No. 8-C	
1336	B25	24	30	25	660s	660w	Hill & Meeker, Bass Fed. #1-25	
1337	C29	24	30	29	660s	660e	Ford Chapman & Associates, Fed.-Nettles No. 1	
1338	T02	24	31	2	1980n	1980w	Skelly Oil Co., Todd "2" St. #1	
1339	J03	24	31	3	660s	660e	Max Wilson, Jennings Fed. No. 1	
1340	F03	24	31	3	660n	660w	Jack L. McClellan, Jennings Fed. No. 1	
1341	S04	24	31	4	660n	660e	Texaco, Inc., M.M. Stewart Fed. #1	
1342	H04	24	31	4	2482n	193w	Fenix & Scisson, Inc., WIPP No. H-9C	
1343	B04	24	31	4	1659n	2310w	Sundance Oil Co., Betty Fed. #1	
1344	E04	24	31	4	1980n	1980w	El Paso Natural Gas Co., Sundance Fed. #1	
1345	D06	24	31	6	1980n	1980w	American Quasar, Dunes Unit Fed. #1	
1346	Y07	24	31	7	660s	660e	Ambassador Oil Corp., Fed. "Y" #1	
1347	G11	24	31	11	660n	1980e	Gulf Oil Corp., Fed. Littlefield "CT" #1	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1348	E12	24	31	12	1980s	1980w	Coquina Oil Corp., El Paso Fed. No. 1	
1349	W17	24	31	17	660n	660e	W.J. Weaver, Continental Fed. #1	Ref elev calc from log
1350	R18	24	31	18	660s	660e	Charles B. Read, Ritchie Fed. #1	
1351	P20	24	31	20	660n	660e	Pauley Petroleum Inc., Jennings Fed. #1	
1352	F20	24	31	20	660s	1980w	David Fasken, Poker Lake #40	
1353	H21	24	31	21	660n	660e	Hill & Meeker, Carper Fed. #1-21	
1354	T24	24	31	24	660s	1980e	The Texas Co., T. Heflin-Fed. #1	
1355	M28	24	31	28	660s	660e	Pan American Petroleum Corp., Poker Lake Unit #36	
1356	M35	24	31	35	1980s	660w	Texaco, Inc., Cotton Draw Unit No. 67	
1357	U01	24	32	1	660s	1980e	Union Oil Co. of California, Union Fed. "1" #1	
1358	C01	24	32	1	1980s	660w	Cabeen Exploration Corp., Continental Fed. #1-L	
1359	M02	24	32	2	1990n	1990w	Calco, Marathon St. #1	
1360	O02	24	32	2	1980n	660e	P.M. Drilling Co., Ohio St. No. 1	
1361	H06	24	32	6	660n	1980e	Curtis Hankamer, Bondurant Fed. No. 1	
1362	G10	24	32	10	1980s	1980e	Gulf Oil Corp., Fed. Hanagan D #1	
1363	C11	24	32	11	660n	660e	Continental Oil Co., Wimberly #2	
1364	N11	24	32	11	660s	1980e	Curtis Hankamer, Hanagan Fed. No. 2	
1365	H11	24	32	11	1980s	660e	Gulf Oil Corp., Fed. Hanagan D #3	
1366	F11	24	32	11	1980s	1980e	Gulf Oil Corp., Fed. Hanagan D #2	
1367	G11	24	32	11	660s	660e	Curtis Hankamer, Gulf Hanagan #1	
1368	W11	24	32	11	1980n	1980e	Continental Oil Co., Wimberly #1	
1369	W12	24	32	12	660n	660e	Continental Oil Co., Wimberly 12 #1	Loc rev from geoph log
1370	C12	24	32	12	1980n	660e	Continental Oil Co., Wimberly "12" #2	
1371	H12	24	32	12	1980n	660w	Curtis Hankamer, Hanagan Fed. No. 3	Ref elev rev from log
1372	W13	24	32	13	660s	660e	WeSt.s Petroleum Corp. of Texas, Woolley #1	
1373	A13	24	32	13	660n	1980e	Continental Oil Co., Wimberly "A" #1	
1374	J14	24	32	14	660n	1980w	Tenneco Oil Co., #1 USA Jennings	
1375	T14	24	32	14	882s	882w	Tenneco Oil Co., USA Jennings N.M. 033503 No. 2	
1376	F14	24	32	14	1980s	1650w	Tenneco Oil Co., Jennings Fed. No. 4	
1377	U14	24	32	14	660n	1980e	Tenneco Oil Co., USA Jennings N.M. 033503 Well #3	
1378	F15	24	32	15	660s	720e	Gulf Oil Corp., Fed. Hanagan "B" #2	
1379	G15	24	32	15	1980s	660e	Gulf Oil Corp., Fed. Hanagan "B" #3	
1380	T15	24	32	15	660s	1980w	Tenneco Oil Co., Hicks-Fed. #1	
1381	H15	24	32	15	660s	1980e	Gulf Oil Corp., Fed. Hanagan "B" #1	
1382	B22	24	32	22	1980s	1980e	Charles B. Read, Bradley #1	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1383	R22	24	32	22	1980n	990e	Charles B. Read, Bradley #2	Ref elev rev from log
1384	G22	24	32	22	1980n	660w	Tenneco Oil Co., U.S. Smelting U.S.A. #2	
1385	S22	24	32	22	1980s	660e	Tenneco Oil Co., U.S. Smelting U.S.A. Well #3	
1386	U22	24	32	22	2310n	1650e	Tenneco Oil Co., U.S Smelting USA #4	
1387	T22	24	32	22	660n	1980e	Tennessee Gas Transmission Co., US Smelting USA #1	
1388	N22	24	32	22	990s	330e	Tenneco Oil Co., U.S. Smelting, USA No. 5	
1389	E23	24	32	23	1980n	660w	Curtis Hankamer, Ernest Fed. #1	
1390	B23	24	32	23	660n	660e	Charles B. Read, Bradley #3	
1391	W27	24	32	27	660n	1980e	Ralph E. Williamson, Wright Fed. No. 1	
1392	P30	24	32	30	1980n	1980e	Union Oil of California, Paduca Fed. #1	
1393	D33	24	32	33	660s	660e	Texaco Inc., Cotton Draw Unit Well #72	
1394	C34	24	32	34	1980s	1980w	Texaco, Inc., Cotton Draw Unit #69	
1395	R35	24	32	35	660s	660w	Sid W. Richardson, Inc., Fed. Delbasin #1	
1396	B01	24	33	1	660n	660e	Continental Oil Co., Bell Lake Unit #7	
1397	H06	24	33	6	1980s	660w	Hondo Drilling Co., Gulf N.W. #2	
1398	G06	24	33	6	660s	660w	Hondo Drilling Co., Gulf St. "NW" #1	
1399	I07	24	33	7	1980n	660w	Tom L. Ingram, St. "O" #2	
1400	O07	24	33	7	660n	660w	Tom L. Ingram, St. "O" #1	
1401	T07	24	33	7	330n	1750w	Tom L. Ingram, St. "P" #1	
1402	R07	24	33	7	660s	660e	George W. Riley Inc., St. #1-7	
1403	F07	24	33	7	2310n	2310w	David Fasken, Gulf St. #7-2	
1404	S08	24	33	8	660n	660w	Sunray Mid-Continent Oil Co., N.M. St. A.G. 1	
1405	B13	24	33	13	1980n	660e	Byard Bennett, Holland #1	
1406	T17	24	33	17	660s	660w	Tenneco Oil Co., St. Lowe #1	
1407	H17	24	33	17	660n	1980e	Robert B. Holt, Holly-St. #1	
1408	C20	24	33	20	660s	1980w	Continental Oil Co., St. "BB" 20 No. 1	
1409	J22	24	33	22	1980n	660w	F.R. Jackson, St. #1	
1410	T27	24	33	27	1980s	1980w	Tenneco Oil Co., Sunray St. #1	
1411	T29	24	33	29	660s	1980e	Tidewater Oil Co., St. "AP" #1	
1412	C30	24	33	30	330n	330w	Kirklin Drilling Co., Inc., Continental St. #1	
1413	G31	24	33	31	1980s	660e	Albert Gackle Operator, Continental St. #1	
1414	K36	24	33	36	660n	660e	Gulf Oil Corp. & Kirklin Drilling, #1 Lea St. "GX"	
1415	H01	24	34	1	1980n	1980e	Hanagan Petroleum Corp., #1 Gerdlag	
1416	D04	24	34	4	660n	1650e	Shell Oil Co., Fed. "BE" #1	
1417	C05	24	34	5	1650n	1650w	Continental Oil Co., Bell Lake Unit #14	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1418	B06	24	34	6	660n	3300e	Continental Oil Co., Bell Lake Unit No. 3	
1419	S09	24	34	9	660n	1980e	Shell Oil Co., Hall Fed. #1	
1420	W05	24	35	5	1980n	1980w	Gulf Oil Co. - U.S., Wilson Fed. Com. #1	
1421	A16	24	35	16	1650n	1980e	Texas International Pet. Corp., Aztec St. No. 1	
1422	F05	24	37	5	1966n	1980e	Texaco Inc., E.D. Fanning No. 7	
1423	H30	24	38	30	535n	2310w	Ralph Lowe, Hair #2	
1424	E28	25	28	28	1980n	1980w	Gulf Oil Corp., Eddy St. FD #1	
1425	B03	25	29	3	660n	660e	J. Glen Bennett, Superior Fed. #1-3	
1426	B08	25	29	8	980n	660w	J. Glen Bennett, Superior #1-8	
1427	W08	25	29	8	660s	660e	Neil H. Wills, Superior Fed. #1	
1428	M14	25	29	14	1980s	1980w	Mobil Oil Corp., Corral Draw Unit #1	
1429	B15	25	29	15	660s	660w	J. Glen Bennett, Superior Fed. 15 No.1	
1430	W22	25	29	22	1580s	1980w	Mobil Oil Corp., Corral Draw Unit #2	
1431	B26	25	29	26	660s	660e	J. Glen Bennett, No. 1-26 Superior Fed.	Ref elev rev from log
1432	B27	25	29	27	660s	660w	J. Glen Bennett, Superior Fed. 1-27	
1433	B29	25	29	29	660n	1880w	Bell Petroleum Co., Fed. #1	
1434	B30	25	29	30	660s	760e	Bell Petroleum Co., Cities Service Fed. #1	
1435	P03	25	30	3	1980s	990e	Bass Enterprises Prod. Co., Poker Lake Unit #47	
1436	P04	25	30	4	1980n	1980w	Pat Oil Corp., R & B Fed. #1	
1437	J04	25	30	4	660s	660w	J.M.C. Ritchie & Chambers & Kennedy, #1 Hopp Fed.	
1438	R08	25	30	8	1980n	660e	Fred Pool Drilling Co., Superior St. #1	Grnd el from topo; ref is +9ft
1439	K08	25	30	8	663s	667w	Ralph Lowe, Poker Lake St. #1	Ref el from log; topo differs
1440	L08	25	30	8	660s	660w	Ralph Lowe, Poker Lake St. #1; ? DUP 1439	Ref el rev from geoph log
1441	T08	25	30	8	660n	660w	Ralph Lowe, T&P St. #1	
1442	S08	25	30	8	1980s	1980w	Ralph Lowe, Superior St. #1	
1443	P08	25	30	8	1980s	660w	Ralph Lowe, Poker Lake St. #3	Ref el from topo; KB not given
1444	A10	25	30	10	660s	645w	Alamo Corp., Poker Lake Unit #5X-1A	
1445	P10	25	30	10	2030n	2180e	Bass Enterprises, Poker Lake #44	
1446	X17	25	30	17	610n	610w	Ralph Lowe, #1-X R&B Fed. "A"	
1447	A17	25	30	17	660s	660w	Alamo Corp., Poker Lake Unit #11A-7	
1448	J17	25	30	17	1980n	660w	J. Ray Stewart, Poker Lake #61	
1449	P17	25	30	17	330n	1650w	Jubilee Energy Corp., Poker Lake Unit 64	
1450	L17	25	30	17	1980s	330w	J. Ray Stewart, 66 Poker Lake Unit	
1451	B18	25	30	18	660n	1980e	Perry R. Bass, Jennings-Fed. No. 1	
1452	M18	25	30	18	660n	660e	Ralph Lowe, R&B Fed. #1	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1453	A18	25	30	18	660s	1980e	Alamo Corp., Poker Lake #12A-9	
1454	P19	25	30	19	330n	900e	Central St.s Oil Co., Poker Lake Unit No. 38	
1455	L19	25	30	19	660n	660e	J.R. Stewart, Poker-Lake Unit No. 65	
1456	C20	25	30	20	1980s	660w	Perry R. Bass, Continental-Fed. #2	
1457	F20	25	30	20	660n	660w	Perry R. Bass, Continental Fed. #1	
1458	A21	25	30	21	660n	660e	Alamo Corp., Poker Lake Unit #6-2A	
1459	P25	25	30	25	660s	660w	Bass Enterprises Prod. Co., Poker Lake Unit No. 56	
1460	D02	25	31	2	1980n	1980e	Texaco Inc., Cotton Draw Unit No. 65	
1461	A28	25	31	28	660n	660w	Alamo Corp., Poker Lake Unit 7-A-3	
1462	C32	25	31	32	660n	660w	J.A. Leonard, Continental St. No. 1	
1463	S35	25	31	35	660s	660w	Gold Metals & Santana Pet. Corp., #1 Del Basin Fed	
1464	C03	25	32	3	1650s	1980e	Texaco, Inc., Cotton Draw Unit No. 49	
1465	R09	25	32	9	330s	330e	Texaco Inc., E.F. Ray NCT-2 No. 1	Grnd el 3451 from topo map
1466	D09	25	32	9	1650s	330e	Texaco Inc., Cotton Draw Unit No. 52	
1467	T10	25	32	10	660n	660w	Tennessee Gas & Oil Co., Ray U.S.A. #1	
1468	C10	25	32	10	1980n	660w	Texaco Inc., Cotton Draw Unit No. 39	
1469	D10	25	32	10	660n	1980w	Texaco Inc., Cotton Draw Unit No. 40	
1470	Q10	25	32	10	2080n	760w	Texaco Inc., Cotton Draw Unit #66	
1471	Y10	25	32	10	660n	660w	Texaco Inc., Cotton Draw Unit No. 63; may dup 1467	
1472	M10	25	32	10	2145n	2310e	Texaco Inc., Cotton Draw Unit No. 60	
1473	R10	25	32	10	1980n	1980w	Texaco Inc., E.F. Ray Fed. "B" No. 2	Grnd el 3454 from topo, no KB
1474	V10	25	32	10	660s	1980e	Texaco Inc., E.F. Ray-Fed. "B" Well #1	Grnd el 3449 from topo map
1475	S10	25	32	10	660s	1980w	Texaco Inc., E.F. Ray Fed. No. 1	Grnd el 3445 from topo map
1476	F10	25	32	10	1980s	1980w	Texaco Inc., E.F. Ray-Fed. (NCT-1) No.2	Grnd el 3448 from topo map
1477	E10	25	32	10	1650s	660w	Tenneco Oil Co., Emily Flint Ray U.S.A. #41	
1478	C11	25	32	11	660s	1980e	WeSt.s Petroleum Corp. of Texas, Cont. Fed. #1	Loc rev from SW1/4, SE1/4
1479	P13	25	32	13	660s	1980w	Patoil Co., Union Fed. #1	
1480	F14	25	32	14	660s	660e	Joseph O'Neill Jr., Fed. "O" #1	
1481	O14	25	32	14	1980s	660e	Joseph O'Neill, Fed. "O" #2	
1482	H14	25	32	14	2310n	330w	Hill & Meeker, Ora Hall-Fed. 14 #1	
1483	U15	25	32	15	660s	660w	Tennessee Gas Transmission, #1 USA G.E. Jordan	
1484	F15	25	32	15	1980n	660w	Texaco Inc., G.E. Jordan Fed. (NCT-2) Well No.1	Grnd el 3441 from topo, +KB
1485	J15	25	32	15	1980s	1980w	Texaco Inc., G.E. Jordan Fed. (NCT-1)#2	Grnd el 3428 from topo, +KB
1486	R15	25	32	15	660n	1980w	Tennessee Gas & Oil Co., G.E. Jordan #3	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1487	E15	25	32	15	660n	1980e	Texaco Inc., G.E. Jordan Fed. (NCT-1) No. 8	Grnd el 3443 from topo, +KB
1488	G15	25	32	15	660n	660w	Texaco Inc., G.E. Jordan-Fed. (NCT-2) No. 2	Grnd el 3443 from topo, +KB
1489	N15	25	32	15	1980s	660w	Tennessee Gas & Oil Co., G.E. Jordan USA #4	
1490	T15	25	32	15	1980n	1980e	Texaco Inc., G.E Jordan Fed. (NCT-1) #6	
1491	M15	25	32	15	1980n	1980w	Tennessee Gas Transmission Co., G.E. Jordan USA #2	
1492	W15	25	32	15	2130s	2130e	Texaco Inc., Cotton Draw Unit No. 46	Grnd el 3431 from topo; +KB
1493	N16	25	32	16	660s	1980w	Tennessee Gas & Oil Co., St. Monsanto #4	
1494	B16	25	32	16	1980n	660e	Tennessee Gas Trans. Co., St. E.L. Bradley #1	
1495	P16	25	32	16	1650s	2310w	Tenneco Oil Co., St. Monsanto #6	
1496	M16	25	32	16	1980s	660e	Tennessee Gas Transmission Co., St. Monsanto #1	
1497	L16	25	32	16	1650s	1650e	Tenneco Oil Co., St. Monsanto #5	
1498	S16	25	32	16	1660s	990w	Tenneco Oil Co., Monsanto St. #8	
1499	F16	25	32	16	660n	660e	Tennessee Gas & Oil Co., St. Bradley #2	
1500	C16	25	32	16	330s	990w	Tenneco Oil Co., St. Monsanto #7	
1501	T16	25	32	16	2310n	2310w	Tenneco Oil Co., St. E.L. Bradley #3	
1502	Z16	25	32	16	1980n	1980e	Continental Oil Co., St. Z 16 #1	
1503	A16	25	32	16	660s	1980e	Tennessee Gas & Oil Co., St. Monsanto #3	
1504	E16	25	32	16	660s	660e	Tennessee Gas & Oil Co., Monsanto #2	
1505	X16	25	32	16	2080n	1650e	Shoreline Exploration Comp., Continental St. #1	Ref el rev from log
1506	D18	25	32	18	660n	1650w	Texaco Inc., Cotton Draw Unit #64	
1507	S18	25	32	18	660n	1980e	The Texas Co., Jack B. Shaw Fed. #1	
1508	C20	25	32	20	1650s	330e	Texaco Inc.(formerly PRBass), Cotton Draw Unit #42	
1509	D21	25	32	21	990s	990e	Texaco Inc., Cotton Draw Unit #57	Grnd el 3392 from topo, +KB
1510	M21	25	32	21	660s	660w	Panther City Investment Co., Perry Fed. #37	
1511	J21	25	32	21	1980s	660w	Panther City Investment Co., Perry Fed. #35	
1512	Y21	25	32	21	1980n	1980w	Panther City Investment, Inc., Perry Fed. No.6	Grnd el 3400 from log, no KB
1513	K21	25	32	21	660n	1980w	Panther City Invest. Inc., Perry Fed. No. 7	
1514	I21	25	32	21	2310s	990e	Panther City Investment Co., Perry Fed. #27	
1515	B21	25	32	21	1980s	1980e	Panther City Investment Co., Perry Fed. #28	
1516	E21	25	32	21	1980n	1980e	Tennessee Gas & Oil Co., #3 E.H. Perry-U.S.A.	
1517	N21	25	32	21	660s	1980w	Panther City Investment Co., Perry Fed. #38	
1518	V21	25	32	21	330s	330e	Perry R. Bass, Perry Fed. #43	
1519	C21	25	32	21	990s	2310e	Texaco Inc.(formerly Panther), Cotton Draw Unit 44	
1520	H21	25	32	21	1980n	660w	Tenneco Oil Co., E.H. Perry "USA" Well No. 36	
1521	P21	25	32	21	660n	660w	Tennessee Gas & Oil Co., E.H. Perry U.S.A. 2	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1522	R21	25	32	21	1980n	660e	Panther City Investment Co., Perry Fed. #2	
1523	T21	25	32	21	660n	1980e	Tennessee Gas Transmission Co., E.H. Perry USA #1	
1524	F21	25	32	21	660n	660e	Panther City Investment Co., Perry Fed. #1	
1525	G21	25	32	21	1980s	1980w	Panther City Investment Co., Perry Fed. #5	Ref elev rev from log
1526	J22	25	32	22	1980n	660w	Texaco Inc., G.E. Jordan Fed. #3	Grnd el 3409 from topo, +KB
1527	E22	25	32	22	660n	660w	Texaco Inc., G.E. Jordan Fed. No. 1	
1528	C22	25	32	22	2310s	330w	Texaco Inc., Cotton Draw Unit No. 48	
1529	T22	25	32	22	510n	1830w	Texaco Inc., G.E. Jordan Fed. NCT-1 #5	
1530	D22	25	32	22	1650n	1650w	Texaco, C.D. Unit No. 18	was T22 in T25S, R33E; misloc
1531	O23	25	32	23	660n	1980e	Joseph L. O'Neill, Fed. "P" #1	
1532	G25	25	32	25	660s	1980w	Texaco Inc., G.E. Jordan Fed. No. 4	
1533	C27	25	32	27	330n	330w	Texaco Inc., Cotton Draw Unit No. 61	
1534	U28	25	32	28	660n	1980w	Texaco Inc., Cotton Draw Unit No. 47	
1535	N28	25	32	28	660n	990e	Texaco Inc., Cotton Draw Unit No. 56	
1536	J28	25	32	28	2310s	1650w	Tenneco Oil Co., J.D. Sena U.S.A. No. 1	
1537	X28	25	32	28	660n	2310e	Texaco Inc., Cotton Draw Unit No. 51	
1538	W28	25	32	28	1980n	2310e	Texaco Inc., Cotton Draw Unit No. 54	
1539	C28	25	32	28	660n	660w	Texaco Inc., Cotton Draw Unit No. 45	
1540	Z28	25	32	28	1650n	990e	Texaco Inc., Cotton Draw Unit No. 59	
1541	V28	25	32	28	1980n	1980w	Texaco Inc., Cotton Draw Unit No. 50	
1542	D28	25	32	28	2310s	990w	Tenneco Oil Co., J.D. Sena Jr. U.S.A. No. 2	
1543	T29	25	32	29	1980n	330e	Texaco Inc., Cotton Draw Unit No. 58	
1544	C29	25	32	29	990s	330e	I.W. Lovelady, Conoco Fed. #1-29	
1545	S31	25	32	31	1980n	660w	Ray Smith, Ray Smith #1	
1546	C32	25	32	32	1980n	1980w	R.C. Graham, Conoco St. No. 1	
1547	W33	25	32	33	1980s	560e	WeSt.s Petroleum Corp. of Texas, Jennings #1	Ref el rev from log
1548	H33	25	32	33	660s	660w	Hill & Meeker, Hall-Fed. 1-33	
1549	M33	25	32	33	2310n	2310w	Hill & Meeker, Jennings-Fed. 1-33	DF 3354 log; grnd el 3346 topo
1550	J01	25	33	1	660n	660w	Perry R. Bass, Fed.-Muse #1	
1551	H05	25	33	5	660n	660e	Hill & Meeker, Bass Fed. #1	
1552	S08	25	33	8	1980s	660e	Santana Petroleum Corp., Annie Bass Fed. #1	
1553	H11	25	33	11	660n	660w	Curtis Hankamer, Muse Fed. #1	
1554	J18	25	33	18	660n	660w	Sam H. Jolliffe Jr., #1 Bass Fed.	
1555	H20	25	33	20	660n	1980e	Curtis Hankamer, Fed. Bass #1	
1556	B21	25	33	21	660n	660e	George L. Buckles Co., Fed. Marshall No. 1	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1557	A21	25	33	21	660s	660e	American Quasar Petroleum Co., Vaca Draw #1	
1558	M23	25	33	23	660s	660w	Hill & Meeker, Muse-Fed. 23 #1	
1559	F24	25	33	24	660s	660w	R.B. Farris, Perry Fed. 1	
1560	K25	25	33	25	1980s	660w	King Resources, Pan American Fed. No. 1	
1561	A25	25	33	25	660s	660e	Ashmun & Hilliard, Fed. No. 1-25	
1562	D27	25	33	27	660s	660e	Robert A. Dean, Harry Dickson #1	
1563	T28	25	33	28	660s	660e	Tidewater Oil Co., Annie R. Bass Fed. #1	
1564	C28	25	33	28	660n	660e	Curtis Hankamer, Conley Fed. #1	
1565	T29	25	33	29	1980n	660w	Tenneco Oil Co., W.H. Jennings Inc USA No. 1	
1566	T31	25	33	31	660s	660w	Tenn. Gas Transmission Co, Richardson & Bass USA#1	
1567	D32	25	33	32	330s	2310e	Pure Oil Co., Red Hills Unit #1	
1568	W32	25	33	32	1980s	660e	Neil H. Wills, Continental St. No. 1	
1569	W36	25	33	36	660s	660w	Max M. Wilson, Marathon-St. #1	
1570	A36	25	33	36	660n	660w	Ashmun Hilliard Oil Co., St. #1-36	
1571	F19	25	34	19	660n	1980w	Ashmun & Hilliard, Fed. 2-19	
1572	C27	25	34	27	1980n	660e	Tenneco Oil Co., Conoco Fed. #1	
1573	S02	25	37	2	2310s	1650e	Continental Oil Co., St. A-2 #2	log not recovered
1574	L03	25	37	3	330s	990w	George L. Buckles Co., Liberty Royalty No. 4	log not recovered
1575	J14	25	37	14	560n	330e	Johnson & French, Fed. "A" #1	log not recovered
1576	L14	25	37	14	1650s	1650e	Atlantic Refining Co., Langlie Fed. #2	
1577	W24	25	37	24	1980n	990w	Western Natural Gas, Wimberly #4	log not recovered
1578	H11	26	29	11	660s	660e	Curtis Hankamer, Hanson "A" #1	
1579	H12	26	29	12	458s	744w	Curtis Hankamer, Hansen Fed. #2	
1580	G13	26	29	13	660s	660w	Curtis Hankamer, Gulf Fed. #4-B	
1581	F13	26	29	13	660s	1980w	Curtis Hankamer, Gulf-Fed. No.1	
1582	C13	26	29	13	1980s	660w	Curtis Hankamer, Gulf Fed. 5-B	
1583	D13	26	29	13	1980s	1980w	S.P. Dillon, Gulf Fed. #1	
1584	G14	26	29	14	1980s	660e	Curtis Hankamer, Gulf Fed. Beady #3	
1585	F14	26	29	14	1980n	660e	Gulf Oil Corp., Fed. Boothe "E" #2	
1586	M22	26	29	22	2310s	330e	Challenger Energy Inc., Mobil "22" Fed. #2	
1587	F23	26	29	23	660s	660w	Gulf Oil Corp., Fed. Boothe E #1	
1588	G24	26	29	24	660n	660w	Curtis Hankamer, Gulf-Beaty No. 1	
1589	A27	26	29	27	2310n	330e	Worth Petroleum Co., Amoco Fed. #4	
1590	F34	26	29	34			Gulf Oil Corp., Fed. Littlefield "BO" #1	
1591	S02	26	30	2	660s	660w	Ford Chapman Associates, Sinclair St. No. 1-2	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1592	S03	26	30	3	660s	660w	Charles B. Read, Scott Fed. #1	
1593	K04	26	30	4	660n	660w	Aztec Oil Co., Fed. K.W. No. 1 [also Late Oil Co.]	Ref el 3179, 3180 from log
1594	B06	26	30	6	660s	660w	J. Glen Bennett, No. 1 Brunson Fed.	
1595	F06	26	30	6	660n	660w	T.W. Loffland, Brunson Fed. #2	
1596	M12	26	30	12	660s	660e	Montery Oil Co., Monteray Blaydes #1	
1597	F18	26	30	18	660s	660w	Curtis Hankamer, #1 AT Fed.	
1598	M18	26	30	18	330s	330w	Curtis Hankamer, McKenna Fed. #2	
1599	R28	26	30	28	1980s	660e	Penroc Oil Corp., Ross Draw Unit #6	
1600	B09	26	31	9	660s	660w	George L. Buckles, Buckles Fed. No. 1	
1601	F15	26	31	15	660s	660w	George L. Buckles Co., Fed. No. 1-15	
1602	P17	26	31	17	1980s	660e	Union Oil Co of Cal, Phantom Banks Unit Fed. 17 #1	
1603	P20	26	31	20	800s	1000w	Texas Pacific Oil Co., Phantom Draw Unit-Fed. #1	
1604	M20	26	31	20	660s	660w	Max Wilson, Hanson Fed. No. 1	
1605	C05	26	32	5	660n	1980w	Fred Pool Drilling Co., Conoco Bradley #1	
1606	B15	26	32	15	1980s	660e	Brown & Krug Co., Ben Fed. #1	Loc rev from NE1/4, SE1/4
1607	R19	26	32	19	660s	1980w	Continental Oil Co., Russell Fed. 19 No. 4	
1608	J25	26	32	25	990n	990w	Continental Oil Co., Wilder #23	
1609	G25	26	32	25	1980s	660e	Continental Oil Co., Wilder #13	
1610	F25	26	32	25	660s	660e	Continental Oil Co., Wilder #12	
1611	E25	26	32	25	1980n	660e	Continental Oil Co., Wilder #10	
1612	B25	26	32	25	1980s	1980e	Continental Oil Co., W.W. Wilder No. 7	
1613	I25	26	32	25	660n	1980w	Continental Oil Co., Wilder #15	Ref el rev from log
1614	H25	26	32	25	1980n	660w	Continental Oil Co., Wilder #14	
1615	A25	26	32	25	1980n	1980w	Continental Oil Co., Wilder #6	Grnd el 3122 from topo, +KB
1616	D25	26	32	25	660n	1980e	Continental Oil Co., W.W. Wilder Fed. #9	
1617	C25	26	32	25	1980n	1980e	Continental Oil Co., W.W. Wilder #8	
1618	K25	26	32	25	330s	330w	Continental Oil Co., Wilder 25 Fed. No. 1	
1619	L17	26	33	17	660s	660w	Gulf Oil Corp., Fed. Littlefield DP Optional #1	
1620	P30	26	33	30	1980s	660w	Continental Oil Co., Payne #3	
1621	Y03	26	34	3	660n	1980w	Gulf Oil Co., Gulf Yates Fed. #1	
1622	B19	26	34	19	1980s	1980e	Continental Oil Co., Bradley 19 #2	
1623	L20	26	34	20	660n	660e	Max Wilson, Leonard Fed. No. 1	
1624	S05	26	36	5	660s	660w	Cities Service Oil Co., Sand Hills Unit #9-A	
1625	J04	26	37	4	990s	990w	Jal Oil Co. Inc., Farnsworth #6	

ID No.	Hole ID	T.	R.	Location Data* Sec	fn,sl	fe,wl	Drillhole Name	Revisions
1626	L11	26	37	11	660s	660e	Stanolind Oil & Gas Co., U.S.A. Leonard Oil Co. #1	
1627	F07	26	38	7	1980s	660w	Forest Oil Corp., Fed. Lowe #1	
1628	S15	21	33	15	1980s	1980e	Getty Oil Co. Stock Unit #1	data entered from geophysical log
1629	S32	21	33	32	1980s	1980w	Amoco Production Co. St. "LT" #1	data entered from geophysical log
1630	H28	22	31	28	89n	175e	Department of Energy WIPP No. H-15	data from SAND89-0202
1631	R05	22	33	5	660s	330e	Dual Production Co. Richardson-Bass St. No. 1	data from geophysical log
1632	G15	22	33	15	1980s	1980e	Getty Oil Co. Getty Fed. "15" No. 1	data from geophysical log
1633	C20	22	33	20	1980n	660w	Davis and Collins Conoco Fed. #1	data from geophysical log
1634	E11	24	29	11	1980n	660e	Exxon Co., USA Exxon Pouche Fed. No. 1	data from geophysical log
1635	H04	24	33	4	1980n	1650w	Getty Oil Co. HNG St. 4-F #1	data from geophysical log
1636	G28	24	33	28	1980s	1680e	Getty Oil Co. Getty 28 St. No. 1	data from geophysical log
1637	S31	25	29	31	1980s	660e	Duncan Drilling Co. Slater "A" #1	data from geophysical log
1638	P05	25	31	5	660n	660w	Pauley Petroleum Poker Lake #46	data from geophysical log
1639	S32	22	33	32	660s	660w	Helbing & Podpechan Shell St. #1-B	data from geophysical log
1640	B14	26	29	14	660n	660w	Ford Chapman Booth Fed. #1	data from geophysical log
1641	Y20	22	31	20	1113s	1241e	H-16	data from SAND89-0203
1642	Z03	23	31	3	1466s	993w	H-17	data from SAND89-0204
1643	Z20	22	31	20	964n	446w	H-18	data from SAND89-0204

* All townships (T) are south and all ranges (R) east of the New Mexico Base Line. Distances from the section lines are in feet and are followed by a letter designation., This letter (n,s,e,w) and number designate the feet from the north, south, east, or west section line, respectively. Other tables of drillhole data are keyed to this location table by the identification number.

** Names of drillholes have been shortened with some consistent abbreviations.

*** A few likely duplications in the original Holt and Powers (1988) data set are noted here.

APPENDIX A-2

TABLE OF DEPTHS TO SELECTED MARKER BEDS OF THE SALADO FORMATION

Table of Depths to Selected Marker Beds of the Salado Formation

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds: Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1001		3	278										
1002	3568	10											
1003	3510	0	316										
1004	3618	1	736										
1005	3466	10	624										
1006	3554	10	587										
1007	3510	9	557										
1008	3766	9	1017										
1009	3733	9	990										
1010	3651	7	840										
1011	3648	18											
1012	3624	10	790										
1013	3631	10	775										
1014	3551	10	785										
1015	3568	3	735										
1016	3566	3	810										
1017	3580	5	830										
1018	3571	0	840										
1019		3	828										
1020	3885	10	1394										
1021	3783	0	1350										
1022	3751	0	1274										
1023	3382	10	1300										
1024	4027	13	1828										
1025	4104	10	1988										
1026	3952	10	1880										
1027	3800	0	1663										
1028	3779	21	1546										
1029	4011	12	1677										
1030	4098	8	1843										
1031		12	2026										
1032	4023	11	2075										
1033	4000	13	2050										
1034	3957	17	1983										
1035	3920	14	1968										
1036	3961	14	1810										
1037	3962	11	1765										
1038	3968	13	1744										
1039	3958	14	1814										
1040	3991	12	1678										
1041	3980	0	1720										
1042	3948	13	2112										
1043	3789	0	2038										
1044	3822	11	2137										

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1045	3816	0	2030										
1046	3783	0	1997										
1047	3698	0	1810										
1048	3750	13											
1049	3660	0	2168										
1050	3664	0	1653										
1051	3399	9	305										
1052		0	218										
1053		0	245										
1054	3402	10	388										
1055	3529	0	740										
1056	3577	21	978										
1057	3559	21	898										
1058	3526	8	746										
1059	3576	16	1172										
1060	3974	10	2150										
1061	3815	13	2080										
1062	3723	0	2045										
1063	3743	0	2052										
1064	3703	12	2080										
1065		0	1680										
1066	3759	11	1704										
1067	3744	11	2038										
1068	3702	0	1446										
1069	3580	0	1397										
1070		0	520										
1071	3325	18											
1072	3505	19	713	874	887	993	1006	1147	1153			1420	1433
1073	3523	16											
1074	3448	16	1170										
1075	3550	16	1495	1650	1660	1770	1794	1937	1943			2184	2200
1076	3510	15	1236	1376	1387	1487	1509	1650	1657			1876	1903
1077	3565	15	1524	1660	1670	1770	1793	1952	1962	2051	2053	2129	2148
1078	3586	7	1756	1907	1918	2022	2046	2230	2244			2408	2422
1079	3524	0	1470										
1080	3509	0	1450										
1081	3642	19	1887	2044	2057	2163	2186	2335	2344			2538	2554
1082	3677	21	2110										
1083	3708	7	1957	2104	2117	2222	2246	2382	2391	2542	2545	2594	2608
1084	3720	10	1949										
1085	3701	0	2315										
1086	3603	0	1218										
1087	3662	0	2330										
1088	3604	0	1671										
1089	3542	0	1635										
1090	3412	20	495										
1091	3471	18	500										

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1092	3472	13	550										
1093	3468	13	740										
1094	3487	17	1145										
1095	3432	18	680										
1096	3309	16	450										
1097	3458	18	655										
1098	3444	18	505										
1099	3177	0	421										
1100	3250	23	502										
1101	3218	22	485	492	508	612	618	785	798	970	975	1040	1063
1102	3347	0											
1103	3428	0	748										
1104	3540	0	811	970	984	1091	1114	1277	1287	1445	1454	1518	1538
1105	3748	14	1890										
1106	3792	18	1945	2104	2116	2216	2235	2390	2400	2555	2562	2610	2628
1107	3793	22	1988										
1108	3740	21	1950										
1109	3668	15	1765										
1110	3652	18	1580	1735	1748	1855	1879	2043	2051	2214	2219	2269	2287
1111	3800	17	1885										
1112	3862	10	2005										
1113	3861	22	1947										
1114	3834	21	1972	2139	2150	2258	2274	2440	2448	2608	2618	2660	2673
1115	3679	21	1455	1630	1645			1953	1963	2198	2202	2240	2258
1116	3798	13	1781	1958	1970	2092	2112	2282	2297	2470	2478	2544	2560
1117	3504	0											
1118	3662	8	982	1162	1178	1297	1318	1500	1508	1691	1700	1770	1787
1119	3780	23	1090	1272	1280	1394	1417	1584	1597	1763	1767	1835	1853
1120	3802	4	2180					2922	2930	3075	3088	3128	3150
1121	3564	0	1758										
1122	3638	17	2095										
1123	3603	11	2200	2359	2374	2483	2500						
1124		0											
1125		0											
1126	3594	5	1670										
1127	3550	0	1660										
1128	3593	10	1670										
1129	3568	0	1720										
1130	3545	10	1720										
1131	3635	0	1900										
1132	3581	0	1817										
1133	3580	3	1817										
1134		0	1377										
1135		0	1368										
1136	3304	12	495										
1137	3023	0	166										
1138	2977	0	130										
1139	3357	20	625										

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1140	3193	18	520	562	573	686	710	880	887	1056	1064	1130	1152
1141	3221	23	600			760	786	950	960	1130	1140	1205	1227
1142	3323	0	677										
1143	3214	1	565										
1144	3358	0	686	824	840	946	970	1133	1140	1315	1327	1393	1419
1145	3376	0	747	908	924	1034	1061	1226	1234	1405	1416	1484	1507
1146	3309	23	535										
1147	3152	0	306										
1148		0	708										
1149	3418	0	962										
1150	3439	13	964	1125	1139	1252	1273	1429	1434	1597	1606	1670	1688
1151	3433	0	973										
1152	3429	0	952										
1153	3541	9	990	1158	1170	1278	1302	1468	1475	1648	1658	1723	1743
1154	3553	0	1100	1276	1291	1405	1425	1602	1608	1784	1792	1862	1887
1155	3508	0	1041										
1156	3510	0	1040	1211	1225	1333	1359	1527	1533	1706	1715	1780	1805
1157	3496	21											
1158	3405	0	845	1031	1042	1161	1183	1359	1372	1543	1551	1622	1645
1159	3484	12	966										
1160	3472	0	946	1108	1120	1234	1260	1428	1434	1598	1610	1678	1702
1161	3345	0	720	884	898	1012	1039	1200	1211	1377	1384	1449	1474
1162	3349	0											
1163	3382	0	783	960	978	1088	1118	1287	1298	1473	1484	1556	1580
1164	3457	0	928										
1165	3426	0	885	1050	1063	1172	1196	1363	1378				
1166	3417	0	867										
1167	3433	0	894										
1168	3420	12	860	1040	1050	1165	1188	1365	1367	1549	1557	1630	1653
1169	3506	0	1058	1229	1244	1354	1378	1550	1556	1730	1740	1809	1832
1170	3546	0	1116	1296	1310	1422	1446	1620	1630	1808	1822	1892	1916
1171	3596	8	1190	1376	1387	1504	1526	1700	1717	1895	1910	1979	1998
1172	3479	0	1084	1258	1276	1400	1422	1601	1619	1789	1806	1866	1888
1173	3508	0	1084	1262	1276	1394	1416	1594	1602	1780	1797	1864	1886
1174	3441	0	928	1108	1124	1240	1268	1446	1456	1644	1660	1728	1752
1175	3473	8	977	1152	1163	1286	1310	1484	1490	1682	1695	1764	1785
1176	3478	0	1008	1188	1204	1312	1336	1506	1514	1694	1706	1774	1796
1177	3398	0	7										
1178	3346	0											
1179	3377	0											
1180	3395	6	826										
1181	3345	0	676	861	874	986	1011	1190	1193	1379	1391	1460	1483
1182	3354	0	656	840	857	965	989	1162	1166	1354	1363	1432	1460
1183	3310	0	542	729	743	860	883	1058	1062	1248	1261	1323	1352
1184	3413	0											
1185	3409	0	880	1062	1077	1200	1226	1400	1410	1591	1610	1668	1693
1186	3644	10	1275	1447	1461	1584	1604	1762	1777	1938	1954	2012	2030
1187	3731	11	1290	1470	1482	1607	1630	1823	1840	2033	2048	2118	2140

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1188	3701	20	1200										
1189	3696	15	1230	1409	1421	1540	1562	1735	1750	1920	1932	2008	2031
1190	3620	9	1245	1429	1440	1562	1583	1758	1768	1940	1957	2022	2041
1191	3640	19	1240										
1192	3687	12	1265	1448	1462	1587	1609	1786	1795	1973	1989	2046	2067
1193	3789	25	1462										
1194	3756	0	1608										
1195	3640	13	2160	2326	2337	2444	2463	2600	2609	2770	2786	2828	2839
1196	3537	0	2092										
1197	3573	0	2185										
1198	3611	18	2225	2353	2383	2487	2506	2638	2643	2794	2808	2842	2854
1199	3613	7	2285										
1200	3611	11	2300										
1201	3623	1											
1202	3581	13	2275										
1203	3610	0											
1204	3533	22	2470										
1205	3571	10	2292										
1206		0	2210										
1207		0	2275										
1208		13	1825										
1209	3571	0	1822										
1210	3587	0	1825										
1211	3552	0	1725										
1212	3540	0	1687										
1213	3560	0	1735										
1214	3582	18	1685	1795	1824	1918	1942	2067	2074	2232	2246	2282	2297
1215	3589	11	2008										
1216	3507	0	1805										
1217	3498	0	1683										
1218	3469	0	1684										
1219	3410	0	1385										
1220	3405	0	1360										
1221	3316	0	1408										
1222	3337	0	1350										
1223		10											
1224		0											
1225	3045	18											
1226	2996	19											
1227	3027	12	212										
1228	3014	12	195										
1229	3024	19	212										
1230	3163	0	283										
1231	3197	24	425										
1232	3028	12	217										
1233	3215	15											
1234	3215	15											
1235	3290	23	470	622	634	754	775	946	956	1141	1155	1211	1232

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1236	3384	13	640										
1237		0	710										
1238	3453	10		1247	1260	1391	1414	1590	1603	1785	1804	1853	1871
1239	3340	0	713	890	904	1028	1052	1234	1240	1436	1452	1510	1532
1240	3336	0	715	894	906	1026	1052	1236	1240	1440	1454	1520	1540
1241	3335	0	626										
1242	3332	0	627	810	828	948	972	1154	1160	1354	1371	1430	1458
1243	3328	8	653										
1244	3323	0	642	822	836	965	990	1173	1180	1372	1388	1446	1468
1245	3492	10	1118	1292	1308	1432	1454	1635	1646	1834	1852	1903	1921
1246	3511	27	1100	1242	1252	1448	1468	1689	1702	1858	1875	1922	1934
1247	3426	0	976										
1248	3381	23	808	993	1005	1130	1149	1332	1348	1540	1557	1608	1629
1249	3374	9	797	979	992	1116	1126	1333	1357	1566	1582	1637	1655
1250	3452	22	1092										
1251	3461	11	1090										
1252	3506	21	1190										
1253	3454	10	1063	1247	1258	1395	1412	1602	1609	1832	1846	1902	1920
1254	3464	27	1070	1246	1260	1380	1400	1602	1610	1827	1843	1897	1916
1255	3459	12	1060										
1256	3402	12	837	1013	1028	1151	1172	1370	1381	1592	1610	1662	1671
1257	3374	22											
1258	3358	8	695	880	892	1038	1058	1235	1248	1458	1473	1528	1545
1259	3392	8	816	1021	1040	1192	1216	1408	1422	1645	1662	1718	1737
1260		7	1095										
1261	3727	12	1584	1752	1767	1883	1904	2072	2093	2250	2267	2308	2328
1262	3699	11	1545	1708	1724	1840	1860	2041	2050	2225	2240	2282	2300
1263	3723	5	1680	1852	1866	1988	2010	2190	2199	2376	2393	2439	2457
1264	3722	12	1640	1812	1828	1940	1957	2132	2140	2320	2335	2378	2395
1265	3622	21											
1266	3697	11	1512	1682	1697	1812	1830	2004	2017	2213	2228	2276	2292
1267	3699	14											1688
1268	3701	10	1517	1688	1702	1819	1840	2018	2026	2212	2230	2274	2290
1269	3720	10	1710	1888	1903	2025	2044	2214	2227	2417	2431	2477	2498
1270	3725	13	1727	1903	1919	2044	2064	2233	2243	2441	2456	2504	2520
1271	3700	13	1683	1863	1878	2002	2020	2194	2210	2405	2420	2470	2485
1272	3720	10	1695	1873	1888	2013	2032	2203	2217	2407	2420	2468	2485
1273	3698	12	1678	1861	1876	2003	2022	2201	2212	2412	2429	2478	2496
1274	3705	9	1680	1860	1873	1996	2010	2188	2200	2394	2410	2457	2474
1275	3659	11	1630	1814	1830	1950	1968	2147	2160	2360	2374	2424	2443
1276	3713	12	1667	1858	1870	1995	2014	2192	2202	2405	2423	2471	2490
1277	3687	0	1535	1714	1730	1850	1868	2048	2059	2257	2273	2321	2338
1278	3551	8	1206	1396	1411	1539	1556	1735	1748	1970	1988	2025	2048
1279	3666	8	1520										
1280	3629	9	1508	1700	1712	1840	1857	2031	2043	2248	2264	2316	2336
1281	3671	11	1623	1821	1837	1970	1990	2172	2180	2390	2407	2460	2478
1282	3694	12	1657	1854	1868	1993	2013	2190	2198	2404	2420	2472	2490
1283	3676	11	1675	1872	1884	2015	2029	2213	2227	2428	2443	2496	2512

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1284	3700	8	1635	1831	1844	1969	1980	2166	2177	2378	2393	2444	2465
1285	3692	12	1653	1846	1860	1995	2014	2194	2207	2414	2430	2482	2500
1286	3663	8	1567	1762	1775	1900	1918	2094	2103	2308	2323	2375	2396
1287	3689	11	1623	1818	1832	1960	1980	2157	2167	2369	2385	2437	2457
1288	3669	11	1655										
1289	3630	8	1505					2044	2054	2265	2280	2332	2350
1290	3695	8	1670	1858	1872	2005	2022	2202	2216	2418	2434	2486	2504
1291	3689	0	1680	1884	1898	2042	2062	2246	2257	2482	2498	2560	2576
1292	3664	11	1673	1864	1877	2010	2030	2210	2220	2430	2445	2500	2516
1293	3636	11	1657	1830	1848	1982	2008	2175	2184	2362	2378	2427	2449
1294	3704	10	1772	1947	1960	2099	2112	2287	2298	2478	2492	2535	2550
1295	3722	11	1757	1929	1945	2072	2096	2263	2274	2455	2470	2515	2534
1296	3715	12	1773	1947	1960	2093	2115	2284	2294	2484	2500	2548	2566
1297	3722	11	1710			2013	2030	2199	2210	2387	2401	2443	2458
1298	3726	9		1958	1975	2103	2117	2295	2304	2488	2504	2550	2565
1299	3711	13	1732	1903	1920	2046	2065	2240	2250	2445	2460	2509	2526
1300	3720	13	1735	1906	1923	2048	2066	2242	2250	2451	2465	2516	2535
1301	3713	13	1710	1875	1892			2204	2212	2400	2416	2464	2479
1302	3703	11	1720	1890	1905	2028	2047	2218	2227	2417	2432	2480	2498
1303	3713	25	1790										
1304	3701	12	1785	1953	1969	2098	2117	2296	2306	2502	2518	2570	2589
1305		11	1760	1940	1956	2085	2102	2280	2289	2493	2510	2560	2578
1306	3683	8	1770	1945	1960	2083	2100	2275	2286	2478	2494	2548	2567
1307	3659	0	1815	1998	2012	2130	2148	2323	2333	2528	2546	2598	2613
1308	3533	0	1469	1660	1675	1810	1830	2000	2012	2209	2224		
1309	3555	19	1605										
1310	3425	14	1275										
1311	3490	22	1400										
1312	3515	0	2030										
1313	3494	9	2020										
1314		0	1663										
1315	3468	0	1950										
1316	3459	0											
1317	3324	0	1337										
1318	3383	0	1493										
1319	3317	0	1287										
1320	3317	0	1228										
1321	3282	11	1620										
1322	3320	9	1435										
1323	2968	10											
1324	2984	0											
1325		6											
1326		0											
1327		4											
1328		6											
1329	2969	28											
1330	2941	11						454	460			665	690
1331	2997	18											

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1332	2924	11	696										
1333	3447	12	660										
1334	3179	11											
1335	3433	0											
1336	3429	12	840	848	858	928	946	1132	1141	1360	1378	1430	1454
1337	3266	5											
1338	3502	23	1250										
1339	3500	9	1010	1152	1167	1300	1320	1509	1517	1722	1736	1788	1805
1340	3432	2	835										
1341	3436	10	832	1017	1032	1155	1178	1368	1380	1582	1600	1645	1663
1342	3406	0	791										
1343	3414	10	812	997	1011	1132	1152	1340	1354	1562	1578	1630	1645
1344	3430	28	805	920	933	1062	1082	1260	1274	1485	1504	1556	1573
1345	3438	23	826										
1346	3535	11	960	960	976	1115	1135	1317	1325	1540	1560	1617	1634
1347	3528	13	1130	1299	1317	1450	1468	1644	1660	1860	1874	1923	1940
1348	3553	13	1098	1300	1312	1448	1466	1651	1667	1889	1905	1966	1986
1349	3553	4	1025										
1350	3514	10	915	944	956	1080	1100	1280	1284	1490	1510	1560	1578
1351	3530	11	965	968	981	1125	1145	1330	1342	1548	1565	1622	1641
1352	3490	12	895	918	924	1040	1062	1245	1252	1455	1472	1530	1549
1353	3535	11	923	993	1012	1140	1160	1340	1350	1562	1580	1629	1647
1354	3551	12	1017										
1355	3502	23											
1356	3508	25	1010										
1357	3620	10	1562	1748	1761	1888	1908	2084	2099	2301	2317	2368	2388
1358	3623	12											
1359	3632	11	1500										
1360	3631	11	1533	1727	1740	1870	1892	2074	2088	2296	2314	2369	2390
1361	3584	8	1246	1439	1453	1580	1600	1776	1783	2000	2017	2067	2088
1362	3628	10	1394	1599	1608	1752	1771	1959	1966	2182	2206	2263	2280
1363	3615	11											
1364		8											
1365	3637	14											
1366	3637	12											
1367	3637	11	1504	1688	1703	1855	1874	2069	2078	2293	2309	2360	2378
1368	3640	11	1502	1698	1708	1852	1867			2288	2304	2361	2376
1369	3590	10				1939	1958	2140	2152	2366	2382	2437	2458
1370	3600	10											
1371	3605	9	1495	1689	1700	1842	1863	2048	2063	2285	2300	2354	2373
1372	3586	0	1503										
1373	3599	9											
1374	3628	8	1445	1628	1640	1844	1966	2089	2104	2324	2340	2393	2410
1375	3588	10	1437	1631	1644	1800	1820	2016	2029	2267	2288	2305	2324
1376	3591	9	1456	1653	1665	1890	1915	2140	2149	2310	2327	2386	2402
1377	3624	10	1453	1638	1650	1850	1870	2066	2080	2295	2311	2363	2380
1378	3606	10	1438	1632	1646	1796	1822	2072	2090	2298	2313	2375	2405
1379	3591	10	1428	1612	1625	1778	1803	1996	2003	2230	2247	2299	2317

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1380	3602	12	1340	1524	1539	1679	1700	1882	1897	2106	2122	2187	2208
1381	3622	10	1396	1571	1585	1730	1753	1940	1955	2174	2192	2252	2271
1382	3608	11	1368	1571	1583	1721	1741	1946	1957	2186	2206	2267	2287
1383	3605	10	1400	1598	1612	1757	1777	1980	1990	2216	2235	2296	2316
1384	3618	12	1312	1513	1528	1667	1688	1874	1887	2112	2130	2192	2212
1385	3607	11	1375	1590	1599	1745	1760	1968	1975	2201	2219	2280	2296
1386	3604	10	1383	1590	1602	1745	1764	1970	1975	2210	2227	2290	2308
1387	3602	11	1384	1579	1592	1735	1758	1958	1967	2192	2211	2275	2295
1388	3591	9	1362	1565	1579	1718	1738	1938	1946	2172	2190	2252	2272
1389	3609	8	1415	1627	1640	1786	1807	2009	2020	2243	2262	2320	2340
1390	3605	10	1412	1602	1618	1763	1783	1984	1992	2218	2234	2295	2316
1391	3589	11	1323	1535	1548	1676	1695	1883	1895	2113	2129	2185	2206
1392	3554	9	1070	1292	1304	1453	1479	1682	1696	1917	1932	1987	2007
1393	3510	10	1145	1345	1359	1485	1508	1707	1716	1937	1955	2010	2030
1394	3519	11	1190	1400	1412	1544	1565	1754	1762	1985	2004	2056	2075
1395	3524	12	1239	1455	1463	1598	1616	1806	1817	2036	2052	2108	2127
1396	3625	19	1806	1981	1995	2120	2140	2312	2324	2520	2539	2599	2613
1397	3606	8	1635	1829	1840	1969	1989	2172	2183	2393	2408	2460	2478
1398	3598	8	1612	1819	1830	1963	1982	2165	2175	2385	2403	2455	2473
1399	3603	10	1595	1797	1810	1948	1967	2152	2161	2371	2388	2442	2463
1400	3590	11	1635	1836	1850	1983	2003	2182	2192	2402	2418	2470	2486
1401	3636	10	1647	1846	1862	1996	2015	2195	2203	2416	2432	2483	2501
1402	3547	14	1620	1829	1835	1968	1987	2158	2168	2376	2392	2440	2457
1403	3578	11	1630	1835	1848	1982	2000	2175	2186	2393	2412	2462	2480
1404	3637	8	1700	1900	1911	2042	2063	2238	2248	2455	2472	2522	2540
1405	3598	11	1785	1988	2004	2135	2154	2342	2354	2562	2577	2633	2651
1406	3554	10	1540										
1407	3592	11	1676	1880	1890	2022	2042	2214	2222	2436	2454	2503	2522
1408	3540	11	1495	1709	1725	1859	1870	2110	2120	2285	2304	2359	2374
1409	3594	12	1735	2004	2024	2165	2190	2385	2396	2702	2723	2792	2820
1410	3502	11	1621	1851	1864	2006	2025	2216	2226	2449	2466	2525	2543
1411	3525	10	1492	1720	1734	1875	1896	2092	2100	2321	2339	2390	2408
1412	3556	10	1410	1620	1637	1773	1792	1982	1990	2203	2220	2270	2288
1413	3524	11	1392	1605	1620	1755	1775	1978	1986	2210	2229	2280	2300
1414		11	1695	1915	1926	2059	2077	2255	2265	2500	2521	2579	2595
1415	3447	10	1125										
1416	3567	19	1537	1735	1750	1885	1904	2089	2100	2308	2338	2400	2418
1417	3619	19	1690										
1418	3630	0	1760										
1419	3570	18	1660										
1420	3488	33	1085										
1421	3378	19	1186										
1422	3295	9											
1423	3156	0	1482										
1424	2997	19											
1425	2985	2	340										
1426	2921	2											
1427	2923	9		417	438	488	508	653	659			835	862

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1428	3118	17	945										
1429	3041	1	775										
1430	3078	16	905										
1431	3044	0	530										
1432	2990	2	414										
1433	2936	12								603	610	630	643
1434	2945	12	393										
1435	3333	9											
1436	3273	13	1096							1769	1781	1808	1823
1437	3283	12	1014										
1438	3222	9	760		772	796	809	955	962	1147	1162	1204	1225
1439	3210	11	1255										
1440	3200	11	915										
1441	3197	10	790										
1442	3210	10	1100										
1443	3192	0	880			1290	1300	1530	1542	1773	1784	1840	1859
1444	3282	2	1235										
1445	3317	14	1050	1061	1077	1212	1230	1404	1414	1626	1640	1688	1703
1446	3210	11	786	787	798	840	858	1014	1022	1225	1240	1283	1303
1447	3219	9	898	898	907	956	976	1139	1146	1307	1325	1360	1372
1448	3207	11		790	804	858	878	1045	1057	1249	1263	1307	1323
1449	3217	7											
1450	3209	11	829	829	840	890	912	1070	1080	1263	1279	1322	1333
1451	3186	10	1075	1076	1083	1140	1163	1404	1413	1558	1574	1592	1609
1452	3192	11	1205			1133	1157	1253	1266	1414	1438	1465	1477
1453	3207	11	1542										
1454	3209	12	1100										
1455	3203	10	942	942	951	1060	1070						
1456	3184	8	840	840	852	900	918	1108	1117	1191	1202	1210	1218
1457	3204	8	915	915	940	957	983	1187	1195	1393	1410	1455	1473
1458	3252	5	1373										
1459	3336	11											
1460	3476	21	1012			1090	1108	1300	1310	1530	1550	1604	1622
1461	3348	2	1123										
1462	3358	8	697	880	892	1037	1058	1235	1250	1448	1464	1528	1547
1463	3319	9	1622	1790	1806	1923	1935	2073	2079	2221	2230	2262	2274
1464	3486	11	1127	1320	1334	1468	1483	1680	1697	1923	1938	1996	2013
1465	3461	10	1160			1304	1327	1520	1535	1762	1780	1833	1850
1466	3461	9	1104	1177	1192	1323	1345	1540		1780	1802	1853	1870
1467	3460	11	1122	1191	1207	1334	1353	1548	1557	1780	1799	1852	1870
1468	3472	10	1130	1229	1245	1380	1397	1594	1609	1834	1850	1908	1923
1469	3478	10	1127	1270	1284	1418	1437	1630	1640	1875	1892	1948	1967
1470	3480	19	1140	1233	1250	1383	1402	1600	1613	1842	1860	1912	1930
1471	3477	9	1125										
1472	3464	9	1118	1240	1255	1390	1408	1595	1610	1840	1859		
1473	3454	0	1123	1210	1227	1368	1384	1580	1595	1821	1840	1893	1913
1474	3459	10	1140	1225	1240	1372	1392	1584	1600	1826	1842	1897	1916
1475	3455	10	1120	1203	1220	1360	1380	1573	1588	1808	1825	1879	1899

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1476	3458	10	1147	1228	1245	1377	1396	1586	1602	1818	1840	1894	1910
1477	3470	11	1140	1220	1237	1366	1385	1572	1590	1812	1830	1883	1903
1478	3410	10	1177										
1479	3468	10	1140	1333	1350	1488	1512	1694	1706	1923	1938	1991	2008
1480	3445	11	1103	1257	1274	1410	1437	1621	1637				
1481	3454	11	1132	1306	1328	1460	1481	1673	1687				
1482	3455	8	1133	1208	1222	1359	1382	1569	1583	1811	1829	1882	1901
1483	3427	10	1137	1137	1149	1262	1281	1466	1480	1688	1704	1753	1772
1484	3451	10	1158	1162	1176	1303	1320	1520	1530	1760	1778	1830	1850
1485	3438	10	1145	1145	1155	1278	1295	1487	1503	1721	1738	1790	1804
1486	3451	11	1144	1205	1222	1354	1374	1568	1581	1803	1820	1872	1895
1487	3453	10	1140	1200	1218	1352	1371			1810	1827	1880	1898
1488	3453	10	1158	1160	1171	1305	1327	1528	1542	1770	1789	1843	1860
1489	3441	11	1138	1138	1150	1273	1293	1488	1500	1722	1739	1792	1810
1490	3447	10	1137	1191	1208	1339	1362	1545	1556	1773	1792	1843	1862
1491	3443	10	1165	1164	1178	1307	1328	1520	1530	1754	1773	1824	1845
1492	3441	10	1150	1152	1162	1295	1312	1503	1520	1738	1753	1804	1826
1493	3421	9	1095		1106	1176	1202	1400	1412	1632	1651	1704	1725
1494	3444	9	1140	1140	1155	1284	1305	1500	1515	1741	1760	1810	1830
1495	3423	10	1098	1099	1112	1201	1222	1420	1432	1654	1670	1729	1747
1496	3439	9	1137	1137	1150	1270	1290	1479	1495	1710	1728	1780	1798
1497	3437	11	1120		1131	1224	1245	1434	1445	1665	1682	1732	1752
1498	3426	12	1077		1090	1183	1205	1410	1420	1650	1669	1728	1748
1499	3458	11	1157	1157	1178	1305	1329	1524	1545	1767	1784	1834	1853
1500	3411	10	1075		1085	1152	1174	1376	1385	1606	1624	1679	1700
1501	3434	11	1110		1125	1221	1243	1441	1457	1678	1698	1751	
1502	3444	13	1128	1127	1140	1258	1282	1485	1495	1720	1739	1792	1812
1503	3434	9	1115	1115	1125	1213	1233	1425	1438	1650	1668	1720	1738
1504	3433	9	1125		1136	1229	1250	1440	1451	1667	1682	1732	1750
1505	3443	8	1130	1130	1142	1265	1284	1482	1498	1721	1738	1792	1810
1506	3431	20	940	986	995	1083	1102	1310	1322	1547	1565	1616	1635
1507	3438	16	1015										
1508	3394	13	1086		1096	1159	1184	1380	1391	1618	1636		
1509	3403	11	1115		1128	1242	1262	1450	1462	1685	1700	1757	1775
1510	3398	19	1117	1115	1127	1188	1204	1395	1409	1630	1645	1700	1720
1511	3396	12	1100		1113	1170	1195	1395	1410	1643	1660	1720	1736
1512		0	1106			1195	1216	1422	1435	1666	1682	1740	1758
1513	3414	12	1097	1097	1110	1185	1203	1400	1413	1632	1647	1700	1718
1514	3406	11	1116		1130	1250	1270	1455	1470	1690	1706	1761	1780
1515	3413	13	1125			1233	1252	1449	1460	1682	1700	1754	1772
1516	3422	10	1125		1139	1234	1255	1450	1462	1691	1709	1762	1789
1517	3404	13	1148	1148	1160	1213	1234	1428	1440	1660	1676	1731	1750
1518	3382	13	1112		1124	1180	1198	1389	1405	1628	1643	1700	1717
1519	3400	11	1132		1145	1232	1253	1438	1452	1671	1686	1741	1758
1520	3404	11	1073	1076	1087	1155	1171	1370	1384	1610	1626	1683	1702
1521	3408	9	1062		1073	1142	1161	1351	1363	1583	1600	1655	1674
1522	3421	12	1109	1108	1122	1240	1262	1455	1469	1688	1706	1759	1777
1523	3428	9	1130		1145	1233	1254	1448	1462	1677	1693	1746	1764

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1524	3430	11	1128		1140	1255	1276	1465	1480	1695	1712	1764	1782
1525	3409	13	1117			1220	1240	1430	1449	1668	1687	1741	1758
1526	3419	10	1130		1141	1263	1288	1465	1480	1687	1702	1752	1772
1527	3419	9	1115	1120	1130	1242	1267	1456	1472	1689	1704	1755	1768
1528	3411	10	1117		1130	1249	1275	1458	1469	1683	1698	1750	1769
1529	3421	9	1142	1144	1155	1272	1296	1475	1490	1694	1710	1760	1778
1530	3414	10	1130	1130	1143	1270	1294	1476	1489	1696	1710	1759	1780
1531	3429	11	1085	1240	1256	1389	1412	1598	1610				
1532	3430	10	1155			1285	1310	1485	1496	1700	1718	1770	1782
1533	3391	11	1130	1132	1144	1266	1284	1470	1482	1700	1719	1770	1787
1534	3392	10	1170		1180	1240	1260	1448	1460	1675	1690	1744	1759
1535	3388	9	1118		1132	1220	1242	1430	1442	1668	1683	1740	1756
1536	3375	10			1268	1333	1356	1537	1552	1767	1782	1833	1850
1537	3398	10	1140			1248	1265	1444	1463	1677	1693	1750	1766
1538	3386	9	1178		1188	1247	1265	1450	1462	1678	1694	1750	1767
1539	3382	10	1175	1175	1188	1244	1266	1457	1470	1685	1701	1753	1772
1540	3386	10	1148	1150	1160	1242	1260	1440	1453	1668	1684	1740	1758
1541	3414	10	1230	1231	1240	1298	1318	1502	1514	1728	1742	1796	1812
1542	3370	11	1335	1336	1350	1390	1409	1596	1608	1850	1872	1922	1937
1543	3356	9	1310	1310	1322	1430	1452						
1544	3366	11	1485		1499	1634	1656						
1545	3311	2	1417										
1546	3307	10	1412	1446	1457	1584	1604	1768	1777	2009	2030	2074	2092
1547	3349	11	1297	1297	1308	1336	1351	1546	1555	1760	1775	1825	1837
1548	3332	9	1440		1449	1550	1573	1741	1752	1962	1975	2009	2027
1549		0	1405		1417	1507	1527	1700	1712	1932	1948	1996	2013
1550	3490	10	1673	1880	1897	2040	2058	2250	2258	2490	2507	2578	2597
1551	3478	11	1433	1668	1682	1816	1836	2032	2045	2260	2278	2333	2352
1552	3456	11	1428	1633	1646	1773	1792	1978	1993	2212	2229	2283	2302
1553	3424	11	1550	1752	1767	1910	1928	2112	2128	2360	2378	2444	2464
1554	3497	8	1312	1524	1538	1665	1689	1872	1883	2098	2116	2169	2188
1555	3431	10	1347	1565	1581	1716	1742	1932	1945	2164	2185	2245	2264
1556		0	1374									2268	2284
1557	3392	34	1335										
1558	3353	11	1410	1608	1625	1758	1778	1960	1976	2190	2206	2259	2280
1559	3358	9	1463	1670	1684	1822	1842	2030	2040	2280	2298	2355	2379
1560	3342	12	1435	1635	1650	1788	1807	1986	2000	2225	2242	2297	2317
1561	3332	11	1395	1596	1612	1744	1763	1950	1964	2198	2217	2271	2292
1562	3320	12	1387	1585	1607	1741	1762	1935	1946	2162	2178	2230	2249
1563	3353	10	1315	1510	1528	1658	1675	1848	1859	2072	2088	2140	2157
1564	3344	11	1339	1528	1545	1675	1695	1862	1873	2082	2099	2152	2170
1565	3422	9	1385	1564	1585	1726	1748	1944	1956	2177	2192	2245	2264
1566	3386	12	1096	1220	1237	1377	1400	1586	1604	1846	1862	1915	1934
1567	3332	0	1192	1374	1392	1535	1552	1734	1748	1977	1992	2042	2062
1568	3391	13	1224	1428	1443	1580	1599	1780	1792	2022	2038	2088	2108
1569	3325	7	1334	1542	1556	1697	1716	1902	1915	2152	2168	2222	2240
1570	3346	11	1432	1625	1642	1783	1801	1983	1998	2222	2240	2292	2310
1571	3346	12	1437	1639	1651	1792	1810	2005	2017	2256	2272	2332	2353

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1572	3339	0	1265	1470	1486	1640	1666	1884	1901	2195	2216	2288	2313
1573	3163	10	1095										
1574	3143	1	1290										
1575	3123	0	1068										
1576	3115	10	1065										
1577	3087	0	973										
1578		0											
1579	3012	4											
1580	2965	10	375	430	447	472	491	652	662	855	872	932	950
1581	2975	11	600	634	645	753	770	923	933				
1582	2978	8											
1583	2993	8	790	810	831								
1584	2953	8	388	434	452	518	539	697	706	912	925	971	986
1585	2964	14	512	512	528	550	564			900	915	939	962
1586	2912	7	330	346	362	431	446			847	871	914	932
1587	2900	12	360	415	426	549	569	712	722	870	886	934	942
1588	2972	9											
1589	2875	9											
1590	2892	10	414	484	499	538	557	650	654	765	778	884	898
1591	3201	1	1545										
1592	3165	10	1632										
1593	3179	9						1580	1590			1677	1687
1594	3059	8	1162										
1595	3090	10											
1596	3210	10	1294	1294	1306	1356	1371	1540	1548	1742	1761	1783	1797
1597	3059	9											
1598		0	850	900	910	929	948	1050	1071				
1599	2982	10											
1600	3220	0	1300	1403	1416	1520	1538	1704	1714	1950	1972	1995	2008
1601		0	1267	1336	1345	1484	1500	1712	1723				
1602	3238	9	1202	1259	1271	1368	1382	1568	1579	1782	1796	1848	1868
1603	3225	32											
1604		0	1245	1270	1280	1348	1365	1550	1558	1720	1730	1754	1772
1605	3282	11	1685										
1606	3177	10	956	956	968	1094	1113	1298	1308	1525	1543	1591	1611
1607	3180	0	1595										
1608	3133	11	963	963	974	1090	1106	1346	1353	1523	1540	1587	1608
1609	3122	11	1020	1024	1035	1165	1183	1388	1400	1642	1660	1713	1735
1610	3113	11	1006	1010	1020	1157	1166	1382	1390	1632	1648	1708	1726
1611	3130	11	1034	1034	1047	1182	1200	1406	1419	1658	1675	1728	1749
1612	3122	11	987	993	1003	1114	1133	1342	1353	1589	1607	1660	1682
1613	3132	11	967	967	982	1097	1103	1298	1307	1522	1538	1583	1602
1614	3124	11	967	969	979	1084	1102	1292	1303	1527	1544	1596	1616
1615	3134	12	975	975	988	1093	1112	1302	1312	1528	1545	1588	1613
1616	3130	19	1005	1009	1018	1144	1163	1361	1371	1604	1622	1673	1696
1617	3131	9	994	994	1008	1126	1147	1347	1358	1585	1603	1652	1673
1618	3113	11	930	930	942	1033	1054	1243	1254	1484	1501	1554	1576
1619	3264	10	1095	1300	1314	1450	1472	1656	1665	1887	1903	1954	1976

Borehole ID no.	Reference Elevation	KB (ft)	Depths (ft) to Marker Beds Top Sal	Top 103	Base 103	Top 109	Base 109	Top VT	Base VT	Top Un'n	Base Un'n	Top 123	Base 124
1620	3122	11	1055	1055	1066	1215	1233	1433	1443	1679	1697	1754	1775
1621	3414	10	1235	1458	1473	1637	1653	1865	1875	2155	2175	2253	2278
1622	3392	11	1115	1342	1356	1509	1532	1743	1756	2030	2048	2118	2142
1623	3332	0	1005			1402	1428	1671	1682	1990	2010	2088	2110
1624		9	1203										
1625		0	1265										
1626	3013	0	1163										
1627	3032	0	1194										
1628	3853	17	2331	2506	2516	2634	2646	2803	2815			3058	3069
1629	3741	26	1878	2076	2087	2212	2230	2398	2410	2600	2609	2674	2693
1630	3480	0											
1631	3659	9	1638	1840	1852	1985	2000	2180	2198	2383	2392	2454	2472
1632	3572	22	1467	1667	1680	1808	1816	1994	2007	2182	2196	2254	2269
1633	3645	11	1227	1412	1430	1557	1578	1742	1758	1937	1955	2010	2030
1634	3094	12	594										
1635	3612	24	1840	2030	2048	2178	2197	2374	2384	2587	2602	2658	2673
1636	3506	20	1550										
1637	2968	8	240										
1638	3456	11				858	874	1058	1068	1288	1308	1360	1377
1639	3726	12	1708	1885	1898	2030	2042	2220	2228	2403	2420	2463	2483
1640		2	1105										
1641	3410	0	842										
1642	3384	0											
1643	3413	0	821										

All drillholes within the Rustler data base were included, even if the Salado was uninterpretable. Drillhole locations, names, and other data are presented in tables of Rustler location data and can be cross-indexed with the identification number.

APPENDIX A-3

TABLE OF DATA ON DEPTH TO RUSTLER UNITS

Table of Data on Depth to Rustler Units

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	ulm	Sal	Revisions
1001		3	118					278	
1002	3568	10							
1003	3510	0	164					316	
1004	3618	1	504	565	582	660	675	736	
1005	3466	10	500			576	587	624	
1006	3554	10	358	411	434	508	525	587	
1007	3510	9	314	375	396	468	483	557	
1008	3766	9	794	841	856	927	942	1017	
1009	3733	9	757	808	824	902	913	990	
1010	3651	7	561	606	628	730	754	840	
1011	3648	18							
1012	3624	10	563	619	634	706	720	790	
1013	3631	10	578	632	650	721	736	775	
1014	3551	10	545	596	618	692	708	785	
1015	3568	3	500	555	576	648	663	735	
1016	3566	3	574	622	640	720	734	810	
1017	3580	5	590	638	660	732	748	830	
1018	3571	0	606	665	682	760	775	840	
1019		3	613	670	687	759	775	828	
1020	3885	10	1158	1207	1222	1302	1322	1394	
1021	3783	0	1103	1150	1168	1260	1275	1350	
1022	3751	0	1017	1044	1060	1157	1168	1274	
1023	3382	10	940	996	1019	1112	1137	1300	
1024	4027	13	1587	1634	1652	1743	1755	1828	
1025	4104	10	1753	1797	1815	1904	1915	1988	
1026	3952	10	1633	1682	1699	1796	1807	1880	
1027	3800	0	1407	1460	1479	1576	1588	1663	Rev loc ctr, NE1/4, SE1/4
1028	3779	21	1278	1330	1351	1447	1462	1546	
1029	4011	12	1483	1525	1540	1602	1615	1677	
1030	4098	8	1631	1675	1694	1774	1783	1843	
1031		12	1775	1824	1842	1932	1947	2026	
1032	4023	11	1820	1872	1892	1985	1999	2075	
1033	4000	13	1793	1852	1870	1960	1972	2050	
1034	3957	17	1714	1775	1793	1885	1905	1983	
1035	3920	14	1745	1794	1807	1885	1900	1968	
1036	3961	14	1600	1645	1658	1733	1750	1810	
1037	3962	11	1562	1604	1619	1690	1705	1765	
1038	3968	13	1535	1580	1595	1668	1683	1744	
1039	3958	14	1598	1643	1657	1737	1748	1814	
1040	3991	12	1512	1566	1582	1647	1653	1678	
1041	3980	0	1501	1547	1562	1640	1657	1720	
1042	3948	13	1853	1908	1926	2022	2036	2112	
1043	3789	0	1825	1870	1883	1945	1948	2038	
1044	3822	11	1909	1958	1969	2042	2050	2137	
1045	3816	0	1811	1855	1870	1940	1943	2030	
1046	3783	0	1783	1828	1840	1904	1908	1997	
1047	3698	0	1643	1685	1700			1810	
1048	3750	13							

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	nlm	Sal	Revisions
1049	3660	0	1965	2007	2017	2084	2090	2168	
1050	3664	0	1520	1560	1572			1653	
1051	3399	9						305	
1052		0				90	114	218	
1053		0				120	142	245	Rev loc NW1/4, NW1/4
1054	3402	10	183	223	245	290	310	388	
1055	3529	0	524	576	596	673	692	740	
1056	3577	21	682	745	764	853	873	978	
1057	3559	21	619	685	702	775	796	898	
1058	3526	8	497	565	586	666	683	746	
1059	3576	16	802	906	927	1045	1064	1172	
1060	3974	10	1855	1920	1940	2037	2063	2150	
1061	3815	13	1805	1867	1884	1979	2000	2080	
1062	3723	0	1761	1822	1840	1944	1963	2045	
1063	3743	0	1753	1818	1838	1950	1966	2052	
1064	3703	12	1779	1845	1863	1970	1995	2080	
1065		0	1480	1525	1538	1604	1614	1680	
1066	3759	11	1474	1517	1533	1650	1660	1704	
1067	3744	11	1777	1828	1841	1942	1955	2038	
1068	3702	0	1230	1280	1293	1363	1371	1446	Rev loc NE1/4, NW1/4
1069	3580	0	1220	1257	1272	1320	1325	1397	
1070		0				403		520	Log lacks loc data
1071	3325	18							
1072	3505	19	480	536	553	629	645	713	
1073	3523	16							
1074	3448	16	828	892	915	1052	1068	1170	
1075	3550	16	1121	1184	1207	1370	1387	1495	
1076	3510	15	883	949	972	1112	1128	1236	
1077	3565	15	1163	1248	1274	1404	1422	1524	
1078	3586	7	1372	1440	1464	1623	1648	1756	
1079	3524	0	1103	1172	1194	1343	1362	1470	
1080	3509	0	1076	1140	1165	1314	1335	1450	
1081	3642	19	1485	1560	1580	1752	1770	1887	
1082	3677	21	1743	1814	1830	1994	2009	2110	
1083	3708	7	1590	1654	1674	1832	1854	1957	
1084	3720	10	1567	1639	1660	1827	1847	1949	
1085	3701	0	1973	2048	2067	2208	2220	2315	
1086	3603	0	1005	1050	1062	1135	1143	1218	
1087	3662	0	1985	2058	2073	2210	2227	2330	
1088	3604	0	1465	1505	1516			1671	
1089	3542	0	1427	1470	1480	1551	1559	1635	
1090	3412	20	187					495	
1091	3471	18	200					500	
1092	3472	13	255				410	550	
1093	3468	13	445				608	740	
1094	3487	17	830	895	915	1012	1032	1145	
1095	3432	18	312	402	423	546	561	680	
1096	3309	16	146				291	450	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	ulm	Sal	Revisions
1097	3458	18	345				490	655	
1098	3444	18	200					505	
1099	3177	0	152	175	193	292	318	421	
1100	3250	23	160					502	
1101	3218	22	130				356	485	
1102	3347	0	215	285	310	420	446	531	rev from geoph log
1103	3428	0	449	513	537	631	653	748	Ref El from SAND79-0284
1104	3540	0	538	598	623	713	739	811	
1105	3748	14	1505	1575	1598	1772	1785	1890	
1106	3792	18	1550	1622	1645	1820	1840	1945	
1107	3793	22	1568	1645	1665	1840	1862	1988	
1108	3740	21	1530			1838	1860	1950	
1109	3668	15	1345			1545	1570	1765	
1110	3652	18	1162	1236	1260	1444	1466	1580	
1111	3800	17	1450	1525	1550	1734	1760	1885	
1112	3862	10	1565	1642	1664	1837	1858	2005	Rev loc SE1/4, SE1/4
1113	3861	22	1515	1593	1617	1833	1858	1947	
1114	3834	21	1555	1630	1654	1840	1857	1972	
1115	3679	21	1056	1110	1130	1282	1303	1455	
1116	3798	13	1293	1360	1382	1610	1635	1781	
1117	3504	0							
1118	3662	8	670	732	758	872	896	982	
1119	3780	23	778	837	860	992	1008	1090	
1120	3802	4	1760	1838	1858	2032	2055	2180	
1121	3564	0	1455	1504	1526	1655	1668	1758	Surf El from log
1122	3638	17	1757	1825	1843	1983	1997	2095	
1123	3603	11	1825	1900	1917	2074	2092	2200	
1124		0	1804	1880	1896	2094	2105		
1125		0							
1126	3594	5	1425	1464	1475	1582	1590	1670	Rev loc SE1/4, SW1/4; log elev
1127	3550	0	1420			1572	1579	1660	
1128	3593	10	1426	1466	1478	1583	1589	1670	Rev loc SE1/4, SW1/4; ?DUP 1126
1129	3568	0	1476	1517	1527	1634	1640	1720	
1130	3545	10	1486	1517	1527	1630	1640	1720	
1131	3635	0	1580	1642	1661	1799	1807	1900	
1132	3581	0	1560	1600	1612	1735	1740	1817	
1133	3580	3	1555	1597	1614	1722	1732	1817	
1134		0	1167	1210	1219	1295	1305	1377	
1135		0	1150	1190	1200	1275	1283	1368	
1136	3304	12						495	
1137	3023	0	0	19	36	61	90	166	
1138	2977	0					43	130	
1139	3357	20	315	380	400	495	515	625	
1140	3193	18	170					520	
1141	3221	23	275					600	
1142	3323	0	401	449	468	550	578	677	
1143	3214	1	232	302	328	447	472	565	Rev loc, elev from SAND79-0279
1144	3358	0	387	452	477	576	595	686	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	ulm	Sal	Revisions
1145	3376	0	462	519	544	636	656	747	
1146	3309	23	215					535	
1147	3152	0	12	79	99	187	208	306	
1148		0	395	454	479	572	591	708	
1149	3418	0	641	700	724	828	849	962	
1150	3439	13	676	740	764	857	881	964	
1151	3433	0	657	716	740	834	860	973	
1152	3429	0	639	707	729	817	836	952	Ref elev typo revised
1153	3541	9	668	727	750	848	873	990	
1154	3553	0	780	839	866	957	979	1100	
1155	3508	0	732	784	809	900	922	1041	
1156	3510	0	734	786	812	904	924	1040	
1157	3496	21							
1158	3405	0	517	564	583	704	725	845	
1159	3484	12	641	703	727	825	848	966	
1160	3472	0	623	685	710	808	827	946	
1161	3345	0	426	490	513	608	628	720	
1162	3349	0	427	492	515	612	632		
1163	3382	0	468	528	553	645	665	783	
1164	3457	0	614	674	698	791	810	928	
1165	3426	0	574	630	654	742	763	885	
1166	3417	0	559	617	641	732	752	867	
1167	3433	0	590	647	672	756	777	894	
1168	3420	12	550	608	632	716	739	860	
1169	3506	0	746	799	823	916	938	1058	
1170	3546	0	759	816	839	972	995	1116	
1171	3596	8	755	830	856	1018	1038	1190	
1172	3479	0	626	703	728	912	936	1084	
1173	3508	0	686	758	781	935	957	1084	
1174	3441	0	610	662	685	782	802	928	
1175	3473	8	668	722	745	829	851	977	rev from TME3159 BDR
1176	3478	0	690	748	774	864	884	1008	Rev loc from OFR78-592
1177	3398	0							
1178	3346	0	357	422	446	545	572		Elev from SAND89-0202; ?Cul
1179	3377	0	457	516	542	627	647		
1180	3395	6	509	565	590	680	700	826	
1181	3345	0	359	424	448	546	567	676	
1182	3354	0	358	418	442	540	560	656	
1183	3310	0	232	296	322	420	436	542	
1184	3413	0	566	623	649	740	766		Rev for H11b3; SAND89-0200
1185	3409	0	562	617	644	738	758	880	
1186	3644	10	860	920	942	1100	1125	1275	
1187	3731	11	950	1005	1025	1140	1165	1290	
1188	3701	20	885	940	960	1072	1103	1200	
1189	3696	15	900	955	980	1090	1110	1230	
1190	3620	9	760	835	860	1070	1090	1245	
1191	3640	19	835	895	920	1080	1110	1240	
1192	3687	12	870	935	960	1100	1125	1265	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	ulm	Sal	Revisions
1193	3789	25	1048	1115	1140	1285	1315	1462	
1194	3756	0	1145	1210	1230	1430	1460	1608	
1195	3640	13	1715	1785	1805	2000	2030	2160	
1196	3537	0	1600	1682	1700	1918	1942	2092	Elev from Richey (1989); KB??
1197	3573	0	1690	1778	1795	2005	2032	2185	
1198	3611	18	1822	1900	1915	2102	2112	2225	
1199	3613	7	1856	1936	1952	2148	2160	2285	
1200	3611	11	1860	1935	1955	2142	2175	2300	
1201	3623	1							
1202	3581	13	1810	1885	1905	2110	2142	2275	
1203	3610	0	1877	1960	1979	2180	2193		
1204	3533	22	1920	2005	2020	2290	2322	2470	
1205	3571	10	1815	1890	1910	2130	2165	2292	
1206		0	1755	1840	1855	2098	2108	2210	
1207		0	1770	1860	1877	2125	2142	2275	
1208		13	1560	1603	1611	1724	1735	1825	
1209	3571	0	1560	1603	1612	1722	1734	1822	
1210	3587	0	1567	1610	1620	1728	1739	1825	
1211	3552	0	1465	1508	1517	1632	1641	1725	
1212	3540	0	1424	1472	1480	1590	1600	1687	
1213	3560	0	1475	1517	1528	1637	1645	1735	
1214	3582	18	1360	1420	1430	1572	1588	1685	
1215	3589	11	1602	1678	1700	1875	1890	2008	
1216	3507	0	1535	1578	1588	1700	1715	1805	
1217	3498	0	1360	1415	1427	1562	1575	1683	
1218	3469	0	1422	1466	1474	1584	1594	1684	
1219	3410	0	1125	1170	1180	1295	1305	1385	Rev loc NW1/4, SW1/4
1220	3405	0	1130	1173	1182			1360	
1221	3316	0	1190					1408	
1222	3337	0	1123	1160	1170	1259	1268	1350	
1223		10							
1224		0							
1225	3045	18							
1226	2996	19							
1227	3027	12						212	
1228	3014	12						195	
1229	3024	19						212	
1230	3163	0	87	117	140	237	274	283	
1231	3197	24						425	
1232	3028	12						217	
1233	3215	15							?DUP 1234
1234	3215	15							
1235	3290	23	150	210	235	330	353	470	DWP reinterp log 9/20/94
1236	3384	13		378	397	489	517	640	Rev from BDR: SAND79-0271
1237		0	310					710	
1238	3453	10	623	700	722	891	917	1068	rev from geoph log
1239	3340	0	382	438	463	562	582	713	Ref elev from OFR78-592
1240	3336	0	391	450	477	565	587	715	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	ulm	Sal	Revisions
1241	3335	0	315	377	403	493	515	626	
1242	3332	0	312	373	398	500	521	627	
1243	3328	8	363	375	414	469	487	653	Data from WTSD-TME-020
1244	3323	0	316	376	402	503	523	642	
1245	3492	10	742	809	833	968	992	1118	
1246	3511	27	794	850	876	968	990	1100	
1247	3426	0	621	678	703	825	849	976	Rev from BDR; SAND90-0201
1248	3381	23	476			657	682	808	
1249	3374	9	460	520	542	645	663	797	
1250	3452	22	763	817	841	942	968	1092	
1251	3461	11	775	830	850	945	978	1090	
1252	3506	21	865	922	940	1050	1072	1190	
1253	3454	10	750	810	830	927	950	1063	
1254	3464	27	758	814	835	922	955	1070	
1255	3459	12	750	806	825	920	945	1060	Rev elev from geophys log
1256	3402	12	497	560	585	680	705	837	
1257	3374	22							
1258	3358	8	360	430	450	570	587	695	
1259	3392	8	430	495	520	622	648	816	
1260		7	780	835	860	950	975	1095	sw1/4,sw1/4 converted
1261	3727	12	1155	1213	1235	1420	1445	1584	
1262	3699	11	1140	1195	1215	1383	1405	1545	
1263	3723	5	1195	1275	1294	1505	1529	1680	
1264	3722	12	1178	1243	1263	1473	1500	1640	
1265	3622	21	1025	1085	1110	1215	1245		
1266	3697	11	1210	1262	1285	1368	1392	1512	Grnd elev from topo map
1267	3699	14	1217	1270	1294	1376	1402		
1268	3701	10	1163	1215	1240	1377	1401	1517	
1269	3720	10	1225	1294	1315	1526	1557	1710	
1270	3725	13	1235	1308	1325	1532	1570	1727	
1271	3700	13	1208	1280	1300	1510	1532	1683	
1272	3720	10	1212	1282	1302	1520	1544	1695	
1273	3698	12	1225	1295	1315	1500	1525	1678	
1274	3705	9	1215	1288	1306	1512	1532	1680	
1275	3659	11	1222	1292	1312	1472	1493	1630	Ref elev rev from log
1276	3713	12	1225	1296	1312	1496	1520	1667	
1277	3687	0	1180	1236	1258	1385	1415	1535	
1278	3551	8	862	923	945	1050	1078	1206	
1279	3666	8	1200	1260	1285	1355	1386	1520	
1280	3629	9	1170	1230	1250	1365	1387	1508	
1281	3671	11	1187	1260	1278	1453	1472	1623	Ref elev rev from log
1282	3694	12	1206	1282	1298	1483	1506	1657	
1283	3676	11		1290	1308	1507	1527	1675	Ref elev rev from log
1284	3700	8	1215	1281	1302	1475	1495	1635	
1285	3692	12	1205	1275	1293	1475	1498	1653	Ref elev rev from log
1286	3663	8	1200	1263	1282	1425	1448	1567	
1287	3689	11	1193	1262	1280	1453	1475	1623	
1288	3669	11	1210	1282	1300	1490	1512	1655	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	nim	Sal	Revisions
1289	3630	8	1183	1233	1252	1355	1387	1505	
1290	3695	8	1207	1276	1295	1496	1526	1670	Ref elev rev from log
1291	3689	0	1210	1280	1296	1493	1517	1680	
1292	3664	11	1206	1278	1297	1495	1517	1673	
1293	3636	11	1160	1240	1260	1485	1507	1657	
1294	3704	10	1260	1340	1355	1600	1622	1772	
1295	3722	11	1270	1350	1367	1588	1612	1757	
1296	3715	12	1268	1350	1367	1590	1615	1773	
1297	3722	11	1230	1310	1328	1545	1568	1710	
1298	3726	9	1290	1370	1387	1610	1635		
1299	3711	13	1230	1310	1327	1550	1571	1732	
1300	3720	13	1233	1310	1330	1550	1573	1735	
1301	3713	13	1222	1296	1313	1530	1553	1710	
1302	3703	11	1225	1303	1320	1541	1568	1720	
1303	3713	25	1285	1364	1385	1610	1634	1790	
1304	3701	12	1280	1358	1376	1597	1620	1785	
1305		11	1252	1333	1349	1577	1600	1760	
1306	3683	8	1268	1343	1360	1582	1606	1770	
1307	3659	0	1310	1395	1415	1650	1672	1815	
1308	3533	0	988	1066	1084	1310	1330	1469	
1309	3555	19	1095	1182	1200	1425	1455	1605	
1310	3425	14	912	984	1006			1275	
1311	3490	22	944					1400	
1312	3515	0	1625	1708	1723	1888	1903	2030	
1313	3494	9	1655	1725	1740	1885	1900	2020	
1314		0	1393	1437	1446	1570	1577	1663	
1315	3468	0		1625	1635	1824	1837	1950	
1316	3459	0	1593	1672	1683				
1317	3324	0	1143	1176	1188	1244	1252	1337	
1318	3383	0	1262					1493	
1319	3317	0	1090	1130	1137	1192	1200	1287	
1320	3317	0	1047	1086	1097	1154	1165	1228	
1321	3282	11	1365	1410	1418	1522	1531	1620	
1322	3320	9	1168	1214	1219	1329	1340	1435	
1323	2968	10							
1324	2984	0							
1325		6							
1326		0							
1327		4							
1328		6							
1329	2969	28							
1330	2941	11							
1331	2997	18							
1332	2924	11	450					696	
1333	3447	12	370			470	493	660	
1334	3179	11							
1335	3433	0	400	467	492	589	614		
1336	3429	12	473	552	572	650	675	840	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	ulm	Sal	Revisions
1337	3266	5							
1338	3502	23	853	912	935	1065	1095	1250	
1339	3500	9	676	750	762	852	880	1010	
1340	3432	2		578	600	696	725	835	
1341	3436	10	485	553	573	688	715	832	
1342	3406	0	465	535	565	665	687	791	
1343	3414	10	453	522	545	648	675	812	
1344	3430	28	455	528	548	658	680	805	
1345	3438	23	478	550	573	700	720	826	
1346	3535	11	600	670	692	790	810	960	
1347	3528	13	768	826	850	986	1010	1130	
1348	3553	13	762	819	843	936	959	1098	
1349	3553	4	665	730	755	850	873	1025	Ref elev calc from log
1350	3514	10	576	645	667	780	795	915	
1351	3530	11	605	670	690	800	820	965	
1352	3490	12	530	597	619	729	750	895	
1353	3535	11	693			792	813	923	
1354	3551	12	695	755	775	872	895	1017	
1355	3502	23	595						
1356	3508	25	628	702	722	828	855	1010	
1357	3620	10	1183	1252	1269	1410	1433	1562	
1358	3623	12							
1359	3632	11	1185	1239	1255	1348	1371	1500	
1360	3631	11	1172	1238	1255	1388	1408	1533	
1361	3584	8	888	947	965	1090	1116	1246	
1362	3628	10	1088	1138	1161	1248	1270	1394	
1363	3615	11							
1364		8							
1365	3637	14							
1366	3637	12							
1367	3637	11	1192	1247	1264	1352	1372	1504	
1368	3640	11	1157	1210	1227	1352	1378	1502	
1369	3606	11							Loc rev from geoph log
1370	3600	10	1204	1254	1270				
1371	3605	9	1130	1201	1220	1347	1370	1495	Ref elev rev from log
1372	3586	0	1187	1238	1260	1352	1371	1503	
1373	3599	9							
1374	3628	8	1132	1184	1204	1295	1315	1445	
1375	3588	10	1122	1182	1200	1283	1308	1437	
1376	3591	9	1130	1190	1210	1301	1323	1456	
1377	3624	10	1142	1199	1218	1309	1327	1453	
1378	3606	10	1122	1180	1198	1287	1306	1438	
1379	3591	10	1110	1158	1180	1275	1298	1428	
1380	3602	12	1025	1083	1102	1191	1208	1340	
1381	3622	10	1065	1126	1145	1239	1258	1396	
1382	3608	11	1052	1106	1122	1213	1235	1368	
1383	3605	10	1070	1132	1151	1243	1265	1400	Ref elev rev from log
1384	3618	12	998	1053	1072	1165	1188	1312	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	ulm	Sal	Revisions
1385	3607	11	1060	1114	1132	1222	1243	1375	
1386	3604	10	1062	1120	1140	1226	1248	1383	
1387	3602	11	1066	1125	1140	1225	1246	1384	
1388	3591	9	1047	1100	1118	1201	1223	1362	
1389	3609	8	1093	1150	1170	1261	1284	1415	
1390	3605	10	1088	1148	1168	1253	1275	1412	
1391	3589	11	1008	1063	1082	1174	1197	1323	
1392	3554	19	746	806	829	928	953	1070	
1393	3510	10	830	890	910	1002	1025	1145	
1394	3519	11	881	940	960	1052	1075	1190	
1395	3524	12	906	962	980	1070	1090	1239	
1396	3625	19	1278	1367	1382	1600	1632	1806	
1397	3606	8	1187	1255	1272	1452	1475	1635	
1398	3598	8	1174	1246	1265	1445	1467	1612	
1399	3603	10	1204	1257	1276	1440	1465	1595	
1400	3590	11	1184	1257	1273	1452	1475	1635	
1401	3636	10	1203	1270	1290	1468	1490	1647	
1402	3547	14	1225	1295	1310	1462	1485	1620	
1403	3578	11	1194	1270	1287	1465	1486	1630	
1404	3637	8	1215	1291	1308	1520	1542	1700	
1405	3598	11	1245	1330	1347	1600	1613	1785	
1406	3554	10	1190	1250	1267	1385	1409	1540	
1407	3592	11	1205	1282	1297	1485	1503	1676	
1408	3540	11	1140	1212	1228	1335	1357	1495	
1409	3594	12	1220	1289	1309	1502	1527	1735	
1410	3502	11	1186	1259	1275	1458	1481	1621	
1411	3525	10	1146	1206	1224	1314	1332	1492	
1412	3556	10	1070	1120	1138	1240	1260	1410	
1413	3524	11	1063	1122	1141	1228	1250	1392	
1414		11	1163	1230	1243	1513	1535	1695	
1415	3447	10				995	1012	1125	
1416	3567	19	1045	1122	1139	1368	1392	1537	
1417	3619	19	1185	1263	1282	1517	1540	1690	
1418	3630	0	1245	1327	1345	1573	1598	1760	
1419	3570	18	1134	1215	1230	1455	1482	1660	
1420	3488	33	835	900	920	1005	1025	1085	
1421	3378	19	820	890	905	1040	1062	1186	
1422	3295	9	1155	1197	1210	1311	1320		
1423	3156	0	1202					1482	
1424	2997	19							
1425	2985	2				147	182	340	
1426	2921	2							
1427	2923	9							
1428	3118	17	670					945	
1429	3041	1						775	
1430	3078	16	680					905	
1431	3044	0	175					530	Ref elev rev from log
1432	2990	2	115					414	

ID No.	Reference Elevation	KB (ft)	Depth (ft) to top of units 49'r	Mag	Tam	Cul	ulm	Sal	Revisions
1433	2936	12							
1434	2945	12	260					393	
1435	3333	9					816	923	
1436	3273	13	848	915	937	1029	1041	1096	
1437	3283	12	888					1014	
1438	3222	9				560	597	760	Grnd el from topo; ref is +9ft
1439	3210	11	970			1078	1094	1255	Ref el from log; topo differs
1440	3200	11	745					915	Ref el rev from geoph log; ?DUP 1439
1441	3197	10	678					790	
1442	3210	10	970					1100	
1443	3192	0	699			820	848	880	Ref el from topo; KB not given
1444	3282	2	900					1235	
1445	3317	14	780	799	809	878	900	1050	
1446	3210	11	595					786	
1447	3219	9	640					898	
1448	3207	11	440	502	524	613	638		
1449	3217	7							
1450	3209	11	498	560	584	663	686	829	
1451	3186	10	725	782	797	886	908	1075	
1452	3192	11	1050					1205	
1453	3207	11	1053			1360	1375	1542	
1454	3209	12	880					1100	
1455	3203	10	756			820		942	
1456	3184	8	608					840	
1457	3204	8	675					915	
1458	3252	5	1178	1194	1208	1270	1283	1373	
1459	3336	11	1165			1243	1275		
1460	3476	21	715			842	870	1012	
1461	3348	2	820	890	915	1010	1032	1123	
1462	3358	8	360	427	450	560	588	697	
1463	3319	9	1325					1622	
1464	3486	11	803	863	882	978	1004	1127	
1465	3461	10	790	855	875	983	1006	1160	Grnd el 3451 from topo map
1466	3461	9	756	820	848	940	967	1104	
1467	3460	11	782	845	866	973	996	1122	
1468	3472	10	787	847	868	965	993	1130	
1469	3478	10	792	850	872	968	993	1127	
1470	3480	19	791	853	872	972	999	1140	
1471	3477	9	780	840	862	964	990	1125	
1472	3464	9	785	848	868	968	993	1118	
1473	3454	0	774	833	854	962	987	1123	Grnd el 3454 from topo, no KB
1474	3459	10	794	860	880	982	1007	1140	Grnd el 3449 from topo map
1475	3455	10	780	845	865	963	988	1120	Grnd el 3445 from topo map
1476	3458	10	793	858	878	980	1005	1147	Grnd el 3448 from topo map
1477	3470	11	793	850	872	972	993	1140	
1478	3410	10	837	899	923	1021	1044	1177	Loc rev from SW1/4, SE1/4
1479	3468	10	808	876	905	991	1013	1140	
1480	3445	11	762	825	848	949	972	1103	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	ulm	Sal	Revisions
1481	3454	11	787	852	875	976	998	1132	
1482	3455	8	773	840	862	962	982	1133	
1483	3427	10	765	828	848	953	982	1137	
1484	3451	10	787	854	875	985	1003	1158	Grnd el 3441 from topo, +KB
1485	3438	10	782	843	863	968	992	1145	Grnd el 3428 from topo, +KB
1486	3451	11	780	843	865	963	993	1144	
1487	3453	10	780	845	867	966	990	1140	Grnd el 3443 from topo, +KB
1488	3453	10	792	858	878	983	1008	1158	Grnd el 3443 from topo, +KB
1489	3441	11	776	841	862	942	965	1138	
1490	3447	10	769	834	855	962	983	1137	
1491	3443	10	787	854	875	982	1003	1165	
1492	3441	10	780	846	867	973	995	1150	Grnd el 3431 from topo; +KB
1493	3421	9	695	758	779	902	927	1095	
1494	3444	9	763	827	850	960	983	1140	
1495	3423	10	743	805	823	915	938	1098	
1496	3439	9	769	833	856	955	980	1137	
1497	3437	11	745	810	832	942	960	1120	
1498	3426	12	715	778	800	898	922	1077	
1499	3458	11	766	828	852	962	984	1157	
1500	3411	10	697	765	786	895	918	1075	
1501	3434	11	742	813	835	940	961	1110	
1502	3444	13	760	822	844	952	972	1128	
1503	3434	9	727	795	816	936	960	1115	
1504	3433	9	772	833	852	953	976	1125	
1505	3443	8	768	836	855	961	983	1130	Ref el rev from log
1506	3431	20	607	668	692	803	822	940	
1507	3438	16	643	705	727	836	857	1015	
1508	3394	13	730	790	812	905	932	1086	
1509	3403	11	740	811	834	938	967	1115	Grnd el 3392 from topo, +KB
1510	3398	19	747	800	822	931	958	1117	
1511	3396	12	726	787	810	916	938	1100	
1512		0	726	792	813	927	953	1106	Grnd el 3400 from log, no KB
1513	3414	12	713	784	803	907	934	1097	
1514	3406	11	737	802	823	943	966	1116	
1515	3413	13	752	815	835	947	975	1125	
1516	3422	10	738	806	826	941	967	1125	
1517	3404	13	775	842	863	962	985	1148	
1518	3382	13	755	812	835	943	962	1112	
1519	3400	11	756	816	836	952	978	1132	
1520	3404	11	707	770	792	894	917	1073	
1521	3408	9	692	756	776	877	905	1062	
1522	3421	12	720	782	806	918	943	1109	
1523	3428	9	730	804	828	945	970	1130	
1524	3430	11	768	845	865	948	973	1128	
1525	3409	13	746	810	832	930	957	1117	Ref elev rev from log
1526	3419	10	748	812	835	942	966	1130	Grnd el 3409 from topo, +KB
1527	3419	9	738	800	825	933	959	1115	
1528	3411	10	747	810	832	935	960	1117	

ID No.	Reference Elevation	KB (ft)	49'r	Depth (ft) to top of units Mag	Tam	Cul	nlm	Sal	Revisions
1529	3421	9	770	825	860	953	977	1142	
1530	3414	10	750	816	837	950	973	1130	
1531	3429	11	748	808	834	930	955	1085	
1532	3430	10	773	838	861	970	993	1155	
1533	3391	11	755	823	845	960	988	1130	
1534	3392	10	785	856	875	984	1008	1170	
1535	3388	9	738	802	822	930	953	1118	
1536	3375	10	900	958	977	1072	1097		
1537	3398	10	782	850	870	960	985	1140	
1538	3386	9	813	875	895	993	1018	1178	
1539	3382	10	818	875	895	993	1018	1175	
1540	3386	10	768	832	855	960	987	1148	
1541	3414	10	868	930	950	1040	1063	1230	
1542	3370	11	957	1023	1042	1140	1166	1335	
1543	3356	9	923	988	1012	1100	1132	1310	
1544	3366	11	1142	1202	1224	1315	1347	1485	
1545	3311	2	1072	1132	1150	1242	1270	1417	
1546	3307	10	1075	1130	1153	1238	1263	1412	
1547	3349	11	935	995	1020	1128	1155	1297	Ref el rev from log
1548	3332	9	1055	1116	1142	1250	1277	1440	
1549		0	1045	1112	1128	1225	1250	1405	DF 3354 log; grnd el 3346 from topo
1550	3490	10	1200	1255	1268	1506	1530	1673	
1551	3478	11	1106	1168	1186	1258	1292	1433	
1552	3456	11	1065	1120	1140	1259	1285	1428	
1553	3424	11	1138	1195	1213	1372	1395	1550	
1554	3497	8	985	1038	1057	1150	1180	1312	
1555	3431	10	1012	1077	1095	1183	1210	1347	
1556		0	1042	1098	1117	1207	1232	1374	
1557	3392	34	1006	1075	1092	1184	1209	1335	
1558	3353	11	1060	1114	1130	1227	1250	1410	
1559	3358	9	1045	1117	1136	1283	1310	1463	
1560	3342	12	1047	1105	1127	1258	1285	1435	
1561	3332	11	1045	1108	1125	1210	1237	1395	
1562	3320	12	1023	1082	1098	1213	1237	1387	
1563	3353	10	975	1038	1053	1143	1170	1315	
1564	3344	11	1002	1056	1074	1167	1188	1339	
1565	3422	9	995	1060	1083	1171	1196	1385	
1566	3386	12	742	800	824	927	951	1096	
1567	3332	0	875	927	945	1042	1067	1192	
1568	3391	13	900	956	971	1070	1096	1224	
1569	3325	7	965	1025	1045	1170	1197	1334	
1570	3346	11	1038	1102	1117	1250	1277	1432	
1571	3346	12	1023	1085	1104	1260	1287	1437	
1572	3339	0	852	905	925	1083	1119	1265	
1573	3163	10	917					1095	
1574	3143	1	1030					1290	
1575	3123	0	870	912	920	980	990	1068	
1576	3115	10	873	913	919	979	992	1065	

ID No.	Reference Elevation	KB (ft)	Depth (ft) to top of units 49'r	Mag	Tam	Cul	uim	Sal	Revisions
1577	3087	0	790	830	838	906	915	973	
1578		0							
1579	3012	4							
1580	2965	10	200				263	375	
1581	2975	11	315			452	477	600	
1582	2978	8	700				858		
1583	2993	8	502	570	594	682	718	790	
1584	2953	8					238	388	
1585	2964	14						512	
1586	2912	7					190	330	
1587	2900	12					240	360	
1588	2972	9							
1589	2875	9							
1590	2892	10						414	
1591	3201	1	1260	1320	1347	1440	1462	1545	
1592	3165	10	1304	1375	1402	1502	1530	1632	
1593	3179	9	1046	1115	1133	1225	1257		Ref el 3179, 3180 from log
1594	3059	8	815			948	978	1162	
1595	3090	10							
1596	3210	10	950	1012	1037	1125	1165	1294	
1597	3059	9							
1598		9	455			688	711	850	
1599	2982	10							
1600	3220	0	1021	1080	1103	1209	1234	1300	topfnr revised 9/27/94
1601		0	1003	1044	1068	1147	1178	1267	
1602	3238	9	1000	1050	1062	1078	1103	1202	
1603	3225	32							
1604		0	920			1093	1115	1245	
1605	3282	11	1388	1445	1460	1542	1567	1685	
1606	3177	10	589	650	667	768	798	956	Loc rev from NE1/4, SE1/4
1607	3180	0	1280	1335	1350	1453	1467	1595	
1608	3133	11	583	643	662	770	794	963	
1609	3122	11	625	687	708	828	855	1020	
1610	3113	11	623	684	702	830	847	1006	
1611	3130	11	633	698	717	852	874	1034	
1612	3122	11	600	665	682	805	825	987	
1613	3132	11	587	653	672	792	813	967	Ref el rev from log
1614	3124	11	590	648	664	780	802	967	
1615	3134	12	593	656	676	798	816	975	Grnd el 3122 from topo, +KB
1616	3130	19	623	690	708	824	848	1005	
1617	3131	9	595	670	687	807	828	994	
1618	3113	11	540	600	620	745	765	930	
1619	3264	10	740	808	826	930	956	1095	
1620	3122	11	659	727	746	876	897	1055	
1621	3414	10	856	915	926	1052	1084	1235	
1622	3392	11	744	810	830	943	972	1115	
1623	3332	0	635	699	714	833	862	1005	
1624		9	1054	1102	1117	1152	1168	1203	

ID No.	Reference Elevation	KB (ft)	Depth (ft) to top of units 49'r	Mag	Tam	Cnl	ulm	Sal	Revisions
1625		0	983	1034	1045	1145	1156	1265	
1626	3013	0	932	972	981			1163	
1627	3032	0	970			1082	1102	1194	
1628	3853	17	1905	1983	2002	2202	2217	2331	
1629	3741	26	1422	1503	1523	1716	1737	1878	
1630	3480	0	692	748	773	859	885		
1631	3659	9	1164	1225	1248	1467	1490	1638	
1632	3572	22	1155	1210	1230	1340	1362	1467	
1633	3645	11	922	986	1008	1112	1137	1227	
1634	3094	12	266					594	
1635	3612	24	1322	1403	1422	1648	1673	1840	
1636	3506	20	1170	1226	1242	1392	1416	1550	
1637	2968	8						240	
1638	3456	11							
1639	3726	12	1212	1288	1308	1533	1558	1708	
1640		2	400	520	545	722	753	1105	
1641	3410	0	532	590	616	703	724	842	Data from BDR SAND89-0203
1642	3384	0	509	564	591	706	731		Data from BDR SAND89-0204
1643	3413	0	506	571	594	689	713	821	Data from BDR SAND89-0204

All drillholes within the Rustler data base were included, even if parts or all of the Rustler were uninterpretable. Drillhole location, names, and other data are presented in tables of Rustler location data and can be cross-indexed with the identification number.

APPENDIX A-4

TABLE OF DATA FOR DEPTHS TO DEWEY LAKE AND SANTA ROSA FORMATIONS

Table of Data for Depth to Dewey Lake and Santa Rosa Formations

Borehole ID no.	Reference Elevation	Rustler Fm	DEPTH (in feet) to Top of: Dewey Lake	Santa Rosa	"Chinle"
1072		480	130	0	0
1074	3448	828	520	355	
1075		1121	625	400	
1076	3510	883	450	230	
1077		1163	730	520	
1078		1372	905	690	
1079	3524	1103	635	415	100
1080	3509	1076	610	370	
1090	3412	187	90		
1091	3471	200	70		
1092	3472	255	40		
1093	3468	445	50		
1094	3487	830	620	510	10
1095		312	60		
1096	3309	146	30		
1099	3177	152	79		
1102	3347				
1103	3427	449	0		
1104	3540	538	72	17	
1105	3748	1505	1035	805	310
1106	3792	1550	1065	830	345
1107	3793	1568	1050	820	455
1108	3740	1530	1040	750	400
1109	3668	1345	840	565	
1110		1162	625	440	
1111	3800	1450	855	615	360
1112	3862	1565	985	825	
1113	3861	1515	1030	800	
1114	3834	1555	1055	790	
1115	3679	1056	580		
1118	3662	670	115		
1119		778	250		
1120	3802	1760	1275	1015	355
1137	3023				
1138	2977				
1141	3221	275	40		
1142	3323	401	44		
1143	3212	232	17		
1144	3358	387	42		
1145	3376	462	8		
1147	3152	12			
1148		395	20		
1149	3418	641	120		
1150	3439	676	174	42	
1151	3433	657	154	11	

Borehole ID no.	Reference Elevation	Rustler Fm	DEPTH (in feet) to Top of: Dewey Lake	Santa Rosa	"Chinle"
1152	3249	639	141	15	
1153	3541	668	177	35	
1154	3553	780	261	6	
1155	3508	732	224	8	
1156	3510	734	225	8	
1158	3405	517	80		
1159	3484	641	168	30	
1160	3472	623	146	12	
1161	3345	426	38		
1162	3349	427			
1163	3382	468	41		
1164	3457	614	140	8	
1165	3426	574	80		
1166	3417	559	73	40	
1167	3433	590	96	14	
1168	3420	550	63	54	
1169	3506	746	224	9	
1170	3546	759	232	8	
1172	3479	626	87	9	
1173	3508	686	151	8	
1174	3441	610	99	8	
1175	3473	668	133	46	
1176	3478	690	164	38	
1177	3398				
1178	3345	357	35		
1179	3377	457	32		
1180	3395	509			
1181	3345	359	40		
1182	3354	358	18		
1183	3310	232	32		
1184	3409	557	162	36	
1185	3409	562	66	11	
1186	3644	860	394		
1187	3731	950	450	90	
1188	3701	885	530		
1189	3696	900	395		
1190	3620	760	240	10	
1191	3640	835	330		
1192	3487	870	330	37	
1193	3789	1048	513		
1194	3756	1145	625		
1230	3163	87	57		
1237	3426	310	110		
1238		623	62		
1239	3339	382	46		
1240	3336	391	38		

Borehole ID no.	Reference Elevation	Rustler Fm	DEPTH (in feet) to Top of: Dewey Lake	Santa Rosa	"Chinle"
1241	3335	315			
1242	3332	312	45		
1244	3323	316	32		
1245		742	190		
1247	3425	621	70		
1248		476	64		
1249	3374	460	44		
1250		763	215	25	
1251	3461	775	210	135	
1252	3506	865	620		
1253	3454	750	190		
1254	3464	758	630		
1255	3458	750	120		
1256	3402	497	140		
1259		430	50		
1260		780	215		
1261	3727	1155	542	400	
1262	3699	1140	582	370	
1263	3723	1195	655	390	
1264	3722	1178	637	370	
1265	3622	1025	480	275	
1266	3696	1210	665	445	
1267	3699	1217	670	465	
1268	3701	1163	615	405	
1269	3720	1225	693	450	
1270	3725	1235	700	535	
1271	3700	1208	655	480	
1272	3720	1212	660	360	
1273	3698	1225	673	455	
1274	3705	1215	665	448	
1275	3658	1222	670	452	
1276	3713	1225	670	446	
1277	3687	1180	630	408	
1278	3551	862	330		
1279	3666	1200	640	420	
1280	3629	1170	630	445	
1281	3670	1187	635	408	
1282	3694	1206	640	420	
1283	3675		590	360	
1284	3700	1215	655	413	
1285	3691	1205	655	445	
1286	3663	1200	655	430	
1287	3689	1193	625	395	
1288	3669	1210	652	430	
1289	3630	1183	640	460	
1290	3694	1207	660	440	
1291	3689	1210	727		

Borehole ID no.	Reference Elevation	Rustler Fm	DEPTH (in feet) to Top of: Dewey Lake	Santa Rosa	"Chinle"
1292	3664	1206	650	420	
1293	3636	1160	637	365	
1294	3704	1260	790	496	
1295	3722	1270	740	504	
1296	3715	1268	730	506	
1297	3722	1230	700	475	
1298	3726	1290	745	525	
1299	3711	1230	695	455	
1300	3720	1233	695	470	
1301	3713	1222	690	440	
1302	3703	1225	690	445	
1303	3713	1285	700		
1304	3701	1280	705	500	
1305		1252	705	480	
1306	3686	1268	715	490	
1307	3659	1310	735	540	
1332	2924	450	20		
1333		370	205		
1335	3433	400	155	65	
1338	3502	853	290		
1341	3436	485	30		
1342	3406	465			
1343	3414	453	70		
1344	3430	455	70		
1345	3438	478	145		
1346	3535	600	155		
1347		768	210		
1348		762	250		
1349	3553	665	235		
1350	3514	576	120		
1351	3530	605	95		
1352	3490	530	165	85	
1353	3535	693	145		
1354	3551	695	165		
1355	3502	595	150		
1356	3508	628	270		
1357	3620	1183	635	455	
1359	3632	1185	615	435	
1360	3631	1172	555	380	
1361	3584	888	350	140	
1362	3628	1088	580	405	
1367	3637	1192	635	425	
1368	3640	1157	595	380	
1370	3600	1204	635	410	
1371		1130	590	350	
1372	3586	1187	605	390	
1374	3628	1132	520	375	
1375	3688	1122	510	305	

Borehole ID no.	Reference Elevation	Rustler Fm	DEPTH (in feet) to Top of: Dewey Lake	Santa Rosa	"Chinle"
1376	3591	1130	510	295	
1377	3624	1142	585	370	
1378	3606	1122	585	315	
1379	3591	1110	500	260	
1380	3602	1025	475	240	
1381	3622	1065	495	265	
1382	3608	1052	490	315	
1383	3604	1070	505	305	
1384	3618	998	450	225	
1385	3607	1060	485	300	
1386	3604	1062	490	305	
1387	3602	1066	495	280	
1388	3591	1047	475	270	
1389	3609	1093	520	340	
1390	3605	1088	505	295	
1391		1008	440		
1392		746	360		
1393	3510	830	295		
1394	3619	881	425	305	
1395		906	405		
1396	3625	1278	820	650	
1397	3606	1187	630	410	
1398	3598	1174	635	405	
1403	3578	1194	620	390	
1404	3637	1215	635	410	
1405	3598	1245	670	445	
1406	3554	1190	605	395	
1407	3592	1205	620	385	
1408	3540	1140	555	315	
1410	3502	1186	585	355	
1411	3525	1146	570	345	
1412	3556	1070	475	265	
1413	3524	1063	495	265	
1414		1163	665	340	
1436	3273	848	570		
1437	3283	888	485		
1440	3199	745	405		
1441	3197	678	350		
1443	3190	699	365		
1444	3282	900	400	200	
1445	3317	780	360	220	
1446	3210	595	360	195	
1447	3219	640	280		
1448		440	230		
1450		498	230		
1451	3186	725	470	380	
1452	3192	1050	705		
1453	3207	1053			

Borehole ID no.	Reference Elevation	Rustler Fm	DEPTH (in feet) to Top of: Dewey Lake	Santa Rosa	"Chinle"
1454	3209	880	330		
1455		756	300	190	
1456	3184	608	265		
1457	3204	675	375		
1458	3252	1178	595	305	
1459		1165			
1460	3476	715	345		
1461	3348	820	285		
1463	3319	1325	660	390	
1464	3486	803	280		
1465		790	250		
1466	3461	756	225		
1468	3472	787	260		
1471	3477	780	255		
1472	3464	785	255		
1473		774	240		
1474		794	250		
1477	3470	793	260		
1478	3410	837	300		
1479	3468	808	270		
1480	3445	762	210		
1481	3454	787	230		
1482	3455	773	215		
1486	3451	780	235		
1487		780	240		
1488		792	210		
1491	3443	787	240		
1492		780	225		
1495	3423	743	210		
1496	3439	769	220		
1499	3458	766	185		
1500	3411	697	215		
1501	3434	742	190		
1502	3444	760	215		
1503	3434	727	210		
1506	3431	607	190		
1507	3438	643	225		
1508	3394	730	220		
1509		740	145		
1512		726	215		
1513	3414	713	220		
1514	3406	737	170		
1515	3413	752	190		
1517	3404	775	195		
1522	3421	720	165		
1524	3430	768	210		
1526		748	160		
1527	3419	738	160		

Borehole ID no.	Reference Elevation	Rustler Fm	DEPTH (in feet) to Top of: Dewey Lake	Santa Rosa	"Chinle"
1528	3411	747	185		
1529	3421	770	200		
1530		770	140		
1531	3429	748	190		
1532	3430	773	175		
1533	3391	755	235		
1534	3392	785	215		
1535	3388	738	175		
1536	3375	900	225		
1537	3398	782	215		
1538	3386	813	255		
1539	3382	818	255		
1540	3386	768	205		
1541	3414	868	315		
1542	3370	957	385	125	
1543	3356	923	410	360	
1544	3366	1142	560		
1545	3311	1072	565	330	
1546	3307	1075	585	380	
1547	3348	935	350		
1548	3332	1055	700		
1549	3354	1045	450		
1550	3490	1200	580	320	
1551	3478	1106	525	270	
1552	3456	1065	460	255	
1553	3424	1138	530	270	
1554	3497	985	425	165	
1555	3431	1012	410	165	
1556		1042	430	200	
1557	3392	1006	385	180	
1558	3353	1060	465	230	
1559	3358	1045	445	205	
1560	3342	1047	455	255	
1561	3332	1045	410	200	
1562	3320	1023	520	225	
1563	3353	975	382	190	
1564	3344	1002	410	180	
1565	3422	995	390	200	
1566	3386	742	150		
1567	3332	875	285		
1568	3391	900	360	160	
1569	3325	965	360	165	
1570	3346	1038	445	220	
1580		200	20		
1581		315	130		
1582		700	220		
1591		1260	815	695	
1592		1304	845	755	

Borehole ID no.	Reference Elevation	Rustler Fm	DEPTH (in feet) to Top of: Dewey Lake	Santa Rosa	"Chinle"
1593		1048	530		
1594	3059	815	135		
1596		950	700	530	150
1598		605	455		
1600		1021	450	275	
1601		1003	605	445	
1602		1000			
1604		920	575	385	
1605	3282	1388	815	550	
1606	3177	589	50		
1607	3180	1280	860	685	
1608	3133	583	80		
1609	3122	625	85		
1611	3130	633	80		
1612	3122	600	95		
1613	3131	587	75		
1614	3124	590	95		
1615		593	85		
1616	3130	623	100		
1617	3131	595	80		
1618	3113	540	95		
1619	3264	740	125		
1620	3122	659	75		
1628		1905	1415	1160	190
1629		1422	895	670	
1630		693	170	90	
1631		1164	636		
1632		1155	560		
1633		922	460		
1634		266	55		
1635		1322	750	520	80
1636		1170	670		
1639		1212	670		
1640		400	245	150	
1641	3410	532	52		37
1642	3384	509	55		22
1643	3413	506	20		8

Drillhole locations, names, and other data are presented in tables of Rustler location data and can be cross-indexed with the identification number.

Appendix B

APPENDIX B

RUSTLER FORMATION STRATIGRAPHIC DATA FROM RICHEY (1989)

APPENDIX B-1

DRILLHOLE NAME AND LOCATION DATA FROM RICHEY (1989)

Drillhole Name and Location Data from Richey (1989)

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
001	20	33	3	660s	660w	Fed. Trigg #1	
002	20	33	3	658n	660e	Fed. "Lea" #2-3	
004	20	33	7	660s	1980e	Brooks 7 Fed. #3	
005	20	33	10	330s	330e	Anderson Pritchard Fed. #1	
006	20	33	11	660s	660w	#1 Fed. 11	
007	20	33	14	2310n	990w	Fed. #4	
008	20	33	14	990s	2310w	Fed. C-1	
009	20	33	14	1980n	1650w	Fed. #3	
010	20	33	14	2310s	1980w	Fed. #1B	
011	20	33	14	660n	660w	Fed. #1A	
012	20	33	15	660n	660e	Fed. #1	
013	20	33	16	660n	1980e	St. Lea (886) #2	
014	20	33	18	1980n	660w	Welsh-St. #2	
015	20	33	19	2005n	1880w	Bass Fed. No. 1	
016	20	33	22	1980s	660e	"Wills" Fed. TA #1	
017	20	33	23	330n	1980e	Fed. Lindsey #1	
018	20	33	24	330s	330e	Dinnin #2	
019	20	33	26	660s	660w	Hudson Fed. #1	
020	20	33	30	1980n	1980w	#1 Bass Fed.	
021	20	33	30	660s	1300e	Bass Fed. #2	
022	20	33	31	660s	1980e	St. of New Mexico CM No. 1	
023	20	33	33	1980s	660w	#1 Aztec Fed.	
024	20	33	34	660s	1980e	Fed. "34" - #1	
025	20	33	35	660n	1980e	Shell Fed. #1	
026	20	33	35	660n	1980w	Shell Fed. #1	
027	20	33	35	1650n	990w	R.R. Morrison C & E Fed. #1	
028	19	35	5	1980n	1980w	Jackson #1	
029	19	35	12	1980s	1980w	W.M. Snyder #1	
030	19	35	15	330s	660e	Cabot St. #2	
031	19	35	17	1980s	1980e	Gulf Roberts #1	
032	19	35	19	990s	660w	Superior-Alves Trustee #1	
033	19	35	21	660s	1980e	McIntosh D #3	
034	19	35	24	1650n	660w	Texaco-Hamon St. A-1	
035	19	35	25	1980n	668e	Record No. 2	
036	19	35	29	2310n	990w	St. "PK" #1	
037	19	35	34	660n	660w	St. W.M.A. #1	
038	19	35	36	1980n	1980w	St. "PJ" #1	
039	20	32	10	330n	990w	Perry Fed. #1	
040	20	32	13	660s	1980w	Hanson St. #1	
041	20	32	15	1980s	1980w	Plata Deep Unit #1	
042	20	32	16	2310n	2310w	St. Little Eddy Unit #16	
043	20	32	21	1980s	660w	Big Eddy Unit #1-21	
044	20	32	23	1980s	1980w	Baetz "23" #1	
045	20	32	25	660s	660e	Audie Richards #1	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
046	20	32	36	1976n	660e	St. of New Mexico "CH" No. 1	
047	20	34	14	660s	1980e	Fed. Hanson B No. 1	
048	20	34	18	1980s	1980e	Fed. #1	
049	20	34	21	660s	660e	Muse No. 2	
050	20	34	26	330s	330w	Cruces No. 1	
051	20	34	27	330s	1650e	Fed. Keohone "A" No. 1	
052	20	34	27	330s	330e	Fletcher No. 2	
053	20	34	34	1650n	2310w	Lynch No. "A"-9	
054	20	34	34	660s	1980e	B.V. Lynch "A" No. 5	
055	20	34	34	1650s	660e	B.V. Lynch "A" No. 8	
056	20	34	34	1980n	1980e	Lynch "A" No. 11	
057	20	34	34	660n	1980w	B.V. Lynch "A" No. 10	
058	20	34	35	1650s	990w	Lynch A-7	
059	20	34	35	1650s	2310e	Neal No. 1	
060	20	34	35	990n	1650w	Fed. #4	
061	20	34	35	990n	990w	Fletcher No. 1	
062	20	35	3	670n	1980w	Linam 1	
063	20	35	5	1980s	330e	#8 Fed. Saunders	
064	20	35	6	660n	660e	Featherstone Fed. No. 1	
065	20	35	12	660n	660e	Leonard St. #1	
066	20	35	13	660n	660w	St. 13 #1	
067	20	35	17	1980s	660e	Hudson Fed. #1	
068	20	35	23	660n	660w	U.S.A. West Monument #1	
069	20	35	28	660s	660w	Phillips St. #1	
070	20	35	30			Sunray St. No. 1	
071	19	32	6	1980n	1980e	W.H. Peckham No. 1	
072	19	32	13	990s	990e	W.E. Bondurant #3	
073	19	32	13	2310n	330e	W.E. Bondurant #2	
074	19	32	13	2310s	330e	W.E. Bondurant #1	
075	19	32	15	1980n	660e	#8 Plains Unit	
076	19	32	16	660s	660w	Humble St. #1	
077	19	32	18	1980n	990e	Middleton Fed. "A" #1	
078	19	32	19	1980n	2310e	Southern Calif. Pet. Corp. No. 1	
079	19	32	21	1650s	990w	Atlantic No. 1	
080	19	32	33	660n	660w	Boellner Fed. No. 2	
081	19	32	25	330n	330e	Fed. Big Circle #1	
082	19	32	34	1980s	660e	Fed.-Boellner #1	
083	19	33	8	1980s	660w	USA Culbertson Irwin #1	
084	19	33	18	1980s	2035w	Fed. 18 No. 5	
085	19	33	18	2130n	689w	Fed. 18 No. 1	
086	19	33	18	2310s	330w	Fed. 18 No. 7	
087	19	33	21	660n	1980w	Bright Fed. No. 1	
088	19	33	22	1980s	495e	Miller-Fed. #1	
089	19	33	24	800s	330w	Donohue #1	
090	19	33	26	660s	1980w	Bates Fed. #1	
091	19	33	29	330s	1980e	Fed. No. 1	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
092	19	33	29	660n	660w	Fed. Carder #1	
093	19	33	30	660n	1980e	Signal Ross #1	
094	19	33	30	1980n	2004w	Signal Ross Fed. #2	
095	19	33	3	2082n	1980w	Buffalo Unit #1	
096	19	34	5	330n	660w	Fed. Littlefield "EA" #1	
097	19	34	7	1980n	1980e	Mescalero Unit #1	
098	19	34	12	660n	660w	U.S. Smelting St. #1	
099	19	34	13	2310s	330w	Atlantic Richfield #1	
100	19	34	15	330s	330w	Gulf Fed. #1	
101	19	34	25	1980s	660w	Superior Fed. #4	
102	19	34	28	990s	2310w	Fed. #1	
103	19	34	30	2310s	330w	Drlg. & Exploration Gillespie No. 1-"B"	
104	19	34	36	660s	330e	Pure St. #1	
105	21	30	25	1098s	969w	Wills-Crosby #1	
106	21	30	26	983n	1361w	Wills-Crosby #2	
107	21	30	26	660s	1980w	James "D" #1	
108	21	31	31	264n	471w	Wills #7	
109	21	31	32	300n	2540w	FC-63 (Kerr McGee)	
110	21	31	32	141s	141e	FC-68 (Kerr McGee)	
111	21	31	34	250n	2207e	FC-52 (Kerr McGee)	
112	21	31	34	100s	100w	FC-65 (Kerr McGee)	
113	21	31	34	141n	160w	FC-69 (Kerr McGee)	
114	22	30	1	990s	1980w	Cabana #1	rev'd 974s, 1976w w/log data
115	22	30	2	660s	2011e	James "A" #1	
116	22	30	3	693n	977e	Duval #96	
117	22	30	3	1320s	300e	USB&C #168	
118	22	30	4	50n	650e	Gypsy Oil Co. #3	
119	22	30	9	315s	291w	USPC #97A	
120	22	30	9	1320n	2600w	USB&C #163	
121	22	30	9	2406n	578w	IMC #322	
122	22	30	9	1485s	650w	IMC #343	
123	22	30	10	1883n	2574e	Duval #82	
124	22	30	11	1976n	1981e	James "E" #1	
125	22	30	11	1247s	1301w	D-121	
126	22	30	13	1574n	1566w	D-120	
127	22	30	14	136s	2178e	D-48	
128	22	30	21	109s	81e	Duval #33	
129	22	30	21	1320n	2640e	IMC #111	
130	22	30	21	1320s	1320w	IMC #112	
132	22	30	27	2664s	2625e	Duval #181	
133	22	30	27	38s	2643w	Duval #198	
134	22	30	27	500s	20w	Duval #200	
135	22	30	27	2370s	224e	Duval #231	
136	22	30	36	2463s	1124w	D-160	
137	22	30	36	660s	2006e	James Ranch #1	
138	22	31	6	1173s	1147w	U-134 (Miss. Chem. Corp.)	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
139	22	31	6	1978n	660w	Campana #1	
140	22	31	8	143s	249e	FC-92 (Kerr McGee)	
141	22	31	8	154s	37w	FC-82 (Kerr McGee)	
142	22	31	9	107n	91e	NF-1 (Kerr McGee)	
143	22	31	34	2022s	1978w	Fed. Cotton Baby #1	
144	23	29	1	2763s	2964e	Duval #29	
145	23	29	1	528s	528w	IMC I-184	
146	23	29	1	1320n	1320e	IMC I-263	
147	23	29	4	1255n	1374e	Arco #9	
148	23	29	12	2600n	700e	Shell Oil Co. #17 (Dogtown #)	
149	23	29	13	2100n	300e	Shell Oil Co. #21 (Dogtown #15)	
150	23	29	15	202n	2524e	Duval #8	
151	23	29	15	1160n	3276e	Duval #14	
152	23	29	17	660s	1980w	Teledyne "17" #1	
153	23	29	24	300n	300e	Shell Oil Co. #19 (Dogtown #13)	
154	23	29	25	200n	2500e	Shell Oil Co. #22 (Dogtown #16)	
155	23	29	27	660s	1980w	Laguna Grande #2	
156	23	29	28	1380s	990e	#1 Laguna Grande Unit	
157	23	29	35	1900s	100e	A-29	
158	23	29	36	1800s	1200e	A-31	
159	23	30	1	1834n	1978w	Hudson Fed. #1	
160	23	30	1	1973s	1648e	James Ranch Unit #3	
161	23	30	2	101s	1169w	Duval #1	
162	23	30	2	143n	112w	Duval D-31	
163	23	30	2	2655n	2655e	Duval D-179	
164	23	30	17	2505n	317w	Shell Oil Co. #6 (Dogtown #1)	
165	23	30	19	2244n	2096e	Duval #10	
166	23	30	24	1980n	660w	Sandy Unit #1	
167	23	30	26			USGS #22	
168	23	30	28	175s	232w	Duval #4	
169	23	30	29	261n	261e	Shell Oil Co. #7 (Dogtown #2)	
170	23	30	30	215n	2300w	Shell Oil Co. #20 (Dogtown #14)	
171	23	30	31	2640n	1750e	Arco #24	
172	23	30	32	1411n	2510e	Shell Oil Co. #23 (Dogtown #17)	
173	23	30	36	2150n	3090w	Leonard ?????? #1-S	
174	24	28	2	1980s	660w	Malaga "A" #1	
175	24	29	3	2030n	2310w	Weiner & McDonald Kerr #1	
176	24	29	4	1327s	1321e	Arco core test #13	
177	24	29	19	480n	330w	Bun #1	
178	24	29	27	660s	660w	Mobil Fed. "27" #1	
179	24	29	29	1980s	660w	Ellis Fed. 1-X	
180	24	30	2	200s	200w	Shell Oil Co. #16 (Dogtown #11)	
181	24	30	5	1147n	406e	Shell Oil Co. #11 (Dogtown #6)	
182	24	30	6	1990n	2185w	Arco #8	
183	24	30	9	2001n	2001e	Shell Oil Co. #8 (Dogtown #3)	
184	24	30	11	316s	390w	Shell Oil Co. #12 (Dogtown #)	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
185	24	30	15	200n	200w	Shell Oil Co. #13 (Dogtown #)	
186	24	30	16	150n	2590e	Shell Oil Co. #24 (Dogtown #18)	
187	24	30	18	460n	660e	Poker Lake Unit #45	
188	24	30	20	100n	1320w	Southern Production Co. core test #6	
189	24	30	23	1606n	2294e	Shell Oil Co. #9 (Dogtown #4)	
190	24	30	23	660s	660w	Shugart Fed. 23 #1	
191	24	30	25	660s	660w	Bass Fed. #1-25	
192	24	30	27	336n	270e	Shell Oil Co. #10 (Dogtown #)	
193	24	30	29	660s	660e	Fed. Nettles (?) #1	
194	24	31	2	1980n	1980w	#1-2 Todd Fed.	rev'd 1945w to 1980w w/log data
195	24	31	3	660s	660e	Jennings Fed. #1	
196	24	31	4	660n	660e	Stewart Fed. #1	
197	24	31	4	1659n	2310w	Bestly (?) Fed. #1	
198	24	31	5	330n	330e	USGS potash core test #13	
199	24	31	6	1098n	2193e	Shell Oil Co. #15	
200	24	31	6	1980n	1980w	Dunes (?) Unit Fed. #1	
201	24	31	7	660s	660e	Fed. "Y" #1	
202	24	31	11	2531n	178e	Shell Oil Co. #4 (Fed. G-NM #4)	
203	24	31	11	660n	1980e	Fed. Littlefield "CT" #1	
204	24	31	13	1980s	1980e	1-13 Fed.	
205	24	31	17	660n	660e	Continental Fed. #1	rev'd 740e to 660e w/log data
206	24	31	18	660s	660e	Ritchie Fed. #1	
207	24	31	20	660n	660e	Jennings Fed. #1	
208	24	31	20	660s	1980w	Poker Lake #40	
209	24	31	21	660n	660e	Carper Fed. #1-21	
210	24	31	21	660s	660w	Poker Lake Unit #43	
211	24	31	28	660s	660e	Poker Lake #36	
212	24	31	24	660s	1980e	Heflin Fed. #1	
213	24	31	33	2310n	2313e	Ramley (?) #1	
214	24	31	35	1980s	660w	Cotton Draw Unit #67	
215	25	30	1	660n	660e	Poker Lake Unit #2	
216	25	30	4	1980n	1980w	R&B Fed. #1	
217	25	31	2	100n	1500w	Dog Town #2	
218	25	31	2	1980n	1980e	Cotton Draw Unit #65	FFG 602 eliminated as duplicate
219	25	31	10	1980n	1980e	Pauley & Harrison #2	
220	25	31	12	660n	660w	Pauley & Harrison #1	
221	25	31	15	780n	1230w	Pauley & Harrison PH-1	
222	25	31	28	660n	660w	Poker Lake Unit #7-A-3	
223	25	31	35	660s	660w	Del Basin #1	
224	21	32	1	330n	1380e	Sheperd #1	
225	21	32	1	3255n	1972e	ETZ Fed. #1	
226	21	32	1	660s	1980w	Fed. #1	
227	21	32	2	660s	1980e	#1 Hat Mesa "A"	
228	21	32	2	3300n	660w	Pubco Fed. #1	
229	21	32	3	660s	1980e	#1 TSS Fed. Comm.	
230	21	32	3	3300s	1980w	New Mexico Fed. "B" #1	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
231	21	32	4	1980n	1980e	New Mexico Fed. "A" #2	
232	21	32	4	3300s	1980w	New Mexico Fed. "D" #1	
233	21	32	4	1683n	1650w	New Mexico Fed. #1	
234	21	32	5	4650s	1980w	New Mexico Fed. "F" #1	
235	21	32	5	3300s	660e	New Mexico Fed. "E" #1	
236	21	32	6	3371n	2072w	Aid Fed. #1	
237	21	32	9	1980n	1980e	Halfway Fed. #1	
238	21	32	10	1980n	1980e	Government "H" Com. #1	
239	21	32	11	660s	660e	Fed. 1	
240	21	32	11	1980n	1980e	Hat Mesa #1	
241	21	32	12	1980s	660w	Fed. HM "12" #1	
242	21	32	21	660n	660w	Salt Lake South Unit #1	
243	21	32	26	1980n	660e	San Simon #1	
244	21	32	35	1980n	1980w	Chaney Fed. #1	
245	21	33	9	1980n	660e	South Lynch #1	
246	21	33	11	660n	640w	Mobil St. #2	
247	21	33	13	660s	1880e	New Mexico St. #1	
248	21	33	13	1980s	1980e	Berry St. #1	
249	21	33	15	1980s	1980e	Stock Unit #1	
250	21	33	18	660s	1980e	Eaves Unit #1	
251	21	33	24	660s	660e	St. SLA #1	
252	21	33	32	1980s	1980w	St. "LT" #1	
253	21	33	33	1980n	660e	#1 R.F. Legget	
254	21	33	34	1980n	660w	R.F. Legget "A" No. 1	
255	21	33	35	660n	660w	No. 1 Amarada St.	
256	21	34	2	1980s	1980e	"F" St. #1	
257	21	34	5	1980s	660w	Berry "5" St. Com. No. 1	
258	21	34	13	660n	660e	Shell St. No. 10	
259	21	34	16	660s	990e	Shell St. "A" No. 2	
260	21	34	24	2310n	1650w	St. "P" No. 5	
261	21	34	24	990s	2310e	St. #33	
262	21	34	31	660s	750w	Mascho Unit Well #1	
263	21	34	32	660s	1980e	Shamrock St. #1	
264	23	32	9	660s	1980e	Continental Fed. #1-9	
265	23	32	15	1980n	1980e	Fed. Continental 1-15	
266	23	32	24	660s	660e	Fields Fed. No. 1	
267	23	33	32	660n	1980e	Humble St. #1-32	
268	23	33	35	660s	660w	St. 1-35	
269	23	34	30	660s	3300e	Bell Lake Unit #2	
270	23	34	27	660s	1980w	Harris Fed. #1 (#1 Antelope Ridge Unit)	
271	23	34	26	660s	1980w	St. "FO" #1	
272	22	32	31	660n	1980e	Perry Fed. #1-31	
273	23	32	7	510n	660e	Fed. "WL" #5-7	
274	22	32	14	660s	1980w	#2 Red Tank Unit	
275	22	32	15	1980s	1980e	#1 Connally Fed.	
276	22	32	17	1980s	1980e	Fed. 1-17	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
277	22	32	18	660s	660e	Fed. Jennings #1-18	
278	22	32	19	660s	660e	Bass Fed. #1	
279	22	32	20	1980n	1980e	#1 Fed.	
280	22	32	22	1980n	660w	Fed. Red Tank Unit #1-22	
281	22	32	25	660n	1980w	Covington "A" Fed. #1	
282	22	32	36	330n	1980w	Shell et al Bootleg Ridge Unit #1	
283	22	33	1	660n	1980e	Cotter Fed. No. 1	
284	22	33	4	2310s	800w	Reed Fed. #1	
285	22	33	5	660s	330e	Richardson-Bass St. No. 1	
286	22	33	7	660s	660w	St. "K" #1	
287	22	33	7	1980s	1980e	S.S.T. St. #7-1	
288	22	33	9	660n	660w	Hudson Fed. No. 1	
289	22	33	15	1980s	1980e	Getty Fed. "15" No. 1	
290	22	33	20	1980n	660w	Conoco Fed. #1	
291	22	33	32	660s	660w	Shell St. #1-B	
292	22	33	33	660n	660e	Phillips St. #1"	
293	22	33	34	660s	1980e	#1 Humble St.	
294	22	34	1	1980s	660w	St. "AR" #1	
295	22	34	2	660s	1980w	New Mexico St. BU #1	
296	22	34	3	1650n	660w	#1 St. GRA	
297	22	34	4	2310n	2310w	#4 Fed. "GR"	
298	22	34	7	660s	660w	Bell Lake Unit #8	
299	22	34	8	660s	1980e	New Mexico St. "AE" No. 1	
300	22	34	22	330n	330e	Jacquie Ann #1	
301	22	34	26	1980s	660e	Merchant "B" #1	
302	22	35	1	660s	660w	Jalmat Deep #1	
303	22	35	3	660n	660w	Donegan St. No. 1	
304	22	35	9	1980s	1980w	Humble St. #1	
305	22	35	14	660n	1700w	Jalmat Water Supply #2	
306	22	35	16	1980n	1980e	North Rock Lake Unit #1	
307	22	35	17	660n	660e	Shell St. #1	
308	22	35	20	1980n	660e	Carper Aztec No. 1	
309	22	35	23	660s	1980w	St. Nix #1-23	
310	22	35	25	1980n	660w	Cone Jalmat Yates Pool Unit Tract 8 - #5	
311	22	35	28	1980s	660w	Rock Lake Unit #1	
312	22	35	35	660s	660w	Gulf St. 1-A	
313	22	32	6	1980n	660e	Fed. "CK" Com. #1	
314	22	32	13	660s	660e	B & H Fed. #1 (Texico-Weaver)	
315	23	32	3	1980n	660e	Fed. #1	rev'd 1969n to 1980n w/log data
316	23	32	11	1980n	1980e	Matthews "11" #1	
317	23	32	18	1980n	660e	Fed. Sand 18-1	
318	23	32	20	660s	1980e	Fed. Estill AF-1	
319	23	32	21	660n	1980w	Gulf-Fed. "A-A" #1	
320	23	32	25	990n	2310w	Wehrli-Fed. #1	
321	23	32	25	990s	330w	Fields No. 2	
322	23	32	26	330s	330e	Fed. "WL" #3-26	rev'd 660e to 330e w/log data

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
323	23	32	26	660s	1980w	Fed. Field #1	
324	23	32	28	660n	1980w	Continental Fed. No. 1	
325	23	32	31	660s	660w	Hankamer No. 1 Continental Fed.	
326	23	32	33	1980n	660e	Holder Fed. #1	
327	23	32	34	1980s	330e	Fed. "K" No. 1	
328	23	32	35	1650n	2310e	Fed. W L #1-35	
329	23	32	36	1980n	660w	Gulf St. #1	
330	23	32	36	1980s	1980e	Brinninstool Deep Unit #1	
331	23	33	4	660s	660e	Continental Fed. #1-P	
332	23	33	6	330s	330e	Shell Fed. #1-6	
333	23	33	7	660s	660w	Fed. 7 Well #1	
334	23	33	17	660s	660w	Texaco St. No. 1	
335	23	33	18	660s	660w	#1 "A" Shell St.	
336	23	33	19	1980s	1910w	Marshall #19-2	
337	23	33	20	660s	660e	Levick Fed. #1	
338	23	33	31	660n	660e	Lea St. #1	
339	23	33	35	1980n	660e	8104 JVP Hat No. 1	
340	23	33	36	1980s	660e	Bell Lake Unit 1 #18	
341	23	34	1	660s	660w	Allan Hargrave #1 St.	
342	23	34	6	660s	1980e	Bell Lake Unit #6	
343	23	34	10	1560n	1830w	#1Y Fed. "AA"	
344	23	34	15	330s	330e	No. 1 Hall/ Hall-Fed. #1	
345	23	34	18	1980s	1980w	Bell Lake #9	
346	23	34	19	1980n	1980w	Bell Lake Unit #10	
347	23	34	22	1980n	1980e	North Antelope Ridge Unit #1	
348	23	34	23	660s	1980w	St. 23 Comm #1	
349	23	34	25	660s	1980w	St. R #1	
350	23	34	26	660n	1980w	St. "EO" #1	
351	23	34	31	330s	2970e	Bell Lake Unit-1-A St.	
352	23	34	31	660s	3300e	Bell Lake Unit #1	
353	23	34	32	1980s	1650w	Bell Lake Unit #17	
354	23	34	35	990n	1980w	St. AR #1	
355	20	27	1	2310n	2310w	Mary Jane No. 1	
356	20	27	13	1980n	1980w	Donahue No. 1	
357	20	28	5	1980s	660w	Wright Fed. No. 1	
358	20	28	15	1980n	660e	#1 Trigg Fed.	
359	20	28	26	2310s	330w	Connally #1	
360	20	28	30	1980n	660w	No. 1 Sun St.	
361	20	29	1	660n	1980e	Superior Fed. #2	
362	20	29	3	1980n	660e	Lambie Fed. #1	
363	20	29	4	660n	1980w	#1-X Fed.	
364	20	29	7	330s	330e	Yates Fed. #2	
365	20	29	9	1980n	660e	Lambie Fed. No. 1	
366	20	29	10	990n	990e	Jennings Fed. No. 1	
367	20	29	11	2310s	2310w	#1 McKee	
368	20	29	12	330s	990w	McKee Fed. No. 1	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
369	20	29	13	1470n	1170w	Texaco Fed. No. 2	
370	20	29	13	660n	1980w	#1 Texaco Fed.	
371	20	29	13	660n	2310e	#1 Union	
372	20	29	14	2310s	2310e	Texaco No. 1	
373	20	29	16	660n	1980w	Fed. "X" #1-16	
374	20	29	17	660s	660e	#1 Yates Fed.	
375	20	29	18	660n	1980e	Yates Fed. #1	
376	20	29	25	330n	330w	Nicholas #1	
377	20	29	28	1650s	1650e	Pauline Trigg Fed. No. 1	
378	20	29	30	1980n	990e	Stebbins Fed. Deep #1	
379	20	29	31	330n	2310e	Yates Petroleum Corp. No. 1	
380	20	29	32	660s	660e	No. 1 Yates Fed.	
381	20	29	36	1980s	660w	#1 Zachary	
382	20	29	36	2080s	1880e	Golden Lane "36" Fed. #1	
383	20	30	1	660s	1980e	#1-1 Fed. "PA"	
384	20	30	5	1980n	1980w	Continental Fed. #1	
385	20	30	22	1980s	1980e	#1 Fed.	
386	22	28	2	1650n	1650w	Ford No. 2	
387	20	30	28	330s	1980w	Fed. No. 7	
388	20	30	28	1980n	1980w	USA Emperor Oil Co. #1	
389	20	30	31	1980n	760e	Lowe Fed. #1	
390	20	30	32	660n	330e	Eddy St. "BD" No. 1	
391	20	30	32	1980n	330e	Eddy St. "BD" No. 2	
392	20	30	33	1650n	990e	Gulf Fed. #1	
393	20	31	4	660s	660e	Big Eddy Unit 33	
394	20	31	6	660s	660e	#3 Big Eddy Unit	
395	20	31	7	1650s	660e	Big Eddy Unit #11	
396	20	31	30	330s	330e	Big Eddy Unit #1-30	
397	21	28	1	4620s	1980e	#1 Cowan	
398	21	28	2	3300s	660w	St. #1	
399	21	28	3	3630s	2310e	#1 Cowan	
400	21	28	5	1565n	1985w	BIg Eddy Unit #13	
401	21	28	7	660n	660w	#1 Richardson & Bass	
402	21	28	12	1980s	660e	Big Eddy Unit No. 36	
403	21	28	15	660s	660w	Big Eddy Unit #32	
404	21	28	20	1980s	1980e	Big Eddy Unit No. 60	
405	21	28	27	660s	660e	Fed. "GN" #1	
406	21	28	29	1180s	1980w	Big Eddy Unit #54	
407	21	28	29	1980n	1980e	Big Eddy No. 39	
408	21	28	30	1750s	1750e	#2 Nix & Yates Fed.	
409	21	28	30	1650n	1650w	#1 Nix-Yates Fed.	
410	21	28	31	535s	660w	Big Eddy Unit #31	
411	21	28	33	560s	660w	Richardson Bass Fed. No. 1	
412	21	28	35	990n	1650w	Big Eddy #59	
413	21	28	35	1980n	1980w	Big Eddy #47	
414	21	28	35	330s	2310w	Big Eddy Unit #62	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
415	21	28	35	1650s	330w	Big Eddy Unit #49	
416	21	28	35	1980n	2310e	Big Eddy Unit #56	
417	21	28	35	2310s	1650w	Big Eddy #58	
418	21	29	3	1980n	1980w	Big Eddy Unit #18	
419	21	29	4	4620s	1980w	Cowden Fed. #1	
420	21	29	4	838n	1650w	#1 Hudson Fed.	
421	21	29	5	630n	1980e	#1 Trigg Fed. "AA"	
422	21	29	5	1980n	660e	#1 Harris Bell	
423	21	29	5	2825n	2310w	#1 Harris Fed.	
424	21	29	6	3147n	660e	Harris "6" #1	
425	21	29	18	1980s	1980e	Big Eddy Unit #16	
426	21	29	19	660s	660e	Big Eddy Unit #55	
427	21	29	21	660s	660e	#1 Nix-Hall	
428	21	29	22	1980n	1980e	Big Eddy Unit No. 40	
429	21	29	34	660n	1980w	Big Eddy Unit No. 38	
430	21	30	16	1908n	751e	Big Eddy 45-Y	
432	21	30	35	1980s	660w	James "C" #1	
433	22	28	2	330n	2310w	Ford St. No. 1	
434	22	28	7	330s	794w	Old Indian Draw Unit #16	
435	22	28	7	330s	1650w	Old Indian Draw Unit #14	
436	22	28	7	2324n	2330e	Old Indian Draw Unit #33	
437	22	28	18	2310n	2150w	Old Indian Draw No. 7	
438	22	31	1	530s	330w	SCL Fed. #1	
439	22	28	18	2002s	1721w	Old Indian Draw No. 6	
440	22	28	18	660s	1980e	Old Indian Draw #2	
441	22	28	18	1980s	1980e	#1 Old Indian Draw Unit	
442	22	28	19	660n	1973w	Old Indian Draw Unit #17	
443	22	28	21	1980n	1980e	Pecos Irrigation #1	
444	22	28	22	1980n	1980w	Big Chief #1	
445	22	28	25	1980s	1980e	Big Eddy Unit #43	
446	22	28	27	1980n	1980w	Little Squaw #1	
447	22	28	29	660s	990w	C.R. Lopez "A" #1	
448	22	28	29	2210s	1980w	City of Carlsbad #1	
449	22	28	30	990s	330w	Nichols "HV" #1	
450	22	28	30	2310n	990e	Harroun #1	
451	22	28	31	900n	1650e	Eastland Brantley #1	
452	22	28	31	990n	330e	Gourley Fed. #3	
453	23	31	2	660n	660e	St. AA 2 #1	
454	23	31	6	1957n	1973e	James Ranch Unit #7	
455	23	31	11	660s	660e	Bauerdorf-Fed. #1	rev'd 330e to 660e w/log data
456	23	31	14	1980s	1980w	Todd Fed. "14" No. 1	
457	23	31	16	1980s	1980w	Arco St. #1-16	
458	23	31	21	660s	660e	Muse-Fed. #1	
459	23	31	25	1980n	1970w	#1-Z Todd "25" Fed.	
460	23	31	26	1980n	1650e	Todd "26" Fed. #2	
461	23	31	26	1980n	1980e	Todd Fed. "26" No. 1	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
462	23	31	27	1980s	660w	Wright-Fed. #1	
463	23	31	32	660n	660w	Continental St. No. 1	
464	23	31	33	660n	1980e	Wright-Fed. #3	
465	23	31	33	1980n	660w	Wright-Fed. #2	
466	23	31	36	660s	660w	Pauley Harrison St. #1	
467	23	35	8	2310n	330w	Fed. SR #1-8	
468	23	35	9	1980s	1980e	Sand Well Unit #1	
469	23	35	12	1980n	1980w	#1 Fed. "F"	
470	23	35	14	660n	1983e	Ann Davis #1	
471	23	35	17	660n	660e	St. Henry #1-17	
472	23	35	28	660n	1980w	North Custer Mountain Unit #1	
473	23	35	36	660n	660w	St. "D" #1	
474	24	32	1	1980s	660w	Continental Fed. #1-L	
475	24	32	2	1980n	660e	Ohio St. No. 1	
476	24	32	6	660n	1980e	Bondurant Fed. No. 1	
477	24	32	10	1980s	1980e	Fed. Hanagan D #1	
478	24	32	11	1980s	1980e	Fed. Hanagan D #2	
479	24	32	11	1980n	1980w	Fed. Hanagan D-4	
480	24	32	12	1980n	660w	Hanagan Fed. No. 3	
481	24	32	13	660s	660e	Woolley #1	
482	24	32	14	660n	1980w	#1 USA Jennings	
483	24	32	15	660s	1980w	Hicks-Fed. #1	
484	24	32	22	1980n	990e	Bradley #2	
485	24	32	22	1980s	1980e	Bradley #1	
486	24	32	23	1980n	660w	Ernest Fed. #1	
487	24	32	23	1650n	330w	Exxon A Fed. No. 2	
488	24	32	24	330n	330w	Bon Durant Fed. No. 1	
489	24	32	25	1980n	1980w	Fed. "BM" #1	
490	24	32	29	1980n	660w	#1 Payne	
491	24	32	30	1980n	1980e	Paduca Fed. #1	
492	24	32	33	660s	660e	Cotton Draw Unit Well #72	
493	24	32	34	1980s	1980w	#69 Cotton Draw Unit	
494	24	32	34	660s	1980w	Cotton Draw Unit #74	
495	24	32	35	660s	660w	Fed. Del Basin #1	
496	24	33	1	1980n	1980e	#5 Bell Lake Unit	
497	24	33	7	660s	660e	St. #1-7	
498	24	33	8	660n	660w	New Mexico St. A.G. 1	
499	24	33	13	1980n	660e	Holland #1	
500	24	33	17	660n	1980e	Holly-St. #1	
501	24	33	20	660s	1980w	St. "BB" 20 No. 1	
502	24	33	22	1980n	660w	St. #1	
503	24	33	27	1980s	1980w	Sunray St. #1	
504	24	33	29	660s	1980e	St. "AP" #1	
505	24	33	30	330n	330w	Continental St. #1	
506	24	33	31	1980s	660e	Continental St. #1	
507	24	33	36	660n	660e	#1 Lea St. "GX"	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
508	24	34	2	1980s	1980w	St. "2" #2	
509	24	34	3	1980n	1980e	Antelope Ridge #6	
510	24	34	4	660n	1650e	Fed. "BE" #1	
511	24	34	6	660n	3300e	Bell Lake Unit No. 3	
512	24	34	10	1980n	1980e	Alexander #1	
513	24	34	11	660n	1980w	Madera Comm. #1	
514	24	34	13	660s	660w	Fed. Johnson #1	
515	24	34	17	1980s	1980e	Government M #1	
516	24	34	21	660n	1980e	Shell-Fed. "B" #1	
517	24	35	5	1980n	1980w	Wilson Fed. Com. #1	
518	24	35	8	1980s	1980e	Fed. "CR 8" #1	
519	24	35	9	1980s	1980w	Custer Mountain Unit Fed. #1	
520	24	35	10	660n	660w	Lea St. "GB" #2	
521	24	35	10	1980n	1650w	Cinta Roja "10" No. 1	
522	24	35	12	1980n	1980w	Fields #1	
523	24	35	13	1980s	660e	Peggy M. Baetz No. 1	
524	24	35	15	1980n	1980e	Lea St. "GB" #1	
525	24	35	13	660n	1980e	Luzon Fed. #1	
526	19	30	5	1980n	330w	#3 Perkins "AD"	
527	19	30	13	660s	1980e	C & I Fed. #1	
528	19	30	14	2310n	330e	#1 Southern California Petroleum	
529	19	30	16	2310n	990e	St. No. 1	
530	19	30	20	660s	1980w	#1 Kelly Fed.	
531	19	30	23	2310n	990e	Union Fed. #3	
532	19	30	24	1980s	330w	Fed. Holder #1	
533	19	30	24	1705s	1650w	Fed. "CR" No. 4	
534	19	30	24	1650s	2310e	C.R. Holder #5	
535	19	30	24	2310n	660w	Fed. Holder "CR" No. 3	
536	19	30	24	940s	1725w	Fed. Holder "CR" No. 6	
537	19	30	24	990s	330w	Fed. Holder "CR" No. 2	
538	19	30	24	990s	2310e	Fed. Holder "CR" #7	
539	19	30	25	1980n	1650e	Lebow Fed. No. 7	
540	19	30	25	660n	660e	Lebow Fed. No. 5	
541	19	30	25	990s	660e	Lebow Fed. No. 10	
542	19	30	25	660s	660w	Lebow Fed. No. 12	
543	19	30	28	990s	330w	Yates Fed. "A" No. 1	
544	19	30	29	990s	990e	Lane #1	
545	19	30	30	660s	1980e	Fed. Yates #1	
546	19	30	31	660s	660w	Fed. "B" #1	
547	19	30	32	330n	2310w	Lowe St. #1	
548	19	30	36	1650s	1650e	Aikman Stanolind St. #1	
549	25	29	3	660n	660e	Superior Fed. #1-3	
550	25	29	8	660s	660e	Superior Fed. #1	
552	25	29	15	660s	660w	Superior Fed. 15 No. 1	
556	25	29	27	660s	660w	Superior Fed. #1-27	
559	25	29	31	1980s	660e	#1 Slater	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
561	26	31	1	660s	1980e	#1 Ruth Ross "O"	
562	26	31	9	660s	660w	Buckles Fed. No. 1	
563	26	31	11	1980s	660e	Baverdorf #1	
564	26	31	15	660s	660w	Fed. No. 1-15	
565	26	31	17	1980s	660e	Phantom Banks Unit Fed. 17 #1	top Rustler 302.5, not 332.5
566	26	31	20	660s	660w	Hanson Fed. No. 1	
568	26	31	25	330s	330w	Hanson #1	
569	26	31	25	1650s	330w	Hanson #3	
570	26	31	34	330n	330e	Hanson #2	
572	25	30	4	660s	660w	#1 Hopp Fed.	
575	25	30	7	660n	660w	Carper Hanson Superior St. No. 1	
577	25	30	8	1980s	660w	Poker Lake St. #3	
580	25	30	8	1980n	660e	Superior St. #1	
582	25	30	9	660s	660w	Richardson & Bass Fed. #1	
583	25	30	10	660s	645w	Poker Lake Unit #5X-1A	
584	25	30	10	2030n	2180e	Poker Lake #44	
585	25	30	12	1980n	1980w	Shugart Fed. No. 1	
586	25	30	14	1980n	660w	Poker Lake Unit #10A-6	
589	25	30	17	660s	660w	Poker Lake Unit #11A-7	
593	25	30	20	1980s	660w	Continental Fed. #2	
594	25	30	21	660n	660w	Poker Lake #6-2A	
595	25	30	21	1980s	660e	Poker Lake Unit #4	
596	25	30	22	1980s	660w	#3 Poker Lake Unit	
599	25	30	30	660s	660w	#1-30 Superior Fed.	
600	25	30	35	1980n	660e	Marshall Fed. #1	
601	25	30	35	660s	660w	Richardson & Bass Fed. No. 1	
602	25	31	2	1980n	1980e		Data dropped; Same as FFG218
606	25	31	35	660n	1980e	Big Sinks Fed. Unit #1	
607	25	35	5	660s	660w	Fed. Mounsey "B" #1	
608	25	35	6	460n	660w	Mounsey Fed. #1	
609	25	35	7	660n	660w	Mounsey "A" Fed. #1	
610	25	35	18	660s	660w	McCormick #1	
611	25	35	20	1980n	660w	Fed. Mounsey "C" #1	
612	25	35	22	660s	660w	Elliott Fed. #1	
613	25	35	26	660s	660e	Harper Fed. #1	
614	26	29	1	660s	1980e	Continental Fed. #1	
615	26	29	2	660n	660e	St. #1	
617	26	29	6	660s	660w	Ashland Fed. #1	
618	26	29	11	660s	660e	Hanson "A" #1	
620	26	29	13	1980s	1980w	Gulf Fed. #1	
621	26	29	13	1980s	660w	Gulf Fed. "B" #5	
624	26	29	14	660n	660w	Booth Fed. #1	
627	26	29	19	300n	2096e	Baker Fed. No. 1	
628	26	29	22	1980s	1980w	Ashland Fed. #1	
629	26	29	23	660s	660w	Fed. Boothe E #1	
630	26	29	24	660n	1980e	Gulf-Fed.-Beatty #2	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
631	26	29	24	660n	660w	Gulf-Beatty No. 1	
637	26	29	34	949n	1660e	Fed. Littlefield "BO" #1	?= #1590 (F34) in Appendix A
638	26	30	2	660s	660w	Sinclair St. No. 1-2	
639	26	30	3	660s	660w	Scott Fed. #1	
640	26	30	4	660n	660w	Fed. K.W. No. 1	
642	26	30	6	660s	660w	No. 1 Brunson Fed.	
643	26	30	12	660s	660e	Monteray Blaydes #1	
644	26	30	16	660s	660e	St. #1	
645	26	30	18	660s	660w	#1 AT Fed.	
647	26	30	20	2310n	330w	U.S.A. #1	
648	26	30	24	1980n	1980w	#1-24 Strat Test	
652	19	31	2	330n	2310e	St. No. 2	
653	19	31	3	2310s	1980e	Hanson Fed. No. 2	
654	19	31	4	660n	990e	Carper Fed. No. 1-A	
655	19	31	4	760n	1980w	South Shugart Deep Fed. Unit #1	
656	19	31	4	1650n	2310e	Carper Welch #2	
657	19	31	5	330n	330w	Pan American Fed. #1	
658	19	31	5	2310n	2310e	Pan American Fed. #1-X	
659	19	31	6	990s	330e	Hodges Fed. #1	
660	19	31	6	330n	330w	Featherstone Fed. No. 1-B	
661	19	31	9	1980s	1980e	Continental Fed. No. 1	
662	19	31	11	660s	1980w	General Energy Corp. Fed. #1	
663	19	31	11	1980n	1980w	Gulf Oil Corp. #1 Holder "CT" Fed.	
664	19	31	13	1980s	2310w	H.J. "13" Fed. Comm. #1	
665	19	31	15	1980n	660w	Robert A. Dean & Jack McCellan #1 Fed. #15	
666	19	31	16	660s	1980w	Gulf St. #1	
667	19	31	17	660n	660e	Ross-Fed. #1	
668	19	31	18	660s	660w	Holt Fed. #1	
669	19	31	19	1980s	1980e	Tidewater "FE" #2	
670	19	31	20	990s	2310w	Sun Fed. #1	
671	19	31	20	660n	1980w	English Fed. #2	
672	19	31	20	330s	1980e	English Fed. #1	
673	19	31	20	1980s	990w	Sun-Fed. #2	
674	19	31	21	330s	330w	Tenneco #2-21	
675	19	31	23	1980n	660e	Jones Fed. #1	
676	19	31	23	1980n	1980w	Jones Fed. No. 2	
677	19	31	28	330n	330w	Tenneco-Fed. #1	
678	19	31	29	2310s	2310w	Barbera Fed. #1	
679	19	31	29	660n	1980e	CEM Oil Co. Fed. #1	
680	19	31	30	1980n	330w	Southern Fed. No. 6	
681	19	31	30	990s	330w	Southern Fed. No. 7	
682	19	31	30	1980n	667e	#2-Y Southern Union	
683	19	31	31	330n	330w	Brook & Adams Fed. No. 1	
684	19	31	32	330n	660e	Machris St. #1	
685	22	29	6	660s	660e	#1 Eddy Fed.	
689	25	32	3	1650s	1980e	Cotton Draw Unit No. 49	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
690	25	32	9	1650s	330e	Cotton Draw Unit No. 52	
691	25	32	10	2145n	2310e	Cotton Draw Unit No. 60	
692	25	32	11	660s	1980e	Continental Fed. #1	
693	25	32	14	2310n	330w	Ora Hall Fed. 14 #1	
694	25	32	15	660s	1980w	G.E. Jordan Fed. No. 4	
695	25	32	15	660n	1980w	G.L. Jordan #3	
696	25	32	15	455n	1980w	Cotton Draw Unit No. 75	
697	25	32	16	1980n	1980e	St. Z 16 #1	
698	25	32	18	660n	1650w	Cotton Draw Unit #64	
699	25	32	20	1650s	330e	Cotton Draw Unit #42	
700	25	32	20	330s	330e	Perry Fed. #43	
701	25	32	21	990s	990e	Cotton Draw Unit #57	
702	25	32	22	2310s	330w	Cotton Draw Unit No. 48	
703	25	32	23	660n	1980e	Fed. "P" #1	
704	25	32	27	330n	330w	Cotton Draw Unit No. 61	
705	25	32	28	2310s	990w	J.D. Sena Jr.	
706	25	32	28	2310s	1650w	J.D. Sena U.S.A. No. 1	
707	25	32	29	1980n	330e	Cotton Draw Unit No. 58	
708	25	32	29	330n	330e	Cotton Draw Unit No. 55	
709	25	32	31	1980n	660w	Ray Smith #1	
710	25	32	32	1980n	1980w	Conoco St. No. 1	
711	25	32	33	660s	660w	Hall-Fed. "33" #1	
712	25	32	33	1980s	560e	Jennings #1	
713	25	32	33	660s	1980e	Jennings #3	
714	25	32	34	660n	660w	Fed. Sunshine Royalty #1	
715	25	32	34	660n	660e	Sunshine Royalties #1	
716	25	33	1	660n	660w	Fed.-Muse #1	
717	25	33	5	660n	660e	Bass Fed. #1	
718	25	33	8	1980s	660e	Annie Bass Fed. #1	
719	25	33	11	660n	660w	Muse Fed. #1	
720	25	33	13	980s	660e	Fed. "BK" #1	
721	25	33	15	1980n	1980e	Ochoa Fed. No. 1	
722	25	33	18	660n	660w	#1 Bass Fed.	tops Tamarisk, Mag wrong
723	25	33	19	1980s	660w	Fed. #1-19	
724	25	33	20	660n	1980e	Fed. Bass #1	
725	25	33	21	660n	660e	Fed. Marshall No. 1	
726	25	33	23	660s	660w	Muse-Fed. 23 #1	
727	25	33	24	660s	660w	Perry Fed. #1	
728	25	33	25	660s	660e	Fed. No. 1-25	
729	25	33	27	660s	660e	Harry Dickson #1	
730	25	33	28	660s	660e	Annie R. Bass Fed. #1	
731	25	33	28	660n	660e	Conley Fed. #1	
732	25	33	29	1980n	660w	W.H. Jennings Inc. U.S.A. No. 1	
733	25	33	31	660s	660w	Richardson & Bass USA #1	
734	25	33	32	1980s	660e	Continental St. No. 1	
735	25	33	36	660n	660w	St. #1-36	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
736	25	34	2	660s	1980w	Southeast Bell Unit #1	
737	25	34	5	660n	660w	Bass Fed. #1	
738	25	34	8	660s	660e	Fed.-Muse #1	
739	25	34	10	660s	660w	Mildred Smith #1	
740	25	34	14	990s	1980e	Mildred Smith #1	
741	25	34	19	660s	1980e	No. 1-19 Fed.	
742	25	34	21	1980s	1980w	Ethel Nolen Fed. #1	
743	25	34	27	1980n	660e	Conoco Fed. #1	
744	25	34	31	660n	660e	Continental Fed. No. 1	
745	25	34	35	1980s	1980e	Olson Fed. No. 1	
746	25	34	36	660n	1980w	New Mexico St. #1	
747	26	32	1	1980s	660e	8105 JV-P Mesa #1	
748	26	32	1	660s	660w	Richardson-Fed. #1	
749	26	32	4	1980n	2310w	Sun Fed. "4" #1	
750	26	32	5	330s	2310e	Sun Fed. No. 1	
751	26	32	5	660n	1980w	Conoco Bradley #1	
753	26	32	7	990n	660e	N.C. Higgins Fed. #2	
754	26	32	7	660s	1980w	Continental Fed. #1	
755	26	32	8	1980s	660w	#1 N.C. Higgins Fed.	
756	26	32	15	1980s	660e	Ben Fed. #1	
757	26	32	16	1980s	1980w	Ohio St. No. 1	
759	26	32	18	1980n	660e	Thompson Fed. 18 No. 5	
760	26	32	18	1650s	1980w	#4-18 Thompson Fed.	
761	26	32	21	660s	660e	Fed. Payne No. 1	
762	26	32	24	330s	1650e	Fed.-Littlefield DR #1	
763	26	32	25	990n	990w	Wilder #23	
764	25	32	25	660s	1980w	Wilder 25-2	
765	26	32	26	1980n	1980e	Wilder #25	
766	26	32	30	660s	1980e	Russell Fed. 30 #1	
767	26	32	31	760n	2002w	Russell #1	
768	26	32	35	490s	330e	E. Payne 35 Fed. #1	
769	26	32	35	660n	660w	Bradley 35 #2	
770	26	33	1	660n	660e	Continental Fed. #1	
771	26	33	2	660n	1980w	Texaco St. "2" #1	
772	26	33	4	660s	660e	G.W. Miller Fed. NCT-1 No. 1	
773	26	33	6	1750s	1750e	Jones Fed. #1	
774	26	33	8	660s	660e	Miller-Fed. #1	
775	26	33	10	1980s	1980w	Goedeke Fed. No. 1	
776	26	33	10	2310n	2310w	Malcom R. Madera No. B-1	
777	26	33	13	660s	660e	Bradley 13 #1	
778	26	33	15	660n	1710e	Conoco Fed. #2	
779	26	33	15	660n	1980w	Fed. No. 1	
780	26	33	17	660s	660w	Fed. Littlefield DP Optional #1	
781	26	33	19	660s	660w	Fed. Littlefield "DO" #1	
782	26	33	21	1980s	660w	Continental Fed. #1	
783	26	33	22	660n	660w	Madera Fed. #1	

FFG No.	Location Data T.	R.	Sec.	Distance from section line*		Drillhole Name**	Revision
784	26	33	23	660s	1980w	Humble Madera #1	
785	26	33	25	660n	1980w	Elliott Fed. #1	
786	26	33	26	660s	1980e	Fed. Hall #1	
787	26	33	27	1980s	660w	Dixon 27 #1	
788	26	33	29	1880n	660e	Gulf Fed. Littlefield #1	
789	26	33	30	1980s	660w	Payne #3	
790	26	33	31	660n	660w	Payne #7	
791	26	34	2	330s	330e	Lea St. "JV" #1	
792	26	34	3	660n	1980w	Gulf Yates Fed. #1	
793	26	34	4	660s	660w	Yates Fed. #1-4	
794	26	34	6	1980s	660w	Fed. K #1	
795	26	34	9	660s	660e	Yates Fed. No. 1	
796	26	34	18	660n	660e	Continental-Fed. #1	
797	26	34	18	1980s	1996w	Pogo No. 1 Fed. 18	
798	26	34	19	660n	660w	Bradley 19 #1	
799	26	34	20	660n	660e	Leonard Fed. No. 1	
800	26	34	22	660n	1980e	Fed. "CH" #1	
801	26	34	26	660n	660e	Kirklin Drilling Hondo Fed. #1	
802	26	34	33	660s	660e	Elliott-Fed. #1	
803	26	35	1	1650s	660w	#1 Sinclair Fed. "A"	
804	26	35	2	660s	1980w	Talco Unit #2	
805	26	35	6	1980s	1980e	Perro Grande Unit #1	
806	26	35	10	330n	660w	Sinclair et al "A" #1	
807	26	35	10	300n	300e	Sinclair Fed. "B" #1	
808	26	35	11	660s	660w	De Mooy Fed. No. 1	
809	26	35	11	330n	330e	Sinclair et al Fed. "B" #1	
810	26	35	11	1980n	660e	Talco Unit #1	
811	26	35	13	660n	660e	Fed. #1	
812	26	35	21	1980n	1980w	New Mexico Fed. "P" #1	
813	26	35	22	1980s	1980w	Byers Fed. No. 1	
814	26	35	25	1980n	1980w	Sinclair et al "C" #1	
815	26	35	27	660n	660e	Fed. Boothe "BD" #1	
817	26	32	3	660n	660w	Fed. Boothe "BD" #1	

* The distances for the borehole locations are measured in feet from north, south, west, or east for the section (square mile) as noted by n, s, w, or e.

* Some consistent abbreviations have been used to shorten names.

The location data for this table was taken from Table 2 of Richey (1989). The FFG number is used to cross-refer to other data tables based on the work of Richey.

APPENDIX B-2

TABLE OF RUSTLER FORMATION DATA FROM RICHEY (1989)

Table of Rustler Formation Data From Richey (1989)

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	uim	Salado salt	Revisions
001	1083.0	396.8					507.5	
002	1090.3	404.2	422.8	429.8	465.5	472.2	511.5	
004	1068.3	329.2	350.5	357.5	401.7	408.4	440.4	
005	1089.7	395.9	414.8	421.8	461.2	467.6	507.8	
006	1091.5	402.6	421.5	430.1	474.9	483.4		
007	1093.9	415.7	438.0	444.1	491.9	500.2	534.9	
008	1099.1	424.3			499.9	506.9	540.1	
009	1094.8	416.7	437.4	444.7	490.7	498.3	519.7	
010	1096.4	418.5			493.2	500.8	536.4	
011	1092.7	408.1	428.5	435.6	482.8	489.2	522.4	
012	1092.1	405.1	424.3	432.5	478.2	485.9	520.0	
013	1080.2	383.4	405.4	412.4	434.0	445.9	497.7	
014	1068.6	326.7	347.5	355.1	400.8	409.7	445.6	
015	1082.0	342.6	363.6	370.3				
016	1099.7	432.8	454.8	462.1	511.8	520.3	554.7	
017	1100.9	431.3	452.6	460.2	506.0	513.6	545.6	
018	1116.5	444.1	464.2	470.6	517.9	525.8	558.1	
019	1111.0	444.7	466.3	473.4	522.4	530.7	562.1	
020	1091.5	350.8	373.1	379.2	429.5	436.2	469.1	
021	1096.4	361.5	385.3	392.6			481.9	
022	1106.7	384.6	412.0	419.6			495.2	
023	1109.8	431.3	455.7	462.4	513.6	522.1	556.3	
024	1124.6	462.6	485.8	492.5	545.5	552.8	585.4	
025	1117.6	443.5	465.4	471.5	519.1	525.8	557.2	
026	1116.0	445.2	466.5	472.6	523.5	530.5	563.4	
027	1117.4	453.2	474.3	481.0	531.9	538.9	571.8	
028	1183.9	554.1	571.2	576.4	605.3	611.4	634.3	
029	1145.4	529.4	546.2	551.4	581.9	587.3	607.5	
030	1154.3	537.7	556.0	561.4	591.3	597.1	621.5	
031	1168.3	558.7	578.2	584.3	613.9	620.9	645.9	
032	1158.5	546.6	566.4	572.5	609.1	612.4	639.5	
033	1143.6	536.4	555.3	560.8	594.4	601.4	624.8	
034	1139.3	538.0	556.9	561.4	590.7	596.8	621.5	
035	1121.1	530.8	548.5	554.6	587.2	590.2	616.2	
036	1147.6	545.0	565.4	570.9	606.2	612.0	637.3	
037	1129.3	536.4	557.5	562.4	595.3	600.5	626.4	
038	1118.3	538.9	558.7	564.2	594.7	600.8	626.4	
039	1046.1	247.5	267.3	274.0	314.2	320.6	351.7	
040	1077.2	336.5	356.3	363.6	421.8	431.9	452.3	
041	1065.3	264.3	284.7	291.7	331.6	338.9	373.4	
042	1069.5	264.0	284.1	291.7	328.9	339.5	374.3	
043	1067.1	257.1	279.0	285.1	331.4	338.4	370.1	
044	1080.5	318.2	339.5	346.9	391.4	399.6	434.9	
045	1091.8	344.4	367.3	374.9		432.2	466.3	
046	1094.2	340.2					464.2	
047	1112.8	479.4	498.9	505.3	551.7	556.8	586.7	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	nim	Salado salt	Revisions
048	1106.1	452.9	475.2	482.8	525.8	532.8	578.5	
049	1119.2	477.3	498.3	504.4	551.7	559.6	592.5	
050	1132.5	484.5	504.9	511.0	550.0	557.6	595.1	
051	1131.1	482.2	503.8	509.0	557.2	564.8	600.2	
052	1132.0	480.4	501.7	507.8	536.8	542.2	566.3	
053	1137.5	494.7	514.2	522.1	574.5	581.9	627.0	
054	1150.2	508.3	529.6	536.9	587.5	593.6	631.4	
055	1145.1	503.5	524.0	532.5	579.4	587.3	623.9	
056	1136.6	492.3	514.8	521.2	572.1	579.7	615.7	
057	1134.8	489.2	509.6	517.2	570.0	576.7	610.2	
058	1147.7	506.7	524.1	532.6	578.4	586.9	621.0	
059	1156.1	512.7	532.5	538.6	586.4	591.3	626.4	
060	1138.4	492.9	511.1	520.3	569.1	575.2	605.6	
061	1137.5	491.6	511.5	517.6	566.9	572.4	605.0	
062	1122.6	548.3	569.4	575.5	608.7	615.4	643.4	
063	1118.1	583.4	604.4	609.6	647.4	652.3	679.7	
064	1127.2	567.5	588.6	595.3	629.7	638.3	666.0	
065	1110.7	567.8	590.1	595.3	638.9	646.2	661.1	
066	1113.7	616.9	639.8	644.3	679.4	684.6	712.0	
067	1127.5	590.4	611.1	616.3	657.5	663.5	691.6	
068	1125.0	628.5	643.1	649.2	694.9	701.0	728.5	
069	1130.2	605.9	627.8	633.9	682.7	688.8	722.3	
070	1130.8	577.0	598.6	604.7	646.2	651.7	688.8	
071	1115.3	304.2	324.6	331.0	360.3	367.0	415.1	
072	1105.2	365.5	384.1	390.2	424.0	431.0	459.4	
073	1107.4	389.6	407.9	416.8	448.1	455.2	484.1	
074	1107.0	383.3	403.7	408.6	440.6	446.7	476.3	
075	1108.3	335.0	352.3	359.1	390.4	396.2	424.9	
076	1097.3	260.9	279.2	286.8	319.7	325.8	355.4	
077	1095.8						323.7	
078	1087.2	212.8	232.0	240.2	272.5	279.5	310.3	
079	1091.2	243.2	261.5	267.6	304.2	310.3	340.8	
080	1082.3	254.8	274.0	281.9	316.7	324.0	354.8	
081	1097.0	350.2	369.1	376.1	413.9	422.1	452.6	
082	1084.8	305.7	325.5	331.6	373.7	379.5	411.8	
083	1115.6	422.6	440.9	447.0	477.5	483.6	511.0	
084	1107.6	386.5	405.4	413.0	446.2	452.9	481.6	
085	1108.9	394.7	413.3	421.5	453.5	459.9	488.0	
086	1107.3	384.7	401.7	410.0	442.3	449.9	477.0	
087	1107.3	409.3	427.3	435.9	470.6	477.3	506.0	
088	1108.9	414.5	434.3	441.7	482.8	486.2	513.6	
089	1108.6	432.8	452.6	459.0	494.7	502.0	531.9	
090	1094.5	394.7					494.1	
091	1091.2	371.2	390.8	398.4	438.9	447.4	477.0	
092	1097.6	362.7	381.0	391.1	426.7	435.3	463.9	
093	1097.9	360.6	379.8	387.7	424.3	429.8	460.2	
094	1095.1	354.5	374.9	381.9	420.9	428.5	458.1	
095	1138.7	432.2	449.9	457.2	487.1	493.5	520.0	
096	1174.4	484.9	503.2	509.3	538.9	545.0	569.4	
097	1149.4	478.2	497.7	504.4	534.6	541.0	568.8	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
098	1208.2	562.7	582.8	588.3	620.3	626.4	652.3	
099	1205.8	564.2	584.9	590.4	623.3	631.2	655.6	
100	1153.1	528.2	549.2	555.0	588.3	594.4	622.7	
101	1142.7	549.6	567.8	573.3	609.0	615.4	642.5	
102	1127.2	513.3	533.7	539.8	578.2	584.3	614.8	
103	1108.6	434.0	453.2	456.6	499.3	506.9		
104	1127.5	555.0	576.4	582.5	619.4	625.4	653.2	
105	995.2	68.3	85.6	93.9	127.7	133.8	182.3	
106	981.5	26.8	41.8	49.7	78.9	86.9	140.8	
107	987.6	42.4	64.6	70.7	99.7	108.8	151.5	
108	1015.9	82.3	97.5	103.6	137.2	146.3	179.8	
109	1039.1	121.9	140.2	146.3	176.8	182.9	207.3	
110	1045.5	158.5	179.8	185.9	213.4	221.0	246.9	
111	1062.2	165.5	190.5	195.1	225.6	231.6	256.0	
112	1056.1	176.8	195.1	201.2	231.6	239.3	271.3	
113	1054.9	161.5	179.8	185.9	216.4	224.0	252.7	
114	1014.7	90.5	109.1	116.4	144.2	151.5	185.9	
115	970.5	56.7	75.0	81.1	113.1	122.2	167.0	
116	972.0	42.7	61.0	67.1	100.6	106.7	176.8	
117	966.2	30.5	54.9	64.0	97.5	109.7	155.4	
118	968.7						124.1	
119	950.1	12.2			79.2	85.3	121.9	
120	956.5	12.2	33.5	42.7	82.3	91.4	137.2	
121	958.6	12.2	30.5	36.6	76.2	85.3	128.0	
122	954.0	9.1	27.4	33.5	77.7	85.3	140.2	
123	961.6	33.5	61.0	67.1	94.5	100.6	146.3	
124	977.2	76.8	111.9	119.5	139.3	146.3	191.7	
125	976.2	64.0	85.3	93.0	125.0	134.1		
126	1014.2	109.7	128.0	134.1	161.5	167.6	201.2	
127	1019.2	109.7	128.0	134.1	158.5	167.6	195.1	
128	994.3	46.3	67.7	76.8	107.3	116.7	141.7	
129	961.9	38.1	62.5	68.6	103.6	109.7	146.3	
130	979.9	25.9	50.3	59.4	82.3	91.4	125.0	
132	1002.2	45.7	67.1	73.2	103.6	111.3	149.4	
133	993.0	33.5	54.9	61.0	91.4	97.5	155.4	
134	988.2	24.4	44.2	52.7	83.8	91.4	126.5	
135	1002.5	65.2	85.0	91.7	121.6	127.4	158.5	
136	1007.5	73.2	88.4	96.0	125.0	131.1	163.1	
137	1007.4	60.6	79.5	88.1	114.6	122.8	154.2	
138	1023.9	126.5	143.3	149.4	179.8	189.0	225.6	
139	1023.5	115.8	133.8	141.1	167.9	175.6	213.4	
140	1042.6	193.5	213.4	219.5	249.9	257.6	292.6	
141	1030.4	157.3	176.2	184.7	210.3	217.9	247.5	
142	1042.8	193.5	213.4	221.0	246.9	254.5	285.0	
143	1052.7	196.9	213.4	221.0	248.7	255.4		
144	905.0	1.5			10.7	21.3	79.9	
145	905.3	0.0			12.2	18.3	74.7	
146	912.9	0.0			6.1	15.2	86.9	
147	908.3	10.4	10.4	14.6	25.6	32.9	92.0	
148	907.7	0.0			7.6	12.8	75.6	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
149	916.5	4.3			5.8	13.4	74.4	
150	903.7	1.5					79.2	
151	901.6	10.7			12.2	21.3	79.2	
152	905.3	12.2					68.6	
153	917.1	0.0				15.2	88.4	
154	933.3	8.2					95.7	
155	918.1	4.0	4.0	12.5	16.8	24.1	87.2	
156	908.3	1.8			1.8	12.8	70.7	
157	926.0	10.7	10.7	18.9	21.9	27.4		
158	941.8	4.6	4.6	10.7	13.7	23.8	85.0	
159	1001.3	45.1	64.6	72.5	102.7	109.7	141.7	
160	1002.5	52.4	72.8	78.3	107.3	116.4	146.9	
161	987.9	30.5	51.8	57.9	86.9	93.0	131.1	
162	988.8	32.9	55.5	63.4	96.9	104.2	131.1	
163	988.8	33.5	54.9	61.0	91.4	100.6	132.6	
164	955.9	0.0			18.3	27.4	101.2	
165	935.7	0.0			22.9	33.5	96.9	
166	993.0	38.7	57.0	64.6	93.0	101.2	134.7	
167	1019.6	82.9	97.5	105.2	132.6	141.7	182.9	
168	1001.0	33.5	56.4	67.1	94.5	102.1	157.9	
169	986.0	5.8	28.7	36.9	66.8	76.8	124.7	
170	934.8	1.2	11.9	18.0	31.1	41.8	95.7	
171	956.8	25.3	25.3	32.6	34.7	47.5	108.8	
172	986.0	48.8	48.8	53.0	70.7	79.9	134.1	
173	1022.6	87.8	108.5	116.1	145.7	154.8	191.1	
174	908.6	2.1						
175	937.0	116.4					175.3	
176	927.5	59.4					135.0	
177	913.2	24.1			24.1	33.2	100.6	
178	888.2	170.1			170.1	176.8	349.0	
179	896.4	9.8			9.8	21.3	79.6	
180	1062.2	118.3	141.7	147.2	179.2	187.5	237.1	
181	1016.5	65.2	65.2	69.8	86.0	93.6	147.5	
182	986.0	129.5	138.4	143.6	173.4	181.7	228.9	
183	1020.5	81.4			116.1	127.1	183.2	
184	1047.9	120.1	120.1	123.1	156.7	164.3	196.3	
185	1022.6	88.1	88.1	92.7	123.1	130.8	182.6	
186	1013.5	149.7	149.7	155.8	185.6	194.2	247.2	
187	965.6						275.5	
188	979.0	104.9	104.9	110.0	133.2	141.4	197.8	
189	1046.1	123.4	143.9	151.8	178.3	186.5	241.1	
190	1037.8	136.2	155.4	163.1	194.2	202.7	244.4	
191	1041.5	140.2	163.4	171.0	196.0	202.1	261.5	
192	1031.4	196.9	216.1	224.9	256.9	267.0	323.4	
193	994.0	247.8			247.8	262.1	324.6	
194	1075.4	235.7	253.3	259.8	286.9	294.8	336.6	
195	1059.2	203.9	225.2	230.4	255.7	266.4	305.7	
196	1042.4	144.8	165.5	172.5	205.4	214.9	249.9	
197	1034.5	135.0	156.4	163.7	193.5	203.3	244.4	
198	1031.4	133.2	153.9	160.0	190.5	199.6	247.5	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	uim	Salado salt	Revisions
199	1038.8	150.0	171.3	178.9	211.8	220.1	258.2	
200	1040.9	138.4	160.0	167.9	202.7	212.8	255.7	
201	1074.1	179.5	200.9	208.5	235.9	244.1	295.4	
202	1075.6	241.4	259.1	267.3	301.8	312.4	352.0	
203	1071.4	230.1	248.4	255.7	295.4	303.9	343.8	
204	1096.4	231.6	249.9	258.5	282.9	291.1	329.2	
205	1082.0	201.4	221.5	228.8	256.9	265.4	313.5	
206	1067.7	171.9	193.2	200.3	230.7	239.6	288.3	
207	1072.6	180.4	200.3	207.6	239.0	246.6	296.9	
208	1060.1	157.3	178.0	185.9	217.0	225.6	279.8	
209	1074.1	200.9	200.9	207.9	235.9	244.4	286.8	
210	1066.2	180.4	200.3	207.3	238.7	247.5	300.2	
211	1060.4	174.3					283.5	
212	1078.4	207.9	225.6	233.2	260.9	269.4	310.0	
213	1051.6	148.1	177.1	183.2	213.7	222.8	256.3	
214	1061.6	183.8	206.7	213.4	243.2	253.0	303.9	
215	1041.8	189.3	210.6	218.2	248.7	256.9	307.2	
216	993.6	256.6	276.8	283.2	304.8	310.9	473.0	
217	1057.7	184.1	206.3	214.0	242.9	252.1	301.4	
218	1053.1	189.6	209.1	217.3	249.6	258.8	309.1	dup FFG 602; deleted 602
219	1036.3	125.9	146.6	156.4	187.5	196.0	253.0	
220	1051.0	191.1	214.3	218.8	252.4	261.5	308.8	
221	1027.8	213.4	231.6	240.8	271.3	283.5	342.9	
222	1019.9	249.3	270.1	278.3	306.6	314.9	415.4	
223	1008.9						491.0	
224	1133.6	456.6	477.9	485.5	535.8	543.5	575.5	
225	1138.3	454.6	475.9	482.0	534.8	540.3	572.0	
226	1150.3	467.1	489.3	496.3	548.5	555.5	588.4	
227	1149.4	471.2					598.9	
228	1133.6	459.9	481.9	490.4	545.3	552.9	584.3	
229	1146.0	444.4	466.6	474.0	531.3	538.9	573.9	
230	1134.5	445.9	469.4	476.4	533.4	539.5	576.1	
231	1120.1	416.1	438.3	445.9	500.2	506.3	541.9	
232	1124.1	406.3	428.5	435.9	492.6	498.3	538.0	
233	1114.7	405.4	428.9	435.9	490.7	496.8	532.8	
234	1112.8	367.0	390.1	397.8	452.6	459.3	496.5	
235	1117.1	394.7	418.5	425.8	481.6	488.6	521.2	
236	1101.2	332.8	354.8	362.7	418.5	424.0	459.3	
237	1137.8	402.5	425.7	433.0	491.6	503.4	537.0	
238	1152.8	436.2	461.8	467.3	524.3	531.3	568.5	
239	1177.1	474.0	498.0	503.8	556.6	563.6	606.6	
240	1162.2	467.0	491.0	497.7	552.3	559.6	593.4	
241	1165.3	476.4	499.0	506.3	560.2	567.2	602.6	
242	1115.0	315.2	331.9	338.3	382.8	390.8	433.7	
243	1153.7	389.9	410.6	418.2	485.3	494.4	538.6	
244	1120.0	321.6	339.2	346.9	398.7	404.8	430.7	
245	1170.7	573.6	597.7	603.8	659.9	667.2	700.1	
246	1161.9	560.2	583.4	588.9	645.9	653.8	688.8	
247	1145.4	556.3	581.6	587.4	644.1	651.7	685.3	
248	1150.0	555.3	578.8	584.0	643.4	651.7	685.5	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
249	1169.2	575.5	599.5	605.0	663.9	670.9	705.0	
250	1159.8	485.7	508.3	515.3	572.3	579.3	614.3	
251	1139.0	570.3	594.1	600.5	661.7	669.0	706.8	
252	1134.1	425.5	450.2	456.3	514.5	521.5	566.6	
253	1108.6	448.1	469.4	476.1	541.9	547.1	586.7	
254	1111.6	460.6	481.6	487.7	549.6	556.9	593.8	
255	1122.6	512.7	534.9	542.5	608.1	616.3	655.3	
256	1136.0	578.2	600.8	606.2	658.1	665.1	697.1	
257	1137.2	536.8	557.8	563.6	613.9	620.0	653.2	
258	1120.4	505.4	525.5	532.8	574.2	584.0	622.7	
259	1139.6	554.7	578.5	586.1	636.4	644.7	682.8	
260	1111.0	489.2	507.2	513.6	554.7	562.1	595.9	
261	1106.1	495.9	513.3	519.7	563.9	568.8	603.5	
262	1109.5				623.9	632.5	669.0	
263	1115.6	562.2	589.0	594.5	659.1	667.1	708.8	
264	1121.1	343.5	360.6	367.9	417.3	424.9	467.6	
265	1130.8	355.4	374.9	381.0	444.7	453.5	496.2	
266	1131.4	372.5	394.7	400.5	466.0	474.6	521.8	
267	1120.4	384.0	406.9	412.1	479.1	487.7	537.7	
268	1115.9	399.9	425.2	431.3	502.3	509.6	552.6	
269	1105.8	376.6	403.4	408.9	478.1	488.2	537.5	
270	1057.0	265.2	282.5	287.7	326.7	335.9	367.6	
271	1049.4	215.5	234.4	240.5	275.5	281.6	316.1	
272	1073.5	226.9	251.0	257.1	321.7	329.6	376.3	
273	1079.2	262.3	281.8	289.1	326.0	333.9	377.5	
274	1137.2	286.2	303.0	310.0	344.1	351.4	389.8	
275	1135.7	277.1	295.4	301.4	335.0	341.1	368.5	
276	1125.9	264.3	280.7	288.3	323.1	330.1	359.7	
277	1123.2	269.7	286.5	294.1	327.7	334.1	369.7	
278	1098.2	229.8	252.4	259.7	321.6	332.8	375.8	
279	1107.9	247.8	267.0	274.6	331.0	340.2	372.2	
280	1120.3	261.7	283.0	289.4	331.5	340.3	382.1	
281	1147.3	311.5	333.1	339.9	384.7	392.9	438.0	
282	1146.4	349.3					485.5	
283	1090.9	506.3	527.0	532.8	594.7	601.7	640.4	
284	1117.1	386.8	405.1	411.2	469.1	475.8	520.9	
285	1112.5	352.3	371.2	377.6	442.9	452.0	496.5	
286	1101.5	264.0	281.3	287.4	327.7	335.5	372.8	
287	1094.6	282.6	301.5	308.5	356.4	361.3	401.5	
288	1110.4	344.7	365.5	371.6	441.7	447.8	493.5	
289	1081.9	345.6	362.0	368.1	401.3	408.0	442.8	
290	1103.4	277.7	296.9	303.9	332.5	342.6	370.0	
291	1132.0	365.8	389.5	395.3	463.3	471.2	516.9	
292	1090.6	316.4	332.2	338.3	365.8	372.8	403.9	
293	1085.1	319.1	334.4	340.5	367.0	374.6	412.7	
294	1095.5	500.2	522.7	528.5	591.0	598.0	637.3	
295	1087.5	504.7	527.3	532.8	598.0	607.5	648.6	
296	1106.4	513.9					661.7	
297	1104.9	537.4	565.7	572.4	635.8	649.5	684.6	
298	1070.0	500.8	517.6	523.3	541.9	549.6	580.0	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
299	1078.4	484.0	509.3	514.2	580.6	588.6	637.0	
300	1062.2	518.5	541.6	546.8	581.6	589.2	645.3	
301	1046.4	531.6	555.3	560.8	610.5	616.0	687.0	
302	1092.7	550.2	574.2	578.5	649.2	655.9	672.4	
303	1099.3	563.4	588.1	594.2	650.3	657.3	694.5	
304	1088.1	547.7	570.6	575.2	642.2	649.2	688.8	
305	1093.9	559.3	584.6	590.7	650.7	659.3	694.3	
306	1075.9	583.7	606.6	610.8	662.9	670.6	714.5	
307	1078.7	560.8	585.2	590.7	646.5	654.4	694.9	
308	1075.9	584.6	610.2	615.4	699.8	708.1	752.9	
309	1093.6	558.4	585.5	590.4	659.0	665.7	705.0	
310	1087.5	523.3	548.3	552.9	612.3	618.4	657.5	
311	1085.4	586.7	598.9	604.4	656.8	665.1	698.0	
312	1076.9	539.5	566.3	572.4	647.1	652.9	692.8	
313	1106.1	171.8	191.0	198.0	235.8	244.1	273.9	
314	1121.1	258.8	278.0	285.0	332.2	339.5	386.2	
315	1131.1	348.2	366.8	372.6	429.6	436.9	480.2	
316	1133.2	361.8	385.3	391.1	454.8	463.0	509.0	
317	1097.6	305.4	320.6	324.9	365.2	372.5	404.5	
318	1123.5	365.5	381.3	388.9	413.3	420.9	457.5	
319	1120.7	351.4	369.1	374.9	416.1	424.3	458.7	
320	1129.6	367.3	388.3	394.1	460.2	467.6	513.6	
321	1124.7	364.2	386.8	392.6	456.3	463.0	511.8	
322	1124.7	369.6	391.5	397.3	454.9	462.5	507.9	
323	1120.4	369.3	390.9	397.0	445.2	452.5	493.6	
324	1122.0	360.3	376.7	384.0	422.5	429.8	468.8	
325	1079.9	260.3	279.5	286.5	317.6	326.7	366.4	
326	1117.7	363.3	381.6	388.6	411.2	419.7	460.2	
327	1102.2	353.9	373.1	378.6	412.4	420.3	456.9	
328	1121.4	364.4	386.9	392.7	447.6	456.7	500.9	
329	1120.4	364.8	386.5	392.0	451.4	459.0	507.2	
330	1115.6	360.7	382.4	387.6	446.1	454.6	504.0	
331	1103.7	350.2	375.2	381.0	450.8	456.9	501.1	
332	1124.7	380.7	405.4	410.9	485.2	491.9	537.7	
333	1130.5	384.2	407.7	413.2	479.9	487.5	531.7	
334	1125.9	382.8	407.8	413.3	481.0	488.9	536.8	
335	1129.6	372.5	395.9	404.8	466.3	474.6	521.8	
336	1124.1	369.7	393.5	399.0	466.0	473.7	520.9	
337	1124.4	385.9	410.6	416.4	482.5	490.1	539.8	
338	1123.5	378.7	402.8	408.3	476.6	484.5	533.9	
339	1107.9	396.8	423.1	427.6	496.2	503.8	554.1	
340	1107.0	385.6	413.0	418.2	489.2	497.7	547.1	
341	1025.0	523.3					623.3	
342	1056.1	308.5	329.2	335.9	373.4	379.8	404.5	
343	1032.1	732.1						
344	1040.6	327.2	347.9	355.5	381.5	389.7	418.0	
345	1073.2	297.7	321.1	326.6	394.6	401.9	444.6	
346	1076.9	328.1	354.6	360.1			482.0	
347	1039.7	273.7	295.0	303.0	340.2	346.9	384.4	
348	1035.7	244.8	262.4	267.6	297.2	302.7	349.6	

FFG No.	Reference Elevation	Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
		Depths (meters) to Top of Units						
349	1034.8	270.6	292.6	296.8	320.3	325.5	356.0	
350	1041.5	232.6	252.4	258.5	296.3	301.8	329.2	
351	1102.8	370.6	397.2	401.7	473.4	481.6	531.3	
352	1103.1	371.6	397.5	403.6	473.7	481.3	530.0	
353	1095.8	344.1	369.1	374.6	444.7	451.7	497.4	
354	1051.0	233.2	250.2	255.7	289.0	295.0	328.6	
355	1027.2	32.3						
356	1008.9	45.1					120.4	
357	1011.9	54.3						
358	988.6	25.1						
359	985.4	41.1					144.8	
360	1008.9							
361	1012.5	1.5	25.6	29.9	57.3	64.0	106.7	
362	1010.7	54.3			91.4	99.7	169.2	
363	1009.5	36.6			62.5	71.6	128.0	
364	993.6	50.9			75.3	83.8		
365	1003.4	60.0						
366	1010.4	50.0	69.8	76.5	98.8	106.4	146.6	
367	1006.4	30.5	51.8	57.9	74.7	83.8	129.5	
368	1012.5	-0.3						
369	1012.1							
370	1012.9	0.0			44.2	50.3	93.6	
371	1012.9	0.0	15.2	18.3	47.2	54.3	93.0	
372	1006.4				57.3	64.9		
373	998.1	53.1			89.1	96.1		
374	995.2	48.8	54.3	65.5	86.9	93.0	140.2	
375	994.3	76.2						
376	1010.4	25.6			62.8	70.7	114.0	
377	996.7	118.0					225.2	
378	986.6	72.2						
379	986.0	89.0						
380	989.4	80.6					210.8	
381	1021.4	0.0			106.7	112.8	146.3	
382	1034.8	60.7						
383	1046.1	90.8	107.3	114.9	137.8	143.9	178.9	
384	976.0		30.2	38.1	54.9	63.7		
385	990.6	68.6			74.7	83.8	134.1	
386	961.9	58.2					153.3	
387	1019.9	53.3	79.6	85.3	108.8	118.3	157.9	
388	1019.6	60.4	82.9	90.2	118.9	125.9		
389	1008.0	31.4			83.2	90.5		
390	1022.6	48.2	68.6	77.1	103.0	109.1	159.1	
391	1025.3	51.8	73.8	80.8	106.1	112.2	157.0	
392	1019.6	51.8	71.0	77.7	109.1	115.2	156.4	
393	1061.6	226.0	245.5	251.0	276.0	280.6	308.9	
394	1050.3	124.4	141.7	147.2	167.9	173.1	203.6	
395	1059.2	140.8	157.6	163.4	184.7	191.7	217.0	
396	1090.0	188.4	205.7	212.8	236.2	242.9	302.7	
397	1036.9	254.8	285.0	290.2	338.3	358.1		
398	1011.6	185.9	206.0	213.1	239.9	244.4		

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
399	1001.6	163.1			216.4	221.0		
400	980.5	74.1						
401	972.3	97.5			132.6	138.7		
402	1023.1	20.6	43.7	51.1	76.0	86.4		
403	995.2	32.2	53.8	59.9	80.6	91.9	148.3	
404	976.6	50.9	75.0	79.2	103.3	109.4		
405	970.2	62.2					144.5	
406	968.4	0.0						
407	969.9	11.6	29.9	37.5	61.9	71.0		
408	965.0	51.8	51.8	56.4	57.9	64.0	137.2	
409	970.5				27.4	38.1		
410	950.7	94.0					223.6	
411	957.7	70.4			70.4	83.8	168.6	
412	970.2	14.9					125.3	
413	968.7	53.6			53.6	62.5	133.5	
414	965.8	47.7					157.4	
415	964.4	32.6					114.9	
416	971.1	40.8					130.8	
417	966.7	46.6					128.6	
418	1033.9	50.6			103.6	110.9		
419	1052.5	55.5	75.9	83.5	109.7	115.8		
420	1045.1	52.4	71.6	80.8	108.2	117.3		
421	1047.0	63.4	86.9	92.0	123.7	133.2	167.6	
422	1054.3	77.7	96.0	108.2	131.1	138.7		
423	1057.0	196.9					299.3	
424	1057.7	247.8						
425	1003.7	40.2					158.2	
426	996.1	34.1			69.2	76.8	139.6	
427	1042.7	94.5					166.1	
428	1048.5	110.9					205.7	
429	1044.2	63.1					160.6	
430	1007.7	44.5					198.4	
432	978.4	46.6	54.3	60.4	93.9	101.5	141.1	Surf el, top Rust wrong?
433	968.0	47.5			70.4	75.6	151.2	
434	944.6	41.1					118.2	
435	943.7	0.0					94.5	
436	943.4	42.2					120.3	
437	937.9	27.9					118.7	
438	1082.2	189.6	207.6	215.5	246.6	252.4	284.7	
439	941.2	23.8						
440	938.5	51.5					120.1	
441	938.8	32.3					120.7	
442	937.0							
443	934.2						113.7	
444	943.4	32.8					118.2	
445	960.7	40.5			40.5	49.1	133.5	
446	937.0	19.8					107.6	
447	922.3	25.0					98.8	
448	924.2	6.4					108.8	
449	931.8						112.5	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
450	925.7						106.4	
451	929.3	9.1					106.7	
452	934.2						126.8	
453	1049.5	187.3			267.2	276.6	323.0	
454	1011.8	87.2					184.7	
455	1061.3	223.7	243.8	250.9	291.1	299.9	337.4	
456	1063.4	234.4	250.9	258.2	286.8	293.5	332.5	
457	1023.5	138.4	155.4	162.2	192.3	200.9	239.0	
458	1025.8	137.6	153.2	163.5	192.5	200.7	240.3	
459	1070.5	253.9	271.0	278.6	309.1	318.2	353.3	
460	1049.7	225.6					321.0	
461	1047.6	222.2					317.9	
462	1032.1	148.0	166.3	174.6	203.5	211.4	250.8	
463	1021.1	107.6	128.0	134.7	166.7	177.4	209.7	
464	1035.4	135.0	155.4	163.1	192.0	201.8	247.8	
465	1031.4	128.6	148.4	156.1	186.5	196.3	247.5	
466	1070.5	235.6					331.6	
467	1025.7	519.5	537.5	542.4	594.8	602.7	645.4	
468	1064.7	571.2	599.2	604.7	687.0	691.6	742.5	
469	1046.4	612.3					688.5	
470	1067.1	557.5	582.2	587.0	659.0	664.5	707.1	
471	1036.6	510.8	536.1	541.6	610.5	616.0	664.2	
472	1032.4	468.2	494.1	499.6	530.7	536.8	593.1	
473	1060.7	569.1	592.5	597.1	670.3	677.0	721.2	
474	1100.6	349.9	371.2	377.3	423.1	428.9	465.7	
475	1103.7	354.0	374.8	379.9	417.4	426.0	465.9	
476	1090.1	268.3	285.1	292.7	329.9	338.4	378.7	
477	1102.8	328.3	342.0	351.1	376.1	384.0	423.1	
478	1104.8	349.2	365.1	371.2	402.2	410.8	449.5	
479	1106.4	353.9	370.0	376.4	399.6	407.5	445.3	
480	1096.1	341.7	363.6	369.7	408.1	414.8	454.5	
481	1090.9	359.1	375.2	381.9	409.3	416.4	455.7	
482	1103.4	342.0	359.1	364.8	391.7	399.6	438.0	
483	1094.2	309.1	326.4	332.8	353.0	361.5	403.3	
484	1095.6	323.4	342.0	347.5	369.7	374.9	423.4	
485	1096.5	317.1	333.9	339.7	366.2	373.5	413.7	
486	1097.6	331.3	348.1	354.2	381.6	389.2	428.9	
487	1097.0	333.1	350.5	356.6	381.6	390.1	427.6	
488	1088.6	340.6	357.4	362.0	390.3	396.1	439.7	
489	1086.6	322.0	338.2	344.3	369.3	377.8	423.5	
490	1072.6	217.0	233.8	239.9	265.8	271.3	306.9	
491	1077.5	221.6	241.1	247.2	277.7	284.4	324.9	
492	1067.4	249.9	268.8	274.9	301.8	310.3	346.9	
493	1069.2	265.6	283.9	289.4	316.8	326.0	359.5	
494	1069.5	258.2	277.4	283.5	315.5	322.5	356.3	
495	1072.3	272.9	289.3	295.1	322.5	329.2	375.9	
496	1108.3	392.9	419.7	424.0	492.3	504.1	552.9	
497	1090.6	369.1	389.5	395.0	440.7	448.4	488.9	
498	1104.9	367.9	390.8	396.5	459.3	467.3	515.7	
499	1091.5	376.1	402.0	406.9	479.1	488.3	541.6	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
500	1091.5	365.5	386.8	392.9	448.1	456.3	508.7	
501	1075.6	344.1	365.5	371.6	402.6	410.0	450.2	
502	1092.4	367.6	389.5	395.0	454.2	461.5	525.2	
503	1064.1	358.7	380.1	384.7	440.1	447.8	490.4	
504	1070.5	346.9	364.5	370.6	396.2	402.9	451.7	
505	1077.8	323.1	338.3	343.5	375.5	381.6	427.3	
506	1069.8	320.6	338.9	344.4	369.7	379.2	420.3	
507	1051.9	339.1	359.5	363.5	444.9	452.5	502.8	
508	1051.9	288.6	307.8	313.3	363.0	371.2	423.1	
509	1066.5	298.7	321.3	327.4	398.4	404.2	450.2	
510	1080.5	313.2	335.7	341.8	410.4	421.7	465.3	
511	1102.8	374.6	400.5	406.3	473.7	483.4	532.2	
512	1073.5	325.2	352.7	358.7	429.8	438.9	496.8	
513	1061.0	298.0	320.3	326.1	394.0	401.7	455.0	
514	1060.1	305.4	328.9	334.1	414.2	423.1	482.8	
515	1082.3	359.7	384.4	389.5	465.1	471.5	526.1	
516	1075.0	359.1	383.7	389.5	462.4	473.4	529.1	
517	1053.1	243.8	264.3	269.4	297.8	302.4	320.6	
518	1036.3	238.4	258.2	264.3	294.1	300.5	316.1	
519	1033.9	268.2	290.2	293.8	329.8	337.4	374.0	
520	1030.8	377.8	395.4	399.1	439.9	445.4	488.1	
521	1028.7	355.4	373.7	378.3	395.6	400.5	424.0	
522	1055.2	523.5	550.9	555.5	621.0	627.7	672.8	
523	1041.8	500.5	524.9	532.5	592.5	598.6	652.9	
524	1024.1	331.0	349.0	353.3	408.1	416.7	462.4	
525	1047.0	503.7	533.3	538.5	603.1	610.4	658.6	
526	1033.9	60.4			83.2	90.8	122.8	
527	1031.7	72.8	93.0	98.1	137.5	143.6	160.6	
528	1023.5	71.9	89.3	97.5	127.4	132.0	159.4	
529	1022.3	36.3						
530	1016.5	16.2			50.6	58.8	86.3	
531	998.2	78.9			103.3	109.4	143.0	
532	990.3	74.7		83.2	110.6	117.3	151.8	
533	994.3	65.5					138.7	
534	1021.1	74.7			128.3	137.8		
535	995.9	56.2	76.0	83.1	113.8	120.2	145.5	
536	996.1	67.7			103.6	111.6	142.6	
537	985.4	80.8			105.5	112.8	144.8	
538	1017.1	73.2						
539	1019.6	86.0					182.6	
540	1028.1	79.6					178.9	
541	1047.0	103.3					189.9	
542	1011.9	104.9					204.5	
543	997.9	27.0			65.7	71.2		
544	999.7	19.7					101.3	
545	1013.8	12.8						
546	1013.5	30.2	33.2	37.8	59.1	66.8		
547	1000.0	27.4					118.9	
548	1047.3	116.7	133.2	139.6	164.0	170.1		
549	909.8	37.5				55.8	110.0	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
550	889.1	35.4					99.1	
552	922.9	190.2			190.2	200.9		
556	908.9	60.4			60.4	75.6		
559	902.3	0.0			102.7	108.8	171.3	
561	1002.2							
562	981.5	310.9	329.2	336.2	359.7	367.0		
563	969.9	387.4	405.1	412.4	432.5	441.7		
564	969.3	306.3					411.5	
565	984.2	302.5	317.3	321.3	337.4	341.1	389.2	Rustler 302.5, not 332.5
566	971.3	277.4	292.0	317.0	336.8	342.9	393.2	
568	957.1	322.5			325.2	331.3		
569	952.2	263.0	281.6	289.0	319.4	328.0		
570	945.8	387.7				415.1		
572	995.2	252.4			252.4		320.0	
575	966.2	333.1						
577	972.9	203.1						
580	979.6	164.9					244.1	
582	981.8	271.6					356.9	
583	998.2	275.2					377.3	
584	1006.8	233.6	239.1	242.5	264.1	270.2	315.9	
585	1025.0	294.1			338.3	346.6	381.6	
586	1020.2	376.7					465.7	
589	975.4	192.5					280.3	
593	968.0	181.9					261.4	
594	989.7	253.0						
595	999.1	328.6						
596	1004.9	352.1						
599	942.4	247.7					298.9	
600	1003.4	274.3	275.8	281.3	303.3	310.9		
601	983.9	338.3	360.9	368.2	403.9	411.2		
602								Data dropped; Same as FFG218
606	1012.9	289.9	309.4	317.0	339.2	345.3	409.7	
607	1001.3	258.2	278.0	282.9	320.0	329.5	377.0	
608	1018.6	264.0	286.8	292.0	355.4	363.9	424.9	
609	1025.3	267.0	286.5	292.6	368.8	378.6	439.2	
610	1023.2	276.5	300.8	310.0	374.0	383.1	434.9	
611	1009.2	277.4	301.8	306.0	365.2	373.7	429.8	
612	977.1	243.7	261.4	264.4	298.0	307.4	352.2	
613	945.9	217.4	232.4	240.0	268.0	277.2	324.1	
614	919.0	242.3						
615	926.9	200.3					281.0	
617	881.2	18.3						
618	897.0	195.1			210.3	217.9		
620	909.9	150.1	171.4	178.7				
621	905.9	210.9						
624	907.1					71.2		
627	870.5					69.5		
628	881.5	13.3						
629	881.8	51.2					128.6	
630	912.6	56.7						

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
631	903.1	44.7						
637	878.4							Location in question
638	975.4	383.7	402.3	408.1	438.6	445.3		
639	961.5	395.2	417.7	424.1	453.4	463.1		
640	966.2	317.1	335.4	343.1	368.4	379.6	446.7	
642	929.9			246.0			358.7	
643	975.4	286.5	305.7	313.0	333.1	338.3	399.3	
644	936.7	213.2	230.3	235.5	259.5	266.2		
645	929.6	165.7						
647	931.5	158.5						
648	960.7	402.3	419.4	424.6	447.4	460.2		
652	1106.4	227.7	246.6	252.7	283.5	290.5	320.0	
653	1096.1	216.1	236.2	242.0	273.4	280.4	307.5	
654	1098.5	199.0	218.5	223.7	252.7	259.4	286.2	
655	1093.0	195.7	214.9	219.8	245.7	252.7	280.1	
656	1091.8	197.5	214.9	221.0	246.6	253.3	282.9	
657	1083.3	177.1	193.5	199.6	220.4	227.1	253.3	
658	1088.1	189.9	206.3	213.7	238.7	245.4	271.9	
659	1072.6	170.7	186.5	192.9	215.8	224.0	251.5	
660	1071.1	151.9	169.6	174.2	197.7	204.7	226.0	
661	1082.0					215.8	243.2	
662	1085.7	191.1	209.4	214.9	242.3	248.4	275.5	
663	1093.9	209.4					294.1	
664	1084.5	196.3	216.1	222.5	248.1	253.6	289.6	
665	1075.3	157.0					237.4	
666	1063.1	125.0	142.6	148.7	173.1	179.2	203.0	
667	1059.2	135.9	153.6	159.7	183.5	189.9	213.4	
668	1043.3	95.6			117.2	123.9	138.2	
669	1036.3	102.1			123.4	130.5	145.7	
670	1049.1	103.0	122.2	129.8	151.8	160.0	173.1	
671	1044.9	127.2			144.9	153.7	171.4	
672	1058.0	114.3	132.3	138.1	160.9	168.2	189.9	
673	1037.2	122.5			143.0	149.7	166.7	
674	1064.7	127.7	143.0	149.7	171.3	179.2	204.5	
675	1078.4	182.4	200.7	206.8	226.9	234.2	259.2	
676	1084.5	179.5	192.6	200.3	222.2	229.8	252.7	
677	1064.4	132.0	146.6	153.9	174.7	181.1	207.3	
678	1062.8	127.1					197.8	
679	1060.7	125.9	143.6	150.3	169.5	176.8	199.6	
680	1043.6	86.3					162.5	
681	1041.2	93.9					168.6	
682	1059.2	92.4					168.6	
683	1032.7	140.5						
684	1061.9	152.7					231.3	
685	1003.5	85.4			85.4	92.4	177.8	
689	1059.2	242.0	259.7	265.5	294.7	302.4	341.1	
690	1052.2	227.4	247.2	253.3	283.5	291.4	334.1	
691	1052.5	236.2	256.3	262.1	291.7	299.6	341.1	
692	1057.7	251.5	271.3	277.4	307.8	316.1		
693	1050.6	232.9	253.6	259.7	290.2	296.9	338.0	

FFG No.	Reference Elevation	Forty niner	Depths (meters) to Top of Units Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
694	1042.4	232.3	253.0	259.1	292.0	299.3	362.1	
695	1048.5	234.4	253.6	259.7	292.0	299.3	345.9	
696	1050.6	234.7	253.6	260.0	292.3	299.0	347.5	
697	1045.8	227.7	246.6	252.1	285.6	291.7	345.9	
698	1039.7	178.3	198.1	204.2	237.7	244.4	304.8	
699	1029.6	218.5	236.8	242.9	274.0	280.1	338.6	
700	1027.1	225.7	244.6	250.1	277.8	282.7	344.9	
701	1032.1	221.5	243.5	250.2	282.5	291.3	345.6	
702	1036.6	224.9	243.8	249.9	281.0	289.6	342.9	
703	1047.0	229.8	248.1	255.4	285.3	293.2	330.1	
704	1032.7	226.5	247.2	253.3	287.1	295.4	346.3	
705	1023.8	288.3	308.2	314.2	344.1	352.0	413.0	
706	1025.7	270.7	289.6	295.0	323.4	331.3	388.6	
707	1019.3	278.3	299.0	305.1	332.5	342.3	402.6	
708	1026.6	235.0	253.3	259.4	289.9	297.8	356.9	
709	1008.6	327.1	344.1	349.9	375.8	382.8		
710	1007.4	324.9	342.0	348.1	375.8	382.2	428.2	
711	1012.9	318.5	337.7	344.7	378.3	386.8	442.3	
712	1018.0	282.4	299.2	307.1	339.7	348.5		
713	1011.3	338.8	355.5	363.2	390.6	397.6		
714	1024.1	233.8	253.9	262.2	292.6	299.0		
715	1025.3	225.6	242.3	250.5	283.5	290.2		
716	1060.6	362.7	379.8	384.0	455.7	463.3	507.5	
717	1056.1	333.6	352.8	358.0	383.9	390.9	434.2	
718	1044.9	321.4	338.2	344.0	380.2	388.8	432.1	
719	1040.4	343.7	361.0	366.2	414.4	421.7	469.2	
720	1019.9	320.3	340.8	348.4	394.1	405.4	449.3	
721	1026.9	328.9	347.8	353.3	380.7	387.4	432.5	
722	1063.4	297.8	345.0	350.5	348.1	357.2	396.8	Top Tamarisk, Magenta wrong
723	1054.3	246.1	262.6	269.0	291.5	299.2	341.8	
724	1044.2	305.3	325.1	330.6	357.7	366.2	410.4	
725	1029.6	317.3	334.7	339.9	376.7	383.1	419.1	
726	1018.6	319.7	335.9	341.1	370.0	377.6	429.5	
727	1020.8	317.9	340.8	345.9	381.6	390.1	445.3	
728	1012.2	315.8	334.4	338.9	365.5	374.0	421.8	
729	1014.4	307.8	325.5	330.7	365.5	373.4	418.5	
730	1018.9	294.1	313.3	317.6	345.3	353.6	396.2	
731	1022.3	301.6	319.3	324.5	351.9	359.5	404.6	
732	1040.3	300.8	319.7	327.1	353.9	362.1		
733	1028.4	221.9	240.8	247.2	278.6	286.5	330.1	
734	1029.0	270.4	287.1	292.0	321.6	329.8	374.9	
735	1016.5	312.4	331.9	337.4	377.6	386.2	432.5	
736	1025.6	266.9	286.5	293.2	349.2	357.8	410.2	
737	1040.5	337.9	357.7	361.7	420.2	428.7	481.2	
738	1018.3	304.5	321.3	325.8	356.3	363.9	408.1	
739	1015.1	261.2	280.7	285.3	320.3	331.3	386.5	
740	1015.6	260.9	278.9	285.0	353.0	362.4	406.6	
741	1014.7	293.5	311.8	317.0	356.0	363.6	412.4	
742	1023.8	249.3	270.1	275.2	323.1	333.1	377.3	
743	1013.2	256.0	272.8	278.0	327.1	338.0	382.5	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
744	1012.5	272.8	289.6	294.7	335.3	341.7	382.5	
745	1006.4	276.1	297.5	300.5	348.7	356.0	408.1	
746	1007.5	287.7	308.4	314.5	362.0	370.3	425.7	
747	1016.2	234.1	253.0	259.1	290.2	297.2		
748	999.7	207.9	224.6	231.6	259.7	267.9	315.5	
749	1000.7	362.1	380.4	386.5	412.7	419.1	474.0	
750	996.4	298.7	315.8	323.7	351.1	359.7		
751	997.0	419.7	436.8	441.7	466.6	475.2	510.2	
753	991.5	329.1	354.1	359.5	389.4	397.3		
754	983.6	272.2	292.3	299.0	327.4	335.9	382.8	
755	980.8	342.6	357.2	364.8	375.5	383.1	552.3	
756	965.3	176.8	195.1	201.2	222.8	230.7	294.7	
757	966.8	173.7	192.6	197.2	226.2	234.7	292.6	
759	975.4						384.7	
760	983.0	386.0	402.5	408.0	433.9	443.0	480.2	
761	953.4	178.9					282.2	
762	956.5	192.5	214.1	219.9	252.8	261.4	317.8	
763	951.6	174.0	192.3	198.7	239.3	246.9	297.5	
764	945.8	167.0	185.6	191.7	222.2	229.5		
765	946.4	164.1	182.7	191.9	226.6	232.7	290.6	
766	950.7	252.1	270.7	277.4	306.6	315.8	363.3	
767	959.2	277.1	294.4	299.9	329.5	337.7	377.6	
768	941.5	153.6	172.2	178.6	216.1	223.7	278.0	
769	943.4	143.6	162.8	168.9	208.8	214.6	271.0	
770	1011.6	282.3	297.0	301.8	331.7	340.6	386.6	
771	1011.6	292.3	310.6	316.7	356.9	365.5	411.2	
772	1014.7	274.6	294.1	299.3	332.5	341.1	386.5	
773	1007.7	234.6	253.2	259.3	290.1	298.6	343.7	
774	1003.4	237.3	257.1	263.5	302.2	309.8	354.0	
775	1016.5	280.1	300.2	306.6	338.6	345.6	399.0	
776	1015.0	276.5	295.4	301.4	338.9	348.1	393.5	
777	1022.6	239.9	258.2	263.7	294.1	303.9	345.9	
778	1009.5	280.8	299.7	306.1	336.9	345.7	389.3	
779	1002.8	272.5	291.4	298.4	328.9	338.0	383.7	
780	991.8	222.4	243.1	248.9	280.3	288.2	331.8	
781	958.9	206.3	227.7	233.2	267.3	277.4	334.1	
782	990.3	234.1	253.9	261.5	290.8	299.6	344.7	
783	1002.8	266.7	286.2	292.0	323.1	330.7	373.7	
784	1005.5	256.3	274.6	279.5	321.0	326.4	363.0	
785	1019.3	244.1	266.7	274.3	304.8	313.3	356.6	
786	1014.7	253.6	271.9	278.0	310.6	320.0	358.4	
787	995.2	242.9	261.5	268.2	301.1	309.1	350.8	
788	976.3	219.8	239.9	245.4	277.7	285.9	325.2	
789	950.4	197.8	218.2	224.0	263.0	270.1	322.8	
790	943.1	185.6	204.5	210.0	246.6	255.7	312.7	
791	1005.2	292.5	316.8	322.0	366.8	376.3	422.0	
792	1008.3	257.6	276.1	279.5	317.0	326.4	373.4	
793	1016.5	235.9	254.2	259.4	324.0	333.1	353.3	
794	1014.4	240.8	256.3	262.1	290.5	298.7	344.4	
795	1011.3	232.0	251.2	254.8	293.8	302.1	346.3	

FFG No.	Reference Elevation	Depths (meters) to Top of Units: Forty niner	Mag-enta	Tama-risk	Cul-ebra	ulm	Salado salt	Revisions
796	1027.2	213.4	231.6	237.7	271.0	279.2	322.5	
797	1027.8	228.6	246.3	252.4	284.1	293.5	334.7	
798	1027.8	231.0	250.2	256.6	289.5	298.1	337.7	
799	1015.3	194.2	213.4	217.9	256.0	262.7	306.3	
800	987.7	239.3	257.3	261.2	294.4	301.8	349.9	
801	979.0	289.4	307.1	311.7	354.3	363.5	408.3	
802	1001.3	249.3	267.0	271.0	309.7	318.8	366.1	
803	929.0	204.8	224.9	228.6	266.7	276.8	322.5	
804	953.4	241.2	261.7	265.0	301.6	311.4	356.5	
805	999.6	310.2	335.0	338.9	382.2	390.8	445.6	
806	963.2	314.2	331.9	335.6	366.1	374.0	417.3	
807	944.3	260.0	280.1	285.6	317.9	326.7	371.9	
808	935.7	266.1					378.0	
809	929.0	210.0	230.7	235.0	271.0	280.4	325.8	
810	928.7	222.8	242.9	246.9	287.1	293.5	339.2	
811	909.9	377.2	391.8	396.4	432.0	441.2	488.4	
812	961.0	302.4	334.1	337.1	409.7	423.4	475.2	
813	939.7	287.4	312.4	317.0	375.8	386.2	443.5	
814	905.3	206.5	225.4	229.4	265.0	274.2	316.8	
815	932.0	275.7	301.6	304.6	350.4	359.5	415.0	
817	1009.8	327.7	351.4	359.7	399.3	406.9		

This table was created by reproducing Table 2 of Richey (1989) with a few additional notations where obvious typographical errors or duplications occurred.
Locations and other data for each borehole can be found in a supplemental table in this appendix.
Cross-referencing is through the FFG number assigned to the drillhole by Richey.

Appendix C

APPENDIX C

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_2O as Ore Mineral

Drill-hole no.: Drill-hole designations: P, Energy Research and Development Administration; FC, Farm Chemical Res. Dev. Corp.; IMC, International Minerals and Chemical Corp; NFU, Farmers Edu. and Coop. Union of America; D, Duval Sulphur and Potash Co.; U, U.S. Potash Co., Inc; Arc, arcanite; Bs, bischofite; Bl, bloedite; C, carnallite; Gl, glaserite; Gu, Glauberite; Ka, Kainite; Ki, kieserite; L, langbeinite; Le, leonite; Lo, loewite; S, sylvite; Va, vanthoffite.

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_2O as Ore Minerals (percent)	Weighted average K_2O as ore mineral for all intervals in Ore Zone (feet and percent)
P-1	5	9	1440.47-1441.35	0.88	8	76	—	15.0	Tr/Ka[1]	3.4/L	
	5	10	1441.35-1442.30	0.95	9	86	—	4.4		1.0/L	
	5	11	1442.30-1443.50	1.20	—	79	—	—	14.0/Ka Tr/Bl[1]	—	
	5	12	1443.50-1444.35	0.85	—	95	—	2.34	—	0.53/L	
	5	13	1444.35-1445.30	0.95	1	79	—	17.07	—	3.87/L	4.83-1.67/L
P-2	10	14	1627.15-1628.35	1.20	1	39	—	39.9	1.9/Ka 5.0/Le	9.05/L	
	10	15	1628.35-1629.52	1.17	1	46	—	43.1	2.6/Ka 0.5/Le	9.78/L	2.37-9.41/L
	4	5	1802.70-1804.00	1.30	1	39	—	38.0	12.9/Ka	8.6/L	
	4	6	1804.00-1805.00	1.00	6	80	—	—	—	—	
	4	7	1805.00-1805.85	0.85	5	89	—	—	—	—	
	4	8	1805.85-1806.30	0.45	6	60	—	20.0	4.0/Ka 3.7/Le	4.54/L	3.60-3.67/L
	2	1	1833.08-1834.00	0.92	2	79	—	4.4	1.9/Ka	3.14/L	
	2	2	1834.00-1834.50	0.50	—	38	—	52.9	0.5/Ka	12.0/L	1.42-6.26/L
P-3	4	3	1596.30-1597.60	1.30	2	72	—	24.7	0.5/Ka	5.6/L	
	4	4	1597.60-1598.70	1.10	2	62	—	18.6	0.5/Ka	4.22/L	
	4	5	1598.70-1599.53	0.83	34	38	—	23.4	—	5.31/L	3.23-5.06/L
P-4	10	2	1572.60-1574.97	2.37	1	56	46.0	—	—	29.40/S	
	10	3	1574.97-1576.17	1.20	4	64	27.6	—	—	17.48/S	
	10	4	1576.17-1577.77	1.60	3	86	7.0	—	—	4.32/S	
	10	5	1577.77-1578.69	0.92	4	64	28.0	—	—	17.46/S	6.09-18.66/S
P-5	10	6	1546.69-1548.65	1.96	6	65	28.0	—	—	18.28/S	
	10	7	1548.65-1549.66	1.01	4	76	13.3	—	—	8.42/S	
	10	8	1549.66-1551.40	1.74	3	60	21.0	—	—	13.41/S	
	10	9	1551.40-1552.75	1.35	2	65	14.5	—	—	9.14/S	6.06-13.2/S
P-6	4	12	1476.00-1477.45	1.45	6	74	—	22.0	1.0/Ki	5.01/L	
	4	13	1477.45-1478.37	0.92	1	83	2.0	8.0	6.0/Ki	1.90/L 1.26/S	
	4	14	1478.37-1480.00	1.63	3	84	—	12.0	—	2.78/L	4.00-3.39/L
	2	18	1510.50-1511.32	0.82	1	37	2.0	54.0	6.0/Ki	12.31/L	
	2	19	1511.32-1512.10	0.78	—	53	—	42.0	—	9.65/L	
	2	20	1512.10-1513.05	0.95	7	79	3.0	1.0	8.6/Ka	0.19/L	2.55-6.98/L
P-7	4	2	1479.73-1481.20	1.47	2	65	1.0	29.0	—	6.53/L	
	4	3	1481.20-1483.00	1.80	—	89	2.0	3.0[4]	—	0.75/L[4]	
	4	4	1483.00-1483.48	0.48	3	69	2.0	3.8	5.7/Ka 1.0/Le 1.0/Bl	3.8/L	3.75-3.41/L

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_20 as Ore Minerals (percent)	Weighted average K_20 as ore mineral for all intervals in Ore Zone (feet and percent)
P-8	10	2	1363.70-1365.00	1.30	—	52	29.0	25.0	—	18.45/S 5.62/L	
	10	3	1365.00-1366.72	1.72	1	46	3.0	45.0	4.0/Ka 2.0/Le	10.3/L 1.65/S	
	10	4	1366.72-1368.05	1.33	1	86	—	14.0	—	8.23/L	4.35-6.74/L 4.35-6.17/S mixed ore equivalent 4.35-9.2/L
P-9	10	8	1522.56-1523.41	0.85	1	42	7.0	48.0	0.67/Ka	4.73/S 10.8/L	
	10	9	1523.41-1524.07	0.66	1	93	2.0	—	3.0/Ki	0.96/S	
	10	10	1524.07-1524.70	0.63	2	17	7.0	63.37	—	4.42/S 14.37/L	
	10	11	1524.70-1526.04	1.34	3	95	—	1.10	—	0.24/L	
	10	12	1526.04-1526.74	0.70	2	65	—	31.31	—	7.1/L	4.18-5.63/L 2.14-3.48/S mixed ore equivalent 4.18-6.34/L
	4	17	1703.65-1705.23	1.58	2	70	—	28.70	—	6.51/L	
	4	18	1705.23-1705.65	0.42	1	89	—	6.80	3.0/Ka	1.55/L	2.00-5.47/L
P-10	11	1	1650.38-1651.22	0.84	6	89	1.8	—	1.0/Ka	1.13/S	
	11	2	1651.22-1652.03	0.81	7	81	6.1	—	2.0/Ki	3.83/S	
	11	3	1652.03-1653.83	1.80	5	85	7.7	—	1.0/Ki	4.85/S	3.45-3.70/S
	11	4	1653.83-1654.58	0.75	6	94	—	—	—	—	
P-11	11	2	1601.90-1603.56	1.66	—	56	5.0	—	3.60/Ki 1.0/C	3.34/S	
	11	3	1603.56-1604.64	1.08	3	61	2.0	—	31.0/Ka 3.0/C	1.48/S	
	11	4	1604.64-1605.38	0.74	4	84	3.0	—	7.0/Ka 2.0/C	2.20/S	3.48-2.52/S
	10	7	1670.70-1671.84	1.14	1	71	19.0	8.0	1.0/Ki	12.0/S 1.82/L	
	10	8	1671.84-1673.42	1.58	2	66	10.0	18.0	1.0/Ki	6.32/S 3.98/L	
	10	9	1673.42-1674.70	1.28	3	71	16.7	—	1.0/Ki	10.53/S	4.00-9.29/S 2.72-3.07/L mixed ore equivalent 4.00-14.51/S
	9	14	1688.72-1689.60	0.88	3	76	22.0	—	—	13.74/S	
	9	15	1689.60-1690.89	1.29	1	64	36.9	—	—	23.30/S	
	9	16	1690.89-1691.95	1.06	1	71	21.3	—	2.0/C	13.43/S	
	9	17	1691.95-1693.28	1.33	2	92	2.0	—	1.0/C	1.24/S	4.56-12.73/S
	4	19	1840.60-1842.35	1.75	1	58	—	40.0	5.0/Ki	9.14/L	
	4	20	1842.35-1843.40	1.05	4	76	5.0	4.9	—	1.11/L 2.98/S	2.80-6.0/L

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_20 as Ore Minerals (percent)	Weighted average K_20 as ore mineral for all intervals in Ore Zone (feet and percent)
P-11	2	22	1868.67-1870.28	1.61	1	38	2.0	60.00	2.0/Ki	13.65/L	
	2	23	1870.28-1871.10	0.82	—	54	5.0	45.00	1.0/Ki	13.53/L	
	2	24	1871.10-1872.30	1.20	—	27	—	58.30	8.0/Ka	13.24/L	3.63-13.49/L
									Tr/B1		
									& Lo[1]		
P-12	10	2a	1344.97-1345.27	0.3	4	36	62.3	—	1.0/Ki	39.38/S	
	10	2b[4]	1345.27-1345.90	0.63	—	10	24.0[2]	—	59.0/Ki	15.08/S	
	10	3	1345.90-1346.95	1.05	1	59	18.0	—	18.0/Ki	11.39/S	
	10	4	1346.95-1348.90	1.95	3	64	18.0	—	19.0/Ki	11.36/S	
	10	5	1348.90-1349.91	1.01	7	44	20.0	—	8.6/Ki		
									8.7/Ka	12.63/S	
	10	6	1349.91-1350.80	0.89	3	67	16.0[3]	—	2.0/Ka	10.42/S	5.83-13.29/S
	8	14	1390.19-1390.97	0.78	4	80	15.5	—	—	9.77/S	
	8	15	1390.97-1392.66	1.69	7	88	7.0	—	—	4.12/S	
	8	16	1392.66-1394.29	1.63	4	88	10.3	—	—	6.47/S	
	8	17	1394.29-1394.90	0.61	8	51	35.5	—	—	22.42/S	4.71-8.24/S
	4	21	1520.00-1521.55	1.55	1	22	23.0	45.00	9.0/Ki	14.47/S	
										10.13/L	2.39-7.08/L
	4	22	1521.55-1522.39	0.84	10	48	7.0	6.0	16.0/Ka	1.44/L	2.39-10.94/S
									10.0/Le	4.42/S	mixed ore equivalent:
											4.00-8.23/L
	3	26	1533.50-1535.05	1.55	—	40	11.0	49.0	—	7.0/S	
										8.59L	
	3	27	1535.05-1535.59	0.54	34	86	1.0	8.0	1.0/Ki	1.80/L	
										0.62/S	3.51-5.98/L
	3	28	1535.59-1537.01	1.42	2	47	10.0	21.0	—	4.72/L	3.51-5.74/S
										6.32/S	
											mixed ore equivalent:
											3.51-8.27/L
	2	34	1549.79-1550.65	0.86	3	85	—[4]	11.0	2.42/L	0.54/L	
	2	35a	1550.65-1551.29	0.64	—	20	5.0	70.0	1.0/Ka		
									Tr/Le[1]	15.93/L	
	2	35b	1551.29-1551.61	0.32	—	21	5.0	30.0	18.0/Ka		
									19.0/Le		
									17.01/B1	12.48/L	1.82-8.05/L
P-13	10	29	1318.02-1319.00	0.98	1	46	49.5	—	—	31.32/S	
	10	30	1319.00-1320.22	1.22	1	62	17.0	2.0	15.0/Ki	10.92/S	
	10	31	1320.22-1320.88	0.66	3	97	—	—	—	—	
	10	32[4]	1320.88-1321.87	0.99	1	30	20.0	10.0	30.0/Ki	12.6/S	3.85-14.67/S
									10.0/Ka	2.27/L	
	9	36	1334.82-1336.38	1.56	2	94	2.0	—	—	1.12/S	
	9	37	1336.38-1337.32	0.94	2	62	34.8	—	—	21.99/S	
	9	38	1337.32-1338.64	1.32	—	90	3.8	—	—	2.41/S	3.82-6.7/S
	8	21	1359.65-1360.63	0.98	2	67	30.2	—	—	19.13/S	
	8	22	1360.63-1361.70	1.07	8	80	9.14	—	—	4.97/S	2.05-11.74/S
	4	2	1480.20-1481.73	1.53	2	82	2.0	9.0	3.0/Ki	2.03/L	
	4	3	1481.73-1482.78	1.05	1	63	—	33.2	0.4/Le	7.53/L	3.53-4.06/L
	4	4	1482.78-1483.73	0.95	1	64	—	7.0	7.0/B1	1.59/L	
	3	8	1493.23-1493.88	0.65	2	86	—	7.0	—	1.59/L	
	3	9	1493.88-1494.58	0.70	—	15	—	53.0	—	12.06/L	

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_20 as Ore Minerals (percent)	Weighted average K_20 as ore mineral for all intervals in Ore Zone (feet and percent)
P-13	3	10	1494.58-1495.50	0.92	3	86	—	10.0	—	2.21/L	2.27-5.07/L 4.00-2.88/L[5]
P-14	10	2	1255.24-1255.64	0.40	—	41	57.0	—	—	36.03/S	
	10	3	1255.64-1257.56	1.92	—	41	57.0	—	—	36.06/S 8.84/S	
	10	4	1257.56-1259.07	1.51	3	84	14.0	18.0	Tr/Ka[1]	3.99/L	
	10	5	1259.07-1260.15	1.08	4	74	7.0	22.0	—	4.36/S 4.88/L	
	10	6	1260.15-1261.05	0.90	2	55	12.0[6]	—	16.0/Ka	6.21/S	5.81-18.47/S 2.59-4.36/L mixed ore equivalent 5.81-23.33/S
	5	10	1364.44-1366.11	1.67	5	74	5.0	15.0	1.0/Ka	3.35/L 3.00/S	
	5	11	1366.11-1367.86	1.75	3	83	—	19.0	Tr/Ka[1]	4.3/L	
	5	12[6]	1367.86-1369.26	1.40	1	80	—	13.0	Tr/Ka[1]	3.03/L	4.82-3.60/L 1.67-3.0/S mixed ore equiralent 4.82-4.02/L
	4	18	1440.79-1441.98	1.19	4	46	6.0	38.5	—	8.74/L 3.99/S	
	4	19	1441.98-1442.84	0.86	5	95	—	—	—	—	
	4	20	1442.84-1443.98	1.14	16	56	4.0	23.0	Tr/Le 2.0/Ka	5.22/L 2.53/S	
	4	21	1443.98-1444.61	0.63	3	88	—	11.0	—	2.50/L	3.82-4.69/L 3.19-2.39/S
P-15	4	7	1371.94-1372.81	0.87	6	76	—	25.0	—	5.59/L	
	4	8	1372.81-1374.77	1.96	8	89	—	4.0	—	1.00/L	
	4	9	1374.77-1375.80	1.03	9	64	—	28.0	—	6.30/L	3.86-3.45/L
	2	13	1399.66-1400.38	0.72	3	64	—	32.0	4.0/Ka	7.18/L	
	2	14	1400.38-1401.51	1.13	—	78	—	17.0	3.0/Ka 3.0/Le	4.28/L	1.85-5.41/L
P-16	10	4	1301.94-1302.57	0.63	3	93	0.7	4.0	—	0.47/S 0.89/L	
	10	5	1302.57-1303.91	1.34	3	79	—	21.0	—	4.77/L	
	10	6	1303.91-1304.39	0.48	—	61.0	—	34	8.1/Ka 8.0/Le Tr/Ki[1]	7.77/L	2.45-4.63/L
	4	10	1476.76-1478.40	1.64	—	36	2.0	53.0	Tr/Ka & Le[1]	12.01/L 1.26/S	
	4	11	1478.40-1478.95	0.55	2	86	—	8.7	—	1.98/L	2.19-9.49/L
	4	12	1490.12-1491.00	0.88	1	83	1.0	14.1	—	4.94/L	
	4	13	1491.00-1491.56	0.56	0	39	7.0	19.7[7]	—	4.40/L 4.12/S	
	4	14	1491.56-1492.64	1.08	7	79	—	12.0	—	2.75/L	

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_20 as Ore Minerals (percent)	Weighted average K_20 as ore mineral for all intervals in Ore Zone (feet and percent)
P-16	4	15	1492.64-1493.89	1.25	2	56	3.0	31.0	6.0/Le	7.05/L	
									2.0/Ka	2.09/S	3.77-4.93/L
	2	19	1526.90-1528.00	1.10	1	51	1.0	42.0	2.0/Ka	9.05/L	1.10-9.60/L
P-17	10	2	1365.60-1367.20	1.60	1	27	—	68.8	—	15.61/L	
	10	3	1367.20-1368.45	1.25	3	76	—	12.6	2.0/Ka	2.87/L	
	10	4	1368.45-1369.70	1.25	3	44	—	6.64	30.0/Le	1.51/L	4.10-7.43/L
									9.0/Ka		
	4	8	1542.90-1543.68	0.78	—	48	—	38.0	13.0/Le	8.62/L	
									Tr/Ka[1]		
	4	9	1543.68-1544.46	0.78	—	43	—	53.0	3.0/Le	12.03/L	1.56-10.33/L
	2	18	1591.39-1592.71	1.32	1	44	—	46.0	1.0/Ka	10.46/L	
	2	19	1592.71-1594.21	1.50	4	83	—	2.4	2.0/Ka	0.53/L	2.82-5.18/L
P-18	10	3	1728.40-1728.78	0.38	1	41	33.0	35.0	—	22.83/S	
										7.94/L	
	10	4	1728.78-1730.45	1.67	3	86	9.0	—	—	5.61/S	
	10	5	1730.45-1731.49	1.04	6	80	0.72	—	—	0.45/S	
	10	6	1731.49-1732.29	0.80	4	74	0.81	—	—	0.51/S	3.89-4.86/S
											0.38-7.94/L
											mixed ore equivalent:
											3.89-6.8/S
P-19	10	7	1741.80-1742.35	0.55	1	55	6.70	36.0	—	4.23/S	
										8.24/L	
	10	8	1742.35-1743.72	1.37	1	26	2.0	59.0	—	1.20/S	
										13.39/L	
	10	9	1743.72-1745.09	1.37	4	81	1.0	15.0	—	0.62/S	
										3.40/L	
	10	10	1745.09-1746.00	0.91	2	53	—	30.0	8.4/Le	9.21/L	4.20-8.03/L
									2.0/Ka		
	4	21	1925.20-1925.90	0.70	1	74	—	11.0	12.0/Ki	2.50/L	
	4	22	1925.90-1926.70	0.80	1	27	—	57.0	2.0/Ka	12.93/L	
									9.0/Ki		
	4	23	1926.70-1927.94	1.24	2	62	—	3.6	5.0/Ka	0.82/L	2.74-4.79/L
									Tr/Le[1]		
	2	26	1956.40-1957.36	0.96	6	64	1.0	16.0	15.0/Ki	3.74/L	
	2	27	1957.36-1958.71	1.35	1	29	—	65	Tr/Ka[1]	14.83/L	
	2	28	1958.71-1959.21	0.50	0.5	61	—	25.0	Tr/Ka[1]	5.72/L	2.81-9.42/L
P-20	10	2	1725.00-1726.15	1.15	2	72	21.2	Tr/L[4]	—	13.43/S	
	10	3	1726.15-1728.10	1.95	4	64	7.0	35.0	—	4.42/S	
										8.01/L	
	10	4	1728.10-1729.62	1.52	3	60	28.0[6]	—	6.0/Ka	17.69/S	1.95-8.01/L
	10	5	1729.62-1731.48	1 86	3	60	34.0	—	—	21.48/S	6.51-14.03/S
											mixed ore equivalent:
											6.51-20.03/S
	4	10	1898.80-1900.45	1.65	5	53	1.0	37.0	5.0/Ka	8.35/L	
	4	11	1900.45-1901.77	1.32	16	85	—	1.3	—	0.30/L	
	4	12	1901.77-1903.35	1.58	10	74	—	17.7	—	4.0/L	4.55-4.5/L
	2	14[4]	1925.08-1926.30	1.22	3	95	—	0.88	—	0.2/L	
	2	15	1926.30-1927.75	1.45	1	61	—	35.5	—	8 05/L	2.67-4.46/L

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_20 as Ore Minerals (percent)	Weighted average K_20 as ore mineral for all intervals in Ore Zone (feet and percent)
P-21	10	2	1644.03-1644.84	0.81	4	80	17.0	—	—	10.82/S	
	10	3	1644.84-1646.00	1.16	4	81	11.8	—	2.0/Ki	7.46/S	
	10	4	1646.00-1646.33	0.33	1	28	20.2[6]	—	42.0/Ki	12.76/S	
	10	5	1646.33-1647.20	0.87	1	41	25.5[6]	—	18.0/Ki	16.14/S	
	10	6	1647.20-1648.22	1.02	1	62	29.5[2]	—	1.0/Ki	18.66/S	
	10	7	1648.22-1649.23	1.01	3	64	31.3	—	—	19.81/S	5.20-14.37/S
	8	15	1685.17-1686.48	1.31	0	55	45.0	—	—	28.4/S	
	8	16	1686.48-1687.20	0.72	4	83	6.06	—	—	3.72/S	
	8	17	1687.20-1688.24	1.04	5	92	3.0	—	—	1.95/S	
	8	18	1688.24-1688.77	0.53	4	95	0.8	—	—	0.52/S	
	8	19	1688.77-1690.19	1.42	6	86	9.9	—	—	6.24/S	
	8	20	1690.19-1691.26	1.07	8	90	1.0	—	—	0.75/S	
	8	21	1691.26-1692.40	1.14	3	65	33.0	—	—	21.16/S	
	8	22	1692.40-1693.34	0.94	5	65	13.0	—	—	8.18/S	8.17-10.24/S
	4	24	1809.90-1811.50	1.60	0	31	3.0	64.0	2.5/Ka 3.9/Le	14.60/L	1.92-14.69/L
	4	25	1811.50-1811.82	0.32	0	18	5.0[2]	54.66	9.0/Ka 10.60/Le	15.12/L	4.00-7.05/L[5]
	4	30	1815.51-1816.10	0.59	11	51	5.0	27.0	9.0/Ki	6.08/L	
	4	31	1816.10-1817.25	1.15	3	42	5.0	44.0	8.0/Ka	9.95/L	1.74-8.64/L 4.00-3/76/L[5]
AEC-8	10	10	1589.10-1589.70	0.60	1	85	5.0	—	5/Ki 2/An	2.97/S	
	10	11	1589.70-1591.70	2.00	—	43	16.0	—	40/Ki	10.32/S	
	10	12[6]	1591.70-1592.20	0.50	—	37	24.0	—	6/C 30/Ki 0.1/An	15.16/S	
	10	13[6]	1592.20-1594.50	2.30	—	49	32.0	—	7/C 9/Ka 0.8/An	20.31/S	
	10	14	1594.50-1594.70	0.20	—	38	4.0	—	51/C 9/Ka 1/Ki 0.1/An	2.34/S	
	10	15[6]	1594.70-1594.50	0.80	2	85	3.0	—	4/C 2/Ki 9/Ka 0.9/An	2.18/S	6.4-12.33/S
	4	2	1752.70-1753.40	0.70	—	95	—	4.0	—	0.86/L	
	4	3	1753.40-1754.00	0.60	1	69	2.0	33.0	3/Ka	7.39/L	
	4	4	1754.00-1755.00	1.00	—	33	2.0	68.0	2/Ka	13.90/L	
	4	5	1755.00-1756.70	1.70	—	24	—	69.0	3/Le	15.38/L	4-11.27/L
FC-70	10	2	1377.67-1379.00	1.33	2	65	11.2	—	20.0/Ki	7.11/S	
	10	3	1379.00-1381.00	2.00	2	51	39.1[6]	—	1.0/Ki	24.72/S	
	10	4	1381.00-1382.00	1.00	2	64	19.4[6]	—	3.0/C 3.0/Ki	12.29/S	4 33-16.44/S
	9	6	1391.50-1393.00	1 50	1	53	28.0	—	—	17.74	1.5-17.74/S
	8	7	1415.08-1415.75	0.67	2	70	25.0	—	Tr/Ki[1]	16.10/S	
	8	8	1415.75-1416.50	0.75	5	89	2.0	—	Tr/Ki[1]	1.35/S	

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_20 as Ore Minerals (percent)	Weighted average K_20 as ore mineral for all intervals in Ore Zone (feet and percent)
FC-70	8	9	1416.50-1418.00	1.50	2	97	1.0	—	1.0/Ka Tr/Ki[1]	0.57/S	
	8	10	1418.00-1419.50	1.50	3	91	3.0	—	—	1.62/S	
	8	11	1419.50-1420.42	0.92	2	80	16.0	—	1.0/Ka Tr/Ki[1]	10.04/S	
	8	12	1420.42-1421.50	1.08	1	71	16.0	—	1.0/Ka	10.21/S	6.42-5.5/S
	5	16	1466.00-1467.58	1.58	—	72	—	19.6	—	4.43/L	
	5	17	1467.58-1469.00	1.42	1	53	—	40.7	—	9.22/L	
	5	18	1469.00-1469.67	0.67	1	70	—	24.2	—	5.49/L	3.67-6.48/L
	4	19	1529.92-1531.42	1.50	1	36	—	52.6	—	11.93/L	
	4	20	1531.42-1532.42	1.00	—	45	—	33.0[6]	—	7.42/L	2.5-10.13/L
FC-81	8	7	1564.17-1564.92[6]	0.75	2	58	36.6	—	2.0/C	23.16/S	
	8	8	1564.92-1566.13	1.21	2	79	15.3	—	4.0/C	9.71/S	
	8	9	1566.13-1567.38	1.25	5	66	8.9	6.1	10.0/C	5.62/S 1.38/L	3.21-11.26/S 3.21-0.54/L mixed ore equivalent 3.21-12.61/S
	4	10	1687.00-1688.21	1.21	—	20	—	74.0	4.0/Ka Tr/Va[1]	16.71/L	
	4	11	1688.21-1689.46	1.25	1	25	—	67.0	Tr/Va[1]	15.31/L	2.46-16.0/L
	2	15	1712.88-1714.46	1.58	1	40	—	56.0	2.2/Le	12.7/L	
	2	16	1714.46-1715.46	1.00	—	65	—	30.3	3.0/Ka	6.9/L	
	2	17	1715.46-1716.00	0.54	4	45	—	42.8	Tr/Le[1]	9.71/L	3.12-10.4/L
FC-82	5	1	1541.42-1541.79	0.37	—	17	—	72.2	2.0/Le 6.0/C	16.34/L	
	5	2	1541.79-1542.29	0.50	—	85	7.0	7.2	—	1.63/L	
	5	3	1542.29-1543.96	1.67	2	5	—	49.8	4.0/Lo 20.9/C	11.3/L	
	5	4	1543.96-1544.50	0.54	1	59	5.0	20.0	Tr/Le[1]	4.54/L	3.08-9.37/L
	4	5	1613.42-1615.08	1.66	—	17	—	63.0	9.3/Ki Tr/Lo[1]	14.3/L	
	4	6	1615.08-1615.92	0.84	1	48	0.7	12.8	17.7/Le 12.0/Ki	2.9/L	2.5-10.52/L
	3	7	1624.33-1625.58	1.25	2	57	—	31.1	3.5/B1 3.7/Ka	7.06/L	
	3	8	1625.58-1627.00	1.42	2	67	—	29.9	0.6/C	6.78/L	
	3	9	1627.00-1627.75	0.75	1	28	—	62.2	Tr/B1[1] 5.0/G1	14.11/L	3.42-8.49/L
FC-91	4	34	1712.25-1712.66	0.42	1	18	—	50.0	11.0/Ka 7.5/Le 6.0/Ki	11.35/L	
	4	35	1712.66-1713.08	0.42	—	62	—	—	5.0/Ka 3.4/Ki	—	
	4	36	1713.08-1714.17	1.08	1	25	—	64.6	5.0/Ki	14.66/L	
	4	37	1714.17-1714.75	0 58	2	32	—	58.7	5.0/Ka 1 3/Ki	13.32	
	4	38	1715.75-1715.75	1.00	20	38	—	47.0	5.0/Ka Tr/Gu[1]	10.66	

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_2O as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_2O as Ore Minerals (percent)	Weighted average K_2O as ore mineral for all intervals in Ore Zone (feet and percent)
FC-91	4	39	1715.75-1716.33	0.58	6	31	—	54.0	6.2/Ka 4.0/Gl 1.2/Ki	12.25/L	4.08-11.3/L
	4	40	1718.66-1719.42	0.75	3	81	—	8.0	3.0/Ka 9.0Bs	1.82/L	
	4	41	1719.42-1720.75	1.33	2	37	—	59.5	—	13.5/L	
	4	42	1720.75-1722.00	1.25	—	60	—	37.08	Tr/Gu 3.4/Bs	8.41/L	
	4	43	1722.00-1722.58	0.58	—	71	—	13.5	0.4/Ka 6.0/Bs Tr/Gu[1]	3.06/L	3.91-8.08/L
	2	44	1742.75-1743.25	0.50	—	15	—	62.0	8.8/Ka Tr/Va[4]	14.07/L	
	2	45	1743.25-1744.25	1.00	—	47	—	30.5	10.0/Ki 10.0/Va	6.92/L	
	2	46	1744.25-1745.00	0.75	—	61	—	1.0	3.2/Ka 10.1/Ki 24.0/Va Tr/Gu[1]	0.73/L	2.25-6.44/L
FC-92[9]	8	5	1604.92-1606.04	1.12	1	51	47.0	Tr[1]	Tr/C[1]	29.0/S	
	8	6	1606.04-1606.50	0.46	—	50	49.0	Tr[1]	Tr/C[1]	31.0/S	
	8	7	1606.50-1606.75	0.25	—	60	29.0	1.0	5.7/C	18.5/S	1.83-28/S
	4	57	1740.66-1741.58	0.92	1	51	—	46.7	—	10.6/L	
	4	58	1741.58-1742.25	0.66	1	36	—	61.0	—	13.85/L	
	4	59	1742.25-1743.25	1.00	1	36	—	61.2	0.1/Ki	13.89/L	
	4	60	1743.25-1744.08	0.83	1	34	—	61.3	—	13.91/L	
	4	61	1744.08-1745.00	0.92	2	38	—	48.8	1.8/Ki	11.07/L	4.33-12.6/L
	2	62	1769.42-1770.08	0.66	1	42	—	55.4	3.0/Va	12.57/L	
	2	63	1770.08-1771.42	1.33	1	51	—	45.7	2.0/Va 1.0/Arc	10.37/L	
	2	64	1777.42-1772.08	0.66	—	39	—	33.0	17.0/Va 8.0/Ki 1.0/Gu	7.49/L	
	2	65	1772.08-1772.58	0.50	—	73	—	1.5	14.0/Va 1.0/Gu	0.34/L	3.16-8.64/L
IMC-374	4	8	1430.70-1432.10	1.40	6	86	0.7	2.0	0.7/Ki 0.3/Ka	0.46/L 0.44/S	
	4	9	1432.10-1433.10	1.00	13	68	1.0	6.4	1.35/Le	1.46/L 0.63/S	2.4-0.88/L 2.4-0.51/S
IMC-375	4	7	1627.90-1629.00	1.10	2	78	—	6.6	2.0/Ka	1.50/L	
	4	8	1629.00-1630.50	1.50	4	70	2.0	13.2	2.0/Le 1.0/Ka	3.0/L 1.3/S	2.5-2.46/L 1.5-1.3/S
IMC-376	10	2	1427.00-1427.70	0.7	—	60	38.4	—	—	24.3/S	
	10	3	1427.70-1428.30	0.6	—	98	0.2	—	—	0.1/S	
	10	4	1428.30-1429.20	0.9	1	96	0.4	—	—	0.26/S	
	10	5	1429.20-1431.00	1.8	2	86	11.2	—	—	7.1/S	4.0-7.52/S
	5	13	1528.00-1528.90	0.9	2	89	1.0	2.8	—	0.63/L	
	5	14	1528.90-1530.90	2.0	0	45	—	51.3	1.0/Le	11.65/L	3.7-6.5/L

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_20 as Ore Minerals (percent)	Weighted average K_20 as ore mineral for all intervals in Ore Zone (feet and percent)
IMC-376	5	15	1530.90-1531.70	0.8	2	93	1.0	1.05	—	0.25/L	(4.0-6.03/L)[5]
NFU-1[10]	8		1536.25-1540.17	3.92	—	—	—	—	—	19.67/S	3.92-19.67/S
	4		1646.75-1649.08	2.33	—	—	—	—	—	11.96/L	2.33-11.96/L
NFU[10]	10		1441.08-1445.17	4.08	—	—	—	—	—	0.8/S	4.08-.08/S
	8		1479.80-1483.80	4.00	—	—	—	—	—	9.1/S	4.0-9.1/S
	4		1598.50-1602.70	4.20	—	—	—	—	—	13.1/L	4.2-13.1/L
D-120[10]	10		1248.30-1249.80	1.50	—	—	—	—	—	31.63/S	
	10		1249.80-1251.10	1.30	—	—	—	—	—	10.4/S	
	10		1251.10-1252.50	1.40	—	—	—	—	—	7.34/S	4.2-15.3/S
	4		1419.60-1421.30	1.70	—	—	—	—	—	13.8/S	2.2-10.7/S
	4		1421.30-1421.80	0.50	—	—	—	—	—	0.5/S	2.2-7.5/L
											mixed ore equivalent:
											2.2-29.45/S
D-48[10]	10		1236.60-1240.60	4.00	—	—	—	—	—	—	4.0-11/S
											4.0-2.1/L
											(visual estimate)
	8		1280.52-1289.78	9.26	—	—	—	—	—	—	9.26-17.37/S
	4		1414.20-1416.20	2.00	—	—	—	—	—	—	2.0-8.8/L
											(visual estimate)
D-207	10	24	1358.60-1359.60	1.00	4	87	5	—	2/Ka	3.34/S	
	10	25	1359.60-1360.20	0.60	4	89	5	1	2/Ka	3.34/S	
										0.25/L	
	10	26	1360.20-1360.60	0.40	1	75	4	1	6/Ka	0.31/L	
	10	27[4]	1360.60-1361.20	0.60	1	47	6	16	5/Ka	3.79/S	
										3.70/L	
	10	28	1361.20-1361.80	0.60	2	69	2	9	2/Ka	2.04/L	
	10	29	1361.80-1362.30	0.50	7	62	5	10	7/Ka	3.34/S	
										2.31/L	
	10	30	1362.30-1363.10	0.80	6	83	4	—	1/C	2.66/S	4.5-2.54/S
									3/Ka		2.7-1.8/L
											mixed ore equivalent:
											4.5-5.24/S
	4	33	1533.10-1533.50	0.40	2	53	36	7.0	—	1.51/L	
										22.74/S	
	4	34	1533.50-1533.80	0.30	4	86	2	11.0	—	2.43/L	
	4	35	1533.80-1534.40	0.60	2	85	1	2.0	—	0.50/L	
	4	36	1534.40-1534.70	0.30	3	95	—	4.0	—	0.85/L	
	4	37	1534.70-1535.00	0.30	2	74	4	1.0	3.0/Ki	0.14/L	
	4	38	1535.00-1539.80	4.80	6	87	2.0	4.0	—	0.85/L	6.7-0.90/L
											0.4-22.74/S
											mixed ore equivalent:
	3	44	1545.90-1546.30	0.40	1	66	—	32.0	0.74/Le	7.2/L	
	3	45	1546.30-1546.66	0.30	1	11	—	73.2	9.0/Ki	16.6/L	
	3	46	1546.66-1548.00	1.40	2	62	—	30.3	3.8/Le	6.89/L	
	3	47	1548.00-1548.60	0.60	1	43	—	54.7	—	12.4/L	2.7-9.24/L
	2	52	1552.20-1553.00	0.80	11	83	—	5.0	—	1.05/L	
	2	53	1553.00-1553.20	0.20	11	45	—	41.5	2.0/Le	9.41/L	
	2	54	1553.20-1553.60	0.40	4	81	—	15.8	—	3.59/L	
	2	55	1553.60-1554.00	0.40	1	47	—	49.4	1.32/Le	11.19/L	

Calculated Mineral Content of Selected Samples from Potassium - Bearing Intervals with Summation of Percent K_20 as Ore Mineral

					Calculated Minerals Present (weight percent)						
Drillhole No.	Ore Zone	Sample No.	Depths of Interval (feet)	Thickness (feet)	Polyhalite	Halite	Sylvite	Langbeinite	Other Minerals	K_20 as Ore Minerals (percent)	Weighted average K_20 as ore mineral for all intervals in Ore Zone (feet and percent)
D-207	2	56	1554.00-1554.80	0.80	18	86	1.4	8.8	—	2.0/L	
										0.9/S	2.6-3.94/L
											Tr/S[4]
D-104[10]	10		1340.40-1341.70	1.30	—	—	—	—	—	—	
	10		1341.70-1343.20	1.50	—	—	—	—	—	—	
	10		1343.20-1344.00	0.80	—	—	—	—	—	—	
	10		1344.00-1344.70	0.70	—	—	—	—	—	—	6.0-5.5/S
	10		1344.70-1346.40	1.70	—	—	—	—	—	—	3.2-4.71/L
											mixed ore equivalent:
											6.0-11.78/S
	8		1391.10-1392.00	0.9	—	—	—	—	—	—	
	8		1392.00-1395.30	3.30	—	—	—	—	—	—	
	8		1395.30-1396.30	1.00	—	—	—	—	—	—	5.2-10.8/S
	4		1519.90-1522.80	2.90	—	—	—	—	—	—	2.9-9.4/L
D-104[10]	3		1527.50-1528.90	1.40	—	—	—	—	—	—	1.4-5.0/L
	3		1528.90-1530.50	1.60	—	—	—	—	—	—	2.9-11.4/S
											mixed ore equivalent:
											2.9-6.66/L
	2		1539.50-1540.20	1.20	—	—	—	—	—	—	1.2-15.0/L
U-134[10]	10		1319.58-1321.25	1.69	3	—	6.0	—	2.0/Ka		
									0.7/C	3.79/S	
			1321.25-1322.83	1.58	2	—	—	—	12.5/Ka	17.22/S	3.27-10.28/S
	8		1361.10-1362.17	1.08	—	—	—	—	—	—	
	8		1362.17-1364.50	2.33	—	—	—	—	—	—	
	8		1364.50-1366.50	2.00	—	—	—	—	—	—	6.33-7.89/S
	8		1366.50-1367.42	0.92	—	—	—	—	—	—	(4.0-12.5/S)[5]
	5		1406.75-1409.42	2.66	—	—	—	—	—	14.44/L	
	5		1409.42-1410.00	0.58	—	—	—	—	—	8.03/L	
	5		1410.00-1411.66	1.66	—	—	—	—	—	7.05/L	4.9-11.2/L
	4		1471.66-1474.00	2.33	—	—	—	—	—	8.54/L	2.33-8.54/L
	3		1484.91-1487.33	2.42	—	—	—	—	—	3.6/L	
	3		1487.33-1490.25	2.92	—	—	—	—	—	1.86/L	
	3		1490.25-1491.33	1.08	—	—	—	—	—	8.7/L	6.42-3.7/L[3]

*Values in table for percent mineral and K_20 equivalent are not consistent owing to independent rounding of assays and conversion factors by numerous authors and investigators.

[1] Trace amount; equals 0 to 2.0 percent
[2] Incomplete dissolution of sample
[3] 5.9 percent insolubles, by weight
[4] Incomplete or unreliable assay
[5] Grade adjusted to 4-foot interval
[6] High insoluble content
[7] 7.1 percent potassium assay used
[8] Outside of the ERDA area by 300 feet, included due to influence
[9] Raw data unavailable; these are company figures
[10] Company interval data; raw data unavailable; no sample numbers assigned

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix BIR

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Transuranic Waste Baseline Inventory Report

DOE/CAO-95-1121

Transuranic Waste Baseline Inventory Report (Revision 2)

December 1995

Prepared by Carlsbad Area Office Technical Assistance Contractor
for U.S. Department of Energy
under Contract No. DE-AC04-95AL-89446

Volume 1

PREFACE

TRANSURANIC WASTE BASELINE INVENTORY REPORT
REVISION 2, CAO/DOE-95-1121

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ACRONYMS AND ABBREVIATIONS

AE	Argonne National Laboratory-East site identifier
AL	Ames Laboratory site identifier
AM	ARCO Medical Products Company site identifier
ANL-E	Argonne National Laboratory-East
AW	ANL-W site identifier
ANL-W	Argonne National Laboratory-West
BC	Battelle Columbus Laboratory site identifier
BEMR	Baseline Environmental Management Report
BT	Bettis Atomic Power Laboratory site identifier
C&C Agreement	Agreement for Consultation and Cooperation between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant
CFR	Code of Federal Regulations
CH	contact handled
CY	calendar year
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
ET	Energy Technology Engineering Center site identifier
ETEC	Energy Technology Engineering Center
FFCAct	Federal Facility Compliance Act
FGE	Fissile Gram Equivalent
HDPE	high-density polyethylene
HQ	(DOE) Headquarters
ID	identification
IDB	Integrated Data Base
IDC	item description code
IN	Idaho National Engineering Laboratory site identifier
INEL	Idaho National Engineering Laboratory
IMWIR	Interim Mixed Waste Inventory Report
IT	Inhalation Toxicology Research Institute site identifier
ITRI	Inhalation Toxicology Research Institute
KA	Knolls Atomic Power Laboratory-Schenectady site identifier
KAPL	Knolls Atomic Power Laboratory - Schenectady
kg	kilograms
LA	Los Alamos National Laboratory site identifier
LANL	Los Alamos National Laboratory
LB	Lawrence Berkeley Laboratory site identifier
LBL	Lawrence Berkeley Laboratory
LL	Lawrence Livermore National Laboratory site identifier
LLNL	Lawrence Livermore National Laboratory
LWA	Land Withdrawal Act
MC	U.S. Army Material Command
MD	Mound Plant site identifier
MITI95	Material Inventory and Tracking Information Database 1995
m^3	cubic meters

mrem	millirem
MU	University of Missouri Research Reactor site identifier
MTRU	mixed transuranic
MWIR	Mixed Waste Inventory Report
NMVP	No-Migration Variance Petition
NRC	Nuclear Regulatory Commission
NT	Nevada Test Site site identifier
NTS	Nevada Test Site
OR	Oak Ridge National Laboratory site identifier
ORIGEN-2	Oak Ridge Isotope Generation and Depletion Code
ORNL	Oak Ridge National Laboratory
PA	performance assessment (in text only)
PA	Paducah Gaseous Diffusion Plant site identifier (in waste profiles only)
PCB	polychlorinated biphenyls
PGDP	Paducah Gaseous Diffusion Plant
PX	Pantex site identifier
RCRA	Resource Conservation and Recovery Act
RF	Rocky Flats Environmental Technology Site site identifier
RFETS	Rocky Flats Environmental Technology Site
RH	remote handled
RL	Hanford (Richland) site identifier
SA	Sandia National Laboratories/New Mexico site identifier
SARP	Safety Analysis Report for Packaging
SEIS	Supplemental Environmental Impact Statement
SNL/NM	Sandia National Laboratories/New Mexico
SR	Savannah River Site site identifier
SRS	Savannah River Site
SWB	Standard Waste Box
TB	Teledyne Brown Engineering
TDOP	Ten Drum Overpack
TRU	transuranic
TRUCON	Transuranic Package Transporter-II Content Codes
TRUPACT-II	Transuranic Package Transporter-II
TSCA	Toxic Substances Control Act
TWBID	Transuranic Waste Baseline Inventory Database
TWBIR	Transuranic Waste Baseline Inventory Report
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Plant
WMC	waste matrix code
WMP	waste material parameter
WS	waste stream
WTWBIR	Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report
WV	West Valley Demonstration Project site identifier
WVDP	West Valley Demonstration Project

PREFACE

The information in this report summarizes the U.S. Department of Energy's (DOE) transuranic (TRU) waste inventory, projections, and characteristics. Revision 0 of the *Waste Isolation Pilot Plant (WIPP) Transuranic Waste Baseline Inventory Report* (WTWBIR) published in June 1994, was the first attempt ever made by the DOE complex to report all of its TRU waste at the waste stream level. The waste data reported in Revision 0 was considered preliminary until quality checks of the data were completed by the DOE TRU waste generator/storage sites. Data changes resulting from the site reviews were contained in Revision 1 of the WTWBIR.

This document, Revision 2 of the *Transuranic Waste Baseline Inventory Report* (TWBIR) reports **all** DOE TRU waste, WIPP and non-WIPP TRU wastes, that have been identified by DOE TRU waste generator/storage sites. The primary differences between Revision 1 and Revision 2 are as follows:

- The name of the document has changed from WTWBIR to TWBIR to reflect the inclusion of all DOE TRU waste.
- Revision 1 was primarily developed to support Sandia National Laboratories, New Mexico (SNL/NM) performance assessment (PA) of the WIPP. Revision 2 TWBIR questionnaire continues to support the SNL/NM PA analyses and also supports additional WIPP program (e.g., WIPP Land Withdrawal Act requirements, WIPP transportation studies, the RCRA Part B Permit Application, WIPP No-Migration Variance Petition for Operations Period, and the Supplemental Environmental Impact Statement for Disposal Phase).
- Revision 2 incorporates a change in the plutonium residue processing assumptions at the Rocky Flats Environmental Technology Site (RFETS). In Revision 1, the RFETS TRU waste and radionuclide inventory projections reflected the plan to process the plutonium residues for actinide separation. In Revision 2, at the WIPP level, the RFETS TRU waste and radionuclide inventory projections reflect the plan to repackage/process the plutonium residues to meet WIPP Waste Acceptance Criteria, and safe storage requirements. This results in an increase to the WIPP waste inventory of approximately 1,320 cubic meters and an increase to the WIPP radionuclide inventory of approximately 1.35 million curies in the RFETS submittal.
- Revision 1 reported Hanford Site's submittal as approximately 46,000 cubic meters projected RH-TRU, of which 43,000 cubic meters were called "suspect" RH-TRU due to insufficient information from the Hanford Site. Reevaluation of the 46,000 m^3 of projected RH-TRU by Hanford personnel has resulted in a decrease of reported projected RH-TRU to approximately 21,500 m^3 for Revision 2 of the TWBIR. Additional evaluations of the reported Hanford Site RH-TRU waste volumes is ongoing and the results will be reported in future revisions of the TWBIR.
- Revision 2 defines waste streams to a more detailed level than Revision 1 of the WTWBIR. Savannah River Site (SRS), Idaho National Engineering Laboratory (INEL), Hanford Site, and RFETS divided their waste streams to the Local Identification level which will provide the detail desired to support the additional programs requesting DOE TRU waste inventory information. This resulted in an increase in the number of waste streams from 360 to approximately 970.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The *Transuranic Waste Baseline Inventory Report* (TWBIR) establishes a methodology for grouping wastes of similar physical and chemical properties, from across the U.S. Department of Energy (DOE) transuranic (TRU) waste system, into a series of "waste profiles" that can be used as the basis for waste form discussions with regulatory agencies. The majority of this document reports TRU waste inventories of the DOE defense sites.

The purpose of Revisions 0 and 1 of this report was to provide data to be included in the SNL/NM performance assessment (PA) processes. This revision of the document is also intended to support the WIPP Land Withdrawal Act requirement for providing the total DOE TRU waste inventory. Therefore, this document includes a chapter and an appendix that discusses the total DOE TRU waste inventory including non-defense, commercial, PCB contaminated, and buried (pre-1970) TRU wastes.

The WIPP baseline inventory is estimated using waste streams identified by the DOE TRU waste generator/storage sites. Each waste stream is defined in a waste stream profile and has been assigned to a Final Waste Form by the DOE TRU waste generator/storage sites. The sites provided and/or authorized all information in the Waste Stream Profiles. Waste stream profiles that have similar physical and chemical properties can be combined into the same Final Waste Form and is documented in a site-specific waste profile for each TRU waste generator/storage site.

Based on the methodology presented in this TWBIR, a maximum of 11 site-specific waste profiles have been identified for contact-handled (CH) TRU waste and a maximum of 11 have been identified for remote-handled (RH) TRU waste for each site. Each of these site-specific waste profiles have unique Final Waste Form criteria, and they are developed, if appropriate, for each of the TRU waste generator/storage sites. A particular site-specific waste profile, with a specific Final Waste Form, can be combined with other site-specific waste profiles having identical Final Waste Forms from the TRU waste generator/storage sites to derive a WIPP waste profile.

The WIPP anticipated (stored and projected) inventory of TRU waste is defined as the sum of retrievably stored waste plus currently projected TRU waste volumes. The anticipated inventory for CH-TRU waste is not sufficient to fill the maximum CH-TRU disposal inventory for WIPP (calculated to be 5,950,000 cubic feet or approximately 168,500 cubic meters). Scaling has been developed as a means for Sandia National Laboratories/New Mexico (SNL/NM) to model the impacts of a full repository. Scaling has not been applied to the RH-TRU inventory since the sites have reported sufficient RH-TRU waste to fill the RH-TRU disposal inventory (250,000 cubic feet or approximately 7,080 cubic meters). Additionally, it is anticipated that the data on wastes to be generated in the future from environmental restoration (ER) and decontamination and decommissioning (D&D) activities at the sites will be available in the Baseline Environmental Management Report that is currently under preparation by the DOE. Because of the difficulty in estimating detailed characteristics of these future ER and D&D wastes on a waste stream basis (as is required by the TWBIR), it was possible for only three sites (Battelle Columbus Laboratories, Bettis Atomic Power Laboratories, and Hanford) to report ER and D&D projections for this document.

The TWBIR also estimates the WIPP disposal inventory in terms of 12 waste material parameters and additional packaging materials that have been identified by Sandia National Laboratories/New Mexico, as necessary for PA. The 12 waste material parameters and additional packaging materials are waste constituents of TRU waste and are input parameters for one or more PA models or are required to adequately describe the waste form. These parameters may change as a result of PA efforts.

The 12 waste material parameters and additional packaging materials are listed below:

Waste Material Parameters
- Iron-base metal/alloys
- Aluminum-base metal/alloys
- Other metal/alloys
- Other inorganic materials
- Vitrified
- Cellulosics
- Rubber
- Plastics
- Solidified inorganic material
- Solidified organic material
- Cement (solidified)
- Soils

Packaging Materials
- Steel
- Plastic
- Lead

The waste material parameters in the waste stream, site-specific and WIPP waste profiles are expressed on a weight/volume (kilograms per cubic meter) basis. However, the occurrence of more than one waste material parameter at the maximum value within a waste stream is highly unlikely. If required by PA calculations, the sampling statistics must be controlled so that several waste material parameters do not get sampled all at their maximum value (weight/volume), thereby exceeding the average weight/volume. This revision of the TWBIR provides diskettes that contain the TRU Waste Baseline Inventory Database (TWBID) in Microsoft Access in either a run-time only version (not requiring purchase of Access) or a full version (requiring Access).

There are two types of distributions of the TWBIR, Revision 2 document. One will be presented in three volumes: Volume 1 contains the TWBID diskettes, the Preface; Executive Summary through Chapter 8; Volumes II and III contain Appendices A through P. This document presentation will be distributed to regulatory agencies, DOE and other top-level interfaces. A second distribution will be presented in one volume with the elimination of Volumes 2 and 3. For this second type of distribution the volume will contain the TWBID diskettes; the Preface; Executive Summary through Chapter 8; and Appendices A through N. Information for Appendices O and P can be found on the diskettes. This document presentation will be distributed to all other users of the TWBIR.

Attached to this Executive Summary are several summary tables from the remainder of the TWBIR which are frequently requested by TWBIR users:

- Table ES-1. WIPP CH-TRU Waste Material Parameter Disposal Inventory

- Table ES-2. WIPP RH-TRU Waste Material Parameter Disposal Inventory
- Table ES-3. WIPP CH-TRU Waste Anticipated Inventory by Site
- Table ES-4. WIPP RH-TRU Waste Anticipated Inventory by Site
- Table ES-5. WIPP Contact-Handled Mixed and Non-Mixed Disposal Inventory by Site (Final Waste Form)
- Table ES-6. WIPP Remote-Handled Mixed and Non-Mixed Disposal Inventory by Site (Final Waste Form)
- Table ES-7. Summary Radionuclide Inventory

Table ES-1

WIPP CH-TRU Waste Material Parameter Disposal Inventory

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2.6E+03	1.7E+02	0.0E+00
Aluminum Base Metal/Alloys	8.0E+02	1.8E+01	0.0E+00
Other Metal/Alloys	1.6E+03	6.7E+01	0.0E+00
Other Inorganic Materials	1.4E+03	3.1E+01	0.0E+00
Vitrified	2.5E+03	5.5E+01	0.0E+00
Cellulosics	9.6E+02	5.4E+01	0.0E+00
Rubber	6.3E+02	1.0E+01	0.0E+00
Plastics	8.9E+02	3.4E+01	0.0E+00
Solidified Inorganic Material	2.2E+03	5.4E+01	0.0E+00
Solidified Organic Material	1.4E+03	5.6E+00	0.0E+00
Cement (Solidified)	1.2E+03	5.0E+01	0.0E+00
Soils	1.6E+03	4.4E+01	0.0E+00

Container Materials - Kg/m3

Steel	139
Plastic/ Liners	26

Table ES-2

WIPP RH-TRU Waste Material Parameter Disposal Inventory

Waste Material Parameters (Kg/m3	Maximum	Average	Minimum
Iron Base Metal/Alloys	1.7E+03	1.0E+02	0.0E+00
Aluminum Base Metal/Alloys	1.7E+02	7.1E+00	0.0E+00
Other Metal/Alloys	9.1E+02	2.5E+02	0.0E+00
Other Inorganic Materials	2.0E+03	6.4E+01	0.0E+00
Vitrified	2.5E+03	4.7E+00	0.0E+00
Cellulosics	5.7E+02	1.7E+01	0.0E+00
Rubber	4.4E+02	3.3E+00	0.0E+00
Plastics	6.2E+02	1.5E+01	0.0E+00
Solidified Inorganic Material	6.1E+02	2.2E+01	0.0E+00
Solidified Organic Material	8.1E+02	9.3E-01	0.0E+00
Cement (Solidified)	5.8E+02	1.9E+01	0.0E+00
Soils	2.4E+01	1.0E+00	0.0E+00

Container Materials - Kg/m3

Steel	446
Plastic/Liners	3.1
Lead	465
Steel Plug	2145

Table ES-3

WIPP CH-TRU Waste Anticipated Inventory By Site

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Ames Laboratory - Iowa State Univ.	0.0E+00	4.2E-01	4.2E-01
Argonne National Laboratory - East	1.1E+01	1.3E+02	1.4E+02
Argonne National Laboratory - West	6.5E+00	7.4E+02	7.5E+02
Bettis Atomic Power Laboratory	0.0E+00	1.2E+02	1.2E+02
Energy Technology Engineering Center	1.7E+00	0.0E+00	1.7E+00
Hanford (Richland) Site	1.2E+04	3.3E+04	4.6E+04
Idaho National Engineering Laboratory	2.9E+04	0.0E+00	2.9E+04
Lawrence Livermore National Laboratory	2.3E+02	7.1E+02	9.4E+02
Los Alamos National Laboratory	1.1E+04	7.4E+03	1.8E+04
Mound Plant	2.7E+02	0.0E+00	2.7E+02
Nevada Test Site	6.2E+02	9.0E+00	6.3E+02
Oak Ridge National Laboratory	1.3E+03	2.6E+02	1.6E+03
Paducah Gaseous Diffusion Plant	0.0E+00	1.9E+00	1.9E+00
Pantex Plant	6.2E-01	0.0E+00	6.2E-01
Rocky Flats Environmental Technology Site	7.1E+02	4.4E+03	5.1E+03
Sandia National Laboratory - Albuquerque	6.7E+00	7.5E+00	1.4E+01
Savannah River Site	2.9E+03	6.8E+03	9.6E+03
Teledyne Brown Engineering	2.1E-01	0.0E+00	2.1E-01
U.S. Army Material Command	2.5E+00	0.0E+00	2.5E+00
University of Missouri Research Reactor	2.1E-01	8.3E-01	1.0E+00
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**

Table ES-4

WIPP RH-TRU Waste Anticipated Inventory By Site

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Argonne National Laboratory - West	1.9E+01	1.3E+03	1.3E+03
Battelle Columbus Laboratories	5.8E+02	0.0E+00	5.8E+02
Bettis Atomic Power Laboratory	0.0E+00	6.7E+00	6.7E+00
Energy Technology Engineering Center	8.9E-01	0.0E+00	8.9E-01
Hanford (Richland) Site	2.0E+02	2.2E+04	2.2E+04
Idaho National Engineering Laboratory	2.2E+02	0.0E+00	2.2E+02
Los Alamos National Laboratory	9.4E+01	9.9E+01	1.9E+02
Oak Ridge National Laboratory	2.5E+03	4.5E+02	2.9E+03
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**

Table ES-5. WIPP Contact-Handled Mixed and Non-Mixed Disposal Inventory by Site (Final Waste Form)

Storage/Generator Site	Stored Volumes (m3)		Projected Volumes (m3)	
	Mixed	Non-Mixed	Mixed	Non-Mixed
Ames Laboratory - Iowa State Univ.	0.0E+00	0.0E+00	4.2E-01	0.0E+00
Argonne National Laboratory - East	6.5E+00	5.0E+00	1.3E+00	1.3E+02
Argonne National Laboratory - West	4.3E+00	2.3E+00	2.0E+00	7.4E+02
Bettis Atomic Power Laboratory	0.0E+00	0.0E+00	0.0E+00	1.2E+02
Energy Technology Engineering Center	0.0E+00	1.7E+00	0.0E+00	0.0E+00
Hanford (Richland) Site	2.0E+02	1.2E+04	1.3E+04	2.0E+04
Idaho National Engineering Laboratory	2.3E+04	5.3E+03	0.0E+00	0.0E+00
Lawrence Livermore National Laboratory	8.3E+00	2.2E+02	5.0E+01	6.6E+02
Los Alamos National Laboratory	7.7E+03	3.3E+03	3.8E+03	3.6E+03
Mound Plant	3.5E+00	2.7E+02	0.0E+00	0.0E+00
Nevada Test Site	6.1E+02	5.7E+00	9.0E+00	0.0E+00
Oak Ridge National Laboratory	7.0E+02	6.1E+02	2.6E+02	0.0E+00
Paducah Gaseous Diffusion Plant	0.0E+00	0.0E+00	1.9E+00	0.0E+00
Pantex Plant	0.0E+00	6.2E-01	0.0E+00	0.0E+00
Rocky Flats Environmental Technology Site	4.4E+02	2.7E+02	3.3E+03	1.1E+03
Sandia National Laboratory - Albuquerque	0.0E+00	6.7E+00	0.0E+00	7.5E+00
Savannah River Site	1.5E+03	1.4E+03	2.9E+03	3.9E+03
Teledyne Brown Engineering	0.0E+00	2.1E-01	0.0E+00	0.0E+00
U.S. Army Material Command	0.0E+00	2.5E+00	0.0E+00	0.0E+00
University of Missouri Research Reactor	2.1E-01	0.0E+00	8.3E-01	0.0E+00
Totals	3.4E+04	2.4E+04	2.4E+04	3.0E+04

Table ES-6. WIPP Remote-Handled Mixed and Non-Mixed Disposal Inventory by Site (Final Waste Form)

Storage/Generator Site	Stored Volumes (m3)		Projected Volumes (m3)	
	Mixed	Non-Mixed	Mixed	Non-Mixed
Argonne National Laboratory - West	1.8E+00	1.8E+01	3.5E+01	1.2E+03
Battelle Columbus Laboratories	0.0E+00	5.8E+02	0.0E+00	0.0E+00
Bettis Atomic Power Laboratory	0.0E+00	0.0E+00	0.0E+00	6.7E+00
Energy Technology Engineering Center	8.9E-01	0.0E+00	0.0E+00	0.0E+00
Hanford (Richland) Site	2.7E+00	2.0E+02	1.5E+04	6.3E+03
Idaho National Engineering Laboratory	1.9E+02	2.6E+01	0.0E+00	0.0E+00
Los Alamos National Laboratory	1.7E+01	7.7E+01	3.4E+01	6.5E+01
Oak Ridge National Laboratory	2.4E+03	8.5E+01	4.5E+02	0.0E+00
Totals	2.6E+03	9.9E+02	1.6E+04	7.6E+03

Table ES-7. Summary Radionuclide Inventory[1]

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)
Am241	2.60E+00	8.42E-01
Ba137m	4.53E-02	2.89E+01
Cm244	4.72E-02	4.45E-02
Co58	1.81E-18	1.47E+00
Cs137	4.78E-02	3.05E+01
Pu238	2.26E+01	2.05E-01
Pu239	4.64E+00	1.45E+00
Pu240	1.23E+00	7.16E-01
Pu241	1.55E+01	2.00E+01
Sr90	4.07E-02	2.95E+01
Y90	4.07E-02	2.95E+01

[1]Summary shows the ten radionuclides with the highest concentration in curies per cubic meter of the waste.

CHAPTER 1

1. INTRODUCTION

1.1 BACKGROUND

Transuranic (TRU) waste is defined as waste that is contaminated with alpha-emitting radionuclides with an atomic number greater than 92, with half-lives greater than 20 years, and concentrations of TRU isotopes greater than 100 nanocuries per gram of waste (DOE, 1988). TRU wastes are classified as either contact-handled (CH) waste or remote-handled (RH) waste, depending on the dose rate at the surface of the waste container. CH-TRU wastes are packaged TRU wastes with an external surface dose rate of 200 millirems (mrem) or less per hour, while RH-TRU wastes are packaged TRU wastes with an external surface dose rate exceeding 200 mrem per hour. Unless otherwise indicated, for the purposes of this document, all references to TRU waste include TRU waste and mixed TRU waste (waste that contains both radioactive and hazardous components, as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act [RCRA] as codified in Title 40 Code of Federal Regulations [CFR] Part 261.3 [EPA, 1980]).

The Waste Isolation Pilot Plant (WIPP) is a TRU waste management facility operated by the U.S. Department of Energy (DOE). The WIPP is currently identified as the permanent disposal site for TRU wastes generated at various DOE sites after 1970 from defense activities of the United States including weapons production and research and development.

The DOE is committed to demonstrating compliance with all applicable regulations prior to permanent disposal of TRU defense wastes in the WIPP repository. These regulations are the environmental standards for management and disposal of TRU defense wastes as mandated in 40 CFR Part 191 (EPA, 1993) and Part 194 (EPA, 1995), and the RCRA regulations. Compliance demonstration through Sandia National Laboratory/New Mexico (SNL/NM) performance assessment (PA) calculations will be based on the inventory of existing and currently projected waste streams compiled in this document, as reported by the DOE TRU waste generator/storage sites. The WIPP is scheduled to receive and dispose of TRU defense wastes from 8 major and additional minor DOE TRU waste generator/storage sites (see Figure 1-1). In addition to the sites identified in Figure 1-1, there are several small quantity sites that may have DOE TRU wastes in storage and/or projected. These sites are listed below:

- Babcock & Wilcox – Parks Township; Vandergrift, PA
- GE Vallecitas Nuclear Center; Pleasanton, CA
- Massachusetts Institute of Technology; Boston, MA
- National Institute of Standards and Technology; Gaithersburg, MD
- Site A/Plot M; Argonne, IL
- Special Process Research Unit; Schenectady, NY

The TWBIR team contacted these sites and requested data on their TRU waste inventories. These sites were not able to respond to the TWBIR Revision 2 data call with sufficient information to be included in this revision of the TWBIR, but could be included in future revisions as more detailed data are submitted.

AE Argonne National Laboratory–East
AL Ames Laboratory
AM ARCO Medical Products Company
AW Argonne National Laboratory–West
BC Battelle Columbus Laboratory
BL Babcock & Wilcox–Lynchburg
BT Bettis Atomic Power Laboratory
ET Energy Technology Engineering Center
IN Idaho National Engineering Laboratory
IT Inhalation Toxicology Research Institute
KA Knolls Atomic Power Laboratory – Schenectady
LA Los Alamos National Laboratory
LB Lawrence Berkeley Laboratory
LL Lawrence Livermore National Laboratory
MC U.S. Army Material Command
MD Mound Plant
MU University of Missouri Research Reactor
NT Nevada Test Site
OR Oak Ridge National Laboratory
PA Paducah Gaseous Diffusion Plant
PX Pantex Plant
RF Rocky Flats Environmental Technology Site
RL Hanford (Richland) Site
SA Sandia National Laboratories/New Mexico
SR Savannah River Site
TB Teledyne Brown Engineering
WV West Valley Demonstration Project

♦ Indicates Small Quantity Site
★ Indicates Major Site

Figure 1-1. U.S. Department of Energy Transuranic Waste Generator/Storage Sites.

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Inhalation Toxicology Research Institute reports their waste stream profiles with Sandia National Laboratories/New Mexico submittals in Appendix P. Two Small Quantity Site, Babcock & Wilcox-Lynchburg and General Electric Vallecitas Nuclear Center, provided TRU waste volumes only. There is insufficient information provided to generate waste stream profiles for these wastes, so they are incorporated as "Possible Future Waste" for WIPP and are listed in Section 5.4.

1.2 PURPOSE

The purpose of the *Transuranic Waste Baseline Inventory Report* (TWBIR) is to document the total inventory of DOE TRU waste as defined by the DOE TRU waste generator/storage sites. This includes both the TRU waste that is planned to be disposed at the WIPP site and the TRU waste that will not be sent to WIPP. The WIPP portion of the TRU waste inventory will be used in the SNL/NM PA calculations and sensitivity analyses that will support the development of compliance applications to the appropriate regulatory agencies regarding the operations and post-closure timeframes of the WIPP repository. The total DOE TRU waste inventory will be used in the development of the DOE plan to define the disposal options for all WIPP and non-WIPP transuranic waste as required by the Land Withdrawal Act (LWA) (Public Law, 1992b).

To accomplish this purpose, the TWBIR has been developed from the best available information and acceptable knowledge provided by the DOE TRU waste generator/storage sites. In support of PA, the TWBIR describes a process for grouping individual waste streams with similar physical and chemical properties into waste profiles, based on their waste matrix code (WMC) (DOE, 1995b) assigned by the DOE TRU waste generator/storage sites. Waste profiles with similar WMCs, are then combined across the DOE TRU waste system to provide estimated total volumes and total waste material parameters (WMPs). The methodology for this grouping and combining is discussed in detail in Chapter 2, Waste Profile Methodology. The individual waste streams also are evaluated to estimate the occurrence and quantities of non-radioactive waste material parameters as defined in Appendix B and listed in Table 1-1 (e.g., cellulosics, plastics, iron-base metal/alloys, etc.) that have been identified by SNL/NM as being potentially important to the performance of the WIPP repository. The methodology, assumptions, and totals of these waste material parameters are described in Chapter 3, WIPP Disposal Inventory.

The information/data presented in this report is derived from the Transuranic Waste Baseline Inventory Database (TWBID). The TWBID supports most programs at WIPP that require waste information and/or volumes. Examples of some of the programs that are supported by the TWBID are: Performance Assessment (PA), RCRA Part B Permit Application (DOE, 1995f), WIPP No-Migration Variance Petition for Operations Period (DOE, 1995c), and the Supplemental Environmental Impact Statement (SEIS)-II for Disposal Phase (in development phase). In addition, the TWBID can support other projects and applications requiring waste information in formats different than that presented in the TWBIR. The TWBID structure and a data dictionary are included in Chapter 6 and Appendix L of this report.

1.3 WASTE INVENTORY TERMINOLOGY

The derivation of a disposal inventory from individual waste streams is a formidable and complex process. To document each step of this process, a system of waste inventory terminology needs to be defined so the reader may easily follow the process. The following sections provide

TABLE 1-1. TECHNICAL DATA NEEDS FOR PERFORMANCE ASSESSMENT WASTE MATERIAL PARAMETERS

Waste Material Parameter	Input Variable in Current PA Models		Input Variable in PA Models Under Development	Input Variable in Possible Future PA Models
	Gas Generation	Mechanical Characteristics		
Iron-Base Metal/Alloys	YES	YES	YES	YES
Aluminum-Base Metal/Alloys[1]		YES	YES	
Other Metal/Alloys		YES		POSSIBLE
Other Inorganic Materials		YES		POSSIBLE
Vitrified[2]		YES	POSSIBLE	POSSIBLE
Cellulosics	YES	YES	YES	YES
Rubber	YES[3]	YES	YES	YES
Plastics	YES[3]	YES	YES	YES
Solidified Inorganic Material		YES	YES	YES
Solidified Organic Material		YES	YES	YES
Cement (solidified)[4,5]	YES		YES	POSSIBLE
Soils[6]		YES	POSSIBLE	POSSIBLE

1 Future model for PA does not include aluminum.
2 New waste material parameter corresponding to treatment, identified by some sites, to be used in the future.
3 Only one-half of materials assumed to generate gas.
4 Percentage of material to generate gas is unknown at the present time.
5 Information on this waste material parameter is needed for non-PA scoping calculations for assessment of its importance.
6 May impact colloids.

definitions of terminology used throughout the TWBIR. These definitions are also summarized in Chapter 7, Glossary. A list of acronyms and abbreviations used are provided in the front of the document.

1.3.1 Inventory Terminology

Stored Inventory – The part of the TRU inventory currently in retrievable storage at the time of the last data call for inventory information is known as "stored inventory." For Revision 2, stored waste includes that waste in storage as of December 31, 1994, unless a different inventory date is indicated in the waste stream profiles (Appendices O and P). Retrievably stored waste includes

waste stored since approximately 1970 in buildings or in berms with earthen cover and does not include any waste that was buried prior to 1970 (DOE, 1990a).

As Generated Waste – The chemical and physical status of waste when it is generated. The "As-Generated" term applies to both stored and future generation waste.

Projected Inventory – The part of the TRU inventory that has not been generated but is currently estimated to be generated at some time in the future by the TRU waste generator/storage sites is known as "projected inventory." Because of the current uncertainty associated with environmental restoration (ER) and decontamination and decommissioning (D&D) waste inventory projections, the ER and D&D wastes are not included in the projected inventory, except for a few waste streams at some sites. For Revision 2, a projected inventory includes waste scheduled for generation from calendar year (CY) 1995 to 2022. "Newly generated waste" is sometimes used as a synonym for the projected inventory.

Anticipated Inventory – For the TWBIR, this is the sum of the stored and projected inventories, calculated as:

Stored Inventory	+	Projected Inventory	=	Anticipated Inventory

Scaling – The process for adjusting, if needed, the projected inventory to the design limit (disposal inventory) of the WIPP repository is called "scaling." Chapter 3, describes the scaling process used for developing the TWBIR.

Stored Inventory + Projected Inventory (scaled as needed) = Disposal Inventory

Disposal Inventory – The inventory volume defined for WIPP emplacement to be used for PA calculations is the "disposal inventory." The LWA defines the total amount of TRU waste allowed for disposal in the WIPP as 6,200,000 cubic feet (approximately 175,600 cubic meters) (Public Law, 1992b). The "Agreement for Consultation and Cooperation" (C&C Agreement) limits the RH-TRU inventory to 250,000 cubic feet (approximately 7,080 cubic meters) (DOE and State of New Mexico, 1981). Therefore by difference, the CH-TRU inventory will be limited to 5,950,000 cubic feet (approximately 168,500 cubic meters) if all of the RH-TRU allowance is filled.

1.3.2 Waste Matrix Code Terminology

Waste Matrix Code (WMC) - The WMCs were developed by DOE, in response to the Federal Facilities Compliance Act (FFCAct) (Public Law 1992a), as a methodology to aid in categorizing mixed waste streams in the DOE system into a series of five-digit alphanumeric codes (e.g., S5400; Heterogeneous Debris) that represent different physical/chemical matrices (DOE, 1995b). The WMC is assigned by the TRU waste generator/storage sites for all mixed waste streams and some non-mixed waste streams. The TWBIR has adopted this system to remain consistent with common terminology used by the DOE waste generator/storage sites.

Final Waste Form – Final Waste Form of a waste stream consists of a series of WMCs that are grouped together, which for PA purposes have similar physical and chemical properties. The Final Waste Form applies to both stored and future generation waste. An example of combining three waste streams which either contain particulates or are cemented particulate waste is presented below:

WMC S3100 (inorganic process residues)
WMC S3110 (inorganic particulates)
WMC S3150 (solidified process residues)
] Solidified Inorganics

Because of the restriction on particulate wastes in the *TRU Waste Acceptance Criteria (WAC) for the Waste Isolation Pilot Plant*, Revision 4 (DOE, 1991), particulate waste will usually be immobilized prior to shipment to WIPP. Therefore, all three of these WMCs would be the same basic waste form when emplaced in WIPP and have similar physical and chemical properties. The Final Waste Form for this example is solidified inorganics. Table 1-2 presents all anticipated WMCs for TRU waste and indicates the Final Waste Form typically assigned to each WMC for the TWBIR. There are 11 Final Waste Forms used in this TWBIR. The last two rows in Table 1-2, excluded waste streams and unknown, group WMCs that will not be accepted at WIPP unless additional characterization and/or processing occurs to meet the WIPP WAC (DOE, 1991). Wastes that are categorized as "Excluded" or "Unknown" are listed in Section 5.4, Possible Future Waste. Some sites did not assign WMCs to non-mixed TRU streams; but they did assign Final Waste Forms based on the physical and chemical properties of the waste stream.

1.3.3 Waste Profile Terminology

Waste Stream Profile – This is a description of a CH-TRU or RH-TRU waste stream. Sites were requested to define a waste stream as presented in Figure 1-2 and to describe their waste streams at the lowest practical level of Figure 1-2. The waste stream profile is presented in tabular format and is intended to provide a summary of important information about a particular waste stream. Examples of information included in a waste stream profile are:

- Waste Stream description.
- Waste Stream source description.
- Currently used identification codes, including the DOE TRU waste site matrix description;
- Final waste form assigned by the TRU waste generator/storage sites;
- As-generated waste form volumes and Final Waste Form volumes:
- Estimated minimum, average, and maximum weights of waste material parameters per cubic meter of final waste form volume (e.g., iron-base metal/alloys, aluminum-base metal/alloys, cellulosics, etc.);
- Indication as to whether the waste is CH-TRU or RH-TRU;
- Indication as to whether the waste is mixed or non-mixed;

TABLE 1-2. WASTE MATRIX CODES AND THEIR ANTICIPATED FINAL WASTE FORM

Final Waste Form	Waste Matrix Codes
Solidified Inorganics	L1000[1], L1100[1], L1110[1], L1120[1], L1130[1], L1140[1], L1190[1],1200[1], L1210[1], L1220[1], L1230[1], L1240[1], L1290[1], S3000[2], S3100[3], S3110[3], S3111[3], S3112[3], S3113[3], S3115[3], S3118[3], S3119[3], S3120[1], S3121[1], S3122[1], S3123[1], S3124[1], S3125[1], S3129[1], S3130[1 or 3], S3131[1 or 3], S3132[1 or 3], S3139[1 or 3], S3144[3], S3150, S3160[3], S3190[1 or 3], S3900[2], X6000[4], X6200[5], X6300[6], X6400[5], X6900[4], X7300[3], X7500[8], X7510[8], X7520[8], X7530[8], X7590[8], L9000[2], Z1110, Z1190
Salt	S3000[2], S3140, S3141, S3142, S3143, S3149, S3900[2], L9000[2]
Solidified Organics	L2000[1], L2100[1], L2110[1], L2120[1], L2190[1], L2200[1], L2210[1], L2220[1], L2290[1], L2900[1], S3000[2], S3114[3], S3200[3], S3210[3], S3211[3], S3212[3], S3219[3], S3220[1], S3221[1], S3222[1], S3223[1], S3229[1], S3230[3], S3290[1 or 3], S3900[2], S5340[3], X6000[4], X6100[5], X6190[4], X6900[4], L9000[2], Z1110, Z1190
Soils	S4000, S4100, S4200, S4300, S4900,
Uncategorized Metal (Metal Waste Other Than Lead and/or Cadmium)	S3116, S5000[9], S5100[7], S5110, S5111, S5119, S5190, X6200, X7000[10], X7290, X7400[11], X7430, X7490[11], X7520[8], Z1140, Z1190, Z2100[10]
Lead/Cadmium Metal	S5000[9], S5100[7], S5110, S5112, S5113, S5119, S5190, X6220[8], X7000[10], X7200, X7210, X7211, X7212, X7219, X7220, X7290, X7400[11], X7410[11], X7420[11], X7490[11], Z2100[10]
Inorganic Non-Metal	S3117, S3118, S3160, S5000[9], S5100[7], S5120, S5121, S5122, S5123, S5124, S5125, S5126, S5129, S5190, Z1120, Z1150, Z1190
Combustible	S5000[9], S5300, S5310, S5311, S5312, S5313, S5319, S5320, S5330, S5390, Z1130, Z1190, Z1200
Graphite	S5000[9], S5126
Heterogeneous	S5000[9], S5100[9], S5400, S5420, S5440, S5450, S5460, S5490, X7520[8], Z2900
Filter	S5000[9], S5410
Excluded Waste Streams[12]	X7000, X7100, X7600, X7700
Unknown[13]	S5190, X7900, L9000, S9000, Z9000, U9999

TABLE 1-2. FINAL WASTE FORM NAMES (CONTINUED)

[1] Liquid waste streams are assumed to be solidified prior to sending to WIPP.

[2] WMCs S3000, S3900, and L9000 are placed in "solidified inorganics," "salt," or "solidified organics," depending on the information provided by the TRU waste generator/storage site.

[3] Particulate waste streams are assumed to be solidified prior to sending to WIPP.

[4] WMCs X6000 and X6900 are placed in "solidified organics," or "solidified inorganics," depending on the information provided by the TRU waste generator/storage site.

[5] Liquid lab pack waste is assumed to be solidified prior to sending to WIPP.

[6] Solid lab packs are assumed to be solidified prior to sending to WIPP.

[7] WMC S5100 is placed in "uncategorized metal," "lead-cadmium metal," or in "inorganic non-metal," depending on the information provided by the generator/storage site.

[8] Waste stream is assumed to be treated prior to sending to WIPP.

[9] WMC S5000 is placed in "uncategorized metal," "lead/cadmium metal," "inorganic non-metal," "combustible," "graphite," "heterogeneous," or "filter," depending on the information provided by the generator/storage site.

[10] WMC Z2100 is placed in "uncategorized metal" or "lead/cadmium metal," depending on the information provided by the generator/storage site.

[11] WMCs X7400, X7410, X7420, and X7490 are assumed to be drained of liquid and contain only metal waste.

[12] These waste streams are excluded from disposal in WIPP at this time, e.g., PCB and elemental mercury.

[13] If adequate information is provided by the TRU waste generator/storage site, these WMCs are changed. If there is not enough information, these waste streams remain as "unknown" and are excluded from disposal in WIPP until characterized.

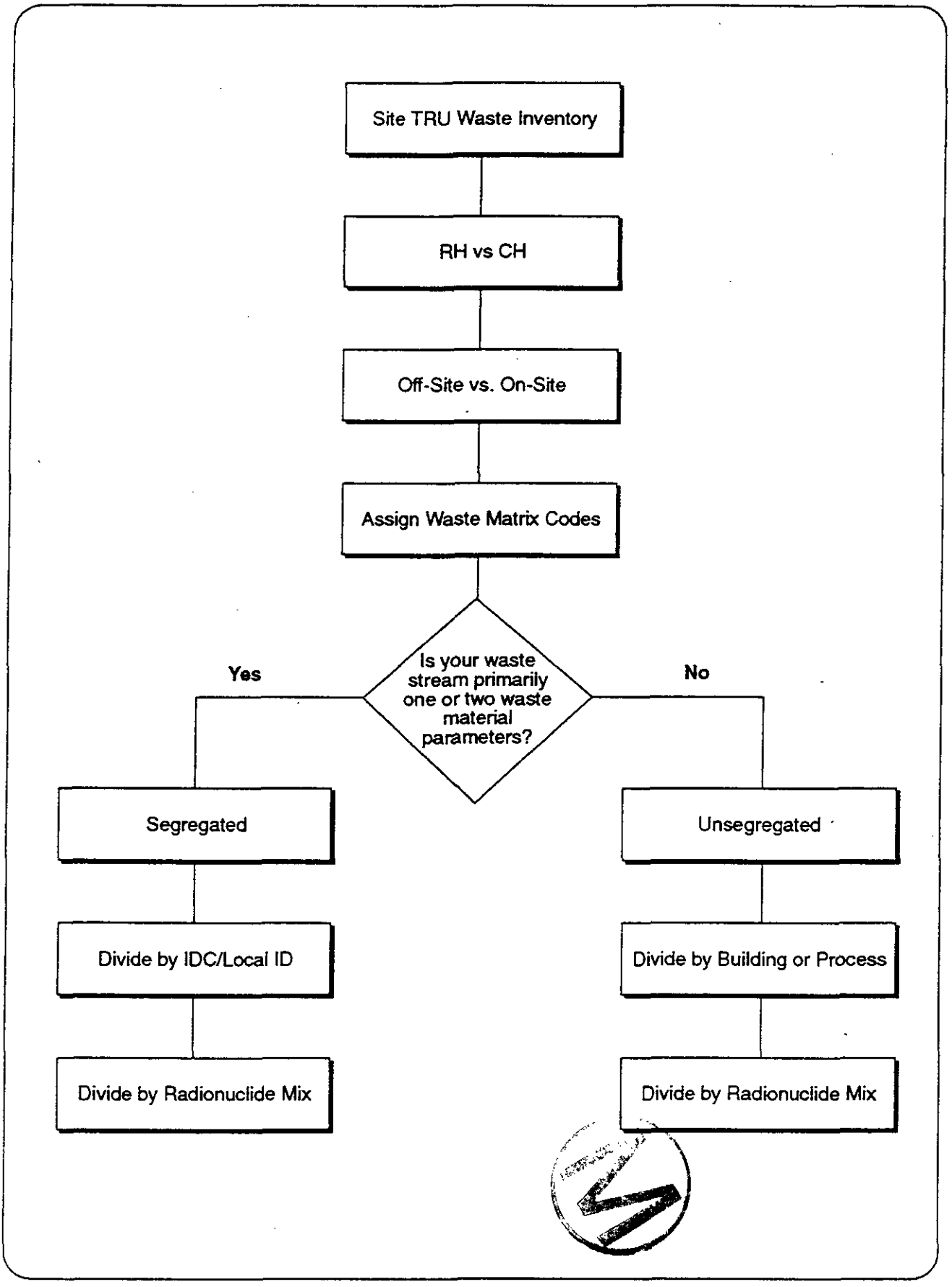

Figure 1-2. Definition of a Waste Stream

- As-generated Hazardous waste codes (EPA codes) as assigned by the DOE TRU waste generator/storage sites for the RCRA regulated portion of the waste stream. Some waste streams (waste stream profiles) contain hazardous waste codes that would not be currently acceptable for disposal in WIPP (e.g., D001, D002, and D003) under the most recent WIPP Part B Permit Application (DOE, 1995f). These hazardous waste codes are applied to the waste in its current physical form. These waste streams will have to be treated for any unacceptable hazardous constituents prior to transport to WIPP for disposal.
- Final Waste Form radionuclide inventory: activity in curies per cubic meter.
- Comments provided by the TRU waste generator/storage sites to further explain the data provided.
- TRUPACT-II Content (TRUCON) Codes (DOE, 1994c) and No Migration Variance Petition (NMVP) (DOE, 1990b) identifiers, where provided by the site.

Figure 1-3 provides an example of a blank waste stream profile form. The methodology for developing waste stream profiles is described in Chapter 2 and the TRU waste stream profiles are provided in Appendices O, P, and in the TWBID database files.

Site-Specific Waste Profile – This represents a Final Waste Form at a particular DOE TRU waste generator/storage site. That is, one or more waste stream profiles at a particular DOE TRU waste site, that have been placed in the same Final Waste Form, are summarized in the site-specific waste profile. Examples of information included in a site-specific waste profile are:

- DOE TRU waste generator/storage site identification;
- The Final Waste Form that the profile represents;
- Listing of the waste streams (represented by waste stream profiles provided by the TRU waste generator/storage sites) that are included in the site-specific waste profile, including the waste stream identification;
- Final Waste Form volumes (both stored and currently projected); and
- Summary of minimum, volume weighted average, and maximum weights of waste material parameters per cubic meter of final waste form volume on a site basis (e.g., iron-base metal/alloys, aluminum-base metal/alloys, cellulosics, etc.).

Figure 1-4 provides an example of a blank site-specific waste profile form. The methodology for developing site-specific waste profiles is described in Chapter 2 and printouts of WIPP TRU site-specific waste profiles are provided in Appendix A.

Waste Sub-stream – A waste sub-stream is one that results from a waste stream being divided into two or more fractions (for the purposes of reporting) in order to provide an additional level of detail about a site's current plans for repackaging or treating the waste.

WIPP Waste Profile – The WIPP waste profile represents a summary of TRU wastes at all DOE TRU waste generator/storage sites that have an identical Final Waste Form. Examples of information included in a WIPP waste profile are:

- The Final Waste Form that the profile represents;

TWBIR ID:

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:		Handling:		NMVP #:		Stream Name:				Inventory Date:	
Local ID:		Type:		Generator Site:		Final Waste Form:		Waste Matrix Code:		TRUCON Code:	

AS-GENERATED EPA CODES

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		

FINAL WASTE FORM DESCRIPTORS

Defense:

Residues:

Asbestos:

PCBs:

Source:

SITE IDCs

FINAL FORM RADIONUCLIDES

Isotope Activity (Ci/m3)

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	96-97	98-02	03-12	13-22	Totals

Final Waste Form Volumes

Container	Stored	96-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: Projected: Total:

Final Waste Form: Stored: Projected: Total:

WASTE STREAM DESCRIPTION

WASTE STREAM SOURCE DESCRIPTION

CURRENT CONTAINER COMMENTS

Figure 1-3. Blank Waste Stream Profile Form

TWBIR ID:

TRU WASTE BASELINE INVENTORY WASTE PROFILE

COMMENTS	
EPA COMMENTS	
MANAGEMENT COMMENTS	
ACCEPTANCE COMMENTS	

Figure 1-3. Blank Waste Stream Profile Form (continued)

Site-Specific Contact Handled Waste Profiles

Site Name:

Final Waste Form:

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)

Total Volume:

Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metals			
Aluminum Base Metals			
Other Metals			
Other Inorganic Material			
Vitrified			
Cellulosics			
Rubber			
Plastics			
Solidified Inorganic Materi			
Solidified Organic Materia			
Cement (Solidified)			
Soils			

Figure 1-4. Blank Site-Specific Waste Profile Form

- Listing of the DOE TRU waste sites (represented by the same Final Waste Form) that are included in the WIPP waste profile, including the name of the DOE TRU waste site;
- Final Waste Form volumes of stored and currently projected waste for each site and
- Summary of minimum, volume weighted average, and maximum weights of waste material parameters per cubic meter of final waste form volume on a WIPP basis (e.g., iron-base metal/alloys, aluminum-base metal/alloys, cellulosics, etc.).

Figure 1-5 provides an example of a blank WIPP waste profile form. The methodology and assumptions for developing WIPP waste profiles and printouts of the WIPP profiles are described in Chapters 2 and 3.

1.3.4 Database Terminology

Integrated Data Base (IDB) – The IDB refers to the latest version of the *Integrated Data Base: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics* (DOE, 1995d).

Transuranic Waste Baseline Inventory Database (TWBID) – The TWBID is the database specifically developed to support the TWBIR and any other applications that might need TRU waste information on a waste–stream basis or for higher–level roll-ups.

1.3.5 Other Terminology

Waste Material Parameter – This is one or more nonradioactive waste constituents that occur in a TRU waste stream that is an input parameter into one or more current PA models or PA models under development, a potential future model, or is required to adequately describe the waste form (see Appendix B). The 12 waste material parameters have been grouped by their chemical/physical properties. These waste material parameters and additional packaging materials that are reported in densities (kg/m^3) and included in the TWBIR are:

WASTE MATERIAL PARAMETERS
- Iron-base metal/alloys
- Aluminum-base metal/alloys
- Other metal/alloys
- Other inorganic materials
- Vitrified
- Cellulosics
- Rubber
- Plastics
- Solidified inorganic material
- Solidified organic material
- Cement (solidified)
- Soils

PACKAGING MATERIALS
- Steel
- Plastic
- Lead

Definitions for these waste material parameters can be found in Chapter 2.

WIPP Contact Handled Waste Profiles

Final Waste Form:

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)

Total Volume _____

	Material Parameters (Kg/m3)		
	Maximum	Average	Minimum
Iron Base Metals			
Aluminum Base Metals			
Other Metals			
Other Inorganic Material			
Vitrified			
Cellulosics			
Rubber			
Plastics			
Solidified Inorganic Materi			
Solidified Organic Materia			
Cement (Solidified)			
Soils			

Figure 1-5. Blank WIPP Waste Profile Form

1.4 OBJECTIVES

The objectives of the TWBIR are:

1. **Establish a consistent DOE complex-wide methodology for grouping TRU wastes of similar physical and chemical composition.** A consistent methodology, in support of PA, for grouping TRU wastes of similar physical and chemical properties into "waste profiles" will provide a common frame of reference for discussion of TRU waste issues with regulatory organizations.

2. **Define the inventory of TRU wastes destined for WIPP.** The anticipated inventory of CH-TRU and RH-TRU wastes is defined as the sum of the existing volumes of stored and currently projected waste streams at each of the TRU waste generator/storage sites. The WIPP disposal inventory is defined in Section 1.3.1.

   Scaling of the currently projected CH-TRU waste inventory is necessary to attain the WIPP capacity. There is a high level of uncertainty in and a current lack of consistent data on waste projected to be produced by D&D and ER activities. DOE is developing the ER and D&D inventories through the 1995 *Baseline Environmental Management Report* (BEMR) data call (in development). The data for this report were not available in time to be incorporated in this revision of the TWBIR. Therefore, the projected inventory has been scaled to the WIPP capacity (disposal inventory).

3. **Calculate the disposal inventory in terms of waste material parameters.** Several waste material parameters (e.g., iron-base metal/alloys, rubber, plastics, etc.) have been identified by SNL/NM as being potentially significant in relation to the performance of the WIPP repository (see Table 1-1). Calculating the WIPP disposal inventory in terms of these parameters provides input for the PA calculations and sensitivity analyses needed to determine compliance with federal standards.

4. **Define the total DOE TRU waste inventory.** The Land Withdrawal Act requires that DOE develop recommendations and schedules for the disposal of all DOE TRU waste (Public Law, 1992b). The inventory presented in this document will be used in the development of the plan to respond to the LWA requirement.

1.5 TRU SYSTEM-WIDE DATA ASSUMPTIONS

As stated earlier, the TWBIR was developed using the best available information from the TRU *waste generator/storage sites. Some sites used different assumptions and methodologies for* reporting their waste stream data. Because of these differences, the TWBIR team had to make assumptions and take specific steps to ensure consistency among the sites' reported data. This section addresses the system-wide assumptions and actions taken by the TWBIR team in reporting the waste stream data. All adjustments made to the TRU waste generator/storage sites' data by the TWBIR team were approved by the sites. For a description of site-specific assumptions, see discussion in front of each site's waste stream profiles in Appendices O and P.

1.5.1 Waste Material Parameter Assumptions

The waste material parameter information reported by the sites must be summed and averaged to obtain data at the site-specific and WIPP waste profile levels. For some waste streams, however, not all of the waste parameter data were available from the sites. In order to calculate material parameters from the waste stream data provided by the sites, the following assumptions were made by the TWBIR team:

- If no minimum was provided, but a maximum was provided, the minimum was assumed to be zero.
- If a maximum and minimum were provided, but no average, the average was assumed to be one half the sum of the maximum and minimum.
- If an average was provided but no minimum or maximum, the average was assigned to the minimum and maximum.
- If only a minimum was provided, the minimum was assigned to both the maximum and the average.

For those waste streams where the site did not provide any waste material parameter information, but which could be assigned to a final waste form, an average set of parameters was calculated and used. This average set of parameters was calculated by volume averaging the parameters provided for other waste streams with the same final waste form.

Waste material parameter data contained in the body of this report are based on these assumptions, whereas, individual waste stream profiles included in Appendices O and P or in the database which accompanies this report contain the original, unchanged data as reported by the TRU waste generator/storage sites.

1.5.2 General Inventory Volume Assumptions

Other assumptions had to be made by the TWBIR team to ensure consistency in inventory volumes:

- Some sites did not provide final waste form volumes for waste streams that would be shipped to WIPP. Final waste form volumes are used in determining the overall inventories. In those instances, the TWBIR team assumed that the reported, as-generated volume would be the same as the final waste form volume.
- Many sites reported the final waste form containers (volumes) in the year that the waste will be treated or repackaged and not in the year the waste is initially generated. Because it is not the intent of the TWBIR to be a WIPP load management document, the TWBIR team put those treated/repackaged waste volumes in the year of initial generation, rather than show the work-off plans for the sites.

1.5.3 Changes to Rocky Flats Environmental Technology Site Volume and Curies Due to Change in Processing Option for Plutonium Residues

The Rocky Flats Environmental Technology Site (RFETS) changed their processing option for plutonium residues after the Revision 2 TWBIR data were submitted. The waste stream data provided in the TWBIR Revision 2 data update are based on processing of plutonium residues to recover plutonium. The current processing option is to repackage the plutonium residues to meet WIPP WAC (DOE, 1991) and ship as TRU waste to WIPP for disposal. There was not

enough time left in Revision 2 TWBIR update for RFETS to completely restructure their waste stream profiles to the new processing option in time to achieve the TWBIR Revision 2 schedule. Therefore, in order to more accurately represent the new treatment option (repackaging; ship as waste to WIPP) for plutonium residues, the following supplementary information was requested from RFETS (see Appendix J):

- Changes in total volume of waste by "Final Waste Form" due to the change in processing options
- Report the additional amount of radionuclides that would occur in the RFETS inventories as a result of not processing the plutonium residues to recover plutonium.

The methodology used to incorporate this supplemental information from RFETS, due to the new processing option, into the anticipated inventory (volumes) and the disposal radionuclide inventory (curies) is outlined below.

- The RFETS waste stream profiles are reported (Appendix P or the database that accompanies this report) as submitted with the older processing option, recovery of plutonium.
- In the RFETS site transuranic waste volume (Chapter 4), after all the individual waste stream profiles have been summed for a particular final waste form, the summed volumes are adjusted per the RFETS memo (Appendix J) and this adjustment is indicated in a footnote to the WIPP waste profiles.
- The "adjusted" final waste form volumes for RFETS are then in the summation of all TRU waste site volumes by final waste form to calculate the volumes for the WIPP waste profiles.
- The waste material parameter distributions for the new "ship as waste" option is assumed to be the same as that calculated in the "process to recover plutonium" option.
- Finally, the increased curies reported by RFETS due to the changes in processing options are added to the RFETS radionuclide inventory (Appendix D) and the WIPP radionuclide inventory (Table 3-4). The increased plutonium residue curies are not decayed to end of CY 1994 because RFETS did not have enough time to provide the residue radionuclide inventory for each year.

1.5.4 Packaging Material Assumptions

The TRU waste container data were not always reported consistently. While most did, some of the sites did not provide data for final waste form in WIPP approved containers as defined in WIPP WAC, Revision 3 (DOE, 1989). Some reported their waste in as-generated containers while others did not provide container information. Adjustments had to be made to the data to:

- Achieve consistency at the waste stream level in the presentation of data in the waste stream profiles (Appendices O and P or in the database which accompanies this report).
- Produce the upper-level waste packaging roll-ups needed by PA as inputs to the modeling activities.

1.5.5 Waste Profile Assumptions

The DOE TRU waste generator/storage sites assigned the TRUCON and NMVP codes based on the best available information. Many of the waste streams reported in Appendices O and P (or the database that accompanies this report) do not have TRUCON codes. The generator/storage sites will be required to generate the characterization paperwork necessary for DOE to include these waste streams in TRUCON. The cross-correlation table presented in Appendix E identifies each waste stream, TRUCON code, and NMVP code (if available).

Each waste stream profile was reviewed for consistency in reporting packaging configurations. In cases where incomplete information was submitted, clarifications were requested from the TRU waste generator/storage sites. In those cases where clarifications were not received from these sites, the following assumptions were made, concerning the waste stream profiles:

- If a particular waste container (e.g., 55-gallon drum) was reported by the sites (but no further information was provided), "standard" values of the waste container properties (see Table 1-3) were added to the waste profile forms. An example of this process is listed below for a reported 55-gallon drum without any additional information:

  - Type of material used to fabricate the waste container (steel)

  - The internal volume of the container (0.208 m^3)

  - Inclusion of a "standard" density for the container (131 kg/ m^3).

- If sites reported a "plastic" or "rigid" liner without any further definition of the liner then the values in Table 1-3 were used in the waste stream profiles:

  - A 90-mil high density polyethylene (HDPE) liner was assumed

  - The density for that type of liner was assumed (37 kg/m^3).

For RH-TRU waste, the following assumptions were made:

- If the waste was reported in drums, the drums were assumed to be overpacked in RH canisters at a maximum of three drums per canister.
- If the waste was not reported to be in drums, the waste was assumed to be direct loaded into RH canisters. The standard internal volume for RH canisters and the reported waste stream volume were used to determine the number of RH canisters.
- The lead in the RH canister (464 kg/m^3) is assumed in the packaging roll-ups even if it was not stated on each RH waste stream profile by the TRU waste generator/storage site.

Sites were requested to provide inventories and projections in number of containers. To be consistent with other DOE inventory reports (i.e., proposed Site Treatment Plans, IDB), the TWBIR team converted the number of containers to cubic meters using the internal container volume provided by the sites.

Table 1-3. Packaging Material Assumptions*

Container Configuration	Steel (kg/m^3)	Plastic (kg/m^3)	Lead (kg/m^3)	Volume (m^3)
55-gallon drum	131	37	N/A	0.208
SWB (direct load)	154	1.2	N/A	1.89
SWB (overpack) (4 55-gallon drums)	211	16	N/A	1.89
RH-TRU Canister (direct load)	434	0	464	0.89
RH-TRU Canister (overpack of 3 55-gallon drums)	526	26	464	0.89

*See calculations in Appendix M.

1.5.6 Radionuclide Information Assumptions

Some TRU waste sites reported incomplete radionuclide information (e.g., some show mixed fission products but no transuranic isotopes) for some waste streams. It is assumed that these waste streams will be demonstrated to be TRU upon completion of the radionuclide characterization.

Some sites did not report the radionuclide inventories for some waste streams in the units required by the TWBIR (curies per cubic meter). If the sites could provide the conversion factors, the TWBIR team converted the units to curies per cubic meter. If the conversion factors could not be provided, the radionuclides for these waste stream profiles were not reported in Appendices O and P or in the database that accompanies this report.

As indicated in Section 1.5.3, RFETS requested to change their TWBIR Revision 2 data package after submission. The data package modification was to incorporate a change in processing options for plutonium residues from recovery of plutonium to repackage and ship as waste to WIPP for disposal. The additional increment of curies due to the change in processing options has been included in the RFETS radionuclide submittal for Revision 2, which is reflected in the disposal radionuclide inventory presented later in Chapter 3, Table 3-4 and Appendix D.

The reported radionuclide information provided by the TRU waste generator/storage sites on a waste stream basis for most waste stream profiles is reported in Appendices O and P or in the database that accompanies this document. These data are provided for informational purposes only. The waste stream specific radionuclide data are not used in the calculation of the radionuclide inventory in Chapter 3.

1.6 SOURCE OF TRU WASTE INFORMATION

The TRU waste disposal inventory is derived from existing information on waste, which has been provided by the DOE TRU waste generator/storage sites and is primarily based on acceptable knowledge (see Glossary in Chapter 7). In addition to the general acceptable knowledge of a waste stream for non-radionuclide parameters, the radionuclide inventories are derived from non-

destructive assay, with some chemical analyses (to detect isotopes that do not lend themselves to non-destructive analyses or to evaluate waste streams that cannot be effectively analyzed through non-destructive methods), and on-site accountability and tracking records of special nuclear materials including any changes of isotopic ratios during processing.

Transuranic waste information primarily exists in two forms within the DOE TRU waste system:

- On-site documentation developed by the TRU waste generator/storage sites during the history of their operations.
- Summary reports, usually prepared to support WIPP documentation requirements. These summary reports have either been generated by the DOE area office in charge of WIPP or at the DOE-Headquarters (HQ) level. The information contained in these reports is derived from the TRU waste generator/storage sites.

Each of these two forms of waste information is described below.

1.6.1 Site-Specific Waste Information

The TRU waste generator/storage sites use a variety of on-site documents and records in order to derive the information listed for each individual waste stream in Appendices O and P or the database that accompanies this report. The documents/records can include many different sources, some of which might be the following: procurement records, waste stream process manuals, operating procedures, on-site safety documentation, process diagrams, waste production records, storage records, on-site waste database management systems, interviews with existing and former workers, transportation records, waste container tracking records, on-site documentation prepared for local, state, or regional regulators. This list is not meant to be inclusive or representative of all records used at every site, but is intended to be used for example purposes only. The number and types of documents can vary greatly from site-to-site so it is impractical to list them as references in this document.

The TWBIR team provided each DOE TRU waste site with a data package defining each TRU waste stream at their site that was reported in the WTWBIR, Revision 1 from their previous data submittals. The TRU waste generator/storage sites reviewed, changed, and authorized the characterization as valid for use in developing the TRU inventory for the TWBIR, Revision 2.

1.6.2 Existing Summary Documents on TRU Waste Information

In support of various programs, the DOE has published a series of documents over the years that contain varying amounts of waste information. Listed below are those documents that have formed the foundation of summary TRU waste information prior to the publication of the TWBIR.

Mixed Waste Inventory Report

The FFCAct required that the DOE, within 180 days of enactment of the FFCAct, submit to the EPA Administrator and the governor of each state in which the DOE stores or generates mixed wastes a report that contains:

- National inventory of all mixed wastes, regardless of the time they were generated, on a state-by-state basis and
- National inventory of mixed waste treatment capacities and technologies.

The FFCAct also stipulated specific reporting requirements for each of these inventories. The DOE submitted the six-volume set entitled: *U.S. Department of Energy Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capacities and Technologies* (IMWIR), DOE/NBM-1100, dated April 1993 (DOE, 1993b), to fulfill these requirements. Since issuance of the "interim" report, DOE has requested additional information from the DOE TRU waste generator/storage sites and published two updated reports entitled:

- *Release of Phase I Mixed Waste Inventory Report Data*, dated April 1, 1994 (Phase I MWIR) (DOE, 1994b), which includes a data diskette (Version .97B) and the draft *Mixed Waste Inventory Report Data Base System User's Guide*.
- *Distribute* [Distribution] *of the Phase II Mixed Waste Inventory Report Data*, dated May 17, 1994 (Phase II MWIR) (DOE, 1994a), which includes a data diskette (Version 1.00) and the draft *User's Guide for National Data Base System for the Final Mixed Waste Inventory Report* (May 1994).
- *1995 National Mixed Waste Inventory Report Data System* which is the updated *1995 Mixed Waste Inventory Report* (DOE 1995g).

The Phase II MWIR was the basis of the mixed waste streams that were included in Revision 0 of the WTWBIR. The *1995 National Mixed Waste Inventory Report Data System*, Revision 11 of the IDB, and Revision 2 of the TWBIR were based on a joint request for data. Because the waste streams reported in the MWIR are the same as the mixed waste streams reported in the TWBIR, it was decided to expand the data call to accommodate both systems.

Integrated Data Base

The IDB (DOE, 1995d) is published by Oak Ridge National Laboratory (ORNL) for the DOE. The ORNL assembles radioactive waste inventories provided by DOE TRU waste generator/storage sites. This database does not report by waste stream, but rather, by the total inventory at each DOE site. The IDB also contains the radionuclide isotopic distribution for the waste stored at each site. In the past there were apparent inconsistencies between the WIPP TRU Waste Baseline Inventory Report and the IDB inventories due to the time differences and assumptions associated with the two data calls and due to the differences in reporting formats (e.g., "as-generated" versus "final form" volumes). In an effort to eliminate such inconsistencies, the TRU waste section of Revision 11 of the IDB (DOE, 1995d) was developed based on the Revision 1 WTWBIR data call and is presented in Appendix G of this document.

Other Sources of TRU Waste Information

There are additional summary documents that have been produced which contain extensive information about TRU waste. The amount and form of the documentation varies between documents due to the initial purpose for including waste information. These include:

- TRUCON (DOE, 1994c) - This document was developed to provide waste information to the Nuclear Regulatory Commission (NRC) in support of the TRUPACT-II certification application. The TRUCON concentrated on those waste parameters that were important for safe transportation of TRU waste (e.g., thermal heat loading, criticality, free liquids, etc.)
- NMVP (DOE, 1990b) - The No-Migration Variance Petition (NMVP) was developed by DOE to obtain a variance from the land disposal restrictions for mixed waste during the WIPP test phase as allowed under 40 CFR 268.6 (EPA, 1986). The NMVP waste information

concentrated on defining the volumes of various known TRU and MTRU waste streams in the DOE system at that time, and identifying the hazardous constituents expected to be found in the MTRU waste streams. Text was provided in the NMVP on each known waste stream at that time which summarized the acceptable knowledge and sampling and analysis information available (many TWBIR waste streams were not defined at the time the NMVP was developed). A NMVP for the operations/disposal phase will be submitted in 1996 to the EPA. The most current version of the TWBID will be the basis of the waste inventories in the operations/disposal phase NMVP.

- WIPP RCRA Part B Permit Application (DOE, 1995f) – This document has been submitted to the State of New Mexico to obtain a RCRA Part B Permit for WIPP.

TRU waste streams that are included in the TRUCON and the NMVP are cross correlated, if possible, to TWBIR waste streams in Appendix E. The designation of each waste stream in the TRUCON and NMVP, if applicable, can be found on the waste stream profile (Figure 1-3). The TWBIR should be considered the most current source of waste stream information when there is a discrepancy in information between the TWBIR and the TRUCON or NMVP documents.

1.7 METHODOLOGY FOR DEVELOPMENT OF DISPOSAL INVENTORY

Development of the WIPP TRU waste disposal inventory is accomplished by a series of steps starting with the individual waste streams submitted by the TRU waste generator/storage sites that are identified in Appendices O and P or the database that accompanies this report. These waste stream profiles are grouped together, based on similar physical and chemical properties, into common "WIPP waste profiles," which should facilitate discussions concerning the disposal waste inventory with regulatory agencies and stakeholders. The waste profiles also contain information on waste material parameters that could affect the performance of the WIPP repository and that may be direct inputs to the PA models. A more detailed explanation of the waste profile methodology is found in Chapter 2.

Because the volume of the anticipated inventory (as defined in Section 1.3.1) is not sufficient to fill the maximum calculated CH-TRU capacity of WIPP, scaling of the projected CH-TRU inventory is necessary to attain the following WIPP disposal inventory:

- Maximum calculated CH-TRU inventory = 5.95 million cubic feet (approximately 168,500 cubic meters) (see Section 1.3.1)

The anticipated inventory (as defined in Section 1.3.1) consists of up to 11 overall CH-TRU WIPP Final Waste Forms based on the physical and chemical properties of the waste streams. The CH-TRU scaling factor is computed as follows:

- For CH waste:

$$\frac{\text{maximum calculated CH-TRU inventory - stored CH-TRU inventory}}{\text{projected CH-TRU inventory}} = \text{CH-TRU scaling factor}$$

If the sum of the anticipated RH-TRU and CH-TRU inventories are less than the maximum allowable WIPP capacity, the projected inventory in future revisions of the TWBIR will include volumes of waste anticipated from D&D and ER activities as these estimates are made available.

The WIPP disposal inventory is the inventory to be used in PA calculations. To calculate the disposal inventory by Final Waste Form for CH-TRU waste, the projected inventory is multiplied by the scaling factor, added to the stored inventory for each Final Waste Form and summed together. See Section 3.2 for further details.

The RH-TRU anticipated inventory is greater than the WIPP C&C Agreement limit (DOE and State of New Mexico, 1981) of approximately 7,080 cubic meters. DOE will abide by the WIPP C&C Agreement for RH-TRU waste volumes and the Land Withdrawal Act which limits the curies of RH-TRU waste allowed in WIPP to 5.1 million curies (Public Law, 1992b). As stated earlier, one purpose of the TWBIR is to report the DOE TRU inventory in such a way that it will facilitate performance assessment by SNL/NM and support development of compliance applications to the appropriate regulatory agencies. **This is not a WIPP load management document. For these reasons, the RH-TRU inventory has not been scaled back in this document to the regulatory limit.** The RH-TRU inventory for WIPP will be averaged across all RH-TRU waste sites and reported as kg/m^3 for the waste material parameters and curies/m^3 for radionuclides.

1.8 BASELINE INVENTORY UPDATES

The TWBIR represents the best available TRU waste inventory information in support of the WIPP Project. It is anticipated that the TWBIR will be updated periodically. This update cycle will be modified based on the availability of additional waste information and/or the data needs of the WIPP Project as determined by the DOE.

1.9 DOCUMENT ORGANIZATION

The TWBIR is organized into chapters of text, figures, tables and supporting appendices. It flows from specific, detailed TRU waste information (provided by the TRU waste generator/storage sites) to the top level development and description of waste profiles and waste material parameters. The contents of remaining chapters in this document are summarized below:

- Chapter 2 discusses the waste profile methodology .
- Chapter 3 presents the WIPP disposal inventory: volumes, waste material parameters, and radionuclide inventory.
- Chapter 4 provides the stored and currently projected WIPP CH-TRU and RH-TRU inventories by site.
- Chapter 5 provides waste streams that are currently unacceptable for disposal in WIPP.
- Chapter 6 contains a description of the TWBID.
- Chapter 7 contains a glossary of important terms used in this document.
- Chapter 8 lists references cited in the TWBIR.
- Appendix A provides the WIPP site-specific waste profiles.
- Appendix B provides the SNL/NM memorandum describing the WIPP inventory data needed for PA modeling.
- Appendix C provides the TWBIR Revision 2 questionnaire.

- Appendix D provides the site-specific stored radionuclide inventories decayed to December 1995.
- Appendix E provides the cross-correlation table for the TWBIR Revision 2, TRUCON, and the NMVP.
- Appendix F provides the MWIR code designations and descriptions.
- Appendix G provides the TRU waste section of the 1995 Integrated Data Base, Revision 11.
- Appendix H provides a cross-reference table for the WTWBIR Revision 1 waste streams and the TWBIR Revision 2 waste streams.
- Appendix I provides a table of the phosphates, sulfates, and nitrates reported by the DOE generator/storage sites.
- Appendix J provides the Rocky Flats Environmental Technology Site memorandum that describes the volume and curie changes due to the change in processing assumptions for plutonium residues.
- Appendix K provides summary information of the mixed and non-mixed WIPP waste by site.
- Appendix L provides the TWBID Revision 2 Data Dictionary.
- Appendix M provides Waste Packaging Material Derivation Calculations.
- Appendix N provides the guidelines for review of generator/storage site waste stream profiles.
- Appendix O provides the non-WIPP waste stream profiles.
- Appendix P provides the WIPP waste stream profiles.

There will be two distributions of the TWBIR, Revision 2 document. One will be presented in three volumes: Volume 1 contains the TWBID diskettes; the Preface; Executive Summary through Chapter 8; Volumes 2 and 3 contain Appendices A through P. This document presentation will be distributed to regulatory agencies, DOE and other top-level interfaces. A second distribution will be presented in one volume. For this second type of distribution, the volume will contain the TWBID diskettes; the Preface; Eecutive Summary through Chapter 8; and Appendices A through N. Information for Appendices O and P can be found on the diskettes. This document presentation will be distributed to all other users of the TWBIR.

CHAPTER 2

2. WASTE PROFILE METHODOLOGY

2.1 INTRODUCTION

The lowest tier of information in the TWBIR is the waste stream profile, which documents specific information for each separate TRU waste stream identified by each DOE TRU waste generator/storage site. In this chapter the waste stream profile will be discussed along with the methodology for grouping waste streams into site-specific profiles and WIPP waste profiles.

2.1.1 Waste Stream Profile Description

Each DOE TRU waste generator/storage site was provided data packages that contained the characterization information provided by the TRU waste sites for Revision 1 of the WTWBIR. Each DOE site was asked to review the data packages and update the information as necessary (see Appendix C for the TWBIR Revision 2 Questionnaire). Some sites divided their WTWBIR, Revision 1 waste streams into two or more sub-streams to provide greater characterization detail. A cross reference table for WTWBIR, Revision 1 waste streams and TWBIR, Revision 2 waste streams is provided in Appendix H. Additionally, the sites were required to generate data packages for any waste streams that were not defined in the WTWBIR, Revision 1 (e.g., new waste streams or excluded waste streams). This data submittal from the DOE generator/storage sites provided approximately 970 individual TRU waste streams that were used in developing the waste stream profiles (see Appendices O and P or the database that accompanies this report). Figure 2-1 provides an example TRU waste stream profile for an INEL waste stream.

In addition to presenting the density of waste material parameters (if reported by the TRU waste generator/storage sites) in each DOE waste stream, the waste stream profile also provides a cross-reference (top of the waste stream profile form) to the different waste stream nomenclature used in previously generated DOE documents (i.e., TRUCON, NMVP). Appendix E provides a cross correlation table for a TWBIR waste stream with the NMVP and the TRUCON. The fields utilized on the waste stream profile, the sources of the information, and a short explanation of the data located in a particular field are described in Table 2-1. All data (except the MWIR ID which may be provided by the MWIR team) in all waste profiles are provided by the TRU waste generator/storage sites. A complete set of the waste stream profiles is provided in Appendices O and P or in the database that accompanies this report. The waste stream profiles do not incorporate all the data collected in the TWBIR data call questionnaire. Other information, such as that presented in Appendix K, can be obtained by querying the TWBID.

DOE has directed the TRU waste generator/storage sites to append their hazardous waste codes (EPA codes) to further define the waste in order to develop an appropriate treatment technology. These appended codes are recorded in the TWBIR, if they were provided by the generator/storage sites, to maintain consistency with other characterization documents and to provide the maximum characterization information available. These code designations and descriptions are presented in Appendix F. For example, D003 is defined by EPA as a hazardous waste that exhibits "reactive" characteristics. DOE further subdivided this code as D003A (reactive cyanide), D003B (reactive sulfides), D003C (explosives), D003D (water reactives), and D003E (other reactives).

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	IN-W169	Handling:	CH	NMVP #:	116	Stream Name:	DRY PAPER AND RAGS:CH-Cert-repack	Inventory Date:	
Local ID:	ID-RFO-330T	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

APP8, F005, F003, F002, F001, D029, D022, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	36.8	0.0	233.0
Other Inorganic Material:	27.2	0.0	196.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	135.0	6.6	817.0
Rubber:	57.2	0.0	330.0
Plastics:	168.0	14.8	887.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

116, 216

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
U-238	8.48E-11
U-235	2.60E-06
Pu-242	9.75E-06
Pu-241	3.61E+00
Pu-240	1.36E-01
Pu-239	5.98E-01
Pu-238	2.11E-02
Am-241	3.78E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	4266.8	0.0	0.0	0.0	0.0	4266.8
Totals	4266.8	0.0	0.0	0.0	0.0	4266.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4267.1	0.0	0.0	0.0	0.0	4267.1
Totals	4267.1	0.0	0.0	0.0	0.0	4267.1

As-Generated Form: Stored: 4266.8 Projected: 0.0 Total: 4266.8

Final Waste Form: Stored: 4267.1 Projected: 0.0 Total: 4267.1

Figure 2-1. Example of Waste Stream Profile from Idaho National Engineering Laboratory

WASTE STREAM DESCRIPTION	This waste stream is the largest combustible waste stream. The waste stream is from Rocky Flats Plant and primarily consists of line- and nonline-generated dry combustible materials such as paper, rags, plastics, surgical gloves, cloth overalls and booties, cardboard, wood, wood filter frames, PE bottles, and laundry lint. Some combustibles may be damp or moist. Limited amounts of noncombustibles such as glass, concrete, cement, leaded glovebox gloves, batteries, and metal scrap may also be present. There is a lack of information about the waste shipped prior to 1975. The average waste organic material content may range from 6 lb/ft3 for boxes to over 14 lb/ft3 for drums. Although limited fines are expected from floor sweepings, powder, etc., levels of fines should be within WIPP-WAC limits. The waste is packaged with no free liquids, sludges, explosives, compressed gases, pyrophoric or corrosive materials. Depending on when and where the waste was generated at Rocky Flats, the waste packaging may vary. For wastes generated prior to 1975, packaging information is incomplete. Line-generated waste may be double contained in plastic or placed in PE bottles and then double bagged. Nonline-generated wastes were single-bagged or placed directly into the waste container. Oil-Dri may have been added to some drums. After 1974, some waste was drummed, and some waste was placed in 4 ft x 4 ft x 7 ft boxes. Some combustibles are single, double or quadruple bagged or wrapped PVC and PE bags or plastic. Combustibles such as clothing and dryer lint are placed directly into 55-gallon drums. Some wastes are placed in 1-gallon PE bottles. Some drummed waste was repacked into boxes to reduce volume. During repacking, any noncombustibles were removed. Some boxes may contain moist combustible waste and up to 100 lb of Oil-Dri. Drums containing wastes from the Americium Recovery Line are lead-lined. Drums shipped prior to 1977 contain compacted wastes.
WASTE STREAM SOURCE	This record represents the [CH-Cert-repack] portion (73.89%) of the MWIR waste stream, [DRY PAPER AND RAGS] after processing. The proposed processing sequence is {SWEPP:segpk IWPF:segpk segpk TRANS:trans WIPP:disp}. This waste will be segregated during future characterization and processing activities. It currently exists only as the unsegregated mixed waste stream, IN-W169, reported in the DOE National Core Mixed and TRU Waste Data Requirements. The storage data is reported in Section 4 and the generation data is reported in Section 5. This record is subject to redefinition based on changes in the availability/utilization of INEL's treatment resources. It is not recognized as an INEL waste stream. It represents a proposed approach to the processing of the unsegregated mixed waste stream.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The EPA list in 3.4.3 is based on generator supplied process knowledge and/or headspace gas sampling. No TCLP or Total Analysis has been done.
MANAGEMENT COMMENTS	Total inventory figures as to number of containers and volume of waste, is considered to be fairly accurate. All waste is presently stored on indoor or earthen covered pads. Retrieval from the earthen covered pads will begin in the next 1 - 2 years.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	All containers of this WTWBIR waste stream are included in the amount listed above. See 8.2.15.1.13 for the years.

Figure 2-1. Example of Waste Stream Profile from Idaho National Engineering Laboratory

TABLE 2-1. SOURCES OF INFORMATION USED IN WASTE STREAM PROFILES

Information Field	Explanation
TWBIR ID	The TWBIR ID number assigned by the TRU waste generator/storage site
HQ ID	The unique identifier assigned by the Headquarters Waste Inventory team (MWIR)
Local ID	On-site ID used at the TRU waste generator/storage site
Handling	CH – Contact-Handled TRU waste RH – Remote-Handled TRU waste
[Waste] Type	MTRU – mixed TRU waste TRU – nonmixed TRU waste
NMVP #	If applicable, what a waste stream is called in the No Migration Variance Petition (DOE, 1990b)
Generator Site	TRU waste site that originally generated the waste
Stream Name	Name used to identify waste stream by the TRU waste generator/storage site
Final Waste Form	Grouping of wastes into 11 WIPP profiles (see Table 1-2)
Waste Matrix Code	Physical/chemical waste matrix code assigned by the TRU waste generator/storage site (DOE, 1995b)
Inventory Date	Date of the waste volume inventory
TRUCON Code	If applicable, what a waste stream is called in the TRUCON (DOE, 1994c)
As-Generated EPA Codes	Identifies the applicable EPA codes for the waste at the time of generation
Waste Material Parameters	The average (nominal), minimum, and maximum densities of the non-radionuclide waste materials in the waste stream (kg/m^3)
Final Waste Form Descriptors	Identifies if the waste stream is defense, non-defense, or commercial; if it contains residues, asbestos, PCBs, identifies the source for the waste stream
Final Form Radionuclides	Radionuclide inventory of the Final Waste Form of the waste stream. Provides estimate of "typical" radionuclide concentration expected in waste stream on a curies/m^3 basis.
Waste Volume Detail	The as-generated waste form volumes and the final waste form volumes (in cubic meters)
Waste Stream Description	Description of the physical/chemical nature of the waste from Section 3.1 of the TWBIR, Revision 2 Questionnaire (see Appendix C).
Waste Stream Source Description	Description of the waste stream generating process from Section 8.2.9.1 of the TWBIR, Revision 2 Questionnaire (see Appendix C)
Management Comments	Additional information (if provided by the sites) that may be pertinent to the status of current or planned management of the waste stream.
Acceptance Comments	Additional information (if provided by the site) that may be pertinent to the acceptance of the data reported for the waste stream.
Current Container Comments	Additional information (if provided by the site) that may be pertinent to describing the as-generated waste.
EPA Comments	Additional information (if provided by the site) that may be pertinent to the hazardous waste characterization of the waste stream.

2.1.2 Waste Material Parameter Description

This section defines the waste material parameters to be evaluated in PA calculations. Waste material parameter information is provided on the waste stream profile by the TRU waste generator/storage sites. In those cases where waste material parameter information could not be provided by the TRU waste generator/storage sites for waste streams with volumes in the final waste form. An alternative methodology was adopted as described in Section 2.1.3. If a waste stream is to be packaged in Final Waste Form into more than one type of container (e.g., drums and SWBs) and the waste material parameters are different for each container, then the Waste Stream Profile for the waste stream in Appendix O or P will provide a weighted average for all containers for the waste material parameters. The database that accompanies the report will provide the waste material parameters for each container. This waste material parameter information is used to estimate the anticipated WIPP inventory, which is then scaled, if necessary, to obtain the WIPP disposal inventory. This WIPP inventory is presented as a weighted average with a maximum and minimum expected weight/volume for each waste material parameter. The packaging materials are also reported as weight/volume, but there is no range because standard packaging densities in Table 1-3 are used for roll-ups.

The waste material parameter information, which is provided by the TRU waste generator/storage sites, consists of 12 waste material parameters and additional packaging materials that are inputs into the PA models. These are presented below.

- Iron-base metal/alloys – This designation is meant to include iron and steel alloys in the waste and does not include the waste container materials. This also includes an iron-base metallic phase associated with any vitrification process, if applicable.
- Aluminum-base metal/alloys – Aluminum or aluminum-base alloys in the waste materials.
- Other Metal/Alloys – All other metals found in the waste materials (e.g., copper, lead, zirconium, tantalum, etc.). The lead portion of lead rubber gloves/aprons is also included in this category.
- Other Inorganic Materials – Includes inorganic non-metal waste materials such as concrete, glass, firebrick, ceramics, graphite, sand, and inorganic sorbents.
- Vitrified – This refers to waste that has been melted or fused at high temperatures with glass forming additives such as soil or silica in appropriate proportions to result in a homogeneous glass-like matrix. (Note that any unoxidized metallic phases, if present, are included in the "Iron-base metal/alloys" WMP.)
- Cellulosics – Includes those materials generally derived from high polymer plant carbohydrates. Examples are paper, cardboard, kimwipes, wood, cellophane, cloth, etc.
- Rubber – Includes natural or manmade elastic latex materials. Examples are Hypalon®, neoprene, surgeons' gloves, leaded-rubber gloves (rubber part only), etc.
- Plastics – Includes generally manmade materials, often derived from petroleum feedstock. Examples are polyethylene, polyvinylchloride, Lucite®, Teflon, etc.

- Solidified Inorganic Material – Includes any homogenous materials consisting of sludge or aqueous-base liquids that are solidified with cement, Envirostone®, or other solidification agents. Examples are wastewater treatment sludge, cemented aqueous liquids, and inorganic particulates, etc. If a TRU waste site has not reported cement used as part of the solidification process in the "cement (solidified)" WMP, the density of the cement is included in this field.
- Solidified Organic Material – Includes cemented organic resins, solidified organic liquids, and sludges.
- Cement (solidified) – Includes the cement used in solidifying liquids, particulates, and sludges. If for a solidified final waste form this field is left blank, it means that either cement is not the solidifying agent or that the cement is included in the "solidified inorganic material" WMP.
- Soils – Generally consists of naturally occurring soils that have been contaminated with inorganic radioactive waste materials.

Packaging Materials

The TRU waste generator/storage sites have been asked in each waste stream profile to define the final waste form and volumes in containers that are currently approved for shipment. Listed below are the currently approved CH–TRU packaging configurations for TRUPACT–II (NRC, 1995) and anticipated approved RH–TRU packaging configurations (VECTRA Technologies, Inc., 1994):

- TRUPACT–II
  - 55-gallon drum
  - Standard Waste Box (SWB)
  - 55-gallon drums (maximum of 4) overpacked in SWB.
  - Ten drum overpack (TDOP)
- RH–TRU cask (anticipated acceptable packaging configurations for the RH–TRU cask)
  - RH–TRU canister
  - maximum of three 55-gallon or 30-gallon drums overpacked in a RH–TRU canister.

For the rollups in the site-specific and WIPP profiles, the standard values provided in Table 1-3 were used for the packaging materials.

In cases where the sites defined a type of waste container, but not the weight/volume of the packaging, assumptions were made about the weight of the containers in order to include these estimates as part of the overall inventory destined for WIPP. If overpacking a waste container was necessary for transport in a shipping cask, overpacking was assumed. The densities assumed are included as part of the "TRU system–wide data assumptions" included in Section 1.5.4 and Table 1-3.

- Steel – The weight of the steel part of the packaging from container information provided by the TRU waste generator/storage sites. Any necessary overpacking is included in the weight.
- Plastics – The weight of any plastic packaging submitted by the TRU sites. When weight of a rigid liner is not given a 90-mil HDPE liner is assumed.
- Lead – The weight of the lead shielding in a RH-TRU canister is assumed if not provided by the TRU waste generator/storage sites. The weight is included in the "Packaging Material Assumptions" in Section 1.5.

2.1.3 Assignment of the Final Waste Form

The DOE TRU waste generator/storage sites have assigned an overall Final Waste Form to each waste stream based on the physical and chemical form of the waste. The WIPP Project has developed the WIPP WAC (DOE, 1991) for any waste packages to be shipped to WIPP to ensure the safe handling, transport, and emplacement of the waste packages in the WIPP. In general, the final waste forms that meet the Department of Transportation (DOT) regulations and are acceptable for emplacement in WIPP are listed in Table 1-2. The WMC and Final Waste Form are located on each waste stream profile. The assignment of the WMC is based on *DOE Waste Treatability Group Guidance* (DOE, 1995b).

For the purpose of this document, TRU waste generator/storage sites were requested to provide Final Waste Forms for the waste after the sites process, treat, or repackage the waste. The Final Waste Form is indicated on the waste stream profile. For most waste stream profiles, the TRU waste generator/storage sites have provided estimates of the waste material parameters (e.g., an INEL waste stream profile is used for illustrative purposes in Figure 2-1). However, in some cases the TRU waste generator/storage sites were unable to provide waste material parameter values for some waste streams. This resulted in the following possible changes to the overall methodology presented in this chapter:

- In some cases the TRU waste generator/storage sites could categorize the waste stream profile into one of the 11 WIPP Final Waste Forms (Table 1-2) but could not give any waste material parameter information. In these cases, the TWBIR derived the parameters as follows:
  - If the waste stream was reported with waste material parameters in the WTWBIR, Revision 1, the TWBIR team used the Revision 1 parameters.
  - If the waste stream was not reported with waste material parameters in the WTWBIR, Revision 1, the TWBIR team assumed that the waste stream has the same range and average waste material parameters as that of the particular WIPP Final Waste Form

profile. For example, if a salt waste stream did not contain any waste material parameter information, but has been identified by a TRU waste generator/storage site as being a salt final waste form, then the volume of that waste stream was added to the total volume of all other salt waste streams in the WIPP Waste Profile for salt waste.

- In a few cases, TRU waste generator/storage sites were unable to categorize a TRU waste stream into one of the WIPP Final Waste Forms (Table 1-2). In these cases the waste stream profile is placed in the "unknown" category. The "unknown" waste streams are not documented as part of the WIPP inventory, but are listed in the "Possible Future Waste" in Section 5.4. "Unknown" wastes will have to be characterized and may require treatment prior to emplacement in WIPP.

2.2 REVIEW OF WASTE STREAM PROFILES

The TWBIR technical staff conducted a thorough review of each waste stream profile submitted by the generator/storage sites. Appendix N provides the reviewer guidelines for waste stream profile evaluations. If there are questions about the waste stream profiles, the TWBIR team contacts the TRU waste generator/storage site to resolve the issues. In some instances, a member of the team visited the site to support resolution of major discrepancies. Concurrence by TRU waste generator/storage site representative on data changes to waste stream profiles are required prior to publication. Figure 2-2 provides a flow diagram of the waste stream profile review process. New/updated data that are entered in the TWBID are quality checked (QC) to ensure the accuracy of the database.

2.3 SITE-SPECIFIC WASTE PROFILE METHODOLOGY

Waste streams at each TRU waste generator/storage site with similar WMCs can be grouped together into Final Waste Forms (Table 1-2) for a site-specific waste profile. In other words, a site-specific waste profile presents a roll-up of the data for all waste streams at a given site that have the same final waste form. The methodology for grouping waste streams within generator/storage site is shown in Figure 2-3. The grouping of individual waste stream profiles into a site-specific waste profile is based on the similar physical and chemical properties of the waste streams and how that information is used in the PA models (see Appendix B). In the example in Figure 2-3, due to their similar properties for PA modeling, concrete waste, glass waste, firebrick waste, and ceramic waste mainly influence the estimation of porosity and permeability in the PA calculations. Therefore, the three waste streams within DOE TRU Waste Site #1 and the two at DOE TRU Waste Site #2 can be grouped together at each site based on similar physical and chemical properties and placed into the site-specific waste profile "inorganic non-metal" waste, with the Final Waste Form defined in Table 1-2.

A site-specific waste profile is developed at each of the TRU waste generator/storage sites for each of the Final Waste Forms that have individual waste streams at the site. These site-specific waste profiles provide a roll-up of the waste material parameter and volume information found in the waste stream profiles for each site. Since there are 11 Final Waste Forms, there is a maximum of 11 possible CH-TRU and 11 possible RH-TRU site-specific waste profiles at any generator/storage site; however, most sites have fewer profiles due to differences in waste segregation practices. An example site-specific waste profile is provided in Figure 2-4. All the site-specific waste profiles for TRU waste are provided in Appendix A.

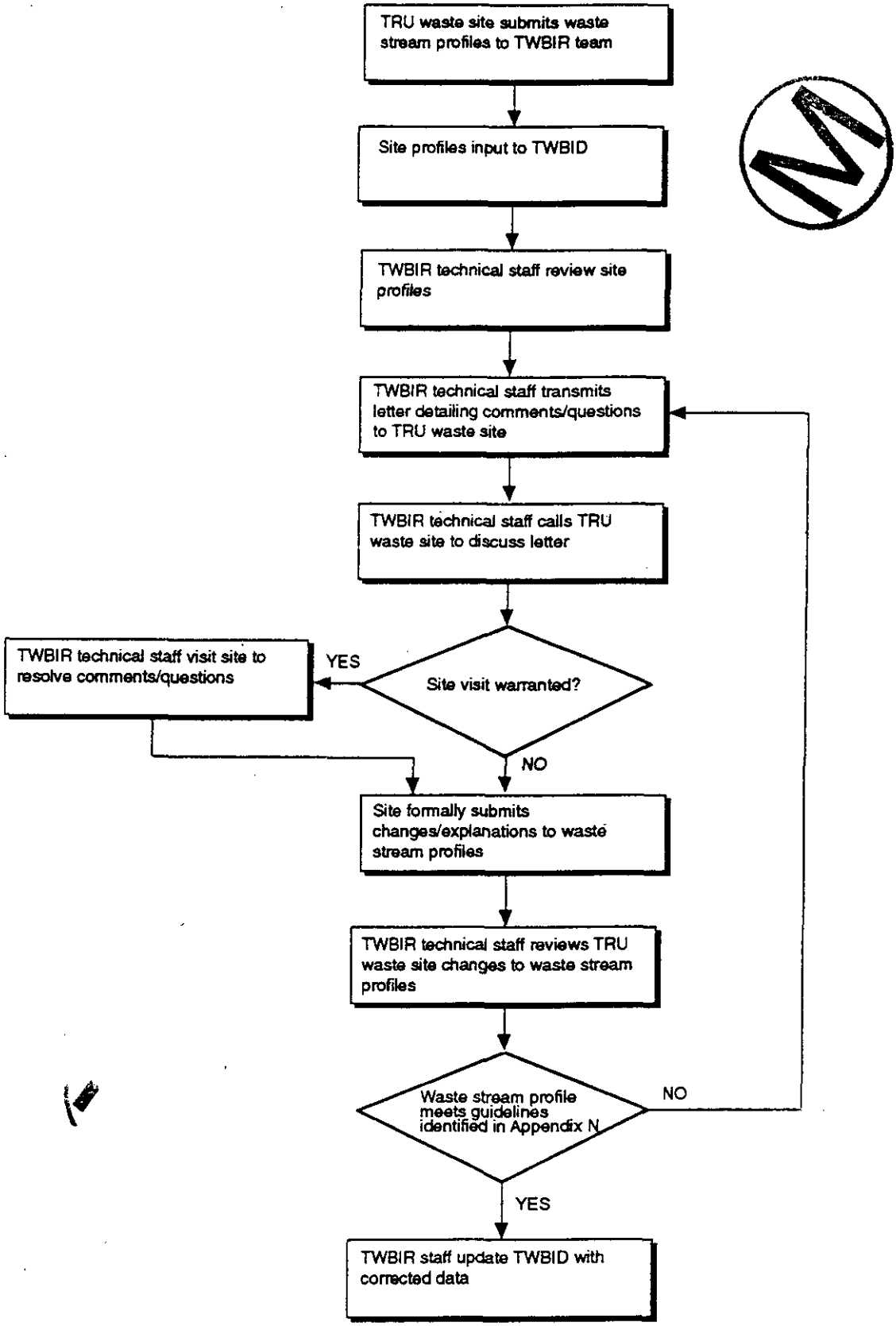

Figure 2-2. Schematic of Review Methodology of Waste Stream Profiles

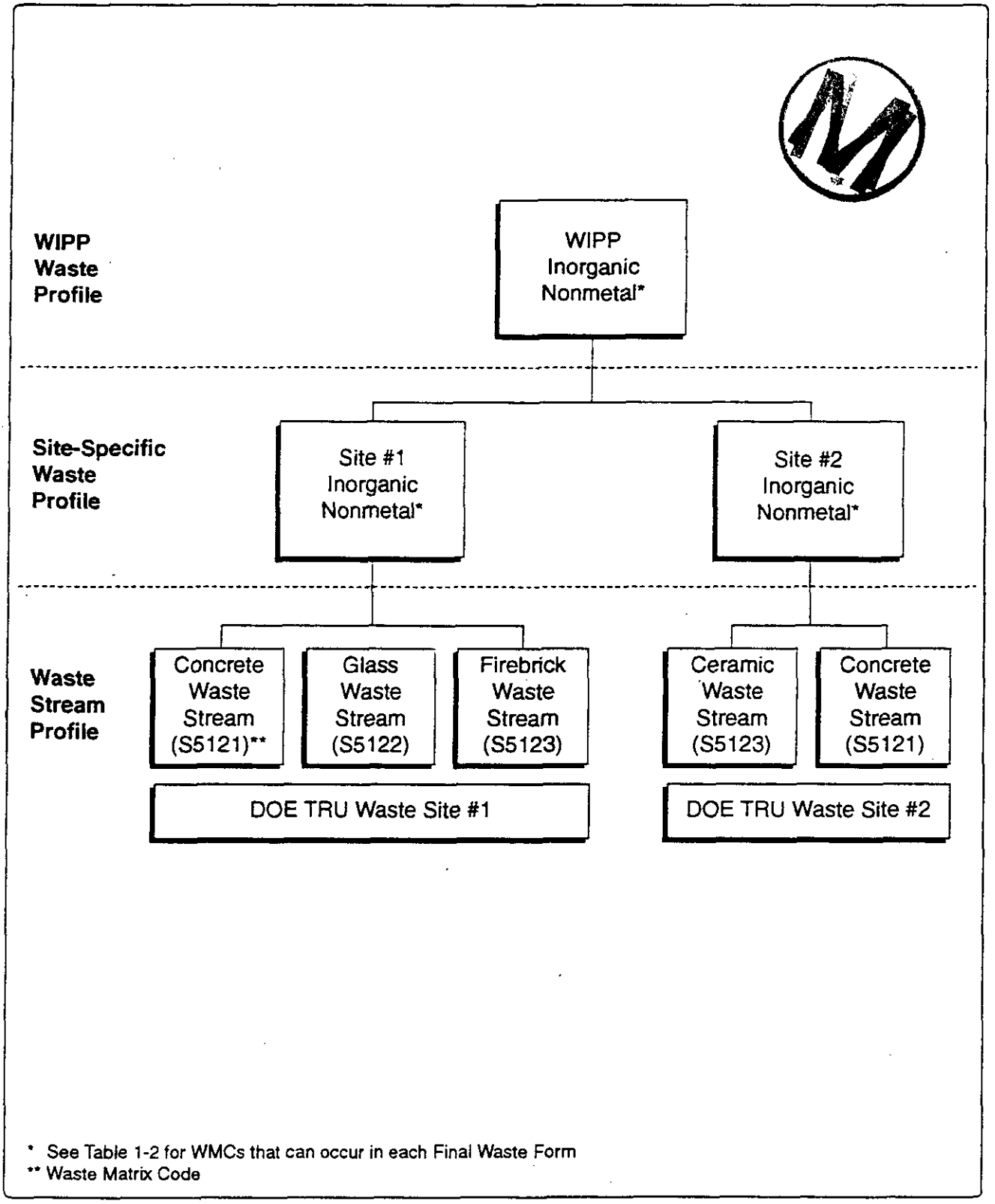

Figure 2-3. Schematic of Waste Stream Profile Methodology.

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W186.187	2695.2643	0.0000	2695.2643
IN-W198.202	119.6000	0.0000	119.6000
IN-W198.804	32.8230	0.0000	32.8230
IN-W199.1039	0.8885	0.0000	0.8885
IN-W202.1092	0.8885	0.0000	0.8885
IN-W202.224	109.6160	0.0000	109.6160
IN-W205.1086	0.8320	0.0000	0.8320
IN-W205.220	0.6805	0.0000	0.6805
IN-W250.259	14.0670	0.0000	14.0670
IN-W250.941	50.9600	0.0000	50.9600
IN-W252.283	117.7280	0.0000	117.7280
IN-W252.811	32.8230	0.0000	32.8230
IN-W254.289	2.3445	0.0000	2.3445
IN-W254.290	7.2800	0.0000	7.2800
IN-W256.1062	20.5920	0.0000	20.5920
IN-W256.295	5.9935	0.0000	5.9935
IN-W269.510	5.9935	0.0000	5.9935
IN-W269.535	20.8000	0.0000	20.8000
IN-W305.1068	37.4400	0.0000	37.4400
IN-W305.828	10.6825	0.0000	10.6825
IN-W327.1085	3.5360	0.0000	3.5360
IN-W327.735	1.3045	0.0000	1.3045
IN-W330.677	6.0320	0.0000	6.0320

Figure 2-4. Example of Site-Specific Waste Profile

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Combustible

IN-W330.678	1.9285	0.0000	1.9285
IN-W336.660	4.1600	0.0000	4.1600
IN-W336.820	0.6805	0.0000	0.6805
Total Volume:	**3304.94**	**0.00**	**3304.94**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	167.8	2.2	0.0
Aluminum Base Metal/Alloys	0.3	0.0	0.0
Other Metal/Alloys	474.5	7.8	0.0
Other Inorganic Materials	119.0	6.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	961.5	479.6	0.0
Rubber	629.0	75.3	0.0
Plastics	706.7	145.9	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Figure 2-4. Example of Site-Specific Waste Profile (continued)

The TWBIR technical staff performs QC on the site-level rollups to be sure that the database rollups are correct, and reviews the summary data to ascertain if the data are "reasonable" based on the experience of the technical staff. If the data appear unreasonable, the TWBIR participant will question the site to be sure that the data have been properly reported. If a change is required, formal documentation from the site is received.

2.4 WIPP WASTE PROFILE METHODOLOGY

The WIPP waste profiles are the highest tier of information in the TWBIR. Site-specific waste profiles with the same Final Waste Form are combined across the TRU waste generator/storage sites into what is defined as an overall WIPP waste profile. To illustrate the methodology for grouping similar site-specific waste profiles into WIPP waste profiles, the CH-TRU WIPP waste profile for "inorganic non-metal" waste (exemplified in Figure 2-3) is provided in Figure 3-5. The TWBIR technical staff evaluates the WIPP-level rollups in a similar manner as described for the site-level rollups.

As described in Sections 2.1 and 2.2, each waste stream from each TRU waste generator/storage site is defined in a waste stream profile, then grouped by site Final Waste Forms into site-specific waste profiles. These site-specific waste profiles are then rolled-up into WIPP waste profiles by combining identical Final Waste Forms from all the TRU waste generator/storage sites. For example, all site-specific waste profiles for "inorganic non-metal" waste are grouped together to generate the WIPP waste profile, "inorganic non-metal" waste. As with the site-specific waste profiles, there can be a maximum of 11 possible WIPP waste profiles for CH-TRU and 11 possible WIPP waste profiles for RH-TRU waste.

CHAPTER 3

3. WIPP DISPOSAL INVENTORY

3.1 INTRODUCTION

The highest tier of information in the TWBIR is the WIPP waste profiles, waste material parameter densities, disposal radionuclide inventory, and the WIPP disposal inventory volumes. This chapter will present these upper level WIPP data sets and the methodology used in deriving the data sets.

3.2 WIPP DISPOSAL INVENTORY VOLUMES FOR EACH FINAL WASTE FORM

As discussed in Section 1.3, the disposal inventory is defined by the LWA (Public Law, 1992b) and the WIPP C&C Agreement (DOE and the State of New Mexico, 1981) as: the maximum allowable WIPP capacity is approximately 175,600 cubic meters, of which RH-TRU disposal inventory is limited to approximately 7,080 cubic meters resulting in a calculated CH-TRU disposal inventory limit of approximately 168,500 cubic meters.

Using volumes for all the defense TRU waste streams (including the mixed and non-mixed TRU waste volumes) in the TWBID, a disposal inventory of TRU waste has been developed using the methodology described in this and the preceding sections. This inventory is presented in Table 3-1 (by Final Waste Forms) and depicts both the anticipated and disposal inventory volumes.

As defined in Section 1.3.1, the anticipated CH-TRU inventory volumes are the sum of the "stored" and "projected" volumes. The procedure to scale to the disposal inventory is summarized below. Scaling of the disposal inventory is for PA purposes to allow PA to model a capacity waste load based on currently anticipated profiles.

- Applying the formula given in Chapter 1:

$$\frac{\underset{\text{(CH-TRU disposed inventory)}}{1.685 \times 10^5 m^3} - \underset{\text{(stored inventory)}}{5.8 \times 10^4\ m^3}}{5.4 \times 10^4\ m^3 \text{ (projected inventory)}} \approx 2.05 \text{ (scaling factor)}$$

- Multiply the CH-TRU waste projected inventory volumes by the scaling factor for all the Final Waste Forms, and add the stored volumes (which results in the numbers in the "Disposal Inventory" column of Table 3-1).

The CH-TRU waste stream volume on a system-wide Final Waste Form basis is increased by 50 percent to account for the difference between the anticipated inventory and the maximum calculated WIPP CH-TRU disposal inventory.

The RH-TRU WIPP inventory has not been scaled. The RH-TRU anticipated inventory is greater than the amount of RH-TRU waste allowed in the WIPP by the C&C Agreement (DOE and the State of New Mexico, 1981). DOE is committed to abide by all agreements and laws regarding RH-TRU limitations. DOE and SNL/NM will evaluate this inventory to determine the disposal

Table 3-1

TRANSURANIC WASTE DISPOSAL INVENTORY FOR WIPP

Contact Handled Waste (Cubic Meters)

Final Waste Forms	Stored Volumes	Projected Volumes	Anticipated Volumes	WIPP Disposal Volumes
Combustible	5.8E+03	4.6E+03	1.0E+04	1.4E+04
Filter	2.2E+02	5.1E+02	7.3E+02	1.2E+03
Graphite	5.1E+02	4.8E+01	5.6E+02	6.0E+02
Heterogeneous	2.7E+04	1.3E+04	4.0E+04	5.1E+04
Inorganic Non-Metal	3.1E+03	9.4E+02	4.1E+03	4.9E+03
Lead/Cadmium Metal Waste	3.5E+01	3.3E+02	3.7E+02	6.6E+02
Salt Waste	2.1E+01	3.3E+02	3.5E+02	6.4E+02
Soils	4.1E+02	6.0E+03	6.4E+03	1.2E+04
Solidified Inorganics	9.6E+03	4.5E+03	1.4E+04	1.8E+04
Solidified Organics	9.1E+02	7.5E+01	9.8E+02	1.1E+03
Uncategorized Metal	1.1E+04	2.3E+04	3.4E+04	5.4E+04
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**	**1.6E+05**
Remote Handled Waste				
Combustible	3.6E+01	4.9E+01	8.5E+01	
Heterogeneous	2.3E+03	5.5E+03	7.8E+03	
Inorganic Non-Metal	4.6E+01	2.1E+01	6.8E+01	
Lead/Cadmium Metal Waste	7.1E+00	6.7E+01	7.4E+01	
Solidified Inorganics	1.1E+03	2.3E+02	1.3E+03	
Solidified Organics	3.6E+00	0.0E+00	3.6E+00	
Uncategorized Metal	1.2E+02	1.7E+04	1.8E+04	
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**	
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**	**1.7E+05**

options for all DOE RH-TRU waste. This inventory has not been scaled down to the limit imposed by the C&C Agreement so that all available data are presented to DOE and SNL/NM to conduct modeling and other evaluations to determine the disposition of this waste.

3.3 ROLL-UP OF WIPP WASTE MATERIAL PARAMETERS BY FINAL WASTE FORM

The roll-ups of waste material parameters by Final Waste Forms, or by site, are developed from the volumes from the TWBID. The roll-ups by Final Waste Forms or by site require combining data from several TWBID waste streams. A weighted average value for the waste material parameters is calculated from the average densities provided by the TRU waste generator/storage sites modified by the TWBID volume fractions and summed as follows:

$$\text{Average Density of waste material parameter} = \sum \text{Average Density}_i \times \frac{(\text{Volume TWBIR Stream}_i)}{(\text{Total Volume of Final Waste Form})}$$

where i is an index representing individual waste streams of the same Final Waste Form

The minimum density is chosen as the smallest minimum density of a particular waste material parameter in the TWBID waste streams in a particular site-specific roll-up. The maximum density is chosen in a similar manner, except that the largest maximum density was chosen. Thus, the maximum and minimum values reported in Tables 3-2 and 3-3 are the **absolute extreme values** reported across the system, and in many cases they only apply to a very small volume of waste. If required, the user can use the data in the database to calculate a "weighted average maximum" value to obtain a maximum value that may be more representative of the total inventory.

In some cases, the TRU waste generator/storage sites did not have data for minimum and maximum densities, even though average densities were provided. In these cases, for roll-up purposes only, the assumptions identified in Section 1.5.1 were implemented. This ensures that the calculated and rolled-up maximum densities are equal to or greater than the average densities. However, the maximum density may not be a true maximum but rather the maximum average density (see Chapter 6 for further TWBID information).

The waste material parameters that are inputs into the PA models are presented in Table 3-2 for CH-TRU waste and Table 3-3 for RH-TRU waste. These tables represent the waste material parameters for the WIPP disposal inventory.

3.4 UTILIZATION OF WASTE MATERIAL PARAMETER DATA IN APPLICATIONS

The waste material parameter data presented in Tables 3-2 and 3-3 must be used with certain limitations. If the "average" weight/volume (density) composition of CH-TRU and RH-TRU wastes in terms of the waste material parameters is needed then the middle column of Tables 3-2 and 3-3 labelled "Average" should be used in the calculations. If the task requires a distribution of values then the "Maximum" and "Minimum" columns should be used in conjunction with the "Average" column with the following limitations:

Table 3-2

WIPP CH-TRU Waste Material Parameter Disposal Inventory

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2.6E+03	1.7E+02	0.0E+00
Aluminum Base Metal/Alloys	8.0E+02	1.8E+01	0.0E+00
Other Metal/Alloys	1.6E+03	6.7E+01	0.0E+00
Other Inorganic Materials	1.4E+03	3.1E+01	0.0E+00
Vitrified	2.5E+03	5.5E+01	0.0E+00
Cellulosics	9.6E+02	5.4E+01	0.0E+00
Rubber	6.3E+02	1.0E+01	0.0E+00
Plastics	8.9E+02	3.4E+01	0.0E+00
Solidified Inorganic Material	2.2E+03	5.4E+01	0.0E+00
Solidified Organic Material	1.4E+03	5.6E+00	0.0E+00
Cement (Solidified)	1.2E+03	5.0E+01	0.0E+00
Soils	1.6E+03	4.4E+01	0.0E+00

Container Materials - Kg/m3

Steel	139
Plastic/ Liners	26

Table 3-3

WIPP RH-TRU Waste Material Parameter Disposal Inventory

Waste Material Parameters (Kg/m3	Maximum	Average	Minimum
Iron Base Metal/Alloys	1.7E+03	1.0E+02	0.0E+00
Aluminum Base Metal/Alloys	1.7E+02	7.1E+00	0.0E+00
Other Metal/Alloys	9.1E+02	2.5E+02	0.0E+00
Other Inorganic Materials	2.0E+03	6.4E+01	0.0E+00
Vitrified	2.5E+03	4.7E+00	0.0E+00
Cellulosics	5.7E+02	1.7E+01	0.0E+00
Rubber	4.4E+02	3.3E+00	0.0E+00
Plastics	6.2E+02	1.5E+01	0.0E+00
Solidified Inorganic Material	6.1E+02	2.2E+01	0.0E+00
Solidified Organic Material	8.1E+02	9.3E-01	0.0E+00
Cement (Solidified)	5.8E+02	1.9E+01	0.0E+00
Soils	2.4E+01	1.0E+00	0.0E+00

Container Materials - Kg/m3

Steel	446
Plastic/Liners	3.1
Lead	465
Steel Plug	2145

- The sum of all the waste material parameters in the "average" column represents the "average" weight of a cubic meter of CH-TRU or RH-TRU expected at WIPP. For instance, the "average" cubic meter of CH-TRU waste expected at WIPP is (see Table 3-2):

  592.6 kg/m^3 CH-TRU waste + 165 kg/m^3 of packaging = 757.6 kg/m^3

- The weight of packaging is not expected to vary, so if any "sampling" of distributions of densities is required, the sampling should only be on the waste part of the above equation.
- If sampling of the waste material parameters is needed, caution should be taken in not over- or under-estimating the waste material parameters during analyses. The minimum and maximum values are the absolute extremes and never should a site have an entire waste stream which resulted with values at either extreme. Within a waste stream there may be only one container (as small as 0.002 m^3) that is packaged at either extreme. Additionally, these extremes could result from a projected waste volume which contains more uncertainty than stored waste.

The same sampling methodology, if needed, should be used for the RH-TRU waste as reported in Table 3-3.

TO OBTAIN THE TOTAL WASTE MATERIAL PARAMETER WEIGHTS FOR THE DISPOSAL INVENTORY, USERS OF THE DATA SHOULD MULTIPLY THE AVERAGE DENSITIES OF THE WASTE MATERIAL PARAMETERS FOR CH-TRU (TABLE 3-2) AND RH-TRU (TABLE 3-3) BY THEIR RESPECTIVE DISPOSAL INVENTORY VOLUMES AS DEFINED IN SECTION 1.3.1.

For example:

The expected (average) CH-TRU inventory of cellulosics for WIPP is (Table 3-2):

54 kg/m^3 x 168,500 m^3 (design basis) = 9,099,500 kg cellulosics

For steel in CH-TRU waste:

170 kg/m^3(waste) + 139 kg/m^3(container) = 309 kg/m^3

309 kg/m^3 x 168,500 m^3 = 52,066,500 kg steel

3.5 WIPP WASTE PROFILES

Figures 3-1 through 3-18 present the WIPP profiles by Final Waste Form. These profiles provide the WIPP level volumes and summary waste material parameter densities of each Final Waste Form.

WIPP Contact Handled Waste Profiles

Final Waste Form: Combustible

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Mound Plant	7.07	0.00	7.07
Hanford (Richland) Site	455.73	1247.26	1702.99
Rocky Flats Environmental Technology Site	185.54	861.08	1046.62
Los Alamos National Laboratory	1821.45	2376.19	4197.64
Idaho National Engineering Laboratory	3304.94	0.00	3304.94
Argonne National Laboratory - West	0.00	101.64	101.64
Total Volume	**5774.73**	**4586.18**	**10360.91**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	265.2	109.0	0.0
Aluminum Base Metal/Alloys	4.9	0.2	0.0
Other Metal/Alloys	474.5	10.4	0.0
Other Inorganic Materials	370.2	8.7	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	961.5	192.5	0.0
Rubber	629.0	30.0	0.0
Plastics	706.7	59.5	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	7.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	7.5	0.0	0.0

Figure 3 - 1
WIPP CH-TRU Waste Profile for Final Waste Form Combustible

WIPP Contact Handled Waste Profiles

Final Waste Form: Filter

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Rocky Flats Environmental Technology Site	72.09	477.51	549.60
Mound Plant	0.83	0.00	0.83
Lawrence Livermore National Laboratory	15.54	32.28	47.82
Idaho National Engineering Laboratory	131.05	0.00	131.05
Total Volume	**219.51**	**509.79**	**729.30**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	150.0	5.3	0.0
Aluminum Base Metal/Alloys	191.6	12.5	0.0
Other Metal/Alloys	20.0	0.8	0.0
Other Inorganic Materials	293.3	15.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	429.5	56.3	0.0
Rubber	20.0	3.3	0.0
Plastics	100.0	4.6	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Figure 3 - 2
WIPP CH-TRU Waste Profile for Final Waste Form Filter

WIPP Contact Handled Waste Profiles

Final Waste Form: Graphite

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Rocky Flats Environmental Technology Site	13.73	47.57	61.30
Idaho National Engineering Laboratory	498.19	0.00	498.19
Total Volume	511.91	47.57	559.48

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	764.4	1.4	0.0
Aluminum Base Metal/Alloys	38.2	0.0	0.0
Other Metal/Alloys	46.6	0.0	0.0
Other Inorganic Materials	812.5	299.9	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	9.8	4.8	0.0
Rubber	0.0	0.0	0.0
Plastics	51.4	5.6	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Figure 3 - 3
WIPP CH-TRU Waste Profile for Final Waste Form Graphite

WIPP Contact Handled Waste Profiles

Final Waste Form: Heterogeneous

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
University of Missouri Research Reactor	0.21	0.83	1.04
Los Alamos National Laboratory	16.02	29.12	45.14
Hanford (Richland) Site	11190.75	6271.29	17462.04
Lawrence Livermore National Laboratory	198.85	663.78	862.63
Energy Technology Engineering Center	1.68	0.00	1.68
Idaho National Engineering Laboratory	10608.50	0.00	10608.50
Nevada Test Site	613.26	8.98	622.24
Mound Plant	0.62	0.00	0.62
Bettis Atomic Power Laboratory	0.00	123.27	123.27
U.S. Army Material Command	2.50	0.00	2.50
Savannah River Site	2611.61	5475.85	8087.46
Sandia National Laboratory - Albuquerque	6.66	7.49	14.14
Argonne National Laboratory - West	6.54	345.35	351.89
Oak Ridge National Laboratory	1304.16	256.26	1560.42
Rocky Flats Environmental Technology Site	3.86	0.00	3.86
Pantex Plant	0.62	0.00	0.62
Total Volume	**26565.83**	**13182.22**	**39748.05**

Figure 3 - 4
WIPP CH-TRU Waste Profile for Final Waste Form Heterogeneous

WIPP Contact Handled Waste Profiles

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1716.4	247.3	0.0
Aluminum Base Metal/Alloys	800.0	46.0	0.0
Other Metal/Alloys	800.0	5.7	0.0
Other Inorganic Materials	1442.3	26.2	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	961.5	86.1	0.0
Rubber	330.0	19.4	0.0
Plastics	887.0	71.5	0.0
Solidified Inorganic Material	300.0	3.8	0.0
Solidified Organic Material	331.6	0.4	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	628.4	2.9	0.0

Figure 3-4 (continued)
WIPP CH-TRU Waste Profile for Final Waste Form Heterogeneous

WIPP Contact Handled Waste Profiles

Final Waste Form: Inorganic Non-Metal

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Hanford (Richland) Site	34.74	69.06	103.79
Paducah Gaseous Diffusion Plant	0.00	1.89	1.89
Teledyne Brown Engineering	0.21	0.00	0.21
Idaho National Engineering Laboratory	3028.24	0.00	3028.24
Rocky Flats Environmental Technology Site	58.29	866.74	925.03
Total Volume	**3121.47**	**937.68**	**4059.16**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	63.6	2.8	0.0
Aluminum Base Metal/Alloys	3.9	0.0	0.0
Other Metal/Alloys	76.6	0.2	0.0
Other Inorganic Materials	1250.0	99.6	0.0
Vitrified	2500.0	1414.6	0.0
Cellulosics	850.0	15.9	0.0
Rubber	47.6	0.4	0.0
Plastics	166.9	6.7	0.0
Solidified Inorganic Material	327.0	1.4	0.0
Solidified Organic Material	0.9	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	865.8	0.0	0.0

Figure 3 - 5
WIPP CH-TRU Waste Profile for Final Waste Form Inorganic Non-Metal

WIPP Contact Handled Waste Profiles

Final Waste Form: Lead/Cadmium Metal Waste

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Argonne National Laboratory - East	1.07	1.29	2.36
Rocky Flats Environmental Technology Site	3.95	298.27	302.22
Los Alamos National Laboratory	1.89	0.00	1.89
Hanford (Richland) Site	14.17	34.53	48.69
Idaho National Engineering Laboratory	14.37	0.00	14.37
Total Volume	**35.45**	**334.09**	**369.53**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	488.7	133.8	0.0
Aluminum Base Metal/Alloys	61.6	16.6	0.0
Other Metal/Alloys	1438.1	52.2	0.0
Other Inorganic Materials	40.9	11.7	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	87.9	4.0	0.0
Rubber	125.5	15.5	0.0
Plastics	91.7	22.3	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.9	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Figure 3 - 6
WIPP CH-TRU Waste Profile for Final Waste Form Lead/Cadmium Metal Waste

WIPP Contact Handled Waste Profiles

Final Waste Form: Salt Waste

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Rocky Flats Environmental Technology Site	0.00	325.92	325.92
Idaho National Engineering Laboratory	20.52	0.00	20.52
Lawrence Livermore National Laboratory	0.62	3.02	3.64
Total Volume	**21.14**	**328.93**	**350.07**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	540.0	181.4	0.0
Aluminum Base Metal/Alloys	80.0	0.1	0.0
Other Metal/Alloys	212.0	2.3	0.0
Other Inorganic Materials	625.0	170.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	211.7	164.2	0.0
Rubber	20.0	0.0	0.0
Plastics	100.0	0.6	0.0
Solidified Inorganic Material	10.0	0.0	0.0
Solidified Organic Material	10.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Figure 3 - 7
WIPP CH-TRU Waste Profile for Final Waste Form Salt Waste

WIPP Contact Handled Waste Profiles

Final Waste Form: Soils

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Mound Plant	177.18	0.00	177.18
Los Alamos National Laboratory	110.57	29.12	139.69
Hanford (Richland) Site	119.48	5961.70	6081.17
Total Volume	407.23	5990.82	6398.04

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	29.1	1.7	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	17.4	1.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	68.7	3.7	0.0
Rubber	56.4	1.7	0.0
Plastics	131.0	3.2	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	138.2	0.1	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	1600.0	756.9	0.0

Figure 3 - 8
WIPP CH-TRU Waste Profile for Final Waste Form Soils

WIPP Contact Handled Waste Profiles

Final Waste Form: Solidified Inorganics

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Hanford (Richland) Site	12.94	7.07	20.02
Argonne National Laboratory - East	5.20	0.00	5.20
Nevada Test Site	5.67	0.00	5.67
Savannah River Site	200.19	1169.61	1369.80
Rocky Flats Environmental Technology Site	165.36	1257.64	1423.01
Idaho National Engineering Laboratory	4344.44	0.00	4344.44
Mound Plant	6.03	0.00	6.03
Los Alamos National Laboratory	4888.20	2033.82	6922.02
Ames Laboratory - Iowa State Univ.	0.00	0.42	0.42
Lawrence Livermore National Laboratory	14.35	5.82	20.18
Total Volume	**9642.39**	**4474.39**	**14116.78**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2375.0	181.4	0.0
Aluminum Base Metal/Alloys	50.0	0.0	0.0
Other Metal/Alloys	544.0	0.8	0.0
Other Inorganic Materials	985.1	80.7	0.0
Vitrified	2473.0	32.4	0.0
Cellulosics	100.0	0.4	0.0
Rubber	32.9	0.0	0.0
Plastics	100.0	2.2	0.0
Solidified Inorganic Material	2180.0	415.6	0.0
Solidified Organic Material	365.0	0.1	0.0
Cement (Solidified)	1166.0	388.1	0.0
Soils	671.5	0.6	0.0

Figure 3 - 9
WIPP CH-TRU Waste Profile for Final Waste Form Solidified Inorganics

WIPP Contact Handled Waste Profiles

Final Waste Form: Solidified Organics

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Rocky Flats Environmental Technology Site	109.82	31.11	140.93
Hanford (Richland) Site	7.36	9.36	16.72
Los Alamos National Laboratory	1.46	29.12	30.58
Idaho National Engineering Laboratory	789.67	0.00	789.67
Argonne National Laboratory - East	0.21	0.00	0.21
Lawrence Livermore National Laboratory	1.04	5.82	6.86
Total Volume	**909.56**	**75.41**	**984.97**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	100.0	0.3	0.0
Aluminum Base Metal/Alloys	50.0	0.0	0.0
Other Metal/Alloys	20.0	0.0	0.0
Other Inorganic Materials	673.1	115.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	100.0	0.3	0.0
Rubber	20.0	0.0	0.0
Plastics	126.5	6.7	0.0
Solidified Inorganic Material	1014.0	20.6	0.0
Solidified Organic Material	1375.6	612.2	0.0
Cement (Solidified)	1166.0	129.8	0.0
Soils	137.2	0.2	0.0

Figure 3 - 10
WIPP CH-TRU Waste Profile for Final Waste Form Solidified Organics

WIPP Contact Handled Waste Profiles

Final Waste Form: Uncategorized Metal

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Savannah River Site	70.35	120.54	190.89
Argonne National Laboratory - East	4.99	128.54	133.54
Mound Plant	82.48	0.00	82.48
Argonne National Laboratory - West	0.00	293.76	293.76
Idaho National Engineering Laboratory	5866.82	0.00	5866.82
Hanford (Richland) Site	444.86	19635.15	20080.01
Los Alamos National Laboratory	4214.43	2853.76	7068.19
Rocky Flats Environmental Technology Site	93.31	236.12	329.43
Total Volume	**10777.24**	**23267.87**	**34045.12**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2595.2	153.5	0.0
Aluminum Base Metal/Alloys	73.7	3.5	0.0
Other Metal/Alloys	1586.5	210.3	0.0
Other Inorganic Materials	812.5	14.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	184.8	12.2	0.0
Rubber	113.7	0.7	0.0
Plastics	149.0	7.9	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.1	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	3.5	0.0	0.0

Figure 3 - 11
WIPP CH-TRU Waste Profile for Final Waste Form Uncategorized Metal

WIPP Remote Handled Waste Profiles

Final Waste Form: Combustible

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Idaho National Engineering Laboratory	21.36	0.00	21.36
Los Alamos National Laboratory	15.13	48.95	64.08
Total Volume	**36.49**	**48.95**	**85.44**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	265.2	193.3	0.0
Aluminum Base Metal/Alloys	0.4	0.3	0.0
Other Metal/Alloys	330.9	16.6	0.0
Other Inorganic Materials	50.3	8.6	3.3
Vitrified	0.0	0.0	0.0
Cellulosics	98.3	49.0	0.0
Rubber	438.7	64.4	0.0
Plastics	71.1	7.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Figure 3 - 12
WIPP RH-TRU Waste Profile for Final Waste Form Combustible

WIPP Remote Handled Waste Profiles

Final Waste Form: Heterogeneous

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Oak Ridge National Laboratory	1432.01	240.30	1672.31
Los Alamos National Laboratory	11.57	0.00	11.57
Battelle Columbus Laboratories	580.50	0.00	580.50
Bettis Atomic Power Laboratory	0.00	6.67	6.67
Idaho National Engineering Laboratory	49.84	0.00	49.84
Hanford (Richland) Site	199.36	4066.41	4265.77
Argonne National Laboratory - West	0.00	1208.62	1208.62
Total Volume	**2273.28**	**5522.00**	**7795.29**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1716.4	175.5	0.0
Aluminum Base Metal/Alloys	167.8	23.7	0.0
Other Metal/Alloys	500.0	14.1	0.0
Other Inorganic Materials	2000.0	185.7	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	572.8	57.4	0.0
Rubber	231.4	10.4	0.0
Plastics	621.9	49.1	0.0
Solidified Inorganic Material	83.0	9.0	0.0
Solidified Organic Material	31.0	2.9	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	24.4	3.5	0.0

Figure 3 - 13
WIPP RH-TRU Waste Profile for Final Waste Form Heterogeneous

WIPP Remote Handled Waste Profiles

Final Waste Form: Inorganic Non-Metal

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Argonne National Laboratory - West	0.00	21.36	21.36
Idaho National Engineering Laboratory	46.28	0.00	46.28
Total Volume	**46.28**	**21.36**	**67.64**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	4.3	0.9	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	9.1	0.1	0.0
Other Inorganic Materials	592.8	55.7	0.0
Vitrified	2500.0	1852.5	0.0
Cellulosics	40.8	6.1	0.0
Rubber	6.1	0.2	0.0
Plastics	48.8	3.8	0.0
Solidified Inorganic Material	2.9	0.4	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.4	0.0	0.0

Figure 3 - 14
WIPP RH-TRU Waste Profile for Final Waste Form Inorganic Non-Metal

WIPP Remote Handled Waste Profiles

Final Waste Form: Lead/Cadmium Metal Waste

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Argonne National Laboratory - West	0.00	6.23	6.23
Energy Technology Engineering Center	0.89	0.00	0.89
Hanford (Richland) Site	2.67	60.52	63.19
Idaho National Engineering Laboratory	3.56	0.00	3.56
Total Volume	7.12	66.75	73.87

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	345.0	24.2	4.7
Aluminum Base Metal/Alloys	43.1	2.1	0.0
Other Metal/Alloys	585.3	512.7	104.7
Other Inorganic Materials	29.2	1.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	7.1	0.5	0.0
Rubber	17.4	1.9	0.0
Plastics	49.6	2.8	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	202.7	5.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Figure 3 - 15
WIPP RH-TRU Waste Profile for Final Waste Form Lead/Cadmium Metal Waste

WIPP Remote Handled Waste Profiles

Final Waste Form: Solidified Inorganics

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Oak Ridge National Laboratory	1036.85	206.48	1243.33
Idaho National Engineering Laboratory	65.27	0.00	65.27
Argonne National Laboratory - West	1.78	28.48	30.26
Total Volume	**1103.90**	**234.96**	**1338.86**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	199.9	3.8	0.0
Aluminum Base Metal/Alloys	0.1	0.0	0.0
Other Metal/Alloys	2.3	0.1	0.0
Other Inorganic Materials	109.6	2.7	0.0
Vitrified	40.5	0.7	0.0
Cellulosics	0.8	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	6.8	0.3	0.0
Solidified Inorganic Material	609.6	390.5	33.9
Solidified Organic Material	0.5	0.0	0.0
Cement (Solidified)	584.4	385.6	22.6
Soils	0.6	0.0	0.0

Figure 3 - 16
WIPP RH-TRU Waste Profile for Final Waste Form Solidified Inorganics

WIPP Remote Handled Waste Profiles

Final Waste Form: Solidified Organics

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Idaho National Engineering Laboratory	3.56	0.00	3.56
Total Volume	**3.56**	**0.00**	**3.56**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.9	0.3	0.1
Aluminum Base Metal/Alloys	0.4	0.0	0.0
Other Metal/Alloys	0.1	0.0	0.0
Other Inorganic Materials	220.4	115.4	37.8
Vitrified	0.0	0.0	0.0
Cellulosics	1.0	0.3	0.2
Rubber	0.2	0.0	0.0
Plastics	14.1	6.7	1.1
Solidified Inorganic Material	36.0	20.6	17.0
Solidified Organic Material	808.1	612.2	391.2
Cement (Solidified)	195.7	129.8	75.9
Soils	0.2	0.2	0.2

Figure 3 - 17
WIPP RH-TRU Waste Profile for Final Waste Form Solidified Organics

WIPP Remote Handled Waste Profiles

Final Waste Form: Uncategorized Metal

Site	Retrievably Stored (m3)	Projected (m3)	Total (m3)
Argonne National Laboratory - West	17.51	0.00	17.51
Idaho National Engineering Laboratory	30.85	0.00	30.85
Los Alamos National Laboratory	67.64	49.84	117.48
Hanford (Richland) Site	0.00	17400.39	17400.39
Total Volume	**116.00**	**17450.23**	**17566.23**

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1146.1	75.3	0.0
Aluminum Base Metal/Alloys	33.5	0.4	0.0
Other Metal/Alloys	913.5	375.5	0.0
Other Inorganic Materials	52.0	15.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	129.6	0.8	0.0
Rubber	11.5	0.0	0.0
Plastics	104.5	0.5	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Figure 3 - 18
WIPP RH-TRU Waste Profile for Final Waste Form Uncategorized Metal

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3.6 WIPP DISPOSAL RADIONUCLIDE INVENTORY

The waste–stream level radionuclide data reported in Appendices O and P (and/or on the accompanying TWBID diskettes) are insufficient to derive a WIPP radionuclide inventory because not all sites provided radionuclide data for each individual waste stream. Therefore, the site–level radionuclide inventories collected in the joint IDB and Revision 2 TWBIR data call were used. Table 3-4 provides the radionuclide inventory reported in curies per cubic meter and total curies. The generator/storage sites report the total curies for each isotope for stored waste only. All numbers (except the RFETS plutonium residues as explained in Section 1.5.3) have been decayed to December 1995, using the Oak Ridge Isotope Generation and Depletion Code (ORIGEN 2) (Croff, 1980 and Croff, 1983). The TWBIR team calculated the WIPP radionuclide inventory as follows:

CH-TRU

- All sites (except RFETS)

$$\frac{\text{Total Stored Decayed Curies (IDB)}}{\text{Total Stored Volume (TWBIR)}} = \text{Stored Ci/m}^3$$

- For RFETS

$$\frac{\text{Total Stored Decayed Curies (IDB)}}{\underset{\text{(TWBIR)}}{\text{Total Stored Volume}} - \underset{\text{(TWBIR, Appendix J)}}{\text{RFETS Actinide Separation Residue Volume}}} = \text{Stored Ci/m}^3$$

Because RFETS did not report plutonium residue curies in the IDB submittals, the RFETS plutonium residue volumes had to be subtracted from the TWBIR stored volumes to make the TWBIR consistent with the IDB.

To calculate the radionuclide inventory for all sites (except RFETS) the following formula was used:

$$\underset{\text{(TWBIR)}}{\text{Stored Decayed Curies (IDB)} + [(\text{Scaled Projected Volumes})\ (\text{Stored Ci/m}^3)]} = \text{Total Decayed CH-TRU WIPP Curies for all sites except RFETS}$$

For the RFETS, the following formula was used:

$$\text{Stored Decayed Curies (IDB)} + \text{RFETS (ship as waste) Undecayed Curies (TWBIR, Appendix J)} + \left[\left(\text{Scaled Projected Volumes (TWBIR)}\right)\left(\text{Stored Ci/m}^3\right)\right] = \text{Total Decayed CH-TRU WIPP Curies for RFETS}$$

To calculate the WIPP CH-TRU radionuclide inventory in Ci/m^3):

$$\frac{\text{Total Decayed CH-TRU WIPP Curies for all sites}}{\text{CH-TRU Disposal Inventory}} = \text{CH-TRU radionuclide inventory (Ci/m}^3\text{)}$$

RH-TRU

$$\frac{\text{Total Stored Decayed Curies (IDB)}}{\text{Total Stored Volume (TWBIR)}} = \text{Stored Ci/m}^3$$

$$\text{Stored Decayed Curies (IDB)} + [(\text{Total Projected Volumes (TWBIR)})(\text{Stored Ci/m}^3)] = \text{Total Decayed RH-TRU WIPP Curies}$$

To calculate the WIPP RH-TRU radionuclide inventory in Ci/m^3:

$$\frac{\text{Total Decayed RH-TRU WIPP Curies}}{\text{Total RH-TRU (stored \& projected) Inventory}} = \text{RH-TRU radionuclide inventory (Ci/m}^3\text{)}$$

Reporting the radionuclide inventory and curies per cubic meter (see Table 3-4) will allow the users of the data the opportunity to scale the radionuclide inventory to various volumes for sensitivity studies. Reporting in terms of curies per cubic meter also eliminates the requirement to scale down the RH-TRU inventory to the WIPP disposal RH-TRU inventory. Assuming that the *radionuclide distribution for the WIPP inventory will be the same as that reported for the stored* inventory, the total CH-TRU and RH-TRU radionuclide inventory is estimated in Table 3-4 by multiplying the respective disposal inventories as defined in Section 1.3.1 (168,500 cubic meters for CH-TRU and 7,080 cubic meters for RH-TRU).

Appendix D presents the radionuclide inventory in decayed curies for each TRU waste site for the stored waste inventories provided by the TRU waste generator/storage sites. Again, these numbers were decayed to December, 1995 using ORIGEN 2. The RFETS plutonium residue curies, which are included in the numbers in Table 3-4, are undecayed values (see Appendix J)

and were added to their decayed site radionuclide inventory submittal to calculate the total RFETS radionuclide inventory. The results are reported as the RFETS radionuclide inventory in Appendix D.

Since Oak Ridge National Laboratory (ORNL) reported a very conservative inventory for U-235 in RH-TRU waste, the anticipated transportation requirements of the RH-TRU canister have been imposed on the RH-TRU inventory in order to estimate the curies per cubic meter of U-235 in the WIPP radionuclide inventory for RH-TRU waste.

The basis for the new estimate for U-235 is the anticipated initial transportation limit of a maximum of 325 grams of Pu-239 fissile gram equivalent (FGE) for an RH canister (DOE, 1991). Based on the curies per cubic meter calculated for Pu-239 (1.45 Ci/m^3) and U-233 (4.50E-03 Ci/m^3) in Table 3-4 for RH-TRU waste, it was estimated that these two radionuclides would contribute a total of approximately 21.8 grams of Pu-239 FGE per RH canister. If the transportation limit of 325 Pu-239 FGE is imposed, the maximum amount of U-235 that can be transported would equal not more than 303.8 Pu-239 FGE. Assuming a 1:1 equivalence for U-235 in terms of Pu-239 FGE (Nuclear Packaging, 1991) and 2.19 curies per gram of U-235, the curies per cubic meter of U-235 is estimated as,

$$= \frac{303.8 \text{ g of U-235}}{\text{RH Canister}} \times \frac{1 \text{ RH Canister}}{0.89 \text{ m}^3} \times \frac{2.19\text{E-06 Curies of U-235}}{1 \text{ g of U-235}}$$

$$= 7.47\text{E-04 Ci/m}^3$$

To avoid discrepancies in reporting the radionuclide inventory between the IDB and the Baseline Inventory Report, the TRU waste section of Revision 11 of the IDB is based on Revision 1 of the WTWBIR. Appendix G of this report presents the site-level radionuclide inventory as reported in Revision 11 of the IDB (DOE, 1995d).

Table 3-4. Disposal Radionuclide Inventory[1]

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Ac225	1.71E-05	4.89E-06	2.88E+00	3.46E-02
Ac227	3.61E-06	2.05E-07	6.08E-01	1.45E-03
Ac228	4.43E-06	1.10E-05	7.46E-01	7.76E-02
Ag109M	9.32E-05	NR	1.57E+01	NR
Ag110	4.20E-14	2.46E-13	7.07E-09	1.74E-09
Ag110M	7.48E-12	1.85E-11	1.26E-06	1.31E-07
Am241	2.60E+00	8.42E-01	4.39E+05	5.96E+03
Am243	1.93E-04	3.23E-08	3.25E+01	2.28E-04
Am245	7.89E-15	4.06E-20	1.33E-09	2.87E-16
At217	1.71E-05	4.89E-06	2.88E+00	3.46E-02
Ba137m	4.53E-02	2.89E+01	7.63E+03	2.04E+05
Bi210	1.52E-05	1.00E-09	2.55E+00	7.08E-06
Bi211	3.61E-06	2.05E-07	6.09E-01	1.45E-03
Bi212	1.61E-04	8.53E-05	2.71E+01	6.04E-01
Bi213	1.71E-05	4.89E-06	2.88E+00	3.46E-02
Bi214	6.91E-05	4.97E-09	1.16E+01	3.52E-05
Bk249	5.44E-10	2.80E-15	9.16E-05	1.98E-11
Bk250	2.59E-16	NR	4.37E-11	NR
C14	6.43E-05	2.89E-04	1.08E+01	2.05E+00
Cd109	9.31E-05	NR	1.57E+01	NR
Cd113m	1.09E-11	7.71E-11	1.84E-06	5.46E-07

NR = Not reported by sites.
[1]Decayed to December 1995. RFETS plutonium residue curies are included, but not decayed.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

Table 3-4. Disposal Radionuclide Inventory (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Ce144	3.71E-07	7.25E-04	6.26E-02	5.14E+00
Cf249	3.81E-07	6.31E-07	6.42E-02	4.47E-03
Cf250	1.96E-06	NR	3.30E-01	NR
Cf251	2.24E-08	NR	3.78E-03	NR
Cf252	1.41E-03	1.82E-04	2.37E+02	1.29E+00
Cm242	1.92E-08	NR	3.23E-03	NR
Cm243	1.63E-05	6.98E-03	2.75E+00	4.95E+01
Cm244	4.72E-02	4.45E-02	7.96E+03	3.15E+02
Cm245	6.64E-04	2.07E-10	1.12E+02	1.46E-06
Cm246	6.06E-07	NR	1.02E-01	NR
Cm247	1.91E-14	NR	3.21E-09	NR
Cm248	5.29E-07	2.89E-08	8.91E-02	2.05E-04
Co58	1.81E-18	1.75E-15	3.05E-13	1.24E-11
Co60	3.83E-04	1.47E+00	6.46E+01	1.04E+04
Cr51	NR	4.29E-10	NR	3.04E-06
Cs134	7.97E-08	2.60E-03	1.34E-02	1.84E+01
Cs135	2.98E-09	1.66E-08	5.02E-04	1.17E-04
Cs137	4.78E-02	3.05E+01	8.06E+03	2.16E+05
Es254	2.51E-16	NR	4.24E-11	NR
Eu150	2.08E-10	NR	3.51E-05	NR
Eu152	7.46E-06	1.73E-01	1.26E+00	1.22E+03
Eu154	6.81E-06	8.36E-02	1.15E+00	5.92E+02

NR = Not reported by sites.
[1]Decayed to December 1995. RFETS plutonium residue curies are included, but not decayed.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

Table 3-4. Disposal Radionuclide Inventory (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Eu155	1.86E-03	1.67E-02	3.14E+02	1.18E+02
Fe55	1.13E-10	2.38E-05	1.91E-05	1.68E-01
Fe59	1.57E-12	NR	2.64E-07	NR
Fr221	1.71E-05	4.89E-06	2.88E+00	3.46E-02
Fr223	4.98E-08	2.83E-09	8.39E-03	2.01E-05
H3	5.15E-06	9.33E-06	8.68E-01	6.60E-02
I129	4.11E-12	NR	6.93E-07	NR
Kr85	1.20E-06	2.37E-04	2.02E-01	1.68E+00
Mn54	5.06E-09	3.31E-06	8.52E-04	2.34E-02
Nb95	1.51E-14	1.48E-07	2.54E-09	1.05E-03
Nb95m	5.04E-17	1.16E-10	8.50E-12	8.19E-07
Ni59	4.39E-08	NR	7.40E-03	NR
Ni63	5.35E-06	1.40E-04	9.02E-01	9.89E-01
Np237	3.26E-04	6.85E-06	5.49E+01	4.85E-02
Np239	2.20E-04	3.23E-08	3.71E+01	2.28E-04
Np240M	8.91E-12	3.12E-15	1.50E-06	2.21E-11
Pa231	2.67E-06	1.24E-06	4.51E-01	8.79E-03
Pa233	3.26E-04	6.85E-06	5.49E+01	4.85E-02
Pa234	3.05E-07	2.64E-07	5.14E-02	1.87E-03
Pa234m	2.35E-04	2.03E-04	3.96E+01	1.44E+00
Pb209	1.71E-05	4.89E-06	2.88E+00	3.46E-02

NR = Not reported by sites.
[1]Decayed to December 1995. RFETS plutonium residue curies are included, but not decayed.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

Table 3-4. Disposal Radionuclide Inventory (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Pb210	1.52E-05	1.00E-09	2.55E+00	7.08E-06
Pb211	3.61E-06	2.05E-07	6.09E-01	1.45E-03
Pb212	1.61E-04	8.53E-05	2.71E+01	6.04E-01
Pb214	6.91E-05	4.97E-09	1.16E+01	3.52E-05
Pd107	4.40E-10	2.45E-09	7.41E-05	1.73E-05
Pm147	4.68E-05	1.52E-03	7.88E+00	1.07E+01
Po210	1.52E-05	1.00E-09	2.55E+00	7.08E-06
Po211	1.01E-08	5.75E-10	1.71E-03	4.07E-06
Po212	1.03E-04	5.47E-05	1.73E+01	3.87E-01
Po213	1.67E-05	4.78E-06	2.82E+00	3.39E-02
Po214	6.91E-05	4.97E-09	1.16E+01	3.52E-05
Po215	3.61E-06	2.05E-07	6.09E-01	1.45E-03
Po216	1.61E-04	8.63E-05	2.71E+01	6.11E-01
Po218	6.91E-05	4.97E-09	1.16E+01	3.52E-05
Pr144	3.67E-07	8.68E-04	6.18E-02	6.14E+00
Pu236	6.16E-08	NR	1.04E-02	NR
Pu238	2.26E+01	2.05E-01	3.80E+06	1.45E+03
Pu239	4.64E+00	1.45E+00	7.82E+05	1.03E+04
Pu240	1.23E+00	7.16E-01	2.08E+05	5.07E+03
Pu241	1.55E+01	2.00E+01	2.61E+06	1.42E+05
Pu242	6.93E-03	2.11E-05	1.17E+03	1.50E-01

NR = Not reported by sites.
[1]Decayed to December 1995. RFETS plutonium residue curies are included, but not decayed.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

Table 3-4. Disposal Radionuclide Inventory (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Pu243	1.91E-14	NR	3.21E-09	NR
Pu244	8.92E-12	3.12E-15	1.50E-06	2.21E-11
Ra223	1.39E-05	2.05E-07	2.34E+00	1.45E-03
Ra224	1.61E-04	8.53E-05	2.71E+01	6.04E-01
Ra225	1.71E-05	4.89E-06	2.88E+00	3.46E-02
Ra226	6.95E-05	4.97E-09	1.17E+01	3.52E-05
Ra228	4.43E-06	1.10E-05	7.46E-01	7.76E-02
Rh106	1.72E-07	1.54E-03	2.90E-02	1.09E+01
Rn219	3.61E-06	2.05E-07	6.09E-01	1.45E-03
Rn220	1.61E-04	8.53E-05	2.71E+01	6.04E-01
Rn222	6.91E-05	4.97E-09	1.16E+01	3.52E-05
Ru106	1.72E-07	1.54E-03	2.90E-02	1.09E+01
Sb125	7.17E-07	2.67E-04	1.21E-01	1.89E+00
Sb126	8.02E-10	4.46E-09	1.35E-04	3.16E-05
Sb126m	5.73E-09	3.18E-08	9.65E-04	2.25E-04
Se79	2.58E-09	1.44E-08	4.35E-04	1.02E-04
Sm151	8.76E-06	5.06E-05	1.48E+00	3.58E-01
Sn119m	2.46E-11	1.35E-10	4.14E-06	9.59E-07
Sn121M	1.58E-07	9.46E-07	2.66E-02	6.70E-03
Sn126	5.80E-09	3.18E-08	9.77E-04	2.25E-04
Sr89	NR	2.65E-08	NR	1.88E-04

NR = Not reported by sites.
[1]Decayed to December 1995. RFETS plutonium residue curies are included, but not decayed.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

Table 3-4. Disposal Radionuclide Inventory (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Sr90	4.07E-02	2.95E+01	6.85E+03	2.09E+05
Ta182	NR	5.95E-12	NR	4.21E-08
Tc99	1.49E-04	8.26E-07	2.52E+01	5.85E-03
Te125m	1.75E-07	6.57E-05	2.95E-02	4.65E-01
Te127	7.72E-13	2.42E-13	1.30E-07	1.72E-09
Te127m	7.88E-13	2.47E-13	1.33E-07	1.75E-09
Th227	3.56E-06	2.03E-07	6.01E-01	1.43E-03
Th228	1.61E-04	8.53E-05	2.71E+01	6.04E-01
Th229	1.71E-05	4.89E-06	2.88E+00	3.46E-02
Th230	5.36E-07	1.04E-06	9.03E-02	7.34E-03
Th231	7.60E-05	9.38E-03	1.28E+01	6.64E+01
Th232	5.41E-06	1.31E-05	9.11E-01	9.24E-02
Th234	2.35E-04	2.03E-04	3.96E+01	1.44E+00
Tl207	3.60E-06	2.05E-07	6.07E-01	1.45E-03
Tl208	5.77E-05	3.07E-05	9.73E+00	2.17E-01
Tl209	3.69E-07	1.06E-07	6.22E-02	7.48E-04
U232	1.56E-04	8.31E-05	2.63E+01	5.88E-01
U233	1.18E-02	4.50E-03	2.00E+03	3.18E+01
U234	3.28E-03	5.55E-03	5.53E+02	3.93E+01
U235	7.60E-05	7.34E-04	1.28E+01	5.20E+00
U236	1.89E-06	3.70E-07	3.19E-01	2.62E-03

NR = Not reported by sites.
[1]Decayed to December 1995. RFETS plutonium residue curies are included, but not decayed.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

Table 3-4. Disposal Radionuclide Inventory (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
U237	2.31E-04	4.91E-04	3.89E+01	3.48E+00
U238	2.35E-04	2.03E-04	3.96E+01	1.44E+00
U240	8.91E-12	3.12E-15	1.50E-06	2.21E-11
Y90	4.07E-02	2.95E+01	6.85E+03	2.09E+05
Zn65	4.13E-14	NR	6.96E-09	NR
Zr93	NR	2.89E-07	NR	2.04E-03
Zr95	NR	1.56E-08	NR	1.10E-04
TOTALS	**4.68E+01**	**1.43E+02**	**7.88E+06**	**1.02E+06**

NR = Not reported by sites.
[1]Decayed to December 1995. RFETS plutonium residue curies are included, but not decayed.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

CHAPTER 4

4. STORED AND PROJECTED WIPP CH-TRU AND RH-TRU INVENTORIES BY SITE

As described in Chapter 2, each WIPP waste stream from each waste generator/storage site is characterized in a waste stream profile (Appendix P or the accompanying TWBID). These waste stream profiles are rolled-up by Final Waste Forms for each generator/storage site. Summary tables of contact-handled and remote-handled WIPP (only) waste volumes by site are provided in Tables 4-1 and 4-2. Summary profiles of WIPP waste volumes by Final Waste Form for each site are provided in Tables 4-3 through 4-23. Additional information is presented in Appendix K.

Table 4 - 1

WIPP CH-TRU Waste Anticipated Inventory By Site

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Ames Laboratory - Iowa State Univ.	0.0E+00	4.2E-01	4.2E-01
Argonne National Laboratory - East	1.1E+01	1.3E+02	1.4E+02
Argonne National Laboratory - West	6.5E+00	7.4E+02	7.5E+02
Bettis Atomic Power Laboratory	0.0E+00	1.2E+02	1.2E+02
Energy Technology Engineering Center	1.7E+00	0.0E+00	1.7E+00
Hanford (Richland) Site	1.2E+04	3.3E+04	4.6E+04
Idaho National Engineering Laboratory	2.9E+04	0.0E+00	2.9E+04
Lawrence Livermore National Laboratory	2.3E+02	7.1E+02	9.4E+02
Los Alamos National Laboratory	1.1E+04	7.4E+03	1.8E+04
Mound Plant	2.7E+02	0.0E+00	2.7E+02
Nevada Test Site	6.2E+02	9.0E+00	6.3E+02
Oak Ridge National Laboratory	1.3E+03	2.6E+02	1.6E+03
Paducah Gaseous Diffusion Plant	0.0E+00	1.9E+00	1.9E+00
Pantex Plant	6.2E-01	0.0E+00	6.2E-01
Rocky Flats Environmental Technology Site	7.1E+02	4.4E+03	5.1E+03
Sandia National Laboratory - Albuquerque	6.7E+00	7.5E+00	1.4E+01
Savannah River Site	2.9E+03	6.8E+03	9.6E+03
Teledyne Brown Engineering	2.1E-01	0.0E+00	2.1E-01
U.S. Army Material Command	2.5E+00	0.0E+00	2.5E+00
University of Missouri Research Reactor	2.1E-01	8.3E-01	1.0E+00
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**

Table 4 - 2

WIPP RH-TRU Waste Anticipated Inventory By Site

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Argonne National Laboratory - West	1.9E+01	1.3E+03	1.3E+03
Battelle Columbus Laboratories	5.8E+02	0.0E+00	5.8E+02
Bettis Atomic Power Laboratory	0.0E+00	6.7E+00	6.7E+00
Energy Technology Engineering Center	8.9E-01	0.0E+00	8.9E-01
Hanford (Richland) Site	2.0E+02	2.2E+04	2.2E+04
Idaho National Engineering Laboratory	2.2E+02	0.0E+00	2.2E+02
Los Alamos National Laboratory	9.4E+01	9.9E+01	1.9E+02
Oak Ridge National Laboratory	2.5E+03	4.5E+02	2.9E+03
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**

Table 4 - 3

Ames Laboratory - Iowa State Univ. Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Solidified Inorganics	0.00	0.42	0.42
Total CH Volumes	**0.00**	**0.42**	**0.42**

Table 4 - 4

Argonne National Laboratory - East Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Lead/Cadmium Metal Waste	1.07	1.29	2.36
Solidified Inorganics	5.20	0.00	5.20
Solidified Organics	0.21	0.00	0.21
Uncategorized Metal	4.99	128.54	133.54
Total CH Volumes	**11.47**	**129.83**	**141.30**

Table 4 - 5

Argonne National Laboratory - West Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Combustible	0.00	101.64	101.64
Heterogeneous	6.54	345.35	351.89
Uncategorized Metal	0.00	293.76	293.76
Total CH Volumes	**6.54**	**740.76**	**747.30**
Remote Handled Waste			
Heterogeneous	0.00	1208.62	1208.62
Inorganic Non-Metal	0.00	21.36	21.36
Lead/Cadmium Metal Waste	0.00	6.23	6.23
Solidified Inorganics	1.78	28.48	30.26
Uncategorized Metal	17.51	0.00	17.51
Total RH Volumes	**19.29**	**1264.69**	**1283.98**

Table 4 - 6

Battelle Columbus Laboratories Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Total CH Volumes			
Remote Handled Waste			
Heterogeneous	580.50	0.00	580.50
Total RH Volumes	**580.50**	**0.00**	**580.50**

Table 4 - 7

Bettis Atomic Power Laboratory Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	0.00	123.27	123.27
Total CH Volumes	**0.00**	**123.27**	**123.27**
Remote Handled Waste			
Heterogeneous	0.00	6.67	6.67
Total RH Volumes	**0.00**	**6.67**	**6.67**

Table 4 - 8

Energy Technology Engineering Center Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	1.68	0.00	1.68
Total CH Volumes	**1.68**	**0.00**	**1.68**
Remote Handled Waste			
Lead/Cadmium Metal Waste	0.89	0.00	0.89
Total RH Volumes	**0.89**	**0.00**	**0.89**

Table 4 - 9

Hanford (Richland) Site Final Waste Form Volumes

(Cubic Meters)

Final Waste Form	Retrievably Stored	Projected	Total
Contact Handled Waste			
Combustible	455.73	1247.26	1702.99
Heterogeneous	11190.75	6271.29	17462.04
Inorganic Non-Metal	34.74	69.06	103.79
Lead/Cadmium Metal Waste	14.17	34.53	48.69
Soils	119.48	5961.70	6081.17
Solidified Inorganics	12.94	7.07	20.02
Solidified Organics	7.36	9.36	16.72
Uncategorized Metal	444.86	19635.15	20080.01
Total CH Volumes	**12280.03**	**33235.41**	**45515.44**
Remote Handled Waste			
Heterogeneous	199.36	4066.41	4265.77
Lead/Cadmium Metal Waste	2.67	60.52	63.19
Uncategorized Metal	0.00	17400.39	17400.39
Total RH Volumes	**202.03**	**21527.32**	**21729.35**

Table 4 - 10

Idaho National Engineering Laboratory Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Combustible	3304.94	0.00	3304.94
Filter	131.05	0.00	131.05
Graphite	498.19	0.00	498.19
Heterogeneous	10608.50	0.00	10608.50
Inorganic Non-Metal	3028.24	0.00	3028.24
Lead/Cadmium Metal Waste	14.37	0.00	14.37
Salt Waste	20.52	0.00	20.52
Solidified Inorganics	4344.44	0.00	4344.44
Solidified Organics	789.67	0.00	789.67
Uncategorized Metal	5866.82	0.00	5866.82
Total CH Volumes	**28606.72**	**0.00**	**28606.72**
Remote Handled Waste			
Combustible	21.36	0.00	21.36
Heterogeneous	49.84	0.00	49.84
Inorganic Non-Metal	46.28	0.00	46.28
Lead/Cadmium Metal Waste	3.56	0.00	3.56
Solidified Inorganics	65.27	0.00	65.27
Solidified Organics	3.56	0.00	3.56
Uncategorized Metal	30.85	0.00	30.85
Total RH Volumes	**220.72**	**0.00**	**220.72**

Table 4 - 11

Lawrence Livermore National Laboratory Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Filter	15.54	32.28	47.82
Heterogeneous	198.85	663.78	862.63
Salt Waste	0.62	3.02	3.64
Solidified Inorganics	14.35	5.82	20.18
Solidified Organics	1.04	5.82	6.86
Total CH Volumes	**230.40**	**710.73**	**941.13**

Table 4 - 12

Los Alamos National Laboratory Final Waste Form Volumes

(Cubic Meters)

Final Waste Form	Retrievably Stored	Projected	Total
Contact Handled Waste			
Combustible	1821.45	2376.19	4197.64
Heterogeneous	16.02	29.12	45.14
Lead/Cadmium Metal Waste	1.89	0.00	1.89
Soils	110.57	29.12	139.69
Solidified Inorganics	4888.20	2033.82	6922.02
Solidified Organics	1.46	29.12	30.58
Uncategorized Metal	4214.43	2853.76	7068.19
Total CH Volumes	**11054.01**	**7351.14**	**18405.15**
Remote Handled Waste			
Combustible	15.13	48.95	64.08
Heterogeneous	11.57	0.00	11.57
Uncategorized Metal	67.64	49.84	117.48
Total RH Volumes	**94.34**	**98.79**	**193.13**

Table 4 - 13

Mound Plant Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Combustible	7.07	0.00	7.07
Filter	0.83	0.00	0.83
Heterogeneous	0.62	0.00	0.62
Soils	177.18	0.00	177.18
Solidified Inorganics	6.03	0.00	6.03
Uncategorized Metal	82.48	0.00	82.48
Total CH Volumes	**274.22**	**0.00**	**274.22**

Table 4 - 14

Nevada Test Site Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	613.26	8.98	622.24
Solidified Inorganics	5.67	0.00	5.67
Total CH Volumes	**618.93**	**8.98**	**627.91**

Table 4 - 15

Oak Ridge National Laboratory Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	1304.16	256.26	1560.42
Total CH Volumes	**1304.16**	**256.26**	**1560.42**
Remote Handled Waste			
Heterogeneous	1432.01	240.30	1672.31
Solidified Inorganics	1036.85	206.48	1243.33
Total RH Volumes	**2468.86**	**446.78**	**2915.64**

Table 4 - 16

Paducah Gaseous Diffusion Plant Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Inorganic Non-Metal	0.00	1.89	1.89
Total CH Volumes	**0.00**	**1.89**	**1.89**

Table 4 - 17

Pantex Plant Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	0.62	0.00	0.62
Total CH Volumes	**0.62**	**0.00**	**0.62**

Table 4 - 18

Rocky Flats Environmental Technology Site Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Combustible	185.54	861.08	1046.62
Filter	72.09	477.51	549.60
Graphite	13.73	47.57	61.30
Heterogeneous	3.86	0.00	3.86
Inorganic Non-Metal	58.29	866.74	925.03
Lead/Cadmium Metal Waste	3.95	298.27	302.22
Salt Waste	0.00	325.92	325.92
Solidified Inorganics	165.36	1257.64	1423.01
Solidified Organics	109.82	31.11	140.93
Uncategorized Metal	93.31	236.12	329.43
Total CH Volumes	**705.96**	**4401.95**	**5107.91**

Table 4 - 19

Sandia National Laboratory - Albuquerque Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	6.66	7.49	14.14
Total CH Volumes	**6.66**	**7.49**	**14.14**

Table 4 - 20

Savannah River Site Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	2611.61	5475.85	8087.46
Solidified Inorganics	200.19	1169.61	1369.80
Uncategorized Metal	70.35	120.54	190.89
Total CH Volumes	**2882.14**	**6766.01**	**9648.15**

Table 4 - 21

Teledyne Brown Engineering Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Inorganic Non-Metal	0.21	0.00	0.21
Total CH Volumes	**0.21**	**0.00**	**0.21**

Table 4 - 22

U.S. Army Material Command Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	2.50	0.00	2.50
Total CH Volumes	**2.50**	**0.00**	**2.50**

Table 4 - 23

University of Missouri Research Reactor Final Waste Form Volumes

	(Cubic Meters)		
Final Waste Form	**Retrievably Stored**	**Projected**	**Total**
Contact Handled Waste			
Heterogeneous	0.21	0.83	1.04
Total CH Volumes	**0.21**	**0.83**	**1.04**

CHAPTER 5

5. DEPARTMENT OF ENERGY TRANSURANIC WASTE INVENTORY

5.1 INTRODUCTION

The *Waste Isolation Pilot Plant Land Withdrawal Act* states that "The Secretary may commence emplacement of transuranic waste underground for disposal at WIPP only upon completion of ... the submittal to the Congress by the Secretary of comprehensive recommendations for the disposal of all transuranic waste under the control of the Secretary, including a timetable for the disposal of such waste..." (Public Law, 1992b). This section identifies waste streams not included in the WIPP inventory. The combined waste streams from Appendices O and P define all known TRU waste reported by the TRU waste generator/storage sites. Non-WIPP waste streams in Appendix O are summarized in Section 5.2.

There are some materials that have not been declared TRU waste by the DOE TRU waste generator/storage sites at this time that may become TRU waste in the future. These possible future wastes are also discussed in this chapter.

5.2 WASTE STREAMS EXCLUDED FROM WIPP

The DOE has several categories of waste that are not authorized for disposal in WIPP. These are summarized below:

- **Commercial and Non-Defense Waste** – The *National Security Programs* (Public Law, 1979), which authorized the construction of the WIPP, states that WIPP is to be a defense activity. Therefore those wastes that are identified as non-defense or commercial are not allowed to be disposed in WIPP. The non-defense or commercial waste streams are identified in Table 5-1.

- **Pre-1970 Buried Waste** – Several sites (i.e., Los Alamos National Laboratory, Savannah River Site, Sandia National Laboratories, Hanford Site, Idaho National Engineering Laboratory, Oak Ridge National Laboratory, and West Valley) have TRU waste that were buried prior to 1970. The final disposition of the buried TRU wastes at DOE sites is still undecided. The waste streams presented in Table 5-2 provide the volume of pre-1970 buried waste that has been reported to date.

- **Classified Waste** – Sites that have classified waste will be required to declassify the waste prior to shipment to WIPP. Several generator/storage sites have identified classified waste in storage. These sites have planned declassification of these waste streams. If declassification is anticipated, the Final Waste Form is a part of the WIPP disposal inventory. If declassification is not anticipated, the Final Waste Form is excluded from WIPP. There was no classified waste in Final Waste Form reported in the Revision 2 TWBIR data call.

- **Polychlorinated Biphenyls (PCBs)** – This category of Toxic Substances Control Act (TSCA) waste is not permitted in WIPP if the PCB concentrations exceed 50 ppm (DOE, 1995f). The TRU waste generator/storage sites have identified several waste streams that are regulated under TSCA (i.e., containing PCBs). Because the concentrations

Table 5-1

Non Defense and Commercial Waste (Final Waste Form)

(Cubic Meters)

Commercial TRU Waste

Waste Stream ID	Waste Stream Name	Stored Volumes	Projected Volumes	Total Volumes
AM-W001	Nuclear Pacemakers	0.0E+00	4.2E-01	4.2E-01
WV-M005	TRU Filters	4.9E+01	4.6E+01	9.5E+01
WV-M007	TRU General Waste	1.0E+01	0.0E+00	1.0E+01
WV-M008	TRU Concrete	2.1E-01	0.0E+00	2.1E-01
WV-M010	TRU Spent Absorbents	4.2E-01	0.0E+00	4.2E-01
WV-M012	Glove Boxes	2.1E-01	0.0E+00	2.1E-01
WV-M013	Sweeping Compound	1.5E+00	0.0E+00	1.5E+00
WV-M015	Chemical Process Cell General Waste	1.8E+01	0.0E+00	1.8E+01
WV-T001	Fissile Material - Solids	3.7E+00	0.0E+00	3.7E+00
WV-T002	Fissile Material - Alpha Lab Liquids	6.2E-01	0.0E+00	6.2E-01
WV-T003	Fissile Material-UNH Solution	2.1E-01	0.0E+00	2.1E-01
WV-T004	Fissile Material - Other	4.2E-01	0.0E+00	4.2E-01
WV-T006	TRU General Waste	1.3E+01	8.8E+01	1.0E+02
WV-T009	TRU General Laboratory Waste	2.1E+00	2.9E+01	3.1E+01
WV-T011	TRU Glove Boxes	2.1E-01	0.0E+00	2.1E-01
WV-T014	Chemical Process Cell Vessels	9.0E+01	0.0E+00	9.0E+01
WV-T016	Chemical Process Cell Miscellaneous Equipment	1.5E+02	0.0E+00	1.5E+02
WV-T017	Spent Filter Media	3.8E+00	0.0E+00	3.8E+00
WV-W024	TRU Lead	2.1E+00	0.0E+00	2.1E+00
WV-W041	TRU Paint (Dry) with Metals	4.2E-01	0.0E+00	4.2E-01
	Totals	3.4E+02	1.6E+02	5.1E+02

Non-Defense TRU Waste

Waste Stream ID	Waste Stream Name	Stored Volumes	Projected Volumes	Total Volumes
KA-T001	Transuranic Debris	2.5E+00	5.1E+01	5.4E+01
KA-W016	Transuranic Debris	0.0E+00	6.9E+00	6.9E+00
LB-T001	LBL - Waste	6.2E-01	1.0E+00	1.7E+00
OR-W051	CH-TRU Heterogeneous Debris (nondefense)	1.0E+00	0.0E+00	1.0E+00
OR-W052	CH-TRU Uncategorized (nondefense, nonmixed)	4.4E+00	0.0E+00	4.4E+00
	Totals	8.5E+00	5.9E+01	6.8E+01

Table 5-2. Pre-1970 Buried Waste

Site	Waste Stream ID	Current Volume (m^3)	Total Curies (estimates)
LANL	LA-Z001	14,000	9,230[1]
ORNL	OR-Z001	176	20[1]
Hanford	RL-Z001	63,629	93,800[1]
SNL/NM	SA-Z001	1.33	Not available
SRS	SR-Z001	4,874	30,500[1]
INEL	IN-Z001	57,000	248,830[2]
WVDP	WV-Z001	1,353	652,000[2,3]

[1] Decayed to December 1993
[2] Not decayed
[3] TRU radionuclides only

of the PCBs frequently is unknown, it is assumed that any waste identified as PCB contaminated cannot be accepted at WIPP under the WIPP permit applications without being treated. These waste streams are summarized in Table 5-3 and are not included in the WIPP disposal inventory.

5.3 ANTICIPATED DOE TRU WASTE INVENTORY

The anticipated DOE TRU waste inventory that has been identified to date is provided in Tables 5-4 and 5-5. Tables 5-4 and 5-5 include the WIPP transuranic waste disposal inventory provided in Tables 4-1 and 4-2 with the addition of the excluded wastes discussed in Section 5.2. Table 5-2 provides the total pre-1970 buried waste inventory by site. This information is not included in Tables 5-4 or 5-5 because the handling (CH-TRU or RH-TRU) is unknown.

5.4 POSSIBLE FUTURE WIPP WASTE

There are several categories of material that have not been declared TRU waste at this time that may be placed in the TRU waste category in the future:

- One of these is plutonium residues at sites other than RFETS. RFETS has declared their (<50% Pu) plutonium residues TRU waste and the volumes and radionuclide inventories are included in the WIPP-level profiles. The *Defense Nuclear Facilities Safety Board Recommendation 94-1 Implementation Plan* (DOE, 1995a) provides estimates of residues and mixed oxides (<50% assay) at other DOE TRU waste sites as presented in Table 5-6. The units for Table 5-6 is kilogram which departs from units used elsewhere in this document. These are the units used in the *94-1 Implementation Plan*. Although the RFETS residues are included in the Defense Nuclear Facilities Safety Board document, they are not listed in Table 5-6 because they are already included in the WIPP disposal inventory.

Table 5-3

Polychlorinated Biphenyl (PCB) TRU Waste (Final Waste Form)

		(Cubic Meters)		
WASTE Stream ID	Waste Stream Name	Stored Volumes	Projected Volumes	Total Volumes
RF-MT0831	PCB Solids-Compatibles/TRM			
RL-W327	2345Z Uncat met debris CH RC/TS MTRU w/ met(Hg)	6.6E+01	1.1E+02	1.8E+02
RL-W328	2345Z Pb/Cd debris CH RC/TS MTRU w/ met(Hg)	3.8E+00	0.0E+00	3.8E+00
RL-W329	2345Z Solidif org CH RC/TS MTRU w/ ign	2.1E+00	8.3E+00	1.0E+01
RL-W333	2345Z Solidif org debris CH TSCA MTRU	1.2E+00	2.5E+00	3.7E+00
RL-W334	2345Z Uncat mt debris CH TSCA MTRU	2.1E-01	0.0E+00	2.1E-01
	Totals	7.3E+01	1.2E+02	1.9E+02

No volumes are shown for the waste stream from Rocky Flats because the Final Waste Form for this stream has not been determined by the site.

Table 5-4

Total Contact-Handled Transuranic Waste Inventory By Site

Contact Handled TRU Waste Site	(Cubic Meters)		
Generator/Storage Site	**Stored Volumes**	**Projected Volumes**	**Anticipated Volumes**
Ames Laboratory - Iowa State Univ.	0.0E+00	4.2E-01	4.2E-01
ARCO Medical Products Co.	0.0E+00	4.2E-01	4.2E-01
Argonne National Laboratory - East	2.5E+01	1.3E+02	1.5E+02
Argonne National Laboratory - West	6.5E+00	7.4E+02	7.5E+02
Bettis Atomic Power Laboratory	0.0E+00	1.2E+02	1.2E+02
Energy Technology Engineering Center	1.7E+00	0.0E+00	1.7E+00
Hanford (Richland) Site	1.2E+04	3.3E+04	4.6E+04
Idaho National Engineering Laboratory	2.9E+04	0.0E+00	2.9E+04
Lawrence Berkeley Laboratory	6.2E-01	1.0E+00	1.7E+00
Lawrence Livermore National Laboratory	2.3E+02	7.1E+02	9.4E+02
Los Alamos National Laboratory	1.1E+04	7.4E+03	1.8E+04
Mound Plant	3.2E+02	0.0E+00	3.2E+02
Nevada Test Site	6.2E+02	9.0E+00	6.3E+02
Oak Ridge National Laboratory	1.3E+03	2.6E+02	1.6E+03
Paducah Gaseous Diffusion Plant	0.0E+00	5.7E+00	5.7E+00
Pantex Plant	6.2E-01	0.0E+00	6.2E-01
Rocky Flats Environmental Technology Site	7.1E+02	4.4E+03	5.1E+03
Sandia National Laboratory - Albuquerque	6.7E+00	7.5E+00	1.4E+01
Savannah River Site	2.9E+03	6.8E+03	9.6E+03
Teledyne Brown Engineering	2.1E-01	0.0E+00	2.1E-01
U.S. Army Material Command	2.5E+00	0.0E+00	2.5E+00
University of Missouri Research Reactor	2.1E-01	8.3E-01	1.0E+00
West Valley Demonstration Project	3.9E+01	1.2E+02	1.6E+02
Totals	5.8E+04	5.4E+04	1.1E+05

Table 5-5

Total Remote-Handled Transuranic Waste Inventory By Site

Remote Handled TRU Waste Site	(Cubic Meters)		
Generator/Storage Site	**Stored Volumes**	**Projected Volumes**	**Anticipated Volumes**
Argonne National Laboratory - West	1.9E+01	1.3E+03	1.3E+03
Battelle Columbus Laboratories	5.8E+02	0.0E+00	5.8E+02
Bettis Atomic Power Laboratory	0.0E+00	6.7E+00	6.7E+00
Energy Technology Engineering Center	6.3E+00	8.3E-01	7.1E+00
Hanford (Richland) Site	2.0E+02	2.2E+04	2.2E+04
Idaho National Engineering Laboratory	2.2E+02	0.0E+00	2.2E+02
Knolls Atomic Power Laboratory - Schenectady	2.5E+00	5.8E+01	6.1E+01
Los Alamos National Laboratory	9.4E+01	9.9E+01	1.9E+02
Oak Ridge National Laboratory	2.5E+03	4.5E+02	2.9E+03
West Valley Demonstration Project	3.0E+02	4.6E+01	3.5E+02
Totals	3.9E+03	2.3E+04	2.7E+04

Table 5-6. Possible Future Waste - Residues

Site	Radionuclide Inventory (kgs)	Number of Items
Argonne National Laboratory-East	<1	12
Hanford (Richland) Site	1,500	5000
Lawrence Berkley Laboratory	<1	250
Lawrence Livermore National Laboratory	35	182
Los Alamos National Laboratory	1,400	6,300
Mound	3	39
Oak Ridge National Laboratories	0.1	12
Savannah River Site	Classified	1,306

- Another category of possible future TRU waste is from Hanford site. The tank wastes at Hanford can be classified as high-level wastes (HLW), transuranic (TRU) wastes, or low-level (LLW). For purposes of receipt, storage, and management, all tank wastes are managed as HLW. As the tank wastes are characterized and retrieved, those wastes classified as TRU wastes will be maintained as a separate waste stream for purposes of treatment and immobilization at Hanford and potential disposal at the Waste Isolation Pilot Project (WIPP). A very preliminary estimate of the volume of immobilized TRU tank waste from Hanford that would be potentially disposed in WIPP as the tank wastes are characterized and retrieved (if these wastes are able to be segregated), is approximately 1300 m^3.
- Waste streams that have been declared "unknown" make up another category of possible future WIPP waste and are summarized in Table 5-7. These wastes have not been characterized adequately to determine the Final Waste Form and/or other significant parameters. If these wastes are characterized they will be included in the WIPP inventory.
- Babcock and Wilcox in Lynchburg, VA, currently has in storage approximately 18.1 m^3 of TRU waste in on-site storage silos that are classified as possible future TRU waste. Virtually all of the material is a result of the Light Water Reactor Extended Burnup Program. The program was responsible for sending test elements of normal commercial reactor fuel to various hot cells, including the one at Lynchburg, for examination. The waste consists mostly of cellulosics, rubber, and lead lined gloves. In addition, some TRU materials and spent fuel currently reside in TRU-waste contaminated hot cells; however, these materials have not been declared TRU waste.
- General Electric Vallecitas Nuclear Center currently has in storage approximately 5.33 m^3 of CH-TRU waste and 8 m^3 of RH-TRU wastes. They anticipate generating an additional 3.5 m^3 of CH-TRU and 5.33 m^3 of RH-TRU waste during D&D activities of the DOE programs. This waste was generated in support of the Nuclear Energy's boiling water reactor (BWR) activities conducted for DOE and the Atomic Energy Commission.
- RFETS particulate waste streams will be shipped and disposed in a 55-gallon drum containing a 6-inch or 12-inch steel pipe component. The 6-inch pipe will add 88 pounds of steel and 97 pounds of fiberboard per container. The 12-inch pipe will add 195 pounds of steel and 65 pounds of fiberboard per drum. It is anticipated that RFETS will have an estimate of the total number of drums in TWBIR, Rev. 3.

Table 5-7

Possible Future Waste for WIPP

		(Cubic Meters)		
Waste Stream ID	Waste Stream Name	Stored Volumes	Projected Volumes	Total Volumes
AE-T001	Solid heterogeneous inorganic/organic waste	1.3E+01	0.0E+00	1.3E+01
AW-N028	TRU WASTE USED PRE-FILTERS			
AW-W018	SODIUM - TRU			
AW-W019	SODIUM POTASSIUM -NaK- TRU			
ET-T001A	Hot Lab & PU Facility D&D	5.4E+00	8.3E-01	6.2E+00
MD-T004	Uncategorized unknowns	4.2E+00	0.0E+00	4.2E+00
MD-T004	Uncategorized unknowns	2.3E+01	0.0E+00	2.3E+01
MD-W018	PCB TRU WASTE	2.1E-01	0.0E+00	2.1E-01
MD-W018	PCB TRU WASTE	1.9E+01	0.0E+00	1.9E+01
OR-W049	CH-TRU Uncategorized (nonmixed)	1.8E+01	0.0E+00	1.8E+01
OR-W050	RH-TRU Uncategorized (nonmixed)	8.9E-01	0.0E+00	8.9E-01
OR-W052	CH-TRU Uncategorized (nondefense, nonmixed)	4.4E+00	0.0E+00	4.4E+00
PA-B015	Transuranic and Technetium Wastes - Liquid	0.0E+00	1.9E+00	1.9E+00
PA-W014	Transuranic Waste Liquid	0.0E+00	1.9E+00	1.9E+00
RL-W284	201C Unk form CH RCRA MTRU w/ met	4.2E-01	0.0E+00	4.2E-01
RL-W332	2345Z Unk form CH St MTRU	2.0E-01	0.0E+00	2.0E-01
RL-W357	KAPL Unk form CH/r TRU	2.1E-01	0.0E+00	2.1E-01
RL-W366	202A Unk form CH TRU	1.5E+00	8.3E-01	2.3E+00
RL-W382	2345Z Unk form CH TRU	1.9E+01	6.1E+01	8.0E+01
RL-W391	308 Comb unk form CH TRU	4.2E-01	0.0E+00	4.2E-01
	Totals	1.1E+02	6.7E+01	1.8E+02

No volumes are shown for the waste streams from Argonne-West because the Final Waste Form for these streams has not been determined by the site.

CHAPTER 6

6. TRANSURANIC WASTE BASELINE INVENTORY DATABASE

A Transuranic Waste Baseline Inventory Database (TWBID) has been developed to support the Transuranic Waste Baseline Inventory Report (TWBIR). This database was used to summarize the waste data and print out the various tables and reports used in the TWBIR. The database is operated in the Microsoft Access version 2.0 system.

6.1 DATABASE DESCRIPTION

The database actually consists of two databases with essentially the same primary data tables. The first database is TWBIR.MDB. This database contains the original data submitted by the sites or amended data as agreed upon by the sites through discussions with TWBIR personnel. This database is used to produce the forms in Appendices O and P. The second database is called REPORTS.MDB and is used to produce the tables and figures in the remainder of the report. Summary tables produced by REPORTS.MDB are the result of a series of calculations based on data from TWBIR.MDB utilizing assumptions outlined in Chapter 1, Appendix O and Appendix P. These calculations and the associated methodology are described in this section of the report. The basic data tables in each database are the same with the exception of one additional table called Container_Data in the Reports.MDB database.

Each record in the database represents one waste stream as defined by a unique Waste Stream ID (WIPP_ID) and a Survey ID (Survey_ID). The Survey ID is the record identifier for the Material Inventory and Tracking Information Database for 1995 (MITI95) data call. The MITI95 database is the source of information for the 1995 Mixed Waste Inventory Report (to be published in Winter 1995). The WIPP_ID is a unique TWBIR identifier for the records containing the TRU waste stream data reported in the MITI95 data call. There may be more than one WIPP_ID for each Survey_ID because some of the sites presented the WIPP waste streams at a finer level of detail. Under the WIPP_ID records there is another level of detail associated with containers as currently existing or as planned to be generated plus containers in final form as expected to arrive at the WIPP.

The reports and tables produced for the TWBIR are produced from different data sorts based on the WIPP_ID, Site_Name, Handling and Final_Waste_Form fields. The Site_Name specifies the site which reported and is typically storing the waste. The generator site may differ from the storage site. The Handling field defines whether the waste is categorized as CH-TRU or RH-TRU waste. The Final_Waste_Form defines a general grouping based on the physical and chemical properties in the waste stream.

The volumes are rolled-up from the stored and projected final waste form containers provided by the sites. The date on which the stored inventory is based may not be consistent among sites.

In Table 3-1, a column, titled "WIPP Disposal Volumes," was calculated to match the maximum calculated CH-TRU disposal inventory. This was done by increasing all the Final_Waste_Form projected volumes proportionately, except Unknown, so that the total CH-TRU volume would equal the maximum calculated WIPP capacity for CH-TRU. Additional waste volume was calculated for each waste stream proportionate to the projected volumes for each stream such that the sum of the scaled volumes for contact handled waste equaled 168,500 cubic meters. Enough waste is already identified to fill the WIPP to capacity for RH-TRU waste.

The other fields used to develop summaries for the tables in the reports are the waste material parameters. The TRU waste generator/storage sites were asked to estimate an average, minimum and maximum concentration of materials in each waste stream. For example, weights of metals such as brass, copper, tantalum and materials simply described as metals were included under the field OM_xxx (where xxx is min, max, or avg) which stands for "Other Metals" (see the data dictionary; Appendix L). Note that because some materials are described only as metals, aluminum and iron can be in the OM_xxx field as well as in the IB_xxx (iron-base) or AB_xxx (aluminum-base) fields.

Four categories of sludges and solidified materials are represented by fields. These are solidified inorganic material (SIM_xxx), solidified organic material (SOM_xxx), vitrified (VIT_xxx) and cement (solidified). The particular category into which a sludge or solidified material is placed is determined by the overall matrix of the resulting material after any solidification or stabilization steps. For example, a small amount of inorganic liquids/sludges solidified in an inorganic matrix would be placed in the solidified inorganic material category and a drum of organic base resin beads solidified in cement would be placed in the solidified organic material category.

The rest of the fields are reasonably self explanatory, but additional discussion on Cel_xxx, Rub_xxx, and Plas_xxx, may be helpful. Cel_xxx includes all cellulose-base materials and will typically include paper, cloth, wood, kimwipes and other materials derived from plant base materials. It is assumed that cloth is plant derived material such as cotton and not plastic based such as rayon or nylon. Rub_xxx consists of rubber based materials. Included in this category are Hypalon®, neoprene, and surgeons gloves. Plas_xxx represents plastics such as Lucite®, polyethylene, Tyvek®, teflon and polyvinyl chloride. Plastic bags are used extensively in packaging the waste and would be included in this category. The plastic drum or container liners were not included in this category and were requested separately.

The waste material parameter information is structured in the database so that the waste material parameters can be summed and averaged at the WIPP, site and Final Waste Form levels. Waste streams for which no waste material parameters are provided or for which average, minimum and maximum parameters are not all provided cannot be rationally averaged and summed. Therefore, in order to calculate averaged parameters from the waste stream data provided, certain data assumptions are necessary. These assumptions are summarized below. If the parameters for a particular waste material were incomplete, the following assumptions were used so that averages and sums could be provided:

- If no minimum was provided, but a maximum was provided, the minimum was assumed to be zero.
- If a maximum and minimum was provided, but no average, the average was assumed to be one half the sum of the maximum and minimum.
- If an average was provided but no minimum or maximum, the average was assigned to the minimum and maximum.
- If only a minimum was provided, the minimum was assigned to both the maximum and the average.

For those waste streams where the site did not provide any waste parameter information, but which could be assigned to a final waste form, an average set of parameters was calculated and used. This average set of parameters was calculated by volume averaging the parameters provided for other waste streams with the same final waste form.

The data that are printed on all the tables in the report are based on these calculations and assumptions and are derived from the REPORTS.MDB database. The individual stream data printed in Appendices O and P are the original data submitted by the TRU waste generator/storage sites or amended data as agreed to by the sites through discussions and questions with the TWBIR team and is contained in the TWBIR.MDB database.

The minimum density is chosen as the smallest minimum density of a particular material parameter in the TWBIR streams in a particular Final_Waste_Form. The maximum density is chosen in a similar manner except that the largest maximum density was chosen. Note that the maximum and minimum densities apply to individual containers and cannot be used to directly calculate a maximum and minimum density of particular material parameters for the entire WIPP inventory. Also note, that it is possible, that the maximum density may not be a true maximum but a maximum average density, if a site provided only averages and no maximums and these averages are higher than other sites' maximums.

The amount of and type of materials in the containers and liners was requested separately in the waste stream profiles. Many of the sites did not provide complete data for final waste form containers. In order to add up packaging materials for the waste as it would arrive at WIPP, standard container configurations were assumed for waste from all sites. This was done because many sites did not provide liner information and assuming standard liners will generally maximize the amount of liner material. The standard packaging configurations used are shown in Table 6-1. This data is used in generating the packaging material assumptions provided in Table 1-3.

The tables and reports for the TWBIR were produced using the various data organization features provided by the Microsoft Access Version 2.0 database system. These tables and reports consist primarily of various sorts based on waste streams, final waste forms, sites, etc. and summations of volumes and waste material parameter weights.

6.2 DATA DICTIONARY

Appendix L presents a data dictionary for the TWBIR and REPORTS databases. The tables in the databases are the same except for an additional table in REPORTS called Container_Data. Except for tables Page_1 and Container_Data, tables are the same as tables in the MITI95 data call with some minor changes and field additions. Certain temporary tables or tables used to hold intermediate data that were used to produce reports are not included in the dictionary.

6.3 DATABASE OPERATING INSTRUCTIONS

The Transuranic (TRU) Waste Baseline Inventory Report (TWBIR), Revision 2, database is a Microsoft Access 2.0 database. It requires the user to possess a copy of Access 2.0 and be running under the Windows 3.1 operating system. Access, unlike most other databases, provides a single structure that contains objects such as queries, reports, program segments, macros,

Table 6-1. Table of Materials for CH and RH Waste Containers (Weights in kg per container, Volume in m^3 per container)

CH Waste			
Container Characteristic	**Drum**	**SWB**	**SWB Overpack[1]**
Steel Weight	27.3	290.9	400.1 (includes 4 drums)
Liner Type	Rigid Drum Liner	Bag	Rigid Drum Liners and Bag
Liner Material	90 mil HDPE	Plastic	90 mil HDPE and Plastic
Liner Weight	7.7	2.2	33
Volume (Capacity)	0.208	1.89	1.89
Payload Volume[2]	0.208	1.89	0.832 (4 drums)

RH Waste		
Container Characteristics	**RH Canister**	**RH Canister Overpack[3]**
Steel Weight	386.4	468 (3 drums)
Lead Weight	412.7	412.7
Steel Plug Weight	1911.6	1911.6
Liner Type	None	Rigid Liner in Drums
Liner Material	N/A	90 mil HDPE
Liner Weight	N/A	23.1
Volume (Capacity)	0.89	0.89
Payload Volume[2]	0.89	0.624 (3 drums)

[1] Four 55-gallon drums overpacked in an SWB
[2] Payload volume is the actual volume of waste which can be placed in the container.
[3] Three 55-gallon drums overpacked in an RH Canister

indexes, relations, and multiple data tables. This means there is only one file to work with, one with the suffix, .MDB. A second file normally accompanies the database file, one with the suffix .LDB and having the same name. It is not normally used except for certain file maintenance operations. For those users who do not have a copy of Access 2.0, a "run-time" only version also accompanies this report.

Two databases are provided as part of the compressed file on the TWBID distribution disk. The first database is TWBIR_1, which contains the original data by waste stream from all generator/storage sites. This is the database used to print out the individual stream data in Appendices O and P.

The second database is called REPORTS. This is the database used to produce the other tables and figures in the report. The databases are separate because the summaries for some TWBIR tables require some changes to the data to produce technically corrected numbers in appendices, tables and figures.

INSTALLATION: The two databases are compressed into a file on the distribution disk called TWBIR.EXE. Approximately 26 megabytes of hard disc space should be available to install the database. To install the TWBIR Revision 2 database, copy TWBIR.EXE to a convenient directory on your hard disk, go to the directory containing TWBIR.EXE, type TWBIR and press the enter key. The database should be expanded into the directory. The directory should now contain TWBIR.EXE, TWBIR1.MDB, TWBIR1.LDB, TWBIR.HLP, REPORTS.MDB, and REPORTS.LDB. TWBIR.HLP contains the data field descriptions. (See the latest installation instructions in the file README.TXT on the first disc.) This procedure can be performed either in DOS, a DOS prompt in Windows or from File Manager in Windows. Enter Windows and start Access, and open the TWBIR_1 or REPORTS database. See the Access User's Manual in case of difficulty.

TWBIR_1 INSTRUCTIONS: The TWBIR Revision 2 database has a built-in program (a macro called "autoexec") which takes control immediately upon opening the database file. It brings up a screen from which the user can view, edit, and locate various waste streams using the normal Access 2.0 tool bar features. In addition, a large printer icon button appears midway down the left side of the screen. This button affords the user the opportunity of printing the waste stream being viewed, waste streams for a specific site, or waste streams for all sites in the database. Scroll bars are provided to scroll between waste streams at the bottom left of the screen. For a given waste stream, the gray section contains waste container data for the various containers used to store this stream, and a scroll bar is provided in the bottom left to scroll among the types of containers for that waste stream. For a given type of container, the typical nuclides for that type of container are listed in a white area inset into the gray and a scroll bar provided.

Descriptions of the data fields can be viewed by opening the desired data table in Access's Table Mode, Design View. If the TWBIR_1.HLP file was copied into the directory occupied by the TWBIR database files, limited descriptions of the data fields in the TWBIR database are available when the cursor is placed in a data box and the F1 function key is pressed.

Reports Instructions:

The first step is to open the database REPORTS.MDB. An "autoexec" macro executes when the database opens. This macro presents a form, titled "Figure and Table Viewer", listing the reports available for viewing.

The reports and tables available for review are listed with a number on the left side. If all entries cannot be seen, the scrolling arrows on the right side of the form can be used to scroll the entries. On the bottom of the form is a series of buttons. Each form can be viewed (in report preview mode) by clicking on the command button with the same number as the number to the left of the list of figures and tables.

When the table appears on screen, the size of the window for viewing the table can be adjusted by clicking on the upper right corner up or down arrow in the report window. The report preview window also permits moving between pages of multi-page sets of figures and tables by using the arrows on the lower left corner.

The table or figure can be printed from the report preview window. The tables and figures were originally printed from and formatted for a Laserjet III printer. When printing the tables and figures, make sure the margins are set so that the entire table or figure is contained on one page, other wise blank pages may be printed.

6.4 TWBID QUALITY CONTROL

To ensure that proper controls and documentation were in place during development and population of the TWBID, several quality control activities were implemented by the TWBIR Team. Project quality control objectives were to:

- Define a method for receiving, tracking, reviewing, updating, and documenting data received from the waste generator/storage sites.
- Identify and document the contents of each project baseline.
- Establish and implement a process for releasing and maintaining the TWBID.
- Create a master library for TWBID software and documentation.
- Ensure that TWBID-generated reports and database copies are produced from released database revisions.

The activities performed to meet these objectives are described in the Transuranic Baseline Inventory Report Database Management Procedure (DOE, 1995e). The procedure identifies the responsible individuals and actions required for developing, populating, and maintaining the TWBID, and for managing the data used to produce the TWBIR and other summary documents if required in the future.

CHAPTER 7

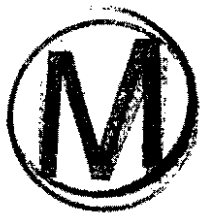

7. GLOSSARY

40 CFR Part 191, Protection of Environment. EPA: Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes – The EPA's environmental standards for the storage (Subpart A) and disposal (Subpart B) of spent nuclear fuel, and high-level and TRU radioactive wastes. This is the primary post-closure standard that applies to WIPP.

40 CFR Part 268, Protection of Environment. EPA: Land Disposal Restrictions – Restricts the land disposal of all hazardous wastes and specifies strict treatment standards that must be met before these wastes can be land-disposed.

Acceptable Knowledge – Includes process knowledge and results from previous testing, sampling, and analysis associated with the waste. Acceptable knowledge includes information regarding the raw materials used in a process or operation, process description, products produced, and associated wastes. Acceptable knowledge documentation may include the site history and mission, site-specific processes or operations, administration building controls, and all previous and current activities that generate a specific waste.

Americium (Am) – A TRU radionuclide having an atomic number of 95, containing 95 electrons and 95 protons. Am-241 (half-life 432.7 y) results from the decay of Pu-241 (half-life 14.4 y). Waste initially rich in Pu-241 will therefore "grow" in Am-241 for several decades as the Pu decays. Am-241 exists in finite amounts in TRU waste at some DOE sites.

Anticipated Inventory – The sum of the stored and projected inventories, as defined in this document.

As-Generated Waste – The chemical and physical status of waste when it is generated.

Buried Waste – TRU waste buried in shallow trenches prior to the 1970 Atomic Energy Commission policy that required TRU waste to be retrievably stored.

Californium (Cf) – A TRU element having an atomic number 98 (the number of protons in the nucleus). An alpha emitter (half-life 2.64 y), Cf-252 also spontaneously fissions, thus making it desirable as a neutron source. Cf-252 is created by neutron bombardment of Cm-244 targets. Oak Ridge National Laboratory (ORNL) is the only production agency for Cf. As a result, the ORNL inventory is the only TRU waste inventory showing finite quantities of this element.

Code of Federal Regulations (CFR) – (1) A codification of the general and permanent rules published in the **Federal Register** by the department and agencies of the federal government. The CFR is divided into 50 titles that represent broad areas subject to federal regulation. It is issued quarterly and revised annually. (2) All federal regulations in force are published annually in codified form in the CFR.

Contact-Handled (CH) TRU Waste – Packaged TRU wastes with an external surface dose rate of 200 mrem or less per hour.

Curie – A quantitative measure of radioactivity equal to 3.7×10^{10} disintegrations per second.

Curium (Cm) – A TRU element having an atomic number of 96 (the number of protons in the nucleus). An alpha emitter (half-life 18.1 y), Cm-244 is used for neutron bombardment of targets for the production of Cf-252 at ORNL. In spite of its half-life being less than 20 years, ORNL manages Cm-244 as if it were a TRU nuclide. Some TRU waste at both ORNL and Savannah River Site contains Cm-244.

Decontamination and Decommissioning (D&D) – The process through which DOE facilities which are no longer operational are cleared of contamination and removed from service. In particular, a reference to D&D waste is a reference to the waste materials that are generated during D&D activities.

Defense Waste – (1) Radioactive waste from any activity performed in whole or in part in support of DOE atomic energy defense activities; excludes waste under purview of the Nuclear Regulatory Commission or generated by the commercial nuclear power industry. (2) Nuclear waste derived mostly from the manufacture of nuclear weapons, weapons-related research programs, the operation of naval reactors, and the decontamination of nuclear weapons production facilities. (DOE, 1993a)

Department of Energy Site – A DOE-owned or -controlled tract used for DOE operations. Either a tract owned by DOE or a tract leased or otherwise made available to the federal government under terms that afford to DOE rights of access and control substantially equal to those that DOE would possess if it were the holder of the fee (or pertinent interest therein) as agent of and on behalf of the government. One or more DOE operations/program activities are carried out within the boundaries of the described tract.

Disposal – Emplacement of waste in a manner that assures isolation from the biosphere for the foreseeable future with no intent of retrieval and that requires deliberate action to regain access to the waste. For example, disposal of wastes in a mined geologic repository occurs when all of the shafts to the repository area are backfilled and sealed.

Disposal Inventory – The inventory volume defined for WIPP emplacement to be used for PA calculations is the "disposal inventory." The LWA defines the total amount of TRU waste allowed in the WIPP as 6,200,000 cubic feet (approximately 176,000 cubic meters) (Public Law, 1992b). The "Agreement for Consultation and Cooperation" (C&C Agreement) limits the RH-TRU inventory to 250,000 cubic feet (approximately 7,080 cubic meters) (DOE and State of New Mexico, 1981). Therefore by difference, the CH-TRU inventory is limited to 5,950,000 cubic feet (approximately 168,920 cubic meters).

Environmental Restoration (ER) – Those activities associated with the remediation of sites contaminated with hazardous and/or radioactive materials. In particular, a reference to remediation activities conducted under the auspices of the DOE Office of Environmental Management, Office of Environmental Restoration, EM-40.

Federal Facility Compliance Act (FFCAct) – Public law 102-386, 1992.

Final Waste Form – Consists of a series of WMCs that for PA purposes has similar physical and chemical properties.

Gas Generation – Three gas generation processes are expected to be a factor associated with the degradation of TRU wastes in the WIPP repository. The generation of gases is expected to occur through chemical (i.e., corrosion), microbial, and radiolytic processes.

Generator/Storage Sites – See Waste Generator/Storage Sites.

Hazardous Waste – Those wastes that are designated hazardous by EPA (or state) regulations through the RCRA.

Integrated Data Base (IDB) – The latest version of the IDB, the *Integrated Data Base for [1995]: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics* (DOE, 1995d)

Mixed TRU Waste – TRU waste that contains both radioactive and hazardous components as defined by the Atomic Energy Act and the RCRA as codified in 40 CFR Parts 261.3 (EPA, 1980).

Mixed Waste Inventory Report (MWIR) – The latest release of information from the MWIR database that supports requirements under the FFCAct of 1992 (Public Law 102-386).

Newly Generated Wastes – See Projected Inventory.

No-Migration Variance Petition (NMVP) – Section 3004 of RCRA allows EPA to grant a variance from the land disposal restrictions when a determination can be made that, to a reasonable degree of certainty, there will be no migration of hazardous constituents from the disposal unit for as long as the waste remains hazardous. Specific requirements for making this demonstration are found in 40 CFR 268.6, and EPA has published a draft guidance document to assist petitioners in preparing a variance petition.

Non-Defense Waste – The balance of radioactive waste (including TRU) belonging to DOE that is not from support of DOE atomic energy defense activities.

Non-Mixed TRU Waste – Transuranic waste that does not contain hazardous constituents or exhibit hazardous characteristics, as identified in 40 CFR 261, Subparts C and D.

Performance Assessment (PA) – (1) A systematic analysis of the potential risks posed by waste management systems to the public and environment and a comparison of those risks to established performance objectives. (2) An analysis that (a) identifies the processes and events that might affect the disposal system, (b) examines the effects of these processes and events on the performance of the disposal system, and (c) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable. (3) A term used to denote all activities (qualitative and quantitative) carried out to (a) determine the long-term ability of a site/facility to effectively isolate the waste and ensure the long-term health and safety of the public and (b) provide the basis for demonstrating regulatory compliance. (SNL/NM, 1993)

Plutonium (Pu) – A radionuclide having an atomic number of 94. Pu isotopes exist in some TRU waste at all the major DOE storage facilities. The significant isotopes that may exist in measurable quantities at these facilities are Pu-238 through Pu-242. Each isotope is an alpha emitter; the respective half-lives in years are: 238=87.7, 239=24,000, 240=6,563, 241=14.4, 242=376,000. Because of its high activity, Pu-238 can contribute significantly to the thermal loading on some TRU waste. Pu-241 decays, primarily by beta emission, to Am-241.

Process Knowledge – A qualitative evaluation of the contents of a waste container through the study of existing records of production history of the waste.

Projected Inventory – That part of the inventory that has not been generated but is estimated to be generated at some time in the future by the TRU waste generator/storage sites. The estimated timeframe may vary, but is usually between 20 and 30 years. "Newly generated waste" also is sometimes used as a synonym for the projected inventory.

Radioactive – Term used to refer to an unstable atomic nuclei that decays with the spontaneous emission of ionizing radiation (also see "radionuclide").

Radionuclide – (1) A species of atom having an unstable nucleus, that is subject to spontaneous decay or disintegration and usually accompanied by the emission of ionizing radiation. (2) Any nuclide that emits radiation. A nuclide is a species of atom characterized by the constitution of its nucleus and hence by the number of protons, the number of neutron, and the energy content.

Remote-Handled (RH) TRU Waste – Packaged TRU wastes with an external surface dose rate exceeding 200 mrem per hour.

Repository – As used in this report: designated location for the permanent disposal of post-1970 defense transuranic wastes; the Waste Isolation Pilot Plant.

Resource Conservation and Recovery Act (RCRA) – (1) Establishes a system for controlling hazardous waste from generation to disposal. (2) A Federal law passed in 1976, and amended under the HSWA of 1984, that established a structure to track and regulate hazardous wastes from the time of generation to disposal. The law requires safe and secure procedures to be used in treating, handling, transporting, storing, and disposing of hazardous substances. RCRA is designed to prevent new uncontrolled hazardous waste sites. The law also regulates the disposal of solid waste that may not be considered hazardous. (3) Specifically, Subtitle D of RCRA governs the management of solid waste. (Note: 40 CFR Parts 260-272 are the regulations for complying with RCRA with respect to hazardous waste and hazardous waste treatment, storage, and disposal facilities.)

Retrievable Storage – Designated storage location for transuranic wastes that is designed, operated, and maintained in such a manner that the wastes remain accessible for subsequent retrieval.

Scaling – The process for adjusting the anticipated inventory to equal the maximum authorized disposal inventory of the WIPP repository for the purposes of WIPP performance assessment modeling.

Site-Specific Waste Profile – Represents a summary of the characteristics of all waste streams at a particular DOE TRU waste generator/storage site that belong to the same Final Waste Form.

Stakeholders – Those persons and/or groups of people and organizations who are affected or perceive they are affected by the DOE waste management program. Stakeholders include DOE management, employees, and contractors (internal); and executive, legislative, and regulatory groups, public representatives, the general public, intervenor groups, special interest groups, contractors, suppliers, and universities (external).

Stored Inventory – That part of the TRU waste inventory currently in retrievable storage as of the time of the last data call for inventory information. Retrievably stored waste includes waste stored in buildings or in berms with earthen cover since 1970 and does not include any waste that was buried prior to 1970. Stored inventory can be in the "as-generated" form or "final waste form."

Thorium (Th) – A radionuclide having an atomic number of 90. Although not TRU, Th-232 is an alpha emitter (half-life 14 billion years) and exists in finite amounts in some TRU waste at Hanford Site, Idaho National Engineering Laboratory, and Oak Ridge National Laboratory. [Note: Thorium is naturally occurring and contributes to background radiation at some sites (e.g., INEL)]

Transuranic – Pertaining to elements that have atomic numbers greater than 92, including neptunium, plutonium, americium, and curium; all are radioactive, are not naturally occurring, and are members of the actinide group.

Transuranic (TRU) Waste – (1) Waste containing alpha-emitting radionuclides with an atomic number greater than 92 and half-lives greater than 20 years, at concentrations of TRU isotopes greater than 100 nanocuries per gram of waste. **This core definition appears in modified form in various relevant documents as follows:** (a) For purposes of management, DOE Order 5820.2A: (i) considers TRU waste, as defined above, "without regard to source or form" *(The proposed revision to the Order [DOE Order 5820.2A Major Issues for Revision, May 6, 1992]* contemplates removing this clause); (ii) allows head of field elements to determine that wastes containing other alpha-emitting radionuclides must be managed as TRU waste; and (iii) adds "at time of assay," implying both that the classification of a waste as TRU waste is to be made based on an assay, and that such classification can be superseded only by another assay. (b) For purposes of setting standards for management and disposal, 40 CFR 191.02(i) adds "except for: (i) high-level wastes; (ii) wastes that the DOE has determined, with the concurrence of the EPA Administrator, do not need the degree of isolation required by this part; or (iii) wastes that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR 61. (2) Waste materials contaminated with U-233 (and its daughter products), with certain isotopes of plutonium, or with other nuclides with atomic numbers greater than 92. In order to be classified as TRU waste, the long-lived alpha activity from subject isotopes must exceed 100 nanocuries per gram of waste material independent of the level of beta-gamma activity. These wastes are produced primarily from reprocessing spent fuel and from the use of plutonium in the fabrication of nuclear weapons. (3) Wastes that are contaminated with radioactive elements heavier than uranium, thus the name trans-(or beyond) uranic.

TRUCON – See TRUPACT-II Content Codes.

TRUPACT-II Content Codes (TRUCON) – The document containing a description of the waste stream, waste form, and package configuration for each waste content code authorized for shipment in TRUPACT-II containers.

Uranium (U) – A naturally radioactive element with the atomic number of 92 (number of protons in the nucleus) and an atomic weight of approximately 238. The two principal naturally occurring isotopes are the fissionable U-235 (0.7 percent of natural uranium) and the fertile U-238 (99.3 percent of natural uranium). (Note: An alpha emitter [half-life 159,000 y], U-233 also spontaneously fissions; it is present in finite quantities in some TRU waste inventories at INEL, LANL, and ORNL.)

Waste Acceptance Criteria (WAC) – The criteria used to determine if waste packages are acceptable. For the purposes of this document, WAC refers to WIPP WAC.

Waste Form – The physical form of the waste such as sludges, combustibles, metals, etc.

Waste Generator/Storage Sites – The 10 largest DOE facilities and several smaller sites throughout the U.S. that generate and store TRU waste.

Waste Isolation Pilot Plant (WIPP) – (1) The project authorized under Section 213 of the DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Public Law 96-164; 93 Stat. 1259, 1265) to demonstrate the safe, and environmentally sound, disposal of radioactive waste materials generated by atomic energy defense activities. (2) A research and development facility, located near Carlsbad, New Mexico, to be used for demonstrating a practical, long-term solution to a complex problem: the safe disposal in deep geologic repositories of TRU waste resulting from DOE activities.

Waste Material Parameter – A waste material that occurs in TRU waste that is an input parameter into one or more current PA models or PA model under development, a potential future model, or is required to adequately describe the waste form.

Waste Matrix Code (WMC) – A DOE-developed coding system for grouping waste streams that have similar matrix constituents especially for treatment objectives. This coding system allows waste streams within the DOE TRU waste system that have similar physical and chemical waste form properties to be categorized together. WMCs also have been called "waste treatability codes" in other DOE documents. An example of a WMC for "heterogeneous waste" would be 5400 (DOE, 1995b).

Waste Stream – A flow of waste materials with specific definable characteristics that remain the same throughout the life of the process generating the waste stream.

Waste Stream Name – A site-specific, unique descriptive identifier for a TRU waste stream.

Waste Stream Profile – A description of a CH-TRU or RH-TRU waste stream destined for shipment to and disposal in WIPP, if authorized under permits and certifications by appropriate regulatory agencies for disposal in the WIPP repository. The waste stream profile is presented in tabular format and is intended to provide a summary of the important information about a particular waste stream.

Waste Stream Site ID – A *site-specific alphanumeric identification code which provides a unique* identifier for an individual TRU waste stream.

Waste Sub-stream – A waste sub-stream is one that results from a waste stream being divided into two or more fractions (for the purposes of reporting) in order to provide an additional level of detail about a site's current plans for repackaging or treating the waste.

WIPP Waste Profile – Represents a summary of TRU waste at all DOE TRU waste generator/storage sites that have an identical Final Waste Form.

CHAPTER 8

8. REFERENCES

Croff, A. G., 1983, "ORIGEN2: A Versatile Computer Code for Calculating the Nuclide Compositions and Characteristics of Nuclear Materials," *Nuclear Technology*, Vol. 62, pp. 335-352, November 1983.

Croff, A. B., 1980, *A User's Manual for the ORIGEN2 Code*, ORNL/TM-7175, Oak Ridge National Laboratory, July 1980.

DOE – See U.S. Department of Energy.

EPA – See U.S. Environmental Protection Agency.

NRC – See U.S. Nuclear Regulatory Commission

SNL/NM – See Sandia National Laboratory/NM

Nuclear Packaging, Inc., 1991, *Safety Analysis Report for the TRUPACT-II Shipping Package*, Revision 11, June 1991.

Public Law, 1992a, Public Law 102-386, 1992, *Federal Facility Compliance Act of 1992.*

Public Law, 1992b, Public Law 102-579, 1992, *Waste Isolation Pilot Plant Land Withdrawal Act.*

Public Law, 1979, Public Law 96-1C4, 1979, *National Security Programs.*

Sandia National Laboratory/New Mexico, 1993, *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance*, SAND92-0700/5, Sandia National Laboratories, Albuquerque, New Mexico, August 1993.

U.S. Department of Energy, 1995a, *Defense Nuclear Facilities Safety Board Recommendation 94-1*, February 28, 1995.

U.S. Department of Energy, 1995b, *DOE Waste Treatability Group Guidance*, DOE/LLW-217, Revision 0, January 1995.

U.S. Department of Energy, 1995c, *Draft, No-Migration Variance Petition*, DOE/CAO 95-2043, Carlsbad, New Mexico, May 31, 1995.

U.S. Department of Energy, 1995d, *Integrated Data Base for 1995: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Revision 11, September 1995.

U.S. Department of Energy, 1995e, NTP Branch Procedure, *Transuranic Baseline Inventory Report Database Management*, October 31, 1995.

U.S. Department of Energy, 1995f, *WIPP RCRA Part B Permit Application*, DOE/WIPP 91-005, Revision 5, May 19, 1995.

U.S. Department of Energy, 1995g, *1995 National Mixed Waste Inventory Report Data System*, Version 10/25/95, November 3, 1995.

U.S. Department of Energy, 1994a, *Distribute of the Phase II Mixed Waste Inventory Report Data*, memo from Patty Bubar to Distribution dated May 17, 1994, Washington, D.C. (includes data diskette [Version 1.00] the draft *User's Guide for National Data Base System for the Final Mixed Waste Inventory Report* [May, 1994] and *Mixed Waste Inventory Report Data Base System User's Guide*).

U.S. Department of Energy, 1994b, *Release of Phase I Mixed Waste Inventory Report Data*, memo from Patty Bubar to Distribution, dated April 1, 1994, Washington, D.C. (includes data diskette [Version .97B] and *Mixed Waste Inventory Report Data Base System User's Guide*).

U.S. Department of Energy, 1994c, *TRUPACT-II Content Codes (TRUCON)*, DOE/WIPP 89-004, Revision 8, October, 1994.

U.S. Department of Energy, 1993a, *Lexicon*, Second Edition, June 1993.

U.S. Department of Energy, 1993b, *U.S. Department of Energy Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capacities and Technologies*, 6 volumes, DOE/NBM-1100, April 1993.

U.S. Department of Energy, 1991, *TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, WIPP-DOE-069, Revision 4, December 1991.

U.S. Department of Energy, 1990a, *Final Supplemental Environmental Impact Statement*, Volume 3, DOE/EIS-0026-FS, January 1990.

U.S. Department of Energy, 1990b, *No-Migration Variance Petition*, Volumes I through VIII, DOE/WIPP 89-011, Revision 1, Carlsbad, New Mexico.

U.S. Department of Energy, 1989, *TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, WIPP-DOE-069, Revision 3, January 1989.

U.S. Department of Energy, 1988, *Radioactive Waste Management*, DOE 5820.2A, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy and State of New Mexico, 1981, "Agreement for Consultation and Cooperation Between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant," July 1, 1981 (dated April 18, 1988).

U.S. Environmental Protection Agency, 1995, *Criteria for Certification of Compliance with Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Wastes*, 40 CFR 194, notice of proposed rulemaking, Federal Register, Vol. 58, Page 792, January 30, 1995.

U.S. Environmental Protection Agency, 1993, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, 40 CFR 191, final rule, Federal Register, Vol. 58, Page 66398, December 20, 1993.

U.S. Environmental Protection Agency, 1980, *Listing of Hazardous Waste*, 40 Code of Federal Regulations, Part 261, May 19, 1980.

U.S. Nuclear Regulatory Commission, 1995, *Certificate of Compliance No. 9218*, Revision No. 6, for the Model No. TRUPACT-II, March 30, 1995.

VECTRA Technologies, Inc., 1994, *Safety Analysis Report for the RH-TRU 72-B Waste Shipping Package*, Revision 0, December 1994.

DOE/CAO-95-1121

Transuranic Waste Baseline Inventory Report (Revision 2)

December 1995

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Volume 2

APPENDIX A

Site-Specific Contact Handled Waste Profiles

Site Name: Ames Laboratory - Iowa State Univ.

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AL-W005	0.0000	0.4160	0.4160
Total Volume:	**0.00**	**0.42**	**0.42**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	528.8	394.2	173.1
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	528.6	399.0	173.1
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Argonne National Laboratory - East

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AE-W041	0.6240	0.6240	1.2480
AE-W042	0.4440	0.6660	1.1100
Total Volume:	**1.07**	**1.29**	**2.36**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	256.1	120.6	0.0
Aluminum Base Metal/Alloys	27.8	13.1	0.0
Other Metal/Alloys	913.5	171.9	24.7
Other Inorganic Materials	29.3	13.8	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	45.3	3.5	0.0
Rubber	0.0	0.0	0.0
Plastics	67.6	7.1	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Argonne National Laboratory - East

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AE-W038	4.7840	0.0000	4.7840
AE-W040	0.4160	0.0000	0.4160
Total Volume:	**5.20**	**0.00**	**5.20**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	528.8	124.5	101.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	528.8	230.9	168.3
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Argonne National Laboratory - East

Final Waste Form: Solidified Organics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AE-W039	0.2080	0.0000	0.2080
Total Volume:	**0.21**	**0.00**	**0.21**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	548.1	351.0	28.8
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	726.0	346.2	101.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Argonne National Laboratory - East

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AE-T003	4.9920	128.5440	133.5360
Total Volume:	**4.99**	**128.54**	**133.54**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	913.5	302.9	76.9
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Argonne National Laboratory - West

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AW-N027.531	0.0000	2.0415	2.0415
AW-T032.1324	0.0000	99.6015	99.6015
Total Volume:	**0.00**	**101.64**	**101.64**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	112.8	109.7	108.2
Aluminum Base Metal/Alloys	0.2	0.2	0.2
Other Metal/Alloys	41.9	10.4	8.5
Other Inorganic Materials	14.8	8.7	3.9
Vitrified	0.0	0.0	0.0
Cellulosics	314.5	191.3	61.2
Rubber	71.4	30.2	22.8
Plastics	101.6	59.0	38.8
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Argonne National Laboratory - West

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AW-N026.82	4.2525	0.0000	4.2525
AW-T033.1325	2.2880	24.5005	26.7885
AW-T034.1327	0.0000	320.8525	320.8525
Total Volume:	**6.54**	**345.35**	**351.89**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	566.8	235.5	207.8
Aluminum Base Metal/Alloys	55.9	42.3	41.8
Other Metal/Alloys	48.8	7.1	2.4
Other Inorganic Materials	95.2	52.3	47.5
Vitrified	0.0	0.0	0.0
Cellulosics	300.1	81.4	18.7
Rubber	67.5	17.9	6.8
Plastics	191.9	67.8	22.9
Solidified Inorganic Material	8.9	4.7	4.4
Solidified Organic Material	5.4	0.8	0.6
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	3.0	3.0

Site-Specific Contact Handled Waste Profiles

Site Name: Argonne National Laboratory - West

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AW-T030.1321	0.0000	293.7610	293.7610
Total Volume:	**0.00**	**293.76**	**293.76**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	223.5	126.9	90.3
Aluminum Base Metal/Alloys	6.9	2.4	1.7
Other Metal/Alloys	406.9	266.5	214.2
Other Inorganic Materials	21.4	14.6	10.2
Vitrified	0.0	0.0	0.0
Cellulosics	12.7	8.3	6.7
Rubber	1.5	0.5	0.3
Plastics	11.4	5.4	1.8
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Bettis Atomic Power Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
BT-T002	0.0000	15.1200	15.1200
BT-T003	0.0000	107.7300	107.7300
BT-T004	0.0000	0.2080	0.2080
BT-T005	0.0000	0.2080	0.2080
Total Volume:	**0.00**	**123.27**	**123.27**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	700.0	301.8	0.0
Aluminum Base Metal/Alloys	40.0	4.3	0.0
Other Metal/Alloys	10.0	0.1	0.0
Other Inorganic Materials	40.0	14.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	20.0	7.1	0.0
Rubber	10.0	0.9	0.0
Plastics	40.0	4.3	0.0
Solidified Inorganic Material	4.8	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	10.0	0.1	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Energy Technology Engineering Center

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
ET-T001B	1.6800	0.0000	1.6800
Total Volume:	**1.68**	**0.00**	**1.68**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	566.8	235.5	207.8
Aluminum Base Metal/Alloys	55.9	42.3	41.8
Other Metal/Alloys	48.8	7.1	2.4
Other Inorganic Materials	95.2	52.3	47.5
Vitrified	0.0	0.0	0.0
Cellulosics	300.1	81.4	18.7
Rubber	67.5	17.9	6.8
Plastics	191.9	67.8	22.9
Solidified Inorganic Material	8.9	4.7	4.4
Solidified Organic Material	5.4	0.8	0.6
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	3.0	3.0

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-W278	0.4160	0.0000	0.4160
RL-W289	2.0800	0.0000	2.0800
RL-W293	1.2480	0.0000	1.2480
RL-W296	3.1616	0.0000	3.1616
RL-W298	16.5900	0.4160	17.0060
RL-W300	0.4160	0.0000	0.4160
RL-W305	2.0800	8.3200	10.4000
RL-W309	0.2080	0.0000	0.2080
RL-W314	4.5760	17.0560	21.6320
RL-W321	0.2080	0.0000	0.2080
RL-W322	0.8320	2.2880	3.1200
RL-W325	0.4160	1.2480	1.6640
RL-W331	50.7860	101.5360	152.3220
RL-W335	2.0980	0.0000	2.0980
RL-W340	0.2080	0.0000	0.2080
RL-W343	0.6240	0.0000	0.6240
RL-W347	0.2080	0.0000	0.2080
RL-W356	1.2480	0.0000	1.2480
RL-W360	4.7840	0.0000	4.7840
RL-W365	11.8560	7.9040	19.7600
RL-W368	0.6240	0.6240	1.2480
RL-W371	6.0680	2.2880	8.3560
RL-W372	0.4160	0.0000	0.4160

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Combustible

RL-W377	303.7880	1018.7100	1322.4980
RL-W378	16.7840	43.8140	60.5980
RL-W384	0.6240	0.0000	0.6240
RL-W388	16.7300	0.6240	17.3540
RL-W389	0.2080	0.0000	0.2080
RL-W397	3.5360	7.9040	11.4400
RL-W398	0.2080	0.0000	0.2080
RL-W401	0.6240	32.4480	33.0720
RL-W404	2.0800	2.0800	4.1600
Total Volume:	**455.73**	**1247.26**	**1702.99**

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Combustible

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	144.2	17.7	0.0
Aluminum Base Metal/Alloys	4.9	0.0	0.0
Other Metal/Alloys	185.5	0.8	0.0
Other Inorganic Materials	80.2	3.5	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	103.0	40.7	0.0
Rubber	105.4	18.1	0.0
Plastics	283.8	48.9	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	7.0	0.3	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	7.5	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-T101	567.9440	0.0000	567.9440
RL-T102	200.1240	0.0000	200.1240
RL-T104	4.9920	0.0000	4.9920
RL-T105	80.4040	0.0000	80.4040
RL-T106	8.1120	0.0000	8.1120
RL-T107	6156.0920	0.0000	6156.0920
RL-T108	192.6200	0.0000	192.6200
RL-T109	19.7200	0.0000	19.7200
RL-T110	494.0320	0.0000	494.0320
RL-T112	137.7360	0.0000	137.7360
RL-T113	42.7960	0.0000	42.7960
RL-T114	19.5800	0.0000	19.5800
RL-T115	1025.4320	0.0000	1025.4320
RL-T116	11.0240	0.0000	11.0240
RL-T118	261.9600	0.0000	261.9600
RL-T120	133.8120	0.0000	133.8120
RL-T122	29.3040	0.0000	29.3040
RL-T123	0.6240	0.0000	0.6240
RL-T125	15.1840	0.0000	15.1840
RL-T127	283.6040	0.0000	283.6040
RL-T128	0.4160	0.0000	0.4160
RL-T129	28.7480	0.0000	28.7480
RL-T130	0.2080	0.0000	0.2080

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Heterogeneous

RL-T131	30.1600	0.0000	30.1600
RL-T132	28.7040	0.0000	28.7040
RL-T133	0.2080	0.0000	0.2080
RL-T134	0.2080	0.0000	0.2080
RL-T135	0.4160	0.0000	0.4160
RL-T137	151.6320	0.0000	151.6320
RL-T140	138.1120	0.0000	138.1120
RL-T143	403.7120	0.0000	403.7120
RL-T145	711.1920	0.0000	711.1920
RL-W279	6.9264	0.0000	6.9264
RL-W294	1.0400	0.0000	1.0400
RL-W301	0.6240	0.0000	0.6240
RL-W302	0.4160	0.0000	0.4160
RL-W303	0.2080	0.0000	0.2080
RL-W304	2.5140	0.0000	2.5140
RL-W379	0.2080	0.0000	0.2080
RL-W408	0.0000	763.7760	763.7760
RL-W410	0.0000	83.1600	83.1600
RL-W411	0.0000	34.0200	34.0200
RL-W412	0.0000	34.0200	34.0200
RL-W415	0.0000	2449.4400	2449.4400
RL-W417	0.0000	1.9845	1.9845
RL-W437	0.0000	759.4080	759.4080
RL-W438	0.0000	1096.3880	1096.3880
RL-W440	0.0000	206.2260	206.2260

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Heterogeneous

RL-W441	0.0000	0.2080	0.2080
RL-W442	0.0000	5.6700	5.6700
RL-W443	0.0000	668.5120	668.5120
RL-W444	0.0000	168.4760	168.4760
Total Volume:	**11190.75**	**6271.29**	**17462.04**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	706.7	491.7	0.0
Aluminum Base Metal/Alloys	168.9	99.3	0.0
Other Metal/Alloys	479.2	2.6	0.0
Other Inorganic Materials	95.2	45.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	300.1	64.0	2.7
Rubber	67.5	19.8	0.0
Plastics	191.9	64.2	0.8
Solidified Inorganic Material	15.0	7.6	0.0
Solidified Organic Material	331.6	0.3	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	18.2	6.4	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Inorganic Non-Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-W292	0.2080	0.0000	0.2080
RL-W315	0.4160	0.4160	0.8320
RL-W336	0.4160	0.0000	0.4160
RL-W342	0.8320	0.0000	0.8320
RL-W352	0.2080	0.0000	0.2080
RL-W353	0.8320	0.0000	0.8320
RL-W358	2.4960	0.0000	2.4960
RL-W364	2.0800	1.4560	3.5360
RL-W367	2.9120	2.0800	4.9920
RL-W376	16.2240	53.2480	69.4720
RL-W387	1.4560	0.2080	1.6640
RL-W392	0.2080	0.0000	0.2080
RL-W393	5.4080	9.3600	14.7680
RL-W400	0.2080	2.2880	2.4960
RL-W403	0.6240	0.0000	0.6240
RL-W405	0.2080	0.0000	0.2080
Total Volume:	**34.74**	**69.06**	**103.79**

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Inorganic Non-Metal

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	59.5	17.6	0.0
Aluminum Base Metal/Alloys	3.9	0.1	0.0
Other Metal/Alloys	76.6	0.8	0.0
Other Inorganic Materials	463.5	129.4	52.2
Vitrified	0.0	0.0	0.0
Cellulosics	28.8	16.1	0.0
Rubber	47.6	9.0	0.0
Plastics	166.9	31.8	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.9	0.1	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	1.5	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-W277	0.6048	0.0000	0.6048
RL-W287	0.4160	0.0000	0.4160
RL-W290	2.2880	0.0000	2.2880
RL-W306	0.8320	2.2880	3.1200
RL-W311	4.4096	13.1040	17.5136
RL-W312	2.2880	8.5280	10.8160
RL-W317	1.0400	2.2880	3.3280
RL-W318	1.6640	8.3200	9.9840
RL-W339	0.4160	0.0000	0.4160
RL-W349	0.2080	0.0000	0.2080
Total Volume:	**14.17**	**34.53**	**48.69**

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Lead/Cadmium Metal Waste

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	345.0	14.0	0.0
Aluminum Base Metal/Alloys	43.1	0.2	0.0
Other Metal/Alloys	1380.9	139.5	23.5
Other Inorganic Materials	38.4	4.5	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	87.9	14.2	1.7
Rubber	125.5	96.0	0.0
Plastics	91.7	36.1	4.3
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.9	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Soils

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-T103	99.6320	0.0000	99.6320
RL-W283	11.6480	0.0000	11.6480
RL-W310	0.2912	0.2080	0.4992
RL-W316	0.2080	0.0000	0.2080
RL-W323	0.6240	2.0800	2.7040
RL-W351	0.2080	0.0000	0.2080
RL-W354	0.2080	0.0000	0.2080
RL-W381	6.2400	23.7120	29.9520
RL-W406	0.4160	0.0000	0.4160
RL-W439	0.0000	5935.6961	5935.6961
Total Volume:	**119.48**	**5961.70**	**6081.17**

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Soils

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	29.1	1.8	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	17.4	1.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	68.7	3.9	0.0
Rubber	56.4	1.8	0.0
Plastics	131.0	3.4	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	138.2	0.1	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	1055.7	744.1	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-W281	0.3744	0.0000	0.3744
RL-W383	9.4500	0.0000	9.4500
RL-W394	3.1200	7.0720	10.1920
Total Volume:	**12.94**	**7.07**	**20.02**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	34.6	32.7	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	49.4	26.7	21.7
Vitrified	0.0	0.0	0.0
Cellulosics	17.4	8.8	0.0
Rubber	2.4	1.2	0.0
Plastics	32.4	22.7	0.3
Solidified Inorganic Material	641.3	338.1	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.6	0.3	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Solidified Organics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-W280	0.2080	0.0000	0.2080
RL-W282	0.3328	0.0000	0.3328
RL-W285	1.2064	0.0000	1.2064
RL-W286	0.2080	0.0000	0.2080
RL-W326	1.8720	8.3200	10.1920
RL-W338	0.2080	0.0000	0.2080
RL-W344	0.2080	0.0000	0.2080
RL-W345	2.0800	1.0400	3.1200
RL-W348	0.2080	0.0000	0.2080
RL-W361	0.6240	0.0000	0.6240
RL-W380	0.2080	0.0000	0.2080
Total Volume:	**7.36**	**9.36**	**16.72**

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Solidified Organics

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	74.3	6.9	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	1.0	0.0	0.0
Other Inorganic Materials	162.3	70.7	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	48.4	11.9	0.0
Rubber	18.6	0.6	0.0
Plastics	126.5	60.2	1.5
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	110.2	1.6	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	137.2	8.5	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-W288	1.0400	0.0000	1.0400
RL-W291	7.9760	0.0000	7.9760
RL-W295	1.8720	0.0000	1.8720
RL-W297	1.6640	0.0000	1.6640
RL-W299	0.6240	0.0000	0.6240
RL-W307	1.8900	0.0000	1.8900
RL-W308	0.4160	0.2080	0.6240
RL-W313	9.2240	15.8800	25.1040
RL-W319	7.5600	0.0000	7.5600
RL-W320	1.6640	8.3200	9.9840
RL-W324	3.7800	0.0000	3.7800
RL-W330	32.1300	37.8000	69.9300
RL-W341	0.2080	0.0000	0.2080
RL-W346	0.4160	0.0000	0.4160
RL-W350	0.2080	0.0000	0.2080
RL-W355	2.0800	0.0000	2.0800
RL-W359	16.6400	0.0000	16.6400
RL-W362	2.9120	2.0800	4.9920
RL-W363	0.2080	0.2080	0.4160
RL-W369	33.4960	19.3440	52.8400
RL-W370	0.4160	0.0000	0.4160
RL-W373	80.2120	1.2480	81.4600
RL-W374	182.4020	396.5860	578.9880

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Uncategorized Metal

RL-W375	21.6220	37.9900	59.6120
RL-W385	8.1120	0.6240	8.7360
RL-W386	0.4160	0.0000	0.4160
RL-W390	0.6240	0.0000	0.6240
RL-W395	23.3860	22.8800	46.2660
RL-W396	0.2080	0.0000	0.2080
RL-W399	0.2080	3.5360	3.7440
RL-W402	1.2480	2.0800	3.3280
RL-W407	0.0000	542.7000	542.7000
RL-W409	0.0000	7800.8399	7800.8399
RL-W413	0.0000	842.4000	842.4000
RL-W414	0.0000	8.7035	8.7035
RL-W416	0.0000	9049.3199	9049.3199
RL-W418	0.0000	842.4000	842.4000
Total Volume:	**444.86**	**19635.15**	**20080.01**

Site-Specific Contact Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Uncategorized Metal

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2595.2	123.9	0.0
Aluminum Base Metal/Alloys	6.9	2.3	0.0
Other Metal/Alloys	442.2	253.5	0.0
Other Inorganic Materials	55.8	13.9	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	63.4	8.5	0.0
Rubber	113.7	0.7	0.0
Plastics	104.6	6.1	0 0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.1	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	3.5	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W186.187	2695.2643	0.0000	2695.2643
IN-W198.202	119.6000	0.0000	119.6000
IN-W198.804	32.8230	0.0000	32.8230
IN-W199.1039	0.8885	0.0000	0.8885
IN-W202.1092	0.8885	0.0000	0.8885
IN-W202.224	109.6160	0.0000	109.6160
IN-W205.1086	0.8320	0.0000	0.8320
IN-W205.220	0.6805	0.0000	0.6805
IN-W250.259	14.0670	0.0000	14.0670
IN-W250.941	50.9600	0.0000	50.9600
IN-W252.283	117.7280	0.0000	117.7280
IN-W252.811	32.8230	0.0000	32.8230
IN-W254.289	2.3445	0.0000	2.3445
IN-W254.290	7.2800	0.0000	7.2800
IN-W256.1062	20.5920	0.0000	20.5920
IN-W256.295	5.9935	0.0000	5.9935
IN-W269.510	5.9935	0.0000	5.9935
IN-W269.535	20.8000	0.0000	20.8000
IN-W305.1068	37.4400	0.0000	37.4400
IN-W305.828	10.6825	0.0000	10.6825
IN-W327.1085	3.5360	0.0000	3.5360
IN-W327.735	1.3045	0.0000	1.3045
IN-W330.677	6.0320	0.0000	6.0320

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Combustible

IN-W330.678	1.9285	0.0000	1.9285
IN-W336.660	4.1600	0.0000	4.1600
IN-W336.820	0.6805	0.0000	0.6805
Total Volume:	**3304.94**	**0.00**	**3304.94**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	112.8	1.7	0.0
Aluminum Base Metal/Alloys	0.2	0.0	0.0
Other Metal/Alloys	474.5	7.8	0.0
Other Inorganic Materials	119.0	6.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	961.5	480.0	0.0
Rubber	629.0	75.4	0.0
Plastics	706.7	146.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Filter

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W206.935	10.8905	0.0000	10.8905
IN-W207.980	0.8885	0.0000	0.8885
IN-W207.981	0.4160	0.0000	0.4160
IN-W208.988	2.3445	0.0000	2.3445
IN-W209.994	10.2665	0.0000	10.2665
IN-W210.1001	1.0965	0.0000	1.0965
IN-W211.1009	98.4690	0.0000	98.4690
IN-W212.1058	3.4410	0.0000	3.4410
IN-W213.1069	1.9285	0.0000	1.9285
IN-W214.1075	0.6240	0.0000	0.6240
IN-W214.755	0.6805	0.0000	0.6805
Total Volume:	**131.05**	**0.00**	**131.05**

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Filter

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	10.6	5.2	0.0
Aluminum Base Metal/Alloys	57.4	12.4	0.0
Other Metal/Alloys	1.6	0.8	0.0
Other Inorganic Materials	293.3	16.3	2.4
Vitrified	0.0	0.0	0.0
Cellulosics	341.9	55.8	0.5
Rubber	17.0	3.3	0.0
Plastics	23.3	4.5	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Graphite

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W271.532	0.8885	0.0000	0.8885
IN-W272.504	0.8885	0.0000	0.8885
IN-W272.974	1.6640	0.0000	1.6640
IN-W275.502	1.7205	0.0000	1.7205
IN-W275.967	5.2000	0.0000	5.2000
IN-W276.500	86.7465	0.0000	86.7465
IN-W276.966	313.4560	0.0000	313.4560
IN-W367.973	4.6890	0.0000	4.6890
IN-W368.971	1.0965	0.0000	1.0965
IN-W369.837	3.2330	0.0000	3.2330
IN-W369.970	9.9840	0.0000	9.9840
IN-W370.836	15.1635	0.0000	15.1635
IN-W370.929	53.4560	0.0000	53.4560
Total Volume:	**498.19**	**0.00**	**498.19**

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Graphite

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	764.4	0.5	0.0
Aluminum Base Metal/Alloys	38.2	0.0	0.0
Other Metal/Alloys	46.6	0.0	0.0
Other Inorganic Materials	812.5	303.6	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	9.8	5.4	0.0
Rubber	0.0	0.0	0.0
Plastics	51.4	6.3	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W139.627	12.2720	0.0000	12.2720
IN-W169.191	4267.1201	0.0000	4267.1201
IN-W169.985	41.7850	0.0000	41.7850
IN-W170.189	0.6805	0.0000	0.6805
IN-W170.938	0.4160	0.0000	0.4160
IN-W171.184	3.5360	0.0000	3.5360
IN-W171.801	0.6805	0.0000	0.6805
IN-W172.182	132.4960	0.0000	132.4960
IN-W172.911	36.8880	0.0000	36.8880
IN-W189.1048	4.9920	0.0000	4.9920
IN-W189.131	1.7205	0.0000	1.7205
IN-W197.802	510.2240	0.0000	510.2240
IN-W197.803	45.2260	0.0000	45.2260
IN-W203.1081	0.6805	0.0000	0.6805
IN-W203.210	73.2160	0.0000	73.2160
IN-W204.215	0.8885	0.0000	0.8885
IN-W204.216	1.6640	0.0000	1.6640
IN-W225.127	21.6320	0.0000	21.6320
IN-W225.800	1.0965	0.0000	1.0965
IN-W259.552	10.0585	0.0000	10.0585
IN-W265.516	7.9220	0.0000	7.9220
IN-W278.1090	0.8885	0.0000	0.8885
IN-W281.487	317.8240	0.0000	317.8240

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Heterogeneous

IN-W283.481	0.2080	0.0000	0.2080
IN-W283.534	0.6805	0.0000	0.6805
IN-W285.471	63.0240	0.0000	63.0240
IN-W285.815	2.3445	0.0000	2.3445
IN-W289.466	25.3760	0.0000	25.3760
IN-W291.454	0.6805	0.0000	0.6805
IN-W291.456	634.4000	0.0000	634.4000
IN-W298.812	15.3715	0.0000	15.3715
IN-W302.299	23.4450	0.0000	23.4450
IN-W302.913	84.8640	0.0000	84.8640
IN-W306.633	2361.2160	0.0000	2361.2160
IN-W306.817	998.8135	0.0000	998.8135
IN-W308.816	864.9125	0.0000	864.9125
IN-W323.562	0.8885	0.0000	0.8885
IN-W325.1076	0.4160	0.0000	0.4160
IN-W325.679	0.6805	0.0000	0.6805
IN-W329.681	0.8885	0.0000	0.8885
IN-W334.675	1.5125	0.0000	1.5125
IN-W334.961	4.5760	0.0000	4.5760
IN-W338.657	0.8885	0.0000	0.8885
IN-W338.956	1.0400	0.0000	1.0400
IN-W339.655	2.1365	0.0000	2.1365
IN-W339.955	7.0720	0.0000	7.0720
IN-W341.671	0.2080	0.0000	0.2080
IN-W341.954	0.6805	0.0000	0.6805

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Heterogeneous

IN-W345.669	14.3520	0.0000	14.3520
IN-W345.819	0.8885	0.0000	0.8885
IN-W350.650	0.6805	0.0000	0.6805
IN-W350.923	0.2080	0.0000	0.2080
IN-W351.648	0.8885	0.0000	0.8885
IN-W351.922	1.2480	0.0000	1.2480
Total Volume:	**10608.50**	**0.00**	**10608.50**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1634.6	82.2	0.0
Aluminum Base Metal/Alloys	55.9	5.6	0.0
Other Metal/Alloys	233.0	16.3	0.0
Other Inorganic Materials	1442.3	19.7	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	961.5	106.1	0.0
Rubber	330.0	29.3	0.0
Plastics	887.0	116.2	0.0
Solidified Inorganic Material	8.9	0.5	0.0
Solidified Organic Material	5.4	0.1	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	144.2	0.3	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Inorganic Non-Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W157.907	9.3600	0.0000	9.3600
IN-W159.120	0.4160	0.0000	0.4160
IN-W161.231	97.5520	0.0000	97.5520
IN-W161.806	15.7875	0.0000	15.7875
IN-W163.234	0.4160	0.0000	0.4160
IN-W169.192	14.5600	0.0000	14.5600
IN-W187.121	0.2080	0.0000	0.2080
IN-W197.196	2.2880	0.0000	2.2880
IN-W198.203	0.2080	0.0000	0.2080
IN-W199.209	0.2080	0.0000	0.2080
IN-W203.211	3.3280	0.0000	3.3280
IN-W205.1087	0.2080	0.0000	0.2080
IN-W206.936	22.4640	0.0000	22.4640
IN-W207.238	0.2080	0.0000	0.2080
IN-W208.242	1.4560	0.0000	1.4560
IN-W209.244	3.1200	0.0000	3.1200
IN-W210.247	0.2080	0.0000	0.2080
IN-W211.249	22.4640	0.0000	22.4640
IN-W212.251	150.5920	0.0000	150.5920
IN-W213.252	0.4160	0.0000	0.4160
IN-W216.99	255.0080	0.0000	255.0080
IN-W218.109	183.8720	0.0000	183.8720
IN-W219.110	3.9520	0.0000	3.9520

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Inorganic Non-Metal

IN-W222.117	39.1040	0.0000	39.1040
IN-W228.102	198.8480	0.0000	198.8480
IN-W230.229	4.2730	0.0000	4.2730
IN-W230.940	14.7680	0.0000	14.7680
IN-W240.272	167.6480	0.0000	167.6480
IN-W240.931	1.9285	0.0000	1.9285
IN-W243.274	174.3040	0.0000	174.3040
IN-W243.275	7.2800	0.0000	7.2800
IN-W243.808	46.0580	0.0000	46.0580
IN-W245.1034	0.2080	0.0000	0.2080
IN-W245.301	37.5120	0.0000	37.5120
IN-W245.302	133.7440	0.0000	133.7440
IN-W247.1038	0.2080	0.0000	0.2080
IN-W247.810	27.5100	0.0000	27.5100
IN-W249.1071	2.2880	0.0000	2.2880
IN-W249.527	1.0965	0.0000	1.0965
IN-W252.1000	0.2080	0.0000	0.2080
IN-W254.1044	0.2080	0.0000	0.2080
IN-W257.558	0.2080	0.0000	0.2080
IN-W259.920	2.4960	0.0000	2.4960
IN-W260.565	0.2080	0.0000	0.2080
IN-W265.517	0.6240	0.0000	0.6240
IN-W267.1005	1.0965	0.0000	1.0965
IN-W267.514	1.2480	0.0000	1.2480
IN-W278.495	4.1600	0.0000	4.1600

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Inorganic Non-Metal

IN-W281.488	0.6240	0.0000	0.6240
IN-W283.963	0.2080	0.0000	0.2080
IN-W291.455	1.4560	0.0000	1.4560
IN-W294.1057	0.4160	0.0000	0.4160
IN-W296.329	520.2080	0.0000	520.2080
IN-W298.979	0.4160	0.0000	0.4160
IN-W306.632	187.2000	0.0000	187.2000
IN-W308.618	503.5680	0.0000	503.5680
IN-W309.609	108.5760	0.0000	108.5760
IN-W317.1028	0.2080	0.0000	0.2080
IN-W319.583	0.2080	0.0000	0.2080
IN-W321.578	0.2080	0.0000	0.2080
IN-W322.851	0.8885	0.0000	0.8885
IN-W322.952	1.6640	0.0000	1.6640
IN-W323.951	0.2080	0.0000	0.2080
IN-W329.682	0.2080	0.0000	0.2080
IN-W337.673	0.2080	0.0000	0.2080
IN-W337.957	0.6805	0.0000	0.6805
IN-W348.846	4.1600	0.0000	4.1600
IN-W357.1022	0.6805	0.0000	0.6805
IN-W357.850	0.2080	0.0000	0.2080
IN-W358.948	0.2080	0.0000	0.2080
IN-W361.1021	1.5125	0.0000	1.5125
IN-W361.849	2.0800	0.0000	2.0800
IN-W362.1020	5.3695	0.0000	5.3695

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Inorganic Non-Metal

IN-W362.848	8.7360	0.0000	8.7360
IN-W363.1019	0.8885	0.0000	0.8885
IN-W363.847	1.0400	0.0000	1.0400
IN-W364.1011	0.8885	0.0000	0.8885
IN-W364.844	0.6240	0.0000	0.6240
IN-W365.1010	1.3045	0.0000	1.3045
IN-W365.842	1.0400	0.0000	1.0400
IN-W366.1004	2.0800	0.0000	2.0800
IN-W366.841	1.0965	0.0000	1.0965
IN-W367.840	0.2080	0.0000	0.2080
IN-W368.839	0.2080	0.0000	0.2080
IN-W373.1003	0.6805	0.0000	0.6805
IN-W373.830	0.2080	0.0000	0.2080
IN-W374.1091	2.0800	0.0000	2.0800
IN-W374.829	2.3445	0.0000	2.3445
IN-W375.827	7.9040	0.0000	7.9040
Total Volume:	**3028.24**	**0.00**	**3028.24**

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Inorganic Non-Metal

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	4.3	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	13.1	0.1	0.0
Other Inorganic Materials	1250.0	63.1	0.0
Vitrified	2500.0	1896.1	0.0
Cellulosics	850.0	19.1	0.0
Rubber	8.7	0.1	0.0
Plastics	69.9	3.7	0.0
Solidified Inorganic Material	69.9	1.8	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	865.8	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W260.566	8.3380	0.0000	8.3380
IN-W260.916	6.0320	0.0000	6.0320
Total Volume:	**14.37**	**0.00**	**14.37**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	345.0	115.6	4.7
Aluminum Base Metal/Alloys	43.1	14.2	0.2
Other Metal/Alloys	163.3	128.9	104.7
Other Inorganic Materials	29.2	10.0	0.6
Vitrified	0.0	0.0	0.0
Cellulosics	7.1	3.4	1.7
Rubber	17.4	13.2	11.2
Plastics	49.6	19.1	4.3
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.9	0.9	0.9
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Salt Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W311.1013	5.4080	0.0000	5.4080
IN-W311.604	1.7205	0.0000	1.7205
IN-W312.602	1.0965	0.0000	1.0965
IN-W312.942	2.7040	0.0000	2.7040
IN-W314.1017	1.0400	0.0000	1.0400
IN-W314.606	0.6805	0.0000	0.6805
IN-W354.1016	0.2080	0.0000	0.2080
IN-W354.858	0.6805	0.0000	0.6805
IN-W355.1015	1.0400	0.0000	1.0400
IN-W355.857	0.8885	0.0000	0.8885
IN-W356.1014	3.7440	0.0000	3.7440
IN-W356.856	1.3045	0.0000	1.3045
Total Volume:	**20.52**	**0.00**	**20.52**

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Salt Waste

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	57.7	11.2	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	212.0	39.1	0.0
Other Inorganic Materials	625.0	208.2	2.9
Vitrified	0.0	0.0	0.0
Cellulosics	26.2	4.4	0.0
Rubber	0.0	0.0	0.0
Plastics	35.0	5.9	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W146.699	2.2880	0.0000	2.2880
IN-W159.1072	0.6805	0.0000	0.6805
IN-W163.1007	0.6805	0.0000	0.6805
IN-W166.151	15.9955	0.0000	15.9955
IN-W166.928	56.7840	0.0000	56.7840
IN-W174.1082	30.3680	0.0000	30.3680
IN-W174.154	134.3170	0.0000	134.3170
IN-W177.1083	141.0240	0.0000	141.0240
IN-W177.156	39.2325	0.0000	39.2325
IN-W179.1084	4.5760	0.0000	4.5760
IN-W179.158	1.5125	0.0000	1.5125
IN-W181.162	9.5680	0.0000	9.5680
IN-W187.1094	0.6805	0.0000	0.6805
IN-W188.1093	1.0400	0.0000	1.0400
IN-W188.160	0.6805	0.0000	0.6805
IN-W216.875	1478.8800	0.0000	1478.8800
IN-W216.98	555.6465	0.0000	555.6465
IN-W218.909	101.9100	0.0000	101.9100
IN-W219.914	2.3445	0.0000	2.3445
IN-W220.114	122.8025	0.0000	122.8025
IN-W220.925	443.0400	0.0000	443.0400
IN-W221.113	11.6480	0.0000	11.6480
IN-W221.927	3.6490	0.0000	3.6490

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Solidified Inorganics

IN-W222.116	24.7495	0.0000	24.7495
IN-W222.965	10.6080	0.0000	10.6080
IN-W228.101	287.3335	0.0000	287.3335
IN-W228.883	608.8161	0.0000	608.8161
IN-W247.523	173.6800	0.0000	173.6800
IN-W257.947	0.6805	0.0000	0.6805
IN-W263.520	14.3520	0.0000	14.3520
IN-W315.601	0.4160	0.0000	0.4160
IN-W332.661	0.6805	0.0000	0.6805
IN-W332.962	0.8320	0.0000	0.8320
IN-W347.646	51.7920	0.0000	51.7920
IN-W347.818	3.4410	0.0000	3.4410
IN-W348.1012	2.3445	0.0000	2.3445
IN-W353.859	0.6805	0.0000	0.6805
IN-W353.917	0.2080	0.0000	0.2080
IN-W375.1096	4.4810	0.0000	4.4810
Total Volume:	**4344.44**	**0.00**	**4344.44**

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Solidified Inorganics

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	199.9	4.4	0.0
Aluminum Base Metal/Alloys	0.1	0.0	0.0
Other Metal/Alloys	3.4	2.0	0.0
Other Inorganic Materials	754.8	74.5	0.0
Vitrified	40.5	0.8	0.0
Cellulosics	85.2	1.1	0.0
Rubber	0.0	0.0	0.0
Plastics	68.3	6.9	0.0
Solidified Inorganic Material	947.0	366.2	0.0
Solidified Organic Material	0.5	0.0	0.0
Cement (Solidified)	584.4	212.7	0.0
Soils	671.5	2.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Solidified Organics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W157.144	49.9150	0.0000	49.9150
IN-W157.906	163.6960	0.0000	163.6960
IN-W164.1060	1.6640	0.0000	1.6640
IN-W164.153	0.8885	0.0000	0.8885
IN-W167.149	36.6800	0.0000	36.6800
IN-W167.926	131.4560	0.0000	131.4560
IN-W309.610	352.7680	0.0000	352.7680
IN-W317.757	39.1040	0.0000	39.1040
IN-W317.758	11.5145	0.0000	11.5145
IN-W319.584	0.6805	0.0000	0.6805
IN-W321.1023	1.3045	0.0000	1.3045
Total Volume:	**789.67**	**0.00**	**789.67**

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Solidified Organics

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.9	0.0	0.0
Aluminum Base Metal/Alloys	0.4	0.0	0.0
Other Metal/Alloys	0.1	0.0	0.0
Other Inorganic Materials	673.1	133.9	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	1.0	0.0	0.0
Rubber	0.2	0.0	0.0
Plastics	25.7	5.2	0.0
Solidified Inorganic Material	36.0	1.4	0.0
Solidified Organic Material	1072.0	623.5	39.2
Cement (Solidified)	542.8	133.8	0.0
Soils	0.2	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W159.119	0.2080	0.0000	0.2080
IN-W203.212	0.2080	0.0000	0.2080
IN-W204.217	0.2080	0.0000	0.2080
IN-W213.253	0.2080	0.0000	0.2080
IN-W214.756	0.2080	0.0000	0.2080
IN-W228.103	31.8240	0.0000	31.8240
IN-W249.528	0.2080	0.0000	0.2080
IN-W271.533	0.2080	0.0000	0.2080
IN-W280.1066	28.4960	0.0000	28.4960
IN-W280.448	8.3380	0.0000	8.3380
IN-W280.449	0.2080	0.0000	0.2080
IN-W287.460	211.9520	0.0000	211.9520
IN-W294.342	406.8480	0.0000	406.8480
IN-W294.814	33.5035	0.0000	33.5035
IN-W296.327	3450.3041	0.0000	3450.3041
IN-W296.813	47.9865	0.0000	47.9865
IN-W298.317	54.7040	0.0000	54.7040
IN-W300.308	1509.4560	0.0000	1509.4560
IN-W300.930	4.6890	0.0000	4.6890
IN-W304.860	8.7540	0.0000	8.7540
IN-W304.861	59.0720	0.0000	59.0720
IN-W342.652	0.6805	0.0000	0.6805
IN-W342.953	0.4160	0.0000	0.4160

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Uncategorized Metal

IN-W358.854	0.8885	0.0000	0.8885
IN-W358.855	3.3280	0.0000	3.3280
IN-W359.853	0.8320	0.0000	0.8320
IN-W360.852	0.6805	0.0000	0.6805
IN-W360.912	0.2080	0.0000	0.2080
IN-W371.1018	0.2080	0.0000	0.2080
IN-W371.831	0.6805	0.0000	0.6805
IN-W372.832	1.3045	0.0000	1.3045
Total Volume:	**5866.82**	**0.00**	**5866.82**

Site-Specific Contact Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Uncategorized Metal

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1634.6	128.7	0.0
Aluminum Base Metal/Alloys	73.7	11.6	0.0
Other Metal/Alloys	538.0	113.9	0.0
Other Inorganic Materials	812.5	24.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	184.8	6.9	0.0
Rubber	16.4	1.1	0.0
Plastics	149.0	21.2	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Lawrence Livermore National Laboratory

Final Waste Form: Filter

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LL-T005	15.5360	32.2840	47.8200
Total Volume:	**15.54**	**32.28**	**47.82**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	150.0	66.3	0.0
Aluminum Base Metal/Alloys	50.0	20.7	0.0
Other Metal/Alloys	20.0	10.0	0.0
Other Inorganic Materials	50.0	20.7	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	130.0	65.7	0.0
Rubber	20.0	10.0	0.0
Plastics	100.0	20.7	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Lawrence Livermore National Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LL-M001	5.4080	17.2640	22.6720
LL-T002	47.9120	502.8800	550.7920
LL-T003	143.6400	117.1800	260.8200
LL-W018	1.8900	26.4600	28.3500
Total Volume:	**198.85**	**663.78**	**862.63**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	800.0	14.3	0.0
Aluminum Base Metal/Alloys	800.0	4.9	0.0
Other Metal/Alloys	800.0	2.0	0.0
Other Inorganic Materials	800.0	1.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	500.0	66.9	0.0
Rubber	200.0	3.7	0.0
Plastics	365.0	67.4	0.0
Solidified Inorganic Material	300.0	4.1	0.0
Solidified Organic Material	300.0	4.1	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Lawrence Livermore National Laboratory

Final Waste Form: Salt Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LL-T004	0.6240	3.0160	3.6400
Total Volume:	**0.62**	**3.02**	**3.64**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	100.0	20.0	0.0
Aluminum Base Metal/Alloys	80.0	5.0	0.0
Other Metal/Alloys	50.0	2.0	0.0
Other Inorganic Materials	365.0	290.0	100.0
Vitrified	0.0	0.0	0.0
Cellulosics	50.0	2.0	0.0
Rubber	20.0	1.0	0.0
Plastics	100.0	20.0	5.0
Solidified Inorganic Material	10.0	1.0	0.0
Solidified Organic Material	10.0	1.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Lawrence Livermore National Laboratory

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LL-T001	14.3520	5.8240	20.1760
Total Volume:	**14.35**	**5.82**	**20.18**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	100.0	30.0	0.0
Aluminum Base Metal/Alloys	50.0	5.0	0.0
Other Metal/Alloys	20.0	1.0	0.0
Other Inorganic Materials	20.0	1.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	100.0	10.0	0.0
Rubber	20.0	1.0	0.0
Plastics	100.0	20.0	5.0
Solidified Inorganic Material	365.0	100.0	50.0
Solidified Organic Material	365.0	100.0	50.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Lawrence Livermore National Laboratory

Final Waste Form: Solidified Organics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LL-W019	1.0400	5.8240	6.8640
Total Volume:	**1.04**	**5.82**	**6.86**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	100.0	30.0	0.0
Aluminum Base Metal/Alloys	50.0	5.0	0.0
Other Metal/Alloys	20.0	1.0	0.0
Other Inorganic Materials	20.0	1.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	100.0	10.0	0.0
Rubber	20.0	1.0	0.0
Plastics	100.0	20.0	5.0
Solidified Inorganic Material	365.0	100.0	50.0
Solidified Organic Material	365.0	100.0	50.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-T004	1555.1560	1677.3120	3232.4681
LA-W004	266.2940	698.8800	965.1740
Total Volume:	**1821.45**	**2376.19**	**4197.64**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	265.2	257.7	254.0
Aluminum Base Metal/Alloys	0.4	0.4	0.4
Other Metal/Alloys	89.7	18.8	18.8
Other Inorganic Materials	6.8	6.8	6.8
Vitrified	0.0	0.0	0.0
Cellulosics	68.7	64.0	59.2
Rubber	1.2	1.1	1.0
Plastics	5.7	5.3	4.9
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-T007	6.6560	29.1200	35.7760
LA-W067	8.9440	0.0000	8.9440
LA-W068	0.4160	0.0000	0.4160
Total Volume:	**16.02**	**29.12**	**45.14**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	822.2	264.9	69.2
Aluminum Base Metal/Alloys	55.9	8.8	0.0
Other Metal/Alloys	91.3	25.5	2.4
Other Inorganic Materials	95.2	10.9	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	300.1	16.9	0.0
Rubber	67.5	3.7	0.0
Plastics	191.9	14.1	0.0
Solidified Inorganic Material	8.9	1.0	0.0
Solidified Organic Material	5.4	0.2	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	0.6	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-W066	1.8900	0.0000	1.8900
Total Volume:	**1.89**	**0.00**	**1.89**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	345.0	115.6	4.7
Aluminum Base Metal/Alloys	43.1	14.2	0.2
Other Metal/Alloys	163.3	128.9	104.7
Other Inorganic Materials	29.2	10.0	0.6
Vitrified	0.0	0.0	0.0
Cellulosics	7.1	3.4	1.7
Rubber	17.4	13.2	11.2
Plastics	49.6	19.1	4.3
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.9	0.9	0.9
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Soils

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-T008	110.5700	29.1200	139.6900
Total Volume:	**110.57**	**29.12**	**139.69**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	1600.0	1200.0	1000.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-M002	3053.5340	553.2800	3606.8140
LA-T006	4.9920	81.5360	86.5280
LA-W003	1277.4760	559.1040	1836.5800
LA-W006	552.1940	839.9040	1392.0980
Total Volume:	**4888.20**	**2033.82**	**6922.02**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	48.1	20.7	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	2180.0	583.5	335.3
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	1166.0	641.1	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Solidified Organics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-T002	1.4560	29.1200	30.5760
Total Volume:	**1.46**	**29.12**	**30.58**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	1014.0	603.0	507.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	1166.0	693.0	583.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-T001	95.9560	559.1040	655.0600
LA-T005	1503.0280	1118.2080	2621.2360
LA-T009	53.5440	58.2400	111.7840
LA-W001	2203.3460	139.7760	2343.1220
LA-W005	214.7100	698.8800	913.5900
LA-W009	143.8480	279.5520	423.4000
Total Volume:	**4214.43**	**2853.76**	**7068.19**

M

Site-Specific Contact Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Uncategorized Metal

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	822.2	265.1	69.2
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	913.5	166.6	7.7
Other Inorganic Materials	6.8	6.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	68.7	28.2	0.0
Rubber	1.2	0.5	0.0
Plastics	5.7	2.3	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Mound Plant

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
MD-T008	3.7440	0.0000	3.7440
MD-T009	0.2080	0.0000	0.2080
MD-W003	1.6640	0.0000	1.6640
MD-W017	1.4560	0.0000	1.4560
Total Volume:	**7.07**	**0.00**	**7.07**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	112.8	109.7	108.2
Aluminum Base Metal/Alloys	0.2	0.2	0.2
Other Metal/Alloys	41.9	10.4	8.5
Other Inorganic Materials	14.8	8.7	3.9
Vitrified	0.0	0.0	0.0
Cellulosics	314.5	191.3	61.2
Rubber	71.4	30.2	22.8
Plastics	101.6	59.0	38.8
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Mound Plant

Final Waste Form: Filter

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
MD-M001	0.4160	0.0000	0.4160
MD-T010	0.4160	0.0000	0.4160
Total Volume:	**0.83**	**0.00**	**0.83**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	10.6	5.3	0.0
Aluminum Base Metal/Alloys	57.4	12.5	1.8
Other Metal/Alloys	1.6	0.8	0.0
Other Inorganic Materials	69.1	15.0	2.4
Vitrified	0.0	0.0	0.0
Cellulosics	341.9	56.3	3.7
Rubber	17.0	3.3	0.2
Plastics	23.3	4.6	0.6
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Mound Plant

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
MD-T012	0.6240	0.0000	0.6240
Total Volume:	**0.62**	**0.00**	**0.62**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	566.8	235.5	207.8
Aluminum Base Metal/Alloys	55.9	42.3	41.8
Other Metal/Alloys	48.8	7.1	2.4
Other Inorganic Materials	95.2	52.3	47.5
Vitrified	0.0	0.0	0.0
Cellulosics	300.1	81.4	18.7
Rubber	67.5	17.9	6.8
Plastics	191.9	67.8	22.9
Solidified Inorganic Material	8.9	4.7	4.4
Solidified Organic Material	5.4	0.8	0.6
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	3.0	3.0

Site-Specific Contact Handled Waste Profiles

Site Name: Mound Plant

Final Waste Form: Soils

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
MD-T003	146.9400	0.0000	146.9400
MD-T005	30.2400	0.0000	30.2400
Total Volume:	**177.18**	**0.00**	**177.18**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	1315.0	846.8	566.0

Site-Specific Contact Handled Waste Profiles

Site Name: Mound Plant

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
MD-T001	4.1600	0.0000	4.1600
MD-W002	1.8720	0.0000	1.8720
Total Volume:	**6.03**	**0.00**	**6.03**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	199.9	51.5	0.0
Aluminum Base Metal/Alloys	0.1	0.0	0.0
Other Metal/Alloys	1.0	0.2	0.0
Other Inorganic Materials	109.6	22.9	0.0
Vitrified	40.5	9.2	0.0
Cellulosics	0.6	0.1	0.0
Rubber	0.0	0.0	0.0
Plastics	2.6	0.6	0.0
Solidified Inorganic Material	1204.0	916.6	305.8
Solidified Organic Material	0.5	0.0	0.0
Cement (Solidified)	584.4	120.4	0.0
Soils	0.6	0.2	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Mound Plant

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
MD-T006	58.5900	0.0000	58.5900
MD-T007	23.8920	0.0000	23.8920
Total Volume:	**82.48**	**0.00**	**82.48**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	223.5	126.9	90.3
Aluminum Base Metal/Alloys	6.9	2.4	1.7
Other Metal/Alloys	406.9	266.5	214.2
Other Inorganic Materials	21.4	14.6	10.2
Vitrified	0.0	0.0	0.0
Cellulosics	12.7	8.3	6.7
Rubber	1.5	0.5	0.3
Plastics	11.4	5.4	1.8
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Nevada Test Site

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
NT-W001	613.2620	8.9800	622.2420
Total Volume:	**613.26**	**8.98**	**622.24**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	554.0	72.2	0.0
Aluminum Base Metal/Alloys	512.0	12.3	0.0
Other Metal/Alloys	483.0	5.8	0.0
Other Inorganic Materials	475.0	4.8	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	318.0	52.5	0.0
Rubber	168.0	3.8	0.0
Plastics	318.0	50.1	1.9
Solidified Inorganic Material	177.0	11.8	0.0
Solidified Organic Material	177.0	11.8	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.1	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Nevada Test Site

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
NT-W021	5.6700	0.0000	5.6700
Total Volume:	**5.67**	**0.00**	**5.67**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	544.0	272.0	0.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Oak Ridge National Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
OR-W041	170.7680	0.0000	170.7680
OR-W044	522.9120	256.2560	779.1680
OR-W045	5.4080	0.0000	5.4080
OR-W047	154.1280	0.0000	154.1280
OR-W048	15.1840	0.0000	15.1840
OR-W053	435.7600	0.0000	435.7600
Total Volume:	**1304.16**	**256.26**	**1560.42**

Site-Specific Contact Handled Waste Profiles

Site Name: Oak Ridge National Laboratory

Final Waste Form: Heterogeneous

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1716.4	96.2	0.0
Aluminum Base Metal/Alloys	1.6	0.0	0.0
Other Metal/Alloys	21.3	0.0	0.0
Other Inorganic Materials	24.0	2.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	184.8	80.9	0.0
Rubber	17.9	7.4	0.0
Plastics	149.0	64.9	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	3.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Paducah Gaseous Diffusion Plant

Final Waste Form: Inorganic Non-Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
PA-A015	0.0000	1.8900	1.8900
Total Volume:	**0.00**	**1.89**	**1.89**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	63.6	63.6	63.6
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Pantex Plant

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
PX-T001	0.6240	0.0000	0.6240
Total Volume:	**0.62**	**0.00**	**0.62**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	95.8	87.0	78.4
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	12.4	11.3	10.2
Plastics	12.4	11.3	10.2
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-MT0339	22.8800	138.1120	160.9920
RF-MT0341	0.0000	0.0000	0.0000
RF-MT0821	0.4160	0.0000	0.4160
RF-MT0831	44.9280	223.7520	268.6800
RF-MT0832	72.3840	312.4784	384.8624
RF-MT0833	8.7360	46.9620	55.6980
RF-MT2116	2.0800	0.0000	2.0800
RF-TT0302	0.0000	0.0000	0.0000
RF-TT0821	12.4800	59.6960	72.1760
RF-TT0822	0.0000	0.0000	0.0000
RF-TT0825	21.6320	80.0800	101.7120
Total Volume:	**185.54**	**861.08**	**1046.62**

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Combustible

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	112.8	0.0	0.0
Aluminum Base Metal/Alloys	0.2	0.0	0.0
Other Metal/Alloys	41.9	0.0	0.0
Other Inorganic Materials	370.2	33.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	647.8	47.2	0.0
Rubber	217.4	21.7	0.0
Plastics	349.2	20.6	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Filter

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-MT-0335	1.4560	400.4000	401.8560
RF-MT-0338	0.0000	0.0000	0.0000
RF-MT-0491	0.6240	26.6240	27.2480
RF-TR0335	1.4560	0.0000	1.4560
RF-TT0335	19.3440	30.7216	50.0656
RF-TT0338	2.0800	5.8240	7.9040
RF-TT0376	8.9440	12.4800	21.4240
RF-TT0490	22.1740	1.4560	23.6300
RF-TT0491	16.0160	0.0000	16.0160
Total Volume:	**72.09**	**477.51**	**549.60**

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Filter

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	10.6	0.0	0.0
Aluminum Base Metal/Alloys	191.6	11.9	0.0
Other Metal/Alloys	1.6	0.0	0.0
Other Inorganic Materials	236.0	14.1	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	429.5	55.6	0.0
Rubber	19.4	2.7	0.0
Plastics	25.6	3.2	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Graphite

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-TT0300	12.8960	4.7840	17.6800
RF-TT0303	0.2080	0.0000	0.2080
RF-TT0312	0.6240	42.7835	43.4075
Total Volume:	**13.73**	**47.57**	**61.30**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	17.3	8.7	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	381.9	270.4	51.9
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-MT0374	1.2480	0.0000	1.2480
RF-TT0374	0.6240	0.0000	0.6240
RF-TT2116	0.2080	0.0000	0.2080
RF-TT2216	1.7805	0.0000	1.7805
Total Volume:	**3.86**	**0.00**	**3.86**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	628.4	132.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	483.0	144.9	12.0
Rubber	46.1	13.3	0.0
Plastics	139.0	45.9	9.6
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	628.4	31.5	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Inorganic Non-metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-MT-0368	0.6240	2.9120	3.5360
RF-MT-0438	0.4160	15.8080	16.2240
RF-MT0440	5.6340	195.8863	201.5203
RF-MT0442	6.6560	584.2720	590.9280
RF-MT0444	2.7220	8.3920	11.1140
RF-MT0855	0.2080	1.6640	1.8720
RF-MT0856	0.2080	5.4080	5.6160
RF-TR0334	0.4160	0.0000	0.4160
RF-TT0438	7.6960	7.2800	14.9760
RF-TT0440	5.6340	21.8300	27.4640
RF-TT0442	28.0800	23.2860	51.3660
Total Volume:	**58.29**	**866.74**	**925.03**

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Inorganic Non-metal

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	24.3	10.3	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	5.3	0.5	0.0
Other Inorganic Materials	789.8	216.2	1.9
Vitrified	0.0	0.0	0.0
Cellulosics	12.6	5.5	0.0
Rubber	3.1	0.3	0.0
Plastics	78.1	13.9	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-MT0321	3.7440	7.9040	11.6480
RF-MT0480	0.2080	290.3659	290.5739
Total Volume:	**3.95**	**298.27**	**302.22**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	488.7	154.2	0.0
Aluminum Base Metal/Alloys	61.6	19.4	0.0
Other Metal/Alloys	1438.1	33.1	0.0
Other Inorganic Materials	40.9	12.9	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	7.6	2.4	0.0
Rubber	8.9	2.8	0.0
Plastics	64.7	20.4	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Salt Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-TT0999	0.0000	325.9173	325.9173
Total Volume:	**0.00**	**325.92**	**325.92**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	540.0	193.9	47.5
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	237.6	166.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	211.7	176.1	140.4
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-MR0089	0.0000	0.0000	0.0000
RF-MR0423	0.0000	0.0000	0.0000
RF-MT-0823	0.2080	0.0000	0.2080
RF-MT0001	3.7440	0.0000	3.7440
RF-MT0007	0.8320	0.0000	0.8320
RF-MT0377	3.5360	0.0000	3.5360
RF-MT0800	65.5200	38.8960	104.4160
RF-MT0803	2.9120	2.0800	4.9920
RF-MT0806	0.0000	923.8050	923.8050
RF-MT0807	73.4240	41.6000	115.0240
RF-T010	0.6240	0.0000	0.6240
RF-TT0802	7.4880	26.0000	33.4880
RF-TT0806	0.0000	202.1760	202.1760
RF-TT0823	7.0720	23.0880	30.1600
Total Volume:	**165.36**	**1257.64**	**1423.01**

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Solidified Inorganics

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	199.9	0.0	0.0
Aluminum Base Metal/Alloys	0.1	0.0	0.0
Other Metal/Alloys	98.7	0.6	0.0
Other Inorganic Materials	985.1	470.8	0.0
Vitrified	40.5	0.0	0.0
Cellulosics	49.7	0.0	0.0
Rubber	32.9	0.0	0.0
Plastics	35.5	0.2	0.0
Solidified Inorganic Material	609.6	155.9	0.0
Solidified Organic Material	0.5	0.0	0.0
Cement (Solidified)	584.4	81.7	0.0
Soils	0.6	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Solidified Organics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-MT0003	0.6240	0.0000	0.6240
RF-MT0375	0.2080	0.0000	0.2080
RF-MT0801	108.9920	0.0000	108.9920
RF-TT0809	0.0000	31.1085	31.1085
Total Volume:	**109.82**	**31.11**	**140.93**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	362.2	47.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	74.6	9.7	0.0
Solidified Inorganic Material	7.7	0.0	0.0
Solidified Organic Material	1375.6	779.3	0.6
Cement (Solidified)	54.3	7.1	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RF-MT0320	1.4560	19.5520	21.0080
RF-TT0320	4.5760	3.7440	8.3200
RF-TT0479	0.0000	0.0000	0.0000
RF-TT0480	77.2940	193.0610	270.3550
RF-TT0481	0.2080	0.0000	0.2080
RF-TT0485	0.0000	0.0000	0.0000
RF-TT0824	9.7760	19.7600	29.5360
Total Volume:	**93.31**	**236.12**	**329.43**

Site-Specific Contact Handled Waste Profiles

Site Name: Rocky Flats Environmental Technology Site

Final Waste Form: Uncategorized Metal

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	488.7	137.5	0.0
Aluminum Base Metal/Alloys	61.6	10.7	0.0
Other Metal/Alloys	406.9	133.9	0.0
Other Inorganic Materials	40.9	14.0	0.1
Vitrified	0.0	0.0	0.0
Cellulosics	12.7	4.9	0.0
Rubber	8.9	1.6	0.0
Plastics	64.7	12.5	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Sandia National Laboratory - Albuquerque

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
SA-T001	5.4080	5.8240	11.2320
SA-W134	1.2480	1.6640	2.9120
Total Volume:	**6.66**	**7.49**	**14.14**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	110.0	95.9	10.0
Aluminum Base Metal/Alloys	10.0	3.4	1.0
Other Metal/Alloys	15.0	6.8	2.0
Other Inorganic Materials	20.0	12.1	1.0
Vitrified	0.0	0.0	0.0
Cellulosics	5.0	2.8	1.0
Rubber	9.0	4.4	1.0
Plastics	10.0	5.0	1.0
Solidified Inorganic Material	60.0	31.8	0.0
Solidified Organic Material	9.0	4.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Savannah River Site

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
T001-221F-HET	938.7040	1598.4800	2537.1841
T001-221H-HET	158.1424	971.5057	1129.6481
T001-235F-HET	162.9680	205.1920	368.1600
T001-772F-HET	29.0784	11.4816	40.5600
T001-773A-HET	22.0896	257.4624	279.5520
T003-773A-HET	0.6240	6.8640	7.4880
W026-221F-HET	0.0000	1402.9600	1402.9600
W026-221H-HET	0.0000	691.3920	691.3920
W026-235F-HET	0.0000	144.7680	144.7680
W026-772F-HET	0.0000	11.6480	11.6480
W026-773A-HET	0.0000	174.0960	174.0960
W027-221F-HET	265.6160	0.0000	265.6160
W027-221H-HET	125.4240	0.0000	125.4240
W027-235F-HET	34.7360	0.0000	34.7360
W027-772F-HET	515.4240	0.0000	515.4240
W027-773A-HET	331.1360	0.0000	331.1360
W027-999-HET	27.6640	0.0000	27.6640
Total Volume:	**2611.61**	**5475.85**	**8087.46**

Site-Specific Contact Handled Waste Profiles

Site Name: Savannah River Site

Final Waste Form: Heterogeneous

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	566.8	3.7	0.0
Aluminum Base Metal/Alloys	55.9	0.7	0.0
Other Metal/Alloys	48.8	0.1	0.0
Other Inorganic Materials	95.2	1.9	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	576.9	115.3	0.0
Rubber	67.5	11.2	0.0
Plastics	191.9	33.9	0.0
Solidified Inorganic Material	8.9	0.1	0.0
Solidified Organic Material	5.4	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: Savannah River Site

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
T001-221F-VIT	23.1504	141.0302	164.1807
T001-221H-VIT	33.8000	478.4208	512.2208
T001-235F-VIT	1.4768	85.5338	87.0106
T001-772F-VIT	0.1872	7.5816	7.7688
T001-773A-CLAS	4.5760	0.0000	4.5760
T001-773A-VIT	0.3952	15.1424	15.5376
T003-773A-VIT	0.2080	0.0000	0.2080
W006-773A-VIT	0.5179	0.0000	0.5179
W026-221F-VIT	0.0000	65.6885	65.6885
W026-221H-VIT	0.0000	299.2475	299.2475
W026-235F-VIT	0.0000	63.0344	63.0344
W026-772F-VIT	0.0000	5.3082	5.3082
W026-773A-VIT	0.0000	8.6258	8.6258
W027-221F-VIT	33.1760	0.0000	33.1760
W027-221H-VIT	25.8773	0.0000	25.8773
W027-235F-VIT	16.5880	0.0000	16.5880
W027-772F-VIT	10.6163	0.0000	10.6163
W027-773A-VIT	17.2515	0.0000	17.2515
W027-999-VIT	31.8490	0.0000	31.8490
W053-773A-VIT	0.5179	0.0000	0.5179
Total Volume:	**200.19**	**1169.61**	**1369.80**

Site-Specific Contact Handled Waste Profiles

Site Name: Savannah River Site

Final Waste Form: Solidified Inorganics

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2375.0	1854.4	87.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	2473.0	331.4	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Savannah River Site

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
T001-221F-MET	23.8140	70.6860	94.5000
T001-221H-MET	0.7938	14.3262	15.1200
T001-235F-MET	0.0000	1.8900	1.8900
T001-772F-MET	0.0000	1.8900	1.8900
T001-773A-MET	0.3780	31.7520	32.1300
W027-221F-MET	1.8900	0.0000	1.8900
W027-221H-MET	1.8900	0.0000	1.8900
W027-235F-MET	1.8900	0.0000	1.8900
W027-772F-MET	32.1300	0.0000	32.1300
W027-773A-MET	7.5600	0.0000	7.5600
Total Volume:	**70.35**	**120.54**	**190.89**

Site-Specific Contact Handled Waste Profiles

Site Name: Savannah River Site

Final Waste Form: Uncategorized Metal

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	317.0	91.0	0.0
Aluminum Base Metal/Alloys	6.9	0.4	0.0
Other Metal/Alloys	1586.5	207.2	0.0
Other Inorganic Materials	21.4	18.5	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	12.7	1.4	0.0
Rubber	1.5	0.1	0.0
Plastics	11.4	0.9	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: Teledyne Brown Engineering

Final Waste Form: Inorganic Non-Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
TB-W001	0.2080	0.0000	0.2080
Total Volume:	**0.21**	**0.00**	**0.21**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	327.0	327.0	327.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Contact Handled Waste Profiles

Site Name: U.S. Army Material Command

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
MC-W001	2.4960	0.0000	2.4960
Total Volume:	**2.50**	**0.00**	**2.50**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	566.8	235.5	207.8
Aluminum Base Metal/Alloys	55.9	42.3	41.8
Other Metal/Alloys	48.8	7.1	2.4
Other Inorganic Materials	95.2	52.3	47.5
Vitrified	0.0	0.0	0.0
Cellulosics	300.1	81.4	18.7
Rubber	67.5	17.9	6.8
Plastics	191.9	67.8	22.9
Solidified Inorganic Material	8.9	4.7	4.4
Solidified Organic Material	5.4	0.8	0.6
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	3.0	3.0

M

Site-Specific Contact Handled Waste Profiles

Site Name: University of Missouri Research Reactor

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
MU-W002	0.2080	0.8320	1.0400
Total Volume:	**0.21**	**0.83**	**1.04**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	20.0	11.3	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	60.0	25.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	10.0	2.5	0.0
Rubber	50.0	25.0	0.0
Plastics	80.0	37.5	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Argonne National Laboratory - West

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AW-T031.1322	0.0000	1208.6200	1208.6200
Total Volume:	**0.00**	**1208.62**	**1208.62**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	566.8	235.5	207.8
Aluminum Base Metal/Alloys	55.9	42.3	41.8
Other Metal/Alloys	48.8	7.1	2.4
Other Inorganic Materials	95.2	52.3	47.5
Vitrified	0.0	0.0	0.0
Cellulosics	300.1	81.4	18.7
Rubber	67.5	17.9	6.8
Plastics	191.9	67.8	22.9
Solidified Inorganic Material	8.9	4.7	4.4
Solidified Organic Material	5.4	0.8	0.6
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	3.0	3.0

Site-Specific Remote Handled Waste Profiles

Site Name: Argonne National Laboratory - West

Final Waste Form: Inorganic Non-Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AW-T035.1326	0.0000	21.3600	21.3600
Total Volume:	**0.00**	**21.36**	**21.36**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	4.3	2.8	0.5
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	1.0	0.2	0.0
Other Inorganic Materials	190.1	98.9	23.2
Vitrified	1421.7	1421.7	1421.7
Cellulosics	40.8	15.7	3.8
Rubber	0.9	0.4	0.2
Plastics	13.4	6.7	1.9
Solidified Inorganic Material	2.9	1.4	0.2
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.4	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Argonne National Laboratory - West

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AW-W021.16	0.0000	6.2300	6.2300
Total Volume:	**0.00**	**6.23**	**6.23**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	345.0	115.6	4.7
Aluminum Base Metal/Alloys	43.1	14.2	0.2
Other Metal/Alloys	163.3	128.9	104.7
Other Inorganic Materials	29.2	10.0	0.6
Vitrified	0.0	0.0	0.0
Cellulosics	7.1	3.4	1.7
Rubber	17.4	13.2	11.2
Plastics	49.6	19.1	4.3
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.9	0.9	0.9
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Argonne National Laboratory - West

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AW-W012.10	0.0000	21.3600	21.3600
AW-W016.20	0.0000	4.4500	4.4500
AW-W020.13	1.7800	1.7800	3.5600
AW-W022.22	0.0000	0.8900	0.8900
Total Volume:	**1.78**	**28.48**	**30.26**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	199.9	166.0	131.3
Aluminum Base Metal/Alloys	0.1	0.0	0.0
Other Metal/Alloys	1.0	0.7	0.6
Other Inorganic Materials	109.6	73.9	44.6
Vitrified	40.5	29.7	13.5
Cellulosics	0.6	0.3	0.0
Rubber	0.0	0.0	0.0
Plastics	2.6	2.0	1.7
Solidified Inorganic Material	609.6	413.4	305.8
Solidified Organic Material	0.5	0.1	0.1
Cement (Solidified)	584.4	387.9	295.1
Soils	0.6	0.6	0.4

Site-Specific Remote Handled Waste Profiles

Site Name: Argonne National Laboratory - West

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
AW-T029.1323	17.5063	0.0000	17.5063
Total Volume:	**17.51**	**0.00**	**17.51**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	223.5	126.9	90.3
Aluminum Base Metal/Alloys	6.9	2.4	1.7
Other Metal/Alloys	406.9	266.5	214.2
Other Inorganic Materials	21.4	14.6	10.2
Vitrified	0.0	0.0	0.0
Cellulosics	12.7	8.3	6.7
Rubber	1.5	0.5	0.3
Plastics	11.4	5.4	1.8
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Remote Handled Waste Profiles

Site Name: Battelle Columbus Laboratories

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
BC-T001	580.5025	0.0000	580.5025
Total Volume:	**580.50**	**0.00**	**580.50**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	2000.0	2000.0	2000.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Bettis Atomic Power Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
BT-T001	0.0000	6.6750	6.6750
Total Volume:	**0.00**	**6.67**	**6.67**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	500.0	425.0	350.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	20.0	10.0	0.0
Rubber	0.0	0.0	0.0
Plastics	550.0	450.0	350.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Energy Technology Engineering Center

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
ET-M001	0.8900	0.0000	0.8900
Total Volume:	**0.89**	**0.00**	**0.89**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	345.0	115.6	4.7
Aluminum Base Metal/Alloys	43.1	14.2	0.2
Other Metal/Alloys	163.3	128.9	104.7
Other Inorganic Materials	29.2	10.0	0.6
Vitrified	0.0	0.0	0.0
Cellulosics	7.1	3.4	1.7
Rubber	17.4	13.2	11.2
Plastics	49.6	19.1	4.3
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.9	0.9	0.9
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Remote Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-T121	53.4000	0.0000	53.4000
RL-T124	0.8900	0.0000	0.8900
RL-T147	27.5900	0.0000	27.5900
RL-T148	24.0300	0.0000	24.0300
RL-T149	69.4200	0.0000	69.4200
RL-W161	5.3400	0.0000	5.3400
RL-W162	18.6900	0.0000	18.6900
RL-W419	0.0000	67.6400	67.6400
RL-W421	0.0000	28.4800	28.4800
RL-W422	0.0000	224.2800	224.2800
RL-W424	0.0000	1014.6000	1014.6000
RL-W425	0.0000	1183.7000	1183.7000
RL-W428	0.0000	213.6000	213.6000
RL-W430	0.0000	622.1100	622.1100
RL-W431	0.0000	8.9000	8.9000
RL-W433	0.0000	676.4000	676.4000
RL-W435	0.0000	26.7000	26.7000

Site-Specific Remote Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Heterogeneous

Total Volume:	**199.36**	**4066.41**	**4265.77**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	744.8	215.0	60.0
Aluminum Base Metal/Alloys	167.8	31.3	0.0
Other Metal/Alloys	60.0	22.8	0.0
Other Inorganic Materials	95.2	51.1	35.0
Vitrified	0.0	0.0	0.0
Cellulosics	300.1	49.5	0.0
Rubber	67.5	10.9	0.0
Plastics	191.9	43.5	6.0
Solidified Inorganic Material	83.0	15.1	0.0
Solidified Organic Material	31.0	5.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	24.4	5.5	0.0

M

Site-Specific Remote Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-W276	1.7800	0.0000	1.7800
RL-W337	0.8900	60.5200	61.4100
Total Volume:	**2.67**	**60.52**	**63.19**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	66.4	8.8	7.1
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	585.3	577.6	310.4
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	202.7	5.7	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
RL-W420	0.0000	801.0000	801.0000
RL-W423	0.0000	801.0000	801.0000
RL-W426	0.0000	115.7000	115.7000
RL-W427	0.0000	696.8700	696.8700
RL-W429	0.0000	2162.7000	2162.7000
RL-W432	0.0000	35.6000	35.6000
RL-W434	0.0000	2509.8000	2509.8000
RL-W436	0.0000	10277.7198	10277.7198

Site-Specific Remote Handled Waste Profiles

Site Name: Hanford (Richland) Site

Final Waste Form: Uncategorized Metal

Total Volume:	**0.00**	**17400.39**	**17400.39**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	241.0	74.1	0.0
Aluminum Base Metal/Alloys	6.9	0.4	0.0
Other Metal/Alloys	596.0	376.6	0.0
Other Inorganic Materials	52.0	15.5	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	12.7	0.8	0.0
Rubber	1.5	0.0	0.0
Plastics	11.4	0.5	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W198.204	2.3733	0.0000	2.3733
IN-W252.282	17.8000	0.0000	17.8000
IN-W254.1045	1.1867	0.0000	1.1867
Total Volume:	**21.36**	**0.00**	**21.36**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	330.9	9.9	0.0
Other Inorganic Materials	50.3	14.0	3.3
Vitrified	0.0	0.0	0.0
Cellulosics	98.3	4.0	0.0
Rubber	438.7	254.1	0.0
Plastics	71.1	12.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W169.193	17.8000	0.0000	17.8000
IN-W197.197	16.6133	0.0000	16.6133
IN-W283.964	1.1867	0.0000	1.1867
IN-W298.318	8.3067	0.0000	8.3067
IN-W306.635	2.3733	0.0000	2.3733
IN-W349.924	3.5600	0.0000	3.5600

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Heterogeneous

Total Volume:	**49.84**	**0.00**	**49.84**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1146.1	44.4	0.0
Aluminum Base Metal/Alloys	55.9	3.8	0.0
Other Metal/Alloys	163.4	14.9	0.0
Other Inorganic Materials	137.4	19.5	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	572.8	55.2	0.0
Rubber	231.4	18.1	0.0
Plastics	621.9	73.9	0.0
Solidified Inorganic Material	8.9	0.3	0.0
Solidified Organic Material	5.4	0.1	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	3.1	0.2	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Inorganic Non-Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W169.194	1.1867	0.0000	1.1867
IN-W197.198	1.1867	0.0000	1.1867
IN-W198.205	1.1867	0.0000	1.1867
IN-W208.243	1.1867	0.0000	1.1867
IN-W216.876	8.3067	0.0000	8.3067
IN-W228.884	4.7467	0.0000	4.7467
IN-W243.276	3.5600	0.0000	3.5600
IN-W243.277	1.1867	0.0000	1.1867
IN-W245.1035	2.3733	0.0000	2.3733
IN-W247.524	2.3733	0.0000	2.3733
IN-W259.921	7.1200	0.0000	7.1200
IN-W260.567	1.1867	0.0000	1.1867
IN-W296.331	4.7467	0.0000	4.7467
IN-W306.634	1.1867	0.0000	1.1867
IN-W308.621	1.1867	0.0000	1.1867
IN-W349.667	1.1867	0.0000	1.1867
IN-W364.845	1.1867	0.0000	1.1867
IN-W365.843	1.1867	0.0000	1.1867

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Inorganic Non-Metal

Total Volume:	**46.28**	**0.00**	**46.28**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	9.1	0.1	0.0
Other Inorganic Materials	592.8	35.7	0.0
Vitrified	2500.0	2051.3	0.0
Cellulosics	24.8	1.7	0.0
Rubber	6.1	0.1	0.0
Plastics	48.8	2.4	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Lead/Cadmium Metal Waste

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W260.568	3.5600	0.0000	3.5600
Total Volume:	**3.56**	**0.00**	**3.56**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	345.0	115.6	4.7
Aluminum Base Metal/Alloys	43.1	14.2	0.2
Other Metal/Alloys	163.3	128.9	104.7
Other Inorganic Materials	29.2	10.0	0.6
Vitrified	0.0	0.0	0.0
Cellulosics	7.1	3.4	1.7
Rubber	17.4	13.2	11.2
Plastics	49.6	19.1	4.3
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.9	0.9	0.9
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W216.877	43.9067	0.0000	43.9067
IN-W228.886	21.3600	0.0000	21.3600
Total Volume:	**65.27**	**0.00**	**65.27**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	2.3	1.6	0.0
Other Inorganic Materials	71.8	21.5	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.8	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	6.8	5.1	1.5
Solidified Inorganic Material	396.6	262.8	33.9
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	264.4	175.2	22.6
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Solidified Organics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W317.1029	3.5600	0.0000	3.5600
Total Volume:	**3.56**	**0.00**	**3.56**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.9	0.3	0.1
Aluminum Base Metal/Alloys	0.4	0.0	0.0
Other Metal/Alloys	0.1	0.0	0.0
Other Inorganic Materials	220.4	115.4	37.8
Vitrified	0.0	0.0	0.0
Cellulosics	1.0	0.3	0.2
Rubber	0.2	0.0	0.0
Plastics	14.1	6.7	1.1
Solidified Inorganic Material	36.0	20.6	17.0
Solidified Organic Material	808.1	612.2	391.2
Cement (Solidified)	195.7	129.8	75.9
Soils	0.2	0.2	0.2

Site-Specific Remote Handled Waste Profiles

Site Name: Idaho National Engineering Laboratory

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
IN-W228.885	1.1867	0.0000	1.1867
IN-W294.343	9.4933	0.0000	9.4933
IN-W296.330	13.0533	0.0000	13.0533
IN-W358.949	2.3733	0.0000	2.3733
IN-W372.918	4.7467	0.0000	4.7467
Total Volume:	**30.85**	**0.00**	**30.85**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1146.1	81.7	0.0
Aluminum Base Metal/Alloys	33.5	3.7	0.0
Other Metal/Alloys	406.9	124.7	0.0
Other Inorganic Materials	41.5	15.3	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	129.6	7.1	0.0
Rubber	11.5	1.0	0.0
Plastics	104.5	15.8	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Remote Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Combustible

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-TR04	15.1300	48.9500	64.0800
Total Volume:	**15.13**	**48.95**	**64.08**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	265.2	257.7	254.0
Aluminum Base Metal/Alloys	0.4	0.4	0.4
Other Metal/Alloys	89.7	18.8	18.8
Other Inorganic Materials	6.8	6.8	6.8
Vitrified	0.0	0.0	0.0
Cellulosics	68.7	64.0	59.2
Rubber	1.2	1.1	1.0
Plastics	5.7	5.3	4.9
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-TR07	11.5700	0.0000	11.5700
Total Volume:	**11.57**	**0.00**	**11.57**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	822.2	272.6	69.2
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	91.3	30.3	7.7
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

M

Site-Specific Remote Handled Waste Profiles

Site Name: Los Alamos National Laboratory

Final Waste Form: Uncategorized Metal

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
LA-TR05	50.7300	16.0200	66.7500
LA-WR01	2.6700	0.0000	2.6700
LA-WR05	14.2400	33.8200	48.0600
Total Volume:	**67.64**	**49.84**	**117.48**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	822.2	258.0	69.2
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	913.5	296.7	7.7
Other Inorganic Materials	6.8	6.8	6.8
Vitrified	0.0	0.0	0.0
Cellulosics	68.7	1.5	0.0
Rubber	1.2	0.0	0.0
Plastics	5.7	0.1	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Oak Ridge National Laboratory

Final Waste Form: Heterogeneous

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
OR-W040	922.0400	240.3000	1162.3400
OR-W043	425.4200	0.0000	425.4200
OR-W054	84.5500	0.0000	84.5500
Total Volume:	**1432.01**	**240.30**	**1672.31**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	1716.4	96.2	0.0
Aluminum Base Metal/Alloys	1.6	0.0	0.0
Other Metal/Alloys	21.3	0.0	0.0
Other Inorganic Materials	24.0	2.4	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	184.6	80.9	0.0
Rubber	17.9	7.4	0.0
Plastics	149.0	64.9	0.0
Solidified Inorganic Material	0.0	0.0	0.0
Solidified Organic Material	3.0	0.0	0.0
Cement (Solidified)	0.0	0.0	0.0
Soils	0.0	0.0	0.0

Site-Specific Remote Handled Waste Profiles

Site Name: Oak Ridge National Laboratory

Final Waste Form: Solidified Inorganics

Waste Stream ID	Retrievably Stored (m3)	Projected (m3)	Total (m3)
OR-W042	175.3300	0.0000	175.3300
OR-W046	861.5200	206.4800	1068.0000
Total Volume:	**1036.85**	**206.48**	**1243.33**

Waste Material Parameters (kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	0.0	0.0	0.0
Aluminum Base Metal/Alloys	0.0	0.0	0.0
Other Metal/Alloys	0.0	0.0	0.0
Other Inorganic Materials	0.0	0.0	0.0
Vitrified	0.0	0.0	0.0
Cellulosics	0.0	0.0	0.0
Rubber	0.0	0.0	0.0
Plastics	0.0	0.0	0.0
Solidified Inorganic Material	528.9	396.6	173.1
Solidified Organic Material	0.0	0.0	0.0
Cement (Solidified)	528.9	396.6	173.1
Soils	0.0	0.0	0.0

APPENDIX B

M

APPENDIX B

Sandia National Laboratories

Managed and Operated by Sandia Corporation
a Lockheed Martin Company
Albuquerque, New Mexico 87185-1328

date : November 6, 1995

to : R. L. Bisping, DOE/CAO, WOIC 3, MS-560

from : L. C. Sanchez, Org 6342, MS-1328 (505)848-0685

subject : **CH and RH-TRU Waste Parameters Potentially Important in WIPP PA**

A) **Requested PA Data From TWBIR**

Below you will find an updated list of waste material parameters that have been identified as being potentially important to the performance analysis of the WIPP repository. It is requested that these parameters be be supplied in Rev. 2 of the Transuranic Waste Baseline Inventory Report (TWBIR). Itemized below you will find the two categories of requested waste parameter data.

1) **Non-radioactive Materials**
The non-radioactive materials are those which influence gas generation potential and those that are needed for mechanical models which predict waste consolidation and shear strength properties. The list of the non-radioactive materials is shown in Table 1.

2) **Radionuclide**
At this time there are no new requests for additional radionuclide inventory data beyond those previously reported in Rev. 1 of the WTWBIR. If there are significant inventory increases in radionuclides due to special circumstances (such as inclusion of residues to the TRU inventory), sufficient footnote explanations should be supplied.

Table 1. Justification of TWBIR Nonradioactive Waste Parameters.

Waste Parameter	Input Variable in Current PA Models		Input Variable in PA Models Under Development	Input Variable in Possible Future PA Models
	Gas Generation	Mechanical Characteristics		
Iron-Based Metals and Alloys	X	X	X	X
Aluminum-Based Metals and Alloys (a)		X	X	
Other Metals		X		?
Other Inorganics		X		?
Cellulosics	X	X	X	X
Plastics	½ (b)	X	X (d)	X
Rubbers	½ (b)	X	X (e)	X
Solidified Inorganics		X	X	X
Solidified Organics Matrix		X	X	X
Soils (c)		X	?	?

(a) Future model for PA does not include aluminum.
(b) Only one-half of material is assumed to generate gas.
(c) May impact colloids.
(d) As is.
(e) Percentage of material to generate gas is unknown at the present time.

B) Special Request Non-PA Items

Also wanted at this time is additional information for several waste material characteristics. Although these characteristics have not been identified as waste material parameters to be used for WIPP PA, they are needed for non-PA scoping calculations to assess their influence on PA. Since these items are not currently PA parameters, inventory estimates of these characteristics as "additional information" in the TWBIR or supplied outside of the TWBIR via written correspondence. Below you will find an itemized list of these special request items.

1) **Non-radioactive Materials**
Additional information is needed on the five waste material characteristics (see Table 2): 1) vitrified wastes, 2) nitrates (NO_3^-), 3) sulfates (SO_4^{2-}), 4) phosphorus, and 5) cement. Of these waste parameters, the last four are needed for the gas generation modeling. The nitrates and the sulfates are involved in the denitrification and sulfate reduction processes which breakup the cellulosics, while the phosphorus is a nutrient for biodecay of cellulosics. The estimate of the mass quantities of cement in the waste inventory should include both the cement that is contained in the waste as cement itself (due to D&D activities, etc.,) and the cement found in various sludges. Cement consumes CO_2 due to its content of $Ca(OH)_2$. The estimates for this non-radioactive waste constituent need only be "best estimates" at this present time so that non-PA scoping calculations can be made to determine their importance on overall repository performance. (Do not generate upper-bound estimates that are overly conservative.)

2) **Residues**
"Best estimates" are needed for residues, in addition to those already identified at the Rocky Flats Plant (RFP), that have the possibility of being changed from a resource category to a TRU waste category.

3) **Organic Ligands (Chelating Agents)**
"Best estimates", from currently available information, are needed for major water-soluble organic ligands which are under consideration for the actinide source term (see Table 3). If it is not possible to obtain data from major waste generating sites then supply guidance on how a first-order estimate may be made (from existing information such as process knowledge etc.,) so that non-PA scoping calculations can be performed to identify if the presence of these ligands would have any significant impacts. (Do not generate estimates that are overly conservative.) Requested data is for final form "process-level" quantities used in production only for the key sites. If information on the "process-level" values does not exist at the key sites, then "laboratory-scale" values should be used in the requested assessment of the inventory. Should it be determined that more detailed information on organic ligands will be needed, you will be given a specific written request at a future time. This effort should be performed in parallel with the TWBIR. Technical data should be supplied in memorandum form by the end of February 1996 with supporting documentation by the end of March 1996.

Table 2. Justification of Special Request Non-PA Non-Radioactive Waste Materials. (a)

Waste Parameter	Input Variable in Current PA Models		Input Variable in PA Models Under Development	Input Variable in Possible Future PA Models
	Gas Generation	Mechanical Characteristics		
Vitrified (b)		X	?	?
Nitrates (NO_3)	X (c)		X	?
Sulfates (SO_4)	X (c)		X	?
Phosphorus	X (c)		X	?
Cement (d)	X		X	?

(a) Information on these additional waste materials are needed for non-PA scoping calculations for assessment of their importance. These waste characteristics can be reported at the "best estimate" level.
(b) New waste parameter corresponding to treatment, identified by some of the sites, to be anticipated in the future.
(c) Input variable is of concern when predicting the rates of microbial action and is used in currently existing reaction path model, which will not become a baseline PA model.
(d) Any concrete or cement (including dry portland cement) that contains calcium oxide.

Table 3. Justification of Special Request For Info On Organic Complexing Agents. (a)

Ligand (b)	Discussion (c)
1) Total Complexants	The most valuable information at this time is a "best estimate" of the total amount of water soluble complexing agents (ligands) in the TRU waste matrix.
2) Citrate	Preliminary information indicates that citrate (citric acid) may be the largest used ligand at TRU waste generating sites. Hence, inventory quantities are very important.
3) Lactate	This is an important ligand that is produced by bacteria as part of its own metabolism. What is requested here is a "best estimate" of the quantity of lactate that actually exists in the TRU waste matrix (not just an initial amount supplied as part of a waste stream). However, if this information cannot be developed, then supply information on the initial amount.
4) Oxalate	This is an important ligand that is produced by bacteria as part of its own metabolism. What is requested here is a "best estimate" of the quantity of oxalate that actually exists in the TRU waste matrix (not just an initial amount supplied as part of a waste stream). However, if this information cannot be developed, then supply information on the initial amount.
5) EDTA	This ligand (ethylenediaminetetraacetic acid) is also of major importance due to its common use as a cleaning solvent.

(a) Information on these additional waste materials are needed for non-PA scoping calculations for assessment of their importance. The presence of these complexing agents are important for the actinide source term, with respect to increasing the solubility of radionuclides.
(b) These items are ranked in the order of their importance in the actinide source term.
(c) Also supply any available information that TRU waste generation sites may have on the degradation or decay rates of ligands in current (and expected) waste matrixes if possible. In cases where no information is available, supply guidance on estimating first-order quantities.

LCS:6741:lcs/(95-2082)

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APPENDIX B

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File - SWCF-A WBS 1.1.6.2; PA; PBWAC - WIPP ACTIVITY

APPENDIX C

APPENDIX C

TWBIR

DATA REQUIREMENTS

REVISION 8

APRIL 14, 1995

1.1.1 DOE Site Name: _____

2.1.1 Unique HQ WS ID: _____

2.1.2 Site WS ID: _____

2.1.3 Waste Stream Name: _____

2.1.4 PSTP WS ID: _____

2.3 Waste Stream Source

2.3.1 Waste Stream Source Description:

_____
_____
_____
_____

2.3.2 Source Category (choose only one)

- o Pollution Control or Waste Treatment Process
- o Materials Production/Recovery Effluents
- o Facility/Equipment Operation and Maintenance Waste
- o Discarding Excess/Expired Materials
- o Analytical Laboratory Waste
- o R&D/R&D Laboratory Waste
- o Remediation/D&D Waste
- o Spill Clean-ups/Emergency Response Actions
- o Other/Multiple Sources
- o Source Information Not Compiled
- o Source Unknown

M

2.3.3 Name of the site(s) that generated this waste stream: _____

3.1 Waste Stream Description:

_____
_____
_____
_____
_____

3.2.1 Waste Type: o HLW o MTRU o TRU o MLLW o M11e(2)

3.2.2 Contact Handled or Remote Handled: o CH o RH

3.2.6 Radionuclides

Radionuclide	Concentration			Basis
	Typical	Range	Units	(S, P, B or U)

3.4.3 EPA/State Regulated Contaminant List

EPA/ STATE CODE	LDR CODE	CONTAMINANT NAME	CONCENTRATION (Typical or Range)	UNIT	BASIS S/P/B/U	Total or Extract

S = Sampling; P = Process Knowledge; B = Both; U = Unknown

3.4.4 Does this waste stream contain PCB's?
○ Yes ○ No ○ Unknown

3.4.4.1 Is this waste stream subject to TSCA regulations for PCB's?
○ Yes ○ No ○ Unknown

3.4.4.2 If yes, indicate the PCB concentration range (ppm):
○ <50 ○ $50 \leq$ PCB's < 500 ○ ≥ 500 ○ Unknown

3.4.6 Does this waste stream contain asbestos?
○ Yes ○ No ○ Unknown

3.4.6.1 Is this waste stream subject to TSCA or CAA regulations for asbestos?
○ Yes ○ No ○ Unknown

3.4.6.2 If asbestos is known, or believed, to be present, provide details on the condition of the asbestos:

_____
_____
_____
_____

8. WIPP Transuranic Waste Baseline Inventory Report (WTWBIR) Data Requirements

8.1 Provide the WTWBIR WS ID numbers that apply to this MWIR WS:

8.1.1 _____
8.1.2 _____
8.1.3 _____
8.1.4 _____

M

8.2 WTWBIR Level of Information (Repeat this section for each WTWBIR WS ID listed in section 8.1)

8.2.1 WTWBIR WS ID: _____ WTWBIR Waste Stream Name: _____

8.2.2 Unique HQ WS ID: _____ MWIR Waste Stream Name: _____

Waste Stream Difference Comments: _____
_____
_____

8.2.3 Final Waste Form Group (Select the one that best represents the overall waste stream):

____ Combustible
____ Filter
____ Graphite
____ Heterogeneous
____ Inorganic Non-Metal
____ Lead/Cadmium Metal Waste
____ Salt Waste
____ Soils
____ Solidified Inorganics
____ Solidified Organics
____ Uncategorized Metal
____ Unknown

8.2.4 Does this WTWBIR waste stream contain residues?

____ Yes
____ No

8.2.5 What best describes the source of this WTWBIR waste stream (Check only one)?

____ Commercial TRU Waste
____ Defense TRU Waste
____ Non-Defense TRU Waste
____ Unknown

8.2.6 What is the No Migration Variance Petition (NMVP) ID for this WTWBIR waste stream? _____

8.2.7 What TRUCON codes apply to this WTWBIR waste stream?

_____
_____
_____
_____

8.2.8 What final waste form IDC's apply to this WTWBIR waste stream?

_____
_____
_____
_____

8.2.9 Is the information for this WTWBIR waste stream the same as provided for the MWIR waste stream for section 2.3?

____ Yes
____ No

If Yes, go to section 8.2.10
If No, continue

8.2.9.1 Waste Stream Source Description

_____
_____
_____
_____

8.2.9.2 Source Category (choose only one)

____ Pollution Control or Waste Treatment Process
____ Materials Production/Recovery Effluents
____ Facility/Equipment Operation and Maintenance Waste
____ Discarding Excess/Expired Materials
____ Analytical Laboratory Waste
____ R&D/R&D Laboratory Waste
____ Remediation/D&D Waste
____ Spill Clean-ups/Emergency Response Actions
____ Other/Multiple Sources
____ Source Information Not Compiled
____ Source Unknown

8.2.10 Is the information for this WTWBIR waste stream the same as provided for the MWIR waste stream in section 3.4.3?

____ Yes
____ No

If Yes, go to section 8.2.11
If No, continue

M

8.2.10.1 EPA/State Regulated Contaminant List						
EPA/ STATE CODE	LDR CODE	CONTAMINANT NAME	CONCENTRATION (Typical or Range)	UNIT	BASIS S/P/B/U	Total or Extract

S = Sampling; P = Process Knowledge; B = Both; U = Unknown

8.2.11 Does this WTWBIR waste stream contain the following in concentrations greater than 1 wt%?		
Component	Y/N	Estimated Concentration (wt%)
Nitrates		
Sulfates		
Phosphate		

8.2.12 List the container types and sizes that are used/have been used/will be used to store this WTWBIR waste stream (e.g., Drum/55 gal; Box/4 x 4 x 7 ft; box/112 ft3; SWB):		
Current Container Type/Size:	Radionuclides same as 3.2.6? (Y/N)	Comments:

M

8.2.13 Select the container types that will be used to ship the final forms of this WTWBIR waste stream to WIPP (indicate all that apply):		
Container:	(Y/N)	Radionuclides same as 3.2.6? (Y/N)
55 Gallon Drum		
Standard Waste Box		
SWB used to overpack 55 gallon drums		
RH Canister		
RH Canister used to overpack 55 gallon drums		
RH Canister used to overpack 30 gallon drums		

8.2.14 Current Container Information for this WTWBIR waste stream:

8.2.14.1 Current Container Type/Size: _____

8.2.14.1.1 Material of Construction (Check all that apply)?

____ Cement
____ Plastic
____ Steel, Carbon
____ Steel, Galvanized
____ Steel, Stainless
____ Wood
____ Other: _____

8.2.14.1.2 Liner Types (check all that apply):

____ Bag
____ Drum
____ Rigid liner
____ Shielding
____ None

8.2.14.1.3 Liner Material (check all that apply):

____ Cement
____ Fiberboard
____ HDPE
____ Lead
____ None
____ Plastic
____ Steel
____ Wood
____ Other: _____

8.2.14.1.4 Internal Volume (payload volume) per container (M3): ____

NOTE: If the current container type includes several sizes, use the average internal volume of all the sizes (e.g., 55 gal + 30 gal + 70 gal = 52 gal X 0.0038 M3/gal = 0.20 M3).

8.2.14.1.5 Estimated % containers less than 350 lb/container (required only for drums): ____

8.2.14.1.6 Estimated % containers between 350 and 500 lbs/container (required only for drums): ____

8.2.14.1.7 Estimated % of containers with less than 23 Pu-239 Fissile Gram Equivalents (required only for drums): _____

8.2.14.1.8 Estimated % of containers with between 23 and 200 Pu-239 Fissile Gram Equivalents (required only for drums): _____

8.2.14.1.9 Number Currently in storage: _____

8.2.14.1.10 Date of this inventory: _____

8.2.14.1.11 Total Number of these containers projected from date of inventory to end of 2022 (Do not include the current inventory): _____

8.2.14.1.12 Estimated TRU Waste Generation by number of containers:		
WTWBIR WS ID:		
Container Type/Size:		
Year	Number of Containers Projected	Comments
1993	(*)	
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		

2008		
2009		
2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		
2021		
2022		

(*) Indicate 0 if the entire calendar year is included in the "Number Currently in Storage".

8.2.14.1.13 WAC Revision 3 Certifiability

8.2.14.1.13.1 Is all of this current container type/size certifiable to WIPP WAC Revision 3?

____ Yes (100% of the containers are certifiable)
____ No

If Yes, go to section 8.2.14.1.14
If No, continue

8.2.14.1.13.2 What % of these containers are non-certifiable? _____

8.2.14.1.13.3 For containers not certifiable to WIPP WAC Revision 3, is it due to:

8.2.14.1.13.3.1 Repackaging Required?

____ No (repackaging is not required)
____ Yes (repackaging is required)

If No, go to section 8.2.14.1.13.3.2
If Yes, continue

8.2.14.1.13.3.1.1 What % of the non-certifiable containers require repackaging?

____

8.2.14.1.13.3.1.2 WAC repackaging requirement table		
Repackaging Cause:	Y/N	% of Containers affected (0 - 100)
Particulates		
Pu Equivalent		
Nonapproved Container		
Curies/Vol (RH)		
Dose Rates		
Liquids		
Explosives/Pyrophorics		
Surface Contamination		
Other: _____		

8.2.14.1.13.3.2 Treatment Required

____ No (treatment is not required)
____ Yes (treatment is required)

If No, go to section 8.2.14.1.14
If Yes, continue

8.2.14.1.13.3.2.1 What % of the non-certifiable containers require treatment?

____

8.2.14.1.13.3.2.2 WAC treatment requirements table		
Treatment Cause:	Y/N	% of Containers affected (0 - 100)
PCBs		
Corrosives		
Reactives		
Ignitables		
Liquids		
Particulates		
Other: _____		

8.2.14.1.14 TRAMPAC Certifiability

8.2.14.1.14.1 Is all of this current container type/size certifiable to TRAMPAC (shipment to WIPP via TRUPACT-II)?

____ Yes (100% of the containers are certifiable)
____ No

If Yes, go to section 8.2.14.2 or 8.2.15 (as applicable)
If No, continue

8.2.14.1.14.2 What % of these containers are non-certifiable? _____

8.2.14.1.14.3 For containers not certifiable to TRAMPAC (shipment to WIPP via TRUPACT-II) is it due to:

8.2.14.1.14.3.1 Filters/liner vents?

____ No (filters/liner vents not required)
____ Yes (filters/liner vents are required)

If No, go to section 8.2.14.1.14.3.2
If Yes, continue

8.2.14.1.14.3.1.1 What % of the non-certifiable containers require filters/liner vents? ____

8.2.14.1.14.3.2 Repackaging Required?

____ No (repackaging is not required)
____ Yes (repackaging is required)

If No, go to section 8.2.14.1.14.3.3
If Yes, continue

8.2.14.1.14.3.2.1 What % of the non-certifiable containers require repackaging? _____

8.2.14.1.14.3.2.2 TRAMPAC repackaging requirements table		
Repackaging Cause:	Y/N	% of Containers affected (0 - 100)
Watt Limit		
Chemical Compatibility		
Liquids		
Packaging Configuration (*)		
Explosives/Pyrophorics		
Corrosives		
Compressed gases		
VOCs (flammable - 500 ppm limit)		
Dose Rate		
Shielding		
Not in TRUCON		
Nonapproved Container		
Other: _____		

(*) Sealed containers, layers of packaging per TRUCON, etc.

8.2.14.1.14.3.3 Treatment required?

_____ No (treatment is not required)
_____ Yes (treatment is required)

If No, go to section 8.2.14.2 or 8.2.15 (as applicable)
If Yes, continue

8.2.14.1.14.3.3.1 What % of the non-certifiable containers require treatment?

_____

8.2.14.1.14.3.3.2 TRAMPAC treatment requirements table		
Treatment Cause:	Y/N	% of Containers affected (0 - 100)
PCBs		
Corrosives		
Reactives		
Ignitables		
Liquids		
Particulates		
Other: _____		

8.2.14.1.14.3.4 Current Container comments:

_____

_____

_____

8.2.15 Final Waste Form Container information for this WTWBIR waste stream

8.2.15.1 Container Type: The final waste form is or will be packaged in WIPP acceptable 55 Gallon Drums?

____ No (Go to 8.2.15.2)
____ Yes, continue

8.2.15.1.1 *Container Material (Check all that apply):*

____ Steel, Carbon
____ Steel, Galvanized
____ Steel, Stainless
____ *Other:* _____

8.2.15.1.2 Liner Type (Check all that apply):

____ Bag
____ Drum
____ Rigid liner
____ Shielding
____ None

8.2.15.1.3 *Liner Material (Check all that apply):*

____ Cement
____ Fiberboard
____ HDPE
____ Lead
____ None
____ Plastic
____ Steel
____ Wood
____ *Other:* _____

8.2.15.1.4 Internal Volume (payload volume) per Container (M3): 0.208

8.2.15.1.5 Estimated % containers less than 350 lbs/container: ____

8.2.15.1.6 Estimated % containers between 350 and 500 lbs/container: ____

8.2.15.1.7 Estimated % of containers with less than 23 Pu-239 Fissile Gram Equivalents: ____

8.2.15.1.8 Estimated % of containers with between 23 and 200 Pu-239 Fissile Gram Equivalents: ____

8.2.15.1.9 Number Currently in storage: _____

8.2.15.1.10 Date of this inventory: _____

8.2.15.1.11 Total Number of these containers projected from date of inventory to the end of 2022 (Do not include the current inventory): _____

8.2.15.1.12 Comments (55 Gallon Drum):

_____

_____

8.2.15.1.13 Estimated Rates of TRU Waste Generation (Number of Containers)		
WTWBIR WS ID:		
Container Type: 55 Gallon Drum		
Year	Projected Number of Container Type	Comments
1993	(*)	
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		

M

2007		
2008		
2009		
2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		
2021		
2022		

NOTE: (*) Indicate 0 if the entire calendar year is included in the "Number Currently in Storage".

8.2.15.1.14 Typical Waste Material Weights for Final Waste Form (Kg/M3)				
WTWBIR WS ID:				
Container Type: 55 Gallon Drum				
Material Parameters	Average	Lower Limit	Upper Limit	Comment
Iron-Based Metal				
Aluminum-Based Metal				
Other Metal				

Other Inorganic Materials				
Cellulosics				
Rubber				
Plastics				
Solidified, Inorganic Matrix				
Solidified, Organic Matrix				
Soils				
Packaging Material, Steel	131	0	0	
Packaging Material, Plastic	37	0	0	

8.2.15.2 Container Type: The final waste form is or will be packaged in WIPP acceptable Standard Waste Boxes?

____ No (Go to 8.2.15.3)
____ Yes, continue

8.2.15.2.1 Container Material (Check all that apply):

XXXX Steel, Carbon
____ Steel, Galvanized
____ Steel, Stainless
____ Other: _____

8.2.15.2.2 Liner Type (Check all that apply):

____ Bag
____ Drum
____ Rigid liner
____ Shielding
____ None

8.2.15.2.3 Liner Material (Check all that apply):

____ Cement
____ Fiberboard
____ HDPE
____ Lead
____ None
____ Plastic
____ Steel
____ Wood
____ Other: _____

M

8.2.15.2.4 Internal Volume (payload volume) per Container (M3): 1.89

8.2.15.2.5 Number Currently in storage: _____

8.2.15.2.6 Date of this inventory: _____

8.2.15.2.7 Total Number of these containers projected from date of inventory to the end of 2022 (Do not include the current inventory): _____

8.2.15.2.8 Ccomments (Standard Waste Box):

8.2.15.2.9 Estimated Rates of TRU Waste Generation (Number of Containers)		
WTWBIR WS ID:		
Container Type: Standard Waste Box		
Year	Projected Number of Container Type	Comments
1993	(*)	
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		
2008		
2009		

2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		
2021		
2022		

(*) Indicate 0 if the entire calendar year is included in the "Number Currently in Storage".

8.2.15.2.10 Typical Waste Material Weights for Final Waste Form (Kg/M3)				
WTWBIR WS ID:				
Container Type: Standard Waste Box				
Material Parameters	Average	Lower Limit	Upper Limit	Comment
Iron-Based Metal				
Aluminum-Based Metal				
Other Metal				
Other Inorganic Materials				
Cellulosics				
Rubber				

Plastics				
Solidified, Inorganic Matrix				
Solidified, Organic Matrix				
Soils				
Packaging Material, Steel	154	0	0	
Packaging Material, Plastic	1.2	0	0	

M

8.2.15.3 Container Type: The final waste form is or will be packaged in WIPP acceptable Standard Waste Boxes (SWB) used to overpack 55 gallon drums?

____ No (Go to 8.2.15.4)
____ Yes, continue

8.2.15.3.1 Container Material (Check all that apply):

XXXX Steel, Carbon
____ Steel, Galvanized
____ Steel, Stainless
____ Other: _____

8.2.15.3.2 Liner Type (Check all that apply):

____ Bag
____ Drum
____ Rigid liner
____ Shielding
____ None

8.2.15.3.3 Liner Material (Check all that apply):

____ Cement
____ Fiberboard
____ HDPE
____ Lead
____ None
____ Plastic
____ Steel
____ Wood
____ Other: _____

M

8.2.15.3.4 Internal Volume (payload volume) per Container (M3): 1.89

8.2.15.3.5 Number Currently in storage: _____

8.2.15.3.6 Date of this inventory: _____

8.2.15.3.7 Total Number of these containers projected from the date of inventory to the end of 2022 (Do not include the current inventory):

_____

8.2.15.3.8 Comments (SWB used to overpack 55 gallon drums):

8.2.15.3.9 Estimated Rates of TRU Waste Generation (Number of Containers)		
WTWBIR WS ID:		
Container Type: SWB used to overpack 55 gallon drums		
Year	Projected Number of Container Type	Comments
1993	(*)	
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		
2008		

2009		
2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		
2021		
2022		

(*) Indicate 0 if the entire calendar year is included in the "Number Currently in Storage".

8.2.15.3.10 Typical Waste Material Weights for Final Waste Form (Kg/M3)				
WTWBIR WS ID:				
Container Type: SWB used to overpack 55 gallon drums				
Material Parameters	Average	Lower Limit	Upper Limit	Comment
Iron-Based Metal				
Aluminum-Based Metal				
Other Metal				
Other Inorganic Materials				
Cellulosics				

Rubber				
Plastics				
Solidified. Inorganic Matrix				
Solidified. Organic Matrix				
Soils				
Packaging Material. Steel	212	0	0	
Packaging Material. Plastic	17.5	0	0	

M

8.2.15.4 Container Type: The final waste form is or will be packaged in WIPP acceptable RH Canisters?

____ No (Go to 8.2.15.5)
____ Yes, continue

8.2.15.4.1 Container Material (Check all that apply):

XXXX Steel, Carbon
____ Steel, Galvanized
____ Steel, Stainless
____ Other: _____

8.2.15.4.2 Liner Type (Check all that apply):

____ Bag
____ Drum
____ Rigid liner
____ Shielding
____ None

8.2.15.4.3 Liner Material (Check all that apply):

____ Cement
____ Fiberboard
____ HDPE
____ Lead
____ None
____ Plastic
____ Steel
____ Wood
____ Other: _____

M

8.2.15.4.4 Internal Volume (payload volume) per Container (M3): 0.89

8.2.15.4.5 Number Currently in storage: _____

8.2.15.4.6 Date of this inventory: _____

8.2.15.4.7 Total Number of these containers projected from date of inventory to the end of 2022 (Do not include the current inventory): _____

8.2.15.4.8 Comments (RH Canister):

8.2.15.4.9 Estimated Rates of TRU Waste Generation (Number of Containers)		
WTWBIR WS ID:		
Container Type: RH Canister		
Year	Projected Number of Container Type	Comments
1993	(*)	
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		
2008		
2009		

2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		
2021		
2022		

(*) indicate 0 if the entire calendar year is included in the "Number Currently in Storage".

8.2.15.4.10 Typical Waste Material Weights for Final Waste Form (Kg/M3)				
WTWBIR WS ID:				
Container Type: RH Canister				
Material Parameters	Average	Lower Limit	Upper Limit	Comment
Iron-Based Metal				
Aluminum-Based Metal				
Other Metal				
Other Inorganic Materials				
Cellulosics				
Rubber				

Plastics				
Solidified, Inorganic Matrix				
Solidified, Organic Matrix				
Soils				
Packaging Material, Steel	435	0	0	
Packaging Material, Plastic	0	0	0	

M

8.2.15.5 Container Type: The final waste form is or will be packaged in WIPP acceptable RH Canisters used to overpack 55 gallon drums?

____ No (Go to 8.2.15.6)
____ Yes, continue

8.2.15.5.1 Container Material (Check all that apply):

XXXX Steel, Carbon
____ Steel, Galvanized
____ Steel, Stainless
____ Other: _____

8.2.15.5.2 Liner Type (Check all that apply):

____ Bag
____ Drum
____ Rigid liner
____ Shielding
____ None

8.2.15.5.3 Liner Material (Check all that apply):

____ Cement
____ Fiberboard
____ HDPE
____ Lead
____ None
____ Plastic
____ Steel
____ Wood
____ Other: _____

M

8.2.15.5.4 Internal Volume (payload volume) per Container (M3): 0.89

8.2.15.5.5 Number Currently in storage: _____

8.2.15.5.6 Date of this inventory: _____

8.2.15.5.7 Total Number of these containers projected from the date of inventory to the end of 2022 (Do not include the current inventory):

_____

8.2.15.5.8 Comments (RH Canisters used to overpack 55 gallon drums):

8.2.15.5.9 Estimated Rates of TRU Waste Generation (Number of Containers)		
WTWBIR WS ID:		
Container Type: RH Canister used to overpack 55 Gallon drums		
Year	Projected Number of Container Type	Comments
1993	(*)	
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		
2008		

2009		
2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		
2021		
2022		

(*) Indicate 0 if the entire calendar year is included in the "Number Currently in Storage".

8.2.15.5.10 Typical Waste Material Weights for Final Waste Form (Kg/M3)				
WTWBIR WS ID:				
Container Type: RH canister used to overpack 55 gallon drums				
Material Parameters	Average	Lower Limit	Upper Limit	Comment
Iron-Based Metal				
Aluminum-Based Metal				
Other Metal				
Other Inorganic Materials				
Cellulosics				

Rubber				
Plastics				
Solidified, Inorganic Matrix				
Solidified, Organic Matrix				
Soils				
Packaging Material, Steel	527	0	0	
Packaging Material, Plastic	26	0	0	

8.2.15.6 Container Type: The final waste form is or will be packaged in WIPP acceptable RH Canisters used to overpack 30 gallon drums?

____ No (Go to 8.3 if applicable)
____ Yes, continue

8.2.15.6.1 Container Material (Check all that apply):

XXXX Steel, Carbon
____ Steel, Galvanized
____ Steel, Stainless
____ Other: _____

8.2.15.6.2 Liner Type (Check all that apply):

____ Bag
____ Drum
____ Rigid liner
____ Shielding
____ None

8.2.15.6.3 Liner Material (Check all that apply):

____ Cement
____ Fiberboard
____ HDPE
____ Lead
____ None
____ Plastic
____ Steel
____ Wood
____ Other: _____

M

8.2.15.6.4 Internal Volume (payload volume) per Container (M3): 0.89

8.2.15.6.5 Number Currently in storage: _____

8.2.15.6.6 Date of this inventory: _____

8.2.15.6.7 Total Number of these containers projected from date of inventory to the end of 2022 (Do not include the current inventory): _____

8.2.15.6.8 Comments (RH Canisters used to overpack 30 gallon drums):

8.2.15.6.9 Estimated Rates of TRU Waste Generation (Number of Containers)		
WTWBIR WS ID:		
Container Type: RH Canister used to overpack 30 gallon drums		
Year	Projected Number of Container Type	Comments
1993	(*)	
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		
2008		

2009		
2010		
2011		
2012		
2013		
2014		
2015		
2016		
2017		
2018		
2019		
2020		
2021		
2022		

(*) Indicate 0 if the entire calendar year is included in the "Number Currently in Storage".

8.2.15.6.10 Typical Waste Material Weights for Final Waste Form (Kg/M3)				
WTWBIR WS ID:				
Container Type: RH Canister used to overpack 30 gallon drums				
Material Parameters	Average	Lower Limit	Upper Limit	Comment
Iron-Based Metal				
Aluminum-Based Metal				
Other Metal				
Other Inorganic Materials				
Cellulosics				

Rubber				
Plastics				
Solidified, Inorganic Matrix				
Solidified, Organic Matrix				
Soils				
Packaging Material, Steel	485	0	0	
Packaging Material, Plastic	14	0	0	

DOE/CAO-95-1121
December 1995

3/13/95

WTWBIR DATA ENTRY INSTRUCTIONS FOR SECTION 8: MIXED AND NON MIXED TRU WASTE DATA

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WTWBIR Data Entry Instructions

8. WIPP Transuranic Waste Baseline Inventory Report (WTWBIR) Data Requirements

General Instructions: This section should be completed for all mixed and non mixed TRU waste streams. If the site includes additional information in the comment entry for this section, list the question number in the section to which the comment applies in the comment section.

8. 1 Provide the WTWBIR WS ID numbers that apply to this MWIR WS:

Provide the applicable WTWBIR WS ID number for the waste stream. These should be the same numbers used in WTWBIR revision 1, unless the site has divided the streams to better comply with WIPP requirements or this is a stream not included in WTWBIR revision 1. There may be more than one WTWBIR stream for each MWIR stream and section 8.2 must be filled out for each WTWBIR stream. If a WTWBIR waste stream is deleted, please indicate the reason for the deletion in the data submittal.

8.2 WTWBIR Level of Information (Repeat this section for each WTWBIR WS ID listed in section 8.1)

8.2.1 Provide the WTWBIR WS ID for the waste stream data to be entered in the following sections.

8.2.2 Provide the applicable MWIR ID. The comment field should be used to describe the difference between the MWIR stream and the WTWBIR stream. If applicable, describe how the MWIR stream is subdivided.

8.2.3 Check the Final Waste Form Group that best describes the final form of this waste stream as it will arrive at WIPP. These groups are broad and it should be possible to check one of the groups other than "Unknown". Do not check "Unknown" unless it is justifiable. The choice for the Final Waste Form Group should be based on the new MWIR treatability guidance that was just published. A table showing a match between treatability groups and final waste form groups is attached to these instructions.

8.2.4 Check yes or no. residues are quantities of plutonium or plutonium contaminated material which are or have been previously defined as containing economically recoverable plutonium. Unless the materials are officially defined as residues, "No" should be checked.

8.2.5 Check one of the selections. If unknown is selected, provide additional information in the comments section. The additional information should describe why the source of the waste is unknown. Only on source can be checked. If the waste originates from more than one source, the waste stream must be divided into two or more waste streams.

8.2.6 List the NMVP ID. If this waste did not appear in the NMVP, leave blank.

8.2.7 List the applicable TRUCON codes. Only list TRUCON codes that have been officially assigned through the appropriate WIPP procedures and appear in revision 6 of TRUCON.

8.2.8 List the IDCs or other site identifiers for this waste stream that apply to the waste form as it will be received by the WIPP.

8.2.9 & 8.2.10 Complete these questions for this specific WTWBIR WS ID stream if it differs from that provided in the MWIR section of the report. The instructions for these questions are the same as provided for the referenced MWIR sections except for the following additions and clarifications.

The answer to 8.2.9.1 should describe the processes producing the waste, the inputs and outputs for the processes and the buildings or areas which generated the waste. This description should include all major inputs into the process, any reactions that changed materials in the process and any additions to the waste stream which resulted in the final waste form. Unless further treatment is planned before shipment to WIPP, The description should be consistent with the Final Waste Form Group in section 8.2.3 and the distribution of waste material parameters to be provided in section 8.2.15.3.10.

Information in addition to that requested in the MWIR section is being requested by WIPP for Table 8.2.10.1. List all the RCRA Appendix VIII contaminants which occur in this waste stream. These additional entries should be entered without an EPA code. Provide state codes, if applicable, for the Appendix VIII constituents.

8.2.11 Provide estimates for the specified components in the waste stream. If the answer in the Y/N column is Y, but no estimated concentration can be provided, describe the source of the component and the reason for the unknown estimated concentration.

8.2.12 List the container types/sizes in which the waste is currently stored or in which the waste will be stored as it is generated in the future. This table defines those containers for which additional information will be requested in section 8.2.14. List all waste containers whether in final form containers that comply with WIPP WAC revision 3 and the TRAMPAC or non compliant containers in this table. Final form containers are also to be indicated in section 8.2.13. This table should also include TRU wastes which are not planned to be sent to WIPP.

Indicate in the second column whether the radionuclide information for the container is the same as provided in section 3.2.6 for the MWIR. If the entry is "Y", WIPP will use the information provided in section 3.2.6. If the entry is "N", describe the difference in the comment field. If the isotopic distribution is the same but the concentration is different, provide the value by which to multiply the concentrations in section 3.2.6 to obtain the concentrations for this container in the comment field. If the isotopic distributions are different, so indicate in the comment field and provide a table, similar to the table in section 3.2.6, but in paper form, for the container type and WTWBIR WS ID.

8.2.13 Indicate in the Y/N column the container types/sizes in which this waste will arrive at WIPP. Only containers currently approved by WIPP are permitted. This table defines those containers for which additional information will be requested in section 8.2.15. All waste in this stream that is planned for disposition at WIPP should be included in this table and section 8.2.15. The site should estimate the number and type of containers required for the non WIPP compliant wastes listed in 8.2.12 that are destined for WIPP.

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Indicate in the third column whether the radionuclide information for the container is the same as provided in section 3.2.6 for the MWIR. If the entry is "Y", WIPP will use the information provided in section 3.2.6. If the entry is "N", describe the difference in the comment fields in sections 8.2.15.1.12 or 8.2.15.2 - 6.8 where additional container data is requested. If the isotopic distribution is the same but the concentration is different, provide the value by which to multiply the concentrations in section 3.2.6 to obtain the concentrations for this container in the comment field. If the isotopic distributions are different, so indicate in the comment field and provide a table, similar to the table in section 3.2.6, but in paper form, for the container type and WTWBIR WS ID.

Sections 8.2.14 and 8.2.15 ask for information by container type. Non WIPP compliant and WIPP compliant waste is placed in section 8.2.14 and WIPP compliant wastes only are placed in 8.2.15. All waste planned for disposition at WIPP should be included in both sections 8.2.14 and 8.2.15. WIPP compliant is defined as compliance with WIPP WAC revision 3 and the TRAMPAC.

Information for sections 8.2.14 and 8.2.15 is to be provided for each container indicated in sections 8.2.12 and 8.2.13 respectively.

8.2.14 Current Container Information for this WTWBIR waste stream:

This section requests information for the waste in the current or planned packaging. The same waste which appears in this section will appear in 8.2.15 in WIPP compliant form and packaging based on site plans or estimates.

WIPP would prefer that a separate section 8.2.14.x (where x represents separate package type defined by 1, 2, etc.) be completed for each type and size of package. To accommodate situations where this is not appropriate, multiple answers are permitted for some questions.

8.2.14.1 Provide the standard descriptive title for the container used by the generator/storage site. For example, 55 gallon drum, steel box, 4X4X7 wooden box, etc.

8.2.14.1.1 Indicate all the materials used to construct the containers. Enter a material in the Other field, if a specific material is not listed.

8.2.14.1.2 Provide the internal volume of the container in cubic meters. This is the maximum amount of waste that will fit into the container. If this stream includes containers of different sizes enter an average volume and state that the volume is an average of the different containers in the comment entry for this section (8.2.14.x.14.3.4; x = 1, 2, 3, etc.). Generally enter the volume of the container, such as a drum, even if the drum is only partially full. In other circumstances, such as partially full tanks, enter the actual or average volume of the waste in the tanks. Describe these situations in the comment field.

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WIPP will use this volume and the number of containers to calculate the volume of this waste stream. If there is some additional information that WIPP requires to do this accurately, provide the information in the comment field 8.2.14.x.14.3.4.

8.2.14.1.3 Check each liner type that is used in this waste stream. Check shielding, if internal shielding such as lead or concrete is used with these containers. If only some containers include internal shielding or liners, describe the approximate percent of containers which include internal shielding or liners in the comment section (8.2.14.x.14.3.4).

8.2.14.1.4 Check all the liner (or shielding materials) used in the containers. If a liner material is not listed, enter the liner material in the other field.

8.2.14.5 - 8.2.14.8 These questions are included to support WIPP transportation planning activities. These questions apply only to drums. The site should provide their best estimates for the answers to these questions. The comment section can be used to add qualifications or additional information, if desired.

8.2.14.1.9 Provide the number of containers that the site includes in storage. The date of this inventory should be provided in 8.2.14.1.10.

8.2.14.1.10 Provide the date for the inventory provided in 8.2.14.1.9. WIPP strongly prefers that all sites use 12/31/94 as the inventory date so that the inventory data can be legitimately rolled up between sites.

8.2.14.1.11 Provide the number of containers projected from the date in 8.2.14.1.10 through 2022.

8.2.14.1.12 Estimate the number of containers to be generated per year. The first few entries (for 1993, 1994, etc.) should not include containers included in section 8.2.14.1.9. The entries should be the projected number of containers to be generated that year. These entries should add up to the number provided in section 8.2.14.1.11. WIPP will use the volume provided in 8.2.14.1.2 and the number of containers provided here to calculate volumes. If WIPP needs additional information to do this accurately, please provide this information in the comment section 8.2.15.1.15.

The next sections ask about compliance with the WIPP WAC revision 3 and the TRAMPAC.

8.2.14.1.13 This section contains questions about the certifiability of the current containers based on WAC revision 3. The sites should provide their best estimates on a waste stream basis. Qualifications or additional information may be provided in the comments section. Additional instructions are provided only when deemed necessary. Those questions such as 8.2.14.1.13.1 and 8.2.14.1.13.3.1 which ask

whether the containers do not meet some WAC requirement should be answered yes if this is true for all or only a portion of the waste stream. Additional questions will request an estimate of the percent of containers affected.

8.2.14.1.14 This section contains questions about compliance with TRAMPAC. The same instructions provided above for 8.2.14.1.13 apply to this section.

8.2.14.1.14.3.4 Provide any comments or additional information in this field for this container type.

8.2.15 Final Waste Form Container information for this WTWBIR waste stream

This section requests information for all the waste in WIPP compliant form. If the wastes as listed in 8.2.14, do not comply with WIPP WAC revision 3 and the TRAMPAC, the waste should be entered here in site estimated WIPP compliant form and packaging. All wastes, planned for disposition at WIPP, should be placed in 8.2.15. WIPP will use the data in this section to estimate the eventual WIPP inventory.

A separate section is provided for each type of container currently acceptable at WIPP. Containers are not allowed to be mixed in this section. The different container sections are identified by number as 8.2.15.x, where x is 1, 2, 3, etc.

For waste reported in section 8.2.14 for which the site does not have plans or schedules for putting the waste in WIPP compliant form and WIPP acceptable containers, the site should estimate the WIPP compliant form and WIPP acceptable containers to be used and should place the waste in the same years used in sections 8.2.14.1.9 -12.

8.2.15.1 The container description requested is provided by the electronic form. Section 8.2.15.1 is the 55 gallon drum, section 8.2.15.2 is the Standard Waste Box, etc.

8.2.15.1.1 Indicate all the materials used to construct the containers. Enter a material in the "other" field, if a material is not listed.

8.2.15.1.2 The requested internal volume is provided by the electronic form.

8.2.15.1.3 Check each liner type that is used in this waste stream. Check shielding, if internal shielding such as lead or concrete is used with these containers. If only some containers include internal shielding or liners, describe the approximate percent of containers which include internal shielding or liners in the comment section (8.2.15.1.12).

8.2.15.1.4 Check all the liner (or shielding materials) used in the containers. If a liner material is not listed, enter the liner material in the other field.

8.2.15.1.5 - 8.2.15.1.8 These questions are included to support WIPP transportation planning activities. These questions apply only to drums. The site should provide their best estimates for the answers

to these questions. The comment section (8.2.15.1.12) can be used to add qualifications or additional information, if desired. These questions are not included in sections 8.2.15.2 - 6.

8.2.15.1.9 Provide the number of containers that the site includes in storage. The date of this inventory should be provided in section 8.2.15.1.10.

8.2.15.1.10 Provide the date for the inventory provided in section 8.2.15.1.9. WIPP strongly prefers that all sites use 12/31/94 as the inventory date so that the inventory data can be legitimately rolled up between sites.

8.2.15.1.11 Provide the number of containers projected from the date in 8.2.15.1.10 through 2022.

8.2.15.1.12 Provide any comments or additional information in this field.

8.2.15.1.13 Estimate the number of containers to be generated per year. The first few entries (for 1993, 1994, etc.) should not include containers included in section 8.2.15.1.9. The entries should be the projected number of containers to be generated that year. These entries should add up to the number provided in section 8.2.15.1.11. WIPP will use the volume provided in 8.2.15.1.2 and the number of containers provided here to calculate volumes. If WIPP needs additional information to do this accurately, please provide this information in the comment section 8.2.15.1.12.

8.2.15.1.14 Provide estimates of the physical materials in the waste. The information is requested for an average, a lower limit and an upper limit in kilograms per cubic meter for broad categories of materials. Comment space is provided for qualifications or additional information. Please provide a list of materials (in decreasing order of appearance, if possible) in the comment field for the materials Other Metal, Other Inorganic Materials, Solidified Inorganic Matrix and Solidified Organic Matrix. Note that the fields for iron based metal and plastic do not include the outer container and the rigid liner and or liner bags. For instance, they do not include the 55 gallon drum and the rigid and/or bag liners or the SWB and the plastic liner. The container and rigid and/or bag liner information is placed only in the fields for packaging material, steel and packaging material, plastic. Note that all data is requested in kilograms per cubic meter and not in weight per container. The volume to use for these calculations is the volume in 8.2.15.1.2.

Sections 8.2.15.2 - 6

These sections are slightly different from section 8.2.15.1 because they do not include sections 8.2.15.1.5 - 8. Otherwise the questions are the same. Section 8.2.15.2 instructions are provided below:

Sections 8.2.15.2.1 -4 instructions are the same as for sections 8.2.15.1.1-4. The comment field in sections 8.2.15.2-6 is in section 8.2.15.x.8 instead of 8.2.15.1.12.

The rest of the section 8.2.15.2 instructions are the same as equivalent section 8.2.15.1 questions but the numbering is different and the instructions are presented below:

8.2.15.2.5 Provide the number of containers that the site includes in storage. The date of this inventory should be provided in section 8.2.15.2.6.

8.2.15.2.6 Provide the date for the inventory provided in section 8.2.15.2.5. WIPP strongly prefers that all sites use 12/31/94 as the inventory date so that the inventory data can be legitimately rolled up between sites.

8.2.15.2.7 Provide the number of containers projected from the date in 8.2.15.2.6 through 2022.

8.2.15.2.8 Provide any comments or additional information in this field.

8.2.15.2.9 Estimate the number of containers to be generated per year. The first few entries (for 1993, 1994, etc.) should not include containers included in section 8.2.15.1.5. The entries should be the projected number of containers to be generated that year. These entries should add up to the number provided in section 8.2.15.1.7. WIPP will use the volume provided in 8.2.15.2.2 and the number of containers provided here to calculate volumes. If WIPP needs additional information to do this accurately, please provide this information in the comment section 8.2.15.1.8.

8.2.15.1.10 Provide estimates of the physical materials in the waste. The information is requested for an average, a lower limit and an upper limit in kilograms per cubic meter for broad categories of materials. Comment space is provided for qualifications or additional information. Please provide a list of materials (in decreasing order of appearance, if possible) in the comment field for the materials Other Metal, Other Inorganic Materials, Solidified Inorganic Matrix and Solidified Organic Matrix. Note that the fields for iron based

metal and plastic do not include the outer container and the rigid liner and or liner bags. For instance, they do not include the 55 gallon drum and the rigid and/or bag liners or the SWB and the plastic liner. The container and rigid and/or bag liner information is placed only in the fields for packaging material, steel and packaging material, plastic. Note that all data is requested in kilograms per cubic meter and not in weight per container. The volume to use for these calculations is the volume in 8.2.15.2.2.

APPENDIX D

SITE-SPECIFIC STORED RADIONUCLIDE INVENTORIES

CH Curies on a Site-by-Site[1,2] Basis
(Decayed to the End of 1995)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Ac225			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Ac227		1.98E-15	4.09E-14	1.02E-04	3.86E-02	1.35E-19
Ac228			2.87E-18	5.60E-02	3.08E-01	1.69E-19
Ag109M						
Ag110				5.08E-10	3.55E-09	
Ag110M				3.82E-08	2.67E-07	
Am241			5.19E-01	4.73E+03	9.01E+04	9.17E-02
Am243				9.01E-02	3.79E-01	3.85E-02
Am245					1.12E-09	3.60E-14
At217			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Ba137M				6.46E+02	5.71E+01	
Bi210	5.22E-15		2.05E-15	5.30E-06	2.70E-02	8.96E-03
Bi211		1.98E-15	4.09E-14	1.02E-04	3.87E-02	1.35E-19
Bi212			1.10E-18	5.18E-02	2.62E+01	8.59E-20
Bi213			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Bi214	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Bk249					7.70E-05	2.48E-09
Bk250						8.68E-08

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
C14				1.60E+00	1.66E-01	
Cd109						
Cd113M				1.25E-09	3.20E-08	
Ce144				4.42E-03	3.15E-02	
Cf249					1.02E-02	3.10E-03
Cf250						1.97E-04
Cf251						
Cf252				3.52E+01	2.19E-03	
Cm242					2.73E-08	
Cm243				1.52E-02		
Cm244				6.83E+01	4.93E+02	8.70E-02
Cm245				1.68E+01	9.09E-06	2.27E-06
Cm246					1.53E-03	4.83E-07
Cm247						
Cm248				7.82E-03	4.73E-07	
Co58					1.22E-14	
Co60					6.24E+01	
Cs134				2.45E-04	1.20E-03	
Cs135				1.91E-07	8.07E-06	
Cs137				6.83E+02	6.04E+01	
Es254						8.67E-08
Eu150					3.50E-05	

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]*Data include undecayed curies from the RFETS residues from the following radioinuclides:* 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Eu152				7.34E-07	1.62E-01	
Eu154				6.22E-05	6.43E-01	
Eu155				1.06E-03	3.83E-01	
Fe55					1.91E-05	
Fe59					3.38E-21	
Fr221			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Fr223		2.73E-17	5.64E-16	1.41E-06	5.33E-04	1.86E-21
H3					8.01E-01	
I129						
Kr85						
Mn54					8.51E-04	
Nb95				1.80E-11	2.38E-09	
Nb95M				6.00E-14	7.95E-12	
Ni59						
Ni63					9.06E-05	
Np237			9.49E-07	2.72E-01	8.53E-01	6.32E-06
Np239				9.01E-02	3.79E-01	3.85E-02
Np240M				5.80E-10	3.50E-14	
Pa231		1.88E-13	6.73E-13	4.83E-04	1.33E-05	1.99E-18
Pa233			9.49E-07	2.72E-01	8.53E-01	6.32E-06
Pa234			6.06E-17	7.61E-03	1.50E-04	2.40E-14
Pa234M			4.66E-14	5.86E+00	1.16E-01	1.84E-11

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Pb209			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Pb210	5.22E-15		2.05E-15	5.30E-06	2.70E-02	8.96E-03
Pb211		1.98E-15	4.09E-14	1.02E-04	3.87E-02	1.35E-19
Pb212			1.10E-18	5.18E-02	2.62E+01	8.59E-20
Pb214	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Pd107				2.82E-08	1.19E-06	
Pm147				4.78E-02	2.62E+00	
Po210	1.42E-15		2.05E-15	5.30E-06	2.70E-02	8.96E-03
Po211		5.53E-18	1.14E-16	2.87E-07	1.08E-04	3.78E-22
Po212			7.04E-19	3.32E-02	1.68E+01	5.50E-20
Po213	4.28E-15		2.19E-15	1.28E-01	1.49E+00	5.33E-06
Po214	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Po215		1.98E-15	4.09E-14	1.02E-04	3.87E-02	1.35E-19
Po216			1.10E-18	5.18E-02	2.62E+01	8.59E-20
Po218	6.86E-13	1.40E-11	4.56E-14	3.15E-05	4.80E-02	3.37E-02
Pr144				4.36E-03	3.12E-02	
Pu236					1.04E-02	
Pu238	3.70E+02		1.11E-01	8.05E+04	5.98E+04	2.32E-04
Pu239		1.80E+01	1.79E+00	2.63E+04	4.01E+04	8.45E-06
Pu240			6.12E-01	6.14E+03	9.84E+03	5.14E-03
Pu241			6.22E+00	3.78E+04	1.50E+05	4.48E-07
Pu242			5.00E-05	3.80E-01	9.45E-01	1.01E-02

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Pu243						
Pu244				5.80E-10	3.50E-14	
Ra223		1.98E-15	4.09E-14	1.02E-04	3.87E-02	1.35E-19
Ra224			1.10E-18	5.18E-02	2.62E+01	8.59E-20
Ra225			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Ra226	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Ra228			2.87E-18	5.60E-02	3.08E-01	1.69E-19
Rh106				2.17E-03	1.12E-02	
Rn219		1.98E-15	4.09E-14	1.02E-04	3.87E-02	1.35E-19
Rn220			1.10E-18	5.18E-02	2.62E+01	8.59E-20
Rn222	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Ru106				2.17E-03	1.12E-02	
Sb125				5.91E-04	3.53E-03	
Sb126				5.13E-08	2.17E-06	
Sb126M				3.67E-07	1.55E-05	
Se79				1.66E-07	7.00E-06	
Sm151				6.14E-04	2.39E-02	
Sn119M				2.95E-07	2.10E-06	
Sn121M				1.20E-05	4.38E-04	
Sn126				3.67E-07	1.55E-05	
Sr90			2.00E-01	6.92E+02	1.96E+00	
Tc99				9.51E-06	2.16E-03	

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Te125M				1.44E-04	8.62E-04	
Te127				3.95E-09	1.02E-07	
Te127M				4.03E-09	1.04E-07	
Th227		1.95E-15	4.03E-14	1.01E-04	3.82E-02	1.33E-19
Th228			1.10E-18	5.18E-02	2.62E+01	8.59E-20
Th229			2.23E-15	1.31E-01	1.52E+00	5.75E-06
Th230	4.75E-09		5.25E-11	8.11E-03	2.08E-02	1.50E-13
Th231		1.77E-08	1.06E-08	1.71E+00	6.18E-02	3.32E-14
Th232			1.61E-17	6.71E-02	3.30E-01	5.33E-19
Th234			4.66E-14	5.86E+00	1.16E-01	1.84E-11
Tl207		1.97E-15	4.07E-14	1.02E-04	3.86E-02	1.34E-19
Tl208			3.95E-19	1.86E-02	9.42E+00	3.09E-20
Tl209			4.83E-17	2.82E-03	3.28E-02	1.18E-07
U232					2.53E+01	
U233			1.20E-11	8.00E+01	8.99E+02	4.81E-03
U234	1.05E-03		1.93E-06	5.37E+01	6.18E+00	4.73E-09
U235		1.77E-08	1.06E-08	1.71E+00	6.18E-02	3.32E-14
U236			1.09E-07	2.49E-03	5.27E-03	1.87E-09
U237			1.53E-04	9.27E-01	3.67E+00	1.10E-11
U238			4.66E-14	5.86E+00	1.16E-01	1.84E-11
U240				5.80E-10	3.50E-14	
Y90			2.00E-01	6.92E+02	1.96E+00	

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Zn65					1.51E-09	
Total by Site	**3.70E+02**	**1.80E+01**	**9.65E+00**	**1.58E+05**	**3.52E+05**	**5.08E-01**

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Ac225	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Ac227	2.31E-01	3.32E-10	2.99E-12	2.41E-14	2.10E-04	9.85E-03
Ac228	1.59E-03	1.59E-16			1.90E-16	7.11E-04
Ag109M	6.56E+00					
Ag110	2.87E-11	6.12E-17			5.55E-11	
Ag110M	3.06E-07				4.18E-09	
Am241	1.17E+04	1.44E+02		3.24E-01	2.84E+02	1.61E+03
Am243	3.83E+00	2.45E-02			1.22E+00	1.16E+01
Am245	1.95E-15				5.29E-14	1.49E-10
At217	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Ba137M	4.55E+01	1.57E-06			3.41E-01	2.20E+03
Bi210	2.80E-01	2.38E-13	5.20E-10		6.69E-02	1.26E+00
Bi211	2.32E-01	3.32E-10	2.99E-12	1.83E-17	2.09E-04	9.85E-03
Bi212	1.32E-03	6.13E-17			1.64E-02	2.83E-01
Bi213	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Bi214	9.04E-01	9.47E-12	4.46E-09	1.94E-22	2.49E-01	6.49E+00
Bk249	1.35E-10				3.65E-09	1.03E-05

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Bk250					4.11E-11	9.51E-13
C14	2.00E-07				2.50E-04	
Cd109	6.55E+00					
Cd113M	7.41E-07				6.50E-09	1.03E-08
Ce144	3.03E-04				7.88E-04	
Cf249	9.64E-04				1.14E-02	2.82E-02
Cf250					3.18E-01	1.49E-03
Cf251	1.58E-03					
Cf252					1.70E-02	1.60E-01
Cm242	3.42E-17	1.70E-04				1.39E-03
Cm243	1.11E+00					
Cm244	1.56E+02	6.54E+01			2.28E+02	1.06E+03
Cm245	1.60E-06				9.44E-06	3.35E-05
Cm246	4.01E-02	5.22E-04			6.14E-04	1.60E-05
Cm247	1.34E-09					
Cm248	2.53E-10				3.57E-06	2.55E-02
Co58	1.22E-13					
Co60	7.91E-06					1.84E-06
Cs134	4.24E-03				4.03E-04	
Cs135	2.05E-04				1.20E-06	
Cs137	4.81E+01	1.66E-06			3.60E-01	2.33E+03
Es254					4.11E-11	

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Eu150						
Eu152	4.18E-04	1.33E-06			1.06E+00	6.18E-04
Eu154	2.45E-02	5.25E-07			4.28E-01	
Eu155	2.41E-01				3.80E-03	
Fe55						
Fe59	1.35E-16					1.87E-07
Fr221	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Fr223	3.19E-03	4.58E-12	5.08E-14	2.52E-19	2.89E-06	1.36E-04
H3					6.46E-02	
I129						
Kr85					1.96E-01	
Mn54	5.48E-08					
Nb95	1.76E-11				1.51E-17	
Nb95M	5.89E-14				5.05E-20	
Ni59						
Ni63						1.09E-04
Np237	3.22E-02	4.71E-04		2.28E-04	5.78E-03	7.27E-01
Np239	3.83E+00	2.45E-02			1.22E+00	1.49E+01
Np240M	1.94E-07				9.99E-07	1.10E-09
Pa231	1.24E-03	2.72E-07	1.89E-11	8.97E-16	5.00E-04	3.14E-01
Pa233	3.22E-02	4.71E-04		2.28E-04	5.78E-03	7.32E-01
Pa234	3.07E-05	3.94E-05		1.51E-10	2.13E-07	5.53E-05

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Pa234M	2.38E-02	3.03E-02		1.16E-07	3.46E-04	4.26E-02
Pb209	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Pb210	2.80E-01	2.38E-13	5.20E-10		6.69E-02	1.26E+00
Pb211	2.32E-01	3.32E-10	2.99E-12	1.83E-17	2.09E-04	9.85E-03
Pb212	6.16E-03	6.13E-17			1.64E-02	2.83E-01
Pb214	9.04E-01	9.47E-12	4.46E-09	1.94E-22	2.49E-01	6.49E+00
Pd107	3.03E-05				1.78E-07	
Pm147	2.00E+00				1.05E-01	1.94E-02
Po210	2.80E-01	1.97E-13	5.20E-10		6.69E-02	1.26E+00
Po211	6.50E-04	9.28E-13	8.38E-15	5.12E-20	5.86E-07	2.76E-05
Po212	8.48E-04	3.93E-17			1.05E-02	1.82E-01
Po213	7.89E-02	9.60E-13		1.55E-13	2.36E-03	2.02E-01
Po214	9.04E-01	9.47E-12	4.46E-09	1.93E-22	2.49E-01	6.49E+00
Po215	2.32E-01	3.32E-10	2.99E-12	1.83E-17	2.09E-04	9.85E-03
Po216	1.32E-03	6.13E-17			1.64E-02	2.83E-01
Po218	9.05E-01	9.47E-12	4.47E-09	1.94E-22	2.50E-01	6.49E+00
Pr144	3.00E-04				7.79E-04	
Pu236	5.37E-17					
Pu238	1.15E+05	7.65E+01	4.97E+02		3.15E+04	3.50E+03
Pu239	7.91E+04	1.64E+02	6.28E+00	2.46E-02	2.76E+03	2.72E+03
Pu240	1.01E+02	6.44E+01			2.66E+01	9.48E+02
Pu241	1.62E+03	1.63E+03		6.32E-03	2.40E+02	4.79E+04

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[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Pu242	4.85E+02	2.02E-02			8.70E-02	2.37E-01
Pu243	1.34E-09					
Pu244	1.94E-07				1.00E-06	1.10E-09
Ra223	2.32E-01	2.32E-01	2.99E-12	1.83E-17	2.09E-04	9.85E-03
Ra224	1.32E-03	6.13E-17			1.71E-02	2.83E-01
Ra225	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Ra226	9.05E-01	3.99E-08	4.47E-09	1.94E-22	2.50E-01	6.54E+00
Ra228	1.59E-03	1.59E-16			1.90E-16	9.92E-04
Rh106	9.97E-04				8.74E-04	
Rn219	2.32E-01	3.32E-10	2.99E-12	1.83E-17	2.09E-04	9.85E-03
Rn220	1.32E-03	6.13E-17			1.64E-02	2.83E-01
Rn222	9.05E-01	9.47E-12	4.47E-09	1.94E-22	2.50E-01	6.49E+00
Ru106	9.97E-04				8.74E-04	
Sb125	4.67E-02				1.37E-03	
Sb126	5.52E-05				3.23E-07	
Sb126M	3.94E-04				2.31E-06	
Se79	1.78E-04				1.04E-06	
Sm151	6.02E-01				3.75E-03	
Sn119M	1.66E-08				2.97E-08	
Sn121M	1.09E-02				7.17E-05	
Sn126	3.99E-04				2.31E-06	
Sr90	4.44E+01				3.10E-01	1.48E+03

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Tc99	1.02E-02				5.99E-05	1.78E+01
Te125M	1.14E-02				3.33E-04	
Te127	7.45E-10				2.29E-12	
Te127M	7.60E-10				2.34E-12	
Th227	2.29E-01	7.39E-08	2.95E-12	1.80E-17	2.06E-04	9.72E-03
Th228	1.32E-03	6.13E-17			1.64E-02	2.83E-01
Th229	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Th230	4.90E-04	3.06E-08	1.86E-06	1.34E-18	9.98E-07	2.45E-04
Th231	5.27E-01	1.76E-03	1.05E-07	3.75E-08	6.15E-05	1.45E-02
Th232	2.29E-03	9.37E-16			8.19E-16	8.57E-04
Th234	2.36E-02	3.03E-02		1.16E-07	3.18E-04	4.26E-02
Tl207	2.31E-01	3.31E-10	3.20E-12	1.82E-17	2.09E-04	9.82E-03
Tl208	4.76E-04	2.20E-17			5.89E-03	1.02E-01
Tl209	1.74E-03	2.12E-14		3.43E-15	5.20E-05	4.47E-03
U232	1.67E-03				1.65E-02	2.90E-01
U233	4.46E+01	5.95E-09		1.78E-09	1.81E+00	1.77E+02
U234	6.06E+00	3.29E-03	2.47E-02	2.98E-13	1.26E-02	1.57E+01
U235	5.27E-01	5.93E-04	1.05E-07	4.44E-11	1.17E-02	1.33E-02
U236	3.21E-04	7.62E-06			4.20E-06	3.40E-04
U237	3.98E-02	4.00E-02		1.55E-07	5.88E-03	1.18E+00
U238	2.36E-02	3.03E-02		1.16E-07	1.64E-04	4.26E-02
U240	1.94E-07				9.99E-07	1.10E-09

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[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Y90	4.44E+01				3.10E-01	1.48E+03
Zn65						3.85E-09
Total by Site	**2.08E+05**	**2.15E+03**	**5.03E+02**	**3.55E-01**	**3.50E+04**	**6.55E+04**

Nuclide	PAD	PANT	RFETS	SRS	Total Curies
Ac225	4.02E-07		3.55E-11	1.31E-05	1.94E+00
Ac227	1.27E-12	4.83E-17	1.58E-10	3.70E-07	2.80E-01
Ac228			1.49E-14	1.01E-02	3.76E-01
Ag109M					6.56E+00
Ag110					4.14E-09
Ag110M					6.16E-07
Am241			1.19E+05	3.76E+03	2.31E+05[2]
Am243				7.55E-01	1.80E+01
Am245					1.27E-09
At217	4.02E-07		3.55E-11	1.31E-05	1.94E+00
Ba137M				7.11E+00	2.96E+03
Bi210			4.54E-12	1.11E-06	1.65E+00
Bi211	1.27E-12	4.83E-17	1.58E-10	3.70E-07	2.81E-01
Bi212			4.98E-15	9.20E-03	2.66E+01
Bi213	4.02E-07		3.55E-11	1.31E-05	1.94E+00
Bi214			9.77E-11	7.30E-06	7.72E+00

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	SRS	Total Curies
Bk249					8.73E-05
Bk250					8.68E-08
C14					1.77E+00
Cd109					6.55E+00
Cd113M					7.91E-07
Ce144				8.72E-13	3.70E-02
Cf249					5.39E-02
Cf250					3.20E-01
Cf251					1.58E-03
Cf252				3.62E-01	3.58E+01
Cm242					1.56E-03
Cm243					1.12E+00
Cm244				7.46E+02	2.82E+03
Cm245					1.68E+01
Cm246					4.28E-02
Cm247					1.34E-09
Cm248				1.61E-04	3.34E-02
Co58					1.34E-13
Co60				3.56E-01	6.28E+01
Cs134				3.19E-06	6.09E-03
Cs135					2.15E-04
Cs137				7.51E+00	3.12E+03

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	SRS	Total Curies
Es254					8.68E-08
Eu150					3.50E-05
Eu152					1.22E+00
Eu154				2.84E-04	1.10E+00
Eu155				5.28E+01	5.34E+01
Fe55					1.91E-05
Fe59					1.87E-07
Fr221	4.02E-07		3.55E-11	1.31E-05	1.94E+00
Fr223	1.75E-14	6.67E-19	2.19E-12	5.11E-09	3.87E-03
H3					8.65E-01
I129				1.17E-07	1.17E-07
Kr85					1.96E-01
Mn54				1.00E-10	8.51E-04
Nb95					2.41E-09
Nb95M					8.06E-12
Ni59				1.25E-03	1.25E-03
Ni63				1.52E-01	1.52E-01
Np237	5.50E+01		1.70E-02	8.59E+00	6.55E+01
Np239				7.55E-01	2.12E+01
Np240M				1.59E-11	1.19E-06
Pa231	2.09E-11	2.31E-15	2.70E-09	1.68E-06	3.16E-01
Pa233	5.50E+01		1.70E-02	8.59E+00	6.55E+01

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	SRS	Total Curies
Pa234			1.94E-17	7.42E-06	7.90E-03
Pa234M			1.49E-14	5.71E-03	6.08E+00
Pb209	4.02E-07		3.55E-11	1.31E-05	1.94E+00
Pb210			4.54E-12	1.11E-06	1.65E+00
Pb211	1.27E-12	4.83E-17	1.58E-10	3.70E-07	2.81E-01
Pb212			4.98E-15	9.20E-03	2.66E+01
Pb214			9.77E-11	7.30E-06	7.72E+00
Pd107					3.17E-05
Pm147				1.24E-05	4.80E+00
Po210			4.50E-12	1.11E-06	1.65E+00
Po211	3.55E-15	1.35E-19	4.43E-13	1.04E-09	7.86E-04
Po212			3.19E-15	5.89E-03	1.70E+01
Po213	3.93E-07		3.47E-11	1.28E-05	1.90E+00
Po214			9.77E-11	7.30E-06	7.72E+00
Po215	4.03E-12	4.83E-17	1.58E-10	3.70E-07	2.81E-01
Po216			4.98E-15	9.20E-03	2.66E+01
Po218			9.77E-11	7.30E-06	7.73E+00
Pr144				8.62E-13	3.66E-02
Pu236					1.04E-02
Pu238			8.49E+03	4.87E+05	7.86E+05[2]
Pu239	5.57E+01	5.55E-02	1.83E+05	9.30E+03	3.44E+05[2]
Pu240			4.70E+04	2.29E+03	6.63E+04[2]

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	SRS	Total Curies
Pu241			1.07E+06	6.20E+04	1.37E+06[2]
Pu242			9.63E-05	3.75E-01	4.87E+02
Pu243					1.34E-09
Pu244				2.09E-11	1.20E-06
Ra223	1.27E-12	4.83E-17	1.58E-10	3.70E-07	5.13E-01
Ra224			4.98E-15	9.20E-03	2.66E+01
Ra225	4.02E-07	4.02E-07	3.55E-11	1.31E-05	1.94E+00
Ra226			9.77E-11	7.30E-06	7.77E+00
Ra228			1.49E-14	1.01E-02	3.76E-01
Rh106				1.84E-10	1.52E-02
Rn219	1.27E-12	4.83E-17	1.58E-10	3.70E-07	2.81E-01
Rn220			4.98E-15	9.20E-03	2.66E+01
Rn222			9.77E-11	7.30E-06	7.73E+00
Ru106				1.84E-10	1.52E-02
Sb125				2.61E-05	5.22E-02
Sb126				2.41E-08	5.78E-05
Sb126M				1.72E-07	4.12E-04
Se79					1.86E-04
Sm151				3.13E-04	6.31E-01
Sn119M					2.44E-06
Sn121M					1.14E-02
Sn126				1.72E-07	4.17E-04

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	SRS	Total Curies
Sr90				6.98E+00	2.22E+03
Tc99				4.50E-06	1.78E+01
Te125M				6.37E-06	1.27E-02
Te127					1.07E-07
Te127M					1.09E-07
Th227	1.25E-12	4.77E-17	1.56E-10	3.65E-07	2.77E-01
Th228			4.98E-15	9.20E-03	2.66E+01
Th229	4.02E-07		3.55E-11	1.31E-05	1.94E+00
Th230			1.16E-07	2.35E-03	3.20E-02
Th231	3.29E-07	1.09E-10	4.78E-05	5.84E-03	2.32E+00
Th232			1.02E-13	2.13E-02	4.22E-01
Th234			1.49E-14	5.71E-03	6.08E+00
Tl207	1.27E-12	4.82E-17	1.58E-10	3.69E-07	2.80E-01
Tl208			1.79E-15	3.31E-03	9.55E+00
Tl209	8.67E-09		7.66E-13	2.83E-07	4.19E-02
U232				8.94E-02	2.57E+01
U233	1.42E-03		1.29E+01	3.75E+00	1.22E+03
U234			4.81E-03	2.56E+01	1.07E+02
U235	3.29E-07	1.09E-10	4.78E-05	5.84E-03	2.33E+00
U236			9.17E-04	4.78E-02	5.72E-02
U237			1.28E+00	1.52E+00	8.66E+00
U238			1.49E-14	5.71E-03	6.08E+00

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	SRS	Total Curies
U240				1.59E-11	1.19E-06
Y90				6.98E+00	2.22E+03
Zn65					5.36E-09
Total by Site	**1.66E+02**	**5.55E-02**	**1.43E+06**	**5.65E+05**	**2.82E+06[2]**

ABBREVIATIONS

ARCO ARCO Medical Center, Pennsylvania
ARMY US Army Materiel Command
ETEC Energy Technology Engineering Center
HANF Hanford
INEL Idaho National Engineering Laboratory
KAPL Knolls Atomic Power Laboratory
LANL Los Alamos National Laboratory
LBL Lawrence Berkeley Laboratory
LLNL Lawrence Livermore National Laboratory
Mound Mound Facility
MURR University of Missouri
NTS Nevada Test Site
ORNL Oak Ridge National Laboratory
PAD Paducah
PANT Pantex
RFETS Rocky Flats Environmental Technology Site
SRS Savannah River Site

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

[2]Data include undecayed curies from the RFETS residues from the following radioinuclides: 8,143 Ci (Pu238); 173,500 Ci (Pu239); 39,750 Ci (Pu240); 1,016,000 Ci (Pu241); and 108,500 Ci (Am241).

RH Curies on a Site-by-Site[1] Basis (Decayed to the End of 1995)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Ac225	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Ac227	1.05E-16	1.70E-05	2.61E-07	3.82E-09	4.60E-07
Ac228		1.60E-03	3.87E-05		
Ag110			4.14E-09		9.88E-10
Ag110M			3.11E-07		7.43E-08
Am241	5.85E-02	1.93E+02	4.68E+01	5.07E-02	
Am243			6.91E-04		
Am245					
At217	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Ba137M	2.48E+00	6.61E+03	1.80E+03	5.40E+01	1.28E+02
Bi210		2.33E-07	6.06E-12	1.87E-16	5.61E-17
Bi211	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Bi212		1.49E-03	2.65E-05		
Bi213	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Bi214		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Bk249					
C14			4.00E-02		
Cd113M			1.15E-07		8.88E-07
Ce144			3.98E+00	1.56E+00	1.60E-02
Cf249					
Cf250					
Cf252					
Cm243			1.45E-02		

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Cm244			9.63E-02		
Cm245					
Cm246					
Cm248					
Co58			4.37E-11		
Co60	2.30E+00	3.36E+02	1.30E+01	2.75E-01	4.17E+00
Cr51			1.08E-05		
Cs134			5.38E+01	4.73E+00	2.42E-02
Cs135			2.36E-05		1.91E-04
Cs137	2.62E+00	6.98E+03	1.90E+03	5.71E+01	1.35E+02
Eu152			1.14E-01		5.09E-04
Eu154			7.90E-01	1.40E+00	3.50E-02
Eu155			3.35E-01	1.81E-01	1.77E+00
Fe55			5.96E-01		
Fr221	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Fr223	1.45E-18	2.35E-07	3.60E-09	1.86E-20	6.34E-09
H3			1.43E-01		
Kr 85			5.95E+00		
Mn54			8.30E-02		
Nb95			5.28E-12		2.14E-14
Nb95M			1.76E-14		7.15E-17
Ni63			3.50E+00		
Np237	2.26E-08	1.58E-03	8.10E-04	2.25E-08	
Np239			6.91E-04		

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Np240M					
Pa231	6.68E-15	6.21E-05	2.24E-06	7.51E-17	2.39E-06
Pa233	2.26E-08	1.58E-03	8.10E-04	2.25E-08	
Pa234		1.33E-05	1.80E-06	4.48E-18	2.60E-08
Pa234M		1.03E-02	1.38E-03	3.45E-15	2.00E-05
Pb209	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Pb210		2.33E-07	6.06E-12	1.87E-16	5.61E-17
Pb211	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Pb212		1.49E-03	2.65E-05		
Pb214		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Pd107			3.49E-06		2.83E-05
Pm147			1.49E+01	4.34E+00	1.13E+01
Po210		2.33E-07	4.06E-12	8.21E-17	1.60E-17
Po211	2.94E-19	4.77E-08	7.30E-10	3.78E-21	1.29E-09
Po212		9.54E-04	1.70E-05		
Po213	3.00E-18	5.33E-04	1.72E-04	4.02E-18	
Po214		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Po215	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Po216		1.49E-03	2.65E-05		
Po218		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Pr144			3.93E+00	1.54E+00	1.58E-02
Pu238		4.67E+01	6.09E+01	9.27E-01	3.90E+00
Pu239	4.00E-01	3.35E+02	2.98E+01	3.30E-03	9.28E+01
Pu240		1.67E+02	2.48E+01	3.10E-03	

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Pu241		4.67E+03	4.81E+01	7.77E-01	
Pu242		4.92E-03	1.01E-03	1.56E-05	
Pu244					
Ra223	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Ra224		1.49E-03	2.65E-05		
Ra225	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Ra226		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Ra228		1.60E-03	3.87E-05	2.37E-17	
Rh106			6.65E-02	4.98E-01	3.38E-01
Rn219	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Rn220		1.49E-03	2.65E-05		
Rn222		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Ru106			6.65E-02	4.98E-01	3.38E-01
Sb125			9.81E-01	5.33E-01	2.79E+00
Sb126			6.35E-06		5.15E-05
Sb126M			4.53E-05		3.68E-04
Se79			2.05E-05		1.66E-04
Sm151			7.53E-02		5.82E-01
Sn119M			2.33E-06		5.20E-07
Sn121M			1.36E-03		1.09E-02
Sn126			4.53E-05		3.68E-04
Sr89			6.64E-04		
Sr90	2.62E+00	6.46E+03	1.70E+03	5.70E+01	1.24E+02
Ta182			1.49E-07		

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Tc99			1.18E-03		9.54E-03
Te125M			2.39E-01	1.30E-01	6.88E-01
Te127			5.79E-09		1.39E-10
Te127M			5.91E-09		1.42E-10
Th227	1.03E-16	1.68E-05	2.57E-07	1.33E-18	4.53E-07
Th228		1.49E-03	2.65E-05		
Th229	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Th230		2.42E-04	1.37E-06	4.36E-11	5.01E-11
Th231	4.73E-10	1.46E-01	6.42E-03	4.53E-12	8.78E-03
Th232		1.95E-03	7.51E-05	4.68E-21	
Th234		1.03E-02	1.38E-03	3.45E-15	2.00E-05
Tl207	1.05E-16	1.70E-05	2.60E-07	1.35E-18	4.58E-07
Tl208		5.35E-04	9.52E-06		
Tl209	6.63E-20	1.18E-05	3.80E-06	8.88E-20	
U232					
U233	6.55E-14	4.15E-01	3.91E-01	7.62E-14	
U234		1.29E+00	1.51E-01	4.98E-06	1.11E-05
U235	4.73E-10	1.46E-01	5.38E-03	4.53E-12	8.78E-03
U236		8.63E-05	3.52E-06	1.24E-10	
U237		1.14E-01	1.18E-03	1.91E-05	
U238		1.03E-02	3.57E-03	3.45E-15	2.00E-05
U240					
Y90	2.62E+00	6.46E+03	1.70E+03	5.70E+01	1.24E+02
Zr93			2.65E-04		3.40E-03

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Zr95			2.38E-12		9.64E-15
Total by Site	**1.31E+01**	**3.23E+04**	**7.40E+03**	**2.43E+02**	**6.30E+02**

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	Total Curies
Ac225	8.80E-14	5.40E-02	2.96E-15	6.40E-18	7.44E-15	5.47E-02
Ac227	9.88E-13	2.81E-03	4.20E-13	2.77E-20		2.82E-03
Ac228	3.63E-18	8.70E-02				8.87E-02
Ag110						5.12E-09
Ag110M						3.85E-07
Am241	4.85E-01	2.42E+02	6.79E-02	1.02E-02	5.39E-01	4.83E+02
Am243		9.98E-05	1.60E-05			8.07E-04
Am245		8.61E-16				8.61E-16
At217	8.80E-14	5.40E-02	2.96E-15	6.40E-18	5.77E-03	6.05E-02
Ba137M		9.25E+03	6.49E+00		5.06E+01	1.79E+04
Bi210		9.40E-11	1.24E-16		1.51E-12	2.33E-07
Bi211	9.88E-13	2.81E-03	4.20E-13	4.20E-13		2.82E-03
Bi212	2.08E-18	1.68E+00				1.68E+00
Bi213	8.80E-14	5.40E-02	2.96E-15	6.40E-18	7.44E-15	5.47E-02
Bi214		6.25E-10	1.64E-14	7.34E-20	2.38E-11	1.16E-06
Bk249		5.94E-11				5.94E-11
C14		6.11E+00				6.15E+00
Cd113M						1.00E-06

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	Total Curies
Ce144		1.20E+01				1.75E+01
Cf249		1.34E-02				1.34E-02
Cf250	1.81E-01					1.81E-01
Cf252		3.86E+00				3.86E+00
Cm243		1.48E+02				1.48E+02
Cm244	1.55E+02	9.44E+02	4.68E+00			1.10E+03
Cm245		4.39E-06				4.39E-06
Cm246	3.95E-04					3.95E-04
Cm248		6.13E-04				6.13E-04
Co58						4.37E-11
Co60		6.14E+02				9.70E+02
Cr 51						1.08E-05
Cs134		9.57E+00				6.81E+01
Cs135						2.15E-04
Cs137		9.78E+03	6.86E+00		5.35E+01	1.89E+04
Eu152		3.66E+03				3.66E+03
Eu154		1.77E+03				1.78E+03
Eu155		3.51E+02				3.53E+02
Fe55						5.96E-01
Fr221	8.80E-14	5.40E-02	2.96E-15	6.40E-18	7.44E-15	5.47E-02
Fr223	1.36E-14	3.87E-05	5.80E-15	3.82E-22		3.90E-05
H3		7.71E-02	1.39E-02			2.34E-01
Kr85						5.95E+00
Mn54						8.30E-02

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	Total Curies
Nb95		3.15E-03				3.15E-03
Nb95M		2.46E-06				2.46E-06
Ni63						3.50E+00
Np237	3.19E-06	5.07E-04	1.43E-05	1.00E-08	1.49E-06	2.92E-03
Np239		9.98E-05	1.60E-05			8.07E-04
Np240M		6.62E-11				6.62E-11
Pa231	6.39E-12	2.07E-02	2.67E-11	5.21E-19		2.08E-02
Pa233	3.19E-06	5.07E-04	1.75E-05	1.00E-08	1.49E-06	2.92E-03
Pa234	3.31E-21	4.38E-03				4.39E-03
Pa234M	2.54E-18	3.37E+00				3.38E+00
Pb209	8.80E-14	5.40E-02	2.96E-15	6.40E-18	7.44E-15	5.47E-02
Pb210		9.40E-11	1.24E-16		1.51E-12	2.33E-07
Pb211	9.88E-13	2.81E-03	4.20E-13	2.46E-12		2.82E-03
Pb212	2.08E-18	1.68E+00				1.68E+00
Pb214		6.25E-10	1.64E-14	7.34E-20	2.38E-11	1.16E-06
Pd107						3.18E-05
Pm147	1.53E+00		1.34E+00			3.34E+01
Po210		9.40E-11	3.40E-17		1.51E-12	2.33E-07
Po211	2.76E-15	7.86E-06	1.18E-15	5.38E-15		7.91E-06
Po212	1.34E-18	1.07E+00				1.07E+00
Po213	8.61E-14	5.28E-02	2.89E-15	6.26E-18	7.28E-15	5.35E-02
Po214	1.91E-15	6.31E-10	1.64E-14	7.34E-20	2.38E-11	1.16E-06
Po215	9.88E-13	2.81E-03	4.20E-13	2.77E-20		2.82E-03
Po216	2.08E-18	1.68E+00		1.01E-02		1.69E+00

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	Total Curies
Po218		6.25E-10	1.64E-14	7.34E-20	2.38E-11	1.16E-06
Pr144		1.51E+01				2.05E+01
Pu238		2.81E+01	8.83E+00	4.92E-06	1.98E+01	1.69E+02
Pu239	2.36E+00	9.85E+01	1.06E-02	2.00E-06		5.59E+02
Pu240	2.54E-01	1.07E+00	5.06E-04			1.93E+02
Pu241	6.60E-05	3.97E-07				4.71E+03
Pu242	4.27E-09					5.95E-03
Pu244		6.63E-11				6.63E-11
Ra223	9.88E-13	2.81E-03	4.20E-13	2.77E-20		2.82E-03
Ra224	2.08E-18	1.68E+00				1.68E+00
Ra225	8.80E-14	5.40E-02	2.96E-15	6.40E-18	7.44E-15	5.47E-02
Ra226		6.25E-10	1.64E-14	7.34E-20	2.38E-11	1.16E-06
Ra228	3.63E-18	8.70E-02				8.87E-02
Rh106		3.21E+01				3.30E+01
Rn219	9.88E-13	2.81E-03	4.20E-13	2.77E-20		2.82E-03
Rn220	2.08E-18	1.68E+00				1.68E+00
Rn222		6.25E-10	1.64E-14	7.34E-20	2.38E-11	1.16E-06
Ru106		3.21E+01				3.30E+01
Sb125						4.30E+00
Sb126						5.78E-05
Sb126M						4.13E-04
Se79						1.86E-04
Sm151						6.58E-01
Sn119M						2.85E-06

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	Total Curies
Sn121M						1.23E-02
Sn126						4.13E-04
Sr89						6.64E-04
Sr90		3.52E+04	6.85E+00		1.96E+01	4.36E+04
Ta182						1.49E-07
Tc99	1.48E-04					1.09E-02
Te125M						1.06E+00
Te127						5.93E-09
Te127M						6.05E-09
Th227	9.74E-13	2.77E-03	4.14E-13	2.73E-20		2.79E-03
Th228	2.08E-18	1.68E+00				1.68E+00
Th229	8.80E-14	5.40E-02	2.96E-15	6.40E-18	7.44E-15	5.47E-02
Th230		1.98E-07	1.13E-10	2.54E-16	1.92E-08	2.43E-04
Th231	3.71E-08	1.86E+02	1.26E-06	9.85E-15		1.86E+02
Th232	1.24E-17	9.89E-02	1.24E-22			1.01E-01
Th234	2.54E-18	3.37E+00				3.38E+00
Tl207	9.85E-13	2.80E-03	4.19E-13	2.76E-20		2.82E-03
Tl208	7.49E-19	6.02E-01				6.02E-01
Tl209	1.90E-15	1.17E-03	6.39E-17	1.38E-19	1.61E-16	1.18E-03
U232		1.76E+00				1.76E+00
U233	1.40E-10	5.73E+01	6.26E-11	6.66E-14	2.76E-11	5.81E+01
U234	2.02E-23	2.02E-03	2.51E-05	2.81E-11	4.94E-04	1.45E+00
U235	3.71E-08	1.86E+02	1.26E-06	9.85E-15		1.86E+02
U236	5.24E-08	2.32E-07	7.54E-12			9.01E-05

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	Total Curies
U237	1.62E-09	9.74E-12				1.16E-01
U238	2.54E-18	3.37E+00				3.38E+00
U240		6.62E-11				6.62E-11
Y90		3.52E+04	6.85E+00		1.96E+01	4.36E+04
Zr93						3.67E-03
Zr95		3.31E-04				3.31E-04
Total by Site	**1.60E+02**	**9.79E+04**	**4.20E+01**	**2.03E-02**	**1.64E+02**	**1.39E+05**

ABBREVIATIONS

ETEC Energy Technology Engineering Center
HANF Hanford
INEL Idaho National Engineering Laboratory
KAPL Knolls Atomic Power Laboratory
LANL Los Alamos National Laboratory
NTS Nevada Test Site
ORNL Oak Ridge National Laboratory
SRS Savannah River Site
SNL/NM Sandia National Laboratory-Albuquerque
WVDP West Valley Demonstration Plant

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

APPENDIX E

Appendix E

TRUCON AND NMVP CROSS-CORRELATION TABLE

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
AE-T001	AE-T001		SOLID HETEROGENEOUS INORGANIC/ORGANIC WASTE	AE-131		Unassigned	CH
AE-T003	AE-T003		NONHAZARDOUS METALS	RF-321		Unassigned	CH
AE-W038	AE-W038		AQUEOUS LAB PACKS	AE-131		Unassigned	CH
AE-W039	AE-W039		ORGANIC RESINS	RF-806.1		Unassigned	CH
AE-W040	AE-W040		WASTEWATER TREATMENT SLUDGES	RF-800		Unassigned	CH
AE-W041	AE-W041		NON-ACTIVATED LEAD	RF-321		Unassigned	CH
AE-W042	AE-W042		CADMIUM CONTAINING METAL DEBRIS	RF-480		Unassigned	CH
AL-W005	AL-W005	Glovebox	AQUEOUS LIQUIDS/SLURRIES	RF-800		Unassigned	CH
AM-W001	AM-W001		NUCLEAR PACEMAKERS				CH
AW-W026	AW-N026.82	CH-ANL-505T	ALHC UPGRADE DECON DEBRIS				CH
AW-W027	AW-N027.531	CH-ANL-142T	LEAD CONTAMINATED WASTE				CH
AW-W028	AW-N028	CH-ANL-503T	TRU WASTE USED PRE-FILTERS				RH
AW-W029	AW-T029.1323	CH-ANL-538	RSWF TRANSURANIC WASTE				RH
AW-W030	AW-T030.1321	CH-ANL-539	FCF TRU (CH) DISCARDED METAL DEBRIS				CH
AW-W031	AW-T031.1322	CH-ANL-540	FCF (RH) MISCELLANEOUS TRU WASTE				RH
AW-W032	AW-T032.1324	CH-ANL-541	FCF TRU (CH) COMBUSTIBLES				CH
AW-W033	AW-T033.1325	CH-ANL-542	ANL-752 TRU WASTE				CH
AW-W034	AW-T034.1327	CH-ANL-543	FCF TRU (CH) COMPACTIBLE WASTE				CH
AW-W035	AW-T035.1326	CH-ANL-544	FCF (RH) TRU GLASS-METAL WASTE				RH
AW-W012	AW-W012.10	CH-ANL-218T	ELECTROREFINER STRIPPED SALT - BA AND CD				RH
AW-W016	AW-W016.20	CH-ANL-245T	ELECTROREFINER STRIPPED CADMIUM				RH
AW-W018	AW-W018	CH-ANL-180T	SODIUM - TRU				RH
AW-W019	AW-W019	CH-ANL-182T	SODIUM POTASSIUM -NAK- TRU				RH
AW-W020	AW-W020.13	CH-ANL-241T	TRU-CD-HOT CELL WASTE				RH
AW-W021	AW-W021.16	CH-ANL-243T	ELEMENT HARDWARE FCF WASTE				RH
AW-W022	AW-W022.22	CH-ANL-246T	ELECTROREFINER INSOLUBLES W/ CADMIUM				RH
BC-T001	BC-T001		RH/TRU RUBBLE/DEBRIS			Unassigned	RH
BT-T001	BT-T001	BT-T001	IRRADIATED TRU MATERIAL WASTE	BT-T001	N/A	N/A	RH
BT-T002	BT-T002	BT-T002	CONTAMINATED PIPING SYSTEM	BT-T002	N/A	N/A	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
BT-T003	BT-T003	BT-T003	UNIRRADIATED ALPHA CONTAMINATED WASTE	BT-T003	N/A	N/A	CH
BT-T004	BT-T004	BT-T004	AMERICIUM-243 SOURCE	BT-T004	N/A	N/A	CH
BT-T005	BT-T005	BT-T005	CALIFORNIUM-252 SOURCE	BT-T005	N/A	N/A	CH
ET-W002	ET-M001	ET	HOT LAB & PU FACILITY D&D		NA		RH
ET-W021	ET-T001A	ET	HOT LAB & PU FACILITY D&D		NA		RH
ET-W027	ET-T001B	ET	HOT LAB & PU FACILITY D&D		NA	Unassigned	CH
IN-W112	IN-W112	ID-CPP-172	HEPA FILTERS				RH
IN-W139	IN-W139.627	ID-INL-142T	TRANSURANIC CONTAMINATED LEAD DEBRIS				CH
IN-W146	IN-W146.699	ID-TRA-291T	TRU HEAVY METAL SLUDGE				CH
IN-W157	IN-W157.144	ID-RFO-004T	SPECIAL SETUPS (CEMENT):DIRECT SHIP	4		213	CH
IN-W157	IN-W157.906	ID-RFO-004T	SPECIAL SETUPS (CEMENT):CERT-REPACK	4		213	CH
IN-W157	IN-W157.907	ID-RFO-004T	SPECIAL SETUPS (CEMENT):UNCERTIFIABLE				CH
IN-W159	IN-W159.1072	ID-MDO-811T	EVAPORATOR AND DISSOLVER SLUDGE:DIRECT SHIP	811			CH
IN-W159	IN-W159.119	ID-MDO-811T	EVAPORATOR AND DISSOLVER SLUDGE:UNCERT-MERCURY				CH
IN-W159	IN-W159.120	ID-MDO-811T	EVAPORATOR AND DISSOLVER SLUDGE:UNCERT-OTHER				CH
IN-W161	IN-W161.231	ID-RFO-371T	FIREBRICK:CERT-REPACK	371	122	122, 222	CH
IN-W161	IN-W161.806	ID-RFO-371T	FIREBRICK:DIRECT SHIP	371	122	122, 222	CH
IN-W163	IN-W163.1007	ID-RFO-375T	OIL-DRI RESIDUE FROM INCINERATOR:DIRECT SHIP	375			CH
IN-W163	IN-W163.234	ID-RFO-375T	OIL-DRI RESIDUE FROM INCINERATOR:UNCERTIFIABLE				CH
IN-W164	IN-W164.1060	ID-RFO-700T	ORGANIC AND SLUDGE IMMOBILIZATION SYSTEM:CERT-REPACK	700			CH
IN-W164	IN-W164.153	ID-RFO-700T	ORGANIC AND SLUDGE IMMOBILIZATION SYSTEM:DIRECT SHIP	700			CH
IN-W166	IN-W166.151	ID-RFO-114T	SOLIDIFIED INORGANIC PROCESS SOLUTION:DIRECT SHIP	114		114	CH
IN-W166	IN-W166.928	ID-RFO-114T	SOLIDIFIED INORGANIC PROCESS SOLUTION:CERT-REPACK	114		114	CH
IN-W167	IN-W167.149	ID-RFO-112T	SOLIDIFIED ORGANICS:DIRECT SHIP	112		112	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W167	IN-W167.926	ID-RFO-112T	SOLIDIFIED ORGANICS:CERT-REPACK	112		112	CH
IN-W169	IN-W169.191	ID-RFO-330T	DRY PAPER AND RAGS:CH-CERT-REPACK	330	116	116, 216	CH
IN-W169	IN-W169.192	ID-RFO-330T	DRY PAPER AND RAGS:CH-UNCERT				CH
IN-W169	IN-W169.193	ID-RFO-330T	DRY PAPER AND RAGS:RH-CERT-REPACK	330	116	116, 216	RH
IN-W169	IN-W169.194	ID-RFO-330T	DRY PAPER AND RAGS:RH-UNCERT				RH
IN-W169	IN-W169.985	ID-RFO-330T	DRY PAPER AND RAGS:DIRECT SHIP	330	116	116, 216	CH
IN-W170	IN-W170.189	ID-AEO-120T	DECONTAMINATION AND DECOMMISIONING WASTE:DIRECT SHIP	120			CH
IN-W170	IN-W170.938	ID-AEO-120T	DECONTAMINATION AND DECOMMISIONING WASTE:CERT-REPACK	120			CH
IN-W171	IN-W171.184	ID-AEO-110T	RESEARCH GENERATED WASTE COMPACTIBLE & C: CERT-REPACK	110			CH
IN-W171	IN-W171.801	ID-AEO-110T	RESEARCH GENERATED WASTE COMPACTIBLE & C:DIRECT SHIP	110			CH
IN-W172	IN-W172.182	ID-BTO-010T	COMBUSTIBLES:CERT-REPACK	10			CH
IN-W172	IN-W172.911	ID-BTO-010T	COMBUSTIBLES:DIRECT SHIP	10			CH
IN-W174	IN-W174.1082	ID-MDO-834T	HIGH-LEVEL ACID:CERT-REPACK	834			CH
IN-W174	IN-W174.154	ID-MDO-834T	HIGH-LEVEL ACID:DIRECT SHIP	834			CH
IN-W177	IN-W177.1083	ID-MDO-835T	HIGH-LEVEL CAUSTIC:CERT-REPACK	835			CH
IN-W177	IN-W177.156	ID-MDO-835T	HIGH-LEVEL CAUSTIC:DIRECT SHIP	835			CH
IN-W179	IN-W179.1084	ID-MDO-836T	HIGH-LEVEL SLUDGE/CEMENT:CERT-REPACK	836			CH
IN-W179	IN-W179.158	ID-MDO-836T	HIGH-LEVEL SLUDGE/CEMENT:DIRECT SHIP	836			CH
IN-W181	IN-W181.162	ID-RFO-978T	LAUNDRY SLUDGE	978		211	CH
IN-W186	IN-W186.187	ID-RFO-116T	COMBUSTIBLE WASTE	116		116	CH
IN-W187	IN-W187.1094	ID-RFO-980T	EQUIPMENT:DIRECT SHIP	980			CH
IN-W187	IN-W187.121	ID-RFO-980T	EQUIPMENT:UNCERTIFIABLE				CH
IN-W188	IN-W188.1093	ID-RFO-976T	BLDG 776 PROCESS SLUDGE:CERT-REPACK	976		211	CH
IN-W188	IN-W188.160	ID-RFO-976T	BLDG 776 PROCESS SLUDGE:DIRECT SHIP	976		211	CH
IN-W189	IN-W189.1048	ID-RFO-464T	BENELEX AND PLEXIGLASS:CERT-REPACK	464		221	CH
IN-W189	IN-W189.131	ID-RFO-464T	BENELEX AND PLEXIGLASS:DIRECT SHIP	464		221	CH
IN-W197	IN-W197.196	ID-RFO-336T	MOIST PAPER AND RAGS:CH-UNCERT				CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W197	IN-W197.197	ID-RFO-336T	MOIST PAPER AND RAGS:RH-CERT-REPACK	336	116	116, 216	RH
IN-W197	IN-W197.198	ID-RFO-336T	MOIST PAPER AND RAGS:RH-UNCERT				RH
IN-W197	IN-W197.802	ID-RFO-336T	MOIST PAPER AND RAGS:CH-CERT-REPACK	336	116	116, 216	CH
IN-W197	IN-W197.803	ID-RFO-336T	MOIST PAPER AND RAGS:DIRECT SHIP	336	116	116, 216	CH
IN-W198	IN-W198.202	ID-RFO-337T	PLASTICS, TEFLON, WASH, PVC:CH-CERT-REPACK	337	116	116, 216	CH
IN-W198	IN-W198.203	ID-RFO-337T	PLASTICS, TEFLON, WASH, PVC:CH-UNCERT				CH
IN-W198	IN-W198.204	ID-RFO-337T	PLASTICS, TEFLON, WASH, PVC:RH-CERT-REPACK	337	116	116, 216	RH
IN-W198	IN-W198.205	ID-RFO-337T	PLASTICS, TEFLON, WASH, PVC:RH-UNCERT				RH
IN-W198	IN-W198.804	ID-RFO-337T	PLASTICS, TEFLON, WASH, PVC:DIRECT SHIP	337	116	116, 216	CH
IN-W199	IN-W199.1039	ID-RFO-460T	WASHABLES, RUBBER, PLASTICS:DIRECT SHIP	460			CH
IN-W199	IN-W199.209	ID-RFO-460T	WASHABLES, RUBBER, PLASTICS:UNCERTIFIABLE				CH
IN-W202	IN-W202.1092	ID-RFO-970T	WOOD:DIRECT SHIP	970		216	CH
IN-W202	IN-W202.224	ID-RFO-970T	WOOD:CERT-REPACK	970		216	CH
IN-W203	IN-W203.1081	ID-MDO-826T	COMBUSTIBLE EQUIPMENT BOXES OR FLOOR SWE:DIRECT SHIP	826			CH
IN-W203	IN-W203.210	ID-MDO-826T	COMBUSTIBLE EQUIPMENT BOXES OR FLOOR SWE:CERT-REPACK	826			CH
IN-W203	IN-W203.211	ID-MDO-826T	COMBUSTIBLE EQUIPMENT BOXES OR FLOOR SWE:UNCERT-SWEEPINGS				CH
IN-W203	IN-W203.212	ID-MDO-826T	COMBUSTIBLE EQUIPMENT BOXES OR FLOOR SWE:UNCERT-HG				CH
IN-W204	IN-W204.215	ID-MDO-827T	COMBUSTIBLE EQUIPMENT DRUMS:DIRECT SHIP	827			CH
IN-W204	IN-W204.216	ID-MDO-827T	COMBUSTIBLE EQUIPMENT DRUMS:CERT-REPACK	827			CH
IN-W204	IN-W204.217	ID-MDO-827T	COMBUSTIBLE EQUIPMENT DRUMS:UNCERT-HG				CH
IN-W205	IN-W205.1086	ID-RFO-900T	LOW SPECIFIC ACTIVITY PLASTICS, PAPER, E:CERT-REPACK	900		216	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W205	IN-W205.1087	ID-RFO-900T	LOW SPECIFIC ACTIVITY PLASTICS, PAPER, E:UNCERT				CH
IN-W205	IN-W205.220	ID-RFO-900T	LOW SPECIFIC ACTIVITY PLASTICS, PAPER, E:DIRECT SHIP	900		216	CH
IN-W206	IN-W206.935	ID-RFO-119T	HEPA FILTER WASTE:DIRECT SHIP	119		119	CH
IN-W206	IN-W206.936	ID-RFO-119T	HEPA FILTER WASTE:UNCERTIFIABLE				CH
IN-W207	IN-W207.238	ID-RFO-328T	FULFLO INCINERATOR FILTERS:UNCERTIFIABLE				CH
IN-W207	IN-W207.980	ID-RFO-328T	FULFLO INCINERATOR FILTERS:DIRECT SHIP	328			CH
IN-W207	IN-W207.981	ID-RFO-328T	FULFLO INCINERATOR FILTERS:CERT-REPACK	328			CH
IN-W208	IN-W208.242	ID-RFO-335T	ABSOLUTE 8 X 8 FILTERS:CH-UNCERT				CH
IN-W208	IN-W208.243	ID-RFO-335T	ABSOLUTE 8 X 8 FILTERS:RH-UNCERT				RH
IN-W208	IN-W208.988	ID-RFO-335T	ABSOLUTE 8 X 8 FILTERS:DIRECT SHIP	335	119	119, 219	CH
IN-W209	IN-W209.244	ID-RFO-338T	INSULATION AND CHEMICAL WARFARE SERVICE :UNCERTIFIABLE				CH
IN-W209	IN-W209.994	ID-RFO-338T	INSULATION AND CHEMICAL WARFARE SERVICE :DIRECT SHIP	338		219	CH
IN-W210	IN-W210.1001	ID-RFO-360T	INSULATION:DIRECT SHIP	360			CH
IN-W210	IN-W210.247	ID-RFO-360T	INSULATION:UNCERTIFIABLE				CH
IN-W211	IN-W211.1009	ID-RFO-376T	CEMENTED INSULATION AND FILTER MEDIA:DIRECT SHIP	376	119	119	CH
IN-W211	IN-W211.249	ID-RFO-376T	CEMENTED INSULATION AND FILTER MEDIA:UNCERTIFIABLE				CH
IN-W212	IN-W212.1058	ID-RFO-490T	CHEMICAL WARFARE SERVICE FILTERS:DIRECT SHIP	490	119	119, 219	CH
IN-W212	IN-W212.251	ID-RFO-490T	CHEMICAL WARFARE SERVICE FILTERS:UNCERTIFIABLE				CH
IN-W213	IN-W213.1069	ID-MDO-805T	ASBESTOS FILTERS:DIRECT SHIP	805			CH
IN-W213	IN-W213.252	ID-MDO-805T	ASBESTOS FILTERS:UNCERTIFIABLE				CH
IN-W213	IN-W213.253	ID-MDO-805T	ASBESTOS FILTERS:MERCURY				CH
IN-W214	IN-W214.1075	ID-MDO-813T	GLASS FILTERS AND FIBERGLASS:CERT-REPACK	813			CH
IN-W214	IN-W214.755	ID-MDO-813T	GLASS FILTERS AND FIBERGLASS:DIRECT SHIP	813			CH
IN-W214	IN-W214.756	ID-MDO-813T	GLASS FILTERS AND FIBERGLASS:UNCERT-MERCURY				CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W216	IN-W216.875	ID-RFO-001T	FIRST STAGE SLUDGE:CH-CERT-REPACK	1		211	CH
IN-W216	IN-W216.876	ID-RFO-001T	FIRST STAGE SLUDGE:RH-UNCERTIFIABLE				RH
IN-W216	IN-W216.877	ID-RFO-001T	FIRST STAGE SLUDGE:RH-CERT-REPACK	1		211	RH
IN-W216	IN-W216.98	ID-RFO-001T	FIRST STAGE SLUDGE:DIRECT SHIP	1		211	CH
IN-W216	IN-W216.99	ID-RFO-001T	FIRST STAGE SLUDGE:CH-UNCERTIFIABLE				CH
IN-W218	IN-W218.109	ID-RFO-007T	BLDG 374 DRY SLUDGE:UNCERTIFIABLE				CH
IN-W218	IN-W218.909	ID-RFO-007T	BLDG 374 DRY SLUDGE:DIRECT SHIP	7	111	111,211	CH
IN-W219	IN-W219.110	ID-BTO-030T	SOLIDIFIED GRINDING SLUDGE, ETC.:UNCERTIFIABLE				CH
IN-W219	IN-W219.914	ID-BTO-030T	SOLIDIFIED GRINDING SLUDGE, ETC.:RH DIRECT SHIP	30			CH
IN-W220	IN-W220.114	ID-OFS-111T	RESEARCH GENERATED WASTE NONCOMPACTIBLE :DIRECT SHIP	111		111	CH
IN-W220	IN-W220.925	ID-OFS-111T	RESEARCH GENERATED WASTE NONCOMPACTIBLE :CERT-REPACK	111		111	CH
IN-W221	IN-W221.113	ID-RFO-113T	SOLID LAB WASTE:CERT-REPACK	113		113	CH
IN-W221	IN-W221.927	ID-RFO-113T	SOLID LAB WASTE:DIRECT SHIP	113		113	CH
IN-W222	IN-W222.116	ID-RFO-292T	CEMENTED SLUDGE:DIRECT SHIP	292			CH
IN-W222	IN-W222.117	ID-RFO-292T	CEMENTED SLUDGE:UNCERTIFIABLE				CH
IN-W222	IN-W222.965	ID-RFO-292T	CEMENTED SLUDGE:CERT-REPACK	292			CH
IN-W225	IN-W225.127	ID-RFO-302T	BENELEX AND PLEXIGLASS:CERT-REPACK	302	121	121, 221	CH
IN-W225	IN-W225.800	ID-RFO-302T	BENELEX AND PLEXIGLASS:DIRECT SHIP	302	121	121, 221	CH
IN-W228	IN-W228.101	ID-RFO-002T	SECOND STAGE SLUDGE:DIRECT SHIP	2		211	CH
IN-W228	IN-W228.102	ID-RFO-002T	SECOND STAGE SLUDGE:CH-UNCERT-OTHER				CH
IN-W228	IN-W228.103	ID-RFO-002T	SECOND STAGE SLUDGE:CH-UNCERT-HG				CH
IN-W228	IN-W228.883	ID-RFO-002T	SECOND STAGE SLUDGE:CH-CERT-REPACK	2		211	CH
IN-W228	IN-W228.884	ID-RFO-002T	SECOND STAGE SLUDGE:RH-UNCERT-OTHER				RH
IN-W228	IN-W228.885	ID-RFO-002T	SECOND STAGE SLUDGE:RH-UNCERT-HG				RH
IN-W228	IN-W228.886	ID-RFO-002T	SECOND STAGE SLUDGE:RH-CERT-REPACK	2		211	RH
IN-W230	IN-W230.229	ID-RFO-122T	INORGANIC SOLID WASTE:DIRECT SHIP	122		122	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W230	IN-W230.940	ID-RFO-122T	INORGANIC SOLID WASTE:CERT-REPACK	122		122	CH
IN-W240	IN-W240.272	ID-RFO-118T	GLASS WASTE:CERT-REPACK	118		118	CH
IN-W240	IN-W240.931	ID-RFO-118T	GLASS WASTE:DIRECT SHIP	118		118	CH
IN-W243	IN-W243.274	ID-RFO-440T	GLASS:CH-CERT-REPACK	440	118	118	CH
IN-W243	IN-W243.275	ID-RFO-440T	GLASS:CH-UNCERT				CH
IN-W243	IN-W243.276	ID-RFO-440T	GLASS:RH-CERT-REPACK	440	118	118	RH
IN-W243	IN-W243.277	ID-RFO-440T	GLASS:RH-UNCERT				RH
IN-W243	IN-W243.808	ID-RFO-440T	GLASS:DIRECT SHIP	440	118	118	CH
IN-W245	IN-W245.1034	ID-RFO-441T	UNLEACHED RASHIG RINGS:CH-UNCERT				CH
IN-W245	IN-W245.1035	ID-RFO-441T	UNLEACHED RASHIG RINGS:RH-CERT-REPACK	441		225	RH
IN-W245	IN-W245.301	ID-RFO-441T	UNLEACHED RASHIG RINGS:DIRECT SHIP	441		225	CH
IN-W245	IN-W245.302	ID-RFO-441T	UNLEACHED RASHIG RINGS:CH-CERT-REPACK	441		225	CH
IN-W247	IN-W247.1038	ID-RFO-442T	LEACHED RASHIG RINGS:CH-UNCERT				CH
IN-W247	IN-W247.523	ID-RFO-442T	LEACHED RASHIG RINGS:CH-CERT-REPACK	442	118	118, 218	CH
IN-W247	IN-W247.524	ID-RFO-442T	LEACHED RASHIG RINGS:RH-CERT-REPACK	442	118	118, 218	RH
IN-W247	IN-W247.810	ID-RFO-442T	LEACHED RASHIG RINGS:DIRECT SHIP	442	118	118, 218	CH
IN-W249	IN-W249.1071	ID-MDO-810T	GLASS, FLASKS, SAMPLE VIALS, ETC.:CERT-REPACK	810			CH
IN-W249	IN-W249.527	ID-MDO-810T	GLASS, FLASKS, SAMPLE VIALS, ETC.:DIRECT SHIP	810			CH
IN-W249	IN-W249.528	ID-MDO-810T	GLASS, FLASKS, SAMPLE VIALS, ETC.:HG				CH
IN-W250	IN-W250.259	ID-RFO-123T	LEADED RUBBER:DIRECT SHIP	123		123	CH
IN-W250	IN-W250.941	ID-RFO-123T	LEADED RUBBER:CERT-REPACK	123		123	CH
IN-W252	IN-W252.1000	ID-RFO-339T	LEADED RUBBER GLOVES AND APRONS:CH-UNCERT				CH
IN-W252	IN-W252.282	ID-RFO-339T	LEADED RUBBER GLOVES AND APRONS:RH-CERT-REPACK	339	123	123, 223	RH
IN-W252	IN-W252.283	ID-RFO-339T	LEADED RUBBER GLOVES AND APRONS:CH-CERT-REPACK	339	123	123, 223	CH
IN-W252	IN-W252.811	ID-RFO-339T	LEADED RUBBER GLOVES AND APRONS:CH-CERT	339	123	123, 223	CH
IN-W254	IN-W254.1044	ID-RFO-463T	LEADED RUBBER GLOVES AND APRONS:CH-UNCERT				CH

Appendix E

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W254	IN-W254.1045	ID-RFO-463T	LEADED RUBBER GLOVES AND APRONS:RH-CERT-REPACK	463		223	RH
IN-W254	IN-W254.289	ID-RFO-463T	LEADED RUBBER GLOVES AND APRONS:DIRECT SHIP	463		223	CH
IN-W254	IN-W254.290	ID-RFO-463T	LEADED RUBBER GLOVES AND APRONS:CH-CERT-REPACK	463		223	CH
IN-W256	IN-W256.1062	ID-MDO-802T	DRY BOX GLOVES AND O-RINGS:CERT-REPACK	802			CH
IN-W256	IN-W256.295	ID-MDO-802T	DRY BOX GLOVES AND O-RINGS:DIRECT SHIP	802			CH
IN-W257	IN-W257.558	ID-CPP-151T	SOLIDIFIED FUEL SLUDGE:UNCERTIFIABLE				CH
IN-W257	IN-W257.947	ID-CPP-151T	SOLIDIFIED FUEL SLUDGE:DIRECT SHIP	151			CH
IN-W259	IN-W259.552	ID-AEO-104T	ALPHA HOT CELL WASTE:DIRECT SHIP	104			CH
IN-W259	IN-W259.920	ID-AEO-104T	ALPHA HOT CELL WASTE:CH-UNCERTIFIABLE				CH
IN-W259	IN-W259.921	ID-AEO-104T	ALPHA HOT CELL WASTE:RH-UNCERTIFIABLE				RH
IN-W260	IN-W260.565	ID-BTO-040T	SOLID BINARY SCRAP POWDER, ETC.:CH-UNCERTIFIABLE				CH
IN-W260	IN-W260.566	ID-BTO-040T	SOLID BINARY SCRAP POWDER: RH-DIRECT SHIP	40			CH
IN-W260	IN-W260.567	ID-BTO-040T	SOLID BINARY SCRAP POWDER, ETC.:RH-UNCERTIFIABLE				RH
IN-W260	IN-W260.568	ID-BTO-040T	SOLID BINARY SCRAP POWDER, ETC.:RH-CERT-REPACK	40			RH
IN-W260	IN-W260.916	ID-BTO-040T	SOLID BINARY SCRAP POWDER, ETC.:CH-CERT-REPACK	40			CH
IN-W263	IN-W263.520	ID-MDO-842T	CONTAMINATED SOIL				CH
IN-W265	IN-W265.516	ID-RFO-374T	BLACKTOP, CONCRETE, DIRT, AND SAND:DIRECT SHIP	374	121	121	CH
IN-W265	IN-W265.517	ID-RFO-374T	BLACKTOP, CONCRETE, DIRT, AND SAND:UNCERTIFIABLE				CH
IN-W267	IN-W267.1005	ID-RFO-372TN	GRIT:DIRECT SHIP	372			CH
IN-W267	IN-W267.514	ID-RFO-372TN	GRIT:UNCERTIFIABLE				CH
IN-W269	IN-W269.510	ID-INL-150T	LABORATORY WASTE:DIRECT SHIP	150			CH
IN-W269	IN-W269.535	ID-INL-150T	LABORATORY WASTE:CERT-REPACK	150			CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W271	IN-W271.532	ID-MDO-814T	CONTAMINATED MERCURY OR GRAPHITE CRUCIBL:DIRECT SHIP	814			CH
IN-W271	IN-W271.533	ID-MDO-814T	CONTAMINATED MERCURY OR GRAPHITE CRUCIBL:MERCURY				CH
IN-W272	IN-W272.504	ID-RFO-312T	COARSE GRAPHITE:DIRECT SHIP	312			CH
IN-W272	IN-W272.974	ID-RFO-312T	COARSE GRAPHITE:CERT-REPACK	312			CH
IN-W275	IN-W275.502	ID-RFO-301T	GRAPHITE CORES:DIRECT SHIP	301			CH
IN-W275	IN-W275.967	ID-RFO-301T	GRAPHITE CORES:CERT-REPACK	301			CH
IN-W276	IN-W276.500	ID-RFO-300T	GRAPHITE:DIRECT SHIP	300	115	115, 215	CH
IN-W276	IN-W276.966	ID-RFO-300T	GRAPHITE:CERT-REPACK	300	115	115, 215	CH
IN-W278	IN-W278.1090	ID-RFO-950T	LOW SPECIFIC ACTIVITY METAL, GLASS, ETC.:DIRECT SHIP	950			CH
IN-W278	IN-W278.495	ID-RFO-950T	LOW SPECIFIC ACTIVITY METAL, GLASS, ETC.:UNCERTIFIABLE				CH
IN-W280	IN-W280.1066	ID-MDO-803T	METAL, EQUIPMENT, PIPES, VALVES, ETC.:CERT-REPACK	803			CH
IN-W280	IN-W280.448	ID-MDO-803T	METAL, EQUIPMENT, PIPES, VALVES, ETC.:DIRECT SHIP	803			CH
IN-W280	IN-W280.449	ID-MDO-803T	METAL, EQUIPMENT, PIPES, VALVES, ETC.:MERCURY				CH
IN-W281	IN-W281.487	ID-MDO-824T	NONCOMBUSTIBLE EQUIPMENT BOXES:CERT-REPACK	824			CH
IN-W281	IN-W281.488	ID-MDO-824T	NONCOMBUSTIBLE EQUIPMENT BOXES:UNCERTIFIABLE				CH
IN-W283	IN-W283.481	ID-RFO-241T	AMERICIUM PROCESS RESIDUE:CH-CERT-REPACK	241		225	CH
IN-W283	IN-W283.534	ID-RFO-241T	AMERICIUM PROCESS RESIDUE:DIRECT SHIP	241		225	CH
IN-W283	IN-W283.963	ID-RFO-241T	AMERICIUM PROCESS RESIDUE:CH-UNCERTIFIABLE				CH
IN-W283	IN-W283.964	ID-RFO-241T	AMERICIUM PROCESS RESIDUE:RH-CERT-REPACK	241		225	RH
IN-W285	IN-W285.471	ID-BCO-201T	NONCOMBUSTIBLE SOLIDS:CERT-REPACK	201			CH
IN-W285	IN-W285.815	ID-BCO-201T	NONCOMBUSTIBLE SOLIDS:DIRECT SHIP	201			CH
IN-W287	IN-W287.460	ID-AEO-101T	CUT UP GLOVEBOXES	101			CH
IN-W289	IN-W289.466	ID-OFS-121T	DECONTAMINATION AND DECOMMISSIONING WAST	121		121	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W291	IN-W291.454	ID-AEO-100T	GENERAL PLANT WASTE:DIRECT SHIP	100			CH
IN-W291	IN-W291.455	ID-AEO-100T	GENERAL PLANT WASTE:UNCERT-COMB				CH
IN-W291	IN-W291.456	ID-AEO-100T	GENERAL PLANT WASTE:CERT-REPACK	100			CH
IN-W294	IN-W294.1057	ID-RFO-481T	LEACHED NONSPECIAL SOURCE METAL:CH-UNCERT				CH
IN-W294	IN-W294.342	ID-RFO-481T	LEACHED NONSPECIAL SOURCE METAL:CH-CERT-REPACK	481		217	CH
IN-W294	IN-W294.343	ID-RFO-481T	LEACHED NONSPECIAL SOURCE METAL:RH-CERT-REPACK	481		217	RH
IN-W294	IN-W294.814	ID-RFO-481T	LEACHED NONSPECIAL SOURCE METAL:DIRECT SHIP	481		217	CH
IN-W296	IN-W296.327	ID-RFO-480T	NONSPECIAL SOURCE METAL:CH-CERT-REPACK	480	117	117. 217	CH
IN-W296	IN-W296.329	ID-RFO-480T	NONSPECIAL SOURCE METAL:CH-UNCERT				CH
IN-W296	IN-W296.330	ID-RFO-480T	NONSPECIAL SOURCE METAL:RH-CERT-REPACK	480	117	117, 217	RH
IN-W296	IN-W296.331	ID-RFO-480T	NONSPECIAL SOURCE METAL:RH-UNCERT				RH
IN-W296	IN-W296.813	ID-RFO-480T	NONSPECIAL SOURCE METAL:DIRECT SHIP	480	117	117, 217	CH
IN-W298	IN-W298.317	ID-RFO-320T	TANTALUM:CH-CERT-REPACK	320	117	117, 217	CH
IN-W298	IN-W298.318	ID-RFO-320T	TANTALUM:RH-CERT-REPACK	320	117	117, 217	RH
IN-W298	IN-W298.812	ID-RFO-320T	TANTALUM:DIRECT SHIP	320	117	117, 217	CH
IN-W298	IN-W298.979	ID-RFO-320T	TANTALUM:CH-UNCERT				CH
IN-W300	IN-W300.308	ID-RFO-117T	METAL WASTE:CERT-REPACK	117		117	CH
IN-W300	IN-W300.930	ID-RFO-117T	METAL WASTE:DIRECT SHIP	117		117	CH
IN-W302	IN-W302.299	ID-BTO-020T	NONCOMPRESSIBLE, NONCOMBUSTIBLE:DIRECT SHIP	20			CH
IN-W302	IN-W302.913	ID-BTO-020T	NONCOMPRESSIBLE, NONCOMBUSTIBLE:CERT-REPACK	20			CH
IN-W304	IN-W304.860	ID-MDO-825TN	NONCOMBUSTIBLE EQUIPMENT DRUMS:DIRECT SHIP	825			CH
IN-W304	IN-W304.861	ID-MDO-825TN	NONCOMBUSTIBLE EQUIPMENT DRUMS:CERT-REPACK	825			CH
IN-W305	IN-W305.1068	ID-MDO-804TN	PLASTIC, TYGON, MANIPULATOR BOOTS, ETC.:CERT-REPACK	804			CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W305	IN-W305.828	ID-MDO-804TN	PLASTIC, TYGON, MANIPULATOR BOOTS, ETC.:DIRECT SHIP	804			CH
IN-W306	IN-W306.632	ID-RFO-9999T	PRE-73 DRUMS:CH-UNCERT				CH
IN-W306	IN-W306.633	ID-RFO-9999T	PRE-73 DRUMS:CH-CERT-REPACK	9999			CH
IN-W306	IN-W306.634	ID-RFO-9999T	PRE-73 DRUMS:RH-UNCERT				RH
IN-W306	IN-W306.635	ID-RFO-9999T	PRE-73 DRUMS:RH-CERT-REPACK	9999			RH
IN-W306	IN-W306.817	ID-RFO-9999T	PRE-73 DRUMS:DIRECT SHIP	9999			CH
IN-W308	IN-W308.618	ID-RFO-000T	NOT RECORDED - UNKNOWN:CH-UNCERTIFIABLE				CH
IN-W308	IN-W308.621	ID-RFO-000T	NOT RECORDED - UNKNOWN:RH-UNCERTIFIABLE				RH
IN-W308	IN-W308.816	ID-RFO-000T	NOT RECORDED - UNKNOWN:DIRECT SHIP	0			CH
IN-W309	IN-W309.609	ID-RFO-003T	ORGANIC SETUPS, OIL SOLIDS:UNCERT				CH
IN-W309	IN-W309.610	ID-RFO-003T	ORGANIC SETUPS, OIL SOLIDS:CERT-REPACK	3		212	CH
IN-W311	IN-W311.1013	ID-RFO-409T	MOLTEN SALTS - 30% UNPULVERIZED:CERT-REPACK	409			CH
IN-W311	IN-W311.604	ID-RFO-409T	MOLTEN SALTS - 30% UNPULVERIZED:DIRECT SHIP	409			CH
IN-W312	IN-W312.602	ID-RFO-124TN	CERTIFIED TRU PYROCHEMICAL SALT WASTE:DIRECT SHIP	124		124	CH
IN-W312	IN-W312.942	ID-RFO-124TN	CERTIFIED TRU PYROCHEMICAL SALT WASTE:CERT-REPACK	124		124	CH
IN-W314	IN-W314.1017	ID-RFO-414T	DIRECT OXIDE REDUCTION SALT:CERT-REPACK	414			CH
IN-W314	IN-W314.606	ID-RFO-414T	DIRECT OXIDE REDUCTION SALT:DIRECT SHIP	414			CH
IN-W315	IN-W315.601	ID-RFO-005T	EVAPORATOR SALTS				CH
IN-W317	IN-W317.1028	ID-RFO-432T	LEACHED AND CEMENTED RESIN:CH-UNCERT				CH
IN-W317	IN-W317.1029	ID-RFO-432T	LEACHED AND CEMENTED RESIN:RH-CERT-REPACK	432		226	RH
IN-W317	IN-W317.757	ID-RFO-432T	LEACHED AND CEMENTED RESIN:CH-CERT-REPACK	432		226	CH
IN-W317	IN-W317.758	ID-RFO-432T	LEACHED AND CEMENTED RESIN:DIRECT SHIP	432		226	CH
IN-W319	IN-W319.583	ID-RFO-431T	LEACHED RESIN:UNCERTIFIABLE				CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W319	IN-W319.584	ID-RFO-431T	LEACHED RESIN:DIRECT SHIP	431			CH
IN-W321	IN-W321.1023	ID-RFO-430T	UNLEACHED ION COLUMN RESIN:DIRECT SHIP	430			CH
IN-W321	IN-W321.578	ID-RFO-430T	UNLEACHED ION COLUMN RESIN:UNCERTIFIABLE				CH
IN-W322	IN-W322.851	ID-TRA-154TN	SAMPLE FUEL:DIRECT SHIP	154			CH
IN-W322	IN-W322.952	ID-TRA-154TN	SAMPLE FUEL:CERT-REPACK	154			CH
IN-W323	IN-W323.562	ID-INL-153TN	COMBUSTIBLE LAB WASTE:DIRECT SHIP	153			CH
IN-W323	IN-W323.951	ID-INL-153TN	COMBUSTIBLE LAB WASTE:UNCERTIFIABLE				CH
IN-W325	IN-W325.1076	ID-MDO-815T	CLASSIFIED PARTS:CERT-REPACK	815			CH
IN-W325	IN-W325.679	ID-MDO-815T	CLASSIFIED PARTS:DIRECT SHIP	815			CH
IN-W327	IN-W327.1085	ID-MDO-847T	LOW SPECIFIC ACTIVITY (< 100 NCI/G) COMB:CERT-REPACK	847			CH
IN-W327	IN-W327.735	ID-MDO-847T	LOW SPECIFIC ACTIVITY (< 100 NCI/G) COMB:DIRECT SHIP	847			CH
IN-W329	IN-W329.681	ID-MDO-848T	LOW SPECIFIC ACTIVITY (< 100 NCI/G) NONC:DIRECT SHIP	848			CH
IN-W329	IN-W329.682	ID-MDO-848T	LOW SPECIFIC ACTIVITY (< 100 NCI/G) NONC:UNCERTIFIABLE				CH
IN-W330	IN-W330.677	ID-MDO-801T	RAGS, PAPER, WOOD, ETC.:CERT-REPACK	801			CH
IN-W330	IN-W330.678	ID-MDO-801T	RAGS, PAPER, WOOD, ETC.:DIRECT SHIP	801			CH
IN-W332	IN-W332.661	ID-BCO-204T	SOLIDIFIED SOLUTIONS:DIRECT SHIP	204			CH
IN-W332	IN-W332.962	ID-BCO-204T	SOLIDIFIED SOLUTIONS:CERT-REPACK	204			CH
IN-W334	IN-W334.675	ID-BCO-203T	PAPER, METALS, GLASS:DIRECT SHIP	203			CH
IN-W334	IN-W334.961	ID-BCO-203T	PAPER, METALS, GLASS:CERT-REPACK	203			CH
IN-W336	IN-W336.660	ID-BCO-202T	COMBUSTIBLE SOLIDS:CERT-REPACK	202			CH
IN-W336	IN-W336.820	ID-BCO-202T	COMBUSTIBLE SOLIDS:DIRECT SHIP	202			CH
IN-W337	IN-W337.673	ID-TAN-200T	AMERICIUM SOURCES:CERT-REPACK	200			CH
IN-W337	IN-W337.957	ID-TAN-200T	AMERICIUM SOURCES:DIRECT SHIP	200			CH
IN-W338	IN-W338.657	ID-ANL-163T	ANL-W ACL COLD-LINE ABSORBED LIQUID, MIS:DIRECT SHIP	163			CH
IN-W338	IN-W338.956	ID-ANL-163T	ANL-W ACL COLD-LINE ABSORBED LIQUID, MIS:CERT-REPACK	163			CH
IN-W339	IN-W339.655	ID-ANL-162T	ANL-W FMF EFL ZR-U FUEL CASTING ALLOYS R:DIRECT SHIP	162			CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W339	IN-W339.955	ID-ANL-162T	ANL-W FMF EFL ZR-U FUEL CASTING ALLOYS R:CERT-REPACK	162			CH
IN-W341	IN-W341.671	ID-ANL-160T	ANL-W HFEF ANALYTICAL CHEMISTRY AND META:CERT-REPACK	160			CH
IN-W341	IN-W341.954	ID-ANL-160T	ANL-W HFEF ANALYTICAL CHEMISTRY AND META:DIRECT SHIP	160			CH
IN-W342	IN-W342.652	ID-INL-157T	MISCELLANEOUS SOURCES:DIRECT SHIP	157			CH
IN-W342	IN-W342.953	ID-INL-157T	MISCELLANEOUS SOURCES:CERT-REPACK	157			CH
IN-W345	IN-W345.669	ID-INL-155T	SCRAP:CERT-REPACK	155			CH
IN-W345	IN-W345.819	ID-INL-155T	SCRAP:DIRECT SHIP	155			CH
IN-W347	IN-W347.646	ID-AEO-102T	ABSORBED LIQUIDS:CERT-REPACK	102			CH
IN-W347	IN-W347.818	ID-AEO-102T	ABSORBED LIQUIDS:DIRECT SHIP	102			CH
IN-W348	IN-W348.1012	ID-RFO-393TN	SAND, SLAG, AND CRUCIBLE HEELS:DIRECT SHIP	393			CH
IN-W348	IN-W348.846	ID-RFO-393TN	SAND, SLAG, AND CRUCIBLE HEELS:UNCERTIFIABLE				CH
IN-W349	IN-W349.667	ID-AEO-107T	REMOTE-HANDLED WASTE:RH-UNCERTIFIABLE				RH
IN-W349	IN-W349.924	ID-AEO-107T	REMOTE-HANDLED WASTE:RH-CERTIFIABLE	107			RH
IN-W350	IN-W350.650	ID-AEO-106T	SPECIAL SOURCE MATERIAL:DIRECT SHIP	106			CH
IN-W350	IN-W350.923	ID-AEO-106T	SPECIAL SOURCE MATERIAL: CERT-REPACK	106			CH
IN-W351	IN-W351.648	ID-AEO-105T	EMPTY BOTTLES:DIRECT SHIP	105			CH
IN-W351	IN-W351.922	ID-AEO-105T	EMPTY BOTTLES: CERT-REPACK	105			CH
IN-W353	IN-W353.859	ID-BTO-050TN	SOLIDIFIED SOLUTIONS:DIRECT SHIP	50			CH
IN-W353	IN-W353.917	ID-BTO-050TN	SOLIDIFIED SOLUTIONS:CERT-REPACK	50			CH
IN-W354	IN-W354.1016	ID-RFO-412TN	GIBSON SALTS:CERT-REPACK	412		224	CH
IN-W354	IN-W354.858	ID-RFO-412TN	GIBSON SALTS:DIRECT SHIP	412		224	CH
IN-W355	IN-W355.1015	ID-RFO-411TN	ELECTROREFINING SALT:CERT-REPACK	411	124	124, 224	CH
IN-W355	IN-W355.857	ID-RFO-411TN	ELECTROREFINING SALT:DIRECT SHIP	411	124	124, 224	CH
IN-W356	IN-W356.1014	ID-RFO-410TN	MOLTEN SALTS - 30% PULVERIZED:CERT-REPACK	410		224	CH
IN-W356	IN-W356.856	ID-RFO-410TN	MOLTEN SALTS - 30% PULVERIZED:DIRECT SHIP	410		224	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W357	IN-W357.1022	ID-RFO-425TN	FLUID BED ASH:DIRECT SHIP	425			CH
IN-W357	IN-W357.850	ID-RFO-425TN	FLUID BED ASH:UNCERTIFIABLE				CH
IN-W358	IN-W358.854	ID-INL-152TN	PU NEUTRON SOURCES:RH DIRECT SHIP	152			CH
IN-W358	IN-W358.855	ID-INL-152TN	PU NEUTRON SOURCES:CH-CERT-REPACK	152			CH
IN-W358	IN-W358.948	ID-INL-152TN	PU NEUTRON SOURCES:CH-UNCERTIFIABLE				CH
IN-W358	IN-W358.949	ID-INL-152TN	PU NEUTRON SOURCES:RH-CERT-REPACK	152			RH
IN-W359	IN-W359.853	ID-BTO-015TN	NEUTRON SOURCES	15			CH
IN-W360	IN-W360.852	ID-BTO-012TN	MISCELLANEOUS SOURCES:RH DIRECT SHIP	12			CH
IN-W360	IN-W360.912	ID-BTO-012TN	MISCELLANEOUS SOURCES:CERT-REPACK	12			CH
IN-W361	IN-W361.1021	ID-RFO-422TN	SOOT:DIRECT SHIP	422			CH
IN-W361	IN-W361.849	ID-RFO-422TN	SOOT:UNCERTIFIABLE				CH
IN-W362	IN-W362.1020	ID-RFO-421TN	ASH HEELS:DIRECT SHIP	421			CH
IN-W362	IN-W362.848	ID-RFO-421TN	ASH HEELS:UNCERTIFIABLE				CH
IN-W363	IN-W363.1019	ID-RFO-420TN	VIRGIN INCINERATOR ASH:DIRECT SHIP	420			CH
IN-W363	IN-W363.847	ID-RFO-420TN	VIRGIN INCINERATOR ASH:UNCERTIFIABLE				CH
IN-W364	IN-W364.1011	ID-RFO-392TN	SAND, SLAG AND CRUCIBLES:DIRECT SHIP	392			CH
IN-W364	IN-W364.844	ID-RFO-392TN	SAND, SLAG AND CRUCIBLES:CH-UNCERT				CH
IN-W364	IN-W364.845	ID-RFO-392TN	SAND, SLAG AND CRUCIBLES:RH-UNCERT				RH
IN-W365	IN-W365.1010	ID-RFO-391TN	CRUCIBLES AND SAND:DIRECT SHIP	391			CH
IN-W365	IN-W365.842	ID-RFO-391TN	CRUCIBLES AND SAND:CH-UNCERT				CH
IN-W365	IN-W365.843	ID-RFO-391TN	CRUCIBLES AND SAND:RH-UNCERT				RH
IN-W366	IN-W366.1004	ID-RFO-370TN	LECO CRUCIBLES:CERT-REPACK	370		222	CH
IN-W366	IN-W366.841	ID-RFO-370TN	LECO CRUCIBLES:DIRECT SHIP	370		222	CH
IN-W367	IN-W367.840	ID-RFO-311TN	GRAPHITE HEELS:UNCERTIFIABLE				CH
IN-W367	IN-W367.973	ID-RFO-311TN	GRAPHITE HEELS:DIRECT SHIP	311			CH
IN-W368	IN-W368.839	ID-RFO-310TN	GRAPHITE SCARFINGS:UNCERTIFIABLE				CH
IN-W368	IN-W368.971	ID-RFO-310TN	GRAPHITE SCARFINGS:DIRECT SHIP	310			CH
IN-W369	IN-W369.837	ID-RFO-303TN	SCARFED GRAPHITE CHUNKS:DIRECT SHIP	303	115	115	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
IN-W369	IN-W369.970	ID-RFO-303TN	SCARFED GRAPHITE CHUNKS:CERT-REPACK	303	115	115	CH
IN-W370	IN-W370.836	ID-RFO-115TN	GRAPHITE WASTE:DIRECT SHIP	115		115	CH
IN-W370	IN-W370.929	ID-RFO-115TN	GRAPHITE WASTE:CERT-REPACK	115		115	CH
IN-W371	IN-W371.1018	ID-RFO-416TN	ZINC MAGNESIUM ALLOY METAL:CERT-REPACK	416		217	CH
IN-W371	IN-W371.831	ID-RFO-416TN	ZINC MAGNESIUM ALLOY METAL:DIRECT SHIP	416		217	CH
IN-W372	IN-W372.832	ID-BTO-081TN	MET SAMPLES FISSILE:DIRECT SHIP	81			CH
IN-W372	IN-W372.918	ID-BTO-081TN	MET SAMPLES FISSILE:RH-CERT-REPACK	81			RH
IN-W373	IN-W373.1003	ID-RFO-361TN	INSULATION HEELS:DIRECT SHIP	361			CH
IN-W373	IN-W373.830	ID-RFO-361TN	INSULATION HEELS:UNCERTIFIABLE				CH
IN-W374	IN-W374.1091	ID-RFO-960TN	CONCRETE, ASPHALT, ETC.:UNCERTIFIABLE				CH
IN-W374	IN-W374.829	ID-RFO-960TN	CONCRETE, ASPHALT, ETC.:DIRECT SHIP	960			CH
IN-W375	IN-W375.1096	ID-RFO-995TN	SLUDGE:DIRECT SHIP	995			CH
IN-W375	IN-W375.827	ID-RFO-995TN	SLUDGE:UNCERTIFIABLE				CH
IN-Z001	IN-Z001		INEL BURIED TRU WASTE				U
KA-T001	KA-T001	KA-T001	TRANSURANIC DEBRIS	OR-001	NA		RH
KA-W016	KA-W016	KA-W016	TRANSURANIC DEBRIS	OR-001	NA		RH
LA-W047	LA-M002	LA-M002	CEMENTED PROCESS SLUDGE	002	LA 111A; 211	LA 111A; 211A	CH
LA-W055	LA-T001	LA-T001	MIXED SCRAP METAL	001	LA 125A	LA 125A	CH
LA-W065	LA-T002	LA-T002	CEMENTED PROCESS SLUDGE	002	LA 111A; 211	LA 111A LA 211A	CH
LA-W056	LA-T004	LA-T004	COMBUSTIBLE WASTE	004	LA 116A	LA 116A	CH
LA-W057	LA-T005	LA-T005	NON COMBUSTIBLE WASTE	005	LA 117A; 118	LA 117A; 118A	CH
LA-W058	LA-T006	LA-T006	SOLIDIFIED INORGANIC PROCESS SOLIDS	006	LA 114A; LA 1	LA 114A	CH
LA-W059	LA-T007	LA-T007	HOT-CELL WASTE	007	unknown	Unassigned	CH
LA-W060	LA-T008	LA-T008	SOILS	008	unknown	Unassigned	CH
LA-W061	LA-T009	LA-T009	GLOVEBOX AND DUCTING MATERIAL		unknown	Unassigned	CH
LA-W062	LA-TR04	LA-TR04	COMBUSTIBLE WASTE	004	LA 116A	LA-116A	RH
LA-W063	LA-TR05	LA-TR05	NONCOMBUSTIBLE WASTE		unknown	Unassigned	RH
LA-W064	LA-TR07	LA-TR07	NONCOMBUSTIBLE HOT-CELL WASTE		unknown	Unassigned	RH
LA-W046	LA-W001	LA-M001	MIXED SCRAP METAL	001	LA 125A	LA 125A	CH
LA-W048	LA-W003	LA-M003	SOLIDIFIED AQUEOUS WASTE	003	LA 111B; 211	LA 111B; 211B	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
LA-W049	LA-W004	LA-M004	COMBUSTIBLE WASTE	004	LA 116A	LA 116A	CH
LA-W050	LA-W005	LA-M005	NON COMBUSTIBLE WASTE	005	LA 117A; 118	LA 117A; 118A	CH
LA-W051	LA-W006	LA-M006	SOLIDIFIED INORGANIC PROCESS SOLIDS	006	LA 114A; LA 1	LA 114A	CH
LA-W052	LA-W009	LA-M009	GLOVEBOX AND DUCTING MATERIAL		unknown		CH
LA-W066	LA-W066	LA-M001	METALLIC WASTE	Unknown	N/A	N/A	CH
LA-W067	LA-W067	LA-T004	COMBUSTIBLE DEBRIS	None	None	None	CH
LA-W068	LA-W068	LA-T005	NON COMBUSTIBLE DEBRIS	N/A	N/A	N/A	CH
LA-W053	LA-WR01	LA-MR01	SCRAP METAL	003	LA 117A; 118	LA 125A	RH
LA-W054	LA-WR05	LA-MR05	NON COMBUSTIBLE WASTE	005	unknown	LA 117A; 118A	RH
LA-Z001	LA-Z001		LOS ALAMOS NATIONAL LABORATORY BURIED TRU WASTE				U
LB-T001	LB-T001		LBL - WASTE	UNK	N/A	UNK	CH
LL-W028	LL-M001	Form 1 Mixed	R&D GLOVEBOX WASTE (FORM 1)	001	LL 116	LL 116A	CH
LL-W029	LL-T001	Form 2 Non-mixe	SOLIDIFIED WASTE (FORM 2)	002	LL 111	LL 111A LL 113A	CH
LL-W030	LL-T002	Form 1 Non-mixe	R&D GLOVEBOX WASTE (FORM 1)	001	LL 116	LL 116A	CH
LL-W031	LL-T003	Form 3 Non-mixe	COMBINED METAL SCRAP & INCIDENTAL COMBUST (FORM 3)	003	LL 125	LL 125A	CH
LL-W032	LL-T004	Form 4 Non-mixe	PYROCHEMICAL SALT WASTE (FORM 4)	004	LL 124	LL 124A	CH
LL-W033	LL-T005	Form 5 Non-mixe	HEPA FILTERS (FORM 5)	005		Unassigned	CH
LL-W018	LL-W018	Form 3 Mixed	COMBINED METAL SCRAP & INCIDENTAL COMBUST.(FORM 3)	003	LL 125	LL 125A	CH
LL-W019	LL-W019	Form 2 Mixed	SOLIDIFIED WASTE (FORM 2)	002	LL 111	LL 111A	CH
MC-W001	MC-W001		USAMC TRU WASTE				CH
MD-M001	MD-M001	N/A	ASBESTOS DEBRIS	824			CH
MD-T001	MD-T001	N/A	CEMENT FORMS	836			CH
MD-T003	MD-T003	N/A	CONTAMINATED SOIL	842			CH
MD-T004	MD-T004	N/A	UNCATEGORIZED UNKNOWNS				CH
MD-T005	MD-T005	N/A	CONTAMINATED SOILS WITH DEBRIS	842			CH
MD-T006	MD-T006	N/A	METAL DEBRIS W/O LEAD OR CADMIUM	824			CH
MD-T007	MD-T007	N/A	UNCATEGORIZED METAL DEBRIS				CH
MD-T008	MD-T008	N/A	UNCATEGORIZED PLASTICS/RUBBER DEBRIS	827			CH
MD-T009	MD-T009	N/A	UNKNOWN/OTHER ORGANIC DEBRIS	827			CH
MD-T010	MD-T010	N/A	COMPOSITE FILTERS	824			CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
MD-T012	MD-T012	N/A	UNCATEGORIZED HETEROGENEOUS DEBRIS				CH
MD-W002	MD-W002	N/A	ABSORBED AQUEOUS LIQUIDS				CH
MD-W003	MD-W003	N/A	LEADED GLOVES/APRONS	827			CH
MD-W017	MD-W017	N/A	PAPER/CLOTH DEBRIS	827			CH
MD-W018	MD-W018	N/A	PCB TRU WASTE				CH
MU-W002	MU-W002		HETEROGENEOUS DEBRIS	OR-001	NA	Unassigned	CH
NT-W001	NT-W001	None	HETEROGENEOUS DEBRIS, UNCATEGORIZED	001	NT 111A;116A	NT 111A; 116A; 21	CH
NT-W001	NT-W001	None	HETEROGENEOUS DEBRIS, UNCATEGORIZED	292	NT 111A;116A	NT 111A; 116A; 21	CH
NT-W001	NT-W001	None	HETEROGENEOUS DEBRIS, UNCATEGORIZED	002	NT 111A;116A	NT 111A; 116A; 21	CH
NT-W001	NT-W001	None	HETEROGENEOUS DEBRIS, UNCATEGORIZED	993	NT 111A;116A	NT 111A; 116A; 21	CH
NT-W001	NT-W001	None	HETEROGENEOUS DEBRIS, UNCATEGORIZED	330	NT 111A;116A	NT 111A; 116A; 21	CH
NT-W001	NT-W001	None	HETEROGENEOUS DEBRIS, UNCATEGORIZED	961	NT 111A;116A	NT 111A; 116A; 21	CH
NT-W021	NT-W021		V3XA SPHERES	Unknown	Unknown	None	CH
OR-W040	OR-W040	2308	RH-TRU HETEROGENEOUS DEBRIS	OR-001		Unassigned	RH
OR-W086	OR-W041	T2301	CH-TRU HETEROGENEOUS DEBRIS (NONDEFENSE, NONMIXED)	OR-001		Unassigned	CH
OR-W042	OR-W042	2311	RH-TRU SLUDGE (INACTIVE TANK)	OR-001		Unassigned	RH
OR-W087	OR-W043	B2301	RH-TRU HETEROGENEOUS DEBRIS (BURIED)	OR-001		Unassigned	RH
OR-W044	OR-W044	2305	CH-TRU HETEROGENEOUS DEBRIS	OR-001	OR 125A; 125	OR 125A; 125B	CH
OR-W045	OR-W045	2307	CH-TRU UNCATEGORIZED	OR-001		Unassigned	CH
OR-W046	OR-W046	2313	RH-TRU SLUDGE (ACTIVE TANK)	OR-001		Unassigned	RH
OR-W047	OR-W047	2306	CH-TRU HETEROGENEOUS DEBRIS (WITH LIQUIDS)	OR-001		Unassigned	CH
OR-W088	OR-W048	B2302	CH-TRU HETEROGENEOUS DEBRIS (BURIED)	OR-001		Unassigned	CH
OR-W089	OR-W049	T2303	CH-TRU UNCATEGORIZED (NONMIXED)	OR-001		Unassigned	CH
OR-W090	OR-W050	T2305	RH-TRU UNCATEGORIZED (NONMIXED)	OR-001		Unassigned	RH
OR-W091	OR-W051	2315	CH-TRU HETEROGENEOUS DEBRIS (NONDEFENSE)	OR-001		Unassigned	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
OR-W092	OR-W052	T2302	CH-TRU UNCATEGORIZED (NONDEFENSE, NONMIXED)	OR-001		Unassigned	CH
OR-W093	OR-W053	T2304	CH-TRU HETEROGENEOUS DEBRIS (NONMIXED)	OR-001		Unassigned	CH
OR-W094	OR-W054	T2306	RH-TRU HETEROGENEOUS DEBRIS (NONMIXED)	OR-001		Unassigned	RH
OR-Z001	OR-Z001		OAK RIDGE NATIONAL LABORATORY BURIED TRU WASTE				U
PA-A015	PA-A015	PA-A015	TRANSURANIC - SOLID				CH
PA-B015	PA-B015	PA-B015	TRANSURANIC AND TECHNETIUM WASTES - LIQUID				CH
PA-W014	PA-W014	PA-W014	TRANSURANIC WASTE LIQUID				CH
PX-T001	PX-T001	N/A	PANTEX		N/A	Unassigned	CH
RF-W063	RF-MR-0070	None	MISCELLANEOUS LIQUIDS/TRM	RF-806			CH
RF-W063	RF-MR-0200	None	MISCELLANEOUS LIQUIDS/TRM	RF-800			CH
RF-W068	RF-MR-0292	None	PARTICULATE SLUDGE/TRM	RF-806			CH
RF-W068	RF-MR-0299	None	PARTICULATE SLUDGE/TRM	RF-806			CH
RF-W066	RF-MR-0331	None	FILTERS & MEDIA/TRM	RF-376			CH
RF-W065	RF-MR-0333	IDC 333	CALCIUM METAL/TRM	Future			CH
RF-W067	RF-MR-0338	None	CEMENTED FILTERS/TRM	RF-376			CH
RF-W066	RF-MR-0342	None	FILTERS & MEDIA/TRM	RF-335			CH
RF-W058	RF-MR-0365	None	MISC. PU RECOVERY BYPRODUCTS/TRM	Future		Unassigned	CH
RF-W067	RF-MR-0376	None	CEMENTED FILTERS/TRM	RF-376	RF 119	RF 119	CH
RF-W059	RF-MR-0387	None	SAND, SLAG, AND CRUCIBLE/TRM	RF-806		Unassigned	CH
RF-W059	RF-MR-0390	None	SAND, SLAG AND CRUCIBLE/TRU	RF-806			CH
RF-W059	RF-MR-0391	None	SAND, SLAG AND CRUCIBLE/TRM	RF-806			CH
RF-W059	RF-MR-0392	None	SAND, SLAG AND CRUCIBLE/TRM	RF-806			CH
RF-W059	RF-MR-0393	None	SAND, SLAG AND CRUCIBLE/TRM	RF-806			CH
RF-W059	RF-MR-0395	None	SAND, SLAG AND CRUCIBLE/TRM	RF-806			CH
RF-W063	RF-MR-0400	None	MISCELLANEOUS LIQUIDS/TRM	RF-806			CH
RF-W063	RF-MR-0401	None	MISCELLANEOUS LIQUIDS/TRM	RF-806			CH
RF-W058	RF-MR-0409	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH
RF-W058	RF-MR-0411	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH
RF-W058	RF-MR-0413	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH
RF-W058	RF-MR-0414	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RF-W058	RF-MR-0434	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH
RF-W063	RF-MR-0500	None	MISCELLANEOUS LIQUIDS/TRM	RF-806			CH
RF-W063	RF-MR-0503	None	MISCELLANEOUS LIQUIDS/TRM	RF-802			CH
RF-W063	RF-MR-0508	None	MISCELLANEOUS LIQUIDS/TRM	RF-806			CH
RF-W063	RF-MR-0527	None	MISCELLANEOUS LIQUIDS/TRM	RF-802			CH
RF-W063	RF-MR-0541	None	MISCELLANEOUS LIQUIDS/TRM	RF-802			CH
RF-W063	RF-MR-X200	None	MISCELLANEOUS LIQUIDS/TRM	RF-800			CH
RF-W076	RF-MR0089	None	PROCESS RESIDUES/TRM	RF-806		Unassigned	CH
RF-W076	RF-MR0090	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W076	RF-MR0091	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W076	RF-MR0092	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W076	RF-MR0097	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W076	RF-MR0099	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W076	RF-MR0290	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W037	RF-MR0320	IDC 320	HEAVY METAL (NON-SS)/TRM	RF-320	RF 117	RF 117	CH
RF-W028	RF-MR0321	IDC 321	LEAD/TRM	RF-321			CH
RF-W012	RF-MR0330	None	COMBUSTIBLES, DRY/REM	RF-831	None	None	CH
RF-W076	RF-MR0332	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W012	RF-MR0336	None	COMBUSTIBLES/TRM	RF-832	None	None	CH
RF-W012	RF-MR0337	None	COMBUSTIBLES/TRM	RF-833	None	None	CH
RF-W029	RF-MR0339	IDC 339	LEADED DRY BOX GLOVES/REM	RF-339	RF 123	RF 123	CH
RF-W076	RF-MR0340	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W041	RF-MR0341	IDC 341	LEADED GLOVES-ACID CONTAMINATED/TRM	RF-339			CH
RF-W036	RF-MR0371	IDC 377,378,373,	FIREBRICK, /REM			RF-377	CH
RF-W036	RF-MR0373	IDC 377,378,373,	FIREBRICK HEEL/REM	RF-377			CH
RF-W008	RF-MR0374	IDC 374	SOIL & CLEANUP DEBRIS/REM	RF-374			CH
RF-W036	RF-MR0377	IDC 377,378,373,	FIREBRICK COARSE/REM	RF-377			CH
RF-W036	RF-MR0378	IDC 377,378,373,	FIREBRICK, PULVERIZED OR FINES/REM	RF-806			CH
RF-W040	RF-MR0419	None	INCINERATOR ASH/TRM	RF-806			CH
RF-W040	RF-MR0420	None	INCINERATOR ASH/TRM	RF-806			CH
RF-W040	RF-MR0421	None	INCINERATOR ASH/TRM	RF-806			CH
RF-W076	RF-MR0422	None	PROCESS RESIDUES/TRM	RF-806			CH
RF-W076	RF-MR0423	None	PROCESS RESIDUES/TRM	RF-806			CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RF-W040	RF-MR0428	None	INCINERATOR ASH/TRM	RF-806			CH
RF-W091	RF-MR0533	0533, 0535, N/A	ORGANICS DISCARD LEVEL/TRM	RF-801			CH
RF-W091	RF-MR0535	0533, 0535, N/A	ORGANICS DISCARD LEVEL/TRM	RF-801			CH
RF-W068	RF-MT-0292	None	PARTICULATE SLUDGE/TRM	RF-806			CH
RF-W068	RF-MT-0299	None	PARTICULATE SLUDGE/TRM	RF-806			CH
RF-W066	RF-MT-0328	None	FILTERS & MEDIA/TRM	RF-376			CH
RF-W066	RF-MT-0331	None	FILTERS & MEDIA/TRM	RF-376			CH
RF-W066	RF-MT-0335	None	FILTERS & MEDIA/TRM	RF-335	RF 119	RF 119	CH
RF-W067	RF-MT-0338	None	CEMENTED FILTERS/TRM	RF-376	RF 119	RF 119	CH
RF-W066	RF-MT-0342	None	FILTERS & MEDIA/TRM	RF-335			CH
RF-W056	RF-MT-0368	None	MG OXIDE CRUCIBLES/TRM	RF-368	RF 118	RF 118	CH
RF-W068	RF-MT-0372	None	PARTICULATE SLUDGE/TRM	RF-806			CH
RF-W059	RF-MT-0391	None	SAND, SLAG AND CRUCIBLE/TRM	RF-806.2			CH
RF-W059	RF-MT-0392	None	SAND, SLAG AND CRUCIBLE/TRM	RF-806			CH
RF-W059	RF-MT-0393	None	SAND, SLAG AND CRUCIBLE/TRM	RF-806			CH
RF-W063	RF-MT-0400	None	MISCELLANEOUS LIQUIDS/TRM	RF-802			CH
RF-W058	RF-MT-0409	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH
RF-W058	RF-MT-0411	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH
RF-W058	RF-MT-0412	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH
RF-W058	RF-MT-0414	None	MISC PU RECOVERY BYPRODUCT/TRM	Future			CH
RF-W057	RF-MT-0438	IDC 438	INSULATION/TRM	RF-438	RF 122	RF 122	CH
RF-W066	RF-MT-0491	None	FILTERS & MEDIA/TRM	RF-491	RF 119	RF 119	CH
RF-W066	RF-MT-0492	None	FILTERS & MEDIA/TRM	RF-490			CH
RF-W063	RF-MT-0541	None	MISCELLANEOUS LIQUIDS/TRM	RF-802			CH
RF-W068	RF-MT-0823	None	PARTICULATE SLUDGE/TRM	RF-823			CH
RF-W010	RF-MT0001	None	AQUEOUS SLUDGE/TRM	RF-0001	None	None	CH
RF-W013	RF-MT0003	IDC 801	SOLIDIFIED ORGANICS/TRM	RF-801		Unassigned	CH
RF-W010	RF-MT0007	None	BYPASS SLUDGE BLDG 374/TRM	RF-0007	None	None	CH
RF-W037	RF-MT0320	IDC 320	HEAVY METAL (NON-SS)/TRM	RF-320	RF 117	RF 117	CH
RF-W028	RF-MT0321	IDC 321	LEAD/TRM	RF-321	RF 117	RF 117	CH
RF-W012	RF-MT0330	None	COMBUSTIBLES, DRY/TRM	RF-831	None	None	CH
RF-W012	RF-MT0336	None	COMBUSTIBLES/TRM	RF832	None	None	CH
RF-W012	RF-MT0337	None	COMBUSTIBLES/TRM	RF-833	None	None	CH
RF-W029	RF-MT0339	IDC 339	LEADED DRY BOX GLOVES/TRM	RF-339	RF 123	RF 123	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RF-W041	RF-MT0341	IDC 341	LEADED GLOVES-ACID CONTAMINATED/TRM	RF-339			CH
RF-W008	RF-MT0374	IDC 374	SOIL & CLEANUP DEBRIS/TRM	RF-374	RF 121	RF 121	CH
RF-W026	RF-MT0375	IDC 375	USED ABSORBENTS/TRM	RF-375	RF 122	RF 122	CH
RF-W036	RF-MT0377	IDC 377,378,373,	FIREBRICK, COARSE/TRM	RF-377	RF 122	RF 122	CH
RF-W036	RF-MT0378	IDC 377,378,373,	FIREBRICK, PULVERIZED OR FINES/TRM	RF-806			CH
RF-W040	RF-MT0420	None	INCINERATOR ASH/TRM	RF-806			CH
RF-W040	RF-MT0425	None	INCINERATOR ASH/TRM	RF-806			CH
RF-W052	RF-MT0440	None	GLASS/TRM	RF-440	RF 118	RF 118	CH
RF-W052	RF-MT0442	None	GLASS/TRM	RF-442	RF 118	RF 118	CH
RF-W032	RF-MT0444	IDC 444, 855	GROUND LEADED GLASS/TRM	RF-0444	RF 118	RF 118	CH
RF-W011	RF-MT0480	IDC 480	LIGHT METAL/TRM	RF-480	RF 117	RF 117	CH
RF-W090	RF-MT0544	0544	EXCESS CHEMICALS/TRM				CH
RF-W010	RF-MT0800	None	SOLIDIFIED SLUDGE - BLDG 774 / TRM	RF-800	RF 111	RF 111	CH
RF-W013	RF-MT0801	IDC 801	SOLIDIFIED ORGANICS - BLDG 774/TRM	RF-801	RF 112	RF 112	CH
RF-W010	RF-MT0803	None	SOLIDIFIED SLUDGE - BLDG 774 / TRM	RF-803	RF 111	RF 111	CH
RF-W097	RF-MT0806	IDC 806	SOLIDIFIED PROCESS SOLIDS/TRM	RF-806	RF 114	RF 114	CH
RF-W010	RF-MT0807	None	SOLIDIFIED SLUDGE - BLDG 374 / TRM	RF-807	RF 111	RF 111	CH
RF-W012	RF-MT0821	None	COMBUSTIBLES/TRM	RF-831	None	None	CH
RF-W012	RF-MT0822	None	COMBUSTIBLES/TRM	RF-832	None	None	CH
RF-W012	RF-MT0831	None	COMBUSTIBLES/TRM		RF-831	RF 116	CH
RF-W092	RF-MT0831P	0831	PCB SOLIDS-COMPATIBLES/TRM	RF-831			CH
RF-W012	RF-MT0832	None	COMBUSTIBLES/TRM	RF-832	RF 116	RF 116	CH
RF-W012	RF-MT0833	None	COMBUSTIBLES/TRM	RF-833	RF 116	RF 116	CH
RF-W012	RF-MT0853	None	COMBUSTIBLES/TRM	RF-833	RF 116	RF 116	CH
RF-W032	RF-MT0855	IDC 444, 855	GROUND GLASS/TRM	RF-855			CH
RF-W052	RF-MT0856	None	GLASS/TRM	RF-856	RF 118	RF118	CH
RF-W096	RF-MT2116	2116	SUPERCOMPACTED COMBUSTIBLES/TRM	2116	RF-116	RF-116C	CH
RF-W094	RF-MTX111	N/A	WASTEWATER/TRM	RF-801			CH
RF-W089	RF-MTX112	N/A	WET SLURRY/TRM				CH
RF-W091	RF-MTX115	0533, 0535, N/A	ORGANICS DISCARD LEVEL/TRM				CH
RF-W108	RF-T010	None	AQUEOUS SLUDGE/TRU		RF 111	RF 111	CH
RF-W123	RF-TR0044	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0067	None	OXIDES/TRU	TBD		Unassigned	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RF-W123	RF-TR0080	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0081	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0082	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0083	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0084	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0086	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0087	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0089	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0145	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0146	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0289	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W104	RF-TR0290	None	PARTICULATE SLUDGE/TRU	RF-806			CH
RF-W104	RF-TR0299	None	PARTICULATE SLUDGE/TRU	RF-806			CH
RF-W117	RF-TR0300	None	COARSE GRAPHITE/TRU	RF-300			CH
RF-W117	RF-TR0301	None	COARSE GRAPHITE/TRU	RF-300		Unassigned	CH
RF-W117	RF-TR0303	None	COARSE GRAPHITE/TRU	RF-303	RF115	RF 115	CH
RF-W117	RF-TR0310	None	COARSE GRAPHITE/TRU	RF-312		Unassigned	CH
RF-W117	RF-TR0312	None	COARSE GRAPHITE/TRU	RF-312			CH
RF-W111	RF-TR0320	None	HEAVY METAL (NON-SS)/TRU	RF-320		Unassigned	CH
RF-W101	RF-TR0330	None	COMBUSTIBLES/TRU	RF-831	None	None	CH
RF-W120	RF-TR0331	None	FILTERS & MEDIA/TRU	RF-376			CH
RF-W115	RF-TR0334	None	FIREBLANKET/TRU	RF-334		Unassigned	CH
RF-W120	RF-TR0335	None	FILTERS & MEDIA/TRU	RF-335			CH
RF-W101	RF-TR0336	None	COMBUSTIBLES/TRU	RF832	None	None	CH
RF-W101	RF-TR0337	None	COMBUSTIBLES/TRU	RF-833	None	None	CH
RF-W120	RF-TR0338	None	FILTERS & MEDIA/TRU	RF-376			CH
RF-W120	RF-TR0342	None	FILTERS & MEDIA/TRU		RF 119	RF 119	CH
RF-W114	RF-TR0368	None	MG OXIDE CRUCIBLES/TRU	RF-368		Unassigned	CH
RF-W114	RF-TR0370	None	MG OXIDE CRUCIBLES/TRU	RF-370		Unassigned	CH
RF-W121	RF-TR0376	None	CEMENTED FILTERS/TRU	RF-376		Unassigned	CH
RF-W116	RF-TR0390	None	SAND, SLAG AND CRUCIBLE/TRU	RF-806			CH
RF-W116	RF-TR0391	None	SAND, SLAG AND CRUCIBLE/TRU	RF-806			CH
RF-W116	RF-TR0392	None	SAND, SLAG AND CRUCIBLE/TRU	RF-806			CH
RF-W114	RF-TR0394	None	MG OXIDE SAND/TRU	RF-806			CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RF-W116	RF-TR0395	None	SAND, SLAG AND CRUCIBLE/TRU	RF-806			CH
RF-W116	RF-TR0396	None	SAND, SLAG AND CRUCIBLE/TRU	RF-806			CH
RF-W116	RF-TR0398	None	SAND, SLAG AND CRUCIBLE/TRU	RF-806			CH
RF-W103	RF-TR0404	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0405	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0406	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0407	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0408	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0409	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0410	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0411	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0412	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0413	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0414	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0415	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0416	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0417	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0418	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0427	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0429	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W122	RF-TR0430	None	ORGANIC RESINS/TRU	RF-809			CH
RF-W122	RF-TR0431	None	ORGANIC RESINS/TRU	RF-809			CH
RF-W103	RF-TR0433	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W103	RF-TR0434	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W115	RF-TR0438	None	INSULATION/TRU	RF-438	RF 122	RF 122	CH
RF-W113	RF-TR0440	None	GLASS/TRU	RF-440		Unassigned	CH
RF-W113	RF-TR0441	None	GLASS/TRU	RF-442		Unassigned	CH
RF-W113	RF-TR0442	None	GLASS/TRU	RF-442		Unassigned	CH
RF-W102	RF-TR0444	IDC 444	GROUND LEADED GLASS/TRU	RF-0444			CH
RF-W103	RF-TR0473	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W109	RF-TR0479	None	METAL/TRU	RF-480		Unassigned	CH
RF-W109	RF-TR0480	None	METAL/TRU	RF-480		Unassigned	CH
RF-W109	RF-TR0484	None	METAL/TRU			Unassigned	CH
RF-W109	RF-TR0485	None	METAL/TRU			Unassigned	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RF-W109	RF-TR0486	None	METAL/TRU	RF-480		Unassigned	CH
RF-W109	RF-TR0489	None	METAL/TRU	RF-480		Unassigned	CH
RF-W118	RF-TR0504	None	MISCELLANEOUS LIQUIDS/TRU	RF-802			CH
RF-W118	RF-TR0527	None	MISCELLANEOUS LIQUIDS/TRU	RF-802			CH
RF-W118	RF-TR0541	None	MISCELLANEOUS LIQUIDS/TRU	RF-802			CH
RF-W123	RF-TR0600	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0601	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W123	RF-TR0653	None	OXIDES/TRU	TBD		Unassigned	CH
RF-W103	RF-TR0654	None	MISC PU RECOVERY BYPRODUCT/TRU	Future			CH
RF-W116	RF-TR0655	None	SAND, SLAG AND CRUCIBLE/TRU	RF-806			CH
RF-W117	RF-TT0300	None	COARSE GRAPHITE/TRU	RF-300	RF115	RF 115	CH
RF-W117	RF-TT0301	None	COARSE GRAPHITE/TRU	RF-300	RF115	RF 115	CH
RF-W101	RF-TT0302	None	COMBUSTIBLES/TRU	RF-833		Unassigned	CH
RF-W117	RF-TT0303	None	COARSE GRAPHITE/TRU	RF-312			CH
RF-W117	RF-TT0312	None	COARSE GRAPHITE/TRU	RF-312	RF115	RF 115	CH
RF-W111	RF-TT0320	None	HEAVY METAL (NON-SS)/TRU	RF-320	RF 117	RF 117	CH
RF-W101	RF-TT0330	None	COMBUSTIBLES/TRU	RF-831	None	None	CH
RF-W120	RF-TT0335	None	FILTERS & MEDIA/TRU	RF-335	RF 119	RF 119	CH
RF-W101	RF-TT0336	None	COMBUSTIBLES/TRU	RF832	None	None	CH
RF-W101	RF-TT0337	None	COMBUSTIBLES/TRU	RF-833	None	None	CH
RF-W120	RF-TT0338	None	FILTERS & MEDIA/TRU	RF-338	RF 119	RF 119	CH
RF-W107	RF-TT0374	IDC 374	SOIL & CLEANUP DEBRIS/TRU	RF-374	RF 121	RF 121	CH
RF-W121	RF-TT0376	None	CEMENTED FILTERS/TRU	RF-376	RF 119	RF 119	CH
RF-W122	RF-TT0430	None	ORGANIC RESINS/TRU	RF-809			CH
RF-W122	RF-TT0431	None	ORGANIC RESINS/TRU	RF-809			CH
RF-W115	RF-TT0438	None	INSULATION/TRU	RF-438		Unassigned	CH
RF-W113	RF-TT0440	None	GLASS/TRU	RF-440	RF 118	RF 118	CH
RF-W113	RF-TT0441	None	GLASS	RF-442	RF 118	RF 118	CH
RF-W113	RF-TT0442	None	GLASS/TRU	RF-442	RF 118	RF 118	CH
RF-W109	RF-TT0479	None	METAL/TRU	RF-480		Unassigned	CH
RF-W109	RF-TT0480	None	METAL/TRU	RF-480	RF 117	RF 117	CH
RF-W109	RF-TT0481	None	METAL/TRU	RF-481	RF 117	RF 117	CH
RF-W109	RF-TT0484	None	METAL/TRU	RF-480		Unassigned	CH
RF-W109	RF-TT0485	None	METAL/TRU	RF-320		Unassigned	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RF-W109	RF-TT0486	None	METAL/TRU	RF-480		Unassigned	CH
RF-W101	RF-TT0487	None	COMBUSTIBLES/TRU	RF-833	None	None	CH
RF-W109	RF-TT0489	None	METAL/TRU	RF-480		Unassigned	CH
RF-W120	RF-TT0490	None	FILTERS & MEDIA/TRU	RF-490	RF 119	RF 119	CH
RF-W120	RF-TT0491	None	FILTERS & MEDIA/TRU	RF-491	RF 119	RF 119	CH
RF-W118	RF-TT0508	None	MISCELLANEOUS LIQUIDS/TRU	RF-806			CH
RF-W118	RF-TT0541	None	MISCELLANEOUS LIQUIDS/TRU				CH
RF-W112	RF-TT0802	IDC 802	SOLIIFIED LAB WASTE/TRU	RF-802	RF 113	RF 113	CH
RF-W105	RF-TT0806	IDC 806	SOLIDIFIED PROCESS SOLIDS/TRU	RF-806	RF 114	RF 114	CH
RF-W122	RF-TT0809	None	ORGANIC RESINS/TRU	RF-809	RF 126	RF 126	CH
RF-W101	RF-TT0821	None	COMBUSTIBLES/TRU	RF-821		Unassigned	CH
RF-W101	RF-TT0822	None	COMBUSTIBLES/TRU	RF-822	RF 116	RF 116	CH
RF-W100	RF-TT0823	IDC 823	CEMENTED SLUDGE/TRU	RF-823			CH
RF-W109	RF-TT0824	None	METAL/TRU	RF-824	RF 117	RF 117	CH
RF-W101	RF-TT0825	None	COMBUSTIBLES/TRU		RF 116	RF 116	CH
RF-W101	RF-TT0831	None	COMBUSTIBLES/TRU	RF-821	None	None	CH
RF-W101	RF-TT0832	None	COMBUSTIBLES/TRU	RF-822	None	None	CH
RF-W101	RF-TT0833	None	COMBUSTIBLES/TRU	RF-822	None	None	CH
RF-W103	RF-TT0999	None	MISC PU RECOVERY BYPRODUCTS/TRU	Future			CH
RF-W106	RF-TT2116	None	SUPERCOMPACTED COMBUSTIBLES/TRU	2116	RF-116	RF-116C	CH
RF-W106	RF-TT2216	None	SUPERCOMPACTED COMBUSTIBLES/TRU	2116	RF-116	RF-116C	CH
RF-W011	RF-W011	IDC 480	METAL/TRM	RF-480	RF 117	RF 117	CH
RL-W236	RL-T101		202A BLDG TRU WASTE			Unassigned	CH
RL-W237	RL-T102		202-AL BLDG TRU WASTE	001		Unassigned	CH
RL-W238	RL-T103		216-Z-9 RETRIEVED SOIL	072		Unassigned	CH
RL-W239	RL-T104		221-T TRU WASTE	001		Unassigned	CH
RL-W240	RL-T105		222-S TRU WASTE	001		Unassigned	CH
RL-W241	RL-T106		233-S TRU WASTE	001		Unassigned	CH
RL-W242	RL-T107		234-5Z TRU WASTE	001		Unassigned	CH
RL-W243	RL-T108		MISC 200 WEST AREA TRU WASTE	001		Unassigned	CH
RL-W244	RL-T109		308 BLDG TRU WASTE	001		Unassigned	CH
RL-W245	RL-T110		324, 325 AND 327 BLDG OPER TRU WASTE	001		Unassigned	CH
RL-W246	RL-T112		340 BLDG OPER AND R&D TRU WASTE	001		Unassigned	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RL-W247	RL-T113		100 AREAS AND 200 AREAS R&D TRU WASTE	001		Unassigned	CH
RL-W248	RL-T114		209 E BLDG TRU WASTE	001		Unassigned	CH
RL-W249	RL-T115		231-Z BLDG TRU WASTE	001		Unassigned	CH
RL-W250	RL-T116		303C BLDG TRU WASTE	001		Unassigned	CH
RL-W251	RL-T118		300 AREA R&D TRU WASTE	001		Unassigned	CH
RL-W252	RL-T120		TRU CONSTRUCTION DEBRIS	001		Unassigned	CH
RL-W253	RL-T121		105-KE BLDG TRU WASTE	001		Unassigned	RH
RL-W254	RL-T122		105-C, 105KE, AND 105-N BLDG TRU WASTE	001		Unassigned	CH
RL-W255	RL-T123		ARGONNE NAT LAB TYPE 1 TRU WASTE	001		Unassigned	CH
RL-W256	RL-T124		ARGONNE NAT LAB TYPE II TRU WASTE	001		Unassigned	RH
RL-W257	RL-T125		ARGONNE NAT LAB TYPE III TRU WASTE	001		Unassigned	CH
RL-W258	RL-T127		BABCOCK WILCOX TRU WASTE	001		Unassigned	CH
RL-W259	RL-T128		BARTLESVILLE TRU WASTE	001		Unassigned	CH
RL-W260	RL-T129		BATTELLE COLUMBUS TRU WASTE	001		Unassigned	CH
RL-W261	RL-T130		BETTIS TRU WASTE	001		Unassigned	CH
RL-W262	RL-T131		ENERGY SYSTEMS GROUP TRU WASTE	001		Unassigned	CH
RL-W263	RL-T132		EXXON TRU WASTE	001		Unassigned	CH
RL-W264	RL-T133		INTERNATIONAL ATOMIC ENERGY AGENCY TRU WASTE	001		Unassigned	CH
RL-W265	RL-T134		LAWRENCE BERKELEY NAT LAB TRU WASTE	001		Unassigned	CH
RL-W266	RL-T135		LAWRENCE LIVERMORE TRU WASTE	001		Unassigned	CH
RL-W267	RL-T137		KERR MCGEE TRU WASTE	001		Unassigned	CH
RL-W268	RL-T140		ROCKY FLATS TRU WASTE	001		Unassigned	CH
RL-W269	RL-T143		GE SAN JOSE AND VALLECITOS TRU WASTE	001		Unassigned	CH
RL-W270	RL-T145		WARD TRU WASTE	001		Unassigned	CH
RL-W271	RL-T147		325 AND 325B BLDG OP TRU CAISSON WASTE	001		Unassigned	RH
RL-W272	RL-T148		324 AND 327C TRU WASTE	001		Unassigned	RH
RL-W273	RL-T149		325A AND 325B R&D TRU WASTE	001		Unassigned	RH
RL-W274	RL-W161		202A BLDG REMOTE-HANDLED TRU WASTE				RH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RL-W275	RL-W162		202AL AND 222S BLDG REMOTE-HANDLED TRU WASTE				RH
RL-W276	RL-W276		ARGON PB/CD MET LEAD RH ST MTRU				RH
RL-W277	RL-W277		BATCO PB/CD MET LEAD CH RCRA MTRU W/ MET				CH
RL-W278	RL-W278		ESG COMB DEBRIS CH RCRA MTRU W/ MET				CH
RL-W279	RL-W279		MCGEE HETER DEBRIS CH ST MTRU				CH
RL-W280	RL-W280		MCGEE SOLIDIF ORG DEBRIS CH ST MTRU				CH
RL-W281	RL-W281		183H SOLIDIF INORG LABPKS CH RCRA MTRU W/ MET IGN				CH
RL-W282	RL-W282		200W SOLIDIF ORG DEBRIS CH ST MTRU				CH
RL-W283	RL-W283		201C SOILS CH/R RCRA MTRU W/ MET				CH
RL-W284	RL-W284		201C UNK FORM CH RCRA MTRU W/ MET				CH
RL-W285	RL-W285		202A SOLIDIF ORG DEBRIS CH RCRA MTRU W/ ORG IGN				CH
RL-W286	RL-W286		MCGEE SOLIDIF ORG INORG PART CH ST MTRU				CH
RL-W287	RL-W287		202A PB/CD MET DEBRIS CH RCRA MTRU W/ MET COR				CH
RL-W288	RL-W288		202A UNCAT MET DEBRIS CH RCRA MTRU W/ MET COR				CH
RL-W289	RL-W289		202A COMB DEBRIS CH RCRA MTRU W/ MET COR				CH
RL-W290	RL-W290		202A PB/CD MET DEBRIS CH RCRA MTRU W/ MET				CH
RL-W291	RL-W291		202A UNCAT MET DEBRIS CH RCRA MTRU W/ MET				CH
RL-W292	RL-W292		202A INORG NON-MET DEBRIS CH RCRA MTRU W/ MET COR				CH
RL-W293	RL-W293		202A COMB DEBRIS CH RCRA MTRU W/ MET				CH
RL-W294	RL-W294		202A HETER DEBRIS CH RCRA MTRU W/ MET(HG)				CH
RL-W295	RL-W295		202A UNCAT DEBRIS CH RCRA MTRU W/ COR				CH
RL-W296	RL-W296		202A COMB DEBRIS CH RCRA MTRU W/ COR				CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RL-W297	RL-W297		202A UNCAT MET DEBRIS CH ST MTRU				CH
RL-W298	RL-W298		202A COMB DEBRIS CH ST MTRU				CH
RL-W299	RL-W299		202AL UNCAT MET DEBRIS CH RCRA MTRU W/ MET COR				CH
RL-W300	RL-W300		202AL COMB DEBRIS CH RCRA MTRU W/ MET				CH
RL-W301	RL-W301		209E HETER LEAD CH RCRA MTRU W/ MET				CH
RL-W302	RL-W302		222S HETER DEBRIS CH RCRA MTRU W/ MET				CH
RL-W303	RL-W303		224T HETER DEBRIS CH ST MTRU				CH
RL-W304	RL-W304		231Z HETER DEBRIS CH ST MTRU				CH
RL-W305	RL-W305		2345Z COMB DEBRIS CH RCRA MTRU W/ ORG MET				CH
RL-W306	RL-W306		2345Z PB/CD MET DEBRIS CH RCRA MTRU W/ ORG MET				CH
RL-W307	RL-W307		2345Z UNCAT MET DEBRIS CH RCRA MTRU W/ ORG MET COR				CH
RL-W308	RL-W308		2345Z UNCAT MET DEBRIS CH RCRA MTRU W/ ORG				CH
RL-W309	RL-W309		2345Z COMB DEBRIS CH RCRA MTRU W/ ORG				CH
RL-W310	RL-W310		2345Z SOIL DEBRIS CH RCRA MTRU W/ ORG IGN				CH
RL-W311	RL-W311		2345Z PB/CD MET DEBRIS CH RCRA MTRU W/ MET				CH
RL-W312	RL-W312		2345Z PB/CD MET DEBRIS CH RCRA MTRU W/ MET COR				CH
RL-W313	RL-W313		2345Z UNCAT MET DEBRIS CH RCRA MTRU W/ MET				CH
RL-W314	RL-W314		2345Z COMB DEBRIS CH RCRA MTRU W/ MET				CH
RL-W315	RL-W315		2345Z INORG NON-MET DEBRIS CH RCRA MTRU W/ MET IGN				CH
RL-W316	RL-W316		2345Z SOILS CH RCRA MTRU W/ MET COR				CH
RL-W317	RL-W317		2345Z PB/CD MET UNK FORM CH RCRA MTRU W/ MET(HG)				CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RL-W318	RL-W318		2345Z PB/CD MET DEBRIS CH RCRA MTRU W/ MET(HG) COR				CH
RL-W319	RL-W319		2345Z UNCAT MET DEBRIS CH RCRA MTRU W/ MET(HG)				CH
RL-W320	RL-W320		2345Z UNCAT MET DEBRIS CH RCRA MTRU W/ MET(HG) COR				CH
RL-W321	RL-W321		2345Z COMB DEBRIS CH RCRA MTRU W/ MET(HG)				CH
RL-W322	RL-W322		2345Z COMB DEBRIS CH RCRA MTRU W/ MET(HG) COR				CH
RL-W323	RL-W323		2345Z SOILS DEBRIS CH RCRA MTRU W/ MET(HG)				CH
RL-W324	RL-W324		2345Z UNCAT MET DEBRIS CH RCRA MTRU W/ COR				CH
RL-W325	RL-W325		2345Z COMB DEBRIS CH RCRA MTRU W/ COR				CH
RL-W326	RL-W326		2345Z SOLIDIF ORG LABPACKS CH RCRA MTRU W/ ORG IGN				CH
RL-W327	RL-W327		2345Z UNCAT MET DEBRIS CH RC/TS MTRU W/ MET(HG)				CH
RL-W328	RL-W328		2345Z PB/CD DEBRIS CH RC/TS MTRU W/ MET(HG)				CH
RL-W329	RL-W329		2345Z SOLIDIF ORG CH RC/TS MTRU W/ IGN				CH
RL-W330	RL-W330		2345Z UNCAT MET DEBRIS CH ST MTRU				CH
RL-W331	RL-W331		2345Z COMB DEBRIS CH ST MTRU				CH
RL-W332	RL-W332		2345Z UNK FORM CH ST MTRU				CH
RL-W333	RL-W333		2345Z SOLIDIF ORG DEBRIS CH TSCA MTRU				CH
RL-W334	RL-W334		2345Z UNCAT MT DEBRIS CH TSCA MTRU				CH
RL-W335	RL-W335		2718E COMB DEBRIS CH ST MTRU				CH
RL-W336	RL-W336		318 INORG NON-MET PART CH ST MTRU				CH
RL-W337	RL-W337		324 PB/CD MET RH ST MTRU				RH
RL-W338	RL-W338		325 SOLIDIF ORG CH RCRA MTRU W/ ORG MET IGN/COR				CH
RL-W339	RL-W339		325 PB/CD MET LEAD CH RCRA MTRU W/ MET(HG)				CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RL-W340	RL-W340		325 COMB DEBRIS CH RCRA MTRU W/ COR				CH
RL-W341	RL-W341		325A UNCAT MT DEBRIS CH/R RCRA MTRU W/ ORG MET(HG)				CH
RL-W342	RL-W342		325A INORG N-MT DEBR CH/R RCRA MTRU W/ORG MET(HG)				CH
RL-W343	RL-W343		325A COMB DEBRIS CH/R RCRA MTRU W/ ORG MET(HG)				CH
RL-W344	RL-W344		340 SOLIDIF ORG DEBRIS CH/R RCRA MTRU W/ ORG				CH
RL-W345	RL-W345		2345Z SOLIDIF ORG DEBRIS CH ST MTRU				CH
RL-W346	RL-W346		308 UNCAT MT DEBRIS CH RCRA MTRU W/ MET				CH
RL-W347	RL-W347		308 COMBUS DEBRIS CH RCRA MTRU W/ MET(HG)				CH
RL-W348	RL-W348		308 SOLID ORG DEBRIS CH RCRA MTRU W/ MET(HG) COR				CH
RL-W349	RL-W349		308 INORG NON-MET CH RCRA MTRU W/ MET				CH
RL-W350	RL-W350		308 UNCAT MET DEBRIS CH ST MTRU				CH
RL-W351	RL-W351		CUPRC SOIL CH TRU				CH
RL-W352	RL-W352		CUPRC INORG NON-MET DEBRIS CH TRU				CH
RL-W353	RL-W353		ESG INORG NON-MET PART CH TRU				CH
RL-W354	RL-W354		ESG SOIL CH/R TRU				CH
RL-W355	RL-W355		ESG UNCAT MET DEBRIS CH TRU				CH
RL-W356	RL-W356		ESG COMB DEBRIS CH TRU				CH
RL-W357	RL-W357		KAPL UNK FORM CH/R TRU				CH
RL-W358	RL-W358		MCGEE INORG NON-MET DEBRIS CH TRU				CH
RL-W359	RL-W359		MCGEE UNCAT MET DEBRIS CH TRU				CH
RL-W360	RL-W360		MCGEE COMB DEBRIS CH TRU				CH
RL-W361	RL-W361		MCGEE SOLIDIF ORG CH TRU				CH
RL-W362	RL-W362		202A UNCAT MET DEBRIS CH TRU				CH
RL-W363	RL-W363		202A PB/CD MET UNK FORM CH TRU				CH
RL-W364	RL-W364		202A INORG NON-MET DEBRIS CH TRU				CH
RL-W365	RL-W365		202A COMB DEBRIS CH TRU				CH
RL-W366	RL-W366		202A UNK FORM CH TRU				CH

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MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RL-W367	RL-W367		202AL INORG NON-MET DEBRIS CH TRU				CH
RL-W368	RL-W368		202AL COMB DEBRIS CH TRU				CH
RL-W369	RL-W369		209E UNCAT MET DEBRIS CH TRU				CH
RL-W370	RL-W370		209E UNCAT MET DEBRIS CH/R TRU				CH
RL-W371	RL-W371		209E COMB DEBRIS CH TRU				CH
RL-W372	RL-W372		209E COMB DEBRIS CH/R TRU				CH
RL-W373	RL-W373		231Z UNCAT MET UNK FORM CH TRU				CH
RL-W374	RL-W374		2345Z UNCAT MET DEBRIS CH TRU				CH
RL-W375	RL-W375		2345Z UNCAT MET DEBRIS CH/R TRU				CH
RL-W376	RL-W376		2345Z INORG NON-MET DEBRIS CH TRU				CH
RL-W377	RL-W377		2345Z COMB DEBRIS CH TRU				CH
RL-W378	RL-W378		2345Z COMB DEBRIS CH/R TRU				CH
RL-W379	RL-W379		2345Z HETER DEBRIS CH TRU				CH
RL-W380	RL-W380		2345Z SOLIDIF ORG DEBRIS CH TRU				CH
RL-W381	RL-W381		2345Z SOIL DEBRIS CH TRU				CH
RL-W382	RL-W382		2345Z UNK FORM CH TRU				CH
RL-W383	RL-W383		2345Z SOLIDIF INORG LABPACKS CH/R TRU				CH
RL-W384	RL-W384		2718E COMB DEBRIS CH TRU				CH
RL-W385	RL-W385		308 UNCAT MET DEBRIS CH TRU				CH
RL-W386	RL-W386		308 UNCAT MET DEBRIS CH/R TRU				CH
RL-W387	RL-W387		308 INORG NON-MET DEBRIS CH TRU				CH
RL-W388	RL-W388		308 COMB DEBRIS CH TRU				CH
RL-W389	RL-W389		308 COMB DEBRIS CH/R TRU				CH
RL-W390	RL-W390		308 PB/CD MET UNK FORM CH TRU				CH
RL-W391	RL-W391		308 COMB UNK FORM CH TRU				CH
RL-W392	RL-W392		324 INORG NON-MET PART CH TRU				CH
RL-W393	RL-W393		325 INORG NON-MET DEBRIS CH TRU				CH
RL-W394	RL-W394		325 SOLIDIF INORG PART CH TRU				CH
RL-W395	RL-W395		325 UNCAT MET DEBRIS CH TRU				CH
RL-W396	RL-W396		325 UNCAT MET DEBRIS CH/R TRU				CH
RL-W397	RL-W397		325 COMB DEBRIS CH TRU				CH
RL-W398	RL-W398		325 COMB DEBRIS CH/R TRU				CH
RL-W399	RL-W399		327C UNCAT MET DEBRIS CH/R TRU				CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RL-W400	RL-W400		327C INORG NON-MET DEBRIS CH/R TRU				CH
RL-W401	RL-W401		327C COMB DEBRIS CH/R TRU				CH
RL-W402	RL-W402		340 UNCAT MET DEBRIS CH TRU				CH
RL-W403	RL-W403		340 INORG NON-MET DEBRIS CH TRU				CH
RL-W404	RL-W404		340 COMB DEBRIS CH TRU				CH
RL-W405	RL-W405		3720 INORG NON-MET DEBRIS CH TRU				CH
RL-W406	RL-W406		6652H SOILS CH TRU				CH
RL-W407	RL-W407		202A NON-SURPL FAC MT PRG D&D TRU				CH
RL-W408	RL-W408		221T/2706T NON-SURPL FAC MT PRG D&D TRU				CH
RL-W409	RL-W409		2345Z NON-SURPL FAC MT PRG D&D TRU				CH
RL-W410	RL-W410		308 NON-SURPL FAC MT PRG D&D TRU				CH
RL-W411	RL-W411		231-Z NON-SURPL FAC MT PRG D&D TRU				CH
RL-W412	RL-W412		327 NON-SURPL FAC MT PRG D&D TRU				CH
RL-W413	RL-W413		TWRS VIT FAC WASTE TRU TYPE 1				CH
RL-W414	RL-W414		202A NON-SURPL FAC MT PROG D&D MTRU				CH
RL-W415	RL-W415		221T/2706T NON-SURPL FAC MT PRG D&D MTRU				CH
RL-W416	RL-W416		2345Z NON-SURPL FAC MT PRG D&D MTRU				CH
RL-W417	RL-W417		231-Z NON-SURPL FAC MT PRG D&D MTRU				CH
RL-W418	RL-W418		TWRS VIT FAC WASTE MTRU TYPE 1				CH
RL-W419	RL-W419		100K K-BASIN OPERATIONS TRU				RH
RL-W420	RL-W420		TWRS VIT FAC WASTE TRU TYPE 2				RH
RL-W421	RL-W421		221T/2706T T-PLANT OPERATIONS MTRU				RH
RL-W422	RL-W422		TANK WASTE RETRIEVAL MTRU				RH
RL-W423	RL-W423		TWRS VIT FAC WASTE MTRU TYPE 2				RH
RL-W424	RL-W424		327 NON-SURPLUS FACILITY MGMT PRG D&D TRU/RH				RH
RL-W425	RL-W425		100N NON-SURPLUS FACILITY MGMT PRG D&D TRU/RH				RH
RL-W426	RL-W426		202A NON-SURPLUS FACILITY MGMT PRG D&D TRU/RH				RH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
RL-W427	RL-W427		202-A TUNNEL NON-SURPLUS FACILITY MGMT PRG D&D TRU/RH				RH
RL-W428	RL-W428		221T/2706T NON-SURPLUS FACILITY MGMT PRG D&D TRU/RH				RH
RL-W429	RL-W429		2345Z NON-SURPLUS FACILITY MGMT PRG D&D TRU/RH				RH
RL-W430	RL-W430		SURPLUS FACILITY MGMT PRG D&D MTRU/RH				RH
RL-W431	RL-W431		327 NON-SURPLUS FACILITY MGMT PRG D&D MTRU/RH				RH
RL-W432	RL-W432		202A NON-SURPLUS FACILITY MGMT PRG D&D MTRU/RH				RH
RL-W433	RL-W433		221T/2706T NON-SURPLUS FACILITY MGMT PRG D&D MTRU/RH				RH
RL-W434	RL-W434		2345Z NON-SURPLUS FACILITY MGMT PRG D&D MTRU/RH				RH
RL-W435	RL-W435		340 NON-SURPLUS FACILITY MGMT PRG D&D MTRU/RH				RH
RL-W436	RL-W436		TWRS LONG-LENGTH TANK EQUIPMENT MTRU/RH				RH
RL-W437	RL-W437		SURPLUS FACILITY MGMT PRG D&D TRU/CH				CH
RL-W438	RL-W438		NON-TRANSITION PROGRAM TRU/CH				CH
RL-W439	RL-W439		ENVIRONMENTAL RESTORATION PROGRAM TRU/CH SOILS				CH
RL-W440	RL-W440		K BASINS OPERATIONS TRU/CH				CH
RL-W441	RL-W441		K BASIN PROJECT TRU/CH				CH
RL-W442	RL-W442		TWRS CROSS-SITE TRANSFER PROJECT TRU/CH				CH
RL-W443	RL-W443		SURPLUS FACILITY MGMT PRG D&D MTRU/CH				CH
RL-W444	RL-W444		NON-TRANSITION PROGRAM MTRU/CH				CH
RL-Z001	RL-Z001		HANFORD BURIED TRU WASTE				U
SA-T001	SA-T001	NA	LOVELACE ITRI WASTE STREAM		na	Unassigned	CH
SA-W134	SA-W134	NA	TRANSURANIC WASTE AT HOT CELL FACILITY		na	Unassigned	CH
SA-Z001	SA-Z001		SANDIA NATIONAL LABORATORY/NM BURIED TRU WASTE				U

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
SR-Z001	SR-Z001		SAVANNAH RIVER BURIED TRU WASTE				U
SR-W074	T001-221F-HET	SR-T001	CH TRU - HETEROGENEOUS DEBRIS FROM 221F	001	sr125A	SR125A	CH
SR-W074	T001-221F-MET	SR-T001	CH TRU - METAL DEBRIS FROM 221F	n/a	undetermined	undetermined	CH
SR-W074	T001-221F-VIT	SR-T001	CH TRU - VITRIFIED DEBRIS FROM 221F	n/a	undetermined	undetermined	CH
SR-W074	T001-221H-HET	SR-T001	CH TRU - HETEROGENEOUS DEBRIS FROM 221H	001	SR125A	SR125A Unassigned	CH
SR-W074	T001-221H-MET	SR-T001	CH TRU - METAL DEBRIS FROM 221H	n/a	undetermined	undetermined	CH
SR-W074	T001-221H-VIT	SR-T001	CH TRU - VITRIFIED DEBRIS FROM 221H	n/a	undetermined	undetermined	CH
SR-W074	T001-235F-HET	SR-T001	CH TRU HETEROGENEOUS DEBRIS FROM 235F	001	SR125A	SR125A	CH
SR-W074	T001-235F-MET	SR-T001	CH TRU - METAL DEBRIS FROM 235F	n/a	Undetermined	Undetermined	CH
SR-W074	T001-235F-VIT	SR-T001	CH TRU - VITRIFIED DEBRIS FROM 235F	n/a	Undetermined	undetermined	CH
SR-W074	T001-772F-HET	SR-T001	CH TRU - HETEROGENEOUS DEBRIS FROM 772F	001	SR125A	SR125A	CH
SR-W074	T001-772F-MET	SR-T001	CH TRU - METAL DEBRIS FROM 772F	n/a	Undetermined	undetermined	CH
SR-W074	T001-772F-VIT	SR-T001	CH TRU - VITRIFIED DEBRIS FROM 772F	n/a	Undetermined	undetermined	CH
SR-W074	T001-773A-CLAS	SR-T001	CH TRU - CLASSIFIED WASTE FROM 773A	n/a	N/A	N/A	CH
SR-W074	T001-773A-HET	SR-T001	CH TRU - HETEROGENEOUS DEBRIS FROM 773A	001	SR125A	SR125A	CH
SR-W074	T001-773A-MET	SR-T001	CH TRU - METAL DEBRIS FROM 773A	n/a	Undetermined	undetermined	CH
SR-W074	T001-773A-VIT	SR-T001	CH TRU - VITRIFIED DEBRIS FROM 773A	n/a	Undetermined	undetermined	CH
SR-W076	T003-773A-HET	SR-T003	RH TRU HETEROGENEOUS DEBRIS FROM 773A	001	SR125A	SR125A	CH
SR-W076	T003-773A-VIT	SR-T003	RH TRU VITRIFIED DEBRIS FROM 773A	n/a	Undetermined	Undetermined	CH
TB-W001	TB-W001		TELEDYNE BROWN VITRIFIED BOROSILICATE GLASS				CH
SR-W006	W006-773A-VIT	SR-W006	CONTACT HANDLED TRU/LIQUIDS FROM 773A	n/a	none at this tim	none at this time	CH
SR-W026	W026-221F-HET	SR-W026	CH MIXED TRU/THIRDS HETEROGENEOUS DEBRIS FROM 221F	001	SR125A	SR125A	CH
SR-W026	W026-221F-VIT	SR-W026	CH MIXED TRU/THIRDS - VITRIFIED DEBRIS FROM 221F	n/a	undetermined	Undetermined	CH
SR-W026	W026-221H-HET	SR-W026	CH MIXED TRU/THIRDS HETEROGENEOUS DEBRIS FROM 221H	001	SR125A	SR125A	CH
SR-W026	W026-221H-VIT	SR-W026	CH MIXED TRU/THIRDS - VITRIFIED DEBRIS FROM 221H	n/a	Undetermined	Undetermined	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
SR-W026	W026-235F-HET	SR-W026	CH MIXED TRU/THIRDS HETEROGENEOUS DEBRIS FROM 235F	001	sr125A	SR125A	CH
SR-W026	W026-235F-VIT	SR-W026	CH MIXED TRU/THIRDS - VITRIFIED DEBRIS FROM 235F	N/A	Undetermined	Undetermined	CH
SR-W026	W026-772F-HET	SR-W026	CH MIXED TRU/THIRDS HETEROGENEOUS DEBRIS FROM 772F	001	SR125A	SR125A	CH
SR-W026	W026-772F-VIT	SR-W026	CH MIXED TRU/THIRDS - VITRIFIED DEBRIS FROM 772F	n/a	Undetermined	undetermined	CH
SR-W026	W026-773A-HET	SR-W026	CH MIXED TRU/THIRDS HETEROGENEOUS DEBRIS FROM 773A	001	SR125A	SR125A	CH
SR-W026	W026-773A-VIT	SR-W026	CH MIXED TRU/THIRDS - VITRIFIED DEBRIS FROM 773A	n/a	Undetermined	undetermined	CH
SR-W027	W027-221F-HET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - HETEROGENEOUS DEBRIS FROM 221F	001	SR125A	SR125A	CH
SR-W027	W027-221F-MET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - METAL DEBRIS FROM 221F	n/a	Undetermined	undetermined	CH
SR-W027	W027-221F-VIT	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - VITRIFIED DEBRIS FROM 221F	n/a	Undetermined	Undetermined	CH
SR-W027	W027-221H-HET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - HETEROGENEOUS DEBRIS FROM 221H	001	SR125A	SR125A	CH
SR-W027	W027-221H-MET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - METAL DEBRIS FROM 221H	n/a	Undetermined	Undetermined	CH
SR-W027	W027-221H-VIT	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - VITRIFIED DEBRIS FROM 221H	n/a	Undetermined	Undetermined	CH
SR-W027	W027-235F-HET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - HETEROGENEOUS DEBRIS FROM 235F	001	SR125A	SR125A	CH
SR-W027	W027-235F-MET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - METAL DEBRIS FROM 235F	n/a	Undetermined	Undetermined	CH
SR-W027	W027-235F-VIT	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - VITRIFIED DEBRIS FROM 235F	n/a	Undetermined	Undetermined	CH
SR-W027	W027-772F-HET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - HETEROGENEOUS DEBRIS FROM 772F	001	SR125A	SR125A	CH
SR-W027	W027-772F-MET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - METAL DEBRIS FROM 772F	n/a	Undetermined	Undetermined	CH
SR-W027	W027-772F-VIT	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - VITRIFIED DEBRIS FROM 772F	n/a	Undetermined	undetermined	CH
SR-W027	W027-773A-HET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - HETEROGENEOUS DEBRIS FROM 773A	001	SR125A	SR125A	CH

MWIR ID	TWBIR ID	LOCAL ID	Stream Name	IDC	NMVP	TRUCON Code	Handling
SR-W027	W027-773A-MET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - METAL DEBRIS FROM 773A		Undetermined		CH
SR-W027	W027-773A-VIT	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - VITRIFIED DEBRIS FROM 773A	n/a	Undetermined	Undetermined	CH
SR-W027	W027-999-HET	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - HETEROGENEOUS DEBRIS FROM OFFSITE	001	SR125A	SR125A	CH
SR-W027	W027-999-VIT	SR-W0027	CH MIXED TRU/F LISTED SOLVENTS - VITRIFIED DEBRIS FROM OFFSITE	n/a	Undetermined	undetermined	CH
SR-W053	W053-773A-VIT	SR-W053	CONTACT HANDLED MIXED TRU/RESIDUES FROM 773A	n/a	none at this tim	N/A	CH
WV-M005	WV-M005	N/A	TRU FILTERS	N/A	N/A	N/A	RH
WV-M007	WV-M007	N/A	TRU GENERAL WASTE (UNCLASSIFIED)	N/A	N/A	N/A	CH
WV-M008	WV-M008	N/A	TRU CONCRETE	N/A	N/A	N/A	CH
WV-M010	WV-M010		TRU SPENT ABSORBENTS	N/A	N/A	N/A	CH
WV-M012	WV-M012		GLOVE BOXES	N/A	N/A	N/A	CH
WV-M013	WV-M013		SWEEPING COMPOUND	N/A	N/A	N/A	CH
WV-M015	WV-M015	N/A	CHEMICAL PROCESS CELL GENERAL WASTE	N/A	N/A	N/A	RH
WV-T001	WV-T001	N/A	FISSILE MATERIAL - SOLIDS	N/A	N/A	N/A	CH
WV-T002	WV-T002		FISSILE MATERIAL - ALPHA LAB LIQUIDS	N/A	N/A	N/A	CH
WV-T003	WV-T003	N/A	FISSILE MATERIAL-UNH SOLUTION	N/A	N/A	N/A	CH
WV-T004	WV-T004		FISSILE MATERIAL - OTHER	N/A	N/A	N/A	CH
WV-T006	WV-T006	N/A	TRU GENERAL WASTE (CLASSIFIED)	N/A	N/A	N/A	CH
WV-T009	WV-T009	N/A	TRU GENERAL LABORATORY WASTE	N/A	N/A	N/A	CH
WV-T011	WV-T011		TRU GLOVE BOXES (CLASSIFIED)	N/A	N/A	N/A	CH
WV-T014	WV-T014		CHEMICAL PROCESS CELL VESSELS	N/A	N/A	N/A	RH
WV-T016	WV-T016		CHEMICAL PROCESS CELL MISCELLANEOUS EQUIPMENT	N/A	N/A	N/A	RH
WV-T017	WV-T017		SPENT FILTER MEDIA		N/A	N/A	CH
WV-W024	WV-W024	NA	TRU LEAD	N/A	N/A	N/A	CH
WV-W041	WV-W041	NA	TRU PAINT (DRY) WITH METALS	N/A	N/A	N/A	CH
WV-Z001	WV-Z001		WEST VALLEY BURIED TRU WASTE				U

APPENDIX F

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APPENDIX F
MWIR CODE DESIGNATIONS AND DESCRIPTIONS

Code	Description	Code	Description
D001A	High TOC Ignitable Liquids	F001-F005	Solvents
D001B	Descr. Based on 40 CFR 261.21, High TOC Subcat., Managed CWA	F005A	Spent Nonhalogenated Solvents
D001C	Descr. Based on 40 CFR 261.21, High TOC Subcat., Non-CWA	F005B	Listed for 2-Nitropropane
D001X	Unspecified Ignitable Wastes	F005C	Listed for 2-Ethoxyethanol
D002A	Acid, Alkaline, & Other Subcat Based on 40 CFR 261.22 CWA	F005D	Cyclohexanone/Methanol/Carbon Disulfide
D002B	Acid, Alkaline, & Other Subcat Based on 40 CFR 261.22 Non-CWA	F005X	Unspecified Nonhalogenated Solvents
D003A	Reactive Cyanides	F025A	Light Ends
D003B	Reactive Sulfides	P047A	4,6-Dinitro-o-Cresol
D003C	Explosives	P047B	4,6-Dinitro-o-Cresol Salts
D003D	Water Reactives	P047X	Unspecified 4,6-Dinitro-o-Cresol Waste
D003E	Other Reactives	P059A	Heptachlor
D003X	Unspecified Reactives	P059B	Heptachlor epoxide
D006A	TCLP Toxic for Cadmium	P059X	Unspecified Heptachlor
D006B	Cadmium-containing Batteries	P065A	High Mercury Incinerator or RMERC Residues Containing Mercury
D008A	TCLP Toxic for Lead	P065B	Residues That Are Not Incinerator or RMERC Residues
D008B	Lead Acid Batteries	P065C	Low Mercury RMERC Residues Containing Mercury Fulminate
D008C	Radioactive Lead Solids	P065D	Low Mercury Incinerator Residues (NOT RMERC)
D009A	TCLP Toxic for Mercury	P065E	Wastewaters
D009B	High Mercury (Contains Organics)	P065X	Unspecified Mercury Fulminate Waste
D009C	High Mercury (Contains Inorganics)	P092A	High Mercury Incinerator or RMERC Residues Containing Phenyl Mercury Acetate

Code	Description	Code	Description
D009D	Elemental Mercury Contaminated with Radioactive Materials	P092B	Residues That Are Not Incinerator or RMERC Residues
D009E	Hydraulic Oil Contaminated with Mercury Radioactive Material	P092C	Low Mercury RMERC Residues Containing Phenyl Mercury Acetate
D009F	High Level Wastes	P092D	Low Mercury Incinerator Residues Not RMERC Containing Phenyl Mercury Acetate
D009X	Unspecified Mercury	P092E	Wastewaters
D010A	TCLP Toxic for Selenium	P092X	Unspecified Phenyl Mercury Acetate Waste
D010B	High Level Wastes	U151A	High Mercury Residues from RMERC
D011A	TCLP Toxic for Silver	U151B	Low Mercury Residues from RMERC
D011B	High Level Wastes	U151C	Low Mercury Residues
		U151D	Radioactive Elemental Mercury
		U151E	Mercury Wastewaters
		U151X	Unspecified Mercury Waste
		U240A	2,4-D (Dichlorophenoxyacetic Acid)
		U240B	2,4-D Salts and Esters
		U240X	Unspecified 2,4-D Waste

M

APPENDIX G

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APPENDIX G

DOE/RW-0006, Rev. 11

September 1995

Integrated Data Base Report—1994: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics

Prepared for

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Environmental Management
Washington, D.C. 20585

Prepared by

Oak Ridge National Laboratory
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PREFACE

The information in this report summarizes the U.S. Department of Energy (DOE) data base for inventories, projections, and characteristics of domestic spent nuclear fuel and radioactive waste. This report is updated annually to keep abreast of continual waste inventory and projection changes in both the government and commercial sectors. Baseline information is provided for DOE program planning purposes and to support DOE program decisions. Although the primary purpose of this document is to provide background information for program planning within the DOE community, it has also been found useful by state and local governments, the academic community, and some private citizens. To sustain the objectives of this program in providing accurate and complete data in this field of operation, comments and suggestions to improve the quality and coverage are encouraged. Such comments and any general inquiries should be directed to the U.S. Department of Energy at either of the following:

Office of Civilian Radioactive Waste Management
Route Symbol RW-44
1000 Independence Avenue, SW
Washington, DC 20585-0001

Office of Environmental Management
Route Symbol EM-332 or 432
Trevion II
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This report was prepared by the Integrated Data Base Program, which is jointly sponsored by the DOE Office of Civilian Radioactive Waste Management and the DOE Office of Environmental Management. Suggestions, questions, and requests for information may be directed to any of the following:

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An important part of the Integrated Data Base Program is the Steering Committee, whose members provide both generic guidance and technical input. The membership of this committee, shown on the following page, represents all of the major DOE sites and programs for spent nuclear fuel and radioactive waste management. Each support committee member is assisted by a technical liaison as needed. The participation and assistance of these individuals are acknowledged with appreciation.

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3. TRANSURANIC WASTE

3.1 INTRODUCTION

This chapter presents information on the inventories and characteristics of transuranic waste (TRUW) at various DOE waste generator and/or storage sites in the United States. TRUW is a waste category specific to DOE; it does not apply to wastes regulated by the U.S. Nuclear Regulatory Commission. DOE Order 5820.2A defines TRUW as waste that (1) is contaminated with alpha-emitting transuranic (TRU) (i.e., atomic numbers greater than 92) radionuclides with half-lives greater than 20 years and (2) contains a total concentration of such radionuclides in excess of 100 nCi/g of waste at the time of assay.[1]

DOE Order 5820.2A also states that heads of field elements can determine that other alpha-contaminated waste at the site(s) may be managed as TRUW.[1] As a consequence of this provision, wastes containing radionuclides such as ^{233}U, ^{241}Pu, and ^{244}Cm, which do not meet the strict definition of TRU radionuclides because of their respective atomic numbers or half-lives, may be managed as TRUW at some sites.

Most TRUW exists in solid form (e.g., items such as protective clothing, paper, rags, glass, miscellaneous tools, and equipment that have become contaminated with TRU radionuclides).[2] Some TRUW is in the form of sludges or liquids resulting from chemical processing for recovery of plutonium or other TRU elements.[2] Some of the liquids have been solidified, and some sludges have been dewatered. All sludge and liquid wastes scheduled for disposal in the Waste Isolation Pilot Plant (WIPP) will be solidified prior to shipment to meet the current WIPP waste acceptance criteria.[3]

Before 1970, TRUW was disposed of on-site in shallow, landfill-type, DOE-owned burial sites. TRUW disposed of in this manner is referred to as "buried" TRUW. In 1970, DOE's predecessor agency, the U.S. Atomic Energy Commission, concluded that waste containing long-lived alpha-emitting radionuclides should have greater confinement from the environment. Thus, TRUW generated since the early 1970s has been segregated from other waste types and placed in retrievable storage pending shipment and final disposal in a permanent geologic repository.[4] This waste is referred to as "retrievably stored" TRUW.

Retrievably stored waste is contained in a variety of packagings (e.g., metal drums and wooden and metal boxes) and is stored in various facilities such as earth-mounded berms, concrete culverts, buildings, and on outdoor pads. Many of these facilities have been upgraded and are now in compliance with applicable hazardous waste storage regulations.

TRUW packages are classified as either "contact handled" (CH) or "remote handled" (RH), depending on the radiation level at the surface of the package at the time of packaging. If this level exceeds 200 mrem/h, the package is classified as RH TRUW.

CH TRUW contains relatively small quantities of fission and activation products that produce highly penetrating radiation; typically, its emissions consists mostly of alpha particles and some neutrons and primarily low-energy gamma and X-rays. RH TRUW typically contains a greater proportion of fission and activation products that produce highly penetrating radiation and produce a higher level of radiation at the surface of the package.

TRUW waste which contains, in addition to radioactive constituents, hazardous constituents defined and regulated in accordance with the Resource Conservation and Recovery Act (RCRA) is defined as mixed TRUW. Examples of mixed TRUW are radionuclide-contaminated sludges from plutonium recovery, discarded materials contaminated with both solvents and radioactive materials, scintillation fluids, and discarded contaminated lead shielding. Mixed TRUW must be managed to comply with both the applicable hazardous waste regulations (e.g., RCRA), as well as the regulations applying only to radioactive TRUW.

Some TRUW may also be contaminated with hazardous materials defined by regulations other than RCRA (e.g., Toxic Substances Control Act and state regulations). Once identified, DOE continues to manage these wastes appropriately to meet all other hazardous waste regulations in addition to RCRA (if applicable).

Under existing arrangements, retrievably stored TRUW is the responsibility of the DOE Office of Waste

Management (EM-30). It is planned that the retrievably stored TRUW and newly generated TRUW from routine site operational activities will be shipped to WIPP for disposal; whereas, buried TRUW and TRUW generated from site remediation activities and decontamination and decommissioning (D&D) activities are the responsibility of the Office of Environmental Restoration (EM-40). (See Chapter 6 of this document for a discussion of environmental restoration wastes.)

3.2 TRUW INVENTORIES

3.2.1 Sources of Data

Quantitative information contained in this chapter is derived from data furnished by the DOE sites in response to the integrated data call issued for Rev. 10 of this report[5] and Rev. 1 of the *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report* (WTWBIR)[2] (Sect. 3.2.3.1). As programs and plans evolve or are changed, modifications or additions will be made to the data and other information in this chapter. It is expected that the quality and accuracy of the data will improve with each annual revision of this document, thus improving the usefulness of the data for program planning and decision purposes.

Early TRUW inventory practices were not as stringent as current ones with regard to requirements for waste identification, categorization, and segregation. Consequently, early inventory data are based largely on process knowledge and on various studies and summaries related to site-specific practices.[6] As these efforts continue and TRUW is further characterized, there may be revisions in the estimated overall quantities of TRUW.

3.2.2 Site Locations—Summarized Volumes and Radioactivity

TRUW management activities (generation, retrievable storage, etc.) are performed at 10 major sites and 13 small-quantity sites (SQS). Figure 3.1 shows the locations of the DOE's TRUW generator and/or storage sites. Tables 3.1–3.10 and Figs. 3.2–3.5, which are discussed later in this chapter, summarize the distribution of retrievably stored and projected TRUW in its final form at various DOE generator and storage sites. Unlike previous versions of this report, the volumes reported in this revision are final-form volumes (i.e., after the sites process, treat, or repackage the waste). Tables 3.11 and 3.12 provide a breakdown of the major TRUW radionuclides by radioactivity. These tables display the decayed radioactivities that have been estimated from the data reported by the sites for retrievably stored CH and RH TRUW, as of December 31, 1993. A breakdown for CH and RH TRUW in terms of decayed mass is provided in Tables 3.13 and 3.14, respectively.

3.2.3 Development of Detailed Inventory Data

To optimize its resources and to enhance data quality, DOE integrated the TRUW data needs of the IDB report (Rev. 10)[5] with those of the WTWBIR, Rev. 1,[2] in forming a joint data call to the sites.[7] The information contained in this chapter is a summary of the detailed data gathered through this integrated data-call process and is based on the TRUW final-form-volume projections, as reported in the WTWBIR, Rev. 1.[2] For a complete set of the information collected, refer to the source documents.

The WTWBIR, Rev. 1,[2] describes the disposal inventory of TRUW to be emplaced in WIPP, as defined by the DOE TRUW generator and/or storage sites. This information will be used to support the development of various compliance applications for the operations and postclosure phases of the WIPP repository. To meet the needs of the WTWBIR, site data were collected at the waste-stream level in both their initial and final forms. The data were grouped by similar physical and chemical properties and aggregated to produce estimated total volumes of the waste.

To maintain continuity with the previous revision of the IDB, Table 3.1 presents the changes in reported retrievably stored volumes between the IDB and the WTWBIR. The first column in this table presents the volumes at the end of 1993 that were reported in the previous revision of the IDB (Rev. 10).[5] The next two columns present updated estimates of this same volume (i.e., end of 1993 data) in terms of both initial and final forms, respectively, as reported in the WTWBIR, Rev. 1.[2] The data derived from the WTWBIR, Rev. 1,[2] and reported in subsequent tables in this chapter include the final-form volumes at the end of 1993, and the projected increase in these final-form volumes from 1994 through 2022. In addition, the volumes reported in the attached tables are higher for some sites than those reported in the WTWBIR, Rev. 1,[2] because these volumes include some TRUW regulated under TSCA that was not included in the WIPP inventory defined in WTWBIR, Rev. 1.[2]

Because the radionuclide inventory is not yet available for each waste stream, the radionuclide data in this chapter are derived from the data submittal in support of Rev. 10 of the IDB report.[5] Also taken from the IDB report are the volume data for buried TRUW (Table 3.15), TRU-contaminated soil (Table 3.16), and the retrievably stored TRUW (as of the end of 1993) that is shown in Table 3.1.

The remaining data are compiled from data presented earlier in Rev. 1 of the WTWBIR.[2]

3.2.3.1 Site data submittal process

As stated previously, all of the quantitative TRUW information presented in this chapter was derived from the data received from the sites in response to the integrated WTWBIR–IDB data call. In response to the data call, the sites provided waste stream profiles for each waste stream in their respective current and projected inventories through 2022. The waste stream profiles included such information as waste stream description, initial- and final-form volumes, specific container data, and estimates of the amount of various materials present in the waste (e.g., iron-based metals and alloys, cellulosics, plastics, etc.). In addition, the sites were provided with a list of acceptable final waste forms for disposal at WIPP and asked to assign the appropriate final waste form to each waste stream. The assignment of final waste form helps to identify the general physical and chemical properties of the final form for each waste stream.

The sites provided radionuclide compositions and curies of each radionuclide added in each year of TRUW accumulation. The annual radioactivities in the site submittals were on an as-stored basis; that is, they represent the curies of each radionuclide added each year at the end of the year in which the waste was placed in storage. Only the cumulative site radioactivities have been included in this chapter. For a complete set of references for the TRUW site data submittals, see ref. 7 of Sect. 3.5.

3.2.3.2 Site data review and modification

The site data submittals for TRUW were reviewed to make certain, to the greatest extent possible, that the data supplied met the requirements of completeness and consistency. The data review process included modifying the formats of the data so that they could be easily converted to input data files.

In support of the WTWBIR, waste streams at each TRUW generator and/or storage site that were assigned the same final waste form were grouped together to form site-specific waste profiles. These profiles provide a condensed summary of the volume and waste material information found in the waste stream profiles for each site. Site-specific waste profiles with the same final waste form were then combined for all the TRUW generator and/or storage sites to produce WIPP waste profiles. The summary tables and figures presented in this chapter are based on the detailed waste stream profile data reported in the WTWBIR., Rev. 1.[2]

3.2.3.3 As-stored TRUW volumes

Tables 3.2–3.14 and Figs. 3.2–3.5 summarize a small portion of the information in the WTWBIR site submittals. These tables show the volumes and decayed radioactivities of retrievably stored CH and RH TRUW at each site at the end of 1993, projected generation from 1994 through 2022, and the ending volume inventory amounts at the end of 2022. Each table is constructed to highlight a different aspect of TRUW characteristics.

Table 3.2 shows the total estimated TRUW inventory in storage at the end of 1993 and projected through 2022 for each DOE site, and Tables 3.3–3.8 show the breakup of this total inventory into total CH TRUW (Table 3.3), mixed CH TRUW (Table 3.4), nonmixed CH TRUW (Table 3.5), total RH TRUW (Table 3.6), mixed RH TRUW (Table 3.7), and nonmixed RH TRUW (Table 3.8). The information in these tables is also presented graphically in Figs. 3.2–3.5.

Tables 3.9 and 3.10 show the volumes of TRUW at each site distributed among the 11 final waste forms (plus unknown) defined in the WTWBIR, Rev. 1.[2] Table 3.9 shows the final waste form distribution for the major sites, whereas Table 3.10 presents the same for the SQS.

3.2.3.4 Calculation of annual decayed radioactivities

Decayed radioactivities shown in Rev. 10 of the IDB report[5] were calculated by the ORNL computer code RADAC, using the end-of-1993 data submitted to the IDB by the sites. This code converts the annual as-stored radioactivities to annual decayed radioactivities and accumulates these quantities to produce tables showing decayed grams, curies, and watts on a year-by-year, site-by-site, and radionuclide-by-radionuclide basis. Annual added volumes and cumulative volumes are also calculated. Volumes are assumed to be unaffected by decay.

In some cases, the site data were not sufficiently detailed to permit the desired decay calculations. The difficulty most frequently encountered was that radionuclide compositions were not adequately specified on a radionuclide-by-radionuclide basis. In such cases, data conversion codes were used to convert site input data to the radionuclide-specific forms required for decay calculations. The procedures followed in making these adjustments follow accepted precedents set in previous IDB editions and are described in Rev. 9 of the IDB report.[5]

3.2.4 Results of Radionuclide Inventory Calculations

For the purposes of this report, primary radionuclides are those that cumulatively contribute 98% of either the total radionuclide activity or mass.

3.2.4.1 Retrievably stored wastes

Tables 3.11–3.14 show the distribution of the primary TRUW radionuclides for all the DOE sites (decayed to the end of 1993) for both CH TRUW and RH TRUW both by radioactivity and by mass. As shown in these tables, ^{238}Pu, ^{241}Pu, ^{239}Pu, ^{241}Am, and ^{240}Pu cumulatively contribute more than 98% of the total activity for the CH TRUW (Table 3.11), whereas ^{238}U, ^{232}Th, ^{239}Pu, ^{235}U, and ^{242}Pu contribute more than 98% of the total radionuclide mass for CH TRUW (Table 3.13). Similar information on RH TRUW and on the relative distribution of both the radioactivity and mass of the primary radionuclides for the various DOE sites can also be derived from Tables 3.12 and 3.14.

3.2.4.2 Buried TRUW

Table 3.15 summarizes the buried TRUW volumes and associated radioactivity, both as-stored and as-decayed. Buried TRUW volumes and radioactivities shown in Table 3.15 are based on data provided in the site submittals. The form of the site-submitted data for buried waste is identical to that of the retrievably stored waste except that no distinction is made between CH and RH buried wastes. Table 3.15 shows both cumulative as-stored and as-decayed radioactivities for all nuclides, as well as for TRU nuclides only.

3.2.4.3 Contaminated soil

Over the years, many of the older buried waste containers have developed leaks and contaminated the adjacent soil. Also, at some sites, soil has become contaminated by liquid spills or has been used as an ion-exchange medium for dilute liquid waste streams. It is difficult to make accurate estimates of the actual quantity of the contaminated soil. The data reported by the sites are shown in Table 3.16. Additional characterization efforts will be required to reduce the uncertainties of this data.

3.3 PROJECTED FUTURE QUANTITIES OF TRUW

Tables 3.2–3.10 show the data submitted by the sites for estimated future volumes of TRUW generation. The sites were not requested to estimate the radioactivities or isotopic compositions of these wastes because it was believed that there would be little basis for such estimates. The estimated volumes are given in terms of average annual rates (m^3/year) for four time periods from 1994 to 1997 and for two cumulative time periods (1998–2002 and 2003–2022).

3.4 TRUW DISPOSAL

The goals of the DOE TRUW Program are to terminate interim storage and achieve permanent disposal of DOE TRUW.[9] As stated in Public Law 96-164,[10] WIPP was to be constructed ". . . as a defense activity of the DOE for the purpose of providing a research and development facility to demonstrate the safe disposal of radioactive waste resulting from defense activities and programs of the United States." Construction of the facility is essentially complete, and WIPP is now the only facility specifically designed for isolation of TRUW. It is designed to contain about 175,000 m^3 (6.2 million ft^3)[11] of TRUW 650 m below ground in a mined salt formation.

Waste received at WIPP must meet the WIPP waste acceptance criteria and associated quality assurance requirements specified in WIPP/DOE-069.[3] A number of other approvals remain to be completed before DOE can begin disposal operations at the facility. DOE is committed to demonstrating compliance with all applicable regulations before the permanent disposal of TRUW in the WIPP repository. These regulations are the environmental standards for management and disposal of TRU wastes, as mandated in 40 CFR Part 191 (ref. 12) and Part 194 (ref. 13), and the RCRA regulations. Compliance will be demonstrated through performance assessment calculations based on the inventory of existing and currently projected waste streams as reported by the DOE TRUW generator and/or storage sites in the WTWBIR, Rev. 1.[2]

In 1992 the WIPP Legislative Land Withdrawal Act[11] was passed, confirming congressional intent to have DOE continue with development and permitting of the facility. Since then, DOE has stated its intent to accelerate processes leading to the start of waste disposal operations at the WIPP.

3.5 REFERENCES

1. U.S. Department of Energy, *Radioactive Waste Management*, DOE Order 5820.2A, Washington, D.C. (Sept. 26, 1988).

2. U.S. Department of Energy, *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report*, CAO-94-1005, Rev. 1, Carlsbad, New Mexico (February 1995).

3. U.S. Department of Energy, *TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, WIPP/DOE-069, Rev. 4, Carlsbad, New Mexico (December 1991).

4. K. S. Hollingsworth, *Policy Statement Regarding Solid Waste Burial*, AEC Directive IAD No. 0511-21, Washington, D.C. (Mar. 20, 1970).

5. U.S. Department of Energy, *Integrated Data Base Report—1993: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 10, Oak Ridge National Laboratory, Oak Ridge, Tennessee (December 1994).

6. U.S. Department of Energy, *Defense Waste Management Plan for Buried Transuranic-Contaminated Waste, Transuranic-Contaminated Soil, and Difficult-to-Certify Transuranic Waste*, DOE/DP-0044, Washington, D.C. (June 1987).

7. DOE site TRUW data submittal attachments, submitted to the IDB Program and WTWBIR Project. The following TRUW submittals were received and reviewed by the IDB Program and WTWBIR Project before analysis and integration. Preceding each submittal is the site (in parentheses) to which it refers.

   a. (Ames) Kay M. Lampe Hannasch, Ames Laboratory, Ames, Iowa, correspondence to James E. Fletcher, DOE Chicago Operations Office, Argonne, Illinois, "Data Requests for TRU Waste, WIPP Baseline Inventory, IDB Request," dated Sept. 28, 1994.

   b. (ANL–E) Michael Sodaro, Argonne National Laboratory, Argonne, Illinois, correspondence to Jeff Williams, DOE Carlsbad Area Office, Carlsbad, New Mexico, "WIPP TRU Baseline Inventory Report and Integrated Database Forecasts," dated Sept. 30, 1994.

   c. (ANL–W) Nancy Stewart and Roy Grant, Argonne National Laboratory–West, Idaho Falls, Idaho, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, transmitting site data for inclusion into the IDB report (Rev. 10) and WTWBIR (Rev. 1), dated Jan. 17, 1995.

   d. (BAPL) E. D. Shollenberger, DOE Pittsburgh Naval Reactors Office, West Mifflin, Pennsylvania, correspondence to Mark L. Matthews, DOE Carlsbad Area Office, Carlsbad, New Mexico, "Waste Isolation Pilot Project Transuranic Waste (TRU) Baseline Inventory Report and Updated Integrated Database TRU Information for the Bettis Atomic Power Laboratory," dated Oct. 21, 1994.

   e. (BAPL) Jim Sage, DOE Pittsburgh Naval Reactors Office, West Mifflin, Pennsylvania, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, "WTWBIR Input for the Bettis Atomic Power Laboratory," dated Oct. 21, 1994.

   f. (BCL) No cover letter provided with site data submittal.

   g. (ETEC) G. G. Gaylord, Rockwell International Corporation, Canoga Park, California, correspondence to Mark L. Matthews, DOE Carlsbad Area Office, Carlsbad, New Mexico, "TRU Inventory at ETEC," 94ETEC-DRF-1667, dated Oct. 31, 1994.

h. (ETEC) Alan Von Arx, Energy Technology Engineering Center, Canoga Park, California, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, "Updated Tables 2, 3, 5, 9, & 11," dated Nov. 17, 1994.

i. (Hanford) R. D. Wojtasek, Westinghouse Hanford Company, Richland, Washington, correspondence to Lise Wachter, Martin Marietta Energy Systems, Inc., HAZWRAP, Oliver Springs, Tennessee, "Request for Office of Waste Management, Waste Information Update," 9305688B R1, dated Aug. 30, 1993.

j. (Hanford) F. M. Coony, Westinghouse Hanford Company, Richland, Washington, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, transmitting information on TRUW added to Hanford inventory during CY 1993, dated Dec. 7, 1994.

k. (Hanford) F. M. Coony, Westinghouse Hanford Company, Richland, Washington, correspondence to Jim Teak, Advanced Sciences, Inc., Albuquerque, New Mexico, "Memorandum, Mark L. Matthews, P.E., National TRU Program Office, to Distribution, Extension of Data Package Review, dated Oct. 13, 1994," dated Nov. 1, 1994.

l. (Hanford) F. M. Coony, Westinghouse Hanford Company, Richland, Washington, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, transmitting completed data forms for the 1994 input to the IDB (Rev. 10), dated Dec. 8, 1994.

m. (INEL) Joel T. Case, DOE Idaho Operations Office, Idaho Falls, Idaho, correspondence to Mark L. Matthews, DOE Carlsbad Area Office, Carlsbad, New Mexico, "Integrated Data Base (IDB) TRU Waste 1994 Data Call," OPE-WM-94-307, dated Oct. 6, 1994.

n. (INEL) Joel T. Case, DOE Idaho Operations Office, Idaho Falls, Idaho, correspondence to Jim Teak, Advanced Sciences, Inc., Albuquerque, New Mexico, "Integrated Data Base (IDB) TRU Waste 1994 Data Call," OPE-WM 94-308, dated Oct. 6, 1994.

o. (INEL) T. L. Clements, Jr., Idaho National Engineering Laboratory, Idaho Falls, Idaho, correspondence to J. T. Case, DOE Idaho Operations Office, Idaho Falls, Idaho, "Integrated Data Base (IDB) TRU Waste 1994 Data Call," TLC-122-94, dated Sept. 29, 1994.

p. (ITRI) Bruce B. Boecker, Inhalation Toxicology Research Institute, Albuquerque, New Mexico, correspondence to Jeff Williams, DOE Carlsbad Area Office, Carlsbad, New Mexico, "Response to the Waste Isolation Pilot Plant (WIPP) Transuranic Waste Baseline Inventory Report (WTWBIR) Data Package," dated Nov. 29, 1994.

q. (KAPL) M. Monaco, Knolls Atomic Power Laboratory, Schenectady, New York, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, transmitting data for inclusion into the IDB report (Rev. 10) and WTWBIR (Rev. 1), dated Jan. 16, 1995.

r. (LANL) Davis Christensen, Los Alamos National Laboratory, Los Alamos, New Mexico, correspondence to Mark L. Matthews, DOE Carlsbad Area Office, Carlsbad, New Mexico, "WIPP Transuranic Waste Baseline Inventory Report," CST14-94-061, Nov. 1, 1994.

s. (LANL) Davis Christensen, Los Alamos National Laboratory, Los Alamos, New Mexico, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, transmitting data for inclusion into the IDB report (Rev. 10) and WTWBIR (Rev. 1), dated Nov. 29, 1994 and Dec. 2, 1994.

t. (LBL) Tim Wan, University of California, Berkeley, California, correspondence to Jeff Williams, DOE Carlsbad Area Office, Carlsbad, New Mexico, "Data Package for the Waste Isolation Pilot Plant TRU Waste Baseline Inventory Report," HW-94-342, dated Sept. 13, 1994.

u. (LLNL) Roy Kearns, DOE Oakland Operations Office, Oakland, California, correspondence to Jeff Williams, DOE Carlsbad Area Office, Carlsbad, New Mexico, "Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report and 1994 Integrated Database for Lawrence Livermore National Laboratory," 94W399/5484.a.13, dated Oct. 18, 1994.

v. (LLNL) Kem Hainebach, Lawrence Livermore National Laboratory, Livermore, California, correspondence to Roy Kearns, DOE Oakland Operations Office, Oakland, California, "Corrections to WIPP TRU Waste Baseline Inventory Report," dated Dec. 5, 1994.

w. (Mound) Raymond J. Finney, EG&G Mound Applied Technologies, Miamisburg, Ohio, correspondence to Robert S. Rothman, DOE Miamisburg Area Office, Miamisburg, Ohio, "Response to the Waste Isolation Pilot Plant (WIPP) Transuranic Waste Baseline Inventory Report (WTWBIR) Data Package," dated Sept. 27, 1994.

x. (Mound) Raymond J. Finney, EG&G Mound Applied Technologies, Miamisburg, Ohio, correspondence to Robert S. Rothman, DOE Miamisburg Area Office, Miamisburg, Ohio, "Response to the Waste Isolation Pilot Plant (WIPP) Transuranic Waste Baseline Inventory Report (WTWBIR) Completed Data Package," dated Oct. 26, 1994.

y. (MURR) W. Derek Pickett, University of Missouri, Columbia, Missouri, correspondence to Jim Teak, Advanced Sciences, Inc., Albuquerque, New Mexico, transmitting MURR TRUW information and data for the IDB report (Rev. 10) and WTWBIR (Rev. 1), dated Sept. 29, 1994.

z. (NTS) Joseph M. Ginanni, DOE Nevada Operations Office, Las Vegas, Nevada, correspondence to Jerry Klein, Oak Ridge National Laboratory, Oak Ridge, Tennessee; Jim Teak, Advance Sciences, Inc., Albuquerque, New Mexico; and Jeff Williams, DOE Carlsbad Area Office, Carlsbad, New Mexico, "Nevada Test Site Transuranic and Mixed Transuranic Inventory Data for the 1994 Integrated Data Base Report (DOE/RW-0006, Rev. 10)," dated Oct. 14, 1994.

aa. (ORNL) P. E. Arakawa, Oak Ridge National Laboratory, Oak Ridge, Tennessee, correspondence to Mac Roddye, DOE Oak Ridge Operations Office, Oak Ridge, Tennessee, "Complete Review and Revision of Data Package for the WIPP Transuranic Waste Baseline Inventory Report (WTWBIR)," dated Nov. 2, 1994.

ab. (ORNL) Brad Farrar, S. M. Stoller Corporation, Oak Ridge, Tennessee, correspondence to Jim Teak, Advanced Sciences, Inc., Albuquerque, New Mexico, "1993 IDB Data Call," dated Oct. 3, 1994.

ac. (ORNL) P. E. Arakawa, Oak Ridge National Laboratory, Oak Ridge, Tennessee, correspondence to M. G. Zimmerman, Consolidated Technical Services, Inc., Albuquerque, New Mexico, "Response to Comments on the ORNL WTWBIR Data Submittal, Table 11," dated Nov. 21, 1994.

ad. (ORNL) P. E. Arakawa, Oak Ridge National Laboratory, Oak Ridge, Tennessee, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, "Response to Second Set of Comments on the ORNL WTWBIR Data Submittal," dated Dec. 16, 1994.

ae. (ORNL) Kenneth P. Guay, Oak Ridge National Laboratory, Oak Ridge, Tennessee, correspondence to P. E. Arakawa, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Response to Comments on the ORNL WTWBIR Data Submittal," dated Dec. 16, 1994.

af. (PAD) Greg Shala, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, "TRU/MTRU Data Request," dated Jan. 13, 1995.

ag (PANT) D. L. Heim, DOE Amarillo Area Office, Amarillo, Texas, correspondence to Jeff Williams, DOE Carlsbad Area Office, Carlsbad, New Mexico, "WIPP Transuranic (TRU) Waste Baseline Inventory Report and Integrated Database Report," dated Sept. 28, 1994.

ah. (RFETS) G. A. O'Leary, EG&G Rocky Flats Inc., Golden, Colorado, correspondence to Paul Drez, Drez and Associates, Albuquerque, New Mexico, "Transmittal of the Rocky Flats Environmental Technology Site (RFETS) Data Forms for the Waste Isolation Pilot Plant (WIPP) Transuranic (TRU) Waste Baseline Inventory Report (WTWBIR), GAO-039-94," 94-RF-10526, dated Oct. 13, 1994.

ai. (SNL/NM) E. D. Conway, Sandia National Laboratories, Albuquerque, New Mexico, correspondence to Jeff Williams, DOE Carlsbad Area Office, Carlsbad, New Mexico, transmitting data package for WTWBIR (Rev. 1), dated Oct. 24, 1994.

aj. (SNL/NM) Joe Jones, Sandia National Laboratories, Albuquerque, New Mexico, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, "WIPP TRU Waste Comments," dated Nov. 22, 1994.

ak. (SRS) S. J. Mentrup, Westinghouse Savannah River Company, Aiken, South Carolina, correspondence to Stan Massingill, DOE Savannah River Operations Office, Aiken, South Carolina, "SRS Data Package for WIPP TRU Waste Baseline Inventory Report (U)," SWE-SWE-94-0550, dated Oct. 12, 1994.

al. (WVDP) P. S. Klanian, West Valley Nuclear Services Company, Inc., West Valley, New York, correspondence to Jeff Williams, DOE Carlsbad Area Office, Carlsbad, New Mexico, "Data Package for WIPP Transuranic Waste Baseline Inventory Report (WTWBIR)," dated Oct. 14, 1994.

am. (WVDP) Connie King, West Valley Nuclear Services Company, Inc., West Valley, New York, correspondence to Royes Salmon, Oak Ridge National Laboratory, Oak Ridge, Tennessee, transmitting input to IDB report (Rev. 10), dated Nov. 14, 1994.

an. (WVDP) Connie King, West Valley Nuclear Services Company, Inc., West Valley, New York, correspondence to E. W. Krieger, MAC Technical Services Company, Albuquerque, New Mexico, transmitting responses to WTWBIR Comments, dated Dec. 12, 1994.

8. U.S. Department of Energy, *Integrated Data Base for 1993: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 9, Oak Ridge National Laboratory, Oak Ridge, Tennessee (March 1994).

9. U.S. Department of Energy, *Long Range Master Plan for Defense Transuranic Waste Program*, DOE/WIPP 88-028, Carlsbad, New Mexico, (December 1988).

10. U.S. Congress, *Department of Energy National Security and Military Application of Nuclear Energy Authorization Act of 1980*, Pub. L. 96-164 (1980).

11. U.S. Congress, *Waste Isolation Pilot Plant Land Withdrawal Act*, Pub. L. 102-579 (1992).

12. U.S. Environmental Protection Agency, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, 40 CFR Part 191, final rule, *Fed. Regist.* **58**, 66398 (Dec. 20, 1993).

13. U.S. Environmental Protection Agency, *Criteria for Certification of Compliance with Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Wastes*, 40 CFR Part 194, notice of proposed rulemaking, *Fed. Regist.* **58**, 792 (Jan. 30, 1995).

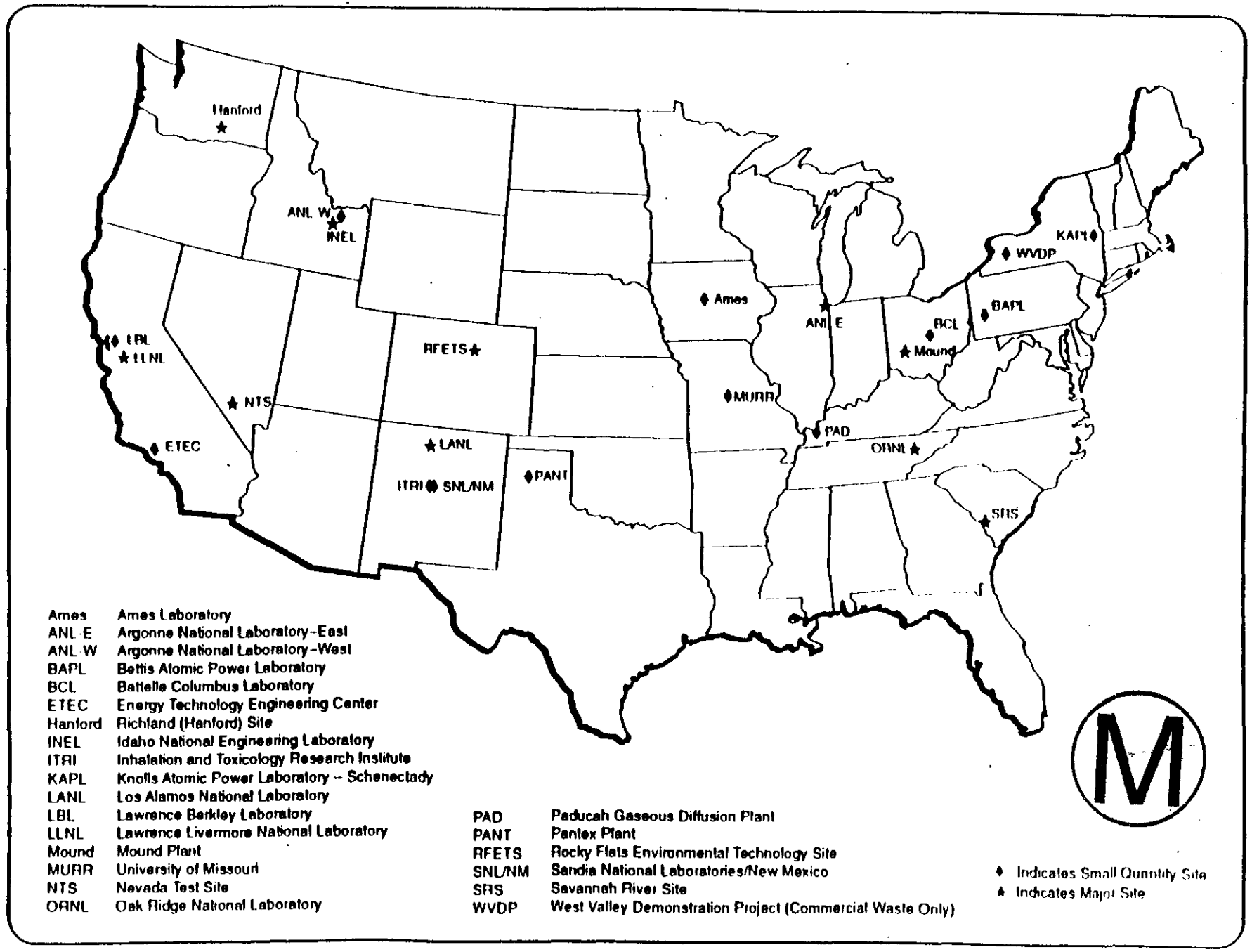

Fig. 3.1. U.S. Department of Energy transuranic waste generation/storage sites.

ORNL-DWG 95-1590R

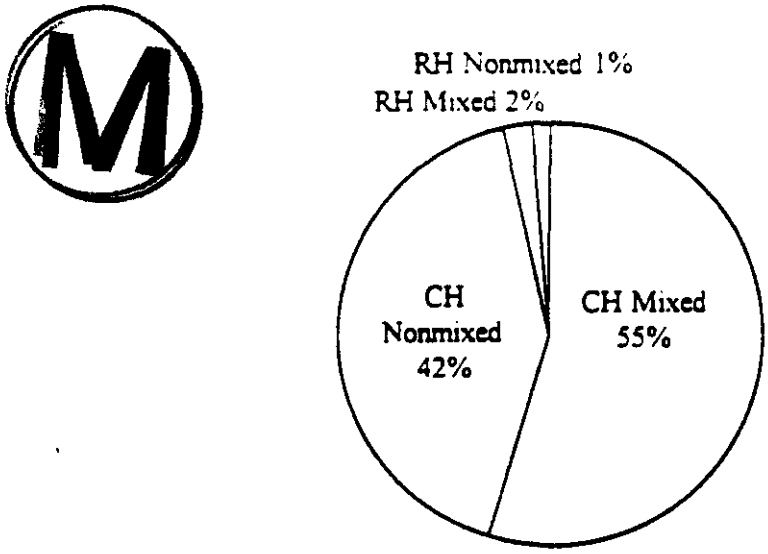

Total TRUW at End of 2022

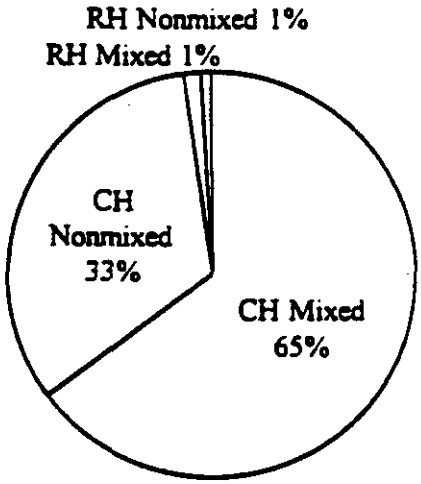

Total Stored TRUW

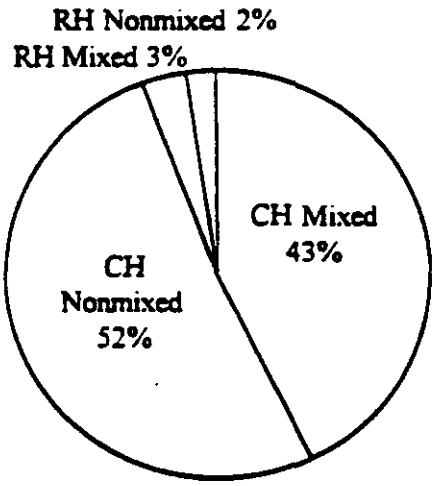

Total Projected TRUW

NOTE: All amounts shown are for final waste form

Fig. 3.2. Retrievably stored and projected TRUW volumes by radioactivity classification.

ORNL DWG 95-1591R

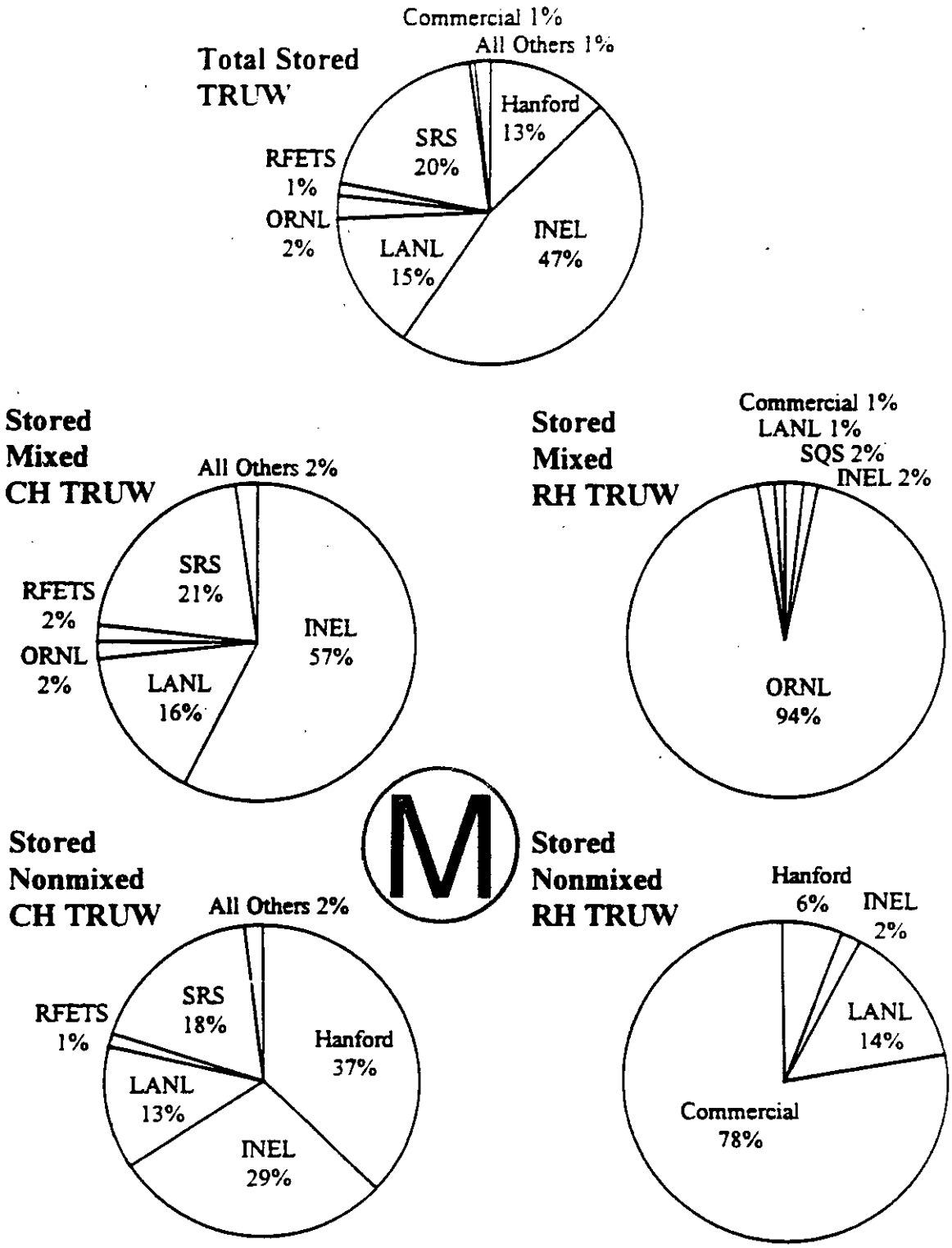

NOTE: All amounts shown are for final waste form

Fig. 3.3. Retrievably stored TRUW volumes by site.

ORNL-DWG 95-1592

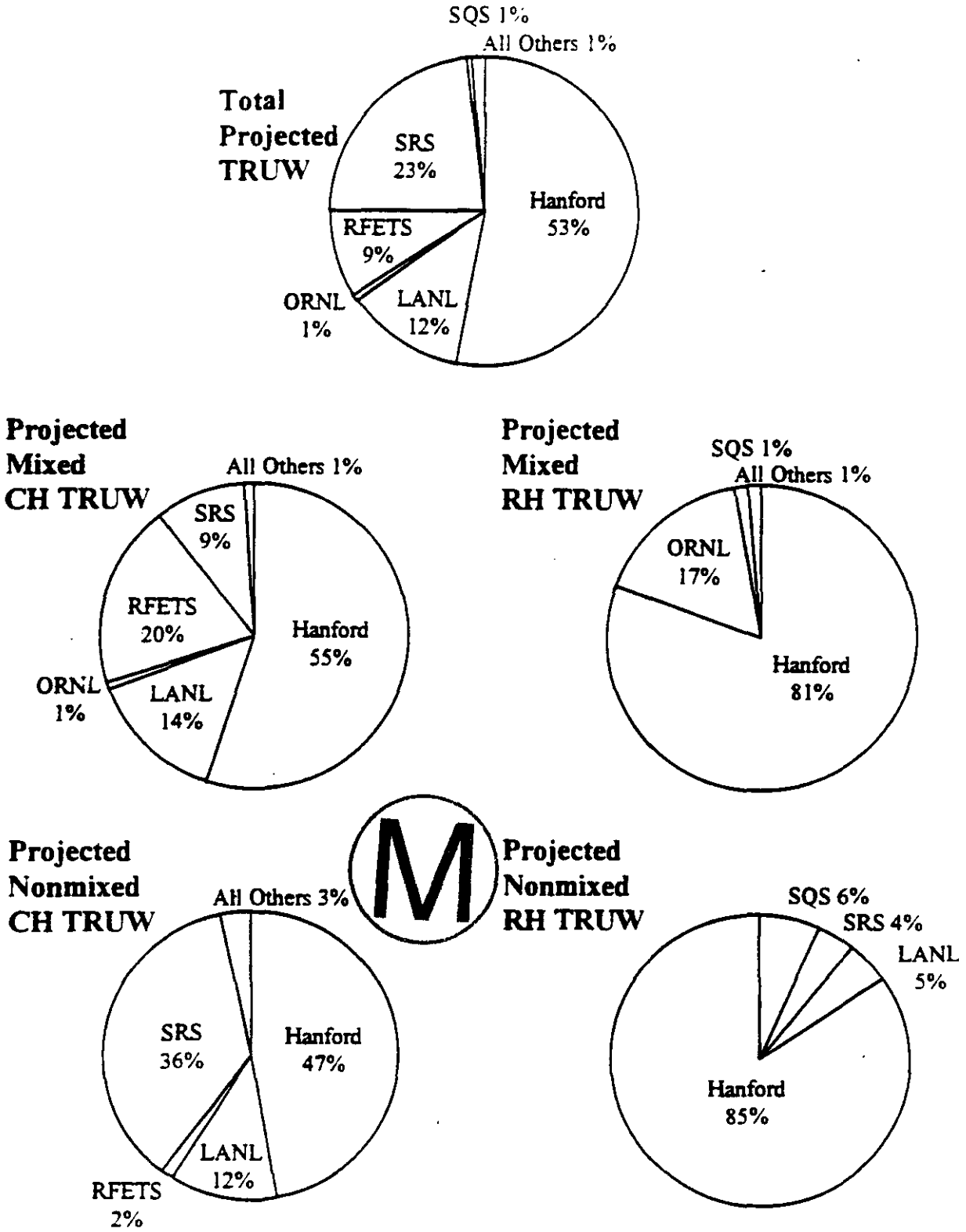

NOTE: All amounts shown are for final waste form

Fig. 3.4. Projected TRUW volumes by site.

ORNL DWG 95-1593R

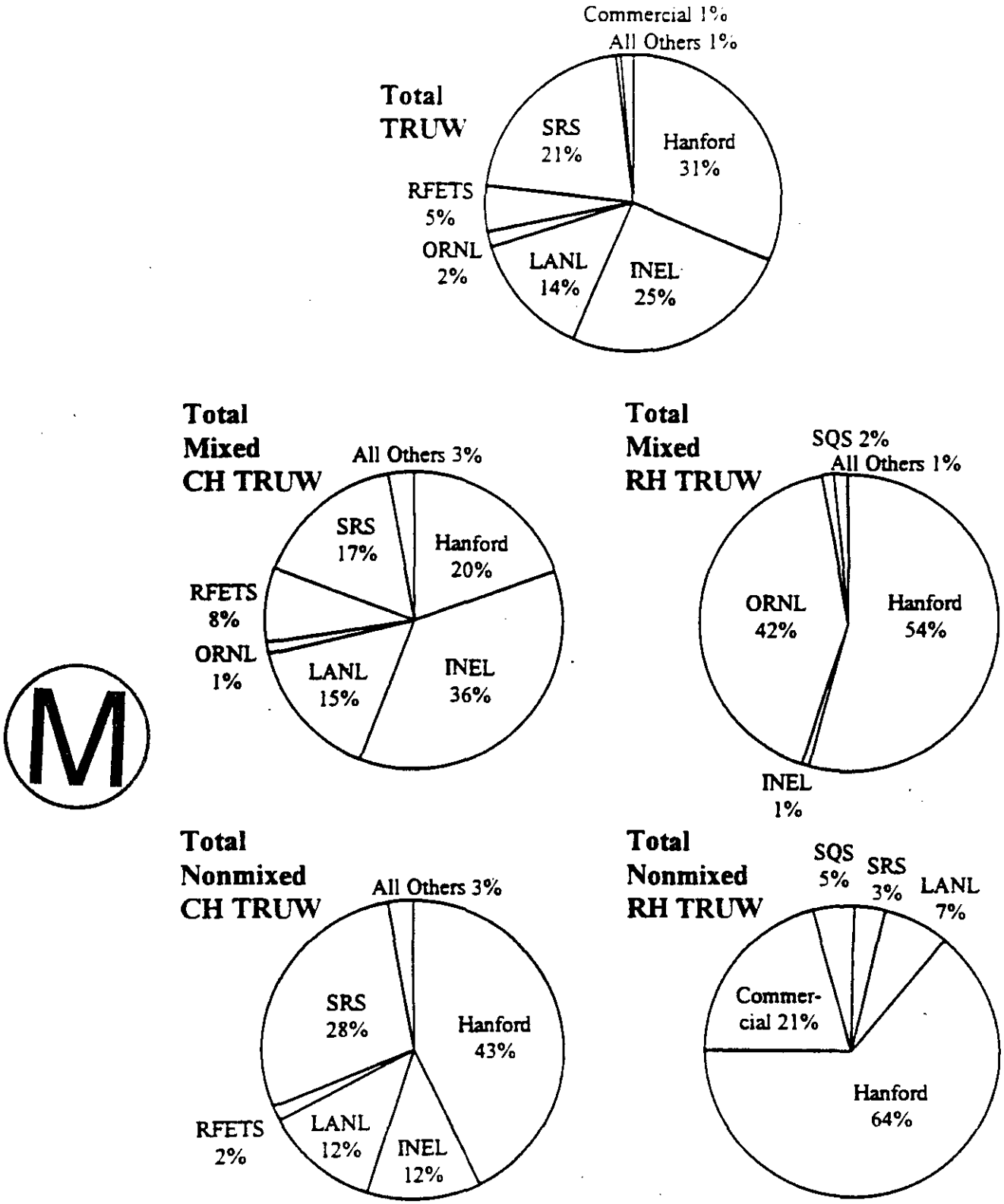

NOTE: All amounts shown are for final waste form

Fig. 3.5. Estimated TRUW volumes by end of year 2022.

Table 3.1. Comparison of IDB and WTWBIR retrievably stored volumes of TRUW[a,b]

(Volumes are expressed in m^3)

Site	Contact-handled TRUW			Remote-handled TRUW		
	As stored		In final form	As stored		In final form
	1993 IDB[c]	1993 WTWBIR[d]	1993 WTWBIR[d]	1993 IDB[c]	1993 WTWBIR[d]	1993 WTWBIR[d]
Major sites						
ANL-E	2.91E+01	2.91E+01	2.91E+01	1.70E+00	0.00E+00[e]	0.00E+00
Hanford	1.56E+04	8.06E+03[f]	9.39E+03[g]	2.01E+02	3.20E+01[h]	3.32E+01[g]
INEL	6.48E+04	3.92E+04[f]	3.47E+04[g]	7.98E+01	3.10E+01[i]	3.10E+01
LANL	1.08E+04	1.09E+04	1.09E+04	9.13E+01	9.13E+01	9.13E+01
LLNL	2.35E+02	2.24E+02	2.24E+02	0.00E+00	0.00E+00	0.00E+00
Mound	1.19E+01	2.63E+02[i]	2.63E+02	0.00E+00	0.00E+00	0.00E+00
NTS	6.07E+02	6.13E+02	6.20E+02[g]	5.30E+00	0.00E+00	0.00E+00
ORNL	2.02E+03	7.83E+02[i]	7.83E+02	5.64E+02	9.94E+02[i]	9.94E+02
RFETS	1.04E+03	1.06E+03	1.13E+03[g]	0.00E+00	0.00E+00	0.00E+00
SRS	8.93E+03	9.34E+03[i]	1.46E+04[g]	0.00E+00	0.00E+00	0.00E+00
Subtotal	1.04E+05	7.04E+04	7.26E+04	9.43E+02	1.15E+03	1.15E+03
Small-quantity sites						
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ANL-W	0.00E+00	2.00E-02[j]	2.00E-02	0.00E+00	8.65E+00[j]	8.65E+00
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BAPL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ETEC	1.90E+00	1.87E+00	1.87E+00	0.00E+00	0.00E+00	0.00E+00
KAPL	0.00E+00	2.40E+00[i]	2.40E+00	2.40E+00	1.12E+01[i]	1.12E+01
LBL	9.00E-01	8.40E-01	8.40E-01	0.00E+00	0.00E+00	0.00E+00
MURR	1.00E-01	6.00E-02[i]	6.00E-02	0.00E+00	0.00E+00	0.00E+00
PAD	4.30E+00	2.10E+00[i]	3.45E+00[g]	0.00E+00	0.00E+00	0.00E+00
PANT	6.00E-01	6.24E-01	6.24E-01	0.00E+00	0.00E+00	0.00E+00
SNL/NM	9.00E-01	8.04E+00[i]	8.04E+00	9.00E-01	0.00E+00[i]	0.00E+00
Subtotal	8.70E+00	1.60E+01	1.73E+01	3.30E+00	1.99E+01	1.99E+01

Table 3.1 (continued)

Site	Contact-handled TRUW			Remote-handled TRUW		
	As stored		In final form	As stored		In final form
	1993 IDB[c]	1993 WTWBIR[d]	1993 WTWBIR[d]	1993 IDB[c]	1993 WTWBIR[d]	1993 WTWBIR[d]
Commercial site						
WVDP	4.91E+01	5.06E+01	5.06E+01	4.27E+02	4.27E+02	4.27E+02
Total	1.04E+05	7.05E+04	7.26E+04	1.37E+03	1.59E+03	1.60E+03

[a]Small changes between the 1993 IDB and 1993 WTWBIR (as stored) volumes are expected because of anticipated rounding methods and differences in reporting methodologies. Volumes reported by the IDB are the as-stored volumes shown by the sites in their data submittals to the IDB.

[b]Some volumes of TSCA waste are included in this table that are not included in the WIPP inventory defined in WTWBIR, Rev. 1. See Tables 3.3, 3.4, and 3.5 for details.

[c]See ref. 5.

[d]See ref. 2.

[e]Volume reported in Hanford submittal.

[f]Adjusted to delete α-LLW volume included in previous IDB submittals.

[g]Difference between "as-stored" and "final-form" volumes primarily caused by volume expansion from repackaging for WIPP waste acceptance criteria (WAC) compliance. INEL shows an overall decrease in volume because of thermal processing of some waste streams.

[h]Approximately 200 m^3 reported with CH-TRUW inventory are from waste streams containing both CH TRUW and RH TRUW (ref. 2, WTWBIR, Rev. 1, Table 6-1).

[i]Volume differences resulting from revised inventory assessment.

[j]Volume previously included in INEL submittal.

Table 3.2. Summary of final waste-form volumes (m^3) of retrievably stored and projected TRUW (mixed and nonmixed CH and RH wastes)[a,b]

Site	EOY[c] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Major sites									
ANL-E	2.91E+01	1.68E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E+00	3.08E+01
Hanford	9.42E+03	1.71E+02	4.91E+02	6.19E+02	1.91E+02	1.29E+03	3.11E+04	3.38E+04	4.33E+04
INEL	3.47E+04	0.00E+00	6.00E-01	6.00E-01	1.60E+00	3.00E+00	1.20E+01	1.78E+01	3.47E+04
LANL	1.10E+04	2.66E+02	2.77E+02	2.77E+02	2.77E+02	1.34E+03	5.32E+03	7.76E+03	1.87E+04
LLNL	2.24E+02	2.11E+01	2.50E+01	2.50E+01	2.50E+01	1.25E+02	5.00E+02	7.21E+02	9.45E+02
Mound	2.63E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.63E+02
NTS	6.20E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.20E+02
ORNL	1.78E+03	2.14E+01	2.14E+01	2.14E+01	2.14E+01	1.07E+02	4.28E+02	6.21E+02	2.40E+03
RFETS	1.13E+03	6.64E+01	1.22E+02	9.31E+01	2.58E+01	1.40E+02	5.45E+03	5.90E+03	7.03E+03
SRS	1.46E+04	5.13E+02	5.11E+02	5.11E+02	5.11E+02	2.56E+03	1.02E+04	1.48E+04	2.94E+04
Subtotal	7.37E+04	1.06E+03	1.45E+03	1.55E+03	1.05E+03	5.56E+03	5.30E+04	6.37E+04	1.37E+05
Small-quantity sites									
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-01	1.00E-01	1.00E-01
ANL-W	8.67E+00	2.24E+00	8.60E-01	1.20E+00	1.76E+00	7.01E+00	2.04E+01	3.35E+01	4.21E+01
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.10E+01	0.00E+00	7.10E+01	7.10E+01
BAPL	0.00E+00	0.00E+00	7.28E-01	2.68E+01	1.74E+01	7.65E+01	3.90E+00	1.25E+02	1.25E+02
ETEC	1.87E+00	0.00E+00	5.20E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E+00	7.07E+00
KAPL	1.36E+01	8.70E-01	8.70E-01	8.70E-01	8.70E-01	4.35E+00	1.74E+01	2.52E+01	3.89E+01
LBL	8.40E-01	0.00E+00	4.20E-01	0.00E+00	0.00E+00	8.00E-01	3.20E+00	4.42E+00	5.26E+00
MURR	6.00E-02	8.00E-02	8.00E-02	8.00E-02	1.36E+00	0.00E+00	0.00E+00	1.60E+00	1.66E+00
PAD	3.45E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.45E+00
PANT	6.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.24E-01
SNL/NM	8.04E+00	0.00E+00	5.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	7.00E+00	1.50E+01
Subtotal	3.72E+01	3.19E+00	1.32E+01	2.90E+01	2.14E+01	1.61E+02	4.60E+01	2.73E+02	3.11E+02
Commercial site									
WVDP	4.78E+02	5.46E+01	2.93E+01	6.33E+00	6.33E+00	9.04E+01	0.00E+00	1.87E+02	6.64E+02
Total	*7.42E+04*	*1.12E+03*	*1.49E+03*	*1.58E+03*	*1.08E+03*	*5.81E+03*	*5.31E+04*	*6.41E+04*	*1.38E+05*

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.

[b]Some volumes of TSCA-contaminated wastes are included in this table that are not included in WTWBIR, Rev. 1 (ref. 2). See Tables 3.3, 3.4, and 3.5 for details.

[c]EOY = end of (calendar) year.

Table 3.3. Summary of final waste-form volumes (m^3) of retrievably stored and projected mixed and nonmixed CH TRUW[a]

Site	EOY[b] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Major sites									
ANL-E	2.91E+01	1.68E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E+00	3.08E+01
Hanford	9.39E+03[c]	1.69E+02	3.88E+02	5.80E+02	1.82E+02	1.19E+03	2.83E+04	3.09E+04[d]	4.02E+04
INEL	3.47E+04	0.00E+00	0.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	1.00E+00	3.47E+04
LANL	1.09E+04	2.54E+02	2.65E+02	2.65E+02	2.65E+02	1.33E+03	5.30E+03	7.67E+03	1.85E+04
LLNL	2.24E+02[e]	2.11E+01	2.50E+01	2.50E+01	2.50E+01	1.25E+02	5.00E+02	7.21E+02[f]	9.45E+02
Mound	2.63E+02[g]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.63E+02
NTS	6.20E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.20E+02
ORNL	7.83E+02	9.10E+00	9.10E+00	9.10E+00	9.10E+00	4.55E+01	1.82E+02	2.64E+02	1.05E+03
RFETS	1.13E+03	6.64E+01	1.22E+02	9.31E+01	2.58E+01	1.40E+02	5.45E+03	5.90E+03	7.03E+03
SRS	1.46E+04	5.09E+02	5.09E+02	5.09E+02	5.09E+02	2.55E+03	1.02E+04	1.48E+04	2.94E+04
Subtotal	7.26E+04	1.03E+03	1.32E+03	1.48E+03	1.02E+03	5.37E+03	5.00E+04	6.02E+04	1.33E+05
Small-quantity sites									
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-01	1.00E-01	1.00E-01
ANL-W	2.00E-02	1.92E+00	4.40E-01	4.40E-01	4.40E-01	2.20E+00	4.00E-01	5.84E+00	5.86E+00
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BAPL	0.00E+00	0.00E+00	4.16E-01	2.66E+01	1.71E+01	7.59E+01	3.80E+00	1.24E+02	1.24E+02
ETEC	1.87E+00	0.00E+00	5.20E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E+00	7.07E+00
KAPL	2.40E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E+00
LBL	8.40E-01	0.00E+00	4.20E-01	0.00E+00	0.00E+00	8.00E-01	3.20E+00	4.42E+00	5.26E+00
MURR	6.00E-02	8.00E-02	8.00E-02	8.00E-02	1.36E+00	0.00E+00	0.00E+00	1.60E+00	1.66E+00
PAD	3.45E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.45E+00
PANT	6.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.24E-01
SNL/NM	8.04E+00	0.00E+00	5.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	7.00E+00	1.50E+01
Subtotal	1.73E+01	2.00E+00	1.16E+01	2.71E+01	1.89E+01	7.99E+01	8.50E+00	1.48E+02	1.65E+02

Table 3.3 (continued)

Site	EOY[b] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Commercial site									
WVDP	5.06E+01	5.46E+01	2.93E+01	6.33E+00	6.33E+00	9.04E+01	0.00E+00	1.87E+02	2.37E+02
Total	7.26E+04	1.09E+03	1.36E+03	1.52E+03	1.04E+03	5.54E+03	5.00E+04	6.05E+04	1.33E+05

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.
[b]EOY = end of (calendar) year.
[c]7.42E+01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[d]9.67E+03 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[e]1.68E+01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[f]3.26E+01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[g]8.00E-01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).

Table 3.4. Final waste-form volumes (m^3) of retrievably stored and projected mixed CH TRUW[a]

Site	EOY[b] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Major sites									
ANL-E	6.21E+00	5.60E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.60E-01	6.77E+00
Hanford	2.10E+02[c]	1.41E+01	3.13E+01	4.60E+01	1.39E+01	1.39E+02	1.49E+04	1.51E+04[d]	1.54E+04
INEL	2.76E+04	0.00E+00	0.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	1.00E+00	2.76E+04
LANL	7.66E+03	1.24E+02	1.35E+02	1.35E+02	1.35E+02	6.75E+02	2.70E+03	3.90E+03	1.16E+04
LLNL	7.92E+00	6.24E-01	1.57E+00	1.57E+00	1.57E+00	7.87E+00	3.15E+01	4.47E+01	5.26E+01
Mound	2.70E+00[e]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E+00
NTS	6.20E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.20E+02
ORNL	7.83E+02	9.10E+00	9.10E+00	9.10E+00	9.10E+00	4.55E+01	1.82E+02	2.64E+02	1.05E+03
RFETS	8.28E+02	4.69E+01	7.49E+01	6.09E+01	2.21E+01	1.13E+02	5.07E+03	5.38E+03	6.21E+03
SRS	1.01E+04	8.84E+01	8.84E+01	8.84E+01	8.84E+01	4.42E+02	1.77E+03	2.56E+03	1.27E+04
Subtotal	4.79E+04	2.84E+02	3.40E+02	3.41E+02	2.71E+02	1.42E+03	2.47E+04	2.73E+04	7.52E+04
Small-quantity sites									
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-01	1.00E-01	1.00E-01
ANL-W	2.00E-02	1.92E+00	2.00E-02	2.00E-02	2.00E-02	1.00E-01	4.00E-01	2.48E+00	2.50E+00
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BAPL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ETEC	2.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-01
KAPL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LBL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MURR	6.00E-02	8.00E-02	8.00E-02	8.00E-02	1.36E+00	0.00E+00	0.00E+00	1.60E+00	1.66E+00
PAD	3.45E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.45E+00
PANT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SNL/NM	1.04E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.04E+00
Subtotal	4.78E+00	2.00E+00	1.00E-01	1.00E-01	1.38E+00	1.00E-01	5.00E-01	4.18E+00	8.96E+00
Commercial site									
WVDP	3.19E+01	4.36E+01	2.38E+01	7.90E-01	7.90E-01	6.27E+01	0.00E+00	1.32E+02	1.64E+02
Total	4.79E+04	3.29E+02	3.64E+02	3.42E+02	2.73E+02	1.48E+03	2.47E+04	2.74E+04	7.54E+04

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.
[b]EOY = end of (calendar) year.
[c]7.40E+01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[d]9.62E+03 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[e]2.00E-01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).

Table 3.5. Final waste-form volumes (m^3) of retrievably stored and projected nonmixed CH TRUW[a]

Site	EOY[b] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Major sites									
ANL-E	2.29E+01	1.12E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E+00	2.40E+01
Hanford	9.18E+03[c]	1.55E+02	3.56E+02	5.34E+02	1.68E+02	1.05E+03	1.34E+04	1.57E+04[d]	2.49E+04
INEL	7.02E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.02E+03
LANL	3.20E+03	1.30E+02	1.30E+02	1.30E+02	1.30E+02	6.50E+02	2.60E+03	3.77E+03	6.97E+03
LLNL	2.16E+02[e]	2.05E+01	2.34E+01	2.34E+01	2.34E+01	1.17E+02	4.68E+02	6.76E+02[f]	8.92E+02
Mound	2.61E+02[g]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.61E+02
NTS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ORNL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RFETS	3.05E+02	1.96E+01	4.67E+01	3.22E+01	3.67E+00	2.70E+01	3.88E+02	5.17E+02	8.22E+02
SRS	4.47E+03	4.21E+02	4.21E+02	4.21E+02	4.21E+02	2.10E+03	8.42E+03	1.22E+04	1.67E+04
Subtotal	2.47E+04	7.47E+02	9.77E+02	1.14E+03	7.46E+02	3.95E+03	2.53E+04	3.29E+04	5.76E+04
Small-quantity sites									
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ANL-W	0.00E+00	0.00E+00	4.20E-01	4.20E-01	4.20E-01	2.10E+00	0.00E+00	3.36E+00	3.36E+00
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BAPL	0.00E+00	0.00E+00	4.16E-01	2.66E+01	1.71E+01	7.59E+01	3.80E+00	1.24E+02	1.24E+02
ETEC	1.66E+00	0.00E+00	5.20E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E+00	6.86E+00
KAPL	2.40E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E+00
LBL	8.40E-01	0.00E+00	4.20E-01	0.00E+00	0.00E+00	8.00E-01	3.20E+00	4.42E+00	5.26E+00
MURR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PAD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PANT	6.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.24E-01
SNL/NM	7.00E+00	0.00E+00	5.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	7.00E+00	1.40E+01
Subtotal	1.25E+01	0.00E+00	1.15E+01	2.70E+01	1.75E+01	7.98E+01	8.00E+00	1.44E+02	1.56E+02

Table 3.5 (continued)

Site	EOY[b] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Commercial site									
WVDP	1.87E+01	1.10E+01	5.54E+00	5.54E+00	5.54E+00	2.77E+01	0.00E+00	5.53E+01	7.40E+01
Total	2.47E+04	7.58E+02	9.94E+02	1.17E+03	7.69E+02	4.06E+03	2.53E+04	3.31E+04	5.78E+04

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.
[b]EOY = end of (calendar) year.
[c]2.00E-01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[d]2.70 E+00 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[e]1.68E+01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[f]3.26E+01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).
[g]6.00E-01 m^3 (approximately) of TSCA waste included from Table 3-2, WTWBIR, Rev. 1 (ref. 2).

Table 3.6. Summary of final waste-form volumes (m^3) of retrievably stored and projected mixed and nonmixed RH TRUW[a]

Site	EOY[b] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Major sites									
ANL-E	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hanford	3.32E+01	2.00E+00	1.03E+02	3.90E+01	8.76E+00	1.00E+02	2.72E+03	2.97E+03	3.01E+03
INEL	3.10E+01	0.00E+00	6.00E-01	6.00E-01	6.00E-01	3.00E+00	1.20E+01	1.68E+01	4.78E+01
LANL	9.13E+01	1.17E+01	1.17E+01	1.17E+01	1.17E+01	1.19E+01	2.40E+01	8.27E+01	1.74E+02
LLNL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mound	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NTS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ORNL	9.94E+02	1.23E+01	1.23E+01	1.23E+01	1.23E+01	6.15E+01	2.46E+02	3.57E+02	1.35E+03
RFETS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SRS	0.00E+00	4.00E+00	2.14E+00	2.14E+00	2.14E+00	1.05E+01	4.30E+01	6.39E+01	6.39E+01
Subtotal	1.15E+03	3.00E+01	1.30E+02	6.57E+01	3.55E+01	1.87E+02	3.05E+03	3.49E+03	4.64E+03
Small-quantity sites									
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ANL-W	8.65E+00	3.20E-01	4.20E-01	7.56E-01	1.32E+00	4.81E+00	2.00E+01	2.76E+01	3.63E+01
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.10E+01	0.00E+00	7.10E+01	7.10E+01
BAPL	0.00E+00	0.00E+00	3.12E-01	2.08E-01	3.12E-01	6.25E-01	1.00E-01	1.56E+00	1.56E+00
ETEC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KAPL	1.12E+01	8.70E-01	8.70E-01	8.70E-01	8.70E-01	4.35E+00	1.74E+01	2.52E+01	3.65E+01
LBL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MURR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PAD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PANT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SNL/NM	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Subtotal	1.99E+01	1.19E+00	1.60E+00	1.83E+00	2.50E+00	8.08E+01	3.75E+01	1.25E+02	1.45E+02
Commercial site									
WVDP	4.27E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.27E+02
Total	1.60E+03	3.12E+01	1.31E+02	6.76E+01	3.80E+01	2.68E+02	3.08E+03	3.62E+03	5.22E+03

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding
[b]EOY = end of (calendar) year.

Table 3.7. Final waste-form volumes (m^3) of retrievably stored and projected mixed RH TRUW[a]

Site	EOY[b] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Major sites									
ANL-E	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hanford	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.76E+00	2.02E+01	1.70E+03	1.73E+03	1.73E+03
INEL	2.12E+01	0.00E+00	6.00E-01	6.00E-01	6.00E-01	3.00E+00	1.20E+01	1.68E+01	3.80E+01
LANL	1.50E+01	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+01	1.50E+01	3.00E+01
LLNL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mound	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NTS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ORNL	9.94E+02	1.23E+01	1.23E+01	1.23E+01	1.23E+01	6.15E+01	2.46E+02	3.57E+02	1.35E+03
RFETS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SRS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Subtotal	1.03E+03	1.33E+01	1.39E+01	1.39E+01	2.07E+01	8.57E+01	1.97E+03	2.12E+03	3.15E+03
Small-quantity sites									
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ANL-W	8.65E+00	3.20E-01	4.20E-01	4.20E-01	4.20E-01	3.10E-01	2.00E+00	3.89E+00	1.25E+01
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BAPL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ETEC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KAPL	1.12E+01	8.70E-01	8.70E-01	8.70E-01	8.70E-01	4.35E+00	1.74E+01	2.52E+01	3.65E+01
LBL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MURR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PAD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PANT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SNL/NM	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Subtotal	1.99E+01	1.19E+00	1.29E+00	1.29E+00	1.29E+00	4.66E+00	1.94E+01	2.91E+01	4.90E+01
Commercial site									
WVDP	1.05E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.05E+01
Total	1.06E+03	1.45E+01	1.52E+01	1.52E+01	2.20E+01	9.03E+01	1.99E+03	2.15E+03	3.21E+03

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding
[b]EOY = end of (calendar) year.

Table 3.8. Final waste-form volumes (m^3) of retrievably stored and projected nonmixed RH TRUW[a]

Site	EOY[b] 1993	Annual increase				Cumulative increase		Projected increase	Total EOY 2022
		1994	1995	1996	1997	1998–2002	2003–2022	1994–2022	
Major sites									
ANL-E	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hanford	3.32E+01	2.00E+00	1.03E+02	3.90E+01	2.00E+00	8.00E+01	1.02E+03	1.25E+03	1.28E+03
INEL	9.76E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.76E+00
LANL	7.63E+01	1.07E+01	1.07E+01	1.07E+01	1.07E+01	1.09E+01	1.40E+01	6.77E+01	1.44E+02
LLNL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mound	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NTS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ORNL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RFETS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SRS	0.00E+00	4.00E+00	2.14E+00	2.14E+00	2.14E+00	1.05E+01	4.30E+01	6.39E+01	6.39E+01
Subtotal	1.19E+02	1.67E+01	1.16E+02	5.18E+01	1.48E+01	1.01E+02	1.08E+03	1.38E+03	1.50E+03
Small-quantity sites									
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ANL-W	0.00E+00	0.00E+00	0.00E+00	3.36E-01	9.00E-01	4.50E+00	1.80E+01	2.37E+01	2.37E+01
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.10E+01	0.00E+00	7.10E+01	7.10E+01
BAPL	0.00E+00	0.00E+00	3.12E-01	2.08E-01	3.12E-01	6.25E-01	1.00E-01	1.56E+00	1.56E+00
ETEC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KAPL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LBL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MURR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PAD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PANT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SNL/NM	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Subtotal	0.00E+00	0.00E+00	3.12E-01	5.44E-01	1.21E+00	7.61E+01	1.81E+01	9.63E+01	9.63E+01
Commercial site									
WVDP	4.16E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.16E+02
Total	5.36E+02	1.67E+01	1.16E+02	5.24E+01	1.61E+01	1.78E+02	1.10E+03	1.47E+03	2.01E+03

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.
[b]EOY = end of (calendar) year.

Table 3.9. Estimated final-form volume (m^3) composition of retrievably stored and projected TRUW for major sites[a]

Major sites	Category	Contact-handled			Remote-handled		
		Stored	Projected	Total	Stored	Projected	Total
ANL-E	Lead/cadmium metal waste	1.10	0.00	1.10	0.00	0.00	0.00
	Solidified inorganics	23.05	1.12	24.17	0.00	0.00	0.00
	Solidified organics	0.03	0.00	0.03	0.00	0.00	0.00
	Uncategorized metal	4.96	0.56	5.52	0.00	0.00	0.00
	Subtotal	29.14	1.68	30.82	0.00	0.00	0.00
Hanford	Combustible	530.07[a]	12,698.57[b]	13,228.64	0.00	0.00	0.00
	Heterogeneous	8,568.55	827.16	9,395.71	33.16	2,973.71	3,006.87
	Lead/cadmium metal waste	3.13	0.29	3.42	0.00	0.00	0.00
	Soils	111.69	309.27	420.96	0.00	0.00	0.00
	Solidified inorganics	2.93[c]	3,153.57[d]	3,156.50	0.00	0.00	0.00
	Solidified organics	4.48[e]	31.44[f]	35.92	0.00	0.00	0.00
	Uncategorized metal	170.17[g]	13,837.04[h]	14,007.21	0.00	0.00	0.00
	Subtotal	9,391.02	30,857.34	40,248.36	33.16	2,973.71	3,006.87
INEL	Combustible	670.90	0.00	670.90	0.00	0.00	0.00
	Filter	323.56	0.00	323.56	0.00	0.00	0.00
	Graphite	650.70	0.00	650.70	0.00	0.00	0.00
	Heterogeneous	9,649.50	1.00	9,650.50	13.63	2.80	16.43
	Inorganic nonmetal	1,052.89	0.00	1,052.89	0.00	0.00	0.00
	Lead/cadmium metal waste	0.00	0.00	0.00	0.00	5.60	5.60
	Salt Waste	22.91	0.00	22.91	0.00	2.80	2.80
	Soils	3.80	0.00	3.80	0.00	0.00	0.00
	Solidified inorganics	12,164.28	0.00	12,164.28	2.10	0.00	2.10
	Solidified organics	912.60	0.00	912.60	0.00	0.00	0.00
	Uncategorized metal	7,564.09	0.00	7,564.09	4.11	5.60	9.71
	Unknown	1,655.91	0.00	1,655.91	11.13	0.00	11.13
	Subtotal	34,671.14	1.00	34,672.14	30.97	16.80	47.77
LANL	Combustible	1,768.33	2,464.60	4,232.93	14.84	3.16	18.00
	Soils	109.37	144.60	253.97	0.00	0.00	0.00
	Solidified inorganics	4,848.38	2,059.03	6,907.41	0.00	0.00	0.00
	Uncategorized metals	4,134.80	3,006.17	7,140.97	76.46	79.50	155.96
	Subtotal	10,860.88	7,674.40	18,535.28	91.30	82.66	173.96
LLNL	Combustible	48.88	372.32	421.20	0.00	0.00	0.00
	Filter	16.63[i]	32.63[j]	49.26	0.00	0.00	0.00
	Salt waste	0.62	2.91	3.53	0.00	0.00	0.00
	Solidified inorganics	13.30	66.15	79.45	0.00	0.00	0.00
	Uncategorized metal	144.33	247.00	391.33	0.00	0.00	0.00
	Subtotal	223.76	721.01	944.77	0.00	0.00	0.00

Table 3.9 (continued)

Major sites	Category	Contact-handled			Remote-handled		
		Stored	Projected	Total	Stored	Projected	Total
Mound	Combustible	5.61	0.00	5.61	0.00	0.00	0.00
	Heterogeneous	1.04[k]	0.00	1.04	0.00	0.00	0.00
	Inorganic nonmetal	0.21[l]	0.00	0.21	0.00	0.00	0.00
	Soils	146.88	0.00	146.88	0.00	0.00	0.00
	Solidified inorganics	7.28	0.00	7.28	0.00	0.00	0.00
	Uncategorized metal	102.28	0.00	102.28	0.00	0.00	0.00
	Subtotal	263.30	0.00	263.30	0.00	0.00	0.00
NTS	Heterogeneous	619.50	0.00	619.50	0.00	0.00	0.00
ORNL	Heterogeneous	672.98	263.90	936.88	382.81	182.70	565.51
	Solidified inorganics	110.00	0.00	110.00	611.00	174.00	785.00
	Subtotal	782.98	263.90	1,046.88	993.81	356.70	1,350.51
RFETS	Filter	103.96	1,087.59	1,191.55	0.00	0.00	0.00
	Graphite	18.06	43.40	61.46	0.00	0.00	0.00
	Heterogeneous	312.86	804.58	1,117.44	0.00	0.00	0.00
	Inorganic nonmetal	110.68	318.68	429.36	0.00	0.00	0.00
	Lead/cadmium metal waste	51.87	124.18	176.05	0.00	0.00	0.00
	Salt waste	9.45	56.60	66.05	0.00	0.00	0.00
	Solidified inorganics	228.63	2,988.11	3,216.74	0.00	0.00	0.00
	Solidified organics	132.80	48.82	181.62	0.00	0.00	0.00
	Uncategorized metal	164.82	429.50	594.32	0.00	0.00	0.00
	Subtotal	1,133.13	5,901.46	7,034.59	0.00	0.00	0.00
SRS	Combustible	4,066.80	11,962.50	16,029.30	0.00	0.00	0.00
	Heterogeneous	10,132.20	2,563.60	12,695.80	0.00	63.92	63.92
	Solidified inorganics	0.04	0.00	0.04	0.00	0.00	0.00
	Solidified organics	404.85	240.70	645.55	0.00	0.00	0.00
	Subtotal	14,603.89	14,766.80	29,370.69	0.00	63.92	63.92
	Major sites total	72,578.74	60,187.59	132,766.33	1,149.24	3,493.79	4,643.03

[a]Includes 3.59 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[b]Includes 429.54 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[c]Includes 1.47 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[d]Includes 228.81 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[e]Includes 2.31 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[f]Includes 16.19 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[g]Includes 66.82 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[h]Includes 8,946.09 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[i]Includes 16.63 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[j]Includes 32.63 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[k]Includes 0.62 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).
[l]Includes 0.21 m^3 of TSCA waste not shown in the WTWBIR, Rev. 1 (ref. 2).

Table 3.10. Estimated final-form volume (m^3) composition of retrievably stored and projected TRUW for small-quantity and commercial sites[a]

Major sites	Category	Contact-handled			Remote-handled		
		Stored	Projected	Total	Stored	Projected	Total
		Small-quantity sites (SQS)					
Ames	Solidified inorganics	0.00	0.10	0.10	0.00	0.00	0.00
ANL-W	Filter	0.00	0.00	0.00	0.89	2.09	2.98
	Heterogeneous	0.00	3.36	3.36	0.59	0.08	0.67
	Lead/cadmium metal waste	0.02	2.48	2.50	0.00	0.36	0.36
	Uncategorized metal	0.00	0.00	0.00	7.17	1.36	8.53
	Unknown	0.00	0.00	0.00	0.00	23.74	23.74
	Subtotal	0.02	5.84	5.86	8.65	27.63	36.28
BCL	Heterogeneous	0.00	0.00	0.00	0.00	71.00	71.00
BAPL	Heterogeneous	0.00	123.82	123.82	0.00	1.56	1.56
ETEC	Heterogeneous	1.66	5.20	6.86	0.00	0.00	0.00
	Lead/cadmium metal waste	0.21	0.00	0.21	0.00	0.00	0.00
	Subtotal	1.87	5.20	7.07	0.00	0.00	0.00
KAPL	Heterogeneous	2.40	0.00	2.40	11.23	25.23	36.46
LBL	Heterogeneous	0.84	4.42	5.26	0.00	0.00	0.00
MURR	Heterogeneous	0.06	1.60	1.66	0.00	0.00	0.00
PAD	Solidified inorganics	3.45	0.00	3.45	0.00	0.00	0.00
PANT	Heterogeneous	0.62	0.00	0.62	0.00	0.00	0.00
SNL/NM	Heterogeneous	8.04	7.00	15.04	0.00	0.00	0.00
	SQS subtotal[a]	17.30	147.98	165.28	19.88	125.41	145.30
		Commercial site					
WVDP	Filter	18.97	131.63	150.60	0.00	0.00	0.00
	Heterogeneous	14.76	55.28	70.04	0.00	0.00	0.00
	Lead/cadmium metal waste	0.21	0.00	0.21	0.00	0.00	0.00
	Solidified inorganics	4.57	0.00	4.57	0.00	0.00	0.00
	Solidified organics	0.42	0.00	0.42	0.00	0.00	0.00
	Uncategorized metal	0.42	0.00	0.42	416.46	0.00	416.46
	Unknown	11.23	0.00	11.23	10.49	0.00	10.49
	Commercial site subtotal[a]	50.57	186.91	237.48	426.95	0.00	426.95
	Total	72,646.61	60,522.48	133,169.09	1,596.08	3,619.20	5,215.28

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.

Table 3.11. Summary of decayed radioactivity isotopic content of retrievably stored CH TRUW[a]

Site	^{238}Pu	^{241}Pu	^{239}Pu	^{241}Am	^{240}Pu	^{137}Cs	Sum of curies	Curies (%)
				Major sites				
ANL-E	2.14E+00	5.98E+01	3.28E+01	5.73E+00	9.42E+00		1.10E+02	0.01
Hanford	8.18E+04	9.43E+04	2.70E+04	2.98E+03	6.06E+03	7.03E+02	2.13E+05	14.11
INEL	6.07E+04	1.65E+05	4.01E+04	8.98E+04	9.82E+03	6.32E+01	3.65E+05	24.19
LANL	1.15E+05	1.77E+00	7.33E+04	8.70E+03	1.52E-01	5.32E+01	1.97E+05	13.08
LLNL	1.97E+01	1.67E+03	1.46E+02	1.26E+02	6.06E+01	1.99E-06	2.03E+03	0.13
Mound	7.16E+02		1.99E+02				9.14E+02	0.06
NTS	1.98E+02	2.64E+02	2.76E+03	2.84E+02	1.87E+01	3.97E-01	3.53E+03	0.23
ORNL	6.78E+03	5.52E+04	7.95E+02	2.33E+03	7.25E+02	2.17E+03	6.80E+04	4.51
RFETS	3.47E+02	5.72E+04	9.93E+03	1.08E+04	7.21E+03		8.55E+04	5.66
SRS	4.71E+05	6.30E+04	8.56E+03	1.60E+04	2.12E+03	6.77E-01	5.61E+05	37.16
Subtotal	7.37E+05	4.36E+05	1.63E+05	1.31E+05	2.60E+04	2.99E+03	1.50E+06	99.14
				Small-quantity sites (SQS)				
Ames								
ANL-W								
BCL								
BAPL								
ETEC	1.12E-01	8.06E+00	1.76E+00	4.43E-01	6.01E-01	2.40E-01	1.12E+01	0.00
KAPL								
LBL	2.36E-04	2.89E-07	7.70E-03	9.20E-02	5.07E-03		1.05E-01	0.00
MURR			2.05E-02	4.80E-02			6.85E-02	0.00
PAD			5.56E+01				5.56E+01	0.00
PANT			5.55E-02				5.55E-02	0.00
SNL/NM			2.00E-06	1.00E-02			1.00E-02	0.00
Subtotal	1.12E-01	8.06E+00	5.75E+01	5.93E-01	6.06E-01	2.40E-01	6.71E+01	0.00
				Commercial site				
WVDP		3.43E+01		2.15E+00		1.95E+00	3.84E+01	0.00
Total (all sites)	7.37E+05	4.37E+05	1.63E+05	1.31E+05	2.60E+04	3.00E+03	1.50E+06	99.15
Total Ci, %	48.84	28.92	10.79	8.68	1.72	0.20		
Cumulative, %	48.84	77.76	88.55	97.23	98.95	99.15		

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.

Table 3.12. Summary of decayed radioactivity (Ci) isotopic content of retrievably stored RH TRUW[a]

Site	^{90}Sr	^{90}Y	^{137}Cs	^{137m}Ba	^{152}Eu	^{60}Co	^{154}Eu	^{241}Pu	^{244}Cm	^{155}Eu	Sum of curies	Curies (%)
Major sites												
ANL-E			1.18E+01	1.12E+01				8.23E-01			2.38E+01	0.01
Hanford	5.74E+03	5.74E+03	6.67E+03	6.31E+03	2.83E+02	4.77E+03	1.43E+03	4.58E+03		5.76E+02	3.61E+04	10.37
INEL	1.78E+03	1.78E+03	1.99E+03	1.88E+03	2.07E-02	1.68E+01	8.20E-01	5.30E+01		3.32E-01	7.49E+03	2.15
LANL	2.69E+03	2.69E+03	2.95E+03	2.79E+03	5.96E-04	5.43E+00	4.34E-02			5.45E+01	1.12E+04	3.21
LLNL												
Mound												
NTS								7.26E-05	1.68E+02		1.68E+02	0.05
ORNL	9.71E+04	9.71E+04	3.90E+04	3.69E+04	8.75E+03	1.73E+03	4.57E+03	1.03E-07	1.78E+03	9.37E+02	2.88E+05	82.69
RFETS												
SRS												
Subtotal	1.07E+05	1.07E+05	5.07E+04	4.79E+04	9.04E+03	6.52E+03	6.01E+03	4.63E+03	1.95E+03	1.57E+03	3.43E+05	98.48
Small-quantity sites (SQS)												
Ames												
ANL-W												
BCL												
BAPL												
ETEC												
KAPL	2.46E+01	2.46E+01	2.47E+01	2.33E+01	3.62E-06	1.14E-01	3.56E-04	2.00E-01		8.11E-03	9.76E+01	0.03
LBL												
MURR												
PAD												
PANT												
SNL/NM												
Subtotal	2.46E+01	2.46E+01	2.47E+01	2.33E+01	3.62E-06	1.14E-01	3.56E-04	2.00E-01		8.11E-03	9.76E+01	0.03
Commercial site												
WVDP												
Total (all sites)	1.07E+05	1.07E+05	5.07E+04	4.79E+04	9.04E+03	6.52E+03	6.01E+03	4.63E+03	1.95E+03	1.57E+03	3.43E+05	98.51
Total Ci, %	30.82	30.82	14.56	13.77	2.60	1.87	1.72	1.33	0.56	0.45		
Cumulative, %	30.82	61.65	76.20	89.98	92.57	94.44	96.17	97.50	98.06	98.51		

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.

Table 3.13. Summary of decayed mass (g) isotopic content of retrievably stored CH TRUW[a]

Site	^{238}U	^{232}Th	^{239}Pu	^{235}U	^{242}Pu	^{233}U	^{240}Pu	Sum of mass	Mass (%)
				Major sites					
ANL-E	1.59E+02	1.48E-09	5.27E+02	2.75E+02	2.62E+00	3.10E+00	4.13E+01	1.01E+03	0.00
Hanford	1.80E+07	5.82E+05	4.35E+05	2.63E+05	9.70E+01	8.18E+03	2.66E+04	1.93E+07	73.79
INEL	3.44E+05	3.01E+06	6.45E+05	2.85E+04	2.47E+02	9.28E+04	4.31E+04	4.16E+06	15.90
LANL	1.20E+04	2.19E+04	1.18E+06	1.93E+05	1.33E+05	4.61E+03	6.65E-01	1.54E+06	5.90
LLNL	1.05E+03	3.37E-09	2.34E+03	6.10E+01	5.04E+00	2.26E-07	2.66E+02	3.72E+03	0.01
Mound			3.20E+03	9.51E-01				3.20E+03	0.01
NTS	1.66E+02	4.19E-09	4.44E+04	2.60E+01	2.28E+01	1.87E+02	8.21E+01	4.49E+04	0.17
ORNL	1.05E+05	3.12E+05	1.28E+04	3.04E+03	1.43E+03	9.22E+03	3.18E+03	4.47E+05	1.71
RFETS		2.97E-07	1.60E+05	1.30E+01		7.78E-06	3.16E+04	1.91E+05	0.73
SRS	1.56E+04	9.41E+04	1.38E+05	2.52E+03	9.82E+01	9.14E-01	9.29E+03	2.59E+05	0.99
Subtotal	1.85E+07	4.02E+06	2.62E+06	4.91E+05	1.35E+05	1.15E+05	1.14E+05	2.60E+07	99.22
				Small-quantity sites (SQS)					
Ames									
ANL-W									
BCL									
BAPL									
ETEC			2.83E+01		1.05E-02		2.64E+00	3.10E+01	0.00
KAPL									
LBL	4.55E-05	3.37E-12	1.24E-01	1.75E-05	2.64E+00	4.97E-01	2.23E-02	3.28E+00	0.00
MURR	2.97E-04		3.29E-01					3.30E-01	0.00
PAD			8.95E+02					8.95E+02	0.00
PANT			8.93E-01					8.93E-01	0.00
SNL/NM			3.22E-05	2.73E-09		5.99E-13		3.22E-05	0.00
Subtotal	3.43E-04	3.37E-12	9.24E+02	1.75E-05	2.65E+00	4.97E-01	2.66E+00	9.30E+02	0.00
				Commercial site					
WVDP						7.77E-09		7.77E-09	0.00
Total (all sites)	1.85E+07	4.02E+06	2.62E+06	4.91E+05	1.35E+05	1.15E+05	1.14E+05	2.60E+07	99.22
Total mass, %	70.59	15.35	10.01	1.87	0.52	0.44	0.44		
Cumulative, %	70.59	85.95	95.96	97.83	98.35	98.79	99.22		

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding

Table 3.14. Summary of decayed mass (g) isotopic content of retrievably stored RH TRUW[a]

Site	^{238}U	^{235}U	Sum of mass	Mass (%)
ANL-E				
Hanford	3.07E+04		3.07E+04	0.33
INEL	4.11E+03		4.11E+03	0.04
LANL	5.95E+01		5.95E+01	0.00
LLNL				
Mound				
NTS	4.25E-12		4.25E-12	0.00
ORNL	6.46E+06	2.62E+06	9.08E+06	98.98
RFETS				
SRS				
Subtotal	6.49E+06	2.62E+06	9.11E+06	99.36
Small-quantity sites (SQS)				
Ames				
ANL-W				
BCL				
BAPL				
ETEC				
KAPL	2.95E-09		2.95E-09	0.00
LBL				
MURR				
PAD				
PANT				
SNL/NM				
Subtotal	2.95E-9		2.95E-09	0.00
Commercial site				
WVDP				
Total	6.49E+06	2.62E+06	9.11E+06	99.36
Total mass, %	70.80	28.57		
Cumulative, %	70.80	99.36		

[a]Any small differences in volumes reported in this table and WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding.

Table 3.15. Summary of buried TRUW volume and radioactivity as of December 31, 1993[a]

Site	Cumulative volume (m^3)	Cumulative as-stored radioactivity		Decayed radioactivity	
		All nuclides (10^3 Ci)	TRU only (10^3 Ci)	All nuclides (10^3 Ci)	TRU only (10^3 Ci)
		Major sites			
ANL-E	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hanford	6.36E+04	6.02E+02	1.14E+02	1.73E+02	9.38E+01
INEL	5.71E+04	2.49E+02	b	b	b
LANL	1.40E+04	c	d	c	c
LLNL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mound	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NTS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ORNL	1.76E+02	2.40E-01	1.00E-01	5.43E+02	2.00E-01
RFETS	0.00E-00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SRS	4.87E+03	3.37E+01	3.37E+01	3.05E+01	3.05E+01
Subtotal	1.40E+05	8.84E+02	1.48E+02	7.47E+02	1.25E+02
		Small-quantity sites (SQS)			
Ames	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ANL-W	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BCL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BAPL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ETEC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KAPL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LBL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MURR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PAD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PANT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SNL/NM	1.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Subtotal	1.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Commercial site			
WVDP	1.35E+03	6.52E+02	6.52E+02	0.00E+00	0.00E+00
Total	1.41E+05	1.54E+03	8.00E+02	7.47E+02	1.25E+02

[a]Any small differences in volumes reported in this table and in WTWBIR, Rev. 1 (ref. 2) and in the numerical totals shown result from rounding. See ref. 5.

[b]INEL data did not include any isotopic compositions, so no TRU isotope or decay calculations could be made.

[c]Information not available.

[d]An estimate of 9230 Ci was reported for LANL as-stored TRU alpha radioactivity (as of the end of CY 1991) in *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 8 (October 1992).

Table 3.16. Volumes and radioactivities of TRU-contaminated soils[a]

Site	Soil contaminated with TRUW			
	Solid		Liquid	
	Volume (m^3)	Radioactivity (Ci)	Volume (m^3)	Radioactivity (Ci)
		Major sites		
ANL-E	0	0	0	0
Hanford	b	b	32,000	80,591
INEL	c	c	c	c
LANL	d	e	d	e
LLNL	0	0	0	0
Mound	d	d	d	d
NTS	d	d	c	c
ORNL	d	d	d	d
RFETS	2	40	c	c
SRS	0	0	0	0
		Small-quantity sites (SQS)		
Ames	f	f	f	f
ANL-W	f	f	f	f
BCL	f	f	f	f
BAPL	f	f	f	f
ETEC	0	0	0	0
ITRI	f	f	f	f
KAPL	0	0	0	0
LBL	0	0	0	0
MURR	f	f	f	f
PAD	c	c	c	c
PANT	f	f	f	f
SNL/NM	d	d	d	d
		Commercial site		
WVDP	f	f	f	f

[a]See ref. 5 of this chapter.
[b]Included in buried TRUW.
[c]Listed in submittal as not applicable.
[d]Unknown.
[e]Partial data submitted.
[f]No data submitted.

APPENDIX H

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APPENDIX H
WASTE STREAM IDENTIFICATION CROSS REFERENCE TABLE FOR WTWBIR REVISION 1 AND TWBIR REVISION 2

Ames Laboratory [AL]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
AL-W001	AL-W001

ARCO Medical Products Company [AM]

N/A	AM-W001

Argonne National Laboratory - East [AE]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
AE-T001	AE-T001
AE-T003	AE-T003
AE-W038	AE-W038
AE-W039	AE-W039
AE-W040	AE-W040
AE-W041	AE-W041
AE-W042	AE-W042

Argonne National Laboratory - West [AW]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2

AW-M001	AW-N026.82
AW-M002	AW-N027.531
AW-M003	AW-N028
N/A	AW-T029.1323
N/A	AW-T030.1321
N/A	AW-T031.1322
N/A	AW-T032.1324
N/A	AW-T033.1325
N/A	AW-T034.1327
N/A	AW-T035.1326
IN-M001	AW-W012.10
AW-W016/IN-M004	AW-W016.20
AW-W018	AW-W018
AW-W019	AW-W019
AW-W020/IN-M002	AW-W020.13
AW-W021/IN-M003	AW-W021.16
AW-W022/IN-M005	AW-W022.22

Battelle Columbus Laboratories [BC]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
BC-T001	BC-T001

Bettis Atomic Power Laboratory [BT]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2

BT-T001	BT-T001
BT-T002	BT-T002
BT-T003	BT-T003
BT-T004	BT-T004
BT-T005	BT-T005

Energy Technology Engineering Center [ET]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
ET-M001	ET-M001
ET-T001	ET-T001A
ET-T001	ET-T001B

Idaho National Engineering Laboratory [IN]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
N/A	IN-W112
IN-W139	IN-W139.627
IN-W146	IN-W146.699
IN-W157	IN-W157.144
IN-W157	IN-W157.906
IN-T001	IN-W157.907
IN-T001	IN-W159.1072
IN-T001	IN-W159.119
IN-T001	IN-W159.120
IN-W161	IN-W161.231

IN-W161	IN-W161.806
IN-T001	IN-W163.1007
IN-T001	IN-W163.234
IN-T001	IN-W164.1060
IN-T001	IN-W164.153
IN-W166	IN-W166.151
IN-W166	IN-W166.928
IN-W167	IN-W167.149
IN-W167	IN-W167.926
IN-W169	IN-W169.191
IN-T001	IN-W169.192
IN-W169	IN-W169.193
IN-T001	IN-W169.194
IN-W169	IN-W169.985
IN-W170	IN-W170.189
IN-W170	IN-W170.938
IN-W171	IN-W171.184
IN-W171	IN-W171.801
IN-W172	IN-W172.182
IN-W172	IN-W172.911
IN-W174	IN-W174.1082
IN-W174	IN-W174.154
IN-W177	IN-W177.1083
IN-W177	IN-W177.156
IN-W179	IN-W179.1084
IN-W179	IN-W179.158

IN-W181	IN-W181.162
IN-W186	IN-W186.187
IN-T001	IN-W187.1094
IN-T001	IN-W187.121
IN-W188	IN-W188.1093
IN-W188	IN-W188.160
IN-W189	IN-W189.1048
IN-W189	IN-W189.131
IN-T001	IN-W197.196
IN-W197	IN-W197.197
IN-T001	IN-W197.198
IN-W197	IN-W197.802
IN-W197	IN-W197.803
IN-W198	IN-W198.202
IN-T001	IN-W198.203
IN-W198	IN-W198.204
IN-T001	IN-W198.205
IN-W198	IN-W198.804
IN-W199	IN-W199.1039
IN-T001	IN-W199.209
IN-W202	IN-W202.1092
IN-W202	IN-W202.224
IN-W203	IN-W203.1081
IN-W203	IN-W203.210
IN-T001	IN-W203.211
IN-T001	IN-W203.212

IN-W204	IN-W204.215
IN-W204	IN-W204.216
IN-T001	IN-W204.217
IN-W205	IN-W205.1086
IN-T001	IN-W205.1087
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IN-T001	IN-W206.936
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IN-W220	IN-W220.925
IN-W221	IN-W221.113
IN-W221	IN-W221.927
IN-W222	IN-W222.116
IN-T001	IN-W222.117
IN-W222	IN-W222.965
IN-W225	IN-W225.127
IN-W225	IN-W225.800
IN-W228	IN-W228.101
IN-T001	IN-W228.102
IN-T001	IN-W228.103
IN-W228	IN-W228.883
IN-T001	IN-W228.884
IN-T001	IN-W228.885

IN-W228	IN-W228.886
IN-W230	IN-W230.229
IN-W230	IN-W230.940
IN-W240	IN-W240.272
IN-W240	IN-W240.931
IN-W243	IN-W243.274
IN-T001	IN-W243.275
IN-W243	IN-W243.276
IN-T001	IN-W243.277
IN-W243	IN-W243.808
IN-T001	IN-W245.1034
IN-W245	IN-W245.1035
IN-W245	IN-W245.301
IN-W245	IN-W245.302
IN-T001	IN-W247.1038
IN-W247	IN-W247.523
IN-W247	IN-W247.524
IN-W247	IN-W247.810
IN-W249	IN-W249.1071
IN-W249	IN-W249.527
IN-T001	IN-W249.528
IN-W250	IN-W250.259
IN-W250	IN-W250.941
IN-T001	IN-W252.1000
IN-W252	IN-W252.282
IN-W252	IN-W252.283

IN-W252	IN-W252.811
IN-T001	IN-W254.1044
IN-W254	IN-W254.1045
IN-W254	IN-W254.289
IN-W254	IN-W254.290
IN-W256	IN-W256.1062
IN-W256	IN-W256.295
IN-T001	IN-W257.558
IN-T001	IN-W257.947
IN-W259	IN-W259.552
IN-T001	IN-W259.920
IN-T001	IN-W259.921
IN-T001	IN-W260.565
IN-W260	IN-W260.566
IN-T001	IN-W260.567
IN-W260	IN-W260.568
IN-W260	IN-W260.916
IN-W263	IN-W263.520
IN-W265	IN-W265.516
IN-T001	IN-W265.517
IN-T001	IN-W267.1005
IN-T001	IN-W267.514
IN-W269	IN-W269.510
IN-W269	IN-W269.535
IN-W271	IN-W271.532
IN-T001	IN-W271.533

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IN-T001	IN-W280.449
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IN-W285	IN-W285.815
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IN-W298	IN-W298.812
IN-T001	IN-W298.979
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IN-W306	IN-W306.633
IN-T001	IN-W306.634
IN-W306	IN-W306.635
IN-W306	IN-W306.817
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IN-T001	IN-W308.621

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IN-W309	IN-W309.610
IN-W311	IN-W311.1013
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IN-W314	IN-W314.1017
IN-W314	IN-W314.606
IN-W317	IN-W317.1028
IN-W317	IN-W317.1029
IN-W317	IN-W317.757
IN-W317	IN-W317.758
IN-T001	IN-W315..601
IN-T001	IN-W319.583
IN-T001	IN-W319.584
IN-T001	IN-W321.1023
IN-T001	IN-W321.578
IN-W322	IN-W322.851
IN-W322	IN-W322.952
IN-W323	IN-W323.562
IN-T001	IN-W323.951
IN-W325	IN-W325.1076
IN-W325	IN-W325.679
IN-W327	IN-W327.1085
IN-W327	IN-W327.735

IN-W329	IN-W329.681
IN-T001	IN-W329.682
IN-W330	IN-W330.677
IN-W330	IN-W330.678
IN-W332	IN-W332.661
IN-W332	IN-W332.962
IN-W334	IN-W334.675
IN-W334	IN-W334.961
IN-W336	IN-W336.660
IN-W336	IN-W336.820
IN-W337	IN-W337.673
IN-W337	IN-W337.957
IN-W338	IN-W338.657
IN-W338	IN-W338.956
IN-W339	IN-W339.655
IN-W339	IN-W339.955
IN-W341	IN-W341.671
IN-W341	IN-W341.954
IN-W342	IN-W342.652
IN-W342	IN-W342.953
IN-W345	IN-W345.669
IN-W345	IN-W345.819
IN-W347	IN-W347.646
IN-W347	IN-W347.818
IN-T001	IN-W348.1012
IN-T001	IN-W348.846

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IN-W350	IN-W350.650
IN-W350	IN-W350.923
IN-W351	IN-W351.648
IN-W351	IN-W351.922
IN-W353	IN-W353.859
IN-W353	IN-W353.917
IN-W354	IN-W354.1016
IN-W354	IN-W354.858
IN-W355	IN-W355.1015
IN-W355	IN-W355.857
IN-W356	IN-W356.1014
IN-W356	IN-W356.856
IN-T001	IN-W357.1022
IN-T001	IN-W357.850
IN-W358	IN-W358.854
IN-W358	IN-W358.855
IN-T001	IN-W358.948
IN-W358	IN-W358.949
IN-W359	IN-W359.853
IN-W360	IN-W360.852
IN-W360	IN-W360.912
IN-T001	IN-W361.1021
IN-T001	IN-W361.849
IN-T001	IN-W362.1020

M

IN-T001	IN-W362.848
IN-T001	IN-W363.1019
IN-T001	IN-W363.847
IN-T001	IN-W364.1011
IN-T001	IN-W364.844
IN-T001	IN-W364.845
IN-T001	IN-W365.1010
IN-T001	IN-W365.842
IN-T001	IN-W365.843
IN-W366	IN-W366.1004
IN-W366	IN-W366.841
IN-T001	IN-W367.840
IN-T001	IN-W367.973
IN-T001	IN-W368.839
IN-T001	IN-W368.971
IN-W369	IN-W369.837
IN-W369	IN-W369.970
IN-W370	IN-W370.836
IN-W370	IN-W370.929
IN-W371	IN-W371.1018
IN-W371	IN-W371.831
IN-W372	IN-W372.832
IN-W372	IN-W372.918
IN-T001	IN-W373.1003
IN-T001	IN-W373.830
IN-T001	IN-W374.1091

IN-W374	IN-W374.829
IN-T001	IN-W375.1096
IN-T001	IN-W375.827
N/A	IN-Z001

Knolls Atomic Power Laboratory - Schnecetedy [KA]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
KA-T001	KA-T001
KA-W016	KA-W016

Los Alamos National Laboratory [LA]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
LA-W001	LA-W001
LA-W002	LA-M002
LA-W003	LA-W003
LA-W004	LA-W004
LA-W005	LA-W005
LA-W006	LA-W006
LA-W009	LA-W009
LA-WR01	LA-WR01
LA-WR05	LA-WR05
LA-T001	LA-T001
LA-T004	LA-T004
LA-T005	LA-T005

LA-T006	LA-T006
LA-T007	LA-T007
LA-T008	LA-T008
LA-T009	LA-T009
LA-T010	LA-TR04
LA-T011	LA-TR05
LA-T012	LA-TR07
LA-W002	LA-T002
LA-W001	LA-W066
LA-T004	LA-W067
LA-T005	LA-W068
N/A	LA-Z001

Lawrence Berkeley Laboratory [LB]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
LB-T001	LB-T001

Lawrence Livermore National Laboratory [LB]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
LL-W018	LL-W018
LL-W019	LL-W019
LL-M001	LL-M001
LL-T001	LL-T001
LL-T002	LL-T002

LL-T003	LL-T003
LL-T004	LL-T004
LL-T005	LL-T005

U.S. Army Material Command [MC]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
N/A	MC-W001

Mound Plant [MD]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
MD-M001/MD-T010	MD-M001
MD-T001	MD-T001
MD-T003	MD-T003
MD-T004/MD-T007	MD-T004
MD-T005	MD-T005
MD-T006	MD-T006
MD-T007/MD-T004/MD-T011	MD-T007
MD-T008/MD-T002	MD-T008
MD-T009	MD-T009
MD-T010	MD-T010
MD-T012	MD-T012
MD-W002	MD-W002
MD-T013	MD-W003
MD-T002	MD-W017

M

N/A	MD-W018

University of Missouri [MU]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
MU-W002	MU-W002

Nevada Test Site [NT]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
NT-W001	NT-W001
N/A	NT-W021

Oak Ridge National Laboratory [OR]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
OR-W040	OR-W040
OR-W042	OR-W042
OR-W044	OR-W044
OR-W045	OR-W045
OR-W046	OR-W046
OR-W047	OR-W047
N/A	OR-W041
N/A	OR-W043
N/A	OR-W048
N/A	OR-W049

N/A	OR-W050
OR-W044	OR-W051
N/A	OR-W052
N/A	OR-W053
N/A	OR-W054
N/A	OR-Z001

Paducah Gaseous Diffusion Plant [PA]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
PA-W014	PA-A015
PA-W015	PA-B015
PA-W015A	PA-W014

Pantex Plant [PX]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
PX-T001	PX-T001

Rocky Flats Environmental Technology Site [RF]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
RF-T001	RF-TT0823
RF-T002	RF-TR0330
RF-T002	RF-TR0336
RF-T002	RF-TR0337

RF-T002	RF-TT0302
RF-T002	RF-TT0330
RF-T002	RF-TT0336
RF-T002	RF-TT0337
RF-T002	RF-TT0487
RF-T002	RF-TT0821
RF-T002	RF-TT0822
RF-T002	RF-TT0825
RF-T002	RF-TT0831
RF-T002	RF-TT0832
RF-T002	RF-TT0833
RF-T003	RF-TR0444
RF-T004	RF-TR0404
RF-T004	RF-TR0405
RF-T004	RF-TR0406
RF-T004	RF-TR0407
RF-T004	RF-TR0408
RF-T004	RF-TR0409
RF-T004	RF-TR0410
RF-T004	RF-TR0411
RF-T004	RF-TR0412
RF-T004	RF-TR0413
RF-T004	RF-TR0414
RF-T004	RF-TR0415
RF-T004	RF-TR0416
RF-T004	RF-TR0417

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RF-T004	RF-TR0418
RF-T004	RF-TR0427
RF-T004	RF-TR0429
RF-T004	RF-TR0433
RF-T004	RF-TR0434
RF-T004	RF-TR0473
RF-T004	RF-TR0654
RF-T004	RF-TT0999
RF-T005	RF-TR0290
RF-T005	RF-TR0299
RF-T006	RF-TT0806
RF-T007	RF-TT2116
RF-T007	RF-TT2216
RF-W008	RF-TT0374
RF-T010	RF-T010
RF-T011	RF-TR0479
RF-T010	RF-TR0480
RF-T011	RF-TR0484
RF-T011	RF-TR0485
RF-T011	RF-TR0486
RF-T011	RF-TR0489
RF-T011	RF-TT0479
RF-T011	RF-TT0480
RF-T011	RF-TT0481
RF-T011	RF-TT0484
RF-T011	RF-TT0485

RF-T011	RF-TT0486
RF-T011	RF-TT0489
RF-T011	RF-TT0824
RF-T037	RF-TR0320
RF-T037	RF-TT0320
RF-T038, RF-W038	RF-TT0802
RF-T052	RF-TR0440
RF-T052	RF-TR0442
RF-T052	RF-TT0440
RF-T052	RF-TT0441
RF-T052	RF-TT0442
RF-T056	RF-TR0368
RF-T056	RF-TR0370
RF-T056	RF-TR0394
RF-T057	RF-TR0334
RF-T057	RF-TR0438
RF-T057	RF-TT0438
RF-T059	RF-TR0390
RF-T059	RF-TR0391
RF-T059	RF-TR0392
RF-T059	RF-TR0395
RF-T059	RF-TR0396
RF-T059	RF-TR0398
RF-T059	RF-TR0655
RF-T060	RF-TR0300
RF-T060	RF-TR0301

RF-T060, RF-W060	RF-TR0303
RF-T060	RF-TR0310
RF-T060, RF-W060	RF-TR0312
RF-T060	RF-TT0300
RF-T060	RF-TT0301
RF-T060, RF-W060	RF-TT0303
RF-T060, RF-W060	RF-TT0312
RF-T063	RF-TR0504
RF-T063	RF-TR0527
RF-T063	RF-TR0541
RF-T063	RF-TT0508
RF-T063	RF-TT0541
RF-T066	RF-TR0331
RF-T066	RF-TR0335
RF-T066	RF-TR0338
RF-T066	RF-TR0342
RF-T066	RF-TT0335
RF-T066	RF-TT0338
RF-T066	RF-TT0490
RF-T066	RF-TT0491
RF-T067	RF-TR0376
RF-T067	RF-TT0376
RF-T069	RF-TR0430
RF-T069	RF-TR0431
RF-T069	RF-TT0430
RF-T069	RF-TT0431

RF-T069, RF-W069	RF-TT0809
RF-T076	RF-TR0044
N/A	RF-TR0067
N/A	RF-TR0080
N/A	RF-TR0081
N/A	RF-TR0082
N/A	RF-TR0083
N/A	RF-TR0084
N/A	RF-TR0086
N/A	RF-TR0087
N/A	RF-TR0089
N/A	RF-TR0145
N/A	RF-TR0146
N/A	RF-TR0289
N/A	RF-TR0600
N/A	RF-TR0601
N/A	RF-TR0653
RF-W008	RF-MR0374
RF-W008	RF-MT0374
RF-W010	RF-MT0001
RF-W010	RF-MT0007
RF-W010	RF-MT0800
RF-W010	RF-MT0803
RF-W010	RF-MT0807
RF-W011	RF-MT0480
RF-W011	RF-W011

RF-W012	RF-MR0330
RF-W012	RF-MR0336
RF-W012	RF-MR0337
RF-W012	RF-MT0330
RF-W012	RF-MT0336
RF-W012	RF-MT0337
RF-W012	RF-MT0821
RF-W012	RF-MT0822
RF-W012	RF-MT0831
RF-W012	RF-MT0832
RF-W012	RF-MT0833
RF-W012	RF-MT0853
N/A	RF-MT0003
RF-W013	RF-MT0801
RF-W026	RF-MT0375
RF-W028	RF-MR0321
RF-W028	RF-MT0321
RF-W029	RF-MR0339
RF-W029	RF-MT0339
RF-W032	RF-MT0444
RF-W032	RF-MT0855
RF-W036, RF-T036	RF-MR0371
RF-W036, RF-T036	RF-MR0373
RF-W036, RF-T036	RF-MR0377
RF-W036, RF-T036	RF-MR0378
RF-W036, RF-T036	RF-MT0377

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RF-W036, RF-T036	RF-MT0378
RF-W037	RF-MR0320
RF-W037	RF-MT0320
RF-W040	RF-MR0420
RF-W040	RF-MR0421
RF-W040	RF-MR0428
RF-W040	RF-MR0419
RF-W040	RF-MT0420
RF-W040	RF-MT0425
RF-W041	RF-MR0341
RF-W041	RF-MT0341
RF-W052	RF-MT0440
RF-W052	RF-MT0442
RF-W052	RF-MT0856
RF-W056	RF-MT-0368
RF-W057	RF-MT-0438
RF-W058	RF-MR-0365
RF-W058	RF-MR-0409
RF-W058	RF-MR-0411
RF-W058	RF-MR-0413
RF-W058	RF-MR-0414
RF-W058	RF-MR-0434
RF-W058	RF-MT-0409
RF-W058	RF-MT-0411
RF-W058	RF-MT-0412
RF-W058	RF-MT-0414

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RF-W059	RF-MR-0392
RF-W059	RF-MR-0393
RF-W059	RF-MR-0395
RF-W059	RF-MT-0391
RF-W059	RF-MT-0392
RF-W059	RF-MT-0393
RF-W063	RF-MR-0070
N/A	RF-MR-0200
RF-W063	RF-MR-0400
RF-W063	RF-MR-0401
RF-W063	RF-MR-0500
RF-W063	RF-MR-0503
RF-W063	RF-MR-0508
RF-W063	RF-MR-0527
RF-W063	RF-MR-0541
N/A	RF-MR-X200
RF-W063	RF-MT-0400
RF-W063	RF-MT-0541
RF-W065	RF-MR-0333
RF-W066	RF-MR-0331
RF-W066	RF-MR-0342
RF-W066	RF-MT-0328
RF-W066	RF-MT-0331

RF-W066	RF-MT-0335
RF-W066	RF-MT-0342
RF-W066	RF-MT-0491
RF-W066	RF-MT-0492
RF-W067	RF-MR-0338
RF-W067	RF-MR-0376
RF-W067	RF-MT-0338
RF-W068	RF-MR-0292
RF-W068	RF-MR-0299
RF-W068	RF-MT-0292
RF-W068	RF-MT-0299
RF-W068	RF-MT-0372
RF-W068	RF-MT-0823
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N/A	RF-MR0090
N/A	RF-MR0091
N/A	RF-MR0092
N/A	RF-MR0097
RF-W076	RF-MR0099
RF-W076	RF-MR0290
RF-W076	RF-MR0332
RF-W076	RF-MR0340
RF-W076	RF-MR0422
RF-W076	RF-MR0423
N/A	RF-MTX112
N/A	RF-MT0544

N/A	RF-MR0533
N/A	RF-MR0535
N/A	RF-MTX115
N/A	RF-MT0831P
N/A	RF-MTX111
RF-M002	RF-MT2116
RF-M001	RF-MT0806

Hanford (Richland) Site [RL]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
N/A	RL-T101
N/A	RL-T102
N/A	RL-T103
N/A	RL-T104
N/A	RL-T105
N/A	RL-T106
N/A	RL-T107
N/A	RL-T108
N/A	RL-T109
N/A	RL-T110
N/A	RL-T112
N/A	RL-T113
N/A	RL-T114
N/A	RL-T115
N/A	RL-T116

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N/A	RL-T118
N/A	RL-T120
N/A	RL-T121
N/A	RL-T122
N/A	RL-T123
N/A	RL-T124
N/A	RL-T125
N/A	RL-T127
N/A	RL-T128
N/A	RL-T129
N/A	RL-T130
N/A	RL-T131
N/A	RL-T132
N/A	RL-T133
N/A	RL-T134
N/A	RL-T135
N/A	RL-T137
N/A	RL-T140
N/A	RL-T143
N/A	RL-T145
N/A	RL-T147
N/A	RL-T148
N/A	RL-T149
N/A	RL-W161
N/A	RL-W162
N/A	RL-W276

N/A	RL-W277
N/A	RL-W278
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N/A	RL-W282
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N/A	RL-W302

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N/A	RL-W440
N/A	RL-W441
N/A	RL-W442
N/A	RL-W443
N/A	RL-W444
N/A	RL-Z001

Sandia National Laboratories [SA]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
SA-T001	SA-T001
SA-W134	SA-W134
N/A	SA-Z001

Savannah River Site [SR]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
SR-W006	SR-W006-773A-VIT
SR-W026	SR-W026-221F-HET

SR-W026	SR-W026-221F-VIT
SR-W026	SR-W026-221H-HET
SR-W026	SR-W026-221H-VIT
SR-W026	SR-W026-235F-HET
SR-W026	SR-W026-235F-VIT
SR-W026	SR-W026-772F-HET
SR-W026	SR-W026-772F-VIT
SR-W026	SR-W026-773A-HET
SR-W026	SR-W026-773A-VIT
SR-W027	SR-W027-221F-HET
SR-W027	SR-W027-221F-MET
SR-W027	SR-W027-221F-VIT
SR-W027	SR-W027-221H-HET
SR-W027	SR-W027-221H-MET
SR-W027	SR-W027-221H-VIT
SR-W027	SR-W027-235F-HET
SR-W027	SR-W027-235F-MET
SR-W027	SR-W027-235F-VIT
SR-W027	SR-W027-772F-HET
SR-W027	SR-W027-772F-MET
SR-W027	SR-W027-772F-VIT
SR-W027	SR-W027-773A-HET
SR-W027	SR-W027-773A-MET
SR-W027	SR-W027-773A-VIT
SR-W027	SR-W027-999-HET
SR-W027	SR-W027-999-VIT

SR-W053	SR-W0053-773A-VIT
SR-T001/SR-T002	SR-T001-221F-HET
SR-T001/SR-T002	SR-T001-221F-MET
SR-T001/SR-T002	SR-T001-221F-VIT
SR-T001/SR-T002	SR-T001-221H-HET
SR-T001/SR-T002	SR-T001-221H-MET
SR-T001/SR-T002	SR-T001-221H-VIT
SR-T001/SR-T002	SR-T001-235F-HET
SR-T001/SR-T002	SR-T001-235F-MET
SR-T001/SR-T002	SR-T001-235-F-VIT
SR-T001/SR-T002	SR-T001-772F-HET
SR-T001/SR-T002	SR-T001-772F-MET
SR-T001/SR-T002	SR-T001-772F-VIT
SR-T001/SR-T002	SR-T001-773A-CLAS
SR-T001/SR-T002	SR-T001-773A-HET
SR-T001/SR-T002	SR-T001-773A-MET
SR-T001/SR-T002	SR-T001-773A-VIT
SR-T003	SR-T003-773A-HET
SR-T003	SR-T003-773A-VIT
N/A	SR-Z001

Teledyne Brown Engineering [TB]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
N/A	TB-W001

West Valley Demonstration Project [WV]

WIPP ID WTWBIR Rev. 1	WIPP ID TWBIR Rev. 2
WV-M005	WV-M005
WV-M007	WV-M007
WV-M008	WV-M008
WV-M010	WV-M010
WV-M012	WV-M012
WV-M013	WV-M013
WV-M015	WV-M015
WV-T001	WV-T001
WV-T002	WV-T002
WV-T003	WV-T003
WV-T004	WV-T004
WV-T006	WV-T006
WV-T009	WV-T009
WV-T011	WV-T011
WV-T014	WV-T014
WV-T016	WV-T016
WV-T017	WV-T017
WV-W024	WV-W024
WV-W041	WV-W041
N/A	WV-Z001

APPENDIX I

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APPENDIX I
PHOSPHATES, NITRATES AND SULFATES

Listed in this Appendix are the positive responses from the TRU waste generator/storage sites on the questions concerning the occurrence of greater than 1 weight percent phosphate, sulfate, and/or nitrate in their waste streams. The intent of the question was that it applied only to "solidified" waste streams. In some cases, the TRU waste sites answered the question for "debris" waste streams. In addition to those positive responses in Revision 2 data call, several sites provided negative responses indicating that these constituents do not occur in the waste in greater than 1 weight percent concentrations, but not necessarily for all waste streams from a site. A detailed listing of the negative responses can be found in the database. No response was received from INEL. Overall only seven sites responded to this question as listed below. Listed below are the sites that provided negative responses and the number of waste streams for each site:

TRU Waste Site	Number of Waste Streams with Negative Responses
BT	5
LA	5
MC	1
RF	16
TB	1
SR	45

PHOSPHATES, NITRATES, SULFATES

Site	TWBIR ID	Phosphates (wt%)	Nitrates (wt%)	Sulfates (wt%)
AL	AL-W005		5	
RF	MT0807		4	
RF	MT0001		8	
RF	MT0800		4	
BT	BT-T005			Unknown

APPENDIX J

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DOE/CAO-95-1121
December 1995

EG&G ROCKY FLATS

EG&G ROCKY FLATS, INC.
ROCKY FLATS PLANT, P.O. BOX 464, GOLDEN, COLORADO 80402-0464 • (303) 966-7000

June 30, 1995 95-RF-05535

R. L. DeVries, MS-2420
Lockheed Martin Idaho Technologies
2525 North Fremont
Idaho Falls, Idaho 83415

TRANSMITTAL OF MITI95 ROCKY FLATS DATA - RLG-013-95

Per guidance in the Matthew J. Zenkowich and Marilyn Tolbert-Smith letter dated April 27, 1995, I have enclosed two diskettes containing transuranic waste stream data, mixed low-level waste waste stream data, and treatment system data for the Rocky Flats Environmental Technology Site (Site). These diskettes are labeled RF-tru.waste.treat Disk #1 and Disk #2. The files on these diskettes were created using the data comprehension utility provided with the MITI95 database. Included in the transuranic waste stream data on these diskettes is the information requested by the Carlsbad Area Office for the Waste Isolation Pilot Plant (WIPP) Transuranic Waste Baseline Inventory Report. Additionally, these data were transferred via Internet to Richard Ahlstrom.

Also enclosed is supplemental activity information for residues at the Site. This information is being provided directly to Paul Drez by copy of this letter. These data address the change in strategy for residue processing from actinide separation to repackaging only, and are being provided to facilitate the safety analysis process for the WIPP.

Please advise me if there are any problems accessing the data files. I can be reached at (303) 966-4934.

Robert L. Griffis, P.E.
EG&G Rocky Flats, Inc.

Enclosures:
As Stated (2)

cc:
J. C. Leifer - DOE, RFFO
W. J. Prymak - " "
M. M. Strum - SAIC
[redacted] - WTAC
S. A. Anderson - EG&G Rocky Flats, Inc.
G. A. O'Leary - " " " "
V. S. Sendelweck - " " " "

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Enclosure 1
95-RF-05535
Page 1 of 1

The following tables provide total projected waste volumes and activity for different residue processing scenarios. Current plans are to process the residues under the 94-1 initiative and ship as waste without actinide separation. Actinide separation was used in the WTWBIR submittal, Rev. 2, as instructed to make the submittal consistent with the Site's Preliminary Site Treatment Plan (PSTP).

WTWBIR Final Waste Form (1)	Final Volume in Cubic Meters for Actinide Separation Option	Final Volume in Cubic Meters for 94-1 Repackaging Initiative
Combustible	401.05	184.39
Filter	816.13	592.83
Graphite	43.41	47.1
Heterogeneous	13.21	3.77
Inorganic Non-Metal	28.32	2,509.61
Lead/Cadmium Metal Waste	55.82	7.6
Salt Waste	56.61	376.52
Soils	0	0
Solidified Inorganics	1,303.26	404.62
Solidified Organics	19.44	
Uncategorized Metal	124.35	55.47

(1) These are the final waste forms as defined in Revision 1 of the WTWBIR.

Radionuclide (1)	Curies (2)
Pu-238	8,143
Pu-239	173,500
Pu-240	39,750
Pu-241	1,016,000
Am-241	108,500

(1) Any isotope that contributes more than 0.1% of the activity.

(2) Curies/isotopes that represent the total curies that will be sent to WIPP as the Actinide Separation processing submittal did not project any curies.

APPROVED:

G. A. O'Leary, TRU Program Manager

for J. Leifer, DOE-Residues

V. Sendelweck, Residue Stabilization

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APPENDIX K

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APPENDIX K
SUPPLEMENTARY INFORMATION FOR WIPP TRU WASTE

K.1 INTRODUCTION

The TWBIR, Revision 2 data call requested information to support several WIPP-related programs and studies such as transportation, waste acceptance criteria, permitting, and engineered alternatives. Due to the length of the data call (see Appendix C), it is not possible to present all the information received from the generator/storage sites for each waste stream in Appendix P. This chapter will summarize some of the information that is not presented in the waste stream profiles. The data supporting the information presented in this appendix and other information that may be of interest to the user, such as the source of the waste streams and the certifiability of stored waste, can be obtained by conducting searches of the TWBID that accompanies this report.

K.2 WASTE TYPE AND HANDLING

The type and handling of the waste streams documented in Appendix P is summarized in Figure K-1 and provided in detail in Tables K-1 and K-2, and is based on the percentage of the anticipated volumes of final waste forms. This chart is based on TWBID, Revision 2 data. It is not identical to a similar chart published in the 1995 IDB (DOE, 1995b) because this IDB is based on Revision 1 of the WTWBID.

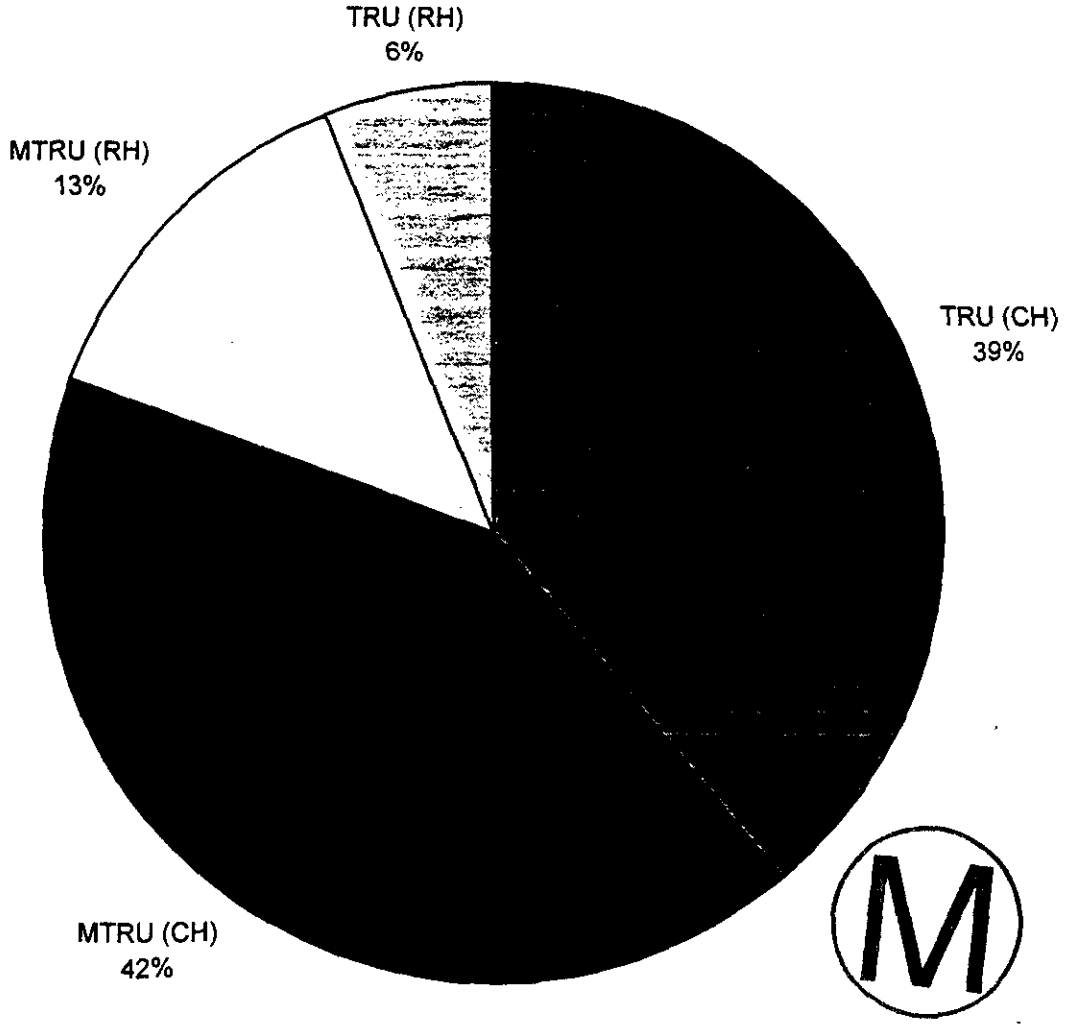

Figure K-1. Summary of Type and Handling of WIPP Waste Streams

Table K-1. WIPP Contact-Handled Mixed and Non-Mixed Disposal Inventory by Site (Final Waste Form)

Storage/Generator Site	Stored Volumes (m3)		Projected Volumes (m3)	
	Mixed	Non-Mixed	Mixed	Non-Mixed
Ames Laboratory - Iowa State Univ.	0.0E+00	0.0E+00	4.2E-01	0.0E+00
Argonne National Laboratory - East	6.5E+00	5.0E+00	1.3E+00	1.3E+02
Argonne National Laboratory - West	4.3E+00	2.3E+00	2.0E+00	7.4E+02
Bettis Atomic Power Laboratory	0.0E+00	0.0E+00	0.0E+00	1.2E+02
Energy Technology Engineering Center	0.0E+00	1.7E+00	0.0E+00	0.0E+00
Hanford (Richland) Site	2.0E+02	1.2E+04	1.3E+04	2.0E+04
Idaho National Engineering Laboratory	2.3E+04	5.3E+03	0.0E+00	0.0E+00
Lawrence Livermore National Laboratory	8.3E+00	2.2E+02	5.0E+01	6.6E+02
Los Alamos National Laboratory	7.7E+03	3.3E+03	3.8E+03	3.6E+03
Mound Plant	3.5E+00	2.7E+02	0.0E+00	0.0E+00
Nevada Test Site	6.1E+02	5.7E+00	9.0E+00	0.0E+00
Oak Ridge National Laboratory	7.0E+02	6.1E+02	2.6E+02	0.0E+00
Paducah Gaseous Diffusion Plant	0.0E+00	0.0E+00	1.9E+00	0.0E+00
Pantex Plant	0.0E+00	6.2E-01	0.0E+00	0.0E+00
Rocky Flats Environmental Technology Site	4.4E+02	2.7E+02	3.3E+03	1.1E+03
Sandia National Laboratory - Albuquerque	0.0E+00	6.7E+00	0.0E+00	7.5E+00
Savannah River Site	1.5E+03	1.4E+03	2.9E+03	3.9E+03
Teledyne Brown Engineering	0.0E+00	2.1E-01	0.0E+00	0.0E+00
U.S. Army Material Command	0.0E+00	2.5E+00	0.0E+00	0.0E+00
University of Missouri Research Reactor	2.1E-01	0.0E+00	8.3E-01	0.0E+00
Totals	3.4E+04	2.4E+04	2.4E+04	3.0E+04

Table K- 2. WIPP Remote-Handled Mixed and Non-Mixed Disposal Inventory by Site (Final Waste Form)

Storage/Generator Site	Stored Volumes (m3)		Projected Volumes (m3)	
	Mixed	Non-Mixed	Mixed	Non-Mixed
Argonne National Laboratory - West	1.8E+00	1.8E+01	3.5E+01	1.2E+03
Battelle Columbus Laboratories	0.0E+00	5.8E+02	0.0E+00	0.0E+00
Bettis Atomic Power Laboratory	0.0E+00	0.0E+00	0.0E+00	6.7E+00
Energy Technology Engineering Center	8.9E-01	0.0E+00	0.0E+00	0.0E+00
Hanford (Richland) Site	2.7E+00	2.0E+02	1.5E+04	6.3E+03
Idaho National Engineering Laboratory	1.9E+02	2.6E+01	0.0E+00	0.0E+00
Los Alamos National Laboratory	1.7E+01	7.7E+01	3.4E+01	6.5E+01
Oak Ridge National Laboratory	2.4E+03	8.5E+01	4.5E+02	0.0E+00
Totals	2.6E+03	9.9E+02	1.6E+04	7.6E+03

APPENDIX L

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Appendix L. TWBID Data Dictionary (TWBIR specific tables)

Table Name Field Name	Type	Description
Page_1 Top level table for TRU waste stream data		
MWIR_ID	text	Unique Waste Stream ID for MITI95
WIPP_ID	text	Waste Stream ID Asssiged for WIPP Project Purposes
LOCAL_ID	text	Locally assigned ID number for the waste stream
NoMigrationAssign	text	No Migration Variance Petition Code
Waste_Type	text	MTRU or TRU
Handling	text	CH or RH
Stream_Name	text	Abbreviation Description/Name of the Stream
Stream_description	memo	Memo field to describe the type of stream (TWBIR and MITI95)
MWIR_matrix_code	text	Matrix Code, from MITI95 if applicable and relevant
Final_Waste_Form	text	This is the code of the final (to WIPP) form of the waste stream;
Matrix_Description	memo	Description and comments for the waste matrix in its final form for WIPP
Waste_Ownership	text	Defense, non-defense, commercial, or unknown
Waste_source	text	R&D, Operational, Residues, ER and D&D, ER, D&D, etc.
TSCA_data	text	Regulated for PCBs; Yes or No
Asbestos_data	text	Regulated for Asbestos; Yes or No
Matrix_Code_Name	text	Matrix name associated with the MITI95 matrix code
TRU_Source_Desc	memo	The source description form MITI95 part of data call updated to include source description from the WTWBIR portion of the data call, if different.
WS_Source_Desc	memo	The source description form MITI95 part of data call
Source_Category	text	The source categories only from the MITI95 portion of the form
WasteStream_Name	text	Stream name from the MITI95 portion of the data
WS_Name_Diff_Comments	text	Describes why WasteStream_Name differs from WTWBIR_WS_Name (if appropriate)
Site_Code	text	Storage Site
Ops_Code	text	Field Office Code
State	text	State Code
PSTP_WS_ID	text	Site treatment plan ID
RPC_Code	text	MITI95 Rad code
Rad_Confidence	text	Confidence in Rad estimate

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
Rad_Comments	memo	Rad Comments by site
Storage_Other	text	Storage Type
Currently_Treated	text	Is this waste treated
Secondary_Streams	text	Are secondary streams produced
Classification	text	Are there classification concerns
Management_Comments	memo	Site Comments
Acceptance_Comments	memo	Site Comments
Site_Name	text	Site Name
EPA_Regs	text	Is regulated under EPA regs?
State_Regs	text	reg. under more restrictive state regs?
LDR_Standards	text	Does at least one epa/state code meet LDR
PCB	text	Does waste stream contain PCBs?
PCB_Range	text	PCB concentration range
CPC_Code	text	MITI95 Contaminant Code
Asbestos	text	Does this WS contain asbestos?
Asbestos_Comments	memo	details of asbestos condition
EPA_Confidence	text	Confidence level
EPA_Comments	memo	Contaminant Comments
Residues	text	Does this waste contain residues
Redist_Comments	memo	Comments on Redistribution
Redistributed	text	Is this stream redistributed
Page1_Footnotes	memo	WTWBIR only footnotes
Container_Data Table of waste parameter and container data used in the Reports database		
MWIR_ID	Text	"Survey_ID"
WIPP_ID	Text	"TWBIR_ID"
WTWS	Text	Combined TWBIR_ID and Ship_Container to make unique ID
Handling	Text	CH or RH - same as page 1 - referent
Waste_Type	Text	MTRU, TRU
Final_Waste_Form	Text	final waste form - same as page 1 - referent

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
Type/Size	Text	Title describing container - "Ship_Container"
Int_Volume	Number	cubic meters per container
Nbr_Stored	Number	total volume of this type of container stored. "Currently_Stored"
Inventory_Date	Date/Time	"Inventory_Date" for Nbr_Stored
Nbr_Projected	Number	"Total_Num_Projected" Total volume of this type of container for this waste stream projected through the last year of projections
IB_avg	Number	Iron-base constituents, Average, in kg/m3
IB_min	Number	Iron-base constituents, Minimum, in kg/m3
IB_max	Number	Iron-base constituents, Maximum, in kg/m3
AB_avg	Number	Aluminum-base constituents, Average, in kg/m3
AB_min	Number	Aluminum-base constituents, Minimum, in kg/m3
AB_max	Number	Aluminum-base constituents, Maximum, in kg/m3
OM_avg	Number	Other metals constituents, Average, in kg/m3
OM_min	Number	Other metals constituents, Minimum, in kg/m3
OM_max	Number	Other metals constituents, Maximum, in kg/m3
OI_avg	Number	Other inorganics constituents, Average, in kg/m3
OI_Min	Number	Other inorganics constituents, Minimum, in kg/m3
OI_max	Number	Other inorganics constituents, Maximum, in kg/m3
Cel_avg	Number	Cellulosics constituents, Average, in kg/m3
Cel_min	Number	Cellulosics constituents, Minimum, in kg/m3
Cel_max	Number	Cellulosics constituents, Maximum, in kg/m3
Rub_avg	Number	Rubber constituents, Average, in kg/m3
Rub_min	Number	Rubber constituents, Minimum, in kg/m3
Rub_max	Number	Rubber constituents, Maximum, in kg/m3
Plas_avg	Number	Plastic constituents, Average, in kg/m3
Plas_min	Number	Plastic constituents, Minimum, in kg/m3
Plas_max	Number	Plastic constituents, Maximum, in kg/m3
SIM_avg	Number	Solidified Inorganic Material constituents, Average, in kg/m3
SIM_min	Number	Solidified Inorganic Material constituents, Minimum, in kg/m3

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
SIM_max	Number	Solidified Inorganic Material constituents, Maximum, in kg/m3
SOM_avg	Number	Solidified Organic Material constituents, Average, in kg/m3
SOM_min	Number	Solidified Organic Material constituents, Minimum, in kg/m3
SOM_max	Number	Solidified Organic Material constituents, Maximum, in kg/m3
SL_avg	Number	Soils, Average, kg/m3
SL_min	Number	Soils, Minimum, kg/m3
SL_max	Number	Soils, Maximum, kg/m3
CMS_avg	Number	Cement (Solidified), Average, kg/m3
CMS_min	Number	Cement (Solidified), Minimum, kg/m3
CMS_max	Number	Cement (Solidified), Maximum, kg/m3
VIT_avg	Number	Vitrified, Average, kg/m3
VIT_min	Number	Vitrified, Minimum, kg/m3
VIT_max	Number	Vitrified, Maximum, kg/m3
PM_Steel	Number	Packaging materials, steel, kg/m3
PM_Plastic	Number	Packaging materials, plastic, kg/m3
PM_Lead	Number	Packaging materials, lead kg/m3
FF_End_of_93	Number	The waste volume of the waste on hand at end of year in its estimated Final form for shipment to the WIPP, the increment added during the year.
FF_End_of_94	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_95	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_96	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_97	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_98	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_99	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_00	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
FF_End_of_01	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_02	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_03	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_04	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_05	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_06	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_07	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_08	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_09	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_10	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_11	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_12	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_13	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_14	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_15	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_16	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_17	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_18	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
FF_End_of_19	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_20	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_21	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
FF_End_of_22	Number	The waste volume of the waste on hand at end of year in its estimated final form for shipment to the WIPP, the increment added during the year.
ADD>2022	Text	Are projections beyond 2022 added into 2022? (Yes/No)
FF>2022	Number	Amount added into 2022 from years beyond 2022
Comments	Memo	Miscellaneous comments
Container_Footnotes	Memo	Footnotes applicable to a given container/waste combination.
CONTACTS This table contains the list of primary and alternate contacts for both the Treatment and Waste Stream surveys.		
Contact_Code	Text	The unique code generated by the system.
Last_Name	Text	1.2.1/1.3.1 The last name of the contact.
First_Name	Text	1.2.1/1.3.1 The first name of the contact.
Middle	Text	1.2.1/1.3.1 The middle initial of the contact.
Address	Text	1.2.2/1.3.2 The address of the contact.
City	Text	1.2.2/1.3.2 The city of the contact.
State	Text	1.2.2/1.3.2 The state of the contact.
Zip	Text	1.2.2/1.3.2 The ZIP-Code of the contact.
Phone	Text	1.2.3/1.3.3 The phone number of the contact.
Fax	Text	1.2.4/1.3.4 The FAX number of the contact.
E_mail	Text	1.2.5/1.3.5 The E-Mail address of the contact.
TRU_COMPONENTS This table contains the components that apply to this TWBIR waste stream.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Component	Text	8.2.11 The component found in this TWBIR waste stream with a concentration greater than 1 wt%. (Nitrates, Sulfates, Phosphates)

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
Component_Exists	Text	8.2.11 Does this component exist in this TWBIR waste stream with a concentration greater than 1 wt%? (Yes, No)
Est_Concentration	Number	8.2.11 The estimated concentration for the component.
TRU_EPA_CODES This table contains the list of EPA codes found in the TWBIR waste stream.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
EPA_Code	Text	8.2.10.1 The EPA code found in the waste stream. (Look-up EPA_LU)
LDR_Code	Text	8.2.10.1 The LDR code corresponding to the EPA code listed. (Look up EPA_LU)
Contam_Name	Text	8.2.10.1 The contaminant name that corresponds to the EPA code.
Concentration	Text	8.2.10.1 The concentration (typical or range) that this contaminant reaches in the waste stream.
Concentration_Unit	Text	8.2.10.1 The units of measure for the concentration.
Concentration_Basis	Text	8.2.10.1 The basis for the concentration values. (Sampling/Process Knowledge/Both/Unknown)
Total_Or_Extract	Text	8.2.10.1 Distinguishes the nature of the concentration value or range. (Total/Extract/Unknown)
TRU_IDCs This table contains the IDCs that apply to this TWBIR waste stream.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
IDC	Text	8.2.8 The final waste form IDCs that apply to this TWBIR waste stream.
	TRU_SHC_EST_GENERATION This table contains the annual estimated amounts of shipping container generation for the TWBIR waste stream.	
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Ship_Container	Text	8.2.13 The container type/size used to ship the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Ship_Container used for table relationships
Year	Number	8.2.15.1.12 The year for which the amounts are estimated.
Est_Containers	Number	8.2.15.1.12 The estimated number of containers that will be generated for the year.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
NA	Yes/No	8.2.15.1.12 The number for this year is in the "Number Currently in Storage" (7.2.15.1.9).
Comments	Text	8.2.15.1.12 Comments for the amount listed for the year.
TRU_SHC_ESTIMATES This table contains volumes and estimated values for the shipping container.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Ship_Container	Text	8.2.13 The container type/size used to ship the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Ship_Container used for table relationships
Internal_Volume	Number	8.2.15.1.4 The internal volume (payload volume) per container (m3).
Less350LB	Number	8.2.15.1.5 The estimated percent of containers less than 350lb/container (drums only).
Between350_500LB	Number	8.2.15.1.6 The estimated percent of containers between 350 and 500 lbs/container (drums only).
Less23PUFGE	Number	8.2.15.1.7 The estimated percent of containers with less than 23 Pu-239 Fissile Gram Equivalents (drums only).
Between23_200PUFGE	Number	8.2.15.1.8 The estimated percent of containers with between 23 and 200 Pu-239 Fissile Gram Equivalents (drums only).
Currently_Stored	Number	8.2.15.1.9 The number of this container type currently in storage.
Inventory_Date	Date/Time	8.2.15.1.10 The date of this inventory.
Total_Num_Projected	Number	8.2.15.1.11 The total number of these containers projected from the inventory date to the end of 2022.
FF_Comments	Memo	8.2.15.1.14 Final Form comments.
TRU_SHC_LINER This table contains the liner types used for the shipping container.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Ship_Container	Text	8.2.13 The container type/size used to ship the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Ship_Container used for table relationships
Liner_Type	Text	8.2.15.1.2 The liner types found in this container. Look-up TRU_LINER_LU.
TRU_SHC_LINER_MATERIAL This table contains the liner materials used in the shipping container.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Ship_Container	Text	8.2.13 The container type/size used to ship the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Ship_Container used for table relationships
Liner_Material	Text	8.2.15.1.3 The material used to line the container. Look-up TRU_LINER_MATERIAL_LU.
Liner_Material_Other	Text	8.2.15.1.3 The (other) liner material used in the container.
TRU_SHC_MATERIAL This table contains the construction materials used for the shipping container.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Ship_Container	Text	8.2.13 The container type/size used to ship the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Ship_Container used for table relationships
Material	Text	8.2.15.1.1 The material used to construct the container. Look-up TRU_MATERIAL_LU.
Material_Other	Text	8.2.15.1.1 The (other) material used to construct the container.
TRU_SHC_WEIGHTS This table contains the typical waste material weights for the Final Waste Form for the shipping container in the TWBIR waste stream.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Ship_Container	Text	8.2.13 The container type/size used to ship the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Ship_Container used for table relationships
Material_Parameter	Text	8.2.15.1.13 The material parameter. Look-up TRU_WEIGHTS_LU.
Avg	Number	8.2.15.1.13 The average weight of this material.
LL	Number	8.2.15.1.13 The lower limit for the weight of this material.
UL	Number	8.2.15.1.13 The upper limit for the weight of this material.
Comments	Text	8.2.15.1.13 Any comments applicable.
TRU_SHIP_CONTAINER This table contains the current container type/sizes used to store the TWBIR waste stream.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Ship_Container	Text	8.2.13 The container type that will be used to ship the final forms of this TWBIR waste stream to WIPP. Look-up TRU_SHIP_CONTAINER_LU.
WTWS	Text	A combination of TWBIR_ID and Ship_Container used for table relationships
Same_Nucs	Text	8.2.13 Is the radionuclide information for this container the same as reported in section 3.2.6? (Yes;No)
TRU_STC_EST_GENERATION This table contains the annual estimated amounts of storage container generation for the TWBIR waste stream.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Year	Number	8.2.14.1.12 The year for which the amounts are estimated.
Est_Containers	Number	8.2.14.1.12 The estimated number of containers that will be generated for the year.
NA	Yes/No	8.2.14.1.12 The number for this year is in the "Number Currently in Storage" (7.2.14.1.9).
Comments	Text	8.2.14.1.12 Comments for the amount listed for the year.
TRU_STC_ESTIMATES This table contains volumes and estimated values for the storage container.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Internal_Volume	Number	8.2.14.1.4 The internal volume (payload volume) per container (m3).
Less350LB	Number	8.2.14.1.5 The estimated percent of containers less than 350lb/container (drums only).
Between350_500LB	Number	8.2.14.1.6 The estimated percent of containers between 350 and 500 lbs/container (drums only).
Less23PUFGE	Number	8.2.14.1.7 The estimated percent of containers with less than 23 Pu-239 Fissile Gram Equivalents (drums only).
Between23_200PUFGE	Number	8.2.14.1.8 The estimated percent of containers with between 23 and 200 Pu-239 Fissile Gram Equivalents (drums only).

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
Currently_Stored	Number	8.2.14.1.9 The number of this container type currently in storage.
Inventory_Date	Date/Time	8.2.14.1.10 The date of this inventory.
Total_Num_Projected	Number	8.2.14.1.11 The total number of these containers projected from the inventory date to the end of 2022.
TRU_STC_LINER This table contains the liner types used for the storage container.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Liner_Type	Text	8.2.14.1.2 The liner types found in this container. Look-up TRU_LINER_LU.
TRU_STC_LINER_MATERIAL This table contains the liner materials used in the storage container.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Liner_Material	Text	8.2.14.1.3 The material used to line the container. Look-up TRU_LINER_MATERIAL_LU.
Liner_Material_Other	Text	8.2.14.1.3 The (other) liner material used in the container.
TRU_STC_MATERIAL This table contains the construction materials used for the storage container.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Material	Text	8.2.14.1.1 The material used to construct the container. Look-up TRU_MATERIAL_LU.
Material_Other	Text	8.2.14.1.1 The (other) material used to construct the container.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
TRU_STC_TRAMPAC This table contains information concerning TRAMPAC Certifiability.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
TRAMPAC_Cert	Text	8.2.14.1.14.1 Are all of this current container type/size certifiable to TRAMPAC (shipment to WIPP via TRUPACT-II (Yes; No)
Num_Non_Cert	Number	8.2.14.1.14.2 What percent of these containers are non-certifiable?
FiltLiner_Required	Text	8.2.14.1.14.3.1 For containers not certifiable to TRAMPAC, are Filters/Liner vents required? (No ; Yes)
Num_FiltLiner_Required	Number	8.2.14.1.14.3.1.1 The percent of the non-certifiable containers that require filter/liner vents.
Repack_Required	Text	8.2.14.1.14.3.2 For containers not certifiable to TRAMPAC, is repackaging required? (No; Yes)
Num_Repack_Required	Number	8.2.14.1.14.3.2.1 The percent of the non-certifiable containers that require repackaging.
Treatment_Required	Text	8.2.14.1.14.3.3 For containers not certifiable to TRAMPAC, is treatment required? (No; Yes)
Num_Treatment_Required	Number	8.2.14.1.14.3.3.1 The percent of the non-certifiable containers that require treatment.
CF_Comments	Memo	8.2.14.1.14.4 Current Form comments.
TRU_STC_TRAMPAC_REPACK This table contains information concerning containers not-certifiable to TRAMPAC due to repackaging requirements.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Repack_Cause	Text	8.2.14.1.13.3.1.2 The cause of repackaging required. Look-up TRU_REPACK_LU
Repack_Cause_Other	Text	8.2.14.1.13.3.1.2 The (other) cause of repackaging required.
Containers_Affected	Number	8.2.14.1.13.3.1.2 The estimated percent of containers affected.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
TRU_STC_TRAMPAC_TREAT This table contains information concerning containers not-certifiable to TRAMPAC due to treatment requirements.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Treatment_Cause	Text	8.2.14.1.13.3.2.2 The cause of treatment required. Look-up TRU_TREATMENT_LU
Treatment_Cause_Other	Text	8.2.14.1.13.3.2.2 The (other) cause of repackaging required.
Containers_Affected	Number	8.2.14.1.13.3.2.2 The estimated percent of containers affected.
TRU_STC_WACv3 This table contains information concerning the WAC Revision 3 Certifiability.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
WIPPWACv3_Cert	Text	8.2.14.1.13.1 Are all of this current container type/size certifiable to WIPP WAC Revision 3? (Yes; No)
Num_Non_Cert	Number	8.2.14.1.13.2 What percent of these containers are non-certifiable?
Repack_Required	Text	8.2.14.1.13.3.1 For containers not certifiable to WIPP WAC Revision 3, is repackaging required? (No; Yes)
Num_Repack_Required	Number	8.2.14.1.13.3.1.1 The percent of the non-certifiable containers that require repackaging.
Treatment_Required	Text	8.2.14.1.13.3.2 For containers not certifiable to WIPP WAC Revision 3, is treatment required? (No; Yes)
Num_Treatment_Required	Number	8.2.14.1.13.3.2.1 The percent of the non-certifiable containers that require treatment.
TRU_STC_WACv3_REPACK This table contains information concerning containers not-certifiable to WIPP WAC Revision 3 due to repackaging requirements.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Repack_Cause	Text	8.2.14.1.13.3.1.2 The cause of repackaging required. Look-up TRU_REPACK_LU
Repack_Cause_Other	Text	8.2.14.1.13.3.1.2 The (other) cause of repackaging required.
Containers_Affected	Number	8.2.14.1.13.3.1.2 The estimated percent of containers affected.
TRU_STC_WACv3_TREAT This table contains information concerning containers not-certifiable to WIPP WAC Revision 3 due to treatment requirements.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Treatment_Cause	Text	8.2.14.1.13.3.2.2 The cause of treatment required. Look-Up TRU_TREATMENT_LU
Treatment_Cause_Other	Text	8.2.14.1.13.3.2.2 The (other) cause of repackaging required.
Containers_Affected	Number	8.2.14.1.13.3.2.2 The estimated percent of containers affected.
TRU_STOR_CONTAINER This table contains the current container type/sizes used to store the TWBIR waste stream.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
WTWS	Text	A combination of TWBIR_ID and Stor_Container used for table relationships
Stor_Container	Text	8.2.12 The container type/size used to store the TWBIR waste stream.
Same_Nucs	Text	8.2.12 Is the radionuclide information for this container the same as reported in section 3.2.6? (Yes;No)
Container_Comments	Text	8.2.12 Container Comments
TRU_TRUCON_CODES This table contains the TRUCON codes that apply to this TWBIR waste stream.		
Survey_ID	Text	2.1.1 (8.2.2) The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
TRUCON_Code	Text	8.2.7 The TRUCON code that applies to this TWBIR waste stream.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
EPACODES This table contains the list of EPA codes found in the waste stream.		
Survey_ID	Text	2.1.1 The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
EPA_Code	Text	3.4.3 The EPA code found in the waste stream. (Look-up EPA_LU)
LDR_Code	Text	3.4.3 The LDR code corresponding to the EPA code listed. (Look-up EPA_LU)
Contam_Name	Text	3.4.3 The contaminant name that corresponds to the EPA code.
Concentration	Text	3.4.3 The concentration (typical or range) that this contaminant reaches in the waste stream.
Concentration_Unit	Text	3.4.3 The units of measure for the concentration.
Concentration_Basis	Text	3.4.3 The basis for the concentration values. (Sampling/Process Knowledge/Both/Unknown)
Total_Or_Extract	Text	3.4.3 Distinguishes the nature of the concentration value or range. (Total/Extract/Unknown)
WS_GEN_SITES This table contains the names of the sites that generated this waste stream for the		
survey.		
Survey_ID	Text	2.1.1 The unique waste stream ID generated by the computer and assigned to the questionnaire.
Site_Code	Text	2.3.3 The code of the site that generated this waste stream.
Site_Name	Text	2.3.3a The name of the site that generated this waste stream.
WS_GENERATION This table contains waste stream generation information.		
Survey_Id	Text	2.1.1 The unique waste stream ID generated by the computer and assigned to the questionnaire.
Generation	Text	5.1.1 Is this waste stream currently generated or, if not, will this waste stream be generated in the future? (Yes/No)
Generation_Desc	Text	5.1.2 The current of future generation of this waste is best described as; (Routine/One-time, or sporadic)
WT_WS_RAD_CONC This table contains the radionuclides found in the waste stream for this survey.		
Survey_ID	Text	2.1.1 The unique waste stream ID generated by the computer and assigned to the questionnaire.
TWBIR_ID	Text	8.1 (8.2.1) The Transuranic Waste Baseline Inventory Report ID that applies to this waste stream.
Radionuclide	Text	3.2.6 The radionuclide found in the waste stream. (Look-up Radionuclide_LU)
Rad_Other	Text	3.2.6 The (Other) radionuclide.

Appendix L. TWBID Data Dictionary (TWBIR specific tables) (continued)

Table Name Field Name	Type	Description
Concentration_Value	Number	3.2.6 The typical concentration for this radionuclide.
Concentration_Units	Text	3.2.6 The units of measure for the concentration.
Concentration_Basis	Text	3.2.6 The basis for the concentration values. (Sampling/Process
Knowledge/Both/Unknown)		
WS_SECONDARY_ID This table contains the secondary stream IDs created as a result of treatment of the parent waste stream.		
Survey_ID	Text	2.1.1 The unique waste stream ID generated by the computer and assigned to the questionnaire.
Secondary_ID	Text	6.2.2.1 The secondary ID, for the waste stream created as a result of treatment of the parent waste stream.
WS_STORAGE This table contains the storage methods used for the waste stream.		
Survey_ID	Text	2.1.1 The unique waste stream ID generated by the computer and assigned to the questionnaire.
Storage	Text	6.1.1.1 What is the storage method for this waste stream? (Look-up WS_Storage_LU)
Storage_Other	Text	6.1.1.1.5 The (other) storage method used for this waste stream.
WS_STORAGE_FAC This table contains the facilities where the waste stream is being stored.		
Survey_ID	Text	2.1.1 The unique waste stream ID generated by the computer and assigned to the questionnaire.
Facility_Name	Text	6.1.1.2 The facility name where the waste stream is stored.
Building_Number	Text	6.1.1.2 The building number where the waste stream is stored.
WS_SURVEY_INFO This table contains the information contacts for the survey.		
Survey_ID	Text	2.1.1 The unique waste stream ID generated by the computer and assigned to the questionnaire.
Site_Code	Text	1.1.1 The code of the site for this survey. Look-up SITE_LU.Site_Code.
Ops_Code	Text	1.1.2 The code of the operations office for this survey. Look-up SITE_LU.Ops_Code.
State	Text	1.1.3 The state for this survey. Look-up SITE_LU.State.
Pri_Contact_Code	Text	1.2 The code for the primary contact. Look-up CONTACTS.Contact_Code.
Alt_Contact_Code	Text	1.3 The code for the alternate contact. Look-up CONTACTS.Contact_Code.

APPENDIX M

M

APPENDIX M
CALCULATION OF PACKAGING MATERIALS FOR DIFFERENT CONTAINERS

The calculations for the amount of packaging materials (i.e., steel, plastic, or lead) present in each type of TRU waste container that is currently planned to be shipped to WIPP are based on the packaging material assumptions stated in Chapter 1. The actual calculations to estimate the amount of each packaging material in kilograms per cubic meter (kg/m^3) is presented in Sections M.1 to M.5.

M.1 Packaging Materials for a 55-gallon drum

Steel
Based on the assumption that a 55-gallon drum is made up of steel and weighs 60 pounds, the amount of steel is calculated as follows:

$$\text{Amount of steel} = \frac{60 \text{ lbs} / (2.205 \text{ lbs/kg})}{0.208 \text{ m}^3 \text{ per drum}} = 130.8 \text{ kg/m}^3$$

Plastic
Based on the assumption that the rigid liner in a 55-gallon drum weighs 7.7 kilograms, the amount of plastic packaging in a 55-gallon drum is calculated as follows:

$$\text{Amount of plastic} = \frac{7.7 \text{ kg}}{0.208 \text{ m}^3} = 37.01 \text{ kg/m}^3$$

M.2 Packaging Materials for a Direct-Load SWB

Steel
Based on the assumption that a SWB is made up of steel and weighs 640 pounds, the amount of steel is calculated as follows:

$$\text{Amount of steel} = \frac{640 \text{ lbs} / (2.205 \text{ lbs/kg})}{1.89 \text{ m}^3 \text{ per SWB}} = 153.5 \text{ kg/m}^3$$

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Plastic

Based on the assumption that the 11-mil PVC liner in a directly loaded SWB weighs approximately 2.25 kilograms, the amount of plastic packaging in a directly loaded SWB is calculated as follows:

$$\text{Amount of plastic} = \frac{2.25 \text{ kg}}{1.89 \text{ m}^3} = 1.19 \text{ kg/m}^3$$

M.3 Packaging Materials for an SWB Used to Overpack Four 55-gallon Drums

Steel

For the case of four 55-gallon drums overpacked in a SWB, the total weight of steel is a combination of the steel in the SWB and the steel in the four 55-gallon drums. Based on the assumptions made earlier about the weight of a 55-gallon drum (60 lbs) and the weight of a SWB (640 lbs) the amount of steel is calculated as follows:

$$\text{Amount of steel} = \frac{(4 \times 60 + 640)\ \text{lbs} / (2.205\ \text{lbs/kg})}{1.89\ \text{m}^3\ \text{per SWB}} = 211.1\ \text{kg/m}^3$$

Plastic

It is assumed that the 11-mil PVC liner for the SWB will not be used when the drums are overpacked in the SWB. Thus, the plastic will be contributed entirely by the rigid liners in the four overpacked drums. Based on the assumption, the amount of plastic packaging is calculated as follows:

$$\text{Amount of plastic} = \frac{4\ \text{drums} \times 7.7\ \text{kg of plastic per drum}}{1.89\ \text{m}^3\ \text{per SWB}} = 16.29\ \text{kg/m}^3$$

M.4 Packaging Materials for a Direct-Load RH Canister

Steel

The total weight of an empty RH Canister is 1,762 lbs, of which 852 lbs is steel and 910 lbs is lead. This does not include the shield plug. Based on the 852 lbs of steel and a volume of 0.89 m^3 for the RH Canister, the amount of steel is calculated as follows:

$$\text{Amount of steel} = \frac{852\ \text{lbs} / (2.205\ \text{lbs/kg})}{0.89\ \text{m}^3\ \text{per RH Canister}} = 434.15\ \text{kg/m}^3$$

Plastic

For a directly loaded RH Canister, it is assumed that there would not be any plastic packaging involved. Therefore, the amount of plastic for this case is zero.

Lead

Based on the 910 lbs of lead in an RH Canister mentioned earlier and a volume of 0.89 m^3 for the RH Canister, the amount of lead is calculated as follows:

$$\text{Amount of lead} = \frac{910\ \text{lbs} / (2.205\ \text{lbs/kg})}{0.89\ \text{m}^3\ \text{per RH Canister}} = 463.7\ \text{kg/m}^3$$

M.5 Packaging Materials for an RH Canister Used to Overpack Three 55-gallon Drums

Steel

For the case of three 55-gallon drums overpacked in an RH Canister, the total weight of steel is a combination of the steel in the RH Canister and the steel in the three 55-gallon drums. Based on the assumptions made earlier about the weight of a 55-gallon drum (60 lbs) and the weight of steel in an RH Canister (852 lbs) the amount of steel is calculated as follows:

$$\text{Amount of steel} = \frac{(3 \times 60 + 852)\ \text{lbs} / (2.205\ \text{lbs/kg})}{0.89\ \text{m}^3\ \text{per RH Canister}} = 525.8\ \text{kg/m}^3$$

Plastic

The plastic will be contributed entirely by the rigid liners in the three overpacked drums. Based on the assumption, the amount of plastic packaging is calculated as follows:

$$\text{Amount of plastic} = \frac{3\ \text{drums} \times 7.7\ \text{kg of plastic per drum}}{0.89\ \text{m}^3\ \text{per RH Canister}} = 25.9\ \text{kg/m}^3$$

Lead

Since the 55-gallon drums do not contribute any lead, the calculation for this case is the same as that of a directly loaded RH Canister. Thus, based on the 910 lbs of lead in an RH Canister mentioned earlier and a volume of 0.89 m^3 for the RH Canister, the amount of lead is calculated as follows:

$$\text{Amount of lead} = \frac{910\ \text{lbs} / (2.205\ \text{lbs/kg})}{0.89\ \text{m}^3\ \text{per RH Canister}} = 463.7\ \text{kg/m}^3$$

APPENDIX N

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APPENDIX N
GUIDELINES FOR REVIEW OF TRU WASTE GENERATOR/STORAGE SITE WASTE STREAM PROFILES

1.1.1 *DOE Site Name:* Must contain two-letter site code

2.1.1 *Unique HQ WS ID:* Formerly called the MWIR ID. Same as 8.2.2. The HQ ID must begin with the two digit site identifier, followed by the letter "W", then a three digit number (i.e., RF-W012). If this number does not directly relate to the WTWBIR WS ID, verify that this is the intent of the site.

2.1.2 *Site WS ID:* Should contain the site identifier(s) used by the sites, but does not necessarily have to be filled in

2.1.3 *Waste Stream Name:* Name filled in should correlate well with answers to Description (3.1), and Final Waste Form Group (8.2.3)

2.1.4 *PSTP WS ID:* Should only be in the following format DD-WXXX, also make sure this is a MTRU stream in the answer to 3.2.1

2.3.1 *Waste Stream Source Description:* Make sure the description is consistent with the source category chosen in the next question (2.3.2)

2.3.2 *Source Category:* Make sure that only one of these is checked and it is consistent with the response to 2.3.1.

2.3.3 *Generator Site Name:* Must contain two letter code. If this is different from the answer to 1.1.1, then do a reality check to make sure that it is not an error. In most cases this should be the same as 1.1.1

3.1 *Waste Stream Description*: Description should correlate well with answers to Waste Stream Name (2.1.3), and Final Waste Form Group (8.2.3)

3.2.1 *Waste Type:* Only TRU or MTRU should be checked

3.2.2 *Waste Handling:* Only one of the choices should be checked (either CH or RH)

3.2.6 *Radionuclide:* Make sure that the "typical" value reported does not fall outside of the reported "range". Check for consistency of reporting format to make sure that there is enough information to report the data in terms of Ci/m^3 if necessary. Also, look out for any obvious errors or typos (e.g., Ca instead of Cs). Check with Appendix A of the WTWBIR

Revision 1 to determine if the radionuclides are reasonable (i.e., curie counts are similar or the same)in comparison to the radionuclides presented in this section.

3.4.3 *EPA/State Regulated Contaminant List:* If the response to 3.2.1 is MTRU, then there should be some EPA codes here, otherwise this field should be empty. Check if Appendix VIII information is listed. If none is listed check cover letter or comment section. If no information from site, call site to check why Appendix VIII is not listed (i.e., whether it is not listed due to lack of information or whether the site knows for sure that these are not present in the waste).

3.4.4 thru 3.4.6.2 Make sure that only one option is filled for each question, and the responses are consistent.

8. WIPP Transuranic Waste Baseline Inventory Report (WTWBIR) Data Requirements

8.1 Provide the WTWBIR WS ID numbers that apply to this MWIR WS

8.1.1 thru *8.1.#* *WTWBIR ID*: The WTWBIR ID should start with the site identifier (see Figure 1-1 of the WTWBIR Rev. 1, or contact Eric Krieger for new sites). The next code is generally a "W", "M", or "T". The WTWBIR ID can be any number series generated by the sites. The only requirement is that it begin with the two digit site identifier.

8.2 WTWBIR Level of Information (Repeat this section for each WTWBIR WS ID listed in section 8.1)

8.2.1 *WTWBIR WS ID:* Make sure that the number entered is the same as that which was entered in 8.1.

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WTWBIR WS Name: Use the appropriate site-specific, unique descriptive identifier for a TRU waste stream. (i.e., metal debris, rubber/plastic debris, heterogeneous debris, HEPA filters, etc).

8.2.2 *Unique HQ WS ID:* Formerly called the MWIR ID. Same as 2.1.1. The HQ ID must begin with the two digit site identifier, followed by the letter "W", then a three digit number (i.e., RF-W012). If this number does not directly relate to the WTWBIR WS ID, verify that this is the intent of the site.

MWIR WS Name: Use the appropriate site-specific, unique descriptive identifier for a MWIR (HQ WS ID) waste stream. (i.e., metal debris, rubber/plastic debris, heterogeneous debris, HEPA filters, etc).

WS Difference Comments: Comments relating to the differences between the MWIR WS and the WTWBIR WS. In addition, any comments relating to subdivision of the MWIR WS.

8.2.3 *Final Waste Form Group: Select the one that best represents the overall WS.* The Final Waste Form Group should be consistent with the *Typical Waste Material Weights for Final Waste Form* in section 8.2.15.1.14 or 8.2.15.x.10 (as applicable) and section 3.1, Waste Stream Description. The reviewer needs to check to see if the Final Waste Form Group entry is consistent with the Updated Waste Matrix Code Group Numbers supplied for this review. If the Final Waste Form Group entry is NOT consistent with the Updated Waste Matrix Code Group Numbers, then verify with the site.

8.2.4 *Does the WTWBIR WS contain residues?* Yes or No should be checked. Sites expected to have residues per the Defense Nuclear Facilities Safety Board Recommendation 94-1 include Rocky Flats, Savannah River Site, Richland (Hanford), Los Alamos, and Lawrence Livermore

8.2.5 *WTWBIR WS source:* Only one category should be checked. If any of the major sites check anything other than defense, you will need to verify this with the site.

8.2.6 *NMVP ID:* Use the content code from Table 2-1 Vol. II of the NMVP. Not all WS's will have a NMVP ID. NA should be used if the WS does not appear in the NMVP. If something is filled in for the NMVP ID, there should also be an entry for the TRUCON Code in section 8.2.7. If the NMVP ID is left blank, check the NMVP Table 2-1, or verify with the site. For RH TRU waste this should be blank or N/A.

8.2.7 *Applicable TRUCON codes:* TRUCON codes are obtained from the content code assessments sections of the DOE document TRUPACT-II Content Codes (TRUCON) and are listed by major site. (Chapters 12 to 21 in Rev. 4). More than one TRUCON code may apply. Assignment should be made at the time of waste stream profile review. The TRUCON Code should correlate to the entry to Final Waste Form Group, section 8.2.3. If the category is left blank, check the TRUCON Codes (Chapters 12 to 21 in Rev. 4), or verify with the site. Table 3 "Content Codes for Newly Generated Waste" and Table 4 "Content Codes for Retrievably Stored Waste" are included as an attachment to verify these codes.

8.2.8 *Applicable Final IDC's*: Site specific code. Can be cross referenced with TRUCON content code. This may be left blank.

8.2.9 *WTWBIR WS same as MWIR WS from section 2.3:* Check with section 2.3 for information on MWIR WS. If yes, get the information from section 2.3 and 2.3.2. If No, section 8.2.9.1 should contain information relative to the differences between the WTWBIR WS and the MWIR WS (i.e., major inputs into the process, any reactions that changed materials in the process and any additions to the waste stream which resulted in the final waste form). If no further treatment is planned before shipment to WIPP, the description should be consistent with the Final Waste Form Group in section 8.2.3 and the distribution of waste material parameters to be provided in section 8.2.15.1.14 and any of 8.2.15.x.10 (as applicable). Section 8.2.9.2 should have only one category checked. There may be entries that contain more than one category. These types of entries should be explained in 8.2.9.1.

8.2.10 *WTWBIR WS same as MWIR WS from section 3.4.3:* Check with section 3.4.3 for information on MWIR WS. If yes, get information from 3.4.3. If no, continue to section 8.2.10.1; EPA/State Regulated Contaminant List should contain a subset of the same information as 3.4.3. If the response to section 3.2.1 is MTRU, then there should be some EPA codes in section 8.2.10.1, otherwise this field should be blank. Check if Appendix VIII information is listed. If none is listed check cover letter or comment section. If no information from site, call site to check why Appendix VIII is not listed (i.e., whether it is not listed due to lack of information or whether the site knows for sure that these are not present in the waste).

8.2.11 *Concentrations greater than 1 wt% in WTWBIR WS:* (Data for SNL); Nitrates, Sulfates, Phosphate. If the answer in the Y/N column is Y, but no estimated concentrations are provided, a description of the source of the component and the reasons for the unknown estimated concentrations should be provided. If a blank or an N is shown for a waste stream such as a solidified sludge, make a note for review of data for the WTWBIR team, there may be a need to verify with the site.

8.2.12 *Container types and size that are used/have been used/will be used to STORE this WTWBIR WS (e.g., Drum/55 gal; Box/4 x 4 x 7 ft; Box 112 ft^3; SWB).* This information defines current and planned containers and will be used in section 8.2.14. All TRU waste whether it is to be sent to WIPP or not should be included in this table. Column one: Current container type/size Column two: Are radionuclides the same as section 3.2.6 for the MWIR (Yes/No); If yes, the information will be used for the WTWBIR. If NO is entered, reasons for difference should be in

column three; Column three: Comments should be on each container listed in column one that do not have the same radionuclides as those used in section 3.2.6.

If the isotopic distribution is the same but the concentration is different, the value by which to multiply the concentrations in section 3.2.6 should be provided to obtain the concentrations for the given container in the comment field. If the isotopic distribution is different it should be indicated in the comment field for the given container type and a table should be provided (similar to the table in section 3.2.6) for the container type and WTWBIR WS ID. This table should be on hard copy or in the comment section of 8.2.14.1.14.3.4.

8.2.13 *Selection of container types that will be used to ship the final forms of the WTWBIR WS to WIPP (indicate all that apply).* All waste that is planned for disposal in the WIPP repository should be included in this table. Column two: Select type(s) that will apply to final waste form container (Y/N); The container(s) picked by the generator/storage site will be used in section 8.2.15; Column three: Are radionuclides the same as section 3.2.6 for the MWIR (Yes/No). If Y is entered, WTWBIR will use the information provided in section 3.2.6. If N is entered, the differences should be described in the appropriate comment section for the given container; e.i., Section 8.2.15.1.12 (55 gallon drum), 8.2.15.2.8(SWB), 8.2.15.3.8 (SWB used to overpack 55 gallon drums), 8.2.15.4.8 (RH canister), 8.2.15.5.8 (RH canisters used to overpack 55 gallon drums), or section 8.2.15.6.8 (RH canisters used to overpack 30 gallon drums). A table should also be provided (similar to the table in section 3.2.6) for the container type and WTWBIR WS ID. This table should be on hard copy or in the comment section of 8.2.14.1.14.3.4.

If the isotopic distribution is the same but the concentration is different, the value by which to multiply the concentrations in section 3.2.6 should be provided to obtain the concentrations for the given container in the comment field.

8.2.14 *Current container information for this WTWBIR WS:* This section requests information for the waste in the current or planned packaging. WIPP prefers that a separate 8.2.14.x (where x represents a separate package type defined by 1, 2, etc.) Where this is not appropriate, multiple answers are permitted for some questions to accommodate the situation. This entry should be consistent with 8.2.12.

8.2.14.1 *Current container type/size:* This field should contain a description of the container as to size or volume. It should not indicate the composition of the container (e.g., steel). Examples of entries that might occur:

Under "Drum" - 55 gallon; 30 gallon; 83 gallon
Under "SWB" - nothing
Under "Box" - the size (4x4x7) or name of box (#6)
Under "SWB Overpack" - nothing

This information should have automatically transferred from section 8.2.12. Check to make sure that the entry is consistent with 8.2.12.

8.2.14.1.1 *Material of construction (check all that apply):* This should indicate the composition of the container in the current container field, section 8.2.14.1. E.g., Carbon steel, Stainless steel, Wood etc. If "Other" is used, check to sure that it is reasonable. If more than one entry is made (e.g., carbon steel and stainless steel), then the response should include enough information to match the *Type/Size* of the container to its material of construction.

8.2.14.1.2 *Liner types (check all that apply):* This should indicate the type of liner used in the packaging of the current container field, section 8.2.14.1. E.g., Bag, Rigid liner, etc. NOTE: If only some containers include internal shielding or liners, a description of the approximate percent of containers with shielding or liners should be in the comment section 8.2.14.1.14.3.4. If more than one entry is made (e.g., bag and rigid liner), then the response should include enough information to match the *Type/Size* of the container to its liner type.

8.2.14.1.3 *Liner material (check all that apply):* This should indicate the composition of the liner(s) in the Liner type field used in the current container(s). E.g., Cement, HDPE, Plastic. etc. If "Other" is used, check to make sure that it is reasonable. If the section is left blank, make a note for the WTWBIR team to review this data and determine if there is a need to verify the lack of information with the site. If more than one entry is made (e.g., HDPE and fiberboard), then the response should include enough information to match the *Type/Size* of the container to its liner material.

8.2.14.1.4 *Internal volume (payload volume) per container in m^3*: NOTE: If the current container type includes several sizes, an average internal volume for all the sizes will be used (e.g., 55 gal + 30 gal + 70 gal = 52 gal X 0.0038 m^3/gal = 0.20 m^3). NOTE: Check to make sure that the entry

is reasonable (a single 55 gallon drum has an internal volume of 0.208 m^3). For containers, expect the volume of the container. For tanks expect the volume of the waste.

8.2.14.1.5 *Estimated percent (%) containers less than 350 lbs/container (required only for drums):* The total for % containers less than 350 lbs/container and 8.2.14.1.6, % containers between 350 and 500 lbs/container, should add up to less than or equal to 100% for the drums. NOTE: The comment section 8.2.1.4.1.14.3.4 may be used for additional information or to clarify these estimates.

8.2.14.1.6 *Estimated percent (%) containers between 350 and 500 lbs/container (required only for drums):* The total for % containers between 350 and 500 lbs/container and 8.2.14.1.5, % containers less than 350 lbs/container, should add up to less than or equal to 100% for the drums. NOTE: The comment section 8.2.1.4.1.14.3.4 may be used for additional information or to clarify these estimates.

8.2.14.1.7 *Estimated percent (%) containers less than 23 Pu-239 fissile gram equivalents (required only for drums):* The total for % containers less than 23 Pu-239 fissile gram equivalents and 8.2.14.1.8, % containers between 23 and 200 Pu-239 fissile gram equivalents, should add up to less than or equal to 100% for the drums. NOTE: The comment section 8.2.1.4.1.14.3.4 may be used for additional information or to clarify these estimates.

8.2.14.1.8 Estimated *percent (%) containers with between 23 and 200 fissile gram equivalents (required only for drums):* The total for % containers with between 23 and 200 fissile gram equivalents and 8.2.14.1.7, % containers less than 23 Pu-239 fissile gram equivalents, should add up to less than or equal to 100% for the drums. NOTE: The comment section 8.2.1.4.1.14.3.4 may be used for additional information or to clarify these estimates.

8.2.14.1.9 *Number currently in storage:* The number of containers currently in storage at the site for this WS should be listed (the date of this inventory should be provided in 8.2.14.1.10).

8.2.14.1.10 *Date of this inventory:* Date of the inventory provided in section 8.2.14.1.9. The WTWBIR WS data should be consistent with the data provided in the MWIR section. NOTE: WTWBIR prefers that all sites use 12/31/94 as the inventory date so that the inventory data are consistent.

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8.2.14.1.11 *Total number of these containers projected from date of inventory to end of 2022 (Do not include the current inventory):* Should not include the current inventory reported in 8.2.14.1.9. This should only include the number of projected containers from the date in 8.2.14.1.10 to the year 2022. This total should be the same as the added sum for 8.2.14.1.12. NOTE: These are annual inventories, NOT cumulative.

8.2.14.1.12 *Estimated TRU waste generation by numbers of containers: Includes WTWBIR WS ID and the container type/size:* For the years 1993, 1994 and perhaps 1995 should NOT include containers from section 8.2.14.1.9. A zero (0) should be entered for these first few years for containers currently in storage. The entry should be a projection of the number of containers for that given year only. A zero should also be entered for a year that has no projections (i.e., No waste is generated for that year). These entries should add up to total number provided in section 8.2.14.1.11. WTWBIR will use this total and the volume provided in 8.2.14.1.1 to calculate total volumes. Check the comment field in column three for any pertinent comments. Information for the calculations of total volume may also be provided in the comment section 8.2.14.1.14.3.4.

8.2.14.1.13 *WAC revision 3 certifiability:* This section contains questions about the certifiability of the current containers based on WIPP WAC revision 3. Check the comment field in section 8.2.14.1.14.3.4 for any additional information or qualifications.

8.2.14.1.13.1 *Is all of this current container type/size certifiable to WIPP WAC revision 3?*: YES indicates that 100% of the containers are certifiable and the reviewer should skip down to section 8.2.14.1.14. If NO is checked, continue through the rest of section 8.2.14.1.13.

8.2.14.1.13.2 *What percent (%) of these containers are non-certifiable?:* The % provided should be greater than zero and less than 100.

8.2.14.1.13.3 *For containers not certifiable to WIPP WAC revision 3, is it due to:*
Section 8.2.14.1.13.3.1 Repackaging or
Section 8.2.14.1.13.3.2 Treatment.

8.2.14.1.13.3.1 *Repackaging required?:* If NO is entered the reviewer should skip down to section 8.2.14.1.13.3.2, Treatment required. If YES is entered continue to section 8.2.14.1.13.3.1.1.

8.2.14.1.13.3.1.1 *What percent (%) of the non-certifiable containers require repackaging?:* The percent should be greater than zero and less than or equal to 100.

8.2.14.1.13.3.1.2 *WAC repackaging requirement table:* Column two should have Y/N provided for each repackaging cause. Column three should provide the % of containers affected (0 - 100). The % affected could range from 0 to 100 % and does not necessarily add up to 100 (i.e., The total of column three can be less than, greater than, or equal to 100%). The % affected should be zero if an "N" is entered in column two.

8.2.14.1.13.3.2 *Treatment required?:* If NO is entered the reviewer should skip down to section 8.2.14.1.14, TRAMPAC Certifiability. If YES is entered continue to section 8.2.14.1.13.3.2.1

8.2.14.1.13.3.2.1 *What percent (%) of the non-certifiable containers require treatment?:* The percent should be greater than zero and less than or equal to 100.

8.2.14.1.13.3.2.2 *WAC treatment requirements table:* Column two should have Y/N provided for each treatment cause. Column three should provide the % of containers affected (0 - 100). The % affected could range from 0 to 100 % and does not necessarily add up to 100 (i.e., The total of column three can be less than, greater than, or equal to 100%). The % affected should be zero if an "N" is entered in column two.

8.2.14.1.14 *TRAMPAC certifiability:* This section contains questions about the certifiability of the current containers based on TRAMPAC compliance. Check the comment field in section 8.2.14.1.14.3.4 for any additional information or qualifications.

8.2.14.1.14.1 *Is all of this current container type/size certifiable to TRAMPAC (shipment to WIPP via TRUPACT-II)?:* YES indicates that 100% of the containers are certifiable and the reviewer should skip down to section 8.2.15 as applicable. If NO is checked continue through the rest of section 8.2.14.1.14.

8.2.14.1.14.2 *What percent (%) of these containers are non-certifiable?:* The % provided should be greater than zero and less than or equal to 100.

8.2.14.1.14.3 *For containers not certifiable to TRAMPAC (shipment to WIPP via TRUPACT-II) is it due to:*
Section 8.2.14.1.14.3.1 Filters/liner vents or
Section 8.2.14.1.14.3.2 Repackaging required.
Section 8.2.14.1.14.3.3 Treatment required.

8.2.14.1.14.3.1 *Filters/liner vents?:* If NO is entered the reviewer should skip down to section 8.2.14.1.14.3.2, Repackaging required. If YES is entered continue to section 8.2.14.1.14.3.1.1.

8.2.14.1.14.3.1.1 *What percent (%) of the non-certifiable containers require filters/liner vents?:* The percent should be greater than zero and less than or equal to 100.

8.2.14.1.14.3.2 *Repackaging required?:* If NO is entered the reviewer should skip down to section 8.2.14.1.14.3.3, Treatment required. If YES is entered continue to section 8.2.14.1.14.3.2.1.

8.2.14.1.14.3.2.1 *What percent (%) of the non-certifiable containers require repackaging?:* The percent should be greater than zero and less than or equal to 100. NOTE: If "Not in TRUCON" is the only entry identified in section 8.2.14.1.14.3.2.2, then repackaging may not actually be necessary and a zero (0) may be entered in the percent (%) of non-certifiable containers that require repackaging.

8.2.14.1.14.3.2.2 *TRAMPAC repackaging requirements table:* Column two should have Y/N provided for each repackaging cause. Column three should provide the % of containers affected (0 - 100). The % affected could range from 0 to 100 % and does not necessarily add up to 100 (i.e., The total of column three can be less than, greater than, or equal to 100%). The % affected should be zero if an "N" is entered in column two. If "Not in TRUCON" is the only entry identified, then repackaging may not actually be necessary. The reviewer needs to verify with the site. If this only requires the authorization to get a TRUCON code, identify this for the WTWBIR database personnel.

8.2.14.1.14.3.3 *Treatment required?:* If NO is entered the reviewer should skip down to section 8.2.14.2 or 8.2.15 as applicable. If YES is checked continue to section 8.2.14.1.14.3.3.1.

8.2.14.1.14.3.3.1 *What percent (%) of the non-certifiable containers require treatment?:* The percent should be greater than zero and less than or equal to 100.

8.2.14.1.14.3.3.2 *TRAMPAC treatment requirements table:* Column two should have Y/N provided for each treatment cause. Column three should provide the % of containers affected (0 - 100). The % affected could range from 0 to 100 % and does not necessarily add up to 100 (i.e., The total of column three can be less than, greater than, or equal to 100%). The % affected should be zero if an "N" is entered in column two.

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8.2.14.1.14.3.4 *Current Container comments:* This section may contain comments for any of the sections in 8.2.14.

8.2.15 **Final waste form container information for this WTWBIR waste stream**

This section requires information for all the waste in WIPP compliant form. Therefore **"FINAL WASTE FORM"**.

8.2.15.1 *Container Type: The final waste form is or will be packaged in WIPP acceptable 55 gallon drums?:* NO indicates that another container type will be used for this WTWBIR WS. The reviewer should skip all sections in 8.2.15.1 and go to 8.2.15.2. Yes indicates that for this WTWBIR WS some but not necessarily all containers used will be 55 gal drums.

8.2.15.1.1 *Container material (check all that apply):* This should indicate the composition of the container for the waste in final form. E.g., Carbon steel, Stainless steel, etc. If "Other" is used, check to be sure that it is reasonable.

8.2.15.1.2 *Liner type (check all that apply):* This should indicate the type of liner used in the packaging of the final waste container. E.g., Bag, Rigid liner, etc. NOTE: If only some containers include internal shielding or liners, a description of the approximate percent of containers with shielding or liners should be in the comment section 8.2.15.1.12.

8.2.15.1.3 *Liner material (check all that apply):* This should indicate the composition of the liner(s) in the Liner type field used in the final waste container. E.g., Cement, HDPE, Plastic. etc. If "Other" is used, check to sure that it is reasonable. If the section is left blank, make a note for the WTWBIR team to review this data and determine if there is a need to verify the lack if information with the site. If more than one entry is made (e.g., HDPE and fiberboard), then the response should include enough information to match the *Type/Size* of the container to its liner material.

8.2.15.1.4 *Internal volume (payload volume) per container in m^3*: This is provided by the form electronically. 0.208 m^3

8.2.15.1.5 *Estimated percent (%) containers less than 350 lbs/container:* The total for % containers less than 350 lbs/container and 8.2.15.1.6, % containers between 350 and 500 lbs/container, should add up to less than or equal to 100%. NOTE: The comment section 8.2.15.1.12 may be used for addition information or to clarify these estimates.

8.2.15.1.6 *Estimated percent (%) containers between 350 and 500 lbs/container:* The total for % containers between 350 and 500 lbs/container and 8.2.15.1.5, % containers less than 350 lbs/container, should add up to less than or equal to 100%. NOTE: The comment section 8.2.15.1.12 may be used for addition information or to clarify these estimates.

8.2.15.1.7 *Estimated percent (%) containers less than 23 Pu-239 fissile gram equivalents:* The total for % containers less than 23 Pu-239 fissile gram equivalents and 8.2.15.1.8, % containers between 23 and 200 Pu-239 fissile gram equivalents, should add up to less than or equal to 100%. NOTE: The comment section 8.2.15.1.12 may be used for addition information or to clarify these estimates.

8.2.15.1.8 Estimated *percent (%) containers with between 23 and 200 fissile gram equivalents:* The total for % containers with between 23 and 200 fissile gram equivalents and 8.2.15.1.7, % containers less than 23 Pu-239 fissile gram equivalents, should add up to less than or equal to 100%. NOTE: The comment section 8.2.15.1.12 may be used for addition information or to clarify these estimates.

8.2.15.1.9 *Number currently in storage:* The number of containers currently in storage at the site for this WS should be listed (the date of this inventory should be provided in 8.2.15.1.10).

8.2.15.1.10 *Date of this inventory:* Date of the inventory provided in section 8.2.15.1.9. The WTWBIR WS data should be consistent with the data provided in the MWIR section. NOTE: WTWBIR prefers that all sites use 12/31/94 as the inventory date so that the inventory data are consistent.

8.2.15.1.11 *Total number of these containers projected from date of inventory to end of 2022 (Do not include the current inventory):* Do not include the current inventory from section 8.2.15.1.9. This should only include the number of projected containers from the date in 8.2.15.1.10 to the year 2022. This total should be the same as the added sum for 8.2.15.1.13. NOTE: These are annual inventories, NOT cumulative.

8.2.15.1.12 *Comments (55 gallon drum):* Any additional comments or clarification of information for sections 8.2.15.1 (55 gallon drums) should be included in this comment field.

8.2.15.1.13 *Estimated rates of TRU waste generation (numbers of containers): Incudes WTWBIR WS ID and the container type/size (55 gallon drums):* For the years 1993, 1994 and perhaps 1995 should NOT include containers from section 8.2.15.1.9. A zero (0) should be entered for

these first few years for containers currently in storage. The entry should be a projection of the number of containers for that given year only. A zero should also be entered for a year that has no projections. These entries should add up to total number provided in section 8.2.15.1.11. WTWBIR will use this total and the volume provide in 8.2.15.1.4 to calculate total volumes. Check the comment field in column three for any pertinent comments. NOTE: Waste reported in section 8.2.14 for which the sites do not have plans or schedules for putting the waste in WIPP compliant form and WIPP acceptable containers or the schedule is beyond the year 2022, the sites should estimate the WIPP compliant form and WIPP acceptable containers to be used and should have placed the waste in the year 2022 and state in the comment section that the site has no schedule or that the schedule is beyond the year 2022. A description of the schedule should also be included.

8.2.15.1.14 *Typical waste material weights for Final Waste Form (kg/m^3); WTWBIR WS ID: and Container type (55 gallon drum) included:* The information entered here should be in kg/m^3. The fields for iron-base metal and plastic do not include the outer container and the rigid liner and or liner bags. The container and the liner information is placed only in the fields for packaging material. The average, lower limit, and the upper limit should be reasonable. Check to make sure that they are in the right column.

8.2.15.2 *Container Type: The final waste form is or will be packaged in WIPP acceptable Standard Waste Boxes?:* NO indicates that another container type will be used for this WTWBIR WS. The reviewer should skip all sections in 8.2.15.2 and go to 8.2.15.3. Yes indicates that for this WTWBIR WS some but not necessarily all containers used will be Standard Waste Boxes.

8.2.15.2.1 *Container material (check all that apply):* This should indicate the composition of the container for the waste in final form. E.g., Carbon steel, Stainless steel, etc. If "Other" is used, check to be sure that it is reasonable.

8.2.15.2.2 *Liner type (check all that apply):* This should indicate the type of liner used in the packaging of the final waste container. E.g., Bag, Rigid liner, etc. NOTE: If only some containers include internal shielding or liners, a description of the approximate percent of containers with shielding or liners should be in the comment section 8.2.15.2.8.

8.2.15.2.3 *Liner material (check all that apply):* This should indicate the composition of the liner(s) in the Liner type field used in the final waste container. E.g., Cement, HDPE, Plastic. etc. If "Other" is used, check to make sure that it is reasonable. If the section is left blank, make a note for the WTWBIR team to review this data and determine if there is a need to verify the lack if information with the site. If more than one entry is made (e.g., HDPE and fiberboard), then the response should include enough information to match the *Type/Size* of the container to its liner material.

8.2.15.2.4 *Internal volume (payload volume) per container in m^3*: This is provided by the form electronically. 1.89 m^3

8.2.15.2.5 *Number currently in storage:* The number of containers currently in storage at the site for this WS should be listed (the date of this inventory should be provided in 8.2.15.2.6).

8.2.15.2.6 *Date of this inventory:* Date of the inventory provided in section 8.2.15.2.5. The WTWBIR WS data should be consistent with the data provided in the MWIR section. NOTE: WTWBIR prefers that all sites use 12/31/94 as the inventory date so that the inventory data are consistent.

8.2.15.2.7 *Total number of these containers projected from date of inventory to end of 2022 (Do not include the current inventory):* Do not include the current inventory from section 8.2.15.2.5. This should only include the number of projected containers from the date in 8.2.15.2.6 to the year 2022. This total should be the same as the added sum for 8.2.15.2.9. NOTE: These are annual inventories, NOT cumulative.

8.2.15.2.8 *Comments (Standard Waste Boxes):* Any additional comments or clarification of information for sections 8.2.15.2 (Standard Waste Boxes) should be included in this comment field.

8.2.15.2.9 *Estimated rates of TRU waste generation (numbers of containers): Incudes WTWBIR WS ID and the container type/size (Standard Waste Boxes):* For the years 1993, 1994 and perhaps 1995 should NOT include containers from section 8.2.15.2.5. A zero (0) should be entered for these first few years for containers currently in storage. The entry should be a projection of the number of containers for that given year only. A zero should also be entered for a year that has no projections. These entries should add up to total number provided in section 8.2.15.2.7. WTWBIR will use this total and the volume provide in 8.2.15.2.4 to calculate total volumes. Check the comment field in column three for any pertinent comments. NOTE: Waste reported in

section 8.2.14 for which the sites do not have plans or schedules for putting the waste in WIPP compliant form and WIPP acceptable containers or the schedule is beyond the year 2022, the sites should estimate the WIPP compliant form and WIPP acceptable containers to be used and should have placed the waste in the year 2022 and state in the comment section that the site has no schedule or that the schedule is beyond the year 2022. A description of the schedule should also be included.

8.2.15.2.10 *Typical waste material weights for Final Waste Form (kg/m^3); WTWBIR WS ID: and Container type (Standard Waste Boxes) included:* The information entered here should be in kg/m^3. The fields for iron-base metal and plastic do not include the outer container and the rigid liner and or liner bags. The container and the liner information is placed only in the fields for packaging material. The average, lower limit, and the upper limit should be reasonable. Check to make sure that they are in the right column.

8.2.15.3 *Container Type: The final waste form is or will be packaged in WIPP acceptable Standard Waste Boxes (SWB) used to overpack 55 gallon drums?:* NO indicates that another container type will be used for this WTWBIR WS. The reviewer should skip all sections in 8.2.15.3 and go to 8.2.15.4. Yes indicates that for this WTWBIR WS some but not necessarily all containers used will be Standard Waste Boxes (SWB) used to overpack 55 gallon drums.

8.2.15.3.1 *Container material (check all that apply):* This should indicate the composition of the container for the waste in final form. E.g., Carbon steel, Stainless steel, etc. If "Other" is used, check to be sure that it is reasonable.

8.2.15.3.2 *Liner type (check all that apply):* This should indicate the type of liner used in the packaging of the final waste container. E.g., Bag, Rigid liner, etc. NOTE: If only some containers include internal shielding or liners, a description of the approximate percent of containers with shielding or liners should be in the comment section 8.2.15.3.8.

8.2.15.3.3 *Liner material (check all that apply):* This should indicate the composition of the liner(s) in the Liner type field used in the final waste container. E.g., Cement, HDPE, Plastic. etc. If "Other" is used, check to make sure that it is reasonable. If the section is left blank, make a note for the WTWBIR team to review this data and determine if there is a need to verify the lack if information with the site. If more than one

entry is made (e.g., HDPE and fiberboard), then the response should include enough information to match the *Type/Size* of the container to its liner material.

8.2.15.3.4 *Internal volume (payload volume) per container in m^3*: This is provided by the form electronically. 1.89 m^3

8.2.15.3.5 *Number currently in storage:* The number of containers currently in storage at the site for this WS should be listed (the date of this inventory should be provided in 8.2.15.3.6).

8.2.15.3.6 *Date of this inventory:* Date of the inventory provided in section 8.2.15.3.5. The WTWBIR WS data should be consistent with the data provided in the MWIR section. NOTE: WTWBIR prefers that all sites use 12/31/94 as the inventory date so that the inventory data are consistent.

8.2.15.3.7 *Total number of these containers projected from date of inventory to end of 2022 (Do not include the current inventory):* Do not include the current inventory from section 8.2.15.3.5. This should only include the number of projected containers from the date in 8.2.15.3.6 to the year 2022. This total should be the same as the added sum for 8.2.15.3.9. NOTE: These are annual inventories, NOT cumulative.

8.2.15.3.8 *Comments (Standard Waste Boxes (SWB) used to overpack 55 gallon drums):* Any additional comments or clarification of information for sections 8.2.15.3 (Standard Waste Boxes (SWB) used to overpack 55 gallon drums) should be included in this comment field.

8.2.15.3.9 *Estimated rates of TRU waste generation (numbers of containers): Incudes WTWBIR WS ID and the container type/size (Standard Waste Boxes (SWB) used to overpack 55 gallon drums):* For the years 1993, 1994 and perhaps 1995 should NOT include containers from section 8.2.15.3.5. A zero (0) should be entered for these first few years for containers currently in storage. The entry should be a projection of the number of containers for that given year only. A zero should also be entered for a year that has no projections. These entries should add up to total number provided in section 8.2.15.3.7. WTWBIR will use this total and the volume provide in 8.2.15.3.4 to calculate total volumes. Check the comment field in column three for any pertinent comments. NOTE: Waste reported in section 8.2.14 for which the sites do not have plans or schedules for putting the waste in WIPP compliant form and WIPP acceptable containers or the schedule is beyond the year 2022, the sites should estimate the WIPP compliant form and WIPP acceptable containers to be used and should have placed the waste in the year 2022

and state in the comment section that the site has no schedule or that the schedule is beyond the year 2022. A description of the schedule should also be included.

8.2.15.3.10 *Typical waste material weights for Final Waste Form (kg/m^3); WTWBIR WS ID: and Container type (Standard Waste Boxes (SWB) used to overpack 55 gallon drums) included:* The information entered here should be in kg/m^3. The fields for iron-base metal and plastic do not include the outer container and the rigid liner and or liner bags. The container and the liner information is placed only in the fields for packaging material. The average, lower limit, and the upper limit should be reasonable. Check to make sure that they are in the right column.

8.2.15.4 *Container Type: The final waste form is or will be packaged in WIPP acceptable RH canisters?:* NO indicates that another container type will be used for this WTWBIR WS. The reviewer should skip all sections in 8.2.15.4 and go to 8.2.15.5. Yes indicates that for this WTWBIR WS some but not necessarily all containers used will be *RH canisters*.

8.2.15.4.1 *Container material (check all that apply):* This should indicate the composition of the container for the waste in final form. E.g., Carbon steel, Stainless steel, etc. If "Other" is used, check to be sure that it is reasonable.

8.2.15.4.2 *Liner type (check all that apply):* This should indicate the type of liner used in the packaging of the final waste container. E.g., Bag, Rigid liner, etc. NOTE: If only some containers include internal shielding or liners, a description of the approximate percent of containers with shielding or liners should be in the comment section 8.2.15.4.8.

8.2.15.4.3 *Liner material (check all that apply):* This should indicate the composition of the liner(s) in the Liner type field used in the final waste container. E.g., Cement, HDPE, Plastic. etc. If "Other" is used, check to make sure that it is reasonable. If the section is left blank, make a note for the WTWBIR team to review this data and determine if there is a need to verify the lack if information with the site. If more than one entry is made (e.g., HDPE and fiberboard), then the response should include enough information to match the *Type/Size* of the container to its liner material.

8.2.15.4.4 *Internal volume (payload volume) per container in m^3*: This is provided by the form electronically. 0.89 m^3

8.2.15.4.5 *Number currently in storage:* The number of containers currently in storage at the site for this WS should be listed (the date of this inventory should be provided in 8.2.15.4.6).

8.2.15.4.6 *Date of this inventory:* Date of the inventory provided in section 8.2.15.4.5. The WTWBIR WS data should be consistent with the data provided in the MWIR section. NOTE: WTWBIR prefers that all sites use 12/31/94 as the inventory date so that the inventory data are consistent.

8.2.15.4.7 *Total number of these containers projected from date of inventory to end of 2022 (Do not include the current inventory):* Do not include the current inventory from section 8.2.15.4.5. This should only include the number of projected containers from the date in 8.2.15.4.6 to the year 2022. This total should be the same as the added sum for 8.2.15.4.9. NOTE: These are annual inventories, NOT cumulative.

8.2.15.4.8 *Comments (RH canisters):* Any additional comments or clarification of information for sections 8.2.15.4 (RH Canisters) should be included in this comment field.

8.2.15.4.9 *Estimated rates of TRU waste generation (numbers of containers): Incudes WTWBIR WS ID and the container type/size (RH canisters):* For the years 1993, 1994 and perhaps 1995 should NOT include containers from section 8.2.15.4.5. A zero (0) should be entered for these first few years for containers currently in storage. The entry should be a projection of the number of containers for that given year only. A zero should also be entered for a year that has no projections. These entries should add up to total number provided in section 8.2.15.4.7. WTWBIR will use this total and the volume provide in 8.2.15.4.4 to calculate total volumes. Check the comment field in column three for any pertinent comments. NOTE: Waste reported in section 8.2.14 for which the sites do not have plans or schedules for putting the waste in WIPP compliant form and WIPP acceptable containers or the schedule is beyond the year 2022, the sites should estimate the WIPP compliant form and WIPP acceptable containers to be used and should have placed the waste in the year 2022 and state in the comment section that the site has no schedule or that the schedule is beyond the year 2022. A description of the schedule should also be included.

8.2.15.4.10 *Typical waste material weights for Final Waste Form (kg/m^3); WTWBIR WS ID: and Container type (RH canisters) included:* The information entered here should be in kg/m^3. The fields for iron-base metal and plastic do not include the outer container and the rigid liner and or liner bags. The container and the liner information is placed only in the

fields for packaging material. The average, lower limit, and the upper limit should be reasonable. Check to make sure that they are in the right column.

8.2.15.5 *Container Type: The final waste form is or will be packaged in WIPP acceptable RH canisters used to over pack 55 gallon drums?:* NO indicates that another container type will be used for this WTWBIR WS. The reviewer should skip all sections in 8.2.15.5 and go to 8.2.15.6. Yes indicates that for this WTWBIR WS some but not necessarily all containers used will be RH canisters used to over pack 55 gallon drums.

8.2.15.5.1 *Container material (check all that apply):* This should indicate the composition of the container for the waste in final form. E.g., Carbon steel, Stainless steel, etc. If "Other" is used, check to be sure that it is reasonable.

8.2.15.5.2 *Liner type (check all that apply):* This should indicate the type of liner used in the packaging of the final waste container. E.g., Bag, Rigid liner, etc. NOTE: If only some containers include internal shielding or liners, a description of the approximate percent of containers with shielding or liners should be in the comment section 8.2.15.5.8.

8.2.15.5.3 *Liner material (check all that apply):* This should indicate the composition of the liner(s) in the Liner type field used in the final waste container. E.g., Cement, HDPE, Plastic. etc. If "Other" is used, check to make sure that it is reasonable. If the section is left blank, make a note for the WTWBIR team to review this data and determine if there is a need to verify the lack if information with the site. If more than one entry is made (e.g., HDPE and fiberboard), then the response should include enough information to match the *Type/Size* of the container to its liner material.

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8.2.15.5.4 *Internal volume (payload volume) per container in m^3*: This is provided by the form electronically. 0.89 m^3

8.2.15.5.5 *Number currently in storage:* The number of containers currently in storage at the site for this WS should be listed (the date of this inventory should be provided in 8.2.15.5.6).

8.2.15.5.6 *Date of this inventory:* Date of the inventory provided in section 8.2.15.5.5. The WTWBIR WS data should be consistent with the data provided in the MWIR section. NOTE: WTWBIR prefers that all sites use 12/31/94 as the inventory date so that the inventory data are consistent.

8.2.15.5.7

Total number of these containers projected from date of inventory to end of 2022 (Do not include the current inventory): Do not include the current inventory from section 8.2.15.5.5. This should only include the number of projected containers from the date in 8.2.15.5.6 to the year 2022. This total should be the same as the added sum for 8.2.15.5.9. NOTE: These are annual inventories, NOT cumulative.

8.2.15.5.8

Comments (RH Canisters used to overpack 55 gallon drums): Any additional comments or clarification of information for sections 8.2.15.5 (RH Canisters used to overpack 55 gallon drums) should be included in this comment field.

8.2.15.5.9

Estimated rates of TRU waste generation (numbers of containers): Incudes WTWBIR WS ID and the container type/size (RH Canisters used to overpack 55 gallon drums): For the years 1993, 1994 and perhaps 1995 should NOT include containers from section 8.2.15.5.5. A zero (0) should be entered for these first few years for containers currently in storage. The entry should be a projection of the number of containers for that given year only. A zero should also be entered for a year that has no projections. These entries should add up to total number provided in section 8.2.15.5.7. WTWBIR will use this total and the volume provide in 8.2.15.5.4 to calculate total volumes. Check the comment field in column three for any pertinent comments. NOTE: Waste reported in section 8.2.14 for which the sites do not have plans or schedules for putting the waste in WIPP compliant form and WIPP acceptable containers or the schedule is beyond the year 2022, the sites should estimate the WIPP compliant form and WIPP acceptable containers to be used and should have placed the waste in the year 2022 and state in the comment section that the site has no schedule or that the schedule is beyond the year 2022. A description of the schedule should also be included.

8.2.15.5.10

Typical waste material weights for Final Waste Form (kg/m^3); WTWBIR WS ID: and Container type (RH Canisters used to overpack 55 gallon drums) included: The information entered here should be in kg/m^3. The fields for iron-base metal and plastic do not include the outer container and the rigid liner and or liner bags. The container and the liner information is placed only in the fields for packaging material. The average, lower limit, and the upper limit should be reasonable. Check to make sure that they are in the right column.

8.2.15.6

Container Type: The final waste form is or will be packaged in WIPP acceptable RH canisters used to over pack 30 gallon drums?: NO indicates that another container type will be used for this WTWBIR WS. The reviewer should skip all sections in 8.2.15.6 and go to 8.3, if

applicable. Yes indicates that for this WTWBIR WS some but not necessarily all containers used will be RH canisters used to over pack 30 gallon drums.

8.2.15.6.1 *Container material (check all that apply):* This should indicate the composition of the container for the waste in final form. E.g., Carbon steel, Stainless steel, etc. If "Other" is used, check to be sure that it is reasonable.

8.2.15.6.2 *Liner type (check all that apply):* This should indicate the type of liner used in the packaging of the final waste container. E.g., Bag, Rigid liner, etc. NOTE: If only some containers include internal shielding or liners, a description of the approximate percent of containers with shielding or liners should be in the comment section 8.2.15.6.8.

8.2.15.6.3 *Liner material (check all that apply):* This should indicate the composition of the liner(s) in the Liner type field used in the final waste container. E.g., Cement, HDPE, Plastic. etc. If "Other" is used, check to make sure that it is reasonable. If the section is left blank, make a note for the WTWBIR team to review this data and determine if there is a need to verify the lack if information with the site. If more than one entry is made (e.g., HDPE and fiberboard), then the response should include enough information to match the *Type/Size* of the container to its liner material.

8.2.15.6.4 *Internal volume (payload volume) per container in m^3:* This is provided by the form electronically. 0.89 m^3

8.2.15.6.5 *Number currently in storage:* The number of containers currently in storage at the site for this WS should be listed (the date of this inventory should be provided in 8.2.15.6.6).

8.2.15.6.6 *Date of this inventory:* Date of the inventory provided in section 8.2.15.6.5. The WTWBIR WS data should be consistent with the data provided in the MWIR section. NOTE: WTWBIR prefers that all sites use 12/31/94 as the inventory date so that the inventory data are consistent.

8.2.15.6.7 *Total number of these containers projected from date of inventory to end of 2022 (Do not include the current inventory):* Do not include the current inventory from section 8.2.15.6.5. This should only include the number of projected containers from the date in 8.2.15.6.6 to the year 2022. This total should be the same as the added sum for 8.2.15.6.9. NOTE: These are annual inventories, NOT cumulative.

8.2.15.6.8 *Comments (RH Canisters used to overpack 30 gallon drums):* Any additional comments or clarification of information for sections 8.2.15.6 (RH Canisters used to overpack 30 gallon drums) should be included in this comment field.

8.2.15.6.9 *Estimated rates of TRU waste generation (numbers of containers): Incudes WTWBIR WS ID and the container type/size (RH Canisters used to overpack 30 gallon drums):* For the years 1993, 1994 and perhaps 1995 should NOT include containers from section 8.2.15.6.5. A zero (0) should be entered for these first few years for containers currently in storage. The entry should be a projection of the number of containers for that given year only. A zero should also be entered for a year that has no projections. These entries should add up to total number provided in section 8.2.15.6.7. WTWBIR will use this total and the volume provide in 8.2.15.6.4 to calculate total volumes. Check the comment field in column three for any pertinent comments. NOTE: Waste reported in section 8.2.14 for which the sites do not have plans or schedules for putting the waste in WIPP compliant form and WIPP acceptable containers or the schedule is beyond the year 2022, the sites should estimate the WIPP compliant form and WIPP acceptable containers to be used and should have placed the waste in the year 2022 and state in the comment section that the site has no schedule or that the schedule is beyond the year 2022. A description of the schedule should also be included.

8.2.15.6.10 *Typical waste material weights for Final Waste Form (kg/m^3); WTWBIR WS ID: and Container type (RH Canisters used to overpack 30 gallon drums) included:* The information entered here should be in kg/m^3. The fields for iron-base metal and plastic do not include the outer container and the rigid liner and or liner bags. The container and the liner information is placed only in the fields for packaging material. The average, lower limit, and the upper limit should be reasonable. Check to make sure that they are in the right column.

APPENDIX O
WASTE STREAM PROFILES (NON-WIPP)

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ARGONNE NATIONAL LABORATORY - EAST

Location and Description

Argonne National Laboratory-East (ANL-E) occupies the central 1,700 acres of a 3,740-acre tract in DuPage County, 35 kilometers southwest of downtown Chicago and 39 kilometers west of Lake Michigan. It lies north of the Des Plaines River Valley, south of Interstate Highway 55 and west of Illinois Highway 83. The 2,040 acres surrounding the site was formerly ANL-E property, but was deeded to the DuPage County Forest Preserve District in 1973 for their use as a public recreational area, nature preserve and demonstration forest.

The terrain is gently rolling, partially wooded, former prairie and farmland. The grounds contain a number of small ponds and streams, the principal one being Sawmill Creek, which runs through the site in a southerly direction and enters the Des Plaines River about 2.1 kilometers southeast of the center of the site.

Mission

Since World War II, ANL-E has been engaged in nuclear energy research. Currently it is a multidisciplinary research and development laboratory conducting basic and applied research to support development of energy-related technologies.

Waste Information

Processes

Most of the TRU and TRU mixed waste has been generated by three operations:

1. The Alpha Gamma Hot Cell Facility located in Building 205
2. The New Brunswick Laboratory (NBL), Building 305
3. Chemistry, chemical technology, and analytical programs.

The Alpha Gamma Hot Cell Facility does destructive examinations of fuel and components primarily associated with the Reactor Program. The waste component of this stream consists of metal and combustible trash containing adventitious quantities of TRU. The radioactive material originated in Idaho and is currently returned to the Radioactive Waste Management Complex (RWMC) at INEL for interim storage.

New Brunswick Laboratory does uranium and plutonium assay analyses for the DOE system. This stream generates approximately 130 cubic feet of waste per year. This stream consists of TRU nitrate solutions containing as estimated 130 grams of TRU annually.

The Reactor Program has generated small volumes of TRU waste contaminated with cadmium. This is a mixed waste that contains significant quantities of plutonium and uranium.

Some plutonium-containing liquid waste stream from the NBL analytical laboratories has been processed by the experimental/demonstration TRUEX process in Building 205. This TRUEX process is being replaced by a new transuranic neutralization precipitation process. Hot cells in Buildings 200, 205, and 212 are used to package remote-handled TRU waste.

TRU wastes are generated in dozens of laboratories on site. Most of these wastes are collected in containers smaller than 5 gallons because of the nature of the work performed at the Laboratory. The waste is transported to Building 306 where the waste is treated. Solid TRU waste treatment consists only of preparing it for interim storage.

Liquid TRU waste (which is normally hazardous because of corrosivity) will be treated in a new process (TRU neutralization/precipitation process). The solid waste from this treatment process will also simply be put into storage until WIPP begins accepting waste.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	AE-T001	Handling:	CH	NMVP #:	N/A	Stream Name:	Solid heterogeneous inorganic/organic waste
Local ID:		Type:	TRU	Generator Site:	AE	Final Waste Form:	Unknown

Inventory Date:

Waste Matrix Code: Z9000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	101.0	101.0	101.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	216.3	168.3	259.6
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
U-238	2.24E-05
U-235	2.50E-05
U-233	1.20E-09
Pu-241	6.10E-01
Pu-239	1.17E+00
Pu-238	4.07E-06
Np-237	6.43E-03
Am-243	4.00E-02
Am-241	2.13E+00

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WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	13.3	0.0	0.0	0.0	0.0	13.3
Totals	13.3	0.0	0.0	0.0	0.0	13.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	13.3	0.0	0.0	0.0	0.0	13.3
Totals	13.3	0.0	0.0	0.0	0.0	13.3

As-Generated Form: Stored: 13.3 Projected: 0.0 Total: 13.3

Final Waste Form: Stored: 13.3 Projected: 0.0 Total: 13.3

WASTE STREAM DESCRIPTION	6/6/95 This waste stream is Solidified nonhazardous TRU-CH liquids stored mostly at the at 317 Area vaults
WASTE STREAM SOURCE	$ Not reported $ Non-mixed TRU derived from IDB
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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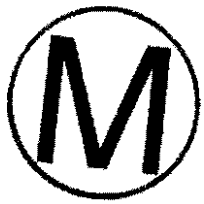
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ARCO MEDICAL PRODUCTS COMPANY

Location and Description

Nuclear pacemakers developed by the ARCO Medical Products Company (AM) are the product of a research program conducted with the DOE during the 1970's. The purpose of the program was to evaluate the practicality of using a radioisotope-fueled pacemaker in humans. Direct program management is provided under contract by Roy F. Weston, Inc. The AM storage facility is located in West Chester, Pennsylvania.

Mission

ARCO's Corporate Environmental Remediation group is responsible for oversight of the surviving pacemakers. Presently, 50 of the pacemakers are in storage. Roy F. Weston also tracks the remaining implanted pacemakers and arranges for shipment of the devices from the hospital where they are explanted, to their storage facility. Eighty pacemakers remain implanted in patients. The pacemakers are being explanted at a rate of about three per year. The maximum life span of the device is estimated to be 20 to 40 years.

Waste Information

Processes

Each pacemaker device consists of three sub-assemblies: a nuclear battery, an electronics assembly, and a cardiac lead. The nuclear battery includes a 0.5 gm Pu-238 oxide fuel pellet, triple encapsulated in three successive right circular cylinders.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	AM-W001	Handling:	CH	NMVP #:	N/A	Stream Name:	Nuclear Pacemakers
Local ID:		Type:	TRU	Generator Site:	AM	Final Waste Form:	Heterogeneous

Inventory Date: 1/31/95

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.1	0.0	0.0
Other Metals/Alloys:	0.2	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Commercial TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source:

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-238	3.73E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	0.04	0.01	0.01	0.02	0.02	0.1
Totals	0.0	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.4	0.0	0.0	0.4
Totals	0.0	0.0	0.4	0.0	0.0	0.4

As-Generated Form: Stored: 0.04 Projected: 0.1 Total: 0.10

Final Waste Form: Stored: 0.0 Projected: 0.4 Total: 0.4

WASTE STREAM DESCRIPTION	Waste stream consists of radioisotope-powered pacemaker. Each pacemaker device includes 3 sub-assemblies: a nuclear battery, an electronics assembly, and a cardiac lead. The nuclear battery includes a 0.5 gm Pu-238 oxide fuel pellet, triple encapsulated in 3 successive right circular cylinders.
WASTE STREAM SOURCE	Waste stream consists of radioisotope-powered cardiac pacemakers, each containing 0.5 gram of Pu-238. The pacemakers were originally manufactured by the Nuclear Material and Equipment Corporation. One hundred and twenty-six of these pacemakers were implanted in patients at various medical centers throughout the U.S. At present, 50 pacemakers are in storage at ARCO's Roy F. Weston facility in Pennsylvania. The remaining pacemakers are in use.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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ARGONNE NATIONAL LABORATORY - WEST

Location and Description

Argonne National Laboratory-West (ANL-W) is located approximately 56 kilometers west of Idaho Falls, Idaho, in the southeastern portion of the Idaho National Engineering Laboratory (INEL). ANL-W is in Bingham County in the State of Idaho. The ANL-W administrative area covers slightly more than one square mile and is managed by the DOE/Chicago Office. The Management and Operating Contractor is the University of Chicago.

Mission

ANL-W is a research and development laboratory. Much of the work done there supports development of advanced nuclear power plant technology. This support includes irradiation and safety tests, reactor physics studies, and fuel examination studies.

ANL-W consists of several major complexes: Experimental Breeder Reactor II (EBR II) the Transient Reactor Test Facility (TREAT), the Zero Power Physics Reactor (ZPPR), the Hot Fuel Examination Facility (HFEF), The Fuel Conditioning Facility (FCF), the Fuel Manufacturing Facility (FMF), Laboratory and Office Building, support complexes such as the Radioactive Liquid Waste Treatment Facility (RLWTF) and the Radioactive Scrap and Waste Facility (RSWF), and the Sodium Process Facility.

Waste Information

Processes

Solid radioactive waste generated at ANL-W is primarily associated with irradiated experimental fuel subassemblies and capsules from EBR-II and, to a lesser degree, TREAT. After irradiation in ANL-W reactors, the subassemblies and capsules were conveyed to appropriate facilities for dismantling, sampling, and examination. If they were not contaminated with sodium, these reactor pieces and parts were shipped to the RWMC as remote-handled waste. Sodium-contaminated reactor parts are stored in the RSWF at ANL-W.

The ANL-W Waste Operations Program encompasses all ANL-W non-production facilities, operations, and sites used for the storage, treatment, or disposal of radioactive, hazardous, mixed, and sanitary waste materials that have been property characterized, packages, and labeled. Facilities used exclusively for long-term storage of ANL-W waste material are also covered in this program.

Waste management activities are those concerned with minimization, treatment, storage, and disposal of radioactive, hazardous, mixed, and non-hazardous wastes generated as a result of ongoing operations at active facilities and from other resources such as the Environmental Restoration Program. Many of these activities support continuity of operations at ANL-W.

Routine operations include shipping TRU waste from ANL-W to the Radioactive Waste Management Complex on the INEL for storage and then eventual disposal to WIPP. Operations at the RSWF involves TRU and mostly TRU mixed waste which is contaminated with elemental sodium. The waste will be moved from this interim holding area to approved and appropriate DOE waste treatment or disposal areas, when identified.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	AW-W028	Handling:	RH	NMVP #:	N/A	Stream Name:	TRU WASTE USED PRE-FILTERS
Local ID:	CH-ANL-503T	Type:	MTRU	Generator Site:	AW	Final Waste Form:	Unknown

Inventory Date: 4/30/95

Waste Matrix Code: S5410

AS-GENERATED EPA CODES

D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Wooden Box	0.9	0.0	0.0	0.0	0.0	0.9
Totals	0.9	0.0	0.0	0.0	0.0	0.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.9 Projected: 0.0 Total: 0.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream consists of metal or wood framed pre-filters. Pre filters are 2' X 2' X 0.5'. The filters have screen mesh covering high efficiency filtering media. The concentration of radioisotopes and RCRA metals varies in each filter. These filters were generated from the deontamination of the analytical hot cells in 1993 and 1994. Final waste form has not been determined yet.

WASTE STREAM SOURCE

This waste stream was generated at Bldg ANL-752, Analytical Laboratory: Typical laboratory operations, analytical and radiochemistry. The facility also houses and experimental fuels casting lab, and areas for small-scale testing of experimental processes related to nuclear fuels fabrication. Wastes were generated primarily from hot cell refurbishment.. The generating process is: Pre-filters are used to control airborne radioactive particulate emissions from hot cells, hot repair areas, analytical lab hoods and other radioactively contaminated systems. Refurbishment of hot cells and hot repair areas has generated lead, cadmium, and chromium dusts from paint removal, stainless steel cutting, and fuel experiment dissolution decontamination. The filters trap the metals in the filter media in concentrations high enough to classify the filters as mixed waste.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Grab samples were taken from 6 of the 16 filters. Samples were analyzed for total metal content in the filter media. Sample results were extrapolated to estimate the concentration of a representative sample of the entire filter, not including the housing. TCLP was not conducted, due to the high radiation levels of the sample.

Grab samples were taken from 6 of the 16 filters. Samples were analyzed for total metal content in the filter media. Sample results were extrapolated to estimate the concentration of a representative sample of the entire filter, not including the housing. TCLP was not conducted, due to the high radiation levels of the sample.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

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Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	AW-W018	Handling:	RH	NMVP #:	N/A	Stream Name:	SODIUM - TRU
Local ID:	CH-ANL-180T	Type:	MTRU	Generator Site:	AW	Final Waste Form:	Unknown

Inventory Date: 4/30/95

Waste Matrix Code: X7520

AS-GENERATED EPA CODES

D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Metal Box (.127cm)	10.2	0.0	0.0	0.0	0.0	10.2
Metal Box (.13cm)	2.9	0.0	0.0	0.0	0.0	2.9
Metal Box (1cm)	0.1	0.0	0.0	0.0	0.0	0.1
Metal Box (.22cm)	0.2	0.0	0.0	0.0	0.0	0.2
Metal Box (25cm)	0.3	0.0	0.0	0.0	0.0	0.3
Totals	13.6	0.0	0.0	0.0	0.0	13.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 13.6 Projected: 0.0 Total: 13.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Sodium is used as a primary and was used as a secondary coolant for the EBR-II reactor. Waste sodium metal is a hazardous constituent of some of the TRU waste stored at the ANL-W Radioactive Scrap and Waste Facility (RSWF). The waste is generated during maintenance and operational activities. The sodium typically coats waste metal equipment, experiments, and components removed during reactor operations and maintenance activities. This waste will require treatment prior to disposal at WIPP. Final waste form has not been determined yet.

WASTE STREAM SOURCE

This waste stream was generated at ANL-767, EBR-II Reactor Building, and ANL-785, Hot Fuel Examination Facility: (ANL-767) Typical nuclear reactor operations including maintenance activities on control systems. (ANL-785) Hot cells operations including dismantling and examination of nuclear fuels and experiments which contain elemental sodium.. The generating process is: Some maintenance activities in Bldg. 767 involve working on and replacement of sodium wetted equipment associated with the EBR-II cooling systems. If the waste equipment cannot be cleaned of the sodium metal, it is stored in the RSSF, Also, the secondary cooling systems at EBR-II occasionally leak sodium metal. Cleanup operations generate sodium-contaminated wastes. All 767 wastes are contact-handled. Processes in Bldg. 785 more routinely generate sodium contaminated wastes because materials handled and examined in the facility (nuclear fuel rods and assemblies, and experiments) contain sodium. All 785 wastes are remote handled.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS Sodium is not dispersed uniformly throughout the waste matrix.

MANAGEMENT COMMENTS Alpha Containment

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	AW-W019	Handling:	RH	NMVP #:	N/A	Stream Name:	SODIUM POTASSIUM -NaK- TRU
Local ID:	CH-ANL-182T	Type:	MTRU	Generator Site:	AW	Final Waste Form:	Unknown

Inventory Date: 4/30/95

Waste Matrix Code: X7520

AS-GENERATED EPA CODES

D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Metal Box (.127cm)	0.3	0.0	0.0	0.0	0.0	0.3
Totals	0.3	0.0	0.0	0.0	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	Sodium potassium alloy (NaK) is used as a coolant for some components of the EBR-II Reactor. Waste NaK metal is a hazardous constituent of some transuranic wastes stored at the ANL-W Radioactive Scrap and Waste Facility (RSWF). The remote-handled NaK waste at RSWF is contained in stainless steel capsules or tubing and placed inside carbon steel waste cans which then are placed in stainless steel outer cans. The entire package is then stored in RSWF storage liners (carbon steel soil storage vaults). The NaK is generated during maintenance and operational activities. NaK waste is in canisters with TRU waste metal pieces and rods from reactor experiments. This waste will require treatment prior to disposal at WIPP. Final waste form has not been determined yet.
WASTE STREAM SOURCE	This waste stream was generated at ANL-767, EBR-II REactor Building: Typical nuclear reactor operations including maintenance activities on control systems.. The generating process is: The remote-handled NaK waste currently stored at RSWF is contained in stainless steel capsules or tubing as part of nuclear experiments. The waste is in canisters with TRU waste metal pieces and rods from reactor experiments.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Waste is stored at RSWF in various liners with varying amounts of NaK contamination.
MANAGEMENT COMMENTS	Alpha Containment
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

ET Energy Technology Engineering Center

ENERGY TECHNOLOGY ENGINEERING CENTER

Location and Description

Energy Technology Engineering Center (ET) occupies 90 acres of 290 acres of land shared with the Santa Susana Field Laboratory. The Santa Susana site is composed of a total of 2,700 acres located in the Simi Hills of Ventura County, approximately 48 kilometers northwest of downtown Los Angeles, California. Both DOE and the Rocketdyne Division of Rockwell International Corp. own facilities within this area. The Rockwell facilities include former fuel fabrication facilities, a hot cell, a reactor test building, a storage vault, an on-site transport cask, and other radiologically contaminated support laboratories and areas.

Mission

ET provides facilities for the testing of equipment, materials, and components for nuclear and other energy programs. Components include steam generators, pumps, valves, instrumentation, and other support elements for power plant design. Various types of testing include reliability, seismic, and performance demonstrations. Current activities include non-nuclear testing, and cleanup and environmental restoration from prior nuclear testing programs, such as decontamination and decommissioning of an NRC-licensed hot cell that was used for DOE activities.

Waste Information

Processes

ET TRU waste streams are CH waste comprised of absorbent materials plastics, rags, and other laboratory disposal solids. A second waste stream of similar composition was generated during DOE fuel decladding and decontamination and decommissioning operations. The second waste stream includes a small quantity of lead.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: ET-W021 | Handling: RH | NMVP #: NA | Stream Name: Hot Lab & PU Facility D&D | Inventory Date: 5/15/95

Local ID: ET | Type: MTRU | Generator Site: ET | Final Waste Form: Unknown | Waste Matrix Code: S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Sr-90	7.50E-04
Pu-239	7.50E-05
Cs-137	7.50E-04
Co-60	7.50E-04
Am-241	1.50E-05

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WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	5.5	0.8	0.0	0.0	0.0	6.3
Totals	5.5	0.8	0.0	0.0	0.0	6.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	0.8	0.0	0.0	0.0	6.2
Totals	5.4	0.8	0.0	0.0	0.0	6.2

As-Generated Form: Stored: 5.5 Projected: 0.8 Total: 6.3

Final Waste Form: Stored: 5.4 Projected: 0.8 Total: 6.2

WASTE STREAM DESCRIPTION	Dry residue and debris from the drain piping removed during the Hot lab D&D activities. Waste is characterized by high radiation level (RH). Radiological evaluation has determined that the waste contains TRU elements above the 100nCi/g, and potentially could contain hazardous constituents, there by it has been managed as mixed TRU waste.
WASTE STREAM SOURCE	D&D activities at the Hot Lab
CURRENT CONTAINER COMMENTS	Storage conatiner is a concrete lined drum for shielding. Shipping containers will be selected after completion of radiochemical analysis and determination of the waste disposition.
EPA COMMENTS	Regulated constituents that may be present will be determined by laboratory analysis (now pending)
MANAGEMENT COMMENTS	Pending sampling and analysis, this W.S. will continue to be managed as potentailly mixed TRU
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Storage conatiner is a concrete lined drum for shielding. Shipping containers will be selected after completion of radiochemical analysis and determination of the waste disposition. herefore Sections 8.2.7, 8.2.8, 8.2.14.1.13, 8.2.14.1.14 & 8.2.15 are left incomplete.

IN Idaho National Engineering Laboratory

IDAHO NATIONAL ENGINEERING LABORATORY

Location and Description

The Idaho National Engineering Laboratory (IN) is located in two primary areas: (1) the remote areas known as "the Site" along the northern edge of the Snake River Plain in southeastern Idaho, and (2) multiple locations southeast of the Site in the City of Idaho Falls. Lying at the foot of the Lost River, Lemhi, and Bitterroot-Centennial Mountain ranges, the Site covers nearly 2300 square kilometers (890 mi^2) of dry, cool desert. Most of the land withdrawn from public domain for use by the U.S. Department of Energy (DOE) is undeveloped. The facilities located in Idaho Falls include administrative, scientific support, and non-nuclear research laboratories.

During World War II, the U.S. Navy and U.S. Army Air Corps used a portion of the present Site as a gunnery range. In 1949, the Site was formally established as the National Reactor Testing Station (NRTS), a place where the Atomic Energy Commission (AEC) could build, test, and operate various types of nuclear reactors. Fifty-two reactors have been built at the INEL; of these, seven are operating or operable.

The Radioactive Waste Management Complex (RWMC) encompasses 144 acres in the southwestern corner of the INEL. The RWMC was established in 1952 as a controlled area for burial of solid radioactive wastes generated by INEL operations. In 1954, the burial ground was designated as a solid transuranic (TRU) waste disposal site. Until 1970, all TRU was buried below grade at the RWMC. In November 1970, the Transuranic Storage Area (TSA) was established for retrievable storage of waste contaminated with greater than 10 nanocuries (nCi) of TRU alpha activity per gram of waste. In November 1976, the Intermediate Level TRU Storage Facility (ILTSF) was established for retrievable storage of remote-handled (RH) TRU contaminated waste (greater than 200 millirem per hour). At the ILTSF the radioactive waste is stored in abovegrade vaults.

The DOE/Idaho Operations Office administers the INEL excluding Argonne National Laboratory-West. The current operator for the majority of the facilities is Lockheed Martin Idaho Technologies.

Mission

The INEL is a multiprogram laboratory and has provided innovative technologies, defense-related support and unique scientific and engineering capabilities to the nation. At present, areas of primary emphasis include nuclear reactor technology research and development, waste management and environmental restoration, advanced energy production and utilization technology development, defense-related support, technology transfer, and non-nuclear research and development projects. Development, transfer, and deployment of technologies to avoid and/or dispose of hazardous and/or radioactive waste and for remediation/restoration of previous disposal sites to protect the public, employees, and environment are also part of INEL's mission.

Waste Information

Processes

Solid TRU waste generated in national defense programs and research activities was buried or stored at the RWMC. This TRU waste typically includes cloth, paper, plastics, metals, rubber, sludge, ad concrete. TRU waste received at the INEL from November 1970 through July 1980 was placed on asphalt pads and covered with an earthen-cover to protect the waste from the environment until it could be permanently disposed. Waste received after this timeframe was placed in air-supported buildings for interim storage.

The Stored Waste Examination Pilot Plant (SWEPP) was constructed in 1984 and provides a facility for the nondestructive examination and assay (NDE/NDA) of TRU-contaminated wastes. The facility operated at production levels (5,000 drums per year) from August 1985 through September 1989. In 1989, the facility was placed in standby due to the change sin the Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria (WAC). The WAC requirements were changed in 1989 to include the requirements of the Transuranic Package Transport (TRUPACT-II). The facility has remained in standby condition with the exception of the waste required to support the WIPP Waste Characterization Program.

The TSA Retrieval Enclosure (RE) is being constructed over the top of the earthen-covered waste and will allow year-round retrieval operations. The facility is expected to be completed in fiscal year 1997. Retrieval rates for the facility are expected to be 20,000 drum equivalents (DE) per year. Retrieval of all earthen-covered waste in the TSA is expected to be completed between 2010 and 2014.

In 2003, all INEL TRU-contaminated waste in storage is expected to be treated at the Advanced Mixed Waste Treatment Facility for disposal at WIPP. The processing rate for the facility is expected to be approximately 5,000 m^3 per year with a volume reduction of about 65%.

Due to the Spent Nuclear Fuel Settlement Agreement which was signed with the State of Idaho, DOE has agreed to ship 3,100 m^3 (15,000 DE) of untreated waste from the INEL by 12/31/2002. After 1/01/2003, the INEL is required to ship a running average of 2,000 m^3 of stored inventory per year. All TRU waste stored at the INEL is required to be out of the state no later than 12/31/2018.

Notes on the INEL Reporting Format

The INEL data submittal did not provide any information on the type and number of currently stored containers for each waste stream reported in the TWBIR Rev. 2. The only information about stored containers included in the site submittal was the type and the total number of containers for each *unsegregated* waste stream as it currently exists at the site. In general, for the purposes of reporting for the Rev. 2 data submittal, each of the *unsegregated* streams have been segregated by INEL into two or more sub-streams to be shipped to WIPP. As a result, there has been a substantial increase in the number of streams reported for TWBIR Rev. 2 as compared to WTWBIR Rev. 1.

The first basis for segregation into sub-streams is whether the unsegregated waste stream contains a mixture of CH-TRU and RH-TRU waste, followed by whether it requires repackaging or treatment prior to shipment to WIPP, or whether there is a portion of it that can be certified and shipped directly without any need for either repackaging or treatment. The site nomenclature for an unsegregated waste stream is **IN-WXYZ**, whereas the nomenclature for any sub-streams resulting from this unsegregated stream is of the format **IN-WXYZ.ABC** etc. The fraction of the original unsegregated waste stream that is included in each sub-stream reported in the TWBIR Rev. 2 is stated under the Waste Stream Source description in each INEL waste stream profile. The Waste Stream Source description for a sub-stream also includes the phrases "Direct-ship" (i.e., it is certifiable and planned to be directly shipped to WIPP),"Cert-repack" (i.e., it will be certifiable upon repackaging) and "Uncertifiable" which refers to those sub-streams that will require treatment in order to become certifiable to the WIPP-WAC.

Notes on As-generated Containers

Since INEL did not submit any break-up of as-generated containers on a TWBIR sub-stream basis, this information has been derived (with the site's permission) from the percentages reported for each sub-stream in the Waste Stream Source description. For unsegregated waste streams with very small volumes (e.g., 1 to 10 drums), it was not always possible to precisely match the percentages reported in the source descriptions and allocate as-generated containers to each sub-stream. In such cases, the number of as-generated containers has been rounded off to the nearest integer. The as-generated volume of waste has been calculated using the same assumptions that have been used by the site, which is 0.212 m^3 for all drums, 3.17 m^3 for all boxes, 3.5 m^3 for all bins, and 0.212 m^3 for all inserts. However, for final waste form containers to be shipped to WIPP, the site assumed 0.208 m^3 as the volume of a 55-gallon drum. Because of the different assumptions for the volume of a drum between the as-generated waste and the final waste form, there may be minor discrepancies in the waste stream profiles for sub-streams that can be certified and shipped to WIPP without any repackaging or treatment.

Notes on Waste Material Parameters

INEL did not submit any waste material parameter data as part of the TWBIR Rev. 2 data submittal. Based on consultation and agreement with site representative(s), the TWBIR team has matched the waste streams reported in the Rev. 2 data submittal with their counterparts in Rev. 1 and thus assigned waste material parameters for each stream wherever possible.

Notes on the Final Waste Form Volume

Except for the waste streams that are expected to be directly shipped (upon WIPP-WAC certification) without any need for repackaging or treatment, no other waste streams are currently stored in final form. The uncertifiable streams are projected to be repackaged or treated at the site *at a later date*, as required, in order to be certifiable to the WIPP-WAC prior to their shipment to WIPP. However, for the purpose of reporting on the waste stream profiles, these uncertifiable streams are presented as "currently stored" in final form in order to avoid the error of double-counting these streams as both "currently stored" and "projected".

Notes on Waste Stream Description

The waste stream description applies only to the unsegregated waste stream and is therefore the same for all sub-streams that originate from a given unsegregated waste stream.

Notes on Handling Characteristics of Final Waste Form Containers

The handling characteristics (i.e., CH versus RH) of some of the waste streams may seem inconsistent with the waste stream description. This is because the handling (CH or RH) reflects the *expected* characteristics of the stream after it is repackaged or treated to meet the WIPP-WAC, whereas the waste stream description applies only to the unsegregated waste stream prior to any repackaging or treatment. All *apparent* discrepancies noted in the handling characteristics of a waste stream were brought to the site's attention during the BIR data review process, and the INEL site representative confirmed that the *expected* characteristics of the final form is what is presented in the data submittal.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: IN-W112	Handling: RH	NMVP #: N/A	Stream Name: HEPA FILTERS		Inventory Date: 12/30/99
Local ID: ID-CPP-172	Type: MTRU	Generator Site: IN	Final Waste Form: Unknown		Waste Matrix Code: S5410

AS-GENERATED EPA CODES

U328, U238, U228, U227, U226, U225, U220, U219, U218, U217, U215, U211, U210, U208, U207, U204, U201, U196, U191, U190, U188, U182, U171, U170, U169, U165, U162, U159, U151, U147, U145, U144, U140, U138, U135, U134, U133, U131, U128, U127,

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

M

FINAL FORM RADIONUCLIDES

Isotope	(Ci/ml)
H-3	3.70E-07
Ce-144	9.80E-06
Co-60	1.16E-06
Cs-134	1.00E-05
Cs-137	2.03E-04
Am-241	5.50E-08
Eu-155	1.89E-06
Tc-99	1.12E-08
Ni-63	3.40E-08
Np-237	2.40E-09
Pu-238	4.80E-07
Pu-239	6.30E-08
Ru-106	4.50E-06
Sb-125	7.80E-07
Sr-90	2.17E-04
Eu-154	2.54E-06

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

HEPA filters for off-gas cleaning of ventillation. The filters are considered MTRU waste because they are derived from treatment of HLW and spent fuel processing that contain TRU constituents. HEPA filters from CPP-633 and 659 may contain F, P, and U listed waste codes resulting from laboratory quantities of waste dumped to the ICPP waste systems filtered by these HEPA filters.

This waste stream contains nine NWCF (New Waste Calcining Facility) off-gas filters previously reported as part of ID-EGG-118-158, NWCF Filters. These waste streams have been combined and ID-EGG-118-158 has been made inactive.

WASTE STREAM SOURCE

This waste stream was generated at CPP-659, CPP-633: Primarily from system HEPA filters for off-gas cleaning from processing HLW and spent fuel waste. The generating process is: Waste generated from the off-gas cleaning HEPA filters associated with operation of the waste calciner's located in CPP-659 and CPP-633. This waste stream will be treated at INEL and is not supposed to be shipped to WIPP.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

The HEPA filters from CPP-659 and CPP-633 filter off-gas from systems that treat waste containing large quantities of TCLP metals (i.e., hundreds to thousands ppm). Therefore, these filters are most likely to have metals in concentrations which equal or exceed TCLP levels. EPA waste codes were obtained from HFLS Part A submitted in the Part B Permit application dated 7/93.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: IN-Z001	Handling: U	NMVP #: N/A	Stream Name: INEL Buried TRU Waste		Inventory Date:
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Unknown		Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	
PCBs:	
Source:	

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Not contained	31000.0	0.0	0.0	0.0	0.0	31000.0
Totals	31000.0	0.0	0.0	0.0	0.0	31000.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 31000.0 Projected: 0.0 Total: 31000.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	The INEL disposed of approximately 57,000 m3 of TRU-contaminated waste in the Radioactive Waste Management Complex Subsurface Disposal Area up until 1970. It is planned to retrieve and treat 100% of the buried TRU waste, subject to the Record of Decision in 1998. Remediation efforts with Pit 9 are expected to begin in August 1996 Remaining TRU pits and trenches would be remediated in 2003-2016. The anticipated treatment will be vitrification, producing 31,000 m3 (1.01e08 kg) of vitrified product that will be stored in 55-gallon drums until final disposition. This waste will not go to WIPP.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

KA Knolls Atomic Power Laboratory - Schenectady

M

KNOLLS ATOMIC POWER LABORATORY

Location and Description

Knolls Atomic Power Laboratory (KA) is located in Niskayuna, New York, about 3.2 km east of Schenectady. KA is operated by KAPL, Inc., a wholly owned subsidiary of the Martin Marietta Corporation under contract to the DOE. KA is a component of the Naval Nuclear Propulsion Program, and provides basic research and design on nuclear propulsion plants for Navy submarines. Facilities at the site include machine shops, waste-handling facilities, a boiler house, and chemistry, physics, and metallurgy laboratories.

Mission

The primary mission of KA is the design and testing of naval nuclear propulsion plants and reactor components. KA also provides fuel sample investigation support for the Idaho National Engineering Laboratory .

Waste Information

Processes

KA manages both CH and RH TRU heterogeneous debris. The TRU waste generated at KA is a result of the destructive evaluation of irradiated test specimens. KA has established a radioactive waste minimization practices program, including waste stream review, work planning, and waste stream segregation.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: KA-T001	Handling: RH	NMVP #: NA	Stream Name: Transuranic Debris		Inventory Date: 12/31/94
Local ID: KA-T001	Type: TRU	Generator Site: KA	Final Waste Form: Heterogeneous		Waste Matrix Code: X7000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	98.2	0.0	1634.6
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.1	0.0	22.7
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.0	0.0	184.6
Rubber:	7.3	0.0	16.4
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Non-Defense TRU Waste
Residues: No
Asbestos: No
PCBs: No
Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

M

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	9.60E-01
Sr-90	9.60E-01
Pu-242	2.60E-06
Pu-241	1.30E-01
Pu-240	4.20E-04
Pu-239	4.90E-04
Pu-238	3.10E-01
MFP	4.60E-01
Cs-137	9.60E-01
Co-60	5.00E-02
Ba-137m	9.20E+01
Am-241	7.20E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister / 5-gallon	0.2	0.5	0.9	1.8	1.8	5.2
Totals	0.2	0.5	0.9	1.8	1.8	5.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.5	5.0	8.9	18.7	18.7	53.9
Totals	2.5	5.0	8.9	18.7	18.7	53.9

As-Generated Form: Stored: 0.2 Projected: 4.9 Total: 5.2

Final Waste Form: Stored: 2.5 Projected: 51.4 Total: 53.9

WASTE STREAM DESCRIPTION	Organic and inorganic particulate and debris.
WASTE STREAM SOURCE	Waste from laboratory testing and analysis.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Material in this waste stream is not a hazardous waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	The current inventory identified in section 4.1.2.1 and the projected generation identified in section 5.1.3 consists of stored TRU which has not been completely characterized. It is expected that 50% of this material will be finally classified as LLW or MLLW. It is expected that 10% of this material will be finally classified as MTRU waste (KA-W016). The remainder will be finally classified as TRU waste. Data date is 12/31/94.
FINAL FORM COMMENTS	KAPL expects that once the 5 gallon container is in the 55 gallon drum, the 55 gallon drum will be CH, but that would not change the characterization of the waste.

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Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: KA-W016
Local ID: KA-W016

Handling: RH | NMVP #: NA | Stream Name: Transuranic Debris | Inventory Date: 12/31/94
Type: MTRU | Generator Site: KA | Final Waste Form: Heterogeneous | Waste Matrix Code: S5000

AS-GENERATED EPA CODES

F005, F003, F002, F001, D040, D039, D035, D018, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	98.2	0.0	1634.6
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.1	0.0	22.7
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.5
Rubber:	7.3	0.0	16.4
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Non-Defense TRU Waste
Residues: No
Asbestos: No
PCBs: No
Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

M

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	9.60E-01
Sr-90	9.60E-01
Pu-242	2.60E-06
Pu-241	1.30E-01
Pu-240	4.20E-04
Pu-239	4.90E-04
Pu-238	3.10E-01
MFP	4.60E-01
Cs-137	9.60E-01
Co-60	5.00E-02
Ba-137m	9.20E+01
Am-241	7.20E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister / 5-gallon	0.0	0.1	0.1	0.2	0.2	0.7
Totals	0.0	0.1	0.1	0.2	0.2	0.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	1.2	1.5	2.1	2.1	6.9
Totals	0.0	1.2	1.5	2.1	2.1	6.9

As-Generated Form: Stored: 0.0 Projected: 0.7 Total: 0.7

Final Waste Form: Stored: 0.0 Projected: 6.9 Total: 6.9

WASTE STREAM DESCRIPTION	This transuranic mixed waste has not yet been generated. Waste will be segregated to the extent possible (considering ALARA) into inorganic, organic and heterogeneous waste streams and packaged separately. Details of waste characteristics will be developed upon generation. This waste stream will not be moratorium waste.
WASTE STREAM SOURCE	Waste generated through R&D programs
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	This waste has not yet been generated. The identification of hazardous constituents listed is based on process knowledge of potential contaminants.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This data is consistent with the data provided to the State and EPA in the Proposed Site Treatment Plan. Data date is 12/31/94.
FINAL FORM COMMENTS	N/A

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LA Los Alamos National Laboratory

DOE/CAO-95-1121
December 1995

LOS ALAMOS NATIONAL LABORATORY

Location and Description

The Los Alamos National Laboratory (LANL) is located approximately 97 kilometers north of Albuquerque and 40 kilometers west of Santa Fe in Los Alamos County, New Mexico. The laboratory facilities are dispersed among numerous Technical Areas (TAs) spread over a 111-square kilometer site on the Pajarito Plateau. The plateau consists of several finger-like mesas extending eastward from the Jemez Mountains to the Rio Grande Valley with steep eroded canyons separating the mesas. The elevation of the mesas range from 1890 to 2377 meters. Some TAs are located in canyons.

The Los Alamos effort was the beginning of what is today the nationwide Albuquerque Operations Office laboratory and industrial complex of the DOE.

Mission

The Los Alamos Scientific Laboratory was established in 1943 by the U.S. Army's Manhattan Engineer District for the purpose of developing the first atomic bombs. Known as the Los Alamos Scientific Laboratory for many years, the name was changed to the Los Alamos National Laboratory in December 1980. LANL was the research, development, engineering design, and testing center for the Manhattan Project. The mission was the application of science and technology to problems of national security, including the maintenance of a strong defense, the fulfillment of arms controls commitments and the guarantee of a secure energy supply for the future.

During the wartime Manhattan Project, Los Alamos, New Mexico, was wholly-owned and controlled by the Government.

LANL's mission since World War II has included nuclear device design, research, development, testing, stockpile certification, and plutonium storage. Major programs currently include research in nuclear and conventional weapons development; nuclear fission and fusion; nuclear safeguards and security; verification and control technologies; fundamental research in particle physics, mathematics, chemistry, and materials; and waste management technology development and testing.

Research on peaceful uses of nuclear energy has included space applications, power reactor programs, magnetic and inertial fusion, radiobiology, and medicine. Other programs include astrophysics, earth sciences, lasers, computer sciences, solar energy, geothermal energy, biomedical and environmental research, and nuclear waste management research.

Today, the Waste Management Facilities Operations Group, CST-27, is responsible for all waste management facilities at LANL, except those related to high-explosives waste and sanitary waste, and those operated by waste generators in preparing their wastes for disposal. The Waste Management Program includes treating radioactive liquid and solid waste; packaging, transporting, treating, and disposing of hazardous chemical waste; and operating the disposal and storage sites for mixed waste. The Waste Management Program provides treatment, storage and disposal for Environmental Restoration Program-generated waste.

Waste Information

Processes

Major CH TRU waste generators at LANL are: Analytical Chemical Group (CHM-1), Nuclear Fuel Development and Facilities Operations Group (MST-11), Nuclear Materials Process Technology Group (MST-12), and Plutonium Metal Technology Group (MST-13).

RH TRU waste is generated by the Irradiated Materials Examination Group (MST-14).

CHM-1 is involved in analysis of radioactive materials. The waste generated by CHM-1 are combustibles (paper, rags, plastics, rubber) and non-combustibles (glass, ceramic, porcelain, metal, transite, chemicals, and equipment).

Wastes generated in MST-12 are process residues in solid and liquid TRU waste streams left when all economically recoverable quantities of special nuclear materials have been removed from a nuclear material item.

The wastes generated in MST-13 are combustible solids, noncombustible scrap (small tools, cans, small equipment items), and cemented process residues (process leached solids, filter cakes, and evaporator bottoms) stabilized in Portland or Gypsum cement.

The Size Reduction Facility's waste consists of metal equipment, either whole or sectional along with its combustible components, and the small volumes of combustibles generated during decommissioning, sectioning, and packaging (mostly gloveboxes, process equipment, and ductwork from decommissioning operations).

MST-14 generates both contact and remote handled solid wastes from hot cell operations.

Modifications/Assumptions/Development

LANL reported radionuclides in total Curies. The TWBIR team used the volumes reported for each waste stream to calculate the radionuclides in terms of Ci/m^3.

LANL's waste material parameters Solidified, Inorganic Matrix and Cement (Solidified) for waste streams LA–M002, LA–W003, LA–W006, LA–T002, and LA–T006 were calculated based on the proposed amount of cement that will be used to solidify these waste streams.

For final form containers, the estimated generation for newly generated waste was reported in the years 1995 to 2000. For the years 2001 to 2022 a bulk amount was reported. The TWBIR team converted this bulk amount into containers/year, assuring a constant generation rate per year between 2001 and 2022.

LANL assumes the internal volume for a 85 gallon drum used to overpack a 55 gallon drum is 0.208 m^3. This is assumed because all waste from 55 gallon drums that are currently overpacked in 85 gallon drums will be repackaged into 55 gallon drums for shipment to WIPP (upon WIPP–WAC certification).

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: LA-Z001	Handling: U	NMVP #: N/A	*Stream Name:* Los Alamos National Laboratory Buried TRU Waste		Inventory Date:
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Unknown		Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	
PCBs:	
Source:	

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Not contained	14000.0	0.0	0.0	0.0	0.0	14000.0
Totals	14000.0	0.0	0.0	0.0	0.0	14000.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 14000.0 Projected: 0.0 Total: 14000.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	A total of approximately 14,000 m3 of TRU-contaminated waste is bured at the Los Alamos National Laboratory site. As of December 31, 1991, the radioactivity from the TRU radionuclides associated with this volume of buried waste is estimated to be 9,230 Curies. This waste will not go to WIPP.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

M

LB Lawrence Berkeley Laboratory

LAWRENCE BERKELEY LABORATORY

Location and Description

Lawrence Berkeley Laboratory (LB) is located in an urban environment on 130 acres across the bay from San Francisco, California, in the hills overlooking the University of California-Berkeley. The site is bordered on the north by predominately single-family homes, and on the west by multi-unit dwellings, student residence halls, and commercial districts.

Mission

LB is operated by the University of California for DOE. Its mission is to: 1) perform multidisciplinary research in the energy sciences, general sciences, and life sciences; 2) develop and operate unique national experimental facilities that are available to qualified investigators; and 3) transfer knowledge and technologies innovations and foster productive relationships between LB and research programs, universities, and industry to promote national economic competitiveness. In addition, LB provides scientific support to DOE through operation of particle accelerators, chemistry and biomedical research laboratories, and support facilities.

Waste Information

Processes

TRU waste was generated as a result of several activities including research activities performed in the chemical sciences and earth sciences areas. Typical research areas included the determination of the solubility and speciation of actinide elements in various sample acids and acidic brines. LB's TRU waste also came from the removal of sources from smoke detectors.

The TRU Waste generated by LB for past DOE projects does not currently fit into the defense category, making LB one of the small generator sites with waste not acceptable to WIPP. The waste generated on-site is now being packaged for shipment off-site for interim storage at Hanford's Solid Waste Treatment, Storage, and Disposal Facility.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: LB-T001 | Handling: CH | NMVP #: N/A | Stream Name: LBL - Waste | Inventory Date: 5/31/95

Local ID: | Type: TRU | Generator Site: | Final Waste Form: Heterogeneous | Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	390.0	40.0	800.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	425.0	50.0	850.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	150.0	60.0	200.0
Rubber:	0.0	0.0	0.0
Plastics:	450.0	150.0	600.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	150.0	50.0	250.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Non-Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

UNK

M

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
U-233	4.81E-03
Ra-226	3.38E-02
Pu-242	1.01E-02
Pu-240	5.05E-03
Pu-238	2.54E-04
Es-254	5.29E-03
Es-253	4.81E-04
Cm-244	1.19E-01
Cf-250	4.81E-05
Cf-249	3.16E-03
Am-243	3.85E-02
Am-241	9.32E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.2	0.4	0.4	1.7
Totals	0.6	0.0	0.2	0.4	0.4	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.2	0.4	0.4	1.7
Totals	0.6	0.0	0.2	0.4	0.4	1.7

As-Generated Form: Stored: 0.6 Projected: 1.0 Total: 1.7

Final Waste Form: Stored: 0.6 Projected: 1.0 Total: 1.7

WASTE STREAM DESCRIPTION	Transuranic wastes with isotopes only
WASTE STREAM SOURCE	The LBL is operated by UC for DOE and performs multi-disciplinary research in the energy sciences, life sciences, and general sciences. During the research a small amount of TRU waste is generated.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data of regulated contaminant characteristics is solely provided by generators. No laboratory chemical analysis has been performed to verify these data.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

M

MOUND PLANT

Location and Description

Mound (MD) is located within the southern city limits of Miamisburg in Montgomery County in southwestern Ohio. The plant occupies 306 acres of land overlooking Miamisburg and the Great Miami River. The metropolitan area of Dayton is located 10 miles north-northeast of Mound.

The DOE Dayton Area Office was established as part of the Albuquerque Operations Office in 1947.

The Mound Plant (MD) is one of the principal DOE sites. The facility was utilized as an integrated research, development, and production facility to perform work in support of DOE weapons and energy programs. Mound manufactured non-nuclear and tritium-containing components for nuclear weapons. These components included detonators, timers, transducers, firing sets, pellets, and unique production testers. Activities also included recovery and purification of tritium wastes. Earlier activities included manufacturing of polonium-210 and plutonium-238 radioisotopic heat sources.

Mission

Mound originated as a technical organization in 1943 and was responsible for determining the chemical and metallurgical properties of plutonium for the Manhattan Project. Permanent facilities were first constructed in 1947 and occupied in 1948. The plant was assigned new production and development functions in 1955.

In 1993, the Secretary of Energy announced that the Defense Program Mission was to be ended at Mound. Mound's new mission is the safe shutdown of Defense Programs and commercialization of some of the area offices.

Waste Information

Processes

TRU waste may be generated by the Decontamination and Decommissioning (D&D) operations in the Plutonium Processing Building and the Research Building.

Large quantities of the line-generated solid wastes, including gloveboxes, fume hoods, piping, tools and other non-burnables, as well as rags, chemwipes, and other combustible waste was and will be generated by the Pu Processing and Research Buildings D&D Project.

TRU alpha wastes are generated from decontamination operations in the Pu Processing Areas.

Other major D&D efforts included the removal of underground piping which formerly transmitted Pu-contaminated liquid waste from the processing area to the waste water treatment facility.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

M

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T004	Handling:	CH	NMVP #:	N/A	Stream Name:	Uncategorized unknowns
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Unknown

Inventory Date: 5/5/95

Waste Matrix Code: Z9000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	150.4		
Packaging Material Plastic:	20.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Source Unknown

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-240	2.00E+01
Pu-239	3.70E-01
Pu-238	5.16E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Box / Type 003	2.3	0.0	0.0	0.0	0.0	2.3
Box / Type 004	21.0	0.0	0.0	0.0	0.0	21.0
Totals	27.5	0.0	0.0	0.0	0.0	27.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Standard Waste Box	22.7	0.0	0.0	0.0	0.0	22.7
Totals	26.8	0.0	0.0	0.0	0.0	26.8

As-Generated Form: Stored: 27.5 Projected: 0.0 Total: 27.5

Final Waste Form: Stored: 26.8 Projected: 0.0 Total: 26.8

WASTE STREAM DESCRIPTION	MOST (>50%) INPUT FORMS DO NOT HAVE ANY INFORMATION AS TO WHAT MAY BE INSIDE. THIS WASTE IS EVERYTHING THAT DOES NOT FIT IN THE OTHER STREAMS OR THERE IS TOO LITTLE INFORMATION AVAILABLE TO CATEGORIZE INTO ONE OF THE OTHER STREAMS.
WASTE STREAM SOURCE	Uncategorized TRU waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: MD-W018	Handling: CH	NMVP #: N/A	Stream Name: PCB TRU WASTE		Inventory Date: 5/5/95
Local ID: N/A	Type: TRU	Generator Site: MD	Final Waste Form: Unknown		Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	153.7		
Packaging Material Plastic:	0.4		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

		TRUCON CODE	FINAL FORM RADIONUCLIDES
Category:	Defense TRU Waste	N/A	N/A
Residues:	No		
Asbestos:	No		
PCBs:	Yes		
Source:	Facility/Equipment Operation and Maintenance Waste		

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
LLW Box	2.8	0.0	0.0	0.0	0.0	2.8
Totals	3.0	0.0	0.0	0.0	0.0	3.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Standard Waste Box	18.9	0.0	0.0	0.0	0.0	18.9
Totals	19.1	0.0	0.0	0.0	0.0	19.1

As-Generated Form: Stored: 3.0 Projected: 0.0 Total: 3.0

Final Waste Form: Stored: 19.1 Projected: 0.0 Total: 19.1

WASTE STREAM DESCRIPTION	PCB contaminated waste. Its origin is unknown. There is no paperwork or any other information about this waste.
WASTE STREAM SOURCE	PCB contaminated waste. Only information known at present (6/6/95) is the outside type and volume of the outside contrainer. There is a press is inside a plywood box which is inside the LLW box.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is low due to the number of unknowns.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Storage and shipping container were assumed to be the same

M

OAK RIDGE NATIONAL LABORATORY

Location and Description

The Oak Ridge National Laboratory (ORNL) is located 10 miles southwest of downtown Oak Ridge, Tennessee, and 32 kilometers northwest of Knoxville, Tennessee. The ORNL site occupies about 10,000 acres of the 35,252 acre Oak Ridge Reservation. The site covers portions of both Melton and Bethel Valleys. Approximately 1100 acres within the Melton and Bethel Valleys have been developed.

The ORNL is under the auspices of the DOE/Oak Ridge Operations Office which supports production of nuclear weapon components for national defense programs, production of enriched uranium for defense requirements and for fuelling nuclear power plants, the processing of uranium feed materials for DOE's plutonium production reactors, and extensive energy research and development in all DOE program areas.

Mission

ORNL was established in 1942 in support of the Manhattan Project. The primary mission of ORNL has been to carry out applied research and engineering development in fission, fusion, and other energy technologies, and to conduct scientific research in basic physical and life sciences. Relevant missions include isotope production and processing, research and development, waste management, and D&D of operating units, and advanced reactor development work. In addition, ORNL conducts several activities for DOE Defense Programs. The principal nonweapons-related activities include nuclear power development and magnetic fusion research. ORNL conducts activities in support of DOE's Transuranic Element Program, the Californium and Loan Program, and the Mark 42 Program.

During the wartime Manhattan Project, the town of Oak Ridge, Tennessee, was wholly-owned and controlled by the Government.

Waste Information

Processes

The Y-12 Plant was built originally as part of the Manhattan Project to separate and concentrate uranium-235 isotopes by the electromagnetic process. With the successful demonstration of the more efficient gaseous diffusion process, the plant was modified to carry out other weapons production operations. The major operations at the Y-12 Plant were production of weapon components, uranium, uranium alloys, and lithium compounds that were shipped to other sites.

The K-25 Site (formerly the Oak Ridge Gaseous Diffusion Plant) was a production and development facility for uranium enrichment using a gaseous diffusion process. Production operations were shut down in 1985. The current mission of K-25 involves environmental restoration, decontamination and decommissioning, and waste management. DOE's TSCA incinerator is located at the K-25 site.

Waste streams at ORNL tend to be different from K-25 and Y-12 waste streams in that they are smaller in volume, constantly changing, and could contain virtually any radionuclide, depending on the research activity that generated the waste stream. In these respects, they are probably similar to the waste streams generated at all the national labs. Of the three main facilities at ORR, only ORNL generates TRU waste (from research reactors), although K-25 and Y-12 waste streams may contain concentrations of transuranic isotopes below 100 nanocuries per gram.

In contrast, the waste generating processes at K-25 and Y-12 tend to be stable and have their own signature isotopes. Waste streams at K-25 may often be contaminated with technicium, either depleted or enriched uranium, and trace concentrations of transuranics. Y-12 waste streams are also often contaminated with depleted or enriched uranium. Some waste streams at Y-12 are derived from classified activities; data about these waste streams are also classified.

Most of the TRU waste residing at ORNL has been generated as a result of the Californium and U-233 Program or has come from off-site waste generators. Additional TRU waste is produced by the ORNL Analytical Chemistry facilities as a result of sample analysis. Some TRU waste may also be generated by the K-25 Site during decontamination and decommissioning activities.

RH-TRU solid waste consists primarily of miscellaneous hot-cell waste (e.g., paper, glass, plastic tubing, shoe covers, wipes, etc.), HEPA filters from off-gas cleanup systems, and discarded equipment (e.g., chemical processing racks, vacuum pumps, etc.). The unshielded individual waste packages within the casks typically have radiation levels that measure between 10 and 2000 rem/h; the majority are below 100 rem/h. RCRA materials in RH TRU solid waste primarily consist of lead that was used as shielding, and limited amounts of mercury from discarded mercury-vapor lamps. The RH TRU solid waste is typically contained in cylindrical concrete casks 1.4 m (4.5 ft) in diameter by 2.3 m (7.5 ft) high. Wall thickness of the casks are currently either 15.2 or 30.5 cm (6 or 12 in) thick, depending on the radiation level of the contents.

The majority of RH TRU sludges as ORNL are the result of waste accumulation from the past 50 years of ORNL liquid waste operations. These sludges are residuals from sluicing operations conducted in the early 1980s when the majority of the inactive gunite tank contents were removed for hydrofracture disposal at ORNL. RH TRU sludges continue to accumulate due to on-going R&D programs which produce transuranium isotopes for medical, industrial, and government applications. The surface equivalent dose rates of these sludges are generally near 10 rem/h (unshielded).

Most CH TRU waste is generated at ORNL by activities related to isotope research and production, including analytical support. The waste results primarily form hot cell and glovebox operations, and most of it can be accommodated in 55-gallon drums.

CH TRU waste at ORNL consists of general laboratory wastes such as various glassware, plastic ware, empty reagent bottles, vials, and other containers, cloth and paper wipes, rubber and cotton gloves, contaminated clothing, gaskets and other rubber parts, metal parts, tools and machinery, electrical equipment, ion-exchange resins, ventilation filters, and other general waste generated during the operation of gloveboxes and hot cells. A given container of waste may contain several different TRU radionuclides.

One of ORNL's offsite generators is the Paducah Gaseous Diffusion Plant (PA) in Kentucky serves as the first stage in the DOE uranium enrichment complex. TRU isotopes have been separated from the uranium feed and collected at the bottom of the cascade. Some drums containing TRU waste have been shipped to ORNL for storage while the remaining TRU waste containers continue to be stored at PA.

Nuclear Fuels Services, Inc. (NFS) at Erwin, Tennessee, sent 800+ drums of CH TRU waste to ORNL.

Other off-site generators include the New Brunswick Laboratory, West Valley Decommissioning Project, and the Knolls Atomic Power Laboratory.

Modifications/Assumptions/Development

ORNL reported radionuclides in total Curies. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the final waste form volumes reported by OR.

ORNL's waste material parameters Solidified, Inorganic Matrix and Cement (Solidified) for waste streams OR-W042 and OR-W046 were calculated based on the proposed amount of cement that will be used to solidify these waste streams.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: OR-W089	Handling: CH	NMVP #: N/A	Stream Name: CH-TRU Uncategorized (nonmixed)		Inventory Date: 12/31/94
Local ID: T2303	Type: TRU	Generator Site: OR	Final Waste Form: Unknown		Waste Matrix Code: S9000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Source Information Not Compiled

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-238	1.72E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Metal	8.2	0.0	0.0	0.0	0.0	8.2
Box /Wood	5.1	0.0	0.0	0.0	0.0	5.1
Cask /Concrete	2.8	0.0	0.0	0.0	0.0	2.8
Drum / 55-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Totals	17.8	0.0	0.0	0.0	0.0	17.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	17.7	0.0	0.0	0.0	0.0	17.7
Totals	17.7	0.0	0.0	0.0	0.0	17.7

As-Generated Form: Stored: 17.8 Projected: 0.0 Total: 17.8

Final Waste Form: Stored: 17.7 Projected: 0.0 Total: 17.7

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU waste which has not been classified or characterized. It is believed that the physical form is either solid, liquid, mixed (both solid and liquid), or unknown and does not contain hazardous constituents. This waste is categorized as uncategorized (matrix code 9000).
WASTE STREAM SOURCE	Hot Cell Waste, Radiochemical Processing for Isotope Separation and Purification
CURRENT CONTAINER COMMENTS	Waste will have to be repackaged into acceptable containers for shipment and disposal.
	Waste will have to be repackaged into acceptable containers for shipment and disposal.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Final treatment will be decided upon characterization and categorization of this waste stream. The waste currently stored in casks will have to be repackaged into acceptable containers for shipment and disposal.
ACCEPTANCE COMMENTS	Bldg 118 is not designated as a TRU Storage Facility. The waste inside this building will be evaluated as being TRU or LLW. Bldg 7834 is a closed non-RCRA storage facility. The waste containers stored in this building will be evaluated to determine if they are mixed or non-mixed TRU since this is a non-RCRA facility.
FINAL FORM COMMENTS	Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. No newly generated waste is projected for this waste stream. 77 additional 55 gallon drums will be required to repack the existing waste.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W090	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Uncategorized (nonmixed)
Local ID:	T2305	Type:	TRU	Generator Site:	OR	Final Waste Form:	Unknown

Inventory Date: 12/31/94

Waste Matrix Code: S9000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	
PCBs:	No
Source:	Source Information Not Compiled

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
U-235	2.96E-04
U-233	5.30E-01
Th-232	2.46E-07

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cask /Concrete	0.03	0.0	0.0	0.0	0.0	0.03
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	0.9	0.0	0.0	0.0	0.0	0.9
Totals	0.9	0.0	0.0	0.0	0.0	0.9

As-Generated Form: Stored: 0.03 Projected: 0.0 Total: 0.03

Final Waste Form: Stored: 0.9 Projected: 0.0 Total: 0.9

WASTE STREAM DESCRIPTION	This waste stream consists of RH-TRU waste which has not been classified or characterized. It is believed that the physical form is either solid, liquid, mixed (both solid and liquid), or unknown and does not contain hazardous constituents. This waste is categorized as uncategorized (matrix code 9000).
WASTE STREAM SOURCE	Unknown
CURRENT CONTAINER COMMENTS	This waste will have to be repackaged into acceptable containers.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Final treatment will be decided upon characterization and categorization of this waste stream. The waste currently stored in casks will have to be repackaged into acceptable containers for shipment and disposal.
ACCEPTANCE COMMENTS	Bldg 7829 is not designated as a TRU Storage Facility. The waste inside will be evaluated as being TRU or LLW. One container in this waste stream will be evaluated as possibly being Spent Nuclear Fuel.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums were reported in the inventory and no waste is projected for the future. 1 RH canister used to overpack 55 gallon drums will be required to repack the existing waste.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W091	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (nondefense)
Local ID:	2315	Type:	MTRU	Generator Site:	AR	Final Waste Form:	Heterogeneous

Inventory Date: 12/31/94

Waste Matrix Code: S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Non-Defense TRU Waste
Residues:	No
Asbestos:	
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Ra-226	4.71E+00
Pu-239	3.55E-01
Pu-238	4.84E+01
Am-241	1.01E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Other	0.03	0.0	0.0	0.0	0.0	0.03
Totals	0.9	0.0	0.0	0.0	0.0	0.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

As-Generated Form: Stored: 0.9 Projected: 0.0 Total: 0.9

Final Waste Form: Stored: 1.0 Projected: 0.0 Total: 1.0

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids which were generated from nondefense programs. The physical form is solid and is suspected to contain hazardous constituents. It has not been determined if these wastes have been examined by WEAF. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Sources and Sealed Sources
CURRENT CONTAINER COMMENTS	Other types of storage containers exist and will require repackaging into acceptable containers. Waste contents will require repackaging into an acceptable containers.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	This waste has been determined to come from nondefense related programs. Resolution of the nondefense issue for shipment to WIPP will have to take place prior to final disposal of this waste stream.
ACCEPTANCE COMMENTS	Bldg 7826 is a closed non-RCRA storage facility. The waste containers stored in this building will be evaluated to determine if they are mixed or non-mixed TRU since this is a non-RCRA facility.
FINAL-FORM COMMENTS	Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. No newly generated waste is projected for this waste stream. 1 additional 55 gallon drum will be required to repack the existing waste.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W092	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Uncategorized (nondefense, nonmixed)
Local ID:	T2302	Type:	TRU	Generator Site:	PR	Final Waste Form:	Unknown

Inventory Date: 12/31/94

Waste Matrix Code: S9000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Non-Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Source Information Not Compiled

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Co-60	1.37E+04
Ag-110M	1.37E+04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cask /Concrete	4.4	0.0	0.0	0.0	0.0	4.4
Totals	4.39	0.0	0.0	0.0	0.0	4.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.4	0.0	0.0	0.0	0.0	4.4
Totals	4.4	0.0	0.0	0.0	0.0	4.4

As-Generated Form: Stored: 4.4 Projected: 0.0 Total: 4.4

Final Waste Form: Stored: 4.4 Projected: 0.0 Total: 4.4

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU waste which has not been classified or characterized. It is believed that the physical form is either solid, liquid, mixed (both solid and liquid), or unknown and may contain hazardous constituents. This waste is categorized as uncategorized (matrix code 9000).
WASTE STREAM SOURCE	Control and Shim Rods with data to be verified.
CURRENT CONTAINER COMMENTS	Waste contents will require repackaging into an acceptable containers.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Final treatment , if required, will be decided upon characterization and utilization of process knowledge for the categorization of this waste stream. The waste stored in casks will have to be repackaged into approved shipping containers. Resolution of the nondefense issue will have to be resolved if this waste stream is to be shipped to WIPP.
ACCEPTANCE COMMENTS	Bldg 119 is not designated as a TRU Storage Facility and the waste inside will be assessed as being TRU or LLW.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums were reported in the inventory and no waste is projected for the future. 21 55 gallon drums will be required to repack the existing waste.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: OR-Z001	Handling: U	NMVP #: N/A	Stream Name: Oak Ridge National Laboratory Buried TRU Waste		Inventory Date:
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Unknown		Waste Matrix Code:

AS-GENERATED EPA CODES	FINAL WASTE FORM DESCRIPTORS		TRUCON CODE	FINAL FORM RADIONUCLIDES
N/A	Category:	Defense TRU Waste	N/A	N/A
	Residues:			
	Asbestos:			
	PCBs:			
	Source:			

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Not contained	176.0	0.0	0.0	0.0	0.0	176.0
Totals	176.00	0.0	0.0	0.0	0.0	176.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 176.0 Projected: 0.0 Total: 176.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	A total of approximately 176 m3 of TRU-contaminated waste is buried at the Oak Ridge National Laboratory site. This total does not include approximately 9,500 m3 of TRU waste that was injected by yydrofracture at ORNL, which is equivalent to abount 680,000 Curies of as-stored radioactivity. As of December 31, 1993, the decayed radioactivity from the TRU radionuclides associated with this volume of buried waste is estimated to be 20 Curies. The TRU radionuclide total includes 244-Cm, which is considered to be a TRU radionuclide at ORNL. This waste will not go to WIPP.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

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PA Paducah Gaseous Diffusion Plant

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PADUCAH GASEOUS DIFFUSION PLANT

Location and Description

The Paducah Gaseous Diffusion Plant (PA) is situated in northwestern Kentucky, 26 kilometers west of Paducah, near the Ohio River. The site encompasses 750 acres (including 74 acres of process buildings). The site is included in a 3422-acre tract of DOE-owned property.

The PA is operated from DOE/Oak Ridge Operations Office with Lockheed Martin Utilities Services as the Management and Operating Contractor.

Mission

The DOE uranium enrichment complex of which PA is a component, was originally constructed to produce highly enriched uranium for nuclear weapons. The complex is now used primarily to provide low enriched uranium for domestic and foreign nuclear power reactors and, to a lesser degree, to provide the highly enriched uranium used in nuclear propulsion (naval) reactors and some research and test reactors.

The principle on-site process at PA is the separation of uranium isotopes through gaseous diffusion. The process produces enriched uranium to levels of up to 3% U-235. Most of the enriched product is shipped to the Portsmouth Gaseous Diffusion Plant for further processing.

Waste Information

Processes

During its defense-related operations, recovery of a reactor material resulted in the generation of TRU waste. Although most of the TRU waste has been shipped to ORNL for storage, some wastes remain on site. No additional TRU waste generation is expected at the PGDP.

Modifications/Assumptions/Development

PA reported radionuclides in Ci per kilogram. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the mass and final form volumes reported by PA.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	PA-B015	*Handling:*	CH	*NMVP #:*	N/A	*Stream Name:*	*Transuranic and Technetium Wastes - Liquid*
Local ID:	PA-B015	Type:	MTRU	Generator Site:	PA	Final Waste Form:	Unknown

Inventory Date: 12/31/94

Waste Matrix Code: L1190

AS-GENERATED EPA CODES

D002, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	59.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	212.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Tc-99	3.79E+00
Pu-239	1.66E-01
Np-237	4.56E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum/55-gallon in overpack	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.60	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
SWB used to overpack 55 gallon drums	0.0	0.0	0.0	0.0	1.9	1.9
Totals	0.0	0.0	0.0	0.0	1.9	1.9

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 1.9 Total: 1.9

WASTE STREAM DESCRIPTION	Transuranic and Technitium waste class C Liquid
WASTE STREAM SOURCE	C-400
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: PA-W014	Handling: CH	NMVP #: N/A	Stream Name: Transuranic Waste Liquid		Inventory Date: 12/31/94
Local ID: PA-W014	Type: MTRU	Generator Site: PA	Final Waste Form: Unknown		Waste Matrix Code: L1220

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	212.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum/55-gallon in overpack	0.3	0.0	0.0	0.0	0.0	0.3
Totals	0.30	0.0	0.0	0.0	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
SWB used to overpack	0.0	0.0	0.0	0.0	1.9	1.9
Totals	0.0	0.0	0.0	0.0	1.9	1.9

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 0.0 Projected: 1.9 Total: 1.9

WASTE STREAM DESCRIPTION	Transuranic Waste Basic class C Green Sludge
WASTE STREAM SOURCE	C -400
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

RF Rocky Flats Environmental Technology Site

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DOE/CAO-95-1121
December 1995

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

Location and Description

The Rocky Flats Environmental Technology Site (RFETS) is located in Jefferson County, Colorado, approximately 26 kilometers northwest of downtown Denver, near the suburban communities of Westminster, Boulder, Broomfield, Golden and Arvada, Colorado. It is a 384-acre complex in the center of a 6550-acre reservation.

The facilities at RFETS are divided into two main areas. The area on the north contains all of the facilities related to plutonium operations. Security fences and intrusion-detection systems surround all buildings in which plutonium is handled or stored, and various other measures are used to provide safeguards and security. This area is referred to as the "Protected Area". The area to the south contains both nonplutonium manufacturing facilities, which are located in secure areas, plutonium waste storage facilities, and general support facilities, some of which are in secured areas.

Mission

The original mission of the Rocky Flats Plant (original name for RFETS) was the manufacture of nuclear weapons components fabricated from plutonium, enriched uranium, and conventional metals. It was originally a key weapons material production facility. Plant construction began in March 1951 and operations began in 1952. The Plant used specialized machine shops to process raw nuclear material into the finished components required by the warhead designs. Plutonium and beryllium components were fabricated into the shells of fissionable materials, called pits. A former mission of RFETS was to dissemble the pits from retiring weapons. The recovered pit was chemically processed to remove americium and plutonium. Plutonium scrap recovery was also performed at RF.

In 1989, the Secretary of Energy halted all plutonium production operations at the RFETS in order to improve the conduct of operations, standards of performance, and the management structure. On September 27, 1991, the President of the United States announced his cancellation of several nuclear-weapons programs, leaving the W-88 war head for the Trident II missile as the only remaining system requiring the fabrication of plutonium components at RFETS. This requirement was eliminated in 1992, when the President decided to cancel further production of the Trident II missile and its nuclear warhead.

In response to the President's decisions, the Secretary of Energy proceeded with several initiatives directed at a more cost-effective execution of the defense mission which included revising plans at RFETS for plutonium and nonplutonium manufacturing areas.

RFETS new mission is to clean out and stabilize production process systems, decontaminate obsolete or excess buildings and facilities; stabilize residues in preparation for transport to storage or disposal sites; possibly transfer non-plutonium manufacturing to other locations; maintain a contingency status. Approximately 140 structures at RFETS include major manufacturing, chemical processing, plutonium recovery, and waste treatment facilities. Plant operations also include chemical laboratories, research and development, and support of other DOE facilities.

RFETS has stopped weapons production operations. Future relevant activities will be TRU waste management, including preparation of existing material for geologic disposal, and decontamination and decommissioning.

Waste Information

Processes

Production activities included metal working, fabrication and component assembly, chemical recovery and purification of transuranic nuclides. The plant utilized specialized facilities for recovering nuclear components from obsolete weapons.

Prior to 1960, the main plutonium purification process was dissolution followed by a solvent extraction step that used tributylphosphate as the solvent and dodecane as the diluent. The solvent extraction step was followed by cation exchange. Around 1960, solvent extraction was eliminated from the recovery process because the materials going through the process were becoming more and more varied and could not be adequately handled by the process. The solvent extraction process was replaced by dissolution in the nitric acid followed by ion exchange and peroxide precipitation. The purified plutonium oxide was converted to plutonium fluoride and reduced to plutonium metal using calcium. Other chemical processes, such as molten salt extraction, have also been used at RFETS.

A need to process americium arose because of a personnel exposure problem from its gamma ray emissions. From late 1957 until the late 1970s, americium was recovered and purified at the plant for resale. The demand for americium dropped off in the late 1970s, and the americium was processed as waste.

Depleted uranium operations were a significant part of the original manufacturing performed at the plant. Operations included casting, machining, rolling, and forming. Alloying of depleted uranium with niobium began in 1966, although full-scale production did not occur until the early 1970s. Depleted uranium, which contains less than 0.7% U-235 by mass, is rich in the U-238 radionuclide. The RFETS depleted uranium is assumed to be material type U-12, which is composed of 99.78% U-238, 0.215% U-235, 0.006% U-236, and 0.001% U-234 by mass.

Enriched uranium, containing about 93% U-235 by mass, was processed at the RFETS from 1952 to 1964. This concentration of U-235 is material type U-38, which is composed of 93.08% U-235, 5.65% U-238, 0.93% U-234, and 0.34% U-236 by mass. The enriched uranium manufacturing processes included casting, forming, machining, assembly, recovery, and purification.

The enriched uranium chemical recovery line began operations in 1954. The chemical recovery used a solvent extraction process with dibutylethylcarbutol as the solvent and dodecane as the diluent. This process was similar to the early solvent extraction process used for plutonium recovery. A solvent still was operated at the plant, and some of the distilled solvent was reused. The discarded solvent and oils were drummed and later became part of the organic sludge waste stream. Enriched uranium operations were shut down in 1962.

Some U-233 was processed from the late 1950s to the early 1970s. The U-233 processing included casting, machining, aqueous processing, and separations. Records indicate that the INEL received 56 grams of U-233 as waste from the RFETS in 1967.

All the plutonium operations were carried out in enclosures that are operated under subatmospheric pressure to minimize uncontrolled releases of radioactive material into the operating area. These enclosures are called gloveboxes, and the ventilation systems pass through a high-efficiency particulate air filter system. Leaded rubber gloves are used to protect operations personnel from the gamma activity associated with the plutonium and americium.

The filters from the ventilation systems and the filters used in other systems eventually become waste. The leaded rubber becomes contaminated and also becomes waste. Some of the processes used produce liquid waste streams. These liquid streams are converted to a sludge or solid with adsorbents or cements. contaminated equipment, clothing, tools, etc, end up as radioactive waste. Waste is also generated by decontamination projects and modifications to facilities.

All radioactive waste from the RFETS that was sent to INEL from 1954 to 1970 was buried at the RWMC. Transuranic waste received at INEL from RFETS after October 1970 has been stored aboveground at the Transuranic Storage Area.

Modifications/Assumptions/Development

The approach used and the assumptions made in preparing the RF waste stream profiles are as follows:

- Projection volumes were taken from the Comprehensive Waste Management Plan (CWMP) with the exception of Solid Stabilization (formerly Residue Elimination). The program projection available for Solid Stabilization at the time the CWMP was being drafted was a "not to exceed" volume. The volume and breakdown of final form waste streams used in preparing the TWBIR was an updated, projected volume taken from the Conceptual Design Report for Residue Elimination at Rocky Flats, RES-005-001, May 1994.
- The planned treatment for waste streams requiring treatment to meet WIPP WAC and TRAMPAC requirements are taken from the Draft Site Treatment Plan (DSTP) and the Treatment System Definition Report (TSDR) published by the Waste Compliance Programs.
- In the case where the waste stream or some portion of the waste stream requires treatment to change to the final waste form, the volume of waste resulting from the treatment of the original waste stream is included in the final waste form volume of the resulting waste stream. For example, the volume of waste resulting from treatment of Incinerator Ash is included in the final waste form volumes of the resulting waste stream, Solidified Process Solids.
- Volume increases due to repackaging waste that exceed the current decay heat limit when no other treatment is required were not included.
- To remain consistent with the volumes reported in the other RFETS publications, 0.21 m^3 was used as the container volume of a standard DOT-17C 55-gallon drum. The volume used for other containers was as specified on the data forms.
- Waste in boxes other than standard waste boxes (SWB) are assumed to be repackaged into SWBs, such that the waste from one 4'x4'x7' box is repacked into two SWBs. Therefore, the final waste form volumes for SWBs include the projected volume increase resulting from such repackaging activities.

- The values for the Typical Waste Material Weights for Final Waste Form data for the TRU waste streams are the same as the corresponding TRU mixed waste streams.
- The waste generation rates for each waste form were prorated based on the fraction represented by the waste form on a Waste and Environmental Management System (WEMS) generation report showing actual generation.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W092	Handling: CH	NMVP #: N/A	Stream Name: PCB Solids-Compatibles/TRM			Inventory Date:	10/20/94
Local ID: 0831	Type: MTRU	Generator Site: RF	Final Waste Form: Inorganic Non-Metal			Waste Matrix Code:	S5330

AS-GENERATED EPA CODES

F005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	Yes
Source:	Spill Clean-ups/Emergency Response Actions

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.83	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These dry combustibles are likely personal protective equipment (PPE), wipes, and rags from cleanup operations.
WASTE STREAM SOURCE	IDC 831 PCB solids were generated in Building 771 in 1988. These dry combustibles are likely personal protective equipment (PPE), wipes, and rags from cleanup operations.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	These containers were assigned EPA codes F001, F002, and F005 by the generator based on process knowledge.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

M

RL Hanford (Richland) Site

M

DOE/CAO-95-1121
December 1995

HANFORD SITE

Location and Description

The Hanford Site (RL) is located north of the Tri Cities, Washington (Richland, Kennewick, and Pasco), on a 1450 square kilometer area of semiarid land within the Columbia River Basin in the southeastern corner of Washington State. Normal Columbia River elevations range from 119 meters, where the Columbia River enters RL near the Priest Rapids Dam, to 104 meters where it leaves the RL near the 300 area.

Activities at RL are centralized in numerically designated areas. The reactor facilities are located along the Columbia River in what is known as the 100-Area. The reactor fuel processing and waste management facilities are in the 200-Area. The 300-Area, located adjacent to, and north of, Richland, contains the reactor fuel manufacturing facilities and the research and development laboratories. The 400-Area, five miles northwest of the 300-Area, contains the Fast Flux Test Facility, a sodium-cooled fast breeder reactor. The 600-Area covers all locations not specifically given an area designation. Adjacent to, and north of, Richland, the 1100-Area contains facilities associated with administration, maintenance, transportation, and materials procurement and distribution. The 3000-Area, contains engineering and administrative offices. Administrative buildings, including the Federal Building, are located in the 700-Area, which is in downtown Richland.

RL is administered by the DOE Richland Operations Office. The current Management and Operating Contractor is Westinghouse Hanford Company.

Mission

The Hanford Site was acquired by the Federal Government in 1943 for the construction and operation of facilities to produce plutonium for the atomic weapons program during World War II. For more than 30 years, Hanford Site facilities were primarily dedicated to the production of plutonium for national defense and management of the wastes generated by chemical processing operations. In later years, programs at the Hanford Site became increasingly diverse, involving research and development for advanced reactors, renewable energy technologies, waste disposal technologies, and cleanup of contamination from past practices. The DOE has ended the production mission at the Hanford Site and is currently reorienting activities toward management of its wastes cleanup of the site. The mission now is one of environmental management, demonstration and application of advanced remediation technologies, and restoration of the Hanford Site.

During the wartime Manhattan Project, the town of Richland, Washington, was wholly-owned and controlled by the Government.

Waste Information

Processes

Retrievably stored, CH TRU waste has been received from 55 generating areas, buildings, and offsite facilities.

The Plutonium Finishing Plant (PFP) (Z Plant) is one of Hanford's waste generators and is the major source of CH TRU solid waste by volume (approximately 53.6%) The PFP where the Pu Reclamation Facility, Pu conversion, product handling, decontamination and decommissioning, analytical and chemical technology laboratories are located. Waste common to all of these are: surgical gloves, paper, glass, glovebox gloves, metal tools and equipment. ·d HEPA filters.

At the Pu Reclamation Facility, Pu was reclaimed from scrap solutions and solids. The scrap was treated in various ways to produce soluble and/or leachable forms of Pu for recovery. Waste generated included acid-soaked rags, liquid organics, and sludges.

Pu Conversion takes place at the Remote Mechanical C Line (RMC Line) where the Pu conversion processes received Pu nitrate as feed and converted it to either Pu oxide or metal. Waste generated included sludges, hydraulic oils, and acid-soaked rags.

Product handling includes receipt, shipment, repackaging, and nondestructive assay of special nuclear materials. Waste generated included damp rags, leather gloves, and empty metal cans used for shipping.

Decontamination and Decommissioning removed selected PFP facilities such as process gloveboxes and associated systems, ventilation systems, vacuum systems, and drain systems and dispose of them. Waste generated included damp rags, and building rubble (e.g., concrete, steel, wool, etc.).

Analytical and Chemical Technology Laboratories provide laboratory services to other PFP operations. Waste generated here included liquid organics, sludges, damp rags, and empty metal cans for shipping.

Another waste generator at Hanford was the Plutonium Uranium Extraction (PUREX) Plant. Products from this plant were weapons-grade plutonium, fuel-grade plutonium, depleted uranium, slightly enriched uranium, neptunium, and thorium. The plutonium conversion, process solution sampling, laboratory analyses, plant ventilation, and facility ventilation generated waste that was common to all these PUREX operations including surgical gloves, plastic (polyvinyl chloride and polyethylene), tape, paper, glass, glovebox gloves, and metal tools and equipment.

The overall PUREX Plant process consisted of seven fundamental interfacing processing units: feed preparation; solvent extraction, separation, and purification;
solvent recovery and treatment for recycling; backcycle waste system; acid recovery; waste treatment; offgas treatment; and conversion of plutonium nitrate to plutonium oxide.

Pu conversion operations received Pu nitrate as feed and converted the Pu to Pu oxide. Wastes generated were old and failed equipment, port covers, replaced windows, brackets and hardware, and acid-soaked rags.

Process solution sampling operations extract liquid samples from process control points to be used in system analysis and control. After use, all liquids are drained to the PUREX liquid waste system. Waste generated at this facility included broken glassware and plasticware, wet rags and paper, and piping and valving equipment.

Laboratory Analysis Operations were performed on liquid process samples used for system analysis and control. After use, all liquids were drained to the PUREX liquid waste system. Waste generated were broken glassware and plasticware, and wet rags and paper.

During Plant ventilation operations, air from contaminated areas was exhausted through HEPA filters to remove airborne contamination. TRU waste generated during these operations include contaminated HEPA filters. All HEPA filters are packaged as uncertified waste as there is no current technology available at PUREX to determine which HEPA filters meet the WIPP Waste Acceptance Criteria.

Facility Modification Operations were performed to improve overall plant performance. Modifications included the disposal of outdated and damaged equipment. Waste generated included tanks, process equipment and gloveboxes, and building materials.

Modifications/Assumptions/Development

New radionuclide data were submitted two days prior to going to print. The data were not reviewed by the technical team.

APPROACH

The approach used in preparing the RL waste stream profiles is as follows:

- Waste is divided between "past practice waste" (1970 through 1986) and currently-generated waste (1987 through 2028). Currently-generated waste includes projected waste generation.
- Past practice waste is grouped by generators, whereas currently-generated waste is grouped by waste matrix. The reasons for grouping the data in this manner are as follows: 1) the interim storage practice was changed from below ground surface (trenches) to above surface (storage buildings) in the 1986/1987 time period; 2) the By-Product Rule was issued by DOE on May 1, 1987, which compelled the hazardous components of TRU waste to be regulated by EPA under RCRA; 3) more detailed matrix information per container has been collected from the generator since 1987, and stored in the site's record waste tracking system; and 4) starting approximately 1986, waste generators began packaging the waste in accordance with the WIPP Waste Acceptance Criteria, thus reducing the need for additional waste processing prior to shipping to WIPP.
- Currently-generated waste streams were identified by reviewing each container record in the site's solid waste tracking system. Groups of containers that have similar physical characteristics and chemical contaminants (mixed only) were placed into a treatability group waste stream. The waste was then separated into drums, boxes, and RH canisters.

ASSUMPTIONS

The following assumptions were made by the site in repackaging the waste into the final waste form:

1. General

   A. A portion of the thermocouple assemblies, transfer pumps, mixing pumps, and other equipment in the single-shell and double-shell tanks will be removed, size-reduced, decontaminated, and assayed. Assay information will be used to designate the waste packages as low-level waste or TRU waste. The projection is that 10% of the equipment will be designated as RH-TRU, mixed waste and 90% will be designated as remote-handled, low level mixed waste. (WHC-EP 0768, Solid Waste 30-Year Volume Summary, p. 4-6, Table 4-1)

   B. TRU waste forecast volume data has been provided from the following off-site waste generators: AL, AE, BCL, LB, LL, and Santa Susana Field Laboratory (Rockwell, Canoga Park). The assumption is that TRU waste from these off-site waste generators will be received at RL for treatment in the Waste Receiving and Processing Facility (WRAP) and shipment to WIPP. (WHC-EP-0768, Solid Waste 30-Year Volume Summary)

   C. PUREX transition activities will generate 117 m^3 of CH-TRU and mixed TRU waste. The PUREX facility is currently undergoing transition activities towards decontamination and decommissioning. The facility transition activities at PUREX will provide a model for the subsequent transition of other canyon-type facilities in the future. Waste generation estimates from PUREX and other canyon type facilities have been included in the forecast. (WHC-EP-0768, Solid Waste 30-Year Volume Summary)

   D. Approximately 140 m^3 of spent research reactor fuel stored in trenches with the TRU waste is managed as TRU waste. Future evaluations may determine that this waste should be managed by the National Spent Fuel Program. (WHC-SD-SNF-TI-001, Revision 0)

2. Retrieval of Stored TRU Waste

   A. Stored TRU waste consists of existing TRU waste generated since May 1970 through December 1993. This waste does not include waste, originally designated as TRU waste, that has been assayed and redesignated as low-level waste during the calendar years (CY) 1986 to 1993.

   B. CH-TRU Waste

      - Of the TRU waste stored from May 1970 to December 1985 that has not been assayed and redesignated as low-level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. (WHC-EP-0225, Revision 1, Table 4-26)

- Waste is drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging the waste will result in a 35% increase in the volume of TRU-certified waste in drums. (WHC-SD-W026-SDRD-001, Revision 3)

- Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected.

- The site's solid waste tracking system does not distinguish between specific types of metals. If lead is present, then "other metals" is assumed to represent 100% of the metals in the container. Otherwise, iron-based metals is assumed to be 80% and aluminum-based metal is assumed to be 20% of the metal (reference: WHC-EP-225 Rev 1, TRU Waste Characterization Based on Current Records).

C. RH-TRU Waste

- No volume reduction is projected due to size reduction for transport in RH canisters.

3. Newly-generated TRU waste

A. This waste will be generated during the fiscal years 1994 through 2013.

B. CH-TRU Waste

- One hundred percent of the waste in drums will be managed as TRU waste with 10% considered noncertifiable and requiring treatment.

- All boxed waste (except waste in SWBs) will require size reduction in the WRAP facility.

C. RH-TRU Waste

- Newly-generated RH-TRU waste will be stored in shielded drums pending repackaging in RH-canisters in the WRAP facility.

- RH-TRU waste retrieved from the 618-11 burial ground will include some soil surrounding breached containers. It is assumed that this soil will increase the waste volume to be retrieved by 25%. No volume reduction is projected for treatment in the WRAP facility.

- A portion of the single-shell and double-shell tank equipment will be size-reduced and decontaminated, assayed, and shipped to WIPP as RH-TRU waste. The assumption is the 90% of the equipment will be classified as remote-handled, low level mixed waste and 10% will be RH-TRU, mixed waste.

- Most of the waste generated between 1987 and 1993 is debris waste. As such, projected RH-TRU waste is assumed to be debris waste.

- The mixed waste contaminants and radionuclide composition of projected RH-TRU waste are unknown.

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Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W284	Handling:	CH	NMVP #:	N/A	Stream Name:	201C Unk form CH RCRA MTRU w/ met
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Unknown

Inventory Date: 12/1/94

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

D010, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	41.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	3.1	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	17.2	0.0	0.0
Rubber:	4.5	0.0	0.0
Plastics:	30.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	2.47E+00
Pu-241	8.00E-02
Pu-240	0.00E+00
Pu-239	1.00E-02
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.42	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, PAPER/CARDBOARD, RUBBER, LEAD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is unknown waste form contact handled RCRA regulated mixed TRU waste with metal contaminants from the Demolition of the Semi-works facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W327	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RC/TS MTRU w/ met(Hg)
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	198.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	21.7	0.0	0.0
Other Inorganic Material:	16.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.3	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	15.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	Yes
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	66.6	79.9	133.2	106.6	66.6	452.9
Totals	66.61	79.9	133.2	106.6	66.6	452.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	66.2	22.7	37.8	30.2	18.9	175.8
Totals	66.2	22.7	37.8	30.2	18.9	175.8

As-Generated Form: Stored: 66.6 Projected: 386.3 Total: 452.9

Final Waste Form: Stored: 66.2 Projected: 109.6 Total: 175.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, LEAD, CONCRETE, GLASS, CLOTH/RAGS/NYLON, OILS, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA/TSCA (PCB) reg. mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W328	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Pb/Cd debris CH RC/TS MTRU w/ met(Hg)		Inventory Date: 12/1/94
Local ID:	Type: MTRU	Generator Site: RL	Final Waste Form: Lead/Cadmium Metal Waste		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	58.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	228.2	0.0	0.0
Other Inorganic Material:	2.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	38.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	Yes
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	3.2	0.0	0.0	0.0	0.0	3.2
Totals	3.17	0.0	0.0	0.0	0.0	3.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	3.8	0.0	0.0	0.0	0.0	3.8
Totals	3.8	0.0	0.0	0.0	0.0	3.8

As-Generated Form: Stored: 3.2 Projected: 0.0 Total: 3.2

Final Waste Form: Stored: 3.8 Projected: 0.0 Total: 3.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, LEAD, METAL/IRON/GALVANIZED/SHEET, GLASS.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA/TSCA (PCB) reg. mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W329	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Solidif org CH RC/TS MTRU w/ ign
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics

Inventory Date: 12/1/94

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	84.2	0.0	0.0
Rubber:	4.7	0.0	0.0
Plastics:	71.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	Yes
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.7	2.1	2.5	2.1	10.5
Totals	2.10	1.7	2.1	2.5	2.1	10.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.7	2.1	2.5	2.1	10.4
Totals	2.1	1.7	2.1	2.5	2.1	10.4

As-Generated Form: Stored: 2.1 Projected: 8.4 Total: 10.5

Final Waste Form: Stored: 2.1 Projected: 8.3 Total: 10.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, ORGANICS, CLOTH/RAGS/NYLON, RUBBER, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA/TSCA (PCB) reg. mixed TRU waste with ignitable contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W332	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Unk form CH St MTRU
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Unknown

Inventory Date: 12/1/94

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.23	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This stream is unknown waste form contact handled State regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

M

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W333	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Solidif org debris CH TSCA MTRU
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	56.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.8	0.0	0.0
Rubber:	1.3	0.0	0.0
Plastics:	61.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	29.8	0.0	0.0
Packaging Material Steel:	1.6		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: Yes

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	4.00E-02

M

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.3	1.0	1.0	0.4	0.0	3.8
Totals	1.26	1.0	1.0	0.4	0.0	3.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	1.0	1.0	0.4	0.0	3.7
Totals	1.2	1.0	1.0	0.4	0.0	3.7

As-Generated Form: Stored: 1.3 Projected: 2.5 Total: 3.8

Final Waste Form: Stored: 1.2 Projected: 2.5 Total: 3.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, CONWEB PADS, OILS, CLOTH/RAGS/NYLON, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, PCB.
WASTE STREAM SOURCE	This stream is solidified organics contact handled TSCA (PCB) regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

M

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W334	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Uncat mt debris CH TSCA MTRU		Inventory Date: 12/1/94
Local ID:	Type: MTRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	261 9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0 0	0 0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	76 2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0 0	0.0	0.0
Packaging Material Steel:	9.5		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	Yes
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.21	0 0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, CONWEB PADS, DIRT/SOIL/DIATOMACEOUS EARTH.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled TSCA (PCB) regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W357	Handling:	CH	NMVP #:	N/A	Stream Name:	KAPL Unk form CH/r TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Unknown

Inventory Date: 12/1/94

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	7.81E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.21	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CHEMICALS.
WASTE STREAM SOURCE	This stream is unknown waste form contact handled packaged remote non-mixed TRU waste from the Knolls Atomic Power Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W366 | Handling: CH | NMVP #: N/A | Stream Name: 202A Unk form CH TRU | Inventory Date: 12/1/94

Local ID: | Type: TRU | Generator Site: RL | Final Waste Form: Unknown | Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.8	0.0	0.0	0.0	2.3
Totals	1.47	0.8	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.8	0.0	0.0	0.0	2.3
Totals	1.5	0.8	0.0	0.0	0.0	2.3

As-Generated Form: Stored: 1.5 Projected: 0.8 Total: 2.3

Final Waste Form: Stored: 1.5 Projected: 0.8 Total: 2.3

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS MISCELLANEOUS/UNKNOWN/OTHER.
WASTE STREAM SOURCE	This stream is unknown waste form contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W382	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Unk form CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Unknown

Inventory Date: 12/1/94

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	18.7	11.9	16.7	18.3	14.6	80.2
Totals	18.74	11.9	16.7	18.3	14.6	80.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	18.7	11.9	16.6	18.3	14.6	80.1
Totals	18.7	11.9	16.6	18.3	14.6	80.1

As-Generated Form: Stored: 18.7 Projected: 61.4 Total: 80.2

Final Waste Form: Stored: 18.7 Projected: 61.4 Total: 80.1

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS MISCELLANEOUS/UNKNOWN/OTHER.
WASTE STREAM SOURCE	This stream is unknown waste form contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W391	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Comb unk form CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Unknown

Inventory Date: 12/1/94

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	76.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	120.1	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.42	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ORGANICS, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-Z001	Handling:	U	NMVP #:	N/A	Stream Name:	Hanford Buried TRU Waste
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Unknown

Inventory Date:

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues:

Asbestos:

PCBs:

Source:

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

M

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Not contained	63629.0	0.0	0.0	0.0	0.0	63629.0
Totals	63629.00	0.0	0.0	0.0	0.0	63629.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 63629.0 Projected: 0.0 Total: 63629.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION N/A

WASTE STREAM SOURCE A total of approximately 63,629 m3 of TRU-contaminated waste is buried at the Hanford Site. It is anticipated that upon retrieval of this waste, a significant amount of the soil will become contaminated and will thereby increase the volume of waste. The estimated waste and associated contaminated soil volume is 109,000 m3. As of December 31, 1993, the decayed radioactivity from the TRU radionuclides associated with this volume of buried waste is estimated to be 93,800 Curies and the total decayed radioactivity from all radionuclides is estimated to be 173,410 Curies. This waste will not go to WIPP.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

SA Sandia National Laboratories/New Mexico

SANDIA NATIONAL LABORATORIES

Location and Description

Sandia National Laboratories/New Mexico (SNL/NM) is located immediately southeast of Albuquerque, New Mexico, on Kirtland Air Force Base. The SNL/NM consists not only of the headquarters facilities in Albuquerque, New Mexico, but also the laboratory facility in Livermore, California, the Tonopah Test Range in Nevada, and occupies about 7,600 acres (not including Tonopah Test Range).

Prior to the Trinity shot in 1945, the Manhattan project had a small facility on Sandia Base (now Kirtland AFB) to perform ordnance engineering, nonnuclear atomic bomb assembly and military training. In March 1948, the Sandia Laboratory was established as a formal branch of the Los Alamos Scientific Laboratory (LASL) now LA. In 1949, Sandia Corporation was organized as a wholly-owned subsidiary of the Western Electric Company, and approximately 1,700 LASL employees were transferred. In 1984, Sandia Corporation became a wholly-owned subsidiary of the AT&T Technologies Corporation.

SNL/NM is administered by the DOE/Albuquerque Operations Office and is currently operated by the Lockheed Martin Corporation.

Mission

SNL/NM's mission was research, development, and engineering of nuclear weapons systems except for the nuclear explosive. This included nuclear weapons systems ordnance engineering, nonnuclear component design and development, field and laboratory testing, and manufacturing engineering.

SNL/NM has operated the Tonopah Test Range near Tonopah, Nevada, since the range was established in 1957. The site is located about 322 kilometers northwest of Las Vegas, Nevada, on 1360 squire kilometers of land provided by the Air Force in accordance with a use permit. Tonopah Test Range is a major facility for the field testing of nonnuclear and denuclearized weapons, research rockets, and artillery. Aerodynamic stability, the compatibility of various ballistic shapes, trajectories, times of fall, accuracy of delivery, and functioning of fuzing components are tested under conditions simulating actual use. Certain types of high explosive ordnance are also tested at the test range.

Waste Information

Processes

One of SNL/NM's generators is the Inhalation Toxicology Research Institute (IT). Since 1960, ITRI has performed a variety of research programs for the DOE. The original research was dedicated to the evaluation of health effects caused by inhalation of fission products. Research is now conducted on the health effects of transuranic elements such as plutonium, americium, curium, and nonradioactive airborne materials in various environments.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: SA-Z001	Handling: U	NMVP #: N/A	Stream Name: Sandia National Laboratory/NM Buried TRU Waste		Inventory Date:
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Unknown		Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

		TRUCON CODE	FINAL FORM RADIONUCLIDES
Category:	Defense TRU Waste	N/A	N/A
Residues:			
Asbestos:			
PCBs:			
Source:			

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Not contained	1.3	0.0	0.0	0.0	0.0	1.3
Totals	1.33	0.0	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	A total of approximately 1.33 m3 of TRU-contaminated waste is buried at the Sandia National Laboratory/New Mexico site. Radioactivity information is not available. This waste will not go to WIPP.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

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SAVANNAH RIVER SITE

Location and Description

The Savannah River Site (SRS) is located about 31 kilometers southeast of Aiken, South Carolina, on 198,334 acres (803 square kilometers) along the Savannah River. The SRS encompasses parts of three counties, Aiken, Barnwell, and Allendale in western South Carolina. The closest major cities are Aiken, South Carolina, and Augusta, Georgia. The site is a controlled area with limited public access. The facilities occupy less than 8 percent of the site. The remaining 92 percent is divided into forest (80%) and wetlands (20%).

The Savannah River Site is a government owned, contractor operated (GOCO) site that is managed by the DOE Savannah River Operations Office. The current Management and Operating Contractor for the Site is Westinghouse Savannah River Company.

Mission

The primary mission of the SRS has been to support national security as a major source of reactor-produced materials, primarily tritium, plutonium, heavy water (deuterium) and other special nuclear materials for weapons manufacturing. The mission was broadened over the years to include the production of other isotopes, such as Pu-238. SRS's production activities also included the loading of tritium containers for the nuclear weapons, reclamation of tritium containers and the purification of tritium recovered from retired weapons.

The decision in 1950 to go ahead with the Savannah River Plant was driven by the perceived need for tritium in the fusion weapon program following President Truman's directive of January 31, 1950, to develop a thermonuclear weapon (the "super"). While production of tritium in the Hanford reactor had been demonstrated, the new plant at Savannah River was necessary to avoid serious curtailment in the production of plutonium at Hanford for the fission program. If thermonuclear weapons proved unfeasible or tritium requirements turned out to be less than anticipated, the construction of Savannah River was further justified in order to increase plutonium production, to provide a higher efficiency in the use of uranium ore, to provide security against attack of the Hanford reactors, and to provide replacement reactors in the event of the retirement of older Hanford reactors.

Five reactors (currently shut down), two chemical processing plants, a tritium extraction, purification, and loading facility, and a high-level waste solidification facility comprise the major elements of the Defense Program operations and facilities at SRS.

The SRS waste management mission is to comply with applicable federal and state regulations, DOE Orders, and the Management and Operating Contractor policies, to minimize effects on the environment and the generation of new waste, and to the extent possible, contain waste handling, treatment, storage, and disposal within the site. Other mission objectives include the demonstration and application of remediation technologies and the environmental restoration of the SRS site. With the changing defense posture, environmental restoration is receiving increased emphasis versus weapons materials production.

Waste Information

Processes

At SRS, production of useful radioactive isotopes is accompanied by production of radioactive waste. These wastes must be safely contained and stored until the risk associated with their radioactivity is eliminated by decay or the waste is permanently disposed. In both production and power nuclear reactors, neutrons strike uranium-235 atoms in the reactor fuel, add energy and cause the atoms to become unstable and split apart or "fission." This results in the production of fission products and more neutrons, initiating a sustained chain reaction and a steady supply of neutrons. In addition to fuel, the SRS reactors contained long cylinders of material called targets. When neutrons strike the targets, useful radionuclides are created through transmutation. The fuel and target assemblies are then removed from the reactor and, after a suitable cooling period, are sent to the chemical separation areas for processing to recover the desired radionuclides (uranium, plutonium, tritium, etc).

Currently, TRU waste at SRS is generated primarily from radiochemical separations processes, analytical laboratories, and research and development activities. Primary contaminants in the waste are Pu-238 and Pu-239. The major on-site facilities that generate TRU waste are the FB-Line, the HB Line, 235-F, 772-F, and 773-A.

FB-Line and HB-Line generate TRU waste containing plutonium and neptunium. The waste is generated during the use of gloveboxes, contamination control huts, and decontamination processes waste. TRU waste is placed in 5-gallon cans, assayed, sealed in a drum liner, and placed in 55-gallon drums before transport to the waste TRU storage facility.

In the HB Separation Line, uranium, neptunium (Np) and plutonium (Pu) are recovered from irradiated enriched uranium fuels and transferred to the HB line for processing. The HB line uses three independent facilities to process Np, Pu, and recoverable scrap. TRU waste, containing Pu-238, is generated during decontamination operations, replacement of equipment, maintenance, inspection, and sampling.

In the FB Separation Line, irradiated metal alloys from the reactors are dissolved and separated into uranium, Pu metal, and high-level liquid waste using the Purex process. Uranium and plutonium are recovered and TRU waste, containing Pu-239 is generated during decontamination operations, maintenance, inspection, replacement of equipment, sampling and laboratory analysis.

The 235-F facility generates TRU waste from three waste streams, the Actinide Billet Line, the Plutonium Experimental Facility, and Plutonium Fuel Fabrication. The three streams yield neptunium and plutonium isotopes. Waste materials consist of lead-lined gloves, neoprene gloves, process waste, equipment, and filters.

The 772-F TRU waste generated in the Central Laboratory Facility results from the handling and analysis of various plutonium and neptunium samples. The routine laboratory TRU solid waste consists of paper, plastic, glass, metal, lead-lined gloves, HEPA filters, and IX resins.

The 773-A, the Savannah River Technology Center (SRTC) Solid Waste Assay Facility (SWAF) receives boxes of waste from other laboratories within the SRTC complex. The SWAF processes includes x-raying, weighing, and assaying the boxes. After processing, the waste boxes are placed in drums before shipping to the site waste disposal facility.

Solid TRU waste, such as processing equipment, glassware, and gloveboxes too large for 55-gallon drums are packaged and stored in large steel or concrete containers. The separation areas produce most of the solid TRU waste.

Off-site generators that have sent TRU waste to SRS are Los Alamos National Laboratory, Mound Laboratory, Allied-General Nuclear Services, National Institute of Standards Technology, General Sciences, Department of Defense, and Knolls Atomic Power Laboratory.

Modifications/Assumptions/Development

Savannah River's Vitrified waste stream Waste Material Parameters were recalculated by the TWBIR team to provide closure approximations to the 1000 lbs per 55 gallon drum weight limits required by the TRUPACT-II Safety Analysis Report for Packaging (SARP). In recalculating these parameters the volumes and number of final form containers were increased. This increase may hinder SRS's cost effectiveness for shipment to WIPP.

The composition of SRS final waste forms was determined using acceptable knowledge (Processing knowledge) and existing waste form research work performed by Savannah River Technical Center (SRTC).

A combination of waste descriptions, waste codes, and acceptable knowledge were used to determine the general waste types stored at SRS. This includes only the waste types affecting the final waste forms.

Waste stream volumes for SR-T001, SR-W006, SR-W026, SR-W027, and SR-W053 were separated and reported by generator and waste types.

Waste, which is classified because of shape, was identified and reported separately by SRS. The shape of this waste is expected to be destroyed during waste processing. Other classified waste was not reported by SRS because of the contents of the waste.

Waste volumes and number of containers to be shipped to WIPP were based on the type of disposal container used, the size reduction factors after waste processing, and the volume of waste to be processed. The volume of waste to be processed was based on TRU waste volumes as of 12/31/94 and waste forecasts contained in the Proposed Site Treatment Plan (PSTP) and the Waste Management Environment Impact Statement (WMEIS). These forecasts include TRU waste from operational, D&D, and ER activities.

Most of SRS's metal waste is currently packaged in large steel boxes. The waste in these steel boxes is (assumed by the site to be) 80% bulk metal and 20% heterogeneous debris. The size reduction factor for large metal components is 3.5 to 1.

No volume reduction is expected from the repackaging of heterogeneous waste streams.

The preferred technology for treating SRS TRU waste is solidification by vitrification (i.e., Hybrid Plasma Treatment). The process design provides sufficient mixing controls to ensure WIPP WAC compliance. The assumed volume reduction factor using this technology is 30 to 1. This factor applies to waste streams SR-W026, SR-W027, SR- T001, SR-T003. SR-W053, and SR-W006.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: SR-Z001	Handling: U	NMVP #: N/A	Stream Name: Savannah River Buried TRU Waste		Inventory Date:
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Unknown		Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

		TRUCON CODE	FINAL FORM RADIONUCLIDES
Category:	Defense TRU Waste	N/A	N/A
Residues:			
Asbestos:			
PCBs:			
Source:			

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Not contained	4874.0	0.0	0.0	0.0	0.0	4874.0
Totals	4874.00	0.0	0.0	0.0	0.0	4874.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4874.0 Projected: 0.0 Total: 4874.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	A total of approximately 4,874 m3 of TRU-contaminated waste is buried at the Savannah River Site. This volume of waste was buried at the site from 1952 through 1974. As of December 31, 1993, the decayed radioactivity from the TRU radionuclides associated with this volume of buried waste is estimated to be 30,500 Curies. Information on non-TRU radionuclides is not available. This waste will not go to WIPP.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

WV West Valley Demonstration Project

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WEST VALLEY DEMONSTRATION PROJECT

Location and Description

The West Valley Demonstration Project (WV) is located at the site of the only commercial nuclear fuel reprocessing plant to have operated in the United States. WV facilities occupy approximately 0.8 km^2 of the 13.5 km^2 Western New York Nuclear Services Center (WNYNSC) in West Valley, New York. The site includes the only commercial nuclear reprocessing plant operated from 1966 to 1972 under a long-term lease from the New York State Energy Research and Development Authority (NYSERDA). In 1976, the plant operator notified NYSERDA of its intention to cease operations.

In 1980, the West Valley Demonstration Project Act (Act) authorized DOE to conduct a high-level radioactive waste (HLW) management demonstration project at the WNYNSC. WV was established to demonstrate that liquid waste from the reprocessing of spent nuclear fuel can be managed safely in the United States. DOE, with its contractor West Valley Nuclear Services, Inc., assumed operational control of the site in 1982. WV is jointly funded by DOE and NYSERDA. Upon completion of the project, DOE will leave the premises.

Mission

The primary mission at WV is to pretreat, remove, solidify, and temporarily store HLW. The following activities comprise the project: 1) solidify the liquid HLW; 2) develop containers suitable for permanent disposal of solidified HLW; 3) transport solidified waste to a Federal repository; 4) dispose of low-level and TRU waste generated during the solidification process; and 5) decontaminate and decommission facilities used in HLW treatment.

Waste Information

Processes

The only operations waste at WV is that associated with preparations for the solidification of HLW. Mixed TRU waste stream sources are routine laboratory analyses performed in conjunction with the treatment of HLW, and the maintenance and repair of facilities and equipment.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

No RH-TRU Canisters currently exist at WV. The assumption is that all RH-TRU currently stored waste will be repackaged into an RH Canister at a later date.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-M005	Handling: RH	NMVP #: N/A	Stream Name: TRU Filters		Inventory Date:
Local ID: N/A	Type: TRU	Generator Site:	Final Waste Form: Filter		Waste Matrix Code: S5410

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	351.2		
Packaging Material Plastic:	0.4		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
60 cubic ft. lead shielded box	23.8	30.6	32.3	0.0	0.0	86.7
70 cubic ft. Type A waste box	19.8	13.9	15.8	0.0	0.0	49.5
90 cubic ft. waste box	5.0	0.0	0.0	0.0	0.0	5.0
Totals	48.6	44.5	48.1	0.0	0.0	141.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	49.0	0.0	17.8	0.0	0.0	66.8
Standard Waste Box	0.0	13.2	15.1	0.0	0.0	28.3
Totals	49.0	13.2	32.9	0.0	0.0	95.1

As-Generated Form: Stored: 48.6 Projected: 92.6 Total: 141.2

Final Waste Form: Stored: 49.0 Projected: 46.1 Total: 95.1

WASTE STREAM DESCRIPTION	This waste stream consists of filters generated from normal site operations. The specific contents include pre-filters, High Efficiency Particulate Air (HEPA) filters, and roughing filters.
WASTE STREAM SOURCE	Filters generated from changeout of various ventillation systems roughing and HEPA filters from normal site operations.
CURRENT CONTAINER COMMENTS	The lead shielding is integral with the box and does not come in contact with the waste
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	WVNS container ID numbers: 12-1513, 12-1514, TC-036, TC-042, TC-045, TC-073, TC-076, TC-086, TC-089, 1994: TC-001, TC-043, TC-117, TC-132, TC-134, TC-137, TC-139, TC-140, TC-141, TC-148, TC-152, TC-153, TC-154, TC-155, TC-156, TC-157, TC-159
ACCEPTANCE COMMENTS	None
FINAL FORM COMMENTS	No RH-TRU canisters currently exist at WV. The assumption is that all RH-TRU currently stored waste will be repackaged into RH-TRU canisters at a later date.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	WV-M007	Handling:	CH	NMVP #:	N/A	Stream Name:	TRU General Waste
Local ID:	N/A	Type:	MTRU	Generator Site:		Final Waste Form:	Unknown

Inventory Date: 12/31/94

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

unknown

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	10.1	0.0	0.0	0.0	0.0	10.1
Totals	10.1	0.0	0.0	0.0	0.0	10.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.0	0.0	0.0	0.0	0.0	10.0
Totals	10.0	0.0	0.0	0.0	0.0	10.0

As-Generated Form: Stored: 10.1 Projected: 0.0 Total: 10.1

Final Waste Form: Stored: 10.0 Projected: 0.0 Total: 10.0

WASTE STREAM DESCRIPTION	This waste stream consists of uncharacterized (i.e., requires hazardous characterization) general site waste generated from normal site operations. The specific contents of this waste stream are unknown.
WASTE STREAM SOURCE	General site waste requiring hazardous characterization generated from normal site operations.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Further sampling and analysis required to determine the contents of these containers, and if RCRA contaminants are present.
MANAGEMENT COMMENTS	WVNS Container ID #s for this waste stream are: 5046, 5047, 5069, 5099, 5153, 5253, 5263, 5304, 5321, 5334, 5348, 5382, 5563, 5856, 6310, TD-008, TD-017, TD-028, TD-034, TD-035, TD-036, TD-040, TD-043, TD-184, TD-240, TD-268, TD-271, TD-294, TD-304, TD-308, TD-367, TD-387, TD-389, TD-399, TD-402, TD-407, TD-546, TD-554, TD-581, TD-596, TD-606, TD-607, TD-622, TD-629, TD-634, TD-924, TD-926, TD-931.
ACCEPTANCE COMMENTS	None
FINAL FORM COMMENTS	Some volume reduction may be performed on reduce the number of shipping containers required

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Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-M008	Handling: CH	NMVP #: N/A	Stream Name: TRU Concrete		Inventory Date: 12/31/94
Local ID: N/A	Type: TRU	Generator Site:	Final Waste Form: Solidified Inorganics		Waste Matrix Code: S3150

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	1.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

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WASTE STREAM DESCRIPTION	This waste stream consists of samples solidified with cement generated from the on-site A&PC laboratory.
WASTE STREAM SOURCE	Concrete samples generated from the on-site Analytical & Process Chemistry (A&PC) laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	WVNS TD-076
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	N/A

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Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	WV-M010	Handling:	CH	NMVP #:	N/A	Stream Name:	TRU Spent Absorbents
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Solidified Inorganics

Inventory Date: 12/31/94

Waste Matrix Code: S3190

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	This waste stream consists of spent absorbents generated from site operations. The media absorbed is not known for this waste stream.
WASTE STREAM SOURCE	Spent absorbents generated from site operations.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	WVNS TD-707, WVNS TD-713
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	WV-M012	Handling:	CH	NMVP #:	N/A	Stream Name:	Glove Boxes
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Uncategorized Metal

Inventory Date: 12/31/94

Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste stream consists of a glove box and general waste generated from the laboratory on-site as a result of previous decommissioning and decontamination activities and normal site operations.
WASTE STREAM SOURCE	Glove boxes and general waste generated from previous decomissioning and decontamination activities and normal site operations.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	This waste stream is not considered mixed waste
MANAGEMENT COMMENTS	WVNS TD-551
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	N/A

M

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-M013	Handling: CH	NMVP #: N/A	Stream Name: Sweeping Compound		Inventory Date: 12/31/94
Local ID:	Type: MTRU	Generator Site:	Final Waste Form: Solidified Inorganics		Waste Matrix Code: S3131

AS-GENERATED EPA CODES

D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	*0.0*	*0.0*	*0.0*
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	*0.0*	*0.0*	*0.0*
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

As-Generated Form: Stored: 1.5 Projected: 0.0 Total: 1.5

Final Waste Form: Stored: 1.5 Projected: 0.0 Total: 1.5

WASTE STREAM DESCRIPTION	This waste stream consists of sweeping compound generated from normal site operations. The specific contents include grid and floor debris This waste stream is considered as hazardous/radioactively contaminated based on the assumption that the waste contains lead and chromium contaminated paint chips.
WASTE STREAM SOURCE	Grid and floor debris generated from normal site operations.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	It is not known whether paint chips are in this waste stream. Sampling and analysis are required.
MANAGEMENT COMMENTS	WVNS TD-006, WVNS TD-009, WVNS TD-011, WVNS TD-025, WVNS TD-042, WVNS TD-048, WVNS TD-122
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	WV-M015	Handling:	RH	NMVP #:	N/A	Stream Name:	Chemical Process Cell General Waste
Local ID:	N/A	Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous

Inventory Date: 12/31/94

Waste Matrix Code: S5420

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
370 cubic foot waste box	10.5	0.0	0.0	0.0	0.0	10.5
70 cubic ft. Type A waste box	7.9	0.0	0.0	0.0	0.0	7.9
Totals	18.4	0.0	0.0	0.0	0.0	18.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	17.8	0.0	0.0	0.0	0.0	17.8
Totals	17.8	0.0	0.0	0.0	0.0	17.8

As-Generated Form: Stored: 18.4 Projected: 0.0 Total: 18.4

Final Waste Form: Stored: 17.8 Projected: 0.0 Total: 17.8

WASTE STREAM DESCRIPTION	This waste stream was generated as a result of the decommissioning and decontamination of the Chemical Process Cell (CPC). The CPC was previously used to reprocess spent fuel rods. The specific contents of this container include vacuum lines, air lines, floor debris, pipe, & hoses.
WASTE STREAM SOURCE	Floor debris, vacuum lines, pipe, and hose generated from clean-up of the Chemical Process Cell.
CURRENT CONTAINER COMMENTS	Contains 6, 44"by 44" by 44" boxes
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	WVNS container ID's for these boxes: TC-172, TD-173, TD-174, TD-175, 3E-1/7E-5/7E-8
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	WVDP does not currently have RH canisters available. It is estimated that 20 canisters would be required to repackage this waste stream for shipment. No RH-TRU canisters currently exist at WV. The assumption is that all RH-TRU currently stored waste will be repackaged into RH-TRU canisters at a later date.

M

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T001	Handling: CH	NMVP #: N/A	Stream Name: Fissile Material - Solids		Inventory Date: 12/31/94
Local ID: N/A	Type: TRU	Generator Site:	Final Waste Form: Heterogeneous		Waste Matrix Code: S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
U(unspec)	0.00E+00
Pu-239	0.00E+00
Pu(unspec)	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	3.8	0.0	0.0	0.0	0.0	3.8
Totals	3.8	0.0	0.0	0.0	0.0	3.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

As-Generated Form: Stored: 3.8 Projected: 0.0 Total: 3.8

Final Waste Form: Stored: 3.7 Projected: 0.0 Total: 3.7

WASTE STREAM DESCRIPTION	This waste stream consists of solid fissile material generated from previous decontamination and decommissioning activities. The specific contents include CUNO filters, vacuum cans, glove box debris, etc.
WASTE STREAM SOURCE	Solid fissile material generated from previous decontamination and decommissioning activities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	WVNS 55-gallon drum container ID's: TD-583, TD-461, TD-507, TD-509, TD-502, TD-506, TD-505, TD-476, TD-500, TD-474, TD-471, TD-492, TD-602, TD-932, TD-715, TD-933, TD-497, TD-797
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	It estimated the 18, 55-gallon currently in storage could be consolidated into 15 drums.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T002	Handling: CH	NMVP #: N/A	Stream Name: Fissile Material - Alpha Lab Liquids		Inventory Date: 12/31/94
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Solidified Inorganics		Waste Matrix Code: X6900

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	This waste stream consists of liquid waste stream with associated fissile material generated from previous decontamination and decommissioning activities. The specific contents include Alpha contaminated laboratory liquids.
WASTE STREAM SOURCE	Liquid waste stream with associated fissile material generated from previous decontamination and decommissioning activities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	This waste stream is not mixed waste
MANAGEMENT COMMENTS	WVNS TD-566, WVNS TD-560, WVNS TD-557
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	N/A

M

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T003	Handling: CH	NMVP #: N/A	Stream Name: Fissile Material-UNH Solution		Inventory Date: 12/31/94
Local ID: N/A	Type: TRU	Generator Site:	Final Waste Form: Solidified Inorganics		Waste Matrix Code: L1200

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste Stream consists of liquid waste stream with associated fissile material generated from previous decontamination and decommissioning activities. The specific contents include Uranyl Nitrate Hexahydrate (UNH) solution.
WASTE STREAM SOURCE	Uranyl Nitrate Hexahydrate solution containing fissile material generated from previous decontamination and decommissioning activities
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	It is not known whether this waste stream is acidic.
MANAGEMENT COMMENTS	WVNS TD-501
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T004	Handling: CH	NMVP #: N/A	Stream Name: Fissile Material - Other		Inventory Date: 12/31/94
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Unknown		Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	1.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	This waste stream consists of liquid waste with associated fissile material generated from previous decontamination and decommissioning activities. The specific contents are unknown.
WASTE STREAM SOURCE	Fissile material generated from previous decontamination and decommissioning activities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	the specific contents of this waste stream are unknown.
MANAGEMENT COMMENTS	WVNS TD-478, WVNS TD-640
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T006	Handling: CH	NMVP #: N/A	Stream Name: TRU General Waste		Inventory Date: 12/31/94
Local ID: N/A	Type: TRU	Generator Site:	Final Waste Form: Heterogeneous		Waste Matrix Code: S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	1.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	143.4		
Packaging Material Plastic:	17.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	11.3	5.7	9.4	18.9	18.9	64.3
70 cubic ft. Type A waste box	2.0	5.9	9.9	19.8	19.8	57.4
Totals	13.3	11.6	19.3	38.7	38.7	121.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.2	4.2	6.2	12.5	12.5	46.6
Standard Waste Box	1.9	5.7	9.4	18.9	18.9	54.8
Totals	13.1	9.8	15.7	31.4	31.4	101.4

As-Generated Form: Stored: 13.3 Projected: 108.4 Total: 121.7

Final Waste Form: Stored: 13.1 Projected: 88.3 Total: 101.4

WASTE STREAM DESCRIPTION	This waste stream consists of radiologically and hazardous general site waste generated from normal site operations. The specific contents include but are not limited to anticontamination clothing, hoses, glove bags, and tools.
WASTE STREAM SOURCE	Radiologically and hazardous general site waste generated from normal site operation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	none
MANAGEMENT COMMENTS	WVNS 55-gallon drum Container ID #s for this waste stream are: 4581, 6224, TD-002, TD-024, TD-026, TD-027, TD-030, TD-037, TD-049, TD-058, TD-102, TD-103, TD-110, TD-113, TD-115, TD-117, TD-120, TD-132, TD-139, TD-142, TD-260, TD-305, TD-332, TD-379, TD-386, TD-395, TD-415, TD-422, TD-440, TD-441, TD-442, TD-445, TD-477, TD-522, TD-525, TD-528, TD-529, TD-531, TD-553, TD-573, TD-585, TD-587, TD-591, TD-595, TD-610, TD-632, TD-637, TD-647, TD-648, TD-649, TD-659, TD-719, TD-937. For 1994, TD-1015, TD-1034, TD-1039, TD-969 and box TC-052.
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	It is estimated that with volume reduction, 170 containers would be needed for shipment.

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Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T009	Handling: CH	NMVP #: N/A	Stream Name: TRU General Laboratory Waste		Inventory Date: 12/31/94
Local ID: N/A	Type: TRU	Generator Site:	Final Waste Form: Heterogeneous		Waste Matrix Code: S5420

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Commercial TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	2.1	4.4	7.3	14.7	14.7	43.3
Totals	2.1	4.4	7.3	14.7	14.7	43.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	3.1	5.2	10.4	10.4	31.2
Totals	2.1	3.1	5.2	10.4	10.4	31.2

As-Generated Form: Stored: 2.1 Projected: 41.2 Total: 43.3

Final Waste Form: Stored: 2.1 Projected: 29.1 Total: 31.2

WASTE STREAM DESCRIPTION	This waste stream consists of general laboratory waste generated on-site. The specific contents include anticontamination clothing, bags, wipes, samples, etc.
WASTE STREAM SOURCE	General laboratory waste generated on-site.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	none
MANAGEMENT COMMENTS	WVNS Container ID's for these 10, 55-gallon drums; TD-026, TD-142, TD-659, TD-1009, TD-1028, TD-1029, TD-1043, TD-958, TD-963, TD-966, TD-969.
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	It is estimated that the 10 containers currently in storage and the 196 projected containers could be volume reduced down to 140, 55-gallon drums.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T011	Handling: CH	NMVP #: N/A	Stream Name: TRU Glove Boxes		Inventory Date: 12/31/94
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste stream consists of radiologically and hazardous glove boxes generated from decommissioning and decontamination activities. The specific contents include glove boxes and tools.
WASTE STREAM SOURCE	Radiologically and hazardous glove boxes generated from decomissioning and decontamination activities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	None
MANAGEMENT COMMENTS	WVNS Container ID number is TD-370
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	NONE

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	WV-T014	Handling:	RH	NMVP #:	N/A	Stream Name:	Chemical Process Cell Vessels
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Uncategorized Metal

Inventory Date: 12/31/94

Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Various size metal waste boxes	270.0	0.0	0.0	0.0	0.0	270.0
Totals	270.0	0.0	0.0	0.0	0.0	270.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	89.9	0.0	0.0	0.0	0.0	89.9
Totals	89.9	0.0	0.0	0.0	0.0	89.9

As-Generated Form: Stored: 270.0 Projected: 0.0 Total: 270.0

Final Waste Form: Stored: 89.9 Projected: 0.0 Total: 89.9

WASTE STREAM DESCRIPTION	This waste stream was generated as a result of the decommissioning and decontamination of the Chemical Process Cell. The specific contents of these containers include evaporators, dissolvers, tanks, condensers, etc. These vessels were previously used to reprocess spent fuel rods.
WASTE STREAM SOURCE	Vessels removed from the Chemical Process Cell.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	3C-1 (fuel dissolver), 3C-2 (fuel dissolver), 7C-2 (LLW evaporator), 3E-2/3E-3 (dissolver condensers), 7C-4 (recycle evaporator), 7D-10 (LLW accountability and neutralizer tank), 7C-1 (HLW evaporator), 3D-1 (fuel accountability and feed adjustment tank), 7D-4 (HLW accountability and neutralizer tank)
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	The West Valley Demonstration Project does not currently have RH Canisters. It is estimated that 101 canisters would be needed to repackage the waste for shipment following size reduction. No RH-TRU canisters currently exist at WV. The assumption is that all RH-TRU currently stored waste will be repackaged into RH-TRU canisters at a later date.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T016	Handling: RH	NMVP #: N/A	Stream Name: Chemical Process Cell Miscellaneous Equipment		Inventory Date: 12/31/94
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
432 cubic ft. 6ft by 6ft by 12 ft.	146.8	0.0	0.0	0.0	0.0	146.8
Totals	146.8	0.0	0.0	0.0	0.0	146.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	146.8	0.0	0.0	0.0	0.0	146.8
Totals	146.8	0.0	0.0	0.0	0.0	146.8

As-Generated Form: Stored: 146.8 Projected: 0.0 Total: 146.8

Final Waste Form: Stored: 146.8 Projected: 0.0 Total: 146.8

WASTE STREAM DESCRIPTION	This waste stream was generated as a result of the decommissioning and decontamination of the Chemical Process Cell (CPC). The specific contents of these containers include various jumpers and miscellaneous equipment, etc. The CPC was previously used to reprocess spent fuel rods.
WASTE STREAM SOURCE	Various jumpers and miscellaneous equipment generated from the decontamination and decomissioning of the Chemical Process Cell
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Jumper Boxes J1 Through J-12 Each jumper box is 432 cubic feet and contains a inner container which houses the jumpers and misc. waste
ACCEPTANCE COMMENTS	NONE
FINAL FORM COMMENTS	The West Valley Demonstration Project does not currently have RH canisters. It is estimated that approximately 165 canisters would be needed to repackage the waste for shipment. No RH-TRU canisters currently exist at WV. The assumption is that all RH-TRU currently stored waste will be repackaged into RH-TRU canisters at a later date.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-T017	Handling: CH	NMVP #: N/A	Stream Name: Spent Filter Media		Inventory Date: 12/31/94
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Solidified Inorganics		Waste Matrix Code: S3115

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
80 cubic foot HIC	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	3.8	0.0	0.0	0.0	0.0	3.8
Totals	3.8	0.0	0.0	0.0	0.0	3.8

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 3.8 Projected: 0.0 Total: 3.8

WASTE STREAM DESCRIPTION	This waste stream consists of spent filter media generated from filtration of the Fuel Receiving & Storage pool where the remaining spent fuel rods are stored.
WASTE STREAM SOURCE	Spent filter media generated from normal site activities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	HIC-A
ACCEPTANCE COMMENTS	1, 80 cubic foot High Integrity Container
FINAL FORM COMMENTS	@, standard waste boxes would be required to ship this waste stream.

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Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-W024	Handling: CH	NMVP #: N/A	Stream Name: TRU Lead		Inventory Date: 12/31/94
Local ID: NA	Type: MTRU	Generator Site: WV	Final Waste Form: Lead/Cadmium Metal Waste		Waste Matrix Code: S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Commercial TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Discarding Excess/Expired Materials

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.2	0.0	0.0	0.0	0.0	0.2
70 cubic ft. Type A waste box	2.0	0.0	0.0	0.0	0.0	2.0
Totals	2.2	0.0	0.0	0.0	0.0	2.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 2.2 Projected: 0.0 Total: 2.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	This waste stream consists of transuranic lead in the following configurations: lead bricks and lead shielding. Note: The size of the waste stream components may be highly variable. In addition to the lead materials listed above, the following wastes are also part of the contents of the containers included in this waste stream: glassware, bags, bottles. oven, ultrasonic chiller, and an old style 8D-2 sample cask. The wastes included in this stream are characterized as mixed because they exhibit the characteristic of toxicity for lead.
WASTE STREAM SOURCE	This waste stream consists of lead as specified in section 3.1. This waste was previously used as shielding in radiologically contaminated areas and was identified as excess material.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The high confidence level for regulated contaminant characteristics data is based on the process knowledge (i.e., content descriptions) that lead is present in these containers. The specific amount of elemental lead present in these containers is not available at this time.
MANAGEMENT COMMENTS	WVNS Container ID #s for this waste stream are: TC-100, TD-416.
ACCEPTANCE COMMENTS	None.
FINAL FORM COMMENTS	following decontamination of the lead as a pretreatment step, it is anticipated that this waste stream will no longer be classified as transuranic waste and there will be no TRU disposal required.

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-W041	Handling: CH	NMVP #: N/A	Stream Name: TRU Paint (Dry) with Metals		Inventory Date: 12/31/94
Local ID: NA	Type: MTRU	Generator Site: WV	Final Waste Form: Heterogeneous		Waste Matrix Code: S5900

AS-GENERATED EPA CODES

D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Commercial TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55-GALLON DRUM	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	This waste stream consists of transuranic paint waste (i.e., paint cans) and the following nonhazardous wastes: glove box gloves, glove box debris, wipes, general waste, boots, sample bottles, beakers, and flasks. This waste was characterized as mixed because it is assumed to exhibit the characteristic of toxicity for chromium and lead.
WASTE STREAM SOURCE	This waste stream consists of transuranic paint waste and other nonhazardous waste as specified in section 3.1. This waste was generated as a result of decontamination and decommissioning activities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The medium level of confidence for regulated contaminant characteristics data is based on the uncertainty of whether or not the dried paint that is assumed to be present in the paint cans contains lead and chromium. The characterization of D007 and D008 was made based on process knowledge (i.e., lead and chromium containing paints were previously used on-site).
MANAGEMENT COMMENTS	WVNS container ID #s for this waste stream are: TD-417, TD-724.
ACCEPTANCE COMMENTS	None.
FINAL FORM COMMENTS	N/A

Non-WIPP TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: WV-Z001	Handling: U	NMVP #: N/A	Stream Name: West Valley Buried TRU Waste		Inventory Date:
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Unknown		Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Commercial TRU Waste

Residues:

Asbestos:

PCBs:

Source:

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Not contained	1353.0	0.0	0.0	0.0	0.0	1353.0
Totals	1353.0	0.0	0.0	0.0	0.0	1353.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1353.0 Projected: 0.0 Total: 1353.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION N/A

WASTE STREAM SOURCE A total of approximately 1,353 m3 of TRU-contaminated waste is buried at the West Valley Demonstration Project site. As of December 31, 1993, the as-stored radioactivity from the TRU radionuclides associated with this volume of buried waste is estimated to be 652,000 Curies. Information about non-TRU radionuclides and about decayed radioactivity is not available. This waste will not go to WIPP.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

DOE/CAO-95-1121

Transuranic Waste Baseline Inventory Report (Revision 2)

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Volume 3

LA Los Alamos National Laboratory

LOS ALAMOS NATIONAL LABORATORY

Location and Description

The Los Alamos National Laboratory (LANL) is located approximately 97 kilometers north of Albuquerque and 40 kilometers west of Santa Fe in Los Alamos County, New Mexico. The laboratory facilities are dispersed among numerous Technical Areas (TAs) spread over a 111-square kilometer site on the Pajarito Plateau. The plateau consists of several finger-like mesas extending eastward from the Jemez Mountains to the Rio Grande Valley with steep eroded canyons separating the mesas. The elevation of the mesas range from 1890 to 2377 meters. Some TAs are located in canyons.

The Los Alamos effort was the beginning of what is today the nationwide Albuquerque Operations Office laboratory and industrial complex of the DOE.

Mission

The Los Alamos Scientific Laboratory was established in 1943 by the U.S. Army's Manhattan Engineer District for the purpose of developing the first atomic bombs. Known as the Los Alamos Scientific Laboratory for many years, the name was changed to the Los Alamos National Laboratory in December 1980. LANL was the research, development, engineering design, and testing center for the Manhattan Project. The mission was the application of science and technology to problems of national security, including the maintenance of a strong defense, the fulfillment of arms controls commitments and the guarantee of a secure energy supply for the future.

During the wartime Manhattan Project, Los Alamos, New Mexico, was wholly-owned and controlled by the Government.

LANL's mission since World War II has included nuclear device design, research, development, testing, stockpile certification, and plutonium storage. Major programs currently include research in nuclear and conventional weapons development; nuclear fission and fusion; nuclear safeguards and security; verification and control technologies; fundamental research in particle physics, mathematics, chemistry, and materials; and waste management technology development and testing.

Research on peaceful uses of nuclear energy has included space applications, power reactor programs, magnetic and inertial fusion, radiobiology, and medicine. Other programs include astrophysics, earth sciences, lasers, computer sciences, solar energy, geothermal energy, biomedical and environmental research, and nuclear waste management research.

Today, the Waste Management Facilities Operations Group, CST-27, is responsible for all waste management facilities at LANL, except those related to high-explosives waste and sanitary waste, and those operated by waste generators in preparing their wastes for disposal. The Waste Management Program includes treating radioactive liquid and solid waste; packaging, transporting, treating, and disposing of hazardous chemical waste; and operating the disposal and storage sites for mixed waste. The Waste Management Program provides treatment, storage and disposal for Environmental Restoration Program-generated waste.

Waste Information

Processes

Major CH TRU waste generators at LANL are: Analytical Chemical Group (CHM-1), Nuclear Fuel Development and Facilities Operations Group (MST-11), Nuclear Materials Process Technology Group (MST-12), and Plutonium Metal Technology Group (MST-13).

RH TRU waste is generated by the Irradiated Materials Examination Group (MST-14).

CHM-1 is involved in analysis of radioactive materials. The waste generated by CHM-1 are combustibles (paper, rags, plastics, rubber) and non-combustibles (glass, ceramic, porcelain, metal, transite, chemicals, and equipment).

Wastes generated in MST-12 are process residues in solid and liquid TRU waste streams left when all economically recoverable quantities of special nuclear materials have been removed from a nuclear material item.

The wastes generated in MST-13 are combustible solids, noncombustible scrap (small tools, cans, small equipment items), and cemented process residues (process leached solids, filter cakes, and evaporator bottoms) stabilized in Portland or Gypsum cement.

The Size Reduction Facility's waste consists of metal equipment, either whole or sectional along with its combustible components, and the small volumes of combustibles generated during decommissioning, sectioning, and packaging (mostly gloveboxes, process equipment, and ductwork from decommissioning operations).

MST-14 generates both contact and remote handled solid wastes from hot cell operations.

Modifications/Assumptions/Development

LANL reported radionuclides in total Curies. The TWBIR team used the volumes reported for each waste stream to calculate the radionuclides in terms of Ci/m^3.

LANL's waste material parameters Solidified, Inorganic Matrix and Cement (Solidified) for waste streams LA–M002, LA–W003, LA–W006, LA–T002, and LA–T006 were calculated based on the proposed amount of cement that will be used to solidify these waste streams.

For final form containers, the estimated generation for newly generated waste was reported in the years 1995 to 2000. For the years 2001 to 2022 a bulk amount was reported. The TWBIR team converted this bulk amount into containers/year, assuring a constant generation rate per year between 2001 and 2022.

LANL assumes the internal volume for a 85 gallon drum used to overpack a 55 gallon drum is 0.208 m^3. This is assumed because all waste from 55 gallon drums that are currently overpacked in 85 gallon drums will be repackaged into 55 gallon drums for shipment to WIPP (upon WIPP–WAC certification).

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W047	Handling:	CH	NMVP #:	LA 111A; 211A	Stream Name:	Cemented Process Sludge	Inventory Date:	12/31/94
Local ID:	LA-M002	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

F005, F002, F001, D009, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	603.0	507.0	1014.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	693.0	583.0	1166.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	149.3		
Packaging Material Plastic:	8.5		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 111A; 211A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	3.10E-03
U-238	2.50E-06
U-235	7.86E-06
U-234	1.16E-06
U-233	6.55E-06
Th	3.57E-08
Sr-90	3.10E-03
Pu-241	8.94E-04
Pu-239	2.73E-01
Pu-238	4.75E-02
Cs-137	3.10E-03
AM240	2.09E-06
Am-241	4.55E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	181.0	59.3	98.8	197.6	197.6	734.2
Drum / 85-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Metal Pipe	2870.6	0.0	0.0	0.0	0.0	2870.6
Totals	3053.3	59.3	98.8	197.6	197.6	3606.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	182.6	59.3	98.8	197.6	197.6	735.9
Standard Waste Box	2870.9	0.0	0.0	0.0	0.0	2870.9
Totals	3053.5	59.3	98.8	197.6	197.6	3606.8

As-Generated Form: Stored: 3053.3 Projected: 553.3 Total: 3606.5

Final Waste Form: Stored: 3053.5 Projected: 553.3 Total: 3606.8

WASTE STREAM DESCRIPTION	Solidified aqueous waste, cemented sludge. The sludge is a residue from numerous treatment and filtration operations involving aqueous liquid radioactive waste. This treatment produces a thin sludge (approximately 25 percent solids) that is alkaline and is compatible with Portland cement. Final cemented waste monoliths are produced by mixing the waste in 55-gallon steel drums containing empirically determined quantities of sludge, Portland cement, vermiculite, and sodium silicate.
WASTE STREAM SOURCE	Cemented Aqueous waste
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	8 55 gallon drums are generated from the repackaging of 85 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W055	Handling:	CH	NMVP #:	LA 125A	Stream Name:	Mixed Scrap Metal	Inventory Date:	12/31/94
Local ID:	LA-T001	Type:	TRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	134.3		
Packaging Material Plastic:	31.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-242	9.54E-07
Pu-241	1.93E-01
Pu-240	1.15E-02
Pu-239	2.68E-01
Pu-238	1.03E+00
Cm-244	2.43E-06

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	1.2	59.9	99.8	199.7	199.7	560.4
fiberglass Reinfocre Plywood	92.3	0.0	0.0	0.0	0.0	92.3
standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	95.5	59.9	99.8	199.7	199.7	654.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	59.9	99.8	199.7	199.7	560.6
Standard Waste Box	94.5	0.0	0.0	0.0	0.0	94.5
Totals	96.0	59.9	99.8	199.7	199.7	655.1

As-Generated Form: Stored: 95.5 Projected: 559.1 Total: 654.6

Final Waste Form: Stored: 96.0 Projected: 559.1 Total: 655.1

WASTE STREAM DESCRIPTION	Mixed metal scrap and incidental combustibles. This waste is generated at various TAs throughout LANL. The waste consists mostly of metals or metal equiptment, either whole or sectioned, and lesser amounts of combustible components. In addition, it contains small volumes of combustibles generated during decommissioning, sectioning, and packaging. The waste forms primarily include gloveboxes, process equiptment, and ductwork from decommissioning operations. Gloveboxes may include gloves, wiring, plastic, glass windows, plastic wrapping, and lead shielding.
WASTE STREAM SOURCE	Mixed scrap metals and incidental combustibles generated at various TA's throughout the lab.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	based on process knowledge
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	1 55 gallon drum is generated from the overpacking of the 30 gallon drum. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W065	Handling:	CH	NMVP #:	LA 111A; 211A	Stream Name:	Cemented Process Sludge	Inventory Date:	12/31/94
Local ID:	LA-T002	Type:	TRU	Generator Site:	LA	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	603.0	507.0	1014.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	693.0	583.0	1166.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

LA 111A
LA 211A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
U-235	2.17E-05
Pu-239	1.78E+00
Pu-238	9.13E-02
Am-241	2.62E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon drum	1.5	3.1	5.2	10.4	10.4	30.6
Totals	1.5	3.1	5.2	10.4	10.4	30.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	3.1	5.2	10.4	10.4	30.6
Totals	1.5	3.1	5.2	10.4	10.4	30.6

As-Generated Form: Stored: 1.5 Projected: 29.1 Total: 30.6

Final Waste Form: Stored: 1.5 Projected: 29.1 Total: 30.6

WASTE STREAM DESCRIPTION	Cemented aqueous waste, solidified with Portland cement to form a noncorrosive solid monolith. The sludge is a residue from the treatment of blended acidic and caustic aqueous liquid radioactive waste with calcium hydroxide, ferric sulfate, and a flocculation aid. This treatment produces a thin sludge that is always alkaline and is compatible with Portland cement. Final cemented waste monoliths are produced by tumbling 55-gallon steel drums containing empirically determined quantities of sludge, Portland cement, vermiculite, and sodium silicate.
WASTE STREAM SOURCE	Cemented aqueous waste, solidified with Portland cement to form a noncorrosive solid monolith.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	represents waste stream LA-T002
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W056	Handling:	CH	NMVP #:	LA 116A	Stream Name:	Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-T004	Type:	TRU	Generator Site:	LA	Final Waste Form:	Combustible	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.4	0.4	0.4
Other Metals/Alloys:	18.8	18.8	89.7
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.9		
Packaging Material Plastic:	35.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 116A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-240	1.48E-01
Am-243	3.18E-06
Ba-137m	6.92E-02
Cm-243	9.58E-04
Cm-244	3.89E-02
Cs-137	6.92E-02
Np-237	2.02E-06
Am-241	1.93E-02
Pu-239	5.80E-01
Y-90	6.92E-02
Pu-241	3.02E+00
Pu-242	5.64E-04
Pu-244	4.66E-10
Sr-90	6.92E-02
U-233	2.08E-05
U-234	1.30E-05
U-235	2.10E-06
U-236	5.18E-08
U-238	2.27E-06
Pu-238	3.84E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	30.7	0.0	0.0	0.0	0.0	30.7
Drum / 55-gallon	1373.0	179.7	299.5	599.0	599.0	3050.3
Drum / 85-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Fiberglass Reinfocre Plywood	123.2	0.0	0.0	0.0	0.0	123.2
Totals	1527.8	179.7	299.5	599.0	599.0	3205.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1430.4	179.7	299.5	599.0	599.0	3107.7
Standard Waste Box	124.7	0.0	0.0	0.0	0.0	124.7
Totals	1555.2	179.7	299.5	599.0	599.0	3232.5

As-Generated Form: Stored: 1527.8 Projected: 1677.3 Total: 3205.1

Final Waste Form: Stored: 1555.2 Projected: 1677.3 Total: 3232.5

WASTE STREAM DESCRIPTION	Combustible waste including plastic-basedand cellulose-based waste generated at the lab. Plastic-based waste includes, but may not be limited to , tape, polyethylene, and vinyl; gloves; plastic vials; polystyrene;Tygon tubing; polyvinyl chloride plastic;Teflon producrts; plexiglass; and dry box gloves. Cellulose -based waste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar miscellaneous materials. Waste may also contain a small fraction of noncombustible scrap metal.
WASTE STREAM SOURCE	Combustibe waste including plastic-based and cellulose-based waste generated at the lab.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	272 55 gallon drums are generated from the overpacking of the 30 gallon drum and 4 55 gallon drums are generated from the repackaging of the 85 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W057	Handling:	CH	NMVP #:	LA 117A; 118A	Stream Name:	Non Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-T005	Type:	TRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	302.9	76.9	913.5
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	134.1		
Packaging Material Plastic:	32.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 117A; 118A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Po-210	6.65E-07
Am-241	5.02E-02
Am-243	1.38E-04
Ba-137m	8.46E-03
Bk-249	6.65E-07
Cd-109	1.76E+00
Cf-249	6.65E-07
Cm-242	6.79E-07
Cm-244	1.08E-01
Co-60	6.65E-07
Cs-137	8.46E-03
Ac-227	2.91E-04
Pa-231	7.39E-07
Y-90	8.46E-03
Pu-238	4.11E+01
Pu-239	3.03E+00
Pu-240	7.16E-01
Pu-241	1.19E+01
Pu-242	6.18E-04
Pu-244	4.32E-10
Ra-226	6.02E-04
Sr-90	8.46E-03
U-233	2.72E-02
U-234	2.13E-05
U-235	2.13E-06
U-236	3.78E-08
U-238	6.97E-04
Np-237	1.72E-06

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	36.5	0.0	0.0	0.0	0.0	36.5
Drum / 55-gallon	1084.1	119.8	199.7	399.4	399.4	2202.3
Drum / 85-gallon	0.2	0.0	0.0	0.0	0.0	0.2
fiberglass Reinfocre Plywood	343.0	0.0	0.0	0.0	0.0	343.0
standard Waste Box	7.6	0.0	0.0	0.0	0.0	7.6
Totals	1471.4	119.8	199.7	399.4	399.4	2589.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1151.5	119.8	199.7	399.4	399.4	2269.7
Standard Waste Box	351.5	0.0	0.0	0.0	0.0	351.5
Totals	1503.0	119.8	199.7	399.4	399.4	2621.2

As-Generated Form: Stored: 1471.4 Projected: 1118.2 Total: 2589.6

Final Waste Form: Stored: 1503.0 Projected: 1118.2 Total: 2621.2

WASTE STREAM DESCRIPTION	Non-combustible scrap - small tools, cans, small equipment items, HEPA filters, glass ware, metal, leaded rubber, graphite and pyrochemical waste generated at several site around the laboratory.
WASTE STREAM SOURCE	Noncombustible waste consisting of HEPA filters, glass ware, metal \, leaded rubber waste, graphite and pyrochemical sal wases.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	data entered by the waste generators
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	323 55 gallon drums are generated from the overpacking of the 30 gallon drum and 1 55 gallon drum is generated from the repackaging of the 85 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W058	Handling:	CH	NMVP #:	LA 114A; LA 126	Stream Name:	Solidified Inorganic process solids	Inventory Date:	12/31/94
Local ID:	LA-T006	Type:	TRU	Generator Site:	LA	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.3	38.5	48.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	447.1	335.3	491.8
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	514.4	385.7	565.9
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 114A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
U-238	1.33E-05
U-236	6.18E-08
U-235	4.53E-07
U-234	1.45E-05
U-233	1.90E-04
Pu-244	2.19E-10
Pu-242	2.69E-04
Pu-241	6.43E+00
Pu-240	3.10E-01
Pu-239	1.26E+00
Pu-238	1.20E+02
Np-237	1.41E-06
Am-241	8.63E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cardboard Box	0.2	0.0	0.0	0.0	0.0	0.2
Drum / 30-gallon	0.3	0.0	0.0	0.0	0.0	0.3
Drum / 55-gallon	4.2	8.7	14.6	29.1	29.1	85.7
Totals	4.7	8.7	14.6	29.1	29.1	86.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.0	8.7	14.6	29.1	29.1	86.5
Totals	5.0	8.7	14.6	29.1	29.1	86.5

As-Generated Form: Stored: 4.7 Projected: 81.5 Total: 86.3

Final Waste Form: Stored: 5.0 Projected: 81.5 Total: 86.5

WASTE STREAM DESCRIPTION	Cemented process residues. Solidified inorganic and organic process solids. This waste consists of process leached solids, ash, filter cakes, salts, metal oxides, fines and evaporator bottoms stabilized in Portland or gypsum cement.
WASTE STREAM SOURCE	Solidified inorganic and organic process solids. This waste consists of process leached solids, ash, filter cakes, salts, metal oxides, fines and evaporator bottoms stabilized in Portland or gypsum cement.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	From database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Pu-239 FGE based on present drums identified. 3 55 gallon drums are generated from the overpacking of the 30 gallon drum and 1 55 gallon drum is generated from the repackaging of the cardboard box. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W059	Handling:	CH	NMVP #:	unknown	Stream Name:	Hot-Cell Waste	Inventory Date:	12/31/94
Local ID:	LA-T007	Type:	TRU	Generator Site:	LA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	7.12E+01
U-238	2.38E-08
U-236	3.49E-07
U-235	4.65E-04
U-234	8.17E-05
Sr-90	7.12E+01
Pu-242	2.70E-06
Pu-241	6.24E-01
Pu-240	3.93E-02
Pu-239	6.47E+00
Pu-238	3.60E+00
Cs-137	7.12E+01
Ba-137m	7.12E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	5.6	3.1	5.2	10.4	10.4	34.7
Other	0.9	0.0	0.0	0.0	0.0	0.9
Totals	6.6	3.1	5.2	10.4	10.4	35.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.7	3.1	5.2	10.4	10.4	35.8
Totals	6.7	3.1	5.2	10.4	10.4	35.8

As-Generated Form: Stored: 6.6 Projected: 29.1 Total: 35.7

Final Waste Form: Stored: 6.7 Projected: 29.1 Total: 35.8

WASTE STREAM DESCRIPTION	Contact handled hot cell waste including both combustible and noncombustible waste forms. This waste is generated by MST-5 in the CRM building.
WASTE STREAM SOURCE	Contact handled hot cell waste including both combustible and noncombustible waste forms.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	None
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	5 55 gallon drums are generated from the overpacking of Other containers. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W060	Handling:	CH	NMVP #:	unknown	Stream Name:	Soils	Inventory Date:	12/31/94
Local ID:	LA-T008	Type:	TRU	Generator Site:	LA	Final Waste Form:	Soils	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1200.0	1000.0	1600.0
Packaging Material Steel:	147.5		
Packaging Material Plastic:	11.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-242	2.67E-07
Pu-241	2.29E-02
Pu-240	3.73E-04
Pu-239	2.49E-01
Pu-238	1.90E+00
Am-241	5.43E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	10.4	3.1	5.2	10.4	10.4	39.5
fiberglass Reinfocre Plywood	98.8	0.0	0.0	0.0	0.0	98.8
Totals	109.2	3.1	5.2	10.4	10.4	138.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.4	3.1	5.2	10.4	10.4	39.5
Standard Waste Box	100.2	0.0	0.0	0.0	0.0	100.2
Totals	110.6	3.1	5.2	10.4	10.4	139.7

As-Generated Form: Stored: 109.2 Projected: 29.1 Total: 138.3

Final Waste Form: Stored: 110.6 Projected: 29.1 Total: 139.7

WASTE STREAM DESCRIPTION	Soils contaminated with Transuranic material. This waste was produced at several sites throughout LANL. A good portion of the waste came from TA-21
WASTE STREAM SOURCE	Soils contaminated with Transuranic material. THis waste was produced at several sites throughout LANL. A good portion of the waste came from TA-21
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	from TRU database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W061	Handling:	CH	NMVP #:	unknown	Stream Name:	Glovebox and Ducting Material	Inventory Date:	12/31/94
Local ID:	LA-T009	Type:	TRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	141.9		
Packaging Material Plastic:	20.1		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-242	6.11E-05
Pu-241	6.19E+00
Pu-240	2.10E-01
Pu-239	7.53E-01
Pu-238	7.79E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon drum	0.6	6.2	10.4	20.8	20.8	58.9
fiberglass Reinfocre Plywood	53.1	0.0	0.0	0.0	0.0	53.1
Totals	53.7	6.2	10.4	20.8	20.8	111.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	6.2	10.4	20.8	20.8	58.9
Standard Waste Box	52.9	0.0	0.0	0.0	0.0	52.9
Totals	53.5	6.2	10.4	20.8	20.8	111.8

As-Generated Form: Stored: 53.7 Projected: 58.2 Total: 111.9

Final Waste Form: Stored: 53.5 Projected: 58.2 Total: 111.8

WASTE STREAM DESCRIPTION	Metal from gloveboxes & equipment repackaged from FRP boxes. THis waste was proced by several sites throughout LANL.
WASTE STREAM SOURCE	Glovebox and Ducting waste generated at several site throughout LANL.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	limited informantion in the database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W062	Handling:	RH	NMVP #:	LA 116A	Stream Name:	Combustible Waste	Inventory Date:	12/31/91
Local ID:	LA-TR04	Type:	TRU	Generator Site:	LA	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.4	0.4	0.4
Other Metals/Alloys:	18.8	18.8	89.7
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA-116A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	2.48E+01
U-238	1.95E-06
U-236	8.88E-09
U-235	3.18E-04
U-234	2.01E-06
Sr-90	2.48E+01
Pu-242	5.00E-06
Pu-241	3.70E-01
Pu-240	1.21E-02
Pu-239	2.90E+00
Pu-238	5.34E-03
Cs-137	2.48E+01
Ba-137m	2.48E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 2 gallon	0.2	0.0	0.0	0.0	0.0	0.2
LANL RH Can	14.9	0.0	0.0	0.0	0.0	14.9
Totals	15.0	0.0	0.0	0.0	0.0	15.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	15.1	3.6	8.9	17.8	18.7	64.1
Totals	15.1	3.6	8.9	17.8	18.7	64.1

As-Generated Form: Stored: 15.0 Projected: 0.0 Total: 15.0

Final Waste Form: Stored: 15.1 Projected: 49.0 Total: 64.1

WASTE STREAM DESCRIPTION	Combustible waste - paper, rags, plastic, rubber, etc., including plastic-based and cellulose-based waste generated at the laoboratory. Plastic-based waste includes, but may not be limited to, tape, polyethylene, and vinyl; gloves; plastic vials; polystyrene; Tygon tubing; polyvinyl chloride plastic; Teflon products; plexiglass; and dry box gloves (unleaded Neoprene base). Cellulose-based wste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar miscellaneous materials. The waste may also contain a small fraction of noncombustible solids (e.g., scrap metals, metal lids).
WASTE STREAM SOURCE	Combustible waste including plastic based and cellulose-based waste generated at the laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	limited information i the database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	17 RH Canisters are generated from the repackaging of current RH containers. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W063	Handling:	RH	NMVP #:	unknown	Stream Name:	Noncombustible Waste	Inventory Date:	12/31/94
Local ID:	LA-TR05	Type:	TRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	302.9	76.9	913.5
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	8.42E-02
U-238	1.91E-10
U-236	2.80E-09
U-235	2.05E-08
U-234	6.56E-07
Sr-90	8.42E-02
Ru-106	4.85E-04
Pu-242	7.50E-08
Pu-241	6.68E-03
Pu-240	2.10E-04
Pu-239	4.49E-04
Pu-238	6.47E-05
Cs-137	8.99E-02
Ba-137m	8.99E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
drum / 2 gallon	0.01	0.0	0.0	0.0	0.0	0.01
LANL RH Can	50.9	0.0	0.0	0.0	0.0	50.9
Totals	51.0	0.0	0.0	0.0	0.0	51.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	50.7	0.0	0.0	7.1	8.9	66.7
Totals	50.7	0.0	0.0	7.1	8.9	66.7

As-Generated Form: Stored: 51.0 Projected: 0.0 Total: 51.0

Final Waste Form: Stored: 50.7 Projected: 16.0 Total: 66.8

WASTE STREAM DESCRIPTION	Non-combustible scrap - small tools, cans, small equipment items, broken glass, etc. This waste consists of the following subgroups: high-efficiency particulate air (HEPA) filter waste (no subgroup number); glass waste [005(LG)]; metal waste [005(LM)]; leaded rubber waste and metal waste [005(P1)]; graphite waste [005(P2G)]; and pyrochemical salt waste [005(P2S)]. Discarded HEPA filter waste is generated at TA-55-4. 005(LG) consists of glass waste and included, but may not be limited to, discarded labware, windows, and bottles. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream. Metal waste (e.g., motors, pumps, tools, and process equiptment) comprises 005(LM). A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream. 005(P1) is leaded rubber waste and metal waste. This waste stream also includes lead-lined glovebox gloves discarded along with metal waste, such as motors and tools. 005(P2G) is graphite solid waste which consists of discarded graphite mold and furnance equiptment generated during plutonium casting and other operations conducted in room 327 at TA-55-4. 005(P2S) is pyrochemical salt waste which consists of used chloride salts from pyrochemical processes such as electrorefining, molten salt extraction, salt stripping, flouride reduction, and direct oxide reduction. these processes occur at TA-55-4. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream.
WASTE STREAM SOURCE	Non-combustible waste consisting oF HEPA filters, glass, graphite and pyrochemical salt waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	57 RH Canisters are generated from the repackaging of current RH containers. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W064	Handling:	RH	NMVP #:	unknown	Stream Name:	Noncombustible Hot-Cell Waste	Inventory Date:	12/31/94
Local ID:	LA-TR07	Type:	TRU	Generator Site:	LA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	4.44E+01
U-235	3.02E-04
Sr-90	4.44E+01
Pu-239	3.17E+00
Cs-137	4.44E+01
Ba-137m	4.44E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
drum / 2 gallon	0.3	0.0	0.0	0.0	0.0	0.3
LANL RH Can	10.5	0.0	0.0	0.0	0.0	10.5
Totals	10.8	0.0	0.0	0.0	0.0	10.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	11.6	0.0	0.0	0.0	0.0	11.6
Totals	11.6	0.0	0.0	0.0	0.0	11.6

As-Generated Form: Stored: 10.8 Projected: 0.0 Total: 10.8

Final Waste Form: Stored: 11.6 Projected: 0.0 Total: 11.6

WASTE STREAM DESCRIPTION	Remote handled hot cell waste including both combustible and noncombustible waste forms. This waste is generated by MST-5 in the CRM building.
WASTE STREAM SOURCE	Contact handled hot cell waste including both combustible and noncombustible waste forms.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	from database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	This waste stream in not currently generated and will require only that the old waste be repackaged. 13 RH Canisters are generated from the repackaging of current RH containers.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W046	Handling:	CH	NMVP #:	LA 125A	Stream Name:	Mixed Scrap Metal	Inventory Date:	12/31/94
Local ID:	LA-M001	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.2	4.9	5.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	151.8		
Packaging Material Plastic:	4.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No.

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-242	1.57E-06
Ba-137m	6.49E-04
Cf-251	7.26E-07
Cs-137	1.37E-01
Eu-155	2.78E-05
H-3	0.00E+00
Np-237	1.82E-13
Pm-147	3.94E-05
Pu-238	2.23E+00
Pu-239	2.36E-01
Am-241	3.39E-06
Pu-241	1.74E-01
Y-90	1.37E-01
Pu-244	7.33E-13
Ra-226	5.90E-07
Rh-106	5.08E-06
Ru-106	5.08E-06
Sb-125	2.81E-05
Sr-90	1.37E-01
Te-125m	1.17E-05
U-233	0.00E+00
U-234	4.53E-07
U-235	1.40E-05
U-236	8.85E-10
U-238	6.63E-07
Pu-240	1.07E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon drum	80.7	15.0	25.0	49.9	49.9	220.5
Drum/30 gallon	4.0	0.0	0.0	0.0	0.0	4.0
Fiberglass Reinfocre Plywood	2108.5	0.0	0.0	0.0	0.0	2108.5
standard Waste Box	13.2	0.0	0.0	0.0	0.0	13.2
Totals	2206.4	15.0	25.0	49.9	49.9	2346.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	84.7	15.0	25.0	49.9	49.9	224.4
Standard Waste Box	2118.7	0.0	0.0	0.0	0.0	2118.7
Totals	2203.3	15.0	25.0	49.9	49.9	2343.1

As-Generated Form: Stored: 2206.4 Projected: 139.8 Total: 2346.2

Final Waste Form: Stored: 2203.3 Projected: 139.8 Total: 2343.1

WASTE STREAM DESCRIPTION	Mixed metal scrap and incidental combustibles. This waste is generated at various TAs throughout LANL. The waste consists mostly of metals or metal equipment, either whole or sectioned, and lesser amounts of combustible components. In addition, it contains small volumes of combustibles generated during decommissioning, sectioning, and packaging. The waste forms primarily include gloveboxes, process equipment, and ductwork from facility operations. Gloveboxes may include gloves, wiring, plastic, glass windows, plastic wrapping, and lead shielding.
WASTE STREAM SOURCE	This waste is generated at various Technical Areas (TA) throughout LANL.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	19 55 gallon drums are generated from the repackaging of 30 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W048	Handling:	CH	NMVP #:	LA 111B; 211B	Stream Name:	Solidified aqueous waste	Inventory Date:	12/31/94
Local ID:	LA-M003	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3121

AS-GENERATED EPA CODES

F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.3	38.5	48.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	650.1	546.6	1093.2
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	645.9	543.4	1086.8
Soils:	0.0	0.0	0.0
Packaging Material Steel:	132.6		
Packaging Material Plastic:	34.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 111B; 211B

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.49E-05
U-235	8.53E-08
Sr-90	2.49E-05
Pu-241	4.06E-05
Pu-239	3.36E-01
Pu-238	1.04E-01
Cs-137	2.49E-05
Am-241	3.33E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon drum	1151.9	59.9	99.8	199.7	199.7	1711.0
Drum / 85-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Other	124.7	0.0	0.0	0.0	0.0	124.7
Totals	1277.4	59.9	99.8	199.7	199.7	1836.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1152.7	59.9	99.8	199.7	199.7	1711.8
Standard Waste Box	124.7	0.0	0.0	0.0	0.0	124.7
Totals	1277.5	59.9	99.8	199.7	199.7	1836.6

As-Generated Form: Stored: 1277.4 Projected: 559.1 Total: 1836.5

Final Waste Form: Stored: 1277.5 Projected: 559.1 Total: 1836.6

WASTE STREAM DESCRIPTION	Solidified aqueous waste , is a dewatered sludge generated by the vacume filtration of solids from a pretreated aqueous waste slurry. These solids are first trapped on the surface of the filter media (diatomaceous earth). The filter medium with the entrapped filtrate is then placed in drums with dry concrete absorbent.
WASTE STREAM SOURCE	Solidified Aqueous Waste, dewatered sludge generated by the vacuum filtration of solids from the pretrated aqueous waste slurry.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	4 55 gallon drums are generated from the repackaging of 85 gallon drums. projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W049	Handling:	CH	NMVP #:	LA 116A	Stream Name:	Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-M004	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

U080, F002, F001, D040, D019, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.4	0.4	0.4
Other Metals/Alloys:	18.8	18.8	89.7
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	*0.0*	*0.0*	*0.0*
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.1		
Packaging Material Plastic:	36.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 116A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
U-238	2.71E-08
U-236	1.08E-07
U-235	8.00E-07
U-234	2.56E-05
Th	4.09E-11
Pu-244	3.71E-10
Pu-242	4.64E-04
Pu-241	1.70E+01
Pu-240	1.07E+00
Pu-239	4.47E+00
Pu-238	1.65E+01
Np-237	2.91E-06
Cm-246	9.76E-05
Am-243	3.47E-05
Am-241	6.68E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
30 Gallon Drum	15.5	0.0	0.0	0.0	0.0	15.5
Drum / 55-gallon	232.1	74.9	124.8	249.6	249.6	931.0
Other	4.8	0.0	0.0	0.0	0.0	4.8
Totals	252.4	74.9	124.8	249.6	249.6	951.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	260.6	74.9	124.8	249.6	249.6	959.5
Standard Waste Box	5.7	0.0	0.0	0.0	0.0	5.7
Totals	266.3	74.9	124.8	249.6	249.6	965.2

As-Generated Form: Stored: 252.4 Projected: 698.9 Total: 951.3

Final Waste Form: Stored: 266.3 Projected: 698.9 Total: 965.2

WASTE STREAM DESCRIPTION	Combustible waste - paper, rags, plastic, rubber, etc., including plastic-based and cellulose-based waste generated at the laboratory. Plastic-based waste includes, but may not be limited to, tape, polyethylene, and vinyl; gloves; plastic vials; polystyrene; Tygon tubing; polyvinyl chloride plastic; Teflon products; plexiglass; and dry box gloves (unleaded Neoprene base). Cellulose-based wste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar miscellaneous materials. The waste may also contain a small fraction of noncombustible solids (e.g., scrap metals, metal lids).
WASTE STREAM SOURCE	Combustible waste including plastic based and cellulose-based waste generated at the laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	137 55 gallon drums are generated from the overpacking of 30 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W050	Handling:	CH	NMVP #:	LA 117A; 118A	Stream Name:	Non Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-M005	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

D040, D019, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	302.9	76.9	913.5
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.1		
Packaging Material Plastic:	36.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 117A; 118A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
U-238	7.08E-04
U-236	1.00E-07
U-235	7.42E-07
U-234	2.38E-05
U-232	2.33E-09
Pu-244	3.05E-09
Pu-242	3.82E-03
Pu-241	1.21E+02
Pu-240	7.16E+00
Pu-239	2.89E+01
Pu-238	3.34E+00
Np-237	1.48E-06
Cm-246	6.57E-05
Am-243	2.16E-05
Am-241	9.04E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	209.0	74.9	124.8	249.6	249.6	907.9
Other	4.0	0.0	0.0	0.0	0.0	4.0
Totals	213.1	74.9	124.8	249.6	249.6	911.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	209.0	74.9	124.8	249.6	249.6	907.9
Standard Waste Box	5.7	0.0	0.0	0.0	0.0	5.7
Totals	214.7	74.9	124.8	249.6	249.6	913.6

As-Generated Form: Stored: 213.1 Projected: 698.9 Total: 911.9

Final Waste Form: Stored: 214.7 Projected: 698.9 Total: 913.6

WASTE STREAM DESCRIPTION	Non-combustible scrap - small tools, cans, small equipment items, broken glass, etc. This waste consists of the following subgroups: high-efficiency particulate air (HEPA) filter waste (no subgroup number); glass waste [005(LG)]; metal waste [005(LM)]; leaded rubber waste and metal waste [005(P1)]; graphite waste [005(P2G)]; and pyrochemical salt waste [005(P2S)]. Discarded HEPA filter waste is generated at TA-55-4. 005(LG) consists of glass waste and included, but may not be limited to, discarded labware, windows, and bottles. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream. Metal waste (e.g., motors, pumps, tools, and process equipment' comprises 005(LM). A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream. 005(P1) is leaded rubber waste and metal waste. This waste stream also includes lead-lined glovebox gloves discarded along with metal waste, such as motors and tools. 005(P2G) is graphite solid waste which consists of discarded graphite mold and furnance equiptment generated during plutonium casting and other operations conducted in room 327 at TA-55-4. 005(P2S) is pyrochemical salt waste which consists of used chloride salts from pyrochemical processes such as electrorefining, molten salt extraction, salt stripping, flouride reduction, and direct oxide reduction. these processes occur at TA-55-4. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream.
WASTE STREAM SOURCE	Non-combustible waste consisting oF HEPA filters, glass, graphite and pyrochemical salt waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W051	Handling:	CH	NMVP #:	LA 114A; LA 126	Stream Name:	Solidified Inorganic process solids	Inventory Date:	12/31/94
Local ID:	LA-M006	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

F003, F002, F001, D039, D021, D019, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.3	38.5	48.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	453.4	340.0	498.7
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	508.1	381.0	559.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.3		
Packaging Material Plastic:	36.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 114A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.87E+01
Am-243	2.67E+01
Bk-249	2.72E-06
Cf-249	1.77E-07
Cm-246	2.46E-05
Pu-238	5.17E+00
Am-241	2.94E+01
Pu-240	1.69E+00
U-238	3.47E-04
Pu-242	3.14E-03
Pu-244	2.85E-09
Th	4.15E-06
U-233	1.71E-04
U-234	1.53E-04
U-235	1.19E-05
U-236	6.99E-08
Pu-239	6.92E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	27.8	0.0	0.0	0.0	0.0	27.8
Drum / 55-gallon	435.6	89.9	149.8	299.5	300.8	1275.5
Drum / 85-gallon	48.5	0.0	0.0	0.0	0.0	48.5
Other	15.8	0.0	0.0	0.0	0.0	15.8
Totals	527.7	89.9	149.8	299.5	300.8	1367.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	535.2	89.9	149.8	299.5	300.8	1375.1
Standard Waste Box	17.0	0.0	0.0	0.0	0.0	17.0
Totals	552.2	89.9	149.8	299.5	300.8	1392.1

As-Generated Form: Stored: 527.7 Projected: 839.9 Total: 1367.6

Final Waste Form: Stored: 552.2 Projected: 839.9 Total: 1392.1

WASTE STREAM DESCRIPTION	Solidified inorganic and organic process solids. This waste consists of process leached solids, ash, filter cakes, salts, metal oxides, fines, or evaporator bottoms stabilized in portland or gypsum cement. These waste streams are generated at TA-55-4.
WASTE STREAM SOURCE	Solidified inorgainc and orgainc process solids.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Drums will be repackaged to meet WIPP WAC. 246 55 gallon drums are generated from the overpacking of 30 gallon drums and 233 55 gallon drums are generated from the repackaging of 85 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W052	Handling:	CH	NMVP #:	unknown	Stream Name:	Glovebox and Ducting Material	Inventory Date:	12/31/94
Local ID:	LA-M009	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	138.8		
Packaging Material Plastic:	24.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-242	5.61E-07
Pu-241	1.47E-01
Pu-240	9.72E-03
Pu-239	4.15E-02
Pu-238	1.22E-03
Am-241	3.26E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	30.0	49.9	99.8	99.8	279.8
Fiberglass Reinfocre Plywood	142.2	0.0	0.0	0.0	0.0	142.2
Totals	142.4	30.0	49.9	99.8	99.8	422.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	30.0	49.9	99.8	99.8	279.8
Standard Waste Box	143.6	0.0	0.0	0.0	0.0	143.6
Totals	143.8	30.0	49.9	99.8	99.8	423.4

As-Generated Form: Stored: 142.4 Projected: 279.6 Total: 422.0

Final Waste Form: Stored: 143.8 Projected: 279.6 Total: 423.4

WASTE STREAM DESCRIPTION	Metal waste from gloveboxes and equipment. Gloveboxes and associated ducting, equipment and construction debri associated with the removal of glovebox operations from different location throughout the laboratory.
WASTE STREAM SOURCE	Gloveboxes and associated ducting, equipment and construction debri associated with the removal of glovebox operations
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Based on generators original disposal records, complete before RCRA requirements
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste accumulated from the repackaging of FRP boxes. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Metallic Waste	Inventory Date:	12/31/94
Local ID:	LA-M001	Type:	MTRU	Generator Site:	SA	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	1.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 4 ft X 4 ft X 8 ft	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	Metal plates in 4 x 4 x 8 FRP-Wood crate.
WASTE STREAM SOURCE	Metal plate in 4 x 4 x 8 FRP-wood crate.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Waste stream from Sandia National Laboratory - Albuquerque.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	The typical waste material weights for the final waste form for this waste steam is unknown at this time. 1 SWB is generated from the repackaging of the current box container.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W067	Handling:	CH	NMVP #:	None	Stream Name:	Combustible Debris	Inventory Date:	12/31/94
Local ID:	LA-T004	Type:	TRU	Generator Site:	IT	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
U-238	9.97E-08
U-233	1.17E-06
Pu-239	8.12E-02
Pu-238	6.31E-01
Cm-244	7.55E-01
Cm-243	1.86E-02
Am-241	5.58E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.9	0.0	0.0	0.0	0.0	8.9
Totals	8.9	0.0	0.0	0.0	0.0	8.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.9	0.0	0.0	0.0	0.0	8.9
Totals	8.9	0.0	0.0	0.0	0.0	8.9

As-Generated Form: Stored: 8.9 Projected: 0.0 Total: 8.9

Final Waste Form: Stored: 8.9 Projected: 0.0 Total: 8.9

WASTE STREAM DESCRIPTION	Lovelace ITRI TRU waste packaged into 90 mil lined drums.
WASTE STREAM SOURCE	Inhalation Toxicology Reasearch Institute (ITRI) TRU waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Typical waste material weights for final waste form are unknown for this waste stream at this time.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Non Combustible Debris	Inventory Date:	12/31/94
Local ID:	LA-T005	Type:	TRU	Generator Site:	SA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	3.56E-01
Pu-238	5.00E-01
Np-237	1.20E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Those in 001922, metal plates in boxes into 4 x 4 x 8 FRP-wood crate, HEPA filters
WASTE STREAM SOURCE	Sandia National Laboratory - Albuquerque generated this waste.
CURRENT CONTAINER COMMENTS	Package volume listed as 0.209
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Typical waste material weights for final waste form for this waste stream is unknown at this time.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W053	Handling:	RH	NMVP #:	LA 117A; 118A	Stream Name:	Scrap Metal	Inventory Date:	12/31/94
Local ID:	LA-MR01	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.2	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	7.97E+00
Co-60	1.12E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 2 gallon	0.02	0.0	0.0	0.0	0.0	0.02
LANL RH Can	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	2.7	0.0	0.0	0.0	0.0	2.7
Totals	2.7	0.0	0.0	0.0	0.0	2.7

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.7 Projected: 0.0 Total: 2.7

WASTE STREAM DESCRIPTION	Mixed metal scrap and incidental combustibles. This waste is generated at various TA's throughout LANL. THe waste consists of mostly metal or metal equipmet, either whole or sectioned and lessor amounts of combustible components. In addition, it contians small volumes of combustibles generated during the decommissioning, sectioning and packaging. The waste forms primarily include gloveboxes, process equipment, and ductwork from decomissioning operations. Gloveboxes may include gloves, wiring, plastic, glass windows, plastic wrapping and lead shielding.
WASTE STREAM SOURCE	Waste comprised of mixed metal scrape and incidental combustibles.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	None
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in bulk shafts will have to be removed and repackaged into RH canister. 3 RH Canisters are generated from the repackaging of current RH canisters.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W054	Handling:	RH	NMVP #:	unknown	Stream Name:	Non Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-MR05	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	302.9	76.9	913.5
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 117A; 118A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.91E+02
U-235	4.85E-05
Te-125m	3.53E+00
Sr-90	1.91E+02
Sb-125	8.50E+00
Ru-106	1.53E+00
Rh-106	1.52E+00
Pu-239	9.66E+00
Pm-147	1.19E+01
Eu-155	3.90E+00
Cs-137	2.09E+02
Ba-137m	1.96E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
LANL RH Can	14.2	2.7	4.4	8.9	17.8	48.1
Totals	14.2	2.7	4.4	8.9	17.8	48.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	14.2	2.7	4.4	8.9	17.8	48.1
Totals	14.2	2.7	4.4	8.9	17.8	48.1

As-Generated Form: Stored: 14.2 Projected: 33.8 Total: 48.1

Final Waste Form: Stored: 14.2 Projected: 33.8 Total: 48.1

WASTE STREAM DESCRIPTION	Non-combustible scrap - small tools, cans, equipment items, broken glass, HEPA filters leaded gloves, graphite and pyrochemical waste generated throughout the lab.
WASTE STREAM SOURCE	Non-combustible waste including HEPA filters, glass, metal , leaded rubber gloves, graphite, and pyrochemical wastes
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	None
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Additioni containers wil be produced as the bulk waste is retrieved and repackaged into RH canisters.

LL Lawrence Livermore National Laboratory

LAWRENCE LIVERMORE NATIONAL LABORATORY

Location and Description

The Lawrence Livermore National Laboratory (LLNL) is located approximately 64 kilometers east of San Francisco, California, at the southeast end of the Livermore Valley in Alameda County. LLNL consists of two sites: 1) Livermore Main Site, which is approximately 2.6 square kilometers in size and bordering on the eastern border of the City of Livermore, and 2) Site 300, which is a remote high-explosives testing facility approximately 24 kilometers southeast of the Main Site and 16 kilometers southwest of the Town of Tracy. Site 300 occupies 41 square kilometers in Alameda and San Joaquin Counties.

LLNL is owned by the Department of Energy (DOE) and is operated by the University of California for DOE. The Laboratory was established in 1952 to conduct research on nuclear weapons. Since then, other major programs have been added: magnetic fusion energy, laser fusion and laser isotope separation, biomedical sciences, environmental sciences, environmental restoration and waste management, and applied energy technology. These programs perform research in chemistry and materials science, computer science and technology, biomedical sciences, engineering, and physics.

The DOE Oakland Operations Office (DOE-OAK) is the field organization responsible for the implementation of Waste Management Plans at LLNL. The Hazardous Waste Management Division (HWM) is responsible for preparing those plans and for managing and processing all hazardous wastes, radioactive wastes, and mixed wastes generated at LLNL for the purposes of storage, treatment, and transportation for off-site disposal.

Mission

The Livermore site was purchased by the U.S. Navy in 1942 and was initially used as a flight training base and engine overhaul facility. The transition from Navy operations to research began in 1950, when the Atomic Energy commission authorized the construction for a materials-test accelerator at the site. The Commission established the University of California Radiation Laboratory, Livermore Site (the predecessor of the Lawrence Livermore National Laboratory) as a facility for nuclear weapons research.

The current mission of the LLNL, a multi-program laboratory, is research testing, and development focusing on national defense and security, energy, the environment, and biomedicine. The Laboratory's specific defense mission is the research, testing, and development of technologies related to nuclear weapons. Over the years, the Laboratory's overall mission has been broadened to meet national needs, such as the enhancement of economic competitiveness and science education. These objectives are expected to continue for the foreseeable future. Current major programs at LLNL include defense and related programs, laser fusion (also called inertial confinement fusion), laser isotope separation, magnetic fusion energy, biomedical and environmental research, energy and resources, and environmental restoration and waste management.

Waste Information

Processes

Generation and Handling: TRU waste, both non-mixed and mixed, is generated only at the Livermore Main Site. Defense programs at the Plutonium Facility (Building 332) and the Heavy Element Facility (Building 251) generate virtually all of LLNL's TRU waste. Building 332 is involved with plutonium chemistry and metallurgy, and Building 251 was principally involved with the handling of transuranics during tracer experiments. Building 332 is still operating; whereas Building 251 is currently undergoing cleanup, resulting in continued TRU waste generation.

By volume, approximately 95% of LLNL's TRU waste is contaminated primarily by plutonium isotopes. The remaining 5% is contaminated with isotopes of americium, neptunium, curium, and californium, which constitute about 60% of the total activity of the LLNL TRU waste inventory because of their higher specific activities.

Initial waste characterization is performed at the point of generation and is based on acceptable knowledge, mainly generator knowledge. Waste is assayed by the generators to determine the activity and radionuclide composition, though the latter is often determined by acceptable knowledge. Waste is then accepted for storage at the Hazardous Waste Management (HWM) storage facilities. Further waste characterization, such as real time radiography and drum headspace gas sapling, takes place at HWM.

Treatment: HWM stores no TRU waste known to require treatment to meet the WIPP WAC. However some may prove to require treatment such as HEPA filters, which may require immobilization of fine particles and waste that does not meet TRUPACT-II wattage limits or actual gas generation requirements for transport.

Storage: TRU wastes are stored at HWM's Buildings 625 and 612-1, located in the Area 612 Facility, and in Building 233 Facility, while awaiting the availability of disposal at WIPP. The Building 233 Facility, used to store high curie TRU waste, will be replaced by Building 280 to reduce site personnel exposure resulting rom its continued operations.

Disposal: TRU waste from LLNL will be disposed of at WIPP. All currently existing waste either meets the WIPP WAC and TRUPACT-II Authorized Methods for Payload Control (TRAMPAC) criteria or will meet them after repackaging or, in a few cases, treatment.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W028	Handling:	CH	NMVP #:	LL 116	Stream Name:	R&D Glovebox Waste (Form 1)	Inventory Date:	3/1/95
Local ID:	Form 1 Mixed	Type:	MTRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

D040, D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	5.0	0.0	365.0
Aluminum-base Metal/Alloys:	5.0	0.0	365.0
Other Metals/Alloys:	2.0	0.0	365.0
Other Inorganic Material:	1.0	0.0	200.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	100.0	0.0	365.0
Rubber:	5.0	0.0	200.0
Plastics:	100.0	5.0	365.0
Solidified Inorganic Material:	5.0	0.0	100.0
Solidified Organic Material:	5.0	0.0	100.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Yes

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 116A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	2.83E+01
Pu-240	9.26E-01
Pu-239	2.06E+00
Pu-238	2.46E+00
Cm-244	3.03E+00
Am-241	2.59E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon	5.4	1.9	3.1	6.2	6.0	22.7
Totals	5.4	1.9	3.1	6.2	6.0	22.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	1.9	3.1	6.2	6.0	22.7
SWB used to overpack 55 gallon drums	0.0	0.0	0.0	0.0	0.0	0.0
Totals	5.4	1.9	3.1	6.2	6.0	22.7

As-Generated Form: Stored: 5.4 Projected: 17.3 Total: 22.7

Final Waste Form: Stored: 5.4 Projected: 17.3 Total: 22.7

WASTE STREAM DESCRIPTION	The waste consists mostly of untreated dry solids such as tissues, paper, assorted plastics, glassware, ceramics, and metals. Portland cement or Aquaset is used to solidify small amounts of water-based liquids; Envirostone or Petroset is used to solidify small amounts of solvents and oil-based liquids. The composition varies considerably, but it is predominantly organics (> 90% by weight). The waste does contain small amounts of RCRA listed hazardous materials. Typical hazardous materials are leaded gloves or materials contaminated with solvents.
WASTE STREAM SOURCE	Form 1 Mixed: The waste consists of glovebox bagout waste, laboratory trash and some contaminated equipment. The waste contains small amounts of RCRA materials such as solvents or lead shielding. The waste may occasionally include small quantities of solidified liquids, but these are usually segregated as waste form 2.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Regulated contaminants reported are based on generator reports of laboratory experimental processes. This waste stream is included in LLNL's PSTP report of waste stream number LL-W018. That waste stream also included waste packages possibly, but not known to be contaminated with RCRA hazardous materials. More process knowledge and analysis will be done to further characterize those packages. Note that in this report (WTWBIR & MWIR), LL-W018 consists only of metal scrap waste, mostly in boxes, that is known to be mixed waste.
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. I have not included in this waste stream any waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Repackaging may be required due to approximately 50% of waste containers not meeting thermal power requirements of TRAMPAC; however I don't know how much repackaging will actually be required and how many extra drums would be generated thereby. Therefore, my estimates in 8.2.15 are the same as in 8.2.14. Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W029	Handling:	CH	NMVP #:	LL 111	Stream Name:	Solidified Waste (Form 2)	Inventory Date:	3/1/95
Local ID:	Form 2 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3120

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	30.0	0.0	100.0
Aluminum-base Metal/Alloys:	5.0	0.0	50.0
Other Metals/Alloys:	1.0	0.0	20.0
Other Inorganic Material:	1.0	0.0	20.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.0	0.0	100.0
Rubber:	1.0	0.0	20.0
Plastics:	20.0	5.0	100.0
Solidified Inorganic Material:	100.0	50.0	365.0
Solidified Organic Material:	100.0	50.0	365.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 111A
LL 113A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.95E+01
Pu-240	6.32E-01
Pu-239	1.40E+00
Am-241	9.09E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	14.4	0.0	0.0	0.0	5.8	20.2
Totals	14.4	0.0	0.0	0.0	5.8	20.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	14.4	0.6	1.0	2.1	2.1	20.2
Totals	14.4	0.6	1.0	2.1	2.1	20.2

As-Generated Form: Stored: 14.4 Projected: 5.8 Total: 20.2

Final Waste Form: Stored: 14.4 Projected: 5.8 Total: 20.2

WASTE STREAM DESCRIPTION	50 to 90% of this waste matrix consists of liquids solidified in 1 to 5 gallon plastic containers using Portland cement or Aquaset for the water based liquids and Envirostone or Petroset for the oil-based liquids. The remainder consists of glovebox waste similar to form 1 waste. The waste does not contain any RCRA-listed hazardous materials.
WASTE STREAM SOURCE	Form 2 Non-mixed: More than 50 volume percent of this waste consists of solidified water-based or oil-based liquids or solidified fine particles. The remaining waste consists of glovebox bagout waste, laboratory trash and some contaminated equipment.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W030	Handling:	CH	NMVP #:	LL 116	Stream Name:	R&D Glovebox Waste (Form 1)	Inventory Date:	1/1/95
Local ID:	Form 1 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	5.0	0.0	365.0
Aluminum-base Metal/Alloys:	5.0	0.0	365.0
Other Metals/Alloys:	2.0	0.0	365.0
Other Inorganic Material:	1.0	0.0	200.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	100.0	0.0	365.0
Rubber:	5.0	0.0	200.0
Plastics:	100.0	3.0	365.0
Solidified Inorganic Material:	5.0	0.0	100.0
Solidified Organic Material:	5.0	0.0	100.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	163.2		
Packaging Material Plastic:	22.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 116A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	3.17E+01
Pu-240	1.03E+00
Pu-239	2.50E+00
Pu-238	3.24E-01
Am-241	1.79E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	40.4	0.0	0.0	0.0	291.2	331.6
SWB used to overpack 55 gallon drums	7.6	22.7	37.8	75.6	75.6	219.2
Totals	47.9	22.7	37.8	75.6	366.8	550.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	40.4	31.2	52.0	104.0	104.0	331.6
SWB used to overpack 55 gallon drums	7.6	22.7	37.8	75.6	75.6	219.2
Totals	47.9	53.9	89.8	179.6	179.6	550.8

As-Generated Form: Stored: 47.9 Projected: 502.9 Total: 550.8

Final Waste Form: Stored: 47.9 Projected: 502.9 Total: 550.8

WASTE STREAM DESCRIPTION	The waste consists mostly of untreated dry solids such as tissues, paper, assorted plastics, glassware, ceramics, and metals. Portland cement or Aquaset is used to solidify small amounts of water-based liquids; Envirostone or Petroset is used to solidify small amounts of solvents and oil-based liquids. The composition varies considerably, but it is predominantly organics (> 90% by weight). The waste does not contain any RCRA listed hazardous materials.
WASTE STREAM SOURCE	Form 1 Non-Mixed: The waste consists of glovebox bagout waste, laboratory trash and some contaminated equipment. The waste may occasionally include small quantities of solidified liquids, but these are usually segregated as waste form 2.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W031	Handling:	CH	NMVP #:	LL 125	Stream Name:	Combined metal scrap & incidental combust (Form 3)	Inventory Date:	1/1/95
Local ID:	Form 3 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5420

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	20.0	0.0	30.0
Aluminum-base Metal/Alloys:	3.0	0.0	30.0
Other Metals/Alloys:	1.0	0.0	30.0
Other Inorganic Material:	1.0	0.0	5.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.0	0.0	5.0
Rubber:	1.0	0.0	5.0
Plastics:	1.0	0.0	10.0
Solidified Inorganic Material:	0.0	0.0	5.0
Solidified Organic Material:	0.0	0.0	5.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No,
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

LL 125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.45E+00
Pu-240	8.02E-02
Pu-239	9.92E-02
Pu-238	7.02E-02
Am-241	1.35E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Capital Indus. Box #1 /	7.6	0.0	0.0	0.0	0.0	7.6
Capital Indus. Box #2 /	60.0	0.0	0.0	0.0	0.0	60.0
Capital Indus. Box #3 /	6.4	0.0	0.0	0.0	0.0	6.4
Capital Indus. Box #4 /	7.5	0.0	0.0	0.0	0.0	7.5
Rogers Chem. Box #1 /	4.2	0.0	0.0	0.0	0.0	4.2
Rogers Chem. Box #2 /	5.6	0.0	0.0	0.0	0.0	5.6
Rogers Chem. Box #3 /	5.8	0.0	0.0	0.0	0.0	5.8
Rogers Chem. Box #4 /	7.6	0.0	0.0	0.0	0.0	7.6
Rogers Chem. Box #5 /	24.9	0.0	0.0	0.0	0.0	24.9
Rogers Chem. Box #6 /	8.9	0.0	0.0	0.0	0.0	8.9
Standard Waste Box /	3.8	22.7	18.9	37.8	37.8	121.0
Totals	142.4	22.7	18.9	37.8	37.8	259.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	143.6	22.7	18.9	37.8	37.8	260.8
Totals	143.6	22.7	18.9	37.8	37.8	260.8

As-Generated Form: Stored: 142.4 Projected: 117.2 Total: 259.6

Final Waste Form: Stored: 143.6 Projected: 117.2 Total: 260.8

WASTE STREAM DESCRIPTION	The waste consists mostly of metal scrap such as decommissioned gloveboxes, hoods and other large equipment as well as laboratory trash. Typically it will contain metal components, glassware, ceramics, plastics, paper, and wood. It will be mostly inorganic materials, but can vary widely. This waste does not contain RCRA listed hazardous materials.
WASTE STREAM SOURCE	Form 3 non-mixed: This waste consists of contaminated equipment and laboratory trash too big to fit in 55 gallon drums. This waste does not contain RCRA hazardous materials.
CURRENT CONTAINER COMMENTS	Contains nuclides submitted in MWIR/BIR, Rev. 1 data call in 1994, copy enclosed.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Average radionuclide content of final containers (SWBs) will depend on content of existing boxes to be repackaged and existing SWBs plus content of SWBs to be generated. Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W032	Handling:	CH	NMVP #:	LL 124	Stream Name:	Pyrochemical salt waste (Form 4)	Inventory Date:	1/1/95
Local ID:	Form 4 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3140

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	20.0	0.0	100.0
Aluminum-base Metal/Alloys:	5.0	0.0	80.0
Other Metals/Alloys:	2.0	0.0	50.0
Other Inorganic Material:	290.0	100.0	365.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.0	0.0	50.0
Rubber:	1.0	0.0	20.0
Plastics:	20.0	5.0	100.0
Solidified Inorganic Material:	1.0	0.0	10.0
Solidified Organic Material:	1.0	0.0	10.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 124A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	5.10E+01
Pu-240	1.66E+00
Pu-239	2.06E+00
Pu-238	4.74E-01
Am-241	2.81E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.4	0.5	1.0	1.0	3.6
Totals	0.6	0.4	0.5	1.0	1.0	3.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.4	0.5	1.0	1.0	3.6
Totals	0.6	0.4	0.5	1.0	1.0	3.6

As-Generated Form: Stored: 0.6 Projected: 3.0 Total: 3.6

Final Waste Form: Stored: 0.6 Projected: 3.0 Total: 3.6

WASTE STREAM DESCRIPTION	The waste consists primarily of used chloride and fluoride salts from pyrochemical processes such as electrorefining, molten salt extraction, and direct oxide reduction. There may also be up to 20% heterogeneous organic glovebox bagout waste packaged with the salt waste. This waste does not contain any RCRA listed hazardous materials.
WASTE STREAM SOURCE	Form 4 non-mixed: The waste consists of used chloride and fluoride salts from pyrochemical processes such as electrorefining, molten salt extraction, and direct oxide reduction.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W033	Handling:	CH	NMVP #:	N/A	Stream Name:	HEPA filters (Form 5)	Inventory Date:	1/1/95
Local ID:	Form 5 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	66.3	0.0	132.6
Aluminum-base Metal/Alloys:	20.7	0.0	41.3
Other Metals/Alloys:	10.0	0.0	20.0
Other Inorganic Material:	20.7	0.0	41.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	65.7	0.0	126.1
Rubber:	10.0	0.0	20.0
Plastics:	20.7	4.3	47.8
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	151.0		
Packaging Material Plastic:	4.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Yes

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.64E+00
Pu-240	1.84E-01
Pu-239	2.28E-01
Pu-238	1.68E-01
Cm-244	4.14E+00
Am-241	5.09E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Capital Indus. Box #2 /	16.0	0.0	0.0	0.0	0.0	16.0
Drum / 55 gallon	0.4	0.6	1.0	2.1	2.1	6.2
Standard Waste Box /	0.0	2.8	4.7	9.4	9.4	26.5
Totals	16.4	3.5	5.8	11.5	11.5	48.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.6	1.0	2.1	2.1	6.2
Standard Waste Box	15.1	2.8	4.7	9.4	9.4	41.6
Totals	15.5	3.5	5.8	11.5	11.5	47.8

As-Generated Form: Stored: 16.4 Projected: 32.3 Total: 48.7

Final Waste Form: Stored: 15.5 Projected: 32.3 Total: 47.8

WASTE STREAM DESCRIPTION	The waste matrix is mostly wood framed HEPA filters although some small metal cased HEPA filters are also included. Some of the filters contain asbestos.
WASTE STREAM SOURCE	Form 5 non-mixed: HEPA filters
CURRENT CONTAINER COMMENTS	
	Contains nuclides submitted in MWIR/BIR, Rev. 1 data call in 1994, copy enclosed.
EPA COMMENTS	Generator knowledge about old HEPA filters is largely lacking; however some of these filters are known to contain asbestos.
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste. Also, HEPA filters, if found to fail fine particles requirements, would require immobilization of fine particles.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as 55-gallon drum storage estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W018	Handling:	CH	NMVP #:	LL 125	Stream Name:	Combined metal scrap & incidental combust.(Form 3)	Inventory Date:	3/1/95
Local ID:	Form 3 Mixed	Type:	MTRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5420

AS-GENERATED EPA CODES

F002, D040, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	150.0	0.0	800.0
Aluminum-base Metal/Alloys:	20.0	0.0	800.0
Other Metals/Alloys:	10.0	0.0	800.0
Other Inorganic Material:	5.0	0.0	800.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.0	0.0	500.0
Rubber:	2.0	0.0	100.0
Plastics:	20.0	5.0	200.0
Solidified Inorganic Material:	2.0	0.0	300.0
Solidified Organic Material:	2.0	0.0	300.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	5.94E-01
Pu-240	2.03E-02
Pu-239	8.78E-03
Am-241	1.04E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box /	1.9	3.8	3.8	9.5	9.5	28.5
Totals	1.9	3.8	3.8	9.5	9.5	28.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	3.8	3.8	9.4	9.4	28.3
Totals	1.9	3.8	3.8	9.4	9.4	28.3

As-Generated Form: Stored: 1.9 Projected: 26.6 Total: 28.5

Final Waste Form: Stored: 1.9 Projected: 26.5 Total: 28.3

WASTE STREAM DESCRIPTION	The waste is potentially radioactive inorganic scrap metal generated from on-site laboratory research and maintenance, including laboratory clean up. Includes lead bricks and metal shavings. These materials may contain transuranic activity (80.6 lbs. in 55-gal. drum) Waste is used and discarded metal parts generated from on-site research and development activities.
WASTE STREAM SOURCE	Form 3 mixed: This waste consists of contaminated equipment and laboratory trash too big to fit in 55 gallon drums. This waste does contain RCRA hazardous materials. Inorganic scrap metal generated from on-site laboratory research and maintenance, including laboratory clean up.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Regulated contaminants reported are based on generator reports of laboratory experimental processes. This waste stream is included in LLNL's PSTP report of waste stream number LL-W018. That waste stream also included waste packages possibly, but not known to be contaminated with RCRA hazardous materials. More process knowledge and analysis will be done to further characterize those packages. Note that in this report (WTWBIR & MWIR), LL-W018 consists only of metal scrap waste, mostly in boxes, that is known to be mixed waste.
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. I have not included in this waste stream any waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W019	Handling:	CH	NMVP #:	LL 111	Stream Name:	Solidified Waste (Form 2)	Inventory Date:	3/1/95
Local ID:	Form 2 Mixed	Type:	MTRU	Generator Site:	LL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3220

AS-GENERATED EPA CODES

F002, D040

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	30.0	0.0	100.0
Aluminum-base Metal/Alloys:	5.0	0.0	50.0
Other Metals/Alloys:	1.0	0.0	20.0
Other Inorganic Material:	1.0	0.0	20.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.0	0.0	100.0
Rubber:	1.0	0.0	20.0
Plastics:	20.0	5.0	100.0
Solidified Inorganic Material:	100.0	50.0	365.0
Solidified Organic Material:	100.0	50.0	365.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 111A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.01E+01
Pu-240	6.63E-01
Pu-239	7.89E-01
Am-241	1.24E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	5.8	6.9
Totals	1.0	0.0	0.0	0.0	5.8	6.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.6	1.0	2.1	2.1	6.9
Totals	1.0	0.6	1.0	2.1	2.1	6.9

As-Generated Form: Stored: 1.0 Projected: 5.8 Total: 6.9

Final Waste Form: Stored: 1.0 Projected: 5.8 Total: 6.9

WASTE STREAM DESCRIPTION	The waste is radioactive halogenated solvents generated from on-site cleaning of tanks and equipment and operating of research laboratories and machining shops. Waste consists of TCE and TCA and may contain transuranic activity (0.6 lbs. in a 55-gallon drum). Waste is generated from the on-site cleaning of tanks and equipment used in changing R & D activities.
WASTE STREAM SOURCE	Form 2 Mixed: More than 50 volume percent of this waste consists of solidified water-based or oil-based liquids or solidified fine particles. The remaining waste consists of glovebox bagout waste, laboratory trash and some contaminated equipment.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Regulated contaminants reported are based on generator reports of laboratory experimental processes. This waste stream is included in LLNL's PSTP report of waste stream number LL-W018. That waste stream also included waste packages possibly, but not known to be contaminated with RCRA hazardous materials. More process knowledge and analysis will be done to further characterize those packages. Note that in this report (WTWBIR & MWIR), LL-W018 consists only of metal scrap waste, mostly in boxes, that is known to be mixed waste.
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. I have not included in this waste stream any waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

MC U.S. Army Material Command

U.S. ARMY MATERIAL COMMAND

Location and description

The U.S. Army Material Command (MC) is located at Rock Island, Illinois, near Davenport, Iowa. MC is responsible for coordinating logistical demands for the various programmatic functions of the U.S. Army, including research and development of weapons.

Mission

MC is responsible for disposal of radioactive waste resulting from U.S. Army applications.

Waste Information

Processes

Currently the Army possesses packaged americium and plutonium sources in man-portable containers. Some of the sources are mixed with beryllium, potentially rendering the material mixed waste. Most of this waste is packaged and ready for shipment in trucks.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MC-W001	Handling:	CH	NMVP #:	N/A	Stream Name:	USAMC TRU Waste	Inventory Date:	1/1/95
Local ID:		Type:	TRU	Generator Site:	MC	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source:

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.11E-01
Pu-239	2.43E-02
Am-241	6.21E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.5	0.0	0.0	0.0	0.0	2.5
Totals	2.5	0.0	0.0	0.0	0.0	2.5

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 2.5 Projected: 0.0 Total: 2.5

WASTE STREAM DESCRIPTION	Army sources
WASTE STREAM SOURCE	Discarded sources.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

MD Mound Plant

MOUND PLANT

Location and Description

Mound (MD) is located within the southern city limits of Miamisburg in Montgomery County in southwestern Ohio. The plant occupies 306 acres of land overlooking Miamisburg and the Great Miami River. The metropolitan area of Dayton is located 10 miles north-northeast of Mound.

The DOE Dayton Area Office was established as part of the Albuquerque Operations Office in 1947.

The Mound Plant (MD) is one of the principal DOE sites. The facility was utilized as an integrated research, development, and production facility to perform work in support of DOE weapons and energy programs. Mound manufactured non-nuclear and tritium-containing components for nuclear weapons. These components included detonators, timers, transducers, firing sets, pellets, and unique production testers. Activities also included recovery and purification of tritium wastes. Earlier activities included manufacturing of polonium-210 and plutonium-238 radioisotopic heat sources.

Mission

Mound originated as a technical organization in 1943 and was responsible for determining the chemical and metallurgical properties of plutonium for the Manhattan Project. Permanent facilities were first constructed in 1947 and occupied in 1948. The plant was assigned new production and development functions in 1955.

In 1993, the Secretary of Energy announced that the Defense Program Mission was to be ended at Mound. Mound's new mission is the safe shutdown of Defense Programs and commercialization of some of the area offices.

Waste Information

Processes

TRU waste may be generated by the Decontamination and Decommissioning (D&D) operations in the Plutonium Processing Building and the Research Building.

Large quantities of the line-generated solid wastes, including gloveboxes, fume hoods, piping, tools and other non-burnables, as well as rags, chemwipes, and other combustible waste was and will be generated by the Pu Processing and Research Buildings D&D Project.

TRU alpha wastes are generated from decontamination operations in the Pu Processing Areas.

Other major D&D efforts included the removal of underground piping which formerly transmitted Pu-contaminated liquid waste from the processing area to the waste water treatment facility.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-M001	Handling:	CH	NMVP #:	N/A	Stream Name:	Asbestos Debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Filter	Waste Matrix Code:	S5125

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Yes

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	2.98E-02
Pu-238	1.63E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Assorted asbestos and other filter media. Predominantly asbestos.
WASTE STREAM SOURCE	805, Asbestos and other filters utilized in first stage hood line ventilation exhaust.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Since the majority of questions were answered as unknown our confidence level is LOW.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This is not a MTRU waste stream. It was incorrectly assigned as MTRU in previous reports and is being officially corrected in this report.
FINAL FORM COMMENTS	Assumption is that shipping and storage containers are the same.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T001	Handling:	CH	NMVP #:	N/A	Stream Name:	Cement Forms	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	Z1110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	1143.0	964.0	1204.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-238	1.20E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 4.2 Projected: 0.0 Total: 4.2

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	WD TRU sludge, batch #194. Sludge wastewater mixed with cement to form a cement monolith inside a 55 gallon drum.
WASTE STREAM SOURCE	836, Solidified TRU Sludge (20% solids and 80% water) solidified with portland cement in WD Building. Solids included carbon and calcium.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence is LOW due to unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T003	Handling:	CH	NMVP #:	N/A	Stream Name:	Contaminated soil	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Soils	Waste Matrix Code:	S4100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	891.0	603.0	1315.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	1.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-238	2.63E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Type 004	46.3	0.0	0.0	0.0	0.0	46.3
Box / Type 005	66.4	0.0	0.0	0.0	0.0	66.4
Box / Type 008	3.2	0.0	0.0	0.0	0.0	3.2
Totals	115.8	0.0	0.0	0.0	0.0	115.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	146.9	0.0	0.0	0.0	0.0	146.9
Totals	146.9	0.0	0.0	0.0	0.0	146.9

As-Generated Form: Stored: 115.8 Projected: 0.0 Total: 115.8

Final Waste Form: Stored: 146.9 Projected: 0.0 Total: 146.9

WASTE STREAM DESCRIPTION	SM building and hillside hot spot #3 excavation
WASTE STREAM SOURCE	842DD000 TRU soil. Soil from SM building and hillside remediation of the Waste Transfer system (WTS).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level based on the number of unknowns reported.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	62 SWB will be potentially required based on volume alone. This is a soil waste stream and based on the weight it would have been impossible to fill the storage containers completely full, therefore 62 is a worst case scerino. Another issue is the possible additional waste created by disposing of the storage containers if they are TRU also.

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T005	Handling:	CH	NMVP #:	N/A	Stream Name:	Contaminated soils with debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Soils	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	632.0	566.0	1293.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-238	1.45E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Type 004	25.3	0.0	0.0	0.0	0.0	25.3
Box / Type 005	4.7	0.0	0.0	0.0	0.0	4.7
Totals	30.0	0.0	0.0	0.0	0.0	30.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	30.2	0.0	0.0	0.0	0.0	30.2
Totals	30.2	0.0	0.0	0.0	0.0	30.2

As-Generated Form: Stored: 30.0 Projected: 0.0 Total: 30.0

Final Waste Form: Stored: 30.2 Projected: 0.0 Total: 30.2

WASTE STREAM DESCRIPTION	SM-10 & Hillside hot spot #3 excavation.
WASTE STREAM SOURCE	842, TRU soil with rock debris. Soil and rock from SM building and hillside remediation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is LOW based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T006	Handling:	CH	NMVP #:	N/A	Stream Name:	Metal debris w/o lead or cadmium	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-238	5.36E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Type 003	7.0	0.0	0.0	0.0	0.0	7.0
Box / Type 004	46.3	0.0	0.0	0.0	0.0	46.3
Box / Type 008	6.3	0.0	0.0	0.0	0.0	6.3
Totals	59.6	0.0	0.0	0.0	0.0	59.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	58.6	0.0	0.0	0.0	0.0	58.6
Totals	58.6	0.0	0.0	0.0	0.0	58.6

As-Generated Form: Stored: 59.6 Projected: 0.0 Total: 59.6

Final Waste Form: Stored: 58.6 Projected: 0.0 Total: 58.6

WASTE STREAM DESCRIPTION	Metal debris from D&D of Bldgs. 38-10 & 13, SM-10 & 25, R-120 & 149 and Waste Transfer system (WTS).
WASTE STREAM SOURCE	824, D&D metal debris. Waste Transfer System (WTS) piping consisting of steel pipe withj some type of plastic lining. Steel tank from Building 41. Floor drains and piping from SM, PP and R Buildings.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is low based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Repackaging into SWB would require 31 containers based on volume only. Additonal waste from the empty containers would also be genereated.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T007	Handling:	CH	NMVP #:	N/A	Stream Name:	Uncategorized metal debris.	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	149.2		
Packaging Material Plastic:	7.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	3.96E-01
Pu-238	1.29E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.0	0.0	0.0	0.0	0.0	5.0
Box / Type 003	2.3	0.0	0.0	0.0	0.0	2.3
Box / Type 004	12.6	0.0	0.0	0.0	0.0	12.6
Box / Type 008	3.2	0.0	0.0	0.0	0.0	3.2
Totals	23.1	0.0	0.0	0.0	0.0	23.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.0	0.0	0.0	0.0	0.0	5.0
Standard Waste Box	18.9	0.0	0.0	0.0	0.0	18.9
Totals	23.9	0.0	0.0	0.0	0.0	23.9

As-Generated Form: Stored: 23.1 Projected: 0.0 Total: 23.1

Final Waste Form: Stored: 23.9 Projected: 0.0 Total: 23.9

WASTE STREAM DESCRIPTION	Miscellaneous equipment - hood line trash.
WASTE STREAM SOURCE	825 TRU metal debris. Inline Noncombustible waste removed from hood lines.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is LOW due to the number of unknowns.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Assumption is that current drum is WIPP acceptable.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T008	Handling:	CH	NMVP #:	N/A	Stream Name:	Uncategorized plastics/rubber debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Combustible	Waste Matrix Code:	S5319

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-239	2.98E-02
Pu-238	2.72E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 3.7 Projected: 0.0 Total: 3.7

WASTE STREAM DESCRIPTION	Plastic and rubber debris from Bldg. 38, Room 149
WASTE STREAM SOURCE	804, Uncategorized plastics/rubber debris. Combustible waste removed from hood lines.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	LOW confidence level based on the number of unknowns.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T009	Handling:	CH	NMVP #:	N/A	Stream Name:	Unknown/Other Organic Debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	8.37E+00
Pu-238	3.10E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Uncategorized combustible debris
WASTE STREAM SOURCE	801+804, Uncategorized combustible debris.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is LOW due to the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T010	Handling:	CH	NMVP #:	N/A	Stream Name:	Composite filters	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-239	1.49E-02
Pu-238	8.17E-01
Np-237	8.17E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Filters from Bldgs. 38, room 113.
WASTE STREAM SOURCE	825, Glass + metal filters, cans-glass. First stage filters for hood line exhaust ventilation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T012	Handling:	CH	NMVP #:	N/A	Stream Name:	Uncategorized heterogeneous debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	1.01E+01
Pu-238	1.95E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	Bldg. 38, room 113, R, room 140
WASTE STREAM SOURCE	825 Metal, glass, asbestos filters
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level LOW due to the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-W002	Handling:	CH	NMVP #:	N/A	Stream Name:	Absorbed Aqueous Liquids	Inventory Date:	5/5/95
Local ID:	N/A	Type:	MTRU	Generator Site:	MD	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3113

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	2.32E-02
Pu-238	7.24E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	This waste is corrosive TRU solutions (primarily nitric acid) absorbed into an inorganic particulate absorbent. There is no free liquid, therefore this waste stream does not currently meet the D002 definition and not mixed. It will remain classified as MTRU until proven othewise by a WIPP acceptable method and under control of a QAPjP.
WASTE STREAM SOURCE	This process and analytical waste was generated from Pu-238 operations. 833 Corrosives - TRU Acidic and Basic waste absorbed on FLORCO
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The D002 code is maintained due to the question of whether this waste remains corrsive.
MANAGEMENT COMMENTS	Building 23 Mixed waste storage facility.
ACCEPTANCE COMMENTS	Plutonium processing and analysis. The entire inventory is indicated as not subject to the LDR storage prohibition as it was stored before the LDR effective date.
FINAL FORM COMMENTS	The shipping and storage containers are assumed to be the same.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-W003	Handling:	CH	NMVP #:	N/A	Stream Name:	Leaded Gloves/Aprons	Inventory Date:	5/5/95
Local ID:	N/A	Type:	MTRU	Generator Site:	MD	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	6.16E+00
Pu-238	8.89E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 1.7 Projected: 0.0 Total: 1.7

WASTE STREAM DESCRIPTION	Lead loaded drygloves removed from gloveboxes during decommissioning operations.
WASTE STREAM SOURCE	Generated from decommissioning of gloveboxes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is based on the number of unknowns.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	New leaded gloves are no longer introduced into the Mound Facility which is why the "expected generation termination date" is indicated as 1/1/93. However, it is possible additional leaded gloves (transuranic) at Mound which have not yet been declared waste may be generated. Although the possibility exists for additional waste, it is impossible to predict when and what the quantles would be.
FINAL FORM COMMENTS	Storage and shipping containers were assumed to be the same

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-W017	Handling:	CH	NMVP #:	N/A	Stream Name:	Paper/Cloth Debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Combustible	Waste Matrix Code:	S5330

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-239	3.86E-01
Pu-238	2.66E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

As-Generated Form: Stored: 1.5 Projected: 0.0 Total: 1.5

Final Waste Form: Stored: 1.5 Projected: 0.0 Total: 1.5

WASTE STREAM DESCRIPTION	Paper and cloth waste removed from hood lines as a result of routine production operations in Building 38.
WASTE STREAM SOURCE	Paper and Cloth from PP Building
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Assuming that the storage and shipping container are the same.

UNIVERSITY OF MISSOURI RESEARCH REACTOR

Location and Description

The University of Missouri-Columbia (MU) is located in Columbia, Missouri at the University's Research Park. MU maintains a 10 mW research reactor licensed by the NRC. The Missouri University Research Reactor is one of only a few high-quality research reactors in the United States. The University is contracted by Rockwell International to conduct experiments to separate radioactive actinide elements from PUREX spent fuel for DOE.

Mission

MU conducts a wide variety of nuclear energy experiments. Research at MU has focused on many areas, including studies of the effects of trace elements on human health; studies of the basic wave nature of particles using neutron interferometry, development of radioisotopes for human therapy, and development of the TRUMP-S process to separate TRU materials from nuclear waste (PUREX).

Waste Information

Processes

MU currently has several grams of TRU materials provided by the DOE for experiments on the TRUMP-S Program. TRU waste is generated as a part of normal program operations. Additional TRU waste is expected at the conclusion of the program when the facility is decontaminated and decommissioned. Management of the TRU waste generated from the TRUMP-S experiments conducted at MU is the responsibility of the DOE program office overseeing nuclear energy research.

Modifications/Assumptions/Development

MU reported radionuclides in Curies per gram. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the final waste form volumes reported by MU.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MU-W002	Handling:	CH	NMVP #:	NA	Stream Name:	Heterogeneous Debris	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:	MU	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

D011, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	11.3	0.0	20.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	25.0	0.0	60.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.5	0.0	10.0
Rubber:	25.0	0.0	50.0
Plastics:	37.5	0.0	80.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
U-238	1.65E-07
Pu-239	3.62E-02
Np-237	3.23E-04
Am-241	1.50E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.6	0.2	0.0	0.0	1.0
Totals	0.2	0.6	0.2	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.6	0.2	0.0	0.0	1.0
Totals	0.2	0.6	0.2	0.0	0.0	1.0

As-Generated Form: Stored: 0.2 Projected: 0.8 Total: 1.0

Final Waste Form: Stored: 0.2 Projected: 0.8 Total: 1.0

WASTE STREAM DESCRIPTION

MTRU Heterogeneous Debris. The radioactive wastes generated on the project will come first from normal operations and second from the D&D of the facility at the end of the project. Radioactive wastes from normal operation will consist of the following:

- o HEPA filters from the glove box
- o HEPA filters from offgas and room filtration systems
- o paper wipes from periodic cleaning of the glove boxes
- o used sample bottles
- o damaged glove box gloves
- o used crucibles, tubes, and wires

WASTE STREAM SOURCE

The radioactive wastes generated on the project will come first fro n normal operations and second from the D&D of the facility at the end of the project. Radioactive wastes from normal operation will consist of the following:

- o HEPA filters from the glove box
- o HEPA filters from offgas and room filtration systems
- o paper wipes from periodic cleaning of the glove boxes
- o used sample bottles
- o damaged glove box gloves
- o used crucibles, tubes, and wires $ $ Mixed TRU Waste

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Waste has not yet been characterized

MANAGEMENT COMMENTS

MURR, costar tower 5th level in containment.

ACCEPTANCE COMMENTS

□□GENERAAREA: MURR Alpha Room□□GENOPERATI: The TRUMP-S test program uses three glove boxes located in the Alpha Lab: the argon box, the air box, and the ICP box. The three boxes are equipped with various pieces of test equipment.

The argon box is used to conduct the electrochemical experiments that are the objective if the program. Actinide metals are unpacked in this box, subdivided, and repackaged. Chloride salts of the actinides are prepared here. Samples of the materials used in the experiments are obtained in the argon box for analysis. The argon box is frequently cleaned using paper wipes, which are packaged in small waste cans for disposal.

The air box is used to prepare aqueous samples for analysis in the ICP box. These samples are later prepared for recovery of the actinides by evaporating the water. Tantalum materials that have been used in the argon box are cleaned in the air box for later reuse in the electrochemical tests. The air box is also frequently cleaned using paper wipes and these are likewise placed in waste cans for disposal.

The ICP box is used to analyze the chemical composition of various aqueous samples. The nebulizer of the ICP unit is located within the ICP box to contain the analysis samples. The atmosphere within the ICP box is air.

Materials used in the actinide tests: Test materials, along with paper wipes and waste cans for cleanup, are passed into the argon box through a transfer port from the Alpha lab. The test materials include the following items:

- o Actinide and rare earth elements as metals and chlorides
- o Cadmium as both metal and chloride
- o Tantalum and alumina crucibles
- o Tantalum, iron, and silver wire

- o Chloride salts (Ag, Li, K)
- o Alumina and Pyrex tubing
- o Tantalum foil
- o Sample bottles
- o NAA samples returned for use

Some solid samples of test materials are removed from the argon box through the neutron activation analysis (NAA) sample station for neutron activation or gamma spectrometer analysis. All other exits from the argon box are to the air box. Samples for analysis in the ICP, crucibles containing mixtures of actinides along with salts and cadmium, used tantalum materials, broken or used Pyrex and alumina, wire (Ta, Fe, and Ag), damaged glove box gloves, and packaged wastes (paper wipes) are all transferred to the air box through an interconnecting transfer port. Tantalum materials are normally cleaned and reused in the electrochemistry tests a number of times before they are disposed of as waste.

Aqueous chemicals, water, and beakers are transferred into the air box from the Alpha Lab for preparing and handling aqueous samples. These samples are analyzed in the ICP box and then returned to the air box. The air box is also cleaned frequently with paper wipes, and these are packaged in waste cans for disposal. Materials that are removed during test operations from the air box are either actinide materials that are being sent to storage, or wastes that are placed in 55-gal drums. Actinide materials consist of original actinide metal, crucibles containing actinides, salt, and cadmium metal, sample residue (oxides and chlorides remaining from aqueous samples), and NAA samples. Actinide materials are routinely removed from the glove boxes and returned to storage in sealed storage containers. The wastes removed from the air box will be used HEPA filters and refuse packaged in waste cans. Items removed from the air box are sealed in plastic bags as they exit the transfer port into the Alpha Lab.□□RECLASS_CO: classification of MURR waste is not complete□□CATION: NA□□WASTE_PACK: 55-gallon drums

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FINAL FORM COMMENTS N/A

NEVADA TEST SITE

Location and Description

The Nevada Test Site (NTS) is located in Ny County approximately 105 kilometers northwest of Las Vegas, Nevada. The 3497-square-kilometer site is adjacent to the Nellis Air Force Ranges. The eight offsite test areas include the Central NTS and Shoal Test Area, Nevada; Amchitka Island, Alaska; the Rio Blanco and Rulison gas stimulation test sites, Colorado; the Gasbuggy gas stimulation and Gnome-Coach test sites, New Mexico; and Salmon test site, Mississippi. The Nevada Operations Office (NV) is located in Las Vegas with the NTS Office in Mercury, Nevada.

The NTS was selected as the continental proving ground for field testing nuclear weapons in 1950 with the first nuclear test occurring in January 1951. When the decision was made to conduct tests year-round, NV was created in 1962. Although some off-site tests were conducted, all tests since 1973 have been conducted at NTS.

Mission

The original mission of the NTS was field testing of nuclear weapons in support of the nuclear weapons laboratory and weapons-effects testing in support of the Defense Advanced Research Projects Agency and the Defense Nuclear Agency (DNA).

Today's mission of NTS is to maintain the readiness mode for the resumption of nuclear testing, remediate contaminated areas, and to serve as the largest disposal site for DOE and DOD defense-related low-level radioactive waste.

Waste Information

Processes

The NTS serves as a major disposal facility for low level waste and has inactive disposal facilities that were used for TRU waste. The NTS accepted TRU waste from the Lawrence Livermore National Laboratory (LLNL), for the purpose of storage from 1974 until 1990. This waste is considered mixed waste and is stored in a sprung steel building on a RCRA compliant curbed asphalt pad enclosed by a security fence. In keeping with the agreement made with the State of Nevada, the NTS will no longer accept TRU waste for storage.

Modifications/Assumptions/Development

NT reported radionuclides in nanocuries per gram. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the final waste form volumes reported by NT.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	NT-W001	Handling:	CH	NMVP #:	NT 111A;116A;2	Stream Name:	Heterogeneous Debris, Uncategorized
Local ID:	None	Type:	MTRU	Generator Site:	LL	Final Waste Form:	Heterogeneous

Inventory Date: 4/30/95

Waste Matrix Code: S5490

AS-GENERATED EPA CODES

P015, F003, F002, F001, D011, D008, D007, D006, D003, D002, D001, CA352, CA181

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	72.2	6.1	422.5
Aluminum-base Metal/Alloys:	12.3	0.0	399.0
Other Metals/Alloys:	5.8	0.0	383.4
Other Inorganic Material:	4.8	0.4	304.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	52.5	0.0	315.8
Rubber:	3.8	0.0	121.7
Plastics:	50.1	3.7	234.3
Solidified Inorganic Material:	11.8	4.4	155.7
Solidified Organic Material:	11.8	4.4	155.7
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	141.1		
Packaging Material Plastic:	28.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

NT 111A; 116A; 211A;225A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
MFP	3.39E-02
Am-243	1.99E-03
C-14	4.09E-07
Cf-249	1.89E-05
Cf-250	5.29E-04
Cf-252	8.94E-03
Cm-243	1.10E-06
Cm-244	6.78E-03
Cm-248	1.05E-11
Cs-137	6.53E-05
Depleted U	1.97E-07
Eu-152	3.33E-03
Eu-154	1.99E-03
Am-241	4.91E-01
Kr-85	6.53E-04
Pu-244	1.63E-09
U-235	1.71E-07
U-234	8.15E-06
U-233	2.94E-03
U-232	2.95E-05
H-3	2.04E-04
Ra-226	4.09E-04
U-238	5.45E-08
Pu-242	1.42E-04
Pu-241	5.61E-01
Pu-240	3.04E-02
Pu-239	4.53E+00
Pu-238	2.41E-01
Pa-231	8.15E-07
Np-237	7.83E-06
Sr-90	2.23E-07

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon	343.0	0.0	0.0	2.4	2.8	348.2
Drum / 85 gallon	0.3	0.0	0.0	0.3	0.0	0.6
Nonstandard Box	271.4	0.0	0.0	0.0	0.0	271.4
Totals	614.8	0.0	0.0	2.8	2.8	620.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	343.0	0.0	0.0	2.4	2.8	348.2
Standard Waste Box	270.3	0.0	0.0	3.8	0.0	274.0
Totals	613.3	0.0	0.0	6.2	2.8	622.2

As-Generated Form: Stored: 614.8 Projected: 5.5 Total: 620.3

Final Waste Form: Stored: 613.3 Projected: 9.0 Total: 622.2

WASTE STREAM DESCRIPTION

This waste stream consists of glovebox parts, laboratory trash, contaminated equipment and solidified sludges. Real time radiography has been performed on the waste to verify that there are no free liquids present, with the exception of liquid in aerosol cans, which, when treated will be eliminated from this waste stream. Most of the waste is contact-handled TRU waste; 3 drums are remote-handled.* The waste stream was generated at the Lawrence Livermore National Laboratory, Livermore, CA (LLNL) and shipped to the NTS from 1974 until 1990. The waste was declared as potentially mixed TRU waste by the generator in April, 1991.
*Due to recent storage reconfigurations and surveys, only three of the 4 previously reported packages are considered remote-handled.

WASTE STREAM SOURCE

NTS STORED, TRU WASTE FROM LLNL
This waste stream, consisting of glovebox parts, laboratory trash, contaminated equipment, and solidified sludges, was generated from operations activities conducted at LLNL Buildings 251, 332, and 419. Actual activities and processes conducted to generate this waste stream are unknown.

CURRENT CONTAINER COMMENTS

Currently, all 55-gal. drums are overpacked within 85-gal. vented drums.
Vented drum of decon debris
58 total; 70x69x81 (bxwxh) max. dimensions

EPA COMMENTS

Regulated contaminant information is based on process knowledge. No sampling of waste constituents has been conducted to date.

MANAGEMENT COMMENTS

The Nevada Test Site (NTS) is located about 105 km (65 mi) northwest of Las Vegas, and occupies 3,497 km2 (1,350 mi2) of federally owned land in southeastern Nevada's Nye County. The Area 5 Radioactive Waste Management Site (RWMS) is located in Frenchman Flat within the southeast corner of the NTS, approximately 15 miles north of Mercury, Nevada and 80 miles northwest of Las Vegas, Nevada. The developed portion of the Area 5 RWMS occupies 37 hectares (ha) (92 acres) in the southeast corner of the 296 ha (732 acres) designated area of NTS Area 5. Building 5-24, a 21,470 square-foot fabric-covered structure, is located within the 92-acre RWMS on the TRU Waste Storage Pad, an asphalt pad comprising an area of 0.829 ha (2.05 acres) constructed to meet RCRA standards.

ACCEPTANCE COMMENTS

The majority of this waste inventory was packaged before RCRA characterization requirements were imposed. Lawrence Livermore National Laboratory (LLNL) (the generator) declared the inventory to be "mixed" in April 1991. EPA Codes were estimated on the basis of TRU waste assessments and other information provided by the generator. The actual waste matrix and contaminant parameters will be further defined during future waste characterization and certification activities for the express purpose of certifying the waste to meet TRUPACT transport and WIPP disposal requirements.**This TRU waste inventory originated from LLNL/ Bldg. 251, LLNL/Bldg. 332, and LLNL/Bldg. 419; contact: Kem Heinebach, LLNL, (510) 422-4572□. LLNL/Bldg. 251 generated TRU waste containing debris potentially contaminated with the following RCRA solvents and acids: nitric acid dried on Kimwipes (ignitable) (EPA code D001), and RCRA metals cadmium in "silver" solder (EPA code D006) and lead (EPA code D008).**LLNL/Bldg. 332 generated TRU waste debris potentially contaminated with: carbon tetrachloride (CC1-4) on Kimwipes (F001), ethyl alcohol (D001), freon TF on cotton wipes and Kimwipes (F001), methanol on Kimwipes (F003), nitric acid (D002, and if >45%, an oxidizer (D001), nitric acid on Kimwipes (ignitable) (D001), trichloroethylene (TCE) (F001), varnish and paints (D001); RCRA metals calcium (D003), and lead (D008); and the following CA hazardous wastes: beryllium, sometimes as flakes, (CA code 181), cerium (CA 181), copper (CA 181), copper shavings (CA 181), gallium (CA 181), Invoil-42 (an oil, potentially CA hazardous) (CA 352), kerosene (an oil, potentially CA hazardous) (CA 352), magnesium powder (CA 181), oil and oily rags (CA 352), and yttrium oxide (CA 181).
LLNL /Bldg. 419: TRU waste debris potentially contaminated with: trichloroethylene (TCE) (F001), and CA hazardous waste oil (California code 352).**Past assay efforts resulted in undetermined final numbers on gram content; re-assay to be conducted.**It has been established that the bulk of the TRU mixed wastes stored at the Area 5 RWMS were placed into storage prior to the effective date of the LDR prohibitions applicable to solvent waste and that any attempt to move the wastes to another facility would trigger LDR requirements. Mixed wastes stored prior to the effective date of applicable LDR requirements "are not subject to the LDR storage prohibition as long as they are not removed from storage or otherwise actively managed while in storage." (57 Federal Register 22024, 22041 [05-26-92]).**The management of the Area 5 RWMS TRU mixed waste inventory is governed by a Settlement Agreement between the state of Nevada and DOE/NV. The TRU mixed waste shall remain in storage until such time that EPA issues a no-migration variance to WIPP, after the test phase, or when suitable treatment capacity is developed with which to treat the wastes. The TRU mixed waste is contained in 1636 0.208 m3 (55-gallon) steel drums and 58 steel boxes of various sizes. The 55-gallon drums are overpacked in 0.321 m3 (85-gallon) DOT Type A drums which are vented with carbon-composite filters. The inventory also includes one 0.321 m3 (85-gallon) drum which is vented with a carbon-composite filter. The containers are stored on pallets inside the TRU Cover Building 5-24. The drums are triple-stacked and boxes double-stacked. Three-foot aisleways between container rows provide for routine RCRA inspections, and 4-foot fire aisles are located at all four personnel exits.** Lead may have been used as shielding inside

some containers. Liquids are solidified in individual one-gallon, metal paint can containers which are then placed in 55-gallon drums, although several containers were found to contain small amounts of free liquids (via RTR). Boxed waste includes decommissioned glove boxes, hoods, and large pieces of contaminated equipment. Combustibles (tissues, paper, assorted plastics, and bagging) fill the void spaces in both boxes and drums. Most boxes have permanent skids, but all are stored on pallets. A standard eight-ton forklift is used to shuttle the boxes, and a drum-handler is attached to the fork tines to shuttle drums.

FINAL FORM COMMENTS

Included in current storage numbers is the assumption that two boxes containing 12 drums will be transferred into 12 0.208m3 drums (55 gallon drums). Projections include 25 55 gallon drums from decon activities.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	NT-W021	Handling:	CH	NMVP #:	Unknown	Stream Name:	V3XA Spheres	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	LL	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	544.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	1.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-242	1.15E-04
Pu-241	3.19E+01
Pu-240	1.30E+00
Pu-239	5.69E+00
Pu-238	1.92E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Sphere/3-ft. dia X 4-ft. dia Stainless Steel	0.9	0.0	0.0	0.0	0.0	0.9
Totals	0.9	0.0	0.0	0.0	0.0	0.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	5.7	0.0	0.0	0.0	0.0	5.7
Totals	5.7	0.0	0.0	0.0	0.0	5.7

As-Generated Form: Stored: 0.9 Projected: 0.0 Total: 0.9

Final Waste Form: Stored: 5.7 Projected: 0.0 Total: 5.7

WASTE STREAM DESCRIPTION	The two steel vessels are 1-inch thick by 3-feet diameter, weighing about 2700 lbs. each. The vessels contain heterogeneous mixtures of the following materials: Plutonium, D-38, Beryllium metal, Completely burned high explosive, Stainless steel, Brass, Polystyrene foam, Aluminum, Coke (degassed coal), Water absorbed by the coke, Steel, Glass, Epoxy resin, Thermalite (aerated cement block), Plaster, Hortag (fly-ash and clay), Wood, and Krypton-85 tracer gas for leak detection. The UK has had similar vessels in storage for over ten years, but none containing plutonium have ever been opened. Vessels containing D-38 only have been opened, with small amounts of water vapor and some loose debris found inside. The bulk of the materials were found to be trapped within the thick coke layer lining the inner surface of the vessel. No more wastes of this type are planned to be generated.
WASTE STREAM SOURCE	This waste stream was received for storage at the NTS Area 5 RWMS TRU Waste Storage Pad in 1994, and was generated by LLNL, Livermore, CA. This is a "one-time" generated TRU waste stream, resulting from joint US/UK tests conducted in the United Kingdom. Each vessel is a 3-foot diameter sphere, weighing about 2,700 pounds. High explosives were detonated inside the vessel chamber, resulting in a concrete-like, heterogeneous substance made up of plutonium, depleted uranium, beryllium, pulverized coke, glass, wood, steel, and aluminum debris.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	This waste stream is not "mixed."
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Previously, LLNL had inquired about having an exemption from WIPP WAC issued for this waste stream. Per correspondence from Arlen Hunt (ALO/WIPP) to Daniel Nakahara (DOE/SAN) [memo TSIT:HJD 90-0049, "TRU Material Above WIPP-WAC Safety Limits", March 6, 1990], the Waste Acceptance Criteria Certification Committee could not determine "if these containers will ever qualify for disposal at WIPP." Until such time that an alternative disposal site is made available, or exemption from the WIPP-WAC is received, this waste stream will remain in safe storage at the NTS.
FINAL FORM COMMENTS	Internal volume of SWB is assumed to be 1.89 cubic meters; total waste stream volume (external) estimated at 5.678 cu. m., divided by 1.89 = 3 SWBs. Plastic bagging would be used to contain any contamination. This also assumes, although highly unlikely, that the vessels are size-reduced to fit inside SWBs, as opposed to being shipped within TDOPs. Considering FGE within each vessel, two TDOPs could probably be used for shipping this waste stream to WIPP.

OR Oak Ridge Reservation

DOE/CAO-95-1121
December 1995

OAK RIDGE NATIONAL LABORATORY

Location and Description

The Oak Ridge National Laboratory (ORNL) is located 10 miles southwest of downtown Oak Ridge, Tennessee, and 32 kilometers northwest of Knoxville, Tennessee. The ORNL site occupies about 10,000 acres of the 35,252 acre Oak Ridge Reservation. The site covers portions of both Melton and Bethel Valleys. Approximately 1100 acres within the Melton and Bethel Valleys have been developed.

The ORNL is under the auspices of the DOE/Oak Ridge Operations Office which supports production of nuclear weapon components for national defense programs, production of enriched uranium for defense requirements and for fuelling nuclear power plants, the processing of uranium feed materials for DOE's plutonium production reactors, and extensive energy research and development in all DOE program areas.

Mission

ORNL was established in 1942 in support of the Manhattan Project. The primary mission of ORNL has been to carry out applied research and engineering development in fission, fusion, and other energy technologies, and to conduct scientific research in basic physical and life sciences. Relevant missions include isotope production and processing, research and development, waste management, and D&D of operating units; and advanced reactor development work. In addition, ORNL conducts several activities for DOE Defense Programs. The principal nonweapons-related activities include nuclear power development and magnetic fusion research. ORNL conducts activities in support of DOE's Transuranic Element Program, the Californium and Loan Program, and the Mark 42 Program.

During the wartime Manhattan Project, the town of Oak Ridge, Tennessee, was wholly-owned and controlled by the Government.

Waste Information

Processes

The Y-12 Plant was built originally as part of the Manhattan Project to separate and concentrate uranium-235 isotopes by the electromagnetic process. With the successful demonstration of the more efficient gaseous diffusion process, the plant was modified to carry out other weapons production operations. The major operations at the Y-12 Plant were production of weapon components, uranium, uranium alloys, and lithium compounds that were shipped to other sites.

The K-25 Site (formerly the Oak Ridge Gaseous Diffusion Plant) was a production and development facility for uranium enrichment using a gaseous diffusion process. Production operations were shut down in 1985. The current mission of K-25 involves environmental restoration, decontamination and decommissioning, and waste management. DOE's TSCA incinerator is located at the K-25 site.

Waste streams at ORNL tend to be different from K-25 and Y-12 waste streams in that they are smaller in volume, constantly changing, and could contain virtually any radionuclide, depending on the research activity that generated the waste stream. In these respects, they are probably similar to the waste streams generated at all the national labs. Of the three main facilities at ORR, only ORNL generates TRU waste (from research reactors), although K-25 and Y-12 waste streams may contain concentrations of transuranic isotopes below 100 nanocuries per gram.

In contrast, the waste generating processes at K-25 and Y-12 tend to be stable and have their own signature isotopes. Waste streams at K-25 may often be contaminated with technicium, either depleted or enriched uranium, and trace concentrations of transuranics. Y-12 waste streams are also often contaminated with depleted or enriched uranium. Some waste streams at Y-12 are derived from classified activities; data about these waste streams are also classified.

Most of the TRU waste residing at ORNL has been generated as a result of the Californium and U-233 Program or has come from off-site waste generators. Additional TRU waste is produced by the ORNL Analytical Chemistry facilities as a result of sample analysis. Some TRU waste may also be generated by the K-25 Site during decontamination and decommissioning activities.

RH-TRU solid waste consists primarily of miscellaneous hot-cell waste (e.g., paper, glass, plastic tubing, shoe covers, wipes, etc.), HEPA filters from off-gas cleanup systems, and discarded equipment (e.g., chemical processing racks, vacuum pumps, etc.). The unshielded individual waste packages within the casks typically have radiation levels that measure between 10 and 2000 rem/h; the majority are below 100 rem/h. RCRA materials in RH TRU solid waste primarily consist of lead that was used as shielding, and limited amounts of mercury from discarded mercury-vapor lamps. The RH TRU solid waste is typically contained in cylindrical concrete casks 1.4 m (4.5 ft) in diameter by 2.3 m (7.5 ft) high. Wall thickness of the casks are currently either 15.2 or 30.5 cm (6 or 12 in) thick, depending on the radiation level of the contents.

The majority of RH TRU sludges as ORNL are the result of waste accumulation from the past 50 years of ORNL liquid waste operations. These sludges are residuals from sluicing operations conducted in the early 1980s when the majority of the inactive gunite tank contents were removed for hydrofracture disposal at ORNL. RH TRU sludges continue to accumulate due to on-going R&D programs which produce transuranium isotopes for medical, industrial, and government applications. The surface equivalent dose rates of these sludges are generally near 10 rem/h (unshielded).

Most CH TRU waste is generated at ORNL by activities related to isotope research and production, including analytical support. The waste results primarily form hot cell and glovebox operations, and most of it can be accommodated in 55-gallon drums.

CH TRU waste at ORNL consists of general laboratory wastes such as various glassware, plastic ware, empty reagent bottles, vials, and other containers, cloth and paper wipes, rubber and cotton gloves, contaminated clothing, gaskets and other rubber parts, metal parts, tools and machinery, electrical equipment, ion-exchange resins, ventilation filters, and other general waste generated during the operation of gloveboxes and hot cells. A given container of waste may contain several different TRU radionuclides.

One of ORNL's offsite generators is the Paducah Gaseous Diffusion Plant (PA) in Kentucky serves as the first stage in the DOE uranium enrichment complex. TRU isotopes have been separated from the uranium feed and collected at the bottom of the cascade. Some drums containing TRU waste have been shipped to ORNL for storage while the remaining TRU waste containers continue to be stored at PA.

Nuclear Fuels Services, Inc. (NFS) at Erwin, Tennessee, sent 800+ drums of CH TRU waste to ORNL.

Other off-site generators include the New Brunswick Laboratory, West Valley Decommissioning Project, and the Knolls Atomic Power Laboratory.

Modifications/Assumptions/Development

ORNL reported radionuclides in total Curies. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the final waste form volumes reported by OR.

ORNL's waste material parameters Solidified, Inorganic Matrix and Cement (Solidified) for waste streams OR-W042 and OR-W046 were calculated based on the proposed amount of cement that will be used to solidify these waste streams.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

DOE/CAO-95-1121

Transuranic Waste Baseline Inventory Report (Revision 2)

December 1995

Prepared by Carlsbad Area Office Technical Assistance Contractor
for U.S. Department of Energy
under Contract No. DE-AC04-95AL-89446

Volume 3

LA Los Alamos National Laboratory

LOS ALAMOS NATIONAL LABORATORY

Location and Description

The Los Alamos National Laboratory (LANL) is located approximately 97 kilometers north of Albuquerque and 40 kilometers west of Santa Fe in Los Alamos County, New Mexico. The laboratory facilities are dispersed among numerous Technical Areas (TAs) spread over a 111-square kilometer site on the Pajarito Plateau. The plateau consists of several finger-like mesas extending eastward from the Jemez Mountains to the Rio Grande Valley with steep eroded canyons separating the mesas. The elevation of the mesas range from 1890 to 2377 meters. Some TAs are located in canyons.

The Los Alamos effort was the beginning of what is today the nationwide Albuquerque Operations Office laboratory and industrial complex of the DOE.

Mission

The Los Alamos Scientific Laboratory was established in 1943 by the U.S. Army's Manhattan Engineer District for the purpose of developing the first atomic bombs. Known as the Los Alamos Scientific Laboratory for many years, the name was changed to the Los Alamos National Laboratory in December 1980. LANL was the research, development, engineering design, and testing center for the Manhattan Project. The mission was the application of science and technology to problems of national security, including the maintenance of a strong defense, the fulfillment of arms controls commitments and the guarantee of a secure energy supply for the future.

During the wartime Manhattan Project, Los Alamos, New Mexico, was wholly-owned and controlled by the Government.

LANL's mission since World War II has included nuclear device design, research, development, testing, stockpile certification, and plutonium storage. Major programs currently include research in nuclear and conventional weapons development; nuclear fission and fusion; nuclear safeguards and security; verification and control technologies; fundamental research in particle physics, mathematics, chemistry, and materials; and waste management technology development and testing.

Research on peaceful uses of nuclear energy has included space applications, power reactor programs, magnetic and inertial fusion, radiobiology, and medicine. Other programs include astrophysics, earth sciences, lasers, computer sciences, solar energy, geothermal energy, biomedical and environmental research, and nuclear waste management research.

Today, the Waste Management Facilities Operations Group, CST-27, is responsible for all waste management facilities at LANL, except those related to high-explosives waste and sanitary waste, and those operated by waste generators in preparing their wastes for disposal. The Waste Management Program includes treating radioactive liquid and solid waste; packaging, transporting, treating, and disposing of hazardous chemical waste; and operating the disposal and storage sites for mixed waste. The Waste Management Program provides treatment, storage and disposal for Environmental Restoration Program-generated waste.

Waste Information

Processes

Major CH TRU waste generators at LANL are: Analytical Chemical Group (CHM-1), Nuclear Fuel Development and Facilities Operations Group (MST-11), Nuclear Materials Process Technology Group (MST-12), and Plutonium Metal Technology Group (MST-13).

RH TRU waste is generated by the Irradiated Materials Examination Group (MST-14).

CHM-1 is involved in analysis of radioactive materials. The waste generated by CHM-1 are combustibles (paper, rags, plastics, rubber) and non-combustibles (glass, ceramic, porcelain, metal, transite, chemicals, and equipment).

Wastes generated in MST-12 are process residues in solid and liquid TRU waste streams left when all economically recoverable quantities of special nuclear materials have been removed from a nuclear material item.

The wastes generated in MST-13 are combustible solids, noncombustible scrap (small tools, cans, small equipment items), and cemented process residues (process leached solids, filter cakes, and evaporator bottoms) stabilized in Portland or Gypsum cement.

The Size Reduction Facility's waste consists of metal equipment, either whole or sectional along with its combustible components, and the small volumes of combustibles generated during decommissioning, sectioning, and packaging (mostly gloveboxes, process equipment, and ductwork from decommissioning operations).

MST-14 generates both contact and remote handled solid wastes from hot cell operations.

Modifications/Assumptions/Development

LANL reported radionuclides in total Curies. The TWBIR team used the volumes reported for each waste stream to calculate the radionuclides in terms of Ci/m^3.

LANL's waste material parameters Solidified, Inorganic Matrix and Cement (Solidified) for waste streams LA–M002, LA–W003, LA–W006, LA–T002, and LA–T006 were calculated based on the proposed amount of cement that will be used to solidify these waste streams.

For final form containers, the estimated generation for newly generated waste was reported in the years 1995 to 2000. For the years 2001 to 2022 a bulk amount was reported. The TWBIR team converted this bulk amount into containers/year, assuring a constant generation rate per year between 2001 and 2022.

LANL assumes the internal volume for a 85 gallon drum used to overpack a 55 gallon drum is 0.208 m^3. This is assumed because all waste from 55 gallon drums that are currently overpacked in 85 gallon drums will be repackaged into 55 gallon drums for shipment to WIPP (upon WIPP–WAC certification).

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W047	Handling:	CH	NMVP #:	LA 111A; 211A	Stream Name:	Cemented Process Sludge	Inventory Date:	12/31/94
Local ID:	LA-M002	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

F005, F002, F001, D009, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	603.0	507.0	1014.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	693.0	583.0	1166.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	149.3		
Packaging Material Plastic:	8.5		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 111A; 211A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	3.10E-03
U-238	2.50E-06
U-235	7.86E-06
U-234	1.16E-06
U-233	6.55E-06
Th	3.57E-08
Sr-90	3.10E-03
Pu-241	8.94E-04
Pu-239	2.73E-01
Pu-238	4.75E-02
Cs-137	3.10E-03
AM240	2.09E-06
Am-241	4.55E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	181.0	59.3	98.8	197.6	197.6	734.2
Drum / 85-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Metal Pipe	2870.6	0.0	0.0	0.0	0.0	2870.6
Totals	3053.3	59.3	98.8	197.6	197.6	3606.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	182.6	59.3	98.8	197.6	197.6	735.9
Standard Waste Box	2870.9	0.0	0.0	0.0	0.0	2870.9
Totals	3053.5	59.3	98.8	197.6	197.6	3606.8

As-Generated Form: Stored: 3053.3 Projected: 553.3 Total: 3606.5

Final Waste Form: Stored: 3053.5 Projected: 553.3 Total: 3606.8

WASTE STREAM DESCRIPTION	Solidified aqueous waste, cemented sludge. The sludge is a residue from numerous treatment and filtration operations involving aqueous liquid radioactive waste. This treatment produces a thin sludge (approximately 25 percent solids) that is alkaline and is compatible with Portland cement. Final cemented waste monoliths are produced by mixing the waste in 55-gallon steel drums containing empirically determined quantities of sludge, Portland cement, vermiculite, and sodium silicate.
WASTE STREAM SOURCE	Cemented Aqueous waste
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	8 55 gallon drums are generated from the repackaging of 85 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W055	Handling:	CH	NMVP #:	LA 125A	Stream Name:	Mixed Scrap Metal	Inventory Date:	12/31/94
Local ID:	LA-T001	Type:	TRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	134.3		
Packaging Material Plastic:	31.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-242	9.54E-07
Pu-241	1.93E-01
Pu-240	1.15E-02
Pu-239	2.68E-01
Pu-238	1.03E+00
Cm-244	2.43E-06

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	1.2	59.9	99.8	199.7	199.7	560.4
fiberglass Reinfocre Plywood	92.3	0.0	0.0	0.0	0.0	92.3
standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	95.5	59.9	99.8	199.7	199.7	654.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	59.9	99.8	199.7	199.7	560.6
Standard Waste Box	94.5	0.0	0.0	0.0	0.0	94.5
Totals	96.0	59.9	99.8	199.7	199.7	655.1

As-Generated Form: Stored: 95.5 Projected: 559.1 Total: 654.6

Final Waste Form: Stored: 96.0 Projected: 559.1 Total: 655.1

WASTE STREAM DESCRIPTION	Mixed metal scrap and incidental combustibles. This waste is generated at various TAs throughout LANL. The waste consists mostly of metals or metal equiptment, either whole or sectioned, and lesser amounts of combustible components. In addition, it contains small volumes of combustibles generated during decommissioning, sectioning, and packaging. The waste forms primarily include gloveboxes, process equiptment, and ductwork from decommissioning operations. Gloveboxes may include gloves, wiring, plastic, glass windows, plastic wrapping, and lead shielding.
WASTE STREAM SOURCE	Mixed scrap metals and incidental combustibles generated at various TA's throughout the lab.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	based on process knowledge
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	1 55 gallon drum is generated from the overpacking of the 30 gallon drum. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W065	Handling:	CH	NMVP #:	LA 111A; 211A	Stream Name:	Cemented Process Sludge	Inventory Date:	12/31/94
Local ID:	LA-T002	Type:	TRU	Generator Site:	LA	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	603.0	507.0	1014.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	693.0	583.0	1166.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

LA 111A
LA 211A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
U-235	2.17E-05
Pu-239	1.78E+00
Pu-238	9.13E-02
Am-241	2.62E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon drum	1.5	3.1	5.2	10.4	10.4	30.6
Totals	1.5	3.1	5.2	10.4	10.4	30.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	3.1	5.2	10.4	10.4	30.6
Totals	1.5	3.1	5.2	10.4	10.4	30.6

As-Generated Form: Stored: 1.5 Projected: 29.1 Total: 30.6

Final Waste Form: Stored: 1.5 Projected: 29.1 Total: 30.6

WASTE STREAM DESCRIPTION	Cemented aqueous waste, solidified with Portland cement to form a noncorrosive solid monolith. The sludge is a residue from the treatment of blended acidic and caustic aqueous liquid radioactive waste with calcium hydroxide, ferric sulfate, and a flocculation aid. This treatment produces a thin sludge that is always alkaline and is compatible with Portland cement. Final cemented waste monoliths are produced by tumbling 55-gallon steel drums containing empirically determined quantities of sludge, Portland cement, vermiculite, and sodium silicate.
WASTE STREAM SOURCE	Cemented aqueous waste, solidified with Portland cement to form a noncorrosive solid monolith.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	represents waste stream LA-T002
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W056	Handling:	CH	NMVP #:	LA 116A	Stream Name:	Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-T004	Type:	TRU	Generator Site:	LA	Final Waste Form:	Combustible	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.4	0.4	0.4
Other Metals/Alloys:	18.8	18.8	89.7
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.9		
Packaging Material Plastic:	35.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 116A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-240	1.48E-01
Am-243	3.18E-06
Ba-137m	6.92E-02
Cm-243	9.58E-04
Cm-244	3.89E-02
Cs-137	6.92E-02
Np-237	2.02E-06
Am-241	1.93E-02
Pu-239	5.80E-01
Y-90	6.92E-02
Pu-241	3.02E+00
Pu-242	5.64E-04
Pu-244	4.66E-10
Sr-90	6.92E-02
U-233	2.08E-05
U-234	1.30E-05
U-235	2.10E-06
U-236	5.18E-08
U-238	2.27E-06
Pu-238	3.84E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	30.7	0.0	0.0	0.0	0.0	30.7
Drum / 55-gallon	1373.0	179.7	299.5	599.0	599.0	3050.3
Drum / 85-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Fiberglass Reinfocre Plywood	123.2	0.0	0.0	0.0	0.0	123.2
Totals	1527.8	179.7	299.5	599.0	599.0	3205.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1430.4	179.7	299.5	599.0	599.0	3107.7
Standard Waste Box	124.7	0.0	0.0	0.0	0.0	124.7
Totals	1555.2	179.7	299.5	599.0	599.0	3232.5

As-Generated Form: Stored: 1527.8 Projected: 1677.3 Total: 3205.1

Final Waste Form: Stored: 1555.2 Projected: 1677.3 Total: 3232.5

WASTE STREAM DESCRIPTION	Combustible waste including plastic-basedand cellulose-based waste generated at the lab. Plastic-based waste includes, but may not be limited to , tape, polyethylene, and vinyl; gloves; plastic vials; polystyrene;Tygon tubing; polyvinyl chloride plastic;Teflon producrts; plexiglass; and dry box gloves. Cellulose -based waste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar miscellaneous materials. Waste may also contain a small fraction of noncombustible scrap metal.
WASTE STREAM SOURCE	Combustibe waste including plastic-based and cellulose-based waste generated at the lab.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	272 55 gallon drums are generated from the overpacking of the 30 gallon drum and 4 55 gallon drums are generated from the repackaging of the 85 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W057	Handling:	CH	NMVP #:	LA 117A; 118A	Stream Name:	Non Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-T005	Type:	TRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	302.9	76.9	913.5
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	134.1		
Packaging Material Plastic:	32.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 117A; 118A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Po-210	6.65E-07
Am-241	5.02E-02
Am-243	1.38E-04
Ba-137m	8.46E-03
Bk-249	6.65E-07
Cd-109	1.76E+00
Cf-249	6.65E-07
Cm-242	6.79E-07
Cm-244	1.08E-01
Co-60	6.65E-07
Cs-137	8.46E-03
Ac-227	2.91E-04
Pa-231	7.39E-07
Y-90	8.46E-03
Pu-238	4.11E+01
Pu-239	3.03E+00
Pu-240	7.16E-01
Pu-241	1.19E+01
Pu-242	6.18E-04
Pu-244	4.32E-10
Ra-226	6.02E-04
Sr-90	8.46E-03
U-233	2.72E-02
U-234	2.13E-05
U-235	2.13E-06
U-236	3.78E-08
U-238	6.97E-04
Np-237	1.72E-06

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	36.5	0.0	0.0	0.0	0.0	36.5
Drum / 55-gallon	1084.1	119.8	199.7	399.4	399.4	2202.3
Drum / 85-gallon	0.2	0.0	0.0	0.0	0.0	0.2
fiberglass Reinfocre Plywood	343.0	0.0	0.0	0.0	0.0	343.0
standard Waste Box	7.6	0.0	0.0	0.0	0.0	7.6
Totals	1471.4	119.8	199.7	399.4	399.4	2589.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1151.5	119.8	199.7	399.4	399.4	2269.7
Standard Waste Box	351.5	0.0	0.0	0.0	0.0	351.5
Totals	1503.0	119.8	199.7	399.4	399.4	2621.2

As-Generated Form: Stored: 1471.4 Projected: 1118.2 Total: 2589.6

Final Waste Form: Stored: 1503.0 Projected: 1118.2 Total: 2621.2

WASTE STREAM DESCRIPTION	Non-combustible scrap - small tools, cans, small equipment items, HEPA filters, glass ware, metal, leaded rubber, graphite and pyrochemical waste generated at several site around the laboratory.
WASTE STREAM SOURCE	Noncombustible waste consisting of HEPA filters, glass ware, metal \, leaded rubber waste, graphite and pyrochemical sal wases.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	data entered by the waste generators
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	323 55 gallon drums are generated from the overpacking of the 30 gallon drum and 1 55 gallon drum is generated from the repackaging of the 85 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W058	Handling:	CH	NMVP #:	LA 114A; LA 126	Stream Name:	Solidified Inorganic process solids	Inventory Date:	12/31/94
Local ID:	LA-T006	Type:	TRU	Generator Site:	LA	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.3	38.5	48.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	447.1	335.3	491.8
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	514.4	385.7	565.9
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 114A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
U-238	1.33E-05
U-236	6.18E-08
U-235	4.53E-07
U-234	1.45E-05
U-233	1.90E-04
Pu-244	2.19E-10
Pu-242	2.69E-04
Pu-241	6.43E+00
Pu-240	3.10E-01
Pu-239	1.26E+00
Pu-238	1.20E+02
Np-237	1.41E-06
Am-241	8.63E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cardboard Box	0.2	0.0	0.0	0.0	0.0	0.2
Drum / 30-gallon	0.3	0.0	0.0	0.0	0.0	0.3
Drum / 55-gallon	4.2	8.7	14.6	29.1	29.1	85.7
Totals	4.7	8.7	14.6	29.1	29.1	86.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.0	8.7	14.6	29.1	29.1	86.5
Totals	5.0	8.7	14.6	29.1	29.1	86.5

As-Generated Form: Stored: 4.7 Projected: 81.5 Total: 86.3

Final Waste Form: Stored: 5.0 Projected: 81.5 Total: 86.5

WASTE STREAM DESCRIPTION	Cemented process residues. Solidified inorganic and organic process solids. This waste consists of process leached solids, ash, filter cakes, salts, metal oxides, fines and evaporator bottoms stabilized in Portland or gypsum cement.
WASTE STREAM SOURCE	Solidified inorganic and organic process solids. This waste consists of process leached solids, ash, filter cakes, salts, metal oxides, fines and evaporator bottoms stabilized in Portland or gypsum cement.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	From database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Pu-239 FGE based on present drums identified. 3 55 gallon drums are generated from the overpacking of the 30 gallon drum and 1 55 gallon drum is generated from the repackaging of the cardboard box. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W059	Handling:	CH	NMVP #:	unknown	Stream Name:	Hot-Cell Waste	Inventory Date:	12/31/94
Local ID:	LA-T007	Type:	TRU	Generator Site:	LA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	7.12E+01
U-238	2.38E-08
U-236	3.49E-07
U-235	4.65E-04
U-234	8.17E-05
Sr-90	7.12E+01
Pu-242	2.70E-06
Pu-241	6.24E-01
Pu-240	3.93E-02
Pu-239	6.47E+00
Pu-238	3.60E+00
Cs-137	7.12E+01
Ba-137m	7.12E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	5.6	3.1	5.2	10.4	10.4	34.7
Other	0.9	0.0	0.0	0.0	0.0	0.9
Totals	6.6	3.1	5.2	10.4	10.4	35.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.7	3.1	5.2	10.4	10.4	35.8
Totals	6.7	3.1	5.2	10.4	10.4	35.8

As-Generated Form: Stored: 6.6 Projected: 29.1 Total: 35.7

Final Waste Form: Stored: 6.7 Projected: 29.1 Total: 35.8

WASTE STREAM DESCRIPTION	Contact handled hot cell waste including both combustible and noncombustible waste forms. This waste is generated by MST-5 in the CRM building.
WASTE STREAM SOURCE	Contact handled hot cell waste including both combustible and noncombustible waste forms.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	None
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	5 55 gallon drums are generated from the overpacking of Other containers. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W060	Handling:	CH	NMVP #:	unknown	Stream Name:	Soils	Inventory Date:	12/31/94
Local ID:	LA-T008	Type:	TRU	Generator Site:	LA	Final Waste Form:	Soils	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1200.0	1000.0	1600.0
Packaging Material Steel:	147.5		
Packaging Material Plastic:	11.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-242	2.67E-07
Pu-241	2.29E-02
Pu-240	3.73E-04
Pu-239	2.49E-01
Pu-238	1.90E+00
Am-241	5.43E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	10.4	3.1	5.2	10.4	10.4	39.5
fiberglass Reinfocre Plywood	98.8	0.0	0.0	0.0	0.0	98.8
Totals	109.2	3.1	5.2	10.4	10.4	138.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.4	3.1	5.2	10.4	10.4	39.5
Standard Waste Box	100.2	0.0	0.0	0.0	0.0	100.2
Totals	110.6	3.1	5.2	10.4	10.4	139.7

As-Generated Form: Stored: 109.2 Projected: 29.1 Total: 138.3

Final Waste Form: Stored: 110.6 Projected: 29.1 Total: 139.7

WASTE STREAM DESCRIPTION	Soils contaminated with Transuranic material. This waste was produced at several sites throughout LANL. A good portion of the waste came from TA-21
WASTE STREAM SOURCE	Soils contaminated with Transuranic material. THis waste was produced at several sites throughout LANL. A good portion of the waste came from TA-21
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	from TRU database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W061	Handling:	CH	NMVP #:	unknown	Stream Name:	Glovebox and Ducting Material	Inventory Date:	12/31/94
Local ID:	LA-T009	Type:	TRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	141.9		
Packaging Material Plastic:	20.1		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-242	6.11E-05
Pu-241	6.19E+00
Pu-240	2.10E-01
Pu-239	7.53E-01
Pu-238	7.79E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon drum	0.6	6.2	10.4	20.8	20.8	58.9
fiberglass Reinfocre Plywood	53.1	0.0	0.0	0.0	0.0	53.1
Totals	53.7	6.2	10.4	20.8	20.8	111.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	6.2	10.4	20.8	20.8	58.9
Standard Waste Box	52.9	0.0	0.0	0.0	0.0	52.9
Totals	53.5	6.2	10.4	20.8	20.8	111.8

As-Generated Form: Stored: 53.7 Projected: 58.2 Total: 111.9

Final Waste Form: Stored: 53.5 Projected: 58.2 Total: 111.8

WASTE STREAM DESCRIPTION	Metal from gloveboxes & equipment repackaged from FRP boxes. THis waste was proced by several sites throughout LANL.
WASTE STREAM SOURCE	Glovebox and Ducting waste generated at several site throughout LANL.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	limited informantion in the database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W062	Handling:	RH	NMVP #:	LA 116A	Stream Name:	Combustible Waste	Inventory Date:	12/31/91
Local ID:	LA-TR04	Type:	TRU	Generator Site:	LA	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.4	0.4	0.4
Other Metals/Alloys:	18.8	18.8	89.7
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA-116A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	2.48E+01
U-238	1.95E-06
U-236	8.88E-09
U-235	3.18E-04
U-234	2.01E-06
Sr-90	2.48E+01
Pu-242	5.00E-06
Pu-241	3.70E-01
Pu-240	1.21E-02
Pu-239	2.90E+00
Pu-238	5.34E-03
Cs-137	2.48E+01
Ba-137m	2.48E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 2 gallon	0.2	0.0	0.0	0.0	0.0	0.2
LANL RH Can	14.9	0.0	0.0	0.0	0.0	14.9
Totals	15.0	0.0	0.0	0.0	0.0	15.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	15.1	3.6	8.9	17.8	18.7	64.1
Totals	15.1	3.6	8.9	17.8	18.7	64.1

As-Generated Form: Stored: 15.0 Projected: 0.0 Total: 15.0

Final Waste Form: Stored: 15.1 Projected: 49.0 Total: 64.1

WASTE STREAM DESCRIPTION	Combustible waste - paper, rags, plastic, rubber, etc., including plastic-based and cellulose-based waste generated at the laoboratory. Plastic-based waste includes, but may not be limited to, tape, polyethylene, and vinyl; gloves; plastic vials; polystyrene; Tygon tubing; polyvinyl chloride plastic; Teflon products; plexiglass; and dry box gloves (unleaded Neoprene base). Cellulose-based wste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar miscellaneous materials. The waste may also contain a small fraction of noncombustible solids (e.g., scrap metals, metal lids).
WASTE STREAM SOURCE	Combustible waste including plastic based and cellulose-based waste generated at the laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	limited information i the database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	17 RH Canisters are generated from the repackaging of current RH containers. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W063	Handling:	RH	NMVP #:	unknown	Stream Name:	Noncombustible Waste	Inventory Date:	12/31/94
Local ID:	LA-TR05	Type:	TRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	302.9	76.9	913.5
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	8.42E-02
U-238	1.91E-10
U-236	2.80E-09
U-235	2.05E-08
U-234	6.56E-07
Sr-90	8.42E-02
Ru-106	4.85E-04
Pu-242	7.50E-08
Pu-241	6.68E-03
Pu-240	2.10E-04
Pu-239	4.49E-04
Pu-238	6.47E-05
Cs-137	8.99E-02
Ba-137m	8.99E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
drum / 2 gallon	0.01	0.0	0.0	0.0	0.0	0.01
LANL RH Can	50.9	0.0	0.0	0.0	0.0	50.9
Totals	51.0	0.0	0.0	0.0	0.0	51.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	50.7	0.0	0.0	7.1	8.9	66.7
Totals	50.7	0.0	0.0	7.1	8.9	66.7

As-Generated Form: Stored: 51.0 Projected: 0.0 Total: 51.0

Final Waste Form: Stored: 50.7 Projected: 16.0 Total: 66.8

WASTE STREAM DESCRIPTION	Non-combustible scrap - small tools, cans, small equipment items, broken glass, etc. This waste consists of the following subgroups: high-efficiency particulate air (HEPA) filter waste (no subgroup number); glass waste [005(LG)]; metal waste [005(LM)]; leaded rubber waste and metal waste [005(P1)]; graphite waste [005(P2G)]; and pyrochemical salt waste [005(P2S)]. Discarded HEPA filter waste is generated at TA-55-4. 005(LG) consists of glass waste and included, but may not be limited to, discarded labware, windows, and bottles. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream. Metal waste (e.g., motors, pumps, tools, and process equiptment) comprises 005(LM). A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream. 005(P1) is leaded rubber waste and metal waste. This waste stream also includes lead-lined glovebox gloves discarded along with metal waste, such as motors and tools. 005(P2G) is graphite solid waste which consists of discarded graphite mold and furnance equiptment generated during plutonium casting and other operations conducted in room 327 at TA-55-4. 005(P2S) is pyrochemical salt waste which consists of used chloride salts from pyrochemical processes such as electrorefining, molten salt extraction, salt stripping, flouride reduction, and direct oxide reduction. these processes occur at TA-55-4. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream.
WASTE STREAM SOURCE	Non-combustible waste consisting oF HEPA filters, glass, graphite and pyrochemical salt waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	57 RH Canisters are generated from the repackaging of current RH containers. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W064	Handling:	RH	NMVP #:	unknown	Stream Name:	Noncombustible Hot-Cell Waste	Inventory Date:	12/31/94
Local ID:	LA-TR07	Type:	TRU	Generator Site:	LA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	4.44E+01
U-235	3.02E-04
Sr-90	4.44E+01
Pu-239	3.17E+00
Cs-137	4.44E+01
Ba-137m	4.44E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
drum / 2 gallon	0.3	0.0	0.0	0.0	0.0	0.3
LANL RH Can	10.5	0.0	0.0	0.0	0.0	10.5
Totals	10.8	0.0	0.0	0.0	0.0	10.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	11.6	0.0	0.0	0.0	0.0	11.6
Totals	11.6	0.0	0.0	0.0	0.0	11.6

As-Generated Form: Stored: 10.8 Projected: 0.0 Total: 10.8

Final Waste Form: Stored: 11.6 Projected: 0.0 Total: 11.6

WASTE STREAM DESCRIPTION	Remote handled hot cell waste including both combustible and noncombustible waste forms. This waste is generated by MST-5 in the CRM building.
WASTE STREAM SOURCE	Contact handled hot cell waste including both combustible and noncombustible waste forms.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	from database
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	This waste stream in not currently generated and will require only that the old waste be repackaged. 13 RH Canisters are generated from the repackaging of current RH containers.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W046	Handling:	CH	NMVP #:	LA 125A	Stream Name:	Mixed Scrap Metal	Inventory Date:	12/31/94
Local ID:	LA-M001	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.2	4.9	5.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	151.8		
Packaging Material Plastic:	4.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No.

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-242	1.57E-06
Ba-137m	6.49E-04
Cf-251	7.26E-07
Cs-137	1.37E-01
Eu-155	2.78E-05
H-3	0.00E+00
Np-237	1.82E-13
Pm-147	3.94E-05
Pu-238	2.23E+00
Pu-239	2.36E-01
Am-241	3.39E-06
Pu-241	1.74E-01
Y-90	1.37E-01
Pu-244	7.33E-13
Ra-226	5.90E-07
Rh-106	5.08E-06
Ru-106	5.08E-06
Sb-125	2.81E-05
Sr-90	1.37E-01
Te-125m	1.17E-05
U-233	0.00E+00
U-234	4.53E-07
U-235	1.40E-05
U-236	8.85E-10
U-238	6.63E-07
Pu-240	1.07E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon drum	80.7	15.0	25.0	49.9	49.9	220.5
Drum/30 gallon	4.0	0.0	0.0	0.0	0.0	4.0
Fiberglass Reinfocre Plywood	2108.5	0.0	0.0	0.0	0.0	2108.5
standard Waste Box	13.2	0.0	0.0	0.0	0.0	13.2
Totals	2206.4	15.0	25.0	49.9	49.9	2346.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	84.7	15.0	25.0	49.9	49.9	224.4
Standard Waste Box	2118.7	0.0	0.0	0.0	0.0	2118.7
Totals	2203.3	15.0	25.0	49.9	49.9	2343.1

As-Generated Form: Stored: 2206.4 Projected: 139.8 Total: 2346.2

Final Waste Form: Stored: 2203.3 Projected: 139.8 Total: 2343.1

WASTE STREAM DESCRIPTION	Mixed metal scrap and incidental combustibles. This waste is generated at various TAs throughout LANL. The waste consists mostly of metals or metal equipment, either whole or sectioned, and lesser amounts of combustible components. In addition, it contains small volumes of combustibles generated during decommissioning, sectioning, and packaging. The waste forms primarily include gloveboxes, process equipment, and ductwork from facility operations. Gloveboxes may include gloves, wiring, plastic, glass windows, plastic wrapping, and lead shielding.
WASTE STREAM SOURCE	This waste is generated at various Technical Areas (TA) throughout LANL.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	19 55 gallon drums are generated from the repackaging of 30 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W048	Handling:	CH	NMVP #:	LA 111B; 211B	Stream Name:	Solidified aqueous waste	Inventory Date:	12/31/94
Local ID:	LA-M003	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3121

AS-GENERATED EPA CODES

F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.3	38.5	48.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	650.1	546.6	1093.2
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	645.9	543.4	1086.8
Soils:	0.0	0.0	0.0
Packaging Material Steel:	132.6		
Packaging Material Plastic:	34.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 111B; 211B

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.49E-05
U-235	8.53E-08
Sr-90	2.49E-05
Pu-241	4.06E-05
Pu-239	3.36E-01
Pu-238	1.04E-01
Cs-137	2.49E-05
Am-241	3.33E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon drum	1151.9	59.9	99.8	199.7	199.7	1711.0
Drum / 85-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Other	124.7	0.0	0.0	0.0	0.0	124.7
Totals	1277.4	59.9	99.8	199.7	199.7	1836.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1152.7	59.9	99.8	199.7	199.7	1711.8
Standard Waste Box	124.7	0.0	0.0	0.0	0.0	124.7
Totals	1277.5	59.9	99.8	199.7	199.7	1836.6

As-Generated Form: Stored: 1277.4 Projected: 559.1 Total: 1836.5

Final Waste Form: Stored: 1277.5 Projected: 559.1 Total: 1836.6

WASTE STREAM DESCRIPTION	Solidified aqueous waste , is a dewatered sludge generated by the vacume filtration of solids from a pretreated aqueous waste slurry. These solids are first trapped on the surface of the filter media (diatomaceous earth). The filter medium with the entrapped filtrate is then placed in drums with dry concrete absorbent.
WASTE STREAM SOURCE	Solidified Aqueous Waste, dewatered sludge generated by the vacuum filtration of solids from the pretrated aqueous waste slurry.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	4 55 gallon drums are generated from the repackaging of 85 gallon drums. projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W049	Handling:	CH	NMVP #:	LA 116A	Stream Name:	Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-M004	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

U080, F002, F001, D040, D019, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.4	0.4	0.4
Other Metals/Alloys:	18.8	18.8	89.7
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.3	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	*0.0*	*0.0*	*0.0*
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.1		
Packaging Material Plastic:	36.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 116A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
U-238	2.71E-08
U-236	1.08E-07
U-235	8.00E-07
U-234	2.56E-05
Th	4.09E-11
Pu-244	3.71E-10
Pu-242	4.64E-04
Pu-241	1.70E+01
Pu-240	1.07E+00
Pu-239	4.47E+00
Pu-238	1.65E+01
Np-237	2.91E-06
Cm-246	9.76E-05
Am-243	3.47E-05
Am-241	6.68E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
30 Gallon Drum	15.5	0.0	0.0	0.0	0.0	15.5
Drum / 55-gallon	232.1	74.9	124.8	249.6	249.6	931.0
Other	4.8	0.0	0.0	0.0	0.0	4.8
Totals	252.4	74.9	124.8	249.6	249.6	951.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	260.6	74.9	124.8	249.6	249.6	959.5
Standard Waste Box	5.7	0.0	0.0	0.0	0.0	5.7
Totals	266.3	74.9	124.8	249.6	249.6	965.2

As-Generated Form: Stored: 252.4 Projected: 698.9 Total: 951.3

Final Waste Form: Stored: 266.3 Projected: 698.9 Total: 965.2

WASTE STREAM DESCRIPTION	Combustible waste - paper, rags, plastic, rubber, etc., including plastic-based and cellulose-based waste generated at the laboratory. Plastic-based waste includes, but may not be limited to, tape, polyethylene, and vinyl; gloves; plastic vials; polystyrene; Tygon tubing; polyvinyl chloride plastic; Teflon products; plexiglass; and dry box gloves (unleaded Neoprene base). Cellulose-based wste includes, but may not be limited to, rags, wood, paper, cardboard, laboratory coats and coveralls, booties and cotton gloves, and similar miscellaneous materials. The waste may also contain a small fraction of noncombustible solids (e.g., scrap metals, metal lids).
WASTE STREAM SOURCE	Combustible waste including plastic based and cellulose-based waste generated at the laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	137 55 gallon drums are generated from the overpacking of 30 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W050	Handling:	CH	NMVP #:	LA 117A; 118A	Stream Name:	Non Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-M005	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

D040, D019, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	302.9	76.9	913.5
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.1		
Packaging Material Plastic:	36.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 117A; 118A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
U-238	7.08E-04
U-236	1.00E-07
U-235	7.42E-07
U-234	2.38E-05
U-232	2.33E-09
Pu-244	3.05E-09
Pu-242	3.82E-03
Pu-241	1.21E+02
Pu-240	7.16E+00
Pu-239	2.89E+01
Pu-238	3.34E+00
Np-237	1.48E-06
Cm-246	6.57E-05
Am-243	2.16E-05
Am-241	9.04E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	209.0	74.9	124.8	249.6	249.6	907.9
Other	4.0	0.0	0.0	0.0	0.0	4.0
Totals	213.1	74.9	124.8	249.6	249.6	911.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	209.0	74.9	124.8	249.6	249.6	907.9
Standard Waste Box	5.7	0.0	0.0	0.0	0.0	5.7
Totals	214.7	74.9	124.8	249.6	249.6	913.6

As-Generated Form: Stored: 213.1 Projected: 698.9 Total: 911.9

Final Waste Form: Stored: 214.7 Projected: 698.9 Total: 913.6

WASTE STREAM DESCRIPTION	Non-combustible scrap - small tools, cans, small equipment items, broken glass, etc. This waste consists of the following subgroups: high-efficiency particulate air (HEPA) filter waste (no subgroup number); glass waste [005(LG)]; metal waste [005(LM)]; leaded rubber waste and metal waste [005(P1)]; graphite waste [005(P2G)]; and pyrochemical salt waste [005(P2S)]. Discarded HEPA filter waste is generated at TA-55-4. 005(LG) consists of glass waste and included, but may not be limited to, discarded labware, windows, and bottles. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream. Metal waste (e.g., motors, pumps, tools, and process equipment' comprises 005(LM). A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream. 005(P1) is leaded rubber waste and metal waste. This waste stream also includes lead-lined glovebox gloves discarded along with metal waste, such as motors and tools. 005(P2G) is graphite solid waste which consists of discarded graphite mold and furnance equiptment generated during plutonium casting and other operations conducted in room 327 at TA-55-4. 005(P2S) is pyrochemical salt waste which consists of used chloride salts from pyrochemical processes such as electrorefining, molten salt extraction, salt stripping, flouride reduction, and direct oxide reduction. these processes occur at TA-55-4. A small fraction of combustible waste, such as plastics (mainly packaging), may also be present in this waste stream.
WASTE STREAM SOURCE	Non-combustible waste consisting oF HEPA filters, glass, graphite and pyrochemical salt waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W051	Handling:	CH	NMVP #:	LA 114A; LA 126	Stream Name:	Solidified Inorganic process solids	Inventory Date:	12/31/94
Local ID:	LA-M006	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3000

AS-GENERATED EPA CODES

F003, F002, F001, D039, D021, D019, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.3	38.5	48.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	453.4	340.0	498.7
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	508.1	381.0	559.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.3		
Packaging Material Plastic:	36.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 114A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.87E+01
Am-243	2.67E+01
Bk-249	2.72E-06
Cf-249	1.77E-07
Cm-246	2.46E-05
Pu-238	5.17E+00
Am-241	2.94E+01
Pu-240	1.69E+00
U-238	3.47E-04
Pu-242	3.14E-03
Pu-244	2.85E-09
Th	4.15E-06
U-233	1.71E-04
U-234	1.53E-04
U-235	1.19E-05
U-236	6.99E-08
Pu-239	6.92E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	27.8	0.0	0.0	0.0	0.0	27.8
Drum / 55-gallon	435.6	89.9	149.8	299.5	300.8	1275.5
Drum / 85-gallon	48.5	0.0	0.0	0.0	0.0	48.5
Other	15.8	0.0	0.0	0.0	0.0	15.8
Totals	527.7	89.9	149.8	299.5	300.8	1367.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	535.2	89.9	149.8	299.5	300.8	1375.1
Standard Waste Box	17.0	0.0	0.0	0.0	0.0	17.0
Totals	552.2	89.9	149.8	299.5	300.8	1392.1

As-Generated Form: Stored: 527.7 Projected: 839.9 Total: 1367.6

Final Waste Form: Stored: 552.2 Projected: 839.9 Total: 1392.1

WASTE STREAM DESCRIPTION	Solidified inorganic and organic process solids. This waste consists of process leached solids, ash, filter cakes, salts, metal oxides, fines, or evaporator bottoms stabilized in portland or gypsum cement. These waste streams are generated at TA-55-4.
WASTE STREAM SOURCE	Solidified inorgainc and orgainc process solids.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Drums will be repackaged to meet WIPP WAC. 246 55 gallon drums are generated from the overpacking of 30 gallon drums and 233 55 gallon drums are generated from the repackaging of 85 gallon drums. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W052	Handling:	CH	NMVP #:	unknown	Stream Name:	Glovebox and Ducting Material	Inventory Date:	12/31/94
Local ID:	LA-M009	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	138.8		
Packaging Material Plastic:	24.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-242	5.61E-07
Pu-241	1.47E-01
Pu-240	9.72E-03
Pu-239	4.15E-02
Pu-238	1.22E-03
Am-241	3.26E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	30.0	49.9	99.8	99.8	279.8
Fiberglass Reinfocre Plywood	142.2	0.0	0.0	0.0	0.0	142.2
Totals	142.4	30.0	49.9	99.8	99.8	422.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	30.0	49.9	99.8	99.8	279.8
Standard Waste Box	143.6	0.0	0.0	0.0	0.0	143.6
Totals	143.8	30.0	49.9	99.8	99.8	423.4

As-Generated Form: Stored: 142.4 Projected: 279.6 Total: 422.0

Final Waste Form: Stored: 143.8 Projected: 279.6 Total: 423.4

WASTE STREAM DESCRIPTION	Metal waste from gloveboxes and equipment. Gloveboxes and associated ducting, equipment and construction debri associated with the removal of glovebox operations from different location throughout the laboratory.
WASTE STREAM SOURCE	Gloveboxes and associated ducting, equipment and construction debri associated with the removal of glovebox operations
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Based on generators original disposal records, complete before RCRA requirements
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste accumulated from the repackaging of FRP boxes. Projections are based on present generation rates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Metallic Waste	Inventory Date:	12/31/94
Local ID:	LA-M001	Type:	MTRU	Generator Site:	SA	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	1.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 4 ft X 4 ft X 8 ft	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	Metal plates in 4 x 4 x 8 FRP-Wood crate.
WASTE STREAM SOURCE	Metal plate in 4 x 4 x 8 FRP-wood crate.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Waste stream from Sandia National Laboratory - Albuquerque.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	The typical waste material weights for the final waste form for this waste steam is unknown at this time. 1 SWB is generated from the repackaging of the current box container.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W067	Handling:	CH	NMVP #:	None	Stream Name:	Combustible Debris	Inventory Date:	12/31/94
Local ID:	LA-T004	Type:	TRU	Generator Site:	IT	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
U-238	9.97E-08
U-233	1.17E-06
Pu-239	8.12E-02
Pu-238	6.31E-01
Cm-244	7.55E-01
Cm-243	1.86E-02
Am-241	5.58E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.9	0.0	0.0	0.0	0.0	8.9
Totals	8.9	0.0	0.0	0.0	0.0	8.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.9	0.0	0.0	0.0	0.0	8.9
Totals	8.9	0.0	0.0	0.0	0.0	8.9

As-Generated Form: Stored: 8.9 Projected: 0.0 Total: 8.9

Final Waste Form: Stored: 8.9 Projected: 0.0 Total: 8.9

WASTE STREAM DESCRIPTION	Lovelace ITRI TRU waste packaged into 90 mil lined drums.
WASTE STREAM SOURCE	Inhalation Toxicology Reasearch Institute (ITRI) TRU waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Typical waste material weights for final waste form are unknown for this waste stream at this time.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Non Combustible Debris	Inventory Date:	12/31/94
Local ID:	LA-T005	Type:	TRU	Generator Site:	SA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	3.56E-01
Pu-238	5.00E-01
Np-237	1.20E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Those in 001922, metal plates in boxes into 4 x 4 x 8 FRP-wood crate, HEPA filters
WASTE STREAM SOURCE	Sandia National Laboratory - Albuquerque generated this waste.
CURRENT CONTAINER COMMENTS	Package volume listed as 0.209
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Typical waste material weights for final waste form for this waste stream is unknown at this time.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W053	Handling:	RH	NMVP #:	LA 117A; 118A	Stream Name:	Scrap Metal	Inventory Date:	12/31/94
Local ID:	LA-MR01	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	272.6	69.2	822.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.3	7.7	91.3
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.0	59.2	68.7
Rubber:	1.1	1.0	1.2
Plastics:	5.2	4.9	5.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	7.97E+00
Co-60	1.12E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 2 gallon	0.02	0.0	0.0	0.0	0.0	0.02
LANL RH Can	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	2.7	0.0	0.0	0.0	0.0	2.7
Totals	2.7	0.0	0.0	0.0	0.0	2.7

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.7 Projected: 0.0 Total: 2.7

WASTE STREAM DESCRIPTION	Mixed metal scrap and incidental combustibles. This waste is generated at various TA's throughout LANL. THe waste consists of mostly metal or metal equipmet, either whole or sectioned and lessor amounts of combustible components. In addition, it contians small volumes of combustibles generated during the decommissioning, sectioning and packaging. The waste forms primarily include gloveboxes, process equipment, and ductwork from decomissioning operations. Gloveboxes may include gloves, wiring, plastic, glass windows, plastic wrapping and lead shielding.
WASTE STREAM SOURCE	Waste comprised of mixed metal scrape and incidental combustibles.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	None
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in bulk shafts will have to be removed and repackaged into RH canister. 3 RH Canisters are generated from the repackaging of current RH canisters.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LA-W054	Handling:	RH	NMVP #:	unknown	Stream Name:	Non Combustible Waste	Inventory Date:	12/31/94
Local ID:	LA-MR05	Type:	MTRU	Generator Site:	LA	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	257.7	254.0	265.2
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	302.9	76.9	913.5
Other Inorganic Material:	6.8	6.8	6.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

LA 117A; 118A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.91E+02
U-235	4.85E-05
Te-125m	3.53E+00
Sr-90	1.91E+02
Sb-125	8.50E+00
Ru-106	1.53E+00
Rh-106	1.52E+00
Pu-239	9.66E+00
Pm-147	1.19E+01
Eu-155	3.90E+00
Cs-137	2.09E+02
Ba-137m	1.96E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
LANL RH Can	14.2	2.7	4.4	8.9	17.8	48.1
Totals	14.2	2.7	4.4	8.9	17.8	48.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	14.2	2.7	4.4	8.9	17.8	48.1
Totals	14.2	2.7	4.4	8.9	17.8	48.1

As-Generated Form: Stored: 14.2 Projected: 33.8 Total: 48.1

Final Waste Form: Stored: 14.2 Projected: 33.8 Total: 48.1

WASTE STREAM DESCRIPTION	Non-combustible scrap - small tools, cans, equipment items, broken glass, HEPA filters leaded gloves, graphite and pyrochemical waste generated throughout the lab.
WASTE STREAM SOURCE	Non-combustible waste including HEPA filters, glass, metal , leaded rubber gloves, graphite, and pyrochemical wastes
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	None
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Additioni containers wil be produced as the bulk waste is retrieved and repackaged into RH canisters.

LL Lawrence Livermore National Laboratory

LAWRENCE LIVERMORE NATIONAL LABORATORY

Location and Description

The Lawrence Livermore National Laboratory (LLNL) is located approximately 64 kilometers east of San Francisco, California, at the southeast end of the Livermore Valley in Alameda County. LLNL consists of two sites: 1) Livermore Main Site, which is approximately 2.6 square kilometers in size and bordering on the eastern border of the City of Livermore, and 2) Site 300, which is a remote high-explosives testing facility approximately 24 kilometers southeast of the Main Site and 16 kilometers southwest of the Town of Tracy. Site 300 occupies 41 square kilometers in Alameda and San Joaquin Counties.

LLNL is owned by the Department of Energy (DOE) and is operated by the University of California for DOE. The Laboratory was established in 1952 to conduct research on nuclear weapons. Since then, other major programs have been added: magnetic fusion energy, laser fusion and laser isotope separation, biomedical sciences, environmental sciences, environmental restoration and waste management, and applied energy technology. These programs perform research in chemistry and materials science, computer science and technology, biomedical sciences, engineering, and physics.

The DOE Oakland Operations Office (DOE-OAK) is the field organization responsible for the implementation of Waste Management Plans at LLNL. The Hazardous Waste Management Division (HWM) is responsible for preparing those plans and for managing and processing all hazardous wastes, radioactive wastes, and mixed wastes generated at LLNL for the purposes of storage, treatment, and transportation for off-site disposal.

Mission

The Livermore site was purchased by the U.S. Navy in 1942 and was initially used as a flight training base and engine overhaul facility. The transition from Navy operations to research began in 1950, when the Atomic Energy commission authorized the construction for a materials-test accelerator at the site. The Commission established the University of California Radiation Laboratory, Livermore Site (the predecessor of the Lawrence Livermore National Laboratory) as a facility for nuclear weapons research.

The current mission of the LLNL, a multi-program laboratory, is research testing, and development focusing on national defense and security, energy, the environment, and biomedicine. The Laboratory's specific defense mission is the research, testing, and development of technologies related to nuclear weapons. Over the years, the Laboratory's overall mission has been broadened to meet national needs, such as the enhancement of economic competitiveness and science education. These objectives are expected to continue for the foreseeable future. Current major programs at LLNL include defense and related programs, laser fusion (also called inertial confinement fusion), laser isotope separation, magnetic fusion energy, biomedical and environmental research, energy and resources, and environmental restoration and waste management.

Waste Information

Processes

Generation and Handling: TRU waste, both non-mixed and mixed, is generated only at the Livermore Main Site. Defense programs at the Plutonium Facility (Building 332) and the Heavy Element Facility (Building 251) generate virtually all of LLNL's TRU waste. Building 332 is involved with plutonium chemistry and metallurgy, and Building 251 was principally involved with the handling of transuranics during tracer experiments. Building 332 is still operating; whereas Building 251 is currently undergoing cleanup, resulting in continued TRU waste generation.

By volume, approximately 95% of LLNL's TRU waste is contaminated primarily by plutonium isotopes. The remaining 5% is contaminated with isotopes of americium, neptunium, curium, and californium, which constitute about 60% of the total activity of the LLNL TRU waste inventory because of their higher specific activities.

Initial waste characterization is performed at the point of generation and is based on acceptable knowledge, mainly generator knowledge. Waste is assayed by the generators to determine the activity and radionuclide composition, though the latter is often determined by acceptable knowledge. Waste is then accepted for storage at the Hazardous Waste Management (HWM) storage facilities. Further waste characterization, such as real time radiography and drum headspace gas sapling, takes place at HWM.

Treatment: HWM stores no TRU waste known to require treatment to meet the WIPP WAC. However some may prove to require treatment such as HEPA filters, which may require immobilization of fine particles and waste that does not meet TRUPACT-II wattage limits or actual gas generation requirements for transport.

Storage: TRU wastes are stored at HWM's Buildings 625 and 612-1, located in the Area 612 Facility, and in Building 233 Facility, while awaiting the availability of disposal at WIPP. The Building 233 Facility, used to store high curie TRU waste, will be replaced by Building 280 to reduce site personnel exposure resulting rom its continued operations.

Disposal: TRU waste from LLNL will be disposed of at WIPP. All currently existing waste either meets the WIPP WAC and TRUPACT-II Authorized Methods for Payload Control (TRAMPAC) criteria or will meet them after repackaging or, in a few cases, treatment.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W028	Handling:	CH	NMVP #:	LL 116	Stream Name:	R&D Glovebox Waste (Form 1)	Inventory Date:	3/1/95
Local ID:	Form 1 Mixed	Type:	MTRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

D040, D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	5.0	0.0	365.0
Aluminum-base Metal/Alloys:	5.0	0.0	365.0
Other Metals/Alloys:	2.0	0.0	365.0
Other Inorganic Material:	1.0	0.0	200.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	100.0	0.0	365.0
Rubber:	5.0	0.0	200.0
Plastics:	100.0	5.0	365.0
Solidified Inorganic Material:	5.0	0.0	100.0
Solidified Organic Material:	5.0	0.0	100.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Yes

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 116A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	2.83E+01
Pu-240	9.26E-01
Pu-239	2.06E+00
Pu-238	2.46E+00
Cm-244	3.03E+00
Am-241	2.59E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon	5.4	1.9	3.1	6.2	6.0	22.7
Totals	5.4	1.9	3.1	6.2	6.0	22.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	1.9	3.1	6.2	6.0	22.7
SWB used to overpack 55 gallon drums	0.0	0.0	0.0	0.0	0.0	0.0
Totals	5.4	1.9	3.1	6.2	6.0	22.7

As-Generated Form: Stored: 5.4 Projected: 17.3 Total: 22.7

Final Waste Form: Stored: 5.4 Projected: 17.3 Total: 22.7

WASTE STREAM DESCRIPTION	The waste consists mostly of untreated dry solids such as tissues, paper, assorted plastics, glassware, ceramics, and metals. Portland cement or Aquaset is used to solidify small amounts of water-based liquids; Envirostone or Petroset is used to solidify small amounts of solvents and oil-based liquids. The composition varies considerably, but it is predominantly organics (> 90% by weight). The waste does contain small amounts of RCRA listed hazardous materials. Typical hazardous materials are leaded gloves or materials contaminated with solvents.
WASTE STREAM SOURCE	Form 1 Mixed: The waste consists of glovebox bagout waste, laboratory trash and some contaminated equipment. The waste contains small amounts of RCRA materials such as solvents or lead shielding. The waste may occasionally include small quantities of solidified liquids, but these are usually segregated as waste form 2.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Regulated contaminants reported are based on generator reports of laboratory experimental processes. This waste stream is included in LLNL's PSTP report of waste stream number LL-W018. That waste stream also included waste packages possibly, but not known to be contaminated with RCRA hazardous materials. More process knowledge and analysis will be done to further characterize those packages. Note that in this report (WTWBIR & MWIR), LL-W018 consists only of metal scrap waste, mostly in boxes, that is known to be mixed waste.
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. I have not included in this waste stream any waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Repackaging may be required due to approximately 50% of waste containers not meeting thermal power requirements of TRAMPAC; however I don't know how much repackaging will actually be required and how many extra drums would be generated thereby. Therefore, my estimates in 8.2.15 are the same as in 8.2.14. Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W029	Handling:	CH	NMVP #:	LL 111	Stream Name:	Solidified Waste (Form 2)	Inventory Date:	3/1/95
Local ID:	Form 2 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3120

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	30.0	0.0	100.0
Aluminum-base Metal/Alloys:	5.0	0.0	50.0
Other Metals/Alloys:	1.0	0.0	20.0
Other Inorganic Material:	1.0	0.0	20.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.0	0.0	100.0
Rubber:	1.0	0.0	20.0
Plastics:	20.0	5.0	100.0
Solidified Inorganic Material:	100.0	50.0	365.0
Solidified Organic Material:	100.0	50.0	365.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 111A
LL 113A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.95E+01
Pu-240	6.32E-01
Pu-239	1.40E+00
Am-241	9.09E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	14.4	0.0	0.0	0.0	5.8	20.2
Totals	14.4	0.0	0.0	0.0	5.8	20.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	14.4	0.6	1.0	2.1	2.1	20.2
Totals	14.4	0.6	1.0	2.1	2.1	20.2

As-Generated Form: Stored: 14.4 Projected: 5.8 Total: 20.2

Final Waste Form: Stored: 14.4 Projected: 5.8 Total: 20.2

WASTE STREAM DESCRIPTION	50 to 90% of this waste matrix consists of liquids solidified in 1 to 5 gallon plastic containers using Portland cement or Aquaset for the water based liquids and Envirostone or Petroset for the oil-based liquids. The remainder consists of glovebox waste similar to form 1 waste. The waste does not contain any RCRA-listed hazardous materials.
WASTE STREAM SOURCE	Form 2 Non-mixed: More than 50 volume percent of this waste consists of solidified water-based or oil-based liquids or solidified fine particles. The remaining waste consists of glovebox bagout waste, laboratory trash and some contaminated equipment.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W030	Handling:	CH	NMVP #:	LL 116	Stream Name:	R&D Glovebox Waste (Form 1)	Inventory Date:	1/1/95
Local ID:	Form 1 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	5.0	0.0	365.0
Aluminum-base Metal/Alloys:	5.0	0.0	365.0
Other Metals/Alloys:	2.0	0.0	365.0
Other Inorganic Material:	1.0	0.0	200.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	100.0	0.0	365.0
Rubber:	5.0	0.0	200.0
Plastics:	100.0	3.0	365.0
Solidified Inorganic Material:	5.0	0.0	100.0
Solidified Organic Material:	5.0	0.0	100.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	163.2		
Packaging Material Plastic:	22.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 116A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	3.17E+01
Pu-240	1.03E+00
Pu-239	2.50E+00
Pu-238	3.24E-01
Am-241	1.79E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	40.4	0.0	0.0	0.0	291.2	331.6
SWB used to overpack 55 gallon drums	7.6	22.7	37.8	75.6	75.6	219.2
Totals	47.9	22.7	37.8	75.6	366.8	550.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	40.4	31.2	52.0	104.0	104.0	331.6
SWB used to overpack 55 gallon drums	7.6	22.7	37.8	75.6	75.6	219.2
Totals	47.9	53.9	89.8	179.6	179.6	550.8

As-Generated Form: Stored: 47.9 Projected: 502.9 Total: 550.8

Final Waste Form: Stored: 47.9 Projected: 502.9 Total: 550.8

WASTE STREAM DESCRIPTION	The waste consists mostly of untreated dry solids such as tissues, paper, assorted plastics, glassware, ceramics, and metals. Portland cement or Aquaset is used to solidify small amounts of water-based liquids; Envirostone or Petroset is used to solidify small amounts of solvents and oil-based liquids. The composition varies considerably, but it is predominantly organics (> 90% by weight). The waste does not contain any RCRA listed hazardous materials.
WASTE STREAM SOURCE	Form 1 Non-Mixed: The waste consists of glovebox bagout waste, laboratory trash and some contaminated equipment. The waste may occasionally include small quantities of solidified liquids, but these are usually segregated as waste form 2.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W031	Handling:	CH	NMVP #:	LL 125	Stream Name:	Combined metal scrap & incidental combust (Form 3)	Inventory Date:	1/1/95
Local ID:	Form 3 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5420

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	20.0	0.0	30.0
Aluminum-base Metal/Alloys:	3.0	0.0	30.0
Other Metals/Alloys:	1.0	0.0	30.0
Other Inorganic Material:	1.0	0.0	5.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.0	0.0	5.0
Rubber:	1.0	0.0	5.0
Plastics:	1.0	0.0	10.0
Solidified Inorganic Material:	0.0	0.0	5.0
Solidified Organic Material:	0.0	0.0	5.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No,
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

LL 125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.45E+00
Pu-240	8.02E-02
Pu-239	9.92E-02
Pu-238	7.02E-02
Am-241	1.35E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Capital Indus. Box #1 /	7.6	0.0	0.0	0.0	0.0	7.6
Capital Indus. Box #2 /	60.0	0.0	0.0	0.0	0.0	60.0
Capital Indus. Box #3 /	6.4	0.0	0.0	0.0	0.0	6.4
Capital Indus. Box #4 /	7.5	0.0	0.0	0.0	0.0	7.5
Rogers Chem. Box #1 /	4.2	0.0	0.0	0.0	0.0	4.2
Rogers Chem. Box #2 /	5.6	0.0	0.0	0.0	0.0	5.6
Rogers Chem. Box #3 /	5.8	0.0	0.0	0.0	0.0	5.8
Rogers Chem. Box #4 /	7.6	0.0	0.0	0.0	0.0	7.6
Rogers Chem. Box #5 /	24.9	0.0	0.0	0.0	0.0	24.9
Rogers Chem. Box #6 /	8.9	0.0	0.0	0.0	0.0	8.9
Standard Waste Box /	3.8	22.7	18.9	37.8	37.8	121.0
Totals	142.4	22.7	18.9	37.8	37.8	259.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	143.6	22.7	18.9	37.8	37.8	260.8
Totals	143.6	22.7	18.9	37.8	37.8	260.8

As-Generated Form: Stored: 142.4 Projected: 117.2 Total: 259.6

Final Waste Form: Stored: 143.6 Projected: 117.2 Total: 260.8

WASTE STREAM DESCRIPTION	The waste consists mostly of metal scrap such as decommissioned gloveboxes, hoods and other large equipment as well as laboratory trash. Typically it will contain metal components, glassware, ceramics, plastics, paper, and wood. It will be mostly inorganic materials, but can vary widely. This waste does not contain RCRA listed hazardous materials.
WASTE STREAM SOURCE	Form 3 non-mixed: This waste consists of contaminated equipment and laboratory trash too big to fit in 55 gallon drums. This waste does not contain RCRA hazardous materials.
CURRENT CONTAINER COMMENTS	Contains nuclides submitted in MWIR/BIR, Rev. 1 data call in 1994, copy enclosed.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Average radionuclide content of final containers (SWBs) will depend on content of existing boxes to be repackaged and existing SWBs plus content of SWBs to be generated. Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W032	Handling:	CH	NMVP #:	LL 124	Stream Name:	Pyrochemical salt waste (Form 4)	Inventory Date:	1/1/95
Local ID:	Form 4 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3140

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	20.0	0.0	100.0
Aluminum-base Metal/Alloys:	5.0	0.0	80.0
Other Metals/Alloys:	2.0	0.0	50.0
Other Inorganic Material:	290.0	100.0	365.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.0	0.0	50.0
Rubber:	1.0	0.0	20.0
Plastics:	20.0	5.0	100.0
Solidified Inorganic Material:	1.0	0.0	10.0
Solidified Organic Material:	1.0	0.0	10.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 124A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	5.10E+01
Pu-240	1.66E+00
Pu-239	2.06E+00
Pu-238	4.74E-01
Am-241	2.81E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.4	0.5	1.0	1.0	3.6
Totals	0.6	0.4	0.5	1.0	1.0	3.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.4	0.5	1.0	1.0	3.6
Totals	0.6	0.4	0.5	1.0	1.0	3.6

As-Generated Form: Stored: 0.6 Projected: 3.0 Total: 3.6

Final Waste Form: Stored: 0.6 Projected: 3.0 Total: 3.6

WASTE STREAM DESCRIPTION	The waste consists primarily of used chloride and fluoride salts from pyrochemical processes such as electrorefining, molten salt extraction, and direct oxide reduction. There may also be up to 20% heterogeneous organic glovebox bagout waste packaged with the salt waste. This waste does not contain any RCRA listed hazardous materials.
WASTE STREAM SOURCE	Form 4 non-mixed: The waste consists of used chloride and fluoride salts from pyrochemical processes such as electrorefining, molten salt extraction, and direct oxide reduction.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W033	Handling:	CH	NMVP #:	N/A	Stream Name:	HEPA filters (Form 5)	Inventory Date:	1/1/95
Local ID:	Form 5 Non-mixed	Type:	TRU	Generator Site:	LL	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	66.3	0.0	132.6
Aluminum-base Metal/Alloys:	20.7	0.0	41.3
Other Metals/Alloys:	10.0	0.0	20.0
Other Inorganic Material:	20.7	0.0	41.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	65.7	0.0	126.1
Rubber:	10.0	0.0	20.0
Plastics:	20.7	4.3	47.8
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	151.0		
Packaging Material Plastic:	4.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Yes

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.64E+00
Pu-240	1.84E-01
Pu-239	2.28E-01
Pu-238	1.68E-01
Cm-244	4.14E+00
Am-241	5.09E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Capital Indus. Box #2 /	16.0	0.0	0.0	0.0	0.0	16.0
Drum / 55 gallon	0.4	0.6	1.0	2.1	2.1	6.2
Standard Waste Box /	0.0	2.8	4.7	9.4	9.4	26.5
Totals	16.4	3.5	5.8	11.5	11.5	48.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.6	1.0	2.1	2.1	6.2
Standard Waste Box	15.1	2.8	4.7	9.4	9.4	41.6
Totals	15.5	3.5	5.8	11.5	11.5	47.8

As-Generated Form: Stored: 16.4 Projected: 32.3 Total: 48.7

Final Waste Form: Stored: 15.5 Projected: 32.3 Total: 47.8

WASTE STREAM DESCRIPTION	The waste matrix is mostly wood framed HEPA filters although some small metal cased HEPA filters are also included. Some of the filters contain asbestos.
WASTE STREAM SOURCE	Form 5 non-mixed: HEPA filters
CURRENT CONTAINER COMMENTS	
	Contains nuclides submitted in MWIR/BIR, Rev. 1 data call in 1994, copy enclosed.
EPA COMMENTS	Generator knowledge about old HEPA filters is largely lacking; however some of these filters are known to contain asbestos.
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. This waste stream may contain waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste. Also, HEPA filters, if found to fail fine particles requirements, would require immobilization of fine particles.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as 55-gallon drum storage estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W018	Handling:	CH	NMVP #:	LL 125	Stream Name:	Combined metal scrap & incidental combust.(Form 3)	Inventory Date:	3/1/95
Local ID:	Form 3 Mixed	Type:	MTRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5420

AS-GENERATED EPA CODES

F002, D040, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	150.0	0.0	800.0
Aluminum-base Metal/Alloys:	20.0	0.0	800.0
Other Metals/Alloys:	10.0	0.0	800.0
Other Inorganic Material:	5.0	0.0	800.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.0	0.0	500.0
Rubber:	2.0	0.0	100.0
Plastics:	20.0	5.0	200.0
Solidified Inorganic Material:	2.0	0.0	300.0
Solidified Organic Material:	2.0	0.0	300.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	5.94E-01
Pu-240	2.03E-02
Pu-239	8.78E-03
Am-241	1.04E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box /	1.9	3.8	3.8	9.5	9.5	28.5
Totals	1.9	3.8	3.8	9.5	9.5	28.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	3.8	3.8	9.4	9.4	28.3
Totals	1.9	3.8	3.8	9.4	9.4	28.3

As-Generated Form: Stored: 1.9 Projected: 26.6 Total: 28.5

Final Waste Form: Stored: 1.9 Projected: 26.5 Total: 28.3

WASTE STREAM DESCRIPTION	The waste is potentially radioactive inorganic scrap metal generated from on-site laboratory research and maintenance, including laboratory clean up. Includes lead bricks and metal shavings. These materials may contain transuranic activity (80.6 lbs. in 55-gal. drum) Waste is used and discarded metal parts generated from on-site research and development activities.
WASTE STREAM SOURCE	Form 3 mixed: This waste consists of contaminated equipment and laboratory trash too big to fit in 55 gallon drums. This waste does contain RCRA hazardous materials. Inorganic scrap metal generated from on-site laboratory research and maintenance, including laboratory clean up.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Regulated contaminants reported are based on generator reports of laboratory experimental processes. This waste stream is included in LLNL's PSTP report of waste stream number LL-W018. That waste stream also included waste packages possibly, but not known to be contaminated with RCRA hazardous materials. More process knowledge and analysis will be done to further characterize those packages. Note that in this report (WTWBIR & MWIR), LL-W018 consists only of metal scrap waste, mostly in boxes, that is known to be mixed waste.
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. I have not included in this waste stream any waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	LL-W019	Handling:	CH	NMVP #:	LL 111	Stream Name:	Solidified Waste (Form 2)	Inventory Date:	3/1/95
Local ID:	Form 2 Mixed	Type:	MTRU	Generator Site:	LL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3220

AS-GENERATED EPA CODES

F002, D040

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	30.0	0.0	100.0
Aluminum-base Metal/Alloys:	5.0	0.0	50.0
Other Metals/Alloys:	1.0	0.0	20.0
Other Inorganic Material:	1.0	0.0	20.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.0	0.0	100.0
Rubber:	1.0	0.0	20.0
Plastics:	20.0	5.0	100.0
Solidified Inorganic Material:	100.0	50.0	365.0
Solidified Organic Material:	100.0	50.0	365.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

LL 111A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.01E+01
Pu-240	6.63E-01
Pu-239	7.89E-01
Am-241	1.24E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	5.8	6.9
Totals	1.0	0.0	0.0	0.0	5.8	6.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.6	1.0	2.1	2.1	6.9
Totals	1.0	0.6	1.0	2.1	2.1	6.9

As-Generated Form: Stored: 1.0 Projected: 5.8 Total: 6.9

Final Waste Form: Stored: 1.0 Projected: 5.8 Total: 6.9

WASTE STREAM DESCRIPTION	The waste is radioactive halogenated solvents generated from on-site cleaning of tanks and equipment and operating of research laboratories and machining shops. Waste consists of TCE and TCA and may contain transuranic activity (0.6 lbs. in a 55-gallon drum). Waste is generated from the on-site cleaning of tanks and equipment used in changing R & D activities.
WASTE STREAM SOURCE	Form 2 Mixed: More than 50 volume percent of this waste consists of solidified water-based or oil-based liquids or solidified fine particles. The remaining waste consists of glovebox bagout waste, laboratory trash and some contaminated equipment.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Regulated contaminants reported are based on generator reports of laboratory experimental processes. This waste stream is included in LLNL's PSTP report of waste stream number LL-W018. That waste stream also included waste packages possibly, but not known to be contaminated with RCRA hazardous materials. More process knowledge and analysis will be done to further characterize those packages. Note that in this report (WTWBIR & MWIR), LL-W018 consists only of metal scrap waste, mostly in boxes, that is known to be mixed waste.
MANAGEMENT COMMENTS	Some waste may need to be repackaged in order to meet transportation (TRAMPAC) requirements for gas generation. I have not included in this waste stream any waste containing hazardous constituents that the state of California would regulate (more stringently than RCRA) if the waste were not also radioactive. California now has authority to regulate only RCRA mixed waste.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Date of inventory and number of containers projected are the same as storage container estimates.

MC U.S. Army Material Command

U.S. ARMY MATERIAL COMMAND

Location and description

The U.S. Army Material Command (MC) is located at Rock Island, Illinois, near Davenport, Iowa. MC is responsible for coordinating logistical demands for the various programmatic functions of the U.S. Army, including research and development of weapons.

Mission

MC is responsible for disposal of radioactive waste resulting from U.S. Army applications.

Waste Information

Processes

Currently the Army possesses packaged americium and plutonium sources in man-portable containers. Some of the sources are mixed with beryllium, potentially rendering the material mixed waste. Most of this waste is packaged and ready for shipment in trucks.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MC-W001	Handling:	CH	NMVP #:	N/A	Stream Name:	USAMC TRU Waste	Inventory Date:	1/1/95
Local ID:		Type:	TRU	Generator Site:	MC	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source:

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.11E-01
Pu-239	2.43E-02
Am-241	6.21E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.5	0.0	0.0	0.0	0.0	2.5
Totals	2.5	0.0	0.0	0.0	0.0	2.5

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 2.5 Projected: 0.0 Total: 2.5

WASTE STREAM DESCRIPTION	Army sources
WASTE STREAM SOURCE	Discarded sources.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

MD Mound Plant

MOUND PLANT

Location and Description

Mound (MD) is located within the southern city limits of Miamisburg in Montgomery County in southwestern Ohio. The plant occupies 306 acres of land overlooking Miamisburg and the Great Miami River. The metropolitan area of Dayton is located 10 miles north-northeast of Mound.

The DOE Dayton Area Office was established as part of the Albuquerque Operations Office in 1947.

The Mound Plant (MD) is one of the principal DOE sites. The facility was utilized as an integrated research, development, and production facility to perform work in support of DOE weapons and energy programs. Mound manufactured non-nuclear and tritium-containing components for nuclear weapons. These components included detonators, timers, transducers, firing sets, pellets, and unique production testers. Activities also included recovery and purification of tritium wastes. Earlier activities included manufacturing of polonium-210 and plutonium-238 radioisotopic heat sources.

Mission

Mound originated as a technical organization in 1943 and was responsible for determining the chemical and metallurgical properties of plutonium for the Manhattan Project. Permanent facilities were first constructed in 1947 and occupied in 1948. The plant was assigned new production and development functions in 1955.

In 1993, the Secretary of Energy announced that the Defense Program Mission was to be ended at Mound. Mound's new mission is the safe shutdown of Defense Programs and commercialization of some of the area offices.

Waste Information

Processes

TRU waste may be generated by the Decontamination and Decommissioning (D&D) operations in the Plutonium Processing Building and the Research Building.

Large quantities of the line-generated solid wastes, including gloveboxes, fume hoods, piping, tools and other non-burnables, as well as rags, chemwipes, and other combustible waste was and will be generated by the Pu Processing and Research Buildings D&D Project.

TRU alpha wastes are generated from decontamination operations in the Pu Processing Areas.

Other major D&D efforts included the removal of underground piping which formerly transmitted Pu-contaminated liquid waste from the processing area to the waste water treatment facility.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-M001	Handling:	CH	NMVP #:	N/A	Stream Name:	Asbestos Debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Filter	Waste Matrix Code:	S5125

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Yes

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	2.98E-02
Pu-238	1.63E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Assorted asbestos and other filter media. Predominantly asbestos.
WASTE STREAM SOURCE	805, Asbestos and other filters utilized in first stage hood line ventilation exhaust.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Since the majority of questions were answered as unknown our confidence level is LOW.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This is not a MTRU waste stream. It was incorrectly assigned as MTRU in previous reports and is being officially corrected in this report.
FINAL FORM COMMENTS	Assumption is that shipping and storage containers are the same.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T001	Handling:	CH	NMVP #:	N/A	Stream Name:	Cement Forms	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	Z1110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	1143.0	964.0	1204.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-238	1.20E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 4.2 Projected: 0.0 Total: 4.2

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	WD TRU sludge, batch #194. Sludge wastewater mixed with cement to form a cement monolith inside a 55 gallon drum.
WASTE STREAM SOURCE	836, Solidified TRU Sludge (20% solids and 80% water) solidified with portland cement in WD Building. Solids included carbon and calcium.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence is LOW due to unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T003	Handling:	CH	NMVP #:	N/A	Stream Name:	Contaminated soil	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Soils	Waste Matrix Code:	S4100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	891.0	603.0	1315.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	1.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-238	2.63E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Type 004	46.3	0.0	0.0	0.0	0.0	46.3
Box / Type 005	66.4	0.0	0.0	0.0	0.0	66.4
Box / Type 008	3.2	0.0	0.0	0.0	0.0	3.2
Totals	115.8	0.0	0.0	0.0	0.0	115.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	146.9	0.0	0.0	0.0	0.0	146.9
Totals	146.9	0.0	0.0	0.0	0.0	146.9

As-Generated Form: Stored: 115.8 Projected: 0.0 Total: 115.8

Final Waste Form: Stored: 146.9 Projected: 0.0 Total: 146.9

WASTE STREAM DESCRIPTION	SM building and hillside hot spot #3 excavation
WASTE STREAM SOURCE	842DD000 TRU soil. Soil from SM building and hillside remediation of the Waste Transfer system (WTS).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level based on the number of unknowns reported.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	62 SWB will be potentially required based on volume alone. This is a soil waste stream and based on the weight it would have been impossible to fill the storage containers completely full, therefore 62 is a worst case scerino. Another issue is the possible additional waste created by disposing of the storage containers if they are TRU also.

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T005	Handling:	CH	NMVP #:	N/A	Stream Name:	Contaminated soils with debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Soils	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	632.0	566.0	1293.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-238	1.45E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Type 004	25.3	0.0	0.0	0.0	0.0	25.3
Box / Type 005	4.7	0.0	0.0	0.0	0.0	4.7
Totals	30.0	0.0	0.0	0.0	0.0	30.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	30.2	0.0	0.0	0.0	0.0	30.2
Totals	30.2	0.0	0.0	0.0	0.0	30.2

As-Generated Form: Stored: 30.0 Projected: 0.0 Total: 30.0

Final Waste Form: Stored: 30.2 Projected: 0.0 Total: 30.2

WASTE STREAM DESCRIPTION	SM-10 & Hillside hot spot #3 excavation.
WASTE STREAM SOURCE	842, TRU soil with rock debris. Soil and rock from SM building and hillside remediation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is LOW based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T006	Handling:	CH	NMVP #:	N/A	Stream Name:	Metal debris w/o lead or cadmium	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-238	5.36E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Type 003	7.0	0.0	0.0	0.0	0.0	7.0
Box / Type 004	46.3	0.0	0.0	0.0	0.0	46.3
Box / Type 008	6.3	0.0	0.0	0.0	0.0	6.3
Totals	59.6	0.0	0.0	0.0	0.0	59.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	58.6	0.0	0.0	0.0	0.0	58.6
Totals	58.6	0.0	0.0	0.0	0.0	58.6

As-Generated Form: Stored: 59.6 Projected: 0.0 Total: 59.6

Final Waste Form: Stored: 58.6 Projected: 0.0 Total: 58.6

WASTE STREAM DESCRIPTION	Metal debris from D&D of Bldgs. 38-10 & 13, SM-10 & 25, R-120 & 149 and Waste Transfer system (WTS).
WASTE STREAM SOURCE	824, D&D metal debris. Waste Transfer System (WTS) piping consisting of steel pipe withj some type of plastic lining. Steel tank from Building 41. Floor drains and piping from SM, PP and R Buildings.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is low based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Repackaging into SWB would require 31 containers based on volume only. Additonal waste from the empty containers would also be genereated.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T007	Handling:	CH	NMVP #:	N/A	Stream Name:	Uncategorized metal debris.	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	149.2		
Packaging Material Plastic:	7.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	3.96E-01
Pu-238	1.29E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.0	0.0	0.0	0.0	0.0	5.0
Box / Type 003	2.3	0.0	0.0	0.0	0.0	2.3
Box / Type 004	12.6	0.0	0.0	0.0	0.0	12.6
Box / Type 008	3.2	0.0	0.0	0.0	0.0	3.2
Totals	23.1	0.0	0.0	0.0	0.0	23.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.0	0.0	0.0	0.0	0.0	5.0
Standard Waste Box	18.9	0.0	0.0	0.0	0.0	18.9
Totals	23.9	0.0	0.0	0.0	0.0	23.9

As-Generated Form: Stored: 23.1 Projected: 0.0 Total: 23.1

Final Waste Form: Stored: 23.9 Projected: 0.0 Total: 23.9

WASTE STREAM DESCRIPTION	Miscellaneous equipment - hood line trash.
WASTE STREAM SOURCE	825 TRU metal debris. Inline Noncombustible waste removed from hood lines.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is LOW due to the number of unknowns.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Assumption is that current drum is WIPP acceptable.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T008	Handling:	CH	NMVP #:	N/A	Stream Name:	Uncategorized plastics/rubber debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Combustible	Waste Matrix Code:	S5319

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-239	2.98E-02
Pu-238	2.72E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 3.7 Projected: 0.0 Total: 3.7

WASTE STREAM DESCRIPTION	Plastic and rubber debris from Bldg. 38, Room 149
WASTE STREAM SOURCE	804, Uncategorized plastics/rubber debris. Combustible waste removed from hood lines.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	LOW confidence level based on the number of unknowns.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T009	Handling:	CH	NMVP #:	N/A	Stream Name:	Unknown/Other Organic Debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	8.37E+00
Pu-238	3.10E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Uncategorized combustible debris
WASTE STREAM SOURCE	801+804, Uncategorized combustible debris.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is LOW due to the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T010	Handling:	CH	NMVP #:	N/A	Stream Name:	Composite filters	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-239	1.49E-02
Pu-238	8.17E-01
Np-237	8.17E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Filters from Bldgs. 38, room 113.
WASTE STREAM SOURCE	825, Glass + metal filters, cans-glass. First stage filters for hood line exhaust ventilation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-T012	Handling:	CH	NMVP #:	N/A	Stream Name:	Uncategorized heterogeneous debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	1.01E+01
Pu-238	1.95E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	Bldg. 38, room 113, R, room 140
WASTE STREAM SOURCE	825 Metal, glass, asbestos filters
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level LOW due to the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-W002	Handling:	CH	NMVP #:	N/A	Stream Name:	Absorbed Aqueous Liquids	Inventory Date:	5/5/95
Local ID:	N/A	Type:	MTRU	Generator Site:	MD	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3113

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	2.32E-02
Pu-238	7.24E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	This waste is corrosive TRU solutions (primarily nitric acid) absorbed into an inorganic particulate absorbent. There is no free liquid, therefore this waste stream does not currently meet the D002 definition and not mixed. It will remain classified as MTRU until proven othewise by a WIPP acceptable method and under control of a QAPjP.
WASTE STREAM SOURCE	This process and analytical waste was generated from Pu-238 operations. 833 Corrosives - TRU Acidic and Basic waste absorbed on FLORCO
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The D002 code is maintained due to the question of whether this waste remains corrsive.
MANAGEMENT COMMENTS	Building 23 Mixed waste storage facility.
ACCEPTANCE COMMENTS	Plutonium processing and analysis. The entire inventory is indicated as not subject to the LDR storage prohibition as it was stored before the LDR effective date.
FINAL FORM COMMENTS	The shipping and storage containers are assumed to be the same.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-W003	Handling:	CH	NMVP #:	N/A	Stream Name:	Leaded Gloves/Aprons	Inventory Date:	5/5/95
Local ID:	N/A	Type:	MTRU	Generator Site:	MD	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	6.16E+00
Pu-238	8.89E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 1.7 Projected: 0.0 Total: 1.7

WASTE STREAM DESCRIPTION	Lead loaded drygloves removed from gloveboxes during decommissioning operations.
WASTE STREAM SOURCE	Generated from decommissioning of gloveboxes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is based on the number of unknowns.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	New leaded gloves are no longer introduced into the Mound Facility which is why the "expected generation termination date" is indicated as 1/1/93. However, it is possible additional leaded gloves (transuranic) at Mound which have not yet been declared waste may be generated. Although the possibility exists for additional waste, it is impossible to predict when and what the quantles would be.
FINAL FORM COMMENTS	Storage and shipping containers were assumed to be the same

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MD-W017	Handling:	CH	NMVP #:	N/A	Stream Name:	Paper/Cloth Debris	Inventory Date:	5/5/95
Local ID:	N/A	Type:	TRU	Generator Site:	MD	Final Waste Form:	Combustible	Waste Matrix Code:	S5330

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-239	3.86E-01
Pu-238	2.66E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

As-Generated Form: Stored: 1.5 Projected: 0.0 Total: 1.5

Final Waste Form: Stored: 1.5 Projected: 0.0 Total: 1.5

WASTE STREAM DESCRIPTION	Paper and cloth waste removed from hood lines as a result of routine production operations in Building 38.
WASTE STREAM SOURCE	Paper and Cloth from PP Building
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Confidence level is based on the number of unknowns
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Assuming that the storage and shipping container are the same.

UNIVERSITY OF MISSOURI RESEARCH REACTOR

Location and Description

The University of Missouri-Columbia (MU) is located in Columbia, Missouri at the University's Research Park. MU maintains a 10 mW research reactor licensed by the NRC. The Missouri University Research Reactor is one of only a few high-quality research reactors in the United States. The University is contracted by Rockwell International to conduct experiments to separate radioactive actinide elements from PUREX spent fuel for DOE.

Mission

MU conducts a wide variety of nuclear energy experiments. Research at MU has focused on many areas, including studies of the effects of trace elements on human health; studies of the basic wave nature of particles using neutron interferometry, development of radioisotopes for human therapy, and development of the TRUMP-S process to separate TRU materials from nuclear waste (PUREX).

Waste Information

Processes

MU currently has several grams of TRU materials provided by the DOE for experiments on the TRUMP-S Program. TRU waste is generated as a part of normal program operations. Additional TRU waste is expected at the conclusion of the program when the facility is decontaminated and decommissioned. Management of the TRU waste generated from the TRUMP-S experiments conducted at MU is the responsibility of the DOE program office overseeing nuclear energy research.

Modifications/Assumptions/Development

MU reported radionuclides in Curies per gram. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the final waste form volumes reported by MU.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	MU-W002	Handling:	CH	NMVP #:	NA	Stream Name:	Heterogeneous Debris	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:	MU	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

D011, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	11.3	0.0	20.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	25.0	0.0	60.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.5	0.0	10.0
Rubber:	25.0	0.0	50.0
Plastics:	37.5	0.0	80.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
U-238	1.65E-07
Pu-239	3.62E-02
Np-237	3.23E-04
Am-241	1.50E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.6	0.2	0.0	0.0	1.0
Totals	0.2	0.6	0.2	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.6	0.2	0.0	0.0	1.0
Totals	0.2	0.6	0.2	0.0	0.0	1.0

As-Generated Form: Stored: 0.2 Projected: 0.8 Total: 1.0

Final Waste Form: Stored: 0.2 Projected: 0.8 Total: 1.0

WASTE STREAM DESCRIPTION

MTRU Heterogeneous Debris. The radioactive wastes generated on the project will come first from normal operations and second from the D&D of the facility at the end of the project. Radioactive wastes from normal operation will consist of the following:

- o HEPA filters from the glove box
- o HEPA filters from offgas and room filtration systems
- o paper wipes from periodic cleaning of the glove boxes
- o used sample bottles
- o damaged glove box gloves
- o used crucibles, tubes, and wires

WASTE STREAM SOURCE

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- o HEPA filters from offgas and room filtration systems
- o paper wipes from periodic cleaning of the glove boxes
- o used sample bottles
- o damaged glove box gloves
- o used crucibles, tubes, and wires $ $ Mixed TRU Waste

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Waste has not yet been characterized

MANAGEMENT COMMENTS

MURR, costar tower 5th level in containment.

ACCEPTANCE COMMENTS

□□GENERAAREA: MURR Alpha Room□□GENOPERATI: The TRUMP-S test program uses three glove boxes located in the Alpha Lab: the argon box, the air box, and the ICP box. The three boxes are equipped with various pieces of test equipment.

The argon box is used to conduct the electrochemical experiments that are the objective if the program. Actinide metals are unpacked in this box, subdivided, and repackaged. Chloride salts of the actinides are prepared here. Samples of the materials used in the experiments are obtained in the argon box for analysis. The argon box is frequently cleaned using paper wipes, which are packaged in small waste cans for disposal.

The air box is used to prepare aqueous samples for analysis in the ICP box. These samples are later prepared for recovery of the actinides by evaporating the water. Tantalum materials that have been used in the argon box are cleaned in the air box for later reuse in the electrochemical tests. The air box is also frequently cleaned using paper wipes and these are likewise placed in waste cans for disposal.

The ICP box is used to analyze the chemical composition of various aqueous samples. The nebulizer of the ICP unit is located within the ICP box to contain the analysis samples. The atmosphere within the ICP box is air.

Materials used in the actinide tests: Test materials, along with paper wipes and waste cans for cleanup, are passed into the argon box through a transfer port from the Alpha lab. The test materials include the following items:

- o Actinide and rare earth elements as metals and chlorides
- o Cadmium as both metal and chloride
- o Tantalum and alumina crucibles
- o Tantalum, iron, and silver wire

- o Chloride salts (Ag, Li, K)
- o Alumina and Pyrex tubing
- o Tantalum foil
- o Sample bottles
- o NAA samples returned for use

Some solid samples of test materials are removed from the argon box through the neutron activation analysis (NAA) sample station for neutron activation or gamma spectrometer analysis. All other exits from the argon box are to the air box. Samples for analysis in the ICP, crucibles containing mixtures of actinides along with salts and cadmium, used tantalum materials, broken or used Pyrex and alumina, wire (Ta, Fe, and Ag), damaged glove box gloves, and packaged wastes (paper wipes) are all transferred to the air box through an interconnecting transfer port. Tantalum materials are normally cleaned and reused in the electrochemistry tests a number of times before they are disposed of as waste.

Aqueous chemicals, water, and beakers are transferred into the air box from the Alpha Lab for preparing and handling aqueous samples. These samples are analyzed in the ICP box and then returned to the air box. The air box is also cleaned frequently with paper wipes, and these are packaged in waste cans for disposal. Materials that are removed during test operations from the air box are either actinide materials that are being sent to storage, or wastes that are placed in 55-gal drums. Actinide materials consist of original actinide metal, crucibles containing actinides, salt, and cadmium metal, sample residue (oxides and chlorides remaining from aqueous samples), and NAA samples. Actinide materials are routinely removed from the glove boxes and returned to storage in sealed storage containers. The wastes removed from the air box will be used HEPA filters and refuse packaged in waste cans. Items removed from the air box are sealed in plastic bags as they exit the transfer port into the Alpha Lab.□□RECLASS_CO: classification of MURR waste is not complete□□CATION: NA□□WASTE_PACK: 55-gallon drums

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FINAL FORM COMMENTS N/A

NEVADA TEST SITE

Location and Description

The Nevada Test Site (NTS) is located in Ny County approximately 105 kilometers northwest of Las Vegas, Nevada. The 3497-square-kilometer site is adjacent to the Nellis Air Force Ranges. The eight offsite test areas include the Central NTS and Shoal Test Area, Nevada; Amchitka Island, Alaska; the Rio Blanco and Rulison gas stimulation test sites, Colorado; the Gasbuggy gas stimulation and Gnome-Coach test sites, New Mexico; and Salmon test site, Mississippi. The Nevada Operations Office (NV) is located in Las Vegas with the NTS Office in Mercury, Nevada.

The NTS was selected as the continental proving ground for field testing nuclear weapons in 1950 with the first nuclear test occurring in January 1951. When the decision was made to conduct tests year-round, NV was created in 1962. Although some off-site tests were conducted, all tests since 1973 have been conducted at NTS.

Mission

The original mission of the NTS was field testing of nuclear weapons in support of the nuclear weapons laboratory and weapons-effects testing in support of the Defense Advanced Research Projects Agency and the Defense Nuclear Agency (DNA).

Today's mission of NTS is to maintain the readiness mode for the resumption of nuclear testing, remediate contaminated areas, and to serve as the largest disposal site for DOE and DOD defense-related low-level radioactive waste.

Waste Information

Processes

The NTS serves as a major disposal facility for low level waste and has inactive disposal facilities that were used for TRU waste. The NTS accepted TRU waste from the Lawrence Livermore National Laboratory (LLNL), for the purpose of storage from 1974 until 1990. This waste is considered mixed waste and is stored in a sprung steel building on a RCRA compliant curbed asphalt pad enclosed by a security fence. In keeping with the agreement made with the State of Nevada, the NTS will no longer accept TRU waste for storage.

Modifications/Assumptions/Development

NT reported radionuclides in nanocuries per gram. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the final waste form volumes reported by NT.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	NT-W001	Handling:	CH	NMVP #:	NT 111A;116A;2	Stream Name:	Heterogeneous Debris, Uncategorized
Local ID:	None	Type:	MTRU	Generator Site:	LL	Final Waste Form:	Heterogeneous

Inventory Date: 4/30/95

Waste Matrix Code: S5490

AS-GENERATED EPA CODES

P015, F003, F002, F001, D011, D008, D007, D006, D003, D002, D001, CA352, CA181

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	72.2	6.1	422.5
Aluminum-base Metal/Alloys:	12.3	0.0	399.0
Other Metals/Alloys:	5.8	0.0	383.4
Other Inorganic Material:	4.8	0.4	304.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	52.5	0.0	315.8
Rubber:	3.8	0.0	121.7
Plastics:	50.1	3.7	234.3
Solidified Inorganic Material:	11.8	4.4	155.7
Solidified Organic Material:	11.8	4.4	155.7
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	141.1		
Packaging Material Plastic:	28.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

NT 111A; 116A; 211A;225A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
MFP	3.39E-02
Am-243	1.99E-03
C-14	4.09E-07
Cf-249	1.89E-05
Cf-250	5.29E-04
Cf-252	8.94E-03
Cm-243	1.10E-06
Cm-244	6.78E-03
Cm-248	1.05E-11
Cs-137	6.53E-05
Depleted U	1.97E-07
Eu-152	3.33E-03
Eu-154	1.99E-03
Am-241	4.91E-01
Kr-85	6.53E-04
Pu-244	1.63E-09
U-235	1.71E-07
U-234	8.15E-06
U-233	2.94E-03
U-232	2.95E-05
H-3	2.04E-04
Ra-226	4.09E-04
U-238	5.45E-08
Pu-242	1.42E-04
Pu-241	5.61E-01
Pu-240	3.04E-02
Pu-239	4.53E+00
Pu-238	2.41E-01
Pa-231	8.15E-07
Np-237	7.83E-06
Sr-90	2.23E-07

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55 gallon	343.0	0.0	0.0	2.4	2.8	348.2
Drum / 85 gallon	0.3	0.0	0.0	0.3	0.0	0.6
Nonstandard Box	271.4	0.0	0.0	0.0	0.0	271.4
Totals	614.8	0.0	0.0	2.8	2.8	620.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	343.0	0.0	0.0	2.4	2.8	348.2
Standard Waste Box	270.3	0.0	0.0	3.8	0.0	274.0
Totals	613.3	0.0	0.0	6.2	2.8	622.2

As-Generated Form: Stored: 614.8 Projected: 5.5 Total: 620.3

Final Waste Form: Stored: 613.3 Projected: 9.0 Total: 622.2

WASTE STREAM DESCRIPTION

This waste stream consists of glovebox parts, laboratory trash, contaminated equipment and solidified sludges. Real time radiography has been performed on the waste to verify that there are no free liquids present, with the exception of liquid in aerosol cans, which, when treated will be eliminated from this waste stream. Most of the waste is contact-handled TRU waste; 3 drums are remote-handled.* The waste stream was generated at the Lawrence Livermore National Laboratory, Livermore, CA (LLNL) and shipped to the NTS from 1974 until 1990. The waste was declared as potentially mixed TRU waste by the generator in April, 1991.
*Due to recent storage reconfigurations and surveys, only three of the 4 previously reported packages are considered remote-handled.

WASTE STREAM SOURCE

NTS STORED, TRU WASTE FROM LLNL
This waste stream, consisting of glovebox parts, laboratory trash, contaminated equipment, and solidified sludges, was generated from operations activities conducted at LLNL Buildings 251, 332, and 419. Actual activities and processes conducted to generate this waste stream are unknown.

CURRENT CONTAINER COMMENTS

Currently, all 55-gal. drums are overpacked within 85-gal. vented drums.
Vented drum of decon debris
58 total; 70x69x81 (bxwxh) max. dimensions

EPA COMMENTS

Regulated contaminant information is based on process knowledge. No sampling of waste constituents has been conducted to date.

MANAGEMENT COMMENTS

The Nevada Test Site (NTS) is located about 105 km (65 mi) northwest of Las Vegas, and occupies 3,497 km2 (1,350 mi2) of federally owned land in southeastern Nevada's Nye County. The Area 5 Radioactive Waste Management Site (RWMS) is located in Frenchman Flat within the southeast corner of the NTS, approximately 15 miles north of Mercury, Nevada and 80 miles northwest of Las Vegas, Nevada. The developed portion of the Area 5 RWMS occupies 37 hectares (ha) (92 acres) in the southeast corner of the 296 ha (732 acres) designated area of NTS Area 5. Building 5-24, a 21,470 square-foot fabric-covered structure, is located within the 92-acre RWMS on the TRU Waste Storage Pad, an asphalt pad comprising an area of 0.829 ha (2.05 acres) constructed to meet RCRA standards.

ACCEPTANCE COMMENTS

The majority of this waste inventory was packaged before RCRA characterization requirements were imposed. Lawrence Livermore National Laboratory (LLNL) (the generator) declared the inventory to be "mixed" in April 1991. EPA Codes were estimated on the basis of TRU waste assessments and other information provided by the generator. The actual waste matrix and contaminant parameters will be further defined during future waste characterization and certification activities for the express purpose of certifying the waste to meet TRUPACT transport and WIPP disposal requirements.**This TRU waste inventory originated from LLNL/ Bldg. 251, LLNL/Bldg. 332, and LLNL/Bldg. 419; contact: Kem Heinebach, LLNL, (510) 422-4572□. LLNL/Bldg. 251 generated TRU waste containing debris potentially contaminated with the following RCRA solvents and acids: nitric acid dried on Kimwipes (ignitable) (EPA code D001), and RCRA metals cadmium in "silver" solder (EPA code D006) and lead (EPA code D008).**LLNL/Bldg. 332 generated TRU waste debris potentially contaminated with: carbon tetrachloride (CC1-4) on Kimwipes (F001), ethyl alcohol (D001), freon TF on cotton wipes and Kimwipes (F001), methanol on Kimwipes (F003), nitric acid (D002, and if >45%, an oxidizer (D001), nitric acid on Kimwipes (ignitable) (D001), trichloroethylene (TCE) (F001), varnish and paints (D001); RCRA metals calcium (D003), and lead (D008); and the following CA hazardous wastes: beryllium, sometimes as flakes, (CA code 181), cerium (CA 181), copper (CA 181), copper shavings (CA 181), gallium (CA 181), Invoil-42 (an oil, potentially CA hazardous) (CA 352), kerosene (an oil, potentially CA hazardous) (CA 352), magnesium powder (CA 181), oil and oily rags (CA 352), and yttrium oxide (CA 181).
LLNL /Bldg. 419: TRU waste debris potentially contaminated with: trichloroethylene (TCE) (F001), and CA hazardous waste oil (California code 352).**Past assay efforts resulted in undetermined final numbers on gram content; re-assay to be conducted.**It has been established that the bulk of the TRU mixed wastes stored at the Area 5 RWMS were placed into storage prior to the effective date of the LDR prohibitions applicable to solvent waste and that any attempt to move the wastes to another facility would trigger LDR requirements. Mixed wastes stored prior to the effective date of applicable LDR requirements "are not subject to the LDR storage prohibition as long as they are not removed from storage or otherwise actively managed while in storage." (57 Federal Register 22024, 22041 [05-26-92]).**The management of the Area 5 RWMS TRU mixed waste inventory is governed by a Settlement Agreement between the state of Nevada and DOE/NV. The TRU mixed waste shall remain in storage until such time that EPA issues a no-migration variance to WIPP, after the test phase, or when suitable treatment capacity is developed with which to treat the wastes. The TRU mixed waste is contained in 1636 0.208 m3 (55-gallon) steel drums and 58 steel boxes of various sizes. The 55-gallon drums are overpacked in 0.321 m3 (85-gallon) DOT Type A drums which are vented with carbon-composite filters. The inventory also includes one 0.321 m3 (85-gallon) drum which is vented with a carbon-composite filter. The containers are stored on pallets inside the TRU Cover Building 5-24. The drums are triple-stacked and boxes double-stacked. Three-foot aisleways between container rows provide for routine RCRA inspections, and 4-foot fire aisles are located at all four personnel exits.** Lead may have been used as shielding inside

some containers. Liquids are solidified in individual one-gallon, metal paint can containers which are then placed in 55-gallon drums, although several containers were found to contain small amounts of free liquids (via RTR). Boxed waste includes decommissioned glove boxes, hoods, and large pieces of contaminated equipment. Combustibles (tissues, paper, assorted plastics, and bagging) fill the void spaces in both boxes and drums. Most boxes have permanent skids, but all are stored on pallets. A standard eight-ton forklift is used to shuttle the boxes, and a drum-handler is attached to the fork tines to shuttle drums.

FINAL FORM COMMENTS

Included in current storage numbers is the assumption that two boxes containing 12 drums will be transferred into 12 0.208m3 drums (55 gallon drums). Projections include 25 55 gallon drums from decon activities.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	NT-W021	Handling:	CH	NMVP #:	Unknown	Stream Name:	V3XA Spheres	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	LL	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	544.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	1.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-242	1.15E-04
Pu-241	3.19E+01
Pu-240	1.30E+00
Pu-239	5.69E+00
Pu-238	1.92E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Sphere/3-ft. dia X 4-ft. dia Stainless Steel	0.9	0.0	0.0	0.0	0.0	0.9
Totals	0.9	0.0	0.0	0.0	0.0	0.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	5.7	0.0	0.0	0.0	0.0	5.7
Totals	5.7	0.0	0.0	0.0	0.0	5.7

As-Generated Form: Stored: 0.9 Projected: 0.0 Total: 0.9

Final Waste Form: Stored: 5.7 Projected: 0.0 Total: 5.7

WASTE STREAM DESCRIPTION	The two steel vessels are 1-inch thick by 3-feet diameter, weighing about 2700 lbs. each. The vessels contain heterogeneous mixtures of the following materials: Plutonium, D-38, Beryllium metal, Completely burned high explosive, Stainless steel, Brass, Polystyrene foam, Aluminum, Coke (degassed coal), Water absorbed by the coke, Steel, Glass, Epoxy resin, Thermalite (aerated cement block), Plaster, Hortag (fly-ash and clay), Wood, and Krypton-85 tracer gas for leak detection. The UK has had similar vessels in storage for over ten years, but none containing plutonium have ever been opened. Vessels containing D-38 only have been opened, with small amounts of water vapor and some loose debris found inside. The bulk of the materials were found to be trapped within the thick coke layer lining the inner surface of the vessel. No more wastes of this type are planned to be generated.
WASTE STREAM SOURCE	This waste stream was received for storage at the NTS Area 5 RWMS TRU Waste Storage Pad in 1994, and was generated by LLNL, Livermore, CA. This is a "one-time" generated TRU waste stream, resulting from joint US/UK tests conducted in the United Kingdom. Each vessel is a 3-foot diameter sphere, weighing about 2,700 pounds. High explosives were detonated inside the vessel chamber, resulting in a concrete-like, heterogeneous substance made up of plutonium, depleted uranium, beryllium, pulverized coke, glass, wood, steel, and aluminum debris.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	This waste stream is not "mixed."
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Previously, LLNL had inquired about having an exemption from WIPP WAC issued for this waste stream. Per correspondence from Arlen Hunt (ALO/WIPP) to Daniel Nakahara (DOE/SAN) [memo TSIT:HJD 90-0049, "TRU Material Above WIPP-WAC Safety Limits", March 6, 1990], the Waste Acceptance Criteria Certification Committee could not determine "if these containers will ever qualify for disposal at WIPP." Until such time that an alternative disposal site is made available, or exemption from the WIPP-WAC is received, this waste stream will remain in safe storage at the NTS.
FINAL FORM COMMENTS	Internal volume of SWB is assumed to be 1.89 cubic meters; total waste stream volume (external) estimated at 5.678 cu. m., divided by 1.89 = 3 SWBs. Plastic bagging would be used to contain any contamination. This also assumes, although highly unlikely, that the vessels are size-reduced to fit inside SWBs, as opposed to being shipped within TDOPs. Considering FGE within each vessel, two TDOPs could probably be used for shipping this waste stream to WIPP.

OR Oak Ridge Reservation

DOE/CAO-95-1121
December 1995

OAK RIDGE NATIONAL LABORATORY

Location and Description

The Oak Ridge National Laboratory (ORNL) is located 10 miles southwest of downtown Oak Ridge, Tennessee, and 32 kilometers northwest of Knoxville, Tennessee. The ORNL site occupies about 10,000 acres of the 35,252 acre Oak Ridge Reservation. The site covers portions of both Melton and Bethel Valleys. Approximately 1100 acres within the Melton and Bethel Valleys have been developed.

The ORNL is under the auspices of the DOE/Oak Ridge Operations Office which supports production of nuclear weapon components for national defense programs, production of enriched uranium for defense requirements and for fuelling nuclear power plants, the processing of uranium feed materials for DOE's plutonium production reactors, and extensive energy research and development in all DOE program areas.

Mission

ORNL was established in 1942 in support of the Manhattan Project. The primary mission of ORNL has been to carry out applied research and engineering development in fission, fusion, and other energy technologies, and to conduct scientific research in basic physical and life sciences. Relevant missions include isotope production and processing, research and development, waste management, and D&D of operating units; and advanced reactor development work. In addition, ORNL conducts several activities for DOE Defense Programs. The principal nonweapons-related activities include nuclear power development and magnetic fusion research. ORNL conducts activities in support of DOE's Transuranic Element Program, the Californium and Loan Program, and the Mark 42 Program.

During the wartime Manhattan Project, the town of Oak Ridge, Tennessee, was wholly-owned and controlled by the Government.

Waste Information

Processes

The Y-12 Plant was built originally as part of the Manhattan Project to separate and concentrate uranium-235 isotopes by the electromagnetic process. With the successful demonstration of the more efficient gaseous diffusion process, the plant was modified to carry out other weapons production operations. The major operations at the Y-12 Plant were production of weapon components, uranium, uranium alloys, and lithium compounds that were shipped to other sites.

The K-25 Site (formerly the Oak Ridge Gaseous Diffusion Plant) was a production and development facility for uranium enrichment using a gaseous diffusion process. Production operations were shut down in 1985. The current mission of K-25 involves environmental restoration, decontamination and decommissioning, and waste management. DOE's TSCA incinerator is located at the K-25 site.

Waste streams at ORNL tend to be different from K-25 and Y-12 waste streams in that they are smaller in volume, constantly changing, and could contain virtually any radionuclide, depending on the research activity that generated the waste stream. In these respects, they are probably similar to the waste streams generated at all the national labs. Of the three main facilities at ORR, only ORNL generates TRU waste (from research reactors), although K-25 and Y-12 waste streams may contain concentrations of transuranic isotopes below 100 nanocuries per gram.

In contrast, the waste generating processes at K-25 and Y-12 tend to be stable and have their own signature isotopes. Waste streams at K-25 may often be contaminated with technicium, either depleted or enriched uranium, and trace concentrations of transuranics. Y-12 waste streams are also often contaminated with depleted or enriched uranium. Some waste streams at Y-12 are derived from classified activities; data about these waste streams are also classified.

Most of the TRU waste residing at ORNL has been generated as a result of the Californium and U-233 Program or has come from off-site waste generators. Additional TRU waste is produced by the ORNL Analytical Chemistry facilities as a result of sample analysis. Some TRU waste may also be generated by the K-25 Site during decontamination and decommissioning activities.

RH-TRU solid waste consists primarily of miscellaneous hot-cell waste (e.g., paper, glass, plastic tubing, shoe covers, wipes, etc.), HEPA filters from off-gas cleanup systems, and discarded equipment (e.g., chemical processing racks, vacuum pumps, etc.). The unshielded individual waste packages within the casks typically have radiation levels that measure between 10 and 2000 rem/h; the majority are below 100 rem/h. RCRA materials in RH TRU solid waste primarily consist of lead that was used as shielding, and limited amounts of mercury from discarded mercury-vapor lamps. The RH TRU solid waste is typically contained in cylindrical concrete casks 1.4 m (4.5 ft) in diameter by 2.3 m (7.5 ft) high. Wall thickness of the casks are currently either 15.2 or 30.5 cm (6 or 12 in) thick, depending on the radiation level of the contents.

The majority of RH TRU sludges as ORNL are the result of waste accumulation from the past 50 years of ORNL liquid waste operations. These sludges are residuals from sluicing operations conducted in the early 1980s when the majority of the inactive gunite tank contents were removed for hydrofracture disposal at ORNL. RH TRU sludges continue to accumulate due to on-going R&D programs which produce transuranium isotopes for medical, industrial, and government applications. The surface equivalent dose rates of these sludges are generally near 10 rem/h (unshielded).

Most CH TRU waste is generated at ORNL by activities related to isotope research and production, including analytical support. The waste results primarily form hot cell and glovebox operations, and most of it can be accommodated in 55-gallon drums.

CH TRU waste at ORNL consists of general laboratory wastes such as various glassware, plastic ware, empty reagent bottles, vials, and other containers, cloth and paper wipes, rubber and cotton gloves, contaminated clothing, gaskets and other rubber parts, metal parts, tools and machinery, electrical equipment, ion-exchange resins, ventilation filters, and other general waste generated during the operation of gloveboxes and hot cells. A given container of waste may contain several different TRU radionuclides.

One of ORNL's offsite generators is the Paducah Gaseous Diffusion Plant (PA) in Kentucky serves as the first stage in the DOE uranium enrichment complex. TRU isotopes have been separated from the uranium feed and collected at the bottom of the cascade. Some drums containing TRU waste have been shipped to ORNL for storage while the remaining TRU waste containers continue to be stored at PA.

Nuclear Fuels Services, Inc. (NFS) at Erwin, Tennessee, sent 800+ drums of CH TRU waste to ORNL.

Other off-site generators include the New Brunswick Laboratory, West Valley Decommissioning Project, and the Knolls Atomic Power Laboratory.

Modifications/Assumptions/Development

ORNL reported radionuclides in total Curies. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the final waste form volumes reported by OR.

ORNL's waste material parameters Solidified, Inorganic Matrix and Cement (Solidified) for waste streams OR-W042 and OR-W046 were calculated based on the proposed amount of cement that will be used to solidify these waste streams.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W040	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Heterogeneous Debris	Inventory Date:	12/31/94
Local ID:	2308	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

D011, D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.6
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Co-60	3.80E-03
Am-241	5.31E-03
Am-243	1.08E-07
Bk-249	1.08E-07
Cf-249	3.66E-06
Cf-252	2.83E-04
Ac-227	1.08E-06
Cm-244	1.88E-03
UNID	4.87E-05
Cs-137	1.97E-03
Pu-239	2.06E-03
Ra-223	1.08E-06
Sr-90	1.20E-02
Th-232	1.08E-06
U-233	4.32E-04
U-235	1.53E-07
U-238	5.51E-08
Cm-242	7.59E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Metal	0.1	0.0	0.0	0.0	0.0	0.1
Cask /Concrete	646.3	0.0	0.0	0.0	0.0	646.3
Drum / 55-gallon	0.0	18.7	31.2	62.4	62.4	174.7
Other	0.1	0.0	0.0	0.0	0.0	0.1
Totals	646.5	18.7	31.2	62.4	62.4	821.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	922.0	17.8	44.5	89.0	89.0	1162.3
Totals	922.0	17.8	44.5	89.0	89.0	1162.3

As-Generated Form: Stored: 646.5 Projected: 174.7 Total: 821.2

Final Waste Form: Stored: 922.0 Projected: 240.3 Total: 1162.3

WASTE STREAM DESCRIPTION	This waste stream consists of RH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Waste from Glove Box Operations, Laboratory Operations, Hot Cell Clean Up Operations, Equipment Repair and Maintenance, Sources.
CURRENT CONTAINER COMMENTS	Waste will have to be repackaged into acceptable containers for shipment and disposal. This is forecasted waste yet to be generated
EPA COMMENTS	No characterization existed for legacy waste. Limited data is available from process log sheets. No data is obtainable from Waste Examination and Assay Facility due to the level of radiation in RH contaminated materials. EPA codes are based on CH-TRU data and the similarity due to the generating processes.
MANAGEMENT COMMENTS	The waste currently stored in metal boxes and concrete casks will have to be packaged in acceptable containers.
ACCEPTANCE COMMENTS	Bldg 7823A is not designated as a TRU storage facility and has been designated as a LLW storage facility. Waste stored in this building is being assessed whether it is TRU or LLW. One container in this waste stream will be evaluated as possibly being Spent Nuclear Fuel. Bldgs 7878 and 7879 are suppose to contain CH TRU waste only. Evaluation of the waste stored in these buildings will determine the disposition the waste containers.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums are currently in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. The projected inventory includes 840 55-gallon containers of newly generated waste only and does not include the existing total inventory volume (640 m3) which does not include any 55-gallon drums. Therefore, the entire current inventory will have to be repackaged into 55-gallon drums. The value reported in section 8.2.15.1.11 reflects the number of RH canisters projected which includes 3 55-gallon drums in each canister. 1036 RH Canisters will be required to repack currently stored waste. Projections are for newly generated waste only.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W086	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (nondefense, nonmixed)	Inventory Date:	12/31/94
Local ID:	T2301	Type:	TRU	Generator Site:	NU	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
UNID	0.00E+00
U-238	1.20E-07
U-235	7.23E-09
U-234	1.15E-04
U-233	1.87E-06
Pu-242	2.10E-07
Pu-241	3.77E-02
Pu-240	2.25E-03
Pu-239	4.50E-03
Pu-238	6.24E-04
Am-241	1.68E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	170.8	0.0	0.0	0.0	0.0	170.8
Totals	170.8	0.0	0.0	0.0	0.0	170.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	170.8	0.0	0.0	0.0	0.0	170.8
Totals	170.8	0.0	0.0	0.0	0.0	170.8

As-Generated Form: Stored: 170.8 Projected: 0.0 Total: 170.8

Final Waste Form: Stored: 170.8 Projected: 0.0 Total: 170.8

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids which were generated from nondefense programs. The physical form is solid and is not believed to contain hazardous constituents. It has not been determined if these wastes have been examined by WEAF. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Sludge collected from several sources for temporary storage and prior to mixing with grout for underground injection.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	No treatment is expected for final disposal. It may be required that the waste stream be repackaged for further characterization and certification activities.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Calculation of the Pu-239 FGE was not completed. ORNL is attempting to obtain a copy of the TRAMPAC to obtain the required constants and equations needed for the calculations.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W042	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Sludge (inactive tank)	Inventory Date:	12/31/94
Local ID:	2311	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3121

AS-GENERATED EPA CODES

D009, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	396.6	173.1	528.9
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	396.6	173.1	528.9
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Eu-154	3.16E-03
C-14	3.32E-05
Cf-252	2.06E-03
Cm-244	8.79E-03
Co-60	7.78E-03
Cs-134	3.81E-05
Am-241	2.27E-04
Eu-152	3.51E-03
U-238	1.94E-04
Eu-155	2.85E-04
H-3	1.42E-05
Pu-238	1.91E-03
Pu-239	9.99E-04
Sr-90	1.19E+00
Th-232	5.64E-06
U-233	6.47E-04
Cs-137	4.15E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Single shell tank / Gunite	123.0	0.0	0.0	0.0	0.0	123.0
Totals	123.0	0.0	0.0	0.0	0.0	123.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	175.3	0.0	0.0	0.0	0.0	175.3
Totals	175.3	0.0	0.0	0.0	0.0	175.3

As-Generated Form: Stored: 123.0 Projected: 0.0 Total: 123.0

Final Waste Form: Stored: 175.3 Projected: 0.0 Total: 175.3

WASTE STREAM DESCRIPTION	The waste stream is comprised of RH-TRU sludge which has settled and separated from wastewater that has been stored in large underground storage tanks. The waste is a product of past operations at ORNL involving various nuclear research and radioisotope fabrication processes and is currently undergoing RI/FS as part of a CERCLA program involving these tanks and contents. This waste is under the responsibility of DOE EM-40 and as such are not technically a RCRA mixed waste. However, since the waste has been reported in the ORR LDR FFCA, it is included in the MWIR. However, it is anticipated that the reporting responsibility will be turned over to the appropriate EM-40 organization.
WASTE STREAM SOURCE	Waste from sludge which has settled and separated from wastewater that has been stored in large underground tanks. The sludge is a product of past operations at ORNL involving various nuclear research and radioisotope fabrication processes.
CURRENT CONTAINER COMMENTS	Treatment of the RH TRU sludge waste has not been determined to date. It is anticipated that the sludge will be packaged in 55-gallon drums and shipped in the RH canister.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	The RH TRU sludge is currently stored in underground tanks which are currently inactive and located at the North Tank Farm, South Tank Farm, and at the Old Hydrofracture Facility. ORNL is currently assessing the use of existing facilities that would allow the mobilization and packaging of the sludge waste for final disposal.
ACCEPTANCE COMMENTS	Bldgs 3023, 3507, and 7852 are not designated at TRU storage facilities.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums are currently in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. 197 RH Canisters will be required to repack currently stored waste.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W087	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Heterogeneous Debris (buried)	Inventory Date:	12/31/94
Local ID:	B2301	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.6
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
UNID	1.13E-01
U-235	6.29E-07
Pu-239	5.44E-03
I-131	1.18E-03
Cs-137	1.02E-01
Cm-244	2.58E-03
Cm-242	5.88E-04
Cf-252	4.96E-04
Am-243	4.68E-09
Am-241	3.22E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cask /Concrete	298.5	0.0	0.0	0.0	0.0	298.5
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	298.7	0.0	0.0	0.0	0.0	298.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	425.4	0.0	0.0	0.0	0.0	425.4
Totals	425.4	0.0	0.0	0.0	0.0	425.4

As-Generated Form: Stored: 298.7 Projected: 0.0 Total: 298.7

Final Waste Form: Stored: 425.4 Projected: 0.0 Total: 425.4

WASTE STREAM DESCRIPTION	This waste stream consists of RH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids and retrievably buried in trenches or pits at ORNL. The physical form is solid. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Hot Cell Waste
CURRENT CONTAINER COMMENTS	Waste will have to be repackaged into acceptable containers for shipment and disposal. Condition of containers is unknown at this time. Condition of containers is unkown at this time. If retrieval is conducted, it may be necessary to repackage the drummed waste due excessive deterioration.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	It has not been determined whether the buried TRU waste will be retrieved and packaged for final disposal at a repository or left in place as final disposal.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because only 1 55-gallon drums is currently in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. The projected inventory includes 840 55-gallon containers of newly generated waste only and does not include the existing total inventory volume (640 m3) which does not include any 55-gallon drums. Therefore, the entire current inventory will have to be repackaged into 55-gallon drums. 478 RH canisters used to overpack 55 gallon drums will be required to repack the existing waste.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W044	Handling:	CH	NMVP #:	OR 125A; 125B	Stream Name:	CH-TRU Heterogeneous Debris	Inventory Date:	12/31/94
Local ID:	2305	Type:	MTRU	Generator Site:	KA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

OR 125A; 125B

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Co-60	3.51E-09
Pm-147	1.27E-03
Am-241	2.68E-03
Np-237	1.41E-05
Gd-153	0.00E+00
Fe-59	7.65E-03
Zn-65	5.35E-06
Cs-137	4.89E-01
Pu-238	5.47E-02
Cm-248	9.69E-06
Cm-244	5.38E-03
Cm-242	4.14E-03
Cf-252	2.67E-05
Cf-249	9.62E-06
Bk-249	3.30E-04
Am-243	1.95E-04
Es-254M	2.08E-02
U-232	4.00E-05
Y-90	6.50E-09
UNID	5.00E-04
U-238	9.50E-07
U-236	8.52E-08
U-235	1.19E-07
Pa-231	5.98E-04
U-233	3.24E-04
Pu-239	1.08E-03
Th-232	1.03E-07
Tc-99	1.31E-03
Sr-90	4.51E-01
Ra-226	5.07E-04
Pu-242	9.40E-06
Pu-241	2.99E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Metal	165.9	0.0	0.0	0.0	0.0	165.9
Box / Wood	15.1	0.0	0.0	0.0	0.0	15.1
Cask /Concrete	4.9	0.0	0.0	0.0	0.0	4.9
Drum / 30-gallon	1.1	0.0	0.0	0.0	0.0	1.1
Drum / 55-gallon	331.1	27.5	45.8	91.5	91.5	587.4
Other	4.0	0.0	0.0	0.0	0.0	4.0
Totals	522.1	27.5	45.8	91.5	91.5	778.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	522.9	27.5	45.8	91.5	91.5	779.2
Totals	522.9	27.5	45.8	91.5	91.5	779.2

As-Generated Form: Stored: 522.1 Projected: 256.3 Total: 778.4

Final Waste Form: Stored: 522.9 Projected: 256.3 Total: 779.2

Pu-240	2.08E-02
U-234	2.47E-07

WASTE STREAM DESCRIPTION

This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid. These wastes have been examined by WEAF and do not contain free or containerized liquids. This waste is categorized as heterogeneous debris (matrix code 5490).

WASTE STREAM SOURCE

Waste from Glove Box Operations, Laboratory Operations, Hot Cell Clean Up Operations, Equipment Repair and Maintenance, Sources, Radiochemical Processing for Isotope Separation and Purification.

CURRENT CONTAINER COMMENTS

Waste will have to be repackaged into acceptable containers for shipment and disposal.

This waste is also forecasted to be generated.

Waste will have to be repackaged into acceptable containers for shipment and disposal.

30-gallon containers may have to be overpacked into a 55-gallon drum or waste emptied out an repackaged into a 55-gallon drum.

Waste contents will require repackaging into an acceptable containers.

EPA COMMENTS

The majority of this waste stream was generated prior to 1986 and has very limited data available. EPA codes are based on generator process knowledge and evaluations from the
Waste Examination and Assay Facility.

MANAGEMENT COMMENTS

The waste currently stored in casks, metal and wood boxes, and other types of containers will have to be repackaged into acceptable containers for shipment and disposal.

ACCEPTANCE COMMENTS

Bldgs 2364, 3019A, 3030, 7823, 7823A, are not designated as TRU storage facilities. Some of the waste in these buildings are being evaluated to determine if the waste is TRU or LLW. Several containers in this waste stream will be assessed as possibly being Spent Nuclear Fuel. Several containers stored in Bldg 3019A may have been sent back to the generators in 1976 however the data bases show they are still being stored. An evaluation will be conducted to reconcile this deficiency. Bldg 7823 has been designated as a LLW storage facility. Bldgs 7826 and 7834 are closed non-RCRA storage facilities. The waste containers stored in these buildings will be evaluated to determine if they are mixed or non-mixed TRU since these are non-RCRA facilities.

FINAL FORM COMMENTS

Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. The projected inventory includes 1,232 55-gallon containers of newly generated waste only and does not include the existing total inventory volume. Since this is CH TRU waste, it is anticipated it will be transported in the TRUPACT-II cask. 922 additional 55 gallon drums will be required to repack the non-certifiable containers currently stored for this waste stream.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W045	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Uncategorized	Inventory Date:	12/31/94
Local ID:	2307	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S9000

AS-GENERATED EPA CODES

D011, D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.1	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: UNK

PCBs: No

Source: Source Information Not Compiled

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.29E+01
Pu-240	1.20E+00
Pu-239	6.92E-01
Pu-238	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Metal	4.0	0.0	0.0	0.0	0.0	4.0
Drum / 55-gallon	1.5	0.0	0.0	0.0	0.0	1.5
Totals	5.4	0.0	0.0	0.0	0.0	5.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	0.0	0.0	0.0	0.0	5.4
Totals	5.4	0.0	0.0	0.0	0.0	5.4

As-Generated Form: Stored: 5.4 Projected: 0.0 Total: 5.4

Final Waste Form: Stored: 5.4 Projected: 0.0 Total: 5.4

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU waste which has not been classified or characterized. It is believed that the physical form is either solid, liquid, mixed (both solid and liquid), or unknown and is suspected to contain hazardous constituents. This waste is categorized as uncategorized (matrix code 9000).
WASTE STREAM SOURCE	Glove Box Waste
CURRENT CONTAINER COMMENTS	Waste contained in metal boxes will have to be repackaged into acceptable containers.
EPA COMMENTS	The majority of this waste stream was generated prior to 1986 and has very limited data available. EPA codes are based on generator process knowledge and evaluations from the Waste Examination and Assay Facility.
MANAGEMENT COMMENTS	Final treatment, if required, will be decided upon further characterization and utilization of process knowledge for the categorization of this waste stream. The waste currently stored in casks, metal and wood boxes will have to be repackaged into acceptable containers for shipment and disposal.
ACCEPTANCE COMMENTS	Bldg 7823E is not designated as a TRU storage facility. Waste inside this building is being assessed if it is TRU or LLW. Bldg 7826 is a closed non-RCRA storage facility. The waste containers stored in this building will be evaluated to determine if they are mixed or non-mixed TRU since this is a non-RCRA facility.
FINAL FORM COMMENTS	Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. No newly generated waste is projected for this waste stream. 19 additional 55 gallon drums will be required to repack the non-certifiable containers currently stored for this waste stream.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W046	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Sludge (active tank)	Inventory Date:	12/31/94
Local ID:	2313	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3100

AS-GENERATED EPA CODES

D009, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	396.6	173.1	528.9
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	396.6	173.1	528.9
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Eu-154	2.59E-02
C-14	5.35E-05
Ce-144	1.67E-03
Cm-243	1.63E-03
Cm-244	7.75E-03
Co-60	1.12E-02
Cs-134	3.83E-04
Am-241	2.07E-03
Eu-152	4.62E-02
Zr-95	4.50E-03
Eu-155	6.75E-03
Nb-95	3.14E-04
Pu-239	8.10E-04
Ru-106	3.07E-03
Sr-90	2.49E-01
U-232	8.98E-06
U-233	5.20E-04
U-235	1.69E-03
Cs-137	5.84E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	18.1	30.2	60.3	60.3	168.9
Single shell tank / SS	704.4	0.0	0.0	0.0	0.0	704.4
Totals	704.4	18.1	30.2	60.3	60.3	873.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	861.5	22.2	36.9	73.9	73.9	1068.4
Totals	861.5	22.2	36.9	73.9	73.9	1068.4

As-Generated Form: Stored: 704.4 Projected: 168.9 Total: 873.3

Final Waste Form: Stored: 861.5 Projected: 206.5 Total: 1068.0

WASTE STREAM DESCRIPTION	This waste stream is comprised of liquid low level waste that has been concentrated by evaporation and subsequently stored in large underground storage tanks. The waste is generated as relatively dilute low-level waste in various nuclear research and radioisotope fabrication processes. These streams are collected and centrally volume reduced in an evaporator facility. After the waste has been stored, it separates into phases. The resulting solids (sludge phase) is fairly homogeneous chemically and radiochemically. Since the sludge is a product of solids concentration, it has been classified as a TRU waste. This waste is categorized as sludge (matrix code 3121).
WASTE STREAM SOURCE	Liquid Low Level Waste sludge concentrated by processing in Liquid Low Level Waste Evaporator Facility.
CURRENT CONTAINER COMMENTS	Treatment of the RH TRU sludge waste has not been determined to date. It is anticipated that the sludge will be packaged in 55-gallon drums and shipped in the RH canister. This is forecasted waste to be generated.
EPA COMMENTS	TCLP levels provided are based on absolute analysis for specific metals. These analysis were based on the formerly used EP-TOX methodology. TCLP for organics has not been performed. Typical values for metals are listed in mg/kg.
MANAGEMENT COMMENTS	The RH TRU sludge is currently stored in underground tanks which are currently active and located at the the Melton Valley Storeage Tank area and the Evaporator Facility in Bethel Valley. ORNL is currently assessing the use of existing facilities that would allow the mobilization and packaging of the sludge waste for final disposal.
ACCEPTANCE COMMENTS	Bldgs 2531 and 7830 are not designated as TRU Storeage Facilities.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums were reported in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. The projected inventory includes 812 55-gallon containers of newly generated waste only and does not include the existing total inventory volume (587 m3) which does not include any 55-gallon drums. Therefore, the entire current inventory will have to be repackaged into 55-gallon drums. The value reported in section 8.2.15.1.11 reflects the number of RH canisters projected which includes 3 55-gallon drums in each canister. 968 additional RH canisters will be required to repack the existing waste in current tanks.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W047	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (with liquids)	Inventory Date:	12/31/94
Local ID:	2306	Type:	MTRU	Generator Site:	NB	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

D011, D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.6	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Eu-152	6.49E-09
Am-241	3.71E-03
Am-243	6.79E-04
Bk-249	5.29E-04
Cf-249	6.49E-06
Cf-252	8.73E-04
Cm-240	6.49E-06
Cm-242	5.37E-02
Cm-244	9.16E-03
Cm-246	6.49E-08
Ac-227	6.49E-08
Es-253	5.19E-02
U-238	3.82E-09
Np-237	7.77E-05
Pu-238	1.09E-01
Pu-239	1.34E-03
Pu-240	2.19E-03
Pu-241	3.70E-01
Pu-242	9.30E-05
Ra-226	3.80E-05
Th-230	7.79E-08
Th-232	1.02E-07
U-232	3.06E-06
U-233	1.26E-03
U-235	2.41E-07
Cs-137	6.49E-08

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Drum / 55-gallon	153.1	0.0	0.0	0.0	0.0	153.1
Totals	153.6	0.0	0.0	0.0	0.0	153.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	154.1	0.0	0.0	0.0	0.0	154.1
Totals	154.1	0.0	0.0	0.0	0.0	154.1

As-Generated Form: Stored: 153.6 Projected: 0.0 Total: 153.6

Final Waste Form: Stored: 154.1 Projected: 0.0 Total: 154.1

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid. These wastes have been examined by WEAF and found to contain free and/or containerized liquids. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Waste from Glove Box Operations, Laboratory Operations, Hot Cell Clean Up Operations, Equipment Repair and Maintenance, and Sources.
CURRENT CONTAINER COMMENTS	Waste will be repackaged to eliminate free liquids.
EPA COMMENTS	The majority of this waste stream was generated prior to 1986 and has very limited data available. EPA codes are based on generator process knowledge and evaluations from the Waste Examination and Assay Facility.
MANAGEMENT COMMENTS	This waste stream has been processed through WEAF and determined to contain excess free liquids. The waste contents will have to repackaged to eliminate the free liquids prior to shipment to WIPP.
ACCEPTANCE COMMENTS	Bldg 7823 is not designated as a TRU Storeage Facility but has been designated as a LLW storage Facility. The waste inside this building is being assessed whether it is TRU or LLW. Bldg 7834 is a closed non-RCRA storage facility. The waste containers stored in this building will be evaluated to determine if they are mixed or non-mixed TRU since this is a non-RCRA facility.
FINAL FORM COMMENTS	Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. No newly generated waste is projected for this waste stream. 5 additional 55 gallon drums will be required to repack the existing waste from 30 gallon drums.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W088	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (buried)	Inventory Date:	12/31/94
Local ID:	B2302	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
U-233	5.27E-06
Th-232	6.59E-10
Sr-90	6.59E-06
Pu-239	6.59E-08
P-32	4.94E-02
I-131	4.94E-02
H-3	4.94E-02
Cs-137	6.59E-06
Cm-244	1.65E-02
C-14	4.94E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Dumpster	3.1	0.0	0.0	0.0	0.0	3.1
GI Can	3.2	0.0	0.0	0.0	0.0	3.2
Other	8.5	0.0	0.0	0.0	0.0	8.5
Totals	15.0	0.0	0.0	0.0	0.0	15.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	15.2	0.0	0.0	0.0	0.0	15.2
Totals	15.2	0.0	0.0	0.0	0.0	15.2

As-Generated Form: Stored: 15.0 Projected: 0.0 Total: 15.0

Final Waste Form: Stored: 15.2 Projected: 0.0 Total: 15.2

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids and retrievably buried in trenches or pits at ORNL. The physical form is solid. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Contaminated Equipment, Cleanup Debris
CURRENT CONTAINER COMMENTS	This waste will have to be packaged in acceptable containers. Condition of containers is unknown at this time. If waste is retrieved, it may require repackaging due to excessive deterioration of the drums. This waste will have to be packaged in acceptable containers.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	t has not been determined whether the buried TRU waste will be retrieved and packaged for final disposal at a repository or left in place as final disposal. The waste currently stored in casks , dumpsters, and other types of containers will have to be repackaged into acceptable containers for shipment and disposal.
ACCEPTANCE COMMENTS	Facilities 7822TB, 7822TH, and 7822TL are not designated as TRU Storage Facilities. Several containers in this waste stream may actually be stored instead of buried and may be LLW instead of TRU. Evaluation of these concerns will be conducted. One container is this waste stream may not be CH and may instead be RH because the storage facilities require that only RH be allowed.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because only 1 55-gallon drums is currently in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. The projected inventory includes 840 55-gallon containers of newly generated waste only and does not include the existing total inventory volume (640 m3) which does not include any 55-gallon drums. Therefore, the entire current inventory will have to be repackaged into 55-gallon drums. 72 additional 55 gallon drums will be required to repack the existing waste.

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W093	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (nonmixed)	Inventory Date:	12/31/94
Local ID:	T2304	Type:	TRU	Generator Site:	NB	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Po-209	2.29E-05
Am-243	2.07E-04
Bk-249	3.48E-06
Cf-249	9.75E-09
Cf-252	1.16E-06
Cm-242	8.62E-06
Cm-244	7.09E-05
Cm-248	2.24E-03
Cs-137	1.16E-05
Eu-152	5.48E-06
Ni-63	1.49E-06
Np-237	2.55E-07
Am-241	2.52E+00
Pm-147	2.75E-06
UNID	2.25E-09
Pu-238	4.59E-09
Pu-239	2.41E-02
Pu-240	3.16E-04
Pu-241	7.50E-05
Pu-242	8.86E-02
Ra-223	2.14E-06
Ra-226	2.75E-06
Sr-90	3.60E-06
U-232	1.07E-09
U-233	9.52E-08
U-234	4.26E-03
U-235	2.98E-07
U-236	9.99E-08
U-238	1.87E-08
Pa-231	1.18E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Metal	2.7	0.0	0.0	0.0	0.0	2.7
Box /Wood	337.1	0.0	0.0	0.0	0.0	337.1
Drum / 55-gallon	42.0	0.0	0.0	0.0	0.0	42.0
Other	47.8	0.0	0.0	0.0	0.0	47.8
Plastic	6.2	0.0	0.0	0.0	0.0	6.2
Totals	435.9	0.0	0.0	0.0	0.0	435.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	435.8	0.0	0.0	0.0	0.0	435.8
Totals	435.8	0.0	0.0	0.0	0.0	435.8

As-Generated Form: Stored: 435.9 Projected: 0.0 Total: 435.9

Final Waste Form: Stored: 435.8 Projected: 0.0 Total: 435.8

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid and is believed not to contain hazardous constituents. It has not been determined if these wastes have been examined by WEAF. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Waste from Glove Box Operations, Laboratory Operations, Hot Cell Clean Up Operations, Equipment Repair and Maintenance, Sources, and Radiochemical Processing for Isotope Separation and Purification
CURRENT CONTAINER COMMENTS	This waste is probably wrapped in plastic and would have to be packaged into an acceptable container. Waste will have to be repackaged into acceptable containers for shipment and disposal.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Further utilization of process knowledge and characterization will be required to verify the absence of hazardous constituents. Waste stored in casks, metal and wood boxes and some drums will require repackaging into appropriate shipping containers.
ACCEPTANCE COMMENTS	Bldgs 7822, 7841, and 7886-3 are not designated as TRU Storage Facilities. The waste inside these buildings will be assessed whether they are TRU or LLW. Bldg 7834 is a closed non-RCRA storage facility. The waste containers stored in this building will be evaluated to determine if they are mixed or non-mixed TRU since this is a non-RCRA facility.
FINAL FORM COMMENTS	Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. No newly generated waste is projected for this waste stream. 1893 additional 55 gallon drums will be required to repack the existing waste.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W094	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Heterogeneous Debris (nonmixed)	Inventory Date:	12/31/94
Local ID:	T2306	Type:	TRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.6
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
UNID	0.00E+00
U-233	6.51E-06
Pu-239	3.90E-03
Cs-137	1.46E-02
Cm-244	1.20E-03
Cf-252	2.98E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Wood	18.7	0.0	0.0	0.0	0.0	18.7
Cask /Concrete	40.6	0.0	0.0	0.0	0.0	40.6
Totals	59.3	0.0	0.0	0.0	0.0	59.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	84.5	0.0	0.0	0.0	0.0	84.5
Totals	84.5	0.0	0.0	0.0	0.0	84.5

As-Generated Form: Stored: 59.3 Projected: 0.0 Total: 59.3

Final Waste Form: Stored: 84.5 Projected: 0.0 Total: 84.5

WASTE STREAM DESCRIPTION	This waste stream consists of RH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid and is believed not to contain hazardous constituents. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Hot Cell Waste and Radiochemical Processing for Isotope Separation and Purification.
CURRENT CONTAINER COMMENTS	Waste will have to be repackaged into acceptable containers for shipment and disposal.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Further utilization of process knowledge and characterization will be required to verify the absence of hazardous constituents. Waste stored in casks, metal and wood boxes and some drums will require repackaging into appropriate shipping containers.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums were reported in the inventory and no waste is projected for the future. 95 RH canisters used to overpack 55 gallon drums will be required to repack the existing waste.

PA Paducah Gaseous Diffusion Plant

PADUCAH GASEOUS DIFFUSION PLANT

Location and Description

The Paducah Gaseous Diffusion Plant (PA) is situated in northwestern Kentucky, 26 kilometers west of Paducah, near the Ohio River. The site encompasses 750 acres (including 74 acres of process buildings). The site is included in a 3422-acre tract of DOE-owned property.

The PA is operated from DOE/Oak Ridge Operations Office with Lockheed Martin Utilities Services as the Management and Operating Contractor.

Mission

The DOE uranium enrichment complex of which PA is a component, was originally constructed to produce highly enriched uranium for nuclear weapons. The complex is now used primarily to provide low enriched uranium for domestic and foreign nuclear power reactors and, to a lesser degree, to provide the highly enriched uranium used in nuclear propulsion (naval) reactors and some research and test reactors.

The principle on-site process at PA is the separation of uranium isotopes through gaseous diffusion. The process produces enriched uranium to levels of up to 3% U-235. Most of the enriched product is shipped to the Portsmouth Gaseous Diffusion Plant for further processing.

Waste Information

Processes

During its defense-related operations, recovery of a reactor material resulted in the generation of TRU waste. Although most of the TRU waste has been shipped to ORNL for storage, some wastes remain on site. No additional TRU waste generation is expected at the PGDP.

Modifications/Assumptions/Development

PA reported radionuclides in Ci per kilogram. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the mass and final form volumes reported by PA.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	PA-A015	Handling:	CH	NMVP #:	N/A	Stream Name:	Transuranic - Solid	Inventory Date:	12/31/94
Local ID:	PA-A015	Type:	MTRU	Generator Site:	PA	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	63.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	212.0		
Packaging Material Plastic:	17.5		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
U	6.58E+00
Th-230	1.34E-02
Tc-99	7.09E-01
Pu-239	6.60E-02
Np-237	9.94E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum/55-gallon in overpack	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
SWB used to overpack 55 gallon drums	0.0	0.0	0.0	0.0	1.9	1.9
Totals	0.0	0.0	0.0	0.0	1.9	1.9

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 0.0 Projected: 1.9 Total: 1.9

WASTE STREAM DESCRIPTION	Transuranic Waste Class C, andTransuranic Waste Basic, class C filter/White Powder
WASTE STREAM SOURCE	C-400
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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PANTEX PLANT

Location and Description

The Pantex Plant (PX) is located 26 kilometers northeast of Amarillo, Texas, on U.S. Highway 60. PX occupies more than 320 buildings and is comprised of 2 contiguous tracts of land; 10,080 acres are owned by DOE and 5,806 acres are leased from Texas Tech University and used primarily as a safety and security buffer zone. Activities include weapons production, maintenance and modification, and disassembly of weapons retired from stockpile. PX is operated by Mason & Hanger-Silas Mason Co. Inc.

Mission

The PX primary missions include meeting DOE's responsibilities for nuclear weapons disassembly, assembly, stockpile monitoring, modifications, quality evaluation, and maintenance of the nation's weapons stockpile. PX also conducts research and development in high explosives design in support of weapons design and development program, and production engineering for DOE.

Waste Information

Processes

The assembly and dismantlement of nuclear weapons includes high explosives and solvents. PXs TRU waste was generated as a result of a pit cracking while removing high explosives. The waste is primarily debris from the cleanup operations.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	PX-T001	Handling:	CH	NMVP #:	N/A	Stream Name:	Pantex	Inventory Date:	6/29/95
Local ID:	N/A	Type:	TRU	Generator Site:	PX	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S0000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	87.0	78.4	95.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	11.3	10.2	12.4
Plastics:	11.3	10.2	12.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Spill Clean-ups/Emergency Response Actions

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	7.64E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	This material is contaminated PPE and tools generated during weapons dismantlement.
WASTE STREAM SOURCE	$ 48 $ Weapons dismantlement support material.
CURRENT CONTAINER COMMENTS	Same Nuclides
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

Location and Description

The Rocky Flats Environmental Technology Site (RFETS) is located in Jefferson County, Colorado, approximately 26 kilometers northwest of downtown Denver, near the suburban communities of Westminster, Boulder, Broomfield, Golden and Arvada, Colorado. It is a 384-acre complex in the center of a 6550-acre reservation.

The facilities at RFETS are divided into two main areas. The area on the north contains all of the facilities related to plutonium operations. Security fences and intrusion-detection systems surround all buildings in which plutonium is handled or stored, and various other measures are used to provide safeguards and security. This area is referred to as the "Protected Area". The area to the south contains both nonplutonium manufacturing facilities, which are located in secure areas, plutonium waste storage facilities, and general support facilities, some of which are in secured areas.

Mission

The original mission of the Rocky Flats Plant (original name for RFETS) was the manufacture of nuclear weapons components fabricated from plutonium, enriched uranium, and conventional metals. It was originally a key weapons material production facility. Plant construction began in March 1951 and operations began in 1952. The Plant used specialized machine shops to process raw nuclear material into the finished components required by the warhead designs. Plutonium and beryllium components were fabricated into the shells of fissionable materials, called pits. A former mission of RFETS was to dissemble the pits from retiring weapons. The recovered pit was chemically processed to remove americium and plutonium. Plutonium scrap recovery was also performed at RF.

In 1989, the Secretary of Energy halted all plutonium production operations at the RFETS in order to improve the conduct of operations, standards of performance, and the management structure. On September 27, 1991, the President of the United States announced his cancellation of several nuclear-weapons programs, leaving the W-88 war head for the Trident II missile as the only remaining system requiring the fabrication of plutonium components at RFETS. This requirement was eliminated in 1992, when the President decided to cancel further production of the Trident II missile and its nuclear warhead.

In response to the President's decisions, the Secretary of Energy proceeded with several initiatives directed at a more cost-effective execution of the defense mission which included revising plans at RFETS for plutonium and nonplutonium manufacturing areas.

RFETS new mission is to clean out and stabilize production process systems, decontaminate obsolete or excess buildings and facilities; stabilize residues in preparation for transport to storage or disposal sites; possibly transfer non-plutonium manufacturing to other locations; maintain a contingency status. Approximately 140 structures at RFETS include major manufacturing, chemical processing, plutonium recovery, and waste treatment facilities. Plant operations also include chemical laboratories, research and development, and support of other DOE facilities.

RFETS has stopped weapons production operations. Future relevant activities will be TRU waste management, including preparation of existing material for geologic disposal, and decontamination and decommissioning.

Waste Information

Processes

Production activities included metal working, fabrication and component assembly, chemical recovery and purification of transuranic nuclides. The plant utilized specialized facilities for recovering nuclear components from obsolete weapons.

Prior to 1960, the main plutonium purification process was dissolution followed by a solvent extraction step that used tributylphosphate as the solvent and dodecane as the diluent. The solvent extraction step was followed by cation exchange. Around 1960, solvent extraction was eliminated from the recovery process because the materials going through the process were becoming more and more varied and could not be adequately handled by the process. The solvent extraction process was replaced by dissolution in the nitric acid followed by ion exchange and peroxide precipitation. The purified plutonium oxide was converted to plutonium fluoride and reduced to plutonium metal using calcium. Other chemical processes, such as molten salt extraction, have also been used at RFETS.

A need to process americium arose because of a personnel exposure problem from its gamma ray emissions. From late 1957 until the late 1970s, americium was recovered and purified at the plant for resale. The demand for americium dropped off in the late 1970s, and the americium was processed as waste.

Depleted uranium operations were a significant part of the original manufacturing performed at the plant. Operations included casting, machining, rolling, and forming. Alloying of depleted uranium with niobium began in 1966, although full-scale production did not occur until the early 1970s. Depleted uranium, which contains less than 0.7% U-235 by mass, is rich in the U-238 radionuclide. The RFETS depleted uranium is assumed to be material type U-12, which is composed of 99.78% U-238, 0.215% U-235, 0.006% U-236, and 0.001% U-234 by mass.

Enriched uranium, containing about 93% U-235 by mass, was processed at the RFETS from 1952 to 1964. This concentration of U-235 is material type U-38, which is composed of 93.08% U-235, 5.65% U-238, 0.93% U-234, and 0.34% U-236 by mass. The enriched uranium manufacturing processes included casting, forming, machining, assembly, recovery, and purification.

The enriched uranium chemical recovery line began operations in 1954. The chemical recovery used a solvent extraction process with dibutylethylcarbutol as the solvent and dodecane as the diluent. This process was similar to the early solvent extraction process used for plutonium recovery. A solvent still was operated at the plant, and some of the distilled solvent was reused. The discarded solvent and oils were drummed and later became part of the organic sludge waste stream. Enriched uranium operations were shut down in 1962.

Some U-233 was processed from the late 1950s to the early 1970s. The U-233 processing included casting, machining, aqueous processing, and separations. Records indicate that the INEL received 56 grams of U-233 as waste from the RFETS in 1967.

All the plutonium operations were carried out in enclosures that are operated under subatmospheric pressure to minimize uncontrolled releases of radioactive material into the operating area. These enclosures are called gloveboxes, and the ventilation systems pass through a high-efficiency particulate air filter system. Leaded rubber gloves are used to protect operations personnel from the gamma activity associated with the plutonium and americium.

The filters from the ventilation systems and the filters used in other systems eventually become waste. The leaded rubber becomes contaminated and also becomes waste. Some of the processes used produce liquid waste streams. These liquid streams are converted to a sludge or solid with adsorbents or cements. contaminated equipment, clothing, tools, etc, end up as radioactive waste. Waste is also generated by decontamination projects and modifications to facilities.

All radioactive waste from the RFETS that was sent to INEL from 1954 to 1970 was buried at the RWMC. Transuranic waste received at INEL from RFETS after October 1970 has been stored aboveground at the Transuranic Storage Area.

Modifications/Assumptions/Development

The approach used and the assumptions made in preparing the RF waste stream profiles are as follows:

- Projection volumes were taken from the Comprehensive Waste Management Plan (CWMP) with the exception of Solid Stabilization (formerly Residue Elimination). The program projection available for Solid Stabilization at the time the CWMP was being drafted was a "not to exceed" volume. The volume and breakdown of final form waste streams used in preparing the TWBIR was an updated, projected volume taken from the Conceptual Design Report for Residue Elimination at Rocky Flats, RES-005-001, May 1994.
- The planned treatment for waste streams requiring treatment to meet WIPP WAC and TRAMPAC requirements are taken from the Draft Site Treatment Plan (DSTP) and the Treatment System Definition Report (TSDR) published by the Waste Compliance Programs.
- In the case where the waste stream or some portion of the waste stream requires treatment to change to the final waste form, the volume of waste resulting from the treatment of the original waste stream is included in the final waste form volume of the resulting waste stream. For example, the volume of waste resulting from treatment of Incinerator Ash is included in the final waste form volumes of the resulting waste stream, Solidified Process Solids.
- Volume increases due to repackaging waste that exceed the current decay heat limit when no other treatment is required were not included.
- To remain consistent with the volumes reported in the other RFETS publications, 0.21 m^3 was used as the container volume of a standard DOT-17C 55-gallon drum. The volume used for other containers was as specified on the data forms.
- Waste in boxes other than standard waste boxes (SWB) are assumed to be repackaged into SWBs, such that the waste from one 4'x4'x7' box is repacked into two SWBs. Therefore, the final waste form volumes for SWBs include the projected volume increase resulting from such repackaging activities.

- The values for the Typical Waste Material Weights for Final Waste Form data for the TRU waste streams are the same as the corresponding TRU mixed waste streams.
- The waste generation rates for each waste form were prorated based on the fraction represented by the waste form on a Waste and Environmental Management System (WEMS) generation report showing actual generation.

In the following waste streams, the actual volumes reported are less than .01 m^3 and are rounded to 0.0 m^3 in the TWBIR:

RF-MR0527	RF-MTX111	RF-MTX112	RF-MTX115
RF-TR0082	RF-MR-X200	RF-TR0084	RF-TR0089
RF-TR0395	RF-TR0396	RF-TR0527	RF-TR0601
RF-W011			

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

These wastes are aqueous acidic liquid residues.

WASTE STREAM SOURCE

IDC 070 is high-level plutonium nitrate feed solution (nitric acid solution containing plutonium) generated at Anion Exchange or High-Level Dissolution. This solution is feed, batched for Precipitation in Building 771.

High-Level Dissolution in Building 771 dissolved high-purity-plutonium content residues to recover plutonium. These residues were dissolved in nitric acid and heated. The resulting plutonium nitrate was filtered to remove undissolved solids and particulates. The solution (IDC 070) was batched by combining it with other plutonium nitrate or ion column eluate and evaporator bottoms from various processes to achieve the desired concentration. The plutonium nitrate feed solutions were transferred to an evaporator chamber which resulted in steam condensate (IDC 513) and evaporator bottoms (IDC 100).

RE: Section 6.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

RFETS does expect nitrate concentration to be >1% , but has no data indicating the actual concentration or range.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation A

Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22.

Subpopulation H

These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals.

In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process.

This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F009, F007, F005, F003, F002, F001, D043, D040, D039, D038, D022, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D003, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 200 is analytical standards. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

F002, F005, F001, D011, D010, D009, D008, D007, D006, D005, D004, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

IDC 292 was intended for incinerator sludge from the recovery incinerator in Building 771. IDC 292 materials were reassessed under Waste Form 1, Incinerator Ash. However, there is one box WEMS incorrectly assigned this IDC. According to the waste-box log sheet dated October 14, 1987, the box contains Electrochemical Milling Sludge generated in Building 881. This operation generated sludge from the milling of various metals including stainless steel. It was indicated that no cyanides were used in the ECM operations in Building 881. The IDC for this box should be changed to 299.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this

drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

F005, F002, D040, D035, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Drum / 55-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

This IDC has been used for sludges that were not accurately categorized as IDC 290 or 340 and could have been generated in any plutonium processing building. However, the backlog miscellaneous sludge was generated in Building 771 during the processing of residues, in Building 371 in the analytical laboratory, and in Building 883 by the Rolling Process. Process pipe sludge, sludge dissolution heel, and filter plenum sludge from Building 771 were processed through nitric acid dissolution and sparging. Soil and sludge samples from around the site were analyzed in Building 371, and the waste was stored for processing. IDC 299 materials generated in Building 883 include quench sludge and uranium oxide sludge from the rolling Process. This group also includes one container of electrochemical milling sludge generated in Building 881 in October 1987. The container is assigned IDC 292.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F002, F001, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	37.4	0.0	0.0	0.0	0.0	37.4
Totals	37.4	0.0	0.0	0.0	0.0	37.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 37.4 Projected: 0.0 Total: 37.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

331 - Ful-Flo filters used to filter solids from aqueous solutions. Additional required processing undetermined. Because of the potential of liquids in this IDC, it requires a compatibility code when packaging.

WASTE STREAM SOURCE

These Ful-Flo filters are in-line cartridge filters used throughout Rocky Flats to remove particulates from fluid streams and typically filter down to 5, 1, and 0.5 micron-sized particulates. Ful-Flo filters are used in various liquid systems that include nitric- and chloride-acid systems, such as those found in plutonium recovery operations; caustic systems, such as those found in utilities scrubbing; solvent systems using carbon tetrachloride in machining operations; water systems, such as steam cleaning; and condensate collection. These filters are also used in lubricant oil filtration.

Ful-Flo filters are poly-fiber-wound cartridges, about 10" long by 3.5" in diameter. Other fiber filters, such as R-6 pads, may be included in this IDC. R-6 pads are cloth filters, about sixteen inches in diameter, used to filter solids from nitric acid solutions. Therefore, backlog material in this IDC cannot be considered homogeneous. filter elements are produced by combining a media blanket and spirally wound matrix yarn on an inner core. The filter elements might have a polypropylene cap on one end. Both the media blanket and matrix yarn can be cotton or polypropylene. The inner core material can be constructed of polypropylene, tinned steel, or stainless steel. Warehouse data from Rocky Flats indicate that the inner-core material is polypropylene.

during normal process operations, IDC 331 Ful-Flo filters in this backlog population were used to filter particulates from liquid waste streams in Buildings 371, 707, 771, 776, 777, and 779. These waste streams were primarily from filtration of caustic solutions in Building 371, the carbon tetrachloride system and oil systems, and from filtration of water and developer in Building 707. In Building 771, the primary wste streams filtered were anion column feed, potassium hydroxide, nitrate feed, spent nitric acid and hydrofluoric acid from the scrubber, eluate and effluent exiting the ion-exchange columns, floor pick-up solution, steam condensate, and miscellaneous aqueous solutions. Hydraulic oil and floor pick-up solution were filtered in Building 776. In Buildings 777 and 779, Ful-Flo filters were used in the carbon tetrachloride system for purification of Freon TF and for filtration of incoming waters.

Typically, Ful-Flo filters were placed on drying racks pending bag-out of a glovebox. Filters were not always dried before removal from the glovebox. Filters were then "bagged out" of the glovebox and placed in a second layer of plastic. Next, the filters were placed in a "Poly Bottle" or "Clam Shell" (hard plastic container), then placed in a double-lined drum.

These Ful-Flo filters may be contaminated with acids, bases, carbon tetrachloride, chromium, Freon, and oil. They may contain relatively small amounts of free liquids.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 326 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the

characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W065	Handling:	CH	NMVP #:	N/A	Stream Name:	Calcium Metal/TRM	Inventory Date:	
Local ID:	IDC 333	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	X7590

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDC 333. This material is elemental calcium pellets used in plutonium reduction operations.
WASTE STREAM SOURCE	This IDC consists primarily of partially oxidized or hydrated calcium metal generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal using calcium metal as the reductant. This reduction operation was performed in a reaction vessle within Glovebox (Line) 17 in Building 771. Magnesium oxide sand was used as an insulating material in the annulus between a magnesium oxide crucible and the reaction vessel wall. Plutonium tetrafluoride, calcium metal, and a pyrotechnic initiator (magnesium metal, sodium peroxide, and potassium iodate) were placed in the magnesium oxide crucible. The reduction vessel was then sealed, placed in an induction furnace, purged with argon, and heated until the reaction initiated. After the reduction vessel had cooled, the vessel was opened and the materials were separated. Calcium metal residue is generated from the cleanup of calcium metal spillage on the glovebox floor. Calcium metal is placed in metal cans for removal from the glovebox. After the cans are bagged out, they are assayed individually. The cans are placed in drums or vaults for storage.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being present or absent). Item Description Code 333 There is no analytical information for this waste form that will assist in Resource Conservation and Recovery Act (RCRA) characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 (EG&G 1992). WSRIC Waste Stream 771-11-17, IDC 333, is also characterized as D003 waste. The IDC 333 Calcium Metal Residue Analysis Study concurs with the D003 characterization (KMI 1992a). According to the Hazardous Chemicals Desk Reference, calcium exhibits the following properties: "Flammable when heated or in intimate contact with moisture or acids...reacts with moisture or acids to liberate large quantities of hydrogen; can develop explosive pressure in containers...violent reaction with water may evolve explosive hydrogen gas." IDC 333 is Subpopulation 59A and was identifed based on specific process knowledge. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal waste is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Based on this information, the waste exhibits the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, the Colorado Department of Health (CDH) has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ingition source, and there must be a high probability of these elements occurring at the same time (DOE 1994).
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W067	Handling:	CH	NMVP #:	N/A	Stream Name:	Cemented filters/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	21.6	0.0	0.0	0.0	0.0	21.6
Totals	21.6	0.0	0.0	0.0	0.0	21.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 21.6 Projected: 0.0 Total: 21.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of filters used in ventilation systems. Some of it has had cement sprinkled on it to neutralize the acid on the filters.

WASTE STREAM SOURCE

The material in this IDC is either the filter media portion of HEPA filters or surface-water filters. HEPA filters are used on gloveboxes and in large filter plenums. Sock filters were used to prefilter operable unit 2 (OU-2) surface water prior to activated carbon treatment.

Used HEPA filters were processed to segregate those portions with high plutonium content and those with low content. The wood frames were separated from the media and almost always disposed of as waste by packing in drums that were assigned IDC 330. the filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste.

This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from the production Building 707 and could be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon. IDC 338 was meant to be used as a residue IDC and not as a waste IDC. Because sorting between IDCs was not accurate, some of the IDC 338 backlog containers are below the economic discard limit (EDL) and are therefore not residue.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, D&D, and limited Emergency Response actions.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation DB

Subpopulation DB consists of IDC 338 filter media that could have been exposed to saltcrete in Building 374. Room 3809 was used for Saltcrete Processing (WSRIC Process 374-5). HEPA filters were used to filter nitrate salt particles from the baghouse air stream. The single container of filters in this subpopulation is characterized as RCRA hazardous, and its characterization is based on the current WSRIC characterization for saltcrete. EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 have therefore been applied. The EPA Code D001 is applied because nitrate salts may have formed on these filters.

Subpopulation DC

Subpopulation DC includes all IDC 338 filter media generated from Building 771. There are 111 containers in this subpopulation. This filter medium might be derived from IDC 342 filters (acid contaminated-see Subpopulations EB and EC), and is characterized the same as the IDC 342 filters from Subpopulation EB. Because this filter medium might have been used to filter nitric acid and nitric salts have been reported to form on the filter media, it could exhibit the characteristic of ignitability and is considered to be an oxidizer due to the presence of nitrate salts. This filter medium is a RCRA-hazardous waste and EPA Code D001 has been applied.

Subpopulation FA

Subpopulation FA includes containers of IDC 376 processed filter media generated throughout Rocky Flats that are characterized as nonhazardous. This processed filter medium is derived from filters generated from processes for which there would be no "carry over" of solvent contamination from vapors. Exclusion of filters from "carry over" contamination is based on WSRIC information and a Waste Technical Support Memorandum. The memorandum states that these HEPA filters are nonhazardous unless RCRA hazardous liquids have condensed from the uncontained gases. It is assumed that these containers do not have free liquids.

MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

342 - Drybox filters from all acid lines. This waste must be neutralized, then changed to IDC 815 to disposal.

WASTE STREAM SOURCE

HEPA filters are used on all gloveboxes to remove particulates from the atmosphere exiting the glovebox to the plenum exhaust system. The filters in IDC 342 are from gloveboxes with atmospheres that could cause the filters to be contaminated with acids or bases used in chemical processing.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 16-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc. Pu Recovery Byproducts/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.03	0.0	0.0	0.0	0.0	0.03
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.03 Projected: 0.0 Total: 0.03

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Calcined plutonium oxide was placed in a magnesium oxide crucible with calcium chloride and calcium metal. The crucible and contents were placed in a furnace and heated until the contents were molten. The molten material was stirred to initiate and promote the reduction of the plutonium oxide. After the reaction, the melt was allowed to separate into plutonium metal and salt phases. After cooling, the crucible was broken and separated from the salt, calcium, and plutonium metal. This process produced IDCs 365 and 414.

IDCs 365 and 414 are composed primarily of calcium chloride, calcium oxide, calcium metal entrained in the salt, and various plutonium compounds. A "button" of excess calcium may also be present in some containers of these salts. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W067	Handling:	CH	NMVP #:	RF 119	Stream Name:	Cemented filters/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of filters used in ventilation systems. Some of it has had cement sprinkled on it to neutralize the acid on the filters.

WASTE STREAM SOURCE

The materials in this IDC is the filter media portion of acid-contaminated glovebox or plenum HEPA filters of Ful-Flo filters with free liquids. Processing was performed in the Site Reduction Vaults in Building 776.

Used HEPA filters were processed to separate any portions containing high plutonium content from portions with low content. The wood frames were separated from the media and usually disposed of as waste by packing in a drum that was assigned IDC 330. The filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identifies as IDC 376 and packaged for shipment as waste. the media were placed in crates, Portland cement was added, then crates were sealed. some IDC 376 material could be the remaining material after the IDC 338 media were processed to recover the plutonium.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

The waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, D&D, and limited Emergency Response actions.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation DB

Subpopulation DB consists of IDC 338 filter media that could have been exposed to saltcrete in Building 374. Room 3809 was used for Saltcrete Processing (WSRIC Process 374-5). HEPA filters were used to filter nitrate salt particles from the baghouse air stream. The single container of filters in this subpopulation is characterized as RCRA hazardous, and its characterization is based on the current WSRIC characterization for saltcrete. EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 have therefore been applied. The EPA Code D001 is applied because nitrate salts may have formed on these filters.

Subpopulation DC

Subpopulation DC includes all IDC 338 filter media generated from Building 771. There are 111 containers in this subpopulation. This filter medium might be derived from IDC 342 filters (acid contaminated-see Subpopulations EB and EC), and is characterized the same as the IDC 342 filters from Subpopulation EB. Because this filter medium might have been used to filter nitric acid and nitric salts have been reported to form on the filter media, it could exhibit the characteristic of ignitability and is considered to be an oxidizer due to the presence of nitrate salts. This filter medium is a RCRA-hazardous waste and EPA Code D001 has been applied.

Subpopulation FA

Subpopulation FA includes containers of IDC 376 processed filter media generated throughout Rocky Flats that are characterized as nonhazardous. This processed filter medium is derived from filters generated from processes for which there would be no "carry over" of solvent contamination from vapors. Exclusion of filters from "carry over" contamination is based on WSRIC information and a Waste Technical Support Memorandum. The memorandum states that these HEPA filters are nonhazardous unless RCRA hazardous liquids have condensed from the uncontained gases. It is assumed that these containers do not have free liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag, and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 4-liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 387, reburned SS&C sweepings, is generated from the cleanup of the Plutonium Tetrafluoride Reduction Process within Glovebox (Line) 17 in Building 771. The fine material (sand, slag, and crucible) is swept from the glovebox floor and is placed in metal cans for transfer to Glovebox (Line) 22. In Glovebox 22, the sweepings are heated in an Inconel pan on a hotplate to oxidize plutonium metal that may be present in the sweepings. The reburned sweepings are stored in metal cans prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	sand, Slag and Crucible/TRU	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 390 consists primarily of unpulverized slag generated as a residue from the reduction of plutonium tetrafluoride to plutonium metalusing calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771.

The unpulverized slag is generated from the separation of calciu fluoride slag from the sand and crucible residues following the removal of the plutonium metal button. Calcium fluoride is produced from the reaction of the calcium metal with the plutonium fluoride.

Unpulverized slag is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas

when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.3	0.0	0.0	0.0	0.0	0.3
Drum / 55-gallon	5.6	0.0	0.0	0.0	0.0	5.6
Totals	5.9	0.0	0.0	0.0	0.0	5.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 5.9 Projected: 0.0 Total: 5.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 391 consists primarily of unpulverized sand and crucible generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771.

The unpulverized sand and crucible are generated from the separation of sand and crucible residues from the calcium fluoride slag following the removal of the plutonium metal button.

Unpulverized sand anc crucible is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	12.9	0.0	0.0	0.0	0.0	12.9
Totals	13.0	0.0	0.0	0.0	0.0	13.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 13.0 Projected: 0.0 Total: 13.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 392 consists of unseperated IDC 391 materials.

Unpulverized sand, slag, and crucible are placed in 4-liter, wide-mouthed, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The sand, slag, and crucible are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible

Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 393 is produced in the Dissolution Process in Gloveboxes (Lines) 23 and 25 in Building 771. Pulverized sand, slag, and crucible from the Crushing Process is placed in a dissolution pot with heated nitric acid and aluminum nitrate. The solution (plutonium nitrate) is pulled by vacuum through an R-6 filter to remove undissolved solids.

The undissolved solids are sand, slag, and crucible heels that are dried on a hot plate and placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The residue sand, slag, and crucible heels are stored awaiting plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore,

	this waste exhibits the characteristic of reactivity (D003).
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	LDR_DETERM: Net and gross weight data are not available for all container types. RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

This IDC consists primarily of unpulverized slag and crucible generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771.

The unpulverized slag and crucible are generated from the separation of calcium fluoride slag and crucible residues from the magnesium oxide sand following the removal of the plutonium metal button. Calcium fluoride is produced from the reaction of the calcium metal with the plutonium fluoride.

Unpulverized slag and crucible are placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Returned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The returned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas

when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 400 is ion column feed (plutonium nitrate solution) with less than 5 g/l plutonium which is to be processed through Anion Exchange to remove any impurities. These solutions come from various aqueous recovery operations for purification of plutonium. Dissolution in Building 771 dissolved high-impurity, low-plutonium content residues to recover plutonium. Cation Exchange in Building 771 processed chloride solutions (hydrochloric acid containing plutonium) from the laboratories in Building 371, 559, and 771. Precipitation Feed Batching in Building 771 combined plutonium nitrate or ion column eluate and evaporator bottoms to achieve the desired plutonium concentration. The solutions (IDC 400) in which impurity concentrations were too high were sent for purification. Reduction and Button Break-Out in Building 771 produced a purified plutonium metal product. In this process, the metal was pickled in a water bath to remove residual calcium. The resulting solutions (IDC 400) was mostly water containing plutonium and elemental impurities. Miscellaneous Residue Processing in Building 771 generated IDC 400 from sludge dissolution. Sludge from the process filter plenum was dissolved in heated nitric acid and drained through a filter resulting in nitrate solution (IDC 400). The heel that was formed on the filter was dried on a hot plate and also dissolved. RE: Section 5.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D008, D006, D005, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.05	0.0	0.0	0.0	0.0	0.05
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.05 Projected: 0.0 Total: 0.05

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 401 is ion column feed (plutonium nitrate solution) with greater than 5 g/l plutonium processed through Anion Exchange. These solutions come from various aqueous recovery operations for purification of plutonium. IDC 401 was generated by the same processes as IDC 400, the only difference being the amount of plutonium contained in the solution. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D007, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the ammericium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDC 409.

IDC 409 was formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

F005, F003, F002, F001, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Nonspecification plutonium metal, cast as an anode, was combined with and equimolar mixture of sodium chloride and potassium chloride in a magnesium oxide crucible. Magnesium chloride was then added to initiate the plutonium oxidation. The metal and salts were placed in a furnace and heated until molten. The molten mixture was stirred, and a current applied to the anode which flowed through the molten mixture to the cathode. Plutonium ions migrated from the molten anode through the molten salt to the cathode and were reduced to purified metal. After cooling, the crucible was broken and the salt, anode heel, and purified plutonium metal were separated. This process produced IDC 411 salts.

IDC 411 is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metals, and various plutonium compounds. These salts may contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. IDC 411 salt packaged for off-site shipment was assigned IDC 473.

RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.4	0.0	0.0	0.0	0.0	0.4
Drum / 55-gallon	6.7	0.0	0.0	0.0	0.0	6.7
Totals	7.1	0.0	0.0	0.0	0.0	7.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 7.1 Projected: 0.0 Total: 7.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

This salt was generated by the scraping and cleaning of pyrochemical furnace cells and consists of spent pyrochemical salts and magnesium calcium, sodium, and potassium metals which vaporized during the pyrochemical processes and collected on the cold parts of the cells. The scraped-out material may have been reheated in a furnace to oxidize the metals; however, this did not always occur. This salt could contain compounds present in any of the pyrochemical salts.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operations and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could

have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Drum / 55-gallon	6.4	0.0	0.0	0.0	0.0	6.4
Totals	6.7	0.0	0.0	0.0	0.0	6.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.7 Projected: 0.0 Total: 6.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Calcined plutonium oxide was placed in a magnesium oxide crucible with calcium chloride and calcium metal. The crucible and contents were placed in a furnace and heated until the contents were molten. The molten material was stirred to initiate and promote the reduction of the plutonium oxide. After the reaction, the melt was allowed to separate into plutonium metal and salt phases. After cooling, the crucible was broken and separated from the salt, calcium, and plutonium metal. This process produced IDCs 365 and 414.

IDCs 365 and 414 are composed primarily of calcium chloride, calcium oxide, calcium metal entrained in the salt, and various plutonium compounds. A "button" of excess calcium may also be present in some containers of these salts. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Salt Scrub was a process used to recover plutonium from MSE salts. In this process, MSE salts were combined with a reducing agent and an alloying agent; the combinations of magnesium and aluminum, calcium, and gallium, and calcium and cerium have been used. The crucible and contents were placed in a furnace and heated until the contents were molten and the mixture was stirred. While molten, the plutonium and americium were reduced by the calcium or magnesium and the actinides went into the metal alloy phase. After cooling, the crucible was broken and the salt and scrub alloy separated. This process produced IDCs 429 and 433-435 salts.

IDC 434 salt was generated using calcium and gallium. This IDC represents salts produced from the salt scrub of MSE DCHP salts. This salt is composed primarily of calcium chloride, cesium chloride, entrained calcium and gallium metal, and various plutonium and americium compounds. A "button" of excess calcium may also be present in some containers of this salt.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operations and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics.	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 500 is plutonium and enriched uranium nitrate solution from Oralloy Leaching. The material is eluate solution ready for Oralloy Preparation. Oralloy Leaching in Building 771 removed small amounts of plutonium from uranium parts. Nitric acid was sprayed into the parts and then was collected and transferred to a steam-heated evaporator. The concentrated acid (IDC 500) was then piped to Oralloy Precipitation where the plutonium and uranium solids were precipitated out. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH.	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.04 Projected: 0.0 Total: 0.04

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

These wastes are aqueous acidic liquid residues.

WASTE STREAM SOURCE

IDC 503 is miscellaneous spent acid waste contaminated with plutonium generated during various research and development operations.

Calcination in Building 771 removed excess nitric acid and moisture from plutonium peroxide cake (green cake). Because some of the plutonium peroxide cake was entrained in off-gas, the off-gas passed through a packed-bed nitric acid scrubber to dissolve the peroxide cake. The nitric acid was then filtered and piped to Anion Exchange.

Spray Leach used a nitric- and sulfuric-acid mixture or nitric and hydrofluoric acids as leaching agents for plutonium parts or fixtures. The filtered leachate (IDC 503) was piped to Anion Exchange.

Vacuum systems in Building 771 generated nitric acid waste from cleaning the receiving tank. This waste was sent to Anion Exchange.

H-4 Support Vacuum Systems generated water composed of acidic plutonium solution diluted in seal liquid. This liquid was drained into the process piping system during daily maintenance. The liquid was transferred to tanks for eventual treatment in Anion Exchange.

Nitrate solutions were generated by a dissolution process in Building 779 similar to those in Building 771. The solutions in this process consisted of sodium nitrate, silver nitrate, nitric acid, plutonium nitrate, and water. These solutions are below the EDL.

Ferrite Actinide Removal in Building 779 adsorbed actinides from low-level aqueous wastes containing uranium, americium, and plutonium with ferrite materials. Nitric acid was used to strip actinides from the ferrite material. Ferrite wash water was generated from rinsing ferric materials after actinides had been removed.

RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation A

Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22.

Subpopulation H

These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals.

In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process.

This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

These wastes are aqueous acidic liquid residues.

WASTE STREAM SOURCE

IDC 508 is hydrochloric acid (HCl) containing plutonium generated by various process operations and glovebox-cleaning operations using HCl. Process operations and glovebox-cleaning operations were definec based on preliminary analytical results.

IDC 508 was generated in Cation Exchange in Building 771 from washing residual impurities from the resin with dilute nitric acid.

Chemical Technology in Building 771 generated miscellaneous chloride acid solutions from Batch Chloride Dissolution. This process dissolved plutonium oxide with hydrochloric acid.

Dicesium hexachloroplutonate (DCHP) preparation in Building 371 also generated IDC 508. This process produced DCHP, a salt used to remove americium from nonspecification and impure plutonium oxide. The oxide was dissolved in hydrochloric acid and filtered. The filtrate was then precipitated using cesium chloride and sodium nitrite in hydrochloric acid and then filtered again. Plutonium was recovered from the DCHP precipitation filtrate through chloride anion exchange. This was achieved by processing the solution through ion columns, and the plutonium loaded onto the anion exchange resin while most of the impurities stayed in the solution. This solution then left the column as effluent (IDC 501). The ion column was later washed to release the chloride eluate (IDC 508).

Peroxide Precipitation in Building 779 reacted ion exchange effluent with hydrogen peroxide to produce plutonium peroxide, which was then calcined to produce plutonium oxide. The plutonium peroxide precipitate was filtered and washed.

Residue Recovery Extraction in Building 779 recovered actinides using aqueous leaching techniques. Hydrofluoric acid solutions containing aluminium fluoride, cesium chloride, calcium fluoride, and sodium nitrate were generated.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation A

Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22.

Subpopulation H

These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals.

In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process.

This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 527 is caustic waste solutions consisting of sodium hydroxide or potassium hydroxide. Dissolution in Building 771 used potassium hydroxide for flushing the condenser when dissolvind incinerator ash. H-4 Support Vacuum Systems used potassium hydroxide in an aqueous solution as a seal liquid. Vacuum Systems also used a seal liquid made up of water only. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supportin data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F009, F007, F005, F003, F002, F001, D043, D040, D039, D038, D035, D028, D022, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D003, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	The Building 371 analytical laboratory receives liquid and solid samples from the entire plant site. Samples that are destined for Building 881 are analyzed in Building 371 to screen out those with high levels of radioactivity. Sludge and aqueous samples from Building 374 are analyzed for total alpha activity and plutonium, uranium, and americium content. Prior to analysis, the sludges are dissolved in nitric acid, hydrogen fluoride, or hydrochloric acid. Reagents are also used in sample preparation. Unused portions or excess prepared sample are placed in 4-liter plastic bottles. The Building 559 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various ions, iron, silicon, isotopic composition, and americium, gallium, neptunium, plutonium, uranium, and other metals (Resource Conservation and Recovery Act [RCRA] - regulated and nonregulated). Solid samples are dissolved in a variety of acids, including nitric and hydrochloric. Other chemicals used in the laboratory include methanol, chloroform, and other organic solvents; titanium trichloride; ceric ammonium nitrate; sodium hydroxide; silver chloride; silver nitrate; and various metals standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also place on the bottles. The Building 771 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various metals and ions, pH, and radioactivity. The principal chemicals used in the lab include sodium hydroxide, hydrochloric acid, nitric acid, cyclohexane, trioctyl phosphine oxide, yttrium, and various metal standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F005, F003, F002, F001, D043, D040, D038, D035, D029, D028, D019, D018, D011, D010, D009, D008, D007, D006, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	Group X200 is analytical standards. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 089 is produced in the calcination process in Glovebox 16 in Building 771. Grease oxide is a mixture of plutonium greencake from the calciner equipment. The grease is applied to the wear plates on the calciner. Grease and greencake can mix together near the breech of the calciner where the product greencake is removed. Grease oxide is placed in metal cans for storage prior to calcination and eventual dissolution for recovery. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

The volumes and the radionuclide concentrations developed in the profile were based on processing plutonium residues for actinide separation. RFETS has modified this processing plan. Residues will be processed to meet WIPP WAC, TRAMPAC, and safe storage conditions. The modified volumes and radionuclide concentrations are reflected in the WIPP level roll-ups.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 090 is produced in the Flourination Process is Glovebox 7 in Building 771. Calcined plutonium oxide, "green cake", is transferred to Glovebox 7 by an enclosed pneumatic transfer system. The plutonium oxide is manually fed into a hopper from which it is augured into the hydrofluorinator. The hydrofluorinator is a slightly inclined, horizontal, rotary-tube furnace. Anhydrous hydrogen fluoride gas is introduced at the discharge zone of the tube. The plutonium tetrafluoride is collected in plastic bottles and transferred to the Fluoride Reduction Process. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is posaible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.3	0.0	0.0	0.0	0.0	0.3
Totals	0.3	0.0	0.0	0.0	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 091 is produced in the Fluorination Process in Gloveboxes 6 and 7 in Building 771. The plutonium tetrafluoride is produced in the same manner as described for IDC 090 but is not pure enough for fluoride reduction. The impure fluoride is collected from the equipment and floor of Glovebox 7 or is filtered from the hydrofluorinator scrubber liquid (potassium hydroxide solution) in Glovebox 6. The impure fluoride was placed in metal cans and stored prior to acid dissolution (for plutonium recovery) in Gloveboxes 3 and 24. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 092/097 is produced in the Dissolution Process in Gloveboxes 3 and 24 in Building 771. IDC 091 impure plutonium tetrafluoride is placed in a dissolution pot with heated nitric acid. The solution (plutonium nitrate) is pulled by vacuum through an R-6 filter to remove undissolved solids. The undissolved solids are impure fluoride heels that are dried on a hot plate. The impure fluoride heels are placed in metal cans and stored for recycle into the same Dissoloution Process. IDC 097 differs from IDC 092 in packaging only. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 092/097 is produced in the Dissolution Process in Gloveboxes 3 and 24 in Building 771. IDC 091 impure plutonium tetrafluoride is placed in a dissolution pot with heated nitric acid. The solution (plutonium nitrate) is pulled by vacuum through an R-6 filter to remove undissolved solids. The undissolved solids are impure fluoride heels that are dried on a hot plate. The impure fluoride heels are placed in metal cans and stored for recycle into the same Dissoloution Process. IDC 097 differs from IDC 092 in packaging only. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 099 is produced in the Fluorination Process in Gloveboxes 6 and 7 in Building 771. The grease fluoride is a mixture of plutonium fluoride and grease from the hydrofluorination equipment. The grease fluoride is placed in metal cans for strorage prior to calcination and eventual dissolution for recovery. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm

(total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F005, F003, F002, F001, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.9	0.0	0.0	0.0	0.0	6.9
Totals	6.9	0.0	0.0	0.0	0.0	6.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.9 Projected: 0.0 Total: 6.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

The backlog inventory of IDC 290 includes materials generated as high-vacuum grease (green cake) in the Calcination Process in Building 771; as incinerator sludge from Building 771; as lab waste from Building 559 and 771; as miscellaneous sludge from an unknown source in Building 771; and as vacuum pump sludge from Building 771. High-vacuum grease, would have been produced when bvacuum grease applied to stainless-steel plates at either end of the rotary tube calciner became contaminated with plutonuim oxide during the calcination of plutonium peroxide. Incinerator sludge could have been generated by the recovery incinerator in Building 771. Lab waste could have been generated by laboratory processes in Buildings 559 and 771. The vacuum pump (Nash pump) sludge could have been generated by pumps in Building 771. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5

ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W037	Handling:	CH	NMVP #:	RF 117	Stream Name:	Heavy Metal (non-SS)/TRM	Inventory Date:	10/20/94
Local ID:	IDC 320	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.3	0.0	0.0	0.0	0.0	3.3
Totals	3.3	0.0	0.0	0.0	0.0	3.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.3 Projected: 0.0 Total: 3.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

IDC 320 - Scrap metals which are heavier than iron and steel. Metal above Cu on the periodic table. Mainly used tantalum crucibles. Does not include lead.

WASTE STREAM SOURCE

Heavy metals have been produced as by-products of Rocky Flats operations in Buildings 371, 707, 771, 776, 777, 779, and 865; they are identified by IDC 320. The IDC 320 heavy nonspecial source metal was generated in various locations throughout the Rocky Flats and is stored in Resource Conservation and Recovery Act (RCRA) Units 11, 12, 13, 15A, and 20. This IDC includes nonstainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987. IDC 320 originally included lead.

During maintenance operations, the maintenance shop in Building 371 generated heavy metal vessels, instruments, rods, and plates fabricated from tantalum, tungsten, and platinum. The shop generated these items during 4 1/2 years of operation from 1983 until 1988. Of these containers in storage, 19 backlog containers have an EPA Code of D008 (lead); eight of these were produced after 1987. Building 707, Modules A and J, generated heavy metals in its foundry operations. These heavy metals were primarily crucibles and pans used for presampling. These processes generated material during 6 1/2 years of operation from 1985 until 1991. Nine backlog containers have an EPA Code of D008 (lead). The plutonium recovery operations in Building 771 generated leached Oralloy parts consisting of tantalum, tungsten, and platinum. The system generated material during 3 years of operation from 1987 until 1990. Five backlog containers have an EPA Code of D008 (lead); four of these backlog containers were produced after 1987. Building 776, Pyrochemical Processing, generated material during almost three years of operation from 1988 until 1990. This material consists primarily of tantalum crucibles, stirrers, and cans from MSE, salt scrub, and anode heel processes. Eight containers have an EPA Code of D008 (lead). Building 777, the Coatings Laboratory, generated material during a 2-year period of operation from 1988 until 1990. This material consists primarily of various heavy metals used in the research and development of coating technologies. These backlog containers have been associated with lead as a constituent and were produced after 1987. The Residue Treatment Technology Group, Building 779, generated crucibles, stirrers, and other general lab equipment derived from tantalum and tungsten. In Building 779, the Physical Metallurgy Group generated tantalum materials used in casting and cast testing. Additionally, the Surface Analysis Laboratory in Building 779 generated heavy metal samples primarily of depleted uranium (D-38). IDC 320 material was produced by Building 779 operations over a 10-year period from 1981 until 1991. Nine backlog containers have an EPA Code of D008 (lead), six were produced after 1987.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation (25A) was identified based on specific process knowledge and generation date. The EPA Code D008 was assigned to this subpopulation because of contact with known lead products and process association. This subpopulation consists of containers produced before or during 1987. The WEMS database lists the EPA Code D008 for these containers. Because of the generation date, a conservative position has been taken by placing backlog drums with the DOO8 (lead) EPA Code in this subpopulation. The primary buildings of generation were 371, 707, 771, 776, 779.

Subpopulation 25B was identified based on specific process knowledge and generation date. At this time, the generation date has been used judiciously in separating and characterizing containers with lead. The EPA Code D008 was assigned to this subpopulation because of contact with known lead products and process association. This subpopulation consists of containers produced before or during 1987. The WEMS database lists the EPA Code D008 for these containers. Because of the generation date, a conservative position has been taken by placing backlog drums with the D008 (lead) EPA Code in this subpopulation. The primary buildings of generation were 371, 707, 771, 776, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. Future generation is projected beyond 1999.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W028	Handling:	CH	NMVP #:	N/A	Stream Name:	Lead/TRM	Inventory Date:	10/20/94
Local ID:	IDC 321	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7211

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of metallic lead in the form of sheets, bricks, or tape.

Physical form: solid

Currently, no analytical data for lead waste is available. Process knowledge is the basis for characterization of this waste form. Lead waste (IDC 321) from non-specific sources is believed to have only lead (D008) as a hazardous constituent. In numerous tests of elemental lead, EP toxicity values exceed those listed in Table 1, 40 CFR 261.24. It is assumed that IDC 321 would also exceed EP toxicity limits for lead.

WASTE STREAM SOURCE

Transuranic lead was generated at a number of locations throughout Rocky Flats and includes IDC 321. The as-low-as-reasonably- achievable (ALARA) principle requires that the exposure of workers to radiation be kept "as low as reasonable achievable." In support of this principle, selected components and surfaces of gloveboxes enclosing materials that generate elevated levels of penetrating radiation (primarily gamma radiation) are commonly covered with metallic lead sheeting. The lead serves to attenuate the radiation dose received by employees working in the glovebox or in proximity to the glovebox. Lead waste (IDC 321) components are generally composed of lead bricks, lead shielding, and lead tape.

The lead or lead-covered components may become waste due to replacement, modification, or decommissioning activities. The dates of generation for IDC 321 range from August 15, 1986 to March 1, 1994.

The lead waste form is not a by-product of any process routinely performed at Rocky Flats. According to WSRIC Building Books, lead is most commonly generated as a result of maintenance activities. The lead waste is generally composed of lead shielding, scrap lead metal, and lead tape. The lead waste is collected in standard waste drums. The lead waste form was generated in Buildings 371, 559, 707, 771, 776, 777, and 779.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Drums Containing Scrap Lead Metal and Lead Shielding

Scrap lead metal and lead shielding exhibit the characteristic of toxicity for lead (D008). Subpopulation 8A was identified based on specific process knowledge and analytical results from elemental lead waste. According to WEMS, WSRIC, drums reports, and internal correspondence, the waste primarily consists of lead bricks, lead shielding, and scrap lead metal. Although some of waste could have come in contact with solvents, it is not considered to be a listed waste if the metal was wiped down with solvents for decontamination or paint stripping purposes, or if it was generated by the decommissioning of gloveboxes or other container-like apparatuses. Additional EPA codes are assigned to the waste based on process knowledge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined this waste form to be LDR waste based on process knowledge available for TRU lead waste (IDC 321) and the fact that elemental lead exceeds values for EP toxicity pursuant to 40 CFR 261 24. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: This waste is packaged in 55-gallon drums lined with a fiberboard liner and two polyethylene bag liners.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles, dry/REM	Inventory Date:	10/24/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, F005, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
drum / 55-gallon	19.1	0.0	0.0	0.0	0.0	19.1
Totals	19.1	0.0	0.0	0.0	0.0	19.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 19.1 Projected: 0.0 Total: 19.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	IDC 330 is Dry Combustibles. This IDC is dry combustibles such as cloth, paper, and wood. This IDC changes to 821, 831, 851, or 861 at the point of assay, depending on radiological content. Containers of IDC 330 currently in inventory were generated in all buildings handling fissile material. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	See Comment ##
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 332 includes oily sludge generated in Building 776 in an unknown location, and solidified scintillation cocktail waste generated in Building 771. In the past, the oily sludge generated in Building 776 was sent to Building 771 for dissolution. Each container of sludge was opened for inspection; some cans were processed while others were not. The cans that were not processed were labeled IDC 332 and stored, awaiting recovery processing. The scintillation cocktail waste includeds liquid scintillation waste to which diatomaceous earth was added as a solidifying agent. IDC 332 was assigned to this material because it was felt that it was more appropriate than any other IDC.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates 1 wt% but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP

extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F003, F002, F001, D008, D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	20.2	0.0	0.0	0.0	0.0	20.2
Totals	20.2	0.0	0.0	0.0	0.0	20.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 20.2 Projected: 0.0 Total: 20.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Item Description 336, Combustibles, Wet Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This IDC changes to 822, 832, 852, or 862 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, F005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	IDC 337 represents PVC sheeting, poly bottles, supplied-air suits, polyethylene, and other plastics. IDC 337 changes to 825, 833, 853, or 863 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W029	Handling:	CH	NMVP #:	RF 123	Stream Name:	Leaded Dry Box Gloves/REM	Inventory Date:	10/20/94
Local ID:	IDC 339	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 123

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a solid matrix consisting of gloves with lead lining. There could be some free liquids in waste containers.

WASTE STREAM SOURCE

Leaded glovebox gloves are generated as waste at Rocky Flats by processes requiring a controlled atmosphere in Buildings 371, 374, 559, 707, 771, 774, 776, 777, 778, and 779 and encompasses IDCs 339 and 341. Prior to January 22, 1986, all leaded glovebox gloves were accumulated together as IDC 339 (Leaded Glovebox Gloves). At that time, IDC 341 (Leaded Glovebox Gloves, Acid Contaminated) was created. IDC 339 became "Leaded Glovebox Gloves, Nonacid Contaminated." Leaded glovebox gloves are replaced by schedule or as needed.

All backlog leaded glovebox gloves (IDC 0339 and 0341) were washed in Building 776 until about September 1989, at which time the process was curtailed. The primary purpose of the washing process was to remove the accountable material; however, the acid from the acid-contaminated gloves (IDC 341) was removed as well. After the acid-contaminated gloves were washed, the IDC was changed from 341 to 339. The glove washing process was curtailed upon completion of the inventory of backlog gloves.

Due to degradation from contact with process materials during normal process operations and age, the leaded glovebox gloves are replaced according to schedule or as necessary. Nonacid-contaminated leaded glovebox gloves (IDC 339) are generated as waste or residue depending on the assay, in Buildings 371, 374, 559, 707, 771, 774, 776, 779. Acid contaminated leaded glovebox gloves (IDC 341) were washed in Building 776 after which they were assigned IDC 339.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

In addition to the reference documents and WEMS information, analytical data compiled by Rocky Flats were reviewed. This analytical information shows the presence of lead above the regulatory level stated in 6 CCR 1007-3, Section 261.24, in one sample, borderline in another, and well below the regulatory level in another.

Characterization is identified based on process knowledge. This population includes all IDC 339 nonacid contaminated gloves generated after the creation of IDC 341 (January 22, 1986). This population contains no acid-contaminated (IDC 341) gloves. This population exhibits the characteristic of toxicity for lead (D008). The primary buildings of generation were 371, 374, 559, 707, 771, 774, 776, 777, and 779.

One drum of IDC 339 gloves was generated before the creation of IDC 341 (January 22, 1986). Therefore, this drum could contain both acid- and nonacid-contaminated gloves.

Although numerous acids are used in aqueous processing, nitric is the acid of greatest concern because it dissolves the outer Hypalon layer of the gloves and reacts with the lead oxide layer to form lead nitrate and organic nitrate or nitro-organic compounds. These compounds are in very small quantities and do not cause the gloves to exhibit the characteristic of ignitability as outlined in 6 CCR 1007-3, Section 261.21. However, when dried, the compound decomposes violently at temperatures ranging from 60 to 130 degrees C. Also, the compound explodes when subjected to an impact load or when confined and ignited with a fuse. Unconfined, the compound burns violently when ignited with a spark. This drum is therefore assigned D003 for reactivity as outlined in 6 CCR 1007-3, Section 261.23 (a) (6).

Population 42A: Identified based on process knowledge, EPA codes, and generation dates. This population includes all IDC 339 nonacid contaminated gloves generated after the creation of IDC 341 (January 22, 1986). This population contains no acid-contaminated (IDC 341) gloves. This population exhibits the characteristic of toxicity for lead (D008). The primary buildings of generation were 371, 374, 559, 707, 771, 774, 776, 777, and 779.

Subpopulation 43B: This subpopulation includes all acid-contaminated leaded glove box gloves. As previously discussed, these gloves exhibit the characteristic of toxicity for lead (D008) and reactivity (D003). The primary buildings of generation were 371, 771, 777, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on the fact that lead is a RCRA listed waste exhibiting the characteristic of toxicity. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The gloves are packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F002, F001, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 340 includes sludge generated during the washing of leaded glovebox gloves and non-RCRA-regulated metals with water in the size reduction vault in Building 776. The entire backlog inventory of IDC 340 was generated in Building 776. The wash water and sludge were separated in a tank, and the sludge was then sent to Building 771 for nondestructive assay and was put into drums there. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm

(total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W041	Handling:	CH	NMVP #:	N/A	Stream Name:	Leaded Gloves-Acid Contaminated/TRM	Inventory Date:	10/20/94
Local ID:	IDC 341	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D008, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

IDC No. 341. This waste stream consists of leaded rubber gloves used in the glovebox systems for plutonium recovery operations in Buildings 771 and 371. These gloves are contaminated with nitric acid and other acids when replaced and discarded as waste.

WASTE STREAM SOURCE

Leaded Glovebox Gloves

Waste Form/Item Description Code/Waste Form Code Background for the Leaded Glovebox Gloves Waste Form

Leaded glovebox gloves are generated as waste or residue at Rocky Flats by processes requiring a controlled atmosphere in Buildings 371, 374, 559, 707, 771, 774, 776, 777, 778, and 779 and encompasses IDCs 339 and 341. Prior to January 22, 1986, all leaded glovebox gloves were accumulated together as IDC 339 (Leaded Glovebox Gloves). At that time, IDC 341 (Leaded Glovebox Gloves, Acid Contaminated) was created. IDC 339 became "Leaded Glovebox Gloves, Nonacid Contaminated." Leaded glovebox gloves are replaced by schedule or as needed.

All backlog leaded glovebox gloves (IDC 0339 and 0341) were washed in Building 776 until about September 1989, at which time the process was curtailed. The primary purpose of the washing process was to remove the accountable material; however, the acid from the acid-contaminated gloves (IDC 341) was removed as well. After the acid-contaminated gloves were washed, the IDC was changed from 341 to 339. The glove washing process was curtailed upon completion of the inventory of backlog gloves.

Item Description Code 341

Acid-contaminated leaded glovebox gloves (IDC 341) are generated as waste or residue depending on the assay, in Buildings 371, 771, 777, and 779. Due to degradation from contact with process materials and age, the gloves are replaced according to schedule or as necessary. When acid-contaminated gloves (IDC 0341) were washed, the IDC was changed to 0339.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

In addition to the reference documents and WEMS information, analytical data compiled by Rocky Flats were reviewed. This analytical information shows the presence of lead above the regulatory level stated in 6 CCR 1007-3, Section 261.24, in one sample, borderline in another and well below the regulatory level in another.

Leaded glovebox gloves are manufactured with a lead oxide layer between two or more layers of neoprene-Hypalon, for shielding against penetrating radiation. The available analytical data were obtained from unused, 30-millimeter-thick gloves. Analytical data for the lead content of 50- and 80-millimeter-thick leaded gloves are not available. However, the lead content is assumed to be substantially higher than the 30-millimeter-thick gloves. Also, the lead from used gloves, degraded from contact with process materials, may leach more readily than from unused gloves.

Toxicity Characteristic Leaching Procedure (TCLP) metals by Inductively Coupled Plasma Emission Spectroscopy showed the lead above the regulatory limit. Other contaminants include acid and base solutions and listed solvents. Glovebox gloves used in processes that require listed solvents are not considered listed solvent wastes because the gloves do not retain solvents in the same way paper or cloth wipes do. Contact of the gloves with solvents is considered incidental contact. Therefore, the gloves are not subject to the mixture rule.

IDC 341 includes leaded gloves exposed to acids which have not been washed. Although numerous acids are used in aqueous processing, nitric is the acid of greatest concern because it dissolves the outer Hypalon layer of the gloves and reacts with the lead oxide layer to form lead nitrate and organic nitrate or nitro-organic compounds. These compounds are in very small quantities and do not cause the gloves to exhibit the characteristic of ignitability as outlined in 6 CCR 1007-3, Section 261.21. However, when dried, the compound decomposes violently at temperatures ranging from 60 to 130 degrees C. Also, the compound explodes when subjected to an impact load or when confined and ignited with a fuse. Unconfined, the compound burns violently when ignited with a spark. IDC 341 leaded gloves are therefore

assigned D003 for reactivity as outlined in 6 CCR 1007-3, Section 261.23 (a)(6).

This subpopulation includes all IDC 341 acid-contaminated leaded glovebox gloves. As previously discussed, IDC 341 gloves exhibit the characteristic of toxicity for lead (D008), and reactivity (D003). The primary buildings of generation were 371, 771, 777, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that leaded gloves and acid-contaminated leaded gloves are LDR waste based on the process knowledge available. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick, /REM	Inventory Date:	10/20/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F002, F001, F005, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF-377

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	3.1	0.0	0.0	0.0	0.0	3.1
Totals	3.1	0.0	0.0	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.1 Projected: 0.0 Total: 3.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form is firebrick that has been crushed and pulverized.

WASTE STREAM SOURCE

IDC 371 was generated during maintenance operations in the incineration systems in Building 771. This material was also generated during incinerator stripout operations in Building 371. Firebrick consists of brick and chunks of high-density alumina ceramic material used to line the firebox of the incinerator.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt% but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulations IK, IL, IM, IN

EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Fu-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

Net and gross weight data are not available for all container types.
RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick Heel/REM	Inventory Date:	10/20/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form is firebrick that has been crushed and pulverized.
WASTE STREAM SOURCE	During dissolution of scarfed firebrick (IDC 377 and 378), undissolved firebrick heel was generated in Building 771. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Those layers were pulverized and subjected to a nitric acid dissolution process. The material that did not dissolve was filtered, dried, assayed, and set aside for additional processing. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulations IK, IL, IM, IN EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational. A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Net and gross weight data are not available for all container types. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W008	Handling:	CH	NMVP #:	N/A	Stream Name:	Soil & Cleanup Debris/REM
Inventory Date:	10/20/94						
Local ID:	IDC 374	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal
Waste Matrix Code:	S5190						

AS-GENERATED EPA CODES

F002, F001, F005, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION This waste consists of blacktop/concrete/dirt/sand.

WASTE STREAM SOURCE Soil and cleanup-debris (IDC 374) were generated during cleanup and construction activities around Rocky Flats. In most cases, construction or demolition activities generated rubble consisting of blacktop, concrete, dirt, sand , and rock. The rubble was packaged in plywood boxes with a fiberboard liner and a polyvinyl chloride (PVC) bag liner or in 55-gallon, DOT Type 7A drups. The waste was generated on a nonroutine basis. Information describing spendid activities generating soil and debris were often unavailable.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Subpopulation 23B-Container Number D48510

Drum D48510 was generated in Building 374, Room 3803. Room 3803 houses part of the Building 374 Sludge Immobilization Process. The process generated solidified sludge. The waste in drum D48510 is potentially contaminated with process sludge. The sludge consists of RCRA-regulated materials from Decontamination-Precipitation and Neutralization Processes in the Building 374 Liquid Waste Treatment Facility. Building 374 solidified sludge is characterized in the Building 374 Solidified Sludge Backlog Baseline Book.

Building 374 sludge was intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Sampling and analysis of solidified sludge found the waste exceeded toxicity characteristic criteria for chromium (EPA Code D007) and selenium (D010) but at very low levels. It will be assumed that the waste contained in drum D48510 would not exhibit the characteristic of toxicity for chromium and selenium because of dilution by the soil and debris. Toxicity Characteristic Leaching Procedure (TCLP) analysis of the waste under EPA SW-846 is required to prove the waste does not exceed toxicity characteristic criteria.

Contaminated soil and cleanup debris must also carry the listed EPA codes associated with Building 374 solidified sludge. The EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 are assigned to the waste and it will not be considered as meeting the Land Disposal Restrictions (LDR) treatment standards until sampling and analysis proves otherwise.

Subpopulation 23D-Container Number D75005

WEMS indicates drum D75005 was generated in Building 776. However, the waste was repackaged in Building 776 in April 1988 after a failed drum containing the waste was discovered in the Property Utilization and Disposal storage yard.

The drum contains soil and two sample vials of chromium oxide and aluminum oxide. It will be assumed that the waste contained in drum D75005 exhibits the characteristic of toxicity for chromium (D007) because of chromium oxide contamination. TCLP analysis of the waste under EPA SW-846 is required to prove the waste does not exceed toxicity characteristic criteria.

Subpopulation 23E-Soil and Asphalt from the 750 and 904 Pads Earth Anchor Installation

The installation of earth anchors for the 750 and 904 Pads in 1990 and 1991 generated a large amount of soil and asphalt. The waste was packaged in half-boxes with the generation prefix 788. Some of the half-boxes were rejects but were used because the waste was expected to remain in the reject containers for a short time before remediation activities began. During remediation of the pads, containers of soil and debris were to be emptied and the waste treated. These activities never occurred and the waste is still in the rejected containers.

The soil and debris may have been contaminated with pondcrete and saltcrete waste stored in the pad areas. The work procedure required that EPA codes associated with pondcrete and saltcrete be assigned to the soil and debris. An explanation of codes applicable to pondcrete and saltcrete is provided in the Pondcrete Backlog Baseline Book and the Saltcrete Backlog Baseline Book.

Pondcrete and saltcrete were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Sampling and analysis of saltcrete found the waste did not exhibit a characteristic for RCRA metals. Sampling and analysis of pondcrete found the waste exceeded toxicity characteristic criteria for cadmium (EPA Code D006) and chromium (EPA Code D007) but at very low levels. It is assumed that the soil and debris from the earth anchor installation does not exhibit the characteristic of toxicity for cadmium and chromium because of dilution by the soil and debris. TCLP analysis of the waste under EPA SW-846 (EPA 1990) is required to prove the waste does not exceed toxicity characteristic criteria.

Contaminated soil and debris from the earth anchor installation must carry the listed EPA codes associated with pondcrete and saltcrete. The EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 are assigned to the waste and it will not be considered as meeting the LDR treatment standards until sampling and analysis proves otherwise.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

GENERAAREA: Plutonium process areas. GENOPERATION: Generated in multiple buildings in which aqueous plutonium recovery or plutonium fabrication processes were conducted. RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed. CATION: Not Applicabe. OTHER_CHAR: Not Applicable.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon carbon steel DOT 7A Type A Drum.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick coarse/REM	Inventory Date:	10/20/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	5.2	0.0	0.0	0.0	0.0	5.2
Totals	5.2	0.0	0.0	0.0	0.0	5.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 5.2 Projected: 0.0 Total: 5.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form is firebrick that has been crushed and pulverized
WASTE STREAM SOURCE	During maintenance operations, coarse chunks of scarfed firebrick were generated in Building 771. This material was also generated during incinerator stripout operations in Building 371. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Coarse firebrick consists of chunks of the unpulverized, plutonium-bearing surface layer of the high-density alumina ceramic firebrick material. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulations IK, IL, IM, IN EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational. A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Net and gross weight data are not available for all container types. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner. Projected future generation begins in CY2005.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick, pulverized or fines/REM	Inventory Date:	10/29/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.7	0.0	0.0	0.0	0.0	0.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.7 Projected: 0.0 Total: 0.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form is firebrick that has been crushed and pulverized.

WASTE STREAM SOURCE

During maintenance operations, pulverized scarfed firebrick was generated in Building 771. This material was also generated during incinerator stripout operations in Building 371. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Pulverized firebrick consists of chunks granular, fine, and very fine, plutonium-bearing surface layer of the high-density alumina ceramic firebrick material.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulations IK, IL, IM, IN

EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

Net and gross weight data are not available for all container types.
RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	incinerator ash/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

Item Description Code 419, Unpulverized Incinerator Ash

Unpulverized incinerator ash was generated as an intermediate product during routine operation of the incinerator in Building 771. This material was also generated during incinerator stripout operations in Building 371. The unpulverized ash consists of a mixture of coarse, granular, fine, and very fine particulates. The ash contains miscellaneous tramp metal, bits of unburned feed material, and carbon from the incomplete oxidation of feed material. The coarse materials consist of fused ash, clinkers, or unburned materials that fell through the stationary grate of the incinerator.

IDC 419 is mixed residue only.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	Incinerator ash/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

		TRUCON CODE	FINAL FORM RADIONUCLIDES
Category:	Defense TRU Waste	N/A	N/A
Residues:	Yes		
Asbestos:	No		
PCBs:	No		
Source:	Pollution Control or Waste Treatment Process		

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Drum / 10-gallon	0.04	0.0	0.0	0.0	0.0	0.04
Drum / 55-gallon	161.8	0.0	0.0	0.0	0.0	161.8
Totals	161.9	0.0	0.0	0.0	0.0	161.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 161.9 Projected: 0.0 Total: 161.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

The FBIs in Building 776 were developed as pilot operations. Their test function was to develop new technology to reduce volume and destroy volatile constituents prior to plutonium recovery operations. The only incinerator to generate backlog waste covered by this waste form was the Full-Scale Unit. The first runs of this incinerator (1978 to 1981) used newspaper, Building 776 low-level waste (LLW), combustible waste, kerosene, garage oil, and grease as test materials. The tests were conducted with methanol, diesel products, and nonradioactive surrogate combustibles (shredded coveralls, leather gloves, rolls of polyvinyl chloride [PVC] plastic, wood, and paper). The by-product of this process was FBI ash (IDC 425).

Item Description Code 420, Pulverized Incinerator Ash

Pulverized incinerator ash was generated as an intermediate product during routine operation of the incinerator in Building 771. This material was also generated during incinerator stripout operations in Building 371. The pulverized ash consists of a mixture of coarse, granular, fine, and very fine particulates that have been ground by the ball mill. The ash contains miscellaneous tramp metal, bits of unburned feed material, and carbon from the incomplete oxidation of feed material.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one-bag liner.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	Incinerator ash/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 10-gallon	0.04	0.0	0.0	0.0	0.0	0.04
drum / 55-gallon	68.0	0.0	0.0	0.0	0.0	68.0
Totals	68.1	0.0	0.0	0.0	0.0	68.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 68.1 Projected: 0.0 Total: 68.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

Item Description Code 421, Ash Heel

During dissolution of incinerator ash (IDC 419 and 420), undissolved incinerator ash heel was generated in Building 771. Incinerator ash was subjected to a nitric acid dissolution process. The material that did not dissolve was filtered, dried, assayed, and set aside for additional processing.

IDC 421 is mixed residue only.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D006, D004, F005, F003, F002, F001, D010, D008, D009, D007, D005, D011

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.5	0.0	0.0	0.0	0.0	3.5
Totals	3.5	0.0	0.0	0.0	0.0	3.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.5 Projected: 0.0 Total: 3.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 069 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

Incinerator soot (IDC 422) was generated as an intermediate product during routine filter change operations of the incinerator plenum in Building 771. This material was also generated during incinerator stripout operations in Building 371. The soot consists of a fine and very fine particulate fly ash that was removed from the incinerator off-gas treatment system. The soot generally contained a higher concentration of carbon and fine particulate oxidation of some feed materials. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 069: D007 was identified based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F005, F002, F001, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

After incinerator soot (IDC 422) generated in Building 771 was dissoved in acid for plutonium recovery, the solution| was filtered and dried. The soot heel that remained (IDC 423) was assayed and set aside for additional processing. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm

(total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

The volumes and the radionuclide concentrations developed in the profile were based on processing plutonium residues for actinide separation. RFETS has modified this processing plan. Residues will be processed to meet WIPP WAC, TRAMPAC, and safe storage conditions. The modified volumes and radionuclide concentrations are reflected in the WIPP level roll-ups.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	Incinerator ash/TRM	Inventory Date:	
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Drum / 55-gallon	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

Item Description Code 428, Incinerator Ash

After incinerator ash (IDC 420) was generated in Building 771, this material was prepared, assayed, and packaged in Building 371, for transportation to an alternate DOE site for plutonium recovery processing. This material does not differ from incinerator ash IDC 420.

IDC 428 is mixed residue only.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W091	Handling:	CH	NMVP #:	N/A	Stream Name:	Organics Discard Level/TRM	Inventory Date:	10/24/94
Local ID:	0533, 0535, N/A	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

F003, F002, D022, D007, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This liquid waste stream includes machine oils and coolants contaminated with organic solvents.
WASTE STREAM SOURCE	Item Description Code 533 This IDC includes principally machine oils and coolants contaminated with organic solvents used in cleaning and, in some cases, contaminated with RCRA-regulated metals. According to Waste Stream Identification and Characterization (WSIC) information, Building 779 used acetone, trichloroethane, and methylene chloride in its Machine and Nuclear Joining processes. WSIC information also indicated that Building 881 used, or generated as sample waste, acetone, carbon tetrachloride, chloroform, ethanol, methanol, hexane, isopropanol, toluene, ethylbenzene, xylene, methylene chloride, 1,2-dichloroethane, and 1,1,2-trichloro-1,2,2-trifluoroethane in various analytical processes. Also, machining and manufacturing Research and Development operations, and possibly model construction operations produced oils contaminated with cadmium, chromium, lead, and selenium. WSIC information stated that Building 883 used chloroform, trichloroethane, toluene, xylene, and 1,1,2-trichloro-1,2,2-trifluoroethane in its metallurgical operations. Building 444 used acetone, 1,2-dichloroethene, trichloroethane, toluene, and ethylbenzene in its plating operations; acetone, 1,1,2-trichloro-1,2,2-trichfluoroethane, methylene chloride, and toluene in its fabrication operations; and trichloroethane in its tool and gauge operations. Where analytical data for this IDC exist, most of these organic solvents usually were not detected.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based on waste generation and general knowledge of waste type or source.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W091	Handling:	CH	NMVP #:	N/A	Stream Name:	organics Discard Level/TRM	Inventory Date:	10/24/94
Local ID:	0533, 0535, N/A	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

F005, F003, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION This liquid waste stream includes machine oils and coolants contaminated with organic solvents.

WASTE STREAM SOURCE

Item Description Code 535

This IDC includes laboratory quantities of RCRA-regulated organic solvents. The backlog inventory of this IDC was generated in Building 881 in various analytical laboratories. According to WSIC information, the solvents include toluene, 1,1,2-trichloro-1,2,2-trifluoroethane, xylene, acetone, carbon tetrachloride, chloroform, ethanol, methanol, hexane, isopropanol, ethylbenzene, methylene chloride, and 1,2-dichloroethane.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS Process knowledge based on waste generation and general knowledge of waste type or source.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

F002, F005, F001, D011, D010, D009, D008, D007, D006, D005, D004, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.77E+01
Pu-240	1.16E+00
Pu-239	5.08E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	17.3	7.2	5.1	29.9	13.8	73.3
Totals	17.3	7.2	5.1	29.9	13.8	73.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 17.3 Projected: 57.0 Total: 74.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

IDC 292 was intended for incinerator sludge from the recovery incinerator in Building 771. IDC 292 materials were reassessed under Waste Form 1, Incinerator Ash. However, there is one box WEMS incorrectly assigned this IDC. According to the waste-box log sheet dated October 14, 1987, the box contains Electrochemical Milling Sludge generated in Building 881. This operation generated sludge from the milling of various metals including stainless steel. It was indicated that no cyanides were used in the ECM operations in Building 881. The IDC for this box should be changed to 299.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphateds >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is

recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

F002, F005, D040, D035, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.77E+01
Pu-240	1.16E+00
Pu-239	5.08E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.3	0.3	1.5	0.7	3.5
Totals	0.8	0.3	0.3	1.5	0.7	3.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 2.7 Total: 3.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

This IDC has been used for sludges that were not accurately categorized as IDC 290 or 340 and could have been generated in any plutonium processing building. However, the backlog miscellaneous sludge was generated in Building 771 during the processing of residues, in Building 371 in the analytical laboratory, and in Building 883 by the Rolling Process. Process pipe sludge, sludge dissolution heel, and filter plenum sludge from Building 771 were processed through nitric acid dissolution and sparging. Soil and sludge samples from around the site were analyzed in Building 371, and the waste was stored for processing. IDC 299 materials generated in Building 883 include quench sludge and uranium oxide sludge from the rolling Process. This group also includes one container of electrochemical milling sludge generated in Building 881 in October 1987. The container is assigned IDC 292.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 65, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F005, F003, F002, F001, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.7	0.2	19.5	17.6	39.0
Totals	1.0	0.7	0.2	19.5	17.6	39.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 37.9 Total: 38.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

328 - Flu-Flo filters from the recovery incineration, building 771. Must be processed into IDC 376. Mixed Waste.

WASTE STREAM SOURCE

These Ful-Flo filters are in-line cartridge filters used to remove particulates from specific fluid streams in Building 771.

During normal process operations, IDC 328 Ful-Flo filters in the backlog population were used to filter particulates from the incinerator fume scrubber system in Building 771. These filters were used for the filtration of caustic solutions; therefore, they are contaminated with bases and may contain free liquids.

During normal process operations, IDC 331 Ful-Flo filters in this backlog population were used to filter particulates from liquid waste streams in Buildings 371, 707, 771, 776, 777, and 779. These waste streams were primarily from filtration of caustic solutions in Building 371, the carbon tetrachloride system and oil systems, and from filtration of water and developer in Building 707. In Building 771, the primary waste streams filtered were anion column feed, potassium hydroxide, nitrate feed, spent nitric acid and hydrofluoric acid from the scrubber, eluate and effluent exiting the ion-exchange columns, floor pick-up solution were filtered in Building 776. In Buildings 777 and 779, Ful-Flo filters were used in the carbon tetrachloride system for purification of Freon TF and for filtration of incoming waters.

Typically, Ful-Flo filters were placed on drying racks pending bag-out of a glovebox. Filters were not always dried before removal from the glovebox. Filters were then "bagged out" of the glovebox and placed in a second layer of plastic. Next, the filters were placed in a "Poly bottle" or "Clam Shell" (hard plastic container), then placed in a double-lined drum.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335

filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F002, F001, D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.6	3.0	0.8	86.1	102.5	197.0
Totals	4.6	3.0	0.8	86.1	102.5	197.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.6 Projected: 192.4 Total: 197.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

331 - Ful-Flo filters used to filter solids from aqueous solutions. Additional required processing undetermined. Because of the potential of liquids in this IDC, it requires a compatibility code when packaging.

WASTE STREAM SOURCE

These Ful-Flo filters are in-line cartridge filters used throughout Rocky Flats to remove particulates from fluid streams and typically filter down to 5, 1, and 0.5 micron-sized particulates. Ful-Flo filters are used in various liquid systems that include nitric- and chloride-acid systems, such as those found in plutonium recovery operations; caustic systems, such as those found in utilities scrubbing; solvent systems using carbon tetrachloride in machining operations; water systems, such as steam cleaning; and condensate collection. These filters are also used in lubricant oil filtration.

Ful-Flo filters are poly-fiber-wound cartridges, about 10" long by 3.5" in diameter. Other fiber filters, such as R-6 pads, may be included in this IDC. R-6 pads are cloth filters, about sixteen inches in diameter, used to filter solids from nitric acid solutions. Therefore, backlog material in this IDC cannot be considered homogeneous. filter elements are produced by combining a media blanket and spirally wound matrix yarn on an inner core. The filter elements might have a polypropylene cap on one end. Both the media blanket and matrix yarn can be cotton or polypropylene. The inner core material can be constructed of polypropylene, tinned steel, or stainless steel. Warehouse data from Rocky Flats indicate that the inner-core material is polypropylene.

during normal process operations, IDC 331 Ful-Flo filters in this backlog population were used to filter particulates from liquid waste streams in Buildings 371, 707, 771, 776, 777, and 779. These waste streams were primarily from filtration of caustic solutions in Building 371, the carbon tetrachloride system and oil systems, and from filtration of water and developer in Building 707. In Building 771, the primary wste streams filtered were anion column feed, potassium hydroxide, nitrate feed, spent nitric acid and hydrofluoric acid from the scrubber, eluate and effluent exiting the ion-exchange columns, floor pick-up solution, steam condensate, and miscellaneous aqueous solutions. Hydraulic oil and floor pick-up solution were filtered in Building 776. In Buildings 777 and 779, Ful-Flo filters were used in the carbon tetrachloride system for purification of Freon TF and for filtration of incoming waters.

Typically, Ful-Flo filters were placed on drying racks pending bag-out of a glovebox. Filters were not always dried before removal from the glovebox. Filters were then "bagged out" of the glovebox and placed in a second layer of plastic. Next, the filters were placed in a "Poly Bottle" or "Clam Shell" (hard plastic container), then placed in a double-lined drum.

These Ful-Flo filters may be contaminated with acids, bases, carbon tetrachloride, chromium, Freon, and oil. They may contain relatively small amounts of free liquids.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 326 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the

incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

M

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F002, F001, D019, D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	8.3	0.6	56.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	9.8	0.7	66.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.4	4.8	429.5
Rubber:	2.8	0.2	19.1
Plastics:	3.8	0.3	25.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.5	1.0	0.2	27.3	33.1	63.0
Totals	1.5	1.0	0.2	27.3	33.1	63.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	13.9	1.6	173.9	211.1	401.9
Totals	1.5	13.9	1.6	173.9	211.1	401.9

As-Generated Form: Stored: 1.5 Projected: 61.6 Total: 63.0

Final Waste Form: Stored: 1.5 Projected: 400.4 Total: 401.9

WASTE STREAM DESCRIPTION

335 - High efficiency particulate air filters used on glovebox air intakes and exhausts.

WASTE STREAM SOURCE

The material in this IDC is High Efficiency Particulate Air (HEPA) filters used in ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large filter plenums that filter the room air.

Used filters were removed from their position in the ventilation system and packaged for further processing. The filters used on gloveboxes (nominal 8" x 8" x 5") were identified as IDC 335 if they were not acid contaminated.

RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and

Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers

of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY I sach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

Projection in section 8.2.15.1.13 include generation of IDC-335 and IDC-342 to be processed to IDC-335.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W067	Handling:	CH	NMVP #:	RF 119	Stream Name:	Cemented filters/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F039, F009, F007, F006, F005, F003, F002, F001, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.60E+01
Pu-240	1.51E+00
Pu-239	6.61E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.7	0.2	19.7	23.9	45.5
Totals	1.0	0.7	0.2	19.7	23.9	45.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 1.0 Projected: 44.1 Total: 45.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of filters used in ventilation systems. Some of it has had cement sprinkled on it to neutralize the acid on the filters.

WASTE STREAM SOURCE

The material in this IDC is either the filter media portion of HEPA filters or surface-water filters. HEPA filters are used on gloveboxes and in large filter plenums. Sock filters were used to prefilter operable unit 2 (OU-2) surface water prior to activated carbon treatment.

Used HEPA filters were processed to segregate those portions with high plutonium content and those with low content. The wood frames were separated from the media and almost always disposed of as waste by packing in drums that were assigned IDC 330. the filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste.

This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from the production Building 707 and could be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon. IDC 338 was meant to be used as a residue IDC and not as a waste IDC. Because sorting between IDCs was not accurate, some of the IDC 338 backlog containers are below the economic discard limit (EDL) and are therefore not residue.

RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation DB

Subpopulation DB consists of IDC 338 filter media that could have been exposed to saltcrete in Building 374. Room 3809 was used for Saltcrete Processing (WSRIC Process 374-5). HEPA filters were used to filter nitrate salt particles from the baghouse air stream. The single container of filters in this subpopulation is characterized as RCRA hazardous, and its characterization is based on the current WSRIC characterization for saltcrete. EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 have therefore been applied. The EPA Code D001 is applied because nitrate salts may have formed on these filters.

Subpopulation DC

Subpopulation DC includes all IDC 338 filter media generated from Building 771. There are 111 containers in this subpopulation. This filter medium might be derived from IDC 342 filters (acid contaminated-see Subpopulations EB and EC), and is characterized the same as the IDC 342 filters from Subpopulation EB. Because this filter medium might have been used to filter nitric acid and nitric salts have been reported to form on the filter media, it could exhibit the characteristic of ignitability and is considered to be an oxidizer due to the presence of nitrate salts. This filter medium is a RCRA-hazardous waste and EPA Code D001 has been applied.

Subpopulation FA

Subpopulation FA includes containers of IDC 376 processed filter media generated throughout Rocky Flats that are characterized as nonhazardous. This processed filter medium is derived from filters generated from processes for which there would be no "carry over" of solvent contamination from vapors. Exclusion of filters from "carry over" contamination is based on WSRIC information and a Waste Technical Support Memorandum. The memorandum states that these HEPA filters are nonhazardous unless RCRA hazardous liquids have condensed from the uncontained gases. It is assumed that these containers do not have free liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

D008, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.9	4.8	1.4	148.0	179.7	341.7
Totals	7.9	4.8	1.4	148.0	179.7	341.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 7.9 Projected: 330.9 Total: 338.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

342 - Drybox filters from all acid lines. This waste must be neutralized, then changed to IDC 815 to disposal.

WASTE STREAM SOURCE

HEPA filters are used on all gloveboxes to remove particulates from the atmosphere exiting the glovebox to the plenum exhaust system. The filters in IDC 342 are from gloveboxes with atmospheres that could cause the filters to be contaminated with acids or bases used in chemical processing.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002, EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W056	Handling:	CH	NMVP #:	RF 118	Stream Name:	Mg Oxide Crucibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5123

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	11.9	0.0	23.8
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	564.2	252.6	789.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	26.9	13.5	53.8
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	3.30E+00
Pu-240	1.26E+00
Pu-239	5.50E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	1.4	1.7	3.6
Totals	0.6	0.0	0.0	1.4	1.7	3.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	1.4	1.7	3.6
Totals	0.6	0.0	0.0	1.4	1.7	3.6

As-Generated Form: Stored: 0.6 Projected: 2.9 Total: 3.5

Final Waste Form: Stored: 0.6 Projected: 2.9 Total: 3.5

WASTE STREAM DESCRIPTION

This waste stream includes any type or size of ceramic crucibles or liners including LECO crucibles. This waste consists of magnesium oxide ceramic crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing plutonium residue.

WASTE STREAM SOURCE

Transuranic waste and residue crucibles were generated at Rocky Flats by the pyrochemical development work in Buildings 779 and 776; production processes in Buildings 371, 771, and 776; laboratories in Buildings 559 and 771; and electrorefining in Buildings 371, 776 and 779. The generation of these waste populations encompasss IDCs 360, 368, 370, and 655. IDC 360, aluminum oxide ceramic crucibles, backlog containers are stored in Buildings 707 and 776. IDC 368, magnesium oxide ceramic crucibles - not LECO, backlog containers are stored in Buildings 371, 444C, 569, 664, 707, 771, 776, 777, and 964C. IDC 370, LECO crucibles, backlog containers are stored in Buildings 371, 771, 776, and 777. IDC 655, ER ceramic from plutonium/neptunium (Pu/Np), backlog drums are stored in Buildings 371 and 779. The backlog dates of generation recorded in the WEMS database range from August 3, 1973, to February 25, 1992.

During the hazardous determination and reassessment characterization phase of the project, the WEMS database was first queried to identify the waste containers constituting the waste form IDCs 360, 368, 370, and 655 populations. The information gained from the WEMS query provided the basis for subpopulation identification. References used during the continuing identification of waste form subpopulations are listed in Section 2.41.6. Additionally, comments and information provided at the reassessment meeting held on August 15, 1994 were incorporated into this revision.

Item Description Code 368

During normal process operations, the Electrorefining, Reduction and Button Breakout, Direct Oxide Reduction, and Salt Scrub processes in Buildings 559, 771, and 779 generated broken magnesium oxide crucible pieces. A detailed description of the generating processes presented above can be found in the WSRIC Building Books. However, in general, the crucibles were used to heat plutonium with salts or accelerators allowing for purification or recovery of actinide metals. Upon cooling to room temperature, the crucible or crucible insert used in the process would be broken and its contents removed.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

Process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 3 gallon nalgene jars, double bagged, placed in "clamshell" containers, placed in 55 gallon DOT 7A TYPE A drums with polyethylene rigid liner and bag liner.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.77E+01
Pu-240	1.16E+00
Pu-239	5.08E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.3	0.2	1.1	0.5	2.7
Totals	0.6	0.3	0.2	1.1	0.5	2.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 2.1 Total: 2.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

This IDC was generated by grit blasting operations in Building 371 (primarily for cleaning steel and iron) and Building 777 in the Machining and Coating processes (primarily cleaning shields). A variety of materials were used for the grit, including iron shot, walnut shells, glasss beads, and ceramic beads. The majority of the grit is thought to be iron shot ranging in size from fines to irregular particles. There were apparently no other RCRA-regulated metals involved in the grit blasting. There is one drum of IDC 372 shown in WEMS as being generated in Building 371. However, no grit blasting operation could be identified in that building.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates <1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is

recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: *Defense TRU Waste*

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.91E+02
Pu-240	8.01E+00
Pu-239	3.50E+01
Am-241	4.76E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	2.2	2.7	5.4
Totals	0.4	0.0	0.0	2.2	2.7	5.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 5.0 Total: 5.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 391 consists primarily of unpulverized sand and crucible generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771.

The unpulverized sand and crucible are generated from the separation of sand and crucible residues from the calcium fluoride slag following the removal of the plutonium metal button.

Unpulverized sand and crucible is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas

when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS

LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

Projected generation of this waste stream begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.91E+02
Pu-240	8.01E+00
Pu-239	3.50E+01
Am-241	4.76E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	2.2	2.7	5.4
Totals	0.4	0.0	0.0	2.2	2.7	5.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 5.0 Total: 5.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 392 consists of unseperated IDC 391 materials.

Unpulverized sand, slag, and crucible are placed in 4-liter, wide-mouthed, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The sand, slag, and crucible are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS

LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

Projected generation of this waste stream begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.91E+02
Pu-240	8.01E+00
Pu-239	3.50E+01
Am-241	4.76E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	11.2	0.0	0.0	62.2	75.9	149.3
Totals	11.2	0.0	0.0	62.2	75.9	149.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 11.2 Projected: 136.9 Total: 148.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 393 is produced in the Dissolution Process in Gloveboxes (Lines) 23 and 25 in Building 771. Pulverized sand, slag, and crucible from the Crushing Process is placed in a dissolution pot with heated nitric acid and aluminum nitrate. The solution (plutonium nitrate) is pulled by vacuum through an R-6 filter to remove undissolved solids.

The undissolved solids are sand, slag, and crucible heels that are dried on a hot plate and placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The residue sand, slag, and crucible heels are stored awaiting plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore,

	this waste exhibits the characteristic of reactivity (D003).
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	LDR_DETERM: Net and gross weight data are not available for all container types. RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel. Projected generation of this waste stream begins in CY2005.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: L1190

AS-GENERATED EPA CODES

D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

These wastes are aqueous acidic liquid residues.

WASTE STREAM SOURCE

IDC 400 is ion column feed (plutonium nitrate solution) with less than 5 g/l plutonium which is to be processed through Anion Exchange to remove any impurities. These solutions come from various aqueous recovery operations for purification of plutonium.

Dissolution in Building 771 dissolved high-impurity, low-plutonium content residues to recover plutonium. Cation Exchange in Building 771 processed chloride solutions (hydrochloric acid containing plutonium) from the laboratories in Buildings 371, 559, and 771.

Precipitation Feed Batching in Building 771 combined plutonium nitrate or ion column eluate and evaporator bottoms to achieve the desired plutonium concentration. The solutions (IDC 400) in which impurity concentrations were too high were sent for purification.

Reduction and Button Break-Out in Building 771 produced a purified plutonium metal product. In this process, the metal was pickled in a water bath to remove residual calcium. The resulting solution (IDC 400) was mostly water containing plutonium and elemental impurities.

Miscellaneous Residue Processing in Building 771 generated IDC 400 from sludge dissolution. Sludge from the process filter plenum was dissolved in heated nitric acid and drained through a filter resulting in nitrate solution (IDC 400). The heel that was formed on the filter was dried on a hot plate and also dissolved.

Spray Leach in Building 771 separated metal contaminant from plutonium metal. Certain parts were pretreated by soaking in nitric, hydrofluoric, or sulfuric acids. These acids and acid from the glovebox (GB) floor pick-up were then filtered.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation A

Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22.

Subpopulation H

These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals.

In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process.

This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 10/20/94

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

D007, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	13.0	15.9	29.1
Totals	0.2	0.0	0.0	13.0	15.9	29.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 28.7 Total: 28.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the ammericium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDC 409.

IDC 409 was formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 416.

RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

Projected generation of this waste form begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 10/20/94

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

D007, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	7.9	9.7	17.8
Totals	0.2	0.0	0.0	7.9	9.7	17.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 17.5 Total: 17.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Nonspecification plutonium metal, cast as an anode, was combined with and equimolar mixture of sodium chloride and potassium chloride in a magnesium oxide crucible. Magnesium chloride was then added to initiate the plutonium oxidation. The metal and salts were placed in a furnace and heated until molten. The molten mixture was stirred, and a current applied to the anode which flowed through the molten mixture to the cathode. Plutonium ions migrated from the molten anode through the molten salt to the cathode and were reduced to purified metal. After cooling, the crucible was broken and the salt, anode heel, and purified plutonium metal were separated. This process produced IDC 411 salts.

IDC 411 is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metals, and various plutonium compounds. These salts may contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. IDC 411 salt packaged for off-site shipment was assigned IDC 473.

RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

Projected generation of this waste form begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 10/20/94

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

D007, D003, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.2	0.2	0.8
Totals	0.4	0.0	0.0	0.2	0.2	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.4 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Impure metal was placed in a crucible with sodium chloride, potassium chloride, and zinc chloride. The crucible and contents were heated in a furnace until the contents were molten and the mixture was stirred. While molten, the zinc chloride reacted with the plutonium metal to form plutonium chloride and zinc metal. The contents separated into salt and metal products at process temperature. After cooling and breakout, the plutonium-rich salt phase was reloaded into a crucible along with calcium metal. The crucible and contents were heated in a furnace until the contents were molten and the mixture was stirred. While molten, the calcium reduced the plutonium chloride to plutonium metal. After cooling, the crucible was broken and the metal and salt were separated. This process produced IDC 412 salts.

IDC 412 is a Glyson salt which was generated by an experimental pyroredox process. The salt is composed primarily of sodium chloride, potassium chloride, calcium chloride, residual zinc chloride, entrained zinc and calcium metal, and various plutonium and americium compounds. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

Projected generation of this waste form begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 10/20/94

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.7	0.0	0.0	0.2	0.2	9.1
Totals	8.7	0.0	0.0	0.2	0.2	9.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 8.7 Projected: 0.4 Total: 9.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals. .

WASTE STREAM SOURCE

Calcined plutonium oxide was placed in a magnesium oxide crucible with calcium chloride and calcium metal. The crucible and contents were placed in a furnace and heated until the contents were molten. The molten material was stirred to initiate and promote the reduction of the plutonium oxide. After the reaction, the melt was allowed to separate into plutonium metal and salt phases. After cooling, the crucible was broken and separated from the salt, calcium, and plutonium metal. This process produced IDCs 365 and 414.

IDCs 365 and 414 are composed primarily of calcium chloride, calcium oxide, calcium metal entrained in the salt, and various plutonium compounds. A "button" of excess calcium may also be present in some containers of these salts. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

Projected generation of this waste form begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W057	Handling:	CH	NMVP #:	RF 122	Stream Name:	Insulation/TRM	Inventory Date:	10/20/94
Local ID:	IDC 438	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5129

AS-GENERATED EPA CODES

F009, F001, F002, F003, F005, F007, F039, F006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	91.7	1.9	353.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.8	0.0	9.6
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 122

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.48E+01
Pu-240	6.24E-01
Pu-239	2.73E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.9	1.4	6.5	7.2	16.4
Totals	0.4	0.9	1.4	6.5	7.2	16.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.9	1.4	6.5	7.2	16.4
Totals	0.4	0.9	1.4	6.5	7.2	16.4

As-Generated Form: Stored: 0.4 Projected: 15.8 Total: 16.2

Final Waste Form: Stored: 0.4 Projected: 15.8 Total: 16.2

WASTE STREAM DESCRIPTION

This waste stream is contaminated insulation.

WASTE STREAM SOURCE

Item Description Code 438

Maintenance, repair, and strip-out operations in Buildings 371, 374, 444, 559, 666, 707, 771, 774, 776, 777, 779, 865, 881, and 883 produced waste insulation. Insulation waste is generated by replacement of furnace heating elements, construction, maintenance, and demolition activities within the Protected Area at Rocky Flats. During these activities, insulation material is removed from furnaces, boilers, piping, ceilings and walls, and heating and cooling systems.

WEMS data indicate that insulation waste was generated in:

Building 374 Acid Neutralization, Radioactive Decontamination, Sludge Solidification, Evaporation, Spray Dryer and Saltcrete, and General Building Operations.

Building 444 Maintenance

Buildings 559 and 779 Utilities

Building 666 Drum Repack

Building 707 Foundry Operations-Module A, Casting-Module K, X-Y Retriever-Module J, Maintenance, and Modules A-H

Building 771, Maintenance and General Building Waste

Building 774 Microwave Process

Building 776 during the replacement of furnace heating elements.

Generated by construction and demolition activities.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 53D, IDC 438, was identified based on WEMS data, IDC, and discussion with generating personnel. The insulation in this subpopulation was used on pipes, walls, and other barriers and could have come in contact with listed constituents when leaks or spills occurred. According to the generator, the insulation was visibility contaminated with sludge and salt produced in Building 374. The D-codes currently assigned to containers in this subpopulation are not appropriate based on the volume of insulation relative to the amount of caked on sludge. The following EPA Codes were assigned to this waste: F001, F002, F003, F005, F006, F007, F009, and F039. This inventory was generated in Building 374.
Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums DOT 7A TYPE A; metal boxes.

FINAL FORM COMMENTS N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F009, F007, F006, F005, F003, F002, F001, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	15.0	0.8	38.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.0	0.8	38.8
Rubber:	7.4	0.3	19.4
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.4	0.1	11.9	14.4	27.4
Totals	0.6	0.4	0.1	11.9	14.4	27.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.4	0.1	11.9	14.4	27.4
Totals	0.6	0.4	0.1	11.9	14.4	27.4

As-Generated Form: Stored: 0.6 Projected: 26.6 Total: 27.2

Final Waste Form: Stored: 0.6 Projected: 26.6 Total: 27.2

WASTE STREAM DESCRIPTION

491 - Room air exhaust filters only. This waste must be collected in 55-gallon or 35-gallon drums for assay.

WASTE STREAM SOURCE

The material in this IDC is a variety of plenum prefilters used in the ventilation systems at Rocky Flats. Plenum prefilters have been and are used in all of the buildings that contain plutonium processing activities. These prefilters are used in large plenums that filter the room and glovebox air. Used prefilters were removed from their position in the ventilation system and packaged for furtehr processing.

IDC 491 plenum prefilters range from furnace-type filters to pleated fiberglass filters and can be as large as 24" x 24" x 12". The filter medium consists of fiberglass packing or paper which may be more or less dense, depending on filtering needs. Wire mesh can be used to hold the media in place. The frame material for these prefilters is cardboard.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 371 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W066	Handling: CH	NMVP #: N/A	Stream Name: Filters & media/TRM		Inventory Date: 10/20/94
Local ID: None	Type: MTRU	Generator Site: RF	Final Waste Form: Filter		Waste Matrix Code: S5410

AS-GENERATED EPA CODES

F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box /	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

492 - High efficiency particulate air filters, 24x24x12. All IDC 492 HEPA filters must be repackaged in size reduction. This waste form must be neutralized and changed to IDC 815.

WASTE STREAM SOURCE

The material in this IDC is HEPA filters in the ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large plenums that filter the room and glovebox air.

Used filters were removed from their position in the ventilation system and packaged for further processing. The larger-sized filters used in filters plenums were identified and packaged as IDC 492 if acid contaminated.

IDC 492 HEPA filters (24" x 24"), acid contaminated, are large HEPA filters (nominal 24" x 24" x 5" or 24" x 24" x 12") that were used in filter plenum racks. These filters consist of filter media contained within a wooden or metal frame.

RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F009, F007, F005, F003, F002, F001, D043, D040, D039, D038, D035, D028, D022, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D003, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	The Building 371 analytical laboratory receives liquid and solid samples from the entire plant site. Samples that are destined for Building 881 are analyzed in Building 371 to screen out those with high levels of radioactivity. Sludge and aqueous samples from Building 374 are analyzed for total alpha activity and plutonium, uranium, and americium content. Prior to analysis, the sludges are dissolved in nitric acid, hydrogen fluoride, or hydrochloric acid. Reagents are also used in sample preparation. Unused portions or excess prepared sample are placed in 4-liter plastic bottles. The Building 559 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various ions, iron, silicon, isotopic compaition, and americium, gallium, neptunium, plutonium, uranium, and other metals (Resource Conservation and Recoverey Act [RCRA] - regulated and nonregulated). Solid samples are dissolved in a variety of acids, including nitric and hydrochloric. Other chemicals used in the laboratory include methanol, chloroform, and other organic solvents; titanium trichloride; ceric ammonium nitrate; sodium hydroxide; silver chloride; silver nitrate; and various metals standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also place on the bottles. The Building 771 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various metals and ions, pH, and radioactivity. The principal chemicals used in the lab include sodium hydroxide, hydrochloric acid, nitric acid, cyclohexane, trioctyl phosphine oxide, yttrium, and various metal standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles. RE: Section 6.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	29.3	0.7	98.7
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	10.5	0.2	35.5
Solidified Inorganic Material:	26.3	0.6	88.6
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	17.5	0.4	59.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.77E+01
Pu-240	1.16E+00
Pu-239	5.08E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

IDC 823, cemented miscellaneous sludge, was generated when sludge designated as inorganic particulate and sludgy material that was below the economic discard limit (EDL) was placed in 1-gallon paint cans and covered with Portland cement or mixed with cement into a block. The first scenario was conducted in Building 771 and the second in Building 371. This could have included IDCs 290-299 and was done to meet the Waste Isolation Pilot Plant (WIPP) waste acdceptance criteria. The material came primarily from Nash pumps in Building 771 and included vacuum grease and oily sludge. One drum of the material was apparently generated when the pit in front of Building 707 was cleaned out. However, the contents of the pit sludge could not be ascertained. One drum was generated in the Size Reduction Vault in Building 776. Six drums were generated in Building 774 and are stored in Building 371. Drum-specifiec information was requested but was not received. The drums from Building 559 are incorrectly assigned IDC 823 in WEMS. The drums are stored in Building 771 and are labeled with IDC 863. It appears that IDC 823 was entered incorrectly in WEMS. Therefore, these drums should be changed to IDC 863 in WEMS.

RE: Section 8.2.11, RFETs doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, D&D, and limited Emergency Response actions.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	None	Stream Name:	Aqueous Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, D002, D001, F009, F007, F006, F005, F003, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	312.8	312.8	312.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	281.5	281.5	281.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	187.6	187.6	187.6
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 3.7 Projected: 0.0 Total: 3.7

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge. Re: Section 8.2.11. RFETS doesn't expect sulfates, phosphates >1% , but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR) treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous

sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based pirmarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W013	Handling:	CH	NMVP #:	N/A	Stream Name:	Solidified Organics/TRM	Inventory Date:	10/20/94
Local ID:	IDC 801	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3222

AS-GENERATED EPA CODES

F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	615.9	229.0	858.4
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	2.56E+01
Pu-240	1.08E-01
Pu-239	4.70E-01
Am-241	2.65E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION

This waste stream consists of a cemented solid, with some free liquids. It can also have some small chunks in it.

WASTE STREAM SOURCE

Solidified organics are cemented waste oils and solvents that were generated as a result of machining and tool degreasing. Waste oil was transferred primarily from Buildings 707 and 777. Cementation was performed in Waste Management Unit (WMU) 56, Room 210, Building 774. The earliest generation date for the backlog inventory is June 1984. The Organic and Sludge Immobilization System (OASIS) Process generating solidified organics stopped in January 1990. These containers are assigned IDC 0003 and 0801.

Solidified organics waste currently stored at Rocky Flats was generated by the Grease Plant Process or the OASIS Process. The Grease Plant Process operated until November 1985. The OASIS Process began operating in November 1985. The last OASIS runs occurred in 1991.

Tanks T-1 and T-2, Tank T-374A, and Tanks T-13 and T-14 have all received waste oils and solvents for treatment at various times. The waste oils and solvents were generated primarily by processes in Buildings 707 and 777. Solvent-contaminated waste oils were generated by plutonium machining and tool degreasing. Ultrasonic cleaners consisting of trichloroethane baths were used to clean parts. Buildings 707 and 777 also cleaned metal turnings and scrap in carbon tetrachloride baths before forming them into briquettes.

Laboratory wastes in bottles were poured into containers of solidified organics in the past. Laboratory waste contaminants included organophosphates and nitrobenzene. According to the generator, bottled laboratory wastes were poured into five or fewer solidified organics containers. However, there is no documentation specifying the individual drums.

The majority of wastes fed to the solidified organics generation processes consisted of plutonium-contaminated oils and solvents. A cutting oil, usually Texaco Regal "A," flowed onto a part during machining. After machining, the part was rinsed to remove residual oil. Various solvents were used to rinse machined parts and degrease tools. These included trichloroethylene and tetrachloroethylene. According to the generator, trichloroethylene and tetrachloroethylene use stopped in 1973.

Spent carbon tetrachloride and trichloroethane from cleaning baths were also fed to the solidified organics generation processes. Parts for assembly from Buildings 707 and 777 were cleaned in ultrasonic wash tanks before welding. The tanks contained 15 gallons of trichloroethane. In another cleaning process, metal turnings and scraps were placed into perforated metal baskets and dipped into a series of tanks containing carbon tetrachloride. Each of the steel tanks held 4 gallons of solvent. The cleaned metal was then formed into briquettes. Carbon tetrachloride and trichloroethane baths were replaced periodically.

Waste oil and solvents were drained and pumped into storage tanks. The wastes were then filtered to recover the actinides. After filtering, the plutonium and uranium concentrations in the waste were measured. If the concentrations were above specified transfer limits, the waste was refiltered in the Ful-Flo filtration system. When the concentrations of plutonium and uranium were below transfer limits, the waste was transferred to the solidified organics generation processes in Building 774.

Tanks T-1 and T-2, Tank T-374A, and Tanks T-13 and T-14 received waste oils from the same processes in Buildings 707 and 777. Tanks T-1 and T-2 fed waste oils to the Grease Plant Process and the OASIS Process. Tank T-374A began feeding waste oils to the OASIS Process after damage to Tanks T-1 and T-2 was identified and they were removed from operation. Tanks T-13 and T-14 began feeding waste oils after Tank T-374A. Tanks T-374A, T-13, and T-14 were used simultaneously until Tank T-374A was removed from operation. Tanks T-13 and T-14 continued feeding the OASIS Process until it stopped in January 1990.

In the Grease Plant Process, waste oil and Microcel E (calcium silicate) were fed separately into a continuous mixer. Small amounts of Oil Dri were sometimes added to the mixture as well. The amounts of materials added to the mixture were not metered. However, the operator would adjust the composition if the outgoing mixture did not have a paste-like consistency. The mixture would then drop into an O-ring bag contained in a 55-gallon drum. Drums of solidified organics from the Grease Plant Process were subsequently transported to the Size Reduction Facility in Building 776 for inspection and sealing.

OASIS was a batch-type process generating one drum per run. Waste oils were pumped into an O-ring bag contained in a 55-gallon drum attached to the bottom of the OASIS glovebox. Envirostone emulsifier, gypsum cement, and accelerator were also metered into the bag. House water, which had not been used in any other processes, was added to the mixture as well. A Lightning Mixer was lowered into the drum after all of the materials were added. The amount of materials added to the mixture was operator controlled.

The drums were transferred to WMU 73, Room 241, after they had been inspected and sealed. Solidified organics containers from the OASIS process were stored in Building 774 until they were transferred to Building 371 for nondestructive assay (NDA). After RTR, drums were usually sent to Building 664, where they were stored until shipment off site. Solidified organics waste is not being shipped at this time. Consequently, Building 664 has reached capacity and solidified organics are also being stored in Buildings 371, 569, 774, and 776.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Solidified organics were generated by the OASIS process after November 11, 1985.

Analytical information regarding solidified organics was not found in the WSRIC Sampling and Analysis database. However, non-WSRIC analytical data from 1988 and 1989 are considered in the characterization of the waste. The analytical method was not specified for the results. However, Toxicity Characteristic Leaching Procedure (TCLP) analysis was not typically performed in 1988 and 1989. The results are assumed to be from Totals analysis. Validated headpsace analysis performed on drums containing solidified organics are considered as well. Headspace analytical results support the 1988 and 1989 results from sampling and analysis.

Wastes received by Tanks T-1 and T-2, T-374A, and T-13 and T-14 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) organics. Carbon tetrachloride (D019), nitrobenzene (D036), and trichloroethylene (D040) were cited contaminants. Nitrobenzene was a contaminant in nonroutine laboratory waste and was introduced into five or fewer drums. Contaminated drums could be not be identified. However, the solidified organics population, as a whole, does not exhibit the toxicity characteristic for nitrobenzene.

Sampling and analysis of three solidified organics samples in 1988 and 1989 indicated the waste exceeded toxicity characteristic criteria for carbon tetrachloride (EPA Code D019). The waste did not exceed toxicity characteristic criteria for any of the other cited RCRA organics. TCLP analysis of the waste under EPA SW-846 is required to support the analytical results and confirm the assumptions.

Based on the "mixture" rule and the "derived-from" rule, solidified organics would carry the listed EPA codes associated with the wastes fed to the solidified organics generation processes. EPA Codes F001 and F002 are assigned to all solidified organics because wastes received by Tanks T-1 and T-2, T-374A, and T-13 and T-14 were contaminated with regulated spent solvents in the past.

Sampling and analysis of solidified organics waste in 1988 and 1989 indicated the waste exceeded the F001 and F002 LDR treatment standards for carbon tetrachloride and 1,1,1-trichloroethane. The analyses found detectable concentrations of other F001 and F002 constituents, as well. Total analysis of the waste under EPA SW-846 is required to confirm these results.

Based on the "mixture" rule and the "derived from" rule, solidified organics would carry the listed EPA codes associated with wastes set to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned because wastes set to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at elevated levels. Solidified organics will not be considered as meeting F001, F002, F003, and F005 Land Disposal restrictions (LDR) treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SE-846 is required.

The EPA Codes F006, F007, and F009 are assigned because of contamination with waste from electroplating operations.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to solidified organics. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste. Cited laboratory chemicals like nitrobenzene were used for their intended purpose as reagents and were not discarded commercial chemical products.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is stored in 55-gallon carbon steel drums with a rigid polyethylene liner and one or two bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	None	Stream Name:	Bypass Sludge Bldg 374/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, F005, F039, F009, F007, F006, F003, D010, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	217.7	217.7	217.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	196.0	196.0	196.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	130.6	130.6	130.6
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.8 Projected: 0.0 Total: 0.8

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge.

Re: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR)

treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower

than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based pirmarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W037	Handling:	CH	NMVP #:	RF 117	Stream Name:	Heavy Metal (non-SS)/TRM	Inventory Date:	10/20/94
Local ID:	IDC 320	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	60.5	0.0	168.7
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	141.0	29.0	393.3
Other Inorganic Material:	14.0	2.9	39.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	1.14E+02
Pu-240	4.79E+00
Pu-239	2.09E+01
Am-241	2.59E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.5	0.0	0.0	8.7	10.8	21.0
Totals	1.5	0.0	0.0	8.7	10.8	21.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	8.7	10.8	21.0
Totals	1.5	0.0	0.0	8.7	10.8	21.0

As-Generated Form: Stored: 1.5 Projected: 19.6 Total: 21.0

Final Waste Form: Stored: 1.5 Projected: 19.6 Total: 21.0

WASTE STREAM DESCRIPTION	IDC 320 - Scrap metals which are heavier than iron and steel. Metal above Cu on the periodic table. Mainly used tantalum crucibles. Does not include lead.
WASTE STREAM SOURCE	Heavy metals have been produced as by-products of Rocky Flats operations in Buildings 371, 707, 771, 776, 777, 779, and 865; they are identified by IDC 320. The IDC 320 heavy nonspecial source metal was generated in various locations throughout the Rocky Flats and is stored in Resource Conservation and Recovery Act (RCRA) Units 11, 12, 13, 15A, and 20. This IDC includes nonstainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987. IDC 320 originally incl:ded lead. During maintenance operations, the maintenance shop in Building 371 generated heavy metal vessels, instruments, rods, and plates fabricated from tantalum, tungsten, and platinum. The shop generated these items during 4 1/2 years of operation from 1983 until 1988. Of these containers in storage, 19 backlog containers have an EPA Code of D008 (lead); eight of these were produced after 1987. Building 707, Modules A and J, generated heavy metals in its foundry operations. These heavy metals were primarily crucibles and pans used for presampling. These processes generated material during 6 1/2 years of operation from 1985 until 1991. Nine backlog containers have an EPA Code of D008 (lead). The plutonium recovery operations in Building 771 generated leached Oralloy parts consisting of tantalum, tungsten, and platinum. The system generated material during 3 years of operation from 1987 until 1990. Five backlog containers have an EPA Code of D008 (lead); four of these backlog containers were produced after 1987. Building 776, Pyrochemical Processing, generated material during almost three years of operation from 1988 until 1990. This material consists primarily of tantalum crucibles, stirrers, and cans from MSE, salt scrub, and anode heel processes. Eight containers have an EPA Code of D008 (lead). Building 777, the Coatings Laboratory, generated material during a 2-year period of operation from 1988 until 1990. This material consists primarily of various heavy metals used in the research and development of coating technologies. These backlog containers have been associated with lead as a constituent and were produced after 1987. The Residue Treatment Technology Group, Building 779, generated crucibles, stirrers, and other general lab equipment derived from tantalum and tungsten. In Building 779, the Physical Metallurgy Group generated tantalum materials used in casting and cast testing. Additionally, the Surface Analysis Laboratory in Building 779 generated heavy metal samples primarily of depleted uranium (D-38). IDC 320 material was produced by Building 779 operations over a 10-year period from 1981 until 1991. Nine backlog containers have an EPA Code of D008 (lead), six were produced after 1987.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	One subpopulation (25A) was identified based on specific process knowledge and generation date. The EPA Code D008 was assigned to this subpopulation because of contact with known lead products and process association. This subpopulation consists of containers produced before or during 1987. The WEMS database lists the EPA Code D008 for these containers. Because of the generation date, a conservative position has been taken by placing backlog drums with the DOO8 (lead) EPA Code in this subpopulation. The primary buildings of generation were 371, 707, 771, 776, 779. Subpopulation 25B was identified based on specific process knowledge and generation date. At this time, the generation date has been used judiciously in separating and characterizing containers with lead. The EPA Code D008 was assigned to this subpopulation because of contact with known lead products and process association. This subpopulation consists of containers produced before or during 1987. The WEMS database lists the EPA Code D008 for these containers. Because of the generation date, a conservative position has been taken by placing backlog drums with the D008 (lead) EPA Code in this subpopulation. The primary buildings of generation were 371, 707, 771, 776, and 779.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. Future generation is projected beyond 1999.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W028	Handling:	CH	NMVP #:	RF 117	Stream Name:	Lead/TRM	Inventory Date:	10/20/94
Local ID:	IDC 321	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7211

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	668.3	16.2	1438.1
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.05E+00
Pu-240	1.28E-01
Pu-239	5.60E-01
Am-241	1.86E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.9	1.4	2.8	2.8	11.7
Totals	3.7	0.9	1.4	2.8	2.8	11.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.9	1.4	2.8	2.8	11.7
Totals	3.7	0.9	1.4	2.8	2.8	11.7

As-Generated Form: Stored: 3.7 Projected: 7.9 Total: 11.6

Final Waste Form: Stored: 3.7 Projected: 7.9 Total: 11.6

WASTE STREAM DESCRIPTION

This waste form consists of metallic lead in the form of sheets, bricks, or tape.

Physical form: solid

Currently, no analytical data for lead waste is available. Process knowledge is the basis for characterization of this waste form. Lead waste (IDC 321) from non-specific sources is believed to have only lead (D008) as a hazardous constituent. In numerous tests of elemental lead, EP toxicity values exceed those listed in Table 1, 40 CFR 261.24. It is assumed that IDC 321 would also exceed EP toxicity limits for lead.

WASTE STREAM SOURCE

Transuranic lead was generated at a number of locations throughout Rocky Flats and includes IDC 321. The as-low-as-reasonably- achievable (ALARA) principle requires that the exposure of workers to radiation be kept "as low as reasonable achievable." In support of this principle, selected components and surfaces of gloveboxes enclosing materials that generate elevated levels of penetrating radiation (primarily gamma radiation) are commonly covered with metallic lead sheeting. The lead serves to attenuate the radiation dose received by employees working in the glovebox or in proximity to the glovebox. Lead waste (IDC 321) components are generally composed of lead bricks, lead shielding, and lead tape.

The lead or lead-covered components may become waste due to replacement, modification, or decommissioning activities. The dates of generation for IDC 321 range from August 15, 1986 to March 1, 1994.

The lead waste form is not a by-product of any process routinely performed at Rocky Flats. According to WSRIC Building Books, lead is most commonly generated as a result of maintenance activities. The lead waste is generally composed of lead shielding, scrap lead metal, and lead tape. The lead waste is collected in standard waste drums. The lead waste form was generated in Buildings 371, 559, 707, 771, 776, 777, and 779.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Drums Containing Scrap Lead Metal and Lead Shielding

Scrap lead metal and lead shielding exhibit the characteristic of toxicity for lead (D008). Subpopulation 8A was identified based on specific process knowledge and analytical results from elemental lead waste. According to WEMS, WSRIC, drums reports, and internal correspondence, the waste primarily consists of lead bricks, lead shielding, and scrap lead metal. Although some of waste could have come in contact with solvents, it is not considered to be a listed waste if the metal was wiped down with solvents for decontamination or paint stripping purposes, or if it was generated by the decommissioning of gloveboxes or other container-like apparatuses. Additional EPA codes are assigned to the waste based on process knowledge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined this waste form to be LDR waste based on process knowledge available for TRU lead waste (IDC 321) and the fact that elemental lead exceeds values for EP toxicity pursuant to 40 CFR 261 24. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: This waste is packaged in 55-gallon drums lined with a fiberboard liner and two polyethylene bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles, dry/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	IDC 330 is Dry Combustibles. This IDC is dry combustibles such as cloth, paper, and wood. This IDC changes to 821, 831, 851, or 861 at the point of assay, depending on radiological content. Containers of IDC 330 currently in inventory were generated in all buildings handling fissile material. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible

Inventory Date: 10/20/94

Waste Matrix Code: S5390

AS-GENERATED EPA CODES

F002, F001, D019, D011, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This IDC changes to 822, 832, 852, or 862 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible

Inventory Date: 10/20/94

Waste Matrix Code: S5390

AS-GENERATED EPA CODES

F002, F001, D019, D011, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	IDC 337 represents PVC sheeting, poly bottles, supplied-air suits, polyethylene, and other plastics. IDC 337 changes to 825, 833, 853, or 863 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W029	Handling:	CH	NMVP #:	RF 123	Stream Name:	Leaded Dry Box Gloves/TRM	Inventory Date:	10/20/94
Local ID:	IDC 339	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D003, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	187.2	1.2	370.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	110.0	0.7	217.4
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 123

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.17E+01
Pu-240	9.13E-01
Pu-239	3.99E+00
Am-241	2.02E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	22.9	12.0	7.0	38.5	43.6	124.0
Totals	22.9	12.0	7.0	38.5	43.6	124.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	22.9	42.1	8.4	41.3	46.3	160.9
Totals	22.9	42.1	8.4	41.3	46.3	160.9

As-Generated Form: Stored: 22.9 Projected: 101.1 Total: 124.0

Final Waste Form: Stored: 22.9 Projected: 138.1 Total: 161.0

WASTE STREAM DESCRIPTION

This waste stream is a solid matrix consisting of gloves with lead lining. There could be some free liquids in waste containers.

WASTE STREAM SOURCE

Leaded glovebox gloves are generated as waste at Rocky Flats by processes requiring a controlled atmosphere in Buildings 371, 374, 559, 707, 771, 774, 776, 777, 778, and 779 and encompasses IDCs 339 and 341. Prior to January 22, 1986, all leaded glovebox gloves were accumulated together as IDC 339 (Leaded Glovebox Gloves). At that time, IDC 341 (Leaded Glovebox Gloves, Acid Contaminated) was created. IDC 339 became "Leaded Glovebox Gloves, Nonacid Contaminated." Leaded glovebox gloves are replaced by schedule or as needed.

All backlog leaded glovebox gloves (IDC 0339 and 0341) were washed in Building 776 until about September 1989, at which time the process was curtailed. The primary purpose of the washing process was to remove the accountable material; however, the acid from the acid-contaminated gloves (IDC 341) was removed as well. After the acid-contaminated gloves were washed, the IDC was changed from 341 to 339. The glove washing process was curtailed upon completion of the inventory of backlog gloves.

Due to degradation from contact with process materials during normal process operations and age, the leaded glovebox gloves are replaced according to schedule or as necessary. Nonacid-contaminated leaded glovebox gloves (IDC 339) are generated as waste or residue depending on the assay, in Buildings 371, 374, 559, 707, 771, 774, 776, 779. Acid contaminated leaded glovebox gloves (IDC 341) were washed in Building 776 after which they were assigned IDC 339.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

In addition to the reference documents and WEMS information, analytical data compiled by Rocky Flats were reviewed. This analytical information shows the presence of lead above the regulatory level stated in 6 CCR 1007-3, Section 261.24, in one sample, borderline in another, and well below the regulatory level in another.

Characterization is identified based on process knowledge. This population includes all IDC 339 nonacid contaminated gloves generated after the creation of IDC 341 (January 22, 1986). This population contains no acid-contaminated (IDC 341) gloves. This population exhibits the characteristic of toxicity for lead (D008). The primary buildings of generation were 371, 374, 559, 707, 771, 774, 776, 777, and 779.

One drum of IDC 339 gloves was generated before the creation of IDC 341 (January 22, 1986). Therefore, this drum could contain both acid- and nonacid-contaminated gloves.

Although numerous acids are used in aqueous processing, nitric is the acid of greatest concern because it dissolves the outer Hypalon layer of the gloves and reacts with the lead oxide layer to form lead nitrate and organic nitrate or nitro-organic compounds. These compounds are in very small quantities and do not cause the gloves to exhibit the characteristic of ignitability as outlined in 6 CCR 1007-3, Section 261.21. However, when dried, the compound decomposes violently at temperatures ranging from 60 to 130 degrees C. Also, the compound explodes when subjected to an impact load or when confined and ignited with a fuse. Unconfined, the compound burns violently when ignited with a spark. This drum is therefore assigned D003 for reactivity as outlined in 6 CCR 1007-3, Section 261.23 (a) (6).

Population 42A: Identified based on process knowledge, EPA codes, and generation dates. This population includes all IDC 339 nonacid contaminated gloves generated after the creation of IDC 341 (January 22, 1986). This population contains no acid-contaminated (IDC 341) gloves. This population exhibits the characteristic of toxicity for lead (D008). The primary buildings of generation were 371, 374, 559, 707, 771, 774, 776, 777, and 779.

Subpopulation 43B: This subpopulation includes all acid-contaminated leaded glove box gloves. As previously discussed, these gloves exhibit the characteristic of toxicity for lead (D008) and reactivity (D003). The primary buildings of generation were 371, 771, 777, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS	RFP has assumed this waste to be LDR based on the fact that lead is a RCRA listed waste exhibiting the characteristic of toxicity. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The gloves are packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.
FINAL FORM COMMENTS	Projections include generation from processing IDC 341 to IDC 339.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W041	Handling:	CH	NMVP #:	N/A	Stream Name:	Leaded Gloves-Acid Contaminated/TRM	Inventory Date:	10/20/94
Local ID:	IDC 341	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D008, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	2.91E+01
Pu-240	1.22E+00
Pu-239	5.34E+00
Am-241	7.94E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	26.2	0.0	0.0	0.0	0.0	26.2
Totals	26.2	0.0	0.0	0.0	0.0	26.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 26.2 Projected: 0.0 Total: 26.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

IDC No. 341. This waste stream consists of leaded rubber gloves used in the glovebox systems for plutonium recovery operations in Buildings 771 and 371. These gloves are contaminated with nitric acid and other acids when replaced and discarded as waste.

WASTE STREAM SOURCE

Leaded Glovebox Gloves

Waste Form/Item Description Code/Waste Form Code Background for the Leaded Glovebox Gloves Waste Form

Leaded glovebox gloves are generated as waste or residue at Rocky Flats by processes requiring a controlled atmosphere in Buildings 371, 374, 559, 707, 771, 774, 776, 777, 778, and 779 and encompasses IDCs 339 and 341. Prior to January 22, 1986, all leaded glovebox gloves were accumulated together as IDC 339 (Leaded Glovebox Gloves). At that time, IDC 341 (Leaded Glovebox Gloves, Acid Contaminated) was created. IDC 339 became "Leaded Glovebox Gloves, Nonacid Contaminated." Leaded glovebox gloves are replaced by schedule or as needed.

All backlog leaded glovebox gloves (IDC 0339 and 0341) were washed in Building 776 until about September 1989, at which time the process was curtailed. The primary purpose of the washing process was to remove the accountable material; however, the acid from the acid-contaminated gloves (IDC 341) was removed as well. After the acid-contaminated gloves were washed, the IDC was changed from 341 to 339. The glove washing process was curtailed upon completion of the inventory of backlog gloves.

Item Description Code 341

Acid-contaminated leaded glovebox gloves (IDC 341) are generated as waste or residue depending on the assay, in Buildings 371, 771, 777, and 779. Due to degradation from contact with process materials and age, the gloves are replaced according to schedule or as necessary. When acid-contaminated gloves (IDC 0341) were washed, the IDC was changed to 0339.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

In addition to the reference documents and WEMS information, analytical data compiled by Rocky Flats were reviewed. This analytical information shows the presence of lead above the regulatory level stated in 6 CCR 1007-3, Section 261.24, in one sample, borderline in another and well below the regulatory level in another.

Leaded glovebox gloves are manufactured with a lead oxide layer between two or more layers of neoprene-Hypalon, for shielding against penetrating radiation. The available analytical data were obtained from unused, 30-millimeter-thick gloves. Analytical data for the lead content of 50- and 80-millimeter-thick leaded gloves are not available. However, the lead content is assumed to be substantially higher than the 30-millimeter-thick gloves. Also, the lead from used gloves, degraded from contact with process materials, may leach more readily than from unused gloves.

Toxicity Characteristic Leaching Procedure (TCLP) metals by Inductively Coupled Plasma Emission Spectroscopy showed the lead above the regulatory limit. Other contaminants include acid and base solutions and listed solvents. Glovebox gloves used in processes that require listed solvents are not considered listed solvent wastes because the gloves do not retain solvents in the same way paper or cloth wipes do. Contact of the gloves with solvents is considered incidental contact. Therefore, the gloves are not subject to the mixture rule.

IDC 341 includes leaded gloves exposed to acids which have not been washed. Although numerous acids are used in aqueous processing, nitric is the acid of greatest concern because it dissolves the outer Hypalon layer of the gloves and reacts with the lead oxide layer to form lead nitrate and organic nitrate or nitro-organic compounds. These compounds are in very small quantities and do not cause the gloves to exhibit the characteristic of ignitability as outlined in 6 CCR 1007-3, Section 261.21. However, when dried, the compound decomposes violently at temperatures ranging from 60 to 130 degrees C. Also, the compound explodes when subjected to an impact load or when confined and ignited with a fuse. Unconfined, the compound burns violently when ignited with a spark. IDC 341 leaded gloves are therefore

assigned D003 for reactivity as outlined in 6 CCR 1007-3, Section 261.23 (a)(6).

This subpopulation includes all IDC 341 acid-contaminated leaded glovebox gloves. As previously discussed, IDC 341 gloves exhibit the characteristic of toxicity for lead (D008), and reactivity (D003). The primary buildings of generation were 371, 771, 777, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that leaded gloves and acid-contaminated leaded gloves are LDR waste based on the process knowledge available. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W008	Handling:	CH	NMVP #:	RF 121	Stream Name:	Soil & Cleanup Debris/TRM	Inventory Date:	10/20/94
Local ID:	IDC 374	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5190

AS-GENERATED EPA CODES

F001, F002, F006, F009, F003, F005, F007, F039, D006, D007, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	273.1	208.9	628.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.0	12.0	12.0
Rubber:	0.0	0.0	0.0
Plastics:	12.0	12.0	12.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	64.9	9.6	628.4
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

RF 121

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	3.30E+00
Pu-240	1.39E-01
Pu-239	6.06E-01
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 1.2 Projected: 0.0 Total: 1.2

WASTE STREAM DESCRIPTION

This waste consists of blacktop/concrete/dirt/sand.

WASTE STREAM SOURCE

Soil and cleanup-debris (IDC 374) were generated during cleanup and construction activities around Rocky Flats. In most cases, construction or demolition activities generated rubble consisting of blacktop, concrete, dirt, sand , and rock. The rubble was packaged in plywood boxes with a fiberboard liner and a polyvinyl chloride (PVC) bag liner or in 55-gallon, DOT Type 7A drups. The waste was generated on a nonroutine basis. Information describing spendid activities generating soil and debris were often unavailable.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 23B-Container Number D48510

Drum D48510 was generated in Building 374, Room 3803. Room 3803 houses part of the Building 374 Sludge Immobilization Process. The process generated solidified sludge. The waste in drum D48510 is potentially contaminated with process sludge. The sludge consists of RCRA-regulated materials from Decontamination-Precipitation and Neutralization Processes in the Building 374 Liquid Waste Treatment Facility. Building 374 solidified sludge is characterized in the Building 374 Solidified Sludge Backlog Baseline Book.

Building 374 sludge was intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Sampling and analysis of solidified sludge found the waste exceeded toxicity characteristic criteria for chromium (EPA Code D007) and selenium (D010) but at very low levels. It will be assumed that the waste contained in drum D48510 would not exhibit the characteristic of toxicity for chromium and selenium because of dilution by the soil and debris. Toxicity Characteristic Leaching Procedure (TCLP) analysis of the waste under EPA SW-846 is required to prove the waste does not exceed toxicity characteristic criteria.

Contaminated soil and cleanup debris must also carry the listed EPA codes associated with Building 374 solidified sludge. The EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 are assigned to the waste and it will not be considered as meeting the Land Disposal Restrictions (LDR) treatment standards until sampling and analysis proves otherwise.

Subpopulation 23D-Container Number D75005

WEMS indicates drum D75005 was generated in Building 776. However, the waste was repackaged in Building 776 in April 1988 after a failed drum containing the waste was discovered in the Property Utilization and Disposal storage yard.

The drum contains soil and two sample vials of chromium oxide and aluminum oxide. It will be assumed that the waste contained in drum D75005 exhibits the characteristic of toxicity for chromium (D007) because of chromium oxide contamination. TCLP analysis of the waste under EPA SW-846 is required to prove the waste does not exceed toxicity characteristic criteria.

Subpopulation 23E-Soil and Asphalt from the 750 and 904 Pads Earth Anchor Installation

The installation of earth anchors for the 750 and 904 Pads in 1990 and 1991 generated a large amount of soil and asphalt. The waste was packaged in half-boxes with the generation prefix 788. Some of the half-boxes were rejects but were used because the waste was expected to remain in the reject containers for a short time before remediation activities began. During remediation of the pads, containers of soil and debris were to be emptied and the waste treated. These activities never occurred and the waste is still in the rejected containers.

The soil and debris may have been contaminated with pondcrete and saltcrete waste stored in the pad areas. The work procedure required that EPA codes associated with pondcrete and saltcrete be assigned to the soil and debris. An explanation of codes applicable to pondcrete and salcrete is provided in the Pondcrete Backlog Baseline Book and the Saltcrete Backlog Baseline Book.

Pondcrete and saltcrete were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Sampling and analysis of saltcrete found the waste did not exhibit a characteristic for RCRA metals. Sampling and analysis of pondcrete found the waste exceeded toxicity characteristic criteria for cadmium (EPA Code D006) and chromium (EPA Code D007) but at very low levels. It is assumed that the soil and debris from the earth anchor installation does not exhibit the characteristic of toxicity.for cadmium and chromium because of dilution by the soil and debris. TCLP analysis of the waste under EPA SW-846 (EPA 1990) is required to prove the waste does not exceed toxicity characteristic criteria.

Contaminated soil and debris from the earth anchor installation must carry the listed EPA codes associated with pondcrete and saltcrete. The EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 are assigned to the waste and it will not be considered as meeting the LDR treatment standards until sampling and analysis proves otherwise.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

GENERAAREA: Plutonium process areas. GENOPERATION: Generated in multiple buildings in which aqueous plutonium recovery or plutonium fabrication processes were conducted. RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed. CATION: Not Applicabe. OTHER_CHAR: Not Applicable.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon carbon steel DOT 7A Type A Drum.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W026	Handling:	CH	NMVP #:	RF 122	Stream Name:	Used Absorbents/TRM	Inventory Date:	10/20/94
Local ID:	IDC 375	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3114

AS-GENERATED EPA CODES

F002, D019, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	167.3	167.3	167.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	7.7	7.7	7.7
Solidified Organic Material:	7.7	7.7	7.7
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 122

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	8.32E-01
Pu-240	3.24E-02
Pu-239	1.42E-01
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste form is vermiculite with absorbed organic liquid.
WASTE STREAM SOURCE	This waste stream was previously named "Spent Absorbent/TRU (Oil Dri)". This waste stream was not specifically identified in the Storage or Inventory Report prepared by RFP in fulfillment of FFCA requirements. This waste is the TRU fraction of the waste titled "Oil Dri/LLW Mixed" in the Inventory Report. Normally it is LLW, but occasionally some assays as TRU. This waste stream is IDC No. 375 Absorbents, usually vermiculite materials, which are used in the plutonium and uranium process areas for cleanup of hazardous liquid spills (spent solvents), oil absorption, or absorption of any liquids as needed. One of the most commonly used absorbents is Oil Dri(R). Spent absorbents are assumed to be radiologically contaminated. The waste is packaged in 55-gallon drums lined with two polyethylene bags. IDC 375 - Any type of absorbent vermiculite material. Mixed waste. Oil Dri is an absorbent vermiculite material.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	No sample analysis of this material has been performed. Characterization is based on process knowledge. Subpopulation 18C This single drum, D72372, is in Subpopulation 18C. Based on process knowledge information on this drum and the use of carbon tetrachloride and Freon TF in Building 707, Module C, shown in WSRIC, this drum's contents are considered to be RCRA hazardous. It is further assumed that the contents exhibit the characteristic of toxicity for carbon tetrachloride; therefore, EPA Code D019 is assigned. EPA codes have also been assigned for the F-listed solvents. The CCC for this drum is 1020. No analytical data are available for this subpopulation.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP has assumed this waste to be LDR based on process knowledge characterization and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: This waste is packaged in a 55 gallon carbon steel drum.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	RF 122	Stream Name:	Firebrick, coarse/TRM	Inventory Date:	10/20/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	71.2	30.4	180.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	19.6	8.4	49.7
Rubber:	13.0	5.5	32.9
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 122

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	2.85E+01
Pu-240	1.20E+00
Pu-239	5.24E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.5	0.0	0.0	0.0	0.0	3.5
Totals	3.5	0.0	0.0	0.0	0.0	3.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	0.0	0.0	0.0	0.0	3.5
Totals	3.5	0.0	0.0	0.0	0.0	3.5

As-Generated Form: Stored: 3.5 Projected: 0.0 Total: 3.5

Final Waste Form: Stored: 3.5 Projected: 0.0 Total: 3.5

WASTE STREAM DESCRIPTION	This waste form is firebrick that has been crushed and pulverized.
WASTE STREAM SOURCE	During maintenance operations, pulverized scarfed firebrick was generated in Building 771. This material was also generated during incinerator stripout operations in Building 371. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Pulverized firebrick consists of chunks granular, fine, and very fine, plutonium-bearing surface layer of the high-density alumina ceramic firebrick material. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulations IK, IL, IM, IN EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational. A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Net and gross weight data are not available for all container types. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner. Projected future generation begins in CY2005.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick, pulverized or fines/TRM
Local ID:	IDC 377,378,373,3	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.85E+01
Pu-240	1.20E+00
Pu-239	5.24E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form is firebrick that has been crushed and pulverized.
WASTE STREAM SOURCE	During maintenance operations, pulverized scarfed firebrick was generated in Building 771. This material was also generated during incinerator stripout operations in Building 371. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Pulverized firebrick consists of chunks granular, fine, and very fine, plutonium-bearing surface layer of the high-density alumina ceramic firebrick material. The current inventory contains 45 drums mixed transuranic waste and residues. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulations IK, IL, IM, IN EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational. A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Net and gross weight data are not available for all container types. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	incinerator ash/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	4.08E+01
Pu-240	1.72E+00
Pu-239	7.49E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771, Fluidized Bed Incinerator (FBI) in Building 776, and test runs by the incinerator in Building 371.

The Low-Specific Activity (LSA) and High-Specific Activity (HSA) incinerators in Building 371 were developed as volume-reduction incinerators. The startup operation test used noncontaminated materials throughout the processes. The test revealed design concerns; therefore, these incinerators never became operational. No WSRIC information is available to describe this process in greater detail.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

Item Description Code 420, Pulverized Incinerator Ash

Pulverized incinerator ash was generated as an intermediate product during routine operation of the incinerator in Building 771. This material was also generated during incinerator stripout operations in Building 371. The pulverized ash consists of a mixture of coarse, granular, fine, and very fine particulates that have been ground by the ball mill. The ash contains miscellaneous tramp metal, bits of unburned feed material, and carbon from the incomplete oxidation of feed material.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	incinerator ash/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: S3111

AS-GENERATED EPA CODES

D007, F005, F003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.08E+01
Pu-240	1.72E+00
Pu-239	7.49E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Fluidized Bed Incinerator (FBI) in Building 776.

The FBIs in Building 776 were developed as pilot operations. Their test function was to develop new technology to reduce volume and destroy volatile constituents prior to plutonium recovery operations. The only incinerator to generate backlog waste covered by this waste form was the Full-Scale Unit. The first runs of this incinerator (1978 to 1981) used newspaper, Building 776 low-level waste (LLW), combustible waste, kerosene, garage oil, and grease as test materials. The tests were conducted with methanol, diesel products, and nonradioactive surrogate combustibles (shredded coveralls, leather gloves, rolls of polyvinyl chloride [PVC] plastic, wood, and paper). The by-product of this process was FBI ash (IDC 425).

Item Description Code 425, Fluidized Bed Ash

This waste is a mixture of aluminum oxide and a chromium oxide oxidation catalyst, sodium carbonate, and ash, mainly catalyst and sodium carbonate ash from Building 776. During the incineration of materials containing chloride compounds, a portion of the sodium carbonate changes to sodium chloride.

The Pilot-Scale FBI Unit was operated from 1971 to 1978. The first runs used PVC, polyethylene, and paper as test materials. After 1974, paint thinner from the Building 333 paint shop, tributyl phosphate, kerosene, and hydrazine hydrate were burned. Polychlorinated biphenyls (PCBs), mixed 1 part PCB to 4-5 parts diesel fuel or kerosene were burned in 1978. Unless containers of backlog waste were generated during maintenance operations of the Pilot-Scale Unit, all containers in the current inventory were generated after 1978 and are assumed to be from the Full-Scale Unit. Though the Pilot-Scale Unit burned PCBs, the ash is not Toxic Substance Control Act (TSCA) regulated. The incinerator burned at a high destruction efficiency and PCBs over the TSCA regulatory limit of 50 parts per million (ppm) are not anticipated in the ash.

The Full-Scale Unit was operated from 1978 to 1981, and again from 1985 to 1988. The first runs (1978 to 1981) used newspaper, Building 776 LLW, combustible waste, kerosene, garage oil, and grease as test materials. The tests from 1985 to 1988 were conducted with methanol, diesel products, and nonradioactive surrogate combustibles (shredded coveralls, leather gloves, rolls of PVC plastic, wood, and paper).

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes

D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W052	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

D009, D008, D005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	2.0	0.0	5.3
Other Inorganic Material:	136.8	16.8	352.5
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	1.2	0.0	3.1
Plastics:	30.3	3.7	78.1
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	138.7		
Packaging Material Plastic:	34.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.75E+00
Pu-240	2.83E-01
Pu-239	1.28E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	8.3	10.7	22.8	21.9	67.4
Standard waste box /	1.9	4.0	5.2	11.2	11.8	34.0
Totals	5.6	12.3	15.9	33.9	33.7	101.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	8.3	10.7	22.8	21.9	67.4
Standard Waste Box	1.9	4.0	5.2	11.2	11.8	34.0
Totals	5.6	12.3	15.9	33.9	33.7	101.4

As-Generated Form: Stored: 5.6 Projected: 95.8 Total: 101.4

Final Waste Form: Stored: 5.6 Projected: 95.8 Total: 101.4

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 440 includes glass waste from analytical laboratories and recovery processes, standard light bulbs generated inside the PA, and ceramic materials. Glass waste assigned IDC 440 was generated in Buildings 123,371, 444, 559, 707, 771, 776, 777, 889. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data. This waste stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Item Description Code 440 This IDC was separated from IDC 444 (created in 1989 specifically for ground glass and leaded glass) because the two waste forms exhibit different chemical characteristics, hazardous constituents, and EPA codes. Therefore, drums of IDC 440 materials generated prior to 1989 could contain leaded glass. These are included in Subpopulation 17G and are assigned EPA codes D005 and D008. Item Description Code 442 In addition to the reference documents and WEMs information used, analytical data compiled by EG&G Rocky Flats were reviewed. The data shows that the concentrations of Toxicity Characteristic (TC) metals barium, cadmium, chromium, lead, and silver were well below regulated levels provided in 6 CCR 1007-3, Section 261.24. Subpopulation 17F includes Raschig Rings assigned IDC 442 that are contaminated with carbon tetrachloride, 1,1,1-trichloroethane, or both. Based on analytical data, Raschig Rings do not exhibit the characteristic of toxicity for metals. All containers in this group were generated in Building 777 according to WEMS. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. Therefore, it is assumed that these rings are all contaminated with carbon tetrachloride or 1,1,1-trichloroethane sludge. They are, therefore, assigned EPA Waste Codes F001 and F002. Subpopulation 27B is assigned EPA code D009 because of mercury in the spent fluorescent lamps.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP has determined that this grouping is LDR waste based on available process knowledge with some of the IDCs identified containing listed hazardous components. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of is generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: DOT 7A TYPE A metal boxes and DOT 7A TYPE A drums.
FINAL FORM COMMENTS	Assuming 67% of projected generation will be in 55-gallon drums based on current container inventory.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W052	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.7	0.0	24.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	250.8	19.1	415.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.6	0.0	12.6
Rubber:	0.0	0.0	0.0
Plastics:	8.7	0.6	14.5
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	6.75E+00
Pu-240	2.83E-01
Pu-239	1.28E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.7	21.7	28.0	59.6	59.0	174.9
Totals	6.7	21.7	28.0	59.6	59.0	174.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.7	20.4	28.0	59.6	59.0	173.6
Totals	6.7	20.4	28.0	59.6	59.0	173.6

As-Generated Form: Stored: 6.7 Projected: 168.3 Total: 174.9

Final Waste Form: Stored: 6.7 Projected: 168.3 Total: 174.9

WASTE STREAM DESCRIPTION

This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.

WASTE STREAM SOURCE

Raschig Rings currently in WEMS assigned IDC 442 were generated in Buildings 771, 776, and 777. Prior to being replaced, the tanks were drained and the rings were leached with dilute nitric acid or water. The rings generated in Building 771 are from the production processes and Tanks D80-65, d0-360, D-361, D-451, D-454, D-467, D-750, D-706, D-922, D-973, D-974, D-980, D-1008, D-1013, D-1022, and D-1081. Rings generated in Building 776 are from the Size Reduction Process and Tanks SR 3, 4, and 5 and as unused rings. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. The building 777 rings should be assigned IDC 443 as discussed in the following section.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Item Description Code 440

This IDC was separated from IDC 444 (created in 1989 specifically for ground glass and leaded glass) because the two waste forms exhibit different chemical characteristics, hazardous constituents, and EPA codes. Therefore, drums of IDC 440 materials generated prior to 1989 could contain leaded glass. These are included in Subpopulation 17G and are assigned EPA codes D005 and D008.

Item Description Code 442

In addition to the reference documents and WEMs information used, analytical data compiled by EG&G Rocky Flats were reviewed. The data shows that the concentrations of Toxicity Characteristic (TC) metals barium, cadmium, chromium, lead, and silver were well below regulated levels provided in 6 CCR 1007-3, Section 261.24.

Subpopulation 17F includes Raschig Rings assigned IDC 442 that are contaminated with carbon tetrachloride, 1,1,1-trichloroethane, or both. Based on analytical data, Raschig Rings do not exhibit the characteristic of toxicity for metals. All containers in this group were generated in Building 777 according to WEMS. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. Therefore, it is assumed that these rings are all contaminated with carbon tetrachloride or 1,1,1-trichloroethane sludge. They are, therefore, assigned EPA Waste Codes F001 and F002.

Subpopulation 27B is assigned EPA code D009 because of mercury in the spent fluorescent lamps.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that this grouping is LDR waste based on available process knowledge with some of the IDCs identified containing listed hazardous components. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of is generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: DOT 7A TYPE A metal boxes and DOT 7A TYPE A drums.

FINAL FORM COMMENTS N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W032	Handling:	CH	NMVP #:	RF 118	Stream Name:	Ground Leaded Glass/TRM	Inventory Date:	10/20/94
Local ID:	IDC 444, 855	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

D008, D005, D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	135.5	61.3	193.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.1	1.1	1.1
Rubber:	1.1	1.1	1.1
Plastics:	19.8	19.8	19.8
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	130.9		
Packaging Material Plastic:	8.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.33E+00
Pu-240	5.61E-02
Pu-239	2.45E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.1	0.1	0.3	0.3	1.7
metal box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Standard waste box /	1.9	0.3	0.3	0.7	0.6	3.8
Totals	5.9	0.4	0.5	1.0	0.9	8.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.1	0.1	0.3	0.3	1.7
Standard Waste Box	1.9	1.1	1.3	2.6	2.5	9.4
Totals	2.7	1.2	1.5	2.9	2.8	11.1

As-Generated Form: Stored: 5.9 Projected: 2.7 Total: 8.6

Final Waste Form: Stored: 2.7 Projected: 8.4 Total: 11.1

WASTE STREAM DESCRIPTION	Matrix consits of crushed glass light bulbs and leaded glass that is crushed on removal.
WASTE STREAM SOURCE	IDC 444 includes ground fluorescent bulbs and leaded glass used throughout the plutonium-and-uranium-processing areas. The material was generated as waste or residue when glovebox glass was replaced, or as low-level waste when fluorescent light bulbs were replaced. IDC 444 materials in the backlog inventory were generated in Building 371, 374, 559, 707, 771, and 776. This stream is generated from Facilities Operations, Analytical Laboratories, and R&D Laboratories. Re: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt% but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Analytical data showed the presence of toxic metals in some containers of IDC 444. Based on these analytical data, these materials are characterized as hazardous and assigned EPA codes D005 and D008. Analytical data for IDC 855 show that there are enough cases where the samples fail the Toxicity Characteristic Leaching Procedure (TCLP), that the waste bulbs should be managed as hazardous waste and assigned the EPA code D009. EPA codes are assigned to newly generated waste by the generator based on process knowledge. Subpopulation 17G includes containers of leaded glovebox glass. Based on analytical data, these materials are characterized as hazardous and assigned EPA Waste Codes.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	LDR_DETERM: Net and gross weight data are not available for all container types. RFP has assumed this waste to be LDR based on the fact that it is a RCRA listed waste. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The glass waste is packaged in 55- gallon drums that are lined with one fiberboard liner and two polyethylene bags or metal boxes. Drums are placed in TRUPACT II containers.
FINAL FORM COMMENTS	Assuming 13% of projected generation will be 55-gallon drums based on current inventory.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W011	Handling:	CH	NMVP #:	RF 117	Stream Name:	LIGHT METAL/TRM	Inventory Date:	10/20/94
Local ID:	IDC 480	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

D007, D002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	160.4	1.7	488.7
Aluminum-base Metal/Alloys:	20.2	0.2	61.6
Other Metals/Alloys:	7.6	0.0	23.3
Other Inorganic Material:	13.4	0.1	40.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.5	0.0	7.6
Rubber:	2.9	0.0	8.9
Plastics:	21.2	0.2	64.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.10E+01
Pu-240	4.64E-01
Pu-239	2.03E+00
Am-241	1.84E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	34.4	14.9	155.8	95.2	300.6
Totals	0.2	34.4	14.9	155.8	95.2	300.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	34.4	14.9	155.8	95.2	300.6
Totals	0.2	34.4	14.9	155.8	95.2	300.6

As-Generated Form: Stored: 0.2 Projected: 300.4 Total: 300.6

Final Waste Form: Stored: 0.2 Projected: 300.4 Total: 300.6

WASTE STREAM DESCRIPTION	This waste stream is metal tools, etc. generated during glovebox operations.
WASTE STREAM SOURCE	The one container of IDC 480, Light metal, in this waste form was generated in Building 707, Module K, in April 1991. The metal in this container is line generated material.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed. RFP has assumed this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and several bag liners.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W090	Handling:	CH	NMVP #:	N/A	Stream Name:	Excess Chemicals/TRM
Local ID:	0544	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: X6900

AS-GENERATED EPA CODES

D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is lab packs and excess chemicals that are generated throughout Rocky Flats.
WASTE STREAM SOURCE	RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based on general knowledge of the waste type or source.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	RF 111	Stream Name:	Solidified Sludge - Bldg 774 / TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, F005, F009, F007, F006, F003, D040, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	387.6	44.3	528.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	193.8	22.2	264.1
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	193.8	22.1	264.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 111

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	65.5	1.3	2.5	25.8	9.7	104.8
Totals	65.5	1.3	2.5	25.8	9.7	104.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	65.5	1.3	2.5	25.8	9.7	104.8
Totals	65.5	1.3	2.5	25.8	9.7	104.8

As-Generated Form: Stored: 65.5 Projected: 38.9 Total: 104.4

Final Waste Form: Stored: 65.5 Projected: 38.9 Total: 104.4

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge.

Re: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR)

treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower

than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based pirmarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W013	Handling:	CH	NMVP #:	RF 112	Stream Name:	Solidified Organics - Bldg 774/TRM	Inventory Date:	10/20/94
Local ID:	IDC 801	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3222

AS-GENERATED EPA CODES

D040, F006, F005, F003, F001, F009, D019, D011, D010, D009, D008, D007, D006, D005, D004, F007, F002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	987.1	367.1	1375.6
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 112

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.56E+01
Pu-240	1.08E-01
Pu-239	4.70E-01
Am-241	2.65E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	109.0	0.0	0.0	0.0	0.0	109.0
Totals	109.0	0.0	0.0	0.0	0.0	109.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	109.0	0.0	0.0	0.0	0.0	109.0
Totals	109.0	0.0	0.0	0.0	0.0	109.0

As-Generated Form: Stored: 109.0 Projected: 0.0 Total: 109.0

Final Waste Form: Stored: 109.0 Projected: 0.0 Total: 109.0

WASTE STREAM DESCRIPTION

This waste stream consists of a cemented solid, with some free liquids. It can also have some small chunks in it.

WASTE STREAM SOURCE

Solidified organics are cemented waste oils and solvents that were generated as a result of machining and tool degreasing. Waste oil was transferred primarily from Buildings 707 and 777. Cementation was performed in Waste Management Unit (WMU) 56, Room 210, Building 774. The earliest generation date for the backlog inventory is June 1984. The Organic and Sludge Immobilization System (OASIS) Process generating solidified organics stopped in January 1990. These containers are assigned IDC 0003 and 0801.

Solidified organics waste currently stored at Rocky Flats was generated by the Grease Plant Process or the OASIS Process. The Grease Plant Process operated until November 1985. The OASIS Process began operating in November 1985. The last OASIS runs occurred in 1991.

Tanks T-1 and T-2, Tank T-374A, and Tanks T-13 and T-14 have all received waste oils and solvents for treatment at various times. The waste oils and solvents were generated primarily by processes in Buildings 707 and 777. Solvent-contaminated waste oils were generated by plutonium machining and tool degreasing. Ultrasonic cleaners consisting of trichloroethane baths were used to clean parts. Buildings 707 and 777 also cleaned metal turnings and scrap in carbon tetrachloride baths before forming them into briquettes.

Laboratory wastes in bottles were poured into containers of solidified organics in the past. Laboratory waste contaminants included organophosphates and nitrobenzene. According to the generator, bottled laboratory wastes were poured into five or fewer solidified organics containers. However, there is no documentation specifying the individual drums.

The majority of wastes fed to the solidified organics generation processes consisted of plutonium-contaminated oils and solvents. A cutting oil, usually Texaco Regal "A," flowed onto a part during machining. After machining, the part was rinsed to remove residual oil. Various solvents were used to rinse machined parts and degrease tools. These included trichloroethylene and tetrachloroethylene. According to the generator, trichloroethylene and tetrachloroethylene use stopped in 1973.

Spent carbon tetrachloride and trichloroethane from cleaning baths were also fed to the solidified organics generation processes. Parts for assembly from Buildings 707 and 777 were cleaned in ultrasonic wash tanks before welding. The tanks contained 15 gallons of trichloroethane. In another cleaning process, metal turnings and scraps were placed into perforated metal baskets and dipped into a series of tanks containing carbon tetrachloride. Each of the steel tanks held 4 gallons of solvent. The cleaned metal was then formed into briquettes. Carbon tetrachloride and trichloroethane baths were replaced periodically.

Waste oil and solvents were drained and pumped into storage tanks. The wastes were then filtered to recover the actinides. After filtering, the plutonium and uranium concentrations in the waste were measured. If the concentrations were above specified transfer limits, the waste was refiltered in the Ful-Flo filtration system. When the concentrations of plutonium and uranium were below transfer limits, the waste was transferred to the solidified organics generation processes in Building 774.

Tanks T-1 and T-2, Tank T-374A, and Tanks T-13 and T-14 received waste oils from the same processes in Buildings 707 and 777. Tanks T-1 and T-2 fed waste oils to the Grease Plant Process and the OASIS Process. Tank T-374A began feeding waste oils to the OASIS Process after damage to Tanks T-1 and T-2 was identified and they were removed from operation. Tanks T-13 and T-14 began feeding waste oils after Tank T-374A. Tanks T-374A, T-13, and T-14 were used simultaneously until Tank T-374A was removed from operation. Tanks T-13 and T-14 continued feeding the OASIS Process until it stopped in January 1990.

In the Grease Plant Process, waste oil and Microcel E (calcium silicate) were fed separately into a continuous mixer. Small amounts of Oil Dri were sometimes added to the mixture as well. The amounts of materials added to the mixture were not metered. However, the operator would adjust the composition if the outgoing mixture did not have a paste-like consistency. The mixture would then drop into an O-ring bag contained in a 55-gallon drum. Drums of solidified organics from the Grease Plant Process were subsequently transported to the Size Reduction Facility in Building 776 for inspection and sealing.

OASIS was a batch-type process generating one drum per run. Waste oils were pumped into an O-ring bag contained in a 55-gallon drum attached to the bottom of the OASIS glovebox. Envirostone emulsifier, gypsum cement, and accelerator were also metered into the bag. House water, which had not been used in any other processes, was added to the mixture as well. A Lightning Mixer was lowered into the drum after all of the materials were added. The amount of materials added to the mixture was operator controlled.

The drums were transferred to WMU 73, Room 241, after they had been inspected and sealed. Solidified organics containers from the OASIS process were stored in Building 774 until they were transferred to Building 371 for nondestructive assay (NDA). After RTR, drums were usually sent to Building 664, where they were stored until shipment off site. Solidified organics waste is not being shipped at this time. Consequently, Building 664 has reached capacity and solidified organics are also being stored in Buildings 371, 569, 774, and 776.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Solidified organics were generated by the OASIS process after November 11, 1985.

Analytical information regarding solidified organics was not found in the WSRIC Sampling and Analysis database. However, non-WSRIC analytical data from 1988 and 1989 are considered in the characterization of the waste. The analytical method was not specified for the results. However, Toxicity Characteristic Leaching Procedure (TCLP) analysis was not typically performed in 1988 and 1989. The results are assumed to be from Totals analysis. Validated headpsace analysis performed on drums containing solidified organics are considered as well. Headspace analytical results support the 1988 and 1989 results from sampling and analysis.

Wastes received by Tanks T-1 and T-2, T-374A, and T-13 and T-14 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) organics. Carbon tetrachloride (D019), nitrobenzene (D036), and trichloroethylene (D040) were cited contaminants. Nitrobenzene was a contaminant in nonroutine laboratory waste and was introduced into five or fewer drums. Contaminated drums could be not be identified. However, the solidified organics population, as a whole, does not exhibit the toxicity characteristic for nitrobenzene.

Sampling and analysis of three solidified organics samples in 1988 and 1989 indicated the waste exceeded toxicity characteristic criteria for carbon tetrachloride (EPA Code D019). The waste did not exceed toxicity characteristic criteria for any of the other cited RCRA organics. TCLP analysis of the waste under EPA SW-846 is required to support the analytical results and confirm the assumptions.

Based on the "mixture" rule and the "derived-from" rule, solidified organics would carry the listed EPA codes associated with the wastes fed to the solidified organics generation processes. EPA Codes F001 and F002 are assigned to all solidified organics because wastes received by Tanks T-1 and T-2, T-374A, and T-13 and T-14 were contaminated with regulated spent solvents in the past.

Sampling and analysis of solidified organics waste in 1988 and 1989 indicated the waste exceeded the F001 and F002 LDR treatment standards for carbon tetrachloride and 1,1,1-trichloroethane. The analyses found detectable concentrations of other F001 and F002 constituents, as well. Total analysis of the waste under EPA SW-846 is required to confirm these results.

Based on the "mixture" rule and the "derived from" rule, solidified organics would carry the listed EPA codes associated with wastes set to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned because wastes set to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at elevated levels. Solidified organics will not be considered as meeting F001, F002, F003, and F005 Land Disposal restrictions (LDR) treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SE-846 is required.

The EPA Codes F006, F007, and F009 are assigned because of contamination with waste from electroplating operations.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to solidified organics. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste. Cited laboratory chemicals like nitrobenzene were used for their intended purpose as reagents and were not discarded commercial chemical products.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is stored in 55-gallon carbon steel drums with a rigid polyethylene liner and one or two bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	RF 111	Stream Name:	Solidified Sludge - Bldg 774 / TRM	Inventory Date:	10/20/95
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, F005, F039, F009, F007, F006, F003, D010, D008, D007, D006, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	317.6	262.4	414.5
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	262.0	216.5	342.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	55.6	45.9	72.5
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 111

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.9	0.1	0.1	1.3	0.5	4.9
Totals	2.9	0.1	0.1	1.3	0.5	4.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	0.1	0.1	1.2	0.6	4.9
Totals	2.9	0.1	0.1	1.2	0.6	4.9

As-Generated Form: Stored: 2.9 Projected: 2.1 Total: 5.0

Final Waste Form: Stored: 2.9 Projected: 2.1 Total: 5.0

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge.

Re: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR)

treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower

than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W097	Handling:	CH	NMVP #:	RF 114	Stream Name:	Solidified Process Solids/TRM
Local ID:	IDC 806	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: Z1110

AS-GENERATED EPA CODES

D008, D004, D005, D007, D009, D010, D011, F003, D006, F005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	489.0	376.2	635.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	135.8	104.5	176.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	73.1	56.2	95.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 114

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	62.1	11.8	491.0	545.8	1110.7
Totals	0.0	62.1	11.8	491.0	545.8	1110.7

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 1110.7 Total: 1110.7

WASTE STREAM DESCRIPTION	This waste stream represents the solidified final form of all particulate and sludge type materials. Particulates and sludge type materials are immobilized with Portland cement. The cemented wastes are cast into 1-gallon molds and allowed to cure prior to packaging. This is the final waste form for Firebrick, Pulverized or Fines/TRM (RF-W036), Incinerator Ash/TRM (RF-W040), Particulate Sludge/TRM (RF-W068), and Sand, Slag, and Crucible/TRM (RF-W059). IDC 806 - All inorganic particulate and inorganic sludge waste must be immobilized by processing into a solid and identified as IDC 806.
WASTE STREAM SOURCE	This is a new waste stream and includes IDC 806 only. It represents the solidified final form of Firebrick, Pulverized or Fines/TRM (RF-W036), Incinerator Ash/TRM (RF-W040), Particulate Sludge/TRM (RF-W068), and Sand, Slag, and Crucible/TRM (RF-W059). Particulates and sludge type materials are immobilized with Portland Cement. The cemented wastes are cast into 1-gallon molds and allowed to cure prior to packaging. There is currently no inventory of this waste at Rocky Flats. However, generation of this waste is expected as the plant progresses in its mission of environmental cleanup and waste management. Therefore, some IDC 806 material is expected to be generated in the 20-year horizon as waste management and disposal activities continue. For these reasons, this waste must be reported in the Baseline Inventory Report; it is included here to maintain consistency between this report and the BIR.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The characterization basis for this waste is to apply EPA hazardous waste numbers from the four feed materials identified above that would be expected to apply to the final solidified waste form as well. These are projected hazardous waste numbers and may not apply after the waste is generated and analytical work completed. Projected list of contaminants based on those present in source wastes.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Volumes include final form waste from treating the following streams: RF-MT0377, RF-MT0378, RF-MT0420, RF-MT0425, RF-MT0292, RF-MT0299, RF-MT0372, RF-MT0391, RF-MT0392, RF-MT0393.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	RF 111	Stream Name:	Solidified Sludge - Bldg 374 / TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, F039, F009, F007, F005, F003, D011, D010, D009, D008, D007, D006, D005, D004, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	409.8	279.8	730.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	338.1	230.8	602.2
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	71.7	49.0	127.8
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 111

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	73.4	1.3	2.7	27.6	10.3	115.5
Totals	73.4	1.3	2.7	27.6	10.3	115.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	73.4	1.3	2.7	27.6	10.3	115.5
Totals	73.4	1.3	2.7	27.6	10.3	115.5

As-Generated Form: Stored: 73.4 Projected: 41.6 Total: 115.0

Final Waste Form: Stored: 73.4 Projected: 41.6 Total: 115.0

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge.

Re: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR)

treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower

than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based pirmarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS

The projections given in Section 8.2.15.1.13 are in cubic meters

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Item Description 831, Combustibles, Dry, TRU Mixed Waste Dry combustibles such as paper, cloth, wood, etc. This waste has been identified as being low level mixed waste. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, F005, F003, D011, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Wet combustible transuranic wastes, such as paper, cloth, and wood, which contain a discernible amount of moisture must be drained or wrung out prior to packaging to prevent accumulation of free liquid. These wastes are classified as IDC 822. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	RF-831	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, F009, F007, F006, F005, F003, D035, D019, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	69.2	4.8	258.5
Rubber:	6.6	0.5	24.7
Plastics:	20.1	1.1	75.2
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	112.6		
Packaging Material Plastic:	44.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	44.9	13.7	9.6	84.3	78.4	230.9
Drum / 85-gallon	0.6	0.0	0.0	0.0	0.0	0.6
metal box / 4x4x7	12.8	0.0	0.0	0.0	0.0	12.8
Totals	58.3	13.7	9.6	84.3	78.4	244.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	44.9	13.7	9.6	83.5	78.4	230.1
Standard Waste Box	0.0	9.8	1.6	13.7	12.7	37.8
Totals	44.9	23.4	11.2	97.2	91.2	267.9

As-Generated Form: Stored: 58.3 Projected: 186.0 Total: 244.3

Final Waste Form: Stored: 44.9 Projected: 223.8 Total: 268.7

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	tem Description 831, Combustibles, Dry, TRU Mixed Waste Dry combustibles such as paper, cloth, wood, etc. This waste has been identified as being low level mixed waste. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	The projections given in Section 8.2.15.1.13 are in m^3. Assume 86% of IDC 831 generation will be Drum/55-gal based on current container distribution.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

D006, D019, D022, D028, D029, F006, D040, D043, F007, F009, D011, D010, F039, F002, D038, F003, F001, D002, D035, D018, F005, D003, D004, D005, D007, D008, D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.1	0.0	0.5
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	65.0	1.4	347.6
Rubber:	6.2	0.1	33.2
Plastics:	18.9	0.4	101.1
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	72.4	26.0	18.3	160.8	149.3	426.8
Totals	72.4	26.0	18.3	160.8	149.3	426.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	72.4	29.1	18.3	160.8	149.3	429.9
Totals	72.4	29.1	18.3	160.8	149.3	429.9

As-Generated Form: Stored: 72.4 Projected: 354.4 Total: 426.8

Final Waste Form: Stored: 72.4 Projected: 357.6 Total: 429.9

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, D011, F009, F007, F006, F005, F003, D019, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	32.8	4.2	69.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.2	0.0	0.3
Rubber:	2.2	0.3	4.7
Plastics:	53.5	6.9	112.8
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	138.0		
Packaging Material Plastic:	36.4		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.7	2.1	1.5	13.0	12.3	37.6
metal box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Totals	11.9	2.1	1.5	13.0	12.3	40.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.7	3.1	1.5	13.0	12.3	38.7
Standard Waste Box	0.0	6.2	0.6	3.6	6.6	17.0
Totals	8.7	9.4	2.1	16.6	18.9	55.7

As-Generated Form: Stored: 11.9 Projected: 28.9 Total: 40.8

Final Waste Form: Stored: 8.7 Projected: 47.0 Total: 55.7

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Item Description 853, Plastic (Teflon, PVC, and Polyethylene) This waste has been identified as being a low level mixed waste, consisting of PVC sheeting, poly bottles, supplied-air suits, and other plastics. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	Assume 70% of IDC 833 generation will be drum/55-gal based on current container distribution.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, D019

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Item Description 853, Plastic (Teflon, PVC, and Polyethylene) This waste has been identified as being a low level mixed waste, consisting of PVC sheeting, poly bottles, supplied-air suits, and other plastics. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1986. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W032	Handling:	CH	NMVP #:	N/A	Stream Name:	Ground glass/TRM	Inventory Date:	10/20/94
Local ID:	IDC 444, 855	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	77.6	77.6	77.6
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Solis:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.33E+00
Pu-240	5.61E-02
Pu-239	2.45E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.2	0.3	0.6	0.6	1.9
Totals	0.2	0.2	0.3	0.6	0.6	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.2	0.3	0.6	0.6	1.9
Totals	0.2	0.2	0.3	0.6	0.6	1.9

As-Generated Form: Stored: 0.2 Projected: 1.7 Total: 1.9

Final Waste Form: Stored: 0.2 Projected: 1.7 Total: 1.9

WASTE STREAM DESCRIPTION	Matrix consits of crushed glass light bulbs and leaded glass that is crushed on removal.
WASTE STREAM SOURCE	Item Description Code 855-Ground Glass 855 IDC includes ground glass from fluorescent light bulbs. It can be used for waste generated outside the PA and for nonline-generated waste. In other words, it can *only be used for low-level mixed waste.* This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories. RE: Section 8.2.11, REFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Analytical data showed the presence of toxic metals in some containers of IDC 444. Based on these analytical data, these materials are characterized as hazardous and assigned EPA codes D005 and D008. Analytical data for IDC 855 show that there are enough cases where the samples fail the Toxicity Characteristic Leaching Procedure (TCLP), that the waste bulbs should be managed as hazardous waste and assigned the EPA code D009. EPA codes are assigned to newly generated waste by the generator based on process knowledge. Subpopulation 17G includes containers of leaded glovebox glass. Based on analytical data, these materials are characterized as hazardous and assigned EPA Waste Codes.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	LDR_DETERM: Net and gross weight data are not available for all container types. RFP has assumed this waste to be LDR based on the fact that it is a RCRA listed waste. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The glass waste is packaged in 55- gallon drums that are lined with one fiberboard liner and two polyethylene bags or metal boxes. Drums are placed in TRUPACT II containers.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W052	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	10.3	10.3	10.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	176.8	176.8	176.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.4	5.4	5.4
Rubber:	0.0	0.0	0.0
Plastics:	6.2	6.2	6.2
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF118

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	6.75E+00
Pu-240	2.83E-01
Pu-239	1.28E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.7	0.9	1.9	1.9	5.5
Totals	0.2	0.7	0.9	1.9	1.9	5.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.7	0.9	1.9	1.9	5.5
Totals	0.2	0.7	0.9	1.9	1.9	5.5

As-Generated Form: Stored: 0.2 Projected: 5.4 Total: 5.6

Final Waste Form: Stored: 0.2 Projected: 5.4 Total: 5.6

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 856 includes Raschig Rings which are removed from vessels containing RCRA regulated solvents. There is also glass from spent fluorescent lamps in some of these containers. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data. This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Item Description Code 440 This IDC was separated from IDC 444 (created in 1989 specifically for ground glass and leaded glass) because the two waste forms exhibit different chemical characteristics, hazardous constituents, and EPA codes. Therefore, drums of IDC 440 materials generated prior to 1989 could contain leaded glass. These are included in Subpopulation 17G and are assigned EPA codes D005 and D008. Item Description Code 442 In addition to the reference documents and WEMs information used, analytical data compiled by EG&G Rocky Flats were reviewed. The data shows that the concentrations of Toxicity Characteristic (TC) metals barium, cadmium, chromium, lead, and silver were well below regulated levels provided in 6 CCR 1007-3, Section 261.24. Subpopulation 17F includes Raschig Rings assigned IDC 442 that are contaminated with carbon tetrachloride, 1,1,1-trichloroethane, or both. Based on analytical data, Raschig Rings do not exhibit the characteristic of toxicity for metals. All containers in this group were generated in Building 777 according to WEMS. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. Therefore, it is assumed that these rings are all contaminated with carbon tetrachloride or 1,1,1-trichloroethane sludge. They are, therefore, assigned EPA Waste Codes F001 and F002. Subpopulation 27B is assigned EPA code D009 because of mercury in the spent fluorescent lamps.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP has determined that this grouping is LDR waste based on available process knowledge with some of the IDCs identified containing listed hazardous components. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of is generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: DOT 7A TYPE A metal boxes and DOT 7A TYPE A drums.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W096	Handling:	CH	NMVP #:	RF-116	Stream Name:	Supercompacted Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	2116	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S3290

AS-GENERATED EPA CODES

F001, D008, F002, F005, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	375.7	251.3	483.0
Rubber:	35.9	24.0	46.1
Plastics:	108.1	72.3	139.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	301.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Pollution Control or Waste Treatment Process

TRUCON CODE

RF-116C

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.44E+01
Pu-240	1.02E+00
Pu-239	4.08E+00
Am-241	3.46E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	This waste consists of cloth and paper products from cleanup of gloveboxes and spills, which has been supercompacted for volume reduction.
WASTE STREAM SOURCE	Item Description Code 2116 - IDC 2116 is Supercompacted TRU-mixed combustible waste (IDCs 831, 832, and 833). Refer to Waste Form RF-W012 for details of these IDCs. Containers of IDC 2116 were generated in Building 776. The WSRIC stream number is 776-13-40 (a/o 3/2/95). Soft wastes are inspected for rejectable items, including free liquids and metal, which are separated from the soft waste for further disposition. Soft wastes are moved to the precompactor where they are placed in an empty 35-gallon drum located in the precompactor. The soft waste is precompacted using a 30-ton precompactor. Once the drum is filled with precompacted waste, the lid is placed on the drum. The drum is transferred to the appropriate glovebox line for piercing. Prior to supercompaction, drums of soft waste are pierced with four holes to allow air to escape and to reduce the amount of "springback" during supercompaction. After piercing, the drums are moved to the supercompactor. A mold is lowered over the drum. Once the mold is in place, the supercompactor is lowered, compacting the drum. Liquid forced out of the waste during compaction is collected by the liquid waste collection system. After supercompaction, the pucks (supercompacted 35-gallon drums) are moved to staging. An operator selects from the available pucks to efficiently fill 55-gallon loadout drums.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	This waste is characterized with the same EPA hazardous waste numbers as the waste being processed. Refer to RF-W012, Combustibles/TRM, for IDCs 831, 832, and 833.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W094	Handling:	CH	NMVP #:	N/A	Stream Name:	Wastewater/TRM	Inventory Date:	10/20/94
Local ID:	N/A	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	L1130

AS-GENERATED EPA CODES

D002, D007, D011

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Tanks/Misc Size	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream consists of aqueous waste water from different Buildings on the plant site. Most of the water comes from Building 771 and from rain water. This waste stream is treated and sent to Building 374 for final treatment.
WASTE STREAM SOURCE	This waste stream consists of aqueous waste water from different Buildings on the plant site. Most of the water comes from Building 771 and from rain water. This waste stream is treated and sent to Building 374 for final treatment.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based upon general knowledge of waste type or source.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W089	Handling: CH	NMVP #: N/A	Stream Name: WET SLURRY/TRM		Inventory Date: 12/30/99
Local ID: N/A	Type: MTRU	Generator Site: RF	Final Waste Form: Solidified Inorganics		Waste Matrix Code: L1290

AS-GENERATED EPA CODES

D011, D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream consists of solids that are removed from aqueous process waste streams. The aqueous waste streams come into Building 774 from other Buildings on plant site. The aqueous waste is then put through a three stage precipitation, flocculation, and clarification procedure. The solids removed are stored in Tank 40 in Building 774.
WASTE STREAM SOURCE	RE: section *.2.222, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. RFETS does not expect nitrate concentration to be >1%, but has no data indicating the actual concentration range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based upon general knowledge and waste generators in the building.
MANAGEMENT COMMENTS	Projected generation is beyond CY1999.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W091	Handling:	CH	NMVP #:	N/A	Stream Name:	Organics Discard Level/TRM
Local ID:	0533, 0535, N/A	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics

Inventory Date: 10/20/94

Waste Matrix Code:

AS-GENERATED EPA CODES

F002, F001, D019

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Tank/Misc Sizes	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This liquid waste stream includes machine oils and coolants contaminated with organic solvents.
WASTE STREAM SOURCE	Waste oil being transferred from Buildings 707, 776, and 777 is stored in Tanks T-13 and T-14. From Tanks T-13 and T-14, the waste oil is pumped to the OASIS mixer. The pump is enclosed in a small glovebox. Waste oil, water, emulsifier, Envirostone, and accelerator (to speed up the settling process) are mixed in a 55-gallon drum attached to the bottom of the glovebox. The waste is then sampled for plutonium, americium, and uranium. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based on waste generation and general knowledge of waste type or source.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W108	Handling:	CH	NMVP #:	RF 111	Stream Name:	Aqueous Sludge/TRU	Inventory Date:	
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	395.6	44.2	767.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	260.3	28.8	498.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	140.2	15.5	268.5
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues:

Asbestos: No

PCBs: No

Source:

TRUCON CODE

RF 111

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	This waste stream consists of aqueous sludge from wastewater treatment mixed with 30% Portland cement. IDC No. 800, 803, 807. The waste is generated as a result of process waste water treatment in Building 374 and 774. Aqueous sludge is produced by vacuum filtration of precipitated solids from pretreated aqueous waste slurry. Entrapped solids are skimmed off the surface of the filter medium of the rotating drum as wet sludge. The recipitated solids are chiefly hydroxides with pH of 10-12. The final waste form is obtained by mixing the wet sludge with approximately 30% Portland cement. RFP has several drums of aqueous sludge that were returned by INEL. These old drums were packaged by alternating the layers of cement and wet sludge or by adding cement to the top and bottom of a drum containing wet sludge. This older waste is described by IDC's 001, 002, and 007.
WASTE STREAM SOURCE	N/A
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/Tru
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 044 was produced in the Americium Purification Process in Glovebox 1 in Building 771. This process has been out of operation for many years. The americium oxide was produced in a similar method to plutonium oxide. The americium oxide was collected in stainless-steel vials that were placed in lead pigs for radiation shielding. The lead pigs are enclosed in storage cans that are stored in vaults.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	[illegible]	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.5	0.0	0.0	0.0	0.0	0.5
Totals	0.5	0.0	0.0	0.0	0.0	0.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.5 Projected: 0.0 Total: 0.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 067 consists of chlorinated plutonium oxide generated during research in Building 779, for possible use in a variety of processes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 080 consists of plutonium oxide generated by the Calcination Process in Building 771. The Feed Evaporation Process concentrated the plutonium nitrate solution from High-Level Dissolution and Anion Exchange. The resulting precipitate was calcined to form plutonium oxide. This product was then transferred to Hydrofluorination for further processing.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W123	Handling: CH	NMVP #: N/A	Stream Name: Oxides/TRU		Inventory Date: 3/6/95
Local ID: None	Type: TRU	Generator Site: RF	Final Waste Form: Solidified Inorganics		Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 081 consists primarily of the impure plutonium oxide collected from the glovebox floor of the Calcination Process in Building 771. In addition, oxide encrusted on the calciner equipment was removed during maintenance operations and assigned IDC 081.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 062 consists of plutonium oxide stored in small stacker cans.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.03	0.0	0.0	0.0	0.0	0.03
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.03 Projected: 0.0 Total: 0.03

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 083 consists of plutonium oxide feed for the Direct Oxide Reduction Process in Building 776 Pyrochemical Processing. This product consists of oxide from a variety of sources used by the process to produce metal for production purposes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: *Stored:* 0.00 *Projected:* 0.0 *Total:* 0.00

Final Waste Form: *Stored:* 0.0 *Projected:* 0.0 *Total:* 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 084 consists of plutonium oxide generated at the Hanford facility and shipped to Rocky Flats for processing. The oxide was assayed then blended in preparation for Direct Oxide Reduction in Building 776 or Hydrofluorination prior to Reduction and Button Break-out in Building 771.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.04 Projected: 0.0 Total: 0.04

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 086 consists of plutonium oxide generated by the Electrorefining tilt/pour furnaces in Building 371. During cleaning of the furnaces, molten plutonium metal was scraped from the walls. The metal was burned to oxide then assayed before being sent to Dissolution in Building 771. The oxide could contain tungsten or tantalum from furnace components.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.04 Projected: 0.0 Total: 0.04

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 067 consists primarily of the impure plutonium oxide collected from the glovebox floor of the Calcination Process in Building 771 (see discussion of IDC 061) that is stored in small stacker cans.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/Tru	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 089 is produced in the calcination process in Glovebox 16 in Building 771. Grease oxide is a mixture of plutonium greencake from the calciner equipment. The grease is applied to the wear plates on the calciner. Grease and greencake can mix together near the breech of the calciner where the product greencake is removed. Grease oxide is placed in metal cans for storage prior to calcination and eventual dissolution for recovery. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 145 consists of plutonium oxide generated during loss-on-ignition testing in Building 371. The LOI test was developed to minimize the possibility of container pressurization during shipment. The oxide was heated for a designated period, then weighed to determine the percent of weight loss. If more than 1 percent was lost, it was determined that there was enough moisture or impurities present to represent a risk of the container pressurizing during shipment. If the oxide failed, the material was typically tested a second time.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CR	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 146 consists of plutonium oxide failing loss-on-ignition testing in Building 371 multiple times. Typically, oxide failing the LOI test twice was sent to Building 771 and reburned for dissolution.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 289 consists of low-concentration plutonium oxide heel generated in the Dissolution Process in Building 771. This oxide consists of the undissolved material after the plutonium nitrate dissolution solution was run through an R-6 filter. The resulting heel was dried on a hot plate then staged to be recycled back into the dissolution process. This oxide consists of the heel that had been cycled through the process multiple times.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W104	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of IDCs 292 and 299. This waste is packaged in 55-gallon drums with multiple bag liners. Final waste form for this waste is Solidified Process Solids/TRU (IDC 806).
WASTE STREAM SOURCE	IDC 292 was intended for incinerator sludge from the recovery incinerator in Building 771. IDC 292 materials were reassessed under Waste Form 1, Incinerator Ash. However, there is one box WEMS incorrectly assigned this IDC. According to the waste-box log sheet dated October 14, 1987, the box contains Electrochemical Milling Sludge generated in Building 881. This operation generated sludge from the milling of various metals including stainless steel. It was indicated that no cyanides were used in the ECM operations in Building 881. The IDC for this box should be changed to 299. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphateds >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W104	Handling: CH	NMVP #: N/A	Stream Name: Particulate Sludge/TRU		Inventory Date: 3/6/95
Local ID: None	Type: TRU	Generator Site: RF	Final Waste Form: Solidified Inorganics		Waste Matrix Code: S3129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of IDCs 292 and 299. This waste is packaged in 55-gallon drums with multiple bag liners. Final waste form for this waste is Solidified Process Solids/TRU (IDC 806).
WASTE STREAM SOURCE	This IDC has been used for sludges that were not accurately categorized as IDC 290 or 340 and could have been generated in any plutonium processing building. However, the backlog miscellaneous sludge was generated in Building 771 during the processing of residues, in Building 371 in the analytical laboratory, and in Building 883 by the Rolling Process. Process pipe sludge, sludge dissolution heel, and filter plenum sludge from Building 771 were processed through nitric acid dissolution and sparging. Soil and sludge samples from around the site were analyzed in Building 371, and the waste was stored for processing. IDC 299 materials generated in Building 883 include quench sludge and uranium oxide sludge from the rolling Process. This group also includes one container of electrochemical milling sludge generated in Building 881 in October 1987. The container is assigned IDC 292. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.03	0.0	0.0	0.0	0.0	0.03
Drum / 55-gallon	26.0	0.0	0.0	0.0	0.0	26.0
Totals	26.0	0.0	0.0	0.0	0.0	26.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 26.0 Projected: 0.0 Total: 26.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 300, Graphite Molds During the casting of plutonium in production foundry operations, the plutonium casting operations in Building 707 generated used graphite molds. The working surfaces were coated with calcium fluoride prior to using the mold. After the plutonium casting was removed from the mold, the molds were collected in a drum. Drums that contained recoverable amounts of plutonium were stored for subsequent scarfing of molds.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	17.3	0.0	0.0	0.0	0.0	17.3
Totals	17.3	0.0	0.0	0.0	0.0	17.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 17.3 Projected: 0.0 Total: 17.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 301, Classified Graphite Shapes During the casting of plutonium in production foundry operations, classified molds are segregated from non-classified molds. Prior to 1984, the classified molds were destroyed in Building 776.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	RF115	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 115

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 303, Scarfed Graphite Chunks After the casting of plutonium in production foundry operations, IDCs 300 and 301 were mechanically cleaned using a hand-held rotary-type sanding tool to grind off contamination in buildings 371, 707, 771, and 777, generating Scarfed Graphite Chunks. The mechanical cleaning (scarfing) of the mold surface removes most of the mold coating and plutonium contamination. This process generated IDC 303 and 310, as well as, IDC 312.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	17.5	0.0	0.0	0.0	0.0	17.5
Totals	17.5	0.0	0.0	0.0	0.0	17.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 17.5 Projected: 0.0 Total: 17.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 310, Graphite Scarfing and Fines After the casting of plutonium in production foundry operations, IDC 300 was mechanically cleaned in Buildings 371, 707, 771, and 777, generating graphite scarfings and fines. The mechanical cleaning (scarfing) of the mold surface removes most of the mold coating and plutonium contamination. Material generated in this process were fines and small pieces of graphite coated with calcium fluoride and plutonium. This material was then subjected to nondestructive assay to determine actinide content, and collected for disposition.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	24.1	0.0	0.0	0.0	0.0	24.1
Totals	24.2	0.0	0.0	0.0	0.0	24.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 24.2 Projected: 0.0 Total: 24.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 312, Graphite Coarse After the casting of plutonium in production foundry operations, IDC 300 was mechanically cleaned in Buildings 371, 707, 771, and 777, generating coarse graphite. Material generated in this process were chunk pieces of graphite produced as a by-product of IDC 310 generation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W111	Handling:	CH	NMVP #:	N/A	Stream Name:	Heavy Metal (non-SS)/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 3/6/95

Waste Matrix Code: S5119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	7.9	0.0	0.0	0.0	0.0	7.9
Totals	7.9	0.0	0.0	0.0	0.0	7.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 7.9 Projected: 0.0 Total: 7.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	Typically, these scrap metals consist of crucibles, funnels, rods and fixturing from several processes and production operations. Tantalum, tungsten and platinum are examples of scrap metals at the RFP.
WASTE STREAM SOURCE	Heavy metals have been produced as by-products of Rocky Flats operations in Buildings 371, 707, 771, 776, 777, 779, and 865; they are identified by IDC 320. The IDC 320 heavy nonspecial source metal was generated in various locations throughout the Rocky Flats. This IDC includes nonstainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	17.3	0.0	0.0	0.0	0.0	17.3
Totals	17.3	0.0	0.0	0.0	0.0	17.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 17.3 Projected: 0.0 Total: 17.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 330 is Dry Combustibles. This IDC is dry combustibles such as cloth, paper, and wood. This IDC changes to 821, 831, 851, or 861 at the point of assay, depending on radiological content. Containers of IDC 330 currently in inventory were generated in all buildings handling fissile material. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	2.5	0.0	0.0	0.0	0.0	2.5
Totals	2.5	0.0	0.0	0.0	0.0	2.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.5 Projected: 0.0 Total: 2.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters.

WASTE STREAM SOURCE

These Ful-Flo filters are in-line cartridge filters used throughout Rocky Flats to remove particulates from fluid streams and typically filter down to 5, 1, and 0.5 micron-sized particulates. Ful-Flo filters are used in various liquid systems that include nitric- and chloride-acid systems, such as those found in plutonium recovery operations; caustic systems, such as those found in utilities scrubbing; solvent systems using carbon tetrachloride in machining operations; water systems, such as steam cleaning; and condensate collection. These filters are also used in lubricant oil filtration.

Ful-Flo filters are poly-fiber-wound cartridges, about 10" long by 3.5" in diameter. Other fiber filters, such as R-6 pads, may be included in this IDC. R-6 pads are cloth filters, about sixteen inches in diameter, used to filter solids from nitric acid solutions. Therefore, backlog material in this IDC cannot be considered homogeneous, filter elements are produced by combining a media blanket and spirally wound matrix yarn on an inner core. The filter elements might have a polypropylene cap on one end. Both the media blanket and matrix yarn can be cotton or polypropylene. The inner core material can be constructed of polypropylene, tinned steel, or stainless steel. Warehouse data from Rocky Flats indicate that the inner-core material is polypropylene.

Typically, Ful-Flo filters were placed on drying racks pending bag-out of a glovebox. Filters were not always dried before removal from the glovebox. Filters were then "bagged out" of the glovebox and placed in a second layer of plastic. Next, the filters were placed in a "Poly Bottle" or "Clam Shell" (hard plastic container), then placed in a double-lined drum.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS N/A

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W115	Handling:	CH	NMVP #:	N/A	Stream Name:	Fireblanket/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	91.7	1.9	353.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.8	0.0	9.6
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cans/2-liter	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	This waste stream is contaminated insulation.
WASTE STREAM SOURCE	Item Description Code 334 During normal operations, fire blankets become soiled, contaminated, or are no longer needed in an area. There is one backlog drum of IDC 334. This drum was generated in Building 771 from July 1991 to December 1991.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	The volumes and the radionuclide concentrations developed in the profile were based on processing plutonium residues for actinide separation. RFETS has modified this processing plan. Residues will be processed to meet WIPP WAC, TRAMPAC, and safe storage conditions. The modified volumes and radionuclide concentrations are reflected in the WIPP level roll-ups.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	8.3	0.6	56.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	9.8	0.7	66.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.4	4.8	429.5
Rubber:	2.8	0.2	19.1
Plastics:	3.8	0.3	25.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 1.5 Projected: 0.0 Total: 1.5

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is High Efficiency Particulate Air (HEPA) filters used in ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large filter plenums that filter the room air. Used filters were removed from their position in the ventilation system and packaged for further processing. The filters used on gloveboxes (nominal 8" x 8" x 5") were identified as IDC 335 if they were not acid contaminated. RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections in section 8.2.15.1.13 include generation of IDC-335 and IDC-342 to be processed to IDC-335. The volumes and the radionuclide concentrations developed in the profile were based on processing plutonium residues for actinide separation. RFETS has modified this processing plan. Residues will be processed to meet WIPP WAC, TRAMPAC, and safe storage conditions. The modified volumes and radionuclide concentrations are reflected in the WIPP level roll-ups.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	44.3	0.0	0.0	0.0	0.0	44.3
Totals	44.3	0.0	0.0	0.0	0.0	44.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 44.3 Projected: 0.0 Total: 44.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This IDC changes to 822, 832, 852, or 862 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES: N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE: None

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	10.2	0.0	0.0	0.0	0.0	10.2
Totals	10.2	0.0	0.0	0.0	0.0	10.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 10.2 Projected: 0.0 Total: 10.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 337 represents PVC sheeting, poly bottles, supplied-air suits polyethylene, and other plastics. IDC 337 changes to 825, 833, 853, or 863 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	20.6	0.0	0.0	0.0	0.0	20.6
Totals	20.6	0.0	0.0	0.0	0.0	20.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 20.6 Projected: 0.0 Total: 20.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.

WASTE STREAM SOURCE

The material in this IDC is either the filter media portion of HEPA filters or surface-water filters. HEPA filters are used on gloveboxes and in large filter plenums. Sock filters were used to prefilter operable unit 2 (OU-2) surface water prior to activated carbon treatment.

Used HEPA filters were processed to segregate those portions with high plutonium content and those with low content. The wood frames were separated from the media and almost always disposed of as waste by packing in drums that were assigned IDC 330. the filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste.

This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from the production Building 707 and could be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon. IDC 338 was meant to be used as a residue IDC and not as a waste IDC. Because sorting between IDCs was not accurate, some of the IDC 338 backlog containers are below the economic discard limit (EDL) and are therefore not residue.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS N/A

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	HEPA filters are used on all gloveboxes to remove particulates from the atmosphere exiting the glovebox to the plenum exhaust system. The filters in IDC 342 are from gloveboxes with atmospheres that could cause the filters to be contaminated with acids or bases used in chemical processing. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W114	Handling:	CH	NMVP #:	N/A	Stream Name:	Mg Oxide Crucibles/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal

Inventory Date: 3/6/95

Waste Matrix Code: S5123

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.3	0.0	0.0	0.0	0.0	0.3
Drum / 55-gallon	12.3	0.0	0.0	0.0	0.0	12.3
Totals	12.6	0.0	0.0	0.0	0.0	12.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 12.6 Projected: 0.0 Total: 12.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream includes any type or size or ceramic crubicles or liners including LECO crucibles. This waste consists of magnesium oxide ceramic crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing plutonium residue.
WASTE STREAM SOURCE	Item Description Code 368 During normal process operations, the Electrorefining, Reduction and Button Breakout, Direct Oxide Reduction, and Salt Scrub processes in Buildings 559, 771, and 779 generated broken magnesium oxide crucible pieces. A detailed description of the generating processes presented above can be found in the WSRIC Building Books. However, in general, the crucibles were used to heat plutonium with salts or accelerators allowing for purification or recovery of actinide metrals. Upon cooling to room temperature, the crucible or crucible insert used in the process would be broken and its contents removed.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W114	Handling:	CH	NMVP #:	N/A	Stream Name:	Mg Oxide Crucibles/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal

Inventory Date: 3/6/95

Waste Matrix Code: S5123

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	33.1	0.0	0.0	0.0	0.0	33.1
Totals	33.1	0.0	0.0	0.0	0.0	33.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 33.1 Projected: 0.0 Total: 33.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream includes any type or size or ceramic crubicles or liners including LECO crucibles. This waste consists of magnesium oxide ceramic crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing plutonium residue.
WASTE STREAM SOURCE	Item Description Code 370 The laboratories in Buildings 559 and 771 generated LECO crucibles and broken LECO crucible pieces. These crucibles were used for carbon analyses of plutonium metals and oxides. Stainless steel pins were also heated in these crucibles for calibration purposes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W121	Handling:	CH	NMVP #:	N/A	Stream Name	Cemented filters/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.9	0.0	0.0	0.0	0.0	6.9
Totals	6.9	0.0	0.0	0.0	0.0	6.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.9 Projected: 0.0 Total: 6.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	Processed filter media, IDC 376, is material which has been treated using Portland cement to absorb moisture and neutralize acid contamination. Filter waste is packaged in 55-gallon drums and metal standard waste boxes. Inventory data include residues within the same IDCs because they are regulated as waste.
WASTE STREAM SOURCE	The material in this IDC is the filter media portion of acid-contaminated glovebox or plenum HEPA filters or Ful-Flo filters with free liquids. Processing was performed in the Site Reduction Vaults in Building 776. Used HEPA filters were processed to separate any portions containing high plutonium content from portions with low content. The wood frames were separated from the media and usually disposed of as waste by packing in a drum that was assigned IDC 330. The filter media pieces were identified as IDC 339 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste. The media were placed in crates, Portland cement was added, then crates were sealed. Some IDC 376 material could be the remaining material after the IDC 338 media were processed to recover the plutonium. Ful-Flo filters which were used to filter corrosive gas were also processed to separate any portions containing high plutonium content from portions with low plutonium content. Pieces of media with low activity were identified as IDC 376 and packaged for shipment as waste. The media were placed in approximately 10-gallon plastic bags and Portland cement was added. The bags were then sealed and placed in a drum. IDC 376 filter media in this backlog population was derived from the processing of HEPA filters from Buildings 371, 771, 776, and 770. The HEPA filters could have orginally been assigned ICDs 335 342, 490, 491 or 492. Filter media from Building 771 could have been used to filter nitric acid vapors.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 390 This IDC consists primarily of unpulverized slag generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771. The unpulverized slag is generated from the seperation of calcium fluoride slag from the sand and crucible residues following the removal of the plutonium metal button. Calcium fluoride is produced from the reaction of the calcium metal with the plutonium fluoride. Unpulverized slag is placed in 4-liter, wide mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 391 This IDC constists primarily of unpulverized sand and crucible generated as a residue form the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771. The unpulverized sand and crucible are generated from the separation of sand and crucible residues from the calcium fluoride slag following the removal of the plutonium metal button. Unpulverized sand and crucible is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	IDC 392 consists of unseparated IDC 391 materials. Unpulverized sand, slag, and crucible are placed in 4-liter, wide-mouthed, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The sand, slag, and crucible are stored awaiting crushing prior to plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W114	Handling:	CH	NMVP #:	N/A	Stream Name:	Mg Oxide Sand/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5123

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Drum / 55-gallon	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream includes any type or size or ceramic crubicles or liners including LECO crucibles. This waste consists of magnesium oxide ceramic crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing plutonium residue.
WASTE STREAM SOURCE	Item Description Code 394 Button breakout sand, contains fine particulates and may contain reactive metals (calcium and plutonium). Must be solidified prior to certification to NTS or WIPP. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 395 This IDC consists primarily of unpulverized slag and crucible generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771. The unpulverized slag and crucible are generated from the separation of calcium fluoride slag and crucible residues from the magnesium oxide sand following the removal of the plutonium metal button. Calcium fluoride is produced from the reaction of the calcium metal with the plutonim fluoride. Unpulverized slag and crucible are placed in 4-liter, wide-mouth, polyethylene bottles for removal from the gotvebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL *(cu. meters)*

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 396 This IDC consists primarily of pulverized slag generated from the crushing and grinding of calcium fluoride slag in preparation for dissolution. This crushing operation was performed with the jaw crusher and hammer mill (constructed of mild steel) within Gloveboxes (Lines) 43B and 43C in Building 771. The pulverized slag is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	5.6	0.0	0.0	0.0	0.0	5.6
Totals	5.6	0.0	0.0	0.0	0.0	5.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 5.6 Projected: 0.0 Total: 5.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 398 This IDC consists primarily of pulverized sand, slag, and crucible generated from the crushing and grinding of magnesium oxide sand, calcium fluoride slag, and broken reduction crucibles in preparation for dissolution. This crushing operation was performed with the jaw crusher and hammer mill (constructed of mild steel) in Gloveboxes (Lines) 43B and 43C in Building 771. The pulverized sand, slag, and crucible are placed in 4-liter, wide-mouth, polyethylene bottles for removal from the gotvebox. After the bottles are bagged out, they are assayed individually. The containers are stored awaiting plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 404 salt is composed primarily of sodium chloride, potassium chloride, calcium chloride, residual zinc chloride, entrained zinc and calcium metal, and various plutonium and americium compounds. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cans/2-liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	6.0	0.0	0.0	0.0	0.0	6.0
Totals	6.0	0.0	0.0	0.0	0.0	6.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.0 Projected: 0.0 Total: 6.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cans/2-liter	0.05	0.0	0.0	0.0	0.0	0.05
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.05 Projected: 0.0 Total: 0.05

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	4.0	0.0	0.0	0.0	0.0	4.0
Totals	4.0	0.0	0.0	0.0	0.0	4.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.0 Projected: 0.0 Total: 4.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405–410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cans/2-liter	0.05	0.0	0.0	0.0	0.0	0.05
Drum / 55-gallon	56.2	0.0	0.0	0.0	0.0	56.2
Totals	56.2	0.0	0.0	0.0	0.0	56.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 56.2 Projected: 0.0 Total: 56.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	4.6	0.0	0.0	0.0	0.0	4.6
Drum / 55-gallon	34.3	0.0	0.0	0.0	0.0	34.3
Totals	38.9	0.0	0.0	0.0	0.0	38.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 38.9 Projected: 0.0 Total: 38.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Nonspecification plutonium metal, cast as an anode, was combined with and equimolar mixture of sodium chloride and potassium chloride in a magnesium oxide crucible. Magnesium chloride was then added to initiate the plutonium oxidation. The metal and salts were placed in a furnace and heated until molten. The molten mixture was stirred, and a current applied to the anode which flowed through the molten mixture to the cathode. Plutonium ions migrated from the molten anode through the molten salt to the cathode and were reduced to purified metal. After cooling, the crucible was broken and the salt, anode heel, and purified plutonium metal were separated. This process produced IDC 411 salts. IDC 411 is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metals, and various plutonium compounds. These salts may contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. IDC 411 salt packaged for off-site shipment was assigned IDC 473. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Impure metal was placed in a crucible with sodium chloride, potassium chloride, and zinc chloride. The crucible and contents were heated in a furnace until the contents were molten and the mixture was stirred. While molten, the zinc chloride reacted with the plutonium metal to form plutonium chloride and zinc metal. The contents separated into salt and metal products at process temperature. After cooling and breakout, the plutonium-rich salt phase was reloaded into a crucible along with calcium metal. The crucible and contents were heated in a furnace until the contents were molten and the mixture was stirred. While molten, the calcium reduced the plutonium chloride to plutonium metal. After cooling, the crucible was broken and the metal and salt were separated. This process produced IDC 412 salts. IDC 412 is a Glvson salt which was generated by an experimental pyroredox process. The salt is composed primarily of sodium chloride, potassium chloride, calcium chloride, residual zinc chloride, entrained zinc and calcium metal, and various plutonium and americium compounds. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 413 was generated by the scraping and cleaning of pyrochemical furnace cells and consists of spent pyrochemical salts and magnesium, calcium, sodium, and potassium metals which vaporized during the pyrochemical processes and collected on the cold parts of the cells. The scraped-out material may have been reheated in a furnace to oxidize the metals; however, this did not always occur. This salt could contain compounds present in any of the pyrochemical salts.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Calcined plutonium oxide was placed in a magnesium oxide crucible with calcium chloride and calcium metal. The crucible and contents were placed in a furnace and heated until the contents were molten. The molten material was stirred to initiate and promote the reduction of the plutonium oxide. After the reaction, the melt was allowed to separate into plutonium metal and salt phases. After cooling, the crucible was broken and seperated from the salt, calcium, and plutonium metal. This process produced IDCs 365 and 414. IDCs 365 and 414 are composed primarily of calcium chloride, calcium oxide, calcium metal entrained in the salt, and various plutonium compounds. A "button" of excess calcium may also be present in some containers of these salts. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Drum / 55-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	The salt assigned IDC 415 was generated by an experimental MSE process which used plutonium trichloride as an oxidizer. The spent salt is composed primarily of calcium chloride with various plutonium and americium compounds. No reactive metals are present in this salt. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	[illegible]	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 416 is small billets or ingots of zinc-magnesium alloy metal containing plutonium which were generated from a research and development (R&D) salt cleanup project in Building 776 and 779. The weight percent of magnesium in alloy will range from 10 percent to 30 percent (EG&G Idaho 1982). RE: Section 5.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 417 is decesium hexachloroplutonate salt synthesized for use in the molten salt extraction process. With the change of the plant mission from recovery and production to environmental cleanup, the material became a waste. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.3	0.0	0.0	0.0	0.0	0.3
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.3	0.0	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	In March 1989, the MSE process was converted from the use of magnesium chloride as an oxidizer to the use of dicesium hexachloroplutonate (DCHP) and calcium chloride instead of the equimolar mixture of sodium chloride and potassium chloride. The converted process produced IDC 427 composed primarily of calcium chloride, cesium chloride, and various plutonium and americium compounds. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	9.2	0.0	0.0	0.0	0.0	9.2
Totals	9.2	0.0	0.0	0.0	0.0	9.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 9.2 Projected: 0.0 Total: 9.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 429 salt was generated using magnesium and aluminum. This IDC represents salts produced from the salt scrub of MSE salts using magnesium chloride. This salt is composed primarily of sodium chloride, potassium chloride, magnesium chloride, entrained magnesium and aluminum metal, and various plutonium and americium compounds.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	N/A	Stream Name:	Organic Resins/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	The ion-exchange resins were important to the plutonium purification processes at RFETS. Plutonium-contaminated materials were often dissolved in nitric acid and processed through ion exchange. The ion-exchange resin contained in an ion-exchange column was charged with highly concentrated nitric acids by trickling this solution through the columns. A plutonium-contaminated solution was then trickled through the column. The charged resin beads attracted the plutonium from the contaminated solution to the surface of the resin bead. The loaded resin beads were then leached by trickling another nitric acid solution through the tube. This final nitric acid solution drew the plutonium from the beads into solution and allowed for purification of the plutonium. The resin was periodically replaced when this process had depleted the efficiency of the resin. The ion exchange resins in use at Rocky Flats were generally small plastic (polystyrene) beads in which long-chain organic compounds with an activated group are imbedded (such as Dowex 1 x 2). Unleached resin IDC 430, was produced when the resin ion exchange columns were replaced. Though this IDC is titled "unleached" resin, the generators of resins confirm that all resins were rinsed with, at least, weak acid before the resins were removed from the columns. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data..
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	N/A	Stream Name:	Organic Resins/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	[illegible]	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	3.1	0.0	0.0	0.0	0.0	3.1
Totals	3.1	0.0	0.0	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.1 Projected: 0.0 Total: 3.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	The ion-exchange resins were important to the plutonium purification processes at RFETS. Plutonium-contaminated materials were often dissolved in nitric acid and processed through ion exchange. The ion-exchange resin contained in an ion-exchange column was charged with highly concentrated nitric acids by trickling this solution through the columns. A plutonium-contaminated solution was then trickled through the column. The charged resin beads attracted the plutonium from the contaminated solution to the surface of the resin bead. The loaded resin beads were then leached by trickling another nitric acid solution through the tube. This final nitric acid solution drew the plutonium from the beads into solution and allowed for purification of the plutonium. The resin was periodically replaced when this process had depleted the efficiency of the resin. The ion exchange resins in use at Rocky Flats were generally small plastic (polystyrene) beads in which long-chain organic compounds with an activated group are imbedded (such as Dowex 1 x 2). Leached resin IDC 431, was produced when the resin ion exchange columns was replaced. The resin was leached (rinsed) with water before the resin was removed from the columns. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 433 salt was also generated using magnesium and aluminum. This IDC represents salts produced from the salt scrub of IDC 427 MSE salts. This salt is composed primarily of calcium chloride, cesium chloride, entrained magnesium and aluminum metal, and various plutonium and americium compounds. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 434 was generated using calcium and gallium. This IDC represents salts produced from the salt scrub of MSE DCHP salts. This salt is composed primarily of calcium chloride, cesium chloride, entrained calcium and gallium metal, and various plutonium and americium compounds. A "button" of excess calcium may also be present in some containers of this salt. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W115	Handling:	CH	NMVP #:	RF 122	Stream Name:	Insulation/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

RF 122

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is contaminated insulation.
WASTE STREAM SOURCE	Item Description Code 438 Maintenance, repair, and strip-out operations in Buildings 371, 374, 444, 559, 666, 707, 771, 774, 776, 777, 779, 865, 881, and 883 produced waste insulation. Insulation waste is generated by replacement of furnace heating elements, construction, maintenance, and demolition activities within the Protected Area at Rocky Flats. During these activities, insulation material is removed from furnaces, boilers, piping, ceilings and walls, and heating and cooling systems.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	N/A	Stream Name:	Glass/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 440 includes glass waste from analytical laboratories and recovery processes, standard light bulbs generated inside the PA, and ceramic materials. Glass waste assigned IDC 440 was generated in Buildings 123,371, 444, 559, 707, 771, 776, 777, 889. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data. This waste stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	N/A	Stream Name:	Glass/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 441 includes unleached Raschig Rings to be discarded. Raschig Rings are borosilicate glass rings used to maintain subcritical conditions in fissile solution storage tanks that are not safe by dimension. The boron in the rings is a neutron poison, an element that absorbs neutrons. The volume of the ring displaces a proportionate volume of solution and, in combination with the boron, creates a critically safe configuration. Over time, the rings can become broken or otherwise damaged, especially in air-sparged tanks. In those cases, the rings were removed and replaced. The rings were also replaced if the assay of the tank exceeded acceptable limits. The old rings were assayed, and if the material count was above the economic discard limit (EDL), the rings were leached (rinsed with water or acid) and stored for plutonium recovery. If the material count was below EDL, the rings were packaged for discard without leaching. The unleached rings were assigned IDC 441. Raschig Rings assigned IDC 441 were generated in Buildings 371 and 771. Rings generated in Building 371 were generated by the Process Vent Scrubber System in Rooms 1105 and 2319. The system removed nitric- and sulfuric-acid vapors and entrained liquids from the process vent header streams connected to the Building 371 tanks. The acids were neutralized with potassium hydroxide and water. Vent scrubbers D229 A and B were filled with Raschig Rings. Rings generated in Building 771 were generated in production processes in tanks used to temporarily store radioactive solutions. The solutions could have contained nitric or sulfuric acids, or potassium hydroxide.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	N/A	Stream Name:	Glass/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	Raschig Rings currently in WEMS assigned IDC 442 were generated in Buildings 771, 776, and 777. Prior to being replaced, the tanks were drained and the rings were leached with dilute nitric acid or water. The rings generated in Building 771 are from the production processes and Tanks D80-85, d0-360, D-361, D-451, D-454, D-467, D-750, D-706, D-922, D-973, D-974, D-980, D-1006, D-1013, D-1022, and D-1081. Rings generated in Building 776 are from the Size Reduction Process and Tanks SR 3, 4, and 5 and as unused rings. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W102	Handling:	CH	NMVP #:	N/A	Stream Name:	Ground Leaded Glass/TRU
Local ID:	IDC 444	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal

Inventory Date: 3/6/95

Waste Matrix Code: S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.5	0.0	0.0	0.0	0.0	7.5
Totals	7.5	0.0	0.0	0.0	0.0	7.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 7.5 Projected: 0.0 Total: 7.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	IDC 444 includes ground fluorescent bulbs and leaded glass used throughout the plutonium- and uranium-processing areas. The material was generated as waste or residue when glovebox glass was replaced, or as low-level waste when fluorescent light bulbs were replaced. IDC 444 materials in the backlog inventory were generated in Building 371, 374, 559, 707, 771, and 776.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.4	0.0	0.0	0.0	0.0	2.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.4 Projected: 0.0 Total: 2.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Nonspecification plutonium metal, cast as an anode, was combined with and equimolar mixture of sodium chloride and potassium chloride in a magnesium oxide crucible. Magnesium chloride was then added to initiate the plutonium oxidation. The metal and salts were placed in a furnace and heated until molten. The molten mixture was stirred, and a current applied to the anode which flowed through the molten mixture to the cathode. Plutonium ions migrated from the molten anode through the molten salt to the cathode and were reduced to purified metal. After cooling, the crucible was broken and the salt, anode heel, and purified plutonium metal were separated. This process produced IDC 411 salts. IDC 411 is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metals, and various plutonium compounds. These salts may contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. IDC 411 salt packaged for off-site shipment was assigned IDC 473. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.9	0.0	0.0	0.0	0.0	2.9
Totals	2.9	0.0	0.0	0.0	0.0	2.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.9 Projected: 0.0 Total: 2.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 479 is assigned to empty reusable cans generated in Buildings 559, 707, and 771 (containers currently in WEMS from these buildings). Stainless-steel cans were used to handle plutonium-contaminated material. Primary generation was through the use of these cans to manually transfer materials between gloveboxes. Cans that were introduced tot he process were typically recycled and reused. there were no generation process descriptions in WSRIC for this waste in Buildings 559, 707, and 771. In Building 371, the Dicesium Hexachloroplutonate (DCHP) Process often used the cans for transferring materials into the stacker.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 3/6/95

Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	15.8	0.0	0.0	0.0	0.0	15.8
Totals	15.9	0.0	0.0	0.0	0.0	15.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 15.9 Projected: 0.0 Total: 15.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 480 is assigned to line- and nonline-generated light metals generated in Buildings 371, 374, 444, 559, 707, 771, 774, 776, 777, 779, 865, and 991 (containers currently in WEMS these buildings). Light metals include aluminum, copper, iron, brass, bronze, galvanized metal, stainless steel, carbon steel, and other metal alloys contained in waste mechanical and electrical parts, tools, containers, scrap metals, piping, wire, cable, gauges, valves, foil, planchets, and a variety of other metal items. The maintenance operation was inextricably linked with the generation of the material that created this IDC. The maintenance-generated materials were generated throughout the entire facility. Backlog containers of this IDC may contain a matrix of all light metals listed above.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 484 was assigned to classified non-nuclear material scrap metal shapes made primarily of stainless steel and aluminum. Prior to 1987, IDC 484 included beryllium shapes. These items were generated in Buildings 777 and 779 during disassembly operations of site-return units. Buildings 444, 707, and 883 generated rejected parts. Containers in inventory were generated from February 1983 to May 1991.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	Metal/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 485 was assigned to scrap D-38 classified metal shapes. Generation of this material occurred in Buildings 777 during disassembly of site-return units. Building 444 generated rejected parts. Containers in inventory were generated from July 1987 to August 1992.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 486 was assigned to classified tooling for disposal. Generation of these tools occurred in Buildings 707 and 777. The material consists primarily of obsolete tooling including pot chucks and inspection gauges. Containers in inventory were generated from October 1982 to December 1992.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 3/6/95

Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.5 Projected: 0.0 Total: 1.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 489 was assigned to scrap D-38 classified metal shapes generated in Building 777 and 779 during disassembly of site-return units. Containers in inventory were generated from February 1986 to September 1990.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.
WASTE STREAM SOURCE	The miscellaneous liquids waste form includes uranium solutions from criticality laboratories (IDC 504).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.
WASTE STREAM SOURCE	IDC 527 is caustic waste solutions consisting of sodium hydroxide or potassium hydroxide. Low-Level Dissolution in Building 771 used potassium hydroxide for flushing the condenser when dissolvind incinerator ash. H-4 Support Vacuum Systems used potassium hydroxide in an aqueous solution as a seal liquid. Vacuum Systems also used a seal liquid made up of water only. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supportin data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.

WASTE STREAM SOURCE

The Building 371 analytical laboratory receives liquid and solid samples from the entire plant site. Samples that are destined for Building 881 are analyzed in Building 371 to screen out those with high levels of radioactivity. Sludge and aqueous samples from Building 374 are analyzed for total alpha activity and plutonium, uranium, and americium content. Prior to analysis, the sludges are dissolved in nitric acid, hydrogen fluoride, or hydrochloric acid. Reagents are also used in sample preperation. Unused portions or excess prepared sample are placed in 4-liter plastic bottles.

The Building 559 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various ions, iron, silicon, isotopic compsition, and americium, gallium, neptunium, plutonium, uranium, and other metals (Resource Conservation and Recoverey Act [RCRA] - regulated and nonregulated). Solid samples are dissolved in a variety of acids, including nitric and hydrochloric. Other chemicals used in the laboratory include methanol, chloroform, and other organic solvents; titanium trichloride; ceric ammonium nitrate; sodium hydroxide; silver chloride; silver nitrate; and various metals standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also place on the bottles.

The Building 771 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various metals and ions, pH, and radioactivity. The principal chemicals used in the lab include sodium hydroxide, hydrochloric acid, nitric acid, cyclohexane, trioctyl phosphine oxide, yttrium, and various metal standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles.

RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS N/A

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 600 consists of an aluminum-magnesium-plutonium alloy generated by the Salt Scrub Process in Building 776 Pyrochemical Processing. The salt from the magnesium chloride-based Molten Salt Extraction Process and small quantities of salt from electrorefining process (R&D only) were combined with elemental aluminum (alloying agent) and magnesium (reductant) in a ceramic crucible. The mixture was melted in a furnace and stirred, resulting in a metal button. When cool, the button was separated from the salt and prepared for transfer to the Savannah River Site for processing.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 601 was produced in the pyrochemistry research in Building 776 and 779. This IDC was produced during developmental studies of aluminum oxide and magnesium oxide crucibles. These studies were conducted to determine the resistance on the crucible materials to thermal shock. The crucibles would break during processing. IDC 601 is used to describe the pieces of the crucibles collected. The crucibles could be contaminated with pyrochemistry process residues such as salt, plutonium, and small amounts of sodium metal. The aluminum and magnesium oxide was placed in metal cans and stored.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 653 consists of the free metal brushed from thesurface of plutonium-neptunium alloy buttons generated by electrorefining in Building 776 Pyrochemical Processing. The brushings were burned and sent to Buildign 771 and reburned prior to dissolution.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.03	0.0	0.0	0.0	0.0	0.03
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 654 salt was generated from experimental ER work to study the distribution of neptunium during electrorefining of plutonium. This salt is composed primarily of sodium chloride and potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and neptunium compounds. This salt may also contain sodium and potassium metal produced during the electrolysis of the molten salt mixture. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 655 During normal process operations, the electrorefining of plutonium-neptunium alloy processes in Buildings 776 and 779 generated broken magnesium oxide crucible pieces. The plutonium-neptunium combination was a special case and limited work was performed to generate this material. Upon cooling to room temperature, the crucible used in the process would be broken and its contents removed.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	RF115	Stream Name:	Coarse Graphite/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	17.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	318.3	51.9	381.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 115

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.93E+01
Pu-240	1.23E+00
Pu-239	5.38E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	12.9	0.0	0.0	2.2	2.6	17.7
Totals	12.9	0.0	0.0	2.2	2.6	17.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	12.9	0.0	0.0	2.2	2.6	17.7
Totals	12.9	0.0	0.0	2.2	2.6	17.7

As-Generated Form: Stored: 12.9 Projected: 4.8 Total: 17.7

Final Waste Form: Stored: 12.9 Projected: 4.8 Total: 17.7

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 300, Graphite Molds During the casting of plutonium in production foundry operations, the plutonium casting operations in Building 707 generated used graphite molds. The working surfaces were coated with calcium fluoride prior to using the mold. After the plutonium casting was removed from the mold, the molds were collected in a drum. Drums that contained recoverable amounts of plutonium were stored for subsequent scarfing of molds.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	RF115	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 9/5/94

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 115

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.93E+01
Pu-240	1.23E+00
Pu-239	5.38E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.2	0.0	0.0	0.7	0.9	5.8
Totals	4.2	0.0	0.0	0.7	0.9	5.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.2 Projected: 1.7 Total: 5.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 301, Classified Graphite Shapes During the casting of plutonium in production foundry operations, classified molds are segregated from non-classified molds. Prior to 1984, the classified molds were destroyed in Building 776.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	N/A	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
metal box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Totals	3.6	0.0	0.0	0.0	0.0	3.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Standard Waste Box	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 3.6 Projected: 0.0 Total: 3.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 302 includes Benelex and Plexiglas. Benelex is a very dense organic material used for radiation shielding around gloveboxes and tanks. In some cases, Benelex is laminated with lead. However, none of the containers identified here have lead lamination. The Benelex used by RFETS is usually 2 inches thick although occasionally two 2-inch thick pieces were bolted toghether to increase shield thickness. Plexiglas is a trade name used to describe a family of polycarbonate materials used for radiation shielding in glovebox windows and equipment enclosures. Plexiglas glovebox windows are generally 2- to 4-inches thick and can be in various sizes and shapes. Benelex and Plexiglas in the inventory were generated in Buildings 371, 707, 771, and 776. The IDC was generated as waste during replacement of shielding or stripout of unnecessary shielding during the installation of new gloveboxes or tanks.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	17.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	318.3	51.9	381.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.93E+01
Pu-240	1.23E+00
Pu-239	5.38E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.1	0.1	0.4
Totals	0.2	0.0	0.0	0.1	0.1	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.2 Total: 0.4

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 303, Scarfed Graphite Chunks After the casting of plutonium in production foundry operations, IDCs 300 and 301 were mechanically cleaned using a hand-held rotary-type sanding tool to grind off contamination in buildings 371, 707, 771, and 777, generating Scarfed Graphite Chunks. The mechanical cleaning (scarfing) of the mold surface removes most of the mold coating and plutonium contamination. This process generated IDC 303 and 310, as well as, IDC 312.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	RF115	Stream Name:	Coarse Graphite/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	17.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	250.7	155.7	345.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 115

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	2.93E+01
Pu-240	1.23E+00
Pu-239	5.38E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	18.7	23.3	42.6
Totals	0.6	0.0	0.0	18.7	23.3	42.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 42.0 Total: 42.6

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 312, Graphite Coarse After the casting of plutonium in production foundry operations, IDC 300 was mechanically cleaned in Buildings 371, 707, 771, and 777, generating coarse graphite. Material generated in this process were chunk pieces of graphite produced as a by-product of IDC 310 generation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	IDC 310, 312, 303.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W111	Handling:	CH	NMVP #:	RF 117	Stream Name:	Heavy Metal (non-SS)/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	60.5	0.0	168.7
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	141.0	29.0	393.3
Other Inorganic Material:	14.0	2.9	39.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.28E+01
Pu-240	2.22E+00
Pu-239	9.69E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.6	0.0	0.0	1.7	2.1	8.4
Totals	4.6	0.0	0.0	1.7	2.1	8.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.6	0.0	0.0	1.7	2.1	8.4
Totals	4.6	0.0	0.0	1.7	2.1	8.4

As-Generated Form: Stored: 4.6 Projected: 3.7 Total: 8.3

Final Waste Form: Stored: 4.6 Projected: 3.7 Total: 8.3

WASTE STREAM DESCRIPTION	Typically, these scrap metals consist of crucibles, funnels, rods and fixturing from several processes and production operations. Tantalum, tungsten and platinum are examples of scrap metals at the RFP.
WASTE STREAM SOURCE	Heavy metals have been produced as by-products of Rocky Flats operations in Buildings 371, 707, 771, 776, 777, 779, and 865; they are identified by IDC 320. The IDC 320 heavy nonspecial source metal was generated in various locations throughout the Rocky Flats. This IDC includes nonstainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
metal box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.2 Projected: 0.0 Total: 4.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 330 is Dry Combustibles. This IDC is dry combustibles such as cloth, paper, and wood. This IDC changes to 821, 831, 851, or 861 at the point of assay, depending on radiological content. Containers of IDC 330 currently in inventory were generated in all buildings handling fissile material. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	8.3	0.6	56.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	9.8	0.7	66.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.4	4.8	429.5
Rubber:	2.8	0.2	19.1
Plastics:	3.8	0.3	25.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.32E+01
Pu-240	1.40E+00
Pu-239	6.10E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	19.3	3.3	0.4	22.3	27.6	73.0
Totals	19.3	3.3	0.4	22.3	27.6	73.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	19.3	3.3	0.4	22.3	27.6	73.0
Totals	19.3	3.3	0.4	22.3	27.6	73.0

As-Generated Form: Stored: 19.3 Projected: 53.7 Total: 73.0

Final Waste Form: Stored: 19.3 Projected: 53.7 Total: 73.0

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is High Efficiency Particulate Air (HEPA) filters used in ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large filter plenums that filter the room air. Used filters were removed from their position in the ventilation system and packaged for further processing. The filters used on gloveboxes (nominal 8" x 8" x 5") were identified as IDC 335 if they were not acid contaminated. RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections in section 8.2.15.1.13 include generation of IDC-335 and IDC-342 to be processed to IDC-335.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This IDC changes to 822, 832, 852, or 862 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 337 represents PVC sheeting, poly bottles, supplied-air suits, polyethylene, and other plastics. IDC 337 changes to 825, 833, 853, or 863 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter

Inventory Date: 9/5/94

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	47.0	10.1	122.5
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	78.1	33.4	236.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.32E+01
Pu-240	1.40E+00
Pu-239	6.10E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.3	0.1	2.4	3.0	7.9
Totals	2.1	0.3	0.1	2.4	3.0	7.9

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 5.8 Total: 7.9

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the diceslum hexachlorsplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is either the filter media portion of HEPA filters or surface-water filters. HEPA filters are used on gloveboxes and in large filter plenums. Sock filters were used to prefilter operable unit 2 (OU-2) surface water prior to activated carbon treatment. Used HEPA filters were processed to segregate those portions with high plutonium content and those with low content. The wood frames were separated from the media and almost always disposed of as waste by packing in drums that were assigned IDC 330. the filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste. This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from the production Building 707 and could be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon. IDC 338 was meant to be used as a residue IDC and not as a waste IDC. Because sorting between IDCs was not accurate, some of the IDC 338 backlog containers are below the economic discard limit (EDL) and are therefore not residue. RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W107	Handling:	CH	NMVP #:	RF 121	Stream Name:	Soil & Cleanup Debris/TRU	Inventory Date:	9/5/94
Local ID:	IDC 374	Type:	TRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	273.1	208.9	628.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.0	12.0	12.0
Rubber:	0.0	0.0	0.0
Plastics:	12.0	12.0	12.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	64.9	9.6	628.4
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 121

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	3.30E+00
Pu-240	1.39E-01
Pu-239	6.06E-01
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	This waste stream is construction rubble generated during decontamination and decommissioning activities. This waste consists of blacktop/concrete/dirt/sand. The waste is generated from construction/demolition within the plutonium process buildings. The waste is usually packed in 55-gal. drums with multiple bag liners, a fiberboard liner, and a rigid polyethylene liner. Also, the waste can be packaged in DOT 7A, Type A metal boxes which are lined with a fiberboard and PVC liner. This waste is identified by IDC 374. Inventory data include mixed residues in this IDC. IDC 374-Construction rubble generated during decontamination and decommissioning operations. Metals are considered to be potentially present in the rubble from demolition and cleanup activities. Solvents are potentially present from the materials used during decontamination.
WASTE STREAM SOURCE	Soil and cleanup-debris (IDC 374) were generated during cleanup and construction activities around Rocky Flats. In most cases, construction or demolition activities generated rubble consisting of blacktop, concrete, dirt, sand , and rock. The rubble was packaged in plywood boxes with a fiberboard liner and a polyvinyl chloride (PVC) bag liner or in 55-gallon, DOT Type 7A drups. The waste was generated on a nonroutine basis. Information describing spendid activities generating soil and debris were often unavailable.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A-Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being present or absent). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort is in progress and the results will be incorporated when the effort is complete. No information available regarding uncertainty.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W121	Handling:	CH	NMVP #:	RF 119	Stream Name:	Cemented filters/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	63.3	27.1	191.6
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	78.1	33.4	236.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	3.60E+01
Pu-240	1.51E+00
Pu-239	6.61E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.9	0.7	0.1	5.2	6.5	21.5
Totals	8.9	0.7	0.1	5.2	6.5	21.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.9	1.5	0.1	5.2	6.5	22.2
Totals	8.9	1.5	0.1	5.2	6.5	22.2

As-Generated Form: Stored: 8.9 Projected: 12.5 Total: 21.4

Final Waste Form: Stored: 8.9 Projected: 12.5 Total: 21.4

WASTE STREAM DESCRIPTION	Processed filter media, IDC 376, is material which has been treated using Portland cement to absorb moisture and neutralize acid contamination. Filter waste is packaged in 55-gallon drums and metal standard waste boxes. Inventory data include residues within the same IDCs because they are regulated as waste.
WASTE STREAM SOURCE	The material in this IDC is the filter media portion of acid-contaminated glovebox or plenum HEPA filters or Ful-Flo filters with free liquids. Processing was performed in the Site Reduction Vaults in Building 776. Used HEPA filters were processed to separate any portions containing high plutonium content from portions with low content. The wood frames were separated from the media and usually disposed of as waste by packing in a drum that was assigned IDC 330. The filter media pieces were identified as IDC 339 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste. The media were placed in crates, Portland cement was added, then crates were sealed. Some IDC 376 material could be the remaining material after the IDC 338 media were processed to recover the plutonium. Ful-Flo filters which were used to filter corrosive gas were also processed to separate any portions containing high plutonium content from portions with low plutonium content. Pieces of media with low activity were identified as IDC 376 and packaged for shipment as waste. The media were placed in approximately 10-gallon plastic bags and Portland cement was added. The bags were then sealed and placed in a drum. IDC 376 filter media in this backlog population was derived from the processing of HEPA filters from Buildings 371, 771, 776, and 770. The HEPA filters could have orginally been assigned ICDs 335 342, 490, 491 or 492. Filter media from Building 771 could have been used to filter nitric acid vapors.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	N/A	Stream Name:	Organic Resins/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	9.97E+00
Pu-240	4.19E-01
Pu-239	1.83E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	The ion-exchange resins were important to the plutonium purification processes at RFETS. Plutonium-contaminated materials were often dissolved in nitric acid and processed through ion exchange. The ion-exchange resin contained in an ion-exchange column was charged with highly concentrated nitric acids by trickling this solution through the columns. A plutonium-contaminated solution was then trickled through the column. The charged resin beads attracted the plutonium from the contaminated solution to the surface of the resin bead. The loaded resin beads were then leached by trickling another nitric acid solution through the tube. This final nitric acid solution drew the plutonium from the beads into solution and allowed for purification of the plutonium. The resin was periodically replaced when this process had depleted the efficiency of the resin. The ion exchange resins in use at Rocky Flats were generally small plastic (polystyrene) beads in which long-chain organic compounds with an activated group are imbedded (such as Dowex 1 x 2). Unleached resin IDC 430, was produced when the resin ion exchange columns was replaced. Though this IDC is titled "unleached" resin, the generators of resins confirm that all resins were rinsed with at least, weak acid before the resins were removed from the columns. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt% but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	N/A	Stream Name:	Organic Resins/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics

Inventory Date: 9/5/94

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	9.97E+00
Pu-240	4.19E-01
Pu-239	1.83E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	The ion-exchange resins were important to the plutonium purification processes at RFETS. Plutonium-contaminated materials were often dissolved in nitric acid and processed through ion exchange. The ion-exchange resin contained in an ion-exchange column was charged with highly concentrated nitric acids by trickling this solution through the columns. A plutonium-contaminated solution was then trickled through the column. The charged resin beads attracted the plutonium from the contaminated solution to the surface of the resin bead. The loaded resin beads were then leached by trickling another nitric acid solution through the tube. This final nitric acid solution drew the plutonium from the beads into solution and allowed for purification of the plutonium. The resin was periodically replaced when this process had depleted the efficiency of the resin. The ion exchange resins in use at Rocky Flats were generally small plastic (polystyrene) beads in which long-chain organic compounds with an activated group are imbedded (such as Dowex 1 x 2). ILeached resin IDC 431, was produced when the resin ion exchange columns were replaced. The resin was leached (rinsed) with water before the resin was removed from the columns. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W115	Handling:	CH	NMVP #:	N/A	Stream Name:	Insulation/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	91.7	1.9	353.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.8	0.0	9.6
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.54E+01
Pu-240	1.07E+00
Pu-239	4.67E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.7	0.7	0.9	2.7	2.9	14.9
Totals	7.7	0.7	0.9	2.7	2.9	14.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.7	0.7	1.1	2.7	2.9	15.1
Totals	7.7	0.7	1.1	2.7	2.9	15.1

As-Generated Form: Stored: 7.7 Projected: 7.3 Total: 15.0

Final Waste Form: Stored: 7.7 Projected: 7.3 Total: 15.0

WASTE STREAM DESCRIPTION	This waste stream is contaminated insulation.
WASTE STREAM SOURCE	Item Description Code 438 Maintenance, repair, and strip-out operations in Buildings 371, 374, 444, 559, 666, 707, 771, 774, 776, 777, 779, 865, 881, and 883 produced waste insulation. Insulation waste is generated by repalcement of furnace heating elements, construction, maintenance, and demolition activities within the Protected Area at Rocky Flats. During these activities, insulation material is removed from furnaces, boilers, piping, ceilings and walls and heating and cooling systems.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRU	Inventory Date:	
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	2.0	0.0	5.3
Other Inorganic Material:	136.8	16.8	352.5
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	1.2	0.0	3.1
Plastics:	30.3	3.7	78.1
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	150.0		
Packaging Material Plastic:	10.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	9.30E+00
Pu-240	3.91E-01
Pu-239	1.71E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	15.0	0.7	0.0	0.2	0.2	16.0
metal box / 4x4x7	9.4	0.0	0.0	0.0	0.0	9.4
Standard Waste Box	0.0	1.5	0.0	0.2	0.2	1.9
Totals	24.4	2.2	0.0	0.3	0.4	27.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.7	0.0	0.2	0.2	4.8
Standard Waste Box	1.9	20.4	0.0	0.2	0.2	22.7
Totals	5.6	21.1	0.0	0.3	0.4	27.5

As-Generated Form: Stored: 24.4 Projected: 2.9 Total: 27.4

Final Waste Form: Stored: 5.6 Projected: 21.8 Total: 27.5

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 440 includes glass waste from analytical laboratories and recovery processes, standard light bulbs generated inside the PA, and ceramic materials. Glass waste assigned IDC 440 was generated in Buildings 123,371, 444, 559, 707, 771, 776, 777, 889. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data. This waste stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Assuming 67% of projected generation will be in 55-gallon drums based on current container inventory.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass	Inventory Date:	10/20/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	9.30E+00
Pu-240	3.91E-01
Pu-239	1.71E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.0	0.4	0.0	0.1	0.1	4.6
Totals	4.0	0.4	0.0	0.1	0.1	4.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.0 Projected: 0.6 Total: 4.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	Raschig Rings currently in WEMS assigned IDC 442 were generated in Buildings 771, 776, and 777. Prior to being replaced, the tanks were drained and the rings were leached with dilute nitric acid or water. The rings generated in Building 771 are from the production processes and Tanks D80-85, d0-360, D-361, D-451, D-454, D-467, D-750, D-706, D-922, D-973, D-974, D-980, D-1008, D-1013, D-1022, and D-1081. Rings generated in Building 776 are from the Size Reduction Process and Tanks SR 3, 4, and 5 and as unused rings. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.7	0.0	24.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	250.8	19.1	415.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.6	0.0	12.6
Rubber:	0.0	0.0	0.0
Plastics:	8.7	0.6	14.5
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	153.7		
Packaging Material Plastic:	31.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	9.30E+00
Pu-240	3.91E-01
Pu-239	1.71E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	28.1	1.6	0.0	0.4	0.5	30.6
metal box / 4x4x7	15.9	0.0	0.0	0.0	0.0	15.9
Totals	43.9	1.6	0.0	0.4	0.5	46.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	28.1	1.6	0.0	0.4	0.5	30.6
Standard Waste Box	0.0	3.0	0.0	7.9	9.9	20.8
Totals	28.1	4.6	0.0	8.3	10.4	51.4

As-Generated Form: Stored: 43.9 Projected: 2.5 Total: 46.4

Final Waste Form: Stored: 28.1 Projected: 23.3 Total: 51.4

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	Raschig Rings currently in WEMS assigned IDC 442 were generated in Buildings 771, 776, and 777. Prior to being replaced, the tanks were drained and the rings were leached with dilute nitric acid or water. The rings generated in Building 771 are from the production processes and Tanks D80-85, d0-360, D-361, D-451, D-454, D-467, D-750, D-706, D-922, D-973, D-974, D-980, D-1008, D-1013, D-1022, and D-1081. Rings generated in Building 776 are from the Size Reduction Process and Tanks SR 3, 4, and 5 and as unused rings. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 479 is assigned to empty reusable cans generated in Buildings 559, 707, and 771 (containers currently in WEMS from these buildings). Stainless-steel cans were used to handle plutonium-contaminated material. Primary generation was through the use of these cans to manually transfer materials between gloveboxes. Cans that were introduced to the process were typically recycled and reused. There were no generation process descriptions in WSRIC for this waste in Buildings 559, 707, and 771. In Building 371, the Dicesium Hexachloroplutonate (DCHP) Process often used the cans for transferring materials into the stacker.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	RF 117	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	78.4	0.8	238.9
Aluminum-base Metal/Alloys:	9.9	0.1	30.1
Other Metals/Alloys:	3.7	0.0	11.4
Other Inorganic Material:	6.5	0.0	20.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.2	0.0	3.7
Rubber:	1.4	0.0	4.4
Plastics:	10.4	0.1	31.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	142.8		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	64.1	16.1	7.6	34.9	16.5	139.2
Drum / 85-gallon	0.3	0.0	0.0	0.0	0.0	0.3
metal box / 4x4x7	44.4	0.0	0.0	0.0	0.0	44.4
plywood box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Standard Waste Box /	13.2	16.1	7.7	35.0	16.8	88.8
Totals	125.2	32.2	15.2	70.0	33.2	275.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	64.1	16.1	7.6	34.9	16.5	139.2
Standard Waste Box	13.2	72.8	7.7	35.0	16.8	145.5
Totals	77.3	88.9	15.2	70.0	33.2	284.7

As-Generated Form: Stored: 125.2 Projected: 150.7 Total: 275.8

Final Waste Form: Stored: 77.3 Projected: 207.4 Total: 284.7

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 480 is assigned to line- and nonline-generated light metals generated in Buildings 371, 374, 444, 559, 707, 771, 776, 777, 779, 865, and 991 (containers currently in WEMS these buildings). Light metals include aluminum, copper, iron, brass, bronze, galvanized metal, stainless steel, carbon steel, and other metal alloys contained in waste mechanical and electrical parts, tools, containers, scrap metals, piping, wire, cable, gauges, valves, foil, planchets, and a variety of other metal items. The maintenance operation was inextricably linked with the generation of the material that created this IDC. The maintenance-generated materials were generated throughout the entire facility. Backlog containers of this IDC may contain a matrix of all light metals listed above.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	RF 117	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	160.4	1.7	488.7
Aluminum-base Metal/Alloys:	20.2	0.2	61.6
Other Metals/Alloys:	7.6	0.0	23.3
Other Inorganic Material:	13.4	0.1	40.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.5	0.0	7.6
Rubber:	2.9	0.0	8.9
Plastics:	21.2	0.2	64.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 481 was assigned to light, nonspecial source metals. This material consisted primarily of stainless-steel and aluminum equipment used throughout the plant; this equipment was rinsed to remove plutonium contamination. This IDC is no longer active and has been replaced by IDC 480. The three containers in inventory were generated in Building 771, 776, and 777 in November 1984.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	5.2	0.0	0.0	0.0	0.0	5.2
Totals	5.2	0.0	0.0	0.0	0.0	5.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 5.2 Projected: 0.0 Total: 5.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 484 was assigned to classified non-nuclear material scrap metal shapes made primarily of stainless steel and aluminum. Prior to 1987, IDC 484 included beryllium shapes. These items were generated in Buildings 777 and 779 during disassembly operations of site-return units. Building 444, 707, and 883 generated rejected parts. Containers in inventory were generated from February 1983 to May 1991.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 485 was assigned to scrap D-38 classified metal shapes. Generation of this material occurred in Building 777 during disassembly of site-return units. Building 444 generated rejected parts. Containers in inventory were generated from July 1987 to August 1992.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 9/5/94

Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.1	0.0	0.0	0.0	0.0	3.1
Totals	3.1	0.0	0.0	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.1 Projected: 0.0 Total: 3.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 486 was assigned to classified tooling for disposal. Generation of these tools ocurred in Buildings 707 and 777. The material consists primarily of obsolete tooling including pot chucks and inspection gauges. Containers in inventory were generated from October 1982 to December 1992.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 487 is classified plastic shapes used in handling and shipping. If TRU, shapes must be declassified prior to shipment. If LLW, IDC must be authorized by NTS prior to shipment. Classified Waste drums must be stenciled and handled according to Safeguards and Security procedures.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 489 was assigned to scrap D-38 classified metal shapes generated in Buildings 777 and 779 during disassembly of site-return units. Containers in inventory were generated from February 1986 to September 1990.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	37.6	11.5	66.8
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	22.8	7.0	40.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	13.9	0.0	27.8
Rubber:	0.2	0.0	0.3
Plastics:	0.3	0.0	0.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	[illegible]	0.0	0.0
Packaging Material Steel:	146.7		
Packaging Material Plastic:	37.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	3.32E+01
Pu-240	1.40E+00
Pu-239	6.10E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.9	1.5	0.2	10.4	12.9	33.9
metal box / 4x4x7	9.5	0.0	0.0	0.0	0.0	9.5
Standard Waste Box /	13.2	0.0	0.0	0.0	0.0	13.2
Totals	31.7	1.5	0.2	10.4	12.9	56.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.9	1.5	0.2	10.4	12.9	33.9
Standard Waste Box	13.2	0.0	0.0	0.0	0.0	13.2
Totals	22.2	1.5	0.2	10.4	12.9	47.1

As-Generated Form: Stored: 31.7 Projected: 25.0 Total: 56.6

Final Waste Form: Stored: 22.2 Projected: 25.0 Total: 47.1

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is HEPA filters in the ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large plenums that filter the room and glovebox air. Used filters were removed from their position in the ventilation system and packaged for further processing. The larger-sized filters used in filters plenums were identified and packaged as IDC 492 if acid contaminated. IDC 492 HEPA filters (24" x 24"), acid contaminated, are large HEPA filters (nominal 24" x 24" x 5" or 24" x 24" x 12") that were used in filter plenum racks. These filters consist of filter media contained within a wooden or metal frame. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter

Inventory Date: 9/5/94

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	19.0	0.0	38.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	11.5	0.0	23.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	47.6	0.0	99.1
Rubber:	0.6	0.0	1.1
Plastics:	1.0	0.0	2.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	187.1		
Packaging Material Plastic:	2.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.32E+01
Pu-240	1.40E+00
Pu-239	6.10E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	16.0	0.0	0.0	0.0	0.0	16.0
Totals	16.0	0.0	0.0	0.0	0.0	16.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.0	0.0	0.0	0.0	0.0	16.0
Totals	16.0	0.0	0.0	0.0	0.0	16.0

As-Generated Form: Stored: 16.0 Projected: 0.0 Total: 16.0

Final Waste Form: Stored: 16.0 Projected: 0.0 Total: 16.0

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is a variety of plenum prefilters used in the ventilation systems at Rocky Flats. Plenum prefilters have been and are used in all of the buildings that contain plutonium processing activities. These prefilters are used in large plenums that filter the room and glovebox air. Used prefilters were removed from their position in the ventilation system and packaged for furtehr processing. IDC 491 plenum prefilters range from furnace-type filters to pleated fiberglass filters and can be as large as 24" x 24" x 12". The filter medium consists of fiberglass packing or paper which may be more or less dense, depending on filtering needs. Wire mesh can be used to hold the media in place. The frame material for these prefilters is cardboard. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.
WASTE STREAM SOURCE	IDC 508 is hydrochloric acid (HCl) containing plutonium generated by various process operations and glovebox-cleaning operations using HCl. Process operations and glovebox-cleaning operations were definec based on preliminary analytical results. IDC 508 was generated in Cation Exchange in Building 771 from washing residual impurities from the resin with dilute nitric acid. Chemical Technology in Buiding 771 generated miscellaneous chloride acid solutions from Batch Chloride Dissolution. This process dissolved plutonium oxide with hydrochloric acid. Dicesium hexachloroplutonate (DCHP) preparation in Building 371 also generated IDC 508. This process produced DCHP, a salt used to remove americium from nonspecification and impure plutonium oxide. The oxide was dissolved in hydrochloric acid and filtered. The filtrate was then precipitated using cesium chloride and sodium nitrite in hydrochloric acid and then filtered again. Plutonium was recovered from the DCHP precipitation filtrate through chloride anion exchange. This was achieved by processing the solution through ion columns, and the plutonium loaded onto the anion exchange resin while most of the impurities stayed in the solution. This solution then left the column as effluent (IDC 501). The ion column was later washed to release the chloride eluate (IDC 508). Peroxide Precipitation in Building 779 reacted ion exchange effluent with hydrogen peroxide to produce plutonium peroxide, which was then calcined to produce plutonium oxide. The plutonium peroxide precipitate was filtered and washed. Residue Recovery Extraction in Building 779 recovered actinides using aqueous leaching techniques. Hydrofluoric acid solutions containing aluminium fluoride, cesium chloride, calcium fluoride, and sodium nitrate were generated. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.

WASTE STREAM SOURCE

Item Description Code 541

Building 371

The Building 371 analytical laboratory receives liquid and solid samples from the entire plant site. Samples that are destined for Building 881 are analyzed in Building 371 to screen out those with high levels of radioactivity. Sludge and aqueous samples from Building 374 are analyzed for total alpha activity and plutonium, uranium, and americium content. Prior to analysis, the sludges are dissolved in nitric acid, hydrogen fluoride, or hydrochloric acid. Reagents are also used in sample preparation. Unused portions or excess prepared sample are placed in 4-liter plastic bottles.

Building 559

The Building 559 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various ions, iron, silicon, isotopic composition, and americium, gallium, neptunium, plutonium, uranium, and other metals (Resource Conservation and Recovery Act [RCRA]-regulated and nonregulated). Solid samples are dissolved in a variety of acids, including nitric and hydrochloric. Other chemicals used in the laboratory include methanol, chloroform, and other organic solvents; titanium trichloride; ceric ammonium nitrate; sodium hydroxide; silver chloride; silver nitrate; and various metals standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles.

Building 771

The Building 771 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various metals and ions, pH, and radioactivity. The principal chemicals used in the lab include sodium hydroxide, hydrochloric acid, nitric acid, cyclohexane, trioctyl phosphine oxide, yttrium, and various metal standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS N/A

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W112	Handling:	CH	NMVP #:	RF 113	Stream Name:	Solified Lab Waste/TRU	Inventory Date:	9/5/94
Local ID:	IDC 802	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	Z1110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	847.2	303.9	985.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	190.3	68.4	221.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	112.0	40.1	130.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 113

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	9.76E-01
Pu-240	4.10E-02
Pu-239	1.79E-01
Am-241	3.15E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.5	26.3	0.0	0.0	0.0	33.8
Totals	7.5	26.3	0.0	0.0	0.0	33.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.5	26.3	0.0	0.0	0.0	33.8
Totals	7.5	26.3	0.0	0.0	0.0	33.8

As-Generated Form: Stored: 7.5 Projected: 26.0 Total: 33.5

Final Waste Form: Stored: 7.5 Projected: 26.0 Total: 33.5

WASTE STREAM DESCRIPTION	IDC 802 is a cemented final waste form.
WASTE STREAM SOURCE	IDC No. 802. This waste stream is liquid waste solidified with Portland Cement. This waste consists of waste liquids from the analytical labs, research and development laboratories, and maintenance shops which are packaged and sent to Building 774 for immobilization with Portland cement and absorbent cement. These are wastes which are incompatible with the process collection system and the liquid waste treatment plant. Acidic wastes are neutralized before immobilization. Immobilization is done in 55-gallon drums. Approximately 21 gallons of waste are added to each drum prior to storage. This waste steam is newly identified since the Storage and Inventory Report.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W105	Handling:	CH	NMVP #:	RF 114	Stream Name:	Solidified Process Solids/TRU	Inventory Date:	9/5/94
Local ID:	IDC 806	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	489.0	376.2	635.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	135.8	104.5	176.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	73.1	56.2	95.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source:

TRUCON CODE

RF 114

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.91E+02
Pu-240	8.01E+00
Pu-239	3.50E+01
Am-241	4.76E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	0.0	0.0	89.9	112.3	202.2
Totals	0.0	0.0	0.0	89.9	112.3	202.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	89.9	112.3	202.2
Totals	0.0	0.0	0.0	89.9	112.3	202.2

As-Generated Form: Stored: 0.0 Projected: 202.2 Total: 202.2

Final Waste Form: Stored: 0.0 Projected: 202.2 Total: 202.2

WASTE STREAM DESCRIPTION	Cemented final waste form.
WASTE STREAM SOURCE	This waste stream represents the solidified final form of all particulate and sludge type materials. Particulates and sludge type materials are immobilized with Portland cement. The cemented wastes are cast into 1-gallon molds and allowed to cure prior to packaging. This is the final waste form for Firebrick, Pulverized or Fines/TRM (RF-T036), Particulate Sludge/TRM (RF-T005), and Sand, Slag, and Crucible/TRM (RF-T059). IDC 806 - All inorganic particulate and inorganic sludge waste must be immobilized by processing into a solid and identified as IDC 806.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	RF 126	Stream Name:	Organic Resins/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	213.6	2.3	362.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	44.0	0.5	74.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	59.5	0.6	100.8
Cement (solidified):	32.0	0.4	54.3
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

RF 126

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	9.97E+00
Pu-240	4.19E-01
Pu-239	1.83E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	0.0	0.0	15.6	19.5	35.2
Totals	0.0	0.0	0.0	15.6	19.5	35.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	15.6	19.5	35.2
Totals	0.0	0.0	0.0	15.6	19.5	35.2

As-Generated Form: Stored: 0.0 Projected: 35.2 Total: 35.2

Final Waste Form: Stored: 0.0 Projected: 35.2 Total: 35.2

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	IDC 809 is leached ion column resin which has been cemented. Resin cannot be cemented into IDC 806 since it is organic.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Volumes include final form waste from treating the following streams: RF-TR0431, RF-TT0430, RF-TT0431, RF-TR0430.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	N/A	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	67.4	1.4	289.5
Rubber:	6.4	0.1	27.7
Plastics:	19.6	0.4	84.2
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	12.5	8.8	6.7	22.2	18.3	68.4
Totals	12.5	8.8	6.7	22.2	18.3	68.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	12.5	11.6	6.7	22.2	19.8	72.7
Totals	12.5	11.6	6.7	22.2	19.8	72.7

As-Generated Form: Stored: 12.5 Projected: 56.0 Total: 68.4

Final Waste Form: Stored: 12.5 Projected: 59.7 Total: 72.2

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Item Description 821, dry combustibles such as paper, cloth, wood, etc. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No.

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	10.8	25.5	22.1	72.9	65.4	196.8
Totals	10.8	25.5	22.1	72.9	65.4	196.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 10.8 Projected: 186.0 Total: 196.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Wet combustible transuranic wastes, such as paper, cloth, and wood, which contain a discernible amount of moisture must be drained or wrung out prior to packaging to prevent accumulation of free liquid. These wastes are classified as IDC 822. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W100	Handling:	CH	NMVP #:	N/A	Stream Name:	Cemented Sludge/TRU	Inventory Date:	9/5/94
Local ID:	IDC 823	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	Z1110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	29.3	0.7	98.7
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	10.5	0.2	35.5
Solidified Inorganic Material:	26.3	0.6	88.6
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	17.5	0.4	59.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	7.20E-01
Pu-240	3.02E-02
Pu-239	1.32E-01
Am-241	3.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.1	2.7	4.1	8.2	8.2	30.2
Totals	7.1	2.7	4.1	8.2	8.2	30.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.1	2.7	4.1	8.2	8.2	30.2
Totals	7.1	2.7	4.1	8.2	8.2	30.2

As-Generated Form: Stored: 7.1 Projected: 23.1 Total: 30.2

Final Waste Form: Stored: 7.1 Projected: 23.1 Total: 30.2

WASTE STREAM DESCRIPTION	This waste consists of cemented miscellaneous sludge (IDC 823)
WASTE STREAM SOURCE	IDC 823, cemented miscellaneous sludge, was generated when sludge designated as inorganic particulate and sludgy material that was below the economic discard limit (EDL) was placed in 1-gallon paint cans and covered with Portland cement or mixed with cement into a block. The first scenario was conducted in Building 771 and the second in Building 371. This could have included IDCs 290-299 and was done to meet the Waste Isolation Pilot Plant (WIPP) waste acceptance criteria. The material came primarily from Nash pumps in Building 771 and included vacuum grease and oily sludge. One drum of the material was apparently generated when the pit in front of Building 707 was cleaned out. However, the contents of the pit sludge could not be ascertained. One drum was generated in the Size Reduction Vault in Building 776. Six drums were generated in Bulding 774 and stored in Building 371.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	RF 117	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	169.4	1.7	365.2
Aluminum-base Metal/Alloys:	21.3	0.2	46.0
Other Metals/Alloys:	8.0	0.0	17.4
Other Inorganic Material:	14.2	0.1	30.6
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.6	0.0	5.7
Rubber:	3.1	0.0	6.7
Plastics:	22.4	0.2	48.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	9.8	4.1	1.6	8.6	5.4	29.5
Totals	9.8	4.1	1.6	8.6	5.4	29.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	9.8	4.1	1.6	8.6	5.4	29.5
Totals	9.8	4.1	1.6	8.6	5.4	29.5

As-Generated Form: Stored: 9.8 Projected: 19.8 Total: 29.5

Final Waste Form: Stored: 9.8 Projected: 19.8 Total: 29.5

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 824 is assigned to transuranic light metals generated in Buildings 371, 559, 707, and 771 (containers currently in WEMS from these buildings). Light metals include aluminum, copper, iron, brass, bronze, galvanized metal, stainless steel, carbon steel, and other metal alloys contained in waste mechanical and electrical parts, tools, containers, scrap metals, piping, wire, cable, gauges, valves, foil, planchets, and a variety of other metal items.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRU	Inventory Date:	9/4/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	25.7	0.7	56.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.1	0.0	0.3
Rubber:	1.7	0.0	3.8
Plastics:	42.0	1.2	92.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	21.6	9.4	8.1	27.1	24.1	90.3
Totals	21.6	9.4	8.1	27.1	24.1	90.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	21.6	20.4	8.2	27.2	24.3	101.8
Totals	21.6	20.4	8.2	27.2	24.3	101.8

As-Generated Form: Stored: 21.6 Projected: 68.6 Total: 90.3

Final Waste Form: Stored: 21.6 Projected: 80.1 Total: 101.7

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 825 is PVC sheeting, poly bottles, supplied-air suits, and other plastics. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Assume 70% of IDC 833 generation will be drum/55-gal based on current container distribution.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	10.0	0.0	0.0	0.0	0.0	10.0
Standard waste box /	9.4	0.0	0.0	0.0	0.0	9.4
Totals	19.4	0.0	0.0	0.0	0.0	19.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 19.4 Projected: 0.0 Total: 19.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 831 is dry combustibles such as cloth, paper, and wood. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible

Inventory Date: 9/5/94

Waste Matrix Code: S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	66.1	0.0	0.0	0.0	0.0	66.1
Totals	66.1	0.0	0.0	0.0	0.0	66.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 66.1 Projected: 0.0 Total: 66.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.2	0.0	0.0	0.0	0.0	6.2
Totals	6.2	0.0	0.0	0.0	0.0	6.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.2 Projected: 0.0 Total: 6.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 833 represents PVC sheeting, poly bottles, supplied-air suits, polyethylene, and other plastics. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery Byproducts/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 12/30/99

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	193.9	47.5	540.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	166.4	0.0	237.6
Vitrified:	0.0	0.0	0.0
Cellulosics:	176.1	140.4	211.7
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	34.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	7.2	0.0	112.1	140.1	259.4
Totals	0.0	7.2	0.0	112.1	140.1	259.4

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 259.4 Total: 259.4

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Oxidized salt, IDC 0999, is a projected waste form based on current plans for treatment of pyrochemical salts to meet the WIPP-WAC and DOT requirements. There will be no appreciable increase in the volume of these salts due to treatment (oxidation), but there will be a slight, as yet unquantified, mass increase due to the addition of oxidant.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W106	Handling:	CH	NMVP #:	RF-116	Stream Name:	Supercompacted Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5330

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	375.7	251.3	483.0
Rubber:	35.9	24.0	46.1
Plastics:	108.1	72.3	139.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	301.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF-116C

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	IDC 2116 is supercompacted combustible waste consisting of any combination of IDC 831, 832, or 835 waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W106	Handling:	CH	NMVP #:	RF-116	Stream Name:	Supercompacted Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5330

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	257.7	33.4	380.1
Rubber:	24.6	3.2	36.3
Plastics:	74.2	9.6	109.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	301.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF-116C

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 3.7 Projected: 0.0 Total: 3.7

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	Soft wastes are inspected for rejectable items, including free liquids and metal, which are separated from the soft waste for further disposition. Soft wastes are moved to the precompactor where they are placed in an empty 35-gallon drum located in the precompactor. The soft waste is precompacted using a 30-ton precompactor. Once the drum is filled with precompacted waste, the lid is placed on the drum. The drum is transferred to the appropriate glovebox line for piercing. Prior to supercompaction, drums of soft waste are pierced with four holes to allow air to escape and to reduce the amount of "springback" during supercompaction. After piercing, the drums are moved to the supercompactor. A mold is lowered over the drum. Once the mold is in place, the supercompactor is lowered, compacting the drum. Liquid forced out of the waste during compaction is collected by the liquid waste collection system. After supercompaction, the pucks (supercompacted 35-gallon drums) are moved to staging. An operator selects from the available pucks to efficiently fill 55-gallow loadout drums.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W011	Handling:	CH	NMVP #:	RF 117	Stream Name:	Metal/TRM
Local ID:	IDC 480	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/30/99

Waste Matrix Code: S5112

AS-GENERATED EPA CODES

D007, D002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.10E+01
Pu-240	4.64E-01
Pu-239	2.03E+00
Am-241	1.84E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
As-Generated Form:	Stored: 0.0	Projected: 0.0			Total: 0.0	

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Final Waste Form:	Stored: 0.0	Projected: 0.0			Total: 0.0	

WASTE STREAM DESCRIPTION	This waste stream is metal tools, etc. generated during glovebox operations.
WASTE STREAM SOURCE	The one container of IDC 480, Light metal, in this waste form was generated in Building 707, Module K, in April 1991. The metal in this container is line generated material.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed. RFP has assumed this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and several bag liners.
FINAL FORM COMMENTS	

HANFORD SITE

Location and Description

The Hanford Site (RL) is located north of the Tri Cities, Washington (Richland, Kennewick, and Pasco), on a 1450 square kilometer area of semiarid land within the Columbia River Basin in the southeastern corner of Washington State. Normal Columbia River elevations range from 119 meters, where the Columbia River enters RL near the Priest Rapids Dam, to 104 meters where it leaves the RL near the 300 area.

Activities at RL are centralized in numerically designated areas. The reactor facilities are located along the Columbia River in what is known as the 100-Area. The reactor fuel processing and waste management facilities are in the 200-Area. The 300-Area, located adjacent to, and north of, Richland, contains the reactor fuel manufacturing facilities and the research and development laboratories. The 400-Area, five miles northwest of the 300-Area, contains the Fast Flux Test Facility, a sodium-cooled fast breeder reactor. The 600-Area covers all locations not specifically given an area designation. Adjacent to, and north of, Richland, the 1100-Area contains facilities associated with administration, maintenance, transportation, and materials procurement and distribution. The 3000-Area, contains engineering and administrative offices. Administrative buildings, including the Federal Building, are located in the 700-Area, which is in downtown Richland.

RL is administered by the DOE Richland Operations Office. The current Management and Operating Contractor is Westinghouse Hanford Company.

Mission

The Hanford Site was acquired by the Federal Government in 1943 for the construction and operation of facilities to produce plutonium for the atomic weapons program during World War II. For more than 30 years, Hanford Site facilities were primarily dedicated to the production of plutonium for national defense and management of the wastes generated by chemical processing operations. In later years, programs at the Hanford Site became increasingly diverse, involving research and development for advanced reactors, renewable energy technologies, waste disposal technologies, and cleanup of contamination from past practices. The DOE has ended the production mission at the Hanford Site and is currently reorienting activities toward management of its wastes cleanup of the site. The mission now is one of environmental management, demonstration and application of advanced remediation technologies, and restoration of the Hanford Site.

During the wartime Manhattan Project, the town of Richland, Washington, was wholly-owned and controlled by the Government.

Waste Information

Processes

Retrievably stored, CH TRU waste has been received from 55 generating areas, buildings, and offsite facilities.

The Plutonium Finishing Plant (PFP) (Z Plant) is one of Hanford's waste generators and is the major source of CH TRU solid waste by volume (approximately 53.6%) The PFP where the Pu Reclamation Facility, Pu conversion, product handling, decontamination and decommissioning, analytical and chemical technology laboratories are located. Waste common to all of these are: surgical gloves, paper, glass, glovebox gloves, metal tools and equipment, and HEPA filters.

At the Pu Reclamation Facility, Pu was reclaimed from scrap solutions and solids. The scrap was treated in various ways to produce soluble and/or leachable forms of Pu for recovery. Waste generated included acid-soaked rags, liquid organics, and sludges.

Pu Conversion takes place at the Remote Mechanical C Line (RMC Line) where the Pu conversion processes received Pu nitrate as feed and converted it to either Pu oxide or metal. Waste generated included sludges, hydraulic oils, and acid-soaked rags.

Product handling includes receipt, shipment, repackaging, and nondestructive assay of special nuclear materials. Waste generated included damp rags, leather gloves, and empty metal cans used for shipping.

Decontamination and Decommissioning removed selected PFP facilities such as process gloveboxes and associated systems, ventilation systems, vacuum systems, and drain systems and dispose of them. Waste generated included damp rags, and building rubble (e.g., concrete, steel, wool, etc.).

Analytical and Chemical Technology Laboratories provide laboratory services to other PFP operations. Waste generated here included liquid organics, sludges, damp rags, and empty metal cans for shipping.

Another waste generator at Hanford was the Plutonium Uranium Extraction (PUREX) Plant. Products from this plant were weapons-grade plutonium, fuel-grade plutonium, depleted uranium, slightly enriched uranium, neptunium, and thorium. The plutonium conversion, process solution sampling, laboratory analyses, plant ventilation, and facility ventilation generated waste that was common to all these PUREX operations including surgical gloves, plastic (polyvinyl chloride and polyethylene), tape, paper, glass, glovebox gloves, and metal tools and equipment.

The overall PUREX Plant process consisted of seven fundamental interfacing processing units: feed preparation; solvent extraction, separation, and purification;
solvent recovery and treatment for recycling; backcycle waste system; acid recovery; waste treatment; offgas treatment; and conversion of plutonium nitrate to plutonium oxide.

Pu conversion operations received Pu nitrate as feed and converted the Pu to Pu oxide. Wastes generated were old and failed equipment, port covers, replaced windows, brackets and hardware, and acid-soaked rags.

Process solution sampling operations extract liquid samples from process control points to be used in system analysis and control. After use, all liquids are drained to the PUREX liquid waste system. Waste generated at this facility included broken glassware and plasticware, wet rags and paper, and piping and valving equipment.

Laboratory Analysis Operations were performed on liquid process samples used for system analysis and control. After use, all liquids were drained to the PUREX liquid waste system. Waste generated were broken glassware and plasticware, and wet rags and paper.

During Plant ventilation operations, air from contaminated areas was exhausted through HEPA filters to remove airborne contamination. TRU waste generated during these operations include contaminated HEPA filters. All HEPA filters are packaged as uncertified waste as there is no current technology available at PUREX to determine which HEPA filters meet the WIPP Waste Acceptance Criteria.

Facility Modification Operations were performed to improve overall plant performance. Modifications included the disposal of outdated and damaged equipment. Waste generated included tanks, process equipment and gloveboxes, and building materials.

Modifications/Assumptions/Development

New radionuclide data were submitted two days prior to going to print. The data were not reviewed by the technical team.

APPROACH

The approach used in preparing the RL waste stream profiles is as follows:

- Waste is divided between "past practice waste" (1970 through 1986) and currently-generated waste (1987 through 2028). Currently-generated waste includes projected waste generation.
- Past practice waste is grouped by generators, whereas currently-generated waste is grouped by waste matrix. The reasons for grouping the data in this manner are as follows: 1) the interim storage practice was changed from below ground surface (trenches) to above surface (storage buildings) in the 1986/1987 time period; 2) the By-Product Rule was issued by DOE on May 1, 1987, which compelled the hazardous components of TRU waste to be regulated by EPA under RCRA; 3) more detailed matrix information per container has been collected from the generator since 1987, and stored in the site's record waste tracking system; and 4) starting approximately 1986, waste generators began packaging the waste in accordance with the WIPP Waste Acceptance Criteria, thus reducing the need for additional waste processing prior to shipping to WIPP.
- Currently-generated waste streams were identified by reviewing each container record in the site's solid waste tracking system. Groups of containers that have similar physical characteristics and chemical contaminants (mixed only) were placed into a treatability group waste stream. The waste was then separated into drums, boxes, and RH canisters.

ASSUMPTIONS

The following assumptions were made by the site in repackaging the waste into the final waste form:

1. General

   A. A portion of the thermocouple assemblies, transfer pumps, mixing pumps, and other equipment in the single-shell and double-shell tanks will be removed, size-reduced, decontaminated, and assayed. Assay information will be used to designate the waste packages as low-level waste or TRU waste. The projection is that 10% of the equipment will be designated as RH-TRU, mixed waste and 90% will be designated as remote-handled, low level mixed waste. (WHC-EP 0768, Solid Waste 30-Year Volume Summary, p. 4-6, Table 4-1)

   B. TRU waste forecast volume data has been provided from the following off-site waste generators: AL, AE, BCL, LB, LL, and Santa Susana Field Laboratory (Rockwell, Canoga Park). The assumption is that TRU waste from these off-site waste generators will be received at RL for treatment in the Waste Receiving and Processing Facility (WRAP) and shipment to WIPP. (WHC-EP-0768, Solid Waste 30-Year Volume Summary)

   C. PUREX transition activities will generate 117 m^3 of CH-TRU and mixed TRU waste. The PUREX facility is currently undergoing transition activities towards decontamination and decommissioning. The facility transition activities at PUREX will provide a model for the subsequent transition of other canyon-type facilities in the future. Waste generation estimates from PUREX and other canyon type facilities have been included in the forecast. (WHC-EP-0768, Solid Waste 30-Year Volume Summary)

   D. Approximately 140 m^3 of spent research reactor fuel stored in trenches with the TRU waste is managed as TRU waste. Future evaluations may determine that this waste should be managed by the National Spent Fuel Program. (WHC-SD-SNF-TI-001, Revision 0)

2. Retrieval of Stored TRU Waste

   A. Stored TRU waste consists of existing TRU waste generated since May 1970 through December 1993. This waste does not include waste, originally designated as TRU waste, that has been assayed and redesignated as low-level waste during the calendar years (CY) 1986 to 1993.

   B. CH-TRU Waste

      - Of the TRU waste stored from May 1970 to December 1985 that has not been assayed and redesignated as low-level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. (WHC-EP-0225, Revision 1, Table 4-26)

- Waste is drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging the waste will result in a 35% increase in the volume of TRU-certified waste in drums. (WHC-SD-W026-SDRD-001, Revision 3)

- Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected.

- The site's solid waste tracking system does not distinguish between specific types of metals. If lead is present, then "other metals" is assumed to represent 100% of the metals in the container. Otherwise, iron-based metals is assumed to be 80% and aluminum-based metal is assumed to be 20% of the metal (reference: WHC-EP-225 Rev 1, TRU Waste Characterization Based on Current Records).

C. RH-TRU Waste

- No volume reduction is projected due to size reduction for transport in RH canisters.

3. Newly-generated TRU waste

A. This waste will be generated during the fiscal years 1994 through 2013.

B. CH-TRU Waste

- One hundred percent of the waste in drums will be managed as TRU waste with 10% considered noncertifiable and requiring treatment.

- All boxed waste (except waste in SWBs) will require size reduction in the WRAP facility.

C. RH-TRU Waste

- Newly-generated RH-TRU waste will be stored in shielded drums pending repackaging in RH-canisters in the WRAP facility.

- RH-TRU waste retrieved from the 618-11 burial ground will include some soil surrounding breached containers. It is assumed that this soil will increase the waste volume to be retrieved by 25%. No volume reduction is projected for treatment in the WRAP facility.

- A portion of the single-shell and double-shell tank equipment will be size-reduced and decontaminated, assayed, and shipped to WIPP as RH-TRU waste. The assumption is the 90% of the equipment will be classified as remote-handled, low level mixed waste and 10% will be RH-TRU, mixed waste.

- Most of the waste generated between 1987 and 1993 is debris waste. As such, projected RH-TRU waste is assumed to be debris waste.

- The mixed waste contaminants and radionuclide composition of projected RH-TRU waste are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W236	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	619.3	0.0	0.0
Aluminum-base Metal/Alloys:	122.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.3	0.0	0.0
Rubber:	25.6	0.0	0.0
Plastics:	71.0	0.0	0.0
Solidified Inorganic Material:	10.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	10.2	0.0	0.0
Packaging Material Steel:	141.0		
Packaging Material Plastic:	21.4		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	4.76E-02
U-238	3.42E-13
U-235	1.57E-14
U-234	3.51E-13
Sr-90	4.76E-02
Pu-242	2.08E-05
Pu-241	9.32E+00
Pu-240	3.46E-01
Pu-239	1.54E+00
Pu-238	4.54E-02
Cs-137	5.08E-02
Ba-137m	4.68E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	247.6	0.0	0.0	0.0	0.0	247.6
Drum / 55-gallon	237.7	0.0	0.0	0.0	0.0	237.7
Totals	485.4	0.0	0.0	0.0	0.0	485.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	320.9	0.0	0.0	0.0	0.0	320.9
Standard Waste Box	247.0	0.0	0.0	0.0	0.0	247.0
Totals	567.9	0.0	0.0	0.0	0.0	567.9

As-Generated Form: Stored: 485.4 Projected: 0.0 Total: 485.4

Final Waste Form: Stored: 567.9 Projected: 0.0 Total: 567.9

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Fuel Reprocessing Plant using the Plutonium/Uranium Solvent Extraction Process.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W237	Handling:	CH	NMVP #:	N/A	Stream Name:	202-AL Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	553.5	0.0	0.0
Aluminum-base Metal/Alloys:	87.8	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	104.1	0.0	0.0
Rubber:	44.6	0.0	0.0
Plastics:	106.2	0.0	0.0
Solidified Inorganic Material:	14.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	17.8	0.0	0.0
Packaging Material Steel:	131.2		
Packaging Material Plastic:	36.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	6.61E-04
U-238	5.57E-09
U-235	2.57E-10
U-234	5.74E-09
Sr-90	6.61E-04
Pu-242	7.52E-10
Pu-241	3.36E-04
Pu-240	1.25E-05
Pu-239	5.58E-05
Pu-238	1.64E-06
Cs-137	7.06E-04
Ba-137m	6.49E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	1.3	0.0	0.0	0.0	0.0	1.3
Drum / 55-gallon	146.8	0.0	0.0	0.0	0.0	146.8
Totals	148.1	0.0	0.0	0.0	0.0	148.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	198.2	0.0	0.0	0.0	0.0	198.2
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	200.1	0.0	0.0	0.0	0.0	200.1

As-Generated Form: Stored: 148.1 Projected: 0.0 Total: 148.1

Final Waste Form: Stored: 200.1 Projected: 0.0 Total: 200.1

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the laboratory at the Fuel Reprocessing Plant.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified waste in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified waste in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W238	Handling:	CH	NMVP #:	N/A	Stream Name:	216-Z-9 Retrieved Soil	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	324.0	162.0	324.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	285.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	ci/m3)
Y-90	2.29E-04
Sr-90	2.29E-04
Pu-242	6.33E-04
Pu-241	2.83E+02
Pu-240	1.05E+01
Pu-239	4.69E+01
Pu-238	1.38E+00
Cs-137	2.45E-04
Ba-137m	2.25E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	73.8	0.0	0.0	0.0	0.0	73.8
Totals	73.8	0.0	0.0	0.0	0.0	73.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	99.6	0.0	0.0	0.0	0.0	99.6
Totals	99.6	0.0	0.0	0.0	0.0	99.6

As-Generated Form: Stored: 73.8 Projected: 0.0 Total: 73.8

Final Waste Form: Stored: 99.6 Projected: 0.0 Total: 99.6

WASTE STREAM DESCRIPTION	Waste consists of soil contaminated with TRU solutions. Soil is contained in a 0.3 mm polyethylene bag within an inner container. The outer container is a standard 55-gallon drum. Vermiculite is a packing material between the inner and outer container.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the retrieved contaminated soil from the 216-Z-9 Trench. Soil is contaminated by TRU liquid waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W239	Handling:	CH	NMVP #:	N/A	Stream Name:	221-T TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	9.26E-05
U-238	6.34E-09
U-235	2.92E-10
U-234	6.53E-09
Sr-90	9.26E-05
Pu-242	4.32E-08
Pu-241	1.93E-02
Pu-240	7.17E-04
Pu-239	3.19E-03
Pu-238	9.38E-05
Cs-137	9.89E-05
Ba-137m	9.10E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.0	0.0	0.0	0.0	0.0	5.0
Totals	5.0	0.0	0.0	0.0	0.0	5.0

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 5.0 Projected: 0.0 Total: 5.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the T Plant Fuel Reprocessing Plant.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W240	Handling:	CH	NMVP #:	N/A	Stream Name:	222-S TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	621.5	0.0	0.0
Aluminum-base Metal/Alloys:	123.8	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.0	0.0	0.0
Rubber:	24.9	0.0	0.0
Plastics:	69.8	0.0	0.0
Solidified Inorganic Material:	10.2	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	9.9	0.0	0.0
Packaging Material Steel:	141.3		
Packaging Material Plastic:	20.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	5.22E-04
U-238	6.16E-10
U-235	5.72E-08
U-234	5.57E-07
U-233	1.17E-02
Sr-90	5.22E-04
Pu-242	1.01E-06
Pu-241	4.53E-01
Pu-240	1.68E-02
Pu-239	7.51E-02
Pu-238	2.21E-03
Cs-137	5.58E-04
Ba-137m	5.13E-04
Am-241	1.72E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	43.5	0.0	0.0	0.0	0.0	43.5
Drum / 55-gallon	32.9	0.0	0.0	0.0	0.0	32.9
Totals	76.4	0.0	0.0	0.0	0.0	76.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	44.3	0.0	0.0	0.0	0.0	44.3
Standard Waste Box	36.1	0.0	0.0	0.0	0.0	36.1
Totals	80.4	0.0	0.0	0.0	0.0	80.4

As-Generated Form: Stored: 76.4 Projected: 0.0 Total: 76.4

Final Waste Form: Stored: 80.4 Projected: 0.0 Total: 80.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Chemical Separation Areas Operations Laboratory.
CURRENT CONTAINER COMMENTS	N/A average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified waste in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified waste in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W241	Handling:	CH	NMVP #:	N/A	Stream Name:	233-S TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	9.45E-05
Sr-90	9.45E-05
Pu-242	9.80E-06
Pu-241	4.40E+00
Pu-240	1.63E-01
Pu-239	7.28E-01
Pu-238	2.14E-02
Cs-137	1.01E-04
Ba-137m	9.28E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.0	0.0	0.0	0.0	0.0	6.0
Totals	6.0	0.0	0.0	0.0	0.0	6.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.1	0.0	0.0	0.0	0.0	8.1
Totals	8.1	0.0	0.0	0.0	0.0	8.1

As-Generated Form: Stored: 6.0 Projected: 0.0 Total: 6.0

Final Waste Form: Stored: 8.1 Projected: 0.0 Total: 8.1

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the REDOX Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W242	Handling:	CH	NMVP #:	N/A	Stream Name:	234-5Z TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	633.8	0.0	0.0
Aluminum-base Metal/Alloys:	130.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	55.5	0.0	0.0
Rubber:	21.4	0.0	0.0
Plastics:	63.2	0.0	0.0
Solidified Inorganic Material:	9.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	8.5	0.0	0.0
Packaging Material Steel:	143.2		
Packaging Material Plastic:	18.1		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	6.48E-03
U-238	5.70E-05
U-235	3.07E-06
U-234	1.37E-04
U-233	6.76E-05
Th-232	1.01E-08
Sr-90	6.48E-03
Pu-242	3.57E-05
Pu-241	1.59E+01
Pu-240	5.92E-01
Pu-239	2.65E+00
Pu-238	1.66E+01
Cs-137	6.92E-03
Ba-137m	6.36E-03
Am-241	6.48E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	3246.5	0.0	0.0	0.0	0.0	3246.5
Drum / 55-gallon	2149.3	0.0	0.0	0.0	0.0	2149.3
Totals	5395.7	0.0	0.0	0.0	0.0	5395.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2901.4	0.0	0.0	0.0	0.0	2901.4
Standard Waste Box	3254.7	0.0	0.0	0.0	0.0	3254.7
Totals	6156.1	0.0	0.0	0.0	0.0	6156.1

As-Generated Form: Stored: 5395.7 Projected: 0.0 Total: 5395.7

Final Waste Form: Stored: 6156.1 Projected: 0.0 Total: 6156.1

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Plutonium Finishing Plant.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The contact-handled TRU waste from Building 2345A was reported in Waste Nos. RL-T146 and RL-T150 in Revision 1 of the WTWBIR. This waste is reported in RL-T107 in Revision 2; RL-T146 and RL-T150 have been deleted in Revision 2.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W243	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc 200 West Area TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	700.0	0.0	0.0
Aluminum-base Metal/Alloys:	165.4	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	39.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.4	0.0	0.0
Rubber:	4.6	0.0	0.0
Plastics:	27.8	0.0	0.0
Solidified Inorganic Material:	4.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.8	0.0	0.0
Packaging Material Steel:	153.0		
Packaging Material Plastic:	2.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.09E-04
U-238	1.48E-07
U-235	6.79E-09
U-234	1.52E-07
Sr-90	1.09E-04
Pu-242	6.51E-07
Pu-241	2.91E-01
Pu-240	1.08E-02
Pu-239	4.82E-02
Pu-238	9.14E-02
Cs-137	1.17E-04
Ba-137m	1.07E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	187.8	0.0	0.0	0.0	0.0	187.8
Drum / 55-gallon	6.0	0.0	0.0	0.0	0.0	6.0
Totals	193.9	0.0	0.0	0.0	0.0	193.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.0	0.0	0.0	0.0	8.3
Standard Waste Box	184.3	0.0	0.0	0.0	0.0	184.3
Totals	192.6	0.0	0.0	0.0	0.0	192.6

As-Generated Form: Stored: 193.9 Projected: 0.0 Total: 193.9

Final Waste Form: Stored: 192.6 Projected: 0.0 Total: 192.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixtures, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the 200 Area Waste Tank Farms and other miscellaneous sources in the Chemical Separations Area.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W244	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Bldg TRU Waste	Inventory Date:	12/19/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	641.4	0.0	0.0
Aluminum-base Metal/Alloys:	134.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	50.9	0.0	0.0
Rubber:	19.1	0.0	0.0
Plastics:	59.1	0.0	0.0
Solidified Inorganic Material:	8.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	7.6	0.0	0.0
Packaging Material Steel:	144.3		
Packaging Material Plastic:	16.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	5.81E-04
U-238	4.03E-04
U-235	1.57E-05
U-234	1.18E-03
U-233	5.54E-03
Sr-90	5.81E-04
Pu-242	8.43E-06
Pu-241	3.77E+00
Pu-240	1.40E-01
Pu-239	6.24E-01
Pu-238	1.84E-02
Cs-137	6.21E-04
Ba-137m	5.71E-04
Am-241	3.75E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	14.3	0.0	0.0	0.0	0.0	14.3
Drum / 55-gallon	6.2	0.0	0.0	0.0	0.0	6.2
Totals	20.5	0.0	0.0	0.0	0.0	20.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.0	0.0	0.0	0.0	8.3
Standard Waste Box	11.4	0.0	0.0	0.0	0.0	11.4
Totals	19.7	0.0	0.0	0.0	0.0	19.7

As-Generated Form: Stored: 20.5 Projected: 0.0 Total: 20.5

Final Waste Form: Stored: 19.7 Projected: 0.0 Total: 19.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Wastes in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reductin is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W245	Handling:	CH	NMVP #:	N/A	Stream Name:	324, 325 and 327 Bldg Oper TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	592.5	0.0	0.0
Aluminum-base Metal/Alloys:	108.4	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	42.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.5	0.0	0.0
Rubber:	33.3	0.0	0.0
Plastics:	85.3	0.0	0.0
Solidified Inorganic Material:	12.2	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	13.3	0.0	0.0
Packaging Material Steel:	137.0		
Packaging Material Plastic:	27.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.13E-02
U-238	3.86E-04
U-235	1.33E-04
U-234	2.76E-03
U-233	2.30E-04
Th-232	5.17E-06
Sr-90	1.13E-02
Pu-242	3.86E-05
Pu-241	1.73E+01
Pu-240	6.41E-01
Pu-239	2.86E+00
Pu-238	1.40E-01
Cs-137	1.21E-02
Ba-137m	1.11E-02
Am-241	5.67E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	129.5	0.0	0.0	0.0	0.0	129.5
Drum / 55-gallon	270.2	0.0	0.0	0.0	0.0	270.2
Totals	399.7	0.0	0.0	0.0	0.0	399.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	364.8	0.0	0.0	0.0	0.0	364.8
Standard Waste Box	129.2	0.0	0.0	0.0	0.0	129.2
Totals	494.0	0.0	0.0	0.0	0.0	494.0

As-Generated Form: Stored: 399.7 Projected: 0.0 Total: 399.7

Final Waste Form: Stored: 494.0 Projected: 0.0 Total: 494.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Chemical Materials Engineering Laboratory and Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	N/A volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The contact-handled TRU waste from Building 327C was reported as Waste No. RL-T111A in Revision 1 of the WTWBIR. RL-T111A has been deleted in Revision 2 of the WTWBIR.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W246	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Bldg Oper and R&D TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	650.2	0.0	0.0
Aluminum-base Metal/Alloys:	139.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	45.6	0.0	0.0
Rubber:	16.6	0.0	0.0
Plastics:	54.5	0.0	0.0
Solidified Inorganic Material:	8.3	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	6.6	0.0	0.0
Packaging Material Steel:	145.6		
Packaging Material Plastic:	14.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	9.12E-04
U-238	2.32E-04
U-235	3.71E-04
U-234	5.34E-03
U-233	5.71E-05
Th-232	1.95E-06
Sr-90	9.12E-04
Pu-242	1.83E-05
Pu-241	8.21E+00
Pu-240	3.04E-01
Pu-239	1.36E+00
Pu-238	2.12E-01
Cs-137	9.74E-04
Ba-137m	8.96E-04
Am-241	4.46E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	89.5	0.0	0.0	0.0	0.0	89.5
Drum / 55-gallon	37.2	0.0	0.0	0.0	0.0	37.2
Totals	126.8	0.0	0.0	0.0	0.0	126.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	50.3	0.0	0.0	0.0	0.0	50.3
Standard Waste Box	87.4	0.0	0.0	0.0	0.0	87.4
Totals	137.7	0.0	0.0	0.0	0.0	137.7

As-Generated Form: Stored: 126.8 Projected: 0.0 Total: 126.8

Final Waste Form: Stored: 137.7 Projected: 0.0 Total: 137.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Retention and Neutralization Facility.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W247	Handling:	CH	NMVP #:	N/A	Stream Name:	100 Areas and 200 Areas R&D TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	841.3	0.0	0.0
Aluminum-base Metal/Alloys:	134.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	51.0	0.0	0.0
Rubber:	19.2	0.0	0.0
Plastics:	59.2	0.0	0.0
Solidified Inorganic Material:	8.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	7.6	0.0	0.0
Packaging Material Steel:	144.3		
Packaging Material Plastic:	16.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	2.18E-04
Sr-90	2.18E-04
Pu-242	1.95E-07
Pu-241	8.71E-02
Pu-240	3.23E-03
Pu-239	1.44E-02
Pu-238	1.32E-03
Cs-137	2.32E-04
Ba-137m	2.14E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	24.0	0.0	0.0	0.0	0.0	24.0
Drum / 55-gallon	13.3	0.0	0.0	0.0	0.0	13.3
Totals	37.3	0.0	0.0	0.0	0.0	37.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	18.1	0.0	0.0	0.0	0.0	18.1
Standard Waste Box	24.7	0.0	0.0	0.0	0.0	24.7
Totals	42.8	0.0	0.0	0.0	0.0	42.8

As-Generated Form: Stored: 37.3 Projected: 0.0 Total: 37.3

Final Waste Form: Stored: 42.8 Projected: 0.0 Total: 42.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Biological Laboratory, Radioactive Particle Research Laboratory, and other R&D Sources in the Reactor and Chemical Separation Areas.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W248	Handling:	CH	NMVP #:	N/A	Stream Name:	209 E Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	567.0	0.0	0.0
Aluminum-base Metal/Alloys:	94.9	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	42.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	95.9	0.0	0.0
Rubber:	40.7	0.0	0.0
Plastics:	99.0	0.0	0.0
Solidified Inorganic Material:	14.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	16.3	0.0	0.0
Packaging Material Steel:	133.2		
Packaging Material Plastic:	33.5		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.80E-03
Sr-90	2.80E-03
Pu-242	6.45E-05
Pu-241	2.89E+01
Pu-240	1.07E+00
Pu-239	4.78E+00
Pu-238	1.41E-01
Cs-137	2.99E-03
Ba-137m	2.75E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	3.2	0.0	0.0	0.0	0.0	3.2
Drum / 55-gallon	13.1	0.0	0.0	0.0	0.0	13.1
Totals	16.3	0.0	0.0	0.0	0.0	16.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	17.7	0.0	0.0	0.0	0.0	17.7
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	19.6	0.0	0.0	0.0	0.0	19.6

As-Generated Form: Stored: 16.3 Projected: 0.0 Total: 16.3

Final Waste Form: Stored: 19.6 Projected: 0.0 Total: 19.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Critical Mass Laboratory.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W249	Handling:	CH	NMVP #:	N/A	Stream Name:	231-Z Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	677.5	0.0	0.0
Aluminum-base Metal/Alloys:	153.5	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	29.0	0.0	0.0
Rubber:	8.7	0.0	0.0
Plastics:	39.8	0.0	0.0
Solidified Inorganic Material:	6.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	3.4	0.0	0.0
Packaging Material Steel:	149.7		
Packaging Material Plastic:	7.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	6.27E-05
U-238	4.45E-05
U-235	1.14E-06
U-234	4.03E-04
Th-232	4.35E-08
Sr-90	6.27E-05
Pu-242	4.97E-06
Pu-241	2.23E+00
Pu-240	8.25E-02
Pu-239	3.69E-01
Pu-238	1.08E-02
Cs-137	6.69E-05
Ba-137m	6.16E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	832.3	0.0	0.0	0.0	0.0	832.3
Drum / 55-gallon	143.1	0.0	0.0	0.0	0.0	143.1
Totals	975.4	0.0	0.0	0.0	0.0	975.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	193.2	0.0	0.0	0.0	0.0	193.2
Standard Waste Box	832.2	0.0	0.0	0.0	0.0	832.2
Totals	1025.4	0.0	0.0	0.0	0.0	1025.4

As-Generated Form: Stored: 975.4 Projected: 0.0 Total: 975.4

Final Waste Form: Stored: 1025.4 Projected: 0.0 Total: 1025.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Materials Engineering Laboratory.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W250	Handling:	CH	NMVP #:	N/A	Stream Name:	303C Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.02E+00
U-238	5.64E-06
U-235	5.24E-04
U-234	5.10E-03
U-233	4.27E+00
Th-232	3.21E-03
Sr-90	1.02E+00
Pu-242	1.88E-04
Pu-241	8.43E+01
Pu-240	3.12E+00
Pu-239	1.39E+01
Pu-238	4.11E-01
Cs-137	1.09E+00
Ba-137m	1.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.1	0.0	0.0	0.0	0.0	8.1
Totals	8.1	0.0	0.0	0.0	0.0	8.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.0	0.0	0.0	0.0	0.0	11.0
Totals	11.0	0.0	0.0	0.0	0.0	11.0

As-Generated Form: Stored: 8.1 Projected: 0.0 Total: 8.1

Final Waste Form: Stored: 11.0 Projected: 0.0 Total: 11.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Material Evaluation Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W251	Handling:	CH	NMVP #:	N/A	Stream Name:	300 Area R&D TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	572.2	0.0	0.0
Aluminum-base Metal/Alloys:	97.7	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	42.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	92.8	0.0	0.0
Rubber:	39.2	0.0	0.0
Plastics:	96.2	0.0	0.0
Solidified Inorganic Material:	13.6	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	15.7	0.0	0.0
Packaging Material Steel:	134.0		
Packaging Material Plastic:	32.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	1.64E-03
U-238	6.00E-04
U-235	6.33E-05
U-234	3.18E-03
U-233	9.48E-05
Th-232	1.26E-05
Sr-90	1.64E-03
Pu-242	7.85E-06
Pu-241	3.51E+00
Pu-240	1.30E-01
Pu-239	5.82E-01
Pu-238	1.38E-01
Cs-137	1.75E-03
Ba-137m	1.61E-03
Am-241	1.46E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	34.2	0.0	0.0	0.0	0.0	34.2
Drum / 55-gallon	168.7	0.0	0.0	0.0	0.0	168.7
Totals	202.9	0.0	0.0	0.0	0.0	202.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	227.8	0.0	0.0	0.0	0.0	227.8
Standard Waste Box	34.2	0.0	0.0	0.0	0.0	34.2
Totals	262.0	0.0	0.0	0.0	0.0	262.0

As-Generated Form: Stored: 202.9 Projected: 0.0 Total: 202.9

Final Waste Form: Stored: 262.0 Projected: 0.0 Total: 262.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Radiological Calibrations Laboratory, Chemical Engineering Building, Radiochemistry Building laboratory and hot cells, and cesium recovery facility of the Radiochemistry Building, and Radioanalytical Laboratory.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The contact-handled TRU waste from Building 318 was reported as Waste No. RL-T117 in Revision 1 of the WTWBIR. This waste is reported in RL-T118 in Revision 2; RL-T117 has been deleted.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W252	Handling:	CH	NMVP #:	N/A	Stream Name:	TRU Construction Debris	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	655.2	0.0	0.0
Aluminum-base Metal/Alloys:	141.7	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	42.5	0.0	0.0
Rubber:	15.2	0.0	0.0
Plastics:	51.7	0.0	0.0
Solidified Inorganic Material:	7.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	6.0	0.0	0.0
Packaging Material Steel:	146.3		
Packaging Material Plastic:	13.1		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	5.71E-03
U-238	4.11E-09
U-235	1.89E-10
U-234	4.22E-09
Sr-90	5.71E-03
Pu-242	2.87E-06
Pu-241	1.28E+00
Pu-240	4.75E-02
Pu-239	2.12E-01
Pu-238	6.24E-03
Cs-137	6.10E-03
Ba-137m	5.61E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	87.2	0.0	0.0	0.0	0.0	87.2
Drum / 55-gallon	32.9	0.0	0.0	0.0	0.0	32.9
Totals	120.1	0.0	0.0	0.0	0.0	120.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	44.5	0.0	0.0	0.0	0.0	44.5
Standard Waste Box	89.3	0.0	0.0	0.0	0.0	89.3
Totals	133.8	0.0	0.0	0.0	0.0	133.8

As-Generated Form: Stored: 120.1 Projected: 0.0 Total: 120.1

Final Waste Form: Stored: 133.8 Projected: 0.0 Total: 133.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the construction activities.
CURRENT CONTAINER COMMENTS	N/A volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W253	Handling:	RH	NMVP #:	N/A	Stream Name:	105-KE Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	710.0	0.0	0.0
Aluminum-base Metal/Alloys:	164.5	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	22.5	0.0	0.0
Rubber:	6.6	0.0	0.0
Plastics:	34.6	0.0	0.0
Solidified Inorganic Material:	5.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	2.1	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	6.06E-01
Sr-90	6.06E-01
Pu-242	1.72E-06
Pu-241	3.86E+00
Pu-240	5.83E-02
Pu-239	1.17E-01
Pu-238	1.87E-02
Cs-137	6.47E-01
Ba-137m	5.96E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	49.0	0.0	0.0	0.0	0.0	49.0
Drum / 55-gallon	4.6	0.0	0.0	0.0	0.0	4.6
Totals	53.6	0.0	0.0	0.0	0.0	53.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	53.4	0.0	0.0	0.0	0.0	53.4
Totals	53.4	0.0	0.0	0.0	0.0	53.4

As-Generated Form: Stored: 53.6 Projected: 0.0 Total: 53.6

Final Waste Form: Stored: 53.4 Projected: 0.0 Total: 53.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the operation of the Fuel Storage Basins.
CURRENT CONTAINER COMMENTS	N/A volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W254	Handling:	CH	NMVP #:	N/A	Stream Name:	105-C, 105KE, and 105-N Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	692.4	0.0	0.0
Aluminum-base Metal/Alloys:	161.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	39.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	20.0	0.0	0.0
Rubber:	4.4	0.0	0.0
Plastics:	31.8	0.0	0.0
Solidified Inorganic Material:	5.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1.7	0.0	0.0
Packaging Material Steel:	151.9		
Packaging Material Plastic:	4.5		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	3.29E-01
U-238	5.52E-05
U-235	5.13E-03
U-234	4.98E-02
Th-232	3.78E-06
Sr-90	3.29E-01
Pu-242	2.50E-06
Pu-241	1.12E+00
Pu-240	4.17E-02
Pu-239	1.85E-01
Pu-238	5.47E-03
Cs-137	3.52E-01
Ba-137m	3.24E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	26.4	0.0	0.0	0.0	0.0	26.4
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	28.5	0.0	0.0	0.0	0.0	28.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.7	0.0	0.0	0.0	0.0	2.7
Standard Waste Box	26.6	0.0	0.0	0.0	0.0	26.6
Totals	29.3	0.0	0.0	0.0	0.0	29.3

As-Generated Form: Stored: 28.5 Projected: 0.0 Total: 28.5

Final Waste Form: Stored: 29.3 Projected: 0.0 Total: 29.3

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the operation of the reactors.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W255	Handling:	CH	NMVP #:	N/A	Stream Name:	Argonne Nat Lab Type 1 TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	AE	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
U-238	1.06E-04
U-235	9.81E-03
U-234	9.56E-02
Th-232	1.44E-05
Pu-242	3.46E-04
Pu-241	1.55E+02
Pu-240	5.74E+00
Pu-239	2.55E+01
Pu-238	7.53E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Argonne National Laboratory-East.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W256	Handling:	RH	NMVP #:	N/A	Stream Name:	Argonne Nat Lab Type II TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	AE	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	744.8	0.0	0.0
Aluminum-base Metal/Alloys:	117.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	57.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	141.3	0.0	0.0
Rubber:	60.3	0.0	0.0
Plastics:	144.7	0.0	0.0
Solidified Inorganic Material:	20.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	24.4	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.98E+01
U-233	2.03E-01
Th-232	1.56E-04
Sr-90	2.98E+01
Cs-137	3.19E+01
Ba-137m	2.93E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.9	0.0	0.0	0.0	0.0	0.9
Totals	0.9	0.0	0.0	0.0	0.0	0.9

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.9 Projected: 0.0 Total: 0.9

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the Argonne National Laboratory-East.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	This waste stream was erroneously identified as contact-handled TRU waste in Revision 1 of the WTWBIR. It has been reclassified as remote-handled waste in Revision 2 of the WTWBIR.
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W257	Handling:	CH	NMVP #:	N/A	Stream Name:	Argonne Nat Lab Type III TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	AE	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.81E+01
U-233	2.92E-01
Th-232	1.70E-04
Sr-90	2.81E+01
Pu-242	2.93E-10
Pu-241	1.32E-04
Pu-240	4.86E-06
Pu-239	2.17E-05
Pu-238	6.39E-07
Cs-137	3.00E+01
Ba-137m	2.76E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	11.2	0.0	0.0	0.0	0.0	11.2
Totals	11.2	0.0	0.0	0.0	0.0	11.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	15.2	0.0	0.0	0.0	0.0	15.2
Totals	15.2	0.0	0.0	0.0	0.0	15.2

As-Generated Form: Stored: 11.2 Projected: 0.0 Total: 11.2

Final Waste Form: Stored: 15.2 Projected: 0.0 Total: 15.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Argonne National Laboratory-East.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W258	Handling:	CH	NMVP #:	N/A	Stream Name:	Babcock Wilcox TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	617.3	0.0	0.0
Aluminum-base Metal/Alloys:	121.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	65.5	0.0	0.0
Rubber:	26.1	0.0	0.0
Plastics:	72.1	0.0	0.0
Solidified Inorganic Material:	10.5	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	10.4	0.0	0.0
Packaging Material Steel:	140.7		
Packaging Material Plastic:	21.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	3.44E-03
U-238	3.32E-05
U-235	5.96E-07
U-234	2.82E-04
Sr-90	3.44E-03
Pu-242	4.73E-05
Pu-241	2.12E+01
Pu-240	7.85E-01
Pu-239	3.51E+00
Pu-238	1.03E-01
Cs-137	3.67E-03
Ba-137m	3.38E-03
Am-241	1.15E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	118.8	0.0	0.0	0.0	0.0	118.8
Drum / 55-gallon	121.5	0.0	0.0	0.0	0.0	121.5
Totals	240.3	0.0	0.0	0.0	0.0	240.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	163.9	0.0	0.0	0.0	0.0	163.9
Standard Waste Box	119.7	0.0	0.0	0.0	0.0	119.7
Totals	283.6	0.0	0.0	0.0	0.0	283.6

As-Generated Form: Stored: 240.3 Projected: 0.0 Total: 240.3

Final Waste Form: Stored: 283.6 Projected: 0.0 Total: 283.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Babcock Wilcox.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W259	Handling:	CH	NMVP #:	N/A	Stream Name:	Bartlesville TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	5.54E-02
Sr-90	5.54E-02
Pu-242	7.85E-10
Pu-241	3.51E-04
Pu-240	1.30E-05
Pu-239	5.81E-05
Pu-238	1.71E-06
H-3	1.13E+01
Cs-137	5.91E-02
C-14	2.67E+00
Ba-137m	5.44E-02
Am-241	1.72E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Bartlesville.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W260	Handling:	CH	NMVP #:	N/A	Stream Name:	Battelle Columbus TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	BC	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	644.0	0.0	0.0
Aluminum-base Metal/Alloys:	135.7	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	49.3	0.0	0.0
Rubber:	18.4	0.0	0.0
Plastics:	57.7	0.0	0.0
Solidified Inorganic Material:	8.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	7.3	0.0	0.0
Packaging Material Steel:	144.7		
Packaging Material Plastic:	15.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	2.81E-03
U-238	5.74E-05
U-235	1.85E-05
U-234	2.67E-04
Sr-90	2.81E-03
Pu-242	6.40E-06
Pu-241	2.86E+00
Pu-240	1.06E-01
Pu-239	4.75E-01
Pu-238	4.70E+00
Cs-137	3.00E-03
Ba-137m	2.76E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	17.0	0.0	0.0	0.0	0.0	17.0
Drum / 55-gallon	8.7	0.0	0.0	0.0	0.0	8.7
Totals	25.7	0.0	0.0	0.0	0.0	25.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.6	0.0	0.0	0.0	0.0	11.6
Standard Waste Box	17.1	0.0	0.0	0.0	0.0	17.1
Totals	28.7	0.0	0.0	0.0	0.0	28.7

As-Generated Form: Stored: 25.7 Projected: 0.0 Total: 25.7

Final Waste Form: Stored: 28.7 Projected: 0.0 Total: 28.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Battelle Columbus Laboratory.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type II Battelle Columbus waste reported as Waste No. RL-T130 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Type I waste reported in RL-T129. RL-T130 has been replaced n Revision 2 of the WTWBIR with TRU waste generated by Bettis Atomic Power Laboratory.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W261	Handling:	CH	NMVP #:	N/A	Stream Name:	Bettis TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	BC	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	4.32E-01
U-238	4.40E-07
U-235	4.09E-05
U-234	3.99E-04
Sr-90	4.32E-01
Pu-242	1.88E-06
Pu-241	8.43E-01
Pu-240	3.13E-02
Pu-239	1.40E-01
Pu-238	4.11E-03
Cs-137	4.61E-01
Ba-137m	4.24E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Bettis Atomic Power Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type II Battelle Columbus waste reported as Waste No. RL-T130 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Type I waste reported in RL-T129. RL-T130 has been replaced n Revision 2 of the WTWBIR with TRU waste generated by Bettis Atomic Power Laboratory.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W262	Handling:	CH	NMVP #:	N/A	Stream Name:	Energy Systems Group TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	1.24E-02
U-238	5.71E-07
U-235	2.78E-05
U-234	2.73E-04
Sr-90	1.24E-02
Pu-242	1.27E-05
Pu-241	5.68E+00
Pu-240	2.10E-01
Pu-239	9.41E-01
Pu-238	2.77E-02
Cs-137	1.37E-02
Ba-137m	1.26E-02
Am-241	3.39E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	22.3	0.0	0.0	0.0	0.0	22.3
Totals	22.3	0.0	0.0	0.0	0.0	22.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	30.2	0.0	0.0	0.0	0.0	30.2
Totals	30.2	0.0	0.0	0.0	0.0	30.2

As-Generated Form: Stored: 22.3 Projected: 0.0 Total: 22.3

Final Waste Form: Stored: 30.2 Projected: 0.0 Total: 30.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W263	Handling:	CH	NMVP #:	N/A	Stream Name:	Exxon TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	4.63E-03
U-238	8.30E-03
U-235	3.81E-04
U-234	8.54E-03
Sr-90	4.63E-03
Pu-242	1.32E-03
Pu-241	5.89E+02
Pu-240	2.19E+01
Pu-239	9.78E+01
Pu-238	2.87E+00
Cs-137	4.95E-03
Ba-137m	4.55E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	21.2	0.0	0.0	0.0	0.0	21.2
Totals	21.2	0.0	0.0	0.0	0.0	21.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	28.7	0.0	0.0	0.0	0.0	28.7
Totals	28.7	0.0	0.0	0.0	0.0	28.7

As-Generated Form: Stored: 21.2 Projected: 0.0 Total: 21.2

Final Waste Form: Stored: 28.7 Projected: 0.0 Total: 28.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Exxon.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Exxon waste reported as Waste No. RL-T133 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Exxon waste reported in RL-T132. RL-T133 has been replaced in Revision 2 of the WTWBIR with TRU waste generated by the International Atomic Energy Agency.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W264	Handling:	CH	NMVP #:	N/A	Stream Name:	International Atomic Energy Agency TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Source Unknown

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	4.97E-03
Sr-90	4.97E-03
Pu-242	1.52E-04
Pu-241	6.81E+01
Pu-240	2.53E+00
Pu-239	1.13E+01
Pu-238	3.32E-01
Cs-137	5.31E-03
Ba-137m	4.88E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the International Atomic Energy Agency.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Exxon waste reported as Waste No. RL-T133 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Exxon waste reported in RL-T132. RL-T133 has been replaced in Revision 2 of the WTWBIR with TRU waste generated by the International Atomic Energy Agency.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W265	Handling:	CH	NMVP #:	N/A	Stream Name:	Lawrence Berkeley Nat Lab TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	LB	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	3.99E+00
Sr-90	3.99E+00
Pu-242	7.85E-06
Pu-241	3.51E+00
Pu-240	1.30E-01
Pu-239	5.82E-01
Pu-238	1.71E-02
Cs-137	4.26E+00
Ba-137m	3.92E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Lawrence Berkeley National Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W266	Handling:	CH	NMVP #:	N/A	Stream Name:	Lawrence Livermore TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.49E-04
U-238	1.11E-03
U-235	1.78E-05
U-234	9.97E-03
Sr-90	2.49E-04
Pu-242	1.83E-05
Pu-241	8.20E+00
Pu-240	3.04E-01
Pu-239	1.36E+00
Pu-238	4.00E-02
Cs-137	2.66E-04
Ba-137m	2.44E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Lawrence Livermore National Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type II Lawrence Livermore National Laboratories waste reported as Waste No. RL-T136 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Type I waste reported in RL-T135. RL-T136 has been deleted in Revision 2 of the WTWBIR.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W267	Handling:	CH	NMVP #:	N/A	Stream Name:	Kerr McGee TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	4.18E-03
U-238	3.99E-05
U-235	1.84E-06
U-234	4.11E-05
Sr-90	4.18E-03
Pu-242	6.32E-05
Pu-241	2.83E+01
Pu-240	1.05E+00
Pu-239	4.69E+00
Pu-238	1.38E-01
Cs-137	4.46E-03
Ba-137m	4.11E-03
Am-241	1.33E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	112.3	0.0	0.0	0.0	0.0	112.3
Totals	112.3	0.0	0.0	0.0	0.0	112.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	151.6	0.0	0.0	0.0	0.0	151.6
Totals	151.6	0.0	0.0	0.0	0.0	151.6

As-Generated Form: Stored: 112.3 Projected: 0.0 Total: 112.3

Final Waste Form: Stored: 151.6 Projected: 0.0 Total: 151.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Kerr McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W268	Handling:	CH	NMVP #:	N/A	Stream Name:	Rocky Flats TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	8.29E-03
U-238	2.12E-02
U-235	3.54E-04
U-234	1.90E-01
Sr-90	8.29E-03
Pu-242	1.66E-05
Pu-241	7.45E+00
Pu-240	2.76E-01
Pu-239	1.23E+00
Pu-238	3.63E-02
Cs-137	8.85E-03
Ba-137m	8.14E-03
Am-241	7.39E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	102.3	0.0	0.0	0.0	0.0	102.3
Totals	102.3	0.0	0.0	0.0	0.0	102.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	138.1	0.0	0.0	0.0	0.0	138.1
Totals	138.1	0.0	0.0	0.0	0.0	138.1

As-Generated Form: Stored: 102.3 Projected: 0.0 Total: 102.3

Final Waste Form: Stored: 138.1 Projected: 0.0 Total: 138.1

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Rocky Flats.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type II Rocky Flats waste reported as Waste No. RL-T141 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Type I waste reported in RL-T140. RL-T141 has been deleted in Revision 2 of the WTWBIR.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W269	Handling:	CH	NMVP #:	N/A	Stream Name:	GE San Jose and Vallecitos TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	GE	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	697.6	0.0	0.0
Aluminum-base Metal/Alloys:	164.1	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	39.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	16.9	0.0	0.0
Rubber:	2.9	0.0	0.0
Plastics:	29.1	0.0	0.0
Solidified Inorganic Material:	5.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1.1	0.0	0.0
Packaging Material Steel:	152.6		
Packaging Material Plastic:	3.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	2.95E-04
U-238	6.69E-05
U-235	5.84E-06
U-234	9.55E-05
Sr-90	2.95E-04
Pu-242	2.25E-06
Pu-241	1.01E+00
Pu-240	3.74E-02
Pu-239	1.67E-01
Pu-238	4.92E-03
Cs-137	3.15E-04
Ba-137m	2.90E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	384.4	0.0	0.0	0.0	0.0	384.4
Drum / 55-gallon	17.7	0.0	0.0	0.0	0.0	17.7
Totals	402.1	0.0	0.0	0.0	0.0	402.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	23.7	0.0	0.0	0.0	0.0	23.7
Standard Waste Box	380.0	0.0	0.0	0.0	0.0	380.0
Totals	403.7	0.0	0.0	0.0	0.0	403.7

As-Generated Form: Stored: 402.1 Projected: 0.0 Total: 402.1

Final Waste Form: Stored: 403.7 Projected: 0.0 Total: 403.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste consists of typically contact-handled TRU waste from the General Electric Plants at San Jose and Vallecitos.
CURRENT CONTAINER COMMENTS	N/A average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type I and II GE Pleasanton waste reported in Waste Nos. RL-T138 and RL-T139 and RL-139, and the GE Vallecitos waste reported in RL-T144 in Revision 1 of the WTWBIR have been merged in Revision 2 with the waste reported in RL-T143. RL-T138, RL-T139, and RL-T144 have been deleted in Revision 2.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W270	Handling:	CH	NMVP #:	N/A	Stream Name:	Ward TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	678.5	0.0	0.0
Aluminum-base Metal/Alloys:	154.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.5	0.0	0.0
Rubber:	8.4	0.0	0.0
Plastics:	39.3	0.0	0.0
Solidified Inorganic Material:	6.3	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	3.3	0.0	0.0
Packaging Material Steel:	149.8		
Packaging Material Plastic:	7.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.94E-03
U-238	1.75E-05
U-235	7.46E-06
U-234	1.26E-04
Th-232	1.37E-07
Sr-90	1.94E-03
Pu-242	3.64E-06
Pu-241	1.63E+00
Pu-240	6.03E-02
Pu-239	2.70E-01
Pu-238	7.94E-03
Cs-137	2.07E-03
Ba-137m	1.90E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	582.0	0.0	0.0	0.0	0.0	582.0
Drum / 55-gallon	96.1	0.0	0.0	0.0	0.0	96.1
Totals	678.1	0.0	0.0	0.0	0.0	678.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	129.8	0.0	0.0	0.0	0.0	129.8
Standard Waste Box	581.4	0.0	0.0	0.0	0.0	581.4
Totals	711.2	0.0	0.0	0.0	0.0	711.2

As-Generated Form: Stored: 678.1 Projected: 0.0 Total: 678.1

Final Waste Form: Stored: 711.2 Projected: 0.0 Total: 711.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Westinghouse Advanced Reactor Division (WARD).
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Ward waste reported in Waste Nos. RL-T144 in Revision 1 of the WTWBIR has been merged in Revision 2 with the waste reported in RL-T145. RL-T144 has been deleted in Revision 2.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W271	Handling:	RH	NMVP #:	N/A	Stream Name:	325 and 325B Bldg Op TRU Caisson Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	709.3	0.0	0.0
Aluminum-base Metal/Alloys:	165.4	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	20.1	0.0	0.0
Rubber:	5.5	0.0	0.0
Plastics:	32.4	0.0	0.0
Solidified Inorganic Material:	5.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1.7	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	8.07E+01
U-238	3.23E-04
U-235	4.30E-03
U-234	4.41E-02
U-233	1.85E-02
Th-232	1.06E-05
Sr-90	8.07E+01
Pu-242	1.82E-04
Pu-241	3.89E+02
Pu-240	6.17E+00
Pu-239	1.24E+01
Pu-238	1.98E+00
Cs-137	8.62E+01
Ba-137m	7.93E+01
Am-241	3.62E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	26.2	0.0	0.0	0.0	0.0	26.2
Drum / 55-gallon	1.9	0.0	0.0	0.0	0.0	1.9
Totals	28.1	0.0	0.0	0.0	0.0	28.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	27.6	0.0	0.0	0.0	0.0	27.6
Totals	27.6	0.0	0.0	0.0	0.0	27.6

As-Generated Form: Stored: 28.1 Projected: 0.0 Total: 28.1

Final Waste Form: Stored: 27.6 Projected: 0.0 Total: 27.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the Radiochemistry Building and Shielded Laboratory Annex.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	The remote-handled TRU waste from Building 324 reported under Waste No. RL-T147 in Revision 1 of the WTWBIR has been merged with waste reported under RL-T148. This waste is reported in RL-T148 in Revision 2.
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W272	Handling:	RH	NMVP #:	N/A	Stream Name:	324 and 327C TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	737.6	0.0	0.0
Aluminum-base Metal/Alloys:	127.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	54.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	116.7	0.0	0.0
Rubber:	49.2	0.0	0.0
Plastics:	121.9	0.0	0.0
Solidified Inorganic Material:	17.6	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	19.8	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	1.78E+03
U-238	4.78E-04
U-235	6.66E-03
U-234	6.81E-02
U-233	1.12E-02
Th-232	5.37E-05
Sr-90	1.78E+03
Pu-242	2.29E-04
Pu-241	4.91E+02
Pu-240	7.78E+00
Pu-239	1.56E+01
Pu-238	2.50E+00
Cs-137	1.90E+03
Co-60	8.02E+01
Ba-137m	1.74E+03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	4.5	0.0	0.0	0.0	0.0	4.5
Drum / 55-gallon	19.3	0.0	0.0	0.0	0.0	19.3
Totals	23.8	0.0	0.0	0.0	0.0	23.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	24.0	0.0	0.0	0.0	0.0	24.0
Totals	24.0	0.0	0.0	0.0	0.0	24.0

As-Generated Form: Stored: 23.8 Projected: 0.0 Total: 23.8

Final Waste Form: Stored: 24.0 Projected: 0.0 Total: 24.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of typically remote-handled TRU waste from the Chemical Engineering Building and Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	The remote-handled TRU waste from Building 324 reported under Waste No. RL-T147 in Revision 1 of the WTWBIR has been merged with waste reported under RL-T148. This waste is reported in RL-T148 in Revision 2.
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W273	Handling:	RH	NMVP #:	N/A	Stream Name:	325A and 325B R&D TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	707.6	0.0	0.0
Aluminum-base Metal/Alloys:	167.8	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	39.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	14.1	0.0	0.0
Rubber:	2.8	0.0	0.0
Plastics:	26.8	0.0	0.0
Solidified Inorganic Material:	4.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.5	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	3.05E+01
U-238	7.13E-08
U-235	6.65E-06
U-234	6.48E-05
U-233	1.09E-01
Th-232	5.97E-04
Sr-90	3.05E+01
Pu-242	3.74E-07
Pu-241	8.02E-01
Pu-240	1.27E-02
Pu-239	2.55E-02
Pu-238	4.08E-03
Cs-137	3.12E+01
Ba-137m	2.92E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	68.0	0.0	0.0	0.0	0.0	68.0
Drum / 55-gallon	1.5	0.0	0.0	0.0	0.0	1.5
Totals	69.4	0.0	0.0	0.0	0.0	69.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	69.4	0.0	0.0	0.0	0.0	69.4
Totals	69.4	0.0	0.0	0.0	0.0	69.4

As-Generated Form: Stored: 69.4 Projected: 0.0 Total: 69.4

Final Waste Form: Stored: 69.4 Projected: 0.0 Total: 69.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the Cesium Recovery Facility and Shielded Laboratory Annex of the Radiochemistry Building.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	This waste stream has been expanded in Revision 2 of the WTWBIR to report remote-handled waste from both Buildings 325A and 325B.
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W274	Handling:	RH	NMVP #:	N/A	Stream Name:	202A Bldg Remote-Handled TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	725.8	0.0	0.0
Aluminum-base Metal/Alloys:	143.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	48.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	76.3	0.0	0.0
Rubber:	30.9	0.0	0.0
Plastics:	84.5	0.0	0.0
Solidified Inorganic Material:	12.5	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	12.2	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	1.50E-01
Sr-90	1.50E-01
Pu-242	1.98E-07
Pu-241	4.25E-01
Pu-240	6.73E-03
Pu-239	1.35E-02
Pu-238	2.16E-03
Cs-137	1.61E-01
Ba-137m	1.48E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	2.6	0.0	0.0	0.0	0.0	2.6
Drum / 55-gallon	2.7	0.0	0.0	0.0	0.0	2.7
Totals	5.3	0.0	0.0	0.0	0.0	5.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	5.3	0.0	0.0	0.0	0.0	5.3
Totals	5.3	0.0	0.0	0.0	0.0	5.3

As-Generated Form: Stored: 5.3 Projected: 0.0 Total: 5.3

Final Waste Form: Stored: 5.3 Projected: 0.0 Total: 5.3

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the Purex Canyon and Service Facility.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W275	Handling:	RH	NMVP #:	N/A	Stream Name:	202AL and 222S Bldg Remote-Handled TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	744.8	0.0	0.0
Aluminum-base Metal/Alloys:	117.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	57.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	141.3	0.0	0.0
Rubber:	60.3	0.0	0.0
Plastics:	144.7	0.0	0.0
Solidified Inorganic Material:	20.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	24	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	3.10E-01
U-238	8.87E-08
U-235	4.09E-09
U-234	9.14E-08
Sr-90	3.10E-01
Pu-242	5.87E-10
Pu-241	1.26E-03
Pu-240	1.99E-05
Pu-239	4.00E-05
Pu-238	6.40E-06
Cs-137	3.31E-01
Ba-137m	3.04E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	18.5	0.0	0.0	0.0	0.0	18.5
Totals	18.5	0.0	0.0	0.0	0.0	18.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	18.7	0.0	0.0	0.0	0.0	18.7
Totals	18.7	0.0	0.0	0.0	0.0	18.7

As-Generated Form: Stored: 18.5 Projected: 0.0 Total: 18.5

Final Waste Form: Stored: 18.7 Projected: 0.0 Total: 18.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30% of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from process analytical laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W276	Handling:	RH	NMVP #:	N/A	Stream Name:	ARGON Pb/Cd Met lead RH St MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	66.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	310.4	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	202.7	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	1.43E+03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	1.8	0.0	0.0	0.0	0.0	1.8
Totals	1.8	0.0	0.0	0.0	0.0	1.8

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 1.8 Projected: 0.0 Total: 1.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, METAL/IRON/GALVANIZED/SHEET, CEMENT.
WASTE STREAM SOURCE	This stream is lead cadmium metal remote handled State regulated mixed TRU waste from the Argonne National Laboratory - East
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W277	Handling:	CH	NMVP #:	N/A	Stream Name:	BATCO Pb/Cd Met lead CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

P015, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	9.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Battelle Columbus Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W278	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Comb debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	22.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	37.2	0.0	0.0
Other Inorganic Material:	9.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	56.3	0.0	0.0
Rubber:	52.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	30.5		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	4.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS WOOD/LUMBER/PLYWOOD, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE, PAPER/CARDBOARD, STAINLESS STEEL.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal contaminants from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W279	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Heter debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	104.9	0.0	0.0
Aluminum-base Metal/Alloys:	1.8	0.0	0.0
Other Metals/Alloys:	0.2	0.0	0.0
Other Inorganic Material:	16.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	27.4	0.0	0.0
Rubber:	4.1	0.0	0.0
Plastics:	31.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	4.7	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.2	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	3.24E+00
Pu-240	1.20E-01
Pu-239	5.40E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.9	0.0	0.0	0.0	0.0	6.9
Totals	6.9	0.0	0.0	0.0	0.0	6.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	69.3	0.0	0.0	0.0	0.0	69.3
Totals	69.3	0.0	0.0	0.0	0.0	69.3

As-Generated Form: Stored: 6.9 Projected: 0.0 Total: 6.9

Final Waste Form: Stored: 69.3 Projected: 0.0 Total: 69.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS STAINLESS STEEL, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, FILTERS, METAL/IRON/GALVANIZED/SHEET, SOLVENTS/THINNERS, RUBBER, CONCRETE, PAINTS/LUCITE, ABSORBENT/KITY LTR/VERMICULITE, WOOD/LUMBER/PLYWOOD, SLUDGES, SAND, ALUMIN.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled State regulated mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W280	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Solidif org debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	61.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	5.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.6	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	16.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	110.2	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	39.2	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	0.00E+00
Pu-241	3.24E+00
Pu-240	1.20E-01
Pu-239	5.40E-01
Beta/Gamma	5.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, SLUDGES, WATER, SOLVENTS/THINNERS, PLASTIC/POLYURETHANE, FILTERS, PAINTS/LUCITE, CONCRETE.
WASTE STREAM SOURCE	This stream is solidified organics contact handled State regulated mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W281	Handling:	CH	NMVP #:	N/A	Stream Name:	183H Solidif inorg labpks CH RCRA MTRU w/ met ign	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	X6200

AS-GENERATED EPA CODES

U123, P120, P106, P098, P030, P029, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	49.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.3	0.0	0.0
Solidified Inorganic Material:	617.8	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.3	0.0	0.0	0.0	0.0	0.3
Totals	0.3	0.0	0.0	0.0	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.3	0.0	0.0	0.0	0.0	3.3
Totals	3.3	0.0	0.0	0.0	0.0	3.3

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 3.3 Projected: 0.0 Total: 3.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LIQUID, ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is solidified inorganics contact handled RCRA regulated mixed TRU waste with metal ignitable contaminants from the Solidified dewatered fuel fabrication sludge.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W282	Handling:	CH	NMVP #:	N/A	Stream Name:	200W Solidif org debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S4000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	37.3	0.0	0.0
Rubber:	18.6	0.0	0.0
Plastics:	18.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.3	0.0	0.0	0.0	0.0	0.3
Totals	0.3	0.0	0.0	0.0	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.3	0.0	0.0	0.0	0.0	3.3
Totals	3.3	0.0	0.0	0.0	0.0	3.3

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 3.3 Projected: 0.0 Total: 3.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, MISCELLANEOUS/UNKNOWN/OTHER, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is solidified organics contact handled State regulated mixed TRU waste from the Chemical Separations Area.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W283	Handling:	CH	NMVP #:	N/A	Stream Name:	201C Soils CH/r RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4000

AS-GENERATED EPA CODES

D010, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	29.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	68.7	0.0	0.0
Rubber:	21.2	0.0	0.0
Plastics:	33.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.1	0.0	0.0
Packaging Material Steel:	428.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	2.47E+00
Pu-241	8.00E-02
Pu-240	0.00E+00
Pu-239	1.00E-02
Beta/Gamma	1.14E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.6	0.0	0.0	0.0	0.0	11.6
Totals	11.6	0.0	0.0	0.0	0.0	11.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	116.5	0.0	0.0	0.0	0.0	116.5
Totals	116.5	0.0	0.0	0.0	0.0	116.5

As-Generated Form: Stored: 11.6 Projected: 0.0 Total: 11.6

Final Waste Form: Stored: 116.5 Projected: 0.0 Total: 116.5

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, WOOD/LUMBER/PLYWOOD, METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, HAZARDOUS CONSTITUENTS, RUBBER, FILTERS, ANIMAL WASTE.
WASTE STREAM SOURCE	This stream is soils contact handled packaged remote RCRA regulated mixed TRU waste with metal contaminants from the Demolition of the Semi-works facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W285	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Solidif org debris CH RCRA MTRU w/ org ign	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

F003, D019, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	74.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	11.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	61.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	12.1	0.0	0.0	0.0	0.0	12.1
Totals	12.1	0.0	0.0	0.0	0.0	12.1

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 12.1 Projected: 0.0 Total: 12.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CONWEB PADS, METAL/IRON/GALVANIZED/SHEET, HAZARDOUS CONSTITUENTS, GLASS, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA regulated mixed TRU waste with organic ignitable contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W286	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Solidif org inorg part CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	162.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	1.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	8.7	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	3.24E+00
Pu-240	1.20E-01
Pu-239	5.40E-01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, OILS, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is solidified organics contact handled State regulated mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W287	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Pb/Cd Met debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	31.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	158.0	0.0	0.0
Other Inorganic Material:	13.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.1	0.0	0.0
Rubber:	62.0	0.0	0.0
Plastics:	81.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	6.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, RUBBER, LEAD, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, ABSORBENT/KITY LTR/VERMICULITE, CHEMICALS.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W288	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat met debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	177.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.1	0.0	0.0
Rubber:	1.7	0.0	0.0
Plastics:	61.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	3.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.4	0.0	0.0	0.0	0.0	10.4
Totals	10.4	0.0	0.0	0.0	0.0	10.4

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 10.4 Projected: 0.0 Total: 10.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, LEAD, RUBBER, CHEMICALS, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W289	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	46.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	48.6	0.0	0.0
Other Inorganic Material:	1.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.9	0.0	0.0
Rubber:	9.9	0.0	0.0
Plastics:	118.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	8.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	21.0	0.0	0.0	0.0	0.0	21.0
Totals	21.0	0.0	0.0	0.0	0.0	21.0

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 21.0 Projected: 0.0 Total: 21.0

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, RUBBER, STAINLESS STEEL, CLOTH/RAGS/NYLON, LEAD, GLASS, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W290	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Pb/Cd Met debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	4.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	191.9	0.0	0.0
Other Inorganic Material:	33.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.0	0.0	0.0
Rubber:	110.2	0.0	0.0
Plastics:	28.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	23.1	0.0	0.0	0.0	0.0	23.1
Totals	23.1	0.0	0.0	0.0	0.0	23.1

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 23.1 Projected: 0.0 Total: 23.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, LEAD, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, GLASS.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W291	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat met debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	61.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.7	0.0	0.0
Other Inorganic Material:	0.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	6.0	0.0	0.0
Rubber:	0.1	0.0	0.0
Plastics:	13.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Box	7.1	0.0	0.0	0.0	0.0	7.1
Totals	7.6	0.0	0.0	0.0	0.0	7.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Standard Waste Box	7.6	0.0	0.0	0.0	0.0	7.6
Totals	11.7	0.0	0.0	0.0	0.0	11.7

As-Generated Form: Stored: 7.6 Projected: 0.0 Total: 7.6

Final Waste Form: Stored: 11.7 Projected: 0.0 Total: 11.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD, CONCRETE, CLOTH/RAGS/NYLON, LEAD, RUBBER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W292	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Inorg non-met debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	76.6	0.0	0.0
Other Inorganic Material:	78.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.0	0.0	0.0
Rubber:	47.6	0.0	0.0
Plastics:	38.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	1.30E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, LEAD, CLOTH/RAGS/NYLON, CHEMICALS.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W293	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	20.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	53.0	0.0	0.0
Other Inorganic Material:	0.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.6	0.0	0.0
Rubber:	81.6	0.0	0.0
Plastics:	73.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	6.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.3	0.0	0.0	0.0	0.0	1.3
Totals	1.3	0.0	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	12.7	0.0	0.0	0.0	0.0	12.7
Totals	12.7	0.0	0.0	0.0	0.0	12.7

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 12.7 Projected: 0.0 Total: 12.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, LEAD, STAINLESS STEEL, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, GLASS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W294	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Heter debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D009, D008, D006, D005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	15.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	55.0	0.0	0.0
Other Inorganic Material:	36.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	8.1	0.0	0.0
Rubber:	32.1	0.0	0.0
Plastics:	50.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.4	0.0	0.0	0.0	0.0	10.4
Totals	10.4	0.0	0.0	0.0	0.0	10.4

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 10.4 Projected: 0.0 Total: 10.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, RUBBER, LEAD, FILTERS, ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, GLASS, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON, BATTERIES.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W295	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat debris CH RCRA MTRU w/ cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	100.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	5.5	0.0	0.0
Other Inorganic Material:	0.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.7	0.0	0.0
Rubber:	22.9	0.0	0.0
Plastics:	55.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	18.9	0.0	0.0	0.0	0.0	18.9
Totals	18.9	0.0	0.0	0.0	0.0	18.9

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 18.9 Projected: 0.0 Total: 18.9

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, RUBBER, CLOTH/RAGS/NYLON, LEAD, GLASS, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is uncategorized contact handled RCRA regulated mixed TRU waste with corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W296	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH RCRA MTRU w/ cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	29.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	7.4	0.0	0.0
Other Inorganic Material:	0.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	11.0	0.0	0.0
Rubber:	55.0	0.0	0.0
Plastics:	71.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No.

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	2.00E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.1	0.0	0.0	0.0	0.0	3.1
Totals	3.1	0.0	0.0	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	31.6	0.0	0.0	0.0	0.0	31.6
Totals	31.6	0.0	0.0	0.0	0.0	31.6

As-Generated Form: Stored: 3.1 Projected: 0.0 Total: 3.1

Final Waste Form: Stored: 31.6 Projected: 0.0 Total: 31.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, RUBBER, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, LEAD, GLASS, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W297	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat met debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	115.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	4.4	0.0	0.0
Other Inorganic Material:	11.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.9	0.0	0.0
Rubber:	28.3	0.0	0.0
Plastics:	39.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	2.10E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.8	0.0	0.0	0.0	0.0	16.8
Totals	16.8	0.0	0.0	0.0	0.0	16.8

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 16.8 Projected: 0.0 Total: 16.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET, RUBBER, PAPER/CARDBOARD, BRICK/FIREBRICK, CLOTH/RAGS/NYLON, LEAD, WOOD/LUMBER/PLYWOOD, COPPER METAL.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled State regulated mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W298	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	21.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	6.7	0.0	0.0
Other Inorganic Material:	0.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.6	0.0	0.0
Rubber:	35.8	0.0	0.0
Plastics:	45.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	1.10E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.9	0.4	0.0	0.0	0.0	11.3
Box	5.0	0.0	0.0	0.0	0.0	5.0
Totals	16.0	0.4	0.0	0.0	0.0	16.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	109.2	0.4	0.0	0.0	0.0	109.6
Standard Waste Box	5.7	0.0	0.0	0.0	0.0	5.7
Totals	114.9	0.4	0.0	0.0	0.0	115.3

As-Generated Form: Stored: 16.0 Projected: 0.0 Total: 16.0

Final Waste Form: Stored: 114.9 Projected: 0.4 Total: 115.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, FILTERS, RUBBER, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, STAINLESS STEEL, LEAD, WOOD/LUMBER/PLYWOOD, COPPER METAL, GLASS, PAPER/CARDBOARD, LEATHER, ALUMINUM.
WASTE STREAM SOURCE	This stream is combustible contact handled State regulated mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W299	Handling:	CH	NMVP #:	N/A	Stream Name:	202AL Uncat met debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	258.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	46.8	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.7	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	104.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	9.82E+01
Pu-240	3.65E+00
Pu-239	1.63E+01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.0	0.0	0.0	0.0	6.2
Totals	6.2	0.0	0.0	0.0	0.0	6.2

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 6.2 Projected: 0.0 Total: 6.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, LEAD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility Support Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W300	Handling:	CH	NMVP #:	N/A	Stream Name:	202AL Comb debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	23.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	185.5	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	283.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	9.82E+01
Pu-240	3.65E+00
Pu-239	1.63E+01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, LEAD, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuel Reprocessing Facility Support Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W301	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Heter lead CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	118.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	237.1	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	45.0	0.0	0.0
Rubber:	12.1	0.0	0.0
Plastics:	16.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	1.72E+02
Pu-240	6.35E+00
Pu-239	2.83E+01
Beta/Gamma	8.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.0	0.0	0.0	0.0	6.2
Totals	6.2	0.0	0.0	0.0	0.0	6.2

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 6.2 Projected: 0.0 Total: 6.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, CADMIUM, LEAD, PLASTIC/POLYURETHANE, RUBBER, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, FIBERGLASS.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled RCRA regulated mixed TRU waste with metal contaminants from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W302	Handling:	CH	NMVP #:	N/A	Stream Name:	222S Heter debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	479.2	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	56.9	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	74.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	28.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.84E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CONWEB PADS, FILTERS, WOOD/LUMBER/PLYWOOD, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled RCRA regulated mixed TRU waste with metal contaminants from the Process Analytical Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W303	Handling:	CH	NMVP #:	N/A	Stream Name:	224T Heter debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	15.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	42.8	0.0	0.0
Rubber:	21.5	0.0	0.0
Plastics:	45.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	31.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	1.14E+00
Pu-239	7.45E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, GLASS, MISCELLANEOUS/UNKNOWN/OTHER, CONCRETE, CORK, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is heterogeneous contact handled State regulated mixed TRU waste from the Transuranic Assaying and Storage Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W304	Handling:	CH	NMVP #:	N/A	Stream Name:	231Z Heter debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	22.5	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	3.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.10E-01
Pu-241	1.80E+00
Pu-240	6.00E-02
Pu-239	2.80E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	2.5	0.0	0.0	0.0	0.0	2.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.0	0.0	0.0	0.0	6.2
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	8.1	0.0	0.0	0.0	0.0	8.1

As-Generated Form: Stored: 2.5 Projected: 0.0 Total: 2.5

Final Waste Form: Stored: 8.1 Projected: 0.0 Total: 8.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS FILTERS, FIBERGLASS, WOOD/LUMBER/PLYWOOD, METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is heterogeneous contact handled State regulated mixed TRU waste from the PNL Materials Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W305	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ org met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D019, D011, D010, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	12.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	49.1	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	23.3	0.0	0.0
Rubber:	105.4	0.0	0.0
Plastics:	70.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	3.5	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	31.6		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.7	2.1	2.5	2.1	10.4
Totals	2.1	1.7	2.1	2.5	2.1	10.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.7	2.1	2.5	2.1	10.4
Totals	2.1	1.7	2.1	2.5	2.1	10.4

As-Generated Form: Stored: 2.1 Projected: 8.3 Total: 10.4

Final Waste Form: Stored: 2.1 Projected: 8.3 Total: 10.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, HAZARDOUS CONSTITUENTS, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD, CEMENT, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, CHEMICALS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with organic metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W306	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Pb/Cd Met debris CH RCRA MTRU w/ org met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D019, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	37.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	64.3	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	40.8	0.0	0.0
Rubber:	90.1	0.0	0.0
Plastics:	66.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	39.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.8	1.0	0.4	0.0	3.1
Totals	0.8	0.8	1.0	0.4	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.8	1.0	0.4	0.0	10.6
Totals	8.3	0.8	1.0	0.4	0.0	10.6

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 8.3 Projected: 2.3 Total: 10.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, HAZARDOUS CONSTITUENTS, DIRT/SOIL/DIATOMACEOUS EARTH, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, LEAD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with organic metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W307	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ org met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D019, D011, D008, D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	236.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	55.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	15.0	0.0	0.0
Plastics:	62.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	2.0	0.0	0.0	0.0	0.0	2.0
Totals	2.0	0.0	0.0	0.0	0.0	2.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 2.0 Projected: 0.0 Total: 2.0

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, HAZARDOUS CONSTITUENTS, ASBESTOS, PLASTIC/POLYURETHANE, RUBBER, ANTI-CORROSIVE RADPAD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with organic metal corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W308	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ org
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

D019

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	137.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	14.9	0.0	0.0
Rubber:	96.1	0.0	0.0
Plastics:	67.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	21.6		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.2	0.0	0.0	0.0	0.6
Totals	0.4	0.2	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.2	0.0	0.0	0.0	0.6
Totals	0.4	0.2	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.4 Projected: 0.2 Total: 0.6

Final Waste Form: Stored: 0.4 Projected: 0.2 Total: 0.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, RUBBER, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with organic contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W309	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ org	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D019

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	144.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	25.1	0.0	0.0
Rubber:	4.8	0.0	0.0
Plastics:	177.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	27.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, RUBBER, PAPER/CARDBOARD, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with organic contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W310	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Soil debris CH RCRA MTRU w/ org ign	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

F003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	34.3	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	81.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	82.3		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.3	0.3	0.0	0.0	0.0	0.6
Totals	0.3	0.3	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	0.2	0.0	0.0	0.0	3.1
Totals	2.9	0.2	0.0	0.0	0.0	3.1

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 2.9 Projected: 0.2 Total: 3.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, PLASTIC/POLYURETHANE, CONWEB PADS, ORGANICS, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is soils contact handled RCRA regulated mixed TRU waste with organic ignitable contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W311	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Pb/Cd Met debris CH RCRA MTRU w/ met
Inventory Date:	12/1/94						
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste
Waste Matrix Code:	S5300						

AS-GENERATED EPA CODES

D008, D007, D006, D005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	13.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	150.5	0.0	0.0
Other Inorganic Material:	5.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.9	0.0	0.0
Rubber:	76.9	0.0	0.0
Plastics:	32.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	27.3		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.4	3.6	4.2	3.4	2.1	17.6
Totals	4.4	3.6	4.2	3.4	2.1	17.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.4	3.5	4.2	3.3	2.1	17.5
Totals	4.4	3.5	4.2	3.3	2.1	17.5

As-Generated Form: Stored: 4.4 Projected: 13.2 Total: 17.6

Final Waste Form: Stored: 4.4 Projected: 13.1 Total: 17.5

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, RUBBER, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, HAZARDOUS CONSTITUENTS, LEAD SHIELDING, PAPER/CARDBOARD, GLASS, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W312	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Pb/Cd Met debris CH RCRA MTRU w/ met cor		Inventory Date: 12/1/94
Local ID:	Type: MTRU	Generator Site: RL	Final Waste Form: Lead/Cadmium Metal Waste		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D008, D007, D006, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	17.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	218.8	0.0	0.0
Other Inorganic Material:	0.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.7	0.0	0.0
Rubber:	125.5	0.0	0.0
Plastics:	44.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	25.5		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	1.9	2.1	2.5	2.1	10.9
Totals	2.3	1.9	2.1	2.5	2.1	10.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	1.9	2.1	2.5	2.1	10.8
Totals	2.3	1.9	2.1	2.5	2.1	10.8

As-Generated Form: Stored: 2.3 Projected: 8.6 Total: 10.9

Final Waste Form: Stored: 2.3 Projected: 8.5 Total: 10.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, LEAD, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD SHIELDING, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, LEATHER, GLASS, BATTERIES, STAINLESS STEEL, HAZARDOUS
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W313	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D007, D006, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	59.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	6.9	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	11.1	0.0	0.0
Rubber:	4.7	0.0	0.0
Plastics:	12.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	4.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Box	7.5	7.5	7.5	0.0	0.0	22.5
Totals	9.2	9.2	9.6	2.5	2.1	32.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Standard Waste Box	7.6	3.8	3.8	0.0	0.0	15.1
Totals	9.2	5.4	5.9	2.5	2.1	25.1

As-Generated Form: Stored: 9.2 Projected: 23.4 Total: 32.6

Final Waste Form: Stored: 9.2 Projected: 15.9 Total: 25.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, LEAD, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, HAZARDOUS CONSTITUENTS, RUBBER, CLOTH/RAGS/NYLON, GLASS, LEATHER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W314	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D010, D008, D007, D006, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	24.9	0.0	0.0
Other Inorganic Material:	3.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	23.5	0.0	0.0
Rubber:	61.4	0.0	0.0
Plastics:	53.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	1.6	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	18.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.6	3.8	4.2	5.0	4.2	21.7
Totals	4.6	3.8	4.2	5.0	4.2	21.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.6	3.7	4.2	5.0	4.2	21.6
Totals	4.6	3.7	4.2	5.0	4.2	21.6

As-Generated Form: Stored: 4.6 Projected: 17.1 Total: 21.7

Final Waste Form: Stored: 4.6 Projected: 17.1 Total: 21.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, RUBBER, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD, CLOTH/RAGS/NYLON, HAZARDOUS CONSTITUENTS, GLASS, GROUT, ANTI-CORROSIVE RADPAD, STAINLESS STEEL, CONWEB PADS,
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W315	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Inorg non-met debris CH RCRA MTRU w/ met ign	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D007, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	2.4	0.0	0.0
Other Inorganic Material:	64.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.9	0.0	0.0
Rubber:	1.2	0.0	0.0
Plastics:	166.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	50.2		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.4	0.0	0.0	0.0	0.8
Totals	0.4	0.4	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.4	0.0	0.0	0.0	4.6
Totals	4.2	0.4	0.0	0.0	0.0	4.6

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.4 Total: 4.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, ASBESTOS, DIRT/SOIL/DIATOMACEOUS EARTH, CONWEB PADS, HAZARDOUS CONSTITUENTS, LEAD, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled RCRA regulated mixed TRU waste with metal ignitable contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W316	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Soils CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008, D007, D006, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.3	0.0	0.0
Rubber:	56.4	0.0	0.0
Plastics:	31.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	91.9		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, HAZARDOUS CONSTITUENTS, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, GLASS.
WASTE STREAM SOURCE	This stream is soils contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W317	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Pb/Cd met unk form CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

D009, D008, D007, D006, D005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	3.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	23.5	0.0	0.0
Other Inorganic Material:	1.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.2	0.0	0.0
Rubber:	105.1	0.0	0.0
Plastics:	26.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	42.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.8	1.0	0.4	0.0	3.3
Totals	1.0	0.8	1.0	0.4	0.0	3.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.4	0.8	1.0	0.4	0.0	12.7
Totals	10.4	0.8	1.0	0.4	0.0	12.7

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 10.4 Projected: 2.3 Total: 12.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, HAZARDOUS CONSTITUENTS, PLASTIC/POLYURETHANE, LEAD, DIRT/SOIL/DIATOMACEOUS EARTH, PAPER/CARDBOARD, GLASS, WOOD/LUMBER/PLYWOOD, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W318	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Pb/Cd met debris CH RCRA MTRU w/ met(Hg) cor
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D009, D008, D007, D006, D005, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	3.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	40.1	0.0	0.0
Other Inorganic Material:	1.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.0	0.0	0.0
Rubber:	105.4	0.0	0.0
Plastics:	27.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	47.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Totals	1.7	1.7	2.1	2.5	2.1	10.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Totals	1.7	1.7	2.1	2.5	2.1	10.0

As-Generated Form: Stored: 1.7 Projected: 8.4 Total: 10.0

Final Waste Form: Stored: 1.7 Projected: 8.3 Total: 10.0

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, HAZARDOUS CONSTITUENTS, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, CLOTH/RAGS/NYLON, LEAD, WOOD/LUMBER/PLYWOOD, METAL/IRON/GALVANIZED/SHEET, GLASS, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal (Hg) corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W319	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

D009, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	248.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.6	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	13.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	7.1	0.0	0.0	0.0	0.0	7.1
Totals	7.1	0.0	0.0	0.0	0.0	7.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	7.6	0.0	0.0	0.0	0.0	7.6
Totals	7.6	0.0	0.0	0.0	0.0	7.6

As-Generated Form: Stored: 7.1 Projected: 0.0 Total: 7.1

Final Waste Form: Stored: 7.6 Projected: 0.0 Total: 7.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W320	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ met(Hg) cor
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D009, D008, D007, D006, D005, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	9.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	193.8	0.0	0.0
Other Inorganic Material:	7.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	6.0	0.0	0.0
Rubber:	113.7	0.0	0.0
Plastics:	36.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	32.9		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Totals	1.7	1.7	2.1	2.5	2.1	10.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Totals	1.7	1.7	2.1	2.5	2.1	10.0

As-Generated Form: Stored: 1.7 Projected: 8.4 Total: 10.0

Final Waste Form: Stored: 1.7 Projected: 8.3 Total: 10.0

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, LEAD, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, LEAD SHIELDING, GLASS, CLOTH/RAGS/NYLON, HAZARDOUS CONSTITUENTS, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, MERCURY.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal (Hg) corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W321	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D009, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	16.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.4	0.0	0.0
Rubber:	102.7	0.0	0.0
Plastics:	73.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	38.1		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, HAZARDOUS CONSTITUENTS, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, GLASS, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W322	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ mel(Hg) cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D009, D008, D007, D006, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	2.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	8.1	0.0	0.0
Rubber:	17.4	0.0	0.0
Plastics:	46.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	6.8		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.8	1.0	0.4	0.0	3.1
Totals	0.8	0.8	1.0	0.4	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.8	1.0	0.4	0.0	10.6
Totals	8.3	0.8	1.0	0.4	0.0	10.6

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 8.3 Projected: 2.3 Total: 10.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, CONWEB PADS, HAZARDOUS CONSTITUENTS, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH, PAPER/CARDBOARD, ABSORBENT/KITY LTR/VERMICULITE, ACID, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, MERCURY.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal (Hg) corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W323	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Soils debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D009, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	29.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	2.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	21.8	0.0	0.0
Rubber:	38.6	0.0	0.0
Plastics:	19.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	61.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.6	1.0	0.4	0.0	2.7
Totals	0.6	0.6	1.0	0.4	0.0	2.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.6	1.0	0.4	0.0	8.3
Totals	6.2	0.6	1.0	0.4	0.0	8.3

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 6.2 Projected: 2.1 Total: 8.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, HAZARDOUS CONSTITUENTS, DIRT/SOIL/DIATOMACEOUS EARTH, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, GLASS, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is soils contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W324	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ cor
Inventory Date:	12/1/94						
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal
Waste Matrix Code:	S5400						

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	214.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.1	0.0	0.0
Rubber:	0.9	0.0	0.0
Plastics:	27.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	3.2	0.0	0.0	0.0	0.0	3.2
Totals	3.2	0.0	0.0	0.0	0.0	3.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	3.8	0.0	0.0	0.0	0.0	3.8
Totals	3.8	0.0	0.0	0.0	0.0	3.8

As-Generated Form: Stored: 3.2 Projected: 0.0 Total: 3.2

Final Waste Form: Stored: 3.8 Projected: 0.0 Total: 3.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W325	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ cor
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	10.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	65.9	0.0	0.0
Rubber:	14.3	0.0	0.0
Plastics:	16.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	23.9		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.4	0.4	0.4	0.0	1.7
Totals	0.4	0.4	0.4	0.4	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.4	0.4	0.4	0.0	1.7
Totals	0.4	0.4	0.4	0.4	0.0	1.7

As-Generated Form: Stored: 0.4 Projected: 1.3 Total: 1.7

Final Waste Form: Stored: 0.4 Projected: 1.2 Total: 1.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, PAPER/CARDBOARD, PLASTIC/POLYURETHANE, CHEMICALS, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W326	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Solidif org labpacks CH RCRA MTRU w/ org ign
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics

Inventory Date: 12/1/94

Waste Matrix Code: X6100

AS-GENERATED EPA CODES

D019, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	98.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	47.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	1.7	2.1	2.5	2.1	10.2
Totals	1.9	1.7	2.1	2.5	2.1	10.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	1.7	2.1	2.5	2.1	10.2
Totals	1.9	1.7	2.1	2.5	2.1	10.2

As-Generated Form: Stored: 1.9 Projected: 8.3 Total: 10.2

Final Waste Form: Stored: 1.9 Projected: 8.3 Total: 10.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS HAZARDOUS CONSTITUENTS, GLASS, ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, CONWEB PADS, ANTI-CORROSIVE RADPAD.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA regulated mixed TRU waste with organic ignitable contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W330	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	94.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.4	0.0	0.0
Rubber:	0.2	0.0	0.0
Plastics:	42.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	5.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	32.1	48.2	80.3	32.1	0.0	192.7
Totals	32.1	48.2	80.3	32.1	0.0	192.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	32.1	11.3	18.9	7.6	0.0	69.9
Totals	32.1	11.3	18.9	7.6	0.0	69.9

As-Generated Form: Stored: 32.1 Projected: 160.6 Total: 192.7

Final Waste Form: Stored: 32.1 Projected: 37.8 Total: 69.9

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON, DIRT/SOIL/DIATOMACEOUS EARTH, HAZARDOUS CONSTITUENTS, RUBBER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled State regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W331	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	21.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	45.5	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	21.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.1	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	7.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	2.7	3.1	2.9	2.1	14.4
Box	47.5	47.5	79.2	74.0	52.8	301.1
Totals	51.1	50.2	82.4	76.9	54.9	315.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	2.7	3.1	2.9	2.1	14.4
Standard Waste Box	47.3	17.0	28.3	26.5	18.9	138.0
Totals	50.8	19.7	31.5	29.4	21.0	152.3

As-Generated Form: Stored: 51.1 Projected: 264.4 Total: 315.5

Final Waste Form: Stored: 50.8 Projected: 101.5 Total: 152.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS WOOD/LUMBER/PLYWOOD, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, FILTERS, HAZARDOUS CONSTITUENTS, PLEXIGLASS, ABSORBENT/KITY LTR/VERMICULITE, CEMENT, ANTI-CORROSIVE R
WASTE STREAM SOURCE	This stream is combustible contact handled State regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W335	Handling:	CH	NMVP #:	N/A	Stream Name:	2718E Comb debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	47.6	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	3.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	1.00E-02
Pu-239	7.00E-02
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Box	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.5	0.0	0.0	0.0	0.0	2.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	4.0	0.0	0.0	0.0	0.0	4.0

As-Generated Form: Stored: 2.5 Projected: 0.0 Total: 2.5

Final Waste Form: Stored: 4.0 Projected: 0.0 Total: 4.0

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS FILTERS, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is combustible contact handled State regulated mixed TRU waste from the PNL Critical Mass Storage Facility
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W336	Handling:	CH	NMVP #:	N/A	Stream Name:	318 Inorg non-met part CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	19.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	46.5	0.0	0.0
Other Inorganic Material:	164.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, LEAD, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled State regulated mixed TRU waste from the PNL Radiological Calibrations Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W337	Handling: RH	NMVP #: N/A	Stream Name: 324 Pb/Cd met RH St MTRU		Inventory Date: 12/1/94
Local ID:	Type: MTRU	Generator Site: RL	Final Waste Form: Lead/Cadmium Metal Waste		Waste Matrix Code: X7210

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	7.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	585.3	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	8.80E-01
Pu-240	1.00E-02
Pu-239	3.00E-02
Beta/Gamma	4.38E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.8	12.2	20.3	14.6	8.1	55.9
Totals	0.8	12.2	20.3	14.6	8.1	55.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.9	13.3	22.2	16.0	8.9	61.4
Totals	0.9	13.3	22.2	16.0	8.9	61.4

As-Generated Form: Stored: 0.8 Projected: 55.1 Total: 55.9

Final Waste Form: Stored: 0.9 Projected: 60.5 Total: 61.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, ZIRCOLOY, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is lead cadmium metal remote handled State regulated mixed TRU waste from the PNL Chemical Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W338	Handling: CH	NMVP #: N/A	Stream Name: 325 Solidif org CH RCRA MTRU w/ org met ign/cor		Inventory Date: 12/1/94
Local ID:	Type: MTRU	Generator Site: RL	Final Waste Form: Solidified Organics		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

F003, D007, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	121.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	78.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	18.7	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	3.80E-01
Pu-240	1.00E-02
Pu-239	2.00E-02
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CONWEB PADS, ABSORBENT/KITY LTR/VERMICULITE, GLASS, LIQUID.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA regulated mixed TRU waste with organic metal ign/cor contaminants from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W339	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Pb/Cd met lead CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	585.4	0.0	0.0
Other Inorganic Material:	26.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	26.5	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	9.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	3.80E-01
Pu-240	1.00E-02
Pu-239	2.00E-02
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, WOOD/LUMBER/PLYWOOD, GLASS, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W340	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Comb debris CH RCRA MTRU w/ cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	21.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	80.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	2.4	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	9.00E-02
Pu-241	3.80E-01
Pu-240	1.00E-02
Pu-239	2.00E-02
Beta/Gamma	7.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CONWEB PADS, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, GLASS, LIQUID.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with cor contaminants from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W341	Handling:	CH	NMVP #:	N/A	Stream Name:	325A Uncat mt debris CH/r RCRA MTRU w/ org met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

F005, F004, F003, F002, F001, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	19.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	24.0	0.0	0.0
Rubber:	4.8	0.0	0.0
Plastics:	9.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	5.00E-02
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	3.97E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, GLASS, METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, RUBBER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote RCRA regulated mixed TRU waste with organic metal (Hg) contaminants from the PNL Cesium Recovery Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W342	Handling:	CH	NMVP #:	N/A	Stream Name:	325A Inorg n-mt debr CH/r RCRA MTRU w/org met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

F005, F004, F003, F002, F001, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	3.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	117.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.8	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	40.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	5.00E-02
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.48E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.0	0.0	0.0	0.0	8.3
Totals	8.3	0.0	0.0	0.0	0.0	8.3

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 8.3 Projected: 0.0 Total: 8.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, GLASS, PLASTIC/POLYURETHANE, CERAMICS, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE, ALUMINUM.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled packaged remote RCRA regulated mixed TRU waste with organic metal (Hg) contaminants from the PNL Cesium Recovery Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W343	Handling:	CH	NMVP #:	N/A	Stream Name:	325A Comb debris CH/r RCRA MTRU w/ org met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

F005, F004, F003, F002, F001, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	32.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.8	0.0	0.0
Rubber:	3.2	0.0	0.0
Plastics:	17.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	5.00E-02
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	1.63E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.0	0.0	0.0	0.0	6.2
Totals	6.2	0.0	0.0	0.0	0.0	6.2

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 6.2 Projected: 0.0 Total: 6.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, GLASS, PLASTIC/POLYURETHANE, CERAMICS, METAL/IRON/GALVANIZED/SHEET, RUBBER.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote RCRA regulated mixed TRU waste with organic metal (Hg) contaminants from the PNL Cesium Recovery Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W344	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Solidif org debris CH/r RCRA MTRU w/ org	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

F005, F004, F003, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	9.6	0.0	0.0
Rubber:	7.2	0.0	0.0
Plastics:	7.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	4.8		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	6.00E-02
Pu-241	5.00E-02
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	1.84E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, PLASTIC/POLYURETHANE, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH.
WASTE STREAM SOURCE	This stream is solidified organics contact handled packaged remote RCRA regulated mixed TRU waste with organic contaminants from the Waste Loadout Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W345 | Handling: CH | NMVP #: N/A | Stream Name: 2345Z Solidif org debris CH St MTRU | Inventory Date: 12/1/94

Local ID: | Type: MTRU | Generator Site: RL | Final Waste Form: Solidified Organics | Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	29.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	48.4	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	126.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.6	0.4	0.0	0.0	3.1
Totals	2.1	0.6	0.4	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.6	0.4	0.0	0.0	3.1
Totals	2.1	0.6	0.4	0.0	0.0	3.1

As-Generated Form: Stored: 2.1 Projected: 1.0 Total: 3.1

Final Waste Form: Stored: 2.1 Projected: 1.0 Total: 3.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, CONWEB PADS, ORGANICS, WOOD/LUMBER/PLYWOOD, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is solidified organics contact handled State regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W346	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Uncat mt debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	146.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	55.2	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	19.2	0.0	0.0
Rubber:	18.6	0.0	0.0
Plastics:	62.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, EQUIPMENT, RUBBER, PAPER/CARDBOARD, STAINLESS STEEL, 10 MIL LINER, LEATHER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W347	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Combus debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	57.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.8	0.0	0.0
Rubber:	81.7	0.0	0.0
Plastics:	40.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, RUBBER, STAINLESS STEEL, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, 10 MIL LINER.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W348	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Solid org debris CH RCRA MTRU w/ met(Hg) cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D009, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	4.3	0.0	0.0
Plastics:	10.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	88.[illegible]	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS ANIMAL WASTE, 10 MIL LINER, RUBBER, BATTERIES, GLASS.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA regulated mixed TRU waste with metal (Hg) cor contaminants from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W349	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Inorg non-met CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1380.9	0.0	0.0
Other Inorganic Material:	38.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	87.9	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	91.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, CLOTH/RAGS/NYLON, 10 MIL LINER, GLASS.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled RCRA regulated mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W350	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Uncat met debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	62.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	18.6	0.0	0.0
Other Inorganic Material:	44.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	19.4	0.0	0.0
Rubber:	26.9	0.0	0.0
Plastics:	43.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, RUBBER, CERAMICS, PAPER/CARDBOARD, GLASS, CLOTH/RAGS/NYLON, LEAD, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled State regulated mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W351	Handling:	CH	NMVP #:	N/A	Stream Name:	CUPRC Soil CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	4.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	3.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	23.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	256.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ROCK/GRAVEL, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is soils contact handled non-mixed TRU waste from the Ceer University Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W352	Handling:	CH	NMVP #:	N/A	Stream Name:	CUPRC Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5120

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	23.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	463.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CONCRETE, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Ceer University Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W353	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Inorg non-met part CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	8.9	0.0	0.0
Aluminum-base Metal/Alloys:	2.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	164.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.7	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	2.91E+01
Pu-240	1.08E+00
Pu-239	4.82E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.8 Projected: 0.0 Total: 0.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, GLASS, ALUMINUM.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W354	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Soil CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	17.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	138.2	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.[illegible]	0.0	0.0
Packaging Material Steel:	185.2		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	2.91E+01
Pu-240	1.08E+00
Pu-239	4.82E+00
Beta/Gamma	1.71E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, CEMENT, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is soils contact handled packaged remote non-mixed TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W355	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Uncat met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	268.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.2	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	17.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	2.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	2.91E+01
Pu-240	1.08E+00
Pu-239	4.82E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET, GRAPHITE, FILTERS, PLASTIC/POLYURETHANE, COPPER METAL, GLASS, ALUMINUM.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W356	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	10.0	0.0	0.0
Aluminum-base Metal/Alloys:	4.9	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	67.3	0.0	0.0
Rubber:	68.8	0.0	0.0
Plastics:	14.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	7.5	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	2.91E+01
Pu-240	1.08E+00
Pu-239	4.82E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.3	0.0	0.0	0.0	0.0	1.3
Totals	1.3	0.0	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 1.2 Projected: 0.0 Total: 1.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS RUBBER, COTTON/KOTEX, WOOD/LUMBER/PLYWOOD, PLASTIC/POLYURETHANE, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, PAINTS/LUCITE, ALUMINUM, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W358	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	59.5	0.0	0.0
Aluminum-base Metal/Alloys:	3.9	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	174.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	14.2	0.0	0.0
Rubber:	2.5	0.0	0.0
Plastics:	16.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	1.74E+00
Pu-240	6.00E-02
Pu-239	2.90E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.5	0.0	0.0	0.0	0.0	2.5
Totals	2.5	0.0	0.0	0.0	0.0	2.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.5	0.0	0.0	0.0	0.0	2.5
Totals	2.5	0.0	0.0	0.0	0.0	2.5

As-Generated Form: Stored: 2.5 Projected: 0.0 Total: 2.5

Final Waste Form: Stored: 2.5 Projected: 0.0 Total: 2.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CONCRETE, ABSORBENT/KITY LTR/VERMICULITE, STAINLESS STEEL, FILTERS, PLASTIC/POLYURETHANE, SAND, METAL/IRON/GALVANIZED/SHEET, WOOD/LUMBER/PLYWOOD, ALUMINUM, RUBBER, PAPER/CARDBOARD, COPPER METAL.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W359	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Uncat met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	156.1	0.0	0.0
Aluminum-base Metal/Alloys:	4.0	0.0	0.0
Other Metals/Alloys:	0.6	0.0	0.0
Other Inorganic Material:	9.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	13.7	0.0	0.0
Rubber:	3.1	0.0	0.0
Plastics:	32.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	3.5	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	0.00E+00
Pu-241	1.74E+00
Pu-240	6.00E-02
Pu-239	2.90E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.6	0.0	0.0	0.0	0.0	16.6
Totals	16.6	0.0	0.0	0.0	0.0	16.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.6	0.0	0.0	0.0	0.0	16.6
Totals	16.6	0.0	0.0	0.0	0.0	16.6

As-Generated Form: Stored: 16.6 Projected: 0.0 Total: 16.6

Final Waste Form: Stored: 16.6 Projected: 0.0 Total: 16.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS STAINLESS STEEL, PLASTIC/POLYURATHENE, METAL/IRON/GALVANIZED/SHEET, FILTERS, PAPER/CARDBOARD, ALUMINUM, RUBBER, WOOD/LUMBER/PLYWOOD, CONCRETE, ABSORBENT/KITY LTR/VERMICULITE, RESINS, SAND, COPPER METAL, FIBERGLASS, FLOO
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W360	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	37.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.8	0.0	0.0
Other Metals/Alloys:	0.2	0.0	0.0
Other Inorganic Material:	20.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.5	0.0	0.0
Rubber:	1.1	0.0	0.0
Plastics:	97.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	7.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	6.4	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	1.74E+00
Pu-240	6.00E-02
Pu-239	2.90E-01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.8	0.0	0.0	0.0	0.0	4.8
Totals	4.8	0.0	0.0	0.0	0.0	4.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.8	0.0	0.0	0.0	0.0	4.8
Totals	4.8	0.0	0.0	0.0	0.0	4.8

As-Generated Form: Stored: 4.8 Projected: 0.0 Total: 4.8

Final Waste Form: Stored: 4.8 Projected: 0.0 Total: 4.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, WOOD/LUMBER/PLYWOOD, FILTERS, METAL/IRON/GALVANIZED/SHEET, CONCRETE, SLUDGES, PAPER/CARDBOARD, ABSORBENT/KITY LTR/VERMICULITE, RESINS, RUBBER, ALUMINUM, FIBERGLASS, GLASS, COPPER M
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W361	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Solidif org CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	18.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	20.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	42.3	0.0	0.0
Rubber:	1.8	0.0	0.0
Plastics:	15.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	137.2	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	1.74E+00
Pu-240	6.00E-02
Pu-239	2.90E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS FILTERS, RESINS, WOOD/LUMBER/PLYWOOD, ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, RUBBER.
WASTE STREAM SOURCE	This stream is solidified organics contact handled non-mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W362	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	142.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	49.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	9.0	0.0	0.0
Rubber:	2.4	0.0	0.0
Plastics:	51.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	3.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	2.1	0.0	0.0	0.0	5.0
Totals	2.9	2.1	0.0	0.0	0.0	5.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	2.1	0.0	0.0	0.0	5.0
Totals	2.9	2.1	0.0	0.0	0.0	5.0

As-Generated Form: Stored: 2.9 Projected: 2.1 Total: 5.0

Final Waste Form: Stored: 2.9 Projected: 2.1 Total: 5.0

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, RUBBER, GLASS, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W363	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Pb/Cd met unk form CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	98.7	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.8	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.2	0.0	0.0	0.0	0.4
Totals	0.2	0.2	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.2	0.0	0.0	0.0	0.4
Totals	0.2	0.2	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.2 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS EQUIPMENT, FILTERS.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W364	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	21.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	61.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	22.6	0.0	0.0
Rubber:	2.0	0.0	0.0
Plastics:	26.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.5	0.0	0.0	0.0	3.6
Totals	2.1	1.5	0.0	0.0	0.0	3.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.5	0.0	0.0	0.0	3.5
Totals	2.1	1.5	0.0	0.0	0.0	3.5

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 1.5 Total: 3.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE, RUBBER, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, COTTON/KOTEX, CORK.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W365	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	12.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.1	0.0	0.0
Other Inorganic Material:	17.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	42.9	0.0	0.0
Rubber:	8.5	0.0	0.0
Plastics:	60.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	9.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.8	8.0	0.0	0.0	0.0	19.7
Totals	11.8	8.0	0.0	0.0	0.0	19.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.9	7.9	0.0	0.0	0.0	19.8
Totals	11.9	7.9	0.0	0.0	0.0	19.8

As-Generated Form: Stored: 11.8 Projected: 0.0 Total: 11.8

Final Waste Form: Stored: 11.9 Projected: 7.9 Total: 19.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, RUBBER, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET, WOOD/LUMBER/PLYWOOD, ABSORBENT/KITY LTR/VERMICULITE, STAINLESS STEEL, LEATHER, COTTON/KOTEX, CORK, LEAD.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W367	Handling:	CH	NMVP #:	N/A	Stream Name:	202AL Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	52.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	21.6	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	24.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	4.58E+00
Pu-240	1.70E-01
Pu-239	7.60E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	2.1	0.0	0.0	0.0	5.0
Totals	2.9	2.1	0.0	0.0	0.0	5.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	2.1	0.0	0.0	0.0	5.0
Totals	2.9	2.1	0.0	0.0	0.0	5.0

As-Generated Form: Stored: 2.9 Projected: 0.0 Total: 2.9

Final Waste Form: Stored: 2.9 Projected: 2.1 Total: 5.0

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, METAL/IRON/GALVANIZED/SHEET, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Fuel Reprocessing Facility Support Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W368	Handling:	CH	NMVP #:	N/A	Stream Name:	202AL Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	7.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	23.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	23.0	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	30.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	4.58E+00
Pu-240	1.70E-01
Pu-239	7.60E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.6	0.0	0.0	0.0	1.3
Totals	0.6	0.6	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.6	0.0	0.0	0.0	1.2
Totals	0.6	0.6	0.0	0.0	0.0	1.2

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.6 Total: 1.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, METAL/IRON/GALVANIZED/SHEET, RUBBER.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Fuel Reprocessing Facility Support Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W369	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Uncat met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	81.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.3	0.0	0.0
Other Inorganic Material:	0.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.4	0.0	0.0
Rubber:	1.1	0.0	0.0
Plastics:	14.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	1.20E-01
Pu-241	2.49E+01
Pu-240	9.10E-01
Pu-239	3.96E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.8	34.0	50.2	46.6	35.8	177.4
Box	22.4	0.0	0.0	0.0	0.0	22.4
Totals	33.1	34.0	50.2	46.6	35.8	199.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.8	4.0	5.8	5.4	4.2	30.2
Standard Waste Box	22.7	0.0	0.0	0.0	0.0	22.7
Totals	33.5	4.0	5.8	5.4	4.2	52.8

As-Generated Form: Stored: 33.1 Projected: 166.6 Total: 199.8

Final Waste Form: Stored: 33.5 Projected: 19.3 Total: 52.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, PLEXIGLASS, FOAM/STYROFOAM/PYROFOAM, RUBBER, GLASS, STAINLESS STEEL, FIBERGLASS, WOOD/LUMBER/PLYWOOD, BRASS METAL.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W370	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Uncat met debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	146.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	31.6	0.0	0.0
Rubber:	20.6	0.0	0.0
Plastics:	19.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.20E-01
Pu-241	2.49E+01
Pu-240	9.10E-01
Pu-239	3.96E+00
Beta/Gamma	5.10E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, PLASTIC/POLYURETHANE, RUBBER, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W371	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Comb debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	3.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	14.1	0.0	0.0
Rubber:	11.0	0.0	0.0
Plastics:	39.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.20E-01
Pu-241	2.49E+01
Pu-240	9.10E-01
Pu-239	3.96E+00
Beta/Gamma	5.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	0.8	1.0	0.4	0.0	4.6
Box	3.2	0.0	0.0	0.0	0.0	3.2
Totals	5.5	0.8	1.0	0.4	0.0	7.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	0.8	1.0	0.4	0.0	4.6
Standard Waste Box	3.8	0.0	0.0	0.0	0.0	3.8
Totals	6.1	0.8	1.0	0.4	0.0	8.4

As-Generated Form: Stored: 5.5 Projected: 2.3 Total: 7.8

Final Waste Form: Stored: 6.1 Projected: 2.3 Total: 8.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, CLOTH/RAGS/NYLON, RUBBER, FOAM/STYROFOAM/PYROFOAM, FIBERGLASS, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W372	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Comb debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	38.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	103.0	0.0	0.0
Rubber:	3.6	0.0	0.0
Plastics:	5.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.20E-01
Pu-241	2.49E+01
Pu-240	9.10E-01
Pu-239	3.96E+00
Beta/Gamma	2.90E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PAPER/CARDBOARD, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, PLASTIC/POLYURETHANE, RUBBER.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W373	Handling:	CH	NMVP #:	N/A	Stream Name:	231Z Uncat met unk form CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	68.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.3	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	13.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.00E-02
Pu-241	4.80E-01
Pu-240	2.00E-02
Pu-239	7.00E-02
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.6	0.6	0.0	0.0	2.1
Box	78.4	0.0	0.0	0.0	0.0	78.4
Totals	79.2	0.6	0.6	0.0	0.0	80.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.6	0.6	0.0	0.0	2.1
Standard Waste Box	79.4	0.0	0.0	0.0	0.0	79.4
Totals	80.2	0.6	0.6	0.0	0.0	81.5

As-Generated Form: Stored: 79.2 Projected: 0.0 Total: 79.2

Final Waste Form: Stored: 80.2 Projected: 1.2 Total: 81.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS AIR, METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, RUBBER, GLASS, ABSORBENT/KITY LTR/VERMICULITE, LIQUID, CLOTH/RAGS/NYLON, DIRT/SOIL/DIATOMACEOUS EARTH.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the PNL Materials Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W374	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Uncat met debris CH TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	45.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	9.3	0.0	0.0
Rubber:	4.8	0.0	0.0
Plastics:	17.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.1	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	5.2		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	74.7	48.0	67.8	75.5	60.5	326.6
Box	107.6	33.6	0.0	215.2	269.0	625.3
Totals	182.3	81.6	67.8	290.7	329.5	952.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	74.7	47.8	67.6	75.3	60.3	325.7
Standard Waste Box	107.7	9.4	0.0	60.5	75.6	253.3
Totals	182.4	57.3	67.6	135.8	135.9	579.0

As-Generated Form: Stored: 182.3 Projected: 769.7 Total: 952.0

Final Waste Form: Stored: 182.4 Projected: 396.6 Total: 579.0

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, GLASS, STAINLESS STEEL, PPE CLOTHING (PAPER/PLASTIC), CERAMICS, CONWEB PAD
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W375	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Uncat met debris CH/r TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	44.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	19.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	1.38E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.6	1.0	0.4	0.0	2.9
Box	21.1	10.6	0.0	84.4	105.5	221.6
Totals	21.9	11.2	1.0	84.8	105.5	224.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.6	1.0	0.4	0.0	2.9
Standard Waste Box	20.8	1.9	0.0	15.1	18.9	56.7
Totals	21.6	2.5	1.0	15.5	18.9	59.6

As-Generated Form: Stored: 21.9 Projected: 202.5 Total: 224.5

Final Waste Form: Stored: 21.6 Projected: 38.0 Total: 59.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W376	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Inorg non-met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	10.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	134.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	16.5	0.0	0.0
Rubber:	11.7	0.0	0.0
Plastics:	31.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	19.3		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	1.00E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.1	10.5	14.6	15.9	12.6	69.7
Totals	16.1	10.5	14.6	15.9	12.6	69.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.2	10.4	14.6	15.8	12.5	69.5
Totals	16.2	10.4	14.6	15.8	12.5	69.5

As-Generated Form: Stored: 16.1 Projected: 53.6 Total: 69.7

Final Waste Form: Stored: 16.2 Projected: 53.2 Total: 69.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS GLASS, CONCRETE, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, ASBESTOS, CERAMICS, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W377	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Comb debris CH TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Combustible		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	16.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	3.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	44.2	0.0	0.0
Rubber:	20.0	0.0	0.0
Plastics:	51.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.3	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	12.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	6.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	292.4	187.7	264.8	296.8	238.3	1279.9
Box	10.5	3.5	0.0	28.1	35.1	77.3
Totals	302.9	191.2	264.8	324.9	273.4	1357.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	292.4	186.8	263.5	295.4	237.1	1275.2
Standard Waste Box	11.3	1.9	0.0	15.1	18.9	47.2
Totals	303.8	188.7	263.5	310.5	256.0	1322.5

As-Generated Form: Stored: 302.9 Projected: 1054.3 Total: 1357.2

Final Waste Form: Stored: 303.8 Projected: 1018.7 Total: 1322.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, CLOTH/RAGS/NYLON, RUBBER, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, GLASS, PPE CLOTHING (PAPER/PLASTIC), WOOD/LUMBER/PLYWOOD, STAINLESS STEEL, CONWEB PADS, SLUDGES
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W378	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH/r TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	24.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.8	0.0	0.0
Rubber:	0.5	0.0	0.0
Plastics:	36.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.2		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	1.03E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.3	2.1	2.5	2.1	9.6
Box	14.1	14.1	0.0	112.8	141.0	282.0
Totals	15.8	15.4	2.1	115.3	143.1	291.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.2	2.1	2.5	2.1	9.6
Standard Waste Box	15.1	1.9	0.0	15.1	18.9	51.0
Totals	16.8	3.1	2.1	17.6	21.0	60.6

As-Generated Form: Stored: 15.8 Projected: 275.8 Total: 291.6

Final Waste Form: Stored: 16.8 Projected: 43.8 Total: 60.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, RUBBER, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, GLASS, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W379	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Heter debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	35.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.7	0.0	0.0
Rubber:	12.6	0.0	0.0
Plastics:	42.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	331.6	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	26.8		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CEMENT, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W380	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Solidif org debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	9.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.8	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	96.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	134.6	0.0	0.0
Packaging Material Steel:	28.8		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, WAX, DIRT/SOIL/DIATOMACEOUS EARTH, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is solidified organics contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W381	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Soil debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	12.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	15.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.0	0.0	0.0
Rubber:	14.4	0.0	0.0
Plastics:	30.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	49.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	7.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.3	3.8	6.3	7.5	6.3	30.1
Totals	6.3	3.8	6.3	7.5	6.3	30.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	3.7	6.2	7.5	6.2	30.0
Totals	6.2	3.7	6.2	7.5	6.2	30.0

As-Generated Form: Stored: 6.3 Projected: 23.8 Total: 30.1

Final Waste Form: Stored: 6.2 Projected: 23.7 Total: 30.0

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, RUBBER, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, PPE CLOTHING (PAPER/PLASTIC), CORK, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is soils contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W383	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Solidif Inorg labpacks CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	34.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	21.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	17.4	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	13.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.6	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	9.6	0.0	0.0	0.0	0.0	9.6
Totals	9.6	0.0	0.0	0.0	0.0	9.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	9.4	0.0	0.0	0.0	0.0	9.4
Totals	9.4	0.0	0.0	0.0	0.0	9.4

As-Generated Form: Stored: 9.6 Projected: 0.0 Total: 9.6

Final Waste Form: Stored: 9.4 Projected: 0.0 Total: 9.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, WOOD/LUMBER/PLYWOOD, PLASTIC/POLYURETHANE, OILS.
WASTE STREAM SOURCE	This stream is solidified inorganics contact handled packaged remote non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W384	Handling:	CH	NMVP #:	N/A	Stream Name:	2718E Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	4.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	56.0	0.0	0.0
Rubber:	67.2	0.0	0.0
Plastics:	49.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	5.70E-01
Pu-241	5.38E+00
Pu-240	2.20E-01
Pu-239	9.20E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the PNL Critical Mass Storage Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W385	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Uncat met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	227.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	6.1	0.0	0.0
Other Inorganic Material:	2.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	22.3	0.0	0.0
Rubber:	3.2	0.0	0.0
Plastics:	42.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.2	0.6	0.0	0.0	0.0	8.8
Totals	8.2	0.6	0.0	0.0	0.0	8.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.1	0.6	0.0	0.0	0.0	8.7
Totals	8.1	0.6	0.0	0.0	0.0	8.7

As-Generated Form: Stored: 8.2 Projected: 0.0 Total: 8.2

Final Waste Form: Stored: 8.1 Projected: 0.6 Total: 8.7

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, ORGANICS, RUBBER, CHEMICALS, CLOTH/RAGS/NYLON, STAINLESS STEEL, EQUIPMENT, MISCELLANEOUS/UNKNOWN/OTHER, COTTON/KOTEX, INSULATION
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W386	Handling: CH	NMVP #: N/A	Stream Name: 308 Uncat met debris CH/r TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	178.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.3	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	32.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	6.75E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W387	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	17.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	290.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	8.1	0.0	0.0
Rubber:	1.4	0.0	0.0
Plastics:	37.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.7	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1.5	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.2	0.0	0.0	0.0	1.7
Totals	1.5	0.2	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.2	0.0	0.0	0.0	1.7
Totals	1.5	0.2	0.0	0.0	0.0	1.7

As-Generated Form: Stored: 1.5 Projected: 0.0 Total: 1.5

Final Waste Form: Stored: 1.5 Projected: 0.2 Total: 1.7

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CONCRETE, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, OILS, RUBBER, WATER, 90 MIL LINER.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W388	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	6.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.1	0.0	0.0
Other Inorganic Material:	0.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	9.5	0.0	0.0
Rubber:	3.8	0.0	0.0
Plastics:	18.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.3	0.6	0.0	0.0	0.0	8.0
Box	9.6	0.0	0.0	0.0	0.0	9.6
Totals	16.9	0.6	0.0	0.0	0.0	17.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.3	0.6	0.0	0.0	0.0	7.9
Standard Waste Box	9.4	0.0	0.0	0.0	0.0	9.4
Totals	16.7	0.6	0.0	0.0	0.0	17.4

As-Generated Form: Stored: 16.9 Projected: 0.0 Total: 16.9

Final Waste Form: Stored: 16.7 Projected: 0.6 Total: 17.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS FILTERS, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, RUBBER, CLOTH/RAGS/NYLON, GLASS, CERAMICS, EQUIPMENT, STAINLESS STEEL, ABSORBENT/KITY LTR/VERMICULITE, 10 MIL LINER, CHEM
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W389	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Comb debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	23.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	25.3	0.0	0.0
Rubber:	18.0	0.0	0.0
Plastics:	87.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	9.29E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, RUBBER.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W390	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Pb/Cd met unk form CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	26.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	442.2	0.0	0.0
Other Inorganic Material:	24.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	6.6	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	14.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	4.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS EQUIPMENT, CHEMICALS, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, CERAMICS, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON, PLEXIGLASS, GLASS, 10 MIL LINER.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W392	Handling:	CH	NMVP #:	N/A	Stream Name:	324 Inorg non-met part CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	181.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	2.10E-01
Pu-240	1.00E-02
Pu-239	3.00E-02
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, GLASS.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the PNL Chemical Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W393	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Inorg non-met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	46.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	3.2	0.0	0.0
Other Inorganic Material:	116.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	11.7	0.0	0.0
Rubber:	5.8	0.0	0.0
Plastics:	27.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.9	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.1		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	4.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	2.1	2.7	2.5	2.1	14.8
Totals	5.4	2.1	2.7	2.5	2.1	14.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	2.1	2.7	2.5	2.1	14.8
Totals	5.4	2.1	2.7	2.5	2.1	14.8

As-Generated Form: Stored: 5.4 Projected: 9.4 Total: 14.8

Final Waste Form: Stored: 5.4 Projected: 9.4 Total: 14.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, GLASS, PAPER/CARDBOARD, CERAMICS, RUBBER, CLOTH/RAGS/NYLON, CONCRETE, EQUIPMENT, INSULATION NON-ASBESTOS, MISCELLANEOUS/UNKNOWN/OTHER.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W394	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Solidif inorg part CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Solidified Inorganics

Inventory Date: 12/1/94

Waste Matrix Code: S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	32.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	30.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.2	0.0	0.0
Rubber:	2.4	0.0	0.0
Plastics:	32.4	0.0	0.0
Solidified Inorganic Material:	641.3	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.0	1.2	1.6	2.0	2.0	9.9
Totals	3.0	1.2	1.6	2.0	2.0	9.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.1	1.2	1.7	2.1	2.1	10.2
Totals	3.1	1.2	1.7	2.1	2.1	10.2

As-Generated Form: Stored: 3.0 Projected: 6.8 Total: 9.9

Final Waste Form: Stored: 3.1 Projected: 7.1 Total: 10.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CEMENT, PLASTIC/POLYURETHANE, LIQUID, ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, CHEMICALS, RUBBER, CLOTH/RAGS/NYLON, GLASS, PAPER/CARDBOARD, LEATHER, 10 MIL LINER.
WASTE STREAM SOURCE	This stream is solidified inorganics contact handled non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W395	Handling: CH	NMVP #: N/A	Stream Name: 325 Uncat met debris CH TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	129.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	2.6	0.0	0.0
Other Inorganic Material:	7.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.3	0.0	0.0
Rubber:	4.7	0.0	0.0
Plastics:	19.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	13.9	5.4	7.5	5.8	4.2	36.8
Box	9.8	0.0	0.0	0.0	0.0	9.8
Totals	23.7	5.4	7.5	5.8	4.2	46.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	13.9	5.4	7.5	5.8	4.2	36.8
Standard Waste Box	9.4	0.0	0.0	0.0	0.0	9.4
Totals	23.4	5.4	7.5	5.8	4.2	46.3

As-Generated Form: Stored: 23.7 Projected: 22.8 Total: 46.6

Final Waste Form: Stored: 23.4 Projected: 22.9 Total: 46.3

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, RUBBER, GLASS, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, STAINLESS STEEL, EQUIPMENT, WOOD/LUMBER/PLYWOOD, ABSORBENT/KITY LTR/VERMICULITE, CHARCOAL, INSULATION NON-ASBESTOS, ASBESTOS
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W396	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Uncat met debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2595.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	95.2	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	4.8	0.0	0.0
Plastics:	14.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	1.30E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, EQUIPMENT, PLASTIC/POLYURETHANE, RUBBER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W397	Handling: CH	NMVP #: N/A	Stream Name: 325 Comb debris CH TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Combustible		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	47.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.6	0.0	0.0
Other Metals/Alloys:	1.1	0.0	0.0
Other Inorganic Material:	27.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	20.2	0.0	0.0
Rubber:	48.8	0.0	0.0
Plastics:	93.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	4.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	1.2	2.1	2.5	2.1	11.4
Totals	3.5	1.2	2.1	2.5	2.1	11.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	1.2	2.1	2.5	2.1	11.4
Totals	3.5	1.2	2.1	2.5	2.1	11.4

As-Generated Form: Stored: 3.5 Projected: 7.9 Total: 11.4

Final Waste Form: Stored: 3.5 Projected: 7.9 Total: 11.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, RUBBER, CLOTH/RAGS/NYLON, GLASS, PAPER/CARDBOARD, ASBESTOS, ABSORBENT/KITY LTR/VERMICULITE, CERAMICS, STAINLESS STEEL, FUEL/PINS OR RODS, CONCRETE, LEATHER, ALUMINUM, GRAPHITE, LEAD
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W398	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Comb debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	15.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	80.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.0	0.0	0.0
Rubber:	10.0	0.0	0.0
Plastics:	108.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	2.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS GLASS, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD, RUBBER, CERAMICS.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W399	Handling: CH	NMVP #: N/A	Stream Name: 327C Uncat met debris CH/r TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	146.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	8.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	16.5	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	45.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	5.01E+02
Pu-240	7.91E+00
Pu-239	1.59E+01
Beta/Gamma	4.88E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.1	0.2	0.2	0.1	0.0	0.6
Totals	0.1	0.2	0.2	0.1	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	1.5	1.7	0.4	0.0	3.7
Totals	0.2	1.5	1.7	0.4	0.0	3.7

As-Generated Form: Stored: 0.1 Projected: 0.5 Total: 0.6

Final Waste Form: Stored: 0.2 Projected: 3.5 Total: 3.7

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD, GLASS, CLOTH/RAGS/NYLON, COTTON/KOTEX.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the PNL Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W400	Handling:	CH	NMVP #:	N/A	Stream Name:	327C Inorg non-met debris CH/r TRU
Inventory Date:	12/1/94						
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal
Waste Matrix Code:	S5400						

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	24.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	114.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.7	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	52.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	5.01E+02
Pu-240	7.91E+00
Pu-239	1.59E+01
Beta/Gamma	4.26E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.1	0.1	0.1	0.1	0.0	0.3
Totals	0.1	0.1	0.1	0.1	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.8	1.0	0.4	0.0	2.5
Totals	0.2	0.8	1.0	0.4	0.0	2.5

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.2 Projected: 2.3 Total: 2.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, GLASS, CONCRETE, COTTON/KOTEX, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, CLOTH/RAGS/NYLON, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled packaged remote non-mixed TRU waste from the PNL Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W401	Handling: CH	NMVP #: N/A	Stream Name: 327C Comb debris CH/r TRU		Inventory Date: 12/1/9
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Combustible		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	54.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	21.7	0.0	0.0
Rubber:	0.2	0.0	0.0
Plastics:	95.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	5.01E+02
Pu-240	7.91E+00
Pu-239	1.59E+01
Beta/Gamma	1.51E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	1.6	2.0	1.1	0.7	6.0
Totals	0.6	1.6	2.0	1.1	0.7	6.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	9.6	12.1	6.7	4.2	33.1
Totals	0.6	9.6	12.1	6.7	4.2	33.1

As-Generated Form: Stored: 0.6 Projected: 5.5 Total: 6.0

Final Waste Form: Stored: 0.6 Projected: 32.4 Total: 33.1

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, COTTON/KOTEX, GLASS, RUBBER, CONCRETE, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the PNL Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W402	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Uncat met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	134.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.1	0.0	0.0
Rubber:	5.4	0.0	0.0
Plastics:	45.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	5.73E+01
Pu-240	2.13E+00
Pu-239	9.50E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.3	0.6	1.0	0.4	0.0	3.4
Totals	1.3	0.6	1.0	0.4	0.0	3.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.6	1.0	0.4	0.0	3.3
Totals	1.2	0.6	1.0	0.4	0.0	3.3

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 1.2 Projected: 2.1 Total: 3.3

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Waste Loadout Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W403	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Inorg non-met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	31.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	223.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.6	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	51.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	5.73E+01
Pu-240	2.13E+00
Pu-239	9.50E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CONCRETE, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Waste Loadout Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W404	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	32.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	5.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	44.4	0.0	0.0
Rubber:	0.2	0.0	0.0
Plastics:	73.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	5.73E+01
Pu-240	2.13E+00
Pu-239	9.50E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.6	1.0	0.4	0.0	4.2
Totals	2.1	0.6	1.0	0.4	0.0	4.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.6	1.0	0.4	0.0	4.2
Totals	2.1	0.6	1.0	0.4	0.0	4.2

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 2.1 Total: 4.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, WOOD/LUMBER/PLYWOOD, GLASS, CONCRETE, CERAMICS, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Waste Loadout Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W405	Handling:	CH	NMVP #:	N/A	Stream Name:	3720 Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	23.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	114.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	43.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.60E+00
Pu-241	3.27E+00
Pu-240	1.20E-01
Pu-239	5.40E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, GLASS.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the PNL Chemistry and Metal Sciences Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W406	Handling:	CH	NMVP #:	N/A	Stream Name:	6652H Soils CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	131.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	597.6		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	1.24E+00
Pu-240	5.00E-02
Pu-239	2.10E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is solls contact handled non-mixed TRU waste from the PNL Arid Lands Ecology Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W407	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Non-Surpl Fac Mt Prg D&D TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date:

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	74.9	93.6	168.5
Standard Waste Box	0.0	0.0	0.0	166.3	207.9	374.2
Totals	0.0	0.0	0.0	241.2	301.5	542.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	74.9	93.6	168.5
Standard Waste Box	0.0	0.0	0.0	166.3	207.9	374.2
Totals	0.0	0.0	0.0	241.2	301.5	542.7

As-Generated Form: Stored: 0.0 Projected: 542.7 Total: 542.7

Final Waste Form: Stored: 0.0 Projected: 542.7 Total: 542.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from cleanout of contaminated equipment/removable piping etc. from PUREX facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W408	Handling:	CH	NMVP #:	N/A	Stream Name:	221T/2706T Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	339.5	424.3	763.8
Totals	0.0	0.0	0.0	339.5	424.3	763.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	339.5	424.3	763.8
Totals	0.0	0.0	0.0	339.5	424.3	763.8

As-Generated Form: Stored: 0.0 Projected: 848.6 Total: 848.6

Final Waste Form: Stored: 0.0 Projected: 848.6 Total: 848.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility clean-out and D&D waste from the T-Plant Canyon and Decontamination facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W409	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	49.9	62.4	112.3
Standard Waste Box	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	49.9	62.4	112.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	49.9	62.4	112.3
Standard Waste Box	0.0	0.0	0.0	3417.1	4271.4	7688.5
Totals	0.0	0.0	0.0	3467.0	4333.8	7800.8

As-Generated Form: Stored: 0.0 Projected: 8667.6 Total: 8667.6

Final Waste Form: Stored: 0.0 Projected: 8667.6 Total: 8667.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. . Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from cleanout and D&D of the Plutonium Finishing Plant and Plutonium Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W410	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	34.9	43.7	78.6
Standard Waste Box	0.0	0.0	0.0	0.0	4.5	4.5
Totals	0.0	0.0	0.0	34.9	48.2	83.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	34.9	43.7	78.6
Standard Waste Box	0.0	0.0	0.0	0.0	4.5	4.5
Totals	0.0	0.0	0.0	34.9	48.2	83.2

As-Generated Form: Stored: 0.0 Projected: 91.9 Total: 91.9

Final Waste Form: Stored: 0.0 Projected: 91.9 Total: 91.9

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility cleanout and D&D of the Fuel Fabrication Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W411	Handling:	CH	NMVP #:	N/A	Stream Name:	231-Z Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	15.1	18.9	34.0
Totals	0.0	0.0	0.0	15.1	18.9	34.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	15.1	18.9	34.0
Totalr	0.0	0.0	0.0	15.1	18.9	34.0

As-Generated Form: Stored: 0.0 Projected: 37.8 Total: 37.8

Final Waste Form: Stored: 0.0 Projected: 37.8 Total: 37.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility cleanout and D&D of the Material Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W412	Handling:	CH	NMVP #:	N/A	Stream Name:	327 Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	15.1	18.9	34.0
Totals	0.0	0.0	0.0	15.1	18.9	34.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	15.1	18.9	34.0
Totals	0.0	0.0	0.0	15.1	18.9	34.0

As-Generated Form: Stored: 0.0 Projected: 37.8 Total: 37.8

Final Waste Form: Stored: 0.0 Projected: 37.8 Total: 37.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into CH boxes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W413	Handling:	CH	NMVP #:	N/A	Stream Name:	TWRS Vit Fac Waste TRU Type 1	Inventory Date:
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	374.4	468.0	842.4
Totals	0.0	0.0	0.0	374.4	468.0	842.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	374.4	468.0	842.4
Totals	0.0	0.0	0.0	374.4	468.0	842.4

As-Generated Form: Stored: 0.0 Projected: 936.0 Total: 936.0

Final Waste Form: Stored: 0.0 Projected: 936.0 Total: 936.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from the operation of the planned HLW vitrification facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W414	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Non-Surpl Fac Mt Prog D&D MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.1	0.1
Standard Waste Box	0.0	0.0	0.0	0.0	8.7	8.7
Totals	0.0	0.0	0.0	0.0	8.8	8.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.1	0.1
Standard Waste Box	0.0	0.0	0.0	0.0	8.7	8.7
Totals	0.0	0.0	0.0	0.0	8.8	8.8

As-Generated Form: Stored: 0.0 Projected: 8.7 Total: 8.7

Final Waste Form: Stored: 0.0 Projected: 8.7 Total: 8.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from cleanout of contaminated equipment/removable piping etc. from PUREX facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W415	Handling:	CH	NMVP #:	N/A	Stream Name:	221T/2706T Non-Surpl Fac Mt Prg D&D MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	1088.6	1360.8	2449.4
Totals	0.0	0.0	0.0	1088.6	1360.8	2449.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	1088.6	1360.8	2449.4
Totals	0.0	0.0	0.0	1088.6	1360.8	2449.4

As-Generated Form: Stored: 0.0 Projected: 2721.6 Total: 2721.6

Final Waste Form: Stored: 0.0 Projected: 2721.6 Total: 2721.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility clean-out and D&D waste from the T-Plant Canyon and Decontamination facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W416	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Non-Surpl Fac Mt Prg D&D MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	4021.9	5027.4	9049.3
Totals	0.0	0.0	0.0	4021.9	5027.4	9049.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	4021.9	5027.4	9049.3
Totals	0.0	0.0	0.0	4021.9	5027.4	9049.3

As-Generated Form: Stored: 0.0 Projected: 10054.8 Total: 10054.8

Final Waste Form: Stored: 0.0 Projected: 10054.8 Total: 10054.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from clean-out and D&D of the Plutonium Finishing Plant and Plutonium Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W417	Handling:	CH	NMVP #:	N/A	Stream Name:	231-Z Non-Surpl Fac Mt Prg D&D MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	0.0	2.1	2.1
Totals	0.0	0.0	0.0	0.0	2.1	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	0.0	2.1	2.1
Totals	0.0	0.0	0.0	0.0	2.1	2.1

As-Generated Form: Stored: 0.0 Projected: 2.0 Total: 2.0

Final Waste Form: Stored: 0.0 Projected: 2.0 Total: 2.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility clean-out and D&D of the Material Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W418	Handling:	CH	NMVP #:	N/A	Stream Name:	TWRS Vit Fac Waste MTRU Type 1	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	374.4	468.0	842.4
Totals	0.0	0.0	0.0	374.4	468.0	842.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	374.4	468.0	842.4
Totals	0.0	0.0	0.0	374.4	468.0	842.4

As-Generated Form: Stored: 0.0 Projected: 936.0 Total: 936.0

Final Waste Form: Stored: 0.0 Projected: 936.0 Total: 936.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from the operation of the planned HLW vitrification facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W419	Handling:	RH	NMVP #:	N/A	Stream Name:	100K K-Basin Operations TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	67.6	0.0	0.0	0.0	67.6
Totals	0.0	67.6	0.0	0.0	0.0	67.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	67.6	0.0	0.0	0.0	67.6
Totals	0.0	67.6	0.0	0.0	0.0	67.6

As-Generated Form: Stored: 0.0 Projected: 67.6 Total: 67.6

Final Waste Form: Stored: 0.0 Projected: 67.6 Total: 67.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from operations of the N-Reactor fuel storage basins.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W420	Handling:	RH	NMVP #:	N/A	Stream Name:	TWRS Vit Fac Waste TRU Type 2	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	356.0	445.0	801.0
Totals	0.0	0.0	0.0	356.0	445.0	801.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	356.0	445.0	801.0
Totals	0.0	0.0	0.0	356.0	445.0	801.0

As-Generated Form: Stored: 0.0 Projected: 890.0 Total: 890.0

Final Waste Form: Stored: 0.0 Projected: 890.0 Total: 890.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. .Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from the operation of the planned HLW vitrification facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W421	Handling:	RH	NMVP #:	N/A	Stream Name:	221T/2706T T-Plant Operations MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncomplied

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	7.1	21.4	0.0	0.0	28.5
Totals	0.0	7.1	21.4	0.0	0.0	28.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	7.1	21.4	0.0	0.0	28.5
Totals	0.0	7.1	21.4	0.0	0.0	28.5

As-Generated Form: Stored: 0.0 Projected: 28.5 Total: 28.5

Final Waste Form: Stored: 0.0 Projected: 28.5 Total: 28.5

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous waste related to operation of the T-Plant Canyon and Decontamination Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W422	Handling:	RH	NMVP #:	N/A	Stream Name:	Tank Waste Retrieval MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncomplied

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	99.7	124.6	224.3
Totals	0.0	0.0	0.0	99.7	124.6	224.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	99.7	124.6	224.3
Totals	0.0	0.0	0.0	99.7	124.6	224.3

As-Generated Form: Stored: 0.0 Projected: 249.2 Total: 249.2

Final Waste Form: Stored: 0.0 Projected: 249.2 Total: 249.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid waste from planned tank waste retrieval operations.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W423	Handling:	RH	NMVP #:	N/A	Stream Name:	TWRS Vit Fac Waste MTRU Type 2	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	356.0	445.0	801.0
Totals	0.0	0.0	0.0	356.0	445.0	801.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	356.0	445.0	801.0
Totals	0.0	0.0	0.0	356.0	445.0	801.0

As-Generated Form: Stored: 0.0 Projected: 890.0 Total: 890.0

Final Waste Form: Stored: 0.0 Projected: 890.0 Total: 890.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from the operation of the planned HLW vitrificatioin facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W424	Handling:	RH	NMVP #:	N/A	Stream Name:	327 Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	164.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	60.0	0.0	0.0
Other Inorganic Material:	35.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	6.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	1014.6	1014.6
Totals	0.0	0.0	0.0	0.0	1014.6	1014.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	1014.6	1014.6
Totals	0.0	0.0	0.0	0.0	1014.6	1014.6

As-Generated Form: Stored: 0.0 Projected: 1014.6 Total: 1014.6

Final Waste Form: Stored: 0.0 Projected: 1014.6 Total: 1014.6

WASTE STREAM DESCRIPTION	The waste stream typically contains equipment including but not limited to saws, manipulators, hoists, hoods, lathes, and cabinetry.
WASTE STREAM SOURCE	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into RH canisters.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	The research and development roles expected to be assumed by 327 before closure have not been defined.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W425	Handling:	RH	NMVP #:	N/A	Stream Name:	100N Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	1183.7	1183.7
Totals	0.0	0.0	0.0	0.0	1183.7	1183.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	1183.7	1183.7
Totals	0.0	0.0	0.0	0.0	1183.7	1183.7

As-Generated Form: Stored: 0.0 Projected: 1183.7 Total: 1183.7

Final Waste Form: Stored: 0.0 Projected: 1183.7 Total: 1183.7

WASTE STREAM DESCRIPTION	The waste stream is surplus facility clean-out and D&D waste which range from contaminated clothing, to process equipment.
WASTE STREAM SOURCE	Facility clean-out and D&D from the 100-N Reactor Facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W426	Handling:	RH	NMVP #:	N/A	Stream Name:	202A Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	241.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
	1.20E-06
	8.00E-07
	7.80E-02
	9.30E-02
	7.80E-02
	9.80E-02
	9.90E-04
	1.90E-03
	1.70E-08
	2.20E-07
	6.70E-08
	4.50E-04
	1.10E-03
	6.20E-04
	1.80E-02
	1.70E-06
	2.20E-07
	1.60E-03
	2.60E-03
	2.60E-03
	4.10E-09
	1.90E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	115.7	115.7
Totals	0.0	0.0	0.0	0.0	115.7	115.7

***Final Waste Form Volumes**

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	115.7	115.7
Totals	0.0	0.0	0.0	0.0	115.7	115.7

As-Generated Form: Stored: 0.0 Projected: 115.7 Total: 115.7

Final Waste Form: Stored: 0.0 Projected: 115.7 Total: 115.7

WASTE STREAM DESCRIPTION	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into RH canisters.
WASTE STREAM SOURCE	Cleanout of contaminated equipment/removable piping etc. from PUREX facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W427	Handling:	RH	NMVP #:	N/A	Stream Name:	202-A Tunnel Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	231.0	0.0	0.0
Aluminum-base Metal/Alloys:	4.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	5.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	696.9	696.9
Totals	0.0	0.0	0.0	0.0	696.9	696.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	696.9	696.9
Totals	0.0	0.0	0.0	0.0	696.9	696.9

As-Generated Form: Stored: 0.0 Projected: 696.9 Total: 696.9

Final Waste Form: Stored: 0.0 Projected: 696.9 Total: 696.9

WASTE STREAM DESCRIPTION	Fuel reprocessing equipment (i.e., columns, concentrators, dissolvers, tanks, scrap). One container is filled with fuel ends and fuel handling equipment (22.7m3).
WASTE STREAM SOURCE	Held waste in 2 below grade tunnels that contain equipment too large, bulky and/or highly radioactively contaminated to be stored/disposed of by conventional methods.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W428	Handling:	RH	NMVP #:	N/A	Stream Name:	221T/2706T Non-surplus Facility Mgmt Prg D&D TRU/RH
Inventory Date:	12/31/94						
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous
Waste Matrix Code:	S5400						

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	213.6	213.6
Totals	0.0	0.0	0.0	0.0	213.6	213.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	213.6	213.6
Totals	0.0	0.0	0.0	0.0	213.6	213.6

As-Generated Form: Stored: 0.0 Projected: 213.6 Total: 213.6

Final Waste Form: Stored: 0.0 Projected: 213.6 Total: 213.6

WASTE STREAM DESCRIPTION	The waste stream ranges from contaminated clothing to process equipment.
WASTE STREAM SOURCE	Facility clean-out and D&D waste from the T-Plant Canyon and Decontamination facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W429	Handling:	RH	NMVP #:	N/A	Stream Name:	2345Z Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	190.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	52.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	2162.7	2162.7
Totals	0.0	0.0	0.0	0.0	2162.7	2162.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	2162.7	2162.7
Totals	0.0	0.0	0.0	0.0	2162.7	2162.7

As-Generated Form: Stored: 0.0 Projected: 2162.7 Total: 2162.7

Final Waste Form: Stored: 0.0 Projected: 2162.7 Total: 2162.7

WASTE STREAM DESCRIPTION	This waste stream is major processing equipment, piping, ductwork, and gloveboxes resulting fron the cleanout and D&D of PFP.
WASTE STREAM SOURCE	Cleanout and D&D of the Plutonium Finishing Plant and Plutonium Processing Facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W430	Handling:	RH	NMVP #:	N/A	Stream Name:	Surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D001C, D009X, D002B

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	60.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.0	0.0	0.0
Other Inorganic Material:	75.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	7.0	0.0	0.0
Solidified Inorganic Material:	83.0	0.0	0.0
Solidified Organic Material:	31.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	24.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	622.1	0.0	622.1
Totals	0.0	0.0	0.0	622.1	0.0	622.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	622.1	0.0	622.1
Totals	0.0	0.0	0.0	622.1	0.0	622.1

As-Generated Form: Stored: 0.0 Projected: 622.1 Total: 622.1

Final Waste Form: Stored: 0.0 Projected: 622.1 Total: 622.1

WASTE STREAM DESCRIPTION	The waste stream is surplus facilities cleanout and D&D wastes, ranging from contaminated clothing to process equipment and sludges.
WASTE STREAM SOURCE	Cleanout and D&D of all 100 Area Inactive Facalities (includung C, D, DR, KE, KW, H, F, and N reactors, 104F and H Storage Basins, 100N Deactivation, N Basin Cleanout, Emergency Dump Basin, and the Spacer Silo) and the following 200 Area Inactive Facilities: 202S (REDOX), 233S (Plutonium Concentration Facility), and 221S (U Plant).
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W431	Handling:	RH	NMVP #:	N/A	Stream Name:	327 Non-surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5420

AS-GENERATED EPA CODES

D008A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	68.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	60.0	0.0	0.0
Other Inorganic Material:	35.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	6.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	8.9	8.9
Totals	0.0	0.0	0.0	0.0	8.9	8.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	8.9	8.9
Totals	0.0	0.0	0.0	0.0	8.9	8.9

As-Generated Form: Stored: 0.0 Projected: 8.9 Total: 8.9

Final Waste Form: Stored: 0.0 Projected: 8.9 Total: 8.9

WASTE STREAM DESCRIPTION	The waste stream typically contains equipment including but not limited to saws, manipulators, hoists, hoods, lathes, and cabinetry.
WASTE STREAM SOURCE	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into RH canisters.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	The research and development roles expected to be assumed by 327 before closure have not been defined.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W432	Handling:	RH	NMVP #:	N/A	Stream Name:	202A Non-surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	241.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.80E-02
Ba-137m	9.30E-02
C-14	9.90E-04
Cs-137	9.80E-02
H-3	1.90E-04
I-129	4.10E-09
Np-237	1.70E-08
Pu-238	4.50E-04
Am-241	1.90E-03
Pu-240	6.20E-04
Y-90	7.80E-02
Pu-242	2.20E-07
Rh-106	2.60E-03
Ru-106	2.60E-03
Se-79	8.00E-07
Sm-151	1.60E-03
Sr-90	7.80E-02
U-234	1.70E-06
U-235	6.70E-08
U-236	2.20E-07
U-238	1.20E-06
Pu-239	1.10E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	35.6	35.6
Totals	0.0	0.0	0.0	0.0	35.6	35.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	35.6	35.6
Totals	0.0	0.0	0.0	0.0	35.6	35.6

As-Generated Form: Stored: 0.0 Projected: 35.6 Total: 35.6

Final Waste Form: Stored: 0.0 Projected: 35.6 Total: 35.6

WASTE STREAM DESCRIPTION	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into RH canisters.
WASTE STREAM SOURCE	Cleanout of contaminated equipment/removable piping etc. from PUREX facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W433	Handling:	RH	NMVP #:	N/A	Stream Name:	221T/2706T Non-surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	676.4	676.4
Totals	0.0	0.0	0.0	0.0	676.4	676.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	676.4	676.4
Totals	0.0	0.0	0.0	0.0	676.4	676.4

As-Generated Form: Stored: 0.0 Projected: 676.4 Total: 676.4

Final Waste Form: Stored: 0.0 Projected: 676.4 Total: 676.4

WASTE STREAM DESCRIPTION	The waste stream ranges from contaminated clothing to process equipment, contaminated with RCRA regulated constituents.
WASTE STREAM SOURCE	Facility clean-out and D&D waste from the T-Plant Canyon and Decontamination facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W434	Handling: RH	NMVP #: N/A	Stream Name: 2345Z Non-surplus Facility Mgmt Prg D&D MTRU/RH		Inventory Date: 12/31/94
Local ID:	Type: MTRU	Generator Site:	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5110

AS-GENERATED EPA CODES

D009A, D008A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	190.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	52.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	2509.8	2509.8
Totals	0.0	0.0	0.0	0.0	2509.8	2509.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	2509.8	2509.8
Totals	0.0	0.0	0.0	0.0	2509.8	2509.8

As-Generated Form: Stored: 0.0 Projected: 2509.8 Total: 2509.8

Final Waste Form: Stored: 0.0 Projected: 2509.8 Total: 2509.8

WASTE STREAM DESCRIPTION	This waste stream is major processing equipment, piping, ductwork, and gloveboxes resulting fron the cleanout and D&D of PFP.
WASTE STREAM SOURCE	Cleanout and D&D of the Plutonium Finishinf Plant and Plutonium Processing Facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W435	Handling:	RH	NMVP #:	N/A	Stream Name:	340 Non-surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	26.7	26.7
Totals	0.0	0.0	0.0	0.0	26.7	26.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	26.7	26.7
Totals	0.0	0.0	0.0	0.0	26.7	26.7

As-Generated Form: Stored: 0.0 Projected: 26.7 Total: 26.7

Final Waste Form: Stored: 0.0 Projected: 26.7 Total: 26.7

WASTE STREAM DESCRIPTION	This waste stream includes both TRU and mixed TRU. This waste consists of pumps, thermal couples, and piping contaminated with TRU elements. This equipment cannot be fit into standard size boxes.
WASTE STREAM SOURCE	This waste is incident, non-process waste from single-shell tanks.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W436	Handling:	RH	NMVP #:	N/A	Stream Name:	TWRS Long-Length Tank Equipment MTRU/RH
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Uncategorized Metal

Inventory Date: 12/31/94

Waste Matrix Code: S5119

AS-GENERATED EPA CODES

F005, D007, D002B, F003, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	596.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	240.3	2990.4	7047.0	10277.7
Totals	0.0	0.0	240.3	2990.4	7047.0	10277.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	240.3	2990.4	7047.0	10277.7
Totals	0.0	0.0	240.3	2990.4	7047.0	10277.7

As-Generated Form: Stored: 0.0 Projected: 10277.7 Total: 10277.7

Final Waste Form: Stored: 0.0 Projected: 10277.7 Total: 10277.7

WASTE STREAM DESCRIPTION	Equipment removed from the high level waste tanks (instrument trees, pumps, circulators, agitators, heaters, sluicers, steam coils, air lances, cameras)
WASTE STREAM SOURCE	High Level Waste Tanks (A-101, AN-102, AN-104, AN-107, AZ-101. BY103, C-102, C-103, C-104, C-105, C-106, TX-118)
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W437	Handling:	CH	NMVP #:	N/A	Stream Name:	Surplus Facility Mgmt Prg D&D TRU/CH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	11.9	147.9	571.6	28.1	759.4
Totals	0.0	11.9	147.9	571.6	28.1	759.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	11.9	147.9	571.6	28.1	759.4
Totals	0.0	11.9	147.9	571.6	28.1	759.4

As-Generated Form: Stored: 0.0 Projected: 759.4 Total: 759.4

Final Waste Form: Stored: 0.0 Projected: 759.4 Total: 759.4

WASTE STREAM DESCRIPTION	The waste stream is surplus facilities cleanout and D&D wastes, ranging from contaminated clothing to process equipment and sludges.
WASTE STREAM SOURCE	Cleanout and D&D of all 100 Area Inactive Facalities (includung C, D, DR, KE, KW, H, F, and N reactors, 104F and H Storage Basins, 100N Deactivation, N Basin Cleanout, Emergency Dump Basin, and the Spacer Silo) and the following 200 Area Inactive Facilities: 202S (REDOX), 233S (Plutonium Concentration Facility), and 221S (U Plant).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W438	Handling: CH	NMVP #: N/A	Stream Name: Non-transition program TRU/CH		Inventory Date:
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Heterogeneous		Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Source Unknown

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	60.3	488.0	548.3
Standard Waste Box	0.0	0.0	0.0	121.0	427.1	548.1
Totals	0.0	0.0	0.0	181.3	915.1	1096.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	120.6	427.6	548.3
Standard Waste Box	0.0	0.0	0.0	121.0	427.1	548.1
Totals	0.0	0.0	0.0	241.6	854.8	1096.4

As-Generated Form: Stored: 0.0 Projected: 1096.4 Total: 1096.4

Final Waste Form: Stored: 0.0 Projected: 1096.4 Total: 1096.4

WASTE STREAM DESCRIPTION	Description is presently not available; however typical deactivation waste includes cleanout and removal of equipment, mixers, tanks, vessels and pumps.
WASTE STREAM SOURCE	This represents wastes from deactivation and terminal cleanout activities from facilities not covered under the DOE/EM40 Facilities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W439	Handling:	CH	NMVP #:	N/A	Stream Name:	Environmental Restoration Program TRU/CH Soils	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Soils	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	122.3	1162.5	3121.0	1529.8	5935.7
Totals	0.0	122.3	1162.5	3121.0	1529.8	5935.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	122.3	1162.5	3121.0	1529.8	5935.7
Totals	0.0	122.3	1162.5	3121.0	1529.8	5935.7

As-Generated Form: Stored: 0.0 Projected: 5935.7 Total: 5935.7

Final Waste Form: Stored: 0.0 Projected: 5935.7 Total: 5935.7

WASTE STREAM DESCRIPTION	This waste stream consists of soil contaminated with liquid solutions, previously buried solid waste, and associated contaminated soil, and sludges from previously used tanks or tank-like units.
WASTE STREAM SOURCE	The waste is from retrieval of contaminated soils. The waste may also include solid waste from past practice burial grounds and solidified sludge from miscellaneous past practice tanks.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W440	Handling:	CH	NMVP #:	N/A	Stream Name:	K Basins Operations TRU/CH	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	41.0	133.1	0.0	0.0	174.1
Standard Waste Box	0.0	32.1	0.0	0.0	0.0	32.1
Totals	0.0	73.1	133.1	0.0	0.0	206.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	41.0	133.1	0.0	0.0	174.1
Standard Waste Box	0.0	32.1	0.0	0.0	0.0	32.1
Totals	0.0	73.1	133.1	0.0	0.0	206.2

As-Generated Form: Stored: 0.0 Projected: 206.2 Total: 206.2

Final Waste Form: Stored: 0.0 Projected: 206.2 Total: 206.2

WASTE STREAM DESCRIPTION	Waste consists of rags, plastic, paper, rubber, and absorbed liquids and sludges.
WASTE STREAM SOURCE	This waste is from operations of the N-Reactor fuel storage basins.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This is a new waste stream from the BEMR data call. Characterization data is not available at this time.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W441	Handling:	CH	NMVP #:	N/A	Stream Name:	K Basin Project TRU/CH	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.2	0.0	0.0	0.0	0.2
Totals	0.0	0.2	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.2	0.0	0.0	0.0	0.2
Totals	0.0	0.2	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.0 Projected: 0.2 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.2 Total: 0.2

WASTE STREAM DESCRIPTION	Waste consists of iron-based metal, rags, paper, plastic, and rubber.
WASTE STREAM SOURCE	Source is incidental waste associated with spent fuel.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This is a new waste stream from the BEMR data call. Characterization data is not available at this time.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W442	Handling:	CH	NMVP #:	N/A	Stream Name:	TWRS Cross-Site Transfer Project TRU/CH	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	5.7	0.0	0.0	0.0	5.7
Totals	0.0	5.7	0.0	0.0	0.0	5.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	5.7	0.0	0.0	0.0	5.7
Totals	0.0	5.7	0.0	0.0	0.0	5.7

As-Generated Form: Stored: 0.0 Projected: 5.7 Total: 5.7

Final Waste Form: Stored: 0.0 Projected: 5.7 Total: 5.7

WASTE STREAM DESCRIPTION	Waste consists of contaminated soil that may be encountered during placement of a tank transfer line. This line is being placed adjacent to an existing line. The transfer line provides capability to transfer highly radioactive liquid waste among Hanford's high-level waste tanks.
WASTE STREAM SOURCE	This is a waste that will be generated from a project to improve the cross-site tank transfer pipeline.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This is a new waste stream from the BEMR data call. Characterization data is not available at this time.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W443	Handling:	CH	NMVP #:	N/A	Stream Name:	Surplus Facility Mgmt Prg D&D MTRU/CH	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

D009X, D002B, D001C

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	62.8	577.6	28.1	668.5
Totals	0.0	0.0	62.8	577.6	28.1	668.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	62.8	577.6	28.1	668.5
Totals	0.0	0.0	62.8	577.6	28.1	668.5

As-Generated Form: Stored: 0.0 Projected: 668.5 Total: 668.5

Final Waste Form: Stored: 0.0 Projected: 668.5 Total: 668.5

WASTE STREAM DESCRIPTION	The waste stream is surplus facilities cleanout and D&D wastes, ranging from contaminated clothing to process equipment and sludges.
WASTE STREAM SOURCE	Cleanout and D&D of all 100 Area Inactive Facilities (includung C, D, DR, KE, KW, H, F, and N reactors, 104F and H Storage Basins, 100N Deactivation, N Basin Cleanout, Emergency Dump Basin, and the Spacer Silo) and the following 200 Area Inactive Facilities: 202S (REDOX), 233S (Plutonium Concentration Facility), and 221S (U Plant).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W444	Handling:	CH	NMVP #:	N/A	Stream Name:	Non-transition Program MTRU/CH	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Source Unknown

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	17.9	63.6	81.5
Standard Waste Box	0.0	0.0	0.0	18.9	68.0	86.9
Totals	0.0	0.0	0.0	36.8	131.7	168.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	17.9	63.6	81.5
Standard Waste Box	0.0	0.0	0.0	18.9	68.0	86.9
Totals	0.0	0.0	0.0	36.8	131.7	168.5

As-Generated Form: Stored: 0.0 Projected: 168.5 Total: 168.5

Final Waste Form: Stored: 0.0 Projected: 168.5 Total: 168.5

WASTE STREAM DESCRIPTION	Description is presently not available; however typical deactivation waste includes cleanout and removal of equipment, mixers, tanks, vessels and pumps.
WASTE STREAM SOURCE	This represents wastes from deactivation and terminal cleanout activities from facilities not covered under the DOE/EM40 Facilities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

SA Sandia National Laboratories - New Mexico

DOE/CAO-95-1121
December 1995

SANDIA NATIONAL LABORATORIES

Location and Description

Sandia National Laboratories/New Mexico (SNL/NM) is located immediately southeast of Albuquerque, New Mexico, on Kirtland Air Force Base. The SNL/NM consists not only of the headquarters facilities in Albuquerque, New Mexico, but also the laboratory facility in Livermore, California, the Tonopah Test Range in Nevada, and occupies about 7,600 acres (not including Tonopah Test Range).

Prior to the Trinity shot in 1945, the Manhattan project had a small facility on Sandia Base (now Kirtland AFB) to perform ordnance engineering, nonnuclear atomic bomb assembly and military training. In March 1948, the Sandia Laboratory was established as a formal branch of the Los Alamos Scientific Laboratory (LASL) now LA. In 1949, Sandia Corporation was organized as a wholly-owned subsidiary of the Western Electric Company, and approximately 1,700 LASL employees were transferred. In 1984, Sandia Corporation became a wholly-owned subsidiary of the AT&T Technologies Corporation.

SNL/NM is administered by the DOE/Albuquerque Operations Office and is currently operated by the Lockheed Martin Corporation.

Mission

SNL/NM's mission was research, development, and engineering of nuclear weapons systems except for the nuclear explosive. This included nuclear weapons systems ordnance engineering, nonnuclear component design and development, field and laboratory testing, and manufacturing engineering.

SNL/NM has operated the Tonopah Test Range near Tonopah, Nevada, since the range was established in 1957. The site is located about 322 kilometers northwest of Las Vegas, Nevada, on 1360 squire kilometers of land provided by the Air Force in accordance with a use permit. Tonopah Test Range is a major facility for the field testing of nonnuclear and denuclearized weapons, research rockets, and artillery. Aerodynamic stability, the compatibility of various ballistic shapes, trajectories, times of fall, accuracy of delivery, and functioning of fuzing components are tested under conditions simulating actual use. Certain types of high explosive ordnance are also tested at the test range.

Waste Information

Processes

One of SNL/NM's generators is the Inhalation Toxicology Research Institute (IT). Since 1960, ITRI has performed a variety of research programs for the DOE. The original research was dedicated to the evaluation of health effects caused by inhalation of fission products. Research is now conducted on the health effects of transuranic elements such as plutonium, americium, curium, and nonradioactive airborne materials in various environments.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

M

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SA-T001	Handling:	CH	NMVP #:	na	Stream Name:	Lovelace ITRI Waste Stream
Local ID:	NA	Type:	TRU	Generator Site:	IT	Final Waste Form:	Heterogeneous

Inventory Date: 5/10/95

Waste Matrix Code: S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	100.0	10.0	110.0
Aluminum-base Metal/Alloys:	3.0	1.0	5.0
Other Metals/Alloys:	6.0	2.0	10.0
Other Inorganic Material:	15.0	10.0	20.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.0	1.0	5.0
Rubber:	5.0	1.0	9.0
Plastics:	5.0	2.0	8.0
Solidified Inorganic Material:	40.0	20.0	60.0
Solidified Organic Material:	5.0	1.0	9.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	100.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	5.00E-01
Np-237	1.20E-02
Cm-244	8.00E-01
Am-241	2.50E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	5.4	0.6	1.0	2.1	2.1	11.2
Totals	5.4	0.6	1.0	2.1	2.1	11.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	0.6	1.0	2.1	2.1	11.2
Totals	5.4	0.6	1.0	2.1	2.1	11.2

As-Generated Form: Stored: 5.4 Projected: 5.8 Total: 11.2

Final Waste Form: Stored: 5.4 Projected: 5.8 Total: 11.2

WASTE STREAM DESCRIPTION	Waste is in final form.
WASTE STREAM SOURCE	Heterogeneous mixture of metals and combustible lab trash including solidified waste, stainless steel, brass and aluminum parts, paper, plastics, rubber gloves, PPE, hepa filters and glass. There are no liquids or compressed gasses. All drums were verified through Real Time Radiography, (RTR).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The entire waste stream was viewed through Real Time Radiography and videotapes and photographs of the waste are on file. In addition, the process knowledge from Lovelace ITRI indicates that contaminants are not present.
MANAGEMENT COMMENTS	This waste stream has been characterized by process knowledge as TRU waste. The waste is not mixed.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SA-W134	Handling:	CH	NMVP #:	na	Stream Name:	Transuranic Waste at Hot Cell Facility	Inventory Date:	12/31/94
Local ID:	NA	Type:	TRU	Generator Site:	SA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	80.0	10.0	100.0
Aluminum-base Metal/Alloys:	5.0	1.0	10.0
Other Metals/Alloys:	10.0	4.0	15.0
Other Inorganic Material:	1.0	1.0	1.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.0	1.0	3.0
Rubber:	2.0	1.0	3.0
Plastics:	5.0	1.0	10.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	1.7	0.0	0.0	0.0	2.9
Totals	1.2	1.7	0.0	0.0	0.0	2.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	1.7	0.0	0.0	0.0	2.9
Totals	1.2	1.7	0.0	0.0	0.0	2.9

As-Generated Form: Stored: 1.2 Projected: 1.7 Total: 2.9

Final Waste Form: Stored: 1.2 Projected: 1.7 Total: 2.9

WASTE STREAM DESCRIPTION	Waste is remoted-handled material. Some TRU waste is currently stored in Technical Area V, Bldg. 6580, and 2 drums are stored in Manzano Bunker 7063. Some of the waste is in concrete-shielded containers. Waste stream includes some solidified liquids and labware and related items removed from glove boxes. The waste matrix identified was based on information provided by the generator and may change in the future as additional examination of the waste is performed. Presently, this waste stream is RH, but is reported as CH because the Final Waste Form will be CH.
WASTE STREAM SOURCE	This waste stream was generated during SNL Hot Cell Facility exprements that including the cutting of fuel rods. There are no liquids or compressed gasses in this waste stream.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The confidence level of regulated contaminants is based on process knowledge supplied by the waste generator. No sampling and analysis has been performed.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	8 drums of tru waste are est[illegible]ed to be generated with the FY1996 hot cell decontamination project. This is a one time generation.

M

SR Savannah River Site

DOE/CAO-95-1121
December 1995

SAVANNAH RIVER SITE

Location and Description

The Savannah River Site (SRS) is located about 31 kilometers southeast of Aiken, South Carolina, on 198,334 acres (803 square kilometers) along the Savannah River. The SRS encompasses parts of three counties, Aiken, Barnwell, and Allendale in western South Carolina. The closest major cities are Aiken, South Carolina, and Augusta, Georgia. The site is a controlled area with limited public access. The facilities occupy less than 8 percent of the site. The remaining 92 percent is divided into forest (80%) and wetlands (20%).

The Savannah River Site is a government owned, contractor operated (GOCO) site that is managed by the DOE Savannah River Operations Office. The current Management and Operating Contractor for the Site is Westinghouse Savannah River Company.

Mission

The primary mission of the SRS has been to support national security as a major source of reactor-produced materials, primarily tritium, plutonium, heavy water (deuterium) and other special nuclear materials for weapons manufacturing. The mission was broadened over the years to include the production of other isotopes, such as Pu-238. SRS's production activities also included the loading of tritium containers for the nuclear weapons, reclamation of tritium containers and the purification of tritium recovered from retired weapons.

The decision in 1950 to go ahead with the Savannah River Plant was driven by the perceived need for tritium in the fusion weapon program following President Truman's directive of January 31, 1950, to develop a thermonuclear weapon (the "super"). While production of tritium in the Hanford reactor had been demonstrated, the new plant at Savannah River was necessary to avoid serious curtailment in the production of plutonium at Hanford for the fission program. If thermonuclear weapons proved unfeasible or tritium requirements turned out to be less than anticipated, the construction of Savannah River was further justified in order to increase plutonium production, to provide a higher efficiency in the use of uranium ore, to provide security against attack of the Hanford reactors, and to provide replacement reactors in the event of the retirement of older Hanford reactors.

Five reactors (currently shut down), two chemical processing plants, a tritium extraction, purification, and loading facility, and a high-level waste solidification facility comprise the major elements of the Defense Program operations and facilities at SRS.

The SRS waste management mission is to comply with applicable federal and state regulations, DOE Orders, and the Management and Operating Contractor policies, to minimize effects on the environment and the generation of new waste, and to the extent possible, contain waste handling, treatment, storage, and disposal within the site. Other mission objectives include the demonstration and application of remediation technologies and the environmental restoration of the SRS site. With the changing defense posture, environmental restoration is receiving increased emphasis versus weapons materials production.

Waste Information

Processes

At SRS, production of useful radioactive isotopes is accompanied by production of radioactive waste. These wastes must be safely contained and stored until the risk associated with their radioactivity is eliminated by decay or the waste is permanently disposed. In both production and power nuclear reactors, neutrons strike uranium-235 atoms in the reactor fuel, add energy and cause the atoms to become unstable and split apart or "fission." This results in the production of fission products and more neutrons, initiating a sustained chain reaction and a steady supply of neutrons. In addition to fuel, the SRS reactors contained long cylinders of material called targets. When neutrons strike the targets, useful radionuclides are created through transmutation. The fuel and target assemblies are then removed from the reactor and, after a suitable cooling period, are sent to the chemical separation areas for processing to recover the desired radionuclides (uranium, plutonium, tritium, etc).

Currently, TRU waste at SRS is generated primarily from radiochemical separations processes, analytical laboratories, and research and development activities. Primary contaminants in the waste are Pu-238 and Pu-239. The major on-site facilities that generate TRU waste are the FB-Line, the HB Line, 235-F, 772-F, and 773-A.

FB-Line and HB-Line generate TRU waste containing plutonium and neptunium. The waste is generated during the use of gloveboxes, contamination control huts, and decontamination processes waste. TRU waste is placed in 5-gallon cans, assayed, sealed in a drum liner, and placed in 55-gallon drums before transport to the waste TRU storage facility.

In the HB Separation Line, uranium, neptunium (Np) and plutonium (Pu) are recovered from irradiated enriched uranium fuels and transferred to the HB line for processing. The HB line uses three independent facilities to process Np, Pu, and recoverable scrap. TRU waste, containing Pu-238, is generated during decontamination operations, replacement of equipment, maintenance, inspection, and sampling.

In the FB Separation Line, irradiated metal alloys from the reactors are dissolved and separated into uranium, Pu metal, and high-level liquid waste using the Purex process. Uranium and plutonium are recovered and TRU waste, containing Pu-239 is generated during decontamination operations, maintenance, inspection, replacement of equipment, sampling and laboratory analysis.

The 235-F facility generates TRU waste from three waste streams, the Actinide Billet Line, the Plutonium Experimental Facility, and Plutonium Fuel Fabrication. The three streams yield neptunium and plutonium isotopes. Waste materials consist of lead-lined gloves, neoprene gloves, process waste, equipment, and filters.

The 772-F TRU waste generated in the Central Laboratory Facility results from the handling and analysis of various plutonium and neptunium samples. The routine laboratory TRU solid waste consists of paper, plastic, glass, metal, lead-lined gloves, HEPA filters, and IX resins.

The 773-A, the Savannah River Technology Center (SRTC) Solid Waste Assay Facility (SWAF) receives boxes of waste from other laboratories within the SRTC complex. The SWAF processes includes x-raying, weighing, and assaying the boxes. After processing, the waste boxes are placed in drums before shipping to the site waste disposal facility.

Solid TRU waste, such as processing equipment, glassware, and gloveboxes too large for 55-gallon drums are packaged and stored in large steel or concrete containers. The separation areas produce most of the solid TRU waste.

Off-site generators that have sent TRU waste to SRS are Los Alamos National Laboratory, Mound Laboratory, Allied-General Nuclear Services, National Institute of Standards Technology, General Sciences, Department of Defense, and Knolls Atomic Power Laboratory.

Modifications/Assumptions/Development

Savannah River's Vitrified waste stream Waste Material Parameters were recalculated by the TWBIR team to provide closure approximations to the 1000 lbs per 55 gallon drum weight limits required by the TRUPACT-II Safety Analysis Report for Packaging (SARP). In recalculating these parameters the volumes and number of final form containers were increased. This increase may hinder SRS's cost effectiveness for shipment to WIPP.

The composition of SRS final waste forms was determined using acceptable knowledge (Processing knowledge) and existing waste form research work performed by Savannah River Technical Center (SRTC).

A combination of waste descriptions, waste codes, and acceptable knowledge were used to determine the general waste types stored at SRS. This includes only the waste types affecting the final waste forms.

Waste stream volumes for SR-T001, SR-W006, SR-W026, SR-W027, and SR-W053 were separated and reported by generator and waste types.

Waste, which is classified because of shape, was identified and reported separately by SRS. The shape of this waste is expected to be destroyed during waste processing. Other classified waste was not reported by SRS because of the contents of the waste.

Waste volumes and number of containers to be shipped to WIPP were based on the type of disposal container used, the size reduction factors after waste processing, and the volume of waste to be processed. The volume of waste to be processed was based on TRU waste volumes as of 12/31/94 and waste forecasts contained in the Proposed Site Treatment Plan (PSTP) and the Waste Management Environment Impact Statement (WMEIS). These forecasts include TRU waste from operational, D&D, and ER activities.

Most of SRS's metal waste is currently packaged in large steel boxes. The waste in these steel boxes is (assumed by the site to be) 80% bulk metal and 20% heterogeneous debris. The size reduction factor for large metal components is 3.5 to 1.

No volume reduction is expected from the repackaging of heterogeneous waste streams.

The preferred technology for treating SRS TRU waste is solidification by vitrification (i.e., Hybrid Plasma Treatment). The process design provides sufficient mixing controls to ensure WIPP WAC compliance. The assumed volume reduction factor using this technology is 30 to 1. This factor applies to waste streams SR-W026, SR-W027, SR- T001, SR-T003. SR-W053, and SR-W006.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	sr125A	Stream Name:	CH TRU - Heterogeneous debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	382.5	85.0	212.5	85.0	0.0	765.0
Drum / 55-gallon	49.0	89.6	176.0	88.0	45.2	447.7
Totals	431.5	174.6	388.5	173.0	45.2	1212.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	938.7	0.0	0.0	0.0	1598.5	2537.2
Totals	938.7	0.0	0.0	0.0	1598.5	2537.2

As-Generated Form: Stored: 431.5 Projected: 781.3 Total: 1212.7

Final Waste Form: Stored: 938.7 Projected: 1598.5 Total: 2537.2

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	The stream was produced in 221 FB line, a separations facility for the production of Pu-239.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	undetermined	Stream Name:	CH TRU - Metal debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	382.5	212.5	425.0	170.0	85.0	1275.0
Totals	382.5	212.5	425.0	170.0	85.0	1275.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	23.8	0.0	0.0	0.0	70.7	94.5
Totals	23.8	0.0	0.0	0.0	70.7	94.5

As-Generated Form: Stored: 382.5 Projected: 892.5 Total: 1275.0

Final Waste Form: Stored: 23.8 Projected: 70.7 Total: 94.5

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was produced in 221 FB Line, a separations facility for the production of Pu-239.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	undetermined	Stream Name:	CH TRU - Vitrified debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	467.5	127.5	212.5	212.5	0.0	1020.0
Box / 16in W x 29in L x 32in H	24.5	21.7	42.1	21.4	11.0	120.6
Drum / 55-gallon	10.1	38.3	75.1	38.3	19.4	181.2
Totals	502.1	187.4	329.7	272.2	30.4	1321.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	23.2	0.0	0.0	0.0	141.0	164.2
Totals	23.2	0.0	0.0	0.0	141.0	164.2

As-Generated Form: Stored: 502.1 Projected: 819.7 Total: 1321.8

Final Waste Form: Stored: 23.2 Projected: 141.0 Total: 164.2

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was produced in 221 FB Line, a separations facility for the production of Pu-239.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH TRU - Heterogeneous debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A
Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	42.5	127.5	85.0	42.5	340.0
Drum / 55-gallon	28.1	46.4	78.1	45.0	27.0	224.6
Totals	70.6	88.9	205.6	130.0	69.5	564.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	158.1	0.0	0.0	0.0	971.5	1129.6
Totals	158.1	0.0	0.0	0.0	971.5	1129.6

As-Generated Form: Stored: 70.6 Projected: 493.9 Total: 564.6

Final Waste Form: Stored: 158.1 Projected: 971.5 Total: 1129.6

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 221 HB Line, a separation facility for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	undetermined	Stream Name:	CH TRU - Metal debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.0
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	170.0	212.5	127.5	127.5	680.0
Totals	42.5	170.0	212.5	127.5	127.5	680.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.8	0.0	0.0	0.0	14.3	15.1
Totals	0.8	0.0	0.0	0.0	14.3	15.1

As-Generated Form: Stored: 42.5 Projected: 637.5 Total: 680.0

Final Waste Form: Stored: 0.8 Projected: 14.3 Total: 15.1

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 221HB Line, a separation facility for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	undetermined	Stream Name:	CH TRU - Vitrified debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	807.5	552.5	977.5	425.0	212.5	2975.0
Box / 16in W x 29in L x 32in H	23.2	39.0	65.8	36.5	23.2	187.7
Drum / 55-gallon	96.5	185.7	313.0	179.4	107.8	882.4
Totals	927.2	777.2	1356.2	640.8	343.5	4045.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	33.8	0.0	0.0	0.0	478.4	512.2
Totals	33.8	0.0	0.0	0.0	478.4	512.2

As-Generated Form: Stored: 927.2 Projected: 3117.8 Total: 4045.1

Final Waste Form: Stored: 33.8 Projected: 478.4 Total: 512.2

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 221 HB Line, a separations facility for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH TRU Heterogeneous debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	0.0	0.0	0.0	42.5	85.0
Drum / 55-gallon	2.8	4.8	6.5	16.5	13.5	44.0
Totals	45.3	4.8	6.5	16.5	56.0	129.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	163.0	0.0	0.0	0.0	205.2	368.2
Totals	163.0	0.0	0.0	0.0	205.2	368.2

As-Generated Form: Stored: 45.3 Projected: 83.7 Total: 129.0

Final Waste Form: Stored: 163.0 Projected: 205.2 Total: 368.2

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 235F during separations activites for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Metal debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No,
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	0.0	0.0	0.0	42.5	85.0
Totals	42.5	0.0	0.0	0.0	42.5	85.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	0.0	1.9	1.9
Totals	0.0	0.0	0.0	0.0	1.9	1.9

As-Generated Form: Stored: 42.5 Projected: 42.5 Total: 85.0

Final Waste Form: Stored: 0.0 Projected: 1.9 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 235F during separation activities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Vitrified debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	807.5	0.0	42.5	0.0	85.0	935.0
Box / 16in W x 29in L x 32in H	7.9	4.3	4.8	13.5	11.7	42.3
Drum / 55-gallon	4.0	19.0	24.2	65.2	56.1	168.5
Totals	819.4	23.4	71.5	78.7	152.8	1145.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	85.5	87.0
Totals	1.5	0.0	0.0	0.0	85.5	87.0

As-Generated Form: Stored: 819.4 Projected: 326.4 Total: 1145.8

Final Waste Form: Stored: 1.5 Projected: 85.5 Total: 87.0

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 235F during separations activities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH TRU - Heterogeneous debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	0.0	0.0	0.0	0.0	42.5	42.5
Drum / 55-gallon	21.8	0.4	0.8	1.2	1.0	25.2
Totals	21.8	0.4	0.8	1.2	43.5	67.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	29.1	0.0	0.0	0.0	11.5	40.6
Totals	29.1	0.0	0.0	0.0	11.5	40.6

As-Generated Form: Stored: 21.8 Projected: 45.9 Total: 67.7

Final Waste Form: Stored: 29.1 Projected: 11.5 Total: 40.6

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was produced in 772F, an analytical lab used to support H and F canyon processing, the Pu-238 program, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Metal debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	0.0	0.0	0.0	0.0	42.5	42.5
Totals	0.0	0.0	0.0	0.0	42.5	42.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	0.0	1.9	1.9
Totals	0.0	0.0	0.0	0.0	1.9	1.9

As-Generated Form; Stored: 0.0 Projected: 42.5 Total: 42.5

Final Waste Form; Stored: 0.0 Projected: 1.9 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 772F, an analytical lab used to support H and F canyon processing, Pu-238 program, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Vitrified debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	0.0	0.0	0.0	0.0	42.5	42.5
Box / 16in W x 29in L x 32in H	1.3	0.3	0.5	1.0	1.0	4.1
Drum / 55-gallon	2.8	1.4	2.6	5.0	4.4	16.1
Totals	4.0	1.6	3.1	6.0	47.9	62.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	7.6	7.8
Totals	0.2	0.0	0.0	0.0	7.6	7.8

As-Generated Form: Stored: 4.0 Projected: 58.6 Total: 62.6

Final Waste Form: Stored: 0.2 Projected: 7.6 Total: 7.8

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 772F, an analytical lab used to support H and F canyon processing, the Pu-238 mission, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	N/A	Stream Name:	CH TRU - Classified waste from 773A	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues:

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 162 ft3	23.0	0.0	0.0	0.0	0.0	23.0
Totals	23.0	0.0	0.0	0.0	0.0	23.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.6	0.0	0.0	0.0	0.0	4.6
Totals	4.6	0.0	0.0	0.0	0.0	4.6

As-Generated Form: Stored: 23.0 Projected: 0.0 Total: 23.0

Final Waste Form: Stored: 4.6 Projected: 0.0 Total: 4.6

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in the SED facility with SRTC (Savannah River Technology Center). This facility is no longer operational - D&D will occur.
CURRENT CONTAINER COMMENTS	Classified waste
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	This is classified waste which requires treatment to destroy the current configuration of the waste form.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH TRU - Heterogeneous debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	0.0	0.0	0.0	42.5	85.0
Cask / 27 in x 27 in x 42 in	4.0	0.5	1.5	2.5	2.5	11.0
Drum / 55-gallon	7.5	5.4	8.9	17.8	17.4	57.1
Totals	54.0	5.9	10.4	20.3	62.4	153.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	22.1	0.0	0.0	0.0	257.5	279.6
Totals	22.1	0.0	0.0	0.0	257.5	279.6

As-Generated Form: Stored: 54.0 Projected: 99.1 Total: 153.1

Final Waste Form: Stored: 22.1 Projected: 257.5 Total: 279.6

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 773A, the SRTC laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Metal debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	0.0	0.0	85.0	42.5	170.0
Totals	42.5	0.0	0.0	85.0	42.5	170.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.4	0.0	0.0	0.0	31.8	32.1
Totals	0.4	0.0	0.0	0.0	31.8	32.1

As-Generated Form: Stored: 42.5 Projected: 127.5 Total: 170.0

Final Waste Form: Stored: 0.4 Projected: 31.8 Total: 32.1

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 773A, SRTC labs (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Vitrified debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	0.0	0.0	0.0	42.5	42.5	85.0
Box / 16in W x 29in L x 32in H	5.1	1.0	2.0	4.3	4.6	17.1
Drum / 55-gallon	0.4	2.4	4.0	7.5	7.3	21.6
Totals	5.5	3.4	6.0	54.4	54.4	123.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	15.1	15.5
Totals	0.4	0.0	0.0	0.0	15.1	15.5

As-Generated Form: Stored: 5.5 Projected: 118.2 Total: 123.7

Final Waste Form: Stored: 0.4 Projected: 15.1 Total: 15.5

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 773A, SRTC labs (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	This WTWBIR WS contains Remote Handled that has been processed and became Contact Handled.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W076	Handling:	CH	NMVP #:	SR125A	Stream Name:	RH TRU Heterogeneous Debris from 773A
Local ID:	SR-T003	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous

Inventory Date: 12/31/94

Waste Matrix Code: S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	3.28E+00
Sr-90	3.10E+00
Pu-238	1.69E-01
Pm-147	8.13E-01
Cs-137	3.28E+00
Cm-247	2.43E+00
Ba-137m	3.10E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 27 in. x 27 in. x 42 in.	0.5	1.5	2.5	5.0	5.0	14.5
Totals	0.5	1.5	2.5	5.0	5.0	14.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.7	1.2	2.5	2.5	7.6
Totals	0.6	0.7	1.2	2.5	2.5	7.6

As-Generated Form: Stored: 0.5 Projected: 14.0 Total: 14.5

Final Waste Form: Stored: 0.6 Projected: 6.9 Total: 7.5

WASTE STREAM DESCRIPTION	This waste consists of miscellaneous job control waste such as laboratory supplies used in research programs in the sheilded cells, e.g. glassware, paper wipes, stainless steel samples vials, poly bottles, pipettes and small lab equipment (stirrers, heaters). In addition to the job control waste, this stream contains shavings from the cuttings of a Mark 16 fuel element. Presently, this waste stream is stored as RH, but is reported as CH because after processing this stream will be CH.
WASTE STREAM SOURCE	This stream was generated as a result of experiments and activities at SRTC in the 773-A Shielded Cells Facility (E-wing). Work was performed with samples of low activity waste from tanks 42 and 51, high activity waste from 11 and 15, salt from tank 41 and 13, process waste from tank 17, in addition to other isotopes stored in the cells,
CURRENT CONTAINER COMMENTS	This box is placed in a cask for storage.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Preliminary plans are to vitrify that portion of the stream that must be treated due to meeting WIPP requirements (PE Ci, FGE and Wattage limits). The portion not needing treatment will be repackaged for shipment to WIPP.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W076	Handling:	CH	NMVP #:	Undetermined	Stream Name:	RH TRU Vitrified Debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-T003	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 27 in. x 27 in. x 42 in.	0.5	1.5	2.5	5.0	5.0	14.5
Totals	0.5	1.5	2.5	5.0	5.0	14.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.5 Projected: 14.0 Total: 14.5

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste consists of miscellaneous job control waste such as laboratory supplies used in research programs in the sheilded cells, e.g. glassware, paper wipes, stainless steel samples vials, poly bottles, pipettes and small lab equipment (stirrers, heaters). In addition to the job control waste, this stream contains shavings from the cuttings of a Mark 16 fuel element. Presently, this waste stream is stored as RH, but is reported as CH because after processing this stream will be CH.
WASTE STREAM SOURCE	This stream was generated as a result of experiments and activities at SRTC in the 773-A Shielded Cells Facility (E-wing). Work was performed with samples of low activity waste from tanks 42 and 51, high activity waste from 11 and 15, salt from tank 41 and 13, process waste from tank 17, in addition to other isotopes stored in the cells,
CURRENT CONTAINER COMMENTS	The box is placed in a cask for storage.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Preliminary plans are to vitrify that portion of the stream that must be treated due to meeting WIPP requirements (PE Ci, FGE and Wattage limits). The portion not needing treatment will be repackaged for shipment to WIPP.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Once processed, the final form of this waste stream will become Contact Handled. All final form information for this waste stream is included in SR-T001 projections.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W006	Handling:	CH	NMVP #:	none at this time	Stream Name:	Contact handled TRU/Liquids from 773A	Inventory Date:	12/31/94
Local ID:	SR-W006	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L2000

AS-GENERATED EPA CODES

D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

none at this time

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-239	8.60E+02
Am-241	4.51E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Stainless Steel can / 1 gal	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.5	0.0	0.0	0.0	0.0	0.5
Totals	0.5	0.0	0.0	0.0	0.0	0.5

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.5 Projected: 0.0 Total: 0.5

WASTE STREAM DESCRIPTION	The stream is a xylene-based chelating agent. It is a homogeneous, flammable liquid containing hazardous constituents. Total activity is 100 nCi/g. The waste is contact handled. TTA stands for Thenoyl Trifluoroacetone.
WASTE STREAM SOURCE	This stream is generated from plutonium extraction analytical procedures at the Savannah River Technology Center. It consists of a homogenous, xylene based, liquid chelating agent.
CURRENT CONTAINER COMMENTS	"SAF-T-CAN" Brand, 1 gallon capacity
EPA COMMENTS	This waste is ignitable only - no contaminant concentration values are used, other than xylenes > 99%.
MANAGEMENT COMMENTS	The waste is stored in a stainless steel can, (Safe-T-Can brand for storage of flammable liquids), in a Satellite Accumulation Area (SAA), which is located in a laboratory hood in Lab B-138 of Building 773-A of SRTC. The preferred option in the PSTP is to assay and characterize the waste stream at the TRU Waste Certification/Characterization Facility (TWCCF), followed by preparation for shipment and disposal at WIPP. Because of the small volume of the stream alternative treatment options are being investigated. One alternative is to handle the waste as a 90 day generator, remove the TRU portion of the stream, and treat the ignitable characteristic.
ACCEPTANCE COMMENTS	GENOPERATI: Chemical Analysis and experimentation - laboratory conducts experiments on low- and high-level radioactive materials, in addition to non-radioactive testing. RECLASS_CO: NA. CATION: HNO3 = 10E-3 (Molar Based on solubility after contact with 1Molar HNO3) per lab procedure.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	17.4	59.7	117.3	59.3	29.7	283.4
Totals	17.4	59.7	117.3	59.3	29.7	283.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	1403.0	1403.0
Totals	0.0	0.0	0.0	0.0	1403.0	1403.0

As-Generated Form: Stored: 17.4 Projected: 266.0 Total: 283.4

Final Waste Form: Stored: 0.0 Projected: 1403.0 Total: 1403.0

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	The stream was prodiced in 221F, a separation facility for Pu-239 production.
CURRENT CONTAINER COMMENTS	None
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: SR-W026	Handling: CH	NMVP #: undetermined	Stream Name: CH Mixed TRU/Thirds - Vitrified debris from 221F		Inventory Date: 12/31/94
Local ID: SR-W026	Type: MTRU	Generator Site: SR	Final Waste Form: Solidified Inorganics		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	13[illegible]		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	Unknown
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.6	25.6	50.3	25.2	12.9	117.5
Totals	3.6	25.6	50.3	25.2	12.9	117.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	65.7	65.7
Totals	0.0	0.0	0.0	0.0	65.7	65.7

As-Generated Form: Stored: 3.6 Projected: 114.0 Total: 117.5

Final Waste Form: Stored: 0.0 Projected: 65.7 Total: 65.7

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was produced in 221F a seperations facility for Pu-239.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W033 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final waste form containing >100 nCi/g is combined with SR-W026 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	Unknown
Source:	Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	14.1	30.9	51.9	29.9	18.2	145.1
Totals	14.1	30.9	51.9	29.9	18.2	145.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	691.4	691.4
Totals	0.0	0.0	0.0	0.0	691.4	691.4

As-Generated Form: Stored: 14.1 Projected: 131.0 Total: 145.1

Final Waste Form: Stored: 0.0 Projected: 691.4 Total: 691.4

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was produced in the 221H - Separation facilities for Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/Thirds - Vitrified debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	Unknown
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	49.0	124.1	208.3	119.5	72.1	573.0
Totals	49.0	124.1	208.3	119.5	72.1	573.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	299.2	299.2
Totals	0.0	0.0	0.0	0.0	299.2	299.2

As-Generated Form: Stored: 49.0 Projected: 524.0 Total: 573.0

Final Waste Form: Stored: 0.0 Projected: 299.2 Total: 299.2

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly *booties*, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was prodiced in 221H, separation facilities for Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	sr125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.8	3.4	4.0	10.5	9.7	30.3
Totals	2.8	3.4	4.0	10.5	9.7	30.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	144.8	144.8
Totals	0.0	0.0	0.0	0.0	144.8	144.8

As-Generated Form: Stored: 2.8 Projected: 27.5 Total: 30.3

Final Waste Form: Stored: 0.0 Projected: 144.8 Total: 144.8

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This waste stream was produced in 235-F during separation activities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/Thirds - Vitrified debris from 235F	Inventory Date:	9/30/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.0	12.7	16.1	43.4	37.7	113.8
Totals	4.0	12.7	16.1	43.4	37.7	113.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	63.0	63.0
Totals	0.0	0.0	0.0	0.0	63.0	63.0

As-Generated Form: Stored: 4.0 Projected: 109.8 Total: 113.8

Final Waste Form: Stored: 0.0 Projected: 63.0 Total: 63.0

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This waste stream was produced in 235F during separation activites for the production of Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W033 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final waste form contianing >100 nCi/g is combined with SR0W026 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	0.2	0.6	1.0	0.4	3.4
Totals	1.2	0.2	0.6	1.0	0.4	3.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	11.6	11.6
Totals	0.0	0.0	0.0	0.0	11.6	11.6

As-Generated Form: Stored: 1.2 Projected: 2.2 Total: 3.4

Final Waste Form: Stored: 0.0 Projected: 11.6 Total: 11.6

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This waste stream was produced in 772F, an analytical lab used to support H and F canyon processing, the Pu-238 program etc.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/Thirds - Vitrified debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	Unknown
Source:	Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	1.0	1.6	3.2	3.2	9.3
Totals	0.4	1.0	1.6	3.2	3.2	9.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	5.3	5.3
Totals	0.0	0.0	0.0	0.0	5.3	5.3

As-Generated Form: Stored: 0.4 Projected: 8.9 Total: 9.3

Final Waste Form: Stored: 0.0 Projected: 5.3 Total: 5.3

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This waste stream was produced in 772F an analytical lab used to support H and F canyon processing, the Pu-238 program, etc.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W033 could concentrate the TRU fraction above 100 nCi/g, requiring WIPP disposal. The final waste form containing >100 nCi/g TRU radionuclides is combined with SR-W026 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	3.6	5.9	11.9	11.7	33.1
Totals	0.0	3.6	5.9	11.9	11.7	33.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	174.1	174.1
Totals	0.0	0.0	0.0	0.0	174.1	174.1

As-Generated Form: Stored: 0.0 Projected: 33.1 Total: 33.1

Final Waste Form: Stored: 0.0 Projected: 174.1 Total: 174.1

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly bootles, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was produced in 773A, the SRTC laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/Thirds - Vitrified debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	1.4	2.6	5.0	5.2	14.1
Totals	0.0	1.4	2.6	5.0	5.2	14.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	8.6	8.6
Totals	0.0	0.0	0.0	0.0	8.6	8.6

As-Generated Form: Stored: 0.0 Projected: 14.1 Total: 14.1

Final Waste Form: Stored: 0.0 Projected: 8.6 Total: 8.6

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was produced in 773A, the SRTC laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W033 could concentrate the TRU fraction above 100 nCi/g, requiring WIPP disposal. The final waste form containing >100 nCi/g TRU radionuclides is combined with SR-W026 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	4.2	0.0	0.0	0.0	0.0	4.2
Drum / 55-gallon	265.8	0.0	0.0	0.0	0.0	265.8
Totals	270.0	0.0	0.0	0.0	0.0	270.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	265.6	0.0	0.0	0.0	0.0	265.6
Totals	265.6	0.0	0.0	0.0	0.0	265.6

As-Generated Form: Stored: 270.0 Projected: 0.0 Total: 270.0

Final Waste Form: Stored: 265.6 Projected: 0.0 Total: 265.6

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 221F, a separations facility for the production of Pu-239 .
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 4.2 Projected: 0.0 Total: 4.2

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 221F, a separations facility for the production of Pu-239 .
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	7.0	0.0	0.0	0.0	0.0	7.0
Drum / 55-gallon	289.8	0.0	0.0	0.0	0.0	289.8
Totals	296.8	0.0	0.0	0.0	0.0	296.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	33.2	0.0	0.0	0.0	0.0	33.2
Totals	33.2	0.0	0.0	0.0	0.0	33.2

As-Generated Form: Stored: 296.8 Projected: 0.0 Total: 296.8

Final Waste Form: Stored: 33.2 Projected: 0.0 Total: 33.2

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 221F, a separations facility for the production of Pu-239 .
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final waste form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	6.8	0.0	0.0	0.0	0.0	6.8
Totals	6.8	0.0	0.0	0.0	0.0	6.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	125.4	0.0	0.0	0.0	0.0	125.4
Totals	125.4	0.0	0.0	0.0	0.0	125.4

As-Generated Form: Stored: 6.8 Projected: 0.0 Total: 6.8

Final Waste Form: Stored: 125.4 Projected: 0.0 Total: 125.4

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in the 221H separation facilities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	6.8	0.0	0.0	0.0	0.0	6.8
Totals	6.8	0.0	0.0	0.0	0.0	6.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 6.8 Projected: 0.0 Total: 6.8

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of bootles, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in the 221H separation facilities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	977.5	0.0	0.0	0.0	0.0	977.5
Box / Misc.	0.0	0.0	0.0	0.0	0.0	0.0
Drum / 55-gallon	186.7	0.0	0.0	0.0	0.0	186.7
Totals	1164.2	0.0	0.0	0.0	0.0	1164.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	25.9	0.0	0.0	0.0	0.0	25.9
Totals	25.9	0.0	0.0	0.0	0.0	25.9

As-Generated Form: Stored: 1164.2 Projected: 0.0 Total: 1164.2

Final Waste Form: Stored: 25.9 Projected: 0.0 Total: 25.9

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in the 221H separation facilities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATON: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 235F	Inventory Date:	
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	34.5	0.0	0.0	0.0	0.0	34.5
MSMC	0.0	0.0	0.0	0.0	0.0	0.0
Totals	34.5	0.0	0.0	0.0	0.0	34.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	34.7	0.0	0.0	0.0	0.0	34.7
Totals	34.7	0.0	0.0	0.0	0.0	34.7

As-Generated Form: Stored: 34.5 Projected: 0.0 Total: 34.5

Final Waste Form: Stored: 34.7 Projected: 0.0 Total: 34.7

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 235F due to separation activities during the production of Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / MSMC	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 235F due to separation activities during the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 235F	Inventory Date:	
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	0.0	0.0	0.0	0.0	0.0	0.0
Drum / 55-gallon	137.0	0.0	0.0	0.0	0.0	137.0
MSMC	0.0	0.0	0.0	0.0	0.0	0.0
Totals	137.0	0.0	0.0	0.0	0.0	137.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.6	0.0	0.0	0.0	0.0	16.6
Totals	16.6	0.0	0.0	0.0	0.0	16.6

As-Generated Form: Stored: 137.0 Projected: 0.0 Total: 137.0

Final Waste Form: Stored: 16.6 Projected: 0.0 Total: 16.6

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of bootles, 'sb coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 235F due to separation activities during the production of Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	33.5	0.0	0.0	0.0	0.0	33.5
Drum / 55-gallon	510.2	0.0	0.0	0.0	0.0	510.2
Totals	543.6	0.0	0.0	0.0	0.0	543.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	515.4	0.0	0.0	0.0	0.0	515.4
Totals	515.4	0.0	0.0	0.0	0.0	515.4

As-Generated Form: Stored: 543.6 Projected: 0.0 Total: 543.6

Final Waste Form: Stored: 515.4 Projected: 0.0 Total: 515.4

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 772F, an analytical lab used to support F and H canyon processing, Pu-238 mission, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	33.5	0.0	0.0	0.0	0.0	33.5
Totals	33.5	0.0	0.0	0.0	0.0	33.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	32.1	0.0	0.0	0.0	0.0	32.1
Totals	32.1	0.0	0.0	0.0	0.0	32.1

As-Generated Form: Stored: 33.5 Projected: 0.0 Total: 33.5

Final Waste Form: Stored: 32.1 Projected: 0.0 Total: 32.1

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 772F, an analytical lab used to support F and H canyon processing, Pu-238 mission, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	7.1	0.0	0.0	0.0	0.0	7.1
Drum / 55-gallon	88.6	0.0	0.0	0.0	0.0	88.6
Totals	95.7	0.0	0.0	0.0	0.0	95.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.6	0.0	0.0	0.0	0.0	10.6
Totals	10.6	0.0	0.0	0.0	0.0	10.6

As-Generated Form: Stored: 95.7 Projected: 0.0 Total: 95.7

Final Waste Form: Stored: 10.6 Projected: 0.0 Total: 10.6

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 772F, an analytical lab used to support F and H canyon processing, Pu-238 mission, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	41.0	0.0	0.0	0.0	0.0	41.0
Cask / 27 in x 27 in x 42 in	67.0	0.0	0.0	0.0	0.0	67.0
Drum / 55-gallon	134.0	0.0	0.0	0.0	0.0	134.0
Totals	242.0	0.0	0.0	0.0	0.0	242.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	331.1	0.0	0.0	0.0	0.0	331.1
Totals	331.1	0.0	0.0	0.0	0.0	331.1

As-Generated Form: Stored: 242.0 Projected: 0.0 Total: 242.0

Final Waste Form: Stored: 331.1 Projected: 0.0 Total: 331.1

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of bootles, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was generated in 773A, the SRTC laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	41.0	0.0	0.0	0.0	0.0	41.0
Totals	41.0	0.0	0.0	0.0	0.0	41.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	7.6	0.0	0.0	0.0	0.0	7.6
Totals	7.6	0.0	0.0	0.0	0.0	7.6

As-Generated Form: Stored: 41.0 Projected: 0.0 Total: 41.0

Final Waste Form: Stored: 7.6 Projected: 0.0 Total: 7.6

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of bootles, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was generated in 773A, the SRTC analytical laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	8.2	0.0	0.0	0.0	0.0	8.2
Cask / 27 in x 27 in x 42 in	32.0	0.0	0.0	0.0	0.0	32.0
Drum / 55-gallon	49.4	0.0	0.0	0.0	0.0	49.4
Totals	89.6	0.0	0.0	0.0	0.0	89.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	17.3	0.0	0.0	0.0	0.0	17.3
Totals	17.3	0.0	0.0	0.0	0.0	17.3

As-Generated Form: Stored: 89.6 Projected: 0.0 Total: 89.6

Final Waste Form: Stored: 17.3 Projected: 0.0 Total: 17.3

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was generated in 773A, the SRTC analytical laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from offsite	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	27.9	0.0	0.0	0.0	0.0	27.9
Totals	27.9	0.0	0.0	0.0	0.0	27.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	27.7	0.0	0.0	0.0	0.0	27.7
Totals	27.7	0.0	0.0	0.0	0.0	27.7

As-Generated Form: Stored: 27.9 Projected: 0.0 Total: 27.9

Final Waste Form: Stored: 27.7 Projected: 0.0 Total: 27.7

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This waste was generated and shipped to SRS from the Mound facility and Los Alamos Scientific Laboratory.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. GECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NADR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from offsite	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	26.8	0.0	0.0	0.0	0.0	26.8
Drum / 55-gallon	20.4	0.0	0.0	0.0	0.0	20.4
Totals	47.2	0.0	0.0	0.0	0.0	47.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	31.8	0.0	0.0	0.0	0.0	31.8
Totals	31.8	0.0	0.0	0.0	0.0	31.8

As-Generated Form: Stored: 47.2 Projected: 0.0 Total: 47.2

Final Waste Form: Stored: 31.8 Projected: 0.0 Total: 31.8

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This waste was generated and shipped to SRS from the Mound facility and Los Alamos Scientific Laboratory.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W053	Handling:	CH	NMVP #:	none at this time	Stream Name:	Contact handled mixed TRU/Residues from 773A	Inventory Date:	12/31/94
Local ID:	SR-W053	Type:	MTRU	Generator Site:		Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

F005, F002, F001, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	273.0	87.0	944.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	2415.0	2205.0	2473.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	6.40E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
small carton in 30 gal containers	0.5	0.0	0.0	0.0	0.0	0.5
Totals	0.5	0.0	0.0	0.0	0.0	0.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.5	0.0	0.0	0.0	0.0	0.5
Totals	0.5	0.0	0.0	0.0	0.0	0.5

As-Generated Form: Stored: 0.5 Projected: 0.0 Total: 0.5

Final Waste Form: Stored: 0.5 Projected: 0.0 Total: 0.5

WASTE STREAM DESCRIPTION	This waste stream consists of Rocky Flats Incinerator Ash and F-listed solvents, and is contaminated with TRU nuclides from SRS laboratories. This waste is classified as contact-handled.
WASTE STREAM SOURCE	This ash was sent to SRS from Rocky Flats for research into plutonium recovery. The ash was classified as hazardous by the Colorado Court System based on chemical analysis of F-listed solvent wste processed in the Rocky Flats Incinerator. SRS subsequently cancelled the research. The ash was declared mixed after SRS handled the waste as a Special Nuclear Material (SNM) in a SRTC vault.
CURRENT CONTAINER COMMENTS	paper cartons are placed in 30 gallon shipping containers
EPA COMMENTS	The confidence level is low because process knowledge was used for characterization, no analytical data is available.
MANAGEMENT COMMENTS	The preferred treatment option is to return the ash to Rocky Flats for consolidation and treatment with similar wastes. Treatment (if any) would then be at the discretion of Rocky Flats. Until a full agreement between SRS and RF has been reached, preliminary plans indicate SRS would add this small stream to a larger stream for vitrification. The waste itself is in four small cartons which are placed in 30 gallon shipping containers at a ratio of two small cartons per shipping container.
ACCEPTANCE COMMENTS	One-time generation. Went in storage prior to the effective date of May 8, 1992.
FINAL FORM COMMENTS	This stream is currently stored in a total of 4 cartons which are placed in 30 gallon shipping containers (not TRAMPAC approved). 2 cartons per shipping container. The containers are stored in 235-F.

TELEDYNE-BROWN ENGINEERING

Location and Description

Teledyne-Brown Engineering (TB) in Westwood, New Jersey, provided long-term contract services to DOE for the decontamination and recovery of DOE-owned precious metals. This effort under the DOE Precious Metal Program has since been transferred to Martin Marietta Energy Systems at the Oak Ridge Reservation.

Mission

Since 1986, the TB facility (formerly referred to as Teledyne Isotopes) has been in possession of nine grams of plutonium waste which were transferred from the Rocky Flats Plant with other precious metal-containing materials. Teledyne Isotopes was under contract with Westinghouse Materials Company of Ohio to decontaminate and recover DOE precious metals (e.g., platinum, gold, and rhodium) and return this metal to various DOE pool accounts. Normally the waste from the recovery process was disposed of at commercial sites, but this quantity exceeded disposal site limits. The waste must be shipped to a DOE site.

Waste Information

Processes

The by-product of the recovery process is a single drum of vitrified glass containing nine grams of plutonium. The material consists of approximately 150 pounds of vitrified lead-borosilicate glass chucks which are double-bagged, with each bag containing about 25 pounds. The drum is believed to contain no hazardous constituents other than Pu-239. The waste is stored in a 55-gallon stainless steel drum obtained from Oak Ridge National Laboratory. TB has a NuPAC N-55 overpack container which they plan to use in moving the waste to a DOE site.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	TB-W001	Handling:	CH	NMVP #:	N/A	Stream Name:	Teledyne Brown Vitrified Borosilicate Glass	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	Z1120

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	327.0	327.0	327.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source:

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-239	5.50E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	A 55-gallon stainless steel drum containing 9 grams of DOE-owned plutonium waste in the form of 150 lbs. of lead - borosilicate glass.
WASTE STREAM SOURCE	By-product of a precious metals recovery process. Materials with 9 grams of Pu were transferred from the Rocky Flats Plant to Teledyne Isotopes in 1986 for processing. 150 pounds of Borosilicate glass.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W040	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Heterogeneous Debris	Inventory Date:	12/31/94
Local ID:	2308	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

D011, D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.6
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Co-60	3.80E-03
Am-241	5.31E-03
Am-243	1.08E-07
Bk-249	1.08E-07
Cf-249	3.66E-06
Cf-252	2.83E-04
Ac-227	1.08E-06
Cm-244	1.88E-03
UNID	4.87E-05
Cs-137	1.97E-03
Pu-239	2.06E-03
Ra-223	1.08E-06
Sr-90	1.20E-02
Th-232	1.08E-06
U-233	4.32E-04
U-235	1.53E-07
U-238	5.51E-08
Cm-242	7.59E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Metal	0.1	0.0	0.0	0.0	0.0	0.1
Cask /Concrete	646.3	0.0	0.0	0.0	0.0	646.3
Drum / 55-gallon	0.0	18.7	31.2	62.4	62.4	174.7
Other	0.1	0.0	0.0	0.0	0.0	0.1
Totals	646.5	18.7	31.2	62.4	62.4	821.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	922.0	17.8	44.5	89.0	89.0	1162.3
Totals	922.0	17.8	44.5	89.0	89.0	1162.3

As-Generated Form: Stored: 646.5 Projected: 174.7 Total: 821.2

Final Waste Form: Stored: 922.0 Projected: 240.3 Total: 1162.3

WASTE STREAM DESCRIPTION	This waste stream consists of RH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Waste from Glove Box Operations, Laboratory Operations, Hot Cell Clean Up Operations, Equipment Repair and Maintenance, Sources.
CURRENT CONTAINER COMMENTS	Waste will have to be repackaged into acceptable containers for shipment and disposal. This is forecasted waste yet to be generated
EPA COMMENTS	No characterization existed for legacy waste. Limited data is available from process log sheets. No data is obtainable from Waste Examination and Assay Facility due to the level of radiation in RH contaminated materials. EPA codes are based on CH-TRU data and the similarity due to the generating processes.
MANAGEMENT COMMENTS	The waste currently stored in metal boxes and concrete casks will have to be packaged in acceptable containers.
ACCEPTANCE COMMENTS	Bldg 7823A is not designated as a TRU storage facility and has been designated as a LLW storage facility. Waste stored in this building is being assessed whether it is TRU or LLW. One container in this waste stream will be evaluated as possibly being Spent Nuclear Fuel. Bldgs 7878 and 7879 are suppose to contain CH TRU waste only. Evaluation of the waste stored in these buildings will determine the disposition the waste containers.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums are currently in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. The projected inventory includes 840 55-gallon containers of newly generated waste only and does not include the existing total inventory volume (640 m3) which does not include any 55-gallon drums. Therefore, the entire current inventory will have to be repackaged into 55-gallon drums. The value reported in section 8.2.15.1.11 reflects the number of RH canisters projected which includes 3 55-gallon drums in each canister. 1036 RH Canisters will be required to repack currently stored waste. Projections are for newly generated waste only.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W086	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (nondefense, nonmixed)	Inventory Date:	12/31/94
Local ID:	T2301	Type:	TRU	Generator Site:	NU	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
UNID	0.00E+00
U-238	1.20E-07
U-235	7.23E-09
U-234	1.15E-04
U-233	1.87E-06
Pu-242	2.10E-07
Pu-241	3.77E-02
Pu-240	2.25E-03
Pu-239	4.50E-03
Pu-238	6.24E-04
Am-241	1.68E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	170.8	0.0	0.0	0.0	0.0	170.8
Totals	170.8	0.0	0.0	0.0	0.0	170.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	170.8	0.0	0.0	0.0	0.0	170.8
Totals	170.8	0.0	0.0	0.0	0.0	170.8

As-Generated Form: Stored: 170.8 Projected: 0.0 Total: 170.8

Final Waste Form: Stored: 170.8 Projected: 0.0 Total: 170.8

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids which were generated from nondefense programs. The physical form is solid and is not believed to contain hazardous constituents. It has not been determined if these wastes have been examined by WEAF. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Sludge collected from several sources for temporary storage and prior to mixing with grout for underground injection.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	No treatment is expected for final disposal. It may be required that the waste stream be repackaged for further characterization and certification activities.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Calculation of the Pu-239 FGE was not completed. ORNL is attempting to obtain a copy of the TRAMPAC to obtain the required constants and equations needed for the calculations.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W042	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Sludge (inactive tank)	Inventory Date:	12/31/94
Local ID:	2311	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3121

AS-GENERATED EPA CODES

D009, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	396.6	173.1	528.9
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	396.6	173.1	528.9
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Eu-154	3.16E-03
C-14	3.32E-05
Cf-252	2.06E-03
Cm-244	8.79E-03
Co-60	7.78E-03
Cs-134	3.81E-05
Am-241	2.27E-04
Eu-152	3.51E-03
U-238	1.94E-04
Eu-155	2.85E-04
H-3	1.42E-05
Pu-238	1.91E-03
Pu-239	9.99E-04
Sr-90	1.19E+00
Th-232	5.64E-06
U-233	6.47E-04
Cs-137	4.15E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Single shell tank / Gunite	123.0	0.0	0.0	0.0	0.0	123.0
Totals	123.0	0.0	0.0	0.0	0.0	123.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	175.3	0.0	0.0	0.0	0.0	175.3
Totals	175.3	0.0	0.0	0.0	0.0	175.3

As-Generated Form: Stored: 123.0 Projected: 0.0 Total: 123.0

Final Waste Form: Stored: 175.3 Projected: 0.0 Total: 175.3

WASTE STREAM DESCRIPTION	The waste stream is comprised of RH-TRU sludge which has settled and separated from wastewater that has been stored in large underground storage tanks. The waste is a product of past operations at ORNL involving various nuclear research and radioisotope fabrication processes and is currently undergoing RI/FS as part of a CERCLA program involving these tanks and contents. This waste is under the responsibility of DOE EM-40 and as such are not technically a RCRA mixed waste. However, since the waste has been reported in the ORR LDR FFCA, it is included in the MWIR. However, it is anticipated that the reporting responsibility will be turned over to the appropriate EM-40 organization.
WASTE STREAM SOURCE	Waste from sludge which has settled and separated from wastewater that has been stored in large underground tanks. The sludge is a product of past operations at ORNL involving various nuclear research and radioisotope fabrication processes.
CURRENT CONTAINER COMMENTS	Treatment of the RH TRU sludge waste has not been determined to date. It is anticipated that the sludge will be packaged in 55-gallon drums and shipped in the RH canister.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	The RH TRU sludge is currently stored in underground tanks which are currently inactive and located at the North Tank Farm, South Tank Farm, and at the Old Hydrofracture Facility. ORNL is currently assessing the use of existing facilities that would allow the mobilization and packaging of the sludge waste for final disposal.
ACCEPTANCE COMMENTS	Bldgs 3023, 3507, and 7852 are not designated at TRU storage facilities.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums are currently in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. 197 RH Canisters will be required to repack currently stored waste.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W087	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Heterogeneous Debris (buried)	Inventory Date:	12/31/94
Local ID:	B2301	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.6
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
UNID	1.13E-01
U-235	6.29E-07
Pu-239	5.44E-03
I-131	1.18E-03
Cs-137	1.02E-01
Cm-244	2.58E-03
Cm-242	5.88E-04
Cf-252	4.96E-04
Am-243	4.68E-09
Am-241	3.22E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cask /Concrete	298.5	0.0	0.0	0.0	0.0	298.5
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	298.7	0.0	0.0	0.0	0.0	298.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	425.4	0.0	0.0	0.0	0.0	425.4
Totals	425.4	0.0	0.0	0.0	0.0	425.4

As-Generated Form: Stored: 298.7 Projected: 0.0 Total: 298.7

Final Waste Form: Stored: 425.4 Projected: 0.0 Total: 425.4

WASTE STREAM DESCRIPTION	This waste stream consists of RH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids and retrievably buried in trenches or pits at ORNL. The physical form is solid. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Hot Cell Waste
CURRENT CONTAINER COMMENTS	Waste will have to be repackaged into acceptable containers for shipment and disposal. Condition of containers is unknown at this time. Condition of containers is unkown at this time. If retrieval is conducted, it may be necessary to repackage the drummed waste due excessive deterioration.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	It has not been determined whether the buried TRU waste will be retrieved and packaged for final disposal at a repository or left in place as final disposal.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because only 1 55-gallon drums is currently in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. The projected inventory includes 840 55-gallon containers of newly generated waste only and does not include the existing total inventory volume (640 m3) which does not include any 55-gallon drums. Therefore, the entire current inventory will have to be repackaged into 55-gallon drums. 478 RH canisters used to overpack 55 gallon drums will be required to repack the existing waste.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W044	Handling:	CH	NMVP #:	OR 125A; 125B	Stream Name:	CH-TRU Heterogeneous Debris	Inventory Date:	12/31/94
Local ID:	2305	Type:	MTRU	Generator Site:	KA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

OR 125A; 125B

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Co-60	3.51E-09
Pm-147	1.27E-03
Am-241	2.68E-03
Np-237	1.41E-05
Gd-153	0.00E+00
Fe-59	7.65E-03
Zn-65	5.35E-06
Cs-137	4.89E-01
Pu-238	5.47E-02
Cm-248	9.69E-06
Cm-244	5.38E-03
Cm-242	4.14E-03
Cf-252	2.67E-05
Cf-249	9.62E-06
Bk-249	3.30E-04
Am-243	1.95E-04
Es-254M	2.08E-02
U-232	4.00E-05
Y-90	6.50E-09
UNID	5.00E-04
U-238	9.50E-07
U-236	8.52E-08
U-235	1.19E-07
Pa-231	5.98E-04
U-233	3.24E-04
Pu-239	1.08E-03
Th-232	1.03E-07
Tc-99	1.31E-03
Sr-90	4.51E-01
Ra-226	5.07E-04
Pu-242	9.40E-06
Pu-241	2.99E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Metal	165.9	0.0	0.0	0.0	0.0	165.9
Box / Wood	15.1	0.0	0.0	0.0	0.0	15.1
Cask /Concrete	4.9	0.0	0.0	0.0	0.0	4.9
Drum / 30-gallon	1.1	0.0	0.0	0.0	0.0	1.1
Drum / 55-gallon	331.1	27.5	45.8	91.5	91.5	587.4
Other	4.0	0.0	0.0	0.0	0.0	4.0
Totals	522.1	27.5	45.8	91.5	91.5	778.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	522.9	27.5	45.8	91.5	91.5	779.2
Totals	522.9	27.5	45.8	91.5	91.5	779.2

As-Generated Form: Stored: 522.1 Projected: 256.3 Total: 778.4

Final Waste Form: Stored: 522.9 Projected: 256.3 Total: 779.2

Pu-240	2.08E-02
U-234	2.47E-07

WASTE STREAM DESCRIPTION

This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid. These wastes have been examined by WEAF and do not contain free or containerized liquids. This waste is categorized as heterogeneous debris (matrix code 5490).

WASTE STREAM SOURCE

Waste from Glove Box Operations, Laboratory Operations, Hot Cell Clean Up Operations, Equipment Repair and Maintenance, Sources, Radiochemical Processing for Isotope Separation and Purification.

CURRENT CONTAINER COMMENTS

Waste will have to be repackaged into acceptable containers for shipment and disposal.

This waste is also forecasted to be generated.

Waste will have to be repackaged into acceptable containers for shipment and disposal.

30-gallon containers may have to be overpacked into a 55-gallon drum or waste emptied out an repackaged into a 55-gallon drum.

Waste contents will require repackaging into an acceptable containers.

EPA COMMENTS

The majority of this waste stream was generated prior to 1986 and has very limited data available. EPA codes are based on generator process knowledge and evaluations from the
Waste Examination and Assay Facility.

MANAGEMENT COMMENTS

The waste currently stored in casks, metal and wood boxes, and other types of containers will have to be repackaged into acceptable containers for shipment and disposal.

ACCEPTANCE COMMENTS

Bldgs 2364, 3019A, 3030, 7823, 7823A, are not designated as TRU storage facilities. Some of the waste in these buildings are being evaluated to determine if the waste is TRU or LLW. Several containers in this waste stream will be assessed as possibly being Spent Nuclear Fuel. Several containers stored in Bldg 3019A may have been sent back to the generators in 1976 however the data bases show they are still being stored. An evaluation will be conducted to reconcile this deficiency. Bldg 7823 has been designated as a LLW storage facility. Bldgs 7826 and 7834 are closed non-RCRA storage facilities. The waste containers stored in these buildings will be evaluated to determine if they are mixed or non-mixed TRU since these are non-RCRA facilities.

FINAL FORM COMMENTS

Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. The projected inventory includes 1,232 55-gallon containers of newly generated waste only and does not include the existing total inventory volume. Since this is CH TRU waste, it is anticipated it will be transported in the TRUPACT-II cask. 922 additional 55 gallon drums will be required to repack the non-certifiable containers currently stored for this waste stream.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W045	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Uncategorized	Inventory Date:	12/31/94
Local ID:	2307	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S9000

AS-GENERATED EPA CODES

D011, D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.1	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: UNK

PCBs: No

Source: Source Information Not Compiled

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.29E+01
Pu-240	1.20E+00
Pu-239	6.92E-01
Pu-238	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Metal	4.0	0.0	0.0	0.0	0.0	4.0
Drum / 55-gallon	1.5	0.0	0.0	0.0	0.0	1.5
Totals	5.4	0.0	0.0	0.0	0.0	5.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	0.0	0.0	0.0	0.0	5.4
Totals	5.4	0.0	0.0	0.0	0.0	5.4

As-Generated Form: Stored: 5.4 Projected: 0.0 Total: 5.4

Final Waste Form: Stored: 5.4 Projected: 0.0 Total: 5.4

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU waste which has not been classified or characterized. It is believed that the physical form is either solid, liquid, mixed (both solid and liquid), or unknown and is suspected to contain hazardous constituents. This waste is categorized as uncategorized (matrix code 9000).
WASTE STREAM SOURCE	Glove Box Waste
CURRENT CONTAINER COMMENTS	Waste contained in metal boxes will have to be repackaged into acceptable containers.
EPA COMMENTS	The majority of this waste stream was generated prior to 1986 and has very limited data available. EPA codes are based on generator process knowledge and evaluations from the Waste Examination and Assay Facility.
MANAGEMENT COMMENTS	Final treatment, if required, will be decided upon further characterization and utilization of process knowledge for the categorization of this waste stream. The waste currently stored in casks, metal and wood boxes will have to be repackaged into acceptable containers for shipment and disposal.
ACCEPTANCE COMMENTS	Bldg 7823E is not designated as a TRU storage facility. Waste inside this building is being assessed if it is TRU or LLW. Bldg 7826 is a closed non-RCRA storage facility. The waste containers stored in this building will be evaluated to determine if they are mixed or non-mixed TRU since this is a non-RCRA facility.
FINAL FORM COMMENTS	Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. No newly generated waste is projected for this waste stream. 19 additional 55 gallon drums will be required to repack the non-certifiable containers currently stored for this waste stream.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W046	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Sludge (active tank)	Inventory Date:	12/31/94
Local ID:	2313	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3100

AS-GENERATED EPA CODES

D009, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	396.6	173.1	528.9
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	396.6	173.1	528.9
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Eu-154	2.59E-02
C-14	5.35E-05
Ce-144	1.67E-03
Cm-243	1.63E-03
Cm-244	7.75E-03
Co-60	1.12E-02
Cs-134	3.83E-04
Am-241	2.07E-03
Eu-152	4.62E-02
Zr-95	4.50E-03
Eu-155	6.75E-03
Nb-95	3.14E-04
Pu-239	8.10E-04
Ru-106	3.07E-03
Sr-90	2.49E-01
U-232	8.98E-06
U-233	5.20E-04
U-235	1.69E-03
Cs-137	5.84E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	18.1	30.2	60.3	60.3	168.9
Single shell tank / SS	704.4	0.0	0.0	0.0	0.0	704.4
Totals	704.4	18.1	30.2	60.3	60.3	873.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	861.5	22.2	36.9	73.9	73.9	1068.4
Totals	861.5	22.2	36.9	73.9	73.9	1068.4

As-Generated Form: Stored: 704.4 Projected: 168.9 Total: 873.3

Final Waste Form: Stored: 861.5 Projected: 206.5 Total: 1068.0

WASTE STREAM DESCRIPTION	This waste stream is comprised of liquid low level waste that has been concentrated by evaporation and subsequently stored in large underground storage tanks. The waste is generated as relatively dilute low-level waste in various nuclear research and radioisotope fabrication processes. These streams are collected and centrally volume reduced in an evaporator facility. After the waste has been stored, it separates into phases. The resulting solids (sludge phase) is fairly homogeneous chemically and radiochemically. Since the sludge is a product of solids concentration, it has been classified as a TRU waste. This waste is categorized as sludge (matrix code 3121).
WASTE STREAM SOURCE	Liquid Low Level Waste sludge concentrated by processing in Liquid Low Level Waste Evaporator Facility.
CURRENT CONTAINER COMMENTS	Treatment of the RH TRU sludge waste has not been determined to date. It is anticipated that the sludge will be packaged in 55-gallon drums and shipped in the RH canister. This is forecasted waste to be generated.
EPA COMMENTS	TCLP levels provided are based on absolute analysis for specific metals. These analysis were based on the formerly used EP-TOX methodology. TCLP for organics has not been performed. Typical values for metals are listed in mg/kg.
MANAGEMENT COMMENTS	The RH TRU sludge is currently stored in underground tanks which are currently active and located at the the Melton Valley Storeage Tank area and the Evaporator Facility in Bethel Valley. ORNL is currently assessing the use of existing facilities that would allow the mobilization and packaging of the sludge waste for final disposal.
ACCEPTANCE COMMENTS	Bldgs 2531 and 7830 are not designated as TRU Storeage Facilities.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums were reported in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. The projected inventory includes 812 55-gallon containers of newly generated waste only and does not include the existing total inventory volume (587 m3) which does not include any 55-gallon drums. Therefore, the entire current inventory will have to be repackaged into 55-gallon drums. The value reported in section 8.2.15.1.11 reflects the number of RH canisters projected which includes 3 55-gallon drums in each canister. 968 additional RH canisters will be required to repack the existing waste in current tanks.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W047	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (with liquids)	Inventory Date:	12/31/94
Local ID:	2306	Type:	MTRU	Generator Site:	NB	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

D011, D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.6	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Eu-152	6.49E-09
Am-241	3.71E-03
Am-243	6.79E-04
Bk-249	5.29E-04
Cf-249	6.49E-06
Cf-252	8.73E-04
Cm-240	6.49E-06
Cm-242	5.37E-02
Cm-244	9.16E-03
Cm-246	6.49E-08
Ac-227	6.49E-08
Es-253	5.19E-02
U-238	3.82E-09
Np-237	7.77E-05
Pu-238	1.09E-01
Pu-239	1.34E-03
Pu-240	2.19E-03
Pu-241	3.70E-01
Pu-242	9.30E-05
Ra-226	3.80E-05
Th-230	7.79E-08
Th-232	1.02E-07
U-232	3.06E-06
U-233	1.26E-03
U-235	2.41E-07
Cs-137	6.49E-08

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 30-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Drum / 55-gallon	153.1	0.0	0.0	0.0	0.0	153.1
Totals	153.6	0.0	0.0	0.0	0.0	153.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	154.1	0.0	0.0	0.0	0.0	154.1
Totals	154.1	0.0	0.0	0.0	0.0	154.1

As-Generated Form: Stored: 153.6 Projected: 0.0 Total: 153.6

Final Waste Form: Stored: 154.1 Projected: 0.0 Total: 154.1

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid. These wastes have been examined by WEAF and found to contain free and/or containerized liquids. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Waste from Glove Box Operations, Laboratory Operations, Hot Cell Clean Up Operations, Equipment Repair and Maintenance, and Sources.
CURRENT CONTAINER COMMENTS	Waste will be repackaged to eliminate free liquids.
EPA COMMENTS	The majority of this waste stream was generated prior to 1986 and has very limited data available. EPA codes are based on generator process knowledge and evaluations from the Waste Examination and Assay Facility.
MANAGEMENT COMMENTS	This waste stream has been processed through WEAF and determined to contain excess free liquids. The waste contents will have to repackaged to eliminate the free liquids prior to shipment to WIPP.
ACCEPTANCE COMMENTS	Bldg 7823 is not designated as a TRU Storeage Facility but has been designated as a LLW storage Facility. The waste inside this building is being assessed whether it is TRU or LLW. Bldg 7834 is a closed non-RCRA storage facility. The waste containers stored in this building will be evaluated to determine if they are mixed or non-mixed TRU since this is a non-RCRA facility.
FINAL FORM COMMENTS	Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. No newly generated waste is projected for this waste stream. 5 additional 55 gallon drums will be required to repack the existing waste from 30 gallon drums.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W088	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (buried)	Inventory Date:	12/31/94
Local ID:	B2302	Type:	MTRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
U-233	5.27E-06
Th-232	6.59E-10
Sr-90	6.59E-06
Pu-239	6.59E-08
P-32	4.94E-02
I-131	4.94E-02
H-3	4.94E-02
Cs-137	6.59E-06
Cm-244	1.65E-02
C-14	4.94E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Dumpster	3.1	0.0	0.0	0.0	0.0	3.1
GI Can	3.2	0.0	0.0	0.0	0.0	3.2
Other	8.5	0.0	0.0	0.0	0.0	8.5
Totals	15.0	0.0	0.0	0.0	0.0	15.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	15.2	0.0	0.0	0.0	0.0	15.2
Totals	15.2	0.0	0.0	0.0	0.0	15.2

As-Generated Form: Stored: 15.0 Projected: 0.0 Total: 15.0

Final Waste Form: Stored: 15.2 Projected: 0.0 Total: 15.2

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids and retrievably buried in trenches or pits at ORNL. The physical form is solid. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Contaminated Equipment, Cleanup Debris
CURRENT CONTAINER COMMENTS	This waste will have to be packaged in acceptable containers. Condition of containers is unknown at this time. If waste is retrieved, it may require repackaging due to excessive deterioration of the drums. This waste will have to be packaged in acceptable containers.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	t has not been determined whether the buried TRU waste will be retrieved and packaged for final disposal at a repository or left in place as final disposal. The waste currently stored in casks , dumpsters, and other types of containers will have to be repackaged into acceptable containers for shipment and disposal.
ACCEPTANCE COMMENTS	Facilities 7822TB, 7822TH, and 7822TL are not designated as TRU Storage Facilities. Several containers in this waste stream may actually be stored instead of buried and may be LLW instead of TRU. Evaluation of these concerns will be conducted. One container is this waste stream may not be CH and may instead be RH because the storage facilities require that only RH be allowed.
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because only 1 55-gallon drums is currently in the inventory. The weight estimates assumed 33% of the inventory distributed between <350 lbs, >= 350 <500 lbs, and > 500 lbs. The projected inventory includes 840 55-gallon containers of newly generated waste only and does not include the existing total inventory volume (640 m3) which does not include any 55-gallon drums. Therefore, the entire current inventory will have to be repackaged into 55-gallon drums. 72 additional 55 gallon drums will be required to repack the existing waste.

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W093	Handling:	CH	NMVP #:	N/A	Stream Name:	CH-TRU Heterogeneous Debris (nonmixed)	Inventory Date:	12/31/94
Local ID:	T2304	Type:	TRU	Generator Site:	NB	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.8
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Po-209	2.29E-05
Am-243	2.07E-04
Bk-249	3.48E-06
Cf-249	9.75E-09
Cf-252	1.16E-06
Cm-242	8.62E-06
Cm-244	7.09E-05
Cm-248	2.24E-03
Cs-137	1.16E-05
Eu-152	5.48E-06
Ni-63	1.49E-06
Np-237	2.55E-07
Am-241	2.52E+00
Pm-147	2.75E-06
UNID	2.25E-09
Pu-238	4.59E-09
Pu-239	2.41E-02
Pu-240	3.16E-04
Pu-241	7.50E-05
Pu-242	8.86E-02
Ra-223	2.14E-06
Ra-226	2.75E-06
Sr-90	3.60E-06
U-232	1.07E-09
U-233	9.52E-08
U-234	4.26E-03
U-235	2.98E-07
U-236	9.99E-08
U-238	1.87E-08
Pa-231	1.18E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Metal	2.7	0.0	0.0	0.0	0.0	2.7
Box /Wood	337.1	0.0	0.0	0.0	0.0	337.1
Drum / 55-gallon	42.0	0.0	0.0	0.0	0.0	42.0
Other	47.8	0.0	0.0	0.0	0.0	47.8
Plastic	6.2	0.0	0.0	0.0	0.0	6.2
Totals	435.9	0.0	0.0	0.0	0.0	435.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	435.8	0.0	0.0	0.0	0.0	435.8
Totals	435.8	0.0	0.0	0.0	0.0	435.8

As-Generated Form: Stored: 435.9 Projected: 0.0 Total: 435.9

Final Waste Form: Stored: 435.8 Projected: 0.0 Total: 435.8

WASTE STREAM DESCRIPTION	This waste stream consists of CH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid and is believed not to contain hazardous constituents. It has not been determined if these wastes have been examined by WEAF. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Waste from Glove Box Operations, Laboratory Operations, Hot Cell Clean Up Operations, Equipment Repair and Maintenance, Sources, and Radiochemical Processing for Isotope Separation and Purification
CURRENT CONTAINER COMMENTS	This waste is probably wrapped in plastic and would have to be packaged into an acceptable container. Waste will have to be repackaged into acceptable containers for shipment and disposal.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Further utilization of process knowledge and characterization will be required to verify the absence of hazardous constituents. Waste stored in casks, metal and wood boxes and some drums will require repackaging into appropriate shipping containers.
ACCEPTANCE COMMENTS	Bldgs 7822, 7841, and 7886-3 are not designated as TRU Storage Facilities. The waste inside these buildings will be assessed whether they are TRU or LLW. Bldg 7834 is a closed non-RCRA storage facility. The waste containers stored in this building will be evaluated to determine if they are mixed or non-mixed TRU since this is a non-RCRA facility.
FINAL FORM COMMENTS	Prior estimates on weight distribution were given for this waste stream in section 8.2.14.1 . The same estimates are used in this section. No newly generated waste is projected for this waste stream. 1893 additional 55 gallon drums will be required to repack the existing waste.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	OR-W094	Handling:	RH	NMVP #:	N/A	Stream Name:	RH-TRU Heterogeneous Debris (nonmixed)	Inventory Date:	12/31/94
Local ID:	T2306	Type:	TRU	Generator Site:	OR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.2	0.0	1716.4
Aluminum-base Metal/Alloys:	0.0	0.0	1.6
Other Metals/Alloys:	0.0	0.0	21.3
Other Inorganic Material:	2.4	0.0	24.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.9	0.0	184.6
Rubber:	7.4	0.0	17.9
Plastics:	64.9	0.0	149.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	3.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
UNID	0.00E+00
U-233	6.51E-06
Pu-239	3.90E-03
Cs-137	1.46E-02
Cm-244	1.20E-03
Cf-252	2.98E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box /Wood	18.7	0.0	0.0	0.0	0.0	18.7
Cask /Concrete	40.6	0.0	0.0	0.0	0.0	40.6
Totals	59.3	0.0	0.0	0.0	0.0	59.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	84.5	0.0	0.0	0.0	0.0	84.5
Totals	84.5	0.0	0.0	0.0	0.0	84.5

As-Generated Form: Stored: 59.3 Projected: 0.0 Total: 59.3

Final Waste Form: Stored: 84.5 Projected: 0.0 Total: 84.5

WASTE STREAM DESCRIPTION	This waste stream consists of RH-TRU Waste which is classified as contaminated equipment, decontaminated debris or dry solids. The physical form is solid and is believed not to contain hazardous constituents. This waste is categorized as heterogeneous debris (matrix code 5490).
WASTE STREAM SOURCE	Hot Cell Waste and Radiochemical Processing for Isotope Separation and Purification.
CURRENT CONTAINER COMMENTS	Waste will have to be repackaged into acceptable containers for shipment and disposal.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Further utilization of process knowledge and characterization will be required to verify the absence of hazardous constituents. Waste stored in casks, metal and wood boxes and some drums will require repackaging into appropriate shipping containers.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	No prior estimates on weight distribution or Pu-239 FGEs were given for this waste stream because no 55-gallon drums were reported in the inventory and no waste is projected for the future. 95 RH canisters used to overpack 55 gallon drums will be required to repack the existing waste.

PA Paducah Gaseous Diffusion Plant

PADUCAH GASEOUS DIFFUSION PLANT

Location and Description

The Paducah Gaseous Diffusion Plant (PA) is situated in northwestern Kentucky, 26 kilometers west of Paducah, near the Ohio River. The site encompasses 750 acres (including 74 acres of process buildings). The site is included in a 3422-acre tract of DOE-owned property.

The PA is operated from DOE/Oak Ridge Operations Office with Lockheed Martin Utilities Services as the Management and Operating Contractor.

Mission

The DOE uranium enrichment complex of which PA is a component, was originally constructed to produce highly enriched uranium for nuclear weapons. The complex is now used primarily to provide low enriched uranium for domestic and foreign nuclear power reactors and, to a lesser degree, to provide the highly enriched uranium used in nuclear propulsion (naval) reactors and some research and test reactors.

The principle on-site process at PA is the separation of uranium isotopes through gaseous diffusion. The process produces enriched uranium to levels of up to 3% U-235. Most of the enriched product is shipped to the Portsmouth Gaseous Diffusion Plant for further processing.

Waste Information

Processes

During its defense-related operations, recovery of a reactor material resulted in the generation of TRU waste. Although most of the TRU waste has been shipped to ORNL for storage, some wastes remain on site. No additional TRU waste generation is expected at the PGDP.

Modifications/Assumptions/Development

PA reported radionuclides in Ci per kilogram. The TWBIR team calculated the radionuclides in terms of Ci/m^3 using the mass and final form volumes reported by PA.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	PA-A015	Handling:	CH	NMVP #:	N/A	Stream Name:	Transuranic - Solid	Inventory Date:	12/31/94
Local ID:	PA-A015	Type:	MTRU	Generator Site:	PA	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	63.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	212.0		
Packaging Material Plastic:	17.5		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
U	6.58E+00
Th-230	1.34E-02
Tc-99	7.09E-01
Pu-239	6.60E-02
Np-237	9.94E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum/55-gallon in overpack	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
SWB used to overpack 55 gallon drums	0.0	0.0	0.0	0.0	1.9	1.9
Totals	0.0	0.0	0.0	0.0	1.9	1.9

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 0.0 Projected: 1.9 Total: 1.9

WASTE STREAM DESCRIPTION	Transuranic Waste Class C, andTransuranic Waste Basic, class C filter/White Powder
WASTE STREAM SOURCE	C-400
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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PANTEX PLANT

Location and Description

The Pantex Plant (PX) is located 26 kilometers northeast of Amarillo, Texas, on U.S. Highway 60. PX occupies more than 320 buildings and is comprised of 2 contiguous tracts of land; 10,080 acres are owned by DOE and 5,806 acres are leased from Texas Tech University and used primarily as a safety and security buffer zone. Activities include weapons production, maintenance and modification, and disassembly of weapons retired from stockpile. PX is operated by Mason & Hanger-Silas Mason Co. Inc.

Mission

The PX primary missions include meeting DOE's responsibilities for nuclear weapons disassembly, assembly, stockpile monitoring, modifications, quality evaluation, and maintenance of the nation's weapons stockpile. PX also conducts research and development in high explosives design in support of weapons design and development program, and production engineering for DOE.

Waste Information

Processes

The assembly and dismantlement of nuclear weapons includes high explosives and solvents. PXs TRU waste was generated as a result of a pit cracking while removing high explosives. The waste is primarily debris from the cleanup operations.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	PX-T001	Handling:	CH	NMVP #:	N/A	Stream Name:	Pantex	Inventory Date:	6/29/95
Local ID:	N/A	Type:	TRU	Generator Site:	PX	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S0000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	87.0	78.4	95.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	11.3	10.2	12.4
Plastics:	11.3	10.2	12.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos:

PCBs: No

Source: Spill Clean-ups/Emergency Response Actions

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-239	7.64E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	This material is contaminated PPE and tools generated during weapons dismantlement.
WASTE STREAM SOURCE	$ 48 $ Weapons dismantlement support material.
CURRENT CONTAINER COMMENTS	Same Nuclides
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

Location and Description

The Rocky Flats Environmental Technology Site (RFETS) is located in Jefferson County, Colorado, approximately 26 kilometers northwest of downtown Denver, near the suburban communities of Westminster, Boulder, Broomfield, Golden and Arvada, Colorado. It is a 384-acre complex in the center of a 6550-acre reservation.

The facilities at RFETS are divided into two main areas. The area on the north contains all of the facilities related to plutonium operations. Security fences and intrusion-detection systems surround all buildings in which plutonium is handled or stored, and various other measures are used to provide safeguards and security. This area is referred to as the "Protected Area". The area to the south contains both nonplutonium manufacturing facilities, which are located in secure areas, plutonium waste storage facilities, and general support facilities, some of which are in secured areas.

Mission

The original mission of the Rocky Flats Plant (original name for RFETS) was the manufacture of nuclear weapons components fabricated from plutonium, enriched uranium, and conventional metals. It was originally a key weapons material production facility. Plant construction began in March 1951 and operations began in 1952. The Plant used specialized machine shops to process raw nuclear material into the finished components required by the warhead designs. Plutonium and beryllium components were fabricated into the shells of fissionable materials, called pits. A former mission of RFETS was to dissemble the pits from retiring weapons. The recovered pit was chemically processed to remove americium and plutonium. Plutonium scrap recovery was also performed at RF.

In 1989, the Secretary of Energy halted all plutonium production operations at the RFETS in order to improve the conduct of operations, standards of performance, and the management structure. On September 27, 1991, the President of the United States announced his cancellation of several nuclear-weapons programs, leaving the W-88 war head for the Trident II missile as the only remaining system requiring the fabrication of plutonium components at RFETS. This requirement was eliminated in 1992, when the President decided to cancel further production of the Trident II missile and its nuclear warhead.

In response to the President's decisions, the Secretary of Energy proceeded with several initiatives directed at a more cost-effective execution of the defense mission which included revising plans at RFETS for plutonium and nonplutonium manufacturing areas.

RFETS new mission is to clean out and stabilize production process systems, decontaminate obsolete or excess buildings and facilities; stabilize residues in preparation for transport to storage or disposal sites; possibly transfer non-plutonium manufacturing to other locations; maintain a contingency status. Approximately 140 structures at RFETS include major manufacturing, chemical processing, plutonium recovery, and waste treatment facilities. Plant operations also include chemical laboratories, research and development, and support of other DOE facilities.

RFETS has stopped weapons production operations. Future relevant activities will be TRU waste management, including preparation of existing material for geologic disposal, and decontamination and decommissioning.

Waste Information

Processes

Production activities included metal working, fabrication and component assembly, chemical recovery and purification of transuranic nuclides. The plant utilized specialized facilities for recovering nuclear components from obsolete weapons.

Prior to 1960, the main plutonium purification process was dissolution followed by a solvent extraction step that used tributylphosphate as the solvent and dodecane as the diluent. The solvent extraction step was followed by cation exchange. Around 1960, solvent extraction was eliminated from the recovery process because the materials going through the process were becoming more and more varied and could not be adequately handled by the process. The solvent extraction process was replaced by dissolution in the nitric acid followed by ion exchange and peroxide precipitation. The purified plutonium oxide was converted to plutonium fluoride and reduced to plutonium metal using calcium. Other chemical processes, such as molten salt extraction, have also been used at RFETS.

A need to process americium arose because of a personnel exposure problem from its gamma ray emissions. From late 1957 until the late 1970s, americium was recovered and purified at the plant for resale. The demand for americium dropped off in the late 1970s, and the americium was processed as waste.

Depleted uranium operations were a significant part of the original manufacturing performed at the plant. Operations included casting, machining, rolling, and forming. Alloying of depleted uranium with niobium began in 1966, although full-scale production did not occur until the early 1970s. Depleted uranium, which contains less than 0.7% U-235 by mass, is rich in the U-238 radionuclide. The RFETS depleted uranium is assumed to be material type U-12, which is composed of 99.78% U-238, 0.215% U-235, 0.006% U-236, and 0.001% U-234 by mass.

Enriched uranium, containing about 93% U-235 by mass, was processed at the RFETS from 1952 to 1964. This concentration of U-235 is material type U-38, which is composed of 93.08% U-235, 5.65% U-238, 0.93% U-234, and 0.34% U-236 by mass. The enriched uranium manufacturing processes included casting, forming, machining, assembly, recovery, and purification.

The enriched uranium chemical recovery line began operations in 1954. The chemical recovery used a solvent extraction process with dibutylethylcarbutol as the solvent and dodecane as the diluent. This process was similar to the early solvent extraction process used for plutonium recovery. A solvent still was operated at the plant, and some of the distilled solvent was reused. The discarded solvent and oils were drummed and later became part of the organic sludge waste stream. Enriched uranium operations were shut down in 1962.

Some U-233 was processed from the late 1950s to the early 1970s. The U-233 processing included casting, machining, aqueous processing, and separations. Records indicate that the INEL received 56 grams of U-233 as waste from the RFETS in 1967.

All the plutonium operations were carried out in enclosures that are operated under subatmospheric pressure to minimize uncontrolled releases of radioactive material into the operating area. These enclosures are called gloveboxes, and the ventilation systems pass through a high-efficiency particulate air filter system. Leaded rubber gloves are used to protect operations personnel from the gamma activity associated with the plutonium and americium.

The filters from the ventilation systems and the filters used in other systems eventually become waste. The leaded rubber becomes contaminated and also becomes waste. Some of the processes used produce liquid waste streams. These liquid streams are converted to a sludge or solid with adsorbents or cements. contaminated equipment, clothing, tools, etc, end up as radioactive waste. Waste is also generated by decontamination projects and modifications to facilities.

All radioactive waste from the RFETS that was sent to INEL from 1954 to 1970 was buried at the RWMC. Transuranic waste received at INEL from RFETS after October 1970 has been stored aboveground at the Transuranic Storage Area.

Modifications/Assumptions/Development

The approach used and the assumptions made in preparing the RF waste stream profiles are as follows:

- Projection volumes were taken from the Comprehensive Waste Management Plan (CWMP) with the exception of Solid Stabilization (formerly Residue Elimination). The program projection available for Solid Stabilization at the time the CWMP was being drafted was a "not to exceed" volume. The volume and breakdown of final form waste streams used in preparing the TWBIR was an updated, projected volume taken from the Conceptual Design Report for Residue Elimination at Rocky Flats, RES-005-001, May 1994.
- The planned treatment for waste streams requiring treatment to meet WIPP WAC and TRAMPAC requirements are taken from the Draft Site Treatment Plan (DSTP) and the Treatment System Definition Report (TSDR) published by the Waste Compliance Programs.
- In the case where the waste stream or some portion of the waste stream requires treatment to change to the final waste form, the volume of waste resulting from the treatment of the original waste stream is included in the final waste form volume of the resulting waste stream. For example, the volume of waste resulting from treatment of Incinerator Ash is included in the final waste form volumes of the resulting waste stream, Solidified Process Solids.
- Volume increases due to repackaging waste that exceed the current decay heat limit when no other treatment is required were not included.
- To remain consistent with the volumes reported in the other RFETS publications, 0.21 m^3 was used as the container volume of a standard DOT-17C 55-gallon drum. The volume used for other containers was as specified on the data forms.
- Waste in boxes other than standard waste boxes (SWB) are assumed to be repackaged into SWBs, such that the waste from one 4'x4'x7' box is repacked into two SWBs. Therefore, the final waste form volumes for SWBs include the projected volume increase resulting from such repackaging activities.

- The values for the Typical Waste Material Weights for Final Waste Form data for the TRU waste streams are the same as the corresponding TRU mixed waste streams.
- The waste generation rates for each waste form were prorated based on the fraction represented by the waste form on a Waste and Environmental Management System (WEMS) generation report showing actual generation.

In the following waste streams, the actual volumes reported are less than .01 m^3 and are rounded to 0.0 m^3 in the TWBIR:

RF-MR0527	RF-MTX111	RF-MTX112	RF-MTX115
RF-TR0082	RF-MR-X200	RF-TR0084	RF-TR0089
RF-TR0395	RF-TR0396	RF-TR0527	RF-TR0601
RF-W011			

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

These wastes are aqueous acidic liquid residues.

WASTE STREAM SOURCE

IDC 070 is high-level plutonium nitrate feed solution (nitric acid solution containing plutonium) generated at Anion Exchange or High-Level Dissolution. This solution is feed, batched for Precipitation in Building 771.

High-Level Dissolution in Building 771 dissolved high-purity-plutonium content residues to recover plutonium. These residues were dissolved in nitric acid and heated. The resulting plutonium nitrate was filtered to remove undissolved solids and particulates. The solution (IDC 070) was batched by combining it with other plutonium nitrate or ion column eluate and evaporator bottoms from various processes to achieve the desired concentration. The plutonium nitrate feed solutions were transferred to an evaporator chamber which resulted in steam condensate (IDC 513) and evaporator bottoms (IDC 100).

RE: Section 6.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

RFETS does expect nitrate concentration to be >1% , but has no data indicating the actual concentration or range.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation A

Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22.

Subpopulation H

These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals.

In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process.

This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F009, F007, F005, F003, F002, F001, D043, D040, D039, D038, D022, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D003, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 200 is analytical standards. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

F002, F005, F001, D011, D010, D009, D008, D007, D006, D005, D004, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

IDC 292 was intended for incinerator sludge from the recovery incinerator in Building 771. IDC 292 materials were reassessed under Waste Form 1, Incinerator Ash. However, there is one box WEMS incorrectly assigned this IDC. According to the waste-box log sheet dated October 14, 1987, the box contains Electrochemical Milling Sludge generated in Building 881. This operation generated sludge from the milling of various metals including stainless steel. It was indicated that no cyanides were used in the ECM operations in Building 881. The IDC for this box should be changed to 299.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this

drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

F005, F002, D040, D035, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Drum / 55-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

This IDC has been used for sludges that were not accurately categorized as IDC 290 or 340 and could have been generated in any plutonium processing building. However, the backlog miscellaneous sludge was generated in Building 771 during the processing of residues, in Building 371 in the analytical laboratory, and in Building 883 by the Rolling Process. Process pipe sludge, sludge dissolution heel, and filter plenum sludge from Building 771 were processed through nitric acid dissolution and sparging. Soil and sludge samples from around the site were analyzed in Building 371, and the waste was stored for processing. IDC 299 materials generated in Building 883 include quench sludge and uranium oxide sludge from the rolling Process. This group also includes one container of electrochemical milling sludge generated in Building 881 in October 1987. The container is assigned IDC 292.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F002, F001, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	37.4	0.0	0.0	0.0	0.0	37.4
Totals	37.4	0.0	0.0	0.0	0.0	37.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 37.4 Projected: 0.0 Total: 37.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

331 - Ful-Flo filters used to filter solids from aqueous solutions. Additional required processing undetermined. Because of the potential of liquids in this IDC, it requires a compatibility code when packaging.

WASTE STREAM SOURCE

These Ful-Flo filters are in-line cartridge filters used throughout Rocky Flats to remove particulates from fluid streams and typically filter down to 5, 1, and 0.5 micron-sized particulates. Ful-Flo filters are used in various liquid systems that include nitric- and chloride-acid systems, such as those found in plutonium recovery operations; caustic systems, such as those found in utilities scrubbing; solvent systems using carbon tetrachloride in machining operations; water systems, such as steam cleaning; and condensate collection. These filters are also used in lubricant oil filtration.

Ful-Flo filters are poly-fiber-wound cartridges, about 10" long by 3.5" in diameter. Other fiber filters, such as R-6 pads, may be included in this IDC. R-6 pads are cloth filters, about sixteen inches in diameter, used to filter solids from nitric acid solutions. Therefore, backlog material in this IDC cannot be considered homogeneous. filter elements are produced by combining a media blanket and spirally wound matrix yarn on an inner core. The filter elements might have a polypropylene cap on one end. Both the media blanket and matrix yarn can be cotton or polypropylene. The inner core material can be constructed of polypropylene, tinned steel, or stainless steel. Warehouse data from Rocky Flats indicate that the inner-core material is polypropylene.

during normal process operations, IDC 331 Ful-Flo filters in this backlog population were used to filter particulates from liquid waste streams in Buildings 371, 707, 771, 776, 777, and 779. These waste streams were primarily from filtration of caustic solutions in Building 371, the carbon tetrachloride system and oil systems, and from filtration of water and developer in Building 707. In Building 771, the primary wste streams filtered were anion column feed, potassium hydroxide, nitrate feed, spent nitric acid and hydrofluoric acid from the scrubber, eluate and effluent exiting the ion-exchange columns, floor pick-up solution, steam condensate, and miscellaneous aqueous solutions. Hydraulic oil and floor pick-up solution were filtered in Building 776. In Buildings 777 and 779, Ful-Flo filters were used in the carbon tetrachloride system for purification of Freon TF and for filtration of incoming waters.

Typically, Ful-Flo filters were placed on drying racks pending bag-out of a glovebox. Filters were not always dried before removal from the glovebox. Filters were then "bagged out" of the glovebox and placed in a second layer of plastic. Next, the filters were placed in a "Poly Bottle" or "Clam Shell" (hard plastic container), then placed in a double-lined drum.

These Ful-Flo filters may be contaminated with acids, bases, carbon tetrachloride, chromium, Freon, and oil. They may contain relatively small amounts of free liquids.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 326 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the

characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W065	Handling:	CH	NMVP #:	N/A	Stream Name:	Calcium Metal/TRM	Inventory Date:	
Local ID:	IDC 333	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	X7590

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDC 333. This material is elemental calcium pellets used in plutonium reduction operations.
WASTE STREAM SOURCE	This IDC consists primarily of partially oxidized or hydrated calcium metal generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal using calcium metal as the reductant. This reduction operation was performed in a reaction vessle within Glovebox (Line) 17 in Building 771. Magnesium oxide sand was used as an insulating material in the annulus between a magnesium oxide crucible and the reaction vessel wall. Plutonium tetrafluoride, calcium metal, and a pyrotechnic initiator (magnesium metal, sodium peroxide, and potassium iodate) were placed in the magnesium oxide crucible. The reduction vessel was then sealed, placed in an induction furnace, purged with argon, and heated until the reaction initiated. After the reduction vessel had cooled, the vessel was opened and the materials were separated. Calcium metal residue is generated from the cleanup of calcium metal spillage on the glovebox floor. Calcium metal is placed in metal cans for removal from the glovebox. After the cans are bagged out, they are assayed individually. The cans are placed in drums or vaults for storage.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being present or absent). Item Description Code 333 There is no analytical information for this waste form that will assist in Resource Conservation and Recovery Act (RCRA) characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 (EG&G 1992). WSRIC Waste Stream 771-11-17, IDC 333, is also characterized as D003 waste. The IDC 333 Calcium Metal Residue Analysis Study concurs with the D003 characterization (KMI 1992a). According to the Hazardous Chemicals Desk Reference, calcium exhibits the following properties: "Flammable when heated or in intimate contact with moisture or acids...reacts with moisture or acids to liberate large quantities of hydrogen; can develop explosive pressure in containers...violent reaction with water may evolve explosive hydrogen gas." IDC 333 is Subpopulation 59A and was identifed based on specific process knowledge. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal waste is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Based on this information, the waste exhibits the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, the Colorado Department of Health (CDH) has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ingition source, and there must be a high probability of these elements occurring at the same time (DOE 1994).
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W067	Handling:	CH	NMVP #:	N/A	Stream Name:	Cemented filters/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	21.6	0.0	0.0	0.0	0.0	21.6
Totals	21.6	0.0	0.0	0.0	0.0	21.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 21.6 Projected: 0.0 Total: 21.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of filters used in ventilation systems. Some of it has had cement sprinkled on it to neutralize the acid on the filters.

WASTE STREAM SOURCE

The material in this IDC is either the filter media portion of HEPA filters or surface-water filters. HEPA filters are used on gloveboxes and in large filter plenums. Sock filters were used to prefilter operable unit 2 (OU-2) surface water prior to activated carbon treatment.

Used HEPA filters were processed to segregate those portions with high plutonium content and those with low content. The wood frames were separated from the media and almost always disposed of as waste by packing in drums that were assigned IDC 330. the filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste.

This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from the production Building 707 and could be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon. IDC 338 was meant to be used as a residue IDC and not as a waste IDC. Because sorting between IDCs was not accurate, some of the IDC 338 backlog containers are below the economic discard limit (EDL) and are therefore not residue.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, D&D, and limited Emergency Response actions.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation DB

Subpopulation DB consists of IDC 338 filter media that could have been exposed to saltcrete in Building 374. Room 3809 was used for Saltcrete Processing (WSRIC Process 374-5). HEPA filters were used to filter nitrate salt particles from the baghouse air stream. The single container of filters in this subpopulation is characterized as RCRA hazardous, and its characterization is based on the current WSRIC characterization for saltcrete. EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 have therefore been applied. The EPA Code D001 is applied because nitrate salts may have formed on these filters.

Subpopulation DC

Subpopulation DC includes all IDC 338 filter media generated from Building 771. There are 111 containers in this subpopulation. This filter medium might be derived from IDC 342 filters (acid contaminated-see Subpopulations EB and EC), and is characterized the same as the IDC 342 filters from Subpopulation EB. Because this filter medium might have been used to filter nitric acid and nitric salts have been reported to form on the filter media, it could exhibit the characteristic of ignitability and is considered to be an oxidizer due to the presence of nitrate salts. This filter medium is a RCRA-hazardous waste and EPA Code D001 has been applied.

Subpopulation FA

Subpopulation FA includes containers of IDC 376 processed filter media generated throughout Rocky Flats that are characterized as nonhazardous. This processed filter medium is derived from filters generated from processes for which there would be no "carry over" of solvent contamination from vapors. Exclusion of filters from "carry over" contamination is based on WSRIC information and a Waste Technical Support Memorandum. The memorandum states that these HEPA filters are nonhazardous unless RCRA hazardous liquids have condensed from the uncontained gases. It is assumed that these containers do not have free liquids.

MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

342 - Drybox filters from all acid lines. This waste must be neutralized, then changed to IDC 815 to disposal.

WASTE STREAM SOURCE

HEPA filters are used on all gloveboxes to remove particulates from the atmosphere exiting the glovebox to the plenum exhaust system. The filters in IDC 342 are from gloveboxes with atmospheres that could cause the filters to be contaminated with acids or bases used in chemical processing.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 16-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc. Pu Recovery Byproducts/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.03	0.0	0.0	0.0	0.0	0.03
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.03 Projected: 0.0 Total: 0.03

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Calcined plutonium oxide was placed in a magnesium oxide crucible with calcium chloride and calcium metal. The crucible and contents were placed in a furnace and heated until the contents were molten. The molten material was stirred to initiate and promote the reduction of the plutonium oxide. After the reaction, the melt was allowed to separate into plutonium metal and salt phases. After cooling, the crucible was broken and separated from the salt, calcium, and plutonium metal. This process produced IDCs 365 and 414.

IDCs 365 and 414 are composed primarily of calcium chloride, calcium oxide, calcium metal entrained in the salt, and various plutonium compounds. A "button" of excess calcium may also be present in some containers of these salts. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W067	Handling:	CH	NMVP #:	RF 119	Stream Name:	Cemented filters/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of filters used in ventilation systems. Some of it has had cement sprinkled on it to neutralize the acid on the filters.

WASTE STREAM SOURCE

The materials in this IDC is the filter media portion of acid-contaminated glovebox or plenum HEPA filters of Ful-Flo filters with free liquids. Processing was performed in the Site Reduction Vaults in Building 776.

Used HEPA filters were processed to separate any portions containing high plutonium content from portions with low content. The wood frames were separated from the media and usually disposed of as waste by packing in a drum that was assigned IDC 330. The filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identifies as IDC 376 and packaged for shipment as waste. the media were placed in crates, Portland cement was added, then crates were sealed. some IDC 376 material could be the remaining material after the IDC 338 media were processed to recover the plutonium.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

The waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, D&D, and limited Emergency Response actions.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation DB

Subpopulation DB consists of IDC 338 filter media that could have been exposed to saltcrete in Building 374. Room 3809 was used for Saltcrete Processing (WSRIC Process 374-5). HEPA filters were used to filter nitrate salt particles from the baghouse air stream. The single container of filters in this subpopulation is characterized as RCRA hazardous, and its characterization is based on the current WSRIC characterization for saltcrete. EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 have therefore been applied. The EPA Code D001 is applied because nitrate salts may have formed on these filters.

Subpopulation DC

Subpopulation DC includes all IDC 338 filter media generated from Building 771. There are 111 containers in this subpopulation. This filter medium might be derived from IDC 342 filters (acid contaminated-see Subpopulations EB and EC), and is characterized the same as the IDC 342 filters from Subpopulation EB. Because this filter medium might have been used to filter nitric acid and nitric salts have been reported to form on the filter media, it could exhibit the characteristic of ignitability and is considered to be an oxidizer due to the presence of nitrate salts. This filter medium is a RCRA-hazardous waste and EPA Code D001 has been applied.

Subpopulation FA

Subpopulation FA includes containers of IDC 376 processed filter media generated throughout Rocky Flats that are characterized as nonhazardous. This processed filter medium is derived from filters generated from processes for which there would be no "carry over" of solvent contamination from vapors. Exclusion of filters from "carry over" contamination is based on WSRIC information and a Waste Technical Support Memorandum. The memorandum states that these HEPA filters are nonhazardous unless RCRA hazardous liquids have condensed from the uncontained gases. It is assumed that these containers do not have free liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag, and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 4-liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 387, reburned SS&C sweepings, is generated from the cleanup of the Plutonium Tetrafluoride Reduction Process within Glovebox (Line) 17 in Building 771. The fine material (sand, slag, and crucible) is swept from the glovebox floor and is placed in metal cans for transfer to Glovebox (Line) 22. In Glovebox 22, the sweepings are heated in an Inconel pan on a hotplate to oxidize plutonium metal that may be present in the sweepings. The reburned sweepings are stored in metal cans prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	sand, Slag and Crucible/TRU	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 390 consists primarily of unpulverized slag generated as a residue from the reduction of plutonium tetrafluoride to plutonium metalusing calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771.

The unpulverized slag is generated from the separation of calciu fluoride slag from the sand and crucible residues following the removal of the plutonium metal button. Calcium fluoride is produced from the reaction of the calcium metal with the plutonium fluoride.

Unpulverized slag is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas

when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.3	0.0	0.0	0.0	0.0	0.3
Drum / 55-gallon	5.6	0.0	0.0	0.0	0.0	5.6
Totals	5.9	0.0	0.0	0.0	0.0	5.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 5.9 Projected: 0.0 Total: 5.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 391 consists primarily of unpulverized sand and crucible generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771.

The unpulverized sand and crucible are generated from the separation of sand and crucible residues from the calcium fluoride slag following the removal of the plutonium metal button.

Unpulverized sand anc crucible is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	12.9	0.0	0.0	0.0	0.0	12.9
Totals	13.0	0.0	0.0	0.0	0.0	13.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 13.0 Projected: 0.0 Total: 13.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 392 consists of unseperated IDC 391 materials.

Unpulverized sand, slag, and crucible are placed in 4-liter, wide-mouthed, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The sand, slag, and crucible are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible

Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 393 is produced in the Dissolution Process in Gloveboxes (Lines) 23 and 25 in Building 771. Pulverized sand, slag, and crucible from the Crushing Process is placed in a dissolution pot with heated nitric acid and aluminum nitrate. The solution (plutonium nitrate) is pulled by vacuum through an R-6 filter to remove undissolved solids.

The undissolved solids are sand, slag, and crucible heels that are dried on a hot plate and placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The residue sand, slag, and crucible heels are stored awaiting plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore,

	this waste exhibits the characteristic of reactivity (D003).
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	LDR_DETERM: Net and gross weight data are not available for all container types. RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

This IDC consists primarily of unpulverized slag and crucible generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771.

The unpulverized slag and crucible are generated from the separation of calcium fluoride slag and crucible residues from the magnesium oxide sand following the removal of the plutonium metal button. Calcium fluoride is produced from the reaction of the calcium metal with the plutonium fluoride.

Unpulverized slag and crucible are placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Returned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The returned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas

when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 400 is ion column feed (plutonium nitrate solution) with less than 5 g/l plutonium which is to be processed through Anion Exchange to remove any impurities. These solutions come from various aqueous recovery operations for purification of plutonium. Dissolution in Building 771 dissolved high-impurity, low-plutonium content residues to recover plutonium. Cation Exchange in Building 771 processed chloride solutions (hydrochloric acid containing plutonium) from the laboratories in Building 371, 559, and 771. Precipitation Feed Batching in Building 771 combined plutonium nitrate or ion column eluate and evaporator bottoms to achieve the desired plutonium concentration. The solutions (IDC 400) in which impurity concentrations were too high were sent for purification. Reduction and Button Break-Out in Building 771 produced a purified plutonium metal product. In this process, the metal was pickled in a water bath to remove residual calcium. The resulting solutions (IDC 400) was mostly water containing plutonium and elemental impurities. Miscellaneous Residue Processing in Building 771 generated IDC 400 from sludge dissolution. Sludge from the process filter plenum was dissolved in heated nitric acid and drained through a filter resulting in nitrate solution (IDC 400). The heel that was formed on the filter was dried on a hot plate and also dissolved. RE: Section 5.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D008, D006, D005, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.05	0.0	0.0	0.0	0.0	0.05
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.05 Projected: 0.0 Total: 0.05

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 401 is ion column feed (plutonium nitrate solution) with greater than 5 g/l plutonium processed through Anion Exchange. These solutions come from various aqueous recovery operations for purification of plutonium. IDC 401 was generated by the same processes as IDC 400, the only difference being the amount of plutonium contained in the solution. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D007, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the ammericium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDC 409.

IDC 409 was formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

F005, F003, F002, F001, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Nonspecification plutonium metal, cast as an anode, was combined with and equimolar mixture of sodium chloride and potassium chloride in a magnesium oxide crucible. Magnesium chloride was then added to initiate the plutonium oxidation. The metal and salts were placed in a furnace and heated until molten. The molten mixture was stirred, and a current applied to the anode which flowed through the molten mixture to the cathode. Plutonium ions migrated from the molten anode through the molten salt to the cathode and were reduced to purified metal. After cooling, the crucible was broken and the salt, anode heel, and purified plutonium metal were separated. This process produced IDC 411 salts.

IDC 411 is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metals, and various plutonium compounds. These salts may contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. IDC 411 salt packaged for off-site shipment was assigned IDC 473.

RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.4	0.0	0.0	0.0	0.0	0.4
Drum / 55-gallon	6.7	0.0	0.0	0.0	0.0	6.7
Totals	7.1	0.0	0.0	0.0	0.0	7.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 7.1 Projected: 0.0 Total: 7.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

This salt was generated by the scraping and cleaning of pyrochemical furnace cells and consists of spent pyrochemical salts and magnesium calcium, sodium, and potassium metals which vaporized during the pyrochemical processes and collected on the cold parts of the cells. The scraped-out material may have been reheated in a furnace to oxidize the metals; however, this did not always occur. This salt could contain compounds present in any of the pyrochemical salts.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operations and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could

have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Drum / 55-gallon	6.4	0.0	0.0	0.0	0.0	6.4
Totals	6.7	0.0	0.0	0.0	0.0	6.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.7 Projected: 0.0 Total: 6.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Calcined plutonium oxide was placed in a magnesium oxide crucible with calcium chloride and calcium metal. The crucible and contents were placed in a furnace and heated until the contents were molten. The molten material was stirred to initiate and promote the reduction of the plutonium oxide. After the reaction, the melt was allowed to separate into plutonium metal and salt phases. After cooling, the crucible was broken and separated from the salt, calcium, and plutonium metal. This process produced IDCs 365 and 414.

IDCs 365 and 414 are composed primarily of calcium chloride, calcium oxide, calcium metal entrained in the salt, and various plutonium compounds. A "button" of excess calcium may also be present in some containers of these salts. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Salt Scrub was a process used to recover plutonium from MSE salts. In this process, MSE salts were combined with a reducing agent and an alloying agent; the combinations of magnesium and aluminum, calcium, and gallium, and calcium and cerium have been used. The crucible and contents were placed in a furnace and heated until the contents were molten and the mixture was stirred. While molten, the plutonium and americium were reduced by the calcium or magnesium and the actinides went into the metal alloy phase. After cooling, the crucible was broken and the salt and scrub alloy separated. This process produced IDCs 429 and 433-435 salts.

IDC 434 salt was generated using calcium and gallium. This IDC represents salts produced from the salt scrub of MSE DCHP salts. This salt is composed primarily of calcium chloride, cesium chloride, entrained calcium and gallium metal, and various plutonium and americium compounds. A "button" of excess calcium may also be present in some containers of this salt.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operations and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics.	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 500 is plutonium and enriched uranium nitrate solution from Oralloy Leaching. The material is eluate solution ready for Oralloy Preparation. Oralloy Leaching in Building 771 removed small amounts of plutonium from uranium parts. Nitric acid was sprayed into the parts and then was collected and transferred to a steam-heated evaporator. The concentrated acid (IDC 500) was then piped to Oralloy Precipitation where the plutonium and uranium solids were precipitated out. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH.	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.04 Projected: 0.0 Total: 0.04

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

These wastes are aqueous acidic liquid residues.

WASTE STREAM SOURCE

IDC 503 is miscellaneous spent acid waste contaminated with plutonium generated during various research and development operations.

Calcination in Building 771 removed excess nitric acid and moisture from plutonium peroxide cake (green cake). Because some of the plutonium peroxide cake was entrained in off-gas, the off-gas passed through a packed-bed nitric acid scrubber to dissolve the peroxide cake. The nitric acid was then filtered and piped to Anion Exchange.

Spray Leach used a nitric- and sulfuric-acid mixture or nitric and hydrofluoric acids as leaching agents for plutonium parts or fixtures. The filtered leachate (IDC 503) was piped to Anion Exchange.

Vacuum systems in Building 771 generated nitric acid waste from cleaning the receiving tank. This waste was sent to Anion Exchange.

H-4 Support Vacuum Systems generated water composed of acidic plutonium solution diluted in seal liquid. This liquid was drained into the process piping system during daily maintenance. The liquid was transferred to tanks for eventual treatment in Anion Exchange.

Nitrate solutions were generated by a dissolution process in Building 779 similar to those in Building 771. The solutions in this process consisted of sodium nitrate, silver nitrate, nitric acid, plutonium nitrate, and water. These solutions are below the EDL.

Ferrite Actinide Removal in Building 779 adsorbed actinides from low-level aqueous wastes containing uranium, americium, and plutonium with ferrite materials. Nitric acid was used to strip actinides from the ferrite material. Ferrite wash water was generated from rinsing ferric materials after actinides had been removed.

RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation A

Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22.

Subpopulation H

These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals.

In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process.

This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

These wastes are aqueous acidic liquid residues.

WASTE STREAM SOURCE

IDC 508 is hydrochloric acid (HCl) containing plutonium generated by various process operations and glovebox-cleaning operations using HCl. Process operations and glovebox-cleaning operations were definec based on preliminary analytical results.

IDC 508 was generated in Cation Exchange in Building 771 from washing residual impurities from the resin with dilute nitric acid.

Chemical Technology in Building 771 generated miscellaneous chloride acid solutions from Batch Chloride Dissolution. This process dissolved plutonium oxide with hydrochloric acid.

Dicesium hexachloroplutonate (DCHP) preparation in Building 371 also generated IDC 508. This process produced DCHP, a salt used to remove americium from nonspecification and impure plutonium oxide. The oxide was dissolved in hydrochloric acid and filtered. The filtrate was then precipitated using cesium chloride and sodium nitrite in hydrochloric acid and then filtered again. Plutonium was recovered from the DCHP precipitation filtrate through chloride anion exchange. This was achieved by processing the solution through ion columns, and the plutonium loaded onto the anion exchange resin while most of the impurities stayed in the solution. This solution then left the column as effluent (IDC 501). The ion column was later washed to release the chloride eluate (IDC 508).

Peroxide Precipitation in Building 779 reacted ion exchange effluent with hydrogen peroxide to produce plutonium peroxide, which was then calcined to produce plutonium oxide. The plutonium peroxide precipitate was filtered and washed.

Residue Recovery Extraction in Building 779 recovered actinides using aqueous leaching techniques. Hydrofluoric acid solutions containing aluminium fluoride, cesium chloride, calcium fluoride, and sodium nitrate were generated.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation A

Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22.

Subpopulation H

These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals.

In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process.

This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	IDC 527 is caustic waste solutions consisting of sodium hydroxide or potassium hydroxide. Dissolution in Building 771 used potassium hydroxide for flushing the condenser when dissolvind incinerator ash. H-4 Support Vacuum Systems used potassium hydroxide in an aqueous solution as a seal liquid. Vacuum Systems also used a seal liquid made up of water only. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supportin data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F009, F007, F005, F003, F002, F001, D043, D040, D039, D038, D035, D028, D022, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D003, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	The Building 371 analytical laboratory receives liquid and solid samples from the entire plant site. Samples that are destined for Building 881 are analyzed in Building 371 to screen out those with high levels of radioactivity. Sludge and aqueous samples from Building 374 are analyzed for total alpha activity and plutonium, uranium, and americium content. Prior to analysis, the sludges are dissolved in nitric acid, hydrogen fluoride, or hydrochloric acid. Reagents are also used in sample preparation. Unused portions or excess prepared sample are placed in 4-liter plastic bottles. The Building 559 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various ions, iron, silicon, isotopic composition, and americium, gallium, neptunium, plutonium, uranium, and other metals (Resource Conservation and Recovery Act [RCRA] - regulated and nonregulated). Solid samples are dissolved in a variety of acids, including nitric and hydrochloric. Other chemicals used in the laboratory include methanol, chloroform, and other organic solvents; titanium trichloride; ceric ammonium nitrate; sodium hydroxide; silver chloride; silver nitrate; and various metals standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also place on the bottles. The Building 771 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various metals and ions, pH, and radioactivity. The principal chemicals used in the lab include sodium hydroxide, hydrochloric acid, nitric acid, cyclohexane, trioctyl phosphine oxide, yttrium, and various metal standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F005, F003, F002, F001, D043, D040, D038, D035, D029, D028, D019, D018, D011, D010, D009, D008, D007, D006, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	Group X200 is analytical standards. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 089 is produced in the calcination process in Glovebox 16 in Building 771. Grease oxide is a mixture of plutonium greencake from the calciner equipment. The grease is applied to the wear plates on the calciner. Grease and greencake can mix together near the breech of the calciner where the product greencake is removed. Grease oxide is placed in metal cans for storage prior to calcination and eventual dissolution for recovery. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

The volumes and the radionuclide concentrations developed in the profile were based on processing plutonium residues for actinide separation. RFETS has modified this processing plan. Residues will be processed to meet WIPP WAC, TRAMPAC, and safe storage conditions. The modified volumes and radionuclide concentrations are reflected in the WIPP level roll-ups.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 090 is produced in the Flourination Process is Glovebox 7 in Building 771. Calcined plutonium oxide, "green cake", is transferred to Glovebox 7 by an enclosed pneumatic transfer system. The plutonium oxide is manually fed into a hopper from which it is augured into the hydrofluorinator. The hydrofluorinator is a slightly inclined, horizontal, rotary-tube furnace. Anhydrous hydrogen fluoride gas is introduced at the discharge zone of the tube. The plutonium tetrafluoride is collected in plastic bottles and transferred to the Fluoride Reduction Process. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is posaible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.3	0.0	0.0	0.0	0.0	0.3
Totals	0.3	0.0	0.0	0.0	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 091 is produced in the Fluorination Process in Gloveboxes 6 and 7 in Building 771. The plutonium tetrafluoride is produced in the same manner as described for IDC 090 but is not pure enough for fluoride reduction. The impure fluoride is collected from the equipment and floor of Glovebox 7 or is filtered from the hydrofluorinator scrubber liquid (potassium hydroxide solution) in Glovebox 6. The impure fluoride was placed in metal cans and stored prior to acid dissolution (for plutonium recovery) in Gloveboxes 3 and 24. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 092/097 is produced in the Dissolution Process in Gloveboxes 3 and 24 in Building 771. IDC 091 impure plutonium tetrafluoride is placed in a dissolution pot with heated nitric acid. The solution (plutonium nitrate) is pulled by vacuum through an R-6 filter to remove undissolved solids. The undissolved solids are impure fluoride heels that are dried on a hot plate. The impure fluoride heels are placed in metal cans and stored for recycle into the same Dissoloution Process. IDC 097 differs from IDC 092 in packaging only. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 092/097 is produced in the Dissolution Process in Gloveboxes 3 and 24 in Building 771. IDC 091 impure plutonium tetrafluoride is placed in a dissolution pot with heated nitric acid. The solution (plutonium nitrate) is pulled by vacuum through an R-6 filter to remove undissolved solids. The undissolved solids are impure fluoride heels that are dried on a hot plate. The impure fluoride heels are placed in metal cans and stored for recycle into the same Dissoloution Process. IDC 097 differs from IDC 092 in packaging only. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 099 is produced in the Fluorination Process in Gloveboxes 6 and 7 in Building 771. The grease fluoride is a mixture of plutonium fluoride and grease from the hydrofluorination equipment. The grease fluoride is placed in metal cans for strorage prior to calcination and eventual dissolution for recovery. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm

(total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F005, F003, F002, F001, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.9	0.0	0.0	0.0	0.0	6.9
Totals	6.9	0.0	0.0	0.0	0.0	6.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.9 Projected: 0.0 Total: 6.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

The backlog inventory of IDC 290 includes materials generated as high-vacuum grease (green cake) in the Calcination Process in Building 771; as incinerator sludge from Building 771; as lab waste from Building 559 and 771; as miscellaneous sludge from an unknown source in Building 771; and as vacuum pump sludge from Building 771. High-vacuum grease, would have been produced when bvacuum grease applied to stainless-steel plates at either end of the rotary tube calciner became contaminated with plutonuim oxide during the calcination of plutonium peroxide. Incinerator sludge could have been generated by the recovery incinerator in Building 771. Lab waste could have been generated by laboratory processes in Buildings 559 and 771. The vacuum pump (Nash pump) sludge could have been generated by pumps in Building 771. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5

ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W037	Handling:	CH	NMVP #:	RF 117	Stream Name:	Heavy Metal (non-SS)/TRM	Inventory Date:	10/20/94
Local ID:	IDC 320	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.3	0.0	0.0	0.0	0.0	3.3
Totals	3.3	0.0	0.0	0.0	0.0	3.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.3 Projected: 0.0 Total: 3.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

IDC 320 - Scrap metals which are heavier than iron and steel. Metal above Cu on the periodic table. Mainly used tantalum crucibles. Does not include lead.

WASTE STREAM SOURCE

Heavy metals have been produced as by-products of Rocky Flats operations in Buildings 371, 707, 771, 776, 777, 779, and 865; they are identified by IDC 320. The IDC 320 heavy nonspecial source metal was generated in various locations throughout the Rocky Flats and is stored in Resource Conservation and Recovery Act (RCRA) Units 11, 12, 13, 15A, and 20. This IDC includes nonstainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987. IDC 320 originally included lead.

During maintenance operations, the maintenance shop in Building 371 generated heavy metal vessels, instruments, rods, and plates fabricated from tantalum, tungsten, and platinum. The shop generated these items during 4 1/2 years of operation from 1983 until 1988. Of these containers in storage, 19 backlog containers have an EPA Code of D008 (lead); eight of these were produced after 1987. Building 707, Modules A and J, generated heavy metals in its foundry operations. These heavy metals were primarily crucibles and pans used for presampling. These processes generated material during 6 1/2 years of operation from 1985 until 1991. Nine backlog containers have an EPA Code of D008 (lead). The plutonium recovery operations in Building 771 generated leached Oralloy parts consisting of tantalum, tungsten, and platinum. The system generated material during 3 years of operation from 1987 until 1990. Five backlog containers have an EPA Code of D008 (lead); four of these backlog containers were produced after 1987. Building 776, Pyrochemical Processing, generated material during almost three years of operation from 1988 until 1990. This material consists primarily of tantalum crucibles, stirrers, and cans from MSE, salt scrub, and anode heel processes. Eight containers have an EPA Code of D008 (lead). Building 777, the Coatings Laboratory, generated material during a 2-year period of operation from 1988 until 1990. This material consists primarily of various heavy metals used in the research and development of coating technologies. These backlog containers have been associated with lead as a constituent and were produced after 1987. The Residue Treatment Technology Group, Building 779, generated crucibles, stirrers, and other general lab equipment derived from tantalum and tungsten. In Building 779, the Physical Metallurgy Group generated tantalum materials used in casting and cast testing. Additionally, the Surface Analysis Laboratory in Building 779 generated heavy metal samples primarily of depleted uranium (D-38). IDC 320 material was produced by Building 779 operations over a 10-year period from 1981 until 1991. Nine backlog containers have an EPA Code of D008 (lead), six were produced after 1987.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation (25A) was identified based on specific process knowledge and generation date. The EPA Code D008 was assigned to this subpopulation because of contact with known lead products and process association. This subpopulation consists of containers produced before or during 1987. The WEMS database lists the EPA Code D008 for these containers. Because of the generation date, a conservative position has been taken by placing backlog drums with the DOO8 (lead) EPA Code in this subpopulation. The primary buildings of generation were 371, 707, 771, 776, 779.

Subpopulation 25B was identified based on specific process knowledge and generation date. At this time, the generation date has been used judiciously in separating and characterizing containers with lead. The EPA Code D008 was assigned to this subpopulation because of contact with known lead products and process association. This subpopulation consists of containers produced before or during 1987. The WEMS database lists the EPA Code D008 for these containers. Because of the generation date, a conservative position has been taken by placing backlog drums with the D008 (lead) EPA Code in this subpopulation. The primary buildings of generation were 371, 707, 771, 776, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. Future generation is projected beyond 1999.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W028	Handling:	CH	NMVP #:	N/A	Stream Name:	Lead/TRM	Inventory Date:	10/20/94
Local ID:	IDC 321	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7211

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of metallic lead in the form of sheets, bricks, or tape.

Physical form: solid

Currently, no analytical data for lead waste is available. Process knowledge is the basis for characterization of this waste form. Lead waste (IDC 321) from non-specific sources is believed to have only lead (D008) as a hazardous constituent. In numerous tests of elemental lead, EP toxicity values exceed those listed in Table 1, 40 CFR 261.24. It is assumed that IDC 321 would also exceed EP toxicity limits for lead.

WASTE STREAM SOURCE

Transuranic lead was generated at a number of locations throughout Rocky Flats and includes IDC 321. The as-low-as-reasonably- achievable (ALARA) principle requires that the exposure of workers to radiation be kept "as low as reasonable achievable." In support of this principle, selected components and surfaces of gloveboxes enclosing materials that generate elevated levels of penetrating radiation (primarily gamma radiation) are commonly covered with metallic lead sheeting. The lead serves to attenuate the radiation dose received by employees working in the glovebox or in proximity to the glovebox. Lead waste (IDC 321) components are generally composed of lead bricks, lead shielding, and lead tape.

The lead or lead-covered components may become waste due to replacement, modification, or decommissioning activities. The dates of generation for IDC 321 range from August 15, 1986 to March 1, 1994.

The lead waste form is not a by-product of any process routinely performed at Rocky Flats. According to WSRIC Building Books, lead is most commonly generated as a result of maintenance activities. The lead waste is generally composed of lead shielding, scrap lead metal, and lead tape. The lead waste is collected in standard waste drums. The lead waste form was generated in Buildings 371, 559, 707, 771, 776, 777, and 779.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Drums Containing Scrap Lead Metal and Lead Shielding

Scrap lead metal and lead shielding exhibit the characteristic of toxicity for lead (D008). Subpopulation 8A was identified based on specific process knowledge and analytical results from elemental lead waste. According to WEMS, WSRIC, drums reports, and internal correspondence, the waste primarily consists of lead bricks, lead shielding, and scrap lead metal. Although some of waste could have come in contact with solvents, it is not considered to be a listed waste if the metal was wiped down with solvents for decontamination or paint stripping purposes, or if it was generated by the decommissioning of gloveboxes or other container-like apparatuses. Additional EPA codes are assigned to the waste based on process knowledge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined this waste form to be LDR waste based on process knowledge available for TRU lead waste (IDC 321) and the fact that elemental lead exceeds values for EP toxicity pursuant to 40 CFR 261 24. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: This waste is packaged in 55-gallon drums lined with a fiberboard liner and two polyethylene bag liners.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles, dry/REM	Inventory Date:	10/24/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, F005, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
drum / 55-gallon	19.1	0.0	0.0	0.0	0.0	19.1
Totals	19.1	0.0	0.0	0.0	0.0	19.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 19.1 Projected: 0.0 Total: 19.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	IDC 330 is Dry Combustibles. This IDC is dry combustibles such as cloth, paper, and wood. This IDC changes to 821, 831, 851, or 861 at the point of assay, depending on radiological content. Containers of IDC 330 currently in inventory were generated in all buildings handling fissile material. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	See Comment ##
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 332 includes oily sludge generated in Building 776 in an unknown location, and solidified scintillation cocktail waste generated in Building 771. In the past, the oily sludge generated in Building 776 was sent to Building 771 for dissolution. Each container of sludge was opened for inspection; some cans were processed while others were not. The cans that were not processed were labeled IDC 332 and stored, awaiting recovery processing. The scintillation cocktail waste includeds liquid scintillation waste to which diatomaceous earth was added as a solidifying agent. IDC 332 was assigned to this material because it was felt that it was more appropriate than any other IDC.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates 1 wt% but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP

extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F003, F002, F001, D008, D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	20.2	0.0	0.0	0.0	0.0	20.2
Totals	20.2	0.0	0.0	0.0	0.0	20.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 20.2 Projected: 0.0 Total: 20.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Item Description 336, Combustibles, Wet Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This IDC changes to 822, 832, 852, or 862 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, F005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	IDC 337 represents PVC sheeting, poly bottles, supplied-air suits, polyethylene, and other plastics. IDC 337 changes to 825, 833, 853, or 863 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W029	Handling:	CH	NMVP #:	RF 123	Stream Name:	Leaded Dry Box Gloves/REM	Inventory Date:	10/20/94
Local ID:	IDC 339	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 123

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a solid matrix consisting of gloves with lead lining. There could be some free liquids in waste containers.

WASTE STREAM SOURCE

Leaded glovebox gloves are generated as waste at Rocky Flats by processes requiring a controlled atmosphere in Buildings 371, 374, 559, 707, 771, 774, 776, 777, 778, and 779 and encompasses IDCs 339 and 341. Prior to January 22, 1986, all leaded glovebox gloves were accumulated together as IDC 339 (Leaded Glovebox Gloves). At that time, IDC 341 (Leaded Glovebox Gloves, Acid Contaminated) was created. IDC 339 became "Leaded Glovebox Gloves, Nonacid Contaminated." Leaded glovebox gloves are replaced by schedule or as needed.

All backlog leaded glovebox gloves (IDC 0339 and 0341) were washed in Building 776 until about September 1989, at which time the process was curtailed. The primary purpose of the washing process was to remove the accountable material; however, the acid from the acid-contaminated gloves (IDC 341) was removed as well. After the acid-contaminated gloves were washed, the IDC was changed from 341 to 339. The glove washing process was curtailed upon completion of the inventory of backlog gloves.

Due to degradation from contact with process materials during normal process operations and age, the leaded glovebox gloves are replaced according to schedule or as necessary. Nonacid-contaminated leaded glovebox gloves (IDC 339) are generated as waste or residue depending on the assay, in Buildings 371, 374, 559, 707, 771, 774, 776, 779. Acid contaminated leaded glovebox gloves (IDC 341) were washed in Building 776 after which they were assigned IDC 339.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

In addition to the reference documents and WEMS information, analytical data compiled by Rocky Flats were reviewed. This analytical information shows the presence of lead above the regulatory level stated in 6 CCR 1007-3, Section 261.24, in one sample, borderline in another, and well below the regulatory level in another.

Characterization is identified based on process knowledge. This population includes all IDC 339 nonacid contaminated gloves generated after the creation of IDC 341 (January 22, 1986). This population contains no acid-contaminated (IDC 341) gloves. This population exhibits the characteristic of toxicity for lead (D008). The primary buildings of generation were 371, 374, 559, 707, 771, 774, 776, 777, and 779.

One drum of IDC 339 gloves was generated before the creation of IDC 341 (January 22, 1986). Therefore, this drum could contain both acid- and nonacid-contaminated gloves.

Although numerous acids are used in aqueous processing, nitric is the acid of greatest concern because it dissolves the outer Hypalon layer of the gloves and reacts with the lead oxide layer to form lead nitrate and organic nitrate or nitro-organic compounds. These compounds are in very small quantities and do not cause the gloves to exhibit the characteristic of ignitability as outlined in 6 CCR 1007-3, Section 261.21. However, when dried, the compound decomposes violently at temperatures ranging from 60 to 130 degrees C. Also, the compound explodes when subjected to an impact load or when confined and ignited with a fuse. Unconfined, the compound burns violently when ignited with a spark. This drum is therefore assigned D003 for reactivity as outlined in 6 CCR 1007-3, Section 261.23 (a) (6).

Population 42A: Identified based on process knowledge, EPA codes, and generation dates. This population includes all IDC 339 nonacid contaminated gloves generated after the creation of IDC 341 (January 22, 1986). This population contains no acid-contaminated (IDC 341) gloves. This population exhibits the characteristic of toxicity for lead (D008). The primary buildings of generation were 371, 374, 559, 707, 771, 774, 776, 777, and 779.

Subpopulation 43B: This subpopulation includes all acid-contaminated leaded glove box gloves. As previously discussed, these gloves exhibit the characteristic of toxicity for lead (D008) and reactivity (D003). The primary buildings of generation were 371, 771, 777, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on the fact that lead is a RCRA listed waste exhibiting the characteristic of toxicity. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The gloves are packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F002, F001, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

IDC 340 includes sludge generated during the washing of leaded glovebox gloves and non-RCRA-regulated metals with water in the size reduction vault in Building 776. The entire backlog inventory of IDC 340 was generated in Building 776. The wash water and sludge were separated in a tank, and the sludge was then sent to Building 771 for nondestructive assay and was put into drums there. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm

(total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W041	Handling:	CH	NMVP #:	N/A	Stream Name:	Leaded Gloves-Acid Contaminated/TRM	Inventory Date:	10/20/94
Local ID:	IDC 341	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D008, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

IDC No. 341. This waste stream consists of leaded rubber gloves used in the glovebox systems for plutonium recovery operations in Buildings 771 and 371. These gloves are contaminated with nitric acid and other acids when replaced and discarded as waste.

WASTE STREAM SOURCE

Leaded Glovebox Gloves

Waste Form/Item Description Code/Waste Form Code Background for the Leaded Glovebox Gloves Waste Form

Leaded glovebox gloves are generated as waste or residue at Rocky Flats by processes requiring a controlled atmosphere in Buildings 371, 374, 559, 707, 771, 774, 776, 777, 778, and 779 and encompasses IDCs 339 and 341. Prior to January 22, 1986, all leaded glovebox gloves were accumulated together as IDC 339 (Leaded Glovebox Gloves). At that time, IDC 341 (Leaded Glovebox Gloves, Acid Contaminated) was created. IDC 339 became "Leaded Glovebox Gloves, Nonacid Contaminated." Leaded glovebox gloves are replaced by schedule or as needed.

All backlog leaded glovebox gloves (IDC 0339 and 0341) were washed in Building 776 until about September 1989, at which time the process was curtailed. The primary purpose of the washing process was to remove the accountable material; however, the acid from the acid-contaminated gloves (IDC 341) was removed as well. After the acid-contaminated gloves were washed, the IDC was changed from 341 to 339. The glove washing process was curtailed upon completion of the inventory of backlog gloves.

Item Description Code 341

Acid-contaminated leaded glovebox gloves (IDC 341) are generated as waste or residue depending on the assay, in Buildings 371, 771, 777, and 779. Due to degradation from contact with process materials and age, the gloves are replaced according to schedule or as necessary. When acid-contaminated gloves (IDC 0341) were washed, the IDC was changed to 0339.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

In addition to the reference documents and WEMS information, analytical data compiled by Rocky Flats were reviewed. This analytical information shows the presence of lead above the regulatory level stated in 6 CCR 1007-3, Section 261.24, in one sample, borderline in another and well below the regulatory level in another.

Leaded glovebox gloves are manufactured with a lead oxide layer between two or more layers of neoprene-Hypalon, for shielding against penetrating radiation. The available analytical data were obtained from unused, 30-millimeter-thick gloves. Analytical data for the lead content of 50- and 80-millimeter-thick leaded gloves are not available. However, the lead content is assumed to be substantially higher than the 30-millimeter-thick gloves. Also, the lead from used gloves, degraded from contact with process materials, may leach more readily than from unused gloves.

Toxicity Characteristic Leaching Procedure (TCLP) metals by Inductively Coupled Plasma Emission Spectroscopy showed the lead above the regulatory limit. Other contaminants include acid and base solutions and listed solvents. Glovebox gloves used in processes that require listed solvents are not considered listed solvent wastes because the gloves do not retain solvents in the same way paper or cloth wipes do. Contact of the gloves with solvents is considered incidental contact. Therefore, the gloves are not subject to the mixture rule.

IDC 341 includes leaded gloves exposed to acids which have not been washed. Although numerous acids are used in aqueous processing, nitric is the acid of greatest concern because it dissolves the outer Hypalon layer of the gloves and reacts with the lead oxide layer to form lead nitrate and organic nitrate or nitro-organic compounds. These compounds are in very small quantities and do not cause the gloves to exhibit the characteristic of ignitability as outlined in 6 CCR 1007-3, Section 261.21. However, when dried, the compound decomposes violently at temperatures ranging from 60 to 130 degrees C. Also, the compound explodes when subjected to an impact load or when confined and ignited with a fuse. Unconfined, the compound burns violently when ignited with a spark. IDC 341 leaded gloves are therefore

assigned D003 for reactivity as outlined in 6 CCR 1007-3, Section 261.23 (a)(6).

This subpopulation includes all IDC 341 acid-contaminated leaded glovebox gloves. As previously discussed, IDC 341 gloves exhibit the characteristic of toxicity for lead (D008), and reactivity (D003). The primary buildings of generation were 371, 771, 777, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that leaded gloves and acid-contaminated leaded gloves are LDR waste based on the process knowledge available. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick, /REM	Inventory Date:	10/20/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F002, F001, F005, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF-377

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	3.1	0.0	0.0	0.0	0.0	3.1
Totals	3.1	0.0	0.0	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.1 Projected: 0.0 Total: 3.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form is firebrick that has been crushed and pulverized.

WASTE STREAM SOURCE

IDC 371 was generated during maintenance operations in the incineration systems in Building 771. This material was also generated during incinerator stripout operations in Building 371. Firebrick consists of brick and chunks of high-density alumina ceramic material used to line the firebox of the incinerator.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt% but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulations IK, IL, IM, IN

EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Fu-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

Net and gross weight data are not available for all container types.
RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick Heel/REM	Inventory Date:	10/20/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form is firebrick that has been crushed and pulverized.
WASTE STREAM SOURCE	During dissolution of scarfed firebrick (IDC 377 and 378), undissolved firebrick heel was generated in Building 771. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Those layers were pulverized and subjected to a nitric acid dissolution process. The material that did not dissolve was filtered, dried, assayed, and set aside for additional processing. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulations IK, IL, IM, IN EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational. A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Net and gross weight data are not available for all container types. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W008	Handling:	CH	NMVP #:	N/A	Stream Name:	Soil & Cleanup Debris/REM
Inventory Date:	10/20/94						
Local ID:	IDC 374	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal
Waste Matrix Code:	S5190						

AS-GENERATED EPA CODES

F002, F001, F005, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION This waste consists of blacktop/concrete/dirt/sand.

WASTE STREAM SOURCE Soil and cleanup-debris (IDC 374) were generated during cleanup and construction activities around Rocky Flats. In most cases, construction or demolition activities generated rubble consisting of blacktop, concrete, dirt, sand , and rock. The rubble was packaged in plywood boxes with a fiberboard liner and a polyvinyl chloride (PVC) bag liner or in 55-gallon, DOT Type 7A drups. The waste was generated on a nonroutine basis. Information describing spendid activities generating soil and debris were often unavailable.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Subpopulation 23B-Container Number D48510

Drum D48510 was generated in Building 374, Room 3803. Room 3803 houses part of the Building 374 Sludge Immobilization Process. The process generated solidified sludge. The waste in drum D48510 is potentially contaminated with process sludge. The sludge consists of RCRA-regulated materials from Decontamination-Precipitation and Neutralization Processes in the Building 374 Liquid Waste Treatment Facility. Building 374 solidified sludge is characterized in the Building 374 Solidified Sludge Backlog Baseline Book.

Building 374 sludge was intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Sampling and analysis of solidified sludge found the waste exceeded toxicity characteristic criteria for chromium (EPA Code D007) and selenium (D010) but at very low levels. It will be assumed that the waste contained in drum D48510 would not exhibit the characteristic of toxicity for chromium and selenium because of dilution by the soil and debris. Toxicity Characteristic Leaching Procedure (TCLP) analysis of the waste under EPA SW-846 is required to prove the waste does not exceed toxicity characteristic criteria.

Contaminated soil and cleanup debris must also carry the listed EPA codes associated with Building 374 solidified sludge. The EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 are assigned to the waste and it will not be considered as meeting the Land Disposal Restrictions (LDR) treatment standards until sampling and analysis proves otherwise.

Subpopulation 23D-Container Number D75005

WEMS indicates drum D75005 was generated in Building 776. However, the waste was repackaged in Building 776 in April 1988 after a failed drum containing the waste was discovered in the Property Utilization and Disposal storage yard.

The drum contains soil and two sample vials of chromium oxide and aluminum oxide. It will be assumed that the waste contained in drum D75005 exhibits the characteristic of toxicity for chromium (D007) because of chromium oxide contamination. TCLP analysis of the waste under EPA SW-846 is required to prove the waste does not exceed toxicity characteristic criteria.

Subpopulation 23E-Soil and Asphalt from the 750 and 904 Pads Earth Anchor Installation

The installation of earth anchors for the 750 and 904 Pads in 1990 and 1991 generated a large amount of soil and asphalt. The waste was packaged in half-boxes with the generation prefix 788. Some of the half-boxes were rejects but were used because the waste was expected to remain in the reject containers for a short time before remediation activities began. During remediation of the pads, containers of soil and debris were to be emptied and the waste treated. These activities never occurred and the waste is still in the rejected containers.

The soil and debris may have been contaminated with pondcrete and saltcrete waste stored in the pad areas. The work procedure required that EPA codes associated with pondcrete and saltcrete be assigned to the soil and debris. An explanation of codes applicable to pondcrete and saltcrete is provided in the Pondcrete Backlog Baseline Book and the Saltcrete Backlog Baseline Book.

Pondcrete and saltcrete were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Sampling and analysis of saltcrete found the waste did not exhibit a characteristic for RCRA metals. Sampling and analysis of pondcrete found the waste exceeded toxicity characteristic criteria for cadmium (EPA Code D006) and chromium (EPA Code D007) but at very low levels. It is assumed that the soil and debris from the earth anchor installation does not exhibit the characteristic of toxicity for cadmium and chromium because of dilution by the soil and debris. TCLP analysis of the waste under EPA SW-846 (EPA 1990) is required to prove the waste does not exceed toxicity characteristic criteria.

Contaminated soil and debris from the earth anchor installation must carry the listed EPA codes associated with pondcrete and saltcrete. The EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 are assigned to the waste and it will not be considered as meeting the LDR treatment standards until sampling and analysis proves otherwise.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

GENERAAREA: Plutonium process areas. GENOPERATION: Generated in multiple buildings in which aqueous plutonium recovery or plutonium fabrication processes were conducted. RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed. CATION: Not Applicabe. OTHER_CHAR: Not Applicable.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon carbon steel DOT 7A Type A Drum.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick coarse/REM	Inventory Date:	10/20/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	5.2	0.0	0.0	0.0	0.0	5.2
Totals	5.2	0.0	0.0	0.0	0.0	5.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 5.2 Projected: 0.0 Total: 5.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form is firebrick that has been crushed and pulverized
WASTE STREAM SOURCE	During maintenance operations, coarse chunks of scarfed firebrick were generated in Building 771. This material was also generated during incinerator stripout operations in Building 371. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Coarse firebrick consists of chunks of the unpulverized, plutonium-bearing surface layer of the high-density alumina ceramic firebrick material. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulations IK, IL, IM, IN EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational. A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Net and gross weight data are not available for all container types. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner. Projected future generation begins in CY2005.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick, pulverized or fines/REM	Inventory Date:	10/29/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.7	0.0	0.0	0.0	0.0	0.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.7 Projected: 0.0 Total: 0.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form is firebrick that has been crushed and pulverized.

WASTE STREAM SOURCE

During maintenance operations, pulverized scarfed firebrick was generated in Building 771. This material was also generated during incinerator stripout operations in Building 371. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Pulverized firebrick consists of chunks granular, fine, and very fine, plutonium-bearing surface layer of the high-density alumina ceramic firebrick material.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulations IK, IL, IM, IN

EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

Net and gross weight data are not available for all container types.
RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	incinerator ash/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

Item Description Code 419, Unpulverized Incinerator Ash

Unpulverized incinerator ash was generated as an intermediate product during routine operation of the incinerator in Building 771. This material was also generated during incinerator stripout operations in Building 371. The unpulverized ash consists of a mixture of coarse, granular, fine, and very fine particulates. The ash contains miscellaneous tramp metal, bits of unburned feed material, and carbon from the incomplete oxidation of feed material. The coarse materials consist of fused ash, clinkers, or unburned materials that fell through the stationary grate of the incinerator.

IDC 419 is mixed residue only.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	Incinerator ash/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

		TRUCON CODE	FINAL FORM RADIONUCLIDES
Category:	Defense TRU Waste	N/A	N/A
Residues:	Yes		
Asbestos:	No		
PCBs:	No		
Source:	Pollution Control or Waste Treatment Process		

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Drum / 10-gallon	0.04	0.0	0.0	0.0	0.0	0.04
Drum / 55-gallon	161.8	0.0	0.0	0.0	0.0	161.8
Totals	161.9	0.0	0.0	0.0	0.0	161.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 161.9 Projected: 0.0 Total: 161.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

The FBIs in Building 776 were developed as pilot operations. Their test function was to develop new technology to reduce volume and destroy volatile constituents prior to plutonium recovery operations. The only incinerator to generate backlog waste covered by this waste form was the Full-Scale Unit. The first runs of this incinerator (1978 to 1981) used newspaper, Building 776 low-level waste (LLW), combustible waste, kerosene, garage oil, and grease as test materials. The tests were conducted with methanol, diesel products, and nonradioactive surrogate combustibles (shredded coveralls, leather gloves, rolls of polyvinyl chloride [PVC] plastic, wood, and paper). The by-product of this process was FBI ash (IDC 425).

Item Description Code 420, Pulverized Incinerator Ash

Pulverized incinerator ash was generated as an intermediate product during routine operation of the incinerator in Building 771. This material was also generated during incinerator stripout operations in Building 371. The pulverized ash consists of a mixture of coarse, granular, fine, and very fine particulates that have been ground by the ball mill. The ash contains miscellaneous tramp metal, bits of unburned feed material, and carbon from the incomplete oxidation of feed material.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one-bag liner.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	Incinerator ash/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 10-gallon	0.04	0.0	0.0	0.0	0.0	0.04
drum / 55-gallon	68.0	0.0	0.0	0.0	0.0	68.0
Totals	68.1	0.0	0.0	0.0	0.0	68.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 68.1 Projected: 0.0 Total: 68.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

Item Description Code 421, Ash Heel

During dissolution of incinerator ash (IDC 419 and 420), undissolved incinerator ash heel was generated in Building 771. Incinerator ash was subjected to a nitric acid dissolution process. The material that did not dissolve was filtered, dried, assayed, and set aside for additional processing.

IDC 421 is mixed residue only.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D006, D004, F005, F003, F002, F001, D010, D008, D009, D007, D005, D011

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.5	0.0	0.0	0.0	0.0	3.5
Totals	3.5	0.0	0.0	0.0	0.0	3.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.5 Projected: 0.0 Total: 3.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 069 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

Incinerator soot (IDC 422) was generated as an intermediate product during routine filter change operations of the incinerator plenum in Building 771. This material was also generated during incinerator stripout operations in Building 371. The soot consists of a fine and very fine particulate fly ash that was removed from the incinerator off-gas treatment system. The soot generally contained a higher concentration of carbon and fine particulate oxidation of some feed materials. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 069: D007 was identified based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W076	Handling:	CH	NMVP #:	N/A	Stream Name:	Process Residues/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F005, F002, F001, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form contains some ash, and it also is solid chunks and fine particulate material. Some liquids may be present.

IDC 092 - Impure Fluoride Heel
IDC 290 - Filter Sludge
IDC 332 - Oily sludge
IDC 340 - sludge from size reduction area
IDC 422 - Must be processed into IDC 806 for disposal.
IDC 423 - Must be processed into IDC 806 for disposal.
IDC 089 - Grease Oxide (green cake)
IDC 080 - Pu Tetrafluoride
IDC 090 -
IDC 091 - Non-Spec Fluoride
IDC 097 - Impure Fluoride in small cans -- Building 371
IDC 099 - Grease Fluoride

WASTE STREAM SOURCE

After incinerator soot (IDC 422) generated in Building 771 was dissoved in acid for plutonium recovery, the solution| was filtered and dried. The soot heel that remained (IDC 423) was assayed and set aside for additional processing. RE: Section 8.2.11 RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

IDC 089: D007 was identifed based on spepcific process knowledge. Chromium contamination of plutonium greencake is possible from the nitric acid leaching stainless-steel equipment during calcination. Also, small particles of the stainless steel wear plates are contained in the grease oxide. EPA Code D007 is assigned based on this information.

IDC 090 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in plutonium tetrafluoride have been detected. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the Toxicity Characteristic Leaching Procedure (TCLP) extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 091 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 091, impure fluoride, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. In addition, inside surface corrosion of a stainless-steel container of IDC 091 was recently discovered. The corrosion of stainless steel removes chromium from the container and contaminates the plutonium fluoride. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 092 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 092, impure fluoride heel, would have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the dissolution process. Additional chromium could be added from the leaching of stainless-steel equipment by nitric acid. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 097 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm

(total) in ICD 090 plutonium tetrafluroide have been detected. IDC 097 is assigend based on this inforamtiohn. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

IDC 099 was characterized based on specific process knowledge and plutonium tetrafluoride production analysis. Chromium concentrations of greater than 100 ppm (total) in IDC 090 plutonium tetrafluoride have been detected. IDC 099, grease fluoride, is assumed to have at least the same level of chromium contamination of IDC 090 because it contains additional contamination from the glovebox and equipment. EPA Code D007 is assigned based on this information. The total chromium contamination was divided by 20 to account for the dilution during the TCLP extraction. Assuming all of the chromium would leach during TCLP, a total concentration of 100 ppm or greater would convert to a TCLP concentration of at least 5 ppm, which would be RCRA characteristic.

Subpopulation 33F was identified based on specific process knowledge. The only compounds associated with the sodium fluoride pellets are sodium fluoride and plutonium hexafluoride. These compounds are not listed or characteristic RCRA compounds. Any RCRA-metal contamination of the plutonium feed stream remained in the product or fluid-bed material and did not contaminate the sodium fluoride pellets.

Waste Characterization Regulatory Discussion and Conclusion

The waste form plutonium fluoride and fluoride heel was characterized in conformance with WASTRENS's internal backlog waste reassessment characterization procedures, which are based on 6 CCR 1007-3, 40 CFR 260-280, and "U.S. DOE Definitions

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manges all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

The volumes and the radionuclide concentrations developed in the profile were based on processing plutonium residues for actinide separation. RFETS has modified this processing plan. Residues will be processed to meet WIPP WAC, TRAMPAC, and safe storage conditions. The modified volumes and radionuclide concentrations are reflected in the WIPP level roll-ups.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	Incinerator ash/TRM	Inventory Date:	
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Drum / 55-gallon	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

Item Description Code 428, Incinerator Ash

After incinerator ash (IDC 420) was generated in Building 771, this material was prepared, assayed, and packaged in Building 371, for transportation to an alternate DOE site for plutonium recovery processing. This material does not differ from incinerator ash IDC 420.

IDC 428 is mixed residue only.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W091	Handling:	CH	NMVP #:	N/A	Stream Name:	Organics Discard Level/TRM	Inventory Date:	10/24/94
Local ID:	0533, 0535, N/A	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

F003, F002, D022, D007, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This liquid waste stream includes machine oils and coolants contaminated with organic solvents.
WASTE STREAM SOURCE	Item Description Code 533 This IDC includes principally machine oils and coolants contaminated with organic solvents used in cleaning and, in some cases, contaminated with RCRA-regulated metals. According to Waste Stream Identification and Characterization (WSIC) information, Building 779 used acetone, trichloroethane, and methylene chloride in its Machine and Nuclear Joining processes. WSIC information also indicated that Building 881 used, or generated as sample waste, acetone, carbon tetrachloride, chloroform, ethanol, methanol, hexane, isopropanol, toluene, ethylbenzene, xylene, methylene chloride, 1,2-dichloroethane, and 1,1,2-trichloro-1,2,2-trifluoroethane in various analytical processes. Also, machining and manufacturing Research and Development operations, and possibly model construction operations produced oils contaminated with cadmium, chromium, lead, and selenium. WSIC information stated that Building 883 used chloroform, trichloroethane, toluene, xylene, and 1,1,2-trichloro-1,2,2-trifluoroethane in its metallurgical operations. Building 444 used acetone, 1,2-dichloroethene, trichloroethane, toluene, and ethylbenzene in its plating operations; acetone, 1,1,2-trichloro-1,2,2-trichfluoroethane, methylene chloride, and toluene in its fabrication operations; and trichloroethane in its tool and gauge operations. Where analytical data for this IDC exist, most of these organic solvents usually were not detected.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based on waste generation and general knowledge of waste type or source.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W091	Handling:	CH	NMVP #:	N/A	Stream Name:	organics Discard Level/TRM	Inventory Date:	10/24/94
Local ID:	0533, 0535, N/A	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

F005, F003, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION This liquid waste stream includes machine oils and coolants contaminated with organic solvents.

WASTE STREAM SOURCE

Item Description Code 535

This IDC includes laboratory quantities of RCRA-regulated organic solvents. The backlog inventory of this IDC was generated in Building 881 in various analytical laboratories. According to WSIC information, the solvents include toluene, 1,1,2-trichloro-1,2,2-trifluoroethane, xylene, acetone, carbon tetrachloride, chloroform, ethanol, methanol, hexane, isopropanol, ethylbenzene, methylene chloride, and 1,2-dichloroethane.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS Process knowledge based on waste generation and general knowledge of waste type or source.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

F002, F005, F001, D011, D010, D009, D008, D007, D006, D005, D004, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.77E+01
Pu-240	1.16E+00
Pu-239	5.08E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	17.3	7.2	5.1	29.9	13.8	73.3
Totals	17.3	7.2	5.1	29.9	13.8	73.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 17.3 Projected: 57.0 Total: 74.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

IDC 292 was intended for incinerator sludge from the recovery incinerator in Building 771. IDC 292 materials were reassessed under Waste Form 1, Incinerator Ash. However, there is one box WEMS incorrectly assigned this IDC. According to the waste-box log sheet dated October 14, 1987, the box contains Electrochemical Milling Sludge generated in Building 881. This operation generated sludge from the milling of various metals including stainless steel. It was indicated that no cyanides were used in the ECM operations in Building 881. The IDC for this box should be changed to 299.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphateds >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is

recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

F002, F005, D040, D035, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.77E+01
Pu-240	1.16E+00
Pu-239	5.08E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.3	0.3	1.5	0.7	3.5
Totals	0.8	0.3	0.3	1.5	0.7	3.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 2.7 Total: 3.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

This IDC has been used for sludges that were not accurately categorized as IDC 290 or 340 and could have been generated in any plutonium processing building. However, the backlog miscellaneous sludge was generated in Building 771 during the processing of residues, in Building 371 in the analytical laboratory, and in Building 883 by the Rolling Process. Process pipe sludge, sludge dissolution heel, and filter plenum sludge from Building 771 were processed through nitric acid dissolution and sparging. Soil and sludge samples from around the site were analyzed in Building 371, and the waste was stored for processing. IDC 299 materials generated in Building 883 include quench sludge and uranium oxide sludge from the rolling Process. This group also includes one container of electrochemical milling sludge generated in Building 881 in October 1987. The container is assigned IDC 292.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 65, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F005, F003, F002, F001, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.7	0.2	19.5	17.6	39.0
Totals	1.0	0.7	0.2	19.5	17.6	39.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 37.9 Total: 38.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

328 - Flu-Flo filters from the recovery incineration, building 771. Must be processed into IDC 376. Mixed Waste.

WASTE STREAM SOURCE

These Ful-Flo filters are in-line cartridge filters used to remove particulates from specific fluid streams in Building 771.

During normal process operations, IDC 328 Ful-Flo filters in the backlog population were used to filter particulates from the incinerator fume scrubber system in Building 771. These filters were used for the filtration of caustic solutions; therefore, they are contaminated with bases and may contain free liquids.

During normal process operations, IDC 331 Ful-Flo filters in this backlog population were used to filter particulates from liquid waste streams in Buildings 371, 707, 771, 776, 777, and 779. These waste streams were primarily from filtration of caustic solutions in Building 371, the carbon tetrachloride system and oil systems, and from filtration of water and developer in Building 707. In Building 771, the primary waste streams filtered were anion column feed, potassium hydroxide, nitrate feed, spent nitric acid and hydrofluoric acid from the scrubber, eluate and effluent exiting the ion-exchange columns, floor pick-up solution were filtered in Building 776. In Buildings 777 and 779, Ful-Flo filters were used in the carbon tetrachloride system for purification of Freon TF and for filtration of incoming waters.

Typically, Ful-Flo filters were placed on drying racks pending bag-out of a glovebox. Filters were not always dried before removal from the glovebox. Filters were then "bagged out" of the glovebox and placed in a second layer of plastic. Next, the filters were placed in a "Poly bottle" or "Clam Shell" (hard plastic container), then placed in a double-lined drum.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335

filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F002, F001, D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.6	3.0	0.8	86.1	102.5	197.0
Totals	4.6	3.0	0.8	86.1	102.5	197.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.6 Projected: 192.4 Total: 197.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

331 - Ful-Flo filters used to filter solids from aqueous solutions. Additional required processing undetermined. Because of the potential of liquids in this IDC, it requires a compatibility code when packaging.

WASTE STREAM SOURCE

These Ful-Flo filters are in-line cartridge filters used throughout Rocky Flats to remove particulates from fluid streams and typically filter down to 5, 1, and 0.5 micron-sized particulates. Ful-Flo filters are used in various liquid systems that include nitric- and chloride-acid systems, such as those found in plutonium recovery operations; caustic systems, such as those found in utilities scrubbing; solvent systems using carbon tetrachloride in machining operations; water systems, such as steam cleaning; and condensate collection. These filters are also used in lubricant oil filtration.

Ful-Flo filters are poly-fiber-wound cartridges, about 10" long by 3.5" in diameter. Other fiber filters, such as R-6 pads, may be included in this IDC. R-6 pads are cloth filters, about sixteen inches in diameter, used to filter solids from nitric acid solutions. Therefore, backlog material in this IDC cannot be considered homogeneous. filter elements are produced by combining a media blanket and spirally wound matrix yarn on an inner core. The filter elements might have a polypropylene cap on one end. Both the media blanket and matrix yarn can be cotton or polypropylene. The inner core material can be constructed of polypropylene, tinned steel, or stainless steel. Warehouse data from Rocky Flats indicate that the inner-core material is polypropylene.

during normal process operations, IDC 331 Ful-Flo filters in this backlog population were used to filter particulates from liquid waste streams in Buildings 371, 707, 771, 776, 777, and 779. These waste streams were primarily from filtration of caustic solutions in Building 371, the carbon tetrachloride system and oil systems, and from filtration of water and developer in Building 707. In Building 771, the primary wste streams filtered were anion column feed, potassium hydroxide, nitrate feed, spent nitric acid and hydrofluoric acid from the scrubber, eluate and effluent exiting the ion-exchange columns, floor pick-up solution, steam condensate, and miscellaneous aqueous solutions. Hydraulic oil and floor pick-up solution were filtered in Building 776. In Buildings 777 and 779, Ful-Flo filters were used in the carbon tetrachloride system for purification of Freon TF and for filtration of incoming waters.

Typically, Ful-Flo filters were placed on drying racks pending bag-out of a glovebox. Filters were not always dried before removal from the glovebox. Filters were then "bagged out" of the glovebox and placed in a second layer of plastic. Next, the filters were placed in a "Poly Bottle" or "Clam Shell" (hard plastic container), then placed in a double-lined drum.

These Ful-Flo filters may be contaminated with acids, bases, carbon tetrachloride, chromium, Freon, and oil. They may contain relatively small amounts of free liquids.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 326 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the

incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

M

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F002, F001, D019, D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	8.3	0.6	56.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	9.8	0.7	66.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.4	4.8	429.5
Rubber:	2.8	0.2	19.1
Plastics:	3.8	0.3	25.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.5	1.0	0.2	27.3	33.1	63.0
Totals	1.5	1.0	0.2	27.3	33.1	63.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	13.9	1.6	173.9	211.1	401.9
Totals	1.5	13.9	1.6	173.9	211.1	401.9

As-Generated Form: Stored: 1.5 Projected: 61.6 Total: 63.0

Final Waste Form: Stored: 1.5 Projected: 400.4 Total: 401.9

WASTE STREAM DESCRIPTION

335 - High efficiency particulate air filters used on glovebox air intakes and exhausts.

WASTE STREAM SOURCE

The material in this IDC is High Efficiency Particulate Air (HEPA) filters used in ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large filter plenums that filter the room air.

Used filters were removed from their position in the ventilation system and packaged for further processing. The filters used on gloveboxes (nominal 8" x 8" x 5") were identified as IDC 335 if they were not acid contaminated.

RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and

Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers

of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY I sach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

Projection in section 8.2.15.1.13 include generation of IDC-335 and IDC-342 to be processed to IDC-335.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W067	Handling:	CH	NMVP #:	RF 119	Stream Name:	Cemented filters/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F039, F009, F007, F006, F005, F003, F002, F001, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.60E+01
Pu-240	1.51E+00
Pu-239	6.61E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.7	0.2	19.7	23.9	45.5
Totals	1.0	0.7	0.2	19.7	23.9	45.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 1.0 Projected: 44.1 Total: 45.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of filters used in ventilation systems. Some of it has had cement sprinkled on it to neutralize the acid on the filters.

WASTE STREAM SOURCE

The material in this IDC is either the filter media portion of HEPA filters or surface-water filters. HEPA filters are used on gloveboxes and in large filter plenums. Sock filters were used to prefilter operable unit 2 (OU-2) surface water prior to activated carbon treatment.

Used HEPA filters were processed to segregate those portions with high plutonium content and those with low content. The wood frames were separated from the media and almost always disposed of as waste by packing in drums that were assigned IDC 330. the filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste.

This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from the production Building 707 and could be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon. IDC 338 was meant to be used as a residue IDC and not as a waste IDC. Because sorting between IDCs was not accurate, some of the IDC 338 backlog containers are below the economic discard limit (EDL) and are therefore not residue.

RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation DB

Subpopulation DB consists of IDC 338 filter media that could have been exposed to saltcrete in Building 374. Room 3809 was used for Saltcrete Processing (WSRIC Process 374-5). HEPA filters were used to filter nitrate salt particles from the baghouse air stream. The single container of filters in this subpopulation is characterized as RCRA hazardous, and its characterization is based on the current WSRIC characterization for saltcrete. EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 have therefore been applied. The EPA Code D001 is applied because nitrate salts may have formed on these filters.

Subpopulation DC

Subpopulation DC includes all IDC 338 filter media generated from Building 771. There are 111 containers in this subpopulation. This filter medium might be derived from IDC 342 filters (acid contaminated-see Subpopulations EB and EC), and is characterized the same as the IDC 342 filters from Subpopulation EB. Because this filter medium might have been used to filter nitric acid and nitric salts have been reported to form on the filter media, it could exhibit the characteristic of ignitability and is considered to be an oxidizer due to the presence of nitrate salts. This filter medium is a RCRA-hazardous waste and EPA Code D001 has been applied.

Subpopulation FA

Subpopulation FA includes containers of IDC 376 processed filter media generated throughout Rocky Flats that are characterized as nonhazardous. This processed filter medium is derived from filters generated from processes for which there would be no "carry over" of solvent contamination from vapors. Exclusion of filters from "carry over" contamination is based on WSRIC information and a Waste Technical Support Memorandum. The memorandum states that these HEPA filters are nonhazardous unless RCRA hazardous liquids have condensed from the uncontained gases. It is assumed that these containers do not have free liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

D008, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.9	4.8	1.4	148.0	179.7	341.7
Totals	7.9	4.8	1.4	148.0	179.7	341.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 7.9 Projected: 330.9 Total: 338.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

342 - Drybox filters from all acid lines. This waste must be neutralized, then changed to IDC 815 to disposal.

WASTE STREAM SOURCE

HEPA filters are used on all gloveboxes to remove particulates from the atmosphere exiting the glovebox to the plenum exhaust system. The filters in IDC 342 are from gloveboxes with atmospheres that could cause the filters to be contaminated with acids or bases used in chemical processing.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002, EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W056	Handling:	CH	NMVP #:	RF 118	Stream Name:	Mg Oxide Crucibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5123

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	11.9	0.0	23.8
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	564.2	252.6	789.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	26.9	13.5	53.8
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	3.30E+00
Pu-240	1.26E+00
Pu-239	5.50E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	1.4	1.7	3.6
Totals	0.6	0.0	0.0	1.4	1.7	3.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	1.4	1.7	3.6
Totals	0.6	0.0	0.0	1.4	1.7	3.6

As-Generated Form: Stored: 0.6 Projected: 2.9 Total: 3.5

Final Waste Form: Stored: 0.6 Projected: 2.9 Total: 3.5

WASTE STREAM DESCRIPTION

This waste stream includes any type or size of ceramic crucibles or liners including LECO crucibles. This waste consists of magnesium oxide ceramic crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing plutonium residue.

WASTE STREAM SOURCE

Transuranic waste and residue crucibles were generated at Rocky Flats by the pyrochemical development work in Buildings 779 and 776; production processes in Buildings 371, 771, and 776; laboratories in Buildings 559 and 771; and electrorefining in Buildings 371, 776 and 779. The generation of these waste populations encompasss IDCs 360, 368, 370, and 655. IDC 360, aluminum oxide ceramic crucibles, backlog containers are stored in Buildings 707 and 776. IDC 368, magnesium oxide ceramic crucibles - not LECO, backlog containers are stored in Buildings 371, 444C, 569, 664, 707, 771, 776, 777, and 964C. IDC 370, LECO crucibles, backlog containers are stored in Buildings 371, 771, 776, and 777. IDC 655, ER ceramic from plutonium/neptunium (Pu/Np), backlog drums are stored in Buildings 371 and 779. The backlog dates of generation recorded in the WEMS database range from August 3, 1973, to February 25, 1992.

During the hazardous determination and reassessment characterization phase of the project, the WEMS database was first queried to identify the waste containers constituting the waste form IDCs 360, 368, 370, and 655 populations. The information gained from the WEMS query provided the basis for subpopulation identification. References used during the continuing identification of waste form subpopulations are listed in Section 2.41.6. Additionally, comments and information provided at the reassessment meeting held on August 15, 1994 were incorporated into this revision.

Item Description Code 368

During normal process operations, the Electrorefining, Reduction and Button Breakout, Direct Oxide Reduction, and Salt Scrub processes in Buildings 559, 771, and 779 generated broken magnesium oxide crucible pieces. A detailed description of the generating processes presented above can be found in the WSRIC Building Books. However, in general, the crucibles were used to heat plutonium with salts or accelerators allowing for purification or recovery of actinide metals. Upon cooling to room temperature, the crucible or crucible insert used in the process would be broken and its contents removed.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

Process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 3 gallon nalgene jars, double bagged, placed in "clamshell" containers, placed in 55 gallon DOT 7A TYPE A drums with polyethylene rigid liner and bag liner.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.77E+01
Pu-240	1.16E+00
Pu-239	5.08E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.3	0.2	1.1	0.5	2.7
Totals	0.6	0.3	0.2	1.1	0.5	2.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 2.1 Total: 2.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

This IDC was generated by grit blasting operations in Building 371 (primarily for cleaning steel and iron) and Building 777 in the Machining and Coating processes (primarily cleaning shields). A variety of materials were used for the grit, including iron shot, walnut shells, glasss beads, and ceramic beads. The majority of the grit is thought to be iron shot ranging in size from fines to irregular particles. There were apparently no other RCRA-regulated metals involved in the grit blasting. There is one drum of IDC 372 shown in WEMS as being generated in Building 371. However, no grit blasting operation could be identified in that building.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates <1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is

recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: *Defense TRU Waste*

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.91E+02
Pu-240	8.01E+00
Pu-239	3.50E+01
Am-241	4.76E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	2.2	2.7	5.4
Totals	0.4	0.0	0.0	2.2	2.7	5.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 5.0 Total: 5.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 391 consists primarily of unpulverized sand and crucible generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771.

The unpulverized sand and crucible are generated from the separation of sand and crucible residues from the calcium fluoride slag following the removal of the plutonium metal button.

Unpulverized sand and crucible is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas

when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS

LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

Projected generation of this waste stream begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.91E+02
Pu-240	8.01E+00
Pu-239	3.50E+01
Am-241	4.76E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	2.2	2.7	5.4
Totals	0.4	0.0	0.0	2.2	2.7	5.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 5.0 Total: 5.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 392 consists of unseperated IDC 391 materials.

Unpulverized sand, slag, and crucible are placed in 4-liter, wide-mouthed, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The sand, slag, and crucible are stored awaiting crushing prior to plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS

LDR_DETERM: Net and gross weight data are not available for all container types.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surrounding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel.

Projected generation of this waste stream begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W059	Handling:	CH	NMVP #:	N/A	Stream Name:	sand, Slag and Crucible/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.91E+02
Pu-240	8.01E+00
Pu-239	3.50E+01
Am-241	4.76E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	11.2	0.0	0.0	62.2	75.9	149.3
Totals	11.2	0.0	0.0	62.2	75.9	149.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 11.2 Projected: 136.9 Total: 148.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste form consists of material that is fine particulates to larger chunks. There is sand, and crucible shards from the break-out process.

WASTE STREAM SOURCE

IDC 393 is produced in the Dissolution Process in Gloveboxes (Lines) 23 and 25 in Building 771. Pulverized sand, slag, and crucible from the Crushing Process is placed in a dissolution pot with heated nitric acid and aluminum nitrate. The solution (plutonium nitrate) is pulled by vacuum through an R-6 filter to remove undissolved solids.

The undissolved solids are sand, slag, and crucible heels that are dried on a hot plate and placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The residue sand, slag, and crucible heels are stored awaiting plutonium recovery by dissolution.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

Item Description Code 387

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. This IDC does not appear in active or archived WSRIC information. The IDC 387 Reburned SS&C Sweepings Residue Analysis Study concurs with the D007 characterization.

IDC 387 is Subpopulation 59B and was identified based on specific process knowledge. The heating of the sweepings on the hotplate will oxidize any calcium metal fines that are part of the sweepings. Operational personnel have observed flaking of the Inconel pan after repeated heating and cooling cycles. Inconel is approximately thirteen percent chromium according to the Materials Handbook. The reburned sweepings are conservatively assigned D007 based on the unknown level of chromium contamination from the Inconel flaking.

Item Description Code 390

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 390 Unpulverized Slag Residue Analysis Study provides a D003 characterization based on IDC 390 being derived from IDC 392, which is characterized as D003 in the 1992 WSRIC book.

IDC 390 is Subpopulation 59C and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 390.

Unpulverized slag is known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore, this waste exhibits the characteristic of reactivity (D003).

Item Description Code 391

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 391 Unpulverized Sand and Crucible Residue Analysis Study characterizes the waste form with EPA Code D003 only.

IDC 391 is Subpopulation 59D and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 391.

Unpulverized sand and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 392

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. WSRIC Waste Stream 771-11-12, IDC 392, is also characterized as D003 waste. The IDC 392 Unpulverized Sand, Slag, and Crucible Residue Analysis Study provides a D003 characterization based on the WSRIC Book.

IDC 392 is Subpopulation 39E and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 392.

Unpulverized sand, slag, and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water.

Item Description Code 393

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D007. WSRIC Waste Stream 771-2-6, IDC 393, is also characterized as D007 waste. The IDC 393 Sand, Slag, and Crucible Heel Residue Analysis Study concurs with the D007 characterization.

IDC 393 is Subpopulation 59F and was identified based on specific process knowledge. The grinding and dissolution will oxidize or hydrate any calcium metal fines that are part of the sand, slag, and crucible. Chromium can be added to the heel from the corrosion of the stainless steel in the dissolution process area. The heels are conservatively assigned D007 based on the unknown level of chromium contamination from the acid corrosion of stainless steel.

Item Description Code 395

There is no analytical information for this waste form that will assist in RCRA characterization. The Backlog Residue Hazardous Waste Determination Status Report provides a characterization of D003 and D007. This IDC does not appear in active or archived WSRIC information. The IDC 395 Unpulverized Slag and Crucible Residue Analysis Study assigns a D003 characterization based on IDC 395 being derived from IDC 392.

IDC 395 is Subpopulation 59G and was identified based on specific process knowledge. The chromium contamination source associated with the plutonium reduction process is the plutonium fluoride. Plutonium recovery analysis records of the plutonium metal indicate the chromium contamination in the plutonium fluoride remains with the plutonium metal after the reduction is performed. Based on this process knowledge, EPA Code D007 is not appropriate for IDC 395.

Unpulverized slag and crucible are known by process knowledge to contain chunks of calcium metal. Calcium metal will produce significant quantities of hydrogen gas when added to water. The calcium metal is not sufficiently oxidized or hydrated in its current form to significantly reduce the rate of the reaction with water. Therefore,

	this waste exhibits the characteristic of reactivity (D003).
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	LDR_DETERM: Net and gross weight data are not available for all container types. RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon drum DOT 7A TYPE A, Carbon Steel. Projected generation of this waste stream begins in CY2005.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: L1190

AS-GENERATED EPA CODES

D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

These wastes are aqueous acidic liquid residues.

WASTE STREAM SOURCE

IDC 400 is ion column feed (plutonium nitrate solution) with less than 5 g/l plutonium which is to be processed through Anion Exchange to remove any impurities. These solutions come from various aqueous recovery operations for purification of plutonium.

Dissolution in Building 771 dissolved high-impurity, low-plutonium content residues to recover plutonium. Cation Exchange in Building 771 processed chloride solutions (hydrochloric acid containing plutonium) from the laboratories in Buildings 371, 559, and 771.

Precipitation Feed Batching in Building 771 combined plutonium nitrate or ion column eluate and evaporator bottoms to achieve the desired plutonium concentration. The solutions (IDC 400) in which impurity concentrations were too high were sent for purification.

Reduction and Button Break-Out in Building 771 produced a purified plutonium metal product. In this process, the metal was pickled in a water bath to remove residual calcium. The resulting solution (IDC 400) was mostly water containing plutonium and elemental impurities.

Miscellaneous Residue Processing in Building 771 generated IDC 400 from sludge dissolution. Sludge from the process filter plenum was dissolved in heated nitric acid and drained through a filter resulting in nitrate solution (IDC 400). The heel that was formed on the filter was dried on a hot plate and also dissolved.

Spray Leach in Building 771 separated metal contaminant from plutonium metal. Certain parts were pretreated by soaking in nitric, hydrofluoric, or sulfuric acids. These acids and acid from the glovebox (GB) floor pick-up were then filtered.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation A

Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22.

Subpopulation H

These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals.

In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process.

This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 10/20/94

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

D007, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	13.0	15.9	29.1
Totals	0.2	0.0	0.0	13.0	15.9	29.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 28.7 Total: 28.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the ammericium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDC 409.

IDC 409 was formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 416.

RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

Projected generation of this waste form begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 10/20/94

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

D007, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	7.9	9.7	17.8
Totals	0.2	0.0	0.0	7.9	9.7	17.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 17.5 Total: 17.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Nonspecification plutonium metal, cast as an anode, was combined with and equimolar mixture of sodium chloride and potassium chloride in a magnesium oxide crucible. Magnesium chloride was then added to initiate the plutonium oxidation. The metal and salts were placed in a furnace and heated until molten. The molten mixture was stirred, and a current applied to the anode which flowed through the molten mixture to the cathode. Plutonium ions migrated from the molten anode through the molten salt to the cathode and were reduced to purified metal. After cooling, the crucible was broken and the salt, anode heel, and purified plutonium metal were separated. This process produced IDC 411 salts.

IDC 411 is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metals, and various plutonium compounds. These salts may contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. IDC 411 salt packaged for off-site shipment was assigned IDC 473.

RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

Projected generation of this waste form begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 10/20/94

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

D007, D003, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.2	0.2	0.8
Totals	0.4	0.0	0.0	0.2	0.2	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.4 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals.

WASTE STREAM SOURCE

Impure metal was placed in a crucible with sodium chloride, potassium chloride, and zinc chloride. The crucible and contents were heated in a furnace until the contents were molten and the mixture was stirred. While molten, the zinc chloride reacted with the plutonium metal to form plutonium chloride and zinc metal. The contents separated into salt and metal products at process temperature. After cooling and breakout, the plutonium-rich salt phase was reloaded into a crucible along with calcium metal. The crucible and contents were heated in a furnace until the contents were molten and the mixture was stirred. While molten, the calcium reduced the plutonium chloride to plutonium metal. After cooling, the crucible was broken and the metal and salt were separated. This process produced IDC 412 salts.

IDC 412 is a Glyson salt which was generated by an experimental pyroredox process. The salt is composed primarily of sodium chloride, potassium chloride, calcium chloride, residual zinc chloride, entrained zinc and calcium metal, and various plutonium and americium compounds. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-

C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

Projected generation of this waste form begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W058	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 10/20/94

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.7	0.0	0.0	0.2	0.2	9.1
Totals	8.7	0.0	0.0	0.2	0.2	9.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 8.7 Projected: 0.4 Total: 9.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

Its composition includes chunks and powdered mixed salts, a probable presence of magnesium, sodium and potassium metals. .

WASTE STREAM SOURCE

Calcined plutonium oxide was placed in a magnesium oxide crucible with calcium chloride and calcium metal. The crucible and contents were placed in a furnace and heated until the contents were molten. The molten material was stirred to initiate and promote the reduction of the plutonium oxide. After the reaction, the melt was allowed to separate into plutonium metal and salt phases. After cooling, the crucible was broken and separated from the salt, calcium, and plutonium metal. This process produced IDCs 365 and 414.

IDCs 365 and 414 are composed primarily of calcium chloride, calcium oxide, calcium metal entrained in the salt, and various plutonium compounds. A "button" of excess calcium may also be present in some containers of these salts. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Hazardous Waste Determination and Waste Characterization

The primary sources of information for characterizing pyrochemical salts were two position papers, Reactivity of Pyrochemical Salts at Rocky Flats, and Presence of Chromium in Pyrochemical Salts at Rocky Flats. A memorandum from the DOE Rocky Flats Office regarding the Colorado Department of Health's (CDH's) perspective on the definition of reactivity pursuant to the Colorado Hazardous Waste Regulations, 6 CCR 1007-3, was used, as was a letter from EG&G regarding the CDH reactivity definition.

Subpopulation 34A

IDC 411, were generated from the ER process. Magnesium metal may be entrained in the salt. These salts may also contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. Dissolution of these salts has occurred at Rocky Flats during R&D activities, and hydrogen gas generation has been observed. These dissolutions were always conducted under controlled conditions with extreme caution to account for the hydrogen gas generation, and no ignition of the hydrogen gas occurred during these dissolutions. These salts do not react "violently" with water, they do not generate toxic gases when mixed with water, and the possibility of water entering a container of these salts and forming an explosive mixture of hydrogen and oxygen is unlikely.

Based on this information, these salts do not exhibit the characteristic of reactivity (D003) as defined by 6 CCR 1007-3, Part 261.23. In addition, CDH has interpreted RCRA-reactivity as a condition that requires three key elements: a high reaction rate, containment of the reaction, and an ignition source, and there must be high probability of these elements occurring at the same time.

None of the above IDCs exhibit the characteristic of toxicity for chromium (D007) as defined by 6 CCR 1007-3, Part 261.24. Thermodynamic calculations conclude that chromium could exist only in insignificant amounts in the salt after the reactions, as chromium would alloy with the plutonium metal.

Subpopulation 34H

IDCs 405-410 were generated from the MSE process. Only magnesium metal and nonreactive metals are entrained in the salt. Testing has shown that the reaction of these salts in water is not "violent" and does not create enough heat to ignite the small amount of hydrogen that is produced. Therefore, these salts do not exhibit the characteristic of reactivity as defined in Subpopulations A-C. These salts also do not exhibit the characteristic of toxicity for chromium as explained in Subpopulations A-C.

Subpopulation 34Q

IDCs 404 and 412 were generated from the Pyroredox Process and contain calcium chloride and zinc chloride which are hygroscopic. As a result, these wastes could have absorbed enough water to contain some free liquid. Testing has shown that the pH of a surrogate sample composed of calcium chloride and zinc chloride is about three, which does not meet the definition of corrosivity (D002) in 6 CCR 1007-3, Part 261.22(a)(1). In addition, testing has demonstrated that the liquid does not corrode steel at a rate greater than 0.250 inches per year. Therefore, the material does not exhibit the characteristic of corrosivity as defined by 6 CCR 1007-3, Part 261.22(a)(2).

Zinc and calcium metal may be entrained in these salts. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. However, there is a low probability that any unreacted metals are still present in these salts. Therefore, they would not meet the CDH conditions for reactivity. As a result, these salts do not exhibit the characteristics of reactivity or toxicity for chromium as defined in Subpopulations A-C.

Subpopulation 34S

IDCs 365 and 414 were generated from the DOR process. Calcium metal is entrained in these salts and a "button" of calcium metal may also be packaged with the salt. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. When exposed to water, significantly more hydrogen may be generated by these salts if the calcium metal button present as calcium metal does not passivate when immersed in water, but continues to generate hydrogen until the calcium metal is entirely consumed. These salts have been in storage at RFP in ambient atmosphere for several years, and it is suspected that reaction with water has already occurred on the surface of the calcium metal from water present in the air, resulting in some loss of metal and hydrogen gas generation.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums, DOE 7A TYPE A, Carbon Steel.

Projected generation of this waste form begins in CY2005.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W057	Handling:	CH	NMVP #:	RF 122	Stream Name:	Insulation/TRM	Inventory Date:	10/20/94
Local ID:	IDC 438	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5129

AS-GENERATED EPA CODES

F009, F001, F002, F003, F005, F007, F039, F006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	91.7	1.9	353.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.8	0.0	9.6
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 122

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.48E+01
Pu-240	6.24E-01
Pu-239	2.73E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.9	1.4	6.5	7.2	16.4
Totals	0.4	0.9	1.4	6.5	7.2	16.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.9	1.4	6.5	7.2	16.4
Totals	0.4	0.9	1.4	6.5	7.2	16.4

As-Generated Form: Stored: 0.4 Projected: 15.8 Total: 16.2

Final Waste Form: Stored: 0.4 Projected: 15.8 Total: 16.2

WASTE STREAM DESCRIPTION

This waste stream is contaminated insulation.

WASTE STREAM SOURCE

Item Description Code 438

Maintenance, repair, and strip-out operations in Buildings 371, 374, 444, 559, 666, 707, 771, 774, 776, 777, 779, 865, 881, and 883 produced waste insulation. Insulation waste is generated by replacement of furnace heating elements, construction, maintenance, and demolition activities within the Protected Area at Rocky Flats. During these activities, insulation material is removed from furnaces, boilers, piping, ceilings and walls, and heating and cooling systems.

WEMS data indicate that insulation waste was generated in:

Building 374 Acid Neutralization, Radioactive Decontamination, Sludge Solidification, Evaporation, Spray Dryer and Saltcrete, and General Building Operations.

Building 444 Maintenance

Buildings 559 and 779 Utilities

Building 666 Drum Repack

Building 707 Foundry Operations-Module A, Casting-Module K, X-Y Retriever-Module J, Maintenance, and Modules A-H

Building 771, Maintenance and General Building Waste

Building 774 Microwave Process

Building 776 during the replacement of furnace heating elements.

Generated by construction and demolition activities.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 53D, IDC 438, was identified based on WEMS data, IDC, and discussion with generating personnel. The insulation in this subpopulation was used on pipes, walls, and other barriers and could have come in contact with listed constituents when leaks or spills occurred. According to the generator, the insulation was visibility contaminated with sludge and salt produced in Building 374. The D-codes currently assigned to containers in this subpopulation are not appropriate based on the volume of insulation relative to the amount of caked on sludge. The following EPA Codes were assigned to this waste: F001, F002, F003, F005, F006, F007, F009, and F039. This inventory was generated in Building 374.
Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon drums DOT 7A TYPE A; metal boxes.

FINAL FORM COMMENTS N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W066	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	S5410

AS-GENERATED EPA CODES

F009, F007, F006, F005, F003, F002, F001, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	15.0	0.8	38.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.0	0.8	38.8
Rubber:	7.4	0.3	19.4
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.4	0.1	11.9	14.4	27.4
Totals	0.6	0.4	0.1	11.9	14.4	27.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.4	0.1	11.9	14.4	27.4
Totals	0.6	0.4	0.1	11.9	14.4	27.4

As-Generated Form: Stored: 0.6 Projected: 26.6 Total: 27.2

Final Waste Form: Stored: 0.6 Projected: 26.6 Total: 27.2

WASTE STREAM DESCRIPTION

491 - Room air exhaust filters only. This waste must be collected in 55-gallon or 35-gallon drums for assay.

WASTE STREAM SOURCE

The material in this IDC is a variety of plenum prefilters used in the ventilation systems at Rocky Flats. Plenum prefilters have been and are used in all of the buildings that contain plutonium processing activities. These prefilters are used in large plenums that filter the room and glovebox air. Used prefilters were removed from their position in the ventilation system and packaged for furtehr processing.

IDC 491 plenum prefilters range from furnace-type filters to pleated fiberglass filters and can be as large as 24" x 24" x 12". The filter medium consists of fiberglass packing or paper which may be more or less dense, depending on filtering needs. Wire mesh can be used to hold the media in place. The frame material for these prefilters is cardboard.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 371 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W066	Handling: CH	NMVP #: N/A	Stream Name: Filters & media/TRM		Inventory Date: 10/20/94
Local ID: None	Type: MTRU	Generator Site: RF	Final Waste Form: Filter		Waste Matrix Code: S5410

AS-GENERATED EPA CODES

F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.78E+01
Pu-240	7.49E-01
Pu-239	3.27E+00
Am-241	6.18E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box /	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

492 - High efficiency particulate air filters, 24x24x12. All IDC 492 HEPA filters must be repackaged in size reduction. This waste form must be neutralized and changed to IDC 815.

WASTE STREAM SOURCE

The material in this IDC is HEPA filters in the ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large plenums that filter the room and glovebox air.

Used filters were removed from their position in the ventilation system and packaged for further processing. The larger-sized filters used in filters plenums were identified and packaged as IDC 492 if acid contaminated.

IDC 492 HEPA filters (24" x 24"), acid contaminated, are large HEPA filters (nominal 24" x 24" x 5" or 24" x 24" x 12") that were used in filter plenum racks. These filters consist of filter media contained within a wooden or metal frame.

RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Ful-Flo filters from various buildings are also segregated based on their generation prefixes. The generation prefix corresponds to a Material Balance Account (MBA). Specific gloveboxes in Building 771 have been identified as having nitric acid spray exposure such that "crystals" of nitrate salts have been reported to have formed on the filters causing them to meet the definition of a DOT oxidizer (EG&G 1993d). These gloveboxes were correlated to WSRIC processes and then to generation prefixes to characterize the filters generated from them.

Ful-Flo filters which filtered solutions containing chromium are included in Subpopulations BA, BE, and BH. The EPA Code D007 (chromium) does not apply because the solutions were generated from tanks and are nearly exclusively trivalent chromium. The processes did not generate hexavalent chromium, and these wastes were managed in a non-oxidizing environment (CDH 1994).

Subpopulation 54AA

Subpopulation 54AA consists of all IDC 328 filters. These six drums contain Ful-Flo filters from the Building 771 incinerator. It is assumed that all the drums contain free liquids. Because potassium hydroxide is used to neutralize acidic vapors in the incinerator, the liquid is characterized as RCRA hazardous due to exhibiting the characteristic of corrosivity and assigned EPA Code D002. EPA Codes F001, F002, F003, and F005 are assigned because these codes have been applied to the incinerator ash which has contacted these filters.

Subpopulation 54BA

The four generation prefixes of the nine drums of IDC 331 filters generated in Building 371 indicate that all the filters could have been generated from any process in the building using Ful-Flos. These filters may contain free liquids and exhibit the characteristic of corrosivity. These filters in Subpopulation 54 BA are, therefore, RCRA hazardous and are assigned EPA Code D002.

Subpopulation 54BB

Generation Prefix 12, Module C consists of processes in Building 707 which used IDC 331 Ful-Flo filters to filter oil and carbon tetrachloride. The material filtered is based on information in WSRIC. The single container of filters in Subpopulation 54BB is RCRA hazardous because the filters contain carbon tetrachloride and EPA Code F001 is assigned

Subpopulation 54BC

Generation prefix 15 corresponds to WSRIC Process 6, Machining-Module A, in Building 707. The IDC 331 Ful-Flo filters from this process were used to filter oil and Freon, according to the WSRIC book for Building 707. These 16 containers of filters in Subpopulation 54BC are RCRA hazardous because they contain the F-listed constituent trichloro-trifluoroethane, and are assigned EPA Codes F001 and F002.

Subpopulation 54BD

Generation prefix 22 corresponds to WSRIC processes 4-7, 11-13, 18-20, 23 and 26 in Building 707. The IDC 331 Ful-Flo filters from these processes were used to filter oil, carbon tetrachloride, and Freon, according to WSRIC.

Generation prefix 23 corresponds to WSRIC processes 7,8,9,11, and 12 in Building 777. Generation prefixes 54 and 779 may include any process in Building 779. According to current and archived WSRIC information, the IDC 331 Ful-Flo filters from these processes may have been used to filter oil, carbon tetrachloride, and Freon.

These containers of filters in Subpopulation 54BD are RCRA hazardous because they contain the F-listed constituents carbon tetrachloride and trichloro-trifluoroethane. They are therefore assigned EPA Codes F001 and F002.

Subpopulation 54BE

Subpopulation 54BE consists of all IDC 331 Ful-Flo filters generated from processes in Building 771. There are 146 containers of filters in this subpopulation. These filters could have been used to filter either acidic or caustic liquids, since specific information on the point of generation for each container could not be obtained. Seventeen of these drums were checked for free liquids by Real-Time Radiography (RTR) during "courtesy" inspection in 1993. Because 16 of these drums were evaluated by RTR as having free liquids, all drums in this subpopulation are assumed to have free liquids containing acids or bases that are free liquids. These liquids may exhibit the characteristic of corrosivity, and are assigned EPA Code D002.

Subpopulation 54BF

Generation prefix 04 is used for the Building 777 Radiography Process (Process 777-10). The building of generation should be changed in WEMS from 707 to 777. Based on archived WSRIC information for Radiography, the IDC 331 Ful-Flo filters were used to filter caustic solutions. The single container of filters in Subpopulation 54BF is RCRA hazardous because the filters are assumed to contain free liquids which exhibit the characteristic of corrosivity. EPA Code D002 has therefore been assigned. Additional investigation is warranted to further evaluate if the container has free liquids.

Subpopulation 54BH

Subpopulation 54BH includes all IDC 331 Ful-Flo filters which are shown in WEMS as being generated in Building 776 with prefixes 19, 25, 26, or 57. Based on the WSRIC book for Building 776, these filters could contain acids or bases which are free liquids, and therefore could exhibit the characteristic of corrosivity. The D002 EPA Code is assigned for corrosivity. The filters might have been used to filter oil, carbon tetrachloride, and Freon; therefore, they are assigned EPA Codes F001 and F002.

Subpopulation 54CC

These containers of IDC 335 filters are identified by prefix 746, indicating that they might have been generated from anywhere in Building 774. Because the IDC 335 filters from Process 774-5 are characterized in WSRIC as hazardous and cannot be segregated from other filters in this prefix, all filters in Subpopulation 54CC must be characterized as hazardous. These filters might have been contaminated by sludges containing oil, Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, from the OASIS Process (774-5). EPA Codes F001 and F002 have therefore been applied.

Subpopulation 54EB

Subpopulation 54EB consists of IDC 342 filters generated from processes in Building 771 assigned to prefixes 02 and 74. This subpopulation includes 62 containers of acid-contaminated glovebox HEPA filters. The following gloveboxes have been determined to have had nitric acid spray exposure, and it has been reported that nitrate salt crystals from on HEPA filters from these gloveboxes, causing the filters to meet the DOT definition of an oxidizer.

Gloveboxes A-1, A-2, A-3, and A-4 in Room 174
Gloveboxes 13, 14, and 15 in Room 114
Glovebox 29 in Room 149

The gloveboxes in Room 174 are associated with the OY Leach Process which corresponds to prefix 74. The gloveboxes in Rooms 114 and 149 are associated with Batching, Precipitation, and other processes corresponding to prefix 02.

Because the containers cannot be segregated according to the source of the filters within prefixes 02 and 74, all filters from these prefixes are assumed to be hazardous. These filters have been used to filter air from gloveboxes in which nitric acid has been used and could exhibit the characteristic of ignitability due to the presence of nitric acid. Nitric acid crystals have been observed on these filters. They are, therefore, assigned EPA Code D001.

Subpopulation 54IA

Subpopulation 54IA consists of all IDC 492 HEPA filters. There are two containers in this subpopulation. The filters are not characteristic of corrosivity because they are not in liquid form. These filters are, therefore, RCRA-nonhazardous. The CCC of 02 is applied due to the contact of these filters with acid vapors.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: Filter waste is packaged in 55-gallon drums and metal standard waste boxes.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W063	Handling:	CH	NMVP #:	N/A	Stream Name:	miscellaneous liquids/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L1190

AS-GENERATED EPA CODES

F009, F007, F005, F003, F002, F001, D043, D040, D039, D038, D035, D028, D022, D019, D018, D011, D010, D009, D008, D007, D006, D005, D004, D003, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	These wastes are aqueous acidic liquid residues.
WASTE STREAM SOURCE	The Building 371 analytical laboratory receives liquid and solid samples from the entire plant site. Samples that are destined for Building 881 are analyzed in Building 371 to screen out those with high levels of radioactivity. Sludge and aqueous samples from Building 374 are analyzed for total alpha activity and plutonium, uranium, and americium content. Prior to analysis, the sludges are dissolved in nitric acid, hydrogen fluoride, or hydrochloric acid. Reagents are also used in sample preparation. Unused portions or excess prepared sample are placed in 4-liter plastic bottles. The Building 559 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various ions, iron, silicon, isotopic compaition, and americium, gallium, neptunium, plutonium, uranium, and other metals (Resource Conservation and Recoverey Act [RCRA] - regulated and nonregulated). Solid samples are dissolved in a variety of acids, including nitric and hydrochloric. Other chemicals used in the laboratory include methanol, chloroform, and other organic solvents; titanium trichloride; ceric ammonium nitrate; sodium hydroxide; silver chloride; silver nitrate; and various metals standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also place on the bottles. The Building 771 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various metals and ions, pH, and radioactivity. The principal chemicals used in the lab include sodium hydroxide, hydrochloric acid, nitric acid, cyclohexane, trioctyl phosphine oxide, yttrium, and various metal standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles. RE: Section 6.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulation A Subpopulation A includes acidic solutions generated in the Building 371 Analytical Laboratory. These solutions were sampled for pH and were determined to be corrosive (D002). Therefore, this subpopulation exhibits the characteristic of corrosivity as defined in 6 CCR 1007-3, Section 261.22. Subpopulation H These solutions were sampled for pH and were determined to be corrosive (D002). Twenty-eight bottles of newly generated solutions generated in Building 771 were sampled for metals. Nine bottles contained greater than 1.0 ppm cadmium, 20 contained greater than 5.0 ppm chromium, and nine contained greater than 5.0 ppm lead. Six bottles are below the regulatory levels for these metals. In addition, Building 771 does X-Ray Fluorescence which uses silver chloride in the analysis. Silver is presumed to be in these solutions, but it has not been determined which bottles were generated from this process and if any of the bottles sampled were from this process. This subpopulation exhibits the characteristics of corrosivity (D002) and toxicity for cadmium, chromium, and lead (D006, D007, and D008) as defined in 6 CCR 1007-3, Sections 261.22 and 261.24.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Variability surronding fullness of containers precludes a meaningful computation of density.

2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55-gallon carbon steel drums.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W068	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	ZZ	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3129

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	29.3	0.7	98.7
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	10.5	0.2	35.5
Solidified Inorganic Material:	26.3	0.6	88.6
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	17.5	0.4	59.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.77E+01
Pu-240	1.16E+00
Pu-239	5.08E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION

This waste consists of sludge type material. It is a semi-fluid material. Some of it has had cement added to it to try to solidify it.

WASTE STREAM SOURCE

IDC 823, cemented miscellaneous sludge, was generated when sludge designated as inorganic particulate and sludgy material that was below the economic discard limit (EDL) was placed in 1-gallon paint cans and covered with Portland cement or mixed with cement into a block. The first scenario was conducted in Building 771 and the second in Building 371. This could have included IDCs 290-299 and was done to meet the Waste Isolation Pilot Plant (WIPP) waste acdceptance criteria. The material came primarily from Nash pumps in Building 771 and included vacuum grease and oily sludge. One drum of the material was apparently generated when the pit in front of Building 707 was cleaned out. However, the contents of the pit sludge could not be ascertained. One drum was generated in the Size Reduction Vault in Building 776. Six drums were generated in Building 774 and are stored in Building 371. Drum-specifiec information was requested but was not received. The drums from Building 559 are incorrectly assigned IDC 823 in WEMS. The drums are stored in Building 771 and are labeled with IDC 863. It appears that IDC 823 was entered incorrectly in WEMS. Therefore, these drums should be changed to IDC 863 in WEMS.

RE: Section 8.2.11, RFETs doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, D&D, and limited Emergency Response actions.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 46GA includes 15 containers generated in the Building 371 analytical labs. The WSRIC book for the building includes no IDC 299 waste streams. Until shortly after September 1993, the WSRIC book for Building 371 included a process output numbered 371-4-18 (Low-level Soil Sludges) that was assigned EPA Codes D002-D011, D018, D019, D035, D040, F001, F002, F005-F007, and F009. The current WSRIC book for Building 371 includes a new stream, 371-4-22 (Low-Level Soil Sludges), that replaced number 371-4-18, and that is characterized only as characteristic waste with EPA Waste Codes D004-D011. The WEMS characterization for this group is D007. It is assumed, therefore, that since the containers in this group were generated from 1984 to 1992, the materials are best assigned the same waste codes as the 371-4-18 stream cited above, with the exception of the plating waste codes (F006, F007, and F009), and the reactivity code (D003), because it is known that no plating waste was generated in Building 371 labs and that no reactive wastes were generated. Most likely, all 15 containers do not contain wastes that are assigned all of the codes. It is also possible that some of the remaining waste codes can be removed based on EPA guidance concerning the sample exclusion cited in Section 261.4 (d). However, it could not be determined from personnel in Building 371 whether waste stream 371-4-18 was characterized as toxic for benzene (D018), carbon tetrachloride (D019), methyl ethyl ketone (D035), and trichloroethylene (D040) based on the double listing policy previously used or if the codes were assigned because the waste actually exhibits the characteristic of toxicity for those organics. Nor could it be confirmed whether the F-listed solvent codes were assigned because the lab felt it was generating listed solvent waste or if the codes were assigned because the lab was analyzing the F-listed solvent waste. Therefore, until these issues can be resolved, this subpopulation is characterized as hazardous and assigned EPA Waste Codes D002, D004-D011, D018, D019, D035, D040, F002, and F005. These containers should be analyzed unless data exist that can confirm or refute this characterization. The containers are all LDR regulated.

Subpopulation 46GB includes 11 containers generated in miscellaneous residue processing. All drums are characterized as hazardous and assigned EPA Waste Code D007 (chromium) in WEMS. The WSRIC book dated September 1993 includes process outputs numbered 771-12-14, 771-12-16, and 771-27-7, sludge dissolution heel, pipe sludge, and filter plenum sludge, respectively. These WSRIC outputs were generated by the Miscellaneous Residue Processing and Plenums processes. The sludges generated by residue processing are characterized as D007 wastes because the corrosive liquids the sludges came from leached chromium from the insides of stainless-steel transfer lines. The plenum sludge is characterized as nonhazardous. According to NMC, these streams were being generated during the period from 1984 to 1989, which would coincide with dates of generation for Subpopulation GB. According to NMC, the drums of IDC 299 were most likely generated by the residue processing operation. Therefore, the group is characterized as hazardous and assigned waste code D007 until analytical data are collected that prove otherwise. The containers are also LDR regulated.

Subpopulation 46DA includes one drum generated in Building 371, according to WEMS. WEMS also indicates that the drum contains D007 waste. This drum contains grit from grit blasting of stainless steel and could contain chromium. This information could not be verified or refuted at the time this document was produced. Therefore, the drum is characterized as hazardous and assigned EPA Waste Code D007 until proven otherwise. The drum is also prohibited from land disposal.

Subpopulation 46DB includes nine drums generated in Building 777 by the Machining and Coating processes. WEMS shows these drums to be nonhazardous waste. However, since it is likely that lead shielding was the primary metal that was grit blasted, it is also unlikely that the grit waste is contaminated with lead. Therefore, this group is characterized as hazardous and assigned EPA Waste Code D008 until proven otherwise. The materials are also prohibited from land disposal.

Subpopulation 46EB includes one drum generated in the Size Reduction Vault in Building 776. Since neither the source or contents of the cemented sludge in this drum could be determined, the WEMS characterization cannot be refuted. Therefore, this drum is characterized as D008 and is land disposal restricted. However, it is recommended that the material be sampled and analyzed to confirm the characterization.

Subpopulation 1B consists of approximately 85, IDC 292 incinerator sludge containers. EPA Codes D002, D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter wastes currently contained in the inventory that were generated during the time the incinerator was operational.

A report was generated from the Backlog Waste Reassessment database that summarize the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes: D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste. The EPA Code D002 has been applied, because any liquid in the waste matrix will exceed a pH of 12.5 due to the KOH. Additionally, process description and generator discussion indicates that there was no absorbent added to containers that would have absorbed the remaining liquids.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The waste is packaged in 55-gallon drums with multiple bag liners. These are typically smaller containers within the drums.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	None	Stream Name:	Aqueous Sludge/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, D002, D001, F009, F007, F006, F005, F003, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	312.8	312.8	312.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	281.5	281.5	281.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	187.6	187.6	187.6
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 3.7 Projected: 0.0 Total: 3.7

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge. Re: Section 8.2.11. RFETS doesn't expect sulfates, phosphates >1% , but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR) treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous

sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based pirmarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W013	Handling:	CH	NMVP #:	N/A	Stream Name:	Solidified Organics/TRM	Inventory Date:	10/20/94
Local ID:	IDC 801	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3222

AS-GENERATED EPA CODES

F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	615.9	229.0	858.4
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	2.56E+01
Pu-240	1.08E-01
Pu-239	4.70E-01
Am-241	2.65E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION

This waste stream consists of a cemented solid, with some free liquids. It can also have some small chunks in it.

WASTE STREAM SOURCE

Solidified organics are cemented waste oils and solvents that were generated as a result of machining and tool degreasing. Waste oil was transferred primarily from Buildings 707 and 777. Cementation was performed in Waste Management Unit (WMU) 56, Room 210, Building 774. The earliest generation date for the backlog inventory is June 1984. The Organic and Sludge Immobilization System (OASIS) Process generating solidified organics stopped in January 1990. These containers are assigned IDC 0003 and 0801.

Solidified organics waste currently stored at Rocky Flats was generated by the Grease Plant Process or the OASIS Process. The Grease Plant Process operated until November 1985. The OASIS Process began operating in November 1985. The last OASIS runs occurred in 1991.

Tanks T-1 and T-2, Tank T-374A, and Tanks T-13 and T-14 have all received waste oils and solvents for treatment at various times. The waste oils and solvents were generated primarily by processes in Buildings 707 and 777. Solvent-contaminated waste oils were generated by plutonium machining and tool degreasing. Ultrasonic cleaners consisting of trichloroethane baths were used to clean parts. Buildings 707 and 777 also cleaned metal turnings and scrap in carbon tetrachloride baths before forming them into briquettes.

Laboratory wastes in bottles were poured into containers of solidified organics in the past. Laboratory waste contaminants included organophosphates and nitrobenzene. According to the generator, bottled laboratory wastes were poured into five or fewer solidified organics containers. However, there is no documentation specifying the individual drums.

The majority of wastes fed to the solidified organics generation processes consisted of plutonium-contaminated oils and solvents. A cutting oil, usually Texaco Regal "A," flowed onto a part during machining. After machining, the part was rinsed to remove residual oil. Various solvents were used to rinse machined parts and degrease tools. These included trichloroethylene and tetrachloroethylene. According to the generator, trichloroethylene and tetrachloroethylene use stopped in 1973.

Spent carbon tetrachloride and trichloroethane from cleaning baths were also fed to the solidified organics generation processes. Parts for assembly from Buildings 707 and 777 were cleaned in ultrasonic wash tanks before welding. The tanks contained 15 gallons of trichloroethane. In another cleaning process, metal turnings and scraps were placed into perforated metal baskets and dipped into a series of tanks containing carbon tetrachloride. Each of the steel tanks held 4 gallons of solvent. The cleaned metal was then formed into briquettes. Carbon tetrachloride and trichloroethane baths were replaced periodically.

Waste oil and solvents were drained and pumped into storage tanks. The wastes were then filtered to recover the actinides. After filtering, the plutonium and uranium concentrations in the waste were measured. If the concentrations were above specified transfer limits, the waste was refiltered in the Ful-Flo filtration system. When the concentrations of plutonium and uranium were below transfer limits, the waste was transferred to the solidified organics generation processes in Building 774.

Tanks T-1 and T-2, Tank T-374A, and Tanks T-13 and T-14 received waste oils from the same processes in Buildings 707 and 777. Tanks T-1 and T-2 fed waste oils to the Grease Plant Process and the OASIS Process. Tank T-374A began feeding waste oils to the OASIS Process after damage to Tanks T-1 and T-2 was identified and they were removed from operation. Tanks T-13 and T-14 began feeding waste oils after Tank T-374A. Tanks T-374A, T-13, and T-14 were used simultaneously until Tank T-374A was removed from operation. Tanks T-13 and T-14 continued feeding the OASIS Process until it stopped in January 1990.

In the Grease Plant Process, waste oil and Microcel E (calcium silicate) were fed separately into a continuous mixer. Small amounts of Oil Dri were sometimes added to the mixture as well. The amounts of materials added to the mixture were not metered. However, the operator would adjust the composition if the outgoing mixture did not have a paste-like consistency. The mixture would then drop into an O-ring bag contained in a 55-gallon drum. Drums of solidified organics from the Grease Plant Process were subsequently transported to the Size Reduction Facility in Building 776 for inspection and sealing.

OASIS was a batch-type process generating one drum per run. Waste oils were pumped into an O-ring bag contained in a 55-gallon drum attached to the bottom of the OASIS glovebox. Envirostone emulsifier, gypsum cement, and accelerator were also metered into the bag. House water, which had not been used in any other processes, was added to the mixture as well. A Lightning Mixer was lowered into the drum after all of the materials were added. The amount of materials added to the mixture was operator controlled.

The drums were transferred to WMU 73, Room 241, after they had been inspected and sealed. Solidified organics containers from the OASIS process were stored in Building 774 until they were transferred to Building 371 for nondestructive assay (NDA). After RTR, drums were usually sent to Building 664, where they were stored until shipment off site. Solidified organics waste is not being shipped at this time. Consequently, Building 664 has reached capacity and solidified organics are also being stored in Buildings 371, 569, 774, and 776.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Solidified organics were generated by the OASIS process after November 11, 1985.

Analytical information regarding solidified organics was not found in the WSRIC Sampling and Analysis database. However, non-WSRIC analytical data from 1988 and 1989 are considered in the characterization of the waste. The analytical method was not specified for the results. However, Toxicity Characteristic Leaching Procedure (TCLP) analysis was not typically performed in 1988 and 1989. The results are assumed to be from Totals analysis. Validated headpsace analysis performed on drums containing solidified organics are considered as well. Headspace analytical results support the 1988 and 1989 results from sampling and analysis.

Wastes received by Tanks T-1 and T-2, T-374A, and T-13 and T-14 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) organics. Carbon tetrachloride (D019), nitrobenzene (D036), and trichloroethylene (D040) were cited contaminants. Nitrobenzene was a contaminant in nonroutine laboratory waste and was introduced into five or fewer drums. Contaminated drums could be not be identified. However, the solidified organics population, as a whole, does not exhibit the toxicity characteristic for nitrobenzene.

Sampling and analysis of three solidified organics samples in 1988 and 1989 indicated the waste exceeded toxicity characteristic criteria for carbon tetrachloride (EPA Code D019). The waste did not exceed toxicity characteristic criteria for any of the other cited RCRA organics. TCLP analysis of the waste under EPA SW-846 is required to support the analytical results and confirm the assumptions.

Based on the "mixture" rule and the "derived-from" rule, solidified organics would carry the listed EPA codes associated with the wastes fed to the solidified organics generation processes. EPA Codes F001 and F002 are assigned to all solidified organics because wastes received by Tanks T-1 and T-2, T-374A, and T-13 and T-14 were contaminated with regulated spent solvents in the past.

Sampling and analysis of solidified organics waste in 1988 and 1989 indicated the waste exceeded the F001 and F002 LDR treatment standards for carbon tetrachloride and 1,1,1-trichloroethane. The analyses found detectable concentrations of other F001 and F002 constituents, as well. Total analysis of the waste under EPA SW-846 is required to confirm these results.

Based on the "mixture" rule and the "derived from" rule, solidified organics would carry the listed EPA codes associated with wastes set to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned because wastes set to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at elevated levels. Solidified organics will not be considered as meeting F001, F002, F003, and F005 Land Disposal restrictions (LDR) treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SE-846 is required.

The EPA Codes F006, F007, and F009 are assigned because of contamination with waste from electroplating operations.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to solidified organics. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste. Cited laboratory chemicals like nitrobenzene were used for their intended purpose as reagents and were not discarded commercial chemical products.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is stored in 55-gallon carbon steel drums with a rigid polyethylene liner and one or two bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	None	Stream Name:	Bypass Sludge Bldg 374/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, F005, F039, F009, F007, F006, F003, D010, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	217.7	217.7	217.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	196.0	196.0	196.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	130.6	130.6	130.6
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.8 Projected: 0.0 Total: 0.8

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge.

Re: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR)

treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower

than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based pirmarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W037	Handling:	CH	NMVP #:	RF 117	Stream Name:	Heavy Metal (non-SS)/TRM	Inventory Date:	10/20/94
Local ID:	IDC 320	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5112

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	60.5	0.0	168.7
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	141.0	29.0	393.3
Other Inorganic Material:	14.0	2.9	39.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	1.14E+02
Pu-240	4.79E+00
Pu-239	2.09E+01
Am-241	2.59E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.5	0.0	0.0	8.7	10.8	21.0
Totals	1.5	0.0	0.0	8.7	10.8	21.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	8.7	10.8	21.0
Totals	1.5	0.0	0.0	8.7	10.8	21.0

As-Generated Form: Stored: 1.5 Projected: 19.6 Total: 21.0

Final Waste Form: Stored: 1.5 Projected: 19.6 Total: 21.0

WASTE STREAM DESCRIPTION	IDC 320 - Scrap metals which are heavier than iron and steel. Metal above Cu on the periodic table. Mainly used tantalum crucibles. Does not include lead.
WASTE STREAM SOURCE	Heavy metals have been produced as by-products of Rocky Flats operations in Buildings 371, 707, 771, 776, 777, 779, and 865; they are identified by IDC 320. The IDC 320 heavy nonspecial source metal was generated in various locations throughout the Rocky Flats and is stored in Resource Conservation and Recovery Act (RCRA) Units 11, 12, 13, 15A, and 20. This IDC includes nonstainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987. IDC 320 originally incl:ded lead. During maintenance operations, the maintenance shop in Building 371 generated heavy metal vessels, instruments, rods, and plates fabricated from tantalum, tungsten, and platinum. The shop generated these items during 4 1/2 years of operation from 1983 until 1988. Of these containers in storage, 19 backlog containers have an EPA Code of D008 (lead); eight of these were produced after 1987. Building 707, Modules A and J, generated heavy metals in its foundry operations. These heavy metals were primarily crucibles and pans used for presampling. These processes generated material during 6 1/2 years of operation from 1985 until 1991. Nine backlog containers have an EPA Code of D008 (lead). The plutonium recovery operations in Building 771 generated leached Oralloy parts consisting of tantalum, tungsten, and platinum. The system generated material during 3 years of operation from 1987 until 1990. Five backlog containers have an EPA Code of D008 (lead); four of these backlog containers were produced after 1987. Building 776, Pyrochemical Processing, generated material during almost three years of operation from 1988 until 1990. This material consists primarily of tantalum crucibles, stirrers, and cans from MSE, salt scrub, and anode heel processes. Eight containers have an EPA Code of D008 (lead). Building 777, the Coatings Laboratory, generated material during a 2-year period of operation from 1988 until 1990. This material consists primarily of various heavy metals used in the research and development of coating technologies. These backlog containers have been associated with lead as a constituent and were produced after 1987. The Residue Treatment Technology Group, Building 779, generated crucibles, stirrers, and other general lab equipment derived from tantalum and tungsten. In Building 779, the Physical Metallurgy Group generated tantalum materials used in casting and cast testing. Additionally, the Surface Analysis Laboratory in Building 779 generated heavy metal samples primarily of depleted uranium (D-38). IDC 320 material was produced by Building 779 operations over a 10-year period from 1981 until 1991. Nine backlog containers have an EPA Code of D008 (lead), six were produced after 1987.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	One subpopulation (25A) was identified based on specific process knowledge and generation date. The EPA Code D008 was assigned to this subpopulation because of contact with known lead products and process association. This subpopulation consists of containers produced before or during 1987. The WEMS database lists the EPA Code D008 for these containers. Because of the generation date, a conservative position has been taken by placing backlog drums with the DOO8 (lead) EPA Code in this subpopulation. The primary buildings of generation were 371, 707, 771, 776, 779. Subpopulation 25B was identified based on specific process knowledge and generation date. At this time, the generation date has been used judiciously in separating and characterizing containers with lead. The EPA Code D008 was assigned to this subpopulation because of contact with known lead products and process association. This subpopulation consists of containers produced before or during 1987. The WEMS database lists the EPA Code D008 for these containers. Because of the generation date, a conservative position has been taken by placing backlog drums with the D008 (lead) EPA Code in this subpopulation. The primary buildings of generation were 371, 707, 771, 776, and 779.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. Future generation is projected beyond 1999.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W028	Handling:	CH	NMVP #:	RF 117	Stream Name:	Lead/TRM	Inventory Date:	10/20/94
Local ID:	IDC 321	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7211

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	668.3	16.2	1438.1
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.05E+00
Pu-240	1.28E-01
Pu-239	5.60E-01
Am-241	1.86E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.9	1.4	2.8	2.8	11.7
Totals	3.7	0.9	1.4	2.8	2.8	11.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.9	1.4	2.8	2.8	11.7
Totals	3.7	0.9	1.4	2.8	2.8	11.7

As-Generated Form: Stored: 3.7 Projected: 7.9 Total: 11.6

Final Waste Form: Stored: 3.7 Projected: 7.9 Total: 11.6

WASTE STREAM DESCRIPTION

This waste form consists of metallic lead in the form of sheets, bricks, or tape.

Physical form: solid

Currently, no analytical data for lead waste is available. Process knowledge is the basis for characterization of this waste form. Lead waste (IDC 321) from non-specific sources is believed to have only lead (D008) as a hazardous constituent. In numerous tests of elemental lead, EP toxicity values exceed those listed in Table 1, 40 CFR 261.24. It is assumed that IDC 321 would also exceed EP toxicity limits for lead.

WASTE STREAM SOURCE

Transuranic lead was generated at a number of locations throughout Rocky Flats and includes IDC 321. The as-low-as-reasonably- achievable (ALARA) principle requires that the exposure of workers to radiation be kept "as low as reasonable achievable." In support of this principle, selected components and surfaces of gloveboxes enclosing materials that generate elevated levels of penetrating radiation (primarily gamma radiation) are commonly covered with metallic lead sheeting. The lead serves to attenuate the radiation dose received by employees working in the glovebox or in proximity to the glovebox. Lead waste (IDC 321) components are generally composed of lead bricks, lead shielding, and lead tape.

The lead or lead-covered components may become waste due to replacement, modification, or decommissioning activities. The dates of generation for IDC 321 range from August 15, 1986 to March 1, 1994.

The lead waste form is not a by-product of any process routinely performed at Rocky Flats. According to WSRIC Building Books, lead is most commonly generated as a result of maintenance activities. The lead waste is generally composed of lead shielding, scrap lead metal, and lead tape. The lead waste is collected in standard waste drums. The lead waste form was generated in Buildings 371, 559, 707, 771, 776, 777, and 779.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Drums Containing Scrap Lead Metal and Lead Shielding

Scrap lead metal and lead shielding exhibit the characteristic of toxicity for lead (D008). Subpopulation 8A was identified based on specific process knowledge and analytical results from elemental lead waste. According to WEMS, WSRIC, drums reports, and internal correspondence, the waste primarily consists of lead bricks, lead shielding, and scrap lead metal. Although some of waste could have come in contact with solvents, it is not considered to be a listed waste if the metal was wiped down with solvents for decontamination or paint stripping purposes, or if it was generated by the decommissioning of gloveboxes or other container-like apparatuses. Additional EPA codes are assigned to the waste based on process knowledge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined this waste form to be LDR waste based on process knowledge available for TRU lead waste (IDC 321) and the fact that elemental lead exceeds values for EP toxicity pursuant to 40 CFR 261 24. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: This waste is packaged in 55-gallon drums lined with a fiberboard liner and two polyethylene bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles, dry/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	IDC 330 is Dry Combustibles. This IDC is dry combustibles such as cloth, paper, and wood. This IDC changes to 821, 831, 851, or 861 at the point of assay, depending on radiological content. Containers of IDC 330 currently in inventory were generated in all buildings handling fissile material. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible

Inventory Date: 10/20/94

Waste Matrix Code: S5390

AS-GENERATED EPA CODES

F002, F001, D019, D011, D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This IDC changes to 822, 832, 852, or 862 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible

Inventory Date: 10/20/94

Waste Matrix Code: S5390

AS-GENERATED EPA CODES

F002, F001, D019, D011, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	IDC 337 represents PVC sheeting, poly bottles, supplied-air suits, polyethylene, and other plastics. IDC 337 changes to 825, 833, 853, or 863 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W029	Handling:	CH	NMVP #:	RF 123	Stream Name:	Leaded Dry Box Gloves/TRM	Inventory Date:	10/20/94
Local ID:	IDC 339	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D003, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	187.2	1.2	370.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	110.0	0.7	217.4
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 123

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.17E+01
Pu-240	9.13E-01
Pu-239	3.99E+00
Am-241	2.02E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	22.9	12.0	7.0	38.5	43.6	124.0
Totals	22.9	12.0	7.0	38.5	43.6	124.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	22.9	42.1	8.4	41.3	46.3	160.9
Totals	22.9	42.1	8.4	41.3	46.3	160.9

As-Generated Form: Stored: 22.9 Projected: 101.1 Total: 124.0

Final Waste Form: Stored: 22.9 Projected: 138.1 Total: 161.0

WASTE STREAM DESCRIPTION

This waste stream is a solid matrix consisting of gloves with lead lining. There could be some free liquids in waste containers.

WASTE STREAM SOURCE

Leaded glovebox gloves are generated as waste at Rocky Flats by processes requiring a controlled atmosphere in Buildings 371, 374, 559, 707, 771, 774, 776, 777, 778, and 779 and encompasses IDCs 339 and 341. Prior to January 22, 1986, all leaded glovebox gloves were accumulated together as IDC 339 (Leaded Glovebox Gloves). At that time, IDC 341 (Leaded Glovebox Gloves, Acid Contaminated) was created. IDC 339 became "Leaded Glovebox Gloves, Nonacid Contaminated." Leaded glovebox gloves are replaced by schedule or as needed.

All backlog leaded glovebox gloves (IDC 0339 and 0341) were washed in Building 776 until about September 1989, at which time the process was curtailed. The primary purpose of the washing process was to remove the accountable material; however, the acid from the acid-contaminated gloves (IDC 341) was removed as well. After the acid-contaminated gloves were washed, the IDC was changed from 341 to 339. The glove washing process was curtailed upon completion of the inventory of backlog gloves.

Due to degradation from contact with process materials during normal process operations and age, the leaded glovebox gloves are replaced according to schedule or as necessary. Nonacid-contaminated leaded glovebox gloves (IDC 339) are generated as waste or residue depending on the assay, in Buildings 371, 374, 559, 707, 771, 774, 776, 779. Acid contaminated leaded glovebox gloves (IDC 341) were washed in Building 776 after which they were assigned IDC 339.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

In addition to the reference documents and WEMS information, analytical data compiled by Rocky Flats were reviewed. This analytical information shows the presence of lead above the regulatory level stated in 6 CCR 1007-3, Section 261.24, in one sample, borderline in another, and well below the regulatory level in another.

Characterization is identified based on process knowledge. This population includes all IDC 339 nonacid contaminated gloves generated after the creation of IDC 341 (January 22, 1986). This population contains no acid-contaminated (IDC 341) gloves. This population exhibits the characteristic of toxicity for lead (D008). The primary buildings of generation were 371, 374, 559, 707, 771, 774, 776, 777, and 779.

One drum of IDC 339 gloves was generated before the creation of IDC 341 (January 22, 1986). Therefore, this drum could contain both acid- and nonacid-contaminated gloves.

Although numerous acids are used in aqueous processing, nitric is the acid of greatest concern because it dissolves the outer Hypalon layer of the gloves and reacts with the lead oxide layer to form lead nitrate and organic nitrate or nitro-organic compounds. These compounds are in very small quantities and do not cause the gloves to exhibit the characteristic of ignitability as outlined in 6 CCR 1007-3, Section 261.21. However, when dried, the compound decomposes violently at temperatures ranging from 60 to 130 degrees C. Also, the compound explodes when subjected to an impact load or when confined and ignited with a fuse. Unconfined, the compound burns violently when ignited with a spark. This drum is therefore assigned D003 for reactivity as outlined in 6 CCR 1007-3, Section 261.23 (a) (6).

Population 42A: Identified based on process knowledge, EPA codes, and generation dates. This population includes all IDC 339 nonacid contaminated gloves generated after the creation of IDC 341 (January 22, 1986). This population contains no acid-contaminated (IDC 341) gloves. This population exhibits the characteristic of toxicity for lead (D008). The primary buildings of generation were 371, 374, 559, 707, 771, 774, 776, 777, and 779.

Subpopulation 43B: This subpopulation includes all acid-contaminated leaded glove box gloves. As previously discussed, these gloves exhibit the characteristic of toxicity for lead (D008) and reactivity (D003). The primary buildings of generation were 371, 771, 777, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS	RFP has assumed this waste to be LDR based on the fact that lead is a RCRA listed waste exhibiting the characteristic of toxicity. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The gloves are packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.
FINAL FORM COMMENTS	Projections include generation from processing IDC 341 to IDC 339.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W041	Handling:	CH	NMVP #:	N/A	Stream Name:	Leaded Gloves-Acid Contaminated/TRM	Inventory Date:	10/20/94
Local ID:	IDC 341	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5311

AS-GENERATED EPA CODES

D008, D003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	2.91E+01
Pu-240	1.22E+00
Pu-239	5.34E+00
Am-241	7.94E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	26.2	0.0	0.0	0.0	0.0	26.2
Totals	26.2	0.0	0.0	0.0	0.0	26.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 26.2 Projected: 0.0 Total: 26.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

IDC No. 341. This waste stream consists of leaded rubber gloves used in the glovebox systems for plutonium recovery operations in Buildings 771 and 371. These gloves are contaminated with nitric acid and other acids when replaced and discarded as waste.

WASTE STREAM SOURCE

Leaded Glovebox Gloves

Waste Form/Item Description Code/Waste Form Code Background for the Leaded Glovebox Gloves Waste Form

Leaded glovebox gloves are generated as waste or residue at Rocky Flats by processes requiring a controlled atmosphere in Buildings 371, 374, 559, 707, 771, 774, 776, 777, 778, and 779 and encompasses IDCs 339 and 341. Prior to January 22, 1986, all leaded glovebox gloves were accumulated together as IDC 339 (Leaded Glovebox Gloves). At that time, IDC 341 (Leaded Glovebox Gloves, Acid Contaminated) was created. IDC 339 became "Leaded Glovebox Gloves, Nonacid Contaminated." Leaded glovebox gloves are replaced by schedule or as needed.

All backlog leaded glovebox gloves (IDC 0339 and 0341) were washed in Building 776 until about September 1989, at which time the process was curtailed. The primary purpose of the washing process was to remove the accountable material; however, the acid from the acid-contaminated gloves (IDC 341) was removed as well. After the acid-contaminated gloves were washed, the IDC was changed from 341 to 339. The glove washing process was curtailed upon completion of the inventory of backlog gloves.

Item Description Code 341

Acid-contaminated leaded glovebox gloves (IDC 341) are generated as waste or residue depending on the assay, in Buildings 371, 771, 777, and 779. Due to degradation from contact with process materials and age, the gloves are replaced according to schedule or as necessary. When acid-contaminated gloves (IDC 0341) were washed, the IDC was changed to 0339.

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

In addition to the reference documents and WEMS information, analytical data compiled by Rocky Flats were reviewed. This analytical information shows the presence of lead above the regulatory level stated in 6 CCR 1007-3, Section 261.24, in one sample, borderline in another and well below the regulatory level in another.

Leaded glovebox gloves are manufactured with a lead oxide layer between two or more layers of neoprene-Hypalon, for shielding against penetrating radiation. The available analytical data were obtained from unused, 30-millimeter-thick gloves. Analytical data for the lead content of 50- and 80-millimeter-thick leaded gloves are not available. However, the lead content is assumed to be substantially higher than the 30-millimeter-thick gloves. Also, the lead from used gloves, degraded from contact with process materials, may leach more readily than from unused gloves.

Toxicity Characteristic Leaching Procedure (TCLP) metals by Inductively Coupled Plasma Emission Spectroscopy showed the lead above the regulatory limit. Other contaminants include acid and base solutions and listed solvents. Glovebox gloves used in processes that require listed solvents are not considered listed solvent wastes because the gloves do not retain solvents in the same way paper or cloth wipes do. Contact of the gloves with solvents is considered incidental contact. Therefore, the gloves are not subject to the mixture rule.

IDC 341 includes leaded gloves exposed to acids which have not been washed. Although numerous acids are used in aqueous processing, nitric is the acid of greatest concern because it dissolves the outer Hypalon layer of the gloves and reacts with the lead oxide layer to form lead nitrate and organic nitrate or nitro-organic compounds. These compounds are in very small quantities and do not cause the gloves to exhibit the characteristic of ignitability as outlined in 6 CCR 1007-3, Section 261.21. However, when dried, the compound decomposes violently at temperatures ranging from 60 to 130 degrees C. Also, the compound explodes when subjected to an impact load or when confined and ignited with a fuse. Unconfined, the compound burns violently when ignited with a spark. IDC 341 leaded gloves are therefore

assigned D003 for reactivity as outlined in 6 CCR 1007-3, Section 261.23 (a)(6).

This subpopulation includes all IDC 341 acid-contaminated leaded glovebox gloves. As previously discussed, IDC 341 gloves exhibit the characteristic of toxicity for lead (D008), and reactivity (D003). The primary buildings of generation were 371, 771, 777, and 779.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that leaded gloves and acid-contaminated leaded gloves are LDR waste based on the process knowledge available. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W008	Handling:	CH	NMVP #:	RF 121	Stream Name:	Soil & Cleanup Debris/TRM	Inventory Date:	10/20/94
Local ID:	IDC 374	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5190

AS-GENERATED EPA CODES

F001, F002, F006, F009, F003, F005, F007, F039, D006, D007, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	273.1	208.9	628.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.0	12.0	12.0
Rubber:	0.0	0.0	0.0
Plastics:	12.0	12.0	12.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	64.9	9.6	628.4
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

RF 121

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	3.30E+00
Pu-240	1.39E-01
Pu-239	6.06E-01
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 1.2 Projected: 0.0 Total: 1.2

WASTE STREAM DESCRIPTION

This waste consists of blacktop/concrete/dirt/sand.

WASTE STREAM SOURCE

Soil and cleanup-debris (IDC 374) were generated during cleanup and construction activities around Rocky Flats. In most cases, construction or demolition activities generated rubble consisting of blacktop, concrete, dirt, sand , and rock. The rubble was packaged in plywood boxes with a fiberboard liner and a polyvinyl chloride (PVC) bag liner or in 55-gallon, DOT Type 7A drups. The waste was generated on a nonroutine basis. Information describing spendid activities generating soil and debris were often unavailable.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Subpopulation 23B-Container Number D48510

Drum D48510 was generated in Building 374, Room 3803. Room 3803 houses part of the Building 374 Sludge Immobilization Process. The process generated solidified sludge. The waste in drum D48510 is potentially contaminated with process sludge. The sludge consists of RCRA-regulated materials from Decontamination-Precipitation and Neutralization Processes in the Building 374 Liquid Waste Treatment Facility. Building 374 solidified sludge is characterized in the Building 374 Solidified Sludge Backlog Baseline Book.

Building 374 sludge was intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Sampling and analysis of solidified sludge found the waste exceeded toxicity characteristic criteria for chromium (EPA Code D007) and selenium (D010) but at very low levels. It will be assumed that the waste contained in drum D48510 would not exhibit the characteristic of toxicity for chromium and selenium because of dilution by the soil and debris. Toxicity Characteristic Leaching Procedure (TCLP) analysis of the waste under EPA SW-846 is required to prove the waste does not exceed toxicity characteristic criteria.

Contaminated soil and cleanup debris must also carry the listed EPA codes associated with Building 374 solidified sludge. The EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 are assigned to the waste and it will not be considered as meeting the Land Disposal Restrictions (LDR) treatment standards until sampling and analysis proves otherwise.

Subpopulation 23D-Container Number D75005

WEMS indicates drum D75005 was generated in Building 776. However, the waste was repackaged in Building 776 in April 1988 after a failed drum containing the waste was discovered in the Property Utilization and Disposal storage yard.

The drum contains soil and two sample vials of chromium oxide and aluminum oxide. It will be assumed that the waste contained in drum D75005 exhibits the characteristic of toxicity for chromium (D007) because of chromium oxide contamination. TCLP analysis of the waste under EPA SW-846 is required to prove the waste does not exceed toxicity characteristic criteria.

Subpopulation 23E-Soil and Asphalt from the 750 and 904 Pads Earth Anchor Installation

The installation of earth anchors for the 750 and 904 Pads in 1990 and 1991 generated a large amount of soil and asphalt. The waste was packaged in half-boxes with the generation prefix 788. Some of the half-boxes were rejects but were used because the waste was expected to remain in the reject containers for a short time before remediation activities began. During remediation of the pads, containers of soil and debris were to be emptied and the waste treated. These activities never occurred and the waste is still in the rejected containers.

The soil and debris may have been contaminated with pondcrete and saltcrete waste stored in the pad areas. The work procedure required that EPA codes associated with pondcrete and saltcrete be assigned to the soil and debris. An explanation of codes applicable to pondcrete and salcrete is provided in the Pondcrete Backlog Baseline Book and the Saltcrete Backlog Baseline Book.

Pondcrete and saltcrete were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Sampling and analysis of saltcrete found the waste did not exhibit a characteristic for RCRA metals. Sampling and analysis of pondcrete found the waste exceeded toxicity characteristic criteria for cadmium (EPA Code D006) and chromium (EPA Code D007) but at very low levels. It is assumed that the soil and debris from the earth anchor installation does not exhibit the characteristic of toxicity.for cadmium and chromium because of dilution by the soil and debris. TCLP analysis of the waste under EPA SW-846 (EPA 1990) is required to prove the waste does not exceed toxicity characteristic criteria.

Contaminated soil and debris from the earth anchor installation must carry the listed EPA codes associated with pondcrete and saltcrete. The EPA Codes F001, F002, F003, F005, F006, F007, F009, and F039 are assigned to the waste and it will not be considered as meeting the LDR treatment standards until sampling and analysis proves otherwise.

Other EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

GENERAAREA: Plutonium process areas. GENOPERATION: Generated in multiple buildings in which aqueous plutonium recovery or plutonium fabrication processes were conducted. RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed. CATION: Not Applicabe. OTHER_CHAR: Not Applicable.

RFP has determined this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: 55 gallon carbon steel DOT 7A Type A Drum.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W026	Handling:	CH	NMVP #:	RF 122	Stream Name:	Used Absorbents/TRM	Inventory Date:	10/20/94
Local ID:	IDC 375	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3114

AS-GENERATED EPA CODES

F002, D019, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	167.3	167.3	167.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	7.7	7.7	7.7
Solidified Organic Material:	7.7	7.7	7.7
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 122

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	8.32E-01
Pu-240	3.24E-02
Pu-239	1.42E-01
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste form is vermiculite with absorbed organic liquid.
WASTE STREAM SOURCE	This waste stream was previously named "Spent Absorbent/TRU (Oil Dri)". This waste stream was not specifically identified in the Storage or Inventory Report prepared by RFP in fulfillment of FFCA requirements. This waste is the TRU fraction of the waste titled "Oil Dri/LLW Mixed" in the Inventory Report. Normally it is LLW, but occasionally some assays as TRU. This waste stream is IDC No. 375 Absorbents, usually vermiculite materials, which are used in the plutonium and uranium process areas for cleanup of hazardous liquid spills (spent solvents), oil absorption, or absorption of any liquids as needed. One of the most commonly used absorbents is Oil Dri(R). Spent absorbents are assumed to be radiologically contaminated. The waste is packaged in 55-gallon drums lined with two polyethylene bags. IDC 375 - Any type of absorbent vermiculite material. Mixed waste. Oil Dri is an absorbent vermiculite material.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	No sample analysis of this material has been performed. Characterization is based on process knowledge. Subpopulation 18C This single drum, D72372, is in Subpopulation 18C. Based on process knowledge information on this drum and the use of carbon tetrachloride and Freon TF in Building 707, Module C, shown in WSRIC, this drum's contents are considered to be RCRA hazardous. It is further assumed that the contents exhibit the characteristic of toxicity for carbon tetrachloride; therefore, EPA Code D019 is assigned. EPA codes have also been assigned for the F-listed solvents. The CCC for this drum is 1020. No analytical data are available for this subpopulation.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP has assumed this waste to be LDR based on process knowledge characterization and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: This waste is packaged in a 55 gallon carbon steel drum.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	RF 122	Stream Name:	Firebrick, coarse/TRM	Inventory Date:	10/20/94
Local ID:	IDC 377,378,373,37	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	71.2	30.4	180.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	19.6	8.4	49.7
Rubber:	13.0	5.5	32.9
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 122

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	2.85E+01
Pu-240	1.20E+00
Pu-239	5.24E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.5	0.0	0.0	0.0	0.0	3.5
Totals	3.5	0.0	0.0	0.0	0.0	3.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	0.0	0.0	0.0	0.0	3.5
Totals	3.5	0.0	0.0	0.0	0.0	3.5

As-Generated Form: Stored: 3.5 Projected: 0.0 Total: 3.5

Final Waste Form: Stored: 3.5 Projected: 0.0 Total: 3.5

WASTE STREAM DESCRIPTION	This waste form is firebrick that has been crushed and pulverized.
WASTE STREAM SOURCE	During maintenance operations, pulverized scarfed firebrick was generated in Building 771. This material was also generated during incinerator stripout operations in Building 371. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Pulverized firebrick consists of chunks granular, fine, and very fine, plutonium-bearing surface layer of the high-density alumina ceramic firebrick material. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulations IK, IL, IM, IN EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational. A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Net and gross weight data are not available for all container types. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surronding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner. Projected future generation begins in CY2005.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W036	Handling:	CH	NMVP #:	N/A	Stream Name:	Firebrick, pulverized or fines/TRM
Local ID:	IDC 377,378,373,3	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

F003, D011, D009, D010, F001, D005, D004, D008, F002, F005, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.85E+01
Pu-240	1.20E+00
Pu-239	5.24E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form is firebrick that has been crushed and pulverized.
WASTE STREAM SOURCE	During maintenance operations, pulverized scarfed firebrick was generated in Building 771. This material was also generated during incinerator stripout operations in Building 371. Spent firebrick was subjected to a mechanical scarfing process to remove plutonium-bearing surface layers. Pulverized firebrick consists of chunks granular, fine, and very fine, plutonium-bearing surface layer of the high-density alumina ceramic firebrick material. The current inventory contains 45 drums mixed transuranic waste and residues. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Subpopulations IK, IL, IM, IN EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to these subpopulations based on the characterization of incinerator feed materials. Based on the characterization of the feed, alcohols, glycols, halogenated solvents, and metals may have been introduced into the incinerator. Because the specific sources of the incinerator feed cannot be determined at this time, it has been assumed that the process could have accepted any of the combustible, plastic, or filter waste currently contained in the backlog that were generated during the time the incinerator was operational. A report was generated from the Backlog Waste Reassessment database that summarizes the EPA codes assigned to inventory containers of combustibles (IDCs 330 and 336), plastics (337), and Ful-Flo filters (331) generated about the same time that the incinerator was operational. The following EPA codes were contained in the database for these wastes; D004-D011, D018, D019, D028, D029, D035, D038, F001, F002, F003, and F005. It was assumed that the F-listed solvents would have to be applied due to the "derived-from" rule. The codes for the D-listed metals were applied because these metals would be concentrated during incineration. However, it was assumed that the D-listed solvent would be volatilized and driven off in this process. Therefore, these solvents would not be present at levels exceeding Toxicity Characteristic Leaching Procedure (TCLP) limits due to the thermal treatment. This subpopulation is land disposal restricted due to the presence of RCRA metals. It is not land disposal restricted for F-listed solvents because the Best Demonstrated Available Technology (BDAT) (thermal treatment) was used to treat this waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Net and gross weight data are not available for all container types. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Variability surrounding fullness of containers precludes a meaningful computation of density. 2. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is packaged in 55- gallon drums lined with a rigid polyethylene liner.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	incinerator ash/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: S3111

AS-GENERATED EPA CODES

D011, D010, D009, D006, D004, F005, F003, D007, D008, D005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	4.08E+01
Pu-240	1.72E+00
Pu-239	7.49E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Residue Recovery Incinerator system in Building 771, Fluidized Bed Incinerator (FBI) in Building 776, and test runs by the incinerator in Building 371.

The Low-Specific Activity (LSA) and High-Specific Activity (HSA) incinerators in Building 371 were developed as volume-reduction incinerators. The startup operation test used noncontaminated materials throughout the processes. The test revealed design concerns; therefore, these incinerators never became operational. No WSRIC information is available to describe this process in greater detail.

The function of the Residue Recovery Incinerator was to reduce volume and destroy volatile constituents prior to plutonium recovery operations for combustible wastes from production processes (primarily IDCs 330, 331, 336, and 337). Waste feed was hand-sorted to segregate combustibles. Noncombustibles such as metal and glass were segregated and removed from the process. The by-products of this process included ash (IDCs 419, 420, 421, and 428).

Item Description Code 420, Pulverized Incinerator Ash

Pulverized incinerator ash was generated as an intermediate product during routine operation of the incinerator in Building 771. This material was also generated during incinerator stripout operations in Building 371. The pulverized ash consists of a mixture of coarse, granular, fine, and very fine particulates that have been ground by the ball mill. The ash contains miscellaneous tramp metal, bits of unburned feed material, and carbon from the incomplete oxidation of feed material.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W040	Handling:	CH	NMVP #:	N/A	Stream Name:	incinerator ash/TRM
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: S3111

AS-GENERATED EPA CODES

D007, F005, F003

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.08E+01
Pu-240	1.72E+00
Pu-239	7.49E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This waste stream is a fire particulate ash. It could also be chunky material from moisture.

WASTE STREAM SOURCE

This waste form consists of waste generated by the Fluidized Bed Incinerator (FBI) in Building 776.

The FBIs in Building 776 were developed as pilot operations. Their test function was to develop new technology to reduce volume and destroy volatile constituents prior to plutonium recovery operations. The only incinerator to generate backlog waste covered by this waste form was the Full-Scale Unit. The first runs of this incinerator (1978 to 1981) used newspaper, Building 776 low-level waste (LLW), combustible waste, kerosene, garage oil, and grease as test materials. The tests were conducted with methanol, diesel products, and nonradioactive surrogate combustibles (shredded coveralls, leather gloves, rolls of polyvinyl chloride [PVC] plastic, wood, and paper). The by-product of this process was FBI ash (IDC 425).

Item Description Code 425, Fluidized Bed Ash

This waste is a mixture of aluminum oxide and a chromium oxide oxidation catalyst, sodium carbonate, and ash, mainly catalyst and sodium carbonate ash from Building 776. During the incineration of materials containing chloride compounds, a portion of the sodium carbonate changes to sodium chloride.

The Pilot-Scale FBI Unit was operated from 1971 to 1978. The first runs used PVC, polyethylene, and paper as test materials. After 1974, paint thinner from the Building 333 paint shop, tributyl phosphate, kerosene, and hydrazine hydrate were burned. Polychlorinated biphenyls (PCBs), mixed 1 part PCB to 4-5 parts diesel fuel or kerosene were burned in 1978. Unless containers of backlog waste were generated during maintenance operations of the Pilot-Scale Unit, all containers in the current inventory were generated after 1978 and are assumed to be from the Full-Scale Unit. Though the Pilot-Scale Unit burned PCBs, the ash is not Toxic Substance Control Act (TSCA) regulated. The incinerator burned at a high destruction efficiency and PCBs over the TSCA regulatory limit of 50 parts per million (ppm) are not anticipated in the ash.

The Full-Scale Unit was operated from 1978 to 1981, and again from 1985 to 1988. The first runs (1978 to 1981) used newspaper, Building 776 LLW, combustible waste, kerosene, garage oil, and grease as test materials. The tests from 1985 to 1988 were conducted with methanol, diesel products, and nonradioactive surrogate combustibles (shredded coveralls, leather gloves, rolls of PVC plastic, wood, and paper).

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

One subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes the ash generated by the Full-Scale unit. EPA code D007 was assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

Another subpopulation consists of IDC 425 materials characterized under Backlog Waste Reassessment Task 7, Event 20, but only includes ash generated by the Pilot-Scale unit. EPA codes D007, F003, and F005 were assigned to the subpopulation. The characterization rationale for this subpopulation can be found in the report prepared for this event.

The last subpopulation consists of IDC 420 backlog containers. EPA codes D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation based on the characterization of incinerator feed materials (alcohols, glycols, halogenated solvents, and metals). However, this subpopulation contained no free liquids and thus D002 is not applied.

Subpopulation 1D consists of IDC 425 materials characterized under Task 7, Event 20 but only includes the ash generated by the Pilot-Scale Unit. EPA Codes D007, F003, and F005 were assigned to the subpopulation. Rationale for this subpopulation can be found in the report prepared for this event.

Subpopulations 1F, 1G, 1P, and 1Q, consist of IDCs 420, 421, 423, 371, 373, 377, 378, 422, 428, and 419, respectively, for backlog inventory containers. EPA Codes

D004-D011, F001, F002, F003, and F005 were assigned to this subpopulation.

Limited analytical data indicate that this waste form exceeds the LDR treatment standard for chromium. These data must complete data validation. The results to date are discussed in the Waste Characterization Report, Incinerator Ash, Item Description Codes 420 and 425.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that incinerator ash is LDR waste based on available process knowledge. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. FBI ash was packaged in 55-gallon drums lined with a rigid polyethylene liner and one bag liner.

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W052	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

D009, D008, D005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	2.0	0.0	5.3
Other Inorganic Material:	136.8	16.8	352.5
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	1.2	0.0	3.1
Plastics:	30.3	3.7	78.1
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	138.7		
Packaging Material Plastic:	34.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.75E+00
Pu-240	2.83E-01
Pu-239	1.28E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	8.3	10.7	22.8	21.9	67.4
Standard waste box /	1.9	4.0	5.2	11.2	11.8	34.0
Totals	5.6	12.3	15.9	33.9	33.7	101.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	8.3	10.7	22.8	21.9	67.4
Standard Waste Box	1.9	4.0	5.2	11.2	11.8	34.0
Totals	5.6	12.3	15.9	33.9	33.7	101.4

As-Generated Form: Stored: 5.6 Projected: 95.8 Total: 101.4

Final Waste Form: Stored: 5.6 Projected: 95.8 Total: 101.4

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 440 includes glass waste from analytical laboratories and recovery processes, standard light bulbs generated inside the PA, and ceramic materials. Glass waste assigned IDC 440 was generated in Buildings 123,371, 444, 559, 707, 771, 776, 777, 889. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data. This waste stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Item Description Code 440 This IDC was separated from IDC 444 (created in 1989 specifically for ground glass and leaded glass) because the two waste forms exhibit different chemical characteristics, hazardous constituents, and EPA codes. Therefore, drums of IDC 440 materials generated prior to 1989 could contain leaded glass. These are included in Subpopulation 17G and are assigned EPA codes D005 and D008. Item Description Code 442 In addition to the reference documents and WEMs information used, analytical data compiled by EG&G Rocky Flats were reviewed. The data shows that the concentrations of Toxicity Characteristic (TC) metals barium, cadmium, chromium, lead, and silver were well below regulated levels provided in 6 CCR 1007-3, Section 261.24. Subpopulation 17F includes Raschig Rings assigned IDC 442 that are contaminated with carbon tetrachloride, 1,1,1-trichloroethane, or both. Based on analytical data, Raschig Rings do not exhibit the characteristic of toxicity for metals. All containers in this group were generated in Building 777 according to WEMS. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. Therefore, it is assumed that these rings are all contaminated with carbon tetrachloride or 1,1,1-trichloroethane sludge. They are, therefore, assigned EPA Waste Codes F001 and F002. Subpopulation 27B is assigned EPA code D009 because of mercury in the spent fluorescent lamps.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP has determined that this grouping is LDR waste based on available process knowledge with some of the IDCs identified containing listed hazardous components. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of is generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: DOT 7A TYPE A metal boxes and DOT 7A TYPE A drums.
FINAL FORM COMMENTS	Assuming 67% of projected generation will be in 55-gallon drums based on current container inventory.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W052	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.7	0.0	24.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	250.8	19.1	415.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.6	0.0	12.6
Rubber:	0.0	0.0	0.0
Plastics:	8.7	0.6	14.5
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	6.75E+00
Pu-240	2.83E-01
Pu-239	1.28E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.7	21.7	28.0	59.6	59.0	174.9
Totals	6.7	21.7	28.0	59.6	59.0	174.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.7	20.4	28.0	59.6	59.0	173.6
Totals	6.7	20.4	28.0	59.6	59.0	173.6

As-Generated Form: Stored: 6.7 Projected: 168.3 Total: 174.9

Final Waste Form: Stored: 6.7 Projected: 168.3 Total: 174.9

WASTE STREAM DESCRIPTION

This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.

WASTE STREAM SOURCE

Raschig Rings currently in WEMS assigned IDC 442 were generated in Buildings 771, 776, and 777. Prior to being replaced, the tanks were drained and the rings were leached with dilute nitric acid or water. The rings generated in Building 771 are from the production processes and Tanks D80-65, d0-360, D-361, D-451, D-454, D-467, D-750, D-706, D-922, D-973, D-974, D-980, D-1008, D-1013, D-1022, and D-1081. Rings generated in Building 776 are from the Size Reduction Process and Tanks SR 3, 4, and 5 and as unused rings. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. The building 777 rings should be assigned IDC 443 as discussed in the following section.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data

This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

Item Description Code 440

This IDC was separated from IDC 444 (created in 1989 specifically for ground glass and leaded glass) because the two waste forms exhibit different chemical characteristics, hazardous constituents, and EPA codes. Therefore, drums of IDC 440 materials generated prior to 1989 could contain leaded glass. These are included in Subpopulation 17G and are assigned EPA codes D005 and D008.

Item Description Code 442

In addition to the reference documents and WEMs information used, analytical data compiled by EG&G Rocky Flats were reviewed. The data shows that the concentrations of Toxicity Characteristic (TC) metals barium, cadmium, chromium, lead, and silver were well below regulated levels provided in 6 CCR 1007-3, Section 261.24.

Subpopulation 17F includes Raschig Rings assigned IDC 442 that are contaminated with carbon tetrachloride, 1,1,1-trichloroethane, or both. Based on analytical data, Raschig Rings do not exhibit the characteristic of toxicity for metals. All containers in this group were generated in Building 777 according to WEMS. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. Therefore, it is assumed that these rings are all contaminated with carbon tetrachloride or 1,1,1-trichloroethane sludge. They are, therefore, assigned EPA Waste Codes F001 and F002.

Subpopulation 27B is assigned EPA code D009 because of mercury in the spent fluorescent lamps.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has determined that this grouping is LDR waste based on available process knowledge with some of the IDCs identified containing listed hazardous components. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of is generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: DOT 7A TYPE A metal boxes and DOT 7A TYPE A drums.

FINAL FORM COMMENTS N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W032	Handling:	CH	NMVP #:	RF 118	Stream Name:	Ground Leaded Glass/TRM	Inventory Date:	10/20/94
Local ID:	IDC 444, 855	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

D008, D005, D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	135.5	61.3	193.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.1	1.1	1.1
Rubber:	1.1	1.1	1.1
Plastics:	19.8	19.8	19.8
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	130.9		
Packaging Material Plastic:	8.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.33E+00
Pu-240	5.61E-02
Pu-239	2.45E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.1	0.1	0.3	0.3	1.7
metal box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Standard waste box /	1.9	0.3	0.3	0.7	0.6	3.8
Totals	5.9	0.4	0.5	1.0	0.9	8.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.1	0.1	0.3	0.3	1.7
Standard Waste Box	1.9	1.1	1.3	2.6	2.5	9.4
Totals	2.7	1.2	1.5	2.9	2.8	11.1

As-Generated Form: Stored: 5.9 Projected: 2.7 Total: 8.6

Final Waste Form: Stored: 2.7 Projected: 8.4 Total: 11.1

WASTE STREAM DESCRIPTION	Matrix consits of crushed glass light bulbs and leaded glass that is crushed on removal.
WASTE STREAM SOURCE	IDC 444 includes ground fluorescent bulbs and leaded glass used throughout the plutonium-and-uranium-processing areas. The material was generated as waste or residue when glovebox glass was replaced, or as low-level waste when fluorescent light bulbs were replaced. IDC 444 materials in the backlog inventory were generated in Building 371, 374, 559, 707, 771, and 776. This stream is generated from Facilities Operations, Analytical Laboratories, and R&D Laboratories. Re: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt% but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Analytical data showed the presence of toxic metals in some containers of IDC 444. Based on these analytical data, these materials are characterized as hazardous and assigned EPA codes D005 and D008. Analytical data for IDC 855 show that there are enough cases where the samples fail the Toxicity Characteristic Leaching Procedure (TCLP), that the waste bulbs should be managed as hazardous waste and assigned the EPA code D009. EPA codes are assigned to newly generated waste by the generator based on process knowledge. Subpopulation 17G includes containers of leaded glovebox glass. Based on analytical data, these materials are characterized as hazardous and assigned EPA Waste Codes.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	LDR_DETERM: Net and gross weight data are not available for all container types. RFP has assumed this waste to be LDR based on the fact that it is a RCRA listed waste. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The glass waste is packaged in 55- gallon drums that are lined with one fiberboard liner and two polyethylene bags or metal boxes. Drums are placed in TRUPACT II containers.
FINAL FORM COMMENTS	Assuming 13% of projected generation will be 55-gallon drums based on current inventory.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W011	Handling:	CH	NMVP #:	RF 117	Stream Name:	LIGHT METAL/TRM	Inventory Date:	10/20/94
Local ID:	IDC 480	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

D007, D002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	160.4	1.7	488.7
Aluminum-base Metal/Alloys:	20.2	0.2	61.6
Other Metals/Alloys:	7.6	0.0	23.3
Other Inorganic Material:	13.4	0.1	40.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.5	0.0	7.6
Rubber:	2.9	0.0	8.9
Plastics:	21.2	0.2	64.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.10E+01
Pu-240	4.64E-01
Pu-239	2.03E+00
Am-241	1.84E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	34.4	14.9	155.8	95.2	300.6
Totals	0.2	34.4	14.9	155.8	95.2	300.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	34.4	14.9	155.8	95.2	300.6
Totals	0.2	34.4	14.9	155.8	95.2	300.6

As-Generated Form: Stored: 0.2 Projected: 300.4 Total: 300.6

Final Waste Form: Stored: 0.2 Projected: 300.4 Total: 300.6

WASTE STREAM DESCRIPTION	This waste stream is metal tools, etc. generated during glovebox operations.
WASTE STREAM SOURCE	The one container of IDC 480, Light metal, in this waste form was generated in Building 707, Module K, in April 1991. The metal in this container is line generated material.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed. RFP has assumed this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and several bag liners.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W090	Handling:	CH	NMVP #:	N/A	Stream Name:	Excess Chemicals/TRM
Local ID:	0544	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: X6900

AS-GENERATED EPA CODES

D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is lab packs and excess chemicals that are generated throughout Rocky Flats.
WASTE STREAM SOURCE	RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based on general knowledge of the waste type or source.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	RF 111	Stream Name:	Solidified Sludge - Bldg 774 / TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, F005, F009, F007, F006, F003, D040, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	387.6	44.3	528.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	193.8	22.2	264.1
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	193.8	22.1	264.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 111

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	65.5	1.3	2.5	25.8	9.7	104.8
Totals	65.5	1.3	2.5	25.8	9.7	104.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	65.5	1.3	2.5	25.8	9.7	104.8
Totals	65.5	1.3	2.5	25.8	9.7	104.8

As-Generated Form: Stored: 65.5 Projected: 38.9 Total: 104.4

Final Waste Form: Stored: 65.5 Projected: 38.9 Total: 104.4

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge.

Re: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR)

treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower

than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based pirmarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W013	Handling:	CH	NMVP #:	RF 112	Stream Name:	Solidified Organics - Bldg 774/TRM	Inventory Date:	10/20/94
Local ID:	IDC 801	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3222

AS-GENERATED EPA CODES

D040, F006, F005, F003, F001, F009, D019, D011, D010, D009, D008, D007, D006, D005, D004, F007, F002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	987.1	367.1	1375.6
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 112

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.56E+01
Pu-240	1.08E-01
Pu-239	4.70E-01
Am-241	2.65E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	109.0	0.0	0.0	0.0	0.0	109.0
Totals	109.0	0.0	0.0	0.0	0.0	109.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	109.0	0.0	0.0	0.0	0.0	109.0
Totals	109.0	0.0	0.0	0.0	0.0	109.0

As-Generated Form: Stored: 109.0 Projected: 0.0 Total: 109.0

Final Waste Form: Stored: 109.0 Projected: 0.0 Total: 109.0

WASTE STREAM DESCRIPTION

This waste stream consists of a cemented solid, with some free liquids. It can also have some small chunks in it.

WASTE STREAM SOURCE

Solidified organics are cemented waste oils and solvents that were generated as a result of machining and tool degreasing. Waste oil was transferred primarily from Buildings 707 and 777. Cementation was performed in Waste Management Unit (WMU) 56, Room 210, Building 774. The earliest generation date for the backlog inventory is June 1984. The Organic and Sludge Immobilization System (OASIS) Process generating solidified organics stopped in January 1990. These containers are assigned IDC 0003 and 0801.

Solidified organics waste currently stored at Rocky Flats was generated by the Grease Plant Process or the OASIS Process. The Grease Plant Process operated until November 1985. The OASIS Process began operating in November 1985. The last OASIS runs occurred in 1991.

Tanks T-1 and T-2, Tank T-374A, and Tanks T-13 and T-14 have all received waste oils and solvents for treatment at various times. The waste oils and solvents were generated primarily by processes in Buildings 707 and 777. Solvent-contaminated waste oils were generated by plutonium machining and tool degreasing. Ultrasonic cleaners consisting of trichloroethane baths were used to clean parts. Buildings 707 and 777 also cleaned metal turnings and scrap in carbon tetrachloride baths before forming them into briquettes.

Laboratory wastes in bottles were poured into containers of solidified organics in the past. Laboratory waste contaminants included organophosphates and nitrobenzene. According to the generator, bottled laboratory wastes were poured into five or fewer solidified organics containers. However, there is no documentation specifying the individual drums.

The majority of wastes fed to the solidified organics generation processes consisted of plutonium-contaminated oils and solvents. A cutting oil, usually Texaco Regal "A," flowed onto a part during machining. After machining, the part was rinsed to remove residual oil. Various solvents were used to rinse machined parts and degrease tools. These included trichloroethylene and tetrachloroethylene. According to the generator, trichloroethylene and tetrachloroethylene use stopped in 1973.

Spent carbon tetrachloride and trichloroethane from cleaning baths were also fed to the solidified organics generation processes. Parts for assembly from Buildings 707 and 777 were cleaned in ultrasonic wash tanks before welding. The tanks contained 15 gallons of trichloroethane. In another cleaning process, metal turnings and scraps were placed into perforated metal baskets and dipped into a series of tanks containing carbon tetrachloride. Each of the steel tanks held 4 gallons of solvent. The cleaned metal was then formed into briquettes. Carbon tetrachloride and trichloroethane baths were replaced periodically.

Waste oil and solvents were drained and pumped into storage tanks. The wastes were then filtered to recover the actinides. After filtering, the plutonium and uranium concentrations in the waste were measured. If the concentrations were above specified transfer limits, the waste was refiltered in the Ful-Flo filtration system. When the concentrations of plutonium and uranium were below transfer limits, the waste was transferred to the solidified organics generation processes in Building 774.

Tanks T-1 and T-2, Tank T-374A, and Tanks T-13 and T-14 received waste oils from the same processes in Buildings 707 and 777. Tanks T-1 and T-2 fed waste oils to the Grease Plant Process and the OASIS Process. Tank T-374A began feeding waste oils to the OASIS Process after damage to Tanks T-1 and T-2 was identified and they were removed from operation. Tanks T-13 and T-14 began feeding waste oils after Tank T-374A. Tanks T-374A, T-13, and T-14 were used simultaneously until Tank T-374A was removed from operation. Tanks T-13 and T-14 continued feeding the OASIS Process until it stopped in January 1990.

In the Grease Plant Process, waste oil and Microcel E (calcium silicate) were fed separately into a continuous mixer. Small amounts of Oil Dri were sometimes added to the mixture as well. The amounts of materials added to the mixture were not metered. However, the operator would adjust the composition if the outgoing mixture did not have a paste-like consistency. The mixture would then drop into an O-ring bag contained in a 55-gallon drum. Drums of solidified organics from the Grease Plant Process were subsequently transported to the Size Reduction Facility in Building 776 for inspection and sealing.

OASIS was a batch-type process generating one drum per run. Waste oils were pumped into an O-ring bag contained in a 55-gallon drum attached to the bottom of the OASIS glovebox. Envirostone emulsifier, gypsum cement, and accelerator were also metered into the bag. House water, which had not been used in any other processes, was added to the mixture as well. A Lightning Mixer was lowered into the drum after all of the materials were added. The amount of materials added to the mixture was operator controlled.

The drums were transferred to WMU 73, Room 241, after they had been inspected and sealed. Solidified organics containers from the OASIS process were stored in Building 774 until they were transferred to Building 371 for nondestructive assay (NDA). After RTR, drums were usually sent to Building 664, where they were stored until shipment off site. Solidified organics waste is not being shipped at this time. Consequently, Building 664 has reached capacity and solidified organics are also being stored in Buildings 371, 569, 774, and 776.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS

Solidified organics were generated by the OASIS process after November 11, 1985.

Analytical information regarding solidified organics was not found in the WSRIC Sampling and Analysis database. However, non-WSRIC analytical data from 1988 and 1989 are considered in the characterization of the waste. The analytical method was not specified for the results. However, Toxicity Characteristic Leaching Procedure (TCLP) analysis was not typically performed in 1988 and 1989. The results are assumed to be from Totals analysis. Validated headpsace analysis performed on drums containing solidified organics are considered as well. Headspace analytical results support the 1988 and 1989 results from sampling and analysis.

Wastes received by Tanks T-1 and T-2, T-374A, and T-13 and T-14 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) organics. Carbon tetrachloride (D019), nitrobenzene (D036), and trichloroethylene (D040) were cited contaminants. Nitrobenzene was a contaminant in nonroutine laboratory waste and was introduced into five or fewer drums. Contaminated drums could be not be identified. However, the solidified organics population, as a whole, does not exhibit the toxicity characteristic for nitrobenzene.

Sampling and analysis of three solidified organics samples in 1988 and 1989 indicated the waste exceeded toxicity characteristic criteria for carbon tetrachloride (EPA Code D019). The waste did not exceed toxicity characteristic criteria for any of the other cited RCRA organics. TCLP analysis of the waste under EPA SW-846 is required to support the analytical results and confirm the assumptions.

Based on the "mixture" rule and the "derived-from" rule, solidified organics would carry the listed EPA codes associated with the wastes fed to the solidified organics generation processes. EPA Codes F001 and F002 are assigned to all solidified organics because wastes received by Tanks T-1 and T-2, T-374A, and T-13 and T-14 were contaminated with regulated spent solvents in the past.

Sampling and analysis of solidified organics waste in 1988 and 1989 indicated the waste exceeded the F001 and F002 LDR treatment standards for carbon tetrachloride and 1,1,1-trichloroethane. The analyses found detectable concentrations of other F001 and F002 constituents, as well. Total analysis of the waste under EPA SW-846 is required to confirm these results.

Based on the "mixture" rule and the "derived from" rule, solidified organics would carry the listed EPA codes associated with wastes set to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned because wastes set to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at elevated levels. Solidified organics will not be considered as meeting F001, F002, F003, and F005 Land Disposal restrictions (LDR) treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SE-846 is required.

The EPA Codes F006, F007, and F009 are assigned because of contamination with waste from electroplating operations.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to solidified organics. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste. Cited laboratory chemicals like nitrobenzene were used for their intended purpose as reagents and were not discarded commercial chemical products.

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. The waste is stored in 55-gallon carbon steel drums with a rigid polyethylene liner and one or two bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	RF 111	Stream Name:	Solidified Sludge - Bldg 774 / TRM	Inventory Date:	10/20/95
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, F005, F039, F009, F007, F006, F003, D010, D008, D007, D006, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	317.6	262.4	414.5
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	262.0	216.5	342.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	55.6	45.9	72.5
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 111

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.9	0.1	0.1	1.3	0.5	4.9
Totals	2.9	0.1	0.1	1.3	0.5	4.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	0.1	0.1	1.2	0.6	4.9
Totals	2.9	0.1	0.1	1.2	0.6	4.9

As-Generated Form: Stored: 2.9 Projected: 2.1 Total: 5.0

Final Waste Form: Stored: 2.9 Projected: 2.1 Total: 5.0

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge.

Re: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR)

treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower

than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS

N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W097	Handling:	CH	NMVP #:	RF 114	Stream Name:	Solidified Process Solids/TRM
Local ID:	IDC 806	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 10/20/94

Waste Matrix Code: Z1110

AS-GENERATED EPA CODES

D008, D004, D005, D007, D009, D010, D011, F003, D006, F005, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	489.0	376.2	635.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	135.8	104.5	176.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	73.1	56.2	95.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 114

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	62.1	11.8	491.0	545.8	1110.7
Totals	0.0	62.1	11.8	491.0	545.8	1110.7

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 1110.7 Total: 1110.7

WASTE STREAM DESCRIPTION	This waste stream represents the solidified final form of all particulate and sludge type materials. Particulates and sludge type materials are immobilized with Portland cement. The cemented wastes are cast into 1-gallon molds and allowed to cure prior to packaging. This is the final waste form for Firebrick, Pulverized or Fines/TRM (RF-W036), Incinerator Ash/TRM (RF-W040), Particulate Sludge/TRM (RF-W068), and Sand, Slag, and Crucible/TRM (RF-W059). IDC 806 - All inorganic particulate and inorganic sludge waste must be immobilized by processing into a solid and identified as IDC 806.
WASTE STREAM SOURCE	This is a new waste stream and includes IDC 806 only. It represents the solidified final form of Firebrick, Pulverized or Fines/TRM (RF-W036), Incinerator Ash/TRM (RF-W040), Particulate Sludge/TRM (RF-W068), and Sand, Slag, and Crucible/TRM (RF-W059). Particulates and sludge type materials are immobilized with Portland Cement. The cemented wastes are cast into 1-gallon molds and allowed to cure prior to packaging. There is currently no inventory of this waste at Rocky Flats. However, generation of this waste is expected as the plant progresses in its mission of environmental cleanup and waste management. Therefore, some IDC 806 material is expected to be generated in the 20-year horizon as waste management and disposal activities continue. For these reasons, this waste must be reported in the Baseline Inventory Report; it is included here to maintain consistency between this report and the BIR.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The characterization basis for this waste is to apply EPA hazardous waste numbers from the four feed materials identified above that would be expected to apply to the final solidified waste form as well. These are projected hazardous waste numbers and may not apply after the waste is generated and analytical work completed. Projected list of contaminants based on those present in source wastes.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Volumes include final form waste from treating the following streams: RF-MT0377, RF-MT0378, RF-MT0420, RF-MT0425, RF-MT0292, RF-MT0299, RF-MT0372, RF-MT0391, RF-MT0392, RF-MT0393.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W010	Handling:	CH	NMVP #:	RF 111	Stream Name:	Solidified Sludge - Bldg 374 / TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

F002, F001, F039, F009, F007, F005, F003, D011, D010, D009, D008, D007, D006, D005, D004, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	409.8	279.8	730.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	338.1	230.8	602.2
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	71.7	49.0	127.8
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 111

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	73.4	1.3	2.7	27.6	10.3	115.5
Totals	73.4	1.3	2.7	27.6	10.3	115.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	73.4	1.3	2.7	27.6	10.3	115.5
Totals	73.4	1.3	2.7	27.6	10.3	115.5

As-Generated Form: Stored: 73.4 Projected: 41.6 Total: 115.0

Final Waste Form: Stored: 73.4 Projected: 41.6 Total: 115.0

WASTE STREAM DESCRIPTION

This waste stream is a solid cemented sludge. It could have small amounts of free liquids in the bottom of the container.

WASTE STREAM SOURCE

Prior to 1979, IDC 001 consisted of sludge from the first-stage treatment only. When the first- and second-stage sludges were packaged separately, two vacuum filters were used. From 1979 to 1986, IDC 001 was a combination of the sludges from the first- and second-stage treatment processes. The sludge was produced chemically in the same fashion aqueous waste was treated to produce IDC 800 sludge. The solidification process for IDC 001 differs from the IDC 800 method of adding cement and diatomite as the sludge collects. Portland cement was added to the bottom of the IDC 001 drum prior to placing the sludge in the drum. In some cases additional Portland cement was added on top of the sludge.

Re: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS

N/A

EPA COMMENTS

According to the Building 774 Second-Stage Treatment Log (January 1981 to October 1989), prior to September 1984, the Building 774 aqueous waste treatment system received waste streams that are treated in the Building 374 Liquid Waste Treatment Facility. These streams affected the characterization of Building 774 solidified sludge until September 1985. The choice of the transition date of September 1984 is discussed in detail under the Subpopulation 55A discussion in the Backlog Baseline Book prepared by Rocky Flats.

Information contained in the November 1992 WSRIC Valve Vaults Book has been used to characterize waste streams treated in Building 774 prior to September 1984. The Valve Vaults book describes the process waste sent to Building 374 for treatment. The book was used because it is the only reference that provides detailed characterization information on waste that was sent to Building 774. Other references and interviews have been used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers compatible with the first- and second-stage treatment processes, were treated in Building 774. Some of these wastes exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline-transferred wastes.

There may be other hazardous wastes that were treated in Building 774 during the 1970s that are no longer generated at Rocky Flats. For example, experimental decontamination solvents for the 1969 fire cleanup and effluent from the washing metal and gloves in Size Reduction were generated. No records were found specifying the wastes treated in this time frame.

Wastes sent to Building 774 exhibited the characteristics of ignitability (D001) and corrosivity (D002). However, the characteristic of ignitability, as defined in 40 CFR 261.21, does not apply to any of the Building 774 aqueous sludge subpopulations because they are not liquids, gases, or oxidizers. The characteristic of corrosivity (D002) as defined in 40 CFR 261.22 does not apply because the final waste form is solid. WEMS does not indicate any containers have been rejected for free liquids. The generator has, however, assigned D001 and/or D002 to specific containers. These characterizations are to be reviewed in CY 1995.

Wastes sent to Building 774 were intermittently contaminated with Resource Conservation and Recovery Act (RCRA) metals (EPA Codes D004-D011). Under the "derived from" rule, if a characteristic waste is treated, the final waste form is only a characteristic waste if it continues to exhibit the characteristic. A feed tank to the Building 774 aqueous sludge process, Tank 40, was sampled in 1994. However, one sample is not considered to be representative of the aqueous sludge population. Consequently, it will be assumed that Building 774 aqueous sludge generated prior to September 1985 exhibits the characteristic of toxicity for all of the RCRA metals (EPA Codes D004-D011) until TCLP analysis of the waste under EPA SW-846 proves the waste does not exceed toxicity characteristic criteria.

Based on the "mixture" rule and the "derived from" rule, Building 774 aqueous sludge would carry the listed EPA codes associated with wastes sent to Building 774 for treatment. The EPA Codes F001, F002, F003, and F005 are assigned to Building 774 aqueous sludge generated prior to September 1985 because wastes sent to Building 774 were contaminated with regulated spent solvents in the past. Headspace analyses detected F001, F002, F003, and F005 constituents at high levels. Building 774 aqueous sludge generated prior to September 1985 will not be considered as meeting F001, F002, F003 and F005 Land Disposal Restrictions (LDR)

treatment standards until sampling and analysis proves otherwise. Total analysis of the waste under EPA SW-846 is required.

The EPA codes F006, F007, and F009 are assigned to Building 774 aqueous sludge generated prior to September 1985. Building 774 received wastewaters contaminated with waste from electroplating operations in the past. Analytical results from a feed tank sample in 1994 are insufficient to determine the regulatory status of Building 774 aqueous sludge generated prior to September 1985. TCLP analysis of the waste under EPA SW-846 is required for the determination.

P- and U-listed EPA codes for discarded commercial chemical products will not be assigned to Building 774 aqueous sludge. Excess chemicals are stored on the plant site. However, there is no documentation supporting P- and U-listed waste codes for specific chemicals that were disposed of in process waste.

After August 1984, the Building 774 aqueous waste treatment system received only waste streams from Buildings 771 and 774. Closure, decontamination, or cleaning of the Building 774 treatment system did not occur. However, considering the flow rates through the system and the system volume, it is estimated that the first- and second-stage system volumes were turned over 60 and 12 times a year, respectively. After one year of flushing, it can be assumed that no previous waste resided in the system, so the "old" waste codes can be eliminated from the sludge.
Information contained in the WSRIC Building 771 Book and the WSRIC Building 774 Book was used to characterize waste streams treated in Building 774. Other references and interviews were used to enhance or add to this information as it relates to the waste form.

In addition to the pipeline-transferred waste, wastes in containers that were compatible with the first- and second-stage treatment processes were treated in Building 774. Some of the wastes in containers exhibited hazardous characteristics. However, the EPA codes applicable to these wastes did not include additional codes that were different from those cited for pipeline transferred wastes.

EPA Codes D001 and D002 are not assigned to this subpopulation. P-and U-listed waste codes are also not assigned. The characterization rationale for previously generated waste is the same regarding these waste codes. The rationale is presented under the Subpopulation 55A discussion.

Wastes sent to Building 774 after August 1984 were intermittently contaminated with cadmium (D006), chromium (D007), and silver (D011). It is assumed that Building 774 aqueous sludge generated after August 1985 exhibits the characteristic of toxicity for these metals. EPA Codes D006, D007, and D011 are assigned to this waste following the rationale presented for RCRA metals under the Subpopulation 55A discussion.

EPA codes for RCRA organics are not applicable to Building 774 aqueous sludge generated after August 1985. After August 1984, Building 774 no longer received wastes contaminated with RCRA organics. Analytical results from aqueous sludge samples are limited. One sample was analyzed for volatile organic constituents in 1988. The F001, F002, F003, and F005 LDR treatment standards and toxicity characteristic limits were not exceeded for the detected contaminants. No Quality Control information on the sample analysis is available. It is uncertain if the organic compounds are actually in the sludge or are a result of sample or lab contamination.

Validated headspace analyses performed on drums containing aqueous sludge are also considered in the characteristic of the waste. It is not known how headspace gas constituent levels related to the actual composition of the waste. However, using a partitioning coefficient model designed for environmental media, calculations were performed on headspace analytical results to estimate organic levels in the sludge. The highest organic levels of detected toxicity characteristic constituents from headspace analysis were used in the calculation of waste contaminant levels.

The analytical results from an aqueous sludge sample in 1988 and calculated constituent levels from headspace analytical results both indicate that the waste is below toxicity characteristic criteria for RCRA organics.

The EPA Codes F001, F002, F003, and F005 are not applicable to Building 774 aqueous sludge generated after August 1985. Listed wastes ceased being treated in Building 774 in August 1984. Extensive research was performed by Waste Technical Support to determine if organic and aqueous lab solutions sent to Building 771 for plutonium recovery were treated in Building 774. The research concluded the organic phase was removed by the generating laboratory prior to shipment to Building 771. If the organic phase contained a listed solvent, the separated aqueous phase is not listed waste under the "mixture" rule.

The trace levels of volatile organics found in the sludge in 1988 can be discounted due to the very low levels detected and the lack of quality control data available for the analysis. The headspace analysis for sludge produced after August 1985 shows slight levels of some volatile organics, but the levels are an order of magnitude lower

than pre-August 1985 samples. It is not known how the headspace gas analysis relates to the actual composition of the waste. However, there is good process knowledge that no spent solvents were sent to the Building 774 aqueous waste process after August 1984, so a listed EPA waste code cannot be applied to aqueous sludge generated after a year of flushing.

Sludge from Building 374 is assigned F039 because Interceptor Trench System water (leachate) reports to this sludge.

MANAGEMENT COMMENTS

N/A

ACCEPTANCE COMMENTS

RFP has assumed this waste to be LDR based on process knowledge characterization and limited analytical data. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date.

1. Basis for determining LDR storage prohibition status is based pirmarily on process knowledge. WASTE_ PACK: Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and two bag liners.

FINAL FORM COMMENTS

The projections given in Section 8.2.15.1.13 are in cubic meters

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Item Description 831, Combustibles, Dry, TRU Mixed Waste Dry combustibles such as paper, cloth, wood, etc. This waste has been identified as being low level mixed waste. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, F005, F003, D011, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Wet combustible transuranic wastes, such as paper, cloth, and wood, which contain a discernible amount of moisture must be drained or wrung out prior to packaging to prevent accumulation of free liquid. These wastes are classified as IDC 822. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	RF-831	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, F009, F007, F006, F005, F003, D035, D019, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	69.2	4.8	258.5
Rubber:	6.6	0.5	24.7
Plastics:	20.1	1.1	75.2
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	112.6		
Packaging Material Plastic:	44.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	44.9	13.7	9.6	84.3	78.4	230.9
Drum / 85-gallon	0.6	0.0	0.0	0.0	0.0	0.6
metal box / 4x4x7	12.8	0.0	0.0	0.0	0.0	12.8
Totals	58.3	13.7	9.6	84.3	78.4	244.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	44.9	13.7	9.6	83.5	78.4	230.1
Standard Waste Box	0.0	9.8	1.6	13.7	12.7	37.8
Totals	44.9	23.4	11.2	97.2	91.2	267.9

As-Generated Form: Stored: 58.3 Projected: 186.0 Total: 244.3

Final Waste Form: Stored: 44.9 Projected: 223.8 Total: 268.7

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	tem Description 831, Combustibles, Dry, TRU Mixed Waste Dry combustibles such as paper, cloth, wood, etc. This waste has been identified as being low level mixed waste. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	The projections given in Section 8.2.15.1.13 are in m^3. Assume 86% of IDC 831 generation will be Drum/55-gal based on current container distribution.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

D006, D019, D022, D028, D029, F006, D040, D043, F007, F009, D011, D010, F039, F002, D038, F003, F001, D002, D035, D018, F005, D003, D004, D005, D007, D008, D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.1	0.0	0.5
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	65.0	1.4	347.6
Rubber:	6.2	0.1	33.2
Plastics:	18.9	0.4	101.1
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	72.4	26.0	18.3	160.8	149.3	426.8
Totals	72.4	26.0	18.3	160.8	149.3	426.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	72.4	29.1	18.3	160.8	149.3	429.9
Totals	72.4	29.1	18.3	160.8	149.3	429.9

As-Generated Form: Stored: 72.4 Projected: 354.4 Total: 426.8

Final Waste Form: Stored: 72.4 Projected: 357.6 Total: 429.9

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, D011, F009, F007, F006, F005, F003, D019, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	32.8	4.2	69.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.2	0.0	0.3
Rubber:	2.2	0.3	4.7
Plastics:	53.5	6.9	112.8
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	138.0		
Packaging Material Plastic:	36.4		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.7	2.1	1.5	13.0	12.3	37.6
metal box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Totals	11.9	2.1	1.5	13.0	12.3	40.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.7	3.1	1.5	13.0	12.3	38.7
Standard Waste Box	0.0	6.2	0.6	3.6	6.6	17.0
Totals	8.7	9.4	2.1	16.6	18.9	55.7

As-Generated Form: Stored: 11.9 Projected: 28.9 Total: 40.8

Final Waste Form: Stored: 8.7 Projected: 47.0 Total: 55.7

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Item Description 853, Plastic (Teflon, PVC, and Polyethylene) This waste has been identified as being a low level mixed waste, consisting of PVC sheeting, poly bottles, supplied-air suits, and other plastics. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1988. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	Assume 70% of IDC 833 generation will be drum/55-gal based on current container distribution.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W012	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5390

AS-GENERATED EPA CODES

F002, F001, D019

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.17E+00
Pu-240	2.17E-01
Pu-239	9.49E-01
Am-241	7.34E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consits of rags, paper, cloth, coveralls, plastic, rubber, and wood. The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills. The bulk of these wastes are packaged in 55-gallon drums with one rigid polyethylene liner and several bag liners. In addition, the waste may be packaged in DOT 7A Type A metal boxes which are lined with a fiberboard liner and a PVC liner or standard TRUPACT-II container. The containers are then assayed and transferred to interim status storage areas. These wastes have been shipped to the INEL for stroage in the past. RF-330, 356, 337, 821, 822, 853, 831, 832, 833. Predominantly combustible debris.
WASTE STREAM SOURCE	Item Description 853, Plastic (Teflon, PVC, and Polyethylene) This waste has been identified as being a low level mixed waste, consisting of PVC sheeting, poly bottles, supplied-air suits, and other plastics. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A- Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being absent or present). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort has been completed and the results are available in the Final Backlog Baseline Book dated September 26, 1994.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	GENERAAREA: Numerous locations throughout RFP.GENOPERATI: RECLASS_CO: Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed.CATION: Not applicable OTHER_CHAR: No information available. RFP has assumed this waste to be LDR based on process knowledge characterization, and one sample analyzed for volatiles in 1986. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its genration date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Analytical data are limited. WASTE_PACK: This waste is stored in 55 gallon carbon steel drums with one rigid polyethylene liner and several bag liners and standard metal boxes.
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W032	Handling:	CH	NMVP #:	N/A	Stream Name:	Ground glass/TRM	Inventory Date:	10/20/94
Local ID:	IDC 444, 855	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	77.6	77.6	77.6
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Solis:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.33E+00
Pu-240	5.61E-02
Pu-239	2.45E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.2	0.3	0.6	0.6	1.9
Totals	0.2	0.2	0.3	0.6	0.6	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.2	0.3	0.6	0.6	1.9
Totals	0.2	0.2	0.3	0.6	0.6	1.9

As-Generated Form: Stored: 0.2 Projected: 1.7 Total: 1.9

Final Waste Form: Stored: 0.2 Projected: 1.7 Total: 1.9

WASTE STREAM DESCRIPTION	Matrix consits of crushed glass light bulbs and leaded glass that is crushed on removal.
WASTE STREAM SOURCE	Item Description Code 855-Ground Glass 855 IDC includes ground glass from fluorescent light bulbs. It can be used for waste generated outside the PA and for nonline-generated waste. In other words, it can *only be used for low-level mixed waste.* This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories. RE: Section 8.2.11, REFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Analytical data showed the presence of toxic metals in some containers of IDC 444. Based on these analytical data, these materials are characterized as hazardous and assigned EPA codes D005 and D008. Analytical data for IDC 855 show that there are enough cases where the samples fail the Toxicity Characteristic Leaching Procedure (TCLP), that the waste bulbs should be managed as hazardous waste and assigned the EPA code D009. EPA codes are assigned to newly generated waste by the generator based on process knowledge. Subpopulation 17G includes containers of leaded glovebox glass. Based on analytical data, these materials are characterized as hazardous and assigned EPA Waste Codes.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	LDR_DETERM: Net and gross weight data are not available for all container types. RFP has assumed this waste to be LDR based on the fact that it is a RCRA listed waste. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: The glass waste is packaged in 55- gallon drums that are lined with one fiberboard liner and two polyethylene bags or metal boxes. Drums are placed in TRUPACT II containers.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W052	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRM	Inventory Date:	10/20/94
Local ID:	None	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	10.3	10.3	10.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	176.8	176.8	176.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.4	5.4	5.4
Rubber:	0.0	0.0	0.0
Plastics:	6.2	6.2	6.2
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF118

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	6.75E+00
Pu-240	2.83E-01
Pu-239	1.28E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.7	0.9	1.9	1.9	5.5
Totals	0.2	0.7	0.9	1.9	1.9	5.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.7	0.9	1.9	1.9	5.5
Totals	0.2	0.7	0.9	1.9	1.9	5.5

As-Generated Form: Stored: 0.2 Projected: 5.4 Total: 5.6

Final Waste Form: Stored: 0.2 Projected: 5.4 Total: 5.6

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 856 includes Raschig Rings which are removed from vessels containing RCRA regulated solvents. There is also glass from spent fluorescent lamps in some of these containers. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data. This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Item Description Code 440 This IDC was separated from IDC 444 (created in 1989 specifically for ground glass and leaded glass) because the two waste forms exhibit different chemical characteristics, hazardous constituents, and EPA codes. Therefore, drums of IDC 440 materials generated prior to 1989 could contain leaded glass. These are included in Subpopulation 17G and are assigned EPA codes D005 and D008. Item Description Code 442 In addition to the reference documents and WEMs information used, analytical data compiled by EG&G Rocky Flats were reviewed. The data shows that the concentrations of Toxicity Characteristic (TC) metals barium, cadmium, chromium, lead, and silver were well below regulated levels provided in 6 CCR 1007-3, Section 261.24. Subpopulation 17F includes Raschig Rings assigned IDC 442 that are contaminated with carbon tetrachloride, 1,1,1-trichloroethane, or both. Based on analytical data, Raschig Rings do not exhibit the characteristic of toxicity for metals. All containers in this group were generated in Building 777 according to WEMS. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. Therefore, it is assumed that these rings are all contaminated with carbon tetrachloride or 1,1,1-trichloroethane sludge. They are, therefore, assigned EPA Waste Codes F001 and F002. Subpopulation 27B is assigned EPA code D009 because of mercury in the spent fluorescent lamps.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	RFP has determined that this grouping is LDR waste based on available process knowledge with some of the IDCs identified containing listed hazardous components. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of is generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. WASTE_PACK: DOT 7A TYPE A metal boxes and DOT 7A TYPE A drums.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W096	Handling:	CH	NMVP #:	RF-116	Stream Name:	Supercompacted Combustibles/TRM	Inventory Date:	10/20/94
Local ID:	2116	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S3290

AS-GENERATED EPA CODES

F001, D008, F002, F005, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	375.7	251.3	483.0
Rubber:	35.9	24.0	46.1
Plastics:	108.1	72.3	139.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	301.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Pollution Control or Waste Treatment Process

TRUCON CODE

RF-116C

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.44E+01
Pu-240	1.02E+00
Pu-239	4.08E+00
Am-241	3.46E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	This waste consists of cloth and paper products from cleanup of gloveboxes and spills, which has been supercompacted for volume reduction.
WASTE STREAM SOURCE	Item Description Code 2116 - IDC 2116 is Supercompacted TRU-mixed combustible waste (IDCs 831, 832, and 833). Refer to Waste Form RF-W012 for details of these IDCs. Containers of IDC 2116 were generated in Building 776. The WSRIC stream number is 776-13-40 (a/o 3/2/95). Soft wastes are inspected for rejectable items, including free liquids and metal, which are separated from the soft waste for further disposition. Soft wastes are moved to the precompactor where they are placed in an empty 35-gallon drum located in the precompactor. The soft waste is precompacted using a 30-ton precompactor. Once the drum is filled with precompacted waste, the lid is placed on the drum. The drum is transferred to the appropriate glovebox line for piercing. Prior to supercompaction, drums of soft waste are pierced with four holes to allow air to escape and to reduce the amount of "springback" during supercompaction. After piercing, the drums are moved to the supercompactor. A mold is lowered over the drum. Once the mold is in place, the supercompactor is lowered, compacting the drum. Liquid forced out of the waste during compaction is collected by the liquid waste collection system. After supercompaction, the pucks (supercompacted 35-gallon drums) are moved to staging. An operator selects from the available pucks to efficiently fill 55-gallon loadout drums.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	This waste is characterized with the same EPA hazardous waste numbers as the waste being processed. Refer to RF-W012, Combustibles/TRM, for IDCs 831, 832, and 833.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W094	Handling:	CH	NMVP #:	N/A	Stream Name:	Wastewater/TRM	Inventory Date:	10/20/94
Local ID:	N/A	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	L1130

AS-GENERATED EPA CODES

D002, D007, D011

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Tanks/Misc Size	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream consists of aqueous waste water from different Buildings on the plant site. Most of the water comes from Building 771 and from rain water. This waste stream is treated and sent to Building 374 for final treatment.
WASTE STREAM SOURCE	This waste stream consists of aqueous waste water from different Buildings on the plant site. Most of the water comes from Building 771 and from rain water. This waste stream is treated and sent to Building 374 for final treatment.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based upon general knowledge of waste type or source.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W089	Handling: CH	NMVP #: N/A	Stream Name: WET SLURRY/TRM		Inventory Date: 12/30/99
Local ID: N/A	Type: MTRU	Generator Site: RF	Final Waste Form: Solidified Inorganics		Waste Matrix Code: L1290

AS-GENERATED EPA CODES

D011, D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream consists of solids that are removed from aqueous process waste streams. The aqueous waste streams come into Building 774 from other Buildings on plant site. The aqueous waste is then put through a three stage precipitation, flocculation, and clarification procedure. The solids removed are stored in Tank 40 in Building 774.
WASTE STREAM SOURCE	RE: section *.2.222, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. RFETS does not expect nitrate concentration to be >1%, but has no data indicating the actual concentration range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based upon general knowledge and waste generators in the building.
MANAGEMENT COMMENTS	Projected generation is beyond CY1999.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W091	Handling:	CH	NMVP #:	N/A	Stream Name:	Organics Discard Level/TRM
Local ID:	0533, 0535, N/A	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Solidified Organics

Inventory Date: 10/20/94

Waste Matrix Code:

AS-GENERATED EPA CODES

F002, F001, D019

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Tank/Misc Sizes	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This liquid waste stream includes machine oils and coolants contaminated with organic solvents.
WASTE STREAM SOURCE	Waste oil being transferred from Buildings 707, 776, and 777 is stored in Tanks T-13 and T-14. From Tanks T-13 and T-14, the waste oil is pumped to the OASIS mixer. The pump is enclosed in a small glovebox. Waste oil, water, emulsifier, Envirostone, and accelerator (to speed up the settling process) are mixed in a 55-gallon drum attached to the bottom of the glovebox. The waste is then sampled for plutonium, americium, and uranium. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge based on waste generation and general knowledge of waste type or source.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W108	Handling:	CH	NMVP #:	RF 111	Stream Name:	Aqueous Sludge/TRU	Inventory Date:	
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	395.6	44.2	767.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	260.3	28.8	498.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	140.2	15.5	268.5
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues:

Asbestos: No

PCBs: No

Source:

TRUCON CODE

RF 111

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.81E+00
Pu-240	1.18E-01
Pu-239	5.16E-01
Am-241	2.03E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	This waste stream consists of aqueous sludge from wastewater treatment mixed with 30% Portland cement. IDC No. 800, 803, 807. The waste is generated as a result of process waste water treatment in Building 374 and 774. Aqueous sludge is produced by vacuum filtration of precipitated solids from pretreated aqueous waste slurry. Entrapped solids are skimmed off the surface of the filter medium of the rotating drum as wet sludge. The recipitated solids are chiefly hydroxides with pH of 10-12. The final waste form is obtained by mixing the wet sludge with approximately 30% Portland cement. RFP has several drums of aqueous sludge that were returned by INEL. These old drums were packaged by alternating the layers of cement and wet sludge or by adding cement to the top and bottom of a drum containing wet sludge. This older waste is described by IDC's 001, 002, and 007.
WASTE STREAM SOURCE	N/A
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/Tru
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 044 was produced in the Americium Purification Process in Glovebox 1 in Building 771. This process has been out of operation for many years. The americium oxide was produced in a similar method to plutonium oxide. The americium oxide was collected in stainless-steel vials that were placed in lead pigs for radiation shielding. The lead pigs are enclosed in storage cans that are stored in vaults.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	[illegible]	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.5	0.0	0.0	0.0	0.0	0.5
Totals	0.5	0.0	0.0	0.0	0.0	0.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.5 Projected: 0.0 Total: 0.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 067 consists of chlorinated plutonium oxide generated during research in Building 779, for possible use in a variety of processes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 080 consists of plutonium oxide generated by the Calcination Process in Building 771. The Feed Evaporation Process concentrated the plutonium nitrate solution from High-Level Dissolution and Anion Exchange. The resulting precipitate was calcined to form plutonium oxide. This product was then transferred to Hydrofluorination for further processing.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W123	Handling: CH	NMVP #: N/A	Stream Name: Oxides/TRU		Inventory Date: 3/6/95
Local ID: None	Type: TRU	Generator Site: RF	Final Waste Form: Solidified Inorganics		Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 081 consists primarily of the impure plutonium oxide collected from the glovebox floor of the Calcination Process in Building 771. In addition, oxide encrusted on the calciner equipment was removed during maintenance operations and assigned IDC 081.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 062 consists of plutonium oxide stored in small stacker cans.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.03	0.0	0.0	0.0	0.0	0.03
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.03 Projected: 0.0 Total: 0.03

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 083 consists of plutonium oxide feed for the Direct Oxide Reduction Process in Building 776 Pyrochemical Processing. This product consists of oxide from a variety of sources used by the process to produce metal for production purposes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: *Stored:* 0.00 *Projected:* 0.0 *Total:* 0.00

Final Waste Form: *Stored:* 0.0 *Projected:* 0.0 *Total:* 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 084 consists of plutonium oxide generated at the Hanford facility and shipped to Rocky Flats for processing. The oxide was assayed then blended in preparation for Direct Oxide Reduction in Building 776 or Hydrofluorination prior to Reduction and Button Break-out in Building 771.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.04 Projected: 0.0 Total: 0.04

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 086 consists of plutonium oxide generated by the Electrorefining tilt/pour furnaces in Building 371. During cleaning of the furnaces, molten plutonium metal was scraped from the walls. The metal was burned to oxide then assayed before being sent to Dissolution in Building 771. The oxide could contain tungsten or tantalum from furnace components.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.04 Projected: 0.0 Total: 0.04

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 067 consists primarily of the impure plutonium oxide collected from the glovebox floor of the Calcination Process in Building 771 (see discussion of IDC 061) that is stored in small stacker cans.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/Tru	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 089 is produced in the calcination process in Glovebox 16 in Building 771. Grease oxide is a mixture of plutonium greencake from the calciner equipment. The grease is applied to the wear plates on the calciner. Grease and greencake can mix together near the breech of the calciner where the product greencake is removed. Grease oxide is placed in metal cans for storage prior to calcination and eventual dissolution for recovery. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 145 consists of plutonium oxide generated during loss-on-ignition testing in Building 371. The LOI test was developed to minimize the possibility of container pressurization during shipment. The oxide was heated for a designated period, then weighed to determine the percent of weight loss. If more than 1 percent was lost, it was determined that there was enough moisture or impurities present to represent a risk of the container pressurizing during shipment. If the oxide failed, the material was typically tested a second time.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CR	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 146 consists of plutonium oxide failing loss-on-ignition testing in Building 371 multiple times. Typically, oxide failing the LOI test twice was sent to Building 771 and reburned for dissolution.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 289 consists of low-concentration plutonium oxide heel generated in the Dissolution Process in Building 771. This oxide consists of the undissolved material after the plutonium nitrate dissolution solution was run through an R-6 filter. The resulting heel was dried on a hot plate then staged to be recycled back into the dissolution process. This oxide consists of the heel that had been cycled through the process multiple times.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W104	Handling:	CH	NMVP #:	N/A	Stream Name:	Particulate Sludge/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of IDCs 292 and 299. This waste is packaged in 55-gallon drums with multiple bag liners. Final waste form for this waste is Solidified Process Solids/TRU (IDC 806).
WASTE STREAM SOURCE	IDC 292 was intended for incinerator sludge from the recovery incinerator in Building 771. IDC 292 materials were reassessed under Waste Form 1, Incinerator Ash. However, there is one box WEMS incorrectly assigned this IDC. According to the waste-box log sheet dated October 14, 1987, the box contains Electrochemical Milling Sludge generated in Building 881. This operation generated sludge from the milling of various metals including stainless steel. It was indicated that no cyanides were used in the ECM operations in Building 881. The IDC for this box should be changed to 299. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphateds >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RF-W104	Handling: CH	NMVP #: N/A	Stream Name: Particulate Sludge/TRU		Inventory Date: 3/6/95
Local ID: None	Type: TRU	Generator Site: RF	Final Waste Form: Solidified Inorganics		Waste Matrix Code: S3129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of IDCs 292 and 299. This waste is packaged in 55-gallon drums with multiple bag liners. Final waste form for this waste is Solidified Process Solids/TRU (IDC 806).
WASTE STREAM SOURCE	This IDC has been used for sludges that were not accurately categorized as IDC 290 or 340 and could have been generated in any plutonium processing building. However, the backlog miscellaneous sludge was generated in Building 771 during the processing of residues, in Building 371 in the analytical laboratory, and in Building 883 by the Rolling Process. Process pipe sludge, sludge dissolution heel, and filter plenum sludge from Building 771 were processed through nitric acid dissolution and sparging. Soil and sludge samples from around the site were analyzed in Building 371, and the waste was stored for processing. IDC 299 materials generated in Building 883 include quench sludge and uranium oxide sludge from the rolling Process. This group also includes one container of electrochemical milling sludge generated in Building 881 in October 1987. The container is assigned IDC 292. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.03	0.0	0.0	0.0	0.0	0.03
Drum / 55-gallon	26.0	0.0	0.0	0.0	0.0	26.0
Totals	26.0	0.0	0.0	0.0	0.0	26.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 26.0 Projected: 0.0 Total: 26.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 300, Graphite Molds During the casting of plutonium in production foundry operations, the plutonium casting operations in Building 707 generated used graphite molds. The working surfaces were coated with calcium fluoride prior to using the mold. After the plutonium casting was removed from the mold, the molds were collected in a drum. Drums that contained recoverable amounts of plutonium were stored for subsequent scarfing of molds.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	17.3	0.0	0.0	0.0	0.0	17.3
Totals	17.3	0.0	0.0	0.0	0.0	17.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 17.3 Projected: 0.0 Total: 17.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 301, Classified Graphite Shapes During the casting of plutonium in production foundry operations, classified molds are segregated from non-classified molds. Prior to 1984, the classified molds were destroyed in Building 776.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	RF115	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 115

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 303, Scarfed Graphite Chunks After the casting of plutonium in production foundry operations, IDCs 300 and 301 were mechanically cleaned using a hand-held rotary-type sanding tool to grind off contamination in buildings 371, 707, 771, and 777, generating Scarfed Graphite Chunks. The mechanical cleaning (scarfing) of the mold surface removes most of the mold coating and plutonium contamination. This process generated IDC 303 and 310, as well as, IDC 312.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	17.5	0.0	0.0	0.0	0.0	17.5
Totals	17.5	0.0	0.0	0.0	0.0	17.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 17.5 Projected: 0.0 Total: 17.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 310, Graphite Scarfing and Fines After the casting of plutonium in production foundry operations, IDC 300 was mechanically cleaned in Buildings 371, 707, 771, and 777, generating graphite scarfings and fines. The mechanical cleaning (scarfing) of the mold surface removes most of the mold coating and plutonium contamination. Material generated in this process were fines and small pieces of graphite coated with calcium fluoride and plutonium. This material was then subjected to nondestructive assay to determine actinide content, and collected for disposition.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	24.1	0.0	0.0	0.0	0.0	24.1
Totals	24.2	0.0	0.0	0.0	0.0	24.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 24.2 Projected: 0.0 Total: 24.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 312, Graphite Coarse After the casting of plutonium in production foundry operations, IDC 300 was mechanically cleaned in Buildings 371, 707, 771, and 777, generating coarse graphite. Material generated in this process were chunk pieces of graphite produced as a by-product of IDC 310 generation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W111	Handling:	CH	NMVP #:	N/A	Stream Name:	Heavy Metal (non-SS)/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 3/6/95

Waste Matrix Code: S5119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	7.9	0.0	0.0	0.0	0.0	7.9
Totals	7.9	0.0	0.0	0.0	0.0	7.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 7.9 Projected: 0.0 Total: 7.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	Typically, these scrap metals consist of crucibles, funnels, rods and fixturing from several processes and production operations. Tantalum, tungsten and platinum are examples of scrap metals at the RFP.
WASTE STREAM SOURCE	Heavy metals have been produced as by-products of Rocky Flats operations in Buildings 371, 707, 771, 776, 777, 779, and 865; they are identified by IDC 320. The IDC 320 heavy nonspecial source metal was generated in various locations throughout the Rocky Flats. This IDC includes nonstainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	17.3	0.0	0.0	0.0	0.0	17.3
Totals	17.3	0.0	0.0	0.0	0.0	17.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 17.3 Projected: 0.0 Total: 17.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 330 is Dry Combustibles. This IDC is dry combustibles such as cloth, paper, and wood. This IDC changes to 821, 831, 851, or 861 at the point of assay, depending on radiological content. Containers of IDC 330 currently in inventory were generated in all buildings handling fissile material. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	2.5	0.0	0.0	0.0	0.0	2.5
Totals	2.5	0.0	0.0	0.0	0.0	2.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.5 Projected: 0.0 Total: 2.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters.

WASTE STREAM SOURCE

These Ful-Flo filters are in-line cartridge filters used throughout Rocky Flats to remove particulates from fluid streams and typically filter down to 5, 1, and 0.5 micron-sized particulates. Ful-Flo filters are used in various liquid systems that include nitric- and chloride-acid systems, such as those found in plutonium recovery operations; caustic systems, such as those found in utilities scrubbing; solvent systems using carbon tetrachloride in machining operations; water systems, such as steam cleaning; and condensate collection. These filters are also used in lubricant oil filtration.

Ful-Flo filters are poly-fiber-wound cartridges, about 10" long by 3.5" in diameter. Other fiber filters, such as R-6 pads, may be included in this IDC. R-6 pads are cloth filters, about sixteen inches in diameter, used to filter solids from nitric acid solutions. Therefore, backlog material in this IDC cannot be considered homogeneous, filter elements are produced by combining a media blanket and spirally wound matrix yarn on an inner core. The filter elements might have a polypropylene cap on one end. Both the media blanket and matrix yarn can be cotton or polypropylene. The inner core material can be constructed of polypropylene, tinned steel, or stainless steel. Warehouse data from Rocky Flats indicate that the inner-core material is polypropylene.

Typically, Ful-Flo filters were placed on drying racks pending bag-out of a glovebox. Filters were not always dried before removal from the glovebox. Filters were then "bagged out" of the glovebox and placed in a second layer of plastic. Next, the filters were placed in a "Poly Bottle" or "Clam Shell" (hard plastic container), then placed in a double-lined drum.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS N/A

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W115	Handling:	CH	NMVP #:	N/A	Stream Name:	Fireblanket/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	91.7	1.9	353.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.8	0.0	9.6
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cans/2-liter	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	This waste stream is contaminated insulation.
WASTE STREAM SOURCE	Item Description Code 334 During normal operations, fire blankets become soiled, contaminated, or are no longer needed in an area. There is one backlog drum of IDC 334. This drum was generated in Building 771 from July 1991 to December 1991.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	The volumes and the radionuclide concentrations developed in the profile were based on processing plutonium residues for actinide separation. RFETS has modified this processing plan. Residues will be processed to meet WIPP WAC, TRAMPAC, and safe storage conditions. The modified volumes and radionuclide concentrations are reflected in the WIPP level roll-ups.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	8.3	0.6	56.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	9.8	0.7	66.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.4	4.8	429.5
Rubber:	2.8	0.2	19.1
Plastics:	3.8	0.3	25.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 1.5 Projected: 0.0 Total: 1.5

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is High Efficiency Particulate Air (HEPA) filters used in ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large filter plenums that filter the room air. Used filters were removed from their position in the ventilation system and packaged for further processing. The filters used on gloveboxes (nominal 8" x 8" x 5") were identified as IDC 335 if they were not acid contaminated. RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections in section 8.2.15.1.13 include generation of IDC-335 and IDC-342 to be processed to IDC-335. The volumes and the radionuclide concentrations developed in the profile were based on processing plutonium residues for actinide separation. RFETS has modified this processing plan. Residues will be processed to meet WIPP WAC, TRAMPAC, and safe storage conditions. The modified volumes and radionuclide concentrations are reflected in the WIPP level roll-ups.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	44.3	0.0	0.0	0.0	0.0	44.3
Totals	44.3	0.0	0.0	0.0	0.0	44.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 44.3 Projected: 0.0 Total: 44.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This IDC changes to 822, 832, 852, or 862 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES: N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE: None

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	10.2	0.0	0.0	0.0	0.0	10.2
Totals	10.2	0.0	0.0	0.0	0.0	10.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 10.2 Projected: 0.0 Total: 10.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 337 represents PVC sheeting, poly bottles, supplied-air suits polyethylene, and other plastics. IDC 337 changes to 825, 833, 853, or 863 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	N/A	Stream Name:	Filters & media/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	20.6	0.0	0.0	0.0	0.0	20.6
Totals	20.6	0.0	0.0	0.0	0.0	20.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 20.6 Projected: 0.0 Total: 20.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.

WASTE STREAM SOURCE

The material in this IDC is either the filter media portion of HEPA filters or surface-water filters. HEPA filters are used on gloveboxes and in large filter plenums. Sock filters were used to prefilter operable unit 2 (OU-2) surface water prior to activated carbon treatment.

Used HEPA filters were processed to segregate those portions with high plutonium content and those with low content. The wood frames were separated from the media and almost always disposed of as waste by packing in drums that were assigned IDC 330. the filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste.

This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from the production Building 707 and could be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon. IDC 338 was meant to be used as a residue IDC and not as a waste IDC. Because sorting between IDCs was not accurate, some of the IDC 338 backlog containers are below the economic discard limit (EDL) and are therefore not residue.

RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.

This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS N/A

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	HEPA filters are used on all gloveboxes to remove particulates from the atmosphere exiting the glovebox to the plenum exhaust system. The filters in IDC 342 are from gloveboxes with atmospheres that could cause the filters to be contaminated with acids or bases used in chemical processing. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W114	Handling:	CH	NMVP #:	N/A	Stream Name:	Mg Oxide Crucibles/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal

Inventory Date: 3/6/95

Waste Matrix Code: S5123

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.3	0.0	0.0	0.0	0.0	0.3
Drum / 55-gallon	12.3	0.0	0.0	0.0	0.0	12.3
Totals	12.6	0.0	0.0	0.0	0.0	12.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 12.6 Projected: 0.0 Total: 12.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream includes any type or size or ceramic crubicles or liners including LECO crucibles. This waste consists of magnesium oxide ceramic crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing plutonium residue.
WASTE STREAM SOURCE	Item Description Code 368 During normal process operations, the Electrorefining, Reduction and Button Breakout, Direct Oxide Reduction, and Salt Scrub processes in Buildings 559, 771, and 779 generated broken magnesium oxide crucible pieces. A detailed description of the generating processes presented above can be found in the WSRIC Building Books. However, in general, the crucibles were used to heat plutonium with salts or accelerators allowing for purification or recovery of actinide metrals. Upon cooling to room temperature, the crucible or crucible insert used in the process would be broken and its contents removed.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W114	Handling:	CH	NMVP #:	N/A	Stream Name:	Mg Oxide Crucibles/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal

Inventory Date: 3/6/95

Waste Matrix Code: S5123

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	33.1	0.0	0.0	0.0	0.0	33.1
Totals	33.1	0.0	0.0	0.0	0.0	33.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 33.1 Projected: 0.0 Total: 33.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream includes any type or size or ceramic crubicles or liners including LECO crucibles. This waste consists of magnesium oxide ceramic crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing plutonium residue.
WASTE STREAM SOURCE	Item Description Code 370 The laboratories in Buildings 559 and 771 generated LECO crucibles and broken LECO crucible pieces. These crucibles were used for carbon analyses of plutonium metals and oxides. Stainless steel pins were also heated in these crucibles for calibration purposes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W121	Handling:	CH	NMVP #:	N/A	Stream Name	Cemented filters/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.9	0.0	0.0	0.0	0.0	6.9
Totals	6.9	0.0	0.0	0.0	0.0	6.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.9 Projected: 0.0 Total: 6.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	Processed filter media, IDC 376, is material which has been treated using Portland cement to absorb moisture and neutralize acid contamination. Filter waste is packaged in 55-gallon drums and metal standard waste boxes. Inventory data include residues within the same IDCs because they are regulated as waste.
WASTE STREAM SOURCE	The material in this IDC is the filter media portion of acid-contaminated glovebox or plenum HEPA filters or Ful-Flo filters with free liquids. Processing was performed in the Site Reduction Vaults in Building 776. Used HEPA filters were processed to separate any portions containing high plutonium content from portions with low content. The wood frames were separated from the media and usually disposed of as waste by packing in a drum that was assigned IDC 330. The filter media pieces were identified as IDC 339 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste. The media were placed in crates, Portland cement was added, then crates were sealed. Some IDC 376 material could be the remaining material after the IDC 338 media were processed to recover the plutonium. Ful-Flo filters which were used to filter corrosive gas were also processed to separate any portions containing high plutonium content from portions with low plutonium content. Pieces of media with low activity were identified as IDC 376 and packaged for shipment as waste. The media were placed in approximately 10-gallon plastic bags and Portland cement was added. The bags were then sealed and placed in a drum. IDC 376 filter media in this backlog population was derived from the processing of HEPA filters from Buildings 371, 771, 776, and 770. The HEPA filters could have orginally been assigned ICDs 335 342, 490, 491 or 492. Filter media from Building 771 could have been used to filter nitric acid vapors.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 390 This IDC consists primarily of unpulverized slag generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771. The unpulverized slag is generated from the seperation of calcium fluoride slag from the sand and crucible residues following the removal of the plutonium metal button. Calcium fluoride is produced from the reaction of the calcium metal with the plutonium fluoride. Unpulverized slag is placed in 4-liter, wide mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 391 This IDC constists primarily of unpulverized sand and crucible generated as a residue form the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771. The unpulverized sand and crucible are generated from the separation of sand and crucible residues from the calcium fluoride slag following the removal of the plutonium metal button. Unpulverized sand and crucible is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.02 Projected: 0.0 Total: 0.02

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	IDC 392 consists of unseparated IDC 391 materials. Unpulverized sand, slag, and crucible are placed in 4-liter, wide-mouthed, polyethylene bottles for removal from the glovebox. After the containers are bagged out, they are assayed individually. The sand, slag, and crucible are stored awaiting crushing prior to plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W114	Handling:	CH	NMVP #:	N/A	Stream Name:	Mg Oxide Sand/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5123

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.02	0.0	0.0	0.0	0.0	0.02
Drum / 55-gallon	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream includes any type or size or ceramic crubicles or liners including LECO crucibles. This waste consists of magnesium oxide ceramic crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing plutonium residue.
WASTE STREAM SOURCE	Item Description Code 394 Button breakout sand, contains fine particulates and may contain reactive metals (calcium and plutonium). Must be solidified prior to certification to NTS or WIPP. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 395 This IDC consists primarily of unpulverized slag and crucible generated as a residue from the reduction of plutonium tetrafluoride to plutonium metal, using calcium metal as the reductant. This reduction operation was performed in a reaction vessel within Glovebox (Line) 17 in Building 771. The unpulverized slag and crucible are generated from the separation of calcium fluoride slag and crucible residues from the magnesium oxide sand following the removal of the plutonium metal button. Calcium fluoride is produced from the reaction of the calcium metal with the plutonim fluoride. Unpulverized slag and crucible are placed in 4-liter, wide-mouth, polyethylene bottles for removal from the gotvebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting crushing prior to plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL *(cu. meters)*

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 396 This IDC consists primarily of pulverized slag generated from the crushing and grinding of calcium fluoride slag in preparation for dissolution. This crushing operation was performed with the jaw crusher and hammer mill (constructed of mild steel) within Gloveboxes (Lines) 43B and 43C in Building 771. The pulverized slag is placed in 4-liter, wide-mouth, polyethylene bottles for removal from the glovebox. After the bottles are bagged out, they are assayed individually. The bottles are stored awaiting plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	5.6	0.0	0.0	0.0	0.0	5.6
Totals	5.6	0.0	0.0	0.0	0.0	5.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 5.6 Projected: 0.0 Total: 5.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 398 This IDC consists primarily of pulverized sand, slag, and crucible generated from the crushing and grinding of magnesium oxide sand, calcium fluoride slag, and broken reduction crucibles in preparation for dissolution. This crushing operation was performed with the jaw crusher and hammer mill (constructed of mild steel) in Gloveboxes (Lines) 43B and 43C in Building 771. The pulverized sand, slag, and crucible are placed in 4-liter, wide-mouth, polyethylene bottles for removal from the gotvebox. After the bottles are bagged out, they are assayed individually. The containers are stored awaiting plutonium recovery by dissolution. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 404 salt is composed primarily of sodium chloride, potassium chloride, calcium chloride, residual zinc chloride, entrained zinc and calcium metal, and various plutonium and americium compounds. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cans/2-liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	6.0	0.0	0.0	0.0	0.0	6.0
Totals	6.0	0.0	0.0	0.0	0.0	6.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.0 Projected: 0.0 Total: 6.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cans/2-liter	0.05	0.0	0.0	0.0	0.0	0.05
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.05 Projected: 0.0 Total: 0.05

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	4.0	0.0	0.0	0.0	0.0	4.0
Totals	4.0	0.0	0.0	0.0	0.0	4.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.0 Projected: 0.0 Total: 4.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405–410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Cans/2-liter	0.05	0.0	0.0	0.0	0.0	0.05
Drum / 55-gallon	56.2	0.0	0.0	0.0	0.0	56.2
Totals	56.2	0.0	0.0	0.0	0.0	56.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 56.2 Projected: 0.0 Total: 56.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	4.6	0.0	0.0	0.0	0.0	4.6
Drum / 55-gallon	34.3	0.0	0.0	0.0	0.0	34.3
Totals	38.9	0.0	0.0	0.0	0.0	38.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 38.9 Projected: 0.0 Total: 38.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Nonspecification plutonium metal, cast as an anode, was combined with and equimolar mixture of sodium chloride and potassium chloride in a magnesium oxide crucible. Magnesium chloride was then added to initiate the plutonium oxidation. The metal and salts were placed in a furnace and heated until molten. The molten mixture was stirred, and a current applied to the anode which flowed through the molten mixture to the cathode. Plutonium ions migrated from the molten anode through the molten salt to the cathode and were reduced to purified metal. After cooling, the crucible was broken and the salt, anode heel, and purified plutonium metal were separated. This process produced IDC 411 salts. IDC 411 is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metals, and various plutonium compounds. These salts may contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. IDC 411 salt packaged for off-site shipment was assigned IDC 473. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Impure metal was placed in a crucible with sodium chloride, potassium chloride, and zinc chloride. The crucible and contents were heated in a furnace until the contents were molten and the mixture was stirred. While molten, the zinc chloride reacted with the plutonium metal to form plutonium chloride and zinc metal. The contents separated into salt and metal products at process temperature. After cooling and breakout, the plutonium-rich salt phase was reloaded into a crucible along with calcium metal. The crucible and contents were heated in a furnace until the contents were molten and the mixture was stirred. While molten, the calcium reduced the plutonium chloride to plutonium metal. After cooling, the crucible was broken and the metal and salt were separated. This process produced IDC 412 salts. IDC 412 is a Glvson salt which was generated by an experimental pyroredox process. The salt is composed primarily of sodium chloride, potassium chloride, calcium chloride, residual zinc chloride, entrained zinc and calcium metal, and various plutonium and americium compounds. Sodium and potassium metal may also be present due to the reduction of these metals by the excess calcium metal. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates ? 1wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 413 was generated by the scraping and cleaning of pyrochemical furnace cells and consists of spent pyrochemical salts and magnesium, calcium, sodium, and potassium metals which vaporized during the pyrochemical processes and collected on the cold parts of the cells. The scraped-out material may have been reheated in a furnace to oxidize the metals; however, this did not always occur. This salt could contain compounds present in any of the pyrochemical salts.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Calcined plutonium oxide was placed in a magnesium oxide crucible with calcium chloride and calcium metal. The crucible and contents were placed in a furnace and heated until the contents were molten. The molten material was stirred to initiate and promote the reduction of the plutonium oxide. After the reaction, the melt was allowed to separate into plutonium metal and salt phases. After cooling, the crucible was broken and seperated from the salt, calcium, and plutonium metal. This process produced IDCs 365 and 414. IDCs 365 and 414 are composed primarily of calcium chloride, calcium oxide, calcium metal entrained in the salt, and various plutonium compounds. A "button" of excess calcium may also be present in some containers of these salts. IDC 365 was produced by a failed DOR run and is expected to contain higher levels of plutonium oxide and calcium metal than IDC 414. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.04	0.0	0.0	0.0	0.0	0.04
Drum / 55-gallon	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	The salt assigned IDC 415 was generated by an experimental MSE process which used plutonium trichloride as an oxidizer. The spent salt is composed primarily of calcium chloride with various plutonium and americium compounds. No reactive metals are present in this salt. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	[illegible]	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 416 is small billets or ingots of zinc-magnesium alloy metal containing plutonium which were generated from a research and development (R&D) salt cleanup project in Building 776 and 779. The weight percent of magnesium in alloy will range from 10 percent to 30 percent (EG&G Idaho 1982). RE: Section 5.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 417 is decesium hexachloroplutonate salt synthesized for use in the molten salt extraction process. With the change of the plant mission from recovery and production to environmental cleanup, the material became a waste. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Plutonium metal containing unacceptable levels of americium was combined with an equimolar mixture of sodium chloride and potassium chloride with magnesium chloride. The metal and salts were placed in a tantalum crucible and then in a furnace and heated until molten. The molten material was then stirred. While the mixture was molten, the magnesium chloride oxidized most of the americium and some of the plutonium, and the oxidized actinides went to the salt phase. After stirring, the salt and metal phases were allowed to separate at the elevated temperature. This process produced IDCs 405-410. IDC 405 and 406 were generated when an unknown weight percent of magnesium chloride was used in the fresh salt. IDCs 407 and 408 were produced when an 8-weight-percent ratio of magnesium chloride was used in the fresh salt. IDCs 409 and 410 were formed when a 30-mole-percent ratio of magnesium chloride was used in the fresh salt. For all of these IDCs, the spent salt is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and americium compounds. Any of the above MSE salts which have been packaged for off-site shipment were assigned IDC 418. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste	Waste Matrix Code:	S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.3	0.0	0.0	0.0	0.0	0.3
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.3	0.0	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	In March 1989, the MSE process was converted from the use of magnesium chloride as an oxidizer to the use of dicesium hexachloroplutonate (DCHP) and calcium chloride instead of the equimolar mixture of sodium chloride and potassium chloride. The converted process produced IDC 427 composed primarily of calcium chloride, cesium chloride, and various plutonium and americium compounds. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	9.2	0.0	0.0	0.0	0.0	9.2
Totals	9.2	0.0	0.0	0.0	0.0	9.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 9.2 Projected: 0.0 Total: 9.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 429 salt was generated using magnesium and aluminum. This IDC represents salts produced from the salt scrub of MSE salts using magnesium chloride. This salt is composed primarily of sodium chloride, potassium chloride, magnesium chloride, entrained magnesium and aluminum metal, and various plutonium and americium compounds.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	N/A	Stream Name:	Organic Resins/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	The ion-exchange resins were important to the plutonium purification processes at RFETS. Plutonium-contaminated materials were often dissolved in nitric acid and processed through ion exchange. The ion-exchange resin contained in an ion-exchange column was charged with highly concentrated nitric acids by trickling this solution through the columns. A plutonium-contaminated solution was then trickled through the column. The charged resin beads attracted the plutonium from the contaminated solution to the surface of the resin bead. The loaded resin beads were then leached by trickling another nitric acid solution through the tube. This final nitric acid solution drew the plutonium from the beads into solution and allowed for purification of the plutonium. The resin was periodically replaced when this process had depleted the efficiency of the resin. The ion exchange resins in use at Rocky Flats were generally small plastic (polystyrene) beads in which long-chain organic compounds with an activated group are imbedded (such as Dowex 1 x 2). Unleached resin IDC 430, was produced when the resin ion exchange columns were replaced. Though this IDC is titled "unleached" resin, the generators of resins confirm that all resins were rinsed with, at least, weak acid before the resins were removed from the columns. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data..
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	N/A	Stream Name:	Organic Resins/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	[illegible]	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	3.1	0.0	0.0	0.0	0.0	3.1
Totals	3.1	0.0	0.0	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.1 Projected: 0.0 Total: 3.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	The ion-exchange resins were important to the plutonium purification processes at RFETS. Plutonium-contaminated materials were often dissolved in nitric acid and processed through ion exchange. The ion-exchange resin contained in an ion-exchange column was charged with highly concentrated nitric acids by trickling this solution through the columns. A plutonium-contaminated solution was then trickled through the column. The charged resin beads attracted the plutonium from the contaminated solution to the surface of the resin bead. The loaded resin beads were then leached by trickling another nitric acid solution through the tube. This final nitric acid solution drew the plutonium from the beads into solution and allowed for purification of the plutonium. The resin was periodically replaced when this process had depleted the efficiency of the resin. The ion exchange resins in use at Rocky Flats were generally small plastic (polystyrene) beads in which long-chain organic compounds with an activated group are imbedded (such as Dowex 1 x 2). Leached resin IDC 431, was produced when the resin ion exchange columns was replaced. The resin was leached (rinsed) with water before the resin was removed from the columns. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 433 salt was also generated using magnesium and aluminum. This IDC represents salts produced from the salt scrub of IDC 427 MSE salts. This salt is composed primarily of calcium chloride, cesium chloride, entrained magnesium and aluminum metal, and various plutonium and americium compounds. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 434 was generated using calcium and gallium. This IDC represents salts produced from the salt scrub of MSE DCHP salts. This salt is composed primarily of calcium chloride, cesium chloride, entrained calcium and gallium metal, and various plutonium and americium compounds. A "button" of excess calcium may also be present in some containers of this salt. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W115	Handling:	CH	NMVP #:	RF 122	Stream Name:	Insulation/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

RF 122

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is contaminated insulation.
WASTE STREAM SOURCE	Item Description Code 438 Maintenance, repair, and strip-out operations in Buildings 371, 374, 444, 559, 666, 707, 771, 774, 776, 777, 779, 865, 881, and 883 produced waste insulation. Insulation waste is generated by replacement of furnace heating elements, construction, maintenance, and demolition activities within the Protected Area at Rocky Flats. During these activities, insulation material is removed from furnaces, boilers, piping, ceilings and walls, and heating and cooling systems.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	N/A	Stream Name:	Glass/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 440 includes glass waste from analytical laboratories and recovery processes, standard light bulbs generated inside the PA, and ceramic materials. Glass waste assigned IDC 440 was generated in Buildings 123,371, 444, 559, 707, 771, 776, 777, 889. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data. This waste stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	N/A	Stream Name:	Glass/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 441 includes unleached Raschig Rings to be discarded. Raschig Rings are borosilicate glass rings used to maintain subcritical conditions in fissile solution storage tanks that are not safe by dimension. The boron in the rings is a neutron poison, an element that absorbs neutrons. The volume of the ring displaces a proportionate volume of solution and, in combination with the boron, creates a critically safe configuration. Over time, the rings can become broken or otherwise damaged, especially in air-sparged tanks. In those cases, the rings were removed and replaced. The rings were also replaced if the assay of the tank exceeded acceptable limits. The old rings were assayed, and if the material count was above the economic discard limit (EDL), the rings were leached (rinsed with water or acid) and stored for plutonium recovery. If the material count was below EDL, the rings were packaged for discard without leaching. The unleached rings were assigned IDC 441. Raschig Rings assigned IDC 441 were generated in Buildings 371 and 771. Rings generated in Building 371 were generated by the Process Vent Scrubber System in Rooms 1105 and 2319. The system removed nitric- and sulfuric-acid vapors and entrained liquids from the process vent header streams connected to the Building 371 tanks. The acids were neutralized with potassium hydroxide and water. Vent scrubbers D229 A and B were filled with Raschig Rings. Rings generated in Building 771 were generated in production processes in tanks used to temporarily store radioactive solutions. The solutions could have contained nitric or sulfuric acids, or potassium hydroxide.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	N/A	Stream Name:	Glass/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	Raschig Rings currently in WEMS assigned IDC 442 were generated in Buildings 771, 776, and 777. Prior to being replaced, the tanks were drained and the rings were leached with dilute nitric acid or water. The rings generated in Building 771 are from the production processes and Tanks D80-85, d0-360, D-361, D-451, D-454, D-467, D-750, D-706, D-922, D-973, D-974, D-980, D-1006, D-1013, D-1022, and D-1081. Rings generated in Building 776 are from the Size Reduction Process and Tanks SR 3, 4, and 5 and as unused rings. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W102	Handling:	CH	NMVP #:	N/A	Stream Name:	Ground Leaded Glass/TRU
Local ID:	IDC 444	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal

Inventory Date: 3/6/95

Waste Matrix Code: S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.5	0.0	0.0	0.0	0.0	7.5
Totals	7.5	0.0	0.0	0.0	0.0	7.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 7.5 Projected: 0.0 Total: 7.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	IDC 444 includes ground fluorescent bulbs and leaded glass used throughout the plutonium- and uranium-processing areas. The material was generated as waste or residue when glovebox glass was replaced, or as low-level waste when fluorescent light bulbs were replaced. IDC 444 materials in the backlog inventory were generated in Building 371, 374, 559, 707, 771, and 776.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.4	0.0	0.0	0.0	0.0	2.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.4 Projected: 0.0 Total: 2.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Nonspecification plutonium metal, cast as an anode, was combined with and equimolar mixture of sodium chloride and potassium chloride in a magnesium oxide crucible. Magnesium chloride was then added to initiate the plutonium oxidation. The metal and salts were placed in a furnace and heated until molten. The molten mixture was stirred, and a current applied to the anode which flowed through the molten mixture to the cathode. Plutonium ions migrated from the molten anode through the molten salt to the cathode and were reduced to purified metal. After cooling, the crucible was broken and the salt, anode heel, and purified plutonium metal were separated. This process produced IDC 411 salts. IDC 411 is composed primarily of sodium chloride, potassium chloride, residual magnesium chloride, entrained magnesium metals, and various plutonium compounds. These salts may contain sodium and potassium metal that was produced during the electrolysis of the molten salt mixture. IDC 411 salt packaged for off-site shipment was assigned IDC 473. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.9	0.0	0.0	0.0	0.0	2.9
Totals	2.9	0.0	0.0	0.0	0.0	2.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.9 Projected: 0.0 Total: 2.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 479 is assigned to empty reusable cans generated in Buildings 559, 707, and 771 (containers currently in WEMS from these buildings). Stainless-steel cans were used to handle plutonium-contaminated material. Primary generation was through the use of these cans to manually transfer materials between gloveboxes. Cans that were introduced tot he process were typically recycled and reused. there were no generation process descriptions in WSRIC for this waste in Buildings 559, 707, and 771. In Building 371, the Dicesium Hexachloroplutonate (DCHP) Process often used the cans for transferring materials into the stacker.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 3/6/95

Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.1	0.0	0.0	0.0	0.0	0.1
Drum / 55-gallon	15.8	0.0	0.0	0.0	0.0	15.8
Totals	15.9	0.0	0.0	0.0	0.0	15.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 15.9 Projected: 0.0 Total: 15.9

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 480 is assigned to line- and nonline-generated light metals generated in Buildings 371, 374, 444, 559, 707, 771, 774, 776, 777, 779, 865, and 991 (containers currently in WEMS these buildings). Light metals include aluminum, copper, iron, brass, bronze, galvanized metal, stainless steel, carbon steel, and other metal alloys contained in waste mechanical and electrical parts, tools, containers, scrap metals, piping, wire, cable, gauges, valves, foil, planchets, and a variety of other metal items. The maintenance operation was inextricably linked with the generation of the material that created this IDC. The maintenance-generated materials were generated throughout the entire facility. Backlog containers of this IDC may contain a matrix of all light metals listed above.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 484 was assigned to classified non-nuclear material scrap metal shapes made primarily of stainless steel and aluminum. Prior to 1987, IDC 484 included beryllium shapes. These items were generated in Buildings 777 and 779 during disassembly operations of site-return units. Buildings 444, 707, and 883 generated rejected parts. Containers in inventory were generated from February 1983 to May 1991.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	Metal/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 485 was assigned to scrap D-38 classified metal shapes. Generation of this material occurred in Buildings 777 during disassembly of site-return units. Building 444 generated rejected parts. Containers in inventory were generated from July 1987 to August 1992.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 486 was assigned to classified tooling for disposal. Generation of these tools occurred in Buildings 707 and 777. The material consists primarily of obsolete tooling including pot chucks and inspection gauges. Containers in inventory were generated from October 1982 to December 1992.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 3/6/95

Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	Yes
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.5	0.0	0.0	0.0	0.0	1.5
Totals	1.5	0.0	0.0	0.0	0.0	1.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.5 Projected: 0.0 Total: 1.5

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 489 was assigned to scrap D-38 classified metal shapes generated in Building 777 and 779 during disassembly of site-return units. Containers in inventory were generated from February 1986 to September 1990.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.
WASTE STREAM SOURCE	The miscellaneous liquids waste form includes uranium solutions from criticality laboratories (IDC 504).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.
WASTE STREAM SOURCE	IDC 527 is caustic waste solutions consisting of sodium hydroxide or potassium hydroxide. Low-Level Dissolution in Building 771 used potassium hydroxide for flushing the condenser when dissolvind incinerator ash. H-4 Support Vacuum Systems used potassium hydroxide in an aqueous solution as a seal liquid. Vacuum Systems also used a seal liquid made up of water only. RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supportin data. RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration range.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.

WASTE STREAM SOURCE

The Building 371 analytical laboratory receives liquid and solid samples from the entire plant site. Samples that are destined for Building 881 are analyzed in Building 371 to screen out those with high levels of radioactivity. Sludge and aqueous samples from Building 374 are analyzed for total alpha activity and plutonium, uranium, and americium content. Prior to analysis, the sludges are dissolved in nitric acid, hydrogen fluoride, or hydrochloric acid. Reagents are also used in sample preperation. Unused portions or excess prepared sample are placed in 4-liter plastic bottles.

The Building 559 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various ions, iron, silicon, isotopic compsition, and americium, gallium, neptunium, plutonium, uranium, and other metals (Resource Conservation and Recoverey Act [RCRA] - regulated and nonregulated). Solid samples are dissolved in a variety of acids, including nitric and hydrochloric. Other chemicals used in the laboratory include methanol, chloroform, and other organic solvents; titanium trichloride; ceric ammonium nitrate; sodium hydroxide; silver chloride; silver nitrate; and various metals standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also place on the bottles.

The Building 771 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various metals and ions, pH, and radioactivity. The principal chemicals used in the lab include sodium hydroxide, hydrochloric acid, nitric acid, cyclohexane, trioctyl phosphine oxide, yttrium, and various metal standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles.

RE: Section 8.2.11, RFETS doesn't expect sulfates, phosphates >1 wt%, but has no supporting data.

RFETS does expect nitrate concentration to be >1%, but has no data indicating the actual concentration or range.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS N/A

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 600 consists of an aluminum-magnesium-plutonium alloy generated by the Salt Scrub Process in Building 776 Pyrochemical Processing. The salt from the magnesium chloride-based Molten Salt Extraction Process and small quantities of salt from electrorefining process (R&D only) were combined with elemental aluminum (alloying agent) and magnesium (reductant) in a ceramic crucible. The mixture was melted in a furnace and stirred, resulting in a metal button. When cool, the button was separated from the salt and prepared for transfer to the Savannah River Site for processing.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU	Inventory Date:	3/6/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 601 was produced in the pyrochemistry research in Building 776 and 779. This IDC was produced during developmental studies of aluminum oxide and magnesium oxide crucibles. These studies were conducted to determine the resistance on the crucible materials to thermal shock. The crucibles would break during processing. IDC 601 is used to describe the pieces of the crucibles collected. The crucibles could be contaminated with pyrochemistry process residues such as salt, plutonium, and small amounts of sodium metal. The aluminum and magnesium oxide was placed in metal cans and stored.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W123	Handling:	CH	NMVP #:	N/A	Stream Name:	Oxides/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste was generated from plutonium recovery operations in Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area , grit , soot , and soot heel.
WASTE STREAM SOURCE	IDC 653 consists of the free metal brushed from thesurface of plutonium-neptunium alloy buttons generated by electrorefining in Building 776 Pyrochemical Processing. The brushings were burned and sent to Buildign 771 and reburned prior to dissolution.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery ByProduct/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 3/6/95

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
can / 2-Liter	0.03	0.0	0.0	0.0	0.0	0.03
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	IDC 654 salt was generated from experimental ER work to study the distribution of neptunium during electrorefining of plutonium. This salt is composed primarily of sodium chloride and potassium chloride, residual magnesium chloride, entrained magnesium metal, and various plutonium and neptunium compounds. This salt may also contain sodium and potassium metal produced during the electrolysis of the molten salt mixture. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W116	Handling:	CH	NMVP #:	N/A	Stream Name:	Sand, Slag and Crucible/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics

Inventory Date: 3/6/95

Waste Matrix Code: S3119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Can / 2-Liter	0.00	0.0	0.0	0.0	0.0	0.00
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste includes pulverized and unpulverized sand, slag, and crucible.
WASTE STREAM SOURCE	Item Description Code 655 During normal process operations, the electrorefining of plutonium-neptunium alloy processes in Buildings 776 and 779 generated broken magnesium oxide crucible pieces. The plutonium-neptunium combination was a special case and limited work was performed to generate this material. Upon cooling to room temperature, the crucible used in the process would be broken and its contents removed.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	RF115	Stream Name:	Coarse Graphite/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	17.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	318.3	51.9	381.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 115

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.93E+01
Pu-240	1.23E+00
Pu-239	5.38E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	12.9	0.0	0.0	2.2	2.6	17.7
Totals	12.9	0.0	0.0	2.2	2.6	17.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	12.9	0.0	0.0	2.2	2.6	17.7
Totals	12.9	0.0	0.0	2.2	2.6	17.7

As-Generated Form: Stored: 12.9 Projected: 4.8 Total: 17.7

Final Waste Form: Stored: 12.9 Projected: 4.8 Total: 17.7

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 300, Graphite Molds During the casting of plutonium in production foundry operations, the plutonium casting operations in Building 707 generated used graphite molds. The working surfaces were coated with calcium fluoride prior to using the mold. After the plutonium casting was removed from the mold, the molds were collected in a drum. Drums that contained recoverable amounts of plutonium were stored for subsequent scarfing of molds.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	RF115	Stream Name:	Coarse Graphite/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite

Inventory Date: 9/5/94

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 115

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.93E+01
Pu-240	1.23E+00
Pu-239	5.38E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.2	0.0	0.0	0.7	0.9	5.8
Totals	4.2	0.0	0.0	0.7	0.9	5.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.2 Projected: 1.7 Total: 5.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 301, Classified Graphite Shapes During the casting of plutonium in production foundry operations, classified molds are segregated from non-classified molds. Prior to 1984, the classified molds were destroyed in Building 776.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	N/A	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
metal box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Totals	3.6	0.0	0.0	0.0	0.0	3.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Standard Waste Box	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 3.6 Projected: 0.0 Total: 3.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 302 includes Benelex and Plexiglas. Benelex is a very dense organic material used for radiation shielding around gloveboxes and tanks. In some cases, Benelex is laminated with lead. However, none of the containers identified here have lead lamination. The Benelex used by RFETS is usually 2 inches thick although occasionally two 2-inch thick pieces were bolted toghether to increase shield thickness. Plexiglas is a trade name used to describe a family of polycarbonate materials used for radiation shielding in glovebox windows and equipment enclosures. Plexiglas glovebox windows are generally 2- to 4-inches thick and can be in various sizes and shapes. Benelex and Plexiglas in the inventory were generated in Buildings 371, 707, 771, and 776. The IDC was generated as waste during replacement of shielding or stripout of unnecessary shielding during the installation of new gloveboxes or tanks.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	N/A	Stream Name:	Coarse Graphite/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	17.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	318.3	51.9	381.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.93E+01
Pu-240	1.23E+00
Pu-239	5.38E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.1	0.1	0.4
Totals	0.2	0.0	0.0	0.1	0.1	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.2 Total: 0.4

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 303, Scarfed Graphite Chunks After the casting of plutonium in production foundry operations, IDCs 300 and 301 were mechanically cleaned using a hand-held rotary-type sanding tool to grind off contamination in buildings 371, 707, 771, and 777, generating Scarfed Graphite Chunks. The mechanical cleaning (scarfing) of the mold surface removes most of the mold coating and plutonium contamination. This process generated IDC 303 and 310, as well as, IDC 312.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W117	Handling:	CH	NMVP #:	RF115	Stream Name:	Coarse Graphite/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Graphite	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	17.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	250.7	155.7	345.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 115

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	2.93E+01
Pu-240	1.23E+00
Pu-239	5.38E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	18.7	23.3	42.6
Totals	0.6	0.0	0.0	18.7	23.3	42.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 42.0 Total: 42.6

WASTE STREAM DESCRIPTION	This waste form includes graphite chunks and coarse graphite .
WASTE STREAM SOURCE	Item Description Code 312, Graphite Coarse After the casting of plutonium in production foundry operations, IDC 300 was mechanically cleaned in Buildings 371, 707, 771, and 777, generating coarse graphite. Material generated in this process were chunk pieces of graphite produced as a by-product of IDC 310 generation.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	IDC 310, 312, 303.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W111	Handling:	CH	NMVP #:	RF 117	Stream Name:	Heavy Metal (non-SS)/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5119

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	60.5	0.0	168.7
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	141.0	29.0	393.3
Other Inorganic Material:	14.0	2.9	39.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	5.28E+01
Pu-240	2.22E+00
Pu-239	9.69E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.6	0.0	0.0	1.7	2.1	8.4
Totals	4.6	0.0	0.0	1.7	2.1	8.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.6	0.0	0.0	1.7	2.1	8.4
Totals	4.6	0.0	0.0	1.7	2.1	8.4

As-Generated Form: Stored: 4.6 Projected: 3.7 Total: 8.3

Final Waste Form: Stored: 4.6 Projected: 3.7 Total: 8.3

WASTE STREAM DESCRIPTION	Typically, these scrap metals consist of crucibles, funnels, rods and fixturing from several processes and production operations. Tantalum, tungsten and platinum are examples of scrap metals at the RFP.
WASTE STREAM SOURCE	Heavy metals have been produced as by-products of Rocky Flats operations in Buildings 371, 707, 771, 776, 777, 779, and 865; they are identified by IDC 320. The IDC 320 heavy nonspecial source metal was generated in various locations throughout the Rocky Flats. This IDC includes nonstainless-steel metals that are heavier than iron. Examples of this waste include crucibles, funnels, rods, and process fixtures. These items are made primarily from tantalum, tungsten, and platinum, but some parts could have been manufactured or contaminated with lead if the accumulation start date was prior to 1987.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/95
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
metal box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.2 Projected: 0.0 Total: 4.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 330 is Dry Combustibles. This IDC is dry combustibles such as cloth, paper, and wood. This IDC changes to 821, 831, 851, or 861 at the point of assay, depending on radiological content. Containers of IDC 330 currently in inventory were generated in all buildings handling fissile material. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	8.3	0.6	56.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	9.8	0.7	66.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.4	4.8	429.5
Rubber:	2.8	0.2	19.1
Plastics:	3.8	0.3	25.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.32E+01
Pu-240	1.40E+00
Pu-239	6.10E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	19.3	3.3	0.4	22.3	27.6	73.0
Totals	19.3	3.3	0.4	22.3	27.6	73.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	19.3	3.3	0.4	22.3	27.6	73.0
Totals	19.3	3.3	0.4	22.3	27.6	73.0

As-Generated Form: Stored: 19.3 Projected: 53.7 Total: 73.0

Final Waste Form: Stored: 19.3 Projected: 53.7 Total: 73.0

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is High Efficiency Particulate Air (HEPA) filters used in ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large filter plenums that filter the room air. Used filters were removed from their position in the ventilation system and packaged for further processing. The filters used on gloveboxes (nominal 8" x 8" x 5") were identified as IDC 335 if they were not acid contaminated. RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Projections in section 8.2.15.1.13 include generation of IDC-335 and IDC-342 to be processed to IDC-335.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This IDC changes to 822, 832, 852, or 862 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 337 represents PVC sheeting, poly bottles, supplied-air suits, polyethylene, and other plastics. IDC 337 changes to 825, 833, 853, or 863 at the point of assay. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter

Inventory Date: 9/5/94

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	47.0	10.1	122.5
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	78.1	33.4	236.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.32E+01
Pu-240	1.40E+00
Pu-239	6.10E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.3	0.1	2.4	3.0	7.9
Totals	2.1	0.3	0.1	2.4	3.0	7.9

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 5.8 Total: 7.9

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the diceslum hexachlorsplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is either the filter media portion of HEPA filters or surface-water filters. HEPA filters are used on gloveboxes and in large filter plenums. Sock filters were used to prefilter operable unit 2 (OU-2) surface water prior to activated carbon treatment. Used HEPA filters were processed to segregate those portions with high plutonium content and those with low content. The wood frames were separated from the media and almost always disposed of as waste by packing in drums that were assigned IDC 330. the filter media pieces were identified as IDC 338 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste. This filter media can be free of acid contamination or can be heavily contaminated with acid residue. It can also be moist or dry. It could have originated from the production Building 707 and could be contaminated with used solvents such as trichloroethane, carbon tetrachloride, and Freon. IDC 338 was meant to be used as a residue IDC and not as a waste IDC. Because sorting between IDCs was not accurate, some of the IDC 338 backlog containers are below the economic discard limit (EDL) and are therefore not residue. RE: Section 8.2.11, RFETS deosn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W107	Handling:	CH	NMVP #:	RF 121	Stream Name:	Soil & Cleanup Debris/TRU	Inventory Date:	9/5/94
Local ID:	IDC 374	Type:	TRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	273.1	208.9	628.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.0	12.0	12.0
Rubber:	0.0	0.0	0.0
Plastics:	12.0	12.0	12.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	64.9	9.6	628.4
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 121

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	3.30E+00
Pu-240	1.39E-01
Pu-239	6.06E-01
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	This waste stream is construction rubble generated during decontamination and decommissioning activities. This waste consists of blacktop/concrete/dirt/sand. The waste is generated from construction/demolition within the plutonium process buildings. The waste is usually packed in 55-gal. drums with multiple bag liners, a fiberboard liner, and a rigid polyethylene liner. Also, the waste can be packaged in DOT 7A, Type A metal boxes which are lined with a fiberboard and PVC liner. This waste is identified by IDC 374. Inventory data include mixed residues in this IDC. IDC 374-Construction rubble generated during decontamination and decommissioning operations. Metals are considered to be potentially present in the rubble from demolition and cleanup activities. Solvents are potentially present from the materials used during decontamination.
WASTE STREAM SOURCE	Soil and cleanup-debris (IDC 374) were generated during cleanup and construction activities around Rocky Flats. In most cases, construction or demolition activities generated rubble consisting of blacktop, concrete, dirt, sand , and rock. The rubble was packaged in plywood boxes with a fiberboard liner and a polyvinyl chloride (PVC) bag liner or in 55-gallon, DOT Type 7A drups. The waste was generated on a nonroutine basis. Information describing spendid activities generating soil and debris were often unavailable.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A-Process knowledge based upon general knowledge of waste type or source (e.g., there is some probability of a waste constituent being present or absent). Bounding analytical data have not been compiled in a form that is compatible with this report. This effort is in progress and the results will be incorporated when the effort is complete. No information available regarding uncertainty.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W121	Handling:	CH	NMVP #:	RF 119	Stream Name:	Cemented filters/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	63.3	27.1	191.6
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	78.1	33.4	236.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	3.60E+01
Pu-240	1.51E+00
Pu-239	6.61E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.9	0.7	0.1	5.2	6.5	21.5
Totals	8.9	0.7	0.1	5.2	6.5	21.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.9	1.5	0.1	5.2	6.5	22.2
Totals	8.9	1.5	0.1	5.2	6.5	22.2

As-Generated Form: Stored: 8.9 Projected: 12.5 Total: 21.4

Final Waste Form: Stored: 8.9 Projected: 12.5 Total: 21.4

WASTE STREAM DESCRIPTION	Processed filter media, IDC 376, is material which has been treated using Portland cement to absorb moisture and neutralize acid contamination. Filter waste is packaged in 55-gallon drums and metal standard waste boxes. Inventory data include residues within the same IDCs because they are regulated as waste.
WASTE STREAM SOURCE	The material in this IDC is the filter media portion of acid-contaminated glovebox or plenum HEPA filters or Ful-Flo filters with free liquids. Processing was performed in the Site Reduction Vaults in Building 776. Used HEPA filters were processed to separate any portions containing high plutonium content from portions with low content. The wood frames were separated from the media and usually disposed of as waste by packing in a drum that was assigned IDC 330. The filter media pieces were identified as IDC 339 if they were high in radioactivity and packaged and stored for future recovery of the plutonium. If the pieces of media were low in radioactivity, they were identified as IDC 376 and packaged for shipment as waste. The media were placed in crates, Portland cement was added, then crates were sealed. Some IDC 376 material could be the remaining material after the IDC 338 media were processed to recover the plutonium. Ful-Flo filters which were used to filter corrosive gas were also processed to separate any portions containing high plutonium content from portions with low plutonium content. Pieces of media with low activity were identified as IDC 376 and packaged for shipment as waste. The media were placed in approximately 10-gallon plastic bags and Portland cement was added. The bags were then sealed and placed in a drum. IDC 376 filter media in this backlog population was derived from the processing of HEPA filters from Buildings 371, 771, 776, and 770. The HEPA filters could have orginally been assigned ICDs 335 342, 490, 491 or 492. Filter media from Building 771 could have been used to filter nitric acid vapors.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	N/A	Stream Name:	Organic Resins/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	9.97E+00
Pu-240	4.19E-01
Pu-239	1.83E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	The ion-exchange resins were important to the plutonium purification processes at RFETS. Plutonium-contaminated materials were often dissolved in nitric acid and processed through ion exchange. The ion-exchange resin contained in an ion-exchange column was charged with highly concentrated nitric acids by trickling this solution through the columns. A plutonium-contaminated solution was then trickled through the column. The charged resin beads attracted the plutonium from the contaminated solution to the surface of the resin bead. The loaded resin beads were then leached by trickling another nitric acid solution through the tube. This final nitric acid solution drew the plutonium from the beads into solution and allowed for purification of the plutonium. The resin was periodically replaced when this process had depleted the efficiency of the resin. The ion exchange resins in use at Rocky Flats were generally small plastic (polystyrene) beads in which long-chain organic compounds with an activated group are imbedded (such as Dowex 1 x 2). Unleached resin IDC 430, was produced when the resin ion exchange columns was replaced. Though this IDC is titled "unleached" resin, the generators of resins confirm that all resins were rinsed with at least, weak acid before the resins were removed from the columns. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt% but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	N/A	Stream Name:	Organic Resins/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics

Inventory Date: 9/5/94

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	9.97E+00
Pu-240	4.19E-01
Pu-239	1.83E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	The ion-exchange resins were important to the plutonium purification processes at RFETS. Plutonium-contaminated materials were often dissolved in nitric acid and processed through ion exchange. The ion-exchange resin contained in an ion-exchange column was charged with highly concentrated nitric acids by trickling this solution through the columns. A plutonium-contaminated solution was then trickled through the column. The charged resin beads attracted the plutonium from the contaminated solution to the surface of the resin bead. The loaded resin beads were then leached by trickling another nitric acid solution through the tube. This final nitric acid solution drew the plutonium from the beads into solution and allowed for purification of the plutonium. The resin was periodically replaced when this process had depleted the efficiency of the resin. The ion exchange resins in use at Rocky Flats were generally small plastic (polystyrene) beads in which long-chain organic compounds with an activated group are imbedded (such as Dowex 1 x 2). ILeached resin IDC 431, was produced when the resin ion exchange columns were replaced. The resin was leached (rinsed) with water before the resin was removed from the columns. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W115	Handling:	CH	NMVP #:	N/A	Stream Name:	Insulation/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5129

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	91.7	1.9	353.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.8	0.0	9.6
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.54E+01
Pu-240	1.07E+00
Pu-239	4.67E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.7	0.7	0.9	2.7	2.9	14.9
Totals	7.7	0.7	0.9	2.7	2.9	14.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.7	0.7	1.1	2.7	2.9	15.1
Totals	7.7	0.7	1.1	2.7	2.9	15.1

As-Generated Form: Stored: 7.7 Projected: 7.3 Total: 15.0

Final Waste Form: Stored: 7.7 Projected: 7.3 Total: 15.0

WASTE STREAM DESCRIPTION	This waste stream is contaminated insulation.
WASTE STREAM SOURCE	Item Description Code 438 Maintenance, repair, and strip-out operations in Buildings 371, 374, 444, 559, 666, 707, 771, 774, 776, 777, 779, 865, 881, and 883 produced waste insulation. Insulation waste is generated by repalcement of furnace heating elements, construction, maintenance, and demolition activities within the Protected Area at Rocky Flats. During these activities, insulation material is removed from furnaces, boilers, piping, ceilings and walls and heating and cooling systems.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRU	Inventory Date:	
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	2.0	0.0	5.3
Other Inorganic Material:	136.8	16.8	352.5
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	1.2	0.0	3.1
Plastics:	30.3	3.7	78.1
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	150.0		
Packaging Material Plastic:	10.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	9.30E+00
Pu-240	3.91E-01
Pu-239	1.71E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	15.0	0.7	0.0	0.2	0.2	16.0
metal box / 4x4x7	9.4	0.0	0.0	0.0	0.0	9.4
Standard Waste Box	0.0	1.5	0.0	0.2	0.2	1.9
Totals	24.4	2.2	0.0	0.3	0.4	27.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.7	0.0	0.2	0.2	4.8
Standard Waste Box	1.9	20.4	0.0	0.2	0.2	22.7
Totals	5.6	21.1	0.0	0.3	0.4	27.5

As-Generated Form: Stored: 24.4 Projected: 2.9 Total: 27.4

Final Waste Form: Stored: 5.6 Projected: 21.8 Total: 27.5

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	IDC 440 includes glass waste from analytical laboratories and recovery processes, standard light bulbs generated inside the PA, and ceramic materials. Glass waste assigned IDC 440 was generated in Buildings 123,371, 444, 559, 707, 771, 776, 777, 889. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1wt%, but has no supporting data. This waste stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Assuming 67% of projected generation will be in 55-gallon drums based on current container inventory.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass	Inventory Date:	10/20/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	9.30E+00
Pu-240	3.91E-01
Pu-239	1.71E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.0	0.4	0.0	0.1	0.1	4.6
Totals	4.0	0.4	0.0	0.1	0.1	4.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 4.0 Projected: 0.6 Total: 4.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	Raschig Rings currently in WEMS assigned IDC 442 were generated in Buildings 771, 776, and 777. Prior to being replaced, the tanks were drained and the rings were leached with dilute nitric acid or water. The rings generated in Building 771 are from the production processes and Tanks D80-85, d0-360, D-361, D-451, D-454, D-467, D-750, D-706, D-922, D-973, D-974, D-980, D-1008, D-1013, D-1022, and D-1081. Rings generated in Building 776 are from the Size Reduction Process and Tanks SR 3, 4, and 5 and as unused rings. Rings generated in Building 777 were generated by the Carbon Tetrachloride System in Tanks 1103, 1104, and 1106, Room 131, and by the Trichloroethane Collection and Filter System in Tanks T-1 and T-2, Room 430. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W113	Handling:	CH	NMVP #:	RF 118	Stream Name:	Glass/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5122

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.7	0.0	24.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	250.8	19.1	415.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.6	0.0	12.6
Rubber:	0.0	0.0	0.0
Plastics:	8.7	0.6	14.5
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	153.7		
Packaging Material Plastic:	31.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 118

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	9.30E+00
Pu-240	3.91E-01
Pu-239	1.71E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	28.1	1.6	0.0	0.4	0.5	30.6
metal box / 4x4x7	15.9	0.0	0.0	0.0	0.0	15.9
Totals	43.9	1.6	0.0	0.4	0.5	46.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	28.1	1.6	0.0	0.4	0.5	30.6
Standard Waste Box	0.0	3.0	0.0	7.9	9.9	20.8
Totals	28.1	4.6	0.0	8.3	10.4	51.4

As-Generated Form: Stored: 43.9 Projected: 2.5 Total: 46.4

Final Waste Form: Stored: 28.1 Projected: 23.3 Total: 51.4

WASTE STREAM DESCRIPTION	This waste stream is made up of glass from analytical labs, recovery processes, ceramics, and glovebox windows.
WASTE STREAM SOURCE	Raschig Rings currently in WEMS assigned IDC 442 were generated in Buildings 771, 776, and 777. Prior to being replaced, the tanks were drained and the rings were leached with dilute nitric acid or water. The rings generated in Building 771 are from the production processes and Tanks D80-85, d0-360, D-361, D-451, D-454, D-467, D-750, D-706, D-922, D-973, D-974, D-980, D-1008, D-1013, D-1022, and D-1081. Rings generated in Building 776 are from the Size Reduction Process and Tanks SR 3, 4, and 5 and as unused rings. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1wt%, but has no supporting data This stream is generated from Facility Operations, Analytical Laboratories, and R&D Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 479 is assigned to empty reusable cans generated in Buildings 559, 707, and 771 (containers currently in WEMS from these buildings). Stainless-steel cans were used to handle plutonium-contaminated material. Primary generation was through the use of these cans to manually transfer materials between gloveboxes. Cans that were introduced to the process were typically recycled and reused. There were no generation process descriptions in WSRIC for this waste in Buildings 559, 707, and 771. In Building 371, the Dicesium Hexachloroplutonate (DCHP) Process often used the cans for transferring materials into the stacker.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	RF 117	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	78.4	0.8	238.9
Aluminum-base Metal/Alloys:	9.9	0.1	30.1
Other Metals/Alloys:	3.7	0.0	11.4
Other Inorganic Material:	6.5	0.0	20.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.2	0.0	3.7
Rubber:	1.4	0.0	4.4
Plastics:	10.4	0.1	31.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	142.8		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	64.1	16.1	7.6	34.9	16.5	139.2
Drum / 85-gallon	0.3	0.0	0.0	0.0	0.0	0.3
metal box / 4x4x7	44.4	0.0	0.0	0.0	0.0	44.4
plywood box / 4x4x7	3.2	0.0	0.0	0.0	0.0	3.2
Standard Waste Box /	13.2	16.1	7.7	35.0	16.8	88.8
Totals	125.2	32.2	15.2	70.0	33.2	275.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	64.1	16.1	7.6	34.9	16.5	139.2
Standard Waste Box	13.2	72.8	7.7	35.0	16.8	145.5
Totals	77.3	88.9	15.2	70.0	33.2	284.7

As-Generated Form: Stored: 125.2 Projected: 150.7 Total: 275.8

Final Waste Form: Stored: 77.3 Projected: 207.4 Total: 284.7

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 480 is assigned to line- and nonline-generated light metals generated in Buildings 371, 374, 444, 559, 707, 771, 776, 777, 779, 865, and 991 (containers currently in WEMS these buildings). Light metals include aluminum, copper, iron, brass, bronze, galvanized metal, stainless steel, carbon steel, and other metal alloys contained in waste mechanical and electrical parts, tools, containers, scrap metals, piping, wire, cable, gauges, valves, foil, planchets, and a variety of other metal items. The maintenance operation was inextricably linked with the generation of the material that created this IDC. The maintenance-generated materials were generated throughout the entire facility. Backlog containers of this IDC may contain a matrix of all light metals listed above.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	RF 117	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	160.4	1.7	488.7
Aluminum-base Metal/Alloys:	20.2	0.2	61.6
Other Metals/Alloys:	7.6	0.0	23.3
Other Inorganic Material:	13.4	0.1	40.9
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.5	0.0	7.6
Rubber:	2.9	0.0	8.9
Plastics:	21.2	0.2	64.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 481 was assigned to light, nonspecial source metals. This material consisted primarily of stainless-steel and aluminum equipment used throughout the plant; this equipment was rinsed to remove plutonium contamination. This IDC is no longer active and has been replaced by IDC 480. The three containers in inventory were generated in Building 771, 776, and 777 in November 1984.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	5.2	0.0	0.0	0.0	0.0	5.2
Totals	5.2	0.0	0.0	0.0	0.0	5.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 5.2 Projected: 0.0 Total: 5.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 484 was assigned to classified non-nuclear material scrap metal shapes made primarily of stainless steel and aluminum. Prior to 1987, IDC 484 included beryllium shapes. These items were generated in Buildings 777 and 779 during disassembly operations of site-return units. Building 444, 707, and 883 generated rejected parts. Containers in inventory were generated from February 1983 to May 1991.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 485 was assigned to scrap D-38 classified metal shapes. Generation of this material occurred in Building 777 during disassembly of site-return units. Building 444 generated rejected parts. Containers in inventory were generated from July 1987 to August 1992.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 9/5/94

Waste Matrix Code: S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.1	0.0	0.0	0.0	0.0	3.1
Totals	3.1	0.0	0.0	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 3.1 Projected: 0.0 Total: 3.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 486 was assigned to classified tooling for disposal. Generation of these tools ocurred in Buildings 707 and 777. The material consists primarily of obsolete tooling including pot chucks and inspection gauges. Containers in inventory were generated from October 1982 to December 1992.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 487 is classified plastic shapes used in handling and shipping. If TRU, shapes must be declassified prior to shipment. If LLW, IDC must be authorized by NTS prior to shipment. Classified Waste drums must be stenciled and handled according to Safeguards and Security procedures.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	N/A	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 489 was assigned to scrap D-38 classified metal shapes generated in Buildings 777 and 779 during disassembly of site-return units. Containers in inventory were generated from February 1986 to September 1990.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	37.6	11.5	66.8
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	22.8	7.0	40.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	13.9	0.0	27.8
Rubber:	0.2	0.0	0.3
Plastics:	0.3	0.0	0.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	[illegible]	0.0	0.0
Packaging Material Steel:	146.7		
Packaging Material Plastic:	37.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	3.32E+01
Pu-240	1.40E+00
Pu-239	6.10E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.9	1.5	0.2	10.4	12.9	33.9
metal box / 4x4x7	9.5	0.0	0.0	0.0	0.0	9.5
Standard Waste Box /	13.2	0.0	0.0	0.0	0.0	13.2
Totals	31.7	1.5	0.2	10.4	12.9	56.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.9	1.5	0.2	10.4	12.9	33.9
Standard Waste Box	13.2	0.0	0.0	0.0	0.0	13.2
Totals	22.2	1.5	0.2	10.4	12.9	47.1

As-Generated Form: Stored: 31.7 Projected: 25.0 Total: 56.6

Final Waste Form: Stored: 22.2 Projected: 25.0 Total: 47.1

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is HEPA filters in the ventilation systems at Rocky Flats. HEPA filters have been and are used in all of the buildings which contain plutonium processing activities. HEPA filters are used on gloveboxes and in large plenums that filter the room and glovebox air. Used filters were removed from their position in the ventilation system and packaged for further processing. The larger-sized filters used in filters plenums were identified and packaged as IDC 492 if acid contaminated. IDC 492 HEPA filters (24" x 24"), acid contaminated, are large HEPA filters (nominal 24" x 24" x 5" or 24" x 24" x 12") that were used in filter plenum racks. These filters consist of filter media contained within a wooden or metal frame. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W120	Handling:	CH	NMVP #:	RF 119	Stream Name:	Filters & media/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Filter

Inventory Date: 9/5/94

Waste Matrix Code:

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	19.0	0.0	38.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	11.5	0.0	23.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	47.6	0.0	99.1
Rubber:	0.6	0.0	1.1
Plastics:	1.0	0.0	2.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	187.1		
Packaging Material Plastic:	2.2		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 119

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	3.32E+01
Pu-240	1.40E+00
Pu-239	6.10E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	16.0	0.0	0.0	0.0	0.0	16.0
Totals	16.0	0.0	0.0	0.0	0.0	16.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.0	0.0	0.0	0.0	0.0	16.0
Totals	16.0	0.0	0.0	0.0	0.0	16.0

As-Generated Form: Stored: 16.0 Projected: 0.0 Total: 16.0

Final Waste Form: Stored: 16.0 Projected: 0.0 Total: 16.0

WASTE STREAM DESCRIPTION	This material consists of pieces ranging in size from 20" x 20" x 4" to 2" x 2" square pieces. These pieces are composed of glass fibers with a small percentage of asbestos. An organic binder, elastomeric adhesive, or polyurethane sealant was used during construction. The pieces also contain corrugated aluminum foil. The newer media consist of glass and aromatic polyamide fibers (Nomex) and luminum alloy metal coated wiht a thermoset vinyl or expoxy. Various sealants could be present. The material is not homogenous because of the different materials used and the different manufacturers of the filters. IDC 338 could also contain R-4 filters pads from the dicesium hexachloraplutonate (DCHP) process. The pads are about 12-inch diameter cloth filters.
WASTE STREAM SOURCE	The material in this IDC is a variety of plenum prefilters used in the ventilation systems at Rocky Flats. Plenum prefilters have been and are used in all of the buildings that contain plutonium processing activities. These prefilters are used in large plenums that filter the room and glovebox air. Used prefilters were removed from their position in the ventilation system and packaged for furtehr processing. IDC 491 plenum prefilters range from furnace-type filters to pleated fiberglass filters and can be as large as 24" x 24" x 12". The filter medium consists of fiberglass packing or paper which may be more or less dense, depending on filtering needs. Wire mesh can be used to hold the media in place. The frame material for these prefilters is cardboard. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data. This waste form is generated from Facility/Equipment Operation, Maintenance, Analytical Laboratories, R&D Laboratories, and D&D.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.00	0.0	0.0	0.0	0.0	0.00
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.00 Projected: 0.0 Total: 0.00

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.
WASTE STREAM SOURCE	IDC 508 is hydrochloric acid (HCl) containing plutonium generated by various process operations and glovebox-cleaning operations using HCl. Process operations and glovebox-cleaning operations were definec based on preliminary analytical results. IDC 508 was generated in Cation Exchange in Building 771 from washing residual impurities from the resin with dilute nitric acid. Chemical Technology in Buiding 771 generated miscellaneous chloride acid solutions from Batch Chloride Dissolution. This process dissolved plutonium oxide with hydrochloric acid. Dicesium hexachloroplutonate (DCHP) preparation in Building 371 also generated IDC 508. This process produced DCHP, a salt used to remove americium from nonspecification and impure plutonium oxide. The oxide was dissolved in hydrochloric acid and filtered. The filtrate was then precipitated using cesium chloride and sodium nitrite in hydrochloric acid and then filtered again. Plutonium was recovered from the DCHP precipitation filtrate through chloride anion exchange. This was achieved by processing the solution through ion columns, and the plutonium loaded onto the anion exchange resin while most of the impurities stayed in the solution. This solution then left the column as effluent (IDC 501). The ion column was later washed to release the chloride eluate (IDC 508). Peroxide Precipitation in Building 779 reacted ion exchange effluent with hydrogen peroxide to produce plutonium peroxide, which was then calcined to produce plutonium oxide. The plutonium peroxide precipitate was filtered and washed. Residue Recovery Extraction in Building 779 recovered actinides using aqueous leaching techniques. Hydrofluoric acid solutions containing aluminium fluoride, cesium chloride, calcium fluoride, and sodium nitrate were generated. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates >1 wt%, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W118	Handling:	CH	NMVP #:	N/A	Stream Name:	Miscellaneous Liquids/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Bottle / 4-Liter	0.01	0.0	0.0	0.0	0.0	0.01
Totals	0.0	0.0	0.0	0.0	0.0	0.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 0.01 Projected: 0.0 Total: 0.01

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION

As result of the shutdown of plutonium operations at RFP in November, 1989, several hundred plastic bottles and several tanks of process liquids remained in storage.

WASTE STREAM SOURCE

Item Description Code 541

Building 371

The Building 371 analytical laboratory receives liquid and solid samples from the entire plant site. Samples that are destined for Building 881 are analyzed in Building 371 to screen out those with high levels of radioactivity. Sludge and aqueous samples from Building 374 are analyzed for total alpha activity and plutonium, uranium, and americium content. Prior to analysis, the sludges are dissolved in nitric acid, hydrogen fluoride, or hydrochloric acid. Reagents are also used in sample preparation. Unused portions or excess prepared sample are placed in 4-liter plastic bottles.

Building 559

The Building 559 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various ions, iron, silicon, isotopic composition, and americium, gallium, neptunium, plutonium, uranium, and other metals (Resource Conservation and Recovery Act [RCRA]-regulated and nonregulated). Solid samples are dissolved in a variety of acids, including nitric and hydrochloric. Other chemicals used in the laboratory include methanol, chloroform, and other organic solvents; titanium trichloride; ceric ammonium nitrate; sodium hydroxide; silver chloride; silver nitrate; and various metals standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles.

Building 771

The Building 771 analytical laboratory also receives liquid and solid samples from the entire plant site. Samples are analyzed for various metals and ions, pH, and radioactivity. The principal chemicals used in the lab include sodium hydroxide, hydrochloric acid, nitric acid, cyclohexane, trioctyl phosphine oxide, yttrium, and various metal standards. Unused portions or excess prepared samples are placed in 4-liter plastic bottles. Metal standards are also placed in the bottles.

CURRENT CONTAINER COMMENTS N/A

EPA COMMENTS N/A

MANAGEMENT COMMENTS N/A

ACCEPTANCE COMMENTS N/A

FINAL FORM COMMENTS

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W112	Handling:	CH	NMVP #:	RF 113	Stream Name:	Solified Lab Waste/TRU	Inventory Date:	9/5/94
Local ID:	IDC 802	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	Z1110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	847.2	303.9	985.1
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	190.3	68.4	221.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	112.0	40.1	130.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF 113

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	9.76E-01
Pu-240	4.10E-02
Pu-239	1.79E-01
Am-241	3.15E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.5	26.3	0.0	0.0	0.0	33.8
Totals	7.5	26.3	0.0	0.0	0.0	33.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.5	26.3	0.0	0.0	0.0	33.8
Totals	7.5	26.3	0.0	0.0	0.0	33.8

As-Generated Form: Stored: 7.5 Projected: 26.0 Total: 33.5

Final Waste Form: Stored: 7.5 Projected: 26.0 Total: 33.5

WASTE STREAM DESCRIPTION	IDC 802 is a cemented final waste form.
WASTE STREAM SOURCE	IDC No. 802. This waste stream is liquid waste solidified with Portland Cement. This waste consists of waste liquids from the analytical labs, research and development laboratories, and maintenance shops which are packaged and sent to Building 774 for immobilization with Portland cement and absorbent cement. These are wastes which are incompatible with the process collection system and the liquid waste treatment plant. Acidic wastes are neutralized before immobilization. Immobilization is done in 55-gallon drums. Approximately 21 gallons of waste are added to each drum prior to storage. This waste steam is newly identified since the Storage and Inventory Report.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W105	Handling:	CH	NMVP #:	RF 114	Stream Name:	Solidified Process Solids/TRU	Inventory Date:	9/5/94
Local ID:	IDC 806	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	489.0	376.2	635.7
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	135.8	104.5	176.5
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	73.1	56.2	95.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source:

TRUCON CODE

RF 114

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.91E+02
Pu-240	8.01E+00
Pu-239	3.50E+01
Am-241	4.76E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	0.0	0.0	89.9	112.3	202.2
Totals	0.0	0.0	0.0	89.9	112.3	202.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	89.9	112.3	202.2
Totals	0.0	0.0	0.0	89.9	112.3	202.2

As-Generated Form: Stored: 0.0 Projected: 202.2 Total: 202.2

Final Waste Form: Stored: 0.0 Projected: 202.2 Total: 202.2

WASTE STREAM DESCRIPTION	Cemented final waste form.
WASTE STREAM SOURCE	This waste stream represents the solidified final form of all particulate and sludge type materials. Particulates and sludge type materials are immobilized with Portland cement. The cemented wastes are cast into 1-gallon molds and allowed to cure prior to packaging. This is the final waste form for Firebrick, Pulverized or Fines/TRM (RF-T036), Particulate Sludge/TRM (RF-T005), and Sand, Slag, and Crucible/TRM (RF-T059). IDC 806 - All inorganic particulate and inorganic sludge waste must be immobilized by processing into a solid and identified as IDC 806.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W122	Handling:	CH	NMVP #:	RF 126	Stream Name:	Organic Resins/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Organics	Waste Matrix Code:	

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	213.6	2.3	362.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	44.0	0.5	74.6
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	59.5	0.6	100.8
Cement (solidified):	32.0	0.4	54.3
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

RF 126

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	9.97E+00
Pu-240	4.19E-01
Pu-239	1.83E+00
Am-241	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	0.0	0.0	15.6	19.5	35.2
Totals	0.0	0.0	0.0	15.6	19.5	35.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	15.6	19.5	35.2
Totals	0.0	0.0	0.0	15.6	19.5	35.2

As-Generated Form: Stored: 0.0 Projected: 35.2 Total: 35.2

Final Waste Form: Stored: 0.0 Projected: 35.2 Total: 35.2

WASTE STREAM DESCRIPTION	It consists of unleached resin (IDC 430) and leached resin (IDC 431).
WASTE STREAM SOURCE	IDC 809 is leached ion column resin which has been cemented. Resin cannot be cemented into IDC 806 since it is organic.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Volumes include final form waste from treating the following streams: RF-TR0431, RF-TT0430, RF-TT0431, RF-TR0430.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	N/A	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.4
Vitrified:	0.0	0.0	0.0
Cellulosics:	67.4	1.4	289.5
Rubber:	6.4	0.1	27.7
Plastics:	19.6	0.4	84.2
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	12.5	8.8	6.7	22.2	18.3	68.4
Totals	12.5	8.8	6.7	22.2	18.3	68.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	12.5	11.6	6.7	22.2	19.8	72.7
Totals	12.5	11.6	6.7	22.2	19.8	72.7

As-Generated Form: Stored: 12.5 Projected: 56.0 Total: 68.4

Final Waste Form: Stored: 12.5 Projected: 59.7 Total: 72.2

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Item Description 821, dry combustibles such as paper, cloth, wood, etc. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No.

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	10.8	25.5	22.1	72.9	65.4	196.8
Totals	10.8	25.5	22.1	72.9	65.4	196.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	0.0	0.0	0.0

As-Generated Form: Stored: 10.8 Projected: 186.0 Total: 196.8

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Wet combustible transuranic wastes, such as paper, cloth, and wood, which contain a discernible amount of moisture must be drained or wrung out prior to packaging to prevent accumulation of free liquid. These wastes are classified as IDC 822. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W100	Handling:	CH	NMVP #:	N/A	Stream Name:	Cemented Sludge/TRU	Inventory Date:	9/5/94
Local ID:	IDC 823	Type:	TRU	Generator Site:	RF	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	Z1110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	29.3	0.7	98.7
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	10.5	0.2	35.5
Solidified Inorganic Material:	26.3	0.6	88.6
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	17.5	0.4	59.1
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	7.20E-01
Pu-240	3.02E-02
Pu-239	1.32E-01
Am-241	3.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	7.1	2.7	4.1	8.2	8.2	30.2
Totals	7.1	2.7	4.1	8.2	8.2	30.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.1	2.7	4.1	8.2	8.2	30.2
Totals	7.1	2.7	4.1	8.2	8.2	30.2

As-Generated Form: Stored: 7.1 Projected: 23.1 Total: 30.2

Final Waste Form: Stored: 7.1 Projected: 23.1 Total: 30.2

WASTE STREAM DESCRIPTION	This waste consists of cemented miscellaneous sludge (IDC 823)
WASTE STREAM SOURCE	IDC 823, cemented miscellaneous sludge, was generated when sludge designated as inorganic particulate and sludgy material that was below the economic discard limit (EDL) was placed in 1-gallon paint cans and covered with Portland cement or mixed with cement into a block. The first scenario was conducted in Building 771 and the second in Building 371. This could have included IDCs 290-299 and was done to meet the Waste Isolation Pilot Plant (WIPP) waste acceptance criteria. The material came primarily from Nash pumps in Building 771 and included vacuum grease and oily sludge. One drum of the material was apparently generated when the pit in front of Building 707 was cleaned out. However, the contents of the pit sludge could not be ascertained. One drum was generated in the Size Reduction Vault in Building 776. Six drums were generated in Bulding 774 and stored in Building 371.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W109	Handling:	CH	NMVP #:	RF 117	Stream Name:	METAL/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5111

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	169.4	1.7	365.2
Aluminum-base Metal/Alloys:	21.3	0.2	46.0
Other Metals/Alloys:	8.0	0.0	17.4
Other Inorganic Material:	14.2	0.1	30.6
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.6	0.0	5.7
Rubber:	3.1	0.0	6.7
Plastics:	22.4	0.2	48.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	6.76E+00
Pu-240	2.84E-01
Pu-239	1.24E+00
Am-241	9.54E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	9.8	4.1	1.6	8.6	5.4	29.5
Totals	9.8	4.1	1.6	8.6	5.4	29.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	9.8	4.1	1.6	8.6	5.4	29.5
Totals	9.8	4.1	1.6	8.6	5.4	29.5

As-Generated Form: Stored: 9.8 Projected: 19.8 Total: 29.5

Final Waste Form: Stored: 9.8 Projected: 19.8 Total: 29.5

WASTE STREAM DESCRIPTION	IDCs 480 and 481. This waste includes items such as gloveboxes and machinery, and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal. drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner. This waste also includes final form waste of classified metal (IDC Nos. 484, 485,486, 489) after processing to declassified form. Inventory data include residues in IDCs 480 and 481.
WASTE STREAM SOURCE	IDC 824 is assigned to transuranic light metals generated in Buildings 371, 559, 707, and 771 (containers currently in WEMS from these buildings). Light metals include aluminum, copper, iron, brass, bronze, galvanized metal, stainless steel, carbon steel, and other metal alloys contained in waste mechanical and electrical parts, tools, containers, scrap metals, piping, wire, cable, gauges, valves, foil, planchets, and a variety of other metal items.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	RF 116	Stream Name:	Combustibles/TRU	Inventory Date:	9/4/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	25.7	0.7	56.8
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.1	0.0	0.3
Rubber:	1.7	0.0	3.8
Plastics:	42.0	1.2	92.7
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	51.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

RF 116

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	21.6	9.4	8.1	27.1	24.1	90.3
Totals	21.6	9.4	8.1	27.1	24.1	90.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	21.6	20.4	8.2	27.2	24.3	101.8
Totals	21.6	20.4	8.2	27.2	24.3	101.8

As-Generated Form: Stored: 21.6 Projected: 68.6 Total: 90.3

Final Waste Form: Stored: 21.6 Projected: 80.1 Total: 101.7

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 825 is PVC sheeting, poly bottles, supplied-air suits, and other plastics. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Assume 70% of IDC 833 generation will be drum/55-gal based on current container distribution.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	10.0	0.0	0.0	0.0	0.0	10.0
Standard waste box /	9.4	0.0	0.0	0.0	0.0	9.4
Totals	19.4	0.0	0.0	0.0	0.0	19.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 19.4 Projected: 0.0 Total: 19.4

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 831 is dry combustibles such as cloth, paper, and wood. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible

Inventory Date: 9/5/94

Waste Matrix Code: S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	66.1	0.0	0.0	0.0	0.0	66.1
Totals	66.1	0.0	0.0	0.0	0.0	66.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 66.1 Projected: 0.0 Total: 66.1

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	Wet combustibles are paper, cloth, etc., which contain a discernible amount of moisture and must be drained or wrung out prior to packaging to prevent an accumulation of free liquid. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 8.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W101	Handling:	CH	NMVP #:	None	Stream Name:	Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Combustible	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

None

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	4.86E+00
Pu-240	2.04E-01
Pu-239	8.90E-01
Am-241	9.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.2	0.0	0.0	0.0	0.0	6.2
Totals	6.2	0.0	0.0	0.0	0.0	6.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

As-Generated Form: Stored: 6.2 Projected: 0.0 Total: 6.2

Final Waste Form: Stored: 0.0 Projected: 0.0 Total: 0.0

WASTE STREAM DESCRIPTION	This waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills.
WASTE STREAM SOURCE	IDC 833 represents PVC sheeting, poly bottles, supplied-air suits, polyethylene, and other plastics. This stream is generated from Facility Operation, Analytical Laboratories, R&D Laboratories, and Spill Cleanups. RE: Section 6.2.11, RFETS doesn't expect nitrates, sulfates, phosphates > 1 wt. %, but has no supporting data.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W103	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc Pu Recovery Byproducts/TRU
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Salt Waste

Inventory Date: 12/30/99

Waste Matrix Code: S3141

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	193.9	47.5	540.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	166.4	0.0	237.6
Vitrified:	0.0	0.0	0.0
Cellulosics:	176.1	140.4	211.7
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	34.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	2.03E+02
Pu-240	8.55E+00
Pu-239	3.73E+01
Am-241	4.23E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	7.2	0.0	112.1	140.1	259.4
Totals	0.0	7.2	0.0	112.1	140.1	259.4

As-Generated Form: Stored: 0.0 Projected: 0.0 Total: 0.0

Final Waste Form: Stored: 0.0 Projected: 259.4 Total: 259.4

WASTE STREAM DESCRIPTION	This waste is generated during plutonium recovery operations such as direct oxide reduction, molten salt extration, electrorefining, and salt scrub.
WASTE STREAM SOURCE	Oxidized salt, IDC 0999, is a projected waste form based on current plans for treatment of pyrochemical salts to meet the WIPP-WAC and DOT requirements. There will be no appreciable increase in the volume of these salts due to treatment (oxidation), but there will be a slight, as yet unquantified, mass increase due to the addition of oxidant.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W106	Handling:	CH	NMVP #:	RF-116	Stream Name:	Supercompacted Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5330

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	375.7	251.3	483.0
Rubber:	35.9	24.0	46.1
Plastics:	108.1	72.3	139.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	301.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF-116C

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	IDC 2116 is supercompacted combustible waste consisting of any combination of IDC 831, 832, or 835 waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W106	Handling:	CH	NMVP #:	RF-116	Stream Name:	Supercompacted Combustibles/TRU	Inventory Date:	9/5/94
Local ID:	None	Type:	TRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5330

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	257.7	33.4	380.1
Rubber:	24.6	3.2	36.3
Plastics:	74.2	9.6	109.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	301.0		
Packaging Material Plastic:	64.8		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Pollution Control or Waste Treatment Process

TRUCON CODE

RF-116C

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 3.7 Projected: 0.0 Total: 3.7

WASTE STREAM DESCRIPTION	N/A
WASTE STREAM SOURCE	Soft wastes are inspected for rejectable items, including free liquids and metal, which are separated from the soft waste for further disposition. Soft wastes are moved to the precompactor where they are placed in an empty 35-gallon drum located in the precompactor. The soft waste is precompacted using a 30-ton precompactor. Once the drum is filled with precompacted waste, the lid is placed on the drum. The drum is transferred to the appropriate glovebox line for piercing. Prior to supercompaction, drums of soft waste are pierced with four holes to allow air to escape and to reduce the amount of "springback" during supercompaction. After piercing, the drums are moved to the supercompactor. A mold is lowered over the drum. Once the mold is in place, the supercompactor is lowered, compacting the drum. Liquid forced out of the waste during compaction is collected by the liquid waste collection system. After supercompaction, the pucks (supercompacted 35-gallon drums) are moved to staging. An operator selects from the available pucks to efficiently fill 55-gallow loadout drums.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RF-W011	Handling:	CH	NMVP #:	RF 117	Stream Name:	Metal/TRM
Local ID:	IDC 480	Type:	MTRU	Generator Site:	RF	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/30/99

Waste Matrix Code: S5112

AS-GENERATED EPA CODES

D007, D002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

RF 117

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.10E+01
Pu-240	4.64E-01
Pu-239	2.03E+00
Am-241	1.84E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
As-Generated Form:	Stored: 0.0	Projected: 0.0			Total: 0.0	

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Final Waste Form:	Stored: 0.0	Projected: 0.0			Total: 0.0	

WASTE STREAM DESCRIPTION	This waste stream is metal tools, etc. generated during glovebox operations.
WASTE STREAM SOURCE	The one container of IDC 480, Light metal, in this waste form was generated in Building 707, Module K, in April 1991. The metal in this container is line generated material.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	EPA codes are assigned to this waste form for newly generated waste characterized by the generator using process knowledge. Discussion of these characterizations may be found in the appropriate WSRIC building book.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	Rocky Flats assays wastes to determine waste type instead of relying on process knowledge or historical data. For this reason, the potential for reclassification has not been analyzed. RFP has assumed this waste to be LDR based on process knowledge characterization. RFP currently manages all of its mixed waste as LDR storage prohibited, independent of its generation date. 1. Basis for determining LDR storage prohibition status is based primarily on process knowledge. Waste is packaged in 55 gallon DOT 7A Type A Drums. The drums are lined with one rigid polyethylene liner and several bag liners.
FINAL FORM COMMENTS	

HANFORD SITE

Location and Description

The Hanford Site (RL) is located north of the Tri Cities, Washington (Richland, Kennewick, and Pasco), on a 1450 square kilometer area of semiarid land within the Columbia River Basin in the southeastern corner of Washington State. Normal Columbia River elevations range from 119 meters, where the Columbia River enters RL near the Priest Rapids Dam, to 104 meters where it leaves the RL near the 300 area.

Activities at RL are centralized in numerically designated areas. The reactor facilities are located along the Columbia River in what is known as the 100-Area. The reactor fuel processing and waste management facilities are in the 200-Area. The 300-Area, located adjacent to, and north of, Richland, contains the reactor fuel manufacturing facilities and the research and development laboratories. The 400-Area, five miles northwest of the 300-Area, contains the Fast Flux Test Facility, a sodium-cooled fast breeder reactor. The 600-Area covers all locations not specifically given an area designation. Adjacent to, and north of, Richland, the 1100-Area contains facilities associated with administration, maintenance, transportation, and materials procurement and distribution. The 3000-Area, contains engineering and administrative offices. Administrative buildings, including the Federal Building, are located in the 700-Area, which is in downtown Richland.

RL is administered by the DOE Richland Operations Office. The current Management and Operating Contractor is Westinghouse Hanford Company.

Mission

The Hanford Site was acquired by the Federal Government in 1943 for the construction and operation of facilities to produce plutonium for the atomic weapons program during World War II. For more than 30 years, Hanford Site facilities were primarily dedicated to the production of plutonium for national defense and management of the wastes generated by chemical processing operations. In later years, programs at the Hanford Site became increasingly diverse, involving research and development for advanced reactors, renewable energy technologies, waste disposal technologies, and cleanup of contamination from past practices. The DOE has ended the production mission at the Hanford Site and is currently reorienting activities toward management of its wastes cleanup of the site. The mission now is one of environmental management, demonstration and application of advanced remediation technologies, and restoration of the Hanford Site.

During the wartime Manhattan Project, the town of Richland, Washington, was wholly-owned and controlled by the Government.

Waste Information

Processes

Retrievably stored, CH TRU waste has been received from 55 generating areas, buildings, and offsite facilities.

The Plutonium Finishing Plant (PFP) (Z Plant) is one of Hanford's waste generators and is the major source of CH TRU solid waste by volume (approximately 53.6%) The PFP where the Pu Reclamation Facility, Pu conversion, product handling, decontamination and decommissioning, analytical and chemical technology laboratories are located. Waste common to all of these are: surgical gloves, paper, glass, glovebox gloves, metal tools and equipment, and HEPA filters.

At the Pu Reclamation Facility, Pu was reclaimed from scrap solutions and solids. The scrap was treated in various ways to produce soluble and/or leachable forms of Pu for recovery. Waste generated included acid-soaked rags, liquid organics, and sludges.

Pu Conversion takes place at the Remote Mechanical C Line (RMC Line) where the Pu conversion processes received Pu nitrate as feed and converted it to either Pu oxide or metal. Waste generated included sludges, hydraulic oils, and acid-soaked rags.

Product handling includes receipt, shipment, repackaging, and nondestructive assay of special nuclear materials. Waste generated included damp rags, leather gloves, and empty metal cans used for shipping.

Decontamination and Decommissioning removed selected PFP facilities such as process gloveboxes and associated systems, ventilation systems, vacuum systems, and drain systems and dispose of them. Waste generated included damp rags, and building rubble (e.g., concrete, steel, wool, etc.).

Analytical and Chemical Technology Laboratories provide laboratory services to other PFP operations. Waste generated here included liquid organics, sludges, damp rags, and empty metal cans for shipping.

Another waste generator at Hanford was the Plutonium Uranium Extraction (PUREX) Plant. Products from this plant were weapons-grade plutonium, fuel-grade plutonium, depleted uranium, slightly enriched uranium, neptunium, and thorium. The plutonium conversion, process solution sampling, laboratory analyses, plant ventilation, and facility ventilation generated waste that was common to all these PUREX operations including surgical gloves, plastic (polyvinyl chloride and polyethylene), tape, paper, glass, glovebox gloves, and metal tools and equipment.

The overall PUREX Plant process consisted of seven fundamental interfacing processing units: feed preparation; solvent extraction, separation, and purification;
solvent recovery and treatment for recycling; backcycle waste system; acid recovery; waste treatment; offgas treatment; and conversion of plutonium nitrate to plutonium oxide.

Pu conversion operations received Pu nitrate as feed and converted the Pu to Pu oxide. Wastes generated were old and failed equipment, port covers, replaced windows, brackets and hardware, and acid-soaked rags.

Process solution sampling operations extract liquid samples from process control points to be used in system analysis and control. After use, all liquids are drained to the PUREX liquid waste system. Waste generated at this facility included broken glassware and plasticware, wet rags and paper, and piping and valving equipment.

Laboratory Analysis Operations were performed on liquid process samples used for system analysis and control. After use, all liquids were drained to the PUREX liquid waste system. Waste generated were broken glassware and plasticware, and wet rags and paper.

During Plant ventilation operations, air from contaminated areas was exhausted through HEPA filters to remove airborne contamination. TRU waste generated during these operations include contaminated HEPA filters. All HEPA filters are packaged as uncertified waste as there is no current technology available at PUREX to determine which HEPA filters meet the WIPP Waste Acceptance Criteria.

Facility Modification Operations were performed to improve overall plant performance. Modifications included the disposal of outdated and damaged equipment. Waste generated included tanks, process equipment and gloveboxes, and building materials.

Modifications/Assumptions/Development

New radionuclide data were submitted two days prior to going to print. The data were not reviewed by the technical team.

APPROACH

The approach used in preparing the RL waste stream profiles is as follows:

- Waste is divided between "past practice waste" (1970 through 1986) and currently-generated waste (1987 through 2028). Currently-generated waste includes projected waste generation.
- Past practice waste is grouped by generators, whereas currently-generated waste is grouped by waste matrix. The reasons for grouping the data in this manner are as follows: 1) the interim storage practice was changed from below ground surface (trenches) to above surface (storage buildings) in the 1986/1987 time period; 2) the By-Product Rule was issued by DOE on May 1, 1987, which compelled the hazardous components of TRU waste to be regulated by EPA under RCRA; 3) more detailed matrix information per container has been collected from the generator since 1987, and stored in the site's record waste tracking system; and 4) starting approximately 1986, waste generators began packaging the waste in accordance with the WIPP Waste Acceptance Criteria, thus reducing the need for additional waste processing prior to shipping to WIPP.
- Currently-generated waste streams were identified by reviewing each container record in the site's solid waste tracking system. Groups of containers that have similar physical characteristics and chemical contaminants (mixed only) were placed into a treatability group waste stream. The waste was then separated into drums, boxes, and RH canisters.

ASSUMPTIONS

The following assumptions were made by the site in repackaging the waste into the final waste form:

1. General

   A. A portion of the thermocouple assemblies, transfer pumps, mixing pumps, and other equipment in the single-shell and double-shell tanks will be removed, size-reduced, decontaminated, and assayed. Assay information will be used to designate the waste packages as low-level waste or TRU waste. The projection is that 10% of the equipment will be designated as RH-TRU, mixed waste and 90% will be designated as remote-handled, low level mixed waste. (WHC-EP 0768, Solid Waste 30-Year Volume Summary, p. 4-6, Table 4-1)

   B. TRU waste forecast volume data has been provided from the following off-site waste generators: AL, AE, BCL, LB, LL, and Santa Susana Field Laboratory (Rockwell, Canoga Park). The assumption is that TRU waste from these off-site waste generators will be received at RL for treatment in the Waste Receiving and Processing Facility (WRAP) and shipment to WIPP. (WHC-EP-0768, Solid Waste 30-Year Volume Summary)

   C. PUREX transition activities will generate 117 m^3 of CH-TRU and mixed TRU waste. The PUREX facility is currently undergoing transition activities towards decontamination and decommissioning. The facility transition activities at PUREX will provide a model for the subsequent transition of other canyon-type facilities in the future. Waste generation estimates from PUREX and other canyon type facilities have been included in the forecast. (WHC-EP-0768, Solid Waste 30-Year Volume Summary)

   D. Approximately 140 m^3 of spent research reactor fuel stored in trenches with the TRU waste is managed as TRU waste. Future evaluations may determine that this waste should be managed by the National Spent Fuel Program. (WHC-SD-SNF-TI-001, Revision 0)

2. Retrieval of Stored TRU Waste

   A. Stored TRU waste consists of existing TRU waste generated since May 1970 through December 1993. This waste does not include waste, originally designated as TRU waste, that has been assayed and redesignated as low-level waste during the calendar years (CY) 1986 to 1993.

   B. CH-TRU Waste

      - Of the TRU waste stored from May 1970 to December 1985 that has not been assayed and redesignated as low-level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. (WHC-EP-0225, Revision 1, Table 4-26)

- Waste is drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging the waste will result in a 35% increase in the volume of TRU-certified waste in drums. (WHC-SD-W026-SDRD-001, Revision 3)

- Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected.

- The site's solid waste tracking system does not distinguish between specific types of metals. If lead is present, then "other metals" is assumed to represent 100% of the metals in the container. Otherwise, iron-based metals is assumed to be 80% and aluminum-based metal is assumed to be 20% of the metal (reference: WHC-EP-225 Rev 1, TRU Waste Characterization Based on Current Records).

C. RH-TRU Waste

- No volume reduction is projected due to size reduction for transport in RH canisters.

3. Newly-generated TRU waste

A. This waste will be generated during the fiscal years 1994 through 2013.

B. CH-TRU Waste

- One hundred percent of the waste in drums will be managed as TRU waste with 10% considered noncertifiable and requiring treatment.

- All boxed waste (except waste in SWBs) will require size reduction in the WRAP facility.

C. RH-TRU Waste

- Newly-generated RH-TRU waste will be stored in shielded drums pending repackaging in RH-canisters in the WRAP facility.

- RH-TRU waste retrieved from the 618-11 burial ground will include some soil surrounding breached containers. It is assumed that this soil will increase the waste volume to be retrieved by 25%. No volume reduction is projected for treatment in the WRAP facility.

- A portion of the single-shell and double-shell tank equipment will be size-reduced and decontaminated, assayed, and shipped to WIPP as RH-TRU waste. The assumption is the 90% of the equipment will be classified as remote-handled, low level mixed waste and 10% will be RH-TRU, mixed waste.

- Most of the waste generated between 1987 and 1993 is debris waste. As such, projected RH-TRU waste is assumed to be debris waste.

- The mixed waste contaminants and radionuclide composition of projected RH-TRU waste are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W236	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	619.3	0.0	0.0
Aluminum-base Metal/Alloys:	122.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.3	0.0	0.0
Rubber:	25.6	0.0	0.0
Plastics:	71.0	0.0	0.0
Solidified Inorganic Material:	10.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	10.2	0.0	0.0
Packaging Material Steel:	141.0		
Packaging Material Plastic:	21.4		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	4.76E-02
U-238	3.42E-13
U-235	1.57E-14
U-234	3.51E-13
Sr-90	4.76E-02
Pu-242	2.08E-05
Pu-241	9.32E+00
Pu-240	3.46E-01
Pu-239	1.54E+00
Pu-238	4.54E-02
Cs-137	5.08E-02
Ba-137m	4.68E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	247.6	0.0	0.0	0.0	0.0	247.6
Drum / 55-gallon	237.7	0.0	0.0	0.0	0.0	237.7
Totals	485.4	0.0	0.0	0.0	0.0	485.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	320.9	0.0	0.0	0.0	0.0	320.9
Standard Waste Box	247.0	0.0	0.0	0.0	0.0	247.0
Totals	567.9	0.0	0.0	0.0	0.0	567.9

As-Generated Form: Stored: 485.4 Projected: 0.0 Total: 485.4

Final Waste Form: Stored: 567.9 Projected: 0.0 Total: 567.9

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Fuel Reprocessing Plant using the Plutonium/Uranium Solvent Extraction Process.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W237	Handling:	CH	NMVP #:	N/A	Stream Name:	202-AL Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	553.5	0.0	0.0
Aluminum-base Metal/Alloys:	87.8	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	104.1	0.0	0.0
Rubber:	44.6	0.0	0.0
Plastics:	106.2	0.0	0.0
Solidified Inorganic Material:	14.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	17.8	0.0	0.0
Packaging Material Steel:	131.2		
Packaging Material Plastic:	36.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	6.61E-04
U-238	5.57E-09
U-235	2.57E-10
U-234	5.74E-09
Sr-90	6.61E-04
Pu-242	7.52E-10
Pu-241	3.36E-04
Pu-240	1.25E-05
Pu-239	5.58E-05
Pu-238	1.64E-06
Cs-137	7.06E-04
Ba-137m	6.49E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	1.3	0.0	0.0	0.0	0.0	1.3
Drum / 55-gallon	146.8	0.0	0.0	0.0	0.0	146.8
Totals	148.1	0.0	0.0	0.0	0.0	148.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	198.2	0.0	0.0	0.0	0.0	198.2
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	200.1	0.0	0.0	0.0	0.0	200.1

As-Generated Form: Stored: 148.1 Projected: 0.0 Total: 148.1

Final Waste Form: Stored: 200.1 Projected: 0.0 Total: 200.1

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the laboratory at the Fuel Reprocessing Plant.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified waste in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified waste in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W238	Handling:	CH	NMVP #:	N/A	Stream Name:	216-Z-9 Retrieved Soil	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	324.0	162.0	324.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	285.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	ci/m3)
Y-90	2.29E-04
Sr-90	2.29E-04
Pu-242	6.33E-04
Pu-241	2.83E+02
Pu-240	1.05E+01
Pu-239	4.69E+01
Pu-238	1.38E+00
Cs-137	2.45E-04
Ba-137m	2.25E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	73.8	0.0	0.0	0.0	0.0	73.8
Totals	73.8	0.0	0.0	0.0	0.0	73.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	99.6	0.0	0.0	0.0	0.0	99.6
Totals	99.6	0.0	0.0	0.0	0.0	99.6

As-Generated Form: Stored: 73.8 Projected: 0.0 Total: 73.8

Final Waste Form: Stored: 99.6 Projected: 0.0 Total: 99.6

WASTE STREAM DESCRIPTION	Waste consists of soil contaminated with TRU solutions. Soil is contained in a 0.3 mm polyethylene bag within an inner container. The outer container is a standard 55-gallon drum. Vermiculite is a packing material between the inner and outer container.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the retrieved contaminated soil from the 216-Z-9 Trench. Soil is contaminated by TRU liquid waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W239	Handling:	CH	NMVP #:	N/A	Stream Name:	221-T TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	9.26E-05
U-238	6.34E-09
U-235	2.92E-10
U-234	6.53E-09
Sr-90	9.26E-05
Pu-242	4.32E-08
Pu-241	1.93E-02
Pu-240	7.17E-04
Pu-239	3.19E-03
Pu-238	9.38E-05
Cs-137	9.89E-05
Ba-137m	9.10E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.7	0.0	0.0	0.0	0.0	3.7
Totals	3.7	0.0	0.0	0.0	0.0	3.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.0	0.0	0.0	0.0	0.0	5.0
Totals	5.0	0.0	0.0	0.0	0.0	5.0

As-Generated Form: Stored: 3.7 Projected: 0.0 Total: 3.7

Final Waste Form: Stored: 5.0 Projected: 0.0 Total: 5.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the T Plant Fuel Reprocessing Plant.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W240	Handling:	CH	NMVP #:	N/A	Stream Name:	222-S TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	621.5	0.0	0.0
Aluminum-base Metal/Alloys:	123.8	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.0	0.0	0.0
Rubber:	24.9	0.0	0.0
Plastics:	69.8	0.0	0.0
Solidified Inorganic Material:	10.2	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	9.9	0.0	0.0
Packaging Material Steel:	141.3		
Packaging Material Plastic:	20.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	5.22E-04
U-238	6.16E-10
U-235	5.72E-08
U-234	5.57E-07
U-233	1.17E-02
Sr-90	5.22E-04
Pu-242	1.01E-06
Pu-241	4.53E-01
Pu-240	1.68E-02
Pu-239	7.51E-02
Pu-238	2.21E-03
Cs-137	5.58E-04
Ba-137m	5.13E-04
Am-241	1.72E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	43.5	0.0	0.0	0.0	0.0	43.5
Drum / 55-gallon	32.9	0.0	0.0	0.0	0.0	32.9
Totals	76.4	0.0	0.0	0.0	0.0	76.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	44.3	0.0	0.0	0.0	0.0	44.3
Standard Waste Box	36.1	0.0	0.0	0.0	0.0	36.1
Totals	80.4	0.0	0.0	0.0	0.0	80.4

As-Generated Form: Stored: 76.4 Projected: 0.0 Total: 76.4

Final Waste Form: Stored: 80.4 Projected: 0.0 Total: 80.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Chemical Separation Areas Operations Laboratory.
CURRENT CONTAINER COMMENTS	N/A average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified waste in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified waste in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W241	Handling:	CH	NMVP #:	N/A	Stream Name:	233-S TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	9.45E-05
Sr-90	9.45E-05
Pu-242	9.80E-06
Pu-241	4.40E+00
Pu-240	1.63E-01
Pu-239	7.28E-01
Pu-238	2.14E-02
Cs-137	1.01E-04
Ba-137m	9.28E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	6.0	0.0	0.0	0.0	0.0	6.0
Totals	6.0	0.0	0.0	0.0	0.0	6.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.1	0.0	0.0	0.0	0.0	8.1
Totals	8.1	0.0	0.0	0.0	0.0	8.1

As-Generated Form: Stored: 6.0 Projected: 0.0 Total: 6.0

Final Waste Form: Stored: 8.1 Projected: 0.0 Total: 8.1

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the REDOX Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W242	Handling:	CH	NMVP #:	N/A	Stream Name:	234-5Z TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	633.8	0.0	0.0
Aluminum-base Metal/Alloys:	130.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	55.5	0.0	0.0
Rubber:	21.4	0.0	0.0
Plastics:	63.2	0.0	0.0
Solidified Inorganic Material:	9.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	8.5	0.0	0.0
Packaging Material Steel:	143.2		
Packaging Material Plastic:	18.1		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	6.48E-03
U-238	5.70E-05
U-235	3.07E-06
U-234	1.37E-04
U-233	6.76E-05
Th-232	1.01E-08
Sr-90	6.48E-03
Pu-242	3.57E-05
Pu-241	1.59E+01
Pu-240	5.92E-01
Pu-239	2.65E+00
Pu-238	1.66E+01
Cs-137	6.92E-03
Ba-137m	6.36E-03
Am-241	6.48E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	3246.5	0.0	0.0	0.0	0.0	3246.5
Drum / 55-gallon	2149.3	0.0	0.0	0.0	0.0	2149.3
Totals	5395.7	0.0	0.0	0.0	0.0	5395.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2901.4	0.0	0.0	0.0	0.0	2901.4
Standard Waste Box	3254.7	0.0	0.0	0.0	0.0	3254.7
Totals	6156.1	0.0	0.0	0.0	0.0	6156.1

As-Generated Form: Stored: 5395.7 Projected: 0.0 Total: 5395.7

Final Waste Form: Stored: 6156.1 Projected: 0.0 Total: 6156.1

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Plutonium Finishing Plant.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The contact-handled TRU waste from Building 2345A was reported in Waste Nos. RL-T146 and RL-T150 in Revision 1 of the WTWBIR. This waste is reported in RL-T107 in Revision 2; RL-T146 and RL-T150 have been deleted in Revision 2.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W243	Handling:	CH	NMVP #:	N/A	Stream Name:	Misc 200 West Area TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	700.0	0.0	0.0
Aluminum-base Metal/Alloys:	165.4	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	39.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.4	0.0	0.0
Rubber:	4.6	0.0	0.0
Plastics:	27.8	0.0	0.0
Solidified Inorganic Material:	4.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.8	0.0	0.0
Packaging Material Steel:	153.0		
Packaging Material Plastic:	2.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.09E-04
U-238	1.48E-07
U-235	6.79E-09
U-234	1.52E-07
Sr-90	1.09E-04
Pu-242	6.51E-07
Pu-241	2.91E-01
Pu-240	1.08E-02
Pu-239	4.82E-02
Pu-238	9.14E-02
Cs-137	1.17E-04
Ba-137m	1.07E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	187.8	0.0	0.0	0.0	0.0	187.8
Drum / 55-gallon	6.0	0.0	0.0	0.0	0.0	6.0
Totals	193.9	0.0	0.0	0.0	0.0	193.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.0	0.0	0.0	0.0	8.3
Standard Waste Box	184.3	0.0	0.0	0.0	0.0	184.3
Totals	192.6	0.0	0.0	0.0	0.0	192.6

As-Generated Form: Stored: 193.9 Projected: 0.0 Total: 193.9

Final Waste Form: Stored: 192.6 Projected: 0.0 Total: 192.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixtures, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the 200 Area Waste Tank Farms and other miscellaneous sources in the Chemical Separations Area.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W244	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Bldg TRU Waste	Inventory Date:	12/19/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	641.4	0.0	0.0
Aluminum-base Metal/Alloys:	134.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	50.9	0.0	0.0
Rubber:	19.1	0.0	0.0
Plastics:	59.1	0.0	0.0
Solidified Inorganic Material:	8.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	7.6	0.0	0.0
Packaging Material Steel:	144.3		
Packaging Material Plastic:	16.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	5.81E-04
U-238	4.03E-04
U-235	1.57E-05
U-234	1.18E-03
U-233	5.54E-03
Sr-90	5.81E-04
Pu-242	8.43E-06
Pu-241	3.77E+00
Pu-240	1.40E-01
Pu-239	6.24E-01
Pu-238	1.84E-02
Cs-137	6.21E-04
Ba-137m	5.71E-04
Am-241	3.75E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	14.3	0.0	0.0	0.0	0.0	14.3
Drum / 55-gallon	6.2	0.0	0.0	0.0	0.0	6.2
Totals	20.5	0.0	0.0	0.0	0.0	20.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.0	0.0	0.0	0.0	8.3
Standard Waste Box	11.4	0.0	0.0	0.0	0.0	11.4
Totals	19.7	0.0	0.0	0.0	0.0	19.7

As-Generated Form: Stored: 20.5 Projected: 0.0 Total: 20.5

Final Waste Form: Stored: 19.7 Projected: 0.0 Total: 19.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Wastes in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reductin is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W245	Handling:	CH	NMVP #:	N/A	Stream Name:	324, 325 and 327 Bldg Oper TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	592.5	0.0	0.0
Aluminum-base Metal/Alloys:	108.4	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	42.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	80.5	0.0	0.0
Rubber:	33.3	0.0	0.0
Plastics:	85.3	0.0	0.0
Solidified Inorganic Material:	12.2	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	13.3	0.0	0.0
Packaging Material Steel:	137.0		
Packaging Material Plastic:	27.6		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.13E-02
U-238	3.86E-04
U-235	1.33E-04
U-234	2.76E-03
U-233	2.30E-04
Th-232	5.17E-06
Sr-90	1.13E-02
Pu-242	3.86E-05
Pu-241	1.73E+01
Pu-240	6.41E-01
Pu-239	2.86E+00
Pu-238	1.40E-01
Cs-137	1.21E-02
Ba-137m	1.11E-02
Am-241	5.67E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	129.5	0.0	0.0	0.0	0.0	129.5
Drum / 55-gallon	270.2	0.0	0.0	0.0	0.0	270.2
Totals	399.7	0.0	0.0	0.0	0.0	399.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	364.8	0.0	0.0	0.0	0.0	364.8
Standard Waste Box	129.2	0.0	0.0	0.0	0.0	129.2
Totals	494.0	0.0	0.0	0.0	0.0	494.0

As-Generated Form: Stored: 399.7 Projected: 0.0 Total: 399.7

Final Waste Form: Stored: 494.0 Projected: 0.0 Total: 494.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Chemical Materials Engineering Laboratory and Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	N/A volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The contact-handled TRU waste from Building 327C was reported as Waste No. RL-T111A in Revision 1 of the WTWBIR. RL-T111A has been deleted in Revision 2 of the WTWBIR.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W246	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Bldg Oper and R&D TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	650.2	0.0	0.0
Aluminum-base Metal/Alloys:	139.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	45.6	0.0	0.0
Rubber:	16.6	0.0	0.0
Plastics:	54.5	0.0	0.0
Solidified Inorganic Material:	8.3	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	6.6	0.0	0.0
Packaging Material Steel:	145.6		
Packaging Material Plastic:	14.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	9.12E-04
U-238	2.32E-04
U-235	3.71E-04
U-234	5.34E-03
U-233	5.71E-05
Th-232	1.95E-06
Sr-90	9.12E-04
Pu-242	1.83E-05
Pu-241	8.21E+00
Pu-240	3.04E-01
Pu-239	1.36E+00
Pu-238	2.12E-01
Cs-137	9.74E-04
Ba-137m	8.96E-04
Am-241	4.46E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	89.5	0.0	0.0	0.0	0.0	89.5
Drum / 55-gallon	37.2	0.0	0.0	0.0	0.0	37.2
Totals	126.8	0.0	0.0	0.0	0.0	126.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	50.3	0.0	0.0	0.0	0.0	50.3
Standard Waste Box	87.4	0.0	0.0	0.0	0.0	87.4
Totals	137.7	0.0	0.0	0.0	0.0	137.7

As-Generated Form: Stored: 126.8 Projected: 0.0 Total: 126.8

Final Waste Form: Stored: 137.7 Projected: 0.0 Total: 137.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Retention and Neutralization Facility.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W247	Handling:	CH	NMVP #:	N/A	Stream Name:	100 Areas and 200 Areas R&D TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	841.3	0.0	0.0
Aluminum-base Metal/Alloys:	134.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	51.0	0.0	0.0
Rubber:	19.2	0.0	0.0
Plastics:	59.2	0.0	0.0
Solidified Inorganic Material:	8.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	7.6	0.0	0.0
Packaging Material Steel:	144.3		
Packaging Material Plastic:	16.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	2.18E-04
Sr-90	2.18E-04
Pu-242	1.95E-07
Pu-241	8.71E-02
Pu-240	3.23E-03
Pu-239	1.44E-02
Pu-238	1.32E-03
Cs-137	2.32E-04
Ba-137m	2.14E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	24.0	0.0	0.0	0.0	0.0	24.0
Drum / 55-gallon	13.3	0.0	0.0	0.0	0.0	13.3
Totals	37.3	0.0	0.0	0.0	0.0	37.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	18.1	0.0	0.0	0.0	0.0	18.1
Standard Waste Box	24.7	0.0	0.0	0.0	0.0	24.7
Totals	42.8	0.0	0.0	0.0	0.0	42.8

As-Generated Form: Stored: 37.3 Projected: 0.0 Total: 37.3

Final Waste Form: Stored: 42.8 Projected: 0.0 Total: 42.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Biological Laboratory, Radioactive Particle Research Laboratory, and other R&D Sources in the Reactor and Chemical Separation Areas.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W248	Handling:	CH	NMVP #:	N/A	Stream Name:	209 E Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	567.0	0.0	0.0
Aluminum-base Metal/Alloys:	94.9	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	42.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	95.9	0.0	0.0
Rubber:	40.7	0.0	0.0
Plastics:	99.0	0.0	0.0
Solidified Inorganic Material:	14.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	16.3	0.0	0.0
Packaging Material Steel:	133.2		
Packaging Material Plastic:	33.5		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.80E-03
Sr-90	2.80E-03
Pu-242	6.45E-05
Pu-241	2.89E+01
Pu-240	1.07E+00
Pu-239	4.78E+00
Pu-238	1.41E-01
Cs-137	2.99E-03
Ba-137m	2.75E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	3.2	0.0	0.0	0.0	0.0	3.2
Drum / 55-gallon	13.1	0.0	0.0	0.0	0.0	13.1
Totals	16.3	0.0	0.0	0.0	0.0	16.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	17.7	0.0	0.0	0.0	0.0	17.7
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	19.6	0.0	0.0	0.0	0.0	19.6

As-Generated Form: Stored: 16.3 Projected: 0.0 Total: 16.3

Final Waste Form: Stored: 19.6 Projected: 0.0 Total: 19.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Critical Mass Laboratory.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W249	Handling:	CH	NMVP #:	N/A	Stream Name:	231-Z Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	677.5	0.0	0.0
Aluminum-base Metal/Alloys:	153.5	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	29.0	0.0	0.0
Rubber:	8.7	0.0	0.0
Plastics:	39.8	0.0	0.0
Solidified Inorganic Material:	6.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	3.4	0.0	0.0
Packaging Material Steel:	149.7		
Packaging Material Plastic:	7.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	6.27E-05
U-238	4.45E-05
U-235	1.14E-06
U-234	4.03E-04
Th-232	4.35E-08
Sr-90	6.27E-05
Pu-242	4.97E-06
Pu-241	2.23E+00
Pu-240	8.25E-02
Pu-239	3.69E-01
Pu-238	1.08E-02
Cs-137	6.69E-05
Ba-137m	6.16E-05

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	832.3	0.0	0.0	0.0	0.0	832.3
Drum / 55-gallon	143.1	0.0	0.0	0.0	0.0	143.1
Totals	975.4	0.0	0.0	0.0	0.0	975.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	193.2	0.0	0.0	0.0	0.0	193.2
Standard Waste Box	832.2	0.0	0.0	0.0	0.0	832.2
Totals	1025.4	0.0	0.0	0.0	0.0	1025.4

As-Generated Form: Stored: 975.4 Projected: 0.0 Total: 975.4

Final Waste Form: Stored: 1025.4 Projected: 0.0 Total: 1025.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Materials Engineering Laboratory.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W250	Handling:	CH	NMVP #:	N/A	Stream Name:	303C Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.02E+00
U-238	5.64E-06
U-235	5.24E-04
U-234	5.10E-03
U-233	4.27E+00
Th-232	3.21E-03
Sr-90	1.02E+00
Pu-242	1.88E-04
Pu-241	8.43E+01
Pu-240	3.12E+00
Pu-239	1.39E+01
Pu-238	4.11E-01
Cs-137	1.09E+00
Ba-137m	1.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	8.1	0.0	0.0	0.0	0.0	8.1
Totals	8.1	0.0	0.0	0.0	0.0	8.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.0	0.0	0.0	0.0	0.0	11.0
Totals	11.0	0.0	0.0	0.0	0.0	11.0

As-Generated Form: Stored: 8.1 Projected: 0.0 Total: 8.1

Final Waste Form: Stored: 11.0 Projected: 0.0 Total: 11.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the Material Evaluation Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W251	Handling:	CH	NMVP #:	N/A	Stream Name:	300 Area R&D TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	572.2	0.0	0.0
Aluminum-base Metal/Alloys:	97.7	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	42.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	92.8	0.0	0.0
Rubber:	39.2	0.0	0.0
Plastics:	96.2	0.0	0.0
Solidified Inorganic Material:	13.6	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	15.7	0.0	0.0
Packaging Material Steel:	134.0		
Packaging Material Plastic:	32.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	1.64E-03
U-238	6.00E-04
U-235	6.33E-05
U-234	3.18E-03
U-233	9.48E-05
Th-232	1.26E-05
Sr-90	1.64E-03
Pu-242	7.85E-06
Pu-241	3.51E+00
Pu-240	1.30E-01
Pu-239	5.82E-01
Pu-238	1.38E-01
Cs-137	1.75E-03
Ba-137m	1.61E-03
Am-241	1.46E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	34.2	0.0	0.0	0.0	0.0	34.2
Drum / 55-gallon	168.7	0.0	0.0	0.0	0.0	168.7
Totals	202.9	0.0	0.0	0.0	0.0	202.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	227.8	0.0	0.0	0.0	0.0	227.8
Standard Waste Box	34.2	0.0	0.0	0.0	0.0	34.2
Totals	262.0	0.0	0.0	0.0	0.0	262.0

As-Generated Form: Stored: 202.9 Projected: 0.0 Total: 202.9

Final Waste Form: Stored: 262.0 Projected: 0.0 Total: 262.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Radiological Calibrations Laboratory, Chemical Engineering Building, Radiochemistry Building laboratory and hot cells, and cesium recovery facility of the Radiochemistry Building, and Radioanalytical Laboratory.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The contact-handled TRU waste from Building 318 was reported as Waste No. RL-T117 in Revision 1 of the WTWBIR. This waste is reported in RL-T118 in Revision 2; RL-T117 has been deleted.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W252	Handling:	CH	NMVP #:	N/A	Stream Name:	TRU Construction Debris	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	655.2	0.0	0.0
Aluminum-base Metal/Alloys:	141.7	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	42.5	0.0	0.0
Rubber:	15.2	0.0	0.0
Plastics:	51.7	0.0	0.0
Solidified Inorganic Material:	7.9	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	6.0	0.0	0.0
Packaging Material Steel:	146.3		
Packaging Material Plastic:	13.1		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	5.71E-03
U-238	4.11E-09
U-235	1.89E-10
U-234	4.22E-09
Sr-90	5.71E-03
Pu-242	2.87E-06
Pu-241	1.28E+00
Pu-240	4.75E-02
Pu-239	2.12E-01
Pu-238	6.24E-03
Cs-137	6.10E-03
Ba-137m	5.61E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	87.2	0.0	0.0	0.0	0.0	87.2
Drum / 55-gallon	32.9	0.0	0.0	0.0	0.0	32.9
Totals	120.1	0.0	0.0	0.0	0.0	120.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	44.5	0.0	0.0	0.0	0.0	44.5
Standard Waste Box	89.3	0.0	0.0	0.0	0.0	89.3
Totals	133.8	0.0	0.0	0.0	0.0	133.8

As-Generated Form: Stored: 120.1 Projected: 0.0 Total: 120.1

Final Waste Form: Stored: 133.8 Projected: 0.0 Total: 133.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the construction activities.
CURRENT CONTAINER COMMENTS	N/A volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W253	Handling:	RH	NMVP #:	N/A	Stream Name:	105-KE Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	710.0	0.0	0.0
Aluminum-base Metal/Alloys:	164.5	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	22.5	0.0	0.0
Rubber:	6.6	0.0	0.0
Plastics:	34.6	0.0	0.0
Solidified Inorganic Material:	5.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	2.1	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	6.06E-01
Sr-90	6.06E-01
Pu-242	1.72E-06
Pu-241	3.86E+00
Pu-240	5.83E-02
Pu-239	1.17E-01
Pu-238	1.87E-02
Cs-137	6.47E-01
Ba-137m	5.96E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	49.0	0.0	0.0	0.0	0.0	49.0
Drum / 55-gallon	4.6	0.0	0.0	0.0	0.0	4.6
Totals	53.6	0.0	0.0	0.0	0.0	53.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	53.4	0.0	0.0	0.0	0.0	53.4
Totals	53.4	0.0	0.0	0.0	0.0	53.4

As-Generated Form: Stored: 53.6 Projected: 0.0 Total: 53.6

Final Waste Form: Stored: 53.4 Projected: 0.0 Total: 53.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the operation of the Fuel Storage Basins.
CURRENT CONTAINER COMMENTS	N/A volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W254	Handling:	CH	NMVP #:	N/A	Stream Name:	105-C, 105KE, and 105-N Bldg TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	692.4	0.0	0.0
Aluminum-base Metal/Alloys:	161.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	39.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	20.0	0.0	0.0
Rubber:	4.4	0.0	0.0
Plastics:	31.8	0.0	0.0
Solidified Inorganic Material:	5.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1.7	0.0	0.0
Packaging Material Steel:	151.9		
Packaging Material Plastic:	4.5		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	3.29E-01
U-238	5.52E-05
U-235	5.13E-03
U-234	4.98E-02
Th-232	3.78E-06
Sr-90	3.29E-01
Pu-242	2.50E-06
Pu-241	1.12E+00
Pu-240	4.17E-02
Pu-239	1.85E-01
Pu-238	5.47E-03
Cs-137	3.52E-01
Ba-137m	3.24E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	26.4	0.0	0.0	0.0	0.0	26.4
Drum / 55-gallon	2.1	0.0	0.0	0.0	0.0	2.1
Totals	28.5	0.0	0.0	0.0	0.0	28.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.7	0.0	0.0	0.0	0.0	2.7
Standard Waste Box	26.6	0.0	0.0	0.0	0.0	26.6
Totals	29.3	0.0	0.0	0.0	0.0	29.3

As-Generated Form: Stored: 28.5 Projected: 0.0 Total: 28.5

Final Waste Form: Stored: 29.3 Projected: 0.0 Total: 29.3

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of TRU waste from the operation of the reactors.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W255	Handling:	CH	NMVP #:	N/A	Stream Name:	Argonne Nat Lab Type 1 TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	AE	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
U-238	1.06E-04
U-235	9.81E-03
U-234	9.56E-02
Th-232	1.44E-05
Pu-242	3.46E-04
Pu-241	1.55E+02
Pu-240	5.74E+00
Pu-239	2.55E+01
Pu-238	7.53E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Argonne National Laboratory-East.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W256	Handling:	RH	NMVP #:	N/A	Stream Name:	Argonne Nat Lab Type II TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	AE	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	744.8	0.0	0.0
Aluminum-base Metal/Alloys:	117.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	57.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	141.3	0.0	0.0
Rubber:	60.3	0.0	0.0
Plastics:	144.7	0.0	0.0
Solidified Inorganic Material:	20.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	24.4	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.98E+01
U-233	2.03E-01
Th-232	1.56E-04
Sr-90	2.98E+01
Cs-137	3.19E+01
Ba-137m	2.93E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.9	0.0	0.0	0.0	0.0	0.9
Totals	0.9	0.0	0.0	0.0	0.0	0.9

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.9 Projected: 0.0 Total: 0.9

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the Argonne National Laboratory-East.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	This waste stream was erroneously identified as contact-handled TRU waste in Revision 1 of the WTWBIR. It has been reclassified as remote-handled waste in Revision 2 of the WTWBIR.
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W257	Handling:	CH	NMVP #:	N/A	Stream Name:	Argonne Nat Lab Type III TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	AE	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.81E+01
U-233	2.92E-01
Th-232	1.70E-04
Sr-90	2.81E+01
Pu-242	2.93E-10
Pu-241	1.32E-04
Pu-240	4.86E-06
Pu-239	2.17E-05
Pu-238	6.39E-07
Cs-137	3.00E+01
Ba-137m	2.76E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	11.2	0.0	0.0	0.0	0.0	11.2
Totals	11.2	0.0	0.0	0.0	0.0	11.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	15.2	0.0	0.0	0.0	0.0	15.2
Totals	15.2	0.0	0.0	0.0	0.0	15.2

As-Generated Form: Stored: 11.2 Projected: 0.0 Total: 11.2

Final Waste Form: Stored: 15.2 Projected: 0.0 Total: 15.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Argonne National Laboratory-East.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W258	Handling:	CH	NMVP #:	N/A	Stream Name:	Babcock Wilcox TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	617.3	0.0	0.0
Aluminum-base Metal/Alloys:	121.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	41.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	65.5	0.0	0.0
Rubber:	26.1	0.0	0.0
Plastics:	72.1	0.0	0.0
Solidified Inorganic Material:	10.5	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	10.4	0.0	0.0
Packaging Material Steel:	140.7		
Packaging Material Plastic:	21.9		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	3.44E-03
U-238	3.32E-05
U-235	5.96E-07
U-234	2.82E-04
Sr-90	3.44E-03
Pu-242	4.73E-05
Pu-241	2.12E+01
Pu-240	7.85E-01
Pu-239	3.51E+00
Pu-238	1.03E-01
Cs-137	3.67E-03
Ba-137m	3.38E-03
Am-241	1.15E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	118.8	0.0	0.0	0.0	0.0	118.8
Drum / 55-gallon	121.5	0.0	0.0	0.0	0.0	121.5
Totals	240.3	0.0	0.0	0.0	0.0	240.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	163.9	0.0	0.0	0.0	0.0	163.9
Standard Waste Box	119.7	0.0	0.0	0.0	0.0	119.7
Totals	283.6	0.0	0.0	0.0	0.0	283.6

As-Generated Form: Stored: 240.3 Projected: 0.0 Total: 240.3

Final Waste Form: Stored: 283.6 Projected: 0.0 Total: 283.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Babcock Wilcox.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W259	Handling:	CH	NMVP #:	N/A	Stream Name:	Bartlesville TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	5.54E-02
Sr-90	5.54E-02
Pu-242	7.85E-10
Pu-241	3.51E-04
Pu-240	1.30E-05
Pu-239	5.81E-05
Pu-238	1.71E-06
H-3	1.13E+01
Cs-137	5.91E-02
C-14	2.67E+00
Ba-137m	5.44E-02
Am-241	1.72E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Bartlesville.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W260	Handling:	CH	NMVP #:	N/A	Stream Name:	Battelle Columbus TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	BC	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	644.0	0.0	0.0
Aluminum-base Metal/Alloys:	135.7	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	49.3	0.0	0.0
Rubber:	18.4	0.0	0.0
Plastics:	57.7	0.0	0.0
Solidified Inorganic Material:	8.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	7.3	0.0	0.0
Packaging Material Steel:	144.7		
Packaging Material Plastic:	15.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	2.81E-03
U-238	5.74E-05
U-235	1.85E-05
U-234	2.67E-04
Sr-90	2.81E-03
Pu-242	6.40E-06
Pu-241	2.86E+00
Pu-240	1.06E-01
Pu-239	4.75E-01
Pu-238	4.70E+00
Cs-137	3.00E-03
Ba-137m	2.76E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	17.0	0.0	0.0	0.0	0.0	17.0
Drum / 55-gallon	8.7	0.0	0.0	0.0	0.0	8.7
Totals	25.7	0.0	0.0	0.0	0.0	25.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.6	0.0	0.0	0.0	0.0	11.6
Standard Waste Box	17.1	0.0	0.0	0.0	0.0	17.1
Totals	28.7	0.0	0.0	0.0	0.0	28.7

As-Generated Form: Stored: 25.7 Projected: 0.0 Total: 25.7

Final Waste Form: Stored: 28.7 Projected: 0.0 Total: 28.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Battelle Columbus Laboratory.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type II Battelle Columbus waste reported as Waste No. RL-T130 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Type I waste reported in RL-T129. RL-T130 has been replaced n Revision 2 of the WTWBIR with TRU waste generated by Bettis Atomic Power Laboratory.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W261	Handling:	CH	NMVP #:	N/A	Stream Name:	Bettis TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	BC	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	4.32E-01
U-238	4.40E-07
U-235	4.09E-05
U-234	3.99E-04
Sr-90	4.32E-01
Pu-242	1.88E-06
Pu-241	8.43E-01
Pu-240	3.13E-02
Pu-239	1.40E-01
Pu-238	4.11E-03
Cs-137	4.61E-01
Ba-137m	4.24E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Bettis Atomic Power Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type II Battelle Columbus waste reported as Waste No. RL-T130 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Type I waste reported in RL-T129. RL-T130 has been replaced n Revision 2 of the WTWBIR with TRU waste generated by Bettis Atomic Power Laboratory.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W262	Handling:	CH	NMVP #:	N/A	Stream Name:	Energy Systems Group TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	1.24E-02
U-238	5.71E-07
U-235	2.78E-05
U-234	2.73E-04
Sr-90	1.24E-02
Pu-242	1.27E-05
Pu-241	5.68E+00
Pu-240	2.10E-01
Pu-239	9.41E-01
Pu-238	2.77E-02
Cs-137	1.37E-02
Ba-137m	1.26E-02
Am-241	3.39E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	22.3	0.0	0.0	0.0	0.0	22.3
Totals	22.3	0.0	0.0	0.0	0.0	22.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	30.2	0.0	0.0	0.0	0.0	30.2
Totals	30.2	0.0	0.0	0.0	0.0	30.2

As-Generated Form: Stored: 22.3 Projected: 0.0 Total: 22.3

Final Waste Form: Stored: 30.2 Projected: 0.0 Total: 30.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W263	Handling:	CH	NMVP #:	N/A	Stream Name:	Exxon TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	4.63E-03
U-238	8.30E-03
U-235	3.81E-04
U-234	8.54E-03
Sr-90	4.63E-03
Pu-242	1.32E-03
Pu-241	5.89E+02
Pu-240	2.19E+01
Pu-239	9.78E+01
Pu-238	2.87E+00
Cs-137	4.95E-03
Ba-137m	4.55E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	21.2	0.0	0.0	0.0	0.0	21.2
Totals	21.2	0.0	0.0	0.0	0.0	21.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	28.7	0.0	0.0	0.0	0.0	28.7
Totals	28.7	0.0	0.0	0.0	0.0	28.7

As-Generated Form: Stored: 21.2 Projected: 0.0 Total: 21.2

Final Waste Form: Stored: 28.7 Projected: 0.0 Total: 28.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Exxon.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Exxon waste reported as Waste No. RL-T133 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Exxon waste reported in RL-T132. RL-T133 has been replaced in Revision 2 of the WTWBIR with TRU waste generated by the International Atomic Energy Agency.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W264	Handling:	CH	NMVP #:	N/A	Stream Name:	International Atomic Energy Agency TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Source Unknown

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	4.97E-03
Sr-90	4.97E-03
Pu-242	1.52E-04
Pu-241	6.81E+01
Pu-240	2.53E+00
Pu-239	1.13E+01
Pu-238	3.32E-01
Cs-137	5.31E-03
Ba-137m	4.88E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the International Atomic Energy Agency.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Exxon waste reported as Waste No. RL-T133 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Exxon waste reported in RL-T132. RL-T133 has been replaced in Revision 2 of the WTWBIR with TRU waste generated by the International Atomic Energy Agency.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W265	Handling:	CH	NMVP #:	N/A	Stream Name:	Lawrence Berkeley Nat Lab TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	LB	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	3.99E+00
Sr-90	3.99E+00
Pu-242	7.85E-06
Pu-241	3.51E+00
Pu-240	1.30E-01
Pu-239	5.82E-01
Pu-238	1.71E-02
Cs-137	4.26E+00
Ba-137m	3.92E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Lawrence Berkeley National Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W266	Handling:	CH	NMVP #:	N/A	Stream Name:	Lawrence Livermore TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	LL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	2.49E-04
U-238	1.11E-03
U-235	1.78E-05
U-234	9.97E-03
Sr-90	2.49E-04
Pu-242	1.83E-05
Pu-241	8.20E+00
Pu-240	3.04E-01
Pu-239	1.36E+00
Pu-238	4.00E-02
Cs-137	2.66E-04
Ba-137m	2.44E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Lawrence Livermore National Laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type II Lawrence Livermore National Laboratories waste reported as Waste No. RL-T136 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Type I waste reported in RL-T135. RL-T136 has been deleted in Revision 2 of the WTWBIR.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W267	Handling:	CH	NMVP #:	N/A	Stream Name:	Kerr McGee TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Y-90	4.18E-03
U-238	3.99E-05
U-235	1.84E-06
U-234	4.11E-05
Sr-90	4.18E-03
Pu-242	6.32E-05
Pu-241	2.83E+01
Pu-240	1.05E+00
Pu-239	4.69E+00
Pu-238	1.38E-01
Cs-137	4.46E-03
Ba-137m	4.11E-03
Am-241	1.33E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	112.3	0.0	0.0	0.0	0.0	112.3
Totals	112.3	0.0	0.0	0.0	0.0	112.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	151.6	0.0	0.0	0.0	0.0	151.6
Totals	151.6	0.0	0.0	0.0	0.0	151.6

As-Generated Form: Stored: 112.3 Projected: 0.0 Total: 112.3

Final Waste Form: Stored: 151.6 Projected: 0.0 Total: 151.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Kerr McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W268	Handling:	CH	NMVP #:	N/A	Stream Name:	Rocky Flats TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RF	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	552.0	0.0	0.0
Aluminum-base Metal/Alloys:	87.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	43.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	105.0	0.0	0.0
Rubber:	45.0	0.0	0.0
Plastics:	107.0	0.0	0.0
Solidified Inorganic Material:	15.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	8.29E-03
U-238	2.12E-02
U-235	3.54E-04
U-234	1.90E-01
Sr-90	8.29E-03
Pu-242	1.66E-05
Pu-241	7.45E+00
Pu-240	2.76E-01
Pu-239	1.23E+00
Pu-238	3.63E-02
Cs-137	8.85E-03
Ba-137m	8.14E-03
Am-241	7.39E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	102.3	0.0	0.0	0.0	0.0	102.3
Totals	102.3	0.0	0.0	0.0	0.0	102.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	138.1	0.0	0.0	0.0	0.0	138.1
Totals	138.1	0.0	0.0	0.0	0.0	138.1

As-Generated Form: Stored: 102.3 Projected: 0.0 Total: 102.3

Final Waste Form: Stored: 138.1 Projected: 0.0 Total: 138.1

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from Rocky Flats.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums is expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type II Rocky Flats waste reported as Waste No. RL-T141 in Revision 1 of the WTWBIR has been merged in Revision 2 with the Type I waste reported in RL-T140. RL-T141 has been deleted in Revision 2 of the WTWBIR.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W269	Handling:	CH	NMVP #:	N/A	Stream Name:	GE San Jose and Vallecitos TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	GE	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	697.6	0.0	0.0
Aluminum-base Metal/Alloys:	164.1	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	39.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	16.9	0.0	0.0
Rubber:	2.9	0.0	0.0
Plastics:	29.1	0.0	0.0
Solidified Inorganic Material:	5.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1.1	0.0	0.0
Packaging Material Steel:	152.6		
Packaging Material Plastic:	3.3		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	2.95E-04
U-238	6.69E-05
U-235	5.84E-06
U-234	9.55E-05
Sr-90	2.95E-04
Pu-242	2.25E-06
Pu-241	1.01E+00
Pu-240	3.74E-02
Pu-239	1.67E-01
Pu-238	4.92E-03
Cs-137	3.15E-04
Ba-137m	2.90E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	384.4	0.0	0.0	0.0	0.0	384.4
Drum / 55-gallon	17.7	0.0	0.0	0.0	0.0	17.7
Totals	402.1	0.0	0.0	0.0	0.0	402.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	23.7	0.0	0.0	0.0	0.0	23.7
Standard Waste Box	380.0	0.0	0.0	0.0	0.0	380.0
Totals	403.7	0.0	0.0	0.0	0.0	403.7

As-Generated Form: Stored: 402.1 Projected: 0.0 Total: 402.1

Final Waste Form: Stored: 403.7 Projected: 0.0 Total: 403.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste consists of typically contact-handled TRU waste from the General Electric Plants at San Jose and Vallecitos.
CURRENT CONTAINER COMMENTS	N/A average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Type I and II GE Pleasanton waste reported in Waste Nos. RL-T138 and RL-T139 and RL-139, and the GE Vallecitos waste reported in RL-T144 in Revision 1 of the WTWBIR have been merged in Revision 2 with the waste reported in RL-T143. RL-T138, RL-T139, and RL-T144 have been deleted in Revision 2.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W270	Handling:	CH	NMVP #:	N/A	Stream Name:	Ward TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	678.5	0.0	0.0
Aluminum-base Metal/Alloys:	154.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.5	0.0	0.0
Rubber:	8.4	0.0	0.0
Plastics:	39.3	0.0	0.0
Solidified Inorganic Material:	6.3	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	3.3	0.0	0.0
Packaging Material Steel:	149.8		
Packaging Material Plastic:	7.7		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	1.94E-03
U-238	1.75E-05
U-235	7.46E-06
U-234	1.26E-04
Th-232	1.37E-07
Sr-90	1.94E-03
Pu-242	3.64E-06
Pu-241	1.63E+00
Pu-240	6.03E-02
Pu-239	2.70E-01
Pu-238	7.94E-03
Cs-137	2.07E-03
Ba-137m	1.90E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	582.0	0.0	0.0	0.0	0.0	582.0
Drum / 55-gallon	96.1	0.0	0.0	0.0	0.0	96.1
Totals	678.1	0.0	0.0	0.0	0.0	678.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	129.8	0.0	0.0	0.0	0.0	129.8
Standard Waste Box	581.4	0.0	0.0	0.0	0.0	581.4
Totals	711.2	0.0	0.0	0.0	0.0	711.2

As-Generated Form: Stored: 678.1 Projected: 0.0 Total: 678.1

Final Waste Form: Stored: 711.2 Projected: 0.0 Total: 711.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of contact-handled TRU waste from the Westinghouse Advanced Reactor Division (WARD).
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.A, Radioactive Waste Management. Of the TRU waste stored from May 1970 to December 1986 that has not been assayed and redesignated as low level waste (by December 1993), 50% of the waste stored in 55-gallon drums, and 85% of the waste stored in boxes are expected to be TRU waste upon assaying. The remainder is expected to be low-level waste upon assaying. The reported volumes and radionuclides have been adjusted to take this assumption into account. Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Waste in boxes will be opened, and size-reduced to fit into TRUPACT-II SWBs. No volume reduction is projected. Upper and lower weights for final waste form are unknown.
ACCEPTANCE COMMENTS	The Ward waste reported in Waste Nos. RL-T144 in Revision 1 of the WTWBIR has been merged in Revision 2 with the waste reported in RL-T145. RL-T144 has been deleted in Revision 2.
FINAL FORM COMMENTS	Waste in drums will be opened, examined to remove non-certifiable waste, and then packaged into new drums. The projection is that repackaging will result in a 35% increase in the volume of TRU-certified wastes in drums (WHC-SD-W026-SDRD-001, Rev. 3). Upper and lower weights for final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W271	Handling:	RH	NMVP #:	N/A	Stream Name:	325 and 325B Bldg Op TRU Caisson Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	709.3	0.0	0.0
Aluminum-base Metal/Alloys:	165.4	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	40.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	20.1	0.0	0.0
Rubber:	5.5	0.0	0.0
Plastics:	32.4	0.0	0.0
Solidified Inorganic Material:	5.4	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1.7	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	8.07E+01
U-238	3.23E-04
U-235	4.30E-03
U-234	4.41E-02
U-233	1.85E-02
Th-232	1.06E-05
Sr-90	8.07E+01
Pu-242	1.82E-04
Pu-241	3.89E+02
Pu-240	6.17E+00
Pu-239	1.24E+01
Pu-238	1.98E+00
Cs-137	8.62E+01
Ba-137m	7.93E+01
Am-241	3.62E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	26.2	0.0	0.0	0.0	0.0	26.2
Drum / 55-gallon	1.9	0.0	0.0	0.0	0.0	1.9
Totals	28.1	0.0	0.0	0.0	0.0	28.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	27.6	0.0	0.0	0.0	0.0	27.6
Totals	27.6	0.0	0.0	0.0	0.0	27.6

As-Generated Form: Stored: 28.1 Projected: 0.0 Total: 28.1

Final Waste Form: Stored: 27.6 Projected: 0.0 Total: 27.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the Radiochemistry Building and Shielded Laboratory Annex.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	The remote-handled TRU waste from Building 324 reported under Waste No. RL-T147 in Revision 1 of the WTWBIR has been merged with waste reported under RL-T148. This waste is reported in RL-T148 in Revision 2.
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W272	Handling:	RH	NMVP #:	N/A	Stream Name:	324 and 327C TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	737.6	0.0	0.0
Aluminum-base Metal/Alloys:	127.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	54.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	116.7	0.0	0.0
Rubber:	49.2	0.0	0.0
Plastics:	121.9	0.0	0.0
Solidified Inorganic Material:	17.6	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	19.8	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	1.78E+03
U-238	4.78E-04
U-235	6.66E-03
U-234	6.81E-02
U-233	1.12E-02
Th-232	5.37E-05
Sr-90	1.78E+03
Pu-242	2.29E-04
Pu-241	4.91E+02
Pu-240	7.78E+00
Pu-239	1.56E+01
Pu-238	2.50E+00
Cs-137	1.90E+03
Co-60	8.02E+01
Ba-137m	1.74E+03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	4.5	0.0	0.0	0.0	0.0	4.5
Drum / 55-gallon	19.3	0.0	0.0	0.0	0.0	19.3
Totals	23.8	0.0	0.0	0.0	0.0	23.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	24.0	0.0	0.0	0.0	0.0	24.0
Totals	24.0	0.0	0.0	0.0	0.0	24.0

As-Generated Form: Stored: 23.8 Projected: 0.0 Total: 23.8

Final Waste Form: Stored: 24.0 Projected: 0.0 Total: 24.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of typically remote-handled TRU waste from the Chemical Engineering Building and Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	The remote-handled TRU waste from Building 324 reported under Waste No. RL-T147 in Revision 1 of the WTWBIR has been merged with waste reported under RL-T148. This waste is reported in RL-T148 in Revision 2.
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W273	Handling:	RH	NMVP #:	N/A	Stream Name:	325A and 325B R&D TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	707.6	0.0	0.0
Aluminum-base Metal/Alloys:	167.8	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	39.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	14.1	0.0	0.0
Rubber:	2.8	0.0	0.0
Plastics:	26.8	0.0	0.0
Solidified Inorganic Material:	4.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.5	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Y-90	3.05E+01
U-238	7.13E-08
U-235	6.65E-06
U-234	6.48E-05
U-233	1.09E-01
Th-232	5.97E-04
Sr-90	3.05E+01
Pu-242	3.74E-07
Pu-241	8.02E-01
Pu-240	1.27E-02
Pu-239	2.55E-02
Pu-238	4.08E-03
Cs-137	3.12E+01
Ba-137m	2.92E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	68.0	0.0	0.0	0.0	0.0	68.0
Drum / 55-gallon	1.5	0.0	0.0	0.0	0.0	1.5
Totals	69.4	0.0	0.0	0.0	0.0	69.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	69.4	0.0	0.0	0.0	0.0	69.4
Totals	69.4	0.0	0.0	0.0	0.0	69.4

As-Generated Form: Stored: 69.4 Projected: 0.0 Total: 69.4

Final Waste Form: Stored: 69.4 Projected: 0.0 Total: 69.4

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the Cesium Recovery Facility and Shielded Laboratory Annex of the Radiochemistry Building.
CURRENT CONTAINER COMMENTS	The volumes from "other containers" were combined with volumes in "boxes", and reported as "boxes". The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	This waste stream has been expanded in Revision 2 of the WTWBIR to report remote-handled waste from both Buildings 325A and 325B.
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W274	Handling:	RH	NMVP #:	N/A	Stream Name:	202A Bldg Remote-Handled TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	725.8	0.0	0.0
Aluminum-base Metal/Alloys:	143.3	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	48.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	76.3	0.0	0.0
Rubber:	30.9	0.0	0.0
Plastics:	84.5	0.0	0.0
Solidified Inorganic Material:	12.5	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	12.2	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	1.50E-01
Sr-90	1.50E-01
Pu-242	1.98E-07
Pu-241	4.25E-01
Pu-240	6.73E-03
Pu-239	1.35E-02
Pu-238	2.16E-03
Cs-137	1.61E-01
Ba-137m	1.48E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	2.6	0.0	0.0	0.0	0.0	2.6
Drum / 55-gallon	2.7	0.0	0.0	0.0	0.0	2.7
Totals	5.3	0.0	0.0	0.0	0.0	5.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	5.3	0.0	0.0	0.0	0.0	5.3
Totals	5.3	0.0	0.0	0.0	0.0	5.3

As-Generated Form: Stored: 5.3 Projected: 0.0 Total: 5.3

Final Waste Form: Stored: 5.3 Projected: 0.0 Total: 5.3

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30 % of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Boxes typically contain whole and sectioned glove boxes, hoods, ducting, conduit, lathes, pumps, piping, fans, light fixture, instrumentation, tools, conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oils have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from the Purex Canyon and Service Facility.
CURRENT CONTAINER COMMENTS	The average of the internal box volumes was computed and reported.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final waste form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W275	Handling:	RH	NMVP #:	N/A	Stream Name:	202AL and 222S Bldg Remote-Handled TRU Waste	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5440

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	744.8	0.0	0.0
Aluminum-base Metal/Alloys:	117.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	57.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	141.3	0.0	0.0
Rubber:	60.3	0.0	0.0
Plastics:	144.7	0.0	0.0
Solidified Inorganic Material:	20.7	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	24	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Y-90	3.10E-01
U-238	8.87E-08
U-235	4.09E-09
U-234	9.14E-08
Sr-90	3.10E-01
Pu-242	5.87E-10
Pu-241	1.26E-03
Pu-240	1.99E-05
Pu-239	4.00E-05
Pu-238	6.40E-06
Cs-137	3.31E-01
Ba-137m	3.04E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	18.5	0.0	0.0	0.0	0.0	18.5
Totals	18.5	0.0	0.0	0.0	0.0	18.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	18.7	0.0	0.0	0.0	0.0	18.7
Totals	18.7	0.0	0.0	0.0	0.0	18.7

As-Generated Form: Stored: 18.5 Projected: 0.0 Total: 18.5

Final Waste Form: Stored: 18.7 Projected: 0.0 Total: 18.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of waste in drums is combustible items such as wood, plastics, paper, absorbents, rubber, rags. Approximately 20 to 30% of waste in drums is noncombustible waste, such as failed machinery, tools, glass, concrete, plumbing and fixture and soil. Absorbed combustible liquids such as oils have also been placed in some drums. Drums are also used for disposal of high-efficiency particulate air filters.
WASTE STREAM SOURCE	This waste stream consists of remote-handled TRU waste from process analytical laboratories.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Inventory is from the site's record solid waste tracking system, a requirement of DOE Order 5820.2A, Radioactive Waste Management. Upper and lower weights of final form are unknown.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Upper and lower weights of final waste form are unknown.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W276	Handling:	RH	NMVP #:	N/A	Stream Name:	ARGON Pb/Cd Met lead RH St MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	66.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	310.4	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	202.7	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	526.0		
Packaging Material Plastic:	26.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	1.43E+03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister used to overpack 55 gallon drums	1.8	0.0	0.0	0.0	0.0	1.8
Totals	1.8	0.0	0.0	0.0	0.0	1.8

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 1.8 Projected: 0.0 Total: 1.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, METAL/IRON/GALVANIZED/SHEET, CEMENT.
WASTE STREAM SOURCE	This stream is lead cadmium metal remote handled State regulated mixed TRU waste from the Argonne National Laboratory - East
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W277	Handling:	CH	NMVP #:	N/A	Stream Name:	BATCO Pb/Cd Met lead CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

P015, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	9.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Battelle Columbus Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W278	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Comb debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	22.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	37.2	0.0	0.0
Other Inorganic Material:	9.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	56.3	0.0	0.0
Rubber:	52.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	30.5		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	4.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS WOOD/LUMBER/PLYWOOD, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE, PAPER/CARDBOARD, STAINLESS STEEL.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal contaminants from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W279	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Heter debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	104.9	0.0	0.0
Aluminum-base Metal/Alloys:	1.8	0.0	0.0
Other Metals/Alloys:	0.2	0.0	0.0
Other Inorganic Material:	16.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	27.4	0.0	0.0
Rubber:	4.1	0.0	0.0
Plastics:	31.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	4.7	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	18.2	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	3.24E+00
Pu-240	1.20E-01
Pu-239	5.40E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.9	0.0	0.0	0.0	0.0	6.9
Totals	6.9	0.0	0.0	0.0	0.0	6.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	69.3	0.0	0.0	0.0	0.0	69.3
Totals	69.3	0.0	0.0	0.0	0.0	69.3

As-Generated Form: Stored: 6.9 Projected: 0.0 Total: 6.9

Final Waste Form: Stored: 69.3 Projected: 0.0 Total: 69.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS STAINLESS STEEL, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, FILTERS, METAL/IRON/GALVANIZED/SHEET, SOLVENTS/THINNERS, RUBBER, CONCRETE, PAINTS/LUCITE, ABSORBENT/KITY LTR/VERMICULITE, WOOD/LUMBER/PLYWOOD, SLUDGES, SAND, ALUMIN.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled State regulated mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W280	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Solidif org debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3150

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	61.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	5.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.6	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	16.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	110.2	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	39.2	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	0.00E+00
Pu-241	3.24E+00
Pu-240	1.20E-01
Pu-239	5.40E-01
Beta/Gamma	5.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, SLUDGES, WATER, SOLVENTS/THINNERS, PLASTIC/POLYURETHANE, FILTERS, PAINTS/LUCITE, CONCRETE.
WASTE STREAM SOURCE	This stream is solidified organics contact handled State regulated mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W281	Handling:	CH	NMVP #:	N/A	Stream Name:	183H Solidif inorg labpks CH RCRA MTRU w/ met ign	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	X6200

AS-GENERATED EPA CODES

U123, P120, P106, P098, P030, P029, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	49.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.3	0.0	0.0
Solidified Inorganic Material:	617.8	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Materials Production/Recovery Effluents

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.3	0.0	0.0	0.0	0.0	0.3
Totals	0.3	0.0	0.0	0.0	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.3	0.0	0.0	0.0	0.0	3.3
Totals	3.3	0.0	0.0	0.0	0.0	3.3

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 3.3 Projected: 0.0 Total: 3.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LIQUID, ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is solidified inorganics contact handled RCRA regulated mixed TRU waste with metal ignitable contaminants from the Solidified dewatered fuel fabrication sludge.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W282	Handling:	CH	NMVP #:	N/A	Stream Name:	200W Solidif org debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S4000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	37.3	0.0	0.0
Rubber:	18.6	0.0	0.0
Plastics:	18.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.3	0.0	0.0	0.0	0.0	0.3
Totals	0.3	0.0	0.0	0.0	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.3	0.0	0.0	0.0	0.0	3.3
Totals	3.3	0.0	0.0	0.0	0.0	3.3

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 3.3 Projected: 0.0 Total: 3.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, MISCELLANEOUS/UNKNOWN/OTHER, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is solidified organics contact handled State regulated mixed TRU waste from the Chemical Separations Area.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W283	Handling:	CH	NMVP #:	N/A	Stream Name:	201C Soils CH/r RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4000

AS-GENERATED EPA CODES

D010, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	29.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	68.7	0.0	0.0
Rubber:	21.2	0.0	0.0
Plastics:	33.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.1	0.0	0.0
Packaging Material Steel:	428.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	2.47E+00
Pu-241	8.00E-02
Pu-240	0.00E+00
Pu-239	1.00E-02
Beta/Gamma	1.14E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.6	0.0	0.0	0.0	0.0	11.6
Totals	11.6	0.0	0.0	0.0	0.0	11.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	116.5	0.0	0.0	0.0	0.0	116.5
Totals	116.5	0.0	0.0	0.0	0.0	116.5

As-Generated Form: Stored: 11.6 Projected: 0.0 Total: 11.6

Final Waste Form: Stored: 116.5 Projected: 0.0 Total: 116.5

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, WOOD/LUMBER/PLYWOOD, METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, HAZARDOUS CONSTITUENTS, RUBBER, FILTERS, ANIMAL WASTE.
WASTE STREAM SOURCE	This stream is soils contact handled packaged remote RCRA regulated mixed TRU waste with metal contaminants from the Demolition of the Semi-works facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W285	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Solidif org debris CH RCRA MTRU w/ org ign	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

F003, D019, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	74.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	11.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	61.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	12.1	0.0	0.0	0.0	0.0	12.1
Totals	12.1	0.0	0.0	0.0	0.0	12.1

As-Generated Form: Stored: 1.2 Projected: 0.0 Total: 1.2

Final Waste Form: Stored: 12.1 Projected: 0.0 Total: 12.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CONWEB PADS, METAL/IRON/GALVANIZED/SHEET, HAZARDOUS CONSTITUENTS, GLASS, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA regulated mixed TRU waste with organic ignitable contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W286	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Solidif org inorg part CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	162.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	1.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	8.7	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	3.24E+00
Pu-240	1.20E-01
Pu-239	5.40E-01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, OILS, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is solidified organics contact handled State regulated mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W287	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Pb/Cd Met debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	31.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	158.0	0.0	0.0
Other Inorganic Material:	13.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.1	0.0	0.0
Rubber:	62.0	0.0	0.0
Plastics:	81.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	6.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, RUBBER, LEAD, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, ABSORBENT/KITY LTR/VERMICULITE, CHEMICALS.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W288	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat met debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	177.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.1	0.0	0.0
Rubber:	1.7	0.0	0.0
Plastics:	61.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	3.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.4	0.0	0.0	0.0	0.0	10.4
Totals	10.4	0.0	0.0	0.0	0.0	10.4

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 10.4 Projected: 0.0 Total: 10.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, LEAD, RUBBER, CHEMICALS, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W289	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	46.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	48.6	0.0	0.0
Other Inorganic Material:	1.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.9	0.0	0.0
Rubber:	9.9	0.0	0.0
Plastics:	118.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	8.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	21.0	0.0	0.0	0.0	0.0	21.0
Totals	21.0	0.0	0.0	0.0	0.0	21.0

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 21.0 Projected: 0.0 Total: 21.0

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, RUBBER, STAINLESS STEEL, CLOTH/RAGS/NYLON, LEAD, GLASS, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W290	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Pb/Cd Met debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	4.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	191.9	0.0	0.0
Other Inorganic Material:	33.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.0	0.0	0.0
Rubber:	110.2	0.0	0.0
Plastics:	28.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	23.1	0.0	0.0	0.0	0.0	23.1
Totals	23.1	0.0	0.0	0.0	0.0	23.1

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 23.1 Projected: 0.0 Total: 23.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, LEAD, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, GLASS.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W291	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat met debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	61.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.7	0.0	0.0
Other Inorganic Material:	0.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	6.0	0.0	0.0
Rubber:	0.1	0.0	0.0
Plastics:	13.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Box	7.1	0.0	0.0	0.0	0.0	7.1
Totals	7.6	0.0	0.0	0.0	0.0	7.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Standard Waste Box	7.6	0.0	0.0	0.0	0.0	7.6
Totals	11.7	0.0	0.0	0.0	0.0	11.7

As-Generated Form: Stored: 7.6 Projected: 0.0 Total: 7.6

Final Waste Form: Stored: 11.7 Projected: 0.0 Total: 11.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD, CONCRETE, CLOTH/RAGS/NYLON, LEAD, RUBBER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W292	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Inorg non-met debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	76.6	0.0	0.0
Other Inorganic Material:	78.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.0	0.0	0.0
Rubber:	47.6	0.0	0.0
Plastics:	38.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	1.30E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, LEAD, CLOTH/RAGS/NYLON, CHEMICALS.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W293	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	20.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	53.0	0.0	0.0
Other Inorganic Material:	0.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.6	0.0	0.0
Rubber:	81.6	0.0	0.0
Plastics:	73.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	6.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.3	0.0	0.0	0.0	0.0	1.3
Totals	1.3	0.0	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	12.7	0.0	0.0	0.0	0.0	12.7
Totals	12.7	0.0	0.0	0.0	0.0	12.7

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 12.7 Projected: 0.0 Total: 12.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, LEAD, STAINLESS STEEL, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, GLASS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W294	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Heter debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D009, D008, D006, D005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	15.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	55.0	0.0	0.0
Other Inorganic Material:	36.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	8.1	0.0	0.0
Rubber:	32.1	0.0	0.0
Plastics:	50.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.0	0.0	0.0	0.0	1.0
Totals	1.0	0.0	0.0	0.0	0.0	1.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.4	0.0	0.0	0.0	0.0	10.4
Totals	10.4	0.0	0.0	0.0	0.0	10.4

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 10.4 Projected: 0.0 Total: 10.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, RUBBER, LEAD, FILTERS, ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, GLASS, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON, BATTERIES.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W295	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat debris CH RCRA MTRU w/ cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	100.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	5.5	0.0	0.0
Other Inorganic Material:	0.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.7	0.0	0.0
Rubber:	22.9	0.0	0.0
Plastics:	55.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	18.9	0.0	0.0	0.0	0.0	18.9
Totals	18.9	0.0	0.0	0.0	0.0	18.9

As-Generated Form: Stored: 1.9 Projected: 0.0 Total: 1.9

Final Waste Form: Stored: 18.9 Projected: 0.0 Total: 18.9

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, RUBBER, CLOTH/RAGS/NYLON, LEAD, GLASS, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is uncategorized contact handled RCRA regulated mixed TRU waste with corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W296	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH RCRA MTRU w/ cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	29.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	7.4	0.0	0.0
Other Inorganic Material:	0.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	11.0	0.0	0.0
Rubber:	55.0	0.0	0.0
Plastics:	71.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No.

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	2.00E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.1	0.0	0.0	0.0	0.0	3.1
Totals	3.1	0.0	0.0	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	31.6	0.0	0.0	0.0	0.0	31.6
Totals	31.6	0.0	0.0	0.0	0.0	31.6

As-Generated Form: Stored: 3.1 Projected: 0.0 Total: 3.1

Final Waste Form: Stored: 31.6 Projected: 0.0 Total: 31.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, RUBBER, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, LEAD, GLASS, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with corrosive contaminants from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W297	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat met debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	115.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	4.4	0.0	0.0
Other Inorganic Material:	11.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.9	0.0	0.0
Rubber:	28.3	0.0	0.0
Plastics:	39.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	2.10E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	0.0	0.0	0.0	0.0	1.7
Totals	1.7	0.0	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.8	0.0	0.0	0.0	0.0	16.8
Totals	16.8	0.0	0.0	0.0	0.0	16.8

As-Generated Form: Stored: 1.7 Projected: 0.0 Total: 1.7

Final Waste Form: Stored: 16.8 Projected: 0.0 Total: 16.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET, RUBBER, PAPER/CARDBOARD, BRICK/FIREBRICK, CLOTH/RAGS/NYLON, LEAD, WOOD/LUMBER/PLYWOOD, COPPER METAL.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled State regulated mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W298	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	21.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	6.7	0.0	0.0
Other Inorganic Material:	0.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	7.6	0.0	0.0
Rubber:	35.8	0.0	0.0
Plastics:	45.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	8.27E+01
Pu-240	2.96E+00
Pu-239	1.31E+01
Beta/Gamma	1.10E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.9	0.4	0.0	0.0	0.0	11.3
Box	5.0	0.0	0.0	0.0	0.0	5.0
Totals	16.0	0.4	0.0	0.0	0.0	16.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	109.2	0.4	0.0	0.0	0.0	109.6
Standard Waste Box	5.7	0.0	0.0	0.0	0.0	5.7
Totals	114.9	0.4	0.0	0.0	0.0	115.3

As-Generated Form: Stored: 16.0 Projected: 0.0 Total: 16.0

Final Waste Form: Stored: 114.9 Projected: 0.4 Total: 115.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, FILTERS, RUBBER, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, STAINLESS STEEL, LEAD, WOOD/LUMBER/PLYWOOD, COPPER METAL, GLASS, PAPER/CARDBOARD, LEATHER, ALUMINUM.
WASTE STREAM SOURCE	This stream is combustible contact handled State regulated mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W299	Handling:	CH	NMVP #:	N/A	Stream Name:	202AL Uncat met debris CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	258.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	46.8	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.7	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	104.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	9.82E+01
Pu-240	3.65E+00
Pu-239	1.63E+01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.0	0.0	0.0	0.0	6.2
Totals	6.2	0.0	0.0	0.0	0.0	6.2

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 6.2 Projected: 0.0 Total: 6.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, LEAD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Fuel Reprocessing Facility Support Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W300	Handling:	CH	NMVP #:	N/A	Stream Name:	202AL Comb debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	23.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	185.5	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	283.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	9.82E+01
Pu-240	3.65E+00
Pu-239	1.63E+01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, LEAD, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuel Reprocessing Facility Support Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W301	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Heter lead CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	118.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	237.1	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	45.0	0.0	0.0
Rubber:	12.1	0.0	0.0
Plastics:	16.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	1.72E+02
Pu-240	6.35E+00
Pu-239	2.83E+01
Beta/Gamma	8.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.0	0.0	0.0	0.0	6.2
Totals	6.2	0.0	0.0	0.0	0.0	6.2

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 6.2 Projected: 0.0 Total: 6.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, CADMIUM, LEAD, PLASTIC/POLYURETHANE, RUBBER, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, FIBERGLASS.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled RCRA regulated mixed TRU waste with metal contaminants from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W302	Handling:	CH	NMVP #:	N/A	Stream Name:	222S Heter debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D007

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	479.2	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	56.9	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	74.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	28.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.84E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CONWEB PADS, FILTERS, WOOD/LUMBER/PLYWOOD, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled RCRA regulated mixed TRU waste with metal contaminants from the Process Analytical Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W303	Handling:	CH	NMVP #:	N/A	Stream Name:	224T Heter debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	15.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	42.8	0.0	0.0
Rubber:	21.5	0.0	0.0
Plastics:	45.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	31.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	1.14E+00
Pu-239	7.45E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, GLASS, MISCELLANEOUS/UNKNOWN/OTHER, CONCRETE, CORK, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is heterogeneous contact handled State regulated mixed TRU waste from the Transuranic Assaying and Storage Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W304	Handling:	CH	NMVP #:	N/A	Stream Name:	231Z Heter debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	22.5	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	3.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.10E-01
Pu-241	1.80E+00
Pu-240	6.00E-02
Pu-239	2.80E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	2.5	0.0	0.0	0.0	0.0	2.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.0	0.0	0.0	0.0	6.2
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	8.1	0.0	0.0	0.0	0.0	8.1

As-Generated Form: Stored: 2.5 Projected: 0.0 Total: 2.5

Final Waste Form: Stored: 8.1 Projected: 0.0 Total: 8.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS FILTERS, FIBERGLASS, WOOD/LUMBER/PLYWOOD, METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is heterogeneous contact handled State regulated mixed TRU waste from the PNL Materials Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W305	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ org met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D019, D011, D010, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	12.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	49.1	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	23.3	0.0	0.0
Rubber:	105.4	0.0	0.0
Plastics:	70.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	3.5	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	31.6		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.7	2.1	2.5	2.1	10.4
Totals	2.1	1.7	2.1	2.5	2.1	10.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.7	2.1	2.5	2.1	10.4
Totals	2.1	1.7	2.1	2.5	2.1	10.4

As-Generated Form: Stored: 2.1 Projected: 8.3 Total: 10.4

Final Waste Form: Stored: 2.1 Projected: 8.3 Total: 10.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, HAZARDOUS CONSTITUENTS, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD, CEMENT, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, CHEMICALS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with organic metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W306	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Pb/Cd Met debris CH RCRA MTRU w/ org met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D019, D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	37.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	64.3	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	40.8	0.0	0.0
Rubber:	90.1	0.0	0.0
Plastics:	66.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	39.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.8	1.0	0.4	0.0	3.1
Totals	0.8	0.8	1.0	0.4	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.8	1.0	0.4	0.0	10.6
Totals	8.3	0.8	1.0	0.4	0.0	10.6

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 8.3 Projected: 2.3 Total: 10.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, HAZARDOUS CONSTITUENTS, DIRT/SOIL/DIATOMACEOUS EARTH, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, LEAD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with organic metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W307	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ org met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D019, D011, D008, D007, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	236.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	55.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	15.0	0.0	0.0
Plastics:	62.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	2.0	0.0	0.0	0.0	0.0	2.0
Totals	2.0	0.0	0.0	0.0	0.0	2.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 2.0 Projected: 0.0 Total: 2.0

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, HAZARDOUS CONSTITUENTS, ASBESTOS, PLASTIC/POLYURETHANE, RUBBER, ANTI-CORROSIVE RADPAD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with organic metal corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W308	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ org
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

D019

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	137.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	14.9	0.0	0.0
Rubber:	96.1	0.0	0.0
Plastics:	67.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	21.6		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.2	0.0	0.0	0.0	0.6
Totals	0.4	0.2	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.2	0.0	0.0	0.0	0.6
Totals	0.4	0.2	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.4 Projected: 0.2 Total: 0.6

Final Waste Form: Stored: 0.4 Projected: 0.2 Total: 0.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, RUBBER, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with organic contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W309	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ org	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D019

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	144.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	25.1	0.0	0.0
Rubber:	4.8	0.0	0.0
Plastics:	177.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	27.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, RUBBER, PAPER/CARDBOARD, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with organic contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W310	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Soil debris CH RCRA MTRU w/ org ign	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

F003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	34.3	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	81.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	82.3		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.3	0.3	0.0	0.0	0.0	0.6
Totals	0.3	0.3	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	0.2	0.0	0.0	0.0	3.1
Totals	2.9	0.2	0.0	0.0	0.0	3.1

As-Generated Form: Stored: 0.3 Projected: 0.0 Total: 0.3

Final Waste Form: Stored: 2.9 Projected: 0.2 Total: 3.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, PLASTIC/POLYURETHANE, CONWEB PADS, ORGANICS, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is soils contact handled RCRA regulated mixed TRU waste with organic ignitable contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W311	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Pb/Cd Met debris CH RCRA MTRU w/ met
Inventory Date:	12/1/94						
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste
Waste Matrix Code:	S5300						

AS-GENERATED EPA CODES

D008, D007, D006, D005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	13.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	150.5	0.0	0.0
Other Inorganic Material:	5.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.9	0.0	0.0
Rubber:	76.9	0.0	0.0
Plastics:	32.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	27.3		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.4	3.6	4.2	3.4	2.1	17.6
Totals	4.4	3.6	4.2	3.4	2.1	17.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.4	3.5	4.2	3.3	2.1	17.5
Totals	4.4	3.5	4.2	3.3	2.1	17.5

As-Generated Form: Stored: 4.4 Projected: 13.2 Total: 17.6

Final Waste Form: Stored: 4.4 Projected: 13.1 Total: 17.5

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, RUBBER, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, HAZARDOUS CONSTITUENTS, LEAD SHIELDING, PAPER/CARDBOARD, GLASS, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W312	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Pb/Cd Met debris CH RCRA MTRU w/ met cor		Inventory Date: 12/1/94
Local ID:	Type: MTRU	Generator Site: RL	Final Waste Form: Lead/Cadmium Metal Waste		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D008, D007, D006, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	17.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	218.8	0.0	0.0
Other Inorganic Material:	0.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.7	0.0	0.0
Rubber:	125.5	0.0	0.0
Plastics:	44.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	25.5		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	1.9	2.1	2.5	2.1	10.9
Totals	2.3	1.9	2.1	2.5	2.1	10.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	1.9	2.1	2.5	2.1	10.8
Totals	2.3	1.9	2.1	2.5	2.1	10.8

As-Generated Form: Stored: 2.3 Projected: 8.6 Total: 10.9

Final Waste Form: Stored: 2.3 Projected: 8.5 Total: 10.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, LEAD, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD SHIELDING, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, LEATHER, GLASS, BATTERIES, STAINLESS STEEL, HAZARDOUS
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W313	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D007, D006, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	59.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	6.9	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	11.1	0.0	0.0
Rubber:	4.7	0.0	0.0
Plastics:	12.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	4.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Box	7.5	7.5	7.5	0.0	0.0	22.5
Totals	9.2	9.2	9.6	2.5	2.1	32.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Standard Waste Box	7.6	3.8	3.8	0.0	0.0	15.1
Totals	9.2	5.4	5.9	2.5	2.1	25.1

As-Generated Form: Stored: 9.2 Projected: 23.4 Total: 32.6

Final Waste Form: Stored: 9.2 Projected: 15.9 Total: 25.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, LEAD, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, HAZARDOUS CONSTITUENTS, RUBBER, CLOTH/RAGS/NYLON, GLASS, LEATHER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W314	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D010, D008, D007, D006, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	24.9	0.0	0.0
Other Inorganic Material:	3.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	23.5	0.0	0.0
Rubber:	61.4	0.0	0.0
Plastics:	53.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	1.6	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	18.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.6	3.8	4.2	5.0	4.2	21.7
Totals	4.6	3.8	4.2	5.0	4.2	21.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.6	3.7	4.2	5.0	4.2	21.6
Totals	4.6	3.7	4.2	5.0	4.2	21.6

As-Generated Form: Stored: 4.6 Projected: 17.1 Total: 21.7

Final Waste Form: Stored: 4.6 Projected: 17.1 Total: 21.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, RUBBER, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, LEAD, CLOTH/RAGS/NYLON, HAZARDOUS CONSTITUENTS, GLASS, GROUT, ANTI-CORROSIVE RADPAD, STAINLESS STEEL, CONWEB PADS,
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W315	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Inorg non-met debris CH RCRA MTRU w/ met ign	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008, D007, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	2.4	0.0	0.0
Other Inorganic Material:	64.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.9	0.0	0.0
Rubber:	1.2	0.0	0.0
Plastics:	166.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	50.2		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.4	0.0	0.0	0.0	0.8
Totals	0.4	0.4	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.4	0.0	0.0	0.0	4.6
Totals	4.2	0.4	0.0	0.0	0.0	4.6

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.4 Total: 4.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, ASBESTOS, DIRT/SOIL/DIATOMACEOUS EARTH, CONWEB PADS, HAZARDOUS CONSTITUENTS, LEAD, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled RCRA regulated mixed TRU waste with metal ignitable contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W316	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Soils CH RCRA MTRU w/ met cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D008, D007, D006, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.3	0.0	0.0
Rubber:	56.4	0.0	0.0
Plastics:	31.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	91.9		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, PLASTIC/POLYURETHANE, HAZARDOUS CONSTITUENTS, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, GLASS.
WASTE STREAM SOURCE	This stream is soils contact handled RCRA regulated mixed TRU waste with metal corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W317	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Pb/Cd met unk form CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

D009, D008, D007, D006, D005

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	3.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	23.5	0.0	0.0
Other Inorganic Material:	1.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.2	0.0	0.0
Rubber:	105.1	0.0	0.0
Plastics:	26.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	42.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.0	0.8	1.0	0.4	0.0	3.3
Totals	1.0	0.8	1.0	0.4	0.0	3.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.4	0.8	1.0	0.4	0.0	12.7
Totals	10.4	0.8	1.0	0.4	0.0	12.7

As-Generated Form: Stored: 1.0 Projected: 0.0 Total: 1.0

Final Waste Form: Stored: 10.4 Projected: 2.3 Total: 12.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, HAZARDOUS CONSTITUENTS, PLASTIC/POLYURETHANE, LEAD, DIRT/SOIL/DIATOMACEOUS EARTH, PAPER/CARDBOARD, GLASS, WOOD/LUMBER/PLYWOOD, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W318	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Pb/Cd met debris CH RCRA MTRU w/ met(Hg) cor
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D009, D008, D007, D006, D005, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	3.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	40.1	0.0	0.0
Other Inorganic Material:	1.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	15.0	0.0	0.0
Rubber:	105.4	0.0	0.0
Plastics:	27.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	47.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Totals	1.7	1.7	2.1	2.5	2.1	10.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Totals	1.7	1.7	2.1	2.5	2.1	10.0

As-Generated Form: Stored: 1.7 Projected: 8.4 Total: 10.0

Final Waste Form: Stored: 1.7 Projected: 8.3 Total: 10.0

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, HAZARDOUS CONSTITUENTS, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, CLOTH/RAGS/NYLON, LEAD, WOOD/LUMBER/PLYWOOD, METAL/IRON/GALVANIZED/SHEET, GLASS, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal (Hg) corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W319	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

D009, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	248.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.6	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	13.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	7.1	0.0	0.0	0.0	0.0	7.1
Totals	7.1	0.0	0.0	0.0	0.0	7.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	7.6	0.0	0.0	0.0	0.0	7.6
Totals	7.6	0.0	0.0	0.0	0.0	7.6

As-Generated Form: Stored: 7.1 Projected: 0.0 Total: 7.1

Final Waste Form: Stored: 7.6 Projected: 0.0 Total: 7.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W320	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ met(Hg) cor
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D009, D008, D007, D006, D005, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	9.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	193.8	0.0	0.0
Other Inorganic Material:	7.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	6.0	0.0	0.0
Rubber:	113.7	0.0	0.0
Plastics:	36.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	32.9		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Totals	1.7	1.7	2.1	2.5	2.1	10.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.7	2.1	2.5	2.1	10.0
Totals	1.7	1.7	2.1	2.5	2.1	10.0

As-Generated Form: Stored: 1.7 Projected: 8.4 Total: 10.0

Final Waste Form: Stored: 1.7 Projected: 8.3 Total: 10.0

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, LEAD, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, LEAD SHIELDING, GLASS, CLOTH/RAGS/NYLON, HAZARDOUS CONSTITUENTS, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, MERCURY.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal (Hg) corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W321	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D009, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	16.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.4	0.0	0.0
Rubber:	102.7	0.0	0.0
Plastics:	73.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	38.1		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, HAZARDOUS CONSTITUENTS, PLASTIC/POLYURETHANE, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, GLASS, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W322	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ mel(Hg) cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D009, D008, D007, D006, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	2.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	8.1	0.0	0.0
Rubber:	17.4	0.0	0.0
Plastics:	46.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	6.8		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.8	1.0	0.4	0.0	3.1
Totals	0.8	0.8	1.0	0.4	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.8	1.0	0.4	0.0	10.6
Totals	8.3	0.8	1.0	0.4	0.0	10.6

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 8.3 Projected: 2.3 Total: 10.6

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, CONWEB PADS, HAZARDOUS CONSTITUENTS, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH, PAPER/CARDBOARD, ABSORBENT/KITY LTR/VERMICULITE, ACID, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, MERCURY.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal (Hg) corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W323	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Soils debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D009, D008, D007, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	29.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	2.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	21.8	0.0	0.0
Rubber:	38.6	0.0	0.0
Plastics:	19.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	61.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.6	1.0	0.4	0.0	2.7
Totals	0.6	0.6	1.0	0.4	0.0	2.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.6	1.0	0.4	0.0	8.3
Totals	6.2	0.6	1.0	0.4	0.0	8.3

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 6.2 Projected: 2.1 Total: 8.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS RUBBER, HAZARDOUS CONSTITUENTS, DIRT/SOIL/DIATOMACEOUS EARTH, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, GLASS, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is soils contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W324	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH RCRA MTRU w/ cor
Inventory Date:	12/1/94						
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal
Waste Matrix Code:	S5400						

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	214.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.1	0.0	0.0
Rubber:	0.9	0.0	0.0
Plastics:	27.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	3.2	0.0	0.0	0.0	0.0	3.2
Totals	3.2	0.0	0.0	0.0	0.0	3.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	3.8	0.0	0.0	0.0	0.0	3.8
Totals	3.8	0.0	0.0	0.0	0.0	3.8

As-Generated Form: Stored: 3.2 Projected: 0.0 Total: 3.2

Final Waste Form: Stored: 3.8 Projected: 0.0 Total: 3.8

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W325	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH RCRA MTRU w/ cor
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	10.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	65.9	0.0	0.0
Rubber:	14.3	0.0	0.0
Plastics:	16.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	23.9		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.4	0.4	0.4	0.0	1.7
Totals	0.4	0.4	0.4	0.4	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.4	0.4	0.4	0.0	1.7
Totals	0.4	0.4	0.4	0.4	0.0	1.7

As-Generated Form: Stored: 0.4 Projected: 1.3 Total: 1.7

Final Waste Form: Stored: 0.4 Projected: 1.2 Total: 1.7

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, PAPER/CARDBOARD, PLASTIC/POLYURETHANE, CHEMICALS, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH, METAL/IRON/GALVANIZED/SHEET, HAZARDOUS CONSTITUENTS.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with corrosive contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W326	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Solidif org labpacks CH RCRA MTRU w/ org ign
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics

Inventory Date: 12/1/94

Waste Matrix Code: X6100

AS-GENERATED EPA CODES

D019, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	98.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	47.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	1.7	2.1	2.5	2.1	10.2
Totals	1.9	1.7	2.1	2.5	2.1	10.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.9	1.7	2.1	2.5	2.1	10.2
Totals	1.9	1.7	2.1	2.5	2.1	10.2

As-Generated Form: Stored: 1.9 Projected: 8.3 Total: 10.2

Final Waste Form: Stored: 1.9 Projected: 8.3 Total: 10.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS HAZARDOUS CONSTITUENTS, GLASS, ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, CONWEB PADS, ANTI-CORROSIVE RADPAD.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA regulated mixed TRU waste with organic ignitable contaminants from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W330	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Uncat met debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	94.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	63.4	0.0	0.0
Rubber:	0.2	0.0	0.0
Plastics:	42.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	5.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	32.1	48.2	80.3	32.1	0.0	192.7
Totals	32.1	48.2	80.3	32.1	0.0	192.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	32.1	11.3	18.9	7.6	0.0	69.9
Totals	32.1	11.3	18.9	7.6	0.0	69.9

As-Generated Form: Stored: 32.1 Projected: 160.6 Total: 192.7

Final Waste Form: Stored: 32.1 Projected: 37.8 Total: 69.9

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, CLOTH/RAGS/NYLON, DIRT/SOIL/DIATOMACEOUS EARTH, HAZARDOUS CONSTITUENTS, RUBBER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled State regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W331	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	21.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	45.5	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	21.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.1	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	7.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	2.7	3.1	2.9	2.1	14.4
Box	47.5	47.5	79.2	74.0	52.8	301.1
Totals	51.1	50.2	82.4	76.9	54.9	315.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	2.7	3.1	2.9	2.1	14.4
Standard Waste Box	47.3	17.0	28.3	26.5	18.9	138.0
Totals	50.8	19.7	31.5	29.4	21.0	152.3

As-Generated Form: Stored: 51.1 Projected: 264.4 Total: 315.5

Final Waste Form: Stored: 50.8 Projected: 101.5 Total: 152.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS WOOD/LUMBER/PLYWOOD, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, FILTERS, HAZARDOUS CONSTITUENTS, PLEXIGLASS, ABSORBENT/KITY LTR/VERMICULITE, CEMENT, ANTI-CORROSIVE R
WASTE STREAM SOURCE	This stream is combustible contact handled State regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W335	Handling:	CH	NMVP #:	N/A	Stream Name:	2718E Comb debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	47.6	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	3.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	1.00E-02
Pu-239	7.00E-02
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Box	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.5	0.0	0.0	0.0	0.0	2.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	4.0	0.0	0.0	0.0	0.0	4.0

As-Generated Form: Stored: 2.5 Projected: 0.0 Total: 2.5

Final Waste Form: Stored: 4.0 Projected: 0.0 Total: 4.0

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS FILTERS, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is combustible contact handled State regulated mixed TRU waste from the PNL Critical Mass Storage Facility
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W336	Handling:	CH	NMVP #:	N/A	Stream Name:	318 Inorg non-met part CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	19.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	46.5	0.0	0.0
Other Inorganic Material:	164.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, LEAD, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled State regulated mixed TRU waste from the PNL Radiological Calibrations Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W337	Handling: RH	NMVP #: N/A	Stream Name: 324 Pb/Cd met RH St MTRU		Inventory Date: 12/1/94
Local ID:	Type: MTRU	Generator Site: RL	Final Waste Form: Lead/Cadmium Metal Waste		Waste Matrix Code: X7210

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	7.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	585.3	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	8.80E-01
Pu-240	1.00E-02
Pu-239	3.00E-02
Beta/Gamma	4.38E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.8	12.2	20.3	14.6	8.1	55.9
Totals	0.8	12.2	20.3	14.6	8.1	55.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.9	13.3	22.2	16.0	8.9	61.4
Totals	0.9	13.3	22.2	16.0	8.9	61.4

As-Generated Form: Stored: 0.8 Projected: 55.1 Total: 55.9

Final Waste Form: Stored: 0.9 Projected: 60.5 Total: 61.4

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, ZIRCOLOY, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is lead cadmium metal remote handled State regulated mixed TRU waste from the PNL Chemical Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W338	Handling: CH	NMVP #: N/A	Stream Name: 325 Solidif org CH RCRA MTRU w/ org met ign/cor		Inventory Date: 12/1/94
Local ID:	Type: MTRU	Generator Site: RL	Final Waste Form: Solidified Organics		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

F003, D007, D002, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	121.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	78.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	18.7	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	3.80E-01
Pu-240	1.00E-02
Pu-239	2.00E-02
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CONWEB PADS, ABSORBENT/KITY LTR/VERMICULITE, GLASS, LIQUID.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA regulated mixed TRU waste with organic metal ign/cor contaminants from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W339	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Pb/Cd met lead CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

D009, D008, D006

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	585.4	0.0	0.0
Other Inorganic Material:	26.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	26.5	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	9.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	3.80E-01
Pu-240	1.00E-02
Pu-239	2.00E-02
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, WOOD/LUMBER/PLYWOOD, GLASS, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W340	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Comb debris CH RCRA MTRU w/ cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	21.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	80.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	2.4	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	9.00E-02
Pu-241	3.80E-01
Pu-240	1.00E-02
Pu-239	2.00E-02
Beta/Gamma	7.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CONWEB PADS, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, GLASS, LIQUID.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with cor contaminants from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W341	Handling:	CH	NMVP #:	N/A	Stream Name:	325A Uncat mt debris CH/r RCRA MTRU w/ org met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

F005, F004, F003, F002, F001, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	96.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	19.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	24.0	0.0	0.0
Rubber:	4.8	0.0	0.0
Plastics:	9.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	5.00E-02
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	3.97E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, GLASS, METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, RUBBER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote RCRA regulated mixed TRU waste with organic metal (Hg) contaminants from the PNL Cesium Recovery Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W342	Handling:	CH	NMVP #:	N/A	Stream Name:	325A Inorg n-mt debr CH/r RCRA MTRU w/org met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

F005, F004, F003, F002, F001, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	3.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.6	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	117.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.8	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	40.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	5.00E-02
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.48E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.3	0.0	0.0	0.0	0.0	8.3
Totals	8.3	0.0	0.0	0.0	0.0	8.3

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 8.3 Projected: 0.0 Total: 8.3

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, GLASS, PLASTIC/POLYURETHANE, CERAMICS, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE, ALUMINUM.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled packaged remote RCRA regulated mixed TRU waste with organic metal (Hg) contaminants from the PNL Cesium Recovery Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W343	Handling:	CH	NMVP #:	N/A	Stream Name:	325A Comb debris CH/r RCRA MTRU w/ org met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

F005, F004, F003, F002, F001, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	32.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	64.8	0.0	0.0
Rubber:	3.2	0.0	0.0
Plastics:	17.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	8.00E-02
Pu-241	5.00E-02
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	1.63E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	0.0	0.0	0.0	0.0	6.2
Totals	6.2	0.0	0.0	0.0	0.0	6.2

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 6.2 Projected: 0.0 Total: 6.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, GLASS, PLASTIC/POLYURETHANE, CERAMICS, METAL/IRON/GALVANIZED/SHEET, RUBBER.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote RCRA regulated mixed TRU waste with organic metal (Hg) contaminants from the PNL Cesium Recovery Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W344	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Solidif org debris CH/r RCRA MTRU w/ org	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

F005, F004, F003, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	9.6	0.0	0.0
Rubber:	7.2	0.0	0.0
Plastics:	7.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	4.8		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	6.00E-02
Pu-241	5.00E-02
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	1.84E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS CLOTH/RAGS/NYLON, PLASTIC/POLYURETHANE, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH.
WASTE STREAM SOURCE	This stream is solidified organics contact handled packaged remote RCRA regulated mixed TRU waste with organic contaminants from the Waste Loadout Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W345 | Handling: CH | NMVP #: N/A | Stream Name: 2345Z Solidif org debris CH St MTRU | Inventory Date: 12/1/94

Local ID: | Type: MTRU | Generator Site: RL | Final Waste Form: Solidified Organics | Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	29.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	48.4	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	126.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.00E-02
Pu-241	1.25E+01
Pu-240	4.20E-01
Pu-239	1.86E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.6	0.4	0.0	0.0	3.1
Totals	2.1	0.6	0.4	0.0	0.0	3.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.6	0.4	0.0	0.0	3.1
Totals	2.1	0.6	0.4	0.0	0.0	3.1

As-Generated Form: Stored: 2.1 Projected: 1.0 Total: 3.1

Final Waste Form: Stored: 2.1 Projected: 1.0 Total: 3.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, CONWEB PADS, ORGANICS, WOOD/LUMBER/PLYWOOD, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is solidified organics contact handled State regulated mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W346	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Uncat mt debris CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	146.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	55.2	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	19.2	0.0	0.0
Rubber:	18.6	0.0	0.0
Plastics:	62.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 4.2 Projected: 0.0 Total: 4.2

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, EQUIPMENT, RUBBER, PAPER/CARDBOARD, STAINLESS STEEL, 10 MIL LINER, LEATHER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled RCRA regulated mixed TRU waste with metal contaminants from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W347	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Combus debris CH RCRA MTRU w/ met(Hg)	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D009

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	57.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.8	0.0	0.0
Rubber:	81.7	0.0	0.0
Plastics:	40.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, RUBBER, STAINLESS STEEL, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, 10 MIL LINER.
WASTE STREAM SOURCE	This stream is combustible contact handled RCRA regulated mixed TRU waste with metal (Hg) contaminants from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W348	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Solid org debris CH RCRA MTRU w/ met(Hg) cor	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

D009, D002

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	1.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	4.3	0.0	0.0
Plastics:	10.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	88.[illegible]	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS ANIMAL WASTE, 10 MIL LINER, RUBBER, BATTERIES, GLASS.
WASTE STREAM SOURCE	This stream is solidified organics contact handled RCRA regulated mixed TRU waste with metal (Hg) cor contaminants from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W349	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Inorg non-met CH RCRA MTRU w/ met	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Lead/Cadmium Metal Waste	Waste Matrix Code:	X7210

AS-GENERATED EPA CODES

D008

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	1380.9	0.0	0.0
Other Inorganic Material:	38.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	87.9	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	91.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS LEAD, CLOTH/RAGS/NYLON, 10 MIL LINER, GLASS.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled RCRA regulated mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W350	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Uncat met debris CH St MTRU	Inventory Date:	12/1/94
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	62.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	18.6	0.0	0.0
Other Inorganic Material:	44.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	19.4	0.0	0.0
Rubber:	26.9	0.0	0.0
Plastics:	43.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	7.60E-01
Pu-241	2.33E+00
Pu-240	1.60E-01
Pu-239	6.10E-01
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THE STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, RUBBER, CERAMICS, PAPER/CARDBOARD, GLASS, CLOTH/RAGS/NYLON, LEAD, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled State regulated mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W351	Handling:	CH	NMVP #:	N/A	Stream Name:	CUPRC Soil CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	4.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	3.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	23.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	256.4		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ROCK/GRAVEL, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is soils contact handled non-mixed TRU waste from the Ceer University Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W352	Handling:	CH	NMVP #:	N/A	Stream Name:	CUPRC Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5120

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	23.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	463.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	0.00E+00
Pu-240	0.00E+00
Pu-239	0.00E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CONCRETE, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Ceer University Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W353	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Inorg non-met part CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	8.9	0.0	0.0
Aluminum-base Metal/Alloys:	2.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	164.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.7	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	2.91E+01
Pu-240	1.08E+00
Pu-239	4.82E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.0	0.0	0.0	0.0	0.8
Totals	0.8	0.0	0.0	0.0	0.0	0.8

As-Generated Form: Stored: 0.8 Projected: 0.0 Total: 0.8

Final Waste Form: Stored: 0.8 Projected: 0.0 Total: 0.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, GLASS, ALUMINUM.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W354	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Soil CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	17.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	138.2	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.[illegible]	0.0	0.0
Packaging Material Steel:	185.2		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	2.91E+01
Pu-240	1.08E+00
Pu-239	4.82E+00
Beta/Gamma	1.71E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, CEMENT, ABSORBENT/KITY LTR/VERMICULITE.
WASTE STREAM SOURCE	This stream is soils contact handled packaged remote non-mixed TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W355	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Uncat met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	268.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.2	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	17.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	2.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	2.91E+01
Pu-240	1.08E+00
Pu-239	4.82E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.0	0.0	0.0	0.0	2.1
Totals	2.1	0.0	0.0	0.0	0.0	2.1

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 0.0 Total: 2.1

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET, GRAPHITE, FILTERS, PLASTIC/POLYURETHANE, COPPER METAL, GLASS, ALUMINUM.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W356	Handling:	CH	NMVP #:	N/A	Stream Name:	ESG Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	10.0	0.0	0.0
Aluminum-base Metal/Alloys:	4.9	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	67.3	0.0	0.0
Rubber:	68.8	0.0	0.0
Plastics:	14.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	7.5	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	2.91E+01
Pu-240	1.08E+00
Pu-239	4.82E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.3	0.0	0.0	0.0	0.0	1.3
Totals	1.3	0.0	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.0	0.0	0.0	0.0	1.2
Totals	1.2	0.0	0.0	0.0	0.0	1.2

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 1.2 Projected: 0.0 Total: 1.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS RUBBER, COTTON/KOTEX, WOOD/LUMBER/PLYWOOD, PLASTIC/POLYURETHANE, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, PAINTS/LUCITE, ALUMINUM, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Energy Systems Group.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W358	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	59.5	0.0	0.0
Aluminum-base Metal/Alloys:	3.9	0.0	0.0
Other Metals/Alloys:	1.0	0.0	0.0
Other Inorganic Material:	174.5	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	14.2	0.0	0.0
Rubber:	2.5	0.0	0.0
Plastics:	16.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	1.74E+00
Pu-240	6.00E-02
Pu-239	2.90E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.5	0.0	0.0	0.0	0.0	2.5
Totals	2.5	0.0	0.0	0.0	0.0	2.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.5	0.0	0.0	0.0	0.0	2.5
Totals	2.5	0.0	0.0	0.0	0.0	2.5

As-Generated Form: Stored: 2.5 Projected: 0.0 Total: 2.5

Final Waste Form: Stored: 2.5 Projected: 0.0 Total: 2.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CONCRETE, ABSORBENT/KITY LTR/VERMICULITE, STAINLESS STEEL, FILTERS, PLASTIC/POLYURETHANE, SAND, METAL/IRON/GALVANIZED/SHEET, WOOD/LUMBER/PLYWOOD, ALUMINUM, RUBBER, PAPER/CARDBOARD, COPPER METAL.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W359	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Uncat met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	156.1	0.0	0.0
Aluminum-base Metal/Alloys:	4.0	0.0	0.0
Other Metals/Alloys:	0.6	0.0	0.0
Other Inorganic Material:	9.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	13.7	0.0	0.0
Rubber:	3.1	0.0	0.0
Plastics:	32.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	3.5	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	0.00E+00
Pu-241	1.74E+00
Pu-240	6.00E-02
Pu-239	2.90E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.6	0.0	0.0	0.0	0.0	16.6
Totals	16.6	0.0	0.0	0.0	0.0	16.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.6	0.0	0.0	0.0	0.0	16.6
Totals	16.6	0.0	0.0	0.0	0.0	16.6

As-Generated Form: Stored: 16.6 Projected: 0.0 Total: 16.6

Final Waste Form: Stored: 16.6 Projected: 0.0 Total: 16.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS STAINLESS STEEL, PLASTIC/POLYURATHENE, METAL/IRON/GALVANIZED/SHEET, FILTERS, PAPER/CARDBOARD, ALUMINUM, RUBBER, WOOD/LUMBER/PLYWOOD, CONCRETE, ABSORBENT/KITY LTR/VERMICULITE, RESINS, SAND, COPPER METAL, FIBERGLASS, FLOO
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W360	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	37.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.8	0.0	0.0
Other Metals/Alloys:	0.2	0.0	0.0
Other Inorganic Material:	20.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.5	0.0	0.0
Rubber:	1.1	0.0	0.0
Plastics:	97.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	7.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	6.4	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	1.74E+00
Pu-240	6.00E-02
Pu-239	2.90E-01
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.8	0.0	0.0	0.0	0.0	4.8
Totals	4.8	0.0	0.0	0.0	0.0	4.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.8	0.0	0.0	0.0	0.0	4.8
Totals	4.8	0.0	0.0	0.0	0.0	4.8

As-Generated Form: Stored: 4.8 Projected: 0.0 Total: 4.8

Final Waste Form: Stored: 4.8 Projected: 0.0 Total: 4.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, WOOD/LUMBER/PLYWOOD, FILTERS, METAL/IRON/GALVANIZED/SHEET, CONCRETE, SLUDGES, PAPER/CARDBOARD, ABSORBENT/KITY LTR/VERMICULITE, RESINS, RUBBER, ALUMINUM, FIBERGLASS, GLASS, COPPER M
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W361	Handling:	CH	NMVP #:	N/A	Stream Name:	MCGEE Solidif org CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	18.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	20.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	42.3	0.0	0.0
Rubber:	1.8	0.0	0.0
Plastics:	15.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	137.2	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	1.74E+00
Pu-240	6.00E-02
Pu-239	2.90E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS FILTERS, RESINS, WOOD/LUMBER/PLYWOOD, ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, RUBBER.
WASTE STREAM SOURCE	This stream is solidified organics contact handled non-mixed TRU waste from the Kerr-McGee.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W362	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Uncat met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	142.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	49.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	9.0	0.0	0.0
Rubber:	2.4	0.0	0.0
Plastics:	51.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	3.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	2.1	0.0	0.0	0.0	5.0
Totals	2.9	2.1	0.0	0.0	0.0	5.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	2.1	0.0	0.0	0.0	5.0
Totals	2.9	2.1	0.0	0.0	0.0	5.0

As-Generated Form: Stored: 2.9 Projected: 2.1 Total: 5.0

Final Waste Form: Stored: 2.9 Projected: 2.1 Total: 5.0

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, RUBBER, GLASS, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W363	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Pb/Cd met unk form CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	98.7	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.8	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.2	0.0	0.0	0.0	0.4
Totals	0.2	0.2	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.2	0.0	0.0	0.0	0.4
Totals	0.2	0.2	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.2 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS EQUIPMENT, FILTERS.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W364	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	21.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	61.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	22.6	0.0	0.0
Rubber:	2.0	0.0	0.0
Plastics:	26.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.5	0.0	0.0	0.0	3.6
Totals	2.1	1.5	0.0	0.0	0.0	3.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	1.5	0.0	0.0	0.0	3.5
Totals	2.1	1.5	0.0	0.0	0.0	3.5

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 1.5 Total: 3.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, METAL/IRON/GALVANIZED/SHEET, ABSORBENT/KITY LTR/VERMICULITE, RUBBER, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, COTTON/KOTEX, CORK.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W365	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	12.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.1	0.0	0.0
Other Inorganic Material:	17.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	42.9	0.0	0.0
Rubber:	8.5	0.0	0.0
Plastics:	60.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.00E-02
Pu-241	4.05E+01
Pu-240	1.32E+00
Pu-239	5.70E+00
Beta/Gamma	9.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.8	8.0	0.0	0.0	0.0	19.7
Totals	11.8	8.0	0.0	0.0	0.0	19.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	11.9	7.9	0.0	0.0	0.0	19.8
Totals	11.9	7.9	0.0	0.0	0.0	19.8

As-Generated Form: Stored: 11.8 Projected: 0.0 Total: 11.8

Final Waste Form: Stored: 11.9 Projected: 7.9 Total: 19.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, RUBBER, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET, WOOD/LUMBER/PLYWOOD, ABSORBENT/KITY LTR/VERMICULITE, STAINLESS STEEL, LEATHER, COTTON/KOTEX, CORK, LEAD.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Fuel Reprocessing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W367	Handling:	CH	NMVP #:	N/A	Stream Name:	202AL Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	52.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	21.6	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	24.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	4.58E+00
Pu-240	1.70E-01
Pu-239	7.60E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	2.1	0.0	0.0	0.0	5.0
Totals	2.9	2.1	0.0	0.0	0.0	5.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.9	2.1	0.0	0.0	0.0	5.0
Totals	2.9	2.1	0.0	0.0	0.0	5.0

As-Generated Form: Stored: 2.9 Projected: 0.0 Total: 2.9

Final Waste Form: Stored: 2.9 Projected: 2.1 Total: 5.0

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, METAL/IRON/GALVANIZED/SHEET, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Fuel Reprocessing Facility Support Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W368	Handling:	CH	NMVP #:	N/A	Stream Name:	202AL Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	7.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	23.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	23.0	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	30.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	4.58E+00
Pu-240	1.70E-01
Pu-239	7.60E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.6	0.0	0.0	0.0	1.3
Totals	0.6	0.6	0.0	0.0	0.0	1.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.6	0.0	0.0	0.0	1.2
Totals	0.6	0.6	0.0	0.0	0.0	1.2

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.6 Total: 1.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, METAL/IRON/GALVANIZED/SHEET, RUBBER.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Fuel Reprocessing Facility Support Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W369	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Uncat met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	81.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.3	0.0	0.0
Other Inorganic Material:	0.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.4	0.0	0.0
Rubber:	1.1	0.0	0.0
Plastics:	14.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	1.20E-01
Pu-241	2.49E+01
Pu-240	9.10E-01
Pu-239	3.96E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.8	34.0	50.2	46.6	35.8	177.4
Box	22.4	0.0	0.0	0.0	0.0	22.4
Totals	33.1	34.0	50.2	46.6	35.8	199.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.8	4.0	5.8	5.4	4.2	30.2
Standard Waste Box	22.7	0.0	0.0	0.0	0.0	22.7
Totals	33.5	4.0	5.8	5.4	4.2	52.8

As-Generated Form: Stored: 33.1 Projected: 166.6 Total: 199.8

Final Waste Form: Stored: 33.5 Projected: 19.3 Total: 52.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, PLEXIGLASS, FOAM/STYROFOAM/PYROFOAM, RUBBER, GLASS, STAINLESS STEEL, FIBERGLASS, WOOD/LUMBER/PLYWOOD, BRASS METAL.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W370	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Uncat met debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	146.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	31.6	0.0	0.0
Rubber:	20.6	0.0	0.0
Plastics:	19.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.20E-01
Pu-241	2.49E+01
Pu-240	9.10E-01
Pu-239	3.96E+00
Beta/Gamma	5.10E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, PLASTIC/POLYURETHANE, RUBBER, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W371	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Comb debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	3.5	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	14.1	0.0	0.0
Rubber:	11.0	0.0	0.0
Plastics:	39.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.20E-01
Pu-241	2.49E+01
Pu-240	9.10E-01
Pu-239	3.96E+00
Beta/Gamma	5.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	0.8	1.0	0.4	0.0	4.6
Box	3.2	0.0	0.0	0.0	0.0	3.2
Totals	5.5	0.8	1.0	0.4	0.0	7.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.3	0.8	1.0	0.4	0.0	4.6
Standard Waste Box	3.8	0.0	0.0	0.0	0.0	3.8
Totals	6.1	0.8	1.0	0.4	0.0	8.4

As-Generated Form: Stored: 5.5 Projected: 2.3 Total: 7.8

Final Waste Form: Stored: 6.1 Projected: 2.3 Total: 8.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, CLOTH/RAGS/NYLON, RUBBER, FOAM/STYROFOAM/PYROFOAM, FIBERGLASS, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W372	Handling:	CH	NMVP #:	N/A	Stream Name:	209E Comb debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	38.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	103.0	0.0	0.0
Rubber:	3.6	0.0	0.0
Plastics:	5.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.20E-01
Pu-241	2.49E+01
Pu-240	9.10E-01
Pu-239	3.96E+00
Beta/Gamma	2.90E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PAPER/CARDBOARD, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, PLASTIC/POLYURETHANE, RUBBER.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the Facility/Equipment O&M Waste.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W373	Handling:	CH	NMVP #:	N/A	Stream Name:	231Z Uncat met unk form CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	68.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	4.3	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	13.4	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.00E-02
Pu-241	4.80E-01
Pu-240	2.00E-02
Pu-239	7.00E-02
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.6	0.6	0.0	0.0	2.1
Box	78.4	0.0	0.0	0.0	0.0	78.4
Totals	79.2	0.6	0.6	0.0	0.0	80.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.6	0.6	0.0	0.0	2.1
Standard Waste Box	79.4	0.0	0.0	0.0	0.0	79.4
Totals	80.2	0.6	0.6	0.0	0.0	81.5

As-Generated Form: Stored: 79.2 Projected: 0.0 Total: 79.2

Final Waste Form: Stored: 80.2 Projected: 1.2 Total: 81.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS AIR, METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, RUBBER, GLASS, ABSORBENT/KITY LTR/VERMICULITE, LIQUID, CLOTH/RAGS/NYLON, DIRT/SOIL/DIATOMACEOUS EARTH.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the PNL Materials Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W374	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Uncat met debris CH TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	45.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	9.3	0.0	0.0
Rubber:	4.8	0.0	0.0
Plastics:	17.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.1	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	5.2		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	74.7	48.0	67.8	75.5	60.5	326.6
Box	107.6	33.6	0.0	215.2	269.0	625.3
Totals	182.3	81.6	67.8	290.7	329.5	952.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	74.7	47.8	67.6	75.3	60.3	325.7
Standard Waste Box	107.7	9.4	0.0	60.5	75.6	253.3
Totals	182.4	57.3	67.6	135.8	135.9	579.0

As-Generated Form: Stored: 182.3 Projected: 769.7 Total: 952.0

Final Waste Form: Stored: 182.4 Projected: 396.6 Total: 579.0

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, GLASS, STAINLESS STEEL, PPE CLOTHING (PAPER/PLASTIC), CERAMICS, CONWEB PAD
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W375	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Uncat met debris CH/r TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	44.3	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	19.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	1.38E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.6	1.0	0.4	0.0	2.9
Box	21.1	10.6	0.0	84.4	105.5	221.6
Totals	21.9	11.2	1.0	84.8	105.5	224.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.8	0.6	1.0	0.4	0.0	2.9
Standard Waste Box	20.8	1.9	0.0	15.1	18.9	56.7
Totals	21.6	2.5	1.0	15.5	18.9	59.6

As-Generated Form: Stored: 21.9 Projected: 202.5 Total: 224.5

Final Waste Form: Stored: 21.6 Projected: 38.0 Total: 59.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, CLOTH/RAGS/NYLON, WOOD/LUMBER/PLYWOOD, RUBBER, DIRT/SOIL/DIATOMACEOUS EARTH.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W376	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Inorg non-met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	10.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	134.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	16.5	0.0	0.0
Rubber:	11.7	0.0	0.0
Plastics:	31.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	19.3		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	1.00E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.1	10.5	14.6	15.9	12.6	69.7
Totals	16.1	10.5	14.6	15.9	12.6	69.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.2	10.4	14.6	15.8	12.5	69.5
Totals	16.2	10.4	14.6	15.8	12.5	69.5

As-Generated Form: Stored: 16.1 Projected: 53.6 Total: 69.7

Final Waste Form: Stored: 16.2 Projected: 53.2 Total: 69.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS GLASS, CONCRETE, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, ASBESTOS, CERAMICS, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W377	Handling: CH	NMVP #: N/A	Stream Name: 2345Z Comb debris CH TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Combustible		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	16.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	3.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	44.2	0.0	0.0
Rubber:	20.0	0.0	0.0
Plastics:	51.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.3	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	12.7		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	6.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	292.4	187.7	264.8	296.8	238.3	1279.9
Box	10.5	3.5	0.0	28.1	35.1	77.3
Totals	302.9	191.2	264.8	324.9	273.4	1357.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	292.4	186.8	263.5	295.4	237.1	1275.2
Standard Waste Box	11.3	1.9	0.0	15.1	18.9	47.2
Totals	303.8	188.7	263.5	310.5	256.0	1322.5

As-Generated Form: Stored: 302.9 Projected: 1054.3 Total: 1357.2

Final Waste Form: Stored: 303.8 Projected: 1018.7 Total: 1322.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, CLOTH/RAGS/NYLON, RUBBER, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, GLASS, PPE CLOTHING (PAPER/PLASTIC), WOOD/LUMBER/PLYWOOD, STAINLESS STEEL, CONWEB PADS, SLUDGES
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W378	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Comb debris CH/r TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	24.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.8	0.0	0.0
Rubber:	0.5	0.0	0.0
Plastics:	36.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.2		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	1.03E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.3	2.1	2.5	2.1	9.6
Box	14.1	14.1	0.0	112.8	141.0	282.0
Totals	15.8	15.4	2.1	115.3	143.1	291.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.7	1.2	2.1	2.5	2.1	9.6
Standard Waste Box	15.1	1.9	0.0	15.1	18.9	51.0
Totals	16.8	3.1	2.1	17.6	21.0	60.6

As-Generated Form: Stored: 15.8 Projected: 275.8 Total: 291.6

Final Waste Form: Stored: 16.8 Projected: 43.8 Total: 60.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, RUBBER, PAPER/CARDBOARD, DIRT/SOIL/DIATOMACEOUS EARTH, GLASS, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W379	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Heter debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	35.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.7	0.0	0.0
Rubber:	12.6	0.0	0.0
Plastics:	42.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	331.6	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	26.8		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CEMENT, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, DIRT/SOIL/DIATOMACEOUS EARTH, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is hetergeneous contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W380	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Solidif org debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Solidified Organics	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	9.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.8	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	96.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	134.6	0.0	0.0
Packaging Material Steel:	28.8		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, WAX, DIRT/SOIL/DIATOMACEOUS EARTH, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is solidified organics contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W381	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Soil debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils

Inventory Date: 12/1/94

Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	12.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	15.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.0	0.0	0.0
Rubber:	14.4	0.0	0.0
Plastics:	30.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	49.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	7.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.3	3.8	6.3	7.5	6.3	30.1
Totals	6.3	3.8	6.3	7.5	6.3	30.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	6.2	3.7	6.2	7.5	6.2	30.0
Totals	6.2	3.7	6.2	7.5	6.2	30.0

As-Generated Form: Stored: 6.3 Projected: 23.8 Total: 30.1

Final Waste Form: Stored: 6.2 Projected: 23.7 Total: 30.0

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, GLASS, RUBBER, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, PPE CLOTHING (PAPER/PLASTIC), CORK, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is soils contact handled non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W383	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Solidif Inorg labpacks CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	34.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	21.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	17.4	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	13.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.6	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	9.00E-02
Pu-241	2.11E+01
Pu-240	7.60E-01
Pu-239	3.37E+00
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box	9.6	0.0	0.0	0.0	0.0	9.6
Totals	9.6	0.0	0.0	0.0	0.0	9.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	9.4	0.0	0.0	0.0	0.0	9.4
Totals	9.4	0.0	0.0	0.0	0.0	9.4

As-Generated Form: Stored: 9.6 Projected: 0.0 Total: 9.6

Final Waste Form: Stored: 9.4 Projected: 0.0 Total: 9.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, WOOD/LUMBER/PLYWOOD, PLASTIC/POLYURETHANE, OILS.
WASTE STREAM SOURCE	This stream is solidified inorganics contact handled packaged remote non-mixed TRU waste from the Plutonium Recovery and Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W384	Handling:	CH	NMVP #:	N/A	Stream Name:	2718E Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	4.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	56.0	0.0	0.0
Rubber:	67.2	0.0	0.0
Plastics:	49.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	5.70E-01
Pu-241	5.38E+00
Pu-240	2.20E-01
Pu-239	9.20E-01
Beta/Gamma	2.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON, METAL/IRON/GALVANIZED/SHEET.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the PNL Critical Mass Storage Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W385	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Uncat met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	227.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	6.1	0.0	0.0
Other Inorganic Material:	2.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	22.3	0.0	0.0
Rubber:	3.2	0.0	0.0
Plastics:	42.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.2	0.6	0.0	0.0	0.0	8.8
Totals	8.2	0.6	0.0	0.0	0.0	8.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	8.1	0.6	0.0	0.0	0.0	8.7
Totals	8.1	0.6	0.0	0.0	0.0	8.7

As-Generated Form: Stored: 8.2 Projected: 0.0 Total: 8.2

Final Waste Form: Stored: 8.1 Projected: 0.6 Total: 8.7

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD, ORGANICS, RUBBER, CHEMICALS, CLOTH/RAGS/NYLON, STAINLESS STEEL, EQUIPMENT, MISCELLANEOUS/UNKNOWN/OTHER, COTTON/KOTEX, INSULATION
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W386	Handling: CH	NMVP #: N/A	Stream Name: 308 Uncat met debris CH/r TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	178.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.3	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	32.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	6.75E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W387	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	17.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	290.4	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	8.1	0.0	0.0
Rubber:	1.4	0.0	0.0
Plastics:	37.5	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.7	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	1.5	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.2	0.0	0.0	0.0	1.7
Totals	1.5	0.2	0.0	0.0	0.0	1.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.2	0.0	0.0	0.0	1.7
Totals	1.5	0.2	0.0	0.0	0.0	1.7

As-Generated Form: Stored: 1.5 Projected: 0.0 Total: 1.5

Final Waste Form: Stored: 1.5 Projected: 0.2 Total: 1.7

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CONCRETE, PLASTIC/POLYURETHANE, ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, OILS, RUBBER, WATER, 90 MIL LINER.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W388	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	6.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.1	0.0	0.0
Other Inorganic Material:	0.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	9.5	0.0	0.0
Rubber:	3.8	0.0	0.0
Plastics:	18.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.3	0.6	0.0	0.0	0.0	8.0
Box	9.6	0.0	0.0	0.0	0.0	9.6
Totals	16.9	0.6	0.0	0.0	0.0	17.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	7.3	0.6	0.0	0.0	0.0	7.9
Standard Waste Box	9.4	0.0	0.0	0.0	0.0	9.4
Totals	16.7	0.6	0.0	0.0	0.0	17.4

As-Generated Form: Stored: 16.9 Projected: 0.0 Total: 16.9

Final Waste Form: Stored: 16.7 Projected: 0.6 Total: 17.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS FILTERS, PLASTIC/POLYURETHANE, WOOD/LUMBER/PLYWOOD, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, RUBBER, CLOTH/RAGS/NYLON, GLASS, CERAMICS, EQUIPMENT, STAINLESS STEEL, ABSORBENT/KITY LTR/VERMICULITE, 10 MIL LINER, CHEM
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W389	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Comb debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	23.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	25.3	0.0	0.0
Rubber:	18.0	0.0	0.0
Plastics:	87.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	9.29E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, RUBBER.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W390	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Pb/Cd met unk form CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	26.9	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	442.2	0.0	0.0
Other Inorganic Material:	24.8	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	6.6	0.0	0.0
Rubber:	1.0	0.0	0.0
Plastics:	14.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	2.50E-01
Pu-241	2.20E+01
Pu-240	9.00E-01
Pu-239	3.56E+00
Beta/Gamma	4.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS EQUIPMENT, CHEMICALS, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, CERAMICS, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON, PLEXIGLASS, GLASS, 10 MIL LINER.
WASTE STREAM SOURCE	This stream is lead cadmium metal contact handled non-mixed TRU waste from the Fuels Development Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

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TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W392	Handling:	CH	NMVP #:	N/A	Stream Name:	324 Inorg non-met part CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	14.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	181.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	2.10E-01
Pu-240	1.00E-02
Pu-239	3.00E-02
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, GLASS.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the PNL Chemical Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W393	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Inorg non-met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	46.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	3.2	0.0	0.0
Other Inorganic Material:	116.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	11.7	0.0	0.0
Rubber:	5.8	0.0	0.0
Plastics:	27.8	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.9	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.1		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	4.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	2.1	2.7	2.5	2.1	14.8
Totals	5.4	2.1	2.7	2.5	2.1	14.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	2.1	2.7	2.5	2.1	14.8
Totals	5.4	2.1	2.7	2.5	2.1	14.8

As-Generated Form: Stored: 5.4 Projected: 9.4 Total: 14.8

Final Waste Form: Stored: 5.4 Projected: 9.4 Total: 14.8

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, GLASS, PAPER/CARDBOARD, CERAMICS, RUBBER, CLOTH/RAGS/NYLON, CONCRETE, EQUIPMENT, INSULATION NON-ASBESTOS, MISCELLANEOUS/UNKNOWN/OTHER.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W394	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Solidif inorg part CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Solidified Inorganics

Inventory Date: 12/1/94

Waste Matrix Code: S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	32.1	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	30.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	1.2	0.0	0.0
Rubber:	2.4	0.0	0.0
Plastics:	32.4	0.0	0.0
Solidified Inorganic Material:	641.3	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.0	1.2	1.6	2.0	2.0	9.9
Totals	3.0	1.2	1.6	2.0	2.0	9.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.1	1.2	1.7	2.1	2.1	10.2
Totals	3.1	1.2	1.7	2.1	2.1	10.2

As-Generated Form: Stored: 3.0 Projected: 6.8 Total: 9.9

Final Waste Form: Stored: 3.1 Projected: 7.1 Total: 10.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CEMENT, PLASTIC/POLYURETHANE, LIQUID, ABSORBENT/KITY LTR/VERMICULITE, METAL/IRON/GALVANIZED/SHEET, CHEMICALS, RUBBER, CLOTH/RAGS/NYLON, GLASS, PAPER/CARDBOARD, LEATHER, 10 MIL LINER.
WASTE STREAM SOURCE	This stream is solidified inorganics contact handled non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W395	Handling: CH	NMVP #: N/A	Stream Name: 325 Uncat met debris CH TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	129.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	2.6	0.0	0.0
Other Inorganic Material:	7.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.3	0.0	0.0
Rubber:	4.7	0.0	0.0
Plastics:	19.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	1.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	13.9	5.4	7.5	5.8	4.2	36.8
Box	9.8	0.0	0.0	0.0	0.0	9.8
Totals	23.7	5.4	7.5	5.8	4.2	46.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	13.9	5.4	7.5	5.8	4.2	36.8
Standard Waste Box	9.4	0.0	0.0	0.0	0.0	9.4
Totals	23.4	5.4	7.5	5.8	4.2	46.3

As-Generated Form: Stored: 23.7 Projected: 22.8 Total: 46.6

Final Waste Form: Stored: 23.4 Projected: 22.9 Total: 46.3

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, RUBBER, GLASS, CLOTH/RAGS/NYLON, PAPER/CARDBOARD, STAINLESS STEEL, EQUIPMENT, WOOD/LUMBER/PLYWOOD, ABSORBENT/KITY LTR/VERMICULITE, CHARCOAL, INSULATION NON-ASBESTOS, ASBESTOS
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W396	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Uncat met debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2595.2	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	95.2	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	4.8	0.0	0.0
Plastics:	14.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	1.30E+01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, EQUIPMENT, PLASTIC/POLYURETHANE, RUBBER.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W397	Handling: CH	NMVP #: N/A	Stream Name: 325 Comb debris CH TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Combustible		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	47.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.6	0.0	0.0
Other Metals/Alloys:	1.1	0.0	0.0
Other Inorganic Material:	27.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	20.2	0.0	0.0
Rubber:	48.8	0.0	0.0
Plastics:	93.7	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	4.00E-02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	1.2	2.1	2.5	2.1	11.4
Totals	3.5	1.2	2.1	2.5	2.1	11.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	3.5	1.2	2.1	2.5	2.1	11.4
Totals	3.5	1.2	2.1	2.5	2.1	11.4

As-Generated Form: Stored: 3.5 Projected: 7.9 Total: 11.4

Final Waste Form: Stored: 3.5 Projected: 7.9 Total: 11.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, RUBBER, CLOTH/RAGS/NYLON, GLASS, PAPER/CARDBOARD, ASBESTOS, ABSORBENT/KITY LTR/VERMICULITE, CERAMICS, STAINLESS STEEL, FUEL/PINS OR RODS, CONCRETE, LEATHER, ALUMINUM, GRAPHITE, LEAD
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W398	Handling:	CH	NMVP #:	N/A	Stream Name:	325 Comb debris CH/r TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	15.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	80.2	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.0	0.0	0.0
Rubber:	10.0	0.0	0.0
Plastics:	108.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	1.89E+00
Pu-241	2.16E+01
Pu-240	7.50E-01
Pu-239	2.08E+00
Beta/Gamma	2.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS GLASS, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD, RUBBER, CERAMICS.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the PNL Radiochemistry Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W399	Handling: CH	NMVP #: N/A	Stream Name: 327C Uncat met debris CH/r TRU		Inventory Date: 12/1/94
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	146.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	8.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	16.5	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	45.6	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	5.01E+02
Pu-240	7.91E+00
Pu-239	1.59E+01
Beta/Gamma	4.88E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.1	0.2	0.2	0.1	0.0	0.6
Totals	0.1	0.2	0.2	0.1	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	1.5	1.7	0.4	0.0	3.7
Totals	0.2	1.5	1.7	0.4	0.0	3.7

As-Generated Form: Stored: 0.1 Projected: 0.5 Total: 0.6

Final Waste Form: Stored: 0.2 Projected: 3.5 Total: 3.7

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD, GLASS, CLOTH/RAGS/NYLON, COTTON/KOTEX.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled packaged remote non-mixed TRU waste from the PNL Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W400	Handling:	CH	NMVP #:	N/A	Stream Name:	327C Inorg non-met debris CH/r TRU
Inventory Date:	12/1/94						
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal
Waste Matrix Code:	S5400						

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	24.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	114.7	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	28.7	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	52.3	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	5.01E+02
Pu-240	7.91E+00
Pu-239	1.59E+01
Beta/Gamma	4.26E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.1	0.1	0.1	0.1	0.0	0.3
Totals	0.1	0.1	0.1	0.1	0.0	0.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.8	1.0	0.4	0.0	2.5
Totals	0.2	0.8	1.0	0.4	0.0	2.5

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.2 Projected: 2.3 Total: 2.5

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, GLASS, CONCRETE, COTTON/KOTEX, METAL/IRON/GALVANIZED/SHEET, STAINLESS STEEL, CLOTH/RAGS/NYLON, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled packaged remote non-mixed TRU waste from the PNL Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W401	Handling: CH	NMVP #: N/A	Stream Name: 327C Comb debris CH/r TRU		Inventory Date: 12/1/9
Local ID:	Type: TRU	Generator Site: RL	Final Waste Form: Combustible		Waste Matrix Code: S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	54.8	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.6	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	21.7	0.0	0.0
Rubber:	0.2	0.0	0.0
Plastics:	95.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	5.01E+02
Pu-240	7.91E+00
Pu-239	1.59E+01
Beta/Gamma	1.51E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	1.6	2.0	1.1	0.7	6.0
Totals	0.6	1.6	2.0	1.1	0.7	6.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	9.6	12.1	6.7	4.2	33.1
Totals	0.6	9.6	12.1	6.7	4.2	33.1

As-Generated Form: Stored: 0.6 Projected: 5.5 Total: 6.0

Final Waste Form: Stored: 0.6 Projected: 32.4 Total: 33.1

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, STAINLESS STEEL, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, CLOTH/RAGS/NYLON, COTTON/KOTEX, GLASS, RUBBER, CONCRETE, WOOD/LUMBER/PLYWOOD.
WASTE STREAM SOURCE	This stream is combustible contact handled packaged remote non-mixed TRU waste from the PNL Post Irradiation Test Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W402	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Uncat met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	134.4	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	12.1	0.0	0.0
Rubber:	5.4	0.0	0.0
Plastics:	45.1	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	5.73E+01
Pu-240	2.13E+00
Pu-239	9.50E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.3	0.6	1.0	0.4	0.0	3.4
Totals	1.3	0.6	1.0	0.4	0.0	3.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	0.6	1.0	0.4	0.0	3.3
Totals	1.2	0.6	1.0	0.4	0.0	3.3

As-Generated Form: Stored: 1.3 Projected: 0.0 Total: 1.3

Final Waste Form: Stored: 1.2 Projected: 2.1 Total: 3.3

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS METAL/IRON/GALVANIZED/SHEET, PLASTIC/POLYURETHANE, PAPER/CARDBOARD, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is uncategorized metal contact handled non-mixed TRU waste from the Waste Loadout Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W403	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Inorg non-met debris CH TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal

Inventory Date: 12/1/94

Waste Matrix Code: S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	31.6	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	223.1	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	10.6	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	51.2	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	0.00E+00
Pu-241	5.73E+01
Pu-240	2.13E+00
Pu-239	9.50E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.0	0.0	0.0	0.0	0.6
Totals	0.6	0.0	0.0	0.0	0.0	0.6

As-Generated Form: Stored: 0.6 Projected: 0.0 Total: 0.6

Final Waste Form: Stored: 0.6 Projected: 0.0 Total: 0.6

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS CONCRETE, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, PAPER/CARDBOARD.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the Waste Loadout Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W404	Handling:	CH	NMVP #:	N/A	Stream Name:	340 Comb debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Combustible	Waste Matrix Code:	S5300

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	32.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	5.9	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	44.4	0.0	0.0
Rubber:	0.2	0.0	0.0
Plastics:	73.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Am-241	0.00E+00
Pu-241	5.73E+01
Pu-240	2.13E+00
Pu-239	9.50E+00
Beta/Gamma	2.40E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.6	1.0	0.4	0.0	4.2
Totals	2.1	0.6	1.0	0.4	0.0	4.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	2.1	0.6	1.0	0.4	0.0	4.2
Totals	2.1	0.6	1.0	0.4	0.0	4.2

As-Generated Form: Stored: 2.1 Projected: 0.0 Total: 2.1

Final Waste Form: Stored: 2.1 Projected: 2.1 Total: 4.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS PLASTIC/POLYURETHANE, PAPER/CARDBOARD, METAL/IRON/GALVANIZED/SHEET, WOOD/LUMBER/PLYWOOD, GLASS, CONCRETE, CERAMICS, RUBBER, CLOTH/RAGS/NYLON.
WASTE STREAM SOURCE	This stream is combustible contact handled non-mixed TRU waste from the Waste Loadout Building.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W405	Handling:	CH	NMVP #:	N/A	Stream Name:	3720 Inorg non-met debris CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	S3110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	23.7	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	114.3	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	43.9	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Am-241	8.60E+00
Pu-241	3.27E+00
Pu-240	1.20E-01
Pu-239	5.40E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS ABSORBENT/KITY LTR/VERMICULITE, PLASTIC/POLYURETHANE, METAL/IRON/GALVANIZED/SHEET, GLASS.
WASTE STREAM SOURCE	This stream is inorganic non-metal contact handled non-mixed TRU waste from the PNL Chemistry and Metal Sciences Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W406	Handling:	CH	NMVP #:	N/A	Stream Name:	6652H Soils CH TRU	Inventory Date:	12/1/94
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Soils	Waste Matrix Code:	S4000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	131.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	597.6		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Am-241	0.00E+00
Pu-241	1.24E+00
Pu-240	5.00E-02
Pu-239	2.10E-01
Beta/Gamma	0.00E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	0.0	0.4
Totals	0.4	0.0	0.0	0.0	0.0	0.4

As-Generated Form: Stored: 0.4 Projected: 0.0 Total: 0.4

Final Waste Form: Stored: 0.4 Projected: 0.0 Total: 0.4

WASTE STREAM DESCRIPTION	THIS STREAM CONTAINS DIRT/SOIL/DIATOMACEOUS EARTH, PLASTIC/POLYURETHANE.
WASTE STREAM SOURCE	This stream is solls contact handled non-mixed TRU waste from the PNL Arid Lands Ecology Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W407	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Non-Surpl Fac Mt Prg D&D TRU
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal

Inventory Date:

Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	74.9	93.6	168.5
Standard Waste Box	0.0	0.0	0.0	166.3	207.9	374.2
Totals	0.0	0.0	0.0	241.2	301.5	542.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	74.9	93.6	168.5
Standard Waste Box	0.0	0.0	0.0	166.3	207.9	374.2
Totals	0.0	0.0	0.0	241.2	301.5	542.7

As-Generated Form: Stored: 0.0 Projected: 542.7 Total: 542.7

Final Waste Form: Stored: 0.0 Projected: 542.7 Total: 542.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from cleanout of contaminated equipment/removable piping etc. from PUREX facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W408	Handling:	CH	NMVP #:	N/A	Stream Name:	221T/2706T Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	339.5	424.3	763.8
Totals	0.0	0.0	0.0	339.5	424.3	763.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	339.5	424.3	763.8
Totals	0.0	0.0	0.0	339.5	424.3	763.8

As-Generated Form: Stored: 0.0 Projected: 848.6 Total: 848.6

Final Waste Form: Stored: 0.0 Projected: 848.6 Total: 848.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility clean-out and D&D waste from the T-Plant Canyon and Decontamination facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W409	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	49.9	62.4	112.3
Standard Waste Box	0.0	0.0	0.0	0.0	0.0	0.0
Totals	0.0	0.0	0.0	49.9	62.4	112.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	49.9	62.4	112.3
Standard Waste Box	0.0	0.0	0.0	3417.1	4271.4	7688.5
Totals	0.0	0.0	0.0	3467.0	4333.8	7800.8

As-Generated Form: Stored: 0.0 Projected: 8667.6 Total: 8667.6

Final Waste Form: Stored: 0.0 Projected: 8667.6 Total: 8667.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. . Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from cleanout and D&D of the Plutonium Finishing Plant and Plutonium Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W410	Handling:	CH	NMVP #:	N/A	Stream Name:	308 Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	34.9	43.7	78.6
Standard Waste Box	0.0	0.0	0.0	0.0	4.5	4.5
Totals	0.0	0.0	0.0	34.9	48.2	83.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	34.9	43.7	78.6
Standard Waste Box	0.0	0.0	0.0	0.0	4.5	4.5
Totals	0.0	0.0	0.0	34.9	48.2	83.2

As-Generated Form: Stored: 0.0 Projected: 91.9 Total: 91.9

Final Waste Form: Stored: 0.0 Projected: 91.9 Total: 91.9

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility cleanout and D&D of the Fuel Fabrication Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W411	Handling:	CH	NMVP #:	N/A	Stream Name:	231-Z Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	15.1	18.9	34.0
Totals	0.0	0.0	0.0	15.1	18.9	34.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	15.1	18.9	34.0
Totalr	0.0	0.0	0.0	15.1	18.9	34.0

As-Generated Form: Stored: 0.0 Projected: 37.8 Total: 37.8

Final Waste Form: Stored: 0.0 Projected: 37.8 Total: 37.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility cleanout and D&D of the Material Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W412	Handling:	CH	NMVP #:	N/A	Stream Name:	327 Non-Surpl Fac Mt Prg D&D TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	15.1	18.9	34.0
Totals	0.0	0.0	0.0	15.1	18.9	34.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	15.1	18.9	34.0
Totals	0.0	0.0	0.0	15.1	18.9	34.0

As-Generated Form: Stored: 0.0 Projected: 37.8 Total: 37.8

Final Waste Form: Stored: 0.0 Projected: 37.8 Total: 37.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into CH boxes.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W413	Handling:	CH	NMVP #:	N/A	Stream Name:	TWRS Vit Fac Waste TRU Type 1	Inventory Date:
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	374.4	468.0	842.4
Totals	0.0	0.0	0.0	374.4	468.0	842.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	374.4	468.0	842.4
Totals	0.0	0.0	0.0	374.4	468.0	842.4

As-Generated Form: Stored: 0.0 Projected: 936.0 Total: 936.0

Final Waste Form: Stored: 0.0 Projected: 936.0 Total: 936.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from the operation of the planned HLW vitrification facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W414	Handling:	CH	NMVP #:	N/A	Stream Name:	202A Non-Surpl Fac Mt Prog D&D MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.1	0.1
Standard Waste Box	0.0	0.0	0.0	0.0	8.7	8.7
Totals	0.0	0.0	0.0	0.0	8.8	8.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	0.1	0.1
Standard Waste Box	0.0	0.0	0.0	0.0	8.7	8.7
Totals	0.0	0.0	0.0	0.0	8.8	8.8

As-Generated Form: Stored: 0.0 Projected: 8.7 Total: 8.7

Final Waste Form: Stored: 0.0 Projected: 8.7 Total: 8.7

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from cleanout of contaminated equipment/removable piping etc. from PUREX facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W415	Handling:	CH	NMVP #:	N/A	Stream Name:	221T/2706T Non-Surpl Fac Mt Prg D&D MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	1088.6	1360.8	2449.4
Totals	0.0	0.0	0.0	1088.6	1360.8	2449.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	1088.6	1360.8	2449.4
Totals	0.0	0.0	0.0	1088.6	1360.8	2449.4

As-Generated Form: Stored: 0.0 Projected: 2721.6 Total: 2721.6

Final Waste Form: Stored: 0.0 Projected: 2721.6 Total: 2721.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility clean-out and D&D waste from the T-Plant Canyon and Decontamination facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W416	Handling:	CH	NMVP #:	N/A	Stream Name:	2345Z Non-Surpl Fac Mt Prg D&D MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	4021.9	5027.4	9049.3
Totals	0.0	0.0	0.0	4021.9	5027.4	9049.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	4021.9	5027.4	9049.3
Totals	0.0	0.0	0.0	4021.9	5027.4	9049.3

As-Generated Form: Stored: 0.0 Projected: 10054.8 Total: 10054.8

Final Waste Form: Stored: 0.0 Projected: 10054.8 Total: 10054.8

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from clean-out and D&D of the Plutonium Finishing Plant and Plutonium Processing Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W417	Handling:	CH	NMVP #:	N/A	Stream Name:	231-Z Non-Surpl Fac Mt Prg D&D MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	0.0	2.1	2.1
Totals	0.0	0.0	0.0	0.0	2.1	2.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	0.0	2.1	2.1
Totals	0.0	0.0	0.0	0.0	2.1	2.1

As-Generated Form: Stored: 0.0 Projected: 2.0 Total: 2.0

Final Waste Form: Stored: 0.0 Projected: 2.0 Total: 2.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is from facility clean-out and D&D of the Material Engineering Laboratory.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W418	Handling:	CH	NMVP #:	N/A	Stream Name:	TWRS Vit Fac Waste MTRU Type 1	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	374.4	468.0	842.4
Totals	0.0	0.0	0.0	374.4	468.0	842.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	374.4	468.0	842.4
Totals	0.0	0.0	0.0	374.4	468.0	842.4

As-Generated Form: Stored: 0.0 Projected: 936.0 Total: 936.0

Final Waste Form: Stored: 0.0 Projected: 936.0 Total: 936.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from the operation of the planned HLW vitrification facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W419	Handling:	RH	NMVP #:	N/A	Stream Name:	100K K-Basin Operations TRU	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	67.6	0.0	0.0	0.0	67.6
Totals	0.0	67.6	0.0	0.0	0.0	67.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	67.6	0.0	0.0	0.0	67.6
Totals	0.0	67.6	0.0	0.0	0.0	67.6

As-Generated Form: Stored: 0.0 Projected: 67.6 Total: 67.6

Final Waste Form: Stored: 0.0 Projected: 67.6 Total: 67.6

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from operations of the N-Reactor fuel storage basins.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W420	Handling:	RH	NMVP #:	N/A	Stream Name:	TWRS Vit Fac Waste TRU Type 2	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	356.0	445.0	801.0
Totals	0.0	0.0	0.0	356.0	445.0	801.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	356.0	445.0	801.0
Totals	0.0	0.0	0.0	356.0	445.0	801.0

As-Generated Form: Stored: 0.0 Projected: 890.0 Total: 890.0

Final Waste Form: Stored: 0.0 Projected: 890.0 Total: 890.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. .Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from the operation of the planned HLW vitrification facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	While not forecasted from 1995 to 1999, additional generation is forecasted from 2000 to 2024.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W421	Handling:	RH	NMVP #:	N/A	Stream Name:	221T/2706T T-Plant Operations MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncomplied

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	7.1	21.4	0.0	0.0	28.5
Totals	0.0	7.1	21.4	0.0	0.0	28.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	7.1	21.4	0.0	0.0	28.5
Totals	0.0	7.1	21.4	0.0	0.0	28.5

As-Generated Form: Stored: 0.0 Projected: 28.5 Total: 28.5

Final Waste Form: Stored: 0.0 Projected: 28.5 Total: 28.5

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous waste related to operation of the T-Plant Canyon and Decontamination Facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W422	Handling:	RH	NMVP #:	N/A	Stream Name:	Tank Waste Retrieval MTRU	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncomplied

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	99.7	124.6	224.3
Totals	0.0	0.0	0.0	99.7	124.6	224.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	99.7	124.6	224.3
Totals	0.0	0.0	0.0	99.7	124.6	224.3

As-Generated Form: Stored: 0.0 Projected: 249.2 Total: 249.2

Final Waste Form: Stored: 0.0 Projected: 249.2 Total: 249.2

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid waste from planned tank waste retrieval operations.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W423	Handling:	RH	NMVP #:	N/A	Stream Name:	TWRS Vit Fac Waste MTRU Type 2	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:	RL	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	356.0	445.0	801.0
Totals	0.0	0.0	0.0	356.0	445.0	801.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	356.0	445.0	801.0
Totals	0.0	0.0	0.0	356.0	445.0	801.0

As-Generated Form: Stored: 0.0 Projected: 890.0 Total: 890.0

Final Waste Form: Stored: 0.0 Projected: 890.0 Total: 890.0

WASTE STREAM DESCRIPTION	Typically, 70 to 80% of the waste in the drums is combustible items such as wood, plastics, paper, absorbents, rubber and rags. Approximately 20 to 30% of the waste in drums is noncombustible waste , such as failed machinery, tools, glass, concrete, plumbing fixtures and soil. Boxes typically contain whole and sectioned glove boxes, hoods, conduit, lathes, pumps, fans, light fixtures, tools conveyor sections, wire, etc. The combustible materials in boxes may include cotton rags and clothing, plastic sheeting, plastic pipe, tape, ladders, plexiglass, step benches, polyethylene bottles, gloves and rubber. Absorbed combustible liquids such as oil have also been placed in some drums and boxes. Drums and boxes are also used for disposal of high-efficiency particulate air filters. Several boxes contain only high-efficiency particulate air filters, while others contain these filters and other waste forms.
WASTE STREAM SOURCE	The waste stream is miscellaneous solid wastes from the operation of the planned HLW vitrificatioin facility.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Data are compiled from waste manifest data on each container of TRU waste.
MANAGEMENT COMMENTS	The assumption is that the WIPP No Migration Petition will be approved by EPA and the State of New Mexico. Under the assumption, treatment of the waste stream to meet LDR is not required nor planned.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W424	Handling:	RH	NMVP #:	N/A	Stream Name:	327 Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5100

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	164.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	60.0	0.0	0.0
Other Inorganic Material:	35.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	6.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	1014.6	1014.6
Totals	0.0	0.0	0.0	0.0	1014.6	1014.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	1014.6	1014.6
Totals	0.0	0.0	0.0	0.0	1014.6	1014.6

As-Generated Form: Stored: 0.0 Projected: 1014.6 Total: 1014.6

Final Waste Form: Stored: 0.0 Projected: 1014.6 Total: 1014.6

WASTE STREAM DESCRIPTION	The waste stream typically contains equipment including but not limited to saws, manipulators, hoists, hoods, lathes, and cabinetry.
WASTE STREAM SOURCE	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into RH canisters.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	The research and development roles expected to be assumed by 327 before closure have not been defined.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W425	Handling:	RH	NMVP #:	N/A	Stream Name:	100N Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	1183.7	1183.7
Totals	0.0	0.0	0.0	0.0	1183.7	1183.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	1183.7	1183.7
Totals	0.0	0.0	0.0	0.0	1183.7	1183.7

As-Generated Form: Stored: 0.0 Projected: 1183.7 Total: 1183.7

Final Waste Form: Stored: 0.0 Projected: 1183.7 Total: 1183.7

WASTE STREAM DESCRIPTION	The waste stream is surplus facility clean-out and D&D waste which range from contaminated clothing, to process equipment.
WASTE STREAM SOURCE	Facility clean-out and D&D from the 100-N Reactor Facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W426	Handling:	RH	NMVP #:	N/A	Stream Name:	202A Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	241.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
	1.20E-06
	8.00E-07
	7.80E-02
	9.30E-02
	7.80E-02
	9.80E-02
	9.90E-04
	1.90E-03
	1.70E-08
	2.20E-07
	6.70E-08
	4.50E-04
	1.10E-03
	6.20E-04
	1.80E-02
	1.70E-06
	2.20E-07
	1.60E-03
	2.60E-03
	2.60E-03
	4.10E-09
	1.90E-04

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	115.7	115.7
Totals	0.0	0.0	0.0	0.0	115.7	115.7

***Final Waste Form Volumes**

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	115.7	115.7
Totals	0.0	0.0	0.0	0.0	115.7	115.7

As-Generated Form: Stored: 0.0 Projected: 115.7 Total: 115.7

Final Waste Form: Stored: 0.0 Projected: 115.7 Total: 115.7

WASTE STREAM DESCRIPTION	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into RH canisters.
WASTE STREAM SOURCE	Cleanout of contaminated equipment/removable piping etc. from PUREX facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W427	Handling:	RH	NMVP #:	N/A	Stream Name:	202-A Tunnel Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	231.0	0.0	0.0
Aluminum-base Metal/Alloys:	4.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	5.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	696.9	696.9
Totals	0.0	0.0	0.0	0.0	696.9	696.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	696.9	696.9
Totals	0.0	0.0	0.0	0.0	696.9	696.9

As-Generated Form: Stored: 0.0 Projected: 696.9 Total: 696.9

Final Waste Form: Stored: 0.0 Projected: 696.9 Total: 696.9

WASTE STREAM DESCRIPTION	Fuel reprocessing equipment (i.e., columns, concentrators, dissolvers, tanks, scrap). One container is filled with fuel ends and fuel handling equipment (22.7m3).
WASTE STREAM SOURCE	Held waste in 2 below grade tunnels that contain equipment too large, bulky and/or highly radioactively contaminated to be stored/disposed of by conventional methods.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W428	Handling:	RH	NMVP #:	N/A	Stream Name:	221T/2706T Non-surplus Facility Mgmt Prg D&D TRU/RH
Inventory Date:	12/31/94						
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous
Waste Matrix Code:	S5400						

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	213.6	213.6
Totals	0.0	0.0	0.0	0.0	213.6	213.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	213.6	213.6
Totals	0.0	0.0	0.0	0.0	213.6	213.6

As-Generated Form: Stored: 0.0 Projected: 213.6 Total: 213.6

Final Waste Form: Stored: 0.0 Projected: 213.6 Total: 213.6

WASTE STREAM DESCRIPTION	The waste stream ranges from contaminated clothing to process equipment.
WASTE STREAM SOURCE	Facility clean-out and D&D waste from the T-Plant Canyon and Decontamination facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W429	Handling:	RH	NMVP #:	N/A	Stream Name:	2345Z Non-surplus Facility Mgmt Prg D&D TRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	190.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	52.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	2162.7	2162.7
Totals	0.0	0.0	0.0	0.0	2162.7	2162.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	2162.7	2162.7
Totals	0.0	0.0	0.0	0.0	2162.7	2162.7

As-Generated Form: Stored: 0.0 Projected: 2162.7 Total: 2162.7

Final Waste Form: Stored: 0.0 Projected: 2162.7 Total: 2162.7

WASTE STREAM DESCRIPTION	This waste stream is major processing equipment, piping, ductwork, and gloveboxes resulting fron the cleanout and D&D of PFP.
WASTE STREAM SOURCE	Cleanout and D&D of the Plutonium Finishing Plant and Plutonium Processing Facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W430	Handling:	RH	NMVP #:	N/A	Stream Name:	Surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

D001C, D009X, D002B

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	60.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	30.0	0.0	0.0
Other Inorganic Material:	75.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	7.0	0.0	0.0
Solidified Inorganic Material:	83.0	0.0	0.0
Solidified Organic Material:	31.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	24.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	622.1	0.0	622.1
Totals	0.0	0.0	0.0	622.1	0.0	622.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	622.1	0.0	622.1
Totals	0.0	0.0	0.0	622.1	0.0	622.1

As-Generated Form: Stored: 0.0 Projected: 622.1 Total: 622.1

Final Waste Form: Stored: 0.0 Projected: 622.1 Total: 622.1

WASTE STREAM DESCRIPTION	The waste stream is surplus facilities cleanout and D&D wastes, ranging from contaminated clothing to process equipment and sludges.
WASTE STREAM SOURCE	Cleanout and D&D of all 100 Area Inactive Facalities (includung C, D, DR, KE, KW, H, F, and N reactors, 104F and H Storage Basins, 100N Deactivation, N Basin Cleanout, Emergency Dump Basin, and the Spacer Silo) and the following 200 Area Inactive Facilities: 202S (REDOX), 233S (Plutonium Concentration Facility), and 221S (U Plant).
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W431	Handling:	RH	NMVP #:	N/A	Stream Name:	327 Non-surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5420

AS-GENERATED EPA CODES

D008A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	68.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	60.0	0.0	0.0
Other Inorganic Material:	35.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	5.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	6.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	8.9	8.9
Totals	0.0	0.0	0.0	0.0	8.9	8.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	8.9	8.9
Totals	0.0	0.0	0.0	0.0	8.9	8.9

As-Generated Form: Stored: 0.0 Projected: 8.9 Total: 8.9

Final Waste Form: Stored: 0.0 Projected: 8.9 Total: 8.9

WASTE STREAM DESCRIPTION	The waste stream typically contains equipment including but not limited to saws, manipulators, hoists, hoods, lathes, and cabinetry.
WASTE STREAM SOURCE	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into RH canisters.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	The research and development roles expected to be assumed by 327 before closure have not been defined.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W432	Handling:	RH	NMVP #:	N/A	Stream Name:	202A Non-surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5110

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	241.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.80E-02
Ba-137m	9.30E-02
C-14	9.90E-04
Cs-137	9.80E-02
H-3	1.90E-04
I-129	4.10E-09
Np-237	1.70E-08
Pu-238	4.50E-04
Am-241	1.90E-03
Pu-240	6.20E-04
Y-90	7.80E-02
Pu-242	2.20E-07
Rh-106	2.60E-03
Ru-106	2.60E-03
Se-79	8.00E-07
Sm-151	1.60E-03
Sr-90	7.80E-02
U-234	1.70E-06
U-235	6.70E-08
U-236	2.20E-07
U-238	1.20E-06
Pu-239	1.10E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	35.6	35.6
Totals	0.0	0.0	0.0	0.0	35.6	35.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	35.6	35.6
Totals	0.0	0.0	0.0	0.0	35.6	35.6

As-Generated Form: Stored: 0.0 Projected: 35.6 Total: 35.6

Final Waste Form: Stored: 0.0 Projected: 35.6 Total: 35.6

WASTE STREAM DESCRIPTION	The waste stream is large tanks/dissolvers/pumps/concentrator. Size reduction is required to package the waste into RH canisters.
WASTE STREAM SOURCE	Cleanout of contaminated equipment/removable piping etc. from PUREX facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W433	Handling:	RH	NMVP #:	N/A	Stream Name:	221T/2706T Non-surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	676.4	676.4
Totals	0.0	0.0	0.0	0.0	676.4	676.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	676.4	676.4
Totals	0.0	0.0	0.0	0.0	676.4	676.4

As-Generated Form: Stored: 0.0 Projected: 676.4 Total: 676.4

Final Waste Form: Stored: 0.0 Projected: 676.4 Total: 676.4

WASTE STREAM DESCRIPTION	The waste stream ranges from contaminated clothing to process equipment, contaminated with RCRA regulated constituents.
WASTE STREAM SOURCE	Facility clean-out and D&D waste from the T-Plant Canyon and Decontamination facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W434	Handling: RH	NMVP #: N/A	Stream Name: 2345Z Non-surplus Facility Mgmt Prg D&D MTRU/RH		Inventory Date: 12/31/94
Local ID:	Type: MTRU	Generator Site:	Final Waste Form: Uncategorized Metal		Waste Matrix Code: S5110

AS-GENERATED EPA CODES

D009A, D008A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	190.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	52.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	2509.8	2509.8
Totals	0.0	0.0	0.0	0.0	2509.8	2509.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	2509.8	2509.8
Totals	0.0	0.0	0.0	0.0	2509.8	2509.8

As-Generated Form: Stored: 0.0 Projected: 2509.8 Total: 2509.8

Final Waste Form: Stored: 0.0 Projected: 2509.8 Total: 2509.8

WASTE STREAM DESCRIPTION	This waste stream is major processing equipment, piping, ductwork, and gloveboxes resulting fron the cleanout and D&D of PFP.
WASTE STREAM SOURCE	Cleanout and D&D of the Plutonium Finishinf Plant and Plutonium Processing Facility.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W435	Handling:	RH	NMVP #:	N/A	Stream Name:	340 Non-surplus Facility Mgmt Prg D&D MTRU/RH	Inventory Date:	12/31/94
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	26.7	26.7
Totals	0.0	0.0	0.0	0.0	26.7	26.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	0.0	0.0	26.7	26.7
Totals	0.0	0.0	0.0	0.0	26.7	26.7

As-Generated Form: Stored: 0.0 Projected: 26.7 Total: 26.7

Final Waste Form: Stored: 0.0 Projected: 26.7 Total: 26.7

WASTE STREAM DESCRIPTION	This waste stream includes both TRU and mixed TRU. This waste consists of pumps, thermal couples, and piping contaminated with TRU elements. This equipment cannot be fit into standard size boxes.
WASTE STREAM SOURCE	This waste is incident, non-process waste from single-shell tanks.
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W436	Handling:	RH	NMVP #:	N/A	Stream Name:	TWRS Long-Length Tank Equipment MTRU/RH
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Uncategorized Metal

Inventory Date: 12/31/94

Waste Matrix Code: S5119

AS-GENERATED EPA CODES

F005, D007, D002B, F003, F002, F001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	596.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	434.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	464.7		
Packaging Material Steel Plug:	2145.1		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE: N/A

FINAL FORM RADIONUCLIDES: N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	240.3	2990.4	7047.0	10277.7
Totals	0.0	0.0	240.3	2990.4	7047.0	10277.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
RH Canister	0.0	0.0	240.3	2990.4	7047.0	10277.7
Totals	0.0	0.0	240.3	2990.4	7047.0	10277.7

As-Generated Form: Stored: 0.0 Projected: 10277.7 Total: 10277.7

Final Waste Form: Stored: 0.0 Projected: 10277.7 Total: 10277.7

WASTE STREAM DESCRIPTION	Equipment removed from the high level waste tanks (instrument trees, pumps, circulators, agitators, heaters, sluicers, steam coils, air lances, cameras)
WASTE STREAM SOURCE	High Level Waste Tanks (A-101, AN-102, AN-104, AN-107, AZ-101. BY103, C-102, C-103, C-104, C-105, C-106, TX-118)
CURRENT CONTAINER COMMENTS	Size reduction is assumed for large items. Volume is assumed to remain the same as a result of size reduction.
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W437	Handling:	CH	NMVP #:	N/A	Stream Name:	Surplus Facility Mgmt Prg D&D TRU/CH	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	11.9	147.9	571.6	28.1	759.4
Totals	0.0	11.9	147.9	571.6	28.1	759.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	11.9	147.9	571.6	28.1	759.4
Totals	0.0	11.9	147.9	571.6	28.1	759.4

As-Generated Form: Stored: 0.0 Projected: 759.4 Total: 759.4

Final Waste Form: Stored: 0.0 Projected: 759.4 Total: 759.4

WASTE STREAM DESCRIPTION	The waste stream is surplus facilities cleanout and D&D wastes, ranging from contaminated clothing to process equipment and sludges.
WASTE STREAM SOURCE	Cleanout and D&D of all 100 Area Inactive Facalities (includung C, D, DR, KE, KW, H, F, and N reactors, 104F and H Storage Basins, 100N Deactivation, N Basin Cleanout, Emergency Dump Basin, and the Spacer Silo) and the following 200 Area Inactive Facilities: 202S (REDOX), 233S (Plutonium Concentration Facility), and 221S (U Plant).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: RL-W438	Handling: CH	NMVP #: N/A	Stream Name: Non-transition program TRU/CH		Inventory Date:
Local ID:	Type: TRU	Generator Site:	Final Waste Form: Heterogeneous		Waste Matrix Code: U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Source Unknown

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	60.3	488.0	548.3
Standard Waste Box	0.0	0.0	0.0	121.0	427.1	548.1
Totals	0.0	0.0	0.0	181.3	915.1	1096.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	120.6	427.6	548.3
Standard Waste Box	0.0	0.0	0.0	121.0	427.1	548.1
Totals	0.0	0.0	0.0	241.6	854.8	1096.4

As-Generated Form: Stored: 0.0 Projected: 1096.4 Total: 1096.4

Final Waste Form: Stored: 0.0 Projected: 1096.4 Total: 1096.4

WASTE STREAM DESCRIPTION	Description is presently not available; however typical deactivation waste includes cleanout and removal of equipment, mixers, tanks, vessels and pumps.
WASTE STREAM SOURCE	This represents wastes from deactivation and terminal cleanout activities from facilities not covered under the DOE/EM40 Facilities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W439	Handling:	CH	NMVP #:	N/A	Stream Name:	Environmental Restoration Program TRU/CH Soils	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Soils	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	122.3	1162.5	3121.0	1529.8	5935.7
Totals	0.0	122.3	1162.5	3121.0	1529.8	5935.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	122.3	1162.5	3121.0	1529.8	5935.7
Totals	0.0	122.3	1162.5	3121.0	1529.8	5935.7

As-Generated Form: Stored: 0.0 Projected: 5935.7 Total: 5935.7

Final Waste Form: Stored: 0.0 Projected: 5935.7 Total: 5935.7

WASTE STREAM DESCRIPTION	This waste stream consists of soil contaminated with liquid solutions, previously buried solid waste, and associated contaminated soil, and sludges from previously used tanks or tank-like units.
WASTE STREAM SOURCE	The waste is from retrieval of contaminated soils. The waste may also include solid waste from past practice burial grounds and solidified sludge from miscellaneous past practice tanks.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W440	Handling:	CH	NMVP #:	N/A	Stream Name:	K Basins Operations TRU/CH	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	41.0	133.1	0.0	0.0	174.1
Standard Waste Box	0.0	32.1	0.0	0.0	0.0	32.1
Totals	0.0	73.1	133.1	0.0	0.0	206.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	41.0	133.1	0.0	0.0	174.1
Standard Waste Box	0.0	32.1	0.0	0.0	0.0	32.1
Totals	0.0	73.1	133.1	0.0	0.0	206.2

As-Generated Form: Stored: 0.0 Projected: 206.2 Total: 206.2

Final Waste Form: Stored: 0.0 Projected: 206.2 Total: 206.2

WASTE STREAM DESCRIPTION	Waste consists of rags, plastic, paper, rubber, and absorbed liquids and sludges.
WASTE STREAM SOURCE	This waste is from operations of the N-Reactor fuel storage basins.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This is a new waste stream from the BEMR data call. Characterization data is not available at this time.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W441	Handling:	CH	NMVP #:	N/A	Stream Name:	K Basin Project TRU/CH	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.2	0.0	0.0	0.0	0.2
Totals	0.0	0.2	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.2	0.0	0.0	0.0	0.2
Totals	0.0	0.2	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.0 Projected: 0.2 Total: 0.2

Final Waste Form: Stored: 0.0 Projected: 0.2 Total: 0.2

WASTE STREAM DESCRIPTION	Waste consists of iron-based metal, rags, paper, plastic, and rubber.
WASTE STREAM SOURCE	Source is incidental waste associated with spent fuel.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This is a new waste stream from the BEMR data call. Characterization data is not available at this time.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W442	Handling:	CH	NMVP #:	N/A	Stream Name:	TWRS Cross-Site Transfer Project TRU/CH	Inventory Date:	
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Facility/Equipment Operation and Maintenance Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	5.7	0.0	0.0	0.0	5.7
Totals	0.0	5.7	0.0	0.0	0.0	5.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	5.7	0.0	0.0	0.0	5.7
Totals	0.0	5.7	0.0	0.0	0.0	5.7

As-Generated Form: Stored: 0.0 Projected: 5.7 Total: 5.7

Final Waste Form: Stored: 0.0 Projected: 5.7 Total: 5.7

WASTE STREAM DESCRIPTION	Waste consists of contaminated soil that may be encountered during placement of a tank transfer line. This line is being placed adjacent to an existing line. The transfer line provides capability to transfer highly radioactive liquid waste among Hanford's high-level waste tanks.
WASTE STREAM SOURCE	This is a waste that will be generated from a project to improve the cross-site tank transfer pipeline.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	This is a new waste stream from the BEMR data call. Characterization data is not available at this time.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W443	Handling:	CH	NMVP #:	N/A	Stream Name:	Surplus Facility Mgmt Prg D&D MTRU/CH	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	S4200

AS-GENERATED EPA CODES

D009X, D002B, D001C

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Remediation/D&D Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	62.8	577.6	28.1	668.5
Totals	0.0	0.0	62.8	577.6	28.1	668.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	62.8	577.6	28.1	668.5
Totals	0.0	0.0	62.8	577.6	28.1	668.5

As-Generated Form: Stored: 0.0 Projected: 668.5 Total: 668.5

Final Waste Form: Stored: 0.0 Projected: 668.5 Total: 668.5

WASTE STREAM DESCRIPTION	The waste stream is surplus facilities cleanout and D&D wastes, ranging from contaminated clothing to process equipment and sludges.
WASTE STREAM SOURCE	Cleanout and D&D of all 100 Area Inactive Facilities (includung C, D, DR, KE, KW, H, F, and N reactors, 104F and H Storage Basins, 100N Deactivation, N Basin Cleanout, Emergency Dump Basin, and the Spacer Silo) and the following 200 Area Inactive Facilities: 202S (REDOX), 233S (Plutonium Concentration Facility), and 221S (U Plant).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	RL-W444	Handling:	CH	NMVP #:	N/A	Stream Name:	Non-transition Program MTRU/CH	Inventory Date:	
Local ID:		Type:	MTRU	Generator Site:		Final Waste Form:	Heterogeneous	Waste Matrix Code:	U9999

AS-GENERATED EPA CODES

Uncompiled

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Source Unknown

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	17.9	63.6	81.5
Standard Waste Box	0.0	0.0	0.0	18.9	68.0	86.9
Totals	0.0	0.0	0.0	36.8	131.7	168.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	17.9	63.6	81.5
Standard Waste Box	0.0	0.0	0.0	18.9	68.0	86.9
Totals	0.0	0.0	0.0	36.8	131.7	168.5

As-Generated Form: Stored: 0.0 Projected: 168.5 Total: 168.5

Final Waste Form: Stored: 0.0 Projected: 168.5 Total: 168.5

WASTE STREAM DESCRIPTION	Description is presently not available; however typical deactivation waste includes cleanout and removal of equipment, mixers, tanks, vessels and pumps.
WASTE STREAM SOURCE	This represents wastes from deactivation and terminal cleanout activities from facilities not covered under the DOE/EM40 Facilities.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

SA Sandia National Laboratories - New Mexico

DOE/CAO-95-1121
December 1995

SANDIA NATIONAL LABORATORIES

Location and Description

Sandia National Laboratories/New Mexico (SNL/NM) is located immediately southeast of Albuquerque, New Mexico, on Kirtland Air Force Base. The SNL/NM consists not only of the headquarters facilities in Albuquerque, New Mexico, but also the laboratory facility in Livermore, California, the Tonopah Test Range in Nevada, and occupies about 7,600 acres (not including Tonopah Test Range).

Prior to the Trinity shot in 1945, the Manhattan project had a small facility on Sandia Base (now Kirtland AFB) to perform ordnance engineering, nonnuclear atomic bomb assembly and military training. In March 1948, the Sandia Laboratory was established as a formal branch of the Los Alamos Scientific Laboratory (LASL) now LA. In 1949, Sandia Corporation was organized as a wholly-owned subsidiary of the Western Electric Company, and approximately 1,700 LASL employees were transferred. In 1984, Sandia Corporation became a wholly-owned subsidiary of the AT&T Technologies Corporation.

SNL/NM is administered by the DOE/Albuquerque Operations Office and is currently operated by the Lockheed Martin Corporation.

Mission

SNL/NM's mission was research, development, and engineering of nuclear weapons systems except for the nuclear explosive. This included nuclear weapons systems ordnance engineering, nonnuclear component design and development, field and laboratory testing, and manufacturing engineering.

SNL/NM has operated the Tonopah Test Range near Tonopah, Nevada, since the range was established in 1957. The site is located about 322 kilometers northwest of Las Vegas, Nevada, on 1360 squire kilometers of land provided by the Air Force in accordance with a use permit. Tonopah Test Range is a major facility for the field testing of nonnuclear and denuclearized weapons, research rockets, and artillery. Aerodynamic stability, the compatibility of various ballistic shapes, trajectories, times of fall, accuracy of delivery, and functioning of fuzing components are tested under conditions simulating actual use. Certain types of high explosive ordnance are also tested at the test range.

Waste Information

Processes

One of SNL/NM's generators is the Inhalation Toxicology Research Institute (IT). Since 1960, ITRI has performed a variety of research programs for the DOE. The original research was dedicated to the evaluation of health effects caused by inhalation of fission products. Research is now conducted on the health effects of transuranic elements such as plutonium, americium, curium, and nonradioactive airborne materials in various environments.

Modifications/Assumptions/Development

Waste streams that are expected to be directly shipped to WIPP (upon WIPP–WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double– counting these streams as both "as generated currently stored" and "final form projected."

M

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SA-T001	Handling:	CH	NMVP #:	na	Stream Name:	Lovelace ITRI Waste Stream
Local ID:	NA	Type:	TRU	Generator Site:	IT	Final Waste Form:	Heterogeneous

Inventory Date: 5/10/95

Waste Matrix Code: S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	100.0	10.0	110.0
Aluminum-base Metal/Alloys:	3.0	1.0	5.0
Other Metals/Alloys:	6.0	2.0	10.0
Other Inorganic Material:	15.0	10.0	20.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	3.0	1.0	5.0
Rubber:	5.0	1.0	9.0
Plastics:	5.0	2.0	8.0
Solidified Inorganic Material:	40.0	20.0	60.0
Solidified Organic Material:	5.0	1.0	9.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	100.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	5.00E-01
Np-237	1.20E-02
Cm-244	8.00E-01
Am-241	2.50E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	5.4	0.6	1.0	2.1	2.1	11.2
Totals	5.4	0.6	1.0	2.1	2.1	11.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	5.4	0.6	1.0	2.1	2.1	11.2
Totals	5.4	0.6	1.0	2.1	2.1	11.2

As-Generated Form: Stored: 5.4 Projected: 5.8 Total: 11.2

Final Waste Form: Stored: 5.4 Projected: 5.8 Total: 11.2

WASTE STREAM DESCRIPTION	Waste is in final form.
WASTE STREAM SOURCE	Heterogeneous mixture of metals and combustible lab trash including solidified waste, stainless steel, brass and aluminum parts, paper, plastics, rubber gloves, PPE, hepa filters and glass. There are no liquids or compressed gasses. All drums were verified through Real Time Radiography, (RTR).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The entire waste stream was viewed through Real Time Radiography and videotapes and photographs of the waste are on file. In addition, the process knowledge from Lovelace ITRI indicates that contaminants are not present.
MANAGEMENT COMMENTS	This waste stream has been characterized by process knowledge as TRU waste. The waste is not mixed.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SA-W134	Handling:	CH	NMVP #:	na	Stream Name:	Transuranic Waste at Hot Cell Facility	Inventory Date:	12/31/94
Local ID:	NA	Type:	TRU	Generator Site:	SA	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5490

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	80.0	10.0	100.0
Aluminum-base Metal/Alloys:	5.0	1.0	10.0
Other Metals/Alloys:	10.0	4.0	15.0
Other Inorganic Material:	1.0	1.0	1.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	2.0	1.0	3.0
Rubber:	2.0	1.0	3.0
Plastics:	5.0	1.0	10.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Unassigned

FINAL FORM RADIONUCLIDES

N/A

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	1.7	0.0	0.0	0.0	2.9
Totals	1.2	1.7	0.0	0.0	0.0	2.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.2	1.7	0.0	0.0	0.0	2.9
Totals	1.2	1.7	0.0	0.0	0.0	2.9

As-Generated Form: Stored: 1.2 Projected: 1.7 Total: 2.9

Final Waste Form: Stored: 1.2 Projected: 1.7 Total: 2.9

WASTE STREAM DESCRIPTION	Waste is remoted-handled material. Some TRU waste is currently stored in Technical Area V, Bldg. 6580, and 2 drums are stored in Manzano Bunker 7063. Some of the waste is in concrete-shielded containers. Waste stream includes some solidified liquids and labware and related items removed from glove boxes. The waste matrix identified was based on information provided by the generator and may change in the future as additional examination of the waste is performed. Presently, this waste stream is RH, but is reported as CH because the Final Waste Form will be CH.
WASTE STREAM SOURCE	This waste stream was generated during SNL Hot Cell Facility exprements that including the cutting of fuel rods. There are no liquids or compressed gasses in this waste stream.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	The confidence level of regulated contaminants is based on process knowledge supplied by the waste generator. No sampling and analysis has been performed.
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	8 drums of tru waste are est[illegible]ed to be generated with the FY1996 hot cell decontamination project. This is a one time generation.

M

SR Savannah River Site

DOE/CAO-95-1121
December 1995

SAVANNAH RIVER SITE

Location and Description

The Savannah River Site (SRS) is located about 31 kilometers southeast of Aiken, South Carolina, on 198,334 acres (803 square kilometers) along the Savannah River. The SRS encompasses parts of three counties, Aiken, Barnwell, and Allendale in western South Carolina. The closest major cities are Aiken, South Carolina, and Augusta, Georgia. The site is a controlled area with limited public access. The facilities occupy less than 8 percent of the site. The remaining 92 percent is divided into forest (80%) and wetlands (20%).

The Savannah River Site is a government owned, contractor operated (GOCO) site that is managed by the DOE Savannah River Operations Office. The current Management and Operating Contractor for the Site is Westinghouse Savannah River Company.

Mission

The primary mission of the SRS has been to support national security as a major source of reactor-produced materials, primarily tritium, plutonium, heavy water (deuterium) and other special nuclear materials for weapons manufacturing. The mission was broadened over the years to include the production of other isotopes, such as Pu-238. SRS's production activities also included the loading of tritium containers for the nuclear weapons, reclamation of tritium containers and the purification of tritium recovered from retired weapons.

The decision in 1950 to go ahead with the Savannah River Plant was driven by the perceived need for tritium in the fusion weapon program following President Truman's directive of January 31, 1950, to develop a thermonuclear weapon (the "super"). While production of tritium in the Hanford reactor had been demonstrated, the new plant at Savannah River was necessary to avoid serious curtailment in the production of plutonium at Hanford for the fission program. If thermonuclear weapons proved unfeasible or tritium requirements turned out to be less than anticipated, the construction of Savannah River was further justified in order to increase plutonium production, to provide a higher efficiency in the use of uranium ore, to provide security against attack of the Hanford reactors, and to provide replacement reactors in the event of the retirement of older Hanford reactors.

Five reactors (currently shut down), two chemical processing plants, a tritium extraction, purification, and loading facility, and a high-level waste solidification facility comprise the major elements of the Defense Program operations and facilities at SRS.

The SRS waste management mission is to comply with applicable federal and state regulations, DOE Orders, and the Management and Operating Contractor policies, to minimize effects on the environment and the generation of new waste, and to the extent possible, contain waste handling, treatment, storage, and disposal within the site. Other mission objectives include the demonstration and application of remediation technologies and the environmental restoration of the SRS site. With the changing defense posture, environmental restoration is receiving increased emphasis versus weapons materials production.

Waste Information

Processes

At SRS, production of useful radioactive isotopes is accompanied by production of radioactive waste. These wastes must be safely contained and stored until the risk associated with their radioactivity is eliminated by decay or the waste is permanently disposed. In both production and power nuclear reactors, neutrons strike uranium-235 atoms in the reactor fuel, add energy and cause the atoms to become unstable and split apart or "fission." This results in the production of fission products and more neutrons, initiating a sustained chain reaction and a steady supply of neutrons. In addition to fuel, the SRS reactors contained long cylinders of material called targets. When neutrons strike the targets, useful radionuclides are created through transmutation. The fuel and target assemblies are then removed from the reactor and, after a suitable cooling period, are sent to the chemical separation areas for processing to recover the desired radionuclides (uranium, plutonium, tritium, etc).

Currently, TRU waste at SRS is generated primarily from radiochemical separations processes, analytical laboratories, and research and development activities. Primary contaminants in the waste are Pu-238 and Pu-239. The major on-site facilities that generate TRU waste are the FB-Line, the HB Line, 235-F, 772-F, and 773-A.

FB-Line and HB-Line generate TRU waste containing plutonium and neptunium. The waste is generated during the use of gloveboxes, contamination control huts, and decontamination processes waste. TRU waste is placed in 5-gallon cans, assayed, sealed in a drum liner, and placed in 55-gallon drums before transport to the waste TRU storage facility.

In the HB Separation Line, uranium, neptunium (Np) and plutonium (Pu) are recovered from irradiated enriched uranium fuels and transferred to the HB line for processing. The HB line uses three independent facilities to process Np, Pu, and recoverable scrap. TRU waste, containing Pu-238, is generated during decontamination operations, replacement of equipment, maintenance, inspection, and sampling.

In the FB Separation Line, irradiated metal alloys from the reactors are dissolved and separated into uranium, Pu metal, and high-level liquid waste using the Purex process. Uranium and plutonium are recovered and TRU waste, containing Pu-239 is generated during decontamination operations, maintenance, inspection, replacement of equipment, sampling and laboratory analysis.

The 235-F facility generates TRU waste from three waste streams, the Actinide Billet Line, the Plutonium Experimental Facility, and Plutonium Fuel Fabrication. The three streams yield neptunium and plutonium isotopes. Waste materials consist of lead-lined gloves, neoprene gloves, process waste, equipment, and filters.

The 772-F TRU waste generated in the Central Laboratory Facility results from the handling and analysis of various plutonium and neptunium samples. The routine laboratory TRU solid waste consists of paper, plastic, glass, metal, lead-lined gloves, HEPA filters, and IX resins.

The 773-A, the Savannah River Technology Center (SRTC) Solid Waste Assay Facility (SWAF) receives boxes of waste from other laboratories within the SRTC complex. The SWAF processes includes x-raying, weighing, and assaying the boxes. After processing, the waste boxes are placed in drums before shipping to the site waste disposal facility.

Solid TRU waste, such as processing equipment, glassware, and gloveboxes too large for 55-gallon drums are packaged and stored in large steel or concrete containers. The separation areas produce most of the solid TRU waste.

Off-site generators that have sent TRU waste to SRS are Los Alamos National Laboratory, Mound Laboratory, Allied-General Nuclear Services, National Institute of Standards Technology, General Sciences, Department of Defense, and Knolls Atomic Power Laboratory.

Modifications/Assumptions/Development

Savannah River's Vitrified waste stream Waste Material Parameters were recalculated by the TWBIR team to provide closure approximations to the 1000 lbs per 55 gallon drum weight limits required by the TRUPACT-II Safety Analysis Report for Packaging (SARP). In recalculating these parameters the volumes and number of final form containers were increased. This increase may hinder SRS's cost effectiveness for shipment to WIPP.

The composition of SRS final waste forms was determined using acceptable knowledge (Processing knowledge) and existing waste form research work performed by Savannah River Technical Center (SRTC).

A combination of waste descriptions, waste codes, and acceptable knowledge were used to determine the general waste types stored at SRS. This includes only the waste types affecting the final waste forms.

Waste stream volumes for SR-T001, SR-W006, SR-W026, SR-W027, and SR-W053 were separated and reported by generator and waste types.

Waste, which is classified because of shape, was identified and reported separately by SRS. The shape of this waste is expected to be destroyed during waste processing. Other classified waste was not reported by SRS because of the contents of the waste.

Waste volumes and number of containers to be shipped to WIPP were based on the type of disposal container used, the size reduction factors after waste processing, and the volume of waste to be processed. The volume of waste to be processed was based on TRU waste volumes as of 12/31/94 and waste forecasts contained in the Proposed Site Treatment Plan (PSTP) and the Waste Management Environment Impact Statement (WMEIS). These forecasts include TRU waste from operational, D&D, and ER activities.

Most of SRS's metal waste is currently packaged in large steel boxes. The waste in these steel boxes is (assumed by the site to be) 80% bulk metal and 20% heterogeneous debris. The size reduction factor for large metal components is 3.5 to 1.

No volume reduction is expected from the repackaging of heterogeneous waste streams.

The preferred technology for treating SRS TRU waste is solidification by vitrification (i.e., Hybrid Plasma Treatment). The process design provides sufficient mixing controls to ensure WIPP WAC compliance. The assumed volume reduction factor using this technology is 30 to 1. This factor applies to waste streams SR-W026, SR-W027, SR- T001, SR-T003. SR-W053, and SR-W006.

Waste streams that are expected to be directly shipped to WIPP (upon WIPP-WAC certification) without any need for repackaging or treatment are reported as "currently stored" in final form volume. For waste streams that are currently stored but are projected to be repackaged and/or treated at a later date prior to their shipment to WIPP, are also reported as "currently stored." This is done in order to avoid the error of double- counting these streams as both "as generated currently stored" and "final form projected."

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	sr125A	Stream Name:	CH TRU - Heterogeneous debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	382.5	85.0	212.5	85.0	0.0	765.0
Drum / 55-gallon	49.0	89.6	176.0	88.0	45.2	447.7
Totals	431.5	174.6	388.5	173.0	45.2	1212.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	938.7	0.0	0.0	0.0	1598.5	2537.2
Totals	938.7	0.0	0.0	0.0	1598.5	2537.2

As-Generated Form: Stored: 431.5 Projected: 781.3 Total: 1212.7

Final Waste Form: Stored: 938.7 Projected: 1598.5 Total: 2537.2

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	The stream was produced in 221 FB line, a separations facility for the production of Pu-239.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	undetermined	Stream Name:	CH TRU - Metal debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No.

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	382.5	212.5	425.0	170.0	85.0	1275.0
Totals	382.5	212.5	425.0	170.0	85.0	1275.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	23.8	0.0	0.0	0.0	70.7	94.5
Totals	23.8	0.0	0.0	0.0	70.7	94.5

As-Generated Form: Stored: 382.5 Projected: 892.5 Total: 1275.0

Final Waste Form: Stored: 23.8 Projected: 70.7 Total: 94.5

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was produced in 221 FB Line, a separations facility for the production of Pu-239.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	undetermined	Stream Name:	CH TRU - Vitrified debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	467.5	127.5	212.5	212.5	0.0	1020.0
Box / 16in W x 29in L x 32in H	24.5	21.7	42.1	21.4	11.0	120.6
Drum / 55-gallon	10.1	38.3	75.1	38.3	19.4	181.2
Totals	502.1	187.4	329.7	272.2	30.4	1321.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	23.2	0.0	0.0	0.0	141.0	164.2
Totals	23.2	0.0	0.0	0.0	141.0	164.2

As-Generated Form: Stored: 502.1 Projected: 819.7 Total: 1321.8

Final Waste Form: Stored: 23.2 Projected: 141.0 Total: 164.2

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was produced in 221 FB Line, a separations facility for the production of Pu-239.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH TRU - Heterogeneous debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A
Unassigned

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	42.5	127.5	85.0	42.5	340.0
Drum / 55-gallon	28.1	46.4	78.1	45.0	27.0	224.6
Totals	70.6	88.9	205.6	130.0	69.5	564.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	158.1	0.0	0.0	0.0	971.5	1129.6
Totals	158.1	0.0	0.0	0.0	971.5	1129.6

As-Generated Form: Stored: 70.6 Projected: 493.9 Total: 564.6

Final Waste Form: Stored: 158.1 Projected: 971.5 Total: 1129.6

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 221 HB Line, a separation facility for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	undetermined	Stream Name:	CH TRU - Metal debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.0
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	170.0	212.5	127.5	127.5	680.0
Totals	42.5	170.0	212.5	127.5	127.5	680.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.8	0.0	0.0	0.0	14.3	15.1
Totals	0.8	0.0	0.0	0.0	14.3	15.1

As-Generated Form: Stored: 42.5 Projected: 637.5 Total: 680.0

Final Waste Form: Stored: 0.8 Projected: 14.3 Total: 15.1

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 221HB Line, a separation facility for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	undetermined	Stream Name:	CH TRU - Vitrified debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	807.5	552.5	977.5	425.0	212.5	2975.0
Box / 16in W x 29in L x 32in H	23.2	39.0	65.8	36.5	23.2	187.7
Drum / 55-gallon	96.5	185.7	313.0	179.4	107.8	882.4
Totals	927.2	777.2	1356.2	640.8	343.5	4045.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	33.8	0.0	0.0	0.0	478.4	512.2
Totals	33.8	0.0	0.0	0.0	478.4	512.2

As-Generated Form: Stored: 927.2 Projected: 3117.8 Total: 4045.1

Final Waste Form: Stored: 33.8 Projected: 478.4 Total: 512.2

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 221 HB Line, a separations facility for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH TRU Heterogeneous debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	0.0	0.0	0.0	42.5	85.0
Drum / 55-gallon	2.8	4.8	6.5	16.5	13.5	44.0
Totals	45.3	4.8	6.5	16.5	56.0	129.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	163.0	0.0	0.0	0.0	205.2	368.2
Totals	163.0	0.0	0.0	0.0	205.2	368.2

As-Generated Form: Stored: 45.3 Projected: 83.7 Total: 129.0

Final Waste Form: Stored: 163.0 Projected: 205.2 Total: 368.2

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 235F during separations activites for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Metal debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No,
Asbestos:	No
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	0.0	0.0	0.0	42.5	85.0
Totals	42.5	0.0	0.0	0.0	42.5	85.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	0.0	1.9	1.9
Totals	0.0	0.0	0.0	0.0	1.9	1.9

As-Generated Form: Stored: 42.5 Projected: 42.5 Total: 85.0

Final Waste Form: Stored: 0.0 Projected: 1.9 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 235F during separation activities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Vitrified debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	807.5	0.0	42.5	0.0	85.0	935.0
Box / 16in W x 29in L x 32in H	7.9	4.3	4.8	13.5	11.7	42.3
Drum / 55-gallon	4.0	19.0	24.2	65.2	56.1	168.5
Totals	819.4	23.4	71.5	78.7	152.8	1145.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	1.5	0.0	0.0	0.0	85.5	87.0
Totals	1.5	0.0	0.0	0.0	85.5	87.0

As-Generated Form: Stored: 819.4 Projected: 326.4 Total: 1145.8

Final Waste Form: Stored: 1.5 Projected: 85.5 Total: 87.0

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 235F during separations activities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH TRU - Heterogeneous debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	0.0	0.0	0.0	0.0	42.5	42.5
Drum / 55-gallon	21.8	0.4	0.8	1.2	1.0	25.2
Totals	21.8	0.4	0.8	1.2	43.5	67.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	29.1	0.0	0.0	0.0	11.5	40.6
Totals	29.1	0.0	0.0	0.0	11.5	40.6

As-Generated Form: Stored: 21.8 Projected: 45.9 Total: 67.7

Final Waste Form: Stored: 29.1 Projected: 11.5 Total: 40.6

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was produced in 772F, an analytical lab used to support H and F canyon processing, the Pu-238 program, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Metal debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	0.0	0.0	0.0	0.0	42.5	42.5
Totals	0.0	0.0	0.0	0.0	42.5	42.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.0	0.0	0.0	0.0	1.9	1.9
Totals	0.0	0.0	0.0	0.0	1.9	1.9

As-Generated Form; Stored: 0.0 Projected: 42.5 Total: 42.5

Final Waste Form; Stored: 0.0 Projected: 1.9 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 772F, an analytical lab used to support H and F canyon processing, Pu-238 program, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Vitrified debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	0.0	0.0	0.0	0.0	42.5	42.5
Box / 16in W x 29in L x 32in H	1.3	0.3	0.5	1.0	1.0	4.1
Drum / 55-gallon	2.8	1.4	2.6	5.0	4.4	16.1
Totals	4.0	1.6	3.1	6.0	47.9	62.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	7.6	7.8
Totals	0.2	0.0	0.0	0.0	7.6	7.8

As-Generated Form: Stored: 4.0 Projected: 58.6 Total: 62.6

Final Waste Form: Stored: 0.2 Projected: 7.6 Total: 7.8

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 772F, an analytical lab used to support H and F canyon processing, the Pu-238 mission, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	N/A	Stream Name:	CH TRU - Classified waste from 773A	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues:

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 162 ft3	23.0	0.0	0.0	0.0	0.0	23.0
Totals	23.0	0.0	0.0	0.0	0.0	23.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	4.6	0.0	0.0	0.0	0.0	4.6
Totals	4.6	0.0	0.0	0.0	0.0	4.6

As-Generated Form: Stored: 23.0 Projected: 0.0 Total: 23.0

Final Waste Form: Stored: 4.6 Projected: 0.0 Total: 4.6

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in the SED facility with SRTC (Savannah River Technology Center). This facility is no longer operational - D&D will occur.
CURRENT CONTAINER COMMENTS	Classified waste
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	This is classified waste which requires treatment to destroy the current configuration of the waste form.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH TRU - Heterogeneous debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	0.0	0.0	0.0	42.5	85.0
Cask / 27 in x 27 in x 42 in	4.0	0.5	1.5	2.5	2.5	11.0
Drum / 55-gallon	7.5	5.4	8.9	17.8	17.4	57.1
Totals	54.0	5.9	10.4	20.3	62.4	153.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	22.1	0.0	0.0	0.0	257.5	279.6
Totals	22.1	0.0	0.0	0.0	257.5	279.6

As-Generated Form: Stored: 54.0 Projected: 99.1 Total: 153.1

Final Waste Form: Stored: 22.1 Projected: 257.5 Total: 279.6

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 773A, the SRTC laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Metal debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Others	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	42.5	0.0	0.0	85.0	42.5	170.0
Totals	42.5	0.0	0.0	85.0	42.5	170.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	0.4	0.0	0.0	0.0	31.8	32.1
Totals	0.4	0.0	0.0	0.0	31.8	32.1

As-Generated Form: Stored: 42.5 Projected: 127.5 Total: 170.0

Final Waste Form: Stored: 0.4 Projected: 31.8 Total: 32.1

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 773A, SRTC labs (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W074	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH TRU - Vitrified debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-T001	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Others	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	0.0	0.0	0.0	42.5	42.5	85.0
Box / 16in W x 29in L x 32in H	5.1	1.0	2.0	4.3	4.6	17.1
Drum / 55-gallon	0.4	2.4	4.0	7.5	7.3	21.6
Totals	5.5	3.4	6.0	54.4	54.4	123.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.4	0.0	0.0	0.0	15.1	15.5
Totals	0.4	0.0	0.0	0.0	15.1	15.5

As-Generated Form: Stored: 5.5 Projected: 118.2 Total: 123.7

Final Waste Form: Stored: 0.4 Projected: 15.1 Total: 15.5

WASTE STREAM DESCRIPTION	This waste stream is defense related, contact handled TRU waste and is composed of Job Control waste, sludges and resins, HEPA filters and large, metal equipment
WASTE STREAM SOURCE	This stream was generated in 773A, SRTC labs (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	
MANAGEMENT COMMENTS	The current plan is to assay, sort, size reduce and characterize the job control waste in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The liquids, sludges and resins will be vitrified, the HEPA filters affixed and the heterogeneous debris repackaged prior to shipment to WIPP. The possibility exists that treatment (vitrification) may be required for the heterogeneous debris containing Pu238 since it is currently not economical to ship PU238 in the TRUPACT.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	This WTWBIR WS contains Remote Handled that has been processed and became Contact Handled.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W076	Handling:	CH	NMVP #:	SR125A	Stream Name:	RH TRU Heterogeneous Debris from 773A
Local ID:	SR-T003	Type:	TRU	Generator Site:	SR	Final Waste Form:	Heterogeneous

Inventory Date: 12/31/94

Waste Matrix Code: S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.3
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	No
PCBs:	No
Source:	R&D/R&D Laboratory Waste

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Y-90	3.28E+00
Sr-90	3.10E+00
Pu-238	1.69E-01
Pm-147	8.13E-01
Cs-137	3.28E+00
Cm-247	2.43E+00
Ba-137m	3.10E+00

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 27 in. x 27 in. x 42 in.	0.5	1.5	2.5	5.0	5.0	14.5
Totals	0.5	1.5	2.5	5.0	5.0	14.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.6	0.7	1.2	2.5	2.5	7.6
Totals	0.6	0.7	1.2	2.5	2.5	7.6

As-Generated Form: Stored: 0.5 Projected: 14.0 Total: 14.5

Final Waste Form: Stored: 0.6 Projected: 6.9 Total: 7.5

WASTE STREAM DESCRIPTION	This waste consists of miscellaneous job control waste such as laboratory supplies used in research programs in the sheilded cells, e.g. glassware, paper wipes, stainless steel samples vials, poly bottles, pipettes and small lab equipment (stirrers, heaters). In addition to the job control waste, this stream contains shavings from the cuttings of a Mark 16 fuel element. Presently, this waste stream is stored as RH, but is reported as CH because after processing this stream will be CH.
WASTE STREAM SOURCE	This stream was generated as a result of experiments and activities at SRTC in the 773-A Shielded Cells Facility (E-wing). Work was performed with samples of low activity waste from tanks 42 and 51, high activity waste from 11 and 15, salt from tank 41 and 13, process waste from tank 17, in addition to other isotopes stored in the cells,
CURRENT CONTAINER COMMENTS	This box is placed in a cask for storage.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Preliminary plans are to vitrify that portion of the stream that must be treated due to meeting WIPP requirements (PE Ci, FGE and Wattage limits). The portion not needing treatment will be repackaged for shipment to WIPP.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W076	Handling:	CH	NMVP #:	Undetermined	Stream Name:	RH TRU Vitrified Debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-T003	Type:	TRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5000

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 27 in. x 27 in. x 42 in.	0.5	1.5	2.5	5.0	5.0	14.5
Totals	0.5	1.5	2.5	5.0	5.0	14.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.5 Projected: 14.0 Total: 14.5

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	This waste consists of miscellaneous job control waste such as laboratory supplies used in research programs in the sheilded cells, e.g. glassware, paper wipes, stainless steel samples vials, poly bottles, pipettes and small lab equipment (stirrers, heaters). In addition to the job control waste, this stream contains shavings from the cuttings of a Mark 16 fuel element. Presently, this waste stream is stored as RH, but is reported as CH because after processing this stream will be CH.
WASTE STREAM SOURCE	This stream was generated as a result of experiments and activities at SRTC in the 773-A Shielded Cells Facility (E-wing). Work was performed with samples of low activity waste from tanks 42 and 51, high activity waste from 11 and 15, salt from tank 41 and 13, process waste from tank 17, in addition to other isotopes stored in the cells,
CURRENT CONTAINER COMMENTS	The box is placed in a cask for storage.
EPA COMMENTS	N/A
MANAGEMENT COMMENTS	Preliminary plans are to vitrify that portion of the stream that must be treated due to meeting WIPP requirements (PE Ci, FGE and Wattage limits). The portion not needing treatment will be repackaged for shipment to WIPP.
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	Once processed, the final form of this waste stream will become Contact Handled. All final form information for this waste stream is included in SR-T001 projections.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W006	Handling:	CH	NMVP #:	none at this time	Stream Name:	Contact handled TRU/Liquids from 773A	Inventory Date:	12/31/94
Local ID:	SR-W006	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	L2000

AS-GENERATED EPA CODES

D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	1719.0	1559.0	2375.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	467.0	261.0	516.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source: Analytical Laboratory Waste

TRUCON CODE

none at this time

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-239	8.60E+02
Am-241	4.51E-03

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Stainless Steel can / 1 gal	0.1	0.0	0.0	0.0	0.0	0.1
Totals	0.1	0.0	0.0	0.0	0.0	0.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.5	0.0	0.0	0.0	0.0	0.5
Totals	0.5	0.0	0.0	0.0	0.0	0.5

As-Generated Form: Stored: 0.1 Projected: 0.0 Total: 0.1

Final Waste Form: Stored: 0.5 Projected: 0.0 Total: 0.5

WASTE STREAM DESCRIPTION	The stream is a xylene-based chelating agent. It is a homogeneous, flammable liquid containing hazardous constituents. Total activity is 100 nCi/g. The waste is contact handled. TTA stands for Thenoyl Trifluoroacetone.
WASTE STREAM SOURCE	This stream is generated from plutonium extraction analytical procedures at the Savannah River Technology Center. It consists of a homogenous, xylene based, liquid chelating agent.
CURRENT CONTAINER COMMENTS	"SAF-T-CAN" Brand, 1 gallon capacity
EPA COMMENTS	This waste is ignitable only - no contaminant concentration values are used, other than xylenes > 99%.
MANAGEMENT COMMENTS	The waste is stored in a stainless steel can, (Safe-T-Can brand for storage of flammable liquids), in a Satellite Accumulation Area (SAA), which is located in a laboratory hood in Lab B-138 of Building 773-A of SRTC. The preferred option in the PSTP is to assay and characterize the waste stream at the TRU Waste Certification/Characterization Facility (TWCCF), followed by preparation for shipment and disposal at WIPP. Because of the small volume of the stream alternative treatment options are being investigated. One alternative is to handle the waste as a 90 day generator, remove the TRU portion of the stream, and treat the ignitable characteristic.
ACCEPTANCE COMMENTS	GENOPERATI: Chemical Analysis and experimentation - laboratory conducts experiments on low- and high-level radioactive materials, in addition to non-radioactive testing. RECLASS_CO: NA. CATION: HNO3 = 10E-3 (Molar Based on solubility after contact with 1Molar HNO3) per lab procedure.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	17.4	59.7	117.3	59.3	29.7	283.4
Totals	17.4	59.7	117.3	59.3	29.7	283.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	1403.0	1403.0
Totals	0.0	0.0	0.0	0.0	1403.0	1403.0

As-Generated Form: Stored: 17.4 Projected: 266.0 Total: 283.4

Final Waste Form: Stored: 0.0 Projected: 1403.0 Total: 1403.0

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	The stream was prodiced in 221F, a separation facility for Pu-239 production.
CURRENT CONTAINER COMMENTS	None
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID: SR-W026	Handling: CH	NMVP #: undetermined	Stream Name: CH Mixed TRU/Thirds - Vitrified debris from 221F		Inventory Date: 12/31/94
Local ID: SR-W026	Type: MTRU	Generator Site: SR	Final Waste Form: Solidified Inorganics		Waste Matrix Code: S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	13[illegible]		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	Unknown
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	3.6	25.6	50.3	25.2	12.9	117.5
Totals	3.6	25.6	50.3	25.2	12.9	117.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	65.7	65.7
Totals	0.0	0.0	0.0	0.0	65.7	65.7

As-Generated Form: Stored: 3.6 Projected: 114.0 Total: 117.5

Final Waste Form: Stored: 0.0 Projected: 65.7 Total: 65.7

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was produced in 221F a seperations facility for Pu-239.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W033 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final waste form containing >100 nCi/g is combined with SR-W026 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	Unknown
Source:	Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	(Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	14.1	30.9	51.9	29.9	18.2	145.1
Totals	14.1	30.9	51.9	29.9	18.2	145.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	691.4	691.4
Totals	0.0	0.0	0.0	0.0	691.4	691.4

As-Generated Form: Stored: 14.1 Projected: 131.0 Total: 145.1

Final Waste Form: Stored: 0.0 Projected: 691.4 Total: 691.4

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was produced in the 221H - Separation facilities for Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/Thirds - Vitrified debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	Unknown
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	49.0	124.1	208.3	119.5	72.1	573.0
Totals	49.0	124.1	208.3	119.5	72.1	573.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	299.2	299.2
Totals	0.0	0.0	0.0	0.0	299.2	299.2

As-Generated Form: Stored: 49.0 Projected: 524.0 Total: 573.0

Final Waste Form: Stored: 0.0 Projected: 299.2 Total: 299.2

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly *booties*, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was prodiced in 221H, separation facilities for Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	sr125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	2.8	3.4	4.0	10.5	9.7	30.3
Totals	2.8	3.4	4.0	10.5	9.7	30.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	144.8	144.8
Totals	0.0	0.0	0.0	0.0	144.8	144.8

As-Generated Form: Stored: 2.8 Projected: 27.5 Total: 30.3

Final Waste Form: Stored: 0.0 Projected: 144.8 Total: 144.8

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This waste stream was produced in 235-F during separation activities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentrations may vary from 3.2.6.
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/Thirds - Vitrified debris from 235F	Inventory Date:	9/30/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	4.0	12.7	16.1	43.4	37.7	113.8
Totals	4.0	12.7	16.1	43.4	37.7	113.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	63.0	63.0
Totals	0.0	0.0	0.0	0.0	63.0	63.0

As-Generated Form: Stored: 4.0 Projected: 109.8 Total: 113.8

Final Waste Form: Stored: 0.0 Projected: 63.0 Total: 63.0

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This waste stream was produced in 235F during separation activites for the production of Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W033 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final waste form contianing >100 nCi/g is combined with SR0W026 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	1.2	0.2	0.6	1.0	0.4	3.4
Totals	1.2	0.2	0.6	1.0	0.4	3.4

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	11.6	11.6
Totals	0.0	0.0	0.0	0.0	11.6	11.6

As-Generated Form: Stored: 1.2 Projected: 2.2 Total: 3.4

Final Waste Form: Stored: 0.0 Projected: 11.6 Total: 11.6

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This waste stream was produced in 772F, an analytical lab used to support H and F canyon processing, the Pu-238 program etc.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/Thirds - Vitrified debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	Unknown
Source:	Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.4	1.0	1.6	3.2	3.2	9.3
Totals	0.4	1.0	1.6	3.2	3.2	9.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	5.3	5.3
Totals	0.0	0.0	0.0	0.0	5.3	5.3

As-Generated Form: Stored: 0.4 Projected: 8.9 Total: 9.3

Final Waste Form: Stored: 0.0 Projected: 5.3 Total: 5.3

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This waste stream was produced in 772F an analytical lab used to support H and F canyon processing, the Pu-238 program, etc.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W033 could concentrate the TRU fraction above 100 nCi/g, requiring WIPP disposal. The final waste form containing >100 nCi/g TRU radionuclides is combined with SR-W026 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/Thirds Heterogeneous debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
Other	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	3.6	5.9	11.9	11.7	33.1
Totals	0.0	3.6	5.9	11.9	11.7	33.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	174.1	174.1
Totals	0.0	0.0	0.0	0.0	174.1	174.1

As-Generated Form: Stored: 0.0 Projected: 33.1 Total: 33.1

Final Waste Form: Stored: 0.0 Projected: 174.1 Total: 174.1

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly bootles, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was produced in 773A, the SRTC laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W026	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/Thirds - Vitrified debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W026	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: Unknown

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
Other	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	0.0	1.4	2.6	5.0	5.2	14.1
Totals	0.0	1.4	2.6	5.0	5.2	14.1

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.0	0.0	0.0	0.0	8.6	8.6
Totals	0.0	0.0	0.0	0.0	8.6	8.6

As-Generated Form: Stored: 0.0 Projected: 14.1 Total: 14.1

Final Waste Form: Stored: 0.0 Projected: 8.6 Total: 8.6

WASTE STREAM DESCRIPTION	200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly booties, lab coats, floor sweepings, rags, labware, and other job control wastes. Small Hepas, liquids, sludges and resins may also be found in this stream. The waste is generated primarily through separation activities in the course of plutonium production, includes small amounts of TRU waste from on site laboratories.
WASTE STREAM SOURCE	This stream was produced in 773A, the SRTC laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	Process knowledge was used to characterize this waste stream , and therefore the confidence is medium.
MANAGEMENT COMMENTS	All the waste in this stream is currently stored on TRU Pads 7 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be placed in covered storage on pads 15-19. The current plan is to at least assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W033 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be combined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W033 could concentrate the TRU fraction above 100 nCi/g, requiring WIPP disposal. The final waste form containing >100 nCi/g TRU radionuclides is combined with SR-W026 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	4.2	0.0	0.0	0.0	0.0	4.2
Drum / 55-gallon	265.8	0.0	0.0	0.0	0.0	265.8
Totals	270.0	0.0	0.0	0.0	0.0	270.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	265.6	0.0	0.0	0.0	0.0	265.6
Totals	265.6	0.0	0.0	0.0	0.0	265.6

As-Generated Form: Stored: 270.0 Projected: 0.0 Total: 270.0

Final Waste Form: Stored: 265.6 Projected: 0.0 Total: 265.6

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 221F, a separations facility for the production of Pu-239 .
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	4.2	0.0	0.0	0.0	0.0	4.2
Totals	4.2	0.0	0.0	0.0	0.0	4.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 4.2 Projected: 0.0 Total: 4.2

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 221F, a separations facility for the production of Pu-239 .
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 221F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	7.0	0.0	0.0	0.0	0.0	7.0
Drum / 55-gallon	289.8	0.0	0.0	0.0	0.0	289.8
Totals	296.8	0.0	0.0	0.0	0.0	296.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	33.2	0.0	0.0	0.0	0.0	33.2
Totals	33.2	0.0	0.0	0.0	0.0	33.2

As-Generated Form: Stored: 296.8 Projected: 0.0 Total: 296.8

Final Waste Form: Stored: 33.2 Projected: 0.0 Total: 33.2

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 221F, a separations facility for the production of Pu-239 .
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final waste form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	6.8	0.0	0.0	0.0	0.0	6.8
Totals	6.8	0.0	0.0	0.0	0.0	6.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	125.4	0.0	0.0	0.0	0.0	125.4
Totals	125.4	0.0	0.0	0.0	0.0	125.4

As-Generated Form: Stored: 6.8 Projected: 0.0 Total: 6.8

Final Waste Form: Stored: 125.4 Projected: 0.0 Total: 125.4

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in the 221H separation facilities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	6.8	0.0	0.0	0.0	0.0	6.8
Totals	6.8	0.0	0.0	0.0	0.0	6.8

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 6.8 Projected: 0.0 Total: 6.8

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of bootles, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in the 221H separation facilities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 221H	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / 12ft W x 18ft L x 7ft H	977.5	0.0	0.0	0.0	0.0	977.5
Box / Misc.	0.0	0.0	0.0	0.0	0.0	0.0
Drum / 55-gallon	186.7	0.0	0.0	0.0	0.0	186.7
Totals	1164.2	0.0	0.0	0.0	0.0	1164.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	25.9	0.0	0.0	0.0	0.0	25.9
Totals	25.9	0.0	0.0	0.0	0.0	25.9

As-Generated Form: Stored: 1164.2 Projected: 0.0 Total: 1164.2

Final Waste Form: Stored: 25.9 Projected: 0.0 Total: 25.9

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in the 221H separation facilities for the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATON: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 235F	Inventory Date:	
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	34.5	0.0	0.0	0.0	0.0	34.5
MSMC	0.0	0.0	0.0	0.0	0.0	0.0
Totals	34.5	0.0	0.0	0.0	0.0	34.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	34.7	0.0	0.0	0.0	0.0	34.7
Totals	34.7	0.0	0.0	0.0	0.0	34.7

As-Generated Form: Stored: 34.5 Projected: 0.0 Total: 34.5

Final Waste Form: Stored: 34.7 Projected: 0.0 Total: 34.7

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 235F due to separation activities during the production of Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 235F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / MSMC	2.3	0.0	0.0	0.0	0.0	2.3
Totals	2.3	0.0	0.0	0.0	0.0	2.3

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	1.9	0.0	0.0	0.0	0.0	1.9
Totals	1.9	0.0	0.0	0.0	0.0	1.9

As-Generated Form: Stored: 2.3 Projected: 0.0 Total: 2.3

Final Waste Form: Stored: 1.9 Projected: 0.0 Total: 1.9

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 235F due to separation activities during the production of Pu-238.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 235F	Inventory Date:	
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	0.0	0.0	0.0	0.0	0.0	0.0
Drum / 55-gallon	137.0	0.0	0.0	0.0	0.0	137.0
MSMC	0.0	0.0	0.0	0.0	0.0	0.0
Totals	137.0	0.0	0.0	0.0	0.0	137.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	16.6	0.0	0.0	0.0	0.0	16.6
Totals	16.6	0.0	0.0	0.0	0.0	16.6

As-Generated Form: Stored: 137.0 Projected: 0.0 Total: 137.0

Final Waste Form: Stored: 16.6 Projected: 0.0 Total: 16.6

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of bootles, 'sb coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 235F due to separation activities during the production of Pu-238.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	33.5	0.0	0.0	0.0	0.0	33.5
Drum / 55-gallon	510.2	0.0	0.0	0.0	0.0	510.2
Totals	543.6	0.0	0.0	0.0	0.0	543.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	515.4	0.0	0.0	0.0	0.0	515.4
Totals	515.4	0.0	0.0	0.0	0.0	515.4

As-Generated Form: Stored: 543.6 Projected: 0.0 Total: 543.6

Final Waste Form: Stored: 515.4 Projected: 0.0 Total: 515.4

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 772F, an analytical lab used to support F and H canyon processing, Pu-238 mission, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	33.5	0.0	0.0	0.0	0.0	33.5
Totals	33.5	0.0	0.0	0.0	0.0	33.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	32.1	0.0	0.0	0.0	0.0	32.1
Totals	32.1	0.0	0.0	0.0	0.0	32.1

As-Generated Form: Stored: 33.5 Projected: 0.0 Total: 33.5

Final Waste Form: Stored: 32.1 Projected: 0.0 Total: 32.1

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 772F, an analytical lab used to support F and H canyon processing, Pu-238 mission, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 772F	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	7.1	0.0	0.0	0.0	0.0	7.1
Drum / 55-gallon	88.6	0.0	0.0	0.0	0.0	88.6
Totals	95.7	0.0	0.0	0.0	0.0	95.7

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	10.6	0.0	0.0	0.0	0.0	10.6
Totals	10.6	0.0	0.0	0.0	0.0	10.6

As-Generated Form: Stored: 95.7 Projected: 0.0 Total: 95.7

Final Waste Form: Stored: 10.6 Projected: 0.0 Total: 10.6

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was produced in 772F, an analytical lab used to support F and H canyon processing, Pu-238 mission, etc.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category:	Defense TRU Waste
Residues:	No
Asbestos:	Unknown
PCBs:	No
Source:	Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	41.0	0.0	0.0	0.0	0.0	41.0
Cask / 27 in x 27 in x 42 in	67.0	0.0	0.0	0.0	0.0	67.0
Drum / 55-gallon	134.0	0.0	0.0	0.0	0.0	134.0
Totals	242.0	0.0	0.0	0.0	0.0	242.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	331.1	0.0	0.0	0.0	0.0	331.1
Totals	331.1	0.0	0.0	0.0	0.0	331.1

As-Generated Form: Stored: 242.0 Projected: 0.0 Total: 242.0

Final Waste Form: Stored: 331.1 Projected: 0.0 Total: 331.1

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of bootles, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was generated in 773A, the SRTC laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Metal debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Uncategorized Metal	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	83.7	0.0	317.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	195.2	0.0	1586.5
Other Inorganic Material:	19.3	0.0	19.3
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	154.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	41.0	0.0	0.0	0.0	0.0	41.0
Totals	41.0	0.0	0.0	0.0	0.0	41.0

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Standard Waste Box	7.6	0.0	0.0	0.0	0.0	7.6
Totals	7.6	0.0	0.0	0.0	0.0	7.6

As-Generated Form: Stored: 41.0 Projected: 0.0 Total: 41.0

Final Waste Form: Stored: 7.6 Projected: 0.0 Total: 7.6

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of bootles, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was generated in 773A, the SRTC analytical laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from 773A	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

Undetermined

FINAL FORM RADIONUCLIDES

Isotope (	Ci/m3)
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	8.2	0.0	0.0	0.0	0.0	8.2
Cask / 27 in x 27 in x 42 in	32.0	0.0	0.0	0.0	0.0	32.0
Drum / 55-gallon	49.4	0.0	0.0	0.0	0.0	49.4
Totals	89.6	0.0	0.0	0.0	0.0	89.6

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	17.3	0.0	0.0	0.0	0.0	17.3
Totals	17.3	0.0	0.0	0.0	0.0	17.3

As-Generated Form: Stored: 89.6 Projected: 0.0 Total: 89.6

Final Waste Form: Stored: 17.3 Projected: 0.0 Total: 17.3

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This stream was generated in 773A, the SRTC analytical laboratories (Savannah River Technology Center).
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	Treatment of WS SR-W025 could concentrate the TRU fraction above 100 nCi/g requiring WIPP disposal. The final form containing >100 nCi/g TRU radionuclides is combined with SR-W027 final waste form volumes.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	SR125A	Stream Name:	CH Mixed TRU/F listed solvents - Heterogeneous debris from offsite	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Heterogeneous	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	1.1	0.0	4.2
Vitrified:	0.0	0.0	0.0
Cellulosics:	115.8	0.0	576.9
Rubber:	11.1	0.0	47.8
Plastics:	33.3	0.0	84.4
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

SR125A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.54E+01
Pu-240	3.17E-01
Pu-239	1.28E+01
Pu-238	7.71E+01
OTHERS	1.68E-01
Am-241	2.77E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Drum / 55-gallon	27.9	0.0	0.0	0.0	0.0	27.9
Totals	27.9	0.0	0.0	0.0	0.0	27.9

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	27.7	0.0	0.0	0.0	0.0	27.7
Totals	27.7	0.0	0.0	0.0	0.0	27.7

As-Generated Form: Stored: 27.9 Projected: 0.0 Total: 27.9

Final Waste Form: Stored: 27.7 Projected: 0.0 Total: 27.7

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This waste was generated and shipped to SRS from the Mound facility and Los Alamos Scientific Laboratory.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. GECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NADR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W027	Handling:	CH	NMVP #:	Undetermined	Stream Name:	CH Mixed TRU/F listed solvents - Vitrified debris from offsite	Inventory Date:	12/31/94
Local ID:	SR-W0027	Type:	MTRU	Generator Site:	SR	Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S5400

AS-GENERATED EPA CODES

U239, U226, U220, U211, U209, U161, U154, U151, U144, U134, U133, U080, U052, U032, U002, P120, P113, P048, P015, P012, F005, F003, F002, F001, D026, D025, D024, D023, D022, D019, D018, D011, D009, D008, D007, D006, D004, D003, D001

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	2039.0	1344.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	146.0	0.0	364.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: Unknown

PCBs: No

Source: Other/Multiple Sources

TRUCON CODE

undetermined

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-241	1.00E+01
Pu-240	2.06E-01
Pu-239	8.35E-01
Pu-238	5.01E+01
OTHERS	1.68E-01
Cm-244	1.04E-01
Am-241	1.80E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
Box / Misc.	26.8	0.0	0.0	0.0	0.0	26.8
Drum / 55-gallon	20.4	0.0	0.0	0.0	0.0	20.4
Totals	47.2	0.0	0.0	0.0	0.0	47.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	31.8	0.0	0.0	0.0	0.0	31.8
Totals	31.8	0.0	0.0	0.0	0.0	31.8

As-Generated Form: Stored: 47.2 Projected: 0.0 Total: 47.2

Final Waste Form: Stored: 31.8 Projected: 0.0 Total: 31.8

WASTE STREAM DESCRIPTION	This waste stream is primarily solids consisting of booties, lab coats, floor sweeping, labware, rags, and other job control waste. This stream differs from SR-W026 because solvent rags are suspected to be in the waste.
WASTE STREAM SOURCE	This waste was generated and shipped to SRS from the Mound facility and Los Alamos Scientific Laboratory.
CURRENT CONTAINER COMMENTS	Radionuclide concentration may vary from 3.2.6.
EPA COMMENTS	A conservative interpretation of the mixed waste rule resulted in this waste stream being listed as solvent waste because of the potential presence of solvent rags. Process knowledge is used to characterize this wastestream.
MANAGEMENT COMMENTS	The waste in this stream is currently stored on TRU Pads 2 through 17. Pads 15-17 are enclosed and plans are to enclose pads 18 and 19 in the near future. As part of a mixed waste management plan, SRS is reorganizing the containers so that all mixed waste on pads 7-14 will be moved to covered storage on pads 15-19. Waste on pads 2-6 are buried. Retrieval of this waste is scheduled to begin in FY 97 after which the drums will be vented, purged and then placed on pads 15-19. The current plan is to assay, sort, size reduce and characterize the waste stream in the TRU Waste Certification/Characterization Facility (TWCCP), followed by preparation shipment to, disposal at, WIPP. The possibility exists that treatment may be required before shipment to WIPP since it is currently not economical to ship PU238 in the TRUPACT. Treatment of WS SR-W025 could concentrate the TRU fraction above 100nCi/g requiring WIPP disposal. The final waste forms containing >100nCi/g TRU radionuclides will be ocmbined with SR-W026 final waste volumes.
ACCEPTANCE COMMENTS	Section 7.1: Breakdown of container #'s is estimated from total # in storage. Boxes and drums in culverts on Pads 7-17 are assumed to be TRU. For other pads and containers, 64% are estimated to be TRU. Waste on Pads 1-6 is assumed to be all solvent rags. Section 7.2: SRS TRU waste is found under TRUCON codes SR116A,B,C, SR122A,B,C and SR125A. GENERAAREA: 221 HB-Line, 221 FB-Line, 773-A, 772-F, 235-FGENOPERATI: Production of plutonium, uranium, neptunium, and laboratory support activities. RECLASS_CO: All waste identified by SR-W025, W026, W027, W033 will be assayed to determine TRU classification. Current classifications are based on process knowledge. CATION: NALDR_DETERM: Wastes placed in storage prior to LDR effective date (11/8/86). WASTE_PACK: Waste is double-bagged and placed in a 90-mil polyethylene drum liner inside a 55-gallon carbon steel drum. The liner lid is glued in place. Drums with greater than 0.5 Ci total activity are placed inside concrete culverts for additional shielding. In addition, large carbon steel boxes are used to store waste equipment from the Canyon processes and other large, bulky wastes.
FINAL FORM COMMENTS	N/A

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	SR-W053	Handling:	CH	NMVP #:	none at this time	Stream Name:	Contact handled mixed TRU/Residues from 773A	Inventory Date:	12/31/94
Local ID:	SR-W053	Type:	MTRU	Generator Site:		Final Waste Form:	Solidified Inorganics	Waste Matrix Code:	S3111

AS-GENERATED EPA CODES

F005, F002, F001, D011, D010, D009, D008, D007, D006, D005, D004

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	273.0	87.0	944.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	2415.0	2205.0	2473.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	0.0	0.0	0.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	0.0		
Packaging Material Plastic:	0.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: Yes

Asbestos: No

PCBs: No

Source: R&D/R&D Laboratory Waste

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope	Ci/m3
Pu-239	6.40E+02

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
small carton in 30 gal containers	0.5	0.0	0.0	0.0	0.0	0.5
Totals	0.5	0.0	0.0	0.0	0.0	0.5

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.5	0.0	0.0	0.0	0.0	0.5
Totals	0.5	0.0	0.0	0.0	0.0	0.5

As-Generated Form: Stored: 0.5 Projected: 0.0 Total: 0.5

Final Waste Form: Stored: 0.5 Projected: 0.0 Total: 0.5

WASTE STREAM DESCRIPTION	This waste stream consists of Rocky Flats Incinerator Ash and F-listed solvents, and is contaminated with TRU nuclides from SRS laboratories. This waste is classified as contact-handled.
WASTE STREAM SOURCE	This ash was sent to SRS from Rocky Flats for research into plutonium recovery. The ash was classified as hazardous by the Colorado Court System based on chemical analysis of F-listed solvent wste processed in the Rocky Flats Incinerator. SRS subsequently cancelled the research. The ash was declared mixed after SRS handled the waste as a Special Nuclear Material (SNM) in a SRTC vault.
CURRENT CONTAINER COMMENTS	paper cartons are placed in 30 gallon shipping containers
EPA COMMENTS	The confidence level is low because process knowledge was used for characterization, no analytical data is available.
MANAGEMENT COMMENTS	The preferred treatment option is to return the ash to Rocky Flats for consolidation and treatment with similar wastes. Treatment (if any) would then be at the discretion of Rocky Flats. Until a full agreement between SRS and RF has been reached, preliminary plans indicate SRS would add this small stream to a larger stream for vitrification. The waste itself is in four small cartons which are placed in 30 gallon shipping containers at a ratio of two small cartons per shipping container.
ACCEPTANCE COMMENTS	One-time generation. Went in storage prior to the effective date of May 8, 1992.
FINAL FORM COMMENTS	This stream is currently stored in a total of 4 cartons which are placed in 30 gallon shipping containers (not TRAMPAC approved). 2 cartons per shipping container. The containers are stored in 235-F.

TELEDYNE-BROWN ENGINEERING

Location and Description

Teledyne-Brown Engineering (TB) in Westwood, New Jersey, provided long-term contract services to DOE for the decontamination and recovery of DOE-owned precious metals. This effort under the DOE Precious Metal Program has since been transferred to Martin Marietta Energy Systems at the Oak Ridge Reservation.

Mission

Since 1986, the TB facility (formerly referred to as Teledyne Isotopes) has been in possession of nine grams of plutonium waste which were transferred from the Rocky Flats Plant with other precious metal-containing materials. Teledyne Isotopes was under contract with Westinghouse Materials Company of Ohio to decontaminate and recover DOE precious metals (e.g., platinum, gold, and rhodium) and return this metal to various DOE pool accounts. Normally the waste from the recovery process was disposed of at commercial sites, but this quantity exceeded disposal site limits. The waste must be shipped to a DOE site.

Waste Information

Processes

The by-product of the recovery process is a single drum of vitrified glass containing nine grams of plutonium. The material consists of approximately 150 pounds of vitrified lead-borosilicate glass chucks which are double-bagged, with each bag containing about 25 pounds. The drum is believed to contain no hazardous constituents other than Pu-239. The waste is stored in a 55-gallon stainless steel drum obtained from Oak Ridge National Laboratory. TB has a NuPAC N-55 overpack container which they plan to use in moving the waste to a DOE site.

TRU WASTE BASELINE INVENTORY WASTE PROFILE

HQ ID:	TB-W001	Handling:	CH	NMVP #:	N/A	Stream Name:	Teledyne Brown Vitrified Borosilicate Glass	Inventory Date:	12/31/94
Local ID:		Type:	TRU	Generator Site:		Final Waste Form:	Inorganic Non-Metal	Waste Matrix Code:	Z1120

AS-GENERATED EPA CODES

N/A

WASTE MATERIAL PARAMETERS (kg/m3)

	Avg	Min	Max
Iron-base Metal/Alloys:	0.0	0.0	0.0
Aluminum-base Metal/Alloys:	0.0	0.0	0.0
Other Metals/Alloys:	0.0	0.0	0.0
Other Inorganic Material:	0.0	0.0	0.0
Vitrified:	0.0	0.0	0.0
Cellulosics:	0.0	0.0	0.0
Rubber:	0.0	0.0	0.0
Plastics:	0.0	0.0	0.0
Solidified Inorganic Material:	327.0	327.0	327.0
Solidified Organic Material:	0.0	0.0	0.0
Cement (solidified):	0.0	0.0	0.0
Soils:	0.0	0.0	0.0
Packaging Material Steel:	131.0		
Packaging Material Plastic:	37.0		
Packaging Material Lead:	0.0		
Packaging Material Steel Plug:	0.0		

FINAL WASTE FORM DESCRIPTORS

Category: Defense TRU Waste

Residues: No

Asbestos: No

PCBs: No

Source:

TRUCON CODE

N/A

FINAL FORM RADIONUCLIDES

Isotope (Ci/m3)	
Pu-239	5.50E-01

WASTE VOLUME DETAIL (cu. meters)

As-Generated Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

Final Waste Form Volumes

Container	Stored	Pre-97	98-02	03-12	13-22	Totals
55 Gallon Drum	0.2	0.0	0.0	0.0	0.0	0.2
Totals	0.2	0.0	0.0	0.0	0.0	0.2

As-Generated Form: Stored: 0.2 Projected: 0.0 Total: 0.2

Final Waste Form: Stored: 0.2 Projected: 0.0 Total: 0.2

WASTE STREAM DESCRIPTION	A 55-gallon stainless steel drum containing 9 grams of DOE-owned plutonium waste in the form of 150 lbs. of lead - borosilicate glass.
WASTE STREAM SOURCE	By-product of a precious metals recovery process. Materials with 9 grams of Pu were transferred from the Rocky Flats Plant to Teledyne Isotopes in 1986 for processing. 150 pounds of Borosilicate glass.
CURRENT CONTAINER COMMENTS	N/A
EPA COMMENTS	
MANAGEMENT COMMENTS	N/A
ACCEPTANCE COMMENTS	N/A
FINAL FORM COMMENTS	N/A

DOE/CAO-95-1121

TRANSURANIC WASTE BASELINE INVENTORY REPORT

(REVISION 3)

June 1996

NOTICE TO READERS

This document, Revision 3 of the Transuranic Waste Baseline Inventory Report (TWBIR), has been prepared to document the transuranic (TRU) waste inventory data to be used in the Sandia National Laboratories/New Mexico (SNL/NM) calculations for the Waste Isolation Pilot Plant's (WIPP's) performance assessment (PA). The TWBIR Revision 3, is comprised of previously published information found in Revision 2 of the TWBIR and supplemented with information and data that were specifically requested by the U.S. Department of Energy (DOE) Carlsbad Area Office (CAO) for the SNL/NM PA calculations.

The data contained in this document will also be used as the inventory basis for the WIPP Compliance Certification Application (CCA) to be submitted to the U.S. Environmental Protection Agency. The site information requested in the January 1996 data call has not been included in Revision 3. Future editions of the TWBIR will be identified by the year of data origin.

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ACRONYMS AND ABBREVIATIONS

AE	Argonne National Laboratory-East site identifier
AL	Ames Laboratory site identifier
AM	ARCO Medical Products Company site identifier
AW	ANL-W site identifier
BC	Battelle Columbus Laboratory site identifier
BT	Bettis Atomic Power Laboratory site identifier
C&C Agreement	Agreement for Consultation and Cooperation between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant
CAO	Carlsbad Area Office
CCA	Compliance Certification Application
CFR	Code of Federal Regulations
CH	contact-handled
CY	calendar year
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
ET	Energy Technology Engineering Center site identifier
FFCAct	Federal Facilities Compliance Act
IDB	Integrated Data Base
IN	Idaho National Engineering Laboratory site identifier
IT	Inhalation Toxicology Research Institute site identifier
KA	Knolls Atomic Power Laboratory-Schenectady site identifier
kg	kilograms
LA	Los Alamos National Laboratory site identifier
LANL	Los Alamos National Laboratory
LB	Lawrence Berkeley Laboratory site identifier
LL	Lawrence Livermore National Laboratory site identifier
LWA	Land Withdrawal Act
MC	U.S. Army Material Command
MD	Mound Plant site identifier
m^3	cubic meters
mrem	millirem
MU	University of Missouri Research Reactor site identifier
NT	Nevada Test Site site identifier
OR	Oak Ridge National Laboratory site identifier
ORIGEN2	Oak Ridge Isotope Generation and Depletion Code
ORNL	Oak Ridge National Laboratory
PA	performance assessment (in text only)
PA	Paducah Gaseous Diffusion Plant site identifier (in waste profiles only)
PCB	polychlorinated biphenyls
PX	Pantex site identifier
RCRA	Resource Conservation and Recovery Act
RF	Rocky Flats Environmental Technology Site site identifier
RFETS	Rocky Flats Environmental Technology Site

RH	remote-handled
RL	Hanford (Richland) site identifier
SA	Sandia National Laboratories/New Mexico site identifier
SNL/NM	Sandia National Laboratories/New Mexico
SR	Savannah River Site site identifier
SRS	Savannah River Site
TB	Teledyne Brown Engineering
TOC	total organic carbon
TRU	transuranic
TWBIR	Transuranic Waste Baseline Inventory Report
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Plant
WMC	waste matrix code
WMP	waste material parameter
WV	West Valley Demonstration Project site identifier

EXECUTIVE SUMMARY

The *Transuranic Waste Baseline Inventory Report* (TWBIR) establishes a methodology for grouping wastes of similar physical and chemical properties from across the U.S. Department of Energy (DOE) transuranic (TRU) waste system into a series of "waste profiles" that can be used as the basis for waste form discussions with regulatory agencies.

The purpose of Revisions 0 and 1 of this report was to provide data to be included in the Sandia National Laboratories/New Mexico (SNL/NM) performance assessment (PA) processes for the Waste Isolation Pilot Plant (WIPP). Revision 2 of the document expanded the original purpose and was also intended to support the WIPP Land Withdrawal Act (LWA) requirement for providing the total DOE TRU waste inventory. The document included a chapter and an appendix that discussed the total DOE TRU waste inventory, including nondefense, commercial, polychlorinated biphenyls (PCB)-contaminated, and buried (predominately pre-1970) TRU wastes that are not planned to be disposed of at WIPP.

Revision 3 of the TWBIR is based on the TWBIR Revision 2 data which are supplemented by data in several memoranda issued during early calendar year (CY) 1996. These memoranda summarize additional data requested by the U. S. Department of Energy/Carlsbad Area Office (DOE/CAO) to support the SNL/NM PA modeling. The primary purpose of Revision 3 is to provide the summary data from TWBIR Revision 2 and the supplemental information used by SNL/NM in the development of the Compliance Certification Application (CCA) to be delivered to the Environmental Protection Agency (EPA), and to support the LWA (Public Law, 1992b). The supplemental information was generated from specific data requests to the TRU waste sites since the publication of Revision 2. The supplemental data discussed in detail in Chapter 3 and Appendices A and B are listed below:

- Radionuclide data in support of the Compliance Certification Application.
- Estimate of complexing agents in TRU solidified waste forms scheduled for disposal in WIPP.
- Estimate for SNL/NM PA calculations of nitrate, sulfate, and phosphate content in transuranic solidified wastes destined for disposal in WIPP.
- Estimate of cement content in TRU solidified waste forms scheduled for disposal in WIPP.

Revision 2 of the TWBIR included both the TRU waste that is allowed to be disposed of in WIPP and the DOE TRU waste that is not currently allowed to be disposed of in WIPP (Public Law, 1992b). Because the primary purpose of this Revision 3 TWBIR is to support the CCA and PA, it includes only the DOE TRU waste that is currently allowed to be disposed of in WIPP.

Revision 3 of the TWBIR is different from previous revisions in that it provides the TRU waste inventory information developed for Revision 2 along with supplemental data. It is necessary for the reader to be familiar with Revision 2 of the TWBIR to understand this TWBIR Revision 3 document. Much of the TWBIR Revision 2 information is referenced, rather than repeated, in this document, resulting in an abbreviated document. Revision 3 of the TWBIR consists of one volume having five chapters and four appendices. There is not a new electronic database for

TWBIR Revision 3 because the data in the Revision 2 database are unchanged; therefore new database diskettes are not being published with this document.

The WIPP anticipated (stored and projected) inventory of TRU waste is defined as the sum of retrievably stored waste plus currently projected TRU waste volumes. Current projections do not include waste generated as a result of future environmental restoration (ER) and decontamination and decommissioning (D&D) activities and have only been developed over a 25 year period, consequently the anticipated inventory for CH-TRU waste is not sufficient to fill the maximum CH-TRU disposal inventory for WIPP (calculated to be approximately 168,500 cubic meters or 5,950,000 cubic feet). Scaling has been developed as a means for SNL/NM to model the impacts of a full repository. Scaling has not been applied to the RH-TRU inventory since the sites have reported sufficient RH-TRU waste to fill the RH-TRU disposal inventory (approximately 7,080 cubic meters or 250,000 cubic feet).

The TWBIR also estimates the WIPP disposal inventory in terms of 12 waste material parameters and additional packaging materials that have been identified by SNL/NM as necessary for PA. The 12 waste material parameters and additional packaging materials are constituents of TRU waste and are input parameters for one or more PA models or are required to adequately describe the waste form.

The 12 waste material parameters and additional packaging materials are listed below:

Waste Material Parameters
- Iron-base metal/alloys
- Aluminum-base metal/alloys
- Other metal/alloys
- Other inorganic materials
- Vitrified
- Cellulosics
- Rubber
- Plastics
- Solidified inorganic material
- Solidified organic material
- Cement (solidified)
- Soils

Packaging Materials
- Steel
- Plastic
- Lead (for RH-TRU waste only)

The waste material parameters are expressed on a weight/volume (kilograms per cubic meter) basis. The occurrence of more than one waste material parameter at the maximum value within a waste stream is highly unlikely. If required by PA calculations, the sampling statistics must be controlled so that several waste material parameters do not get sampled all at their maximum value (weight/volume), thereby exceeding the average weight/volume.

Attached to this Executive Summary are several summary tables from the body of the TWBIR Revision 3 which are frequently requested by TWBIR users:

- Table ES-1. WIPP CH-TRU Waste Material Parameter Disposal Inventory
- Table ES-2. WIPP RH-TRU Waste Material Parameter Disposal Inventory
- Table ES-3. WIPP CH-TRU Waste Anticipated Inventory by Site
- Table ES-4. WIPP RH-TRU Waste Anticipated Inventory by Site
- Table ES-5. Summary Radionuclide Inventory

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Table ES-1. WIPP CH-TRU Waste Material Parameter Disposal Inventory*

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2.6E+03	1.7E+02	0.0E+00
Aluminum Base Metal/Alloys	8.0E+02	1.8E+01	0.0E+00
Other Metal/Alloys	1.6E+03	6.7E+01	0.0E+00
Other Inorganic Materials	1.4E+03	3.1E+01	0.0E+00
Vitrified	2.5E+03	5.5E+01	0.0E+00
Cellulosics	9.6E+02	5.4E+01	0.0E+00
Rubber	6.3E+02	1.0E+01	0.0E+00
Plastics	8.9E+02	3.4E+01	0.0E+00
Solidified Inorganic Material	2.2E+03	5.4E+01	0.0E+00
Solidified Organic Material	1.4E+03	5.6E+00	0.0E+00
Cement (Solidified)	1.2E+03	5.0E+01	0.0E+00
Soils	1.6E+03	4.4E+01	0.0E+00
Container Materials - Kg/m3			
Steel		139	
Plastic/ Liners		26	

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*This table is identical to Table ES-1 of TWBIR Revision 2, page ES-4 (DOE, 1995c).

Table ES-2. WIPP RH-TRU Waste Material Parameter Disposal Inventory*

Waste Material Parameters (Kg/m3	Maximum	Average	Minimum
Iron Base Metal/Alloys	1.7E+03	1.0E+02	0.0E+00
Aluminum Base Metal/Alloys	1.7E+02	7.1E+00	0.0E+00
Other Metal/Alloys	9.1E+02	2.5E+02	0.0E+00
Other Inorganic Materials	2.0E+03	6.4E+01	0.0E+00
Vitrified	2.5E+03	4.7E+00	0.0E+00
Cellulosics	5.7E+02	1.7E+01	0.0E+00
Rubber	4.4E+02	3.3E+00	0.0E+00
Plastics	6.2E+02	1.5E+01	0.0E+00
Solidified Inorganic Material	6.1E+02	2.2E+01	0.0E+00
Solidified Organic Material	8.1E+02	9.3E-01	0.0E+00
Cement (Solidified)	5.8E+02	1.9E+01	0.0E+00
Soils	2.4E+01	1.0E+00	0.0E+00
Container Materials - Kg/m3			
Steel		446	
Plastic/Liners		3.1	
Lead		465	
Steel Plug		2145	

*This table is identical to Table ES-2 of TWBIR Revision 2, page ES-5 (DOE, 1995c).

Table ES-3. WIPP CH-TRU Waste Anticipated Inventory By Site*

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Ames Laboratory - Iowa State Univ.	0.0E+00	4.2E-01	4.2E-01
Argonne National Laboratory - East	1.1E+01	1.3E+02	1.4E+02
Argonne National Laboratory - West	6.5E+00	7.4E+02	7.5E+02
Bettis Atomic Power Laboratory	0.0E+00	1.2E+02	1.2E+02
Energy Technology Engineering Center	1.7E+00	0.0E+00	1.7E+00
Hanford (Richland) Site	1.2E+04	3.3E+04	4.6E+04
Idaho National Engineering Laboratory	2.9E+04	0.0E+00	2.9E+04
Lawrence Livermore National Laboratory	2.3E+02	7.1E+02	9.4E+02
Los Alamos National Laboratory	1.1E+04	7.4E+03	1.8E+04
Mound Plant	2.7E+02	0.0E+00	2.7E+02
Nevada Test Site	6.2E+02	9.0E+00	6.3E+02
Oak Ridge National Laboratory	1.3E+03	2.6E+02	1.6E+03
Paducah Gaseous Diffusion Plant	0.0E+00	1.9E+00	1.9E+00
Pantex Plant	6.2E-01	0.0E+00	6.2E-01
Rocky Flats Environmental Technology Site	7.1E+02	4.4E+03	5.1E+03
Sandia National Laboratory - Albuquerque	6.7E+00	7.5E+00	1.4E+01
Savannah River Site	2.9E+03	6.8E+03	9.6E+03
Teledyne Brown Engineering	2.1E-01	0.0E+00	2.1E-01
U.S. Army Material Command	2.5E+00	0.0E+00	2.5E+00
University of Missouri Research Reactor	2.1E-01	8.3E-01	1.0E+00
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**

*This table is identical to Table ES-3 of TWBIR Revision 2, page ES-6 (DOE, 1995c).

Table ES-4. WIPP RH-TRU Waste Anticipated Inventory By Site*

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Argonne National Laboratory - West	1.9E+01	1.3E+03	1.3E+03
Battelle Columbus Laboratories	5.8E+02	0.0E+00	5.8E+02
Bettis Atomic Power Laboratory	0.0E+00	6.7E+00	6.7E+00
Energy Technology Engineering Center	8.9E-01	0.0E+00	8.9E-01
Hanford (Richland) Site	2.0E+02	2.2E+04	2.2E+04
Idaho National Engineering Laboratory	2.2E+02	0.0E+00	2.2E+02
Los Alamos National Laboratory	9.4E+01	9.9E+01	1.9E+02
Oak Ridge National Laboratory	2.5E+03	4.5E+02	2.9E+03
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**

*This table is identical to Table ES-4 of TWBIR Revision 2, page ES-7 (DOE, 1995c).

Table ES-5. Summary Radionuclide Inventory[1*]

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)
Am241	2.62E+00	8.42E-01
Ba137m	4.53E-02	2.89E+01
Cm244	1.87E-01	4.45E-02
Co60	3.83E-04	1.47E+00
Cs137	4.78E-02	3.05E+01
Pu238	1.55E+01	2.05E-01
Pu239	4.66E+00	1.45E+00
Pu240	1.25E+00	7.15E-01
Pu241	1.37E+01	2.00E+01
Sr90	4.07E-02	2.95E+01
Y90	4.07E-02	2.95E+01

[1]Summary shows the ten radionuclides with the highest concentration in curies per cubic meter for both CH-TRU and RH-TRU waste. The list includes eleven radionuclides because the ten radionuclides with the highest concentration are different for CH-TRU and RH-TRU waste.

*This table is an update of Table ES-7, of TWBIR Revision 2, page ES-10 (DOE, 1995c).

1. INTRODUCTION

1.1 BACKGROUND

Transuranic (TRU) waste is defined as waste that is contaminated with alpha-emitting radionuclides with an atomic number greater than 92, with half-lives greater than 20 years, and concentrations of TRU isotopes greater than 100 nanocuries per gram of waste at the time of assay (DOE, 1988). TRU wastes are classified as either contact-handled (CH) waste or remote-handled (RH) waste, depending on the dose rate at the surface of the waste container. CH-TRU wastes are packaged TRU wastes with an external surface dose rate less than 200 millirems (mrem) per hour, while RH-TRU wastes are packaged TRU wastes with an external surface dose rate of 200 mrem or greater per hour (Public Law, 1992b). Unless otherwise indicated, for the purposes of this document, all references to TRU waste include TRU waste and mixed TRU waste (waste that contains both radioactive and hazardous components, as defined by the Atomic Energy Act [Public Law, 1954] and the Resource Conservation and Recovery Act [RCRA] as codified in Title 40 Code of Federal Regulations [CFR] Part 261.3 [EPA, 1980]).

The Waste Isolation Pilot Plant (WIPP) is a TRU waste management facility operated by the U.S. Department of Energy (DOE). The WIPP is currently identified as the permanent disposal site for TRU wastes (in retrievable storage or projected) generated at various DOE sites from defense-related activities of the United States government. The WIPP is scheduled to receive and dispose of TRU defense wastes from 8 major and additional minor DOE TRU waste sites (see Figure 1-1).

The DOE is committed to demonstrating compliance with all applicable regulations prior to permanent disposal of TRU defense wastes in the WIPP repository. These regulations are the environmental standards for management and disposal of TRU defense wastes as mandated in 40 CFR Part 191 (EPA, 1993) and Part 194 (EPA, 1996), and the RCRA regulations. Compliance demonstration through Sandia National Laboratories/New Mexico (SNL/NM) performance assessment (PA) calculations will be based on the inventory of existing and currently projected waste streams compiled in this document and the *Transuranic Waste Baseline Inventory Report* (TWBIR) Revision 2, as reported by the DOE TRU waste sites. Revision 3 of the TWBIR is different from previous revisions in that it provides the TRU waste inventory information developed for Revision 2 along with supplemental data. It is necessary for the reader to be familiar with Revision 2 of the TWBIR (DOE, 1995c) to understand TWBIR Revision 3.

1.2 PURPOSE

The purpose of the TWBIR is to document the total inventory of DOE TRU waste as defined by the DOE TRU waste sites. This document is based on the TWBIR Revision 2 data supplemented by several memoranda prepared during early calendar year (CY) 1996 that summarize additional data requested by the U. S. Department of Energy/Carlsbad Area Office (DOE/CAO) to support the SNL/NM PA modeling. The primary purpose of this document is to provide the summary data from TWBIR Revision 2 and the supplemental information used by SNL/NM for the development of the Compliance Certification Application (CCA) to be delivered to the Environmental Protection Agency (EPA), and to support the Land Withdrawal Act (LWA) (Public Law, 1992b). The supplemental information was generated from specific data requests

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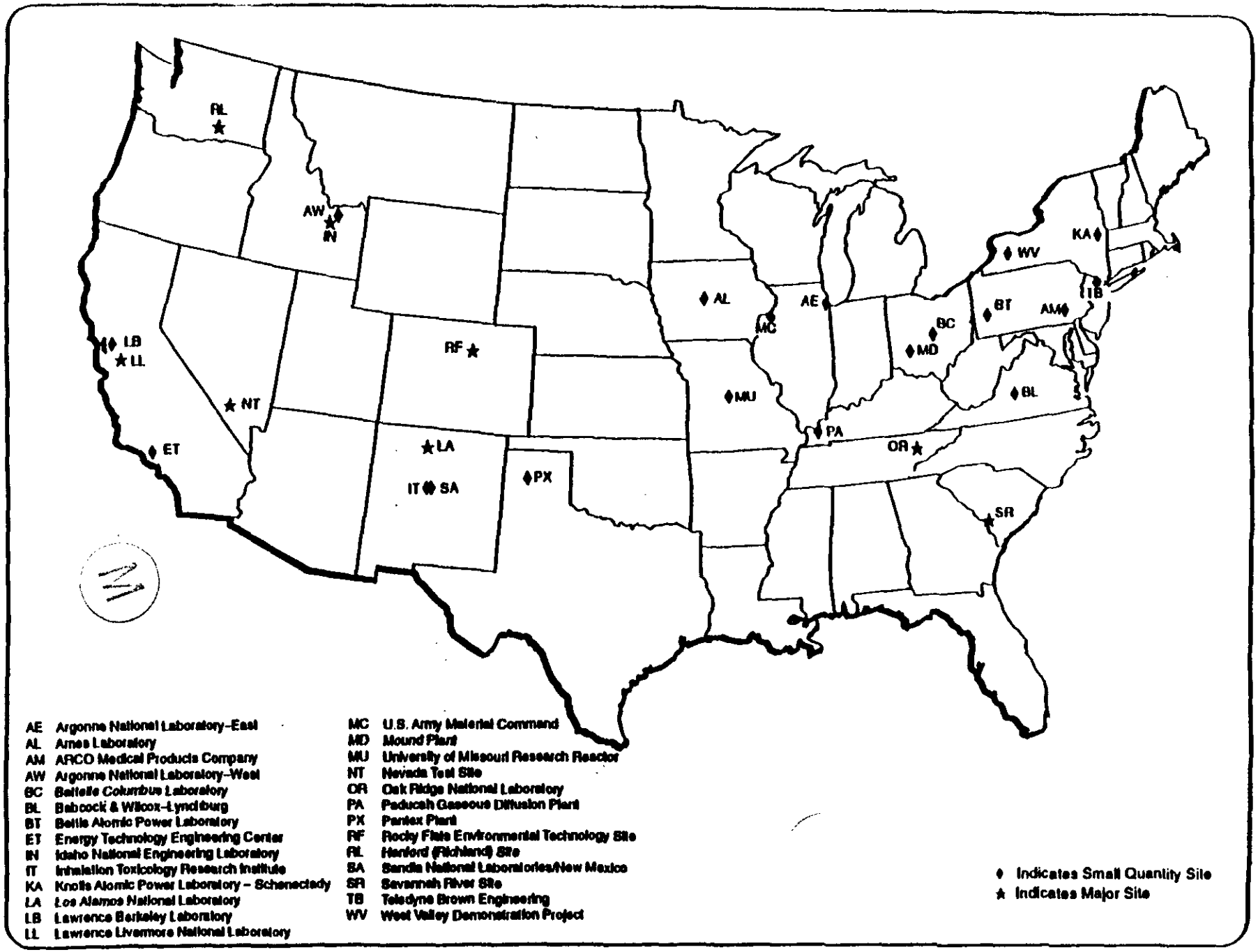

Figure 1-1. U.S. DOE Transuranic Waste Sites*

*This figure is identical to Figure 1-1 in TWBIR Revision 2, page 1-2 (DOE, 1995c).

to the TRU waste sites since the publication of Revision 2.

Revision 2 of the TWBIR included both the TRU waste that is allowed to be disposed of in WIPP and the DOE TRU waste that is not currently allowed to be disposed of in WIPP (Public Law, 1992b). Because the primary purpose of this Revision 3 TWBIR is to support the CCA and PA, it includes only the DOE TRU waste that is currently identified by the sites as being allowed to be disposed of in WIPP.

The TWBIR has been developed from the best available information and acceptable knowledge provided by the DOE TRU waste sites. In support of PA, the TWBIR describes a process for grouping individual waste streams with similar physical and chemical properties into waste profiles, based on their waste matrix code (WMC) (DOE, 1995a) assigned by the DOE TRU waste sites. The individual waste streams are also evaluated to estimate the occurrence and quantities of nonradioactive waste material parameters (WMPs) listed in Table 1-1 (e.g., cellulosics, plastics, iron-base metal/alloys, etc.) that have been identified by SNL/NM as being potentially important to the performance of the WIPP repository. Waste profiles with similar WMCs are then combined across the DOE TRU waste system to provide estimated total volumes and total WMPs.

1.3 WASTE INVENTORY TERMINOLOGY

All terminology in this document is unchanged from the TWBIR Revision 2. A summary of terminology used in this document is provided in this section and in Chapter 5 (Glossary). A list of acronyms and abbreviations used are provided in the front of the document.

Stored Inventory – The part of the TRU inventory currently in retrievable storage at the time of the TWBIR Revision 2 data call for inventory information is known as "stored inventory" in this document. Retrievably stored waste includes waste stored since approximately 1970 in buildings or in berms with earthen cover and does not include any waste that was buried (predominately prior to 1970) (DOE, 1990).

As-Generated Waste – The chemical and physical status of waste when it is generated. The "as-generated" term applies to both stored and projected waste.

Projected Inventory – The part of the TRU waste inventory that has not been generated but is currently estimated to be generated at some time in the future by the TRU waste sites is known as "projected inventory."

Anticipated Inventory – For the TWBIR, this is the sum of the stored and projected inventories, calculated as:

Stored Inventory	+	Projected Inventory	=	Anticipated Inventory

Scaling – The process for adjusting, if needed, the projected inventory to the design limit (disposal inventory) of the WIPP repository is called "scaling."

Stored Inventory + Projected Inventory (scaled as needed) = Disposal Inventory

TABLE 1-1. TECHNICAL DATA NEEDS FOR PERFORMANCE ASSESSMENT WASTE MATERIAL PARAMETERS

Waste Material Parameter	Input Variable in Current PA Models	
	Gas Generation	Mechanical Characteristics
Iron-base metal/alloys	YES	YES
Aluminum-base metal/alloys	-	YES
Other metal/alloys	-	YES
Other inorganic materials	-	YES
Vitrified[1]	-	YES
Cellulosics	YES	YES
Rubber	YES[2]	YES
Plastics	YES[2]	YES
Solidified inorganic material	-	YES
Solidified organic material	-	YES
Cement (solidified)[3,4]	YES	-
Soils[5]	-	YES

[1] Waste material parameter corresponding to treatment, identified by some sites that plan to treat waste in the future.
[2] Only one-half of materials assumed to generate gas.
[3] Percentage of material to generate gas is unknown at the present time.
[4] Information on this waste material parameter is needed for non-PA scoping calculations for assessment of its importance.
[5] May impact colloids.

Disposal Inventory – The inventory volume defined for WIPP emplacement to be used for PA calculations is the "disposal inventory." The LWA defines the total amount of TRU waste allowed for disposal in the WIPP as approximately 175,600 cubic meters (6,200,000 cubic feet) (Public Law, 1992b). The "Agreement for Consultation and Cooperation" (C&C Agreement) limits the RH-TRU inventory to approximately 7,080 cubic meters (250,000 cubic feet) (DOE and State of New Mexico, 1981). Therefore by difference, the CH-TRU inventory will be limited to approximately 168,500 cubic meters (5,950,000 cubic feet) if all of the RH-TRU allowance is filled.

Waste Matrix Code (WMC) - The WMCs were developed by DOE in response to the Federal Facilities Compliance Act (FFCAct) (Public Law, 1992a) as a methodology to aid in categorizing mixed waste streams in the DOE system into a series of five-digit alphanumeric codes (e.g., S3100; Inorganic Process Residues) that represent different physical/chemical matrices (DOE, 1995a).

Final Waste Form – Final waste form of a waste stream refers to the expected physical and chemical form of that stream once the waste has been processed, treated, or repackaged (if necessary) and is ready for disposal. This consists of a series of WMCs that are grouped together. The use of the final waste form helps to group waste streams that are expected to have similar physical and chemical properties at the time of disposal. The final waste form applies to both stored and projected waste. An example of combining three waste streams which either contain particulates or are cemented particulate waste is presented below:

WMC S3100 (inorganic process residues) WMC S3110 (inorganic particulates) WMC S3150 (solidified process residues)	Solidified Inorganics

Particulate waste may be immobilized prior to shipment to WIPP. If so, all three of these waste streams would be the same basic waste form when emplaced in WIPP and have similar physical and chemical properties. The final waste form for this example is solidified inorganics. Table 1-2 presents all anticipated WMCs for TRU waste and indicates the final waste form typically assigned to each WMC for the TWBIR. There are 11 final waste forms used in this TWBIR. The last two rows in Table 1-2, Excluded and Unknown Waste Streams, group WMCs that will not be accepted at WIPP until additional characterization and/or processing occurs to meet the WIPP Waste Acceptance Criteria (WAC) (DOE, 1996).

Waste Material Parameter – This is one (or more) nonradioactive waste constituent(s) that occurs in a TRU waste stream that is an input parameter into one or more PA models or is required to adequately describe the waste form. The waste material parameters and additional packaging materials that are reported in weight/volume (kg/m^3) and included in the TWBIR are:

WASTE MATERIAL PARAMETERS
- Iron-base metal/alloys
- Aluminum-base metal/alloys
- Other metal/alloys
- Other inorganic materials
- Vitrified
- Cellulosics
- Rubber
- Plastics
- Solidified inorganic material
- Solidified organic material
- Cement (solidified)
- Soils

PACKAGING MATERIALS
- Steel
- Plastic
- Lead (for RH-TRU waste only)

WIPP Waste Profile – The WIPP waste profile represents a summary of TRU wastes at all DOE TRU waste sites that have an identical final waste form.

TABLE 1-2. WASTE MATRIX CODES AND THEIR ANTICIPATED FINAL WASTE FORM

Final Waste Form	Waste Matrix Codes
Solidified Inorganics	L1000[1], L1100[1], L1110[1], L1120[1], L1130[1], L1140[1], L1190[1],1200[1], L1210[1], L1220[1], L1230[1], L1240[1], L1290[1], S3000[2], S3100[3], S3110[3], S3111[3], S3112[3], S3113[3], S3115[3], S3118[3], S3119[3], S3120[1], S3121[1], S3122[1], S3123[1], S3124[1], S3125[1], S3129[1], S3130[1 or 3], S3131[1 or 3], S3132[1 or 3], S3139[1 or 3], S3144[3], S3150, S3160[3], S3190[1 or 3], S3900[2], X6000[4], X6200[5], X6300[6], X6400[5], X6900[4], X7300[3], X7500[8], X7510[8], X7520[8], X7530[8], X7590[8], L9000[2], Z1110, Z1190
Salt	S3000[2], S3140, S3141, S3142, S3143, S3149, S3900[2], L9000[2]
Solidified Organics	L2000[1], L2100[1], L2110[1], L2120[1], L2190[1], L2200[1], L2210[1], L2220[1], L2290[1], L2900[1], S3000[2], S3114[3], S3200[3], S3210[3], S3211[3], S3212[3], S3219[3], S3220[1], S3221[1], S3222[1], S3223[1], S3229[1], S3230[3], S3290[1 or 3], S3900[2], S5340[3], X6000[4], X6100[5], X6190[4], X6900[4], L9000[2], Z1110, Z1190
Soils	S4000, S4100, S4200, S4300, S4900,
Uncategorized Metal (Metal Waste Other Than Lead and/or Cadmium)	S3116, S5000[9], S5100[7], S5110, S5111, S5119, S5190, X6200, X7000[10], X7290, X7400[11], X7430, X7490[11], X7520[8], Z1140, Z1190, Z2100[10]
Lead/Cadmium Metal	S5000[9], S5100[7], S5110, S5112, S5113, S5119, S5190, X6220[8], X7000[10], X7200, X7210, X7211, X7212, X7219, X7220, X7290, X7400[11], X7410[11], X7420[11], X7490[11], Z2100[10]
Inorganic Non-Metal	S3117, S3118, S3160, S5000[9], S5100[7], S5120, S5121, S5122, S5123, S5124, S5125, S5126, S5129, S5190, Z1120, Z1150, Z1190
Combustible	S5000[9], S5300, S5310, S5311, S5312, S5313, S5319, S5320, S5330, S5390, Z1130, Z1190, Z1200
Graphite	S5000[9], S5126
Heterogeneous	S5000[9], S5100[9], S5400, S5420, S5440, S5450, S5460, S5490, X7520[8], Z2900
Filter	S5000[9], S5410
Excluded Waste Streams[12]	X7000, X7100, X7600, X7700
Unknown[13]	S5190, X7900, L9000, S9000, Z9000, U9999

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TABLE 1-2. WASTE MATRIX CODES AND THEIR ANTICIPATED FINAL WASTE FORM (CONTINUED)

[1] Liquid waste streams are assumed to be solidified prior to being sent to WIPP.

[2] WMCs S3000, S3900, and L9000 are placed in "solidified inorganics," "salt," or "solidified organics," depending on the information provided by the TRU waste site.

[3] Particulate waste streams are assumed to be solidified prior to being sent to WIPP.

[4] WMCs X6000 and X6900 are placed in "solidified organics" or "solidified inorganics" depending on the information provided by the TRU waste site.

[5] Liquid lab pack waste is assumed to be solidified prior to being sent to WIPP.

[6] Solid lab packs are assumed to be solidified prior to being sent to WIPP.

[7] WMC S5100 is placed in "uncategorized metal," "lead-cadmium metal," or "inorganic non-metal" depending on the information provided by the site.

[8] Waste stream is assumed to be treated prior to being sent to WIPP.

[9] WMC S5000 is placed in "uncategorized metal," "lead/cadmium metal," "inorganic non-metal," "combustible," "graphite," "heterogeneous," or "filter," depending on the information provided by the site.

[10] WMC Z2100 is placed in "uncategorized metal" or "lead/cadmium metal" depending on the information provided by the site.

[11] WMCs X7400, X7410, X7420, and X7490 are assumed to be drained of liquid and contain only metal waste.

[12] These waste streams are excluded from disposal in WIPP at this time, e.g., PCB and elemental mercury.

[13] If adequate information is provided by the TRU waste site, these WMCs are changed. If there is not enough information, these waste streams remain as "unknown" and are excluded from disposal in WIPP until characterized.

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1.4 METHODOLOGY FOR DEVELOPMENT OF DISPOSAL INVENTORY

Development of the WIPP TRU waste disposal inventory is accomplished by a series of steps starting with the individual waste stream profiles submitted by the TRU waste sites. These waste stream profiles are grouped together, based on similar physical and chemical properties, into common "WIPP waste profiles," which should facilitate discussions with regulatory agencies and stakeholders concerning the disposal waste inventory. The process of grouping similar waste streams is exemplified in Figure 1-2. The waste profiles also contain information on waste material parameters that could affect the performance of the WIPP repository and that may be direct inputs to the PA models.

The CH-TRU anticipated inventory consists of up to 11 overall CH-TRU WIPP final waste forms based on the physical and chemical properties of the waste streams. Because the volume of the CH-TRU anticipated inventory is not sufficient to fill the maximum calculated CH-TRU capacity of WIPP, scaling of the projected CH-TRU inventory is necessary to attain the maximum calculated WIPP CH-TRU disposal inventory of approximately 168,500 cubic meters (5.95 million cubic feet). The scaling factor for CH-TRU waste is computed as follows:

$$\frac{\text{maximum calculated CH-TRU inventory - stored CH-TRU inventory}}{\text{projected CH-TRU inventory}} = \text{CH-TRU scaling factor}$$

The WIPP disposal inventory is the inventory to be used in PA calculations. To calculate the disposal inventory by final waste form for CH-TRU waste, the **projected inventory** is multiplied by the scaling factor, added to the stored inventory for each final waste form, and summed together.

The RH-TRU anticipated inventory is greater than the WIPP C&C Agreement limit (DOE and State of New Mexico, 1981) of approximately 7,080 cubic meters. DOE will abide by the WIPP C&C Agreement for RH-TRU waste volumes and the LWA, which limits the curies of RH-TRU waste allowed in WIPP to 5.1 million curies (Public Law, 1992b). As stated earlier, one purpose of the TWBIR is to report the DOE TRU inventory in such a way that it will facilitate performance assessment by SNL/NM and support development of compliance applications to the appropriate regulatory agencies. Since this is not a WIPP load management document, the RH-TRU inventory has not been scaled back in this document to the regulatory limit. The RH-TRU inventory for WIPP will be averaged across all RH-TRU waste sites and reported as kilograms/cubic meter for the waste material parameters and curies/cubic meter for radionuclides.

1.5 DOCUMENT ORGANIZATION

The TWBIR Revision 3 is organized into chapters of text, figures, tables, and supporting appendices. The contents of remaining chapters in this document are summarized below:

- Chapter 2 provides a summary of the WIPP disposal inventory information previously presented in TWBIR Revision 2.
- Chapter 3 presents supplementary disposal inventory information.
- Chapter 4 provides the document references.

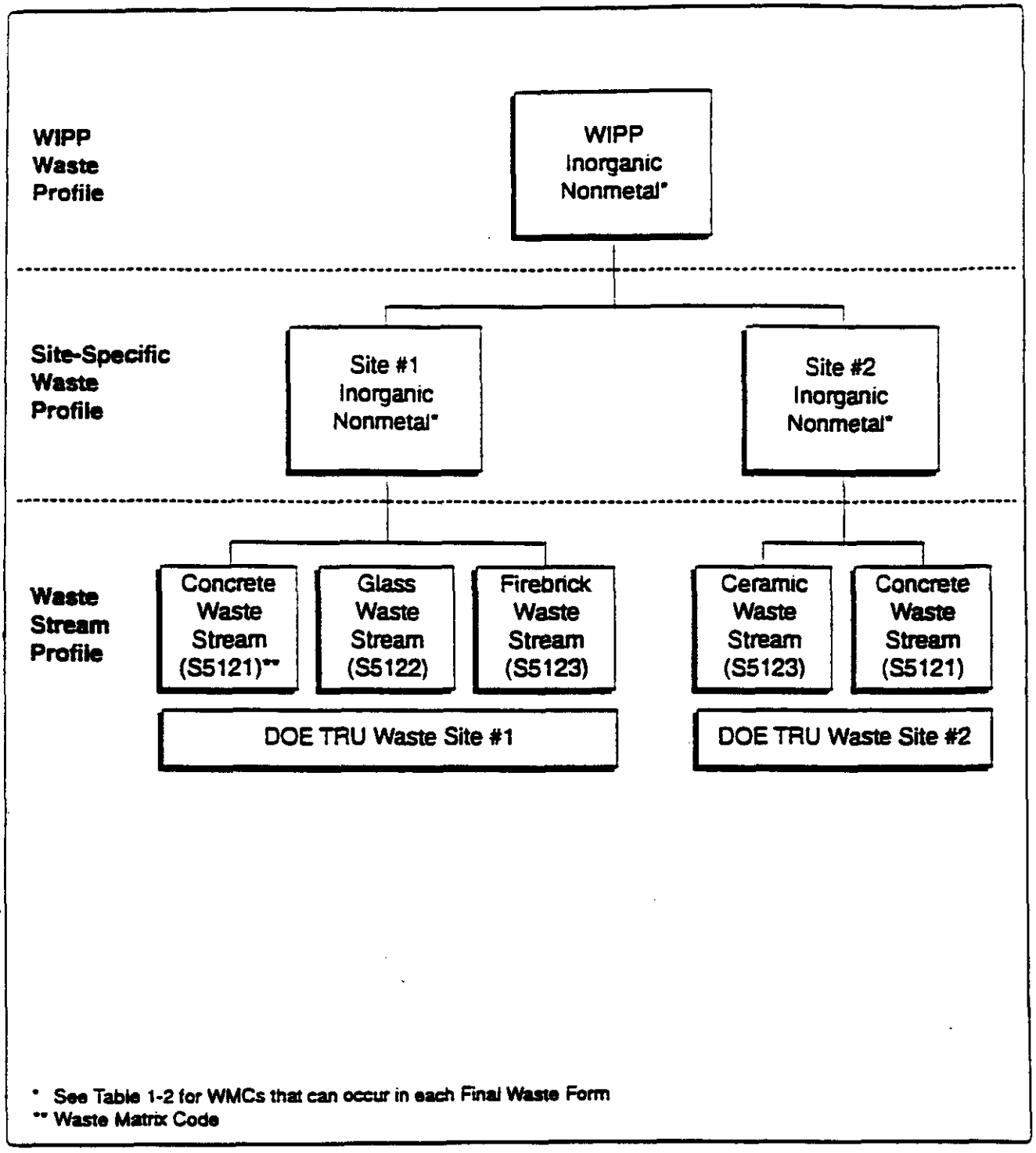

Figure 1-2. Schematic of Waste Stream Profile Methodology*

*This figure is identical to Figure 2-3 of TWBIR Revision 2, page 2-10 (DOE, 1995c).

- Chapter 5 provides a document glossary.
- Appendix A provides the SNL/NM memoranda requesting information to supplement the TWBIR Revision 2.
- Appendix B includes DOE and SNL/NM memoranda that provide information to supplement the TWBIR Revision 2.
- Appendix C provides the site-specific stored radionuclide inventories decayed to December 1995.
- Appendix D provides the correction received from SNL/NM for Cf-252 decayed inventory.

2. SUMMARY OF WIPP DISPOSAL INVENTORY INFORMATION

2.1 INTRODUCTION

The DOE TRU waste sites have assigned an overall final waste form to each waste stream based on the expected physical and chemical form of the waste after the sites process, treat, or repackage the waste (if necessary). Each site provides the stored and projected inventory for each waste stream. The TWBIR generates the WIPP TRU waste inventory by rolling-up the waste stream volumes that have the same final waste form within a site to generate site profiles (see TWBIR Revision 2 [DOE, 1995c] for waste stream and site-specific waste profiles). Then the site-level volumes with the same final waste form are rolled-up to generate the WIPP TRU waste inventory by final waste form (see TWBIR Revision 2 for detailed information on the roll-up methodology).

This chapter summarizes the WIPP-level information for the disposal inventory. The data provided in this chapter are identical to those provided in TWBIR Revision 2. These are the data used by SNL/NM in the WIPP performance assessment to demonstrate regulatory compliance. This chapter will include the following TWBIR Revision 2 information:

- WIPP disposal inventory volumes for each final waste form - taken from Table 3-1 (unchanged) in Section 3.2 of TWBIR Revision 2.
- WIPP disposal inventory waste material parameters - taken from Tables 3-2 and 3-3 (unchanged) in Section 3.3 of TWBIR Revision 2.
- Summary of WIPP anticipated inventory from each site - taken from Tables 4-1 and 4-2 (unchanged) in Chapter 4 of TWBIR Revision 2.

2.2 WIPP DISPOSAL INVENTORY VOLUMES FOR EACH FINAL WASTE FORM

The disposal inventory is defined by the LWA (Public Law, 1992b) and the WIPP C&C Agreement (DOE and the State of New Mexico, 1981) as follows: the maximum allowable WIPP capacity is approximately 175,600 cubic meters, of which RH-TRU disposal inventory is limited to approximately 7,080 cubic meters resulting in a calculated CH-TRU disposal inventory limit of approximately 168,500 cubic meters.

Using volumes for all the retrievably stored and projected defense TRU waste streams (including the mixed and nonmixed TRU waste volumes) a disposal inventory of TRU waste has been developed using the methodology described in Chapter 3 of Revision 2 of the TWBIR. This inventory is presented in Table 2-1 (by final waste forms) and depicts both the anticipated and disposal inventory volumes.

The anticipated CH-TRU inventory volumes are the sum of the stored and projected volumes. Scaling of the disposal inventory is for PA purposes to enable SNL/NM to model a capacity waste load based on currently anticipated profiles.

TABLE 2-1. TRANSURANIC WASTE DISPOSAL INVENTORY FOR WIPP*

Contact Handled Waste (Cubic Meters)

Final Waste Forms	Stored Volumes	Projected Volumes	Anticipated Volumes	WIPP Disposal Volumes
Combustible	5.8E+03	4.6E+03	1.0E+04	1.4E+04
Filter	2.2E+02	5.1E+02	7.3E+02	1.2E+03
Graphite	5.1E+02	4.8E+01	5.6E+02	6.0E+02
Heterogeneous	2.7E+04	1.3E+04	4.0E+04	5.1E+04
Inorganic Non-Metal	3.1E+03	9.4E+02	4.1E+03	4.9E+03
Lead/Cadmium Metal Waste	3.5E+01	3.3E+02	3.7E+02	6.6E+02
Salt Waste	2.1E+01	3.3E+02	3.5E+02	6.4E+02
Soils	4.1E+02	6.0E+03	6.4E+03	1.2E+04
Solidified Inorganics	9.6E+03	4.5E+03	1.4E+04	1.8E+04
Solidified Organics	9.1E+02	7.5E+01	9.8E+02	1.1E+03
Uncategorized Metal	1.1E+04	2.3E+04	3.4E+04	5.4E+04
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**	**1.6E+05**
Remote Handled Waste				
Combustible	3.6E+01	4.9E+01	8.5E+01	
Heterogeneous	2.3E+03	5.5E+03	7.8E+03	
Inorganic Non-Metal	4.6E+01	2.1E+01	6.8E+01	
Lead/Cadmium Metal Waste	7.1E+00	6.7E+01	7.4E+01	
Solidified Inorganics	1.1E+03	2.3E+02	1.3E+03	
Solidified Organics	3.6E+00	0.0E+00	3.6E+00	
Uncategorized Metal	1.2E+02	1.7E+04	1.8E+04	
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**	
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**	**1.7E+05**

*This table is identical to Table 3-1 of TWBIR Revision 2, page 3-2 (DOE, 1995c).

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Applying the formula given in Chapter 1:

- $$\frac{\underset{\text{(CH-TRU disposal inventory)}}{1.685 \times 10^5 m^3} - \underset{\text{(stored inventory)}}{5.8 \times 10^4\ m^3}}{5.4 \times 10^4\ m^3 \text{ (projected inventory)}} \approx \underset{\text{(scaling factor)}}{2.05}$$

- Multiply the CH-TRU waste **projected inventory volumes** by the scaling factor for all the final waste forms, and add the stored volumes (which results in the numbers in the "Disposal Inventory" column of Table 2-1).

The CH-TRU waste stream volume on a system-wide final waste form basis is increased by approximately 50 percent to account for the difference between the anticipated inventory and the maximum calculated WIPP CH-TRU disposal inventory.

The RH-TRU WIPP inventory has not been scaled. The RH-TRU anticipated inventory is greater than the amount of RH-TRU waste allowed in the WIPP by the C&C Agreement (DOE and the State of New Mexico, 1981). DOE is committed to abide by all agreements and laws regarding RH-TRU limitations. DOE and SNL/NM will evaluate this inventory to determine the disposal options for all DOE RH-TRU waste. This inventory has not been scaled back to the limit imposed by the C&C Agreement so that all available data are presented to DOE and SNL/NM to conduct modeling and other evaluations to determine the disposition of this waste.

2.3 ROLL-UP OF WIPP WASTE MATERIAL PARAMETERS BY FINAL WASTE FORM

The roll-ups of waste material parameters by final waste forms are developed from the volumes presented in the TWBIR Revision 2. The roll-ups by final waste forms require combining data from several waste streams. A weighted average value for the waste material parameters is calculated from the average densities provided by the TRU waste sites modified by the volume fractions and summed as follows:

$$\text{Average Density of waste material parameter} = \sum \text{Average Density}_i^{*} \times \frac{\text{(Volume TWBIR Stream}_i\text{)}}{\text{(Total Volume of Final Waste Form)}}$$

*where i is an index representing individual waste streams of the same final waste form

The minimum density is chosen as the smallest minimum density of a particular waste material parameter in the TWBIR Revision 2. The maximum density is chosen in a similar manner, except that the largest maximum density is chosen. Thus, the maximum and minimum values reported in Tables 2-2 and 2-3 are the absolute extreme values reported across the system, and in many cases they only apply to a very small volume of waste. If required, the user can use the data in the TWBIR Revision 2 database to calculate a "weighted average maximum" value to obtain a maximum value that may be more representative of the total inventory.

The waste material parameters that are inputs to the PA models are presented in Table 2-2 for CH-TRU waste and Table 2-3 for RH-TRU waste. These tables represent the waste material parameters for the WIPP disposal inventory.

2.4 SUMMARY OF WIPP ANTICIPATED INVENTORY FROM EACH SITE

Each WIPP waste stream from each TRU waste site is characterized in a waste stream profile in TWBIR Revision 2. Summary tables of CH-TRU and RH-TRU WIPP waste volumes by site are provided in Tables 2-4 and 2-5.

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Table 2-2. WIPP CH-TRU Waste Material Parameter Disposal Inventory*

Waste Material Parameters (Kg/m3)	Maximum	Average	Minimum
Iron Base Metal/Alloys	2.8E+03	1.7E+02	0.0E+00
Aluminum Base Metal/Alloys	8.0E+02	1.8E+01	0.0E+00
Other Metal/Alloys	1.6E+03	6.7E+01	0.0E+00
Other Inorganic Materials	1.4E+03	3.1E+01	0.0E+00
Vitrified	2.5E+03	5.5E+01	0.0E+00
Cellulosics	9.6E+02	5.4E+01	0.0E+00
Rubber	6.3E+02	1.0E+01	0.0E+00
Plastics	8.9E+02	3.4E+01	0.0E+00
Solidified Inorganic Material	2.2E+03	5.4E+01	0.0E+00
Solidified Organic Material	1.4E+03	5.6E+00	0.0E+00
Cement (Solidified)	1.2E+03	5.0E+01	0.0E+00
Soils	1.6E+03	4.4E+01	0.0E+00
Container Materials - Kg/m3			
Steel		139	
Plastic/ Liners		28	

*This table is identical to Table 3-2 in TWBIR Revision 2, page 3-4 (DOE, 1995c).

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Table 2-3. WIPP RH-TRU Waste Material Parameter Disposal Inventory*

Waste Material Parameters (Kg/m3	Maximum	Average	Minimum
Iron Base Metal/Alloys	1.7E+03	1.0E+02	0.0E+00
Aluminum Base Metal/Alloys	1.7E+02	7.1E+00	0.0E+00
Other Metal/Alloys	9.1E+02	2.5E+02	0.0E+00
Other Inorganic Materials	2.0E+03	6.4E+01	0.0E+00
Vitrified	2.5E+03	4.7E+00	0.0E+00
Cellulosics	5.7E+02	1.7E+01	0.0E+00
Rubber	4.4E+02	3.3E+00	0.0E+00
Plastics	6.2E+02	1.5E+01	0.0E+00
Solidified Inorganic Material	6.1E+02	2.2E+01	0.0E+00
Solidified Organic Material	8.1E+02	9.3E-01	0.0E+00
Cement (Solidified)	5.8E+02	1.9E+01	0.0E+00
Soils	2.4E+01	1.0E+00	0.0E+00

Container Materials - Kg/m3	
Steel	446
Plastic/Liners	3.1
Lead	465
Steel Plug	2145

*This table is identical to Table 3-3 in TWBIR Revision 2, page 3-5 (DOE, 1995c).

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Table 2-4. WIPP CH-TRU Waste Anticipated Inventory By Site*

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Ames Laboratory - Iowa State Univ.	0.0E+00	4.2E-01	4.2E-01
Argonne National Laboratory - East	1.1E+01	1.3E+02	1.4E+02
Argonne National Laboratory - West	6.5E+00	7.4E+02	7.5E+02
Bettis Atomic Power Laboratory	0.0E+00	1.2E+02	1.2E+02
Energy Technology Engineering Center	1.7E+00	0.0E+00	1.7E+00
Hanford (Richland) Site	1.2E+04	3.3E+04	4.6E+04
Idaho National Engineering Laboratory	2.9E+04	0.0E+00	2.9E+04
Lawrence Livermore National Laboratory	2.3E+02	7.1E+02	9.4E+02
Los Alamos National Laboratory	1.1E+04	7.4E+03	1.8E+04
Mound Plant	2.7E+02	0.0E+00	2.7E+02
Nevada Test Site	6.2E+02	9.0E+00	6.3E+02
Oak Ridge National Laboratory	1.3E+03	2.6E+02	1.6E+03
Paducah Gaseous Diffusion Plant	0.0E+00	1.9E+00	1.9E+00
Pantex Plant	6.2E-01	0.0E+00	6.2E-01
Rocky Flats Environmental Technology Site	7.1E+02	4.4E+03	5.1E+03
Sandia National Laboratory - Albuquerque	6.7E+00	7.5E+00	1.4E+01
Savannah River Site	2.9E+03	6.8E+03	9.6E+03
Teledyne Brown Engineering	2.1E-01	0.0E+00	2.1E-01
U.S. Army Material Command	2.5E+00	0.0E+00	2.5E+00
University of Missouri Research Reactor	2.1E-01	8.3E-01	1.0E+00
Total CH Volumes	**5.8E+04**	**5.4E+04**	**1.1E+05**

*This table is identical to Table 4-1 in TWBIR Revision 2, page 4-2 (DOE, 1995c).

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Table 2-5. WIPP RH-TRU Waste Anticipated Inventory By Site*

(Cubic Meters)

Storage/Generator Site	Stored Volumes	Projected Volumes	Anticipated Volumes
Argonne National Laboratory - West	1.9E+01	1.3E+03	1.3E+03
Battelle Columbus Laboratories	5.8E+02	0.0E+00	5.8E+02
Bettis Atomic Power Laboratory	0.0E+00	6.7E+00	6.7E+00
Energy Technology Engineering Center	8.9E-01	0.0E+00	8.9E-01
Hanford (Richland) Site	2.0E+02	2.2E+04	2.2E+04
Idaho National Engineering Laboratory	2.2E+02	0.0E+00	2.2E+02
Los Alamos National Laboratory	9.4E+01	9.9E+01	1.9E+02
Oak Ridge National Laboratory	2.5E+03	4.5E+02	2.9E+03
Total RH Volumes	**3.6E+03**	**2.3E+04**	**2.7E+04**
Total TRU Waste Volumes	**6.2E+04**	**7.7E+04**	**1.4E+05**

*This table is identical to Table 4-2 in TWBIR Revision 2, page 4-3 (DOE, 1995c).

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3. SUPPLEMENTAL DISPOSAL INVENTORY INFORMATION

3.1 INTRODUCTION

This chapter summarizes supplemental information about the WIPP disposal inventory that was requested by SNL/NM in support of WIPP PA either after the publication of Revision 2 of the TWBIR or that was not available from the TRU waste sites at the time of publication of Revision 2 of the TWBIR in December 1995 (DOE, 1995c). Appendices A-1 through A-3 are the three memoranda from SNL/NM requesting supplemental information about the WIPP TRU waste inventory.

The first memorandum from SNL/NM (dated November 6, 1995), entitled "CH and RH-TRU Waste Parameters Potentially Important in WIPP PA" (Appendix A-1), was included as Appendix B in Revision 2 of the TWBIR. This memorandum requested information on certain nonradioactive materials present in the TRU waste (nitrates, sulfates, phosphates, cement, and organic ligands), and also requested information on residues present at TRU waste sites other than Rocky Flats Environmental Technology Site (RFETS). The information on residues was provided in Revision 2 of the TWBIR. However, the remainder of the requested information had to be obtained from the sites after the publication of Revision 2 and is presented in this document.

The second and the third memoranda from SNL/NM (dated January 11 and January 30, 1996), both entitled "Information Needed from TWBIR (Revision 2/Addendum)" (Appendices A-2 and A-3), requested additional information about the WIPP disposal radionuclide inventory. This information is also presented in the main body of this document.

The supplemental information provided to SNL/NM in response to the memoranda referenced above is discussed in the following sections:

- Supplemental Radionuclide Information (Section 3.2)
- Supplemental Information for Other Constituents (Section 3.3)

3.2 SUPPLEMENTAL RADIONUCLIDE INFORMATION

In response to the memoranda requesting radionuclide information (Appendices A-2 and A-3), two sets of radionuclide information were provided in support of WIPP PA (Appendices B-1 and B-2). Appendix B-1 is an update of the WIPP disposal radionuclide inventory presented in Table 3-4 of Revision 2 of the TWBIR, while Appendix B-2 presents preliminary activity calculations for seven radionuclides on a waste stream basis. The memoranda reporting these supplemental data and the details of the methodology for calculations are included in Appendices B-1 and B-2. A summary of the information provided by DOE to SNL/NM and the major assumptions used in deriving portions of the data are presented in Sections 3.2.1 and 3.2.2.

3.2.1 Revised WIPP Disposal Radionuclide Inventory

A revised estimate of the WIPP disposal radionuclide inventory (i.e., Table 3-4 in TWBIR Revision 2) was not specifically requested by SNL/NM in the memoranda included in Appendices A-1 through A-3. However, after the publication of TWBIR Revision 2, new and updated

radionuclide information became available from four sites (Hanford, Oak Ridge National Laboratory [ORNL], RFETS, and Savannah River Site [SRS]). A review of the new information indicated that it may result in considerable changes to the WIPP disposal radionuclide inventory published in Revision 2 of the TWBIR. Therefore, the disposal radionuclide inventory was recalculated on the basis of the new information and the results provided to SNL/NM in a format identical to Table 3-4 in TWBIR Revision 2 (see Table 3-1). The methodology and the assumptions used for recalculation of the radionuclide inventory are identical to those described in TWBIR Revision 2, except that the new radionuclide information from the four sites was incorporated. The new information from the four sites is summarized below:

- Hanford Site reported corrections to the values for Cf-252, Cm-244, and Cm-245 from their earlier submittals for the Integrated Data Base (IDB) (DOE, 1995b).

- Preliminary sludge sampling data were obtained for the ORNL RH-TRU sludges, which showed that the primary uranium isotope present in these sludges is U-238 (not U-235, as reported in their previous IDB submittals). The uranium curies reported for RH-TRU waste in previous ORNL IDB submittals were redistributed based on the preliminary sludge sampling data. This corrected the previously high estimates of U-235 in the ORNL RH-TRU inventory.

- The RFETS provided undecayed yearly activity data for the radionuclides present in the RFETS residues, which enabled activity decay calculations for these radionuclides. This was not provided for in TWBIR Revision 2; therefore the radionuclide activity from these residues could not be decayed.

- The SRS provided a break-up of radionuclide activity data for SRS waste between on-site and off-site waste (i.e., waste from other sites that was shipped to SRS for storage in the early 1970s). The activity from the off-site waste was included in the WIPP disposal radionuclide inventory but excluded from any extrapolations for SRS projected waste under the assumption that there would be no future accumulation of off-site Pu-238 dominant waste at SRS.

Based on the above information, Table 3-1 provides the revised WIPP disposal radionuclide inventory estimated in curies per cubic meter and total curies for each radionuclide for both CH-TRU and RH-TRU waste. The revised stored radionuclide inventory for each site in decayed curies is provided in Appendix C for both CH-TRU and RH-TRU waste. Appendix C includes the effect of all corrections, additions, or revisions to the site radionuclide inventories used to develop Table 3-1 and is an update of Appendix D in TWBIR Revision 2. All numbers in Appendix C are decayed to December 1995 using the Oak Ridge Isotope Generation and Depletion Code (ORIGEN 2) (Croff, 1980; 1983).

Based on the total curies shown in Table 3-1, it is estimated that approximately 98.9 percent of the total CH-TRU curies is contributed by Pu-238, Pu-239, Pu-240, Pu-241, and Am-241. In contrast, approximately 96.5 percent of the total RH-TRU curies is contributed by Cs-137, Sr-90, Ba-137m, Pu-241, and Y-90. Thus, the remaining radionuclides contribute a very small fraction of the total curies for the repository.

In comparison to TWBIR Revision 2, the most significant change in the revised disposal radionuclide inventory shown in Table 3-1 is the *decrease* in the estimated concentration of Pu-

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA[1]*

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Ac225	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ac227	3.61E-06	1.07E-07	6.08E-01	7.57E-04
Ac228	4.43E-06	1.10E-05	7.47E-01	7.77E-02
Ag109m	9.32E-05	NR	1.57E+01	NR
Ag110	4.19E-14	2.46E-13	7.07E-09	1.74E-09
Ag110m	3.15E-12	1.85E-11	5.31E-07	1.31E-07
Am241	2.62E+00	8.42E-01	4.42E+05	5.96E+03
Am242	1.04E-05	NR	1.75E+00	NR
Am242m	1.04E-05	NR	1.75E+00	NR
Am243	1.93E-04	3.23E-08	3.26E+01	2.28E-04
Am245	7.89E-15	4.06E-20	1.33E-09	2.87E-16
At217	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ba137m	4.53E-02	2.89E+01	7.63E+03	2.04E+05
Bi210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Bi211	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Bi212	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Bi213	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Bi214	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Bk249	5.44E-10	2.80E-15	9.16E-05	1.98E-11
Bk250	2.59E-16	NR	4.37E-11	NR

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
C14	6.43E-05	2.90E-04	1.08E+01	2.05E+00
Cd109	9.31E-05	NR	1.57E+01	NR
Cd113m	1.08E-11	7.71E-11	1.82E-06	5.46E-07
Ce144	3.71E-07	7.24E-04	6.26E-02	5.13E+00
Cf249	3.81E-07	6.31E-07	6.42E-02	4.47E-03
Cf250	1.96E-06	NR	3.30E-01	NR
Cf251	2.24E-08	NR	3.78E-03	NR
Cf252[3]	1.44E-05	1.82E-04	2.43E+00	1.29E+00
Cm242	6.76E-06	NR	1.14E+00	NR
Cm243	1.61E-05	6.99E-03	2.72E+00	4.95E+01
Cm244	1.87E-01	4.45E-02	3.15E+04	3.15E+02
Cm245	6.81E-08	2.07E-10	1.15E-02	1.46E-06
Cm246	6.06E-07	NR	1.02E-01	NR
Cm247	1.91E-14	NR	3.21E-09	NR
Cm248[3]	2.19E-07	2.89E-08	3.69E-02	2.05E-04
Co58	1.81E-18	1.75E-15	3.05E-13	1.24E-11
Co60	3.83E-04	1.47E+00	6.46E+01	1.04E+04
Cr51	NR	4.29E-10	NR	3.04E-06
Cs134	7.97E-08	2.60E-03	1.34E-02	1.84E+01
Cs135	2.98E-09	1.66E-08	5.02E-04	1.17E-04

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

* This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

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Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Cs137	4.78E-02	3.05E+01	8.06E+03	2.16E+05
Es254	2.51E-16	NR	4.24E-11	NR
Eu150	2.08E-10	NR	3.51E-05	NR
Eu152	7.46E-06	1.73E-01	1.26E+00	1.22E+03
Eu154	6.80E-06	8.34E-02	1.15E+00	5.91E+02
Eu155	5.62E-06	1.67E-02	9.46E-01	1.18E+02
Fe55	1.13E-10	2.38E-05	1.91E-05	1.69E-01
Fe59	1.57E-12	NR	2.64E-07	NR
Fr221	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Fr223	4.98E-08	1.48E-09	8.39E-03	1.04E-05
H3	5.16E-06	9.33E-06	8.69E-01	6.60E-02
I129	4.18E-12	NR	7.05E-07	NR
Kr85	1.20E-06	2.37E-04	2.02E-01	1.68E+00
Mn54	5.05E-09	3.32E-06	8.51E-04	2.35E-02
Nb95	1.51E-14	9.45E-05	2.54E-09	6.69E-01
Nb95m	5.04E-17	3.17E-07	8.50E-12	2.24E-03
Ni59	4.47E-08	NR	7.52E-03	NR
Ni63	5.46E-06	1.40E-04	9.19E-01	9.88E-01
Np237	3.33E-04	4.02E-04	5.61E+01	2.85E+00
Np238	5.20E-08	NR	8.77E-03	NR

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

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Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Np239	1.93E-04	3.23E-08	3.26E+01	2.28E-04
Np240m	8.91E-12	3.12E-15	1.50E-06	2.21E-11
Pa231	2.67E-06	2.70E-07	4.51E-01	1.91E-03
Pa233	3.33E-04	4.02E-04	5.61E+01	2.85E+00
Pa234	3.05E-07	1.92E-06	5.14E-02	1.36E-02
Pa234m	2.35E-04	1.48E-03	3.96E+01	1.05E+01
Pb209	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Pb210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Pb211	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Pb212	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Pb214	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Pd107	4.40E-10	2.45E-09	7.41E-05	1.73E-05
Pm147	4.67E-05	1.52E-03	7.87E+00	1.07E+01
Po210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Po211	1.01E-08	3.00E-10	1.71E-03	2.12E-06
Po212	1.03E-04	6.66E-06	1.73E+01	4.72E-02
Po213	1.67E-05	1.62E-05	2.82E+00	1.15E-01
Po214	6.91E-05	5.05E-09	1.16E+01	3.57E-05
Po215	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Po216	1.61E-04	1.04E-05	2.71E+01	7.36E-02

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

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Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Po218	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Pr144	3.67E-07	7.16E-04	6.18E-02	5.07E+00
Pu236	6.16E-08	NR	1.04E-02	NR
Pu238	1.55E+01	2.05E-01	2.61E+06	1.45E+03
Pu239	4.66E+00	1.45E+00	7.85E+05	1.03E+04
Pu240	1.25E+00	7.15E-01	2.10E+05	5.07E+03
Pu241	1.37E+01	2.00E+01	2.31E+06	1.42E+05
Pu242	6.96E-03	2.11E-05	1.17E+03	1.50E-01
Pu243	1.91E-14	NR	3.21E-09	NR
Pu244	8.92E-12	3.12E-15	1.50E-06	2.21E-11
Ra223	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Ra224	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Ra225	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ra226	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Ra228	4.43E-06	1.10E-05	7.47E-01	7.77E-02
Rh106	1.72E-07	1.54E-03	2.90E-02	1.09E+01
Rn219	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Rn220	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Rn222	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Ru106	1.72E-07	1.54E-03	2.90E-02	1.09E+01

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

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Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Sb125	7.17E-07	2.67E-04	1.21E-01	1.89E+00
Sb126	8.02E-10	4.46E-09	1.35E-04	3.16E-05
Sb126m	5.73E-09	3.18E-08	9.65E-04	2.25E-04
Se79	2.58E-09	1.44E-08	4.35E-04	1.02E-04
Sm151	8.72E-06	5.05E-05	1.47E+00	3.57E-01
Sn119m	2.46E-11	1.35E-10	4.14E-06	9.59E-07
Sn121m	1.58E-07	9.45E-07	2.66E-02	6.69E-03
Sn126	5.73E-09	3.18E-08	9.65E-04	2.25E-04
Sr90	4.07E-02	2.95E+01	6.85E+03	2.09E+05
Ta182	NR	5.95E-12	NR	4.21E-08
Tc99	1.49E-04	8.26E-07	2.52E+01	5.85E-03
Te125m	1.75E-07	6.57E-05	2.95E-02	4.65E-01
Te127	7.72E-13	2.41E-13	1.30E-07	1.71E-09
Te127m	7.88E-13	2.47E-13	1.33E-07	1.75E-09
Th227	3.56E-06	1.06E-07	6.01E-01	7.47E-04
Th228	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Th229	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Th230	4.78E-07	1.07E-06	8.06E-02	7.56E-03
Th231	7.59E-05	6.53E-04	1.28E+01	4.63E+00
Th232	5.42E-06	1.31E-05	9.13E-01	9.25E-02

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

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Table 3-1. WIPP DISPOSAL RADIONUCLIDE INVENTORY FOR THE CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Th234	2.35E-04	1.48E-03	3.96E+01	1.05E+01
Tl207	3.61E-06	1.07E-07	6.07E-01	7.56E-04
Tl208	5.77E-05	3.74E-06	9.73E+00	2.65E-02
Tl209	3.69E-07	3.58E-07	6.22E-02	2.53E-03
U232	1.53E-04	NR	2.58E+01	NR
U233	1.06E-02	2.23E-02	1.79E+03	1.58E+02
U234	2.76E-03	6.03E-03	4.65E+02	4.27E+01
U235	7.59E-05	6.53E-04	1.28E+01	4.63E+00
U236	1.98E-06	1.37E-05	3.33E-01	9.68E-02
U237	3.36E-04	4.91E-04	5.66E+01	3.48E+00
U238	2.35E-04	1.48E-03	3.96E+01	1.05E+01
U240	8.91E-12	3.12E-15	1.50E-06	2.21E-11
Y90	4.07E-02	2.95E+01	6.85E+03	2.09E+05
Zr93	3.34E-08	1.86E-07	5.63E-03	1.32E-03
Zr95	6.80E-15	4.27E-05	1.15E-09	3.02E-01
TOTALS	**3.81E+01**	**1.43E+02**	**6.42E+06**	**1.02E+06**

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.
[3]The values for Cf252 and Cm248 are different from the values reported in Attachment A in Appendix B-1 because these incorporate the corrections received from SNL/NM for these isotopes (see Appendix D) after Appendix B-1 was finalized.

*This table is an update of Table 3-4, of TWBIR Revision 2, pages 3-30 through 3-36 (DOE, 1995c)

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238 for the CH-TRU waste in the repository. This is primarily due to the exclusion of the SRS off-site waste from any future extrapolations. Since this off-site waste has a high concentration of Pu-238, excluding it from the extrapolations decreases the amount of Pu-238 in the projected portion of the inventory. It should be noted that this off-site waste is included in the stored waste portion of the disposal radionuclide inventory. The decrease in the Pu-238 also causes a decrease in the total estimated curies for CH-TRU waste in the repository.

Based on the data corrections from Hanford Site to the Cm-244 and Cm-245 inventories, the estimated concentration of Cm-244 has increased, while that of Cm-245 has decreased. Similarly, based on the correction to the reported value of Cf-252 from the Hanford Site, the revised concentration of Cf-252 has decreased significantly from the values estimated in Revision 2 of the TWBIR. The effect of decaying the activity from the RFETS residues has resulted in a minor decrease in the estimated concentration of Pu-241. Since Pu-241 decays to Am-241, the decrease in the Pu-241 concentration is also accompanied by a corresponding increase in the concentration of Am-241.

The major change for the RH-TRU waste from TWBIR Revision 2 is the decrease in the estimated concentration of U-235 and an increase in the concentration of U-238. Both are a result of the preliminary sludge sampling data from ORNL mentioned earlier.

3.2.2 Activity Calculations for Waste Streams

As documented in the SNL/NM memoranda in Appendices A-2 and A-3, data on radionuclide activity on a waste stream basis was requested for 21 radionuclides. However, the request was subsequently limited to seven radionuclides by SNL/NM WIPP PA staff (Am-241, Cm-244, Pu-238, Pu-239, Pu-240, Pu-241, and U-234). Appendix B-2 presents the results provided to SNL/NM by DOE/CAO in response to this data request.

Since many sites did not have the ability to provide radionuclide data on a detailed waste stream basis for every waste stream in TWBIR Revision 2, the radionuclide activities for many individual waste streams (especially for projected waste) were not reported by the sites for TWBIR Revision 2. Therefore, the radionuclide activity data for the WIPP disposal inventory cannot be directly obtained on a waste stream basis by running queries on the TWBIR Revision 2 database. Due to the unavailability of detailed radionuclide data on a waste stream basis for many waste streams, the WIPP disposal radionuclide inventory presented in all revisions of the TWBIR has always been developed on the basis of the site-level radionuclide inventories reported by the sites in the IDB.

For the sake of consistency with the revised WIPP disposal radionuclide inventory in Attachment A of Appendix B-1 (which is also based on the site-level IDB data), assumptions were required in order to estimate the waste stream radionuclide activities presented in Appendix B-2. These assumptions can be found in Appendix B-2 and are not reproduced here. Thus, it should be noted that the data in Appendix B-2 are *derived* on the basis of assumptions and not directly obtainable from the TWBIR Revision 2 database. Because of the unavailability of the radionuclide data on a waste stream basis, some of the waste streams from small sites are not included in the activity table in Appendix B-2. Efforts are currently underway to ensure that the sites will be able to provide radionuclide data on a waste stream basis for most waste streams in future updates of the TWBIR so that radionuclide activity data for the WIPP disposal inventory can be directly obtained from the TWBIR database.

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3.3 SUPPLEMENTAL INFORMATION FOR OTHER CONSTITUENTS

SNL/NM and DOE/CAO requested supplemental information on several constituents in TRU waste (see Appendix A-1) that were not able to be estimated based on the information reported by the TRU waste sites in Revision 2 of the TWBIR (DOE, 1995c). The information requested can be divided into three general categories which were requested on solidified waste forms destined for disposal in WIPP:

- Complexing Agents
- Nitrate, Sulfate, and Phosphate
- Cement

The TWBIR team worked with those major sites that generate/store most of the solidified waste forms: Los Alamos National Laboratory (LANL), RFETS/INEL, and ORNL. A summary of the results of these supplemental information requests is provided in Section 3.3.1, 3.3.2 and 3.3.3 and the memoranda reporting the data are located in Appendices B-3 through B-7. The detailed methodology for calculating the estimates of these physical/chemical constituents are provided in each memorandum in these Appendices.

3.3.1 Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP

The information on complexing agents in the waste was provided in a series of three memoranda to DOE/CAO. The initial memorandum, entitled "Preliminary Estimate of Complexing Agents in TRU Waste Forms Scheduled for Disposal in WIPP," provided in Appendix B-3, represents the earliest estimate of complexing agents in the TRU Waste. The Appendix B-3 memorandum was superseded by the second estimate, entitled "Current Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP," provided in Appendix B-4. After the Appendix B-4 memorandum was issued, preliminary information from the January 1996 data submittal from INEL was received. The data submittal indicated that over 90% of the stored waste at INEL would be vitrified, a process that should destroy complexing agents in TRU waste. Based on the preliminary data from INEL, the estimated amount of complexing agents due to RFETS waste stored at INEL could be reduced from that reported in Appendix B-4. A synopsis of the INEL information is reported in the third memorandum that estimates complexing agents in the waste, entitled "Revision of Current Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP," provided in Appendix B-5.

Table 3-2 provides a summary of the anticipated mass (in kilograms) of complexing agents in TRU waste reported by RFETS/INEL, LANL, and Hanford. The estimates in Table 3-2 include the anticipated reduction in mass of complexing agents reported from RFETS/INEL based on the preliminary data for proposed vitrification of waste at INEL (Appendix B-5). In addition to the mass of complexing agents reported in Table 3-2, ORNL has provided an estimate of total organic carbon (TOC) in their RH-TRU sludges (Table 3-3). ORNL does not have any analytical data to quantitatively estimate which organic chemicals are responsible for the TOC content of the sludges. However, ORNL has provided a list of chemicals, summarized in Table 3-3, that could contribute to the TOC value reported (see Table 1 in Appendix B-4). It is estimated that most of the TOC in the tanks is not associated with complexing agents, but that has not been verified at this time. As a conservatism, PA calculations can assume that any complexing agents listed in Table 3-3 could form the bulk of the TOC in the ORNL RH-TRU tanks.

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Table 3-2. Estimates of Complexing Agents in Transuranic Waste from RFETS, INEL, LANL, and Hanford*

Compound	Low Estimate (kg)	Recommended Estimate (kg)	High Estimate (kg)
Ascorbic Acid	18	30	34
Acetic Acid	27	44	50
Sodium Acetate	141	282	333
Citric Acid	1110	1120	1130
Sodium Citrate	51	102	120
Oxalic Acid	13700	13700	13700
EDTA	3	6	7
8-Hydroxyquinoline	6	12	14
Tributyl Phosphate	102	111	115
1,10 Phenanthroline	0.03	0.06	0.07
Dihexyl-n,n-diethyl carbamoylmethyl phosphonate	9	18	22

* Refer to Appendices B-4 and B-5 for methodology of calculated estimates.

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Table 3-3. Estimate of Total Organic Carbon (TOC) in ORNL Transuranic Sludge Tanks and Possible Complexing Agents that can Contribute to TOC.

Total Organic Carbon in ORNL Transuranic Sludge = 3691 kg

Possible Complexing Agents and Other Organic Compounds* in ORNL RH-TRU Sludges:

Acetic Acid
Acetone
Adogen-364-HP (~triluarylamine)
Carbon tetrachloride
Deodorized mineral spirits (Amsco)
2,5-di-tert-butylhydroquinone (DBHQ)
Diethylbenzene (DEB)
Diethylenetriaminepentaacetic acid (DPTA)
Di (2-ethylhexyl) phosphoric acid (HDEHP)
Di-isopropylbenzene (DIPB)
Ethanol
Ether
Ethylenediaminetetraacetic acid (EDTA)
2-ethyl-1-hexanol
α-hydroxyisobutyric acid
Isopropanol
Methanol
n-dodecane
n-paraffin (NPH)
Oxalic Acid
Thenoyltrifluoroacetone (TTA)
Tributylphosphate (TBP)
Trichloroethylene (TCE)
Xylene

*Adapted from Table 1 in Appendix B-4.

3.3.2 Estimate of Nitrate, Sulfate, and Phosphate Content in Transuranic Solidified Wastes for Disposal in WIPP

Estimates of nitrate and sulfate in solidified TRU final waste forms were provided in the memorandum entitled "Preliminary Estimate for SNL/NM Performance Assessment Calculations of Nitrate, Sulfate, and Phosphate in Transuranic Solidified Wastes Destined for Disposal in WIPP," provided in Appendix B-6. In that memorandum, it is estimated that densities for the overall disposal inventory are as follows: 9.2 kilograms/cubic meter for nitrate and 3.6 kilograms/cubic meter for sulfate. No estimate of phosphate was reported due to lack of sufficient information.

3.3.3 Estimate of Cement in TRU Solidified Waste Forms for Disposal in WIPP

An estimate of cement (portland-based) in solidified TRU final waste forms was calculated in the memorandum entitled "Estimate of Cement Content in TRU Solidified Waste Forms Scheduled for Disposal in WIPP," provided in Appendix B-7. The estimated density of cement over the entire disposal inventory is 48.6 kilogram/cubic meter. This estimate includes both CH-TRU and RH-TRU final waste forms. The portland cement reported is both reacted and unreacted cement in the waste. There are no data available to estimate the percentage of reacted versus unreacted cement in the waste.

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4. REFERENCES

Croff, A. G., 1983, "ORIGEN2: A Versatile Computer Code for Calculating the Nuclide Compositions and Characteristics of Nuclear Materials," *Nuclear Technology*, Vol. 62, pp. 335-352, November 1983.

Croff, A. G., 1980, *A User's Manual for the ORIGEN2 Code*, ORNL/TM-7175, Oak Ridge National Laboratory, July 1980.

DOE – See U.S. Department of Energy.

EPA – See U.S. Environmental Protection Agency.

SNL/NM – See Sandia National Laboratory/NM.

Public Law, 1992a, Public Law 102-386, 1992, *Federal Facilities Compliance Act of 1992.*

Public Law, 1992b, Public Law 102-579, 1992, *Waste Isolation Pilot Plant Land Withdrawal Act.*

Public Law, 1979, Public Law 96-164, 1979, *National Security Programs*, 93 Stat. 1259, 1265.

Public Law, 1954, U.S. Congress, Atomic Energy Act of 1954, Public Law 83-703, August 15, 1954.

U.S. Department of Energy, 1996, *Waste Acceptance Criteria for the WIPP*, DOE/WIPP-069, Revision 5, April 1996.

U.S. Department of Energy, 1995a, *DOE Waste Treatability Group Guidance*, DOE/LLW-217, Revision 0, January 1995.

U.S. Department of Energy, 1995b, *Integrated Data Base for 1995: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Revision 11, September 1995.

U.S. Department of Energy, 1995c, *Transuranic Waste Baseline Inventory Report*, DOE/CAO-95-1121, Revision 2, December 1995.

U.S. Department of Energy, 1990, *Final Supplement Environmental Impact Statement*, Volume 3, DOE/EIS-0026-FS, January 1990.

U.S. Department of Energy, 1988, *Radioactive Waste Management*, DOE Order 5820.2A, U.S. Department of Energy, Washington, D.C., September 26, 1988.

U.S. Department of Energy and State of New Mexico, 1981, "Agreement for Consultation and Cooperation Between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant," July 1, 1981 (dated April 18, 1988).

U.S. Environmental Protection Agency, 1996, *Criteria for the Certification and Recertification of the Waste isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations*, Final Rule, 40 CFR 194, Federal Register, February 9, 1996.

U.S. Environmental Protection Agency, 1993, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, 40 CFR 191, Final Rule, Federal Register, Vol. 58, Page 66398, December 20, 1993.

U.S. Environmental Protection Agency, 1980, *Listing of Hazardous Waste*, 40 Code of Federal Regulations, Part 261, May 19, 1980.

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5. GLOSSARY

40 CFR Part 191, Protection of Environment. EPA: Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes – The EPA's environmental standards for the storage (Subpart A) and disposal (Subpart B) of spent nuclear fuel, and high-level and TRU radioactive wastes. This is the primary post-closure standard that applies to WIPP.

Anticipated Inventory – The sum of the stored and projected inventories, as defined in this document.

As-Generated Waste – The chemical and physical status of waste when it is generated.

Buried Waste – TRU waste buried in shallow trenches prior to the 1970 Atomic Energy Commission policy that required TRU waste to be retrievably stored.

Code of Federal Regulations (CFR) – (1) A codification of the general and permanent rules published in the **Federal Register** by the department and agencies of the federal government. The CFR is divided into 50 titles that represent broad areas subject to federal regulation. It is issued quarterly and revised annually. (2) All federal regulations in force are published annually in codified form in the CFR.

Contact-Handled (CH) TRU Waste – Packaged TRU wastes with an external surface dose rate of less than 200 mrem per hour.

Defense Waste – (1) Radioactive waste from any activity performed in whole or in part in support of DOE atomic energy defense activities; excludes waste under purview of the Nuclear Regulatory Commission or generated by the commercial nuclear power industry. (2) Nuclear waste derived mostly from the manufacture of nuclear weapons, weapons-related research programs, the operation of naval reactors, and the decontamination of nuclear weapons production facilities.

Department of Energy Site – A DOE-owned or -controlled tract used for DOE operations. Either a tract owned by DOE or a tract leased or otherwise made available to the federal government under terms that afford to DOE rights of access and control substantially equal to those that DOE would possess if it were the holder of the fee (or pertinent interest therein) as agent of and on behalf of the government. One or more DOE operations/program activities are carried out within the boundaries of the described tract.

Disposal – Emplacement of waste in a manner that assures isolation from the biosphere for the foreseeable future with no intent of retrieval and that requires deliberate action to regain access to the waste. For example, disposal of wastes in a mined geologic repository occurs when all of the shafts to the repository area are backfilled and sealed.

Disposal Inventory – The inventory volume defined for WIPP emplacement to be used for PA calculations is the "disposal inventory." The LWA defines the total amount of TRU waste allowed in the WIPP as 6,200,000 cubic feet (approximately 176,000 cubic meters) (Public Law, 1992b). The "Agreement for Consultation and Cooperation" (C&C Agreement) limits the RH-TRU inventory to 250,000 cubic feet (approximately 7,080 cubic meters) (DOE and State of New

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Mexico, 1981). Therefore by difference, the CH-TRU inventory is limited to 5,950,000 cubic feet (approximately 168,500 cubic meters).

Final Waste Form – Consists of a series of WMCs that for PA purposes have similar physical and chemical properties.

Integrated Data Base (IDB) – The latest version of the IDB, the *Integrated Data Base for [1995]: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics* (DOE, 1995b).

Land Withdrawal Act - The 1992 legislation passed by the U.S. Congress withdrawing the surface land and underlying minerals at the WIPP site from public use, transferring the property from the DOI to the DOE, and enabling the start of the WIPP Test Phase. The LWA sets prerequisites to be met before the start of the Test Phase, such as the repromulgation by EPA of 40 CFR 191 and the concurrence of EPA with the Test Phase Plan (Public Law, 1992b).

Mixed TRU Waste – TRU waste that contains both radioactive and hazardous components as defined by the Atomic Energy Act and the RCRA as codified in 40 CFR Parts 261.3 (EPA, 1980).

Newly Generated Wastes – See Projected Inventory.

Performance Assessment (PA) – (1) A systematic analysis of the potential risks posed by waste management systems to the public and environment and a comparison of those risks to established performance objectives. (2) An analysis that (a) identifies the processes and events that might affect the disposal system, (b) examines the effects of these processes and events on the performance of the disposal system, and (c) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable. (3) A term used to denote all activities (qualitative and quantitative) carried out to (a) determine the long-term ability of a site/facility to effectively isolate the waste and ensure the long-term health and safety of the public and (b) provide the basis for demonstrating regulatory compliance.

Projected Inventory – That part of the inventory that has not been generated but is estimated to be generated at some time in the future by the TRU waste generator/storage sites. The estimated timeframe may vary, but is usually between 20 and 30 years. "Newly generated waste" also is sometimes used as a synonym for the projected inventory.

Radioactive – Term used to refer to an unstable atomic nucleus that decays with the spontaneous emission of ionizing radiation (also see "radionuclide").

Radionuclide – (1) A species of atom having an unstable nucleus, that is subject to spontaneous decay or disintegration and usually accompanied by the emission of ionizing radiation. (2) Any nuclide that emits radiation. A nuclide is a species of atom characterized by the constitution of its nucleus and hence by the number of protons, the number of neutron, and the energy content.

Remote-Handled (RH) TRU Waste – Packaged TRU wastes with an external surface dose rate equal to or exceeding 200 mrem per hour.

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Resource Conservation and Recovery Act (RCRA) – (1) Establishes a system for controlling hazardous waste from generation to disposal. (2) A Federal law passed in 1976, and amended under the HSWA of 1984, that established a structure to track and regulate hazardous wastes from the time of generation to disposal. The law requires safe and secure procedures to be used in treating, handling, transporting, storing, and disposing of hazardous substances. RCRA is designed to prevent new uncontrolled hazardous waste sites. The law also regulates the disposal of solid waste that may not be considered hazardous. (3) Specifically, Subtitle D of RCRA governs the management of solid waste. (Note: 40 CFR Parts 260-272 are the regulations for complying with RCRA with respect to hazardous waste and hazardous waste treatment, storage, and disposal facilities.)

Scaling – The process for adjusting the anticipated inventory to equal the maximum authorized disposal inventory of the WIPP repository for the purposes of WIPP performance assessment modeling.

Stored Inventory – That part of the TRU waste inventory currently in retrievable storage as of the time of the last data call for inventory information. Retrievably stored waste includes waste stored in buildings or in berms with earthen cover since 1970 and does not include any waste that was buried prior to 1970. Stored inventory can be in the "as-generated" form or "final waste form."

Transuranic – Pertaining to elements that have atomic numbers greater than 92, including neptunium, plutonium, americium, and curium; all are radioactive, are not naturally occurring, and are members of the actinide group.

Transuranic (TRU) Waste – (1) Waste containing alpha-emitting radionuclides with an atomic number greater than 92 and half-lives greater than 20 years, at concentrations of TRU isotopes greater than 100 nanocuries per gram of waste. **This core definition appears in modified form in various relevant documents as follows**: (a) For purposes of management, DOE Order 5820.2A: (i) considers TRU waste, as defined above, "without regard to source or form" *(The proposed revision to the Order [DOE Order 5820.2A Major Issues for Revision, May 6, 1992]* contemplates removing this clause); (ii) allows head of field elements to determine that wastes containing other alpha-emitting radionuclides must be managed as TRU waste; and (iii) adds "at time of assay," implying both that the classification of a waste as TRU waste is to be made based on an assay, and that such classification can be superseded only by another assay. (b) For purposes of setting standards for management and disposal, 40 CFR 191.02(i) adds "except for: (i) high-level wastes; (ii) wastes that the DOE has determined, with the concurrence of the EPA Administrator, do not need the degree of isolation required by this part; or (iii) wastes that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR 61." (2) Waste materials contaminated with U-233 (and its daughter products), with certain isotopes of plutonium, or with other nuclides with atomic numbers greater than 92. In order to be classified as TRU waste, the long-lived alpha activity from subject isotopes must exceed 100 nanocuries per gram of waste material independent of the level of beta-gamma activity. These wastes are produced primarily from reprocessing spent fuel and from the use of plutonium in the fabrication of nuclear weapons. (3) Wastes that are contaminated with radioactive elements heavier than uranium, thus the name trans-(or beyond) uranic.

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Waste Acceptance Criteria (WAC) – The criteria used to determine if waste packages are acceptable. For the purposes of this document, WAC refers to WIPP WAC.

Waste Form – The physical form of the waste such as sludges, combustibles, metals, etc.

TRU Waste Sites – The 8 major DOE facilities and several smaller sites throughout the U.S. that generate and store TRU waste.

Waste Isolation Pilot Plant (WIPP) – (1) The project authorized under Section 213 of the DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Public Law, 1979) to demonstrate the safe and environmentally sound disposal of radioactive waste materials generated by atomic energy defense activities. (2) A research and development facility located near Carlsbad, New Mexico to be used to demonstrate a practical, long-term solution to a complex problem: the safe disposal in deep geologic repositories of TRU waste resulting from DOE activities.

Waste Material Parameter – A waste material that occurs in TRU waste that is an input parameter into one (or more) current PA model(s) or is required to adequately describe the waste form.

Waste Matrix Code (WMC) – A DOE-developed coding system for grouping waste streams that have similar matrix constituents, especially for treatment objectives. This coding system allows waste streams within the DOE TRU waste system that have similar physical and chemical waste form properties to be categorized together. WMCs also have been called "waste treatability codes" in other DOE documents. An example of a WMC for "heterogeneous waste" is 5400 (DOE, 1995a).

Waste Stream – A flow of waste materials with specific definable characteristics that remain the same throughout the life of the process generating the waste stream.

Waste Stream Profile – A description of a CH-TRU or RH-TRU waste stream destined for shipment to and disposal in WIPP, if authorized under permits and certifications by appropriate regulatory agencies for disposal in the WIPP repository. The waste stream profile is presented in tabular format and is intended to provide a summary of the important information about a particular waste stream.

WIPP Waste Profile – Represents a summary of TRU waste at all DOE TRU waste generator/storage sites that have an identical Final Waste Form.

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APPENDIX A

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APPENDIX A - 1

Sandia National Laboratories

Managed and Operated by Sandia Corporation
a Lockheed Martin Company
Albuquerque, New Mexico 87185-1328

date : November 6, 1995

to : R. L. Bisping, DOE/CAO, WOIC 3, MS-560

from : L. C. Sanchez, Org 6342, MS-1328 (505)848-0685

subject : **CH and RH-TRU Waste Parameters Potentially Important in WIPP PA**

A) **Requested PA Data From TWBIR**

Below you will find an updated list of waste material parameters that have been identified as being potentially important to the performance analysis of the WIPP repository. It is requested that these parameters be be supplied in Rev. 2 of the Transuranic Waste Baseline Inventory Report (TWBIR). Itemized below you will find the two categories of requested waste parameter data.

1) **Non-radioactive Materials**
The non-radioactive materials are those which influence gas generation potential and those that are needed for mechanical models which predict waste consolidation and shear strength properties. The list of the non-radioactive materials is shown in Table 1.

2) **Radionuclide**
At this time there are no new requests for additional radionuclide inventory data beyond those previously reported in Rev. 1 of the WTWBIR. If there are significant inventory increases in radionuclides due to special circumstances (such as inclusion of residues to the TRU inventory), sufficient footnote explanations should be supplied.

Table 1. Justification of TWBIR Nonradioactive Waste Parameters.

Waste Parameter	Input Variable in Current PA Models		Input Variable in PA Models Under Development	Input Variable in Possible Future PA Models
	Gas Generation	Mechanical Characteristics		
Iron-Based Metals and Alloys	X	X	X	X
Aluminum-Based Metals and Alloys (a)		X	X	
Other Metals		X		?
Other Inorganics		X		?
Cellulosics	X	X	X	X
Plastics	½ (b)	X	X (d)	X
Rubbers	½ (b)	X	X (e)	X
Solidified Inorganics		X	X	X
Solidified Organics Matrix		X	X	X
Soils (c)		X	?	?

(a) Future model for PA does not include aluminum.
(b) Only one-half of material is assumed to generate gas.
(c) May impact colloids.
(d) As is.
(e) Percentage of material to generate gas is unknown at the present time.

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B) **Special Request Non-PA Items**

Also wanted at this time is additional information for several waste material characteristics. Although these characteristics have not been identified as waste material parameters to be used for WIPP PA, they are needed for non-PA scoping calculations to assess their influence on PA. Since these items are not currently PA parameters, inventory estimates of these characteristics as "additional information" in the TWBIR or supplied outside of the TWBIR via written correspondence. Below you will find an itemized list of these special request items.

1) **Non-radioactive Materials**
Additional information is needed on the five waste material characteristics (see Table 2): 1) vitrified wastes, 2) nitrates (NO_3^-), 3) sulfates (SO_4^{2-}), 4) phosphorus, and 5) cement. Of these waste parameters, the last four are needed for the gas generation modeling. The nitrates and the sulfates are involved in the denitrification and sulfate reduction processes which breakup the cellulosics, while the phosphorus is a nutrient for biodecay of cellulosics. The estimate of the mass quantities of cement in the waste inventory should include both the cement that is contained in the waste as cement itself (due to D&D activities, etc.,) and the cement found in various sludges. Cement consumes CO_2 due to its content of $Ca(OH)_2$. The estimates for this non-radioactive waste constituent need only be "best estimates" at this present time so that non-PA scoping calculations can be made to determine their importance on overall repository performance. (Do not generate upper-bound estimates that are overly conservative.)

2) **Residues**
"Best estimates" are needed for residues, in addition to those already identified at the Rocky Flats Plant (RFP), that have the possibility of being changed from a resource category to a TRU waste category.

3) **Organic Ligands (Chelating Agents)**
"Best estimates", from currently available information, are needed for major water-soluble organic ligands which are under consideration for the actinide source term (see Table 3). If it is not possible to obtain data from major waste generating sites then supply guidance on how a first-order estimate may be made (from existing information such as process knowledge etc.,) so that non-PA scoping calculations can be performed to identify if the presence of these ligands would have any significant impacts. (Do not generate estimates that are overly conservative.) Requested data is for final form "process-level" quantities used in production only for the key sites. If information on the "process-level" values does not exist at the key sites, then "laboratory-scale" values should be used in the requested assessment of the inventory. Should it be determined that more detailed information on organic ligands will be needed, you will be given a specific written request at a future time. This effort should be performed in parallel with the TWBIR. Technical data should be supplied in memorandum form by the end of February 1996 with supporting documentation by the end of March 1996.

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Table 2. Justification of Special Request Non-PA Non-Radioactive Waste Materials. (a)

Waste Parameter	Input Variable in Current PA Models		Input Variable in PA Models Under Development	Input Variable in Possible Future PA Models
	Gas Generation	Mechanical Characteristics		
Vitrified (b)		X	?	?
Nitrates (NO_3)	X (c)		X	?
Sulfates (SO_4)	X (c)		X	?
Phosphorus	X (c)		X	?
Cement (d)	X		X	?

(a) Information on these additional waste materials are needed for non-PA scoping calculations for assessment of their importance. These waste characteristics can be reported at the "best estimate" level.

(b) New waste parameter corresponding to treatment, identified by some of the sites, to be anticipated in the future.

(c) Input variable is of concern when predicting the rates of microbial action and is used in currently existing reaction path model, which will not become a baseline PA model.

(d) Any concrete or cement (including dry portland cement) that contains calcium oxide.

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Table 3. Justification of Special Request For Info On Organic Complexing Agents. (a)	
Ligand (b)	Discussion (c)
1) Total Complexants	The most valuable information at this time is a "best estimate" of the total amount of water soluble complexing agents (ligands) in the TRU waste matrix.
2) Citrate	Preliminary information indicates that citrate (citric acid) may be the largest used ligand at TRU waste generating sites. Hence, inventory quantities are very important.
3) Lactate	This is an important ligand that is produced by bacteria as part of its own metabolism. What is requested here is a "best estimate" of the quantity of lactate that actually exists in the TRU waste matrix (not just an initial amount supplied as part of a waste stream). However, if this information cannot be developed, then supply information on the initial amount.
4) Oxalate	This is an important ligand that is produced by bacteria as part of its own metabolism. What is requested here is a "best estimate" of the quantity of oxalate that actually exists in the TRU waste matrix (not just an initial amount supplied as part of a waste stream). However, if this information cannot be developed, then supply information on the initial amount.
5) EDTA	This ligand (ethylenediaminetetraacetic acid) is also of major importance due to its common use as a cleaning solvent.

(a) Information on these additional waste materials are needed for non-PA scoping calculations for assessment of their importance. The presence of these complexing agents are important for the actinide source term, with respect to increasing the solubility of radionuclides.
(b) These items are ranked in the order of their importance in the actinide source term.
(c) Also supply any available information that TRU waste generation sites may have on the degradation or decay rates of ligands in current (and expected) waste matrixes if possible. In cases where no information is available, supply guidance on estimating first-order quantities.

LCS:6741:lcs/(95-2082)

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Copy to:
P.E. Drez [Drez Environmental Associates]
D. Bretzke [Science Applications International Corporation]
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MS-1341, R.F. Weiner [Dept. 6747]
MS-1495, P.E. Sanchez [Dept. 6700]
MS-1328, Day File [Dept. 6741]
MS-1328, L.C. Sanchez [Dept. 6741]
File - SWCF-A WBS 1.1.6.2; PA; PBWAC - WIPP ACTIVITY

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APPENDIX A-2

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Sandia National Laboratories

Managed and Operated by Sandia Corporation
a Lockheed Martin Corporation
Albuquerque, New Mexico 87185-1328

date : January 11, 1996

to : S. Chakraborti [Science Applications International Corporation]

from : L. C. Sanchez, Org 6741, MS-1328, PH-(505)848-0685, Fax-848-0705

subject : **Information Needed from TWBIR (Rev. 2/Addendum)**

I have read Paul Drez's memo [Ref. DEA-1] about the Rev. 2 of the TWBIR [Ref. BIR-1]. When updated values are available, please send me a memo with the WIPP-scale values (CH & RH waste material parameters -- Tables 3-2 & 3-3 and CH & RH disposal radionuclide inventory data -- Table 3-4). [Note -- **because the anticipated volume of RH waste is much greater than the WIPP disposal volume, the proper volume that should be used to determine the average waste material parameters should be a "truncated volume", i.e., the truncated volume is equal to the existing stored waste plus only the necessary amount of projected waste necessary to reach the WIPP disposal volume limit.**] When regenerating Table 3-4, please add extra columns which also display the "total curies" (in addition to the data displaying the curie volumetric densities) for both CH & RH radionuclides. The volumes to be used for these conversions are: 1) ~~6.2E+06~~ 5.95E+06 cu.ft. = ~~175,584~~ 168,504. cu.m. for CH-TRU waste and 2) 0.25E+06 cu.ft. = 7,080. cu.m. [the unit conversions for volume were done with the factor 1.0 cu.ft. = 2.832E-02 cu.m. taken from Ref. SNL-1].

LCS 1-12-96

LCS 1-12-96

A second request, which should be documented in a separate memo, is that CH & RH activity loading tables be generated on a per-waste stream basis. The format for the data should look as close to that shown in Table 1 below. It is also needed that the information be made into an ASCII file and placed on a 3.5" diskette (IBM formatted). There are three versions of this table that are needed: 1) values corresponding to stored waste only, 2) values corresponding to projected waste only, and 3) values corresponding to WIPP disposal volume [Note -- remember to use the truncated volumes for the RH waste].

REFERENCES

[DEA-1]
Memo from: P. Drez (Drez Environmental Associates, DEA) to: L.C. Sanchez (Sandia National Laboratories), subject: "BIR Error", dated: January 7, 1996.

[BIR-1]
DOE (U.S. Department of Energy); Transuranic Waste Baseline Inventory Report; DOE/CAO-95-1121; Revision 2; printed December 1995.

[SNL-1]
Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters (SAND92-0700/3)*, section: *Conversion Tables For SI and Common English Units*, Table 5, pg. Conversion Tables - 4. SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories.

Table 1. Radionuclide Activity Loading Table
(to be used for human intrusion calculations)

TRU Type	Site ID	Waste Stream ID	Volume of Waste Stream	Curie Loading $\left[\frac{curies}{vol}\right]$	Curie Loading $[curies]$
CH	*LANL*	*LA-?001*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
CH	*LANL*	*LA-?002*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
CH	*LANL*	*LA-?003*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
CH	*LANL*	*LA-?004*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
CH	*LANL*	*LA-?005*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
CH	*LANL*	*LA-?006*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
CH	*LANL*	↓	↓	↓	↓
CH	*LANL*	--	∑ XXXXX.X	--	∑ X.XXE+KK
CH	*RFETS*	*RF-?001*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
CH	*RFETS*	↓	↓	↓	↓
CH	*RFETS*	--	∑ XXXXX.X	--	∑ X.XXE+KK
CH	↓	↓	↓	↓	↓
CH	**Total**	--	∑ XXXXX.X	--	∑ X.XXE+KK
RH	*LANL*	*LA-?001*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
RH	*LANL*	*LA-?002*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
RH	*LANL*	*LA-?003*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
RH	*LANL*	*LA-?004*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
RH	*LANL*	*LA-?005*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
RH	*LANL*	*LA-?006*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
RH	*LANL*	↓	↓	↓	↓
RH	*LANL*	--	∑ XXXXX.X	--	∑ X.XXE+KK
RH	*RFETS*	*RF-?001*	*XXXX.X*	*X.XXE-KK*	*X.XXE+KK*
RH	*RFETS*	↓	↓	↓	↓
RH	*RFETS*	--	∑ XXXXX.X	--	∑ X.XXE+KK
RH	↓	↓	↓	↓	↓
RH	**Total**	--	∑ XXXXX.X	--	∑ X.XXE+KK

LCS:6741:lcs/(96-2096)

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MS-1328, R.P. Anderson [Dept. 6749]
MS-1328, Day File [Dept. 6741]
MS-1328, L.C. Sanchez [Dept. 6741]
File - SWCF-A WBS 1.1.6.2;PA;PBWAC - WIPP ACTIVITY

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APPENDIX A-3

M

Sandia National Laboratories

Managed and Operated by Sandia Corporation
a Lockheed Martin Corporation
Albuquerque, New Mexico 87185-1328

date : January 30, 1996

to : S. Chakraborti [Science Applications International Corporation]

from : L. C. Sanchez, Org 6741, MS-1328, PH-(505)848-0685, Fax-848-0705

subject : **Information Needed from TWBIR (Rev. 2/Addendum)**

With regards to the two requests previously made (Ref. LCS-1), the first is no longer needed and an update is needed for the second.

Since the data in the TWBIR (Ref. BIR-1) for projected waste material parameters and radionuclide inventory is based on data for stored waste (Ref. SC-1), the first request for data values to be volume averaged using truncated volume is not necessary (i.e., it would yield the same values).

For the second request from Ref. LCS-1, it has been identified that not all the radionuclide data in the TWBIR are incorporated in the radionuclide activity loading tables which are used for the human intrusion calculations (Refs. SNL-1 & JG-1). Instead, an abbreviated list of 21 radionuclides is all that should be used to generate the curie loading table (see Table 1 of Ref. LCS-1). The list of the 21 radionuclides (for both CH and RH) are shown in Table 1 below (this list is based on Table I of Appendix of Ref. EPA-1). Also, since the projected waste data is based on stored data, values generated are needed only for WIPP disposal volumes (data separated for stored and projected data would have yielded the same values).

REFERENCES

[BIR-1]
DOE (U.S. Department of Energy); Transuranic Waste Baseline Inventory Report; DOE/CAO-95-1121; Revision 2; printed December 1995.

[EPA-1]
"Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radionactive Waste: Final Rule," 40CFR191, *Federal Register*, **50**, 38066 (1985).

[JG-1]Communications with J. Garner [Piru Assoc., SNL/Dept 6749], date: January 30, 1996.

[LCS-1]
Memo from: L.C. Sanchez (Dept. 6741) to: S. Chakraborti (Science Applications International Corporation), subject: "Information Needed from TWBIR (Rev. 2/Addendum)", dated: January 11, 1996.

[SC-1]Communications with S. Chakraborti [Science Applications International Corporation], date: January 25, 1996.

[SNL-1]
Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992.* (SAND92-0700),

Table 1. Radionuclides That Should Be Used To Generate Curie Loading

	Radionuclide
1	Am-241
2	Cm-248
3	Cs-137
4	Np-237
5	Pa-231
6	Pb-210
7	Pu-238
8	Pu-239
9	Pu-240
10	Pu-242
11	Pu-244
12	Ra-226
13	Sr-90
14	Th-229
15	Th-230
16	Th-232
17	U-233
18	U-234
19	U-235
20	U-236
21	U-238

LCS:6741:lcs/(96-2098)

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MS-1328, L.C. Sanchez [Dept. 6741]
File - SWCF-A WBS 1.1.6.2:PA:PBWAC - WIPP ACTIVITY

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APPENDIX B

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APPENDIX B - 1

DOE F 1325.8

United States Government **Department of Energy**

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: June 4, 1996

REPLY TO ATTN OF: CAO:NTP:RLB:96-1174

SUBJECT: Revised Radionuclide Data in Support of the Compliance Certification Application

TO: Les E. Shephard, Director, Nuclear Waste Management Programs Center, SNL/NM

Please find attached the revised WIPP disposal radionuclide inventory which was previously transmitted to your staff for their use. This inventory has been recalculated on the basis of new radionuclide information recently available from four TRU waste sites: the Hanford site (Hanford), the Oak Ridge National Laboratory (ORNL), the Rocky Flats Environmental Technology Site (RFETS), and the Savannah River Site (SRS). The revised WIPP disposal radionuclide inventory is provided in Attachment A in a format similar to Table.3-4 of Revision 2 of the Transuranic Waste Baseline Inventory Report (TWBIR).

The values in Attachment A were originally based on the extrapolation of the results of preliminary radionuclide decay calculations that were completed by Sandia National Laboratories (SNL) staff on April 8. These preliminary calculations have recently completed the formal quality assurance/quality control (QA/QC) review process by the SNL QA/QC group, and an approved version of these calculations was obtained on Tuesday, April 17. The QA/QC review process produced some changes in the preliminary values, and these changes have been incorporated in Attachment A.

Since the WIPP Performance Assessment (PA) group at SNL required the revised data as soon as possible in support of the Compliance Certification Application (CCA), Attachment A is being supplied as the most current update until the publication of Revision 3 and should be used by the WIPP PA in support of the CCA. As agreed with the SNL WIPP (PA) staff during the videoconference meeting on March 3, 1996, the revised data shown in Attachment A are based on the final waste form volumes published in Revision 2 of the TWBIR. The information in Attachment A will be included in the TWBIR, Rev. 3, as well as that previously supplied on complexing agents, cement content, and nitrate/sulfate/phosphate content, which will be included as an appendix to the TWBIR.

In summary, the revised data in Attachment A incorporates the effect of the following information received from four sites during the past two months:

- Corrections to the values for Cf-252, Cm-244, and Cm-245 reported in earlier Hanford submittals for the IDB.

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- Preliminary sludge sampling data from ORNL for the RH-TRU sludges showing the distribution of different uranium isotopes in the sludge; this enabled the redistribution of the uranium curies from previous Oak Ridge IDB submittals and corrected the previously high estimates of U-235.

- Break-up of radionuclide data for SRS waste between on-site and off-site waste (i.e., waste from Los Alamos and Mound that was shipped to SRS for storage in the early 1970s); this enabled more realistic extrapolation of the amount of Pu-238 and Pu-239 in SRS waste.

A description of the step-by-step methodology used to incorporate the new information from the four sites and to develop the revised inventory is provided in Attachment B.

If you have any questions concerning the enclosed information, please contact Mr. Russ Bisping of my staff at (505) 234-7446.

Don Watkins
Manager
National TRU Program

Attachments

cc w/attachments:
R. Bisping, CAO
G. Basabilvazo, CAO
J. Mewhinney, CAO
S. Chakraborti, CTAC
P. Drez, CTAC
J. Harvill, CTAC
R. Anderson, SNL
L. Sanchez, SNL
M. Chu, SNL
M. Marietta, SNL

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ATTACHMENT A

WIPP Disposal Radionuclide Inventory for the CCA[1]

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Ac225	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ac227	3.61E-06	1.07E-07	6.08E-01	7.57E-04
Ac228	4.43E-06	1.10E-05	7.47E-01	7.77E-02
Ag109m	9.32E-05	NR	1.57E+01	NR
Ag110	4.19E-14	2.46E-13	7.07E-09	1.74E-09
Ag110m	3.15E-12	1.85E-11	5.31E-07	1.31E-07
Am241	2.62E+00	8.42E-01	4.42E+05	5.96E+03
Am242	1.04E-05	NR	1.75E+00	NR
Am242m	1.04E-05	NR	1.75E+00	NR
Am243	1.93E-04	3.23E-08	3.26E+01	2.28E-04
Am245	7.89E-15	4.06E-20	1.33E-09	2.87E-16
At217	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ba137m	4.53E-02	2.89E+01	7.63E+03	2.04E+05
Bi210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Bi211	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Bi212	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Bi213	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Bi214	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Bk249	5.44E-10	2.80E-15	9.16E-05	1.98E-11
Bk250	2.59E-16	NR	4.37E-11	NR
C14	6.43E-05	2.90E-04	1.08E+01	2.05E+00

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

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ATTACHMENT A

WIPP Disposal Radionuclide Inventory for the CCA (continued)

Nuclide	CH-TRU Waste (Ci/m³)	RH-TRU Waste (Ci/m³)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Cd109	9.31E-05	NR	1.57E+01	NR
Cd113m	1.08E-11	7.71E-11	1.82E-06	5.46E-07
Ce144	3.71E-07	7.24E-04	6.26E-02	5.13E+00
Cf249	3.81E-07	6.31E-07	6.42E-02	4.47E-03
Cf250	1.96E-06	NR	3.30E-01	NR
Cf251	2.24E-08	NR	3.78E-03	NR
Cf252	1.42E-03	1.82E-04	2.39E+02	1.29E+00
Cm242	6.76E-06	NR	1.14E+00	NR
Cm243	1.61E-05	6.99E-03	2.72E+00	4.95E+01
Cm244	1.87E-01	4.45E-02	3.15E+04	3.15E+02
Cm245	6.81E-08	2.07E-10	1.15E-02	1.46E-06
Cm246	6.06E-07	NR	1.02E-01	NR
Cm247	1.91E-14	NR	3.21E-09	NR
Cm248	5.31E-07	2.89E-08	8.95E-02	2.05E-04
Co58	1.81E-18	1.75E-15	3.05E-13	1.24E-11
Co60	3.83E-04	1.47E+00	6.46E+01	1.04E+04
Cr51	NR	4.29E-10	NR	3.04E-06
Cs134	7.97E-08	2.60E-03	1.34E-02	1.84E+01
Cs135	2.98E-09	1.66E-08	5.02E-04	1.17E-04
Cs137	4.78E-02	3.05E+01	8.06E+03	2.16E+05

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

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ATTACHMENT A

WIPP Disposal Radionuclide Inventory for the CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Es254	2.51E-16	NR	4.24E-11	NR
Eu150	2.08E-10	NR	3.51E-05	NR
Eu152	7.46E-06	1.73E-01	1.26E+00	1.22E+03
Eu154	6.80E-06	8.34E-02	1.15E+00	5.91E+02
Eu155	5.62E-06	1.67E-02	9.46E-01	1.18E+02
Fe55	1.13E-10	2.38E-05	1.91E-05	1.69E-01
Fe59	1.57E-12	NR	2.64E-07	NR
Fr221	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Fr223	4.98E-08	1.48E-09	8.39E-03	1.04E-05
H3	5.16E-06	9.33E-06	8.69E-01	6.60E-02
I129	4.18E-12	NR	7.05E-07	NR
Kr85	1.20E-06	2.37E-04	2.02E-01	1.68E+00
Mn54	5.05E-09	3.32E-06	8.51E-04	2.35E-02
Nb95	1.51E-14	9.45E-05	2.54E-09	6.69E-01
Nb95m	5.04E-17	3.17E-07	8.50E-12	2.24E-03
Ni59	4.47E-08	NR	7.52E-03	NR
Ni63	5.46E-06	1.40E-04	9.19E-01	9.88E-01
Np237	3.33E-04	4.02E-04	5.61E+01	2.85E+00
Np238	5.20E-08	NR	8.77E-03	NR
Np239	1.93E-04	3.23E-08	3.26E+01	2.28E-04

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

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ATTACHMENT A

WIPP Disposal Radionuclide Inventory for the CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Np240m	8.91E-12	3.12E-15	1.50E-06	2.21E-11
Pa231	2.67E-06	2.70E-07	4.51E-01	1.91E-03
Pa233	3.33E-04	4.02E-04	5.61E+01	2.85E+00
Pa234	3.05E-07	1.92E-06	5.14E-02	1.36E-02
Pa234m	2.35E-04	1.48E-03	3.96E+01	1.05E+01
Pb209	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Pb210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Pb211	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Pb212	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Pb214	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Pd107	4.40E-10	2.45E-09	7.41E-05	1.73E-05
Pm147	4.67E-05	1.52E-03	7.87E+00	1.07E+01
Po210	1.52E-05	1.01E-09	2.55E+00	7.16E-06
Po211	1.01E-08	3.00E-10	1.71E-03	2.12E-06
Po212	1.03E-04	6.66E-06	1.73E+01	4.72E-02
Po213	1.67E-05	1.62E-05	2.82E+00	1.15E-01
Po214	6.91E-05	5.05E-09	1.16E+01	3.57E-05
Po215	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Po216	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Po218	6.91E-05	5.05E-09	1.16E+01	3.58E-05

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

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ATTACHMENT A

WIPP Disposal Radionuclide Inventory for the CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Pr144	3.67E-07	7.16E-04	6.18E-02	5.07E+00
Pu236	6.16E-08	NR	1.04E-02	NR
Pu238	1.55E+01	2.05E-01	2.61E+06	1.45E+03
Pu239	4.66E+00	1.45E+00	7.85E+05	1.03E+04
Pu240	1.25E+00	7.15E-01	2.10E+05	5.07E+03
Pu241	1.37E+01	2.00E+01	2.31E+06	1.42E+05
Pu242	6.96E-03	2.11E-05	1.17E+03	1.50E-01
Pu243	1.91E-14	NR	3.21E-09	NR
Pu244	8.92E-12	3.12E-15	1.50E-06	2.21E-11
Ra223	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Ra224	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Ra225	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Ra226	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Ra228	4.43E-06	1.10E-05	7.47E-01	7.77E-02
Rh106	1.72E-07	1.54E-03	2.90E-02	1.09E+01
Rn219	3.61E-06	1.07E-07	6.09E-01	7.58E-04
Rn220	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Rn222	6.91E-05	5.05E-09	1.16E+01	3.58E-05
Ru106	1.72E-07	1.54E-03	2.90E-02	1.09E+01
Sb125	7.17E-07	2.67E-04	1.21E-01	1.89E+00

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

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ATTACHMENT A

WIPP Disposal Radionuclide Inventory for the CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Sb126	8.02E-10	4.46E-09	1.35E-04	3.16E-05
Sb126m	5.73E-09	3.18E-08	9.65E-04	2.25E-04
Se79	2.58E-09	1.44E-08	4.35E-04	1.02E-04
Sm151	8.72E-06	5.05E-05	1.47E+00	3.57E-01
Sn119m	2.46E-11	1.35E-10	4.14E-06	9.59E-07
Sn121m	1.58E-07	9.45E-07	2.66E-02	6.69E-03
Sn126	5.73E-09	3.18E-08	9.65E-04	2.25E-04
Sr90	4.07E-02	2.95E+01	6.85E+03	2.09E+05
Ta182	NR	5.95E-12	NR	4.21E-08
Tc99	1.49E-04	8.26E-07	2.52E+01	5.85E-03
Te125m	1.75E-07	6.57E-05	2.95E-02	4.65E-01
Te127	7.72E-13	2.41E-13	1.30E-07	1.71E-09
Te127m	7.88E-13	2.47E-13	1.33E-07	1.75E-09
Th227	3.56E-06	1.06E-07	6.01E-01	7.47E-04
Th228	1.61E-04	1.04E-05	2.71E+01	7.36E-02
Th229	1.71E-05	1.66E-05	2.88E+00	1.17E-01
Th230	4.78E-07	1.07E-06	8.06E-02	7.56E-03
Th231	7.59E-05	6.53E-04	1.28E+01	4.63E+00
Th232	5.42E-06	1.31E-05	9.13E-01	9.25E-02
Th234	2.35E-04	1.48E-03	3.96E+01	1.05E+01

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

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ATTACHMENT A

WIPP Disposal Radionuclide Inventory for the CCA (continued)

Nuclide	CH-TRU Waste (Ci/m^3)	RH-TRU Waste (Ci/m^3)	CH-TRU Waste (Total Curies[2])	RH-TRU Waste (Total Curies[2])
Tl207	3.61E-06	1.07E-07	6.07E-01	7.56E-04
Tl208	5.77E-05	3.74E-06	9.73E+00	2.65E-02
Tl209	3.69E-07	3.58E-07	6.22E-02	2.53E-03
U232	1.53E-04	NR	2.58E+01	NR
U233	1.06E-02	2.23E-02	1.79E+03	1.58E+02
U234	2.76E-03	6.03E-03	4.65E+02	4.27E+01
U235	7.59E-05	6.53E-04	1.28E+01	4.63E+00
U236	1.98E-06	1.37E-05	3.33E-01	9.68E-02
U237	3.36E-04	4.91E-04	5.66E+01	3.48E+00
U238	2.35E-04	1.48E-03	3.96E+01	1.05E+01
U240	8.91E-12	3.12E-15	1.50E-06	2.21E-11
Y90	4.07E-02	2.95E+01	6.85E+03	2.09E+05
Zr93	3.34E-08	1.86E-07	5.63E-03	1.32E-03
Zr95	6.80E-15	4.27E-05	1.15E-09	3.02E-01
TOTALS	**3.81E+01**	**1.43E+02**	**6.42E+06**	**1.02E+06**

NR = Not reported by sites.
[1]Decayed to December 1995.
[2]Total curies estimated by assuming a volume of 168,500 cubic meters for CH-TRU waste and 7,080 cubic meters for RH-TRU waste.

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ATTACHMENT - B

This attachment summarizes the major changes to the undecayed radionuclide data based on the new information obtained from four sites since the publication of Rev. 2 of the TWBIR. It also summarizes the methodology used to develop the revised WIPP disposal radionuclide inventories shown in Attachment A.

Major Changes in Data

The major changes to the undecayed radionuclide data from the four TRU waste sites (Hanford. Oak Ridge, Rocky Flats, and Savannah River) are summarized below for each site:

- Changes to the Hanford Data - There were a few errors in the undecayed curies reported by the Hanford site for Cf-252, Cm-244, and Cm-245 in their previous IDB site submittals for CH-TRU waste. The corrected estimates of yearly activity for these radionuclides that were provided by the Hanford site have been used for the revised radionuclide inventory calculations. The previous and revised undecayed activity values are shown in Table B-1.

- Changes to the Oak Ridge Data - In previous IDB submittals, Oak Ridge reported a very conservative (high) inventory for U-235 in the Oak Ridge RH-TRU waste due to the absence of any sampling data. Recently available mass spectrometry analytical data for the evaporator feed tank sludges at Oak Ridge have provided new distributions of the different uranium isotopes in the RH-TRU sludges showing that the primary uranium isotope by mass is U-238 (not U-235). Since the original IDB data are reported in terms of curies (i.e., not on a mass basis), the TWBIR team used the mass spectrometry data to develop new yearly estimates of activities for each uranium isotope. The previous and revised undecayed activities for uranium isotopes in Oak Ridge RH-TRU waste are shown in Table B-2.

- Changes to the RFETS residues data - The RFETS residues were not included in any of the previous IDB submittals because they were not categorized as waste. Therefore, no break-ups were available for the yearly undecayed activity contributed by each radionuclide in the residues and consequently, no radionuclide decay calculations could be performed for the residues in Rev. 2 of the TWBIR. Based on recent estimates provided by RFETS, it was possible to divide the total undecayed curies for each radionuclide present in the residues into yearly activities. The yearly break-up of undecayed curies from each of these radionuclides is shown in Table B-3.

- Changes to the SRS data - In previous IDB submittals, SRS had reported the total yearly undecayed curies contributed by each radionuclide in SRS CH-TRU waste and therefore no information was available from the IDB regarding the contribution from off-site waste stored at SRS versus on-site waste that was generated at SRS. Based on recent information available from SRS regarding the on-site versus off-site break-up,

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the TWBIR team has divided the total yearly undecayed activities reported in previous SRS IDB submittals into yearly undecayed activities from on-site and off-site waste. The original IDB data and the break-ups are shown in Table B-4.

These new estimates of undecayed radionuclide activities for the four sites and unchanged data for all other sites were provided to SNL staff to perform radionuclide activity decay calculations. The undecayed activity data were decayed by SNL staff to the end of 1995 using the code ORIGEN2. The new decayed radionuclide inventory received from SNL staff has been used to develop the revised WIPP disposal radionuclide inventory shown in Attachment A.

Summary of the Methodology

The methodology used for development of the revised radionuclide inventory is the same as that described in Section 3.6 on pages 3-27 through 3-29 of Revision 2 of the TWBIR with the following exceptions:

- Decayed curies have been used for the RFETS residues (instead of the undecayed curies used in Rev. 2 of the TWBIR)

- Unlike Rev. 2 of the TWBIR, the estimated concentration of U-235 in RH-TRU waste in Attachment A is well within transportation limits for Pu-239 FGE and therefore does not require any adjustments.

- The curies and volumes contributed by TRU waste generated off-site but stored at SRS have been excluded from the process of estimating radionuclide activities for SRS waste to be generated in the future. Only the data for waste that has been generated and stored at SRS since 1970 has been used for this estimation. The curies contributed by the off-site waste stored at SRS are added to the WIPP radionuclide inventory (in a manner similar to the RFETS residues) but they are not included in any data extrapolation for future SRS waste.

TABLE B - 4
SAVANNAH RIVER SITE

PREVIOUS IDB CURIES FOR STORED WASTE AT THE SAVANNAH RIVER SITE (ON-SITE + OFF-SITE WASTE)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Am241	0.00E+00	0.00E+00	4.32E-01	5.28E+00	1.97E+01	1.99E+01	2.58E+01	4.00E+01	5.14E+01	7.06E+01	7.14E+01	1.04E+02	9.08E+01
Np237	0.00E+00	0.00E+00	1.33E-03	1.96E-01	2.89E-01	4.01E-01	2.72E-01	3.37E-01	4.54E-01	1.04E+00	5.79E-01	5.24E-01	8.23E-01
Pu238	0.00E+00	2.08E+05	3.49E+04	1.46E+03	3.87E+03	4.31E+03	6.83E+03	7.89E+03	7.84E+03	2.49E+04	3.48E+04	3.51E+04	4.78E+04
Pu239	0.00E+00	1.27E+02	2.37E+01	3.06E+01	1.13E+02	1.14E+02	1.49E+02	2.30E+02	2.80E+02	1.83E+02	3.92E+02	5.76E+02	4.50E+02
Pu240	0.00E+00	8.84E+01	1.17E+01	7.47E+00	2.73E+01	2.78E+01	3.95E+01	5.57E+01	6.29E+01	4.29E+01	9.89E+01	1.42E+02	1.15E+02
Pu241	0.00E+00	4.50E+03	7.75E+02	2.96E+02	1.06E+03	1.98E+04	2.21E+03	2.17E+03	2.44E+03	1.96E+03	4.06E+03	5.69E+03	4.79E+03
U234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.11E-02	3.22E-02	2.17E-02	1.07E-02	3.10E-02	6.84E-02	3.98E-03	6.18E-03	0.00E+00
U235	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-04	6.55E-04	4.23E-04	2.01E-04	5.83E-04	1.28E-03	7.48E-05	1.18E-04	4.78E-08
U236	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-03	5.43E-03	3.80E-03	1.81E-03	5.24E-03	1.15E-02	6.72E-04	1.04E-03	0.00E+00
U238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-05	3.88E-03	8.30E-04	6.28E-06	3.97E-05	4.01E-05	2.33E-06	3.61E-06	3.69E-06

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
Am241	4.08E+01	1.02E+02	2.48E+02	3.37E+02	1.59E+02	5.46E+02	8.63E+01	6.42E+01	1.72E+01	3.79E+00	7.27E-01	5.90E+00	2.11E+03
Np237	2.34E-01	1.77E+00	2.78E-02	1.46E-02	7.54E-02	3.75E-02	3.39E-02	1.39E+00	9.33E-02	1.88E-03	0.00E+00	5.87E-03	8.58E+00
Pu238	4.44E+04	1.33E+04	2.16E+04	8.84E+03	1.44E+04	5.59E+03	1.73E+03	3.00E+03	2.91E+03	1.40E+03	4.70E+03	1.78E+04	5.57E+05
Pu239	2.23E+02	4.82E+02	1.38E+03	1.88E+03	8.68E+02	8.80E+02	4.90E+02	3.58E+02	9.59E+01	1.00E+01	8.94E+00	3.06E+01	9.29E+03
Pu240	6.04E+01	1.18E+02	3.25E+02	4.45E+02	2.08E+02	2.04E+02	1.14E+02	8.47E+01	2.32E+01	2.61E+00	2.46E+00	1.17E+01	2.29E+03
Pu241	2.70E+03	4.51E+03	1.24E+04	1.89E+04	7.96E+03	7.75E+03	4.30E+03	3.22E+03	9.01E+02	1.12E+02	1.38E+02	6.11E+02	1.11E+05
U234	1.65E-02	0.00E+00	7.50E-03	1.84E-02	1.22E-02	9.14E-03	2.27E-04	7.08E-04	0.00E+00	2.25E-04	2.12E-02	1.90E-02	3.00E-01
U235	3.13E-04	9.94E-06	1.42E-04	3.47E-04	2.29E-04	1.72E-04	4.28E-06	1.38E-05	4.32E-06	4.23E-06	4.18E-04	3.63E-04	5.74E-03
U236	2.78E-03	0.00E+00	1.27E-03	3.11E-03	2.05E-03	1.54E-03	3.83E-06	1.18E-04	0.00E+00	3.80E-05	3.68E-05	3.21E-03	4.70E-02
U238	2.71E-04	7.72E-06	7.50E-05	1.10E-05	7.14E-06	6.70E-06	1.33E-07	3.40E-05	3.36E-07	1.32E-07	4.11E-05	4.21E-04	5.70E-03

REVISED UNDECAYED CURIES FOR STORED WASTE AT THE SAVANNAH RIVER SITE (ON-SITE WASTE)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Am241	0.00E+00	0.00E+00	4.32E-01	5.28E+00	1.97E+01	1.99E+01	2.58E+01	4.00E+01	5.14E+01	7.06E+01	7.14E+01	1.04E+02	9.08E+01
Np237	0.00E+00	0.00E+00	1.33E-03	1.96E-01	2.89E-01	4.01E-01	2.72E-01	3.37E-01	4.54E-01	1.04E+00	5.79E-01	5.24E-01	8.23E-01
Pu238	0.00E+00	0.00E+00	4.00E+01	1.46E+03	3.87E+03	4.31E+03	6.83E+03	7.89E+03	7.84E+03	2.49E+04	3.48E+04	3.51E+04	4.78E+04
Pu239	0.00E+00	0.00E+00	2.48E+00	3.06E+01	1.13E+02	1.14E+02	1.49E+02	2.30E+02	2.80E+02	1.83E+02	3.92E+02	5.76E+02	4.50E+02
Pu240	0.00E+00	0.00E+00	5.65E-01	7.47E+00	2.73E+01	2.78E+01	3.95E+01	5.57E+01	6.29E+01	4.29E+01	9.89E+01	1.42E+02	1.15E+02
Pu241	0.00E+00	0.00E+00	2.15E+01	2.96E+02	1.06E+03	1.98E+04	2.21E+03	2.17E+03	2.44E+03	1.96E+03	4.06E+03	5.69E+03	4.79E+03
U234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.11E-02	3.22E-02	2.17E-02	1.07E-02	3.10E-02	6.84E-02	3.98E-03	6.18E-03	0.00E+00
U235	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-04	6.55E-04	4.23E-04	2.01E-04	5.83E-04	1.28E-03	7.48E-05	1.18E-04	4.78E-08
U236	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-03	5.43E-03	3.80E-03	1.81E-03	5.24E-03	1.15E-02	6.72E-04	1.04E-03	0.00E+00
U238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-05	3.88E-03	8.30E-04	6.28E-06	3.97E-05	4.01E-05	2.33E-06	3.61E-06	3.69E-06

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
Am241	3.94E+01	1.02E+02	2.48E+02	3.37E+02	1.59E+02	5.46E+02	8.63E+01	6.42E+01	1.72E+01	3.79E+00	2.52E-01	5.90E+00	2.11E+03
Np237	2.31E-01	1.77E+00	2.78E-02	1.46E-02	7.54E-02	3.75E-02	3.39E-02	1.39E+00	9.33E-02	1.88E-03	0.00E+00	5.87E-03	8.58E+00
Pu238	4.44E+04	1.33E+04	2.16E+04	8.84E+03	1.44E+04	5.59E+03	1.73E+03	3.00E+03	2.91E+03	1.40E+03	4.69E+03	1.78E+04	3.14E+05
Pu239	2.19E+02	4.82E+02	1.38E+03	1.88E+03	8.68E+02	8.80E+02	4.90E+02	3.58E+02	9.59E+01	1.00E+01	4.27E+00	3.06E+01	9.13E+03
Pu240	5.87E+01	1.18E+02	3.25E+02	4.45E+02	2.08E+02	2.04E+02	1.14E+02	8.47E+01	2.32E+01	2.61E+00	1.83E+00	1.17E+01	2.21E+03
Pu241	2.63E+03	4.51E+03	1.24E+04	1.89E+04	7.96E+03	7.75E+03	4.30E+03	3.22E+03	9.01E+02	1.12E+02	1.14E+02	6.11E+02	1.06E+05
U234	1.84E-02	0.00E+00	7.50E-03	1.84E-02	1.22E-02	9.14E-03	2.27E-04	7.08E-04	0.00E+00	2.25E-04	2.10E-02	1.90E-02	3.00E-01
U235	3.11E-04	9.94E-06	1.42E-04	3.47E-04	2.29E-04	1.72E-04	4.28E-06	1.38E-05	4.32E-06	4.23E-06	4.14E-04	3.63E-04	5.73E-03
U236	2.76E-03	0.00E+00	1.27E-03	3.11E-03	2.05E-03	1.54E-03	3.83E-06	1.18E-04	0.00E+00	3.80E-05	4.20E-06	3.21E-03	4.69E-02
U238	2.71E-04	7.72E-06	7.50E-05	1.10E-05	7.14E-06	6.70E-06	1.33E-07	3.40E-05	3.36E-07	1.32E-07	7.09E-07	4.21E-04	5.66E-03

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REVISED UNDECAYED CURIES FOR STORED WASTE AT THE SAVANNAH RIVER SITE (OFF-SITE WASTE ONLY)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Am241	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu238	0.00E+00	2.08E+05	3.49E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu239	0.00E+00	1.27E+02	2.12E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu240	0.00E+00	8.84E+01	1.11E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu241	0.00E+00	4.50E+03	7.54E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U235	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U236	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
Am241	1.40E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.75E-01	0.00E+00	1.87E+00
Np237	3.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.03E-03
Pu238	4.37E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.57E-01	0.00E+00	0.00E+00	0.00E+00	7.31E+00	0.00E+00	2.43E+05
Pu239	7.37E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.57E-04	0.00E+00	0.00E+00	0.00E+00	2.87E+00	0.00E+00	1.58E+02
Pu240	1.74E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.20E-05	0.00E+00	0.00E+00	0.00E+00	6.33E-01	0.00E+00	7.99E+01
Pu241	6.57E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.56E-03	0.00E+00	0.00E+00	0.00E+00	2.39E+01	0.00E+00	5.34E+03
U234	1.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.12E-04	0.00E+00	3.37E-04
U235	2.23E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.61E-06	0.00E+00	6.84E-06
U236	2.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.68E-05	0.00E+00	5.68E-05
U238	6.96E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.04E-05	0.00E+00	4.04E-05

TABLE B - 3

Rocky Flats Environmental Technology Site

UNDECAYED YEARLY ACTIVITY DATA FOR THE RFETS RESIDUES							
	1982	1983	1984	1985	1986	1987	1988
Am-241	2.06E+04	2.22E+03	6.81E+03	1.56E+04	9.20E+03	7.81E+03	1.03E+04
Pu-238	1.84E+03	1.77E+02	5.43E+02	1.24E+03	7.34E+02	6.23E+02	8.19E+02
Pu-239	3.50E+04	3.77E+03	1.16E+04	2.64E+04	1.56E+04	1.33E+04	1.75E+04
Pu-240	8.01E+03	8.64E+02	2.65E+03	6.05E+03	3.58E+03	3.04E+03	4.00E+03
Pu-241	2.05E+05	2.21E+04	6.77E+04	1.55E+05	9.15E+04	7.77E+04	1.02E+05
Pu-242	1.01E+00	1.09E-01	3.35E-01	7.65E-01	4.52E-01	3.84E-01	5.05E-01

	1989	1990	1991	1992	1993	1994	TOTALS
Am-241	1.74E+04	1.57E+04	9.38E+02	1.04E+02	3.47E+01	1.81E+03	1.08E+05
Pu-238	1.39E+03	1.25E+03	7.47E+01	8.30E+00	2.77E+00	1.44E+02	8.85E+03
Pu-239	2.96E+04	2.67E+04	1.59E+03	1.77E+02	5.90E+01	3.07E+03	1.84E+05
Pu-240	6.78E+03	6.10E+03	3.65E+02	4.05E+01	1.35E+01	7.02E+02	4.22E+04
Pu-241	1.73E+05	1.56E+05	9.32E+03	1.04E+03	3.45E+02	1.80E+04	1.08E+06
Pu-242	8.57E-01	7.72E-01	4.61E-02	5.12E-03	1.71E-03	8.88E-02	5.33E+00

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TABLE B - 2
Oak Ridge National Laboratory

PREVIOUS VALUES OF URANIUM ISOTOPES IN THE IDB (CURIES)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
U232	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	1.25E+00	1.25E+00	1.25E+00	1.25E+00	1.56E+00	1.75E+00	1.29E+00	3.36E+00	1.25E+00	0.00E+00	1.00E-01	0.00E+00	1.00E+00
U234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U235	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-04	2.64E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U238	3.74E-01	3.74E-01	3.74E-01	3.74E-01	3.74E-01	3.74E-01	3.74E-01	3.74E-01	3.74E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
U232	0.00E+00	0.00E+00	9.28E-02	9.28E-02	9.28E-02	9.28E-02	9.28E-02	9.28E-02	9.28E-02	9.28E-02	9.28E-02	9.28E-02	9.28E-01
U233	0.00E+00	0.00E+00	5.37E+00	5.37E+00	5.37E+00	5.37E+00	5.37E+00	5.37E+00	5.37E+00	5.37E+00	5.37E+00	5.37E+00	6.90E+01
U234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U235	0.00E+00	0.00E+00	1.75E+01	1.75E+01	1.75E+01	1.75E+01	1.75E+01	1.75E+01	1.75E+01	1.75E+01	1.75E+01	1.75E+01	1.75E+02
U238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.37E+00

REVISED UNDECAYED ACTIVITY FOR EACH URANIUM ISOTOPE (CURIES)

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
U233	5.58E+00	5.58E+00	5.58E+00	5.58E+00	5.78E+00	5.88E+00	5.60E+00	6.86E+00	5.58E+00	0.00E+00	6.09E-02	0.00E+00	6.08E-01
U234	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	1.25E-01	0.00E+00	4.56E-07	0.00E+00	4.55E-06
U235	5.69E-03	5.69E-03	5.69E-03	5.69E-03	5.69E-03	5.69E-03	5.69E-03	5.69E-03	5.69E-03	0.00E+00	2.07E-08	0.00E+00	2.07E-07
U236	3.45E-03	3.45E-03	3.45E-03	3.45E-03	3.45E-03	3.45E-03	3.45E-03	3.45E-03	3.45E-03	0.00E+00	1.26E-08	0.00E+00	1.26E-07
U238	3.73E-01	3.73E-01	3.73E-01	3.73E-01	3.73E-01	3.73E-01	3.73E-01	3.73E-01	3.73E-01	0.00E+00	1.36E-08	0.00E+00	1.36E-05

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
U233	0.00E+00	0.00E+00	3.83E+01	3.83E+01	3.83E+01	3.83E+01	3.83E+01	3.83E+01	3.83E+01	3.83E+01	3.83E+01	3.83E+01	4.36E+02
U234	0.00E+00	0.00E+00	9.10E-01	9.10E-01	9.10E-01	9.10E-01	9.10E-01	9.10E-01	9.10E-01	9.10E-01	9.10E-01	9.10E-01	1.02E+01
U235	0.00E+00	0.00E+00	5.01E-02	5.01E-02	5.01E-02	5.01E-02	5.01E-02	5.01E-02	5.01E-02	5.01E-02	5.01E-02	5.01E-02	5.53E-01
U236	0.00E+00	0.00E+00	2.51E-02	2.51E-02	2.51E-02	2.51E-02	2.51E-02	2.51E-02	2.51E-02	2.51E-02	2.51E-02	2.51E-02	2.82E-01
U238	0.00E+00	0.00E+00	2.71E+00	2.71E+00	2.71E+00	2.71E+00	2.71E+00	2.71E+00	2.71E+00	2.71E+00	2.71E+00	2.71E+00	3.05E+01

TABLE B - 1
Hanford Site

PREVIOUS UNDECAYED CURIES FOR Cf-252, Cm-244, and Cm-245 IN CH-TRU WASTE AT THE HANFORD SITE

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Cf252	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+03
Cm244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm245	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.42E-01	0.00E+00	0.00E+00	0.00E+00	7.54E+00

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
Cf252	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+03
Cm244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.62E-01	6.72E-03	7.58E+01	0.00E+00	0.00E+00	7.66E+01
Cm245	3.59E-01	1.71E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.54E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E+01

REVISED UNDECAYED CURIES FOR Cf-252, Cm-244, and Cm-245 IN CH-TRU WASTE AT THE HANFORD SITE

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Cf252	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-03
Cm244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E+02	0.00E+00	0.00E+00	0.00E+00	3.72E+02
Cm245	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
Cf252	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-03
Cm244	1.70E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.04E+03	7.62E-01	6.72E-03	7.58E+01	0.00E+00	0.00E+00	4.82E+03
Cm245	0.00E+00	1.71E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.71E-03

APPENDIX B - 2

M

Department of Energy
Carlsbad Area Office
P. O. Box 3090
Carlsbad, New Mexico 88221

June 12, 1996

To: Dr. Les E. Shephard, Director, SNL

Subject: Preliminary Activities for Selected Radionuclides for CH-TRU Waste Streams

The following information from the Transuranic (TRU) Waste Baseline Inventory Report (TWBIR) team was requested during a meeting with SNL representatives on April 23, 1996. The TWBIR team was requested to calculate the radionuclide activity (total curies) for seven radionuclides (Am-241, Cm-244, Pu-238, Pu-239, Pu-240, Pu-241, and U-234) on a waste stream basis for contact-handled (CH)-TRU waste to be disposed of at the WIPP.

During this meeting, it was agreed that since the radionuclide data used by SNL WIPP PA were based on the site-level radionuclide data from the Integrated Data Base (IDB), the waste stream radionuclide data in curies per cubic meter provided by the DOE sites in Revision 2 of the Transuranic Waste Baseline Inventory Report (TWBIR) would be normalized to the extent necessary for consistency with the IDB data. This letter summarizes the methodology for normalization of the waste stream radionuclide data from the TWBIR Rev. 2 and subsequent scale-up of the normalized data to obtain estimates of the total curies of each of the seven selected radionuclides on a waste stream basis. The results of these calculations are presented in Table 1. Please note that the results in Table 1 are not directly obtainable from the TWBIR database; but all of the data in Table 1 are derived from TWBIR Rev. 2 on the basis of the methodology and assumptions discussed later in this memorandum.

Methodology for Normalization of the Waste Stream Radionuclide Data

The waste stream radionuclide data provided by the sites in TWBIR Rev. 2 were first normalized to be consistent with the site-wide values reported for CH-TRU waste in the IDB using the following step-by-step approach:

- Extraction of Volume and Activity Data from the TWBIR Rev. 2 Database - For each CH-TRU waste stream, the stored and projected final waste form volumes as well as activities in curies per cubic meter (Ci/m^3) reported by the sites for the seven selected radionuclides were obtained from the database. All RH-TRU waste streams, non-WIPP waste streams, and waste streams for which no data were reported by the site were excluded.

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- Estimation of Undecayed Total Activity for Each Radionuclide at Each Site - The Ci/m^3 value reported for each radionuclide for each waste stream was multiplied by the stored waste volume to obtain the total undecayed activity of each radionuclide for each waste stream. Next, the total undecayed activity for a given radionuclide (e.g., Pu-238) for all waste streams at a given site were added together to obtain the total undecayed activity for each radionuclide at each site.

- Comparison with IDB Values and Normalization - The total undecayed activity estimated above for a given radionuclide at a given site were compared with the values reported for the same radionuclide by the same site in their IDB submittal. Based on this comparison, a normalization factor (NF) was developed for each radionuclide at each site as follows:

$$NF = \frac{\text{Total curies reported by the site in the IDB}}{\text{Total curies estimated from TWBIR Rev. 2 waste stream data}}$$

  The NFs calculated in this fashion are shown in Table 2. The total activity for each radionuclide for each waste stream was then multiplied by the normalization factor to obtain the total normalized undecayed stored curies on a waste stream basis.

- Estimation of Decayed Activities - For each radionuclide at each site, a ratio of the activity decayed to the end of 1995 to the undecayed activity for each of seven selected radionuclides was calculated based on the ORIGEN2 activity decay calculations performed by SNL staff in support of the development of the WIPP disposal radionuclide inventory for the Compliance Certification Application (CCA). The total normalized undecayed stored curies were then multiplied by this calculated ratio to estimate the decayed curies of each radionuclide that are present in the stored volume of each waste stream. Subsequently, the curies from the stored volume were multiplied by the ratio of the projected to the stored volume to obtain the estimated curies for the projected volume of each waste stream.

Methodology for Scale-up of Waste Stream Decayed Activity to WIPP Repository Volume

This step involves scale-up of the estimated decayed activity for each radionuclide present in the stored volume of each waste stream to the WIPP disposal volume for CH-TRU waste, which is 168,500 m^3. Since the total WIPP activity for CH-TRU waste for each radionuclide has already been estimated in an earlier memorandum prepared in support of the CCA, it was assumed that the total WIPP activity in curies for each of the seven radionuclides would be equal, for the sake of consistency, to the values reported in the earlier memorandum. For each

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radionuclide, a scale-up factor for activity was calculated as follows:

$$SF_a = \frac{\text{Total WIPP Activity from CCA memo - Total Estimated Activity for Stored Volume (all waste streams)}}{\text{Total Estimated Activity for Projected Volume (for all waste streams)}}$$

These SF_a's are shown in Table 3. The estimated activity in curies for the projected volume for each radionuclide for each waste stream was then multiplied by the appropriate scale-up factor derived above, and the result added to the corresponding estimated stored activity in curies to obtain the "Scaled Curies" at a WIPP level for the waste stream. These are the values reported in Table 1.

Methodology for Scale-up of Waste Stream Volumes to WIPP Repository Volume

The summation of the total stored and projected volumes for all CH-TRU waste streams is less than the WIPP disposal capacity for CH-TRU waste (i.e., 168,500 m^3). However, since the WIPP PA modeling is based on the effect of a full repository (i.e., 168,500 m^3 for CH-TRU waste), it is necessary to scale-up the total volume of each waste stream in order to be consistent with the WIPP PA assumptions. This step involves the scale-up of the total volume of each waste stream to the WIPP disposal capacity for CH-TRU waste. A scale-up factor for volume (common to all waste streams) was calculated as follows:

$$SF_v = \frac{\text{WIPP Capacity for CH-TRU Waste (168,500 m}^3\text{) - Total Stored Volume (all waste streams)}}{\text{Total Projected Volume (for all waste streams)}}$$

This factor is shown in Table 4. The projected volume for each waste stream was then multiplied by the scale-up factor derived above, and the result added to the corresponding stored volume to obtain the "Scaled Volume" at a WIPP level for each waste stream. These are the values reported in Table 1.

If you have any questions concerning the enclosed information, please contact Mr. Russ Bisping of my staff at (505) 234-7446.

Don Watkins
Manager
National TRU Program

Enclosures

CAO:NTP:RLB 96-1199

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CAO:NTP:RLB 96-1199

TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
IN	IN-W139.627	12.27	2.84E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W146.699	2.29	8.24E-01	4.91E+02	7.98E-01	6.40E-01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W157.144	49.92	8.51E+00	0.00E+00	1.52E+00	4.22E+01	9.31E+00	1.74E+02	0.00E+00
IN	IN-W157.906	163.70	2.79E+01	0.00E+00	5.00E+00	1.38E+02	3.05E+01	5.69E+02	0.00E+00
IN	IN-W157.907	9.36	3.19E+00	0.00E+00	5.71E-01	1.58E+01	3.49E+00	6.51E+01	0.00E+00
IN	IN-W159.1072	0.68	0.00E+00	0.00E+00	5.05E+02	3.67E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W159.119	0.21	0.00E+00	0.00E+00	5.15E+01	3.74E-01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W159.120	0.42	0.00E+00	0.00E+00	6.17E+02	4.49E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W161.231	97.55	5.22E+00	0.00E+00	1.31E+01	3.63E+02	8.02E+01	1.49E+03	0.00E+00
IN	IN-W161.806	15.79	8.44E-01	0.00E+00	2.12E+00	5.88E+01	1.30E+01	2.42E+02	0.00E+00
IN	IN-W163.1007	0.68	0.00E+00	0.00E+00	5.11E-01	1.42E+01	3.13E+00	5.83E+01	0.00E+00
IN	IN-W163.234	0.42	0.00E+00	0.00E+00	6.25E-01	1.73E+01	3.82E+00	7.13E+01	0.00E+00
IN	IN-W164.1060	1.66	0.00E+00	0.00E+00	2.38E-02	6.60E-01	1.46E-01	2.72E+00	0.00E+00
IN	IN-W164.153	0.89	0.00E+00	0.00E+00	1.27E-02	3.52E-01	7.78E-02	1.45E+00	0.00E+00
IN	IN-W166.151	16.00	4.80E-01	0.00E+00	2.08E+00	5.78E+01	1.27E+01	2.38E+02	0.00E+00
IN	IN-W166.928	56.78	1.70E+00	0.00E+00	7.40E+00	2.05E+02	4.53E+01	8.44E+02	0.00E+00
IN	IN-W167.149	36.68	1.72E+00	0.00E+00	1.05E+00	2.90E+01	6.41E+00	1.19E+02	0.00E+00
IN	IN-W167.926	131.46	6.16E+00	0.00E+00	3.75E+00	1.04E+02	2.30E+01	4.28E+02	0.00E+00
IN	IN-W169.191	4267.12	1.79E+03	0.00E+00	8.48E+01	2.35E+03	5.19E+02	9.67E+03	0.00E+00
IN	IN-W169.192	14.56	6.12E+02	0.00E+00	2.89E+01	8.02E+02	1.77E+02	3.30E+03	0.00E+00
IN	IN-W169.985	41.79	1.76E+01	0.00E+00	8.31E-01	2.30E+01	5.08E+00	9.47E+01	0.00E+00
IN	IN-W170.189	0.68	3.88E+00	0.00E+00	0.00E+00	1.29E+01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W170.938	0.42	2.37E+00	0.00E+00	0.00E+00	7.91E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W171.184	3.54	1.57E+00	0.00E+00	0.00E+00	1.67E+01	0.00E+00	1.16E+02	0.00E+00
IN	IN-W171.801	0.68	3.01E-01	0.00E+00	0.00E+00	3.21E+00	0.00E+00	2.23E+01	0.00E+00
IN	IN-W174.1082	30.37	0.00E+00	0.00E+00	4.35E+02	2.84E-01	5.50E-01	0.00E+00	0.00E+00
IN	IN-W174.154	134.32	0.00E+00	0.00E+00	1.92E+03	1.26E+00	2.43E+00	0.00E+00	0.00E+00
IN	IN-W177.1083	141.02	0.00E+00	0.00E+00	2.32E+03	6.71E-01	4.00E-03	1.88E-01	0.00E+00
IN	IN-W177.156	39.23	0.00E+00	0.00E+00	6.44E+02	1.87E-01	1.11E-03	5.22E-02	0.00E+00
IN	IN-W179.1084	4.58	0.00E+00	0.00E+00	2.99E+01	5.05E-04	2.57E-04	1.64E-02	0.00E+00
IN	IN-W179.158	1.51	0.00E+00	0.00E+00	9.88E+00	1.67E-04	8.48E-05	5.41E-03	0.00E+00
IN	IN-W181.162	9.57	0.00E+00	0.00E+00	1.08E-01	2.99E+00	6.61E-01	1.23E+01	0.00E+00
IN	IN-W186.187	2695.26	2.00E+02	0.00E+00	5.50E+01	1.53E+03	3.37E+02	6.27E+03	0.00E+00
IN	IN-W187.1094	0.68	0.00E+00	0.00E+00	6.84E-02	1.89E+00	4.18E-01	7.79E+00	0.00E+00
IN	IN-W187.121	0.21	0.00E+00	0.00E+00	4.18E-02	1.16E+00	2.56E-01	4.77E+00	0.00E+00
IN	IN-W188.1093	1.04	0.00E+00	0.00E+00	4.26E-02	1.18E+00	2.60E-01	4.85E+00	0.00E+00
IN	IN-W188.160	0.68	0.00E+00	0.00E+00	2.78E-02	7.72E-01	1.70E-01	3.17E+00	0.00E+00
IN	IN-W189.1048	4.99	0.00E+00	0.00E+00	1.36E-01	3.77E+00	8.33E-01	1.55E+01	0.00E+00
IN	IN-W189.131	1.72	0.00E+00	0.00E+00	4.69E-02	1.30E+00	2.87E-01	5.35E+00	0.00E+00
IN	IN-W197.196	2.29	2.09E+02	0.00E+00	5.19E+00	1.44E+02	3.18E+01	5.92E+02	0.00E+00

TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
IN	IN-W197.802	510.22	4.67E+02	0.00E+00	1.16E+01	3.21E+02	7.08E+01	1.32E+03	0.00E+00
IN	IN-W197.803	45.23	4.14E+01	0.00E+00	1.03E+00	2.85E+01	6.28E+00	1.17E+02	0.00E+00
IN	IN-W198.202	119.60	2.16E+02	0.00E+00	3.53E+00	9.78E+01	2.16E+01	4.02E+02	0.00E+00
IN	IN-W198.203	0.21	3.75E+01	0.00E+00	6.14E-01	1.70E+01	3.75E+00	7.00E+01	0.00E+00
IN	IN-W198.804	32.82	5.92E+01	0.00E+00	9.69E-01	2.68E+01	5.93E+00	1.10E+02	0.00E+00
IN	IN-W199.1039	0.89	0.00E+00	0.00E+00	1.10E-01	3.04E+00	6.70E-01	1.25E+01	0.00E+00
IN	IN-W199.209	0.21	0.00E+00	0.00E+00	2.57E+00	7.11E+01	1.57E+01	2.92E+02	0.00E+00
IN	IN-W202.1092	0.89	0.00E+00	0.00E+00	7.20E-03	2.00E-01	4.40E-02	8.21E-01	0.00E+00
IN	IN-W202.224	109.62	0.00E+00	0.00E+00	8.88E-01	2.46E+01	5.43E+00	1.01E+02	0.00E+00
IN	IN-W203.1081	0.68	1.28E-01	0.00E+00	5.78E-01	1.38E-02	6.54E-03	1.69E-03	0.00E+00
IN	IN-W203.210	73.22	1.37E+01	0.00E+00	6.22E+01	1.48E+00	7.04E-01	1.82E-01	0.00E+00
IN	IN-W203.211	3.33	1.25E+00	0.00E+00	5.66E+00	1.35E-01	6.40E-02	1.65E-02	0.00E+00
IN	IN-W203.212	0.21	1.30E-02	0.00E+00	5.89E-02	1.41E-03	6.67E-04	1.72E-04	0.00E+00
IN	IN-W204.215	0.89	7.56E+00	0.00E+00	7.68E+00	1.22E-02	4.01E-03	1.80E-01	0.00E+00
IN	IN-W204.216	1.66	1.42E+01	0.00E+00	1.44E+01	2.29E-02	7.52E-03	3.36E-01	0.00E+00
IN	IN-W204.217	0.21	5.90E-01	0.00E+00	5.99E-01	9.55E-04	3.13E-04	1.40E-02	0.00E+00
IN	IN-W205.1086	0.83	0.00E+00	0.00E+00	1.49E-03	4.12E-02	9.09E-03	1.69E-01	0.00E+00
IN	IN-W205.1087	0.21	0.00E+00	0.00E+00	3.72E-02	1.03E+00	2.27E-01	4.24E+00	0.00E+00
IN	IN-W205.220	0.68	0.00E+00	0.00E+00	1.22E-03	3.37E-02	7.43E-03	1.39E-01	0.00E+00
IN	IN-W206.935	10.89	4.82E-01	0.00E+00	5.41E-01	1.50E+01	3.31E+00	6.17E+01	0.00E+00
IN	IN-W206.936	22.46	1.66E+01	0.00E+00	1.86E+01	5.15E+02	1.14E+02	2.12E+03	0.00E+00
IN	IN-W207.238	0.21	0.00E+00	0.00E+00	1.65E+00	4.56E+01	1.01E+01	1.88E+02	0.00E+00
IN	IN-W207.980	0.89	0.00E+00	0.00E+00	4.22E-01	1.17E+01	2.58E+00	4.81E+01	0.00E+00
IN	IN-W207.981	0.42	0.00E+00	0.00E+00	1.97E-01	5.47E+00	1.21E+00	2.25E+01	0.00E+00
IN	IN-W208.242	1.46	2.13E+01	0.00E+00	2.31E+00	6.41E+01	1.42E+01	2.64E+02	0.00E+00
IN	IN-W208.988	2.34	2.06E+00	0.00E+00	2.24E-01	6.20E+00	1.37E+00	2.55E+01	0.00E+00
IN	IN-W209.244	3.12	6.70E-01	0.00E+00	1.10E+01	3.06E+02	6.76E+01	1.26E+03	0.00E+00
IN	IN-W209.994	10.27	1.32E-01	0.00E+00	2.18E+00	6.04E+01	1.33E+01	2.49E+02	0.00E+00
IN	IN-W210.1001	1.10	0.00E+00	0.00E+00	8.83E-02	2.45E+00	5.40E-01	1.01E+01	0.00E+00
IN	IN-W210.247	0.21	0.00E+00	0.00E+00	2.79E-01	7.74E+00	1.71E+00	3.18E+01	0.00E+00
IN	IN-W211.1009	98.47	8.53E+01	0.00E+00	3.64E+01	1.01E+03	2.23E+02	4.15E+03	0.00E+00
IN	IN-W211.249	22.46	3.24E+02	0.00E+00	1.38E+02	3.83E+03	8.46E+02	1.58E+04	0.00E+00
IN	IN-W212.1058	3.44	1.03E-01	0.00E+00	4.75E-02	1.32E+00	2.90E-01	5.41E+00	0.00E+00
IN	IN-W212.251	150.59	7.50E+01	0.00E+00	3.47E+01	9.60E+02	2.12E+02	3.95E+03	0.00E+00
IN	IN-W213.1069	1.93	0.00E+00	0.00E+00	1.01E+03	5.96E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W213.252	0.42	0.00E+00	0.00E+00	3.62E+03	2.14E+01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W213.253	0.21	0.00E+00	0.00E+00	3.62E+01	2.14E-01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W214.1075	0.62	0.00E+00	0.00E+00	4.51E+02	3.93E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W214.755	0.68	0.00E+00	0.00E+00	4.92E+02	4.29E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W214.756	0.21	0.00E+00	0.00E+00	5.01E+01	4.36E-01	0.00E+00	0.00E+00	0.00E+00

TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
IN	IN-W216.875	1478.88	4.26E+04	0.00E+00	5.67E+01	1.57E+03	3.47E+02	6.46E+03	0.00E+00
IN	IN-W216.98	555.65	1.60E+04	0.00E+00	2.13E+01	5.90E+02	1.30E+02	2.43E+03	0.00E+00
IN	IN-W216.99	255.01	1.47E+04	0.00E+00	1.95E+01	5.42E+02	1.20E+02	2.23E+03	0.00E+00
IN	IN-W218.109	183.87	3.17E+02	0.00E+00	1.91E+00	5.30E+01	1.17E+01	2.18E+02	0.00E+00
IN	IN-W218.909	101.91	8.77E+01	0.00E+00	5.30E-01	1.47E+01	3.24E+00	6.04E+01	0.00E+00
IN	IN-W220.114	122.80	8.39E+02	0.00E+00	2.49E+00	7.42E+01	1.59E+01	2.84E+02	0.00E+00
IN	IN-W220.925	443.04	3.03E+03	0.00E+00	8.98E+00	2.68E+02	5.74E+01	1.03E+03	0.00E+00
IN	IN-W221.113	11.65	0.00E+00	0.00E+00	6.71E-01	1.86E+01	4.10E+00	7.65E+01	0.00E+00
IN	IN-W221.927	3.65	0.00E+00	0.00E+00	2.10E-01	5.82E+00	1.29E+00	2.40E+01	0.00E+00
IN	IN-W222.116	24.75	3.71E-01	0.00E+00	7.19E+00	1.99E+02	4.40E+01	8.20E+02	0.00E+00
IN	IN-W222.117	39.10	1.17E+00	0.00E+00	2.27E+01	6.30E+02	1.39E+02	2.59E+03	0.00E+00
IN	IN-W222.965	10.61	1.59E-01	0.00E+00	3.08E+00	8.54E+01	1.89E+01	3.52E+02	0.00E+00
IN	IN-W225.127	21.63	9.85E-02	0.00E+00	1.80E-01	4.98E+00	1.10E+00	2.05E+01	0.00E+00
IN	IN-W225.800	1.10	4.99E-03	0.00E+00	9.11E-03	2.53E-01	5.57E-02	1.04E+00	0.00E+00
IN	IN-W228.101	287.33	1.18E+02	0.00E+00	8.74E-01	2.42E+01	5.35E+00	9.96E+01	0.00E+00
IN	IN-W228.102	198.85	1.63E+02	0.00E+00	1.21E+00	3.35E+01	7.40E+00	1.38E+02	0.00E+00
IN	IN-W228.103	31.82	4.36E+00	0.00E+00	3.23E-02	8.94E-01	1.97E-01	3.68E+00	0.00E+00
IN	IN-W228.883	608.82	2.50E+02	0.00E+00	1.85E+00	5.13E+01	1.13E+01	2.11E+02	0.00E+00
IN	IN-W230.229	4.27	2.41E-02	0.00E+00	1.19E+00	3.31E+01	7.31E+00	1.36E+02	0.00E+00
IN	IN-W230.940	14.77	8.32E-02	0.00E+00	4.13E+00	1.14E+02	2.53E+01	4.71E+02	0.00E+00
IN	IN-W240.272	167.65	6.48E+01	0.00E+00	1.32E+01	3.67E+02	8.10E+01	1.51E+03	0.00E+00
IN	IN-W240.931	1.93	7.46E-01	0.00E+00	1.52E-01	4.22E+00	9.32E-01	1.74E+01	0.00E+00
IN	IN-W243.274	174.30	2.95E+01	0.00E+00	1.24E+01	3.43E+02	7.58E+01	1.41E+03	0.00E+00
IN	IN-W243.275	7.28	4.93E+00	0.00E+00	2.07E+00	5.73E+01	1.27E+01	2.36E+02	0.00E+00
IN	IN-W243.808	46.06	7.79E+00	0.00E+00	3.27E+00	9.07E+01	2.00E+01	3.73E+02	0.00E+00
IN	IN-W245.1034	0.21	5.63E-03	0.00E+00	5.94E-02	1.65E+00	3.63E-01	6.77E+00	0.00E+00
IN	IN-W245.301	37.51	5.08E-01	0.00E+00	5.36E+00	1.48E+02	3.28E+01	6.11E+02	0.00E+00
IN	IN-W245.302	133.74	1.81E+00	0.00E+00	1.91E+01	5.29E+02	1.17E+02	2.18E+03	0.00E+00
IN	IN-W247.1038	0.21	2.39E-03	0.00E+00	2.86E-02	7.94E-01	1.75E-01	3.26E+00	0.00E+00
IN	IN-W247.523	173.68	9.96E-01	0.00E+00	1.20E+01	3.31E+02	7.31E+01	1.36E+03	0.00E+00
IN	IN-W247.810	27.51	1.58E-01	0.00E+00	1.89E+00	5.25E+01	1.16E+01	2.16E+02	0.00E+00
IN	IN-W249.1071	2.29	0.00E+00	0.00E+00	1.28E+03	9.02E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W249.527	1.10	0.00E+00	0.00E+00	6.15E+02	4.32E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W249.528	0.21	0.00E+00	0.00E+00	3.89E+01	2.73E-01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W250.259	14.07	1.25E-02	0.00E+00	3.09E+00	8.58E+01	1.89E+01	3.53E+02	0.00E+00
IN	IN-W250.941	50.96	4.54E-02	0.00E+00	1.12E+01	3.11E+02	6.86E+01	1.28E+03	0.00E+00
IN	IN-W252.1000	0.21	5.95E+00	0.00E+00	5.01E+00	1.39E+02	3.07E+01	5.72E+02	0.00E+00
IN	IN-W252.283	117.73	3.37E+01	0.00E+00	2.84E+01	7.86E+02	1.74E+02	3.24E+03	0.00E+00
IN	IN-W252.811	32.82	9.39E+00	0.00E+00	7.91E+00	2.19E+02	4.84E+01	9.02E+02	0.00E+00
IN	IN-W254.1044	0.21	0.00E+00	0.00E+00	3.00E+00	8.31E+01	1.83E+01	3.42E+02	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
IN	IN-W254.289	2.34	0.00E+00	0.00E+00	3.38E-01	9.36E+00	2.07E+00	3.85E+01	0.00E+00
IN	IN-W254.290	7.28	0.00E+00	0.00E+00	1.05E+00	2.91E+01	6.42E+00	1.20E+02	0.00E+00
IN	IN-W256.1062	20.59	1.22E+00	0.00E+00	1.91E+03	1.33E+01	2.78E+01	0.00E+00	0.00E+00
IN	IN-W256.295	5.99	3.56E-01	0.00E+00	5.55E+02	3.87E+00	8.08E+00	0.00E+00	0.00E+00
IN	IN-W257.558	0.21	0.00E+00	0.00E+00	1.14E-02	3.16E-01	6.97E-02	1.30E+00	0.00E+00
IN	IN-W257.947	0.68	0.00E+00	0.00E+00	1.86E-02	5.17E-01	1.14E-01	2.13E+00	0.00E+00
IN	IN-W259.552	10.06	0.00E+00	0.00E+00	0.00E+00	2.27E+00	2.44E-01	0.00E+00	0.00E+00
IN	IN-W259.920	2.50	0.00E+00	0.00E+00	0.00E+00	3.75E+00	4.04E-01	0.00E+00	0.00E+00
IN	IN-W263.520	14.35	0.00E+00	0.00E+00	1.98E+01	8.99E-01	1.39E-03	8.89E-02	0.00E+00
IN	IN-W265.516	7.92	8.49E-02	0.00E+00	2.70E-01	7.49E+00	1.65E+00	3.08E+01	0.00E+00
IN	IN-W265.517	0.62	6.69E-01	0.00E+00	2.13E+00	5.90E+01	1.30E+01	2.43E+02	0.00E+00
IN	IN-W267.1005	1.10	0.00E+00	0.00E+00	1.57E+00	4.35E+01	9.59E+00	1.79E+02	0.00E+00
IN	IN-W267.514	1.25	0.00E+00	0.00E+00	3.57E+00	9.89E+01	2.18E+01	4.07E+02	0.00E+00
IN	IN-W269.510	5.99	3.80E+01	0.00E+00	3.77E+01	3.24E+02	3.26E+01	8.38E-01	0.00E+00
IN	IN-W269.535	20.80	1.32E+02	0.00E+00	1.31E+02	1.12E+03	1.13E+02	2.91E+00	0.00E+00
IN	IN-W271.532	0.89	0.00E+00	0.00E+00	0.00E+00	1.33E+01	2.99E+01	0.00E+00	0.00E+00
IN	IN-W271.533	0.21	0.00E+00	0.00E+00	0.00E+00	1.04E+00	2.33E+00	0.00E+00	0.00E+00
IN	IN-W272.504	0.89	0.00E+00	0.00E+00	7.06E-01	1.96E+01	4.32E+00	8.04E+01	0.00E+00
IN	IN-W272.974	1.66	0.00E+00	0.00E+00	1.32E+00	3.66E+01	8.08E+00	1.51E+02	0.00E+00
IN	IN-W275.502	1.72	1.03E-01	0.00E+00	2.68E-01	7.44E+00	1.64E+00	3.06E+01	0.00E+00
IN	IN-W275.967	5.20	3.13E-01	0.00E+00	8.11E-01	2.25E+01	4.96E+00	9.25E+01	0.00E+00
IN	IN-W276.500	86.75	1.39E+01	0.00E+00	1.11E+01	3.07E+02	6.76E+01	1.26E+03	0.00E+00
IN	IN-W276.966	313.46	5.04E+01	0.00E+00	4.00E+01	1.11E+03	2.44E+02	4.56E+03	0.00E+00
IN	IN-W278.1090	0.89	0.00E+00	0.00E+00	5.70E-03	1.58E-01	3.49E-02	6.50E-01	0.00E+00
IN	IN-W278.495	4.16	0.00E+00	0.00E+00	8.90E-02	2.47E+00	5.44E-01	1.01E+01	0.00E+00
IN	IN-W280.1066	28.50	2.91E-01	0.00E+00	1.81E+04	1.19E+02	2.04E-01	1.30E+01	0.00E+00
IN	IN-W280.448	8.34	8.52E-02	0.00E+00	5.30E+03	3.47E+01	5.98E-02	3.82E+00	0.00E+00
IN	IN-W280.449	0.21	7.08E-04	0.00E+00	4.41E+01	2.88E-01	4.97E-04	3.17E-02	0.00E+00
IN	IN-W281.487	317.82	0.00E+00	0.00E+00	4.58E+03	2.16E+01	1.09E-02	6.99E-01	0.00E+00
IN	IN-W281.488	0.62	0.00E+00	0.00E+00	8.98E+02	4.24E+00	2.15E-03	1.37E-01	0.00E+00
IN	IN-W283.481	0.21	0.00E+00	0.00E+00	5.63E-02	1.56E+00	3.44E-01	6.42E+00	0.00E+00
IN	IN-W283.534	0.68	0.00E+00	0.00E+00	1.84E-01	5.11E+00	1.13E+00	2.10E+01	0.00E+00
IN	IN-W283.963	0.21	0.00E+00	0.00E+00	1.88E-01	5.20E+00	1.15E+00	2.14E+01	0.00E+00
IN	IN-W285.471	63.02	0.00E+00	0.00E+00	0.00E+00	1.66E+01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W285.815	2.34	0.00E+00	0.00E+00	0.00E+00	6.19E-01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W287.460	211.95	4.68E-01	0.00E+00	0.00E+00	5.04E+01	5.84E+02	3.80E+01	0.00E+00
IN	IN-W289.466	25.38	1.31E+01	0.00E+00	0.00E+00	1.38E+02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W291.454	0.68	3.95E-01	0.00E+00	0.00E+00	1.36E-01	5.93E-01	0.00E+00	0.00E+00
IN	IN-W291.455	1.46	8.45E+01	0.00E+00	0.00E+00	2.91E+01	1.27E+02	0.00E+00	0.00E+00
IN	IN-W291.456	634.40	3.68E+02	0.00E+00	0.00E+00	1.27E+02	5.53E+02	0.00E+00	0.00E+00

TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
IN	IN-W294.1057	0.42	1.16E-01	0.00E+00	1.45E-01	4.03E+00	8.88E-01	1.66E+01	0.00E+00
IN	IN-W294.342	406.85	3.40E+01	0.00E+00	4.26E+01	1.18E+03	2.61E+02	4.86E+03	0.00E+00
IN	IN-W294.814	33.50	2.80E+00	0.00E+00	3.51E+00	9.73E+01	2.15E+01	4.00E+02	0.00E+00
IN	IN-W296.327	3450.30	9.73E+01	0.00E+00	8.37E+01	2.32E+03	5.12E+02	9.54E+03	0.00E+00
IN	IN-W296.329	520.21	4.89E+01	0.00E+00	4.20E+01	1.17E+03	2.57E+02	4.79E+03	0.00E+00
IN	IN-W296.813	47.99	1.35E+00	0.00E+00	1.16E+00	3.22E+01	7.12E+00	1.33E+02	0.00E+00
IN	IN-W298.317	54.70	7.31E+01	0.00E+00	2.19E+01	6.08E+02	1.34E+02	2.50E+03	0.00E+00
IN	IN-W298.812	15.37	2.05E+01	0.00E+00	6.16E+00	1.71E+02	3.77E+01	7.03E+02	0.00E+00
IN	IN-W298.979	0.42	1.85E+00	0.00E+00	5.56E-01	1.54E+01	3.40E+00	6.34E+01	0.00E+00
IN	IN-W300.308	1509.46	2.05E+02	0.00E+00	8.83E+01	2.45E+03	5.40E+02	1.01E+04	0.00E+00
IN	IN-W300.930	4.69	6.36E-01	0.00E+00	2.74E-01	7.60E+00	1.68E+00	3.13E+01	0.00E+00
IN	IN-W302.299	23.45	2.05E+01	0.00E+00	0.00E+00	3.08E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W302.913	84.86	7.43E+01	0.00E+00	0.00E+00	1.11E+01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W304.860	8.75	0.00E+00	0.00E+00	4.77E+02	2.49E+00	5.13E-01	9.79E-01	0.00E+00
IN	IN-W304.861	59.07	0.00E+00	0.00E+00	3.22E+03	1.68E+01	3.46E+00	6.61E+00	0.00E+00
IN	IN-W305.1068	37.44	0.00E+00	0.00E+00	3.61E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W305.828	10.68	0.00E+00	0.00E+00	1.03E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W308.618	503.57	3.17E+03	0.00E+00	1.53E+02	1.13E+03	2.53E+01	4.72E+02	0.00E+00
IN	IN-W308.816	864.91	8.18E+02	0.00E+00	3.95E+01	2.92E+02	6.52E+00	1.21E+02	0.00E+00
IN	IN-W309.609	108.58	1.25E+01	0.00E+00	3.00E+00	8.31E+01	1.83E+01	3.42E+02	0.00E+00
IN	IN-W309.610	352.77	2.03E+01	0.00E+00	4.87E+00	1.35E+02	2.98E+01	5.55E+02	0.00E+00
IN	IN-W311.1013	5.41	6.81E+02	0.00E+00	6.51E+00	1.80E+02	3.98E+01	7.42E+02	0.00E+00
IN	IN-W311.604	1.72	2.17E+02	0.00E+00	2.07E+00	5.74E+01	1.27E+01	2.36E+02	0.00E+00
IN	IN-W312.602	1.10	0.00E+00	0.00E+00	1.78E+00	4.92E+01	1.09E+01	2.02E+02	0.00E+00
IN	IN-W312.942	2.70	0.00E+00	0.00E+00	4.38E+00	1.21E+02	2.68E+01	4.99E+02	0.00E+00
IN	IN-W314.1017	1.04	9.73E-02	0.00E+00	1.46E+00	4.03E+01	8.90E+00	1.66E+02	0.00E+00
IN	IN-W314.606	0.68	6.37E-02	0.00E+00	9.52E-01	2.64E+01	5.82E+00	1.09E+02	0.00E+00
IN	IN-W315.601	0.42	2.99E+01	0.00E+00	1.14E-02	3.16E-01	6.97E-02	1.30E+00	0.00E+00
IN	IN-W317.1028	0.21	1.26E+00	0.00E+00	1.44E-01	3.99E+00	8.80E-01	1.64E+01	0.00E+00
IN	IN-W317.757	39.10	1.19E+02	0.00E+00	1.35E+01	3.75E+02	8.28E+01	1.54E+03	0.00E+00
IN	IN-W317.758	11.51	3.50E+01	0.00E+00	3.98E+00	1.10E+02	2.44E+01	4.54E+02	0.00E+00
IN	IN-W319.583	0.21	0.00E+00	0.00E+00	1.24E+01	3.43E+02	7.57E+01	1.41E+03	0.00E+00
IN	IN-W319.584	0.68	0.00E+00	0.00E+00	4.05E-01	1.12E+01	2.48E+00	4.62E+01	0.00E+00
IN	IN-W321.1023	1.30	0.00E+00	0.00E+00	1.57E+00	4.35E+01	9.60E+00	1.79E+02	0.00E+00
IN	IN-W321.578	0.21	0.00E+00	0.00E+00	2.50E+01	6.94E+02	1.53E+02	2.85E+03	0.00E+00
IN	IN-W322.851	0.89	0.00E+00	0.00E+00	0.00E+00	1.20E+01	2.42E+00	0.00E+00	0.00E+00
IN	IN-W322.952	1.66	0.00E+00	0.00E+00	0.00E+00	2.24E+01	4.53E+00	0.00E+00	0.00E+00
IN	IN-W323.562	0.89	0.00E+00	0.00E+00	1.82E+00	3.28E-01	0.00E+00	2.61E+00	0.00E+00
IN	IN-W325.1076	0.42	0.00E+00	0.00E+00	1.27E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W325.679	0.68	0.00E+00	0.00E+00	2.07E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
IN	IN-W327.1085	3.54	0.00E+00	0.00E+00	7.43E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W327.735	1.30	0.00E+00	0.00E+00	2.74E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W329.681	0.89	0.00E+00	0.00E+00	1.02E+02	4.37E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W329.682	0.21	0.00E+00	0.00E+00	1.60E+02	6.82E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W330.677	6.03	0.00E+00	0.00E+00	3.67E+02	2.88E-03	1.46E-03	9.35E-02	0.00E+00
IN	IN-W330.678	1.93	0.00E+00	0.00E+00	1.17E+02	9.21E-04	4.68E-04	2.99E-02	0.00E+00
IN	IN-W332.661	0.68	0.00E+00	0.00E+00	6.89E+00	4.88E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W332.962	0.83	0.00E+00	0.00E+00	8.42E+00	5.97E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W334.675	1.51	0.00E+00	0.00E+00	0.00E+00	1.30E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W334.961	4.58	0.00E+00	0.00E+00	0.00E+00	3.93E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W336.660	4.16	0.00E+00	0.00E+00	0.00E+00	5.68E-01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W336.820	0.68	0.00E+00	0.00E+00	0.00E+00	9.29E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W338.657	0.89	0.00E+00	0.00E+00	0.00E+00	3.83E-01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W338.956	1.04	0.00E+00	0.00E+00	0.00E+00	4.48E-01	0.00E+00	0.00E+00	0.00E+00
IN	IN-W339.655	2.14	0.00E+00	0.00E+00	0.00E+00	2.17E+01	8.60E-02	0.00E+00	0.00E+00
IN	IN-W339.955	7.07	0.00E+00	0.00E+00	0.00E+00	7.19E+01	2.85E-01	0.00E+00	0.00E+00
IN	IN-W341.671	0.21	0.00E+00	0.00E+00	0.00E+00	1.80E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W341.954	0.68	0.00E+00	0.00E+00	0.00E+00	5.89E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W342.652	0.68	5.65E+00	0.00E+00	0.00E+00	4.05E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W342.953	0.42	3.45E+00	0.00E+00	0.00E+00	2.48E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W345.669	14.35	9.51E+01	0.00E+00	2.25E+01	1.79E+01	1.10E+01	0.00E+00	0.00E+00
IN	IN-W345.819	0.89	5.89E+00	0.00E+00	1.39E+00	1.11E+00	6.84E-01	0.00E+00	0.00E+00
IN	IN-W347.646	51.79	2.06E+00	0.00E+00	0.00E+00	5.84E+01	1.04E+02	0.00E+00	0.00E+00
IN	IN-W347.818	3.44	1.37E-01	0.00E+00	0.00E+00	3.88E+00	6.91E+00	0.00E+00	0.00E+00
IN	IN-W348.1012	2.34	3.28E-02	0.00E+00	3.19E+00	8.84E+01	1.95E+01	3.64E+02	0.00E+00
IN	IN-W348.846	4.16	1.16E-01	0.00E+00	1.13E+01	3.14E+02	6.92E+01	1.29E+03	0.00E+00
IN	IN-W350.650	0.68	0.00E+00	0.00E+00	0.00E+00	3.60E+01	1.07E+02	0.00E+00	0.00E+00
IN	IN-W350.923	0.21	0.00E+00	0.00E+00	0.00E+00	1.10E+01	3.27E+01	0.00E+00	0.00E+00
IN	IN-W351.648	0.89	0.00E+00	0.00E+00	0.00E+00	1.43E+00	4.79E+00	0.00E+00	0.00E+00
IN	IN-W351.922	1.25	0.00E+00	0.00E+00	0.00E+00	2.01E+00	6.72E+00	0.00E+00	0.00E+00
IN	IN-W353.859	0.68	0.00E+00	0.00E+00	0.00E+00	7.53E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W353.917	0.21	0.00E+00	0.00E+00	0.00E+00	2.30E-02	0.00E+00	0.00E+00	0.00E+00
IN	IN-W354.1016	0.21	0.00E+00	0.00E+00	3.99E-02	1.11E+00	2.44E-01	4.55E+00	0.00E+00
IN	IN-W354.858	0.68	0.00E+00	0.00E+00	1.31E-01	3.62E+00	7.98E-01	1.49E+01	0.00E+00
IN	IN-W355.1015	1.04	0.00E+00	0.00E+00	1.01E+00	2.79E+01	6.16E+00	1.15E+02	0.00E+00
IN	IN-W355.857	0.89	0.00E+00	0.00E+00	8.60E-01	2.38E+01	5.26E+00	9.81E+01	0.00E+00
IN	IN-W356.1014	3.74	6.31E+01	0.00E+00	3.62E-01	1.00E+01	2.22E+00	4.13E+01	0.00E+00
IN	IN-W356.856	1.30	2.20E+01	0.00E+00	1.26E-01	3.50E+00	7.72E-01	1.44E+01	0.00E+00
IN	IN-W357.1022	0.68	0.00E+00	0.00E+00	9.89E-03	2.74E-01	6.05E-02	1.13E+00	0.00E+00
IN	IN-W357.850	0.21	0.00E+00	0.00E+00	6.05E-03	1.68E-01	3.70E-02	6.89E-01	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
IN	IN-W358.854	0.89	0.00E+00	0.00E+00	5.56E+02	2.47E+00	4.62E+00	0.00E+00	0.00E+00
IN	IN-W358.855	3.33	0.00E+00	0.00E+00	2.08E+03	9.26E+00	1.73E+01	0.00E+00	0.00E+00
IN	IN-W358.948	0.21	0.00E+00	0.00E+00	4.34E+02	1.93E+00	3.61E+00	0.00E+00	0.00E+00
IN	IN-W359.853	0.83	0.00E+00	0.00E+00	1.10E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
IN	IN-W361.1021	1.51	1.10E-02	0.00E+00	7.65E-01	2.12E+01	4.68E+00	8.73E+01	0.00E+00
IN	IN-W361.849	2.08	3.04E-02	0.00E+00	2.10E+00	5.83E+01	1.29E+01	2.40E+02	0.00E+00
IN	IN-W362.1020	5.37	0.00E+00	0.00E+00	8.63E+00	2.39E+02	5.28E+01	9.84E+02	0.00E+00
IN	IN-W362.848	8.74	0.00E+00	0.00E+00	2.81E+01	7.78E+02	1.72E+02	3.20E+03	0.00E+00
IN	IN-W363.1019	0.89	0.00E+00	0.00E+00	5.76E-01	1.60E+01	3.52E+00	6.57E+01	0.00E+00
IN	IN-W363.847	1.04	0.00E+00	0.00E+00	1.35E+00	3.74E+01	8.25E+00	1.54E+02	0.00E+00
IN	IN-W364.1011	0.89	0.00E+00	0.00E+00	1.43E+00	3.96E+01	8.74E+00	1.63E+02	0.00E+00
IN	IN-W364.844	0.62	0.00E+00	0.00E+00	2.01E+00	5.56E+01	1.23E+01	2.29E+02	0.00E+00
IN	IN-W365.1010	1.30	9.68E+01	0.00E+00	5.77E-01	1.60E+01	3.53E+00	6.58E+01	0.00E+00
IN	IN-W365.842	1.04	2.57E+02	0.00E+00	1.53E+00	4.25E+01	9.38E+00	1.75E+02	0.00E+00
IN	IN-W366.1004	2.08	3.52E-01	0.00E+00	5.01E-01	1.39E+01	3.06E+00	5.71E+01	0.00E+00
IN	IN-W366.841	1.10	1.86E-01	0.00E+00	2.64E-01	7.31E+00	1.61E+00	3.01E+01	0.00E+00
IN	IN-W367.840	0.21	0.00E+00	0.00E+00	1.03E+01	2.85E+02	6.29E+01	1.17E+03	0.00E+00
IN	IN-W367.973	4.69	0.00E+00	0.00E+00	2.32E+00	6.42E+01	1.42E+01	2.64E+02	0.00E+00
IN	IN-W368.839	0.21	0.00E+00	0.00E+00	2.64E+00	7.31E+01	1.61E+01	3.01E+02	0.00E+00
IN	IN-W368.971	1.10	0.00E+00	0.00E+00	1.39E-01	3.85E+00	8.50E-01	1.58E+01	0.00E+00
IN	IN-W369.837	3.23	5.43E-01	0.00E+00	7.35E-01	2.04E+01	4.49E+00	8.38E+01	0.00E+00
IN	IN-W369.970	9.98	1.68E+00	0.00E+00	2.27E+00	6.29E+01	1.39E+01	2.59E+02	0.00E+00
IN	IN-W370.836	15.16	0.00E+00	0.00E+00	4.22E+00	1.17E+02	2.58E+01	4.81E+02	0.00E+00
IN	IN-W370.929	53.46	0.00E+00	0.00E+00	1.49E+01	4.12E+02	9.10E+01	1.70E+03	0.00E+00
IN	IN-W371.1018	0.21	1.16E+02	0.00E+00	3.23E-01	8.95E+00	1.98E+00	3.68E+01	0.00E+00
IN	IN-W371.831	0.68	3.79E+02	0.00E+00	1.06E+00	2.93E+01	6.46E+00	1.20E+02	0.00E+00
IN	IN-W373.1003	0.68	0.00E+00	0.00E+00	1.24E+00	3.43E+01	7.56E+00	1.41E+02	0.00E+00
IN	IN-W373.830	0.21	0.00E+00	0.00E+00	7.56E-01	2.10E+01	4.63E+00	8.62E+01	0.00E+00
IN	IN-W374.1091	2.08	0.00E+00	0.00E+00	5.32E-01	1.47E+01	3.25E+00	6.07E+01	0.00E+00
IN	IN-W374.829	2.34	0.00E+00	0.00E+00	1.50E-01	4.15E+00	9.17E-01	1.71E+01	0.00E+00
IN	IN-W375.1096	4.48	0.00E+00	0.00E+00	3.38E-02	9.38E-01	2.07E-01	3.86E+00	0.00E+00
IN	IN-W375.827	7.90	0.00E+00	0.00E+00	1.19E-01	3.31E+00	7.30E-01	1.36E+01	0.00E+00
LA	LA-M002	6706.45	7.02E+03	0.00E+00	2.06E+02	4.68E+03	0.00E+00	1.12E-01	3.88E+01
LA	LA-T001	3787.32	0.00E+00	8.14E-03	1.91E+03	1.33E+03	6.21E-01	1.09E+01	0.00E+00
LA	LA-T002	193.71	9.07E+01	0.00E+00	8.55E+00	4.33E+02	0.00E+00	0.00E+00	0.00E+00
LA	LA-T004	12629.26	4.68E+01	4.25E+02	2.55E+05	1.17E+04	2.84E+01	6.03E+02	1.13E+02
LA	LA-T005	8885.76	8.79E+01	8.19E+02	1.98E+05	4.64E+04	1.00E+02	1.71E+03	7.56E+01
LA	LA-T006	543.32	8.38E+01	0.00E+00	3.15E+04	8.64E+02	2.37E+00	5.17E+01	5.44E+00
LA	LA-T007	198.91	0.00E+00	0.00E+00	3.53E+02	1.71E+03	1.12E-01	1.87E+00	1.95E+00
LA	LA-T008	302.83	3.61E-03	0.00E+00	3.53E+02	1.72E+02	2.01E-03	1.24E-01	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
LA	LA-T009	438.06	0.00E+00	0.00E+00	1.79E+01	5.24E+02	1.40E+00	4.28E+01	0.00E+00
LA	LA-W001	3126.19	2.74E-03	0.00E+00	5.14E+03	2.42E+03	7.14E-01	1.13E+01	1.07E+01
LA	LA-W003	4968.84	3.42E+02	0.00E+00	2.97E+02	3.30E+03	0.00E+00	3.42E-03	0.00E+00
LA	LA-W004	4880.50	6.00E+01	0.00E+00	4.02E+04	3.04E+04	7.56E+01	1.26E+03	4.68E+01
LA	LA-W005	4828.92	7.97E+01	0.00E+00	8.01E+03	1.90E+05	4.98E+02	8.81E+03	4.68E+01
LA	LA-W006	6097.49	3.36E+04	0.00E+00	1.62E+04	6.31E+04	1.53E+02	2.72E+03	5.64E+01
LA	LA-W009	1989.53	1.21E+03	0.00E+00	1.23E+00	1.19E+02	2.84E-01	4.49E+00	0.00E+00
LA	LA-W066	1.89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA	LA-W067	8.94	1.46E-01	4.61E+00	4.76E+00	3.00E+00	0.00E+00	0.00E+00	0.00E+00
LA	LA-W068	0.42	0.00E+00	0.00E+00	1.76E-01	6.11E-01	0.00E+00	0.00E+00	0.00E+00
LL	LL-M001	119.39	1.94E+02	3.79E+02	3.16E+02	7.52E+01	5.27E+01	1.46E+03	0.00E+00
LL	LL-T001	52.80	3.44E+01	0.00E+00	0.00E+00	3.34E+01	1.86E+01	5.01E+02	0.00E+00
LL	LL-T002	3368.07	3.71E+03	0.00E+00	1.15E+03	2.41E+03	1.62E+03	4.54E+04	0.00E+00
LL	LL-T003	917.30	8.32E+01	0.00E+00	7.50E+01	3.44E+01	3.79E+01	1.03E+03	0.00E+00
LL	LL-T004	20.54	3.59E+01	0.00E+00	1.04E+01	1.25E+01	1.61E+01	4.49E+02	0.00E+00
LL	LL-T005	228.68	7.41E+01	9.85E+02	4.20E+01	1.67E+01	2.04E+01	5.65E+02	0.00E+00
LL	LL-W018	176.59	1.13E+00	0.00E+00	0.00E+00	4.40E-01	1.67E+00	4.45E+01	0.00E+00
LL	LL-W019	39.49	3.04E+01	0.00E+00	0.00E+00	9.15E+00	1.23E+01	3.40E+02	0.00E+00
MD	MD-M001	0.42	0.00E+00	0.00E+00	4.26E-01	9.63E-03	0.00E+00	0.00E+00	0.00E+00
MD	MD-T001	4.16	0.00E+00	0.00E+00	3.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-T003	146.94	0.00E+00	0.00E+00	2.42E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-T004	26.84	0.00E+00	0.00E+00	8.68E+02	7.72E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-T005	30.24	0.00E+00	0.00E+00	2.74E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-T006	58.59	0.00E+00	0.00E+00	1.97E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-T007	23.89	0.00E+00	0.00E+00	1.93E+02	7.34E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-T008	3.74	0.00E+00	0.00E+00	6.40E+01	8.67E-02	0.00E+00	0.00E+00	0.00E+00
MD	MD-T009	0.21	0.00E+00	0.00E+00	4.04E+00	1.35E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-T010	0.42	0.00E+00	0.00E+00	2.13E-01	4.82E-03	0.00E+00	0.00E+00	0.00E+00
MD	MD-T012	0.62	0.00E+00	0.00E+00	7.64E+00	4.87E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-W002	1.87	0.00E+00	0.00E+00	8.50E+00	3.38E-02	0.00E+00	0.00E+00	0.00E+00
MD	MD-W003	1.66	0.00E+00	0.00E+00	9.28E+01	7.97E+00	0.00E+00	0.00E+00	0.00E+00
MD	MD-W017	1.46	0.00E+00	0.00E+00	2.43E+02	4.37E-01	0.00E+00	0.00E+00	0.00E+00
NT	NT-W001	672.55	3.01E+02	2.57E+02	2.05E+02	2.81E+03	1.42E+01	1.67E+02	3.22E-02
NT	NT-W021	5.67	0.00E+00	0.00E+00	1.43E+00	3.17E+01	5.33E+00	8.26E+01	0.00E+00
OR	OR-W041	170.77	4.21E-01	0.00E+00	1.05E+00	4.91E+01	1.99E+01	1.76E+02	1.64E-01
OR	OR-W044	2214.79	6.08E+00	3.45E+03	8.02E+02	7.09E+01	1.61E+03	1.30E+05	5.77E-02
OR	OR-W045	5.41	0.00E+00	0.00E+00	5.09E+01	2.39E+02	3.38E+02	3.39E+03	0.00E+00
OR	OR-W047	154.13	8.38E-01	3.32E+02	1.66E+02	1.32E+01	1.76E+01	1.56E+03	0.00E+00
OR	OR-W048	15.18	0.00E+00	5.87E+01	0.00E+00	6.38E-05	0.00E+00	0.00E+00	0.00E+00
OR	OR-W049	17.68	0.00E+00	0.00E+00	3.00E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
OR	OR-W053	435.76	1.61E+03	7.25E+00	1.97E-05	6.71E+02	7.15E+00	8.93E-01	1.55E+01
RF	RF-MT-0335	2645.01	1.75E+03	0.00E+00	0.00E+00	2.15E+04	2.96E+04	1.72E+05	0.00E+00
RF	RF-MT-0368	19.85	0.00E+00	0.00E+00	0.00E+00	2.90E+02	3.82E+02	2.43E+02	0.00E+00
RF	RF-MT-0438	104.79	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.66E+03	0.00E+00
RF	RF-MT-0491	176.40	1.17E+02	0.00E+00	0.00E+00	1.44E+03	1.98E+03	1.15E+04	0.00E+00
RF	RF-MT-0823	0.21	0.00E+00	0.00E+00	0.00E+00	8.76E+00	6.32E+00	3.32E+01	0.00E+00
RF	RF-MT0001	3.74	1.34E+02	0.00E+00	0.00E+00	1.60E+01	1.16E+01	6.06E+01	0.00E+00
RF	RF-MT0003	0.62	2.92E+00	0.00E+00	0.00E+00	2.43E+00	1.77E+00	9.21E+01	0.00E+00
RF	RF-MT0007	0.83	2.98E+01	0.00E+00	0.00E+00	3.56E+00	2.57E+00	1.35E+01	0.00E+00
RF	RF-MT0320	130.54	3.65E+03	0.00E+00	0.00E+00	6.93E+03	9.41E+03	5.46E+04	0.00E+00
RF	RF-MT0321	55.93	1.16E+02	0.00E+00	0.00E+00	8.98E+01	1.12E+02	6.46E+02	0.00E+00
RF	RF-MT0339	934.74	2.06E+04	0.00E+00	0.00E+00	9.77E+03	1.30E+04	7.49E+04	0.00E+00
RF	RF-MT0374	1.25	0.00E+00	0.00E+00	0.00E+00	6.27E+00	4.54E+00	2.37E+01	0.00E+00
RF	RF-MT0375	0.21	0.00E+00	0.00E+00	0.00E+00	2.45E-01	1.77E-01	9.97E-01	0.00E+00
RF	RF-MT0377	3.54	0.00E+00	0.00E+00	0.00E+00	1.54E+02	1.11E+02	5.81E+02	0.00E+00
RF	RF-MT0440	637.99	0.00E+00	0.00E+00	0.00E+00	2.06E+03	2.71E+03	1.58E+04	0.00E+00
RF	RF-MT0442	1117.64	0.00E+00	0.00E+00	0.00E+00	3.59E+03	4.74E+03	2.76E+04	0.00E+00
RF	RF-MT0444	58.13	0.00E+00	0.00E+00	0.00E+00	3.92E+01	5.04E+01	2.89E+02	0.00E+00
RF	RF-MT0480	1983.22	3.91E+04	0.00E+00	0.00E+00	9.97E+03	1.37E+04	7.95E+04	0.00E+00
RF	RF-MT0800	322.32	7.94E+03	0.00E+00	0.00E+00	6.09E+02	6.55E+02	3.69E+03	0.00E+00
RF	RF-MT0801	108.99	5.10E+02	0.00E+00	0.00E+00	4.25E+02	3.08E+02	1.61E+04	0.00E+00
RF	RF-MT0803	16.64	4.03E+02	0.00E+00	0.00E+00	3.00E+01	3.32E+01	1.88E+02	0.00E+00
RF	RF-MT0807	348.08	8.61E+03	0.00E+00	0.00E+00	6.65E+02	7.10E+02	4.00E+03	0.00E+00
RF	RF-MT0821	0.42	5.39E+00	0.00E+00	0.00E+00	3.27E+00	2.36E+00	1.24E+01	0.00E+00
RF	RF-MT0831	1522.20	1.22E+04	0.00E+00	0.00E+00	3.83E+03	5.04E+03	2.92E+04	0.00E+00
RF	RF-MT0832	2433.05	1.95E+04	0.00E+00	0.00E+00	6.12E+03	8.05E+03	4.66E+04	0.00E+00
RF	RF-MT0833	318.79	2.55E+03	0.00E+00	0.00E+00	7.98E+02	1.05E+03	6.10E+03	0.00E+00
RF	RF-MT0855	11.19	0.00E+00	0.00E+00	0.00E+00	7.09E+00	9.50E+00	5.48E+01	0.00E+00
RF	RF-MT0856	35.91	0.00E+00	0.00E+00	0.00E+00	1.15E+02	1.52E+02	8.86E+02	0.00E+00
RF	RF-MT2116	2.08	1.27E+02	0.00E+00	0.00E+00	7.04E+01	5.56E+01	2.92E+02	0.00E+00
RF-RES	RF-RESIDUES	2800.00	1.19E+05	0.00E+00	8.09E+03	1.84E+05	4.22E+04	7.22E+05	2.03E-01
RF	RF-T010	0.62	2.24E+01	0.00E+00	0.00E+00	2.67E+00	1.93E+00	1.01E+01	0.00E+00
RF	RF-TT0300	44.48	0.00E+00	0.00E+00	0.00E+00	9.96E+02	9.95E+02	5.55E+03	0.00E+00
RF	RF-TT0303	0.21	0.00E+00	0.00E+00	0.00E+00	9.28E+00	6.70E+00	3.51E+01	0.00E+00
RF	RF-TT0312	278.03	0.00E+00	0.00E+00	0.00E+00	3.72E+03	5.11E+03	2.97E+04	0.00E+00
RF	RF-TT0320	29.29	0.00E+00	0.00E+00	0.00E+00	9.61E+02	1.08E+03	6.15E+03	0.00E+00
RF	RF-TT0335	373.65	0.00E+00	0.00E+00	0.00E+00	6.33E+03	8.11E+03	4.66E+04	0.00E+00
RF	RF-TT0338	40.53	0.00E+00	0.00E+00	0.00E+00	6.86E+02	8.79E+02	5.05E+03	0.00E+00
RF	RF-TT0374	0.62	0.00E+00	0.00E+00	0.00E+00	3.14E+00	2.27E+00	1.19E+01	0.00E+00
RF	RF-TT0376	91.34	0.00E+00	0.00E+00	0.00E+00	1.84E+03	2.21E+03	1.27E+04	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

SITE	Waste Stream ID#	Scaled Volume (m3)	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
			Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
RF	RF-TT0438	55.76	0.00E+00	0.00E+00	0.00E+00	8.54E+02	9.83E+02	5.57E+03	0.00E+00
RF	RF-TT0440	149.76	0.00E+00	0.00E+00	0.00E+00	6.90E+02	8.99E+02	5.19E+03	0.00E+00
RF	RF-TT0442	181.82	0.00E+00	0.00E+00	0.00E+00	1.05E+03	1.18E+03	6.71E+03	0.00E+00
RF	RF-TT0480	1446.53	1.53E+04	0.00E+00	0.00E+00	5.00E+03	6.38E+03	3.67E+04	0.00E+00
RF	RF-TT0481	0.21	3.50E+00	0.00E+00	0.00E+00	2.14E+00	1.55E+00	8.10E+00	0.00E+00
RF	RF-TT0490	186.97	0.00E+00	0.00E+00	0.00E+00	3.61E+03	4.26E+03	2.42E+04	0.00E+00
RF	RF-TT0491	16.02	0.00E+00	0.00E+00	0.00E+00	8.10E+02	5.87E+02	3.06E+03	0.00E+00
RF	RF-TT0802	179.15	6.22E+03	0.00E+00	0.00E+00	8.72E+01	1.13E+02	6.52E+02	0.00E+00
RF	RF-TT0821	406.61	4.35E+03	0.00E+00	0.00E+00	9.61E+02	1.27E+03	7.33E+03	0.00E+00
RF	RF-TT0823	159.51	6.69E+02	0.00E+00	0.00E+00	5.76E+01	7.43E+01	4.29E+02	0.00E+00
RF	RF-TT0824	140.24	1.50E+03	0.00E+00	0.00E+00	5.01E+02	6.26E+02	3.59E+03	0.00E+00
RF	RF-TT0825	550.34	5.91E+03	0.00E+00	0.00E+00	1.33E+03	1.72E+03	9.97E+03	0.00E+00
RL	RL-T101	567.94	0.00E+00	0.00E+00	2.02E+01	7.02E+02	1.64E+02	1.01E+03	3.30E-10
RL	RL-T102	200.12	0.00E+00	0.00E+00	2.57E-04	8.96E-03	2.09E-03	1.28E-02	1.90E-06
RL	RL-T103	99.63	0.00E+00	0.00E+00	1.08E+02	3.75E+03	8.75E+02	5.36E+03	0.00E+00
RL	RL-T104	4.99	0.00E+00	0.00E+00	3.67E-04	1.28E-02	2.99E-03	1.83E-02	5.39E-08
RL	RL-T105	80.40	7.03E-02	0.00E+00	1.39E-01	4.85E+00	1.13E+00	6.92E+00	7.40E-05
RL	RL-T106	8.11	0.00E+00	0.00E+00	1.36E-01	4.74E+00	1.11E+00	6.78E+00	0.00E+00
RL	RL-T107	6156.09	2.03E+01	0.00E+00	8.00E+04	1.31E+04	3.05E+03	1.86E+04	1.39E+00
RL	RL-T108	192.62	0.00E+00	0.00E+00	1.38E+01	7.45E+00	1.74E+00	1.06E+01	4.84E-05
RL	RL-T109	19.72	3.76E-01	0.00E+00	2.84E-01	9.88E+00	2.31E+00	1.41E+01	3.85E-02
RL	RL-T110	494.03	1.42E+01	0.00E+00	5.42E+01	1.13E+03	2.65E+02	1.62E+03	2.25E+00
RL	RL-T112	137.74	3.12E+02	0.00E+00	2.29E+01	1.50E+02	3.50E+01	2.15E+02	1.22E+00
RL	RL-T113	42.80	0.00E+00	0.00E+00	4.42E-02	4.95E-01	1.16E-01	7.08E-01	0.00E+00
RL	RL-T114	19.58	0.00E+00	0.00E+00	2.16E+00	7.51E+01	1.75E+01	1.07E+02	0.00E+00
RL	RL-T115	1025.43	0.00E+00	0.00E+00	8.67E+00	3.04E+02	7.08E+01	4.34E+02	6.83E-01
RL	RL-T116	11.02	0.00E+00	0.00E+00	3.55E+00	1.23E+02	2.88E+01	1.77E+02	9.29E-02
RL	RL-T118	261.96	1.95E+02	0.00E+00	2.83E+01	1.22E+02	2.85E+01	1.75E+02	1.38E+00
RL	RL-T120	133.81	0.00E+00	0.00E+00	6.54E-01	2.28E+01	5.32E+00	3.25E+01	9.33E-07
RL	RL-T122	29.30	0.00E+00	0.00E+00	1.26E-01	4.35E+00	1.02E+00	6.23E+00	2.41E+00
RL	RL-T123	0.62	0.00E+00	0.00E+00	3.68E-01	1.28E+01	3.00E+00	1.84E+01	9.86E-02
RL	RL-T125	15.18	0.00E+00	0.00E+00	7.60E-06	2.64E-04	6.17E-05	3.81E-04	0.00E+00
RL	RL-T127	283.60	1.66E+03	0.00E+00	2.29E+01	7.99E+02	1.86E+02	1.14E+03	1.32E-01
RL	RL-T128	0.42	3.64E+00	0.00E+00	5.57E-07	1.94E-05	4.52E-06	2.77E-05	0.00E+00
RL	RL-T129	28.75	0.00E+00	0.00E+00	1.06E+02	1.10E+01	2.55E+00	1.56E+01	1.27E-02
RL	RL-T130	0.21	0.00E+00	0.00E+00	6.69E-04	2.34E-02	5.45E-03	3.33E-02	1.37E-04
RL	RL-T131	30.16	5.20E+01	0.00E+00	6.54E-01	2.28E+01	5.30E+00	3.25E+01	1.36E-02
RL	RL-T132	28.70	0.00E+00	0.00E+00	6.45E+01	2.25E+03	5.26E+02	3.21E+03	4.05E-01
RL	RL-T133	0.21	0.00E+00	0.00E+00	5.41E-02	1.89E+00	4.40E-01	2.69E+00	0.00E+00
RL	RL-T134	0.21	0.00E+00	0.00E+00	2.79E-03	9.72E-02	2.26E-02	1.39E-01	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
RL	RL-T135	0.42	0.00E+00	0.00E+00	1.30E-02	4.54E-01	1.06E-01	6.48E-01	6.86E-03
RL	RL-T137	151.63	1.03E+03	0.00E+00	1.64E+01	5.71E+02	1.33E+02	8.15E+02	1.03E-02
RL	RL-T140	138.11	5.19E+02	0.00E+00	3.93E+00	1.36E+02	3.19E+01	1.95E+02	4.34E+01
RL	RL-T143	403.71	0.00E+00	0.00E+00	1.56E+00	5.41E+01	1.26E+01	7.75E+01	6.37E-02
RL	RL-T145	711.19	0.00E+00	0.00E+00	4.42E+00	1.54E+02	3.59E+01	2.20E+02	1.48E-01
RL	RL-W277	0.60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RL	RL-W278	0.42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RL	RL-W279	6.93	0.00E+00	0.00E+00	0.00E+00	3.00E+00	6.95E-01	4.26E+00	0.00E+00
RL	RL-W280	0.21	0.00E+00	0.00E+00	0.00E+00	9.02E-02	2.09E-02	1.28E-01	0.00E+00
RL	RL-W281	0.37	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RL	RL-W282	0.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RL	RL-W283	11.65	1.46E+02	0.00E+00	0.00E+00	9.35E-02	0.00E+00	1.77E-01	0.00E+00
RL	RL-W284	0.42	5.23E+00	0.00E+00	0.00E+00	3.34E-03	0.00E+00	6.32E-03	0.00E+00
RL	RL-W285	1.21	0.00E+00	0.00E+00	0.00E+00	1.27E+01	2.99E+00	1.90E+01	0.00E+00
RL	RL-W286	0.21	0.00E+00	0.00E+00	0.00E+00	9.02E-02	2.09E-02	1.28E-01	0.00E+00
RL	RL-W287	0.42	0.00E+00	0.00E+00	0.00E+00	4.38E+00	1.03E+00	6.54E+00	0.00E+00
RL	RL-W288	1.04	0.00E+00	0.00E+00	0.00E+00	1.10E+01	2.58E+00	1.63E+01	0.00E+00
RL	RL-W289	2.08	0.00E+00	0.00E+00	0.00E+00	2.19E+01	5.15E+00	3.27E+01	0.00E+00
RL	RL-W290	2.29	0.00E+00	0.00E+00	0.00E+00	2.41E+01	5.67E+00	3.59E+01	0.00E+00
RL	RL-W291	7.98	0.00E+00	0.00E+00	0.00E+00	8.40E+01	1.97E+01	1.25E+02	0.00E+00
RL	RL-W292	0.21	0.00E+00	0.00E+00	0.00E+00	2.19E+00	5.15E-01	3.27E+00	0.00E+00
RL	RL-W293	1.25	0.00E+00	0.00E+00	0.00E+00	1.31E+01	3.09E+00	1.96E+01	0.00E+00
RL	RL-W294	1.04	0.00E+00	0.00E+00	0.00E+00	1.10E+01	2.58E+00	1.63E+01	0.00E+00
RL	RL-W295	1.87	0.00E+00	0.00E+00	0.00E+00	1.97E+01	4.64E+00	2.94E+01	0.00E+00
RL	RL-W296	3.16	0.00E+00	0.00E+00	0.00E+00	3.33E+01	7.83E+00	4.97E+01	0.00E+00
RL	RL-W297	1.66	0.00E+00	0.00E+00	0.00E+00	1.75E+01	4.12E+00	2.61E+01	0.00E+00
RL	RL-W298	19.34	0.00E+00	0.00E+00	0.00E+00	1.83E+02	4.50E+01	2.88E+02	0.00E+00
RL	RL-W299	0.62	0.00E+00	0.00E+00	0.00E+00	8.15E+00	1.91E+00	1.16E+01	0.00E+00
RL	RL-W300	0.42	0.00E+00	0.00E+00	0.00E+00	5.43E+00	1.27E+00	7.76E+00	0.00E+00
RL	RL-W301	0.62	0.00E+00	0.00E+00	0.00E+00	1.42E+01	3.31E+00	2.03E+01	0.00E+00
RL	RL-W302	0.42	3.89E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RL	RL-W303	0.21	0.00E+00	0.00E+00	0.00E+00	1.24E+00	1.98E-01	0.00E+00	0.00E+00
RL	RL-W304	2.51	1.41E+00	0.00E+00	0.00E+00	5.65E-01	1.26E-01	8.60E-01	0.00E+00
RL	RL-W305	57.01	1.44E+01	0.00E+00	0.00E+00	2.76E+01	1.17E+01	8.75E+01	0.00E+00
RL	RL-W306	15.94	4.07E+00	0.00E+00	0.00E+00	7.98E+00	3.32E+00	2.47E+01	0.00E+00
RL	RL-W307	1.89	7.69E-01	0.00E+00	0.00E+00	2.82E+00	6.64E-01	4.49E+00	0.00E+00
RL	RL-W308	1.79	5.09E-01	0.00E+00	0.00E+00	1.23E+00	4.21E-01	3.05E+00	0.00E+00
RL	RL-W309	0.21	8.46E-02	0.00E+00	0.00E+00	3.11E-01	7.31E-02	4.95E-01	0.00E+00
RL	RL-W310	1.66	4.58E-01	0.00E+00	0.00E+00	1.05E+00	3.77E-01	2.76E+00	0.00E+00
RL	RL-W311	90.93	2.32E+01	0.00E+00	0.00E+00	4.52E+01	1.89E+01	1.41E+02	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
RL	RL-W312	58.59	1.48E+01	0.00E+00	0.00E+00	2.85E+01	1.21E+01	9.01E+01	0.00E+00
RL	RL-W313	114.07	2.97E+01	0.00E+00	0.00E+00	6.05E+01	2.42E+01	1.80E+02	0.00E+00
RL	RL-W314	117.18	2.97E+01	0.00E+00	0.00E+00	5.70E+01	2.41E+01	1.80E+02	0.00E+00
RL	RL-W315	3.16	8.48E-01	0.00E+00	0.00E+00	1.85E+00	6.96E-01	5.12E+00	0.00E+00
RL	RL-W316	0.21	8.46E-02	0.00E+00	0.00E+00	3.11E-01	7.31E-02	4.95E-01	0.00E+00
RL	RL-W317	16.15	4.16E+00	0.00E+00	0.00E+00	8.29E+00	3.39E+00	2.52E+01	0.00E+00
RL	RL-W318	56.60	1.43E+01	0.00E+00	0.00E+00	2.70E+01	1.16E+01	8.65E+01	0.00E+00
RL	RL-W319	7.56	3.08E+00	0.00E+00	0.00E+00	1.13E+01	2.66E+00	1.80E+01	0.00E+00
RL	RL-W320	56.60	1.43E+01	0.00E+00	0.00E+00	2.70E+01	1.16E+01	8.65E+01	0.00E+00
RL	RL-W321	0.21	8.46E-02	0.00E+00	0.00E+00	3.11E-01	7.31E-02	4.95E-01	0.00E+00
RL	RL-W322	15.94	4.07E+00	0.00E+00	0.00E+00	7.98E+00	3.32E+00	2.47E+01	0.00E+00
RL	RL-W323	14.36	3.65E+00	0.00E+00	0.00E+00	7.05E+00	2.97E+00	2.21E+01	0.00E+00
RL	RL-W324	3.78	1.54E+00	0.00E+00	0.00E+00	5.64E+00	1.33E+00	8.99E+00	0.00E+00
RL	RL-W325	8.66	2.21E+00	0.00E+00	0.00E+00	4.30E+00	1.80E+00	1.34E+01	0.00E+00
RL	RL-W326	56.80	1.43E+01	0.00E+00	0.00E+00	2.73E+01	1.17E+01	8.70E+01	0.00E+00
RL	RL-W327	789.89	2.06E+02	0.00E+00	0.00E+00	4.21E+02	1.68E+02	1.25E+03	0.00E+00
RL	RL-W328	3.78	1.54E+00	0.00E+00	0.00E+00	5.64E+00	1.33E+00	8.99E+00	0.00E+00
RL	RL-W329	57.01	1.44E+01	0.00E+00	0.00E+00	2.76E+01	1.17E+01	8.75E+01	0.00E+00
RL	RL-W330	281.70	7.47E+01	0.00E+00	0.00E+00	1.59E+02	6.12E+01	4.52E+02	0.00E+00
RL	RL-W331	721.16	1.86E+02	0.00E+00	0.00E+00	3.75E+02	1.52E+02	1.13E+03	0.00E+00
RL	RL-W332	0.20	8.14E-02	0.00E+00	0.00E+00	2.99E-01	7.03E-02	4.76E-01	0.00E+00
RL	RL-W333	17.73	4.58E+00	0.00E+00	0.00E+00	9.21E+00	3.74E+00	2.77E+01	0.00E+00
RL	RL-W334	0.21	8.46E-02	0.00E+00	0.00E+00	3.11E-01	7.31E-02	4.95E-01	0.00E+00
RL	RL-W335	2.10	0.00E+00	0.00E+00	0.00E+00	1.18E-01	1.75E-02	0.00E+00	0.00E+00
RL	RL-W336	0.42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RL	RL-W338	0.21	9.52E-02	0.00E+00	0.00E+00	3.34E-03	1.74E-03	1.50E-02	0.00E+00
RL	RL-W339	0.42	1.90E-01	0.00E+00	0.00E+00	6.68E-03	3.48E-03	3.00E-02	0.00E+00
RL	RL-W340	0.21	9.52E-02	0.00E+00	0.00E+00	3.34E-03	1.74E-03	1.50E-02	0.00E+00
RL	RL-W341	0.21	8.46E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-03	0.00E+00
RL	RL-W342	0.83	3.39E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-03	0.00E+00
RL	RL-W343	0.62	2.54E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.93E-03	0.00E+00
RL	RL-W344	0.21	6.35E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-03	0.00E+00
RL	RL-W345	8.95	2.54E+00	0.00E+00	0.00E+00	6.17E+00	2.10E+00	1.53E+01	0.00E+00
RL	RL-W346	0.42	1.61E+00	0.00E+00	0.00E+00	2.04E-01	5.57E-02	1.84E-01	0.00E+00
RL	RL-W347	0.21	8.04E-01	0.00E+00	0.00E+00	1.02E-01	2.78E-02	9.21E-02	0.00E+00
RL	RL-W348	0.21	8.04E-01	0.00E+00	0.00E+00	1.02E-01	2.78E-02	9.21E-02	0.00E+00
RL	RL-W349	0.21	8.04E-01	0.00E+00	0.00E+00	1.02E-01	2.78E-02	9.21E-02	0.00E+00
RL	RL-W350	0.21	8.04E-01	0.00E+00	0.00E+00	1.02E-01	2.78E-02	9.21E-02	0.00E+00
RL	RL-W351	0.21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RL	RL-W352	0.21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
RL	RL-W353	0.83	0.00E+00	0.00E+00	0.00E+00	3.22E+00	7.52E-01	4.60E+00	0.00E+00
RL	RL-W354	0.21	0.00E+00	0.00E+00	0.00E+00	8.05E-01	1.88E-01	1.15E+00	0.00E+00
RL	RL-W355	2.08	0.00E+00	0.00E+00	0.00E+00	8.05E+00	1.88E+00	1.15E+01	0.00E+00
RL	RL-W356	1.25	0.00E+00	0.00E+00	0.00E+00	4.83E+00	1.13E+00	6.90E+00	0.00E+00
RL	RL-W357	0.21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RL	RL-W358	2.50	0.00E+00	0.00E+00	0.00E+00	5.81E-01	1.25E-01	8.25E-01	0.00E+00
RL	RL-W359	16.64	0.00E+00	0.00E+00	0.00E+00	3.87E+00	8.35E-01	5.50E+00	0.00E+00
RL	RL-W360	4.78	0.00E+00	0.00E+00	0.00E+00	1.11E+00	2.40E-01	1.58E+00	0.00E+00
RL	RL-W361	0.62	0.00E+00	0.00E+00	0.00E+00	1.45E-01	3.13E-02	2.06E-01	0.00E+00
RL	RL-W362	16.64	5.72E-01	0.00E+00	0.00E+00	3.21E+01	1.19E+01	8.92E+01	0.00E+00
RL	RL-W363	1.58	5.30E-02	0.00E+00	0.00E+00	2.83E+00	1.09E+00	8.28E+00	0.00E+00
RL	RL-W364	11.69	4.03E-01	0.00E+00	0.00E+00	2.27E+01	8.34E+00	6.28E+01	0.00E+00
RL	RL-W365	64.04	2.22E+00	0.00E+00	0.00E+00	1.26E+02	4.59E+01	3.45E+02	0.00E+00
RL	RL-W366	6.95	2.44E-01	0.00E+00	0.00E+00	1.42E+01	5.06E+00	3.79E+01	0.00E+00
RL	RL-W367	16.64	0.00E+00	0.00E+00	0.00E+00	4.28E+00	1.53E+00	1.01E+01	0.00E+00
RL	RL-W368	4.74	0.00E+00	0.00E+00	0.00E+00	1.13E+00	4.22E-01	2.81E+00	0.00E+00
RL	RL-W369	161.21	6.78E+01	0.00E+00	0.00E+00	2.28E+02	8.09E+01	5.40E+02	0.00E+00
RL	RL-W370	0.42	2.54E-01	0.00E+00	0.00E+00	1.32E+00	3.17E-01	1.97E+00	0.00E+00
RL	RL-W371	21.17	9.30E+00	0.00E+00	0.00E+00	3.36E+01	1.12E+01	7.39E+01	0.00E+00
RL	RL-W372	0.42	2.54E-01	0.00E+00	0.00E+00	1.32E+00	3.17E-01	1.97E+00	0.00E+00
RL	RL-W373	88.45	4.33E+00	0.00E+00	0.00E+00	4.65E+00	1.42E+00	7.79E+00	0.00E+00
RL	RL-W374	2800.78	8.11E+02	0.00E+00	0.00E+00	2.61E+03	1.06E+03	7.37E+03	0.00E+00
RL	RL-W375	272.44	7.96E+01	0.00E+00	0.00E+00	2.61E+02	1.05E+02	7.22E+02	0.00E+00
RL	RL-W376	367.78	1.05E+02	0.00E+00	0.00E+00	3.28E+02	1.38E+02	9.56E+02	0.00E+00
RL	RL-W377	7029 61	2.01E+03	0.00E+00	0.00E+00	6.26E+03	2.63E+03	1.83E+04	0.00E+00
RL	RL-W378	306.06	8.81E+01	0.00E+00	0.00E+00	2.79E+02	1.15E+02	8.00E+02	0.00E+00
RL	RL-W379	0.21	9.52E-02	0.00E+00	0.00E+00	5.63E-01	1.32E-01	8.34E-01	0.00E+00
RL	RL-W380	0.21	9.52E-02	0.00E+00	0.00E+00	5.63E-01	1.32E-01	8.34E-01	0.00E+00
RL	RL-W381	162.79	4.64E+01	0.00E+00	0.00E+00	1.43E+02	6.07E+01	4.22E+02	0.00E+00
RL	RL-W382	423.84	1.21E+02	0.00E+00	0.00E+00	3.78E+02	1.59E+02	1.10E+03	0.00E+00
RL	RL-W383	9.45	4.33E+00	0.00E+00	0.00E+00	2.56E+01	6.01E+00	3.79E+01	0.00E+00
RL	RL-W384	0.62	1.81E+00	0.00E+00	0.00E+00	4.61E-01	1.15E-01	6.38E-01	0.00E+00
RL	RL-W385	12.23	1.35E+01	0.00E+00	0.00E+00	2.67E+01	7.87E+00	4.48E+01	0.00E+00
RL	RL-W386	0.42	5.29E-01	0.00E+00	0.00E+00	1.19E+00	3.13E-01	1.74E+00	0.00E+00
RL	RL-W387	2.83	2.91E+00	0.00E+00	0.00E+00	5.33E+00	1.69E+00	9.73E+00	0.00E+00
RL	RL-W388	20.85	2.45E+01	0.00E+00	0.00E+00	5.13E+01	1.44E+01	8.09E+01	0.00E+00
RL	RL-W389	0.21	2.64E-01	0.00E+00	0.00E+00	5.94E-01	1.57E-01	8.70E-01	0.00E+00
RL	RL-W390	0.62	7.93E-01	0.00E+00	0.00E+00	1.78E+00	4.70E-01	2.61E+00	0.00E+00
RL	RL-W391	0.42	5.29E-01	0.00E+00	0.00E+00	1.19E+00	3.13E-01	1.74E+00	0.00E+00
RL	RL-W392	0.21	0.00E+00	0.00E+00	0.00E+00	5.01E-03	1.74E-03	8.30E-03	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
RL	RL-W393	67.21	4.13E+02	0.00E+00	0.00E+00	3.98E+01	2.55E+01	1.83E+02	0.00E+00
RL	RL-W394	49.81	3.03E+02	0.00E+00	0.00E+00	2.85E+01	1.86E+01	1.34E+02	0.00E+00
RL	RL-W395	174.45	1.11E+03	0.00E+00	0.00E+00	1.14E+02	6.87E+01	4.89E+02	0.00E+00
RL	RL-W396	0.21	2.00E+00	0.00E+00	0.00E+00	3.47E-01	1.30E-01	8.55E-01	0.00E+00
RL	RL-W397	55.72	3.39E+02	0.00E+00	0.00E+00	3.19E+01	2.09E+01	1.50E+02	0.00E+00
RL	RL-W398	0.21	2.00E+00	0.00E+00	0.00E+00	3.47E-01	1.30E-01	8.55E-01	0.00E+00
RL	RL-W399	23.55	0.00E+00	0.00E+00	0.00E+00	9.16E+01	8.94E+01	1.42E+03	0.00E+00
RL	RL-W400	15.31	0.00E+00	0.00E+00	0.00E+00	6.02E+01	5.83E+01	9.28E+02	0.00E+00
RL	RL-W401	214.86	0.00E+00	0.00E+00	0.00E+00	8.24E+02	8.12E+02	1.29E+04	0.00E+00
RL	RL-W402	14.98	0.00E+00	0.00E+00	0.00E+00	4.08E+01	1.62E+01	1.08E+02	0.00E+00
RL	RL-W403	0.62	0.00E+00	0.00E+00	0.00E+00	4.76E+00	1.11E+00	6.79E+00	0.00E+00
RL	RL-W404	15.81	0.00E+00	0.00E+00	0.00E+00	4.71E+01	1.76E+01	1.17E+02	0.00E+00
RL	RL-W405	0.21	9.10E+00	0.00E+00	0.00E+00	9.02E-02	2.09E-02	1.29E-01	0.00E+00
RL	RL-W406	0.42	0.00E+00	0.00E+00	0.00E+00	7.01E-02	1.74E-02	9.80E-02	0.00E+00
SR	T001-221F-HET	11492.34	9.51E+03	0.00E+00	7.17E+05	2.78E+04	5.56E+03	1.66E+05	0.00E+00
SR	T001-221F-MET	490.50	3.98E+02	0.00E+00	2.99E+04	1.11E+03	2.32E+02	6.95E+03	0.00E+00
SR	T001-221F-VIT	954.27	4.95E+02	4.68E+03	3.71E+04	1.33E+02	2.88E+02	8.66E+03	0.00E+00
SR	T001-221H-HET	6572.31	5.25E+03	0.00E+00	3.93E+05	1.41E+04	3.05E+03	9.18E+04	0.00E+00
SR	T001-221H-MET	95.38	7.54E+01	0.00E+00	5.64E+03	1.97E+02	4.38E+01	1.32E+03	0.00E+00
SR	T001-221H-VIT	3192.47	1.64E+03	1.57E+04	1.23E+05	4.33E+02	9.53E+02	2.87E+04	0.00E+00
SR	T001-235F-HET	1517.71	1.28E+03	0.00E+00	9.65E+04	3.85E+03	7.48E+02	2.22E+04	0.00E+00
SR	T001-235F-VIT	566.20	2.90E+02	2.79E+03	2.17E+04	7.54E+01	1.68E+02	5.07E+03	0.00E+00
SR	T001-772F-HET	104.88	9.72E+01	0.00E+00	7.46E+03	3.51E+02	5.78E+01	1.68E+03	0.00E+00
SR	T001-772F-VIT	50.24	2.57E+01	2.47E+02	1.92E+03	6.71E+00	1.49E+01	4.51E+02	0.00E+00
SR	T001-773A-CLAS	4.58	5.92E+00	0.00E+00	4.73E+02	3.11E+01	3.66E+00	9.97E+01	0.00E+00
SR	T001-773A-HET	1721.93	1.36E+03	0.00E+00	1.02E+05	3.60E+03	7.93E+02	2.39E+04	0.00E+00
SR	T001-773A-MET	210.01	1.65E+02	0.00E+00	1.24E+04	4.28E+02	9.59E+01	2.90E+03	0.00E+00
SR	T001-773A-VIT	100.37	5.14E+01	4.94E+02	3.84E+03	1.34E+01	2.98E+01	9.00E+02	0.00E+00
SR	T003-773A-HET	45.94	0.00E+00	0.00E+00	5.98E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR	T003-773A-VIT	0.21	1.75E-01	7.85E-01	1.40E+01	9.22E-02	1.08E-01	2.94E+00	0.00E+00
SR	W006-773A-VIT	0.52	1.09E-02	0.00E+00	0.00E+00	2.36E+02	0.00E+00	0.00E+00	0.00E+00
SR	W027-221F-HET	265.62	3.44E+02	0.00E+00	2.75E+04	1.80E+03	2.13E+02	5.79E+03	0.00E+00
SR	W027-221F-MET	1.89	2.45E+00	0.00E+00	1.95E+02	1.28E+01	1.51E+00	4.12E+01	0.00E+00
SR	W027-221F-VIT	33.18	2.79E+01	1.25E+02	2.23E+03	1.47E+01	1.73E+01	4.70E+02	0.00E+00
SR	W027-221H-HET	125.42	1.62E+02	0.00E+00	1.30E+04	8.52E+02	1.00E+02	2.73E+03	0.00E+00
SR	W027-221H-MET	1.89	2.45E+00	0.00E+00	1.95E+02	1.28E+01	1.51E+00	4.12E+01	0.00E+00
SR	W027-221H-VIT	25.88	2.18E+01	9.77E+01	1.74E+03	1.15E+01	1.35E+01	3.66E+02	0.00E+00
SR	W027-235F-HET	34.74	4.50E+01	0.00E+00	3.59E+03	2.36E+02	2.78E+01	7.57E+02	0.00E+00
SR	W027-235F-MET	1.89	2.45E+00	0.00E+00	1.95E+02	1.28E+01	1.51E+00	4.12E+01	0.00E+00
SR	W027-235F-VIT	16.59	1.39E+01	6.26E+01	1.11E+03	7.35E+00	8.63E+00	2.35E+02	0.00E+00

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TABLE - 1
SCALED VOLUME AND ACTIVITIES FOR SELECTED RADIONUCLIDES FOR EACH WASTE STREAM

	Waste	Scaled	SCALED TOTAL CURIES OF EACH RADIONUCLIDE FOR EACH WASTE STREAM						
SITE	Stream ID#	Volume (m3)	Scaled Am-241	Scaled Cm-244	Scaled Pu-238	Scaled Pu-239	Scaled Pu-240	Scaled Pu-241	Scaled U-234
SR	W027-772F-HET	515.42	6.67E+02	0.00E+00	5.33E+04	3.50E+03	4.12E+02	1.12E+04	0.00E+00
SR	W027-772F-MET	32.13	4.16E+01	0.00E+00	3.32E+03	2.18E+02	2.57E+01	7.00E+02	0.00E+00
SR	W027-772F-VIT	10.62	8.93E+00	4.01E+01	7.13E+02	4.70E+00	5.52E+00	1.50E+02	0.00E+00
SR	W027-773A-HET	331.14	4.29E+02	0.00E+00	3.42E+04	2.25E+03	2.65E+02	7.22E+03	0.00E+00
SR	W027-773A-MET	7.56	9.78E+00	0.00E+00	7.81E+02	5.13E+01	6.05E+00	1.65E+02	0.00E+00
SR	W027-773A-VIT	17.25	1.45E+01	6.51E+01	1.16E+03	7.64E+00	8.97E+00	2.44E+02	0.00E+00
SR-OFF	W027-999-HET	27.66	6.85E+01	0.00E+00	1.15E+05	7.87E+01	4.56E+01	9.88E+02	0.00E+00
SR-OFF	W027-999-VIT	31.85	5.12E+01	0.00E+00	8.61E+04	5.91E+00	3.41E+01	7.38E+02	0.00E+00
SR-OFF	W053-773A-VIT	0.52	0.00E+00	0.00E+00	0.00E+00	7.36E+01	0.00E+00	0.00E+00	0.00E+00
TOTALS		168500.00	4.42E+05	3.15E+04	2.61E+06	7.85E+05	2.10E+05	2.31E+06	4.65E+02

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Table 2
NORMALIZATION FACTORS (NF)

TOTAL CURIES ESTIMATED FROM BIR REV. 2 WASTE STREAM DATA

	UNDECAYED STORED CURIES OF EACH RADIONUCLIDE						
SITE	Am241	Cm244	Pu238	Pu239	Pu240	Pu241	U234
AE Total	3.90E+01	0.00E+00	7.45E-05	2.14E+01	0.00E+00	1.12E+01	0.00E+00
AL Total	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AW Total	6.97E+00	0.00E+00	0.00E+00	5.54E-01	0.00E+00	0.00E+00	0.00E+00
BT Total	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ET Total	2.52E-02	0.00E+00	2.02E-02	1.34E-01	3.36E-02	8.40E-01	3.36E-04
IN Total	8.11E+04	9.29E-01	6.34E+04	4.35E+04	1.10E+04	2.38E+05	0.00E+00
LA Total	3.12E+04	2.29E+02	1.36E+05	1.86E+04	4.10E+03	6.97E+04	1.54E-01
LL Total	1.43E+02	8.06E+01	4.18E+01	1.71E+02	7.96E+01	2.44E+03	0.00E+00
MC Total	1.55E-01	0.00E+00	0.00E+00	6.07E-02	0.00E+00	2.77E-01	0.00E+00
MD Total	0.00E+00	0.00E+00	2.44E+03	3.84E+01	5.36E+02	0.00E+00	0.00E+00
NT Total	3.01E+02	4.16E+00	1.49E+02	2.81E+03	2.61E+01	5.25E+02	5.00E-03
OR Total	1.10E+03	4.51E+00	3.55E+02	1.58E+01	1.82E+01	1.75E+03	1.87E+00
RF Total	6.22E+02	0.00E+00	0.00E+00	1.20E+03	2.76E+02	9.07E+03	0.00E+00
RL Total	9.30E+02	0.00E+00	1.03E+05	3.27E+04	7.35E+03	1.99E+05	3.25E+01
SA Total	1.35E+00	4.33E+00	0.00E+00	2.70E+00	0.00E+00	0.00E+00	0.00E+00
SR Total	7.66E+02	1.69E+01	2.13E+05	1.72E+04	8.76E+02	4.26E+04	0.00E+00
SR-OFF	1.34E+01	3.31E+00	3.73E+03	7.12E+02	1.53E+01	7.45E+02	0.00E+00

	TOTAL UNDECAYED CURIES REPORTED BY THE SITE IN THE IDB						
SITE	Am241	Cm244	Pu238	Pu239	Pu240	Pu241	U234
ARCO	0.00E+00	0.00E+00	3.73E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ARMY	0.00E+00	0.00E+00	0.00E+00	1.80E+01	0.00E+00	0.00E+00	0.00E+00
ETEC	4.54E-01	0.00E+00	1.16E-01	1.79E+00	6.12E-01	8.29E+00	0.00E+00
HANF	3.76E+03	4.82E+03	9.06E+04	2.63E+04	6.15E+03	7.08E+04	5.01E+01
INEL	8.79E+04	1.13E+03	6.75E+04	4.01E+04	9.83E+03	2.88E+05	3.36E+00
LANL	8.69E+03	2.23E+02	1.31E+05	7.69E+04	1.00E+02	1.70E+03	0.00E+00
LBL							
LLNL	1.33E+02	7.44E+01	7.75E+01	1.58E+02	6.44E+01	1.97E+03	2.78E-03
MOUND	0.00E+00	0.00E+00	1.68E+03	2.98E+01	0.00E+00	0.00E+00	0.00E+00
MURR	3.24E-01	0.00E+00	0.00E+00	2.46E-02	0.00E+00	6.63E-03	0.00E+00
NEVADA	2.86E+02	3.54E+02	2.16E+02	2.76E+03	1.84E+01	3.31E+02	5.00E-03
ORNL	6.19E+02	2.26E+03	3.98E+03	1.01E+03	9.44E+02	7.84E+04	1.55E+01
PAD							
PANTEX	0.00E+00	0.00E+00	0.00E+00	5.55E-02	0.00E+00	0.00E+00	0.00E+00
RFETS	1.06E+04	0.00E+00	3.56E+02	9.98E+03	7.22E+03	6.58E+04	0.00E+00
RF-RES							
SRS-ON	2.11E+03	1.16E+03	3.14E+05	9.13E+03	2.21E+03	1.06E+05	3.00E-01
SR-OFF	1.87E+00	0.00E+00	2.43E+05	1.58E+02	7.99E+01	5.34E+03	3.37E-04
SR-TOTAL	2.11E+03	1.16E+03	5.57E+05	9.29E+03	2.29E+03	1.11E+05	3.00E-01

Table 2 (continued)
NORMALIZATION FACTORS (NF)

CALCULATION OF IDB/BIR RATIOS (NF)							
SITE	Am241	Cm244	Pu238	Pu239	Pu240	Pu241	U234
RL	4.04E+00	NC	8.81E-01	8.03E-01	8.37E-01	3.56E-01	1.54E+00
IN	1.08E+00	1.22E+03	1.06E+00	9.22E-01	8.97E-01	1.21E+00	NC
LA	2.79E-01	9.74E-01	9.65E-01	4.13E+00	2.44E-02	2.44E-02	0.00E+00
LL	9.31E-01	9.23E-01	1.85E+00	9.26E-01	8.09E-01	8.05E-01	NC
MD	NC	NC	6.90E-01	7.77E-01	0.00E+00	NC	NC
NT	9.49E-01	8.51E+01	1.45E+00	9.83E-01	7.07E-01	6.31E-01	1.00E+00
OR	5.61E-01	5.02E+02	1.12E+01	6.38E+01	5.18E+01	4.47E+01	8.25E+00
RF	1.71E+01	NC	NC	8.29E+00	2.62E+01	7.26E+00	NC
RF-RES							
SR	2.75E+00	6.86E+01	1.47E+00	5.30E-01	2.52E+00	2.49E+00	NC
SR-OFF	1.40E-01	0.00E+00	6.51E+01	2.22E-01	5.21E+00	7.18E+00	NC
SR-TOTAL	2.76E+00	6.86E+01	2.61E+00	5.40E-01	2.62E+00	2.61E+00	NC

NOTE: **NC —> Cannot Be Calculated Due to Data Discrepancy**

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Table 3
RADIONUCLIDE SCALING FACTORS (SF_a)

TOTAL ESTIMATED ACTIVITY FOR STORED VOLUME (Without Scale-up)						
Stored Am-241	Stored Cm-244	Stored Pu-238	Stored Pu-239	Stored Pu-240	Stored Pu-241	Stored U-234
2.40E+05	2.61E+03	7.55E+05	3.60E+05	6.88E+04	1.08E+06	7.54E+01

TOTAL ESTIMATED ACTIVITY FOR PROJECTED VOLUME (Without Scale-up)						
Proj. Am-241	Proj. Cm-244	Proj. Pu-238	Proj. Pu-239	Proj. Pu-240	Proj. Pu-241	Proj. U-234
5.05E+04	3.35E+03	4.94E+05	2.16E+05	3.75E+04	2.96E+05	3.64E+00

TOTAL WIPP ACTIVITIES (Based on CCA Radionuclide Table)						
Am-241	Cm-244	Pu-238	Pu-239	Pu-240	Pu-241	U-234
4.42E+05	3.15E+04	2.61E+06	7.85E+05	2.10E+05	2.31E+06	4.65E+02

CALCULATED SCALING FACTOR FOR EACH NUCLIDE						
Am-241	Cm-244	Pu-238	Pu-239	Pu-240	Pu-241	U-234
4.01	8.61	3.75	1.97	3.76	4.17	106.94

Table 4

VOLUME SCALING FACTOR (SF_v)

WIPP CAPACITY FOR CH-TRU WASTE	
	168500

TOTAL STORED VOLUME FOR ALL WASTE STREAMS	
	58533.25

TOTAL PROJ. VOLUME FOR ALL WASTE STREAMS WITH RAD DATA	
	16865.15

VOLUME SCALING FACTOR (SF_v)	
	6.52

Note: (168500 - 58533.25) / 16865.15 = 6.52

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APPENDIX B - 3

United States Government | Department of Energy

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: MAR 15 1996

REPLY TO ATTN OF: CAO:NTP:RLB 96-0687

SUBJECT: Preliminary Estimate of Complexing Agents in TRU Solidified Waste Forms Scheduled for Disposal in WIPP

TO: Les E. Shephard, Director, SNL/NM

Attached is a copy of the report containing the preliminary estimates of complexing agents in transuranic (TRU) solidified waste forms scheduled for disposal in the Waste Isolation Pilot Plant (WIPP). This information was requested from the Transuranic (TRU) Waste Baseline Inventory Report (TWBIR) team in support of the Performance Assessment (PA) being conducted by Sandia National Laboratory (SNL). Information has been received from the Rocky Flats Environmental Technology Site (RFETS), the Los Alamos National Laboratory (LANL), and the Oak Ridge National Laboratory (ORNL) on potential complexing agents in their solidified waste forms.

The original scope of this request was to ask the TRU waste generator/storage sites about potential "aqueous-soluble chelating agents" in their solidified waste forms. As this subject was researched, two things were realized. First, in lieu of the term "chelating agent," the term "complexing agent" should be used. "Chelating agents" are a subset of "complexing agents" and as such a more complete assessment would cover the presence of potential "complexing agents." Secondly, it was recognized that "aqueous-soluble" is a relative concept in that essentially everything is "aqueous-soluble" at some concentration level. Therefore, the data provided here are for all complexing agents reported by the sites. These data will allow SNL personnel to determine the cutoff of solubility where certain compounds are no longer considered to be of interest for PA calculations.

The final report at the end of March will contain the necessary attached documentation, references, and elaborated text summaries.

If you have any questions concerning the attached information, please contact Mr. Russ Bisping of my staff at (505) 234-7446.

Don Watkins
Manager
National TRU Program

Attachment

printed on recycled paper

cc w/attachment:
K. Hunter, CAO
M. McFadden, CAO
R. Bisping, CAO
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M. Chu, SNL
M. Marietta, SNL

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Complexing Agents
Site Summaries

ORNL

ORNL has provided a list of organic compounds which contain some aqueous-soluble compounds that are apparent complexing agents. A copy of the list of all compounds reported by ORNL to the BIR team is attached for completeness (Table 1). The list in Table 1 is from an ORNL report on low-level waste, but the same compounds are anticipated to occur in the TRU waste based on process history. ORNL cannot quantify these compounds in their solidified wastes, but have provided an estimate of Total Organic Carbon (TOC) for each TRU waste tank (Table 2). The sum of the TOC from all the transuranic RH-TRU tanks is approximately 3691 kg. It is anticipated that most of the TOC in the tanks is not associated with complexing agents, but that has not been verified at this time. As a conservatism, SNL/NM can assume that any complexing agents listed in Table 1 could form the bulk of the TOC in the ORNL RH-TRU tanks.

LANL

Los Alamos National Laboratory has provided estimates of four complexing agents that are anticipated to occur in their TRU solidified waste streams and as materials used in decontamination and spill clean-up operations (that would occur with the debris wastes). The quantities of these compounds are listed in Table 3.

RFETS/INEL

The information provided by RFETS will also be used to estimate the amount of complexing agents in the RFETS retrievable waste (post 1970) at Idaho National Engineering Laboratory (INEL). Attached is a listing of chemicals from RFETS that was provided to the BIR team as a basis for potential complexing agents in TRU waste scheduled for shipment to and disposal in WIPP. This same list was originally put together as part of the documentation requested by the State of Nevada to document that less than 1% "complexing" agents occur in RFETS solidified low-level "saltcrete" waste that would be shipped to NTS for disposal.

The list was provided as a yearly estimate of complexing agents used on site at RFETS. It is conservative to assume that all of these complexing agents would reside in the TRU waste. Based on the authors understanding at this time, the inventory of RFETS complexing agents is across the entire site, so this should include material expected to occur in the debris wastes (this will be verified for the final version of this memo). The mass of complexing agents reported in Table 3 for RFETS results from multiplying the yearly estimates (in kilograms) by 20 years of production at RFETS (1970-1989), which includes RFETS waste in storage at INEL.

PRELIMINARY

Table 1. Organic chemicals used regularly in the TPP (7920) and TURF (7930) and subsequently discharged to the ORNL LLLW system

Chemical	Approximate Annual Usage
Acetic acid	m[a]
Acetone	100 L
Adogen-364-HP (~triluarylamine)	100 L
Carbon tetrachloride	m
Deodorized mineral spirits (Amsco)	1000 L
2,5-di-tert-butylhydroquinone (DBHQ)	m
Diethylbenzene (DEB)	800 L
Diethylenetriaminepentaacetic acid (DPTA)	m
Di (2-ethylhexyl) phosphoric acid (HDEHP)	200 L
Di-isopropylbenzene (DIPB)	100 L
Ethanol	100 L
Ether	m
Ethylenediaminetetraacetic acid (EDTA)	m
2-ethyl-l-hexanol	m
α-hydroxyisobutyric acid	m
Isopropanol	m
Methanol	m
n-dodecane	m
n-paraffin (NPH)	m
Oxalic acid	m
Thenoyltrifluoroacetone (TTA)	m
Tributylphosphate (TBP)	m
Trichloroethylene (TCE)	m
Xylene	m

[a]m = minimal usage: ≤10 kg/year or ≤L/year.
Bates, 1988

PRELIMINARY

Table 2. ORNL Total Organic Carbon Estimates

TRU Tanks	Tank No.	Volume (m3)	Mass (kg)	TOC (mg/kg)	TOC (kg)
INACTIVE TANKS					
North Tank Farm	W-03	5.3	5670	5300	30.05
	W-04	18.2	24527	200	4.91
South Tank Farm	W-07	37.5	45715	1300	59.43
	W-08	11.4	14080	8400	118.27
	W-09	0.8	833	2900	2.42
	W-10	28	31650	4900	155.09
Old Hydrofracture Facility	T-01	3	4845	18600	90.12
	T-02	4.6	7328	28000	205.18
	T-03	7.7	14829	9140	135.54
	T-04	5	6242	4620	28.84
	T-09	1.9	2967	7620	22.61
ACTIVE TANKS					
Evaporator Facility	C-2	45.6	63883	3281	209.50
	W-21	17.5	38524	6480	249.64
	W-22	43.5	60939	22.1	1.35
	W-23	64.2	89818	4120	370.05
MVSTs	W-24	52	72861	2940	214.21
	W-25	90.7	126911	2330	295.70
	W-26	59.2	82930	6220	515.82
	W-27	69.1	96707	3135	303.18
	W-28	16.5	23051	2500	57.63
	W-29	46.4	64913	3531	229.21
	W-30	46	64383	3531	227.34
	W-31	26.3	36828	4470	164.62
				Total TOC	3690.69

PRELIMINARY

Table 3. RF/INEL and LANL Complexing Chemicals Estimate

Potential Complexing Agents in Rocky Flats (Including Stored at INEL) and LANL Waste						
Compound		RF Mass (kg)		LANL Mass (kg)		Total Mass (kg)
Ascorbic Acid		90		7		97
Acetic Acid		132		10		142
Sodium Acetate		1110				1110
Citric Acid		90		1100.5		1191
Sodium Citrate		400				400
Oxalic Acid		90		13706		13796
EDTA		23				23
8-Hydroxyquinoline		46				46
Tributyl Phosphate		74				74
1,10 Phenanthroline		0.24				0
Dihexyl-n,n-diethylcarbamoyl-methylphosphonate		72				72

PRELIMINARY

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ATTACHMENT - 4 OF 4

APPENDIX B - 4

United States Government | Department of Energy

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: March 29, 1996

REPLY TO ATTN OF: NTP:DW:96-1111

SUBJECT: Current Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP

TO: Les E. Shephard, Director, SNL/NM

Attached is a copy of the report containing the preliminary estimates of complexing agents in transuranic (TRU) solidified waste forms scheduled for disposal in the Waste Isolation Pilot Plant (WIPP). This information was requested from the TRU Waste Baseline Inventory Report (TWBIR) team in support of the Performance Assessment (PA) being conducted by Sandia National Laboratory (SNL) and is based on input from the following TRU waste sites: Rocky Flats Environmental Technology Site (RFETS), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), Savannah River Site (SRS), Hanford Operations (Hanford), and Lawrence Livermore National Laboratory (LLNL).

The complexing agent inventories provided in this letter are in response to a Sandia National Laboratory (SNL) request for information from the U. S. Department of Energy (DOE) Carlsbad Area Office (CAO). A copy of the original request for this complexing agent information is contained in Appendix B of Revision 2 of the TWBIR (DOE/CAO-95-1121, December 1995). The documents attached represent the final information requested for this input to the Performance Assessment (PA) and satisfy the commitment on this subject contained in the March 15, 1996, memorandum (CAO:NTP:RLB 96-0687) to respond to SNL before the end of March. It should be specifically noted that all waste inventory volumes quoted are derived from Rev. 2 of the TWBIR.

Tables 1 and 2 provide a summary of Total Organic Carbon (TOC) in the remote-handled (RH)-TRU sludges from ORNL and a list of possible complexing agents that may contribute to the TOC in the sludges. Table 3 provides a summary of specific complexing agents that may be present in the TRU waste for SNL use.

Table 4 summarizes the volume of stored and projected TRU waste that contributes to the estimate of complexing agents in the waste. For contact handled (CH)-TRU waste, greater than 94% of TRU stored and projected final waste forms, greater than 98% of the Solidified Organic final waste forms, and greater than 92% of the Solidified Inorganic final waste forms contribute to the complexing agent estimate. For RH-TRU waste, greater than 86% of TRU stored and projected final waste forms, 100% of the Solidified Organic final waste forms, and 100% of the Solidified Inorganic final waste forms contribute to the complexing agent estimate.

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The attached site summary, tables, and background references contain greater detail about the basis for these estimates.

If you have any questions concerning the enclosed information, please contact Mr. Russ Bisping of my staff at (505) 234-7446.

Don Watkins
Manager
National TRU Program

Attachment

cc w/attachment:
R. Bisping, CAO
G. Basabilvazo, CAO
P. Drez, CTAC
L. Sanchez, SNL
M. Chu, SNL
M. Marietta, SNL
J. Harvill, CTAC

SITE SUMMARY

BACKGROUND

Information has been received from all sites that were requested to provide data on potential complexing agents in their solidified waste forms: Rocky Flats Environmental Technology Site (RFETS), Los Alamos National Laboratory (LANL), and Oak Ridge National Laboratory (ORNL). Several transuranic (TRU) waste sites which either generate no solidified waste forms or small quantities have also responded. A copy of the Carlsbad Area Office (CAO) memorandum requesting the complexing agent information from the sites is included (Attachment 1).

The term "complexing agent" is being used in lieu of "chelating agents" in this memo, since chelating agents usually have a certain structure (chelating comes from the Greek work "chele" for claw, as in a crab) and are considered a subset of complexing agents. That is, the acetate ion will "complex" with some metals and increase their solubility but does not have the structure that would label it as a chelating agent. A "commonly" known chelating agent is EDTA (ethylenediaminetetraacetic acid), which contains functional (acetate) anion groups arranged in parallel which resemble a "claw"-like structure for complexing the cations. EDTA has two claw structures at either end of the molecule.

The original scope of this task was to ask the TRU waste sites about "aqueous-soluble" complexing agents in their solidified waste forms. As this task was researched, the authors realized that the term "aqueous-soluble" is only a relative term, since everything is aqueous-soluble at some concentration level. Therefore, every potential chemical compound that has been reported from the TRU waste sites is included and the task of selecting aqueous-soluble compounds is left to the Sandia National Laboratory (SNL) personnel in charge of Performance Assessment (PA) calculations.

TRU WASTE SITE RESPONSES

Oak Ridge National Laboratory (ORNL)

ORNL has provided a list of organic compounds that contain some aqueous-soluble compounds that are apparent complexing agents. A copy of the list of all compounds reported by ORNL to the TRU Waste Baseline Inventory Report (TWBIR) team is attached for completeness (Table 1). The list in Table 1 is from an ORNL report on low-level waste (Kaiser, 1988), but the same compounds are anticipated to occur in the TRU waste based on process history (but not necessarily at the same concentrations). ORNL cannot quantify these compounds in their remote-handled (RH)-TRU solidified wastes, but have provided an estimate of Total Organic Carbon (TOC) for each RH-TRU waste tank (Table 2). The sum of the TOC from all the RH-TRU tanks is approximately 3691 kg. It is anticipated that most of the TOC in the tanks is not

associated with complexing agents, but that has not been verified at this time. As a conservatism, SNL can assume that any complexing agents listed in Table 1 could form the bulk of the TOC in the ORNL RH-TRU tanks.

Los Alamos National Laboratory (LANL)

LANL has provided estimates of four complexing agents that are anticipated to occur in their TRU solidified waste streams and as materials used in decontamination and spill clean-up operations (that would occur with the debris wastes) (Attachment 2). The quantities of these compounds are summarized in Table 3.

Rocky Flats Environmental Technology Site (RFETS/INEL)

The information provided by RFETS has been used to estimate the amount of complexing agents in the RFETS retrievable waste (post 1970) at Idaho National Engineering Laboratory (INEL). Attached is a listing of chemicals from RFETS that was provided to the TWBIR team as a basis for potential complexing agents in TRU waste scheduled for shipment to and disposal in WIPP (Table 3). This same list was originally put together as part of the documentation requested by the State of Nevada to document that less than 1% "complexing" agents occur in RFETS solidified low-level "saltcrete" waste that would be shipped to the Nevada Test Site (NTS) for disposal (Attachment 3).

The list was provided as a yearly estimate of complexing agents used on site at RFETS. It is conservative to assume that all of these complexing agents would reside in the TRU waste. The inventory of complexing agents is the best estimate for all TRU waste generated across the entire RFETS site, which includes debris wastes. The mass of complexing agents reported in Table 3 for RFETS are arrived at by multiplying the yearly estimates (in kilograms) by 20 years of production at RFETS (1970-1989), which includes RFETS waste in storage at INEL. The yearly estimates can be found in Attachment 3.

Savannah River Site (SRS)

The SRS has provided information (see letter included as Attachment 4) on three complexing agents used on site in connection with their operations: tributyl phosphate (TBP), tri-octyl phosphine oxide (TOPO), and tri-iso octylamine (TiOA). As discussed in the SRS letter, none of these compounds are expected to be found in SRS TRU waste.

Hanford Operations

Hanford Operations has provided a listing from their database of potential chemicals in their TRU waste. The only chemical that appears on the list that might act as a chelating agent in aqueous solutions and has a reportable quantity associated with the waste is tributyl phosphate (TBP). TBP is reported under three different spellings with a total of 92.5 kg. This value is

summarized in Table 3. The entire list of chemicals and the associated quantities (in kg) reported by Hanford are included in Attachment 5.

Lawrence Livermore National Laboratory (LLNL)

LLNL submitted the letter included as Attachment 6 which documents that no chelating agents occur in the LLNL TRU waste streams.

ESTIMATED VOLUME OF TRU WASTE INCLUDED IN COMPLEXING AGENT MEMO

Column 2 of Table 4 contains a list of the total TRU waste destined for disposal in WIPP (stored plus projected to 2022). Column 3 estimates the volume of waste from each major site that has contributed to the estimate of complexing agents in TRU waste. Columns 4 and 5 provide the same data for Solidified Organics and Solidified Inorganics final waste forms. The two rows labeled "PERCENTAGE" provide an estimate of the percentage of waste for which the TRU waste sites have provided data used in estimating the complexing agents in the waste. It should be specifically noted that all waste inventory volumes quoted are derived from Rev. 2 of the TWBIR (DOE, 1995).

REFERENCES

Kaiser, L. L., 1988, "ORNL Inactive Waste Tanks Sampling and Analysis Plan," ORNL/RAP/LTR-88/24, April 29, 1988, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

U. S. Department of Energy, 1995, "Transuranic Waste Baseline Inventory Report (Revision 2)," DOE/CAO-95-1121, December 1995, Carlsbad, New Mexico.

Table 1. Organic Chemicals Used Regularly in the TPP (7920) and TURF (7930) and Subsequently Discharged to the ORNL LLLW System

Chemical	Approximate Annual Usage
Acetic acid	m[a]
Acetone	100 L
Adogen-364-HP (~triluarylamine)	100 L
Carbon tetrachloride	m
Deodorized mineral spirits (Amsco)	1000 L
2,5-di-tert-butylhydroquinone (DBHQ)	m
Diethylbenzene (DEB)	800 L
Diethylenetriaminepentaacetic acid (DPTA)	m
Di (2-ethylhexyl) phosphoric acid (HDEHP)	200 L
Di-isopropylbenzene (DIPB)	100 L
Ethanol	100 L
Ether	m
Ethylenediaminetetraacetic acid (EDTA)	m
2-ethyl-l-hexanol	m
α-hydroxyisobutyric acid	m
Isopropanol	m
Methanol	m
n-dodecane	m
n-paraffin (NPH)	m
Oxalic acid	m
Thenoyltrifluoroacetone (TTA)	m
Tributylphosphate (TBP)	m
Trichloroethylene (TCE)	m
Xylene	m

[a]m = minimal usage: ≤10 kg/year or ≤liters/year.
Bates, 1988

Table 2. ORNL Total Organic Carbon Estimates

TRU TANKS	TANK NO.	VOLUME (m^3)	MASS (kg)	TOC (mg/kg)	TOC (kg)
INACTIVE TANKS					
North Tank Farm	W-03	5.3	5670	5300	30.05
	W-04	18.2	24527	200	4.91
South Tank Farm	W-07	37.5	45715	1300	59.43
	W-08	11.4	14080	8400	118.27
	W-09	0.8	833	2900	2.42
	W-10	28	31650	4900	155.09
Old Hydrofracture Facility	T-01	3	4845	18600	90.12
	T-02	4.6	7328	28000	205.18
	T-03	7.7	14829	9140	135.54
	T-04	5	6242	4620	28.84
	T-09	1.9	2967	7620	22.61
ACTIVE TANKS					
Evaporator Facility	C-2	45.6	63853	3281	209.50
	W-21	27.5	38524	6480	249.64
	W-22	43.5	60939	22.1	1.35
	W-23	64.2	89818	4120	370.05
MVSTs	W-24	52	72861	2940	214.21
	W-25	90.7	126911	2330	295.70
	W-26	59.2	82930	6220	515.82
	W-27	69.1	96707	3135	303.18
	W-28	16.5	23051	2500	57.63
	W-29	46.4	64913	3531	229.21
	W-30	46	64383	3531	227.34
	W-31	26.3	36828	4470	164.62
				Total TOC	3690.69

Table 3. RF/INEL and LANL Complexing Chemicals Estimate

POTENTIAL COMPLEXING AGENTS IN ROCKY FLATS (INCLUDING STORED AT INEL), LANL, HANFORD TRU WASTE				
COMPOUND	RF MASS (kg)[1]	LANL MASS (kg)[2]	HANFORD MASS (kg)[3]	TOTAL MASS (kg)
Ascorbic Acid	90	7		97
Acetic Acid	132	10		142
Sodium Acetate	1110			1110
Citric Acid	90	1100.5		1190.5
Sodium Citrate	400			400
Oxalic Acid	90	13706		13796
EDTA	23			23
8-Hydroxyquinoline	46			46
Tributly Phosphate	74		92.5	166.5
1,10 Phenanthroline	0.24			0.24
Dihexyl-n,n-diethylcarbamoyl-methylphosphonate	72			72

[1] Letter from W.F. Weston to E.S. Goldberg, No. 89-RF-3055, dated September 1, 1989 (Attachment 3)
[2] Memorandum from C.L. Foxx to P. Drez dated March 12, 1996 (Attachment 2)
[3] Memorandum from F.M. Coony and M.R. Kerns to L.C. Sanchez through S. Lott, dated January 25, 1996 (Attachment 5)

United States Government | Department of Energy

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: JAN 5 1996

REPLY TO ATTN OF: CAO:NTP:RLB 96-0605

SUBJECT: Additional Transuranic (TRU) Waste Data Request for Sandia National Laboratories' Waste Isolation Pilot Plan (WIPP) Performance Assessment

TO: Distribution

We have been informed by representatives from Sandia National Laboratories (SNL) working on WIPP Performance Assessment (PA) that they require more information on certain TRU waste-related parameters in order to assess their influence on WIPP PA (see attached copy of relevant pages form SNL memo).

Data for most of these parameters have already been received from the sites either through responses to the Baseline Inventory Report (BIR), Revision 2, questionnaire or by discussions with site representatives. However, since the request from SNL for data on water soluble organic ligands (i.e., chelating agents) was not received in time for inclusion in the BIR Rev. 2 data call, WIPP PA still needs data for this parameter. As per the SNL memo, the data are needed by the end of February 1996, and therefore it is being addressed through this request separately from the upcoming BIR Rev. 3 data call.

As documented in the SNL memo, WIPP PA would like to have "best estimates" that are realistic and not overly conservative. Consequently, all sites that have existing data on chelating agents present in their waste are requested to submit the best available information to the BIR technical staff by February 26, 1996. The details on the nature of the information being requested by WIPP PA are being provided in Table 3 of the attachment.

A representative from SNL WIPP PA will be available at the upcoming BIR, Revision 3, Data Call Meeting to be held in Concord, California, on January 10, 1996. We anticipate that a brief presentation will be made at this meeting by WIPP PA staff explaining the importance of the data followed by any questions from site representatives. If you have any questions/clarifications regarding this matter, please be ready to discuss these at the upcoming meeting in Concord with the SNL WIPP PA representative.

Thank you for your continued cooperation.

Russ Bisping
Russ Bisping
Waste Certification Manager

Attachment

Table 4. Calculation of Amount of Waste Covered

Major Sites	Total TRU (m^3)	Accounted For in Complexing Agent Estimate (m^3)	Solidif. Org (m^3)	Solidif. Inorg. (m^3)
CH-TRU[1]				
RL [9]	45515.43	45515.43	0	23.39
INEL [2]	28606.74	25657.4	789.67	3349.6
LLNL [3]	941.13	941.13	0	20.18
LANL [4]	18405.15	18405.15	30.58	6922.02
NTS [5]	627.91	627.91	0	5.67
ORNL [6]	1560.42	0	0	0
RFETS [7]	5107.92	5107.92	140.93	1423.01
SRS [8]	9648.15	9648.15	0	1369.8
Total Major Sites	110412.85	105903.09	961.18	13113.67
Total CH-TRU	111721.43	111721.43	980	14108.51
PERCENTAGE [10]		94.79%	98.08%	92.95%
RH-TRU[1]				
RL [9]	21729.35	21729.35	0	0
INEL [2]	220.72	196.98	3.56	65.27
LANL [4]	193.13	193.13	0	0
ORNL [6]	2915.64	1243.33	0	1243.33
Total Major Sites	25058.84	23362.79	3.56	1308.6
Total RH-TRU	26930.88	26930.88	3.56	1308.6
PERCENTAGE [10]		86.75%	100.00%	100.00%

(1) Table 4-3 to 4-23, Rev. 2 TWBIR
(2) Non RFETS Waste Subtracted
(3) Letter from K. Hainebach to J. Teak dated March 7, 1996 (Attachment 6)
(4) Memorandum from C.L. Foxx to P. Drez dated March 12, 1996 (Attachment 2)
(5) NTS waste is derived from LLNL only, see (4)
(6) ORNL was only asked to estimate complexing agents in solidified RH-TRU waste per DOE memorandum dated January 5, 1996 (Attachment 1)
(7) Letter from W.F. Weston to E.S. Goldberg, Letter No. 89-RF-3055, dated September 1, 1989 (Attachment 3)
(8) Letter from J. D'Amelio to J. Teak, SWE-SWE-96-0106, dated February 28, 1996 (Attachment 4)
(9) Memorandum from F.M. Coony and M.R. Kerns to L.C. Sanchez through S. Lott, dated January 25, 1996 (Attachment 5)
(10) Volume percentage of total TRU waste, Solidified Organics, and Solidified Inorganics accounted for in complexing agent memorandum.

B) Special Request Non-PA Items

Also wanted at this time is additional information for several waste material characteristics. Although these characteristics have not been identified as waste material parameters to be used for WIPP PA, they are needed for non-PA scoping calculations to assess their influence on PA. Since these items are not currently PA parameters, inventory estimates of these characteristics as "additional information" in the TWBIR or supplied outside of the TWBIR via written correspondence. Below you will find an itemized list of these special request items.

1) **Non-radioactive Materials**

Additional information is needed on the five waste material characteristics (see Table 2): 1) vitrified wastes, 2) nitrates (NO_3^-), 3) sulfates (SO_4^{2-}), 4) phosphorus, and 5) cement. Of these waste parameters, the last four are needed for the gas generation modeling. The nitrates and the sulfates are involved in the denitrification and sulfate reduction processes which breakup the cellulosics, while the phosphorus is a nutrient for biodecay of cellulosics. The estimate of the mass quantities of cement in the waste inventory should include both the cement that is contained in the waste as cement itself (due to D&D activities, etc.,) and the cement found in various sludges. Cement consumes CO_2 due to its content of $Ca(OH)_2$. The estimates for this non-radioactive waste constituent need only be "best estimates" at this present time so that non-PA scoping calculations can be made to determine their importance on overall repository performance. (Do not generate upper-bound estimates that are overly conservative.)

2) **Residues**

"Best estimates" are needed for residues, in addition to those already identified at the Rocky Flats Plant (RFP), that have the possibility of being changed from a resource category to a TRU waste category.

3) **Organic Ligands (Chelating Agents)**

"Best estimates", from currently available information, are needed for major water-soluble organic ligands which are under consideration for the actinide source term (see Table 3). If it is not possible to obtain data from major waste generating sites then supply guidance on how a first-order estimate may be made (from existing information such as process knowledge etc.,) so that non-PA scoping calculations can be performed to identify if the presence of these ligands would have any significant impacts. (Do not generate estimates that are overly conservative.) Requested data is for final form "process-level" quantities used in production only for the key sites. If information on the "process-level" values does not exist at the key sites, then "laboratory-scale" values should be used in the requested assessment of the inventory. Should it be determined that more detailed information on organic ligands will be needed, you will be given a specific written request at a future time. This effort should be performed in parallel with the TWBIR. Technical data should be supplied in memorandum form by the end of February 1996 with supporting documentation by the end of March 1996.

Table 3. Justification of Special Request For Info On Organic Complexing Agents. (a)

Ligand (b)	Discussion (c)
1) Total Complexants	The most valuable information at this time is a "best estimate" of the total amount of water soluble complexing agents (ligands) in the TRU waste matrix.
2) Citrate	Preliminary information indicates that citrate (citric acid) may be the largest used ligand at TRU waste generating sites. Hence, inventory quantities are very important.
3) Lactate	This is an important ligand that is produced by bacteria as part of its own metabolism. What is requested here is a "best estimate" of the quantity of lactate that actually exists in the TRU waste matrix (not just an initial amount supplied as part of a waste stream). However, if this information cannot be developed, then supply information on the initial amount.
4) Oxalate	This is an important ligand that is produced by bacteria as part of its own metabolism. What is requested here is a "best estimate" of the quantity of oxalate that actually exists in the TRU waste matrix (not just an initial amount supplied as part of a waste stream). However, if this information cannot be developed, then supply information on the initial amount.
5) EDTA	This ligand (ethylenediaminetetraacetic acid) is also of major importance due to its common use as a cleaning solvent.

(a) Information on these additional waste materials are needed for non-PA scoping calculations for assessment of their importance. The presence of these complexing agents are important for the actinide source term, with respect to increasing the solubility of radionuclides.
(b) These items are ranked in the order of their importance in the actinide source term.
(c) Also supply any available information that TRU waste generation sites may have on the degradation or decay rates of ligands in current (and expected) waste matrixes if possible. In cases where no information is available, supply guidance on estimating first-order quantities.

LCS:6741:lcz/(95-2082)

Copy to:
P.E. Drez (Drez Environmental Associates)
D. Bretzke (Science Applications International Corporation)
S. Chakraborti (Science Applications International Corporation)
MS-1320, C.F. Novak (Dept. 6119)
MS-1323, H. Jow (Dept. 6741)

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Los Alamos
NATIONAL LABORATORY

memorandum

Waste Management and
Environmental Compliance
NMT-7 MS E501

To/MS: Paul Drez, Drez Environ Assoc.
Thru: James J Balkey, NMT-7, MS E501 JJB

From/MS: C. L. Foxx, NMT-7, MS E501 CLF
Phone/FAX: 7-2328/ 7-9201
Symbol: NMT-7-WM/EC-96-035
Date: March 12, 1996

SUBJECT: CHELATING AGENTS IN LANL WASTE

I am certain that I have not captured all chelating agents, but I believe that I have identified and quantified roughly the important materials. The chelators are found in three waste streams:

1) Cemented evaporator bottoms from TA-55
2) Cemented sludge from the TA-50 Pretreatment Plant and dewatered sludge from the TA-50 Liquid Waste Treatment Plant
3) Combustible waste from TA-55

The three streams are summarized below.

It should be noted that waste generation data and analyses exist over the time frame of 1980 through 1995 or shorter intervals to support the estimated values. In some cases, quantitative data is almost nonexistent and the results are qualitative at best. Like Rocky Flats, plutonium processing at LANL attempts to avoid chelating agents which can interfere with recovery operations. From your list of compounds of interest, I am unaware of any significant usage of lactate or EDTA, so they have been eliminated from detailed consideration. I have added ascorbate which has been used as a reducing agent in HCl solutions, but not in nitric acid which attacks and decomposes ascorbate. One of the above streams is not an immobilized stream, but I believe that it is an important contributor of a soluble chelating agent in the form of citrate. If this information is extraneous to your purposes, just ignore it.

Cemented evaporator bottoms from TA-55. The evaporator bottoms are derived from nitric acid solutions some of which (27%) contain oxalate resulting from the precipitation of plutonium oxalate. Because of the pervasive usage of oxalate, it is contained at lower concentrations even in those solutions that do not arise from filtering an oxalate precipitate. Those numbers are based on analytical results. In addition the drums contain on the average, 3.2 liters of analytical solution residues. Those solutions contribute a negligible additional quantity of oxalate and small quantities of ascorbate, citrate and acetate. We have semi-quantitative values from the analytical organization for those chelators, based on the quantities used in the analytical processes that give rise to the residues. We know that 28 liters of solution went into a drum of cemented waste on the average from 1980 through June of 1988. Since that time, the average has been 43 liters of solution. In addition we have information regarding the number of drums generated from May, 1987 through April, 1995. The drum numbers and alternate cemented forms

for the remaining years are esumated. The totals based on those data and estimates are shown here.

oxalate	1600 kg	90.04 / 88.04	= 1632	
ascorbate	7 kg	176.14 / 175.14	= 7.04	≈ 7
citrate	0.5 kg	192.14 / 191.14	= 0.5	≈ 0.5
acetate	10 kg	60.05 / 59.05		≈ 10

Cemented sludge from the TA-50 Pretreatment Plant and dewatered sludge from the TA-50 Liquid Waste Treatment Plant. Based on experience at the liquid waste treatment plant with upsets in the treatment process due to the presence of chelators in the waste stream, it has been assumed that TA-55 is the only significant source of chelating agents in the sludge generated at that facility. Three waste lines carry liquids from TA-55 to TA-50. The industrial waste line is thought to be reasonably free of chelating agents. The evaporator distillate in the process acid waste line is unlikely to contain significant quantities of chelators because the distillation process creates a sharp reduction in the content of nonvolatile solution species.

The process caustic waste line solution is dominated by oxalate filtrates in hydrochloric acid that have been subjected to caustic treatment and filtration. Under the conditions of that treatment the oxalate and ascorbate (used historically) are soluble and follow the solution to TA-50 for a ferrofloculation treatment. The solution is used to neutralize the nitric acid distillate. Because there is an excess of nitric acid, the neutralization is completed with the addition of stock sodium hydroxide. I have assumed that the short term excess of nitric acid decomposes the ascorbate leaving only the oxalate. I have estimated the oxalate concentration in the hydroxide filtrate at 0.075 moles/liter. If this number drives the calculation then we should sample the solution in the caustic holding tank at TA-50 and get a representative value.

Volumes of caustic solution generated by TA-55 were available for the years 1983 and 1986 through 1992. Volumes for all other years were estimated. I am assuming that the oxalate will appear in the sludges due to the low solubility of calcium oxalate and because the flocculations have relatively high concentrations of calcium. In addition magnesium and aluminum oxalates are insoluble in a caustic environment. The oxalate precipitates will be found in the cemented sludge, whenever generated, and in the dewatered sludge from the early and middle 80's. These oxalates will also be found in the cement-filled corrugated metal pipe (CMP) waste stream generated at DP site when plutonium operations were located there. The total of oxalate in those waste streams is 11,800 kg. = 12070

Combustible waste from TA-55. The combustible waste stream contains rags that were used in decontamination and spill clean-up operations. In spill clean-up the rags from the first pass are nearly always TRU waste as measured on our MEGAS assay instrument. The rags are dampened with a solution labeled "versene". Versene is a name for EDTA. In the very early days of the laboratory versene solution may have contained EDTA, but it had been changed to sodium citrate solution by the time I arrived in 1969. Drums of combustible waste do not usually contain only decontamination rags and often contain no

such rags. However our waste management personnel apparently used a unique identifier over about a four year period (1987 to 1991) for the decontamination rags. Each item also had a net disposal weight associated with it. Thus I was able to get a handle on the weight of decon rags generated in that time frame. The rags were discarded not dripping but distinctly damp. I dampened some cheesecloth, weighing before and after, to estimate the weight of solution contained in the rags. Knowing the weight of solution and the concentration of the citrate, I was able to calculate a weight of citrate in the discarded rags. In May, 1991 the usage of citrate for decontamination was restricted to certain matrices. I was able to locate records for versene solution preparation from 1989 into early 1991 and then again for the past year so I could understand usage before and after 1991. From that I have estimated the usage for the remaining years. With that information, I have estimated that the citrate contained in the combustible waste stream from 1971 to 2033 will be 1100 kg.

Cy: Andy Montoya, NMT-7, MS E501
NMT-7 File

ATTACHMENT 3

CRRES. CONTROL
OUTGOING LTR. NO.

RF 5555

DIST.

HAN, D.J.
ER, C.P.
ROT, R.J.
TZ, E.R.
, R.C.
ER, E.H.
ER, J.E.
, W.A.
TT, J.F.
ERS, G.W.
OKER, J.H.
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NNAL, G.J.
RERA, D.W.
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ETT, J.L.
, J.B.
AN, R.B.
MANN, R.L.
G, D.M. XX
DENBURG, G.E.
MLEY, K.B. X
N, E.R. XX
, R.L.
ER, H.L.
ASQUEZ, R.N.

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APPROVALS
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ELC

A469 (Rev. 4/89)

Rocky Flats Plant
Aerospace Operations
Rockwell International Corporation
P.O. Box 464
Golden, Colorado 80402-0464
(303) 966-7000
Contractor to U.S. Department of Energy

SEP 01 1989

89-RF-3055

Edward S. Goldberg
Acting Area Manager, RFO

Attn: Mark Van Der Puy

APPLICATION TO SHIP SALTCRETE

Attached is a copy of the re-formatted Application to Ship Waste for saltcrete. This application addresses all the comments from the Nevada Operations Office document attached to your letter 1245-RF-89.

Please refer any questions regarding the attached application to E.L. D'Amico at (303) 966-5362 or P.M. Arnold at FTS 320-2056.

W.F. Weston, Director
Plutonium Operations

Orig. and 3 cc - E.S. Goldberg
Enc.

Table 8 (continued)
Reference Documents/Results Outlining Compliance
to the General Waste Form Criteria

		Boxes." specifies Waste Operations personnel to visually inspect for and remove any excessive particulate from each stored saltcrete box.
Gases	Not Applicable	Saltcrete is not a gaseous waste and does not contain radioactive gases.
Stabilization	WO-5004	As described in WO-5004, "Waste Treatment Spray Dryer and Saltcrete Process," cement is added to the salt waste stream to immobilize the particulate, solidify the liquids and moderate oxidizing characteristics.
Etiologic Agents	Not Applicable	Saltcrete does not contain pathogens, infectious wastes or other etiologic agents.
Chelating Agents	Quantity and type of complexing agents used per year at Rocky Flats: Ascorbic Acid: 4.5 kg Acetic Acid: 6.6 kg Sodium Acetate: 55.5 kg Citric Acid: 4.5 kg Sodium Citrate: 20.0 kg Oxalic Acid: 4.5 kg EDTA: 1.15 kg	Between 5/15/87 and 5/7/88, 917 triwall boxes of saltcrete were produced. The estimated saltcrete generation for any given year is between 1200 to 1600 triwalls. The average net weight of one triwall box of saltcrete is approximately 1600 pounds. Total weight of saltcrete produced between 5/15/87 and 5/7/88 is 917 boxes * 1600 pounds * 1 kg/2.2 pounds = $6.67*10^5$ kg. As a worst case, if it is assumed that all 106.36 kg of complexing agents are

Table 8 (continued)
Reference Documents/Results Outlining Compliance
to the General Waste Form Criteria

	8-Hydroxyquinoline: 2.3 kg Tributyl Phosphate: 3.7 kg 1,10 Phenanthroline: 0.012 kg dihexyl-n,n-diethylcarbamoyl methylphosphonate: 3.6 kg Total: 106.36 kg	disposed of with the saltcrete, then, $106.36/6.67*10^5=1.59*10^{-4}$ is the weight fraction of the complexing agents with respect to the saltcrete. Therefore, Rocky Flats' total yearly usage of complexing agents amounts to only 0.0159 weight percent of the total saltcrete production between 5/15/87 and 5/7/88. This extremely conservative estimate is well under the NTS limit of 1 weight percent.
GCD Waste	Not Applicable	Saltcrete does not meet any of the guidelines to be identified as a GCD' waste.
Bulk LLW	Not Applicable	Saltcrete is not a bulk LLW.

4. **Additional Mixed Waste Form Criteria**

Table 9 references the documents (procedures, specifications, etc.) or test/analysis results that specify compliance to the Additional Mixed Waste Form Criteria outlined in Section 2.2.2 of NVO-325.

Table 9
Reference Documents/Results Outlining Compliance
to the Additional Mixed Waste Form Criteria

Criterion	Compliance Documents or Results	Comments
Treated Waste	Not Applicable	Saltcrete is a treated waste that meets the land disposal restrictions and

ATTACHMENT 4

Westinghouse
Savannah River Company

P.O. Box 616
Aiken SC 29802

February 28, 1996

SWE-SWE-96-0106
F/WSWE/XXX/ARNR
Response Required: N/A
Key Words: TRU Waste
Record Retention: Permanent

Jim Teak
Advanced Sciences, Incorporated
6739 Academy Road, N. E.
Albuquerque, New Mexico 87106-3345

Dear Mr. Teak:

FY96 TRANSURANIC WASTE BASELINE INVENTORY REPORT (TWBIR): RESPONSE TO THE TWBIR MEETING MINUTES REGARDING CHELATING AGENTS AND CONCRETE STABILIZATION (U)

The Savannah River Site (SRS) has reviewed its waste practices to determine whether chelating agents are present in retrievably stored TRU waste. SRS also has reviewed these practices to determine whether concrete has been used to solidify/stabilize TRU waste. These reviews revealed that SRS TRU waste steams do not currently contain chelating agents/complexants nor has SRS used concrete to solidify/stabilize TRU waste.

The Separations processes and the analytical/research laboratories at SRS have used chelating agents in the separation of plutonium from irradiated uranium and other materials. For example, tri-butyl phosphate (TBP) is the complexing agent used in SRS's PUREX process and many other laboratory processes. Also, agents such as tri-octyl phosphine oxide (TOPO) and tri-iso octylamine (TiOA) have been used or investigated through the years. However, none of these chelating agents/complexants has entered SRS TRU waste. The complexants are dissolved in organic solvents for use as liquid/liquid extractants in the separation process. These solvents are recycled until depleted and then discarded to SRS's solvent waste tanks in the Waste Disposal Facility. This means that SRS organic liquid streams have not entered the production lines (e.g., HB and FB-Lines) where most of SRS TRU waste is generated. Further, a small amount of liquid TBP containing TRU nuclides is generated by SRS laboratories. This laboratory waste is discarded to liquid waste streams, which are eventually disposed in SRS's High Level Waste Tanks. So, none of these liquid streams that contain complexants have entered SRS solid TRU waste streams.

SRS has not used concrete to solidify/stabilize TRU waste. The processes that generate slurries, which require stabilization, do not contain TRU radionuclides (e.g., plating of depleted uranium). For other processes that generate slurries, the waste is disposed in SRS's High Level Waste Tanks. Even the Low Level Waste (LLW) sludge generated by SRS's Effluent Treatment Facility (ETF) is disposed in the High Level Waste Tanks and is eventually

ed to SRS's Saltstone Facility or the Defense Waste Processing Facility (DWPF). Finally, SRS does not expect to generate TRU waste containing chelating agents nor anticipate using concrete to solidify/stabilize TRU waste in the near-future.

Please direct your questions to L. Williams (803) 557-6759

Sincerely,

Joseph A. D'Amelio
TRU Engineering Manager

JAD:lw

cc: A. Gibbs, 724-21E
W. T. Goldston, 705-3C
F. H. Gunnels, 705-3C
S. J. Mackmull, 703-A
S. J. Mentrup, 724-21E
D. Ormond, 703-A
L. Williams, 705-3C
Records Management, 705-3C
SWE Files, 705-3C

ATTACHMENT 5

To: L. C. Sanchez, SNL January 25, 1996

Thru: Sheila Lott, CTAC

From: F. M. Coony and M. R. Kerns, Hanford Site

RE: Additional TRU Waste Data Request for Sandia National Laboratories' Waste Isolation Pilot Plan Performance Assessment

References: 1) Memorandum, Russ Bisping, DOE/CAO to Distribution, same subject, dated January 5, 1996.

2) Trip Report, F. M. Coony to K. L. Hladek, January 15, 1996

The Reference 1 memo requests additional data on waste soluble organic ligands (i.e. chelating agents) from the generating sites by February 28, 1996.

Hanford's approach for responding to the additional data request is presented in the Reference 2 trip report. The first item of this approach is to provide SNL, through CTAC, a list of all hazardous constituents, and their quantities, that have been reported in solid TRU waste at Hanford since 1987, the date of the By-Product Rule.

The list of hazardous constituents and their quantities, from Hanford's record container tracking system, are presented in Table 2. The chemical names have been truncated to 30 characters. Hanford can provide complete names if needed. In some cases, the constituent is listed more than once because the constituent is spelled differently in the container tracking system. A quantity of 0.00 kg means typically that the constituent has been identified solely because it is a listed hazardous waste under RCRA. In these cases, the quantity is either absent or minimal.

Please evaluate the list of constituents, and indicate, in the space provided for each constituent, if the constituent is a soluble organic ligand. The suggested nomenclature is the following:

- N/A (meaning not soluble organic legend)
- C (meaning citrate
- L (meaning lactate)
- OX (meaning oxalate)
- EDTA (meaning ethylenediaminetetraacetic acids

Please indicate any other relevant information by footnotes.

To meet the requested due date, please provide a response to me (by fax) no later than February 5, 1996. Please copy CTAC on the response.

If you have any questions, please contact Mike Coony at 509-376-9774 or Mark Kerns at 509-372-2383.

MASS
(KG)

Table 2. Quantities of Hanford Constituents

[illegible]	MASS [illegible]
1,1,1-TRICHLOROETHANE	0.00
2-BUTOXYETHANOL	0.02
ACETONE	0.00
ACID	0.14
ALUMINUM NITRATE	0.10
ALUMINUM NITRATE MONOHYDRATE	3.90
AMERCOAT 234	0.05
AMMONIUM CHLORIDE	0.01
ARSENIC	0.02
ASBESTOS	27.00
BARIUM	1.86
BERYLLIUM	0.17
BIS(2-ETHYLHEXYL)PHTHALATE	0.62
BISPHENOL A RESIN	0.54
BUTYL ALCOHOL	0.41
BUTYL GLYCIDYL ETHER	0.11
CADMIUM	99.17
CADMIUM HYDROXIDE	0.10
CALCIUM CHLOROFLUOROPHOSPHATE	0.83
CALCIUM HYDROXIDE	0.06
CARBON TETRACHLORIDE	57.68
CARBONTETRACHLORIDE	95.90
CHLOROFORM	0.00
CHROMIUM	14.52
COPPER	0.00
COPPER SULFATE	0.38
CRESYLIC ACID	0.00
CUPROUS CYANIDE	0.21
CYANIDE SOLUTIONS	0.21
CYCLOHEXANE	0.00
DI(2-ETHYLHEXYL)PHTHALATE	0.08
DI-OCTYL PHTHALATE	0.40
DIOCTYL PHTHALATE	0.20
DIOCTYL PHTHALATE (DOP)	8.47
ETHANOL	0.20
FERRIC NITRATE	4.38
FORMIC ACID	0.21
HEXONE	0.10
HYDRAULIC FLUID	328.20
HYDROCHLORIC ACID	0.07

MASS
(KG)

[illegible]	[illegible]	[illegible]
KEROSINE	0.00	
LEAD	8,915.59	
LEAD ACID	0.27	
LEAD CHROMATE	28.97	
LEAD CHROMATE OXIDE	1.54	
LEAD CHROMATE,CHLORIN.PARAFFIN	1.33	
LEAD CHROMATES	0.05	
LEAD SHIELDING	5,587.50	
LIGHT AROMATIC NAPHTHA	0.30	
MERCURY	1.51	
MERCURY METAL	0.00	
METHYL ETHYL KETONE	0.00	
METHYL ISOBUTYL KETONE	0.00	
METHYLENE CHLORIDE	8.03	
NICKEL HYDROXIDE	0.10	
NITRIC ACID	1.21	
OIL	0.00	
PCB	130.13	
PHOSPHORIC ACID	0.33	
PHTHALIC ACID BENZYL BUTYL EST	0.00	
PHTHALIC ACID BIS(2-ETHYLHEXYL	0.00	
PHTHALIC ACID, BIS(2-ETHYLHEXY	0.05	
POTASSIUM CYANIDE	0.21	
POTASSIUM FLUORIDE	0.00	
POTASSIUM HYDROXIDE	5.80	
RESIDUAL TANK FARM CORE SAMPLE	0.80	
SELENIUM	1.10	
SILVER	0.00	
SODIUM	0.13	
SODIUM CYANIDE	0.21	
SODIUM FLUORIDE	1.08	
SODIUM HYDROXIDE	24.37	
SODIUM NITRATE	173.00	
SODIUM SULFATE	3.92	
STRIPCOAT	34.08	
SULFAMIC ACID	0.04	
SULFURIC ACID	1.53	
THENOYL TRIFLUOROACETONE	0.00	
TRI BUTYL PHOSPHATE	49.30	
TRIBUTYL PHOSPHATE	43.13	
TRIBUTYLPHOSPHATE	0.07	

MASS (KG)

HAZARDOUS CONSTITUENT	MASS (KG)	[illegible]
TRICHLOROETHENE	3.28	
TRIISOOCTYLAMINE	0.00	
TRIMETHYLBENZENE	1.01	
TRIOCTYLPHOSPHINE OXIDE	0.00	
VANADIUM PENTOXIDE AQUEOUS SOL	0.21	
XYLENE	4.23	

ATTACHMENT 6

Lawrence Livermore National Laboratory

WASTE CERTIFICATION PROGRAM
WCP96-055

March 7, 1996

Jim Teak
Advanced Sciences Incorporated
6739 Academy Road NE
Albuquerque, NM 87109

Dear Jim,

This is in response to the CAO request concerning the presence of organic ligands (chelating agents) in TRU waste. I have consulted with Joe Magana, a chemist working in LLNL's Plutonium Facility. He tells me that there are no chelating agents in LLNL's TRU waste.

Sincerely yours,

Kem Hainebach

Kem Hainebach, Ph. D.
Waste Certification Engineer
Environmental Protection Department

KH:lh
c: Robert Fischer

M

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APPENDIX B - 5

United States Government **Department of Energy**

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: June 26, 1996

REPLY TO ATTN OF: CAO:NTP:DW 96-1528

SUBJECT: Revision of Current Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP

TO: Dr. Les E. Shephard, Director, Nuclear Waste Management Programs Center, SNL

The mass of potential complexing agents in transuranic (TRU) waste generated at the Rocky Flats Environmental Technology Site (RFETS) and currently stored at RFETS and Idaho National Engineering Laboratory (INEL) was previously estimated in our March 29, 1996 memorandum, CAO:NTP:DW 96-1111, (Subject: "Current Estimate of Complexing Agents in Transuranic Solidified Waste Forms Scheduled for Disposal in WIPP"). Per our May 3, 1996 discussion, this information has been revised based on assumed or anticipated activities to be performed on the waste prior to final waste form generation.

The assumed or anticipated activities upon which these revisions were made are based on the preliminary submittal by INEL for Revision 3 of the TRU Waste Baseline Inventory Report (TWBIR). From this submittal, a very high percentage of INEL waste will be thermally treated and most complexing agents should therefore be destroyed by the treatment. A methodology is presented for estimating the amount of complexing agents that will be destroyed by the proposed thermal treatment at INEL. Using Ethylene Diamine Tetraaccetic Acid (EDTA) as an example, the original estimate of 23 kg in RFETS waste (stored at INEL and RFETS) has been reduced to a recommended value of 5.9 kg with a high range estimate of 6.9 kg and a low range estimate of 2.9 kg. All other complexing agents reported from RFETS (including that in storage at INEL) in the previous letter should also be reduced by the same methodology.

The original inventory estimates provided in the above referenced letter were based on the following information contained in the original transmittal:

- Estimates provided by the TRU waste sites on the amount of anticipated complexing agents in TRU waste which are summarized in Tables 1, 2, and 3 from TRU waste site memoranda in Attachments 1 through 6.

- Volumes from Revision 2 of the Transuranic Waste Baseline Inventory Report (TWBIR) used in Table 4.

In Revision 2 of the TWBIR, the volumes used for waste stored at the INEL were assumed to be unprocessed through any type of treatment (i.e., thermal) that would destroy potential

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complexing agents. There was a small percentage of RFETS waste (~33%) stored at INEL scheduled for processing by thermal treatment in the TWBIR, Revision 2. Because these percentages of waste scheduled for thermal treatment were low, no credit was assumed in the original letter for the destruction of potential complexing agents occurring in RFETS TRU waste stored at INEL. This assumption also provided a conservative estimate of the potential complexing agents in TRU waste.

However, the INEL preliminary submittal received for Revision 3 of the TWBIR contains a much higher percentage of waste that will be processed thermally prior to shipment to WIPP for disposal. This much higher percentage of RFETS TRU waste that will be thermally processed will make a significant impact on the calculated amounts of potential complexing agents in TRU waste.

As stated in the original letter, most of the complexing agents were expected in the solidified waste forms, particularly in the solidified inorganic waste forms, since Sandia National Laboratory/New Mexico (SNL/NM) was only requesting information on "aqueous-soluble" complexing agents.

The RFETS estimate (Attachment 3 of the original letter) included all known sources (as of the time frame of the RFETS memo) of complexing agents regardless of what waste forms the chemicals occurred in the waste. Discussions with RFETS indicate the most likely occurrences of complexing agents in the waste would be:

Solidified Lab Waste> Solidified Inorganic Sludges> Debris Wastes

Based on the above relative occurrence for complexing agents, three estimates of the effects of extensive planned thermal treatment of RFETS waste at INEL can be made to modify the mass of chelating agents estimated in the original letter.

Tables AD-1, AD-2, and AD-3 summarize the calculations of the amount of decrease of complexing agents for RFETS in storage at INEL using EDTA as an example:

ASSUMPTIONS

- As stated in the original letter, RFETS was in production for 20 years (1971-1990) during which retrievably stored (post 1970) production waste would have been generated. Buried waste is not part of the WIPP inventory in the TWBIR.

- RFETS stopped shipments of waste to INEL initially in October 1988, then shipped additional quantities of waste from March to August 1989.

- Assuming that RFETS essentially caught up on their backlog of waste during the second shipping period and a modest lag of 2 months from date of closure to actual shipping, effectively provides the beginning of July 1989 as the date for TRU waste accumulation at RFETS.

- Therefore, it is assumed that 18 months (1.5 years) of production waste still exists at RFETS in storage and 18.5 years of post 1970 production waste is in storage at INEL.

CALCULATIONS

As shown in Table AD-1 (for Solidified Lab waste - Content Codes 004 and 113), using EDTA as an example:

- 347.7 m^3 of CH-TRU waste is in storage at INEL.

- 280.1 m^3 will be vitrified, and

- 67.5 m^3 will be set aside for direct shipment to WIPP (including 0.33 m^3 for macroencapsulation)

- Therefore, 80.58% will be vitrified

- RFETS provided an EDTA generation rate of 1.15 kg/year (Attachment 3 of Original Complexing Agent Memo)

- 1.15 kg/year x 18.5 years = 21.3 kg EDTA at INEL in storage

- 1.15 kg/year x 18.5 years generation in storage at INEL x 80.58% vitrification of waste = 17.1 kg of EDTA destroyed by vitrification

- Therefore, 4.1 kg of EDTA (21.3 minus 17.1 kg) will be left in the untreated waste at INEL scheduled for shipment and disposal in WIPP

- The total EDTA in RFETS waste (both in storage at INEL and RFETS) = 4.1 kg (untreated waste at INEL) + 1.15 kg/year x 1.5 years (in storage at RFETS) = 5.9 kg

Since Content Codes 004 and 113 are the waste forms most likely to have the complexing agents, 5.9 kg of EDTA is the RECOMMENDED VALUE for performance assessment.

Using similar methodology in Tables AD-2 and AD-3, estimates of EDTA (after treatment at INEL) are 6.9 kg (assuming the distribution of treatment for all inorganic solidified waste forms - 75.68% treated) and 2.9 kg (assuming the distribution of treatment for all RFETS waste in storage at INEL - 94.44% treated).

The value of 5.9 kg of EDTA is the recommended value, since Content Codes 004 and 113 are the waste forms expected to contain the majority of the complexing agents. The other two values, 6.9 kg for inorganic solidified waste and 2.9 kg for all treated RFETS waste, should be considered lower and upper bounds on this analysis. In particular, the 2.9 kg is a nonconservative estimate because INEL is planning to vitrify almost all their debris waste, particularly the organic debris waste, which may contain some EDTA from wipeup of spills, but is expected to be the least contributor to the overall complexing agents in the waste.

All other complexing agents from RFETS should be reduced by the same percentages for those values reported in Table 3 of the original complexing agent letter.

If you have any questions concerning the attached information, please contact Mr. Russ Bisping of my staff at (505) 234-7446.

Don Watkins
Manager
National TRU Program

Attachment

cc w/attachment:
R. Bisping, CAO
S. Chakraborti, CTAC
J. Harvill, CTAC
P. Drez, DEA
R. Anderson, SNL
L. Sanchez, SNL
M. Chu, SNL
M. Marietta, SNL

TABLE AD-1

DETAILS OF EDTA CALCULATIONS
(BASIS: ROCKY FLATS WASTE AT INEL WITH IDCs 004 AND 113)

						UNPROCESSED WASTE VOLUMES (m^3)				
FFCA_ID	WS_ID	CC	Total Vol	CH Vol	RH Vol	CH_Direct Ship	RH_Direct Ship	Vitrified	Amalg	Macro
IN-W157	ID-RFO-004T	4	226.8	226.8	0.0	54.3	0.0	172.3	0.0	0.2
IN-W195	ID-RFO-113	113	2.5	2.5	0.0	0.0	0.0	2.5	0.0	0.0
IN-W221	ID-RFO-113T	113	14.4	14.4	0.0	12.9	0.0	1.5	0.0	0.0
IN-W229	ID-RFO-004	4	103.9	103.9	0.0	0.0	0.0	103.8	0.0	0.1
			347.7	347.7	0.0	67.2	0.0	280.1	0.0	0.3

TOTAL EDTA IN RF WASTE AT INEL —> 21.3 kg
(1.15 kg/yr for 18.5 years)
PERCENT VITRIFIED ———> 80.6%
AMOUNT VITRIFIED (80.58% of 21.3 kg)–> 17.1 kg
AMOUNT IN UNTREATED INEL WASTE—> 4.1 kg

TOTAL EDTA IN RF WASTE AT RF ——> 1.7 kg
(1.15 kg/yr for 1.5 years)

NEW EDTA ESTIMATE ——> 5.9 kg

TABLE AD-2

DETAILS OF REVISED EDTA CALCULATIONS
(BASIS: ALL ROCKY FLATS SLUDGES AT INEL)

						UNPROCESSED WASTE VOLUMES (m^3)				
FFCA_ID	WS_ID	CC	Total Vol	CH Vol	RH Vol	CH_Direct Ship	RH_Direct Ship	Vitrified	Amalg	Macro
IN-W216	ID-RFO-001T	1	2531.8	2531.8	0.0	775.3	0.0	1741.6	0.0	14.9
IN-W190	ID-RFO-001	1	58.9	58.9	0.0	0.0	0.0	58.6	0.0	0.3
IN-W221	ID-RFO-113T	113	14.4	14.4	0.0	12.9	0.0	1.5	0.0	0.0
IN-W195	ID-RFO-113	113	2.5	2.5	0.0	0.0	0.0	2.5	0.0	0.0
IN-W228	ID-RFO-002T	2	1296.8	1296.8	0.0	15.3	0.0	1260.9	12.4	8.2
IN-W191	ID-RFO-002	2	342.4	342.4	0.0	0.0	0.0	336.9	3.3	2.2
IN-W157	ID-RFO-004T	4	226.8	226.8	0.0	54.3	0.0	172.3	0.0	0.2
IN-W229	ID-RFO-004	4	103.9	103.9	0.0	0.0	0.0	103.8	0.0	0.1
IN-W218	ID-RFO-007T	7	461.5	461.5	0.0	461.5	0.0	0.0	0.0	0.0
IN-W192	ID-RFO-007	7	464.3	464.3	0.0	0.0	0.0	464.3	0.0	0.0
IN-X001	ID-RFO-095N	95	4.9	4.9	0.0	0.0	0.0	4.9	0.0	0.0
IN-W375	ID-RFO-995TN	995	19.3	19.3	0.0	0.0	0.0	19.3	0.0	0.0
IN-X002	ID-RFO-995N	995	68.8	68.8	0.0	0.0	0.0	68.8	0.0	0.0
	TOTALS		5596.4	5596.4	0.0	1319.3	0.0	4235.5	15.7	25.9

TOTAL EDTA IN RF WASTE AT INEL ---> 21.3 kg
(1.15 kg/yr for 18.5 years)
PERCENT VITRIFIED ---------> 75.7%
AMOUNT VITRIFIED (75.68% of 21.3 kg)--> 16.1 kg
AMOUNT IN UNTREATED INEL WASTE----> 5.2 kg

TOTAL EDTA IN RF WASTE AT RF -------> 1.7 kg
(1.15 kg/yr for 1.5 years)

NEW EDTA ESTIMATE ------> 6.9 kg

TABLE AD-3

DETAILS OF EDTA CALCULATIONS
(BASIS: ALL ROCKY FLATS WASTE AT INEL)

						UNPROCESSED WASTE VOLUMES (m3)				
FFCA_ID	WS_ID	CC	Total Vol	CH Vol	RH Vol	CH_Direct Ship	RH_Direct Ship	Vitrified	Amalg	Macro
IN-W307	ID-RFO-000	0	136.7	136.7	0.0	0.0	0.0	135.8	0.0	1.0
IN-W308	ID-RFO-000T	0	4139.7	4139.7	0.0	0.0	0.0	4110.7	0.0	29.0
IN-W216	ID-RFO-001T	1	2531.8	2531.8	0.0	775.3	0.0	1741.6	0.0	14.9
IN-W190	ID-RFO-001	1	58.9	58.9	0.0	0.0	0.0	58.6	0.0	0.3
IN-W167	ID-RFO-112T	112	164.1	164.1	0.0	120.2	0.0	43.9	0.0	0.0
IN-W168	ID-RFO-112	112	5.1	5.1	0.0	0.0	0.0	5.1	0.0	0.0
IN-W221	ID-RFO-113T	113	14.4	14.4	0.0	12.9	0.0	1.5	0.0	0.0
IN-W195	ID-RFO-113	113	2.5	2.5	0.0	0.0	0.0	2.5	0.0	0.0
IN-W166	ID-RFO-114T	114	70.8	70.8	0.0	56.2	0.0	14.6	0.0	0.0
IN-W165	ID-RFO-114	114	4.0	4.0	0.0	0.0	0.0	4.0	0.0	0.0
IN-W370	ID-RFO-115TN	115	67.2	67.2	0.0	40.7	0.0	26.5	0.0	0.0
IN-X006	ID-RFO-115N	115	1.1	1.1	0.0	0.0	0.0	1.1	0.0	0.0
IN-W186	ID-RFO-116T	116	2696.6	2696.6	0.0	0.6	0.0	2696.0	0.0	0.0
IN-W185	ID-RFO-116	116	371.1	371.1	0.0	0.0	0.0	371.1	0.0	0.0
IN-W300	ID-RFO-117T	117	1520.2	1520.2	0.0	14.8	0.0	1493.2	0.0	12.2
IN-W299	ID-RFO-117	117	147.5	147.5	0.0	0.0	0.0	146.4	0.0	1.2
IN-W240	ID-RFO-118T	118	174.6	174.6	0.0	7.8	0.0	163.3	0.0	3.5
IN-W241	ID-RFO-118	118	6.4	6.4	0.0	0.0	0.0	6.2	0.0	0.1
IN-W206	ID-RFO-119T	119	383.3	383.3	0.0	36.3	0.0	347.0	0.0	0.0
IN-W232	ID-RFO-119	119	69.2	69.2	0.0	0.0	0.0	69.2	0.0	0.0
IN-W230	ID-RFO-122T	122	18.2	18.2	0.0	10.0	0.0	8.3	0.0	0.0
IN-W231	ID-RFO-122	122	12.3	12.3	0.0	0.0	0.0	12.3	0.0	0.0
IN-W250	ID-RFO-123T	123	63.8	63.8	0.0	37.1	0.0	20.2	0.0	6.5
IN-W251	ID-RFO-123	123	2.3	2.3	0.0	0.0	0.0	2.1	0.0	0.2
IN-W312	ID-RFO-124TN	124	3.2	3.2	0.0	2.3	0.0	0.8	0.0	0.0
IN-W228	ID-RFO-002T	2	1296.8	1296.8	0.0	15.3	0.0	1260.9	12.4	8.2
IN-W191	ID-RFO-002	2	342.4	342.4	0.0	0.0	0.0	336.9	3.3	2.2
IN-W282	ID-RFO-241	241	24.2	24.2	0.0	0.0	0.0	24.1	0.0	0.0
IN-W283	ID-RFO-241T	241	1.1	1.1	0.0	0.0	0.0	1.1	0.0	0.0
IN-W196	ID-RFO-290	290	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0
IN-W222	ID-RFO-292T	292	110.5	110.5	0.0	42.2	0.0	68.3	0.0	0.0
IN-W215	ID-RFO-292	292	4.9	4.9	0.0	0.0	0.0	4.9	0.0	0.0
IN-W309	ID-RFO-003T	3	569.4	569.4	0.0	160.7	0.0	408.7	0.0	0.0
IN-W310	ID-RFO-003	3	1001.9	1001.9	0.0	0.0	0.0	1001.9	0.0	0.0
IN-W276	ID-RFO-300T	300	391.8	391.8	0.0	151.4	0.0	240.4	0.0	0.0
IN-W274	ID-RFO-300	300	18.4	18.4	0.0	0.0	0.0	18.4	0.0	0.0
IN-W275	ID-RFO-301T	301	6.4	6.4	0.0	0.8	0.0	5.5	0.0	0.0

TABLE AD-3

DETAILS OF EDTA CALCULATIONS
(BASIS: ALL ROCKY FLATS WASTE AT INEL)

FFCA_ID	WS_ID	CC	Total Vol	CH Vol	RH Vol	CH_Direct Ship	RH_Direct Ship	Vitrified	Amalg	Macro
IN-W273	ID-RFO-301	301	1.3	1.3	0.0	0.0	0.0	1.3	0.0	0.0
IN-W184	ID-RFO-302	302	55.4	55.4	0.0	0.0	0.0	49.8	0.0	5.5
IN-W225	ID-RFO-302T	302	22.2	22.2	0.0	0.0	0.0	20.0	0.0	2.2
IN-W369	ID-RFO-303TN	303	12.3	12.3	0.0	9.1	0.0	3.2	0.0	0.0
IN-W368	ID-RFO-310TN	310	3.4	3.4	0.0	0.2	0.0	3.2	0.0	0.0
IN-X007	ID-RFO-310N	310	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0
IN-W367	ID-RFO-311TN	311	4.4	4.4	0.0	0.0	0.0	4.4	0.0	0.0
IN-W272	ID-RFO-312T	312	1.9	1.9	0.0	1.9	0.0	0.0	0.0	0.0
IN-W298	ID-RFO-320T	320	74.6	74.6	0.0	21.4	0.0	51.7	0.0	1.5
IN-W297	ID-RFO-320	320	28.6	28.6	0.0	0.0	0.0	28.0	0.0	0.6
IN-W207	ID-RFO-328T	328	1.5	1.5	0.0	0.0	0.0	1.5	0.0	0.0
IN-W233	ID-RFO-328	328	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0
IN-W169	ID-RFO-330T	330	5774.6	5774.6	0.0	18.7	0.0	5756.0	0.0	0.0
IN-W158	ID-RFO-330	330	3150.6	3150.6	0.0	0.0	0.0	3150.6	0.0	0.0
IN-W208	ID-RFO-335T	335	26.2	26.2	0.0	2.5	0.0	23.7	0.0	0.0
IN-W234	ID-RFO-335	335	16.5	16.5	0.0	0.0	0.0	16.5	0.0	0.0
IN-W197	ID-RFO-336T	336	778.3	778.3	0.0	20.4	0.0	758.0	0.0	0.0
IN-W160	ID-RFO-336	336	1452.4	1452.4	0.0	0.0	0.0	1452.4	0.0	0.0
IN-W198	ID-RFO-337T	337	170.4	170.4	0.0	37.5	0.0	132.9	0.0	0.0
IN-W217	ID-RFO-337	337	352.9	352.9	0.0	0.0	0.0	352.9	0.0	0.0
IN-W209	ID-RFO-338T	338	60.2	60.2	0.0	3.4	0.0	56.8	0.0	0.0
IN-W235	ID-RFO-338	338	240.7	240.7	0.0	0.0	0.0	240.7	0.0	0.0
IN-W252	ID-RFO-339T	339	160.2	160.2	0.0	13.4	0.0	0.0	0.0	146.9
IN-W253	ID-RFO-339	339	4.9	4.9	0.0	0.0	0.0	0.3	0.0	4.6
IN-W210	ID-RFO-360T	360	3.4	3.4	0.0	0.0	0.0	3.4	0.0	0.0
IN-W237	ID-RFO-360	360	50.4	50.4	0.0	0.0	0.0	50.4	0.0	0.0
IN-W373	ID-RFO-361TN	361	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0
IN-W366	ID-RFO-370TN	370	2.5	2.5	0.0	0.0	0.0	2.5	0.0	0.0
IN-X008	ID-RFO-370N	370	4.9	4.9	0.0	0.0	0.0	4.9	0.0	0.0
IN-W161	ID-RFO-371T	371	111.4	111.4	0.0	16.7	0.0	94.6	0.0	0.0
IN-W162	ID-RFO-371	371	183.5	183.5	0.0	0.0	0.0	183.5	0.0	0.0
IN-W266	ID-RFO-372N	372	0.8	0.8	0.0	0.0	0.0	0.8	0.0	0.0
IN-W267	ID-RFO-372TN	372	3.0	3.0	0.0	0.0	0.0	3.0	0.0	0.0
IN-W265	ID-RFO-374T	374	53.2	53.2	0.0	9.5	0.0	43.6	0.0	0.0
IN-W264	ID-RFO-374	374	368.0	368.0	0.0	0.0	0.0	368.0	0.0	0.0
IN-W163	ID-RFO-375T	375	0.8	0.8	0.0	0.0	0.0	0.8	0.0	0.0
IN-W223	ID-RFO-375	375	3.2	3.2	0.0	0.0	0.0	3.2	0.0	0.0
IN-W211	ID-RFO-376T	376	460.2	460.2	0.0	215.4	0.0	244.8	0.0	0.0
IN-W238	ID-RFO-376	376	94.7	94.7	0.0	0.0	0.0	94.7	0.0	0.0
IN-W365	ID-RFO-391TN	391	4.7	4.7	0.0	0.0	0.0	4.7	0.0	0.0
IN-W364	ID-RFO-392TN	392	1.5	1.5	0.0	0.0	0.0	1.5	0.0	0.0

TABLE AD-3

DETAILS OF EDTA CALCULATIONS
(BASIS: ALL ROCKY FLATS WASTE AT INEL)

FFCA_ID	WS_ID	CC	Total Vol	CH Vol	RH Vol	CH_Direct Ship	RH_Direct Ship	Vitrified	Amalg	Macro
IN-W348	ID-RFO-393TN	393	10.0	10.0	0.0	3.8	0.0	6.1	0.0	0.0
IN-W157	ID-RFO-004T	4	226.8	226.8	0.0	54.3	0.0	172.3	0.0	0.2
IN-W229	ID-RFO-004	4	103.9	103.9	0.0	0.0	0.0	103.8	0.0	0.1
IN-W311	ID-RFO-409T	409	6.6	6.6	0.0	2.3	0.0	4.2	0.0	0.0
IN-W356	ID-RFO-410TN	410	4.7	4.7	0.0	0.0	0.0	4.7	0.0	0.0
IN-W355	ID-RFO-411TN	411	1.3	1.3	0.0	0.0	0.0	1.3	0.0	0.0
IN-W354	ID-RFO-412TN	412	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0
IN-W314	ID-RFO-414T	414	1.1	1.1	0.0	0.0	0.0	1.1	0.0	0.0
IN-W371	ID-RFO-416TN	416	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0
IN-W363	ID-RFO-420TN	420	2.3	2.3	0.0	0.0	0.0	2.3	0.0	0.0
IN-W362	ID-RFO-421TN	421	21.4	21.4	0.0	0.0	0.0	21.4	0.0	0.0
IN-W361	ID-RFO-422TN	422	5.1	5.1	0.0	0.0	0.0	5.1	0.0	0.0
IN-W357	ID-RFO-425TN	425	0.4	0.4	0.0	0.0	0.0	0.4	0.0	0.0
IN-X009	ID-RFO-425N	425	1.3	1.3	0.0	0.0	0.0	1.3	0.0	0.0
IN-W320	ID-RFO-430	430	1.9	1.9	0.0	0.0	0.0	1.9	0.0	0.0
IN-W321	ID-RFO-430T	430	4.2	4.2	0.0	0.0	0.0	4.2	0.0	0.0
IN-W318	ID-RFO-431	431	0.4	0.4	0.0	0.0	0.0	0.4	0.0	0.0
IN-W319	ID-RFO-431T	431	0.8	0.8	0.0	0.0	0.0	0.8	0.0	0.0
IN-W317	ID-RFO-432T	432	51.5	51.5	0.0	12.9	0.0	38.6	0.0	0.0
IN-W316	ID-RFO-432	432	8.9	8.9	0.0	0.0	0.0	8.9	0.0	0.0
IN-W243	ID-RFO-440T	440	247.7	247.7	0.0	56.2	0.0	191.5	0.0	0.0
IN-W242	ID-RFO-440	440	95.4	95.4	0.0	0.0	0.0	95.4	0.0	0.0
IN-W244	ID-RFO-441	441	164.7	164.7	0.0	0.0	0.0	164.7	0.0	0.0
IN-W245	ID-RFO-441T	441	169.0	169.0	0.0	0.0	0.0	169.0	0.0	0.0
IN-W247	ID-RFO-442T	442	199.5	199.5	0.0	79.3	0.0	120.2	0.0	0.0
IN-W248	ID-RFO-442	442	138.4	138.4	0.0	0.0	0.0	138.4	0.0	0.0
IN-W199	ID-RFO-460T	460	1.3	1.3	0.0	0.0	0.0	1.3	0.0	0.0
IN-W254	ID-RFO-463T	463	10.2	10.2	0.0	0.0	0.0	0.6	0.0	9.5
IN-W255	ID-RFO-463	463	1.1	1.1	0.0	0.0	0.0	0.1	0.0	1.0
IN-W183	ID-RFO-464	464	3.8	3.8	0.0	0.0	0.0	3.1	0.0	0.8
IN-W189	ID-RFO-464T	464	6.1	6.1	0.0	0.0	0.0	4.9	0.0	1.2
IN-W296	ID-RFO-480T	480	5243.4	5243.4	0.0	85.2	0.0	5132.0	0.0	26.2
IN-W295	ID-RFO-480	480	6688.0	6688.0	0.0	0.0	0.0	6654.6	0.0	33.4
IN-W294	ID-RFO-481T	481	443.2	443.2	0.0	11.4	0.0	428.3	0.0	3.5
IN-W293	ID-RFO-481	481	164.3	164.3	0.0	0.0	0.0	163.1	0.0	1.3
IN-W212	ID-RFO-490T	490	2512.4	2512.4	0.0	3.4	0.0	2509.0	0.0	0.0
IN-W239	ID-RFO-490	490	873.4	873.4	0.0	0.0	0.0	873.4	0.0	0.0
IN-W313	ID-RFO-005	5	13.6	13.6	0.0	0.0	0.0	13.6	0.0	0.0
IN-W315	ID-RFO-005T	5	0.6	0.6	0.0	0.0	0.0	0.6	0.0	0.0
IN-W218	ID-RFO-007T	7	461.5	461.5	0.0	461.5	0.0	0.0	0.0	0.0
IN-W192	ID-RFO-007	7	464.3	464.3	0.0	0.0	0.0	464.3	0.0	0.0

TABLE AD-3

DETAILS OF EDTA CALCULATIONS
(BASIS: ALL ROCKY FLATS WASTE AT INEL)

FFCA_ID	WS_ID	CC	Total Vol	CH Vol	RH Vol	CH_Direct Ship	RH_Direct Ship	Vitrified	Amalg	Macro
IN-W164	ID-RFO-700T	700	1.9	1.9	0.0	0.6	0.0	1.3	0.0	0.0
IN-W270	ID-RFO-090	90	28.6	28.6	0.0	0.0	0.0	28.6	0.0	0.0
IN-W205	ID-RFO-900T	900	0.8	0.8	0.0	0.4	0.0	0.0	0.0	0.4
IN-W227	ID-RFO-900	900	92.4	92.4	0.0	0.0	0.0	92.4	0.0	0.0
IN-X001	ID-RFO-095N	95	4.9	4.9	0.0	0.0	0.0	4.9	0.0	0.0
IN-W277	ID-RFO-950	950	1065.0	1065.0	0.0	0.0	0.0	1006.6	0.0	58.4
IN-W278	ID-RFO-950T	950	14.0	14.0	0.0	0.0	0.0	13.2	0.0	0.8
IN-W374	ID-RFO-960TN	960	9.8	9.8	0.0	0.2	0.0	9.5	0.0	0.0
IN-X003	ID-RFO-960N	960	681.4	681.4	0.0	0.0	0.0	681.4	0.0	0.0
IN-W202	ID-RFO-970T	970	109.9	109.9	0.0	0.0	0.0	109.9	0.0	0.0
IN-W224	ID-RFO-970	970	91.3	91.3	0.0	0.0	0.0	91.3	0.0	0.0
IN-W180	ID-RFO-976	976	63.8	63.8	0.0	0.0	0.0	63.8	0.0	0.0
IN-W188	ID-RFO-976T	976	1.1	1.1	0.0	0.0	0.0	1.1	0.0	0.0
IN-W181	ID-RFO-978T	978	9.5	9.5	0.0	0.0	0.0	9.5	0.0	0.0
IN-W182	ID-RFO-978	978	25.4	25.4	0.0	0.0	0.0	25.4	0.0	0.0
IN-W187	ID-RFO-980T	980	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0
IN-W261	ID-RFO-990	990	99.6	99.6	0.0	0.0	0.0	99.6	0.0	0.0
IN-W375	ID-RFO-995TN	995	19.3	19.3	0.0	0.0	0.0	19.3	0.0	0.0
IN-X002	ID-RFO-995N	995	68.8	68.8	0.0	0.0	0.0	68.8	0.0	0.0
IN-W306	ID-RFO-9999T	9999	4492.5	4489.3	3.2	0.0	3.2	4354.5	0.0	134.8
IN-W352	ID-RFO-9999	9999	2993.7	2991.5	2.1	0.0	2.1	2901.7	0.0	89.8
	TOTALS		58402.2	58396.9	5.3	2626.5	5.3	55152.7	15.7	601.9

TOTAL EDTA IN RF WASTE AT INEL ---> 21.3 kg
(1.15 kg/yr for 18.5 years)
PERCENT VITRIFIED ---------> 94.4%
AMOUNT VITRIFIED (94.44% of 21.3 kg)--> 20.1 kg
AMOUNT IN UNTREATED INEL WASTE----> 1.2 kg

TOTAL EDTA IN RF WASTE AT RF -------> 1.7 kg
(1.15 kg/yr for 1.5 years)

NEW EDTA ESTIMATE -----> 2.9 kg

APPENDIX B - 6

M

United States Government | Department of Energy

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: FEB 20 1996

REPLY TO ATTN OF: NTP:DW:96-0655

SUBJECT: Preliminary Estimate for SNL/NM Performance Assessment Calculations of Nitrate, Sulfate, and Phosphate Content in Transuranic Solidified Wastes Destined for Disposal in WIPP

TO: Dr. Les Shephard, SNL/NM

Attached is a copy of the report containing the preliminary estimates for the nitrate, sulfate, and phosphate contents in solidified transuranic (TRU) wastes destined for the Waste Isolation Pilot Plant (WIPP). This information was requested by your staff from the Transuranic (TRU) Waste Baseline Inventory Report (TWBIR) team in support of the Performance Assessment efforts.

Briefly, the enclosed document provides estimates of the average density and total mass of nitrate and sulfate in TRU waste to be disposed of at the WIPP. These values have been estimated based on data obtained from the TRU waste generator/storage sites during the TWBIR preparation process. From these data, the average densities scaled over the entire WIPP disposal inventory are 9.2 kg/m^3 for nitrate and 3.6 kg/m^3 for sulfate. The total masses scaled over the entire WIPP disposal inventory are 1.6E+06 kg for nitrate and 6.3E+05 kg for sulfate. These densities and masses are for combined CH and RH TRU waste inventories. No value for phosphate has been proposed due to the lack of sufficient information. Trace quantities of inorganic phosphate might be expected in some of the sludges and solidification agents, but no supporting analytical data are available to support a specific value. This is discussed in the enclosed report.

If you have any questions concerning the attached information, please contact Mr. Russ Bisping of my staff at (505) 234-7446.

Russ Bisping for

Don Watkins
Manager
National TRU Program

Attachment

Printed on recycled paper

cc w/enclosure:
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Preliminary Estimates of Nitrate, Sulfate, and Phosphate Content in Transuranic Solidified Wastes

I. INTRODUCTION

This report provides preliminary estimates of the amount of nitrate, sulfate, and phosphate expected to be in the transuranic (TRU) inventory that will be transported to and disposal of at the Waste Isolation Pilot Plant (WIPP) (Appendix B: DOE, 1995). Tables 1 and 2 of this report provide the volumetric basis for the nitrate and sulphate estimates, and Tables 3, 4, and 5 provide the calculational methodology. No quantifiable sources of phosphate have been identified in the Inorganic Solidified final waste forms at present. Trace quantities might be expected in some of the sludges and solidification agents, but no data currently exist to support this.

II. BACKGROUND

These **PRELIMINARY** estimates are made based on the following:

- Values presented are those expected for the final waste forms to be disposed of at WIPP.

- Information has been requested from sites based on Solidified Inorganic and Solidified Organic waste forms only, and is the best available data from the TRU waste generator/storage sites:

  - The main source of nitrate is anticipated to be from the Solidified Inorganic waste forms, which in most cases, are sludges produced from the neutralization/solidification of nitric acid-based solutions used at the TRU waste generator/storage sites. Nitrates are very soluble in aqueous solutions and generally do not produce precipitates in the sludges. The nitrates are generally thought to be present as ions sorbed on precipitates or as interstitial solution trapped in the precipitated sludges prior to solidification.

    Minor amounts of nitrate, as evaporites, are anticipated in the debris waste forms that will be acceptable for WIPP disposal, but insufficient data are available to estimate the amount of such TRU waste at this time.

  - The main sources of sulfates are anticipated to be: 1) chemicals (e.g. iron sulfates) added to the inorganic solutions at the time of flocculation and precipitation of sludges, and 2) the use of Envirostone [a gypsum ($CaSO_4$) based solidification material] for solidification of inorganic and/or organic solutions/sludges at some TRU waste generator/storage sites.

No quantifiable sources of phosphate have been identified in the Solidified Inorganic final waste forms at present. Trace quantities might be expected in some of the sludges and solidification agents, but no supporting analytical data are available. The quantities of inorganic phosphate are anticipated to be low in inorganic sludges based on process histories at TRU waste sites.

Analytical data in Attachment 2 provide only "less than 0.0025" weight percent values for phosphate, which are similar to the 0.001 weight percent estimate provided by LANL in Attachment 1. These values are too low to make any reliable estimate of phosphate in TRU waste, but indicate that the quantities will be very small, compared with the nitrate and sulfate values reported. The phosphate value of "40%" reported on page A2-7 is an analytical error. Based on process knowledge and the lack of cations to support such a large value of phosphate in that particular analysis, no such value is possible.

III. GENERAL VOLUME CALCULATIONS

A. Nitrate

1. Nitrate Assumptions

The amount of nitrate is estimated on the basis of the volumes of Solidified Inorganics, which are calculated as explained below:

- Table 1 lists (in Column 2) the final waste form volumes of Solidified Inorganics for Contact-Handled (CH) TRU and Remote Handled (RH) TRU from Figures 3-9 and 3-16 of Revision 2 of the TWBIR (DOE, 1995) for the anticipated WIPP inventory (stored plus projected volumes until 2022).

- Footnotes in Columns 3 and 4 indicate why certain volumes of waste have been eliminated from further consideration in the calculations:

  - Footnote 1 eliminates those volumes of chemically precipitated Solidified Inorganics for which no nitrate estimates in the waste are available. An estimate of the nitrate contribution from these Solidified Inorganics will be accounted for in the scaling process.

  - Footnote 2 eliminates the volume of Solidified Inorganics from SRS from further consideration because it is a "vitrified" waste form which should not contain any significant amount of nitrates due to the thermal treatment proposed for that waste form.

- Footnote 3 eliminates from further consideration those volumes of Solidified Inorganics which represent non-precipitated particulates (e.g., incinerator ash, graphite fines, etc.) which have been cemented to meet the WIPP WAC; nitrates are not expected to be present in these particulates.

- Rocky Flats Environmental Technology Site (RFETS) and Los Alamos National Laboratory (LANL) have provided analytical data/estimates for nitrate in Solidified Inorganics. The RFETS data has been used also for the RFETS waste stored at INEL.

2. Nitrate Mass Calculations

Table 3 contains in Column 1 a list of those waste streams that contain the volume of waste from each TRU waste generator/storage site listed in Column 4 of Table 1. The additional data provided are:

- Column 2 lists the Item Description Codes (IDCs) for waste streams produced at RFETS and/or stored at INEL. The RF111 designation is for Content Code 111 from RFETS, where the IDC is not specified.

- Column 3 lists the stored + projected volume for each waste stream.

- Column 4 lists the sum of the waste material parameters (WMP) for each waste stream from the individual Waste Stream Profiles in Revision 2 of the TWBIR. Exceptions to this rule are listed in footnotes in Table 3.

- Column 5 lists the mass of the waste for each waste stream which is the product of multiplying Columns 3 and 4.

- Column 6 lists the values of nitrate used for each waste stream. The sources of the these values are:

  - For RFETS, the nitrate values are from Appendix I of Revision 2 of the TWBIR. The 8% values for IDC 001 has also been applied to IDCs 002 and 007 at both RFETS and INEL. All these IDCs represent "older" methods of solidification where the sludges contain portland cement mainly as a sorbent interlayered with sludge which did not contain diatomaceous earth (see Clements, 1982 for drawings).

The 4% value listed in Appendix I of the TWBIR for IDC 807 represents a "newer" method of solidification where diatomaceous earth is used as a vacuum filtration agent and portland cement is mixed with the resulting sludge to form a "monolithic" solidified final waste form. The dilution with diatomaceous earth and additional portland cement lowers the overall nitrate value of the final waste form.

- For waste stream IN-W315.601, Clements (1982) indicates that the waste stream is made up of approximately 60% $NaNO_3$ and 30% KNO_3 (assumed weight percents). This calculates as 62% nitrate.

- Attachment 1 represents a memo from LANL that provides estimates for nitrates in the waste streams. Note that the Envirostone process only accounts for a small percentage of stored volume for 3 of the waste streams. The values quoted in Column 6 are based on the small percentage of Envirostone solidification agent in the overall waste streams.

- Column 7 represents the mass of nitrates in kg which is the product of multiplying Columns 5 and 6.

B. Sulfate

1. Sulfate Assumptions

- To determine the amount of solidified wastes that need to be considered for calculating the sulfate content of the WIPP inventory (Table 2), the volume of Solidified Organics must be added to the volume of Solidified Inorganics from Table 1:

  - The Solidified Organics from Figures 3-10 and 3-17 of Revision 2 of the TWBIR (DOE, 1995) have been added to Table 1 (above) to produce Table 2

  - LANL has used an Envirostone (gypsum-based) process for solidification of inorganic sludges in the past (approximately 9% of 4888 m^3 in storage at LANL) but plan to eliminate the process in the future and only use portland-based cement for solidification (as was used in the past prior to usage of the Envirostone)

- Since the mid 1980's, RFETS has used an Envirostone solidification process for their organic sludges. Therefore, some of their waste in storage and projected contain large amounts of sulfate, as well as some Solidified Organics in storage at INEL.

- LLNL is the only other TRU waste site known to be using Envirostone for the solidification of organic liquids/sludges (approximately 7 m^3 stored/projected).

2. Sulfate Mass Calculations

The sulfate calculations presents in Table 4 follow the same format as the nitrate calculations in Table 3. The origin of the values used for sulfate in the RFETS, INEL, LLNL, and LANL waste streams are summarized below:

- **RFETS/INEL**
  - The 0.11% sulfate value is an average of the three analyses marked "7412 Sludge" in Attachment 2 which are applied to IDCs 001 and 002, and at half that value for IDCs 800 and 803 (as explained in the nitrate section).

  - The sulfate value of 0.02% is derived from the Attachment 2 analysis marked "374 Waste Sludge - Dried Sludge". This value is used for IDC 007 and at half value for IDC 807.

  - The sulfate value (25.1%) for the Envirostone solidification of organic sludges (IDC 801) is derived from an average value in Attachment 3, which represents guidelines for mixing constituents together for IDC 801 and IDC 700 (at INEL only in storage).

- **LANL**
  - The values for sulfate quoted in Column 7 are derived from data provided in Attachment 1. As with the nitrate calculations, the percentage of waste in each waste stream solidified by Envirostone versus portland cement is used to calculated the overall sulfate value for each waste stream.

- **LLNL**
  - No value for sulfate was requested from LLNL for their one Solidified Organic waste stream. The same value for Envirostone-solidified waste at RFETS (25.1%) was assumed for the LLNL waste stream.

IV. SUMMARY CALCULATIONS

Table 5 presents the summary calculations for determining the density (kg/m^3) of nitrate and sulfate in the overall WIPP inventory and scaling of the density to take into account those chemically precipitated waste streams for which data was not available. SNL/NM should use the scaled densities for their calculations. The last column in Table 5 provides the estimated mass of nitrate and sulfate if the design capacity of WIPP for CH-TRU and RH-TRU are fully utilized based on the scaled densities for nitrate and sulfate.

V. REFERENCES

Clements, 1982, "Content Code Assessments for INEL Contact-Handled Stored Transuranic Wastes," WM-F1-82-021, Idaho Falls, Idaho.

U. S. Department of Energy, 1995, "Transuranic Waste Baseline Inventory Report (Revision 2)," DOE/CAO-95-1121, Carlsbad, New Mexico.

TABLE 1. TRU VOLUMES FOR NITRATE CALCULATIONS
(SOLIDIFIED INORGANICS ONLY)

TRU WASTE SITE	TOTAL VOLUME (STORED + PROJECTED) (m^3)	VOLUMES WITH NITRATE DATA OR WITH PARTICULATES (m^3)	VOLUMES OF SLUDGES WITH NITRATE DATA (m^3)
Hanford (CH)	23.39	(TO BE SCALED)[1]	(TO BE SCALED)[1]
ANL-E (CH)	5.20	(TO BE SCALED)[1]	(TO BE SCALED)[1]
NTS (CH)	5.67	(TO BE SCALED)[1]	(TO BE SCALED)[1]
SRS (CH)	1369.8	1369.8	[2]
RFETS (CH)	1423.01	1389.52	229.63[3]
INEL (CH)	4344.44	3900.39	3598.84[3]
Mound (CH)	6.03	(TO BE SCALED)[1]	(TO BE SCALED)[1]
LANL(CH)	6922.02	6922.02	6922.02
AL (CH)	0.42	(TO BE SCALED)[1]	(TO BE SCALED)[1]
LLNL (CH)	20.18	(TO BE SCALED)[1]	(TO BE SCALED)[1]
CH TOTAL	14120.15	13581.73	10750.49
ORNL (RH)	1243.33	(TO BE SCALED)[1]	(TO BE SCALED)[1]
INEL (RH)	65.27	65.27	65.27
ANL-E (RH)	30.26	(TO BE SCALED)[1]	(TO BE SCALED)[1]
RH TOTAL	1338.86	65.27	65.27
TRU TOTAL	15459.01	13647.0	10815.76

1 Eliminates those volumes of chemically precipitated solidified inorganics for which no nitrate estimates in the waste are available. An estimate of the nitrate contribution from these solidified inorganics will be accounted for in the scaling process.

2 Eliminates the volume of Solidified Inorganics from SRS from further consideration because it is a "vitrified" waste form which should not contain any significant amount of nitrates due to the thermal treatment proposed for that waste form.

3 Eliminates from further consideration those volumes of Solidified Inorganics which represent non-precipitated particulates (e.g., incinerator ash, graphite fines, etc.) which have been cemented to meet the WIPP WAC and nitrates are not expected to be present in the particulates.

TABLE 2. TRU VOLUMES FOR SULFATE CALCULATIONS

TRU WASTE SITE	FINAL WASTE FORM	TOTAL VOLUME (m^3)	VOLUME WITH SULFATE DATA (m^3)
Hanford (CH)	Solidif. Inorg.	23.39	(TO BE SCALED)[1]
ANL-E (CH)	Solidif. Inorg.	5.20	(TO BE SCALED)[1]
NTS (CH)	Solidif. Inorg.	5.67	(TO BE SCALED)[1]
SRS (CH)	Solidif. Inorg.	1369.8	(TO BE SCALED)[1]
RFETS (CH)	Solidif. Inorg.	1423.01	229.63
INEL (CH)	Solidif. Inorg.	4344.44	3598.42
Mound (CH)	Solidif. Inorg.	6.03	(T BE SCALED)[1]
LANL (CH)	Solidif. Inorg.	6922.02	6922.02
AL (CH)	Solidif. Inorg.	0.42	(TO BE SCALED)[1]
LLNL (CH)	Solidif. Inorg.	20.18	(TO BE SCALED)[1]
RFETS (CH)	Solidif. Org.	140.93	108.99
Hanford (CH)	Solidif. Org.	76.13	(TO BE SCALED)[1]
LANL (CH)	Solidif. Org.	30.58	(TO BE SCALED)[1]
INEL (CH)	Solidif. Org.	789.67	2.55
ANL-E (CH)	Solidif. Org.	0.21	(TO BE SCALED)[1]
LLNL (CH)	Solidif. Org.	6.86	6.86
CH TOTAL		15164.53	10868.93
ORNL (RH)	Solidif. Inorg.	1243.33	(TO BE SCALED)[1]
INEL (RH)	Solidif. Inorg.	65.27	65.27
ANL-E (RH)	Solidif. Inorg.	30.26	(TO BE SCALED)[1]
INEL (RH)	Solidif. Org.	3.56	(TO BE SCALED)[1]
RH TOTAL		1342.42	65.27
TRU TOTAL		16506.95	10933.74

[1] No sulfate data available from these sites for any waste streams.

TABLE 3 : NITRATE CALCULATION

Waste Stream	IDCs	Volume (m3)	Sum WMP (kg/m3)	Mass Waste (kg)	% Nitrate (weight%)	Nitrate (kg)
RF-MT0001	001	3.74	781.9	2924.31	8	233.94
RF-MT0800	800	104.42	775.2	80946.38	4	3237.86
RF-MT0803	803	4.99	635.2	3169.65	4	126.79
RF-MT0807	807	115.02	819.6	94270.39	4	3770.82
RF-T010	800/803/807	0.62	796.1	493.58	4	19.74
TOTAL RFETS		228.79		181804.31		7389.14
IN-W216.875	001/002	1478.88	819.6	1212090.05	8	96967.20
IN-W216.877	001/002	43.91	571.4	25090.17	8	2007.21
IN-W216.98	001/002	555.65	726.6	403735.29	8	32298.82
IN-W218.909*	007	101.91	544.3	55469.61	8	4437.57
IN-W220.114	RF111	122.80	725.6	89103.68	4	3564.15
IN-W220.925	RF111	443.04	819.6	363115.58	4	14524.62
IN-W228.101	002	287.33	317.3	91169.81	8	7293.58
IN-W228.883	002	608.82	358.0	217957.56	8	17436.60
IN-W228.886	002	21.36	249.6	5331.46	8	426.52
IN-W315.601**	005	0.42	664.0	278.88	62	172.91
TOTAL INEL		3664.12		2463342.09		179129.19
LA-M002		3606.81	1296.0	4674425.76	8.8	411349.47
LA-T006		86.53	1004.8	86945.34	8.8	7651.19
LA-W003		1836.58	1339.3	2459731.59	8.7	213996.65
LA-W006		1392.10	1004.8	1398782.08	8.7	121694.04
TOTAL LANL		6922.02		8619884.78		754691.35
TOTAL TRU		10814.93		11265031.18		941209.68

* INEL did not report waste material parameters for this waste stream. The value for this IDC at RFETS was assumed.

** This waste stream was reported in Clements (1983) to be 60% $NaNO_3$ and 30% KNO_3. The weight of the waste for this IDC was used from Clements (1983), since no value was quoted in Revision 2 of the TWBIR.

TABLE 4 : SULFATE CALCULATION

Waste Stream	IDCs	Waste Form	Volume (m3)	Sum WMP (kg/m3)	Mass Waste (kg)	% sulfate (weight%)	Sulfate (kg)
RF-MT0001	001	Sol. Inorg.	3.74	781.9	2924.31	0.11	3.22
RF-MT007	007	Sol. Inorg.	0.83	544.3	452.86	0.02	0.09
RF-MT0800	800	Sol. Inorg.	104.42	775.2	80946.38	0.055	44.52
RF-MT0801	801	Sol. Org.	108.99	877.1	95595.13	25.1	23994.38
RF-MT0803	803	Sol. Inorg.	4.99	635.2	3169.65	0.055	1.74
RF-MT0807	807	Sol. Inorg.	115.02	819.6	94270.39	0.01	9.43
RF-T010	800/803/807	Sol. Inorg.	0.62	796.1	493.58	0.055	0.27
TOTAL RFETS			338.61		277852.30		24053.65
IN-W164.1060*	700	Sol. Org.	1.66	877.1	1455.99	25.1	365.45
IN-W164.153*	700	Sol. Org.	0.89	877.1	780.62	25.1	195.94
IN-W216.875	001/002	Sol. Inorg.	1478.88	819.6	1212090.05	0.11	1333.30
IN-W216.877	001/002	Sol. Inorg.	43.91	571.4	25090.17	0.11	27.60
IN-W216.98	001/002	Sol. Inorg.	555.65	726.6	403735.29	0.11	444.11
IN-W218.909*	007	Sol. Inorg.	101.91	544.3	55469.61	0.02	11.09
IN-W220.114	RF111	Sol. Inorg.	122.80	725.6	89103.68	0.055	49.01
IN-W220.925	RF111	Sol. Inorg.	443.04	819.6	363115.58	0.055	199.71
IN-W228.101	002	Sol. Inorg.	287.33	317.3	91169.81	0.11	100.29
IN-W228.883	002	Sol. Inorg.	608.82	358.0	217957.56	0.11	239.75
IN-W228.886	002	Sol. Inorg.	21.36	249.6	5331.46	0.11	5.86
TOTAL INEL			3666.25		2465299.82		2972.11
LA-M002		Sol. Inorg.	3606.81	1296.0	4674425.76	1.4	65441.96
LA-T006		Sol. Inorg.	86.53	1004.8	86945.34	1.7	1478.07
LA-W003		Sol. Inorg.	1836.58	1339.3	2459731.59	5.5	135285.24
LA-W006		Sol. Inorg.	1392.10	1004.8	1398782.08	8.1	113301.35
TOTAL LANL			6922.02		8619884.78		315506.62
LL-W019**		Sol. Org	6.86	268.0	1838.48	25.1	461.46
TOTAL LLNL			6.86		1838.48		461.46
TOTAL TRU			10933.74		11364875.38		342993.84

* INEL did not report waste material parameters for this waste stream. The value for this IDC at RFETS was assumed.

** Sulfate value for LLNL Solidified Organics was assumed to be the same as for RFETS Solidified Organics (IDC 801).

TABLE 5. NITRATE/SULFATE DENSITY CALCULATIONS

Constituent	Volume Solidified Waste (m3)	Mass Solidified Waste (kg)	Mass Constituent (kg)	Anticipated Waste Volume (m3)	WIPP Average Density of Constituents (kg/m3)	% Sludge Used in Calculations (%)	WIPP Average Scaled Density of Constituents (kg/m3)	Total Mass of Constituent for WIPP Design Capacity (kg)
Footnotes	1	2	3	4	5	6	7	8
Nitrate	10815.76	11265484	941245.9	1.19E+05	7.91	85.6	9.24	1.62E+06
Sulfate	10933.74	11364875	342993.8	1.19E+05	2.88	80	3.60	6.33E+05

1. "Total TRU" Volumes for Tables 3 and 4.
2. "Total TRU" Mass from Tables 3 and 4.
3. "Total TRU" Nitrate/Sulfate from Tables 3 and 4.
4. Anticipated Volume of CH-and RH-TRU Waste (stored + projected to 2022) from Table 3-1 in Rev. 2 of TWBIR. RH-TRU anticipated volume is limited to 7080 m3, the design capacity of WIPP.
5. "Mass of Constituent" column divided by "Anticipated Waste Volume" column.
6. Calculated from Table 1 "Total TRU" data. Nitrate = subtract 10815.76 from 13647 to yield particulate waste (2831.24). Subtract 2831.24 from 15459.01 to get total chemically precipitated waste (12627.77). Divide 10815.76 by 12627.77 and multiply by 100%. Sulfate is calculated in a similar manner.
7. Divide "Density of Constituent" by "% Sludge Used in Calculations."
8. Multiply "Scaled Density of Constituent" by 175,600 m3 (design capacity of WIPP).

TELEPHONE CONFERENCE SUMMARY

Parties: Paul Drez, DEA/CTAC
Davis Christenson, LANL

For Solidified Inorganics waste stream LA-T006; LA-W003; LA-W006; and LA-M002 assume the following composition for final waste form:

Envirostone-based solidified waste forms:

Nitrate 8.2%
Sulfate 38.5%
Phosphate 0.001%

Portland Cement-based solidified waste forms:

Nitrate 8.8%
Sulfate 1.4%
Phosphate 0.001%

LA-M002 has only used portland cement; the other three have use portland cement until 1985 and then Envirostone:

	Stored Wasted		Projected Waste	
WS#	Portland	Envirostone	Portland	Envirostone
LA-T006	84.5%	15.5%	100%	0%
LA-W006	54.65%	45.35%	100%	0%
LA-W003	84.5%	15.5%	100%	0%
LA-M002	100%	0%	100%	0%

ATTACHMENT 2

D61472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80
7412 Sludge PAGE 1

SAMPLE-ID	00-008395	DOC NUMBER	97038000
ENTRY DATE	11-01-79	ACCOUNT CHARGED	8037
COMPLETION DATE	04-10-80	BUILDING	559
		CLASS	SSPI
CUSTOMER	P. T. GODESAIBOIS		

** ATOMIC ABSORPTION SPECTROMETRY RESULTS

CA		86512.	PPM(W)	FE		61597.	PPM(W)
GA	<	50.	PPM(W)	K		6162.	PPM(W)
NA		65501.	PPM(W)	SI		3659.	PPM(W)

** PLUTONIUM CHEMISTRY LABORATORY RESULTS

CL(-)		0.16	%(W)	CO3=		0.36	%(W)
F(-)		57.	PPM(W)	H2O		61.0	%(W)
NO3		4.2	%(W)	PO4	<	0.0025	%(W)
SO4		0.085	%(W)				

** SEMI-QUANTATIVE EMISSION SPEC RESULTS

AG		50.	PPM(W)	AL		20000.	PPM(W)
AS	<	50.	PPM(W)	B		100.	PPM(W)
BA		100.	PPM(W)	BE		50.	PPM(W)
BI	<	50.	PPM(W)	CA	>	200000.	PPM(W)
CD	<	1000.	PPM(W)	CE	<	500.	PPM(W)
CO	<	50.	PPM(W)	CR		500.	PPM(W)
CS	<	1000.	PPM(W)	CU		4000.	PPM(W)
FE		50000.	PPM(W)	GE	<	10.	PPM(W)
HG	<	10.	PPM(W)	K		40000.	PPM(W)
LI	<	1000.	PPM(W)	MG		10000.	PPM(W)
MN		500.	PPM(W)	MO		500.	PPM(W)
NA		50000.	PPM(W)	NB	<	50.	PPM(W)
NI		2000.	PPM(W)	P	<	1000.	PPM(W)
PB	<	50.	PPM(W)	RB	<	500.	PPM(W)
SB	<	50.	PPM(W)	SI		100000.	PPM(W)
SN	<	10.	PPM(W)	SR		10000.	PPM(W)
TA	<	50.	PPM(W)	TE	<	100.	PPM(W)
TH	<	500.	PPM(W)	TI		500.	PPM(W)
TL	<	500.	PPM(W)	U	<	500.	PPM(W)
V	<	5.	PPM(W)	W	<	1000.	PPM(W)
ZN	<	500.	PPM(W)	ZR	<	50.	PPM(W)

** RADIOCHEMISTRY LABORATORY RESULTS

AM 0.0000317 G/G

061472-01 LABORATORY SAMPLE RESULTS DATE 04/10/90

SAMPLE-ID 00-008395

** RADIOCHEMISTRY LABORATORY RESULTS (CONTINUED)

PU	0.0000223	G/G	U	0.0017	G/G

AUTHORIZED SIGNATURE

Howell

061472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80
7412 Sludge PAGE 1

SAMPLE-ID	00-008396	DJO NUMBER	97038000
ENTRY DATE	11-01-79	ACCOUNT CHARGED	8037
COMPLETION DATE	04-10-80	BUILDING	559
		CLASS	SSP1
CUSTOMER	P. T. GODESAIBOIS		

** ATOMIC ABSORPTION SPECTROMETRY RESULTS

CA		194587.	PPM(W)	FE		47915.	PPM(W)
GA	<	50.	PPM(W)	MG		9581.	PPM(W)
NA		105060.	PPM(W)	SI		158.	PPM(W)

** PLUTONIUM CHEMISTRY LABORATORY RESULTS

CL(-)		0.15	%(W)	CO3=		0.74	%(W)
F(-)		101.	PPM(W)	H2O		55.0	%(W)
NO3		8.0	%(W)	PO4	<	0.0025	%(W)
SO4		0.096	%(W)				

** SEMI-QUANTATIVE EMISSION SPEC RESULTS

AG		10.	PPM(W)	AL		10000.	PPM(W)
AS	<	50.	PPM(W)	B		100.	PPM(W)
BA		500.	PPM(W)	BE		1000.	PPM(W)
BI	<	50.	PPM(W)	CA	>	200000.	PPM(W)
CD	<	1000.	PPM(W)	CE	<	500.	PPM(W)
CO	<	50.	PPM(W)	CR		500.	PPM(W)
CS	<	1000.	PPM(W)	CU		500.	PPM(W)
FE		50000.	PPM(W)	GE	<	10.	PPM(W)
HG	<	10.	PPM(W)	K		40000.	PPM(W)
LI	<	1000.	PPM(W)	MG		50000.	PPM(W)
MN		500.	PPM(W)	MO		200.	PPM(W)
NA		50000.	PPM(W)	NB	<	50.	PPM(W)
NI		1000.	PPM(W)	P	<	1000.	PPM(W)
PB		50.	PPM(W)	PU	<	100.	PPM(W)
RB	<	500.	PPM(W)	SB	<	50.	PPM(W)
SI		100000.	PPM(W)	SN	<	10.	PPM(W)
SR		10000.	PPM(W)	TA	<	50.	PPM(W)
TE	<	100.	PPM(W)	TH	<	500.	PPM(W)
TI		500.	PPM(W)	TL	<	500.	PPM(W)
U	<	500.	PPM(W)	V	<	5.	PPM(W)
W	<	1000.	PPM(W)	ZN	<	500.	PPM(W)
ZR	<	50.	PPM(W)				

061472-01 LABORATORY SAMPLE RESULTS DATE 04/10/90
PAGE 2

SAMPLE-ID 00-008396

** RADIOCHEMISTRY LABORATORY RESULTS

AM	0.00000546	G/G			
PU	0.0000389	G/G	U	0.000195	G/G

AUTHORIZED SIGNATURE

061472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80
7412 Sludge PAGE 1

SAMPLE-ID	00-008397	DOD NUMBER	97038000
ENTRY DATE	11-01-79	ACCOUNT CHARGED	8037
COMPLETION DATE	04-10-80	BUILDING	559
		CLASS	SSPL
CUSTOMER	P. T. GODESAIBOIS		

** ATOMIC ABSORPTION SPECTROMETRY RESULTS

CA		121661.	PPM(W)	FE		49286.	PPM(W)
GA	<	50.	PPM(W)	MG		18377.	PPM(W)
NA		100179.	PPM(W)	SI		217.	PPM(W)

** PLUTONIUM CHEMISTRY LABORATORY RESULTS

CL(-)		1.5	%(W)	CO3=		0.59	%(W)
F(-)		143.	PPM(W)	H2O		60.2	%(W)
NO3		9.1	%(W)	PO4	<	0.0025	%(W)
SO4		0.14	%(W)				

** SEMI-QUANTATIVE EMISSION SPEC RESULTS

AG		40000.	PPM(W)	AL		10000.	PPM(W)
AS	<	50.	PPM(W)	B		100.	PPM(W)
BA		50.	PPM(W)	BE		1000.	PPM(W)
BI	<	50.	PPM(W)	CA		200000.	PPM(W)
CD	<	1000.	PPM(W)	CE	<	500.	PPM(W)
CO	<	50.	PPM(W)	CR		500.	PPM(W)
CS	<	1000.	PPM(W)	CU		1000.	PPM(W)
FE		50000.	PPM(W)	GE	<	10.	PPM(W)
HG	<	10.	PPM(W)	K		40000.	PPM(W)
LI	<	1000.	PPM(W)	MG		100000.	PPM(W)
MN		100.	PPM(W)	MO		200.	PPM(W)
NA		60000.	PPM(W)	NB	<	50.	PPM(W)
NI		500.	PPM(W)	P	<	1000.	PPM(W)
PB		50.	PPM(W)	PU	<	100.	PPM(W)
RB	<	500.	PPM(W)	SB	<	50.	PPM(W)
SI		100000.	PPM(W)	SN	<	10.	PPM(W)
SR		10000.	PPM(W)	TA	<	50.	PPM(W)
TE	<	100.	PPM(W)	TH	<	500.	PPM(W)
TI		300.	PPM(W)	TL	<	500.	PPM(W)
U	<	500.	PPM(W)	V	<	5.	PPM(W)
W	<	1000.	PPM(W)	ZN	<	500.	PPM(W)
ZR	<	50.	PPM(W)				

061472-01 LABORATORY SAMPLE RESULTS DATE 04/10/90
PAGE 2

SAMPLE-ID 00-008397

** RADIOCHEMISTRY LABORATORY RESULTS

AM	0.000628	MG/G			
PU	0.00000481	G/G	U	0.000561	G/G

AUTHORIZED SIGNATURE

Hughes

ATTACHMENT 2

Rockwell International

Energy Systems Group
Rocky Flats Plant
P.O. Box 464
Golden, Colorado 80401

ANALYTICAL REPORT

To C.T. Hewitt 374 / File

Account No. 371

Date 7-24-81

Lab. No. M81-1109

Reported by

Approved A.M. Miller

Sample Description

374 Waste Sludge — Dried sludge

Analysis Results

A characterization of the 374 waste sludge was requested. The analysis of a composited sample is given. All results are in %.

Ca	11
Mg	3.8
Si	5.8
Al	0.4
Cr	0.12
Fe	0.9
K	0.25
Na	0.8
C	13
S	0.36
SO_4	0.02
Cl	1.3
F	0.5
PO_4	40
NO_3	6.6
CO_3	0.04
HCO_3	0.33

The cations greater than 1% were determined by A^2 and those less than 1% by emission spectroscopy. The anions, except for HCO_3, CO_3, and NO_3 were determined on a nitric acid leach of the sludge. Eighteen percent of the sludge was soluble in water, and 36% soluble in nitric acid.

CORRES. CONTROL
OUTGOING LTR NO

88-RF-1089

DIST		
SANCHIM O.J		
BADER C.P		
CAMPBELL G.W		
HOOD R.C.		
KINZER J.E.		
KIRBY W.A.		
MCNETT J.F		
MEYERS S.W		
SHANNON W.M		
SMITH R.E		
WEIDNER C.W		
WESTON W.F	X	
WILSON G.L.		
WOZNIAK S.D.		
YOUNG E.R		
BETCHER D.H		
CARNIVAL G.J.		
HARMAN L.K.		
HEBERT J.L.		
HOEY J.B.		
HOFFMAN R.B.		
KRIEG D.M.	X	X
LIM B.W.		
LOUDENBURG G.E.		
NAIMON E.R.	X	
NEWBY R.L.		
ROECKER J.H		
VELASQUEZ R.R.		
CORRES. CONTROL		
BRETZKE C.D.	X	
REINHART W.D.	X	
PAYNTER J.K	X	X
HICKL E.L.	X	
CLASSIFICATION		
UNCLASSIFIED	X	X
CONFIDENTIAL		
SECRET		

AUTH CLASSIFIER SIG
4/6/88
DATE

IN REPLY TO LTR NO
C521-KF-87

DEC + WEIPOU
FOR APPROVALS

JKP/jv

Rocky Flats Plant
North American Space Operations
Rockwell International Corporation
P.O. Box 464
Golden, Colorado 80402-0464
(303) 966-7000
Contractor to U.S. Department of Energy

Rockwell International

April 4, 1988 88-RF-1089

Albert E. Whiteman
Area Manager
DOE, RFAO

ENGINEERING PARAMETERS FOR ROCKY FLATS WASTE FORMS

This information is for the attention of W. C. Rask.

Attached are the engineering parameters for Rocky Flats waste forms that were requested in the letter from J. B. Tollison to distribution, dated March 1, 1988. Information is included for all thirteen Rocky Flats waste forms, which will be transported in the TRUPACT-II container.

If you have questions regarding the enclosed information, contact Jim Alexander at (303) 966-7585 or Jeff Paynter at (303) 966-5252. With your approval please forward to DOE/AL, Waste Transportation.

E. R. Naimon, Manager
Waste Operations
Rocky Flats Plant
Aerospace Operations

Orig. and 3 cc - A. E. Whiteman
Enc.

ENGINEERING PARAMETERS FOR TRUPACT-II

Waste Stream - - TRU SOLIDIFIED ORGANIC WASTE (WF-112)

For data in Section 1, Secondary Container, and Section 2, Arrangement of Secondary Containers, see the General Engineering Parameters for TRUPACT II.

3 WASTE MATERIAL INFORMATION:

3.1 Structural:

3.1.1 Maximum and Minimum Weight - -

Drums: 750 lb max. / 530 lb avg. / 200 lb. min. (including the weight of the drum)

3.1.2 Acceptable Projectile Envelope - - NA, solid monolith cast in the liner inside the drum.

3.2 Thermal:

3.2.1 Quantity of Radionuclides - - Isotopic Composition (Mix Group 9, TRUPACT-II Spec.):

Isotope	Fraction
Pu-238	TRACE
Pu-239	0.930
Pu-240	0.058
Pu-241	0.004
Pu-242	TRACE
Am-241	TRACE
OTHER	0.007

Max. radionuclides (Weapons Grade Pu): 200 grams/drum

Maximum decay heat (Pu): 0.4 watts/drum
(Am): 0.3 watts/drum
Total: 0.7 watts/drum

3.2.2 Chemical Form - -

	min.	max.	ave.
oils	10 %	30 %	
trichloroethane and trichlorotrifluoroethane	5 %	10 %	
carbon tetrachloride	2 %	5 %	
emulsifier (a polyethyl glycol ester)	5 %	10 %	
water	5 %	15 %	
gypsum cement	40 %	50 %	200 lb
total liquid (32 gallons)			250 lb

APPENDIX B - 7

United States Government | Department of Energy

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: April 4, 1996

REPLY TO ATTN OF: CAO:NTP:DW:96-1126

SUBJECT: Estimate of Cement Content in TRU Solidified Waste Forms Scheduled for Disposal in WIPP

TO: Les Shephard, Director, SNL

Attached is a summary of the best estimate of portland cement in stored and projected volumes of solidified waste streams listed in Revision 2 of the Transuranic (TRU) Waste Baseline Inventory Report (TWBIR). This information was requested from the TWBIR team in support of the Performance Assessment team.

These values have been scaled (similar to the methodology used for waste material parameters in the TWBIR) to the full volume of the Waste Isolation Pilot Plant (WIPP) repository. The total estimated weight of portland cement in these scaled solidified waste forms is 8.54E+06 kg. Dividing this value by 6.2E+06 ft^3 (~175,600 m^3), the maximum capacity of WIPP, yields a portland cement density in the overall combined contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste of 48.6 kg/m^3. The portland cement reported is both reacted and unreacted cement in the waste. There are no data available to estimate the percentage of reacted versus unreacted cement.

The basic methodology was to perform a sort of the Revision 2 database that supports the TWBIR for all Solidified Inorganic and Solidified Organic waste streams. This sort resulted in 221 waste streams. Some waste streams were eliminated from further consideration for the following reasons:

- Data about most Rocky Flats waste streams (both residue and nonresidue waste streams) are for waste in current form only and not in final form. The item description code (IDC) for many particulate waste streams will change to final form because the waste is in a cemented final form. A total of 91 current-form RF TRU waste streams were eliminated because of this constraint. (the final form of these waste streams, however, is included in the portland cement estimate.)

- The Solidified Inorganic waste streams listed from Savannah River Site are all vitrified and therefore do not contain any portland cement. A total of 20 waste streams were eliminated because of this constraint.

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If you have any questions concerning the attached information, please contact Mr. Russ Bisping of my staff at (505) 234-7446.

Don Watkins
Manager
National TRU Program

Attachment

cc w/attachment:
M. McFadden, CAO
K. Hunter, CAO
R. Bisping, CAO
P. Drez, CTAC
J. Harvill, CTAC
L. Sanchez, SNL
M. Chu, SNL
M. Marietta, SNL

Calculation Summary

At the bottom of Table 1 the total kilograms of portland cement is summarized for CH-TRU and RH-TRU waste for both stored plus projected waste (in "Total kg" column) and projected only waste (in "Projected kg" column). The TOTAL SCALED portland cement is calculated as follows:

CH-TRU "Total kg" + 2.05 * CH-TRU "Projected kg" + RH-TRU "Total Kg" = TOTAL SCALED kg of portland cement, or

5.28E+06 + 2.05(1.34E+06) + 5.05E+05 = 8.54E+06 kg portland cement

The total density of portland cement is calculated as follows:

8.54E+06 kg/175,600 m^3 = 48.6 kg/ m^3 portland cement

Table 1. Estimate of Portland Cement in TRU Waste for Disposal in the WIPP

TRPID	IN	Waste Type	Handling	Waste Form	Solidification	Solidification	Cement (kg/m³)	Stored (m³)	Projected (m³)	Total kg	Projected kg
W012.10		MTRU	RI	Solidified	inorganics	salt(1)	n/a				
W016.20		MTRU	RI	Solidified	inorganics	encapsulated metal(2)	n/a				
W020.13		MTRU	RI	Solidified	inorganics	evaporitic salt/sludge(3)	[illegible]	1.1	1.1	263.16	131.58
W022.22		MTRU	RI	Solidified	inorganics	sludge/particulates(3)	[illegible]	0	0.3	63.19	63.19
/216.877		MTRU	RI	Solidified	inorganics	[illegible]	2[illegible]	43.9	0	9[illegible]	0
/228.866		MTRU	RI	Solidified	inorganics	[illegible]	[illegible]	2[illegible]	0	[illegible]	0
W042		MTRU	RI	Solidified	inorganics	[illegible]	3[illegible]	[illegible]	0	[illegible]	0
W046		MTRU	RI	Solidified	inorganics	[illegible]	3[illegible]	16[illegible]	206	42[illegible]	81897
/317.1029		MTRU	RI	Solidified	Organics	[illegible]	[illegible]	[illegible]	0	[illegible]	0
W038		MTRU	CI	Solidified	inorganics	resins(3)	[illegible]	4.8	0	330.8	0
W040		MTRU	CI	Solidified	inorganics	acid lab packs(3)	[illegible]				0
W005		MTRU	CI	Solidified	inorganics	evaporitic salt/sludge(3)	[illegible]	0	0.3	39.73	39.73
146.699		MTRU	CI	Solidified	inorganics	nitric acid liquids(2)	271.8	2.3	0	629.74	0
159.1072		MTRU	CI	Solidified	inorganics	Assumed IN-W216.98	n/a				
163.1007		MTRU	CI	Solidified	inorganics	evaporitic salt/sludge	[illegible]	0.7	0	31.13	0
166.151		MTRU	CI	Solidified	inorganics	Ash(3)	[illegible]	[illegible]	0	1160.[illegible]	0
166.928		MTRU	CI	Solidified	inorganics	[illegible]	82.6	36.8	0	4748.48	0
174.1082		MTRU	CI	Solidified	inorganics	[illegible]	n/a				
174.154		MTRU	CI	Solidified	inorganics	Florcel(4)	n/a				
177.1083		MTRU	CI	Solidified	inorganics	Florcel(4)	n/a				
177.156		MTRU	CI	Solidified	inorganics	Florcel(4)	n/a				
179.1081		MTRU	CI	Solidified	inorganics	Florcel(4)	394.[illegible]	4.6	0	1813.34	0
179.158		MTRU	CI	Solidified	inorganics	[illegible](5)	32[illegible]	[illegible]	0	487.5	0
181.162		MTRU	CI	Solidified	inorganics	[illegible](5)	308.[illegible]	[illegible]	0	2964.48	0
187.1094		MTRU	CI	Solidified	inorganics	[illegible]	107	0.[illegible]	0	[illegible]	0
188.1093		MTRU	CI	Solidified	inorganics	Assumed IN-W222.116	308.[illegible]		0	308.[illegible]	0
188.160		MTRU	CI	Solidified	inorganics	[illegible]	[illegible]	0	0	131.8[illegible]	131.8
216.875		MTRU	CI	Solidified	inorganics	[illegible]	308.[illegible]	1438.[illegible]	0	4566[illegible]	0
216.98		MTRU	CI	Solidified	inorganics	[illegible]	[illegible]	[illegible]	0	32122.70	0
218.909		MTRU	CI	Solidified	inorganics	[illegible]	273.[illegible]	[illegible]	0	13108.[illegible]	0
219.914		MTRU	CI	Solidified	inorganics	[illegible]	130.6	10.[illegible]	0	[illegible]	0
220.114		MTRU	CI	Solidified	inorganics	Assumed RE-MT0007	[illegible]		0	[illegible]	0
220.975		MTRU	CI	Solidified	inorganics	Grinding Sludge(3)	27.6	12.[illegible]	0	3289.28	0
221.113		MTRU	CI	Solidified	inorganics	[illegible]	308.[illegible]	44.[illegible]	0	13679[illegible]	0
221.927		MTRU	CI	Solidified	inorganics	[illegible]	137.63	11.6	0	1481.006	0
222.816		MTRU	CI	Solidified	inorganics	[illegible](6)	109.29	[illegible]	0	392.864	0
222.965		MTRU	CI	Solidified	inorganics	[illegible](6)	102	24.7	0	2519.4	0
228.101		MTRU	CI	Solidified	inorganics	[illegible]	113.6	10.9	0	1211.36	0
228.883		MTRU	CI	Solidified	inorganics	[illegible]	111.7	28.[illegible]	0	3181.21	0
241.523		MTRU	CI	Solidified	inorganics	[illegible]	132.8	608.8	0	80848.64	0
257.947		MTRU	CI	Solidified	inorganics	[illegible]	n/a				
263.520		MTRU	CI	Solidified	inorganics	no solidification used	n/a				
315.601		MTRU	CI	Solidified	inorganics	Diatomaceous earth(7)	n/a				
332.661		TRU	CI	Solidified	inorganics	no solidification used	308.[illegible]	0.4	0	123.32	0
332.962		TRU	CI	Solidified	inorganics	Wet Salt-Assumed IN-W216.875	n/a				
347.646		TRU	CI	Solidified	inorganics	Plaster(8)	n/a				
347.819		TRU	CI	Solidified	inorganics	Plaster(8)	n/a				
348.1012		TRU	CI	Solidified	inorganics	Vermiculite(9)	n/a				
353.959		TRU	CI	Solidified	inorganics	Vermiculite(9)	[illegible]	2.3	0	168.13	0
353.917		TRU	CI	Solidified	inorganics	Particulates(3)	[illegible]	0.[illegible]	0	[illegible]	0
375.1096		TRU	CI	Solidified	inorganics	Liquid(3)	[illegible]	0.[illegible]	0	14.62	0
W002		MTRU	CI	Solidified	inorganics	Liquid(3)	[illegible]	[illegible]	0	1[illegible]	0
W003		MTRU	CI	Solidified	inorganics	Sludge- Assumed IN-W216.875	308.[illegible]	[illegible]	0	[illegible]	0
W006		MTRU	CI	Solidified	inorganics	((0)	69.[illegible]	3053.[illegible]	333.[illegible]	2109512.4	3[illegible]16.9
006		TRU	CI	Solidified	inorganics	((0)	645.9	1029.4875	559.[illegible]	1028161.666	36[illegible].69
001		TRU	CI	Solidified	inorganics	((0)	508.[illegible]	301.7[illegible]	839.[illegible]	580016.239	476[illegible].19
						((0)	314.[illegible]	4.23	8[illegible]	44096.92	4123.[illegible]
						((0)	100	14.4	[illegible]	2020	580

Table 1. Estimate of Portland Cement in TRU Waste for Disposal in the WIPP

IPP ID	Waste Type	[illegible]	[illegible]	[illegible]	Solidification	Cement (kg/m³)	Stored (m³)	Projected (m³)	Total kg	Projected kg	
001	TRU	CH		Solidified	Inorganics	Sludge - Assumed IN-W129.1084	392.2	4.2	0	1655.64	0
V002	MTRU	CH		Solidified	Inorganics	Floor(4)	n/a				
/021	TRU	CH		Solidified	Inorganics	Mainly debris	n/a				
110001	MTRU	CH		Solidified	Inorganics	DIR	187.6	3.7	0	694.12	0
110007	MTRU	CH		Solidified	Inorganics	DIR	130.8	0.8	0	104.48	0
110800	MTRU	CH		Solidified	Inorganics	DIR	193.8	65.2	38.9	20232.72	7538.82
110803	MTRU	CH		Solidified	Inorganics	DIR	53.8	3.8	2.2	204.52	118.16
110007	MTRU	CH		Solidified	Inorganics	DIR	71.7	73.2	41.6	8245.5	2282.72
10377	MTRU	CH		Solidified	Inorganics	Particulate(3)	71.7	3.3	0	236.83	0
10806	MTRU	CH		Solidified	Inorganics	DIR	73.1	0	1110.7	81192.17	81192.17
10823	TRU	CH		Solidified	Inorganics	DIR	73.1	7.1	23	526.3	404.23
10806	TRU	CH		Solidified	Inorganics	DIR	73.1	0	202.2	14710.12	14780.82
110	TRU	CH		Solidified	Inorganics	DIR	140.2	0.6	0	84.12	0
10802	TRU	CH		Solidified	Inorganics	DIR(6)	68.32	7.5	26	2288.72	1776.32
281	MTRU	CH		Solidified	Inorganics	Vermiculite(9)	n/a				
383	TRU	CH		Solidified	Inorganics	Vermiculite(9)	n/a				
394	TRU	CH		Solidified	Inorganics	Vermiculite(9)	n/a				
039	MTRU	CH		Solidified	Organics	resins(3)	73.1	0.2	0	14.62	0
157 144	MTRU	CH		Solidified	Organics	DIR(6)	187.88	49.9	0	9375.212	0
151 906	MTRU	CH		Solidified	Organics	DIR(6)	212.168	163.7	0	34830.1216	0
164 1060	MTRU	CH		Solidified	Organics	Envirostone(11)	n/a				
164 153	MTRU	CH		Solidified	Organics	Envirostone(11)	n/a				
167 149	MTRU	CH		Solidified	Organics	calc-silicate(12)	n/a				
167 926	MTRU	CH		Solidified	Organics	calc-silicate(12)	n/a				
109 610	MTRU	CH		Solidified	Organics	calc-silicate(12)	n/a				
117 757	MTRU	CH		Solidified	Organics	resins(3)	73.1	39.1	0	2858.21	0
117 758	MTRU	CH		Solidified	Organics	resins(3)	73.1	11.5	0	840.65	0
119 584	MTRU	CH		Solidified	Organics	resins(3)	73.1	0.7	0	51.17	0
111 1023	MTRU	CH		Solidified	Organics	resins(3)	73.1	1.3	0	95.03	0
12	TRU	CH		Solidified	Organics	(10)	693	1.5	29.1	21205.8	20166.3
19	MTRU	CH		Solidified	Organics	Envirostone(11)	n/a				
10003	MTRU	CH		Solidified	Organics	calc-silicate(12)	n/a				
10801	MTRU	CH		Solidified	Organics	Envirostone(11)	n/a				
10375	MTRU	CH		Solidified	Organics	Oil Drit(13)	n/a				
10809	TRU	CH		Solidified	Organics	DIR	32	0	35.2	1126.4	1126.4
280	MTRU	CH		Solidified	Organics	paint(14)	n/a				
282	MTRU	CH		Solidified	Organics	Mainly debris	n/a				
285	MTRU	CH		Solidified	Organics	Conweb pads(15)	n/a				
286	MTRU	CH		Solidified	Organics	Oil Drit(13)	n/a				
326	MTRU	CH		Solidified	Organics	Conweb pads(15)	n/a				
329	MTRU	CH		Solidified	Organics	PCB waste(16)	n/a				
333	MTRU	CH		Solidified	Organics	PCB waste(16)	n/a				
338	MTRU	CH		Solidified	Organics	Conweb pads(15)	n/a				
344	MTRU	CH		Solidified	Organics	Diatomaceous earth(7)	n/a				
345	MTRU	CH		Solidified	Organics	Conweb pads(15)	n/a				
348	MTRU	CH		Solidified	Organics	animal waste	n/a				
361	TRU	CH		Solidified	Organics	Vermiculite(9)	n/a				
380	TRU	CH		Solidified	Organics	Diatomaceous earth(7)	n/a				
							RH-TRU Total		505118.2	82095.21	kg
							CH-TRU Total		5282085.787	1344061.99	kg
							TOTAL SCALED			8542531.067	kg

Cement equals Stored + Projected plus 2.05 times Projected for CH TRU

us Stored + Projected for RH-TRU

Table 1. Estimate of Portland Cement in TRU Waste for Disposal in the WIPP

[illegible]	[illegible]	[illegible]	[illegible]	Solidification	Cement (kg/m³)	Stored (m³)	Projected (m³)	Total kg	Projected kg	
ult waste, does not contain any portland cement										
icapsulated metal waste, does not contain any portland cement										
ssume RF-MT0806 for final form cement density										
orco (clay) is used as sorbent not portland cement										
ie portland cement for this waste stream in the BIR occurs in the "Other Inorganic Material"										
ily 61% of the solidification agent reported as cement in the TWBIR is portland cement										
atomaceous earth is used as the sorbent in this waste stream										
aster of Paris used as solidification agent										
ermiculite used as sorbent in this waste stream										
lasis for portland cement are values reported in TWBIR supplemented with information provided by LANL										
for previous WIPP memo on nitrate, sulfate, and phosphate										
olidification agent is Envirostone (a gypsum-based process) that does not contain portland cement										
olidification agent is a calcium-silicate process that does not use portland cement										
Oil Dri is used as sorbent										
olidified organics is paint, contains no portland cement										
olidification agent/sorbent is conwed pads (plastic fiber absorbent) +/- vermiculite										
CB containing waste, excluded from current WIPP inventory										

APPENDIX C

APPENDIX C

SITE-SPECIFIC STORED RADIONUCLIDE INVENTORIES

CH Curies on a Site-by-Site[1] Basis
(Decayed to the End of 1995)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Ac225			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Ac227		1.98E-15	4.08E-14	1.02E-04	3.86E-02	1.35E-19
Ac228			2.87E-18	5.60E-02	3.08E-01	1.69E-19
Ag109m						
Ag110				5.08E-10	3.55E-09	
Ag110m				3.81E-08	2.67E-07	
Am241			5.19E-01	4.73E+03	9.01E+04	9.17E-02
Am243				9.02E-02	3.80E-01	3.85E-02
Am245					1.12E-09	3.60E-14
At217			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Ba137m			1.99E-01	6.46E+02	5.71E+01	
Bi210	5.22E-15		2.05E-15	5.30E-06	2.70E-02	8.96E-03
Bi211		1.98E-15	4.08E-14	1.02E-04	3.87E-02	1.35E-19
Bi212			1.10E-18	5.19E-02	2.62E+01	8.59E-20
Bi213			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Bi214	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Bk249					7.70E-05	2.48E-09
Bk250						8.68E-08
C14				1.60E+00	1.66E-01	
Cd109						
Cd113m				1.25E-09	3.20E-08	
Ce144				4.41E-03	3.15E-02	

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Cf249					1.02E-02	3.10E-03
Cf250						1.97E-04
Cf251						
Cf252				3.55E-05	2.19E-03	
Cm242					2.73E-08	
Cm243				1.52E-02		
Cm244				3.70E+03	4.91E+02	8.70E-02
Cm245				1.71E-03	9.09E-06	2.27E-06
Cm246					1.53E-03	4.83E-07
Cm247						
Cm248				8.13E-09	4.73E-07	
Co58					1.22E-14	
Co60					6.23E+01	
Cs134				2.45E-04	1.20E-03	
Cs135				1.91E-07	8.08E-06	
Cs137			2.11E-01	6.83E+02	6.04E+01	
Es254						8.67E-08
Eu150					3.50E-05	
Eu152				7.34E-07	1.62E-01	
Eu154				6.22E-05	6.42E-01	
Eu155				1.06E-03	3.82E-01	
Fe55					1.91E-05	
Fe59					3.38E-21	
Fr221			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Fr223		2.73E-17	5.63E-16	1.41E-06	5.33E-04	1.86E-21
H3					8.02E-01	
I129						

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Kr85						
Mn54					8.49E-04	
Nb95				1.80E-11	2.38E-09	
Nb95m				6.00E-14	7.95E-12	
Ni59						
Ni63					9.06E-05	
Np237			9.49E-07	2.72E-01	8.53E-01	6.32E-06
Np239				9.02E-02	3.80E-01	3.85E-02
Np240m				5.84E-10	3.50E-14	
Pa231		1.88E-13	6.72E-13	4.84E-04	1.33E-05	1.99E-18
Pa233			9.49E-07	2.72E-01	8.53E-01	6.32E-06
Pa234			6.06E-17	7.62E-03	1.50E-04	2.40E-14
Pa234m			4.66E-14	5.86E+00	1.16E-01	1.84E-11
Pb209			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Pb210	5.22E-15		2.05E-15	5.30E-06	2.70E-02	8.96E-03
Pb211		1.98E-15	4.08E-14	1.02E-04	3.87E-02	1.35E-19
Pb212			1.10E-18	5.19E-02	2.62E+01	8.59E-20
Pb214	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Pd107				2.82E-08	1.19E-06	
Pm147				4.78E-02	2.63E+00	
Po210	1.42E-15		2.05E-15	5.30E-06	2.70E-02	8.96E-03
Po211		5.53E-18	1.14E-16	2.87E-07	1.08E-04	3.78E-22
Po212			7.04E-19	3.32E-02	1.68E+01	
Po213			2.19E-15	1.28E-01	1.49E+00	5.33E-06
Po214	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Po215		1.98E-15	4.08E-14	1.02E-04	3.87E-02	1.35E-19
Po216			1.10E-18	5.19E-02	2.62E+01	8.59E-20

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CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Po218	6.86E-13	1.40E-11	4.56E-14	3.15E-05	4.80E-02	3.37E-02
Pr144				4.36E-03	3.12E-02	
Pu236					1.04E-02	
Pu238	3.70E+02		1.11E-01	8.05E+04	5.98E+04	2.32E-04
Pu239		1.80E+01	1.79E+00	2.63E+04	4.01E+04	8.45E-06
Pu240			6.12E-01	6.15E+03	9.82E+03	5.14E-03
Pu241			6.22E+00	3.78E+04	1.50E+05	4.48E-07
Pu242			5.00E-05	3.80E-01	9.45E-01	1.01E-02
Pu243						
Pu244				5.85E-10	3.50E-14	
Ra223		1.98E-15	4.08E-14	1.02E-04	3.87E-02	1.35E-19
Ra224			1.10E-18	5.19E-02	2.62E+01	8.59E-20
Ra225			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Ra226	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Ra228			2.87E-18	5.60E-02	3.08E-01	1.69E-19
Rh106				2.17E-03	1.12E-02	
Rn219		1.98E-15	4.08E-14	1.02E-04	3.87E-02	1.35E-19
Rn220			1.10E-18	5.19E-02	2.62E+01	8.59E-20
Rn222	6.86E-13		4.56E-14	3.15E-05	4.80E-02	3.37E-02
Ru106				2.17E-03	1.12E-02	
Sb125				5.91E-04	3.53E-03	
Sb126				5.13E-08	2.17E-06	
Sb126m				3.67E-07	1.55E-05	
Se79				1.66E-07	7.00E-06	
Sm151				6.14E-04	2.39E-02	
Sn119m				2.95E-07	2.10E-06	
Sn121m				1.20E-05	4.38E-04	

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Sn126				3.67E-07	1.55E-05	
Sr90			2.00E-01	6.92E+02	1.96E+00	
Tc99				9.51E-06	2.16E-03	
Te125m				1.44E-04	8.62E-04	
Te127				3.95E-09	1.02E-07	
Te127m				4.03E-09	1.04E-07	
Th227		1.95E-15	4.02E-14	1.01E-04	3.82E-02	1.33E-19
Th228			1.10E-18	5.19E-02	2.62E+01	8.59E-20
Th229			2.23E-15	1.31E-01	1.52E+00	5.45E-06
Th230	4.75E-09		5.25E-11	8.11E-03	2.08E-02	1.50E-13
Th231		1.77E-08	1.06E-08	1.71E+00	6.17E-02	3.32E-14
Th232			1.61E-17	6.71E-02	3.30E-01	5.33E-19
Th234			4.66E-14	5.86E+00	1.16E-01	1.84E-11
Tl207		1.97E-15	4.07E-14	1.02E-04	3.86E-02	1.34E-19
Tl208			3.95E-19	1.86E-02	9.42E+00	3.09E-20
Tl209			4.83E-17	2.82E-03	3.28E-02	1.18E-07
U232					2.53E+01	
U233			1.20E-11	8.00E+01	8.99E+02	4.81E-03
U234	1.05E-03		1.93E-06	5.37E+01	6.17E+00	4.73E-09
U235		1.77E-08	1.06E-08	1.71E+00	6.17E-02	3.32E-14
U236			1.09E-07	2.49E-03	5.27E-03	1.81E-09
U237			1.53E-04	9.26E-01	3.67E+00	1.10E-11
U238			4.66E-14	5.86E+00	1.16E-01	1.84E-11
U240				5.84E-10	3.50E-14	
Y90			2.00E-01	6.92E+02	1.96E+00	
Zr93				2.14E-06	9.06E-05	
Zr95				8.09E-12	1.07E-09	

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CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ARCO	ARMY	ETEC	HANF	INEL	LBL
Total by Site	3.70E+02	1.80E+01	1.01E+01	1.62E+05	3.51E+05	5.08E-01

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Ac225	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Ac227	2.32E-01	3.32E-10	4.13E-12	1.83E-17	2.09E-04	9.85E-03
Ac228	1.59E-03	1.60E-16			1.90E-16	7.12E-04
Ag109m	6.56E+00					
Ag110	2.87E-11				5.55E-11	
Ag110m	2.16E-09				4.18E-09	
Am241	9.11E+03	1.44E+02		3.24E-01	2.84E+02	1.61E+03
Am243	3.83E+00	2.45E-02			1.22E+00	1.16E+01
Am245	1.95E-15				5.29E-14	1.49E-10
At217	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Ba137m	4.55E+01	1.57E-06			3.41E-01	2.20E+03
Bi210	2.80E-01	2.38E-13	7.23E-10		6.69E-02	1.26E+00
Bi211	2.32E-01	3.32E-10	4.13E-12	1.83E-17	2.09E-04	9.85E-03
Bi212	1.32E-03	6.13E-17			1.64E-02	2.84E-01
Bi213	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Bi214	9.04E-01	9.47E-12	6.88E-09	1.94E-22	2.50E-01	6.49E+00
Bk249	1.35E-10				3.65E-09	1.03E-05
Bk250					4.11E-11	9.51E-13
C14	2.00E-07				2.50E-04	
Cd109	6.55E+00					
Cd113m	7.42E-07				6.50E-09	
Ce144	3.04E-04				7.88E-04	
Cf249	9.64E-04				1.14E-02	2.82E-02

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CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Cf250					3.18E-01	1.49E-03
Cf251	1.58E-03					
Cf252					1.70E-02	1.60E-01
Cm242	3.42E-17	1.70E-04				1.39E-03
Cm243	1.09E+00					
Cm244	1.57E+02	6.54E+01			2.28E+02	1.06E+03
Cm245	1.60E-06				9.44E-06	3.35E-05
Cm246	4.01E-02	5.22E-04			6.14E-04	1.60E-05
Cm247	1.34E-09					
Cm248					3.57E-06	2.55E-02
Co58	1.22E-13					
Co60	2.14E-04					1.84E-06
Cs134	4.24E-03				4.03E-04	
Cs135	2.05E-04				1.20E-06	
Cs137	4.81E+01	1.66E-06			3.60E-01	2.33E+03
Es254					4.11E-11	
Eu150						
Eu152	4.18E-04	1.33E-06			1.06E+00	6.18E-04
Eu154	2.45E-02	5.25E-07			4.28E-01	
Eu155	2.31E-01				3.80E-03	
Fe55						
Fe59	1.35E-16					1.87E-07
Fr221	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Fr223	3.20E-03	4.58E-12	5.70E-14	2.53E-19	2.89E-06	1.36E-04
H3					6.46E-02	
I129						
Kr85					1.96E-01	

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CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Mn54	5.48E-08					
Nb95	1.76E-11				1.51E-17	
Nb95m	5.89E-14				5.05E-20	
Ni59						
Ni63						1.09E-04
Np237	3.24E-02	4.71E-04		2.28E-04	5.78E-03	7.27E-01
Np239	3.83E+00	2.45E-02			1.22E+00	1.16E+01
Np240m	1.94E-07				9.99E-07	1.10E-09
Pa231	1.24E-03	1.54E-08	3.24E-11	8.98E-16	5.00E-04	3.14E-01
Pa233	3.24E-02	4.71E-04		2.28E-04	5.78E-03	7.27E-01
Pa234	3.07E-05	3.94E-05		1.51E-10	2.13E-07	5.54E-05
Pa234m	2.36E-02	3.03E-02		1.16E-07	1.64E-04	4.26E-02
Pb209	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Pb210	2.80E-01	2.38E-13	7.23E-10		6.69E-02	1.26E+00
Pb211	2.32E-01	3.32E-10	4.13E-12	1.83E-17	2.09E-04	9.85E-03
Pb212	1.32E-03	6.13E-17			1.64E-02	2.84E-01
Pb214	9.04E-01	9.47E-12	6.88E-09	1.94E-22	2.50E-01	6.49E+00
Pd107	3.03E-05				1.78E-07	
Pm147	2.00E+00				1.05E-01	1.94E-02
Po210	2.80E-01	1.97E-13	7.23E-10		6.69E-02	1.26E+00
Po211	6.50E-04	9.28E-13	1.16E-14	5.13E-20	5.86E-07	2.76E-05
Po212	8.48E-04	3.93E-17			1.05E-02	1.82E-01
Po213	7.89E-02	9.60E-13		1.55E-13	2.36E-03	2.02E-01
Po214	9.04E-01	9.47E-12	6.87E-09		2.50E-01	6.49E+00
Po215	2.32E-01	3.32E-10	4.13E-12	1.83E-17	2.09E-04	9.85E-03
Po216	1.32E-03	6.13E-17			1.64E-02	2.84E-01
Po218	9.05E-01	9.47E-12	6.88E-09	1.94E-22	2.50E-01	6.49E+00

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Pr144	3.00E-04				7.79E-04	
Pu236	5.37E-17					
Pu238	1.15E+05	7.65E+01	1.53E+03		1.95E+02	3.50E+03
Pu239	7.69E+04	1.58E+02	2.98E+01	2.46E-02	2.76E+03	1.01E+03
Pu240	1.00E+02	6.44E+01			1.88E+01	9.48E+02
Pu241	1.62E+03	1.63E+03		6.32E-03	2.40E+02	4.79E+04
Pu242	4.85E+02	2.02E-02			8.70E-02	2.37E-01
Pu243	1.34E-09					
Pu244	1.94E-07				1.00E-06	1.10E-09
Ra223	2.32E-01	3.32E-10	4.13E-12	1.83E-17	2.09E-04	9.85E-03
Ra224	1.32E-03	6.13E-17			1.64E-02	2.84E-01
Ra225	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Ra226	9.05E-01	9.47E-12	6.88E-09	1.94E-22	2.50E-01	6.49E+00
Ra228	1.59E-03	1.60E-16			1.90E-16	7.12E-04
Rh106	9.97E-04				8.76E-04	
Rn219	2.32E-01	3.32E-10	4.13E-12	1.83E-17	2.09E-04	9.85E-03
Rn220	1.32E-03	6.13E-17			1.64E-02	2.84E-01
Rn222	9.05E-01	9.47E-12	6.88E-09	1.94E-22	2.50E-01	6.49E+00
Ru106	9.97E-04				8.76E-04	
Sb125	4.67E-02				1.37E-03	
Sb126	5.52E-05				3.23E-07	
Sb126m	3.94E-04				2.31E-06	
Se79	1.78E-04				1.04E-06	
Sm151	6.00E-01				3.75E-03	
Sn119m	1.66E-08				2.97E-08	
Sn121m	1.09E-02				7.17E-05	
Sn126	3.94E-04				2.31E-06	

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Sr90	4.44E+01				3.10E-01	1.48E+03
Tc99	1.02E-02				5.99E-05	1.78E+01
Te125m	1.14E-02				3.33E-04	
Te127	7.45E-10				2.29E-12	
Te127m	7.60E-10				2.34E-12	
Th227	2.29E-01	3.27E-10	4.07E-12	1.81E-17	2.06E-04	9.72E-03
Th228	1.32E-03	6.13E-17			1.64E-02	2.84E-01
Th229	8.06E-02	9.81E-13		1.59E-13	2.41E-03	2.07E-01
Th230	4.90E-04	3.06E-08	3.35E-06	1.35E-18	9.98E-07	2.45E-04
Th231	5.27E-01	5.93E-04	2.68E-07	4.45E-11	6.15E-05	8.15E-03
Th232	2.29E-03	9.37E-16			8.19E-16	8.57E-04
Th234	2.36E-02	3.03E-02		1.16E-07	1.64E-04	4.26E-02
Tl207	2.31E-01	3.31E-10	4.12E-12	1.83E-17	2.09E-04	9.82E-03
Tl208	4.76E-04	2.20E-17			5.89E-03	1.02E-01
Tl209	1.74E-03	2.12E-14		3.43E-15	5.20E-05	4.47E-03
U232	5.50E-18				1.65E-02	2.90E-01
U233	4.46E+01	5.95E-09		1.78E-09	1.81E+00	1.77E+02
U234	5.84E+00	3.17E-03	5.52E-02	2.98E-13	1.25E-02	1.57E+01
U235	5.27E-01	5.93E-04	2.68E-07	4.45E-11	6.15E-05	8.15E-03
U236	2.99E-06	7.63E-06			4.20E-06	3.40E-04
U237	3.98E-02	4.00E-02		1.55E-07	5.88E-03	1.18E+00
U238	2.36E-02	3.03E-02		1.16E-07	1.64E-04	4.26E-02
U240	1.94E-07				9.99E-07	1.10E-09
Y90	4.45E+01				3.10E-01	1.48E+03
Zr93	2.30E-03				1.35E-05	
Zr95	7.93E-12				6.81E-18	

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	LANL	LLNL	MOUND	MURR	NTS	ORNL
Total by Site	2.03E+05	2.14E+03	1.56E+03	3.55E-01	3.74E+03	6.38E+04

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	RF-Res	SR-On	SR-Off	TOTAL
Ac225	4.01E-07		3.55E-11	2.14E-09	1.31E-05	1.02E-10	1.94E+00
Ac227	1.27E-12	4.83E-17	1.58E-10	1.62E-08	3.70E-07	2.89E-10	2.80E-01
Ac228			1.49E-14	7.07E-13	1.01E-02	2.13E-14	3.76E-01
Ag109m							6.56E+00
Ag110							4.14E-09
Ag110m							3.11E-07
Am241			1.10E+04	1.19E+05	3.58E+03	1.20E+02	2.40E+05
Am243					7.55E-01		1.80E+01
Am245							1.27E-09
At217	4.01E-07		3.55E-11	2.14E-09	1.31E-05	1.02E-10	1.94E+00
Ba137m					7.11E+00		2.96E+03
Bi210			4.54E-12	1.08E-09	1.69E-07	9.40E-07	1.65E+00
Bi211	1.27E-12	4.83E-17	1.58E-10	1.62E-08	3.70E-07	2.89E-10	2.81E-01
Bi212			4.98E-15	3.82E-13	9.18E-03	1.93E-14	2.66E+01
Bi213	4.01E-07		3.55E-11	2.14E-09	1.31E-05	1.02E-10	1.94E+00
Bi214			9.77E-11	1.35E-08	1.51E-06	5.79E-06	7.72E+00
Bk249							8.73E-05
Bk250							8.68E-08
C14							1.77E+00
Cd109							6.55E+00
Cd113m							7.81E-07
Ce144					8.72E-13		3.70E-02
Cf249							5.39E-02
Cf250							3.20E-01
Cf251							1.58E-03
Cf252					3.62E-01		3.61E+01
Cm242							1.56E-03

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	RF-Res	SR-On	SR-Off	TOTAL
Cm243							1.11E+00
Cm244					6.15E+02		6.32E+03
Cm245							1.77E-03
Cm246							4.28E-02
Cm247							1.34E-09
Cm248					1.61E-04		3.35E-02
Co58							1.34E-13
Co60					3.56E-01		6.27E+01
Cs134					3.18E-06		6.09E-03
Cs135							2.15E-04
Cs137					7.52E+00		3.12E+03
Es254							8.68E-08
Eu150							3.50E-05
Eu152							1.22E+00
Eu154					2.83E-04		1.10E+00
Eu155					3.13E-06		6.18E-01
Fe55							1.91E-05
Fe59							1.87E-07
Fr221	4.01E-07		3.55E-11	2.14E-09	1.31E-05	1.02E-10	1.94E+00
Fr223	1.75E-14	6.67E-19	2.19E-12	2.23E-10	5.10E-09	3.99E-12	3.87E-03
H3							8.66E-01
I129					1.17E-07		1.17E-07
Kr85							1.96E-01
Mn54					1.00E-10		8.49E-04
Nb95							2.41E-09
Nb95m							8.06E-12
Ni59					1.25E-03		1.25E-03

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	RF-Res	SR-On	SR-Off	TOTAL
Ni63					1.53E-01		1.53E-01
Np237	5.49E+01		1.70E-02	3.19E-01	8.59E+00	3.58E-03	6.58E+01
Np239					7.55E-01		1.80E+01
Np240m					1.59E-11		1.20E-06
Pa231	2.09E-11	2.31E-15	2.70E-09	1.59E-07	1.68E-06	1.65E-09	3.16E-01
Pa233	5.49E+01		1.70E-02	3.19E-01	8.59E+00	3.58E-03	6.58E+01
Pa234			1.94E-17	9.23E-12	7.37E-06	5.26E-08	7.90E-03
Pa234m			1.49E-14	7.10E-09	5.67E-03	4.04E-05	6.08E+00
Pb209	4.01E-07		3.55E-11	2.14E-09	1.31E-05	1.02E-10	1.94E+00
Pb210			4.54E-12	1.08E-09	1.69E-07	9.40E-07	1.65E+00
Pb211	1.27E-12	4.83E-17	1.58E-10	1.62E-08	3.70E-07	2.89E-10	2.81E-01
Pb212			4.98E-15	3.82E-13	9.18E-03	1.93E-14	2.66E+01
Pb214			9.77E-11	1.35E-08	1.51E-06	5.79E-06	7.72E+00
Pd107							3.17E-05
Pm147					1.24E-05		4.79E+00
Po210			4.50E-12	1.08E-09	1.69E-07	9.40E-07	1.65E+00
Po211	3.56E-15	1.35E-19	4.43E-13	4.53E-11	1.04E-09	8.10E-13	7.86E-04
Po212			3.19E-15	2.45E-13	5.88E-03	1.24E-14	1.70E+01
Po213	3.93E-07		3.47E-11	2.10E-09	1.28E-05	9.94E-11	1.90E+00
Po214			9.77E-11	1.35E-08	1.51E-06	5.79E-06	7.72E+00
Po215	1.27E-12	4.83E-17	1.58E-10	1.62E-08	3.70E-07	2.89E-10	2.81E-01
Po216			4.98E-15	3.82E-13	9.18E-03	1.93E-14	2.66E+01
Po218			9.77E-11	1.35E-08	1.51E-06	5.79E-06	7.73E+00
Pr144					8.62E-13		3.66E-02
Pu236							1.04E-02
Pu238			3.43E+02	8.09E+03	2.86E+05	2.01E+05	7.56E+05
Pu239	5.57E+01	5.55E-02	9.98E+03	1.84E+05	9.13E+03	1.58E+02	3.51E+05

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	RF-Res	SR-On	SR-Off	TOTAL
Pu240			7.22E+03	4.22E+04	2.21E+03	7.97E+01	6.88E+04
Pu241			5.23E+04	7.22E+05	6.02E+04	1.73E+03	1.07E+06
Pu242			9.63E-05	5.33E+00	3.75E-01		4.93E+02
Pu243							1.34E-09
Pu244					1.59E-11		1.20E-06
Ra223	1.27E-12	4.83E-17	1.58E-10	1.62E-08	3.70E-07	2.89E-10	2.81E-01
Ra224			4.98E-15	3.82E-13	9.18E-03	1.93E-14	2.66E+01
Ra225	4.01E-07		3.55E-11	2.14E-09	1.31E-05	1.02E-10	1.94E+00
Ra226			9.77E-11	1.35E-08	1.51E-06	5.79E-06	7.73E+00
Ra228			1.49E-14	7.07E-13	1.01E-02	2.13E-14	3.76E-01
Rh106					1.84E-10		1.52E-02
Rn219	1.27E-12	4.83E-17	1.58E-10	1.62E-08	3.70E-07	2.89E-10	2.81E-01
Rn220			4.98E-15	3.82E-13	9.18E-03	1.93E-14	2.66E+01
Rn222			9.77E-11	1.35E-08	1.51E-06	5.79E-06	7.73E+00
Ru106					1.84E-10		1.52E-02
Sb125					2.60E-05		5.22E-02
Sb126					2.41E-08		5.78E-05
Sb126m					1.72E-07		4.12E-04
Se79							1.86E-04
Sm151					3.13E-04		6.28E-01
Sn119m							2.44E-06
Sn121m							1.14E-02
Sn126					1.72E-07		4.12E-04
Sr90					6.98E+00		2.22E+03
Tc99					4.50E-06		1.78E+01
Te125m					6.34E-06		1.27E-02
Te127							1.07E-07

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	PAD	PANT	RFETS	RF-Res	SR-On	SR-Off	TOTAL
Te127m							1.09E-07
Th227	1.25E-12	4.77E-17	1.56E-10	1.60E-08	3.64E-07	2.85E-10	2.77E-01
Th228			4.98E-15	3.82E-13	9.18E-03	1.93E-14	2.66E+01
Th229	4.01E-07		3.55E-11	2.14E-09	1.31E-05	1.02E-10	1.94E+00
Th230			1.16E-07	8.88E-06	6.87E-04	1.66E-03	3.20E-02
Th231	3.29E-07	1.09E-10	4.78E-05	1.56E-03	5.83E-03	1.04E-05	2.31E+00
Th232			1.02E-13	2.55E-12	2.13E-02	4.79E-14	4.22E-01
Th234			1.49E-14	7.10E-09	5.67E-03	4.04E-05	6.08E+00
Tl207	1.27E-12	4.82E-17	1.58E-10	1.61E-08	3.69E-07	2.88E-10	2.80E-01
Tl208			1.79E-15	1.37E-13	3.30E-03	6.94E-15	9.55E+00
Tl209	8.67E-09		7.66E-13	4.63E-11	2.83E-07	2.19E-12	4.19E-02
U232							2.56E+01
U233	1.42E-03		1.95E-07	6.56E-06	8.93E-03	1.78E-07	1.20E+03
U234			4.81E-03	2.03E-01	1.06E+01	1.50E+01	1.07E+02
U235	3.29E-07	1.09E-10	4.78E-05	1.56E-03	5.83E-03	1.04E-05	2.31E+00
U236			9.17E-04	1.07E-02	4.77E-02	1.12E-04	6.75E-02
U237			1.28E+00	1.77E+01	1.48E+00	4.23E-02	2.64E+01
U238			1.49E-14	7.10E-09	5.67E-03	4.04E-05	6.08E+00
U240					1.59E-11		1.20E-06
Y90					6.98E+00		2.22E+03
Zr93							2.41E-03
Zr95							1.09E-09
TOTAL	**1.66E+02**	**5.55E-02**	**8.08E+04**	**1.08E+06**	**3.62E+05**	**2.03E+05**	**2.51E+06**

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

CH-TRU Curies on a Site-by-Site Basis (continued)

ABBREVIATIONS

ARCO	ARCO Medical Center, Pennsylvania
ARMY	US Army Materiel Command
ETEC	Energy Technology Engineering Center
HANF	Hanford
INEL	Idaho National Engineering Laboratory
KAPL	Knolls Atomic Power Laboratory
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory
Mound	Mound Facility
MURR	University of Missouri
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
PAD	Paducah
PANT	Pantex
RFETS	Rocky Flats Environmental Technology Site (All waste except residues)
RF-Res	Rocky Flats Environmental Technology Site - Residues Only
SR-On	Savannah River Site, waste generated on-site
SR-Off	Savannah River Site, waste that was generated off-site but currently stored at Savannah River

[1]Argonne National Laboratory-East, Argonne National Laboratory-West, and Teledyne Brown Engineering are not included because no data were received. Data from Sandia National Laboratory-Albuquerque are reported under RH-TRU waste because although the final waste form is expected to be CH-TRU waste, the stored waste is remotely handled at the site.

RH Curies on a Site-by-Site[1] Basis
(Decayed to the End of 1995)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Ac225	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Ac227	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Ac228		1.60E-03	3.87E-05		
Ag110			4.13E-09		9.88E-10
Ag110m			3.11E-07		7.43E-08
Am241	5.85E-02	1.93E+02	4.68E+01	5.07E-02	
Am243			6.91E-04		
Am245					
At217	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Ba137m	2.48E+00	6.61E+03	1.80E+03	5.40E+01	1.28E+02
Bi210		2.33E-07	6.06E-12	1.87E-16	5.61E-17
Bi211	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Bi212		1.49E-03	2.65E-05		
Bi213	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Bi214		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Bk249					
C14			4.00E-02		
Cd113m			1.15E-07		8.88E-07
Ce144			3.98E+00	1.56E+00	1.60E-02
Cf249					
Cf250					
Cf252					
Cm243			1.45E-02		
Cm244			9.63E-02		
Cm245					
Cm246					
Cm248					

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received fr the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Co58			4.37E-11		
Co60	2.30E+00	3.36E+02	1.31E+01	2.75E-01	4.17E+00
Cr51			1.08E-05		
Cs134			5.38E+01	4.73E+00	2.42E-02
Cs135			2.36E-05		1.91E-04
Cs137	2.62E+00	6.98E+03	1.90E+03	5.71E+01	1.35E+02
Eu152			1.14E-01		5.09E-04
Eu154			7.92E-01	1.40E+00	3.50E-02
Eu155			3.35E-01	1.81E-01	1.77E+00
Fe55			5.97E-01		
Fr221	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Fr223	1.45E-18	2.35E-07	3.60E-09	1.87E-20	6.34E-09
H3			1.43E-01		
Kr85			5.95E+00		
Mn54			8.31E-02		
Nb95			5.28E-12		2.14E-14
Nb95m			1.76E-14		7.15E-17
Ni63			3.50E+00		
Np237	2.26E-08	1.58E-03	8.10E-04	2.25E-08	
Np239			6.91E-04		
Np240m					
Pa231	6.68E-15	6.21E-05	1.42E-06	7.51E-17	2.39E-06
Pa233	2.26E-08	1.58E-03	8.10E-04	2.25E-08	
Pa234		1.33E-05	1.80E-06	4.48E-18	2.60E-08
Pa234m		1.03E-02	1.38E-03	3.45E-15	2.00E-05
Pb209	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Pb210		2.33E-07	6.06E-12	1.87E-16	5.61E-17

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Pb211	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Pb212		1.49E-03	2.65E-05		
Pb214		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Pd107			3.49E-06		2.83E-05
Pm147			1.49E+01	4.34E+00	1.13E+01
Po210		2.33E-07	4.06E-12	8.21E-17	1.60E-17
Po211	2.94E-19	4.77E-08	7.30E-10	3.78E-21	1.29E-09
Po212		9.54E-04	1.70E-05		
Po213	3.00E-18	5.33E-04	1.72E-04	4.02E-18	
Po214		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Po215	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Po216		1.49E-03	2.65E-05		
Po218		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Pr144			3.93E+00	1.54E+00	1.59E-02
Pu238		4.67E+01	6.09E+01	9.27E-01	3.90E+00
Pu239	4.00E-01	3.35E+02	2.98E+01	3.30E-03	9.28E+01
Pu240		1.67E+02	1.13E+01	3.10E-03	
Pu241		4.67E+03	4.82E+01	7.77E-01	
Pu242		4.92E-03	1.01E-03	1.56E-05	
Pu244					
Ra223	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07
Ra224		1.49E-03	2.65E-05		
Ra225	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Ra226		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Ra228		1.60E-03	3.87E-05		
Rh106			6.64E-02	4.98E-01	3.38E-01
Rn219	1.05E-16	1.70E-05	2.61E-07	1.35E-18	4.60E-07

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received fr the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
Rn220		1.49E-03	2.65E-05		
Rn222		1.16E-06	3.26E-10	1.24E-14	7.25E-15
Ru106			6.64E-02	4.98E-01	3.38E-01
Sb125			9.81E-01	5.33E-01	2.79E+00
Sb126			6.35E-06		5.15E-05
Sb126m			4.53E-05		3.68E-04
Se79			2.05E-05		1.66E-04
Sm151			7.23E-02		5.82E-01
Sn119m			2.33E-06		5.20E-07
Sn121m			1.36E-03		1.09E-02
Sn126			4.53E-05		3.68E-04
Sr90	2.62E+00	6.46E+03	1.70E+03	5.70E+01	1.24E+02
Ta182			1.49E-07		
Tc99			1.18E-03		9.54E-03
Te125m			2.39E-01	1.30E-01	6.88E-01
Te127			5.78E-09		1.31E-10
Te127m			5.91E-09		1.34E-10
Th227	1.03E-16	1.68E-05	2.57E-07	1.33E-18	4.53E-07
Th228		1.49E-03	2.65E-05		
Th229	3.07E-18	5.45E-04	1.76E-04	4.11E-18	
Th230		2.42E-04	1.37E-06	4.36E-11	5.01E-11
Th231	4.73E-10	1.46E-01	5.41E-03	4.53E-12	8.78E-03
Th232		1.96E-03	7.51E-05	4.68E-21	
Th234		1.03E-02	1.38E-03	3.45E-15	2.00E-05
Tl207	1.05E-16	1.70E-05	2.60E-07	1.35E-18	4.58E-07
Tl208		5.35E-04	9.52E-06		
Tl209	6.63E-20	1.18E-05	3.79E-06	8.88E-20	

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	ETEC	HANF	INEL	KAPL	LANL
U233	6.55E-14	4.15E-01	3.91E-01	7.62E-14	
U234		1.29E+00	1.51E-01	4.98E-06	1.11E-05
U235	4.73E-10	1.46E-01	5.41E-03	4.53E-12	8.78E-03
U236		8.63E-05	3.52E-06	1.24E-10	
U237		1.15E-01	1.18E-03	1.91E-05	
U238		1.03E-02	1.38E-03	3.45E-15	2.00E-05
U240					
Y90	2.62E+00	6.46E+03	1.70E+03	5.70E+01	1.24E+02
Zr93			2.65E-04		2.15E-03
Zr95			2.38E-12		9.64E-15
TOTAL	**1.31E+01**	**3.23E+04**	**7.39E+03**	**2.43E+02**	**6.30E+02**

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	TOTAL
Ac225	8.80E-14	3.02E-01	2.96E-15	6.40E-18	7.44E-15	3.03E-01
Ac227	9.88E-13	7.17E-04	4.20E-13	2.77E-20		7.35E-04
Ac228	3.63E-18	8.73E-02				8.89E-02
Ag110						5.12E-09
Ag110m						3.85E-07
Am241	4.85E-01	2.41E+02	6.79E-02	1.02E-02	5.39E-01	4.82E+02
Am243		9.98E-05	1.60E-05			8.07E-04
Am245		8.61E-16				8.61E-16
At217	8.80E-14	3.02E-01	2.96E-15	6.40E-18	7.44E-15	3.03E-01
Ba137m		9.25E+03	6.49E+00		5.06E+01	1.79E+04
Bi210		2.39E-07	1.24E-16		1.51E-12	4.72E-07
Bi211	9.88E-13	7.19E-04	4.20E-13	2.77E-20		7.37E-04
Bi212	2.08E-18	8.51E-02				8.66E-02

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received frc the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	TOTAL
Bi213	8.80E-14	3.02E-01	2.96E-15	6.40E-18	7.44E-15	3.03E-01
Bi214		1.66E-06	1.64E-14	7.34E-20	2.38E-11	2.82E-06
Bk249		5.94E-11				5.94E-11
C14		6.12E+00				6.15E+00
Cd113m						1.00E-06
Ce144		1.20E+01				1.75E+01
Cf249		1.34E-02				1.34E-02
Cf250	1.81E-01					1.81E-01
Cf252		3.86E+00				3.86E+00
Cm243		1.48E+02				1.48E+02
Cm244	1.55E+02	9.44E+02	4.68E+00			1.10E+03
Cm245		4.39E-06				4.39E-06
Cm246	3.95E-04					3.95E-04
Cm248		6.14E-04				6.14E-04
Co58						4.37E-11
Co60		6.17E+02				9.73E+02
Cr51						1.08E-05
Cs134		9.56E+00				6.81E+01
Cs135						2.15E-04
Cs137		9.78E+03	6.86E+00		5.35E+01	1.89E+04
Eu152		3.66E+03				3.66E+03
Eu154		1.77E+03				1.77E+03
Eu155		3.51E+02				3.53E+02
Fe55						5.97E-01
Fr221	8.80E-14	3.02E-01	2.96E-15	6.40E-18	7.44E-15	3.03E-01
Fr223	1.36E-14	9.90E-06	5.80E-15	3.82E-22		1.01E-05
H3		7.71E-02				2.20E-01

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	TOTAL
Kr85						5.95E+00
Mn54						8.31E-02
Nb95		2.01E+00				2.01E+00
Nb95m		6.72E-03				6.72E-03
Ni63						3.50E+00
Np237	3.19E-06	8.39E+00	1.43E-05	1.01E-08	1.49E-06	8.39E+00
Np239		9.98E-05	1.60E-05			8.07E-04
Np240m		6.62E-11				6.62E-11
Pa231	6.39E-12	8.11E-05	2.67E-11	5.21E-19		1.47E-04
Pa233	3.19E-06	8.39E+00	1.43E-05	1.01E-08	1.49E-06	8.39E+00
Pa234	3.31E-21	3.96E-02				3.96E-02
Pa234m	2.54E-18	3.05E+01				3.05E+01
Pb209	8.80E-14	3.02E-01	2.96E-15	6.39E-18	7.44E-15	3.03E-01
Pb210		2.39E-07	1.24E-16		1.51E-12	4.72E-07
Pb211	9.88E-13	7.19E-04	4.20E-13	2.77E-20		7.37E-04
Pb212	2.08E-18	8.51E-02				8.66E-02
Pb214		1.66E-06	1.64E-14	7.34E-20	2.38E-11	2.82E-06
Pd107						3.18E-05
Pm147			1.34E+00			3.19E+01
Po210		2.39E-07	3.40E-17		1.51E-12	4.72E-07
Po211	2.77E-15	2.01E-06	1.18E-15	7.74E-23		2.06E-06
Po212	1.34E-18	5.45E-02				5.55E-02
Po213	8.61E-14	2.95E-01	2.89E-15	6.26E-18	7.28E-15	2.96E-01
Po214		1.66E-06	1.64E-14	7.34E-20	2.38E-11	2.82E-06
Po215	9.88E-13	7.19E-04	4.20E-13	2.77E-20		7.37E-04
Po216	2.08E-18	8.51E-02				8.66E-02
Po218		1.66E-06	1.64E-14	7.34E-20	2.38E-11	2.82E-06

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received fr the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	TOTAL
Pr144		1.18E+01				1.73E+01
Pu238		2.82E+01	8.83E+00	4.92E-06	1.98E+01	1.69E+02
Pu239	2.36E+00	9.86E+01	1.06E-02	2.00E-06		5.59E+02
Pu240	2.54E-01	1.07E+00	5.06E-04			1.79E+02
Pu241	6.60E-05	3.98E-07				4.71E+03
Pu242	4.27E-09					5.94E-03
Pu244		6.63E-11				6.63E-11
Ra223	9.88E-13	7.19E-04	4.20E-13	2.77E-20		7.37E-04
Ra224	2.08E-18	8.51E-02				8.66E-02
Ra225	8.80E-14	3.02E-01	2.96E-15	6.40E-18	7.44E-15	3.03E-01
Ra226		1.66E-06	1.64E-14	7.34E-20	2.38E-11	2.82E-06
Ra228	3.63E-18	8.73E-02				8.89E-02
Rh106		3.21E+01				3.30E+01
Rn219	9.88E-13	7.19E-04	4.20E-13	2.77E-20		7.37E-04
Rn220	2.08E-18	8.51E-02				8.66E-02
Rn222		1.66E-06	1.64E-14	7.34E-20	2.38E-11	2.82E-06
Ru106		3.21E+01				3.30E+01
Sb125						4.30E+00
Sb126						5.78E-05
Sb126m						4.13E-04
Se79						1.86E-04
Sm151						6.55E-01
Sn119m						2.85E-06
Sn121m						1.23E-02
Sn126						4.13E-04
Sr90		3.53E+04	6.85E+00		1.96E+01	4.36E+04
Ta182						1.49E-07

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

Nuclide	NTS	ORNL	SRS	SNL/NM	WVDP	TOTAL
Tc99						1.07E-02
Te125m						1.06E+00
Te127						5.91E-09
Te127m						6.04E-09
Th227	9.74E-13	7.09E-04	4.14E-13	2.73E-20		7.27E-04
Th228	2.08E-18	8.51E-02				8.66E-02
Th229	8.80E-14	3.02E-01	2.96E-15	6.40E-18	7.44E-15	3.03E-01
Th230		6.64E-04	1.13E-10	2.54E-16	1.92E-08	9.07E-04
Th231	3.71E-08	5.53E-01	1.26E-06	9.85E-15		7.13E-01
Th232	1.24E-17	9.92E-02	1.24E-22			1.01E-01
Th234	2.54E-18	3.05E+01				3.05E+01
Tl207	9.85E-13	7.17E-04	4.19E-13	2.76E-20		7.35E-04
Tl208	7.49E-19	3.06E-02				3.11E-02
Tl209	1.90E-15	6.52E-03	6.39E-17	1.38E-19	1.61E-16	6.54E-03
U233	1.40E-10	4.36E+02	6.26E-11	6.67E-14	2.76E-11	4.36E+02
U234	2.02E-23	1.02E+01	2.51E-05	2.81E-11	4.94E-04	1.17E+01
U235	3.71E-08	5.53E-01	1.26E-06	9.85E-15		7.13E-01
U236	5.24E-08	2.82E-01	7.54E-12			2.82E-01
U237	1.62E-09	9.74E-12				1.16E-01
U238	2.54E-18	3.05E+01				3.05E+01
U240		6.62E-11				6.62E-11
Y90		3.53E+04	6.85E+00		1.96E+01	4.36E+04
Zr93						2.41E-03
Zr95		9.06E-01				9.06E-01
Total by Site	**1.58E+02**	**9.81E+04**	**4.20E+01**	**1.02E-02**	**1.64E+02**	**1.39E+05**

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received fr the site.

RH-TRU Curies on a Site-by-Site Basis (continued)

ABBREVIATIONS

ETEC Energy Technology Engineering Center
HANF Hanford
INEL Idaho National Engineering Laboratory
KAPL Knolls Atomic Power Laboratory
LANL Los Alamos National Laboratory
NTS Nevada Test Site
ORNL Oak Ridge National Laboratory
SRS Savannah River Site
SNL/NM Sandia National Laboratory-Albuquerque
WVDP West Valley Demonstration Plant

[1]Argonne National Laboratory-West is not included in this table because no radionuclide data were received from the site.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix BRAGFLO

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

WIPP PA User's Manual for BRAGFLO

ERRATA

All references to rock compressibility in the BRAGFLO appendix are synonymous with definitions of pore compressibility or formation compressibility.

WIPP PA

User's Manual

for

BRAGFLO, Version 4.00

Document Version 1.01

WPO # 30703

January 31, 1996

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Acronyms

BRAGFLO.....Brine And Gas FLOw

CCA .....Compliance Certification Application

DEC .....Digital Electronic Corporation

DOE.....U.S. Department of Energy

DRZ .....Disturbed Rock Zone

PA .....Performance Assessment

PREBRAG.....Preprocessor for BRAGFLO

QA.....Quality Assurance

VMS.....Virtual Memory System (a DEC operating system)

WIPP.....Waste Isolation Pilot Plant

1.0 INTRODUCTION

This document serves as a User's Manual for BRAGFLO, as used in the 1996 WIPP PA calculation. As such, it describes the code's purpose and function, the user's interaction with the code, and the models and methods employed by the code. Examples of user-accessible input and output files are included for the user's convenience.

1.1 Software Identifier

Code Name: BRAGFLO
WIPP Prefix: BF2
Version Number: 4.00 2/9/96
Platform: FORTRAN 77 for OpenVMS AXP, ver 6.1, on DEC Alpha

The previous version of BRAGFLO was Version 3.62ZO, 9/8/95.

The previous version of the User's Manual was WPO # 24179, Version 1.00, dated 10/3/95.

1.2 Points of Contact

1.2.1 Code Sponsor

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2.0 FUNCTIONAL REQUIREMENTS

R.1 Input defining the problem to be run is read in, including mesh size, simulation time specifications, and output files to be used.

R.2 The time and/or frequency of output to each output file and the variables whose values will be output are specified in the input.

R.3 The code reads input defining the finite difference grid for the problem to be run, including values of Δx, Δy, and Δz, and elevations of grid block centers, or input parameters that allow BRAGFLO to calculate the elevations. These input parameters may also specify how the mesh is rotated or dipped relative to a reference right hand coordinate system.

R.4 The default boundary conditions are no-flow conditions. BRAGFLO also allows constant pressure (Dirichlet) boundary conditions to be applied at specified grid blocks. The Dirichlet conditions fix the brine pressure and gas saturation at their initial values.

R.5 The following initial conditions are specified on input at each grid block: brine pressure, brine saturation, iron concentration, and the concentration of biodegradables.

R.6 Parameters are input that control the numerical behavior of BRAGFLO. These include specifications of convergence tolerances, iteration limits, upstream weighting control parameters, dependent variable increments used to calculate Jacobian element derivatives numerically, and the solver to be used. Only two solvers are currently available, the original LU decomposition solver and the point successive overrelaxation (SOR) solver, and only the original LU decomposition solver will be used in WIPP compliance calculations.

R.7 Material maps at specified times are input. For each material, material properties are input, including two-phase flow parameters, intrinsic permeabilities, reference condition porosities, and compressibilities. Also specified are the relative permeability and capillary pressure model to be used for each material.

R.8 Relative permeabilities and capillary pressure are calculated for each material using one of several available models. The compliance calculations will use either a modified Brooks-Corey model or a van Genuchten/Parker model. Some of the QA tests use relative permeability models that are included in BRAGFLO specifically for those tests.

R.9 A simplified rock fracture model allows the porosity and permeability to increase as pore pressure increases above a threshold value, simulating a fracture network.

R.10 The Klinkenberg effect is included, allowing the gas-phase permeability to become elevated over the intrinsic brine-phase permeability at low pressures in low-permeability materials.

R.11 Brine salinity, density at reference conditions, and compressibility are specified by input values, and the density of brine varies as a function of pressure.

R.12 Gas properties are given by the Redlich-Kwong-Soave (RKS) equation of state. The WIPP compliance calculations will use a single pure gas, H_2.

R.13 Two chemical reactions are modeled in BRAGFLO: anoxic corrosion of iron and microbial degradation of cellulosics. Both of these reactions produce gas (H_2) and consume brine according to specified stoichiometry. Reaction rates are specified for brine-inundated conditions and for humid conditions.

R.14 The effects of salt creep, whereby the surrounding halite closes in on the waste or other excavated regions, compressing them, may be simulated in BRAGFLO. Using this model, the porosity of the waste changes with time and brine pressure. BRAGFLO version 4.00 uses a "porosity surface" for the waste that is similar to that used in version 3.62ZO, but based on improved models of creep closure and new results from SANCHO simulations.

R.15 BRAGFLO numerically calculates the flow of two phases, brine and gas, in porous media as a function of time and space, using an implicit finite difference method with variable time step control.

R.16 Well models in BRAGFLO allow simulation of wells that are completed within the formations or porous media being modeled. The types of wells that can be modeled are constant injection or production rate wells and constant downhole pressure wells.

R.17 BRAGFLO simulates flow through heterogeneous as well as homogeneous porous media.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

In order to run the BRAGFLO code successfully, the user will need a basic knowledge of

- Open VMS
- Digital Command Language
- Sandia's CAMDAT database.

In addition, users should also have access to the WIPP cluster of Alpha microcomputers.

To interpret the input to and results from BRAGFLO, users should have:

- knowledge of basic mathematics through calculus and computational linear algebra
- an understanding of two-phase flow in porous media.

4.0 DESCRIPTION OF THE MODELS AND METHODS

Quantification of the effects of gas and brine flow on radionuclide transport for undisturbed and disturbed conditions requires use of a two-phase flow code. For performance assessment, the DOE uses the two-phase flow code BRAGFLO to simulate gas and brine flow as well as to incorporate the effects of disposal room consolidation and closure, gas generation, and interbed fracture in response to gas pressure. This section develops the governing equations for BRAGFLO,

its initial and boundary conditions, and the submodels incorporated in BRAGFLO that were developed specifically for performance assessment of the WIPP.

4.1 One-Dimensional Fluid Flow in Porous Media

Historically, BRAGFLO was developed as a two phase flow model for petroleum production applications. For this reason, BRAGFLO uses terminology common to the petroleum industry. Further details of the concepts necessary for the finite difference solution of reservoir simulation problems are available in Peaceman (1977), Aziz and Settari (1979), and Thomas (1982).

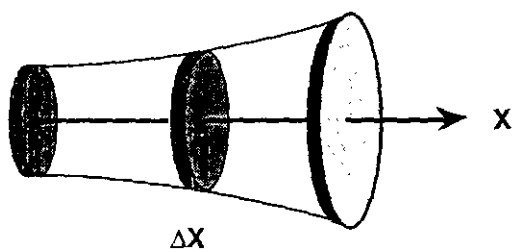

TRI-6342-3875-0 (a)

Figure 1. One dimensional reservoir with area-normal-to-flow as a function of x.

We consider now the material balance equation governing the flow of a fluid in a one dimensional porous media. Figure 1 shows a one-dimensional reservoir with area-normal-to-flow as a function of x; Area = A(x). The flow streamlines will actually flare in or out due to the variable area. However, we make the assumption that density and velocity are representative of average properties over the area normal to flow. From the reservoir, select an element of volume of incremental length Δx.

Let

Q = volume flow rate $[l^3/t]$
ρ = fluid density $[m/l^3]$
q = mass flow rate $[m/t]$
v = flow velocity $[l/t]$
ϕ = porosity [pore volume/bulk volume]
A = normal cross-section area $[l^2]$

where the generic units are:

m = mass
l = length
t = time.

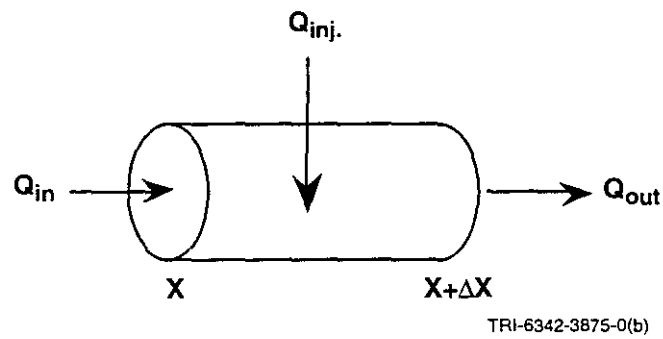

Figure 2. Element of volume of length Δx.

The mass rate and volume rate of flow are related by $q = \rho Q$.

The sign convention on Q_{inj} is

$Q_{inj} > 0$, injection,
$Q_{inj} < 0$, production.

Also, Q_{inj} = volume rate/injected volume, which implies fluid injection is uniformly distributed over control volume $A\Delta x$.

Mass balance requires that

$$q_{in} - q_{out} + q_{inj} A\Delta x = \text{change in fluid mass/time}$$

where

$$q_{inj} = \text{mass injection rate/unit volume.}$$

Now

$$q_{in} = (vA\rho)_x$$

$$q_{out} = (vA\rho)_{x+\Delta x}$$

and

$$\text{rate of change of fluid mass} = \frac{\partial}{\partial t}(\phi A\Delta x\rho).$$

The mass balance is then

$$(vA\rho)_x - (vA\rho)_{x+\Delta x} + q_{inj} A\Delta x = \frac{\partial}{\partial t}(\phi A\Delta x\rho)$$

Express the area as $A = \alpha(x)$, then dividing by Δx yields

$$\frac{(\alpha v \rho)_x - (\alpha v \rho)_{x+\Delta x}}{\Delta x} + \alpha q_{inj} = \frac{\partial}{\partial t}(\alpha \phi \rho).$$

In the limit as $\Delta x \to 0$, we get the material balance equation for one-dimensional single phase flow

$$-\frac{\partial}{\partial x}(\alpha v \rho) + \alpha q_{inj} = \frac{\partial}{\partial t}(\alpha \phi \rho)$$

4.2 Darcy's Law

For the viscous flow of a fluid through a porous media the flow velocity is related to the fluid potential by Darcy's Law. Henry Darcy (1856) at Dijon, France, developed a mathematical model from empirical data gathered in experiments using the device illustrated in Figure 3.

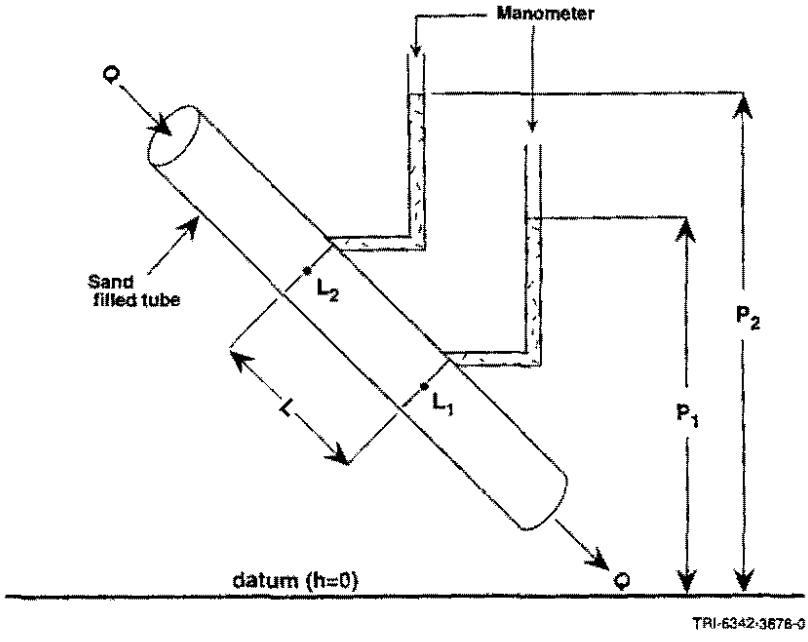

Figure 3. Experiment for illustration of Darcy's Law.

In Figure 3, Q is volume flow rate [l^3/t] and positive distance is measured from L_2 to L_1. Potential is measured as

$$\Phi = p + \rho gh$$

where depth, h, is measured positive upward from a reference datum and gravity acts downward. For example, a fluid in gravity equilibrium, Φ = constant, exhibits a pressure increase with decrease in depth.

Darcy observed that

$$Q > 0, \text{ if } \Phi_2 > \Phi_1$$
$$Q < 0, \text{ if } \Phi_2 < \Phi_1$$

$$Q = 0, \text{ if } \Phi_2 = \Phi_1.$$

The implication is that flow is in the direction of decreasing potential. Next, Darcy observed that if $\Phi_2 - \Phi_1$ is doubled, Q is doubled. Thus

$$Q \approx \Phi_2 - \Phi_1 \quad (\approx \text{ is read proportional to})$$

Also, if L is doubled, Q is halved. Thus

$$Q \approx \frac{\Phi_2 - \Phi_1}{L}$$

If cross-sectional area is doubled, Q is doubled. Thus

$$Q \approx \frac{A(\Phi_2 - \Phi_1)}{L}$$

If the fluid is changed (different viscosity), then

$$Q \approx \frac{A(\Phi_2 - \Phi_1)}{\mu L}$$

Finally,

$$Q = \frac{kA(\Phi_2 - \Phi_1)}{\mu L}$$

where the constant of proportion, k, is called the absolute permeability of the media. The differ-

ential form of Darcy's Law is obtained when $L \rightarrow 0$,

$$Q = \frac{-kA}{\mu}\frac{d\Phi}{dx}.$$

The negative sign in Darcy's Law indicates flow is in the direction of decreasing potential.

The units used in BRAGFLO are

$$Q = m^3/s$$

$$A = m^2$$

$$\mu = Pa \cdot s$$

$$\frac{d\Phi}{dx} = \frac{Pa}{m}$$

The units for permeability are

$$k = \left[\frac{m^3}{s}\right]\left[Pa \cdot s\right]\left[\frac{1}{m^2}\right]\left[\frac{m}{Pa}\right] = m^2.$$

Velocity is given by

$$v = \frac{Q}{A} = -\frac{k}{\mu}\frac{d\Phi}{dx},$$

where v is called the Darcy velocity or superficial flow velocity. The quantity

$$V = \frac{Q}{A\phi} = \frac{v}{\phi} = \frac{\text{bulk volume}}{\text{normal area}} / \text{time}$$

is called the interstitial or average linear velocity, where ϕ is the formation porosity.

The distinction between the Darcy velocity and the intersticial velocity is demonstrated in Figure 4. Assume fluid in the unit bulk volume at the left end of the reservoir is displaced by a piston over unit time into a media with porosity $\phi = 0.20$. The cubic meter of fluid will occupy 5 m^3 of the porous material and the fluid will advance to a position 5 meters from the interface. The velocity of the fluid in the bulk volume is Q/A or the Darcy velocity, while the fluid velocity in the porous material is $Q/A/\phi$ or the intersticial velocity. For example, if a tracer element were introduced into the porous material it would travel at the intersticial velocity. The Darcy velocity is the rate at which the bulk volume is transported.

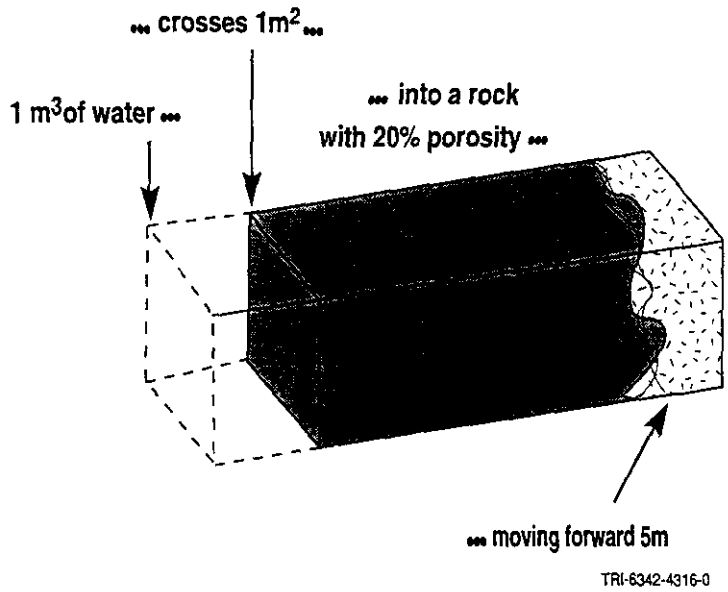

Figure 4. Bulk volume vs. Porous Media Displacement.

4.3 Permeability Tensor, Darcy's Law, and Material Balance in Higher Dimension

The permeability of a geological formation can be direction dependent (anisotropic). For example, a sedimentary formation may consist of uniform sand or lime laminae of high permeability alternating with thin, uniform layers of silty, shaley laminae of low permeability. The large scale permeability characteristics can be approximated as uniformly anisotropic. That is, the layered system is replaced by a homogeneous system having permeabilities k_1 parallel to the plane of the laminae and k_2 normal to this plane. Further, the direction of the laminae may not be parallel or normal to the formation boundary as evident in a cross-bedded structure.

Figure 5 shows two cartesian coordinate systems (ξ,η) and (x,y). Suppose the principal permeabilities are given with respect to (ξ,η) system with k_1 the permeability in the ξ direction and k_2 the permeability in the η direction. Further, assume the reservoir geometry is aligned with respect to the (x,y) system, which implies that the fluid flow equations are to be formulated with respect to the x,y axes.

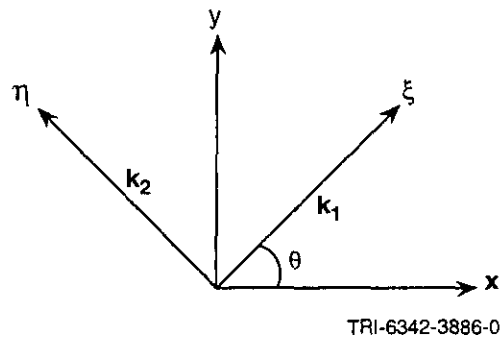

Figure 5. Permeability with anisotropic values k_1 and k_2 in direction ξ and η

The coordinate transformation from the (ξ,η) system to the (x,y) system is

$$x = \xi \cos\theta - \eta \sin\theta.$$

$$y = \xi \sin\theta + \eta \cos\theta.$$

If $\hat{1}_\xi$ and $\hat{1}_\eta$ represent the unit vectors in the ξ,η directions, respectively, then the Darcy velocity vector is

$$\hat{v} = -\frac{k_1}{\mu}\frac{\partial\Phi}{\partial\xi}\hat{1}_\xi - \frac{k_2}{\mu}\frac{\partial\Phi}{\partial\eta}\hat{1}_\eta.$$

The coordinate transformation maps the unit vectors into

$$\hat{1}_\xi \rightarrow \cos\theta\,\hat{1}_x + \sin\theta\,\hat{1}_y$$

and

$$\hat{1}_\eta \rightarrow -\sin\theta\,\hat{1}_x + \cos\theta\,\hat{1}_y.$$

The chain rule gives

$$\frac{\partial\Phi}{\partial\xi} = \cos\theta\frac{\partial\Phi}{\partial x} + \sin\theta\frac{\partial\Phi}{\partial y}$$

and

$$\frac{\partial\Phi}{\partial\eta} = -\sin\theta\frac{\partial\Phi}{\partial x} + \cos\theta\frac{\partial\Phi}{\partial y}.$$

Then the Darcy velocity is

$$\hat{v} = \frac{-k_1}{\mu}\left(\cos\theta\frac{\partial\Phi}{\partial x} + \sin\theta\frac{\partial\Phi}{\partial y}\right)\left(\cos\theta\,\hat{1}_x + \sin\theta\,\hat{1}_y\right)$$
$$\frac{-k_2}{\mu}\left(-\sin\theta\frac{\partial\Phi}{\partial x} + \cos\theta\frac{\partial\Phi}{\partial y}\right)\left(-\sin\theta\,\hat{1}_x + \cos\theta\,\hat{1}_y\right).$$

The vector components of the Darcy velocity are

$$v_x = \frac{-k_1}{\mu}\left(\cos^2\theta\frac{\partial\Phi}{\partial x} + \sin\theta\cos\theta\frac{\partial\Phi}{\partial y}\right)$$
$$\frac{-k_2}{\mu}\left(\sin^2\theta\frac{\partial\Phi}{\partial x} - \sin\theta\cos\theta\frac{\partial\Phi}{\partial y}\right),$$

$$v_y = \frac{-k_1}{\mu}\left(\sin\theta\cos\theta\frac{\partial\Phi}{\partial x} + \sin^2\theta\frac{\partial\Phi}{\partial y}\right)$$
$$\frac{-k_2}{\mu}\left(-\sin\theta\cos\theta\frac{\partial\Phi}{\partial x} + \cos^2\theta\frac{\partial\Phi}{\partial y}\right).$$

The dependence of the Darcy velocity components on pressure gradients in both x and y direction will add significantly to the complexity of the material balance equation in 2-dimensions. A similar analysis with more complexity could be performed in 3-dimensions.

A significant simplification occurs if the directions of the permeability tensor are aligned with the reservoir coordinate axis; that is, $\theta = 0$. If $\theta = 0$, then

$$v_x = \frac{-k_1}{\mu}\frac{\partial\Phi}{\partial x} \quad \text{and} \quad v_y = \frac{-k_2}{\mu}\frac{\partial\Phi}{\partial y}.$$

BRAGFLO makes this assumption. Thus, in three dimensions with anisotropic permeability, the components of the Darcy velocity are

$$v_x = \frac{-k_x}{\mu}\frac{\partial\Phi}{\partial x},\ v_y = \frac{-k_y}{\mu}\frac{\partial\Phi}{\partial y},\ v_z = \frac{-k_z}{\mu}\frac{\partial\Phi}{\partial z}$$

where k_x, k_y, k_z are input permeabilities in the direction of the corresponding coordinate axes.

To generalize the flow equation to higher dimension, we replace the flux term with (Peaceman, 1977)

$$\nabla \bullet \left(\frac{\alpha \rho [k]}{\mu} \nabla \Phi \right) = \left(\frac{\partial}{\partial x} \hat{i} + \frac{\partial}{\partial y} \hat{j} + \frac{\partial}{\partial z} \hat{k} \right) \bullet \left(\frac{\alpha \rho k_x}{\mu} \frac{\partial \Phi}{\partial x} \hat{i} + \frac{\alpha \rho k_y}{\mu} \frac{\partial \Phi}{\partial y} \hat{j} + \frac{\alpha \rho k_z}{\mu} \frac{\partial \Phi}{\partial z} \hat{k} \right)$$
$$= \frac{\partial}{\partial x} \left(\frac{\alpha \rho k_x}{\mu} \frac{\partial \Phi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{\alpha \rho k_y}{\mu} \frac{\partial \Phi}{\partial y} \right) + \frac{\partial}{\partial z} \left(\frac{\alpha \rho k_z}{\mu} \frac{\partial \Phi}{\partial z} \right)$$

where

[k] = permeability tensor,

α = area normal to flow direction in one dimension (x), or

= thickness normal to flow plane in two-dimensions (x,y), or

= 1 in three-dimensions (x,y,z).

The three-dimensional flow of a single fluid incorporating Darcy's law is

$$\frac{\partial}{\partial x} \left(\frac{\alpha \rho k_x}{\mu} \frac{\partial \Phi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{\alpha \rho k_y}{\mu} \frac{\partial \Phi}{\partial y} \right) + \frac{\partial}{\partial z} \left(\frac{\alpha \rho k_z}{\mu} \frac{\partial \Phi}{\partial z} \right) + \alpha q_{inj} = \frac{\partial}{\partial t} (\alpha \phi \rho)$$

4.4 Equation of State

From the previous section the three dimensional flow of a single phase fluid is governed by the equation

$$\frac{\partial}{\partial x} \left(\frac{\alpha \rho k_x}{\mu} \frac{\partial \Phi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{\alpha \rho k_y}{\mu} \frac{\partial \Phi}{\partial y} \right) + \frac{\partial}{\partial z} \left(\frac{\alpha \rho k_z}{\mu} \frac{\partial \Phi}{\partial z} \right) + \alpha q_{inj} = \frac{\partial}{\partial t} (\alpha \phi \rho)$$

This equation has two dependent variables, pressure, p, and density, ρ. Independent variables are space (x, y, and z) and time (t). We must relate ρ and p and hence eliminate one of the dependent variables. This problem is generally treated over three fluid regimes:

- incompressible fluid (ρ = constant)
- slightly compressible fluid (water, oil)
- highly compressible fluid (gas)

The incompressible fluid assumption is not valid for most applications and will not be considered.

Slightly compressible fluid assumes:

$$\frac{d\rho}{dp} = c\rho,$$

where c is fluid compressibility.

For ideal fluid c = constant. Then the differential equation can be solved as

$$\rho = \rho_0 \exp\left(c\left(p - p_0\right)\right)$$

where ρ_0 is density at reference pressure p_0. This is the equation BRAGFLO uses to evaluate brine density.

Recall

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

and if x is close to zero

$$e^x \cong 1 + x.$$

Therefore, if $c(p-p_o)$ is relatively small, then

$$\rho \cong \rho_0\left(1 + c\left(p - p_0\right)\right).$$

This linearization is sometimes used as an approximation to the exponential density function.

A highly compressible fluid such as gas requires a real gas equation of state

$$\rho = \rho(p,T)$$

which, for isothermal flow, gives density as a function of pressure. BRAGFLO uses the Redlich-Kwong-Soave equation of state to relate gas density to pressure (Walas, 1985).

The formation rock behaves as a slightly compressible material which yields an expression for porosity analogous to the expression for brine density. In BRAGFLO the formation porosity is evaluated as

$$\phi = \phi_0 \exp\left(c_r\left(p - p_0\right)\right)$$

where ϕ_o is the porosity at reference pressure p_o and c_r denotes rock compressibility.

With the equation of state the material balance equation is formulated and solved in terms of a single dependent variable, namely pressure. Note that the partial differential equation (PDE) is nonlinear. Nonlinearity occurs from several sources:

- nonlinear dependence of density on pressure
- product of density and pressure gradient
- product of porosity and density in accumulation term since porosity is pressure dependent due to rock compressibility
- viscosity could be pressure dependent for gases, however, BRAGFLO treats viscosity constant for both water and gas.

For the one-dimensional case of the equation presented at the end of Section 4.3,

$$\frac{\partial}{\partial x}\left(\frac{\alpha\rho k_x}{\mu}\frac{\partial\phi}{\partial x}\right)+q_{inj}=\frac{\partial}{\partial t}(\alpha\phi\rho)$$

the material balance equation (PDE) requires:

initial conditions:

$$p(x,0) = f(x),\ \ 0 \le x \le L$$

and

boundary conditions:

$$p(0,t) = g_o(t), \qquad p(L,t) = g_L(t),\ \ t \ge 0$$

or

$$\frac{\partial p}{\partial x}(0,t) = g_o(t), \qquad \frac{\partial p}{\partial x}(L,t) = g_L(t) \qquad t \ge 0.$$

The first type of boundary condition in which the solution is specified at the boundary is called a Dirichlet boundary condition. The condition in which the pressure gradient is specified is called a Neumann boundary condition. Generally, most reservoir simulations assume $\frac{\partial p}{\partial x} = 0$ on the boundary (no flow boundary condition). The boundary condition may be of mixed type. BRAGFLO assumes a no flow Neumann type boundary condition at all exterior grid boundaries.

BRAGFLO has the capability of maintaining (Dirichlet condition) pressure and/or saturation at specified grid blocks. This allows the maintenance of initial conditions at far field locations in the upper formations such as the Culebra.

4.5 Finite Difference and Discretization of Material Balance Equation

Recall Taylor's formula with remainder for a function f expanded about x_o

$$f(x) = f(x_o) + f'(x_o)(x - x_o) + \frac{f^{(2)}(x_o)}{2!}(x - x_o)^2$$
$$+ \ldots + \frac{f^{(n)}(x_o)}{n!}(x - x_o)^n + \frac{f^{(n+1)}(\xi)}{(n+1)!}(x - x_o)^{n+1}$$

where ξ is the interval between x and x_o. Thus

$$f(x) = p(x) + R_n(x,x_o)$$

or

$$f(x) - p(x) = R_n(x,x_o).$$

If $f^{(n+1)}$ is continuous on some interval [a,b] containing, x,x_o, then $f^{(n+1)}$ is bounded,

$$\left|f^{(n+1)}(x)\right| \le M,$$

and

$$\left|f(x) - p(x)\right| \le C\left|x - x_o\right|^{n+1}.$$

Therefore, as $x \to x_o$, the error goes to zero like $(x-x_o)^{n+1}$. Consider the following derivative approximations. First order forward difference requires the Taylor formula:

$$f(x) = f(x_o) + f'(x_o)(x - x_o) + R_2(x,x_o)$$

Let $x = x_o + h$, then

$$\left|\frac{f(x_o + h) - f(x_o)}{h} - f'(x_o)\right| = \left|\frac{R_2(x,x_o)}{h}\right| \le \frac{Ch^2}{h} = Ch.$$

The difference approximation

$$f'(x_o) \cong \frac{f(x_o + h) - f(x_o)}{h}$$

is said to be first order in h. This type of approximation is used for the time derivative.

Second order central approximation:

$$f(x_o + h) = f(x_o) + f'(x_o)h + \frac{f^{(2)}(x_o)}{2!}h^2 + R_3(x_o, x_o + h)$$

$$f(x_o - h) = f(x_o) - f'(x_o)h + \frac{f^{(2)}(x_o)}{2!}h^2 + R_3(x_o, x_o - h)$$

where subtraction yields

$$f(x_o + h) - f(x_o - h) = 2hf'(x_o) + R_3(x_o, x_o + h) - R_3(x_o, x_o - h).$$

This is rearranged to give:

$$\frac{f(x_o + h) - f(x_o - h)}{2h} - f'(x_o) = \frac{R_3(x_o, x_o + h) - R_3(x_o, x_o - h)}{2h}$$

which produces the estimate

$$\left| \frac{f(x_o + h) - f(x_o - h)}{2h} - f'(x_o) \right| \le \frac{Ch^3}{h} = Ch^2.$$

Therefore, the difference approximation $\frac{f(x_o + h) - f(x_o - h)}{h}$ is a second order approximation to $f'(x_o)$.

Consider discretization of the one-dimensional material balance equation:

$$\frac{\partial}{\partial x}\left(\frac{\alpha k \rho}{\mu}\frac{\partial p}{\partial x}\right) + \alpha q_{inj} = \frac{\partial}{\partial t}(\alpha \phi \rho),$$

where we assume the gradient of the depth is zero.
Space discretization requires the partition of the interval [0,L] into IM subintervals with length Δx_i, i=1,2,..., IM.

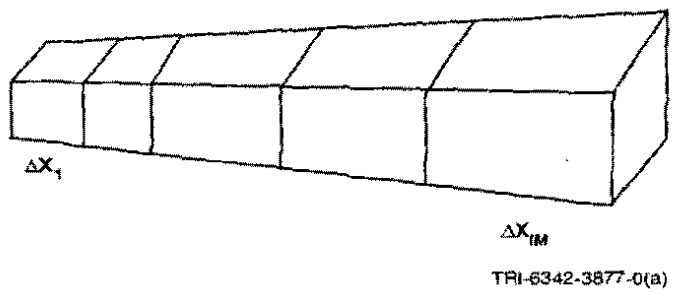

Figure 6. Partition interval [0,L] into IM subintervals.

Consider an arbitrary grid block i and its neighbors i-1, i+1 as shown in Figure 7.

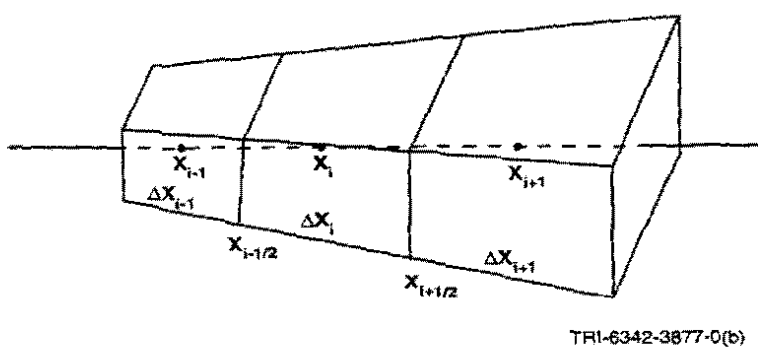

Figure 7. Depiction of arbitrary grid block.

We reference the location of the grid block interfaces as

$x_{i-1/2}$ = location of interface between i-1 and i,

$x_{i+1/2}$ = location of interface between i and i+1.

For example,

$$x_{i-1/2} = x_{i-1} + \Delta x_{i-1/2}.$$

On the ith grid block the partial derivative in the flux term is approximated by the 2nd order correct finite difference

$$\frac{\partial}{\partial x}\left(\frac{\alpha k \rho}{\mu}\frac{\partial p}{\partial x}\right) \cong \frac{\left(\frac{\alpha k \rho}{\mu}\frac{\partial p}{\partial x}\right)_{i+1/2} - \left(\frac{\alpha k \rho}{\mu}\frac{\partial p}{\partial x}\right)_{i-1/2}}{\Delta x_i}.$$

The partials are approximated at the interface by the 2nd order correct finite difference

$$\left(\frac{\alpha k \rho}{\mu}\frac{\partial p}{\partial x}\right)_{i-1/2} = \left(\frac{\alpha k \rho}{\mu}\right)_{i-1/2}\frac{p_i - p_{i-1}}{x_i - x_{i-1}}.$$

A similar expression exists at i + 1/2. If the gridding is nonuniform then the above approximations are no longer 2nd order correct.

Time discretization is as shown below.

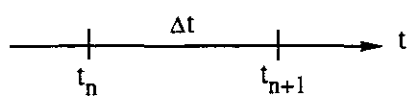

Assume the solution is known at time t_n, and we wish to compute a solution at time t_{n+1} with time step size $\Delta t = t_{n+1} - t_n$. The time discretization of the accumulation term in the ith grid block uses the first order correct finite difference

$$\frac{\partial}{\partial t}(\alpha \phi \rho) \cong \frac{(\alpha \phi \rho)_i^{n+1} - (\alpha \phi \rho)_i^n}{\Delta t},$$

where the superscript references the time index. The fully discretized system of equations can be written as

$$\frac{(\alpha\phi\rho)_i^{n+1}-(\alpha\phi\rho)_i^n}{\Delta t}-\frac{1}{\Delta x_i}\left(\frac{(\alpha k\rho)}{\mu}\right)_{i+1/2}\frac{p_{i+1}-p_i}{x_{i+1}-x_i}+\frac{1}{\Delta x_i}\left(\frac{(\alpha k\rho)}{\mu}\right)_{i-1/2}\frac{p_i-p_{i-1}}{x_i-x_{i-1}}-\alpha_i\left(q_{inj}\right)_i=0,$$

$$i=1,2,\ldots,IM.$$

In this equation, the time level is not indicated on the pressure and pressure dependent variables in the flux and injection terms.

If all the pressures and pressure dependent variables in the flux and source/sink terms are evaluated at the beginning of the time step, $t=t_n$, then the formulation is called explicit. If these quantities are evaluated at the end of the time step, $t=t_{n+1}$ the formulation is called implicit.

The numerical solution of the material balance equation starts at initial time with specified initial pressures. The evaluation of the pressure solution in time requires at each time step the solution of a system of nonlinear equations for the grid block pressures. The error introduced by the discretization of the continuum equation is called truncation error. Errors will also be introduced in the nonlinear equation solver since it will not solve the system exactly (see Subsection 4.6, Newton-Raphson Method). Another source of error involves the choice of discretization. A numerical artifact of the solution of evolution equations is that small errors introduced at early time can either be damped with time (stable) or grow with time (unstable). The errors in an unstable solution will usually grow large enough to dominate the solution with numerical noise. The numerical stability of a discretization can sometimes depend of the size of the space discretization (Δx) relative to the time discretization (Δt). In this case, the method is said to be conditionally stable.

In the above formulations (explicit, implicit) we observe that

Formulation Advantages:

Explicit is simplistic computationally.

Implicit is unconditionally stable.

Formulation Disadvantages:

Implicit is complex computationally.

Explicit is conditionally stable.

The stability question dictates that the BRAGFLO formulation be fully implicit. The evaluation of the interblock flux coefficients at $i\pm1/2$ will be discussed in Subsection 4.8, on Two Phase Flow.

4.6 Newton-Raphson Method for Solution of Nonlinear Algebraic Equations

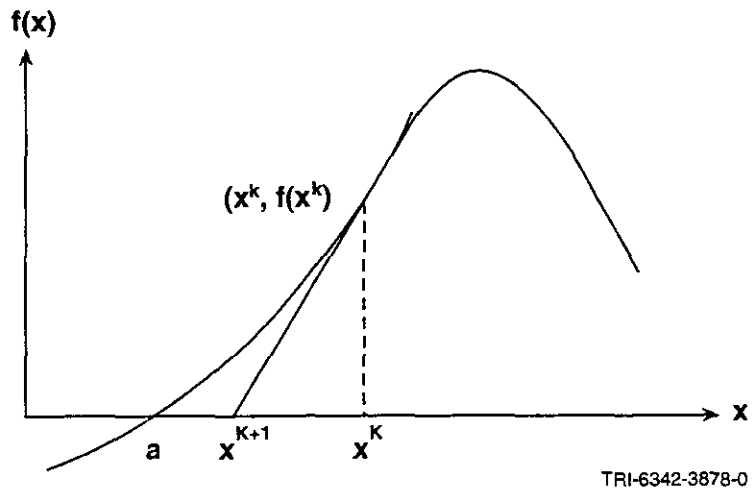

Figure 8. Newton-Raphson method.

Consider a real valued function of a real variable (scalar case). A root of f is a value x = a such that f(a) = 0. Let x^k be an approximation to the root of f (k^{th} iterate approximation). Expand f(x) in a Taylor series about x_k:

$$f(x) = f(x^k) + f'(x^k)(x - x^k) + \frac{f^{(2)}(x^k)}{2!}(x - x^k)^2 + \ldots = 0.$$

Replace the nonlinear root problem with the linear approximation:

$$f(x^k) + f'(x^k)(x - x^k) = 0$$

with solution $x = x^{k+1}$. Define

$$\delta x^k = x^{k+1} - x^k$$

Then

$$\delta x^k = -\frac{f(x^k)}{f'(x^k)},$$

and

$$x^{k+1} = x^k + \delta x^k.$$

The Newton-Raphson iteration requires an initial guess to the root. In Figure 8 it appears from the geometry that the iteration would proceed to the root of f. If the initial guess was not close to the solution, such as to the right of the maximum in Figure 8, then the iteration may not converge or it could converge to another solution. When solving the system of nonlinear material balance equations over a time step, the solution at the beginning of the time step is used as an initial guess for the Newton-Raphson iteration.

In general consider a system of n nonlinear equations (NLS) in n unknowns:

$$\begin{aligned} f_1(x_1,\ldots,x_n) &= 0 \\ f_2(x_1,\ldots,x_n) &= 0 \\ &\vdots \\ f_n(x_1,\ldots,x_n) &= 0 \end{aligned} \qquad \text{(NLS)}$$

In vector notation, the system is written

$$F(x_1,\ldots,x_n) = \begin{pmatrix} f_1(x_1,\ldots x_n) \\ \vdots \\ f_n(x_1,\ldots x_n) \end{pmatrix} = 0,$$

and further, if $\hat{x} = (x_1,\ldots,x_n)$, then, $F(\hat{x}) = 0$ is equivalent to (NLS).

Consider Newton-Raphson for n = 2. Let (x_1^k, x_2^k) be an approximation to the root of

$$\begin{aligned} f_1(x_1, x_2) &= 0 \\ f_2(x_1, x_2) &= 0. \end{aligned}$$

The Taylor series through linear terms expanded about $(x_1^k, x_2^k) = \hat{x}^k$ are

$$f_1(x_1,x_2) = f_1(x_1^k,x_2^k) + \frac{\partial f_1}{\partial x_1}(x_1^k,x_2^k)(x_1 - x_1^k) + \frac{\partial f_1}{\partial x_2}(x_1^k,x_2^k)(x_2 - x_2^k)$$

$$f_2(x_1,x_2) = f_2(x_1^k,x_2^k) + \frac{\partial f_2}{\partial x_1}(x_1^k,x_2^k)(x_1 - x_1^k) + \frac{\partial f_2}{\partial x_2}(x_1^k,x_2^k)(x_2 - x_2^k).$$

Replace the system of nonlinear equations

$$f_1(x_1, x_2) = 0$$
$$f_2(x_1, x_2) = 0$$

by the linear system

$$\frac{\partial f_1}{\partial x_1}(\hat{x}^k)(x_1^{k+1} - x_1^k) + \frac{\partial f_1}{\partial x_2}(\hat{x}^k)(x_2^{k+1} - x_2^k) = -f_1(\hat{x}^k)$$
$$\frac{\partial f_2}{\partial x_1}(\hat{x}^k)(x_1^{k+1} - x_1^k) + \frac{\partial f_2}{\partial x_2}(\hat{x}^k)(x_2^{k+1} - x_2^k) = -f_2(\hat{x}^k)$$

Define the change in iterate values

$$\delta x_1 = x_1^{k+1} - x_1^k$$
$$\delta x_2 = x_2^{k+1} - x_2^k.$$

Then the above linear system is written

$$\frac{\partial f_1}{\partial x_1}(\hat{x}^k)\delta x_1 + \frac{\partial f_1}{\partial x_2}(\hat{x}^k)\delta x_2 = -f_1(\hat{x}^k)$$
$$\frac{\partial f_2}{\partial x_1}(\hat{x}^k)\delta x_1 + \frac{\partial f_2}{\partial x_2}(\hat{x}^k)\delta x_2 = -f_2(\hat{x}^k)$$

The coefficient matrix

$$J(\hat{x}) = \begin{pmatrix} \frac{\partial f_1}{\partial x_1}(\hat{x}) & \frac{\partial f_1}{\partial x_2}(\hat{x}) \\ \frac{\partial f_2}{\partial x_1}(\hat{x}) & \frac{\partial f_2}{\partial x_2}(\hat{x}) \end{pmatrix}$$

is called the Jacobian matrix for the nonlinear system.

Then the $(k+1)^{th}$ iterative step of the Newton-Raphson method is

$$J(\hat{x}^k)\delta\hat{x} = -F(\hat{x}^k)$$

or

$$\delta\hat{x} = -J^{-1}(\hat{x}^k)F(\hat{x}^k)$$

and

$$\hat{x}^{k+1} = \hat{x}^k + \delta\hat{x}.$$

For a system of n equations in n unknowns the Jacobian matrix generalizes to

$$J(\hat{x}) = \begin{pmatrix} \frac{\partial f_1}{\partial x_1}(\hat{x}) \cdots \frac{\partial f_1}{\partial x_n}(\hat{x}) \\ \vdots \\ \frac{\partial f_n}{\partial x_1}(\hat{x}) \cdots \frac{\partial f_n}{\partial x_n}(\hat{x}) \end{pmatrix}$$

or

$$J(\hat{x})_{i,j} = \frac{\partial f_i}{\partial x_j}(\hat{x}).$$

The computation procedure in Newton-Raphson method computes the Jacobian matrix, $J(\hat{x}^k)$, and the function vector, $F(\hat{x}^k)$. The matrix inversion is equivalent to the solution of a system of linear equations which returns the change in iterate values. The iterates are then updated.

When analytical derivatives are not tractable, Newton-Raphson uses difference approximation for partials

$$\frac{\partial f_i}{\partial x_j}(\hat{x}) = \frac{f_i(x_1,\ldots,x_j+\Delta x_j,\ldots,x_n) - f_i(x_1,\ldots,x_n)}{\Delta x_j}.$$

The major computational effort involves the function evaluations. The above numerical approach to the Jacobian requires the evaluation of the function f n^2+n times.

If the Jacobian is evaluated by an analytic derivative then any change in the formulation of properties would require significant code changes. Also, some properties, see Characteristic Curves (Subsection 4.10), use different model descriptions with user input control. In this case it would be difficult to implement the analytic derivative treatment. For these reasons BRAGFLO uses the difference approximation for the Jacobian evaluation.

The modified Newton-Raphson algorithm is

$$J(\hat{x}^1)\delta\hat{x} = -F(\hat{x}^k),\ k = 1,2,\ldots,$$

that is, the Jacobian is not updated each iteration. In BRAGFLO the user can specify from input directives the iteration frequency for the Jacobian evaluation.

Consider now the solution of the nonlinear flow equation. The ith equation represents material balance in i^{th} grid block. Newton-Raphson iteration requires solution of the linear system

$$\begin{bmatrix} J_{11} & J_{12} \ldots & J_{1IM} \\ J_{21} & J_{22} \ldots & J_{2IM} \\ \vdots & & \\ J_{IM1} & J_{IM2} \ldots & J_{IMIM} \end{bmatrix} \begin{bmatrix} \delta p_1 \\ \delta p_2 \\ \vdots \\ \delta p_{IM} \end{bmatrix} = -\begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_{IM} \end{bmatrix}$$

and $p_i^{(k+1)} = p_i^{(k)} + \delta p_i$, where Jacobian and right hand side are evaluated at k^{th} iteration pressures. If the Newton-Raphson iteration converges then

$$\lim_{k \to \infty} p_i^{(k)} = p_i^{n+1}.$$

When testing for convergence during the Newton-Raphson iteration, the following test criteria are applied uniformly over all grid blocks:

- Test gas saturation and brine pressure for physically real values.
- Test if the change in gas saturation over an iteration is sufficiently small.
- Test if the gas material balance equation is satisfied.
- Test if the chance in brine pressure over an iteration is sufficiently small.
- Test if the brine material balance equation is satisfied.
- Test if the changes in gas saturation and brine pressure over the time step are sufficiently small.

See Section 7.2.6 for input parameters that specify when convergence has been obtained or that affect the rate of convergence.

From the flow equations we note the Jacobian matrix has a tridiagonal structure

$$\begin{bmatrix} J_{11} & J_{12} & o \cdots\cdots\cdots\cdots\cdots\cdots & o \\ J_{21} & J_{22} & J_{23} & \\ & \ddots & \ddots & \ddots \\ o \cdots\cdots & J_{i\,i-1} & J_{i\,i} & J_{i\,i+1} \cdots\cdots\cdots\cdots o \\ & & \ddots & \ddots & \ddots \\ o \cdots & & & J_{IM\,IM-1} & J_{IM\,IM} \end{bmatrix} \begin{bmatrix} \delta p_1 \\ \delta p_2 \\ \vdots \\ \delta p_i \\ \vdots \\ \delta p_{IM} \end{bmatrix} = -\begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_i \\ \vdots \\ F_{IM} \end{bmatrix}$$

For both storage and computational considerations the linear equation solver should take advantage of the banded structure. This is true for all the BRAGFLO solvers.

4.7 Discretization in Two-Dimensions

Consider the two dimensional flow equation

$$\frac{\partial}{\partial x}\left(\frac{\alpha k_x \rho}{\mu}\frac{\partial p}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\alpha k_y \rho}{\mu}\frac{\partial p}{\partial y}\right) + \alpha q_{inj} = \frac{\partial}{\partial t}(\alpha\phi\rho)$$

Discretized equation in 2-dimensions with implicit treatment of the well and flux terms is

$$\begin{aligned} &-\frac{(\alpha\phi\rho)_{i,j}^{n+1} - (\alpha\phi\rho)_{i,j}^{n}}{\Delta t} + \frac{1}{\Delta x_i}\left(\frac{\alpha k_x \rho}{\mu}\right)_{i+1/2,j}^{n+1} \frac{p_{i+1,j}^{n+1} - p_{i,j}^{n+1}}{x_{i+1} - x_i} \\ &-\frac{1}{\Delta x_i}\left(\frac{\alpha k_x \rho}{\mu}\right)_{i-1/2,j}^{n+1} \frac{p_{i,j}^{n+1} - p_{i-1,j}^{n+1}}{x_i - x_{i-1}} + \frac{1}{\Delta y_j}\left(\frac{\alpha k_y \rho}{\mu}\right)_{i,j+1/2}^{n+1} \frac{p_{i,j+1}^{n+1} - p_{i,j}^{n+}}{y_{j+1} - y_j} \\ &-\frac{1}{\Delta y_j}\left(\frac{\alpha k_y \rho}{\mu}\right)_{i,j-1/2}^{n+1} \frac{p_{i,j}^{n+1} - p_{i,j-1}^{n+1}}{y_j - y_{j-1}} + \alpha_{i,j}\left(q_{inj}\right)_{i,j} = 0. \end{aligned}$$

A typical two dimensional grid is shown in Figure 9.

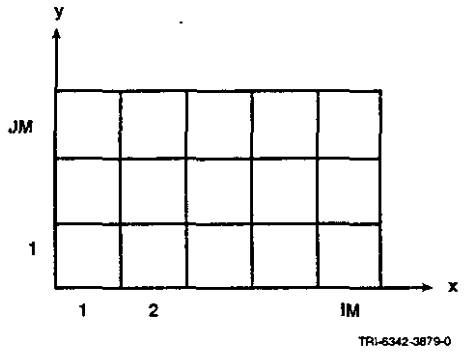

Figure 9. 2-dimensional grid.

A computational molecule or stencil is shown in Figure 10 and the stencil shows the indices of the pressures which appear in the material balance equation for the (i,j) grid block.

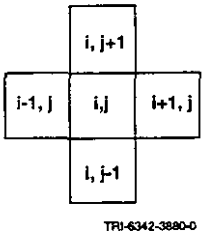

Figure 10. Computational molecule (or stencil).

With IM=5 and JM=3 in Figure 9, the number of equations is NEQ = IM * JM = 5 x 3 = 15. Suppose the equations or grid blocks are sequentially indexed as in Figure 11.

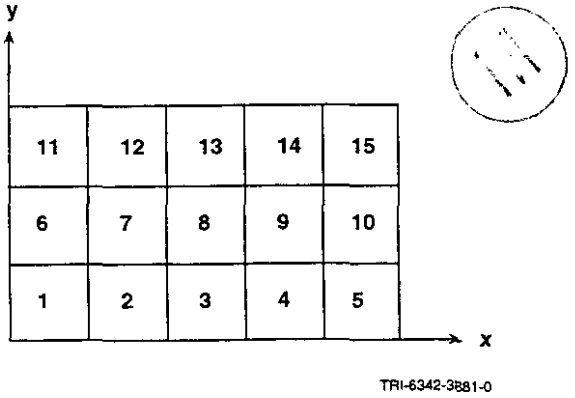

Figure 11. Sequential indexing of equations.

Then the Jacobian matrix has the structure shown in Figure 12 where * entries are the only non-zero values.

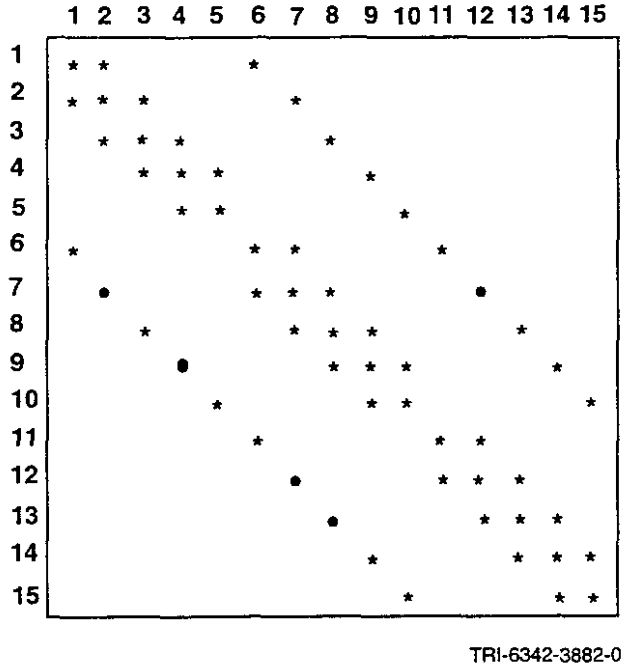

Figure 12. Jacobian matrix.

This is said to have penta-diagonal band structure, with bandwidth = IBW = 2 * IM + 1 (for the example, IBW=11).

Suppose the grid is indexed as in Figure 13.

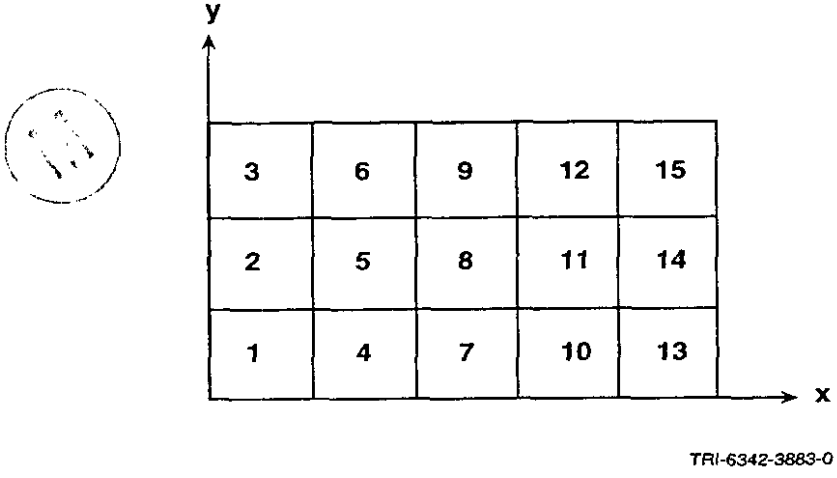

Figure 13. A different sequential indexing.

Then IBW = 2 * JM + 1 (for the example, IBW=7).

Therefore, to minimize the bandwidth, BRAGFLO orders the grid blocks so that sequential indexing proceeds first in the shortest grid direction, then in the longest grid direction. In this case

IBW = 2 * min (IM, JM) + 1.

Storage requirements are as follows:

Full matrix storage = $(IM * JM)^2$ words of memory
Band matrix storage = IM * JM * IBW words of memory

If IM ≤ JM then

$$\frac{\text{Band storage}}{\text{Full matrix storage}} = \frac{(2 * IM + 1) * IM * JM}{(IM * JM)^2} = \frac{2 * IM + 1}{IM * JM} \simeq \frac{2}{JM}$$

For various values of JM storage ratios are given by:

JM	Storage ratio
5	0.4 (40%)
10	0.2 (20%)
50	0.04 (4%)
100	0.02 (2%)

To determine the required computational effort assume the major effort is the multiplications/divisions.

Banded structure:

multiplication/division ≅ NEQ * IB * IB where IB is the half bandwidth,

IB = min (IM,JM).

Full matrix:

multiplication/division ≅ 1/3 NEQ^3

A typical performance assessment grid is

IM = 33
JM = 31
NEQ = 31(33) = 1023
IBW = 2(31) + 1 = 63
IB = 31

Computational effort

banded matrix structure= 1023 (31 * 31) = 983,103
full matrix structure = 1/3 $(1023)^3 \cong$ 3.57 E8.

The disparity in storage and computation between a band matrix solver and a full matrix solver is greater in two-dimensions than in one dimension. Of course, when solving 3-dimensional problems this disparity becomes even greater.

Although the equation solver is a major part of the time step calculation, other calculations involve evaluation of pressure dependent functions, coefficient generation, reporting and other overhead. However, the equation solver is a good indication of the computational effort for the time step solution. If the multiplication/division count of NEQ*IB*IB is used as a measure of equation solver speed, then a grid refinement for which the number of grid blocks is doubled in both the x and y direction (2-dimensional) would result in an increase in the number of equations by a factor of 4 and an increase in the half bandwidth by a factor of 2. Therefore, the computational effort would increase by a factor of 16. This estimate should warn the user that when attempting a grid refinement the computation (and also storage) does not depend linearly on the grid size.

4.8 Two Phase Flow

BRAGFLO assumes a water/gas system.

For miscible flow, the fluids will diffuse within each other and there is not a defined interface between the fluids. Specifically, there is no capillary pressure effect.

Immiscible fluids are not capable of mixing and have interfaces across which pressure discontinuities exist. This interfacial tension effect produces a capillary pressure between phase. In BRAGFLO fluids are assumed to be immiscible.

Phase saturation is the fraction of the pore space occupied by the fluids in a given phase. The notation is

S_w = water saturation
S_g = gas saturation

For example, the volume occupied by water within a bulk volume V with porosity ϕ is $V\phi S_w$.

The saturation constraint for fully saturated media is

$$S_w + S_g = 1.$$

Capillary pressure is defined by

$$p_c = p_g - p_w = p_c(S_w)$$

For a water wetting phase, $p_c \geq 0$.

The ability of a fluid to flow is affected by the presence of another fluid. The relative permeability is the ratio of the effective permeability of a given fluid phase to the permeability at 100% saturation. This is written as

$$k_{rl} = \frac{k_l}{k}$$

where k is the formation or absolute permeability, k_l is the effective permeability of phase l, and k_{rl} is the relative permeability of phase l. We observe that $0 \leq k_{rl} \leq 1$ and k_{rl} will be dependent on the phase saturation.

Typical relative permeability curves are shown in Figure 14, where S_{wr} is the residual water saturation. For water saturation at or below S_{wr}, water will not flow.

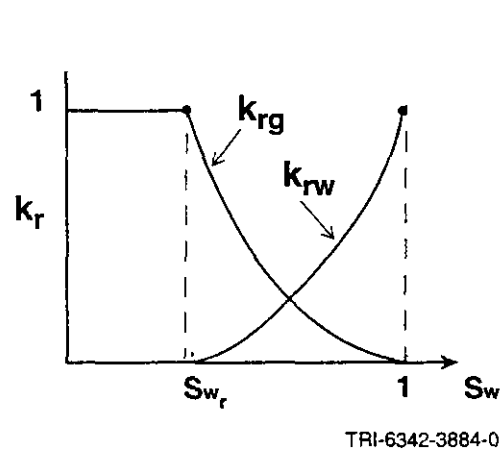

Figure 14. Typical relative permeability curve.

Darcy's Law extended to multiphase flow replaces absolute permeability with an effective permeability

$$\hat{q}_l = -\frac{k k_{rl} \rho}{\mu} \nabla \Phi .$$

The following system of two mass balance equations and two constraint equations is the BRAGFLO description of the two phase flow within a repository site:

Gas Mass Balance:

$$\nabla \bullet \left[\frac{\alpha \rho_g [k] k_{rg}}{\mu_g} \nabla \left(p_g + \rho_g g h \right) \right] + \alpha q_g + \alpha q_{rg} = \alpha \frac{\partial \left(\phi \rho_g S_g \right)}{\partial t}$$

Brine Mass Balance:

$$\nabla \bullet \left[\frac{\alpha \rho_w [k] k_{rw}}{\mu_w} \nabla \left(p_w + \rho_w g h \right) \right] + \alpha q_w + \alpha q_{rw} = \alpha \frac{\partial \left(\phi \rho_w S_w \right)}{\partial t}$$

Saturation Constraint:

$$S_g + S_w = 1$$

Capillary Pressure Constraint:

$$p_c = p_g - p_w.$$

Additional terms include

q_{rg} = rate of gas production (or consumption, if negative) due to chemical reaction.
q_{rw} = rate of water production (or consumption, if negative) due to chemical reaction.

The above system of four equations describes the time and space behavior of the four variables S_g, S_w, p_g, p_w. The finite difference method requires the introduction of a grid in either one, two or three dimensions and then a discretization of the gas and brine mass balance equation with respect to this grid and with respect to time. The resulting system of nonlinear algebraic equations is solved over a time step by the Newton-Raphson method.

The discretization of the gas mass balance equation in two dimensions (x,y) is given by

$$\frac{1}{\Delta x_i}\left\{\frac{1}{x_{i+1}-x_i}\left[\frac{\alpha\rho_g k_x k_{rg}}{\mu_g}\right]^{n+1}_{i+1/2,j}\left(\Phi^{n+1}_{g_{i+1,j}}-\Phi^{n+1}_{g_{i,j}}\right)-\frac{1}{x_i-x_{i-1}}\left[\frac{\alpha\rho_g k_x k_{rg}}{\mu_g}\right]^{n+1}_{i-1/2,j}\left(\Phi^{n+1}_{g_{i,j}}-\Phi^{n+1}_{g_{i-1,j}}\right)\right\}$$

$$+\frac{1}{\Delta y_j}\left\{\frac{1}{y_{j+1}-y_j}\left[\frac{\alpha\rho_g k_y k_{rg}}{\mu_g}\right]^{n+1}_{i,j+1/2}\left(\Phi^{n+1}_{g_{i,j+1}}-\Phi^{n+1}_{g_{i,j}}\right)-\frac{1}{y_j-y_{j-1}}\left[\frac{\alpha\rho_g k_y k_{rg}}{\mu_g}\right]^{n+1}_{i,j-1/2}\left(\Phi^{n+1}_{g_{i,j}}-\Phi^{n+1}_{g_{i,j-1}}\right)\right\}$$

$$+\alpha_{ij}\, q^{n+1}_{g_{i,j}}+\alpha_{ij}\, q^{n+1}_{rg_{i,j}}-\frac{\left(\alpha\phi\rho_g S_g\right)^{n+1}_{i,j}-\left(\alpha\phi\rho_g S_g\right)^{n}_{i,j}}{\Delta t}=0.$$

A similar equation for the brine mass balance is obtained by replacing the gas subscript with the brine subscript. The superscript n refers to the time level t_n at which the solution is known and the superscript n+1 refers to the time level t_{n+1} at which the solution is to be computed. Note that the flux and rate terms are evaluated at time level n+1. Therefore, the formulation is fully implicit.

For each grid block there are two material balance equations. The saturation constraint is used to eliminate brine saturation and the capillary pressure equation is used to eliminate the gas pressure. The remaining unknowns for each grid block are gas saturation, S_g, and brine pressure, p_b. Consequently, at each time step it is necessary to solve 2 * NX * NY equations, where NX, NY are the number of grid blocks in the x,y direction, respectively, for 2 * NX * NY unknowns.

In order to investigate the Jacobian matrix structure, assume for sake of argument that NY<NX. In this case the grid indexing moves most rapid in the y-direction and then in the x-direction. If the number of grid blocks is denoted NGB, then NGB = NX * NY. In BRAGFLO the equation indexing is first with respect to the gas equation, then the brine equation and outer most indexing with respect to the gird block. For example, the equation ordering is as follows:

equation index	equation
1	gas equation in grid block 1
2	brine equation in grid block 1
3	gas equation in grid block 2
4	brine equation in grid block 2
•	
•	
•	
2 * NGB-1	gas equation in grid block NGB
2 * NGB	brine equation in grid block NGB

The unknowns are gas saturation and brine pressure. The unknowns are ordered by gas saturation, then brine pressure and then with respect to grid block. The unknown indexing is:

unknown index	unknown
1	gas saturation in grid block 1
2	brine pressure in grid block 1
3	gas saturation in grid block 2
4	brine pressure in grid block 2
•	
•	
•	
2 * NGB-1	gas saturation in grid block NGB
2 * NGB	brine pressure in grid block NGB

Information at the i,j grid block and its neighboring grid blocks will use the compass notation

P corresponds to information with respect to grid block i,j
E corresponds to information with respect to grid block i+1,j
W corresponds to information with respect to grid block i-1,j
N corresponds to information with respect to grid block i,j+1
S corresponds to information with respect to grid block i,j-1.

Assume that the i,j grid block has sequential index ℓ. Then the Jacobian matrix has a 2x2 block penta diagonal structure and the resulting linear system in the Newton-Raphson iteration step can be represented as follows

$$
\begin{bmatrix}
P_1 & & N_1 & & & & & E_1 & & & & & & & \\
S_2 & & P_2 & N_2 & & & & & E_2 & & & & & & \\
 & \cdot & & \cdot & \cdot & & & & & \cdot & & & & & \\
 & & \cdot & & \cdot & \cdot & & & & & \cdot & & & & \\
 & & & \cdot & & \cdot & \cdot & & & & & \cdot & & & \\
 & & & & \cdot & & \cdot & \cdot & & & & & \cdot & & \\
 & & & & & \cdot & & \cdot & \cdot & & & & & \cdot & \\
\cdot & & & & & & \cdot & & \cdot & \cdot & & & & & \cdot \\
 & W_\ell & & & & & & S_\ell & & P_\ell & N_\ell & & & & E_\ell \\
 & & \cdot & & & & & & \cdot & & \cdot & \cdot & & & \cdot \\
 & & & \cdot & & & & & & \cdot & & \cdot & \cdot & & \\
 & & & & \cdot & & & & & & \cdot & & \cdot & \cdot & \\
 & & & & & \cdot & & & & & & \cdot & & \cdot & \cdot \\
 & & & & & & \cdot & & & & & & \cdot & & \cdot \\
 & & & & & & & \cdot & & & & & & \cdot & \cdot \\
 & & & & & & & & W_{NGB} & & & & S_{NGB} & & P_{NGB}
\end{bmatrix}
\begin{bmatrix} \delta_1 \\ \delta_2 \\ \\ \\ \\ \\ \delta_\ell \\ \\ \\ \\ \\ \\ \delta_{NGB} \end{bmatrix}
= -
\begin{bmatrix} G_1 \\ G_2 \\ \\ \\ \\ \\ G_\ell \\ \\ \\ \\ \\ \\ G_{NGB} \end{bmatrix}
$$

The 2x2 block matrices in the Jacobian are defined by

$$
P_\ell = \begin{pmatrix} \dfrac{\partial F_1(i,j)}{\partial S_g(i,j)} & \dfrac{\partial F_1(i,j)}{\partial p_w(i,j)} \\ \dfrac{\partial F_2(i,j)}{\partial S_g(i,j)} & \dfrac{\partial F_2(i,j)}{\partial p_w(i,j)} \end{pmatrix}
$$

$$
E_\ell = \begin{pmatrix} \dfrac{\partial F_1(i,j)}{\partial S_g(i+1,j)} & \dfrac{\partial F_1(i,j)}{\partial p_w(i+1,j)} \\ \dfrac{\partial F_2(i,j)}{\partial S_g(i+1,j)} & \dfrac{\partial F_2(i,j)}{\partial p_w(i+1,j)} \end{pmatrix} \qquad W_\ell = \begin{pmatrix} \dfrac{\partial F_1(i,j)}{\partial S_g(i-1,j)} & \dfrac{\partial F_1(i,j)}{\partial p_w(i-1,j)} \\ \dfrac{\partial F_2(i,j)}{\partial S_g(i-1,j)} & \dfrac{\partial F_2(i,j)}{\partial p_w(i-1,j)} \end{pmatrix}
$$

$$
N_\ell = \begin{pmatrix} \dfrac{\partial F_1(i,j)}{\partial S_g(i,j+1)} & \dfrac{\partial F_1(i,j)}{\partial p_w(i,j+1)} \\ \dfrac{\partial F_2(i,j)}{\partial S_g(i,j+1)} & \dfrac{\partial F_2(i,j)}{\partial p_w(i,j+1)} \end{pmatrix} \qquad S_\ell = \begin{pmatrix} \dfrac{\partial F_1(i,j)}{\partial S_g(i,j-1)} & \dfrac{\partial F_1(i,j)}{\partial p_w(i,j-1)} \\ \dfrac{\partial F_2(i,j)}{\partial S_g(i,j-1)} & \dfrac{\partial F_2(i,j)}{\partial p_w(i,j-1)} \end{pmatrix}
$$

The block vectors in the unknown solution vector are

$$
\delta_\ell = \begin{pmatrix} \delta S_g(i,j) \\ \delta p_w(i,j) \end{pmatrix}.
$$

The block vectors in the equation vector are

$$G_\ell = \begin{pmatrix} F_1(i,j) \\ F_2(i,j) \end{pmatrix}.$$

In the above, F_1 denotes the left hand side of the gas mass balance equation, and F_2 denotes the left hand side of the brine mass balance equation.

An inspection of the above discretized gas mass balance equation shows that the flux between neighboring grid blocks involves interblock flow terms evaluated at grid block interfaces, such as i+1/2, i-1/2, j+1/2 and j-1/2. It is necessary to discuss how BRAGFLO evaluates these interblock flow terms.

Consider the following term in the brine equation for flow in the x-direction between grid blocks i and i+1:

$$\frac{1}{\Delta x_i (x_{i+1} - x_i)} \left(\frac{\alpha \rho_w k_x k_{rw}}{\mu_w} \right)_{i+1/2} (\Phi_{wi+1} - \Phi_{wi}).$$

Since pressure and saturation are determined at grid block centers x_i and x_{i+1}, the question remains as to how to evaluate the interface term at $x_{i+1/2}$.

First, we define the harmonic average, H, of a_1, a_2, as

$$\frac{1}{H} = \frac{1}{2}\left(\frac{1}{a_1} + \frac{1}{a_2} \right)$$

or

$$H = \frac{2a_1 a_2}{a_1 + a_2}.$$

Further, the weighted harmonic average of a_1, a_2 is

$$\frac{1}{H} = \frac{w_1}{a_1} + \frac{w_2}{a_2}$$

or

$$H = \frac{a_1 a_2}{w_2 a_1 + w_1 a_2},$$

where the weights satisfy $w_1 + w_2 = 1$. Now introduce the shorthand notation

$$\tau_{i+1/2} = \left(\frac{\alpha \rho_w k_x \, k_{rw}}{\mu_w} \right)_{i+1/2}$$

At the i+1/2 interface, assume the mass flux is continuous

$$\bar{q}_{i+1/2} = q^-_{i+1/2} = q^+_{i+1/2}$$

where

$\bar{q}_{i+1/2}$ is average flow between x_i and x_{i+1},

$q^-_{i+1/2}$ is flow to the left of interface,

$q^+_{i+1/2}$ is flow to the right of interface.

From Darcy's Law, neglecting gravity potential

$$\bar{q}_{i+1/2} = \tau_{i+1/2} \frac{p_{i+1} - p_i}{x_{i+1} - x_i}$$

or

$$\bar{q}_{i+1/2} = \tau_{i+1/2} \frac{p_{i+1} - p_i}{1/2\left(\Delta x_i + \Delta x_{i+1}\right)}$$

This yields

$$p_{i+1} - p_i = \frac{\bar{q}_{i+1/2} \frac{1}{2}(\Delta x_i + \Delta x_{i+1})}{\tau_{i+1/2}}$$

Similarly,

$$q^-_{i+1/2} = \tau_i \frac{\left(p_{i+1/2} - p_i\right)}{\frac{1}{2}\Delta x_i}$$

$$q^+_{i+1/2} = \tau_{i+1} \frac{\left(p_{i+1} - p_{i+1/2}\right)}{\frac{1}{2}\Delta x_{i+1}}$$

Pressure drop is then written as

$$p_{i+1} - p_i = p_{i+1} - p_{i+1/2} + \left(p_{i+1/2} - p_i\right).$$

Then

$$\bar{q}_{i+1/2} \frac{\frac{1}{2}\left(\Delta x_i + \Delta x_{i+1}\right)}{\tau_{i+1/2}} = q^{+}_{i+1/2} \frac{\frac{1}{2}\Delta x_{i+1}}{\tau_{i+1}} + q^{-}_{i+1/2} \frac{\frac{1}{2}\Delta x_i}{\tau_i}.$$

Solving for $\tau_{i+1/2}$ yields

$$\tau_{i+1/2} = \frac{\tau_i \tau_{i+1}}{\frac{\Delta x_{i+1}}{\Delta x_i + \Delta x_{i+1}}\tau_i + \frac{\Delta x_i}{\Delta x_i + \Delta x_{i+1}}\tau_{i+1}}.$$

This is the harmonic mean of τ_i, τ_{i+1}, weighted with respect to the distance to the interface.

One further modification is made in the interblock term

$$\tau_{i+1/2} = \left(\frac{\alpha \rho_w k_x \, k_{rw}}{\mu_w}\right)_{i+1/2} = \left(\frac{\alpha \rho_w k_x}{\mu_w}\right)_{i+1/2} \left(k_{rw}\right)_{i+1/2}.$$

The harmonic averaging is used to evaluate

$$\left(\frac{\alpha \rho_w k_x}{\mu_w}\right)_{i+1/2}$$

However, the interblock relative permeability is evaluated by upstream weighting:

$$\begin{aligned}\left(k_{rw}\right)_{i+1/2} &= k_{rw_{i+1}}, \; p_{wi} < p_{w_{i+1}} \\ &= k_{rw_i}, \text{ otherwise.}\end{aligned}$$

This treatment of the interblock flow term is justified by the following process typical in performance assessment analysis. Assume gas is generated and is displacing water from the left to the right as in Figure 15. At the gas front, the gas potential is highest in the ith grid block. Therefore, gas wants to flow from i to i+1 grid block. Although the gas is mobile ($k_{rg} > 0$) in the ith block, it is immobile ($k_{rg} = 0$) in the $i+1^{th}$ block. If the relative permeability is included in the interblock

harmonic averaging, then $\tau_{i+1/2}$ is zero and no gas is transported. By upstream weighting the gas relative permeability we allow the mobile gas to flow from i to i+1 block.

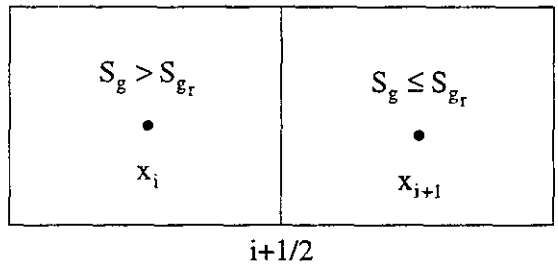

Figure 15. Gas Displacement Front.

Another treatment of relative permeability is to split it out of the harmonic average and evaluate it as an arithmetic average of the two adjacent relative permeabilities.

$$(k_{rw})_{i+1/2} = w_i k_{rw_i} + w_{i+1}\, k_{rw_{i+1}}$$

where the weights sum to 1. The arithmetic average of interblock relative permeability does not correctly treat the following case. Suppose water is displaced from left to right in Figure 16

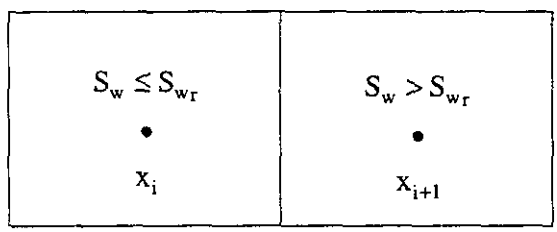

Figure 16. Displacement of Immobile Water.

with potential satisfying $\Phi_{w_i} > \Phi_{w_{i+1}}$. The potential tries to move water from i to i+1 block. Since $k_{rw_i} = 0$ and $k_{rw_{i+1}} > 0$, the interblock relative permeability by arithmetic averaging is greater than zero and the immobile water would be transported from the ith block. Upstream weighting would yield interblock relative permeability of zero with no water transported. Thus the upstream weighting prevents immobile fluid from being transported. The upstream weighting of relative permeability is controlled by input parameters.

4.9 Characteristic Curves

Relative permeability and capillary pressure are computed from several different empirical relations (Brooks, 1964; van Genuchten, 1978; WIPP PA, 1992). Choice of the characteristic curves is controlled by input directives.

The van Genuchten-Parker model determines

Capillary Pressure

$$P_c = P_o\left(S_e^{-1/m} - 1\right)^{1-m}$$

where P_o is a constant determined by equating the van Genuchten-Parker capillary pressure with the Brooks-Corey capillary pressure (discussed below) at S_e=0.5.

Relative Permeabilities

$$k_{rw} = S_e^{1/2}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2$$
$$k_{rg} = \left(1 - S_e\right)^{1/2}\left(1 - S_e^{1/m}\right)^{2m}$$

where the effective saturation is

$$S_e = \frac{S_w - S_{wr}}{1 - S_{gr} - S_{wr}}$$

In the original van Genuchten-Parker model the residual gas saturation S_{gr} was zero. BRAGFLO has the capability of using a nonzero residual gas saturation in the S_e calculation.

The parameter m is related to the input parameter, λ, by

$$m = \frac{\lambda}{1+\lambda}.$$

Typical characteristic curves using the van Genuchten-Parker model are shown in Figure 17 with parameters

$$\lambda = 0.7 \ (m = 0.41)$$
$$S_{wr} = 0.2.$$

The original Brooks-Corey model determines

Capillary Pressure

$$P_c = P_t / S_e^{1/\lambda}$$

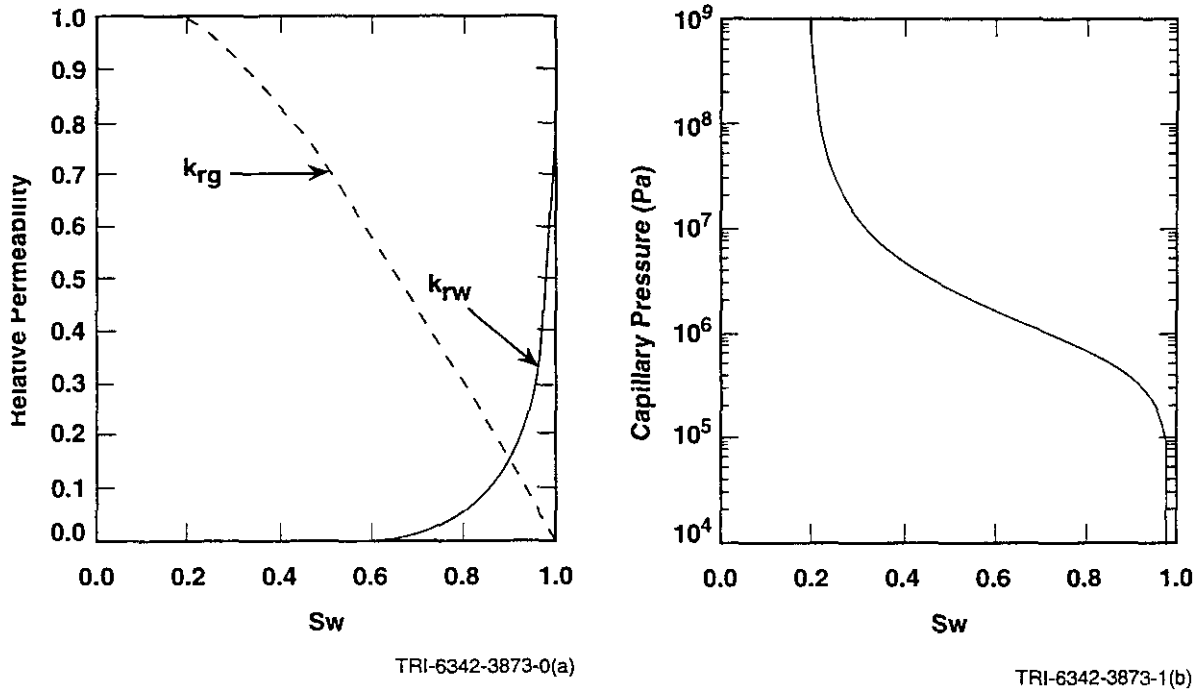

Figure 17. Relative Permeabilities for van Genuchten-Parker Model (left plot) and Capillary Pressure for van Genuchten-Parker Model (right plot).

Relative Permeabilities

$$k_{rw} = S_e^{(2+3\lambda)/\lambda}$$
$$k_{rg} = \left(1 - S_e\right)^2\left(1 - S_e^{(2+\lambda)/\lambda}\right)$$

where $S_e = (S_w - S_{wr})/(1 - S_{wr})$, P_t is threshold pressure and λ is pore size distribution parameter. Note that if this option is used with $P_t = 0$, then P_c is identically zero.

Typical characteristic curves using the original Brooks-Corey model are shown in Figure 18 with parameters

$$\lambda = 0.7$$
$$S_{wr} = 0.2$$
$$P_t = 1.E6.$$

Two modifications of the Brooks-Corey model are available which differ in the treatment of the effective saturation, S_e.

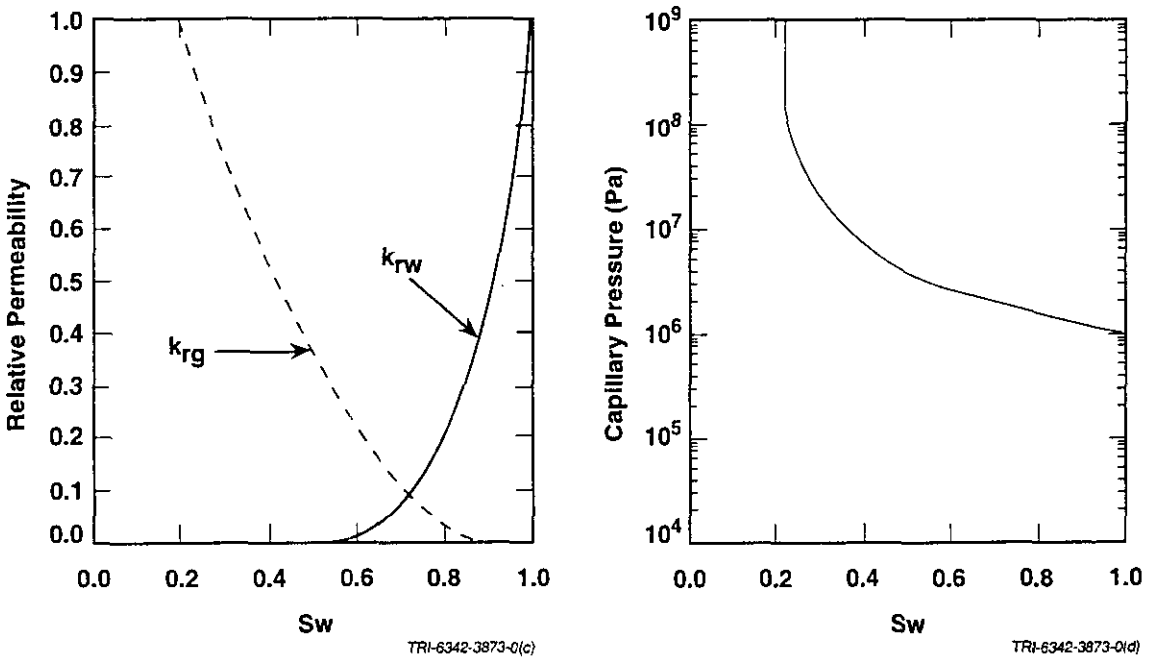

Figure 18. Relative Permeabilities for Original Brooks-Corey Model (left plot) and Capillary Pressure for Original Brooks-Corey Model (right plot).

The first modified Brooks-Corey model computes both phase relative permeabilities using an effective saturation

$$S_e = \frac{S_w - S_{wr}}{1 - S_{gr} - S_{wr}}$$

where S_{gr} is residual gas saturation.

Characteristic curves for this option are shown in Figure 19 with input parameters

$$\lambda = 0.7$$
$$S_{wr} = 0.2$$
$$S_{gr} = 0.2$$
$$P_t = 1.E6.$$

Note that for $S_w \geq 1\text{-}S_{gr}$, gas is immobile and water has 100% mobility. Also, note that the capillary pressure curve assumes the threshold capillary pressure at $S_w = 1\text{-}S_{gr}$.

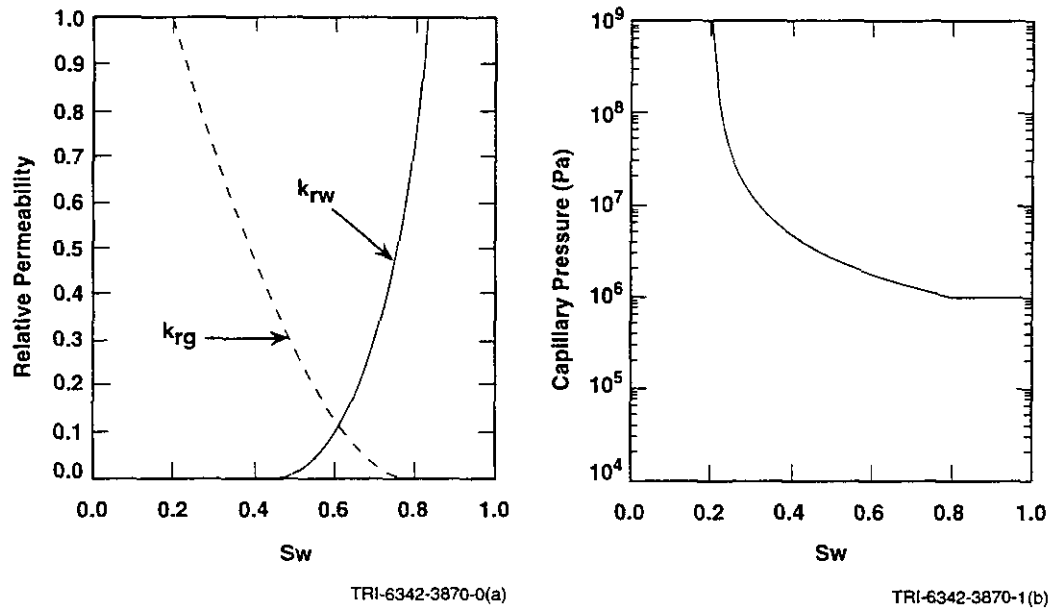

Figure 19. Relative Permeabilities for Modified Brooks-Corey Model (left plot) and Capillary Pressure for Modified Brooks-Corey Model (right plot).

The second modified Brooks-Corey model uses residual gas saturation to calculate effective saturation only for the gas phase. This treatment results in the characteristic curves shown in Figure 20.

Finally, a linear model is available with relative permeability and capillary pressure shown in Figure 21. The only input parameters honored are $S_{wr} = 0.2$ and $P_c = P_t$.

For both the van Genuchten-Parker and the Brooks-Corey model, the capillary pressure function is unbounded from the right ($S_w = S_{wr}^+$). An option is available which truncates the capillary pressure function at the PCMAX value. The capillary pressure curve with this option and PCMAX = 1.E8 is shown in Figure 22 (left plot) for the van Genuchten-Parker model and in Figure 22 (right plot) for the original Brooks-Corey model.

The dependence of the characteristic curves for both van Genuchten-Parker and Brooks-Corey on the pore size distribution parameter λ is shown in Figure 23 and Figure 24.

When the Jacobian is calculated, derivatives with respect to saturation are taken so as not to cross residual brine saturation, where the capillary pressure is either discontinuous or has discontinuous derivatives, depending on which option is chosen to model capillary pressure.

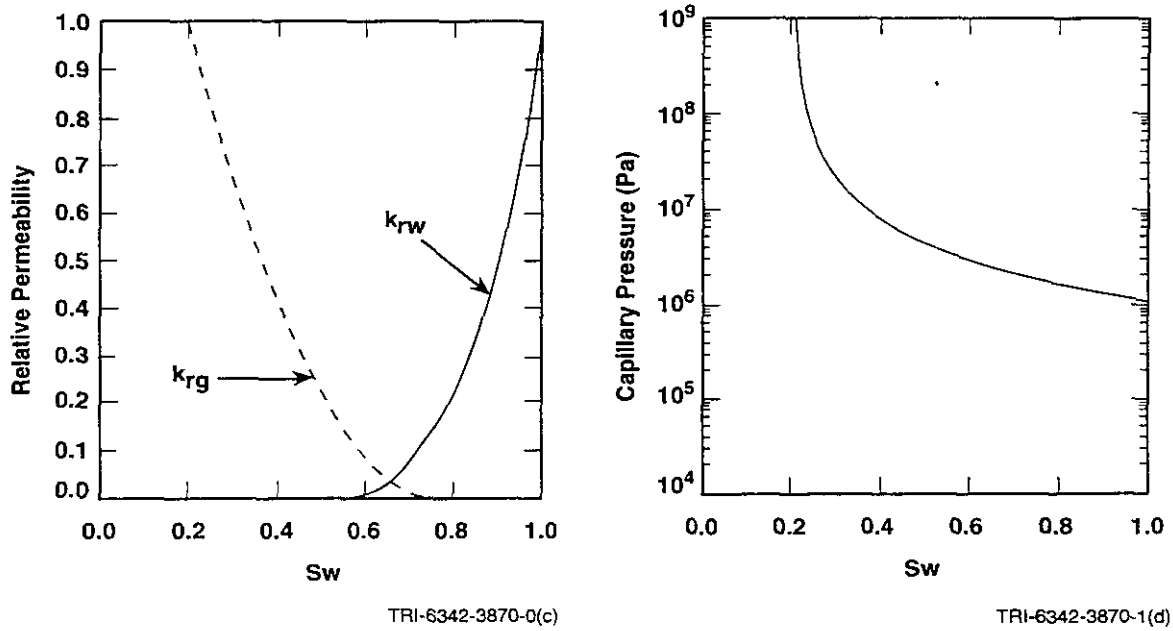

Figure 20. Relative Permeabilities for Second Modified Brooks-Corey Model (left plot) and Capillary Pressure for Second Modified Brooks-Corey Model (right plot).

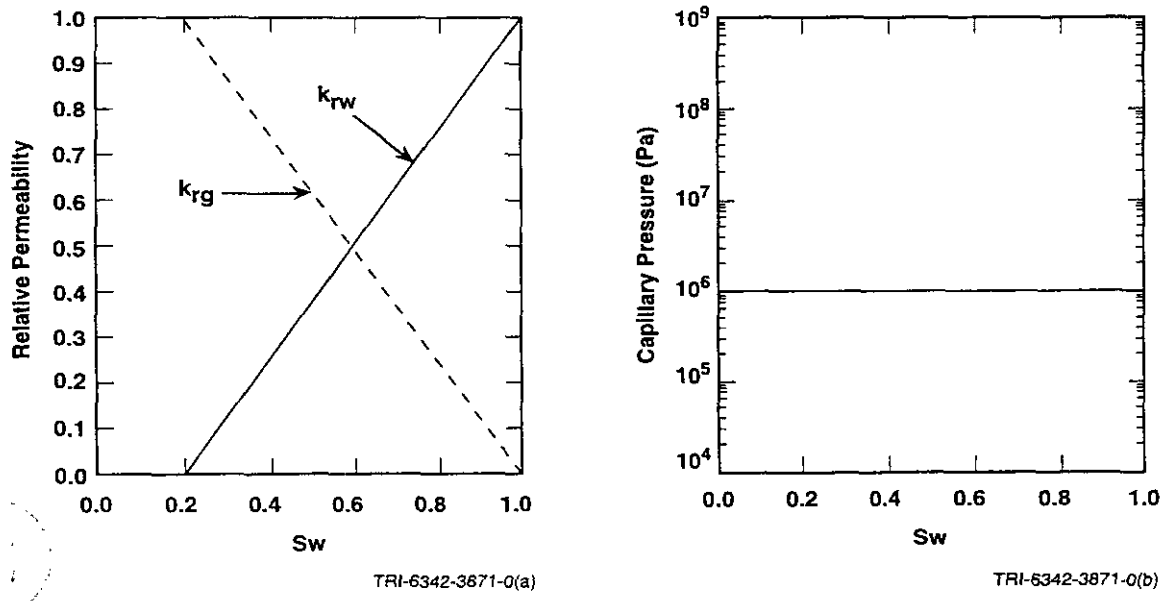

Figure 21. Relative Permeabilities for Linear Model (left plot) and Capillary Pressure for Linear Model (right plot).

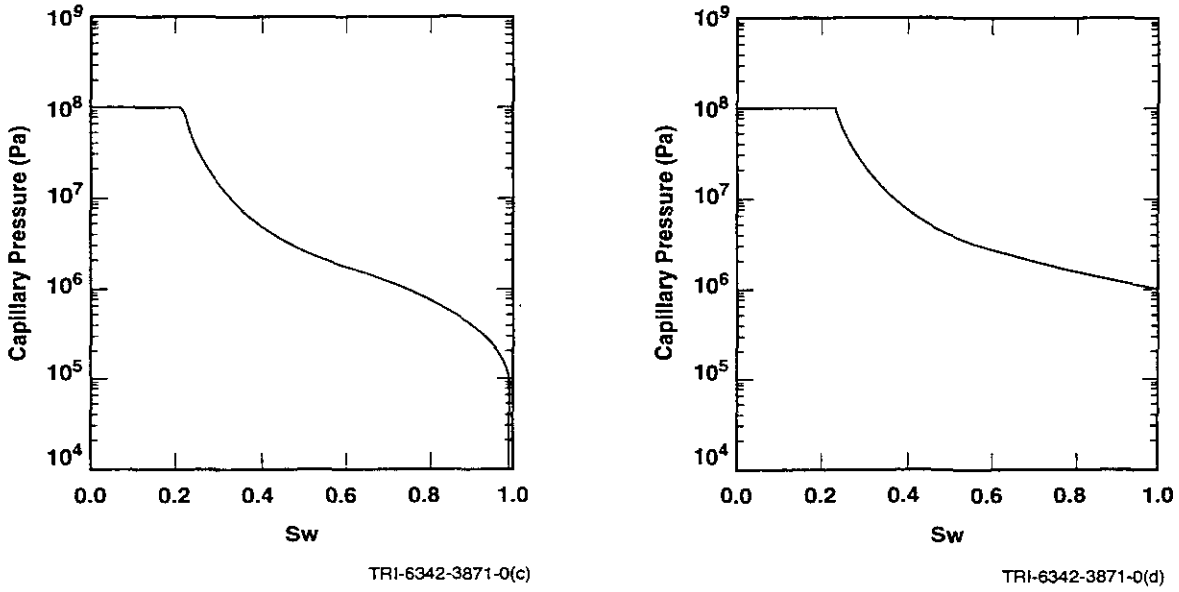

Figure 22. Capillary Pressure for van Genuchten-Parker Model PCMAX=1.0E+08 (left plot) and Capillary Pressure for Original Brooks-Corey Model PCMAX=1.0E+08 (right plot).

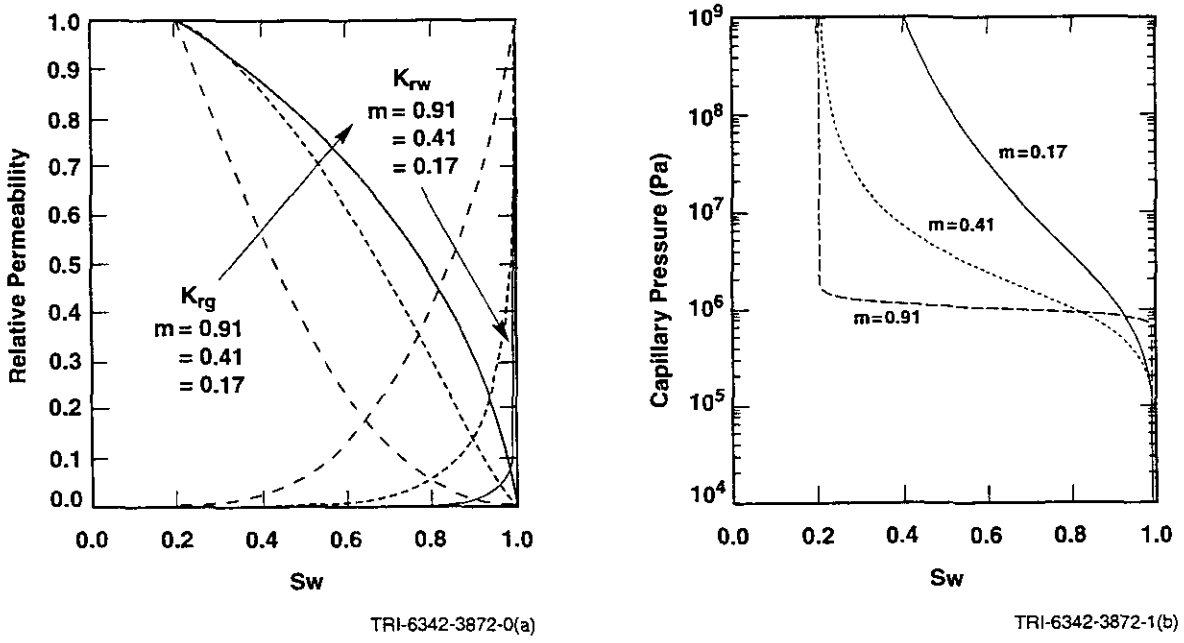

Figure 23. Relative Permeabilities for van Genuchten-Parker Model, effect of parameter m (left plot) and Capillary Pressure for van Genuchten-Parker Model, effect of parameter m (right plot).

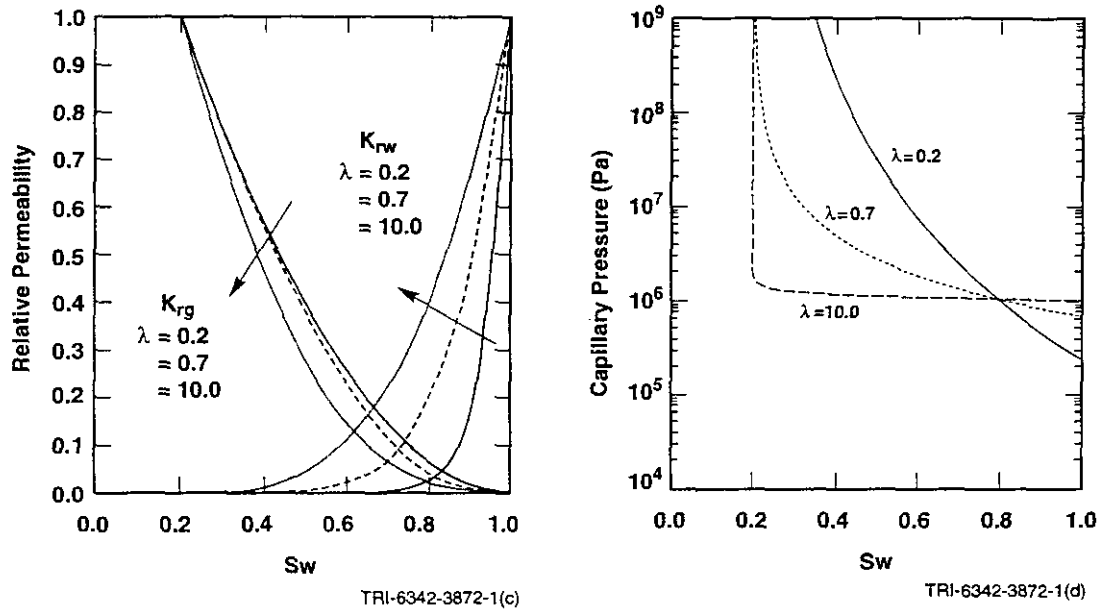

Figure 24. Relative Permeabilities for Brooks-Corey Model effect of pore size distribution parameter (left plot) and Capillary Pressure for Brooks-Corey Model effect of pore size distribution parameter (right plot).

4.10 Pressure-Induced Fracture Treatment

Most fluid flow models for porous media, such as BRAGFLO, allow for coupling to the mechanical system (rock matrix) through the introduction of rock compressibility, which is defined as the relative rate of change of porosity with respect to pressure

$$C = \frac{1}{\phi}\frac{d\phi}{dp}$$

where

C = rock compressibility,
ϕ = porosity,
p = pore pressure.

For constant compressibility, porosity can be expressed as a function of pressure

$$\phi = \phi_o \exp\left(C(p - p_o)\right)$$

where

ϕ_o = porosity at reference pressure p_o.

The fracture treatment in BRAGFLO (Key, 1994) allows for pressure induced alterations to the porosity by introducing a pressure-dependent porosity. Figure 25 shows the piecewise linear rock compressibility function. Below an initiating pressure, p_i, compressibility is a constant intact value, C_i. For pressures above p_i, the compressibility increases linearly to a fully altered compressibility, C_a, at the fully altered pressure, p_a. For pressures above p_a no further alteration occurs, which implies that $C = 0$.

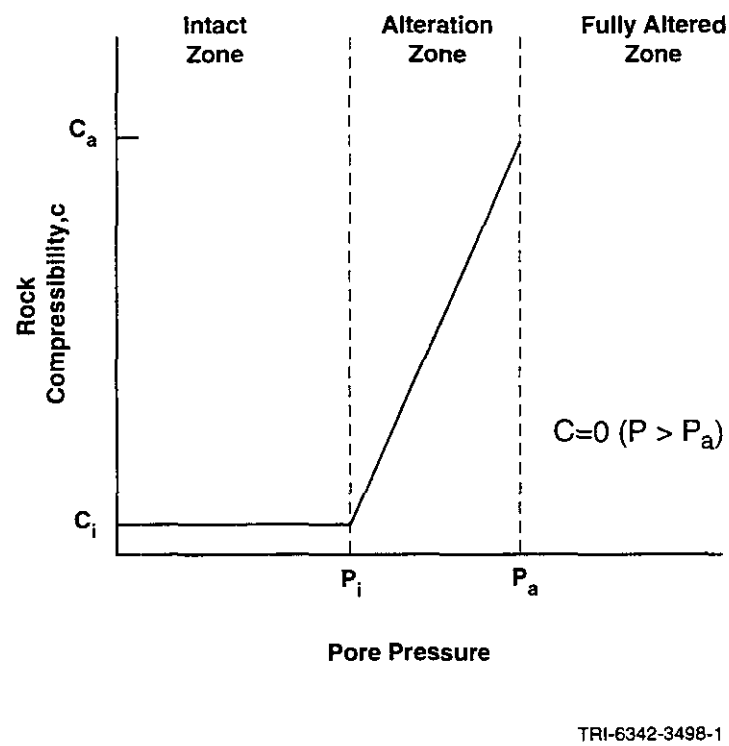

Figure 25. Pressure dependent compressibility.

The porosity can now be computed from the compressibility definition giving for $p \le p_i$

$$\phi = \phi_o \exp\left(C_i\left(p - p_o\right)\right) \tag{A}$$

for $p_i < p \leq p_a$

$$\phi = \phi_o \exp\left\{C_i(p - p_o) + \frac{(C_a - C_i)}{(p_a - p_i)}\frac{(p - p_i)^2}{2}\right\} \tag{B}$$

for $p \geq p_a$

$$\phi = \phi_a. \tag{C}$$

BRAGFLO input requires the pressures p_i and p_a and the porosity at the fully altered conditions, ϕ_a. From this information, the fully altered compressibility, C_a, is determined from equation (B) as

$$C_a = C_i\left[1 - 2\frac{(p_a - p_o)}{p_a - p_i}\right] + \frac{2}{(p_a - p_i)}\ln\left(\frac{\phi_a}{\phi_o}\right).$$

The BRAGFLO fracture treatment further allows for change in the fracture material permeability. The often used parallel plate analogy for flow in fractured rock suggests the form

$$\frac{k}{k_i} = \left[\frac{\phi}{\phi_i}\right]^n$$

where

k = permeability of altered material,
k_i = permeability of intact material,
ϕ = porosity of altered material,
ϕ_i = porosity of intact material,
n = an empirical parameter.

The altered permeability model requires as input n. Also, the anisotropic nature of permeability is specified for the fracture materials.

A geometric realization of the pressure-dependent porosity and permeability within a fracture material is shown in Figure 26.

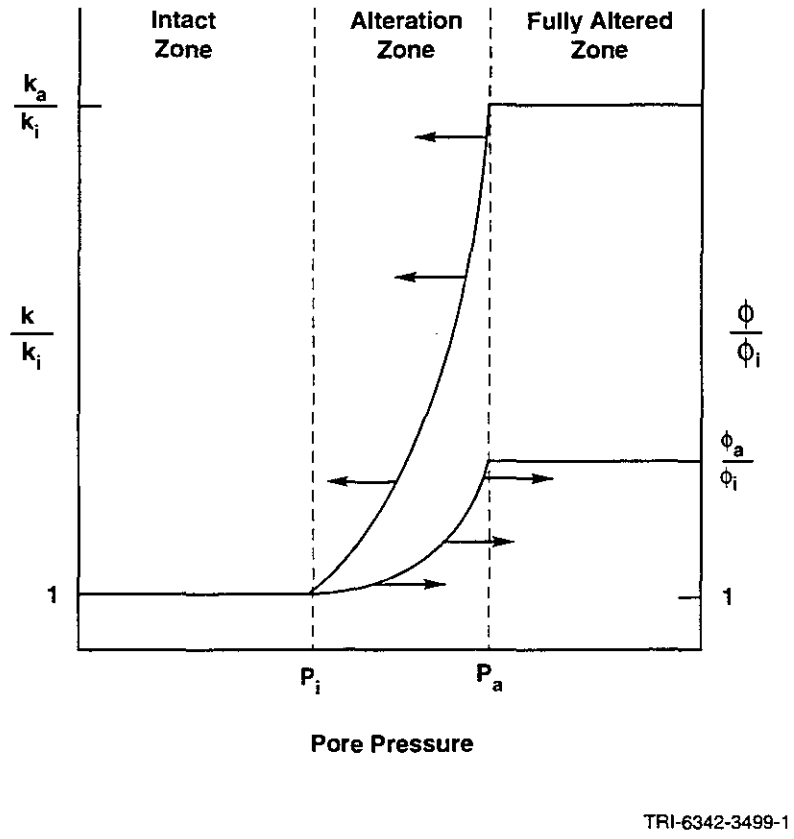

Figure 26. Pressure dependent porosity and permeability.

In a system where gas is displacing water, the fracture treatment can influence the gas migration distance. At elevated pressure, the increased porosity will produce more storage with corresponding shorter gas migration distance, while the increase in permeability will enhance the fluid mobility with resulting longer gas migration. The net effect will depend on the relative magnitudes of the storage and permeability effects.

4.11 Creep Closure

The excavation of the WIPP will result in the plastic deformation of the salt material (creep) and resultant closure (creep closure) of excavated areas. The principal effect of this closure for performance assessment is its effect on repository pressure due to the reduction in void volume accompanying creep closure. Accordingly, creep closure is represented in BRAGFLO by changing the porosity of the waste disposal area in a manner consistent with expectations developed from detailed modeling studies. Detailed modeling studies used the code SANCHO (Butcher et al., 1995), and more recently, SANTOS (Butcher et al., 1995), to develop time- and pressure-dependent predictions of waste disposal area void volume. Pressure variation was consistent with variation in the gas generation rates possible in the waste disposal areas. The results were used to develop a look-up table of porosity as a function of time and waste disposal area pressure that is used in BRAGFLO to vary waste disposal area porosity. Essential features of the look-up table (porosity surface) are shown in Figure 27.

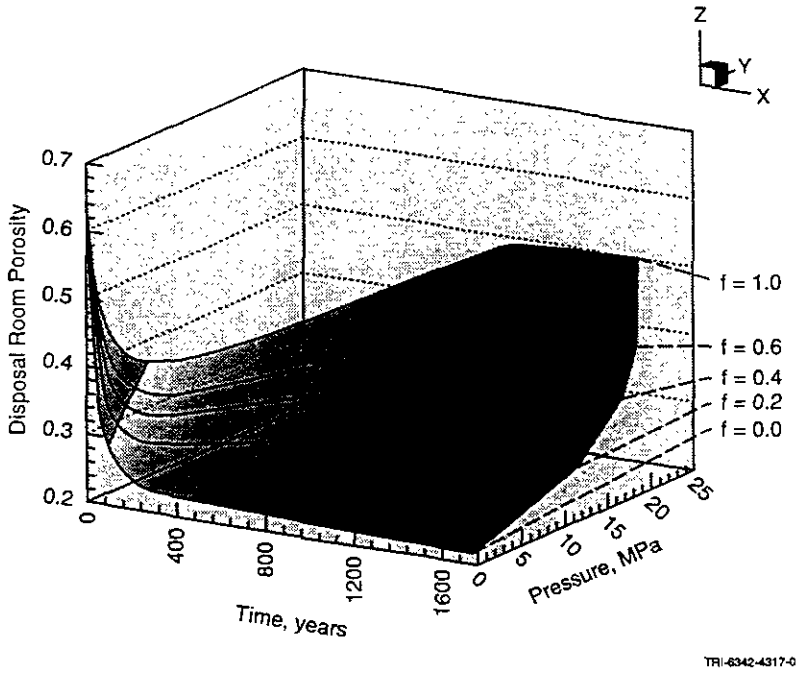

Figure 27. Pressure driven porosity function generated from SANTOS structural mechanics code.

The surface is generated by a family of five f factors which is representative of the level of gas generation. The value of f = 1.0 corresponds to 2 moles of gas per drum per year for 550 years, 1 mole per drum per year from 550 to 1050 years, and zero gas generation after 1050 years. For each f-factor the above rates are scaled by f. BRAGFLO uses a volumetric average pressure over the waste and time to interpolate the surface in Figure 27 for the average waste porosity.

4.12 Klinkenberg Effect

For gases in a tight porous material at low pressures the boundary condition of zero gas velocity at the solid surface is not satisfied (Klinkenberg, 1941; Corey, 1990; WIPP PA, 1992). This phenomenon has been called gas slippage and results in a larger gas velocity. This slipping of the gas flow contributes to an apparent pressure-dependent increase in permeability, which was originally observed by Klinkenberg. A correction to the formation permeability to the gas phase is related to pressure by

$$k_g = k_w\left(1 + b\, k_w^{-a} / p\right)$$

where

k_g = formation permeability to gas [m^2],
k_w = formation permeability to water [m^2],
a,b = formation dependent constants,
p = pressure [Pa].

The constants a,b are input. The recommended values found in the BRAGFLO user's manual are from a tight gas/sand correlation. Figure 28 shows the gas phase permeability as a function of pressure for a family of k_w with $a = 0.33$ and $b = 0.98$.

4.13 Gas Generation Model

Within BRAGFLO there are chemical reactions with the effect of consuming brine and generating gas. One reaction represents the corrosion of the waste containers. A second reaction models the microbial consumption of cellulose material.

Two possible anoxic reactions are used to describe the corrosion when waste drums are exposed to brine:

$$Fe + 2H_2O \rightarrow H_2 + Fe(OH)_2 \qquad (1)$$

$$3Fe + 4H_2O \rightarrow 4H_2 + Fe_3O_4 \qquad (2)$$

If the equations are normalized to unit mole of iron, then equation (2) is written

$$Fe + 4/3\ H_2O \rightarrow 4/3\ H_2 + 1/3\ Fe_3O_4. \qquad (3)$$

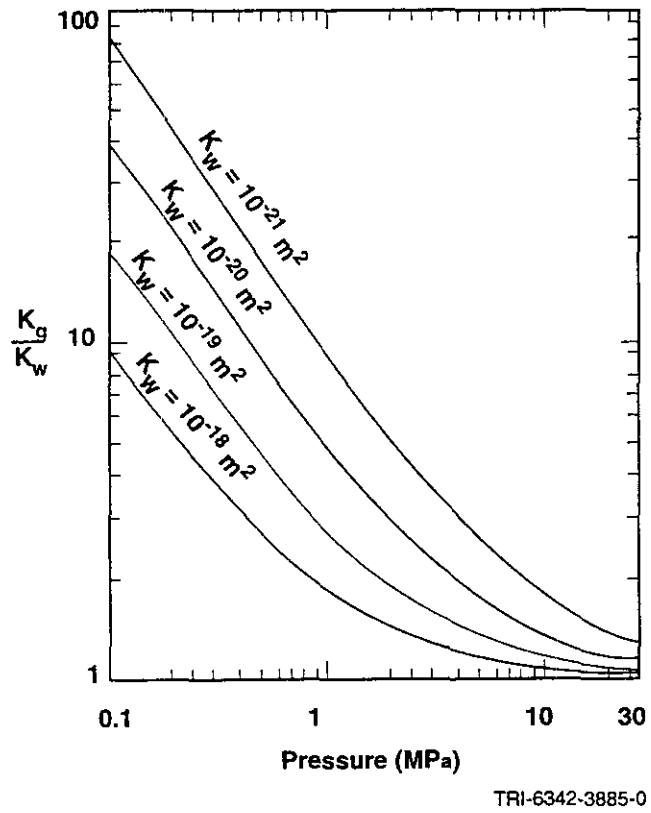

Figure 28. Increase in gas phase permeability due to Klinkenberg effect.

In the performance assessment of the WIPP site, a weighted average of the above two reactions is assumed

$$x\mathrm{Fe} + 2x\ \mathrm{H_2O} + (1\text{-}x)\ \mathrm{Fe} + (1\text{-}x)\ 4/3\ \mathrm{H_2O} \rightarrow x\mathrm{H_2} + (1\text{-}x)\ 4/3\ \mathrm{H_2} + \mathrm{Inerts}$$

where weighting factor x satisfies $0 \leq x \leq 1$. This is written for a unit mole of iron as

$$\mathrm{Fe} + (2x + 4)/3\ \mathrm{H_2O} \rightarrow (4\text{-}x)/3\ \mathrm{H_2} + \mathrm{Inerts}.$$

From input (line 9.8), the corrosion stoichiometry is described by

$$s_{1,2}\mathrm{H_2O} + s_{1,3}\mathrm{Fe} \rightarrow s_{1,1}\mathrm{H_2} + \mathrm{Inerts}.$$

The PA calculations sample x from a uniform distribution on the interval [0,1] and compute stoichiometric coefficients

$$s_{1,1} = (4-x)/3 \qquad \text{[mol } H_2\text{/mol Fe]}$$
$$s_{1,2} = (2x+4)/3 \qquad \text{[mol } H_2O\text{/mol Fe]}$$
$$s_{1,3} = 1.0 \qquad \text{[mol Fe/mol Fe].}$$

In order to account for the material balance of brine and gas, the rate of reaction must be specified. BRAGFLO assumes all reaction rates are zero order (constant). However, BRAGFLO recognizes a different reaction rate if the steel is in contact with liquid brine (inundated condition) or if the steel reacts with brine in the gas phase (humid condition). The input directives describing the two reaction rates are

RK(1) = brine inundated corrosion reaction rate [mol Fe/m^3/s],
HF(1) = factor multiplying RK(1) to get humid corrosion reaction rate.

We introduce the notation

K_{CI} = RK(1), inundated reaction rate,
K_{CH} = HF(1) * RK(1), humid reaction rate.

The portion of steel in contact with brine is assumed to react at the inundated rate, while the portion of steel in contact with gas reacts at the humid rate as long as some liquid phase brine is present to be in equilibrium with the brine in the gas phase. The fraction of steel in contact with brine in a grid block is assumed equal to the volume fraction of brine in the pore space, S_w. Similarly, the fraction of steel in contact with gas is equal to the volume fraction of gas, S_g. Thus the effective corrosion reaction rate becomes

$$K_C = K_{CI}\, S_w + K_{CH}\, S_g.$$

The rate of H_2 production by corrosion per unit volume of panel is

$$q_{CH_2} = K_C s_{1,1} M_{H_2}$$

where M_{H_2} = molecular weight of H_2 [kg/mol].

The rate of brine consumption by corrosion per unit volume of panel is

$$q_{CH_2O} = K_C s_{1,2} M_{H_2O}$$

where M_{H_2O} = molecular weight of H_2O [kg/mol].

In BRAGFLO the biodegradation reaction assumes microbial consumption of cellulose (CH_2O) with hydrogen gas as a product

$$CH_2O + \text{microbes} \rightarrow s_{2,1}\, H_2 + \text{unknowns},$$

where

$s_{2,1}$ = stoichiometric coefficient, [mol H_2/mol CH_2O]

PA samples on $s_{2,1}$ as uniform distribution on the interval [0, 5/3]. The stoichiometric coefficients for the biodegradation reaction are read on input as

$s_{2,1}$	=	(sampled)	[mol H_2/mol CH_2O]
$s_{2,2}$	=	moles H_2O = 0.0	[mol H_2O/mol CH_2O]
$s_{2,3}$	=	moles CH_2O = 1.0	[mol CH_2O/mol CH_2O].

Reaction rates for biodegradation are analogous to the corrosion reaction rates; that is, rates are specified for both inundated and humid conditions. The input directives describing the two reaction rates are

RK(2) = brine inundated biodegradation rate [mol $CH_2O/m^3/s$]
HF(2) = factor multiplying RK(2) to get humid biodegradation rate.

and are used to determine the overall biodegradation rate in the same way RK(1) and HF(1) are used to determine the overall corrosion rate.

Another gas generation model, the reaction path model, was planned and implementation had begun. This model considered a much larger number of possible reactions that could take place within the WIPP repository. Although it was still an equilibrium reaction model, it could account for the different paths that a sequence of reactions could follow. Input and output for the model was completed, together with a multicomponent gas transport scheme (see Sections 7.2.2, 7.2.9, and 7.2.12), but the reaction path model itself has not been implemented.

4.14 Linear Equation Solver

Each iteration step in the Newton-Raphson method requires the solution of a system of linear equations. Linear equation solvers fall into two general categories: direct or elimination type solvers and iterative solvers. Algorithms for direct solvers involve a finite number of arithmetic steps to produce the solution. Solution error in a direct solver occurs from roundoff error in the arithmetic operations which is a result of the finite word length representation of any number on a computer. BRAGFLO is written with double precision word length which produces floating point number representation of 64 bits or approximately 15 significant digits on a single word length machine such as the DEC Alpha. BRAGFLO has available a direct solver which uses LU-decomposition.

For large scale problems accumulation of roundoff error in a direct solver can swamp the true solution. Also storage and computation time may become prohibitive for direct solvers. Iterative solvers are generally advantageous over direct solvers when the problem size becomes large. There are many iterative solvers found in the numerical literature. BRAGFLO includes a successive over relaxation (SOR) solver. Iterative solvers have the disadvantage that the solution depends on the convergence of an iterative procedure. For this reason direct solvers are more simplistic in concept and application.

For performance assessment work the original LU-decomposition method has been used exclusively and is strongly recommended. It has been found from experience that the iterative solvers are not robust enough to successfully solve many of the performance assessment problems.

A description of the LU-decomposition algorithm will be presented. The method will be demonstrated with a small (4x4 matrix) example. The objective is to write the coefficient matrix (Jacobian matrix) as a product of two matrices,

$$\mathbf{LU} = \mathbf{A}$$

where **L** is lower triangular (has non-zero elements only on the diagonal and below) and **U** is upper triangular (has non-zero elements only on the diagonal and above). It is further possible to require the diagonals of **L** to be equal to one. If $\mathbf{A} = (a_{ij})$, $\mathbf{L} = (\alpha_{ij})$ and $\mathbf{U} = (\beta_{ij})$, then for the case of a 4x4 matrix the decomposition would look like

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ \alpha_{21} & 1 & 0 & 0 \\ \alpha_{31} & \alpha_{32} & 1 & 0 \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & 1 \end{bmatrix} \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & \beta_{14} \\ 0 & \beta_{22} & \beta_{23} & \beta_{24} \\ 0 & 0 & \beta_{33} & \beta_{34} \\ 0 & 0 & 0 & \beta_{44} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}$$

For example, it can be checked by matrix multiplication that the following is an LU-decomposition of the given 4x4 matrix:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ -2 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 3 & 3 & 3 \\ 0 & 0 & -2 & -2 \\ 0 & 0 & 0 & 4 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ -2 & 1 & 1 & 1 \\ 0 & 3 & 1 & 1 \\ 1 & 4 & 2 & 6 \end{bmatrix}$$

If the LU-decomposition of the matrix **A** is known then the solution of the system of equations **Ax = b** can be written as

$$\mathbf{Ax} = (\mathbf{LU})\mathbf{x} = \mathbf{L}(\mathbf{Ux}) = \mathbf{b}$$

The solution is obtained by solving for the vector **y** such that

$$\mathbf{Ly} = \mathbf{b}$$

and then solving

$$\mathbf{Ux} = \mathbf{y}$$

The advantage of decomposing one linear set of equations into two successive sets of equations is that the solution of a triangular set of equations is an easy substitution calculation. Recall for the Modified Newton-Raphson method the Jacobian matrix is not updated every iteration while the right-hand side of the system of equations is recalculated each iteration. Once the LU-decomposition of the Jacobian matrix is obtained, the Newton-Raphson iteration step is accomplished by solving the system **Ly = b** with updated right-hand side vector **b** by applying the forward substitution algorithm

$$y_1 = \frac{b_1}{\alpha_{11}}$$

$$y_i = \frac{1}{\alpha_{ii}}\left[b_i - \sum_{j=1}^{i-1}\alpha_{ij}y_j\right] \qquad i = 2,3,\ldots,N$$

and then solving the system **Ux = y** with the back substitution algorithm

$$x_N = \frac{y_N}{\beta_{NN}}$$

$$x_i = \frac{1}{\beta_{ii}}\left[y_i - \sum_{j=i+1}^{N}\beta_{ij}x_j\right] \qquad i = N-1, N-2,\ldots,1$$

Given the coefficient matrix **A**, how are the decomposition matrices **L** and **U** computed? The (i,j)th entry in matrix **A** will be the inner product of the ith row of **L** with the jth column of **U**. If the triangular structure of **L** and **U** are considered, then the resulting product is described by the two cases,

$$\sum_{k=1}^{i}\alpha_{ik}\beta_{kj} = a_{ij} \qquad i = 1,\ldots,j \tag{A1}$$

$$\sum_{k=1}^{j}\alpha_{ik}\beta_{kj} = a_{ij} \qquad i = j+1,\ldots,N \tag{B1}$$

Crout's algorithm (Maron, 1982) solves the equations for the α's and β's by arranging the equations in a certain order. The algorithm is sequential over columns from 1 to N. For the jth column the β_{1j} to β_{jj} are computed from equation (A1) by

$$\beta_{ij} = a_{ij} - \sum_{k=1}^{i-1} \alpha_{ik}\beta_{kj} \qquad \text{for } i = 1,\ldots,j \tag{A2}$$

followed by the solution of α_{j+1j} to α_{Nj} from equation (B1) by

$$\alpha_{ij} = \frac{1}{\beta_{jj}}\left(a_{ij} - \sum_{k=1}^{j-1} \alpha_{ik}\beta_{kj}\right) \qquad \text{for } i = j+1,\ldots,N. \tag{B2}$$

The example will demonstrate that the α's and β's that occur on the right-hand side of equations (A2) and (B2) are already determined by the time they are needed.

Within BRAGFLO the LU-decomposition is done within the band structure of the Jacobian matrix. This is crucial for efficient computation. Therefore, the above algorithms must be modified to work only within the bandwidth of the Jacobian matrix. Further, only the band structure is stored in the BRAGFLO treatment. This allows considerable saving in the storage requirement. Finally, BRAGFLO implements a partial pivoting (row interchanges) which reduces the roundoff errors in the arithmetic and is essential for the numerical stability of Crout's method.

Now consider the example with

$$\mathbf{A} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ -2 & 1 & 1 & 1 \\ 0 & 3 & 1 & 1 \\ 1 & 4 & 2 & 6 \end{bmatrix}$$

Starting with the first column we solve for $\beta_{11} = 1$ from equation (A2) where the sum is taken to mean zero. Equation (B2) is then used to solve sequentially for $\alpha_{21} = -2$, $\alpha_{31} = 0$, and $\alpha_{41} = 1$. We now proceed to the second column and from equation (A2) compute sequentially $\beta_{12} = 1$, $\beta_{22} = 3$. Now from equation (B2) we compute $\alpha_{32} = 1$ and $\alpha_{42} = 1$. This procedure is continued for the 3rd and 4th columns with the resulting **L** and **U** given by the example stated earlier in this Subsection.

Now suppose the solution of the system **Ax** = **b** is required given right-hand side vector **b** = $(4, 1, 5, 13)^T$. We first solve the system **Ly** = **b** by the forward substitution algorithm. The system is

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ -2 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} 4 \\ 1 \\ 5 \\ 13 \end{bmatrix}$$

Forward substitution from the first equation to the fourth equation yields $\mathbf{y} = (4, 9, -4, 4)^T$. We then solve the system $\mathbf{Ux} = \mathbf{y}$. The system is

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 3 & 3 & 3 \\ 0 & 0 & -2 & -2 \\ 0 & 0 & 0 & 4 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} 4 \\ 9 \\ -4 \\ 4 \end{bmatrix}$$

Back substitution from the fourth equation to the first equation yields $\mathbf{x} = (1, 1, 1, 1)^T$.

4.15 Model Geometry

The mesh used in the BRAGFLO simulations attempts to incorporate radial flow phenomena at large distances from the repository and to include the full accessible volume available for multiphase flow. Time and cost constraints currently preclude a full three-dimensional representation of the repository and surrounding strata, so a two-dimensional approximation to the actual geometry is made, as described in WIPP PA Department (1992, Volume 5).

4.16 Well Models

Well behavior is described by an inflow performance relation:

$$q_l = \frac{(PI)\rho_l k_{rl}}{\mu_l}\left(p_l - p_{wf}\right),$$

where

l = phase index ($l = w,g$),
q_l = phase mass flow rate [kg/s],
p_l = phase pressure [Pa],
p_{wf} = flowing wellbore pressure [Pa],
PI = well productivity index [m^3],
ρ_l = phase density [kg/m^3],

μ_l = phase viscosity [Pa s],
k_{rl} = phase relative permeability.

The material balance requires the mass rate for each phase. If a well is operated as rate-specified, the inflow performance equation determines the flowing wellbore pressure, although BRAGFLO does not do this calculation. For this reason, BRAGFLO does not use the PI and P_{wf} values for rate-specified wells, although values are required on input. If the well is operated as pressure-specified, the rate is computed from the inflow performance relation. The required input parameters for either a rate- or pressure-specified well is found in Section 7.2.4.

The well operation is determined by the well type as specified in the input file. The operation by well type is as follows:

INJQ: The well injects ($q_l > 0$) or produces ($q_l < 0$) at a specified rate.

INJP: The well injects at a specified flowing wellbore pressure. If the inflow performance relation predicts $q_l < 0$, then the rate is set to zero.

PROD: The well produces at a specified flowing wellbore pressure. If the inflow performance relation predicts $q_l > 0$, then the rate is set to zero.

BRAGFLO does not allow a well with completion in multiple grid blocks. However, BRAGFLO does allow multiple wells in a single grid block. The information describing well location, number of wells in a grid block, and the time period over which each well is in operation is specified in the input file.

4.17 Gas Dissolution Models

Dissolution of gas in brine can be modeled in BRAGFLO. A bubble point tracking treatment is available but is untested and its use is not recommended. A Henry's law treatment is also available. Additional details and input for these models are described in Section 7.2.8.

5.0 CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

BRAGFLO is the two-phase (brine and gas) finite difference program used to study the fluid flow within the WIPP repository site. The BRAGFLO code is an essential part of the probabilistic modeling necessary for performance assessment of the WIPP site. BRAGFLO has the following capabilities and limitations, which are discussed in detail in Section 4.0:

- Historically, BRAGFLO was developed as a two phase flow model for petroleum production applications. For this reason, BRAGFLO uses terminology common to the petroleum industry (Subsection 4.1).
- BRAFLO assumes that the directions of the permeability tensor are aligned with the reservoir coordinate axis; that is, $\theta = 0$ (Subsection 4.3).
- BRAGFLO evaluates brine density assuming its fluid compressibility is constant (Subsection 4.4).

- BRAGFLO uses the Redlich-Kwong-Soave equation of state to relate gas density to pressure (Subsection 4.4).
- Although viscosity could be pressure dependent for gases, BRAGFLO treats viscosity constant for both water and gas (Subsection 4.4).
- BRAGFLO assumes a no-flow Neumann type boundary condition at all exterior grid boundaries (Subsection 4.4).
- BRAGFLO uses a fully implicit formulation to solve the material balance equations (Subsection 4.5).
- BRAGFLO uses the difference approximation for the Jacobian evaluation (Subsection 4.6).
- In BRAGFLO the user can specify from input directives the iteration frequency for the Jacobian evaluation (Subsection 4.6).
- For both storage and computational considerations the linear equation solver should take advantage of the banded structure. This is true for all the BRAGFLO solvers (Subsection 4.6).
- To minimize the bandwidth, BRAGFLO orders the grid blocks so that sequential indexing proceeds first in the shortest grid direction, then in the longest grid direction (Subsection 4.7).
- BRAGFLO assumes a water/gas system (Subsection 4.8).
- In BRAGFLO fluids are assumed to be immiscible (Subsection 4.8).
- BRAGFLO has the capability of computing relative permeability and capillary pressure using several different empirical relations. Choice of the characteristic curves is controlled by the user (Subsection 4.9).
- BRAGFLO allows for coupling to the mechanical system (rock matrix) through the introduction of rock compressibility (Subsection 4.10).
- The fracture treatment in BRAGFLO allows for pressure induced alterations to the porosity by introducing a pressure-dependent porosity (Subsection 4.10).
- The BRAGFLO fracture treatment further allows for change in the fracture material permeability (Subsection 4.10).
- Representation of the creep closure within BRAGFLO is accomplished by a change in the formation porosity. This porosity function or porosity surface will be time dependent and is also driven by pressure. The resulting closure information comes from a geomechanical simulation using the structural mechanics code SANTOS (Subsection 4.11).
- BRAGFLO corrects for the Klinkenberg effect (Subsection 4.12).
- BRAGFLO can model gas dissolution in brine using a Henry's law treatment (Subsection 4.17).
- Well models in BRAGFLO allow simulation of gas or brine injection or production (Subsection 4.16).

- Within BRAGFLO there are chemical reactions with the effect of consuming brine and generating gas. BRAGFLO accounts for these reactions by assuming that all reaction rates are zero order (constant). However, BRAGFLO recognizes a different reaction rate if the steel is in contact with liquid brine (inundated condition) or if the steel reacts with brine in the gas phase (humid condition) (Subsection 4.13).
- BRAGFLO is written with double precision word length which produces floating point number representation of 64 bits or approximately 15 significant digits on a single word length machine such as the DEC Alpha. BRAGFLO has available one direct solver, which uses LU-decomposition (Subsection 4.14).
- BRAGFLO includes a successive over relaxation (SOR) solver (Subsection 4.14).
- Within BRAGFLO the LU-decomposition is done within the band structure of the Jacobian matrix. This is crucial for efficient computation (Subsection 4.14).
- BRAGFLO implements a partial pivoting (row interchanges) which reduces the roundoff errors in the arithmetic and is essential for the numerical stability of Crout's method (Sectiom 4.14).

6.0 USER INTERACTIONS WITH THE SOFTWARE

To exercise BRAGFLO, the BRAGFLO command (.COM) file must specify the desired input and output files. The following files must be specified:

1. **The BRAGFLO input control (.INP) file for the sampled vector.** This file is the ASCII input file that controls BRAGFLO; it is generated by PREBRAG, the code immediately upstream from BRAGFLO (Figure 29).
2. **The BRAGFLO binary output (.BIN) file for the sampled vector.** This file is the primary results file that is converted by POSTBRAG (Figure 29) into standard .CDB format.
3. **The BRAGFLO ASCII output (.OUT) file for the sampled vector.** This file echoes input and provides user-readable output and QA information.
4. **The BRAGFLO summary (.SUM) file for the sampled vector.** This file contains a limited amount of summary information on results at each time step.
5. **The BRAGFLO restart output (.ROT) file for the sampled vector.** Enough information is stored in this binary file to permit restarting BRAGFLO if execution is halted.
6. **The BRAGFLO restart input (.RIN) file for the sampled vector.** This binary file, a copy of the .ROT file, is read at the beginning of a restart run.

THE NAME OF THE RESTART INPUT FILE MAY BE SPECIFIED, EVEN THOUGH BRAGFLO RUNS FOR THE 1996 WIPP PA CALCUALTIONS DO NOT USE IT.

The above files are specified in the command (.COM) file that runs BRAGFLO. The file names are already entered into the DEFINE lines of the .COM file. A sample .COM file with the six specified file names follows:

```
.
.
.
$ DEFINE BF2_UIF$INPUT BF2_TEST7_R001.INP
$ DEFINE BF2_DBG$OUTPUT BF2_TEST7_R001.OUT
$ DEFINE BF2_DBG$SUMMARY BF2_TEST7_R001.SUM
$ DEFINE BF2_BIN$OUTPUT BF2_TEST7_R001.BIN
$ DEFINE BF2_IN$RESTART BF2_TEST7_R001.RIN
$ DEFINE BF2_OUT$RESTART BF2_TEST7_R001.ROT
.
.
.
```

If so desired, the user can modify those file names by editing the DEFINE lines using the Digital Command Language (DCL) EDIT command. This is accomplished by typing EDIT (or simply EDT) followed by the name of the .COM file, moving the cursor to the file names to be changed, changing the file names (and specifying another directory name if the file exists in another directory), and then, after all the necessary name changes have been made, typing control-Z and EXIT to save the changes to the .COM file.

If the user wishes to run BRAGFLO interactively, he or she can enter the following command after the VMS "$" prompt, followed by a carriage return:

@[name of .COM command file]

If the user wants to run BRAGFLO in "batch" mode, he or she can enter the following command after the VMS "$" prompt, followed by a carriage return:

SUBMIT/QUEUE=BEATLE$BATCH [name of .COM command file]

Both options are shown in Figure 30. Regardless of the approach, BRAGFLO executes as directed by the input control .INP file and outputs the Files 2, 3, 4, 5, and 6, as shown in Figure 30.

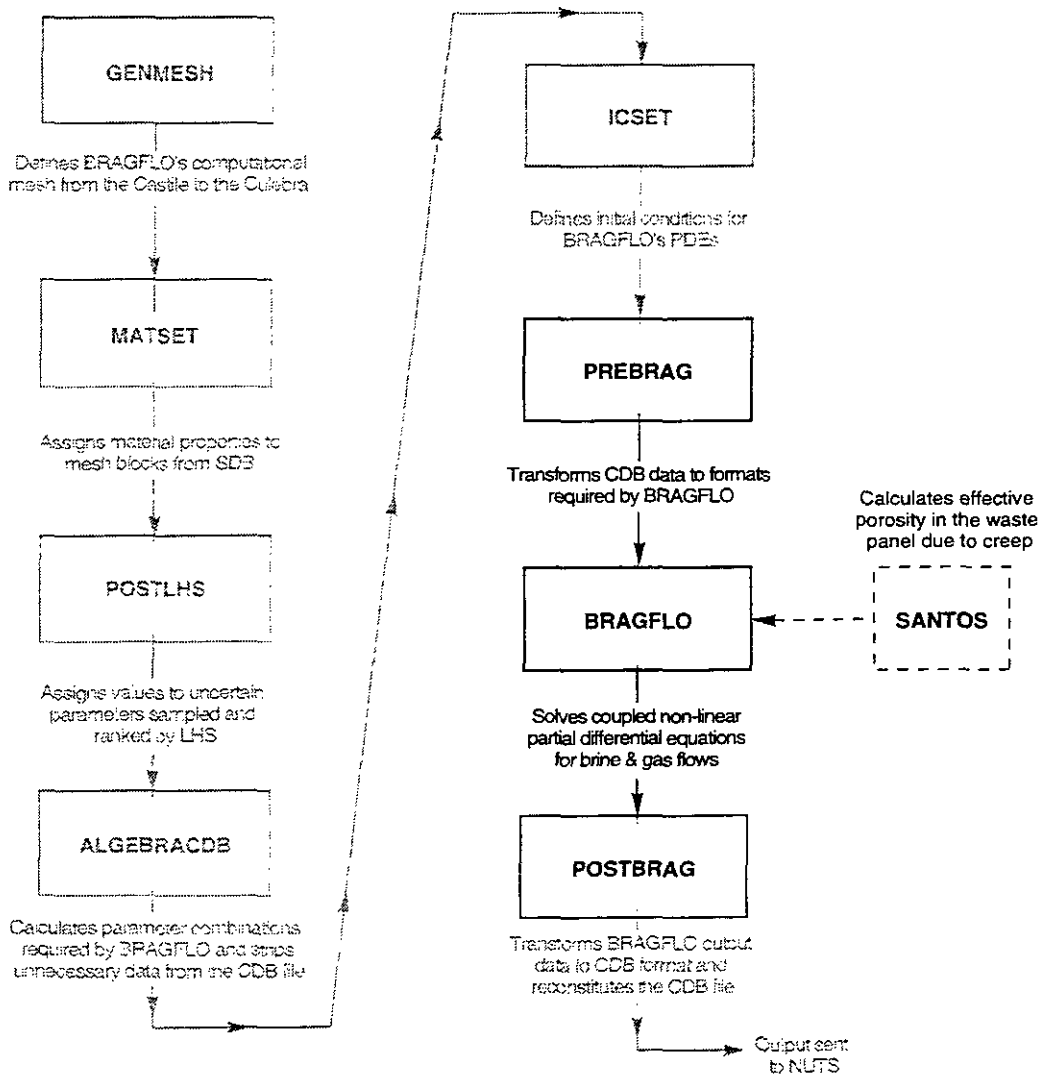

Figure 29. Sample computational flow diagram for BRAGFLO, highlighting flow to and from BRAGFLO.

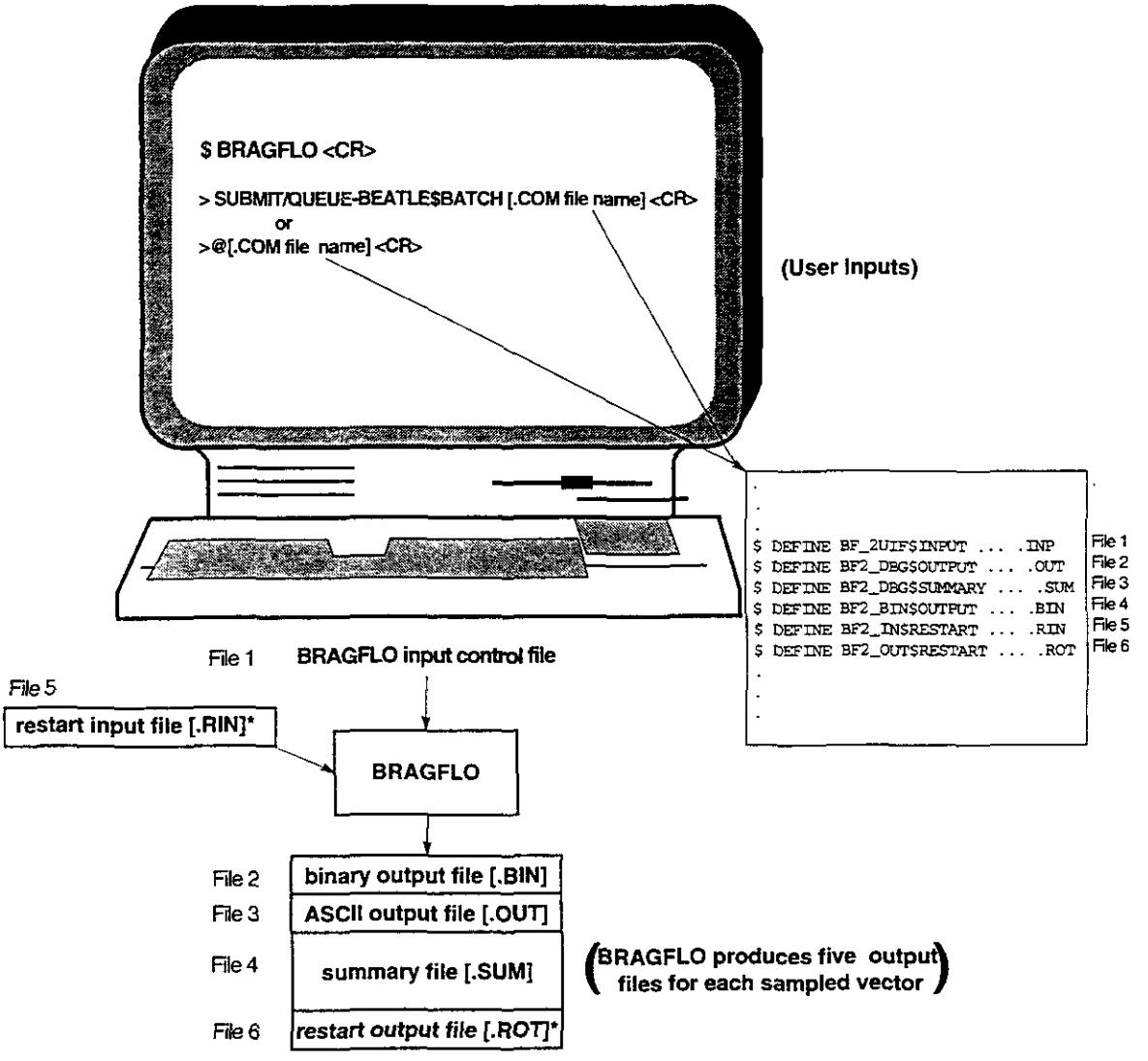

*NOTE: .ROT and .RIN files not used for the 1996 WIPP PA calculation.

Figure 30. User-required file specifications for BRAGFLO.

7.0 DESCRIPTION OF INPUT FILES

7.1 Parameter Statement

BRAGFLO uses one INCLUDE file, BF2_PARAMS.INC, containing a single PARAMETER statement that sets dimensions on many of the arrays used in BRAGFLO. (Where the term "PARAMETER statement" is used in this manual, it refers to the statement in BF2_PARAMS.INC.) An example of the INCLUDE file, used for the Compliance Certification Application (CCA) calculations, follows:

```
C
C     NOTE:  Value of MDIM = 3*(NEQ*[MIN(MX*MY,MX*MZ,MY*MZ)+1]-1)+1
C            Value of IBWM = 3*MAX(MX*MY,MX*MZ,MY*MZ)+1
C
      INTEGER
     1   MX          , MY          , MZ          , MG          ,
     2   NEQ         , MGNEQ       , MDIM        , NPHASE      ,
     3   NWTIME      , NW          , NWPERGRID   , MMAT        ,
     4   NPINT       , NCOMP       , MGAS        , MRAD        ,
     5   MRXYZ       , MAXPRNTASC  , MAXPRNTBIN  , MAXPRNTRST
C
      INTEGER
     1   MAXMATTIMES, NWTIMEP     , NDTFIXMAX   , MAXMATTIMP  ,
     2   NDTFIXMAXP , NSDATA      , NTDATA      , MKLOS       ,
     3   MMON       , MWST        , MDRZ        , NVPR        ,
     4   MXHIV      , MVHIV       , IBWM        , MRWXYZ      ,
     5   MWXYZ      , MGVAR       , MSPEC       , NDIRMAX
C
      PARAMETER(MX=50,MY=40,MZ=10,MG=MX*MY*MZ,NEQ=2,MGNEQ=MG*NEQ,
     1          MDIM=2404,NPHASE=2,NWTIME=10,NW=50,NWPERGRID=2,MMAT=80,
     2          NPINT=10000,NCOMP=3,MGAS=6,MRAD=1,MRXYZ=MRAD*MG,
     3          MAXPRNTASC=100,MAXPRNTBIN=100,MAXPRNTRST=100,
     4          MAXMATTIMES=20,NWTIMEP=NWTIME+1,NDTFIXMAX=50,
     5          MAXMATTIMP=MAXMATTIMES+1,NDTFIXMAXP=NDTFIXMAX+1,
     6          NSDATA=13,NTDATA=214,MKLOS=4,MMON=9,MWST=2,MDRZ=1,
     7          NVPR=95+3*MWST*(1+MRAD),MXHIV=15000,MVHIV=MG,IBWM=1,
     8          MRWXYZ=MRAD*MWST*MG,MWXYZ=MWST*MG,MGVAR=10,MSPEC=23,
     9          NDIRMAX=37)
```

The parameters that can be changed by the user are listed here. Note that all of these parameters are maximum values. They can be set to be larger than required for the problem being run, but to minimize memory requirements, the smallest values needed to run the problem should be used. No values less than one should be used.

TABLE 1. Variables used in BF2_PARAMS.INC

Parameter	Description
MX	Maximum number of grid blocks in the x-direction; can be greater than the actual number of grid blocks in the problem to be run.
MY	Maximum number of grid blocks in the y-direction; can be greater than the actual number of grid blocks in the problem to be run.
MZ	Maximum number of grid blocks in the z-direction; can be greater than the actual number of grid blocks in the problem to be run.
MDIM	Minimum bandwidth of the Jacobian matrix; the value should be calculated using the formula: `MDIM = 3*{NEQ*[MIN(MX*MY,MX*MZ,MY*MZ)+1]-1}+1`
NWTIME	Maximum number of times that well properties will be changed.
NW	Maximum number of wells to be specified at any given time.
NWPERGRID	Maximum number of wells in any grid block.
MMAT	Maximum number of material regions.
MRAD	Maximum number of radionuclides allowed in the transport, decay, and radiolysis calculation.
MAXPRNTASC	Maximum number of times at which an ASCII output dump can be specified.
MAXPRNTBIN	Maximum number of times at which a binary output dump can be specified.
MAXPRNTRST	Maximum number of times at which a restart can be specified.
MAXMATTIMES	Maximum number of times at which a new material map can be specified.
NDTFIXMAX	Maximum number of times that the time step can be fixed.
MMON	Maximum number of monitor grid blocks that can be specified.
MWST	Maximum number of waste regions allowed.
MDRZ	Maximum number of DRZ regions allowed.
MXHIV	Maximum total number of history variables allowed. Includes 10 time- and performance-related history variables; therefore, must be ≥ 10.
MVHIV	Maximum number of history variables per output distribution (e. g., brine pressure or gas saturation).
IBWM	Maximum bandwidth for Jacobian used in solution of multicomponent gas transport model within BRAGFLO; value to be used is computed from the formula: `IBWM = 3*MAX(MX*MY,MX*MZ,MY*MZ)+1` If gas transport is not being modeled, IBWM should be set to 1 to save large amounts of storage.
NDIRMAX	Maximum number of grid blocks in which Dirichlet boundary conditions can be specified.

Several parameters are set in the PARAMETER statement that should not or cannot be changed. These are described below so the user will know why they should not be altered, and, if they are inadvertently changed, how they can be reset to their correct values.

TABLE 2. Constants for BF2_PARAMS.INC

Parameter	Required Value	Description
NEQ	2	Number of equations being solved in BRAGFLO.
NPHASE	2	Number of immiscible fluid phases.
NPINT	10000	Number of pressure intervals at which gas density is evaluated when using the look-up table to obtain gas density.
NCOMP	3	Number of components in all phases. Includes gas, brine, and gas dissolved in brine.
MGAS	6	Number of gases for which equation of state parameters are included in BRAGFLO (H_2, CO_2, CH_4, N_2, O_2, and H_2S).
NSDATA	13	Number of gas-generation-rate entries in creep closure surface data.
NTDATA	214	Number of time entries in creep closure surface data.
MKLOS	4	Number of creep closure surfaces available in BRAGFLO
MGVAR	10	Number of "global" variables printed out to binary and ASCII output files.
MSPEC	23	Maximum number of species to be used in the reaction path model.

The input control file consists of the following sections, each dealing with different types of inputs:

1. startup and time control
2. output control parameters
3. mesh description parameters
4. well parameters and boundary conditions
5. initial conditions
6. numerical control parameters
7. material maps and material properties
8. fluid properties
9. chemical reaction parameters
10. creep closure parameters
11. radionuclide transport and decay parameters
12. multicomponent gas transport parameters.

INPUTS FROM ALL SECTIONS EXCEPT SECTIONS 11 AND 12 ARE ALLOWED FOR THE 1996 WIPP PA CALCULATIONS.

7.2 Input Control File

As is explained in Section 6.0, the input control file for BRAGFLO is created by PREBRAG based on user inputs to PREBRAG. Even though the input control file for BRAGFLO is not technically user-specified, it is still important to understand and is therefore explained in detail in this user's manual.

The input file is composed of several sections, each dealing with different types of input. Within each section, input parameters control specific areas of the simulation. Input generally consists of a line of description or informative comments followed, on the next line, by one or more parameter values. The descriptive line can be any 132 characters. It is intended solely to make the input file easier to read and be understood by the user. None of the information on any of these descriptive lines is used for program control. The content of these lines is entirely at the discretion of the user and will have no effect whatsoever on how the program runs. The line can even be blank, if the user wishes, but there must be a line, informative or blank, and only one line, everywhere that one is indicated. An example input file is provided in Appendix A.

The order of the input is fixed, i.e., each line of input must appear in exactly the order described in below. Any deviation from this order will cause BRAGFLO to abort or run incorrectly.

Many input values have units associated with them, examples being time and initial pressures. BRAGFLO generally allows input to be in either of two systems of units: SI or English. The choice is up to the user, but one system must be used consistently for all input parameters that have units. The description of each input parameter includes in brackets the units that can be used for that parameter, with the SI units given first and the English units second. If the parameter has no units, none is shown. In a few instances, only SI units are allowed. If no English units are mentioned in the description of the parameter, then English units are not allowed for that particular parameter. Further details concerning units are given in Section 7.2.2.

7.2.0 PREBRAG QA Information

Unlike previous versions of BRAGFLO, version 4.00 allows QA information on PREBRAG to be placed into the .CDB file that is created when POSTBRAG processes the BRAGFLO output. This is accomplished by including this information in the BRAGFLO input file created by PREBRAG. Inclusion of this information is optional, in order to maintain compatibility with input files for earlier versions. If PREBRAG is used to set up the BRAGFLO input file, this information is written automatically to the BRAGFLO input file. If the input file is set up manually, this section should be omitted; go directly to Section 7.2.1.

Line 0.1. PREBRAG QA flag.

If PREBRAG QA information is to follow, then the first nonblank characters on this line must be the character string:

QA

Any number of blanks (up to 125) may precede this character string, and the rest of the line (up to 132 characters) can be blank or contain any characters or descriptions

that the user wishes to use; but none of the information on this line will be saved — this line serves only as a flag.

If the characters '**QA**' are *not* the first nonblank characters on this line, then it is assumed that PREBRAG QA information does *not* follow, and this line is assumed to be the title of the run, Line 1.1 (see next section, 7.2.1). In this case, no more input from this section can follow, or BRAGFLO will abort.

Line 0.2. Name of program.

The first nonblank characters on this line should be the string:

```
PREBRAG
```

Any number of blanks (up to 125) may precede this character string, and the rest of the line (to a total of 132 characters) can be blank or may contain any characters or descriptions that the user wishes to use, but none of that information will be saved; only the string 'PREBRAG' will be written to output files.

If the characters 'PREBRAG' are *not* the first nonblank characters on this line, then it is assumed that the input in this section is *not* PREBRAG QA information, and no PREBRAG QA information will be written to the output files. However, it is still necessary to include all of the lines in this section (Lines 0.1 - 0.6). If any of Lines 0.2 - 0.6 is completely blank, BRAGFLO will abort.

If this line does begin with 'PREBRAG', then the information on the next four lines will be written to the BRAGFLO output files.

Line 0.3. PREBRAG version number.

The first 8 characters starting with the first nonblank character must be the version number of PREBRAG used to set up the input file, e. g., '6.00'. If this line is blank, BRAGFLO will abort. Leading blanks and trailing blanks or nonblank characters are permitted, but only the eight characters starting with the first nonblank character will be written to the BRAGFLO output files.

Line 0.4. PREBRAG revision date.

The first 8 characters starting with the first nonblank character must be the revision date of PREBRAG used to set up the input file, e. g., '01/19/96'. If this line is blank, BRAGFLO will abort. Leading blanks and trailing blanks or nonblank characters are permitted, but only the eight characters starting with the first nonblank character will be written to the BRAGFLO output files.

Line 0.5. PREBRAG run date.

The first 8 characters starting with the first nonblank character must be the date on which PREBRAG was run to set up the input file, e. g., '01/25/96'. If this line is blank, BRAGFLO will abort. Leading blanks and trailing blanks or nonblank characters are permitted, but only the eight characters starting with the first nonblank character will be written to the BRAGFLO output files.

Line 0.6. PREBRAG run time.

The first 8 characters starting with the first nonblank character must be the time at which PREBRAG was run to set up the input file, e. g., '11:13:44'. If this line is blank, BRAGFLO will abort. Leading blanks and trailing blanks or nonblank characters are permitted, but only the eight characters starting with the first nonblank character will be written to the BRAGFLO output files.

The rest of the input file is the same as in BRAGFLO version 3.62ZO, beginning with Line 1.1 in Section 7.2.1.

The first 7 lines of the input file will typically appear as in the following example:

```
**QA**
PREBRAG  -- Program name
6.00     -- PREBRAG version number
01/19/96 -- PREBRAG revision date
01/25/96 -- PREBRAG run date
11:13:44 -- PREBRAG run time
Title of the run (Line 1.1)
```

7.2.1 Startup and Time Control

In this section, parameters that initialize the size of the problem and control the simulation time are input.

Line 1.1. Title of run.

This is a descriptive title for the simulation being run. This title is saved and printed to the output files, but otherwise has no effect on the performance of BRAGFLO.

Line 1.2. Descriptor. Logical flags indicating files to be used.

One-line (up to 132 characters) descriptor for the following parameters:

Line 1.3. LWASC, LWBIN, LWSUM, LWRST, LRRST.

Input each flag in free format as a T, .TRUE., F, or .FALSE., separated by one or more spaces or by commas.

M

LWASC: Flag indicating whether an ASCII output file is to be written.
LWBIN: Flag indicating whether a binary output file is to be written.
LWSUM: Flag indicating whether an ASCII summary output file is to be written.
LWRST: Flag indicating whether a binary restart output file is to be written.
LRRST: Flag indicating whether a binary restart input file is to be read. If this flag is .TRUE., then a restart input file for this run must exist in the same directory as the input [.INP] file. This file is created by copying a restart output [.ROT] file from an initial run into a [.RIN] file having the same root name as the input file used in the restart run. (Although it is best for traceability reasons for all files used in both initial runs and in

restart runs to have the same root name, it is not necessary in order for the restart to run correctly.)

RESTART CAPABILITY IS NOT SUPPORTED FOR THE 1996 WIPP PA CALCULATIONS.

Line 1.4. Descriptor. Model type and grid size parameter.
One-line (up to 132 characters) descriptor for the following parameters:

Line 1.5. MODTYPE, NX,NY,NZ.

MODTYPE: Number of dimensions being used for this run. Although BRAGFLO is a fully three-dimensional code, many shortcuts are taken that speed up execution if the problem being run is only one-dimensional (NY = NZ = 1) or two-dimensional (NZ = 1). MODTYPE is given a value of 1, 2, or 3, depending on whether the problem is 1-, 2-, or 3-dimensional, respectively. If a value less than 1 or greater than 3 is input, the program will abort with the following message printed to the screen:

```
*** MODTYPE Error in READSTARTUP ***
```

The ASCII output file provides additional information:

```
**FATAL ERROR in Input:  MODTYPE = <input value>
**MODTYPE must be 1, 2, or 3.
```

NX: Number of grid blocks in the *x*-direction.
NY: Number of grid blocks in the *y*-direction.
NZ: Number of grid blocks in the *z*-direction.

NX, NY, and NZ must be less than or equal to MX, MY, and MZ, respectively, (these are specified in the PARAMETER statement), and they must all be greater than zero. If not, BRAGFLO will abort with the following message printed to the screen:

```
*** Size error in READSTARTUP; invalid NX, NY, or NZ
```

The ASCII output file provides additional information:

```
** FATAL ERROR in Input:          NX,NY,NZ  = <input values>
** Maximum values dimensioned:    MX,MY,MZ  = <values set in
PARAMETER statement>
** Minimum values allowed:      MX,MY,MZ =     1     1     1
```

<u>Coordinate system.</u> BRAGFLO uses a right-handed coordinate system in which the origin is at the front lower left corner of the region being modeled. In this system, the *x*-direction increases to the right, the *y*-direction increases into the page, and the *z*-direction increases upward. Gravity acts in the negative *z*-direction. The grid can be reoriented (for example, to

make the y-direction vertical) with input described in Subsection 7.2.3 (Mesh Parameters). This will be discussed in more detail in Subsection 7.2.3.

Line 1.6. Descriptor. Simulation time limits.

Line 1.7. START, FINISH, MAXITF.

START: Start time for the simulation [s or days]. START can be negative; if so, certain special material properties can be changed at time zero. More details can be found in Subsection 7.2.7 (Material Properties).

FINISH: End time for the simulation [s or days].

MAXITF: Maximum number of time steps allowed in this run. This is the only means for limiting how long the simulation will run. WIPP Performance Assessment simulations typically require about 1000 time steps to complete a 10,000-yr simulation, depending on convergence criteria selected (Subsection 7.2.6). On a few occasions, more than 10,000 steps have been required. A value of MAXITF = 10000 is normally used; if more steps are required, the run can be restarted from where it ended at the 10000th step, because a restart record is always written at the end of a run, provided that LWANS = .TRUE. In a restart run that is to continue from the MAXITFth step, the new input file must have a value for MAXITF that is greater than the MAXITF in the original input file.

Line 1.8. Descriptor. Time step controls.

Line 1.9. DELT, DELTMIN, DELTMAX, DTIMEMAX, ITIMECNTRL, TSWITCH.

DELT: Initial time step [s or days]. Recommended value: 864. s (1/10 day).

DELTMIN: Minimum time step allowed [s or days]. Recommended value: 864. s (1/10 day).

DELTMAX: Maximum time step allowed [s or days]. Recommended value: 1.728 x 10^9 s (20,000 days or about 55 yr).

DTIMEMAX: Maximum fractional increase in time step that will be allowed when auto time step control is used [dimensionless]. A value of 1.0 would, in effect, turn off auto time step control. No check is made to ensure that a value greater than 1.0 is used. A value too close to 1.0, e. g., 1.1, is generally inefficient, not taking full advantage of the tendency for pressures and flows eventually to equilibrate and thereby allow larger time steps. A value that is too large, greater than 2.0, is also inefficient because the solution will fail to converge much more frequently, resulting in wasted calculations as the time step size must be reduced and the time step repeated. The value used for DELTFACTOR (Subsection 7.2.6, Line 6.24) should be taken into consideration in selecting a value for DTIMEMAX. Recommended value: 1.5.

ITIMECNTRL: Flag for automatic time step control . Recommended value: 1.

= 0: A fixed time step of DELT will be used throughout the simulation.

= 1: Auto time step control will be used. Variable changes vary greatly throughout a typical simulation. Auto time step control allows large

time steps to be taken when little is happening, but forces small steps to be used when rapid changes are occurring.

TSWITCH: Value of gas saturation that determines when to switch from relative to absolute change in gas saturation for calculating time step size when auto time step control is used (ITIMECNTRL=1). When the current value of gas saturation is greater than TSWITCH, the time step algorithm uses the relative change in saturation over the previous time step; otherwise, it uses the absolute change in gas saturation. Valid range of input value: 0 - 1. Recommended value: 0.01. In some instances, BRAGFLO will run faster when TSWITCH is turned off by using an input value of TSWITCH = 1.

Line 1.10. Descriptor. Time step changes.

Line 1.11. NDTFIX.

NDTFIX: Number of times at which the time step will be reset to a specified value, overriding the time step computed by the auto time step control. This feature allows computing time to be saved when major changes in material properties at some point in simulation time are likely to cause the auto time step control to cut back the time step repeatedly. By reducing the time step manually, fewer unsuccessful calculations will be performed. If the auto time step control is not being used (ITIMECNTRL = 0), this capability is not used, but some value must still be input for NDTFIX; a value of 0 is recommended. If NDTFIX < 0, BRAGFLO will behave as though NDTFIX = 0. If NDTFIX > NDTFIXMAX (set in PARAMS.INC), the run will abort with a message printed to the screen:

```
 *** ERROR in READSTARTUP:  NDTFIXMAX needs to be larger;
     NDTFIX = <input value>
*** NDTFIX error in READSTARTUP ***
```

The next line is repeated NDTFIX times, each line with these two numbers. If NDTFIX = 0, *no* lines are input for these two parameters. If ITIMECNTRL = 0 (i. e., *no* auto time step control), but NDTFIX > 0, then NDTFIX lines of TIMEDTFIX and DTFIX must still be input, even though they will not be used.

Line 1.12. TIMEDTFIX(K), DTFIX(K).

TIMEDTFIX: Simulation time at which the time step will be reset [s or days].

DTFIX: New time step size to be used in the first time step after TIMEDTFIX is exceeded [s or days].

7.2.2 Output Control Parameters

This section describes input that controls output to the three output files: ASCII, binary, and restart files.

Line 2.1. Descriptor. Output interval specification; units used in input and output.

Line 2.2. IPRTYPEASC, IPRTYPEBIN, IPRTYPERST, UNITSI, UNITSO.

IPRTYPEASC: ASCII output control option.
IPRTYPEBIN: Binary output control option.
IPRTYPERST: Restart output control option.

Three options are available. Additional input is required for each option, and the type of additional input for each option differs.

0: Output at first, last, and fixed frequency of time steps.
1: Output at first and last time step and at fixed time intervals.
2: Output at specified times.

Printing at a fixed frequency of time steps (option 0) offers the advantage of more frequent output over a given time span when rapid changes are occurring and less output when changes are slower. This results when auto time step control is in effect, and the time step is small when changes are rapid and large when changes are small. This option is generally used only for output to the binary output file. Specifying output at selected times (option 2) or at fixed time intervals (option 1) is useful when comparisons of different runs will be made. These two options are usually used for the ASCII and restart output, where less frequent output is desired. The binary output file is intended to be the primary repository for results because more data can be stored more compactly than in the ASCII output. An important output feature in BRAGFLO is that whenever any results are printed to the ASCII file or to the restart file, they are also printed at the same time to the binary output file. Thus, the binary file contains the complete record of all results that have been printed to any output file.

UNITSI: Units used in the input (CHARACTER*8 variable). Options are: 'SI' or 'ENGLISH'. Recommended: 'SI'. The input is read in free format, so the input character string must be enclosed in tick marks.

UNITSO: Units used in the output (CHARACTER*8 variable). Options are: 'SI' or 'ENGLISH'. Recommended: 'SI'. The input character string must be enclosed in tick marks.

The same system of units must be used consistently throughout the input. Only these units can be used in the input:

Subsequent input for output control depends on the input value selected for IPRTYPEASC, IPRTYPEBIN, and IPRTYPERST. ASCII output is dealt with first.

ASCII Output Controls.

Line 2.3. Descriptor. ASCII output time or frequency control parameters.

Table 3. Conversion Factors.

Quantity	SI units	English units	Conversion Factor (multiply by value in English units to obtain value in SI units)
Length	m	ft	0.3048
Mass	kg	lb	0.4535237
Time	s	day	86400
Temperature	K	°R	5/9
Amount of substance	mol	lbmol	0.4535237
Area	m^2	ft^2	0.09290304
Volume	m^3	ft^3	0.028316846592
Pressure	Pa	psi	6894.757293168362
Mass flow rate	kg/s	lb/day	$5.2499116898148148 \times 10^{-6}$
Concentration rate change	$kg/(s \cdot m^3)$	$lb/(day \cdot ft^3)$	0.018539888164305717
Density or concentration	kg/m^3	lb/ft^3	16.01846337396014
Velocity	m/s	ft/day	$3.527777777777778 \times 10^{-6}$
Volumetric rate	m^3/s	ft^3/day	3.2774128×10^{-7}
Viscosity	Pa·s	cP	0.001
Productivity index	m^3	bbl·cP/ (day·psi)	$2.6688839796530887 \times 10^{-13}$
Slope of solution gas-brine ratio *vs.* pressure	Pa^{-1}	$ft^3/(bbl \cdot psi)$	$2.5832324345269173 \times 10^{-5}$
Slope of viscosity *vs.* pressure	s	cP/psi	$1.4503773773020921 \times 10^{-7}$
Permeability	m^2	darcy	$9.8692326671601282 \times 10^{-13}$

If IPRTYPEASC = 0 (output at fixed time step frequency):

Line 2.4. IPRNTASC.
IPRNTASC: ASCII output time step frequency.

If IPRTYPEASC = 1 (output at fixed time interval):

Line 2.4: TMEINTASC, SPTMEASC, FPTMEASC.
TMEINTASC: Time interval [s or days]

SPTMEASC: Starting output time [s or days]
FPTMEASC: Final output time [s or days]

If IPRTYPEASC =2 (output at specified times):

Line 2.4: NPTMEASC.
NPTMEASC: Number of specified times.

Line 2.4a: Descriptor.

Line 2.4b: TIMESASC (NPTMEASC values).
TIMESASC: Specified output times [s or days]

Binary output controls.

Line 2.5. Descriptor. Binary output time or frequency control parameters.

If IPRTYPEBIN = 0 (output at fixed time step frequency):

Line 2.6. IPRNTBIN.
IPRNTBIN: Binary output time step frequency.

If IPRTYPEBIN = 1 (output at fixed time intervals):

Line 2.6. TMEINTBIN, SPTMEBIN, FPTMEBIN.
TMEINTBIN: Binary output time interval [s or days].
SPTMEBIN: Starting time for binary output [s or days].
FPTMEBIN: Final output time for binary output [s or days].

If IPRTYPEBIN = 2 (output at specified times):

Line 2.6. NPTMEBIN.
NPTMEBIN: Number of output times specified.

Line 2.6a. Descriptor. Output times.

Line 2.6b. TIMESBIN (NPTMEBIN values).
TIMESBIN: Specified binary output times [s or days]

Restart Output Controls. The restart capability in BRAGFLO enables a run to be restarted from the point where the restart output is written. This feature is useful when debugging a case that is known to run into problems after much computing time has elapsed. It is also useful when conditions are changed part way through a base case; then, the base case can be run all the way to completion, with restarts written at specified times, and sub-cases can then be run starting from the restarts, rather than starting from the beginning, thereby saving much computing time.

The restart file contains only enough information to enable BRAGFLO to resume from where the restart was written, including values of the dependent variables, certain cumulative variables, and current settings for flags that get changed over the course of a run. A regular input file is still needed to provide all the information normally obtained from an input file. The restart capability is discussed in detail in Subsection 7.3.

NOTE: RESTART CAPABILITY IS NOT ALLOWED FOR THE 1996 WIPP PA CALCULATION.

Line 2.7. Descriptor. Restart output time or frequency control parameters.

If IPRTYPERST = 0 (restart output at fixed time step frequency):

Line 2.8. IPRNTRST.
IPRNTRST: Restart output time step frequency.

If IPRTYPERST = 1 (restart output at fixed time intervals):

Line 2.8. TMEINTRST, SPTMERST, FPTMERST.
TMEINTRST: Restart output time interval [s or days]
SPTMERST: Starting time for restart output [s or days]
FPTMERST: Final time for restart output [s or days]

If IPRTYPERST = 2 (restart output at specified times):

Line 2.8. NPTMERST.
NPTMERST: Number of times to specify restart output.

Line 2.8a. Descriptor. Restart output times.

Line 2.8b. TIMESRST (NPTMERST values).
TIMESRST: Specified restart output times [s or days].

Element Variables. The next input are the ASCII and binary print control flags. These flags indicate which of at least 95 element variables are printed to the output files. Element variables are defined as any variable that has a time-varying value at each grid block. These are listed in Table 4. The number of element variables available to be printed out depends on the number of waste regions in the mesh (defined in Subsection 7.2.7) and the number (if any) of radionuclides being tracked in the transport calculation. There are 95 element variables that are always available, none of which is associated with radionuclide transport. Of these 95 variables, 45 (numbers 49-93) are associated with the reaction-path gas-generation model, which has been partially implemented but is not available for use in the current version of BRAGFLO. Any of the reaction path model variables can be printed out, but their values are all zero. The total number

available is NVPR = 95 + 3 * MWST * (1 + MRAD), where MWST is the number of waste regions, and MRAD is the number of radionuclides involved in transport and decay.

Line 2.9. Descriptor. ASCII print flags.

Line 2.10. NPRNTA (NVPR values).

NPRNTA: Flag to indicate output of element variables to the ASCII output file.
0 = Do *not* print this element variable to the ASCII output file.
1 = *Do* print this element variable to the ASCII output file.

Line 2.11. Descriptor. Binary print flags.

Line 2.12. NPRNTB (NVPR values).

NPRNTB: Flag to indicate output of element variables to the binary output file.
0 = Do *not* print this element variable to the binary output file.
1 = *Do* print this element variable to the binary output file.

History Variables. For purposes of the BRAGFLO input, a history variable is defined as any variable listed in Table 4, at a specified grid block location. History variables are printed at every time step, unlike the rest of the ASCII and binary printout, which is generally *not* printed at every time step, but rather at multiple time steps or at intervals specified in the input, as described above. History variables are printed only to the binary output file, never to the ASCII output file. The purpose for history variables is to allow accurate postprocessing. For example, integration of brine flow past some boundary can be done in postprocessing to give cumulative flows that are as accurate as if they were computed internally to BRAGFLO. Earlier versions of BRAGFLO performed some of this integration, but, without extremely complex input, it was not possible to keep the code general, and not hard-wired to a particular mesh. Without history variables, postprocessing can only be done using the element variables, which are usually output at multistep intervals. Then, variables that change rapidly over a short period of time cannot be integrated accurately.

Line 2.13. Descriptor. History variables.

Line 2.14. NHIV.

NHIV: Total number of element variables (from the list in Table 1) that will be printed as history variables. This is the number of sets of variables to be read from input.

If NHIV = 0, no history variables will be printed out, and no more history variable input will be read from input.

If NHIV > 0, then read NHIV sets of lines 2.15 and 2.16:

Line 2.15. LH, NGBHIV.

LH: Element variable number from Table 1.

NGBHIV: Number of grid blocks to be printed as history variables for variable number LH.

Table 4. Element variables available for printout in BRAGFLO. Variables 1 - 95 are, by default, available in any run. Variables 96 and greater depend on the values of MWST and MRAD. This list is for MWST = 1, MRAD = 3 (Pu240, U236, and Th232), which results in a total of NVPR = 95 + 3 * MWST * (1 + MRAD) = 107 element variables.

No.	CAMCON Element Variable Name	Description	SI Units
1	PRESBRIN	Brine pressure	Pa
2	PRESGAS	Gas pressure	Pa
3	POTO	Brine density × g × potentiometric head	Pa
4	POTG	Gas density × g × potentiometric head	Pa
5	PBUB	Brine bubble pressure	Pa
6	POROS	Porosity	m^3 void/m^3 rock
7	RELPERMB	Relative permeability to brine	dimensionless
8	RELPERMG	Relative permeability to gas	dimensionless
9	DENBRINE	Brine density	kg/m^3
10	DENGAS	Gas density	kg/m^3
11	PERMBRX	Permeability to brine, *x*-direction	m^2
12	PERMBRY	Permeability to brine, *y*-direction	m^2
13	PERMBRZ	Permeability to brine, *z*-direction	m^2
14	PERMGASX	Permeability to gas, *x*-direction	m^2
15	PERMGASY	Permeability to gas, *y*-direction	m^2
16	PERMGASZ	Permeability to gas, *z*-direction	m^2
17	SATBRINE	Brine saturation	fraction void volume
18	SATGAS	Gas saturation	fraction void volume
19	CBRBR	Brine component of brine phase	mass frac brine phase
20	CGASBR	Gas component of brine phase	mass frac brine phase
21	WELLBRIN	Time-averaged well brine flow rate	m^3/s (@ ref. conds)
22	WELLGAS	Time-averaged well gas flow rate	m^3/s (@ ref. conds)
23	CWELLBR	Cumulative well brine flow	fr Orig. Brine In Place
24	CWELLGAS	Cumulative well gas flow	fr Orig. Gas In Place
25	VELDBRX	Brine Darcy velocity, *x*-direction	m/s
26	VELDBRY	Brine Darcy velocity, *y*-direction	m/s
27	VELDBRZ	Brine Darcy velocity, *z*-direction	m/s
28	VELDGASX	Gas Darcy velocity, *x*-direction	m/s
29	VELDGASY	Gas Darcy velocity, *y*-direction	m/s
30	VELDGASZ	Gas Darcy velocity, *z*-direction	m/s
31	FLOWBRX	Time-avg. interblock brine flow, *x*-direction	m^3/s (@ ref. conds)
32	FLOWBRY	Time-avg. interblock brine flow, *y*-direction	m^3/s (@ ref. conds)

No.	CAMCON Element Variable Name	Description	SI Units
33	FLOWBRZ	Time-avg. interblock brine flow, *z*-direction	m^3/s (@ ref. conds)
34	FLOWGASX	Time-avg. interblock gas flow, *x*-direction	m^3/s (@ ref. conds)
35	FLOWGASY	Time-avg. interblock gas flow, *y*-direction	m^3/s (@ ref. conds)
36	FLOWGASZ	Time-avg. interblock gas flow, *z*-direction	m^3/s (@ ref. conds)
37	MASSBALB	Relative Brine mass balance	dimensionless
38	MASSBALG	Relative Gas mass balance	dimensionless
39	CORRATI	Inundated corrosion rate–simple model	mol/s
40	CORRATH	Humid corrosion rate–simple model	mol/s
41	BIORATI	Inundated biodegradation rate–simple model	mol/s
42	BIORATH	Humid biodegradation rate–simple model	mol/s
43	H2RATE	H_2 generation rate–simple model	$kg/(s \cdot m^3)$
44	BRINRATE	Brine consumption rate–simple model	$kg/(s \cdot m^3)$
45	FERATE	Fe consumption rate–simple model	$kg/(s \cdot m^3)$
46	CELLRATE	Biodegrad consumption rate–simple model	$kg/(s \cdot m^3)$
47	FECONC	Fe concentration–simple model	kg/m^3
48	CELLCONC	Biodegradables concentration–simple model	kg/m^3
49	H2_R	H_2 generation rate–reaction path model	$kg/(s \cdot m^3)$
50	CO2_R	CO_2 generation rate–reaction path model	$kg/(s \cdot m^3)$
51	CH4_R	CH_4 generation rate–reaction path model	$kg/(s \cdot m^3)$
52	N2_R	N_2 generation rate–reaction path model	$kg/(s \cdot m^3)$
53	H2S_R	H_2S generation rate–reaction path model	$kg/(s \cdot m^3)$
54	O2_R	O_2 generation rate–reaction path model	$kg/(s \cdot m^3)$
55	H2O_R	H_2O generation rate–reaction path model	$kg/(s \cdot m^3)$
56	H2SO4_R	H_2SO_4 generation rate–reaction path model	$kg/(s \cdot m^3)$
57	HNO3_R	HNO_3 generation rate–reaction path model	$kg/(s \cdot m^3)$
58	CH2O_R	Biodegrad consumption rate–reaction path model	$kg/(s \cdot m^3)$
59	FE_R	Fe consumption rate–reaction path model	$kg/(s \cdot m^3)$
60	FES2F_R	FeS_2 generation rate–reaction path model	$kg/(s \cdot m^3)$
61	FES2O_R	FeS_2 generation rate–reaction path model	$kg/(s \cdot m^3)$
62	FECO3F_R	$FeCO_3$ generation rate–reaction path model	$kg/(s \cdot m^3)$
63	FECO3O_R	$FeCO_3$ generation rate–reaction path model	$kg/(s \cdot m^3)$
64	FEOH2_R	$Fe(OH)_2$ generation rate–reaction path model	$kg/(s \cdot m^3)$
65	FEOOH_R	FeO(OH) generation rate–reaction path model	$kg/(s \cdot m^3)$

No.	CAMCON Element Variable Name	Description	SI Units
66	FE3O4_R	Fe_3O_4 generation rate–reaction path model	kg/(s·m^3)
67	FES_R	FeS generation rate–reaction path model	kg/(s·m^3)
68	CAO_R	CaO generation rate–reaction path model	kg/(s·m^3)
69	CAOH2_R	$Ca(OH)_2$ generation rate–reaction path model	kg/(s·m^3)
70	CACO3_R	$CaCO_3$ generation rate–reaction path model	kg/(s·m^3)
71	H2_RAD_R	H_2 generation rate–radiolysis	kg/(s·m^3)
72	H2_C	H_2 concentration–reaction path model	kg/(s·m^3)
73	CO2_C	CO_2 concentration–reaction path model	kg/m^3
74	CH4_C	CH_4 concentration–reaction path model	kg/m^3
75	N2_C	N_2 concentration–reaction path model	kg/m^3
76	H2S_C	H_2S concentration–reaction path model	kg/m^3
77	O2_C	O_2 concentration–reaction path model	kg/m^3
78	H2O_C	H_2O concentration–reaction path model	kg/m^3
79	H2SO4_C	H_2SO_4 concentration–reaction path model	kg/m^3
80	HNO3_C	HNO_3 concentration–reaction path model	kg/m^3
81	CH2O_C	Biodegradables concentration–reaction path model	kg/m^3
82	FE_C	Fe concentration–reaction path model	kg/m^3
83	FES2F_C	FeS_2 concentration–reaction path model	kg/m^3
84	FES2O_C	FeS_2 concentration–reaction path model	kg/m^3
85	FECO3F_C	$FeCO_3$ concentration–reaction path model	kg/m^3
86	FECO3O_C	$FeCO_3$ concentration–reaction path model	kg/m^3
87	FEOH2_C	$Fe(OH)_2$ concentration–reaction path model	kg/m^3
88	FEOOH_C	FeO(OH) concentration–reaction path model	kg/m^3
89	FE3O4_C	Fe_3O_4 concentration–reaction path model	kg/m^3
90	FES_C	FeS concentration–reaction path model	kg/m^3
91	CAO_C	CaO concentration–reaction path model	kg/m^3
92	CAOH2_C	$Ca(OH)_2$ concentration–reaction path model	kg/m^3
93	CACO3_C	$CaCO_3$ concentration–reaction path model	kg/m^3
94	H2_RAD_C	H_2 concentration–radiolysis	kg/m^3
95	H2OFLOWI	Water inflow rate	kg/s
96	BM1TOT	Total isotope mass from Waste Region 1	kg
97	BC1TOT	Total isotope conc. from Waste Region 1	kg/m^3
98	SM1TOT	Total solid isotope mass from Waste Region 1	kg

No.	CAMCON Element Variable Name	Description	SI Units
99	BM1PU240	Mass of isotope 1 (Pu240) from Waste Region 1	kg
100	BM1U236	Mass of isotope 2 (U236) from Waste Region 1	kg
101	BM1TH232	Mass of isotope 3 (Th232) from Waste Region 1	kg
102	BC1PU240	Conc. of isotope 1 from Waste Region 1	kg/m^3
103	BC1U236	Conc. of isotope 2 from Waste Region 1	kg/m^3
104	BC1TH232	Conc. of isotope 3 from Waste Region 1	kg/m^3
105	SM1PU240	Solid mass of isotope 1 from Waste Region 1	kg
106	SM1U236	Solid mass of isotope 2 from Waste Region 1	kg
107	SM1TH232	Solid mass of isotope 3 from Waste Region 1	kg

Line 2.16. IIHIV, JJHIV, KKHIV (NGBHIV sets).

IIHIV: I-index for grid block location for the history variable.
JJHIV: J-index for grid block location for the history variable.
KKHIV: K-index for grid block location for the history variable.

Monitor Blocks. BRAGFLO prints out certain summary data to the screen and to the .SUM file at each time step to provide the user with continuous information on the how the run is progressing. This summary includes two lines showing simulation time along with time step and global mass balance information (described more fully in Subsection 7.2.15). In addition, the summary allows the user to monitor values of certain element variables at specified grid blocks. These monitor blocks are intended solely to monitor progress, rather than to provide data for post-processing or other later use, so only a few grid blocks should be selected where significant changes are likely to occur or where the behavior is representative of an entire region. Typically, one to three monitor blocks are selected. Because this information is printed both to the screen (or to a log file if run in batch) and to the .SUM file at every time step, the amount of information printed out can become large in a long run if too many monitor blocks are selected. The maximum number of blocks allowed is MMON, which is set in the PARAMETER statement.

In the current version of BRAGFLO, the following nine variables are printed at the monitor grid blocks: PO (brine pressure, Pa), PG (gas pressure, Pa), SO (brine saturation), PHI (porosity), PERMGX (permeability to gas in the x-direction, m^2), CONCFE (iron concentration, kg/m^3), CONCBIO (cellulosics concentration, kg/m^3), QR(1) [H_2 generation rate, $kg/(s\ m^3)$], QOBLOCKI (interblock brine flow in x-direction, m^3/s at reference conditions), QOBLOCKJ (interblock brine flow in y-direction, m^3/s at reference conditions), QGBLOCKI (interblock gas flow in x-direction, m^3/s at reference conditions), QGBLOCKJ (interblock gas flow in y-direction, m^3/s at reference conditions).

Line 2.17. Descriptor. Monitor block parameters.

Line 2.18. MONITOR.

MONITOR: LOGICAL Flag for monitoring key parameters at a specified grid block.

If MONITOR = .TRUE., then read the next two lines (and possibly more, depending on the values read); otherwise, go to Subsection 7.2.3.

Line 2.19. Descriptor. Number of monitor blocks.

Line 2.20. NMON.

NMON: Number of monitor blocks to be specified. NMON should be less than 100, because the monitor block number printout is formatted I2. If NMON > MMON (where MMON is set in the PARAMETER statement), BRAGFLO will abort with a message is printed to the screen:

```
*** ERROR:  Too many Monitor Blocks in Input:
   Specified: NMON = <NMON input value>
   Maximum:   MMON = <MMON value set in PARAMETER statement>
*** Monitor error in READPRTYPE ***
```

Line 2.21. Descriptor. Monitor block locations.

Read NMON repetitions of Line 2.22.

Line 2.22. IMONITOR, JMONITOR, KMONITOR

IMONITOR: I-index of grid block to be monitored.
JMONITOR: J-index of grid block to be monitored.
KMONITOR: K-index of grid block to be monitored.

7.2.3 Mesh Description Parameters

BRAGFLO provides several options for inputting the mesh. With these options, a simple mesh can be easily set up with very little input, yet very complex meshes can still be specified, with correspondingly more detailed input. BRAGFLO uses a rectilinear grid; defining the mesh requires specifying the Δx (DXGRID), Δy (DYGRID), and Δz (DZGRID), and the elevation (DEPTH) for each grid block. How much of this information has to be input depends on which input option is selected.

Line 3.1. Descriptor. Grid data flags.

Line 3.2. IDXFLAG, IDYFLAG, IDZFLAG, IDEPTHFLAG.

IDXFLAG: Specifies how grid block width Δx (DXGRID) are to be read.
IDYFLAG: Specifies how grid block width Δy (DYGRID) are to be read.
IDZFLAG: Specifies how grid block width Δz (DZGRID) are to be read.
IDEPTHFLAG: Specifies how grid block elevations (DEPTH) are to be read.

IDXFLAG = 0: DXGRID does not vary; input one value of DXGRID.
= 1: DXGRID varies in I-direction; input NX values of DXGRID.

IDYFLAG = 0: DYGRID does not vary; input one value of DYGRID.
= 1: DYGRID varies in I-direction; input NX values of DYGRID.
= 2: DYGRID varies in J-direction; input NY values of DYGRID.

IDZFLAG = 0: DZGRID does not vary; input one value of DZGRID.
= 1: DZGRID varies in I-direction; input NX values of DZGRID.
= 2: DZGRID varies in J-direction; input NY values of DZGRID.
= 3: DZGRID varies in K-direction; input NZ values of DZGRID.
= 4: DZGRID varies in I- and J-directions; input NX x NY values of DZGRID.

IDEPTHFLAG = 0: Elevation does not vary; input one value of DEPTH.
= 1: Elevation varies in I-direction; input NX values of DEPTH.
= 2: Elevation varies in J-direction; input NY values of DEPTH.
= 3: Elevation varies in K-direction; input NZ values of DEPTH.
= 4: Elevation varies in I- and J-directions; input NX x NY values of DEPTH.
= 5: Elevation varies in I- and K-directions; input NX x NZ values of DEPTH.
= 6: Elevation varies in J- and K-directions; input NY x NZ values of DEPTH.
= 7: Elevation varies in I-, J-, and K-directions; input NX x NY x NZ values of DEPTH.
= -1: Elevation varies in I-direction; have BRAGFLO calculate values of DEPTH.
= -2: Elevation varies in J-direction; have BRAGFLO calculate values of DEPTH.
= -3: Elevation varies in K-direction; have BRAGFLO calculate values of DEPTH.
= -4: Elevation varies in I- and J-directions; have BRAGFLO calculate values of DEPTH.
= -5: Elevation varies in I- and K-directions; have BRAGFLO calculate values of DEPTH.
= -6: Elevation varies in J- and K-directions; have BRAGFLO calculate values of DEPTH.
= -7: Elevation varies in I-, J-, and K-directions; have BRAGFLO calculate values of DEPTH.

If the input value for any of these flags is outside the range listed above, BRAGFLO will abort, with messages printed to the screen indicating what the problems are. The final messages printed are:

```
Number of FATAL errors in READMESH = <number of errors>
*** FATAL geometry input errors in READMESH ***
```

Subsequent input depends on the values of the geometry flags. There are four sets of input, one each for inputting DXGRID, DYGRID, DZGRID, and DEPTH.

DXGRID input.

Line 3.3. Descriptor. DXGRID input.

If IDXFLAG = 0:

Line 3.4. DXCONST.
DXCONST: Uniform grid block Δx-dimension [m or ft].

If IDXFLAG = 1:

Line 3.4. (DXGRID(I,1,1), I=1, NX).
DXGRID(I,1,1): Grid block Δx-dimensions, varying in the I-direction [m or ft].

BRAGFLO does not allow DXGRID to vary in the J- or K-directions; thus, only values for DXGRID in the I-direction need (and can) be input.

DYGRID input.

Line 3.5. Descriptor. DYGRID input.

If IDYFLAG = 0:

Line 3.6. DYCONST.
DYCONST: Uniform grid block Δy-dimension [m or ft].

If IDYFLAG = 1:

Line 3.6. (DYGRIDI(I), I=1, NX).
DYGRIDI(I): Grid block Δy-dimensions, varying only in the I-direction [m or ft].

If IDYFLAG = 2:

Line 3.6. (DYGRIDJ(J), J=1, NY).
DYGRIDJ(J): Grid block Δy-dimensions, varying only in the J-direction [m or ft].

BRAGFLO does not allow Δy to vary in the K-direction, nor in the I- and J-directions simultaneously.

DZGRID input.

Line 3.7. Descriptor. DZGRID input.

If IDZFLAG = 0:

Line 3.8. DZCONST.

DZCONST: *Uniform grid block Δz dimensions [m or ft].*

If IDZFLAG = 1:

Line 3.8. (DZGRIDI(I), I=1, NX).

DZGRIDI(I): Grid block Δz-dimensions, varying only in the I-direction [m or ft].

If IDZFLAG = 2:

Line 3.8. (DZGRIDJ(J), J=1, NY).

DZGRIDJ(J): Grid block Δz-dimensions, varying only in the J-direction [m or ft].

If IDZFLAG = 3:

Line 3.8. (DZGRIDK(K), K=1, NZ).

DZGRIDK(K): Grid block Δz-dimensions, varying only in the K-direction [m or ft].

If IDZFLAG = 4:

Line 3.8. ((DZGRIDIJ(I,J), I=1, NX), J=1, NY).

DZGRIDIJ(I,J): Grid block dimensions, varying in both I- and J-directions [m or ft].

BRAGFLO does not allow DZGRID to vary simultaneously in all three directions.

IDEPTHFLAG input.

Line 3.9. Descriptor. IDEPTHFLAG input.

Input values are elevations above the origin to the center of grid blocks. Positive values increase with elevation, indicating grid block center elevations above the elevation of the origin. If IDEPTHFLAG is greater than zero, user-specified values of DEPTH are entered. If IDEPTHFLAG is less than zero, elevations will be calculated from input inclinations.

If IDEPTHFLAG = 0:

Line 3.10. DEPTHCONST.

DEPTHCONST: Uniform elevation in all I-, J-, and K-directions [m or ft]. Using a value for IDEPTHFLAG of zero is physically realistic only if the problem is one- or two-dimensional, and NX, NY, or NZ, or two of these, is 1. However, a uniform elevation can be specified for a fully three-dimensional problem or for a two-dimensional problem with a vertical cross-section. The effect, which is sometimes desired, is to "turn off" gravity, because there is no difference in elevation between any adjacent layers in the mesh.

If IDEPTHFLAG = 1:

Line 3.10: (DEPTHI(I), I=1, NX).
DEPTHI(I): Elevations to grid block centers, varying only in the I-direction [m or ft].

If IDEPTHFLAG = 2:

Line 3.10: (DEPTHJ(J), J=1, NY).
DEPTHJ(J): Elevations to grid block centers, varying only in the J-direction [m or ft].

If IDEPTHFLAG = 3:

Line 3.10. (DEPTHK(K), K=1, NZ).
DEPTHK(K): Elevations to grid block centers, varying only in the K-direction [m or ft].

If IDEPTHFLAG = 4:

Line 3.10. ((DEPTHIJ(I,J), I=1, NX), J=1, NY).
DEPTHIJ(I,J): Elevations to grid block centers, varying in both I- and J-directions [m or ft].

If IDEPTHFLAG = 5:

Line 3.10. ((DEPTHIK(I,K), I=1, NX), K=1, NZ).
DEPTHIK(I,K): Elevations to grid block centers, varying in both I- and K-directions [m or ft].

If IDEPTHFLAG = 6:

Line 3.10. ((DEPTHJK(J,K), J=1, NY), K=1, NZ).
DEPTHJK(J,K): Elevations to grid block centers, varying in both J- and K-directions [m or ft].

If IDEPTHFLAG = 7:

Line 3.10. (((DEPTH(I,J,K), I=1, NX), J=1, NY), K=1, NZ).
DEPTH(I,J,K): Elevations to grid block centers, varying in all three directions [m or ft].

If IDEPTHFLAG < 0:
Elevations will be calculated from inclination input. Certain rules must be carefully followed to achieve the proper orientation of the mesh. Start with a right-handed

coordinate system, with the origin at $(x,y,z) = (0,0,0)$ in the center of the front lower left corner block. The x-direction increases to the right; the y-direction increases into the page; and the z-direction increases upward. Translate the mesh so that the new origin is at the center of grid block (IORIG, JORIG, KORIG). Next, set the elevation at the center of this grid block to ZERODEPTH. Finally, rotate the mesh about the axes in the following order: 1) Positive rotation about the original x-axis; 2) Positive rotation about the original y-axis; 3) Positive rotation about the original z-axis. The "original" axes are the axes as they exist after the elevation is set to ZERODEPTH; in other words, the axes of rotation do not change after each rotation.

Line 3.10. IORIG, JORIG, KORIG, ZERODEPTH, THETAX, THETAY, THETAZ.

IORIG: I-index of origin block.
JORIG: J-index of origin block.
KORIG: K-index of origin block.
ZERODEPTH: Elevation of origin block [m or ft].
THETAX: Angle of positive right-handed rotation about the x-axis [degrees].
THETAY: Angle of positive right-handed rotation about the y-axis [degrees].
THETAZ: Angle of positive right-handed rotation about the z-axis [degrees].

If IDEPTHFLAG = -1:

Elevation varies only in I-direction; there must be only one layer in the K-direction. In this case, BRAGFLO allows only rotation about the original y-axis. The only value used from Line 3.10 is THETAY; all other inputs are ignored, but appropriate place holder values (three integers and four real numbers) must be input.

If IDEPTHFLAG = -2:

Elevation varies only in J-direction; there must be only one layer in the K-direction. BRAGFLO allows only rotation about the original x-axis. The only value used from Line 3.10 is THETAX; all other inputs are ignored, but appropriate place holder values (three integers and four real numbers) must be input.

If IDEPTHFLAG < -2:

Elevation can vary in all three directions. This is the most general case, and it is used whenever IDEPTHFLAG < -2. Other specialized cases, for IDEPTHFLAG = -3 to -6, analogous to IDEPTHFLAG = +3 to +6, are not yet implemented in BRAGFLO, so any value of IDEPTHFLAG between -3 and -7, inclusive, is treated as IDEPTHFLAG = -7.

7.2.4 Well Parameters and Boundary Conditions

BRAGFLO is capable of simulating wells that are completed within the formations or porous media being modeled. A well is either an injection well or a production (or withdrawal) well. Each type of well can be treated as a constant-pressure well or as a constant flow rate well.

In a constant-pressure well, fluids (gas and brine) are injected or produced at whatever rate is necessary to maintain the specified pressure. The amount of each phase that is injected or produced is proportional to the saturation of each phase in the grid block containing the well.

A constant-pressure well is useful for simulating constant-pressure boundary conditions, and, in earlier versions of BRAGFLO, this was the only means of maintaining a truly fixed boundary pressure. In the current version, constant-pressure boundary conditions can be specified directly, so wells are no longer used for that purpose.

In a constant-flow injection or production well, the rate of injection or production of each phase is specified, and the pressure in the grid block containing the well fluctuates accordingly. Injection and production wells are useful for simulating sources and sinks, for example, generation of gas by a chemical reaction.

In BRAGFLO, a well exists only in a single grid block. In reality, a well might be completed (i.e., open to the surrounding formation) over a range of depths, which might encompass more than one grid block in the mesh. To simulate such a well using BRAGFLO, multiple wells must be used, one for each grid block in which the well is completed. More than one well may exist in a grid block. Each well in a grid block must be specified individually in the input. All wells are assumed to be located at the center of the grid block. (In fact, BRAGFLO, as a cell-centered finite difference code, considers all properties and influences as occurring at the centers of grid blocks.) It is currently not possible in BRAGFLO for wells to interact directly; for example, fluids withdrawn from one well cannot be injected in another well. Furthermore, injection and production rates are fixed over the specified time period; they cannot be varied over time, except in finite increments as specified explicitly in the input, and they cannot be made to vary as a function of any other rates or processes simulated in BRAGFLO. They depend solely, although implicitly, on the brine pressure and gas saturation within the grid block in which the wells are completed.

Specified well conditions remain in effect only until the next time at which conditions in any well are changed. For example, suppose two constant-pressure wells are specified initially, and a third well, a constant-flow well, is to be added after 1000 years. If only the third well is specified at 1000 years, the two constant-pressure wells will be turned off at 1000 years. If these two wells are to continue to be in effect after 1000 years, their conditions must be specified at 1000 years (along with the third well) as well as at the start of the run. Wells are turned off simply by specifying another time when conditions go into effect, but without specifying any conditions for those wells.

Constant-pressure (Dirichlet) boundary conditions can be specified directly, instead of being simulated by means of constant-pressure wells. BRAGFLO assumes all external mesh boundaries to be no-flow boundaries. Although constant-pressure wells can usually hold the pressure constant in any grid cell where they are applied, numerical problems are sometimes encountered. Using wells also requires that productivity indexes (PIWELL) are judiciously chosen. If PIWELL is too small, the pressure will not be held exactly constant; if PIWELL is too big, numerical difficulties are exacerbated. When gas dissolution is being simulated, constant-pressure wells may not work at all. These problems can be eliminated by specifying Dirichlet bound-

ary conditions. The user has the option of fixing either the brine pressure or the gas saturation, or both, in any grid block in the mesh.

Dirichlet boundary conditions are in effect during the entire run. They cannot be turned on or off at various times the way wells can.

Line 4.1. Descriptor. Well parameters.

Line 4.2. NWELLTIMES.

NWELLTIMES: Number of times to specify well conditions. If NWELLTIMES is greater than NWTIME (which is set in the PARAMETER statement in BF2_PARAMS.INC), BRAGFLO will abort with the message:

```
In READWELL, NWTIME needs to be larger. NWELLTIMES = <NWELLTIMES input
value>
*** Well time errors in READWELL ***
```

The following input is repeated NWELLTIMES.

Line 4.3. WELLTIME, NWELLS.

WELLTIME: Time when conditions go into effect [s or days]. Conditions specified at this time remain in effect only until the next WELLTIME. In order for a well to remain in effect after the next WELLTIME, the description and conditions for that well (Lines 4.4, 4.5, and 4.6) must be repeated at the next WELLTIME. If this information is *not* repeated at the next WELLTIME, the well is, in effect, turned off at that time.

NWELLS: Number of grid blocks containing wells at this WELLTIME.

The following input is repeated NWELLS times.

Line 4.4. IWELLNODE, JWELLNODE, KWELLNODE, NWELLSPERGRID.

IWELLNODE: I-index of grid block containing the well(s).
JWELLNODE: J-index of grid block containing the well(s).
KWELLNODE: K-index of grid block containing the well(s).
NWELLSPERGRID: Number of wells that exist in this grid block.

The following input is repeated NWELLSPERGRID times.

Line 4.5. WELLTYPE.

WELLTYPE: Type of well. This is a CHARACTER*4 variable. It is input in free format, with *no* enclosing tick marks and any number of leading spaces, in contrast to earlier versions of BRAGFLO, which used a formatted read statement. The available options are:

INJP: Pressure-controlled (or constant-pressure) injection well.

INJQ: Flow-rate-controlled injection well.
PROD: Production well.
NONE: None of the above. This is the initial value for WELLTYPE; if not changed by an input value, a well that is otherwise fully specified by input will be ignored and have no effect.

Line 4.6. QGWELL, QOWELL, PIWELL, PW.

QGWELL: Gas mass flow rate [kg/s or lb/day].
QOWELL: Brine mass flow rate [kg/s or lb/day].
PIWELL: Injectivity or productivity index [m^3 or bbl•cP/(day•psi)]. Recommended value: 1.0×10^{-6} m^3, to achieve constant pressure (PO = PW), as when wells are used to maintain a specified boundary condition.
PW: Flowing down-hole well bore pressure [Pa or psi].

The productivity index, PIWELL, is a function of grid block dimensions, permeability, and borehole diameter that allows accurate simulation of well behavior when a small-diameter borehole is completed within a large grid block. To simulate the pressure drop from the formation immediately surrounding a borehole into the borehole, the productivity index must be calibrated to actual measurements of pressure and flow rates. In the WIPP PA, wells are generally used only to maintain fixed pressures at the boundaries of a mesh, rather than to simulate the actual behavior of a well. (Since Dirichlet boundary conditions were implemented, wells are now seldom used at all.) In this case, accurate simulation of the pressure behavior in the vicinity of the well is unimportant, and a large productivity index (say, 1.0×10^{-6} m^3) is used so that the pressure in the grid block is the same as specified for the borehole. Because the productivity index is dependent on grid block dimensions, a "large" value in one grid block may not be large enough in another. However, for grid blocks as large as 15 km x 60 km x 100 m, a productivity index of 1.0×10^{-6} m^3 [3.7×10^{12} bbl•cP/(day•psi)] provides the desired equal pressures in the well borehole and the grid block.

Line 4.7. Descriptor. Constant brine pressure and gas saturation boundary conditions.

Line 4.8. DIRICHLET, NO_DIRGRID.

DIRICHLET: Logical flag (T or F) indicating that Dirichlet boundary conditions will be used.
NO_DIRGRID: Number of grid blocks in which Dirichlet boundary conditions will be applied.

If DIRICHLET is .FALSE., no additional well or boundary condition data are input. If DIRICHLET is .TRUE., the following input is repeated NO_DIRGRID times.

Line 4.9. IR,JR,KR,DIRGRIDP,DIRGRIDS,DIR_PRES,DIR_SATB.

IR: I-index of grid block in which Dirichlet boundary conditions are applied.
JR: J-index of grid block in which Dirichlet boundary conditions are applied.
KR: K-index of grid block in which Dirichlet boundary conditions are applied.

DIRGRIDP: Logical flag (T or F) indicating that a constant brine pressure is to be used.

DIRGRIDS: Logical flag (T or F) indicating that a constant gas saturation is to be used.

DIR_PRES: Brine pressure specified to be constant [Pa].

DIR_SATB: Brine saturation specified to be constant. Because BRAGFLO solves for gas saturation, it is actually the gas saturation that will be held constant. However, to be consistent with the initial condition input, where brine saturation is input, brine saturation is specified here, rather than gas saturation.

Note: DIR_PRES and DIR_SATB *must* be *identical* to the initial values, PIINIT (IR,JR,KR) and SOINIT (IR,JR,KR), respectively (see next subsection). Otherwise, BRAGFLO will run incorrectly. BRAGFLO *does not* check to be sure that DIR_PRES and DIR_SATB are the same as the initial; it is up to the user to ensure that this is true.

7.2.5 Initial Conditions

Initial conditions must be input for brine pressure, brine saturation, iron concentration, and cellulosics concentration.

Line 5.1. Descriptor. Brine pressure initial conditions.

Line 5.2. (((PINIT(I,J,K), I=1, NX), J=1, NY), K=1, NZ).
PINIT: Initial brine pressure [Pa or psi].

Line 5.3. Descriptor. Brine saturation initial conditions.

Line 5.4. (((SOINIT(I,J,K), I=1, NX), J=1, NY), K=1, NZ).
SOINIT: Initial brine saturation [dimensionless].

Line 5.5. Descriptor. Iron concentration initial conditions.

Line 5.6. (((CONCFE(I,J,K), I=1, NX), J=1, NY), K=1, NZ).
CONCFE: Initial iron concentration [kg/m^3 or lb/ft^3].

Line 5.7. Descriptor. Cellulosics concentration initial conditions.

Line 5.8. (((CONCBIO(I,J,K), I=1, NX), J=1, NY), K=1, NZ).
CONCBIO: Initial cellulosics concentration [kg/m^3 or lb/ft^3].

It is sometimes desirable to calculate, rather than input, certain initial conditions, an example being the initial brine pressure distribution in formations surrounding the WIPP repository. In this example, other initial conditions, such as the brine pressure within the repository and initial concentrations of reactants (iron and cellulosics), still need to be specified in the input, even though pressures outside the repository are calculated. BRAGFLO accommodates this need to

calculate initial conditions of only some variables in only part of the mesh by means of a somewhat convoluted interaction between special materials specifications and starting times.

If a run begins at time START ≥ TIMEICRESET (described in Subsection 7.2.7; generally, TIMEICRESET = 0.), BRAGFLO uses only the initial conditions specified in Lines 5.1-5.8 above. This use of initial conditions is straightforward and uncomplicated, being the obvious way that initial conditions are expected to be used.

If a run begins at time START < TIMEICRESET, only some of the initial conditions are used at time START, while other initial conditions from Lines 5.1-5.8 are used at time TIMEICRESET. In this case, initial pressures, PINIT, will be used in all regions *except Waste regions* at time START. Initial brine saturations, SOINIT, will also be used in all regions *except Waste regions* at time START. Reactant concentrations, CONCFE and CONCBIO, are not used until after TIMEICRESET; furthermore, reactions that affect the values of CONCFE and CONCBIO occur only in Waste regions, which are undefined prior to TIMEICRESET.

At TIMEICRESET, brine pressures *only in Reset Material regions* are set to PINIT. At the same time, brine saturations *only in Reset Material regions* are set to SOINIT. Because CONCFE and CONCBIO are unaffected before TIMEICRESET, both of these variables have initial values as specified in Lines 5.6 and 5.8 at time START as well as at time TIMEICRESET.

7.2.6 Numerical Control Parameters

Parameters input in this section allow the user to control the numerical behavior of BRAGFLO. These parameters affect the accuracy of solutions and can have major effects on computing time. The equations solved in BRAGFLO are highly nonlinear, and the discretized equations are solved using an iterative Newton-Raphson technique. The control parameters govern the rate of convergence of the solution procedure, as well as the degree of precision to be achieved in the solution. The Newton-Raphson procedure involves computing a Jacobian matrix, which is the most computationally intensive step in the solution. The control parameters allow the user to specify the frequency at which the Jacobian is recalculated. The Jacobian is always computed at the beginning of each time step. It can be calculated as frequently as each iteration within a time step (at great computational expense), or after every so many iterations.

Line 6.1. Descriptor. Physical realism constraints.

Line 6.2. DEPLIMIT(1), DEPLIMIT(2), SATLIMIT.

DEPLIMIT(1): Limit allowed on gas saturation outside the physically realistic range of 0.0 to 1.0. The solution will not be rejected provided: 1.0 + DEPLIMIT(1) > S_g > -DEPLIMIT(1). Otherwise, the time step size will be reduced and the time step will be repeated. Note that this is only the first of several criteria that must be met before a solution is finally accepted. "Slightly unrealistic" values of gas saturation can (and generally must) be tolerated; if DEPLIMIT(1) is too small, or zero, BRAGFLO will likely struggle excessively (and consume large amounts of

computing time) without appreciably improving the solution. Recommended value: DEPLIMIT(1) = 0.2.

DEPLIMIT(2): Lower limit allowed on brine pressure [Pa or psi]; primarily intended to catch large negative values of pressure. The solution will be accepted provided: PO > DEPLIMIT(2). If PO ≤ DEPLIMIT(2), the time step size will be reduced and the time step will be repeated. As with DEPLIMIT(1), DEPLIMIT(2) should not be set too stringently. These two limits are intended simply to reject the solutions that are beyond hope before any more computational effort is expended on them. Recommended value: -1.0×10^8 Pa.

SATLIMIT: Limit on gas saturation solution beyond which a solution will not be accepted; interstep iterations will continue using the same Δt (i. e., the solution is not accepted, but Δt is not reduced) even if DEPLIMIT(1) is satisfied if: 1.0 + SATLIMIT > S_g > -SATLIMIT provided that DEPLIMIT(1) > SATLIMIT. Nonconvergence occurs once S_g violates the SATLIMIT constraint. This is intended to be a more stringent limit than DEPLIMIT(1), but it is up to the user to ensure that DEPLIMIT(1) > SATLIMIT. Recommended value: 1.0×10^{-3}.

Line 6.3. Descriptor. Limits on variable changes for auto time step control.

These parameters are used in the auto time step control algorithm. They affect the efficiency of BRAGFLO by allowing larger time steps when the variables (gas saturation and brine pressure) are changing slowly. If auto time step is turned off, these parameters are not used, but they must still be input.

Line 6.4. DELTADEPNORM(1), DELTADEPNORM(2).

DELTADEPNORM(1): Relative change in gas saturation across a time step; used to control size of next time step. Input value is the largest relative change in gas saturation in the time step just completed such that the new time step will be the same as the current time step. Using a smaller input value will cause smaller increases in the new time step for a given relative change in gas saturation or reduce the relative change in gas saturation that will be allowed in order to achieve a given increase in time step size. Using a larger input value will have the opposite effect. Recommended value: 0.3.

DELTADEPNORM(2): Absolute change in brine pressure across a time step [Pa or psi]; used to control size of next time step. Input value is the largest absolute change in brine pressure in the time step just completed such that the new time step will be the same as the current time step. Using a smaller input value will cause smaller increases in the new time step for a given absolute change in brine pressure or reduce the absolute change in brine pressure that will be allowed in order to achieve a given increase in time step size. Using a larger input value will have the opposite effect. Recommended value: 5.0×10^5 Pa.

Line 6.5. Descriptor. Maximum absolute variable changes.

Line 6.6. DDEPMAX(1), DDEPMAX(2).

DDEPMAX(1): Maximum absolute gas saturation change allowed over a time step. If a greater change in gas saturation occurs, the time step is repeated using a smaller time step. Recommended value: 1.0. (This allows gas saturation to change from 0.0 to 1.0 in a single step, the most that is physically possible, in effect turning off this control except when unphysical gas saturations are obtained.)

DDEPMAX(2): Maximum absolute pressure change allowed over a time step. If a greater change in brine pressure occurs, the time step is repeated using a smaller time step [Pa or psi]. Recommended value: 1.0×10^7 Pa.

Line 6.7. Descriptor. Newton-Raphson normal convergence criteria.

Line 6.8. ICONVTEST.

ICONVTEST: Flag specifying whether *either* or *both* convergence criteria must be satisfied before a solution is considered to have converged. Recommended value: 1. Requiring both convergence criteria to be met should result in a more accurate solution. However, prohibitively small time steps are sometimes required because the convergence tests tend to over-emphasize the importance of small grid blocks in which small changes can result in relatively large mass balance errors. To get BRAGFLO to run to completion when such problems occur, it may be necessary to relax one of the criteria that must be met. Generally, this has been found to have little impact on gross results. However, in some instances, important short-lived transient results can differ greatly depending on whether either or both convergence criteria are met. Therefore, whenever possible, ICONVTEST = 1 should be used.

= 0: Satisfy *either* EPSNORM *or* FTOLNORM. (described next, on Lines 6.10 and 6.14).

= 1: Satisfy *both* EPSNORM *and* FTOLNORM. (described next, on Lines 6.10 and 6.14).

Line 6.9. Descriptor. Maximum variables changes for normal convergence.

Line 6.10. EPSNORM(1), EPSNORM(2).

EPSNORM(1): Number of digits of accuracy to the right of the decimal in the change in gas saturation. This parameter limits the change in gas saturation when saturations are very small, in which case DDEPMAX(1) is too easily satisfied. Recommended value: 3.

EPSNORM(2): Maximum *relative* change in brine pressure allowed over a time step. This parameter provides control over brine pressure changes when the pressure is small and DDEPMAX(2) (the maximum *absolute* change) is too easily satisfied. Recommended value: 1.0×10^3.

Line 6.11. Descriptor. Loosened Newton-Raphson convergence criteria.

Occasionally, BRAGFLO encounters great difficulty in converging to a solution. If a solution has not been obtained at a particular time step after numerous time step reductions, it is quite likely that further time step reductions will not improve the solution sufficiently to satisfy the normal convergence criteria, EPSNORM(1) and EPSNORM(2). One option at this point is for BRAGFLO to abort. The user would then rerun the problem after adjusting one or more of the control parameters and hope for better results. However, it is often the case that BRAGFLO's difficulties are temporary, and that if it can get past the trouble spot, it will complete the run without further major difficulties. Thus, a second option has been built into BRAGFLO to handle those occasions when repeated time step reductions fail to provide convergence: The convergence criteria are temporarily relaxed. These relaxed criteria are applied after user-specified IJACSWITCH time step reductions have occurred, and they continue to be applied only until convergence is obtained at that time step. After IJACRESET time steps, and at all subsequent time steps, the normal convergence criteria are used. This capability makes BRAGFLO a little more robust, enabling it to complete runs that would otherwise abort and require input modifications before rerunning, at only a minor cost in overall accuracy. This feature becomes important when carrying out large number of runs in automated batch systems. It can be turned off simply by setting all input values of the loosened criteria equal to the normal criteria. Caution is advised when using this feature because large mass balance errors can be introduced which may not be apparent in a cursory examination of the results. *This feature has not been tested for use in PA calculations.*

Line 6.12. EPSLOOSE(1), EPSLOOSE(2).

EPSLOOSE(1): Same meaning as EPSNORM(1); used after IJACSWITCH time step reductions have occurred. Recommended value: 2.0.

EPSLOOSE(2): Same meaning as EPSNORM(2); used after IJACSWITCH time step reductions have occurred. Recommended value: 0.01.

Line 6.13. Descriptor. Normal right-hand-side function (or residual) criteria. BRAGFLO solves a pair of simultaneous mass balance equations: $F_1 = 0$ (gas mass balance), and $F_2 = 0$ (brine mass balance). Because the nonlinear equations are solved numerically and iteratively, F_1 and F_2 are generally not zero. The deviation from zero is the residual, or mass balance error. Ideally, iterations will continue until the residuals are zero, but, in practice, the best that can be hoped for is to get "close" to zero. Discretization errors, roundoff errors, discontinuous functional dependencies, property functions with discontinuous derivatives, and nonlinearities all contribute to making convergence to truly zero residuals unattainable. The degree of closeness of the residuals to zero that is acceptable is input as the tolerances FTOLNORM(1) and FTOLNORM(2).

Line 6.14. FTOLNORM(1), FTOLNORM(2).

FTOLNORM(1): [kg gas in residual/kg gas in grid block]. For gas saturation, the value of the residual is normalized by dividing by the amount of gas present in the grid block, $\phi(\rho_g S_g + C_{gb}\rho_b S_b)$, where ϕ is the porosity, ρ_g and ρ_b are the gas and brine densities at local conditions, S_g and S_b are the gas and brine saturations, and C_{gb} is the mass fraction of gas in the

brine phase(C_{gb} = 0.0 if no dissolved gas is present). The minimum of this normalized residual value is compared with FTOLNORM(1). If ICONVTEST = 0 and the normalized residual is less than FTOLNORM(1), convergence is accepted regardless of EPSNORM(1). If ICONVTEST = 1, the normalized residual must be less than FTOLNORM(1) *and* EPSNORM(1) must be satisfied in order for the solution to be accepted. Recommended value: 1.0×10^{-2}.

FTOLNORM(2): [kg brine in residual/kg brine in grid block]. For brine pressure, the value of the residual is normalized by dividing by the amount of brine present in the grid block, $\phi C_{bb} \rho_b S_b$, where ϕ is the porosity, C_{bb} is the mass fraction of brine in the brine phase (C_{bb} = 1.0 if no dissolved gas is present), ρ_b is the brine density at local conditions, and S_b is the brine saturation. The minimum of this normalized minimum residual value is compared with FTOLNORM(2). If ICONVTEST = 0 and the normalized residual is less than FTOLNORM(2), convergence is accepted regardless of EPSNORM(2). If ICONVTEST = 1, the normalized residual must be less than FTOLNORM(2) *and* EPSNORM(2) must be satisfied in order for the solution to be accepted. Recommended value: 1.0×10^{-2}.

Line 6.15. Descriptor. Loosened right-hand-side function criteria. *This feature has not been tested for use in PA calculations.*

Line 6.16. FTOLLOOSE(1), FTOLLOOSE(2).

FTOLLOOSE(1): Relaxed value of normalized residual for gas saturation below which convergence is accepted regardless of EPSLOOSE(1); used after IJACSWITCH time step reductions have occurred [kg gas in residual/kg gas in grid block]. Recommended value: 1.0×10^{-1}.

FTOLLOOSE(2): Relaxed value of normalized residual for brine pressure below which convergence is accepted regardless of EPSLOOSE(2); used after IJACSWITCH time step reductions have occurred [kg brine in residual/kg brine in grid block]. Recommended value: 1.0×10^{-1}.

Line 6.17. Descriptor. Multicomponent gas constituent transport convergence tolerances.

Line 6.18. EPSGAS(1), EPSGAS(2), EPSGAS(3), EPSGAS(4).

EPSGAS(1): Smallest negative value allowed in the amount of each gas component in a grid block [mol]. If input as a positive number, BRAGFLO sets it negative.

EPSGAS(2): Largest change in a molar concentration of a gas component that is allowed over a Newton-Raphson iteration [mol/m^3].

EPSGAS(3): Smallest value of molar concentration that is considered to be non-zero. Used to ensure that, in calculating the relative change in molar concentration, a zero or essentially zero value is not used [mol/m^3].

EPSGAS(4): Maximum relative change in gas component molar concentration allowed over a Newton-Raphson iteration [dimensionless].

Line 6.19. Descriptor. Equation solver selection.

Line 6.20. CHSOLVER.

CHSOLVER: This is a CHARACTER*3 variable indicating the solver to be used. It is input in free format, with *no* enclosing tick marks and any number of leading spaces. The available options are:

LU: Original LU-decomposition solver, a direct (non-iterative) solver. This is the solver most frequently used in WIPP PA work. Its principal advantage is its great robustness: unless the Jacobian matrix is truly singular (which generally indicates flawed input or a conceptual model error), a solution (i. e., inversion of the given Jacobian) is virtually guaranteed. The main disadvantages are large storage requirements and slow speed, which makes large meshes (such as realistic three-dimensional problems) impractical.

LP: Another LU-decomposition solver from Linpack, a non-proprietary package of linear algebra routines. Essentially identical to the original LU solver, this solver first calculates a condition number, which indicates the degree of singularity of the Jacobian. If the condition number is too small, the LP solver concludes that the matrix is singular and aborts the run, in contrast to the original LU solver, which will continue with the solution unless the Jacobian determinant is exactly zero. The parameters and mesh used by WIPP PA often result in Jacobians that are very nearly singular at times during a run, so the LP solver is generally not used because it aborts too readily. However, the LP solver is sometimes useful for debugging. It has been disabled in BRAGFLO version 4.00 because the massive Jacobian array is rewritten into another array, nearly doubling the memory required to run BRAGFLO. It may be reactivated easily in future versions. If the LP solver is selected, the program will abort with a message printed to the screen:

```
*** Abort in READCNTRL; LP solver not available.
```

MG: Multigrid solver. This is a sophisticated, state-of-the-art high-speed iterative solver. In addition to speed (compared to direct solvers), this solver has the advantage of all iterative solvers in that the storage requirements are far less than for direct solvers, making large three-dimensional simulations possible. However, the multigrid solver originally implemented in BRAGFLO was limited to two dimensions and suffered from a lack of robustness that was intolerable in WIPP PA, where *all* runs must be completed. This option is currently not available, pending development of a robust three-dimensional multigrid solver. Although prospects are poor that a multigrid solver will eventually work in BRAGFLO, the shell for selecting this solver has been retained. If it is selected, the program will abort with a message printed to the screen:

```
*** Abort in READCNTRL; MG solver not available.
```

LSOR: Point successive overrelaxation (SOR) solver. This is another iterative solver, which, like the multigrid solver, lacks robustness. It should work on simple problems or large problems using uniform grid blocks and smoothly-varying material properties.

Line 6.21. Descriptor. Iteration limits; scaling options.

Line 6.22. ITMAX, IRESETMAX, IJACINPUT, LSCALE, P_SCALE, LVARSWTCH.

ITMAX: Maximum number of Newton-Raphson iterations per time step. Recommended value: 10.

IRESETMAX: Maximum number of time step size reductions allowed at any time step should nonconvergence problems be encountered. If this number is exceeded, the run is aborted; this is the only way a BRAGFLO run will cleanly abort (aside from input errors). Note that the time steps obtained as a result of time step reductions following nonconvergence are not restricted in size by the input parameter DELTMIN (Line 1.9). It is possible for a time step smaller than DELTMIN to be obtained that results in convergence after fewer than IRESETMAX time step reductions. This can only occur when nonconvergence causes time steps to be reduced below DELTMIN. In this case, the next time step will automatically be reset to DELTMIN. Convergence requiring time steps smaller than DELTMIN may occur repeatedly and has the potential for causing BRAGFLO to stall out, consuming great quantities of computing time using impracticably small time steps by sidestepping the normal time step minimum through this one loophole. However, it has been found that when BRAGFLO has difficulties resulting in repeated use of time steps smaller than DELTMIN, either these problems are resolved by taking just a couple of time steps smaller than DELTMIN, or they cause IRESETMAX to be exceeded. Recommended value: 40.

IJACINPUT: Default iteration interval frequency for updating the Jacobian. The Jacobian is always evaluated at the start of each time step. Reevaluating the Jacobian at each Newton-Raphson iteration within a time step will, at least in theory, result in the fastest convergence to a solution. However, in some instances, convergence may be just as fast even when the Jacobian is evaluated only before the first iteration. Because evaluating the Jacobian is the most computationally intensive step in the solution, it is highly desirable to do this as infrequently as possible. On the other hand, reevaluating every iteration is more likely to give a solution, especially in difficult problems, whereas doing this, say, just once each time step (every 40 iterations), can sometimes cause the solution to diverge, resulting in more computational effort than simply reevaluating every iteration. Recommended value: 1.

LSCALE: Logical flag specifying whether to scale the Jacobian and the right hand side. Scaling may reduce roundoff errors that cause numerical problems when working with near-singular matrices, which is often the case in WIPP PA. Recommended value: T.

P_SCALE: When LSCALE = T, the Jacobian and right hand side are divided by P_SCALE to reduce the singularity of the Jacobian when the degree of singularity is exacerbated by roundoff errors. Whether LSCALE = T or F, a value must be input here; when LSCALE = F, P_SCALE is read in but is not used. Recommended value: 1.0×10^7 Pa.

LVARSWTCH: Logical flag specifying whether variable switching will be allowed. This flag can be set to T only if dissolved gas is being modeled and Henry's law is to be used (IDGAS = 2). The gas solubility options are described in Subsection 7.2.8. When Henry's law gas solubility is used, LVARSWTCH *should* be set to T; this is not a requirement, but BRAGFLO may not run well or at all if variable switching is not allowed (set to F) when IDGAS = 2. When LVARSWTCH = T, the dependent variables may be automatically changed when the gas phase disappears, from the normal set of gas saturation and brine pressure (S_g and P_o) to P_a and P_o. P_a is the equilibrium Henry's law gas pressure, defined as the gas pressure that would exist if a gas phase were present given the mole fraction of gas that is currently dissolved in the brine. Because gas can dissolve in brine, it is possible for the gas phase to disappear, but a gas component will remain in the liquid phase. When this happens, it is no longer possible to keep track of the amount of gas dissolved in brine because the dissolved gas is no longer in equilibrium with gas in the (nonexistent) gas phase. Instead of solving two equations (gas mass balance and brine mass balance) for two unknowns (S_g and P_o), BRAGFLO will be trying unsuccessfully to solve just one equation, the brine mass balance, for two unknowns, since the gas mass balance is identically zero as a result of S_g being zero. This will cause the run to abort or to flounder, struggling hopelessly by cutting back time steps. The solution to this difficulty is to change the dependent variable from gas saturation to a pseudo-pressure, P_a, which is directly proportional to the mass or mole fraction of gas dissolved in brine:

$$P_a = x_g H,$$

where: x_g = mole fraction of gas dissolved in brine,
H = Henry's law constant [Pa/mol fraction gas in solution].

When a gas phase is present, P_a is identical to P_g. When a single liquid phase is present, P_a is the gas pressure that would exist in equilibrium with the dissolved gas if a gas phase were present. In this manner, BRAGFLO can still use the gas mass balance equation as one of the two equations being solved, but solves, in effect, for the nonzero dissolved gas mass fraction instead of the zero gas saturation. When LVARSWTCH = T, this switching of the dependent variables is done automatically and is transparent to the user, except that informational messages are printed to the screen and to the summary [.SUM] file to indicate when the variables are switched and at which grid blocks. If LVARSWTCH = F when Henry's law is used to model gas dissolution,

BRAGFLO will run smoothly only if a gas phase is always present. Unless this situation can be assured of holding true for the full duration of the run, LVARSWTCH = T should be used. *This feature has not been extensively tested.*

Line 6.23. Descriptor. Upstream weighting frequencies; time step reduction factor; averaging methods for relative permeabilities and mass fractions.

Line 6.24. IUPRPFLAG, IUPMFFLAG, DELTFACTOR, ITRAVE, IMFRAVE.

IUPRPFLAG: Frequency of updating the inter-time step upstream weighting direction for relative permeabilities. The upstream weighting direction can be changed only when the Jacobian is reevaluated; thus, IUPRPFLAG is not simply the number of Newton-Raphson iterations between updating the upstream direction, but rather the number of Jacobian evaluations between updates. For example, if IJACINPUT = 3 (Jacobian reevaluated every third iteration) and IUPRPFLAG = 3, then the upstream direction for relative permeability is updated every 9 iterations. *This option has not been extensively tested*, but it appears that the upstream direction should not be changed every iteration, nor every other iteration (assuming IJACINPUT = 1), because this may cause the solution to oscillate and fail to converge. Recommended value: same as ITMAX, which effectively turns this option off, anchoring the upstream direction at the first iteration. If convergence difficulties suggest that this option may improve convergence, a value of 3 should be tried first.

IUPMFFLAG: Frequency of updating the inter-time step upstream weighting direction for mass fractions. As with relative permeabilities, the upstream weighting direction can be changed only when the Jacobian is reevaluated. IUPMFFLAG the number of Jacobian evaluations between updates. This option will have an effect only if the dissolved gas option is activated (see Section 7.2.8); without dissolved gas, the mass fraction of gas dissolved in brine is always zero everywhere, and the mass fraction of brine component in the brine phase is always 1.0 everywhere, so the upstream direction is not only fixed, but has no impact on the solution. *Although this option is available, it has not been tested sufficiently to know if it has any significant effect on convergence behavior. Until it has been tested more thoroughly, this option should not be used.* Recommended value: same as ITMAX, which turns this option off, anchoring the upstream direction at the first iteration. A value must be input even if the dissolved gas option is not activated.

DELTFACTOR: Time step reduction factor when nonconvergence occurs. Recommended value: 0.5.

ITRAVE: Transmissivity averaging method at block interfaces. Recommended value: 1.

ITRAVE = 0: Use arithmetic average. This method is untested.

ITRAVE = 1: Use harmonic average.

IMFRAVE: *Method for averaging mass fractions at block interfaces when dissolved* gas option is activated. A value must be input even if the dissolved gas option is not activated. Recommended value: 0.
IMFRAVE = 0: Use upstream value of mass fractions.
IMFRAVE = 1: Use harmonic average.

Line 6.25. Descriptor. Jacobian reevaluation control parameters. These parameters are invoked when difficulties arise that cause the time step to be cut back repeatedly, potentially causing the run to abort. The options permit the frequency of Jacobian reevaluation to be changed, convergence tolerances to be relaxed, and upstream directions to be updated at different frequencies. These changes remain in effect for a specified number of time steps before the original set of control parameter values is reinstated.

Line 6.26. IJACSWITCH, IJACMIN, IJACRESET, IUPRPLOOSE, IUPMFLOOSE.

IJACSWITCH: Number of time step reductions allowed before the new set of control parameters is temporarily invoked. This parameter controls when the Jacobian starts to be reevaluated every IJACMIN iterations instead of every IJACINPUT iterations, the looser convergence tolerances are invoked, and upstream direction update frequencies are changed. Recommended value: 10.

IJACMIN: Number of iterations allowed before the Jacobian is reevaluated after IJACSWITCH time step reductions have occurred; the Jacobian is now reevaluated every IJACMIN iterations. Reevaluating the Jacobian more frequently (if IJACINPUT > 1) can sometimes promote convergence when BRAGFLO is encountering difficulties. Although many iterations can be performed in much less computing time than is required for a single evaluation of the Jacobian, convergence is often achieved with a single iteration after reevaluation. If IJACINPUT > 1, this parameter alone should be changed first, before tolerances are loosened or upstream direction frequencies are changed, because this parameter generally has the greatest impact on convergence. Recommended value: 1.

IJACRESET: Number of time steps during which IJACMIN, looser tolerances, and modified upstream direction update frequencies remain in effect following a time step in which IJACSWITCH time step reductions occurred. When BRAGFLO is having severe difficulties, reevaluating the Jacobian more frequently for a few time steps can help it through the difficult period. However, such trouble spots are usually of short duration, so more frequent reevaluations should not be continued indefinitely if not necessary. Looser convergence tolerances should also not be used any longer than necessary because, strictly speaking, the accuracy of the entire run is only as good as the looser tolerances, even though they were used only a few small time steps. Recommended value: 2.

IUPRPLOOSE: Frequency of updating the upstream direction for relative permeabilities. This is the "looser tolerances" value of IUPRPFLAG, and is used for IJACRESET time steps. *This option has not been tested, so its*

use is not recommended; use a value equal to or greater than ITMAX, which turns this option off.

IUPMFLOOSE: Frequency of updating the upstream direction for mass fractions. This is the "looser tolerances" value of IUPMFFLAG, and is used for IJACRESET time steps. *This option has not been tested, so its use is not recommended*; use a value equal to or greater than ITMAX, which turns this option off.

Line 6.27. Descriptor. Relative changes for Jacobian elements.

Line 6.28. DH(1), DH(2).

DH(1): Relative change in gas saturation for Jacobian element derivative calculations. Because the equations being solved are so nonlinear, DH should be as small as possible without losing numerical precision. Recommended value: 1.0×10^{-8}.

DH(2): Relative change in brine pressure for Jacobian element derivative calculations. Recommended value: 1.0×10^{-8}.

Line 6.29. Descriptor. Minimum absolute change for Jacobian elements.

Line 6.30. HMIN(1), HMIN(2).

HMIN(1): Minimum absolute gas saturation change allowed for Jacobian element derivative calculations. This limit prevents the variable change calculated using the *relative* change factor DH from becoming too small when the saturation is small. Recommended value: 1.0×10^{-10}.

HMIN(2): Minimum absolute brine pressure change allowed for Jacobian element derivative calculations [Pa or psi]. Recommended value: 0.01 Pa.

7.2.7 Material Maps and Material Properties

This section describes input that establishes material properties for each grid block. A material type grid map is input in which each grid block is assigned a material type index. This map applies during a specified time period. A series of material maps covers the duration of the run, allowing material properties in each grid block to change for discrete periods of time. Following the material maps, certain special materials are input; for these materials, specialized submodels apply, the most important example being Waste, in which chemical reactions occur that can occur in no other material. Material properties are input next. These include two-phase flow parameters, permeabilities, reference-condition porosities, and compressibilities. Finally, flags and parameters for submodels simulating fracturing and Klinkenberg effect are input.

Line 7.1. Descriptor. Number of material maps.

Line 7.2. NMATTIMES.

NMATTIMES: Number of times to specify a material map. NMATTIMES must be less than or equal to MAXMATTIMES, set in the PARAMETER statement. If NMATTIMES is less than one or greater than MAXMAT-

TIMES, no error message will be printed, but BRAGFLO will abort sooner or later.

Lines 7.3 - 7.6 are repeated NMATTIMES times.

Line 7.3. Descriptor. Start times.

Line 7.4. TIMEMAT.

TIMEMAT: Starting time at which the material map that follows is in effect [s or days]. *If the first TIMEMAT is later than START, the starting time for* the run, no error message is printed, but any results obtained before BRAGFLO aborts will be unpredictable and unreliable.

Line 7.5. Descriptor. Material map.

Line 7.6. (((IMAT(I,J,K), I=1, NX), J=1, NY), K=1, NZ).

IMAT(I,J,K): Material type number for grid block (I,J,K). This number is associated later with the material properties input. BRAGFLO finds the minimum and maximum material type numbers in all NMATTIMES maps and assumes that the total number of materials, NMAT, is equal to the maximum value found in the maps. If any IMAT(I,J,K) is less than 1 or greater than MMAT (set in the PARAMETER statement), BRAGFLO will abort after printing the offending minimum or maximum value of IMAT, with the following message printed to the screen:

```
*** Aborted:  Input material type error in READMAT ***
```

One or more material type numbers between 0 and NMAT may, at the user's option, be omitted from the material maps without causing any problem. However, material properties (starting at Line 7.31 below) must be input for NMAT materials, regardless of how many material numbers are actually used in the maps. For example, if the maps have only two material types, numbered 2 and 8, properties for 8 materials must be input, even though the properties for only two of the eight materials will actually be used. Normally, NMAT materials would actually be used.

Line 7.7. Descriptor. Material names.

The following line is repeated NMAT times. The information on each line is not used in any way in BRAGFLO. It is intended solely to provide space within the input file to help the user identify each material type

Line 7.8. LABEL.

LABEL: Dummy CHARACTER*132 variable. Must be read in, but is not used.

Special Materials.

BRAGFLO has four special material types that have unique capabilities. These have evolved to handle situations encountered in modeling the WIPP, so they have names that apply to regions included in models of the WIPP, but actually have fairly generally applications. The material are referred to as: Waste, DRZ (Disturbed Rock Zone), "Reset" materials, and Borehole.

Waste Material.

In Waste materials, and only in Waste, can chemical reactions take place. Specifically, corrosion of iron can occur, which consumes iron and water and produces hydrogen. In addition, microbial degradation of cellulosics can occur; this reaction consumes cellulosics and produces hydrogen, and, if indicated in the input (described later), can also consume or produce water. Another special capability unique to Waste is simulation of creep closure, in which the porosity decreases over time, the rate depending on the rate of gas production and the pressure within the Waste. Porosity can change in any material as a result of pressure-dependent compressibility, but the change is generally quite small. In contrast, the porosity change resulting from creep closure of the Waste can be very large, changing from an initial 66% porosity to as low as 9% porosity. Only in Waste can there be an *initial* mass of radionuclides, the transport and decay of which can be modeled in any region as long as there was some amount initialized in the Waste. Finally, to be able to simulate an operational period in the WIPP, during which excavations are open to the atmosphere and any brine seepage is removed by means of ventilation or pumping, the initial brine pressure and saturation in the Waste can be specified to be different from the initial conditions described in Subsection 7.2.5. Then, at some later time (TIMEICRESET), the conditions in the Waste can be reset to the initial conditions specified in Subsection 7.2.5.

Line 7.9. Descriptor. Waste regions.

Line 7.10. NWST.
NWST: Number of Waste regions.

If NWST ≤ 0, the next two lines (7.11 and 7.12) are omitted. If NWST > MWST (set in the PARAMETER statement), the run will abort.

Line 7.11. Descriptor. Definition of Waste regions.

Line 7.12. (MAT_WASTEI(I), I=1, NWST), (MAT_WASTE(I), I=1, NWST).
MAT_WASTEI: Material type index of the material at time START that will *become* Waste at time TIMEICRESET. Prior to TIMEICRESET, materials designated as MAT_WASTEI have no special characteristics and receive no special treatment. It is necessary to know which regions are eventually going to become Waste regions, however, to calculate what

will be the Waste region volume, because this information must be known before any initial conditions are printed or any other calculations are done.

MAT_WASTE: Material type index of Waste *after* TIMEICRESET. Porosity will be calculated using the creep closure submodel only for this material type (provided that model is turned on; input controlling this submodel will be discussed later, in Section 10). Corrosion and biodegradation reactions occur only in this material. There should be a one-to-one correspondence between MAT_WASTEI(I) and MAT_WASTE(I); NWST values of each are read in.

Disturbed Rock Zone (DRZ) Material.

In this material, if the porosity increases at time TIMEICRESET, the brine volume is assumed to remained fixed over that change, and the brine saturation is adjusted to account for the increased pore volume. Gas is assumed to fill the additional pore space. The gas appears instantaneously; there is no source for this gas, i. e., it does not flow from any other cell, is not introduced by well injection, and is not created by way of chemical reaction. It just appears suddenly to occupy newly created pore volume. The pressure in this material at TIMEICRESET is specified by input as PRESDRZ. This material arose from a need to simulate the disturbed rock zone surrounding excavations in halite. The time-dependent behavior of disturbed halite is not well-understood, but it is considered likely that the porosity will be greater by the time the repository is filled and sealed. This behavior is currently modeled very simply as an instantaneous increase in porosity at TIMEICRESET, with the additional pore space filled with gas that, in reality, would have flowed in from the adjacent excavated regions through cracks and borings. More than one DRZ material can be used, each with a different reset pressure (PRESDRZ). In modeling the WIPP, a single DRZ material is generally used, and the pressure is reset to PRESDRZ = 1 atm (101.325 kPa), the same as in the Waste at TIMEICRESET, so that the newly-introduced gas in the DRZ does not expand and unrealistically flow into the Waste.

Line 7.13. Descriptor. DRZ regions.

Line 7.14. NDRZ.

NDRZ: Number of DRZ material regions.

If NDRZ ≤ 0, the next two lines (7.15 and 7.16) are omitted. If NDRZ > MDRZ (set in the PARAMETER statement), the run will abort.

Line 7.15. Descriptor. DRZ materials.

Line 7.16. (MAT_DRZ(I), I=1, NDRZ), (MAT_DRZNEW(I), I=1, NDRZ).

MAT_DRZ: Original DRZ material type index number, from the first material map.

MAT_DRZNEW: The DRZ material type index number for the material map starting at time TIMEICRESET (input later); in this material type at time TIMEICRESET, saturations will be adjusted and pressures will be reset to PRESDRZ (input later).

"Reset" Material.

In this material, conditions will be reset to the initial conditions specified in Subsection 7.2.5. This differs from DRZ material in that both saturation and pressure are reset at time TIMEICRESET, and they are reset to the Subsection 7.2.5 conditions. In contrast, in DRZ material, the saturations are adjusted to maintain a fixed brine volume and the pressure is reset to PRESDRZ, rather than to the Subsection 7.2.5 initial pressure. These materials arose in modeling the WIPP from the need to simulate backfilled regions, which are initially excavations, but become backfill at TIMEICRESET. In this case, the conditions calculated just prior to TIMEICRESET are inconsequential, and new specified conditions reflecting newly-emplaced backfill and seals are needed; because the backfilled and sealed regions may cover a large number of grid blocks, these new conditions are most easily provided in the original conditions in Subsection 7.2.5.

Line 7.17. Descriptor. "Reset" materials.

Line 7.18. NMATRESET.

NMATRESET: Number of material regions where initial conditions will be reset at time TIMEICRESET to the original initial conditions.

If NMATRESET ≤ 0, the next two lines (7.19 and 7.20) are omitted. If NMATRESET > NMAT, the run will abort.

Line 7.19. Descriptor. "Reset" materials.

Line 7.20. (MATRESET(I), I=1, NMATRESET).

MATRESET: Material type index numbers for materials in which the brine pressure, PO, and brine saturation, SO, will be reset to the original (Subsection 7.2.5) initial conditions, PINIT and SOINIT, respectively. Waste material index numbers should be included here if PO and SO are to be reset. The material index numbers used should be for the last material map *prior* to TIMEICRESET; this map may be (and generally is) the first map specified (at time START), but if more than one map is specified prior to TIMEICRESET, use the last map immediately before TIMEICRESET.

Borehole Material.

In this material, the solute concentration and solute mass are reset to zero when an intrusion borehole opens. This simulates the removal of radionuclides in both solid and dissolved phases when a drill cuts through the waste. It is a minor adjustment, but easily accomplished in BRAGFLO, so it is done just to make the results reflect reality slightly more accurately. It is used

only when transport is activated. However, if transport is not being modeled, lines 7.21 and 7.22 must still be input, although MAT_BOREHOLE can be any number from 0 to NMAT and is not used.

Line 7.21. Descriptor. Borehole material.

Line 7.22. MAT_BOREHOLE.

MAT_BOREHOLE: Material type index number for borehole material, if transport is activated (see Section 11). If transport is not activated, MAT_BOREHOLE can be any number from 0 to NMAT, but a number must still be input.

Special Material Control and Reset Parameters.

Line 7.23. Descriptor. Reset control parameters.

Line 7.24. TIMEICRESET, ICWASTE.

TIMEICRESET: Time when initial conditions are reset [s or days]. Normally = 0. Used only when START is less than zero. Negative times (START<0) are used in WIPP PA simulations to cover the operational period of the WIPP, prior to the start of the regulatory compliance period, which begins at time zero. The primary objective of using these negative times is to enable realistic pressure distributions in the formations surrounding the WIPP repository to be calculated without doing this in a separate run. Designation of times as positive or negative is largely a question of semantics. All calculations could start at time zero, cover, say, a 20-year operational period and extend to 10,020 years total to cover the 10,000-year compliance period. However, then the plotting and other postprocessing would need to deal with a time period of 20 to 10,020 years, instead of the more clearly understandable period of 0 to 10,000 years specified in regulations. Using negative times for the operational period, and omitting this period from plots and reports, makes discussions of the results simpler and more in line with compliance regulations.

No results are printed to the output files until TIMEICRESET. The initial conditions that are always printed to both the ASCII and binary output files are the conditions at TIMEICRESET, *after* all the special materials have been reset to their respective initial conditions.

ICWASTE: Flag to indicate that waste initial conditions will differ from the initial conditions specified in Subsection 7.2.5. This flag overrides any implied reset control indicated by material type indexes in Lines 7.9 - 7.22, but these lines must still be input.

= 1: Initial conditions specified by POWASTEIC and SOWASTEIC (input next) will be used at time START instead of PINIT and SOINIT (from Subsection 7.2.5).

= 0: Initial conditions PINIT and SOINIT will be used at time START.

If TIMEICRESET = START, the ICWASTE must be 0. Otherwise, BRAGFLO will abort with the message:

```
ICWASTE must be 0 when TIMEICRESET = START.
*** ICWASTE error in READMAT.
```

If ICWASTE is not 0 or 1, BRAGFLO will neither abort nor warn of an error, but results may be unpredictable.

Line 7.25. Descriptor. Pressure initial conditions.

Line 7.26. (POWASTEIC(I), I=1, NWST).

POWASTEIC(I): Brine pressure in Waste region I at time START, uniform throughout Waste region I [Pa or psi]. Used only when ICWASTE = 1, but NWST values must still be input even if ICWASTE = 0.

Line 7.27. Descriptor. Saturation initial conditions.

Line 7.28. (SOWASTEIC(I), I=1, NWST).

SOWASTEIC: Brine saturation in Waste region I at time START, uniform throughout Waste region I. Used only when ICWASTE = 1, but NWST values must still be input even if ICWASTE = 0.

Line 7.29. Descriptor. Reset DRZ pressure.

Line 7.30. (PRESDRZ(I), I=1, NDRZ).

PRESDRZ(I): Brine pressure to which DRZ region I will be reset at time TIMEICRESET [Pa or psi].

Material Property Data.

In this section, material properties are input for each of the NMAT materials in the material map. Properties used include relative permeability and capillary pressure model parameters, intrinsic permeability values, porosities, and compressibilities.

Line 7.31. Descriptor. Relative permeability and capillary pressure model parameters.

The next line is repeated NMAT times. If some material type numbers less than NMAT are not actually used in any material maps, NMAT property values must still be read in. If

there are fewer than NMAT lines of property data, BRAGFLO will abort as a result of an input error while trying to read character data into INTEGER and REAL variables.

Line 7.32. I, XLAMDA(I), SBR(I), SGR(I).

I: Material type number.

XLAMDA(I): Pore-size distribution parameter, λ, for Brooks-Corey and van Genuchten-Parker relative permeability and capillary pressure models. The van Genuchten-Parker model uses a parameter, m, which is obtained from the Brooks-Corey parameter, λ:
$m = \lambda/(1+\lambda)$.

SBR(I): Residual brine saturation, S_{br}.

SGR(I): Residual gas saturation, S_{gr}. The original Brooks-Corey and van Genuchten-Parker models do not use a residual gas saturation, but a value must still be input.

Line 7.33. Descriptor. More relative permeability and capillary pressure model parameters.

Line 7.34. I, SBMIN(I), POMIN(I), PCMAX(I), PCT_A(I), PCT_EXP(I), KRP(I), KPC(I), KPT(I).

I: Material type number.

SBMIN(I): Minimum brine saturation when using capillary pressure model number KPC(I) = 3. It is otherwise not used; however, a value must still be read in, and SBMIN(I) ≥ SBR(I). If SBMIN(I) < SBR(I), BRAGFLO will abort, even if KPC(I) ≠ 3. Recommended value: 1.05 x SBR(I).

POMIN(I): Minimum brine pressure [Pa or psi]. Used to adjust capillary pressure when capillary pressure model KPC(I) = 3 is used. If KPC(I) ≠ 3, POMIN(I) is not used and any value can be input for POMIN(I); however, some value must be input regardless of the capillary pressure model used. If KPC(I) = 3, a value of POMIN(I) = 1.01325 x 10^5 Pa is recommended.

PCMAX(I): Maximum capillary pressure that can be used when capillary pressure model KPC(I) = 2 or 3 is used [Pa or psi]. A value of PCMAX(I) = 1.0 x 10^8 Pa is recommended. If KPC(I) = 1, 4, or 5, a value must still be read in, but PCMAX(I) is not used.

PCT_A(I): Constant, a, in function relating threshold capillary pressure, P_{ct}, to permeability, k:
$P_{ct} = a\, k^{\eta}$. Gives P_{ct} for the Brooks-Corey models. In the van Genuchten-Parker model, a capillary pressure constant, P_o, is used; it is calculated in BRAGFLO by equating the capillary pressure from each of the two models at an effective saturation, S_e, of 0.5 and solving the expression for P_o. [$S_e = (S_b - S_{br})/(1 - S_{br})$]. [Pa]

PCT_EXP(I): Exponent, η, in function relating threshold capillary pressure, P_{ct}, to permeability [dimensionless].

KRP(I): Relative permeability model number:

= 1: van Genuchten-Parker model; modified to use a nonzero residual gas saturation.

= 2: Original Brooks-Corey model.

= 3: Brooks-Corey model, modified to use a residual gas saturation in calculating the effective saturation for both wetting and non-wetting phase relative permeabilities.

= 4: Brooks-Corey model, modified to use a residual gas saturation in calculating the effective saturation for the non-wetting phase relative permeability only.

= 5: Linear relative permeabilities: $k_{rb} = S_{eg}$; $k_{rg} = 1 - S_{eg}$, where: $S_{eg} = (S_b - S_{br})/(1 - S_{gr} - S_{br})$ is the effective saturation using residual gas saturation.

= 6: Linear relative permeabilities: $k_{rb} = S_e$; $k_{rg} = S_{eg}$, where S_{eg} is the same as given above for KRP(5), and $S_e = (S_b - S_{br})/(1-S_{br})$ is the effective saturation without the gas saturation dependence.

= 7: Linear relative permeabilities: $k_{rb} = k_{rg} = 1$.

= 8: Original van Genuchten-Parker model, with zero residual gas saturation.

KPC(I): Capillary pressure model number:

= 1: No special treatment. Numerical problems may occur as brine saturation approaches residual brine saturation and capillary pressure tends to infinity. Below residual brine saturation, the capillary pressure is zero.

= 2: Fixed maximum capillary pressure of PCMAX(I), thereby avoiding potential problems that might be encountered using KPC(I) = 1. BRAGFLO computes a minimum brine saturation at which the capillary pressure equals PCMAX; below this minimum brine saturation, the capillary pressure is PCMAX. This model is recommended.

= 3: Variable maximum capillary pressure. This model has not been fully tested, and its theoretical basis is uncertain. Use this model at your own risk.

= 4: Capillary pressure fixed at PTHRESH(I), which may be zero.

= 5: Linear capillary pressures:

KPT(I): Flag indicating whether threshold capillary pressure will be continuously updated as a function of dynamically varying permeability or fixed in time for a given material.:

= 0: Threshold capillary pressure is fixed in time for material I; computed in BRAGFLO using the function: $P_{ct} = a\ k^{\eta}$, as described above for PCT_A(I) and PCT_EXP(I). The intrinsic permeability in the x-direction, XKX(I) (input on Line 7.36), is used for k.

= 1: Threshold capillary pressure varies in time for material I; computed in BRAGFLO using the function: $P_{ct} = a\ k^{\eta}$, as described above for PCT_A(I) and PCT_EXP(I). Brine

permeability in the x-direction is used for k; it varies as a function of time-dependent porosity in materials that undergo fracturing or creep closure. Fracturing is described below starting at Line 7.37. Creep closure is discussed in Subsection 7.2.10.

Line 7.35. Descriptor. Intrinsic properties.

The next line is repeated NMAT times.

Line 7.36. I, XKX(I), YKY(I), ZKZ(I), PORREFROCK(I), CROCK(I)

I: Material type number.

XKX(I): Intrinsic permeability of material I in the x-direction [m^2 or darcy].

YKY(I): Intrinsic permeability of material I in the y-direction [m^2 or darcy].

ZKZ(I): Intrinsic permeability of material I in the z-direction [m^2 or darcy].

PORREFROCK(I): Porosity of material I at a reference pressure equal to the initial pressure, PINIT, which may be different in each grid block [fraction]. If material I is to undergo creep closure (see Subsection 7.2.10.), PORREFROCK(I) is not used unless material I is used before TIMEICRESET, when creep closure is not yet activated. If a material that will undergo creep closure is used before TIMEICRESET, an appropriate value of PORREFROCK(I) must be input. If such a material is not used until after TIMEICRESET (this is normally the case in WIPP PA), then the input value of PORREFROCK(I) is not used, and any value can be input. If creep closure is later turned off in this material because pressure or time limitations are exceeded, BRAGFLO resets PORREFROCK(I) at the value of porosity that exists at the time when closure is turned off; the reference pressure is reset at the same time and is equal to the current brine pressure in the material or grid block.

CROCK(I): Compressibility of material I at a reference pressure equal to the initial pressure, PINIT [Pa^{-1} or psi^{-1}].

Various checks are done on the material properties input. Errors or inconsistencies may cause BRAGFLO to abort with error messages printed to the screen and to the .SUM file.

Fracture Model.

A crude rock fracture model in BRAGFLO allows the porosity and permeability to increase in a fractured network as pore pressure increases above a threshold value. The implementation uses a pressure-dependent rock compressibility to determine fracture porosity. Permeability in the fractured layer is varied with porosity according to a power law function:

$$k = k_o \left[\frac{\phi_f}{\phi_o} \right]^n ,$$

where k = fractured permeability [m^2];
k_o = intact permeability [m^2];
ϕ_f = fractured porosity [m^3 void/m^3 rock];
ϕ_o = intact porosity [m^3 void/m^3 rock];
n = exponent [dimensionless].

Line 7.37. Descriptor. Fracture model control.

Line 7.38. KFRACTURE.

KFRACTURE: Logical flag indicating whether the fracture model will be used and whether the fracture model parameters will be read in.
= .TRUE.: Use the fracture model in BRAGFLO and read in parameters.
= .FALSE.: Do not use the fracture model, and do not read in fracture model parameters.

Lines 7.39 -7.42 are input *only* if KFRACTURE = .TRUE.

Line 7.39. Descriptor. Number of materials in which the fracture model can be applied.

Line 7.40. NFRAC.

NFRAC: Number of materials in which the fracture model can be applied.

The following two lines are repeated NFRAC times.

Line 7.41. Descriptor. Fracture model parameters.

Line 7.42. I, FRPI(I), FRPF(I), FRPHIMAX(I), FRPRMEXP(I), IFRX(I), IFRY(I), IFRZ(I).

I: Material type number for the material in which fracturing can occur.

FRPI(I): Pressure increment above the initial pressure, PINIT, at which fracturing will initially occur. [Pa or psi]. Typical value: 1.39x 10^6 Pa.

FRPF(I): Pressure increment above the fracture initiation pressure (i.e., increment above PINIT + FRPI), at which the fracture is fully-developed, i. e., the porosity of the fractured material is at its maximum [Pa or psi]. Typical value: 2.5 x 10^6 Pa.

FRPHIMAX(I): [m^3 void/m^3 rock] Maximum allowable fracture porosity. The pressure-dependent porosity will be limited to this value. Typical value: 0.10.

FRPRMEXP(I): Exponent, n, in the permeability-porosity power law relationship [dimensionless]. Typical value: 9.5.

IFRX(I): Flag to indicate whether x-direction permeability will be calculated for fractured material. Recommended value: 1.
= 1: Do calculate permeability for fractured material.

= 0: Permeability will remain the same as the intact permeability for material I.

IFRY(I): Flag to indicate whether *y*-direction permeability will be calculated for fractured material. Recommended value: 0.
= 1: Do calculate permeability for fractured material.
= 0: Permeability will remain the same as the intact permeability for material I.

IFRZ(I): Flag to indicate whether *z*-direction permeability will be calculated for fractured material. Recommended value: 0.
= 1: Do calculate permeability for fractured material.
= 0: Permeability will remain the same as the intact permeability for material I.

Klinkenberg Effect.

At low pressures and in low-permeability materials, the gas phase intrinsic permeability can be significantly higher than the liquid phase intrinsic permeability. This is the Klinkenberg effect. The gas or non-wetting phase permeability, k_{nw}, can be correlated to the brine or wetting phase permeability, k_w, by the Klinkenberg equation:

$$k_{nw} = k_w \, (1 + b / P)$$

where

k_w = brine phase intrinsic permeability [m^2],
P = brine pressure [Pa],
b = Klinkenberg coefficient [Pa]
$= BKLINK \bullet (k_w)^{EXPKLINK}$,
BKLINK = linear parameter in Klinkenberg equation [Pa],
EXPKLINK = exponent in Klinkenberg equation [dimensionless].

It is assumed in BRAGFLO that input values of intrinsic permeability (Line 7.36) are brine phase intrinsic permeabilities. If the Klinkenberg effect is modeled, gas phase intrinsic permeabilities are obtained from the Klinkenberg equation from the input values of brine phase intrinsic permeability. If the fracture model is also activated (Line 7.38; KFRACTURE = .TRUE.), brine phase intrinsic permeabilities are calculated first, using the fracture model parameters, and then gas phase intrinsic permeabilities are calculated using the Klinkenberg equation.

Line 7.43. Descriptor. Klinkenberg effect control parameter.

Line 7.44. KLINK.

KLINK: Logical flag controlling use of Klinkenberg effect:
= .TRUE.: Do include Klinkenberg effect and read in the two parameters.
= .FALSE.: Do not include Klinkenberg effect and do not read in the two parameters.

Lines 7.45 and 7.46 are read in *only* if KLINK = .TRUE.

Line 7.45. Descriptor. Klinkenberg parameters.

Line 7.46. BKLINK, EXPKLINK.

BKLINK: Linear parameter in Klinkenberg equation [Pa]. Recommended value: 9.8×10^{-1} Pa.

EXPKLINK: Exponent in Klinkenberg equation [dimensionless]. Recommended value: -0.33.

7.2.8 Fluid Properties.

This section discusses input for fluid properties and parameters that control their use. BRAGFLO has two fluids: brine and gas. Brine is composed of water and an unspecified solute, the composition of which is of no consequence in BRAGFLO. The gas is a mixture of any of six gases: hydrogen (H_2), carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2), oxygen (O_2), and hydrogen sulfide (H_2S). Brine is treated as an ideal fluid. Gases can be treated either as ideal gases or as real gases using the Redlich-Kwong-Soave equation of state. As an option, gas can dissolve in brine; using either a Henry's law treatment or an unreliable, untested bubble point calculation.

Line 8.1. Descriptor. Reference conditions.

Line 8.2. TREF, PREF.

TREF: Reference temperature for standard densities [K or °R].

PREF: Reference pressure for standard densities [Pa or psi].

Line 8.3. Descriptor. Brine property parameters.

Line 8.4. SALT, DENOSC, KGSAT, IDGAS, BRCOMP.

SALT: Brine salinity [wt % solute]. Lambert (1983) reports two values of solute concentrations in groundwaters from the Salado Formation: 355,100 mg/L and 372,000 mg/L; using the average value of 363,550 mg/L, assuming the reported values are total dissolved solids, and using brine density at 27 °C (300.15 K) of 1230 kg/m^3, the salinity of Salado brine is 29.6 wt %.

DENOSC: Density of brine at reference conditions [kg/m^3 or lb/ft^3]. The density of WIPP brine at 101.325 kPa and 27 °C (300.15 K) averages 1230 kg/m^3.

KGSAT: Flag to indicate initial gas content of brine:

= 0: Brine is initially gas-free.

= 1: Brine is initially saturated with gas. This is the recommended input value.

IDGAS: Flag to indicate treatment of dissolved gas in brine:

= 0: Gas does not dissolve in brine.

= 1: Gas does dissolve in brine, using bubble point tracking.

= 2: Gas does dissolve in brine, using Henry's law treatment.

BRCOMP: Brine compressibility, β [Pa^{-1} or psi^{-1}]. The compressibility of WIPP brine is 2.5 x 10^{-10} Pa^{-1}. The equation BRAGFLO uses to evaluate brine density is:

$$\rho = \rho_o \exp[\beta(p - p_o)]$$

where:

p = brine pressure [Pa],
p_o = reference pressure, PREF (Line 8.2) [Pa],
ρ_o = brine density, DENOSC, at reference pressure [kg/m^3].

If IDGAS = 0, no additional gas dissolution parameters are read in; skip to Line 8.5.

If IDGAS = 1, input Lines 8.4a, 8.4b, 8.4c, and 8.4d:

Line 8.4a. Descriptor. Gas solubility parameters.

The input parameters are coefficients in the empirical correlation relating gas solubility to gas partial pressure. This correlation is commonly used, but it is used in BRAGFLO specifically to account for the solubility of hydrogen in WIPP brine.

$$\ln x_g = D_0 + D_1 \ln P$$

where:

x_g = mole fraction of gas in solution in brine.
D_0 = adjustable fitting coefficient. For hydrogen dissolved in 5 N NaCl brine, D_0 = -10.0789.
D_1 = adjustable fitting coefficient. For hydrogen dissolved in 5 N NaCl brine, D_1 = 0.8205.
P = partial pressure of the gas of interest in the gas phase [MPa].

The bubble point tracking treatment used in BRAGFLO is believed to be flawed, and its use is not recommended. If a user wishes to investigate this feature, the logic can be retained while the bubble point tracking is effectively turned off by using input values for RSOD0 of -100. and RSOD1 of 5.

Line 8.4b. SGBUBMIN, RSOD0, RSOD1.

SGBUBMIN: Minimum gas saturation required for calculating new bubble point. Recommended value: -1.0.
RSOD0: Gas solubility correlation coefficient, D_0.
RSOD1: Gas solubility correlation coefficient, D_1.

Line 8.4c. Descriptor. Slopes of parameters at pressures greater than the bubble pressure.

Line 8.4d. BSLOPE, RSLOPE, VSLOPE.

BSLOPE: Slope of the brine formation volume factor versus pressure curve for undersaturated brine (pressure above initial brine bubble point pres-

sure): d (formation volume factor) / dP [Pa^{-1} or psi^{-1}]. Recommended value: 0.

RSLOPE: Slope of the solution gas-brine ratio versus pressure curve for undersaturated brine (pressure above initial brine bubble point pressure): d (R_{so}) / dP [Pa^{-1} or ft^3/(bbl•psi)]. Recommended value: 0.

VSLOPE: Slope of the brine viscosity versus pressure curve for undersaturated brine (pressure above initial brine bubble point pressure): d (brine viscosity) / dP [s or cP/psi]. Recommended value: 0.

If IDGAS = 2, read Lines 8.4a and 8.4b.

Line 8.4a. Descriptor. Henry's law constant.

Line 8.4b. HENRYC.

HENRYC: Henry's law constant [Pa/mol fraction gas dissolved in brine]. A single value is used for all gases, independent of the actual composition, at a fixed temperature. WIPP PA uses 4.0 x 10^{10} Pa/mol fraction gas. BRAGFLO assumes that the dissolved gas is N_2, regardless of the actual composition of the gas phase, which WIPP PA generally assumes to be pure H_2. These conflicting assumptions are used because the gas found dissolved in native WIPP brines is mostly N_2, whereas the gas generated in the waste, especially by anoxic corrosion of ferrous metals, is mostly H_2. To deal with this situation correctly would require tracking multiple gas components in both the gas phase and in the brine phase. Although BRAGFLO is capable of tracking multiple components in the gas phase, it cannot currently do this in the brine phase, and the computational effort to do so cannot be justified to correct the small errors resulting from these assumptions.

Note: If IDGAS = 2, a value for LVARSWTCH = T should be used; see Line 6.22.

Line 8.5. Descriptor. Fluid viscosities. BRAGFLO does not account for the effects of pressure and composition on viscosity. A single constant value each for brine viscosity and gas viscosity at a temperature, TREF, is read in.

Line 8.6. VISO, VISG.

VISO: Brine viscosity [Pa•s or cP]. The viscosity of WIPP brine at 27 °C (300.15 K) and 101.325 kPa is 1.8 x 10^{-3} Pa•s.

VISG: Gas viscosity [Pa•s or cP]. The viscosity of hydrogen at 27 °C (300.15 K) and 101.325 kPa is 8.92 x 10^{-6} Pa•s.

Line 8.11. Descriptor. Gas density flag.

Line 8.12. INTERPDENG.

INTERPDENG: Flag indicating how gas density will be calculated:

= 1: Interpolate from table set up by BRAGFLO using the Redlich-Kwong-Soave equation of state. This is a very fast and efficient means for calculating gas density accurately, but it can be used only when a single pure gas is used.

= 0: Calculate gas density using the Redlich-Kwong-Soave equation of state. This option provides the greatest accuracy and can be used with any combination of the six gases that can be modeled in BRAGFLO: H_2, CO_2, CH_4, N_2, O_2, and H_2S. However, it is by far the slowest method for calculating gas density. The gases that are available is severely limited because of the lack of binary interaction coefficients for other gases.

= -1: Interpolate from table set up by BRAGFLO using the ideal gas law. This option is made available as a counterpart to INTERPDENG = 1, but because the ideal gas law is so simple and fast, setting up an interpolation table is generally not recommended.

= -2: Use ideal gas law. This option is the fastest method for calculating gas density, but is not as accurate as the Redlich-Kwong-Soave equation of state. Other gases, in addition to the six currently available, could easily be added because the only data required is molecular weight. When using the multicomponent gas transport option (Subsection 7.2.12), the ideal gas law should always be used because the transport model introduces enough inaccuracies that the substantial additional computing time required to use INTERPDENG = 0 is not justified.

If a single pure gas such as hydrogen is used, it is best to interpolate from a table, because it is much faster computationally. In this case, BRAGFLO sets up a table of calculated gas densities using the Redlich-Kwong-Soave equation of state at fixed pressure intervals of 10,000 Pa. The number of table entries is specified in the PARAMETER statement by the constant, NPINT. Intervals of 10,000 Pa provides a sufficiently smooth density curve versus pressure. If much larger intervals are used, results can be noticeably affected; pressure vs. time plots, for example, will acquire a staircase appearance and the results may be seriously in error. To ensure that table values cover the full range of expected pressures, NPINT must be large. It is currently set at NPINT = 10,000, giving a maximum table entry of 100 MPa. If memory is limited, this can be safely reduced to a more practical limit of, say, 20 MPa, or NPINT = 2,000. If pressures higher than the maximum table entry are encountered, BRAGFLO will extrapolate from the two highest entries. If the pressure, P_g, is between 0 and 10,000 Pa, the density is calculated as (P_g/10000) times the density at 10,000 Pa. If the pressure is less than zero, the density is set to 1/10 of the density at 10,000 Pa.

If more than one gas is used, interpolation is not possible, and the full Redlich-Kwong-Soave equation of state (INTERPDENG = 0) must be solved each time a new density is needed.

Line 8.13. Descriptor. Gas composition.

Line 8.14. (YGAS(I), I=1, MGAS), NGAS, N1GAS.

YGAS: Initial mole fraction of each of the MGAS gases currently available in BRAGFLO (MGAS = 6; set in the PARAMETER statement). If the gas transport option is used, this composition can change during the run. If gas transport is not used, this initial gas composition will remain fixed for all time.

NGAS: Number of gases actually being used in the problem.

N1GAS: Gas number from the current list: 1 = H_2, 2 = CO_2, 3 = CH_4, 4 = N_2, 5 = O_2, 6 = H_2S. This is used only if NGAS = 1; otherwise, it can be any number. This parameter is used to simplify the gas density calculation when only one gas is present.

7.2.9 Chemical Reaction Parameters

These parameters govern the chemical reactions that are modeled in BRAGFLO. Two reactions are modeled: corrosion of iron and microbial degradation of cellulosics. These reactions take place only in the Waste. Cellulose is approximated by the pseudo-molecule CH_2O, having a molecular weight of 30.02628 x 10^{-3} kg/mol. The reactions are written as:

Corrosion: $s_{1,2}\,H_2O + s_{1,3}\,Fe \rightarrow s_{1,1}\,H_2 + \text{Inerts}$

Biodegradation: $s_{2,2}\,H_2O + s_{2,3}\,CH_2O \rightarrow s_{2,1}\,\text{Gas} + \text{Inerts}$

Both reactions are assumed to be zeroth order in kinetics with respect to the solid reactants. In other words, the rate of reaction is independent of the iron or cellulose concentration. The gas produced in the biodegradation reaction is assumed to have the physical properties of hydrogen.

Line 9.1. Descriptor.

Line 9.2. IGASVAR.

IGASVAR: Gas generation reaction flag:
= 0: No Fe or CH_2O consumption and no gas generation.
= 1: Fe and CH_2O consumption with gas generation.
= 2: Reaction path gas generation model. (Not yet available.)

If IGASVAR = 0, no more chemical reaction parameters are input; go to Section 10.

Line 9.3. Descriptor. Reaction rate constants for brine-inundated conditions.

Line 9.4. RK(1), RK(2).

RK(1): Corrosion reaction rate constant under brine-inundated conditions [mol Fe/(s•m^3) or lbmol Fe/(day•ft^3)].

RK(2): Biodegradation reaction rate constant under brine-inundated conditions [mol CH_2O/(s•m^3) or lbmol CH_2O/(day•ft^3)].

Line 9.5. Descriptor. Humid rate factors.

Line 9.6. HF(1), HF(2).

HF(1): Factor multiplying RK(1) to get the corrosion reaction rate constant under humid conditions [dimensionless].

HF(2): Factor multiplying RK(2) to get the biodegradation reaction rate constant under humid conditions [dimensionless].

Line 9.7. Descriptor. Stoichiometry for corrosion.

BRAGFLO currently assumes that the two gas generation reactions are written with $s_{1,3} = s_{2,3} = 1.0$. Both of these stoichiometric coefficients must be input with a value of 1.0; if a value other than 1.0 is input, the results will be wrong.

Line 9.8. S(1,1), S(1,2), S(1,3).

S(1,1): Stoichiometric coefficient $s_{1,1}$ for the corrosion reaction [mol H_2/mol Fe].

S(1,2): Stoichiometric coefficient $s_{1,2}$ for the corrosion reaction [mol H_2O/mol Fe].

S(1,3): Stoichiometric coefficient $s_{1,3}$ for the corrosion reaction [mol Fe/mol Fe]. Required input value: 1.0 mol Fe/mol Fe.

Line 9.9. Descriptor. Stoichiometry for biodegradation.

Line 9.10. S(2,1), S(2,2), S(2,3).

S(2,1): Stoichiometric coefficient $s_{2,1}$ for the biodegradation reaction [mol H_2/mol CH_2O].

S(2,2): Stoichiometric coefficient $s_{2,2}$ for the biodegradation reaction [mol H_2O/mol CH_2O].

S(2,3): Stoichiometric coefficient $s_{2,3}$ for the biodegradation reaction [mol CH_2O/mol CH_2O]. Required input value: 1.0 mol CH_2O/mol CH_2O.

Line 9.11. Descriptor. Additional reaction parameters.

Line 9.12. SATWICK, LARXN, ALPHARXN.

SATWICK: Term modifying the brine saturation to simulate the effect of wicking on the net reaction rate by increasing the inundated rate and decreasing the humid rate [dimensionless]. Valid range: 0.0-1.0. A value of 0.0 will turn this feature off. Instead of using the actual brine saturation, S_b, to calculate reaction rates, an effective brine saturation, $S_{b,eff}$, is used, where

$$S_{b,eff} = S_b + S_w\left(1 - e^{\alpha S_b}\right)$$

The factor α is ALPHARXN, and S_w is SATWICK. This function smoothes $S_{b,eff}$; it was intended originally for $S_{b,eff}$ to be $S_{b,eff} = S_b + S_w$, but this function is discontinuous at $S_b = 0$, which can cause numerical difficulties that may lead to incorrect results.

LARXN: Logical flag indicating whether to smooth humid reaction rates (.TRUE.) using the factor ALPHARXN, or use unmodified, discontinuous humid rates (.FALSE.). Recommended value: T.

ALPHARXN: Term used in smoothing functions to eliminate a discontinuity at brine saturation, $S_b = 0$. Always used in expression to obtain $S_{b,eff}$ when wicking is modeled (i. e., when SATWICK > 0.). When LARXN = T, ALPHARXN (or α) is used in the smoothing function for both humid corrosion and biodegradation rates:

$$r_{h,eff} = r_h\left(1 - e^{\alpha S_b}\right)$$

where:

r_h	= humid corrosion or biodegradation rate = HF(1) x RK(1), or HF(2) x RK(2);
$r_{h,eff}$	= effective (smoothed) humid corrosion or biodegradation rate.

If LARXN = F, then ALPHARXN is not used for the humid corrosion and biodegradation rates, and $r_{h,eff} = r_h$. The full corrosion or biodegradation rate is given by [where r_i is the inundated rate, RK(1) or RK(2)]:

$$\begin{aligned} r &= S_b r_i + \left(1 - S_b\right) r_{h,eff}, & S_b > 0 \\ &= 0, & S_b = 0 \end{aligned}$$

so, unless $r_{h,eff} = 0$, r will be discontinuous at $S_b = 0$. This discontinuity tends to cause numerical problems. Generally, BRAGFLO will run better when LARXN = T, although exceptions to this rule have been encountered. ALPHARXN must be a negative value; if a positive value is input, BRAGFLO will convert the input value to a negative value before using it. Recommended value: -1000. A large negative value for ALPHARXN will approximate more closely the discontinuous function originally intended for r while remaining smooth enough to ease the numerical difficulties. Small negative values of ALPHARXN will result in values of $r_{h,eff}$ that are significantly different from r_h, and a value of zero will cause $r_{h,eff}$ to be zero.

7.2.10 Creep Closure Parameters

These parameters activate the creep closure submodel. Using this model, the porosity of the Waste is calculated to simulate salt creep that, over time, closes in on the waste, compressing it. Four closure models, or "surfaces," are available, three that apply to waste and one for nonbackfilled drifts. Two options are available for interpolating over the closure models. The porosity can be based on the quantity of gas present in the waste or on the pressure in the waste. The latter option is more current and conforms more closely to the theoretical basis on which creep closure is modeled.

Line 10.1. Descriptor. Creep closure control flag.

Line 10.2. CLOSURE.

CLOSURE: LOGICAL flag. If CLOSURE = .TRUE., the porosity of the waste will be calculated using the creep closure model. If CLOSURE = .FALSE., the porosity of the waste will instead be calculated based simply on the compressibility of the waste, in the same manner as for all other materials.

If CLOSURE = .FALSE., no more closure data are input; go to Subsection 7.2.11.

Even if CLOSURE = .TRUE., the creep closure model is not used at any time prior to TIMEICRESET. The creep closure model is used only up to the maximum data time for each closure model, TIMEDATA_MAX (3.78716×10^{11} s, or 12,000 yr, in the current version of BRAGFLO. An upper limit of 12,000 yr, instead of 10,000 yr, is used to ensure that interpolation is done properly if a WIPP run goes slightly past 10,000 yr; for example, the completion time [FINISH] for a run is typically set at 3.1557×10^{11} s, which is 10,000.02 yr.); after that time, the porosity of the waste is computed from the compressibility. In order to preserve the waste porosity as a continuous function of time after TIMEDATA_MAX, BRAGFLO sets the reference pressure for porosity calculation, PREFROCK, equal to the current waste pressure, which is uniform throughout the waste in the creep closure model. In addition, the reference porosity, PORREFROCK, is set equal to the current waste porosity, which is also uniform throughout the waste.

Line 10.3. Descriptor. Creep closure parameters.

Line 10.4. NKLOS, KLOSINT, KLOSAVE.

NKLOS: Number of closure models to be used in this run. BRAGFLO currently has three closure surfaces from which to choose. NKLOS must be > 0 and ≤ MKLOS, set in the PARAMETER statement; currently, MKLOS = 4.

KLOSINT: Flag indicating the basis on which interpolation on the creep closure data will be done. Recommended value: 1. KLOSINT = 0 was used exclusively in early versions of BRAGFLO that had closure surface capabilities, but is no longer considered reliable, especially with closure

surfaces 1, 2, and 4 (surface 3 is the original closure surface). If KLOSAVE = 2 is used, KLOSINT = 0 may *not* be used.

= 0: Interpolation based on gas generation rate and quantity of gas present.

= 1: Interpolation based on average waste pore pressure.

KLOSAVE: Flag indicating the scale over which properties are averaged for application of a closure model. Recommended value: 2.

= 1: Average brine pressures in all grid blocks using a given closure model to determine the porosity, which will be identical in all those grid blocks. This is done only when evaluating residuals; creep closure is not modeled when calculating the Jacobian. This averaging method was used exclusively in earlier versions of BRAGFLO. However, because creep closure effects cannot be accounted for in evaluating the Jacobian, convergence problems often arise. In general, this method should not be used except to replicate earlier results. On the other hand, in some instances solutions have been obtained using KLOSAVE = 1 where using KLOSAVE = 2 causes the run to fail.

= 2: Do no averaging; use only the brine pressure in individual grid blocks to obtain porosity from a closure surface, both for evaluating residuals and for evaluating the Jacobian. Because creep closure effects are properly accounted for in the Jacobian, convergence behavior should be superior to using KLOSAVE = 1. If KLOSINT = 0, BRAGFLO will abort with a message warning that KLOSINT must be 1 when KLOSAVE = 2.

Line 10.5. Descriptor. Creep closure parameters.

The following line is repeated NKLOS times:

Line 10.6. I, PLITHO(I), TIME_CLOSOFF(I), CLOSPERMFACT(I), CLOSPERMEXP(I).

I: Closure surface or model number (1, 2, 3, or 4).

PLITHO(I): Maximum pressure allowed for closure to continue. If waste brine pressure exceeds PLITHO(I), closure is tuned off permanently. The user is informed if and when this happens by a warning printed to the screen and to the .SUM file, if it is used. If closure is turned off, the porosity of the waste may continue to vary with pressure depending on the value of compressibility of the waste, as specified in Line 7.36. For this purpose, the reference porosity and reference pressure are the values that exist in the closure region (if KLOSAVE = 1) or in the grid block undergoing closure (if KLOSAVE = 2) at the time when closure is turned off.

TIME_CLOSOFF(I): Time limit for creep closure to be active [s]. As an example, creep closure modeling may be turned off when a human intrusion occurs, since the closure surface is no longer valid under those circum-

stances. If there is no time limit on creep closure, a value equal to or greater than TIMEDATA_MAX(I) or FINISH (Line 1.7, end time for the run) can be input.

CLOSPERMFACT(I): Constant factor, a, in expression relating permeability, k, to porosity, ϕ, in each region undergoing dynamic creep closure [m^2]:

$$k = a\phi^{\eta}$$

If the permeability of any region (KLOSAVE = 1) or grid block (KLOSAVE = 2) undergoing creep closure is to be constant, set CLOSPERMFACT(I) to the initial permeability for that material, XKX (Line 7.36). If KLOSAVE = 1, all grid blocks using the same closure surface will have the same porosity and, consequently, the same permeability. Recommended value: 1.0×10^{-11} m^2.

CLOSPERMEXP(I): Exponent, η, in expression relating permeability, k, to porosity, ϕ, in each region undergoing dynamic creep closure [dimensionless]. If the permeability of any region or grid block is to be constant, set CLOSPERMEXP(I) to zero. Recommended value: 4.6.

Line 10.7. Descriptor. Creep closure material control parameter.

Line 10.8. NMATCLOS.

NMATCLOS: Number of materials in which closure will take place. Each material that undergoes creep closure is referred to as a closure region. The number of closure regions cannot be greater than the number of materials Thus, NMATCLOS must ≤ MMAT (set in the PARAMETER statement) and must be ≥ 0. (Inputting a value of 0 is pointless, but otherwise harmless, so it is permitted.)

If NMATCLOS = 0, no more closure data are input; go to Subsection 7.2.11.

Line 10.9. Descriptor. Creep closure parameters associating a material number with a creep closure model number.

The following line is repeated NMATCLOS times:

Line 10.10. I, MATCLOS(I), MODELCLOS(I).

I: Closure region number. I must be > 0 and ≤ MMAT (set in the PARAMETER statement).

MATCLOS(I): Material type number from the material map that will be a closure region. MATCLOS(I) must be > 0 and ≤ MMAT (set in the PARAMETER statement). It is permissible for a material number not to be used in any material map, but there is no check to be sure that material MATCLOS(I) is used in any map. For example, if an input file has one material map with two materials, numbered, say, 1 and 14 (and 14 sets of material properties are input in Section 8), one may input a value of,

say, MATCLOS(I) = 5 here, which does not refer to any material actually used in the run. Creep closure will be calculated for material 5 even though it does not exist. This may have no effect on the run, but it may cause the run to abort (after it has reached TIMEICRESET) when the creep closure model tries to interpolate on the closure surface using brine pressures of 0.0, which is the default value when a material has not been defined. Thus, it is up to the user to ensure that valid material numbers are used as closure regions.

MODELCLOS(I): Creep closure surface or model number used by closure region MATCLOS(I). MODELCLOS(I) must be >0 and ≤ MKLOS (set in PARAMETER statement; currently, MKLOS = 4). The available options are:

1: Waste without backfill. Used during 1995, this model is no longer considered the best available for application to waste, but is retained in BRAGFLO to enable earlier calculations to be reproduced.

2: Drift without backfill. This model was applied to access drifts ("North End") and the Experimental Region excavations during 1995. It is no longer recommended for application to WIPP, but is retained in BRAGFLO to enable earlier calculations to be reproduced.

3: Waste with backfill. This model was used in the 1992 Preliminary Performance Assessment and in subsequent calculations, until early 1995. Although the waste configuration is no longer considered likely, this model is retained in BRAGFLO to enable earlier calculations to be reproduced.

4: Waste without backfill. This model is used in the 1996 Compliance Certification Application (CCA) calculations (Stone, 1995)

7.2.11 Radionuclide Transport and Decay Parameters

The "transport" model currently implemented in BRAGFLO is really just a simple particle tracking model. Radionuclides originating in waste blocks are carried to other grid blocks by simple advection. The only processes that take place other than advection are dissolution and precipitation and radionuclide decay. Diffusion, adsorption, and any other reactions are not included in the present model. The current implementation of transport is inefficient and computationally intensive, so it should be used with discretion. In particular, the number of radionuclides that are tracked has a strong effect on the amount of computing time required. The transport model is solved explicitly and can become unstable. If this happens, transport is turned off. A warning flag is printed to the screen and to the .SUM file both at the time when this occurs and again at the end of the run, and radionuclide concentrations and masses remain unchanged for the duration of the run.

Because of stability limitations and potentially extreme run times associated with the current implementation of transport and radionuclide decay, this submodel of BRAGFLO is of limited use and is being phased out. It is being replaced by a separate code, NUTS (Nuclide

Transport Simulator), that uses a BRAGFLO flow field, but calculates transport and radionuclide decay implicitly, allowing for much faster and more efficient transport calculations than can be done within BRAGFLO. For now, the transport model remains coded in BRAGFLO, but its use is prohibited because of possible conflicts with the radiolysis model. Radiolysis can also be modeled in BRAGFLO.

Line 11.1. Descriptor. On/off flag for radionuclide decay, either during radiolysis or transport, or both.

Line 11.2. LRADDK.

LRADDK: Logical flag indicating whether radionuclide decay will be calculated. If LRADDK = .TRUE., additional input is required.

Line 11.3. Descriptor. On/off flag for transport.

Line 11.4. LTRANS.

LTRANS: Logical flag indicating whether transport will be calculated. If LTRANS = .TRUE., additional input is required. Transport may be turned off automatically if it becomes unstable.

Note: Transport is currently disabled. If LTRANS = .TRUE. on input, it will be set to .FALSE. If transport parameters that are not also needed for radiolysis are in the input file, and radiolysis is not being modeled (LRADDK = .FALSE.), the run will abort trying to read the rest of the input file.

Line 11.5. Descriptor. On/off flag for radiolysis.

Line 11.6. LRADLSIS.

LRADLSIS: Logical flag indicating whether radiolysis will be calculated.

If LRADLSIS = .FALSE. and LTRANS = .FALSE., then BRAGFLO sets LRADDK to .FALSE. even if it was input as .TRUE., and no additional radionuclide decay parameters are input; go to Subsection 7.2.12.

Line 11.7. Descriptor. Number of radionuclides.

Line 11.8. NRAD.

NRAD: Number of radionuclide species to be tracked in the transport and decay models. NRAD must be greater than zero and less than or equal to MRAD, which is set in the PARAMETER statement. Otherwise, BRAGFLO will abort with the message:

```
*** Aborted in READRAD:  Invalid NRAD value input.
```

Note: None of the rest of the input is checked for validity or consistency.

The following two lines (11.9 and 11.10) are read in only if LRADDK = .TRUE.:

Line 11.9. Descriptor. Transport and decay control parameters.

Line 11.10. XLIM, HALFMAX, T_SCALE, SRADO2, GH2AVG.

XLIM: Minimum decay factor; decay factor is set to zero when it is below XLIM [dimensionless]. Recommended value: 1.0×10^{-7}.

HALFMAX: Maximum number of half-lives during which decay will be calculated. Recommended value: 50.

T_SCALE: Time above which half-life is too large to bother calculating decay; used to shorten the decay chain [s]. Recommended value: 3.1557×10^{7} s (1.0 yr).

SRADO2: Stoichiometric coefficient for O2 from radiolysis [mol O_2/mol H_2]: $H_2O \rightarrow H_2 + (SRADO2)\ O_2$.

The value of *SRADO2* should be between 0.0 and 0.5:

0.0 if O_2 is assumed to react immediately with other materials;
0.5 if O_2 is assumed to be inert.

Note that BRAGFLO, as used in WIPP PA calculations, assumes all gas to be H_2. The mass of gas produced by radiolysis as O_2 is:

$$M_{w,O_2} \cdot SRADO2 = 31.9988 \times 10^{-3}\, SRADO2 \ [\text{kg O}_2 / \text{mol H}_2] \ ,$$

where:

M_{w,O_2} = molecular weight of O_2 [kg O_2 / mol O_2],

M_{w,H_2} = molecular weight of H_2 [kg H_2 / mol H_2].

When this mass is treated as an equal mass of H_2, it is equivalent to:

$$\frac{M_{w,O_2} \cdot SRADO2}{M_{w,H_2}} = \frac{31.9988 \times 10^{-3}\, SRADO2 \left[\dfrac{\text{kg H}_2 (= \text{kg O}_2)}{\text{mol H}_2}\right]}{2.01588 \times 10^{-3} \left[\dfrac{\text{kg H}_2}{\text{mol H}_2}\right]}$$

$$= 15.8734 \cdot SRADO2 \left[\text{mol H}_2 / \text{mol H}_2\right]$$

$$= 7.93668 \left[\text{mol H}_2 / \text{mol H}_2\right]$$

when *SRADO2* = 0.5, which results in a far greater volume of gas (as H_2) than is realistically produced. It may be more realistic in BRAGFLO to consider radiolysis as producing 1/2 *moles* of H_2 (assuming the gas to be inert) (i. e., $H_2O \rightarrow H_2 + 1/2H_2$), rather than

$M_{w,O_2} \cdot SRADO2$ kg of H_2. Then the value *SRADO2* should have in order to produce 0.5 mol H_2 can be calculated from:

$$\frac{1}{2}[\text{mol}\,H_2 / \text{mol}\,H_2] = \frac{M_{w,O_2} \cdot SRADO2}{M_{w,H_2}},$$

or,

$$SRADO2 = \frac{\frac{1}{2} M_{w,H_2}}{M_{w,O_2}}$$

$$= \frac{\left(\frac{1}{2}\right) 2.01588 \times 10^{-3}}{31.9988 \times 10^{-3}}$$

$$= 0.0314993.$$

GH2AVG: Average "G" value for H_2 [molecules/disintegration]. Recommended value: 0.0125.

Line 11.11. Descriptor. Isotope names.

Line 11.12. (IDION(I),I=1,NRAD).

IDION: Name of parent isotope. This is a CHARACTER*8 variable, read in free format, so it must be enclosed in tick marks. The name should be the element symbol followed by the atomic number (e. g., 'Pu238') with no spaces or other punctuation between the element symbol and the atomic number. The element symbol can be either all upper case or upper and lower case. Trailing blanks are optional.

Line 11.13. Descriptor. Daughter names.

Line 11.14. (IDAUG(I),I=1,NRAD).

IDAUG: Name of immediate daughter isotope from the decay of isotope IDION(I). Same input rules as for the parent isotopes. If there is no daughter, use a blank: one to eight spaces between tick marks.

Line 11.15. Descriptor. Element indexes.

Line 11.16. (IELE(I),I=1,NRAD).

IELE: Element index for each isotope; must range from 1 to a maximum of NRAD, depending on how many elements there are. Applies to IDION only. Thus, all IDION isotopes of Pu, for example, will have the same IELE index, and all isotopes of Th will have another IELE index, all the same, but different from the index used for Pu. These are used to calculate the solubility when more than one isotope of an element is present, since the input solubility is of an element, not an isotope.

Line 11.17. Descriptor. Half lives.

Line 11.18. (THALF(I),I=1,NRAD).
THALF: Half-life of isotope IDION [s or yr].

Line 11.19. Descriptor. Atomic weights.

Line 11.20. (AWT(I),I=1,NRAD).
AWT: Atomic weight of isotope IDION [kg/mol or lb/lbmol].

Line 11.21. Descriptor. Solubilities.

Line 11.22. (SOLB_LIM(I),I=1,NRAD).
SOLB_LIM: Solubility limit of element in brine [mol/m^3 or lbmol/ft^3]. Same value should be input for each isotope IDION of the element; i. e., all IDION with the same IELE should have the same SOLB_LIM.

Line 11.23. Descriptor. Disintegration energy.

Line 11.24. (EVDP(I),I=1,NRAD).
EVDP: Disintegration energy if isotope IDION [MeV/disintegration]. Note that input units are MeV/dis; BRAGFLO converts to eV/dis.

The following two lines (11.25 and 11.26) are repeated NRAD times, once for each radionuclide:

Line 11.25. Descriptor. Initial inventory.

Line 11.26. RADINIT(I).
RADINIT(I): Initial total mass of radionuclide IDION(I) in waste [kg or lb]. Assumed to exist initially in solid phase only; BRAGFLO will then calculate how much is dissolved in brine as part of transport and decay calculation, based on input solubilities. This initial inventory is distributed to all gridblocks having initial material type index MAT_WASTEI (Line 7.12) in proportion to the volume of each grid block relative to the total waste volume.

The following two lines are input only if LTRANS = .TRUE.:

Line 11.27. Descriptor. Transport and decay control parameters.

Line 11.28. SOLB_MULT, Q_BVOL_RATIO, TSUB_MAX.

SOLB_MULT: Multiplier on SOLB_LIM (solubility limit of radionuclide species in brine, Line 11.22) to avoid unrealistic precipitation of radionuclide outside of the waste regions [dimensionless]. Recommended value: 1.0×10^5.

Q_BVOL_RATIO: Maximum interblock flow allowed during transport calculation [fraction of grid block volume]. Recommended value: 0.10.

TSUB_MAX: Maximum number of times that BRAGFLO time step DELT is subdivided to keep the transport solution stable. Larger values may actually be needed, but the calculation may then require excessive computing time, so it is best to set some reasonable limit and hope it remains stable. Recommended value: 100 - 200. If the solution becomes unstable, TSUB_MAX should be increased. Q_BVOL_RATIO can be increased, but should remain below 1.0. Increasing either of these will increase the computational effort.

7.2.12 Multicomponent Gas Transport Parameters

The current version of BRAGFLO has the capability to track multiple components of the gas phase as they are produced, consumed, and transported. This transport model accounts only for advective flow; diffusion and retardation are not considered. This feature is intended to supplement the reaction path gas generation model and gas dissolution model. Because the reaction path model has not yet been implemented, the gas transport model has not yet been tested or even debugged, so it should not be used except for testing purposes.

Line 12.1. Descriptor. Gas transport control flag.

Line 12.2. LRXGAST.

LRXGAST: Logical flag (.TRUE. or .FALSE.) indicating whether gas component transport will be used.

If LRXGAST = .FALSE., this is the end of the BRAGFLO input.
The next two lines are repeated MGAS times, where MGAS is the number of gas components, set in the PARAMETER statement.

Line 12.3. Descriptor. Initial gas component concentration.

Line 12.4. (((AFTER(I,J,K), I=1, NX), J=1, NY), K=1, NZ).

AFTER: Initial mole fraction of each gas component [mol fraction].

This is the end of the BRAGFLO input.

7.3 Restart Capability

NOTE: THE RESTART CAPABILITY IS NOT ALLOWED FOR THE 1996 WIPP CALCULATIONS.

The restart capability in BRAGFLO enables runs to be restarted from any point specified in the input file and from the end of a run. The restarted run will continue exactly as it would have if the run had been done from the beginning without interruption. This capability is most useful for debugging, but also allows troublesome runs to be stopped and analyzed before wasting computing time. Occasionally, control parameters can be changed part way through a run, enabling a run to finish when it would otherwise remain stuck.

Some basic information on how to use the restart capability was presented earlier under "Files used by BRAGFLO." Initially, the input file must specify that a restart output file is to be written. This is indicated by setting the logical flag, LWRST, on Line 1.3 to T (.TRUE.). If LWRST is .FALSE., no restart output will be written, and the run cannot be restarted. If LWRST is .TRUE., a restart record will be written as specified in Section 2. Restart records, like ASCII and binary output, can be written at specified times, at specified time intervals, or at a specified time step frequency. If LWRST is .TRUE., a restart record will automatically be written at the end of a run, regardless of how they are specified to be written during a run. The restart record contains all the information needed to resume from the last converged time step before the restart record is written. Although there is no limit to the number of restart records that can be written during a run, the number of restart records needed is generally very small, at most a couple, or perhaps every 500 years in a 10,000-year run. The user has to know when the restart records are written in order to do a restart. This information is written to the screen or log file, to the ASCII output file [if one is being written (LWASC is .TRUE. on Line 1.3)], and to the .SUM file [if one is being written (LWSUM is .TRUE. on Line 1.3)] each time a restart record is written.

The procedure for restarting a BRAGFLO run is as follows:

1. Copy the restart output file [.ROT] into a restart input file [.RIN]. The name of the restart input file does not have to be the same as the restart output file, but it does have to be the same (except for the .RIN extension) as the ASCII input file that will be used for the restart.
2. Edit the ASCII input [.INP] file used in the initial run. If the flag LRRST in Line 1.3 is F, it must be changed to T, indicating that a restart input file will be read. The flag LWRST in Line 1.3 had to have been T in the initial run; it can (and probably should) be left as T, or can be changed to F for the restart, depending on whether the user wished to write any more restart output records during the restart run. If the initial run completed the maximum number of time steps allowed, then MAXITF (Line 1.7) must be increased, or the restart run will stop immediately, having already completed MAXITF steps. If the run is being restarted simply because MAXITF was too small in the initial run, or if the restart is a debugging run, these are the only changes needed. Almost anything in the ASCII input file can be changed for the restart run, with the exception of the dimensions of the problem (NX, NY, NZ, Line 1.5). If these are changed, the restart run will abort. Any parameter specifying the number of something, such as the number of wells, the number of material types, or the number of history variables, can be changed, but should not be changed because it will likely confuse both the user and BRAGFLO and probably eventually abort. Print flags should not be changed because postprocessing will be messed up. Grid block sizes and initial conditions should not be changed. Logically, the

only changes that should be considered, other than file specifications, time or time step limits, and output times or frequencies, are numerical control parameters. In rare instances, one might want to modify material properties. Keep in mind that any changes to the input file that are in effect only at times earlier than the time of the restart, and are no longer in effect at the restart time, will not have any effect on the restart run. For example, if the restart is at 1000 years, and the input file is changed to request additional ASCII output at 500 years, the output at 500 years will not be written. The .INP file name can be changed from the initial run, but the name has to be the same as the restart input file name, except for the .INP extension.

3. Run BRAGFLO. As usual, BRAGFLO prompts for the name of the .INP file. Then it requests the number of the restart record from the restart input .RIN file. If the user wished to start the run from the beginning again (having made changes to the input file), a zero can be entered here. If a number greater than the number of restart records in the .RIN file is entered, the run will abort trying to read past the end of the .RIN file.

4. Postprocessing. The binary file from the restart run will have the same structure as the initial run, but start from the restart time. Before postprocessing in the CAMCON system using POSTBRAG, it is necessary first to run a utility, BINCOMBO, which merges the two binary files into a single binary file.

8.0 ERROR MESSAGES

BRAGFLO outputs a number of error messages and aborts execution when it detects invalid input parameters. Explanations of these error messages can be found in Section 7.0.

9.0 DESCRIPTION OF OUTPUT FILES

9.1 Binary Output (.BIN) File

This file is the primary results file that is converted by POSTBRAG (Figure 29) into standard .CDB format. This file contains output in a more compact form than is possible in an ASCII output file. Most results of interest printed typically every 20 or so time steps and a more limited amount of information printed every time step. The beginning of the file contains QA information, as in the ASCII file (Subsection 9.2). It also contains an output variable glossary. Enough information is stored to enable a postprocessor, POSTBRAG to read the file and place the results into a CAMDAT data base for additional postprocessing and analysis by the downstream codes. The structure of this file is described below. Although it does not contain all the information used in a BRAGFLO run (for example, material properties are absent), it can contain all the results needed for a complete analysis of the results, so it should not be necessary to modify the code or to write additional output files for further postprocessing.

A FORTRAN program that will read the binary output file is listed on the following page to illustrate the structure of the file. In this program, the header information is read and saved as variables whose values are not changed later. The information at each time step is read and stored in local variables that are over-written at the next time step, so this information must be written to the output file at each time step as needed for subsequent analysis and postprocessing.

```
PROGRAM BINREAD
C
C     Translates BRAGFLO binary file into ASCII file.
C     J. Schreiber, SAIC, 03/08/96
C
      PARAMETER (MX=50,MY=40,MZ=10,NVPR=107,MXHIV=15000,
     1   MVHIV=MX*MY*MZ,MGVAR=10)
C
      CHARACTER*8   RTIME(2),PNAME(2),VRSION(2),UNITS,REVDATE(2)
      CHARACTER*8   NAMVAREL(NVPR),NAMVARHI(MXHIV),NAMVARGL(MGVAR)
      CHARACTER*50  LABELEL(NVPR),LABELHI(MXHIV),LABELGL(MGVAR)
      CHARACTER*20  LABUNTEL(NVPR),LABUNTHI(MXHIV),LABUNTGL(MGVAR)
      CHARACTER*9   DATE(2)
      CHARACTER*32  CPUNAME
      CHARACTER*1   FILTYP
      CHARACTER*80  FILNAM(6),BRAGNAM
      CHARACTER*132 TITLE
      DIMENSION IIHIV(MVHIV,NVPR),JJHIV(MVHIV,NVPR),KKHIV(MVHIV,NVPR)
      DIMENSION UNTCNVEL(NVPR),UNTCNVHI(MXHIV),UNTCNVGL(MGVAR)
      DIMENSION DXGRID(MX,MY,MZ),DYGRID(MX,MY,MZ),DZGRID(MX,MY,MZ)
      DIMENSION GRIDVOL(MX,MY,MZ),LHI(NVPR),LE(NVPR),LH(MXHIV),LG(MGVAR)
      DIMENSION HVAR(MXHIV),YY(MX,MY,MZ),NGBHIV(NVPR)
      REAL IBBALMX,JBBALMX,KBBALMX,IGBALMX,JGBALMX,KGBALMX
C
C
      WRITE (*,*) 'Enter name of BRAGFLO binary file.'
      READ  (*,'(A)') BRAGNAM
C
      OPEN (8,FILE=BRAGNAM,STATUS='OLD',FORM='UNFORMATTED')
      OPEN (9,FILE='ASCII.OUT',STATUS='NEW')
C
C     Read header section with QA info, vbl glossary, grid dimensions:
C       Note:  If first record is 'PREBRAG', then the file starts with
C              PREBRAG QA info; otherwise, there is no PREBRAG info, and
C              the file starts with BRAGFLO QA info.
C       PNAME(1)    = Preprocessor name (PREBRAG).
C       VRSION(1)   = PREBRAG version number.
C       REVDATE(1)  = PREBRAG revision date.
C       DATE(1)     = PREBRAG run date.
C       RTIME(1)    = PREBRAG run time.
C       DATE(2)     = BRAGFLO run date.
C       RTIME(2)    = BRAGFLO run time.
C       PNAME(2)    = Program name (BRAGFLO).
C       VRSION(2)   = BRAGFLO version number.
C       REVDATE(2)  = BRAGFLO revision date.
C       CPUNAME     = Name of machine on which BRAGFLO was run.
C       FILTYPE     = Type of file ('B'=binary).
C       NUMFIL      = Number of files used in the BRAGFLO run.
C       FILNAM      = Names of NUMFIL files used by BRAGFLO.
C       TITLE       = Title of run.
C       NX,NY,NZ    = Dimensions of problem run.
C       UNITSO      = Units system used for ouput ('SI' or 'ENGLISH').
C       NVAREL      = Number of element variables.
C       MHIVM       = Number of time- & performance-related history vbls.
```

```
C       MHIV        = Total no. of element vbl-based history vbls printed
C                     at each time step.
C       NHIV        = No. of element vbls that are printed as history vbls.
C       NGVAR       = Number of global variables.
C
      READ (8) PNAME(1)
      IF (PNAME(1)(1:7) .EQ. 'PREBRAG') THEN
         READ (8) VRSION(1)
         READ (8) REVDATE(1)
         READ (8) DATE(1)
         READ (8) RTIME(1)
         READ (8) DATE(2)
      ELSE
         DATE(2) = PNAME(1)
      END IF
C
      READ (8) RTIME(2)
      READ (8) PNAME(2)
      READ (8) VRSION(2)
      READ (8) REVDATE(2)
      READ (8) CPUNAME
      READ (8) FILTYP
      READ (8) NUMFIL
      DO 10 I=1,NUMFIL
         READ (8) FILNAM(I)
   10 CONTINUE
      READ (8) TITLE
      READ (8) NX,NY,NZ
      READ (8) UNITS
      READ (8) NVAREL,MHIVM,MHIV,NHIV,NGVAR
      MHIVT = MHIVM + MHIV
C
C     Read glossary of variables:
C       LHI       = Element vbl no. from User Manual Table 4 for this
C                   history vbl.
C       NGBHIV    = No. of grid blocks to be printed as history vbl for
C                   variable LHI.
C       IIHIV     = I-index of grid block for this history variable.
C       JJHIV     = J-index of grid block for this history variable.
C       KKHIV     = K-index of grid block for this history variable.
C       LE        = Number of the element variable.
C       NAMVAREL = Variable name to be used in POSTBRAG.
C       LABELEL  = Description of this variable.
C       LABUNTEL = Units label for this variable (e.g., Pa).
C       UNTCNVEL = Factor to convert from UNITSO to SI units.
C       LH        = Number of the history variable.
C       NAMVARHI = Variable name to be used in POSTBRAG.
C       LABELHI  = Description of this variable.
C       LABUNTHI = Units label for this variable (e.g., Pa).
C       UNTCNVHI = Factor to convert from UNITSO to SI units.
C       LG        = Number of the global variable.
C       NAMVARGL = Variable name to be used in POSTBRAG.
C       LABELGL  = Description of this variable.
C       LABUNTGL = Units label for this variable (e.g., kg).
C       UNTCNVGL = Factor to convert from UNITSO to SI units.
```

```
C
      DO 20 I=1,NHIV
         READ (8) LHI(I),NGBHIV(I),(IIHIV(J,I),JJHIV(J,I),KKHIV(J,I),
     1      J=1,NGBHIV(I))
   20 CONTINUE
      DO 30 I=1,NVAREL
         READ (8) LE(I),NAMVAREL(I),LABELEL(I),LABUNTEL(I),UNTCNVEL(I)
   30 CONTINUE
      DO 40 I=1,MHIVT
         READ (8) LH(I),NAMVARHI(I),LABELHI(I),LABUNTHI(I),UNTCNVHI(I)
   40 CONTINUE
      DO 50 I=1,NGVAR
         READ (8) LG(I),NAMVARGL(I),LABELGL(I),LABUNTGL(I),UNTCNVGL(I)
   50 CONTINUE
C
C     Mesh dimensions and grid block volumes.
C
      READ (8) (((DXGRID(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
      READ (8) (((DYGRID(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
      READ (8) (((DZGRID(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
      READ (8) (((GRIDVOL(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
C
C     *** End of header section (READ) ***
C
C
      IF (PNAME(1)(1:7) .EQ. 'PREBRAG') THEN
         WRITE (9,*) '** PREBRAG Program Name **'
         WRITE (9,*) PNAME(1)
         WRITE (9,*) '** PREBRAG Version Number **'
         WRITE (9,*) VRSION(1)
         WRITE (9,*) '** PREBRAG Revision Date **'
         WRITE (9,*) REVDATE(1)
         WRITE (9,*) '** PREBRAG Run Date **'
         WRITE (9,*) DATE(1)
         WRITE (9,*) '** PREBRAG Run Time **'
         WRITE (9,*) RTIME(1)
      END IF
C
      WRITE (9,*) '** BRAGFLO Run Date **'
      WRITE (9,*) DATE(2)
      WRITE (9,*) '** BRAGFLO Run Time **'
      WRITE (9,*) RTIME(2)
      WRITE (9,*) '** BRAGFLO Program Name **'
      WRITE (9,*) PNAME(2)
      WRITE (9,*) '** BRAGFLO Version Number **'
      WRITE (9,*) VRSION(2)
      WRITE (9,*) '** BRAGFLO Revision Date **'
      WRITE (9,*) REVDATE(2)
C
      WRITE (9,*) '** Computer Name **'
      WRITE (9,*) CPUNAME
      WRITE (9,*) '** Output File Type **'
      WRITE (9,*) FILTYP
      WRITE (9,*) '** Number of Files Used **'
      WRITE (9,*) NUMFIL
```

```
      WRITE (9,*) '** Names of Files Used **'
      DO 60 I=1,NUMFIL
         WRITE (9,*) FILNAM(I)
   60 CONTINUE
C
      WRITE (9,*) '** Title of Run **'
      WRITE (9,'(A)') TITLE
      WRITE (9,*) '** NX, NY, NZ **'
      WRITE (9,*) NX,NY,NZ
      WRITE (9,*) '** Output Units **'
      WRITE (9,*) UNITS
C
      WRITE (9,*) '** NVAREL, MHIVM, MHIV, NHIV, MGVAR **'
      WRITE (9,*) NVAREL,MHIVM,MHIV,NHIV,NGVAR
      WRITE (9,*)
      WRITE (9,*) '** History Vbl Locations **'
      DO 70 I=1,NHIV
         WRITE (9,'(2I5,10(3X,3I3))') LHI(I),NGBHIV(I),
     1      (IIHIV(J,I),JJHIV(J,I),KKHIV(J,I),J=1,NGBHIV(I))
   70 CONTINUE
      WRITE (9,*)
      WRITE (9,*) '** Element Vbl Labels **'
      DO 80 I=1,NVAREL
         WRITE (9,'(I4,2X,A,2X,A,2X,A,1PE16.6)') LE(I),NAMVAREL(I),
     1      LABELEL(I),LABUNTEL(I),UNTCNVEL(I)
   80 CONTINUE
      WRITE (9,*)
      WRITE (9,*) '** History Vbl Labels **'
      DO 90 I=1,MHIVT
         WRITE (9,'(I4,2X,A,2X,A,2X,A,1PE16.6)') LH(I),NAMVARHI(I),
     1      LABELHI(I),LABUNTHI(I),UNTCNVHI(I)
   90 CONTINUE
      WRITE (9,*)
      WRITE (9,*) '** Global Vbl Labels  **'
      DO 100 I=1,NGVAR
         WRITE (9,'(I4,2X,A,2X,A,2X,A,1PE16.6)') LG(I),NAMVARGL(I),
     1      LABELGL(I),LABUNTGL(I),UNTCNVGL(I)
  100 CONTINUE
C
      WRITE (9,*)
      WRITE (9,*) '** Mesh Sizes:  DXGRID **'
      WRITE (9,*) (((DXGRID(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
      WRITE (9,*)
      WRITE (9,*) '** Mesh Sizes:  DYGRID **'
      WRITE (9,*) (((DYGRID(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
      WRITE (9,*)
      WRITE (9,*) '** Mesh Sizes:  DZGRID **'
      WRITE (9,*) (((DZGRID(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
      WRITE (9,*)
      WRITE (9,*) '** Mesh Sizes:  GRIDVOL **'
      WRITE (9,*) (((GRIDVOL(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
C
C     *** End of header section (WRITE) ***
C
C
```

```
C     *** Cycle through time steps ***
C
C     First read time, time step, CPU time, performance measures:
C       TIME     = Elapsed simulation time [s].
C       TIMED    = Elapsed simulation time [days].
C       TIMEYR   = Elapsed simulation time [yr].
C       DELT     = Time step [s].
C       DELTD    = Time step [days].
C       DELTYR   = Time step [yr].
C       AVGITER  = Average Newton-Raphson iterations per time step.
C       CPUS     = CPU time used for this time step [s].
C       CPUHR    = Total CPU time used so far in the run [hr].
C       RNSTEP   = Time step number (REAL).
C       RITERTOT = Total Newton-Raphson iterations so far (REAL).
C       KBIN     = Flag indicating:
C                    =0: only history vbl output will follow.
C                    =1: history vbls and global and element vbls output
C                        will follow at this time step.
C
      NPO = 0
  110 READ (8,END=130) TIME,TIMED,TIMEYR,DELT,DELTD,DELTYR,AVGITER,
     1   CPUS,CPUHR,RNSTEP,RITERTOT,KBIN
      IF (MHIV .GT. 0) READ (8,END=130) (HVAR(I),I=1,MHIV)
C
      WRITE (9,*)
      WRITE (9,*)
      WRITE (9,*) '** TIME (s,d,y), DELT (s,d,y), IterAvg, CPU (s,hr),'
     1   //' Step No., IterTot, KBIN'
      WRITE (9,*) TIME,TIMED,TIMEYR,DELT,DELTD,DELTYR,AVGITER,
     1   CPUS,CPUHR,RNSTEP,RITERTOT,KBIN
      WRITE (9,*)
      WRITE (9,*) '** History Vbls at Time Step',RNSTEP
      IF (MHIV .LE. 0) THEN
         WRITE (9,*) '    (no element-variable-based history variables)'
      ELSE
         WRITE (9,*) (HVAR(I),I=1,MHIV)
      END IF
C
C     (History vbls only, if KBIN=0)
C
      IF (KBIN .EQ. 1) THEN
C
C        Global vbls (mass balance info at current step) are read next:
C          BBALC   = Brine mass balance error over entire mesh [kg].
C          GBALC   = Gas mass balance error over entire mesh [kg].
C          BBALMX  = Max relative brine mass bal error in any grid block.
C          GBALMX  = Max relative gas mass bal error in any grid block.
C          IBBALMX = I-index of grid block with BBALMX \
C          JBBALMX = J-index of grid block with BBALMX  |  These are
C          KBBALMX = K-index of grid block with BBALMX  |_ saved as
C          IGBALMX = I-index of grid block with GBALMX  |  REAL vbls
C          JGBALMX = J-index of grid block with GBALMX  |
C          KGBALMX = K-index of grid block with GBALMX /
C
         READ (8,END=130) BBALC,GBALC,BBALMX,GBALMX,
```

```
     1       IBBALMX,JBBALMX,KBBALMX,IGBALMX,JGBALMX,KGBALMX
C
         NPO = NPO + 1
         WRITE (9,*)
         WRITE (9,*) '** Mass Balances (Global Vbls) Printout No.',NPO
         WRITE (9,*) BBALC,GBALC,BBALMX,GBALMX
         WRITE (9,*) IBBALMX,JBBALMX,KBBALMX,IGBALMX,JGBALMX,KGBALMX
C
C
C        The Element vbl distributions are read next.
C
         DO 120 L=1,NVAREL
            READ  (8,END=130) (((YY(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
            WRITE (9,*)
            WRITE (9,'(A,I3,3X,A,F10.1)') ' ** Element Vbl: (No., Name,'
     1         //'Time Step No.) =',L,NAMVAREL(L),RNSTEP
            WRITE (9,*) (((YY(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
  120    CONTINUE
      END IF
C
C     Continue to next time step.
C
      GO TO 110
C
  130 CLOSE (8)
      CLOSE (9)
      STOP '** Normal Completion **'
C
      END
```

9.2 ASCII Output (.OUT) File

This file echoes input and provides user-readible output and QA information. It has a "standard" text file format. It starts with QA information, including a time-and-date-of-run stamp, BRAGFLO version number, and revision date. It then echoes the input, but with more information and annotation than found (or allowed) in the input file. Therefore, when problems are encountered with the input, this file should be checked first to be sure that the input was read as intended. Some processed input is then printed out, including information on grid sizes and volumes of each grid block, since this is not necessarily input directly. Then initial conditions are printed, with the amount of information specified by the user. Results specified by the user are printed periodically, at times or frequencies specified by the user. Results at the end of the run are also printed, the amount of information printed being specified by the user. Finally an ending time-and-date stamp is printed. Use of this file is optional when BRAGFLO is run, but is strongly recommended because it always contains an echo of the input, the initial conditions, and results at the end of the run, which makes it useful for debugging input. Additional results are at the discretion of the user and depend on user input. A sample output file is provided in Appendix B.

9.3 Summary (.SUM) File

A limited amount of summary information is written at each time step to the screen (when BRAGFLO is run interactively) or to a log file (when run in background). The same information is written to this summary file so that a detailed time step summary is available later if BRAGFLO is run interactively. This information is often useful for diagnostic purposes when problems occur.

A typical summary output at one time step appears as follows:

```
 1                    3.376E-03  8.043E-08   8.951E-01  6.868E-02
 2                     15 12  1    2 20  1    11 27  1    1 20  1
 3   1146  1.226E+03  1.101E+03  3    3.31   9.96E-03 10 14  1  3.50E+04 19  8  1
 4        -8.44E-05 15 12  1  3.16E-08 11  9  1   8.48E-14  3.21E-18 LU
 5   ** Monitor Block Arrays:  PO, PG, SO, PHI,   PERMGX, CONCFE, CONCBIO, QR(1),
 6                             QOBLOCKI, QOBLOCKJ, QGBLOCKI, QGBLOCKJ
 7      Monitor Block # 1: ( 11, 10,  1)
 8      6.8534030052E+06   6.8534030052E+06   9.9993392867E-01   3.7000000000E-01
 9      3.1650984593E-12   1.3691991909E+02   8.0880900000E+01   0.0000000000E+00
10      1.8074126802E-07   2.3477482289E-09   0.0000000000E+00   2.4378208877E-14
11      Monitor Block # 2: ( 17, 10,  1)
12      6.7853807274E+06   6.7919359916E+06   2.0800797783E-03   1.3559451410E-01
13      5.5888660300E-12   1.3614295550E+02   8.0880900000E+01   7.1966507423E-12
14      0.0000000000E+00   0.0000000000E+00   1.3059617970E-04  -6.8230599392E-05
15      Monitor Block # 3: ( 25, 12,  1)
16      7.3286118606E+06   7.3323394444E+06   1.0000000000E+00   1.7791276293E-02
17      1.8197020000E-19   0.0000000000E+00   0.0000000000E+00   0.0000000000E+00
18     -3.3526725094E-09  -1.5699372612E-09   0.0000000000E+00   0.0000000000E+00
```

Lines 1-2 contain information on how well the variable change or mass balance meets or does not meet the convergence criteria specified in the input. The variables that are written are as follows:

Line 1: `EPSMAX(1), EPSMAX(2), FTOLMAX(1), FTOLMAX(2)`

Line 2: `IEPS(1),JEPS(1),KEPS(1), IEPS(2),JEPS(2),KEPS(2),`
`IFTOL(1),JFTOL(1),KFTOL(1), IFTOL(2),JFTOL(2),KFTOL(2)`

where

$$\mathrm{EPSMAX}(1)=\max\left(\Delta S_g \times 10^{\varepsilon_1}\right),$$

$$\mathrm{EPSMAX}(2)=\max\left(\frac{\Delta P_b}{P_b \varepsilon_2}\right),$$

ΔS_g = change in gas saturation in a grid block since last iteration,

ΔP_b = change in brine pressure in a grid block since last iteration,

P_b = brine pressure at end of current iteration.

$$\text{FTOLMAX(1)} = \begin{cases} \max\left(\dfrac{F_1/T_{3g}}{f_1}\right), & T_{3g} \geq T_{3o} \text{ and } F_1 > f_1, \\ \max\left(\dfrac{F_1}{f_1}\right), & T_{3g} \geq T_{3o} \text{ and } F_1 \leq f_1, \\ 0., & T_{3g} < T_{3o}, \end{cases}$$

$$\text{FTOLMAX(2)} = \begin{cases} \max\left(\dfrac{F_2/T_{3b}}{f_2}\right), & T_{3b} \geq T_{3o} \text{ and } F_2 > f_2, \\ \max\left(\dfrac{F_2}{f_2}\right), & T_{3b} \geq T_{3o} \text{ and } F_2 \leq f_2, \\ 0., & T_{3b} < T_{3o}, \end{cases}$$

F_1 = discretized gas mass balance equation (see p. 38),
F_2 = discretized brine mass balance equation,

and the grid block locations where these occur are, respectively:

```
[ IEPS(1),JEPS(1),KEPS(1)] ,
[ IEPS(2),JEPS(2),KEPS(2)] ,
[ IFTOL(1),JFTOL(1),KFTOL(1)] ,
[ IFTOL(2),JFTOL(2),KFTOL(2)] .
```

T_{3g} and T_{3b} are, respectively, the mass of gas and mass of brine in a grid block in [(kg phase)/(m^3 grid block)]. T_{3o} is a small number, set at 1.0×10^{-15} kg/m^3, intended to prevent division by zero and to de-emphasize minute amounts of phase that may be nothing more than roundoff.

The maxima are taken over the entire grid for the Newton-Raphson iteration just completed.

The convergence limits are specified in the input [Lines 6.10 and 6.14]:

ε_1 = EPSNORM(1)	=	required number of digits of accuracy to the right of the decimal in the change in gas saturation from the last time step.
ε_2 = EPSNORM(2)	=	maximum relative change allowed in brine pressure over a time step.

f_1 = FTOLNORM(1) = maximum allowable residual for the gas mass balance, normalized by the amount of gas present in the grid block.

f_2 = FTOLNORM(2) = maximum allowable residual for the brine mass balance, normalized by the amount of brine present in the grid block.

Thus, `EPSMAX(1)` is the maximum fraction of the total allowable change in the gas saturation. It should have a value less than 1.0 when the solution has converged at each time step if ICONVTEST [Line 6.8] has a value of 1. If ICONVTEST = 0, `EPSMAX(1)` may be greater than 1.0 when the solution has converged. (In this case, at least two of the values on Line 1 above must be less than or equal to 1.0.)

`EPSMAX(2)` is the maximum fraction of the allowable change in the brine pressure over an iteration that was obtained in the time step just completed. It should have a value less than 1.0 if ICONVTEST =1. If ICONVTEST = 0, `EPSMAX(2)` may be greater than 1.0 when the solution has converged (but at least two other values on Line 1 will be less than 1.0).

`FTOLMAX(1)` is the maximum fraction of the allowable normalized residual in the gas mass balance that was obtained in the time step just completed. It should have a value less than 1.0 if ICONVTEST = 1, but may be greater than 1.0 if ICONVTEST = 0.

`FTOLMAX(2)` is the maximum fraction of the allowable normalized residual in the brine mass balance that was obtained in the time step just completed. It should have a value less than 1.0 if ICONVTEST = 1, but may be greater than 1.0 if ICONVTEST = 0.

When convergence is *not* obtained within ITMAX [Line 6.22] iterations, lines 1 and 2 are still printed out, providing valuable information as to the magnitude of the convergence problems and where those problems are occurring.

Lines 3 and 4 include time information and global mass balance results, along with grid block locations where maximum mass balance errors occur:

Line 3: `IPRINT, TIME*SECYR, DELT/DAYSEC, ITER, CPU, DELTASATMAX, IDEPMAX(1), JDEPMAX(1), KDEPMAX(1), DELTAPRESMAX, IDEPMAX(2), JDEPMAX(2), KDEPMAX(2),`

Line 4: `GASBALMAX, IGBALMX, JGBALMX, KGBALMX, BRNBALMAX, IBBALMX, JBBALMX, KBBALMX, GASBALCUM, BRNBALCUM, CHSOLVER.`

where:

`IPRINT`	=	time step number;
`TIME*SECYR`	=	elapsed simulation time since start of run [yr];
`DELT/DAYSEC`	=	time step size [days];
`ITER`	=	number of Newton-Raphson iterations to reach convergence;
`CPU`	=	CPU time to complete this time step [s];
`DELTASATMAX`	=	maximum saturation change since last time step anywhere in the grid;
`IDEPMAX(1)`	=	I-index of grid block where `DELTASATMAX` occurred;
`JDEPMAX(1)`	=	J-index of grid block where `DELTASATMAX` occurred;
`KDEPMAX(1)`	=	K-index of grid block where `DELTASATMAX` occurred;

DELTAPRESMAX	=	maximum brine pressure change since last time step anywhere in the grid [Pa];
IDEPMAX(2)	=	I-index of grid block where DELTAPRESMAX occurred;
JDEPMAX(2)	=	J-index of grid block where DELTAPRESMAX occurred;
KDEPMAX(2)	=	K-index of grid block where DELTAPRESMAX occurred;
GASBALMAX	=	maximum gas mass balance error relative to mass of gas present in a grid block [kg gas (error)/kg gas in grid block];
IGBALMX	=	I-index of grid block where GASBALMAX occurred;
JGBALMX	=	J-index of grid block where GASBALMAX occurred;
KGBALMX	=	K-index of grid block where GASBALMAX occurred;
BRNBALMAX	=	maximum brine mass balance error relative to mass of brine present in a grid block [kg brine (error)/kg brine in grid block];
IBBALMX	=	I-index of grid block where BRNBALMAX occurred;
JBBALMX	=	J-index of grid block where BRNBALMAX occurred;
KBBALMX	=	K-index of grid block where BRNBALMAX occurred;
GASBALCUM	=	sum of gas mass balance errors over all grid blocks for this time step normalized by the mass of gas in the entire mesh [kg gas(error)/kg gas total grid].
BRNBALCUM	=	sum of brine mass balance errors over all grid blocks for this time step, normalized by the mass of brine in the entire mesh [kg brine (error)/kg brine total grid].
CHSOLVER	=	linear equation solver being used [input on Line 6.20].

GASBALMAX and BRNBALMAX are computed as follows:

$$\text{GASBALMAX} = \max(F_1),$$

$$\text{BRNBALMAX} = \max(F_2).$$

These mass balance measures are closely related to FTOLMAX(1) and FTOLMAX(2), respectively, the latter being normalized by $T_{3g}f_1$ or $T_{3b}f_2$ in the denominator.

Lines 5 and 6 indicate which arrays are being monitored (see discussion of Monitor Blocks, Lines 2.17 - 2.22, in Section 7.2.2). In this example, three grid blocks are being monitored; the grid block locations are indicated on lines 7, 11, and 15. For each monitored grid block, the 12 array values being monitored are listed on the three lines that follow the grid block location.

9.4 Restart Output (.ROT) File

This binary file is written, if requested in the input, at specified times during a run. It is always written at the end of a run if the restart write flag has been set in the input. Enough information is saved to enable BRAGFLO to pick up from where it left off. Each batch of information written is referred to as a restart record. It is up to the user to keep track of when each restart record is written so that if a restart run is needed, the point where BRAGFLO is to resume can be indicated by the number of the restart record. Periodic writing of restart records is strongly recommended in calculations that are anticipated to be lengthy as a precaution against computer or power failures or unforeseen input errors that do not go into effect until late in the calculation. A message is

written to the screen and to the summary file (if one is being written) when a restart record is written to assist the user in keeping track of when and how many restart records were written.

10.0 REFERENCES

Aziz, K. and Settari, A., 1979, *Petroleum Reservoir Simulation*, Applied Science Publishers, Essex, England.

Brooks, R.H. and Corey, A.T., 1964, "Hydraulic Properties of Porous Media," Hydrology Paper No. 3. Fort Collins, CO: Colorado State University.

Butcher, B.M., S.W. Webb, and J.W. Berglund. 1995. *System Prioritization Method—Iteration 2. Baseline Position Paper: Disposal Room and Cuttings Models, Volume 2, Appendix F.* March 28, 1995. Albuquerque, NM: Sandia National Laboratories.

Corey, A.T., 1990, *Mechanics of Immiscible Fluids in Porous Media*, Water Resources Publications, Littleton, CO, pg. 98.

Darcy, H. 1856. *Les fontaines publiques de la ville de Dijon.* Dalmont, Paris.

Key, S.,Fewell, M., Vaughn, P., Lord, M. and Labreche, D., 1994. *Background and Basis for the Fluid Flow Model Incorporated in BRAGFLO for Representing Pore Pressure-Induced Alterations in Permeability and Porosity in the Anhydrite Interbeds Above and Below the WIPP Repository Horizon*, SAND94-0381. Albuquerque, NM: Sandia National Laboratories.

Klinkenberg, L.J., 1941, "The Permeability of Porous Media to Liquids and Gases," Drilling and Production Prac., API, pp. 200-213.

Lambert, S. J. 1983. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. SAND82-0461. Albuquerque, NM: Sandia National Laboratories.

Maron, M.J. 1982. *Numerical Analysis: A Practical Approach.* Macmillan Publishing Co., Inc.: New York, New York.

Peaceman, D.W., 1977, *Fundamentals of Numerical Reservoir Simulation*, Elsevier Scientific Publishing Co., Amsterdam.

Stone, C.M. 1995, "Transfer of Porosity and Gas Curves From SANTOS for the Final Porosity Surface," Memorandum to B.M. Butcher, Sandia National Laboratories, Albuquerque, NM. December 19, 1995.

Thomas, G.W., 1982, *Principals of Hydrocarbon Reservoir Simulation*, IHRDC, Publishers, Boston.

Van Genuchten, R., 1978, *Calculating the Unsaturated Hydraulic Conductivity with a New Closed-Form Analytical Model*, Research Report 78-WR-08. Princeton, NJ: Princeton University, Department of Civil Engineering.

Walas, S.M. 1985. *Phase Equilibria in Chemical Engineering*. Butterworth Publishers, Boston, MA, pp. 43-54.

WIPP PA (Performance Assessment) Department, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992-Volume 3: Model Parameters*. SAND92-0700/3, Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992-Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance*. SAND92-0700/5, Albuquerque, NM: Sandia National Laboratories.

11.0 APPENDICES

Appendix A: Sample Input File

```
 **QA**          = PREBRAG QA RECORDS
 PREBRAG         = PROGRAM NAME
 6.00            = PROGRAM VERSION
 01/21/96        = PROGRAM REVISION DATE
 01/24/96        = PROGRAM RUN DATE
 11:16:45        = PROGRAM RUN TIME
 1996 BRAGFLO CASE 2: MEDIAN UNDISTURBED NO MIGRATION VARIANCE PETITION CALCULATION
 FILE FLAGS...ASCII, BINARY, SUMMARY, RESTART OUT, RESTART INPUT
 T T T T F
 MODEL TYPE AND NUMBER OF GRID BLOCKS IN X, Y, AND Z
    2   33   31    1
 TSTART,    TMAX,       MAXSTEPS
  -1.5779E+08   3.1557E+11  10000
 DT_INIT,  DT_MIN,   DT_MAX,   DT_INCR, IAUTODT, TSWITCH
   8.6400E+00   8.6400E-04   1.7280E+09   1.2500E+00  1     1.0000E+00
 TIME-STEP CHANGES: NUMBER OF CHANGES, TIME OF CHANGE, DELT USED
    7
   0.0000E+00   8.6400E+02
   3.1557E+08   8.6400E+02
   7.8892E+08   8.6400E+02
   1.5778E+09   8.6400E+02
   3.1557E+09   8.6400E+02
   6.3114E+09   8.6400E+02
   1.2623E+10   8.6400E+02
 IPRTYPEASC IPRTYPEBIN IPRTYPERST UNITSI UNITSO
    2    0    2      'SI'      'SI'
 ASCII PRINTOUT CONTROLLED BY USER SPECIFIED TIMES
    2
 USER REQUESTED PRINTOUT TIMES
  0.0000E+00   3.1557E+11
 BINARY PRINTOUT CONTROLLED BY STEP INTERVAL, IPRNTBIN
   20
 RESTART PRINTOUT CONTROLLED BY USER SPECIFIED TIMES
    1
 USER REQUESTED RESTART TIMES
  3.1557E+11
 ASCII PRINT FLAGS
  1 1 0 0 0  1 0 0 0 0  0 0 0 0 0  0 0 1 0 0  0 0 0 0 0
  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0  0 1 1 0 0
  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0
  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0
  0 0 0 0 0  0
  0 0
  0 0
  0 0
 BINARY PRINT FLAGS
  1 1 0 0 0  1 0 0 0 1  1 0 0 1 0  0 0 1 0 1  0 0 0 0 0
  0 0 0 0 0  1 1 0 1 1  0 0 0 0 0  0 0 0 1 0  0 1 1 0 0
  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0
  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0  0 0 0 0 0
  0 0 0 0 0  0
  0 0
  0 0
  0 0
 HISTORY VARIABLE OUTPUT
    6
    1   31     NAME=BRINE PRESSURE
  9  8  1   10  8  1   11  8  1   12  8  1   13  8  1   14  8  1
 15  8  1    9  9  1   10  9  1   11  9  1   12  9  1   13  9  1
 14  9  1   15  9  1    9 10  1   10 10  1   11 10  1   12 10  1
 13 10  1   14 10  1   15 10  1   17  8  1   18  8  1   19  8  1
 17  9  1   18  9  1   19  9  1   17 10  1   18 10  1   19 10  1
 12  1  1
   18   30     NAME=GAS SATURATION
  9  8  1   10  8  1   11  8  1   12  8  1   13  8  1   14  8  1
 15  8  1    9  9  1   10  9  1   11  9  1   12  9  1   13  9  1
 14  9  1   15  9  1    9 10  1   10 10  1   11 10  1   12 10  1
 13 10  1   14 10  1   15 10  1   17  8  1   18  8  1   19  8  1
 17  9  1   18  9  1   19  9  1   17 10  1   18 10  1   19 10  1
   31   94     NAME=TIME-AVERAGE INTERBLOCK BRINE FLOW, X-DIRECTION
  3  6  1    3 12  1    3 15  1    3 23  1    3 24  1    3 25  1
  3 26  1    3 27  1    3 28  1    3 29  1    3 30  1    3 31  1
 32  6  1   32 12  1   32 15  1   32 23  1   32 24  1   32 25  1
 32 26  1   32 27  1   32 28  1   32 29  1   32 30  1   32 31  1
  9  6  1    9 12  1    9 15  1   26  6  1   26 12  1   26 15  1
 17  8  1   17  9  1   17 10  1   20  8  1   20  9  1   20 10  1
  9  8  1    9  9  1    9 10  1   16  8  1   16  9  1   16 10  1
 23  6  1   23  7  1   23  8  1   23  9  1   23 10  1   23 11  1
 23 12  1   23 13  1   23 14  1   23 15  1   23 16  1   23 17  1
 23 18  1   23 19  1   23 20  1   23 21  1   23 22  1   23 23  1
 23 24  1   23 25  1   23 26  1   23 27  1   23 28  1   23 29  1
 23 30  1   23 31  1   24  6  1   24  7  1   24  8  1   24  9  1
 24 10  1   24 11  1   24 12  1   24 13  1   24 14  1   24 15  1
 24 16  1   24 17  1   24 18  1   24 19  1   24 20  1   24 21  1
 24 22  1   24 23  1   24 24  1   24 25  1   24 26  1   24 27  1
 24 28  1   24 29  1   24 30  1   24 31  1
   32   46     NAME=TIME-AVERAGE INTERBLOCK BRINE FLOW, Y-DIRECTION
```

```
 9 11  1   10 11  1   11 11  1   12 11  1   13 11  1   14 11  1
15 11  1    9  8  1   10  8  1   11  8  1   12  8  1   13  8  1
14  8  1   15  8  1   17 11  1   18 11  1   19 11  1   17  8  1
18  8  1   19  8  1   23  6  1   23  7  1   23  8  1   23  9  1
23 10  1   23 11  1   23 12  1   23 13  1   23 14  1   23 15  1
23 16  1   23 17  1   23 18  1   23 19  1   23 20  1   23 21  1
23 22  1   23 23  1   23 24  1   23 25  1   23 26  1   23 27  1
23 28  1   23 29  1   23 30  1   23 31  1
   34   94    NAME=TIME-AVERAGE INTERBLOCK GAS FLOW, X-DIRECTION
 3  6  1    3 12  1    3 15  1    3 23  1    3 24  1    3 25  1
 3 26  1    3 27  1    3 28  1    3 29  1    3 30  1    3 31  1
32  6  1   32 12  1   32 15  1   32 23  1   32 24  1   32 25  1
32 26  1   32 27  1   32 28  1   32 29  1   32 30  1   32 31  1
 9  6  1    9 12  1    9 15  1   26  6  1   26 12  1   26 15  1
17  8  1   17  9  1   17 10  1   20  8  1   20  9  1   20 10  1
 9  8  1    9  9  1    9 10  1   16  8  1   16  9  1   16 10  1
23  6  1   23  7  1   23  8  1   23  9  1   23 10  1   23 11  1
23 12  1   23 13  1   23 14  1   23 15  1   23 16  1   23 17  1
23 18  1   23 19  1   23 20  1   23 21  1   23 22  1   23 23  1
23 24  1   23 25  1   23 26  1   23 27  1   23 28  1   23 29  1
23 30  1   23 31  1   24  6  1   24  7  1   24  8  1   24  9  1
24 10  1   24 11  1   24 12  1   24 13  1   24 14  1   24 15  1
24 16  1   24 17  1   24 18  1   24 19  1   24 20  1   24 21  1
24 22  1   24 23  1   24 24  1   24 25  1   24 26  1   24 27  1
24 28  1   24 29  1   24 30  1   24 31  1
   35   46    NAME=TIME-AVERAGE INTERBLOCK GAS FLOW, Y-DIRECTION
 9 11  1   10 11  1   11 11  1   12 11  1   13 11  1   14 11  1
15 11  1    9  8  1   10  8  1   11  8  1   12  8  1   13  8  1
14  8  1   15  8  1   17 11  1   18 11  1   19 11  1   17  8  1
18  8  1   19  8  1   23  6  1   23  7  1   23  8  1   23  9  1
23 10  1   23 11  1   23 12  1   23 13  1   23 14  1   23 15  1
23 16  1   23 17  1   23 18  1   23 19  1   23 20  1   23 21  1
23 22  1   23 23  1   23 24  1   23 25  1   23 26  1   23 27  1
23 28  1   23 29  1   23 30  1   23 31  1
MONITOR PARAMETER VALUES AT GRIDBLOCK(S)
T
NUMBER OF MONITOR BLOCKS
   3
MONITOR BLOCKS (I,J,K)
  12   10    1
  18   10    1
  26   12    1
GRID DATA FLAGS: IDXFLAG, IDYFLAG, IDZFLAG, IDEPTHFLAG
   1    2    1    7
GRID DATA CARDS: GRID BLOCK DX'S
1.500000E+04  5.000000E+03  1.000000E+03  7.500000E+02  5.000000E+02  1.000000E+02
4.000000E+01  1.000000E+01  4.380000E+01  1.000000E+01  2.000000E+00  4.000000E-01
2.000000E+00  1.000000E+01  4.380000E+01  4.000000E+01  1.000000E+02  4.950000E+02
1.000000E+02  8.000000E+01  2.830000E+02  5.000000E+01  1.000000E+01  6.000000E+01
5.000000E+02  1.000000E+01  4.000000E+01  1.000000E+02  5.000000E+02  7.500000E+02
1.000000E+03  5.000000E+03  1.500000E+04
GRID DATA CARDS: GRID BLOCK DY'S
2.728000E+00  4.737200E+01  1.391600E+02  5.000000E+01  1.200000E+01  8.500000E-01
1.380000E+00  1.320800E+00  1.320800E+00  1.320800E+00  2.617600E+00  2.700000E-01
4.610000E+00  4.450000E+00  1.800000E-01  2.390000E+01  5.242000E+01  5.242000E+01
8.588000E+01  8.588000E+01  4.534000E+01  3.728000E+01  3.600000E+01  7.700000E+00
2.480000E+01  8.500000E+00  1.730000E+01  1.060000E+02  4.330000E+01  1.566000E+01
1.000000E-01
GRID DATA CARDS: GRID BLOCK DZ'S
6.131430E+04  2.131430E+04  8.748800E+03  6.561600E+03  3.314300E+03  2.214300E+03
1.834300E+03  1.734300E+03  1.262000E+02  2.880000E+01  4.800000E+00  4.000000E-01
4.800000E+00  2.880000E+01  1.262000E+02  1.000000E+01  1.323000E+02  1.435000E+02
1.416000E+02  1.890000E+01  1.890000E+01  1.890000E+01  9.500000E+00  2.050000E+01
5.310000E+01  1.258900E+03  1.458900E+03  2.018900E+03  3.928000E+03  6.910600E+03
9.214100E+03  2.172690E+04  6.172690E+04
GRID BLOCK ELEVATIONS
 33* 1.293640E+02
 33* 1.544140E+02
  1*-3.441824E+01    1* 1.401058E+02    1* 1.924630E+02    1* 2.077339E+02
  1* 2.186417E+02    1* 2.238774E+02    1* 2.250991E+02    1* 2.255354E+02
  1* 2.260048E+02    1* 2.264743E+02    1* 2.265790E+02    1* 2.266000E+02
  1* 2.266209E+02    1* 2.267256E+02    1* 2.271951E+02    1* 2.279264E+02
  1* 2.291480E+02    1* 2.343401E+02    1* 2.395322E+02    1* 2.411029E+02
  1* 2.442706E+02    1* 2.471764E+02    1* 2.477000E+02    1* 2.483108E+02
  1* 2.531975E+02    1* 2.576478E+02    1* 2.580841E+02    1* 2.593058E+02
  1* 2.645415E+02    1* 2.754493E+02    1* 2.907201E+02    1* 3.430774E+02
  1* 5.176014E+02
  1* 6.014737E+01    1* 2.346714E+02    1* 2.870287E+02    1* 3.022995E+02
  1* 3.132073E+02    1* 3.284430E+02    1* 3.196646E+02    1* 3.201010E+02
  1* 3.205704E+02    1* 3.210399E+02    1* 3.211466E+02    1* 3.211656E+02
  1* 3.211865E+02    1* 3.212912E+02    1* 3.217607E+02    1* 3.224920E+02
  1* 3.237137E+02    1* 3.289057E+02    1* 3.340978E+02    1* 3.356685E+02
  1* 3.388362E+02    1* 3.417420E+02    1* 3.422656E+02    1* 3.428764E+02
  1* 3.477631E+02    1* 3.522134E+02    1* 3.526497E+02    1* 3.538714E+02
  1* 3.591071E+02    1* 3.700149E+02    1* 3.852857E+02    1* 4.376429E+02
  1* 6.121671E+02
  1* 9.064270E+01    1* 2.651668E+02    1* 3.175240E+02    1* 3.327949E+02
  1* 3.437026E+02    1* 3.489384E+02    1* 3.501600E+02    1* 3.505963E+02
  1* 3.510658E+02    1* 3.515353E+02    1* 3.516400E+02    1* 3.516609E+02
  1* 3.516819E+02    1* 3.517866E+02    1* 3.522561E+02    1* 3.529873E+02
  1* 3.542090E+02    1* 3.594011E+02    1* 3.645932E+02    1* 3.661639E+02
  1* 3.693315E+02    1* 3.722373E+02    1* 3.727609E+02    1* 3.733717E+02
  1* 3.782584E+02    1* 3.827088E+02    1* 3.831451E+02    1* 3.843668E+02
  1* 3.896025E+02    1* 4.005103E+02    1* 4.157811E+02    1* 4.681383E+02
  1* 6.426624E+02
```

1* 9.656680E+01	1* 2.710909E+02	1* 3.234481E+02	1* 3.387190E+02
1* 3.496267E+02	1* 3.548625E+02	1* 3.560841E+02	1* 3.565204E+02
1* 3.569899E+02	1* 3.574594E+02	1* 3.575641E+02	1* 3.575851E+02
1* 3.576060E+02	1* 3.577107E+02	1* 3.581802E+02	1* 3.589114E+02
1* 3.601331E+02	1* 3.653252E+02	1* 3.705173E+02	1* 3.720880E+02
1* 3.752556E+02	1* 3.781614E+02	1* 3.786850E+02	1* 3.792958E+02
1* 3.841825E+02	1* 3.886329E+02	1* 3.890692E+02	1* 3.902909E+02
1* 3.955266E+02	1* 4.064343E+02	1* 4.217052E+02	1* 4.740624E+02
1* 6.485865E+02			
1* 9.768167E+01	1* 2.722057E+02	1* 3.245630E+02	1* 3.398338E+02
1* 3.507415E+02	1* 3.559773E+02	1* 3.571989E+02	1* 3.576353E+02
1* 3.581047E+02	1* 3.585742E+02	1* 3.586789E+02	1* 3.586999E+02
1* 3.587208E+02	1* 3.588255E+02	1* 3.592950E+02	1* 3.600263E+02
1* 3.612480E+02	1* 3.664400E+02	1* 3.716321E+02	1* 3.732029E+02
1* 3.763705E+02	1* 3.792763E+02	1* 3.797998E+02	1* 3.804107E+02
1* 3.852974E+02	1* 3.897477E+02	1* 3.901840E+02	1* 3.914057E+02
1* 3.966414E+02	1* 4.075492E+02	1* 4.228200E+02	1* 4.751772E+02
1* 6.497014E+02			
1* 9.903186E+01	1* 2.735559E+02	1* 3.259131E+02	1* 3.411840E+02
1* 3.520918E+02	1* 3.573275E+02	1* 3.585491E+02	1* 3.589854E+02
1* 3.594549E+02	1* 3.599244E+02	1* 3.600291E+02	1* 3.600501E+02
1* 3.600710E+02	1* 3.601757E+02	1* 3.606452E+02	1* 3.613765E+02
1* 3.625981E+02	1* 3.677902E+02	1* 3.729823E+02	1* 3.745530E+02
1* 3.777206E+02	1* 3.806265E+02	1* 3.811501E+02	1* 3.817609E+02
1* 3.866476E+02	1* 3.910979E+02	1* 3.915342E+02	1* 3.927559E+02
1* 3.979916E+02	1* 4.088994E+02	1* 4.241702E+02	1* 4.765274E+02
1* 6.510315E+02			
1* 1.003524E+02	1* 2.748765E+02	1* 3.272337E+02	1* 3.425046E+02
1* 3.534124E+02	1* 3.586481E+02	1* 3.598698E+02	1* 3.603061E+02
1* 3.607755E+02	1* 3.612450E+02	1* 3.613497E+02	1* 3.613707E+02
1* 3.613916E+02	1* 3.614963E+02	1* 3.619658E+02	1* 3.626971E+02
1* 3.639187E+02	1* 3.691108E+02	1* 3.743029E+02	1* 3.758736E+02
1* 3.790413E+02	1* 3.819471E+02	1* 3.824706E+02	1* 3.830815E+02
1* 3.879681E+02	1* 3.924185E+02	1* 3.928548E+02	1* 3.940765E+02
1* 3.993122E+02	1* 4.102200E+02	1* 4.254908E+02	1* 4.778481E+02
1* 6.523721E+02			
1* 1.016731E+02	1* 2.761971E+02	1* 3.285544E+02	1* 3.438252E+02
1* 3.547329E+02	1* 3.599687E+02	1* 3.611903E+02	1* 3.616266E+02
1* 3.620961E+02	1* 3.625656E+02	1* 3.626703E+02	1* 3.626913E+02
1* 3.627122E+02	1* 3.628169E+02	1* 3.632864E+02	1* 3.640177E+02
1* 3.652393E+02	1* 3.704314E+02	1* 3.756235E+02	1* 3.771942E+02
1* 3.803618E+02	1* 3.832677E+02	1* 3.837913E+02	1* 3.844021E+02
1* 3.892888E+02	1* 3.937391E+02	1* 3.941754E+02	1* 3.953971E+02
1* 4.006328E+02	1* 4.115406E+02	1* 4.268114E+02	1* 4.791686E+02
1* 6.536927E+02			
1* 1.036419E+02	1* 2.781660E+02	1* 3.305233E+02	1* 3.457941E+02
1* 3.567019E+02	1* 3.619376E+02	1* 3.631592E+02	1* 3.635956E+02
1* 3.640650E+02	1* 3.645345E+02	1* 3.646392E+02	1* 3.646602E+02
1* 3.646811E+02	1* 3.647858E+02	1* 3.652553E+02	1* 3.659866E+02
1* 3.672083E+02	1* 3.724003E+02	1* 3.775924E+02	1* 3.791631E+02
1* 3.823307E+02	1* 3.852366E+02	1* 3.857602E+02	1* 3.863710E+02
1* 3.912577E+02	1* 3.957080E+02	1* 3.961443E+02	1* 3.973660E+02
1* 4.026017E+02	1* 4.135095E+02	1* 4.287603E+02	1* 4.811375E+02
1* 6.556616E+02			
1* 1.050855E+02	1* 2.796096E+02	1* 3.319668E+02	1* 3.472377E+02
1* 3.581454E+02	1* 3.633812E+02	1* 3.646028E+02	1* 3.650392E+02
1* 3.655086E+02	1* 3.659781E+02	1* 3.660828E+02	1* 3.661038E+02
1* 3.661247E+02	1* 3.662294E+02	1* 3.666989E+02	1* 3.674301E+02
1* 3.686518E+02	1* 3.738439E+02	1* 3.790360E+02	1* 3.806067E+02
1* 3.837743E+02	1* 3.866802E+02	1* 3.872037E+02	1* 3.878146E+02
1* 3.927012E+02	1* 3.971516E+02	1* 3.975879E+02	1* 3.988096E+02
1* 4.040453E+02	1* 4.149531E+02	1* 4.302239E+02	1* 4.825811E+02
1* 6.571052E+02			
1* 1.075252E+02	1* 2.820492E+02	1* 3.344065E+02	1* 3.496773E+02
1* 3.605851E+02	1* 3.658208E+02	1* 3.670424E+02	1* 3.674788E+02
1* 3.679482E+02	1* 3.684177E+02	1* 3.685224E+02	1* 3.685434E+02
1* 3.685643E+02	1* 3.686690E+02	1* 3.691385E+02	1* 3.698698E+02
1* 3.710914E+02	1* 3.762835E+02	1* 3.814756E+02	1* 3.830464E+02
1* 3.862140E+02	1* 3.891198E+02	1* 3.896433E+02	1* 3.902542E+02
1* 3.951409E+02	1* 3.995912E+02	1* 4.000275E+02	1* 4.012492E+02
1* 4.064849E+02	1* 4.173927E+02	1* 4.326635E+02	1* 4.850208E+02
1* 6.595449E+02			
1* 1.120545E+02	1* 2.865786E+02	1* 3.389358E+02	1* 3.542066E+02
1* 3.651144E+02	1* 3.703501E+02	1* 3.715717E+02	1* 3.720081E+02
1* 3.724775E+02	1* 3.729470E+02	1* 3.730517E+02	1* 3.730727E+02
1* 3.730936E+02	1* 3.731983E+02	1* 3.736678E+02	1* 3.743991E+02
1* 3.756208E+02	1* 3.808128E+02	1* 3.860049E+02	1* 3.875757E+02
1* 3.907433E+02	1* 3.936491E+02	1* 3.941727E+02	1* 3.947835E+02
1* 3.996702E+02	1* 4.041205E+02	1* 4.045569E+02	1* 4.057785E+02
1* 4.110142E+02	1* 4.219220E+02	1* 4.371928E+02	1* 4.895500E+02
1* 6.640742E+02			
1* 1.143691E+02	1* 2.888932E+02	1* 3.412504E+02	1* 3.565213E+02
1* 3.674290E+02	1* 3.726647E+02	1* 3.738864E+02	1* 3.743227E+02
1* 3.747922E+02	1* 3.752617E+02	1* 3.753664E+02	1* 3.753873E+02
1* 3.754083E+02	1* 3.755130E+02	1* 3.759825E+02	1* 3.767137E+02
1* 3.779354E+02	1* 3.831275E+02	1* 3.883196E+02	1* 3.898903E+02
1* 3.930579E+02	1* 3.959637E+02	1* 3.964873E+02	1* 3.970981E+02
1* 4.019848E+02	1* 4.064352E+02	1* 4.068715E+02	1* 4.080932E+02
1* 4.133289E+02	1* 4.242366E+02	1* 4.395075E+02	1* 4.918647E+02
1* 6.663888E+02			
1* 1.164073E+02	1* 3.009314E+02	1* 3.532886E+02	1* 3.685594E+02
1* 3.794672E+02	1* 3.847029E+02	1* 3.859246E+02	1* 3.863609E+02
1* 3.868304E+02	1* 3.872998E+02	1* 3.874045E+02	1* 3.874255E+02
1* 3.874464E+02	1* 3.875511E+02	1* 3.880206E+02	1* 3.887519E+02
1* 3.899736E+02	1* 3.951656E+02	1* 4.003578E+02	1* 4.019285E+02

```
  1* 4.050961E+02    1* 4.080019E+02    1* 4.085255E+02    1* 4.091363E+02
  1* 4.140230E+02    1* 4.184733E+02    1* 4.189096E+02    1* 4.201313E+02
  1* 4.253670E+02    1* 4.362748E+02    1* 4.515457E+02    1* 5.039029E+02
  1* 6.784269E+02
  1* 1.645615E+02    1* 3.390855E+02    1* 3.914427E+02    1* 4.067136E+02
  1* 4.176214E+02    1* 4.228571E+02    1* 4.240788E+02    1* 4.245151E+02
  1* 4.249846E+02    1* 4.254540E+02    1* 4.255587E+02    1* 4.255797E+02
  1* 4.256006E+02    1* 4.257054E+02    1* 4.261748E+02    1* 4.269061E+02
  1* 4.281277E+02    1* 4.333199E+02    1* 4.385119E+02    1* 4.400826E+02
  1* 4.432503E+02    1* 4.461561E+02    1* 4.466797E+02    1* 4.472905E+02
  1* 4.521772E+02    1* 4.566275E+02    1* 4.570638E+02    1* 4.582855E+02
  1* 4.635212E+02    1* 4.744290E+02    1* 4.896999E+02    1* 5.420571E+02
  1* 7.165811E+02
  1* 2.169735E+02    1* 3.914976E+02    1* 4.438548E+02    1* 4.591256E+02
  1* 4.700334E+02    1* 4.752691E+02    1* 4.764908E+02    1* 4.769271E+02
  1* 4.773966E+02    1* 4.778661E+02    1* 4.779708E+02    1* 4.779917E+02
  1* 4.780127E+02    1* 4.781174E+02    1* 4.785869E+02    1* 4.793181E+02
  1* 4.805398E+02    1* 4.857319E+02    1* 4.909240E+02    1* 4.924947E+02
  1* 4.956623E+02    1* 4.985681E+02    1* 4.990917E+02    1* 4.997025E+02
  1* 5.045892E+02    1* 5.090396E+02    1* 5.094759E+02    1* 5.106975E+02
  1* 5.159333E+02    1* 5.268410E+02    1* 5.421119E+02    1* 5.944691E+02
  1* 7.689932E+02
  1* 2.861129E+02    1* 4.606370E+02    1* 5.129943E+02    1* 5.282651E+02
  1* 5.391729E+02    1* 5.444086E+02    1* 5.456302E+02    1* 5.460666E+02
  1* 5.465360E+02    1* 5.470055E+02    1* 5.471102E+02    1* 5.471312E+02
  1* 5.471521E+02    1* 5.472568E+02    1* 5.477263E+02    1* 5.484576E+02
  1* 5.496793E+02    1* 5.548713E+02    1* 5.600634E+02    1* 5.616342E+02
  1* 5.648018E+02    1* 5.677076E+02    1* 5.682311E+02    1* 5.688420E+02
  1* 5.737287E+02    1* 5.781790E+02    1* 5.786154E+02    1* 5.798370E+02
  1* 5.850727E+02    1* 5.959805E+02    1* 6.112513E+02    1* 6.636086E+02
  1* 8.381326E+02
  1* 3.719799E+02    1* 5.465040E+02    1* 5.988612E+02    1* 6.141321E+02
  1* 6.250398E+02    1* 6.302755E+02    1* 6.314972E+02    1* 6.319335E+02
  1* 6.324030E+02    1* 6.328724E+02    1* 6.329772E+02    1* 6.329981E+02
  1* 6.330190E+02    1* 6.331238E+02    1* 6.335933E+02    1* 6.343245E+02
  1* 6.355461E+02    1* 6.407383E+02    1* 6.459304E+02    1* 6.475011E+02
  1* 6.506687E+02    1* 6.535745E+02    1* 6.540981E+02    1* 6.547089E+02
  1* 6.595956E+02    1* 6.640460E+02    1* 6.644822E+02    1* 6.657039E+02
  1* 6.709396E+02    1* 6.818474E+02    1* 6.971183E+02    1* 7.494755E+02
  1* 9.239996E+02
  1* 4.375799E+02    1* 6.121040E+02    1* 6.644612E+02    1* 6.797321E+02
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  1* 6.986191E+02    1* 6.987238E+02    1* 6.991933E+02    1* 6.999246E+02
  1* 7.011462E+02    1* 7.063383E+02    1* 7.115304E+02    1* 7.131011E+02
  1* 7.162687E+02    1* 7.191746E+02    1* 7.196981E+02    1* 7.203090E+02
  1* 7.251956E+02    1* 7.296460E+02    1* 7.300823E+02    1* 7.313040E+02
  1* 7.365397E+02    1* 7.474474E+02    1* 7.627183E+02    1* 8.150755E+02
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  1* 4.788837E+02    1* 6.534077E+02    1* 7.057650E+02    1* 7.210358E+02
  1* 7.319436E+02    1* 7.371793E+02    1* 7.384010E+02    1* 7.388373E+02
  1* 7.393068E+02    1* 7.397762E+02    1* 7.398810E+02    1* 7.399019E+02
  1* 7.399228E+02    1* 7.400275E+02    1* 7.404970E+02    1* 7.412283E+02
  1* 7.424500E+02    1* 7.476420E+02    1* 7.528342E+02    1* 7.544048E+02
  1* 7.575725E+02    1* 7.604783E+02    1* 7.610018E+02    1* 7.616127E+02
  1* 7.664994E+02    1* 7.709497E+02    1* 7.713860E+02    1* 7.726077E+02
  1* 7.778434E+02    1* 7.887512E+02    1* 8.040220E+02    1* 8.563793E+02
  1* 1.030903E+03
 33* 7.977001E+02
 33* 8.195501E+02
 33* 8.358001E+02
 33* 8.524501E+02
 33* 8.653501E+02
 33* 9.270001E+02
 33* 1.001650E+03
 33* 1.031130E+03
 33* 1.039010E+03
WELL DATA
 0
DIRICHLET CONDITIONS
T     37
  1  24   1   T   F   8.520000E+05   0.000000E+00
 33  24   1   T   F   8.520000E+05   0.000000E+00
  1  26   1   T   F   9.000000E+05   0.000000E+00
 33  26   1   T   F   9.000000E+05   0.000000E+00
  1  31   1   T   T   1.013250E+05   2.000000E-01
  2  31   1   T   T   1.013250E+05   2.000000E-01
  3  31   1   T   T   1.013250E+05   2.000000E-01
  4  31   1   T   T   1.013250E+05   2.000000E-01
  5  31   1   T   T   1.013250E+05   2.000000E-01
  6  31   1   T   T   1.013250E+05   2.000000E-01
  7  31   1   T   T   1.013250E+05   2.000000E-01
  8  31   1   T   T   1.013250E+05   2.000000E-01
  9  31   1   T   T   1.013250E+05   2.000000E-01
 10  31   1   T   T   1.013250E+05   2.000000E-01
 11  31   1   T   T   1.013250E+05   2.000000E-01
 12  31   1   T   T   1.013250E+05   2.000000E-01
 13  31   1   T   T   1.013250E+05   2.000000E-01
 14  31   1   T   T   1.013250E+05   2.000000E-01
 15  31   1   T   T   1.013250E+05   2.000000E-01
 16  31   1   T   T   1.013250E+05   2.000000E-01
 17  31   1   T   T   1.013250E+05   2.000000E-01
 18  31   1   T   T   1.013250E+05   2.000000E-01
 19  31   1   T   T   1.013250E+05   2.000000E-01
 20  31   1   T   T   1.013250E+05   2.000000E-01
```

```
 21  31   1   T   T   1.013250E+05   2.000000E-01
 22  31   1   T   T   1.013250E+05   2.000000E-01
 23  31   1   T   T   1.013250E+05   8.000000E-01
 24  31   1   T   T   1.013250E+05   2.000000E-01
 25  31   1   T   T   1.013250E+05   2.000000E-01
 26  31   1   T   T   1.013250E+05   2.000000E-01
 27  31   1   T   T   1.013250E+05   2.000000E-01
 28  31   1   T   T   1.013250E+05   2.000000E-01
 29  31   1   T   T   1.013250E+05   2.000000E-01
 30  31   1   T   T   1.013250E+05   2.000000E-01
 31  31   1   T   T   1.013250E+05   2.000000E-01
 32  31   1   T   T   1.013250E+05   2.000000E-01
 33  31   1   T   T   1.013250E+05   2.000000E-01
GRID BLOCK BRINE PRESSURE INITIAL CONDITIONS
  2* 1.550225E+07   29* 1.270000E+07    2* 1.550225E+07
 33* 1.520060E+07
  1* 1.747447E+07    1* 1.537290E+07    1* 1.474243E+07    1* 1.455854E+07
  1* 1.442719E+07    1* 1.436415E+07    1* 1.434944E+07    1* 1.434418E+07
  1* 1.433853E+07    1* 1.433288E+07    1* 1.433161E+07    1* 1.433136E+07
  1* 1.433111E+07    1* 1.432985E+07    1* 1.432420E+07    1* 1.431539E+07
  1* 1.430068E+07    1* 1.423816E+07    1* 1.417564E+07    1* 1.415672E+07
  1* 1.411858E+07    1* 1.408359E+07    1* 1.407728E+07    1* 1.406993E+07
  1* 1.401108E+07    1* 1.395749E+07    1* 1.395224E+07    1* 1.393753E+07
  1* 1.387448E+07    1* 1.374313E+07    1* 1.355925E+07    1* 1.292878E+07
  1* 1.082721E+07
  1* 1.633574E+07    1* 1.423417E+07    1* 1.360370E+07    1* 1.341981E+07
  1* 1.328846E+07    1* 1.322542E+07    1* 1.321071E+07    1* 1.320545E+07
  1* 1.319980E+07    1* 1.319415E+07    1* 1.319289E+07    1* 1.319263E+07
  1* 1.319238E+07    1* 1.319112E+07    1* 1.318547E+07    1* 1.317666E+07
  1* 1.316195E+07    1* 1.309943E+07    1* 1.303691E+07    1* 1.301799E+07
  1* 1.297985E+07    1* 1.294486E+07    1* 1.293855E+07    1* 1.293120E+07
  1* 1.287235E+07    1* 1.281876E+07    1* 1.281351E+07    1* 1.279880E+07
  1* 1.273575E+07    1* 1.260440E+07    1* 1.242052E+07    1* 1.179005E+07
  1* 9.688480E+06
  1* 1.596852E+07    1* 1.386695E+07    1* 1.323648E+07    1* 1.305260E+07
  1* 1.292125E+07    1* 1.285820E+07    1* 1.284349E+07    1* 1.283824E+07
  1* 1.283258E+07    1* 1.282693E+07    1* 1.282567E+07    1* 1.282542E+07
  1* 1.282516E+07    1* 1.282390E+07    1* 1.281825E+07    1* 1.280945E+07
  1* 1.279473E+07    1* 1.273221E+07    1* 1.266969E+07    1* 1.265078E+07
  1* 1.261263E+07    1* 1.257764E+07    1* 1.257134E+07    1* 1.256398E+07
  1* 1.250514E+07    1* 1.245155E+07    1* 1.244629E+07    1* 1.243158E+07
  1* 1.236854E+07    1* 1.223719E+07    1* 1.205330E+07    1* 1.142283E+07
  1* 9.321264E+06
  1* 1.589718E+07    1* 1.379562E+07    1* 1.316515E+07    1* 1.298126E+07
  1* 1.284991E+07    1* 1.278687E+07    1* 1.277215E+07    1* 1.276690E+07
  1* 1.276125E+07    1* 1.275559E+07    1* 1.275433E+07    1* 1.275408E+07
  1* 1.275383E+07    1* 1.275257E+07    1* 1.274691E+07    1* 1.273811E+07
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  1* 1.243380E+07    1* 1.238021E+07    1* 1.237496E+07    1* 1.236025E+07
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  1* 9.249928E+06
  1* 1.588376E+07    1* 1.378219E+07    1* 1.315172E+07    1* 1.296784E+07
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  1* 1.252787E+07    1* 1.249288E+07    1* 1.013250E+05    1* 1.247922E+07
  1* 1.242038E+07    1* 1.236679E+07    1* 1.236153E+07    1* 1.234682E+07
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  1* 9.236503E+06
  1* 1.586750E+07    1* 1.376594E+07    1* 1.313546E+07    1* 1.295158E+07
  1* 1.282023E+07    1* 1.275718E+07    1* 1.274247E+07    1* 1.273722E+07
 17* 1.013250E+05    1* 1.235053E+07    1* 1.234528E+07    1* 1.233056E+07
  1* 1.226752E+07    1* 1.213617E+07    1* 1.195228E+07    1* 1.132181E+07
  1* 9.220245E+06
  1* 1.585160E+07    1* 1.375003E+07    1* 1.311956E+07    1* 1.293567E+07
  1* 1.280433E+07    1* 1.274128E+07    1* 1.272657E+07    1* 1.272132E+07
 17* 1.013250E+05    1* 1.233463E+07    1* 1.232937E+07    1* 1.231466E+07
  1* 1.225161E+07    1* 1.212027E+07    1* 1.193638E+07    1* 1.130591E+07
  1* 9.204342E+06
  1* 1.583570E+07    1* 1.373413E+07    1* 1.310366E+07    1* 1.291977E+07
  1* 1.278843E+07    1* 1.272538E+07    1* 1.271067E+07    1* 1.270541E+07
 17* 1.013250E+05    1* 1.231872E+07    1* 1.231347E+07    1* 1.229876E+07
  1* 1.223571E+07    1* 1.210437E+07    1* 1.192048E+07    1* 1.129001E+07
  1* 9.188461E+06
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  1* 1.266863E+07    1* 1.266737E+07    1* 1.266172E+07    1* 1.265291E+07
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  1* 1.245610E+07    1* 1.242111E+07    1* 1.013250E+05    1* 1.240745E+07
  1* 1.234860E+07    1* 1.229502E+07    1* 1.228976E+07    1* 1.227505E+07
  1* 1.221200E+07    1* 1.208066E+07    1* 1.189677E+07    1* 1.126630E+07
  1* 9.164732E+06
  1* 1.579460E+07    1* 1.369304E+07    1* 1.306257E+07    1* 1.287868E+07
  1* 1.274733E+07    1* 1.268429E+07    1* 1.266957E+07    1* 1.266432E+07
  1* 1.265867E+07    1* 1.265301E+07    1* 1.265175E+07    1* 1.265150E+07
  1* 1.265125E+07    1* 1.264999E+07    1* 1.264433E+07    1* 1.263553E+07
  1* 1.262082E+07    1* 1.255830E+07    1* 1.249577E+07    1* 1.247686E+07
  1* 1.243872E+07    1* 1.240373E+07    1* 1.013250E+05    1* 1.239007E+07
  1* 1.233122E+07    1* 1.227763E+07    1* 1.227238E+07    1* 1.225767E+07
  1* 1.219462E+07    1* 1.206327E+07    1* 1.187938E+07    1* 1.124892E+07
  1* 9.147348E+06
  1* 1.576523E+07    1* 1.366366E+07    1* 1.303319E+07    1* 1.284930E+07
```

1* 1.271796E+07	1* 1.265491E+07	1* 1.264020E+07	1* 1.263494E+07
1* 1.262929E+07	1* 1.262364E+07	1* 1.262238E+07	1* 1.262212E+07
1* 1.262187E+07	1* 1.262061E+07	1* 1.261496E+07	1* 1.260615E+07
1* 1.259144E+07	1* 1.252892E+07	1* 1.246640E+07	1* 1.244748E+07
1* 1.240934E+07	1* 1.237435E+07	1* 1.013250E+05	1* 1.236069E+07
1* 1.230184E+07	1* 1.224825E+07	1* 1.224300E+07	1* 1.222829E+07
1* 1.216524E+07	1* 1.203390E+07	1* 1.185001E+07	1* 1.121954E+07
1* 9.117971E+06			
1* 1.571069E+07	1* 1.360912E+07	1* 1.297865E+07	1* 1.279476E+07
1* 1.266342E+07	1* 1.260037E+07	1* 1.258566E+07	1* 1.258040E+07
1* 1.257475E+07	1* 1.256910E+07	1* 1.256783E+07	1* 1.256758E+07
1* 1.256733E+07	1* 1.256607E+07	1* 1.256042E+07	1* 1.255161E+07
1* 1.253690E+07	1* 1.247438E+07	1* 1.241186E+07	1* 1.239294E+07
1* 1.235480E+07	1* 1.231981E+07	1* 1.013250E+05	1* 1.230615E+07
1* 1.224730E+07	1* 1.219371E+07	1* 1.218846E+07	1* 1.217375E+07
1* 1.211070E+07	1* 1.197936E+07	1* 1.179547E+07	1* 1.116500E+07
1* 9.063431E+06			
1* 1.568281E+07	1* 1.358125E+07	1* 1.295078E+07	1* 1.276689E+07
1* 1.263554E+07	1* 1.257250E+07	1* 1.255778E+07	1* 1.255253E+07
1* 1.254688E+07	1* 1.254122E+07	1* 1.253996E+07	1* 1.253971E+07
1* 1.253946E+07	1* 1.253820E+07	1* 1.253254E+07	1* 1.252374E+07
1* 1.250903E+07	1* 1.244651E+07	1* 1.238398E+07	1* 1.236507E+07
1* 1.232693E+07	1* 1.229194E+07	1* 1.013250E+05	1* 1.227828E+07
1* 1.221943E+07	1* 1.216584E+07	1* 1.216059E+07	1* 1.214588E+07
1* 1.208283E+07	1* 1.195148E+07	1* 1.176759E+07	1* 1.113713E+07
1* 9.035558E+06			
1* 1.553785E+07	1* 1.343629E+07	1* 1.280582E+07	1* 1.262193E+07
1* 1.249058E+07	1* 1.242754E+07	1* 1.241282E+07	1* 1.240757E+07
1* 1.240192E+07	1* 1.239626E+07	1* 1.239500E+07	1* 1.239475E+07
1* 1.239450E+07	1* 1.239324E+07	1* 1.238758E+07	1* 1.237878E+07
1* 1.236407E+07	1* 1.230155E+07	1* 1.223902E+07	1* 1.222011E+07
1* 1.218197E+07	1* 1.214698E+07	1* 1.013250E+05	1* 1.213332E+07
1* 1.207447E+07	1* 1.202088E+07	1* 1.201563E+07	1* 1.200092E+07
1* 1.193787E+07	1* 1.180652E+07	1* 1.162264E+07	1* 1.099217E+07
1* 8.890598E+06			
1* 1.507841E+07	1* 1.297685E+07	1* 1.234638E+07	1* 1.216249E+07
1* 1.203114E+07	1* 1.196809E+07	1* 1.195338E+07	1* 1.194813E+07
1* 1.194248E+07	1* 1.193682E+07	1* 1.193556E+07	1* 1.193531E+07
1* 1.193506E+07	1* 1.193380E+07	1* 1.192814E+07	1* 1.191934E+07
1* 1.190463E+07	1* 1.184210E+07	1* 1.177958E+07	1* 1.176067E+07
1* 1.172253E+07	1* 1.168753E+07	1* 1.013250E+05	1* 1.167388E+07
1* 1.161503E+07	1* 1.156144E+07	1* 1.155619E+07	1* 1.154148E+07
1* 1.147843E+07	1* 1.134708E+07	1* 1.116319E+07	1* 1.053272E+07
1* 8.431157E+06			
1* 1.444728E+07	1* 1.234572E+07	1* 1.171525E+07	1* 1.153136E+07
1* 1.140001E+07	1* 1.133696E+07	1* 1.132225E+07	1* 1.131700E+07
1* 1.131135E+07	1* 1.130569E+07	1* 1.130443E+07	1* 1.130418E+07
1* 1.130393E+07	1* 1.130267E+07	1* 1.129701E+07	1* 1.128821E+07
1* 1.127350E+07	1* 1.121098E+07	1* 1.114845E+07	1* 1.112954E+07
1* 1.109140E+07	1* 1.105641E+07	1* 1.013250E+05	1* 1.104274E+07
1* 1.098390E+07	1* 1.093031E+07	1* 1.092506E+07	1* 1.091035E+07
1* 1.084730E+07	1* 1.071595E+07	1* 1.053206E+07	1* 9.901595E+06
1* 7.800027E+06			
1* 1.361473E+07	1* 1.151316E+07	1* 1.088269E+07	1* 1.069880E+07
1* 1.056745E+07	1* 1.050441E+07	1* 1.048970E+07	1* 1.048444E+07
1* 1.047879E+07	1* 1.047314E+07	1* 1.047188E+07	1* 1.047162E+07
1* 1.047137E+07	1* 1.047011E+07	1* 1.046446E+07	1* 1.045565E+07
1* 1.044094E+07	1* 1.037842E+07	1* 1.031590E+07	1* 1.029698E+07
1* 1.025884E+07	1* 1.022385E+07	1* 1.013250E+05	1* 1.021019E+07
1* 1.015134E+07	1* 1.009775E+07	1* 1.009250E+07	1* 1.007779E+07
1* 1.001474E+07	1* 9.883394E+06	1* 9.699507E+06	1* 9.069037E+06
1* 6.967471E+06			
1* 1.258074E+07	1* 1.047918E+07	1* 9.848706E+06	1* 9.664818E+06
1* 9.533470E+06	1* 9.470423E+06	1* 9.455712E+06	1* 9.450458E+06
1* 9.444806E+06	1* 9.439152E+06	1* 9.437891E+06	1* 9.437639E+06
1* 9.437386E+06	1* 9.436126E+06	1* 9.430472E+06	1* 9.421667E+06
1* 9.406956E+06	1* 9.344434E+06	1* 9.281913E+06	1* 9.262998E+06
1* 9.224856E+06	1* 9.189865E+06	1* 1.013250E+05	1* 9.176204E+06
1* 9.117360E+06	1* 9.063770E+06	1* 9.058516E+06	1* 9.043805E+06
1* 8.980758E+06	1* 8.849410E+06	1* 8.665523E+06	1* 8.035053E+06
1* 5.933486E+06			
1* 1.179081E+07	1* 9.689240E+06	1* 9.058770E+06	1* 8.874882E+06
1* 8.743534E+06	1* 8.680487E+06	1* 8.665777E+06	1* 8.660523E+06
1* 8.654869E+06	1* 8.649216E+06	1* 8.647955E+06	1* 8.647703E+06
1* 8.647450E+06	1* 8.646190E+06	1* 8.640537E+06	1* 8.631731E+06
1* 8.617020E+06	1* 8.554498E+06	1* 8.491977E+06	1* 8.473063E+06
1* 8.434919E+06	1* 8.399928E+06	1* 1.013250E+05	1* 8.386268E+06
1* 8.327424E+06	1* 8.273834E+06	1* 8.268580E+06	1* 8.253869E+06
1* 8.190822E+06	1* 8.059474E+06	1* 7.875587E+06	1* 7.245117E+06
1* 5.143550E+06			
1* 1.129344E+07	1* 9.191873E+06	1* 8.561402E+06	1* 8.377515E+06
1* 8.246167E+06	1* 8.183120E+06	1* 8.168410E+06	1* 8.163155E+06
1* 8.157502E+06	1* 8.151849E+06	1* 8.150588E+06	1* 8.150335E+06
1* 8.150083E+06	1* 8.148823E+06	1* 8.143169E+06	1* 8.134364E+06
1* 8.119653E+06	1* 8.057131E+06	1* 7.994610E+06	1* 7.975695E+06
1* 7.937552E+06	1* 7.902561E+06	1* 1.013250E+05	1* 7.888901E+06
1* 7.830057E+06	1* 7.776467E+06	1* 7.771213E+06	1* 7.756502E+06
1* 7.693455E+06	1* 7.562107E+06	1* 7.378220E+06	1* 6.747750E+06
1* 4.646184E+06			
22* 2.296527E+06	1* 1.013250E+05	10* 2.296527E+06	
22* 8.520000E+05	1* 1.013250E+05	10* 8.520000E+05	
22* 1.837738E+06	1* 1.013250E+05	10* 1.837738E+06	
22* 9.000000E+05	1* 1.013250E+05	10* 9.000000E+05	
22* 1.481906E+06	1* 1.013250E+05	10* 1.481906E+06	
22* 7.395352E+05	1* 1.013250E+05	10* 7.395352E+05	

```
 33* 1.013250E+05
 33* 1.013250E+05
 33* 1.013250E+05
GRID BLOCK BRINE SATURATION INITIAL CONDITIONS
 33* 1.000000E+00
 33* 1.000000E+00
 33* 1.000000E+00
 33* 1.000000E+00
 33* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
  8* 1.000000E+00    7* 6.000000E-04    1* 0.000000E+00    3* 6.000000E-04
  3* 0.000000E+00    1* 8.000000E-01    2* 0.000000E+00    8* 1.000000E+00
  8* 1.000000E+00    7* 6.000000E-04    1* 0.000000E+00    3* 6.000000E-04
  3* 0.000000E+00    1* 8.000000E-01    2* 0.000000E+00    8* 1.000000E+00
  8* 1.000000E+00    7* 6.000000E-04    1* 0.000000E+00    3* 6.000000E-04
  3* 0.000000E+00    1* 8.000000E-01    2* 0.000000E+00    8* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 0.000000E+00   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 1.000000E+00    1* 8.000000E-01   10* 1.000000E+00
 22* 2.000000E-01    1* 8.000000E-01   10* 2.000000E-01
 22* 2.000000E-01    1* 8.000000E-01   10* 2.000000E-01
 22* 2.000000E-01    1* 8.000000E-01   10* 2.000000E-01
GRID BLOCK FE CONCENTRATION INITIAL CONDITIONS
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
  8* 0.000000E+00    7* 1.575201E+02    1* 0.000000E+00    3* 1.575201E+02
 14* 0.000000E+00
  8* 0.000000E+00    7* 1.575201E+02    1* 0.000000E+00    3* 1.575201E+02
 14* 0.000000E+00
  8* 0.000000E+00    7* 1.575201E+02    1* 0.000000E+00    3* 1.575201E+02
 14* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
GRID BLOCK CH2O CONCENTRATION INITIAL CONDITIONS
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
  8* 0.000000E+00    7* 9.244771E+01    1* 0.000000E+00    3* 9.244771E+01
 14* 0.000000E+00
  8* 0.000000E+00    7* 9.244771E+01    1* 0.000000E+00    3* 9.244771E+01
 14* 0.000000E+00
  8* 0.000000E+00    7* 9.244771E+01    1* 0.000000E+00    3* 9.244771E+01
 14* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
 33* 0.000000E+00
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  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
  33* 0.000000E+00
DSATLIM, DPRESLIM, SATLIMIT
  2.0000E-01  -1.0000E+08   1.0000E-03
SATNORM, PRESNORM: NOMINAL CHANGE DEPENDENT VARIABLE
  3.0000E-01   5.0000E+05
MAXIMUM ALLOWABLE VARIABLE CHANGES: DSAT_MAX  DPRES_MAX
  1.0000E+00   1.0000E+07
CONVERGENCE TEST FLAG: 0=OR/1=AND
   1
EPS_SAT, EPS_PRES:  NORMAL CONVERGENCE CRITERIA
  3.0000E+00   1.0000E-02
EPS_SAT, EPS_PRES:  RELAXED CONVERGENCE CRITERIA
  3.0000E+00   1.0000E-02
FTOL_SAT   FTOL_PRES:  NORMAL RESIDUAL' TOLERANCE
  1.0000E-02   1.0000E-02
FTOL_SAT   FTOL_PRES:  RELAXED RESIDUAL' TOLERANCE
  1.0000E-02   1.0000E-02
CAS TRANSPORT TOLERANCES
  1.0000E-05   1.0000E-05   1.0000E-05   1.0000E-05
LINEAR EQUATION SOLVER TYPE
LU
ITMAX, IRESETMAX, IJACINT, LSCALE, P_SCALE, LVARSWITCH
   8   40    1   T     1.0000E+07 F
IUPRPFLAG, IUPMFLAG, DT_REDU, ITRAVZ, IMPRAVE
   9    9   5.0000E-01    1    0
IJACSWITCH, IJACMIN, IJACRESET, IUPRPLOOSE, IUPMPLOOSE
  41    1    5    9    9
DHSAT_REL, DHPRES_REL: REL. CHANGE FOR JACOBIAN ELEMENT CALCS
  1.0000E-08   1.0000E-08
DHSAT_MIN, DHPRES_MIN: MIN. CHANGE ALLOWED FOR JACOBIAN CALCS
  1.0000E-10   1.0000E-02
NUMBER OF TIMES FOR SPECIFYING MATERIAL MAP
8
START TIME FOR MAP 1
-1.5779E+08
MATERIAL TYPE GRID MAP
 2* 10  29* 11   2* 10
33* 10
33*  1
33*  1
33*  1
 8*  3  14*  2   1*  9   2*  2   8*  3
 8*  1  14*  2   1*  9   2*  2   8*  1
 8*  1   7*  6   1*  9   3*  7   1*  9   2*  8   1*  9   2*  8   8*  1
 8*  1   7*  6   1*  9   3*  7   1*  9   2*  8   1*  9   2*  8   8*  1
 8*  1   7*  6   1*  9   3*  7   1*  9   2*  8   1*  9   2*  8   8*  1
 8*  1  14*  2   1*  9   2*  2   8*  1
 8*  4  14*  2   1*  9   2*  2   8*  4
 8*  1  14*  2   1*  9   2*  2   8*  1
 8*  1  14*  2   1*  9   2*  2   8*  1
22*  5   1*  9  10*  5
22*  1   1*  9  10*  1
22*  1   1*  9  10*  1
22*  1   1*  9  10*  1
22*  1   1*  9  10*  1
22*  1   1*  9  10*  1
22*  1   1*  9  10*  1
22*  1   1*  9  10*  1
22* 10   1*  9  10* 10
22* 10   1*  9  10* 10
22* 10   1*  9  10* 10
22* 10   1*  9  10* 10
22* 10   1*  9  10* 10
22* 10   1*  9  10* 10
22* 10   1*  9  10* 10
22* 10   1*  9  10* 10
22* 10   1*  9  10* 10
START TIME FOR MAP 2
0.0000E+00
MATERIAL TYPE GRID MAP
 2* 10  29* 11   2* 10
33* 10
33*  1
33*  1
33*  1
 8*  3  14*  2   1* 27   2*  2   8*  1
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  4  14*  2   1* 27   2*  2   8*  4
 8*  1  14*  2   1* 27   2*  2   8*  1
```

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  8*  1  14*  2   1* 41   2*  2   8*  1
 22*  5   1* 41  10*  5
 22*  1   1* 33  10*  1
 22*  1   1* 28  10*  1
 22*  1   1* 28  10*  1
 22*  1   1* 36  10*  1
 22*  1   1* 36  10*  1
 22*  1   1* 26  10*  1
 22*  1   1* 25  10*  1
 22* 14   1* 24  10* 14
 22* 15   1* 24  10* 15
 22* 16   1* 24  10* 16
 22* 17   1* 24  10* 17
 22* 18   1* 24  10* 18
 22* 19   1* 23  10* 19
 22* 19   1* 23  10* 19
 22* 20   1* 23  10* 20
 22* 20   1* 23  10* 20
START TIME FOR MAP 3
3.1557E+08
MATERIAL TYPE GRID MAP
 2* 10  29* 11   2* 10
33* 10
33*  1
33*  1
33*  1
  8*  3  14*  2   1* 27   2*  2   8*  3
  8*  1  14*  2   1* 27   2*  2   8*  1
  8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
  8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
  8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
  8*  1  14*  2   1* 27   2*  2   8*  1
  8*  4  14*  2   1* 27   2*  2   8*  4
  8*  1  14*  2   1* 27   2*  2   8*  1
  8*  1  14*  2   1* 41   2*  2   8*  1
 22*  5   1* 41  10*  5
 22*  1   1* 34  10*  1
 22*  1   1* 29  10*  1
 22*  1   1* 29  10*  1
 22*  1   1* 36  10*  1
 22*  1   1* 36  10*  1
 22*  1   1* 26  10*  1
 22*  1   1* 25  10*  1
 22* 14   1* 24  10* 14
 22* 15   1* 24  10* 15
 22* 16   1* 24  10* 16
 22* 17   1* 24  10* 17
 22* 18   1* 24  10* 18
 22* 19   1* 23  10* 19
 22* 19   1* 23  10* 19
 22* 20   1* 23  10* 20
 22* 20   1* 23  10* 20
START TIME FOR MAP 4
7.8892E+08
MATERIAL TYPE GRID MAP
 2* 10  29* 11   2* 10
33* 10
33*  1
33*  1
33*  1
  8*  3  14*  2   1* 27   2*  2   8*  3
  8*  1  14*  2   1* 27   2*  2   8*  1
  8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
  8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
  8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
  8*  1  14*  2   1* 27   2*  2   8*  1
  8*  4  14*  2   1* 27   2*  2   8*  4
  8*  1  14*  2   1* 27   2*  2   8*  1
  8*  1  14*  2   1* 41   2*  2   8*  1
 22*  5   1* 41  10*  5
 22*  1   1* 35  10*  1
 22*  1   1* 30  10*  1
 22*  1   1* 30  10*  1
 22*  1   1* 36  10*  1
 22*  1   1* 36  10*  1
 22*  1   1* 26  10*  1
 22*  1   1* 25  10*  1
 22* 14   1* 24  10* 14
 22* 15   1* 24  10* 15
 22* 16   1* 24  10* 16
 22* 17   1* 24  10* 17
 22* 18   1* 24  10* 18
 22* 19   1* 23  10* 19
 22* 19   1* 23  10* 19
 22* 20   1* 23  10* 20
 22* 20   1* 23  10* 20
START TIME FOR MAP 5
1.5578E+09
MATERIAL TYPE GRID MAP
 2* 10  29* 11   2* 10
33* 10
33*  1
33*  1
33*  1
  8*  3  14*  2   1* 27   2*  2   8*  3
```

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 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  4  14*  2   1* 27   2*  2   8*  4
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1  14*  2   1* 41   2*  2   8*  1
22*  5   1* 41  10*  5
22*  1   1* 35  10*  1
22*  1   1* 31  10*  1
22*  1   1* 31  10*  1
22*  1   1* 37  10*  1
22*  1   1* 37  10*  1
22*  1   1* 26  10*  1
22*  1   1* 25  10*  1
22* 14   1* 24  10* 14
22* 15   1* 24  10* 15
22* 16   1* 24  10* 16
22* 17   1* 24  10* 17
22* 18   1* 24  10* 18
22* 19   1* 23  10* 19
22* 19   1* 23  10* 19
22* 20   1* 23  10* 20
22* 20   1* 23  10* 20
START TIME FOR MAP 6
3.1557E+09
MATERIAL TYPE GRID MAP
 2* 10  29* 11   2* 10
33* 10
33*  1
33*  1
33*  1
 8*  3  14*  2   1* 27   2*  2   8*  3
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  4  14*  2   1* 27   2*  2   8*  4
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1  14*  2   1* 41   2*  2   8*  1
22*  5   1* 41  10*  5
22*  1   1* 35  10*  1
22*  1   1* 32  10*  1
22*  1   1* 32  10*  1
22*  1   1* 38  10*  1
22*  1   1* 38  10*  1
22*  1   1* 27  10*  1
22*  1   1* 25  10*  1
22* 14   1* 24  10* 14
22* 15   1* 24  10* 15
22* 16   1* 24  10* 16
22* 17   1* 24  10* 17
22* 18   1* 24  10* 18
22* 19   1* 23  10* 19
22* 19   1* 23  10* 19
22* 20   1* 23  10* 20
22* 20   1* 23  10* 20
START TIME FOR MAP 7
6.3114E+09
MATERIAL TYPE GRID MAP
 2* 10  29* 11   2* 10
33* 10
33*  1
33*  1
33*  1
 8*  3  14*  2   1* 27   2*  2   8*  3
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  4  14*  2   1* 27   2*  2   8*  4
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1  14*  2   1* 41   2*  2   8*  1
22*  5   1* 41  10*  5
22*  1   1* 35  10*  1
22*  1   1* 32  10*  1
22*  1   1* 32  10*  1
22*  1   1* 39  10*  1
22*  1   1* 39  10*  1
22*  1   1* 27  10*  1
22*  1   1* 25  10*  1
22* 14   1* 24  10* 14
22* 15   1* 24  10* 15
22* 16   1* 24  10* 16
22* 17   1* 24  10* 17
22* 18   1* 24  10* 18
22* 19   1* 23  10* 19
22* 19   1* 23  10* 19
22* 20   1* 23  10* 20
22* 20   1* 23  10* 20
START TIME FOR MAP 8
1.2623E+10
```

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MATERIAL TYPE GRID MAP
 2* 10  29* 11   2* 10
33* 10
33*  1
33*  1
33*  1
 8*  3  14*  2   1* 27   2*  2   8*  3
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1   7* 12   1* 42   3* 13   1* 42   2* 21   1* 27   2* 22   8*  1
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  4  14*  2   1* 27   2*  2   8*  4
 8*  1  14*  2   1* 27   2*  2   8*  1
 8*  1  14*  2   1* 41   2*  2   8*  1
22*  5   1* 41  10*  5
22*  1   1* 35  10*  1
22*  1   1* 32  10*  1
22*  1   1* 32  10*  1
22*  1   1* 40  10*  1
22*  1   1* 40  10*  1
22*  1   1* 27  10*  1
22*  1   1* 25  10*  1
22* 14   1* 24  10* 14
22* 15   1* 24  10* 15
22* 16   1* 24  10* 16
22* 17   1* 24  10* 17
22* 18   1* 24  10* 18
22* 19   1* 23  10* 19
22* 19   1* 23  10* 19
22* 20   1* 23  10* 20
22* 20   1* 23  10* 20
 #      NAME
 1      S_HALITE
 2      DRZ_0
 3      S_MB139
 4      S_ANH_AB
 5      S_MB138
 6      CAVITY_1
 7      CAVITY_2
 8      CAVITY_3
 9      CAVITY_4
10      IMPERM_Z
11      CASTILER
12      WAS_AREA
13      REPOSIT
14      UNNAMED
15      CULEBRA
16      TAMARISK
17      MAGENTA
18      FORTYNIN
19      DEWYLAKE
20      SANTAROS
21      BACKFILL
22      EXP_AREA
23      EARTH
24      CLAY
25      ASPHALT
26      CONC_T1
27      CONC_T2
28      CL_M_T1
29      CL_M_T2
30      CL_M_T3
31      CL_M_T4
32      CL_M_T5
33      CL_L_T1
34      CL_L_T2
35      CL_L_T3
36      SALT_T1
37      SALT_T2
38      SALT_T3
39      SALT_T4
40      SALT_T5
41      CLAY_BOT
42      PAN_S_1
NWST
2
MAT_WASTEI   MAT_WASTE
6  7
12 13
NDRZ
0
NMATRESET
4
MATRESET
6  7  8  9
BORE HOLE MATERIAL NUMBER
0
RESET TIME,  ICWASTE
0.0000E+00    1
POWASTEIC
1.013250E+05
1.013250E+05
SOWASTEIC
0.000000E+00
```

0.000000E+00
PRESDRZ

#	LAMBDA	SOR	SGR
1	7.000000E-01	3.000000E-01	2.000000E-01
2	7.000000E-01	0.000000E+00	0.000000E+00
3	7.000000E-01	2.000000E-01	1.650000E-01
4	7.000000E-01	2.000000E-01	1.650000E-01
5	7.000000E-01	2.000000E-01	1.650000E-01
6	7.000000E-01	0.000000E+00	0.000000E+00
7	7.000000E-01	0.000000E+00	0.000000E+00
8	7.000000E-01	0.000000E+00	0.000000E+00
9	7.000000E-01	0.000000E+00	0.000000E+00
10	1.000000E+00	0.000000E+00	0.000000E+00
11	7.000000E-01	2.000000E-01	2.000000E-01
12	7.000000E-01	2.000000E-01	2.000000E-01
13	7.000000E-01	2.000000E-01	2.000000E-01
14	7.000000E-01	2.000000E-01	2.000000E-01
15	7.000000E-01	2.000000E-01	2.000000E-01
16	7.000000E-01	2.000000E-01	2.000000E-01
17	7.000000E-01	2.000000E-01	2.000000E-01
18	7.000000E-01	2.000000E-01	2.000000E-01
19	7.000000E-01	2.000000E-01	2.000000E-01
20	7.000000E-01	2.000000E-01	2.000000E-01
21	7.000000E-01	0.000000E+00	0.000000E+00
22	7.000000E-01	0.000000E+00	0.000000E+00
23	1.700000E+00	2.210000E-01	2.000000E-01
24	1.900000E-01	2.240000E-02	2.240000E-02
25	7.000000E-01	0.000000E+00	0.000000E+00
26	7.000000E-01	2.000000E-01	2.000000E-01
27	7.000000E-01	2.000000E-01	2.000000E-01
28	1.900000E-01	2.240000E-02	2.240000E-02
29	1.900000E-01	2.240000E-02	2.240000E-02
30	1.900000E-01	2.240000E-02	2.240000E-02
31	1.900000E-01	2.240000E-02	2.240000E-02
32	1.900000E-01	2.240000E-02	2.240000E-02
33	1.900000E-01	2.240000E-02	2.240000E-02
34	1.900000E-01	2.240000E-02	2.240000E-02
35	1.900000E-01	2.240000E-02	2.240000E-02
36	7.000000E-01	2.000000E-01	2.000000E-01
37	7.000000E-01	2.000000E-01	2.000000E-01
38	7.000000E-01	2.000000E-01	2.000000E-01
39	7.000000E-01	2.000000E-01	2.000000E-01
40	7.000000E-01	2.000000E-01	2.000000E-01
41	1.900000E-01	2.240000E-02	2.240000E-02
42	7.000000E-01	2.000000E-01	2.000000E-01

#	SBMIN	PBMIN	PCMAX	PCT_A	PCT_EXP	KRP	KPC	KTP
1	3.150000E-01	1.013250E+05	1.000000E+08	9.000000E+06	0.000000E+00	4	2	0
2	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
3	2.100000E-01	1.013250E+05	1.000000E+08	2.630268E-02	-3.460000E-01	4	2	0
4	2.100000E-01	1.013250E+05	1.000000E+08	2.630268E-02	-3.460000E-01	4	2	0
5	2.100000E-01	1.013250E+05	1.000000E+08	2.630268E-02	-3.460000E-01	4	2	0
6	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
7	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
8	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
9	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
10	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
11	2.100000E-01	1.013250E+05	1.000000E+08	5.600000E-01	-3.460000E-01	4	2	0
12	2.100000E-01	1.013250E+05	1.000000E+08	5.600000E-01	-3.460000E-01	4	4	0
13	2.100000E-01	1.013250E+05	1.000000E+08	5.600000E-01	-3.460000E-01	4	4	0
14	2.100000E-01	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
15	2.100000E-01	1.013250E+05	1.000000E+08	5.600000E-01	-3.460000E-01	4	2	0
16	2.100000E-01	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
17	2.100000E-01	1.013250E+05	1.000000E+08	5.600000E-01	-3.460000E-01	4	2	0
18	2.100000E-01	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
19	2.100000E-01	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
20	2.100000E-01	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
21	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
22	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
23	2.320500E-01	1.013250E+05	1.000000E+08	1.422000E+04	0.000000E+00	4	2	0
24	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
25	0.000000E+00	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0
26	2.100000E-01	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
27	2.100000E-01	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
28	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
29	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
30	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
31	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
32	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
33	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
34	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
35	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
36	2.100000E-01	1.013250E+05	1.000000E+08	3.900000E+04	0.000000E+00	4	2	0
37	2.100000E-01	1.013250E+05	1.000000E+08	2.180000E+05	0.000000E+00	4	2	0
38	2.100000E-01	1.013250E+05	1.000000E+08	9.470000E+05	0.000000E+00	4	2	0
39	2.100000E-01	1.013250E+05	1.000000E+08	4.700000E+06	0.000000E+00	4	2	0
40	2.100000E-01	1.013250E+05	1.000000E+08	4.700000E+06	0.000000E+00	4	2	0
41	2.352000E-02	1.013250E+05	1.000000E+08	1.500000E+06	0.000000E+00	4	2	0
42	2.100000E-01	1.013250E+05	1.000000E+08	0.000000E+00	0.000000E+00	4	1	0

#	PERMX	PERMY	PERMZ	POROSITY	COMPRES
1	1.000000E-21	1.000000E-21	1.000000E-21	1.000000E-02	8.054475E-09
2	1.000000E-15	1.000000E-15	1.000000E-15	1.000000E-02	8.279475E-08
3	2.511884E-19	2.511884E-19	2.511884E-19	1.900000E-02	4.120777E-09
4	2.511884E-19	2.511884E-19	2.511884E-19	1.900000E-02	4.120777E-09
5	2.511884E-19	2.511884E-19	2.511884E-19	1.900000E-02	4.120777E-09

```
 6 1.000000E-10 1.000000E-10 1.000000E-10  1.000000E+00  0.000000E+00
 7 1.000000E-10 1.000000E-10 1.000000E-10  1.000000E+00  0.000000E+00
 8 1.000000E-10 1.000000E-10 1.000000E-10  1.000000E+00  0.000000E+00
 9 1.000000E-10 1.000000E-10 1.000000E-10  1.000000E+00  0.000000E+00
10 1.000000E-35 1.000000E-35 1.000000E-35  5.000000E-03  0.000000E+00
11 1.330453E-11 1.330453E-11 1.330453E-11  5.200000E-03  1.923077E-07
12 5.584699E-12 5.584699E-12 5.584699E-12  8.810350E-01  1.203130E-09
13 5.584699E-12 5.584699E-12 5.584699E-12  8.810350E-01  1.203130E-09
14 1.000000E-35 1.000000E-35 1.000000E-35  2.000000E-01  0.000000E+00
15 2.648502E-13 2.648502E-13 2.648502E-13  1.460000E-01  1.417160E-09
16 1.000000E-35 1.000000E-35 1.000000E-35  2.000000E-01  0.000000E+00
17 1.096478E-16 1.096478E-16 1.096478E-16  9.000000E-02  2.199962E-09
18 1.000000E-35 1.000000E-35 1.000000E-35  2.000000E-01  0.000000E+00
19 9.332549E-16 9.332549E-16 9.332549E-16  1.500000E-01  6.666667E-08
20 1.000000E-10 1.000000E-10 1.000000E-10  1.750000E-01  5.714286E-08
21 1.000000E-11 1.000000E-11 1.000000E-11  1.000000E+00  0.000000E+00
22 1.000000E-11 1.000000E-11 1.000000E-11  1.000000E+00  0.000000E+00
23 1.000000E-14 1.000000E-14 1.000000E-14  2.500000E-01  0.000000E+00
24 9.999999E-19 9.999999E-19 9.999999E-19  2.500000E-01  0.000000E+00
25 3.311315E-17 3.311315E-17 3.311315E-17  1.000000E-02  0.000000E+00
26 5.000338E-19 5.000338E-19 5.000338E-19  7.500000E-02  0.000000E+00
27 1.000000E-14 1.000000E-14 1.000000E-14  7.500000E-02  0.000000E+00
28 3.837069E-17 3.837069E-17 3.837069E-17  7.500000E-02  0.000000E+00
29 2.529297E-17 2.529297E-17 2.529297E-17  7.500000E-02  0.000000E+00
30 1.581246E-17 1.581246E-17 1.581246E-17  7.500000E-02  0.000000E+00
31 6.531313E-18 6.531313E-18 6.531313E-18  7.500000E-02  0.000000E+00
32 9.999999E-19 9.999999E-19 9.999999E-19  7.500000E-02  0.000000E+00
33 4.677352E-17 4.677352E-17 4.677352E-17  7.500000E-02  0.000000E+00
34 9.078209E-18 9.078209E-18 9.078209E-18  7.500000E-02  0.000000E+00
35 9.999999E-19 9.999999E-19 9.999999E-19  7.500000E-02  0.000000E+00
36 1.000000E-14 1.000000E-14 1.000000E-14  4.000000E-02  0.000000E+00
37 6.998409E-17 6.998409E-17 6.998409E-17  4.000000E-02  0.000000E+00
38 9.999999E-19 9.999999E-19 9.999999E-19  4.000000E-02  0.000000E+00
39 3.303688E-21 3.303688E-21 3.303688E-21  4.000000E-02  0.000000E+00
40 1.000000E-21 1.000000E-21 1.000000E-21  4.000000E-02  0.000000E+00
41 9.999999E-19 9.999999E-19 9.999999E-19  7.500000E-02  0.000000E+00
42 1.000000E-12 1.000000E-12 1.000000E-12  7.500000E-02  1.333333E-08
FRACTURE MODEL DATA TO FOLLOW :T OR F
T
NFRAC
3
# DELTA_PI     DELTA_PF      FRAC_PHI     FRAC_EXP     IFRX IFRY IFRZ
3 1.800000E+06 2.500000E+06 2.900000E-02 5.320828E+01    1    1    0
4 1.800000E+06 2.500000E+06 2.900000E-02 5.320828E+01    1    1    0
5 1.800000E+06 2.500000E+06 2.900000E-02 5.320828E+01    1    1    0
KLINKENBERG EFFECT TO BE USED? True or False
T
BKLINK         EXPKLINK
 9.80000E-01 -3.30000E-01
REFERENCE TEMPERATURE AND PRESSURE FOR DENSITY CALCULATIONS
 3.00150E+02  1.01325E+05
SALT(WT.%)  DEN_BR  KGSAT  IDGAS   COMPR_BR
2.9600E+01 1.2300E+03    1    0      2.5000E-10
VISC_BR   VISC_GAS
 1.80000E-03  8.92000E-06
GAS DENSITY DATA: =0 COMPUTE; =1 INTERPOLATE
1
GAS MOLE FRACTIONS FOR H2, CO2, CH4, N2, H2S, AND O2
1.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00    1    1
IGASVAR (2= REACTION PATH,  1= USING AVG. STOICH. , 0= USING WELLS)
1
RATE CONSTANTS: CORROSION (RKCOR) AND BIODEGRADATION (RKBIO)
 3.0437E-08   2.6642E-07
HUMIDITY FACTORS: HUMFAC_COR, HUMFAC_BIO
 0.0000E+00   1.0000E-01
SCOR_H2=a,SCOR_H2O=b,SCOR_FE=c: where b*H2O + c*FE=> a*H2 + inert solids
 1.1667E+00   1.6667E+00   1.0000E+00
SBIO_GAS=a,SBIO_H2O=b,SBIO_CH2O=c: where b*H2O + c*CH2O=> a*GAS + inerts
 1.1000E+00   0.0000E+00   1.0000E+00
WICKING SATURATION, HUMID RATE SMOOTHING   ALPHARXN
 5.0000E-01 T   1.0000E+03
CREEP CLOSURE?
 T
NKLOS, KLOSINT (0=MOLES,1=PRESSURE) KLOSAVE (1=REGION AVE,2=CELL)
  1    1    2
CLOSURE PARAMETERS: PRES_LITHO, TIME_OFF PERM_FACTOR, PERM_EXP
4   5.0000E+07   3.1557E+12   5.5847E-12   0.0000E+00
NUMBER OF MATERIAL REGIONS FOR CLOSURE
  2
#  MAT NO.   MODEL 1= WASTE-NOBACKFILL, 2=DRIFT-NOBACKFILL, 3=WASTE-BACKFILL 4=JAN_96:WASTE-NOBACKFILL
1   12          4
2   13          4
WILL RADIONUCLIDE DECAY BE CALCULATED? T or F
F
WILL TRANSPORT BE CALCULATED? T or F
F
WILL RADIOLYSIS BE CALCULATED? T or F
F
BRAGFLO GAS COMPONENT TRANSPORT MODEL
```

Appendix B: Sample Output File

```
*****************************************************************************
** Beginning of BRAGFLO        Version: 4.00          Revised: 01/21/96      **
** Begun on:  01/25/96 at 16:19.05   Run on: LARRY  - ALPHA AXP OpenVMS V6.1 **
*****************************************************************************


        BBBBBB   RRRRRR    AAAAA    GGGGG   FFFFFFF  LL        OOOOO
        BB   BB  RR   RR  AA   AA  GG   GG  FF       LL       OO   OO
        BB   BB  RR   RR  AA   AA  GG       FF       LL       OO   OO
        BBBBBB   RRRRRR   AAAAAAA  GG       FFFFF    LL       OO   OO
        BB   BB  RRRRR    AA   AA  GG  GGG  FF       LL       OO   OO
        BB   BB  RR  RR   AA   AA  GG   GG  FF       LL       OO   OO
        BBBBBB   RR   RR  AA   AA   GGGGG   FF       LLLLLLL   OOOOO


                Written by:    Palmer Vaughn, SNL
                               James D. Schreiber, SAIC

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                               James E. Bean, NMERI
                               Ali A. Shinta, API
                               John Wormeck, Ecodynamics


        ***********************************************************

                                Disclaimer
                                ----------

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        expressed herein do not necessarily state or reflect those
        of the United States Government, any agency thereof or any
        of their contractors or subcontractors.

        ***********************************************************


 **QA**     -- QA info for:
 PREBRAG    -- program name:
 6.00       -- PREBRAG version number:
 01/21/96   -- PREBRAG revision date:
 01/24/96   -- PREBRAG run date:
 11:16:45   -- PREBRAG run time.


Number of file names to follow =   5

*****************************************************************************
Input File Name:
WP$TESTROOT:[BF2.TEST]BF2_NMVP_MED_2.INP;2
*****************************************************************************

*****************************************************************************
ASCII Output File Name:
WP$TESTROOT:[BF2.TEST]BF2_NMVP_MED_2.OUT;1
*****************************************************************************

*****************************************************************************
ASCII Summary File Name:
WP$TESTROOT:[BF2.TEST]BF2_NMVP_MED_2.SUM;1
*****************************************************************************

*****************************************************************************
Binary Output File Name:
WP$TESTROOT:[BF2.TEST]BF2_NMVP_MED_2.BIN;1
*****************************************************************************

*****************************************************************************
Restart Output File Name:
WP$TESTROOT:[BF2.TEST]BF2_NMVP_MED_2.ROT;1
*****************************************************************************


 Simulation title:
 1996 BRAGFLO CASE 2: MEDIAN UNDISTURBED NO MIGRATION VARIANCE PETITION CALCULATION

 Size parameters:   NX,   NY,   NZ
                    33    31     1

 Number of grid blocks = 1023

 Model Type  (MODTYPE) =  2-Dimensional

*****************************************************************************
```

```
Parameters for adjusting DELT:
    Number of times to fix DELT  (NDTFIX) =    7
    TIMEDTFIX = Time for fixing DELT, s
    DTFIX     = DELT to be used when TIMEDTFIX is exceeded, s
       K   TIMEDTFIX(K)      DTFIX(K)
       1   0.000000E+00 8.640000E+02
       2   3.155700E+08 8.640000E+02
       3   7.889200E+08 8.640000E+02
       4   1.577800E+09 8.640000E+02
       5   3.155700E+09 8.640000E+02
       6   6.311400E+09 8.640000E+02
       7   1.262300E+10 8.640000E+02

UNITS used in input:
   SI

UNITS used in output:
   SI
*****************************************************************************************************

Start time of simulation      (START) =-1.57790E+08 s
End time for simulation      (FINISH) = 3.15570E+11 s
Max no. time steps allowed   (MAXITF) = 10000
Initial time step              (DELT) = 8.64000E+00 s
Minimum time step allowed   (DELTMIN) = 8.64000E-04 s
Maximum time step allowed   (DELTMAX) = 1.72800E+09 s
Max fractional increase in time step allowed     (DTIMEMAX) = 1.25000E+00
Flag for auto time step control (0=No,1=Yes)   (ITIMECNTRL) = 1
Switch from relative to absolute change
    in variable for determining time step size   (TSWITCH) = 1.00000E+00
*****************************************************************************************************

ASCII print control type          (IPRTYPEASC) =  2
Binary print control type         (IPRTYPEBIN) =  0
Restart print control type        (IPRTYPERST) =  2

ASCII output at  2 specified times:
    1    0.00000E+00 s
    2    3.15570E+11 s

Binary output timestep interval    (IPRNTBIN) =  20

Restart output at  1 specified times:
    1    3.15570E+11 s
*****************************************************************************************************

 ****  Variable Output Flags  ****
 0 = Do NOT Print to Designated Output File
 1 = DO Print to Designated Output File

  I  ASC  BIN  Variable            Description                                  Units
---  ---  ---  ------------------  -----------                                  -----

  1    1    1  PO                  Brine pressure                               Pa
  2    1    1  PG                  Gas pressure                                 Pa
  3    0    0  POTO                Brine rho*g*potentiometric head              Pa
  4    0    0  POTG                Gas rho*g*potentiometric head                Pa
  5    0    0  PBUB                Brine bubble pressure                        Pa
  6    1    1  PHI                 Porosity                                     dimensionless
  7    0    0  RKO                 Relative permeability to brine               dimensionless
  8    0    0  RKG                 Relative permeability to gas                 dimensionless
  9    0    0  RHOB                Brine density                                kg/m^3
 10    0    1  RHOG                Gas density                                  kg/m^3
 11    0    1  PERMBX              Permeability to brine, x-direction           m^2
 12    0    0  PERMBY              Permeability to brine, y-direction           m^2
 13    0    0  PERMBZ              Permeability to brine, z-direction           m^2
 14    0    1  PERMGX              Permeability to gas, x-direction             m^2
 15    0    0  PERMGY              Permeability to gas, y-direction             m^2
 16    0    0  PERMGZ              Permeability to gas, z-direction             m^2
 17    0    0  SO                  Brine saturation                             fraction void volume
 18    1    1  SG                  Gas saturation                               fraction void volume
 19    0    0  COO                 Brine component of brine phase               mass fr brine phase
 20    0    1  CGO                 Gas component of brine phase                 mass fr brine phase
 21    0    0  QOREFAVE            Time-average well brine flow rate            m^3/s (ref conds)
 22    0    0  QGREFAVE            Time-average well gas flow rate              m^3/s (ref conds)
 23    0    0  QOCUM               Cumulative well brine flow                   fr Orig Brn In Place
 24    0    0  QGCUM               Cumulative well gas flow                     fr Orig Gas In Place
 25    0    0  VODAVEI             Time-avg brine Darcy velocity, x-dir         m/s
 26    0    0  VODAVEJ             Time-avg brine Darcy velocity, y-dir         m/s
 27    0    0  VODAVEK             Time-avg brine Darcy velocity, z-dir         m/s
 28    0    0  VGDAVEI             Time-avg gas Darcy velocity, x-dir           m/s
 29    0    0  VGDAVEJ             Time-avg gas Darcy velocity, y-dir           m/s
 30    0    0  VGDAVEK             Time-avg gas Darcy velocity, z-dir           m/s
 31    0    1  QODAVEI             Time-avg interblock brine flow, x-dir        m^3/s (@ ref conds)
 32    0    1  QODAVEJ             Time-avg interblock brine flow, y-dir        m^3/s (@ ref conds)
 33    0    0  QODAVEK             Time-avg interblock brine flow, z-dir        m^3/s (@ ref conds)
 34    0    1  QGDAVEI             Time-avg interblock gas flow, x-dir          m^3/s (@ ref conds)
 35    0    1  QGDAVEJ             Time-avg interblock gas flow, y-dir          m^3/s (@ ref conds)
 36    0    0  QGDAVEK             Time-avg interblock gas flow, z-dir          m^3/s (@ ref conds)
 37    0    0  BRNBALREL           Relative Brine mass balance                  dimensionless
 38    0    0  GASBALREL           Relative Gas mass balance                    dimensionless
 39    0    0  RXNR(I,J,K,1)       Inundated corrosion rate                     mol/s
 40    0    0  RXNR(I,J,K,2)       Humid corrosion rate                         mol/s
 41    0    0  RXNR(I,J,K,3)       Inundated biodegradation rate                mol/s
 42    0    0  RXNR(I,J,K,4)       Humid biodegradation rate                    mol/s
 43    0    0  QR(I,J,K,1)         H2 generation rate -- simple model           kg/(s*m^3)
 44    0    1  QR(I,J,K,2)         Brine consumption rate -- simple model       kg/(s*m^3)
 45    0    0  QR(I,J,K,3)         Fe consumption rate -- simple model          kg/(s*m^3)
 46    0    0  QR(I,J,K,4)         CH2O consumption rate -- simple model        kg/(s*m^3)
 47    1    1  CONCFE              Fe concentration -- simple model             kg/m^3
 48    1    1  CONCBIO             CH2O concentration -- simple model           kg/m^3
 49    0    0  GENRAT( 1,I,J,K)    H2 generation rate -- reaction path model    kg/(s*m^3)
 50    0    0  GENRAT( 2,I,J,K)    CO2 generation rate -- reaction path model   kg/(s*m^3)
 51    0    0  GENRAT( 3,I,J,K)    CH4 generation rate -- reaction path model   kg/(s*m^3)
 52    0    0  GENRAT( 4,I,J,K)    N2 generation rate -- reaction path model    kg/(s*m^3)
 53    0    0  GENRAT( 5,I,J,K)    H2S generation rate -- reaction path model   kg/(s*m^3)
 54    0    0  GENRAT( 6,I,J,K)    O2 generation rate -- reaction path model    kg/(s*m^3)
```

55	0	0	GENRAT(7,I,J,K)	H2O generation rate -- reaction path model	kg/(s*m^3)
56	0	0	GENRAT(8,I,J,K)	H2SO4 generation rate -- reaction path model	kg/(s*m^3)
57	0	0	GENRAT(9,I,J,K)	HNO3 generation rate -- reaction path model	kg/(s*m^3)
58	0	0	GENRAT(10,I,J,K)	CH2O consumption rate -- reaction path model	kg/(s*m^3)
59	0	0	GENRAT(11,I,J,K)	Fe consumption rate -- reaction path model	kg/(s*m^3)
60	0	0	GENRAT(12,I,J,K)	FeS2_F generation rate -- reaction path model	kg/(s*m^3)
61	0	0	GENRAT(13,I,J,K)	FeS2_O generation rate -- reaction path model	kg/(s*m^3)
62	0	0	GENRAT(14,I,J,K)	FeCO3_F generation rate -- reaction path model	kg/(s*m^3)
63	0	0	GENRAT(15,I,J,K)	FeCO3_O generation rate -- reaction path model	kg/(s*m^3)
64	0	0	GENRAT(16,I,J,K)	Fe(OH)2 generation rate -- reaction path model	kg/(s*m^3)
65	0	0	GENRAT(17,I,J,K)	FeO(OH) generation rate -- reaction path model	kg/(s*m^3)
66	0	0	GENRAT(18,I,J,K)	Fe3O4 generation rate -- reaction path model	kg/(s*m^3)
67	0	0	GENRAT(19,I,J,K)	FeS generation rate -- reaction path model	kg/(s*m^3)
68	0	0	GENRAT(20,I,J,K)	CaO generation rate -- reaction path model	kg/(s*m^3)
69	0	0	GENRAT(21,I,J,K)	Ca(OH)2 generation rate -- reaction path model	kg/(s*m^3)
70	0	0	GENRAT(22,I,J,K)	CaCO3 generation rate -- reaction path model	kg/(s*m^3)
71	0	0	GENRAT(23,I,J,K)	H2 generation rate -- radiolysis	kg/(s*m^3)
72	0	0	CONCRXN(1,I,J,K)	H2 concentration -- reaction path model	kg/m^3
73	0	0	CONCRXN(2,I,J,K)	CO2 concentration -- reaction path model	kg/m^3
74	0	0	CONCRXN(3,I,J,K)	CH4 concentration -- reaction path model	kg/m^3
75	0	0	CONCRXN(4,I,J,K)	N2 concentration -- reaction path model	kg/m^3
76	0	0	CONCRXN(5,I,J,K)	H2S concentration -- reaction path model	kg/m^3
77	0	0	CONCRXN(6,I,J,K)	O2 concentration -- reaction path model	kg/m^3
78	0	0	CONCRXN(7,I,J,K)	H2O concentration -- reaction path model	kg/m^3
79	0	0	CONCRXN(8,I,J,K)	H2SO4 concentration -- reaction path model	kg/m^3
80	0	0	CONCRXN(9,I,J,K)	HNO3 concentration -- reaction path model	kg/m^3
81	0	0	CONCRXN(10,I,J,K)	CH2O concentration -- reaction path model	kg/m^3
82	0	0	CONCRXN(11,I,J,K)	Fe concentration -- reaction path model	kg/m^3
83	0	0	CONCRXN(12,I,J,K)	FeS2_F concentration -- reaction path model	kg/m^3
84	0	0	CONCRXN(13,I,J,K)	FeS2_O concentration -- reaction path model	kg/m^3
85	0	0	CONCRXN(14,I,J,K)	FeCO3_F concentration -- reaction path model	kg/m^3
86	0	0	CONCRXN(15,I,J,K)	FeCO3_O concentration -- reaction path model	kg/m^3
87	0	0	CONCRXN(16,I,J,K)	Fe(OH)2 concentration -- reaction path model	kg/m^3
88	0	0	CONCRXN(17,I,J,K)	FeO(OH) concentration -- reaction path model	kg/m^3
89	0	0	CONCRXN(18,I,J,K)	Fe3O4 concentration -- reaction path model	kg/m^3
90	0	0	CONCRXN(19,I,J,K)	FeS concentration -- reaction path model	kg/m^3
91	0	0	CONCRXN(20,I,J,K)	CaO concentration -- reaction path model	kg/m^3
92	0	0	CONCRXN(21,I,J,K)	Ca(OH)2 concentration -- reaction path model	kg/m^3
93	0	0	CONCRXN(22,I,J,K)	CaCO3 concentration -- reaction path model	kg/m^3
94	0	0	CONCRXN(23,I,J,K)	H2 concentration -- radiolysis	kg/m^3
95	0	0	H2OFLOWIN	Water inflow rate	kg/s
96	0	0	B_MASS_CUM(1)	Total isotope mass from Waste Region 1	kg
97	0	0	B_CONC_CUM(1)	Total isotope conc from Waste Region 1	kg/m^3
98	0	0	S_MASS_CUM(1)	Total solid isotope mass from Waste Region 1	kg
99	0	0	B_MASS_CUM(2)	Total isotope mass from Waste Region 2	kg
100	0	0	B_CONC_CUM(2)	Total isotope conc from Waste Region 2	kg/m^3
101	0	0	S_MASS_CUM(2)	Total solid isotope mass from Waste Region 2	kg
102	0	0	B_MASS(1,1)	Mass of isotope 1 from Waste Region 1	kg
103	0	0	B_MASS(1,2)	Mass of isotope 1 from Waste Region 2	kg
104	0	0	B_CONC(1,1)	Conc of isotope 1 from Waste Region 1	kg/m^3
105	0	0	B_CONC(1,2)	Conc of isotope 1 from Waste Region 2	kg/m^3
106	0	0	S_MASS(1,1)	Solid mass of isotope 1 from Waste Region 1	kg
107	0	0	S_MASS(1,2)	Solid mass of isotope 1 from Waste Region 2	kg

****

Number of variables to be printed as History Variables (NHIV) = 6
NOTE: History variables printed only to Binary output file.

Vbl No.	No. of Grid Blocks	(I,J,K)-Indexes						
1	31	9 8 1	10 8 1	11 8 1	12 8 1	13 8 1	14 8 1	15 8 1
		9 9 1	10 9 1	11 9 1	12 9 1	13 9 1	14 9 1	15 9 1
		10 10 1	11 10 1	12 10 1	13 10 1	14 10 1	15 10 1	17 8 1
		18 8 1	19 8 1	17 9 1	18 9 1	19 9 1	17 10 1	18 10 1
		19 10 1	12 1 1					
18	30	9 8 1	10 8 1	11 8 1	12 8 1	13 8 1	14 8 1	15 8 1
		9 9 1	10 9 1	11 9 1	12 9 1	13 9 1	14 9 1	15 9 1
		9 10 1	10 10 1	11 10 1	12 10 1	13 10 1	14 10 1	15 10 1
		17 8 1	18 8 1	19 8 1	17 9 1	18 9 1	19 9 1	17 10 1
		18 10 1	19 10 1					
31	94	3 6 1	3 12 1	3 15 1	3 23 1	3 24 1	3 25 1	3 26 1
		3 27 1	3 28 1	3 29 1	3 30 1	3 31 1	32 6 1	32 12 1
		32 15 1	32 23 1	32 24 1	32 25 1	32 26 1	32 27 1	32 28 1
		32 29 1	32 30 1	32 31 1	9 6 1	9 12 1	9 15 1	26 6 1
		26 12 1	26 15 1	17 8 1	17 9 1	17 10 1	20 8 1	20 9 1
		20 10 1	9 8 1	9 9 1	9 10 1	16 8 1	16 9 1	16 10 1
		23 6 1	23 7 1	23 8 1	23 9 1	23 10 1	23 11 1	23 12 1
		23 13 1	23 14 1	23 15 1	23 16 1	23 17 1	23 18 1	23 19 1
		23 20 1	23 21 1	23 22 1	23 23 1	23 24 1	23 25 1	23 26 1
		23 27 1	23 28 1	23 29 1	23 30 1	23 31 1	24 6 1	24 7 1
		24 8 1	24 9 1	24 10 1	24 11 1	24 12 1	24 13 1	24 14 1
		24 15 1	24 16 1	24 17 1	24 18 1	24 19 1	24 20 1	24 21 1
		24 22 1	24 23 1	24 24 1	24 25 1	24 26 1	24 27 1	24 28 1
		24 29 1	24 30 1	24 31 1				
32	46	9 11 1	10 11 1	11 11 1	12 11 1	13 11 1	14 11 1	15 11 1
		9 8 1	10 8 1	11 8 1	12 8 1	13 8 1	14 8 1	15 8 1
		17 11 1	18 11 1	19 11 1	17 8 1	18 8 1	19 8 1	23 6 1
		23 7 1	23 8 1	23 9 1	23 10 1	23 11 1	23 12 1	23 13 1
		23 14 1	23 15 1	23 16 1	23 17 1	23 18 1	23 19 1	23 20 1
		23 21 1	23 22 1	23 23 1	23 24 1	23 25 1	23 26 1	23 27 1
		23 28 1	23 29 1	23 30 1	23 31 1			
34	94	3 6 1	3 12 1	3 15 1	3 23 1	3 24 1	3 25 1	3 26 1
		3 27 1	3 28 1	3 29 1	3 30 1	3 31 1	32 6 1	32 12 1
		32 15 1	32 23 1	32 24 1	32 25 1	32 26 1	32 27 1	32 28 1
		32 29 1	32 30 1	32 31 1	9 6 1	9 12 1	9 15 1	26 6 1
		26 12 1	26 15 1	17 8 1	17 9 1	17 10 1	20 8 1	20 9 1
		20 10 1	9 8 1	9 9 1	9 10 1	16 8 1	16 9 1	16 10 1
		23 6 1	23 7 1	23 8 1	23 9 1	23 10 1	23 11 1	23 12 1
		23 13 1	23 14 1	23 15 1	23 16 1	23 17 1	23 18 1	23 19 1
		23 20 1	23 21 1	23 22 1	23 23 1	23 24 1	23 25 1	23 26 1
		23 27 1	23 28 1	23 29 1	23 30 1	23 31 1	24 6 1	24 7 1
		24 8 1	24 9 1	24 10 1	24 11 1	24 12 1	24 13 1	24 14 1
		24 15 1	24 16 1	24 17 1	24 18 1	24 19 1	24 20 1	24 21 1
		24 22 1	24 23 1	24 24 1	24 25 1	24 26 1	24 27 1	24 28 1
		24 29 1	24 30 1	24 31 1				
35	46	9 11 1	10 11 1	11 11 1	12 11 1	13 11 1	14 11 1	15 11 1
		9 8 1	10 8 1	11 8 1	12 8 1	13 8 1	14 8 1	15 8 1
		17 11 1	18 11 1	19 11 1	17 8 1	18 8 1	19 8 1	23 6 1
		23 7 1	23 8 1	23 9 1	23 10 1	23 11 1	23 12 1	23 13 1
		23 14 1	23 15 1	23 16 1	23 17 1	23 18 1	23 19 1	23 20 1
		23 21 1	23 22 1	23 23 1	23 24 1	23 25 1	23 26 1	23 27 1
		23 28 1	23 29 1	23 30 1	23 31 1			

Monitor key parameters (MONITOR): T
Number of Monitor Blocks (NMON) = 3
I-index of grid block 1 to be monitored (IMONITOR) = 12

```
   J-index of grid block 1 to be monitored  (JMONITOR) = 10
   K-index of grid block 1 to be monitored  (KMONITOR) =  1
   I-index of grid block 2 to be monitored  (IMONITOR) = 18
   J-index of grid block 2 to be monitored  (JMONITOR) = 10
   K-index of grid block 2 to be monitored  (KMONITOR) =  1
   I-index of grid block 3 to be monitored  (IMONITOR) = 26
   J-index of grid block 3 to be monitored  (JMONITOR) = 12
   K-index of grid block 3 to be monitored  (KMONITOR) =  1

Geometry Flags -- Specifies how block thicknesses are to be read.
   IDXFLAG    =  1
   IDYFLAG    =  2
   IDZFLAG    =  1
   IDEPTHFLAG =  7

Grid block dimensions in I-direction, m
  1.500000E+04 5.000000E+03 1.000000E+03 7.500000E+02 5.000000E+02
  1.000000E+02 4.000000E+01 1.000000E+01 4.380000E+01 1.000000E+01
  2.000000E+00 4.000000E-01 2.000000E+00 1.000000E+01 4.380000E+01
  4.000000E+01 1.000000E+02 4.950000E+02 1.000000E+02 8.000000E+01
  2.830000E+02 5.000000E+01 1.000000E+01 6.000000E+01 5.000000E+02
  1.000000E+01 4.000000E+01 1.000000E+02 5.000000E+02 7.500000E+02
  1.000000E+03 5.000000E+03 1.500000E+04

Grid block dimensions in J-direction, m
  2.728000E+00 4.737200E+01 1.391600E+02 5.000000E+01 1.100000E+01
  8.500000E-01 1.380000E+00 1.320800E+00 1.320800E+00 1.320800E+00
  2.617600E+00 2.700000E-01 4.620000E+00 4.650000E+00 1.800000E-01
  2.390000E+01 5.242000E+01 5.242000E+01 8.588000E+01 8.588000E+01
  4.534000E+01 3.728000E+01 3.600000E+01 7.700000E+00 2.480000E+01
  8.500000E+00 1.730000E+01 1.060000E+02 4.330000E+01 1.566000E+01
  1.000000E-01

Grid block dimensions in K-direction, m
  6.131430E+04 2.131430E+04 8.748800E+03 6.561600E+03 3.314300E+03
  2.114300E+03 1.834300E+03 1.734300E+03 1.262000E+02 2.880000E+01
  4.800000E+00 4.000000E-01 4.800000E+00 2.880000E+01 1.262000E+02
  1.000000E+01 1.323000E+02 1.435000E+02 1.416000E+02 1.890000E+01
  1.890000E+01 1.890000E+01 9.500000E+00 2.050000E+01 5.310000E+01
  1.258900E+03 1.458900E+03 2.018900E+03 3.928000E+03 6.910600E+03
  9.214100E+03 2.172690E+04 6.172690E+04

Elevations to grid block centers in IJK-direction, m
  1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02
  1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02
  1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02
  1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02
  1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02
  1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02
  1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02 1.293640E+02
  1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02
  1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02
  1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02
  1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02
  1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02
  1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02
  1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02 1.544140E+02
  1.544140E+02-3.441824E+01 1.401058E+02 1.924630E+02 2.077339E+02
  2.186417E+02 2.238774E+02 2.250991E+02 2.255354E+02 2.260048E+02
  2.264743E+02 2.265790E+02 2.266000E+02 2.266209E+02 2.267256E+02
  2.271951E+02 2.279264E+02 2.291480E+02 2.343401E+02 2.395322E+02
  2.411029E+02 2.442706E+02 2.471764E+02 2.477000E+02 2.483108E+02
  2.531975E+02 2.576478E+02 2.580841E+02 2.593058E+02 2.645415E+02
  2.754493E+02 2.907201E+02 3.430774E+02 5.176014E+02 6.014737E+01
  2.346714E+02 2.870287E+02 3.022995E+02 3.132073E+02 3.184430E+02
  3.196646E+02 3.201010E+02 3.205704E+02 3.210399E+02 3.212446E+02
  3.211656E+02 3.211865E+02 3.212912E+02 3.217607E+02 3.224920E+02
  3.237137E+02 3.289057E+02 3.340978E+02 3.356685E+02 3.388362E+02
  3.417420E+02 3.422656E+02 3.428764E+02 3.477631E+02 3.522134E+02
  3.526497E+02 3.538714E+02 3.591071E+02 3.700149E+02 3.852857E+02
  4.376429E+02 6.121671E+02 9.064270E+01 2.651668E+02 3.175240E+02
  3.327949E+02 3.437026E+02 3.489384E+02 3.501600E+02 3.505963E+02
  3.510658E+02 3.515353E+02 3.516400E+02 3.516609E+02 3.516819E+02
  3.517866E+02 3.522561E+02 3.529873E+02 3.542090E+02 3.594011E+02
  3.645932E+02 3.661639E+02 3.693315E+02 3.722373E+02 3.727609E+02
  3.733717E+02 3.782584E+02 3.827088E+02 3.831451E+02 3.843668E+02
  3.896025E+02 4.005103E+02 4.157811E+02 4.681383E+02 6.426624E+02
  9.656680E+01 2.710909E+02 3.234481E+02 3.387190E+02 3.496267E+02
  3.548625E+02 3.560841E+02 3.565204E+02 3.569899E+02 3.574594E+02
  3.575641E+02 3.578851E+02 3.576060E+02 3.577107E+02 3.581802E+02
  3.589114E+02 3.601331E+02 3.653252E+02 3.705173E+02 3.720880E+02
  3.752556E+02 3.781614E+02 3.786850E+02 3.792958E+02 3.841825E+02
  3.886329E+02 3.890692E+02 3.902909E+02 3.955266E+02 4.064343E+02
  4.217052E+02 4.740624E+02 6.485865E+02 9.768167E+01 2.722057E+02
  3.245630E+02 3.398338E+02 3.507415E+02 3.559773E+02 3.571989E+02
  3.576353E+02 3.581047E+02 3.585742E+02 3.586789E+02 3.586999E+02
  3.587208E+02 3.588255E+02 3.592950E+02 3.600263E+02 3.612480E+02
  3.664400E+02 3.716321E+02 3.732029E+02 3.763705E+02 3.792763E+02
  3.797998E+02 3.804107E+02 3.852974E+02 3.897477E+02 3.901840E+02
  3.914057E+02 3.966414E+02 4.075492E+02 4.228200E+02 4.751772E+02
  6.497014E+02 9.903186E+01 2.735559E+02 3.259131E+02 3.411840E+02
  3.520918E+02 3.573275E+02 3.585491E+02 3.589854E+02 3.594549E+02
  3.599244E+02 3.600291E+02 3.600501E+02 3.600710E+02 3.601757E+02
  3.606452E+02 3.613765E+02 3.625981E+02 3.677902E+02 3.729823E+02
  3.745530E+02 3.777206E+02 3.806265E+02 3.811501E+02 3.817609E+02
  3.866476E+02 3.910979E+02 3.915342E+02 3.927559E+02 3.979916E+02
  4.088994E+02 4.241702E+02 4.765274E+02 6.510515E+02 1.003524E+02
  2.748765E+02 3.272337E+02 3.425046E+02 3.534124E+02 3.586481E+02
  3.598698E+02 3.603061E+02 3.607755E+02 3.612450E+02 3.613497E+02
  3.613707E+02 3.613916E+02 3.614963E+02 3.619658E+02 3.626971E+02
  3.639187E+02 3.691108E+02 3.743029E+02 3.758736E+02 3.790413E+02
  3.819471E+02 3.824706E+02 3.830815E+02 3.879681E+02 3.924185E+02
  3.928548E+02 3.940765E+02 3.993122E+02 4.102200E+02 4.254908E+02
  4.778481E+02 6.523721E+02 1.016731E+02 2.761971E+02 3.285544E+02
  3.438252E+02 3.547329E+02 3.599687E+02 3.611903E+02 3.616266E+02
  3.620961E+02 3.625656E+02 3.626703E+02 3.626913E+02 3.627122E+02
  3.628169E+02 3.632864E+02 3.640177E+02 3.652393E+02 3.704314E+02
  3.756235E+02 3.771942E+02 3.803618E+02 3.832677E+02 3.837913E+02
  3.844021E+02 3.892888E+02 3.937391E+02 3.941754E+02 3.953971E+02
  4.006328E+02 4.115406E+02 4.268114E+02 4.791686E+02 6.536927E+02
  1.036419E+02 2.781660E+02 3.305233E+02 3.457941E+02 3.567019E+02
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3.619376E+02	3.631592E+02	3.635956E+02	3.640650E+02	3.645345E+02
3.646392E+02	3.646602E+02	3.646811E+02	3.647858E+02	3.652553E+02
3.659866E+02	3.672083E+02	3.724003E+02	3.775924E+02	3.791631E+02
3.823307E+02	3.852366E+02	3.857602E+02	3.863710E+02	3.912577E+02
3.957080E+02	3.961443E+02	3.973660E+02	4.026017E+02	4.135095E+02
4.287803E+02	4.811375E+02	6.556616E+02	1.050855E+02	2.796096E+02
3.319668E+02	3.472377E+02	3.581454E+02	3.633812E+02	3.646028E+02
3.650392E+02	3.655086E+02	3.659781E+02	3.660828E+02	3.661038E+02
3.661247E+02	3.662294E+02	3.666989E+02	3.674301E+02	3.686518E+02
3.738439E+02	3.790360E+02	3.806067E+02	3.837743E+02	3.866802E+02
3.872037E+02	3.878146E+02	3.927012E+02	3.971516E+02	3.975879E+02
3.988096E+02	4.040453E+02	4.149531E+02	4.302239E+02	4.825811E+02
6.571052E+02	1.075252E+02	2.820492E+02	3.344065E+02	3.496773E+02
3.605851E+02	3.658208E+02	3.670424E+02	3.674788E+02	3.679482E+02
3.684177E+02	3.685224E+02	3.685434E+02	3.685643E+02	3.686690E+02
3.691385E+02	3.698698E+02	3.710914E+02	3.762835E+02	3.814756E+02
3.830464E+02	3.862140E+02	3.891198E+02	3.896433E+02	3.902542E+02
3.951409E+02	3.995912E+02	4.000275E+02	4.012492E+02	4.064849E+02
4.173927E+02	4.326635E+02	4.850208E+02	6.595449E+02	1.120545E+02
2.865786E+02	3.389358E+02	3.542066E+02	3.651144E+02	3.703501E+02
3.715717E+02	3.720081E+02	3.724775E+02	3.729470E+02	3.730517E+02
3.730727E+02	3.730936E+02	3.731983E+02	3.736678E+02	3.743991E+02
3.756208E+02	3.808128E+02	3.860049E+02	3.875757E+02	3.907433E+02
3.936491E+02	3.941727E+02	3.947835E+02	3.996732E+02	4.041205E+02
4.045569E+02	4.057785E+02	4.110142E+02	4.219220E+02	4.371928E+02
4.895500E+02	6.640742E+02	1.143691E+02	2.888932E+02	3.412504E+02
3.565213E+02	3.674290E+02	3.726647E+02	3.738864E+02	3.743227E+02
3.747922E+02	3.752617E+02	3.753664E+02	3.753873E+02	3.754083E+02
3.755130E+02	3.759825E+02	3.767137E+02	3.779354E+02	3.831275E+02
3.883196E+02	3.898903E+02	3.930579E+02	3.959637E+02	3.964873E+02
3.970981E+02	4.019848E+02	4.064352E+02	4.068715E+02	4.080932E+02
4.133289E+02	4.242366E+02	4.395075E+02	4.918647E+02	6.663888E+02
1.264073E+02	3.009314E+02	3.532886E+02	3.685594E+02	3.794672E+02
3.847029E+02	3.859246E+02	3.863609E+02	3.868304E+02	3.872998E+02
3.874045E+02	3.874255E+02	3.874464E+02	3.875511E+02	3.880206E+02
3.887519E+02	3.899736E+02	3.951656E+02	4.003578E+02	4.019285E+02
4.050961E+02	4.080019E+02	4.085255E+02	4.091363E+02	4.140230E+02
4.184733E+02	4.189096E+02	4.201313E+02	4.253670E+02	4.362748E+02
4.518457E+02	5.039029E+02	6.784269E+02	1.645615E+02	3.390855E+02
3.914427E+02	4.067136E+02	4.176214E+02	4.228571E+02	4.240788E+02
4.243151E+02	4.249846E+02	4.254540E+02	4.255587E+02	4.255797E+02
4.256006E+02	4.257054E+02	4.261748E+02	4.269061E+02	4.281277E+02
4.333199E+02	4.385119E+02	4.400826E+02	4.432503E+02	4.461561E+02
4.466797E+02	4.472905E+02	4.523772E+02	4.566275E+02	4.570638E+02
4.582855E+02	4.635212E+02	4.744290E+02	4.896999E+02	5.420571E+02
7.165811E+02	2.169735E+02	3.914976E+02	4.438548E+02	4.591256E+02
4.700334E+02	4.752691E+02	4.764908E+02	4.769271E+02	4.773966E+02
4.778661E+02	4.779708E+02	4.779917E+02	4.780127E+02	4.781174E+02
4.785869E+02	4.793181E+02	4.805398E+02	4.857319E+02	4.909240E+02
4.924947E+02	4.956623E+02	4.985681E+02	4.990917E+02	4.997025E+02
5.045892E+02	5.090396E+02	5.094759E+02	5.106975E+02	5.159333E+02
5.268410E+02	5.421119E+02	5.944691E+02	7.689932E+02	2.861129E+02
4.606370E+02	5.129943E+02	5.282651E+02	5.391729E+02	5.444086E+02
5.456302E+02	5.460666E+02	5.465360E+02	5.470055E+02	5.471102E+02
5.471312E+02	5.471521E+02	5.472568E+02	5.477263E+02	5.484576E+02
5.496793E+02	5.548713E+02	5.600634E+02	5.616342E+02	5.648018E+02
5.677076E+02	5.682311E+02	5.688420E+02	5.737287E+02	5.781790E+02
5.786154E+02	5.798370E+02	5.850727E+02	5.959805E+02	6.112513E+02
6.636086E+02	8.381326E+02	3.719799E+02	5.465040E+02	5.988612E+02
6.141321E+02	6.250398E+02	6.302755E+02	6.314972E+02	6.319335E+02
6.324030E+02	6.328724E+02	6.329772E+02	6.329981E+02	6.330190E+02
6.331238E+02	6.335933E+02	6.343245E+02	6.355461E+02	6.407383E+02
6.459304E+02	6.475011E+02	6.506687E+02	6.535745E+02	6.540981E+02
6.547089E+02	6.595956E+02	6.640460E+02	6.644822E+02	6.657039E+02
6.709396E+02	6.818474E+02	6.971183E+02	7.494755E+02	9.239996E+02
4.375799E+02	6.121040E+02	6.644612E+02	6.797321E+02	6.906398E+02
6.958755E+02	6.970972E+02	6.975335E+02	6.980030E+02	6.984725E+02
6.985772E+02	6.985981E+02	6.986191E+02	6.987238E+02	6.991933E+02
6.999246E+02	7.011462E+02	7.063383E+02	7.115304E+02	7.131011E+02
7.162687E+02	7.191746E+02	7.196981E+02	7.203090E+02	7.251956E+02
7.296460E+02	7.300823E+02	7.313040E+02	7.365397E+02	7.474474E+02
7.627183E+02	8.150755E+02	9.895996E+02	4.788837E+02	6.534077E+02
7.057650E+02	7.210358E+02	7.319436E+02	7.371793E+02	7.384010E+02
7.388373E+02	7.393068E+02	7.397762E+02	7.398810E+02	7.399019E+02
7.399228E+02	7.400275E+02	7.404970E+02	7.412283E+02	7.424500E+02
7.476420E+02	7.528342E+02	7.544048E+02	7.575725E+02	7.604783E+02
7.610018E+02	7.616127E+02	7.664994E+02	7.709497E+02	7.713860E+02
7.726077E+02	7.778434E+02	7.887512E+02	8.040220E+02	8.563793E+02
1.030903E+03	7.977001E+02	7.977001E+02	7.977001E+02	7.977001E+02
7.977001E+02	7.977001E+02	7.977001E+02	7.977001E+02	7.977001E+02
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7.977001E+02	7.977001E+02	7.977001E+02	7.977001E+02	8.195501E+02
8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02
8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02
8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02
8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02
8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02
8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02
8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02	8.195501E+02
8.195501E+02	8.195501E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02	8.358001E+02
8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02
8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02
8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02
8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02
8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02
8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02
8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02
8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02	8.524501E+02
8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02
8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02
8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02
8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02
8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02
8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02	8.653501E+02

```
8.653501E+02 8.653501E+02 8.653501E+02 8.653501E+02 8.653501E+02
8.653501E+02 9.270001E+02 9.270001E+02 9.270001E+02 9.270001E+02
9.270001
```

```
    Maximum number of Newton-Raphson iterations      (ITMAX) =   8
    Maximum number of interval halvings
        if Newton-Raphson encounters errors     (IRESETMAX) =  40
    Interval frequency for updating Jacobian    (IJACINPUT) =   1
    Scaling of matrix to be done before solution   (LSCALE) =   T
    Pressure scaling factor                      (P_SCALE) = 1.000E+07
    Variable switching allowed                  (LVARSWTCH) =   F
    Upstream weighting update frequency for
        relative permeabilities                 (IUPRPFLAG) =   9
    Upstream weighting update frequency for
        mass fractions                          (IUPMFFLAG) =   9
    Timestep reduction factor if error occurs  (DELTFACTOR) = 5.000E-01
    Transmissivity averaging method                 (ITRAVE) =   1
    Mass fraction averaging method                 (IMFRAVE) =   0

Jacobian reevaluation control parameters:
    Number of time step reductions allowed
       before Jacobian starts to be reevaluated
       every IJACMINth iteration    (IJACSWITCH) = 41
    New number of iterations allowed before
       Jacobian is reevaluated          (IJACMIN) =  1
    Number of time steps IJACMIN is in effect
       after violation of IJACSWITCH (IJACRESET) =  5
    Upstream weighting update frequency for
       relative permeabilities while
       IJACMIN is in effect          (IUPRPLOOSE) =  9
    Upstream weighting update frequency for dissolved gas
       while IJACMIN is in effect   (IUPMFLOOSE) =  9

Relative change in variable for Jacobian element derivative calculations (DH):
    DH(1) = 1.000E-08
    DH(2) = 1.000E-08

Minimum variable change allowed for Jacobian element derivative calculations (HMIN):
    HMIN(1) = 1.000E-10
    HMIN(2) = 1.000E-02 Pa

*****************************************************************************************************************************

Number of times to specify material grid (NMATTIMES) =   8
-----------------------------------------------------------------------------------------------------------------------------
Material time number =  1          Starting at time =-1.577900E+08 s
    Layer    1
1    10 10 11 11 12 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 10 10
2    10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
3     1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
4     1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
5     1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
6     3  3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  9  2  2  3  3  3  3  3  3  3  3  3  3
7     1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  9  2  2  1  1  1  1  1  1  1  1  1  1  1
8     1  1  1  1  1  1  1  1  1  6  6  6  6  6  6  6  6  9  7  7  7  9  8  8  9  8  8  1  1  1  1  1  1  1  1  1  1  1
9     1  1  1  1  1  1  1  1  1  6  6  6  6  6  6  6  6  9  7  7  7  9  8  8  9  8  8  1  1  1  1  1  1  1  1  1  1  1
10    1  1  1  1  1  1  1  1  1  6  6  6  6  6  6  6  6  9  7  7  7  9  8  8  9  8  8  1  1  1  1  1  1  1  1  1  1  1
11    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  9  2  2  1  1  1  1  1  1  1  1  1  1  1
12    4  4  4  4  4  4  4  4  4  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  9  2  2  4  4  4  4  4  4  4  4  4  4  4
13    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  9  2  2  1  1  1  1  1  1  1  1  1  1  1
14    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  9  2  2  1  1  1  1  1  1  1  1  1  1  1
15    5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  9  5  5  5  5  5  5  5  5  5  5  5  5  5
16    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  9  1  1  1  1  1  1  1  1  1  1  1  1  1
17    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  9  1  1  1  1  1  1  1  1  1  1  1  1  1
18    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  9  1  1  1  1  1  1  1  1  1  1  1  1  1
19    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  9  1  1  1  1  1  1  1  1  1  1  1  1  1
20    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  9  1  1  1  1  1  1  1  1  1  1  1  1  1
21    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  9  1  1  1  1  1  1  1  1  1  1  1  1  1
22    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  9  1  1  1  1  1  1  1  1  1  1  1  1  1
23   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
24   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
25   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
26   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
27   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
28   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
29   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
30   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
31   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10  9 10 10 10 10 10 10 10 10 10 10 10 10 10
-----------------------------------------------------------------------------------------------------------------------------
Material time number =  2          Starting at time = 0.000000E+00 s
    Layer    1
1    10 10 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 10 10
2    10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
3     1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
4     1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
5     1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
6     3  3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  3  3  3  3  3  3  3  3  3  3  3
7     1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1  1  1  1
8     1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
9     1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
10    1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
11    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1  1  1
12    4  4  4  4  4  4  4  4  4  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  4  4  4  4  4  4  4  4  4  4  4
13    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1  1  1  1
14    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2 41  2  2  1  1  1  1  1  1  1  1  1  1  1
15    5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5 41  5  5  5  5  5  5  5  5  5  5  5  5  5
16    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 33  1  1  1  1  1  1  1  1  1  1  1  1  1
17    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 28  1  1  1  1  1  1  1  1  1  1  1  1  1
18    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 28  1  1  1  1  1  1  1  1  1  1  1  1  1
19    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 36  1  1  1  1  1  1  1  1  1  1  1  1  1
20    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 36  1  1  1  1  1  1  1  1  1  1  1  1  1
21    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 26  1  1  1  1  1  1  1  1  1  1  1  1  1
22    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 25  1  1  1  1  1  1  1  1  1  1  1  1  1
23   14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 24 14 14 14 14 14 14 14 14 14 14 14 14 14
24   15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 24 15 15 15 15 15 15 15 15 15 15 15 15 15
25   16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 24 16 16 16 16 16 16 16 16 16 16 16 16 16
26   17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 24 17 17 17 17 17 17 17 17 17 17 17 17 17
27   18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 24 18 18 18 18 18 18 18 18 18 18 18 18 18
28   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 23 19 19 19 19 19 19 19 19 19 19 19 19 19
29   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 23 19 19 19 19 19 19 19 19 19 19 19 19 19
30   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 23 20 20 20 20 20 20 20 20 20 20 20 20 20
31   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 23 20 20 20 20 20 20 20 20 20 20 20 20 20
-----------------------------------------------------------------------------------------------------------------------------
Material time number =  3          Starting at time = 3.155700E+08 s
```

```
    Layer    1
 1   10 10 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 10 10
 2   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 3    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 4    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 5    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 6    3  3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  3  3
 7    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1
 8    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1  1
 9    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1  1
10    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1  1
11    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1
12    4  4  4  4  4  4  4  4  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  4  4  4  4
13    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1  1  1
14    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1  1  1
15    5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
16    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
17    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
18    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
19    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
20    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
21    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
22    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
23   14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14
24   15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15
25   16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
26   17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17
27   18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
28   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19
29   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19
30   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
31   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
-----------------------------------------------------------------------------------------------------------------------
Material time number =  4          Starting at time = 7.889200E+08 s
    Layer    1
 1   10 10 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 10 10
 2   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 3    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 4    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 5    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 6    3  3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  3  3
 7    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1
 8    1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
 9    1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
10    1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
11    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1
12    4  4  4  4  4  4  4  4  4  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  4  4  4  4
13    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1  1  1
14    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1  1  1
15    5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
16    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
17    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
18    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
19    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
20    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
21    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
22    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
23   14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14
24   15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15
25   16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
26   17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17
27   18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
28   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19
29   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19
30   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
31   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
-----------------------------------------------------------------------------------------------------------------------
Material time number =  5          Starting at time = 1.557800E+09 s
    Layer    1
 1   10 10 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 10 10
 2   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 3    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 4    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 5    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 6    3  3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  3  3
 7    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1
 8    1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
 9    1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
10    1  1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1  1  1
11    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1
12    4  4  4  4  4  4  4  4  4  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  4  4  4  4
13    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1  1  1
14    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1  1  1
15    5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5
16    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
17    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
18    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
19    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
20    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
21    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
22    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
23   14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14
24   15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15
25   16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16
26   17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17
27   18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18
28   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19
29   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19
30   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
31   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
-----------------------------------------------------------------------------------------------------------------------
Material time number =  6          Starting at time = 3.155700E+09 s
    Layer    1
 1   10 10 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 10 10
 2   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 3    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 4    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 5    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 6    3  3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  3  3
 7    1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1
```

```
 8    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
 9    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
10    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
11    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1
12    4  4  4  4  4  4  4  4  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  4  4  4  4  4  4  4  4
13    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1
14    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 41  2  2  1  1  1  1  1  1  1  1
15    5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5 41  5  5  5  5  5  5  5  5  5  5
16    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 35  1  1  1  1  1  1  1  1  1  1
17    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 32  1  1  1  1  1  1  1  1  1  1
18    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 32  1  1  1  1  1  1  1  1  1  1
19    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 38  1  1  1  1  1  1  1  1  1  1
20    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 38  1  1  1  1  1  1  1  1  1  1
21    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 27  1  1  1  1  1  1  1  1  1  1
22    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 25  1  1  1  1  1  1  1  1  1  1
23   14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 24 14 14 14 14 14 14 14 14 14 14
24   15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 24 15 15 15 15 15 15 15 15 15 15
25   16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 24 16 16 16 16 16 16 16 16 16 16
26   17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 24 17 17 17 17 17 17 17 17 17 17
27   18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 24 18 18 18 18 18 18 18 18 18 18
28   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 23 19 19 19 19 19 19 19 19 19 19
29   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 23 19 19 19 19 19 19 19 19 19 19
30   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 23 20 20 20 20 20 20 20 20 20 20
31   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 23 20 20 20 20 20 20 20 20 20 20
-----------------------------------------------------------------------------------------------------------
Material time number =  7          Starting at time = 6.311400E-09 s
   Layer    1
 1   10 10 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 10 10
 2   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 3    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 4    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 5    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 6    3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  3  3  3  3  3  3  3  3
 7    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1
 8    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
 9    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
10    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
11    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1
12    4  4  4  4  4  4  4  4  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  4  4  4  4  4  4  4  4
13    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1
14    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 41  2  2  1  1  1  1  1  1  1  1
15    5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5 41  5  5  5  5  5  5  5  5  5  5
16    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 35  1  1  1  1  1  1  1  1  1  1
17    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 32  1  1  1  1  1  1  1  1  1  1
18    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 32  1  1  1  1  1  1  1  1  1  1
19    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 38  1  1  1  1  1  1  1  1  1  1
20    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 38  1  1  1  1  1  1  1  1  1  1
21    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 27  1  1  1  1  1  1  1  1  1  1
22    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 25  1  1  1  1  1  1  1  1  1  1
23   14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 24 14 14 14 14 14 14 14 14 14 14
24   15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 24 15 15 15 15 15 15 15 15 15 15
25   16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 24 16 16 16 16 16 16 16 16 16 16
26   17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 24 17 17 17 17 17 17 17 17 17 17
27   18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 24 18 18 18 18 18 18 18 18 18 18
28   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 23 19 19 19 19 19 19 19 19 19 19
29   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 23 19 19 19 19 19 19 19 19 19 19
30   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 23 20 20 20 20 20 20 20 20 20 20
31   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 23 20 20 20 20 20 20 20 20 20 20
-----------------------------------------------------------------------------------------------------------
Material time number =  8          Starting at time = 1.262300E+10 s
   Layer    1
 1   10 10 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 10 10
 2   10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
 3    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 4    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 5    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 6    3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  3  3  3  3  3  3  3  3
 7    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1
 8    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
 9    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
10    1  1  1  1  1  1  1  1 12 12 12 12 12 12 12 42 13 13 13 42 21 21 27 22 22  1  1  1  1  1  1  1  1
11    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1
12    4  4  4  4  4  4  4  4  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  4  4  4  4  4  4  4  4
13    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 27  2  2  1  1  1  1  1  1  1  1
14    1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2 41  2  2  1  1  1  1  1  1  1  1
15    5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5  5 41  5  5  5  5  5  5  5  5  5  5
16    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 35  1  1  1  1  1  1  1  1  1  1
17    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 32  1  1  1  1  1  1  1  1  1  1
18    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 32  1  1  1  1  1  1  1  1  1  1
19    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 40  1  1  1  1  1  1  1  1  1  1
20    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 40  1  1  1  1  1  1  1  1  1  1
21    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 27  1  1  1  1  1  1  1  1  1  1
22    1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 25  1  1  1  1  1  1  1  1  1  1
23   14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 14 24 14 14 14 14 14 14 14 14 14 14
24   15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 24 15 15 15 15 15 15 15 15 15 15
25   16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 16 24 16 16 16 16 16 16 16 16 16 16
26   17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 24 17 17 17 17 17 17 17 17 17 17
27   18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 18 24 18 18 18 18 18 18 18 18 18 18
28   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 23 19 19 19 19 19 19 19 19 19 19
29   19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 23 19 19 19 19 19 19 19 19 19 19
30   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 23 20 20 20 20 20 20 20 20 20 20
31   20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 23 20 20 20 20 20 20 20 20 20 20

Material type number and name of material:
      1     S_HALITE
      2     DRZ_0
      3     S_MB139
      4     S_ANH_AB
      5     S_MB138
      6     CAVITY_1
      7     CAVITY_2
      8     CAVITY_3
      9     CAVITY_4
     10     IMPERM_Z
     11     CASTILER
     12     WAS_AREA
     13     REPOSIT
     14     UNNAMED
     15     CULEBRA
     16     TAMARISK
```

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    17      MAGENTA
    18      FORTYNIN
    19      DEWYLAKE
    20      SANTAROS
    21      BACKFILL
    22      EXP_AREA
    23      EARTH
    24      CLAY
    25      ASPHALT
    26      CONC_T1
    27      CONC_T2
    28      CL_M_T1
    29      CL_M_T2
    30      CL_M_T3
    31      CL_M_T4
    32      CL_M_T5
    33      CL_L_T1
    34      CL_L_T2
    35      CL_L_T3
    36      SALT_T1
    37      SALT_T2
    38      SALT_T3
    39      SALT_T4
    40      SALT_T5
    41      CLAY_BOT
    42      PAN_S_1

Special material index numbers:
    Number of waste regions                (NWST) =  2
    Initial waste matl index nos. (MAT_WASTEI) =  6  7

    Final waste matl index numbers (MAT_WASTE) = 12 13

    Number of MAT_DRZ regions              (NDRZ) =  0
    Material type index for DRZ before
        IC's are reset                 (MAT_DRZ) =

    Material type index for DRZ after
        IC's are reset             (MAT_DRZNEW) =

    Number of material regions
        where IC's will be reset   (NMATRESET) =  4
    Material type indexes of material regions
        where IC's will be reset     (MATRESET) =  6  7  8  9

    Borehole matl index number (MAT_BOREHOLE)  =  0

Initial Conditions reset parameters:
    Time when IC's are reset           (TIMEICRESET) =  0.00000E+00 s
    Startup Initial Conditions will be used
        instead of Input IC's for the Waste
        [0=No, 1=Yes]                        (ICWASTE) =  1

        Uniform Waste Region  1 Startup Pressure   (POWASTEIC) =  1.01325E+05 Pa
        Uniform Waste Region  2 Startup Pressure   (POWASTEIC) =  1.01325E+05 Pa
        Uniform Waste Region  1 Startup Brine Satn (SOWASTEIC) =  0.00000E+00
        Uniform Waste Region  2 Startup Brine Satn (SOWASTEIC) =  0.00000E+00

-----------------------------------------------------------------------------------------------------------------------
Material properties:
    XLAMDA      = Brooks-Corey parameter "lambda,"
                  for calculating relative permeability
    SBR         = Residual brine saturation
    SGR         = Residual gas saturation
    XKX         = X-direction permeability, m^2
    YKY         = Y-direction permeability, m^2
    ZKZ         = Z-direction permeability, m^2
    PORROCKMAT  = Rock porosity
    CROCK       = Rock compressibility, 1/Pa
    SBMIN       = Min brine satn at which Pc will be
                  computed using char curve params
    POMIN       = Min brine pressure used to adjust cap
                  pressure when variable model used, Pa
    PCMAX       = Max Pc that can be used, Pa
    PCTA        = Constant in threshold cap press (PCT) correlation, Pa
    PCTEXP      = Exponent in PCT correlation:
                    PCT = PCTA*PERMBX**PCTEXP
    KRP         = Relative permeability model number
    KPC         = Capillary pressure model number
    KPT         = Threshold capillary pressure (PCT) flag:
                  0 = PCT constant
                  1 = PCT function of dynamic permeability
-----------------------------------------------------------------------------------------------------------------------

 I  XLAMDA     SBR       SGR       XKX       YKY       ZKZ   PORREFROCK CROCK     SBMIN     POMIN     PCMAX     PCTA      PCTEXP    KRP KPC KPT
-----------------------------------------------------------------------------------------------------------------------
 1 7.00E-01 3.00E-01 2.00E-01 1.00E-21 1.00E-21 1.00E-21 1.00E-02 8.05E-09 3.15E-01 1.01E+05 1.00E+08 9.00E+06 0.00E+00   4   2   0
 2 7.00E-01 0.00E+00 0.00E+00 1.00E-15 1.00E-15 1.00E-15 1.00E-02 8.28E-08 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
 3 7.00E-01 2.00E-01 1.65E-01 2.51E-19 2.51E-19 2.51E-19 1.90E-02 4.12E-09 2.10E-01 1.01E+05 1.00E+08 2.63E-02-3.46E-01   4   2   0
 4 7.00E-01 2.00E-01 1.65E-01 2.51E-19 2.51E-19 2.51E-19 1.90E-02 4.12E-09 2.10E-01 1.01E+05 1.00E+08 2.63E-02-3.46E-01   4   2   0
 5 7.00E-01 2.00E-01 1.65E-01 2.51E-19 2.51E-19 2.51E-19 1.90E-02 4.12E-09 2.10E-01 1.01E+05 1.00E+08 2.63E-02-3.46E-01   4   2   0
 6 7.00E-01 0.00E+00 0.00E+00 1.00E-10 1.00E-10 1.00E-10 1.00E+00 0.00E+00 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
 7 7.00E-01 0.00E+00 0.00E+00 1.00E-10 1.00E-10 1.00E-10 1.00E+00 0.00E+00 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
 8 7.00E-01 0.00E+00 0.00E+00 1.00E-10 1.00E-10 1.00E-10 1.00E+00 0.00E+00 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
 9 7.00E-01 0.00E+00 0.00E+00 1.00E-10 1.00E-10 1.00E-10 1.00E+00 0.00E+00 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
10 1.00E+00 0.00E+00 0.00E+00 1.00E-35 1.00E-35 1.00E-35 5.00E-03 0.00E+00 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
11 7.00E-01 2.00E-01 2.00E-01 1.33E-11 1.33E-11 1.33E-11 5.20E-03 1.92E-07 2.10E-01 1.01E+05 1.00E+08 5.60E-01-3.46E-01   4   2   0
12 7.00E-01 2.00E-01 2.00E-01 5.58E-12 5.58E-12 5.58E-12 8.81E-01 1.20E-09 2.10E-01 1.01E+05 1.00E+08 5.60E-01-3.46E-01   4   4   0
13 7.00E-01 2.00E-01 2.00E-01 5.58E-12 5.58E-12 5.58E-12 8.81E-01 1.20E-09 2.10E-01 1.01E+05 1.00E+08 5.60E-01-3.46E-01   4   4   0
14 7.00E-01 2.00E-01 2.00E-01 1.00E-35 1.00E-35 1.00E-35 2.00E-01 0.00E+00 2.10E-01 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
15 7.00E-01 2.00E-01 2.00E-01 2.65E-13 2.65E-13 2.65E-13 1.46E-01 1.42E-09 2.10E-01 1.01E+05 1.00E+08 5.60E-01-3.46E-01   4   2   0
16 7.00E-01 2.00E-01 2.00E-01 1.00E-35 1.00E-35 1.00E-35 2.00E-01 0.00E+00 2.10E-01 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
17 7.00E-01 2.00E-01 2.00E-01 1.10E-16 1.10E-16 1.10E-16 9.00E-02 2.20E-09 2.10E-01 1.01E+05 1.00E+08 5.60E-01-3.46E-01   4   2   0
18 7.00E-01 2.00E-01 2.00E-01 1.00E-35 1.00E-35 1.00E-35 2.00E-01 0.00E+00 2.10E-01 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
19 7.00E-01 2.00E-01 2.00E-01 9.33E-16 9.33E-16 9.33E-16 1.50E-01 6.67E-08 2.10E-01 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
20 7.00E-01 2.00E-01 2.00E-01 1.00E-10 1.00E-10 1.00E-10 1.75E-01 5.71E-08 2.10E-01 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
21 7.00E-01 0.00E+00 0.00E+00 1.00E-11 1.00E-11 1.00E-11 1.00E+00 0.00E+00 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
22 7.00E-01 0.00E+00 0.00E+00 1.00E-11 1.00E-11 1.00E-11 1.00E+00 0.00E+00 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
23 1.70E+00 2.21E-01 2.00E-01 1.00E-14 1.00E-14 1.00E-14 2.50E-01 0.00E+00 2.32E-01 1.01E+05 1.00E+08 1.42E+04 0.00E+00   4   2   0
24 1.90E-01 2.24E-02 2.24E-02 1.00E-18 1.00E-18 1.00E-18 2.50E-01 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
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25 7.00E-01 0.00E+00 0.00E+00 3.31E-17 3.31E-17 3.31E-17 1.00E-02 0.00E+00 0.00E+00 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0
26 7.00E-01 2.00E-01 2.00E-01 5.00E-19 5.00E-19 5.00E-19 7.50E-02 0.00E+00 2.10E-01 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
27 7.00E-01 2.00E-01 2.00E-01 1.00E-14 1.00E-14 1.00E-14 7.50E-02 0.00E+00 2.10E-01 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
28 1.90E-01 2.24E-02 2.24E-02 3.84E-17 3.84E-17 3.84E-17 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
29 1.90E-01 2.24E-02 2.24E-02 2.53E-17 2.53E-17 2.53E-17 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
30 1.90E-01 2.24E-02 2.24E-02 1.58E-17 1.58E-17 1.58E-17 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
31 1.90E-01 2.24E-02 2.24E-02 6.53E-18 6.53E-18 6.53E-18 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
32 1.90E-01 2.24E-02 2.24E-02 1.00E-18 1.00E-18 1.00E-18 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
33 1.90E-01 2.24E-02 2.24E-02 4.68E-17 4.68E-17 4.68E-17 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
34 1.90E-01 2.24E-02 2.24E-02 9.08E-18 9.08E-18 9.08E-18 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
35 1.90E-01 2.24E-02 2.24E-02 1.00E-16 1.00E-18 1.00E-18 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
36 7.00E-01 2.00E-01 2.00E-01 1.00E-14 1.00E-14 1.00E-14 4.00E-02 0.00E+00 2.10E-01 1.01E+05 1.00E+08 3.90E+04 0.00E+00   4   2   0
37 7.00E-01 2.00E-01 2.00E-01 7.00E-17 7.00E-17 7.00E-17 4.00E-02 0.00E+00 2.10E-01 1.01E+05 1.00E+08 2.18E+05 0.00E+00   4   2   0
38 7.00E-01 2.00E-01 2.00E-01 1.00E-18 1.00E-18 1.00E-18 4.00E-02 0.00E+00 2.10E-01 1.01E+05 1.00E+08 5.47E+05 0.00E+00   4   2   0
39 7.00E-01 2.00E-01 2.00E-01 3.30E-21 3.30E-21 3.30E-21 4.00E-02 0.00E+00 2.10E-01 1.01E+05 1.00E+08 4.70E+06 0.00E+00   4   2   0
40 7.00E-01 2.00E-01 2.00E-01 1.00E-21 1.00E-21 1.00E-21 4.00E-02 0.00E+00 2.10E-01 1.01E+05 1.00E+08 4.70E+06 0.00E+00   4   2   0
41 1.90E-01 2.24E-02 2.24E-02 1.00E-18 1.00E-18 1.00E-18 7.50E-02 0.00E+00 2.35E-02 1.01E+05 1.00E+08 1.50E+06 0.00E+00   4   2   0
42 7.00E-01 2.00E-01 2.00E-01 1.00E-12 1.00E-12 1.00E-12 7.50E-02 1.33E-08 2.10E-01 1.01E+05 1.00E+08 0.00E+00 0.00E+00   4   1   0

Fracture model will be used?  (KFRACTURE): T

Fracture model parameters:
    Index for material in which fracturing occurs (IFRCMAT) =   3
    Fracture initiation pressure increment        (FRPIINC) = 1.80000E+06 Pa
    Fully-developed fracture pressure increment   (FRPFINC) = 2.50000E+06 Pa
    Maximum fracture porosity                    (FRPHIMAX) = 2.90000E-02
    Fracture permeability function exponent      (FRPRMEXP) = 5.32083E+01
    Flag to calc x-direction perm as fractured       (IFRX) =   1  (yes)
    Flag to calc y-direction perm as fractured       (IFRY) =   1  (yes)
    Flag to calc z-direction perm as fractured       (IFRZ) =   0  (no)

Fracture model parameters:
    Index for material in which fracturing occurs (IFRCMAT) =   4
    Fracture initiation pressure increment        (FRPIINC) = 1.80000E+06 Pa
    Fully-developed fracture pressure increment   (FRPFINC) = 2.50000E+06 Pa
    Maximum fracture porosity                    (FRPHIMAX) = 2.90000E-02
    Fracture permeability function exponent      (FRPRMEXP) = 5.32083E+01
    Flag to calc x-direction perm as fractured       (IFRX) =   1  (yes)
    Flag to calc y-direction perm as fractured       (IFRY) =   1  (yes)
    Flag to calc z-direction perm as fractured       (IFRZ) =   0  (no)

Fracture model parameters:
    Index for material in which fracturing occurs (IFRCMAT) =   5
    Fracture initiation pressure increment        (FRPIINC) = 1.80000E+06 Pa
    Fully-developed fracture pressure increment   (FRPFINC) = 2.50000E+06 Pa
    Maximum fracture porosity                    (FRPHIMAX) = 2.90000E-02
    Fracture permeability function exponent      (FRPRMEXP) = 5.32083E+01
    Flag to calc x-direction perm as fractured       (IFRX) =   1  (yes)
    Flag to calc y-direction perm as fractured       (IFRY) =   1  (yes)
    Flag to calc z-direction perm as fractured       (IFRZ) =   0  (no)

Klinkenberg effect will be included?  (KLINK): T

Klinkenberg equation parameters:
     Linear factor    (BKLINK) = 9.50000E-01 Pa
     Exponent       (EXPKLINK) =-3.30000E-01


Reference conditions:
    Reference temperature   (TREF) = 3.00150E+02 K
    Reference pressure      (PREF) = 1.01325E+05 Pa

Brine salinity                                  (SALT) = 2.9600E+01 wt %
Brine density at ref. conditions             (DENOSC) = 1.2100E+03 kg/m^3
Gas-free (=0) or gas-sat'd brine (=1)         (KGSAT) = 1
Dissolved gas (=1) or no dissolved gas (=0)   (IDGAS) = 0
Brine compressibility                        (BRCOMP) = 2.5000E-10 1/Pa

Brine viscosity  (VISO) =  1.8000E-03 Pa*s
Gas viscosity    (VISG) =  8.9200E-06 Pa*s

Flag for calculating gas density (INTERPDENG):
    INTERPDENG = 1:  Interpolate from table with RKS EOS.

Gas parameters:
    Gas mole fraction  (YGAS)
        H2:    1.000E+00      CO2:   0.000E+00
        CH4:   0.000E+00      N2:    0.000E+00
        H2S:   0.000E+00      O2:    0.000E+00
    Number of gases actually used    (NGAS) = 1
    Gas number used if NGAS=1:
        (1=H2, 2=CO2, 3=CH4, 4=N2
         5=H2S, 6=O2)                (NGAS1) = 1
```

****

```
Gas generation model (IGASVAR) = 1
    Original model:  Zeroth-order corrosion & biodegradation.

Reaction rate constants  (RK):
    Corrosion reaction rate constant       = 2.043700E-08 mol Fe/(s*m^3)
    Biodegradation reaction rate constant = 2.664200E-07 mol cell/(s*m^3)

Factor for humid reaction rate constants  (HF):
    Corrosion reaction       = 0.000000E+00
    Biodegradation reaction = 1.000000E-01

Stoichiometric coeff's for corrosion rxn  (S(1,I)):
    Gas coefficient = 1.166700E+00
    H2O coefficient = 1.666700E+00
    Fe coefficient  = 1.000000E+00

Stoichiometric coeff's for biodegr. rxn  (S(2,I)):
    Gas coefficient = 1.100000E+00
    H2O coefficient = 0.000000E+00
    Bio coefficient = 1.000000E+00

Molecular weights  (WM):
    H2:    2.0159E-03 kg/mol
    H2O:   1.8015E-02 kg/mol
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    Fe:    5.5847E-02 kg/mol
    Bio:   1.0026E-02 kg/mol

 Wicking term  (SATWICK) = 5.000000E-01
 Humid rates to be smoothed?      (LARXN) =  T
 Humid rate smoothing factor  (ALPHARXN) = 1.000000E+03

 Will creep closure be used  (CLOSURE):  T

 Number of closure surfaces  (NKLOS) =    1
 Closure surface interpolation basis (KLOSINT):  1
     [Gas generation rate:      KLOSINT=0]
     [Average waste pressure:  KLOSINT=1]
 Pressure averaging method for closure (KLOSAVG):  2
     [Average all closure surface blocks:  KLOSAVG=1]
     [No averaging; use PO in (I,J,K):     KLOSAVG=2]

 PLITHO        = Maximum pressure for closure
 TIME_CLOSOFF  = Time limit for closure
 CLOSPERMFACT  = Constant factor in permeability-porosity expression
 CLOSPERMEXP   = Exponent in permeability-porosity expression
    Model Number   (PLITHO) [Pa]    (TIME_CLOSOFF) [s]  (CLOSPERMFACT) [m^2]   (CLOSPERMEXP) [-]
          4          5.000000E+07       3.155700E+12         5.584700E-12          0.000000E+00

 Number of materials using closure (NMATCLOS) =   2
        Material Index    Model Number
    #       (MATCLOS)       (MODELCLOS)
    1          12               4
    2          13               4

 Radionuclide decay will be calculated? (LRADDK)  F

 Solute transport will be calculated?    (LTRANS):  F
 Solute radiolysis will be calculated? (LRADLSIS):  F

 Decay has been turned off (LRADDK changed to F),
     since neither transport nor radiolysis is on:
     (LTRANS = LRADLSIS = F)


 Will gas component transport be calculated?  (LRXGAST):   F

*** Waste Region  1 is initialized with PO & SO =   1.013250E+05   0.000000E+00


*** Waste Region  2 is initialized with PO & SO =   1.013250E+05   0.000000E+00


*****************************************************************************************************************
 Total mesh volume  = 1.907061E+12 m^3
 Total waste volume = 4.361532E+05 m^3
 Density of initial brine at ref cond = 1.230000E+03 kg/m^3
 Density of initial gas at ref cond   = 8.179988E-02 kg/m^3
 Mass fraction of initial brine in brine phase at ref. cond = 1.000000E+00
 Mass fraction of initial gas in brine phase at ref. cond   = 0.000000E+00
 Original brine in place at ref. cond = 1.539993E+10 m^3
 Original brine in place              = 1.894192E+13 kg
 Original gas in place at ref. cond   = 4.950996E+08 m^3
 Original gas in place                = 4.049908E+07 kg


 Number of element variables printed to ASCII output =    6

 Number of global  variables printed to ASCII output =   10

       CAMCON   Element Variable                                                          Units Conv
 No.   Vbl Name Description                                      Units Label          Factor
----   -------- ---------------------------------------------- -------------------- -----------
   1   PRESBRIN Brine pressure                                  Pa                   1.000000E+00
   2   PRESGAS  Gas pressure                                    Pa                   1.000000E+00
   6   POROS    Porosity                                        dimensionless        1.000000E+00
  18   SATGAS   Gas saturation                                  fraction void volume 1.000000E+00
  47   FECONC   Fe concentration -- simple model                kg/m^3               1.000000E+00
  48   CELLCONC CH2O concentration -- simple model              kg/m^3               1.000000E+00

       CAMCON   Global Variable                                                           Units Conv
 No.   Vbl Name Description                                      Units Label          Factor
----   -------- ---------------------------------------------- -------------------- -----------
   1   BRNMBCUM Cumulative brine mass balance                   dimensionless        1.000000E+00
   2   GASMBCUM Cumulative gas mass balance                     dimensionless        1.000000E+00
   3   BRNMBMAX Maximum brine mass balance                      dimensionless        1.000000E+00
   4   GASMBMAX Maximum gas mass balance                        dimensionless        1.000000E+00
   5   IBRNMBMX I-index, location of maximum brine mass balance dimensionless        1.000000E+00
   6   JBRNMBMX J-index, location of maximum brine mass balance dimensionless        1.000000E+00
   7   KBRNMBMX K-index, location of maximum brine mass balance dimensionless        1.000000E+00
   8   IGASMBMX I-index, location of maximum gas mass balance   dimensionless        1.000000E+00
   9   JGASMBMX J-index, location of maximum gas mass balance   dimensionless        1.000000E+00
  10   KGASMBMX K-index, location of maximum gas mass balance   dimensionless        1.000000E+00


Grid block dimensions
-----------------------------------------------------------------------------------------------------------------
Grid block dimensions in X-direction                m
   Layer   1
1  1.50000E+04  5.00000E+03  1.00000E+03  7.50000E+02  5.00000E+02  1.00000E+02  4.00000E+01  1.00000E+01  4.38000E+01  1.00000E+01
   2.00000E+00  4.00000E-01  2.00000E+00  1.00000E+01  4.38000E+01  4.00000E+01  1.00000E+02  4.95000E-02  1.00000E+02  8.00000E+01
   2.83000E+02  5.00000E+01  1.00000E+01  6.00000E+01  5.00000E+02  1.00000E+01  4.00000E+01  1.00000E+02  5.00000E+02  7.50000E+02
   1.00000E+03  5.00000E+03  1.50000E+04
2  1.50000E+04  5.00000E+03  1.00000E+03  7.50000E+02  5.00000E+02  1.00000E+02  4.00000E+01  1.00000E+01  4.38000E+01  1.00000E+01
   2.00000E+00  4.00000E-01  2.00000E+00  1.00000E+01  4.38000E+01  4.00000E+01  1.00000E+02  4.95000E-02  1.00000E+02  8.00000E+01
   2.83000E+02  5.00000E+01  1.00000E+01  6.00000E+01  5.00000E+02  1.00000E+01  4.00000E+01  1.00000E+02  5.00000E+02  7.50000E+02
   1.00000E+03  5.00000E+03  1.50000E+04
3  1.50000E+04  5.00000E+03  1.00000E+03  7.50000E+02  5.00000E+02  1.00000E+02  4.00000E+01  1.00000E+01  4.38000E+01  1.00000E+01
   2.00000E+00  4.00000E-01  2.00000E+00  1.00000E+01  4.38000E+01  4.00000E+01  1.00000E+02  4.95000E+02  1.00000E+02  8.00000E+01
   2.83000E+02  5.00000E+01  1.00000E+01  6.00000E+01  5.00000E+02  1.00000E+01  4.00000E+01  1.00000E+02  5.00000E+02  7.50000E+02
   1.00000E+03  5.00000E+03  1.50000E+04
4  1.50000E+04  5.00000E+03  1.00000E+03  7.50000E+02  5.00000E+02  1.00000E+02  4.00000E+01  1.00000E+01  4.38000E+01  1.00000E+01
   2.00000E+00  4.00000E-01  2.00000E+00  1.00000E+01  4.38000E+01  4.00000E+01  1.00000E+02  4.95000E-02  1.00000E+02  8.00000E+01
   2.83000E+02  5.00000E+01  1.00000E+01  6.00000E+01  5.00000E+02  1.00000E+01  4.00000E+01  1.00000E+02  5.00000E+02  7.50000E+02
```

	1.00000E+03	5.00000E+03	1.50000E+04								
5	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
6	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
7	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
8	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
9	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
10	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
11	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
12	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
13	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
14	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
15	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
16	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
17	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
18	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
19	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
20	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
21	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
22	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
23	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
24	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
25	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
26	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
27	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
28	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
29	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
30	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								
31	1.50000E+04	5.00000E+03	1.00000E+03	7.50000E+02	5.00000E+02	1.00000E+02	4.00000E+01	1.00000E+01	4.38000E+01	1.00000E+01	
	2.00000E+00	4.00000E-01	2.00000E+00	1.00000E+01	4.38000E+01	4.00000E+01	1.00000E+02	4.95000E+02	1.00000E+02	8.00000E+01	
	2.83000E+02	5.00000E+01	1.00000E+01	6.00000E+01	5.00000E+02	1.00000E+01	4.00000E+01	1.00000E+02	5.00000E+02	7.50000E+02	
	1.00000E+03	5.00000E+03	1.50000E+04								

Grid block dimensions in Y-direction m

Layer 1

1	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00
	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00
	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00	2.72800E+00
	2.72800E+00	2.72800E+00	2.72800E+00							
2	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01
	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01
	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01	4.73720E+01
	4.73720E+01	4.73720E+01	4.73720E+01							
3	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02
	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02
	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02	1.39160E+02
	1.39160E+02	1.39160E+02	1.39160E+02							
4	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01
	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01
	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01	5.00000E+01
	5.00000E+01	5.00000E+01	5.00000E+01							
5	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01
	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01
	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01	1.10000E+01
	1.10000E+01	1.10000E+01	1.10000E+01							
6	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01
	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01
	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01	8.50000E-01
	8.50000E-01	8.50000E-01	8.50000E-01							
7	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00
	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00
	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00	1.38000E+00
	1.38000E+00	1.38000E+00	1.38000E+00							
8	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00							
9	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00							
10	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00	1.32080E+00
	1.32080E+00	1.32080E+00	1.32080E+00							
11	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00
	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00
	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00	2.61760E+00
	2.61760E+00	2.61760E+00	2.61760E+00							
12	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01
	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01
	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01	2.70000E-01
	2.70000E-01	2.70000E-01	2.70000E-01							
13	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00
	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00
	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00	4.61000E+00
	4.61000E+00	4.61000E+00	4.61000E+00							
14	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00
	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00
	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00	4.45000E+00
	4.45000E+00	4.45000E+00	4.45000E+00							
15	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01
	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01
	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01	1.80000E-01
	1.80000E-01	1.80000E-01	1.80000E-01							
16	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01
	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01
	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01	2.39000E+01
	2.39000E+01	2.39000E+01	2.39000E+01							
17	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01
	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01
	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01
	5.24200E+01	5.24200E+01	5.24200E+01							
18	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01
	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01
	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01	5.24200E+01
	5.24200E+01	5.24200E+01	5.24200E+01							
19	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01
	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01
	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01
	8.58800E+01	8.58800E+01	8.58800E+01							
20	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01
	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01
	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01	8.58800E+01
	8.58800E+01	8.58800E+01	8.58800E+01							
21	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01
	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01
	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01	4.53400E+01
	4.53400E+01	4.53400E+01	4.53400E+01							
22	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01
	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01
	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01	3.72800E+01
	3.72800E+01	3.72800E+01	3.72800E+01							
23	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01
	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01
	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01	3.60000E+01
	3.60000E+01	3.60000E+01	3.60000E+01							
24	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00
	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00
	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00	7.70000E+00
	7.70000E+00	7.70000E+00	7.70000E+00							
25	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01
	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01
	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01	2.48000E+01
	2.48000E+01	2.48000E+01	2.48000E+01							
26	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00
	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00
	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00	8.50000E+00
	8.50000E+00	8.50000E+00	8.50000E+00							
27	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E-	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01
	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+-1	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01
	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+01	1.73000E+02	1.73000E+01
	1.73000E+01	1.73000E+01	1.73000E+01							

28	1.06000E+02	1.06000E-02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02
	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02
	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02	1.06000E+02
	1.06000E+02	1.06000E+02	1.06000E+02							
29	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01
	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01
	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01	4.33000E+01
	4.33000E+01	4.33000E+01	4.33000E+01							
30	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01
	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01
	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01	1.56600E+01
	1.56600E+01	1.56600E+01	1.56600E+01							
31	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01
	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01
	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01	1.00000E-01
	1.00000E-01	1.00000E-01	1.00000E-01							

Grid block dimensions in Z-direction m

Layer 1

1	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
2	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
3	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
4	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
5	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
6	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
7	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
8	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
9	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
10	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
11	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
12	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
13	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
14	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
15	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
16	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
17	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
18	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
19	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
20	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
21	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
22	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03
	9.21410E+03	2.17269E+04	6.17269E+04							
23	6.13143E+04	2.13143E+04	8.74880E+03	6.56160E+03	3.31430E+03	2.11430E+03	1.83430E+03	1.73430E+03	1.26200E+02	2.88000E+01
	4.80000E+00	4.00000E-01	4.80000E+00	2.88000E+01	1.26200E+02	1.00000E+01	1.32300E+02	1.43500E+02	1.41600E+02	1.89000E+01
	1.89000E+01	1.89000E+01	9.50000E+00	2.05000E+01	5.31000E+01	1.25890E+03	1.45890E+03	2.01890E+03	3.92800E+03	6.91060E+03

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    9.21410E+03  2.17269E+04  6.17269E+04
24  6.13143E+04  2.13143E+04  8.74880E+03  6.56160E+03  3.31430E+03  2.11430E+03  1.83430E+03  1.73430E+03  1.26200E+02  2.88000E+01
    4.80000E+00  4.00000E-01  4.80000E+00  2.88000E+01  1.26200E+02  1.00000E+01  1.32300E+02  1.43500E+02  1.41600E+02  1.89000E+01
    1.89000E+01  1.89000E+01  9.50000E+00  2.05000E+01  5.31000E+01  1.25890E+03  1.45890E+03  2.01890E+03  3.92800E+03  6.91060E+03
    9.21410E+03  2.17269E+04  6.17269E+04
25  6.13143E+04  2.13143E+04  8.74880E+03  6.56160E+03  3.31430E+03  2.11430E+03  1.83430E+03  1.73430E+03  1.26200E+02  2.88000E+01
    4.80000E+00  4.00000E-01  4.80000E+00  2.88000E+01  1.26200E+02  1.00000E+01  1.32300E+02  1.43500E+02  1.41600E+02  1.89000E+01
    1.89000E+01  1.89000E+01  9.50000E+00  2.05000E+01  5.31000E+01  1.25890E+03  1.45890E+03  2.01890E+03  3.92800E+03  6.91060E+03
    9.21410E+03  2.17269E+04  6.17269E+04
26  6.13143E+04  2.13143E+04  8.74880E+03  6.56160E+03  3.31430E+03  2.11430E+03  1.83430E+03  1.73430E+03  1.26200E+02  2.88000E+01
    4.80000E+00  4.00000E-01  4.80000E+00  2.88000E+01  1.26200E+02  1.00000E+01  1.32300E+02  1.43500E+02  1.41600E+02  1.89000E+01
    1.89000E+01  1.89000E+01  9.50000E+00  2.05000E+01  5.31000E+01  1.25890E+03  1.45890E+03  2.01890E+03  3.92800E+03  6.91060E+03
    9.21410E+03  2.17269E+04  6.17269E+04
27  6.13143E+04  2.13143E+04  8.74880E+03  6.56160E+03  3.31430E+03  2.11430E+03  1.83430E+03  1.73430E+03  1.26200E+02  2.88000E+01
    4.80000E+00  4.00000E-01  4.80000E+00  2.88000E+01  1.26200E+02  1.00000E+01  1.32300E+02  1.43500E+02  1.41600E+02  1.89000E+01
    1.89000E+01  1.89000E+01  9.50000E+00  2.05000E+01  5.31000E+01  1.25890E+03  1.45890E+03  2.01890E+03  3.92800E+03  6.91060E+03
    9.21410E+03  2.17269E+04  6.17269E+04
28  6.13143E+04  2.13143E+04  8.74880E+03  6.56160E+03  3.31430E+03  2.11430E+03  1.83430E+03  1.73430E+03  1.26200E+02  2.88000E+01
    4.80000E+00  4.00000E-01  4.80000E+00  2.88000E+01  1.26200E+02  1.00000E+01  1.32300E+02  1.43500E+02  1.41600E+02  1.89000E+01
    1.89000E+01  1.89000E+01  9.50000E+00  2.05000E+01  5.31000E+01  1.25890E+03  1.45890E+03  2.01890E+03  3.92800E+03  6.91060E+03
    9.21410E+03  2.17269E+04  6.17269E+04
29  6.13143E+04  2.13143E+04  8.74880E+03  6.56160E+03  3.31430E+03  2.11430E+03  1.83430E+03  1.73430E+03  1.26200E+02  2.88000E+01
    4.80000E+00  4.00000E-01  4.80000E+00  2.88000E+01  1.26200E+02  1.00000E+01  1.32300E+02  1.43500E+02  1.41600E+02  1.89000E+01
    1.89000E+01  1.89000E+01  9.50000E+00  2.05000E+01  5.31000E+01  1.25890E+03  1.45890E+03  2.01890E+03  3.92800E+03  6.91060E+03
    9.21410E+03  2.17269E+04  6.17269E+04
30  6.13143E+04  2.13143E+04  8.74880E+03  6.56160E+03  3.31430E+03  2.11430E+03  1.83430E+03  1.73430E+03  1.26200E+02  2.88000E+01
    4.80000E+00  4.00000E-01  4.80000E+00  2.88000E+01  1.26200E+02  1.00000E+01  1.32300E+02  1.43500E+02  1.41600E+02  1.89000E+01
    1.89000E+01  1.89000E+01  9.50000E+00  2.05000E+01  5.31000E+01  1.25890E+03  1.45890E+03  2.01890E+03  3.92800E+03  6.91060E+03
    9.21410E+03  2.17269E+04  6.17269E+04
31  6.13143E+04  2.13143E+04  8.74880E+03  6.56160E+03  3.31430E+03  2.11430E+03  1.83430E+03  1.73430E+03  1.26200E+02  2.88000E+01
    4.80000E+00  4.00000E-01  4.80000E+00  2.88000E+01  1.26200E+02  1.00000E+01  1.32300E+02  1.43500E+02  1.41600E+02  1.89000E+01
    1.89000E+01  1.89000E+01  9.50000E+00  2.05000E+01  5.31000E+01  1.25890E+03  1.45890E+03  2.01890E+03  3.92800E+03  6.91060E+03
    9.21410E+03  2.17269E+04  6.17269E+04
-----------------------------------------------------------------------------------------------------------------------------------
Grid Block Volumes                                  m^3
   Layer   1
 1  2.50898E+09  2.90727E+08  2.38667E+07  1.34250E+07  4.52071E+06  5.76781E+05  2.00159E+05  4.73117E+04  1.50792E+04  7.85664E+02
    2.51888E+01  4.36480E-01  2.61888E+01  7.85664E+02  1.50792E+04  1.09120E+03  3.60914E+04  1.93777E+05  3.86285E+04  4.12474E+03
    1.45913E+04  2.57796E+03  2.59160E+02  3.35544E+03  7.24284E+04  3.43428E+04  1.59195E+05  5.50756E+05  5.35779E+06  1.41391E+07
    2.51361E+07  2.96355E+08  2.52586E+09
 2  4.35687E+10  5.04851E+09  4.14448E+08  2.33127E+08  7.85025E+07  1.00159E+07  3.47578E+06  8.21573E+05  2.61852E+05  1.36431E+04
    4.54771E+02  7.57952E+00  4.54771E+02  1.36431E+04  2.61852E+05  1.89488E+04  6.26732E+05  3.36495E+06  6.70788E+05  7.16265E+04
    2.53379E+05  4.47665E+04  4.50034E+03  5.82676E+04  1.25771E+06  5.96366E+05  2.76444E+06  9.56393E+06  9.30386E+07  2.45527E+08
    4.36490E+08  5.14623E+09  4.38619E+10
 3  1.27987E+11  1.48305E+10  1.21748E+09  6.84834E+08  2.30609E+08  2.94226E+07  1.02104E+07  2.41345E+06  7.69215E+05  4.00781E+04
    1.33594E+03  2.22656E+01  1.33594E+03  4.00781E+04  7.69215E+05  5.56640E+04  1.84109E+06  9.88488E+06  1.97051E+06  2.10410E+05
    7.44325E+05  1.31506E+05  1.32202E+04  1.71167E+05  3.69470E+06  1.75189E+06  8.12082E+06  2.80950E+07  2.73310E+08  7.21259E+08
    1.28223E+09  1.51176E+10  1.28849E+11
 4  4.59857E+10  5.32858E+09  4.37440E+08  2.46060E+08  8.28575E+07  1.05715E+07  3.66860E+06  8.67150E+05  2.76378E+05  1.44000E+04
    4.80000E+02  8.00000E+00  4.80000E+02  1.44000E+04  2.76378E+05  2.00000E+04  6.61500E+05  3.55163E+06  7.08000E+05  7.56000E+04
    2.67435E+05  4.72500E+04  4.75000E+03  6.15000E+04  1.32750E+06  6.29450E+05  2.91780E+06  1.00945E+07  9.82000E+07  2.59148E+08
    4.60705E+08  5.43173E+09  4.62952E+10
 5  1.01169E+10  1.17229E+09  9.62368E+07  5.41332E+07  1.82287E+07  2.32573E+06  8.07092E+05  1.90773E+05  6.08032E+04  3.16800E+03
    1.05600E+02  1.76000E+00  1.05600E+02  3.16800E+03  6.08032E+04  4.40000E+03  1.45530E+05  7.81358E+05  1.55760E+05  1.66320E+04
    5.88357E+04  1.03950E+04  1.04500E+03  1.35300E+04  2.92050E+05  1.38479E+05  6.41916E+05  2.22079E+06  2.16040E+07  5.70125E+07
    1.01355E+08  1.19498E+09  1.01843E+10
 6  7.81757E+08  9.05858E+07  7.43648E+06  4.18302E+06  1.40858E+06  1.79716E+05  6.23662E+04  1.47415E+04  4.69843E+03  2.44800E+02
    8.16000E+00  1.36000E-01  8.16000E+00  2.44800E+02  4.69843E+03  3.40000E+02  1.12455E+04  6.03776E+04  1.20360E+04  1.28520E+03
    4.54639E+03  8.03250E+02  8.07500E+01  1.04550E+03  2.25675E+04  1.07007E+04  4.96026E+04  1.71607E+05  1.66940E+06  4.40551E+06
    7.83199E+06  9.23393E+07  7.87018E+08
 7  1.26921E+09  1.47069E+08  1.20733E+07  6.79126E+06  2.28687E+06  2.91773E+05  1.01253E+05  2.39333E+04  7.62803E+03  3.97440E+02
    1.32480E+01  2.20800E-01  1.32480E+01  3.97440E+02  7.62803E+03  5.52000E+02  1.82574E+04  9.80248E+04  1.95408E+04  2.08656E+03
    7.38121E-03  1.30410E+03  1.31100E+02  1.69740E+03  3.66390E+04  1.73728E+04  8.05313E+04  2.78608E+05  2.71032E+06  7.15247E+06
    1.27155E+07  1.49916E+08  1.27775E+09
 8  1.21476E+09  1.40760E+08  1.15554E+07  6.49992E+06  2.18876E+06  2.79257E+05  9.69097E+04  2.29066E+04  7.30080E+03  3.80390E+02
    1.26797E+01  2.11328E-01  1.26797E+01  3.80390E+02  7.30080E+03  5.28320E+02  1.74742E+04  9.38197E+04  1.87025E+04  1.99705E+03
    7.06456E+03  1.24816E+03  1.25476E+02  1.62458E+03  3.50672E+04  1.66276E+04  7.70766E+04  2.66656E+05  2.59405E+06  6.84564E+06
    1.21700E+07  1.43484E+08  1.22293E+09
 9  1.21476E+09  1.40760E+08  1.15554E+07  6.49992E+06  2.18876E+06  2.79257E+05  9.69097E+04  2.29066E+04  7.30080E+03  3.80390E+02
    1.26797E+01  2.11328E-01  1.26797E+01  3.80390E+02  7.30080E+03  5.28320E+02  1.74742E+04  9.38197E+04  1.87025E+04  1.99705E+03
    7.06456E+03  1.24816E+03  1.25476E+02  1.62458E+03  3.50672E+04  1.66276E+04  7.70766E+04  2.66656E+05  2.59405E+06  6.84564E+06
    1.21700E+07  1.43484E+08  1.22293E+09
10  1.21476E+09  1.40760E+08  1.15554E+07  6.49992E+06  2.18876E+06  2.79257E+05  9.69097E+04  2.29066E+04  7.30080E+03  3.80390E+02
    1.26797E+01  2.11328E-01  1.26797E+01  3.80390E+02  7.30080E+03  5.28320E+02  1.74742E+04  9.38197E+04  1.87025E+04  1.99705E+03
    7.06456E+03  1.24816E+03  1.25476E+02  1.62458E+03  3.50672E+04  1.66276E+04  7.70766E+04  2.66656E+05  2.59405E+06  6.84564E+06
    1.21700E+07  1.43484E+08  1.22293E+09
11  2.40744E+09  2.78962E+08  2.29009E+07  1.28817E+07  4.33776E+06  5.53439E+05  1.92059E+05  4.53970E+04  1.44689E+04  7.53869E+02
    2.51290E+01  4.18816E-01  2.51290E+01  7.53869E+02  1.44689E+04  1.04704E+03  3.46308E+04  1.85935E+05  3.70652E+04  3.95781E+03
    1.40008E+04  2.47363E+03  2.48672E+02  3.21965E+03  6.94973E+04  3.29530E+04  1.52753E+05  5.28467E+05  5.14097E+06  1.35669E+07
    2.41188E+07  2.84362E+08  2.42365E+09
12  2.48323E+08  2.87743E+07  2.36210E+06  1.32872E+06  4.47431E+05  5.70861E+04  1.98104E+04  4.68261E+03  1.49244E+03  7.77600E+01
    2.59200E+00  4.32000E-02  2.59200E+00  7.77600E+01  1.49244E+03  1.08000E+02  3.57210E+03  1.91788E+04  3.82320E+03  4.08240E+02
    1.44415E+03  2.55150E+02  2.56500E+01  3.32100E+02  7.16850E+03  3.39903E+03  1.57561E+04  5.45103E+04  5.30280E+05  1.39940E+06
    2.48781E+06  2.93313E+07  2.49994E+08
13  4.23988E+09  4.91295E+08  4.03320E+07  2.26867E+07  7.63946E+06  9.74692E+05  3.38245E+05  7.99512E+04  2.54821E+04  1.32768E+03
    4.42560E+01  7.37600E-01  4.42560E+01  1.32768E+03  2.54821E+04  1.84400E+03  6.09903E+04  3.27460E+05  6.52776E+04  6.97032E+03
    2.46575E+04  4.35645E+03  4.37950E+02  5.67030E+03  1.22396E+05  5.80353E+04  2.69021E+05  9.30713E+05  9.05404E+06  2.38934E+07
    4.24770E+07  5.00805E+08  4.26842E+09
14  4.09273E+09  4.74243E+08  3.89322E+07  2.18993E+07  7.37432E+06  9.40864E+05  3.26505E+05  7.71763E+04  2.45976E+04  1.28160E+03
    4.27200E+01  7.12000E-01  4.27200E+01  1.28160E+03  2.45976E+04  1.78000E+03  5.88735E+04  3.16095E+05  6.30120E+04  6.72840E+03
    2.38017E+04  4.20525E+03  4.22750E+02  5.47350E+03  1.18148E+05  5.60211E+04  2.59684E+05  8.98411E+05  8.73980E+06  2.30641E+07
    4.10027E+07  4.83424E+08  4.12027E+09
15  1.65549E+08  1.91829E+07  1.57478E+06  8.85816E+05  2.98287E+05  3.80574E+04  1.32070E+04  3.12174E+03  9.94961E+02  5.18400E+01
    1.72800E+00  2.88000E-02  1.72800E+00  5.18400E+01  9.94961E+02  7.20000E+01  2.38140E+03  1.27858E+04  2.54880E+03  2.72160E+02
    9.62766E+02  1.70100E+02  1.71000E+01  2.21400E+02  4.77900E+03  2.26602E+03  1.05041E+04  3.63402E+04  3.53520E+05  9.32931E+05
    1.65854E+06  1.95542E+07  1.66663E+08
16  2.19812E+10  2.54706E+09  2.09096E+08  1.17617E+08  3.96059E+07  5.05318E+06  1.75359E+06  4.14498E+05  1.32109E+05  6.88320E+03
    2.29440E+02  3.82400E+00  2.29440E+02  6.88320E+03  1.32109E+05  9.56000E+03  3.16197E+05  1.69768E+06  3.38424E+05  3.61368E+04
    1.27834E+05  2.25855E+04  2.27050E+03  2.93970E+04  6.34545E+05  3.00877E+05  1.39471E+06  4.82517E+06  4.69396E+07  1.23873E+08
    2.20217E+08  2.59636E+09  2.21291E+10
17  4.82114E+10  5.58648E+09  4.58612E+08  2.57969E+08  8.68678E+07  1.10832E+07  3.84616E+06  9.09120E+05  2.89755E+05  1.50970E+04
    5.03232E+02  8.38720E+00  5.03232E+02  1.50970E+04  2.89755E+05  2.09680E+04  6.93517E+05  3.72352E+06  7.42267E+05  7.92590E+04
    2.80379E+05  4.95369E+04  4.97990E+03  6.44766E+04  1.39175E+06  6.59915E+05  3.05902E+06  1.05831E+07  1.02953E+08  2.71690E+08
    4.83003E+08  5.69462E+09  4.85359E+10
18  4.82114E+10  5.58648E+09  4.58612E+08  2.57969E+08  8.68678E+07  1.10832E+07  3.84616E+06  9.09120E+05  2.89755E+05  1.50970E+04
    5.03232E+02  8.38720E+00  5.03232E+02  1.50970E+04  2.89755E+05  2.09680E+04  6.93517E+05  3.72352E+06  7.42267E+05  7.92590E+04
    2.80379E+05  4.95369E+04  4.97990E+03  6.44766E+04  1.39175E+06  6.59915E+05  3.05902E+06  1.05831E+07  1.02953E+08  2.71690E+08
    4.83003E+08  5.69462E+09  4.85359E+10
19  7.89851E+10  9.15236E+09  7.51347E+08  4.22633E+08  1.42316E+08  1.81576E+07  6.30119E+06  1.48942E+06  4.74707E+05  2.47334E+04
    8.24448E+02  1.37408E+01  8.24448E+02  2.47334E+04  4.74707E+05  3.43520E+04  1.13619E+06  6.10027E+06  1.21606E+06  1.29851E+05
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    4.59346E+05  8.11566E+04  8.15860E+03  1.05632E+05  2.28011E+06  1.08114E+06  5.01161E+06  1.73383E+07  1.68668E+08  4.45112E+08
    7.91307E+08  9.32953E+09  7.95166E+10
20  7.89851E+10  9.15236E+09  7.51347E+08  4.22633E+08  1.42316E+08  1.81576E+07  6.30119E+06  1.48942E+06  4.74707E+05  2.47334E+04
    8.24448E+02  1.37408E+01  8.24448E+02  2.47334E+04  4.74707E+05  3.43520E+04  1.13619E+06  6.10027E+06  1.21606E+06  1.29851E+05
    4.59346E+05  8.11566E+04  8.15860E+03  1.05632E+05  2.28011E+06  1.08114E+06  5.01161E+06  1.73383E+07  1.68668E+08  4.45112E+08
    7.91307E+08  9.32953E+09  7.95166E+10
21  4.16999E+10  4.83195E+09  3.96671E+08  2.23127E+08  7.51352E+07  9.58624E+06  3.32669E+06  7.86332E+05  2.50620E+05  1.30579E+04
    4.35264E+02  7.25440E+00  4.35264E+02  1.30579E+04  2.50620E+05  1.81360E+04  5.99848E+05  3.22061E+06  6.42014E+05  6.85541E+04
    2.42510E+05  4.28463E+04  4.30730E+03  5.57682E+04  1.20378E+06  5.70785E+05  2.64586E+06  9.15369E+06  8.90478E+07  2.34995E+08
    4.17767E+08  4.92549E+09  4.19805E+10
22  3.42870E+10  3.97299E+09  3.26155E+08  1.83462E+08  6.17786E+07  7.88211E+06  2.73531E+06  6.46547E+05  2.06067E+05  1.07366E+04
    3.57888E+02  5.96480E+00  3.57888E+02  1.07366E+04  2.06067E+05  1.49120E+04  4.93214E+05  2.64809E+06  5.27885E+05  5.63674E+04
    1.99400E+05  3.52296E+04  3.54160E+03  4.58544E+04  9.89784E+05  4.69318E+05  2.17551E+06  7.52646E+06  7.32179E+07  1.93220E+08
    3.43502E+08  4.04989E+09  3.45177E+10
23  3.31097E+10  3.83657E+09  3.14957E+08  1.77163E+08  5.96574E+07  7.61148E+06  2.64139E+06  6.24348E+05  1.98992E+05  1.03680E+04
    3.45600E+02  5.76000E+00  3.45600E+02  1.03680E+04  1.98992E+05  1.44000E+04  4.76280E+05  2.55717E+06  5.09760E+05  5.44320E+04
    1.92553E+05  3.40200E+04  3.42000E+03  4.42800E+04  9.55800E+05  4.53204E+05  2.10082E+06  7.26804E+06  7.07040E+07  1.86588E+08
    3.31708E+08  3.91084E+09  3.33325E+10
24  7.08180E+09  8.20601E+08  6.73658E+07  3.78932E+07  1.27601E+07  1.62801E+06  5.64964E+05  1.33541E+05  4.25622E+04  2.21760E+03
    7.39200E+01  1.23200E+00  7.39200E+01  2.21760E+03  4.25622E+04  3.08000E+03  1.01871E+05  5.46950E+05  1.09032E+05  1.16424E+04
    4.11850E+04  7.27650E+03  7.31500E+02  9.47100E+03  2.04435E+05  9.69353E+04  4.49341E+05  1.55455E+06  1.51228E+07  3.99087E+07
    7.09486E+07  8.36486E+08  7.12946E+09
25  2.28089E+10  2.64297E+09  2.16970E+08  1.22046E+08  4.10973E+07  5.24346E+06  1.81963E+06  4.30106E+05  1.37083E+05  7.14240E+03
    2.38080E+02  3.96800E+00  2.38080E+02  7.14240E+03  1.37083E+05  9.92000E+03  3.28104E+05  1.76161E+06  3.51168E+05  3.74976E+04
    1.32648E+05  2.34360E+04  2.35600E+03  3.05040E+04  6.58440E+05  3.12207E+05  1.44723E+06  5.00687E+06  4.87072E+07  1.28537E+08
    2.28510E+08  2.69414E+09  2.29624E+10
26  7.81757E+09  9.05858E+08  7.43648E+07  4.18302E+07  1.40858E+07  1.79716E+06  6.23662E+05  1.47416E+05  4.69843E+04  2.44800E+03
    8.16000E+01  1.36000E+00  8.16000E+01  2.44800E+03  4.69843E+04  3.40000E+03  1.12455E+05  6.03776E+05  1.20360E+05  1.28520E+04
    4.54639E+04  8.03250E+03  8.07500E+02  1.04550E+04  2.25675E+05  1.07007E+05  4.96026E+05  1.71607E+06  1.66940E+07  4.40551E+07
    7.83199E+07  9.23393E+08  7.87018E+09
27  1.59111E+10  1.84369E+09  1.51354E+08  8.51368E+07  2.86687E+07  3.65774E+06  1.26934E+06  3.00034E+05  9.56268E+04  4.98240E+03
    1.66080E+02  2.76800E+00  1.66080E+02  4.98240E+03  9.56268E+04  6.92000E+03  2.28879E+05  1.22886E+06  2.44968E+05  2.61576E+04
    9.25325E+04  1.63485E+04  1.64350E+03  2.12790E+04  4.59315E+05  2.17790E+05  1.00956E+06  3.49270E+06  3.39772E+07  8.96650E+07
    1.59404E+08  1.87938E+09  1.60181E+10
28  9.74897E+10  1.12966E+10  9.27373E+08  5.21647E+08  1.75658E+08  2.24116E+07  7.77743E+06  1.83836E+06  5.85921E+05  3.05280E+04
    1.01760E+03  1.69600E+01  1.01760E+03  3.05280E+04  5.85921E+05  4.24000E+04  1.40238E+06  7.52945E+06  1.50096E+06  1.60272E+05
    5.66962E+05  1.00170E+05  1.00700E+04  1.30380E+05  2.81430E+06  1.33443E+06  6.18574E+06  2.14003E+07  2.08184E+08  5.49393E+08
    9.76695E+08  1.15153E+10  9.81458E+10
29  3.98236E+10  4.61455E+09  3.78823E+08  2.13088E+08  7.17546E+07  9.15492E+06  3.17701E+06  7.50952E+05  2.39343E+05  1.24704E+04
    4.15680E+02  6.92800E+00  4.15680E+02  1.24704E+04  2.39343E+05  1.73200E+04  5.72859E+05  3.07571E+06  6.13128E+05  6.54696E+04
    2.31599E+05  4.09185E+04  4.11350E+03  5.32590E+04  1.14962E+06  5.45104E+05  2.52681E+06  8.74184E+06  8.50412E+07  2.24422E+08
    3.98971E+08  4.70387E+09  4.00916E+10
30  1.44027E+10  1.66891E+09  1.37006E+08  7.70660E+07  2.59510E+07  3.31099E+06  1.14901E+06  2.71591E+05  8.65616E+04  4.51008E+03
    1.50336E+02  2.50560E+00  1.50336E+02  4.51008E+03  8.65616E+04  6.26400E+03  2.07182E+05  1.11237E+06  2.21746E+05  2.36779E+04
    8.37606E+04  1.47987E+04  1.48770E+03  1.92618E+04  4.15773E+05  1.97144E+05  9.13855E+05  3.16160E+06  3.07562E+07  8.11650E+07
    1.44293E+08  1.70122E+09  1.44996E+10
31  9.19715E+07  1.06572E+07  8.74880E+05  4.92120E+05  1.65715E+05  2.11430E+04  7.33720E+03  1.73430E+03  5.52756E+02  2.88000E+01
    9.60000E-01  1.60000E-02  9.60000E-01  2.88000E+02  5.52756E+02  4.00000E+01  1.32300E+03  7.10325E+03  1.41600E+03  1.51200E+02
    5.34870E+02  9.45000E+01  9.50000E+00  1.23000E+02  2.65500E+03  1.25890E+03  5.83560E+03  2.01890E+04  1.96400E+05  5.18295E+05
    9.21410E+05  1.08635E+07  9.25904E+07

*************************************************************************
    Elapsed Time
     0.000000E+00 sec = 0.000000E+00 day = 0.000000E+00 yr
    DELT
     5.231209E+06 sec = 6.054640E+01 day = 1.657706E-01 yr
    Time Step Number  =   391
    Total Newton-Raphson Iterations          =   1321
    Avg Newton-Raphson Iterations/Time Step  =  3.379
    CPU Time (this time step) =     6.52 sec =  0.00181 hr
    CPU Time (total for run)  =  3865.68 sec =  1.07380 hr
*************************************************************************

    Cumulative Mass Balance
       Brine:  -3.834158E-18
       Gas:    -1.099778E-15

    Maximum Relative Mass Balance (Current Time Step)
       Brine:   1.151902E-06 at (I,J,K) =   20   12    1
       Gas:    -4.896622E-04 at (I,J,K) =   20   12    1
-------------------------------------------------------------------------------------------------------------------------------------
 Brine pressure                                    Pa
    Layer   1
 1  1.55023E+07  1.55023E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07
    1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07
    1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07
    1.27000E+07  1.55023E+07  1.55023E+07
 2  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
    1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
    1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
    1.52006E+07  1.52006E+07  1.52006E+07
 3  1.74745E+07  1.53729E+07  1.47424E+07  1.45585E+07  1.44272E+07  1.43642E+07  1.43494E+07  1.43442E+07  1.43385E+07  1.43329E+07
    1.43316E+07  1.43314E+07  1.43311E+07  1.43299E+07  1.43242E+07  1.43154E+07  1.43007E+07  1.42382E+07  1.41756E+07  1.41567E+07
    1.41186E+07  1.40836E+07  1.40773E+07  1.40699E+07  1.40111E+07  1.39575E+07  1.39522E+07  1.39375E+07  1.38745E+07  1.37431E+07
    1.35591E+07  1.29288E+07  1.08272E+07
 4  1.63357E+07  1.42342E+07  1.36037E+07  1.34198E+07  1.32885E+07  1.32254E+07  1.32107E+07  1.32054E+07  1.31998E+07  1.31941E+07
    1.31928E+07  1.31926E+07  1.31923E+07  1.31911E+07  1.31854E+07  1.31766E+07  1.31619E+07  1.30994E+07  1.30369E+07  1.30179E+07
    1.29798E+07  1.29448E+07  1.29385E+07  1.29312E+07  1.28723E+07  1.28187E+07  1.28135E+07  1.27988E+07  1.27357E+07  1.26044E+07
    1.24205E+07  1.17900E+07  9.68848E+06
 5  1.59685E+07  1.38670E+07  1.32365E+07  1.30526E+07  1.29213E+07  1.28582E+07  1.28382E+07  1.27728E+07  1.27269E+07  1.27212E+07
    1.27199E+07  1.27197E+07  1.27194E+07  1.27182E+07  1.27126E+07  1.27039E+07  1.26893E+07  1.26270E+07  1.25650E+07  1.25466E+07
    1.25106E+07  1.24776E+07  1.24717E+07  1.24642E+07  1.24051E+07  1.23969E+07  1.24421E+07  1.24315E+07  1.23685E+07  1.22372E+07
    1.20533E+07  1.14228E+07  9.32126E+06
 6  1.58972E+07  1.37956E+07  1.31652E+07  1.29813E+07  1.28499E+07  1.27806E+07  1.23350E+07  9.48755E+06  8.30625E+06  8.30057E+06
    8.29931E+06  8.29906E+06  8.29881E+06  8.29755E+06  8.29189E+06  8.28311E+06  8.26841E+06  8.20585E+06  8.14332E+06  8.12447E+06
    8.08662E+06  8.05192E+06  1.01325E+05  8.03811E+06  7.97940E+06  9.40563E+06  1.20081E+07  1.23555E+07  1.22972E+07  1.21659E+07
    1.19820E+07  1.13515E+07  9.24993E+06
 7  1.58838E+07  1.37822E+07  1.31517E+07  1.29678E+07  1.28365E+07  1.27714E+07  1.25661E+07  1.06790E+07  8.29279E+06  8.28712E+06
    8.28586E+06  8.28561E+06  8.28537E+06  8.28411E+06  8.27845E+06  8.26966E+06  8.25497E+06  8.19240E+06  8.12988E+06  8.11102E+06
    8.07318E+06  8.03847E+06  1.01325E+05  8.02486E+06  7.96595E+06  1.05761E+07  1.22061E+07  1.23453E+07  1.22838E+07  1.21524E+07
    1.19685E+07  1.13381E+07  9.23650E+06
 8  1.58675E+07  1.37659E+07  1.31355E+07  1.29516E+07  1.28202E+07  1.27569E+07  1.27036E+07  1.20693E+07  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.17875E+07  1.23148E+07  1.23303E+07  1.22675E+07  1.21362E+07
    1.19523E+07  1.13218E+07  9.22024E+06
 9  1.58516E+07  1.37500E+07  1.31196E+07  1.29357E+07  1.28043E+07  1.27412E+07  1.27196E+07  1.24667E+07  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.21129E+07  1.23240E+07  1.23146E+07  1.22516E+07  1.21203E+07
    1.19364E+07  1.13059E+07  9.20434E+06
10  1.58357E+07  1.37341E+07  1.31037E+07  1.29198E+07  1.27884E+07  1.27253E+07  1.27048E+07  1.24447E+07  1.01325E+05  1.01325E+05
```

```
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.20918E+07  1.23089E+07  1.22987E+07  1.22357E+07  1.21044E+07
    1.19205E+07  1.12900E+07  9.18844E+06
11  1.58120E+07  1.37104E+07  1.30800E+07  1.28961E+07  1.27647E+07  1.27015E+07  1.26541E+07  1.19061E+07  8.22029E+06  8.21523E+06
    8.21395E+06  8.21362E+06  8.21330E+06  8.21202E+06  8.20608E+06  8.19774E+06  8.18312E+06  8.12063E+06  8.05842E+06  8.03949E+06
    8.00172E+06  7.96675E+06  1.01325E+05  7.95300E+06  7.89426E+06  1.16407E+07  1.22636E+07  1.22749E+07  1.22120E+07  1.20807E+07
    1.18969E+07  1.12663E+07  9.16473E+06
12  1.57946E+07  1.36930E+07  1.30626E+07  1.28787E+07  1.27473E+07  1.26831E+07  1.25257E+07  1.02881E+07  8.20219E+06  8.19781E+06
    8.19654E+06  8.19611E+06  8.19564E+06  8.19418E+06  8.18811E+06  8.18027E+06  8.16574E+06  8.10334E+06  8.04151E+06  8.02262E+06
    7.98479E+06  7.94951E+06  1.01325E+05  7.93560E+06  7.87703E+06  1.02007E+07  1.21517E+07  1.22567E+07  1.21946E+07  1.20633E+07
    1.18794E+07  1.12489E+07  9.14735E+06
13  1.57652E+07  1.36637E+07  1.30332E+07  1.28493E+07  1.27180E+07  1.26548E+07  1.26279E+07  1.22585E+07  8.17157E+06  8.16783E+06
    8.16729E+06  8.16654E+06  8.16579E+06  8.16458E+06  8.15778E+06  8.15076E+06  8.13637E+06  8.07412E+06  8.03406E+06  8.02077E+06
    7.96865E+06  7.92041E+06  1.01325E+05  7.90619E+06  7.84942E+06  1.19236E+07  1.22332E+07  1.22282E+07  1.21652E+07  1.20339E+07
    1.18500E+07  1.12195E+07  9.11797E+06
14  1.57107E+07  1.36091E+07  1.29787E+07  1.27948E+07  1.26634E+07  1.26004E+07  1.25846E+07  1.24420E+07  8.16931E+06  8.16764E+06
    8.16631E+06  8.16367E+06  8.16102E+06  8.15936E+06  8.15732E+06  8.13049E+06  8.09631E+06  8.06048E+06  8.03379E+06  8.02049E+06
    7.96833E+06  7.88461E+06  1.01325E+05  7.85158E+06  7.84914E+06  1.20725E+07  1.21880E+07  1.21737E+07  1.21107E+07  1.19794E+07
    1.17955E+07  1.11650E+07  9.06343E+06
15  1.56828E+07  1.35812E+07  1.29508E+07  1.27669E+07  1.26355E+07  1.25724E+07  1.25464E+07  1.23902E+07  8.14166E+06  8.13990E+06
    8.13857E+06  8.13593E+06  8.13328E+06  8.13162E+06  8.12958E+06  8.10275E+06  8.06856E+06  8.03273E+06  8.00601E+06  7.99272E+06
    7.94056E+06  7.85684E+06  1.01325E+05  7.82382E+06  7.82140E+06  1.21000E+07  1.21568E+07  1.21458E+07  1.20828E+07  1.19515E+07
    1.17676E+07  1.11371E+07  9.03556E+06
16  1.55378E+07  1.34363E+07  1.28058E+07  1.26219E+07  1.24906E+07  1.24275E+07  1.24128E+07  1.24071E+07  1.23797E+07  1.23740E+07
    1.23728E+07  1.23725E+07  1.23722E+07  1.23710E+07  1.23653E+07  1.23565E+07  1.23417E+07  1.22792E+07  1.22168E+07  1.21980E+07
    1.21603E+07  1.21208E+07  1.01325E+05  1.21087E+07  1.20533E+07  1.20207E+07  1.20156E+07  1.20009E+07  1.19379E+07  1.18065E+07
    1.16226E+07  1.09922E+07  8.89060E+06
17  1.50784E+07  1.29768E+07  1.23464E+07  1.21625E+07  1.20311E+07  1.19681E+07  1.19534E+07  1.19481E+07  1.19425E+07  1.19368E+07
    1.19356E+07  1.19353E+07  1.19351E+07  1.19338E+07  1.19281E+07  1.19193E+07  1.19046E+07  1.18421E+07  1.17796E+07  1.17607E+07
    1.17225E+07  1.16827E+07  1.01325E+05  1.16705E+07  1.16150E+07  1.15614E+07  1.15562E+07  1.15415E+07  1.14784E+07  1.13471E+07
    1.11632E+07  1.05327E+07  8.43116E+06
18  1.44473E+07  1.23457E+07  1.17152E+07  1.15314E+07  1.14000E+07  1.13370E+07  1.13222E+07  1.13170E+07  1.13113E+07  1.13057E+07
    1.13044E+07  1.13042E+07  1.13039E+07  1.13027E+07  1.12970E+07  1.12882E+07  1.12735E+07  1.12110E+07  1.11484E+07  1.11295E+07
    1.10914E+07  1.10516E+07  1.01325E+05  1.10394E+07  1.09839E+07  1.09303E+07  1.09251E+07  1.09103E+07  1.08473E+07  1.07159E+07
    1.05321E+07  9.90159E+06  7.80003E+06
19  1.36147E+07  1.15132E+07  1.08827E+07  1.06988E+07  1.05674E+07  1.05044E+07  1.04897E+07  1.04844E+07  1.04788E+07  1.04731E+07
    1.04719E+07  1.04716E+07  1.04714E+07  1.04701E+07  1.04645E+07  1.04556E+07  1.04409E+07  1.03784E+07  1.03159E+07  1.02970E+07
    1.02588E+07  1.02191E+07  1.01325E+05  1.02069E+07  1.01513E+07  1.00977E+07  1.00925E+07  1.00778E+07  1.00147E+07  9.88339E+06
    9.69951E+06  9.06904E+06  6.96747E+06
20  1.25807E+07  1.04792E+07  9.84871E+06  9.66482E+06  9.53347E+06  9.47042E+06  9.45571E+06  9.45046E+06  9.44481E+06  9.43915E+06
    9.43789E+06  9.43764E+06  9.43739E+06  9.43613E+06  9.43047E+06  9.42167E+06  9.40696E+06  9.34443E+06  9.28191E+06  9.26300E+06
    9.22486E+06  9.18529E+06  1.01325E+05  9.17303E+06  9.11736E+06  9.06377E+06  9.05852E+06  9.04380E+06  8.98076E+06  8.84941E+06
    8.66552E+06  8.03505E+06  5.93349E+06
21  1.17908E+07  9.68924E+06  9.05877E+06  8.87488E+06  8.74353E+06  8.68049E+06  8.66578E+06  8.66052E+06  8.65487E+06  8.64922E+06
    8.64795E+06  8.64770E+06  8.64745E+06  8.64619E+06  8.64054E+06  8.63173E+06  8.61702E+06  8.55450E+06  8.49198E+06  8.47306E+06
    8.43492E+06  8.39549E+06  1.01325E+05  8.38318E+06  8.32742E+06  8.27383E+06  8.26858E+06  8.25387E+06  8.19082E+06  8.05947E+06
    7.87559E+06  7.24512E+06  5.14355E+06
22  1.12934E+07  9.19187E+06  8.56140E+06  8.37751E+06  8.24617E+06  8.18112E+06  8.16841E+06  8.16315E+06  8.15750E+06  8.15185E+06
    8.15059E+06  8.15034E+06  8.15008E+06  8.14882E+06  8.14317E+06  8.13436E+06  8.11965E+06  8.05713E+06  7.99461E+06  7.97569E+06
    7.93755E+06  7.89820E+06  1.01325E+05  7.88587E+06  7.83006E+06  7.77647E+06  7.77121E+06  7.75650E+06  7.69345E+06  7.56211E+06
    7.37822E+06  6.74775E+06  4.64618E+06
23  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06
    2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06
    2.29653E+06  2.29653E+06  1.01325E+05  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06  2.29653E+06
    2.29653E+06  2.29653E+06  2.29653E+06
24  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05
    8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05
    8.52000E+05  8.52000E+05  1.01325E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05  8.52000E+05
    8.52000E+05  8.52000E+05  8.52000E+05
25  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06
    1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06
    1.83774E+06  1.83774E+06  1.01325E+05  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06  1.83774E+06
    1.83774E+06  1.83774E+06  1.83774E+06
26  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05
    9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05
    9.00000E+05  9.00000E+05  1.01325E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05  9.00000E+05
    9.00000E+05  9.00000E+05  9.00000E+05
27  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06
    1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06
    1.48191E+06  1.48191E+06  1.01325E+05  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06  1.48191E+06
    1.48191E+06  1.48191E+06  1.48191E+06
28  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05
    7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05
    7.39535E+05  7.39535E+05  1.01325E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05  7.39535E+05
    7.39535E+05  7.39535E+05  7.39535E+05
29  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05
30  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05
31  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05  1.01325E+05
    1.01325E+05  1.01325E+05  1.01325E+05
-----------------------------------------------------------------------------------------------------------------------------------
Gas pressure                                    Pa
   Layer   1
 1  1.55023E+07  1.55023E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07
    1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07
    1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07  1.27022E+07
    1.27022E+07  1.55023E+07  1.55023E+07
 2  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
    1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
    1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
    1.52006E+07  1.52006E+07  1.52006E+07
 3  2.30398E+07  2.09382E+07  2.03077E+07  2.01238E+07  1.99925E+07  1.99294E+07  1.99147E+07  1.99095E+07  1.99038E+07  1.98982E+07
    1.98969E+07  1.98967E+07  1.98964E+07  1.98951E+07  1.98895E+07  1.98807E+07  1.98660E+07  1.98035E+07  1.97409E+07  1.97220E+07
    1.96839E+07  1.96489E+07  1.96426E+07  1.96352E+07  1.95764E+07  1.95228E+07  1.95175E+07  1.95028E+07  1.94398E+07  1.93084E+07
    1.91245E+07  1.84941E+07  1.63925E+07
 4  2.19010E+07  1.97995E+07  1.91690E+07  1.89851E+07  1.88518E+07  1.87907E+07  1.87760E+07  1.87707E+07  1.87650E+07  1.87594E+07
    1.87581E+07  1.87579E+07  1.87576E+07  1.87564E+07  1.87507E+07  1.87419E+07  1.87272E+07  1.86647E+07  1.86022E+07  1.85832E+07
    1.85451E+07  1.85101E+07  1.85038E+07  1.84965E+07  1.84376E+07  1.83840E+07  1.83788E+07  1.83641E+07  1.83010E+07  1.81697E+07
    1.79858E+07  1.73553E+07  1.52538E+07
 5  2.15338E+07  1.94322E+07  1.88018E+07  1.86179E+07  1.84865E+07  1.84234E+07  1.84035E+07  1.83381E+07  1.82921E+07  1.82865E+07
    1.82852E+07  1.82850E+07  1.82847E+07  1.82835E+07  1.82779E+07  1.82692E+07  1.82545E+07  1.81923E+07  1.81303E+07  1.81119E+07
    1.80759E+07  1.80429E+07  1.80370E+07  1.80295E+07  1.79704E+07  1.79622E+07  1.80074E+07  1.79968E+07  1.79338E+07  1.78025E+07
    1.76186E+07  1.69881E+07  1.48866E+07
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6	1.59487E+07	1.38472E+07	1.32167E+07	1.30328E+07	1.29015E+07	1.28322E+07	1.23865E+07	9.53910E+06	8.30625E+06	8.30057E+06
	8.29931E+06	8.29906E+06	8.29881E+06	8.29755E+06	8.29189E+06	8.28311E+06	8.26841E+06	8.20585E+06	8.14332E+06	8.12447E+06
	8.08662E+06	8.05192E+06	1.60133E+06	8.03831E+06	7.97940E+06	9.45718E+06	1.20596E+07	1.24071E+07	1.23488E+07	1.22174E+07
	1.20335E+07	1.14031E+07	9.30149E+06							
7	2.14490E+07	1.93475E+07	1.87170E+07	1.85331E+07	1.84018E+07	1.83367E+07	1.81314E+07	1.62443E+07	8.29279E+06	8.28712E+06
	8.28586E+06	8.28561E+06	8.28537E+06	8.28411E+06	8.27845E+06	8.26966E+06	8.25497E+06	8.19240E+06	8.12988E+06	8.11102E+06
	8.07318E+06	8.03847E+06	1.60133E+06	8.02486E+06	7.96595E+06	1.61414E+07	1.77714E+07	1.79106E+07	1.78491E+07	1.77177E+07
	1.75338E+07	1.69034E+07	1.48018E+07							
8	2.14328E+07	1.93312E+07	1.87008E+07	1.85169E+07	1.83855E+07	1.83222E+07	1.82689E+07	1.76346E+07	1.05708E+05	1.05708E+05
	1.05708E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.01325E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.60133E+06	1.01325E+05	1.01325E+05	1.73528E+07	1.78801E+07	1.78956E+07	1.78328E+07	1.77015E+07
	1.75176E+07	1.68871E+07	1.47855E+07							
9	2.14169E+07	1.93153E+07	1.86849E+07	1.85010E+07	1.83696E+07	1.83065E+07	1.82849E+07	1.80320E+07	1.05708E+05	1.05708E+05
	1.05708E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.01325E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.60133E+06	1.01325E+05	1.01325E+05	1.76782E+07	1.78893E+07	1.78799E+07	1.78169E+07	1.76856E+07
	1.75017E+07	1.68712E+07	1.47696E+07							
10	2.14010E+07	1.92994E+07	1.86690E+07	1.84851E+07	1.83537E+07	1.82906E+07	1.82701E+07	1.80100E+07	1.05708E+05	1.05708E+05
	1.05708E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.01325E+05	1.05708E+05	1.05708E+05	1.05708E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.60133E+06	1.01325E+05	1.01325E+05	1.76571E+07	1.78742E+07	1.78640E+07	1.78010E+07	1.76697E+07
	1.74858E+07	1.68553E+07	1.47537E+07							
11	2.13773E+07	1.92757E+07	1.86452E+07	1.84614E+07	1.83300E+07	1.82668E+07	1.82194E+07	1.74714E+07	8.22029E+06	8.21523E+06
	8.21395E+06	8.21362E+06	8.21330E+06	8.21202E+06	8.20608E+06	8.19774E+06	8.18312E+06	8.12063E+06	8.05842E+06	8.03949E+06
	8.00172E+06	7.96675E+06	1.60133E+06	7.95300E+06	7.89426E+06	1.72060E+07	1.78289E+07	1.78402E+07	1.77773E+07	1.76460E+07
	1.74621E+07	1.68316E+07	1.47300E+07							
12	1.58462E+07	1.37446E+07	1.31141E+07	1.29302E+07	1.27989E+07	1.27346E+07	1.25773E+07	1.03397E+07	8.20219E+06	8.19781E+06
	8.19654E+06	8.19611E+06	8.19564E+06	8.19438E+06	8.18813E+06	8.18027E+06	8.16574E+06	8.10334E+06	8.04151E+06	8.02262E+06
	7.98479E+06	7.94951E+06	1.60133E+06	7.93560E+06	7.87703E+06	1.02522E+07	1.22032E+07	1.23083E+07	1.22462E+07	1.21146E+07
	1.19309E+07	1.13005E+07	9.19891E+06							
13	2.13305E+07	1.92290E+07	1.85985E+07	1.84146E+07	1.82833E+07	1.82201E+07	1.81931E+07	1.78238E+07	8.17157E+06	8.16783E+06
	8.16729E+06	8.16654E+06	8.16579E+06	8.16458E+06	8.15778E+06	8.15076E+06	8.13637E+06	8.07412E+06	8.03406E+06	8.02077E+06
	7.96865E+06	7.92041E+06	1.60133E+06	7.90619E+06	7.84942E+06	1.74989E+07	1.77985E+07	1.77935E+07	1.77305E+07	1.75992E+07
	1.74153E+07	1.67848E+07	1.46833E+07							
14	2.12760E+07	1.91744E+07	1.85439E+07	1.83601E+07	1.82287E+07	1.81657E+07	1.81499E+07	1.80073E+07	8.16931E+06	8.16764E+06
	8.16631E+06	8.16367E+06	8.16102E+06	8.15936E+06	8.15732E+06	8.13049E+06	8.09631E+06	8.06048E+06	8.03379E+06	8.02049E+06
	7.96833E+06	7.88461E+06	4.53018E+06	7.85158E+06	7.84914E+06	1.76378E+07	1.77533E+07	1.77390E+07	1.76760E+07	1.75447E+07
	1.73608E+07	1.67303E+07	1.46287E+07							
15	1.57344E+07	1.36328E+07	1.30023E+07	1.28184E+07	1.26871E+07	1.26239E+07	1.25979E+07	1.24418E+07	8.19623E+06	8.19454E+06
	8.19321E+06	8.19059E+06	8.18791E+06	8.18625E+06	8.18416E+06	8.15697E+06	8.12223E+06	8.08639E+06	8.05760E+06	8.04427E+06
	7.99211E+06	7.90839E+06	4.53018E+06	7.87651E+06	7.87540E+06	1.21516E+07	1.22083E+07	1.21974E+07	1.21344E+07	1.20030E+07
	1.18192E+07	1.11887E+07	9.08711E+06							
16	2.11031E+07	1.90016E+07	1.83711E+07	1.81872E+07	1.80559E+07	1.79928E+07	1.79781E+07	1.79724E+07	1.79450E+07	1.79393E+07
	1.79380E+07	1.79378E+07	1.79375E+07	1.79363E+07	1.79306E+07	1.79218E+07	1.79070E+07	1.78445E+07	1.77821E+07	1.77633E+07
	1.77256E+07	1.76861E+07	4.53018E+06	1.76739E+07	1.76186E+07	1.75860E+07	1.75809E+07	1.75662E+07	1.75032E+07	1.73718E+07
	1.71879E+07	1.65575E+07	1.44559E+07							
17	2.06437E+07	1.85421E+07	1.79117E+07	1.77278E+07	1.75964E+07	1.75334E+07	1.75187E+07	1.75134E+07	1.75078E+07	1.75021E+07
	1.75008E+07	1.75006E+07	1.75003E+07	1.74991E+07	1.74934E+07	1.74846E+07	1.74699E+07	1.74074E+07	1.73449E+07	1.73260E+07
	1.72878E+07	1.72480E+07	4.53018E+06	1.72358E+07	1.71803E+07	1.71267E+07	1.71215E+07	1.71068E+07	1.70437E+07	1.69124E+07
	1.67285E+07	1.60980E+07	1.39965E+07							
18	2.00126E+07	1.79110E+07	1.72805E+07	1.70967E+07	1.69653E+07	1.69023E+07	1.68875E+07	1.68823E+07	1.68766E+07	1.68710E+07
	1.68697E+07	1.68695E+07	1.68692E+07	1.68680E+07	1.68623E+07	1.68535E+07	1.68388E+07	1.67763E+07	1.67137E+07	1.66948E+07
	1.66567E+07	1.66169E+07	4.53018E+06	1.66047E+07	1.65492E+07	1.64956E+07	1.64904E+07	1.64756E+07	1.64126E+07	1.62812E+07
	1.60974E+07	1.54669E+07	1.33653E+07							
19	1.91800E+07	1.70785E+07	1.64480E+07	1.62641E+07	1.61327E+07	1.60697E+07	1.60550E+07	1.60497E+07	1.60441E+07	1.60384E+07
	1.60372E+07	1.60369E+07	1.60367E+07	1.60354E+07	1.60298E+07	1.60209E+07	1.60062E+07	1.59437E+07	1.58812E+07	1.58623E+07
	1.58241E+07	1.57844E+07	1.40325E+05	1.57722E+07	1.57166E+07	1.56630E+07	1.56578E+07	1.56431E+07	1.55800E+07	1.54487E+07
	1.52648E+07	1.46343E+07	1.25328E+07							
20	1.81460E+07	1.60445E+07	1.54140E+07	1.52301E+07	1.50988E+07	1.50357E+07	1.50210E+07	1.50158E+07	1.50101E+07	1.50044E+07
	1.50032E+07	1.50029E+07	1.50027E+07	1.50014E+07	1.49958E+07	1.49870E+07	1.49723E+07	1.49097E+07	1.48472E+07	1.48283E+07
	1.47902E+07	1.47506E+07	1.40325E+05	1.47383E+07	1.46827E+07	1.46291E+07	1.46238E+07	1.46091E+07	1.45461E+07	1.44147E+07
	1.42308E+07	1.36003E+07	1.14988E+07							
21	1.73561E+07	1.52545E+07	1.46241E+07	1.44402E+07	1.43088E+07	1.42458E+07	1.42311E+07	1.42258E+07	1.42202E+07	1.42145E+07
	1.42132E+07	1.42130E+07	1.42127E+07	1.42115E+07	1.42058E+07	1.41970E+07	1.41823E+07	1.41198E+07	1.40573E+07	1.40384E+07
	1.40002E+07	1.39608E+07	1.60133E+06	1.39485E+07	1.38927E+07	1.38391E+07	1.38339E+07	1.38192E+07	1.37561E+07	1.36248E+07
	1.34409E+07	1.28104E+07	1.07088E+07							
22	1.68587E+07	1.47572E+07	1.41267E+07	1.39428E+07	1.38115E+07	1.37484E+07	1.37337E+07	1.37284E+07	1.37228E+07	1.37171E+07
	1.37159E+07	1.37156E+07	1.37154E+07	1.37141E+07	1.37085E+07	1.36997E+07	1.36849E+07	1.36224E+07	1.35599E+07	1.35410E+07
	1.35028E+07	1.34635E+07	1.01325E+05	1.34512E+07	1.33954E+07	1.33418E+07	1.33365E+07	1.33218E+07	1.32587E+07	1.31274E+07
	1.29475E+07	1.23130E+07	1.02115E+07							
23	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	4.53018E+05	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	2.29653E+06							
24	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05
	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05
	8.60343E+05	8.60343E+05	4.53018E+06	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05	8.60343E+05
	8.60343E+05	8.60343E+05	8.60343E+05							
25	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	4.53018E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	1.83774E+06							
26	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06
	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06
	1.02356E+06	1.02356E+06	4.53018E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06	1.02356E+06
	1.02356E+06	1.02356E+06	1.02356E+06							
27	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	4.53018E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	1.48191E+06							
28	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05
	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05
	7.39535E+05	7.39535E+05	1.15545E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05	7.39535E+05
	7.39535E+05	7.39535E+05	7.39535E+05							
29	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.15545E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05							
30	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.15545E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05							
31	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.15545E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05							

Porosity										
					dimensionless					
Layer 1										
1	5.00000E-03	5.00000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03
	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03
	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03

	5.20000E-03	5.00000E-03	5.00000E-03								
2	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03
	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03
	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03
	5.00000E-03	5.00000E-03	5.00000E-03								
3	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02
	1.00000E-02	1.00000E-02	1.00000E-02								
4	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02
	1.00000E-02	1.00000E-02	1.00000E-02								
5	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99958E-03	9.99473E-03	9.99149E-03	9.99149E-03	
	9.99149E-03	9.99149E-03	9.99149E-03	9.99149E-03	9.99149E-03	9.99150E-03	9.99151E-03	9.99153E-03	9.99157E-03	9.99161E-03	
	9.99178E-03	9.99194E-03	9.99198E-03	9.99197E-03	9.99194E-03	9.99560E-03	9.99966E-03	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
6	1.90000E-02	1.90000E-02	1.90000E-02	1.90000E-02	1.90000E-02	1.89995E-02	1.89658E-02	1.87450E-02	6.91529E-03	6.91527E-03	
	6.91527E-03	6.91527E-03	6.91528E-03	6.91528E-03	6.91528E-03	6.91529E-03	6.91529E-03	6.91527E-03	6.91527E-03	6.91530E-03	
	6.91547E-03	6.91563E-03	7.50000E-02	6.91566E-03	6.91563E-03	1.87685E-02	1.89713E-02	1.89996E-02	1.90000E-02	1.90000E-02	
	2.90000E-02	1.90000E-02	1.90000E-02								
7	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99983E-03	9.98450E-03	9.83430E-03	6.91527E-03	6.91526E-03	
	6.91526E-03	6.91526E-03	6.91527E-03	6.91527E-03	6.91526E-03	6.91526E-03	6.91529E-03	6.91526E-03	6.91526E-03	6.91529E-03	
	6.91546E-03	6.91563E-03	7.50000E-02	6.91566E-03	6.91562E-03	9.85680E-03	9.98749E-03	9.99988E-03	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
8	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99997E-03	9.99687E-03	9.94635E-03	8.48349E-01	8.48349E-01	
	8.48349E-01	8.48349E-01	8.48349E-01	8.48349E-01	8.48349E-01	7.50000E-02	8.48349E-01	8.48349E-01	8.48349E-01	7.50000E-02	
	1.00000E+00	1.00000E+00	7.50000E-02	1.00000E+00	1.00000E+00	9.95475E-03	9.99754E-03	9.99998E-03	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
9	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99944E-03	9.97951E-03	8.48349E-01	8.48349E-01	
	8.48349E-01	8.48349E-01	8.48349E-01	8.48349E-01	8.48349E-01	7.50000E-02	8.48349E-01	8.48349E-01	8.48349E-01	7.50000E-02	
	1.00000E+00	1.00000E+00	7.50000E-02	1.00000E+00	1.00000E+00	9.98216E-03	9.99957E-03	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
10	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99953E-03	9.97902E-03	8.48349E-01	8.48349E-01	
	8.48349E-01	8.48349E-01	8.48349E-01	8.48349E-01	8.48349E-01	7.50000E-02	8.48349E-01	8.48349E-01	8.48349E-01	7.50000E-02	
	1.00000E+00	1.00000E+00	7.50000E-02	1.00000E+00	1.00000E+00	9.98174E-03	9.99963E-03	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
11	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99998E-03	9.99736E-03	9.93772E-03	6.91485E-03	6.91519E-03	
	6.91518E-03	6.91514E-03	6.91510E-03	6.91509E-03	6.91492E-03	6.91519E-03	6.91524E-03	6.91526E-03	6.91543E-03	6.91543E-03	
	6.91564E-03	6.91565E-03	7.50000E-02	6.91560E-03	6.91566E-03	9.94744E-03	9.99789E-03	9.99999E-03	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
12	1.90000E-02	1.90000E-02	1.90000E-02	1.90000E-02	1.90000E-02	1.89999E-02	1.89887E-02	1.88149E-02	6.91444E-03	6.91517E-03	
	6.91517E-03	6.91506E-03	6.91494E-03	6.91494E-03	6.91460E-03	6.91514E-03	6.91524E-03	6.91531E-03	6.91571E-03	6.91572E-03	
	6.91590E-03	6.91573E-03	7.50000E-02	6.91559E-03	6.91575E-03	1.88381E-02	1.89905E-02	1.89999E-02	1.90000E-02	1.90000E-02	
	1.90000E-02	1.90000E-02	1.90000E-02								
13	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99999E-03	9.99901E-03	9.96972E-03	6.91373E-03	6.91482E-03	
	6.91524E-03	6.91495E-03	6.91467E-03	6.91470E-03	6.91404E-03	6.91506E-03	6.91525E-03	6.91540E-03	6.92827E-03	6.93151E-03	
	6.92348E-03	6.91590E-03	7.50000E-02	6.91557E-03	6.91677E-03	9.97389E-03	9.99921E-03	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
14	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99991E-03	9.98886E-03	6.94372E-03	6.94601E-03	
	6.94598E-03	6.94460E-03	6.94322E-03	6.94299E-03	6.94507E-03	6.93471E-03	6.92354E-03	6.93886E-03	6.95947E-03	6.96271E-03	
	6.95464E-03	6.92663E-03	7.50000E-02	6.91553E-03	6.94791E-03	9.99024E-03	9.99996E-03	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
15	1.90000E-02	1.90000E-02	1.90000E-02	1.90000E-02	1.90000E-02	1.90000E-02	1.89991E-02	1.89873E-02	1.86582E-02	1.86585E-02	
	1.86585E-02	1.86583E-02	1.86581E-02	1.86581E-02	1.86584E-02	1.86570E-02	1.86555E-02	1.86575E-02	1.86603E-02	1.86607E-02	
	1.86597E-02	1.86559E-02	7.50000E-02	1.86544E-02	1.86588E-02	1.89948E-02	1.89997E-02	1.90000E-02	1.90000E-02	1.90000E-02	
	1.90000E-02	1.90000E-02	1.90000E-02								
16	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	9.99996E-03	9.99821E-03	9.99821E-03	
	9.99821E-03	9.99821E-03	9.99821E-03	9.99821E-03	9.99821E-03	9.99820E-03	9.99820E-03	9.99820E-03	9.99821E-03	9.99822E-03	
	9.99825E-03	9.99789E-03	7.50000E-02	9.99801E-03	9.99830E-03	9.99999E-03	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
17	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	9.99961E-03	7.50000E-02	9.99973E-03	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
18	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	9.99961E-03	7.50000E-02	9.99973E-03	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
19	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	9.99962E-03	4.00000E-02	9.99974E-03	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
20	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	9.99963E-03	4.00000E-02	9.99974E-03	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
21	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	9.99964E-03	7.50000E-02	9.99975E-03	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
22	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	9.99965E-03	1.00000E-02	9.99976E-03	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
23	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.50000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.00000E-01								
24	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	
	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	
	1.46000E-01	1.46000E-01	2.50000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	
	1.46000E-01	1.46000E-01	1.46000E-01								
25	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.50000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.00000E-01								
26	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	
	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	
	9.00000E-02	9.00000E-02	2.50000E-01	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	9.00000E-02	
	9.00000E-02	9.00000E-02	9.00000E-02								
27	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.50000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	
	2.00000E-01	2.00000E-01	2.00000E-01								
28	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	
	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	
	1.50000E-01	1.50000E-01	2.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	
	1.50000E-01	1.50000E-01	1.50000E-01								
29	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	

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   1.50000E-01  1.50000E-01  1.50000E-01
30 1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01
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   1.75000E-01  1.75000E-01  2.50000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01
   1.75000E-01  1.75000E-01  1.75000E-01
31 1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01
   1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01
   1.75000E-01  1.75000E-01  2.50000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01  1.75000E-01
   1.75000E-01  1.75000E-01  1.75000E-01
-----------------------------------------------------------------------------------------------------------------------------------
 Gas saturation                                          fraction void volume
   Layer  1
 1 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
 2 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
 3 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
 4 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
 5 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  1.92558E-27  1.89194E-37  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  9.71260E-27  4.03821E-28  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
 6 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.07109-292  4.57515-267  5.46330-246
   3.93890-226  7.35237-208  4.92368-192  4.83145-173  9.24647-158  1.02201-127  4.55561-108  3.02605E-87  1.16018E-66  1.51627E-47
   6.35965E-24  1.23600E-09  2.00000E-01  9.10818E-10  6.38700E-25  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
 7 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.87170E-03  1.11854E-03
   8.02756E-04  8.32346E-06  2.35331E-12  3.41448E-06  4.66282E-04  7.97552E-09  8.86234E-06  2.27949E-15  1.70526E-43  8.16109E-46
   3.21458E-22  4.49964E-09  2.00000E-01  3.29791E-09  3.16999E-23  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
 8 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  9.99400E-01  9.99400E-01
   9.99400E-01  9.99400E-01  9.99400E-01  9.99400E-01  9.99400E-01  1.00000E+00  9.99400E-01  9.99400E-01  9.99400E-01  1.00000E+00
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   0.00000E+00  0.00000E+00  0.00000E+00
 9 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  9.99400E-01  9.99400E-01
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   0.00000E+00  0.00000E+00  0.00000E+00
10 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  9.99400E-01  9.99400E-01
   9.99400E-01  9.99400E-01  9.99400E-01  9.99400E-01  9.99400E-01  1.00000E+00  9.99400E-01  9.99400E-01  9.99400E-01  1.00000E+00
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   0.00000E+00  0.00000E+00  0.00000E+00
11 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  7.75026E-03  1.26811E-02
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   4.26836E-02  3.68385E-02  2.00000E-01  5.11478E-04  2.32309E-02  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
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13 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.17008E-01  7.48246E-01
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   4.07351E-01  5.98714E-02  2.00000E-01  3.01189E-03  2.79560E-01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
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14 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  7.77236E-01  7.81976E-01
   7.85831E-01  7.85527E-01  7.69637E-01  7.06964E-01  6.54748E-01  6.20555E-01  5.75003E-01  5.65656E-01  5.95124E-01  5.96948E-01
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   0.00000E+00  0.00000E+00  0.00000E+00
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   0.00000E+00  0.00000E+00  0.00000E+00
23 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E-00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E-00  0.00000E+00  0.00000E+00  0.00000E+00
   4.34262E-72  3.27733E-18  2.00000E-01  2.27592E-18  4.39973E-73  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
24 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   1.00301E-69  2.68831E-17  2.00000E-01  1.86688E-17  1.39716E-70  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
```

```
25  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    1.36888E-71  4.80875E-18  2.00000E-01  3.33941E-18  1.73730E-72  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
26  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    6.21124E-76  2.22823E-17  2.00000E-01  1.54738E-17  8.72003E-71  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
27  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    6.61621E-71  9.66265E-18  2.00000E-01  6.71014E-18  9.11929E-72  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
28  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    1.19197E-69  2.96709E-17  2.00000E-01  2.06048E-17  1.62185E-70  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
29  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  2.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  8.00000E-01
30  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  2.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  8.00000E-01
31  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  2.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01  8.00000E-01
    8.00000E-01  8.00000E-01  8.00000E-01
```

```
Fe concentration -- simple model                    kg/m^3
  Layer   1
1  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
2  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
3  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
4  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
5  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
6  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
7  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
8  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.57520E+02  1.57520E+02
   1.57520E+02  1.57520E+02  1.57520E+02  1.57520E+02  1.57520E+02  0.00000E+00  1.57520E+02  1.57520E+02  1.57520E+02  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
9  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.57520E+02  1.57520E+02
   1.57520E+02  1.57520E+02  1.57520E+02  1.57520E+02  1.57520E+02  0.00000E+00  1.57520E+02  1.57520E+02  1.57520E+02  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
10 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.57520E+02  1.57520E+02
   1.57520E+02  1.57520E+02  1.57520E+02  1.57520E+02  1.57520E+02  0.00000E+00  1.57520E+02  1.57520E+02  1.57520E+02  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
11 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
12 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
13 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
14 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
15 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
16 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
17 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
18 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
19 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
20 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
```

	0.00000E+00	0.00000E+00	0.00000E+00								
21	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
22	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
23	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
24	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
26	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
27	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
28	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
29	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
30	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
31	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								

CH2O concentration -- simple model kg/m^3

Layer 1

1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
2	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
3	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
4	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
5	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
6	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
7	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
8	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.24477E+01	9.24477E+01	9.24477E+01
	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
9	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.24477E+01	9.24477E+01	9.24477E+01
	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
10	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.24477E+01	9.24477E+01	9.24477E+01
	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	9.24477E+01	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
11	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
12	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
13	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
14	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
15	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00								
16	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

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    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
17  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
18  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
19  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
20  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
21  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
22  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
23  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
24  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
25  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
26  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
27  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
28  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
29  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
30  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00
31  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00

Date:  01/25/96  Time: 17:24:19  CPU Time: 0  1: 4:26.09 (  3866.09 sec)  ASCII

Time Step No. =  391   Elapsed Time = 0.000000E+00 days
Date:  01/25/96  Time: 17:24:20  CPU Time: 0  1: 4:26.31 (  3866.31 sec)  Binary

Time Step No. =  400   Elapsed Time = 2.728293E-02 days
Date:  01/25/96  Time: 17:25:11  CPU Time: 0  1: 5:16.80 (  3916.80 sec)  Binary

Time Step No. =  420   Elapsed Time = 2.717887E-01 days
Date:  01/25/96  Time: 17:27:12  CPU Time: 0  1: 7:15.81 (  4035.81 sec)  Binary

Time Step No. =  440   Elapsed Time = 2.708876E+00 days
Date:  01/25/96  Time: 17:29:14  CPU Time: 0  1: 9:16.65 (  4156.65 sec)  Binary

Time Step No. =  460   Elapsed Time = 1.696966E+02 days
Date:  01/25/96  Time: 17:31:32  CPU Time: 0  1:11:32.72 (  4292.72 sec)  Binary

Time Step No. =  480   Elapsed Time = 3.104677E+03 days
Date:  01/25/96  Time: 17:34:05  CPU Time: 0  1:14: 4.27 (  4444.27 sec)  Binary

Time Step No. =  500   Elapsed Time = 3.654611E+03 days
Date:  01/25/96  Time: 17:34:58  CPU Time: 0  1:14:56.30 (  4496.30 sec)  Binary

Time Step No. =  520   Elapsed Time = 3.844984E+03 days
Date:  01/25/96  Time: 17:36:04  CPU Time: 0  1:16: 1.30 (  4561.30 sec)  Binary

Time Step No. =  540   Elapsed Time = 9.131076E+03 days
Date:  01/25/96  Time: 17:37:29  CPU Time: 0  1:17:23.99 (  4643.99 sec)  Binary

Time Step No. =  560   Elapsed Time = 9.139449E+03 days
Date:  01/25/96  Time: 17:38:16  CPU Time: 0  1:18: 9.84 (  4689.84 sec)  Binary

Time Step No. =  580   Elapsed Time = 9.865662E+03 days
Date:  01/25/96  Time: 17:39:34  CPU Time: 0  1:19:26.39 (  4766.39 sec)  Binary

Time Step No. =  600   Elapsed Time = 1.826182E+04 days
Date:  01/25/96  Time: 17:41:53  CPU Time: 0  1:21:44.59 (  4904.59 sec)  Binary

Time Step No. =  620   Elapsed Time = 1.826525E+04 days
Date:  01/25/96  Time: 17:42:41  CPU Time: 0  1:22:30.71 (  4950.71 sec)  Binary

Time Step No. =  640   Elapsed Time = 1.856271E+04 days
Date:  01/25/96  Time: 17:43:34  CPU Time: 0  1:23:23.22 (  5003.22 sec)  Binary

Time Step No. =  660   Elapsed Time = 3.652432E+04 days
Date:  01/25/96  Time: 17:45:18  CPU Time: 0  1:25: 5.49 (  5105.49 sec)  Binary
```

```
Time Step No. =  680   Elapsed Time = 3.652860E+04 days
Date:  01/25/96  Time: 17:46:06  CPU Time: 0  1:25:51.41 (  5151.41 sec)  Binary

Time Step No. =  700   Elapsed Time = 3.690042E+04 days
Date:  01/25/96  Time: 17:46:53  CPU Time: 0  1:26:37.23 (  5197.23 sec)  Binary

Time Step No. =  720   Elapsed Time = 6.893473E+04 days
Date:  01/25/96  Time: 17:48:41  CPU Time: 0  1:28:23.24 (  5303.24 sec)  Binary

Time Step No. =  740   Elapsed Time = 7.305135E+04 days
Date:  01/25/96  Time: 17:49:32  CPU Time: 0  1:29:13.39 (  5353.39 sec)  Binary

Time Step No. =  760   Elapsed Time = 7.328931E+04 days
Date:  01/25/96  Time: 17:50:26  CPU Time: 0  1:30: 5.56 (  5405.56 sec)  Binary

Time Step No. =  780   Elapsed Time = 9.392955E+04 days
Date:  01/25/96  Time: 17:52:12  CPU Time: 0  1:31:49.43 (  5509.43 sec)  Binary

Time Step No. =  800   Elapsed Time = 1.460996E+05 days
Date:  01/25/96  Time: 17:54:52  CPU Time: 0  1:34:27.93 (  5667.93 sec)  Binary

Time Step No. =  820   Elapsed Time = 1.461127E+05 days
Date:  01/25/96  Time: 17:55:39  CPU Time: 0  1:35:13.91 (  5713.91 sec)  Binary

Time Step No. =  840   Elapsed Time = 1.472474E+05 days
Date:  01/25/96  Time: 17:56:41  CPU Time: 0  1:36:14.71 (  5774.71 sec)  Binary

Time Step No. =  860   Elapsed Time = 1.995843E+05 days
Date:  01/25/96  Time: 17:58:44  CPU Time: 0  1:38:16.07 (  5896.07 sec)  Binary

Time Step No. =  880   Elapsed Time = 3.271868E+05 days
Date:  01/25/96  Time: 18:03:22  CPU Time: 0  1:42:52.74 (  6172.74 sec)  Binary

Time Step No. =  900   Elapsed Time = 3.284052E+05 days
Date:  01/25/96  Time: 18:04:53  CPU Time: 0  1:44:22.18 (  6262.18 sec)  Binary

Time Step No. =  920   Elapsed Time = 4.327011E+05 days
Date:  01/25/96  Time: 18:06:55  CPU Time: 0  1:46:23.62 (  6383.62 sec)  Binary

Time Step No. =  940   Elapsed Time = 7.727755E+05 days
Date:  01/25/96  Time: 18:12:01  CPU Time: 0  1:51:27.93 (  6687.93 sec)  Binary

Time Step No. =  960   Elapsed Time = 7.741322E+05 days
Date:  01/25/96  Time: 18:13:58  CPU Time: 0  1:53:23.17 (  6803.17 sec)  Binary

Time Step No. =  980   Elapsed Time = 8.450515E+05 days
Date:  01/25/96  Time: 18:15:07  CPU Time: 0  1:55: 1.19 (  6901.19 sec)  Binary

Time Step No. = 1000   Elapsed Time = 1.242988E+06 days
Date:  01/25/96  Time: 18:17:35  CPU Time: 0  1:56:58.18 (  7018.18 sec)  Binary

Time Step No. = 1020   Elapsed Time = 1.642988E+06 days
Date:  01/25/96  Time: 18:19:17  CPU Time: 0  1:58:38.26 (  7118.26 sec)  Binary

Time Step No. = 1040   Elapsed Time = 2.042988E+06 days
Date:  01/25/96  Time: 18:20:47  CPU Time: 0  2: 0: 7.75 (  7207.75 sec)  Binary

Time Step No. = 1060   Elapsed Time = 2.442988E+06 days
Date:  01/25/96  Time: 18:22:18  CPU Time: 0  2: 1:36.71 (  7296.71 sec)  Binary

Time Step No. = 1080   Elapsed Time = 2.842988E+06 days
Date:  01/25/96  Time: 18:23:48  CPU Time: 0  2: 3: 5.99 (  7385.99 sec)  Binary

Time Step No. = 1100   Elapsed Time = 3.242988E+06 days
Date:  01/25/96  Time: 18:25:19  CPU Time: 0  2: 4:35.44 (  7475.44 sec)  Binary

Time Step No. = 1120   Elapsed Time = 3.642988E+06 days
Date:  01/25/96  Time: 18:26:49  CPU Time: 0  2: 6: 4.39 (  7564.39 sec)  Binary


Restart information has been written to I/O unit  2 in DISKW, file name:
BF2_OUTSRESTART
  for time step IPRINT = 1121   IRESTARTCOUNT =  1
  TIME =  3.155700000000000E+11s     DELT =  0.000000000000000E+00 s
  IMATTIME+KRESTMAT =  8,   IWELLTIME+KRESTWELL =  0
  KRESTMAT =  0   KRESTWELL =  0


*************************************************************************
   Elapsed Time
    3.155700E+11 sec = 3.652431E+06 day = 1.000002E+04 yr
   DELT
    8.158234E+08 sec = 9.442400E+03 day = 2.585243E+01 yr
   Time Step Number  =  1121
   Total Newton-Raphson Iterations          =   2740
   Avg Newton-Raphson Iterations/Time Step  =  2.444
   CPU Time (this time step) =     4.73 sec =  0.00131 hr
   CPU Time (total for run)  =  7568.86 sec =  2.10246 hr
*************************************************************************


   Cumulative Mass Balance
      Brine:   1.105940E-17
      Gas:     6.088281E-13

   Maximum Relative Mass Balance (Current Time Step)
      Brine:  -5.071291E-07 at (I,J,K) =   15    9    1
      Gas:     4.928396E-05 at (I,J,K) =   12    8    1
-------------------------------------------------------------------------------------------------------------------------
Brine pressure                                        Pa
   Layer   1
1  1.55023E+07  1.55023E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07
   1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07
   1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07  1.27000E+07
   1.27000E+07  1.55023E+07  1.55023E+07
2  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
   1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
   1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07  1.52006E+07
   1.52006E+07  1.52006E+07  1.52006E+07
3  1.74752E+07  1.53735E+07  1.47410E+07  1.45591E+07  1.44290E+07  1.43693E+07  1.43542E+07  1.43486E+07  1.43401E+07  1.43335E+07
   1.43314E+07  1.43297E+07  1.43280E+07  1.43259E+07  1.43195E+07  1.43113E+07  1.42953E+07  1.41858E+07  1.40827E+07  1.40647E+07
```

	1.40329E+07	1.39999E+07	1.40046E+07	1.40092E+07	1.39504E+07	1.39339E+07	1.39296E+07	1.39241E+07	1.38745E+07	1.37436E+07
	1.35597E+07	1.29292E+07	1.08274E+07							
4	1.63357E+07	1.42341E+07	1.36036E+07	1.34200E+07	1.33251E+07	1.33656E+07	1.34288E+07	1.34229E+07	1.33855E+07	1.33707E+07
	1.33624E+07	1.33493E+07	1.33362E+07	1.33279E+07	1.33121E+07	1.33398E+07	1.33199E+07	1.28287E+07	1.24285E+07	1.24196E+07
	1.24374E+07	1.24168E+07	1.25244E+07	1.26372E+07	1.25314E+07	1.26898E+07	1.26897E+07	1.27157E+07	1.27312E+07	1.26043E+07
	1.24204E+07	1.17900E+07	9.68835E+06							
5	1.59684E+07	1.38668E+07	1.32364E+07	1.30533E+07	1.30304E+07	1.31279E+07	1.33166E+07	1.33072E+07	1.31946E+07	1.31653E+07
	1.31682E+07	1.31723E+07	1.31754E+07	1.31462E+07	1.30546E+07	1.31834E+07	1.31387E+07	1.25188E+07	1.20473E+07	1.20448E+07
	1.20788E+07	1.20357E+07	1.22349E+07	1.23857E+07	1.21888E+07	1.23385E+07	1.23458E+07	1.23666E+07	1.23623E+07	1.22370E+07
	1.20532E+07	1.14227E+07	9.32110E+06							
6	1.58971E+07	1.37955E+07	1.31650E+07	1.29820E+07	1.29755E+07	1.30772E+07	1.34621E+07	1.35447E+07	1.36295E+07	1.36295E+07
	1.36295E+07	1.36295E+07	1.36295E+07	1.36295E+07	1.36294E+07	1.36294E+07	1.36292E+07	1.36287E+07	1.36282E+07	1.36280E+07
	1.36277E+07	1.36274E+07	1.23481E+07	1.23408E+07	1.23108E+07	1.22703E+07	1.22796E+07	1.22999E+07	1.22907E+07	1.21656E+07
	1.19818E+07	1.13513E+07	9.24976E+06							
7	1.58836E+07	1.37820E+07	1.31516E+07	1.29686E+07	1.29641E+07	1.30654E+07	1.34481E+07	1.35220E+07	1.36294E+07	1.36294E+07
	1.36294E+07	1.36294E+07	1.36294E+07	1.36294E+07	1.36293E+07	1.36292E+07	1.36291E+07	1.36286E+07	1.36281E+07	1.36279E+07
	1.36276E+07	1.36273E+07	1.23347E+07	1.23273E+07	1.23107E+07	1.22574E+07	1.22666E+07	1.22873E+07	1.22773E+07	1.21522E+07
	1.19684E+07	1.13379E+07	9.23633E+06							
8	1.58674E+07	1.37658E+07	1.31353E+07	1.29523E+07	1.29519E+07	1.30520E+07	1.34317E+07	1.35037E+07	1.36249E+07	1.36249E+07
	1.36249E+07	1.36249E+07	1.36249E+07	1.36248E+07	1.36248E+07	1.36291E+07	1.36246E+07	1.36241E+07	1.36236E+07	1.36278E+07
	1.36275E+07	1.36272E+07	1.23184E+07	1.23110E+07	1.23106E+07	1.22422E+07	1.22512E+07	1.22726E+07	1.22610E+07	1.21359E+07
	1.19521E+07	1.13216E+07	9.22007E+06							
9	1.58515E+07	1.37499E+07	1.31194E+07	1.29364E+07	1.29401E+07	1.30388E+07	1.34156E+07	1.34863E+07	1.36248E+07	1.36247E+07
	1.36247E+07	1.36247E+07	1.36247E+07	1.36247E+07	1.36247E+07	1.36290E+07	1.36245E+07	1.36240E+07	1.36234E+07	1.36277E+07
	1.36273E+07	1.36271E+07	1.23024E+07	1.23109E+07	1.23105E+07	1.22271E+07	1.22361E+07	1.22583E+07	1.22452E+07	1.21200E+07
	1.19362E+07	1.13057E+07	9.20417E+06							
10	1.58355E+07	1.37340E+07	1.31035E+07	1.29205E+07	1.29284E+07	1.30255E+07	1.33997E+07	1.34693E+07	1.36247E+07	1.36246E+07
	1.36246E+07	1.36246E+07	1.36246E+07	1.36246E+07	1.36245E+07	1.36288E+07	1.36243E+07	1.36238E+07	1.36233E+07	1.36275E+07
	1.36272E+07	1.36269E+07	1.22865E+07	1.23108E+07	1.23104E+07	1.22120E+07	1.22211E+07	1.22441E+07	1.22293E+07	1.21041E+07
	1.19203E+07	1.12898E+07	9.18827E+06							
11	1.58118E+07	1.37103E+07	1.30798E+07	1.28967E+07	1.29111E+07	1.30054E+07	1.33760E+07	1.34445E+07	1.36288E+07	1.36288E+07
	1.36288E+07	1.36288E+07	1.36288E+07	1.36288E+07	1.36287E+07	1.36287E+07	1.36285E+07	1.36280E+07	1.36275E+07	1.36273E+07
	1.36270E+07	1.36267E+07	1.22627E+07	1.23106E+07	1.23102E+07	1.21892E+07	1.21986E+07	1.22229E+07	1.22056E+07	1.20804E+07
	1.18965E+07	1.12661E+07	9.16456E+06							
12	1.57944E+07	1.36929E+07	1.30624E+07	1.28793E+07	1.29072E+07	1.32572E+07	1.33962E+07	1.34521E+07	1.36287E+07	1.36287E+07
	1.36286E+07	1.36286E+07	1.36286E+07	1.36286E+07	1.36286E+07	1.36285E+07	1.36284E+07	1.36279E+07	1.36274E+07	1.36272E+07
	1.36269E+07	1.36266E+07	1.22453E+07	1.23105E+07	1.23100E+07	1.21875E+07	1.21974E+07	1.22081E+07	1.21883E+07	1.20630E+07
	1.18792E+07	1.12487E+07	9.14717E+06							
13	1.57651E+07	1.36635E+07	1.30330E+07	1.28499E+07	1.28551E+07	1.32307E+07	1.32840E+07	1.32849E+07	1.36285E+07	1.36284E+07
	1.36284E+07	1.36284E+07	1.36284E+07	1.36284E+07	1.36283E+07	1.36283E+07	1.36281E+07	1.36276E+07	1.36271E+07	1.36270E+07
	1.36266E+07	1.36263E+07	1.22159E+07	1.23103E+07	1.23098E+07	1.21598E+07	1.21590E+07	1.21760E+07	1.21590E+07	1.20336E+07
	1.18498E+07	1.12194E+07	9.11780E+06							
14	1.57105E+07	1.36089E+07	1.29785E+07	1.27953E+07	1.27866E+07	1.31830E+07	1.32303E+07	1.32303E+07	1.36280E+07	1.36280E+07
	1.36279E+07	1.36279E+07	1.36279E+07	1.36279E+07	1.36279E+07	1.36278E+07	1.36277E+07	1.36272E+07	1.36267E+07	1.36265E+07
	1.36262E+07	1.36259E+07	1.21557E+07	1.23099E+07	1.23094E+07	1.21082E+07	1.21037E+07	1.21183E+07	1.21046E+07	1.19791E+07
	1.17953E+07	1.11648E+07	9.06325E+06							
15	1.56826E+07	1.35811E+07	1.29506E+07	1.27674E+07	1.27525E+07	1.31906E+07	1.32472E+07	1.32534E+07	1.34769E+07	1.34812E+07
	1.34805E+07	1.34806E+07	1.34808E+07	1.34800E+07	1.34787E+07	1.34784E+07	1.34779E+07	1.34759E+07	1.34743E+07	1.34737E+07
	1.34722E+07	1.34462E+07	1.21263E+07	1.21758E+07	1.21902E+07	1.20829E+07	1.20757E+07	1.20890E+07	1.20768E+07	1.19512E+07
	1.17674E+07	1.11370E+07	9.03538E+06							
16	1.55377E+07	1.34361E+07	1.28056E+07	1.26222E+07	1.25722E+07	1.26384E+07	1.24716E+07	1.24434E+07	1.23414E+07	1.23038E+07
	1.22750E+07	1.22243E+07	1.21735E+07	1.21451E+07	1.21166E+07	1.21012E+07	1.20839E+07	1.20276E+07	1.19749E+07	1.19562E+07
	1.18944E+07	1.14747E+07	1.19731E+07	1.14249E+07	1.16428E+07	1.19246E+07	1.19226E+07	1.19374E+07	1.15325E+07	1.18063E+07
	1.16225E+07	1.09920E+07	8.89043E+06							
17	1.50783E+07	1.29767E+07	1.23462E+07	1.21624E+07	1.20501E+07	1.20267E+07	1.19442E+07	1.19286E+07	1.18605E+07	1.18305E+07
	1.18078E+07	1.17681E+07	1.17283E+07	1.17058E+07	1.16823E+07	1.16682E+07	1.16513E+07	1.15934E+07	1.15381E+07	1.15185E+07
	1.14525E+07	1.09380E+07	1.14952E+07	1.09323E+07	1.12489E+07	1.14694E+07	1.14677E+07	1.14838E+07	1.14756E+07	1.13469E+07
	1.11630E+07	1.05326E+07	8.43100E+06							
18	1.44471E+07	1.23456E+07	1.17151E+07	1.15312E+07	1.14024E+07	1.13420E+07	1.13066E+07	1.12980E+07	1.12704E+07	1.12553E+07
	1.12455E+07	1.12295E+07	1.12136E+07	1.12039E+07	1.11911E+07	1.11801E+07	1.11644E+07	1.11037E+07	1.10438E+07	1.10229E+07
	1.09447E+07	1.00919E+07	1.08732E+07	1.02085E+07	1.08251E+07	1.08918E+07	1.08862E+07	1.08879E+07	1.08464E+07	1.07158E+07
	1.05319E+07	9.90143E+06	7.79986E+06							
19	1.36146E+07	1.15130E+07	1.08825E+07	1.06987E+07	1.05674E+07	1.05038E+07	1.04863E+07	1.04806E+07	1.04719E+07	1.04648E+07
	1.04623E+07	1.04597E+07	1.04571E+07	1.04546E+07	1.04479E+07	1.04387E+07	1.04239E+07	1.03616E+07	1.02994E+07	1.02769E+07
	1.01738E+07	8.48148E+06	8.48938E+06	8.73950E+06	1.01127E+07	1.00919E+07	1.00870E+07	1.00746E+07	1.00145E+07	9.88325E+06
	9.69936E+06	9.06890E+06	6.96733E+06							
20	1.25806E+07	1.04750E+07	9.84856E+06	9.66467E+06	9.53333E+06	9.47019E+06	9.45526E+06	9.44997E+06	9.44407E+06	9.43830E+06
	9.43693E+06	9.43649E+06	9.43604E+06	9.43468E+06	9.42893E+06	9.42010E+06	9.40538E+06	9.34287E+06	9.28030E+06	9.25708E+06
	9.13878E+06	6.87304E+06	6.79945E+06	7.23461E+06	9.09581E+06	9.06310E+06	9.05792E+06	9.04343E+06	8.98061E+06	8.84927E+06
	8.66539E+06	8.03493E+06	5.93336E+06							
21	1.17904E+07	9.68898E+06	9.05856E+06	8.87469E+06	8.74335E+06	8.68029E+06	8.66555E+06	8.66029E+06	8.65461E+06	8.64894E+06
	8.64766E+06	8.64739E+06	8.64711E+06	8.64584E+06	8.64017E+06	8.63136E+06	8.61665E+06	8.55414E+06	8.49153E+06	8.46750E+06
	8.32752E+06	4.82581E+06	3.44082E+06	5.40983E+06	8.30227E+06	8.27352E+06	8.26834E+06	8.25369E+06	8.19068E+06	8.05935E+06
	7.87547E+06	7.24505E+06	5.14366E+06							
22	1.12926E+07	9.19146E+06	8.56112E+06	8.37727E+06	8.24595E+06	8.18292E+06	8.16820E+06	8.16295E+06	8.15729E+06	8.15163E+06
	8.15037E+06	8.15011E+06	8.14986E+06	8.14859E+06	8.14294E+06	8.13413E+06	8.11942E+06	8.05692E+06	7.99431E+06	7.97013E+06
	7.82630E+06	4.17574E+06	2.94200E+06	4.77968E+06	7.80418E+06	7.77623E+06	7.77105E+06	7.75639E+06	7.69336E+06	7.56204E+06
	7.37820E+06	6.74786E+06	4.64676E+06							
23	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	1.22194E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	2.29653E+06							
24	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05
	8.52001E+05	8.52001E+05	8.52001E+05	8.52001E+05	8.52001E+05	8.52002E+05	8.52003E+05	8.52003E+05	8.52004E+05	8.52005E+05
	8.52010E+05	8.52021E+05	9.03288E+05	8.52010E+05	8.52002E+05	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05	8.52000E+05
	8.52000E+05	8.52000E+05	8.52000E+05							
25	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	9.63391E+05	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	1.83774E+06							
26	9.00000E+05	9.00148E+05	9.00255E+05	9.00325E+05	9.00407E+05	9.00468E+05	9.00489E+05	9.00497E+05	9.00606E+05	9.00819E+05
	9.01054E+05	9.01489E+05	9.01924E+05	9.02159E+05	9.02372E+05	9.03707E+05	9.05168E+05	9.06460E+05	9.07737E+05	9.09253E+05
	9.15152E+05	9.33193E+05	9.84676E+05	9.18793E+05	9.04285E+05	9.00610E+05	9.00596E+05	9.00566E+05	9.00497E+05	9.00405E+05
	9.00320E+05	9.00188E+05	9.00000E+05							
27	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	1.25004E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	1.48191E+06							
28	7.39553E+05	7.40161E+05	7.41503E+05	7.42446E+05	7.43587E+05	7.44452E+05	7.44754E+05	7.44875E+05	7.46419E+05	7.49458E+05
	7.52802E+05	7.59003E+05	7.65204E+05	7.68548E+05	7.71587E+05	7.90617E+05	8.11436E+05	8.29852E+05	8.48096E+05	8.69789E+05
	9.54155E+05	1.00942E+06	1.01011E+06	9.67460E+05	8.46497E+05	7.51383E+05	7.51026E+05	7.50250E+05	7.48470E+05	7.46135E+05
	7.44073E+05	7.41067E+05	7.39583E+05							
29	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05
	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05
	1.01365E+05	2.17043E+05	2.55324E+05	2.17742E+05	1.01356E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05
	1.01355E+05	1.01355E+05	1.01355E+05							
30	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05
	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05
	1.01331E+05	1.01331E+05	1.07050E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05
	1.01331E+05	1.01331E+05	1.01331E+05							

31	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05
	1.01325E+05	1.01325E+05	1.01325E+05							

Gas pressure Pa

Layer 1

1	1.55023E+07	1.55023E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07
	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07
	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07	1.27022E+07
	1.27022E+07	1.55023E+07	1.55023E+07							
2	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07
	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07
	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07	1.52006E+07
	1.52006E+07	1.52006E+07	1.52006E+07							
3	2.30405E+07	2.09388E+07	2.03083E+07	2.01244E+07	1.99943E+07	1.99146E+07	1.99195E+07	1.99139E+07	1.99054E+07	1.98988E+07
	1.98967E+07	1.98950E+07	1.98933E+07	1.98912E+07	1.98848E+07	1.98766E+07	1.98606E+07	1.97510E+07	1.96479E+07	1.96300E+07
	1.95982E+07	1.95652E+07	1.95699E+07	1.95745E+07	1.95157E+07	1.94992E+07	1.94949E+07	1.94894E+07	1.94398E+07	1.93089E+07
	1.91250E+07	1.84945E+07	1.63927E+07							
4	2.19010E+07	1.97994E+07	1.91689E+07	1.89853E+07	1.88904E+07	1.89309E+07	1.89941E+07	1.89881E+07	1.89508E+07	1.89360E+07
	1.89277E+07	1.89146E+07	1.89015E+07	1.88931E+07	1.88774E+07	1.89051E+07	1.88852E+07	1.83940E+07	1.79938E+07	1.79849E+07
	1.80027E+07	1.79821E+07	1.80897E+07	1.82025E+07	1.80967E+07	1.82551E+07	1.82550E+07	1.82810E+07	1.82965E+07	1.81696E+07
	1.79857E+07	1.73552E+07	1.52536E+07							
5	2.15337E+07	1.94321E+07	1.88017E+07	1.86186E+07	1.85956E+07	1.86932E+07	1.89019E+07	1.88725E+07	1.87599E+07	1.87305E+07
	1.87335E+07	1.87376E+07	1.87407E+07	1.87115E+07	1.86199E+07	1.87487E+07	1.87040E+07	1.80841E+07	1.76126E+07	1.76101E+07
	1.76441E+07	1.76010E+07	1.78002E+07	1.79510E+07	1.77541E+07	1.79038E+07	1.79111E+07	1.79319E+07	1.79276E+07	1.78023E+07
	1.76185E+07	1.69880E+07	1.48864E+07							
6	1.59486E+07	1.38470E+07	1.32166E+07	1.30336E+07	1.30270E+07	1.31288E+07	1.35331E+07	1.36290E+07	1.36295E+07	1.36295E+07
	1.36295E+07	1.36295E+07	1.36295E+07	1.36295E+07	1.36294E+07	1.36294E+07	1.36292E+07	1.36287E+07	1.36282E+07	1.36280E+07
	1.36277E+07	1.36274E+07	1.38032E+07	1.23408E+07	1.23108E+07	1.23376E+07	1.23312E+07	1.23515E+07	1.23423E+07	1.22172E+07
	1.20334E+07	1.14029E+07	9.30132E+06							
7	2.14489E+07	1.93473E+07	1.87169E+07	1.85339E+07	1.85294E+07	1.86307E+07	1.90134E+07	1.90872E+07	1.36294E+07	1.36294E+07
	1.36294E+07	1.36294E+07	1.36294E+07	1.36294E+07	1.36293E+07	1.36292E+07	1.36291E+07	1.36286E+07	1.36281E+07	1.36279E+07
	1.36276E+07	1.36273E+07	1.38029E+07	1.23273E+07	1.23107E+07	1.78227E+07	1.78319E+07	1.78526E+07	1.78426E+07	1.77175E+07
	1.75337E+07	1.69032E+07	1.48016E+07							
8	2.14326E+07	1.93311E+07	1.87006E+07	1.85176E+07	1.85172E+07	1.86173E+07	1.89970E+07	1.90690E+07	1.36293E+07	1.36293E+07
	1.36292E+07	1.36292E+07	1.36292E+07	1.36292E+07	1.36292E+07	1.36291E+07	1.36290E+07	1.36285E+07	1.36280E+07	1.36278E+07
	1.36275E+07	1.36272E+07	1.38026E+07	1.23110E+07	1.23106E+07	1.78074E+07	1.78165E+07	1.78379E+07	1.78263E+07	1.77012E+07
	1.75174E+07	1.68869E+07	1.47854E+07							
9	2.14167E+07	1.93152E+07	1.86847E+07	1.85017E+07	1.85054E+07	1.86041E+07	1.89809E+07	1.90516E+07	1.36292E+07	1.36291E+07
	1.36291E+07	1.36291E+07	1.36291E+07	1.36291E+07	1.36291E+07	1.36290E+07	1.36289E+07	1.36283E+07	1.36278E+07	1.36277E+07
	1.36273E+07	1.36271E+07	1.37972E+07	1.23109E+07	1.23105E+07	1.77924E+07	1.78014E+07	1.78236E+07	1.78105E+07	1.76853E+07
	1.75015E+07	1.68710E+07	1.47695E+07							
10	2.14008E+07	1.92993E+07	1.86688E+07	1.84858E+07	1.84937E+07	1.85908E+07	1.89650E+07	1.90346E+07	1.36290E+07	1.36290E+07
	1.36290E+07	1.36290E+07	1.36290E+07	1.36290E+07	1.36289E+07	1.36288E+07	1.36287E+07	1.36282E+07	1.36277E+07	1.36275E+07
	1.36272E+07	1.36269E+07	1.37829E+07	1.23108E+07	1.23104E+07	1.77772E+07	1.77864E+07	1.78094E+07	1.77946E+07	1.76694E+07
	1.74856E+07	1.68551E+07	1.47536E+07							
11	2.13771E+07	1.92756E+07	1.86452E+07	1.84620E+07	1.84764E+07	1.85706E+07	1.89413E+07	1.90098E+07	1.36288E+07	1.36288E+07
	1.36288E+07	1.36288E+07	1.36288E+07	1.36288E+07	1.36287E+07	1.36287E+07	1.36285E+07	1.36280E+07	1.36275E+07	1.36273E+07
	1.36270E+07	1.36267E+07	1.37629E+07	1.23106E+07	1.23102E+07	1.77545E+07	1.77639E+07	1.77882E+07	1.77709E+07	1.76457E+07
	1.74619E+07	1.68314E+07	1.47299E+07							
12	1.58460E+07	1.37444E+07	1.31140E+07	1.29309E+07	1.29745E+07	1.34247E+07	1.35692E+07	1.36259E+07	1.36287E+07	1.36287E+07
	1.36286E+07	1.36286E+07	1.36286E+07	1.36286E+07	1.36286E+07	1.36285E+07	1.36284E+07	1.36279E+07	1.36274E+07	1.36272E+07
	1.36269E+07	1.36266E+07	1.37455E+07	1.23105E+07	1.23100E+07	1.23094E+07	1.23014E+07	1.22651E+07	1.22398E+07	1.21146E+07
	1.19308E+07	1.13003E+07	9.19873E+06							
13	2.13304E+07	1.92288E+07	1.85983E+07	1.84152E+07	1.84204E+07	1.87960E+07	1.88493E+07	1.88501E+07	1.36285E+07	1.36284E+07
	1.36284E+07	1.36284E+07	1.36284E+07	1.36284E+07	1.36283E+07	1.36283E+07	1.36281E+07	1.36276E+07	1.36271E+07	1.36270E+07
	1.36266E+07	1.36263E+07	1.37164E+07	1.23103E+07	1.23098E+07	1.77251E+07	1.77243E+07	1.77413E+07	1.77243E+07	1.75989E+07
	1.74151E+07	1.67847E+07	1.46831E+07							
14	2.12758E+07	1.91742E+07	1.85438E+07	1.83606E+07	1.83519E+07	1.87483E+07	1.87956E+07	1.87956E+07	1.36280E+07	1.36280E+07
	1.36279E+07	1.36279E+07	1.36279E+07	1.36279E+07	1.36279E+07	1.36278E+07	1.36277E+07	1.36272E+07	1.36267E+07	1.36265E+07
	1.36262E+07	1.36259E+07	1.36753E+07	1.23099E+07	1.23094E+07	1.76735E+07	1.76690E+07	1.76836E+07	1.76699E+07	1.75444E+07
	1.73606E+07	1.67301E+07	1.46285E+07							
15	1.57342E+07	1.36326E+07	1.30022E+07	1.28190E+07	1.28041E+07	1.32765E+07	1.33663E+07	1.33904E+07	1.36278E+07	1.36277E+07
	1.36277E+07	1.36277E+07	1.36277E+07	1.36277E+07	1.36277E+07	1.36276E+07	1.36275E+07	1.36269E+07	1.36264E+07	1.36263E+07
	1.36260E+07	1.36257E+07	1.36590E+07	1.23096E+07	1.23092E+07	1.21400E+07	1.21273E+07	1.21406E+07	1.21284E+07	1.20028E+07
	1.18190E+07	1.11885E+07	9.08694E+06							
16	2.11030E+07	1.90014E+07	1.83709E+07	1.81875E+07	1.81375E+07	1.82037E+07	1.80369E+07	1.80087E+07	1.79067E+07	1.78691E+07
	1.78403E+07	1.77896E+07	1.77388E+07	1.77104E+07	1.76819E+07	1.76665E+07	1.76492E+07	1.75929E+07	1.75402E+07	1.75215E+07
	1.74597E+07	1.70400E+07	1.36197E+07	1.69902E+07	1.72081E+07	1.74899E+07	1.74879E+07	1.75027E+07	1.74978E+07	1.73716E+07
	1.71878E+07	1.65573E+07	1.44557E+07							
17	2.06435E+07	1.85420E+07	1.79115E+07	1.77277E+07	1.76154E+07	1.75920E+07	1.75095E+07	1.74939E+07	1.74258E+07	1.73958E+07
	1.73731E+07	1.73333E+07	1.72936E+07	1.72711E+07	1.72476E+07	1.72335E+07	1.72166E+07	1.71587E+07	1.71034E+07	1.70839E+07
	1.70178E+07	1.65033E+07	1.33535E+07	1.64975E+07	1.68142E+07	1.70347E+07	1.70330E+07	1.70491E+07	1.70409E+07	1.69122E+07
	1.67283E+07	1.60979E+07	1.39963E+07							
18	2.00124E+07	1.79108E+07	1.72804E+07	1.70965E+07	1.69677E+07	1.69073E+07	1.68719E+07	1.68633E+07	1.68357E+07	1.68206E+07
	1.68108E+07	1.67948E+07	1.67789E+07	1.67692E+07	1.67564E+07	1.67454E+07	1.67297E+07	1.66690E+07	1.66091E+07	1.65882E+07
	1.65100E+07	1.56572E+07	1.32623E+07	1.57738E+07	1.63904E+07	1.64571E+07	1.64535E+07	1.64532E+07	1.64117E+07	1.62811E+07
	1.60972E+07	1.54667E+07	1.33652E+07							
19	1.91799E+07	1.70783E+07	1.64478E+07	1.62640E+07	1.61327E+07	1.60691E+07	1.60516E+07	1.60459E+07	1.60372E+07	1.60301E+07
	1.60276E+07	1.60250E+07	1.60224E+07	1.60199E+07	1.60132E+07	1.60040E+07	1.59892E+07	1.59269E+07	1.58647E+07	1.58422E+07
	1.57390E+07	1.40468E+07	1.25577E+07	1.43048E+07	1.56780E+07	1.56572E+07	1.56523E+07	1.56399E+07	1.55798E+07	1.54485E+07
	1.52647E+07	1.46342E+07	1.25326E+07							
20	1.81459E+07	1.60443E+07	1.54139E+07	1.52300E+07	1.50986E+07	1.50355E+07	1.50206E+07	1.50153E+07	1.50094E+07	1.50036E+07
	1.50022E+07	1.50018E+07	1.50013E+07	1.50000E+07	1.49942E+07	1.49854E+07	1.49707E+07	1.49082E+07	1.48456E+07	1.48224E+07
	1.47041E+07	1.24383E+07	1.16336E+07	1.27999E+07	1.46611E+07	1.46284E+07	1.46232E+07	1.46087E+07	1.45459E+07	1.44146E+07
	1.42307E+07	1.36002E+07	1.14987E+07							
21	1.73557E+07	1.52543E+07	1.46239E+07	1.44400E+07	1.43086E+07	1.42456E+07	1.42308E+07	1.42256E+07	1.42199E+07	1.42142E+07
	1.42130E+07	1.42127E+07	1.42124E+07	1.42111E+07	1.42055E+07	1.41967E+07	1.41819E+07	1.41194E+07	1.40568E+07	1.40328E+07
	1.38928E+07	1.03911E+07	4.72396E+06	1.09751E+07	1.38676E+07	1.38388E+07	1.38336E+07	1.38190E+07	1.37560E+07	1.36246E+07
	1.34408E+07	1.28101E+07	1.07090E+07							
22	1.68579E+07	1.47568E+07	1.41264E+07	1.39426E+07	1.38112E+07	1.37482E+07	1.37335E+07	1.37282E+07	1.37226E+07	1.37169E+07
	1.37157E+07	1.37154E+07	1.37152E+07	1.37139E+07	1.37082E+07	1.36994E+07	1.36847E+07	1.36222E+07	1.35596E+07	1.35354E+07
	1.33916E+07	9.74103E+06	2.94200E+06	1.03450E+07	1.33695E+07	1.33415E+07	1.33363E+07	1.33217E+07	1.32587E+07	1.31273E+07
	1.29435E+07	1.23132E+07	1.02121E+07							
23	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	2.94371E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06	2.29653E+06
	2.29653E+06	2.29653E+06	2.29653E+06							
24	8.60343E+05	8.60344E+05	8.60344E+05	8.60344E+05	8.60344E+05	8.60344E+05	8.60344E+05	8.60344E+05	8.60344E+05	8.60344E+05
	8.60344E+05	8.60344E+05	8.60344E+05	8.60345E+05	8.60345E+05	8.60345E+05	8.60346E+05	8.60347E+05	8.60348E+05	8.60348E+05
	8.61398E+05	8.64731E+05	2.48225E+06	8.64697E+05	8.60507E+05	8.60344E+05	8.60344E+05	8.60344E+05	8.60344E+05	8.60344E+05
	8.60344E+05	8.60344E+05	8.60343E+05							
25	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	2.62232E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06	1.83774E+06
	1.83774E+06	1.83774E+06	1.83774E+06							
26	1.02356E+06	1.02370E+06	1.02381E+06	1.02388E+06	1.02396E+06	1.02402E+06	1.02404E+06	1.02405E+06	1.02416E+06	1.02438E+06
	1.02461E+06	1.02504E+06	1.02548E+06	1.02571E+06	1.02593E+06	1.02726E+06	1.02872E+06	1.03002E+06	1.03129E+06	1.03261E+06
	1.03871E+06	1.09893E+06	2.52299E+06	1.08051E+06	1.02784E+06	1.02417E+06	1.02415E+06	1.02412E+06	1.02405E+06	1.02396E+06

	1.02388E+06	1.02374E+06	1.02356E+06								
27	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	2.78425E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06	1.48191E+06
	1.48191E+06	1.48191E+06	1.48191E+06								
28	7.39853E+05	7.40161E+05	7.41503E+05	7.42446E+05	7.43587E+05	7.44452E+05	7.44754E+05	7.44875E+05	7.46419E+05	7.49458E+05	
	7.52802E+05	7.59003E+05	7.65204E+05	7.68548E+05	7.71587E+05	7.90617E+05	8.11436E+05	8.29852E+05	8.48096E+05	8.69789E+05	
	9.54155E+05	1.00942E+06	1.02375E+06	9.67460E+05	8.46497E+05	7.51383E+05	7.51026E+05	7.50250E+05	7.48470E+05	7.46135E+05	
	7.44073E+05	7.41067E+05	7.39583E+05								
29	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	
	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	
	1.01365E+05	2.37043E+05	2.68120E+05	2.17742E+05	1.01356E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	1.01355E+05	
	1.01355E+05	1.01355E+05	1.01355E+05								
30	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	
	1.01331E+05	*1.01331E+05*	*1.01331E+05*	*1.01331E+05*	*1.01331E+05*	*1.01331E+05*	*1.01331E+05*	*1.01331E+05*	*1.01331E+05*	*1.01331E+05*	
	1.01331E+05	1.01331E+05	1.21138E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	1.01331E+05	
	1.01331E+05	1.01331E+05	1.01331E+05								
31	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	
	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	
	1.01325E+05	1.01325E+05	1.15545E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	1.01325E+05	
	1.01325E+05	1.01325E+05	1.01325E+05								

Porosity dimensionless

Layer 1											
1	5.00000E-03	5.00000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	
	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	
	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	5.20000E-03	
	5.20000E-03	5.00000E-03	5.00000E-03								
2	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	
	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	
	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	5.00000E-03	
	5.00000E-03	5.00000E-03	5.00000E-03								
3	1.00001E-02	1.00000E-02	1.00000E-02	1.00000E-02	1.00001E-02	1.00004E-02	1.00004E-02	1.00004E-02	1.00001E-02	1.00000E-02	
	9.99999E-03	9.99987E-03	9.99975E-03	9.99968E-03	9.99962E-03	9.99967E-03	9.99957E-03	9.99578E-03	9.99251E-03	9.99259E-03	
	9.99310E-03	9.99326E-03	9.99415E-03	9.99511E-03	9.99511E-03	9.99810E-03	9.99818E-03	9.99891E-03	1.00000E-02	1.00000E-02	
	1.00000E-02	1.00000E-02	1.00000E-02								
4	1.00000E-02	9.99999E-03	9.99999E-03	1.00000E-02	1.00030E-02	1.00113E-02	1.00176E-02	1.00175E-02	1.00150E-02	1.00142E-02	
	1.00137E-02	1.00126E-02	1.00116E-02	1.00110E-02	1.00102E-02	1.00131E-02	1.00127E-02	9.97822E-03	9.95111E-03	9.95192E-03	
	9.95641E-03	9.95756E-03	9.96670E-03	9.97635E-03	9.97258E-03	9.98962E-03	9.99003E-03	9.99331E-03	9.99963E-03	9.99999E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
5	9.99999E-03	9.99999E-03	9.99999E-03	1.00001E-02	1.00088E-02	1.00217E-02	1.00398E-02	1.00378E-02	1.00292E-02	1.00273E-02	
	1.00276E-02	1.00280E-02	1.00283E-02	1.00260E-02	1.00191E-02	1.00302E-02	1.00277E-02	9.98282E-03	9.94999E-03	9.95131E-03	
	9.95710E-03	9.95644E-03	9.97294E-03	9.98565E-03	9.97455E-03	9.99090E-03	9.99191E-03	9.99477E-03	9.99550E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
6	1.90000E-02	1.90000E-02	1.90000E-02	1.90001E-02	1.90098E-02	1.90227E-02	1.90541E-02	1.90610E-02	1.07454E-02	1.07504E-02	
	1.07515E-02	1.07517E-02	1.07520E-02	1.07530E-02	1.07580E-02	1.07658E-02	1.07788E-02	1.08343E-02	1.08901E-02	1.09070E-02	
	1.09412E-02	1.09727E-02	7.50000E-02	9.87506E-03	9.89870E-03	1.89914E-02	1.89925E-02	1.89953E-02	1.89995E-02	1.90000E-02	
	1.90000E-02	1.90000E-02	1.90000E-02								
7	9.99999E-03	9.99999E-03	9.99999E-03	1.00001E-02	1.00103E-02	1.00235E-02	1.00557E-02	1.00621E-02	1.07572E-02	1.07622E-02	
	1.07633E-02	1.07636E-02	1.07638E-02	1.07649E-02	1.07699E-02	1.07777E-02	1.07907E-02	1.08463E-02	1.09021E-02	1.09190E-02	
	1.09533E-02	1.09848E-02	7.50000E-02	9.87504E-03	9.90962E-03	9.99120E-03	9.99236E-03	9.99520E-03	9.99948E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
8	9.99999E-03	9.99999E-03	9.99999E-03	1.00001E-02	1.00106E-02	1.00238E-02	1.00557E-02	1.00619E-02	2.04399E-01	2.04399E-01	
	2.04399E-01	2.04399E-01	2.04399E-01	2.04399E-01	2.04398E-01	8.98246E-02	2.04396E-01	2.04392E-01	2.04387E-01	8.98230E-02	
	1.00000E+00	1.00000E+00	7.50000E-02	1.00000E+00	1.00000E+00	9.99127E-03	9.99242E-03	9.99534E-03	9.99948E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
9	9.99999E-03	9.99999E-03	9.99999E-03	1.00001E-02	1.00109E-02	1.00240E-02	1.00557E-02	1.00618E-02	2.04398E-01	2.04398E-01	
	2.04398E-01	2.04398E-01	2.04398E-01	2.04398E-01	2.04397E-01	8.98244E-02	2.04395E-01	2.04390E-01	2.04385E-01	8.98228E-02	
	1.00000E+00	1.00000E+00	7.50000E-02	1.00000E+00	1.00000E+00	9.99134E-03	9.99249E-03	9.99547E-03	9.99948E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
10	9.99999E-03	9.99999E-03	9.99999E-03	1.00001E-02	1.00113E-02	1.00242E-02	1.00557E-02	1.00617E-02	2.04397E-01	2.04397E-01	
	2.04396E-01	2.04396E-01	2.04396E-01	2.04396E-01	2.04396E-01	8.98243E-02	2.04394E-01	2.04389E-01	2.04384E-01	8.98227E-02	
	1.00000E+00	1.00000E+00	7.50000E-02	1.00000E+00	1.00000E+00	9.99140E-03	9.99256E-03	9.99560E-03	9.99948E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
11	9.99999E-03	9.99999E-03	9.99999E-03	1.00001E-02	1.00118E-02	1.00245E-02	1.00557E-02	1.00616E-02	1.08208E-02	1.08258E-02	
	1.08270E-02	1.08272E-02	1.08274E-02	1.08285E-02	1.08336E-02	1.08414E-02	1.08545E-02	1.09104E-02	1.09665E-02	1.09836E-02	
	1.10180E-02	1.10497E-02	7.50000E-02	9.92015E-03	9.96824E-03	9.99148E-03	9.99266E-03	9.99580E-03	9.99949E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
12	1.90000E-02	1.90000E-02	1.90000E-02	1.90001E-02	1.90125E-02	1.90449E-02	1.90570E-02	1.90618E-02	1.08363E-02	1.08413E-02	
	1.08424E-02	1.08426E-02	1.08429E-02	1.08440E-02	1.08490E-02	1.08569E-02	1.08700E-02	1.09259E-02	1.09822E-02	1.09992E-02	
	1.10337E-02	1.10655E-02	7.50000E-02	9.93433E-03	9.98249E-03	1.89929E-02	1.89941E-02	1.89961E-02	1.89995E-02	1.90000E-02	
	1.90000E-02	1.90000E-02	1.90000E-02								
13	9.99999E-03	9.99999E-03	9.99999E-03	1.00000E-02	1.00110E-02	1.00465E-02	1.00520E-02	1.00525E-02	1.08624E-02	1.08675E-02	
	1.08686E-02	1.08688E-02	1.08691E-02	1.08702E-02	1.08752E-02	1.08831E-02	1.08962E-02	1.09523E-02	1.10087E-02	1.10258E-02	
	1.10604E-02	1.10922E-02	7.50000E-02	9.95834E-03	1.00066E-02	9.99288E-03	9.99323E-03	9.99579E-03	9.99949E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
14	9.99999E-03	9.99999E-03	9.99999E-03	1.00000E-02	1.00099E-02	1.00470E-02	1.00521E-02	1.00525E-02	1.09112E-02	1.09163E-02	
	1.09174E-02	1.09176E-02	1.09178E-02	1.09190E-02	1.09240E-02	1.09319E-02	1.09452E-02	1.10015E-02	1.10581E-02	1.10753E-02	
	1.11100E-02	1.11420E-02	7.50000E-02	1.00031E-02	1.00516E-02	9.99312E-03	9.99318E-03	9.99553E-03	9.99951E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
15	1.90000E-02	1.90000E-02	1.90000E-02	1.90000E-02	1.90092E-02	1.90485E-02	1.90541E-02	1.90550E-02	1.90730E-02	1.90737E-02	
	1.90738E-02	1.90738E-02	1.90738E-02	1.90739E-02	1.90742E-02	1.90749E-02	1.90760E-02	1.90808E-02	1.90856E-02	1.90870E-02	
	1.90899E-02	1.90906E-02	7.50000E-02	1.89920E-02	1.89977E-02	1.89935E-02	1.89934E-02	1.89956E-02	1.89995E-02	1.90000E-02	
	1.90000E-02	1.90000E-02	1.90000E-02								
16	9.99999E-03	9.99999E-03	9.99999E-03	1.00000E-02	1.00066E-02	1.00170E-02	1.00047E-02	1.00029E-02	9.99512E-03	9.99255E-03	
	9.99034E-03	9.98628E-03	9.98221E-03	9.98003E-03	9.97819E-03	9.97767E-03	9.97746E-03	9.97796E-03	9.97875E-03	9.97877E-03	
	9.97686E-03	9.94600E-03	7.50000E-02	9.94311E-03	9.96529E-03	9.99225E-03	9.99251E-03	9.99488E-03	9.99957E-03	9.99998E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
17	*9.99999E-03*	*9.99999E-03*	*9.99999E-03*	*9.99999E-03*	*1.00015E-02*	*1.00047E-02*	*9.99926E-03*	*9.99842E-03*	*9.99340E-03*	*9.99144E-03*	
	9.98971E-03	9.98654E-03	9.98336E-03	9.98166E-03	9.98022E-03	9.97979E-03	9.97962E-03	9.97999E-03	9.98057E-03	9.98052E-03	
	9.97828E-03	9.93981E-03	7.50000E-02	9.94044E-03	9.97055E-03	9.99259E-03	9.99287E-03	9.99536E-03	9.99977E-03	9.99999E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
18	9.99999E-03	9.99999E-03	9.99999E-03	9.99999E-03	1.00002E-02	1.00004E-02	9.99874E-03	9.99847E-03	9.99670E-03	9.99594E-03	
	9.99525E-03	9.99399E-03	9.99273E-03	9.99205E-03	9.99147E-03	9.99129E-03	9.99122E-03	9.99136E-03	9.99157E-03	9.99141E-03	
	9.98819E-03	9.92262E-03	7.50000E-02	9.93303E-03	9.96722E-03	9.99690E-03	9.99703E-03	9.99819E-03	9.99993E-03	9.99999E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
19	9.99999E-03	9.99999E-03	9.99999E-03	9.99999E-03	1.00000E-02	9.99995E-03	9.99973E-03	9.99969E-03	9.99944E-03	9.99933E-03	
	9.99923E-03	9.99904E-03	9.99885E-03	9.99875E-03	9.99866E-03	9.99864E-03	9.99862E-03	9.99864E-03	9.99867E-03	9.99838E-03	
	9.99315E-03	9.86064E-03	4.00000E-02	9.88224E-03	9.99689E-03	9.99953E-03	9.99956E-03	9.99974E-03	9.99998E-03	9.99999E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
20	9.99999E-03	9.99999E-03	9.99999E-03	9.99999E-03	9.99999E-03	9.99998E-03	9.99996E-03	9.99996E-03	9.99994E-03	9.99993E-03	
	9.99992E-03	9.99991E-03	9.99989E-03	9.99988E-03	9.99988E-03	9.99987E-03	9.99987E-03	9.99987E-03	9.99987E-03	9.99952E-03	
	9.99307E-03	9.81512E-03	4.00000E-02	9.84483E-03	9.99826E-03	9.99995E-03	9.99995E-03	9.99997E-03	9.99999E-03	9.99999E-03	
	9.99999E-03	9.99999E-03	9.99999E-03								
21	9.99997E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99999E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	
	9.99998E-03	9.99997E-03	9.99997E-03	9.99997E-03	9.99997E-03	9.99997E-03	9.99997E-03	9.99997E-03	9.99996E-03	9.99955E-03	
	9.99135E-03	9.71623E-03	7.50000E-02	9.76311E-03	9.99797E-03	9.99997E-03	9.99998E-03	9.99999E-03	9.99999E-03	9.99999E-03	
	9.99999E-03	9.99999E-03	1.00000E-02								
22	9.99993E-03	9.99997E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	
	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99998E-03	9.99955E-03	

	9.99104E-03	9.70428E-03	1.00000E-02	9.75268E-03	9.99792E-03	9.99998E-03	9.99999E-03	9.99999E-03	9.99999E-03	9.99999E-03
	1.00000E-02	1.00000E-02	1.00000E-02							
23	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.50000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.00000E-01							
24	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01
	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01
	1.46000E-01	1.46000E-01	2.50000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01	1.46000E-01
	1.46000E-01	1.46000E-01	1.46000E-01							
25	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.50000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.00000E-01							
26	9.00000E-02	9.00000E-02	9.00001E-02	9.00001E-02	9.00001E-02	9.00001E-02	9.00001E-02	9.00001E-02	9.00001E-02	9.00002E-02
	9.00002E-02	9.00003E-02	9.00004E-02	9.00004E-02	9.00005E-02	9.00007E-02	9.00010E-02	9.00013E-02	9.00015E-02	9.00018E-02
	9.00030E-02	9.00066E-02	2.50000E-01	9.00037E-02	9.00008E-02	9.00001E-02	9.00001E-02	9.00001E-02	9.00001E-02	9.00001E-02
	9.00001E-02	9.00000E-02	9.00000E-02							
27	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.50000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01	2.00000E-01
	2.00000E-01	2.00000E-01	2.00000E-01							
28	1.50000E-01	1.50006E-01	1.50020E-01	1.50029E-01	1.50041E-01	1.50049E-01	1.50052E-01	1.50053E-01	1.50069E-01	1.50099E-01
	1.50133E-01	1.50195E-01	1.50257E-01	1.50290E-01	1.50321E-01	1.50512E-01	1.50721E-01	1.50906E-01	1.51090E-01	1.51308E-01
	1.52162E-01	1.52723E-01	2.50000E-01	1.52297E-01	1.51073E-01	1.50119E-01	1.50115E-01	1.50107E-01	1.50089E-01	1.50066E-01
	1.50045E-01	1.50015E-01	1.50000E-01							
29	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01
	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01
	1.50000E-01	1.51363E-01	2.50000E-01	1.51169E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01	1.50000E-01
	1.50000E-01	1.50000E-01	1.50000E-01							
30	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01
	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01
	1.75000E-01	1.75000E-01	2.50000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01
	1.75000E-01	1.75000E-01	1.75000E-01							
31	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01
	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01
	1.75000E-01	1.75000E-01	2.50000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01	1.75000E-01
	1.75000E-01	1.75000E-01	1.75000E-01							

Gas saturation — fraction void volume

Layer 1										
1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
2	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
3	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	4.93054E-31	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
4	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	9.48650E-30	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
5	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	2.50683E-25	0.00000E+00	0.00000E+00	0.00000E+00	6.94210E-25	6.60230E-22	4.12323E-21
	1.95907E-23	7.49361E-22	0.00000E+00	0.00000E+00	0.00000E+00	1.02431E-20	4.01948E-22	1.87356E-25	1.71072E-32	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
6	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.60346E-01	2.32716E-01	3.98027E-01	4.72983E-01
	3.08345E-01	1.60784E-67	1.76881E-51	3.04652E-01	4.73016E-01	3.39591E-01	3.85605E-01	5.35839E-01	6.44542E-01	6.27653E-01
	6.00413E-01	9.07602E-01	1.87087E-01	5.12414E-05	4.16611E-01	1.36254E-01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
7	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	5.13890E-25	2.76595E-25	9.35904E-01	9.35883E-01
	9.35584E-01	9.33383E-01	9.32677E-01	9.33448E-01	9.34619E-01	9.34073E-01	9.34201E-01	9.36998E-01	9.42756E-01	9.41874E-01
	9.38738E-01	9.56539E-01	1.90549E-01	5.82316E-05	9.37504E-01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
8	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.00000E+00	1.00000E+00
	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	9.05007E-01	1.00000E+00	1.00000E+00	1.00000E+00	9.37407E-01
	9.94375E-01	9.93391E-01	1.95548E-01	8.76521E-01	9.85138E-01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
9	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	5.16498E-26	1.00000E+00	1.00000E+00
	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	1.00000E+00	7.84943E-01	1.00000E+00	1.00000E+00	1.00000E+00	8.73168E-01
	9.89606E-01	9.81544E-01	1.98514E-01	9.74431E-01	9.81166E-01	1.00159E-26	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
10	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	2.79541E-26	9.16524E-28	9.99992E-01	9.99996E-01
	9.99997E-01	9.99996E-01	9.99995E-01	9.99996E-01	9.99996E-01	7.82156E-01	9.99996E-01	9.99996E-01	9.99996E-01	7.81436E-01
	9.76738E-01	9.76368E-01	1.98998E-01	9.75933E-01	9.75860E-01	1.11182E-25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
11	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.17241E-01	9.27666E-01
	9.30782E-01	9.25451E-01	9.24442E-01	9.26393E-01	9.26995E-01	9.24754E-01	9.26964E-01	9.27173E-01	9.26245E-01	9.24090E-01
	9.24158E-01	9.34944E-01	2.00039E-01	9.23571E-01	9.18874E-01	5.77922E-21	1.62548E-24	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
12	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.36325E-01	4.49265E-01	4.57099E-01	4.58350E-01	9.12110E-01	9.21014E-01
	9.23781E-01	9.19393E-01	9.18423E-01	9.19912E-01	9.20454E-01	9.20370E-01	9.20433E-01	9.20615E-01	9.19977E-01	9.20004E-01
	9.20052E-01	9.29459E-01	2.00042E-01	9.19902E-01	9.16236E-01	3.62181E-01	3.10533E-01	5.34954E-02	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
13	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.31296E-23	1.47266E-25	0.00000E+00	3.56128E-26	9.12768E-01	9.21304E-01
	9.24017E-01	9.19740E-01	9.18787E-01	9.20224E-01	9.20756E-01	9.20676E-01	9.20737E-01	9.20914E-01	9.20294E-01	9.20321E-01
	9.20368E-01	9.29511E-01	2.00143E-01	9.20244E-01	9.16648E-01	2.49748E-24	0.00000E+00	8.09424E-25	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
14	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	6.01515E-28	2.56096E-26	6.59957E-24	0.00000E+00	9.23396E-01	9.27556E-01
	9.29025E-01	9.27364E-01	9.26840E-01	9.27014E-01	9.27301E-01	9.27260E-01	9.27296E-01	9.27385E-01	9.27192E-01	9.27211E-01
	9.27228E-01	9.30710E-01	2.47435E-02	9.27625E-01	9.25967E-01	0.00000E+00	5.84026E-24	3.89400E-26	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
15	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	4.13756E-04	2.40442E-01	3.54805E-01	3.96463E-01	4.22689E-01	4.14948E-01
	4.16266E-01	4.15907E-01	4.15558E-01	4.17125E-01	4.19410E-01	4.19720E-01	4.20467E-01	4.22941E-01	4.24922E-01	4.25655E-01
	4.27689E-01	4.65929E-01	2.63062E-02	3.89702E-01	3.54552E-01	5.51944E-02	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
16	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.02898E-25	0.00000E+00	1.33127E-26	0.00000E+00	4.69401E-26	4.92173E-24
	0.00000E+00	0.00000E+00	3.91437E-36	3.07067E-25	2.95471E-27	2.87274E-33	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	3.91672E-02	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
17	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.28640E-26	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	1.21626E-27	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	6.04929E-02	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
18	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

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    4.39144E-31 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 1.03243E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
19  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 1.36216E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
20  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 2.11703E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
21  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 1.30697E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
22  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 4.46627E-01 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
23  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    4.34262E-72 1.56014E-13 4.70994E-02 1.08143E-13 4.39973E-73 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
24  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    6.34080E-02 2.04146E-01 3.16650E-02 2.03418E-01 1.06448E-02 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
25  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    1.36888E-71 2.33614E-13 4.05029E-02 1.62232E-13 1.73730E-72 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
26  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    6.14066E-70 1.48667E-01 2.69667E-02 1.37372E-01 2.45618E-32 0.00000E+00 0.00000E+00 0.00000E+00 1.05850E-42 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
27  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    6.61621E-71 4.35605E-14 2.64837E-02 3.02503E-14 9.11929E-72 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
28  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    9.13391E-70 2.13834E-17 1.57561E-01 1.55333E-17 3.62872E-32 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
29  8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01
    8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 7.99944E-01
    2.75220E-01 1.13202E-01 8.62647E-02 1.22603E-01 5.46265E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01
    8.00000E-01 8.00000E-01 8.00000E-01
30  8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01
    8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01
    7.99999E-01 3.06318E-01 1.90771E-01 3.34823E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01
    8.00000E-01 8.00000E-01 8.00000E-01
31  8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01
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    8.00000E-01 8.00000E-01 2.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01 8.00000E-01
    8.00000E-01 8.00000E-01 8.00000E-01
-----------------------------------------------------------------------------------------------------------------------------
Fe concentration -- simple model                    kg/m^3
   Layer   1
 1  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
 2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
 3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
 4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
 5  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
 6  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
 7  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
 8  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 3.79716E+01 1.47250E+02
    1.47119E+02 1.56897E+02 1.47259E+02 6.58417E+01 1.47237E+02 0.00000E+00 1.35983E+02 1.47181E+02 1.47585E+02 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
 9  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 1.43772E+02 1.56700E+02
    1.56700E+02 1.56700E+02 1.56700E+02 1.56700E+02 1.56700E+02 0.00000E+00 1.56700E+02 1.56700E+02 1.56700E+02 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
10  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 4.91939E+01 1.20699E+02
    1.21040E+02 1.09141E+02 1.00650E+02 9.40696E+01 9.89393E+01 0.00000E+00 8.58573E+01 8.63110E+01 1.04339E+02 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
11  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
12  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
13  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
    0.00000E+00 0.00000E+00 0.00000E+00
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14	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
15	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
16	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
17	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
18	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
19	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
20	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
21	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
22	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
23	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
24	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
25	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
26	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
27	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
28	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
29	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
30	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
31	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							

CH2O concentration -- simple model kg/m^3

Layer 1

1	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
2	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
3	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
4	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
5	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
6	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
7	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
8	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.64595E+01
	3.57862E+01	8.57083E+01	3.65037E+01	0.00000E+00	3.63902E+01	0.00000E+00	0.00000E+00	3.61021E+01	3.81661E+01	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00							
9	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.09236E+01	8.45789E+01
	8.45789E+01	8.45789E+01	8.45789E+01	8.45789E+01	8.45090E+01	0.00000E+00	8.45789E+01	8.45789E+01	8.45790E+01	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

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   0.00000E+00  0.00000E+00  0.00000E+00
10 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
11 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
12 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
13 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
14 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
15 0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00
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Time Step No. = 1121   Elapsed Time = 3.652431E+06 days
Date:  01/25/96  Time: 18:26:55  CPU Time: 0  2: 6: 9.76 (  7569.76 sec)  Binary


*********************************************************************
* End of BRAGFLO          Version: 4.00              Revised: 01/21/96    *
* Completed:  01/25/96 at 18:26:56    Run on: LARRY  - ALPHA AXP OpenVMS V6.1 *
*********************************************************************
```

Appendix C: Functionality Not Tested

For BRAGFLO Version 4.00, the following features will not be tested at this time because they will not be used as part of the WIPP compliance calculations:

1) Radionuclide transport. BRAGFLO is no longer used for transport calculations because a faster, more accurate, and more versatile code, NUTS, is now available.

2) Gas dissolution. Dissolution of gas in brine may be simulated using either Henry's law for a single gas or bubble point tracking. The brine may be specified as initially gas-free or fully gas-saturated. This feature will not be used in the WIPP compliance calculations and will not be tested now.

3) Numerous options are available for inputting the description of the mesh. Because only a couple of these are regularly used, the only ones that will be tested now will be those that will be used in the WIPP compliance calculations and in test cases for testing other features.

4) Reaction path gas generation model. This model has been neither fully developed nor implemented and is not available for the WIPP compliance calculations.

5) Multicomponent gas transport. Without a source of multiple gas components (i.e., the reaction path model), there is little point in tracking multiple gas components; this will not be done in the WIPP compliance calculations.

6) Three-dimensional calculations. Although BRAGFLO is a fully 3-D code, time and resource constraints currently preclude doing any 3-D calculations for WIPP compliance.

7) Three earlier creep closure surfaces. Creep closure data used for preliminary performance assessments have been retained in BRAGFLO to enable these calculations to be reproduced, but only the most recent creep closure surface (which became available in January 1996) will be used for WIPP compliance calculations.

8) Alternative equation solvers. In addition to the original LU solver, BRAGFLO also has a Linpack LU solver and a point-SOR iterative solver. The Linpack LU solver offers no advantages over the original LU solver, except for certain debugging capabilities. Because it has been coded very inefficiently, nearly doubling the memory required by BRAGFLO when it is used, it has been disabled in version 4.00. No iterative solver has yet been found that is sufficiently robust for calculations done for WIPP PA; in particular, the point-SOR solver is inadequate for use in the compliance calculations. An iterative multigrid solver is under development, but is not yet available for testing.

9) Capillary pressure treatment. An option in BRAGFLO is to allow the maximum capillary pressure to vary automatically. This model is experimental, has not been well-tested, and will not be used in the WIPP compliance calculations.

10) Numerical control parameters. The experience gained over several years of using BRAGFLO (see WIPP PA, 1991, 1992; NAS 1993 report; SPM1 1994; SPM2, 1995; FEPs Screening, 1995) has shown what values of the various control parameters will

enable BRAGFLO to run successfully. Test cases show that these values are being used as intended in the code. However, because the values of these parameters will not be varied in the WIPP compliance calculations, further testing is not done.

11) Multicomponent gas properties. BRAGFLO is capable of calculating gas properties using either the ideal gas law or the Redlich-Kwong-Soave equation of state. Properties can be calculated for either pure gases or for mixtures of any of the following six gases: H_2, CO_2, CH_4, N_2, O_2, and H_2S. Because the WIPP compliance calculations will use pure hydrogen and the Redlich-Kwong-Soave equation of state, the calculation of mixture properties and use of the ideal gas law are not tested.

12) Restart capability. This feature is used only for debugging and will not be used for the WIPP compliance calculations.

13) Relative permeability and capillary pressure models. BRAGFLO currently has 10 relative permeability and capillary pressure models available. Only two of these are expected to be used for the WIPP compliance calculations, KRP = 1 and 4; these will be tested for software QA. Three others (KRP = 5, 9, and 10) are used in QA testing, so these will also be tested. None of the other five models will be tested at this time.

14) Radiolysis (the radiolytic breakdown of water into hydrogen and oxygen) may be calculated. The initial inventory of radionuclides in the waste is input, and BRAGFLO calculates the decay of this inventory over time, along with the amount of water that is decomposed and the amount of gas generated. This feature will not be used in the WIPP compliance calculations and will not be tested now.

15) Certain little-used options for inputting the mesh are not tested. For parameter IDZFLAG, which specifies how Δz is input, options 2, 3, and 4 are not tested. (IDZFLAG options that are tested include 0 and 1.) For parameter IDEPTHFLAG, which specifies how the grid block elevations are input, options 1, 2, 3, 4, 5, 6, and -1 are not tested. (IDEPTHFLAG options that are tested include 0, -2, -3, and 7.) All available options for parameters IDXFLAG and IDYFLAG, which specify how Δx and Δy are input, are tested.

Appendix D: Review Forms

The review forms for the BRAGFLO User's Manual are provided in this appendix.

NOTE: Copies of the User's Manual Reviewer's Forms are available in the Sandia WIPP Central Files.

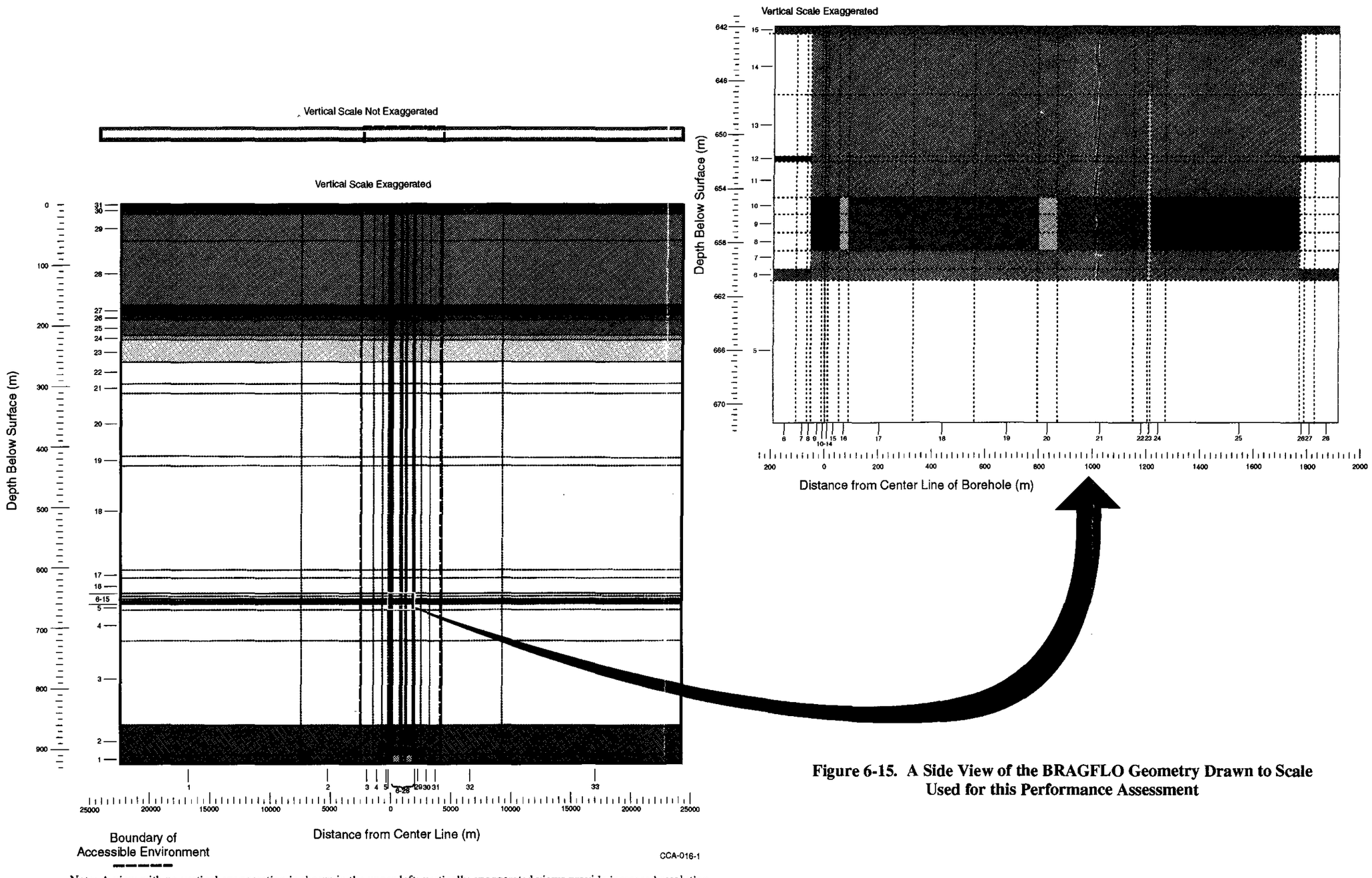

Note: A view with no vertical exaggeration is shown in the upper left; vertically exaggerated views provide increased resolution of imporant model features. Colors correspond to the colors for material regions in Figures 6-13 and 6-14.

Figure 6-15. A Side View of the BRAGFLO Geometry Drawn to Scale Used for this Performance Assessment

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix CCDFGF

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Design Document for CCDFGF and GRIDFLO

Design Document for CCDFGF and GRIDFLO

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Sandia National Laboratories
Albuquerque, NM 87185-1328

WPO #31235

Acknowledgment

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1. Introduction

The Waste Isolation Pilot Plant (WIPP) is located in southeastern New Mexico and is being developed by the U.S. Department of Energy (DOE) as a disposal facility for transuranic (TRU) waste.[1,2] The WIPP must comply with various environmental regulations, including 40 CFR 191, Subpart B, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*,[3] and 40 CFR 268.6, *Petitions to Allow Land Disposal of a Waste Prohibited Under Subpart C of Part* 268.[4] As part of the development process for the WIPP, a sequence of performance assessments (PAs) has been carried out by Sandia National Laboratories (SNL) to organize knowledge currently available about the WIPP and to provide guidance for future research and development efforts.[5,6] The next iteration of these PAs is currently underway at SNL and will form the basis for an application by the DOE to the U.S. Environmental Protection Agency (EPA) in late 1996 for the certification of the WIPP for the disposal of TRU waste.

An important part of the compliance certification application (CCA) for the WIPP is the complementary cumulative distribution function (CCDF) for comparison with the release limits specified in 40 CFR 191.13. In the 1991 and 1992 WIPP PAs, this CCDF was constructed with a procedure based on importance sampling.[7] To provide greater flexibility and improved use of available information, the CCA will use a Monte Carlo procedure for CCDF construction.[8] A similar procedure was also used in the systems prioritization methodology.[9]

This document describes the program CCDFGF that will be written to implement a Monte Carlo CCDF construction in the CCA. The purpose of CCDFGF will be to assemble results obtained from calculations performed with a number of different programs (e.g., BRAGFLO, PANEL, NUTS, SECO-FLOW, SECO-TRANSPORT, CUTTINGS, BLOWOUT) into the CCDF specified in 40 CFR 191.13.

The theoretical basis for CCDFGF is presented in Chapter 2. As described there, three basic entities underlie CCDFGF: (1) a probability space that characterizes the likelihood of different disruptions that could occur at the WIPP site over the next 10,000 yr, (2) a probability space that characterizes the uncertainty in the required inputs to the CCA, and (3) a function f that estimates consequences (e.g., the EPA normalized release) conditional on a specific set of disruptions and a specific set of input values.

The manner in which the probability space for different futures is defined and sampled from is described in Chapter 3. The manner in which the probability space for uncertain parameters is defined and sampled from is outside the scope of CCDFGF and not treated in this presentation, although Chapter 2 does give a high-level overview of how this sampling fits into the overall analysis.

The function f, in concept, is the outcome of the combined operation of the previously indicated programs. However, it is not possible to directly evaluate f with these programs for all possible sets of values that must be

considered in CCDF construction. As a result, CCDFGF must use a relatively small number of mechanistic calculations to evaluate, i.e., approximate, f for the large number of different futures that must be considered in CCDF construction.

Two options are supplied within CCDFGF for evaluation of f. The first option, designated Option A for algebraic construction, involves algebra manipulation of mechanistic results to produce normalized releases to the accessible environment for specific, randomly selected futures. The construction of f under Option A is described in Chapter 4. The second option, designated Option GF as a mnemonic for GRIDFLO, differs from Option A in the use of a more sophisticated procedure (i.e., the GRIDFLO submodule of CCDFGF) to estimate releases from the repository to the Culebra Dolomite in the presence of two or more drilling intrusions of which at least one penetrates pressurized brine (i.e., a brine pocket) in the Castile Formation. Option GF is intended for use in situations that involve large, slowly depressurizing brine pockets in the Castile Formation. The determination of radionuclide releases from the repository to the Culebra under Option GF is described in Chapter 5.

The report then ends with a sequence of chapters that describe the structure of the program (i.e., CCDFGF) that will implement the computational procedures described in Chapters 2, 3, 4 and 5.

2. Theoretical Overview

When viewed at a high-level, three basic entities underlie the PAs conducted by SNL for the WIPP,

EN1: *a probabilistic characterization of the likelihood of different futures occurring at the WIPP site over the next* 10,000 yr,

EN2: a procedure for estimating the radionuclide releases to the accessible environment associated with each of the possible futures that could occur at the WIPP site over the next 10,000 yr,

EN3: a probabilistic characterization of the uncertainty in the parameters used in the definition of EN1 and EN2.

Together, EN1 and EN2 give rise to the CCDF specified in 40 CFR 191 (Fig. 2.1), and EN3 gives rise to an assessment of the confidence with which the location of this CCDF can be estimated.

The preceding entities arise from an attempt to answer three questions about the WIPP,

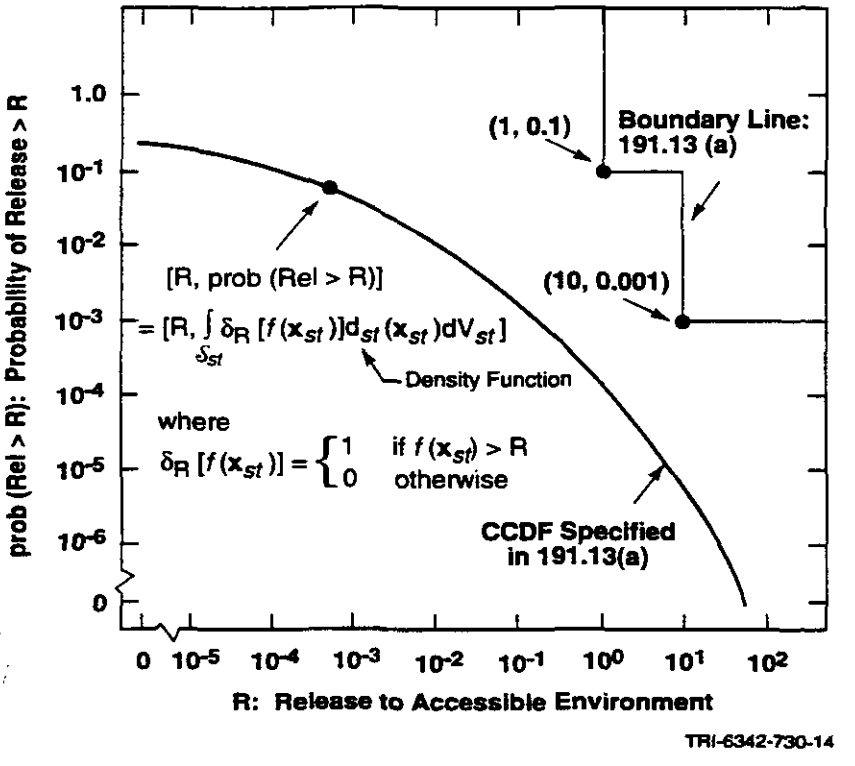

Figure 2.1. Boundary line and associated CCDF specified in 40 CFR 191, Subpart B.

Q1: What occurrences could take place at the WIPP site over the next 10,000 yr?

Q2: How likely are the different occurrences that could take place at the WIPP site over the next 10,000 yr?

Q3: *What are the consequences of the different occurrences that could take place at the WIPP site over the next* 10,000 yr?

and one question about the WIPP PA,

Q4: How much confidence should be placed in answers to the first three questions?

In the WIPP PA, EN1 provides answers to Q1 and Q2, EN2 provides an answer to Q3, and EN3 provides an answer to Q4.

2.1 EN1: Probabilistic Characterization of Different Futures

The entity EN1 is the outcome of the scenario development process for the WIPP and provides a probabilistic characterization of the likelihood of different futures that could occur at the WIPP site over the next 10,000 yr, with the period of 10,000 yr specified in 40 CFR 191. When viewed formally, EN1 is defined by a probability space ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}), with the sample space $\mathcal{S}_{st}$ given by

$$\mathcal{S}_{st} = \{\mathbf{x}_{st}\text{: } \mathbf{x}_{st} \text{ is a possible 10,000 yr sequence of occurrences at the WIPP}\}. \tag{2.1}$$

The subscript *st* refers to stochastic (i.e., aleatory) uncertainty and is used because ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}) is providing a probabilistic characterization of occurrences that may take place in the future.

As a reminder, a probability space ($\mathcal{S}$, $\mathcal{A}$, p) consists of three components: a set $\mathcal{S}$ that contains everything that could occur for the particular "universe" under consideration, a suitably restricted set $\mathcal{A}$ of subsets of $\mathcal{S}$ and a function p defined for elements of $\mathcal{A}$ that actually defines probability. In the terminology of probability theory, $\mathcal{S}$ is the sample space, the elements of $\mathcal{S}$ are elementary events, and the subsets of $\mathcal{S}$ contained in $\mathcal{A}$ are events. In most applied problems, the function p defined on $\mathcal{A}$ is replaced by a probability density function (PDF) d (e.g., d_{st} in Fig. 2.1).

The scenario development process for the WIPP identified exploratory drilling for natural resources as the only disruption with sufficient likelihood and consequence for inclusion in the definition of EN1. In addition, 40 CFR 194 specifies that the occurrence of mining within the land withdrawal boundary must be included in the analysis. As a result, the elements $\mathbf{x}_{st}$ of $\mathcal{S}_{st}$ are anticipated to be vectors of the form

$$\mathbf{x}_{st} = [\underbrace{t_1, p_1, l_1, a_1, d_1, k_1, b_1}_{1^{st}\text{ intrusion}}, \underbrace{t_2, p_2, l_2, a_2, d_2, k_2, b_2}_{2^{nd}\text{ intrusion}}, \ldots, \underbrace{t_n, p_n, l_n, a_n, d_n, k_n, b_n}_{n^{th}\text{ intrusion}}, t_{min}] \tag{2.2}$$

in the 1996 WIPP PA, where n is the number of drilling intrusions, t_i, p_i, l_i, a_i, d_i, k_i and b_i correspond to the time (yr), plugging (i.e., sealing) pattern, location, activity level (Ci/m^2), diameter (m), permeability (m^2), and possible penetration of pressurized brine in the Castile Formation of the ith drilling intrusion, and t_{min} is the time at which potash mining occurs within the land withdrawal boundary. In the development of ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}), the probabilistic characterization of n, t_i and l_i will derive from the assumption that drilling intrusions occur randomly in time and space (i.e., follow a Poisson process), the probabilistic characterization of a_i will derive from the properties of the waste to be emplaced at the WIPP, and the probabilistic characterization of p_i, d_i and k_i will derive from current drilling practices in the sedimentary basin (i.e., the Delaware Basin) in which the WIPP is located, and the probabilistic characterization of b_i will derive from assumed properties of brine pockets. Further, the probabilistic characterization for t_{min} follows from the guidance in 40 CFR 194[10] that the occurrence of potash mining within the land withdrawal boundary should be assumed to occur randomly in time (i.e., follow a Poisson process with a rate constant of $\lambda_m = 10^{-4}$ yr^{-1}).

With respect to the previously indicated questions, $\mathcal{S}_{st}$ provides an answer to Q1, while $\mathcal{A}_{st}$ and p_{st} provide an answer to Q2. In practiee, Q2 will be answered by specifying distributions for n, t_i, p_i, l_i, a_i, d_i, k_i and b_i which in turn lead to definitions for $\mathcal{A}_{st}$ and p_{st}. The CCDF in 40 CFR 191 will be obtained by evaluating an integral involving ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}) (Fig. 2.1).

2.2 EN2: Estimation of Releases

The entity EN2 is the outcome of the model development process for the WIPP and provides a way to estimate radionuclide releases to the accessible environment for the different futures (i.e., elements $\mathbf{x}_{st}$ of $\mathcal{S}_{st}$) that could occur at the WIPP. Estimation of environmental releases corresponds to evaluation of the function f in Fig. 2.1. Release mechanisms associated with f include direct removal to the surface at the time of a drilling intrusion (i.e., cuttings, spallings, brine flow) and release subsequent to a drilling intrusion due to brine flow up a borehole with a degraded plug (i.e., groundwater transport).

The primary computational models intended for use in the 1996 WIPP PA are illustrated in Fig. 2.2. Most of these models involve the numerical solution of partial differential equations used to represent material deformation, fluid flow and radionuclide transport. It is the models indicated in Fig. 2.2 that actually define the function f in Fig. 2.1.

The models in Fig. 2.2 are too complex to permit a closed form evaluation of the integral in Fig. 2.1 that defines the CCDF specified in 40 CFR 191. Rather, a Monte Carlo procedure will be used. Specifically, elements $\mathbf{x}_{st,i}$, $i = 1, 2, \ldots, nS$, will be randomly sampled from $\mathcal{S}_{st}$ in consistency with the definition of ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}). Then, the integral in Fig. 2.1, and hence the associated CCDF, will be approximated by

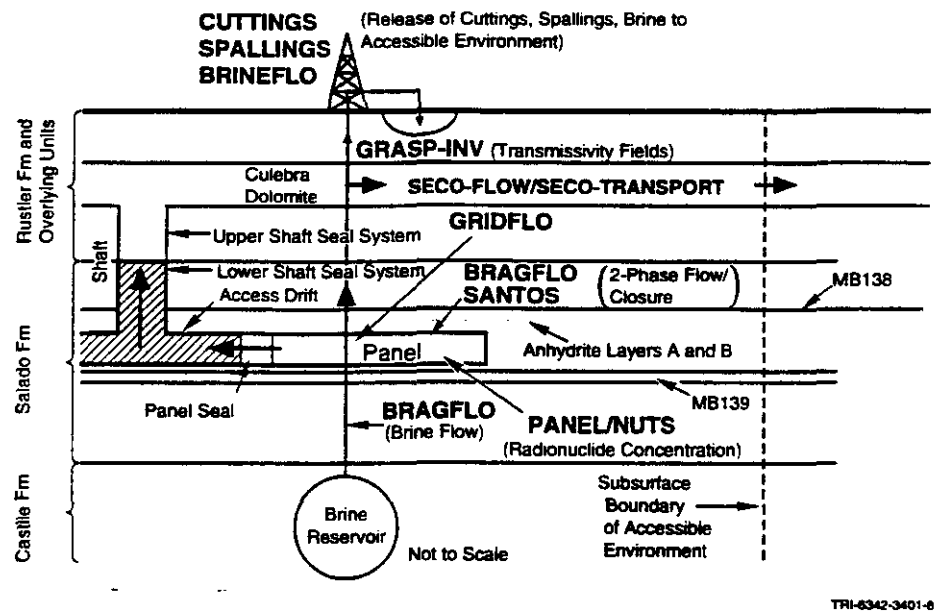

Figure 2.2. Models used in 1996 WIPP PA.

$$prob(Rel > R) = \int_{\mathcal{S}_{st}} \delta_R\left[f(\mathbf{x}_{st})\right] d_{st}(\mathbf{x}_{st})\, dV_{st} \doteq \sum_{i=1}^{nS} \delta_R\left[f(\mathbf{x}_{st,i})\right] / nS. \tag{2.3}$$

The models in Fig. 2.2 are too computationally intensive to permit their evaluation for every element $\mathbf{x}_{st,i}$ of $\mathcal{S}_{st}$ in Eq. (2.3). Due to this constraint, the models in Fig. 2.2 will be evaluated for representative elements of $\mathcal{S}_{st}$ and then the results of these evaluations will be used to construct values of f for the large number of $\mathbf{x}_{st,i}$ (e.g., $1000 \le nS \le 10{,}000$) in Eq. (2.3).

With respect to the previously indicated questions, the models in Fig. 2.2 are providing an answer to Q3.

2.3 EN3: Probabilistic Characterization of Parameter Uncertainty

The entity EN3 is the outcome of the data development effort for the WIPP and provides a probabilistic characterization of the uncertainty in the parameters that underlie the WIPP PA. When viewed formally, EN3 is defined by a probability space $(\mathcal{S}_{su}, \mathcal{S}_{su}, p_{su})$, with the sample space $\mathcal{S}_{su}$ given by

$$\mathcal{S}_{su} = \{\mathbf{x}_{su}: \ \mathbf{x}_{su} \text{ is possibly the correct vector of parameter values to use in the WIPP PA}\}. \tag{2.4}$$

The subscript su refers to subjective (i.e., epistemic) uncertainty and is used because $(\mathcal{S}_{su}, \mathcal{S}_{su}, p_{su})$ is providing a probabilistic characterization of where the appropriate inputs to use in the WIPP PA are believed to be located. In practice, some elements of $\mathbf{x}_{su}$ affect the definition of $(\mathcal{S}_{st}, \mathcal{S}_{st}, p_{st})$ (e.g., the rate constant λ used to define the

Poisson process for drilling intrusions or the mode of the distribution of borehole permeabilities) and other elements relate to the models in Fig. 2.2 that determine the function f in Fig. 2.1 and Eq. (2.3) (e.g., radionuclide solubilities in Castile brine or fracture spacing in the Culebra Dolomite).

If the value for $\mathbf{x}_{su}$ was precisely known, then the CCDF in Fig. 2.1 could be determined with certainty and compared with the boundary line specified in 40 CFR 191. However, given the complexity of the WIPP site and the 10,000 yr time period under consideration, $\mathbf{x}_{su}$ can never be known with certainty. Rather, uncertainty in $\mathbf{x}_{su}$ as characterized by ($\mathcal{S}_{su}$, $\mathcal{A}_{su}$, p_{su}) will lead to a distribution of CCDFs (Fig. 2.3). The proximity of this distribution to the boundary line in Fig. 2.1 provides an indication of the confidence with which 40 CFR 191 will be met.

The distribution of CCDFs in Fig. 2.3 can be summarized by distributions of exceedance probabilities conditional on individual release values (Fig. 2.4). This distribution is defined by a double integral over $\mathcal{S}_{su}$ and $\mathcal{S}_{st}$. In practice, this integral is too complex to permit a closed-form evaluation. Instead, the WIPP PA uses Latin hypercube sampling[7] to evaluate the integral over $\mathcal{S}_{su}$ and, as indicated in Eq. (2.3), simple random sampling to evaluate the integral over $\mathcal{S}_{st}$. Specifically, a Latin hypercube sample $\mathbf{x}_{su,k}$, $k = 1, 2, \ldots, nLHS$, is generated from $\mathcal{S}_{su}$ in consistency with the definition of ($\mathcal{S}_{su}$, $\mathcal{A}_{su}$, p_{su}) and a random sample $\mathbf{x}_{st,i}$, $i = 1, 2, \ldots, nS$, is generated from $\mathcal{S}_{st}$ in consistency with the definition of ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}). The probability $prob(p \le P|R)$ in Fig. 2.4 is then approximated by

$$prob(p \le P|R) \doteq 1 - \sum_{k=1}^{nLHS} \delta_p \left[\sum_{i=1}^{nS} \delta_R \left[f\left(\mathbf{x}_{st,i}, \mathbf{x}_{su,k}\right) \right] / nS \right] / nLHS. \tag{2.5}$$

The result of the preceding calculation is typically displayed by plotting percentile values (e.g., $P_{0.1}$, $P_{0.5}$, $P_{0.9}$ from Fig. 2.4) and also mean values for exceedance probabilities above the corresponding release values (i.e., R) and then connecting these points to form continuous curves (Fig. 2.5). The proximity of these curves to the indicated boundary line provides an indication of the confidence with which 40 CFR 191 will be met.

With respect to the previously indicated questions, ($\mathcal{S}_{su}$, $\mathcal{A}_{su}$, p_{su}) and results derived from ($\mathcal{S}_{su}$, $\mathcal{A}_{su}$, p_{su}) (e.g., the distributions in Figs. 2.3, 2.4 and 2.5) are providing an answer to Q4.

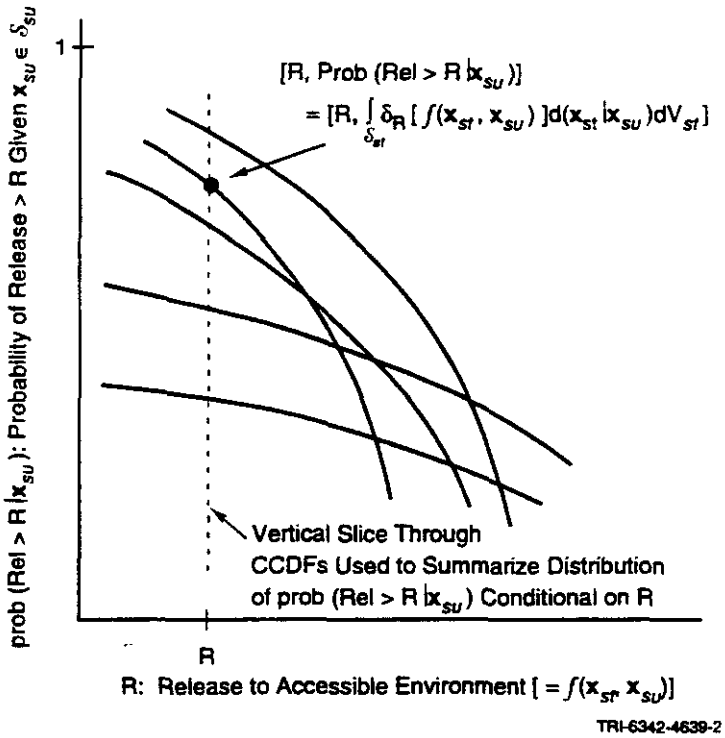

Figure 2.3. Distribution of CCDFs resulting from possible values for $\mathbf{x}_{su} \in \mathcal{S}_{su}$.

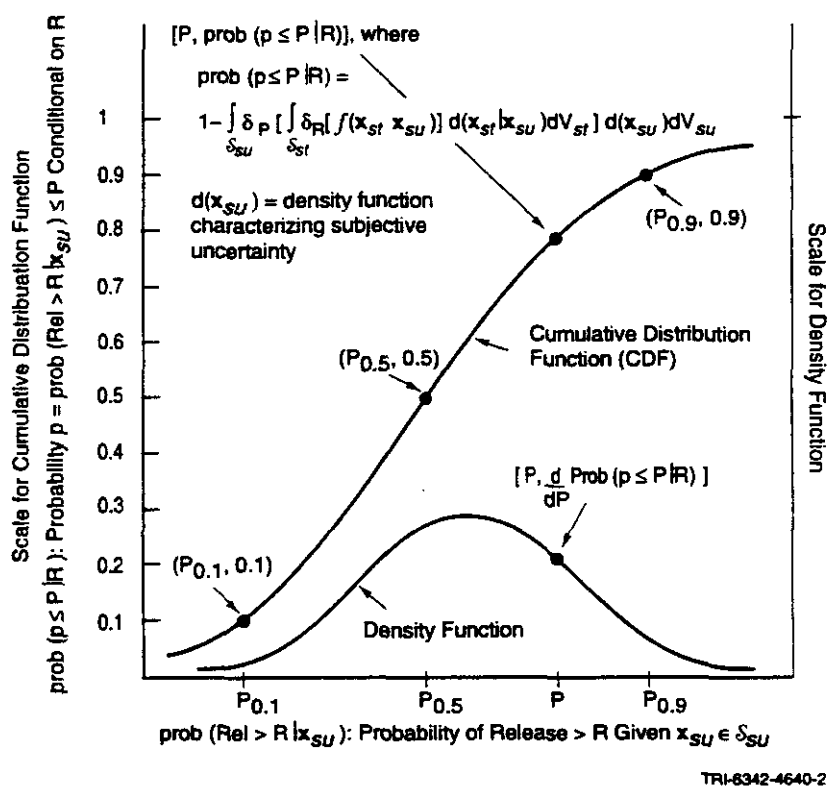

Figure 2.4. Distribution of exceedance probabilities due to subjective uncertainty.

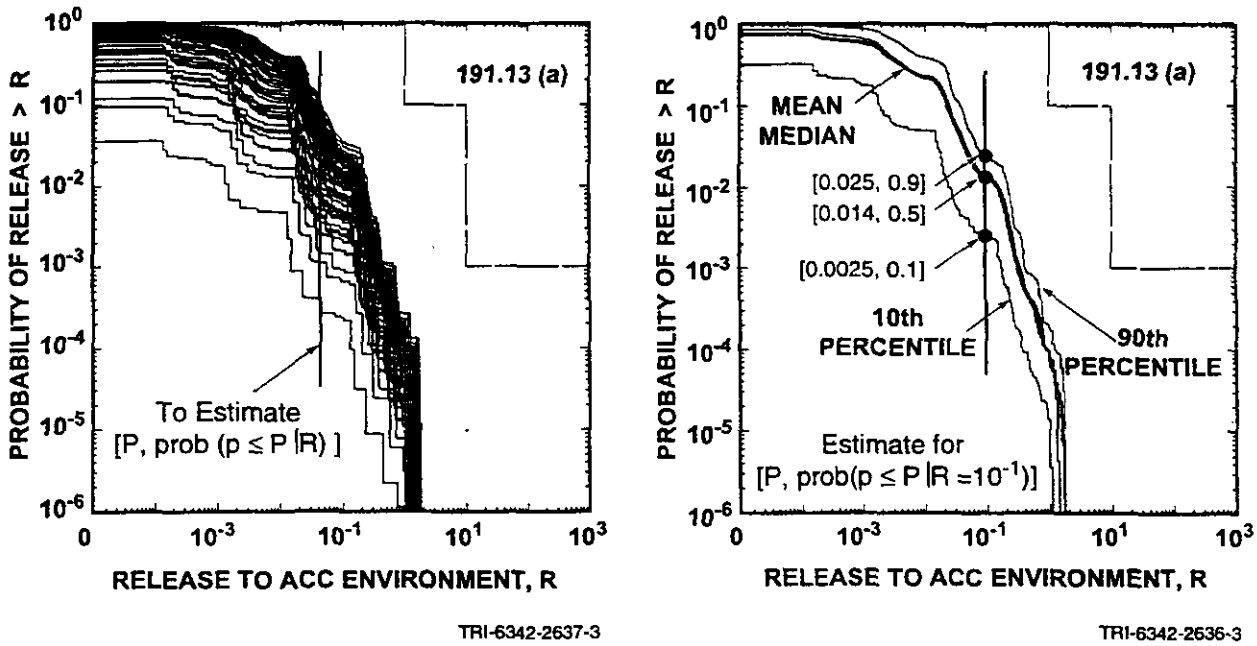

Figure 2.5. Example CCDF distribution from 1992 WIPP PA.

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3. Sampling of Futures

3.1 Probability Space ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}) for Stochastic Uncertainty

The probability space ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}) provides a probabilistic characterization of the events that could occur at the WIPP over the next 10,000 yr. As indicated in Eq. (2.1), the sample space $\mathcal{S}_{st}$ consists of all possible 10,000 yr futures that could occur at the WIPP subsequent to decommissioning. The final definition of ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}) for the 1996 WIPP PA can only be made after the Features, Events, and Processes (FEPs) screening process is complete. Past reviews have concluded that exploratory drilling for natural resources constitutes the only type of future occurrence with sufficient likelihood and potential for initiating releases to the accessible environment to merit inclusion in the definition of ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}). Further, 40 CFR 194 requires that the occurrence of potash mining within the land withdrawal boundary must be included in the analysis. Therefore, this discussion will proceed under the assumption that drilling intrusions and the occurrence of potash mining within the land withdrawal boundary are the only events that require incorporation into ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}). However, the conceptual structure in use and its associated computational implementation should be sufficiently general to allow the incorporation of other types of events into ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}) should this be required (although possibly with some additional programming required).

The following assumptions will underlie the definition of ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}):

(1) Drilling intrusions occur randomly in time and space (i.e., follow a Poisson process). This process will be defined by a rate term λ_d (units: yr^{-1}), with λ_d defined by the drilling rate (e.g., 48 boreholes/$km^2/10^4$ yr) and the area of the repository (or possibly some larger area if the depletion of pressurized brine pockets in the Castile Formation or the penetration of disturbed rock zones around the repository are deemed to be significant).

(2) Different sealing (i.e., plugging) patterns are used for different drilling intrusions. At present, three potential sealing patterns are anticipated for the 1996 WIPP PA: (a) full concrete plug through Salado Formation to Bell Canyon Formation with a permeability of 5×10^{-17} m^2, (b) two plug configuration with plugs at Rustler/Salado and Castile/Bell Canyon interfaces, and (c) three plug configuration with plugs at Rustler/Salado, Salado/Castile and Castile/Bell Canyon interfaces. Specifically, the variation in plugging patterns will be defined by a distribution D_{PL}.

(3) There is a distribution of waste concentration (Ci/m^2) within the repository. In past WIPP PAs, this distribution has been implemented by discretizing the waste into five activity levels with a probability pA_i, $i = 1, 2, \ldots, 5$, that a randomly placed borehole through the repository will pass through waste of activity level i. For the definition of ($\mathcal{S}_{st}$, $\mathcal{A}_{st}$, p_{st}), activity level will be assumed to follow a distribution D_A, where D_A can be either continuous or discrete. For the 1996 WIPP PA, it is anticipated that D_A will be based on the distinction between penetrating contact handled (CH) and remote handled (RH) waste and the individual waste streams associated with each of these waste types.

(4) There is a distribution of drillbit diameters in use (i.e., different drilling intrusions will use different drillbit diameters). The 1991 and 1992 WIPP PAs assumed that all drilling intrusions would use the same drillbit diameter but that the correct value for this diameter was not known; in contrast, the SPM analyses assumed a distribution of drillbit diameters across different drilling intrusions. Specifically, the variation of drillbit diameters across different drilling intrusions will be assumed to follow a distribution D_{DB}, where D_{DB} can be either continuous or discrete.

(5) Different drilling intrusions can result in boreholes with different permeabilities. Past analyses for the WIPP have assumed that *all* boreholes rapidly evolve to the same permeability, although there was assumed to be large uncertainty in what this asymptotic (i.e., long term) permeability was. This does not seem to be reasonable as different boreholes will be plugged in different ways and thus can be reasonably anticipated to have different asymptotic permeabilities. This variability across drilling intrusions is specifically recognized by the EPA in the following statement (Ref. 10, p. 5776):

> For the specific case of borehole seals, EPA is further proposing that boreholes shall be assumed to be sealed at the rate boreholes have been sealed over the past 50 years in the Delaware Basin and that natural processes will degrade or otherwise affect the permeability of boreholes over the regulatory time frame.

In consistency with the preceding guidance, the variation in permeability across different drilling intrusions will be assumed to follow a distribution D_P, where D_P can be either continuous or discrete. A further option will be to define time-dependent distributions for permeabilities above and below the repository, possibly with a specified correlation between these two permeabilities. The distinction between permeability above and below the repository is potentially important due to the role that such permeabilities might play in diverting brine flow from a pressurized brine pocket through the repository.

(6) For the purpose of initiating groundwater transport calculations, the repository (and possibly an adjacent area) will be discretized into a finite number of locations (i.e., nodes) at which drilling intrusions can occur (Fig. 3.1). A discrete probability distribution D_L will define the probability that a randomly placed intrusion into the repository (or possibly an adjacent area if such areas are included in the analysis) will occur at a given location. Specifically, D_L will consist of a sequence of probabilities pL_i, $i = 1, 2, \ldots, nL$, where pL_i is the probability that a randomly placed drilling intrusion will occur at location L_i and nL is the number of discretized locations in use. Due to the assumption that drilling intrusions occur randomly in space, pL_i will derive from the area associated with location L_i. Further, each location L_i can be identified as either being above or not above pressurized brine in the Castile Formation. Thus, L_i will play an important role in the definition of E1, E2 and E1E2 scenarios, where an E1 scenario designates a subset of $\mathcal{S}_{st}$ in which a single drilling intrusion passes through the repository and penetrates pressurized brine, an E2 scenario designates a subset of $\mathcal{S}_{st}$ in which a single drilling intrusion passes through the repository and does not penetrate pressurized brine, and an E1E2 scenario designates a subset of $\mathcal{S}_{st}$ in which two or more drilling intrusions pass through the repository, with at least one of these intrusions penetrating pressurized brine.

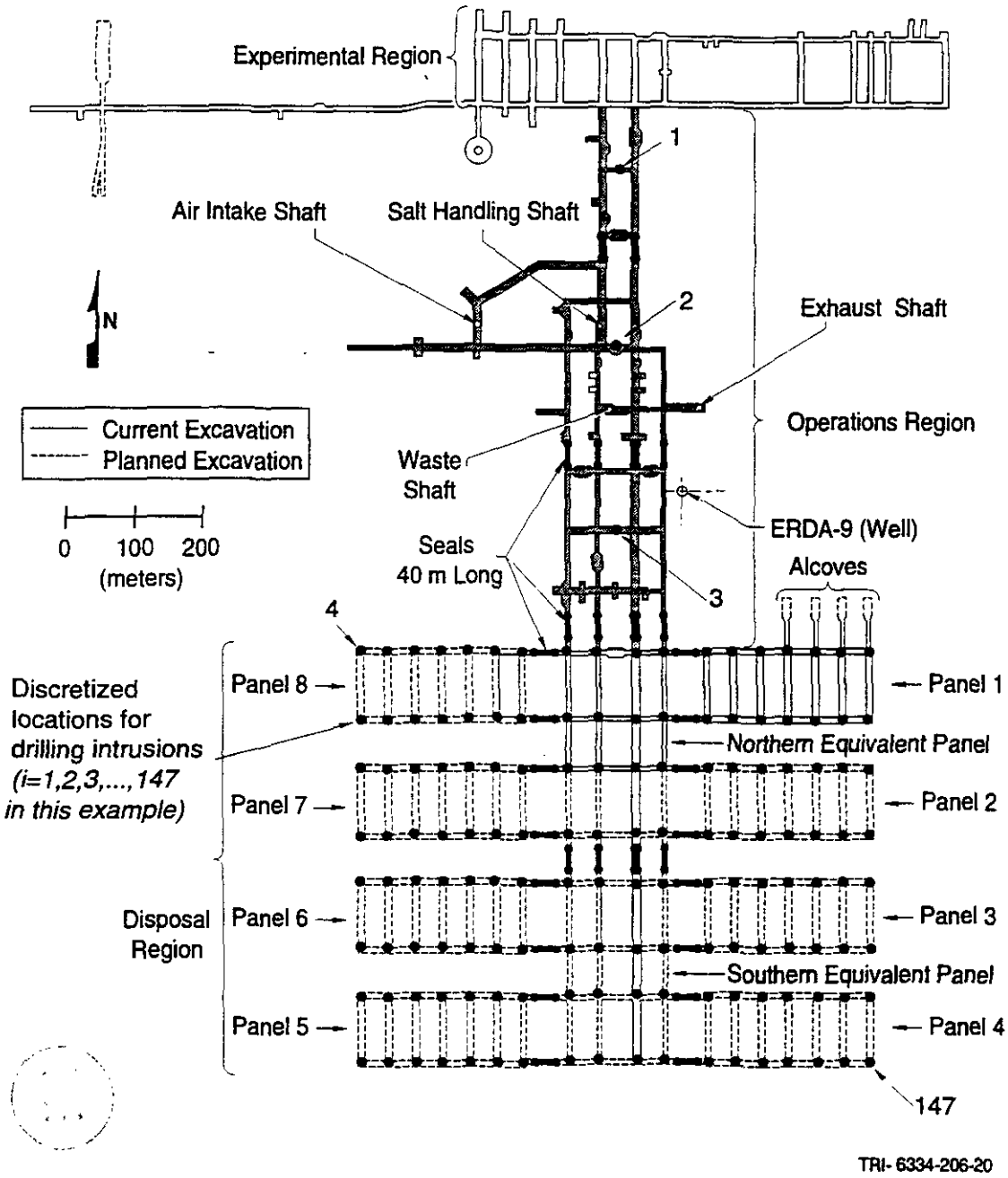

Figure 3.1. Example of discretized drilling locations. Such locations and their associated probabilities will be user-specified input.

(7) A given drilling intrusion may or may not penetrate pressurized brine in the Castile Formation. If the pressurized brine is present in large contiguous areas, then the location of the drilling intrusion (see (6) above) is sufficient to determine whether or not pressurized brine is penetrated. However, if variation in the location of pressurized brine occurs on a finer scale than the specification of the nodes in (6) above, then an additional determination must be made to specify whether or not a given drilling intrusion penetrates pressurized brine. Specifically, a discrete probability distribution D_B can be used to characterize the likelihood that a randomly placed drilling intrusion through the Castile Formation in the vicinity of the waste panels will encounter pressurized brine. Possibilities for D_B include a single probability for encountering pressurized brine anywhere in the vicinity of the WIPP and a different probability for intrusions in the vicinity of each of the nodes in (6) above.

(8) The occurrence of potash mining within the land withdrawal boundary occurs randomly in time (i.e., follows a Poisson process). This process will be defined by a rate term λ_m (units: yr^{-1}). Guidance in 40 CFR 194 specifies $\lambda_m = 1 \times 10^{-4}\ yr^{-1}$.

The probability space $(\mathcal{S}_{st}, \mathcal{A}_{st}, p_{st})$ will be defined by the rate terms λ_d and λ_m, which can be constant or time dependent, and the distributions D_{PL}, D_A, D_{DB}, D_P, D_L and D_B. Specifically, the elements of $\mathbf{x}_{st}$ of $\mathcal{S}_{st}$ will be vectors of the form

$$\mathbf{x}_{st} = [t_1, p_1, l_1, a_1, d_1, k_1, b_1, t_2, p_2, l_2, a_2, d_2, k_2, b_2, \ldots, t_n, p_n, l_n, a_n, d_n, k_n, b_n, t_{min}, 0, 0, 0, 0, 0, \ldots], \quad (3.1)$$

where

t_i = time (yr) of ith drilling intrusion,

p_i = plugging pattern used for i^{th} drilling intrusion,

l_i = location (dimensionless) of ith drilling intrusion (i.e., node associated with i^{th} drilling intrusion),

a_i = activity level of waste penetrated by i^{th} drilling intrusion,

d_i = drillbit diameter (m) used in i^{th} drilling intrusion,

k_i = permeability (m^2) for i^{th} drilling intrusion (Note: if permeabilities above and below the repository are assumed to be different, then two permeabilities will be required for each drilling intrusion; a time dependence for borehole permeability is also possible),

b_i = designator (dimensionless) for penetration of pressurized brine in the Castile Formation (i.e., b_i = 0, 1 implies nonpenetration and penetration, respectively, of pressurized brine),

n = number of drilling intrusions in the 10,000 yr future defined by $\mathbf{x}_{st}$,

t_{min} = time of occurrence (yr) of potash mining within the land withdrawal boundary,

the t_i are assumed to be ordered so that $t_i \le t_{i+1}$ for $i = 1, 2, \ldots, n-1$, and the trailing 0's in Eq. (3.1) are place holders to bring $\mathbf{x}_{st}$ up to the dimensionality assumed for $\mathcal{S}_{st}$ (and in general will be omitted for notational simplicity).

In concept, n could be any positive integer, with the result that $\mathcal{S}_{st}$ is a subset of R^{∞}. As a reminder, R^{∞} denotes the set of all real-valued vectors of infinite length. In practice, the probability of a large number of drilling intrusions (e.g., > 15) will be small (e.g., $< 10^{-4}$) (Table 3.1). Thus, $\mathcal{S}_{st}$ would effectively be a subset of R^{106} if the occurrence of more than 15 drilling intrusions over 10,000 yr was probabilistically insignificant given the definition of λ_d (i.e., 106 = 7 * 15 + 1, where 7 is the number of real-valued quantities associated with each drilling intrusion in Eq. (3.1) and the number 1 derives from t_{min}). For perspective, the probabilities of different numbers of drilling intrusions that result for different λ_d's are shown in Table 3.1.

Given λ_d, λ_m and the distributions D_{PL}, D_A, D_{DB}, D_P, D_L and D_B, the set $\mathcal{S}_{st}$ and the function p_{st} can be formally developed.[11] However, this is not necessary for the computational implementation of the 1996 WIPP PA and therefore will not be done. Rather, random sampling defined by λ_d, λ_m, D_{PL}, D_A, D_{DB}, D_P, D_L and D_B will be used to select elements $\mathbf{x}_{st}$ of $\mathcal{S}_{st}$ in the numerical approximation of the integral in Eq. (2.8) with the summation in Eq. (2.11).

3.2 Generation of Individual Futures

The random sampling to generate an element $\mathbf{x}_{st}$ of $\mathcal{S}_{st}$ will operate in the following manner. The drilling rate λ_d will be used to generate the times at which drilling intrusions occur. For a Poisson process with a constant λ_d (i.e., a stationary process), the cumulative distribution function (CDF) for the time Δt between the successive events is given by (Ref. 12, p. 113):

$$prob(t \le \Delta t) = 1 - e^{-\lambda_d \Delta t}. \tag{3.2}$$

A uniformly distributed random number can be selected from [0, 1]. Then, solution of

$$r_1 = 1 - e^{-\lambda_d t_1} \tag{3.3}$$

for t_1 gives the time of the first drilling intrusion (Fig. 3.2). If 100 yr of administrative control is assumed, then 100 yr would be added to the t_1 obtained in Eq. (3.3) to obtain the time of the first drilling intrusion. Selection of a second random number r_2 and solution of

$$r_2 = 1 - e^{-\lambda_d \Delta t_1} \tag{3.4}$$

Table 3.1. Probability of Different Numbers of Drilling Intrusions over 9900 yrs for Different Drilling Rates

n: No. *BHs*[a]	*prob*(*n*)[b]: Probability of *n BHs*			
	25 BHs/10^4 yr km^2 λ_d = 3.147E–04 yr^{-1}[c]	30 BHs/10^4 yr km^2 λ_d = 3.776E–04 yr^{-1}	48 BHs/10^4 yr km^2 λ_d = 6.050E–04 yr^{-1}	62.5 BHs/10^4 yr km^2 λ_d = 7.868E–04 yr^{-1}
0	4.435E–02	2.379E–02	2.505E–03	4.143E–04
1	1.382E–01	8.893E–02	1.500E–02	3.227E–03
2	2.153E–01	1.662E–01	4.493E–02	1.257E–02
3	2.236E–01	2.072E–01	8.970E–02	3.263E–02
4	1.741E–01	1.936E–01	1.343E–01	6.354E–02
5	1.085E–01	1.448E–01	1.609E–01	9.898E–02
6	5.634E–02	9.021E–02	1.606E–01	1.285E–01
7	2.507E–02	4.818E–02	1.374E–01	1.430E–01
8	9.765E–03	2.252E–02	1.029E–01	1.392E–01
9	3.380E–03	9.354E–03	6.848E–02	1.205E–01
10	1.053E–03	3.497E–03	4.101E–02	9.382E–02
11	2.983E–04	1.189E–03	2.233E–02	6.643E–02
12	7.744E–05	3.703E–04	1.115E–02	4.312E–02
13	1.856E–05	1.065E–04	5.136E–03	2.584E–02
14	4.130E–06	2.844E–05	2.197E–03	1.437E–02
15	8.579E–07	7.088E–06	8.773E–04	7.463E–03
	1.000E+00	1.000E+00	9.995E–01	9.935E–01

a *BHs* ~ Boreholes

b $prob(n) = \left[(9900\,\lambda_d)^n / n!\right]\exp\left(-9900\,\lambda_d\right)$

c λ_d = (25/10^4 yr km^2) (0.1259 km^2), where 0.1259 km^2 is the waste disposal area used in the 1992 WIPP PA.

for Δt_1 gives the time interval between the first and second drilling intrusions, with the outcome that $t_2 = t_1 + \Delta t_1$. This process can be continued until a time t_{n+1} is generated that exceeds 10,000 yr. The times $t_1, t_2, \ldots, t_n$ then constitute the drilling times in $\mathbf{x}_{st}$ in Eq. (3.1). The mining time t_{min} is sampled in a similar manner. An additional $6n$ uniformly distributed random numbers from [0, 1] can then be used to generate the elements $p_i, l_i, a_i, d_i, k_i, b_i, i = 1, 2, \ldots, n$, of $\mathbf{x}_{st}$ from the distributions $D_{PL}, D_A, D_{DB}, D_P, D_L, D_B$. A detailed description of the algorithm for generating individual futures is given in Table 3.2. Further, a hypothetical example of the specification of node properties is given in Fig. 3.3.

The discussion in this section has assumed that drilling intrusions and potash mining within the land withdrawal boundary are the only events involved in the definition of $\mathbf{x}_{st}$ in Eq. (3.1) and hence in the sample space $\mathcal{S}_{st}$ for stochastic uncertainty. If the FEPs screening process identifies additional potential occurrences that should be included in the definition of $(\mathcal{S}_{st}, \mathcal{S}_{st}, p_{st})$, this should present no conceptual problem. Such occurrences will be incorporated into the definition of $\mathbf{x}_{st}$ and their associated probabilities used in the sampling process described in the preceding paragraph. For example, if deemed sufficiently important to the calculation of normalized releases, climatic change could be incorporated into the definition of $\mathbf{x}_{st}$ and hence $(\mathcal{S}_{st}, \mathcal{S}_{st}, p_{st})$.

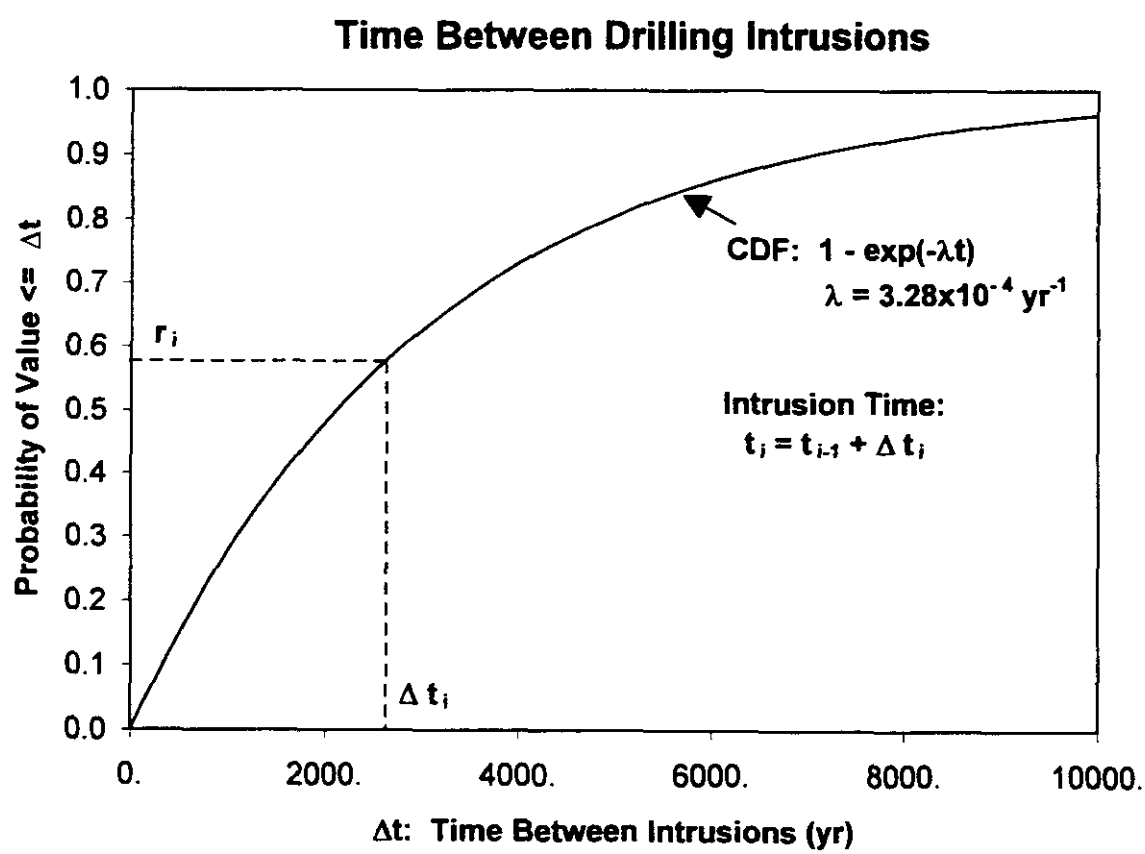

Figure 3.2. Sampling of time intervals between drilling intrusions from cumulative distribution function (CDF) associated with drilling rate $\lambda = \lambda_d$.

Table 3.2. Required Input and Associated Calculations to Generate Single Future $\mathbf{x}_{st}$ of Form Shown in Eqs. (2.2) and (3.1)

Required Input	
λ_d =	drilling rate (yr^{-1}), which is a function of a drilling rate per unit area (e.g., 48 drilling intrusions/ km^2 10^4 yr) and the area encompassed by the nodalization in Fig. 3.1
λ_m =	mining rate (yr^{-1}), which is specified to be 1×10^{-4} yr^{-1} in 40 CFR 194
nPL =	number of plugging patterns in use in vicinity of the WIPP (e.g., 3)
$pPL(j)$ =	probability that a drilling intrusion will be sealed with plugging pattern j, $j = 1, 2, \ldots, nPL$ (e.g., 1 ~ full concrete plug through Salado Formation to Bell Canyon Formation with a permeability of 5×10^{-17} m^2, 2~ two plug configuration with concrete plugs at Rustler/Salado interface and Castile/Bell Canyon interfaces, 3~ three plug configuration with concrete plugs at Rustler/Salado, Salado/Castile and Castile/Bell Canyon interfaces). The effects of these three plugging patterns on release modes from the repository will be written into the code for use with Option A (see Table 3.2).
nR =	number of regions in repository (e.g., $nR = 3$ if the experimental area, operations area and waste disposal area are identified as separate regions)
$pR(j)$ =	probability that a random drilling intrusion into the nR regions will occur in region j, $j = 1, 2, \ldots, nR$ (i.e., $pR(j)$ is the ratio of the area of region j to the total area of all regions)
$pW(j, k)$ =	probability that a random drilling intrusion into the excavated area of region j will encounter waste of type k, $k = 1, 2, 3$, where 1~ no waste, 2~ CH waste, 3~ RH waste
$nN(j)$ =	number of nodes used in nodalization of region j
$pN(j, k)$ =	probability that a random drilling intrusion into region j will occur at node k, $k = 1, 2, \ldots, nNE(j)$
$pE(j,k)$ =	probability that a random drilling intrusion into region j at node k will encounter an excavated area of the repository (i.e., $1 - pE(j)$ is the probability that a random drilling intrusion into region j at node k will not encounter an excavated area)
$pB(j, k)$ =	probability that a drilling intrusion assigned to node k of region j will encounter pressurized brine in the Castile Formation
nBP =	number of brine pockets
$nD(p)$ =	number of drilling intrusions required to deplete brine pocket p, $p = 1, 2, \ldots, nBP$
$iB(j, k)$ =	integer identifier indicating brine pocket associated with node k of region j (i.e., $iB(j, k)$ is an integer between 0 and nBP)
nP =	number of waste panels (e.g., 10)

Table 3.2. Continued

$iP(j, k)$ = integer identifier indicating waste panel associated with node k of region j (i.e., $iP(j, k)$ is an integer between 0 and nP with $iP(j, k) = 0$ implying node not contained in a waste panel and $iP(j, k) = p$ implying that node contained in waste panel p). Allows identification of l_i with specific waste panels.

$iL(j)$ = integer identifier that indicates whether panel j is to be considered a lower panel (i.e., $iL(j) = 1$) or an upper panel (i.e., $iL(j) = 2$) for purpose of implementing blowout and spallings releases, $j = 1, 2, \ldots, nP$ (e.g., $iL(j) = 1$ for Panels 4, 5 and Southern Equivalent Panel in Fig. 3.1 and $iL(j) = 2$ for Panels 1, 2, 3, 6, 7, 8 and Northern Equivalent Panel in Fig. 3.1)

tA = time period (e.g., 100 yr) over which active institutional controls are effective

$tPICD$ = length of time (yr) subsequent to end of active institutional controls over which passive institutional controls (PICs) are effective in reducing the rate of inadvertent human intrusion due to exploratory drilling (e.g., 700 yr)

$fPICD$ = reduction fraction for rate of inadvertent human intrusion due to exploratory drilling in the presence of PICs (i.e., the drilling rate is $fPICD\ \lambda_d$ in the presence of PICs)

$tPICM$ = length of time (yr) subsequent to end of active institutional controls over which passive institutional controls (PICs) are effective in reducing the rate of inadvertent human intrusion due to potash mining (e.g., 700 yr)

$fPICM$ = reduction fraction for rate of inadvertent human intrusion due to potash mining in the presence of PICs (i.e., the mining rate is $fPICM\ \lambda_m$ in the presence of PICs)

tM = length of time period (yr) over which the t_i and t_{min} are defined (i.e., 10,000 yr in analyses to show compliance with 40 CFR 191.13)

D_{DB} = distribution of drillbit diameters. Supplied by user-defined subroutine; initially define as a triangular distribution with user-specified minimum, mode and maximum above and below repository; may be degenerate in 1996 WIPP PA (i.e., only one drillbit diameter in use)

D_P = distribution of borehole permeability. Supplied by user-defined subroutine; initially define as a log triangular distribution with user specified minimum, mode and maximum above and below repository; may be degenerate (i.e., only one borehole permeability in use). In concept, k_i could be a time-dependent function with different values above and below the repository. See Table 3.3.

Generation of $\mathbf{x}_{st} = [t_1, p_1, l_1, a_1, d_1, k_1, b_1, t_2, p_2, l_2, a_2, d_2, k_2, b_2, \ldots, t_n, p_n, l_n, a_n, d_n, k_n, b_n, t_{min}]$

1. Sample t_1 with a time dependent λ_d given by

$$\lambda_d(t) = 0 \qquad \text{if } 0 \le t \le tA$$

$$= fPICD\ \lambda_d \qquad \text{if } tA < t \le tA + tPICD$$

$$= \lambda_d \qquad \text{if } t > tA + tPICD$$

Table 3.2. Continued

The actual generation of t_1 and subsequent intrusion times is based on sampling the elapsed time between intrusions as indicated in conjunction with Fig. 3.2 (see Table 3.4).

2. Sample p_1 with $pPL(j)$

3. Sample l_1 and b_1

   3.1 Use $pR(j)$ to determine region in which intrusion occurs

   3.2 Use $pN(j,k)$ to determine node at which intrusion occurs

   3.3 Use $pB(j,k)$ to determine if intrusion penetrates pressurized brine

   3.4 Increment counter $nH(iB(j, k))$ if pressurized brine is penetrated and $p_1 = 2$ to provide count of number of penetrations into each brine pocket (counter not incremented for $p_1 = 1, 3$, because of limited potential for brine depletion with these plugging patterns)

   3.5 Use $pE(j,k)$ to determine if intrusion penetrates excavated area

      3.5.1 Case 1: Intrusion does not penetrate excavated area. Return to Step 1, generate new t_1 by using $\lambda_d(t)$ to sample elapsed time from initial t_1 to new t_1 and repeat Step 2 (i.e., the initial t_1 is dropped from consideration because it did not penetrate an excavated area in the repository)

      3.5.2 Case 2: Intrusion penetrates excavated area

         3.5.2.1 Assign l_1 integer identifier for node penetrated by drilling intrusion

         3.5.2.2 Assign b_1 as follows:

            $b_1 = 0$ if $p_1 = 1$ (i.e., an intrusion that involves no long term brine flow from the repository to the Culebra due to low borehole permeability)

            $= 1$ if $p_1 = 2$, drilling intrusion penetrates brine pocket p, and $nH(p) \leq nD(p)$ (i.e., an E1 intrusion into brine pocket p that can result in brine flow to the repository)

            $= 2$ if (1) $p_1 = 2$, drilling intrusion penetrates brine pocket p, and $nH(p) > nD(p)$, (2) $p_1 = 2$ and drilling intrusion does not penetrate brine pocket, or (3) $p_1 = 3$ (i.e., an E2 intrusion)

4. Sample a_1 with use of $pW(j, k)$

5. Sample d_1 with use of D_{DB}

6. Sample k_1 with use of D_P

Table 3.2. Continued

7. Repeat Steps 1 - 6 to determine properties (i.e., t_2, p_2, l_2, a_2, d_2, k_2, b_2) of 2nd drilling intrusion

8. Continue until $t_{n+1} > tM$ (i.e., 10,000 yr in analyses to show compliance with 40 CFR 191.13); the 1st n intrusions define the drilling intrusions associated with $\mathbf{x}_{st}$

9. Sample t_{min} (see Table 3.4) with a time dependent λ_m given by

$$\begin{aligned} \lambda_m(t) &= 0 && \text{if } 0 \le t \le tA \\ &= fPICM\,\lambda_m && \text{if } tA < t \le tA + tPICM \\ &= \lambda_m && \text{if } tA + tPICM < t \end{aligned}$$

Notes

1. Include an option where t_{min} is set to the largest integer multiple of 100 yr that is less than or equal to the sampled value of t_{min}. That is, $t_{min} = 100 * AINT(t_{min} / 100)$ as a FORTRAN assignment, where $AINT$ is the greatest integer function.

2. Check to see how hard it is to develop the input so that k_i is always specified as a vector $\mathbf{k}_i$ of time-dependent values above and below the repository as indicated in the discussion for D_P above.

3. The distribution D_{PL} indicated in the text is defined by $pPL(j)$; D_L is defined by $pR(j)$, $pE(j)$, $pNE(j, k)$, $pNN(j, k)$; D_A is defined by $pW(j, k)$; D_B is defined by $pBE(j, k)$.

Table 3.3. Anticipated Definition of D_P for Use in 1996 WIPP PA. Under Option A in CCDFGF, the implications of borehole permeability will be accounted for directly from the values assigned to p_i (i.e., k_i will not be used). However, the permeability assignments indicated in this table will influence the details of the BRAGFLO calculations performed to support the use of CCDFGF.

DPL_{R-S} = distribution of plug life expectancy at the Rustler/Salado interface (e.g., degenerate with a single value of 200 yr)

DPL_{S-C} = distribution of plug life expectancy at the Salado/Castile interface (e.g., log triangular from 500 to 50000 yr with a mode at 5000 yr)

BHP = permeability (m^2) of a sand-filled borehole

Algorithm to define D_P:

1. Use $pPL(j)$ to define plugging pattern p_i used with i^{th} drilling intrusion (see Table 3.2 for definition of $pPL(j)$)

Table 3.3. Continued.

2. Assignment for $p_i = 1$

k_i	$= 1 \times 10^{-9}\ \mathrm{m}^2$	above Rustler/Salado interface for $t_i \le t \le t_i + \Delta t_{R-S}$, where Δt_{R-S} is randomly sampled according to DPL_{R-S}
	$= BHP$	above Rustler/Salado interface for $t_i + \Delta t_{R-S} < t$
	$= 5 \times 10^{-17}\ \mathrm{m}^2$	below Rustler/Salado interface for $t_i \le t$

3. Assignment for $p_i = 2$

k_i	$= 1 \times 10^{-9}\ \mathrm{m}^2$	above and below seal at Rustler/Salado interface for $t_i \le t \le t_i + \Delta t_{R-S}$, where Δt_{R-S} is randomly sampled according to DPL_{R-S}
	$= 5 \times 10^{-17}\ \mathrm{m}^2$	in seal at Rustler/Salado interface for $t_i \le t \le t_i + \Delta t_{R-S}$
	$= BHP$	in entire borehole for $t_i + \Delta t_{R-S} < t \le t_i + \Delta t_{R-S} + 1000$ yr
	$= BHP$	above bottom of waste panel for $t_i + \Delta t_{R-S} + 1000\ \mathrm{yr} < t$
	$= BHP/10$	below bottom of waste panel for $t_i + \Delta t_{R-S} + 1000\ \mathrm{yr} < t$

4. Assignment for $p_i = 3$. Same as in Step 3 but seal at Salado/Castile interface is assigned a value of $5 \times 10^{-17}\ \mathrm{m}^2$ and assumed to last for a time period Δt_{S-C}, which is randomly sampled according to DPL_{S-C} (with the restriction that $\Delta t_{R-S} \le \Delta t_{S-C}$)

Determination of Releases:

1. $p_i = 1$: Cuttings, blowout and spallings releases calculated. Permeability in borehole is assumed to be sufficiently low to prevent releases to the Culebra due to brine flow and also to affect the releases associated with any subsequent intrusions (i.e., is same as no intrusion except for cuttings, blowout and spallings releases).

2. $p_i = 2$: Standard case for which BRAGFLO calculations will be performed. All release modes considered.

3. $p_i = 3$: Define to be same as E2 intrusion at time t_i. Rationale is that the dominant character of an E1 intrusion is the open borehole between the brine pocket and the waste panel for $t_i \le t \le t_i + \Delta t_{R-S}$; this condition will not occur for $p_i = 3$ because $\Delta t_{R-S} \le \Delta t_{S-C}$.

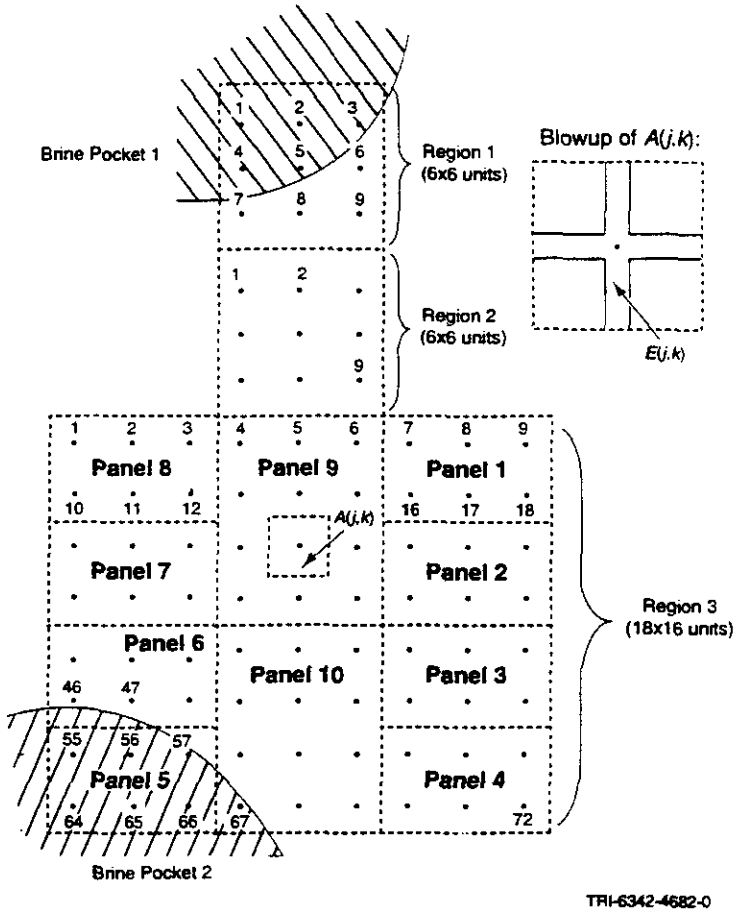

$nR = 3$; $pR(1) = pR(2) = 0.1$, $pR(3) = 0.8$; $nN(1) = nN(2) = 9$, $nN(3) = 72$

$pN(j, k) = 1/nN(j)$, $k = 1, \ldots, nN(j)$, $j = 1, 2, 3$

$$pW(1, k) = pW(2, k) = \begin{cases} 1 & k = 1 \\ 0 & k = 2 \\ 0 & k = 3 \end{cases}, \quad pW(3, k) = \begin{cases} 0 & k = 1 \\ 0.9 & k = 2 \\ 0.1 & k = 3 \end{cases}$$

$$nB = 2,\ pB(j, k) = \begin{cases} 0.1 & \text{if node } k \text{ underlain by pressurized brine} \\ 0 & \text{if node } k \text{ not underlain by pressurized brine} \end{cases}$$

$$iB(j, k) = \begin{cases} i & \text{if node } k \text{ underlain by brine pocket } i \\ 0 & \text{if node } k \text{ not underlain by pressurized brine} \end{cases}$$

$A(j, k)$ = total area (units^2) associated with node k

$E(j, k)$ = excavated area (units^2) associated with node k

$pE(j, k) = E(j, k)/A(j, k)$

$iP(1, k) = iP(2, k) = 0$

$iP(3, k) = 1$, $k = 7, 8, 9, 16, 17, 18, \ldots$, $iP(3, k) = 8$, $k = 1, 2, 3, 10, 11, 12, \ldots$

$$iL(j) = \begin{cases} 1 & j = 1, 2, 3, 6, 7, 8, 9 \\ 2 & j = 4, 5, 10 \end{cases}$$

Figure 3.3. Hypothetical example of specification of node properties.

Table 3.4. Algorithm to Sample Time of a Drilling Intrusion with

$$\lambda(t) = \begin{cases} \mu = fPIC\,\lambda & \text{for } tA \le t \le tA + tPIC \\ \lambda & \text{for } tA + tPIC < t \end{cases}$$

---

1. Sample random number r from uniform distribution on [0, 1]. Then,

   $r = 1 - \exp(-\mu \Delta t_1) \Rightarrow \Delta t_1 = [-\ln(1-r)]/\mu.$

   Two cases:

   1.1 If $tA + \Delta t_1 \le tA + tPIC$, then $t_1 = tA + \Delta t_1$.

   1.2 If $tA + \Delta t_1 > tA + tPIC$, then sample *new* random r and determine *new* Δt_1:

   $r = 1 - \exp(-\lambda \Delta t_1) \Rightarrow \Delta t_1 = [-\ln(1-r)]/\lambda.$

   Then, $t_1 = tA + tPIC + \Delta t_1$.

2. Repeat process to obtain t_2. Two cases:

   2.1 If $t_1 < tA + tPIC$, then identical Step 1 except that tA is replaced by t_1, and the two cases are based on the inequalities

   $t_1 + \Delta t_2 \le t_1 + tPIC$ and $t_1 + \Delta t_2 > t_1 + tPIC$.

   2.2 If $t_1 > tA + tPIC$, then identical to Step 1.2 except that $tA + tPIC$ is replaced by t_1

3. Repeat Step 2 to obtain $t_3, t_4, \ldots, t_{n+1}$, where t_{n+1} is the first time to exceed tM (=10000 yr). Then, $t_1, t_2, \ldots, t_n$ are the desired times.

---

4. Construction of Releases to Accessible Environment for Individual Futures

4.1 Mechanistic Results for Specific Futures

Each sampled future of the form indicated in Eqs. (2.2) and (3.1) will require the determination of a normalized release to the accessible environment. Determination of this release corresponds to evaluation of the function f in Eq. (2.3), which in turn requires evaluation of the programs in Fig. 2.2. Specifically, f is given by

$$\begin{aligned} f(\mathbf{x}_{st}) = {} & f_C(\mathbf{x}_{st}) + f_{BL}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})] + f_{SP}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})] \\ & + f_{MB}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})] + f_{DL}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})] + f_S[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})] \\ & + f_{S-T}\{\mathbf{x}_{st,0}, f_{S-F}(\mathbf{x}_{st,0}), f_{N-P-G}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]\}, \end{aligned} \tag{4.1}$$

where

$\mathbf{x}_{st}$ ~ particular future under consideration,

$\mathbf{x}_{st,0}$ ~ future involving no drilling intrusions but a mining event at the same time t_{min} as in $\mathbf{x}_{st}$,

$f_C(\mathbf{x}_{st})$ ~ cuttings release to accessible environment for $\mathbf{x}_{st}$ calculated with CUTTINGS,

$f_B(\mathbf{x}_{st})$ ~ results calculated for $\mathbf{x}_{st}$ with BRAGFLO; in practice, $f_B(\mathbf{x}_{st})$ would be a vector containing a large amount of information,

$f_{BL}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$ ~ blowout release to accessible environment for $\mathbf{x}_{st}$ calculated with a modified version of BRAGFLO designated BLOWOUT; this calculation requires BRAGFLO results (i.e., $f_B(\mathbf{x}_{st})$) as input,

$f_{SP}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$ ~ spallings release to accessible environment for $\mathbf{x}_{st}$ calculated with the spallings model contained in CUTTINGS; this calculation requires BRAGFLO results (i.e., $f_B(\mathbf{x}_{st})$) as input,

$f_{MB}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$ ~ release through anhydrite marker beds to accessible environment for $\mathbf{x}_{st}$ calculated with NUTS; this calculation requires BRAGFLO results (i.e., $f_B(\mathbf{x}_{st})$) as input,

$f_{DL}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$ ~ release through Dewey Lakes Red Beds to accessible environment for $\mathbf{x}_{st}$ calculated with NUTS; this calculation requires BRAGFLO results (i.e., $f_B(\mathbf{x}_{st})$) as input,

$f_S[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$ ~ release to land surface due to brine flow up a plugged borehole for $\mathbf{x}_{st}$ calculated with NUTS or PANEL; this calculation requires BRAGFLO results (i.e., $f_B(\mathbf{x}_{st})$) as input,

$f_{S-F}(\mathbf{x}_{st,0})$ ~ flow field calculated for $\mathbf{x}_{st,0}$ with SECO-FLOW,

$f_{N-P-G}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$ ~ release to Culebra for $\mathbf{x}_{st}$ calculated with NUTS, PANEL and/or GRIDFLO as appropriate; this calculation requires BRAGFLO results (i.e., $f_B(\mathbf{x}_{st})$) as input,

$f_{S-T}\{\mathbf{x}_{st,0}, f_{S-F}(\mathbf{x}_{st,0}), f_{N-P-G}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]\}$ ~ groundwater transport release through Culebra to accessible environment calculated with SECO-TRANSPORT; this calculation requires SECO-FLOW results (i.e., $f_{S-F}(\mathbf{x}_{st,0})$) and NUTS, PANEL and/or GRIDFLO results (i.e., $f_{N-P-G}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$) as input; $\mathbf{x}_{st,0}$ is used as an argument to f_{S-T} because drilling intrusions are assumed to cause no perturbations to the flow field in the Culebra.

At present, releases to the accessible environment due to flow through the Dewey Lakes Red Beds (i.e., $f_{DL}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$) and also long-term flow up an abandoned borehole (i.e., $f_S[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$) are anticipated to be zero in the 1996 WIPP PA (i.e., there is no upward flow in a plugged and abandoned borehole above the Culebra).

Based on experience from the SPM analyses, the Monte Carlo CCDF construction procedure indicated in Eq. (2.3) and to be implemented by CCDFGF will require a sample size between 1000 and 10,000 (i.e., $1000 \le nS \le 10{,}000$ in Eq. (2.3)). The individual programs in Fig. 2.2 do not run fast enough to allow this number of evaluations of f. As a result, it will be necessary to evaluate the programs in Fig. 2.2 for a limited number of futures and then to use this limited number of evaluations to construct the releases for the large number of futures that must be considered in Eq. (2.3).

Until the final assumptions for the 1996 WIPP PA are decided upon and preliminary calculations with these assumptions are performed and analyzed, it is difficult to select an appropriate set of futures for evaluation with the models in Fig. 2.2 and also to decide on appropriate ways to use these results to estimate the releases for additional futures. However, to build and test the structure of CCDFGF, some assumptions have to be made about the calculations that will be performed with the models in Fig. 2.2. Therefore, this chapter will assume that certain calculated results with the models in Fig. 2.2 are available and then describe a way to use these results in the evaluation of the function f in Eqs. (2.3) and (4.1). Unfortunately, the possibility cannot be avoided that last minute recoding of the manipulations described in this chapter may be required to make the most appropriate use of the necessarily limited number of mechanistic calculations that will be performed.

For notational simplicity at later points in this presentation, the functions on the right hand side of Eq. (4.1) will typically be written with only $\mathbf{x}_{st}$ an argument (e.g., $f_{BL}(\mathbf{x}_{st})$ will be used instead of $f_{BL}[\mathbf{x}_{st}, f_B(\mathbf{x}_{st})]$). However, the underlying dependency on the other arguments will still be present.

4.2 Construction of Cuttings Releases

Cuttings releases will be constructed with results from the CUTTINGS program. Specifically, CUTTINGS will provide the cross-sectional areas of drilling intrusions through CH- and RH-waste. These areas will then be combined with the effective height of the waste and the concentration in individual waste streams to obtain cuttings releases.

The information being supplied to CCDFGF for use in the calculation of cuttings releases is given in Table 4.1. Further, the computational formulas used to determine the cuttings release (i.e., $f_C(\mathbf{x}_{st})$) are given in Table 4.2.

4.3 Construction of Blowout Releases

Blowout releases will be constructed from brine releases (m^3) to the surface obtained from a specialized formulation of BRAGFLO, designated by the name BLOWOUT, and radionuclide concentrations (EPA units/m^3) in brine calculated by PANEL. The results transferred to CCDFGF from BLOWOUT and PANEL are summarized in Tables 4.3 and 4.4. Further, the computational formulas used to determine the blowout release (i.e., $f_{BL}(\mathbf{x}_{st})$) are given in Table 4.5.

In practice, it may not be possible to perform BLOWOUT calculations for all the cases indicated in Table 4.3. In this case, the calculations that are performed will have to be extended to give results for the cases for which calculations are not performed. The manner in which this can be done is described in Table 4.6 and Fig. 4.1.

4.4 Construction of Spallings Releases

The construction of the spallings release $f_{SP}(\mathbf{x}_{st})$ is identical to that described in Sect. 4.3 for the calculation of blowout releases except that volumes of solid material released will be used rather than volumes of brine. These solid releases will be calculated with the spallings submodel of the CUTTINGS program.

The table of input values for spallings releases will be identical in structure to that shown in Table 4.3 for blowout releases (i.e., to obtain the table of input values for the spallings calculation, simply modify Table 4.3 by replacing the letters "*BL*" in the variable names with the letters "*SP*," replacing the word "blowout" with the word "spallings"), and changing the release units from "m^3 brine" to "m^3 solids." Further, similar modifications hold for the computational formulas in Table 4.5 with the additional requirement that the dissolved concentrations (i.e., CAVGE0D(t_i), CAVGE2D(t_i), CAVGE1D(t_i)) be replaced by a concentration per unit volume of solid waste (i.e., CAVG(t_i) • DWS, where CAVG(t_i) is concentration in waste at time t_i, EPA units/kg, and DWS is the density of the solid components of the waste, kg/m^3; see Table 4.4).

Table 4.1 Results from Baseline Inventory (BIR) and Calculations with CUTTINGS Transferred to CCDFGF for Use in Determination of Releases Due to Cuttings Removal. The information in this table will repeat for each element in a sample.

Results Transferred to CCDFGF
DBDIAM: Drillbit diameter (m) used in calculation of cuttings releases (e.g., 0.311 m ~ 12.25 in.)
NCH: Number of waste streams for CH waste (e.g., 569)
ACH: Cross-sectional area (m^2) of waste removed by drilling intrusion through CH waste (calculated by CUTTINGS)
HCH: Emplaced height (m) of CH waste (i.e., ACH • HCH equals volume of original (uncompacted) waste removed by a drilling intrusion) (e.g., 3.96 m)
FCH: Fraction of volume removed by drilling intrusion through portion of repository containing CH waste that is actually CH waste (e.g., 0.4; see Sect. 3.1.1, SAND92-0700/3)
PCH (ICH): Probability that a randomly sampled unit (i.e., drum) of CH waste will come from waste stream ICH, ICH = 1, 2, ..., NCH (Note: Σ_i PCH(i) = 1)
NTMCH: Number of times at which radionuclide concentrations are calculated for CH waste (e.g., 9)
TMCH (ITMCH): Times (yr) at which radionuclide concentrations are calculated for CH waste, ITMCH = 1, 2, ..., NTMCH (e.g., 100, 125, 175, 350, 1000, 3000, 5000, 7500, 10000 yr)
CCH (ICH, ITMCH): Radionuclide concentration (EPA units/m^3, where EPA unit refers to the normalized radionuclide unit defined in 40 CFR 194[3]) in CH waste stream ICH at time TMCH (ITMCH), ICH = 1, 2, ..., NCH and ITMCH = 1, 2, ..., NTMCH
NSMPCH: Number of waste streams intersected by a single drilling intrusion through CH waste (e.g., 3)
NRH, ARH, HRH, FRH, PRH (IRH), NTMRH, TMRH (ITMRH), CRH (IRH, ITMRH, NSMPRH): Same as NCH, ACH, HCH, PCH (ICH), NTMCH, TMCH (ITMCH), CCH (ICH, ITMCH), NSMPCH but for RH waste
Conceptual Structure of Transfer File for One Sample Element
DBDIAM (e.g., 0.311 m)
NCH (e.g., 569)
ACH
HCH (e.g., 3.96 m)
FCH (e.g., 0.4)
PCH (ICH): ICH = 1, ..., NCH
NTMCH (e.g., 9)

Table 4.1 Continued

TMCH (ITMCH): ITMCH = 1, ..., NTMCH (e.g., 100, 125, 175, 350, 1000, 3000, 5000, 7500, 10000)

CCH (ICH, ITMCH): (ITMCH = 1, ..., NTMCH), ICH = 1, ..., NCH

NRH (e.g., 1)

ARH (e.g., DBDIAM)

HRH (e.g.,)

FRH (e.g., 1)

PRH (IRH): IRH = 1, ..., NRH

NTMRH (e.g., 9)

TMRH (ITMRH): ITMRH = 1, ..., NTMRH (e.g., 100, 125, 175, 350, 1000, 3000, 5000, 7500, 10000)

CRH (IRH, ITMRH): (ITMRH = 1, ..., NTMRH), IRH = 1, ..., NRH

Table 4.2. Calculation of Cuttings Release f_C for an Arbitrary Future $\mathbf{x}_{st}$

Arbitrary future:

$$\mathbf{x}_{st} = [t_1, p_1, l_1, a_1, d_1, k_1, b_1, t_2, p_2, l_2, a_2, d_2, k_2, b_2, \ldots, t_n, p_n, l_n, a_n, d_n, k_n, b_n, t_{min}]$$

Notation: cW_{jt} = concentration (EPA units/m^3) in waste stream j at time t_i

$$= \begin{cases} \mathrm{CCH}(j, t_i)^{a} & \text{if } a_i \sim \text{CH waste} \\ \mathrm{CRH}(j, t_i) & \text{if } a_i \sim \text{RH waste} \end{cases}$$

v_i = volume (m^3) of waste removed by i^{th} drilling intrusion

$$= \begin{cases} \text{ACH HCH} & \text{if } a_i \sim \text{CH waste} \\ \text{ARH HRH} & \text{if } a_i \sim \text{RH waste} \end{cases}$$

fW_i = fraction of removed volume that is waste

$$= \begin{cases} \text{FCH} & \text{if } a_i \sim \text{CH waste} \\ \text{FRH} & \text{if } a_i \sim \text{RH waste} \end{cases}$$

δ = drillbit diameter (m)

= DBDIAM

$m(i)$ = number of waste streams intersected by i^{th} drilling intrusion

$$= \begin{cases} \text{NSMPCH} & \text{if } a_i \sim \text{CH waste} \\ \text{NSMPRH} & \text{if } a_i \sim \text{RH waste} \end{cases}$$

Table 4.2. Continued

$n(i)$ = number of waste streams associated with waste class (i.e., CH or RH) intersected by i^{th} drilling intrusion

$$= \begin{cases} \text{NCH} & \text{if } a_i \sim \text{CH waste} \\ \text{NRH} & \text{if } a_i \sim \text{RH waste} \end{cases}$$

π_{ij} = probability of waste stream j for waste class (i.e., CH or RH) intersected by i^{th} drilling intrusion

$$= \begin{cases} \text{PCH}(j) & \text{if } a_i \sim \text{CH waste} \\ \text{PRH}(j) & \text{if } a_i \sim \text{RH waste} \end{cases}$$

$j(i, r)$ = integer randomly selected from 1, 2, ..., $n(i)$ according to probabilities π_{ij}, $j = 1, 2, \ldots, n_{(i)}$, for $r = 1, 2, \ldots, m(i)$

Evaluation of $f_C(\mathbf{x}_{st})$:

$$\overline{cW}_i{}^{b} = 0 \qquad \text{if } a_i \sim \text{no waste}$$

$$= \left(\sum_{r=1}^{m(i)} cW_{i,\, j(i,r)} \right) / \, m(i) \qquad \text{if } a_i \sim \text{CH or RH waste}$$

$$f_C(\mathbf{x}_{st}) = \sum_{i=1}^{n} (d_i / \delta)^2 \, fW_i \, v_i \, \overline{cW}_i$$

a Interpolation is implied when a real value appears in an array rather than an integer. Thus,

$$CCH(j, t_i) = CCH(j, l) + \left[\frac{t_i - TMCH(l)}{TMCH(l+1) - TMCH(l)} \right] \left[CCH(j, l+1) - CCH(j, l) \right],$$

where l is the largest integer such that $TMCH(l) \le t_i$. This notational convention will be used repeatedly to simplify the description of computational procedures that require interpolation.

b Technically, $j(i, r)$ is the outcome of stochastic uncertainty (i.e., variation in the cuttings release due to random variation in where the ith drilling intrusion occurs). Thus, $j\,(i, r)$ is actually part of the definition of a_i discussed in Chapt. 3. When viewed in this manner, a_i becomes a vector of the form $\mathbf{a}_i = \left[a_i, j(i, r), r = 1, 2, \ldots, m(i) \right]$.

Table 4.3. Results from Calculations with BLOWOUT Transferred to CCDFGF for Use in Determination of Releases Due to Blowout. The information in this table will repeat for each sample element.

Results Transferred to CCDFGF
NTMBLE0L: Number of times at which blowout releases are calculated with BLOWOUT for an E0 (i.e., initial) intrusion into the lower waste panel (e.g., 12)
TMBLE0L (ITM): Times (yr) at which blowout releases are calculated for an E0 intrusion into the lower waste panel, ITM = 1, 2, ..., NTMBLE0L (e.g., 100, 350, 1000, 2000, 3000, ..., 10000 yr)
RBLE0L (ITM): Blowout release (m^3 brine) for an E0 intrusion into the lower waste panel at time TMBLE0L (ITM), ITM = 1, 2, ..., NTMBLE0L
NTMBLE0U, TMBLE0U, RBLE0U (ITM): Same as NTMBLE0L, TMBLE0L, RBLE0L (ITM) but for intrusion into the upper waste panels
NTMBLE1S: Number of times at which initial E1 intrusions (i.e., into pressurized brine in the Castile Formation) occur for use in calculation of blowout releases for second and subsequent intrusions into the same waste panel (e.g., 7). See Fig. 4.1 for temporal structure of calculations for second intrusions into the repository.
TMBLE1S (ITM1): Times (yr) at which initial E1 intrusions occur for use in calculation of blowout releases for second and subsequent intrusions into same waste panel, ITM1 = 1, 2, ..., NTMBLE1S (e.g., 100, 350, 1000, 3000, 5000, 7500, 10000 yr)
NTBLE1S2 (ITM1): Number of times at which a second intrusion into a waste panel occurs following an initial E1 intrusion into that panel at time TMBLE1S (ITM1), ITM1 = 1, 2, ..., NTMBLE1S (e.g., 13, 13, 12, 9, 7, 5, 1)
TMBLE1S2 (ITM1, ITM2): Times (yr) at which a second intrusion into a waste panel occurs following an initial E1 intrusion into that panel at time TMBLE1S (ITM1), ITM2 = 1, 2, ..., NTBLE1S2 (ITM1) and ITM1 = 1, 2, ..., NTMBLE1S (e.g., TMBLE1S(1) = 100 yr: 100, 300, 500, 1000, 2000, ..., 10000 yr; TMBLE1S(2) = 350 yr: 350, 550, 750, 1000, 3000, ..., 10000 yr; TMBLE1S(3) = 1000 yr: 1000, 1200, 1400, 2000, 3000, ..., 10000 yr; TMBLE1S(4) = 3000 yr: 3000, 3200, 3400, 4000, 5000, ..., 10000 yr; TMBLE1S(5) = 7500 yr: 7500, 7700, 7900, 9000, 10000 yr; TMBLE1S(6) = 10000 yr: 10000 yr)
RBLE1S2 (ITM1 ITM2): Blowout release (m^3 brine) for a second intrusion into a waste panel at time TMBLE1S2 (ITM2, ITM1) that previously experienced an initial E1 intrusion at time TMBLE1S (ITM1), ITM2 = 1, 2, ..., NTBLE1S2 (ITM1) and ITM1 = 1, 2, ..., NTMBLE1S
NTMBLE1D, TMBLE1D (ITM1), NTBLE1D2 (ITM1), TMBLE1D2 (ITM1, ITM2), RBLE1D2 (ITM1, ITM2): Same as NTMBLE1S, TMBLE1S, NTBLE1S2 (ITM1), TMBLE1S2 (ITM1, ITM2), RBLE1S2 (ITM1, ITM2) except that the second intrusion is into a different waste panel than the first intrusion
NTMBLE2S, TMBLE2S (ITM1), NTBLE2S2 (ITM1), TMBLE2S2 (ITM1, ITM2), RBLE2S2 (ITM1, ITM2), NTMBLE2D, TMBLE2D (ITM1), NTBLE2D2 (ITM1), TMBLE2D2 (ITM1, ITM2), RBLE2D2 (ITM1, ITM2): Same as NTMBLE1S, TMBLE1S (ITM1), NTBLE1S2 (ITM1), TMBLE1S2 (ITM1, ITM2), RBLE1S2 (ITM1, ITM2), NTMBLE1D, TMBLE1D (ITM1), NTBLE1D (ITM1), TMBLE1D2 (ITM1, ITM2), RBLE1D2 (ITM1, ITM2) except for an initial E2 intrusion (i.e., an intrusion that does not penetrate pressurized brine in the Castile Formation) rather than an initial E1 intrusion

Table 4.3. Continued

Conceptual Structure of Transfer File for One Sample Element
NTMBLE0L (e.g., 12)
TMBLE0L (ITM): ITM = 1, ..., NTMBLE0L (e.g., 100, 350, 1000, 2000, 3000, ..., 10000 yr)
RBLE0L (ITM): ITM = 1, ..., NTMBLE0L
NTMBLE0U (e.g., 12)
TMBLE0U (ITM): ITM = 1, ..., NTMBLE0U (e.g., 100, 350, 1000, 2000, 3000, ..., 10000 yr)
RBLE0U (ITM): ITM = 1, ..., NTMBLE0U
NTMBLE1S (e.g., 7)
TMBLE1S (ITM1): ITM1 = 1, ..., NTMBLE1S (e.g., 100, 350, 1000, 3000, 5000, 7500, 10000 yr)
NTBLE1S2 (ITM1): ITM1 = 1, ..., NTMBLE1S (e.g., 13, 13, 12, 9, 7, 5, 1)
TMBLE1S2 (ITM1, ITME2): (ITM2 = 1, ..., NTBLE1S2 (ITM1), ITM1 = 1, ..., NTMBLE1S (e.g., 100, 300, 500, 1000, 2000, ..., 10000 ; 350, 550, 750, 1000, 2000, ..., 10000; 1000, 1200, 1400, 2000, 3000, ..., 10000; 3000, 3200, 3400, 4000, 5000, ..., 10000; 5000, 5200, 5400, 6000, 7000, ..., 10000; 7500, 7700, 7900, 9000, 10000; 10000)
RBLE1S2 (ITM1, ITM2): (ITM2 = 1, ..., NTBLE1S2 (ITM1)), ITM1 = 1, ..., NTMBLE1S
NTMBLE1D (e.g., 7)
TMBLE1D (ITM1): ITM1 = 1, ..., NTMBLE1D (e.g., 100, 350, 1000, 3000, 5000, 7500, 10000 yr)
NTBLE1D2 (ITM1): ITM1 = 1, ..., NTMBLE1D (e.g., 13, 13, 12, 9, 7, 5, 1)
TMBLE1D2 (ITM1, ITM2): (ITM2 = 1, ..., NTBLE1D2 (ITM1), ITM1 = 1, ..., NTMBLE1D (e.g., 100, 300, 500, 1000, 2000, ..., 10000 ; 350, 550, 750, 1000, 2000, ..., 10000; 1000, 1200, 1400, 2000, 3000, ..., 10000; 3000, 3200, 3400, 4000, 5000, ..., 10000; 5000, 5200, 5400, 6000, 7000, ..., 10000; 7500, 7700, 7900, 9000, 10000; 10000)
RBLE1D2 (ITM1, ITM2): (ITM2 = 1, ..., NTBLE1D2 (ITM1)), ITM1 = 1, ..., NTMBLE1D
NTMBLE2S (e.g., 7)
TMBLE2S (ITM1): ITM1 = 1, ..., NTMBLE2S (e.g., 100, 350, 1000, 3000, 5000, 7500, 10000 yr)
NTBLE2S2 (ITM1): ITM1 = 1, ..., NTMBLE2S (e.g., 13, 13, 12, 9, 7, 5, 1)

Table 4.3. Continued

TMBLE2S2 (ITM1, ITM2): (ITM2 = 1, ..., NTBLE2S2 (ITM1), ITM1 = 1, ..., NTMBLE2S (e.g., 100, 300. 500, 1000, 2000, ..., 10000 ; 350, 550, 750, 1000, 2000, ..., 10000; 1000, 1200, 1400, 2000, 3000, ..., 10000; 3000, 3200, 3400, 4000, 5000, ..., 10000; 5000, 5200, 5400, 6000, 7000, ..., 10000; 7500, 7700, 7900, 9000, 10000; 10000)

RBLE2S2 (ITM1, ITM2): (ITM2 = 1, ..., NTBLE2S2 (ITM1)), ITM1 = 1, ..., NTMBLE2S

NTMBLE2D (e.g., 7)

TMBLE2D (ITM1): ITM1 = 1, ..., NTMBLE2D (e.g., 100, 350, 1000, 3000, 5000, 7500, 10000 yr)

NTBLE2D2 (ITM1): ITM1 = 1, ..., NTMBLE2D (e.g., 13, 13, 12, 9, 7, 5, 1)

TMBLE2D2 (ITM1, ITM2): (ITM2 = 1, ..., NTBLE2D2 (ITM1), ITM1 = 1, ..., NTMBLE2D (e.g., 100, 300, 500, 1000, 2000, ..., 10000 ; 350, 550, 750, 1000, 2000, ..., 10000; 1000, 1200, 1400, 2000, 3000, ..., 10000; 3000, 3200, 3400, 4000, 5000, ..., 10000; 5000, 5200, 5400, 6000, 7000, ..., 10000; 7500, 7700, 7900, 9000, 10000; 10000)

RBLE2D2 (ITM1, ITM2): (ITM2 = 1, ..., NTBLE2D2 (ITM1)), ITM1 = 1, ..., NTMBLE2D

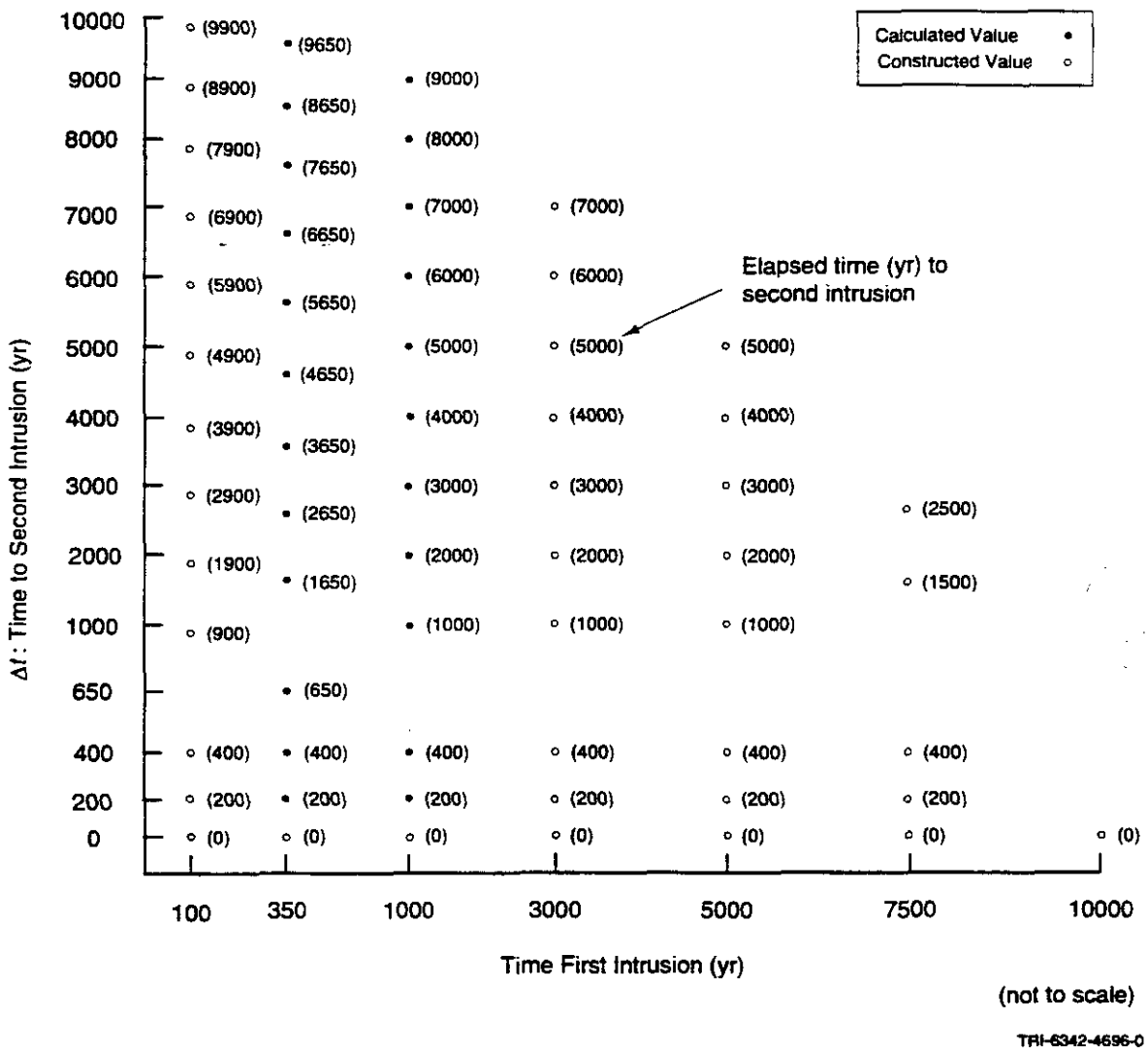

Fig. 4.1. Pairs of drilling intrusions used in the calculation of blowout releases. Solid points (●) represent calculations performed with BLOWOUT; open points (○) represent results constructed from BLOWOUT calculations. Points in table correspond to pairs of times at which RBLE1S (ITM1, ITM2), RBLE1D (ITM1, ITM2), RBLE2S (ITM1, ITM2) and RBLE2D (ITM1, ITM2) will be generated for use in CCDF constructions.

Table 4.4. Results from Calculations with PANEL Transferred to CCDFGF for Use in Determination of Releases Due to Blowout and Spallings. The information in this table will repeat for each sample element.

Results Transferred to CCDFGF
NTMAVG: Number of times at which average radionuclide concentrations over the entire repository are calculated (e.g., 9)
TMAVG (ITMA): Times (yr) at which average radionuclide concentrations are calculated, ITMA = 1, 2, ..., NTMAVG (e.g., 100, 125, 175, 350, 1000, 3000, 5000, 7500, 10000 yr)
CAVG (ITMA): Radionuclide concentration (EPA units/kg) in repository averaged over all waste streams at time TMAVG (ITMA), ITMA = 1, 2, ..., NTMAVG
DWS: Density (kg/m^3) of the solid components of the waste. Product of CAVG (ITMA) and DWS gives radionuclide concentration (EPA units/m^3) in solid material removed in a spallings release at time TMAVG (ITMA)
CAVGE0D (ITMA): Dissolved radionuclide concentration (EPA units/m^3) in repository averaged over all waste streams under E0 (i.e., undisturbed) conditions at time TMAVG (ITMA), ITMA = 1, 2, ..., NTMAVG
CAVGE1D (ITMA): Dissolved radionuclide concentration (EPA units/m^3) in repository averaged over all waste streams at time TMAVG (ITMA) subsequent to an E1 intrusion, ITMA = 1, 2, ..., NTMAVG
CAVGE2D (ITMA): Same as CAVGE1D but for an E2 intrusion
Conceptual Structure of Transfer File for One Sample Element
NTMAVG (e.g., 9)
TMAVG (ITMA): ITMA = 1, ..., NTMAVG (e.g., 100, 125, 175, 350, 1000, 3000, 5000, 7500, 10000)
CAVG (ITMA): ITMA = 1, ..., NTMAVG
CAVGE0D (ITMA): ITMA = 1, ..., NTMAVG
CAVGE1D (ITMA): ITMA = 1, ..., NTMAVG
CAVGE2D (ITMA): ITMA = 1, ..., NTMAVG

Table 4.5. Calculation of Blowout Release f_{BL} for an Arbitrary Future $\mathbf{x}_{st}$

Arbitrary future:

$$\mathbf{x}_{st} = [t_1, p_1, l_1, a_1, d_1, k_1, b_1, t_2, p_2, l_2, a_2, d_2, k_2, b_2, \ldots, t_n, p_n, l_n, a_n, d_n, k_n, b_n, t_{min}]$$

Release rBL_i for intrusion into a pressurized repository (i.e., $i = 1$ or $b_j = 0$ for $j = 1, 2, \ldots, i-1$):

$$\begin{aligned} rBL_i &= 0 && \text{if } l_i \text{ not in waste panel or } a_i \sim \text{no or RH waste} \\ &= \mathrm{VBLE0U}(t_i)^{a} \quad \mathrm{CAVGE0D}(t_i) && \text{if } l_i \text{ in upper waste panels} \\ &= \mathrm{VBLE0L}(t_i) \quad \mathrm{CAVGE0D}(t_i) && \text{if } l_i \text{ in lower waste panels} \end{aligned}$$

Release rBL_i for i^{th} intrusion into a depressurized repository with no E1 intrusion in first $i-1$ intrusions (i.e., $b_k = 0$ for $k = 1, 2, \ldots, j-1$, $b_j = 2$, $b_k \neq 1$ for $k = j+1, j+2, \ldots, i-1$):

$$\begin{aligned} rBL_i &= 0 && \text{if } l_i \text{ not in a waste panel or } a_i \sim \text{no or RH waste} \\ &= \mathrm{VBLE2S2}(t_j, t_i)^{b} \quad \mathrm{CAVGE2D}(t_i) && \text{if } l_j, l_i \text{ in same waste panel} \\ &= \mathrm{VBLE2D2}(t_j, t_i) \quad \mathrm{CAVGE2D}(t_i) && \text{if } l_j, l_i \text{ in different waste panels} \end{aligned}$$

Release rBL_i for i^{th} intrusion into a depressurized repository with first E1 intrusion at time $t_j < t_i$ (i.e., $b_k \neq 1$ for $k = 1, 2, \ldots, j-1$, $b_j = 1$):

$$\begin{aligned} rBL_i &= 0 && \text{if } l_i \text{ not in a waste panel or } a_i \sim \text{no or RH waste} \\ &= \mathrm{VBLE1S2}(t_j, t_i) \quad \mathrm{CAVGE1D}(t_i) && \text{if } l_j, l_i \text{ in same waste panel} \\ &= \mathrm{VBLE1D2}(t_j, t_i) \quad \mathrm{CAVGE1D}(t_i) && \text{if } l_j, l_i \text{ in different waste panels} \end{aligned}$$

Set criterion for terminating blowout release:

$$\begin{aligned} nMX &= n && \text{No termination criterion, use blowout releases from all intrusions} \\ &= \min\{nBL, n\} && \text{Terminate after first } nBL \text{ intrusions} \\ &= \min\{nE1 + nBL, n\} && \text{Terminate after first } nBL \text{ intrusions following initial E1 intrusion at time } t_{nE1} \\ &= \min\{nP, n\} && \text{Terminate after first intrusion time } t_{nP} \text{ at which the borehole permeability } k_{nP} \text{ exceeds a specified value} \end{aligned}$$

Evaluation of $f_{BL}(\mathbf{x}_{st})$:

$$f_{BL}(\mathbf{x}_{st}) = \sum_{i=1}^{nMX} rBL_i$$

[a] Here and elsewhere, appearance of a real quantity as an array subscript implies interpolation (see Table 4.2).
[b] Here and elsewhere, appearance of two real quantities as array subscripts implies two dimensional interpolation.

Table 4.6. Extension of Limited Number of BLOWOUT Calculations to Obtain Results in Table 4.3.

Anticipated Blowout Calculations for 1996 WIPP PA
Initial (i.e., E0) intrusion into lower waste panel at 100, 350, 1000, 2000, 3000, ..., 10000 yr. Defines RBLE0L (ITM), ITM = 1, 2, ..., 12
Initial (i.e., E0) intrusion into upper waste panel at 100, 350, 1000, 2000, 3000, ..., 10000 yr. Defines RBLE0U (ITM), ITM = 1, 2, ..., 12
Initial E1 intrusion at 350 yr followed by intrusion into same waste panel at 550, 750, 1000, 2000, 3000, ..., 10000 yr. Defines RBLE1S (2, ITM2), ITM2 = 2, 3, ..., 13
Initial E1 intrusion at 350 yr followed by intrusions into different waste panel at 550, 750, 1000, 2000, 3000, ..., 10000 yr. Defines RBLE2D (2, ITM2), ITM2 = 2, 3, ..., 13
Initial E1 intrusion at 1000 yr followed by intrusion into same waste panel at 1200, 1400, 2000, 3000, ..., 10000 yr. Defines RBLE1S (3, ITM2), ITM2 = 2, 3, ..., 12
Initial E1 intrusion at 1000 yr followed by intrusion into different waste panel at 1200, 1400, 2000, 3000, ..., 10000 yr. Defines RBLE1D (3, ITM2), ITM2 = 2, 3, ..., 12
Same results calculated for intrusions subsequent to an E2 intrusion (i.e., RBLE2S (2, ITM2), RBLE2D (2, ITM2), RBLE2S (3, ITM2), RBLE2D (3, ITM2))
Extension of Calculated Results (See Fig. 4.1)
1. For initial intrusions at 350 and 1000 yr, assign same value for second intrusion at Δt = 0 yr as for second intrusion at Δt = 200 yr.
2. For initial intrusion at 100 yr, assign value for second intrusion by interpolating on Δt for initial intrusion at 350 yr; value for Δt = 9900 yr requires extrapolation.
3. For initial intrusion at 3000, 5000, 7500 and 10000 yr, assign value for second intrusion by interpolating on Δt for initial intrusion at 1000 yr.

As for blowout calculations, the number of cases for which calculations can be performed will be less than the number of cases indicated in Table 4.3. Thus, it will be necessary to use the extension procedures described in Table 4.6 and Fig. 4.1.

4.5 Radionuclide Transport Away from Repository by Flowing Brine

The information from calculations with NUTS and PANEL that will be transferred to CCDFGF for use in the estimation of radionuclide transport away from the repository by flowing brine is listed in Table 4.7.

Table 4.7. Results from Calculations with NUTS and PANEL Related to Radionuclide Transport Away from the Repository by Flowing Brine Transferred to CCDFGF. The information in this table will repeat for each sample element

Results Transferred to CCDFGF
NDCHAIN: Number of decay chains (e.g., 3)
NMBR (ICH): Number of elements in decay chain ICH, ICH = 1, 2, ..., NDCHAIN (e.g., 1, 1, 2)
RDECAY (ICH, IMBR): Decay constant (yr^{-1}) for element IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., __, __, __, __)
CNVRTCM (ICH, IMBR): Conversion factor from curies to moles (mole/Ci) for element IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., __, __, __, __)
CNVRTKM (ICH, IMBR): Conversion factor from kilograms to moles (mole/kg) for element IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., __, __, __, __)
NMDCMBR (ICH, IMBR): Name of member IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., Pu-239, Am-241, U-234, Th-230)
RLIMIT (ICH, IMBR): EPA release limit (Ci) for element IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., 100, 100, 100, 10 Ci)
TOTINV: Total inventory (Ci) of α-emitting radionuclides placed in repository with halflives greater than 20 yr (e.g., 4.07×10^6 Ci)
NCOLSP: Number of colloid species (e.g., 4)
FRDCLE0 (ICOL, ICH, IMBR): Fraction of element IMBR of decay chain ICH attached to colloid specie ICOL for undisturbed (i.e., E0) conditions, IMBR = 1, 2, ..., NMBR (ICH), ICH = 1, 2, ..., NDCHAIN and ICOL = 1, 2, ..., NCOLSP
FRDCLE1 (ICOL, ICH, IMBR), FRDCLE2 (ICOL, ICH, IMBR): Same as FRDCLE0 (ICOL, ICH, IMBR) except for E1 and E2 intrusions, respectively
NTMRELE0: Number of times used to define intervals over which releases from the repository under undisturbed (i.e., E0) conditions due to brine flow are recorded (e.g., 198)
TMGWRPE0 (ITM): Times (yr) used to define intervals over which releases from the repository under undisturbed (i.e., E0) conditions due to brine flow are recorded, ITM = 1, 2, ..., NTMRELE0 (e.g., 100, 150, 200, ..., 9950, 10000)
RCGWRPE0 (ICH, IMBR, ITM): Cumulative release (kg) of element IMBR of decay chain ICH from the repository to the Culebra under undisturbed (i.e., E0) conditions through time TMGWRPE0 (ITM) due to brine flow, ITM = 1, 2, ..., NTMRELE0, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN
RAGWRPE0 (ITM): Cumulative release (EPA units) of all radioactive species from the repository to the accessible environment under undisturbed (i.e., E0) conditions through time TMGWRPE0 (ITM) due to brine flow in the anhydrite marker beds, ITM = 1, 2, ..., NTMRELE0

Table 4.7. Continued

NTME1: Number of times at which calculations for E1 intrusions are performed (e.g., 7)

TME1 (ITME1): Times (yr) at which calculations for E1 intrusions are performed, ITME1 = 1, 2, ..., NTME1 (e.g., 100, 350, 1000, 3000, 5000, 7000, 9000 yr)

NTMRELE1 (ITME1): Number of times used to define intervals over which releases from the repository are recorded for an E1 intrusion at time TME1 (ITME1), ITME1 = 1, 2, ..., NTME1 (e.g., 198, 193, 180, 140, 100, 60, 20)

TMGWRPE1 (ITME1, ITM): Times (yr) used to define intervals over which releases from the repository due to brine transport are recorded for an E1 intrusion at time TME1 (ITME1), ITME1 = 1, 2, ..., NTME1 and ITM = 1, 2, ..., NTMRELE1 (ITME1)

RGWRPE1 (ITME1, ICH, IMBR, ITM): Cumulative release (kg) of element IMBR of decay chain ICH from the repository to the Culebra through time TMGWRPE1 (ITME1, ITM) due to brine flow for an E1 intrusion at time TME1 (ITME1), ITM = 1, 2, ..., NTMRELE1 (ITME1), IMBR = 1, 2, ..., NMBR (ICH), ICH = 1, 2, ..., NDCHAIN, and ITME1 = 1, 2, ..., NTME1

RAGWRPE1 (ITME1, ITM): Cumulative release (EPA units) from the repository to the accessible environment through time TMGWRPE1 (ITME1, ITM) due to brine flow in the anhydrite marker beds for an E1 intrusion at time TME1 (ITME1), ITME1 = 1, 2, ..., NTME1 and ITM = 1, 2, ..., NTMRELE1 (ITME1)

NTME2, TME2 (ITME2), NTMRELE2 (ITME2), TMGWRPE2 (ITME2, ITM), RCGWRPE2 (ITME2, ICH, IMBR, ITM), RAGWRPE2 (ITME2, ITM): Same as NTME1, TME1 (ITME1), NTMRELE1 (ITME1), TMGWRPE1 (ITME1, ITM), RCGWRPE1 (ITME1, ICH, IMBR, ITM), RAGWRPE1 (ITME1, ITM) but for an E2 intrusion in place at time TME2 (ITME2)

NTME12, TME12 (ITME12), NTMRELE12 (ITME12), TMGWRPE12 (ITME12, ITM), RCGWRPE12 (ITME12, ICH, IMBR, ITM), RAGWRPE12 (ITME12, ITM): Same as NTME1, TME1 (ITME1), NTMRELE1 (ITME1), TMGWRPE1 (ITME1, ITM), RCGWRPE1 (ITME1, ICH, IMBR, ITM), RAGWRPE1 (ITME1, ITM) but for an E1E2 intrusion in place at time TME12 (ITME12)

Conceptual Structure of Transfer File for One Sample Element

NDCHAIN (e.g., 3)

NMBR (ICH): ICH = 1, ..., NDCHAIN (e.g., 1, 1, 2)

NMDCMBR (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN (e.g., Pu-239, Am-241, U-234, Th-230)

RDECAY (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN (e.g., ___, ___, ___, ___)

CNVRTCM (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN (e.g., ___, ___, ___, ___)

RLIMIT (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN (e.g., 100, 100, 100, 100 Ci)

Table 4.7. Continued

TOTINV (e.g., 4.07×10^6 Ci)

NCOLSP (e.g., 4)

FRDCLE0 (ICOL, ICH, IMBR): ((IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN), ICOL = 1, ..., NCOLSP

FRDCLE1 (ICOL, ICH, IMBR): ((IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN), ICOL = 1, ..., NCOLSP

FRDCLE2 (ICOL, ICH, IMBR): ((IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN), ICOL = 1, ..., NCOLSP

NTMRELE0 (e.g., 198)

TMGWRPE0 (ITM): ITM = 1, ..., NTMRELE0 (e.g., 100, 150, 200, ..., 9950, 10000)

RCGWRP (ICH, IMBR, ITM): ((ITM = 1, ..., NTMRELE0), IMBR = 1, ..., NMBR (ICH), ICH = 1, ..., NDCHAIN

RAGWRPE0 (ITM): ITM = 1, ..., NTMRELE0

NTME1 (e.g., 7)

TME1 (ITME1): ITME1 = 1, ..., NTME1 (e.g., 100, 350, 1000, 3000, 5000, 7000, 9000)

NTMRELE1 (ITME1): ITME1 = 1, ..., NTME1 (e.g., 198, 193, 180, 140, 100, 60, 20)

TMGWRPE1 (ITME1, ITM): (ITM = 1, ..., NTMRELE1 (ITME1), ITME1 = 1, ..., NTME1 (e.g., TTME1 = 1 ~ 100 yr: 100, 150, 200, ..., 9950, 10000; ITME1 = 2 ~ 350 yr: 350, 400, 450, ..., 9950, 10000, ...; ITME1 = 7 ~ 9000 yr: 9000, 9050, 9100, ..., 10000)

RCGWRPE1 (ITME1, ICH, IMBR, ITM): (((ITM = 1, ..., NTMRELE1 (ITME1)), IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN), ITME1 = 1, ..., NTME1

RAGWRPE1 (ITME1, ITM): (ITM = 1, ..., NTMRELE1 (ITME1)), ITME1 = 1, ..., NTME1

NTME2 (e.g., 7)

TME2 (ITME2): ITME2 = 1, ..., NTME2 (e.g., 100, 350, 1000, 3000, 5000, 7000, 9000)

NTMRELE2 (ITME2): ITME2 = 1, ..., NTME2 (e.g., 198, 193, 180, 140, 100, 60, 20)

TMGWRPE2 (ITME2, ITM): (ITM = 1, ..., NTMRELE2 (ITME2)), ITME2 = 1, ..., NTME2 (e.g., see TMGWRPE1)

Table 4.7. Continued

RCGWRPE2 (ITME2, ICH, IMBR, ITM): (((ITM = 1, ..., NTMRELE2 (ITME2)), IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN), ITME2 = 1, ..., NTME2

RAGWRPE2 (ITME2, ITM): (ITM = 1, ..., NTMRELE2 (ITME2)), ITME2 = 1, ..., NTME2

NTME12 (e.g., 7)

TME12 (ITME12): ITME2 = 1, ..., NTME12 (e.g., 100, 350, 1000, 3000, 5000, 7000, 9000)

NTMRELE12 (ITME12): ITME2 = 1, ..., NTME12 (e.g., 198, 193, 180, 140, 100, 60, 20)

TMGWRPE12 (ITME2, ITM): (ITM = 1, ..., NTMRELE12 (ITME2)), ITME12 = 1, ..., NTME12 (e.g., see TMGWRPE1)

RCGWRPE12 (ITME12, ICH, IMBR, ITM): (((ITM = 1, ..., NTMRELE12 (ITME12)), IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN), ITME12 = 1, ..., NTME12

RAGWRPE12 (ITME12, ITM): (ITM = 1, ..., NTMRELE12 (ITME12)), ITME12 = 1, ..., NTME12

Two options will be available for the construction of releases from the repository to the Culebra by flowing brine. The first option, Option A, is based on algebraic manipulation of results from NUTS and/or PANEL for all patterns of drilling intrusions, including E1E2 intrusions. This construction procedure is described in Table 4.8.

The second option, Option GF, will involve the use of the GRIDFLO model to calculate brine flow and radionuclide transport in the repository and to the Culebra in the presence of E1E2 intrusions. The GRIDFLO option is intended for use when the repository is brine saturated and a constant or slowly changing potential is present that controls brine flow. Such conditions could exist subsequent to the penetration of a large, slowly depressurizing brine pocket or possibly in the presence of conditions that involve U-tube flow from the Culebra, to the repository, and then back to the Culebra. When the GRIDFLO option is selected, $rE12(tE12_{pm}, j, k, t)$ in Table 4.8, which estimates radionuclide release in the presence of an E1E2 intrusion, is replaced by a calculated release obtained from use of GRIDFLO. Otherwise, the overall computational structure in Table 4.8 remains unchanged. The details of GRIDFLO are described in Chapt. 5.

4.6 Radionuclide Transport Through Anhydrite Marker Beds

Release through the anhydrite marker beds is based on calculations performed with NUTS. *The relevant* transport results calculated by NUTS are listed in Table 4.7. Then, the actual release for an arbitrary future $\mathbf{x}_{st}$ is constructed with the procedure described in Table 4.9.

Table 4.8. Construction of Radionuclide Releases into the Culebra Dolomite Without Use of GRIDFLO for an Arbitrary Future $\mathbf{x}_{st}$

Arbitrary future:

$$\mathbf{x}_{st} = [t_1, p_1, l_1, a_1, d_1, k_1, b_1, t_2, p_2, l_2, a_2, d_2, k_2, b_2, \ldots, t_n, p_n, l_n, a_n, d_n, k_n, b_n, t_{min}]$$

Notation:

nP = number of waste panels

$nI(p)$ = number of drilling intrusions into waste panel p, $p = 1, 2, \ldots, nP$

t_{pi} = time (yr) of ith drilling intrusion into waste panel p, $i = 1, 2, \ldots, nI(p)$, $p = 1, 2, \ldots, nP$

$nE1(p)$ = number of E1 intrusions into waste panel p (i.e., intrusions for which $b_i = 1$)

$nE2(p)$ = number of E2 intrusions into waste panel p (i.e., intrusions for which $b_i = 2$)

$nE12(p)$ = number of E1E2 intrusions into waste panel p, (see $tE12_{pj}$ below)

$tE1_{pj}$ = time (yr) of jth E1 intrusion into waste panel p, $j = 1, 2, \ldots, nE1(p)$

$tE2_{pj}$ = time (yr) of jth E2 intrusion into waste panel p, $j = 1, 2, \ldots, nE2(p)$

$tE12_{p1}$ = time (yr) of 1st E1E2 intrusion into waste panel p (i.e., time when two or more drilling intrusions have penetrated waste panel p, of which at least one encounters pressurized brine in the Castile Formation; the relevant intrusions must have $b_i = 1$ or 2; intrusions for which $b_i = 0$ are not considered for determining long term releases from the repository to the Culebra)

$tE12_{pj}$ = time (yr) of each E1 intrusion (i.e., $b_i = 1$) into waste panel p subsequent to $tE12_{p1}$, $j = 2, 3, \ldots, nE12(p)$ (i.e., $tE1_{pj}$, $j = 2, 3, \ldots, nE1(p)$ if $tE12_{p1} < tE1_{p2}$ and $tE1_{pj}$, $j = 3, 4, \ldots, nE1(p)$ if $tE12_{p1} = tE1_{p2}$)

$rE0(j, k, l)$ = cumulative release (kg) of element k of decay chain j from the repository to the Culebra under undisturbed (i.e., E0) conditions through time l due to brine flow (= RCGWRPE0 (j, k, l))

$rE1(i, j, k, l)$ = cumulative release (kg) of element k of decay chain j from the repository to the Culebra from time i to time l due to brine flow with an E1 intrusion occurring at time i (=RGWRPE1 (i, j, k, l))

$rE2(i, j, k, l)$ = cumulative release (kg) of element k of decay chain j from the repository to the Culebra from time i to time l due to brine flow with an E2 intrusion occurring at time i (=RGWRPE2 (i, j, k, l))

$rE12(i, j, k, l)$ = cumulative release (kg) of element k of decay chain j from the repository to the Culebra from time i to time l due to brine flow with an E1E2 intrusion occurring at time i (=RGWRPE12 (i, j, k, l))

nC = number of colloid species (= NCOLSP)

Table 4.8. Continued

$fCE0(s, j, k)$ = fraction of element k of decay chain j attached to colloid specie s under undisturbed (i.e., E0) conditions

$fCE1(s, j, k), fCE2(s, j, k)$: same as $fCE0(s, j, k)$ but for conditions subsequent to E1 and E2 intrusions, respectively

Cumulative release to Culebra:

$cRD_p(j, k, t)$ = cumulative dissolved release (kg) to Culebra through time t of element k of decay chain j from waste panel p

$$= 0 \quad \text{if } t \le t_{p1}$$

$$= \left[1 - \sum_{s=1}^{nC} fCE1(s, j, k)\right] rE1(t_{p1}, j, k, t) \qquad \text{if } tE1_{p1} = t_{p1} < t \le t_{p2}$$

$$= \left[1 - \sum_{s=1}^{nC} fCE2(s, j, k)\right] rE2(t_{p1}, j, k, t) \qquad \text{if } tE2_{p1} = t_{p1} < t \le tE1_{p1}$$

$$= \left[1 - \sum_{s=1}^{nC} fCE1(s, j, k)\right] rE12(tE12_{pm}, j, k, t) \qquad \text{if } tE12_{pm} < t \le tE12_{p,m+1},\ m = 1, 2, \ldots, nE12(p)$$

$cRD(j, k, t)$ = cumulative dissolved release (Ci) from repository to Culebra through time t of element k of decay chain j

$$= \left[1 - \sum_{s=1}^{nC} fCE0(s, j, k)\right] rE0(j, k, t) \qquad \text{if } t \le t_1$$

$$= \sum_{p=1}^{nP} cRD_p(j, k, t) \qquad \text{if } t > t_1$$

$cRC_p(s, j, k, t)$ = cumulative release (kg) from waste panel p to Culebra through time t of element k of decay chain j sorbed to colloid specie s

$$= 0 \qquad \text{if } t \le t_{p1}$$

$$= fCE1(s, j, k)\, rE1(t_{p1}, j, k, t) \qquad \text{if } tE1_{p1} = t_{p1} < t \le t_{p2}$$

M

Table 4.8. Continued

$$= fCE2(s, j, k)\, rE2(t_{p1}, j, k, t) \qquad \text{if } tE2_{p1} = t_{p1} < t \le tE1_{p1}$$

$$= fCE1(s, j, k)\, rE12(tE12_{pm}, j, k, t) \qquad \text{if } tE12_{pm} < t \le tE12_{p,m+1},\ m = 1, 2, \ldots, nE12(p)$$

$cRC(s, j, k, t)$ = cumulative release (kg) from repository to Culebra through time t of element k of decay chain j sorbed to colloid specie s

$$= fCE0(s, j, k)\ rE0(j, k, t) \qquad \text{if } t \le t_1$$

$$= \sum_{p=1}^{nP} cRC_p(s, j, k, t) \qquad \text{if } t > t_1$$

Table 4.9. Calculation of Anhydrite Marker Bed Release f_{MB} for an Arbitrary Future $\mathbf{x}_{st}$

Arbitrary future:

$$\mathbf{x}_{st} = [t_1, p_1, l_1, a_1, d_1, k_1, b_1, t_2, p_2, l_2, a_2, d_2, k_2, b_2, \ldots, t_n, p_n, l_n, a_n, d_n, k_n, b_n, t_{min}]$$

Notation:

$tE1$ = time (yr) of first E1 intrusion (i.e., first intrusion for which $b_i = 1$)

$tE2$ = time (yr) of first E2 intrusion (i.e., first intrusion for which $b_i = 2$)

$rAE0(l)$ = cumulative release (EPA units) of all radioactive species from the repository to the accessible environment under undisturbed (i.e., E0) conditions through time l due to brine flow in the anhydrite marker beds (= RAGWRPE0(l))

$rAE1(i, l)$ = cumulative release (EPA units) of all radioactive species from the repository to the accessible environment between time i and time l with an E1 intrusion at time i due to brine flow in the anhydrite marker beds (= RAGWRPE1(i, l))

$rAE2(i, l)$: same as $rAE1(i, l)$ but for an E2 intrusion (= RAGWRPE2(i, l))

Evaluation of $f_{MB}(\mathbf{x}_{st})$:

$$f_{MB}(\mathbf{x}_{st}) = rAE0\ (t_l)$$

$$+ rAE2(tE2, \min\{tE1, tM\}) \qquad \text{if } tE2 < tE1$$

$$+ rAE1(tE1, tM) \qquad \text{if } tE1 < tM$$

4.7 Radionuclide Transport Through Dewey Lakes Red Beds

At present, it is anticipated that there will be no significant transport through the Dewey Lakes Red Beds to the accessible environment. If such transport is observed to occur, it can be estimated as described in Sect. 4.6 or 4.9 depending on the level of resolution at which the modeling is done (i.e., with NUTS or SECO-TRANSPORT).

4.8 Radionuclide Transport Through Abandoned Borehole to Surface

At present, it is anticipated that there will be no radionuclide transport through abandoned boreholes to the surface. The transport referred to here is due to long-term brine flow through an abandoned (typically plugged) borehole, and is distinct from the blowout release considered in Sect. 4.3, which occurs through an open borehole at the time of drilling. If transport through abandoned boreholes is observed to occur, it can be estimated as described in Sect. 4.6 with results obtained from NUTS.

4.9 Radionuclide Transport Through Culebra Dolomite

Release through the Culebra Dolomite is based on calculations performed with the SECO-TRANSPORT model. Due to the linearity of the system of partial differential equations that underlies SECO-TRANSPORT (see Apps. A and B), it is possible to evaluate transport results for unit releases into the Culebra and then use these results to construct transport releases for arbitrary time-dependent releases into the Culebra.

The information transferred to CCDFGF for use in the construction of Culebra transport results is listed in Table 4.10. Further, the actual construction procedures are given in Table 4.11.

4.10 CCDF Construction

A sequence $\mathbf{x}_{st,i}$, $i = 1, 2, \ldots, nS$ of futures will be sampled as indicated in Table 3.2. At present, it is anticipated that a sample size between $nS = 1000$ and $nS = 10000$ will be adequate to construct a CCDF for comparison with the boundary line specified in 40 CFR 191.13. A normalized release $f(\mathbf{x}_{st,i})$ for each future will then be constructed as described in Sects. 4.1 - 4.9. Once the $f(\mathbf{x}_{st,i})$ are evaluated, the CCDF in Fig. 2.1 can be approximated as indicated in Eq. (2.3). In practice, a binning technique can be used to construct the desired CCDF (i.e., the consequence axis is divided into a sequence of bins and the number of values for $f(\mathbf{x}_{st,i})$ falling in each bin is accumulated); this avoids having to save and subsequently order all values for $f(\mathbf{x}_{st,i})$.

In addition to the CCDF in Fig. 2.1 over all release modes (see Eq. (4.1)), it will be possible to obtain CCDFs for individual release modes (e.g., cuttings, spallings, blowout, to Culebra, through marker beds, through Culebra).

Table 4.10. Results from Calculations with SECO-TRANSPORT Transferred to CCDFGF for Use in Determination of Releases Due to Groundwater Transport in the Culebra Dolomite. The information in this table will repeat for each sample element

Results Transferred to CCDFGF
NDCHAIN: Number of decay chains (e.g., 3)
NMBR (ICH): Number of elements in decay chain ICH, ICH = 1, 2, ..., NDCHAIN (e.g., 1, 1, 2)
RDECAY (ICH, IMBR): Decay constant (yr^{-1}) for element IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., __, __, __, __)
CNVRTKM (ICH, IMBR): Conversion factor from kg to moles (mole/kg) for element IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., __, __, __, __)
CNVRTKC (ICH, IMBR): Conversion factor from kg to Ci (Ci/kg) for element IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., __, __, __, __)
NMDCMBR (ICH, IMBR): Name of member IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) and ICH = 1, 2, ..., NDCHAIN (e.g., Pu-239, Am-241, U-234, Th-230)
RLIMIT (ICH, IMBR): EPA release limit (Ci) for element IMBR of decay chain ICH, IMBR = 1, 2, ..., NMBR (ICH) (e.g., 100, 100, 100, 100 Ci)
TOTINV: Total inventory (Ci) of α-emitting radionuclides placed in repository with halflives greater than 20 yr (e.g., 4.07×10^6 Ci)
NCOLSP: Number of colloid species (e.g., 4)
NTMGWTP: Number of times used to define intervals over which result of unit radionuclide release to the Culebra Dolomite is calculated (e.g., 198)
TMGWTR (ITM): Times that define intervals over which result of unit radionuclide release to the Culebra Dolomite is calculated (e.g., 100, 150, 200, ..., 9950, 10000 yr)
RRADAEU (ICH, IMBR, IDCND, ITM): Release (kg) to accessible environment for element IDCND of decay chain ICH due to a 1 kg dissolved release of element IMBR of decay chain ICH into the Culebra at the repository during time interval ITM (i.e., from TMGWTR (ITM) to TMGWTR (ITM + 1)) and subsequent transport under undisturbed (i.e., unmined) conditions, ITM = 1, 2, ..., NTMGWTP, IDCND = IMBR, IMBR + 1, ..., NMBR (ICH), IMBR = 1, 2, ..., NMBR (ICH), and ICH = 1, 2, ..., NDCHAIN (Note: IDCND counts over element IMBR of decay chain ICH and all of its daughters, i.e., to the end of decay chain ICH)
RRADAEM (ICH, IMBR, IDCND, ITM): Same as RRADAEU (ICH, IMBR, IDCND, ITM) but for radionuclide transport in the Culebra under disturbed (i.e., mined) conditions rather than undisturbed conditions
RCOLAEU (ICOL, ITM): Cumulative release (kg) to accessible environment through time TMGWTR (ITM) of colloid specie ICOL due to a 1 kg release of colloid specie ICOL into the Culebra at time TMGWTR (1) and subsequent transport under undisturbed conditions, ITM = 1, 2, ..., NTMGWTR and ICOL = 1, 2, ..., NCOLSP

Table 4.10. Continued

RCOLAEM (ICOL, ITM): Same as RCOLAEU (ICOL, ITM) but for colloid transport in the Culebra under disturbed (i.e., mined) conditions rather than undisturbed conditions

Conceptual Structure of Transfer File for One Sample Element

NDCHAIN (e.g., 3)

NMBR (ICH): ICH = 1, ..., NDCHAIN (e.g., 1, 1, 2)

NMDCMBR (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN (e.g., Pu-239, Am-241, U-234, Th-230)

RDECAY (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN (e.g., ___, ___, ___, ___)

CNVRTKM (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH), ICH = 1, ..., NDCHAIN (e.g., ___, ___, ___, ___)

CNVRTKC (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN (e.g., __, __, __, __)

RLIMIT (ICH, IMBR): (IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN (e.g., 100, 100, 100, 100 Ci)

TOTINV (e.g., 4.06×10^6 Ci)

NCOLSP (e.g., 4)

NTMGWTP (e.g., 198)

TMGWTR (ITM): ITM = 1, ..., NTMGWTP (e.g., 100, 150, 200, ..., 9950, 10000 yr)

RRADAEU (ICH, IMBR, IDCND, ITM): (((ITM = 1, ..., NTMGWTP), IDCND = IMBR, ..., NMBR (ICH)), IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN

RRADAEM (ICH, IMBR, IDCND, ITM): (((ITM = 1, ..., NTMGWTP), IDCND = IMBR, ..., NMBR (ICH)), IMBR = 1, ..., NMBR (ICH)), ICH = 1, ..., NDCHAIN

RCOLAEU (ICOL, ITM): (ITM = 1, ..., NTMGWTP), ICOL = 1, ..., NCOLSP

RCOLAEM (ICOL, ITM): (ITM = 1, ..., NTMGWTP), ICOL = 1, ..., NCOLSP

Table 4.11. Calculation of Groundwater Transport Release f_{ST} through the Culebra Dolomite for an Arbitrary Future $\mathbf{x}_{st}$

Arbitrary future:

$$\mathbf{x}_{st} = \left[t_1, p_1, l_1, a_1, d_1, k_1, b_1, t_2, p_2, l_2, a_2, d_2, k_2, b_2, \ldots, t_n, p_n, l_n, a_n, d_n, k_n, b_n, t_{min}\right]$$

Notation:

τ_m = times (yr) used to record results of unit release calculations with SECO-TRANSPORT for the Culebra [= TMGWTR (m)], $m = 1, 2, \ldots, nTI + 1$ (=NTMGWTP−1)

nTI = number of time intervals $\left[\tau_m, \tau_{m+1}\right]$, $m = 1, 2, \ldots, nTI$, defined by τ_m, $m = 1, 2, \ldots, nTI + 1$ (= NTMGWTP − 1)

$cKM(j, k)$ = conversion factor from kg to moles (mole/kg) for element k of decay chain j [= CNVRTCM (j, k)]

$cMK(j, k)$ = conversion factor from moles to kg (kg/mole) for element k of decay chain j [=1/$cKM(j, k)$]

$cKC(j, k)$ = conversion factor from kg to Ci (Ci/kg) for element k of decay chain j [= CNVRTKC(j, k)]

$\lambda(j, k)$ = decay constant (yr^{-1}) for element k of decay chain j [= RDECAY (j, k)]

nDC = number of decay chains [= NDCHAIN]

$nM(j)$ = number of members in decay chain j [= NMBR (j)]

$rL(j, k)$ = EPA release limit (Ci) for element k of decay chain j [= RLIMIT (j, k)]

tI = total inventory (Ci) of α-emitting radionuclides placed in repository with halflives that exceed 20 yr [= TOTINV]

nC = number of colloid species [= NCOLSP]

Dissolved release $rD(j, k)$ of element k of decay chain j:

$uR(j, k, l, m)$ = release (kg) to accessible environment of element l of decay chain j resulting from a 1 kg dissolved release of element k of decay chain j to the Culebra over time interval $\left[\tau_m, \tau_{m+1}\right]$

$$= \begin{cases} \text{RRADAEU}(j, k, l, m) & \text{if } \tau_{m+1} < t_{min} \\ \text{RRADAEM}(j, k, l, m) & \text{if } \tau_{m+1} \geq t_{min} \end{cases}$$

$dRD(j, k, \tau_m, \tau_{m+1})$ = dissolved release (kg) to Culebra of element k of decay chain j over time interval $\left[\tau_m, \tau_{m+1}\right]$

$$= cRD(j, k, \tau_{m+1}) - cRD(j, k, \tau_m)$$

Table 4.11. Continued

$rD(j, k)$ = release (kg) to accessible environment of element k of decay chain j resulting from dissolved releases into the Culebra

$$= \sum_{m=1}^{nTI} \sum_{p=1}^{k} dRD(j, p, \tau_m, \tau_{m+1})\, uR(j, p, k, m)$$

Colloidal release $rC(j, k)$ of element k of decay chain j:

$uC(s, l, m)$ = release (kg) to accessible environment of colloid specie s over time interval $[\tau_m, \tau_{m+1}]$ resulting from a 1 kg release of colloid specie s to the Culebra over time interval $[\tau_l, \tau_{l+1}]$

$$= \begin{cases} \mathrm{RCOLAEU}(s, m+1-l) - \mathrm{RCOLAEU}(s, m-l) & \text{if } \tau_{m+1} < t_{min} \\ \mathrm{RCOLAEM}(s, m+1-l) - \mathrm{RCOLAEM}(s, m-l) & \text{if } \tau_{m+1} \geq t_{min} \end{cases}$$

$dRC(s, j, k, l)$ = amount (kg) of element k of decay chain j attached to colloid specie s released to Culebra over time interval $[\tau_l, \tau_{l+1}]$

$$= cRC(s, j, k, \tau_{l+1}) - cRC(s, j, k, \tau_l)$$

$aC(s, j, k, l, m)$ = amount (kg) of element k of decay chain j attached to colloid specie s over time interval $[\tau_m, \tau_{m+1}]$ due to releases over time interval $[\tau_l, \tau_{l+1}]$

$$= \left\{ \sum_{p=1}^{k} \left(\sum_{q=p}^{k} \left[\frac{\left[\prod_{r=p}^{k} \lambda(j, r) \right] / \lambda(j, k)}{\prod_{\substack{s=p \\ s \neq q}}^{k} [\lambda(j, s) - \lambda(j, q)]} \right] \bullet \exp\left[-\lambda(j, q) \left(\frac{\tau_m + \tau_{m+1}}{2} - \frac{\tau_l + \tau_{l+1}}{2} \right) \right] \right) \right.$$

$$\left. \bullet\, dRC(s, j, p, l)\, cKM(j, p) \right\} cMK(j, k)$$

$rCI(s, j, k, m)$ = amount (kg) of element k of decay chain j attached to colloid specie s released to accessible environment over time interval $[\tau_m, \tau_{m+1}]$

Table 4.11. Continued

$$= \sum_{l=1}^{m} aC(s, j, k, l, m)\, uC(s, l, m)$$

$rC(j, k)$ = release (kg) to accessible environment of element k of decay chain j resulting from colloidal releases into the Culebra

$$= \sum_{s=1}^{nC} \sum_{m=1}^{nTI} rCI(s, j, k, m)$$

Evaluation of $f_{ST}(\mathbf{x}_{st})$:

$$f_{ST}(\mathbf{x}_{st}) = \sum_{j=1}^{nDC} \sum_{k=1}^{nM(j)} \left\{ \frac{[rD(j, k) + rC(j, k)]\, cKC(j, k)}{rL(j, k)} \right\} \left\{ \frac{10^6 \text{ Ci}}{tI} \right\}$$

The CCDF construction indicated in this section is for a single sample element $\mathbf{x}_{su,k}$ of the form indicated in conjunction with Eq. (2.5). Repeated generation of CCDFs for individual sample elements $\mathbf{x}_{su,k}$ will lead to distributions of CCDFs of the form illustrated in Figs. 2.3 - 2.5.

4.11 Data Assembly

The initial component of CCDFGF will be a sequence of subroutines that collects and assembles the information indicated in Tables 4.1, 4.3 (and the equivalent table for spallings releases), 4.4, 4.6, 4.7 and 4.10. In general, this information will repeat for each sample element $\mathbf{x}_{su,k}$ indicated in conjunction with Eq. (2.5).

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5. Fluid Flow and Radionuclide Transport for E1E2 Intrusions

5.1 Rationale for GRIDFLO

In past PAs for the WIPP, groundwater releases to the Culebra have been dominated by E1E2 intrusions in which the repository is penetrated by two or more drilling intrusions, of which at least one penetrates pressurized brine and at least one does not penetrate pressurized brine. The potential for large releases results from the diversion of brine flow from the drilling intrusion that penetrated pressurized brine through the repository to the drilling intrusion that did not penetrate pressurized brine. In the context of the representation for $\mathbf{x}_{sI}$ in Eq. (2.2), an E1E2 intrusion occurs when $n \geq 2$ and at least one of the locations l_i is above pressurized brine.

The modeling of this important intrusion event has been conservative in past PAs. In particular, all flow from the drilling intrusion that penetrates pressurized brine has been assumed to divert to the drilling intrusion that did not penetrate pressurized brine. This is a very conservative assumption because it is equivalent to assuming a perfect plug above the drilling intrusion that penetrates pressurized brine and no plug above the intrusion that does not penetrate pressurized brine. In reality, the amount of diverted brine should depend on the permeability of the two boreholes, the elevation of the two boreholes within the repository (as a reminder, the repository is built on a dip), the permeability of the material within the repository, and the length of the flow path between the two boreholes.

In addition, conservative assumptions have been made about the extent of the waste inventory that would be contacted by the brine diverting between the two boreholes. The 1991 and 1992 WIPP PAs assumed perfect panel seals and that an E1E2 type intrusion will produce a brine flow that contacted the entire inventory of a waste panel. The SPM analysis assumed no panel seals, with the result that an equivalent assumption would have implied that an E1E2 intrusion could contact the entire inventory of the repository. This did not seem reasonable and an *ad hoc* procedure based on the flow paths between the boreholes associated with an E1E2 intrusion was used to reduce the amount of contacted inventory.

In past analyses, BRAGFLO calculations have not been performed for E1E2 intrusions. Rather, BRAGFLO calculations have been performed for E1 intrusions (i.e., a single intrusion that penetrates both the repository and pressurized brine) and then the assumptions indicated in the two preceding paragraphs have been used in conjunction with PANEL to estimate E1E2 releases from E1 flow results.

Given both the potential importance of E1E2 intrusions and the many different occurrence patterns by which two or more drilling intrusions could give rise to an E1E2 intrusion, a modeling approach with more resolution was desirable. Desirable capabilities for such an approach include (1) representation of the geometry of the repository (Fig. 3.1), (2) treatment of multiple drilling intrusions (i.e., ≥ 2), (3) incorporation of location of each drilling intrusion, (4) specification of different properties (i.e., diameter, permeability) for different boreholes,

(5) specification of local properties within the repository (e.g., permeabilities), (6) specification of solubilities or distribution coefficients within the repository, (7) flexibility in the assignment of brine pocket locations and properties, and (8) numerical stability and rapid computation.

In general, it would be hard to meet the preceding desiderata. However, the E1E2 intrusions that are to be modeled are very special situations. In such intrusions, the repository fills with brine. Once the repository is filled with brine, the flow through the repository then depends on the pressure in the brine pocket(s), the permeabilities in the boreholes and the flow paths between boreholes in the repository, and the pressure in the Culebra. Past analyses have indicated that the pressures in brine pockets and in the Culebra tend to remain fixed. Because of this, Darcy's law can be used to describe the resultant constant flow system. Once this flow system is determined, the implementation of a radionuclide transport model within the repository and to the Culebra is relatively simple. The approach is now described in more detail. For convenience, the model being described will be referred to as the GRIDFLO model.

5.2 Mathematical Structure of GRIDFLO

The basic idea in GRIDFLO is to have a system of nodes in the repository defined on a rectilinear grid, with flow between these nodes taking place in the grid (Fig. 3.1). In addition, each node in the repository will have corresponding nodes in the Castile and Culebra that are directly below and above the repository node.

In setting up the problem, grid elements are assumed to run south (–) to north (+), east (–) to west (+) and down (–) to up (+). See Fig. 5.1. Further, the possible flow paths and data associated with a single node are shown in Fig. 5.2. For many nodes, all of the flow paths (i.e., legs) in Fig. 5.2 will not be used.

In setting up the mass balance equation at a node in the repository, flows

(1) from the node to the north, west or up are assumed to remove brine and thus are negative; similarly, flows to the node from the north, west or up are assumed to add brine and thus are positive,

(2) to the node from the south, east or down are assumed to add brine and thus are positive; similarly, flows from the node to the south, east or down are assumed to remove brine and thus are negative;

or, stated in an equivalent form with respect to Fig. 5.2,

(1) Flow in a positive direction in legs 1, 3 or 5 removes brine and flow in a negative direction in legs 1, 3 or 5 adds brine,

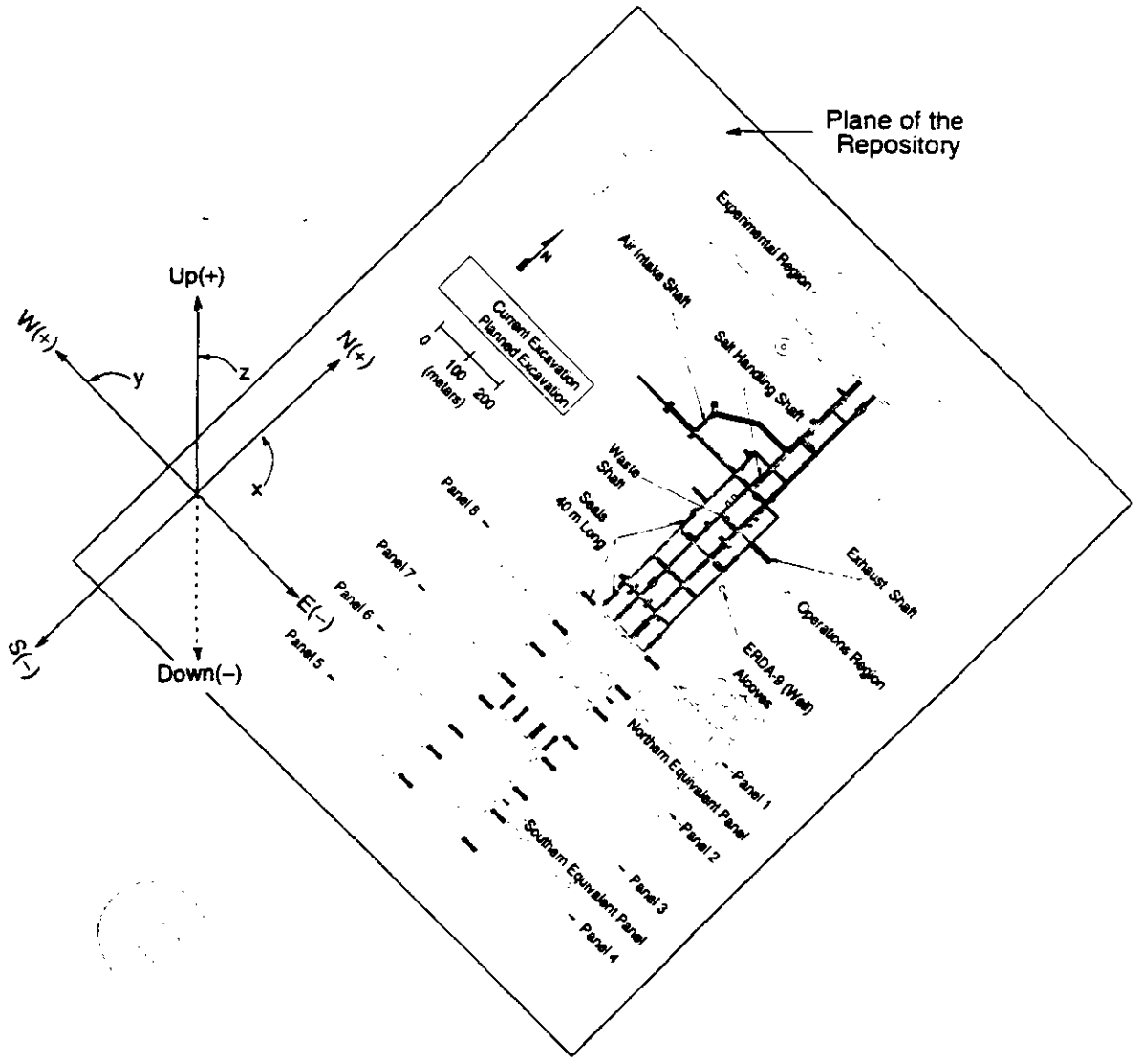

TRI-6334-206-21

Figure 5.1. Coordinate system for calculation of flow within the experimental, operations and waste disposal regions of the WIPP.

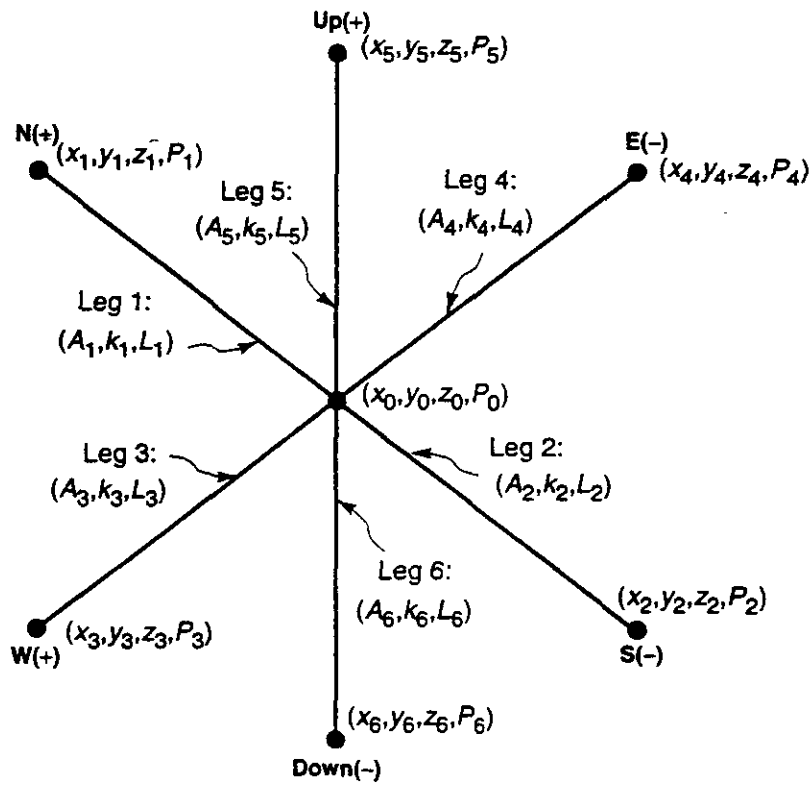

Where

x,y,z ~ x,y,z coordinates

k ~ hydraulic conductivity

P ~ pressure

L ~ length

A ~ cross -sectional area

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Figure 5.2. Flow paths associated with a single node in the repository.

(2) Flow in a positive direction in legs 2, 4 or 6 adds brine and flow in a negative direction in legs 2, 4 or 6 removes brine.

From the preceding conventions and Darcy's Law, net brine flow at a given node in the repository must be 0 and results in the following equation (see Fig. 5.2 for notation):

$$0 = \sum_{i=1}^{6} \text{(flow in leg } i\text{)}$$

$0 < \Rightarrow$ flow towards node (i.e., to south)
$0 > \Rightarrow$ flow away from node (i.e., to north)

$$= \delta_1 \left(\frac{k_1 A_1}{L_1} \right) \overbrace{(Z_1 + P_1 - Z_0 - P_0)}$$

$0 < \Rightarrow$ flow towards node (i.e., to north)
$0 > \Rightarrow$ flow away from node (i.e., to south)

$$+ \delta_2 \left(\frac{k_2 A_2}{L_2} \right) \overbrace{(Z_2 + P_2 - Z_0 - P_0)}$$

$0 < \Rightarrow$ flow towards node (i.e., to east)
$0 > \Rightarrow$ flow away from node (i.e., to west)

$$+ \delta_3 \left(\frac{k_3 A_3}{L_3} \right) \overbrace{(Z_3 + P_3 - Z_0 - P_0)}$$

$0 < \Rightarrow$ flow towards node (i.e., to west)
$0 > \Rightarrow$ flow away from node (i.e., to east)

$$+ \delta_4 \left(\frac{k_4 A_4}{L_4} \right) \overbrace{(Z_4 + P_4 - Z_0 - P_0)}$$

$0 < \Rightarrow$ flow towards node (i.e., down)
$0 > \Rightarrow$ flow away from node (i.e., up)

$$+ \delta_5 \left(\frac{k_5 A_5}{L_5} \right) \overbrace{(Z_5 + P_5 - Z_0 - P_0)}$$

$0 < \Rightarrow$ flow towards node (i.e., up)
$0 > \Rightarrow$ flow away from node (i.e., down)

$$+ \delta_6 \left(\frac{k_6 A_6}{L_6} \right) \overbrace{(Z_6 + P_6 - Z_0 - P_0)} \tag{5.1}$$

where

$$\delta_i = \begin{cases} \text{.f leg } i \text{ is defined} \\ 0 \text{ if leg } i \text{ is undefined} \end{cases} \tag{5.2}$$

Thus,

$$
\begin{aligned}
0 &= \sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right)(Z_i + P_i - Z_0 - P_0) \\
&= \sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) Z_i + \sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) P_i - Z_0 \sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) - P_0 \sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) \\
&= \left[\sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) Z_i + \sum_{i=5}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) P_i - Z_0 \sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right)\right] + \sum_{i=1}^{4} \delta_i \left(\frac{k_i A_i}{L_i}\right) P_i + \left[-\sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right)\right] P_0 . \quad (5.3)
\end{aligned}
$$

There will be one equation of the above form for each node in the repository, with P_0, P_1, P_2, P_3, P_4 being the unknown variables. The pressures in the Castile (i.e., P_6) and the Culebra (i.e., P_5) are assumed to be known.

The preceding equation can also be written in the form

$$
\begin{aligned}
&\sum_{i=1}^{4} \delta_i \left(\frac{k_i A_i}{L_i}\right) P_i + \left[-\sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right)\right] P_0 \\
&= -\sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) Z_i - \sum_{i=5}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) P_i + Z_0 \sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) \\
&= \sum_{i=1}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right)(Z_0 - Z_i) - \sum_{i=5}^{6} \delta_i \left(\frac{k_i A_i}{L_i}\right) P_i, \quad (5.4)
\end{aligned}
$$

which can be viewed as one equation associated with the matrix representation

$$\mathbf{Ax} = \mathbf{b}, \quad (5.5)$$

where

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \text{ is the coefficient matrix}$$

$$\mathbf{x} = \begin{bmatrix} P_1 \\ \vdots \\ P_n \end{bmatrix} \text{ is the vector of unknown node pressures in the repository}$$

$$\mathbf{b} = \begin{bmatrix} b_1 \\ \vdots \\ b_n \end{bmatrix} \text{ is the vector of nonhomogeneous terms}$$

n = number of nodes in repository.

The coefficients (i.e., a_{ij}) in **A** will be defined by the coefficients on P_0, P_1, P_2, P_3, P_4 in Eq. (4.4). The elements of **b** (i.e., b_i) will be defined by the right-hand side of Eq. (5.4). Solution of equations of the form shown in Eq. (5.5) is a standard problem in numerical linear algebra.[13]

The unknowns in Eq. (5.5) are the pressures at the nodes in the repository. Once these pressures are obtained by solving Eq. (5.5), Darcy's law can be used to define brine flow rates between the individual nodes. Once the brine flow rates are known, radionuclide transport calculations can be performed.

The transport calculation can be performed by treating each leg between two nodes (Fig. 3.1) as a "bucket" that contains a certain amount of brine, with this amount deriving from the porosity, cross-sectional area and length of the leg and the assumption that the leg is brine saturated. The brine concentration of each radionuclide within the leg is then set on the basis of an assumed solubility or K_d value. The amount of radionuclide exiting a leg in a given period of time and the legs to which this radionuclide is transported depends on the flows predicted by Darcy's law. In essence, Darcy's law tells how much brine is to be poured out of the leg (i.e., bucket) for a given interval of time. Dynamic control of time-step size can be used to select appropriate time steps. Further, the numerical implementation must account for radioactive decay and inventory limits.

5.3 Implementation of GRIDFLO

The GRIDFLO model provides an alternative to the use of BRAGFLO/NUTS/PANEL results to define the expression $rE12(tE12_{pm}, j, k, t)$ in Table 4.8. Other than this substitution, the CCDF construction procedures in CCDFGF remain the same whether GRIDFLO or interpolation procedures as described in Table 4.8 are used to estimate releases from the repository to the Culebra for E1E2 intrusions.

The operation of GRIDFLO should be set up with two options. In Option 1, GRIDFLO operates on a single waste panel basis as described in Table 4.8 (i.e., E1E2 intrusions are considered only when the relevant drilling intrusions occur within the same waste panel). In Option 2, GRIDFLO operates over the entire repository (i.e., E1E2 intrusions can involve drilling intrusions anywhere in the repository).

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6. Code Architecture

6.1 Control Flow

6.1.1 Initialization

The following input parameters define analysis initialization:

1. Run control parameters
2. Repository inventory parameters
3. Repository grid nodalization parameters
4. Repository region and panel parameters
5. Release parameter tables for:
   a. cuttings
   b. spallings
   c. blowouts
   d. Marker Beds
   e. Dewey Lakes
   f. surface
   g. flows to the Culebra
   h. transport through the Culebra
6. Pre-defined individual borehole intrusion parameters (optional)

Grid leg (internode) properties are defined based on the grid nodalization properties. The intersections of the nodal specification lines correspond to the nodes. All node definitions are processed first. All area definitions are processed after all node definitions have been processed. The final specification for a given area takes precedence over all previous specifications for the same area.

6.1.2 Calculation Structure

Three run execution options are available:

1. Normal execution
2. Preprocessing execution
3. Intermediate execution

Option 1 is the normal execution option but must be preceded by an Option 2 execution. Option 2 must be executed prior to Options 1 or 3 to create release summary tables from previously calculated results from other analysis codes.

Option 3 is used for creating intermediate release results for analysis of release summary tables and is not required for normal execution.

A three-level looping structure is used as the basic calculation structure. The outer calculation loop corresponds to an observation loop, such as in Latin hypercube sampling. The next calculation loop corresponds to a time future loop. The inner calculation loop corresponds to individual timesteps for a single time future. The number of observations and the number of time futures per observation are specified in the run control parameters. The time futures correspond to the total length of time over which releases to the accessible environment are calculated. One or more time futures can be specified per observation.

6.1.3 Borehole Intrusions

Borehole intrusions occur at randomly selected future times based on a Poisson distribution. The pressure head at the repository node corresponding to a borehole intrusion is altered depending on the formations the borehole penetrates outside of the repository, and this in turn affects the pressure heads for all other nodes in the repository.

6.1.4 Releases to Accessible Environment

Cuttings, spallings, and blowout releases for each borehole intrusion are interpolated from release tables versus drilling intrusion time. Releases to the Marker Beds, to the Dewey Lakes, and to the surface are interpolated from release tables versus time. Releases to the Culebra are determined either by interpolation from release tables versus time or by calculation of flow and transport depending on the locations and types of borehole intrusions that have occurred. Culebra transport releases are calculated based on previous unit release calculations to the Culebra.

6.1.5 Flow to the Culebra

Flow to the Culebra is modeled using four different scenarios depending on the number and type of borehole intrusions that have occurred. Before any borehole intrusions occur, releases to the Culebra are interpolated from release tables for undisturbed conditions. After the first borehole intrusion has occurred, releases are interpolated from release tables for individual E1 intrusion scenarios and individual E2 intrusion scenarios. An E1 scenario is an intrusion that penetrates both the repository and a pressurized brine pocket below the repository. An E2 scenario is an intrusion that only penetrates the repository. After the first drilling intrusion that results in an E1E2 scenario, releases are calculated based on one of two methods: (1) interpolation of release tables for E1E2 scenarios or (2) modeling brine flow and associated species transport through the repository (GRIDFLO option). An E1E2 scenario is two or more borehole intrusions, at least one of which must be an E1 intrusion.

6.1.6 Repository Flow and Transport (GRIDFLO Option)

Grid leg (internode) flow rates can then be calculated based on the nodal pressure heads. A difference in the pressure heads between adjacent nodes translates into a flow from the high pressure node to the low pressure node. An Euler-type solution of a system of differential equations is used to model species transport based either on species solubility limits or on species K_d values. This solution is based on the assumption that species transport is essentially constant for each timestep. The species mass in the original waste, the brine solution, and the precipitated waste are reduced due to radioactive decay during each timestep.

6.1.7 Result Distributions

Result distributions for releases from the repository directly to the accessible environment and to the accessible environment through the Culebra formation are accumulated for each species being transported. Each result is based on the total species mass transported from the repository during a single time future. A series of time futures results in a distribution of releases corresponding to an observation. Result distributions are accumulated over all time futures for each observation for the following releases to the accessible environment:

1. Borehole cuttings
2. Borehole spallings
3. Borehole blowouts
4. Marker Beds transport
5. Dewey Lakes transport
6. Transport to the surface
7. Flows to the Culebra
8. Transport through the Culebra

In addition, flows to the Culebra and transport through the Culebra are quantified according to individual species and whether species are dissolved or are attached to colloids.

6.2 Control Logic

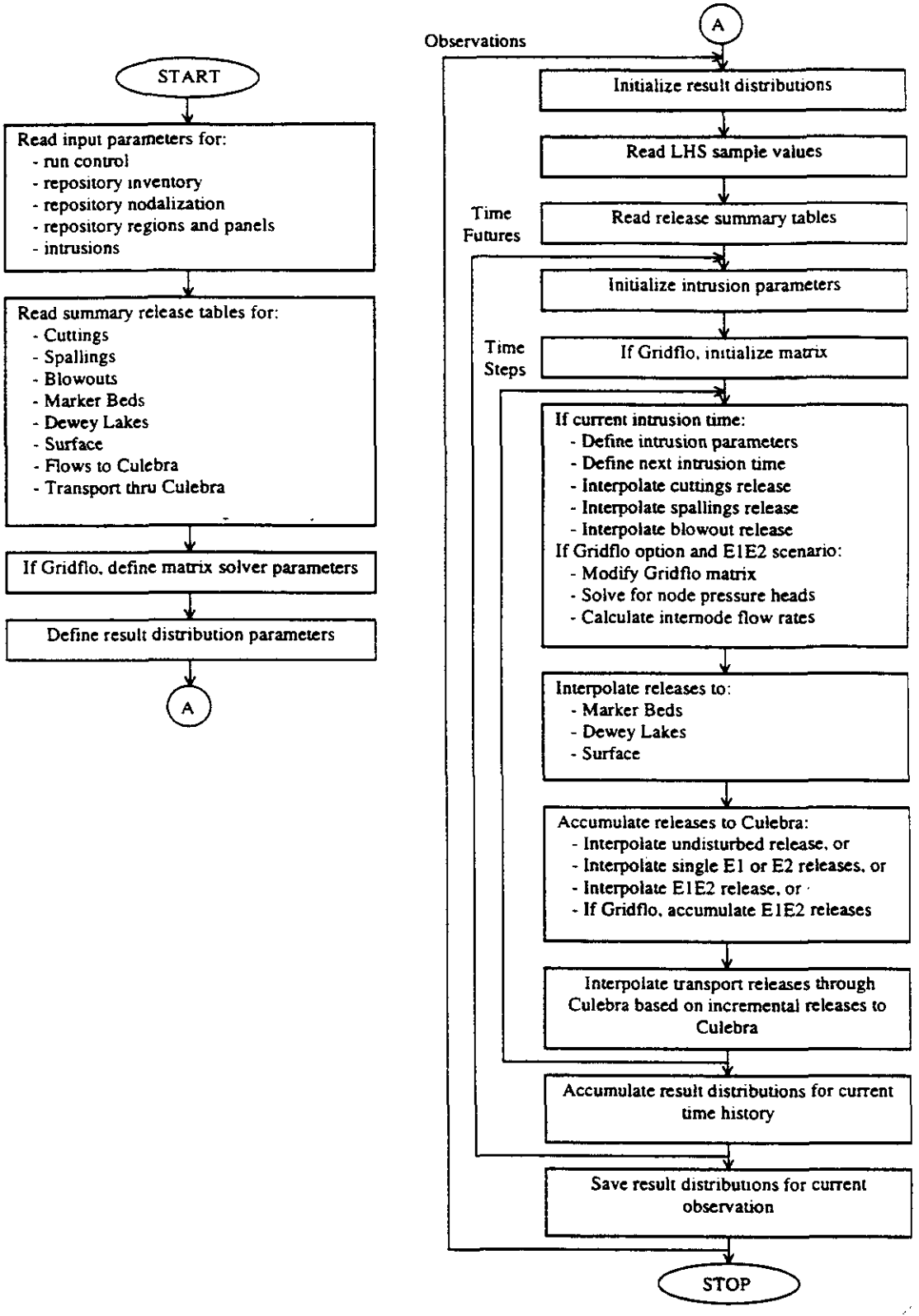

6.3 Data Structures

6.3.1 Run Control Parameters

The following parameters are defined on the run control parameter file:

1. Number of observations
2. Number of time futures per observation
3. Run execution option
4. Spatial solubility flag indicating spatially constant or variable solubility or K_d
5. Solubility limit flag indicating maximum solubility limit or K_d
6. Initial and subsequent administrative control times
7. Flow and transport time parameters
8. Brine parameters
9. Total solids mass in repository
10. Elevations above mean sea level for Culebra and Castile formations
11. Pressure heads for Culebra and Castile formations
12. Drilling intrusion rates and parameters
13. Mining intrusion rates
14. Borehole diameter distribution parameters
15. Borehole permeability distribution parameters
16. Random number generator seed

6.3.2 Repository Nodalization Parameters

The following parameters are defined on the nodalization file. All x-distances and y-distances are referenced to a single point which can be either inside or outside the repository. All parameters refer to either nodal or area specifications:

1. Minimum x-distance
2. Maximum x-distance
3. Minimum y-distance
4. Maximum y-distance
5. Drift height
6. Drift width
7. Hydraulic conductivity
8. Porosity (pore fraction)

9. Waste fractions (0.0=shaft seal, 1.0=waste drift)
10. Elevation above mean sea level
11. Pressure head

6.3.3 Inventory Parameters (GRIDFLO Option)

The following parameters for the repository are read from the inventory file:

1. Species name
2. Species descendent name
3. Total species mass in repository
4. Minimum species solubility limit (kg/m^3) or K_d limit
5. Maximum species solubility limit (kg/m^3) or K_d limit
6. Species radioactive half-life (if colloid, half-life=0.0)
7. Species molecular weight

6.3.4 Accessible Environment Release Parameters

Cuttings, spallings, and blowout releases for each borehole intrusion are interpolated from release tables versus drilling intrusion time. Releases to the Marker Beds, to the Dewey Lakes, and to the surface are interpolated from release tables versus time. Releases to the Culebra are dependent on the number and types of borehole intrusions that have occurred and are determined either by interpolation from release tables versus time or by calculation of flow and transport. Culebra transport releases are calculated based on unit releases to the Culebra.

6.3.5 Borehole Definition Parameters (Optional)

The following parameters are specified from the borehole parameter file. This file specification is optional. If this file is specified, boreholes are pre-defined. Each borehole intrusion is associated with a single repository node specified by x-node and y-node index specifications.

1. x-node index
2. y-node index
3. Diameter
4. Hydraulic conductivity
5. Elevation above mean sea level for penetrated formation (Culebra formation for upper borehole segment or Castile formation for lower borehole segment)

6. Pressure head of penetrated formation (Culebra formation for upper borehole segment or Castile formation for lower borehole segment)
7. Intrusion time

6.4. Allowable/Prescribed Ranges for Input/Output

Allowable ranges for input values are not restrictive except for validation of positive values and that parameters are valid relative to other input parameter specifications.

6.5 Verifiability

Most of the models involve simple algebraic manipulations. The following rates can be verified by simple algebraic manipulations for single intrusions and by probabilistic calculations for thousands of intrusions:

1. Drilling intrusion rate
2. Mining intrusion rate

Interpolation of summary tables for the following releases can be verified by simple algebraic manipulations:

1. Cuttings
    a. Contact-handled (CH) waste
    b. Remote-handled (RH) waste
2. Spallings
    a. Undisturbed conditions
        I. Upper waste panels (1,2,3,6,7,8,9)
        II. Lower waste panels (4,5,10)
    b. Previous E2 intrusion (no E1 intrusions)
        I. Same waste panel
        II. Different waste panel
    c. Previous E1 intrusion
        I. Same waste panel
        II. Different waste panel
3. Blowouts
    a. Undisturbed conditions
        I. Upper waste panels (1,2,3,6,7,8,9)
        II. Lower waste panels (4,5,10)
    b. Previous E2 intrusion (no E1 intrusions)
        I. Same waste panel
        II. Different waste panel

c. Previous E1 intrusion

I. Same waste panel

II. Different waste panel

4. Marker Beds
5. Dewey Lakes
6. Surface
7. Flows to the Culebra
   a. Undisturbed conditions
   b. Single E2 intrusions (no E1 intrusions)
   c. Single E1 intrusions
   d. E1E2 intrusion scenario
8. Transport through the Culebra
   a. No mining intrusions
      I. Dissolved species
      II. Colloid species
   b. Mining intrusions
      I. Dissolved species
      II. Colloid species

The GRIDFLO models requiring verification include:

1. Nodal pressure head calculations
2. Transport based on flows due to pressure/elevation head differences

Both of the above models can be verified by comparison to a two-node analytical solution to simulate one-dimensional flow. A four-node analytical solution can then be used to verify two-dimensional flow between two nodes having two intermediate (alternate path) nodes.

6.6 Consistency/Traceability

All software will be constructed using modular coding techniques to facilitate the consistency of coded algorithms and the traceability of program flow in accordance with the Requirements Document for CCDFGF.

6.7 Technical Feasibility

The feasibility for implementing a banded matrix solver for the determination of node pressure heads has already been demonstrated. The implementation of the transport model has been demonstrated using the Euler-type solution for single species transport. All other models involve linear interpolation of release tables and verification of intrusion rates.

6.8 Implementation

6.8.1 Input Parameter Definitions

Run control parameters and associated input data are read first. The repository inventory parameters are read from the inventory file. Repository node parameter definitions are read from the nodalization file. Repository region and panel parameter definitions are read from the regions and panels file. If borehole intrusions are to be pre-defined, borehole intrusion parameters are read from the borehole parameter file. The following release tables are read from the summary release file for each observation:

1. Cuttings (to accessible environment)
2. Spallings (to accessible environment)
3. Blowouts (to accessible environment)
4. Marker Beds (to accessible environment)
5. Dewey Lakes (to accessible environment)
6. Surface (to accessible environment)
7. Flows to the Culebra
8. Transport through the Culebra (to accessible environment)

6.8.2 Repository Nodalization

Grid leg (internode) properties are defined based on the grid nodalization properties. The intersections of the nodal specification lines correspond to the nodes. All node definitions are processed first. All area definitions are processed after all node definitions have been processed. The last specification for a given area takes precedence over previous specifications for the same area.

6.8.3 Leg Property Definitions

All nodes are connected to up to six other nodes by internode legs, excepting those nodes lying on the outer border of the two-dimensional horizontal grid formed by all the nodes. Up to four of these six nodes lie in the horizontal grid representing the repository. The other two nodes are defined when a borehole intrusion occurs: a single node in the Culebra formation above the repository and a single node in the Castile formation below the repository. The following properties are initialized for each internode leg:

1. Height
2. Width
3. Hydraulic conductivity

4. Porosity
5. Flow rate
6. Total solids mass
7. Total pore volume available for brine
8. Waste fraction (0.0=shaft seal, 1.0=waste drift)

6.8.4 Leg Property Modification

Internode leg properties can be redefined or modified by specifying the x-distance and y-distance ranges with new property values corresponding to an area that is to be redefined. The properties for all legs overlapped by the specified the x-distance and y-distance ranges are redefined. Succeeding leg property specifications take precedence over any preceding specifications. A modified area can contain one or more nodes within its boundary but are not required to contain any nodes to redefine leg properties.

6.8.5 Borehole Intrusion Parameters

Borehole intrusion parameters can be defined either as direct input or as randomly defined parameters based on input ranges specified with the run control parameters. If the borehole intrusion parameters are defined as direct input, the coefficient matrix and nonhomogeneous vector corresponding to the nodal pressure heads is initialized based on no intrusions. The coefficient matrix and nonhomogeneous vector are then modified according to the borehole intrusion parameters. The resulting coefficient matrix and nonhomogeneous vector are solved using a banded matrix solver to determine the resulting nodal pressure heads. Grid leg (internode) flow rates can then be calculated based on the nodal pressure heads. A difference in the pressure heads between adjacent nodes translates into a flow from the high pressure node to the low pressure node.

A single set of parameters is required for the definition of each borehole intrusion which penetrates the Culebra and the repository. Two sets of parameters are required for a borehole intrusion which penetrates the Culebra formation, the repository, and the Castile formation. One set corresponds to the penetration from the Culebra formation to the repository (upper borehole). The second set corresponds to the penetrations from the repository to the Castile formation (lower borehole). The elevation and pressure head specifications correspond to either the Culebra formation or the Castile formation.

Borehole parameters can be specified for a borehole that penetrates the repository and the Castile formation but may not have a second specification corresponding to the borehole that penetrates the Culebra and the repository. The lower segment of a borehole specification is not required to have a corresponding upper segment borehole specification. When borehole parameters are not pre-defined, borehole parameters are randomly selected for defined

ranges and distributions. An upper segment borehole is always associated with a lower segment borehole, but a lower segment borehole is not always associated with an upper segment borehole.

6.8.6 Node Pressure Heads

The banded matrix solver parameters are defined based on the grid nodalization dimensions. The banded matrix solver uses a two-dimensional banded matrix and an associated one-dimensional nonhomogeneous vector to relate nodal pressure heads. The coefficient matrix and associated nonhomogeneous vector are then modified according to the borehole intrusion parameters at each borehole intrusion time. The resulting coefficient matrix and nonhomogeneous vector are solved using a back substitution banded matrix solver to determine the resulting nodal pressure heads.

6.8.7 Repository Flow Rate Calculations

Grid leg (internode) flow rates can be calculated based on the nodal pressure heads. A difference in the pressure heads between adjacent nodes translates into a flow from the high pressure node to the low pressure node. Leg flow rates are calculated based on the following properties for the leg:

1. Length
2. Cross-sectional area
3. Hydraulic conductivity (calculated from permeability)
4. Pore volume
5. Elevations at each end of leg
6. Pressure heads at each end of leg

A positive flow rate indicates flow in the positive x-direction or positive y-direction. A negative flow rate indicates flow in the negative x-direction or negative y-direction. The magnitude of the flow rate determines the maximum timestep allowed for the transport calculations. The minimum ratio of each leg pore volume to the leg flow rate determines this maximum timestep for the transport calculations.

6.8.8 Repository Species Transport

Two basic transport models are used for the transport of species based on brine flow: (1) species solubility limits or (2) species K_d values determined as the ratio of concentration of the species in solid form to the concentration of the species in the brine. For the case of species solubility limits, the species is present in three physical forms: (1) original waste, (2) brine solution, and (3) precipitated waste. For the case of species K_d values, the species is present in two forms: (1) original waste and (2) brine solution. A range of either solubility limits or K_d values is specified for the entire repository grid and these solubility limits or K_d values can be applied as either

spatially constant or spatially variable. A value chosen at random from this range based on a loguniform distribution may be used to specify either the solubility limit or K_d value for the entire grid or for a single leg within the grid. If the value is used for the entire grid, each leg is assigned the same value, resulting in a spatially constant solubility limit or K_d value. For a spatially variable solubility limit or K_d value, different values are randomly selected for each leg in the grid.

An Euler-type solution of a system of differential equations is used to model species transport based on either species solubility limits or species K_d values. This is based on the assumption that species transport is essentially constant for each timestep. The timestep must therefore be small enough to minimize inaccuracies due to this assumption. The maximum timestep allowed is based on the fact that the entire brine volume within a single leg cannot flow completely into adjacent legs during a single timestep. Total brine solution inflow and outflow for each leg are calculated based on the brine solution concentration of each leg at the beginning of the timestep. The species mass in the original waste, the brine solution, and the precipitated waste are reduced due to radioactive decay occurring during each timestep. The species mass in the brine solution is then compared to the solubility limit for the leg. If the brine species mass is greater than the solubility limit for the leg, the species mass in solution is reduced to the solubility limit and the difference is added to the precipitated waste in the grid cell. If the brine species mass is less than the solubility limit, species mass from the precipitated waste is added to the brine species mass to achieve the solubility limit and the difference is removed from the precipitated waste. If the species mass in the brine solution is still less than the solubility limit, species mass from the original waste is added to the brine species mass to achieve the solubility limit and the difference is removed from the original waste.

6.8.9 Releases to Accessible Environment

Cuttings, spallings, and blowout releases for each borehole intrusion are interpolated from release tables versus drilling intrusion time. Releases to the Marker Beds, Dewey Lakes, and the surface for each timestep are interpolated from release tables versus time. Releases to the Culebra are determined either by interpolation from release tables versus time or by calculation of flow and transport depending on the locations and types of borehole intrusions that have occurred. Culebra transport releases are calculated based on previous unit release calculations to the Culebra.

6.8.10 Result Distributions

Result distributions are accumulated for each observation based on an auto-scaling algorithm which stores the distributions in the form of a histogram. These distributions can then be accumulated to determine a CCDF.

The following types of results are accumulated for total releases of one or more species to the accessible environment, summed over all intrusions:

1. Cuttings
2. Spallings
3. Blowouts
4. Marker Beds
5. Dewey Lakes
6. Surface
7. Flows to the Culebra
8. Transport through the Culebra

Flows to the Culebra and transport through the Culebra are accumulated separately for each species. Flows to the Culebra are modeled using four different scenarios depending on the locations and type of borehole intrusions that have occurred. Before any borehole intrusions occur, releases to the Culebra are interpolated from release tables for undisturbed conditions. After the first borehole intrusion has occurred, releases are interpolated from release tables for individual E1 and E2 intrusion scenarios. An E1 scenario is an intrusion that penetrates the repository and a pressurized brine pocket below the repository. An E2 scenario is an intrusion that penetrates only the repository. After the first drilling intrusion that results in an E1E2 scenario, releases are calculated by modeling brine flow and associated species transport through the repository. An E1E2 scenario is two or more borehole intrusions, one of which must be an E1 intrusion. All releases to the Culebra and all transport through the Culebra are accumulated for individual species and for the total release including all species.

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7. Summary

The Requirements Document for CCDFGF specifies the following conditions to be satisfied:

(1) assemble results calculated with BRAGFLO, NUTS, PANEL, CUTTINGS, BRINEFLO, SECO-TRANSPORT and possibly other WIPP PA codes to produce the CCDF specified in 40 CFR 191 (Fig. 2.1),

(2) allow brine pocket location in the Castile Formation to be specified as an input,

(3) construct the distribution of CCDFs that results from subjective uncertainty as indicated in Eq. (2.5) and Figs. 2.3, 2.4 and 2.5,

(4) be quick running (~ 5-10 min CPU time per individual CCDF construction on a VAS Alpha,

(5) have transparent, easily modified coding to facilitate the incorporation of changed assumptions into CCDF construction, and

(6) meet all applicable WIPP QA requirements.

In addition, CCDFGF shall contain a subroutine, to be called GRIDFLO (Fig. 2.2), that calculates releases based on Darcy flow for E1E2-type intrusions (i.e., futures of the form indicated in Eq. (2) that involve two or more drilling intrusions of which at least one penetrates pressurized brine in the Castile Formation). This subroutine must

(1) determine flow patterns through the repository that result from multiple drilling intrusions of which at least one penetrates pressurized brine in the Castile Formation,

(2) be based on Darcy's Law for single phase flow and incorporate (a) the location, diameter and permeability of individual boreholes above and below the repository, (b) the geometric structure of the repository including the waste handling and experimental regions, (c) the presence or absence of seals within the repository, (d) boundary pressures in the Castile Formation and the Culebra Dolomite, (e) radionuclide transport within the repository and to the Culebra Dolomite by flowing brine, including the effects of decay, sorption and solubility, and (f) the penetration or nonpenetration of pressurized brine in the Castile Formation by individual drilling intrusions,

(3) be fast running as several thousand calls to GRIDFLO will likely be required in each CCDF construction with CCDFGF (fast-running can be achieved by considering steady-state solutions to the equations that underlie Darcy's Law, with each solution requiring the evaluation of a single system of linear algebraic equations).

(4) have a stand-alone run capability for the analysis of specific patterns of drilling intrusions,

(5) meet all applicable WIPP QA requirements.

The code described in this document will satisfy the above requirements.

8. References

1. U.S. DOE. 1980. Final Environmental Impact Statement: Waste Isolation Pilot Plant. DOE/EIS-0026. Washington, D.C.

2. U.S. DOE. 1990. Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant. DOE/EIS-0026-FS. Washington, D.C.

3. U.S. EPA. 1985. "40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," Federal Register **50**: 38066-38089.

4. U.S. EPA. 1986. "40 CFR Part 268: Land Disposal Restrictions," as amended and published in the most recent Code of Federal Regulations. Washington, D.C.: Office of the Federal Register, National Archives and Records Administration.

5. WIPP PA Division. 1991. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. SAND91-0893/1-4. Albuquerque, NM: SNL.

6. WIPP PA Department. 1992. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. SAND92-0700/1-5. Albuquerque, NM: SNL.

7. Helton, J.C., and H.J. Iuzzolino. 1993. "Construction of Complementary Cumulative Distribution Functions for Comparison with the EPA Release Limits for Radioactive Waste Disposal." *Reliability Engineering and System Safety* **40**: 277-293.

8. Helton, J.C., and A.W. Shiver. 1996. "A Monte Carlo Procedure for the Construction of Complementary Cumulative Distribution Functions for Comparison with the EPA Release Limits for Radioactive Waste Disposal." *Risk Analysis* **16**: 43-55.

9. Helton, J.C., D.R. Anderson, B.L. Baker, J.E. Bean, J.W. Berglund, W. Beyeler, R. Blaine, K. Economy, J.W. Garner, S.C. Hora, R.C. Lincoln, M.G. Marietta, F.T. Mendenhall, N.H. Prindle, D.K. Rudeen, J.D. Schrieber, A.W. Shiver, L.N. Smith, P.N. Swift, P. Vaughn. 1996. "Computational Implementation of a Systems Prioritization Methodology for the Waste Isolation Pilot Plant: A Preliminary Example." SAND94-3069. Albuquerque, NM: SNL.

10. U.S. EPA (Environmental Protection Agency). 1995. "40 CFR Part 194: Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance With Environmental Standards for the

Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Proposed Rule." *Federal Register* **60**: 5766-5791.

11. W. Feller. 1971. *An Introduction to Probability Theory and Its Applications*, Vol. II (2nd Ed.). New York, NY: Wiley.

12. Ross, S.M. 1987. *Introduction to Probability and Statistics for Engineers and Scientists*. New York, NY: Wiley.

13. W.H. Press, S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery. 1992. *Numerical Recipes in FORTRAN: The Art of Scientific Computing* (2nd Ed.). Cambridge: Cambridge University Press.

Appendix A
Linearity of Equations in SECO-TRANSPORT

The SECO-TRANSPORT calculations are linear with respect to the radionuclide source rate into the Culebra. Conceptually, SECO-TRANSPORT is solving a system of equations of the form

$$\mathbf{Du} = \mathbf{h}, \tag{A.1}$$

where $\mathbf{D}$ is a linear differential operator, $\mathbf{u}$ is radionuclide concentration, and $\mathbf{h}$ is the source rate into the system. If $\mathbf{u}_1$ and $\mathbf{u}_2$ are solutions to

$$\mathbf{Du}_1 = \mathbf{h}_1 \text{ and } \mathbf{Du}_2 = \mathbf{h}_2, \tag{A.2}$$

c_1 and c_2 are constants and $\mathbf{u} = c_1\mathbf{u}_1 + c_2\mathbf{u}_2$, then

$$\mathbf{Du} = \mathbf{D}(c_1\mathbf{u}_1 + c_2\mathbf{u}_2) = c_1\mathbf{Du}_1 + c_2\mathbf{Du}_2 = c_1\mathbf{h}_1 + c_2\mathbf{h}_2 \tag{A.3}$$

and thus $\mathbf{u}$ is a solution to

$$\mathbf{Du} = c_1\mathbf{h}_1 + c_2\mathbf{h}_2. \tag{A.4}$$

As a result, it is possible to solve the transport equations in SECO-TRANSPORT for a sequence of instantaneous unit releases to the Culebra and then use these results to construct the releases to the accessible environment that result from arbitrary time-dependent releases into the Culebra.

The implications of the linearity of Eq. (A.1) is perhaps best seen by formally examining the outcome of the numerical procedure used to obtain approximations to its solution. In SECO-TRANSPORT, Eq. (A.1) is solved with a finite difference procedure that is implicit in time over each time step. This procedure is based on dividing the time interval $[0, t_f]$ under consideration into a sequence of times $0 = t_0 < t_1 < \ldots, t_n = t_f$ and dividing the physical region (i.e., fracture and associated matrix) under consideration into a three dimensional grid of nodes as indicated in Fig. A.1. The approximate solution is then incremented from time t_{i-1} to time t_i by a relationship of the form

$$\mathbf{y}(t_i) = \mathbf{y}(t_{i-1}) + \mathbf{A}(t_{i-1}, t_i)\,\mathbf{y}(t_{i-1}) + \mathbf{B}(t_{i-1}, t_i)\,\mathbf{y}(t_i) + \mathbf{h}(t_{i-1}, t_i), \tag{A.5}$$

where

$\mathbf{y}(t)$ = vector of approximate solutions (i.e., at each node illustrated in Fig. A.1) at time t,

$\mathbf{h}(t_{i-1}, t_i)$ = vector of radionuclide inflows to the system over $[t_{i-1}, t_i]$,

$\mathbf{A}(t_{i-1}, t_i)$ = matrix associated with finite difference procedure for incrementing solution over $[t_{i-1}, t_i]$,

$\mathbf{B}(t_{i-1}, t_i)$ = matrix associated with finite difference procedure for incrementing solution over $[t_{i-1}, t_i]$.

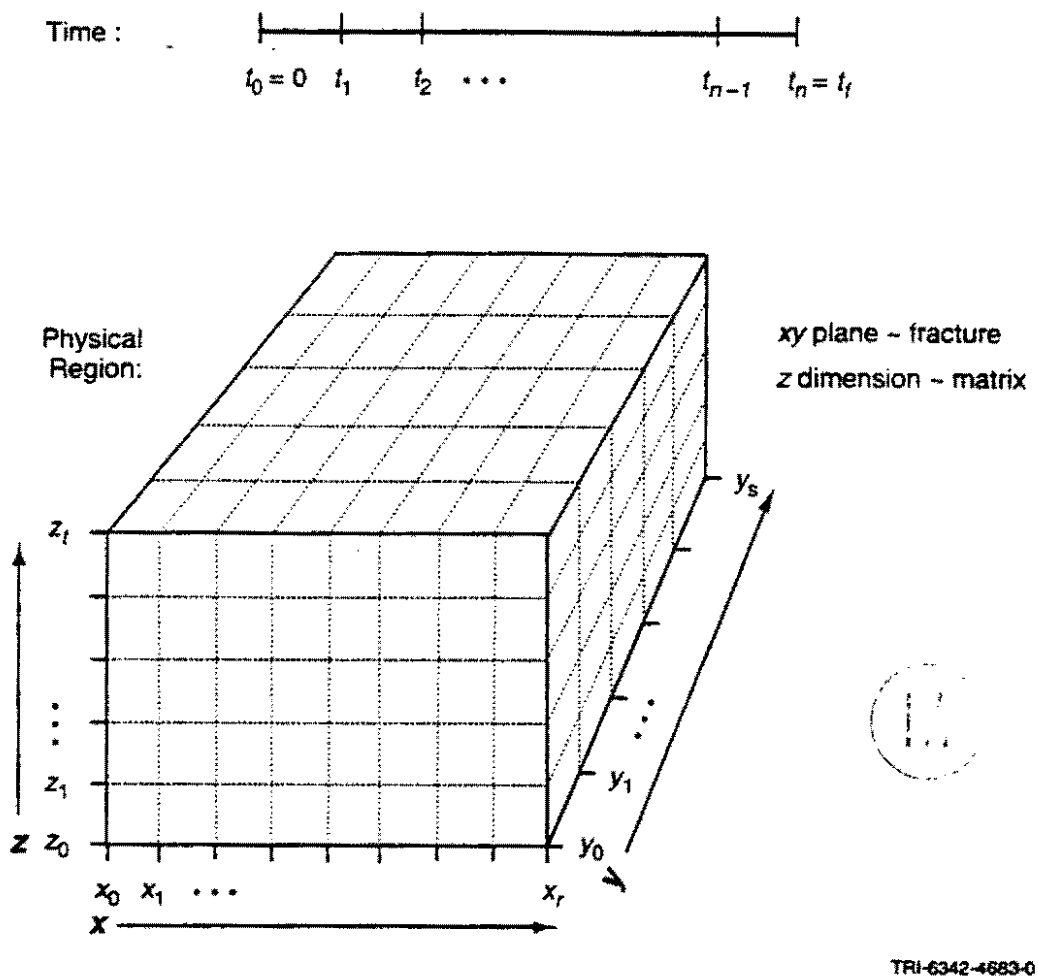

Figure A.1. Conceptual illustration of gridding used in finite difference procedure to solve the transport equations in SECO-TRANSPORT.

For notational convenience in later manipulations, the preceding relationships can be represented by

$$\mathbf{y}_i = \mathbf{y}_{i-1} + \mathbf{A}_i \mathbf{y}_{i-1} + \mathbf{B}_i \mathbf{y}_i + \mathbf{h}_i. \tag{A.6}$$

As an example, if 1000 nodes were used in the finite difference procedure, then $\mathbf{y}$ and $\mathbf{h}$ would be vectors from R^{1000}, and $\mathbf{A}$ and $\mathbf{B}$ would be 1000×1000 matrices. As radionuclide release to the system would occur over a relatively small area, most elements of $\mathbf{h}$ would be zero. Due to the nature of the numerical procedure, $\mathbf{A}$ and $\mathbf{B}$ would be banded matrices with most of their elements also equal to zero.

The numerical procedure indicated in Eqs. (A.5) and (A.6) leads to

$$(\mathbf{I} - \mathbf{B}_i)\mathbf{y}_i = (\mathbf{I} + \mathbf{A}_i)\mathbf{y}_{i-1} + \mathbf{h}_i \tag{A.7}$$

and thus to

$$\mathbf{y}_i = (\mathbf{I} - \mathbf{B}_i)^{-1}(\mathbf{I} + \mathbf{A}_i)\mathbf{y}_{i-1} + (\mathbf{I} - \mathbf{B}_i)^{-1}\mathbf{h}_i. \tag{A.8}$$

The nature of the solution to Eq. (A.1) can be seen by repetitively implementing the relationship in Eq. (A.8):

$$\mathbf{y}_1 = (\mathbf{I} - \mathbf{B}_1)^{-1}(\mathbf{I} + \mathbf{A}_1)\mathbf{y}_0 + (\mathbf{I} - \mathbf{B}_1)^{-1}\mathbf{h}_1 \tag{A.9}$$

$$\begin{aligned} \mathbf{y}_2 &= (\mathbf{I} - \mathbf{B}_2)^{-1}(\mathbf{I} + \mathbf{A}_2)\mathbf{y}_1 + (\mathbf{I} - \mathbf{B}_2)^{-1}\mathbf{h}_2 \\ &= (\mathbf{I} - \mathbf{B}_2)^{-1}(\mathbf{I} + \mathbf{A}_2)(\mathbf{I} - \mathbf{B}_1)^{-1}(\mathbf{I} + \mathbf{A}_1)\mathbf{y}_0 + (\mathbf{I} - \mathbf{B}_2)^{-1}(\mathbf{I} + \mathbf{A}_2)(\mathbf{I} - \mathbf{B}_1)^{-1}\mathbf{h}_1 + (\mathbf{I} - \mathbf{B}_2)^{-1}\mathbf{h}_2 \end{aligned} \tag{A.10}$$

$$\begin{aligned} \mathbf{y}_3 &= (\mathbf{I} - \mathbf{B})^{-1}(\mathbf{I} + \mathbf{A}_3)\mathbf{y}_2 + 1(\mathbf{I} - \mathbf{B}_3)^{-1}\mathbf{h}_3 \\ &= \left[\prod_{j=3}^{1}(\mathbf{I} - \mathbf{B}_3)^{-1}(\mathbf{I} + \mathbf{A}_j)\right]\mathbf{y}_0 + \sum_{i=1}^{3}\left[\prod_{j=3}^{i+1}(\mathbf{I} - \mathbf{B}_j)^{-1}(\mathbf{I} + \mathbf{A}_j)\right](\mathbf{I} - \mathbf{B}_i)^{-1}\mathbf{h}_i \end{aligned} \tag{A.11}$$

$$\bullet$$

$$\bullet$$

$$\bullet$$

$$\begin{aligned} \mathbf{y}_n &= (\mathbf{I} - \mathbf{B}_n)^{-1}(\mathbf{I} + \mathbf{A}_n)\mathbf{y}_{n-1} + (\mathbf{I} - \mathbf{B}_n)^{-1}\mathbf{h}_n \\ &= \left[\prod_{j=n}^{1}(\mathbf{I} - \mathbf{B}_j)^{-1}(\mathbf{I} + \mathbf{A}_j)\right]\mathbf{y}_0 + \sum_{i=1}^{n}\left[\prod_{j=n}^{i+1}(\mathbf{I} - \mathbf{B}_j)^{-1}(\mathbf{I} + \mathbf{A}_j)\right](\mathbf{I} - \mathbf{B}_i)^{-1}\mathbf{h}_i \end{aligned} \tag{A.12}$$

with the identity

$$\prod_{j=n}^{nH}(\mathbf{I} - \mathbf{B}_j)^{-1}(\mathbf{I} + \mathbf{A}_j) = \mathbf{I} \tag{A.13}$$

being assumed for notational convenience.

As examination of the expression in Eq. (A.12) shows, it is possible to separate the part of the solution $\mathbf{y}_n$ that arises from the initial value condition $\mathbf{y}_0$ from the part that arises from the inflows to the system characterized by the $\mathbf{h}_i$. Further, similar terms appear in the parts of the solution associated with $\mathbf{y}_0$ and with the $\mathbf{h}_i$. Due to this repetition and the linearity of matrix multiplication, solutions to Eq. (A.1) for unit inputs to the system at fixed points in time can be used to construct the solutions that would result for an arbitrary function $\mathbf{h}$.

For convenience in discussion, assume that one or more of the elements of the vectors $\mathbf{y}_i$ appearing in Eq. (A.5) and in subsequent equations are used to accumulate integrated releases to the accessible environment and that a is a vector of 0's and 1's such that the total integrated release to the accessible environment through time t_i is given by $\mathbf{a}^T\mathbf{y}_i$. Further, assume that the numerical procedure indicated in Eq. (A.5) has been carried out to obtain

$\mathbf{y}_{u0j}$ = outcome of evaluating Eq. (A.5) through time t_j for a unit initial value $\mathbf{y}_{u0}$ at time t_0 (i.e., $\|\mathbf{y}_{u0}\| = 1$) and no other inputs to the system, (A.14)

$\mathbf{y}_{uij}$ = outcome of evaluating Eq. (A.5) through time t_j for the initial value $\mathbf{y}_0 = 0$, a unit input $\mathbf{h}_{ui}$ over the interval $[t_{i-1},t_i]$ (i.e., $\|\mathbf{h}_{ui}\| = 1$) and no other inputs to the system. (A.15)

As will be shown, $\mathbf{y}_{u0j}$ and $\mathbf{y}_{uij}$ can be used to construct solutions to Eq. (A.1) for initial values $\mathbf{y}_0$ and source rates $\mathbf{h}$ that can be obtained by scaling $\mathbf{y}_{u0}$ and $\mathbf{h}_{ui}$.

Suppose the initial value $\mathbf{y}_0$ and the source rate $\mathbf{h}(t)$ can be approximated by

$$\mathbf{y}_0 = c_0\mathbf{y}_{u0} \tag{A.16}$$

and

$$\int_{t_{i-1}}^{t_i} \mathbf{h}(t)dt = c_i\mathbf{h}_{ui}, \tag{A.17}$$

where the c_i, $i = 0, 1, \ldots, n$, are appropriately chosen constants. The integrated release $iR(t_n)$ to the accessible environment through time t_n associated with $\mathbf{y}_0$ and $\mathbf{h}$ can be approximated by

$$
\begin{aligned}
iR(t_n) &= \mathbf{a}^T \mathbf{y}_n \\
&= \mathbf{a}^T \left\{ \left[\prod_{j=n}^{1} (\mathbf{I}-\mathbf{B}_j)^{-1}(\mathbf{I}+\mathbf{A}_j) \right] \mathbf{y}_0 + \sum_{i=1}^{n} \left[\prod_{j=n}^{i+1} (\mathbf{I}-\mathbf{B}_j)^{-1}(\mathbf{I}+\mathbf{A}_j) \right] (\mathbf{I}-\mathbf{B}_i)^{-1} \mathbf{h}_i \right\} \\
&= \mathbf{a}^T \left\{ c_0 \left[\prod_{j=n}^{1} (\mathbf{I}-\mathbf{B}_j)^{-1}(\mathbf{I}+\mathbf{A}_j) \right] \mathbf{y}_{u0} + \sum_{i=1}^{n} c_i \left[\prod_{j=n}^{i+1} (\mathbf{I}-\mathbf{B}_j)^{-1}(\mathbf{I}+\mathbf{A}_j) \right] (\mathbf{I}-\mathbf{B}_i)^{-1} \mathbf{h}_{ui} \right\} \\
&= \mathbf{a}^T \left\{ c_0 \mathbf{y}_{u0n} + \sum_{i=1}^{n} c_i \mathbf{y}_{uin} \right\} \\
&= \sum_{i=0}^{n} c_i \mathbf{a}^T \mathbf{y}_{uin} \\
&= \sum_{i=0}^{n} c_i \; iR_u(t_i, t_n),
\end{aligned}
\tag{A-18}
$$

where

$$
iR_u(t_i, t_n) = \mathbf{a}^T \mathbf{y}_{uij}
$$

= integrated release to accessible environment between t_i and t_n that results from $\mathbf{y}_{u0}$ for $i = 0$ and from $\mathbf{h}_{ui}$ for $i = 1, 2, \ldots, n$. (A.19)

Thus, by calculating and saving the integrated releases $iR_u(t_i, t_n)$, it is possible to calculate the integrated releases to the accessible environment for many different patterns of release to the Culebra (i.e., release functions $\mathbf{h}$) without repeating the numerical procedure required to solve Eq. (A.1).

The preceding computational strategy can also be used to estimate the release of a member of a decay chain to the accessible environment due to groundwater transport in the Culebra. In particular, if radionuclide k has $nP(k)$ precursors as indicated in Table A.1, $\mathbf{y}_{0l}$ and $\mathbf{h}_l(t)$ are the initial values and source rates associated with radionuclide k and its precursors for $l = k - nP(k), \ldots, k$, and $iR_k(t_n)$ is the integrated release of radionuclide k to the accessible environment through time t_n associated with the quantities $\mathbf{y}_{0l}$ and $\mathbf{h}_l(t)$, then

$$
iR_k(t_n) = \sum_{l=k-nP(k)}^{k} \sum_{i=0}^{n} c_{il} \; iR_{ukl}(t_i, t_n), \tag{A.20}
$$

where

Table A.1. Radionuclides and Decay Chains Used for Transport Calculations in the Culebra Dolomite (adopted from Tables 7.3-1 and 7.3-2 of SAND92-0700/4).

Decay Chains	
(1)	Pu-240
(2)	Am-241 → Np-237→ U-233 → Th-229
(3)	U-234 → Th-230 → Ra-226
(4)	Pu-239

Individual Radionclides (nR = 9)

Radionuclide	Integer Designator	Np(i)	Half Life (yr)
Pu-240	1	0	
Am-241	2	0	
Np-237	3	1	
U-233	4	2	
Th-229	5	3	
U-234	6	0	
Th-230	7	1	
Ra-226	8	2	
Pu-239	9	0	

$\mathbf{y}_{0ul}$ = unit initial value for radionuclide l,

$\mathbf{y}_{0l}$ = $c_{0l}\,\mathbf{y}_{0ul}$ (c_{0l} a constant),

$\mathbf{h}_{uil}$ = unit input of radionuclide l over $[t_{i-1}, t_i]$,

$$\int_{t_{i-1}}^{t_i} \mathbf{h}_l(t)dt = c_{il}\mathbf{h}_{uil} \quad (c_{il} \text{ a constant}),$$

$iR_{ukl}(t_0, t_n)$ = integrated release of radionuclide k to accessible environment between t_0 and t_n due to initial value $\mathbf{y}_{0ul}$ of radionuclide l,

$iR_{ukl}(t_i, t_n)$ = integrated release of radionuclide k to accessible environment between t_i and t_n due to release $\mathbf{h}_{uil}$ of radionuclide l, during $[t_{i-1}, t_i]$.

The expression in Eq. (A.20) can be established by following a sequence of manipulations analogous to those that lead to Eq. (A.18)

If the Culebra flow field obtained from SECO-FLOW is time-dependent, then it will be necessary to obtain the integrated releases $iR_u\left(t_i, t_n\right)$ in Eq. (A.19) from h_{ui} for i = 1, 2, ..., n. However, if the flow field is not time-dependent, then it will be necessary to solve Eq. (A.1) only for the initial value condition $\mathbf{y}_{u0}$ to obtain

$$iR_u\left(t_0, t_j\right),\ j = 1, 2, \ldots, n, \tag{A.21}$$

where $iR_u\left(t_0, t_j\right)$ is the integrated release to the accessible environment between t_0 and t_j that results from $\mathbf{y}_{u0}$. Then,

$$iR_u\left(t_i, t_n\right) = iR_u\left(t_0, t_{n-i}\right),\ i = 1, 2, \ldots, n, \tag{A.22}$$

due to the constancy of the flow field (i.e., a unit release at time t_j will transport in exactly the same manner as a unit release at time $t_0 = 0$. At present, it is anticipated that the 1996 WIPP PA will use constant (i.e., time invariant) flow fields in the Culebra.

Appendix B
Memo from Rebecca L. Blaine
Illustrating Linearity of SECO-TRANSPORT Calculations

ECODYNAMICS MEMORANDUM

TO: Jon Helton
FROM: Rebecca L. Blaine /rlb
DATE: January 30, 1996
RE: Source Term Study

The following calculations were performed to verify the linear behavior of the source term in the SECOTP2D code. The problems were run on the standard local grid, 46x53 elements measuring 125 m on each side. Dual porosity was modeled. Median values from the 1992 PA were used for most parameters with the exception of fracture spacing and chemical retardation. The values for the parameters used are as follows: matrix porosity = .139, matrix tortuosity = .12, fracture spacing = 2 m, fracture porosity = .001, longitudinal dispersivity = 100, and transverse dispersivity = 10. Three radioisotopes were transported, ^{240}PU, ^{241}AM, and ^{233}U. The amount of chemical retardation applied was very small, R = 2.74678, for ^{240}PU and ^{233}U, and no retardation, R = 1, for ^{241}AM. This value of retardation for ^{241}AM was chosen because of the very short half-life of this isotope. If any retardation is used, all of the injected mass is retained in the grid or decays before it reaches the boundary chosen for integration. A constant velocity field was used with a value for Darcy velocity of 1.0E-09 m/sec. (The average Darcy velocity along the path of a particle released from the site to the 2.5km boundary for the 70 transmissivity fields used in the 1992 PA ranges from 1.0E-09 to 9.0E-10.) The duration of each problem was 10,000 years starting at t = 0.0 and with a time step of 5 years.

Six runs were made varying only the source function. The first, baseline case duplicated the "unit source" used for the DCCA calculations. This consisted of a square pulse beginning at t = 0.0 years and ending at t = 50 years with at constant injection rate of 2.0E-09 kg/sec. The total amount of mass injected in this case for each radioisotope was 3.15569 kg. The second case simply doubled the rate to 4.0E-09 kg/sec (which of course doubles the amount of mass injected). The third through sixth cases all used more complicated functions. Figure 1 shows all six source functions used for all three isotopes. Table 1 shows the total amount of mass injected for each isotope in each of the six runs.

Table 1 - Total mass (kg) injected for each isotope in each case

Case number	Total Mass (kg)
1	3.15569
2	6.31138
3	17.356295
4	6.31138
5	315.569
6	757.3656

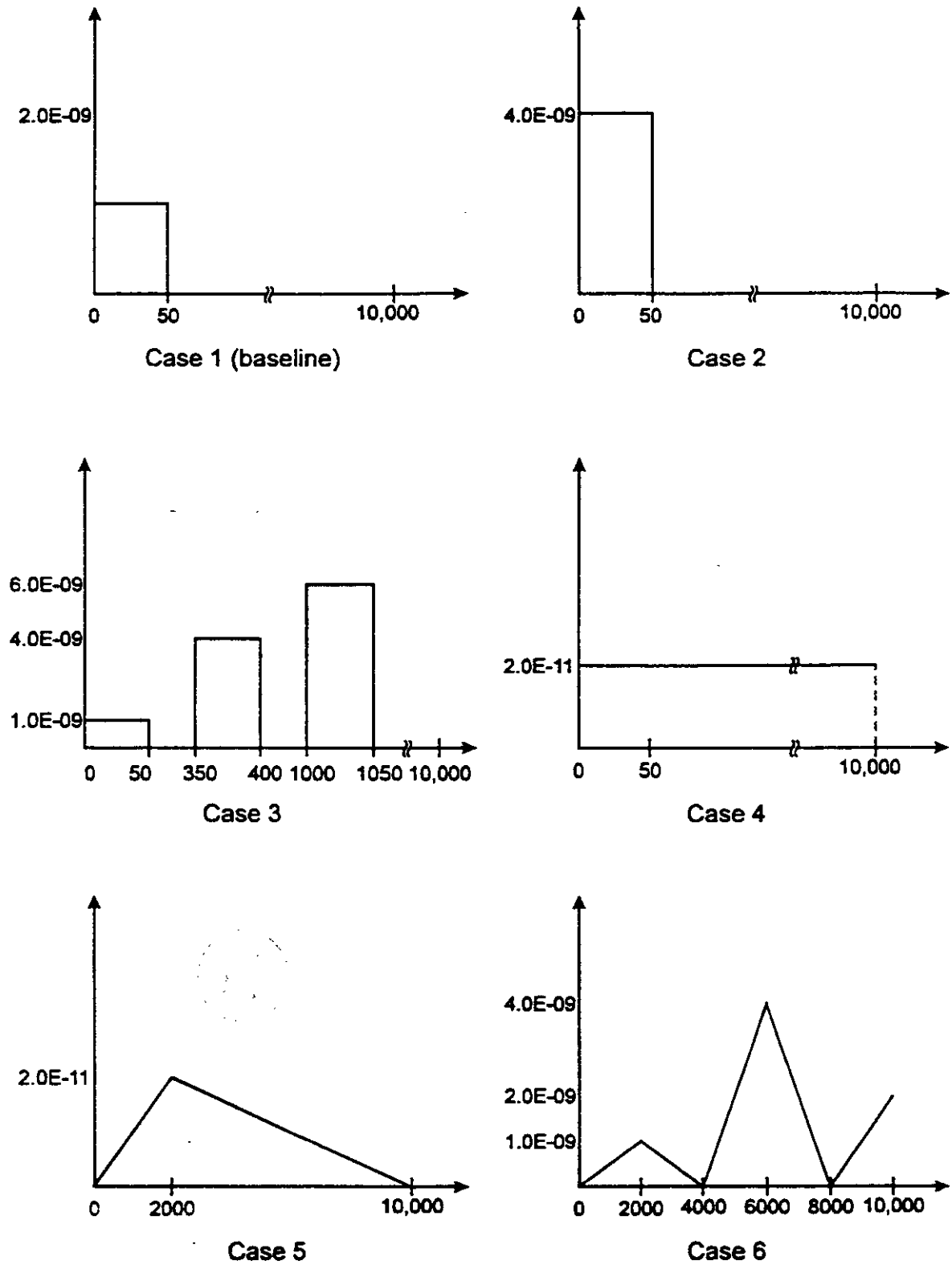

Figure 1 - Input source function for for the six cases

The purpose of running case 2 was to see if doubling the amount of mass injected doubles the amount of mass discharged. The discharge is calculated by summing the mass around a rectangular boundary with the southern edge 2.5 km from the injection point. (The flow was set to be directly south so all of the mass that crosses the discharge boundary crosses the southern edge.) This discharge is calculated by the code at each time step. The total discharge calculated is the integral of this curve over time. Table 2 shows the amount of each radioisotope that crossed the boundary set at 2.5 km from the release point over the entire 10,000 year time period for cases 1 and 2. As the amount injected for each radioisotope was doubled, the amount that crossed the 2.5 km boundary should show a factor of 2 when the results of case 2 are divided by the results of case 1. The values shown in Table 2 verify that the factor is indeed 2.

Table 2 - Comparison of Integrated Discharge for Cases 1 and 2

Radioisotope	Case 1 (kg)	Case 2 (kg)	Factor (case 2/case 1)
^{240}PU	0.185048	0.370095	1.99999
^{241}AM	3.174245E-04	6.348490E-05	2.0
^{233}U	2.033126E-03	4.066235E-03	1.99999

The purpose of running case 3 was to see if the results of this case are a linear combination of the results of case 1. This case is of interest as it represents multiple intrusions at different times. As in case 2, both the total discharge for each radioisotope were compared. The total discharge of each radioisotope in case 3 should be a linear combination of the discharge in case 1 described by the relationship $D = 2D_1 + 3D_2 + 0.5D_3$, where D_1 is the discharge in case 1 integrated over 10,000 years, D_2 is the discharge in case 1 integrated over 9650 years, and D_3 is the discharge in case 1 integrated over 9000 years. Table 3 shows the discharge calculated by running case 3, the value calculated from the discharge in case 1 (using the equation shown), and the percent error between the two values.

Table 3 - Comparison of Integrated Discharge in Case 3 to Calculated Values

Radioisotope	Case 3 (kg)	Calculated (kg)	Percent error
^{240}PU	0.973453	0.966098	.76%
^{241}AM	1.751912E-03	1.745407E-03	.37%
^{233}U	9.318708E-03	9.343115-03	.26%

Cases 4 through 6 were run to verify that the source term calculation maintains its linear behavior with more complicated input functions that would take into account diffusion into and out of the matrix material. Tables 4 - 6 show for cases 4 - 6 respectively the comparison of the discharge calculated with the SECOTP run and the discharge calculated from linear combinations of the results of case 1. The discharge calculated for case 4 was

obtained by the equation $D = .01 \sum D_i$, $i = 1,200$, where D_i is the discharge of case 1 integrated over 10,000 - (i-1)50 years. The sum is multiplied by .01 as the constant rate of the source function of case 4 was .01 of the rate of the source function of case 1. The discharge for cases 5 and 6 was obtained by the equation $D = \sum R_i D_i$, $i = 1,200$, where R_i is the rate of the ith 50 year interval divided by the rate of the 50 year pulse in case 1 and D_i is the discharge of case 1 integrated over 10,000 - (i-1)50 years.

Table 4- Comparison of Integrated Discharge in Case 4 to Calculated Values

Radioisotope	Case 4 (kg)	Calculated (kg)	Percent error
^{240}PU	0.119528	0.120146	0.52%
^{241}AM	4.053027E-04	4.067540E-04	0.36%
^{233}U	5.402719E-04	5.568291-04	3.06%

Table 5 - Comparison of Integrated Discharge in Case 5 to Calculated Values

Radioisotope	Case 5 (kg)	Calculated (kg)	Percent error
^{240}PU	7.402370	7.441312	0.53%
^{241}AM	2.571217E-02	2.579650E-02	0.33%
^{233}U	2.550871E-02	2.646831E-02	3.76%

Table 6 - Comparison of Integrated Discharge in Case 6 to Calculated Values

Radioisotope	Case 6 (kg)	Calculated (kg)	Percent error
^{240}PU	4.438583	4.461932	0.53%
^{241}AM	3.313131E-05	3.354456E-05	1.25%
^{233}U	1.326739E-02	1.376989E-02	3.79%

In addition to the tables presented here showing the percent error in the calculated answer as compared to the answer obtained by running the SECOTP code, Figures 2 - 13 show graphically the comparisons of the cumulative discharge all the isotopes in cases 3 - 6.

Case 3 - Cumulative Discharge for ^{240}PU

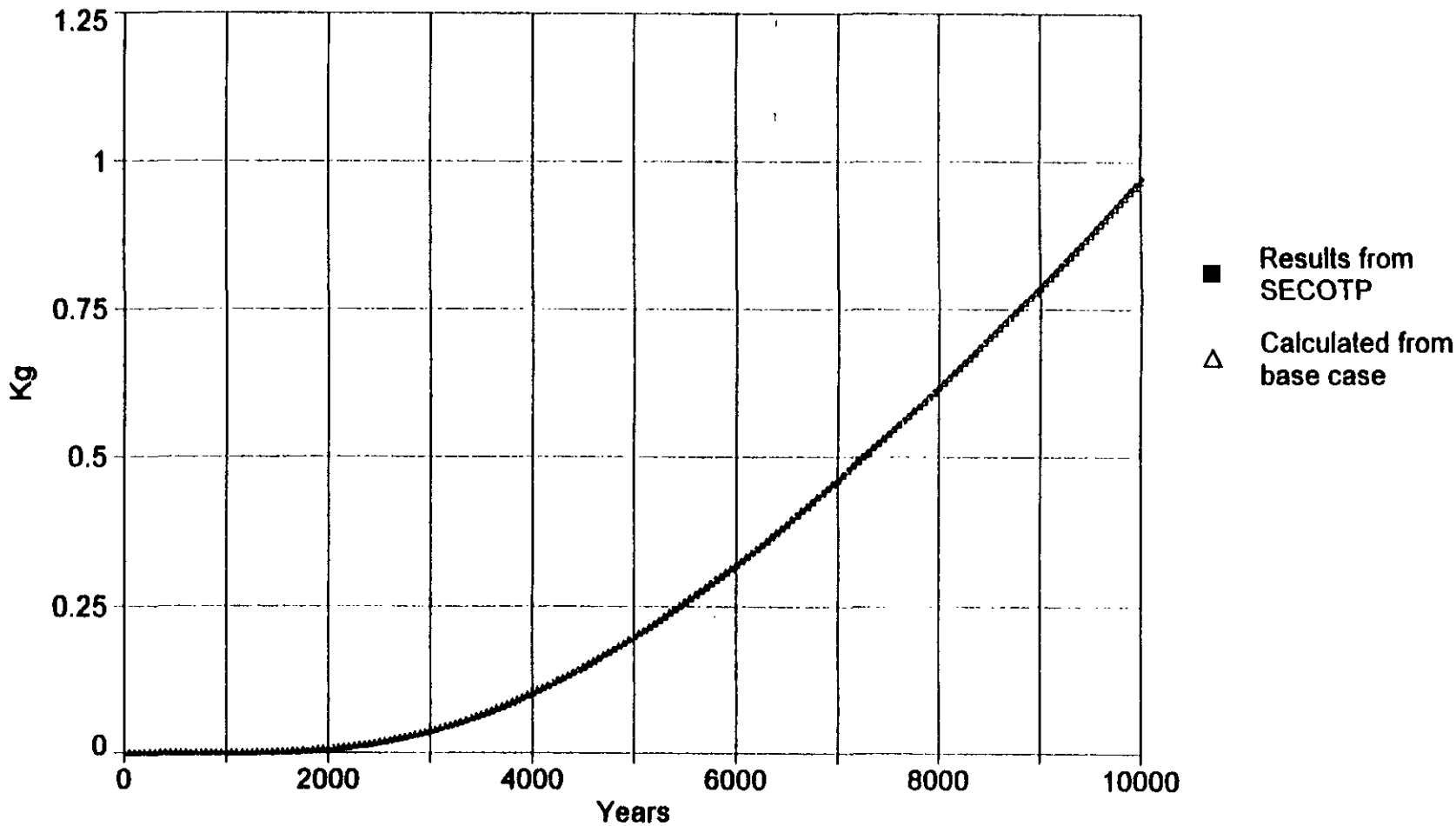

Figure 2

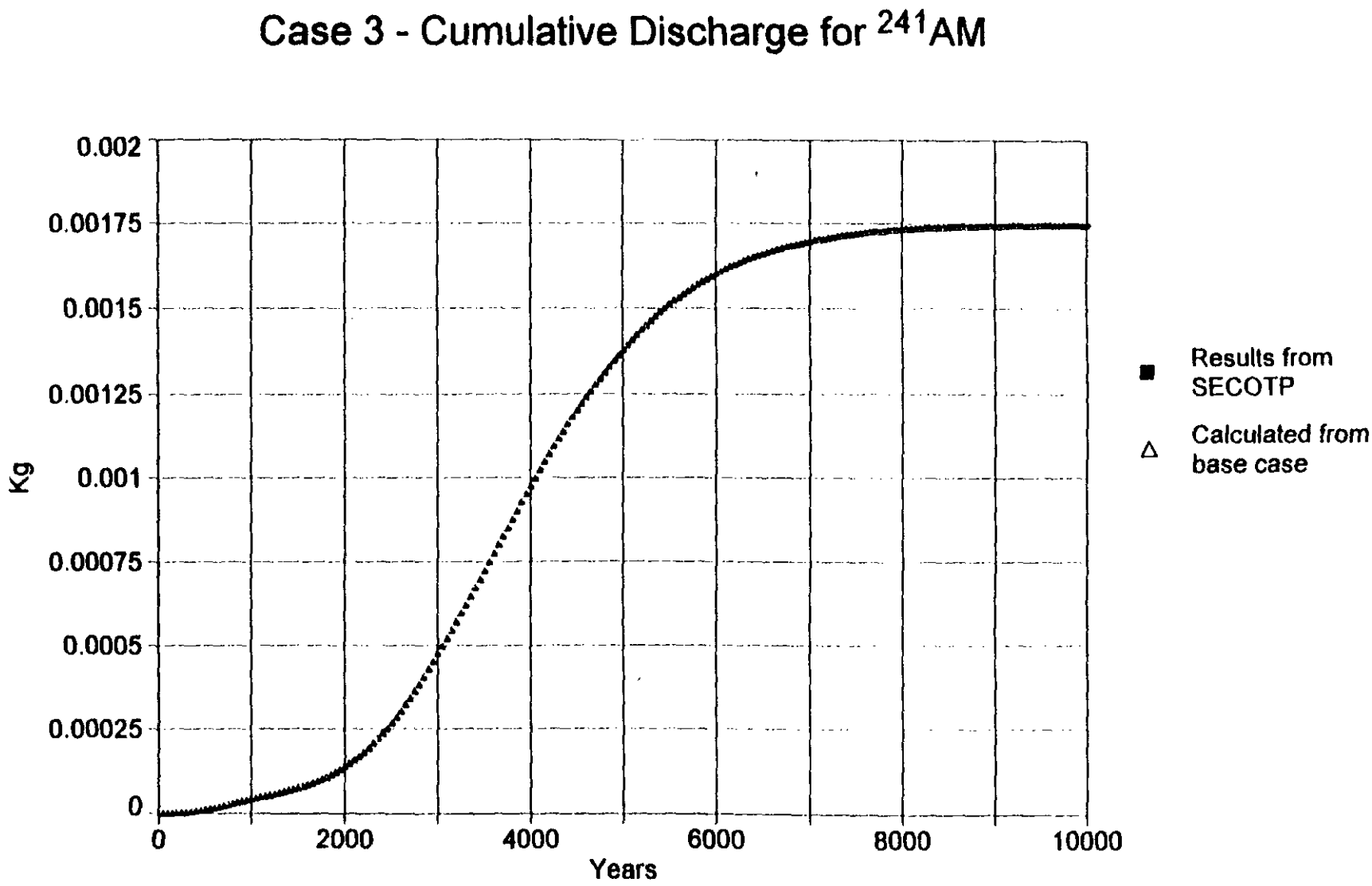
Case 3 - Cumulative Discharge for 241AM
0.002
0.00175
0.0015
0.00125
0.001
0.00075
0.0005
0.00025
0
Kg
0
2000
4000
6000
8000
10000
Years
Results from SECOTP
Calculated from base case

Figure 3

Case 3 - Cumulative Discharge for ^{233}U

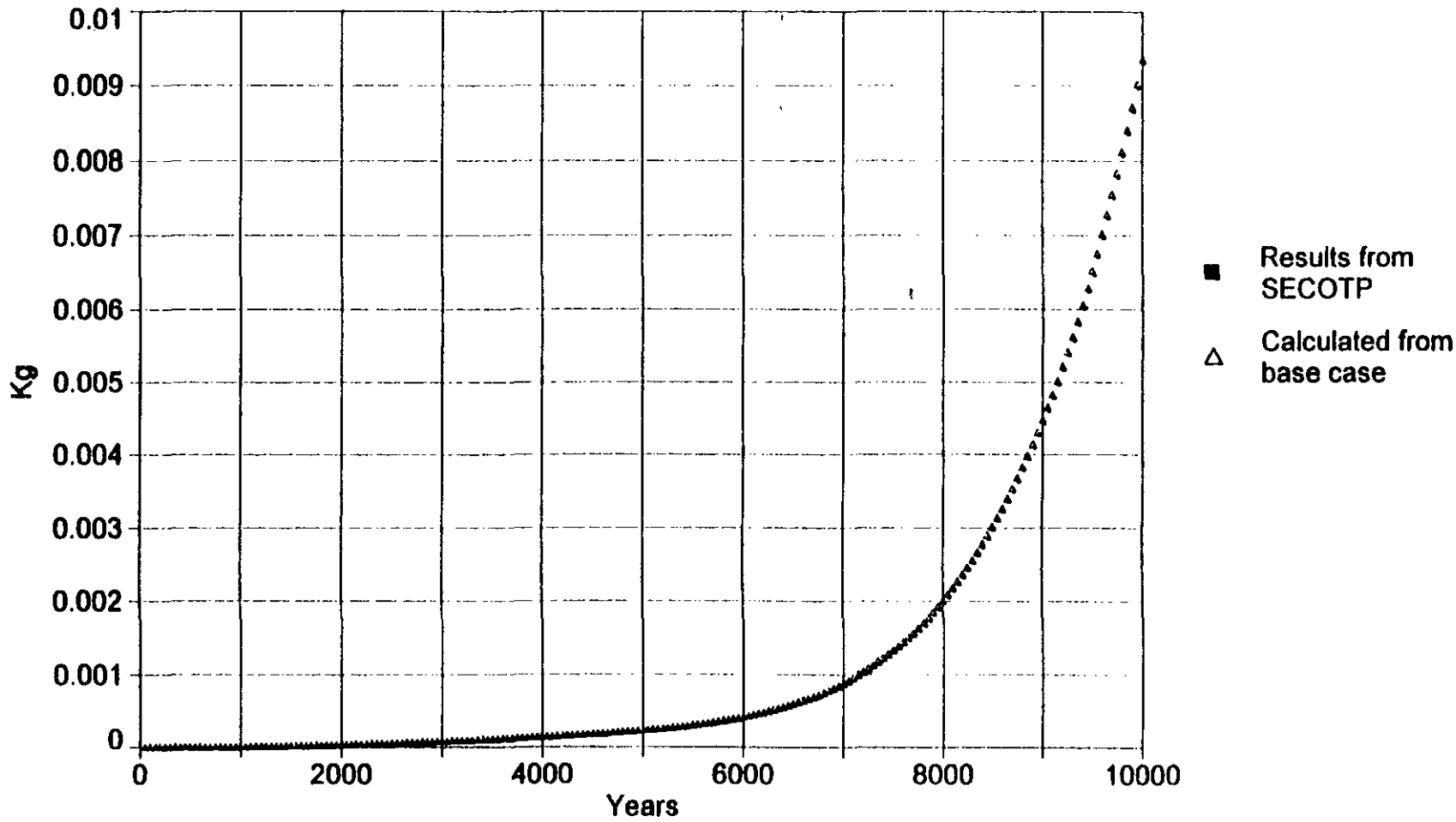

Figure 4

Case 4 - Cumulative Discharge for ^{240}PU

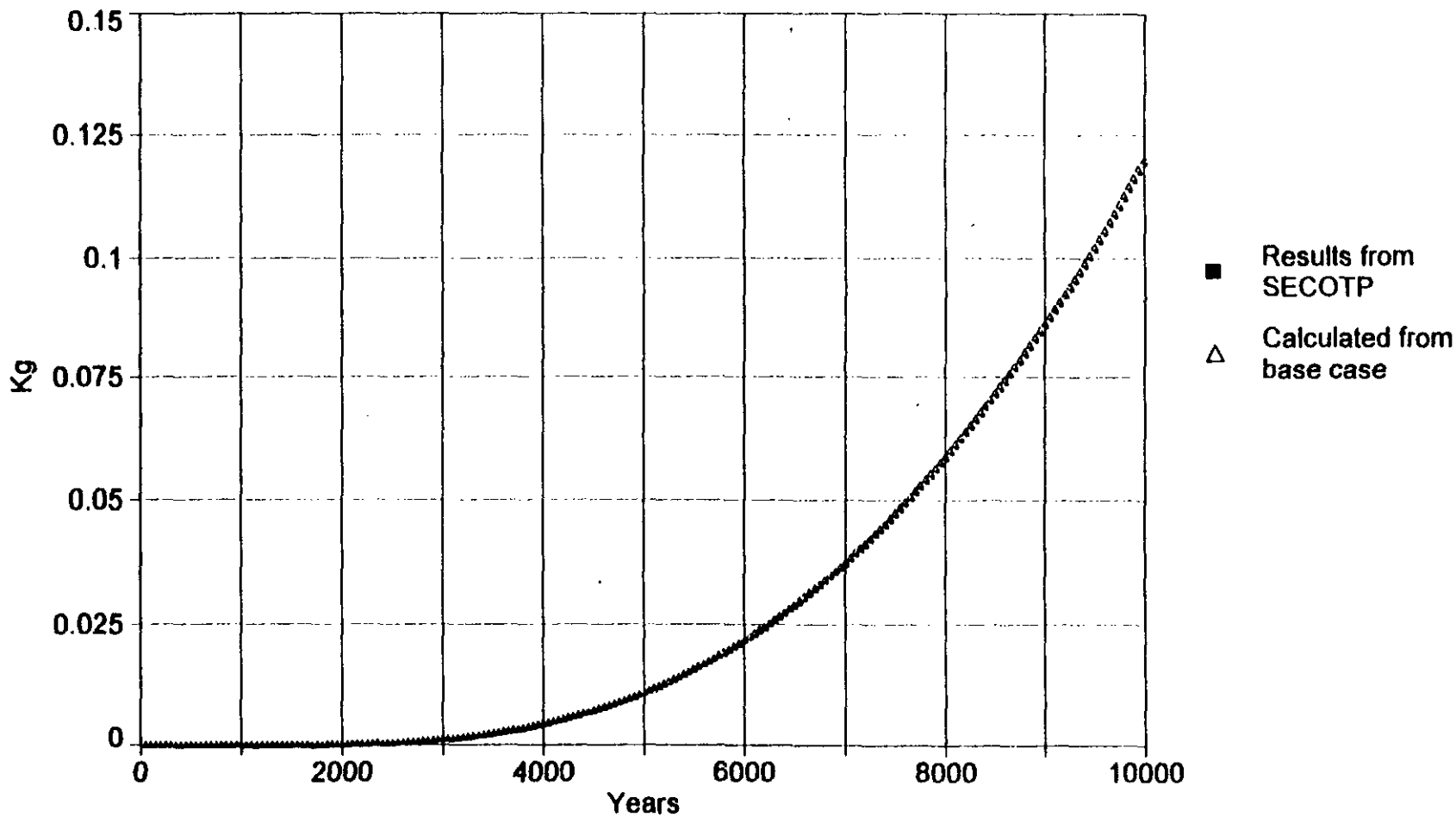

Figure 5

Case 4 - Cumulative Discharge for ^{241}AM

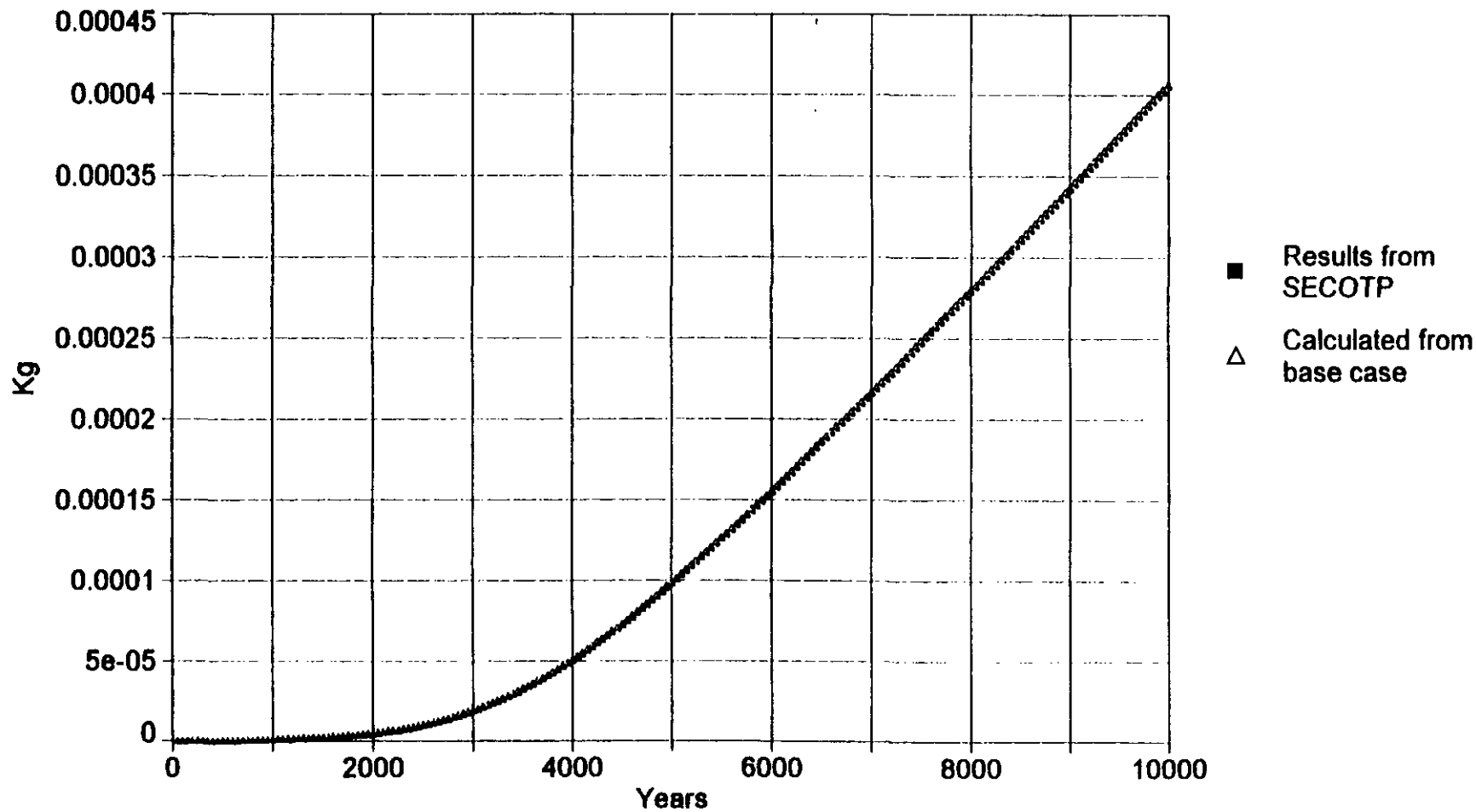

Figure 6

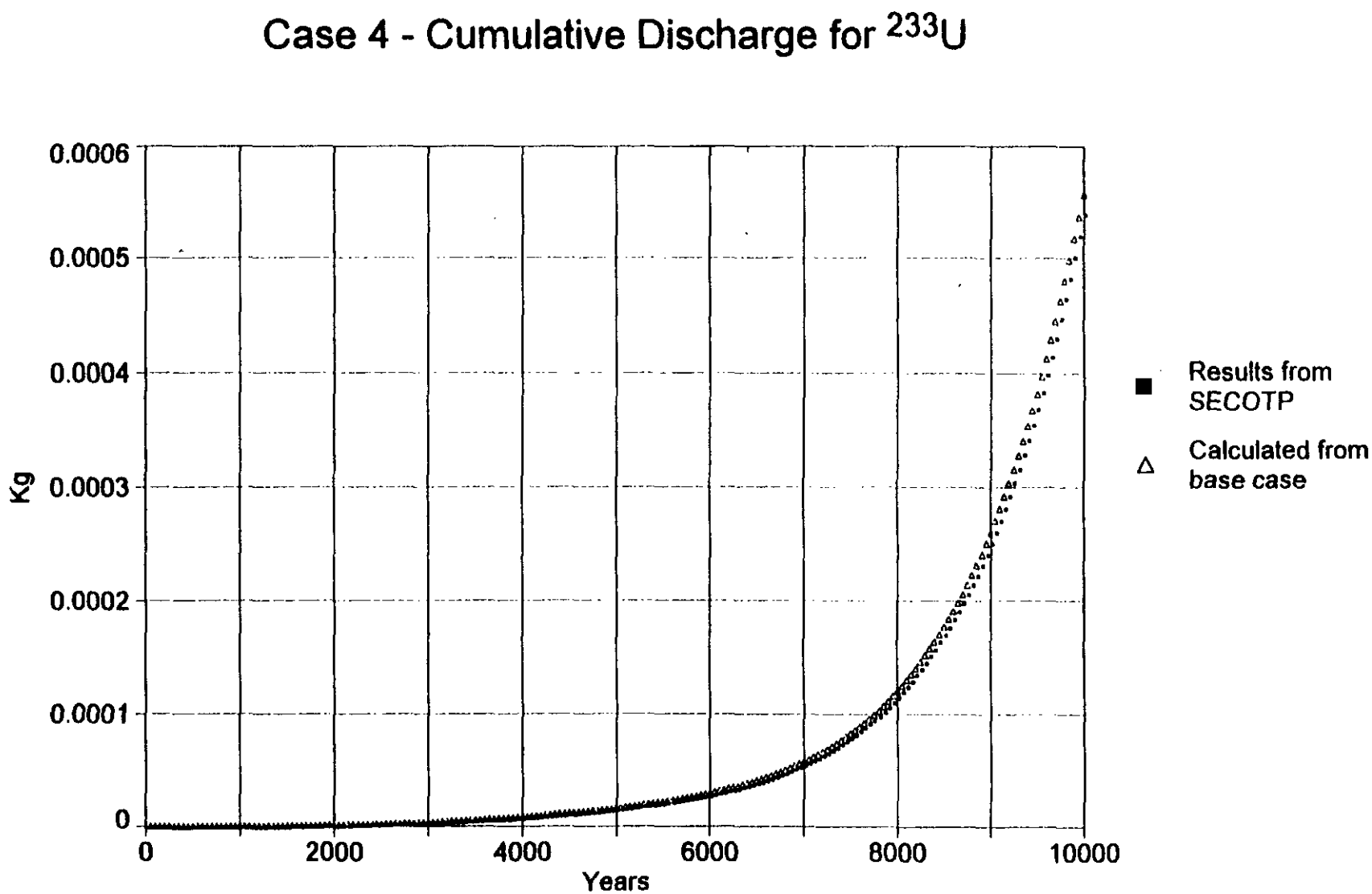
Case 4 - Cumulative Discharge for 233U
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Kg
0
2000
4000
6000
8000
10000
Years
Results from SECOTP
Calculated from base case

Figure 7

Case 5 - Cumulative Discharge for ^{240}PU

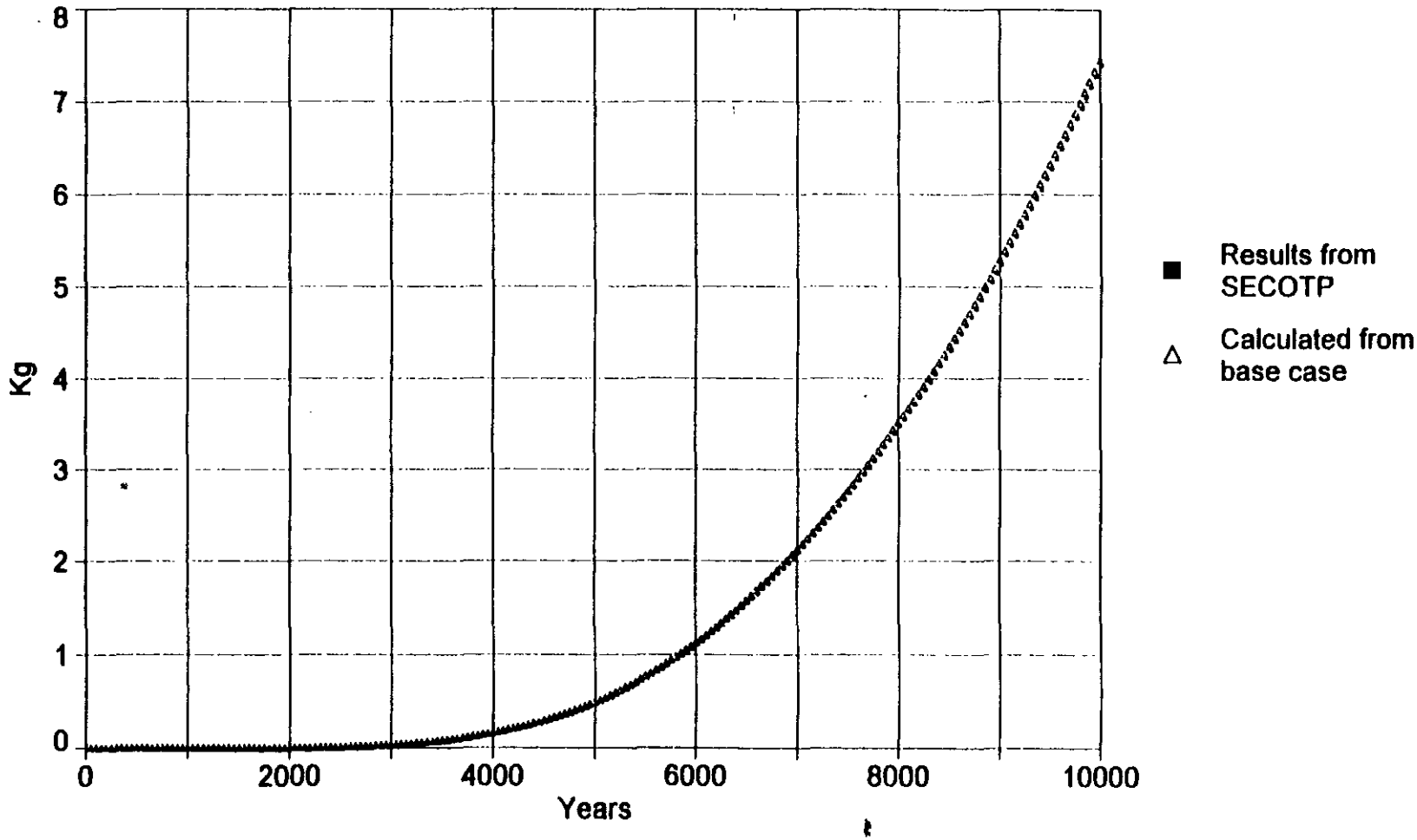

Figure 8

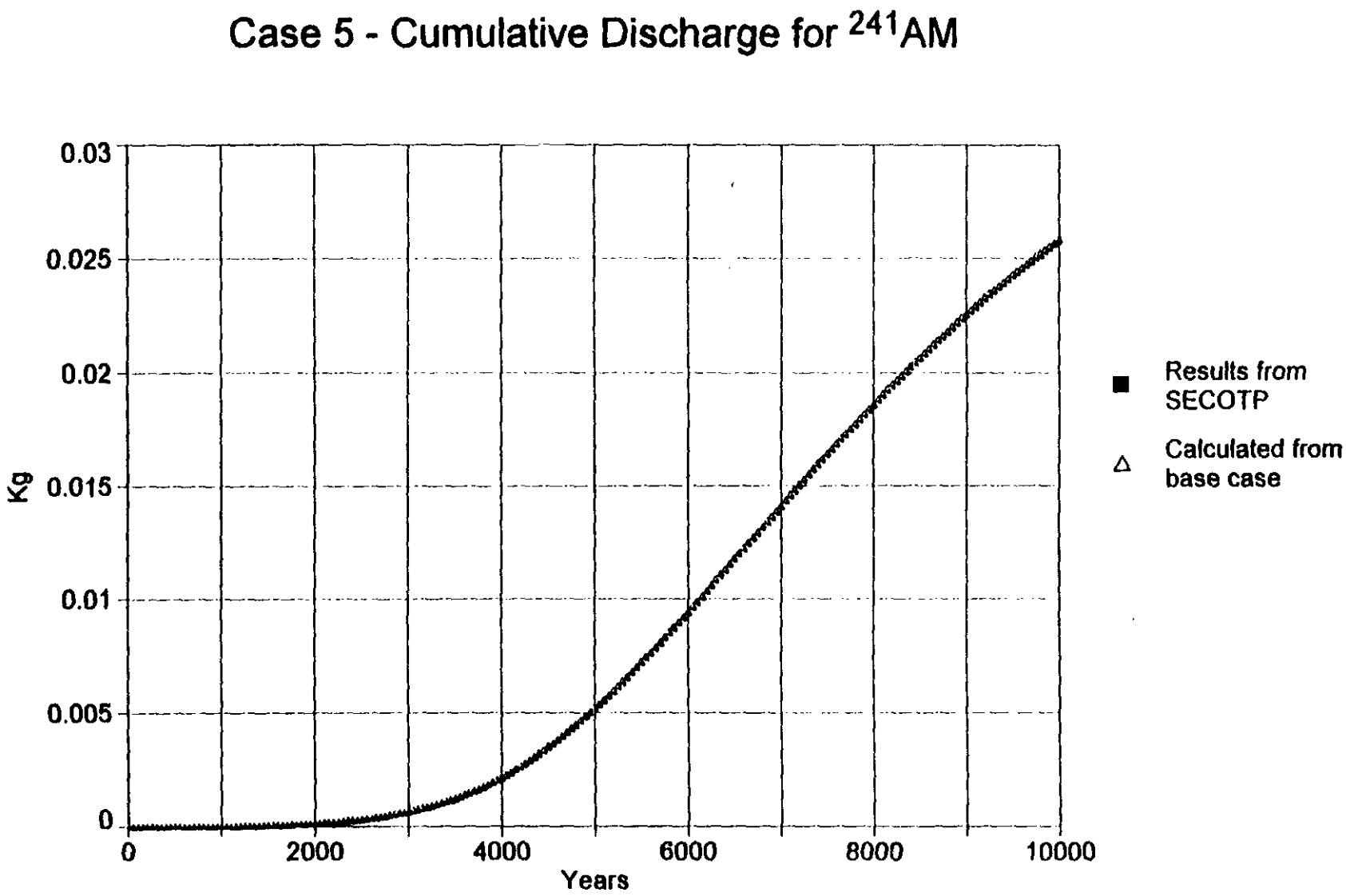
Case 5 - Cumulative Discharge for 241AM
0.03
0.025
0.02
0.015
0.01
0.005
0
Kg
0
2000
4000
6000
8000
10000
Years
Results from SECOTP
Calculated from base case

Figure 9

Case 5 - Cumulative Discharge for ^{233}U

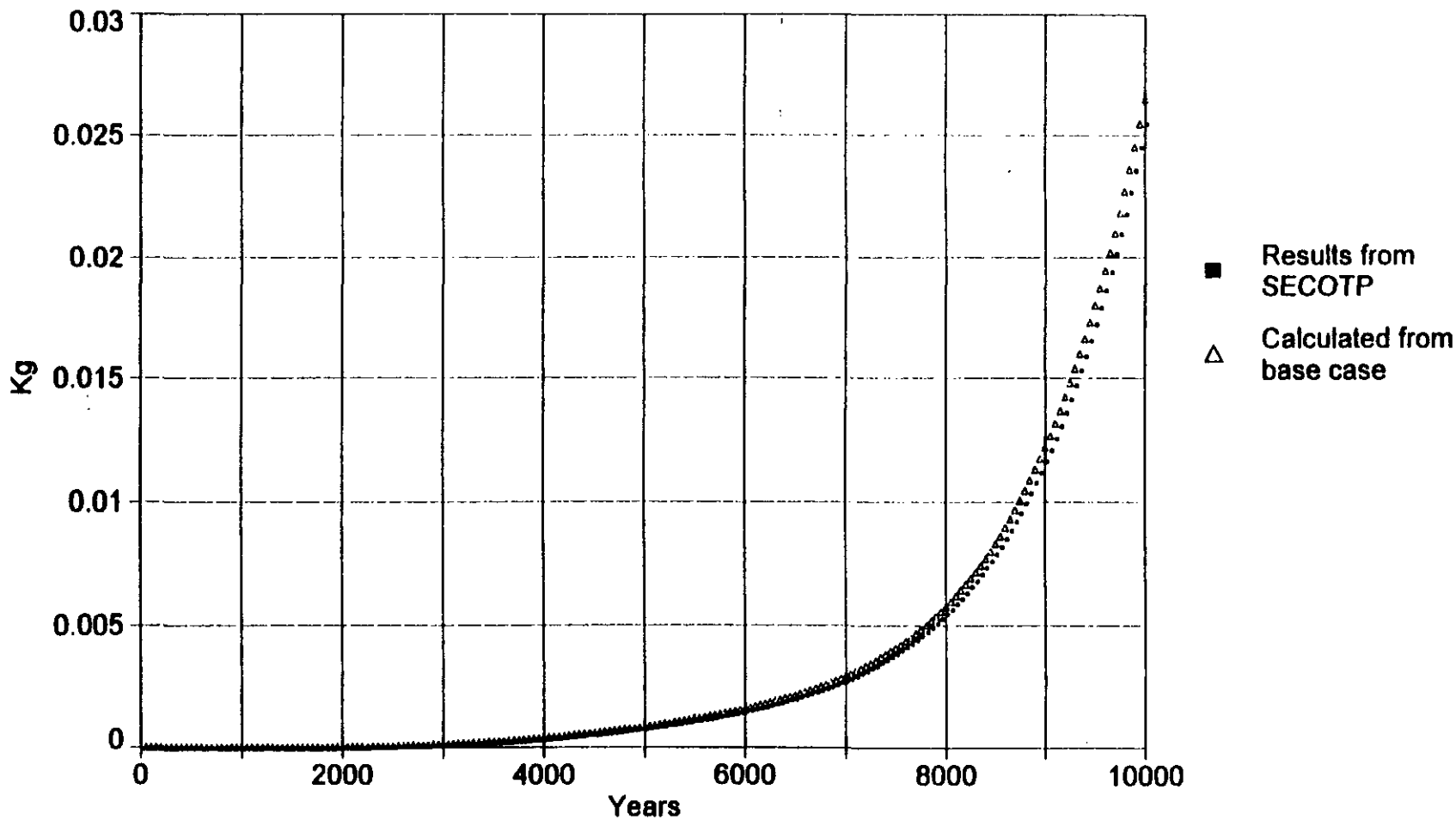

Figure 10

Case 6 - Cumulative Discharge for ^{240}PU

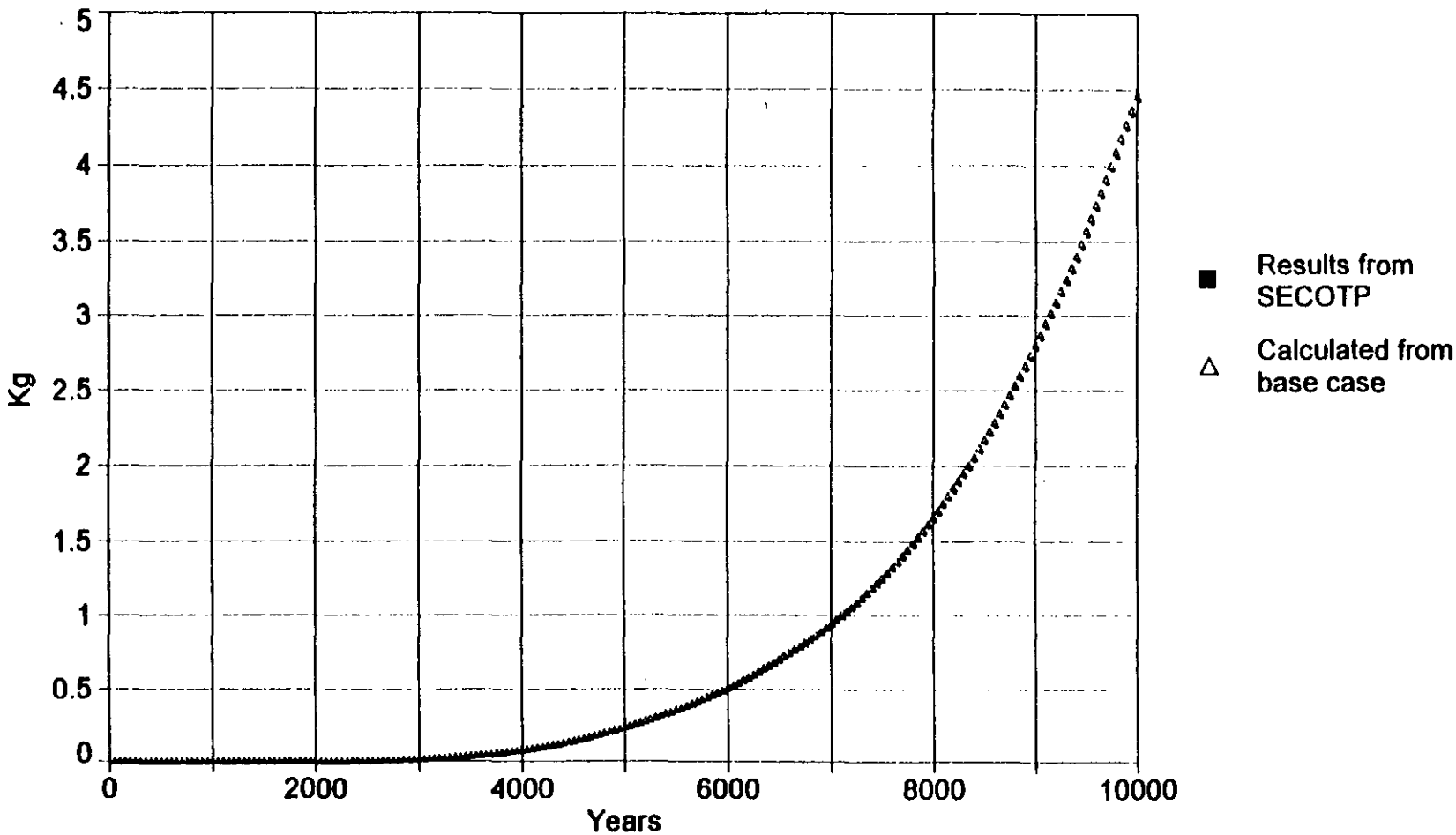

Figure 11

Case 6 - Cumulative Discharge for ^{233}U

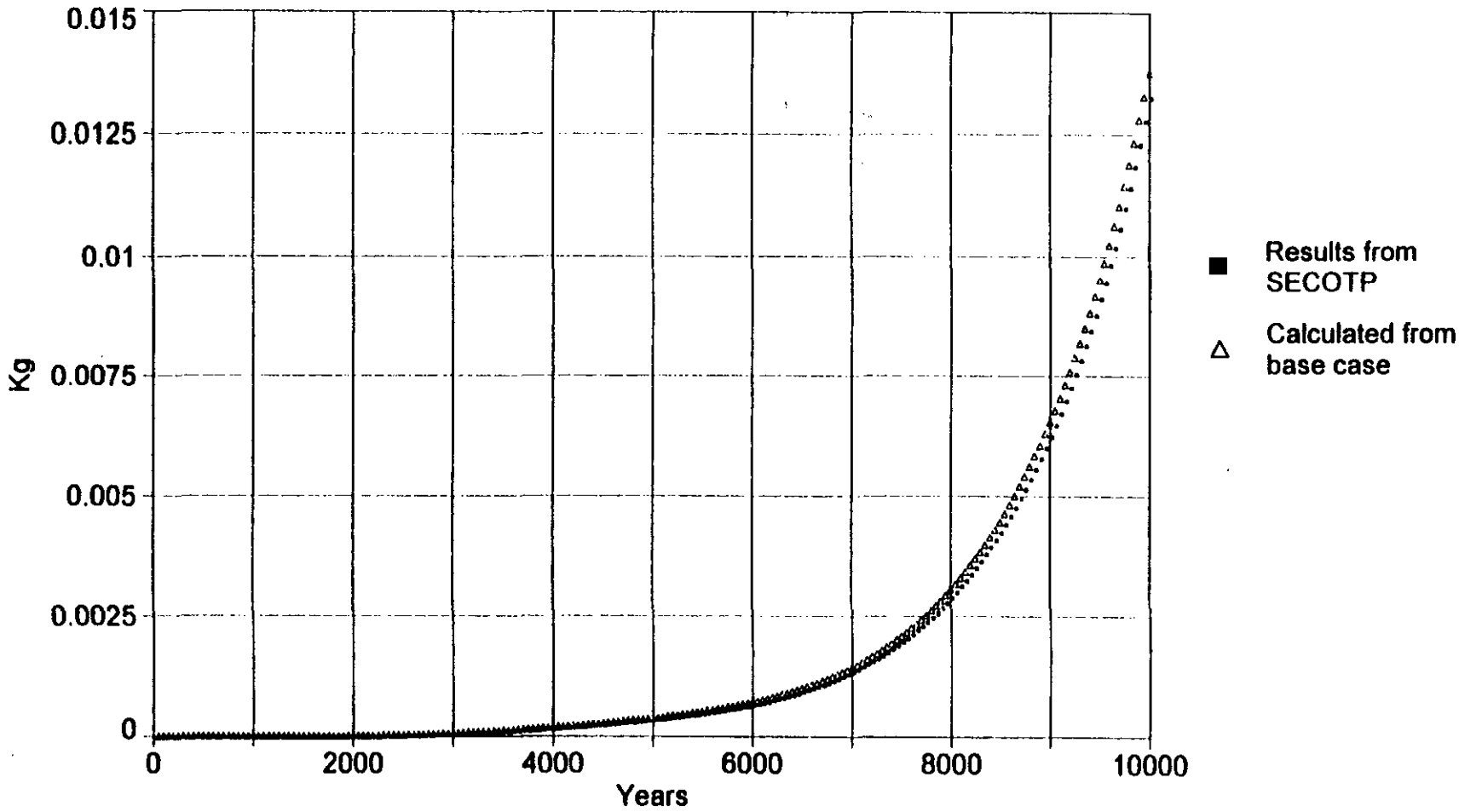

Figure 12

Case 6 - Cumulative Discharge for ^{241}AM

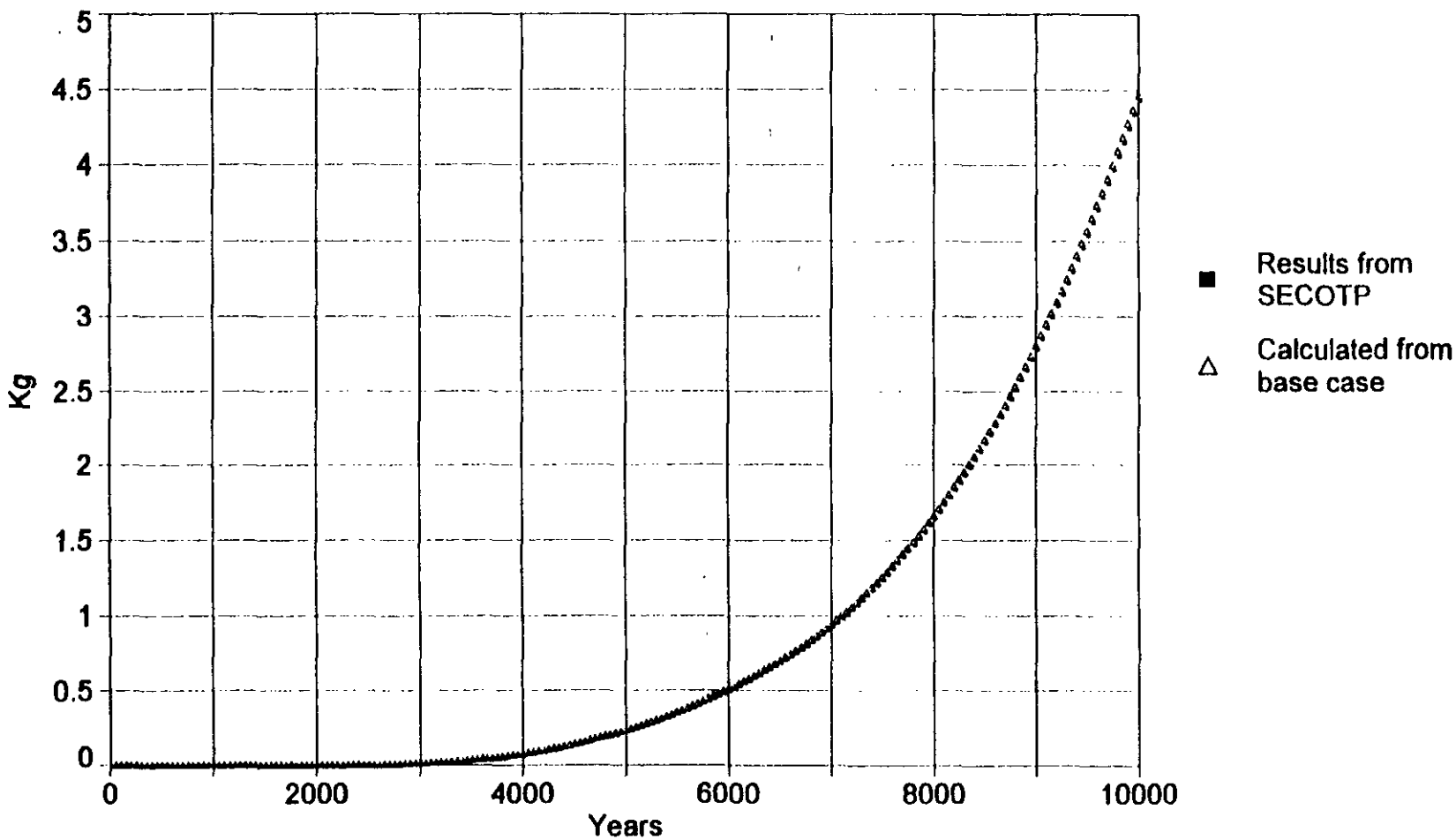

Figure 13

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix CLI

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Long-Term Climate Variability at the Waste Isolation Pilot Plant

CONTRACTOR REPORT

SAND91—7055
Unlimited Release
UC—721

Long-Term Climate Variability at the Waste Isolation Pilot Plant, Southeastern New Mexico, USA

Peter N. Swift
Tech Reps, Inc.
5000 Marble Avenue NE
Albuquerque, NM 87110

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Long-Term Climate Variability at the Waste Isolation Pilot Plant, Southeastern New Mexico, USA*

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ABSTRACT

The United States Department of Energy is developing the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico for the disposal of transuranic wastes generated by defense programs. Because changes in climate during the next 10,000 years (10 ka) may affect performance of the repository, an understanding of long-term climate variability is essential for evaluating regulatory compliance.

Fluctuations in global climate corresponding to glaciation and deglaciation of the northern hemisphere have been regular in both frequency and amplitude for at least 780 ka. Coolest and wettest conditions in the past have occurred at the WIPP during glacial maxima, when the North American ice sheet reached its southern limit roughly 1200 km north of the WIPP and deflected the jet stream southward. Average precipitation in southeastern New Mexico during the last glacial maximum 22 to 18 ka before present (BP) was approximately twice that of the present. Driest conditions (precipitation approximately 90% of present) occurred 6.5 to 4.5 ka BP, after the ice sheet had retreated to its present location. Wet periods of unknown duration have occurred since the retreat of the ice sheet, but none have exceeded glacial conditions. Global climate models suggest that anthropogenic climate changes (i.e., warming caused by an increased greenhouse effect) will not result in an increase in precipitation at the WIPP. The climate of the last glacial maximum is therefore suitable for use as a cooler and wetter limit for variability during the next 10 ka.

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1. Introduction

The Waste Isolation Pilot Plant (WIPP), located 42 km east of Carlsbad, New Mexico (Figure 1), is being evaluated by the United States Department of Energy (DOE) for disposal of transuranic wastes generated since 1970 by defense programs. The repository is excavated approximately 655 m below the ground surface in bedded halite of the Late Permian Salado Formation, deposited approximately 255 million years before the present (255 Ma BP).

Before the WIPP can be used for long-term disposal of transuranic waste, the DOE must demonstrate compliance with the United States Environmental Protection Agency's (EPA) *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Waste* (40 CFR 191) (U.S. EPA, 1985), hereafter referred to as the standard. Although the standard was vacated by a Federal Court of Appeals in 1987 and is undergoing revision, by agreement with the State of New Mexico, the DOE is continuing to evaluate repository performance with respect to the regulation as first promulgated until a new version is available (U.S. DOE and the State of New Mexico, 1981, as modified in 1984 and 1987).

The standard requires that the DOE consider "all significant processes and events that may affect the disposal system" during the 10,000 years (10 ka) following decommissioning. The performance assessment being conducted for the DOE by Sandia National Laboratories is therefore examining, among other things, the likelihood and consequences of long-term changes in climate. Climatic changes have the potential to affect repository performance directly, by altering groundwater recharge and flow in the region, and indirectly, by changing human land-use patterns in the region. Increases in precipitation are of primary concern because they may result in increased groundwater flow and, in the event of a breach of the repository, increased transport of radionuclides to the accessible environment.

2. Modern Climate at the WIPP

At present, the climate at the WIPP is arid to semiarid. Mean annual precipitation at the WIPP has been estimated to be between 28 and 34 cm/yr (Hunter, 1985). At Carlsbad, 100 m lower than the WIPP, 53-yr (1931-1983) annual means for precipitation and temperature are 32 cm/yr and 17.1°C (University of New Mexico, 1989). Short-term variation about the annual means can be considerable, and historic weather data cannot be used to predict long-term climatic shifts. For example, the 105-yr (1878 to 1982) precipitation record from Roswell, 135 km northwest of the WIPP and 60 m

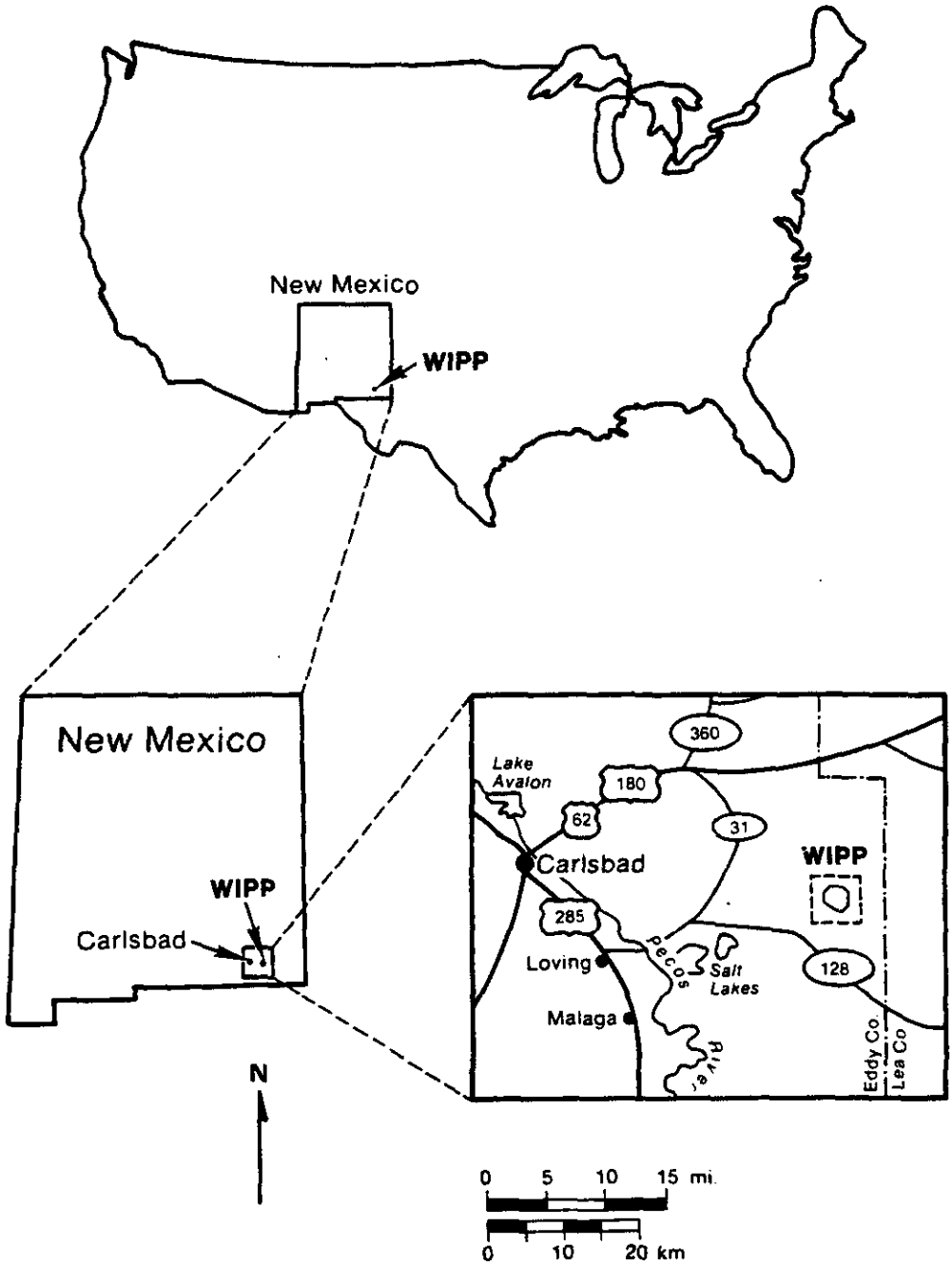

TRI-6342-223-1

Figure 1. Location of the WIPP (after Bertram-Howery and Hunter, 1989).

higher, shows an annual mean of 27 cm/yr with a high of 84 cm/yr and a low of 11 cm/yr (Hunter, 1985).

The climate of southeastern New Mexico is monsoonal: most of the precipitation falls in late summer, when solar warming of the continent creates an atmospheric pressure gradient that draws moist air inland from the Gulf of Mexico (Cole, 1975). The coincidence of precipitation and temperature maxima is typical of a monsoonal climate (Figure 2). Much of the rain falls during localized and often intense summer thunderstorms, and winters are cool and generally dry. Both temperature and precipitation are dependent on elevation, and local climates vary with topography. At lower elevations throughout the region, including the vicinity of the WIPP, potential evaporation greatly exceeds precipitation. Freshwater pan evaporation in the region is estimated to exceed 274 cm/yr (Hunter, 1985). Surface runoff and infiltration of rainwater into the subsurface are limited. Hunter (1985) concluded from a literature review that within the vicinity of the WIPP an average of 96 percent of precipitation is lost to evapotranspiration. Evapotranspiration values may be significantly higher or lower locally.

3. Climatic Change

Presently available long-term climate models are incapable of resolution on the spatial scales required (e.g., Hansen and others, 1988; Mitchell, 1989; Houghton and others, 1990), and it is not realistic to predict the climate of southeastern New Mexico for the next 10 ka. Instead, this report reviews evidence of past climatic changes in the region, and establishes limits on future precipitation based on known and modeled past extremes. Much of the available paleoclimatic data only record long-term average levels of precipitation, and these limits do not reflect the high variability apparent in the modern short-term data. The precipitation record presented here primarily reflects gradual shifts in long-term mean values.

A fundamental assumption, analogous to that made by Spaulding (1985) in a study of climatic variability at the Nevada Test Site, is that climatic extremes of the next 10 ka will not exceed those associated with glaciations and deglaciations that have recurred repeatedly in the northern hemisphere since the late Pliocene (2.5 Ma BP). The possibility that human-induced changes in the composition of the earth's atmosphere may influence future climates complicates projections of this cyclic pattern into the future, but, as presently modeled (e.g., Mitchell, 1989; Houghton and others, 1990), such changes do not appear likely to have a negative effect on the performance of the WIPP. The highest past precipitation levels in southeastern New Mexico,

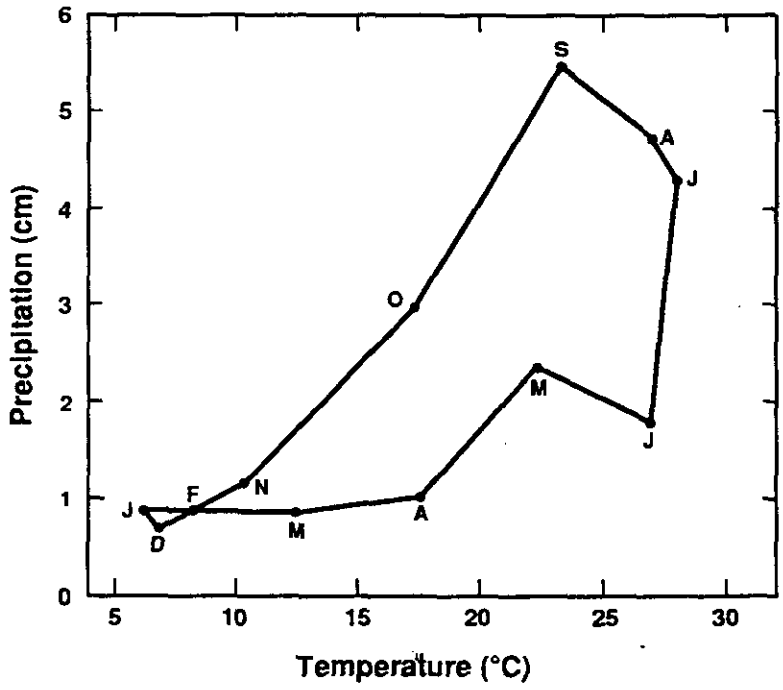

TRI-6342-588-0

Figure 2. Climatograph showing 30-yr (1951-1980) monthly precipitation and temperature means recorded at the Carlsbad, New Mexico airport, approximately 45 km west of the WIPP and 50 m lower (data from NOAA, 1989).

up to twice those of the present, occurred during full-glacial conditions associated with global cooling (e.g., Van Devender and others, 1987; other sources cited below). Presently available greenhouse models, however, predict average equilibrium global warming of 1.8 to 5.2°C for carbon dioxide concentrations twice present levels (Mitchell, 1989; Houghton and other, 1990), a condition that could delay the start of renewed glaciation. Published model predictions of precipitation trends accompanying greenhouse warming are less consistent and less reliable than temperature predictions, but none suggest significantly higher levels of precipitation in southern New Mexico than those of the present (Washington and Meehl, 1984; Wilson and Mitchell, 1987; Schlesinger and Mitchell, 1987; Houghton and others, 1990). Because long-term increases in recharge are improbable without increases in precipitation, the highest-risk climatic change that will be considered here is, therefore, a return to the glacial extremes of the past.

Data that can be used to interpret paleoclimates in southeastern New Mexico and the surrounding region come from a variety of sources, and indicate an alternation of arid and subarid to subhumid climates throughout the Pleistocene. Prior to 18 ka BP, radiometric dates are relatively scarce, and the record is incomplete. From 18 ka BP to the present, however, the climatic record is relatively complete and temporally well constrained by radiocarbon dates. This report cites extensive floral, faunal, and lacustrine data from the region that permit reconstructions of precipitation and temperature during the late Pleistocene and Holocene. These data span the transition from the last full-glacial maximum to the present interglacial period, and, given the global consistency of glacial fluctuations as described below, they can be taken to be broadly representative of extremes for the entire Pleistocene.

4. Variability in Global Climate Over the Last 2.5 Million Years

Core samples of datable marine sediments provide a continuous record that reveals as many as 50 glaciation/deglaciation events in the last 2.5 Ma. Specifically, correlations have been made between major glacial events and variables such as the ratio of $^{18}O/^{16}O$ measured in the remains of calcareous foraminifera and past sea-surface temperatures determined from planktonic assemblages (Ruddiman and Wright, 1987). In addition, glacial cycles have been observed in the past composition of the earth's atmosphere preserved in polar glacial ice (Langway and others, 1985; Jouzel and others, 1987; Barnola and others, 1987) and in a $^{18}O/^{16}O$ record from calcite vein fillings in Nevada (Winograd and others, 1988).

Oxygen isotope ratios from oceanic foraminifera provide the most direct evidence, because they reflect past volumes of glacial ice (Imbrie and others, 1984). Evaporation fractionates ^{18}O and ^{16}O isotopes in water, producing a vapor relatively enriched in ^{16}O and residual seawater relatively enriched in ^{18}O. Glacial ice sheets store large volumes of ^{16}O-enriched meteoric water, thereby preventing the remixing of the two isotope fractions and significantly altering $\delta^{18}O$ values in the world's oceans.* Foraminifera preserve samples of past $\delta^{18}O$ values when they extract oxygen from seawater and incorporate it into calcareous body parts. Abundant fossil remains permit the construction of detailed records such as that shown in Figure 3, covering the last 780 ka. High positive values of $\delta^{18}O$ reflect glacial maxima, and negative values reflect warm interglacial periods. Because the largest volumes of glacial ice were incorporated in the North American sheet, $\delta^{18}O$ fluctuations can be interpreted directly as a first order record of North American glaciation and deglaciation (Mix, 1987; Ruddiman and Wright, 1987). Because the correlation is quantitative, the isotopic record indicates that the most recent glacial event was as severe as any within the last 780 ka. It also indicates that the present value is at or near that of a glacial minimum.

Sea-surface temperature records, although not as closely tied to glacial events, show the same alternating pattern. Temperatures at the surface of northern hemisphere oceans, as determined from the fossil assemblages of planktonic foraminiferal species, were measurably colder during glaciation and warmer during interglacial periods (Ruddiman, 1987).

Samples from the ice sheets of Greenland and Antarctica and calcite vein fillings in Nevada provide independent confirmation of the oceanic data (Langway and others, 1985; Jouzel and others, 1987; Barnola and others, 1987; Winograd and others, 1988). Glacial ice preserves $\delta^{18}O$ and δD values of the precipitation that formed the ice, and, because fractionation of the isotopes is temperature dependent, fluctuations can be interpreted quantitatively as changes in local mean temperature. Bubbles of air trapped within the ice can also be sampled to give a measure of past CO_2 concentrations in the atmosphere, which, because of the importance of CO_2 in the earth's greenhouse effect, correlate well with the isotopic temperature record. Figure 4 shows

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* By convention, $^{18}O/^{16}O$ ratios are reported as:

$$\delta^{18}O = 1000 \times \frac{(^{18}O/^{16}O_{sample} - {}^{18}O/^{16}O_{reference})}{^{18}O/^{16}O_{reference}}$$

Deuterium/hydrogen ratios (D/H) are similarly reported as δD values.

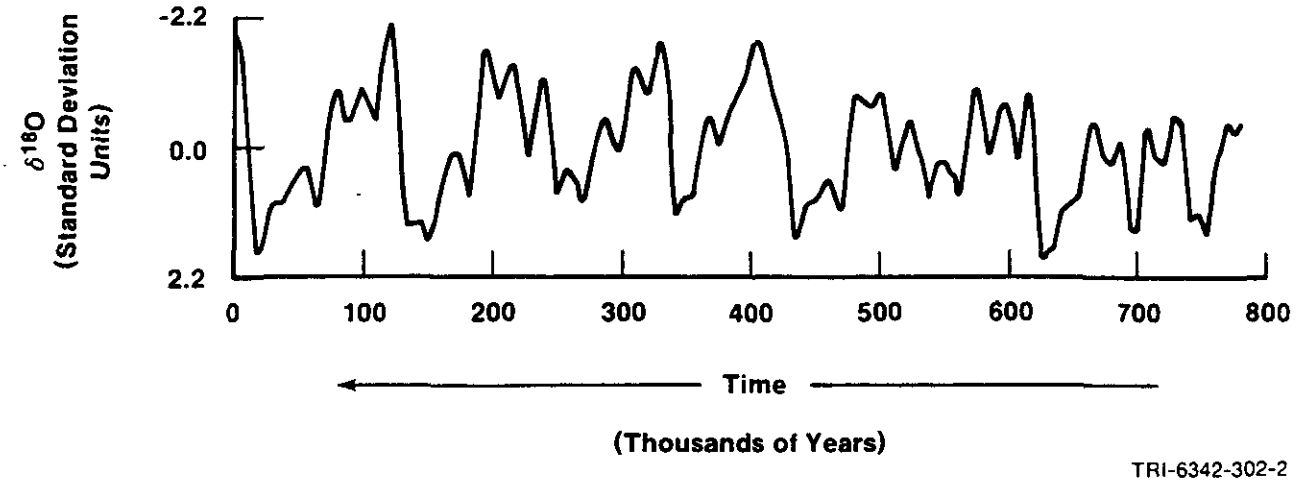

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Figure 3. Foraminiferal $\delta^{18}0$ record of the last 780,000 years. Curve reflects $\delta^{18}0$ variations from five deep-sea core samples. Data have been normalized, stacked, and smoothed with a nine-point Gaussian filter (Imbrie, and others, 1984).

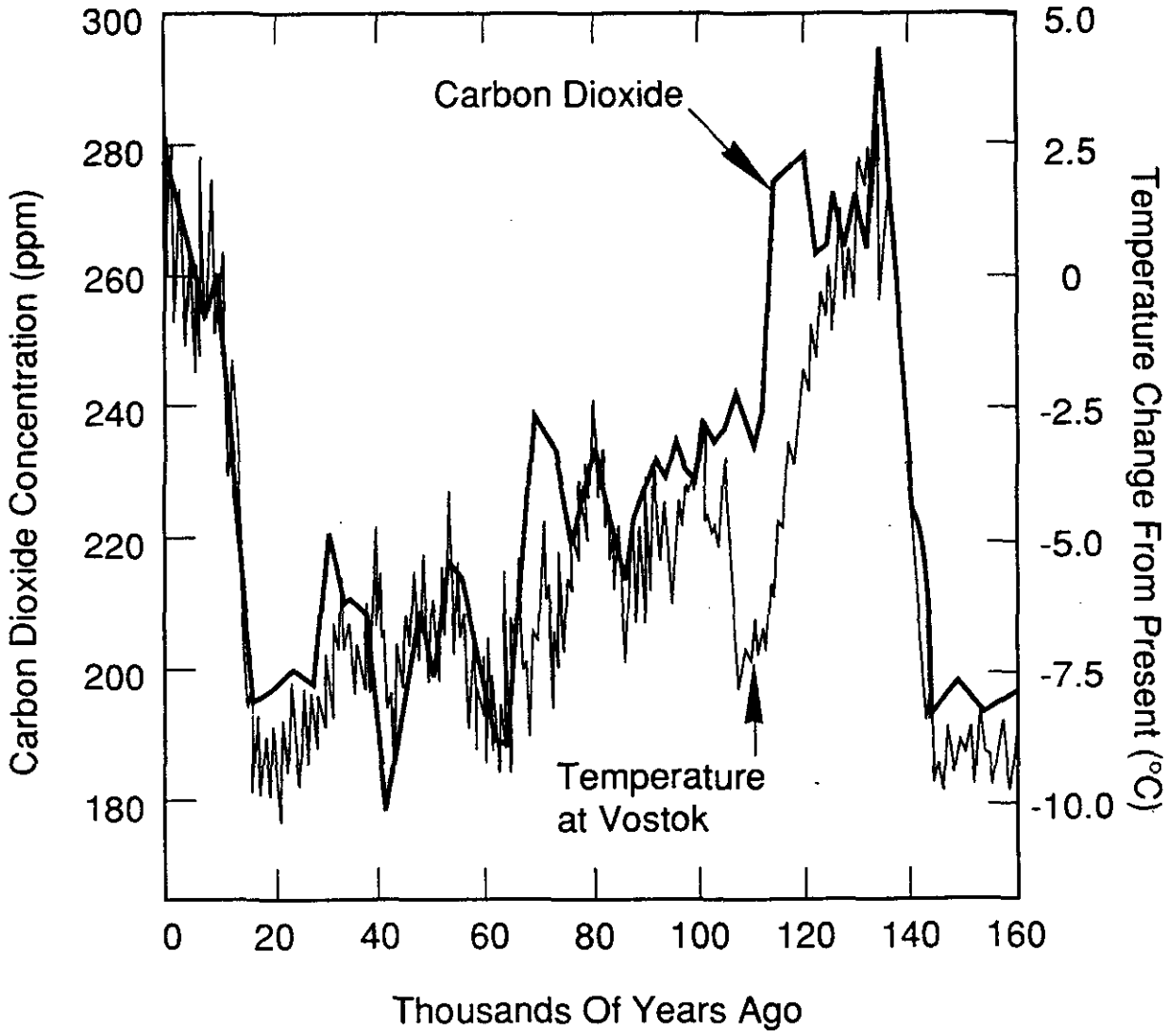

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Figure 4. Atmospheric CO_2 concentration and δD temperature record from the Vostok, Antartica, ice core for the last 160 ka (modified from Schneider, 1990; after Barnola and others, 1987).

the 160-ka record of CO_2 concentration and temperature as determined from the D/H ratio at Vostok in East Antarctica. With some minor discrepancies, the two curves reveal the same basic glacial chronology visible in the last 160 ka of the oceanic $\delta^{18}O$ record shown in Figure 3. The $\delta^{18}O$ record from 50 ka to 310 ka BP from calcite vein fillings in Devils Hole, Nevada, reflects changes in local surface temperature as well as other, less well quantified, factors, including groundwater travel time. This record also shows a chronology similar to that of Figure 3, although peaks in the calcite curve are shifted toward increasingly older times earlier in the record relative to the oceanic curve. The reason for this phase shift, which reaches 28 ka at 272 ka BP, is not known (Winograd and others, 1988).

5. Stability of Glacial Cycles

The causes of glaciation and deglaciation are complex and not fully understood (Ruddiman and Wright, 1987), but the strong periodicity of the isotopic record indicates that climatic alternations have been systematic in the past. Spectral analysis of the foraminiferal $\delta^{18}O$ curve for the last 780 ka shows that within that time the primary control on the periodicity of glacial events has been variation in global insolation caused by irregularities in the earth's orbit (Figure 5). Observed periods of 19, 23, 41, and 100 ka in the oceanic $\delta^{18}O$ curve correspond to calculated periods of northern hemisphere summer insolation minima of 19 and 23 ka related to the precession of the earth's axis, 41 ka related to the tilt of earth's axis, and 94, 125, and 413 ka related to the eccentricity of the earth's orbit (Milankovitch, 1941; Hays and others, 1976; Imbrie and others, 1984; Imbrie, 1985). Calculations based on astronomical observations indicate that orbital parameters have not changed significantly in the last 5 Ma (Berger, 1984), and geological evidence suggests they may have been stable for as long as 300 Ma (Anderson, 1984; Heckel, 1986).

Longer-term global climatic changes, such as the beginning of the present pattern of glaciation and deglaciation 2.5 Ma BP, have been attributed to changes in the configuration of the earth's continents, which in turn controls both the potential distribution of ice sheets and global circulation patterns (e.g., Crowell and Frakes, 1970; Caputo and Crowell, 1985; Crowley and others, 1986; Hyde and others, 1990). Continental masses move at plate-tectonic rates of centimeters per year, several orders of magnitude too low to affect glacial processes within the next 10 ka. Vertical uplift or subsidence of large continental regions may also affect global climate by changing circulation patterns (e.g., Ruddiman and Kutzbach, 1989), but, again, maximum uplift rates are at least an order of magnitude too low to change present circulation patterns within the next 10 ka.

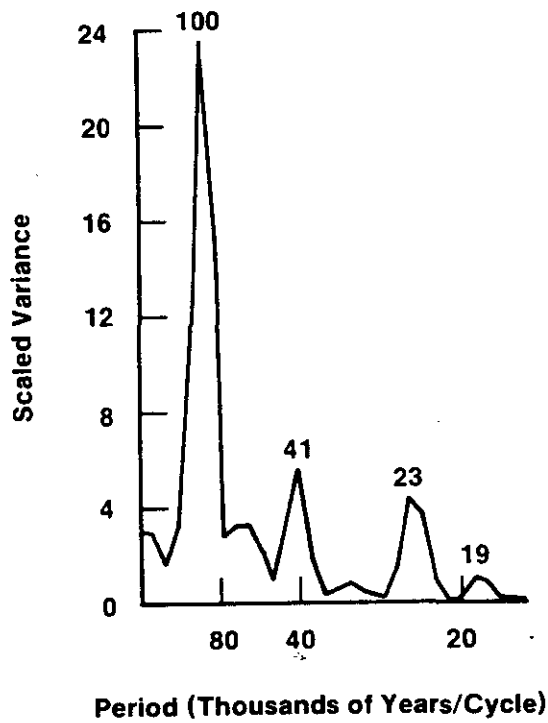

Figure 5. Spectral analysis of the foraminiferal $\delta^{18}0$ record presented in Figure 3, showing periodicity of glaciation and deglaciation (after Imbrie, 1985).

The long-term pattern of the cycles of glaciation and deglaciation provides the basis for concluding that climatic extremes of the next 10 ka will remain within past limits. The relative amplitudes of past glacial cycles (Figure 3) imply that future glaciations will be no more severe than the last one. The periodicity of the pattern indicates that although glacial minima such as that of the present are relatively brief, glacial advances are, in general, slow and the next full maximum will not occur for many tens of thousands of years. Predictions about the precise timing of future glacial events are not straightforward, however. Higher resolution records, such as those available from polar ice cores, show that some glacial advances can occur relatively rapidly. Modeling of glacial processes is complicated by uncertainties about feedback processes involved in the growth of ice sheets, but extrapolation of the isotopic curve of Figure 3 using a relatively simple model for nonlinear climate response to insolation change suggests that, in the absence of anthropogenic effects, the next full glacial maximum could occur in approximately 60 ka (Imbrie and Imbrie, 1980). These observations, combined with the climatic data discussed below, justify the choice of the late Pleistocene full-glacial climate as a conservative upper limit for precipitation during the next 10 ka.

6. Pleistocene and Holocene Climates of Southeastern New Mexico

Early and middle Pleistocene paleoclimatic data for southeastern New Mexico and the surrounding region are incomplete, and permit neither continuous reconstructions of paleoclimates nor direct correlations between climate and glaciation prior to the last glacial maximum 22 to 18 ka BP. Stratigraphic and pedologic data from several locations (Figure 6), however, indicate that cyclical alternation of wetter and drier climates in southeastern New Mexico had begun by the early Pleistocene. Fluvial gravels in the Gatuña Formation exposed in the Pecos River Valley of eastern New Mexico suggest relatively wetter conditions 1.4 Ma BP and again 600 ka BP (Bachman, 1987). The Mescalero caliche, exposed locally over much of southeastern New Mexico, has been interpreted as indicating relatively drier conditions 510 ka BP (Lambert and Carter, 1987), and loosely dated spring deposits in Nash Draw west of the WIPP imply wetter conditions again later in the Pleistocene (Bachman, 1981, 1987). The Blackwater Draw Formation of the southern High Plains of eastern New Mexico and western Texas, time-correlative to both the Gatuña Formation and the Mescalero caliche, contains alternating soil and eolian sand horizons that show at least six climatic cycles beginning more than 1.4 Ma BP and continuing to the present (Holliday, 1989a). The duration, frequency, and total number of Pleistocene climatic cycles in southeastern New Mexico have not been established.

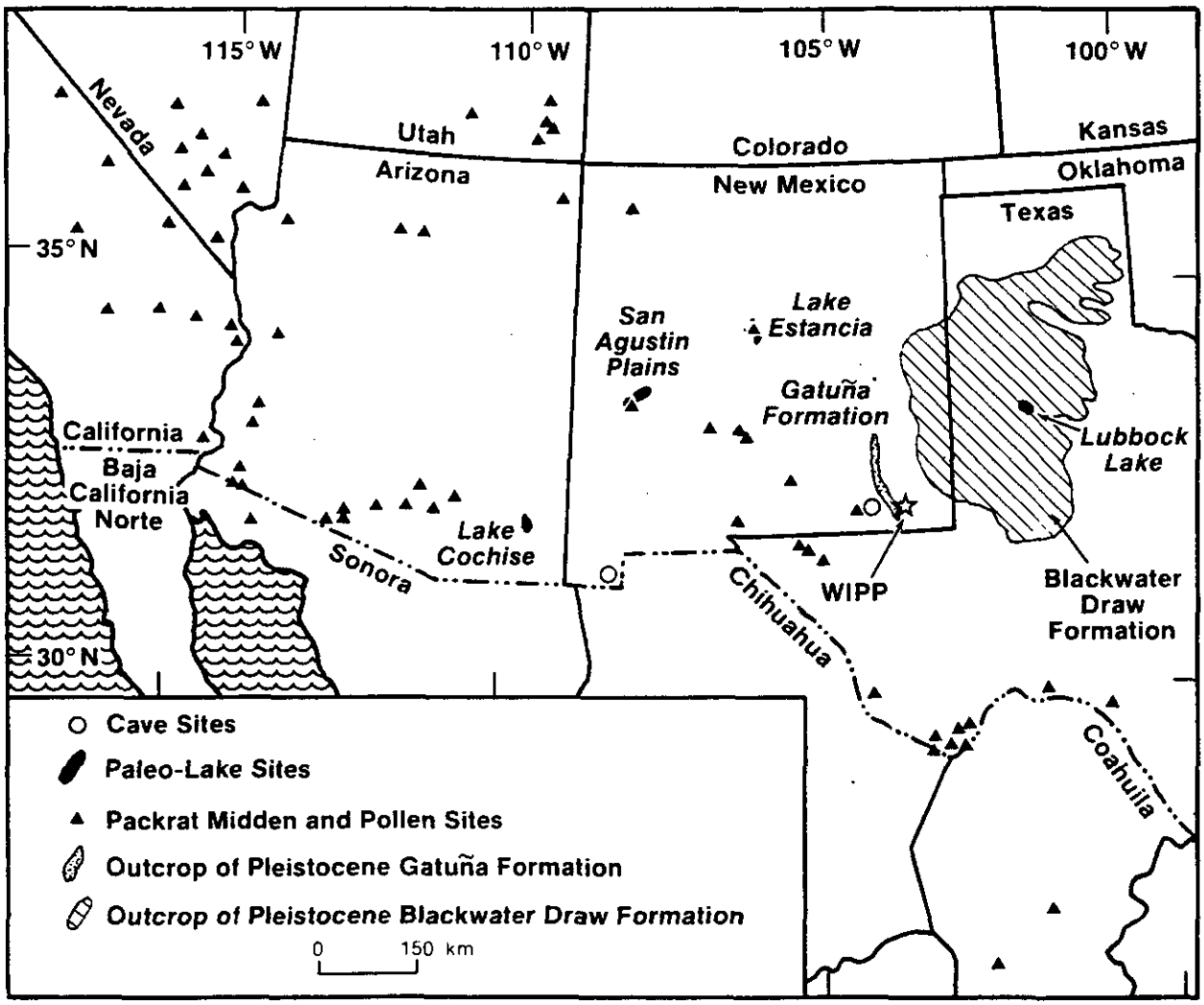

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Figure 6. Location map for paleoclimate data. Data from Bachman (1981); Markgraf and others (1983); Harris (1987); Pierce (1987); Van Devender and others (1987); Waters (1989); Bachhuber (1989); Holliday (1989a); Van Devender (1990); Allen (1991); Phillips and others (1992).

Data used to construct the more detailed climatic record for the latest Pleistocene and Holocene come from multiple lines of evidence dated primarily using carbon-14 techniques. Packrat middens examined at sites throughout the southwestern United States, including locations in southeastern New Mexico, preserve local plant communities and, in some cases, insect remains (Van Devender, 1980, 1990; Van Devender and others, 1984, 1987; Elias, 1987; Elias and Van Devender, 1990). Pollen assemblages have been analyzed from lacustrine deposits in western New Mexico, western Texas, and other locations in the southwestern United States (Martin and Mehringer, 1965; Markgraf and others, 1984; Bryant and Holloway, 1985; Van Devender and others, 1987). Faunal data come from gastropod assemblages from western Texas (Pierce, 1987), ostracode assemblages from western New Mexico (Markgraf and others, 1984; Forester, 1987; Phillips and others, 1992), and vertebrate remains from caves in southern New Mexico (Harris, 1987, 1988). Stable-isotope data are available from ostracodes in western New Mexico (Phillips and others, 1992) and groundwater samples in northwestern New Mexico (Phillips and others, 1986). Paleo-lake level data are available from sites throughout the southwestern United States (Reeves, 1973; Smith and Anderson, 1982; Markgraf and others, 1983, 1984; Benson and Thompson, 1987; Holliday and Allen, 1987; Bachhuber, 1989; Waters, 1989; Wells and others, 1989; Enzel and others, 1989; Benson and others, 1990; Allen, 1991). Figure 6 shows the locations of key sites discussed here and in the references cited.

Because decreases in temperature and increases in precipitation produce similar environmental changes, not all data cited uniquely require the paleoclimatic interpretation presented in this report (Figure 7). For example, lake-level increases can, in theory, result solely from decreased evaporation at lower temperatures. Interpretations drawn individually from each of the data sets are consistent with the overall trends shown in Figure 7, however, and the pattern of change is confirmed by global general circulation climate models (Kutzbach and Guetter, 1986; COHMAP Members, 1988). Furthermore, specific floral and faunal assemblages are sufficiently sensitive to precipitation and temperature effects to distinguish between the two (e.g., Van Devender and others, 1987; Pierce, 1987; Van Devender; 1990). The paleoclimates described here are those that best explain data from all sources.

Prior to the last glacial maximum 22 to 18 ka BP, evidence from mid-Wisconsin faunal assemblages in caves in southern New Mexico, including the presence of extralimital species such as the desert tortoise that are now restricted to warmer climates, suggests warm summers and mild, relatively dry winters (Harris, 1987, 1988). Lacustrine evidence confirms the interpretation that conditions prior to and during the glacial advance that

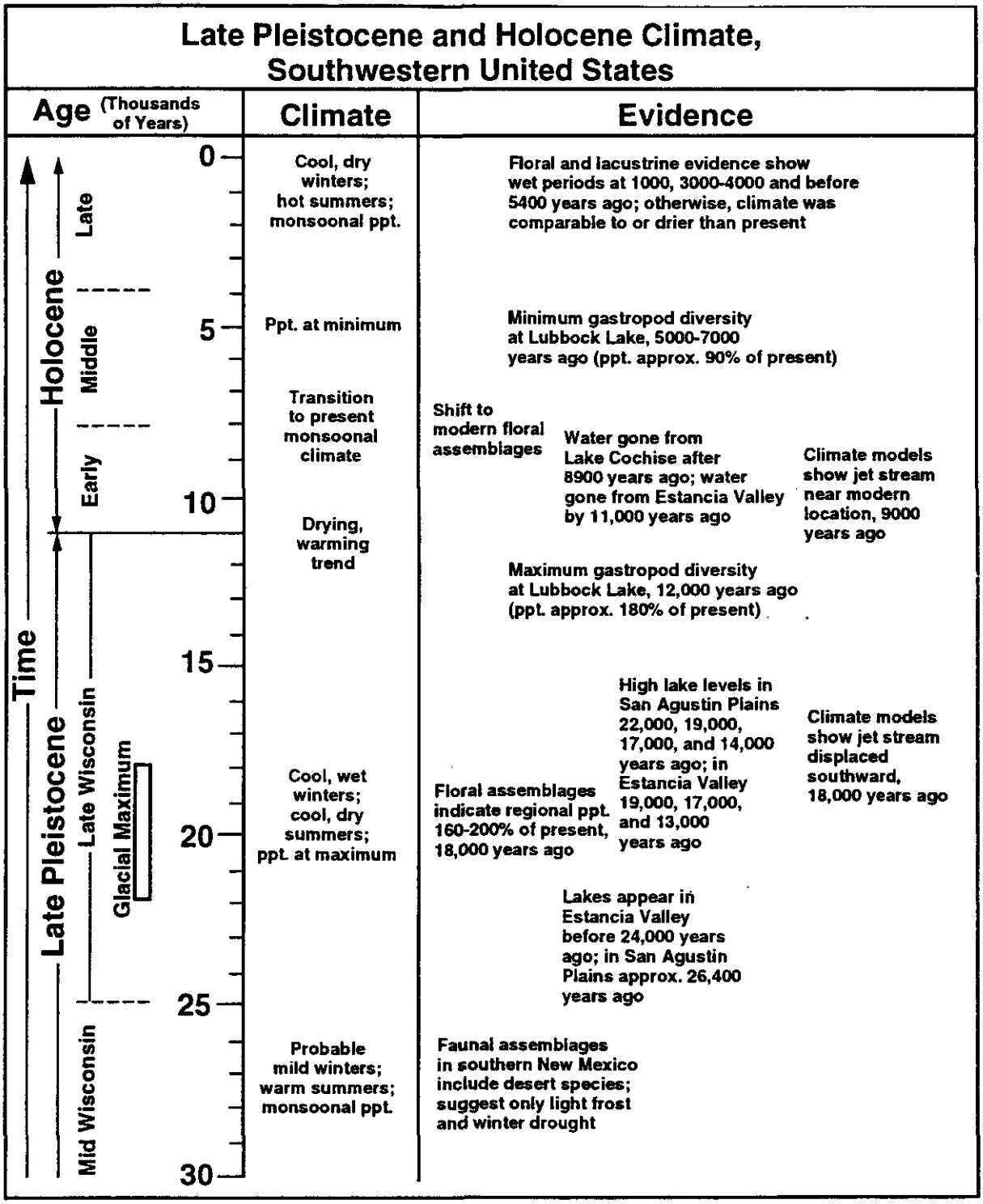

Figure 7. Late Pleistocene and Holocene climate, southwestern United States. Time scale after Van Devender and others (1987). Climate references cited in text.

were generally drier than those at the glacial maximum. Permanent water did not appear in what was later to be a major lake in the Estancia Valley in central New Mexico until sometime before 24 ka BP (Bachhuber, 1989). Late-Pleistocene lake levels in the San Agustin Plains in western New Mexico remained low until approximately 26.4 ka BP, and the $\delta^{18}O$ record from ostracode shells suggests that mean annual temperatures at that location did not decrease significantly until approximately 22 ka BP (Phillips and others, 1992).

Ample floral and lacustrine evidence documents cooler and wetter conditions in southeastern New Mexico and the surrounding region during the glacial peak (Van Devender and others, 1987; Pierce, 1987; Bachhuber, 1989; Allen, 1991; Phillips and others, 1992). These changes were not caused by the immediate proximity of glacial ice. None of the Pleistocene continental glaciations advanced farther southwest than northeastern Kansas, and the most recent, late Wisconsin, ice sheet reached its limit in South Dakota, roughly 1200 km from the WIPP (Andrews, 1987). Discontinuous alpine glaciers formed at the highest elevations throughout the Rocky Mountains, but these isolated ice masses were symptoms, rather than causes, of cooler and wetter conditions, and had little influence on regional climate at lower elevations. The closest such glacier to the WIPP was on the northeast face of Sierra Blanca Peak in the Sacramento Mountains, 220 km to the northwest (Richmond, 1962).

Global climate models indicate that the dominant glacial effect in southeastern New Mexico was the disruption and southward displacement of the westerly jet stream by the physical mass of the ice sheet to the north (Figure 8) (Manabe and Broccoli, 1985; Kutzbach and Guetter, 1986; COHMAP members, 1988). At the glacial peak, climate models show that major Pacific storm systems followed the jet stream across New Mexico and the southern Rocky Mountains, and winters were wetter and longer than either at the present or during the previous interglacial period.

Field evidence does not support the suggestion (Galloway, 1970, 1983; Brakenridge, 1978) that higher lake levels and changed faunal and floral assemblages at the glacial maximum could have resulted solely from lowered temperatures. Plant communities indicate that, regionally, the decrease in mean annual temperatures below present values was significantly less than the 7 to 12°C required by cold and dry climate models (Van Devender and others, 1987; Van Devender, 1990). Interpretation of stable-isotope data from groundwater samples from northwestern New Mexico suggest mean annual temperatures were 5 to 7°C colder than at present at that location (Phillips and others, 1986). Isotopic data from ostracode shells in the San Agustin Plains suggest mean annual temperatures there may have been 8.3°C colder than

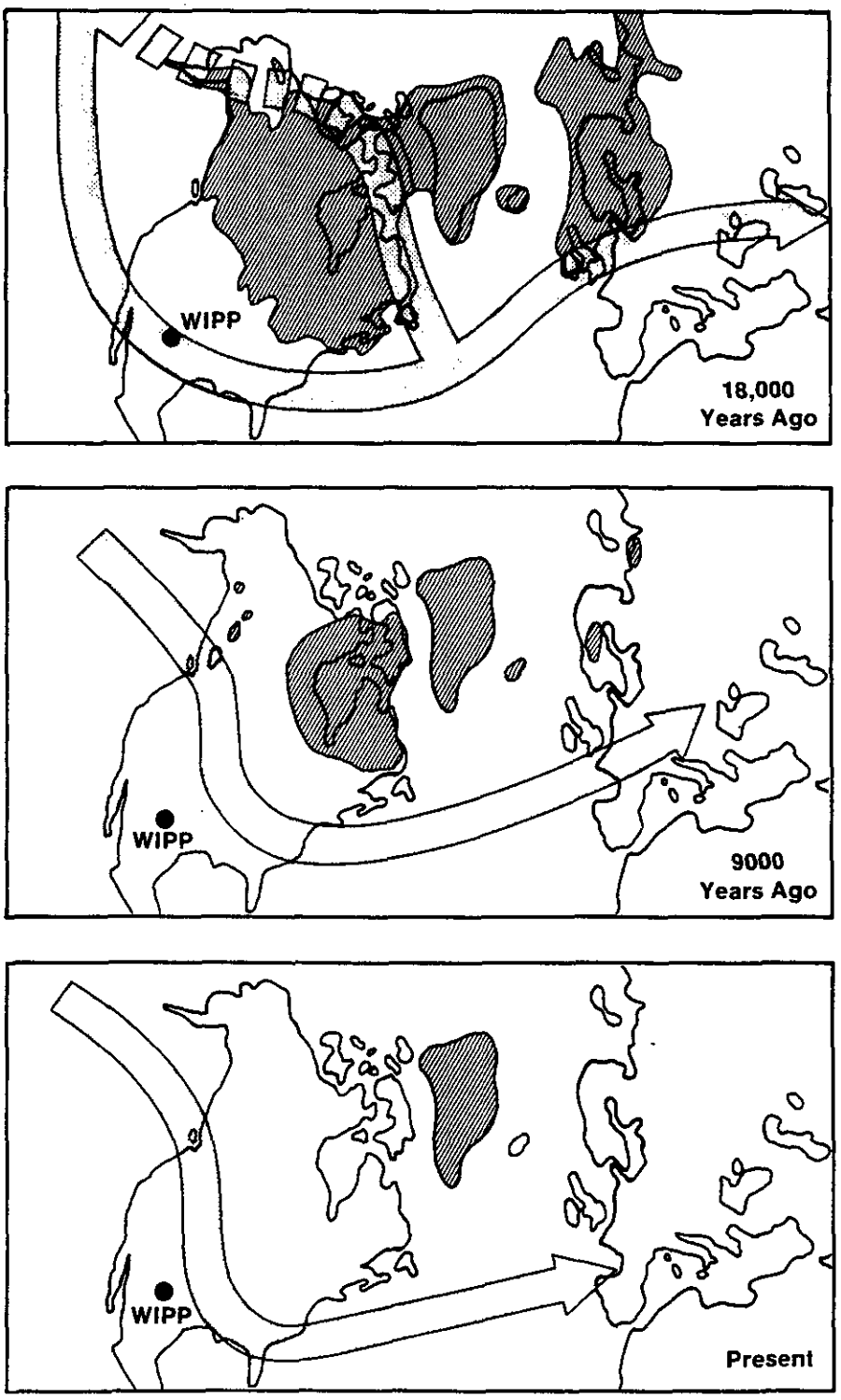

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Figure 8. Distribution of northern hemisphere ice sheets and modeled position of jet stream at 18 ka BP, and present (from COHMAP Members, 1988). Ice shown with dark pattern, jet stream shown with arrow (broken where disrupted or weak).

at present at approximately 21 ka BP, but hydrologic modeling of the basin indicates lake levels were controlled by precipitation rather than evaporation throughout the glacial advance and retreat (Phillips and others, 1992). Gastropod assemblages at Lubbock Lake in western Texas suggest mean annual temperatures 5°C below present values (Pierce, 1987). High water levels in playas in western Texas reflect an increase in runoff best explained by substantially higher levels of precipitation (Reeves, 1973).

Floral and faunal evidence taken together indicate that mean annual precipitation throughout the region at the last glacial maximum was 60 to 100 percent more than today (Spaulding and Graumlich, 1986; Pierce, 1987; Van Devender and others, 1987). Floral evidence also suggests that winters may have continued to be relatively mild, perhaps because the glacial mass blocked the southward movement of arctic air. Summers at the glacial maximum were cooler and drier than at present, without a strongly developed monsoon (Van Devender and others, 1987). Piñons, oaks, and junipers grew at lower elevations throughout southern New Mexico (Van Devender and others, 1987; Van Devender, 1990), probably including the vicinity of the WIPP.

According to climatic modeling, the jet stream shifted northward following the gradual retreat of the ice sheet after 18 ka BP (Figure 8), and the climate responded accordingly. By the Pleistocene/Holocene boundary approximately 11 ka BP, conditions were significantly warmer and drier than previously, although still dominated by winter storms and still wetter than today (Van Devender and others, 1987). Major decreases in total precipitation and the shift toward the modern monsoonal climate did not occur until the margins of the ice sheet had retreated into northeastern Canada in the early Holocene.

Evidence for the late Pleistocene and early Holocene drying trend comes from several sources. In contrast to the northern Great Basin, where lake levels continued to rise until between 15 and 13.5 ka BP (Benson and others, 1990), lake levels in southern New Mexico and the surrounding region decreased following the glacial maximum. Permanent water disappeared from late-Pleistocene lakes in the Estancia Valley between 12 and 11 ka BP, following a series of fluctuations in lake levels with progressively lower high stands at approximately 19, 17, and 13 ka BP (Allen, 1991). Lake Cochise (the modern Willcox Playa) in southeastern Arizona was dry after 8.5 ka BP, following two high stands prior to 14 ka BP and a third between 14 and 13 ka BP (Waters, 1989). Modeling of lake levels in the San Agustin Plains shows high stands at progressively lower elevations at approximately 22, 19, 17, and 14 ka BP (Phillips and others, 1992). Water remained in lakes in the San Agustin Plains until 5 ka BP, but ostracode assemblages suggest an increase in salinity by 8 ka BP, and the pollen record shows a gradual shift

at that location from a spruce-pine forest 18 to 15 ka BP to a juniper-pine forest by 10 ka BP (Markgraf and others, 1984). Packrat middens in Eddy County, New Mexico, indicate that desert-grassland and desert-scrub communities predominated at lower elevations between 10.5 and 10 ka BP (Van Devender, 1980). Soil studies indicate drier conditions at Lubbock Lake after 10 ka BP, although marshes and small lakes persisted at the site until the construction of a dam and reservoir in 1936 (Holliday and Allen, 1987). Based on a decrease in diversity of both terrestrial and aquatic gastropod species, Pierce (1987) estimated a drop in annual precipitation at Lubbock Lake from a high of 80 cm/yr (nearly twice the modern level at that location of 45 cm/yr) at 12 ka BP to 40 cm/yr by 7 ka BP.

Coincident with this decrease in precipitation, evidence from vole remains recovered from caves in southern New Mexico (Harris, 1988) and from plant communities throughout the southwestern United States (Van Devender and others, 1987) indicates a rise in summer temperatures. Mean annual temperatures interpreted from the isotopic composition of groundwater samples from northwestern New Mexico also show a sharp rise in the early Holocene (Phillips and others, 1986).

By middle-Holocene time, the climate was similar to that of the present, with hot, monsoon-dominated summers and cold, dry winters. The pattern has persisted to the present, but not without significant local variations. Soil studies show the southern High Plains were drier from 6.5 to 4.5 ka BP (Holliday, 1989b) than before or since. Gastropod data from Lubbock Lake indicate the driest conditions from 7 to 5 ka BP (precipitation approximately 90 percent of present, mean annual temperature 2.5°C higher than present), with a cooler and wetter period at 1 ka BP (precipitation approximately 145 percent of present, mean annual temperature 2.5°C lower than present) (Pierce, 1987). Plant assemblages from southwestern Arizona suggest steadily decreasing precipitation from the middle Holocene to the present, except for a brief wet period around 990 years ago (Van Devender and others, 1987). Stratigraphic work at Lake Cochise shows two mid-Holocene lake stands, one near or before 5.4 ka BP and one between or before 3 to 4 ka BP, but both were relatively short-lived, and neither reached the maximum depths of the late-Pleistocene high stand that existed before 14 ka BP (Waters, 1989).

Precipitation maxima during these Holocene wet periods were less in both magnitude and duration than those of the late Pleistocene. Enzel and others (1989) observed comparable Holocene wet periods recorded in playa deposits in the Mojave Desert 3620 ± 70 and 390 ± 90 years ago, and related them to short-term changes in global circulation patterns that resulted in increased winter storm activity in the region. Historical records over the last several hundred years indicate numerous lower intensity climatic

fluctuations, some too short in duration to affect floral and faunal assemblages, which may also be the result of temporary changes in global circulation (Neilson, 1986). Sunspot cycles and the related changes in the amount of energy emitted by the sun have been linked to historical climatic changes elsewhere in the world (e.g., Lamb, 1972), but the validity of the correlation is uncertain (Robock, 1979; Stuiver, 1980). Correlations also have been proposed between volcanic activity and climatic change (Robock, 1979; Palais and Sigurdsson, 1989; Bryson, 1989). In general, however, causes for past short-term changes are unknown, and it is impossible at present to predict the amplitude or frequency of recurrence. Despite this uncertainty, the past record does support the conclusion that future short-term fluctuations in southeastern New Mexico will not be as severe as the long-term climatic changes created by major ice sheets in the northern hemisphere. Full-glacial conditions remain a conservative upper limit for mean annual precipitation at the WIPP during the next 10 ka.

7. Climatic Implications of Data from WIPP Groundwater Samples

Isotopic data from groundwater samples collected in the vicinity of the WIPP from the Late Permian Rustler and Dewey Lake Formations that overlie the Salado Formation are generally consistent with the climatic changes described above. Lambert (1986) and Lambert and Harvey (1987) concluded that although deuterium/hydrogen and $^{18}O/^{16}O$ ratios indicate a meteoric origin for water in the confined aquifers, they are sufficiently distinct from modern surface water values to suggest that the contribution of modern recharge to the system is slight. Chapman (1986) disagreed with this interpretation, noting similar ratios in the presumably young waters of the Roswell Artesian Basin immediately to the north, and she concluded that stable-isotope data from the WIPP area do not permit definitive interpretations about the age of the groundwater. Tritium data are less ambiguous. Low tritium levels in all WIPP-area samples indicate minimal contributions from the atmosphere since 1950 (Lambert, 1987; Lambert and Harvey, 1987). The four internally consistent radiocarbon analyses currently available for water samples from the Rustler and Dewey Lake Formations support this interpretation. Modeled minimum ages in each case are between 12 and 16 ka, suggesting that both units have had little recharge since the period immediately following the late Pleistocene glacial maximum (Lambert and Harvey, 1987). Lambert and Carter (1987) presented uranium isotope data that also support this interpretation: observed high $^{234}U/^{238}U$ activity ratios require a conservative minimum residence time in the Culebra Dolomite of several thousands of years and more probably reflect minimum ages of 10 to 30 ka. Chapman (1988) questioned the validity of equating isotope residence times with groundwater age, but agreed that high $^{234}U/^{238}U$ activity ratios occur in

regions of low transmissivity, where flow is presumably slower and residence times are longer.

Lambert (1991) used groundwater isotope data, along with supporting evidence from $^{87}Sr/^{86}Sr$ ratios in vein fillings, to argue that the Rustler Formation has been essentially a closed hydrologic system for the last 12 ka. In his interpretation, significant recharge last occurred during the late Pleistocene, and the present flow field reflects the slow draining of the aquifer. If this interpretation is correct, recharge may not occur again until precipitation levels are substantially higher than at present.

Other data suggest that, isotopic evidence notwithstanding, some recharge may be occurring at the present. Anomalous increases in water levels have been observed at seven WIPP-area wells since 1988 (Beauheim, 1989). Recharge from the surface cannot be ruled out as a cause for these rises, although no specific link to precipitation events has been demonstrated. Other possible causes include decreases in discharge, changes in reservoir volume related to incomplete recovery from the transient pressure changes associated with the pumping test itself, changes in reservoir volume related to external changes in the regional stress field, or undetected recharge from other aquifers or from the surface through existing boreholes (Beauheim, 1989). Numerical modeling of groundwater flow in the WIPP area indicates that, although it is hydraulically possible for present flow to reflect late Pleistocene recharge (Davies, 1989), some component of modern vertical recharge is also compatible with observed conditions (Haug and others, 1987; Davies, 1989). Major ion chemical analyses of groundwater samples support the interpretation of vertical recharge south of the WIPP, where low salinities may be the result of mixing with fresh surface water (Chapman, 1988). Lambert (1991) suggests instead that water chemistry has remained essentially unchanged from the late Pleistocene and is a function of host rock composition, noting that groundwater salinity correlates well with the distribution of halite in the Rustler Formation.

Questions about recharge to the Rustler Formation and the true age of WIPP-area groundwater remain unanswered. In the absence of definitive data, this report makes no assumptions about groundwater age.

8. Discussion and Conclusions

Speculation about future climate variability must be based on observed past fluctuations. The largest global climatic changes in the last 2.5 Ma have been those associated with glaciation and deglaciation in the northern hemisphere. The high degree of consistency in both frequency and intensity

displayed in the glacial record indicates that an accurate interpretation of past climatic cycles does provide a useful guide for estimating future changes.

Geologic data from southeastern New Mexico and the surrounding region show repeated alternations of wetter and drier climates throughout the Pleistocene. Floral, faunal, and lacustrine data permit detailed and quantitative reconstructions of precipitation that can be linked directly to glacial events of the late Pleistocene and Holocene. Figure 9 shows estimated mean annual precipitation for the WIPP for the last 30 ka, interpolated from the composite regional data cited above and based on present average precipitation at the site of 30 cm/yr (Brinster, 1991). This plot should be interpreted with caution, because its resolution and accuracy are limited by the nature of the data used to construct it. Floral and faunal assemblages may change gradually and show only a limited response to climatic fluctuations that occur at frequencies higher than the typical life span of the organisms in question. For long-lived species such as trees, resolution may be limited to hundreds or even thousands of years (Neilson, 1986). Sedimentation in lakes and playas has the potential to record higher frequency fluctuations, including single-storm events, but only under a limited range of circumstances. Once water levels reach a spill point, for example, lakes show only a limited response to further increases in precipitation. Dry playas generally show little response to decreases in precipitation. A more complete record of precipitation would almost certainly show far more variability than that implied by the plot presented here. Specifically, Figure 9 may fail to record abnormal precipitation lows during the Holocene, it may underestimate the number of high-precipitation peaks during the same period, and it may underestimate the magnitude of relatively brief precipitation maxima during the late Pleistocene. Although the magnitude of the long-term shift in precipitation is adequately documented by the data reviewed here, the amplitude of the higher-frequency fluctuations in both the late Pleistocene and the Holocene is not well constrained, and the climate may have been wetter or drier than shown for some intervals.

With these observations in mind, three significant conclusions can be drawn from the climatic record of southeastern New Mexico and the surrounding region. First, maximum precipitation in southeastern New Mexico in the past coincided with the maximum advance of the North American ice sheet. Minimum precipitation occurred after the ice sheet had retreated to its present limits. Second, past maximum long-term average precipitation levels were roughly twice present levels. Minimum levels may have been 90 percent of present levels. Third, short-term fluctuations in precipitation have occurred during both the glacial maximum and the present, relatively dry,

interglacial period, but fluctuations during the present interglacial period have not exceeded the upper limits of the glacial maximum.

It would be unrealistic to attempt a direct extrapolation of the precipitation curve of Figure 9 into the future. Too little is known about the relatively short-term behavior of global circulation patterns, and it is at present impossible to predict the probability of a recurrence of a wetter climate such as that of approximately 1000 years ago. The long-term stability of patterns of glaciation and deglaciation, however, do permit the conclusion that future climatic extremes are unlikely to exceed those of the late Pleistocene. Furthermore, the periodicity of glacial events suggests that a return to full glacial conditions is highly unlikely within the next 10,000 years.

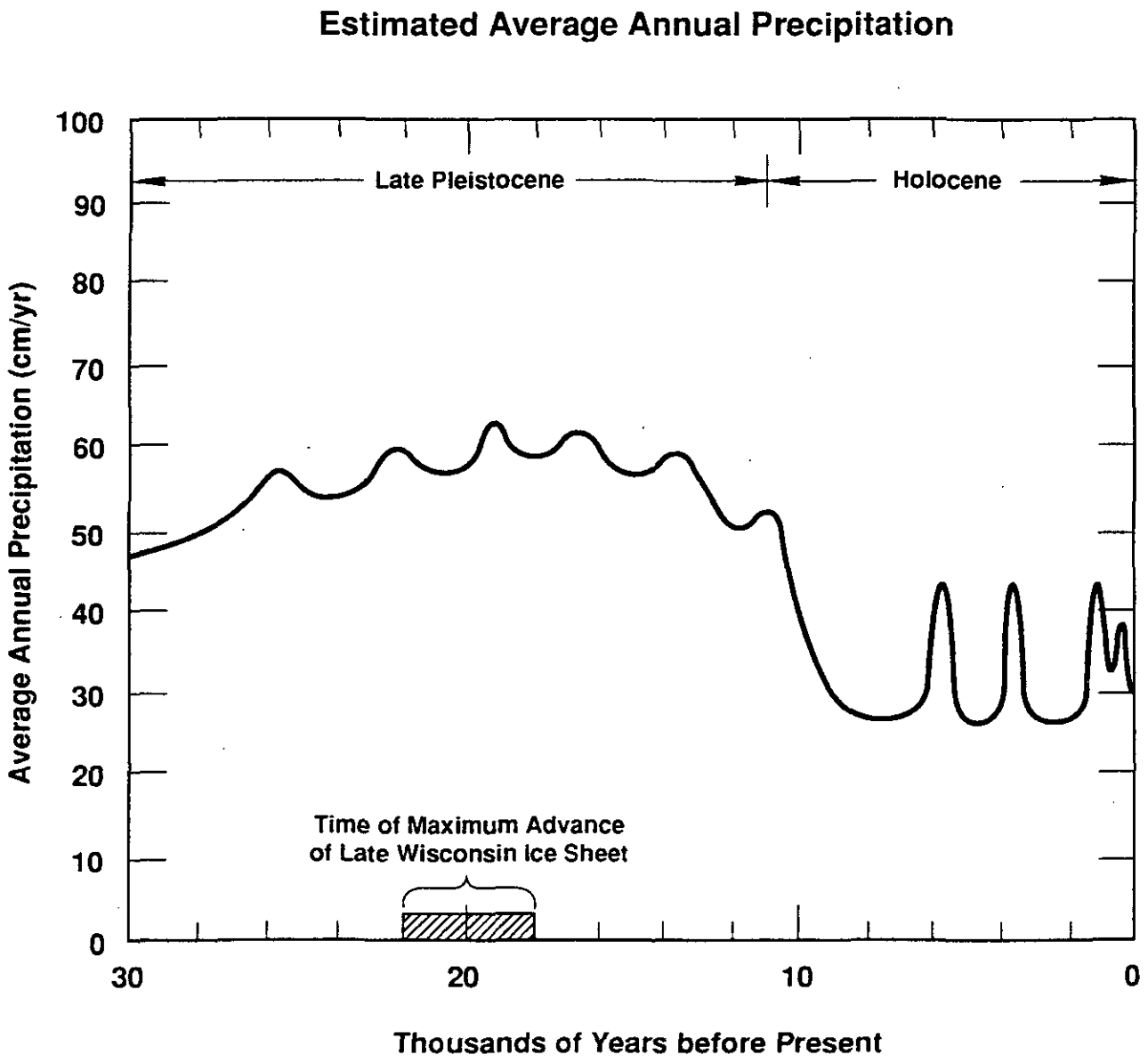

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Figure 9. Estimated mean annual precipitation at the WIPP during the late Pleistocene and Holocene. Amplitudes of relatively high-frequency fluctuations are less well constrained than the amplitude of the shift from glacial conditions of the Pleistocene to interglacial conditions of the Holocene. Data from Van Devender and others (1987); Pierce (1987); Waters (1989); Allen (1991); Phillips and others (1992); and other sources cited in text.

9. LITERATURE CITED

Allen, B.D. 1991. "Effect of Climatic Change on Estancia Valley, New Mexico: Sedimentation and Landscape Evolution in a Closed-Drainage Basin," *Field Guide to Geologic Excursions in New Mexico and Adjacent Areas of Texas and Colorado*. Eds. B. Julian and J. Zidek. New Mexico Bureau of Mines and Mineral Resources Bulletin 137. Socorro, NM: New Mexico Bureau of Mines and Mineral Resources. 166-171.

Anderson, R.Y. 1984. "Orbital Forcing of Evaporite Sedimentation," *Milankovitch and Climate: Understanding the Response to Astronomical Forcing, Proceedings of the NATO Advanced Research Workshop on Milankovitch and Climate, Palisades, NY, November 30-December 4, 1982*. Eds. A Berger, J. Imbrie, J. Hays, G. Kukla, and B. Saltzman. Boston, MA: D. Reidel Publishing Company, Pt. 1, 147-162.

Andrews, J.T. 1987. "The Late Wisconsin Glaciation and Deglaciation of the Laurentide Ice Sheet," *North America and Adjacent Oceans During the Last Deglaciation*. Eds. W.F. Ruddimen and H.E. Wright, Jr. The Geology of North America Volume K-3. Boulder, CO: Geological Society of America, Inc. 13-37.

Bachhuber, F.W. 1989. "The Occurrence and Paleolimnologic Significance of Cutthroat Trout (Oncorhynchus clarki) in Pluvial Lakes of the Estancia Valley, Central New Mexico," *Geological Society of America Bulletin*. Vol. 101 in no. 12, 1543-1551.

Bachman, G.O. 1981. *Geology of the Nash Draw, Eddy County, New Mexico*, U.S. Geological Survey. Open-File Report 81-31. Denver, CO: U.S. Geological Survey.

Bachman, G.O. 1987. *Karst in Evaporites in Southeastern New Mexico*. SAND86-7078. Albuquerque, NM: Sandia National Laboratories.

Barnola, J.M., D. Raynaud, Y.S. Korotkevich, and C. Lorius. 1987. "Vostok Ice Core Provides 160,000-year Record of Atmospheric CO_2," *Nature*. Vol. 329, no. 6138, 408-414.

Beauheim, R.L. 1989. *Interpretation of H-11b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) site*. SAND89-0536. Albuquerque, NM: Sandia National Laboratories.

Benson, L. [V.], and R.S. Thompson. 1987. "The Physical Record of Lakes in the Great Basin," *North America and Adjacent Oceans During the Last Deglaciation*. Eds. W.F. Ruddiman and H.E. Wright, Jr. The Geology of North America Volume K-3. Boulder, CO: Geological Society of America, Inc. 241-260.

Benson, L.V., D.R. Currey, R.I. Dorn, K.R. Lajoie, C.G. Oviatt, S.W. Robinson, G.I. Smith, and S. Stine. 1990. "Chronology of Expansion and Contraction of Four Great Basin Lake Systems During the Past 35,000 Years," *Palaeogeography, Palaeoclimatology, Palaeoecology*. Vol. 78, no. 214, 241-286.

Berger, A.L. 1984. "Accuracy and Frequency Stability of the Earth's Orbital Elements During the Quaternary," *Milankovitch and Climate: Understanding the Response to Astronomical Forcing, Proceedings of the NATO Advanced Research Workshop on Milankovitch and Climate, Palisades, NY, November 30-December 4, 1982*. Eds. A. Berger, J. Imbrie, J. Hays, G. Kukla, and B. Saltzman. Boston, MA: D. Reidel Publishing Company. Pt. 1, 3-39.

Bertram-Howery, S.G., and R.L. Hunter. 1989. *Plans for Evaluation of the Waste Isolation Pilot Plant's Compliance with EPA Standards for Radioactive Waste Management and Disposal*. SAND88-2871. Albuquerque, NM: Sandia National Laboratories.

Bertram-Howery, S.G., M.G. Marietta, R.P. Rechard, P.N. Swift, D.R. Anderson, B.L. Baker, J.E. Bean, Jr., W. Beyeler, K.F. Brinster, R.V. Guzowski, J.C. Helton, R.D. McCurley, D.K. Rudeen, J.D. Schreiber, and P. Vaughn. 1990. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990*. SAND90-2347. Albuquerque, NM: Sandia National Laboratories.

Brakenridge, G.R. 1978. "Evidence for a Cold, Dry Full-Glacial Climate in the American Southwest," *Quaternary Research*. Vol. 9, no. 1, 22-40/

Brinster, K.F. 1991. *Preliminary Geohydrologic Conceptual Model of the Los Medaños Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment*. SAND89-7147. Albuquerque, NM: Sandia National Laboratories.

Bryant, V.M., Jr., and R. G. Holloway. 1985. "A Late-Quaternary Paleoenvironmental Record of Texas: An Overview of the Pollen Evidence," *Pollen Records of Late-Quaternary North American Sediments*. Eds. R.G. Holloway and V.M. Bryant, Jr., Dallas, TX: American Association of Stratigraphic Palynologists Foundation. 39-70.

Bryson, R.A. 1989. "Late Quaternary Volcanic Modulation of Milankovitch Climate Forcing," *Theoretical and Applied Climatology*. Vol. 39, no. 3, 115-125.

Caputo, M.V., and J.C. Crowell. 1985. "Migration of Glacial Centers Across Gondwana During Paleozoic Era," *Geological Society of America Bulletin*. Vol. 96, no. 8, 1020-1036.

Chapman, J.B. 1986. *Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area*. EEG-35. Santa Fe, NM: Environmental Evaluation Group, State of New Mexico.

Chapman, J.B. 1988. *Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico*. EEG-39. Santa Fe, NM: Environmental Evaluation Group, State of New Mexico.

COHMAP Evaluation Group, [Cooperative Holocene Mapping Project] Members. 1988. "Climatic Changes of the Last 18,000 Years: Observations and Model Simulations," *Science*. Vol. 241, no. 4869, 1043-1052.

Cole, F.W. 1975. *Introduction to Meteorology*. 2nd ed. New York, NY: John Wiley and Sons, Inc.

Crowell, J.C., and L.A. Frakes. 1970. "Phanerozoic Glaciation and the Causes of Ice Ages," *American Journal of Science*. Vol. 268, no. 3, 193-224.

Crowley, T.J., D.A. Short, J.G. Mengel, and G.R. North. 1986. "Role of Seasonality in the Evolution of Climate During the Last 100 Million Years," *Science*. Vol. 231, no. 4738, 579-584.

Davies, P.B. 1989. *Variable-Density Ground-Water Flow and Paleohydrology in the Waste Isolation Pilot Plant (WIPP) Region, Southeastern New Mexico*. United States Geological Survey Open-File Report 88-490. Albuquerque, NM: U.S. Geological Survey.

Elias, S.A. 1987. "Paleoenvironmental Significance of Late Quaternary Inspect Fossils from Packrat Middens in South-Central New Mexico," *The Southwestern Naturalist*. Vol. 32, no. 3, 383-390.

Elias, S.A., and T.R. Van Devender. 1990. "Fossil Insect Evidence for Late Quaternary Climatic Change in the Big Bend Region, Chihauhuan Desert. Texas," *Quaternary Research*. Vol. 34, no. 2, 249-261.

Enzel, Y., D.R. Cayan, R.Y. Anderson, and S.G. Wells. 1989. "Atmospheric Circulation During Holocene Lake Stands in the Mojave Desert: Evidence of Regional Climate Change," *Nature*. Vol. 341, no. 6237, 44-47.

Forester, R.M. 1987. "Late Quaternary Paleoclimate Records from Lacustrine Ostracodes," *North America and Adjacent Oceans During the Last Deglaciation*. Eds. W.F. Ruddiman and H.E. Wright, Jr. The Geology of North America Volume K-3. Boulder, CO: Geological Society of America, Inc. 261-276.

Galloway, R.W. 1970. "The Full-Glacial Climate in the Southwestern United States," *Annals of the Association of American Geographers*. Vol. 60, no. 2, 245-256.

Galloway, R.W. 1983. "Full-Glacial Southwestern United States: Mild and Wet or Cold and Dry?" *Quaternary Research*. Vol. 19, no. 1, 236-248.

Hansen, J., I. Fung, A. Lacis, D. Rind, S. Lebedeff, R. Ruedy, and G. Russel. 1988. "Global Climate Changes as Forecast by Goddard Institute for Space Studies Three-Dimensional Model," *Journal of Geophysical Research*. Vol. 93, no. D8, 9341-9364.

Harris, A.H. 1987. "Reconstruction of Mid-Wisconsin Environments in Southern New Mexico," *National Geographic Research*. Vol. 3, no. 2, 142-151.

Harris, A.H. 1988. "Late Pleistocene and Holocene Microtus (Pitymys) (Rodentia: Cricetidae) in New Mexico," *Journal of Vertebrate Paleontology*. Vol. 8, no. 3, 307-313.

Haug, A., V.A. Kelley, A.M. LaVenue, and J.F. Pickens. 1987. *Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site*: Interim Report. SAND86-7167. Albuquerque, NM: Sandia National Laboratories.

Hays, J.D., J. Imbrie, and N.J. Shackleton. 1976. "Variations in the Earth's Orbit: pacemaker of the Ice Ages," *Science*. Vol. 194, no. 4270, 1121-1132.

Heckel, P.H. 1986. "Sea-Level Curve for Pennsylvanian Eustatic Marine Transgressive-Regressive Depositional Cycles Along Midcontinent Outcrop Belt, North America," *Geology*. Vol. 14, no. 4, 330-334.

Holliday, V.T. 1989a. "The Blackwater Draw Formation (Quaternary): A 1.4-plus-m.y. Record of Eolian Sedimentation and Soil Formation on the Southern High Plains," *Geological Society of America Bulletin* Vol. 101, no. 12, 1598-1607.

Holliday, V.T. 1989b. "Middle Holocene Drought on the Southern High Plains," *Quaternary Research*. Vol. 31, no. 1, 74-82.

Holliday, V.T., and B.L. Allen. 1987. "Geology and Soils," *Lubbock Lake: Late Quaternary Studies on the Southern High Plains*. Ed. E. Johnson College Station, TX: Texas A&M University Press. 14-21.

Houghton, J.T., G.J. Jenkins, and J.J. Ephraums. 1990. *Climate Change: The IPCC Scientific Assessment*. New York, NY: Cambridge University Press.

Hunter, R.L. 1985. *A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area*. SAND84-2233. Albuquerque, NM: Sandia National Laboratories.

Hyde, W.T., K-Y. Kim, T.J. Crowley, and G.R. North. 1990. "On the Relation Between Polar Continentality and Climate: Studies With a Nonlinear Seasonal Energy Balance Model," *Journal of Geophysical Research*. Vol. 95, no. D11, 18653-18668.

Imbrie, J. 1985. "A theoretical Framework for the Pleistocene Ice Ages," *Journal of the Geological Society*. Vol. 142, pt. 3, 417-432.

Imbrie, J., and J.Z. Imbrie. 1980. "Modeling the Climatic Response to Orbital Variations," Science. Vol. 207, no. 4434, 943-953.

Imbrie, J., J.D. Hays, D.G. Martinson, A. McIntyre, A.C. Mix, J.J. Morley, N.G. Pisias, W.L. Prell, and N.J. Shackleton. 1984. "The Orbital Theory of Pleistocene Climate: Support from a Revised Chronology of the Marine $\delta^{18}O$ Record," *Understanding the Response to Astronomical Forcing Proceedings of the NATO Advanced Research Workshop on Milankovitch and Climate, Palisades, NY, November 30-December 4, 1982*. Eds. A. Berger, J. Imbrie, J. Hays, G. Kukla, and B. Saltzman. Boston, MA: D. Reidel Publishing Company. Pt. 1, 269-305.

Jouzel, J., C. Lorius, J.R. Petit, C. Genthon, N.I. Barkov, V.M. Kotlyakov, and V.M. Petrov. 1987. "Vostok Ice Core: A Continuous Isotope Temperature Record Over the Last Climatic Cycle (160,000 Years)," *Nature*. Vol. 329, no. 6138, 403-418.

Kutzbach, J.E., and P.J. Guetter. 1986. "The Influence of Changing Orbital Parameters and Surface Boundary Conditions on Climate Simulations for the Past 18,000 Years," *Journal of the Atmosphere Sciences*. Vol. 43, no. 16, 1726-1759.

Lamb, H.H. 1972. *Climate: Present, Past and Future*. London: Methuen and Co. Vol. 1.

Lambert, S.J. 1986. "Stable-Isotope Studies of Groundwaters in Southeastern New Mexico," *The Rustler Formation at the WIPP Site*. EEG-34; SAND85-1978C. Santa Fe, NM: Environmental Evaluation Group, State of New Mexico.

Lambert, S.J. 1987. *Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and Other Nuclides to the Groundwater Hydrology of the Rustler Formation, Southeastern New Mexico*. SAND86-1054. Albuquerque, NM: Sandia National Laboratories.

Lambert, S.J. 1991. "Isotopic Constraints on the Rustler and Dewey Lake Groundwater Systems," *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico*. Eds. M.D. Siegel, S.J. Lambert, and K.L. Robinson. SAND88-1096. Albuquerque, NM: Sandia National Laboratories.

Lambert, S.J., and J.A. Carter. 1987. *Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico. I: Principles and Methods*. SAND87-0388. Albuquerque, NM: Sandia National Laboratories.

Lambert, S.J., and D.M. Harvey. 1987. *Stable-Isotope Geochemistry of Groundwaters in the Delaware Basin of Southeastern New Mexico*. SAND87-0138. Albuquerque, NM: Sandia National Laboratories.

Langway, C.C., Jr., H. Oeschger, and W. Dansgaard, eds. 1985. *Greenland Ice Core: Geophysics, Geochemistry, and the Environment*. Geophysical Monograph 33. Washington, D.C: American Geophysical Union.

Manabe, S., and A.J. Broccoli. 1985. "The Influence of Continental Ice Sheets on the Climate of an Ice Age," *Journal of Geophysical Research*. Vol. 90, no. D1, 2167-2190.

Markgraf, V., J.P. Bradbury, R.M. Forester, W. McCoy, G. Singh, and R. [S]. Sternberg. 1983. "Paleoenvironmental Reassessment of the 1.6-million-year-old record from San Agustin Basin, New Mexico," *in Socorro Region*

II, New Mexico Geological Society Thirty-Fourth Annual Field Conference, Socorro, NM, October 13-15, 1983. Ed. C.E. Chapin. New Mexico Geological Society Guidebook. Volume 34. Roswell, NM: New Mexico Geological Society. 291-297.

Markgraf, V., J.P. Bradbury, R.M. Forester, G. Singh, and R.S. Sternberg. 1984. "San Agustin Plains, New Mexico: Age and Paleoenvironmental Potential Reassessed," *Quaternary Research*. Vol. 22, no. 3, 336-343.

Martin, P.S., and P.J. Mehringer, Jr. 1965. "Pleistocene Pollen Analysis and Biogeography of the Southwest," *The Quaternary of the United States*. Eds. H.E. Wright, Jr. and D.G. Frey. Princeton, NJ. Princeton University Press. 433-451.

Milankovitch, M.M. 1941. *Canon of Insolation and the Ice-Age Problem*. Koniglich Serbische Akademie, Beograd. (English translation by the Israel Program for Scientific Translations). U.S. Department of Commerce and National Science Foundation. (Available from National Technical Information Service, Springfield, VA).

Mitchell, J.F.B. 1989. "The 'Greenhouse' Effect and Climate Change," *Reviews of Geophysics*. Vol. 27, no. 1, 115-139.

Mix, A.C. 1987. "The Oxygen-Isotope Record of Glaciation," *North America and Adjacent Oceans During the Last Deglaciation*. Eds. W.F. Ruddiman and H.E. Wright, Jr. The Geology of North America Volume K-3. Boulder, CO: Geological Society of America, Inc. 111-135.

Neilson, R.P. 1986. "High-Resolution Climatic Analysis and Southwest Biogeography," *Science*. Vol. 232, no. 4746, 27-34.

NOAA (National Oceanic and Atmospheric Administration). 1989. *Climatological Data, New Mexico*. Vol. 93.

Palais, J.M., and H. Sigurdsson. 1989. "Petrologic Evidence of Volatile Emissions from Major Historic and Pre-Historic Volcanic Eruptions," *Understanding Climate Change*. Eds. A. Berger, R.E. Dickinson, and J.W. Kidson. Geophysical Monograph 52, IUGG Volume 7. Washington, D.C: American Geophysical Union. 31-53.

Phillips, F.M., L.A. Peeters, M.K. Tansey, and S.N. Davis. 1986. "Paleoclimatic Inferences from an Isotopic Investigation of Groundwater in the Central San Juan Basin, New Mexico," *Quaternary Research*. Vol. 26, no. 2, 179-193.

Phillips, F.M., A.R. Campbell, C. Kruger, P.S. Johnson, R. Roberts, and E. Keyes. 1992. A reconstruction of the water balance in Western United States lake basins in response to climate change. New Mexico Water Resources Research Institute Report 269. Las Cruces, New Mexico.

Pierce, H.G. 1987. "The Gastropods, with Notes on Other Invertebrates," *Iubbock Lake: Late Quaternary Studies on the Southern High Plains*. Ed. E. Johnson. College Station, TX: Texas A&M University Press. 41-48.

Reeves, C.C., Jr. 1973. "The Full-Glacial Climate of the Southern High Plains, West Texas," *Journal of Geology*. Vol. 81, no. 4, 693-704.

Richmond, G.M. 1962. *Correlation of Some Glacial Deposits in New Mexico*. U.S. Geological Survey Professional Paper 450E. E121-E125.

Robock, A. 1979. "The 'Little Ice Age': Northern Hemisphere Average Observations and Model Calculations," *Science*. Vol. 206, no. 4425, 1402-1404.

Ruddiman, W.F. 1987. "Northern Oceans," *North America and Adjacent Oceans During the Last Deglaciation. Eds. W.F. Ruddiman and H.E. Wright, Jr. The Geology of North America Volume K-3. Boulder, CO: Geological Society of America, Inc. 137-154.*

Ruddiman, W.F., and J.E. Kutzbach. 1989. "Forcing of Late Cenozoic Northern Hemisphere Climate by Plateau Uplift in Southern Asia and the American West," Journal of Geophysical Research. Vol. 94, no. D15, 18409-18427.

Ruddiman, W.F., and H.E. Wright, Jr. 1987. "Introduction," *North America and Adjacent Oceans During the Last Deglaciation.* Eds. W.F. Ruddiman and H.E. Wright, Jr. The Geology of North America Volume K-3. Boulder, CO: Geological Society of America, Inc. 1-12.

Schlesinger, M.E., and J.F.B. Mitchell. 1987. "Climate Model Simulations of the Equilibrium Climatic Response to Increased Carbon Dioxide," *Reviews of Geophysics*. Vol. 25, no. 4, 760-798.

Schneider, S.H. 1990. "The Global Warming Debate Heats Up: An Analysis and Perspective," *Bulletin of the American Meteorological Society*. Vol. 71, no. 9, 1292-1304.

Smith, L.N., and R.Y. Anderson. 1982. "Pleistocene-Holocene Climate of the Estancia Basin, Central New Mexico," *Albuquerque Country II, New Mexico*

Geological Society, 33rd Annual Field Conference, Albuquerque, NM, November 4-6, 1982. Eds. J.F. Callender, J.A. Grambling, and S.G. Wells. New Mexico Geological Society Guidebook Vol. 33. Roswell, NM: New Mexico Geological Society. 347-350.

Spaulding, W.G. 1986. *Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South-Central Nevada.* United States Geological Survey Professional Paper 1329. [Reston, VA]: U.S. Department of the Interior, Geological Survey.

Spaulding, W.G., and L.J. Graumlich. 1986. "The Last Pluvial Climatic Episodes in the Deserts of Southwestern North America," *Nature*. Vol. 320, no. 6061, 441-444.

Stuiver, M. 1980. "Solar Variability and Climatic Change During the Current Millenium," *Nature*. Vol. 286, no. 5776, 868-871.

Swift, P.N. 1991. "Long-Term Climate Variability at the Waste Isolation Pilot Plant, Background Information Presented to the Expert Panel on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant." Eds. R.V. Guzowski and M.M. Gruebel. SAND91-0928. Albuquerque, NM: Sandia National Laboratories.

U.S. DOE (Department of Energy) and State of New Mexico. 1981, as modified. *Agreement for Consultation and Cooperation" on WIPP by the State of New Mexico and U.S. Department of Energy*, modified 11/30/84 and 8/4/87.

U.S. EPA (Environmental Protection Agency). 1985. *40 CFR 191*: "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste: Final Rule," *Federal Register*. Vol. 50, no. 182, 38066-38099.

University of New Mexico. 1989. *New Mexico Statistical Abstract 1989*. Albuquerque, NM: University of New Mexico, Bureau of Business and Economic Research.

Van Devender, T.R. 1980. "Holocene Plant Remains from Rocky Arroyo and Last Chance Canyon, Eddy County, New Mexico," *The Southwestern Naturalist*. Vol. 25, no. 3, 261-372.

Van Devender, T.R. 1990. "Late Quaternary Vegetation and Climate of the Chihuahuan Desert, United States and Mexico," Eds. J.L. Betancourt, T.R. Van Devender, and P.S. Martin. Tucson, AZ: University of Arizona Press. 104-133.

Van Devender, T.R., J.L. Betancourt, and M. Wimberly. 1984. "Biogeographic Implications of a Packrat Midden Sequence from the Sacramento Mountains, South-Central New Mexico," *Quaternary Research*. Vol. 22, no. 3, 344-360.

Van Devender, T.R., R.S. Thompson, and J.L. Betancourt. 1987. "Vegetation History of the Deserts of Southwestern North America; The Nature and Timing of the Late Wisconsin-Holocene Transition," North America and Adjacent Oceans During the Last Deglaciation. Eds. W.F. Ruddiman and H.E. Wright, Jr. The Geology of North America. Volume K-3. Boulder, CO: Geological Society of America, Inc. 323-352.

Washington, W.M., and G.A. Meehl. 1984. "Seasonal Cycle Experiment on the Climate Sensitivity Due to D doubling of CO_2 With an Atmospheric General Circulation Model Coupled to a Simple Mixed-Layer Ocean Model," *Journal of Geophysical Research*. Vol. 89, no. D6, 9475-9503.

Waters, M.R. 1989. "Late Quaternary Lacustrine History and Paleoclimatic Significance of Pluvial Lake Cochise, Southeastern Arizona," *Quaternary Research*. Vol. 32, no. 1, 1-11.

Wells, S.G., R.Y. Anderson, L.D. McFadden, W.J. Brown, Y. Enzel, and J-L. Miossec. 1989. *Late Quaternary Paleohydrology of the Eastern Mojave River Drainage, Southern California: Quantitative Assessment of the Late Quaternary Hydrologic Cycle in Large Arid Watersheds*. WRRI Report No. 242. Las Cruces, NM: New Mexico Water Resources Research Institute..

Wilson, C.A., and J.F.B. Mitchell. 1987. "A Doubled CO_2 Climate Sensitivity Experiment With a Global Climate Model Including a Simple Ocean, *Journal of Geophysical Research*. Vol. 92, no. D11, 13,315-13,343.

Winograd, I.J., B.J. Szabo, T.B. Coplen, and A.C. Riggs. 1988. "A 250,000-Year Climatic Record from Great Basin Vein Calcite: Implications for Milankovitch Theory," *Science*. Vol. 242, no. 4883, 1275-1280.

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Appendix CODELINK

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

The WIPP 1996 Performance Assessment Codes and Their Linkages

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TABLE

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ACRONYMS

CCDF	*complementary cumulative distribution function*
LHS	Latin hypercube sampling
NON-PA SES	nonperformance assessment scientific and engineering software
PA NON-SES	performance assessment nonscientific and engineering software
PA SES	performance assessment scientific and engineering software
QA	quality assurance
SWCF	Sandia WIPP Central Files
t-field	transmissivity field
WIPP	Waste Isolation Pilot Plant

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APPENDIX CODELINK

Presented are overviews of and background for (1) the principal codes used in the analysis following Latin hypercube sampling, and (2) the principal code-linkage sequences that support the Waste Isolation Pilot Plant (WIPP) performance assessment in support of this application. Operational details and supporting references are not included nor are discussions of codes that provide input to the performance assessment. However, detailed user's manuals, one for each compliance software code, have been compiled and archived as part of the quality assurance (QA) procedure for this application. Functional descriptions of each performance assessment scientific and engineering software (PA SES) code are included as appendices. Attachment 1 to this appendix lists the compliance software and the Sandia WIPP Central Files (SWCF) records package identifiers for each code. Codes are categorized as PA SES, PA NON-SES (performance assessment nonscientific and engineering software), and NON-PA SES (nonperformance assessment scientific and engineering software) (see also Table 5-1 in Chapter 5.0 of this application).

CODELINK.1 Introduction

As discussed in Chapter 6.0 of this application, long-term performance assessments of the WIPP disposal system are carried out by applying, in sequence, a number of computer codes designed to model processes that may significantly affect transport of radionuclides from the repository via various routes through the surrounding geological units to the accessible environment. As code development has been an on-going process in WIPP performance assessment research, the codes as well as the code sequences applied to WIPP performance assessments have evolved in time. This discussion focuses on the codes and code sequences that support this compliance application. Table CODELINK-1 lists codes used in the Monte Carlo analysis for this performance assessment, their function and type, and their category with regard to supporting this application, that is, PA SES, PA NON-SES, or NON-PA SES.

Sampling methods used in the Monte Carlo analysis for the performance assessment are described in Section CODELINK.2 below. In Section CODELINK.3, the PA NON-SES utility codes that prepare the way for and support the various PA SES codes are discussed individually. The seven PA SES codes and their functions are introduced in Sections CODELINK.4 through CODELINK.7. The PA SES codes themselves, the repository, and the principal features of the repository are depicted in Figure CODELINK-1. The overall code-linkage sequence for the performance assessment is shown in Figure CODELINK-2. It serves as a guide to and connection diagram for the individual code-linkage sequences, which are shown in Figures CODELINK-3 through CODELINK-9.

CODELINK.2 Sampling Uncertain Parameters—*LHS*

Sampling is carried out by a code called LHS, which stands for Latin hypercube sampling. Application of LHS includes a preprocessor code PRELHS and a postprocessor code

Table CODELINK-1. Codes Used in the Monte Carlo Analysis

Code Name	Function	Category of Code[a]
ALGEBRA	Performs algebraic and other manipulations, for units conversions, calculation of derived parameters, etc.	PA NON-SES
BRAGFLO	Computes brine and gas flows throughout the controlled area.	PA SES
BRAGFLO_DBR	Calculates brine volume removed from repository due to drilling intrusion.	PA SES
CCDFGF	Combines consequence results from PA SES codes for individual events to estimate releases for scenarios, and constructs CCDFs.	PA SES
CUTTINGS_S	Calculates direct releases of radionuclides due to cuttings, cavings, and spallings.	PA SES
GENMESH	Establishes the computational grid for a given model.	PA NON-SES
GRASP-INV	Generates calibrated transmissivity fields for use in SECOFL2D.	NON-PA SES
ICSET	Establishes initial conditions for a given model.	PA NON-SES
LHS	Performs Latin-hypercube sampling of all uncertain parameters.	PA NON-SES
MATSET	Assigns material names, properties, and attribute values to specific blocks of a grid defined by GENMESH.	PA NON-SES
NUTS	Calculates types and amounts of radionuclides transported in BRAGFLO-generated flow fields.	PA SES
PANEL	Calculates radionuclide concentrations in brine as volumes calculated by BRAGFLO.	PA SES
POSTBRAG	Postprocessor for BRAGFLO; converts output to CDB format.	PA NON-SES

Table CODELINK-1. Codes Used in the Monte Carlo Analysis (continued)

Code Name	Function	Category of Code[a]
POSTLHS	Postprocessor to LHS; creates sampled vectors from LHS output for input to modeling codes.	PA NON-SES
POSTSECOFL2D	Postprocessor for SECOFL2D; converts output to CDB format.	PA NON-SES
POSTSECOTP2D	Postprocessor for SECOTP2D; converts output to CDB format.	PA NON-SES
PREBRAG	Preprocessor for BRAGFLO; constructs necessary input file for BRAGFLO.	PA NON-SES
PRELHS	Preprocessor for LHS; interprets user-specified input controls for operation of LHS.	PA NON-SES
PRESECOFL2D	Preprocessor for SECOFL2D; constructs necessary input files for SECOFL2D.	PA NON-SES
PRESECOTP2D	Preprocessor for SECOTP2D; constructs necessary input files for SECOTP2D.	PA NON-SES
RELATE	Interpolates data from one grid to another; combines two sets of data defined on same grid.	PA NON-SES
SANTOS	Used to calculate effective repository porosity for BRAGFLO, due to creep closure of halite and gas pressure.	NON-PA SES
SECOFL2D	Calculates groundwater flow in Culebra.	PA SES
SECOTP2D	Calculates radionuclide transport through Culebra to accessible environment.	PA SES
SUMMARIZE	Used for extraction of data across multiple vectors.	PA NON-SES

[a] Codes are grouped into three categories: PA SES, PA NON-SES. and NON-PA SES. PA SES and NON-PA SES codes model physical or chemical processes. PA NON-SES codes include statistical codes, which perform sampling or provide some type of statistical analysis, and utility codes, which permit user control of the other codes or provide an interface between codes. PA SES and PA NON-SES codes listed are run repeatedly in a performance assessment calculation, using the Latin hypercube sample values drawn from distribution functions for uncertain parameters. NON-PA SES codes—for example, SANTOS and GRASP-INV—are run outside of a given performance assessment calculation for a set of Latin hypercube samples as subsidiary calculations to provide input.

POSTLHS. LHS requires that each uncertain parameter be specified in terms of a probability distribution.

LHS is a stratified Monte Carlo sampling code designed to sample the entire range of variability of all uncertain WIPP parameters. For each of *m* uncertain parameters, LHS divides the likelihood-of-occurrence axis (of the cumulative distribution) into *n* equal-length segments, where *n* is the sample size, and then draws one parameter value randomly from each segment. It then combines, by random pairing, the results to form *n* input vectors, each vector containing a unique ordered set of all *m* of the required uncertain input parameters.

Thus, the outcome of LHS's sampling may be represented as an *m*-row, *n*-column matrix in which every value in a given row is different from every other value in that row. For the analysis described in Chapter 6.0 of this application, the *m*-row, *n*-column table with m=57 and n=100 is presented in Appendix IRES (Tables IRES-2, IRES-3, and IRES-4) for each of the three independent replicates. Once the matrix of actual values has been formed, a second matrix with the identical parameter ordering but listing the ranks of the sampled values is also created and reported. The code user may specify correlations *a priori*, and LHS will then combine the selected parameters in such a way as to assure that the sampled values remain correlated at the correct level.

When a performance assessment code requires sampled input parameters, it exercises POSTLHS (discussed in Section CODELINK.3.3, below). POSTLHS generates a set of *n* output files that are identical except for the values of sampled parameters associated with the code requiring them. LHS results for this performance assessment are presented in Appendix IRES (Tables IRES-2, IRES-3, and IRES-4).

CODELINK.3 PA NON-SES Utility Codes

In this section, only PA NON-SES utility codes are discussed, including all the ones that will be encountered in a performance assessment. They are discussed in roughly the order in which they are used in an actual run sequence; however, no actual performance assessment code sequences will be discussed in this section. Each PA SES code requires its own *individual* utility-code sequence before it can be exercised. Performance assessment code sequences for PA SES codes are shown in Figures CODELINK-3 through CODELINK-9, and the individual PA SES codes themselves are discussed in Sections CODELINK.4 through CODELINK.7.

CODELINK.3.1 GENMESH and GENNET

GENMESH and GENNET are mesh-generating codes that (1) establish the computational-grid geometry of the physical domain being modeled, and (2) create the output file (known as a CDB file) that will collect sequential binary-format results and trace the path of the computational sequence throughout its entire history. Thus, in CUTTINGS_S, GENMESH grids the cylindrical borehole from the bottom of the borehole to ground level with a single grid element that is one unit wide, the width being based on the drill-bit diameter. In

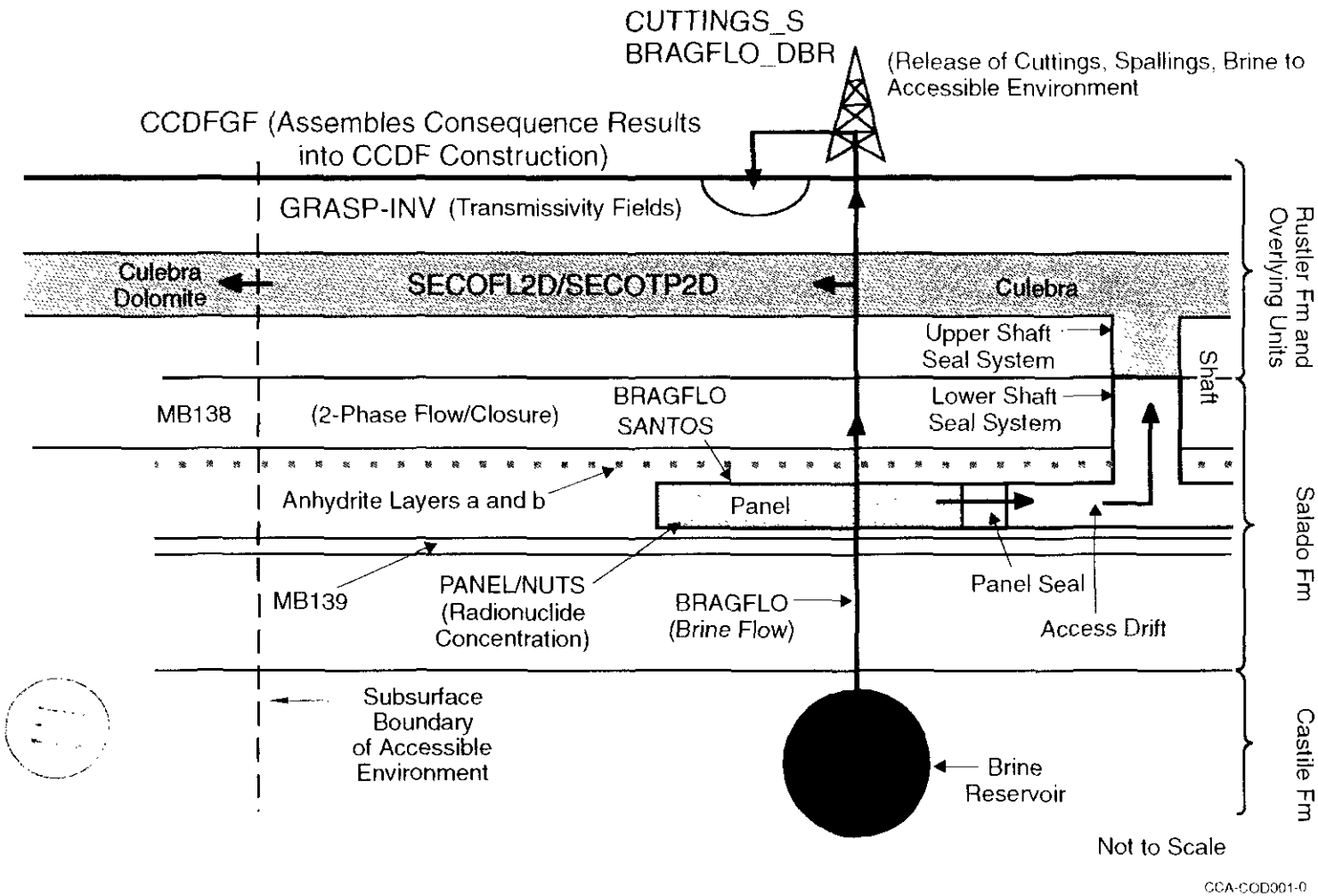

Figure CODELINK-1. Diagrammatic Representation of a Vertical Section Through the Repository, Listing the PA SES and Two NON-PA SES Codes Used in the Monte Carlo Analysis

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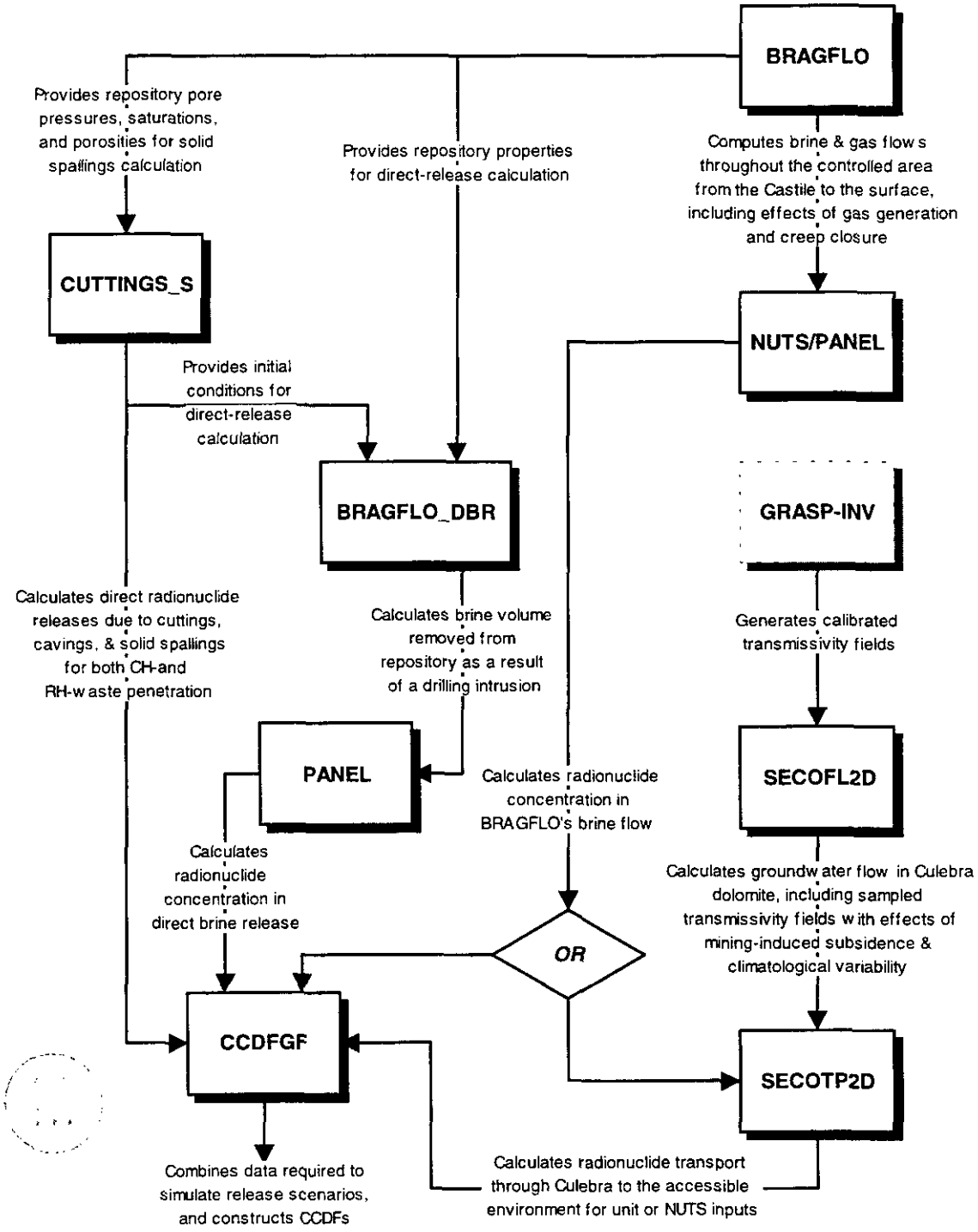

Note: PA SES codes are rectangular. The NON-PA SES code is dashed. See Figures CODELINK-3 through CODELINK-9 for more detailed representations of the individual PA SES-code sequences.

Figure CODELINK-2. Overview of the Performance Assessment Code Sequence

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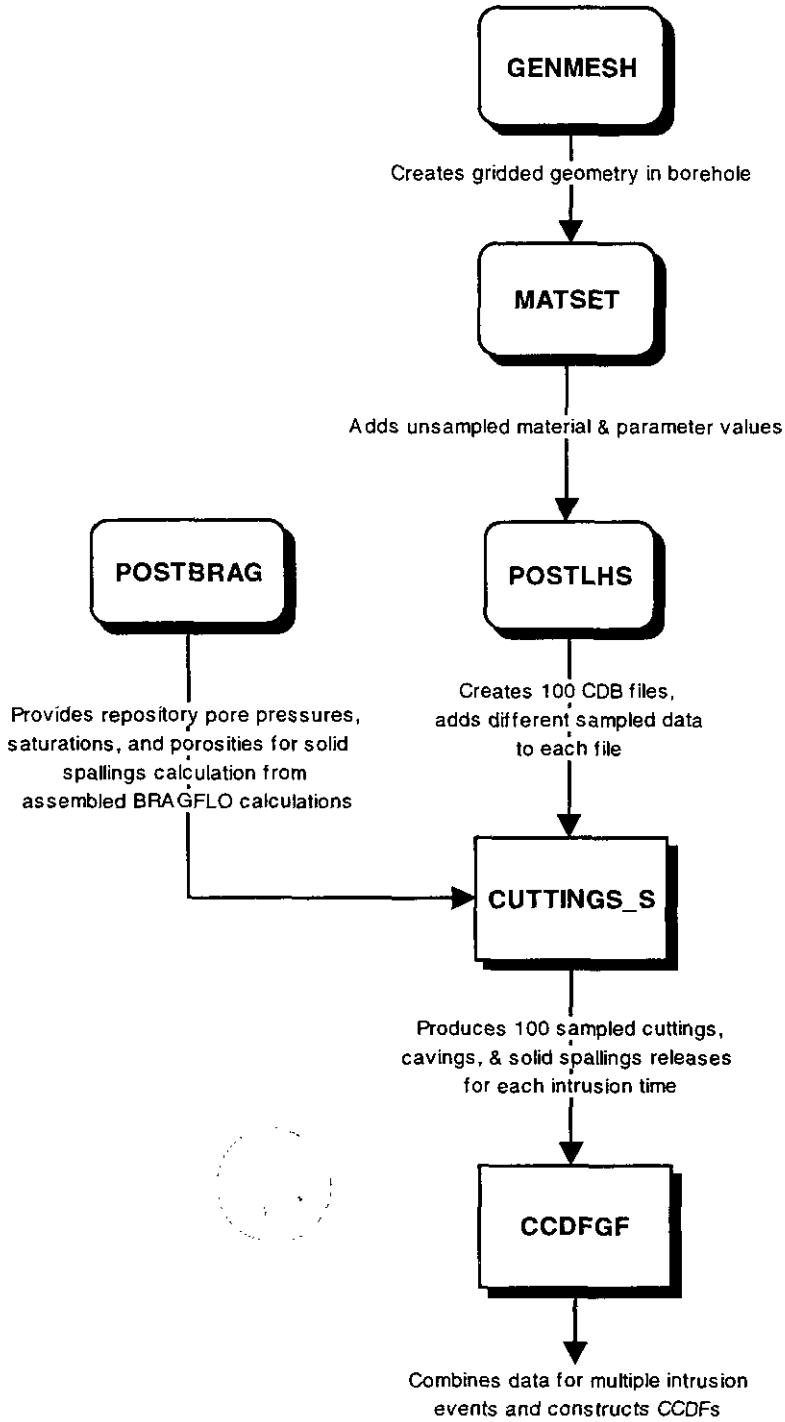

Note: PA SES codes are rectangular; PA NON-SES codes are rounded.

Figure CODELINK-3. The Code Sequence for CUTTINGS_S in the Performance Assessment for One Replicate with 57 Sampled Parameters and Sample Size Equal to 100

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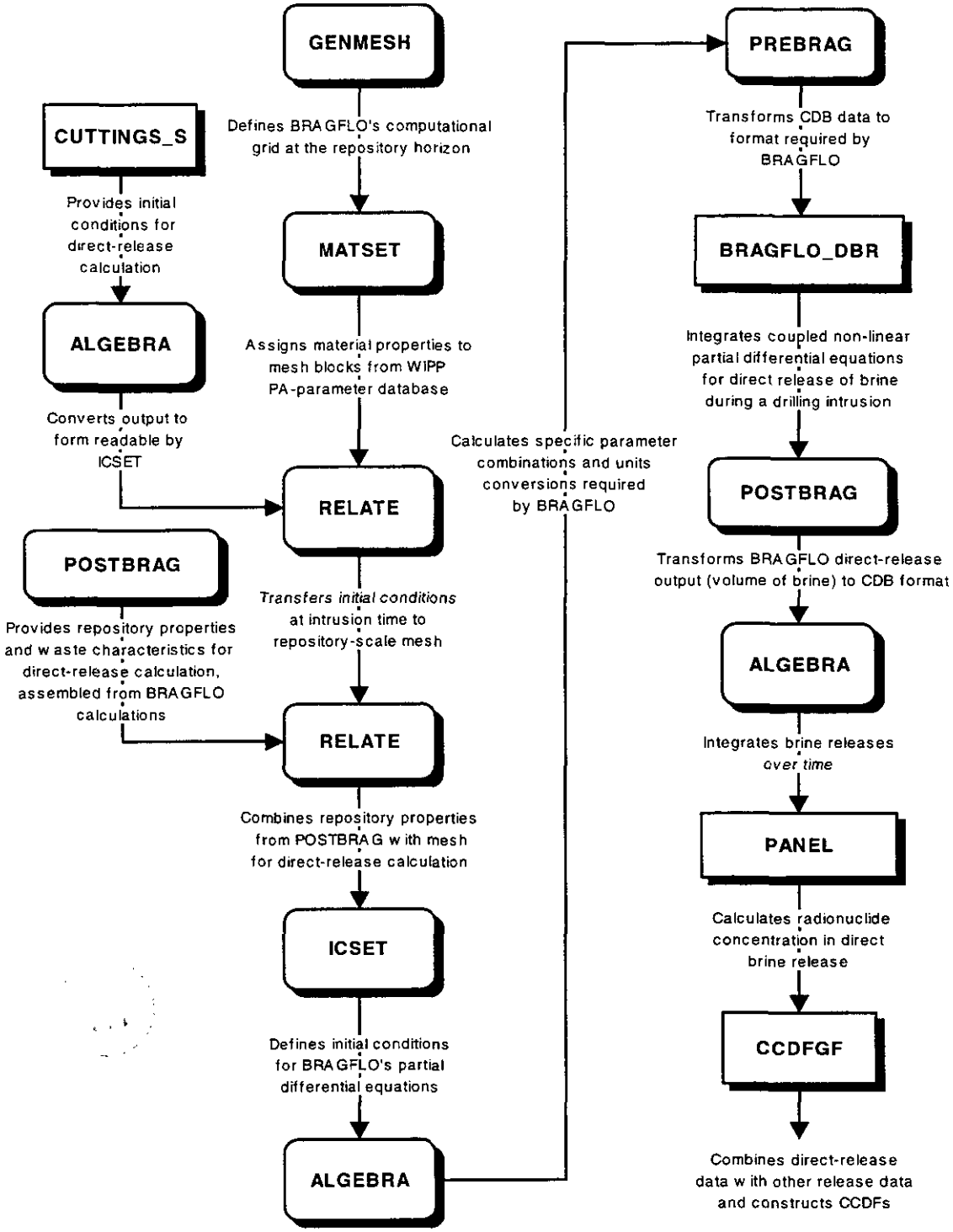

Note: PA SES codes are rectangular; PA NON-SES codes are rounded.

Figure CODELINK-4. The Code Sequence for BRAGFLO_DBR in the Performance Assessment for One Replicate with 57 Sampled Parameters and Sample Size Equal to 100

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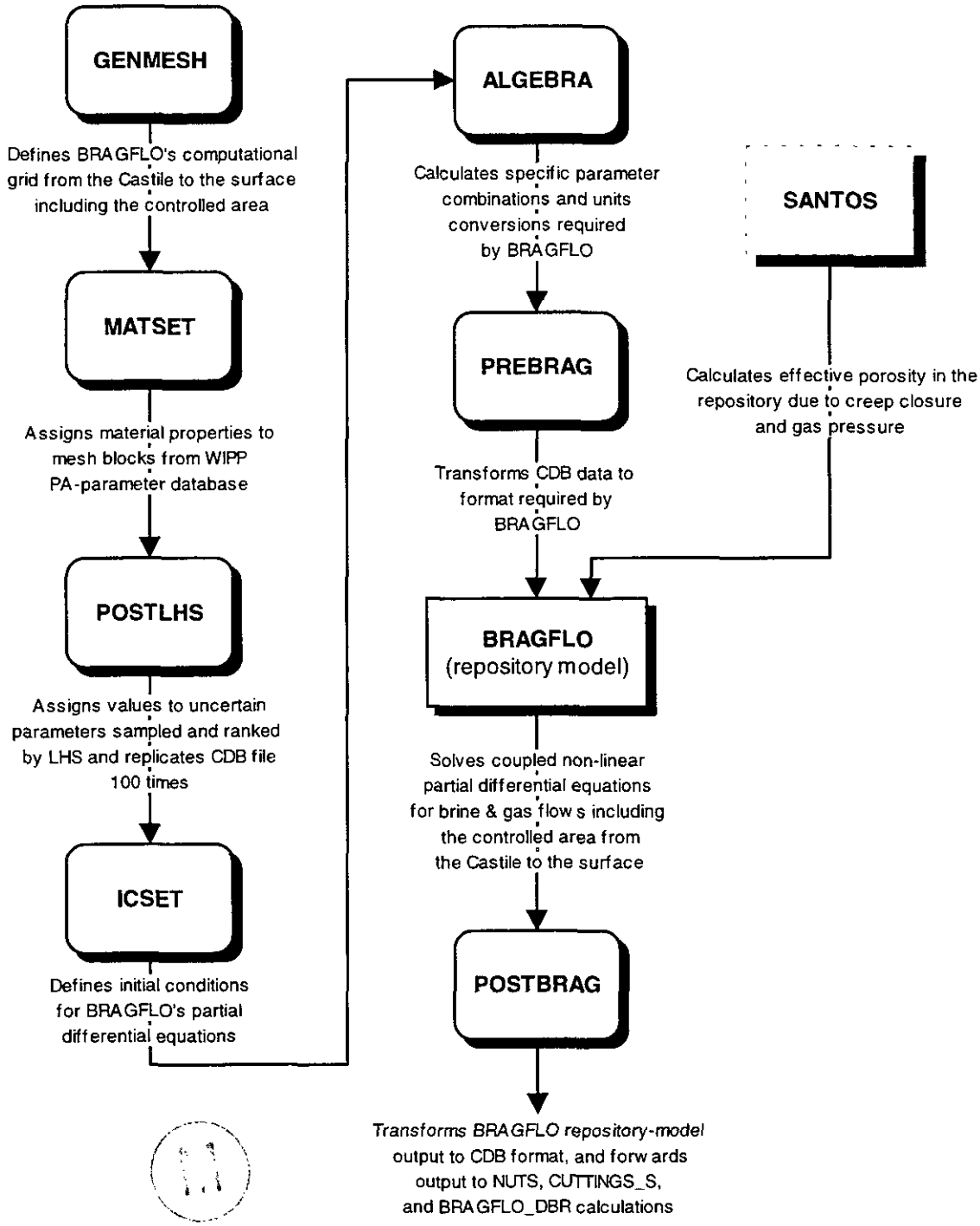

Note: PA SES codes are rectangular; PA NON-SES codes are rounded. The NON-PA SES code is dashed.

Figure CODELINK-5. The Code Sequence for BRAGFLO in the Performance Assessment for One Replicate with 57 Sampled Parameters and Sample Size Equal to 100

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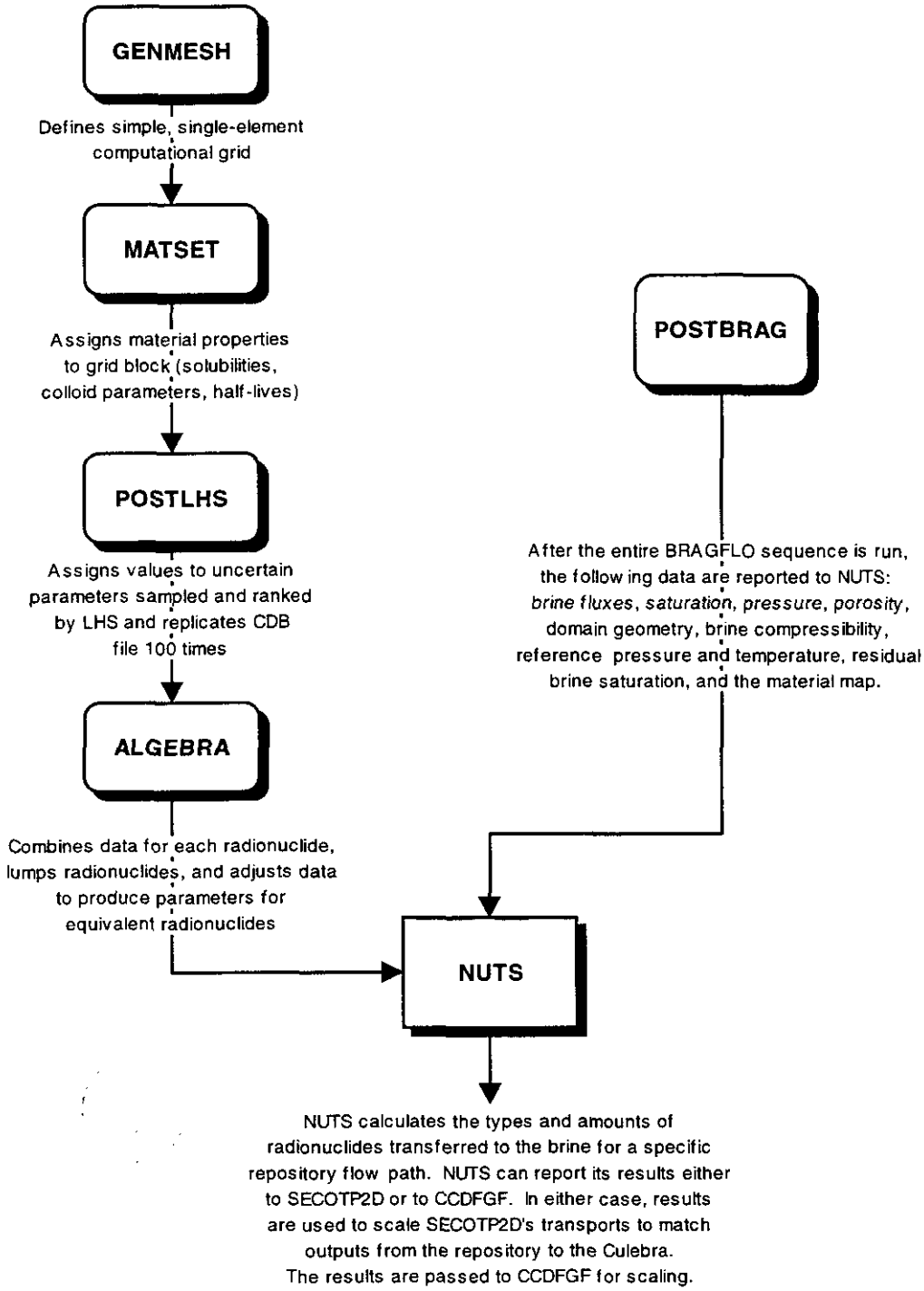

Note: PA SES codes are rectangular; PA NON-SES codes are rounded.

Figure CODELINK-6. The Code Sequence for NUTS in the Performance Assessment for One Replicate with 57 Sampled Parameters and Sample Size Equal to 100

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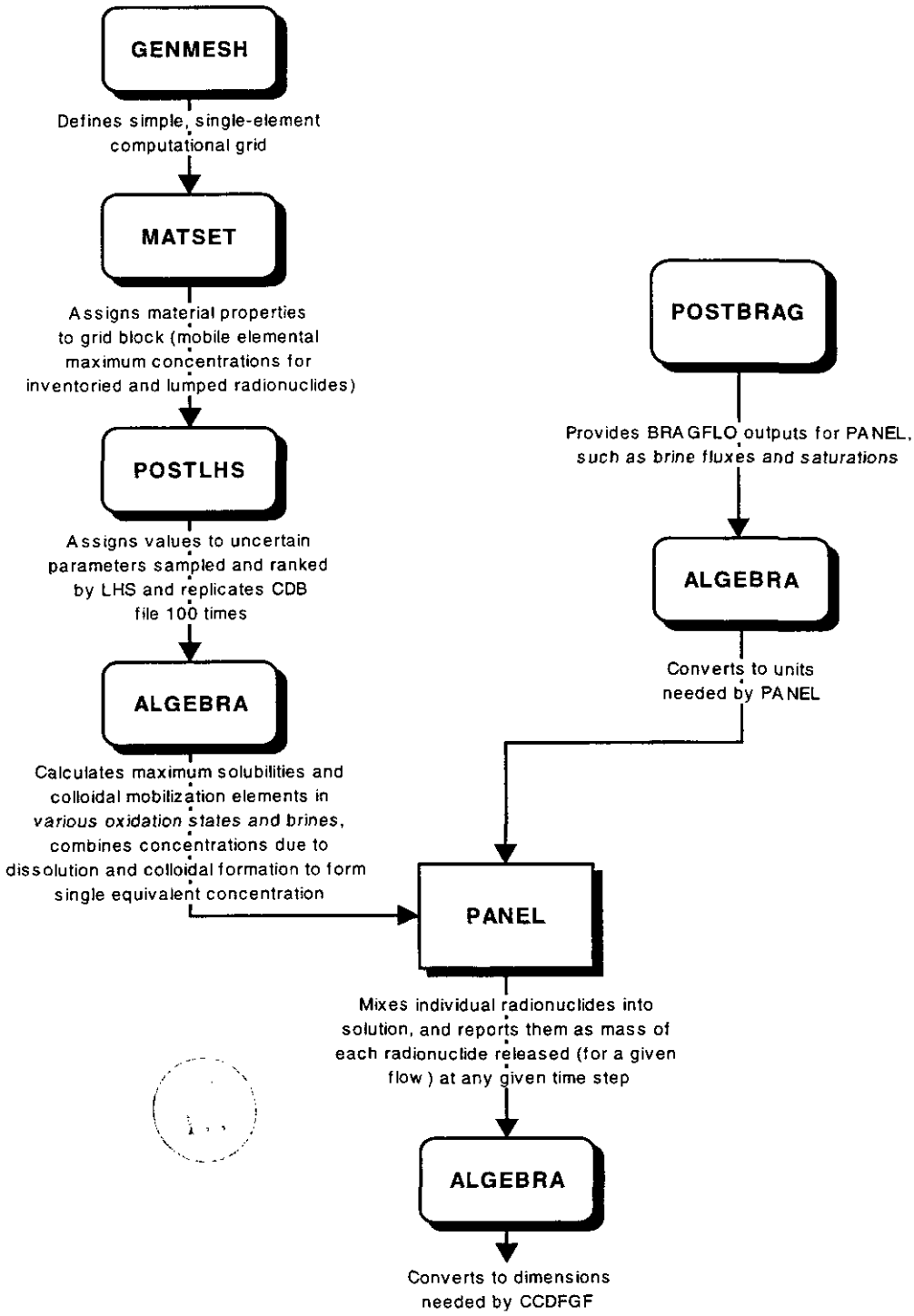

Note: PA SES codes are rectangular; PA NON-SES codes are rounded.

Figure CODELINK-7. The Code Sequence for PANEL in the Performance Assessment for One Replicate with 57 Sampled Parameters and Sample Size Equal to 100

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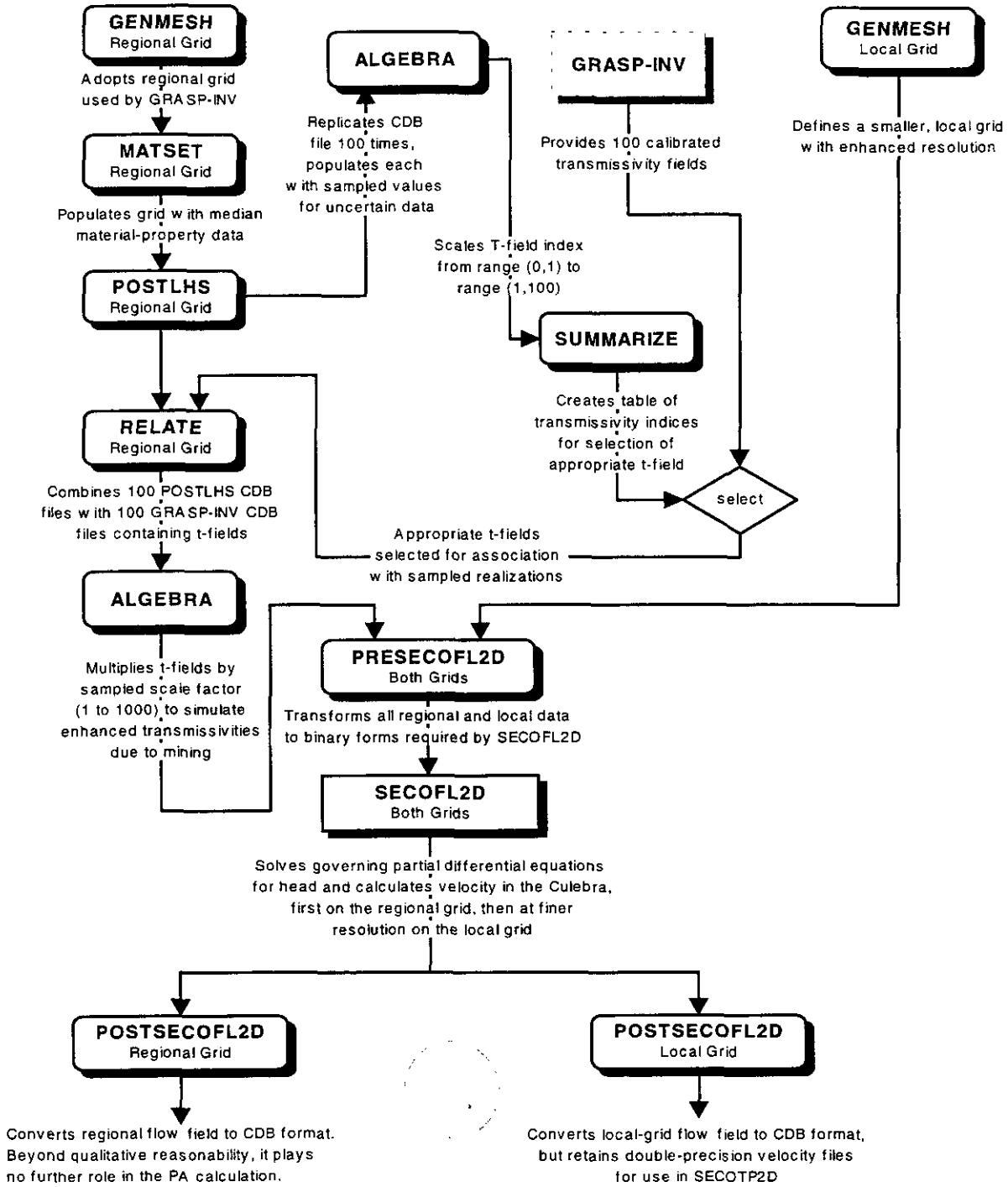

Note: PA SES codes are rectangular; PA NON-SES codes are rounded. The NON-PA SES code is dashed.

Figure CODELINK-8. The Code Sequence for SECOFL2D in the Performance Assessment for One Replicate with 57 Sampled Parameters and Sample Size Equal to 100

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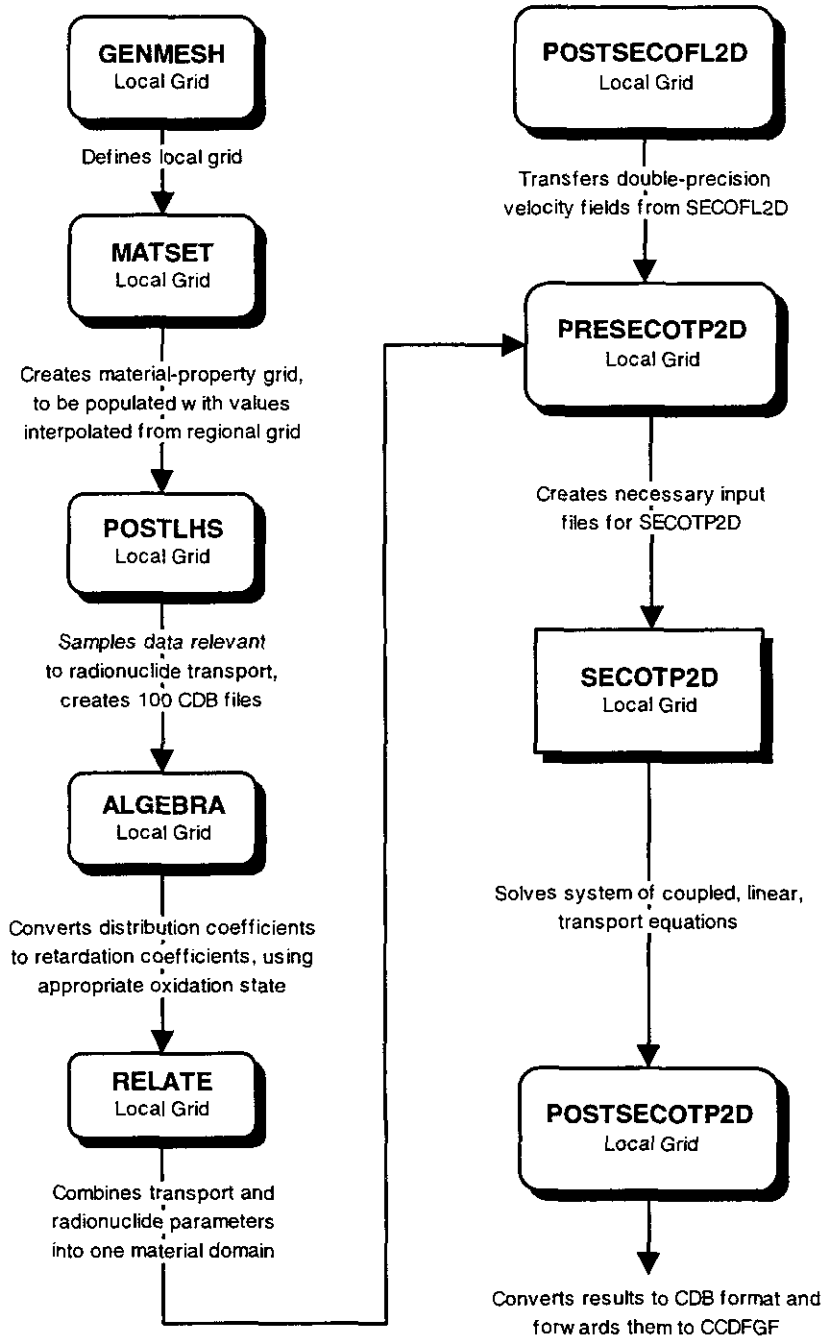

Note: PA SES codes are rectangular; PA NON-SES codes are rounded.

Figure CODELINK-9. The Code Sequence for SECOTP2D in the Performance Assessment for One Replicate with 57 Sampled Parameters and Sample Size Equal to 100

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BRAGFLO, GENMESH grids the entire repository region and surrounding formation from the Castile to the ground surface. In the vertical, it extends from the hypothesized underlying brine reservoir, throughout the Salado, to the overlying Culebra, and on upward to the ground-surface level, which is a boundary of the accessible environment. In the SECO codes, GENMESH grids the Culebra in a horizontally nonuniform regional grid that provides higher resolution in the vicinity of boreholes. It also grids the Culebra in a nonuniform, higher-resolution, local grid centered over the repository.

GENNET is a simplified mesh-generating code that is used for simple code geometries (for example, PANEL).

CODELINK.3.2 MATSET

MATSET's function is to assign material names, associated property values, and attribute values to specific blocks of grid elements identified by material region and defined by GENMESH. It creates its output file by adding its information to the input file it receives from GENMESH (or GENNET), the source of the new data being the performance assessment parameter data base. If used in default mode, MATSET chooses median values for all uncertain parameters. The user may, however, instruct MATSET to choose mean values. Neither alternative is used in probabilistic performance assessment calculations for uncertain parameters, which are sampled, but may be used for fixing values for nonsampled parameters. In performance assessments, the very next code in the utility run sequence is POSTLHS, which replaces MATSET's data choices with sampled values for all uncertain parameters. Thus, MATSET's choices of numerical values for uncertain parameters serve strictly as placeholders.

CODELINK.3.3 POSTLHS

As discussed in Section CODELINK.2 above, POSTLHS is LHS's postprocessor, LHS being the principal Latin-hypercube sampling code and the code whose output file contains the entire suite of n sampled values and rank orderings for all m uncertain parameters. POSTLHS's principal functions are: (1) to replicate the input file it receives from MATSET n times, (2) to assign to each such replicated MATSET file a different numerically-sequential name, and (3) to overwrite on each such file a different sampled value for each parameter from the suite of uncertain parameters that arise for that PA SES code. Except for sampled data, POSTLHS's n output CDB files are identical to one another and to the MATSET CDB file from which they came.

CODELINK.3.4 ICSET

All PA SES codes deal with systems of differential equations that are written as boundary-value problems. For transient problems, all unknown dependent variables must be specified over the entire computational domain, including all interior and boundary-value nodes, at the initial instant from which the computation begins. In physical terms, initial conditions

describe the initial configuration of the physical system, which may or may not have a significant impact on the long-term behavior of the system.

ICSET's principal task is to assign user-specified initial numerical values to all unknown dependent parameters at every point in the computational grid (specified by GENMESH or GENNET). In time-stepping methods, the initial values are the original known quantities from which numerical approximations of the dependent variables and their derivatives are calculated and from which they evolve in time.

ICSET does not appear in the utility code sequence of every PA SES code because some of the codes (SECOFL2D, for example) set initial conditions internally, and others (CUTTINGS_S, for example) use analytically-integrated results that have already incorporated their initial conditions.

CODELINK.3.5 ALGEBRACDB

Occasionally, a parameter, attribute, or value may be listed or output from a code in a form that is unsuitable for direct use in a subsequent code. Typically, parameter units (that is, dimensions) may be inconsistent, a vector magnitude may be required rather than coordinate components of the vector, or the components of a tensor may be decomposed in a different coordinate system. ALGEBRACDB (often called simply ALGEBRA) is designed to make the appropriate changes. ALGEBRA is capable of performing most common algebraic manipulations and/or evaluating most common transcendental functions (trigonometric, logarithmic, exponential, etc.). It reads its instructions from a user-specified ASCII input control file that employs, for user convenience, an algebraic syntax that is similar in appearance to normal FORTRAN syntax.

ALGEBRA does not occur in the preparatory run stream for every PA SES code.

CODELINK.3.6 RELATE

RELATE serves two principal purposes. First, it is capable of interpolating data from one coordinate grid to a different coordinate grid that overlies it. Second, it is capable of combining two data files that are defined over the same grid. For example, SECOFL2D uses RELATE to add to its data files the sampled transmissivity values.

RELATE is not used by every PA SES code.

CODELINK.3.7 SUMMARIZE

SUMMARIZE can produce a single output file that contains similar data collected from across all the sampled CDB data files, thus allowing analysts to choose specific values from different modeling-code runs, at identical intermediate times, from each of the *n* sampled data files. If data-recording times are not identical on the various sampled files, SUMMARIZE can interpolate data on subsequent files to match the times used on the first file, or it can

choose nearest values, as directed by the user. Thus, it facilitates comparisons as may be required by system analysts. Secondly, although it is able to read CDB format, SUMMARIZE outputs data to other common file formats, such as ASCII text, database, and spreadsheet formats.

CODELINK.3.8 Actual Utility Code Usage

The performance assessment code run sequences for the principal PA SES codes differ somewhat from one another, although all use PA NON-SES utility codes from the set of codes discussed in this section. The specific performance assessment code sequences are not discussed here; however, they are shown in correct order in Figures CODELINK-3 through CODELINK-9.

CODELINK.4 PA SES Codes and Performance Assessment Code Sequence

The PA SES codes are exercised together to produce a complete suite of radionuclide-release results, depending on the scenario under consideration. These PA SES codes are discussed briefly below, and each is treated in detail in its own appendix.

One principal performance assessment code sequence calculates long-term releases following drilling that occur through subsurface transport to the accessible environment (see Section 6.4.7.2 in Chapter 6.0 of this application). The performance assessment code sequence involves five PA SES codes: BRAGFLO, NUTS, PANEL, SECOFL2D, and SECOTP2D. Of these, all but NUTS and PANEL are exercised as a triad of codes that include pre- and postprocessor codes.

Another performance assessment code sequence calculates direct releases during drilling to the accessible environment, at ground-surface level immediately above the repository (see Section 6.4.7.1 in Chapter 6.0). The relevant performance assessment code sequences here involve the two PA SES codes CUTTINGS_S and BRAGFLO_DBR.

Each PA SES code is exercised near the end of a sequence of PA NON-SES utility codes that is designed to fit that particular code and interface it to its controlled database. The individual sequences are shown in Figures CODELINK-3 through CODELINK-9. Section CODELINK.5, below, treats only the PA SES codes that arise in direct-release calculations. Section CODELINK.6 treats only the PA SES codes that arise in the code sequence for long-term releases following drilling. The net release for each of the n input vectors is the sum of its direct and long-term releases, both for undisturbed conditions and following drilling. The total release for each sampled future is given by Equation 4.1 in Appendix CCDFGF.

CODELINK.5 PA SES Codes for Calculating Direct Releases

Two codes called CUTTINGS_S and BRAGFLO_DBR model the outcomes associated with direct transport to the surface during the drilling of a borehole that is hypothesized to penetrate the repository. There are four principal categories of phenomena, namely material

removal (1) by cuttings, (2) by cavings, (3) by solid spallings, and (4) by direct brine release. CUTTINGS_S treats the first three items. BRAGFLO_DBR treats the fourth.

CODELINK.5.1 CUTTINGS_S

CUTTINGS_S estimates the direct removal of solid wastes from the repository as the result of inadvertent penetration by a borehole drilled at some time in the future. The word "direct" refers to the fact that CUTTINGS_S releases occur directly to the surface *at the time* of drilling.

Cuttings are those portions of the waste that are directly removed by the drill string and the drilling fluid. The volume of repository material removed as cuttings is the portion of the repository cut by the drill bit. Solids that originally bordered the borehole on its exterior and erode into the drilling fluid as a result of the fluid's frictional effects on the outer cylindrical surface of the borehole are called cavings. Because of that action, the volume of wastes removed from the repository can be larger than the volume of the borehole originally cut through the wastes. CUTTINGS_S allows for both laminar and turbulent shear flow in the circulating fluids, which, in turn, leads to two different models to estimate material removal due to erosion. CUTTINGS_S also calculates spall releases. Appendix CUTTINGS contains a detailed discussion of CUTTINGS_S, and the conceptual models for direct release as discussed in Chapter 6.0 (Section 6.4.7). The total volume of direct-released solids is the sum of these three releases, that is, cuttings, cavings, and spallings.

CUTTINGS_S acquires its parameter data from (i) the input CDB files provided by the codes MATSET and BRAGFLO, (ii) a user-supplied input text file, and (iii) the performance assessment parameter database. Discrete values of sampled data are provided by the code POSTLHS. CUTTINGS_S input includes the rotational speed of the drill string, cutting-bit diameter, the shear-rate-dependent viscosity and density parameters for the drilling mud, borehole roughness, the compacted repository thickness and porosity, the drilling mud flow rate, the drill collar diameter, and the effective failure shear strength of the compacted repository material.

CODELINK.5.2 BRAGFLO_DBR

BRAGFLO_DBR (also referred to as DBR_BRAGFLO) models the brine released to the surface as a direct result of a drilling intrusion into the repository (Appendix MASS, Attachment 16-2). It is in fact a different application (that is, a different grid, a different material map, and a different time scale) of the code BRAGFLO (see Section CODELINK.6.1 herein). The Poettmann-Carpenter wellbore model is implemented to calculate the flowing bottom-hole pressure that is needed to determine the volume of brine released to the surface.

Only the repository horizon is modeled. Local scale features (for example, salt pillars, panel seals, rooms, and passageways) are modeled. Initial brine saturation and pressure, porosity, and panel height within the waste are determined from the 10,000-year BRAGFLO results, using interpolation over intrusion times in the CUTTINGS_S code (Section CODELINK.5.1

above and Appendix MASS, Attachment 16-2). Unsampled parameter values are obtained directly from the performance assessment parameter database, and sampled parameters are incorporated from BRAGFLO results through a RELATE step.

CODELINK.6 PA SES Codes for Calculating Long-Term Releases

In the performance assessment code sequence, BRAGFLO simulates flow of brine and gas within and through the repository and surrounding formation from the Castile to the surface. NUTS and PANEL calculate the amount of radionuclides mobilized by fractions of the repository brine flows estimated by BRAGFLO. Together, they estimate the mass of radioactive material transported to the Culebra or above and through the anhydrite layers, MB138, a & b, and MB139. SECOFL2D simulates the natural groundwater flow in the Culebra on a regional scale (tens of kilometers) centered approximately over the repository's location, and uses it for a recalculation of the flow on a smaller local scale (a few kilometers) in the Culebra immediately above the controlled area. SECOTP2D estimates the amounts of radionuclides that would be transported by SECOFL2D's Culebra flow field given (1) the inputs from NUTS or PANEL, (2) the radioactive decay, and (3) the retarding properties of the Culebra matrix materials. The five PA SES codes are exercised in that order. They are discussed in the same order in the five subsections that follow. Because SECOTP2D is linear in the source term, it is exercised for unit inputs of each radionuclide and its results scaled to NUTS's or PANEL's estimates for each release pathway.

CODELINK.6.1 BRAGFLO

BRAGFLO calculates brine and gas flow everywhere within the controlled area and beyond from the Castile to the ground surface. As discussed in Chapter 6.0 (Section 6.4.2), regions of note include (1) the Culebra, (2) the repository, which is comprised primarily of (3) a thick relatively-impermeable crystalline halite with (4) thin interspersed interbeds of anhydrite materials, (5) disturbed rock zones in the immediate vicinity of the repository and (6) the shaft-seal systems. If exploratory drilling is hypothesized, the above regions are permitted to become interconnected by boreholes that (a) may or may not penetrate the hypothesized brine reservoir, and (b) are assumed to be plugged (prior to abandonment) in ways that reflect present-day practice. BRAGFLO couples the flow of brine and gas to other important repository processes such as creep closure and gas generation. The resulting brine-phase, transient-flow fields are used by NUTS to simulate radionuclide transport in these flow fields.

BRAGFLO is discussed in detail in Appendix BRAGFLO. The conceptual model implemented by BRAGFLO for the performance assessment is described in Chapter 6.0 (Section 6.4).

CODELINK.6.2 NUTS

NUTS is a radionuclide transport code. Its principal capabilities are (1) to decay the inventory, using Bateman's equations, and (2) to transport radionuclides through porous or fractured media considering advection, diffusion, dispersion, and sorption processes. The

latter three processes are not included in the NUTS code for the performance assessment. The largest such path, in terms of volume rate of flow, leads to the Culebra, whose flow field is resolved by SECOFL2D (see Section CODELINK.6.4). NUTS's estimates of the amounts are forwarded as multipliers for the results of SECOTP2D (see Section CODELINK.6.5), the transport code that transports unit inputs of mobilized radionuclides through the Culebra to the edge of the controlled area. NUTS serves that role for most of the consequence analyses for this performance assessment. Some analyses are made with PANEL and these are discussed in Section CODELINK.6.3. NUTS is discussed in detail in Appendix NUTS. The conceptual model implemented by NUTS for the performance assessment is discussed in Chapter 6.0 (Section 6.4.5.4).

NUTS requires the following input parameters: (1) fluxes of brine, saturation, pressure, porosity, and computational-domain geometry from BRAGFLO's binary-output CDB file; (2) brine compressibility, reference pressure and temperature, residual brine saturation, and the material map from BRAGFLO's ASCII input-file, and (3) solubilities, inventories, half-lives and atomic weights of all the inventoried radioisotopes, free-water molecular diffusivity, dispersivities, tortuosity, rock density, and standard-condition density of the brine.

CODELINK.6.3 PANEL

PANEL is a radionuclide mobilization and decay code. Its principal functions are (1) to decay the inventory, which it does using Bateman's equations, and (2) to use the decayed inventory together with the repository brine volume and outflow rate, and the dissolved and colloidal actinide source terms, to estimate the quantity of all modeled radionuclides that are transported up the borehole.

PANEL treats each repository panel as a single isolated mixing cell, and so is not a transport model. In consequence analyses that approximate those conditions, PANEL is applied. PANEL also provides radioisotope concentrations for BRAGFLO_DBR applications.

PANEL is discussed in detail in Appendix PANEL. The conceptual model implemented for PANEL for the performance assessment is described in Chapter 6.0 (Section 6.4.7). PANEL's output is delivered as moles of each radioisotope that is released from the repository (for the assumed flow rate). These are inconvenient units, so the outputs are run through a postprocessing ALGEBRA step. This is a different application of ALGEBRA than the one that precedes PANEL. For BRAGFLO runs, it converts releases in moles to releases in mass (kilograms) for the outflow rates provided it. For BRAGFLO_DBR applications, it converts PANEL's outputs at any given time to units of concentration by dividing them by the mass of brine that flowed through the repository during that time. The mass-per-unit-mass concentration units are then converted to normalized EPA units per cubic meter of brine. These data are then directly usable by BRAGFLO_DBR, whose output is in cubic meters of brine. The product of the two is the direct release to the surface in normalized EPA units.

CODELINK.6.4 GRASP-INV and SECOFL2D (Regional and Local)

GRASP-INV is used outside the performance assessment code runstream. It generates a calibrated field of transmissivities in the Culebra on a regional scale for each of the *n* input vectors. SECOFL2D calculates a groundwater flow field for each of the *n* transmissivity fields. The two-dimensional, single-phase groundwater flow is governed by Darcy's law. Direct measurements of Culebra transmissivities exist at a number of locations throughout the WIPP region. GRASP-INV uses those measurements, their statistical properties, and other related information to solve the inverse groundwater-flow problem, and thereby generate an ensemble of fields that define transmissivity values at *each* node in the computational domain. The transmissivity fields produced have the same statistical properties (means, variances, covariances) as the measured data set, and they agree with measured transmissivities at all points where data exist. GRASP_INV and SECOFL2D are described in Appendices TFIELD and SECOFL2D, respectively. The conceptual model implemented by these codes for the performance assessment is described in Chapter 6.0 (Section 6.4.6.2). After each new transmissivity-field realization has been completed, GRASP-INV writes a new CDB file that contains (1) defining information specifying the computational grid, (2) head values that will be used by SECOFL2D as boundary conditions, and (3) the sampled transmissivity field, which is reported numerically as hydraulic conductivities at each grid block.

Before GRASP-INV's transmissivity fields are reported to SECOFL2D, they are modified by ALGEBRA to simulate the effects of potash mining that may take place in the future (see Section 6.4.6.2.3 of Chapter 6.0).

The SECOFL2D flow calculation is carried out sequentially over two different, overlying meshes for regional and local domains. Boundary conditions for the local domain, which is nested within the regional domain, are interpolated from the regional flow solution, and material properties for the local grid are interpolated from the material properties of the regional grid.

SECOFL2D (i) solves Darcy's system of differential equations for the nonhydrostatic component of the pressure field on the regional grid, (ii) interpolates calculated regional heads to the local grid boundary, and (iii) solves the same system of differential equations a second time on the finer-scale local grid. It produces four output files. Two are results files and contain the calculated heads, Darcy velocities (x and y components), volumetric fluxes (x and y components), and salt concentrations if the working fluid is brine. One is for the regional flow-field calculation and the other is for the local flow-field calculation. A third output file contains all the information derived from the regional flow that is necessary to initialize and run a local-flow calculation. It is useful if several local calculations are to be run from a single regional calculation, which is the case if parametric effects are being studied. However, in normal performance assessment runs, this file may be regarded as a temporary file and discarded. The fourth output file is an ASCII text file that lists summary information about the run and serves as a debug file.

CODELINK.6.5 SECOTP2D

The transport of radionuclides in the Culebra is calculated by SECOTP2D using the flow field generated by SECOFL2D for the local grid. Advection is the main transport process in SECOTP2D, but it is modified by (i) diffusion into the matrix, (ii) chemical retardation, and (iii) natural radioactive decay. For each flow field, SECOTP2D (1) combines the flow results with material and transport parameters that affect radionuclide transport in the Culebra, (2) calculates the concentration of radionuclide everywhere in the local domain as a function of time, and (3) calculates the integrated discharge across user-defined boundaries. SECOTP2D is described in Appendix SECOTP2D. The conceptual model implemented by SECOTP2D for the performance assessment is discussed in Chapter 6.0 (Section 6.4.6.2).

To prepare for the SECOTP2D calculation, it is necessary to create data files that contain the flow fields from SECOFL2D, all the necessary material parameters, and all the required sampled parameters that affect transport. These data files will serve as the input data files for the SECOTP2D code.

The *n* sampled data files needed by SECOTP2D must contain SECOFL2D's *n* flow fields as well as POSTLHS's *n* sampled material parameters. Each of the *n* transmissivity fields is associated with one of the *n* data files.

The inputs to SECOTP2D are the three output files from PRESECOTP2D. The outputs of SECOTP2D are a binary transfer file that gives the spatial distribution of radioisotopes throughout the local grid as a function of time, and a debug file. If it is specified in the PRESECOTP2D text input file, the SECOTP2D output can also include, as a function of time, the amount of each radioisotope transported across a prespecified rectangular box surrounding the source (the user-specified discharge boundary). The latter result is included in the CCDF plots that are used to summarize performance assessment results (see Figure CODELINK-9).

CODELINK.7 CCDF Construction and Statistical Analyses

CCDFGF assembles results obtained from calculations using the described sequences of PA SES codes into the CCDFs. CCDFGF scales BRAGFLO_DBR's and SECOTP2D's results to match radionuclide outputs calculated by NUTS and PANEL. CCDFGF combines all the calculated release data to simulate many different repository histories, generating random sequences of future events, calculating the probabilities associated with those random sequences and, preparing in numerical format, all the data required to produce the CCDF plots that summarize the WIPP's predicted performance. Only a plotting code is required after CCDFGF to represent the entire summary results of the release calculation graphically as CCDFs. The code CCDFGF is treated independently in Appendix CCDFGF.

STEPWISE and PCCSRC are PA NON-SES statistical-analysis codes used in parameter-sensitivity studies. STEPWISE is a stepwise-regression code designed to treat multiple-parameter systems, and PCCSRC is a partial-correlation-coefficient/standardized-regression-

coefficient code. Utility codes like CCD2STEP and LHS2STEP are used to interface with STEPWISE and PCCSRC.

ATTACHMENTS

Attachment 1: Requirements of 40 CFR §194.23(c) and Records Package Identifiers for Software Quality Assurance Documentation in which Requirements are Addressed

Attachment 2: Analysis Packages

Title 40 CFR Part 191
Compliance Certification
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for the
Waste Isolation Pilot Plant

CODELINK Attachment 1

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ATTACHMENT 1

Table CODELINK-A1. Requirements of 40 CFR §194.23(c) and Records Package Identifiers for Software Quality Assurance Documentation in which Requirements Are Addressed.

Requirements:
(1) Descriptions of the theoretical backgrounds of each model and the method of analysis or assessment;
(2) General descriptions of the models; discussions of the limits of applicability of each model; detailed instructions for executing the computer codes, including hardware and software requirements, input and output formats with explanations of each input and output variable and parameter (e.g., parameter name and units); listings of input and output files from a sample computer run; and reports on code verification, benchmarking, validation, and quality assurance procedures;
(3) Detailed descriptions of the structure of computer codes and complete listings of the source codes;
(4) Detailed descriptions of data collection procedures, sources of data, data reduction and analysis, and code input parameter development;
(5) Any necessary licenses; and
(6) An explanation of the manner in which models and computer codes incorporate the effects of parameter correlation.

Notes:
(1) These requirements are generally addressed in the User's Manual (UM), although in some instances a Theory Manual may exist. Some codes will be described and validated in an Analysis Plan (AP) or similar documentation. See also the applicable appendices.
(2) Most of these requirements are addressed in the User's Manual (UM); however, the code-verification and quality-assurance items will be found elsewhere, usually in the Requirements Document / Verification and Validation Plan (RD/VVP) and the Validation Document (VD). Some codes will be described and validated in an Analysis Plan (AP) or similar documentation. See also the applicable appendices.
(3) These are generally provided in the Implementation Document (ID). Some codes will be described and validated in an Analysis Plan (AP) or similar documentation.
(4) Except as described in Requirement (2), these issues are not addressed in any of the code documentation, and thus *will not be treated in this table.* See Appendix PAR for the discussion of parameters.
(5) This requirement *will not be treated in this table.*
(6) This requirement is addressed in Appendix PAR, and *will not be addressed in this table.*

Table CODELINK-A1. Requirements of 40 CFR §194.23(c) and Records Package Identifiers for Software Quality Assurance Documentation in which Requirements Are Addressed. (continued)

CODE	Requirement 1	Requirement 2	Requirement 3
ALGEBRACDB	UM - WPO# 28110	UM - WPO# 28110 RD/VVP - WPO# 28109 VD - WPO# 28112	ID - WPO# 28111
BLOTCDB	UM - WPO# 37501	UM - WPO# 37501 RD/VVP - WPO# 37499 VD - WPO# 37502	ID - WPO# 37500
BRAGFLO	UM - WPO# 30703	UM - WPO# 30703 RD/VVP - WPO# 30702 VD - WPO# 30705	ID - WPO# 30704
CAMCON_LIB	UM - WPO# 27738	UM - WPO# 27738 RD/VVP - WPO# 27736 VD - WPO# 27741	ID - WPO# 27740
CAMDAT_LIB	UM - WPO# 27727	UM - WPO# 27727 RD/VVP - WPO# 27726 VD - WPO# 27730	ID - WPO# 27728
CAMSUPES_LIB	UM - WPO# 27745	UM - WPO# 27745 RD/VVP - WPO# 27744 VD - WPO# 27747	ID - WPO# 27746
CCD2STEP	UM - WPO# 36246	UM - WPO# 36246 RD/VVP - WPO# 36244 VD - WPO# 36247	ID - WPO# 36245
CCDFGF	Design Document - WPO# 31235	UM - WPO# 31236 RD - WPO# 31233 VVP - WPO# 31234 VD - WPO# 31238	ID - WPO# 31237
CCDFSUM	AP for Task 7 - WPO # 36336	AP for Task 7 - WPO # 36336	AP for Task 7 - WPO # 36336
COLUMN	COLUMN: A Computer Program for Fitting Model Parameters to Column Flow Breakthrough Curves (V. 1.3), 4/27/96 - WPO# 37867	COLUMN: A Computer Program for Fitting Model Parameters to Column Flow Breakthrough Curves (V. 1.3), 4/27/96 - WPO# 37867	COLUMN: A Computer Program for Fitting Model Parameters to Column Flow Breakthrough Curves (V. 1.3), 4/27/96 - WPO# 37867
CUTTINGS_S	UM - WPO# 37765	UM - WPO# 37765 RD/VVP - WPO# 37763 VD - WPO# 37768	ID - WPO# 37764
BRAGFLO_DBR	UM - WPO# 30703 SNL Memo - WPO# 38134	UM - WPO# 30703 RD/VVP - WPO# 38122 VD - WPO# 38135	ID - WPO# 38133
EPAUNI	AP#017 - WPO# 39259	AP#017 - WPO# 39259	AP#017 - WPO# 39259
EQ3/EQ6	AP# 32 - Primitive Baseline WPO# 37423	AP# 32 - Primitive Baseline WPO# 37423	AP# 32 - Primitive Baseline WPO# 37423

Table CODELINK-A1. Requirements of 40 CFR §194.23(c) and Records Package Identifiers for Software Quality Assurance Documentation in which Requirements Are Addressed. (continued)

CODE	Requirement 1	Requirement 2	Requirement 3
FMT	UM - WPO# 28119	UM - WPO# 28119 RD/VVP - WPO# 28118 VD - WPO# 28121	ID - WPO# 28120
GENII-A	UM - WPO# 27751	UM - WPO# 27751 RD/VVP - WPO# 27750 VD - WPO# 27753	ID - WPO# 27752
GENMESH	UM - WPO# 30698	UM - WPO# 30698 RD/VVP - WPO# 30697 VD - WPO# 30700	ID - WPO# 30699
GRASP-INV	UM - WPO# 30636	UM - WPO# 30636 RD/VVP - WPO# 30634 VD - WPO# 30637	ID - WPO# 30635
GROPECDB	UM - WPO# 37496	UM - WPO# 37496 RD/VVP - WPO# 37494 VD - WPO# 37497	ID - WPO# 37495
GTFM-PC	UM - WPO# 40244	UM - WPO# 40244 RD/VVP - WP 40245; VD - WPO# 40246	*
ICSET	UM - WPO# 30693	UM - WPO# 30693 RD/VVP - WPO# 30692 VD - WPO# 30695	ID - WPO# 30694
LHS	UM - WPO# 30732	UM - WPO# 30732 RD/VVP - WPO# 30731 VD - WPO# 30734	ID - WPO# 30733
LHS2STEP	UM - WPO# 36916	UM - WPO# 36916 RD/VVP - WPO# 36913 VD - WPO# 36918	ID - WPO# 36915
MATSET	UM - WPO# 30688	UM - WPO# 30688 RD/VVP - WPO# 30687 VD - WPO# 30690	ID - WPO# 30689
NONLIN	UM - WPO# 30740	UM - WPO# 30740 RD/VVP - WPO# 30738 VD - WPO# 30743	ID - WPO# 30742
NUCPLOT	UM - WPO# 37506	UM - WPO# 37506 RD/VVP - WPO# 37504 VD - WPO# 37507	ID - WPO# 37505
NUTS	UM - WPO# 37927	UM - WPO# 37927 RD/VVP - WPO# 37924 VD - WPO# 37929	ID - WPO# 37926
ORIGEN2	Analysis Report - WPO# 36974	Analysis Report - WPO# 36974	Analysis Report - WPO# 36974
PANEL	UM - WPO# 37361	UM - WPO# 37361 RD/VVP - WPO# 37358 VD - WPO# 37362	ID - WPO# 37360

Table CODELINK-A1. Requirements of 40 CFR §194.23(c) and Records Package Identifiers for Software Quality Assurance Documentation in which Requirements Are Addressed. (continued)

CODE	Requirement 1	Requirement 2	Requirement 3
PCCSRC	UM - WPO# 27773	UM - WPO# 27773 RD/VVP - WPO# 27772 VD - WPO# 27775	ID - WPO# 27774
PLT_LIB	UM - WPO# 37491	UM - WPO# 37491 RD/VVP - WPO# 37489 VD - WPO# 37492	ID - WPO# 37490
POSTBRAG	UM - WPO# 30683	UM - WPO# 30683 RD/VVP - WPO# 30681 VD - WPO# 30685	ID - WPO# 30684
POSTGENII	UM - WPO# 27756	UM - WPO# 27756 RD/VVP - WPO# 27755 VD - WPO# 27758	ID - WPO# 27757
POSTLHS	UM - WPO# 30722	UM - WPO# 30722 RD/VVP - WPO# 30719 VD - WPO# 30724	ID - WPO# 30723
POSTSECOFL2D	UM - WPO# 35721	UM - WPO# 35721 RD/VVP - WPO# 35717 VD - WPO# 35722	ID - WPO# 35718
POSTSECOTP2D	UM - WPO# 37306	UM - WPO# 37306 RD/VVP - WPO# 37304 VD - WPO# 37307	ID - WPO# 37305
PREBRAG	UM - WPO# 30677	UM - WPO# 30677 RD/VVP - WPO# 30676 VD - WPO# 30679	ID - WPO# 30678
PREGENII	UM - WPO# 27763	UM - WPO# 27763 RD/VVP - WPO# 27762 VD - WPO# 27765	ID - WPO# 27764
PRELHS	UM - WPO# 30714	UM - WPO# 30714 RD/VVP - WPO# 30712 VD - WPO# 30716	ID - WPO# 30715
PRESECOFL2D	UM - WPO# 35711	UM - WPO# 35711 RD/VVP - WPO# 35709 VD - WPO# 35713	ID - WPO#35710
PRESECOTP2D	UM - WPO# 37297	UM - WPO# 37297 RD/VVP - WPO# 37295 VD - WPO# 37299	ID - WPO# 37296
RELATE	UM - WPO# 24186	UM - WPO# 24186 RD/VVP - WPO# 24184 VD - WPO# 24183	ID - WPO# 34413
SANTOS	Santos User's Manual - WPO# 35674	Santos User's Manual - WPO# 35674 Santos Validation Dcmt - WPO# 35675 QA Dcmt for Santos - WPO# 35673	*

Table CODELINK-A1. Requirements of 40 CFR §194.23(c) and Records Package Identifiers for Software Quality Assurance Documentation in which Requirements Are Addressed. (continued)

CODE	Requirement 1	Requirement 2	Requirement 3
SDBREAD_LIB	UM - WPO# 30629	UM - WPO# 30629 RD/VVP - WPO# 30627 VD - WPO# 30630	ID - WPO# 30628
SECOFL2D	UM - WPO# 37271	UM - WPO# 37271 RD/VVP - WPO# 37269 VD - WPO# 37272	ID - WPO# 37270
SECOTP2D	UM - WPO# 36695	UM - WPO# 36695 RD/VVP - WPO# 36693 VD - WPO# 36696	ID - WPO# 36694
SPECTROM-32	SPECTROM-32 User's Manual - WPO# 20149	SPECTROM-32 User's Manual - WPO# 20149 SPECTROM-32 Code Verification - WPO# 20155 WPO# 20157 WPO# 20159	SPECTROM-32 Source Code Listing - WPO# 20167 WPO# 20155
SPECTROM-41	SPECTROM-41 User's Manual - RE/SPEC internal number RSI-0266, Vol 2-User's Manual	SPECTROM-41 User's Manual - RE/SPEC internal number RSI-0266, Vol 2-User's Manual SPECTROM-41 Code Verification - RE/SPEC internal number RSI-0266, Vol 3-Code Verification	SPECTROM-41 Source Code Listing - RE/SPEC internal number RSI-0266, Vol 4-Source Code listing
SPLAT	UM - WPO# 37484	UM - WPO# 37484 RD/VVP - WPO# 37482 VD - WPO# 37485	ID - WPO# 37483
STEPWISE	UM - WPO# 27768	UM - WPO# 27768 RD/VVP - WPO# 27767 VD - WPO# 27770	ID - WPO# 27769
SUMMARIZE	UM - WPO# 37460	UM - WPO# 37460 RD/VVP - WPO# 37458 VD - WPO# 37461	ID - WPO# 37459
SWIFTII	"Primitive Baseline Software Documentation Package for SWIFT-II, Sandia Waste Isolation Flow and Transport Code (SWIFT II, Version 2F, Primitive Baseline, Volume I & II" - WPO # 38219	"Primitive Baseline Software Documentation Package for SWIFT-II, Sandia Waste Isolation Flow and Transport Code (SWIFT II, Version 2F, Primitive Baseline, Volume I & II" - WPO # 38219	*

Table CODELINK-A1. Requirements of 40 CFR §194.23(c) and Records Package Identifiers for Software Quality Assurance Documentation in which Requirements Are Addressed. (continued)

CODE	Requirement 1	Requirement 2	Requirement 3
THEMM	UM - WPO# 35261	UM - WPO# 35261 RD/VVP - WPO# 35263 VD - WPO# 35259	ID - WPO# 35260
TOUGH28W	UM - WPO# 36535	UM - WPO# 36535 RD/VVP - WPO# 36532 VD - WPO# 36536	ID - WPO# 36537

* *These are virtually commercial codes and source code is proprietary. However, the executables used for the performance assessment are archived and available.*

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

CODELINK Attachment 2

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Table CODELINK-A2. Analysis Packages

Package Name	WPO
Analysis Package for the Salado Flow Calculations (Task 1) of the Performance Assessment Analyses Supporting the Compliance Certification Application	40514
Analysis Package for the Salado Transport Calculations (Task 2) of the Performance Assessment Analysis Supporting the Compliance Certification Application	40515
Analysis Package for the Culebra Flow and Transport Calculations (Task 3) of the Performance Assessment Analyses Supporting the Compliance Certification Application	40516
Analysis of the Generation of Transmissivity Fields for the Culebra Dolomite	40517
Analysis Package for the BRAGFLO Direct Release Calculations (Task 4) of the Performance Assessment Analyses Supporting the Compliance Certification Application	40520
Analysis Package for the Cuttings and Spalling Calculations (Tasks 5 and 6) of the Performance Assessment Analyses Supporting the Compliance Certification Application	40521
Analysis Package for the CCDF Construction (Task 7) of the Performance Assessment Analyses Supporting the Compliance Certification Application	40524

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix CUTTINGS

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

WIPP PA User's Manual for CUTTINGS_S

WIPP PA

User's Manual

for

CUTTINGS_S, Version 5.03

DOCUMENT VERSION 1.00

WPO #37765

22 MAY 1996

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1.0 INTRODUCTION

This document is the User's Manual for the WIPP code called CUTTINGS_S* (version number 5.03). Using repository-height data from SANTOS via BRAGFLO, CUTTINGS_S estimates the volume of wastes brought to the surface as a result of an inadvertent borehole drilled directly over the WIPP repository so as to penetrate a waste panel. The user's manual discusses the code, its execution, and its performance in the context of the 1996 Waste Isolation Pilot Project (WIPP) Compliance Certification Application (CCA) Performance Assessment (PA), and in that context only. The manual identifies the code, its authors and expert consultants (Section 1). It describes the code's WIPP-PA purposes and functions (Section 2), provides recommended user training (Section 3), outlines the code's theoretical basis and numerical methods (Section 4), its inherent capabilities and limitations (Section 5), describes user interactions (Section 6), input files (Section 7), error messages (Section 8), output files (Section 9), and useful reference materials (Section 10). It provides examples of relevant input, output, and debug files in its Appendices as well as a set of sample test problems to familiarize the user with the run sequence.

It is useful to remember that the present version of CUTTINGS_S's evolved in time through a sequence of WIPP PAs. Design criteria for each PA differed slightly from the set before, and careful readers will detect, especially in the appendices, terminology, test cases, and parameter values such as radioisotope decay data, that serve no apparent purpose in the *present* version of the code. Outdated but working subroutines were normally retained within the code so as to provide versatility. Similarly, some portions of the code (for example, the "stuck-pipe" mode) are working and tested, but they do not come into play because of the parameter values in effect for the CCA calculation. Portions of the code that are not actually called and used in the CCA PA calculations are not to be regarded as part of this software quality-assurance procedure, even though references to them may appear on files included in the appendices.

1.1 Software Identifier:

Code Name: CUTTINGS_S, a borehole waste-removal code for cuttings, cavings, and spallings.

WIPP Prefix: CUSP

Version Number: 5.03

Date: 23/ May/ 96

Platform: FORTRAN 77 for Open VMS AXP, ver. 6.1, on a DEC Alpha.

* The final "_S" in the name signifies "spallings", whose effects the code includes.

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2.0 FUNCTIONAL REQUIREMENTS

The functional requirements stated below are identical to those listed in CUSP's Requirements Document (WPO#: 24320).

2.1 Functional Requirements

R.1 CUSP calculates the amount of repository material brought to the surface due to erosion of the borehole resulting from laminar flow in the drilling fluid.

R.2 CUSP calculates the amount of repository material brought to the surface due to erosion of the borehole resulting from turbulent flow in the drilling fluid.

R.3 CUSP calculates the amount of repository material brought to the surface due to blowout of the borehole.

R.4 CUSP calculates radionuclide chains as a result of initial inventory and radioactive decay, based on the time of intrusion.

R.5 CUSP calculates model specific parameter values based on experimental data.

2.2 Performance Requirements

There are no performance requirements for CUSP.

2.3 Attribute Requirements

There are no attribute requirements for CUSP.

2.4 External Interface Requirements

R.6 CUSP utilizes routines from CAMDAT_LIB, CAMCON_LIB, SDBREAD_LIB, and CAMSUPES_LIB. Consequently it must be linked with these libraries.

R.7 CUSP requires one CDB input file from the BRAGFLO code, CUSP_INP$BRAGCDB

R.8 CUSP requires one input file containing preliminary data base information, CUSP_INP$CDB.

R.9 CUSP requires one input file containing model and site dependent parameters and radionuclide properties, inventories, drilling procedures, and characteristics of the drilling fluid, CUSP_INP$TXT0.

R.10 CUSP requires one input file identifying input sample vector values that will be used in the analysis, CUSP_INP$TXT1.

R.11 CUSP generates one output file CUSP_OUT$DBG, which contains information that is used for comparing with acceptance criteria.

R.12 CUSP generates one output file CUSP_OUT$NVERIFY, which contains information that is used in the functional testing for hand calculations, and is not used in production runs.

R.13 CUSP generates one output CDB (binary) file, CUSP_OUT$CDB, containing output generated by the code.

2.5 Other Requirements

There are no other requirements for CUSP.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

To exercise CUTTINGS_S, users should have (1) basic knowledge of open VMS, (2) basic facility with Digital Command Language, and (3) an overall understanding of Sandia's CAMDAT database, which is used in virtually every WIPP code (Rechard, 1992; and Rechard et al., 1993). User's should also have (4) access to the WIPP cluster of DEC Alpha microcomputers with an open VMS AXP (Ver. 6.1) operating system or their functional equivalents.

To manipulate and/or interpret the results of CUTTINGS_S as it is exercised in WIPP PAs, user's should have (1) a basic understanding of the physics of radioactive decay, the mechanics of laminar and turbulent flow of non-Newtonian fluid suspensions in annular conduits, erosion scouring of matrixed materials, flow through permeable media, and of the large-scale deformation and failure of elastic, plastic, and viscoelastic materials (2) a basic understanding of partial-differential equations and integral calculus, as they apply in the mathematical formulation of physical principles and especially of conservation of momentum, energy, and mass*, (3) a generalist's conceptual understanding of numerical methods as they are applied to the numerical solution of the boundary-value problems of mathematical physics and chemistry, and (4) a basic overview understanding of the WIPP PA process, including conceptual models, scenarios, inventories, uncertainty sampling, input-data vectors, and a general familiarity with the files and functions of the WIPP codes that interface with CUTTINGS_S and especially GENMESH, MATSET, POSTLHS, and BRAGFLO (WIPP PA Dept [5 Volumes], 1992).

* Strictly speaking, the decay of radioisotopes is not mass conserving. It requires loss of mass, although the amounts are insignificant for present purposes. Fluid and gas flows associated with CUTTINGS_S are mass conserving.

4.0 DESCRIPTION OF THE MODEL AND METHODS

The discussion of the model and methods given below is but a brief overview of the theory and methods employed by CUTTINGS_S. It is intended for users who have only a cursory interest in the mathematical and fluid dynamical details. A thorough, detailed treatment of the theory and numerics applied in CUTTINGS_S is given in Appendix A of this manual.

4.1 Description of the Model

CUTTINGS_S is a multi-faceted computational procedure to assess the effects of *direct removal* of wastes buried in a WIPP-like nuclear-waste repository. Direct removal is hypothesized to occur as the result of inadvertent penetration of the repository by a borehole drilled in connection with oil or gas exploration at some unknown time in the future (Berglund, 1993). The word "direct" refers to the fact that CUTTINGS_S removals from the repository to the surface occur *at the time* of drilling. Since drilling operations are normally completed on the time scale of weeks, removal of drilled wastes from the repository to the surface (i.e., the accessible environment) takes place entirely within a single timestep of the much-longer-term groundwater transport codes. Hence, the word "direct" should be taken to mean "from the repository to the surface within a single timestep of a typical WIPP groundwater code."

Removal is subdivided according to process, which results in three principal categories, herein labeled A, B, and C. First, the borehole is assumed (A) to penetrate directly through waste containers stored within the repository. The drill bit cuts directly through the waste containers, allowing those repository wastes located on a collision course with the drill bit (called cuttings) to be transported directly and immediately to the surface via the cooling fluid (muddy brine) that is circulated through the borehole during drilling. The volume of repository material removed as cuttings is the portion of the deformed repository cut by the borehole.

Wastes that originally bordered the borehole on its exterior are permitted to erode into the cooling fluid as a result of the fluid's frictional effects on the outer cylindrical surface of the borehole. If shear stresses in the cooling fluid at the wall exceed the shear strength of the matrixed materials located at the wall, (B) erosion will occur and wall material (cavings) will be removed*. As a result, the borehole diameter may increase locally at the level of the repository. Because of that action, the volume of wastes removed from the repository can actually be larger than the volume of the borehole originally cut through the wastes. As the diameter of the borehole increases, the fluid shear stresses at the outer boundary decrease. If they decrease enough that the failure stress of the wall material equals or exceeds the fluid shear stress at the outer boundary of the flow region, then the caving process will terminate. CUTTINGS_S allows for both laminar and turbulent shear flow in the circulating fluids, which, in turn, leads to two different models to assess the effects of material removal due to erosion. If the cooling-fluid flow is laminar, CUTTINGS_S employs an analytical solution of the modeling equations to

* In tightly matrixed or crystaline media such as the WIPP-site halite formation, exploratory boreholes are usually unlined. Rather, the drilling fluid is changed to saturated salt solution to minimize dissolution at the walls, and the borehole is permitted to support itself until the drill bit reaches granular strata below the halite horizon.

evaluate wall stresses and other flow parameters. The analytical solution takes the form of non-linear integral equations, which CUTTINGS_S evaluates via an iterative numerical procedure. If the flow is turbulent, CUTTINGS_S turns to a simpler empirical model to evaluate the turbulent shear stresses. Transition to turbulence is assumed to occur at a Reynolds number greater than 2100. In nature, the transition to turbulence actually occurs over a range of Reynolds numbers and is not an abrupt process. Normally there is a transitional regime during which the flow is partly laminar and partly turbulent with active and chaotic transitions between the two states. CUTTINGS_S does not attempt to model the transition regime. Rather, it assumes the flow becomes fully and abruptly turbulent when the Reynolds exceeds 2100. CUTTINGS_S employs a corrective procedure to compensate for the effects of that assumption (see Appendix A for details). To date, all WIPP-like runs have required turbulent cooling-fluid flow.

The cuttings/cavings model described thus far is functionally similar to the CUTTINGS model used in previous WIPP PAs (WIPP PA Dept, 1992, Vol 1). However, an important new element has been added to the newer CUTTINGS_S code, namely, the inclusion of a third material-removal mechanism, removal in the form of spallings, which is discussed below.

If the repository is pressurized at the time of penetration, and if the pressure within the repository is high enough (i.e., above the hydrostatic pressure in the cooling-fluid column), repository materials originally surrounding the borehole, but interior to the repository-fluid interface, can be (C) forced to deform inward toward the borehole so as to replace the materials already removed by action of (A) the cutting bit and (B) the erosive brine. The solid fraction of these new materials are called spallings*. Depending on the parameters of the problem, spalling deformations can be rapid, or they can be a sluggish, more like a large-amplitude, viscoelastic flow. If repository materials are relatively impermeable, the spalled materials can deform slowly inward so as to press against the rotating drill string. If repository pressures are high enough, frictional forces against the drill string may be high enough to stop the drill from turning. In that event, drillers normally withdraw the drill (vertically) and redrill downward through the spalled materials that clog the borehole. On occasion, that procedure must be repeated more than once. If repository materials are more permeable, the pressurized gas may simply seep through the matrix carrying loose particles with it. Alternatively, if repository pressures are too low, the spallings part of CUTTINGS_S may do nothing at all, in which case CUTTINGS_S will operate as its parent code, CUTTINGS, operated. The possibilities are varied, and CUTTINGS_S is designed to be applicable in any of the various hypothesized WIPP-drilling modes. Thus, CUTTINGS_S is perhaps best thought of as several related models, applicable to several sets of drilling circumstances, rather than as one all-encompassing, single-mode model. Moreover, CUTTINGS_S may have to be applied more than once during an assessment run, at more than one intrusion time, since multiple borehole intrusions are permissible in WIPP PAs.

* If the repository is wet with brine at time of penetration, which possibility is allowed in WIPP PAs, three phases of material could, in principle, flow toward the borehole, namely: pressurized gases, pressurized brine, and solid wastes. CUTTINGS_S estimates only the amount of solids that are moved into the borehole. Pressurized brine that may be released into the borehole is treated by an indepenednt WIPP code named DBR_BRAGFLO. The gas flow, although crucial to the overall deformational process, transports no radioisotopes and is therfore not assessed.

The total volume of repository material removed by CUTTINGS_S is the sum over all intrusions of (A) the material directly in line with the borehole that is directly cut by the drill bit (cuttings), (B) the material directly surrounding the borehole that is eroded into the borehole through the shearing action of the flowing cooling fluid (cavings), and (C) the material that was originally remote from but in the neighborhood of the borehole and was deformed toward and eventually into the borehole by the action of repository gas pressures (spallings). Options (A) and (B) are assumed to operate continuously, whereas option (C) operates only when repository pressure conditions permit it (the cut off being 8MPa.). The amount of material removed by each process, during each hypothesized drilling intrusion is reported in CUTTINGS_S's output in terms of an equivalent area. Downstream WIPP codes, namely CCDFGF, (1) use BRAGFLO's repository-height data (from SANTOS) to convert the equivalent areas to volumes of repository material, and then (2) assign various sampled aged repository contents to convert these material volumes to releases. Thus, (3) CCDFGF evaluates the release effects of striking contact-handled versus remote-handled wastes. The reader is referred to Appendix A for details.

The fluid-flow portion of CUTTINGS_S is based on a non-linear analytical integral solution for laminar helical flow of a non-Newtonian (Oldroyd-type) fluid in an annular pipe, and on empirical equations for turbulent flow in the same geometrical configuration. CUTTINGS_S acquires its parameter data from (i) the input CDB files provided by the WIPP codes MATSET and BRAGFLO, (ii) a user-supplied input text file, and (iii) the carefully controlled and QAed WIPP property database. Discrete values of sampled data are provided by the WIPP sampling code POSTLHS in cases where parameter uncertainty is judged to impact assessments of the repository's performance. CUTTINGS_S input includes the rotational speed of the drill string, cutting-bit diameter, the shear-rate-dependent viscosity and density parameters for the drilling mud, borehole roughness, the compacted repository thickness and porosity, and the effective failure shear strength of the compacted repository material. A few required parameters, namely drilling-mud flow rate and drill-collar diameter, are calculated internally by the code, based on present-day oil-drilling industry guidelines.

4.2 Description of the Modeling Methods

CUTTINGS_S does not endeavor to integrate conservation equations characterizing the flow on a point-for-point, time-for-time basis in search of a detailed space-time history of the removal process. Rather, removal is treated as instantaneous, that is, within a single timestep of the longer-term groundwater codes. Thus, numerical methods are used primarily to determine the limiting values of the physical parameters that represent the final configurations of the various (sampled) drilled systems, which is all that is required to assess radioactive waste removal due to the cuttings, cavings, and spallings that arise during drilling operations. These methods are fairly straightforward, iterative, recursive approximation techniques that involve systems of algebraic equations. They are discussed thoroughly in Appendix A (Sections 2.2.1.1, 2.2.2.1, and 2.4.1.2.1), which is highly recommended to readers who aim to understand this code.

5.0 INHERENT CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

CUTTINGS_S is not presently put forward as a general borehole-mechanics code. Rather, it was developed with WIPP-like conditions and applications firmly in mind. To function properly, it requires inputs from other WIPP PA codes, specifically GENMESH, MATSET, POSTLHS, and BRAGFLO. Thus, although CUTTINGS_S is quite likely to be fully applicable to other kinds of boreholes, other geologies, and other parameter ranges, it is not presently recommended for applications outside the presently-conceived boundaries that define the WIPP, primarily because such applications have not yet been tested. Consequently, no claims are made that CUTTINGS_S should give reasonable results for parameter ranges that are atypical of the WIPP and its immediate environs.

All aspects of CUTTINGS_S are based on the present-day drilling methods and technologies that would apply at a WIPP-like site. CUTTINGS_S has been tested under those conditions and those conditions only. Hence, applications beyond the limits of those assumptions are not recommended at this time.

6.0 USER INTERACTIONS WITH THE SOFTWARE

Before launching into the exercising of CUTTINGS_S, the reader is reminded that CUTTINGS_S is normally exercised as one of a sequence of codes that includes GENMESH, MATSET, and POSTLHS, and requires input data files that originate with the code BRAGFLO. To assist the reader, the code sequence is depicted in figure 1, and examples of the input control files required by GENMESH and MATSET in preparation for a CUTTINGS_S run are given in Appendix B. POSTLHS requires an input control file, but it is empty.

6.1 Exercising CUTTINGS_S Interactively

CUTTINGS_S has been modified in comparison with its parent code, CUTTINGS, so as to remove the possibility of user-interactive runs. This change is in keeping with preparations for the 1996 CCA PA in which no interactive runs are foreseen.

To execute CUTTINGS_S from a command line, it is necessary to define a logical symbol that invokes its executable, by typing either of the following two lines at the VMS $ prompt:

$CUSP := "$WP$PRODROOT:[CUSP.EXE]CUSPPA96.EXE" <CR>*

or

$CUSP := "$WP$TESTROOT:[CUSP.EXE]CUSP_TEST_NODBG.EXE"

The two executables are equivalent. Only their locations on the system differ. The first executable resides in the production-run (the CCA PA) portion of the system, and the second resides in the Quality-Assurance (QA) test-problem Configuration-Management-System (CMS) portion of the system. No matter which definition is used, typing "$CUSP" and striking the carriage-return key will result in invoking CUTTINGS_S's executable.

Like all WIPP codes, CUTTINGS_S must be made aware of the names of and paths to the suite of input files it requires in order to exercise. It must also be given user-selected names for the files to which it will write its output. In command-line execution mode, CUTTINGS_S will search for files by reviewing its internal list of logical symbols associated with input/output files. Thus, the user must inform CUTTINGS_S which of its list of internal logical symbols corresponds to which input or output file for that specific run. That information is normally transferred by typing (at the VMS $ prompt that will appear after defining the executable logical) a line such as the following:

$DEFINE CUSP_INP$CDB XY:[ABC.DEF.GHI]JKL.MNO

* In this user's manual, VMS commands will always be entered by striking the carriage-return key. That instruction will not be repeated hereafter.

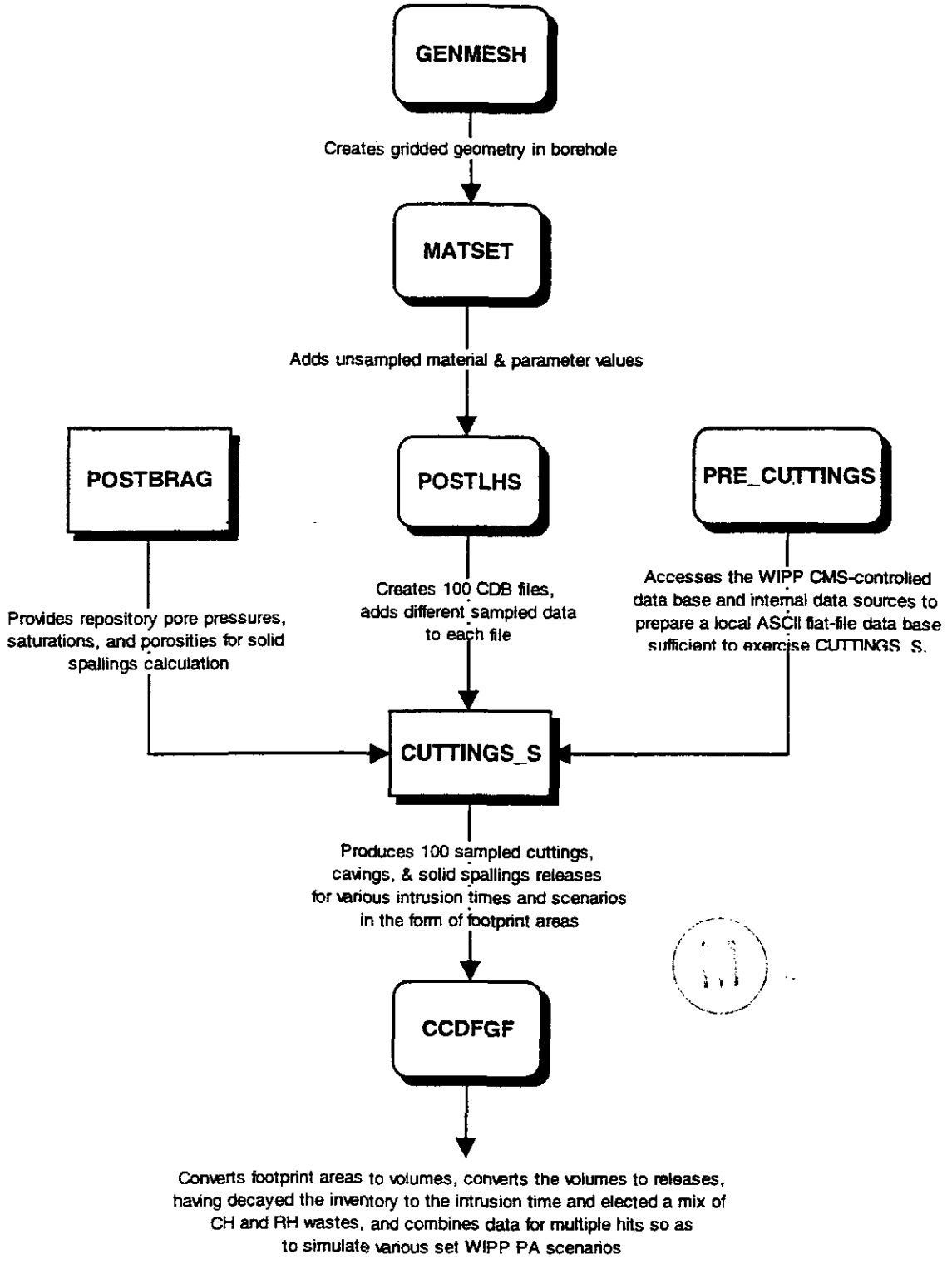

Figure 1: The code sequence for CUTTINGS_S in the 1996 CCA PA.

where XY:[ABC.DEF.GHI]JKL.MNO represents the specific input file the user wishes to associate with the input logical CUSP_INP$CDB . The path need be included only if the file resides other then in the local working-level directory.

6.2 CUTTINGS_S's Input/Output File Structure

Up to 11 logical symbols may be associated with CUTTINGS_S's various input/output files. Of them, 6 are required and 5 are optional in regulatory runs. Before discussing the nature and function of the 11 possible input/output files, we first list them one-by-one, for ready reference, together with their corresponding logical symbols. They are:

File ID No.	Input/Output File Names	Associated Logical Symbol	Is the file Required or Not?
1.	Binary input CAMDAT file (from MATSET)	CUSP_INP$CDB	Yes
2.	Input control file (text) specifying repository/model parameters, initial inventories, generic radioisotope database.	CUSP_INP$TXT0	Yes
3.	Input control file (text) specifying drilling and intrusion parameters	CUSP_INP$TXT1	Yes
4.	BRAGFLO binary output .CDB file.	CUSP_INP$BRAGCDB	
	Regulatory runs		Yes
	Test runs		No
5.	CUTTINGS_S's binary output .CDB file	CUSP_OUT$CDB	Yes
6.	CUTTINGS_S's output debug text file	CUSP_OUT$DBG	Yes
7.	Text file for verification testing	CUSP_OUT$NVERIFY	No
8.	Radioisotope inventory history (in CURIES) output text file	CUSP_OUT$IHISTO	No
9.	Normalized-release-history output text file (EPA 40CFR191, Subpt B) file in ASCII format	CUSP_OUT$NHISTO	No
10.	Time-history plotting text file for:		
	Long half-life radioisotope decay	CUSP_OUT$PLT1	No
	Medium half-life radioisotope decay	CUSP_OUT$PLT2	No
	Short half-life radioisotope decay	CUSP_OUT$PLT3	No
11.	Output text file for transfer to the WIPP code CCDFPERM	CUSP_OUT$ICTRN	No

The first four files of the above list are CUTTINGS_S's input data and control files. They are described briefly in Section 7.0 of this user's manual. The text-format input files include specific examples printed out in full in the appendices of this user's manual. Appendix C is included to assist the user in understanding the format used in CUTTINGS_S's input control files (file numbers 1 and 2).

The last seven files of the above list are CUTTINGS_S's output files. They are described briefly in Section 9.0 of this user's manual. Of the required output files, only the debug file is created in text format. One example of a CUTTINGS_S output file is included in Appendix D. It is a debug file. It is annotated with italicized remarks that identify and explain the various groups of data that are reported therein.

6.3 Exercising CUTTINGS_S

Once the logical symbol CUSP has been defined (see Section 6.1), and the necessary input and output files have been properly assigned (see Sections 6.1 and 6.2), CUTTINGS_S may be exercised simply by typing the logical symbol:

$CUSP

followed by a carriage return. If all goes well, CUTTINGS_S will run and issue a "normal completion" message. If errors are encountered, CUTTINGS_S will abort and issue an error message(s). See Section 8.0 for a listing of the possible error messages CUTTINGS_S can produce.

6.4 Exercising CUTTINGS_S's Test Problems in Batch Mode

To run all five of CUTTINGS_S's QA test problems in a single run, type the following command sequence:

$LIBCUSP

$CFE CUSP_TEST_ALL.COM

$@CUSP_TEST_ALL "Generation Number"

At this point, a command file that defines all of the input and output files associated with the five QA test problems will be invoked, and the five problems will be executed. As a result, all of the various input files and output files generated in the process will be available for examination. It is recommended that new users carry out the above exercise and familiarize themselves with the results before going on to regulatory-type calculations. The command @CUSP_TEST_ALL may have a "generation number" appended as a parameter. In the absence of a generation number, CUTTINGS_S chooses the current test-problem set. If earlier test-problem sets are of interest, they may be specified by appending a generation number to the command.

To run any single test problem, type the following command sequence:

$LIBCUSP

$CFE CUSP_TEST_BAT.COM

$@CUSP_TEST_BAT "Problem Number"

The specified test run will now exercise and produce for the user's perusal the input and output files associated with the specified "Problem Number."

To run the calibration problem; the following command sequence is typed:

$CFE CUSP_TEST_CALIBRATE.COM

$@CUSP_TEST_CALIBRATION

The calibration problem exercises in roughly 10 to 15 minutes, and produces two output files. The first output file is named CUSP_TEST_CAL_EXP.VER and is an echo of the input file. The second output file is named CUSP_TEST_CAL_EXP.PLT and provides a history of the search to find minimized values of FSE, FGE, and FCE (see Appendix A for definitions of nomenclature).

6.5 Using CUTTINGS_S's PRE_CUTTINGS Mode

Because interactions with the controlled WIPP database require large and unnecessary expenditures of input/output time during production runs, CUTTINGS_S includes a special operational mode designed to expedite data acquisitions during production runs. It is called PRE_CUTTINGS, and in it, the WIPP QAed property database is accessed but once during an entire production run. PRE_CUTTINGS reads a template file that interfaces the WIPP property database, extracting the required values and writing them to an ASCII file that can be read time and again by CUTTINGS_S without subsequent reference to the property database. The ASCII data file thus produced is under strict CMS control.

PRE_CUTTINGS's template file, which is shown in Appendix E, treats three data types. The first type is exemplified by CUTTINGS_S's code parameters, which are discussed in the theoretical Manual (see Appendix A). These values are essential to exercising CUTTINGS_S, but were not entered as part of the WIPP's CCA controlled database. They are discussed in detail in Appendix A. The second type are common property values as taken from the WIPP's CCA controlled database. For example, the datum BOREHOLE:L1 is called. In this example, the colon at mid word identifies the form as a WIPP controlled database property. BOREHOLE is the material identifier and L1 is the parameter identifier. Using these two keywords, the WIPP property database is scanned until the numerical value associated with that specific parameter is

located. CUTTINGS_S then writes to the new template the parameter identifier L1 and the corresponding numerical value that was found in the database.

The third data type in the input template file includes the 10 radioisotope decay chains and the 29 specific radioisotopes that have initial inventories, which are denoted by the word "SAVE." CUTTINGS_S tracks selected data for all of these radioisotopes. When CUTTINGS_S encounters the key word "GENERATE_RADIO", it sorts the list alphabetically and for each unique radioisotope, it queries the property database for atomic weight, half life, EPA release limit, initial contact-handled inventories, and initial remote-handled inventories. The code converts the half life in seconds to half life in years and calculates the specific activation energy, which is a function of atomic weight and half life. The code then writes all the necessary radioisotopic properties in tabular form. Appendix F is an example of the output ASCII text file from PRE_CUTTINGS. Appendix G is a sampled "COM" file to test this portion of the code. Because this functionality of the code is basically data in / data out, it was not assigned a specific test problem.

6.6 Using CUTTINGS_S's CHECK_OUT Mode

CUTTINGS_S has a special mode, called "CUSP$CHECK_OUT," designed to check the agreement between Model 2's blowout calculation and corresponding experimental results. CHECK_OUT was added so the blowout model could be used for confirmation of experiential results. The CHECK_OUT mode is set by specifying "CUSP$CHECK_OUT" as TRUE in DEC's Digital Command Language (DCL). Appendix H provides a listing of the DCL nomenclature required to exercise this operational mode. The CUTTINGS_S input file CUSP_INP$TXT0 provides data for the experimental input, the geometry of the test fixture, and the properties of air. It is also shown in Appendix H. In CHECK_OUT mode, three functions can be performed, as follows:

1. The "EXPERIMENT" function is set by including the keyword EXPERIMENT in the CUSP_INP$TXT1 text file. It allows CUTTING_S to be run as though data is being gathered from an experimental run.

2. The "VALIDATE" function is set by including the keyword VALIDATE in the CUSP_INP$TXT1 text file. It allows CUTTINGS_S to be run over the total range of possible inputs and thereby checks the code for numerical instabilities.

3. The "CALIBRATE" function is set by including this keyword CALIBRATE in the CUSP_INP$TXT1 text file. This function searches for the optimum values of FSE & FGE (see Appendix A) to minimize the error between the experiential results and the computer model. The CALIBRATE function is illustrated as a test problem #6 in the Validation Document.

The input files for these three functions are also shown in Appendix H.

7.0 DESCRIPTION OF CUTTINGS_S'S INPUT FILES

CUTTINGS_S's input files are listed in Section 6.2 together with their corresponding CUTTINGS_S logical symbols. They are file numbers 1 through 4 in that listing.

File 1. CUSP_INP$CDB is the principal input CDB file and is absolutely required by CUTTINGS_S. It is the file to which CUTTINGS_S's results will be transferred and it is normally provided by an upstream code such as MATSET. In production runs, sampled data from POSTLHS would be fed to this input file. In that case, there would be N input CDB files, one for each of the sampled values where N is the number of samples employed. In test-case mode or debug mode, it is inconvenient to open the editor and hand build an input CDB file for specific input values. However, even in test or debug mode, CUTTINGS_S expects to receive an input CDB file. As a convenience to users, an all-purpose, input CDB file for use with test problems and in debug runs is stored in the configuration-management-system (CMS) portion of the WIPP Alpha cluster. It is named: CUSP_TEST_1.CDB and can be called by typing:

$LIBCUSP

$CFE CUSP_TEST_1.CDB

File 2. CUSP_INP$TXT0 is an ASCII input control file that contains various repository, drill geometry, and material input parameters required by CUTTINGS_S. File 2 also contains the required radioisotope inventory data for the scenario currently under study. In regulatory calculations, these data are taken directly from the controlled WIPP property database. File 2 also provides radioisotope data essential for (1) the Bateman (1910) decay calculation, for (2) calculation of radioactive release values in Curies, and for (3) normalizing calculated releases in terms of the Environmental Protection Agency's (EPA's) 40CFR191 release limits (WIPP PA Dept [Vol 1], 1992). A sample CUSP_INP$TXT0 file usable for QA test and/or debug problems is available in the CMS portion of the WIPP Alpha cluster. It is named: CUSP_TEST_REPOSITORY.DAT , and it is printed in full in Appendix I of this user's manual. Most of its parameters are specific to the CUTTINGS_S model and to individual radioisotopic properties.

File 3. CUSP_INP$TXT1 is an ASCII input control file that contains various drilling and intrusion input parameters required by CUTTINGS_S. A sample CUSP_INP$TXT1 file usable for test and/or debug runs is available in the CMS portion of the WIPP Alpha cluster. It is named CUSP_TEST_#.INP where # is the QA test problem number and varies from 1 through 5. In a normal production run, this file would contain no specific input data other than an intrusion time. Instead, only character variables would appear, identifying the element property name on the input CDB file. Values would then be assigned from the secondary database (see item 4, below). Appendix J is sample printout of a typical production input file. For specific testing or

debugging, this file would have fixed specific numerical values. Appendix K is a listing of CUSP_TEST_2.INP.

File 4. CUSP_INP$BRAGCDB is the output CDB file from BRAGFLO as it is exercised in the undisturbed or disturbed scenarios. CUTTINGS_S extracts from it (1) the repository porosity at time of decommissioning, and (2) the repository porosity and (3) repository pressure at the specified intrusion time. In regulatory calculations, these data would be provided by a regulatory BRAGFLO run. For QA testing and debug purposes, a fixed BRAGFLO output CDB file has been stored in the CMS portion of the WIPP Alpha cluster. It is named CUSP_TEST_INP_BF.CDB , and it is the BRAGFLO output file used for test problem 1.

8.0 ERROR MESSAGES

Numerous procedural errors can cause CUTTINGS_S to abort. In general, these errors relate to the improper input of data. By noting where the code was when the abort occurred, and what the code was trying to read at the time, these problems can generally be resolved. However, there is not specific advice that can be offered to users in resolving errors beyond the general statement: locate the error and repair it. However, Appendix L, which was extracted primarily from the source code, contains useful operating notes and tips to the user. They are included purely because the code sponsor felt they might be useful to novice users.

To familiarize readers with CUTTINGS_S's error-message patterns, CUTTINGS_S's various error messages are listed below, section for section within the code.

SUBROUTINE ADDMEM(MORMEMR, MORMEMC)

```
   CALL QAABORT(
$  '(ADDMEM) - REAL array size errors detected ***')
   CALL QAABORT(
$  '(ADDMEM) - REAL array memory errors detected ***')
   CALL QAABORT(
$  '(ADDMEM) - CHARACTER array size errors detected ***')
   CALL QAABORT(
$  '(ADDMEM) - CHARACTER array memory errors detected ***')
   CALL QAABORT('(ADDMEM1) - REAL array size errors detected ***')
   CALL QAABORT('(ADDMEM1) - REAL memory errors detected ***')
   CALL QAABORT(
$  '(ADDMEM1) - CHARACTER array size errors detected ***')
   CALL QAABORT(
$  '(ADDMEM1) - CHARACTER array memory errors detected ***')
   CALL QAABORT('(ADDMEM2) - REAL array size errors detected ***')
   CALL QAABORT('(ADDMEM2) - REAL memory errors detected ***')
   CALL QAABORT(
$  '(ADDMEM2) - CHARACTER array size errors detected ***')
   CALL QAABORT(
$  '(ADDMEM2) - CHARACTER array memory errors detected ***')
   CALL QAABORT('(ADDMEM3) - REAL array size errors detected ***')
   CALL QAABORT('(ADDMEM3) - REAL memory errors detected ***')
   CALL QAABORT(
$  '(ADDMEM3) - CHARACTER array size errors detected ***')
   CALL QAABORT(
$  '(ADDMEM3) - CHARACTER array memory errors detected ***')
```

SUBROUTINE BRGCDB(MAXC, MAXQ, IQ, LQ, Q, C, IERRDB)

```
 IF(IERRDB.NE.0)CALL QAABORT('(BRGCDB) - reading input CAMDAT '//
$                    'sizing parameters ***')
 IF(IERRDB.NE.0)CALL QAABORT('(BRGCDB) - reading input CAMDAT '//
$                    'TITLE ***')
 IF(IERRDB.NE.0)CALL QAABORT('(BRGCDB) - reading number of input'//
$                    ' CAMDAT analysis variables ***')
```

SUBROUTINE DRILL(IWASFLG, IHIT, XTINT, DBDIAM, TUNITS, XNEWAREA)

```
    CALL QAABORT('(DRILL) - Negative ROUTER %%%')
```

SUBROUTINE GETVAL(NOUTFL, NUQPRP, NELBLK, VARNAM, IASPRP,
$ XMATPR, NAMELB, NMATPR, XVAL)

```
   CALL QAABORT('(GETVAL) - ILLEGAL I.C. interpolation '//
+          'variable value range name ***')
```

INTEGER FUNCTION GINDX(RADNAM, IDMTRL)

```
   CALL QAABORT('(GINDX) - cannot locate nuclide index in '//
$          'generic radioisotope data base (GRDB) ***')
```

INTEGER FUNCTION GJNDX(RADNAM, NUCNAM)

```
   CALL QAABORT('(GJNDX) - cannot locate nuclide index in '//
$          'unique radioisotope names array (NCUNAM(*)) ***')
```

SUBROUTINE GSDBQA(FSDB, NQAREC, QAINFO)

```
   CALL QAABORT('(GSDBQA) - Error reading SDB version number '//
$          'using SDBREAD_LIB routine: SDBQERRY ***')
   CALL QAABORT('(GSDBQA) - Error reading SDB geology name/t'//
$          'ype using SDBREAD_LIB routine: SDBQERRY ***')
```

PROGRAM CUSP_MAIN

```
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Setting up DYNAMIC'//
$                          ' base arrays ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Opening input '//
$                          ' CAMDAT ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Setting up DYNAMIC'//
$                          ' base arrays ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Opening input '//
$                          ' CAMDAT ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
$                          ' input text file 1 ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
$                          ' input parameter text file  ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
$                          ' input parameter binary file  ***')
 IF(IERRDB.NE.0) CALL QAABORT ('(BRGCDB) - Check BRAG CDB ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Opening output'//
$                          ' CAMDAT and SCRATCH files ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Closing input '//
$                          'CAMDAT ***')
 IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - Trouble closing'//
$                          ' output cdb-scratch & CAMDAT files, etc... ***')
```

SUBROUTINE MEMADJ(MORMEM, MNUSED, Q)

```
   CALL QAABORT('(MEMADJ) - Invalid REAL dynamic array '//
+          'indices detected ***')
   CALL QAABORT('(MEMADJ) - REAL DYNAMIC MEMORY '//
+          'ALLOCATION ERRORS ***')
   CALL QAABORT('(MEMADJ2) - Invalid REAL dynamic array '//
+          'indices detected ***')
   CALL QAABORT('(MEMADJ2) - REAL '//
$           'DYNAMIC MEMORY ALLOCATION ERRORS ***')
   CALL QAABORT('(MEMADJ3) - REAL '//
$           'DYNAMIC MEMORY ALLOCATION ERRORS ***')
```

SUBROUTINE MEMADJC(MORMEMC, MNUSED, C)

```
      CALL QAABORT('(MEMADJ) - Invalid CHARACTER dynamic array '//
     +          'indices detected ***')
      CALL QAABORT('(MEMADJC) - CHARACTER DYNAMIC MEMORY '//
     +          'ALLOCATION ERRORS ***')
      CALL QAABORT('(MEMADJC2) - Invalid CHARACTER dynamic array '//
     +          'indices detected ***')
      CALL QAABORT('(MEMADJC2) - CHARACTER '//
     $           'DYNAMIC MEMORY ALLOCATION ERRORS ***')
      CALL QAABORT('(MEMADJC3) - ### CHARACTER ### '//
     $           'DYNAMIC MEMORY ALLOCATION ERRORS ***')
```

SUBROUTINE PARBIN0

```
      CALL QAABORT(' (PARBIN0) - PARBIN0 error input parameters ***')
```

SUBROUTINE PARTXT0

```
      IF (IERR .GT. 0) CALL QAABORT(
     $                    ' (PARTXT0) - PARTXT0 error input parameters ***')
```

SUBROUTINE PREPRO(FIDB, FTXT0, FBIN0, FTXT1, FODB, FBRG)

```
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening PRE_CUTTINGS'//
     $                 ' input template file ***')
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening PRE_CUTTINGS'//
     $                 ' input desc_0500 file ***')
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening PRE_CUTTINGS'//
     $                 ' input text file 1 ***')
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
     $                 ' output ascii SDB file ***')
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
     $                 ' output binary SDB file ***')
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
     $                 ' input text file 0 ***')
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
     $                 ' input text file 1 ***')
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
     $                 ' output verify file ***')
      IF(IERR.NE.0)CALL QAABORT('(CUSP_MAIN) - opening CUTTINGS'//
     $                 ' output plot file ***')
```

```
SUBROUTINE PROCDB( MAXC, MAXQ, IQ, LQ, Q, C )

  IF(IERR.NE.0)CALL QAABORT('(PROCDB) - reading input CAMDAT '//
$                    'sizing parameters ***')
  IF(IERR.NE.0)CALL QAABORT('(PROCDB) - reading input CAMDAT '//
$                    'TITLE ***')
  IF(IERR.NE.0)CALL QAABORT('(PROCDB) - reading number of input'//
$                    ' CAMDAT analysis variables ***')
```

```
SUBROUTINE PROSDB( MAXC, MAXQ, IQ, LQ, Q, C , IWASFLG, QAINFO )

  IF (IABORT .NE. 0)
& CALL QAABORT('(CUSP_PROSDB) - finding data in the INGRES SDB'//
&            ' database ***')
```

```
REAL*4 FUNCTION QUANKG( DT,    LPOINT, NRILC,  NLEFT,  RADCHN,
$                NGRAD,  IDMTRL, HALFY,  AWT,    XMOLES )

  CALL QAABORT('(QUANKG) - cannot find all radioisotopes in '//
$            'local chain in GRDB rad. names array ***')
```

```
SUBROUTINE REABIN0( NNIC,   RADCHN, IDMTRL, NUCNAM,
$              MAPSAV, SAVNAM, HALFS,  HALFY,  AWT,
$              ACTCNV, EPAREL,CIPMSQ, MAPINV, IWASFLG )

CALL QAABORT(' (PARBIN0) - PARBIN0 error input parameters ***')
```

```
SUBROUTINE REASDB (DBNAME, CALC_NAME, IDMTRL, IDPRAM, MEDIAN,
&              IABORT)

CALL QAABORT('(CUSP_PROSDB) - extracting '//
$          ' idmtrl, idpram ***')
```

```
SUBROUTINE REATXT0( NNIC,   RADCHN, IDMTRL, NUCNAM,
$              MAPSAV, SAVNAM, HALFS,  HALFY,  AWT,
$              ACTCNV, EPAREL, CIPMSQ, MAPINV, IWASFLG )

  IF (ICHECK .GT. 11111)
& CALL QAABORT('(REATXT0) - read errors radionuclide input***')
```

```
 IF(IERR.GT.0)CALL QAABORT('(REATXT0) - read errors ***')
        CALL QAABORT('(REATXT0) - Repeating/Duplicate radio'//
$                'isotope names in chain ***')
   CALL QAABORT('(REATXT0) - Illegal names in "SAVE" '//
$            'radionuclides list %%%')

-----------------------------------------------------------------
 SUBROUTINE REATXT1( IASPRP,  NAMELB,  NMATPR, XMATPR, TINT,      1
&            DIAMMOD, TUNITS,  PORO,   TCLOUT, PRESSR,
&            PARTDIA, SATGASX, CEMSIG, FGE,    FSE,
&            FCE )

    CALL QAABORT('(REATXT1) - ILLEGAL drilling bit diamet'//
&            'er specified (<=0) ***')
 IF(IERR.GT.0)CALL QAABORT('(REATXT1) - read errors ***')

-----------------------------------------------------------------
 SUBROUTINE RECHEA( Q,     C,     IDEBLK, NUMPRP, IASPRP,       1
$            XMATPR, QAINFO, NAMELB, NMATPR )

  IF(IERR.NE.0)
$  CALL QAABORT('(RECHEA) - reading material ID and names array ***')
  IF(IERR.NE.0)
$  CALL QAABORT('(RECHEA) - reading PROPERTY NAMES array ***')
  IF(IERR.NE.0)
$  CALL QAABORT('(RECHEA) - reading PROPERTY values ***')
  IF(IERR.NE.0)CALL QAABORT('(RECHEA) - reading QA array ***')
  IF(IERR.NE.0)CALL QAABORT('(RECHEA) - obtaining input CAMDAT '//
$                'no. of time steps ***')

-----------------------------------------------------------------
SUBROUTINE RGRDB( IDMTRL, HALFS, HALFY, AWT, ACTCNV, EPANORM )  1

   CALL QAABORT('(RGRDB) - read errors ***')
   CALL QAABORT('(RGDB) - counting entries in GRDB ***')

-----------------------------------------------------------------
 SUBROUTINE SCASDB( FSDB,  NENTRY, ID1,   ID2,   ID3,          1
$            ID4,  ID5,   ID6,   ID7,   IDENT )

   CALL QAABORT('(SCASDB) - Bad SDB initialization *****')
   CALL QAABORT('(SCASDB) - Error calling SDBREAD_LIB routine'//
$            ': SDBCASES ***')
   CALL QAABORT('(SCASDB) - Error calling SDBREAD_LIB routine'//
$            ': SDBINFO ***')
```

```
      CALL QAABORT('(SCASDB) - Error calling SDBREAD_LIB routine'//
     $           ': SDBNINFO ***')
      CALL QAABORT('(SCASDB) - keyword IDMTRL missing on SDB '//
     $           'header description ***')
      CALL QAABORT('(SCASDB) - keyword IDPRAM missing in SDB '//
     $           'header description ***')
      CALL QAABORT('(SCASDB) - keyword IDSCAL missing in SDB '//
     $           'header description ***')
      CALL QAABORT('(SCASDB) - keyword MEDIAN missing in SDB '//
     $           'header description ***')
      CALL QAABORT('(SCASDB) - keyword LOWRNG missing in SDB '//
     $           'header description ***')
      CALL QAABORT('(SCASDB) - keyword HIRNGE missing in SDB '//
     $           'header description ***')
      CALL QAABORT('(SCASDB) - keyword UNITS missing in SDB '//
     $           'header description ***')

-----------------------------------------------------------------------
      SUBROUTINE SCATXT0( IWASFLG, NAMELB, KOMAT,  OUTMAT, IDMTRL,    1
     $                    QAINFO,  ISETUP )

      IF(N.NE.NGRAD)CALL QAABORT(
     $' (SCATXT0) - SCATXT0 input text for generic sizing ***')
      IF(IERR.GT.0)CALL QAABORT(
     $' (SCATXT0) - SCATXT0 input text for sizing parameters ***')

-----------------------------------------------------------------------
      SUBROUTINE SCATXT1( IWASFLG, IASPRP, XMATPR, NAMELB, NMATPR,    1
     &                    IDMTRL,  OUTMAT )

      IF (MULTP .NE. JULTP) CALL QAABORT(
     & ' (SCATXT1) - SCATXT1 MULTP gt NULTP ***')
      IF (MULTP .GT. NULTP) CALL QAABORT(
     & ' (SCATXT1) - SCATXT1 order of multiple hits wrong ***')
      IF (INUM .GT. NRMS) CALL QAABORT(
     &    ' (SCATXT1) - SCATXT1 INUM gt NRMS ***')
999   IF(IERR.GT.0)CALL QAABORT(
     &' (SCATXT1) - SCATXT1 input text for sizing parameters ***')

-----------------------------------------------------------------------
      SUBROUTINE SGRDB                                                1

        CALL QAABORT('(SGRDB) - Illegal GRDB format ***')
666   IF(IERR.GT.0)CALL QAABORT('(SGRDB) - read errors ***')
-----------------------------------------------------------------------
```

```
      SUBROUTINE WRCHEA( IWASFLG, Q,     CH,     IASPRP, NMATPR,     1
     $           QAINFO,  LDUMP,  RDUMP,  KOMAT,  NUCNAM,
     $           SAVNAM,  MAPSAV )

      IF(IERR.NE.0)CALL QAABORT(
     $  '(WRCHEA) - ADDING "DENSITY" as a CAMDAT property ***')
      IF(IERR.NE.0)CALL QAABORT(
     $  '(WRCHEA) - ADDING "DOMEGA" as a CAMDAT property ***')
      IF(IERR.NE.0)CALL QAABORT(
     $  '(WRCHEA) - ADDING "ABSRO" as a CAMDAT property ***')
      IF(IERR.NE.0)CALL QAABORT(
     $  '(WRCHEA) - ADDING "TAUFAIL" as a CAMDAT property ***')
      IF(IERR.NE.0)CALL QAABORT(
     $  '(WRCHEA) - ADDING "VISCO" as a CAMDAT property ***')
      IF(IERR.NE.0)CALL QAABORT(
     $  '(WRCHEA) - ADDING "YLDSTRSS" as a CAMDAT property ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Trouble writing '//
     $'CUTTINGS SDB QA record to CDB-scratch file ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Trouble writing '//
     $'CUTTINGS QA record to CDB-scratch file ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Writing "HEADER" '//
     $'section to the final output CAMDAT file ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $  ' NEW GLOBAL variable names (AREA_C) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $  ' NEW GLOBAL variable names (AREA_S) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $  ' NEW GLOBAL variable names (AREA_T) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $  ' NEW GLOBAL variable names (VOL_C) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $  ' NEW GLOBAL variable names (VOL_S) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $  ' NEW GLOBAL variable names (VOL_T) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $  ' NEW GLOBAL variable names (DRILDIAM) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $    ' NEW GLOBAL variable names (NUM_INTR) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $    ' NEW GLOBAL variable names (POROSITY) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $    ' NEW GLOBAL variable names (HFINAL) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
     $    ' NEW GLOBAL variable names (PRESGAS) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
```

```
$     ' NEW GLOBAL variable names (PRESBRIN) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$     ' NEW GLOBAL variable names (SATGAS) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$     ' NEW GLOBAL variable names (SATBRIN) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$     ' NEW GLOBAL variable names (POROSITY) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$     ' NEW GLOBAL variable names (HFINAL) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$     ' NEW GLOBAL variable names (PRESGAS) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$     ' NEW GLOBAL variable names (SATBRIN) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$' NEW GLOBAL variable names (NUCNAM C_) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$' NEW GLOBAL variable names (NUCNAM S_) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRCHEA) - Error writing'//
$' NEW GLOBAL variable names (NUCNAM T_) to CDB ***')

-----------------------------------------------------------------------
  SUBROUTINE WRPLFIL( IWASFLG, MAPSAV,  HALFY,  NUCNAM, RADHIS, 1
$                TINT,   XRAD1,  XRAD2,  XRAD3,  TMPNM1,
$                TMPNM2,  TMPNM3 )

   CALL QAABORT('(WRPLFIL) - Exceeded maximum history plott'//
$            'ing file "width" ***')

-----------------------------------------------------------------------
  SUBROUTINE WRTANA( IWASFLG, Q,      C,      TIME,   HIFLAG,    1
$                AINTC,  DRILDIA, NUCNAM,   MAPSAV,  SUMCI,
$                XPORO, XPRGS, XPRBR, XSATG, KULTP, KH )

  IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$  ' NEW GLOBAL variable values (AINTC(1,KH)) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$  ' NEW GLOBAL variable values (AINTC(2,KH)) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$  ' NEW GLOBAL variable values (AINTC(3,KH)) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$  ' NEW GLOBAL variable values (VOL_C) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$  ' NEW GLOBAL variable values (VOL_S) to CDB ***')
  IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
$  ' NEW GLOBAL variable values (VOL_T) to CDB ***')
```

```
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $  ' NEW GLOBAL variable values (DRILDIA) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (NUM_INTR) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (POROF) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (HFINAL) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (PRESGAS) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (PRESBRIN) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (SATGAS) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (SATBRIN) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (POROF) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (HFINAL) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (PRESGAS) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $    ' NEW GLOBAL variable values (SATBRIN) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing'//
     $  ' NEW GLOBAL variable values (SUMCI) to CDB ***')
      IF(IERR.NE.0)CALL QAABORT('(WRTANA) - Error writing a completed'//
     $' time-step and advancing to next step /DBOSTEP ***')

-----------------------------------------------------------------------

      INTEGER FUNCTION INEXT(INDEX)

      WRITE (6,'(" INCORRECT WORD TYPE WAS FOUND, INEXT")')
      WRITE (6,'(" WORD CMD ",A,
     &          " INTEGER  ",I20,
     &          " RNUMBER  ",E16.8)') C18, NUM1, RNUM1
      STOP ' ERROR INEXT'

-----------------------------------------------------------------------

      REAL*4 FUNCTION RNEXT(INDEX)
```

```
      WRITE (6,'(" INCORRECT WORD TYPE WAS FOUND, RNEXT")')
      WRITE (6,'(" WORD CMD ",A,
     &          " INTEGER  ",I20,
     &          " RNUMBER  ",E16.8)') C18, NUM1, RNUM1
      STOP ' ERROR RNEXT'
```

```
      SUBROUTINE ANEXT (INDEX, AVALUE, NP)

        WRITE (6,100)
100     FORMAT(" NONE REAL NUMBER WAS FOUND, ANEXT")
        STOP ' ERROR ANEXT'

      WRITE (6,130)
130 FORMAT(" NO END OF ARRAY, ANEXT")
      STOP ' ERROR ANEXT'
```

```
      SUBROUTINE SOLID_OUT (DIA, SATBRIN, HF, PG, PARTDIA, PORO,

C
      IF (PG .LT. PSUF) THEN
        WRITE(NOUTFL,
     &     '(/" **** REPOSITORY PRESSURE LESS THAN ATMOSPHERIC")')
        STOP
      ENDIF
C
```

9.0 DESCRIPTION OF CUTTINGS_S'S OUTPUT FILES

CUTTINGS_S's output files are listed above in Section 6.2, together with their identification numbers and the logical symbols CUTTINGS_S associates with them. The output files are file numbers 7 through 13. Each of them is briefly described below. Of the required files, the only user-readable output appears in the debug file, an annotated example of which is given in Appendix D.

File 7. CUSP_OUT$CDB is the principal CUTTINGS_S output CDB file. It contains the calculated total volume (in terms of an areal footprint) of all radioactive materials, isotope by isotope, brought to the surface by the combined actions of cuttings, cavings, and spallings. Being a CDB file, it is binary and therefore not directly human readable.

File 8. CUSP_OUT$DBG is an ASCII output file that echoes the various input files, the input parameter values, and includes a summary of the output calculations given in file 7.

NOTE: There are three run-time debug flags that cause changes in the amount of output written to the DBG output file. They are defined as follows:

DEBUG	= <LOGICAL>	for debugging dynamic memory allocation.
DBRAG	= <LOGICAL>	for debugging the BRAGFLO CDB file
NOECHO	= <LOGICAL>	to cancel echoing of input data to the DBG file

These run-time flags may be invoked and set by typing the variable, for example: DBSPALL on the command line. Alternatively, the user may type the line: $DEFINE CUSP$DPSPALL TRUE prior to the execution of CUTTINGS_S.

File 9. CUSP_OUT$NVERIFY is an optional ASCII output file of intermediate results that is used during developmental phases to verify CUTTINGS_S's calculations against other independent calculations, normally performed by hand.

Files 10 through 11 are optional output files that are normally forwarded to system plotting packages for diagnostic and developmental purposes. See the summary table above for a listing of their logical symbols. Their use in regulatory calculations is not contemplated. Hence, these logicals will either remain undefined or will be defined as NULL or CANCEL, in which case the code will not write to them.

10.0 REFERENCES

Bateman, H. (1910) The Solution of a System of Differential Equations Occurring in the Theory of Radio-active Transformations, *Proc. Cambridge Phil. Soc.* **16**, 423.

Berglund, J. W. (1993) Mechanisms Governing the Direct Removal of Wastes from the WIPP repository Caused by Exploratory Drilling, SAND 92-7295. Sandia National Laboratories, Albuquerque, NM.

Rechard, R. P., ed. (1992). User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller; Version 3.0. SAND90 - 1983. Sandia National Laboratories, Albuquerque NM.

Rechard, R. P. , A. P. Gilkey, H. J. Iuzzolino, D. K. Rudeen, and K. A. Byle. (1993). *Programmer's Manual for CAMCON: Compliance Assessment Methodology Controller.* SAND90 - 1984. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 1: Third Comparison with 40 CFR 191, Subpart B. SAND92 - 0700/1. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 2: Technical Basis. SAND92 - 0700/2. Sandia National Laboratories, Albuquerque NM

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters. SAND92 - 0700/3. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B. SAND92 - 0700/4. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance. SAND92 - 0700/5. Sandia National Laboratories, Albuquerque NM.

APPENDIX A: A REFERENCE MANUAL ON THE THEORY AND NUMERICAL METHODS UNDERLYING THE WIPP CODE CUTTINGS_S (BY J. W. BERGLUND)

This appendix describes the theoretical basis of the CUTTINGS_S computer code which was written to calculate the quantity of solid radioactive material (in curies) brought to the surface from a radioactive waste disposal facility as a consequence of an inadvertent drilling intrusion. The code determines the amount of material removed by several release mechanisms, and decays the releases to the intrusion time. The report describes the background, assumptions, equations, and variables governing the releases and the methods used to solve them. The code was written specifically for the computations required for the Performance Assessment of the Waste Isolation Pilot Project (WIPP) but with due care can be used for other radioactive waste repositories.

1.0 Introduction

The Waste Isolation Pilot Plant (WIPP), located in southern New Mexico, is the first planned, mined geologic repository for transuranic wastes generated by U.S. defense programs. WIPP is currently being evaluated to assess compliance with the requirements of EPA 40 CFR 191 Subpart B. Briefly, this requirement, promulgated by the Environmental Protection Agency, limits the amount of radioactive material that can be released to the accessible environment over a 10,000-year regulatory period.

Of the possible pathways for release during this period, one of the most important is that caused by the inadvertent penetration of a waste storage room by an exploratory drill bit. The current performance assessment model relies on the assumption that future drilling techniques will be similar to those in use today. The validity of this assumption is unknown but is necessary to provide a basis on which predictions of release can be estimated. Assuming that current, standard drilling practices for gas and oil are used, mechanisms governing the direct removal of radioactive waste can be identified and governing equations developed and solved. The following report summarizes the current understanding of the processes related to the direct removal of wastes, presents the governing mechanisms, and describes the solution of the model equations.

1.1 Background

The WIPP repository will consist of a number of excavated waste disposal rooms located in bedded halite (salt) approximately 650m below the ground surface in southeast New Mexico. Most excavated rooms will be approximately 91 m long, 10 m wide and 4 m high. Transuranic waste packaged in 55-gallon drums or standard waste boxes will be placed in each room and backfilled primarily with crushed salt.

After the WIPP repository is filled with waste and sealed, the waste is expected to be slowly compacted vertically by salt creep from an original waste room height of 4 m to a compacted height of 0.5 to 2 m within 100 to 200 years. The overburden (vertical) stress acting on the waste will also increase to the lithostatic stress (~14.8 MPa) during this period. The waste in its unmodified form will consist of a mixture of contaminated organic (e.g., cloth, wood, rubber, plastics) and inorganic (e.g. metals, glass) materials. After placement in the mined (salt) repository, the waste will be compacted by creep closure of the surrounding salt and in addition may become exposed to brine. The exposure of the metallic waste to brine is expected to cause corrosion of the metals and as a by-product will generate gas (H_2). Additional gas will be generated by the biodegradation of the organic materials in the waste inventory. The gas volumes

generated by corrosion and biodegradation are expected to increase continuously for hundreds of years and the pore pressure may reach and possibly exceed the lithostatic overburden stress. During this time the repository is also expected to expand under the influence of the elevated gas pressure.

At some time within the 10,000-year regulatory period, it is probable that one or more exploration boreholes will be drilled into and through the vertically compacted waste and some of the waste will be carried to the surface as a direct result of the drilling process. The volume of waste removed to the ground surface will depend upon the physical properties of the compacted, decomposed wastes, the drilling procedures used, and the pore pressures encountered. Because of radioactive decay, the radioactivity of nuclides in the removed waste (in curies) will also depend upon the time of intrusion.

1.2 Current Drilling Practices

In considering the problem of the direct releases caused by drilling it is important to understand the procedures currently utilized in drilling a gas or oil well. The following description is tailored to practices in use near the WIPP site. Typically, independent drilling companies respond to requests for fixed price bids from oil companies to provide drilled and cased holes of a specified diameter to a specified depth at a location leased by the oil company. The bids are competitive and generally the low bidder is selected. As a result of this bidding process, profit margins for the winning driller are governed by the effectiveness of the driller in maintaining efficient drilling parameters and by solving unforeseen difficulties that may arise quickly and safely. The principal goal of the driller is to "make hole" and meet contract requirements. If this is accomplished the drilling operation will be profitable.

Within the Delaware Basin near the WIPP site, gas and oil wells are started by clearing the site, and drilling a shallow hole (~40') to house a conductor pipe. The conductor pipe is set in cement and serves to prevent surface sands from sloughing into the wellbore during later drilling. Below the conductor, drilling is continued to 300 - 600 feet (to top of salt section) using a large diameter (17-26") drill bit and another steel casing is set. This "surface" casing is cement grouted into the hole and a blowout preventer tree is attached to the casing at the surface. Drilling below the surface casing (in the salt section) uses a drilling mud that consists of a saturated brine solution to prevent dissolution of the salt. Drilling through the salt section proceeds at rates from 50 to 100 feet/hour depending on bit diameter. If higher rates are attempted by increasing the weight on bit (WOB) there is the danger of producing a crooked hole. While in the salt section, drilling mud (brine) is supplied from a large plastic lined reserve pit dug in the ground with a surface area of approximately 4000 ft^2. Drilling mud is pumped from the reserve pit down through the drillpipe and drillbit and up the annulus formed by the drillstring and drilled hole. The drilling mud and drill cuttings are returned directly to the reserve pit where the cuttings settle out. While drilling in the salt section no formal attempt is made to monitor the character of the cuttings or the fluid volume of the reserve pit. A gas analyzer is not attached to the returns until the hole is much deeper than the depth of the WIPP repository. The drillstring generally consists of a drillbit attached to approximately 20, 30 foot long drill collars followed by multiple sections of 30 foot long 4 1/2 " diameter drillpipe. One to four drillbit changes may be necessary when drilling through the salt section. This process requires the removal of the entire drillstring (tripping). Once the drill has passed the salt section (~4500 ft) the hole is again cased and set with cement. At this point, if the repository had been penetrated no further contact would occur between the drilling mud and the exposed WIPP waste.

2.0 Release Processes

Three separate physical processes are assumed to influence the quantity of waste brought to the ground surface as the result of the inadvertent penetration of the repository by an exploratory drill bit. These are:

*Cuttings - waste contained in the cylindrical volume created by the cutting action of the drill bit passing through the waste.

*Cavings - waste that erodes from the borehole in response to the upward-flowing drilling fluid within the annulus, and

*Spallings - waste introduced into the drilling fluid caused by the release of waste-generated gas escaping to the lower-pressure borehole. This requires a repository gas pressure that exceeds the hydrostatic pressure of the drilling mud.

In the above and in the following it is understood that usage of the word "waste" also includes any backfill or other materials that may have been added to the actual waste material.

Spallings can be further subdivided into three regimes that are dependent upon the state of waste permeability and gas pore pressure at the time of intrusion. These are:

**Blowout - the direct release of waste to the surface in waste decomposition gas that has cleared the borehole annulus of drilling mud and is flowing freely to the surface.

**Gas Erosion - low permeability waste that is pressed against the drillstring due to stresses from escaping decomposition gas and is eroded by the flowing drilling mud.

**Stuck Pipe - low permeability waste that is pressed against the drillstring sufficiently hard to prevent normal drilling. This occurs at high gas pressures.

These release processes and when they are active are depicted graphically in Figure 1.

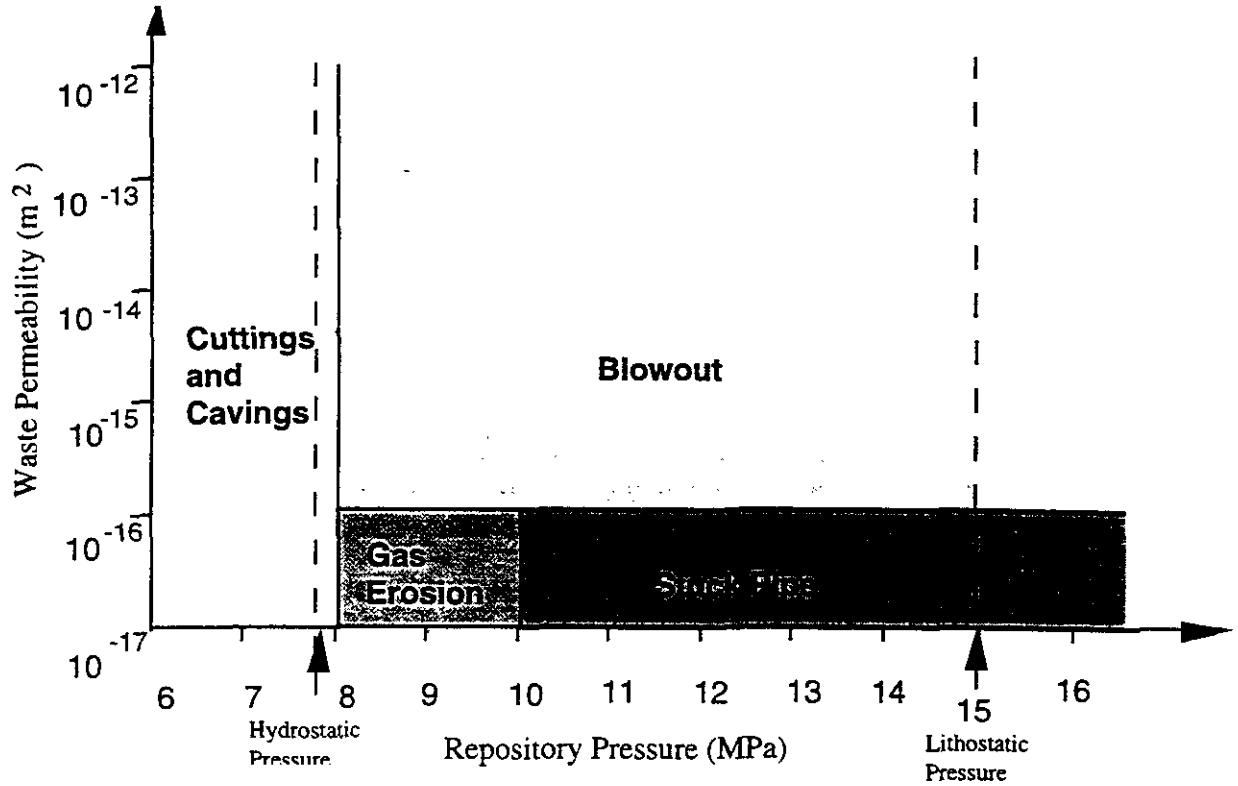

Figure 1. Release process zones

The release process zone boundaries are based on waste permeability and repository gas pressure and will be discussed in the model descriptions for the zones. Detailed descriptions of the release process zones, their principal assumptions, and mathematical formulation will be discussed in the following sections.

2.1 Cuttings

This is the simplest component of the direct release model and is assumed to occur for repository pressures less than the hydrostatic pressure of the drilling mud. This pressure is approximately 8 Mpa (Figure 1). For a gauge borehole, the volume of cuttings removed and transported to the surface is equal to the product of the drill bit area and the drill depth. Thus, to estimate the total solid volume of waste removed due to the cutting action of the drill bit , it is only necessary to know the compacted repository height (H), the porosity at the time of intrusion (φ), and the drill bit area (A).

$$Volume = AH(1-\varphi) \tag{1}$$

The cuttings volume calculated in this manner is a lower bound to the total quantity of waste removed by drilling. In the CUTTINGS_S code the waste is assumed to be uniformly distributed throughout the disposal region. Thus the actual computation for release requires only the drill bit area and the waste curie content per unit area. The actual computation of cuttings release in the CUTTINGS_S code is computed within the module for cavings. This description follows.

2.2 Cavings

The cavings component of direct surface release consists of that quantity of waste material that is eroded from the borehole wall by the action of the flowing drilling fluid after a waste disposal room is penetrated. The erosion process is assumed to be driven solely by the shearing action of the drilling fluid (mud) on the waste as it moves up the borehole annulus. For cavings it is further assumed that the repository is not pressurized by either brine or gas, i.e. the repository pressure is less than the hydrostatic pressure caused by a brine column to the surface (Figure 1). Gas pressurization effects are included in other release processes (spall) and will be discussed later.

In the annulus formed by the collars or drill pipe and the borehole wall, the flow of the drilling fluid has both a vertical and rotational component. Within this helical flow pattern, shear stresses are generated by the relative motion of adjacent fluid regions and by the action of the fluid on the borehole wall. In this model, it is assumed that if the fluid shear stress at the wall exceeds the effective shear resistance to erosion of the wall material (compacted repository wastes), erosion of the wall material will occur, increasing the diameter of the bored hole. The eroded material will then be passed to the surface in the flowing drilling fluid.

Flow in the annulus between the drillpipe and borehole wall is usually laminar (Darley and Gray, 1988, p243). Adjacent to the collars, however, the flow may be either laminar or turbulent as a consequence of the larger collar diameter and resulting higher mud velocities. For laminar flow, the analysis lends itself to classical solution methods. Turbulent flow, where the flow is assumed to be axial with a correction for the rotational component, requires a more approximate approach. A discussion of these two cases follows.

2.2.1 Laminar Flow

Below Reynolds numbers of about 2100 for Newtonian fluids and 2400 for some non-Newtonian fluids (Walker, 1976), experiments have shown that the flow of a fluid in a circular pipe or annulus is well behaved and can be described using a well-defined relationship between the velocity field and the fluid shear stress. This type of flow is called laminar.
Some of the early work on laminar helical flow of a non-Newtonian fluid in an annulus was performed by Coleman and Noll (1959), and Fredrickson (1960). The laminar helical flow solution procedure outlined below and used in the CUTTINGS_S code is, for the most part, an adaptation of methods described in a paper by Savins and Wallick (1966).

One of the principal difficulties in solving for the shear stresses within a helically flowing drilling fluid is the shear rate dependence of the fluid viscosity. This non-Newtonian fluid behavior necessitates choosing a functional form for the variation of viscosity with shear rate for the fluid. There are several functional forms for the viscosity of drilling fluids that can be assumed. For example, in the oil and gas industry the Bingham and power law models are often used to approximate the shear rate dependence of the fluid viscosity. A less common function is a form chosen by Oldroyd (1958) and used in the analysis by Savins and Wallick (1966). Oldroyd assumed that the viscosity varied according to the functional relation

$$\eta = \eta_o \left[\frac{1+\sigma_2 \Gamma^2}{1+\sigma_1 \Gamma^2} \right] \qquad (2)$$

where σ_1 and σ_2 are constants, η_o is the limiting viscosity at zero rate of shear, η_∞ (defined as $\eta_o(\sigma_2/\sigma_1)$) is the limiting viscosity at infinite rate of shear, and Γ is the shear rate. The viscous shear stress is described by $\tau = \eta\Gamma$.

Using the Oldroyd viscosity, Equation (2), the viscous shear stress can be illustrated graphically as in Figure 2a and 2b.

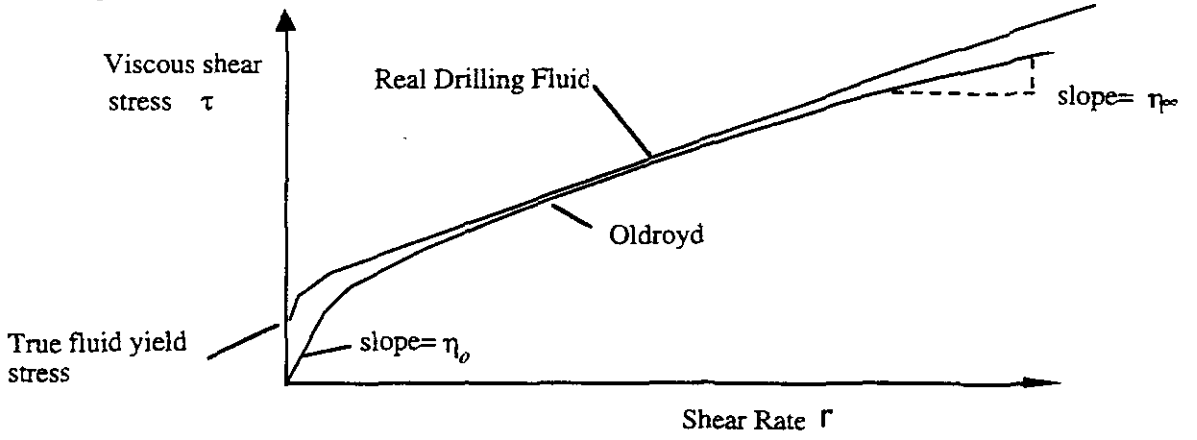

Figure 2a Oldroyd and real drilling fluid

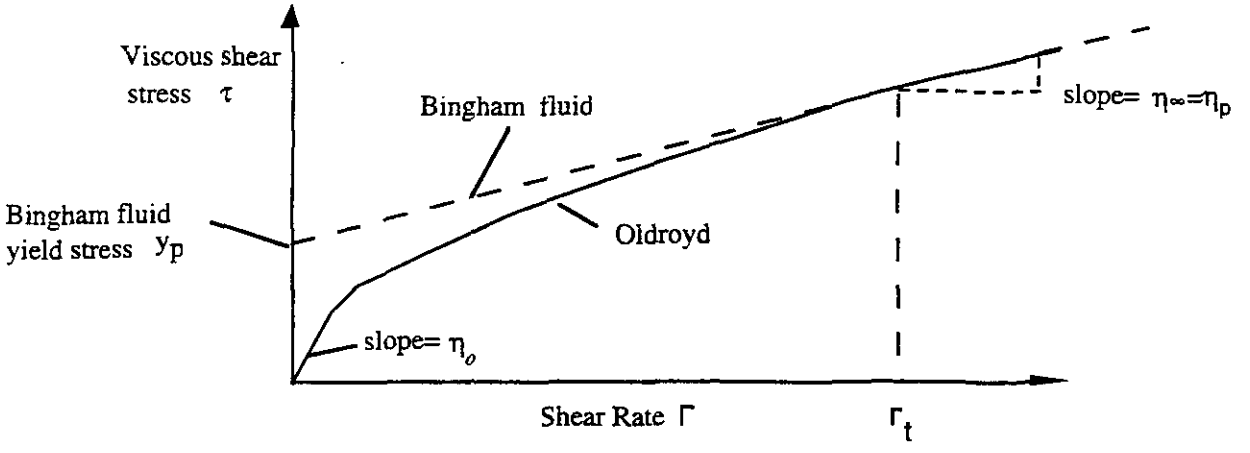

Figure 2b Oldroyd and Bingham fluid

This is a rate softening (pseudoplastic) model that has an initial slope of η_o and a limiting slope of η_∞ for large shear rates.

The Oldroyd model cannot account for drilling fluids that exhibit a yield stress. However, above a shear rate of zero, parameters can be chosen so that the model can be made to approximate the pseudoplastic rate response of many drilling fluids (see Figure 2).

Savins and Wallick (1966), expanding on the work of Coleman and Noll (1959) and Fredrickson (1960), showed that the solution for laminar helical flow of a non-Newtonian fluid in an annulus could be written in terms of three nonlinear integral equations.

$$F_1 = \int_\alpha^1 \left(\frac{\rho^2 - \lambda^2}{\rho} \right) \frac{d\rho}{\eta} = 0$$

$$F_2 = C \int_\alpha^1 \frac{d\rho}{\rho^3 \eta} - \Delta\Omega = 0 \qquad (3)$$

$$F_3 = \frac{4Q}{\pi R^3} + 4\left(\frac{RJ}{2}\right) \int_\alpha^1 \left(\frac{\alpha^2 - \rho^2}{\eta} \right) \left(\frac{\rho^2 - \lambda^2}{\rho} \right) d\rho = 0$$

where α is the ratio of the collar radius over the cutting radius (R_i/R) (Figure 3), $\Delta\Omega$ is the drill string angular velocity, Q is the drilling fluid (mud) flow rate, r is the radial coordinate, and ρ is the non-dimensional radial coordinate representing the ratio r/R.
The unknown parameters λ^2, $RJ/2$, and C are related to the fluid shear stresses through the relations

$$\tau_{r\theta} = \frac{C}{\rho^2}$$

$$\tau_{rz} = \frac{RJ}{2} \left(\frac{\rho^2 - \lambda^2}{\rho} \right) \qquad (4)$$

$$\tau^2 = \tau_{r\theta}^2 + \tau_{rz}^2$$

where r, θ, and z represent radial, tangential, and vertical coordinates associated with the cylindrical geometry of Figure 3.

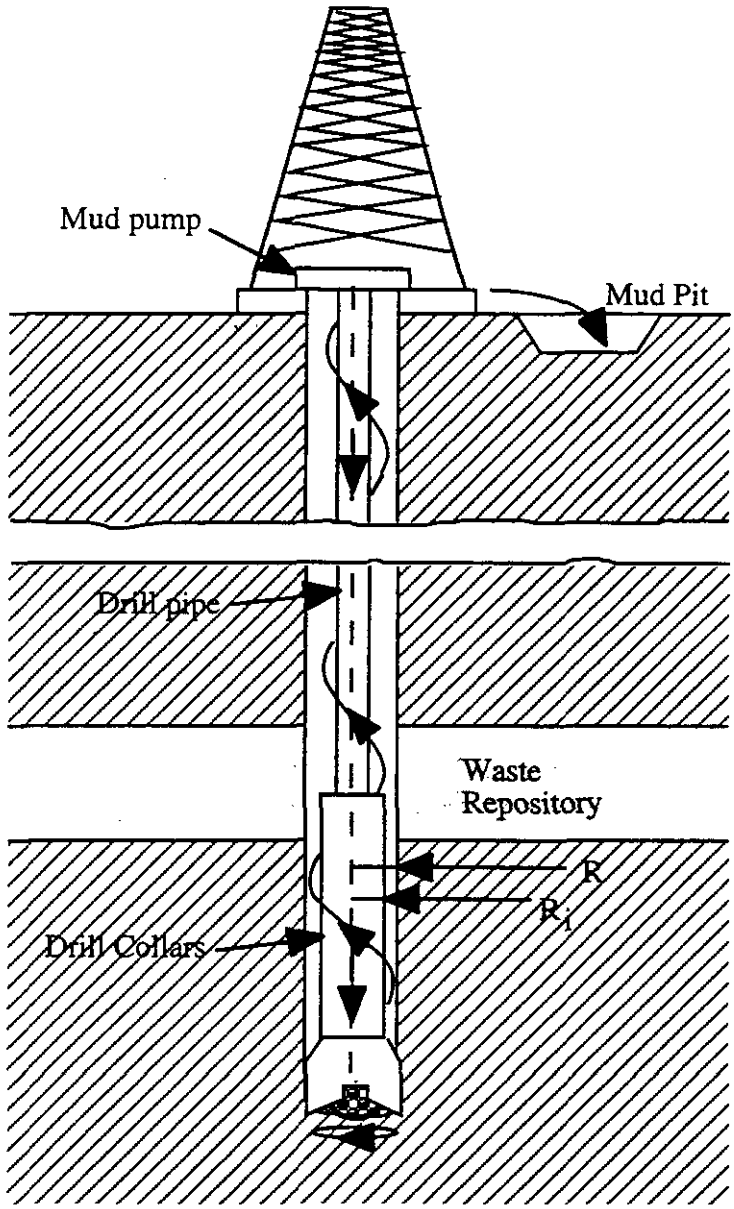

Figure 3. Detail of rotary drill string adjacent to repository.

The three nonlinear integral equations represented by (3) in general must be solved numerically. By expanding each of the integral equations into a Taylor series and retaining only the linear terms, a recursive solution procedure can be used (see Appendix AA)) to find the solution for the unknowns $\delta\lambda^2$, $\delta\left(\frac{RJ}{2}\right)$, and δC. The three linear equations are

$$\frac{\partial F_1}{\partial \lambda^2}\delta\lambda^2 + \frac{\partial F_1}{\partial C}\delta C + \frac{\partial F_1}{\partial\left(\frac{RJ}{2}\right)}\delta\left(\frac{RJ}{2}\right) = -F_1$$

$$\frac{\partial F_2}{\partial \lambda^2}\delta\lambda^2 + \frac{\partial F_2}{\partial C}\delta C + \frac{\partial F_2}{\partial\left(\frac{RJ}{2}\right)}\delta\left(\frac{RJ}{2}\right) = -F_2 \qquad (5)$$

$$\frac{\partial F_3}{\partial \lambda^2}\delta\lambda^2 + \frac{\partial F_3}{\partial C}\delta C + \frac{\partial F_3}{\partial\left(\frac{RJ}{2}\right)}\delta\left(\frac{RJ}{2}\right) = -F_3$$

The solution procedure consists of assuming initial values for λ^2, $\left(\frac{RJ}{2}\right)$, and C and solving the three linear equations in (5) for the corrections $\delta\lambda^2$, $\delta\left(\frac{RJ}{2}\right)$, and δC. The unknowns λ^2, $\left(\frac{RJ}{2}\right)$, and C are then replaced by $\lambda^2 + \delta\lambda^2$, $\left(\frac{RJ}{2}\right) + \delta\left(\frac{RJ}{2}\right)$, and $C + \delta C$. This recursive solution procedure is repeated until $\left|\delta\lambda^2\right|$, $\left|\delta\left(\frac{RJ}{2}\right)\right|$, and $|\delta C|$ are all less than some specified limit.

The coefficients of the unknowns $\delta\lambda^2$, $\delta\left(\frac{RJ}{2}\right)$, and δC in equations (5) are determined by differentiating equations (3). These derivatives are:

$$
\begin{aligned}
\frac{\partial F_1}{\partial \lambda^2} &= -\int_\alpha^1 \frac{1}{\eta\rho}\left[1+\frac{(\rho^2-\lambda^2)}{\eta}\frac{\partial \eta}{\partial \lambda^2}\right]d\rho \\
\frac{\partial F_1}{\partial C} &= -\int_\alpha^1 \frac{1}{\eta\rho}\frac{(\rho^2-\lambda^2)}{\eta}\frac{\partial \eta}{\partial C}d\rho \\
\frac{\partial F_1}{\partial\left(\frac{RJ}{2}\right)} &= -\int_\alpha^1 \frac{1}{\eta\rho}\frac{(\rho^2-\lambda^2)}{\eta}\frac{\partial \eta}{\partial\left(\frac{RJ}{2}\right)}d\rho \\
\frac{\partial F_2}{\partial \lambda^2} &= -C\int_\alpha^1 \frac{1}{\eta^2\rho^3}\frac{\partial \eta}{\partial \lambda^2}d\rho \\
\frac{\partial F_2}{\partial C} &= \int_\alpha^1 \frac{1}{\eta\rho^3}\left[1-\frac{C}{\eta}\frac{\partial \eta}{\partial C}\right]d\rho \\
\frac{\partial F_2}{\partial\left(\frac{RJ}{2}\right)} &= -C\int_\alpha^1 \frac{1}{\eta^2\rho^3}\frac{\partial \eta}{\partial\left(\frac{RJ}{2}\right)}d\rho \\
\frac{\partial F_3}{\partial \lambda^2} &= -4\left(\frac{RJ}{2}\right)\int_\alpha^1 \frac{\alpha^2-\rho^2}{\eta\rho}\left[1+\frac{(\rho^2-\lambda^2)}{\eta}\frac{\partial \eta}{\partial \lambda^2}\right]d\rho \\
\frac{\partial F_3}{\partial C} &= -4\left(\frac{RJ}{2}\right)\int_\alpha^1 \frac{(\alpha^2-\rho^2)}{\eta\rho}\frac{(\rho^2-\lambda^2)}{\eta}\frac{\partial \eta}{\partial C}d\rho \\
\frac{\partial F_3}{\partial\left(\frac{RJ}{2}\right)} &= 4\int_\alpha^1 \frac{(\alpha^2-\rho^2)}{\eta\rho}(\rho^2-\lambda^2)d\rho - 4\left(\frac{RJ}{2}\right)\int_\alpha^1 \frac{(\alpha^2-\rho^2)}{\eta\rho}\frac{(\rho^2-\lambda^2)}{\eta}\frac{\partial \eta}{\partial\left(\frac{RJ}{2}\right)}d\rho
\end{aligned}
\tag{6}
$$

From equations (4) and using the relation $\tau = \eta\Gamma$ the viscosity can be related to the shear rate function $Y(\Gamma)$ by the equation

$$
\eta^2 Y = 2\left[\left(\frac{RJ}{2}\right)^2\left(\frac{\rho^2-\lambda^2}{\rho}\right)^2 + \frac{C^2}{\rho^4}\right] \tag{7}
$$

where

$$
Y = 2\Gamma^2 \tag{8}
$$

For the Oldroyd viscosity function, equation (2), the unknown derivatives of the viscosity in equations (6) can be determined by using the chain rule of differentiation and equation (7).

$$\frac{\partial\eta}{\partial\lambda^2}=\frac{\partial(\eta^2Y)}{\partial\lambda^2}\frac{\partial\eta}{\partial(\eta^2Y)}=-4\left(\frac{RJ}{2}\right)^2\left(\frac{\rho^2-\lambda^2}{\rho^2}\right)\frac{\partial\eta}{\partial(\eta^2Y)}$$

$$\frac{\partial\eta}{\partial C}=\frac{\partial(\eta^2Y)}{\partial C}\frac{\partial\eta}{\partial(\eta^2Y)}=\frac{4C}{\rho^4}\frac{\partial\eta}{\partial(\eta^2Y)} \tag{9}$$

$$\frac{\partial\eta}{\partial\left(\frac{RJ}{2}\right)}=\frac{\partial(\eta^2Y)}{\partial\left(\frac{RJ}{2}\right)}\frac{\partial\eta}{\partial(\eta^2Y)}=4\left(\frac{RJ}{2}\right)\left(\frac{\rho^2-\lambda^2}{\rho}\right)^2\frac{\partial\eta}{\partial(\eta^2Y)}$$

The derivative $\frac{\partial\eta}{\partial(\eta^2Y)}$ can be determined by combining equations (2) and (8) and differentiating to obtain

$$\frac{\partial\eta}{\partial(\eta^2Y)}=\frac{\left(\frac{\sigma_2}{2}\eta_o-\frac{\sigma_1}{2}\eta\right)^2}{\left(\frac{\sigma_2}{2}\eta_o-\frac{\sigma_1}{2}\eta\right)\left[\eta^2+2(\eta-\eta_o)\eta\right]+(\eta-\eta_o)\eta^2\frac{\sigma_1}{2}} \tag{10}$$

A cubic equation for η in terms of the unknown parameters λ^2, $RJ/2$, and C can be written by combining equations (2), (7) and (8)

$$\eta^3-\eta_o\eta^2+\sigma_1\left[\left(\frac{RJ}{2}\right)^2\left(\frac{\rho^2-\lambda^2}{\rho}\right)^2+\frac{C^2}{\rho^4}\right]\eta-\sigma_2\left[\left(\frac{RJ}{2}\right)^2\left(\frac{\rho^2-\lambda^2}{\rho}\right)^2+\frac{C^2}{\rho^4}\right]\eta_o=0 \tag{11}$$

2.2.1.1 Solution Process for Laminar Flow

Laminar helical flow of an Oldroyd fluid in an annulus of a given size with a rotating inner core is based on the solution to the three integral equations (3) which have three unknown parameters λ^2, $RJ/2$, and C. A recursive process for computing the unknowns based on a Taylor series expansion (equation 5) requires the evaluation of the coefficients of the three linear equations. These coefficients (equations 6 combined with 9, 10, and 11) involve integrals across the radius of the annulus which must be integrated numerically. Simpson's 1/3 rule (Salvadori, et al 1962) is used to perform these integrations by dividing the annular radius into ten equal intervals. The initial solution obtained from the recursive process assumes no erosion has occurred and thus corresponds to an annulus with an outer radius equal to one half the borehole diameter. For the specific case of borehole erosion, once a solution to the unknowns (λ^2, $RJ/2$, and C) in the three integral equations in (3) is found, the shear stress in the fluid τ at the wall can be calculated by setting $\rho=1$ in the equations in (4). By changing the outer radius of the hole and repeating the above process a new shear stress in the fluid at the wall can be calculated. By adjusting the outer radius appropriately the fluid shear stress can be forced to equal the repository effective shear resistance to erosion. That radius corresponds to the final eroded radius. The required outer hole radius is determined by iteration as shown in Figure 4. The derivatives required for the iteration $\left(\frac{d\tau}{dR}\right)$ are found numerically by determining the change in shear stress for a small assumed change in outer radius R.

Based upon the preceding equations a Fortran computer code was written to perform the necessary computations for a solution to the problem of laminar helical flow in an annulus. This code was partially verified by comparing its results against those published by Savins and Wallick (1966).

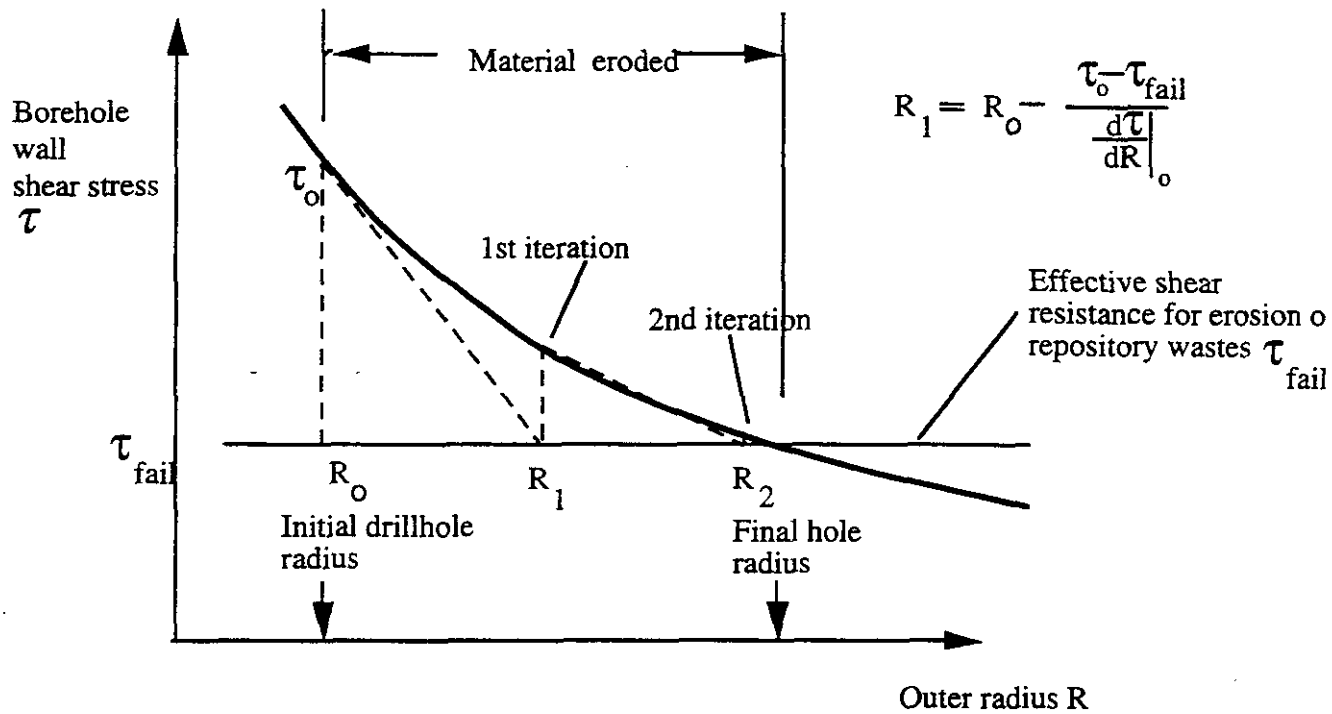

Figure 4. Iterate to find the final hole radius

The final eroded diameter is determined through an iterative process that equates the fluid shear stress adjacent to the waste to a measure of the erosion resistance of the waste. The erosion resistance is governed by the effective shear resistance to erosion, a parameter not directly related to the shear strength as normally determined for granular materials using conventional soil tests.

The effective shear resistance for erosion (τ_{fail}), equals the threshold value of fluid shear stress required to sustain general erosion at the borehole wall. Parthenaides and Passwell (1970), in discussing investigations on the erosion of seabed sediments and in channels, has noted that this effective soil shear resistance is not related to the soil shear strength as normally determined from conventional soil tests. The effective shear resistance for erosion based on seabed data, as determined by Parthenaides and Passwell (1970), is on the order of a few Pa and is thus smaller by several orders of magnitude than the macroscopic soil shear strength.

2.2.2 Turbulent Flow

For Newtonian fluids with Reynolds numbers greater than about 2100, flow in a circular pipe or annulus starts to become more or less random in character, which makes orderly mathematical

analysis of the flow difficult, if not impossible. With increasing Reynolds numbers, this random behavior increases until, at a Reynolds number of about 3000, the flow becomes fully turbulent. In fully turbulent flow, momentum effects dominate and the fluid viscosity is no longer important in characterizing pressure losses.

The Reynolds number (R_e) is defined as

$$R_e = \frac{\overline{\rho}\overline{V}D_e}{\overline{\eta}} \tag{12}$$

where D_e is the equivalent hydraulic diameter, $\overline{\rho}$ is the drilling fluid density, $\overline{V}$ is the average axial fluid velocity, and $\overline{\eta}$ is the average fluid viscosity.

For Newtonian fluids, the value to use for the viscosity is clear since the viscosity is constant for all rates of shear. Non-Newtonian fluids exhibit a changing viscosity with shear rate and present a special problem in calculating R_e. For fluids that exhibit a limiting viscosity at high rates of shear (such as the Bingham model and in our case the Oldroyd model), it has been suggested (Broc, 1982) that the limiting viscosity ($\overline{\eta} = \eta_\infty$) be used in calculating the Reynolds number.

The Reynolds number for an Oldroyd fluid in an annulus can then be written as (Broc, 1982)

$$R_e = \frac{0.8165 D_e \overline{V}\overline{\rho}}{\overline{\eta}} \tag{13}$$

where the equivalent hydraulic diameter is expressed as $D_e = 2(R - R_i)$ (see Figure 3).

The most important influence viscosity has on the calculation of pressure losses in fully turbulent flow of non-Newtonian fluids appears to be in the calculation of the Reynolds number. A far more important parameter is the surface roughness past which the fluid must flow. The Reynolds number, however, does have a role in determining the onset of turbulence. For Newtonian fluids this number is about 2100. For non-Newtonian, rate-thinning fluids, the critical value of R_e tends to be greater than 2100 but less than 2400 (Walker, 1976). For our purposes, a value of 2100 will be used to represent R_{e_C} (the critical Reynolds number) for the Oldroyd fluid model. Since turbulent flow is more effective in generating fluid shear stresses at the borehole wall, this assumption is conservative.

There is a transition region beyond R_{e_C} before the development of fully turbulent flow. In this regime the flow has the character of both laminar and turbulent flow. However, since pressure losses increase rapidly in turbulent flow and affect borehole shear stresses more severely, it will be assumed that beyond R_{e_C} the flow is fully turbulent.

Turbulent flow is very complex and, thus, to characterize the turbulent flow regime, the great bulk of analysis has concentrated on empirical procedures. For axial flow in an annulus, the pressure loss under turbulent conditions can be approximated by (Broc, 1982)

$$\Delta P = \frac{2fL\overline{\rho}\overline{V}^2}{(0.8165)D_e} \tag{14}$$

where f is the coefficient of pressure head loss (Fanning friction factor) and L is the borehole length.

If the shear stress due to the flowing fluid is assumed to be uniformly distributed on the inner and outer surfaces of the annulus, it can be easily shown using Equation (14) that the shear stress is related to the average fluid velocity through the relation

$$\tau = \frac{f\overline{\rho}\overline{V}^2}{2(0.8165)} \tag{15}$$

The Fanning friction factor is empirically related to the Reynolds number and relative roughness by the equation (Whittaker, 1985)

$$\frac{1}{\sqrt{f}} = -4\log_{10}\left[\frac{\varepsilon}{3.72D} + \frac{1.255}{R_e\sqrt{f}}\right] \tag{16}$$

where ε/D is the relative roughness. For circular pipes, D in this equation represents the inside diameter and ε is the absolute roughness or the average depth of pipe wall irregularities. In the absence of a similar equation for flow in an annulus, it is assumed that this equation also applies here, where D is the equivalent hydraulic diameter (D_e) as defined earlier and ε is the absolute roughness of the waste-borehole interface.

For laminar flow within the annulus both axial and rotational flow are modeled. Some of the available literature (Khader and Rao, 1974 ; Bilgen E., Boulos, R., and Akgungor A.C., 1973) indicates the importance of also accounting for drillstring rotation when the drilling mud flow within the annulus is turbulent. Consequently, to account for rotational flow in the turbulent regime, an axial flow velocity correction factor (rotation factor) is introduced into the above formulation that maintains eroded diameter compatibility across the laminar- turbulent flow transition. The rotation factor (F_r) is determined by increasing (or decreasing) the axial velocity $\overline{V}$ in equation 15 until the turbulent flow eroded diameter equals the laminar flow eroded diameter computed at the prescribed angular velocity at a Reynolds number of 2100. The rotation factor is defined as

$$F_r = \frac{\overline{V}_{2100}}{\overline{V}}$$

where $\overline{V}_{2100}$ is the axial velocity required for eroded diameters to be the same for turbulent and laminar flow. This rotation factor is then used to modify the axial turbulent flow velocity at all other turbulent flow Reynolds numbers. The rotation factor is not used when computing the Reynolds number. Equation 15 then can be rewritten

$$\tau = \frac{f\overline{\rho}\left(F_r\overline{V}\right)^2}{2(0.8165)} \tag{17}$$

2.2.2.1 Solution process for turbulent flow

Using a relative roughness and a calculated Reynolds number based on $\overline{V}$, a Fanning friction factor can be determined by iteratively solving Equation (16). The value of the shear stress acting on the borehole wall can then be determined from Equation (17). Using an iterative procedure similar to that for the laminar flow problem, the fluid shear stress can be forced to equal the repository shear resistance to erosion (τ_{fail}) to obtain the final eroded borehole radius (see Figure 4).

The equations governing cavings (and cuttings) based on laminar and turbulent flow form a portion of the Fortran computer code CUTTINGS_S (see figure 1). Using appropriately selected input based on the physical properties of the waste and other drilling parameters, this section of the code calculates the final eroded diameter of the borehole that passes through the waste. In the actual solution sequence employed in the fortran code the Reynolds number is calculated first to determine which solution regime (laminar or turbulent) should first be initiated. For Reynolds

numbers initially less than R_{ec} the code calculates the flow as laminar. Any increase in diameter of the borehole calculated during the laminar calculation will cause the Reynolds number to decrease ensuring that the calculation remains laminar. If the initial Reynolds number is greater than or equal to R_{ec} the turbulent formulation is used to calculate borehole erosion. When the turbulent calculation is complete, a check is again made to determine if the Reynolds number still exceeds R_{ec}. If it does not, the laminar calculation is performed starting with a "critical" borehole radius. The critical borehole radius corresponds to a Reynolds number of R_{ec} and is given by

$$R_{crit} = \frac{\bar{\rho} Q}{1286 \pi \eta_\infty} - R_i \tag{18}$$

2.3 Drilling parameters for cuttings and cavings

The drilling parameters chosen must reflect data typical of that valid near the WIPP repository. For drilling operations through salt in the Delaware basin , the drilling mud most likely to be used is a brine (Pace's letter on pages A-159 through A-164 of (Rechard et al., 1990)), with the density cut somewhat with an emulsified oil. The mud density and viscosity parameters required in the laminar and turbulent regime erosion calculations can be estimated based on the assumption of the use of such a brine-based drilling mud. For the 1992 PA the drilling mud properties used were (Sandia WIPP Project 1992, Table 4.4-1):

Parameter	Median	Range			Units	Distribution Type
Density	1211	1139	-	1378	kg/m^3	Constructed
Bingham Plastic Viscosity η_p	0.00917	0.005	-	0.03	Pa•s	Constructed
Bingham Yield Stress y_p	4	2.4	-	19.2	Pa	Constructed

The values for plastic viscosity and yield stress correspond to parameters for a Bingham plastic fluid (Darley and Grey 1988 , p188) from which the Oldroyd parameters are derived.

If in equation (2) it is assumed that $\eta_\infty = \eta_o \left(\frac{\sigma_2}{\sigma_1} \right) = \eta_p$ where η_p is the Bingham plastic viscosity, and if $\eta_o = 2\eta_\infty$ (a trend based on other drilling muds (Darley and Grey 1988 , p242)) the following relationship can be derived.

$$\sigma_2 = \frac{\eta_p \Gamma_t - y_p}{2\Gamma_t^2 y_p} \tag{19}$$

where Γ_t is the shear rate at which the Oldroyd model and Bingham model coincide (Figure 2b). This shear rate is chosen to be 1020 1/s which corresponds to a reading at 600 rpm on a direct reading viscometer (Darley and Grey 1988 , p214).

For drilling through salt, the drilling speeds can vary from 40 to 220 rpm (Austin, 1983 and Pace's letter on pages A-159 through A-164 of (Rechard et al., 1990)). The most probable speed is about 70 rpm (Pace's letter on pages A-159 through A-164 of (Rechard et al., 1990)).

Mud flow rates are usually selected to be from 30 to 50 gallons/minute per inch of drill bit diameter (Austin, 1983) and usually result in flow velocities in the annulus between the drill collars and the borehole wall at or near the critical flow state (laminar-turbulent transition) (Pace's letter on pages A-159 through A-164 of (Rechard et al., 1990)).

The drill bit diameter is related to the total planned depth of the hole to be drilled. For gas wells in the 4000- to 10,000-foot range, it is likely that the drill bit used that passes through a waste room would have a diameter of 10.5 to 17.5 inches. The most probable drill diameter is 12.25 inches. The collar diameter is assumed to be 8 inches, a value consistent with current drilling practice in the Delaware Basin (Marquis, 1995). For the 1992 PA these parameters are presented in table 4.2-1 (Sandia WIPP Project 1992)

Parameter	Median	Range			Units	Distribution Type
Drill bit diameter	0.355	0.267	-	0.444	m	Uniform
Drill string angular velocity	7.7	4.2	-	23	rad/s	Constructed
Drilling mud flowrate	0.09935	0.0745	-	0.124	$m^3/(s \cdot m)$	Uniform

For turbulent flow, the shear stress acting at the borehole at the repository is dependent on the absolute surface roughness. The value chosen for the calculations exceeds that of very rough concrete or riveted steel piping (Streeter, 1958).

The amount of material eroded from the borehole wall is dependent upon the magnitude of the fluid-generated shear stress acting on the wall and the effective shear resistance to erosion of the compacted, decomposed waste. In the absence of experimental data, the effective shear resistance to erosion of the repository material is assumed to be similar to that of a ocean bay mud (Parthenaides and Passwell, 1970), or a montmorillonite clay, (Sargunam et al., 1973). These values are on the order of a fraction to several Pa.

For the 1992 PA, the roughness and shear resistance parameters were given in table 3.4-1 (Sandia WIPP Project 1992).

Parameter	Median	Range			Units	Distribution Type
Absolute roughness	0.025	0.01	-	0.04	m	Uniform
Erosion shear resistance	1	0.05	-	10	Pa	Constructed

The lower bound to erosion resistance shown above is lower than that used in the 1992 PA and is based on the availability of additional data (Parthenaides and Passwell, 1970).

The hydrostatic pressure at the repository depth resulting from 1211 kg/m^3 drilling mud corresponds to 7.78 MPa. In the CUTTINGS_S code repository pressures below 8 MPa are assumed to cause surface releases from cuttings and cavings. Above 8 MPa releases are caused by spall (see figure 1).

2.4 Spallings

Spallings comprises that quantity of solid waste that reaches the ground surface as the result of the high pressure gas in the waste. If the repository gas pressure exceeds the hydrostatic pressure of the column of drilling fluid, solids releases can occur from blowout, stuck pipe or gas erosion. Contaminated brine can also be expelled during a blowout event, a process not considered in the CUTTINGS_S code. Brine releases to the surface resulting from blowout are computed using a separate code.

2.4.1 Blowout (Solids Removal)

Blowout is assumed to occur when repository gas pressures exceed 8 MPa (~hydrostatic) and when waste permeabilities exceed 10^{-16} m^2 (see figure 1). For permeabilities that are lower than 10^{-16} m^2 the gas flow into the borehole is assumed to be too low to cause well blowout (Berglund 1994).

Two alternative computational models are used to compute the solid waste released to the surface resulting from the sudden penetration of a pressurized WIPP panel. The models assume waste strength based on brine saturation and are self limiting ie. neither model relies on driller response. Of the two models described below, model 2 is more consistent with data obtained from experiment.

2.4.1.2 Solids Removal Caused by Blowout (Model 1)

A borehole penetration of a WIPP panel saturated by decomposition gases at pressures above hydrostatic and with a waste permeability greater than 10^{-16} m^2 is likely to initiate a blowout of the well. The initial flow of gas into the borehole will be restricted somewhat by the presence of drilling mud and a backpressure may develop that could be greater than hydrostatic. As the gas flows into the borehole and rises due to buoyancy, the backpressure will diminish as the weight of the mud column decreases. With a decreasing backpressure the gas flowrate into the borehole will increase. It will also increase as the result of the removal of waste material and the generation of a larger surface through which the gas can flow. Eventually the borehole will be cleared of drilling mud and the backpressure will drop to a value governed by the rate of flow of a compressible fluid in the drillstring annulus.

In the development of a bounding model for waste release due to a blowout it is important to note that the blowout process occurs over a finite time (minutes) and consequently it is not necessary to consider the high transient gas flow rates that occur from the assumption of instantaneous pressures drops. This is especially true for waste with high permeability where pressure profiles in the waste change rapidly. After these initial transients the gas flowrates out of an exposed waste surface become relatively constant for volumes comparable to a WIPP panel. It is this relative constancy of flow that allows for the development of the bounding model described below.

During blowout and after the decay of initial flow transients the gas velocity (V) at an exposed waste surface remains relatively constant for long periods of time. If the gas velocity is great enough and there is little cohesive strength between waste grains, the waste grains at this free

surface will be lofted into the flow of gas (entrained) and be carried into the borehole and to the ground surface. As the waste is removed and the exposed waste surface area increases, the resistance to flow up the borehole annulus increases causing a backpressure to develop in the evacuated volume. Consequently, the velocity of gas at this interface will decrease, eventually reaching a condition where waste is no longer entrained into the flowing gas at the waste surface. At this point an equilibrium condition will have been achieved and the volume associated with the dimensions of the exposed surface will be equal to a bounding waste release due to blowout.

The volume released is dependent on the shape of the void produced near the borehole. The shape is dependent on the waste properties and the character of the release process. A possible shape may be similar to the relatively flat ellipsoidal form shown in Figure 5.

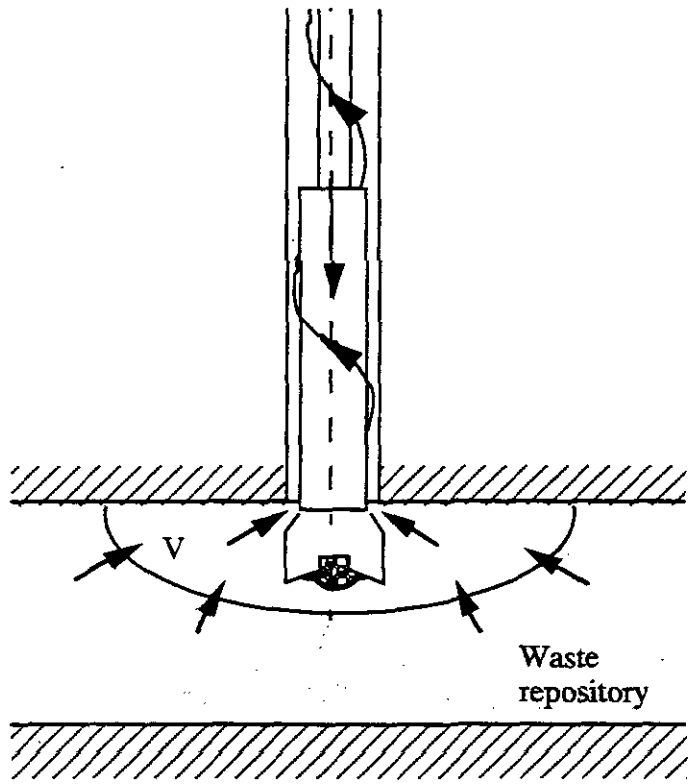

Figure 5 Potential Final Release Volume Configuration

A shape that provides a larger volume for the given exposed surface and one that is easy to calculate is the cylindrical volume shown in Figure 6.
The bounding blowout radius R_b (Figure 6) can then be written

$$R_b = \left[\left(\frac{D_o}{2}\right)^2 - \left(\frac{D_i}{2}\right)^2\right]\frac{M_j c}{2HV_e} \tag{20}$$

where

D_o and D_i are the borehole and collar diameters
M_1 = the mach number for gas flow into the borehole entrance
c = the gas sound speed at the borehole entrance
H = the panel height at time of intrusion
V_e = the entrainment velocity

In this equilibrium condition the gas velocity V is equal to the entrainment velocity V_e and the solid waste volume released to the surface is

$$Volume = \pi R_b^2 H(1-\varphi) \tag{21}$$

where φ is the waste porosity at the time of intrusion. For the "actual" void shape (Figure 5), V_e is the gas velocity required to loft a waste particle vertically in a gravity field. This velocity is also used in the computational model where the void shape is assumed to be cylindrical.

As with cuttings (section 2.1), since the waste is assumed to be uniformly distributed throughout the disposal region, the actual computation for release requires only the area associated with R_b and the waste curie content per unit area. The panel height at the time of intrusion is related to the original height and waste porosity, and to the porosity at the time of intrusion.

$$H = \text{Initial height}\left(\frac{1-\text{intial porosity}}{1-\varphi}\right)$$

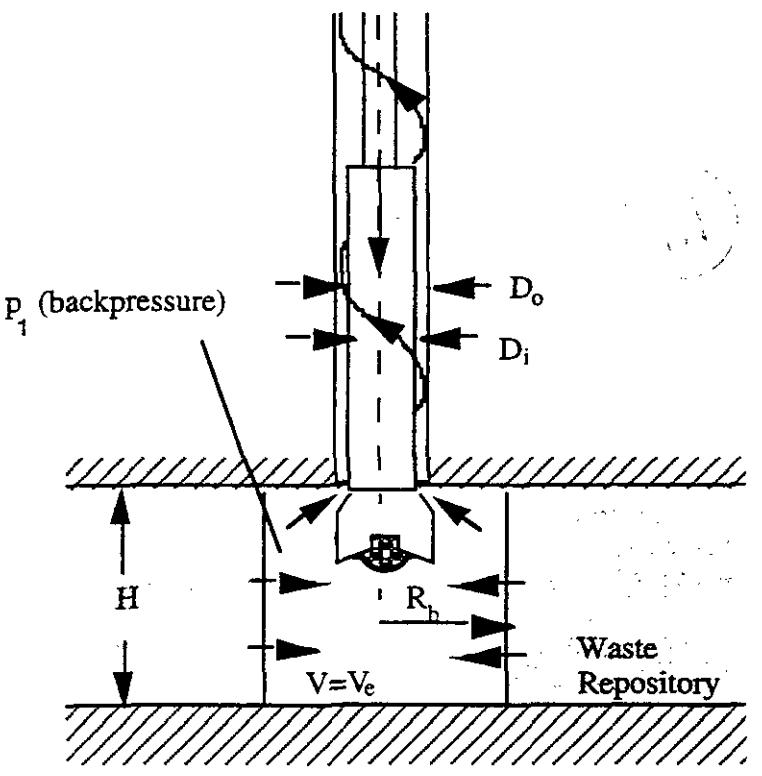

Figure 6 Idealized Cylindrical Final Volume Release Configuration

The borehole entrance mach number is computed based on flow in the borehole annulus and assumes that the borehole is free of drilling mud and undergoing full blowout. Compressible, isothermal flow in a channel (the borehole annulus) with friction is governed by the equation (Binder, 1958)

$$\frac{fl}{D} = \frac{1}{KM_1^2}\left[1-\frac{p_2^2}{p_1^2}\right] - 2\ln\frac{p_1}{p_2} \tag{22}$$

where f=friction factor, D=pipe diameter, l =pipe length, K=ratio of specific heats of the gas, p_1 and p_2= inlet and outlet gas pressures, and M_1= inlet Mach number. The pipe diameter to use for our purposes is the effective hydraulic diameter computed from the annular area. Actually there are two annular areas that are considered for flow up the borehole; one area is adjacent to the drill collars and the other is adjacent to the drill pipe and consequently equation (22) has to be solved over these two regions. The pressure ratio is based on the exit pressure at the ground surface ($p_2 \geq$ atmospheric) and the borehole entrance pressure p_1 (backpressure).

The entrainment velocity V_e is the magnitude of the gas velocity at the exposed waste surface that will cause waste particles to be removed from the surface and transported in the gas to the borehole. For a horizontal waste surface this velocity is assumed to be the terminal velocity of the particle. The terminal velocity is the speed at which a particle will fall in a motionless gas of density ρ_g. For the present model, choosing this value to represent V_e is conservative since the terminal velocity is less than the surface normal gas velocity required to vertically support the particle if the surface is inclined.

The terminal velocity of a spherical particle can be found by equating the particle weight to the drag force acting on the particle when traveling at a velocity V_e. The relationship that results is (Cheremisinoff, 1984)

$$V_e^2 = \frac{4gd(\rho_s - \rho_g)}{3C_D\rho_g} \tag{23}$$

where g= acceleration of gravity, d= particle diameter, ρ_s = particle density, ρ_g = gas density, and C_D is the coefficient of drag. The coefficient of drag for a sphere is an empirical function of the particle reynolds number R_{ed} (Fox et. al. 1973)

where $R_{ed} = \frac{\rho_g V_e d}{\mu}$ and μ is the gas viscosity

For $R_{ed} < 0.4$ $\quad C_D = \frac{24}{R_{ed}}$

For $0.4 < R_{ed} < 200000$ the data can be fit with the following function

$$C_D = 10^{(\bar{a}+\bar{b}x+\bar{c}x^2+\bar{d}x^3+\bar{e}x^4+\bar{f}x^5+\bar{g}x^6)} \tag{24}$$

where

$$\bar{a} = 1.3918$$
$$\bar{b} = -0.907723$$
$$\bar{c} = 0.136371$$
$$\bar{d} = 0.0165093$$
$$\bar{e} = -0.0285484$$
$$\bar{f} = 0.00933281$$
$$\bar{g} = -0.000897166$$

and

$$x = log_{10} R_{ed}$$

For $R_{ed} > 200000$ $C_D = 0.2$

Equations (23) and (24) are solved simultaneously using an iterative process that converges to a value of V_e that satisfies both equations.

The velocity of gas flow (V) out of the cylindrical waste surface can be computed for various waste permeabilities and repository gas pressures using the equation

$$\frac{k}{2\mu}\nabla^2 p^2 = \varphi \frac{\partial p}{\partial t} \tag{25}$$

where k is the permeability, μ is the gas viscosity, φ is the waste porosity, $\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}$, p is the gas pressure, and r is the radial coordinate. The rate is dependent on the pressure boundary condition (p_1) (Figure 6) assumed in the evacuated volume. The gas velocity in the waste at any radius r and time t is a function of the pressure gradient

$$v(r,t) = \frac{k}{\mu}\frac{\partial p(r,t)}{\partial r} \tag{26}$$

and the gas velocity at the free surface is $V = v(R_b, t)$ (27)

Solving equations (20), and (22-27) simultaneously and using stabilized flowrates out of the waste the bounding volumes of waste removed due to blowout can be obtained.

As observed earlier, the blowout process occurs over a finite time and the gas flowrate out of the free surface ($r=R_b$) tends to stabilize and remain constant for long periods of time. The time chosen to measure this "stable" flow condition has been chosen to be 700s after penetration. This is the minimum time necessary to replace the drilling mud in the annulus volume at the maximum expected drilling mud flowrate (50 gal/minute/inch of borehole diameter). This time is a measure of the minimum time necessary to generate full blowout.

The nonlinear partial differential equation for pressure in the waste (equation 25) can only be solved using numerical approximations (this is done in a code called GASFLOW) but the resulting solution is time consuming since it must be solved many times using different boundary conditions (p_1 and R_b). This process can be simplified by analytically solving the steady state form of equation 25 and by using a set of correction factors (calculated in GASFLOW) to obtain the free surface gas velocity at 700s. The steady state form of equation 25 is

$$\nabla^2 p^2 = 0 \tag{28}$$

The general solution to equation 28 is

$$p^2 = C_1 + C_2 \ln(r)$$

where

$$C_2 = \frac{p_1^{\,2} - p_\infty^{\,2}}{\ln \frac{R_b}{R_\infty}} \tag{29}$$

$$C_1 = p_1^{\,2} - C_2 \ln(R_b)$$

In these equations R_∞ is assumed to be the radius of an equivalent WIPP panel (~61m) and p_∞ is the far field gas pressure (ie. the initial pressure in the panel).
The steady state gas velocity at the free surface is

$$V(R_b) = \frac{k}{\mu}\frac{dp(R_b)}{dr} = \frac{k}{\mu}\frac{C_2}{2R_b\left(C_1 + C_2 \ln R_b\right)^{0.5}} \tag{30}$$

Equation 30 generally gives velocities lower than those that would be calculated from equation 26 using the GASFLOW code and setting the time to 700s. To be conservative in computing waste releases, the results from equation 30 should be at least as great as the velocities computed by GASFLOW at 700s. This is accomplished by multiplying the velocity calculated by equation 30 by a factor obtained from specific GASFLOW computations. For example, assuming the repository is pressurized with hydrogen gas (μ=9.3x10^{-6} Pa·s) the following velocity ratios

$$V_R = velocity\ ratio = \frac{Velocity\ from\ GASFLOW\ @\ 700s}{Steadystate\ velocity\ from\ equation\ 30} \tag{31}$$

are obtained for different radii R_b and waste permeabilities k.

let p_∞= 8x10^6 Pa, p_1= 1x10^6 Pa, φ_0=0.19, R_∞= 61m,
then

k (m^2)	velocity ratio V_R R_b=8m	velocity ratio V_R R_b=3m	velocity ratio V_R R_b=1m	velocity ratio V_R R_b=0.3m	velocity ratio V_R R_b=0.1 m
1x10^{-12}	0.558	0.734	0.836	0.897	0.92
1x10^{-13}	1.46	1.38	1.29	1.23	1.18
1x10^{-14}	2.75	2.19	1.78	1.53	1.12
1x10^{-15}	6.98	4.64	3.08	2.25	1.87
1x10^{-16}	20.5	12.23	6.68	3.90	2.79

equation 30 thus becomes

$$V(R_b) = \frac{k}{\mu} \frac{V_R C_2}{2R_b(C_1 + C_2 \ln R_b)^{0.5}} \tag{32}$$

A more complete set of tables for the velocity ratio data is shown in appendix AB. Data from these tables can be used to generate an equation for V_R as a function of the waste permeability. The fit corresponds to data values which produce the largest velocity ratio for a particular permeability. This process is conservative. See appendix AB. The resulting relationship for the velocity ratio is

$$V_R = -12593 - 5040\xi - 806.18\xi^2 - 64.455\xi^3 - 2.5771\xi^4 - 0.04125\xi^5 \tag{33}$$

where

$$\xi = log_{10} k$$

The terminal velocity described above (equations 23 and 24) is based on no cohesive strength between waste particles. Strength can be included in the model by changing the gravity term to that of an effective acceleration of gravity.

2.4.1.2.1 Effect of Strength on Solids Removal caused by Blowout

The model for solids removal during blowout is based on the lofting of particles from a horizontal surface of the waste as the result of the flow of escaping gas from the interior of the waste. Waste is lofted into the flowing gas if the velocity of the gas is equal to the terminal velocity of the waste particle. The equation for terminal velocity (equation 23) can again be written as

$$V_e^2 = \frac{4gd(\rho_s - \rho_g)}{3C_D \rho_g} \tag{34}$$

where g= acceleration of gravity, d= particle diameter, ρ_s = particle density, ρ_g = gas density, and C_D is the coefficient of drag.

The downward force resisting the drag force caused by the flowing gas is the weight of the particle. If there are additional forces acting to resist lofting such as tensile strength an effective gravity force can be computed and used to replace the gravity force in the terminal velocity equation.

Consider a material that has a tensile strength σ . This parting stress on the particle level can be written

$$\sigma = \frac{Parting \text{ force}}{\text{Particle projected area}} = \frac{mg_t}{\pi R^2} = \frac{\frac{4}{3}\pi R^3 \rho_s g_t}{\pi R^2} = \frac{4}{3}\rho_s g_t R \tag{35}$$

where m is the particle mass, R is the particle radius, ρ_s is the particle density and g_t is the effective acceleration of gravity necessary to generate a particle weight equal to the parting force.

Solving equation (35) for g_t obtains

$$g_t = \frac{3}{4}\frac{\sigma}{\rho_s R} \tag{36}$$

The effective acceleration of gravity that accounts for particle weight and strength can then be written

$$g_{eff} = (g + g_t) = g + \frac{3}{4}\frac{\sigma}{\rho_s R} \tag{37}$$

This effective acceleration of gravity can be used in the equation that computes the particle terminal velocity (equation 23) thus accounting for strength. A model for computing the parting stress based on waste saturation and particle size is presented in appendix AD. Additional contributions to strength, such as from cementation between particles, can also be included in the parting stress σ .

2.4.1.2.2 Solution Process for Solids Removal caused by Blowout (Model 1)

Utilizing Boyles Law which relates gas pressure to gas density it is possible to reduce equations 20, 22, 23, 24, and 32 to two simultaneous nonlinear equations in the unknowns R_b and the backpressure p_1. A solution process similar to that described in appendix AA was used to solve this system but it often failed to converge to the solution and was therefore considered unsuitable for use in a code where the input parameters were to vary over considerable ranges. To create a more robust solution to the system of equations, they are solved sequentially starting with equation 22.

As indicated earlier, flow in the borehole annulus is assumed to occur adjacent to both the drill collars and the drillpipe. Consequently, there are two annular areas that must be considered for flow up the borehole and equation (22) has to be solved over these two regions. The pressure ratio is based on the inlet and exit pressures for the two annuli with pressure compatibility maintained at the drillpipe / drill collar connection.

Utilizing conservation of mass, equation 22 can be divided into the two equations

$$\frac{fl_{coll}}{D_{coll}} = \frac{1}{KM_1^2}\left[1 - \frac{p_i^2}{p_1^2}\right] - 2\ln\frac{p_1}{p_i} \tag{38}$$

$$\frac{fl_{drill}}{D_{drill}} = \frac{1}{KM_1^2\left(\frac{p_1}{p_i}\right)^2\left(\frac{D_{coll}}{D_{drill}}\right)^4}\left[1 - \frac{p_{exit}^2}{p_i^2}\right] - 2\ln\frac{p_i}{p_{exit}} \tag{39}$$

where p_{exit}= exit pressure

l_{drill}= length of drillpipe

l_{coll}=collar length
D_{coll}=equivalent diameter of annulus opposite collars (based on annulus area)
D_{drill}=equivalent diameter of annulus opposite drillpipe (based on annulus area)
p_i=intermediate pressure

Eliminating M_1^2 from equations 38 and 39 results in a single nonlinear equation in the dependent variables p_i and p_{exit}.

$$F(p_i, p_{exit})=0 \tag{40}$$

A sequence of solutions to equation 40 for various backpressures p_1 are obtained by systematically scanning over possible values of p_i and p_{exit} and using the additional constraint (Binder, 1958 p 64) that either $\frac{dp}{dl}$ becomes unbounded at the pipe exit or $p_{exit}= p_{atm}$. Using this method results in a discrete set of p_1, M_1 pairs that satisfy equations 38 and 39.

Three equations remain to be satisfied; equations 20, 23 and 32.

For each p_1, the gas density can be determined from Boyles law and the terminal velocity V_e computed from equations 23 and 24 again using an iterative process. For the corresponding mach number in the p_1, M_1 pair it is now possible to compute R_b utilizing equation 20. The velocity V at the waste surface is then obtained from equation 32 using p_1 and R_b. For a valid solution the waste surface velocity V must equal the terminal velocity V_e. New p_1, M_1 pairs are selected sequentially until the V, V_e solutions approach equality and then linear interpolation is used for the final adjustment.

2.4.1.3 Solids Removal Caused by Blowout (Model 2)

Results from steady state flow experiments through granular material in a cylindrical geometry (Lary R. Lenke, et al. 1996) indicate that a porous pattern of channels is formed adjacent to the "borehole". This channeling process does not conform to conceptual model 1 as described above. As a consequence of these experiments a new conceptual model has been defined (model 2) which more closely corresponds to the physical processes that appear to be occurring. The new conceptual model is described below.

Conceptual model 2 is based on a number of assumptions. These are:

1. After intrusion by a drillbit, the pressure gradients associated with the flow of gas toward the borehole fracture the porous (waste) material sufficiently to permit the escaping gas to flow within the fractures rather than through the porous matrix (Figure 7). Consequently, the intrinsic permeability of the matrix no longer restricts gas flow and the gas pressure at the borehole entrance can be assumed to be the initial pore pressure.

2. The gas flow velocity up the borehole is governed by the isothermal flow of gas in a long tube of a given cross-sectional area, tube roughness, and gas pressure at the borehole entrance. (For sufficiently high borehole entrance pressures the flow velocity tends to choke or become self limiting.)

3. The mass flowrate of gas in the fractures at any radial cross-section away from the borehole is equal to the mass flowrate up the borehole.

4. Radial gas flow within the fractures of the waste matrix erode and widen the fractures. Erosion is assumed to occur if the fracture gas velocity exceeds a velocity v_e. (The higher gas velocities in fractures near the borehole create wider channels near the borehole.)

5. The fracture erosion velocity v_e is related to the terminal velocity of a waste particle at the fracture surface and to the cohesive strength afforded by moisture and cementation in the matrix. Experiments will determine the effectiveness of cohesive strength and gravity on erosion and will provide experimentally determined effectiveness factors F_{se} , F_{ge} , and F_{ce} which are related to these factors.

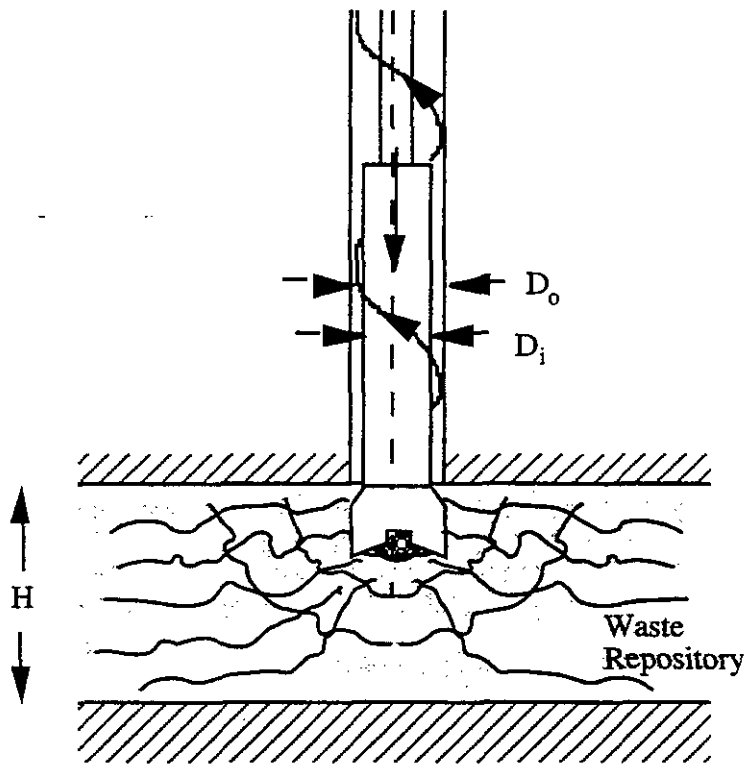

Figure 7 Fractured Waste Matrix after Penetration

2.4.1.3.1 Computation of Release Volume (Model 2)

Since the gas pressure is assumed to be constant throughout the fractured, porous matrix, conservation of mass flow requires (Figure 8)

$$2\pi r V H = A_{borehole} V_{borehole}$$

or

$$V = \frac{A_{borehole} V_{borehole}}{2\pi r H} \qquad (41)$$

where V is the average gas velocity within the matrix at a radius r from the borehole and H is the height of a repository room at the time of intrusion. The borehole annulus area is denoted as $A_{borehole}$ and the average gas velocity up the borehole annulus is denoted $V_{borehole}$.

The local gas velocity within the fractures (Figure 8) can be written as $v = \frac{V}{\varphi_f}$ where φ_f is the fracture porosity. Thus the fracture porosity associated the erosion fracture velocity v_e is

$$\varphi_{fe} = \frac{V}{v_e} = \frac{A_{borehole} V_{borehole}}{2\pi r H v_e} \tag{42}$$

The solid volume eroded from the fractures is

$$V_{ol} = 2\pi H(1-\phi)\int_0^{r_o} \varphi_{fe} r dr = \frac{A_{borehole} V_{borehole}}{v_e}(1-\phi)\int_0^{r_o} dr \tag{43}$$

or

$$V_{ol} = \frac{A_{borehole} V_{borehole} r_o}{v_e}(1-\phi) \tag{44}$$

where ϕ is the matrix porosity at the time of intrusion

Equation (44) indicates that the solid volume of material removed (spalled) due to a borehole penetration is a function of the flowrate up the borehole, the physical extend of a repository room, the waste porosity, and a velocity above which erosion occurs in waste fractures. The gas velocity up the borehole is a known function of the gas pressure at the borehole entrance.

2.4.1.3.2 Erosion Velocity (within fractures)

The fracture erosion velocity v_e is the average threshold gas velocity in a fracture required to "erode" the fracture walls. It is assumed to be related to the terminal velocity of a waste particle and to the cohesive strength between particles caused by pore water and cementation.

Equations 23 and 37 relate the gas velocity required to loft a waste particle to the weight of the particle and to the tensile strength required to separate two particles that are bonded by pore water and cementation. The resulting equation

$v_e^2 = \frac{4 g_{eff} d(\rho_s - \rho_g)}{3 C_D \rho_g}$ depends on an effective gravity term

$g_{eff} = (g + g_t) = g + \frac{3}{4}\frac{\sigma}{\rho_s R} = g + \frac{3}{4}\frac{\sigma_p}{\rho_s R} + \frac{3}{4}\frac{\sigma_c}{\rho_s R}$ where the parting stress (equation 37) is assumed to have contributions resulting from pore water σ_p and intergranular cementation σ_c. For the channeling model, since particle erosion is occurring in the channels

rather than lofting, correction factors are applied to the parting stresses and acceleration of gravity. Thus the effective gravity term becomes

$$g_{eff} = gF_{ge} + \frac{3}{4}\frac{\sigma_p}{\rho_s R}F_{se} + \frac{3}{4}\frac{\sigma_c}{\rho_s R}F_{ce} \tag{45}$$

where F_{ge} is the gravity effectiveness factor and F_{se} and F_{ce} are the stress effectiveness factors. These constants are determined by experiment. Since the fracture erosion velocity v_e is dependent upon a coefficient of drag C_D which is in turn a function of v_e (see equation 24) an iterative solution process is used to converge to a solution for v_e.

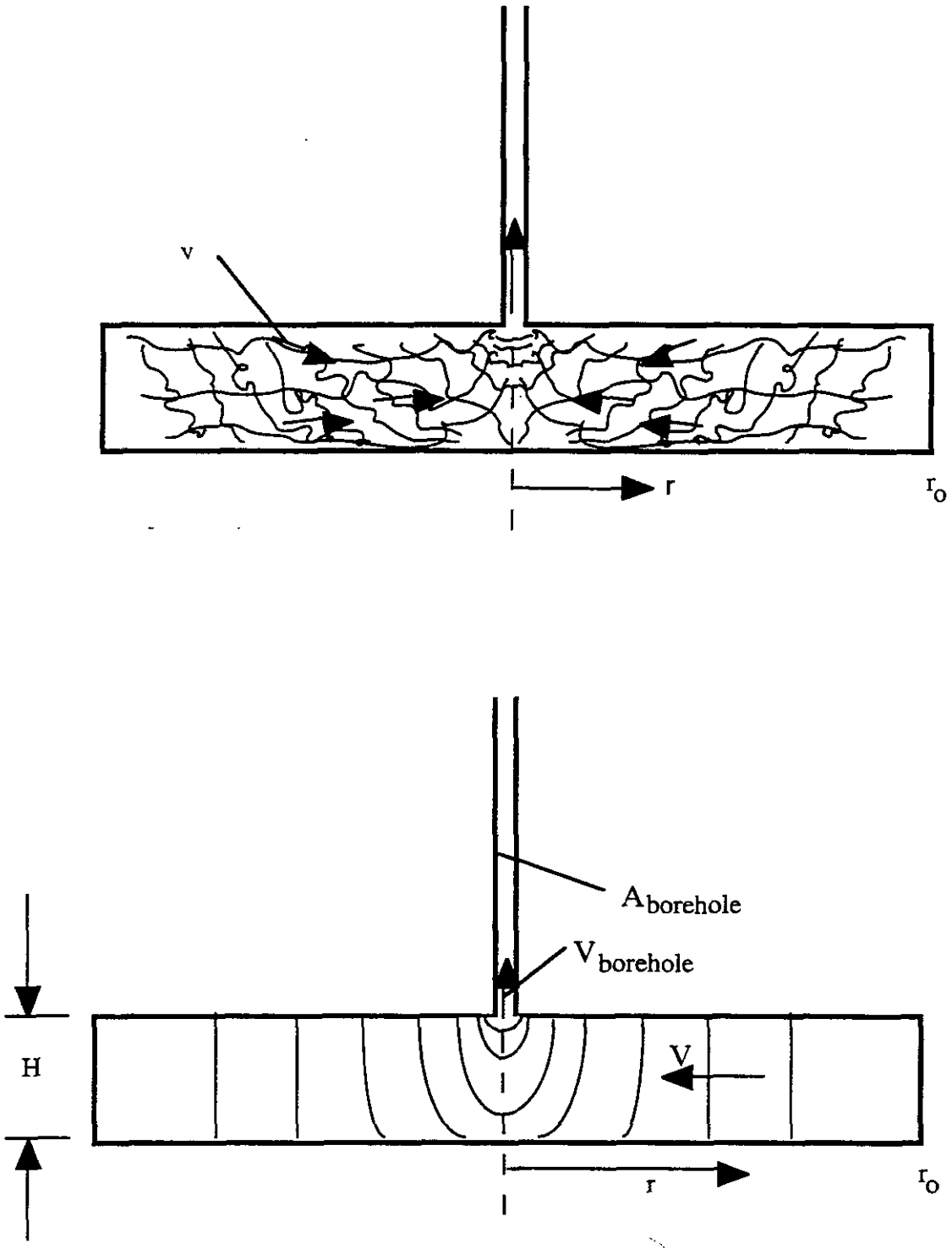

Figure 8 Flow Model

2.4.1.3.3 Solution Process for Solids Removal caused by Blowout (Model 2)

The solution to equation 44 requires 5 quantities. The value r_o is chosen as the equivalent radius of a repository room based on area. For a WIPP room r_o~ 17 m. The borehole area $A_{borehole}$ is detemined by the annulus area or (Figure 7)

$$A_{borehole} = \frac{\pi}{4}\left(D_o^2 - D_i^2\right)$$

To determine $V_{borehole}$ requires the solution of equation 22. As indicated earlier, flow in the borehole annulus is assumed to occur adjacent to both the drill collars and the drillpipe. Consequently, there are two annular areas that must be considered for flow up the borehole and equation (22) has to be solved over these two regions. The pressure ratio is based on the inlet and exit pressures for the two annuli with pressure compatibility maintained at the drillpipe / drill collar connection.

Utilizing conservation of mass, equation 22 can be divided into the two equations

$$\frac{fl_{coll}}{D_{coll}} = \frac{1}{KM_1^2}\left[1 - \frac{p_i^2}{p_1^2}\right] - 2\ln\frac{p_1}{p_i} \tag{46}$$

$$\frac{fl_{drill}}{D_{drill}} = \frac{1}{KM_1^2\left(\frac{p_1}{p_i}\right)^2\left(\frac{D_{coll}}{D_{drill}}\right)^4}\left[1 - \frac{p_{exit}^2}{p_i^2}\right] - 2\ln\frac{p_i}{p_{exit}} \tag{47}$$

where p_{exit}= exit pressure

l_{drill}= length of drillpipe
l_{coll}=collar length
D_{coll}=equivalent diameter for collar annulus (based on annulus area)
D_{drill}=equivalent diameter for drillpipe annulus (based on annulus area)
p_i=intermediate pressure
M_1=inlet Mach number

In addition to equations 46 and 47 the flow requires the additional constraint (Binder, 1958 p 64) that either $\frac{dp}{dl}$ becomes unbounded at the pipe exit or p_{exit}= p_{atm}. A recursive process based on Taylor series expansions (appendix AA) is used to obtain the solution to the three governing equations. Seed values used as initial guesses to the solution are obtained by systematically scanning over possible values of p_i and p_{exit} for a fixed backpressure (p_1= waste gas pore pressure).

The borehole velocity is related to the inlet Mach number by the relation

$$V_{borehole} = CM_1$$

where $C = (KRT)^{\frac{1}{2}}$ is the local sound speed, T is the absolute temperature and K and R are gas constants. For hydrogen gas $K = 1.41$ and $R = 4116.\ \frac{Nm}{kg.s}$ (Obert, 1948, p541)

2.4.1.3.4 Determination of the factors F_{ge} and F_{se}

The gravity effectiveness factor F_{ge} and the stress effectiveness factors F_{se} and F_{ce} are required in equation (45) to compute an effective gravity term for use in model 2 (Section 2.4.1.3.1). Laboratory scale blowout experiments (SNL Contract AL 7022) have been performed which produce data on the volume of material ejected under various conditions of borehole diameter, gas pressure, waste particle size, etc. For arbitrarily selected values of the parameters F_{ge} , F_{se} and F_{ce} various degrees of fit to the data can be achieved. This process is conducted within the CUTTINGS_S code prior to performing any predictions of full scale response. In the present analysis a best fit is achieved when the sum of the squares of the differences in computed volumes and experimental volumes is a minimum for all data points.

Defining the error as E

$$E = \sum_{1}^{n}\left[V_{ei} - V_{mi}\left(F_{se}, F_{ge}, F_{ce}\right)\right]^2 \qquad (48)$$

where V_{ei} is the volume of waste simulant ejected in experiment i

$V_{mi}\left(F_{se}, F_{ge}, F_{ce}\right)$ is the computed volume of waste simulant ejected (calculated by CUTTINGS_S computer code)

n is the number of experiments

A best fit is achieved when F_{ge}, F_{se}, and F_{ce} are chosen such that E is a minimum.

For the set of n data points the computations defined by equation (48) are made within a module of the CUTTINGS_S computer code by scanning over a range of possible values of F_{ge}, F_{se}, and F_{ce}.

2.4.2 Stuck Pipe

If the waste has a low permeability when penetrated by a drillbit, the gas flow into the drilling mud may cause waste failure adjacent to the borehole (Berglund, 1993) and jam the drillbit preventing further drilling. Prior to becoming completely stuck the driller will notice an increase in torque on the drillstring and a decrease in the rotational speed. When sticking occurs the driller will usually initiate a cleanout procedure wherein the drill bit is raised and lowered repeatedly into the sticking formation to clear the obstruction. This process can be continued for as much as 12-24 hours if it is shown to be effective. After this time the problem must be solved by weighting up the mud, spot sealing with cement or setting casing (Short,1982).

During the cleanout procedure waste will be transported to the surface with each thrust of the drillbit into the obstruction. The quantity of waste removed is related to the maximum carrying capacity of the drilling mud and can be estimated based on the observation that for drill cutting loadings above 5% in the drilling mud (Darley & Gray, 1988, p259) tight hole conditions or stuck drillpipe may occur when circulation is stopped for any reason. Thus the maximum solid waste removal rate would consist of 5% of the drilling mud flowrate. The total quantity of solid waste transported to the surface can thus be computed as the waste removal rate multiplied by the cleanout time. The range of releases possible is based on variations in drillbit diameter (10.5 to 17.5 inches), duration of the cleanout procedure (12 to 24 hours) and the drilling mud flowrate (30 to 50 gallons/minute/inch of drill diameter). The releases are based on

$$V_S = 0.05 Q D_o T \tag{49}$$

where

V_S= Solid waste volume brought to ground surface
Q=Drilling mud flow rate/drillbit diameter
T=Cleanout duration
D_o= Drill bit diameter

and varies between 43 to 238 m^3 of solid waste.

The lower limit of repository gas pressure at which sticking would occur (10MPa) is based on a drillstring power of 800hp and a coefficient of friction between the waste and drillcollars of 0.3. For these conditions the drill string angular velocity would decrease by more than 50% from the normal operating range alerting the driller to sticking conditions.

2.4.3 Gas Erosion

This again occurs when the waste has a low permeability and the gas flow to the borehole is very low and either is not detected by the driller or is allowed to trickle slowly along the drillstring and be released at the surface. The waste fails adjacent to the borehole perhaps causing some pipe sticking but the driller is able to continue and does not detect the unusual nature of the drill cuttings being brought to the surface. The flow of gas from the waste to the borehole generates a stress state in the waste adjacent to the borehole that depending on waste strength and the magnitude of the pressure gradient impresses the failed waste against the drillstring causing a continuous process of gas assisted erosion. As waste erodes more waste moves towards the drillstring in response to the gas pressure gradient and the process continues until sufficient gas has been released from the panel to preclude waste failure or until casing is set. Because the driller is either not aware of, or ignores the nature of the drill cuttings being removed in this case, the final volume of waste removed can be substantial.

For compacted waste with little or no strength waste failure will generally occur for all repository gas pressures that exceed the hydrostatic stress of the drilling mud. The failed waste is then transported to the accessible environment in the drilling mud. As with the sticking mode described above, the volume of waste removed can be computed based on the observation that above drill cutting loadings above 5% in the drilling mud (Darley & Gray, 1988, p259) tight hole conditions or stuck drillpipe may occur when circulation is stopped for any reason. Thus under these conditions the driller is not likely to remove waste to the surface at a rate faster than continuous drilling at the 5 percent limit.

The 5 percent cuttings loading will consist of both cuttings (from the hole bottom) and gas spallings. For a fixed mud flowrate the cuttings percentage will vary with the penetration rate. The penetration rate varies between 50 - 100 ft/hr. For high penetration rates the cuttings

percentage will be high leaving only a small amount for spallings to add up to the assumed 5 percent limit. For low penetration rates the cuttings percentage will be small and the spallings percentage correspondingly greater. The quantity of waste removed to the surface will be equal to (spall percentage) X (mud flowrate) X (drilling time). The drilling time is governed by the time required to drill from the elevation of the repository to the elevation at which casing is set which is below the Castile formation at 4500 ft.

The solid volume of waste brought to the surface can by readily computed based on available drilling parameters utilizing the following equation.

$$V_S=[0.05QD_o-\pi(D_o^2/4.)R_p]\Delta/R_p \qquad (50)$$

where

V_S= Solid waste volume brought to ground surface
Q=Drilling mud flow rate/drillbit diameter
D_o=Drill bit diameter
R_p=Penetration rate
Δ=Differential Drilling Depth (distance from repository depth to depth where casing is set)

Based on a differential drilling depth of 2350 ft, and placing the remaining variables at their extreme values the range of volumes of solid waste released to the surface ranges from 44 to 356 m^3.

3.0 Radionuclide Chains and Decay

The radionuclide inventory contained in the waste decays with time and follows several decay pathways or chains until stable elements are attained. The number of atoms of each radioactive waste constituent thus varies with time and the activity of waste brought to the surface as the result of human intrusion must account for the initial radionuclide inventory, the decay pathways, the mass of waste released, and the time of intrusion.

The radioactive decay of a chain of radionucides is governed by the Bateman equations and is described in Kaplan, 1962.

Consider a chain of n radionuclides where N_1, N_2, N_3, N_d .....N_n represent the number of atoms of each of the radionuclides in the repository and where N_n is stable. The differential equations that govern the decay and growth are

$$\frac{dN_1}{dt} = -\lambda_1 N_1$$

$$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2$$

$$\frac{dN_3}{dt} = \lambda_2 N_2 - \lambda_3 N_3 \qquad (51)$$

.....

.....

$$\frac{dN_n}{dt} = \lambda_{n-1} N_{n-1}$$

It will be assumed that the initial number of atoms of radionuclide 1 in the repository is N_1^0 and the initial number of atoms of the daughter atoms are $N_2^0, N_3^0, N_4^0 \ldots\ldots\ldots N_n^0$. The disintegration constants are $\lambda_1, \lambda_2, \lambda_3, \lambda_4 \ldots\ldots\ldots \lambda_{n-1}$. The half lives of the radionuclides are related to the disintegration constants through the relation, $t_{\frac{1}{2}}$ =half life $= \frac{ln\,2}{\lambda}$. Solving the differential equations (7) sequentially

obtains $$N_n = \sum_{j=1}^{n} N_j^0 \prod_{i=j}^{n-1} \lambda_i \sum_{i=j}^{n} \left(\prod_{l=j+1}^{n} \frac{1}{\lambda_l - \lambda_i} \right) e^{-\lambda_i t} \qquad (52)$$

where t is the decay time at the time of intrusion.

Additional details of this derivation are shown in Appendix AC.
The activity (in curies) of each radionucide is related to the number of atoms through the relation (Sandia WIPP Project. 1992, Table 15) $A_i = \frac{1.128x10^{16} N_i}{t_{\frac{1}{2}} M_i}$ where M_i is the gram molecular weight of the ith radionuclide. The activity in curies of the ith radionuclide released to the surface resulting from a human intrusion (a_i) is determined by mutiplying the repository activity A_i by the percent of waste removed or

$$a_i = A_i \left(\frac{Volume\ Released}{Repository\ Volume} \right) = A_i \left(\frac{Projected\ Area\ Removed}{Repository\ Area} \right)$$

Appendix AA

Recursive process for solving a system of non-linear equations (Salvadori, et al 1962)

Given a system of non-linear equations (in our case 3 equations) in the unknowns x,y,z of the form

$$\begin{aligned} F_1(x,y,z) &= 0 \\ F_2(x,y,z) &= 0 \\ F_3(x,y,z) &= 0 \end{aligned} \qquad (A1)$$

A recursive solution procedure can be developed by expanding the equations in Taylor series about an initial guess (x_o, y_o, z_o) for the solution.

$$
\begin{aligned}
F_1(x,y,z) &= F_1(x_o,y_o,z_o)+\frac{\partial F_1(x_o,y_o,z_o)}{\partial x}(x-x_o)+\frac{\partial F_1(x_o,y_o,z_o)}{\partial y}(y-y_o)+\frac{\partial F_1(x_o,y_o,z_o)}{\partial z}(z-z_o)+\ldots=0\\
F_2(x,y,z) &= F_2(x_o,y_o,z_o)+\frac{\partial F_2(x_o,y_o,z_o)}{\partial x}(x-x_o)+\frac{\partial F_2(x_o,y_o,z_o)}{\partial y}(y-y_o)+\frac{\partial F_2(x_o,y_o,z_o)}{\partial z}(z-z_o)+\ldots=0\\
F_3(x,y,z) &= F_3(x_o,y_o,z_o)+\frac{\partial F_3(x_o,y_o,z_o)}{\partial x}(x-x_o)+\frac{\partial F_3(x_o,y_o,z_o)}{\partial y}(y-y_o)+\frac{\partial F_3(x_o,y_o,z_o)}{\partial z}(z-z_o)+\ldots=0
\end{aligned}
\tag{A2}
$$

Retaining only the linear terms of the Taylor series and defining

$$
\begin{aligned}
\delta x &= x - x_o\\
\delta y &= y - y_o\\
\delta z &= z - z_o
\end{aligned}
\tag{A3}
$$

three linear simultaneous equations result

$$
\begin{aligned}
\frac{\partial F_1(x_o,y_o,z_o)}{\partial x}\delta x+\frac{\partial F_1(x_o,y_o,z_o)}{\partial y}\delta y+\frac{\partial F_1(x_o,y_o,z_o)}{\partial z}\delta z+F_1(x_o,y_o,z_o)&=0\\
\frac{\partial F_2(x_o,y_o,z_o)}{\partial x}\delta x+\frac{\partial F_2(x_o,y_o,z_o)}{\partial y}\delta y+\frac{\partial F_2(x_o,y_o,z_o)}{\partial z}\delta z+F_2(x_o,y_o,z_o)&=0\\
\frac{\partial F_3(x_o,y_o,z_o)}{\partial x}\delta x+\frac{\partial F_3(x_o,y_o,z_o)}{\partial y}\delta y+\frac{\partial F_3(x_o,y_o,z_o)}{\partial z}\delta z+F_3(x_o,y_o,z_o)&=0
\end{aligned}
\tag{A4}
$$

Based on an initial trial solution (x_o, y_o, z_o) sufficiently "close" to the actual solution, the three linear equations (A4) can be solved for the increments δx, δy, and δz and new values for x, y, and z can be determined from equations (A3). This process can be repeated until $|\delta x|$, $|\delta y|$, and $|\delta z|$ are less than a specified limit.

Appendix AB
Velocity ratio factors

Calculation of blowout releases using the model of section 2.4.1 requires the value of the gas velocity escaping from a cylindrical waste surface 700s after the drill bit has breached the repository. Since the solution process for the final blowout radius is iterative, the required gas velocity has to be determined many times using a large number of blowout radii. Although this velocity can be computed using the finite difference code GASFLOW, the code is slow and the total computation time necessary would be prohibitive. Therefore rather than using the results of the GASFLOW directly in the computational model a corrected steady state model is used which can be solved quickly in closed form. To calculate conservative blowout releases the steady state model should generate releases at least as great as those that would be predicted using the computationally intensive GASFLOW code. The correction factors required for this are

determined by running both GASFLOW and the steady state model over a range of boundary and initial conditions and by computing the velocity ratios given by

$$V_R = velocity\ ratio = \frac{Velocity\ from\ GASFLOW\ @\ 700s}{Steadystate\ velocity\ from\ equation\ 28}$$

Tabulated values for V_R are given below for a number of cases which cover a wide variable range. By choosing the largest V_R value for a given permeability (indicated in each table) a fit to the data using permeability as the independent variable can be made.

$k=10^{-16}m^2$	p_∞=8 MPa p_1=1Mpa			p_∞=15 MPa p_1=1Mpa		
R_b (m)	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$
0.1	2.41	2.79	3.04	2.17	2.47	2.68
0.3	3.20	3.90	4.40	2.76	3.30	3.69
1.0	5.09	6.68	7.87	4.13	5.31	6.2
3.0	8.82	12.23	14.8	6.81	9.32	11.2
8.0	14.4	20.5	25.1	10.8	15.3	18.7
13.0	17.4	24.9	30.6	12.9	18.5	22.7
20.0	19.0	27.4	33.7	14.1	20.3	24.9

$k=10^{-15}m^2$	p_∞=8 MPa p_1=1Mpa			p_∞=15 MPa p_1=1Mpa		
R_b (m)	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$
0.1	1.69	1.87	1.99	1.56	1.71	1.82
0.3	1.96	2.25	2.45	1.76	2.00	2.16
1.0	2.52	3.08	3.48	2.17	2.6	2.91
3.0	3.55	4.64	5.46	2.89	3.71	4.31
8.0	5.07	6.98	8.42	3.94	5.35	6.41
13.0	5.86	8.21	9.99	4.47	6.21	7.51
20.0	6.25	8.85	10.8	4.71	6.62	8.07

$k=10^{-14}m^2$	p_∞=8 MPa p_1=1Mpa			p_∞=15 MPa p_1=1Mpa		
R_b (m)	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$
0.1	1.29	1.12	1.46	1.21	1.3	1.36
0.3	1.38	1.53	1.63	1.28	1.40	1.49
1.0	1.54	1.78	1.94	1.40	1.58	1.70
3.0	1.80	2.19	2.47	1.56	1.85	2.07
8.0	2.13	2.75	3.22	1.77	2.22	2.57
13.0	2.28	3.03	3.60	1.86	2.39	2.80
20.0	2.3	3.12	3.74	1.87	2.42	2.87

$k=10^{-13}m^2$	p_∞=8 MPa p_1=1Mpa			p_∞=15 MPa p_1=1Mpa		
R_b (m)	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$
0.1	1.17	1.18	1.19	1.11	1.18	1.19
0.3	1.20	1.23	1.24	1.12	1.20	1.22
1.0	1.22	1.29	1.32	1.11	1.24	1.28
3.0	1.25	1.38	1.44	1.09	1.28	1.35
8.0	1.24	1.46	1.58	1.00	1.28	1.41
13.0	1.18	1.48	1.63	0.881	1.23	1.40
20.0	1.03	1.40	1.60	0.677	1.09	1.31

$k=10^{-12}m^2$	p_∞=8 MPa p_1=1Mpa			p_∞=15 MPa p_1=1Mpa		
R_b (m)	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$	$\varphi=0.09$	$\varphi=0.19$	$\varphi=0.29$
0.1	0.692	0.929	1.03	0.460	0.735	0.872
0.3	0.631	0.897	1.01	0.394	0.678	0.831
1.0	0.537	0.836	0.980	0.305	0.587	0.758
3.0	0.414	0.734	0.911	0.208	0.464	0.645
8.0	0.257	0.558	0.762	0.111	0.301	0.467
13.0	0.164	0.416	0.617	0.0646	0.200	0.337
20.0	0.0816	0.253	0.419	0.0292	0.106	0.198

The values of V_R and permeability k are thus

V_R	k
33.7	10^{-16}
10.8	10^{-15}
3.74	10^{-14}
1.63	10^{-13}
1.03	10^{-12}

These can be fit with the function

$$V_R = -12593 - 5040\xi - 806.18\xi^2 - 64.455\xi^3 - 2.5771\xi^4 - 0.04125\xi^5$$

where

$$\xi = log_{10} k$$

Appendix AC

Solution of the Bateman Equations

Consider a chain of n radionuclides where N_1, N_2, N_3, N_d .....N_n represent the number of atoms of each of the radionuclides in the repository and where N_n is stable. The differential equations that govern the decay and growth are

$$\frac{dN_1}{dt} = -\lambda_1 N_1$$

$$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2$$

$$\frac{dN_3}{dt} = \lambda_2 N_2 - \lambda_3 N_3 \qquad (C1)$$

.....

.....

$$\frac{dN_n}{dt} = \lambda_{n-1} N_{n-1}$$

The initial number of atoms of radionuclide 1 in the repository is N_1^0 and the initial number of atoms of the daughter atoms are N_2^0, N_3^0, N_4^0 .....N_n^0. The disintegration constants are $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ .....λ_{n-1} . The half lives of the radionuclides are related to the disintegration constants through the relation, $t_{\frac{1}{2}}$ =half life $= \frac{ln\,2}{\lambda}$.

The Laplace transform of N_i and $\frac{dN_i}{dt}$ will be defined by the notation (Hildebrand, 1962)

$$L\{N_i\} = f_i(s) \text{ and}$$

$$L\left\{\frac{dN_i}{dt}\right\} = sf_i(s) - N_i^0$$

Taking the Laplace transform of both sides of equations C1 results in

$$sf_1(s) - N_1^0 = -\lambda_1 f_1(s)$$
$$sf_2(s) - N_2^0 = \lambda_1 f_1(s) - \lambda_2 f_2(s)$$
$$sf_3(s) - N_3^0 = \lambda_2 f_2(s) - \lambda_3 f_3(s) \qquad (C2)$$

.....

.....

$$sf_n(s) - N_n^0 = \lambda_{n-1} f_{n-1}(s)$$

or solving for $f_1(s)$.....$f_n(s)$

$$f_1(s) = \frac{N_1^0}{s+\lambda_1}$$

$$f_2(s) = \frac{N_2^0 + \lambda_1 f_1(s)}{s+\lambda_2} = \frac{N_2^0}{s+\lambda_2} + \frac{\lambda_1 N_1^0}{(s+\lambda_1)(s+\lambda_2)}$$

$$f_3(s) = \frac{N_3^0 + \lambda_2 f_2(s)}{s+\lambda_3} = \frac{N_3^0}{s+\lambda_3} + \frac{\lambda_2 N_2^0}{(s+\lambda_2)(s+\lambda_3)} + \frac{\lambda_2 \lambda_1 N_1^0}{(s+\lambda_1)(s+\lambda_2)(s+\lambda_3)}$$

..... (C3)

.....

$$f_n(s) = \frac{N_n^0}{s+\lambda_n} + \frac{\lambda_{n-1} N_{n-1}^0}{(s+\lambda_n)(s+\lambda_{n-1})} + \frac{\lambda_{n-1}\lambda_{n-2} N_{n-2}^0}{(s+\lambda_n)(s+\lambda_{n-1})(s+\lambda_{n-2})} + \ldots$$

$$+ \frac{\lambda_{n-1}\lambda_{n-2}\ldots\lambda_1 N_1^0}{(s+\lambda_n)(s+\lambda_{n-1})\ldots(s+\lambda_1)}$$

The terms of equations (C3) can be rewritten in terms of partial fractions as

$$f_1(s) = \frac{N_1^0}{s+\lambda_1}$$

$$f_2(s) = \frac{N_2^0}{s+\lambda_2} + \frac{\lambda_1 N_1^0}{(s+\lambda_1)(\lambda_2-\lambda_1)} + \frac{\lambda_1 N_1^0}{(s+\lambda_2)(\lambda_1-\lambda_2)}$$

$$f_3(s) = \frac{N_3^0}{s+\lambda_3} + \frac{\lambda_2 N_2^0}{(s+\lambda_2)(\lambda_3-\lambda_2)} + \frac{\lambda_2 N_2^0}{(s+\lambda_3)(\lambda_2-\lambda_3)} +$$

$$+ \frac{\lambda_1\lambda_2 N_1}{(s+\lambda_1)(\lambda_2-\lambda_1)(\lambda_3-\lambda_1)} + \frac{\lambda_1\lambda_2 N_1}{(s+\lambda_2)(\lambda_3-\lambda_2)(\lambda_1-\lambda_2)}$$

$$+ \frac{\lambda_1\lambda_2 N_1}{(s+\lambda_3)(\lambda_1-\lambda_3)(\lambda_2-\lambda_3)} \qquad \text{(C4)}$$

.....

.....

$$f_n(s) = \sum_{j=1}^{n} \frac{N_j}{(s+\lambda_n)} \prod_{i=j}^{n-1} \left(\frac{\lambda_i}{s+\lambda_i} \right)$$

Inverting equations (C4) back into the time domain obtains

$$N_1 = N_1^0 e^{-\lambda_1 t}$$

$$N_2 = N_2^0 e^{-\lambda_1 t} + \lambda_1 N_1^0 \left[\frac{e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_1 - \lambda_2)} \right]$$

$$N_3 = N_3^0 e^{-\lambda_1 t} + \lambda_2 N_2^0 \left[\frac{e^{-\lambda_2 t}}{(\lambda_3 - \lambda_2)} + \frac{e^{-\lambda_3 t}}{(\lambda_2 - \lambda_3)} \right]$$

$$+ \lambda_1 \lambda_2 N_1^0 \left[\frac{e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_3 - \lambda_2)(\lambda_1 - \lambda_2)} + \frac{e^{-\lambda_3 t}}{(\lambda_1 - \lambda_3)(\lambda_2 - \lambda_3)} \right] .$$

.....

.....

$$N_n = \sum_{j=1}^{n} N_j^0 \prod_{i=j}^{n-1} \lambda_i \sum_{i=j}^{n} \left(\prod_{l=j+1}^{n} \frac{1}{\lambda_l - \lambda_i} \right) e^{-\lambda_i t}$$

Appendix AD
Parting Stress Based on Pore Water

Consider two spherical particles in contact with a small volume of liquid surrounding the point of contact (Figure D1). Assume that the surface tension is T and the pressure within the liquid is P_c and outside the liquid is P_o. For static equilibrium of a small element of the liquid surface

$$(P_c - P_o)ds'ds'' + 2T\,sin\left(\frac{d\theta'}{2}\right)ds'' - 2T\,sin\left(\frac{d\theta''}{2}\right)ds' = 0 \qquad \text{(D1)}$$

or

$$(P_c - P_o)ds'ds'' + 2T\left(\frac{d\theta'}{2}\right)ds'' - 2T\left(\frac{d\theta''}{2}\right)ds' = 0 \qquad \text{(D2)}$$

thus

$$(P_c - P_o)ds'ds'' + Td\theta'ds'' - Td\theta''ds' = 0 \qquad \text{(D3)}$$

but

$ds' = r'd\theta'$ and $ds'' = r''d\theta''$

Therefore

$$P_c - P_o = T\left(\frac{1}{r''} - \frac{1}{r'}\right) \qquad \text{(D4)}$$

The quantity $P_c - P_o$ represents the capillary pressure in the liquid volume. To physically separate the two spherical particles requires a force F

$$F = 2\pi r''T - (P_c - P_o)\pi r''^2 \qquad \text{(D5)}$$

The parting stress is based on the projected area of a particle and the force F. It can be written

$$\sigma_p = \frac{F}{\pi R^2} = \frac{2\pi r''T - (P_c - P_o)\pi r''^2}{\pi R^2} = \frac{2r''T - T\left(\frac{1}{r''} - \frac{1}{r'}\right)r''^2}{R^2} \qquad \text{(D6)}$$

where from geometry (Figure D2)

$$r'' = -r' + \sqrt{r'^2 + 2r'R} \qquad \text{(D7)}$$

The above analysis assumes that only one fluid contact point is involved in the determination of the parting stress. For more densely packed material as many as three fluid contact points should be considered resulting in a greater stress. However to be conservative only one fluid contact point is assumed.

Waste Saturation

The volume of liquid associated with each particle contact is

$$V_w = 2\pi w^2 h - 2V_R - V_c \tag{D8}$$

Where V_R is the volume associated with a portion of the particle formed by a plane passing through the particle a distance h from the particle surface, and V_c is the toroidal volume defined by an area A rotated around axis a'. The area of the latter is delineated by the straight line 2h and a portion of the circle of radius r' (Figure D3).

$$V_R = \frac{1}{3}\pi h^2(3R - h) \tag{D9}$$

$$V_c = 2\pi A\left[r'' + r' - \frac{2r'}{3}\left(\frac{\sin^3\theta}{\theta - \sin\theta\cos\theta}\right)\right] \tag{D10}$$

where

$$A = \frac{r'^2}{2}(2\theta - \sin 2\theta) \tag{D11}$$

The liquid saturation is defined as the ratio of the liquid volume to the total void volume in a sample of material. Void volume is a function of particle shape, particle size distribution, and packing density. For spherical particles of a single diameter the maximum percent voids (void ratio) is 37.5% (Katz, HS, et al 1978). The number of single size particles (N) within a volume (V) of material at maximum packing density is

$$N = \frac{(1 - 0.375)V}{\frac{4}{3}\pi R^3} \tag{D12}$$

Within the volume V each particle is in contact with 12 surrounding particles. Thus the volume of liquid associated with N particles is

$$V_{wt} = 6V_w N \tag{D13}$$

And the saturation (S) is

$$S = \frac{V_{wt}}{0.375V} \tag{D14}$$

or

$$S = 2.39\frac{V_w}{R^3} \tag{D15}$$

For a known saturation S and particle radius R it is possible to back solve for r' and the parting stress σ_p. This must be done numerically because of the complexity of the governing equations. Using equation (D8) and (D15) a variable Q can be defined thus

$$Q = V_w - \frac{SR^3}{2.39} = 2\pi w^2 h - 2V_R - V_c - \frac{SR^3}{2.39} = 0 \qquad \text{(D16)}$$

The iterative numerical procedure used to determine the value of r' that satisfies equation (D16) is illustrated in Figure D4. The value of r' from the solution of equation (D16) can then be used to determine the parting stress using equations (D6) and (D7). The parting stress can then be used to compute the effective acceleration of gravity utilizing equation (37a).

Strength effects arising from moisture content of the waste can thus be included in the blowout model utilizing the waste saturation at the time of intrusion and the assumed waste particle radius. The waste particle radius is an unknown quantity which will have to be sampled.

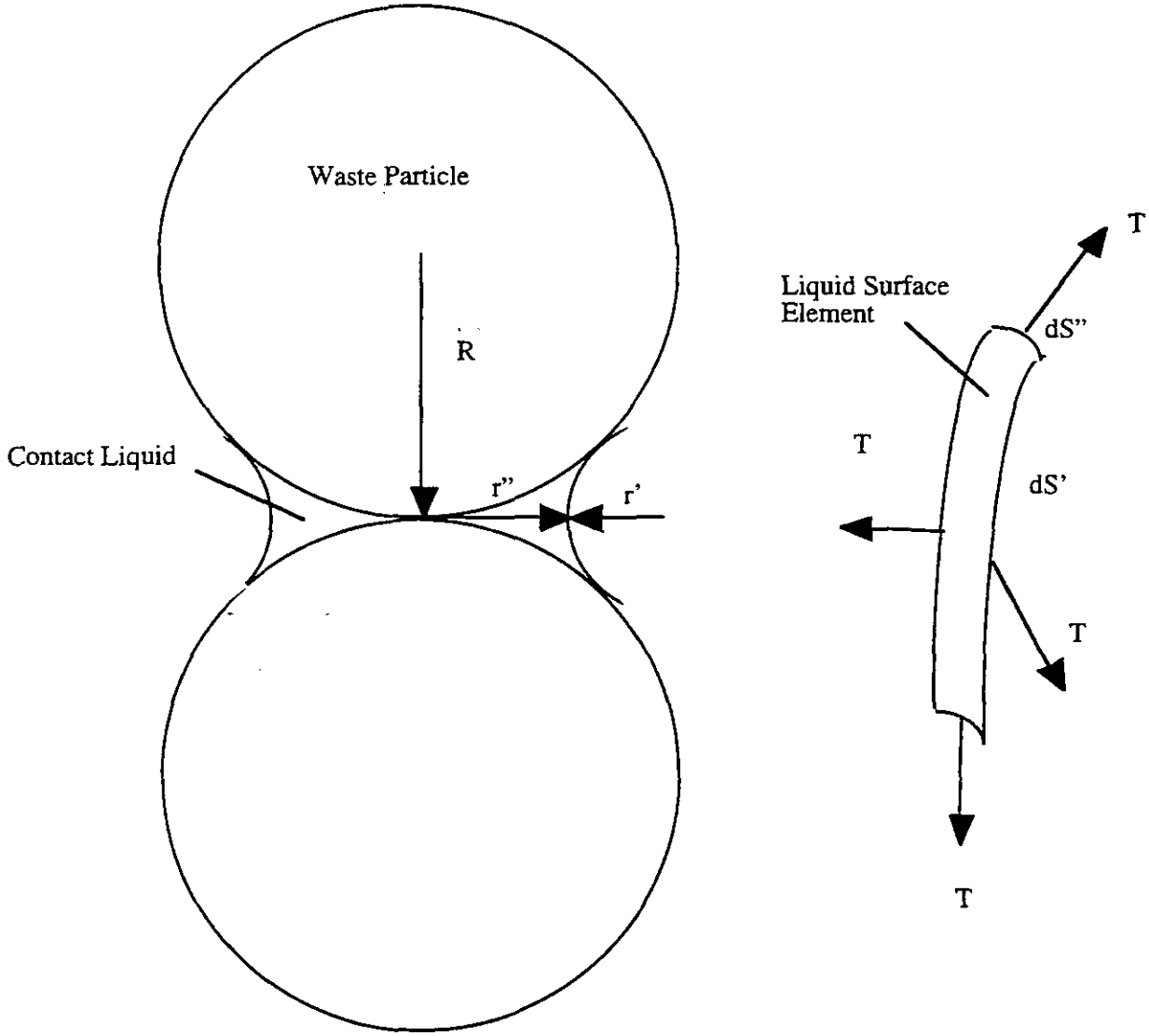
Waste Particle
R
Contact Liquid
r"
r'
Liquid Surface
Element
dS"
dS'
T
T
T
T

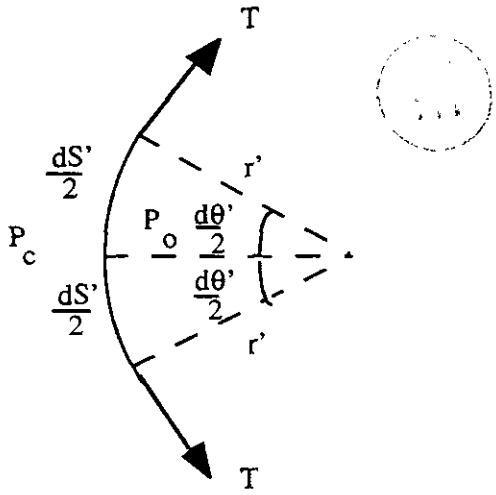
T
dS'
2
r'
P
o
dθ'
2
P
c
dθ'
2
dS'
2
r'
T

Figure D1

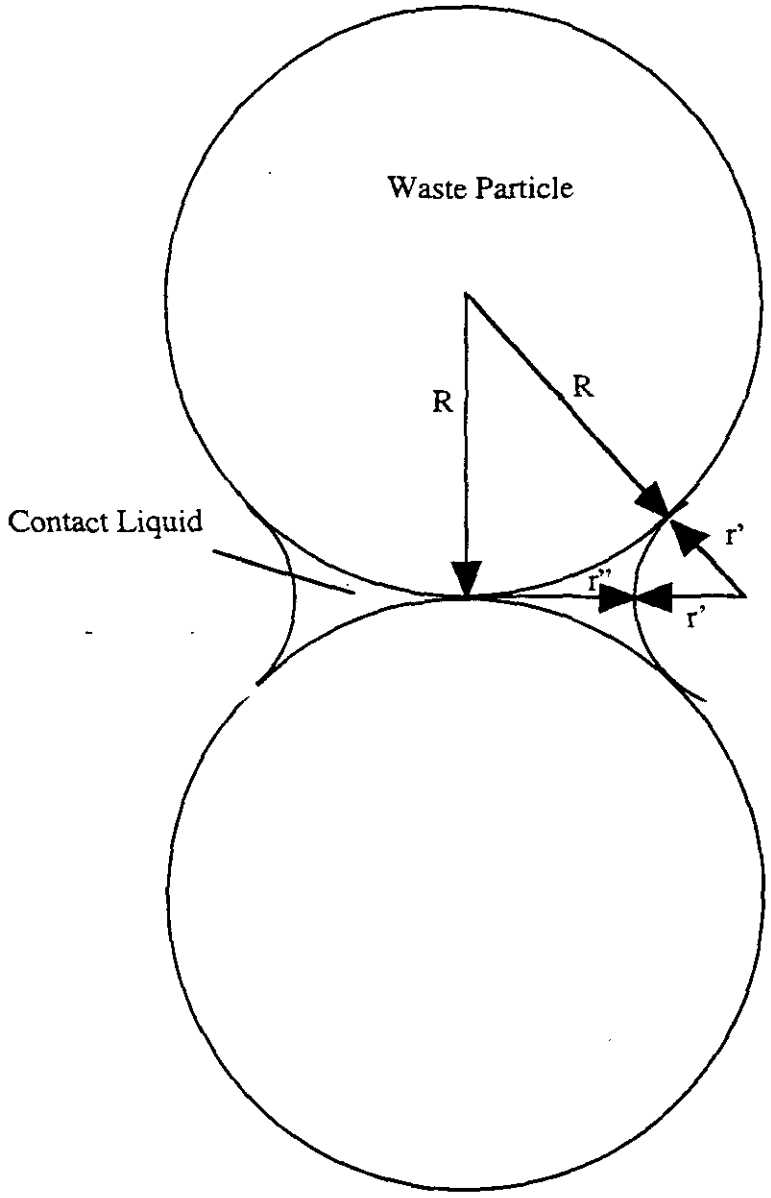

Figure D2

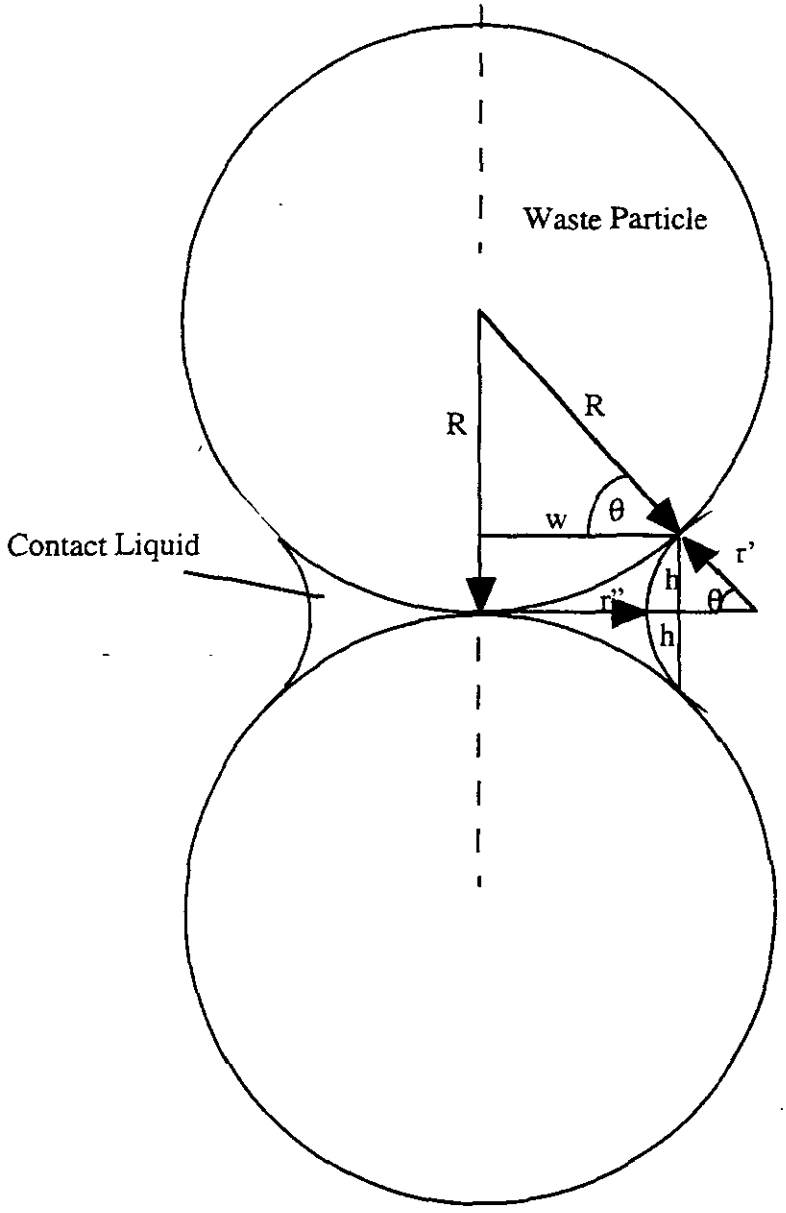

Figure D3

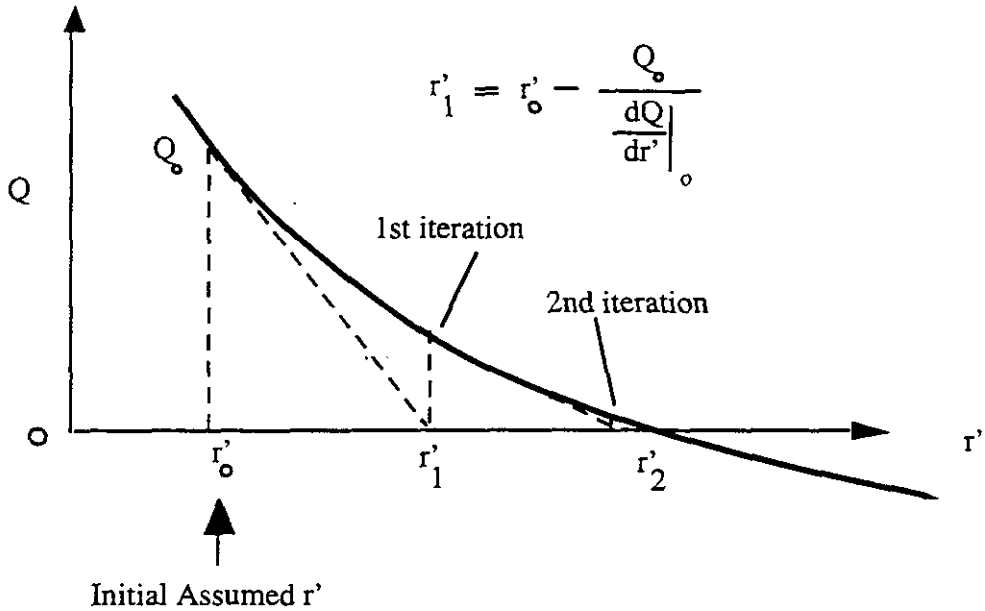
$r'_1 = r'_o - \frac{Q_o}{\left.\frac{dQ}{dr'}\right|_o}$
Q
Q_o
1st iteration
2nd iteration
o
r'_o
r'_1
r'_2
r'
Initial Assumed r'

Figure D4

References

Austin, E.H., 1983, *Drilling Engineering Handbook*, International Human Resources Development Corporation, Boston, p78.

Berglund, J.W., 1993, *Mechanisms Governing the Direct Removal of Wastes from the WIPP Repository Caused by Exploratory Drilling,* SAND-92-7295, Sandia National Laboratories, Albuquerque, NM.

Berglund, J.W., 1994, *The Direct Removal of Waste Caused by a Drilling Intrusion Into a WIPP Panel ---A Position Paper,* Memorandum of Record, 31 August 1994

Bilgen E., Boulos, R., and Akgungor A.C., 1973, "Leakage and Frictional Characteristics of Turbulent Helical Flow In Fine Clearance, "*Journal of Fluids Engineering*, Volume 95, pp 493-497.

Binder . R.C., 1958, *Advanced Fluid Mechanics Volume 1*, Prentice Hall, Inc. Englewood Cliffs N.J. p. 63.

Broc, R., ed. 1982. *Drilling Mud and Cement Slurry Rheology Manual.*, Houston, TX: Gulf Publishing Company.

Cheremisinoff, N. P., and P. N. Cheremisinoff, 1984, *Hydrodynamics of Gas-Solids Fluidization,* Gulf Publishing Company, Houston p 30.

Coleman, B.D., and W. Noll. 1959. "Helical Flow of General Fluids," *Journal of Applied Physics.* Vol. 30, no. 10, 1508-1515.

Darley, H.C.H., and G.R. Gray. 1988. *Composition and Properties of Drilling and Completion Fluids.* Houston, TX: Gulf Publishing Company.

Fox, R. W., and McDonald, A. T., 1973, *Introduction to Fluid Mechanics*, John Wiley and Sons, New York, p 406.

Fredrickson, A.G. 1960. "Helical Flow of an Annular Mass of Visco-Elastic Fluid," *Chemical Engineering Science*. Vol. 11, no. 3, 252-259.

GASFLOW---Code to Compute Gas Flow in a Porous Medium. (Since Model 1 for spall will not be used for performance assessment, this code has not been formally documented)

Hildebrand, F.B., 1962, *Advanced Calculus for Applications*, Prentice Hall, Englewood Cliffs NJ, p53.

Kaplan, I., 1962, *Nuclear Physics*, Addison-Wesley, Reading Massachusetts, p242.

Katz H.S. and Milewski, J.V., Ed., 1978, *Handbook of Fillers and Reinforcements for Plastics*, Van Nostrand Reinhold, New York, p68.

Khader, M.H.A., and H.S. Rao, 1974, "Flow Through Annulus with Large Radial Clearance," *Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division,* HY1, January, 1974.

Lenke, L.R., Berglund, J.W., and Cole R. A., March 1996, *Blowout Experiments using Fine Grained Silica Sands in an Axisymmetric Geometry,* Contractor Report 1996/7/32250, New Mexico Engineering Research Institute, University of New Mexico.

Marquis, J., September 22, 1995. Memorandum of Record SWCF-A:1.1.1.2.7:PA:QA: Summary of Gas/Oil Well Drill Collar Size Survey

Obert, E.F., *Thermodynamics,* McGraw- Hill, New York 1948, Table VI page 541.

Oldroyd, J.G., 1958, *Proceedings of the Royal Society (London),* A245, p. 278.

Parthenaides, E, and R.E. Paaswell, 1970, "Erodibility of Channels with Cohesive Boundary," *Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division,* 99: 555-558.

Rechard, R.P., H. Iuzzolino, and J.S. Sandha. 1990. *Data Used in Preliminary Performance Assessment of the Waste Isolation Pilot Plant (1990).* SAND89-2408. Albuquerque, NM: Sandia National Laboratories.

Salvadori, M.G., and M.L. Baron, 1961, Numerical Methods in Engineering, Prentice-Hall, Englewood Cliffs, N.J..

Sargunam, A., Riley, P., Arulanandan, K., Krone, R.B., 1973, "Physico-Chemical Factors in Erosion of Cohesive Soils", *Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division* ,Vol.99, No. HY3, : 555-558, March 1973.

Savins, J.G., and G.C. Wallick. 1966. "Viscosity Profiles, Discharge Rates, Pressures, and Torques for a Rheologically Complex Fluid in a Helical Flow," *A.I.Ch.E. Journal.* Vol. 12, no. 2, 357-363.

Short, J.A., 1982, *Drilling and Casing Operations*, PennWell Books, Tulsa Oklahoma, p185.

Streeter, V.L., 1958, *Fluid Mechanics*, McGraw-Hill, New York.

Sandia WIPP Project. 1992 *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 3: Model Parameters,* Sandia Report SAND92-0700/3, Albuquerque NM, Sandia National Laboratories.

SNL Contract Document AL-7022, dated October 10,1994 - Period of Performance for this contract is 10/10/94 through 3/31/96.

Walker, R.E., 1976, "Hydraulic Limits are Set by Flow Restrictions", *Oil and Gas Journal*, October 4, 1976, pp 86-90.

Whittaker, A., 1985, Editor, *Theory and Application of Drilling Fluid Hydraulics*, (International Human Resources Development Corporation, Boston).

APPENDIX B: SAMPLES OF INPUT FILES REQUIRED TO RUN GENMESH, MATSET, AND POSTLHS IN PREPARATION TO EXERCISING CUTTINGS_S

This appendix includes brief command files that exercise GENMESH, MATSET, and POSTLHS, as well as the actual input control files necessary to exercise the specific runs required prior to exercising CUTTINGS_S (see Figure 1 in Section 6).

CUSP_GENMESH.COM

```
$! -----
$! MODULE:
$! PURPOSE:
$! DATE:
$! AUTHOR:
$! -----
$!
$  SET NOON
$  EXE_SRC  :== $WP$PRODROOT:[GM.EXE]GM_PA96.EXE
$!
$  DEFINE GM_UIF$INPUT  GM_CUSP_CCA.INP
$  DEFINE GM_CDB$OUTPUT GM_CUSP_CCA.CDB
$  DEFINE GM_DBG$OUTPUT GM_CUSP_CCA.DBG
$!
$  EXE_SRC GM_UIF$INPUT GM_CDB$OUTPUT GM_DBG$OUTPUT
$! -----
$ EXIT
```

GM_CUSP_CCA.INP

```
!==============================================================================
!
! TITLE:      CUSP Input GENMESH file
! ANALYST:    Robert A. Cole
!
!==============================================================================
!
*SETup_grid
  DIMension=        3
  ORIgin=  0.0000E+00,  0.0000E+00,  0.0000E+00
  IJKmax=        2,        2,        2
!
*GRID_spacing
  DEL,COORD=X,DEL=  1.0000E+00,INRANGE=        1,        2
  DEL,COORD=Y,DEL=  1.0000E+00,INRANGE=        1,        2
  DEL,COORD=Z,DEL=  1.0000E+00,INRANGE=        1,        2
!
*REGion
  REGion=        1,IRANGE=        1,        2,JRANGE=        1,        2,KRANGE=
1,        2
!
*END
```

CUSP_MATSET.COM

```
$!=====================================================================
$!
$  EXE_SRC  :== $WP$PRODROOT:[MS.EXE]MATSET_PA96.EXE
$!
$  DEFINE MS_CDB$INPUT  GM_CUSP_CCA.CDB
$  DEFINE MS_UIF$INPUT  MS_CUSP_CCA.INP
$  DEFINE MS_SDB$INPUT  WIPP::WIPP_DB
$  DEFINE MS_SDB_CALC$INPUT CCA4
$  DEFINE MS_CDB$OUTPUT MS_CUSP_CCA.CDB
$  DEFINE MS_DBG$OUTPUT MS_CUSP_CCA.DBG
$!
$  EXE_SRC MS_CDB$INPUT MS_UIF$INPUT MS_SDB$INPUT MS_SDB_CALC$INPUT -
         MS_CDB$OUTPUT MS_DBG$OUTPUT
$!
$  EXIT
```

MS_CUSP_CCA.INP

```
!=====================================================================
!
!   FILETYPE:
!   ANALYSTS:
!   DATE:
!   PURPOSE:
!
!
!
!=====================================================================
!
*PRINT_ASSIGNED_VALUES
!
*HEADING
  TITLE, CUSP MATSET INPUT FILE
  SCALE, LOCAL
  SCENARIO, ALL
!
*UNITS=SI
!
*CREATE_blocks
  BLOCK_IDS=2,3,4
!
*RETRIEVE
  COORD, DIM=3, NAMES=X,Y,Z
!
! ...Define region names
  MATERIAL, 1=BLOWOUT, 2=BOREHOLE, 3=DRILLMUD, 4=WAS_AREA

!1...Define BLOWOUT  property names
  PROPERTY, MATerial=BLOWOUT, NAMES=PARTDIA

!2...Define BOREHOLE property names
  PROPERTY, MATerial=BOREHOLE, NAMES=DIAMMOD, DOMEGA, TAUFAIL
!
```

```
!3...Define DRILLMUD property names
  PROPERTY, MATerial=DRILLMUD, NAMES=DNSFLUID, VISCO, YLDSTRSS
!
!
!4...Define WAS_AREA property names
  PROPERTY, MATerial=WAS_AREA, NAMES=ABSROUGH
!
!
!*SET_VALUES
!
!#### Assign values to material property names not   ####
!#### found in the Secondary Database (PROPERTY.SDB) ####
!
!==================================================================
*END
```

The file that follows is an input control file to exercise POSTLHS in preparation to exercising CUTTINGS_S.

PLHS_CUSP_CCA.INP ----------

```
!
!==================================================================
!  TITLE:    1996 CCA Input File for Realization R1 for the PRELHS Code
!  ANALYST:  Lanny Smith, May 3, 1996
!==================================================================
!
!  DESCRIPTION:
!
!  WIPP 1996 CCA, Realization R1 PRELHS Input File
!
!  This input file to PRELHS is used to generate, as an output file, an LHS
!  input file containing all distribution information and execution options
!  required to create a sample for Realization R1 for the WIPP 1996 CCA
!  analysis.
!
!======== No Comments Allowed between *ECHO and *ENDECHO ================
*ECHOLHS
TITLE 1996 CCA, Realization R1 Input File for the LHS Code
NOBS           100
RANDOM SEED    238766283
CORRELATION MATRIX
    3
    18  19 -0.99
    20  21 -0.99
    28  29 -0.75
OUTPUT CORR HIST DATA
*ENDECHO
!
!== PROPERTIES TO BE RETRIEVED FROM WIPP 1996 CCA DATABASE, 'CCA4' ==
!
*RETRIEVE
!
   MATERIALS,  STEEL
   PROPERTIES, CORRMCO2
!
   MATERIALS,  WAS_AREA
```

```
   PROPERTIES, PROBDEG
!
   MATERIALS,  WAS_AREA
   PROPERTIES, GRATMICI
!
   MATERIALS,  WAS_AREA
   PROPERTIES, GRATMICH
!
   MATERIALS,  CELLULS
   PROPERTIES, FBETA
!
   MATERIALS,  WAS_AREA
   PROPERTIES, SAT_RGAS
!
   MATERIALS,  WAS_AREA
   PROPERTIES, SAT_RBRN
!
   MATERIALS,  WAS_AREA
   PROPERTIES, SAT_WICK
!
   MATERIALS,  CL_L_T1
   PROPERTIES, PRMX_LOG
!
   MATERIALS,  CONC_T1
   PROPERTIES, PRMX_LOG
!
   MATERIALS,  ASPHALT
   PROPERTIES, PRMX_LOG
!
   MATERIALS,  SHFT_DRZ
   PROPERTIES, PRMX_LOG
!
   MATERIALS,  SALT_T1
   PROPERTIES, CUMPROB
!
   MATERIALS,  SALT_T1
   PROPERTIES, SAT_RGAS
!
   MATERIALS,  SALT_T1
   PROPERTIES, SAT_RBRN
!
   MATERIALS,  SALT_T1
   PROPERTIES, PORE_DIS
!
   MATERIALS,  S_HALITE
   PROPERTIES, POROSITY
!
   MATERIALS,  S_HALITE
   PROPERTIES, PRMX_LOG
!
   MATERIALS,  S_HALITE
   PROPERTIES, COMP_RCK
!
   MATERIALS,  S_MB139
   PROPERTIES, PRMX_LOG
!
   MATERIALS,  S_MB139
   PROPERTIES, COMP_RCK
!
   MATERIALS,  S_MB139
```

```
   PROPERTIES, RELP_MOD
!
   MATERIALS,  S_MB139
   PROPERTIES, SAT_RBRN
!
   MATERIALS,  S_MB139
   PROPERTIES, SAT_RGAS
!
   MATERIALS,  S_MB139
   PROPERTIES, PORE_DIS
!
   MATERIALS,  S_HALITE
   PROPERTIES, PRESSURE
!
   MATERIALS,  CASTILER
   PROPERTIES, PRESSURE
!
   MATERIALS,  CASTILER
   PROPERTIES, PRMX_LOG
!
   MATERIALS,  CASTILER
   PROPERTIES, COMP_RCK
!
   MATERIALS,  BH_SAND
   PROPERTIES, PRMX_LOG
!
   MATERIALS,  CASTILER
   PROPERTIES, GRIDFLO
!
   MATERIALS,  BLOWOUT
   PROPERTIES, PARTDIA
!
   MATERIALS,  BOREHOLE
   PROPERTIES, TAUFAIL
!
   MATERIALS,  CULEBRA
   PROPERTIES, MINP_FAC
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
```

```
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
```

```
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
   MATERIALS,  GLOBAL
   PROPERTIES, PRMTZIDX
!
!=====================================================================
!
*END
```

END OF APPENDIX B

APPENDIX C: GRAMMATICAL STRUCTURE OF CUTTINGS_S'S INPUT FILES NOS. 1 & 2

The grammatical structure of CUTTINGS_S's input control files (file numbers 1 and 2) follows the four rules stated below. In Section 6.2, these files are associated with the logical symbols: CUSP_INPT$TXT0 $, and CUSP_INPT$TXT0TXT1 .

(1) Text files consist of keywords followed by (i) a real number, (ii) an integer, or (iii) a character variable. There is no required order for keywords.

(2) Text following an exclamation point (!) is treated as a comment. That is, it is printed out with the file and normally provides the user with useful explanatory information regarding the file, but it is ignored by the code when the file is read.

(3) Arrays can span more than one line of an input file. Arrays of numbers are terminated by any non-numeric character. Character arrays are terminated by any non-numeric, non-alphabetical character. These include the symbols: <>?:[]-+&%$#@!.

(4) If input is specified as a character data field, numerical values will be extracted from the upstream (MATSET or POSTLHS) input CDB file. The character data field must have a colon, (:), separating the CAMDAT material name on the left from the CAMDAT property name on the right. No intervening blanks are permitted. Material and property names are restricted to a maximum of 8 characters.

END OF APPENDIX C

APPENDIX D: SAMPLE CUTTINGS_S DEBUG FILE FROM TEST-RUN PROBLEM #1

This file is taken from QA test problem number 1 (see Section 6.4) The file itself is annotated here and there with explanatory comments that describe the various collections of data. Explanatory comments are printed in italics to offset them from the normal content of the Debug file. The Debug file itself is described in Section 6.1 as file number 8.

Explanatory Comment: The data below are the standard WIPP title page and disclaimer, followed by dynamic memory allocation data. End comment.

```
-----------------------------------------------------------------------------------------
-----------
CUSP_PA96 5.03 PROD PA96 05/23/96                                    06/04/96 09:52:46

 CCCCC   UU   UU   SSSSSS  PPPPPP            PPPPPP    AAAAA     9999    6666
CC   CC  UU   UU  SS      PP    PP           PP    PP  AA   AA   9    9  6
CC       UU   UU  SS      PP    PP           PP    PP  AA   AA   9    9  6
CC       UU   UU   SSSSS  PPPPPP             PPPPPP   AAAAAAA    99999  66666
CC       UU   UU       SS PP                 PP       AA   AA        9  6    6
CC   CC  UU   UU       SS PP                 PP       AA   AA        9  6    6
 CCCCC    UUUUU   SSSSSS  PP        _______  PP       AA   AA    9999    6666

          Program for computing the quantity of radioactive material
        (in Curies) brought to the surface as cuttings/spall generated
      by a drilling operation that penetrates a rad-waste repository.

                        CUSP_PA96 Version 5.03
                       PROD PA96 Built 05/23/96
                      Written by Jerry W. Berglund
                  Sponsored by Robert A. Cole & (J. S. Rath)

                        Run on 06/04/96 at 09:52:46
                     Run on ALPHA AXP BEATLE OpenVMS V6.1

      ************************************************************

      Prepared for
      Sandia National Laboratories
      Albuquerque, New Mexico 87185-5800
      for the United States Department of Energy
      under Contract DE-AC04-76DP00789

      ************************************************************

                              Disclaimer
                              ----------

      This computer program was prepared as an account of work
      sponsored by an agency of the United States Government.
      Neither the United States Government nor any agency thereof,
      nor any of their employees, nor any of their contractors,
      subcontractors, or their employees, makes any warranty,
      express or implied, or assumes any legal liability or
      responsibility for the accuracy, completeness, or usefulness
      of any information, apparatus, product, or process disclosed
      or represents that its use would not infringe privately
      owned rights. Reference herein to any specific commercial
      product, process, or service by trade name, trademark,
      manufacturer, or otherwise, does not necessarily constitute
      or imply its endorsement, recommendation, or favoring by the
      United States Government, any agency thereof or any of their
      contractors or subcontractors. The views and opinions
      expressed herein do not necessarily state or reflect those
      of the United States Government, any agency thereof or any
```

```
            of their contractors or subcontractors.

            ************************************************************

 Program Name      CUT_SPAL
 Program Version
 Program UpDated

CUSP$EXE           WP$PRODROOT:[CUSP.EXE]CUSP_PA96.EXE

 SUMMARY OF INPUT & OUTPUT FILES USED IN THIS RUN

CUSP_INP$TXT0      CUSP_TEST_REPOSITORY.DAT
CUSP_INP$TXT1      CUSP_TEST_1.INP
CUSP_INP$BRAGCDB   CUSP_TEST_INP_BF.CDB
CUSP_OUT$DBG       CUSP_OUT_TEST_1.DBG
CUSP_INP$CDB       CUSP_TEST_1.CDB
CUSP_OUT$CDB       CUSP_OUT_TEST_1.CDB
CUSP_OUT$NVERFY    CUSP_OUT_TEST_1.VER

Debug flag DBRAG is ON

 ***********************************************************************
 (SCATXT0)

Explanatory Comment:  The folowing is an echo of data read from the repository/model
input control file (logical symbol CUSP_INP$TEXTO)        End of Comment.

   MODEL_DATA

!
!
!    The following input variables are hard wired and are related to the
! repository modeling paper written by J. W. Berglund (see Appendix A)
!
! PR_MAX  <>The maximum pressure allowed by model
  PR_MAX            15.0E6

! PR_MIN  <>The minimum pressure allowed by model
  PR_MIN             0.0E6

! PE_MAX  <>The maximum permeability allowed by model
  PE_MAX           1.0E-12

! PE_MIN  <>The minimum permeability allowed by model
  PE_MIN           1.0E-17

! PCUT    <> Pressure (Pa) which defines the border between the
!                     erosion phase and the blowout phase
  PCUT               8.0E6

! PGAS    <> Pressure (Pa) which defines the border between the gas
!                     erosion phase and the stuck-pipe phase
  PGAS              10.0E6

! KCRIT   <> Permeability which defines the phase border the blowout
!                     phase and the gas erosion/stuck pipe phase
  KCRIT            1.0E-16


!
! Properities relative to the model (repository) <<<<<<<<<<<<<<<<<<<<<<<
!
! DELTR   <>  Delta radius for derivative in stress calculation
  DELTR            0.00001
```

```
! ITER     <> Number of iterations to solve for reynolds number
  ITER                  1

! FGE      <>  Gravity  effectiveness factor
  FGE                 18.4

! FSE      <>  Strength effectiveness factor
  FSE                  0.0

! FCE      <>  Cementation  effectiveness factor
  FCE                  0.0

! CEMENT   <>  Cementation stress
  CEMENT               0.0

! SUFTEN   <> Surface tension (N/N)
  SUFTEN            8.0E-2


! Properties of the gas (Hydrogen) in the repository <<<<<<<<<<<<<<<<<<<<<<<
!
! KGAS     <> Ratio of Specific Heats
  KGAS              1.41E0

! RGAS     <> Gas Constant for Hydrogen
  RGAS              4116.0

! VISC     <> Hydrogen viscosity
  VISC             0.92E-5

! PSUF     <> Surface presure (Pa)
  PSUF          0.089465E6


! Properties to do with the repository <<<<<<<<<<<<<<<<<<<<<<<
!
! TREPO    <> Temperature of repository (K)
  TREPO              300.0

! DEPTH    <> Distance from repository depth to depth where casing
!                        is set (m)
  DEPTH              716.0

! FLWCNST <> Percent volume of material that is carried by Drilling
!                        mud (unitless)
  FLWCNST             0.05

! HREPO    <> Height of repository at burial time      (4m)
  HREPO               3.96

! RPANEL   <> The equivalent radius of 1 panel     (910.0m**2)
  RPANEL             60.87

! ROOM     <> The equivalent radius of 1 room      (11,640m**2)
  ROOM                17.1

! RHOS     <> Waste particle density (kg/m**3)
  RHOS              2650.0


! Variables to do with drilling <<<<<<<<<<<<<<<<<<<<<<<
!
! L1       <> Collar Length (m)
  L1                182.88

! L2       <> Drill pipe length (m)
  L2                472.12
```

```
! COLDIA  <> Collar diameter (m)
  COLDIA          0.2032004

! PIPED   <> Drill pipe diameter (m)
  PIPED           0.1143002

! ROUGHP  <> Friction factor (unitless)
  ROUGHP                0.08

!
! APORO   <> A constant in equation to determine permeability as a
!              function of porosity
  APORO             1.0E-11

! NPORO   <> N constant in equation to determine permeability as a
!              function of porosity
  NPORO                  4.6
!
! END_OF_MODEL_INPUT
!


   RADIONUCLIDE_DATA


!GEOMETRY

  INV_AR        1.11520E+05

  RHW_AR        1.11520E+05

  WUF           5.25

!MATERIAL
  OUT_MAT       BOREHOLE

!REPOSITORY_TYPE

 REP_NAME     WIPP
 REP_GEOLogy HALITE

 RADWASte_type  CONtact_handled

!RADIOISOTOPE_chains

!
!  chain1/chain2 from U234  & down are the same:
!  (Both chains are required input)

!          \/       \/       \/       \/       \/       \/       \/

 CHAIN1    PU242    U238     TH234    PA234M   U234     TH230    RA226
           RN222    PO218    PB214    BI214    PO214    PB210    <

 CHAIN2    PU238    U234     TH230    RA226    RN222    PO218
           PB214    BI214    PO214    PB210    <

!  chain3/chain4 from PU239 & down are the same:

 CHAIN3    AM243    NP239    PU239    U235     TH231    PA231    AC227
           TH227    RA223    RN219    PO215    PB211    BI211    TL207    <

 CHAIN4    CM243    PU239    U235     TH231    PA231    AC227    TH227
           RA223    RN219    PO215    PB211    BI211    TL207    <

!  chain5/chain6 from U236  & down are the same:

 CHAIN5    CF252    CM248    PU244    PU240    U236     TH232    RA228
           AC228    TH228    RA224    RN220    PO216    PB212    BI212
           PO212    <
```

```
CHAIN6     CM244   PU240   U236    TH232   RA228   AC228   TH228
           RA224   RN220   PO216   PB212   BI212   PO212   <

CHAIN7     CM245   PU241   AM241   NP237   PA233   U233    TH229
           RA225   AC225   FR221   AT217   BI213   PO213   PB209   <

CHAIN8     CS137   BA137M  <

CHAIN9     PM147   SM147   ND143   <

CHAIN10    SR90    Y90     ZR90    <

!          ^       ^       ^       ^       ^       ^       ^

SAVE     AM241  AM243  CF252  CM243  CM244  CM245  CM248  CS137
         NP237  PA231  PB210  PM147  PU238  PU239  PU240  PU241
         PU242  PU244  RA226  RA228  SR90   TH229  TH230  TH232
         U233   U234   U235   U236   U238  <

  TABULAR_DATA

!
! Example of how radioisotope data are entered:
!
!  ...1st Line: Radionuclide (an asterisk in column 1 follow
!                             by radionuclide name, ex; *AC225 )
!  ...2nd & 3rd line
!
!  ...Field#1 Atomic Weight        (Kg/Mole) AWT     [REAL]  (3(11x,1pe14.6))
!  ...Field#2 Half-Life             (Years)  HALFY   [REAL]          "
!  ...Field#3 Activity Conversion   (Ci/Kg)  AWTCNV  [REAL]          "
!  ...Field#4 EPA Release Limit      (Ci)    EPAREL  [REAL]          "
!  ...Field#5 Inventory              (Ci)    INVCHD  [REAL]          "
!  ...Field#6 Inventory              (Ci)    INVRHD  [REAL]          "
!
!
!*PU241
!xxxaaaaaaaaeeeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeeee
!   AWT       2.410000E-01   HALFY     1.439900E+01   ACTCNV    1.030000E+05
!   EPAREL    1.000000E+07   INVCHD    1.930000E+06   INVRHD    0.000000E+00
!
!
<TABLE_INPUTS
*AC225
   AWT       2.250230E-01   HALFY     2.737909E-02   ACTCNV    5.802700E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*AC227
   AWT       2.270280E-01   HALFY     2.177335E+01   ACTCNV    7.232300E+04
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*AC228
   AWT       2.280310E-01   HALFY     6.993710E-04   ACTCNV    2.241700E+09
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*AM241
   AWT       2.410570E-01   HALFY     4.322347E+02   ACTCNV    3.431200E+03
   EPAREL    1.000000E+02   INVCHD    2.400000E+05
*AM243
   AWT       2.430610E-01   HALFY     7.380313E+03   ACTCNV    1.992900E+02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*AT217
   AWT       2.170050E-01   HALFY     1.023547E-09   ACTCNV    1.609500E+15
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BA137M
   AWT       1.369070E-01   HALFY     4.851550E-06   ACTCNV    5.382400E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BI211
   AWT       2.109870E-01   HALFY     4.049824E-06   ACTCNV    4.184000E+11
```

```
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BI212
   AWT       2.119910E-01   HALFY     1.151253E-04   ACTCNV    1.464800E+10
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BI213
   AWT       2.129940E-01   HALFY     8.679553E-05   ACTCNV    1.933800E+10
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BI214
   AWT       2.139990E-01   HALFY     3.783638E-05   ACTCNV    4.415300E+10
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*CF252
   AWT       2.520820E-01   HALFY     2.638090E+00   ACTCNV    5.375899E+05
   EPAREL    0.000000E+00   INVCHD    2.960000E+03
*CM243
   AWT       2.430610E-01   HALFY     2.850088E+01   ACTCNV    5.160700E+04
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*CM244
   AWT       2.440630E-01   HALFY     1.811013E+01   ACTCNV    8.088299E+04
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*CM245
   AWT       2.450650E-01   HALFY     8.498927E+03   ACTCNV    1.716500E+02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*CM248
   AWT       2.480720E-01   HALFY     3.390698E+05   ACTCNV    4.250200E+00
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*CS137
   AWT       1.369070E-01   HALFY     2.999975E+01   ACTCNV    8.704300E+04
   EPAREL    1.000000E+03   INVCHD    2.070000E+04
*FR221
   AWT       2.210140E-01   HALFY     9.126364E-06   ACTCNV    1.772400E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*ND143
   AWT       1.430000E-01   HALFY     3.168876E+30   ACTCNV    0.000000E+00
   EPAREL    1.000000E+03   INVCHD    0.000000E+00
*NP237
   AWT       2.370480E-01   HALFY     2.139942E+06   ACTCNV    7.047600E-01
   EPAREL    1.000000E+02   INVCHD    6.670000E+01
*NP239
   AWT       2.390530E-01   HALFY     6.448664E-03   ACTCNV    2.319100E+08
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PA231
   AWT       2.310360E-01   HALFY     3.276618E+04   ACTCNV    4.722500E+01
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*PA233
   AWT       2.330400E-01   HALFY     7.392988E-02   ACTCNV    2.075100E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PA234M
   AWT       2.340430E-01   HALFY     2.224551E-06   ACTCNV    6.866600E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PB209
   AWT       2.089810E-01   HALFY     3.764625E-04   ACTCNV    4.544100E+09
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PB210
   AWT       2.099840E-01   HALFY     2.229938E+01   ACTCNV    7.634800E+04
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*PB211
   AWT       2.109890E-01   HALFY     6.863786E-05   ACTCNV    2.468600E+10
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PB212
   AWT       2.119920E-01   HALFY     1.213680E-03   ACTCNV    1.389500E+09
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PB214
   AWT       2.140000E-01   HALFY     5.095553E-05   ACTCNV    3.278500E+10
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PM147
   AWT       1.469150E-01   HALFY     2.623513E+00   ACTCNV    9.275300E+05
   EPAREL    0.000000E+00   INVCHD    5.250000E+02
*PO212
   AWT       2.119890E-01   HALFY     9.506629E-15   ACTCNV    1.773900E+20
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
```

```
*PO213
   AWT       2.129930E-01   HALFY     1.330928E-13   ACTCNV    1.261100E+19
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PO214
   AWT       2.139950E-01   HALFY     5.206464E-12   ACTCNV    3.208700E+17
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PO215
   AWT       2.149990E-01   HALFY     5.640600E-11   ACTCNV    2.947900E+16
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PO216
   AWT       2.160020E-01   HALFY     4.753314E-09   ACTCNV    3.482000E+14
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PO218
   AWT       2.180090E-01   HALFY     5.799044E-06   ACTCNV    2.827800E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*PU238
   AWT       2.380500E-01   HALFY     8.774619E+01   ACTCNV    1.711500E+04
   EPAREL    1.000000E+02   INVCHD    4.240000E+06
*PU239
   AWT       2.390520E-01   HALFY     2.406445E+04   ACTCNV    6.214600E+01
   EPAREL    1.000000E+02   INVCHD    3.920000E+05
*PU240
   AWT       2.400540E-01   HALFY     6.537392E+03   ACTCNV    2.278100E+02
   EPAREL    1.000000E+02   INVCHD    6.930000E+04
*PU241
   AWT       2.410570E-01   HALFY     1.439937E+01   ACTCNV    1.030000E+05
   EPAREL    0.000000E+00   INVCHD    1.930000E+06
*PU242
   AWT       2.420590E-01   HALFY     3.869198E+05   ACTCNV    3.817100E+00
   EPAREL    1.000000E+02   INVCHD    4.910000E+04
*PU244
   AWT       2.440640E-01   HALFY     8.261261E+07   ACTCNV    1.773100E-02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*RA223
   AWT       2.230190E-01   HALFY     3.130533E-02   ACTCNV    5.120600E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RA224
   AWT       2.240200E-01   HALFY     1.001999E-02   ACTCNV    1.592700E+08
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RA225
   AWT       2.250240E-01   HALFY     4.052993E-02   ACTCNV    3.919900E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RA226
   AWT       2.260250E-01   HALFY     1.599966E+03   ACTCNV    9.885801E+02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*RA228
   AWT       2.280310E-01   HALFY     6.699955E+00   ACTCNV    2.340000E+05
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RN219
   AWT       2.190090E-01   HALFY     1.254875E-07   ACTCNV    1.300800E+13
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RN220
   AWT       2.200110E-01   HALFY     1.761895E-06   ACTCNV    9.222600E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RN222
   AWT       2.220180E-01   HALFY     1.046997E-02   ACTCNV    1.538000E+08
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*SM147
   AWT       1.470000E-01   HALFY     1.059355E+11   ACTCNV    2.295400E-05
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*SR90
   AWT       8.990801E-02   HALFY     2.912197E+01   ACTCNV    1.365400E+05
   EPAREL    1.000000E+03   INVCHD    9.850002E+03
*TH227
   AWT       2.270280E-01   HALFY     5.124073E-02   ACTCNV    3.073200E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*TH228
   AWT       2.280290E-01   HALFY     1.913051E+00   ACTCNV    8.195301E+05
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*TH229
```

```
   AWT        2.290320E-01   HALFY      7.339118E+03   ACTCNV     2.126900E+02
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*TH230
   AWT        2.300330E-01   HALFY      7.700370E+04   ACTCNV     2.018300E+01
   EPAREL     1.000000E+01   INVCHD     0.000000E+00
*TH231
   AWT        2.310360E-01   HALFY      2.911247E-03   ACTCNV     5.315200E+08
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*TH232
   AWT        2.320380E-01   HALFY      1.405080E+10   ACTCNV     1.096500E-04
   EPAREL     1.000000E+01   INVCHD     6.110000E-01
*TH234
   AWT        2.340440E-01   HALFY      6.597601E-02   ACTCNV     2.315200E+07
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*TL207
   AWT        2.069770E-01   HALFY      9.069325E-06   ACTCNV     1.904500E+11
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*U233
   AWT        2.330400E-01   HALFY      1.585072E+05   ACTCNV     9.678300E+00
   EPAREL     1.000000E+02   INVCHD     1.310000E+03
*U234
   AWT        2.340410E-01   HALFY      2.445105E+05   ACTCNV     6.247300E+00
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*U235
   AWT        2.350440E-01   HALFY      7.038074E+08   ACTCNV     2.161100E-03
   EPAREL     1.000000E+02   INVCHD     1.150000E+00
*U236
   AWT        2.360460E-01   HALFY      2.341483E+07   ACTCNV     6.468300E-02
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*U238
   AWT        2.380510E-01   HALFY      4.468115E+09   ACTCNV     3.361100E-04
   EPAREL     1.000000E+02   INVCHD     2.010000E-01
*Y90
   AWT        8.990701E-02   HALFY      7.301091E-03   ACTCNV     5.446300E+08
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*ZR90
   AWT        9.000000E-02   HALFY      3.168876E+30   ACTCNV     0.000000E+00
   EPAREL     1.000000E+03   INVCHD     0.000000E+00
END_TABLES>
!
! END_OF_RADIOISOTOPE_INPUT
!

 ***********************************************************************
 (SCATXT1)
```

Explanatory Comment: This ends the listing of data read from the repository/model input control file and begins the echo of drilling/intrusion data read from the (input control) file whose logical symbol is CUSP_INP$TXT1. End of Comment.

```
!
!
!  INTRUSION

 TINTR          100.0
 TAUFAIL   BOREHOLE:TAUFAIL
 *** CUTTINGS variable: TAUFAIL value extracted from CAMDAT ***
     (CAMDAT MATERIAL:PROPERTY:VALUE = BOREHOLE:TAUFAIL   :  8.11200E+00)

 TCLOUT    WAS_AREA:TCLOUT
 *** CUTTINGS variable: TCLOUT(*) value extracted from CAMDAT ***
     (CAMDAT MATERIAL:PROPERTY:VALUE = WAS_AREA:TCLOUT    :  6.48000E+04)

 PARTDIA        0.006

!PROPERTIES

 DNSFLUID  DRILLMUD:DENSITY
 *** CUTTINGS variable: DENSITY value extracted from CAMDAT ***
     (CAMDAT MATERIAL:PROPERTY:VALUE = DRILLMUD:DENSITY   :  1.21000E+03)
```

```
DOMEGA     BOREHOLE:DOMEGA
*** CUTTINGS variable: DOMEGA value extracted from CAMDAT ***
    (CAMDAT MATERIAL:PROPERTY:VALUE = BOREHOLE:DOMEGA    :  7.80000E+00)

VISCO      DRILLMUD:VISCO
*** CUTTINGS variable: VISCO value extracted from CAMDAT ***
    (CAMDAT MATERIAL:PROPERTY:VALUE = DRILLMUD:VISCO     :  9.17000E-03)

YLDSTRSS  DRILLMUD:YLDSTRSS
*** CUTTINGS variable: YLDSTRSS value extracted from CAMDAT ***
    (CAMDAT MATERIAL:PROPERTY:VALUE = DRILLMUD:YLDSTRSS :  4.40000E+00)

ABSROUGH  WAS_AREA:ROUGH
*** CUTTINGS variable: ABSRO value extracted from CAMDAT ***
    (CAMDAT MATERIAL:PROPERTY:VALUE = WAS_AREA:ROUGH     :  2.50000E-02)


!
! BRAGFLOW
!
! Multiple hits (max of 10, 0 thru 9) must be entered in order
!
! MHIT_0   is associated with the hit that CUTTINGS used for BRAG flow
!           properities
!

INTR_0   CAVITY_1        <

INTR_1   CAVITY_1   NO_GRDVOL <
SIMPLE AVERAGE WILL BE USED INSTEAD OF  WEIGHTED AVERAGE VOLUME

INTR_2   457  458  459  <

INTR_3   460  461  462  <

INTR_4   463  464  465  <
```

Explanatory Comment: The following is a summary of the data CUTTINGS_S read from the BRAGFLO output CDB file. Note that block number 7, which contains 21 elements, is the location of the repository. End of Comment.

```
element block names found

block name, block id
 S_HALITE        1
 DRZ_0           2
 TRANS_0         3
 S_MB139         4
 S_ANH_AB        5
 S_MB138         6
 CAVITY_1        7
 CAVITY_2        8
 CAVITY_3        9
 CAVITY_4       10
 IMPERM_Z       11
 CASTILER       12
 WAS_AREA       13
 REPOSIT        14
 DRZ_1          15
 UNNAMED        16
 CULEBRA        17
 TAMARISK       18
 MAGENTA        19
 FORTYNIN       20
 DEWYLAKE       21
 SANTAROS       22
 BACKFILL       23
 EXP_AREA       24
 SHFT_B_1       25
```

SHFT_B_2	26
SHFT_L_1	27
SHFT_L_2	28
SHFT_U_1	29
SHFT_U_2	30
SHFT_LS1	31
SHFT_LS2	32
SHFT_US1	33
SHFT_US2	34
PAN_S_1	35
PAN_S_2	36
BOREHOLE	37
BRINESAL	38
H2	39
PB210	40
RA226	41
RA228	42
TH229	43
TH230	44
TH232	45
PA231	46
U233	47
U234	48
U235	49
U236	50
U238	51
NP237	52
PU238	53
PU239	54
PU240	55
PU241	56
PU242	57
PU244	58
AM241	59
CM244	60
CM248	61
CF252	62
PB	63
RA	64
TH	65
PA	66
U	67
NP	68
PU	69
AM	70
CM	71
CF	72
TRANS_1	73

number of elements per block

block number,	number of elements
1	297
2	64
3	16
4	14
5	14
6	30
7	21
8	9
9	12
10	27
11	275
12	27
13	0
14	0
15	0
16	0
17	0

```
 18          0
 19          0
 20          0
 21          0
 22          0
 23          0
 24          0
 25          0
 26          0
 27          0
 28          0
 29          0
 30          0
 31          0
 32          0
 33          0
 34          0
 35          0
 36          0
 37          0
 38          0
 39          0
 40          0
 41          0
 42          0
 43          0
 44          0
 45          0
 46          0
 47          0
 48          0
 49          0
 50          0
 51          0
 52          0
 53          0
 54          0
 55          0
 56          0
 57          0
 58          0
 59          0
 60          0
 61          0
 62          0
 63          0
 64          0
 65          0
 66          0
 67          0
 68          0
 69          0
 70          0
 71          0
 72          0
 73          0

attribute  names found

 i,   name
 1     THICK
 2     ELEVAT
 3     DEL_X
 4     DEL_Y
 5     DEL_Z
 6     GRIDVOL
```

element #	attribute value
1	1.2799E+11
2	1.4830E+10
3	1.9030E+09
4	2.3061E+08
5	2.9423E+07
6	1.0210E+07
7	2.4135E+06
8	1.8411E+06
9	9.8849E+06
10	1.9705E+06
11	5.5664E+04
12	7.6922E+05
13	4.0078E+04
14	1336.
15	10.96
16	1336.
17	4.0078E+04
18	7.6922E+05
19	2.1041E+05
20	7.4433E+05
21	1.3151E+05
22	1.3220E+04
23	1.7117E+05
24	3.6947E+06
25	1.7519E+06
26	8.1208E+06
27	2.8095E+07
28	2.7331E+08
29	2.0035E+09
30	1.5118E+10
31	1.2885E+11
32	4.5986E+10
33	5.3286E+09
34	6.8375E+08
35	8.2858E+07
36	1.0572E+07
37	3.6686E+06
38	8.6715E+05
39	6.6150E+05
40	3.5516E+06
41	7.0800E+05
42	2.0000E+04
43	2.7638E+05
44	1.4400E+04
45	480.0
46	3.936
47	480.0
48	1.4400E+04
49	2.7638E+05
50	7.5600E+04
51	2.6744E+05
52	4.7250E+04
53	4750.
54	6.1500E+04
55	1.3275E+06
56	6.2945E+05
57	2.9178E+06
58	1.0095E+07
59	9.8200E+07
60	7.1985E+08
61	5.4317E+09
62	4.6295E+10
63	1.0117E+10
64	1.1723E+09
65	1.5043E+08
66	1.8229E+07
67	2.3257E+06
68	8.0709E+05
69	1.9077E+05

70	1.4553E+05
71	7.8136E+05
72	1.5576E+05
73	4400.
74	6.0803E+04
75	3168.
76	105.6
77	0.8660
78	105.6
79	3168.
80	6.0803E+04
81	1.6632E+04
82	5.8836E+04
83	1.0395E+04
84	1045.
85	1.3530E+04
86	2.9205E+05
87	1.3848E+05
88	6.4192E+05
89	2.2208E+06
90	2.1604E+07
91	1.5837E+08
92	1.1950E+09
93	1.0185E+10
94	1.2692E+09
95	1.4707E+08
96	1.8872E+07
97	2.2869E+06
98	2.9177E+05
99	1.0125E+05
100	2.3933E+04
101	1.2148E+09
102	1.4076E+08
103	1.8062E+07
104	2.1888E+06
105	2.7926E+05
106	9.6910E+04
107	2.2907E+04
108	1.2148E+09
109	1.4076E+08
110	1.8062E+07
111	2.1888E+06
112	2.7926E+05
113	9.6910E+04
114	2.2907E+04
115	1.2148E+09
116	1.4076E+08
117	1.8062E+07
118	2.1888E+06
119	2.7926E+05
120	9.6910E+04
121	2.2907E+04
122	2.4074E+09
123	2.7896E+08
124	3.5796E+07
125	4.3378E+06
126	5.5344E+05
127	1.9206E+05
128	4.5397E+04
129	1.7373E+04
130	8.0531E+04
131	2.7861E+05
132	2.7103E+06
133	1.9868E+07
134	1.4992E+08
135	1.2777E+09
136	1.6628E+04
137	7.7077E+04
138	2.6666E+05
139	2.5941E+06

140	1.9016E+07
141	1.4348E+08
142	1.2229E+09
143	1.6628E+04
144	7.7077E+04
145	2.6666E+05
146	2.5941E+06
147	1.9016E+07
148	1.4348E+08
149	1.2229E+09
150	1.6628E+04
151	7.7077E+04
152	2.6666E+05
153	2.5941E+06
154	1.9016E+07
155	1.4348E+08
156	1.2229E+09
157	3.2953E+04
158	1.5275E+05
159	5.2847E+05
160	5.1410E+06
161	3.7686E+07
162	2.8436E+08
163	2.4236E+09
164	8.3326E+09
165	9.6554E+08
166	1.2390E+08
167	1.5014E+07
168	1.9156E+06
169	6.6475E+05
170	1.5713E+05
171	1.1406E+05
172	5.2871E+05
173	1.8291E+06
174	1.7794E+07
175	1.3044E+08
176	9.8423E+08
177	8.3887E+09
178	5.6084E+10
179	6.4987E+09
180	8.3390E+08
181	1.0105E+08
182	1.2893E+07
183	4.4742E+06
184	1.0576E+06
185	8.0677E+05
186	4.3316E+06
187	8.6348E+05
188	2.4392E+04
189	3.3707E+05
190	1.7562E+04
191	585.4
192	4.801
193	585.4
194	1.7562E+04
195	3.3707E+05
196	9.2202E+04
197	3.2616E+05
198	5.7626E+04
199	1.4580E+11
200	1.6895E+10
201	2.1679E+09
202	2.6271E+08
203	3.3518E+07
204	1.1632E+07
205	2.7494E+06
206	2.0974E+06
207	1.1261E+07
208	2.2448E+06
209	6.3412E+04

210	8.7628E+05
211	4.5657E+04
212	1522.
213	12.48
214	1522.
215	4.5657E+04
216	8.7628E+05
217	2.3970E+05
218	8.4793E+05
219	1.4981E+05
220	1.4580E+11
221	1.6895E+10
222	2.1679E+09
223	2.6271E+08
224	3.3518E+07
225	1.1632E+07
226	2.7494E+06
227	2.0974E+06
228	1.1261E+07
229	2.2448E+06
230	6.3412E+04
231	8.7628E+05
232	4.5657E+04
233	1522.
234	12.48
235	1522.
236	4.5657E+04
237	8.7628E+05
238	2.3970E+05
239	8.4793E+05
240	1.4981E+05
241	4.6721E+09
242	5.4138E+08
243	6.9469E+07
244	8.4183E+06
245	1.0741E+06
246	3.7273E+05
247	8.8102E+04
248	6.7208E+04
249	3.6085E+05
250	7.1933E+04
251	2032.
252	2.8080E+04
253	1463.
254	48.77
255	0.3999
256	48.77
257	1463.
258	2.8080E+04
259	7681.
260	2.7171E+04
261	4801.
262	7.5005E+04
263	1.6190E+06
264	7.6768E+05
265	3.5585E+06
266	1.2311E+07
267	1.1976E+08
268	8.7793E+08
269	6.6245E+09
270	5.6462E+10
271	1.9499E+05
272	4.2090E+06
273	1.9957E+06
274	9.2512E+06
275	3.2006E+07
276	3.1135E+08
277	2.2824E+09
278	1.7222E+10
279	1.4678E+11

280	1.9499E+05
281	4.2090E+06
282	1.9957E+06
283	9.2512E+06
284	3.2006E+07
285	3.1135E+08
286	2.2824E+09
287	1.7222E+10
288	1.4678E+11
289	6248.
290	1.3487E+05
291	6.3952E+04
292	2.9645E+05
293	1.0256E+06
294	9.9771E+06
295	7.3137E+07
296	5.5186E+08
297	4.7036E+09
298	1.1246E+04
299	6.0378E+04
300	1.2036E+04
301	340.0
302	4698.
303	244.8
304	8.160
305	6.6916E-02
306	8.160
307	244.8
308	4698.
309	1285.
310	4546.
311	803.3
312	1.8257E+04
313	9.8025E+04
314	1.9541E+04
315	552.0
316	7628.
317	397.4
318	13.25
319	0.1086
320	13.25
321	397.4
322	7628.
323	2087.
324	7381.
325	1304.
326	1046.
327	2.2568E+04
328	1697.
329	3.6639E+04
330	3.4631E+04
331	1.8593E+05
332	3.7065E+04
333	1047.
334	1.4469E+04
335	753.9
336	25.13
337	0.2061
338	25.13
339	753.9
340	1.4469E+04
341	3958.
342	1.4001E+04
343	2474.
344	3572.
345	1.9179E+04
346	3823.
347	108.0
348	1492.
349	77.76

350	2.592
351	2.1256E-02
352	2.592
353	77.76
354	1492.
355	408.2
356	1444.
357	255.1
358	3220.
359	6.9497E+04
360	332.1
361	7169.
362	1.1986E+05
363	6.4355E+05
364	1.2829E+05
365	3624.
366	5.0080E+04
367	2609.
368	86.98
369	0.7132
370	86.98
371	2609.
372	5.0080E+04
373	1.3699E+04
374	4.8459E+04
375	8562.
376	1.1144E+04
377	2.4054E+05
378	7.8176E+08
379	9.0586E+07
380	1.1624E+07
381	1.4086E+06
382	1.7972E+05
383	6.2366E+04
384	1.4742E+04
385	1.0701E+04
386	4.9603E+04
387	1.7161E+05
388	1.6694E+06
389	1.2238E+07
390	9.2339E+07
391	7.8702E+08
392	2.4832E+08
393	2.8774E+07
394	3.6923E+06
395	4.4743E+05
396	5.7086E+04
397	1.9810E+04
398	4683.
399	3399.
400	1.5756E+04
401	5.4510E+04
402	5.3028E+05
403	3.8872E+06
404	2.9331E+07
405	2.4999E+08
406	1.6555E+08
407	1.9183E+07
408	2.4615E+06
409	2.9829E+05
410	3.8057E+04
411	1.3207E+04
412	3122.
413	2381.
414	1.2786E+04
415	2549.
416	72.00
417	995.0
418	51.84
419	1.728

420	1.4170E-02
421	1.728
422	51.84
423	995.0
424	272.2
425	962.8
426	170.1
427	221.4
428	4779.
429	2266.
430	1.0504E+04
431	3.6340E+04
432	3.5352E+05
433	2.5915E+06
434	1.9554E+07
435	1.6666E+08
436	7301.
437	380.4
438	12.68
439	0.1040
440	12.68
441	380.4
442	7301.
443	7301.
444	380.4
445	12.68
446	0.1040
447	12.68
448	380.4
449	7301.
450	7301.
451	380.4
452	12.68
453	0.1040
454	12.68
455	380.4
456	7301.
457	1.7474E+04
458	9.3820E+04
459	1.8703E+04
460	1.7474E+04
461	9.3820E+04
462	1.8703E+04
463	1.7474E+04
464	9.3820E+04
465	1.8703E+04
466	7065.
467	1248.
468	7065.
469	1248.
470	7065.
471	1248.
472	1625.
473	3.5067E+04
474	1625.
475	3.5067E+04
476	1625.
477	3.5067E+04
478	528.3
479	528.3
480	528.3
481	1997.
482	1997.
483	1997.
484	80.75
485	131.1
486	125.5
487	125.5
488	125.5
489	248.7

490	25.65
491	860.7
492	17.10
493	5793.
494	1.5060E+04
495	1.5060E+04
496	482.6
497	3420.
498	731.5
499	2356.
500	807.5
501	1644.
502	1.0070E+04
503	4114.
504	1497.
505	3.3110E+10
506	3.8366E+09
507	4.9230E+08
508	5.9657E+07
509	7.6115E+06
510	2.6414E+06
511	6.2435E+05
512	4.7628E+05
513	2.5572E+06
514	5.0976E+05
515	1.4400E+04
516	1.9899E+05
517	1.0368E+04
518	345.6
519	2.834
520	345.6
521	1.0368E+04
522	1.9899E+05
523	5.4432E+04
524	1.9255E+05
525	3.4020E+04
526	4.4280E+04
527	9.5580E+05
528	4.5320E+05
529	2.1008E+06
530	7.2680E+06
531	7.0704E+07
532	5.1829E+08
533	3.9108E+09
534	3.3333E+10
535	7.0818E+09
536	8.2060E+08
537	1.0530E+08
538	1.2760E+07
539	1.6280E+06
540	5.6496E+05
541	1.3354E+05
542	1.0187E+05
543	5.4695E+05
544	1.0903E+05
545	3080.
546	4.2562E+04
547	2218.
548	73.92
549	0.6062
550	73.92
551	2218.
552	4.2562E+04
553	1.1642E+04
554	4.1185E+04
555	7277.
556	9471.
557	2.0444E+05
558	9.6935E+04
559	4.4934E+05

560	1.5546E+06
561	1.5123E+07
562	1.1086E+08
563	8.3649E+08
564	7.1295E+09
565	2.2809E+10
566	2.6430E+09
567	3.3914E+08
568	4.1097E+07
569	5.2435E+06
570	1.8196E+06
571	4.3011E+05
572	3.2810E+05
573	1.7616E+06
574	3.5117E+05
575	9920.
576	1.3708E+05
577	7142.
578	238.1
579	1.952
580	238.1
581	7142.
582	1.3708E+05
583	3.7498E+04
584	1.3265E+05
585	2.3436E+04
586	3.0504E+04
587	6.5844E+05
588	3.1221E+05
589	1.4472E+06
590	5.0069E+06
591	4.8707E+07
592	3.5705E+08
593	2.6941E+09
594	2.2962E+10
595	7.8176E+09
596	9.0586E+08
597	1.1624E+08
598	1.4086E+07
599	1.7972E+06
600	6.2366E+05
601	1.4742E+05
602	1.1246E+05
603	6.0378E+05
604	1.2036E+05
605	3400.
606	4.6984E+04
607	2448.
608	81.60
609	0.6692
610	81.60
611	2448.
612	4.6984E+04
613	1.2852E+04
614	4.5464E+04
615	8033.
616	1.0455E+04
617	2.2568E+05
618	1.0701E+05
619	4.9603E+05
620	1.7161E+06
621	1.6694E+07
622	1.2238E+08
623	9.2339E+08
624	7.8702E+09
625	1.5911E+10
626	1.8437E+09
627	2.3658E+08
628	2.8669E+07
629	3.6577E+06

630	1.2693E+06
631	3.0003E+05
632	2.2888E+05
633	1.2289E+06
634	2.4497E+05
635	6920.
636	9.5627E+04
637	4982.
638	166.1
639	1.362
640	166.1
641	4982.
642	9.5627E+04
643	2.6158E+04
644	9.2533E+04
645	1.6349E+04
646	2.1279E+04
647	4.5932E+05
648	2.1779E+05
649	1.0096E+06
650	3.4927E+06
651	3.3977E+07
652	2.4907E+08
653	1.8794E+09
654	1.6018E+10
655	9.7490E+10
656	1.1297E+10
657	1.4496E+09
658	1.7566E+08
659	2.2412E+07
660	7.7774E+06
661	1.8384E+06
662	1.4024E+06
663	7.5294E+06
664	1.5010E+06
665	4.2400E+04
666	5.8592E+05
667	3.0528E+04
668	1018.
669	8.345
670	1018.
671	3.0528E+04
672	5.8592E+05
673	1.6027E+05
674	5.6696E+05
675	1.0017E+05
676	3.9824E+10
677	4.6145E+09
678	5.9213E+08
679	7.1755E+07
680	9.1549E+06
681	3.1770E+06
682	7.5095E+05
683	5.7286E+05
684	3.0757E+06
685	6.1313E+05
686	1.7320E+04
687	2.3934E+05
688	1.2470E+04
689	415.7
690	3.409
691	415.7
692	1.2470E+04
693	2.3934E+05
694	6.5470E+04
695	2.3160E+05
696	4.0919E+04
697	1.3038E+05
698	2.8143E+06
699	1.3344E+06

700	6.1857E+06
701	2.1400E+07
702	2.0818E+08
703	1.5261E+09
704	1.1515E+10
705	9.8146E+10
706	5.3259E+04
707	1.1496E+06
708	5.4510E+05
709	2.5268E+06
710	8.7418E+06
711	8.5041E+07
712	6.2339E+08
713	4.7039E+09
714	4.0092E+10
715	1.4495E+10
716	1.6796E+09
717	2.1552E+08
718	2.6117E+07
719	3.3321E+06
720	1.1563E+06
721	2.7333E+05
722	2.0850E+05
723	1.1195E+06
724	2.2316E+05
725	6304.
726	8.7114E+04
727	4539.
728	151.3
729	1.241
730	151.3
731	4539.
732	8.7114E+04
733	2.3829E+04
734	8.4296E+04
735	1.4893E+04
736	1.9385E+04
737	4.1843E+05
738	1.9840E+05
739	9.1969E+05
740	3.1818E+06
741	3.0953E+07
742	2.2690E+08
743	1.7121E+09
744	1.4592E+10
745	2.5090E+09
746	2.9073E+08
747	2.9635E+08
748	2.5259E+09
749	4.3569E+10
750	5.0485E+09
751	6.4781E+08
752	7.8503E+07
753	1.0016E+07
754	3.4758E+06
755	8.2157E+05
756	6.2673E+05
757	3.3650E+06
758	6.7079E+05
759	1.8949E+04
760	2.6185E+05
761	1.3643E+04
762	454.8
763	3.729
764	454.8
765	1.3643E+04
766	2.6185E+05
767	7.1626E+04
768	2.5338E+05
769	4.4767E+04

```
      770          4500.
      771        5.8268E+04
      772        1.2577E+06
      773        5.9637E+05
      774        2.7644E+06
      775        9.5639E+06
      776        9.3039E+07
      777        6.8202E+08
      778        5.1462E+09
      779        4.3862E+10
      780        3.7305E+07
      781        4.5207E+06
      782        5.7678E+05
      783        2.0016E+05
      784        4.7312E+04
      785        3.6091E+04
      786        1.9378E+05
      787        3.8628E+04
      788         1091.
      789        1.5079E+04
      790         785.7
      791         26.19
      792        0.2148
      793         26.19
      794         785.7
      795        1.5079E+04
      796         4125.
      797        1.4591E+04
      798         2578.
      799         259.2
      800         3355.
      801        7.2428E+04
      802        3.4343E+04
      803        1.5920E+05
      804        5.5076E+05
      805        5.3578E+06
      806        3.9275E+07
     1               297
     2                64
     3                16
     4                14
     5                14
     6                30
     7                21
     8                 9
     9                12
    10                27
    11               275
    12                27

number of elements to average over   21

number of elements to average over   21

number of elements to average over    3

number of elements to average over    3

number of element to average over    3

unique property names
```

property number	property name
1	PRMX_LOG
2	POROSITY
3	SP_S_LOG
4	RELP_MOD
5	CAP_MOD
6	PC_MAX
7	SAT_RBRN
8	SAT_RGAS
9	PORE_DIS
10	COMP_RCK
11	SB_MIN
12	PO_MIN
13	PCT_A
14	PCT_EXP
15	PCT_FLAG
16	PTINDEX
17	GRID_ID
18	REF_PRES
19	PTHRESH
20	PRESSURE
21	PERM_EXP
22	PHIMAX
23	DPHIMAX
24	PI_DELTA
25	PF_DELTA
26	P_LITHO
27	FRAC_PMX
28	FRAC_PMY
29	FRAC_PMZ
30	KMAXLOG
31	DELTA_PF
32	CG_NF
33	CG_F
34	CB
35	SAT_IBRN
36	SAT_PUD
37	GRATCORI
38	GRATCORH
39	GRATMICI
40	GRATMICH
41	STOICOR
42	STOIMIC
43	DCELLCHW
44	DCELLRHW
45	DIRONCHW
46	DIRONRHW
47	DPLASCHW
48	DPLASRHW
49	DRUBBCHW
50	DRUBBRHW
51	DIRNCCHW
52	DIRNCRHW
53	DPLSCCHW
54	VOLCHW
55	VOLRHW
56	DRH_METL
57	DCH_METL
58	DRH_BIO
59	DCH_BIO
60	FRAC_PR
61	PRMX
62	STORAGEC
63	DIAMMOD
64	DNSFLUID
65	WTF
66	COMPRES
67	RSOD0
68	RSOD1

```
 69        BSLOPE
 70        RSLOPE
 71        VSLOPE
 72        VISCO
 73        REF_TEMP
 74        INVCHD
 75        INVRHD
 76        HALFLIFE
 77        ATWEIGHT
 78        DIS_ENGY
 79        LOGSOLM
 80        PERM_X
 81        PERM_Y
 82        PERM_Z
 83        SOLUB
 84        PAVE
 85        COMP
```

Explanatory Comment: The data below represent CUTTINGS_S's search (through BRAGFLO's output CDB file) for the time of intrusion. End of Comment.

```
element block   37    3.16599995E-01
TIME-years  0.00000000E+00
TIME-years  5.34747819E-08
TIME-years  2.22228164E-06
TIME-years  1.09104358E-05
TIME-years  7.41431795E-05
TIME-years  2.42588285E-04
TIME-years  2.23672390E-03
TIME-years  2.98848525E-02
TIME-years  6.96178913E-01
TIME-years  3.18654060E+00
TIME-years  1.78978786E+01
TIME-years  2.58163357E+01
TIME-years  3.57182579E+01
TIME-years  5.97380142E+01
TIME-years  6.10059128E+01
TIME-years  6.26197319E+01
TIME-years  7.07265167E+01
TIME-years  7.27253571E+01
TIME-years  7.28040161E+01
TIME-years  7.83843460E+01
TIME-years  8.09984283E+01
TIME-years  8.67234039E+01
TIME-years  1.00000221E+02

Interpolation xval   9.99983311E-01
 for TINT(KINT)    1.00000000E+02
```

Explanatory Comment: The listing below represents all the data CUTTINGS_S extracted from the BRAGFLO output CDB file. End of Comment.

```
RESULTS from BRAGFLOW file: CUSP_INP$BRAGCDB

 Unaltered output follows here:

Diameter of borehole   3.16599995E-01

Initial porosity       8.81034851E-01

 Intrusion          element        average
  time (yrs)       properity        value

Multiple hits_0
     0.00           POROS       8.81034851E-01
```

```
                    PRESGAS     6.80242750E+06
                    PRESBRIN    1.01325008E+05
                    SATGAS      9.95905936E-01
 Multiple hits_1
      0.00          POROS       8.81034970E-01
                    PRESGAS     6.80243050E+06
                    PRESBRIN    1.01325000E+05
                    SATGAS      9.95906115E-01
 Multiple hits_2
      0.00          POROS       8.81034911E-01
                    PRESGAS     6.80242850E+06
                    PRESBRIN    1.01324992E+05
                    SATGAS      9.95905936E-01
 Multiple hits_3
      0.00          POROS       8.81034911E-01
                    PRESGAS     6.80242850E+06
                    PRESBRIN    1.01324992E+05
                    SATGAS      9.95905936E-01
 Multiple hits_4
      0.00          POROS       8.81034911E-01
                    PRESGAS     6.80242850E+06
                    PRESBRIN    1.01324992E+05
                    SATGAS      9.95905936E-01
 Multiple hits_0
    100.00          POROS       3.00751239E-01
                    PRESGAS     1.65183310E+07
                    PRESBRIN    9.81722700E+06
                    SATGAS      9.83161747E-01
 Multiple hits_1
    100.00          POROS       3.00751239E-01
                    PRESGAS     1.65183330E+07
                    PRESBRIN    9.81722900E+06
                    SATGAS      9.83178914E-01
 Multiple hits_2
    100.00          POROS       3.00751209E-01
                    PRESGAS     1.65185040E+07
                    PRESBRIN    9.81740000E+06
                    SATGAS      9.77457225E-01
 Multiple hits_3
    100.00          POROS       3.00751209E-01
                    PRESGAS     1.65183470E+07
                    PRESBRIN    9.81724400E+06
                    SATGAS      9.89357471E-01
 Multiple hits_4
    100.00          POROS       3.00751209E-01
                    PRESGAS     1.65181900E+07
                    PRESBRIN    9.81708600E+06
                    SATGAS      9.82479930E-01

  From these two relationships:

 (1.0-Pi)*Hi = (1.0-Pf)*Hf
             &
        Pf*Hf=Pb*Hi
Where:
  Pi = Initial porosity
  Hi = Initial height
  Pf =  Final  porosity
  Hf =  Final  height
  Pb =  Brag   porosity

Code will calculate porosity as:
  Pf=Pb/(1.0-Pi+Pb)
  Hf=(1.0-Pi)/(1.0-Pf)*Hi

  & output these transformed values
     to the output cuttings CDB


after max, min
```

```
repo pres (pa)    1.5000E+07
permeability       1.0000E-12

*********************************************************************
(DRILL)

Explanatory Comment: The data below are a summary of the inputs and results of
CUTTINGS_S's drilling calculations.                End of Comment.

 DOMEGA  =    7.8000E+00
 ROUTER  =    1.5830E-01
 RINNER  =    1.0160E-01
 DIADRIL =    3.1660E-01
 UPHOLEV =    6.7942E-01
 ETA0    =    1.8340E-02
 SIGMA1  =    1.0821E-06
 SIGMA2  =    5.4103E-07
 DENSITY =    1.2100E+03
 TAUFAIL =    8.1120E+00

 ABSOLUTE BOREHOLE ROUGHNESS =    2.5000E-02
 PLASTIC VISCOSITY           =    9.1700004E-03
 YIELD STRESS                =    4.4000001E+00
 INTRUSION NUMBER (OR HIT)   =          1
 INTRUSION_TIME  (UNITS=Years   ) =    1.0000000E+02

FOR REYNOLDS # ≤2100  ASSUMES LAMINAR HELICAL FLOW
FOR REYNOLDS # >2100  ASSUMES TURBULENT AXIAL FLOW

INITIAL REYNOLDS NUMBER =      8301., FLOW IS TURBULENT.

CRITICAL RADIUS      =    9.2572E-01

VBAR MULTIPLIER (CC) =    1.4987E+00

 INTRUSION  COLLAR     DRILL      FINAL      CRITICAL   VBAR       FINAL      REYNOLDS
SOLUTION
 TIME       RADIUS     RADIUS     RADIUS     RADIUS     MULT.      AREA       NUMBER
ALGORITHM
 ---------- ---------- ---------- ---------- ---------- ---------- ---------- --------
-- ----------
 1.0000E+02 1.0160E-01 1.5830E-01 1.8928E-01 9.2572E-01 1.4987E+00 1.1255E-01
7.3961E+03 TURBULANT-AXIAL

********* WIPP TRU CONTACT HANDLED WASTE ********

<SPALL>      PG         PARTDIA        AREA        VOLUME       VOLUME_S
 ^^^^^    1.5000E+07   6.0000E-03     1.206        2.005        0.5684


     \!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/
     >*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<
     /^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\
     \!/\!/\!/\!/                    \!/\!/\!/\!/
     >*<>*<>*<>*    HIT NUMBER  1    *<>*<>*<>*<
     /^\/^\/^\/^\                    /^\/^\/^\/^\
     \!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/\!/
     >*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<>*<
     /^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\/^\

          diameter (m)           0.3166
          intrusion time (yrs)    100.0
          repository pre (pa)    1.5000E+07
```

```
porosity, initial
          (unitless)    0.8810
porosity (bragflow)     0.3008
porosity (unitless)     0.7166
permeability (m**2)     1.0000E-12
particle dia (m)        6.0000E-03


FINAL RESULTS: Type: SOLID_BLOWOUT
AREA (spall)            1.206
AREA (erosion)         0.1125
AREA (total)            1.319
```

****
(WRIOUT)

Explanatory Comment: The data below are the results of dividing the initial inventory (CMS-controlled data) by INV.AREA, whose numerical value is 1.11520e5 m^2.
End of Comment.

```
INITIAL radioisotope LOADING (CI) with an inventory
  area of  1.11520E+05 M**2 FOR WIPP TRU CH WASTE)
-------------------------------------------------
AM241        2.4000E+05
AM243        0.0000E+00
CF252        2.9600E+03
CM243        0.0000E+00
CM244        0.0000E+00
CM245        0.0000E+00
CM248        0.0000E+00
CS137        2.0700E+04
NP237        6.6700E+01
PA231        0.0000E+00
PB210        0.0000E+00
PM147        5.2500E+02
PU238        4.2400E+06
PU239        3.9200E+05
PU240        6.9300E+04
PU241        1.9300E+06
PU242        4.9100E+04
PU244        0.0000E+00
RA226        0.0000E+00
RA228        0.0000E+00
SR90         9.8500E+03
TH229        0.0000E+00
TH230        0.0000E+00
TH232        6.1100E-01
U233         1.3100E+03
U234         0.0000E+00
U235         1.1500E+00
U236         0.0000E+00
U238         2.0100E-01
```

Explanatory Comment: The data below represent the principal results of CUTTINGS_S's calculations, namely, releases to the surface (in Curies) at the time of intrusion. These data are also printed in the (binary) output CDB file. *End of Comment.*

```
radioisotope RELEASE (CI) for 1 hit
  *** CUTTINGS & CAVING ONLY ***
----------------------------------
AM241        2.6296E-01
AM243        0.0000E+00
CF252        1.1598E-14
CM243        0.0000E+00
CM244        0.0000E+00
CM245        0.0000E+00
```

CM248	2.3237E-08
CS137	2.0726E-03
NP237	7.6122E-05
PA231	2.4936E-09
PB210	3.0864E-09
PM147	1.7776E-15
PU238	1.9421E+00
PU239	3.9448E-01
PU240	6.9201E-02
PU241	1.5811E-02
PU242	4.9544E-02
PU244	1.8757E-14
RA226	6.4693E-09
RA228	6.1663E-07
SR90	9.1989E-04
TH229	1.2425E-05
TH230	4.2647E-07
TH232	6.1663E-07
U233	1.3215E-03
U234	8.3853E-04
U235	1.1995E-06
U236	2.0594E-07
U238	2.0362E-07

radioisotope RELEASE (CI) for 1 hit
*** SPALL ONLY ***

AM241	2.8188E+00
AM243	0.0000E+00
CF252	1.2432E-13
CM243	0.0000E+00
CM244	0.0000E+00
CM245	0.0000E+00
CM248	2.4910E-07
CS137	2.2217E-02
NP237	8.1600E-04
PA231	2.6731E-08
PB210	3.3085E-08
PM147	1.9055E-14
PU238	2.0819E+01
PU239	4.2286E+00
PU240	7.4181E-01
PU241	1.6949E-01
PU242	5.3109E-01
PU244	2.0107E-13
RA226	6.9349E-08
RA228	6.6101E-06
SR90	9.8609E-03
TH229	1.3320E-04
TH230	4.5716E-06
TH232	6.6101E-06
U233	1.4166E-02
U234	8.9887E-03
U235	1.2858E-05
U236	2.2076E-06
U238	2.1828E-06

radioisotope RELEASE (CI) for 1 hit
*** TOTAL CUTTINGS & SPALL ***
ratio of spall area
to cuttings area 10.72
type of blow out: SOLID_BLOWOUT

AM241	3.0818E+00
AM243	0.0000E+00
CF252	1.3592E-13
CM243	0.0000E+00
CM244	0.0000E+00
CM245	0.0000E+00
CM248	2.7233E-07

```
 CS137        2.4290E-02
 NP237        8.9212E-04
 PA231        2.9224E-08
 PB210        3.6172E-08
 PM147        2.0833E-14
 PU238        2.2761E+01
 PU239        4.6231E+00
 PU240        8.1101E-01
 PU241        1.8530E-01
 PU242        5.8064E-01
 PU244        2.1983E-13
 RA226        7.5818E-08
 RA228        7.2267E-06
 SR90         1.0781E-02
 TH229        1.4562E-04
 TH230        4.9981E-06
 TH232        7.2267E-06
 U233         1.5488E-02
 U234         9.8272E-03
 U235         1.4058E-05
 U236         2.4136E-06
 U238         2.3864E-06

*********************************************************************
(CUSP_MAIN)

J.W. BERGLUND: SPM2 MAR 95                          DIS_01  LOCAL   00000000

CAMDAT Version 1

QA Records (6):
   GENNET     C-2.03ZO  03/22/95  14:03:42
    WIPPSLT   X-4.00VV  02/24/95  10:37:00
   MATSET     C-8.07ZO  03/22/95  14:37:07
   POSTLHS    C-4.04VV  03/22/95  14:38:39

   CUSP_PA9   5.03      06/04/96  09:52:46

Number of coordinates per node        =     1
Number of nodes                       =     7
Number of element blocks              =     6
Number of elements                    =     6
Number of nodes per element           =     2
Number of properties                  =    14
Number of attributes                  =     1
Number of node sets                   =     0
Number of side sets                   =     0

CUSP_PA96 CPU time is 0:06 (minute:second)


*** END OF CUSP_PA96 ***
CUSP_PA96 5.03 PROD PA96 05/23/96                        06/04/96 09:52:46
```

END OF APPENDIX D

APPENDIX E: TEMPLATE INPUT DATA FILE FOR PRE_CUTTINGS

This file either (1) defines or (2) calls from the WIPP controlled database all data required to exercise CUTTINGS_S.

```
!!
!!  Template file for PRE_CUSP WIPP property database
!!

   MODEL_DATA
!!
!!  =wipp::my_database:calc_name
!!
=wipp::wipp_db:WIPP_CCA

!
!    The following input variables are hard wired and are related to the
! repository-model paper by J. W. Berglund (see Appendix A)
!
! PR_MAX  <>The maximum pressure allowed by model
  PR_MAX            15.0E6

! PR_MIN  <>The minimum pressure allowed by model
  PR_MIN             0.0E6

! PE_MAX  <>The maximum permeability allowed by model
  PE_MAX           1.0E-12

! PE_MIN  <>The minimum permeability allowed by model
  PE_MIN           1.0E-17

! PCUT    <> Pressure (Pa) which defines the border between the
!                      errosion phase and the bowout phase
  PCUT               8.0E6

! PGAS    <> Pressure (pa) which defines the border between the gas-
!                      erosion phase and the stuck-pipe phase
  PGAS              10.0E6

! KCRIT   <> Permeability which defines the phase border the blowout
!                     phase and the gas-erosion/stuck pipe phase
  KCRIT            1.0E-16


!
! Properties relative to the model (repository) <<<<<<<<<<<<<<<<<<<<<<<
!
! DELTR   <>  Delta radius for derivative in stress calculation
  DELTR            0.00001

! ITER    <> Number of iterations to solve for reynolds number
  ITER         1

! FGE     <>  Gravity  effectiveness factor
  BLOWOUT:FGE

! FSE     <>  Strength effectiveness factor
  BLOWOUT:FSE

! FCE     <>  Cementation  effectiveness factor
  BLOWOUT:FCE

! CEMCEM  <>  Cementation stress
  BLOWOUT:CEMENT

! SUFTEN  <> Surface tension (N/N)
```

```
  BLOWOUT:SUFTEN


! Properties of the gas (Hydrogen) in the repository <<<<<<<<<<<<<<<<<<<<<<<<
!
! KGAS     <> Ratio of Specific Heats
  BLOWOUT:KGAS

! RGAS     <> Gas Constant for Hydrogen
  BLOWOUT:RGAS

! VISC     <> Hydrogen viscosity
  BLOWOUT:VISC

! PSUF     <> Surface presure (Pa)
  BLOWOUT:PSUF


! Properties to do with the repository <<<<<<<<<<<<<<<<<<<<<<<<<<
!
! TREPO    <> Temperature of repository (K)
  BLOWOUT:TREPO

! DEPTH    <> Distance from repository depth to depth where casing
!                    is set (m)
  BLOWOUT             716.0

! FLWCNST <> Percent volume of material that is carried by Drilling
!                       mud (unitless)
  FLWCNST              0.05

! HREPO    <> Height of repository at burial time       (4m)
  BLOWOUT:HREPO

! RPANEL   <> The equivalent radius of 1 panel     (910.0m**2)
  BLOWOUT:RPANEL

! ROOM     <> The equivalent radius of 1 room      (11,640m**2)
  BLOWOUT:ROOM

! RHOS     <> Waste particle density (kg/m**3)
  BLOWOUT:RHOS


! Variables to do with drilling <<<<<<<<<<<<<<<<<<<<<<<<<<<

! L1       <> Collar Length (m)
  BOREHOLE:L1

! L2       <> Drill pipe length (m)
  BOREHOLE:L2

! COLDIA   <> Collar diameter (m)
  BOREHOLE:COLDIA

! PIPED    <> Drill pipe diameter (m)
  BOREHOLE:PIPED

! ROUGHP   <> Friction factor (unitless)
  BOREHOLE:ROUGHP

!
! APORO    <> A constant in equation to determine permeability as a
!                 function of porosity
  BLOWOUT:APORO

! NPORO    <> N constant in equation to determine permeability as a
!                 function of porosity
```

```
  BLOWOUT                0.0
!
! END_OF_MODEL_INPUT
!


   RADIONUCLIDE_DATA


!GEOMETRY

  BOREHOLE:INV_AR

  BOREHOLE:RHW_AR

  BOREHOLE:WUF

!MATERIAL
  OUT_MAT       BOREHOLE

!REPOSITORY_TYPE

 REP_NAME     WIPP
 REP_GEOLogy HALITE

 RADWASte_type  CONtact_handled

!RADIOISOTOPE_chains

!
!  chain1/chain2 from U234  & down are the same:
!  (Both chains are required input)

!          \/       \/       \/       \/       \/       \/       \/

 CHAIN1    PU242    U238     TH234    PA234M   U234     TH230    RA226
           RN222    PO218    PB214    BI214    PO214    PB210    <

 CHAIN2    PU238    U234     TH230    RA226    RN222    PO218
           PB214    BI214    PO214    PB210    <

!  chain3/chain4 from PU239 & down are the same:

 CHAIN3    AM243    NP239    PU239    U235     TH231    PA231    AC227
           TH227    RA223    RN219    PO215    PB211    BI211    TL207    <

 CHAIN4    CM243    PU239    U235     TH231    PA231    AC227    TH227
           RA223    RN219    PO215    PB211    BI211    TL207    PB209    <

!  chain5/chain6 from U236  & down are the same:

 CHAIN5    CF252    CM248    PU244    PU240    U236     TH232    RA228
           AC228    TH228    RA224    RN220    PO216    PB212    BI212
           PO212    <

 CHAIN6    CM244    PU240    U236     TH232    RA228    AC228    TH228
           RA224    RN220    PO216    PB212    BI212    PO212    <


 CHAIN7    CM245    PU241    AM241    NP237    PA233    U233     TH229
           RA225    AC225    FR221    AT217    BI213    PO213     <

 CHAIN8    CS137    BA137M   <

 CHAIN9    PM147    SM147    ND143    <

 CHAIN10   SR90     Y90      ZR90     <

!          ^        ^        ^        ^        ^        ^        ^
```

```
 SAVE     AM241  AM243  CF252  CM243  CM244  CM245  CM248  CS137
          NP237  PA231  PB210  PM147  PU238  PU239  PU240  PU241
          PU242  PU244  RA226  RA228  SR90   TH229  TH230  TH232
          U233   U234   U235   U236   U238  <
```

TABULAR_DATA

```
!
! Example of how radioisotope data are input:
!
!...1st Line: Radionuclide (an asterisk in column 1 follow
!                           by radionuclide name, ex; *AC225 )
!...2nd & 3rd line
!
!...Field#1 Atomic Weight        (Kg/Mole) AWT    [REAL] (3(11x,1pe14.6))
!...Field#2 Half-Life             (Years)  HALFY  [REAL]          "
!...Field#3 Activity Conversion  (Ci/Kg)  AWTCNV [REAL]          "
!...Field#4 EPA Release Limit      (Ci)    EPAREL [REAL]          "
!...Field#5 Inventory              (Ci)    INVCHD [REAL]          "
!...Field#6 Inventory              (Ci)    INVRHD [REAL]          "
!
!*PU241
!xxxaaaaaaaaeeeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeeeeee
!   AWT       2.410000E-01   HALFY     1.439900E+01   ACTCNV    1.030000E+05
!   EPAREL    1.000000E+07   INVCHD    1.930000E+06   INVRHD    0.000000E+00
!
!
<TABLE_INPUTS
<GENERATE_RADIO>
END_TABLES>
!
! END_OF_RADIOISOTOPE_INPUT
!
```

END OF APPENDIX E

APPENDIX F: OUTPUT ASCII FILE FROM PRE_CUTTINGS

This appendix lists the ASCII data file that results from exercising PRE_CUTTINGS. It is controlled under CMS and must be used exactly as it appears. Other output files are possible, but they too are recorded and controlled under the CMS and it is clear which results derive from which output ASCII files.

MODEL_DATA

```
!
!
!    The following input variables are hard wired and related to the Repository model
J. W. Berglund paper: Appendix A, CUTTING_S User's Manual, Ver 5.03
!
! PR_MAX  <>The maximum pressure allowed by model
  PR_MAX            15.0E6

! PR_MIN  <>The minimum pressure allowed by model
  PR_MIN             0.0E0

! PE_MAX  <>The maximum permeability allowed by model
  PE_MAX           1.0E-12

! PE_MIN  <>The minimum permeability allowed by model
  PE_MIN           1.0E-17

! PCUT    <> Pressure (Pa) which defines the border between the
!                     erosion phase and the blowout phase
  PCUT               8.0E6

! PGAS    <> Pressure (Pa) which defines the border between the gas
!                     erosion phase and the stuck pipe phase
  PGAS              10.0E6

! KCRIT   <> Permeability which defines the phase border between the blowout
!                    phase and the gas erosion/stuck pipe phase
  KCRIT            1.0E-16


!
! Properties relative to the model (repository) <<<<<<<<<<<<<<<<<<<<<<<
!
! DELTR   <>  Delta radius for derivative in stress calculation
  DELTR            0.00001

! ITER    <> Number of iterations to solve for Reynolds number
  ITER                  1

! FGE     <>  Gravity  effectiveness factor
  FGE                 18.4

! FSE     <>  Strength effectiveness factor
  FSE                  0.0

! FCE     <>  Cementation  effectiveness factor
  FCE                  0.0

! CEMENT  <>  Cementation stress
  CEMENT               0.0

! SUFTEN  <> Surface tension (N/N)
  SUFTEN            8.0E-2
```

```
! Properties of the gas (Hydrogen) in the repository <<<<<<<<<<<<<<<<<<<<<<<
!
! KGAS     <> Ratio of Specific Heats
  KGAS              1.41E0

! RGAS     <> Gas Constant for Hydrogen (Nm/kg-K)
  RGAS              4116.0

! VISC     <> Hydrogen viscosity (Pa-sec)
  VISC             0.92E-5

! PSUF     <> Surface presure (Pa)
  PSUF           0.089465E6


! Properties to do with the repository <<<<<<<<<<<<<<<<<<<<<<<<
!
! TREPO    <> Temperature of repository (K)
  TREPO              300.0

! DEPTH    <> Distance from repository to where casing
!              is set and gas erosion ceases (m)
  DEPTH             716.0

! FLWCNST <> Percent volume of material that is carried by Drilling
!                        mud (unitless)
  FLWCNST             0.05

! HREPO    <> Height of repository at burial time      (4m)
  HREPO               3.96

! RPANEL   <> The equivalent radius of 1 panel    (116400m**2)
  RPANEL             60.87

! ROOM     <> The equivalent radius of 1 room      (910.0m**2)
  ROOM                17.1

! RHOS     <> Waste particle density (kg/m**3)
  RHOS              2650.0


! Variables to do with drilling <<<<<<<<<<<<<<<<<<<<<<<<
!
! L1       <> Collar Length (m)
  L1                182.88

! L2       <> Drill pipe length (m)
  L2                472.12

! COLDIA   <> Collar diameter (m)
  COLDIA          0.2032004

! PIPED    <> Drill pipe diameter (m)
  PIPED           0.1143002

! ROUGHP   <> Friction factor (unitless)
  ROUGHP              0.08

!
! APORO    <> A constant in equation to determine permeability as a
!              function of porosity
  APORO             1.0E-11

! NPORO    <> N constant in equation to determine permeability as a
!              function of porosity
  NPORO                4.6
```

```
!
! ! END_OF_MODEL_INPUT


   RADIONUCLIDE_DATA

!GEOMETRY

  INV_AR        1.11520E+05

  RHW_AR        1.11520E+05

  WUF           5.25

!MATERIAL
  OUT_MAT       BOREHOLE

!REPOSITORY_TYPE

 REP_NAME    WIPP
 REP_GEOLogy HALITE

 RADWASte_type  CONtact_handled

!RADIOISOTOPE_chains

!
!  chain1/chain2 from U234  & down are the same:
!  (Both chains are input)

!          \/       \/       \/       \/       \/       \/       \/

 CHAIN1    PU242    U238     TH234    PA234M   U234     TH230    RA226
           RN222    PO218    PB214    BI214    PO214    PB210    <

 CHAIN2    PU238    U234     TH230    RA226    RN222    PO218
           PB214    BI214    PO214    PB210    <

!  chain3/chain4 from PU239 & down are the same:

 CHAIN3    AM243    NP239    PU239    U235     TH231    PA231    AC227
           TH227    RA223    RN219    PO215    PB211    BI211    TL207    <

 CHAIN4    CM243    PU239    U235     TH231    PA231    AC227    TH227
           RA223    RN219    PO215    PB211    BI211    TL207    <

!  chain5/chain6 from U236  & down are the same:

 CHAIN5    CF252    CM248    PU244    PU240    U236     TH232    RA228
           AC228    TH228    RA224    RN220    PO216    PB212    BI212
           PO212    <

 CHAIN6    CM244    PU240    U236     TH232    RA228    AC228    TH228
           RA224    RN220    PO216    PB212    BI212    PO212    <


 CHAIN7    CM245    PU241    AM241    NP237    PA233    U233     TH229
           RA225    AC225    FR221    AT217    BI213    PO213    PB209    <

 CHAIN8    CS137    BA137M   <

 CHAIN9    PM147    SM147    ND143    <

 CHAIN10   SR90     Y90      ZR90     <

!          ^        ^        ^        ^        ^        ^        ^
```

```
 SAVE    AM241  AM243  CF252  CM243  CM244  CM245  CM248  CS137
         NP237  PA231  PB210  PM147  PU238  PU239  PU240  PU241
         PU242  PU244  RA226  RA228  SR90   TH229  TH230  TH232
         U233   U234   U235   U236   U238  <
```

TABULAR_DATA

```
!
! Example of how radioisotope data are entered:
!
!  ...1st Line: Radionuclide (an asterisk in column 1 follow
!                              by radionuclide name, ex; *AC225 )
!  ...2nd & 3rd line
!
!  ...Field#1 Atomic Weight        (Kg/Mole) AWT     [REAL]  (3(11x,1pe14.6))
!  ...Field#2 Half-Life             (Years)  HALFY   [REAL]          "
!  ...Field#3 Activity Conversion   (Ci/Kg)  AWTCNV  [REAL]          "
!  ...Field#4 EPA Release Limit      (Ci)    EPAREL  [REAL]          "
!  ...Field#5 Inventory              (Ci)    INVCHD  [REAL]          "
!  ...Field#6 Inventory              (Ci)    INVRHD  [REAL]          "
!
!
!*PU241
!xxxaaaaaaaaeeeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeeeeee
!   AWT       2.410000E-01   HALFY     1.439900E+01   ACTCNV    1.030000E+05
!   EPAREL    1.000000E+07   INVCHD    1.930000E+06   INVRHD    0.000000E+00
!
!
<TABLE_INPUTS
*AC225
   AWT       2.250230E-01   HALFY     2.737909E-02   ACTCNV    5.802700E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*AC227
   AWT       2.270280E-01   HALFY     2.177335E+01   ACTCNV    7.232300E+04
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*AC228
   AWT       2.280310E-01   HALFY     6.993710E-04   ACTCNV    2.241700E+09
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*AM241
   AWT       2.410570E-01   HALFY     4.322347E+02   ACTCNV    3.431200E+03
   EPAREL    1.000000E+02   INVCHD    2.400000E+05
*AM243
   AWT       2.430610E-01   HALFY     7.380313E+03   ACTCNV    1.992900E+02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*AT217
   AWT       2.170050E-01   HALFY     1.023547E-09   ACTCNV    1.609500E+15
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BA137M
   AWT       1.369070E-01   HALFY     4.851550E-06   ACTCNV    5.382400E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BI211
   AWT       2.109870E-01   HALFY     4.049824E-06   ACTCNV    4.184000E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BI212
   AWT       2.119910E-01   HALFY     1.151253E-04   ACTCNV    1.464800E+10
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BI213
   AWT       2.129940E-01   HALFY     8.679553E-05   ACTCNV    1.933800E+10
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*BI214
   AWT       2.139990E-01   HALFY     3.783638E-05   ACTCNV    4.415300E+10
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*CF252
   AWT       2.520820E-01   HALFY     2.638090E+00   ACTCNV    5.375899E+05
   EPAREL    0.000000E+00   INVCHD    2.960000E+03
*CM243
   AWT       2.430610E-01   HALFY     2.850088E+01   ACTCNV    5.160700E+04
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*CM244
```

```
   AWT        2.440630E-01   HALFY      1.811013E+01   ACTCNV     8.088299E+04
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*CM245
   AWT        2.450650E-01   HALFY      8.498927E+03   ACTCNV     1.716500E+02
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*CM248
   AWT        2.480720E-01   HALFY      3.390698E+05   ACTCNV     4.250200E+00
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*CS137
   AWT        1.369070E-01   HALFY      2.999975E+01   ACTCNV     8.704300E+04
   EPAREL     1.000000E+03   INVCHD     2.070000E+04
*FR221
   AWT        2.210140E-01   HALFY      9.126364E-06   ACTCNV     1.772400E+11
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*ND143
   AWT        1.430000E-01   HALFY      3.168876E+30   ACTCNV     0.000000E+00
   EPAREL     1.000000E+03   INVCHD     0.000000E+00
*NP237
   AWT        2.370480E-01   HALFY      2.139942E+06   ACTCNV     7.047600E-01
   EPAREL     1.000000E+02   INVCHD     6.670000E+01
*NP239
   AWT        2.390530E-01   HALFY      6.448664E-03   ACTCNV     2.319100E+08
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PA231
   AWT        2.310360E-01   HALFY      3.276618E+04   ACTCNV     4.722500E+01
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*PA233
   AWT        2.330400E-01   HALFY      7.392988E-02   ACTCNV     2.075100E+07
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PA234M
   AWT        2.340430E-01   HALFY      2.224551E-06   ACTCNV     6.866600E+11
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PB209
   AWT        2.089810E-01   HALFY      3.764625E-04   ACTCNV     4.544100E+09
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PB210
   AWT        2.099840E-01   HALFY      2.229938E+01   ACTCNV     7.634800E+04
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*PB211
   AWT        2.109890E-01   HALFY      6.863786E-05   ACTCNV     2.468600E+10
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PB212
   AWT        2.119920E-01   HALFY      1.213680E-03   ACTCNV     1.389500E+09
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PB214
   AWT        2.140000E-01   HALFY      5.095553E-05   ACTCNV     3.278500E+10
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PM147
   AWT        1.469150E-01   HALFY      2.623513E+00   ACTCNV     9.275300E+05
   EPAREL     0.000000E+00   INVCHD     5.250000E+02
*PO212
   AWT        2.119890E-01   HALFY      9.506629E-15   ACTCNV     1.773900E+20
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PO213
   AWT        2.129930E-01   HALFY      1.330928E-13   ACTCNV     1.261100E+19
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PO214
   AWT        2.139950E-01   HALFY      5.206464E-12   ACTCNV     3.208700E+17
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PO215
   AWT        2.149990E-01   HALFY      5.640600E-11   ACTCNV     2.947900E+16
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PO216
   AWT        2.160020E-01   HALFY      4.753314E-09   ACTCNV     3.482000E+14
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PO218
   AWT        2.180090E-01   HALFY      5.799044E-06   ACTCNV     2.827800E+11
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*PU238
   AWT        2.380500E-01   HALFY      8.774619E+01   ACTCNV     1.711500E+04
```

```
   EPAREL    1.000000E+02   INVCHD    4.240000E+06
*PU239
   AWT       2.390520E-01   HALFY     2.406445E+04   ACTCNV    6.214600E+01
   EPAREL    1.000000E+02   INVCHD    3.920000E+05
*PU240
   AWT       2.400540E-01   HALFY     6.537392E+03   ACTCNV    2.278100E+02
   EPAREL    1.000000E+02   INVCHD    6.930000E+04
*PU241
   AWT       2.410570E-01   HALFY     1.439937E+01   ACTCNV    1.030000E+05
   EPAREL    0.000000E+00   INVCHD    1.930000E+06
*PU242
   AWT       2.420590E-01   HALFY     3.869198E+05   ACTCNV    3.817100E+00
   EPAREL    1.000000E+02   INVCHD    4.910000E+04
*PU244
   AWT       2.440640E-01   HALFY     8.261261E+07   ACTCNV    1.773100E-02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*RA223
   AWT       2.230190E-01   HALFY     3.130533E-02   ACTCNV    5.120600E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RA224
   AWT       2.240200E-01   HALFY     1.001999E-02   ACTCNV    1.592700E+08
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RA225
   AWT       2.250240E-01   HALFY     4.052993E-02   ACTCNV    3.919900E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RA226
   AWT       2.260250E-01   HALFY     1.599966E+03   ACTCNV    9.885801E+02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*RA228
   AWT       2.280310E-01   HALFY     6.699955E+00   ACTCNV    2.340000E+05
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RN219
   AWT       2.190090E-01   HALFY     1.254875E-07   ACTCNV    1.300800E+13
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RN220
   AWT       2.200110E-01   HALFY     1.761895E-06   ACTCNV    9.222600E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*RN222
   AWT       2.220180E-01   HALFY     1.046997E-02   ACTCNV    1.538000E+08
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*SM147
   AWT       1.470000E-01   HALFY     1.059355E+11   ACTCNV    2.295400E-05
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*SR90
   AWT       8.990801E-02   HALFY     2.912197E+01   ACTCNV    1.365400E+05
   EPAREL    1.000000E+03   INVCHD    9.850002E+03
*TH227
   AWT       2.270280E-01   HALFY     5.124073E-02   ACTCNV    3.073200E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*TH228
   AWT       2.280290E-01   HALFY     1.913051E+00   ACTCNV    8.195301E+05
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*TH229
   AWT       2.290320E-01   HALFY     7.339118E+03   ACTCNV    2.126900E+02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*TH230
   AWT       2.300330E-01   HALFY     7.700370E+04   ACTCNV    2.018300E+01
   EPAREL    1.000000E+01   INVCHD    0.000000E+00
*TH231
   AWT       2.310360E-01   HALFY     2.911247E-03   ACTCNV    5.315200E+08
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*TH232
   AWT       2.320380E-01   HALFY     1.405080E+10   ACTCNV    1.096500E-04
   EPAREL    1.000000E+01   INVCHD    6.110000E-01
*TH234
   AWT       2.340440E-01   HALFY     6.597601E-02   ACTCNV    2.315200E+07
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*TL207
   AWT       2.069770E-01   HALFY     9.069325E-06   ACTCNV    1.904500E+11
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
```

```
*U233
   AWT       2.330400E-01   HALFY     1.585072E+05   ACTCNV    9.678300E+00
   EPAREL    1.000000E+02   INVCHD    1.310000E+03
*U234
   AWT       2.340410E-01   HALFY     2.445105E+05   ACTCNV    6.247300E+00
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*U235
   AWT       2.350440E-01   HALFY     7.038074E+08   ACTCNV    2.161100E-03
   EPAREL    1.000000E+02   INVCHD    1.150000E+00
*U236
   AWT       2.360460E-01   HALFY     2.341483E+07   ACTCNV    6.468300E-02
   EPAREL    1.000000E+02   INVCHD    0.000000E+00
*U238
   AWT       2.380510E-01   HALFY     4.468115E+09   ACTCNV    3.361100E-04
   EPAREL    1.000000E+02   INVCHD    2.010000E-01
*Y90
   AWT       8.990701E-02   HALFY     7.301091E-03   ACTCNV    5.446300E+08
   EPAREL    0.000000E+00   INVCHD    0.000000E+00
*ZR90
   AWT       9.000000E-02   HALFY     3.168876E+30   ACTCNV    0.000000E+00
   EPAREL    1.000000E+03   INVCHD    0.000000E+00
END_TABLES>
!
! END_OF_RADIOISOTOPE_INPUT
!
```

END OF APPENDIX F

APPENDIX G: SAMPLE COMMAND FILE FOR PRE_CUTTINGS

This command file exercises PRE_CUTTINGS.

```
$!@CUSP_RUN_PRE_CUTTINGS.COM
$!
$  ON control_y  THEN goto TERMINATE
$  ON control_c  THEN goto TERMINATE
$  ON error      THEN goto TERMINATE
$!
$!
$! The production executable
$!
$  DEFINE CUSP$EXE WP$PRODROOT:[CUSP.EXE]CUSP_PA96.EXE
$!
$!
$! This sets CUSP into the pre_cuttings mode
$!
$  DEFINE CUSP$PRE_CUTTINGS  TRUE
$!
$!
$!  Input files required by PRE_CUTTINGS
$!
$!  This file is a template to reference the WIPP CMS-controlled Data Base
$!   It will have the chains and some hardwired numbers which
$!   can be found in the theoretical manual.
$!  The file will be placed into CMS CUSP
$!
$ DEFINE/NOLOG   CUSP_INP$CDB    CUSP_TEST_1.CDB
$!
$ DEFINE/NOLOG   CUSP_INP$TXT1   CUSP_TEST_1.INP
$!
$ DEFINE/NOLOG   CUSP_INP$SDB    CUSP_CCA_TEMPLATE.INP
$!
$ DEFINE/NOLOG   CUSP_INP$DESC   CUSP_CCA.SDB
$!
$!
$!  A summary of the results of the pre_cuttings
$!
$ DEFINE/NOLOG   CUSP_OUT$DBG         PRE_CUSP_OUTPUT.DBG
$!
$!
$!  The output ASCII file that is read by all production runs
$!
$ DEFINE/NOLOG   CUSP_OUT$DB_ASC      CUSP_CCA_SDB.ASC
$!
$!
$!  The output BINARY file that could be read by all the production runs
$!                                ^^^^^
$!
$ DEFINE/NOLOG   CUSP_OUT$DB_BIN      -
          CUSP_INPUT.BINARY
$!
$!
   CUSP   :=  $CUSP$EXE
$!
$!
$  CUSP
$!
$!
$ TERMINATE:
$!
$! Turn off pre_cuttings mode
$!
$ DEASSIGN       CUSP$PRE_CUTTINGS
$!
$ DEASSIGN       CUSP_INP$CDB
```

```
$ DEASSIGN        CUSP_INP$TXT1
$ DEASSIGN        CUSP_INP$SDB
$ DEASSIGN        CUSP_OUT$DB_ASC
$ DEASSIGN        CUSP_OUT$DB_BIN
$!
$TERMINATE:
$ EXIT
```

END OF APPENDIX G

APPENDIX H: SAMPLE CHECK_OUT PROBLEMS

This file includes a command file that exercises CHECK_OUT and a sequence of actual input control files associated with selected applications of interest.

General Purpose ".COM" file to run CHECK_OUT modes

```
$!@CUSP_CHECK_OUT.COM   "p1"
$!
$!  'p1' > Check_Out Type
$!
$!  Where 'p1': CALIBRATE
$!              EXPERIMENT
$!              VALIDATE
$!
$!
$   ON control_y THEN goto TERMINATE
$   ON control_c THEN goto TERMINATE
$   ON error     THEN goto TERMINATE
$!
$!
$   LIBCUSP
$!
$! Clea up any prexisting logicals
$!
$  IF F$SEARCH("CUSP_DEASSIGN.COM") .eqs.  ""  -
      THEN CFE  CUSP_DEASSIGN.COM  ""
$!
$  @CUSP_DEASSIGN
$!
$!
$  IF F$SEARCH("CUSP$EXE") .eqs. ""
$  THEN
$!
$    IF F$SEARCH("CUSP_TEST_SETUP_CUSP.COM") .eqs.  ""  -
        THEN CFE  CUSP_TEST_SETUP_CUSP.COM  ""
$!
$    @CUSP_TEST_SETUP_CUSP
$!
$  ENDIF
$!
$!
$  DEFINE     CUSP$CHECK_OUT  TRUE
$!
$!
$!  Input files required by CUSP$CHECK_OUT
$!
$ DEFINE/NOLOG   CUSP_INP$TXT0     CUSP_CHECK_OUT.DAT
$ DEFINE/NOLOG   CUSP_INP$TXT1     CUSP_'p1'.INP
$!
$!  Output files required by CUSP$CHECK_OUT
$!
$ DEFINE/NOLOG   CUSP_OUT$NVERFY   CUSP_'p1'.VER
$ DEFINE/NOLOG   CUSP_OUT$PLT1     CUSP_'p1'.PLT
$!
$!
   CUSP   :=  $CUSP$EXE
$!
$  CUSP
$!
$ DEASSIGN  CUSP$CHECK_OUT
$!
$ DEASSIGN  CUSP_INP$TXT0
$ DEASSIGN  CUSP_INP$TXT1
```

```
$ DEASSIGN  CUSP_OUT$NVERFY
$ DEASSIGN  CUSP_OUT$PLT1
$!
$!
$TERMINATE:
$!
$ EXIT
```

Input file for: CALIBRATE

```
!
! TEST_FUNCT
!
  CALIBRATE

  FSEMIN          10.0

  DELFSE           5.0

  IFSE               3

  FGEMIN          10.0

  DELFGE          10.0

  JFGE             - 3

  FCEMIN           0.0

  DELFCE           0.0

  KFCE               0

  ITMAX            200

  DELERR          0.01

  POROST          0.40

START_SEARCH
   .000151    .01021     2.133   394379.  .0007221 .261 295. 85151.  #28
   .000151    .01021     2.133   290958.  .0005760 .261 295. 85151.  #28
   .000151    .01021     2.133   290958.  .0005057 .262 295. 84805.  #29
   .000151    .01021     2.133   290958.  .0006104 .279 296. 84048.  #30
   .000151    ..01021    2.133   222010.  .0004148 .262 295. 84805.  #29
   .000151    .01021     2.133   222010.  .0004817 .261 295. 85151.  #28
   .000151    .01021     2.133   222010.  .0004800 .279 296. 84048.  #30
   .000151    .01021     2.133   153064.  .0003005 .262 295. 84805.  #29
   .000151    .01021     2.133   153064.  .0003642 .261 295. 85151.  #28
   .000151    .01021     2.133   153064.  .0003444 .279 296. 84048.  #30
   .000151    .01021     2.133   118590.  .0001261 .262 295. 84805.  #29
   .000151    .01021     2.133   118590.  .0000663 .261 295. 85151.  #28
   .000151    .01021     2.133   118590.  .0001740 .279 296. 84048.  #30
```

Input file for: EXPERIMENT

```
!
! TEST_FUNCT
!
  EXPERIMENT

  DIA   0.3110

  PARTMIN     0.0002  PARTMAX     0.2   PARTMUL   1.5

  SAT         0.3
```

```
PG        15.0E6

POROF        0.4

FSE        0.010

FGE          1.0
```

Input file for: VALIDATE

```
!
! TEST_FUNCT
!
  VALIDATE
!
  DIA      0.3110
!!
  PARTMIN  0.00002  PARTMAX   0.2   PARTMUL   2.0
!
  SATMIN    0.20    DELSAT   0.05   ISA     9
!
  PGMIN    8.0E6    DELPG   1.0E6   IPG     8
!
  PORMIN     0.2    DELPOR   0.10   IPOR    7
```

Input file: CUSP_CHECK_OUT.DAT

```
  MODEL_DATA

!
!
! The following input variables are related to the Repository and
!  are hard wired or related to the model by J. W. Berglund (see Appendix A)
!
!

! Properties relative to the model (experiments) <<<<<<<<<<<<<<<<<<<<<<

! DELTR    <>  Delta radius for derivative in stress calculation
  DELTR        0.0001

! ITER     <>  Number of iterations to solve for Reynolds number
  ITER         7

! SUFTEN   <> Surface tension (N/m)
  SUFTEN       7.3E-2


! Properties of Air (experiments) <<<<<<<<<<<<<<<<<<<<<<

! KGAS     <> Ratio of Specific Heats
  KGAS         1.4E0

! RGAS     <> Gas Constant for Air
  RGAS         286.5

! VISC     <> Air viscosity
  VISC         1.77E-5

! Properties to do with the experiments <<<<<<<<<<<<<<<<<<<<<<<

! HREPO    <> Height of repository at burial time
  HREPO        0.0762
```

```
! ROOM     <> The equivalent radius of 1 room
  ROOM          0.254

! RHOS     <> Waste particle density (kg/m**3)
  RHOS          2650.0


! Variables to do with drilling <<<<<<<<<<<<<<<<<<<<<<<<

! L2       <> Drill pipe length (m)
  L2            1.0

! COLDIA   <> Collar diameter (m)
  COLDIA        0.0

! PIPED    <> Drill pipe diameter (m)
  PIPED         0.0

! END_OF_MODEL_INPUT
!
```

END OF APPENDIX H

APPENDIX I: EXAMPLE OF THE INPUT FILE: CUSP_INP$TXT0 FOR TEST RUNS

This input file provides various data relevant to the position, size, and nature of the repository and to physical properties of the materials in and around the borehole. The file itself is located in the CMS portion of the WIPP Alpha cluster as : CUSP_TEST_REPOSITORY.DAT . The file is discussed in Section 6.1 as file number 2.

To extract and edit this file from the CMS system, type the following sequence of commands, each followed by a carriage return.

```
$LIBCUSP
$CFE     CUSP_TEST_REPOSITORY.DAT
EDIT    CUSP_TEST_REPOSITORY.DAT
```

```
-----------------------------------------------------------------------------------------
BEGINNING          OF          CUSP_TEST_REPOSITORY.DAT
-----------------------------------------------------------------------------------------

   MODEL_DATA

!
!
!    The following input variables are hard wired and related to the
! Repository model J. W. Berglund paper: Appendix A, CUTTING_S User's Manual,
Ver 5.03
!
! PR_MAX  <>The maximum pressure allowed by model
  PR_MAX            15.0E6

! PR_MIN  <>The minimum pressure allowed by model
  PR_MIN             0.0E0

! PE_MAX  <>The maximum permeability allowed by model
  PE_MAX           1.0E-12

! PE_MIN  <>The minimum permeability allowed by model
  PE_MIN           1.0E-17

! PCUT    <> Pressure (Pa) which defines the border between the
!                       erosion phase and the blowout phase
  PCUT               8.0E6

! PGAS    <> Pressure (Pa) which defines the border between the gas
!                       erosion phase and the stuck pipe phase
  PGAS              10.0E6

! KCRIT   <> Permeability which defines the phase border between the blowout
!                      phase and the gas erosion/stuck pipe phase
  KCRIT            1.0E-16


!
! Properties relative to the model (repository) <<<<<<<<<<<<<<<<<<<<<<<
```

```
!
! DELTR   <>  Delta radius for derivative in stress calculation
  DELTR            0.00001

! ITER    <> Number of iterations to solve for reynolds number
  ITER                   1

! FGE     <>  Gravity  effectiveness factor
  FGE                 18.4

! FSE     <>  Strength effectiveness factor
  FSE                  0.0

! FCE     <>  Cementation  effectiveness factor
  FCE                  0.0

! CEMENT  <>  Cementation stress
  CEMENT               0.0

! SUFTEN  <> Surface tension (N/N)
  SUFTEN            8.0E-2


! Properties of the gas (Hydrogen) in the repository <<<<<<<<<<<<<<<<<<<<<<<
!
! KGAS    <> Ratio of Specific Heats
  KGAS              1.41E0

! RGAS    <> Gas Constant for Hydrogen (Nm/kg-K)
  RGAS              4116.0

! VISC    <> Hydrogen viscosity (Pa-sec)
  VISC             0.92E-5

! PSUF    <> Surface presure (Pa)
  PSUF           0.089465E6


! Properties to do with the repository <<<<<<<<<<<<<<<<<<<<<<<<
!
! TREPO   <> Temperature of repository (K)
  TREPO              300.0

! DEPTH   <> Distance from repository to where casing
!              is set and gas erosion ceases (m)
  DEPTH              716.0

! FLWCNST <> Percent volume of material that is carried by Drilling
!                       mud (unitless)
  FLWCNST             0.05

! HREPO   <> Height of repository at burial time      (4m)
  HREPO               3.96

! RPANEL  <> The equivalent radius of 1 panel    (116400m**2)
  RPANEL             60.87

! ROOM    <> The equivalent radius of 1 room      (910.0m**2)
```

```
  ROOM                17.1

! RHOS     <> Waste particle density (kg/m**3)
  RHOS              2650.0


! Variables to do with drilling <<<<<<<<<<<<<<<<<<<<<<<<
!
! L1       <> Collar Length (m)
  L1                182.88

! L2       <> Drill pipe length (m)
  L2                472.12

! COLDIA   <> Collar diameter (m)
  COLDIA         0.2032004

! PIPED    <> Drill pipe diameter (m)
  PIPED          0.1143002

! ROUGHP   <> Friction factor (unitless)
  ROUGHP              0.08

!
! APORO    <> A constant in equation to determine permeability as a
!             function of porosity
  APORO            1.0E-11

! NPORO    <> N constant in equation to determine permeability as a
!             function of porosity
  NPORO                4.6
!
! END_OF_MODEL_INPUT
!


   RADIONUCLIDE_DATA


!GEOMETRY

  INV_AR        1.11520E+05

  RHW_AR        1.11520E+05

  WUF           5.25

!MATERIAL
  OUT_MAT       BOREHOLE

!REPOSITORY_TYPE

 REP_NAME     WIPP
 REP_GEOLogy HALITE

 RADWASte_type  CONtact_handled

!RADIOISOTOPE_chains

!
```

```
!  chain1/chain2 from U234  & down are the same:
!  (Both chains are required input)

!          \/       \/       \/       \/       \/       \/       \/

 CHAIN1    PU242    U238     TH234    PA234M   U234     TH230    RA226
           RN222    PO218    PB214    BI214    PO214    PB210    <

 CHAIN2    PU238    U234     TH230    RA226    RN222    PO218
           PB214    BI214    PO214    PB210    <

!  chain3/chain4 from PU239 & down are the same:

 CHAIN3    AM243    NP239    PU239    U235     TH231    PA231    AC227
           TH227    RA223    RN219    PO215    PB211    BI211    TL207    <

 CHAIN4    CM243    PU239    U235     TH231    PA231    AC227    TH227
           RA223    RN219    PO215    PB211    BI211    TL207    <

!  chain5/chain6 from U236  & down are the same:

 CHAIN5    CF252    CM248    PU244    PU240    U236     TH232    RA228
           AC228    TH228    RA224    RN220    PO216    PB212    BI212
           PO212    <

 CHAIN6    CM244    PU240    U236     TH232    RA228    AC228    TH228
           RA224    RN220    PO216    PB212    BI212    PO212    <


 CHAIN7    CM245    PU241    AM241    NP237    PA233    U233     TH229
           RA225    AC225    FR221    AT217    BI213    PO213    PB209    <

 CHAIN8    CS137    BA137M   <

 CHAIN9    PM147    SM147    ND143    <

 CHAIN10   SR90     Y90      ZR90     <

!          ^        ^        ^        ^        ^        ^        ^


 SAVE     AM241  AM243  CF252  CM243  CM244  CM245  CM248  CS137
          NP237  PA231  PB210  PM147  PU238  PU239  PU240  PU241
          PU242  PU244  RA226  RA228  SR90   TH229  TH230  TH232
          U233   U234   U235   U236   U238   <


   TABULAR_DATA

!
! Example of how the radioisotope data are input:
!
!  ...1st Line: Radionuclide (an asterisk in column 1 follow
!                             by radionuclide name, ex; *AC225 )
!  ...2nd & 3rd line
!
!  ...Field#1 Atomic Weight        (Kg/Mole) AWT     [REAL]  (3(11x,1pe14.6))
!  ...Field#2 Half-Life             (Years)  HALFY   [REAL]          "
!  ...Field#3 Activity Conversion   (Ci/Kg)  AWTCNV  [REAL]          "
!  ...Field#4 EPA Release Limit      (Ci)    EPAREL  [REAL]          "
```

```
!  ...Field#5 Inventory                (Ci)     INVCHD  [REAL]          "
!  ...Field#6 Inventory                (Ci)     INVRHD  [REAL]          "
!
!
!*PU241
!xxxaaaaaaaaeeeeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeeeeexxxaaaaaaaaeeeeeeeeeeeeeeeeeee
!   AWT        2.410000E-01   HALFY     1.439900E+01   ACTCNV    1.030000E+05
!   EPAREL     1.000000E+07   INVCHD    1.930000E+06   INVRHD    0.000000E+00
!
!
<TABLE_INPUTS
*AC225
   AWT        2.250230E-01   HALFY     2.737909E-02   ACTCNV    5.802700E+07
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*AC227
   AWT        2.270280E-01   HALFY     2.177335E+01   ACTCNV    7.232300E+04
   EPAREL     1.000000E+02   INVCHD    0.000000E+00
*AC228
   AWT        2.280310E-01   HALFY     6.993710E-04   ACTCNV    2.241700E+09
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*AM241
   AWT        2.410570E-01   HALFY     4.322347E+02   ACTCNV    3.431200E+03
   EPAREL     1.000000E+02   INVCHD    2.400000E+05
*AM243
   AWT        2.430610E-01   HALFY     7.380313E+03   ACTCNV    1.992900E+02
   EPAREL     1.000000E+02   INVCHD    0.000000E+00
*AT217
   AWT        2.170050E-01   HALFY     1.023547E-09   ACTCNV    1.609500E+15
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*BA137M
   AWT        1.369070E-01   HALFY     4.851550E-06   ACTCNV    5.382400E+11
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*BI211
   AWT        2.109870E-01   HALFY     4.049824E-06   ACTCNV    4.184000E+11
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*BI212
   AWT        2.119910E-01   HALFY     1.151253E-04   ACTCNV    1.464800E+10
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*BI213
   AWT        2.129940E-01   HALFY     8.679553E-05   ACTCNV    1.933800E+10
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*BI214
   AWT        2.139990E-01   HALFY     3.783638E-05   ACTCNV    4.415300E+10
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*CF252
   AWT        2.520820E-01   HALFY     2.638090E+00   ACTCNV    5.375899E+05
   EPAREL     0.000000E+00   INVCHD    2.960000E+03
*CM243
   AWT        2.430610E-01   HALFY     2.850088E+01   ACTCNV    5.160700E+04
   EPAREL     1.000000E+02   INVCHD    0.000000E+00
*CM244
   AWT        2.440630E-01   HALFY     1.811013E+01   ACTCNV    8.088299E+04
   EPAREL     0.000000E+00   INVCHD    0.000000E+00
*CM245
   AWT        2.450650E-01   HALFY     8.498927E+03   ACTCNV    1.716500E+02
   EPAREL     1.000000E+02   INVCHD    0.000000E+00
*CM248
   AWT        2.480720E-01   HALFY     3.390698E+05   ACTCNV    4.250200E+00
   EPAREL     1.000000E+02   INVCHD    0.000000E+00
*CS137
```

```
   AWT        1.369070E-01  HALFY     2.999975E+01  ACTCNV    8.704300E+04
   EPAREL     1.000000E+03  INVCHD    2.070000E+04
*FR221
   AWT        2.210140E-01  HALFY     9.126364E-06  ACTCNV    1.772400E+11
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*ND143
   AWT        1.430000E-01  HALFY     3.168876E+30  ACTCNV    0.000000E+00
   EPAREL     1.000000E+03  INVCHD    0.000000E+00
*NP237
   AWT        2.370480E-01  HALFY     2.139942E+06  ACTCNV    7.047600E-01
   EPAREL     1.000000E+02  INVCHD    6.670000E+01
*NP239
   AWT        2.390530E-01  HALFY     6.448664E-03  ACTCNV    2.319100E+08
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PA231
   AWT        2.310360E-01  HALFY     3.276618E+04  ACTCNV    4.722500E+01
   EPAREL     1.000000E+02  INVCHD    0.000000E+00
*PA233
   AWT        2.330400E-01  HALFY     7.392988E-02  ACTCNV    2.075100E+07
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PA234M
   AWT        2.340430E-01  HALFY     2.224551E-06  ACTCNV    6.866600E+11
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PB209
   AWT        2.089810E-01  HALFY     3.764625E-04  ACTCNV    4.544100E+09
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PB210
   AWT        2.099840E-01  HALFY     2.229938E+01  ACTCNV    7.634800E+04
   EPAREL     1.000000E+02  INVCHD    0.000000E+00
*PB211
   AWT        2.109890E-01  HALFY     6.863786E-05  ACTCNV    2.468600E+10
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PB212
   AWT        2.119920E-01  HALFY     1.213680E-03  ACTCNV    1.389500E+09
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PB214
   AWT        2.140000E-01  HALFY     5.095553E-05  ACTCNV    3.278500E+10
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PM147
   AWT        1.469150E-01  HALFY     2.623513E+00  ACTCNV    9.275300E+05
   EPAREL     0.000000E+00  INVCHD    5.250000E+02
*PO212
   AWT        2.119890E-01  HALFY     9.506629E-15  ACTCNV    1.773900E+20
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PO213
   AWT        2.129930E-01  HALFY     1.330928E-13  ACTCNV    1.261100E+19
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PO214
   AWT        2.139950E-01  HALFY     5.206464E-12  ACTCNV    3.208700E+17
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PO215
   AWT        2.149990E-01  HALFY     5.640600E-11  ACTCNV    2.947900E+16
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PO216
   AWT        2.160020E-01  HALFY     4.753314E-09  ACTCNV    3.482000E+14
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PO218
   AWT        2.180090E-01  HALFY     5.799044E-06  ACTCNV    2.827800E+11
   EPAREL     0.000000E+00  INVCHD    0.000000E+00
*PU238
```

```
   AWT        2.380500E-01   HALFY      8.774619E+01   ACTCNV     1.711500E+04
   EPAREL     1.000000E+02   INVCHD     4.240000E+06
*PU239
   AWT        2.390520E-01   HALFY      2.406445E+04   ACTCNV     6.214600E+01
   EPAREL     1.000000E+02   INVCHD     3.920000E+05
*PU240
   AWT        2.400540E-01   HALFY      6.537392E+03   ACTCNV     2.278100E+02
   EPAREL     1.000000E+02   INVCHD     6.930000E+04
*PU241
   AWT        2.410570E-01   HALFY      1.439937E+01   ACTCNV     1.030000E+05
   EPAREL     0.000000E+00   INVCHD     1.930000E+06
*PU242
   AWT        2.420590E-01   HALFY      3.869198E+05   ACTCNV     3.817100E+00
   EPAREL     1.000000E+02   INVCHD     4.910000E+04
*PU244
   AWT        2.440640E-01   HALFY      8.261261E+07   ACTCNV     1.773100E-02
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*RA223
   AWT        2.230190E-01   HALFY      3.130533E-02   ACTCNV     5.120600E+07
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*RA224
   AWT        2.240200E-01   HALFY      1.001999E-02   ACTCNV     1.592700E+08
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*RA225
   AWT        2.250240E-01   HALFY      4.052993E-02   ACTCNV     3.919900E+07
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*RA226
   AWT        2.260250E-01   HALFY      1.599966E+03   ACTCNV     9.885801E+02
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*RA228
   AWT        2.280310E-01   HALFY      6.699955E+00   ACTCNV     2.340000E+05
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*RN219
   AWT        2.190090E-01   HALFY      1.254875E-07   ACTCNV     1.300800E+13
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*RN220
   AWT        2.200110E-01   HALFY      1.761895E-06   ACTCNV     9.222600E+11
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*RN222
   AWT        2.220180E-01   HALFY      1.046997E-02   ACTCNV     1.538000E+08
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*SM147
   AWT        1.470000E-01   HALFY      1.059355E+11   ACTCNV     2.295400E-05
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*SR90
   AWT        8.990801E-02   HALFY      2.912197E+01   ACTCNV     1.365400E+05
   EPAREL     1.000000E+03   INVCHD     9.850002E+03
*TH227
   AWT        2.270280E-01   HALFY      5.124073E-02   ACTCNV     3.073200E+07
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*TH228
   AWT        2.280290E-01   HALFY      1.913051E+00   ACTCNV     8.195301E+05
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*TH229
   AWT        2.290320E-01   HALFY      7.339118E+03   ACTCNV     2.126900E+02
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*TH230
   AWT        2.300330E-01   HALFY      7.700370E+04   ACTCNV     2.018300E+01
   EPAREL     1.000000E+01   INVCHD     0.000000E+00
*TH231
```

```
   AWT        2.310360E-01   HALFY      2.911247E-03   ACTCNV     5.315200E+08
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*TH232
   AWT        2.320380E-01   HALFY      1.405080E+10   ACTCNV     1.096500E-04
   EPAREL     1.000000E+01   INVCHD     6.110000E-01
*TH234
   AWT        2.340440E-01   HALFY      6.597601E-02   ACTCNV     2.315200E+07
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*TL207
   AWT        2.069770E-01   HALFY      9.069325E-06   ACTCNV     1.904500E+11
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*U233
   AWT        2.330400E-01   HALFY      1.585072E+05   ACTCNV     9.678300E+00
   EPAREL     1.000000E+02   INVCHD     1.310000E+03
*U234
   AWT        2.340410E-01   HALFY      2.445105E+05   ACTCNV     6.247300E+00
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*U235
   AWT        2.350440E-01   HALFY      7.038074E+08   ACTCNV     2.161100E-03
   EPAREL     1.000000E+02   INVCHD     1.150000E+00
*U236
   AWT        2.360460E-01   HALFY      2.341483E+07   ACTCNV     6.468300E-02
   EPAREL     1.000000E+02   INVCHD     0.000000E+00
*U238
   AWT        2.380510E-01   HALFY      4.468115E+09   ACTCNV     3.361100E-04
   EPAREL     1.000000E+02   INVCHD     2.010000E-01
*Y90
   AWT        8.990701E-02   HALFY      7.301091E-03   ACTCNV     5.446300E+08
   EPAREL     0.000000E+00   INVCHD     0.000000E+00
*ZR90
   AWT        9.000000E-02   HALFY      3.168876E+30   ACTCNV     0.000000E+00
   EPAREL     1.000000E+03   INVCHD     0.000000E+00
END_TABLES>
!
! END_OF_RADIOISOTOPE_INPUT
!
!
!
-----------------------------------------------------------------------------------
                    END    OF    CUSP_TEST_INP_CH_REPOSITORY.DAT
-----------------------------------------------------------------------------------

***********************************************************************************
```

The input file listed above was designed specifically to apply to WIPP-site calculations. In principle, CUTTINGS_S could be applied to other sites, although no such applications are foreseen for regulatory calculations. As a convenience to users, the list below specifies those parameters that could be changed to reflect sites other than the WIPP. It is not to be regarded as part of the code's QA documentation.

```
!Repository Geometry

      VARIable_name  <default value> Only capitalized portion of name is
       or                             required
      VARI           MATERIAL_NAME:PROPERITY_NAME  fetch input from CDB file


                        !Repository Data/Input


    INV_ARea  <no default>  -  Area of repository according to the
                               WIPP TRU waste type (CH or RH)
                               [REAL].
    INV_AR    MATERIAL_NAME:PROPERITY_NAME  fetch input from CDB file


    OUT_MAT   <no default>  -  The CAMDAT material region to
                               which CUTTINGS_S output variables
                               are written (CHARACTER*8).


    RADWAS  <CONtact_handled> - Type of radioisotope waste form (CHARACTER).  Valid
reposes are:

                               REMote_handled;  WIPP Remote-Handled (RH) TRU waste,
                               CONtact_handled; WIPP Contact-Handled (CH) TRU waste,
or
                               INEL_winco;      INEL/WINCO HLW/SNF waste(s).

    CHAIN    <no default>   rad_name_1, rad_name_2, rad_name_3, ...  <

A list of all the radioisotope names in a decay chain.  The order of the list is from
parent to daughter,..., terminating at a stable element.  Repeat the CHAIN keyword and
list of radioisotopes for as many chains as desired.  The half-lives, atomic weights,
activity conversions, EPA release limits, and waste-unit information will be retrieved
from the generic radioisotope data base.  The inventory (in Curies) of each
radioisotope will be extracted from the secondary database (CHARACTER).

    SAVE <all unique radioisotopes> rad_name_1, rad_name_2, rad_name_3, ... <

A list of all unique radioisotope names for which values are to be written to the
output CAMDAT and to the debug/diagnostics file.  As a default, all unique
radioisotope values will be stored/saved to the output CAMDAT and the
debug/diagnostics file.


REP_NAME          <WIPP>        -  Name of the repository (CHARACTER).  Other valid
responses are:      INEL/WINCO.
REP_GEOLogy       <SALT>        -  Repository geologic medium (CHARACTER).  Other
valid responses are:       HALITE, or   GRANITE.
DISPOSal_group    <1>           -  Waste Disposal Group number (INTEGER).  Valid
waste-disposal group numbers are from 1 to 5.  If NAME=WIPP, and GEOLOGY=SALT, the
waste-disposal group number is not used.  By specifying a WDG number, radioisotope
inventory data is accessed from the Secondary Database according to the WDG number.

                        Do not specify PACKage_id !!

PACKage_id        <1>           -  Waste Package ID (INTEGER).  Valid waste package
(WP) IDs are from 1 to 26.  If NAME=WIPP, and GEOLOGY=SALT, the waste package ID is
```

not used. By specifying a WP ID, Radioisotope inventory data is accessed from the Secondary Database according to the WP ID.

Do not specify DISPOSal_group !!

END OF APPENDIX I

APPENDIX J: EXAMPLE OF THE INPUT FILE: CUSP_INP$TXT1 FOR REGULATORY - CALCULATION RUNS

This input file provides various data relevant to the drilling equations and the intrusion time. Because it is designed for a regulatory-type calculation, it does not list specific numerical values for the various parameters. Rather, it identifies them by name (see Appendix C, item 4, for an explanation of input-file formats). Numerical values are then copied over from the input CDB files. This file is discussed in Section 6.1 above as file number 3.

Definitions of the various parameters used in this input file are given at the end of Appendix J.

```
-----------------------------------------------------------------------------------------
                BEGINNING      OF   A   PRODUCTION - LIKE   INPUT   FILE
-----------------------------------------------------------------------------------------
!
!  Intrusion
!
 TINTR          100.0
 PARTDIA    BLOWOUT:PARTDIA

!  Properities

 TAUFAIL    BOREHOLE:TAUFAIL

 DIAMMOD    BOREHOLE:DIAMMOD
 DOMEGA     BOREHOLE:DOMEGA
 DNSFLUID   DRILLMUD:DNSFLUID
 VISCO      DRILLMUD:VISCO
 YLDSTRSS   DRILLMUD:YLDSTRSS
 ABSROUGH   WAS_AREA:ABSROUGH

!
! Bragflow
!
! Multiple hits (max of 10, 0 thru 9)
!
! MHIT_0   is associated with the hit that
!           CUTTINGS used for BRAG flow  properities
!

 INTR_0   CAVITY_1       <
 INTR_1   619  622  625  <
 INTR_2   618  621  624  <
 INTR_3   617  620  623  <
 INTR_4  1010  <
 INTR_5  1023  <
 INTR_6   471  <
 INTR_7   606  <

-----------------------------------------------------------------------------------------
                END          OF          PRODUCTION - LIKE  INPUT  FILE
-----------------------------------------------------------------------------------------
```

END OF APPENDIX J

APPENDIX K: EXAMPLE OF THE INPUT FILE: CUSP_INP$TXT1 FOR A TEST RUN

This input file provides various data relevant to the drilling equations and the intrusion time. Because it is designed for a test run, specific numerical values are defined for each of the various parameters. The file is stored in the CMS portion of the WIPP Alpha cluster under the name: CUSP_TEST_2.INP. Corresponding input files for the other test problems may be found by replacing the number 2 in the file's name by the problem number of interest. This file is discussed in Section 6.1 above as file number 3.

Definitions of the various parameters used in this input file are given at the end of this appendix.

```
-----------------------------------------------------------------------------------------
                BEGINNING        OF     A     TEST - LIKE    INPUT    FILE
-----------------------------------------------------------------------------------------
!
!  TEST PROBLEM 2, STUCK PIPE
!
! INTRUSION

  TINTR          2000.0
  DIAMMOD        0.3556
  PRESSURE       12.5E6
  TCLOUT         6.40E4

!
!  Initial porosity is required, hence two entries
!

  POROSITY         0.88       0.070405

! PROPERTIES

  DNSFLUID     0.1210E+04
  DOMEGA       0.7800E+01
  VISCO        0.9170E-02
  YLDSTRSS     0.4400E+01
  ABSROUGH     0.2500E-01
  TAUFAIL      8.1120E+00

-----------------------------------------------------------------------------------------
                END          OF       A    TEST - LIKE   INPUT   FILE
-----------------------------------------------------------------------------------------
```

Explanation of Input Parameters Used in Appendices J and K

In the list that follows, two entries are made for each listing. The first applies to a test-like input file such as the one given in Appendix E. The second applies to a regulatory-calculation-like input file such as the one given in Appendix D. Both pertain to drilling and intrusion parameters.

```
VARIable_name  <default values> Only capitalized portion of name is
 or                              required
VARI           MATERIAL_NAME:PROPERITY_NAME  fetch input from CDB file
```

Drilling Parameters

```
DENSity    <1.210E+03>   -  Density of the drilling fluid (mud) in kg/m³.
 or
DENS       MATERIAL_NAME:PROPERITY_NAME


DOMEga     <0.7800E+01>  -  Angular velocity of the drill string in rad/s.
 or
DOME       MATERIAL_NAME:PROPERITY_NAME


ROUGH     <.0250>  -  Absolute borehole roughness (m)
 or
ROUGH     MATERIAL_NAME:PROPERITY_NAME


TAUFail    <0.1000E+03>  -  Effective shear resistance to erosion (Pa).
 or
TAUF       MATERIAL_NAME:PROPERITY_NAME


VISCo      <0.9170E-02>  -  Plastic viscosity of drilling mud
 or                          associated with an Oldroyd type fluid model  (Pa-s)
                             (zero shear-rate viscosity).
VISC       MATERIAL_NAME:PROPERITY_NAME


YLDSTrss   <0.4400E+01>  -  Yield Stress of the drilling fluid (mud)   (Pa).
 or
YLDS       MATERIAL_NAME:PROPERITY_NAME
```

Intrusion Parameters

```
VARIable_name  <default value> Only capitalized portion of name is
 or                              required
VARI           MATERIAL_NAME:PROPERITY_NAME  fetch input from CDB file
 or    if nhits .gt. 1 (testing mode), then
VARI  variable(1) variable(2) ... variable(nhits)


UNITS      <SEC> - Type of time units that
UNITS              the times of intrusions
                   are specified [CHARACTER].
                   Valid responses are:
                   YEARS or SECONDS.

NHITS       <1>  - Number of intrusions [REAL]*.
NHITS
```

* [REAL] signifies a real, floating-point number.

```
DBDIAM      <0.5080E+00>   - Drilling bit diameter  (m); (outside
                             diameter of drill-string annulus)
                             corresponding to the first
 or                          intrusion time [REAL].
DBDIAM     MATERIAL_NAME:PROPERITY_NAME
 or
DBDIAM(nhits)


TINTR      <>  -  First intrusion time  (m)  [REAL].
 or
TINTR      MATERIAL_NAME:PROPERITY_NAME
 or
TINTR(nhits)


TCLOUT   <>  - Clean-out time**  (s) [REAL].
 or
TCLOUT     MATERIAL_NAME:PROPERITY_NAME
 or
TCLOUT(nhits)


PARTDIA   <>  - Particle diameter (m) [REAL].
 or
PARTDIA(nhits)
```

Note!!! The following two parameters are NOT required if a BRAGFLO CDB file is attached.

```
POROSITY   <>  - Porosity at time of intrusion (unitless) [REAL].
 or
POROSITY   MATERIAL_NAME:PROPERITY_NAME
 or
POROSITY(nhits)


PRESSure   <>  - Repository pressure at time of intrusion (Pa) [REAL].
 or
PRESS      MATERIAL_NAME:PROPERITY_NAME
 or
PRESS(nhits)
```

Note!!! The preceding two parameters are NOT required if a BRAGFLO CDB file is attached.

END OF APPENDIX K

** Clean-out time is the time required to replace all of the borehole drilling fluid at the present pumping rate.

APPENDIX L: TIPS AND OPERATIONAL HINTS THOUGHT USEFUL TO NEW USERS

This appendix comprises a collection of useful bits of information, extracted primarily from the source code, and thought by the code sponsor to be of potential utility to new users.

```
      Usefull text extracted from source code

*!
*     Real xareas = areasp (flowrate, xtclout, hrepo, flwcnst, poroi)
*************************************************************************
*****                                                                ****
*****  Equivalent A_R_E_A of S_tuck P_ipe, repository removed        ****
*****             - - - -    -      -                                ****
*************************************************************************
*
*  PURPOSE:     Calculates equivalent area of repositoy removed on stuck
*               pipe:
*
*  AUTHORS:     Robert A. Cole
*
*  UPDATED:     02-FEB-1996  --RAC: Deleted write for DBSPALL
*                 -JUL-1994  --RAC: Created
*
*  CALLED BY:   CUTTINGS (main program)
*
*  CALLS:       NONE
*!
*     The following hardwired constants are not presently used
*     DATA ACCNST/1.128E+13/
*     DATA AVOGAD/6.022E+23/
*!
*
*     ...Source: Newton circa (1642-1727)
*     DATA GRAV/9.81/
*
*     Seconds per based on a Tropical Year of 31556926 sec
*     DATA YRPSEC/3.168876E-08/
*
*!
*     Subroutine blowout (dia, hf, perm, porof, pg, partdia, xareas)
*
*************************************************************************
*****                                                                ****
*****  Equivalent B_L_O_W  O_U_T,  calculates the equivalent area    ****
*****                               ejected by a blowout             ****
*****             - - - -  - -                                       ****
*
*  PURPOSE: Calculates final blowout radius, and back pressure,
*           and returns equivalent waste area removed
*
*           Calculates entrance mach number for different
*           Pressure ratios for isothermal flow in pipes with
*           Friction....see eq 3.9 page 63 binder, advanced fluid
*           Mechanics vol1.
*           Assumes two diameters equivalent to the annular areas
```

```
*            adjacent to the collars and drillpipe.  when mach10
*            =mach2 then the value for p2 is correct and the
*            entrance mach number= mach1=mach2.
*
*           Includes additional flow equations to calculate
*           Final blowout radius and back pressure
*             *corrected steady state flow out of waste
*             *annular area and waste surface relationship
*             *terminal velocity of spherical waste particle
*                  includes specific collar diameters
*                  modified to read from input file
*
*
*  AUTHORS:      Jerry W. Berglund & Robert A. Cole
*
*  CALLED BY:    CUTTINGS {main program}
*
*  CALLS:        NONE
*
*********************************************************************
*!
*     Subroutine brgcdb( maxc, maxq, iq, lq, q, c, ierrdb )
*
*********************************************************************
*****                                                            ****
*****            B_R_G_C_D_B  set up read of a BRAGFLO CDB file  ****
*****            - - - -                       -- -    ---      ****
*********************************************************************
*
*  PURPOSE:     Process dynamic memory allocation for input
*               BRAGFLOW CDB file etc...
*
*  AUTHOR:      Robert A. Cole
*
*  CREATED:     02-FEB-1996  --RAC: Created from a copy of PROCDB
*
*  CALLED BY:   CUTTINGS {main program}
*
*  CALLS:       DBISIZES
*               DBITITLE
*               ADDMEM
*               DYNMEM
*               ZERODA
*               DYNMEMC
*               READBRAG
*
*  ARGUMENTS:
*  ENTRY/
*   --through subroutine call
*     MAXC   = Total no. of CHAR*1 words allocated to dynamic storage
*     MAXQ   = Total no. of words allocated to dynamic storage
*     IQ     = INTEGER Dynamic Q-array (equivalenced to Q)
*     LQ     = <LOGICAL> Dynamic Q-array (equivalenced to Q)
*     Q      = REAL Dynamic memory base array
*     C      = CHARACTER Dynamic memory base array
*     IERRDB = INTEGER error code
*
*  LOCAL/
*     MORMEMC= No. additional words to be allocated to C array
*     MORMEMR= No. additoinal words to be allocated to Q array
```

```
*
*  EXIT/
*
*****
************************************************************************
*!
*     Subroutine cal_bra
************************************************************************
*****                                                                 ****
*****            CALIBRATION  checks out model2 with experiments      ****
*****            --- ---                                              ****
*
*  PURPOSE:   To calibrate model2 with experimential data or WIPP data
*              also validate's model2 over possible WIPP variable
*              ranges
*             This subroutine gets activated by defining the LOGICAL
*              variable CUSP$CHECK_OUT to TRUE. This subroutine
*              expects to find the first keyword on the TXT1 input file
*              either CALIBRATE, EXPERIMENT, or VALIDATE
*
*
*  AUTHOR:     Robert A. Cole
*
*  CREATED:    02-FEB-1996  --RAC:
*
*  CALLED BY:  CUTTINGS {main program}
*
*  CALLS:      CAL_INP
*              SOLID_OUT
*
*  LOCAL/
************************************************************************
*!
*     Subroutine cal_inp (test_funct)
************************************************************************
*****                                                                 ****
*****            CALibration INPut   Reads input for calibration      ****
*****            ---         ---                                      ****
*
*  PURPOSE:   To read input required for CALIBRATION, VERIFICATION,
*              & EXPERIMENT
*
*  AUTHOR:     Robert A. Cole
*
*  CREATED:    02-FEB-1996  --RAC:
*
*  CALLED BY:  CAL_BRA
*
*  CALLS:      NEXT0
*              NEXTW
*              NEXT_R
*              NEXT_I
*
************************************************************************
*!
*     Subroutine drill( iwasflg, ihit, xtint, dbdiam, tunits, xnewarea)
*
************************************************************************
*****                                                                 ****
*****     D_R_I_L_L_ing  through  radwaste  repository  module        ****
```

```
*****     - - - - -                                                    ****
*
*  PURPOSE:      Calculates new borehole area based on drilling and
*                penetrating either:
*
*                (1) WIPP repository containing CH or RH type
*                    transuranic waste, or
*                (2) Hypothetical INEL/WINCO repository containing
*                    HLW/SNF waste.
*
*  AUTHORS:      Jerry W. Berglund
*                Jonathan S. Rath
*
*  CALLED BY:    CUTTINGS {main program}
*
*  CALLS:        QAABORT
*                INTERFACE
*                FRICTION {REAL function}
*                F11 {REAL function}
*                F12 {REAL function}
*                F13 {REAL function}
*                F21 {REAL function}
*                F22 {REAL function}
*                F23 {REAL function}
*                F31 {REAL function}
*                F32 {REAL function}
*                F33 {REAL function}
*                EF1 {REAL function}
*                EF2 {REAL function}
*                EF3 {REAL function}
*
*  ARGUMENTS:
*   ENTRY/
*    --through subroutine call
*      IWASFLG= WIPP TRU waste type flag [INTEGER]
*             = 1; Contact Handled (CH) TRU waste
*             = 2; Remote Handled (RH) TRU waste
*      IHIT   = Intrusion (or hit) index [INTEGER]
*      XTINT  = Time of this intrusion (or hit) [REAL]
*      DBDIAM = Drill Bit Diameter for this intrusion (or hit);
*               (Outside diameter of drillstring annulus) [REAL]
*      TUNITS = Units of time (i.e. seconds, years, etc...) [CHAR*8]
*
*********************************************************************
*!    Integer function fgrad (input)
*********************************************************************
*****                                                                ****
*
*  PURPOSE:   To determine the number of unique radionuclides
*
*  AUTHOR:     Robert A. Cole
*
*  CREATED:    02-FEB-1996  --RAC:
*
*  CALLED BY:  PROCIN
*
*****                                                                ****
*********************************************************************
*!
*     Real function gasers (xdbdia, flowrate, drate, depth, hrepo,
```

```
*                              flwcnst, poroi)
*********************************************************************
*****                                                           ****
*****  Equivalent G_A_S_ E_R_o_S_i_o_n,    repository removed      ****
*****              - - - -    -      -                           ****
*
*  PURPOSE:     Calculates equivalent area of repositoy removed because
*               gas erosion:
*
*  AUTHORS:     Robert A. Cole
*
*  UPDATED:     02-FEB-1996  --RAC: Deletet write for DBSPALL
*               xx-JUL-1994  --RAC: Created
*
*  CALLED BY:   CUTTINGS {main program}
*
*  CALLS:       NONE
*
*  ARGUMENTS:
*   ENTRY/
*    --through function arguments
*      DHOLE  = Radius of borehole
*      FLOWRATE=Recommended (from handbook formula) drilling fluid
*               (mud) flowrate based on drillstring diameter [REAL].
*      TCLOUT = Cleanout time for stuck pipe (s)
*      HREPO  = Height of repository (m)
*      POROI  = Initial porosity
*
*   EXIT/
*    --through fucntion value
*      GASERS = Equivalent area of repository removed (REAL)
*
*********************************************************************
*!
*     Subroutine gencut( iwasflg, diammod, aintc,   tint,    nnic,
*    $                   radchn,  nucnam,  MAPSAV,  idmtrl,  halfy,
*    $                   awt,     actcnv,  xmoles,  eparel,  cipmsq,
*    $                   cizero,  sumci,   radhis,  xnorm,   xinvt0,
*    $                            cizersv, xporo,   xprgs,   xprbr,
*    $                   xsatb,   mapinv,  c,       q,       kultp )
*********************************************************************
*****                                                           ****
*****      G_E_N_erate  amount  of  C_U_T_tings  module         ****
*****      - - -                    - - -                       ****
*
*  PURPOSE:     Determines the drill cuttings (in Curies) brought to
*               the surface.  Using the intrusion borehole diameter
*               and intrusion time, the routine determines the amount
*               of cuttings, and ages the cuttings to the intrusion
*               time.
*
*  AUTHORS:     Harold J. Iuzzolino
*               Jonathan S. Rath
*
*  MODIFIED:    Robetr A. Cole
*
*
*  CALLED BY:   CUTTINGS {main program}
*
*  CALLS:       WRTANA
```

```
*                QAMAXERR
*                WRPLFIL
*
*  FUNCTIONS:    QUANKG
*                GINDX
*                GJNDX
*
*  ARGUMENTS:
*   ENTRY/
*    --through subroutine call
*      IWASFLG= radWASte type FLaG (INTEGER)
*             = 1; WIPP Contact Handled (CH) TRU waste
*             = 2; WIPP Remote Handled (RH) TRU waste
*             = 3; INEL/WINCO HLW/SNF
*      DIAMMOD= Outside diameter of drillstring annulus, for each
*               intrusion or hit, array (REAL).
*      AINTC  = Borehole area, as computed by DRILL routine array
*      TINT   = Intrusion times of each hit, in SECONDS array (REAL)
*      NNIC   = No. of Nuclides in each decay chain, array (INTEGER)
*      RADCHN = Names of radioisotopes in each chain, array (CHAR*8)
*      NUCNAM = Names of radioisotopes used by CUTTINGS (CHARACTER*8)
*      IDMTRL = Names of Generic Radioisotope Data Base (GRDB)
*               entries, array (CHARACTER*8)
*      HALFY  = Half-Life of each radioisotope in GRDB [years],
*               array (REAL)
*      AWT    = Atomic WeighT of each radioisotope in GRDB [Kg/Mole],
*               array (REAL)
*      ACTCNV = ACTivity CoNVersion of each radioisotope in
*               GRDB [Ci/Kg], array (REAL)
*      XMOLES = Dummy array used (REAL)
*      CIMPSQ = CURIES per SQ. METER at time zero (REAL)
*      CIZERO = CURIES of each radioisotope, at time zero (REAL)
*      EPAREL = EPA normalization factor for each radioisotope in
*               GRDB, array (REAL)
*      MAPSAV = Map of unique names of radioisotopes to be saved
*                MAPSAV(I) .GT. 0 save
*                MAPSAV(I) .EQ. 0 do not save
*               to output CAMDAT and debug/diagnostics file (CHAR).
*      CIZERSV= Values of radioisotopes to be written to the
*               output CAMDAT and debug/diagnostics file (REAL).
*      C      = Dynamic base array (CHARACTER*1)
*      Q      = Dynamic base array (REAL)
*
*  LOCAL/
*
*  EXIT/
*    --through subroutine call
*      RADHIS = Radioisotope Inventory (Curies) History array [REAL]
*      SUMCI  = Sum of all hits (in Curies) for each radioisotope
*               array (REAL)
*      XNORM  = Normalized radioisotope relaese array (REAL)
*      XINVT0 = Inventory at time=0, array [REAL]
*
*!
*                          Types of data sets
*                          ------------------
*
*  INPUT/
*    BINARY: in units 'IDB'
*    ASCII:  in units 'INPUTP','INPUTF','INPSDB'
```

```
*    BINARY: in UNITS 'IBRAG'
*
*  OUTPUT/
*    BINARY: in units 'ODB', 'DB_BIN'
*    ASCII:  in units 'ICTRN', 'IHISTO','IPLT1','IPLT2','IPLT3',
*                     'NHISTO','NOUTFL','NVERFY', 'DB_ASC'
*
*                            Files used
*                            ----------
*
*  $DEFINE  logical-name   file-path-name
*
*  logical file name   unit  description
*
*  'CUSP_INP$TXT0'       1    Input text file (REQUIRED) (Radionuclide
*                              input, Model & Site specific properities)
*                                or if CUSP_INP$TXT0 is not defined
*  'CUSP_INP$BIN0'       1    Input binary file (REQUIRED) (Radionuclide
*                              input, Model & Site specific properities)
*                                or
*  'CUSP_INP$TXT1'       2    Input text file (REQUIRED) (Drilling
*                              properities and to controll testing inputs
*  'CUSP_INP$BRAGCDB'    7    Input BRAGFLOW CDB file (OPTIONAL)
*  'CUSP_OUT$DBG'        8    Output debug File
*  'CUSP_INP$CDB'       10    Input Computational Data Base (REQUIRED)
*  'CUSP_OUT$CDB'       11    Output CDB File (REQUIRED)
*
*                            The following files are (OPTIONAL):
*  'CUSP_OUT$NVERFY'     9    Output verify File
*  'CUSP_OUT$IHISTO'    20    Output Radionuclide Inventory History
*  'CUSP_OUT$NHISTO'    21    Output Normalized History file
*  'CUSP_OUT$PLT1'      22    Output radioisotope decay plot file (long)
*  'CUSP_OUT$PLT2'      23    Output radioisotope decay plot file (medium
*  'CUSP_OUT$PLT2'      24    Output radioisotope decay plot file (short)
*  'CUSP_OUT$ICTRN'     25    Output CCDFPERM transfer file
*
*
*                            The following files are required for
*                             CUSP$PRE_CUTTINGS:
*
*  'CUSP_INP$CDB'       10    Input Computational Data Base (REQUIRED)
*  'CUSP_INP$SDB'        4    Secondary Data Base Flatfile
*                             (REQUIRED pre_cuttings)
*  'CUSP_INP$TXT1'       2    Input text file (REQUIRED) (Drilling
*                              properities and to controll testing inputs
*  'CUSP_OUT$DBG'        8    Output debug File
*  'CUSP_OUT$DB_ASC'    12    Output  ascii SDB file
*  'CUSP_OUT$DB_BIN'    13    Output binary SDB file
*
*************************************************************************
*!
*************************************************************************
****              PARBIN0                                            ****
*                                                                     ****
*  PURPOSE:     reads a CUTTINGS binary file for parameters inputs   ****
*                                                                     ****
*  AUTHOR:      Robert A. Cole                                       ****
*                                                                     ****
*  UPDATED:     02-FEB-1996  --RAC: First Ed.                        ****
*                                                                     ****
```

```
*  CALLED BY:    PROBIN                                                  ****
*                                                                        ****
*  CALLS:        QAABORT                                                 ****
*                                                                        ****
*****                                                                    ****
*!
*     Subroutine partxt0
*************************************************************************
****                                                                    ****
****        P_A_R_a_m_e_t_e_r_s SCAN of  T_e_X_T  file                  ****
****        - - -                        -   - -                        ****
*
*  PURPOSE:      reads a CUTTINGS input text file for parameters inputs
*
*  AUTHOR:       Robert A. Cole
*
*  UPDATED:      02-FEB-1996  --RAC: First Ed.
*
*  CALLED BY:    PROCIN
*                MAIN (CHK_OUT)
*
*  CALLS:        NEXT0
*                NEXT_I
*                NEXT_R
*
*  ARGUMENTS:
*  ENTRY/
*    --through subroutine call (none)
*
*************************************************************************
*!
*     Subroutine prepro( fidb, ftxt0, fbin0, ftxt1, fodb, fbrg )
*
*  PURPOSE:     Interacts with DEC DCL stream to determine input &
*                outputs file and logical settings
*
*************************************************************************
*!
*     Subroutine probin( maxq,   maxc,    iq,     lq,      q,
*    $                   c,      komat,   outmat, iwasflg, tunits,
*    $                   nqarec, c(lqainfo) )
*************************************************************************
****                                                                    ****
*
*  PURPOSE:     Processes the CUTTINGS binary file (BIN0) information
*                       & the CUTTINGS ASCII  file (TXT1) information
*
*  AUTHOR:      Robert A. Cole
*  CALLED BY:   CUTTINGS {main program}
*
*  CALLS:       SCABIN0
*               SCATXT1
*               PARBIN0
*               ADDMEM2
*               DYNMEM
*               DYNMEMC
*               ZERODA
*               REABIN0
*               REATXT1
*               REAEPA
```

```
*
*  ARGUMENTS:
*  ENTRY/
*   --through subroutine call
*     MAXQ   = Total no. of REAL words allocated (INTEGER)
*     MAXC   = Total no. of CHARACTER*1 words allocated (INTEGER)
*     IQ     = INTEGER Dynamic Q-array (equivalenced to Q)
*     LQ     = <LOGICAL> Dynamic Q-array (equivalenced to Q)
*     Q      = REAL Dynamic memory base array
*     C      = CHARACTER Dynamic memory base array
*
*  EXIT/
*   --through subroutine call
*     MAXQ   = Total no. of REAL words allocated (INTEGER)
*     MAXC   = Total no. of CHARACTER*1 words allocated (INTEGER)
*     KOMAT  = CAMDAT material index to which CUTTINGS output
*              variables will be written as material property values
*              (INTEGER)
*     OUTMAT = CAMDAT material name to which CUTTINGS output
*              variables will be written as material property values
*              (CHARACTER*8)
*     IWASFLG= radWASte type FLaG (INTEGER)
*            = 1; WIPP Contact Handled (CH) TRU waste
*            = 2; WIPP Remote Handled (RH) TRU waste
*            = 3; INEL/WINCO HLW/SNF waste(s)
*     TUNITS = Units associeated with the time of intrusions (CHAR*8)
*
*************************************************************************
*!
*     Subroutine prosdb( maxc, maxq, iq, lq, q, c , iwasflg, qainfo )
*
*************************************************************************
****                                                                  ****
*                                                                     ****
*  PURPOSE:     Read a flat ascii flat to extract properities &       ****
*                data from the INGRESS data base                      ****
*                                                                     ****
*  AUTHOR:      Robert A. Cole                                        ****
*                                                                     ****
*  UPDATED:     02-FEB-1996  --RAC: First Ed.                         ****
*                                                                     ****
*  CALLED BY:   PROSDB  used by PRE_CUSP                              ****
*                                                                     ****
*  CALLS:       SCATXT0                                               ****
*               SDBQUERY                                              ****
*               REASDB                                                ****
*               PROCIN                                                ****
*               CMDREAD                                               ****
*               CHCASE                                                ****
*               BLANK                                                 ****
*               SORT                                                  ****
*               QAABORT                                               ****
*                                                                     ****
****                                                                  ****
*!
*************************************************************************
****             REABIN0                                              ****
*                                                                     ****
*  PURPOSE:     Reads a CUTTINGS binary file                          ****
*                                                                     ****
```

```
*  AUTHOR:       Rovert A. Cole                                          ****
*                                                                        ****
*  UPDATED:      02-FEB-1996  --RAC: First Ed.                           ****
*                                                                        ****
*  CALLED BY:    PROBIN                                                  ****
*                                                                        ****
*  CALLS:        QABORT                                                  ****
*                                                                        ****
****                                                                     ****
*!
*     Subroutine readbrag (diammod, poro, presgas,
*    &                     presbrn, SATGASX, nhits, tint,
*    &                     ele_n, ele_id, ele_blk, att_n,
*    &                     gridvol, prop_n, lvar_b, ele_prp,
*    &                     ele_hprp, ilog, MULTP, ierrdb)
************************************************************************
*
*  PURPOSE:   To extract the BRAD CDB file information
*
*    Arguments to this subroutine
*
*     MULTP    = Number  of multiple intrusions into BRAGCDB file at
*                same intrusion time
*     DIAMMOD  = the drill diameter
*     PORO     <= the porosity in the repository
*     PRESGAS  <= the pressure of the gas in the repository
*     PRESBRN  <= the pressure of the brine in the repository
*     SATGASX  <= the saturation of the brine in the repository
*     NHITS    => number of intrusions
*     TINT     => the intrusion times
*     ELE_N    <= the element block names
*     ELE_ID   <= the element block id's
*     ELE_BLK  <= the number of elements per block
*     ATT_N    <= the attributes names
*     GRIDVOL  <= the array for the grid volumes
*     PROP_N   <= the property names
*     LVAR_B   <= logical property table
*     ELE_PRP  <= element property values
*     ELE_HPRP <= element history property values
*     IERRDB   <= the error flag returned from call to "DBI---"
*
************************************************************************
*!
************************************************************************
****                                                                   ****
*                                                                      ****
*  PURPOSE:      Extract a property value from an INGRES data base   ****
*                                                                      ****
*  AUTHOR:       Robert A. Cole                                        ****
*                                                                      ****
*  UPDATED:      02-FEB-1996  --RAC: First Ed.                         ****
*                                                                      ****
*  CALLED BY:    PROSDB  used by PRE_CUSP                              ****
*                                                                      ****
*  CALLS:        SDBGETL                                               ****
*                QAABORT                                               ****
*                                                                      ****
****                                                                   ****
*!
************************************************************************
```

```
****              SCABIN0                                          ****
*                                                                  ****
*  PURPOSE:      Reads a binary parameter/data file for           ****
*                        sizing parameters                        ****
*                                                                  ****
*  AUTHOR:       Robert A. Cole                                   ****
*                                                                  ****
*  UPDATED:      02-FeB-1996  --RAC: First Ed.                    ****
*                                                                  ****
*  CALLED BY:    PROCIN                                           ****
*                                                                  ****
*  CALLS:                                                         ****
*                                                                  ****
****                                                               ****

      Usefull text extracted from include code

*!
*     /BLOWPROP/ (from FORTRAN statement: include 'CUSP_BLOWPROP.INC')
*
*     PURPOSE:    Provide common space for model 1 & model 2 properties
*                  & WIPP site specific properties
*
*     AUTHOR:     Robert A. Cole
*
*     UPDATED:    02-FEB-1996  --RAC: Added model2
*
*      BRAGCDB = <LOGICAL> <default true>
*                  true    <=> reads BRAGFLOW "CDB", WIPP run
*                  false   <=> check out runs, test problems
*
*      CHK_OUT = <LOGICAL> <default false>
*                  false   <=> WIPP run
*                  true    <=> calibration for experiments
*
*      MODTYPE = Model type:
*                MODEL1
*                MODEL2
*
*      Model 1 & 2 specific inputs:
*
*      The following values are input through the code via
*       the logical input file CUSP_INP$TXT0:
*
*      PR_MAX = The maximum pressure allowed by model
*      PR_MIN = The minimum pressure allowed by model
*      PE_MAX = The maximum permeability allowed by model
*      PE_MIN = The minimum permeability allowed by model
*      PCUT   = Pressure (Pa) which defines the border between the
*               erosion phase and the blowout phase
*      PGAS   = Pressure (Pa) which defines the border between the gas
*               erosion phase and the stuck pipe phase
*      KCRIT  = Permeability which defines the phase border the blowout
*               phase and the gas-erosion/stuck pipe phase
*
*      Model 2 specific inputs:
*
*      DELTR  = Delta radius for derivative in stress calculation
*      FGE    = Gravity     effectiveness factor
*      FSE    = Strength    effectiveness factor
```

```
*       FCE    = Cementation effectiveness factor
*       CEMSIG = Cementation Stress
*       ITER   = Number of iteration to solve for reynolds number
*       SUFTEN = Surface Tension
*
*       Hydrogen specific constants (or Air for Experiments)
*
*       KGAS   = Ration of specific heats (unitless)
*       RGAS   = Gas Constant
*       VISC   = Hydrogen viscosity
*       CHY*   = Hydrogen sound speed (m/s), calculated from:
*                  CHY = SQRT (KGAS * RGAS * TREPO)
*
*       Repository/site specific inputs:
*
*       TREPO  = Temperature of repository (K)
*       RHO1*  = Gas Density in WIPP room  (kg/m**3), calcutated from:
*                RHO1 = PG / TREPO / RGAS
*       PSUF   = Surface presure (Pa)
*       DEPTH  = Distance from repository depth to depth where casing
*                is set (m)
*       HREPO  = Height of repository at burial time       (4m)
*       RPANEL = The equivalent radius of 1 panel    (910.0m**2)
*       ROOM   = The equivalent radius of 1 room     (11,640m**2)
*       RHOS   = Waste particle density (kg/m**3)
*       INPORO = Initial repository porosity
*                Use in CALIBRATION runs
*                Production run uses value from BRAG CDB file
*
*       Drilling specific inputs:
*
*       L1     = Collar Length (m)
*       L2     = Drill pipe length (m)
*       COLDIA = Collar diameter (m)
*       PIPED  = Drill pipe diameter (m)
*       FRICTF = Friction factor (unitless)
*       FLWCNST= Percent volume of material that is carried by Drilling
*                mud (unitless)
*
*
*       APORO  = A constant in equation to determine permeability as a
*                function of porosity
*       NPORO  = N constant in equation to determine permeability as a
*                function of porosity
*
*                permeability = APORO *  porosity ** NPORO
*
******
*************************************************************************
*!
*     /BRGPAR/ ($include 'CUSP_BRGPAR.INC')
*      HEADER_B  = Character description of problem, etc...
*      IMAX_B    = No. of I-lines in grid
*      JMAX_B    = No. of J-lines in grid
*      KMAX_B    = No. of K-lines in grid
*      LESSEL_B  = List of Element Side sets concatenated Element List
*      LESSNL_B  = List of Element Side sets concatenated Nodes associate
*                  with each element side set Node List
*      LNPSNL_B  = List of Nodal Point set concatenated Nodes List
*      MAXNENO_B = Max. no. of nodes of any element
```

```
*      NDIM_B     = Number of physical DIMensions
*      NDBCAM_B   = CAMDAT versoin number
*      NELBLK_B   = Number of ELement BLocKs in mesh
*      NELX_B     = No. of elements along X-axis of mesh
*      NELY_B     = No. of elements along Y-axis of mesh
*      NELZ_B     = No. of elements along Z-axis of mesh
*      NQAREC_B   = Number of QA records
*      NSTEP_B    = No. of time steps in input CAMDAT (INTEGER)
*      NUMEL_B    = NUmber of ELeMents in mesh
*      NUMNOD_B   = NUMber of NODes in mesh
*      NUMNPS_B   = No. of Nodal Point Sets
*      NUMESS_B   = No. of Element Side Sets
*      NUQATR_B   = No. of UniQue ATtRibute names
*      NUQPR0_B   = No. of UniQUe PRoperty names (old)
*      NUQPRP_B   = No. of UniQUe PRoPerty names (new)
*      NVAREL_B   = No. of ELEMENT type ANALYSIS variables
*      NXINFO_B   = No. of information records
*
******
************************************************************************
*!
************************************************************************
*     /CMM_INP/ ($include 'CUSP_CAL_INP.INC')
*      FSEMIN  = Minimum FSE
*      DELFSE  = Delta  FSE
*      IFSE    = No of increment of FSE
*      FGEMIN  = Minimum FGE
*      DELFGE  = Delta  FGE
*      JFGE    = No of increment of FGE
*      FCEMIN  = Minimum FCE
*      DELFCE  = Delta  FCE
*      KFCE    = No of increment of FCE
*      SATMIN  = Minimum SAT
*      DELSAT  = Delta  SAT
*      ISA     = No of increment of SAT
*      PGMIN   = Minimum PG
*      DELPG   = Delta  PG
*      IPG     = No of increment of PG
*      PORMIN  = Minimum POR
*      DELPOR  = Delta  POR
*      DIA     = Diameter
*      POROST  = Porosity
*      IPOR    = No of increment of POR
*      PARTMIN = Minimum diameter
*      PARTMAX = Maximum diameter
*      PARTMUL = Particle multiplier
*      ITMAX   = Maximum number of trys for search of FGE, FSE, & FCE
*      DELERR  = Delta error on convergence
******
************************************************************************
*!
************************************************************************
*      /FILEUN/ (from FORTRAN statement: include 'CUSP_FILEUN.INC')
*       ICTRN  = Device no. of output CCDFPERM transfer file
*       IDB    = Device no. of input CAMDAT file
*       IDBSCR = Device no. of CAMDAT scratch file
*       IHISTO = Device no. of Radioisotope Inventory History file
*       INPUTP = Device no. of input text file or binary file:
*                                Model specific parameters
*                                Site specific parameters
```

```
*                                Radioisotope infomation
*      INPUTF = Device no. of input text file
*      INPSDB = Device no. of secondary data base SDB
*      IPLT1  = Device no. of plotting file #1 ("long-lived")
*      IPLT2  = Device no. of plotting file #2 ("medium-lived")
*      IPLT3  = Device no. of plotting file #3 ("short-lived")
*      NHISTO = Device no. of Normalized Release History file
*      NOUTFL = Device no. of output diagnostics/debug file
*      NVERFY = Device no. of output verify file
*      ODB    = Device no. of output CAMDAT file
*      IBRAG  = Device no. of Bragflow "CDB" file
*      DB_ASC = Device no. of output SDB  ascii file
*      DB_BIN = Device no. of output SDB binary file
*      ISCR3  = Device no. of scratch storage #3
************************************************************************
*
*!
************************************************************************
*    /MISCDAT/ (from FORTRAN statement: include 'CUSP_MISCDAT.INC')
*       Intrusion times are in years
*     NCHAINS = No. of unique radioisotope decay chains (INTEGER)
*     NGRAD   = No. of generic radioisotopes or radionuclides (INTEGER)
*     NHITS   = No. of hits or intrusions (INTEGER)
*     NNUC    = No. of radionuclides used in CUTTINGS (INTEGER)
*     NORIAC  = No. Of Radioisotopes In All Chains (INTEGER)
*     NRADPR  = No. of RADionuclides to be PRinted (saved to
*               output CAMDAT and written to debug/diagnostics
*               file) [INTEGER]
*     SUMCUR  = Sum of all Radioisotope inventory, in Curies (REAL)
*     MULTP   = Number of multiple hits at the same intrusion time
*               Default is 1 if there is no BRAGCDB file
******
************************************************************************
*!
************************************************************************
*     /RDBRAGx/ (from FORTRAN statement: include 'CUSP_RDBRAG.INC')
*
*      NULTP  = Maximum number of hits into brag calculation
*!
************************************************************************
*    /TOOLS/  (from FORTRAN statement: include 'CUSP_TOOLS.INC')
*     DEBUG  =  <LOGICAL>for debugging dynamic memory allocation
*     DBRAG  =  <LOGICAL>for debugging reading bragflow CDB file
*     NOECHO =  <LOGICAL>for no echoing of input to the DBG file
*     VERIFY = <LOGICAL> for writing a file for verifing purposes
*     PRE_CUSP = <LOGICAL> <default false>
*                  false   <=> Calculation
*                  true    <=> Pre_cusp, read SDB data base
*     PLODEC =  <LOGICAL>for writing long, medium, and short half-life
*              radioisotope decay history plot files.
*     WRTCTRN= <LOGICAL> for writing output CCDFPERM transfer file
*     WRTHIS = <LOGICAL> for writing RAD WASTE-radioisotope inventory
*              history table.
*     WRTNHIS= <LOGICAL> for writing Normalized Radioisotope
*              Inventory History
*

      Strucure of where how TXT0 file is read in:

      SUBROUTINE PARTXT0                                                6720
```

```
                                                    Absolute line nunber ^^^^
      IF (CMD .NE. 'MODEL_DATA') GO TO 100                                 74
      IF (CMD .EQ. 'RADIONUCLIDE_DATA') GO TO 900                          75
      IF (CMD .EQ. 'EOF')                    GO TO 900                     81
      IF (CMD .EQ. 'PR_MAX') THEN                                          85
      IF (CMD .EQ. 'PR_MIN') THEN                                          92
      IF (CMD .EQ. 'PE_MAX') THEN                                          99
      IF (CMD .EQ. 'PE_MIN') THEN                                         106
      IF (CMD .EQ. 'PCUT') THEN                                           113
      IF (CMD .EQ. 'PGAS') THEN                                           120
      IF (CMD .EQ. 'KCRIT') THEN                                          127
      IF (CMD .EQ. 'DELTR') THEN                                          134
      IF (CMD .EQ. 'FGE') THEN                                            141
      IF (CMD .EQ. 'FSE') THEN                                            148
      IF (CMD .EQ. 'FCE') THEN                                            155
      IF (CMD .EQ. 'CEMENT') THEN                                         162
      IF (CMD .EQ. 'ITER') THEN                                           169
      IF (CMD .EQ. 'SUFTEN') THEN                                         176
      IF (CMD .EQ. 'KGAS') THEN                                           183
      IF (CMD .EQ. 'RGAS') THEN                                           190
      IF (CMD .EQ. 'VISC') THEN                                           197
      IF (CMD .EQ. 'TREPO') THEN                                          204
      IF (CMD .EQ. 'PSUF') THEN                                           211
      IF (CMD .EQ. 'DEPTH') THEN                                          218
      IF (CMD .EQ. 'HREPO') THEN                                          225
      IF (CMD .EQ. 'RPANEL') THEN                                         232
      IF (CMD .EQ. 'ROOM') THEN                                           239
      IF (CMD .EQ. 'RHOS') THEN                                           246
      IF (CMD .EQ. 'L1') THEN                                             253
      IF (CMD .EQ. 'L2') THEN                                             260
      IF (CMD .EQ. 'COLDIA') THEN                                         267
      IF (CMD .EQ. 'PIPED') THEN                                          274
      IF (CMD .EQ. 'ROUGHP') THEN                                         281
      IF (CMD .EQ. 'FLWCNST') THEN                                        288
      IF (CMD .EQ. 'APORO') THEN                                          295
      IF (CMD .EQ. 'NPORO') THEN                                          302
      IF (CMD .EQ. 'MODEL1') THEN                                         309
      IF (CMD .EQ. 'MODEL2') THEN                                         317
                                                    Relative line nunber ^^^^
```

```
      SUBROUTINE REATXT0( NNIC,   RADCHN, IDMTRL, NUCNAM,                 9513
                                                    Absolute line nunber ^^^^
      IF (CMD .NE. 'RADIONUCLIDE_DATA')  GO TO 100                        122
      IF (CMD .EQ. 'EOF') GO TO 500                                       129
      IF (CMD(1:5) .EQ .'CHAIN') THEN                                     131
      IF (CMD .EQ. 'SAVE') THEN                                           162
      IF (CMD .EQ. '<TABLE_INPUTS') THEN                                  182
        IF (CMD .EQ. 'END_TABLES>') GO TO 110                             188
      IF (CMD(1:1) .EQ. '*') THEN                                         237
          IF (CMD .EQ.   'AWT') THEN                                      254
          IF (CMD .EQ.   'HALFS') THEN                                    261
          IF (CMD .EQ.   'ACTCNV') THEN                                   268
          IF (CMD .EQ.   'EPAREL') THEN                                   275
          IF (CMD .EQ.   'INVEN') THEN                                    282
                                                    Relative line nunber ^^^^
```

```
      SUBROUTINE SCATXT0( IWASFLG, NAMELB, KOMAT,  OUTMAT, IDMTRL,        11038
                                                  Absolute line nunber ^^^^
      IF (CMD .NE. 'RADIONUCLIDE_DATA') GO TO 100                          133
      IF (CMD .EQ. 'EOF')    GO TO 900                                     139
      IF (CMD(1:5).EQ.'CHAIN') THEN                                        144
        IF (CMD(1:4).EQ.'SAVE')THEN                                        177
      IF (CMD(1:6) .EQ. 'INV_AR') THEN                                     203
      IF (CMD(1:6) .EQ. 'RHW_AR') THEN                                     221
      IF (CMD(1:3) .EQ. 'WUF') THEN                                        239
      IF (CMD(1:7) .EQ. 'OUT_MAT') THEN                                    257
      IF (CMD(1:6) .EQ. 'RADWAS') THEN                                     295
          IF (CMD(1:3) .EQ. 'CON' .OR.                                     301
     &        CMD(1:2) .EQ. 'CH')      THEN                                 ^
          IF (CMD(1:3) .EQ. 'REM' .OR.                                     306
     &        CMD(1:2) .EQ. 'RH')      THEN                                 ^
          IF (CMD(1:3) .EQ. 'INE') THEN                                    311
      IF (CMD(1:8) .EQ .'REP_NAME') THEN                                   325
      IF (CMD(1:8) .EQ .'REP_GEOL') THEN                                   346
      IF (CMD(1:6) .EQ .'DISPOS') THEN                                     365
      IF (CMD(1:4) .EQ .'PACK') THEN                                       385
      IF (CMD .EQ. '<TABLE_INPUTS') THEN                                   405
        IF (CMD .EQ. 'END_TABLES>') GO TO 120                              413
        IF (CMD(1:1) .EQ. '*') THEN                                        415
                                                  Relative line nunber ^^^^
```

Strucure of where how TXT1 file is read in:

```
      SUBROUTINE REATXT1( IASPRP,  NAMELB,  NMATPR, XMATPR, TINT,         10016
                                                  Absolute line nunber ^^^^
      IF (CMD .EQ. 'EOF') GO TO 666                                        108
      IF (CMD .EQ. 'UNITS') THEN                                           113
          IF (CMD .EQ. 'SECONDS')THEN                                      119
      IF (CMD .EQ. 'TINTR') THEN                                           135
      IF (CMD .EQ. 'DIAMMOD') THEN                                         165
      IF (CMD .EQ. 'TCLOUT') THEN                                          194
      IF (CMD .EQ. 'PARTDIA') THEN                                         222
      IF (CMD .EQ. 'CEMENT') THEN                                          250
      IF (CMD .EQ. 'FGE') THEN                                             278
      IF (CMD .EQ. 'FSE') THEN                                             306
      IF (CMD .EQ. 'FCE') THEN                                             334
      IF (CMD .EQ. 'POROSITY') THEN                                        362
      IF (CMD .EQ. 'PRESSURE') THEN                                        390
      IF (CMD .EQ. 'SATBRIN') THEN                                         418
                                                  Relative line nunber ^^^^
```

```
      SUBROUTINE SCATXT1( IWASFLG, IASPRP, XMATPR, NAMELB, NMATPR,        11604
                                                  Absolute line nunber ^^^^
      IF (CMD .EQ. 'EOF') GO TO 90                                         115
      IF (CMD(1:5) .EQ. 'NHITS') THEN                                      117
      IF (CMD .EQ. 'EOF') GO TO 999                                        162
      IF (CMD(1:5) .EQ. 'TINTR') THEN                                      165
      IF (CMD .EQ. 'DIAMMOD') THEN                                         194
```

```
IF (CMD .EQ. 'TCLOUT') THEN                                    223
IF (CMD .EQ. 'PARTDIA') THEN                                   252
IF (CMD .EQ. 'DNSFLUID') THEN                                  281
IF (CMD .EQ. 'DOMEGA') THEN                                    307
IF (CMD .EQ. 'ABSROUGH') THEN                                  334
IF (CMD .EQ. 'TAUFAIL') THEN                                   361
IF (CMD .EQ. 'VISCO') THEN                                     388
IF (CMD .EQ. 'YLDSTRSS') THEN                                  415
IF (CMD(1:5) .EQ. 'INTR_' .AND. BRAGCDB) THEN                  442
    IF (CMD .EQ. 'NO_GRDVOL') THEN                             477
IF (CMD .EQ. 'DIABRAG') THEN                                   509
IF (CMD .EQ. 'GRIDVOL') THEN                                   530
IF (CMD .EQ. 'PORO_NM') THEN                                   551
IF (CMD .EQ. 'PRGS_NM') THEN                                   572
IF (CMD .EQ. 'PRBR_NM') THEN                                   593
IF (CMD .EQ. 'SATG_NM') THEN                                   614
IF (CMD .EQ. 'POROSITY') THEN                                  635
IF (CMD .EQ. 'PRESS') THEN                                     668
IF (CMD .EQ. 'SATBRIN') THEN                                   697
                                        Relative line nunber ^^^^
```

END OF APPENDIX L

APPENDIX M: QA REVIEW FORMS

As a convenience to users, this section contains a complete history of all the Quality-Assurance Review Forms issued during the review of this User's Manual. Review forms are issued after the User's Manual has been completed and reviewed. Thus, they will be appended to the manual after it has been paginated and therefore they may not, themselves, be paginated.

END OF APPENDIX M

END OF THE CUTTINGS_S USER'S MANUAL

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix D&D

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Conceptual Decontamination and Decommissioning Plan for the Waste Isolation Pilot Plant

DOE/WIPP-95-2072

Conceptual Decontamination and Decommissioning Plan for the Waste Isolation Pilot Plant

January 1995

Prepared for

United States Department of Energy

Westinghouse Electric Corporation
Waste Isolation Division

NOTICE

The Conceptual Decontamination and Decommissioning Plan (D&D) was developed as a concept for progressing from the final actions of the Disposal Phase, through the Decontamination and Decommissioning Phase, and into the initiation of the Long-Term Monitoring Phase. This plan was written in a manner that coincides with many of the requirements specified in DOE Order 5820.2A, Radioactive Waste Management; ASTM E1167 87, Standard Guide for Radiation Protection Program for Decommissioning Operations; and other documents listed in Attachment 3 of the D&D Plan. However, this conceptual plan does not meet all of the requirements necessary for a Decontamination and Decommissioning plan necessary for submission to the U.S. Congress in accordance with the Land Withdrawal Act (P.L. 102-579). A complete D&D plan that will meet the requirements of all of these documents and of the Land Withdrawal Act will be prepared and submitted to Congress by October 1997.

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1.0 Site Decontamination and Decommissioning Plan

This plan serves to describe the objectives of decommissioning for the Waste Isolation Pilot Plant (WIPP), identifies the elements necessary to accomplish the decommissioning, and defines the steps to execute those elements in a safe and environmentally sound manner.

This document is not intended to delineate the requirements necessary for Resource Conservation and Recovery Act (RCRA) closure. Where this document interfaces with those requirements, there will be guidance that directs the reader to Chapter I of the RCRA Part B Permit Application.

The Waste Isolation Pilot Plant Land Withdrawal Act of 1992 (LWA), PL 102-579, Section 13(a) requires that within 5 years after the date of the enactment of the act (enacted October 30, 1992), the Secretary of Energy (herein called the Secretary) shall submit to the Congress, the State of New Mexico, the Secretary of the Interior, and the Administrator of the EPA, a plan for the decommissioning of WIPP. In addition to activities required under the Agreement (July 1, 1981, Agreement for Consultation and Cooperation, between the State of New Mexico and the U. S. Department of Energy, as amended), the plan shall conform to the disposal regulations that apply to WIPP at the time the plan is prepared, and the Secretary of Energy shall consult with the Secretary of the Interior and the State in the preparation of such plan.

The plan provides a strategy for progressing from the final actions of the Disposal Phase, through the Decontamination and Decommissioning Phase, and into the initiation of the Long-Term Monitoring Phase.

This plan describes a sequence of events for **decontamination** of the WIPP facilities and structures used to manage and contain TRU and TRU mixed waste during the receipt and emplacement operations. Alternative methods of decontamination are provided where practical. The methods for packaging and disposal of the waste generated (derived waste) during this process are discussed. The best available technology at the time of this plan's development, may become outmoded by future technology and alternative strategies . If alternative technologies are identified the affected stakeholder(s), the Secretary of the Interior and the State will be consulted prior to implementation.

Dismantling of the WIPP major structures will be detailed in specifications separate from this plan for each structure.

The disposal of uncontaminated equipment and residue is delineated in Sections 1.6.9, and 1.6.11. Radioactively contaminated and mixed wastes that meet the waste acceptance criteria for decontamination and decommissioning (DD-WAC) will be emplaced into the last Hazardous Waste Management Unit (HWMU) open in the underground. At the WIPP, HWMUs are designated as the combination of waste disposal rooms and connecting drifts that form a panel. Each panel is an HWMU. Equipment, structures, materials, and components will be decontaminated whenever

possible. Residues that meet the definition of "construction and demolition debris,"("'Construction and demolition debris' means materials generally considered to be not water soluble and nonhazardous in nature, but not limited to, steel, glass, brick, concrete asphalt roofing materials, pipe, gypsum wallboard and lumber from the construction or destruction of a structure project, and includes rocks, soil, tree remains, trees and other vegetative matter that normally results from land clearing. If construction and demolition debris is mixed with any other types of solid waste, it loses its classification as construction and demolition debris. Construction and demolition debris does not include asbestos or liquids including but not limited to waste paints, solvents, sealers, adhesives or potentially hazardous materials." SWMR-4, Section 105, Paragraph T) that are free of contamination may be disposed in a Construction Landfill. Mined salt remaining after closure and berm construction will be disposed under Sections 2 and 3 of the Minerals Act of 1947.

Other activities necessary to return the site to as near its original condition as possible are defined in Section 1.6.19.

Generally, stakeholder involvement in the decontamination and decommissioning activities, as well as socioeconomic impacts to the local communities, counties, and state will be provided in the appropriate National Environmental Policy Act (NEPA) *documentation for decommissioning.*

1.1 Facility Description

1.1.1 Background

The U. S. Department of Energy (DOE) was authorized by the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980, Public Law 96-164 (U. S. Congress, 1980) to develop a facility for demonstrating the safe disposal of transuranic (TRU) radioactive wastes generated as the result of national defense activities. This facility, known as the Waste Isolation Pilot Plant, has been constructed in southeastern, New Mexico, 26 miles east of the City of Carlsbad. The site encompasses 10,240 acres in a sparsely populated area. Land use in the area surrounding the WIPP land withdrawal area includes livestock grazing, potash mining, and oil and gas production.

The enactment of Public Law 96-164 authorized the continuation of the phased development of the WIPP. Phased development began with a siting phase during which several sites were evaluated and a preferred site was selected based upon the geological and hydrological factors. During this phase, the host rock and the depth of the facility were selected considering geologic, hydrologic, geochemical and rock-mechanics properties. In the next phase, the site and preliminary design validation phase, two shafts were constructed; an underground testing area was excavated; and geologic, hydrologic, and geotechnical investigations were continued to gain further information on the site's characteristics. Also during this phase, methods for assessing long-term performance were evaluated and advanced. The construction phase followed during which the WIPP facility was constructed, additional data about the site

were collected, and the tools needed for assessing performance were developed and refined. Surface structures were built and additional underground areas were excavated for further experimentation. At the conclusion of the construction phase, the DOE proposed to proceed into a test phase that would include testing with TRU waste.

In October 1992 Congress transferred jurisdiction of the land from the Secretary of the Department of the Interior to the Secretary of the DOE and reserved the land for use by the DOE for the WIPP Program. The LWA also provided additional authorization to continue the activities initiated by Public Law 96-164. The LWA requirements focus on the test phase and the criteria for certification of compliance with the long-term disposal regulations developed by EPA. In late 1993 the DOE announced that the WIPP would not conduct radioactive tests in the WIPP underground. While testing with radioactive waste will not be conducted at the WIPP, many requirements such as development of certification criteria by the EPA, and other requirements necessary to begin disposal are still applicable and are covered in several other documents.

1.1.2 General Plant Description

The waste will be disposed in Hazardous Waste Management Units (HWMU) located 2150 feet below the surface of the WIPP site in bedded salt. The facility capacity is limited to 6.2 million ft^3 of contact handled (CH) and remote handled (RH) TRU wastes many of which are also contaminated with hazardous waste. The RH waste is currently planned to be emplaced in the ribs of the excavated rooms and the CH waste is to be stacked in the excavated rooms.

As each HWMU is filled, the access drifts will be closed to prevent access by personnel and to decrease the potential for release of contaminants. The last HWMU will have space available for acceptance of decontamination waste generated (derived waste) during the execution of this plan.

Descriptions of topography, soils, geology, demography, meteorology, radiological and hazardous materials characteristics, radionuclide inventory, and environmental characteristics are available in the Draft Waste Isolation Pilot Plant Project Technical Baseline for Regulatory Compliance (Reference 54).

1.1.3 Structures

All structures will require removal of office furnishings, telephone service, site computer network, plumbing fixtures and piping, HVAC, electrical service, structure and foundation. Several structures will require the removal of compressed air, large equipment, fluid lines, etc. Removal specifications will be developed for each structure.

The Hot Cell in the RH portion of the Waste Handling Building may remain as part of the permanent marker system. Modifications to the structure may be required if it is determined that it will remain as an artifact. Such modifications will require engineering development.

Temporary Structures

For each temporary structure that exists at the time of decontamination and decommissioning, action requests will initiate work orders with specific instructions for all preliminary work. The actual removal and preparatory activities for removal may be performed by a subcontractor.

Following is a list of the temporary structures at the WIPP site:

906 - U/G OPERATIONS TRAILER
907 - TRANS & HAZ. MATL. HANDLING TRAILER
908A - ENVIRONMENTAL MONITORING LAB TRAILER
908B - UNIVERSITY CONSORTIUM TRAILER
909 - PROJECT CONTROL TRAILER
910 - ENVIRONMENTAL MONITORING TRAILER
911A - SITE LOCKSMITH TRAILER
911B - SANDIA M101 TRAILER
911C - SANDIA OFFICES TRAILER
911E - SANDIA TRAILER
911F - SANDIA B49 AND B49 ANNEX
911G - SANDIA LABS TRAILER
912 - TRAINING TRAILER
915 - NEW MEXICO ENVIRONMENTAL DEPT. TRAILER
916 - SANDIA OFFICES TRAILER
917 - AIS MONITORING
918 - VOC TRAILER
918A - VOC AIR MON. STATION
918B - VOC LAB TRAILER
950 - WORK CONTROL TRAILER
951 - PROCUREMENT/PURCHASING
952 - TRAILER (7-PLEX)
971 - OPERATIONS TRAILER
982 - MAINTENANCE TRAILER
985 - QA TRAILER
986 - PUBL. & PROC. TRAILER
988 - OPERATIONS TRAILER
991 - SANDIA OFFICES TRAILER
992 - SANDIA CAL. LAB TR.
993 - SANDIA OFFICES TRAILER
994 - SANDIA LAB TRAILER
995 - SANDIA QA RECORDS TRLR.

NOTE: This list (current as of 12/94 from the WIPP Site Facility Master Plan (Reference 2)) will be updated as needed.

Permanent Structures

Based upon the results of the Site Radiological Characterization Survey removal specifications or individual D&D plans will be developed for each of the following permanent structures:

PORT-A-CAMP
252 - SPS UTILITY SUBSTATION
253 - 13.8 KV SWITCHGEAR 25P-SWG15/1
254.1- AREA SUB NO. 1 25P-SW15.1
254.2- AREA SUB NO. 2 25P-SW15.2
254.3- AREA SUB NO. 3 25P-SW15.3
254.4- AREA SUB NO. 4 25P-SW15.4
254.5- AREA SUB NO. 5 25P-SW15.5
254.6- AREA SUB NO. 6 25P-SW15.6
254.7- AREA SUB NO. 7 25P-SW15.7
255.1- EMERGENCY GEN. #1 25-PE 503
255.2- EMERGENCY GEN. #2 25-PE 504
311 - WASTE SHAFT
351 - EXHAUST SHAFT
361 - AIR INTAKE SHAFT
362 - AIS/HOIST HOUSE
363 - AIS/WINCH HOUSE
364 - EFFLUENT MON. INSTR. SHED "A"
365 - EFFLUENT MON. INSTR. SHED "B"
366 - AIS HEADFRAME
371 - SALT HANDLING SHAFT
372 - SALT HANDLING SHAFT HEADFRAME
384 - SALT HANDLING SHAFT HOISTHOUSE
384A - LAMPHOUSE
411 - WASTE HANDLING BLDG. CH & RH
412 - TRUPACT MAINT. BLDG.
413 - EXHAUST SHAFT FILTER BLDG.
413A - MONITORING STATION "A"
413B - MONITORING STATION "B"
414 - WATER CHILLER FACILITY & BLDG.
451 - SUPPORT BLDG
452 - SAFETY & EMERG. SERVICES FAC.
453 - WAREHOUSE/SHOPS BLDG.
454 - VEHICLE SERVICE BLDG.
455 - AUXILIARY WAREHOUSE
456 - WATER PUMPHOUSE
457N - WATER TANKS 25-D-001A
457S - WATER TANKS 25-D-001B
458 - GUARD AND SECURITY BLDG.
459 - CORE STORAGE BLDG.
459A - SANDIA ANNEX
463 - COMPRESSOR BLDG.
465 - AUXILIARY AIR INTAKE
468 - TELEPHONE HUT
471 - NW ATMOS. MONITORING STATION
472 - INSTRUMENT BLDG.
473 - ARMORY BLDG.
474 - HAZARDOUS WASTE STORAGE FACILITY
474A - HAZARDOUS WASTE STORAGE BLDG
474B - HAZARDOUS WASTE STORAGE BLDG
474C - OIL & GREASE STORAGE BLDG.
474D - GAS BOTTLE STORAGE BLDG.
474E - HAZARD MATERIAL STORAGE BLDG.
474F - WASTE OIL RETAINER
475 - GATEHOUSE
480 - VEHICLE FUEL STATION
482 - EXH. SHAFT HOIST EQUIP. WAREHOUSE
485 - SULLAIR COMPRESSOR BLDG.
486 - ENGINEERING BLDG.
489 - TRAINING BLDG.
816 - SANDIA TEST WELL
ELECT. SWITCHBOARDS, SUBSTATIONS, AND SWITCHRACKS
ENVIRONMENTAL MONITORING SITES
FIRE MAIN RING HEADER
LANDFILLS
MICROWAVE TOWER
PIPELINE
POWERLINE
ROADS (Paved & Unpaved)
SANDIA GENERATOR NO. 1
SANDIA GENERATOR NO. 2
SEWAGE LAGOON & PIPING
SALT PILE
SNL UNDERGROUND ROOMS
UNDERGROUND STORAGE TANKS (fuel)
WELL PADS
WID UNDERGROUND FACILITIES

NOTE: This list (current as of 12/94 from the WIPP Site Facility Master Plan (Reference 2)) will be updated as needed.

1.1.4 Plant Structures Description

The WIPP is divided into three basic groups of structures; surface structures, shafts, and underground structures.

The WIPP facility surface structures accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of waste from the surface to the underground. The surface structures (excluding Port-a-camp, various storage areas, microwave tower, sewage treatment system, wells, pipeline, power line, access roads, environmental monitoring stations, landfills, Building 471 [Northwest Atmospheric Monitoring Station], Building. 472 [Instrument Building.] and roadbeds) are located in an area of approximately 35 acres within a perimeter security fence.

The primary surface operations at the WIPP facility are conducted in the Waste Handling Building (WHB), which is divided into several separate waste management areas. These areas include, the CH TRU waste handling area, the RH TRU waste handling area, the transuranic package transporter (TRUPACT-II) maintenance facility, and support areas.

The CH TRU waste handling area includes an outdoor truck loading and offloading area, a shielded storage room, an inventory and preparation area, and an overpack and repair room.

The RH TRU waste handling area includes: a shipping and receiving area; a shielded cell for shipping cask unloading, waste canister inspection, overpacking canisters, as required; a canister transfer cell; and facility cask loading.

The TRUPACT-II maintenance facility is a radiologically clean dedicated area, adjacent to the CH TRU waste side of the WHB. Decontamination of a TRUPACT-II, if required, would be accomplished in the CH TRU waste side of the WHB.

Other areas within the WHB include: a site-derived waste area; heating, ventilation, and air conditioning (HVAC) equipment area; and mechanical equipment areas.

The site-derived waste area, located in the WHB, is provided for the handling of waste produced on the site as a result of decontamination operations. Waste water collection from fire main activation in the CH TRU side of the WHB will collect in a sump located in the site-derived waste room. Waste water from fire main actuation in any area with potential contamination (radioactive and/or hazardous) will be reacted to under the Hazardous Materials Spill Response section of the Emergency Services Program Plan (Reference 77).

The WIPP surface structures include the Exhaust Filter Building, Engineering Building, Training Building, Support Building, Safety and Emergency Services Facility, Warehouse buildings, Guard and Security Building, Vehicle Service Building, a sewage treatment plant, underground fuel storage tanks (USTs), and other auxiliary buildings.

The Exhaust Filter Building contains banks of high efficiency particulate air (HEPA) filters that will be used to filter contaminated air from the underground in the unlikely event of a release. The underground ventilation system fans are located outside, adjacent to this building.

The Support Building provides office space, change rooms, and houses the Central Monitoring Room (CMR) and its supporting equipment.

The WIPP is accessible by both road and railway. Access to the site is from U.S. Highway 62/180, about 13 miles to the north, and from Highway 128, four miles to the south. Rail access is provided by a rail line connecting with a spur of the Atchison, Topeka, & Santa Fe railroad six miles southwest of the site.

WIPP has four vertical shafts that extend from the surface to the underground horizon. These are: the Waste Shaft, the Salt Handling (SH) Shaft, the Exhaust Shaft (ES), and the Air Intake Shaft (AIS).

The SH shaft is steel lined to the top of the salt formation (about 850 feet below the surface) and the other shafts are lined with concrete to the top of the salt formation.

The Waste Shaft is located between the CH TRU and RH TRU areas in the WHB. It is nominally 19 feet in diameter and is serviced by a hoist utilizing a hoist cage that is primarily used for transportation of CH TRU and RH TRU wastes from the surface to the underground storage areas. This shaft is also used to transport personnel, materials and supplies, and large equipment.

The SH Shaft is located beneath the salt handling headframe. It is nominally 10 feet in diameter and has a combined mancage/bottom dump salt handling skip. This shaft provides the only means of removing mined materials from the underground. It serves as the secondary ventilation supply shaft for the underground areas. The SH shaft is a route for power, control, monitoring and communication cables. Personnel can also be transported in this shaft.

Salt from the underground mining operations is brought to the surface via the Salt Shaft and stored in the salt pile north of the surface facilities.

The exhaust shaft is located adjacent to the Exhaust Filter Building. It is nominally 14 feet in diameter and serves as the exhaust air duct for the underground areas.

The underground ventilation system consists of five centrifugal exhaust fans, two parallel HEPA filter assemblies, isolation dampers, filter bypass, and associated ductwork. The two main exhaust fans provide unfiltered flow of up to 425,000 cubic feet per minute for normal underground operations. Three filtration fans can each provide 60,000 cubic feet per minute during filtration mode or reduced ventilation mode. Continuous Air Monitors (CAMs) are installed to detect airborne radioactive contaminants in the waste disposal area, the Waste Shaft and station, and in the discharge to the surface discharge stack. One alarm from the Station A Effluent

Sampling System or an alarm received from two like CAMs (two alphas or two beta/gammas) will cause automatic activation of the HEPA filtration system.

The AIS is located to the west of the warehouse. It has three diameters (18 feet concrete lined, 16 feet 7 inches concrete lined and 20 feet 3 inches unlined salt section) and is the primary supply of fresh air underground.

The underground structures are located on the storage horizon and consist of the waste storage area, the experimental area, the mining area, and the waste shaft station.

The waste storage area has four main entries, a number of crosscuts connect the main entries. The layout of the shafts and entries permits mining and storage operations to proceed simultaneously. New hazardous waste management panels will be mined as the preceding panel is filled with waste.

Each waste storage panel will consist of seven rooms. Each room is nominally 33 feet wide by 300 feet long by 13 feet high. The storage rooms are separated by salt pillars 100 feet wide by 300 feet long. The first 200 feet of each panel is 20 feet wide and 13 feet high to facilitate the closure of each panel. After the initial 200 feet the panel is widened out to 33 feet.

The waste shaft station located at the lower end of the waste shaft provides access for personnel and equipment to handle the waste.

Workshop and warehouse facilities are located at the storage horizon. Shops consist of a repair bay, a welding bay, a lubrication bay, an electrical shop, several parking areas, and a warehouse. Offices, electrical substations, and lunch rooms are also located at the storage horizon.

The experimental area of the mine used for experiments using simulated wastes and for geotechnical evaluations consists of several rooms and pillars that are used to perform rock mechanics tests, waste package and waste form experiments, and brine migration tests. In part, tests provided information used in room and pillar design of the waste storage area and support Performance Assessment activities/validation.

1.2 Description of Operating History

1.2.1 Initial Construction and Permitting

Development of the WIPP facility began with a siting phase (in 1973), during which several sites were evaluated and the present site was selected on the basis of extensive geotechnical research, supplemented by surface-based testing. Based upon the geologic properties of the selected site, the repository was designed and safety analyses were prepared. Subsequent research expanded the understanding of the geologic, hydrologic, geochemical, and rock-mechanics properties of the host rock and surrounding strata at the site. The siting phase ended with the publication of a Final

Environmental Impact Statement (FEIS) (Reference 20) in 1980 and associated Record of Decision (ROD), which evaluated alternatives for the safe, long-term isolation of TRU waste at the WIPP facility.

The construction phase followed, authorized by Public Law 96-164 (Reference 38) during which surface structures for receiving waste were built and underground excavations were completed for one panel of rooms designed for permanent waste emplacement. The DOE and the State of New Mexico entered into a Consultation and Cooperation Agreement (Reference 43) to affirm the intent to give consideration for concerns and cooperation in the resolution of those concerns. The end of the construction phase was marked by a decision by the DOE Energy Systems Acquisition Advisory Board (ESAAB), after all prerequisites for ending construction were met and documented (in 1991). These documents used the data collected since 1980 to evaluate the potential short-term and long-term impacts of the WIPP facility. In 1992 the Final Safety Analysis Report (FSAR) (Reference 49) was published.

At the conclusion of the construction phase, the DOE proposed to proceed into a test phase that would include testing with TRU and TRU mixed waste at the WIPP facility. Although the DOE has made the decision not to conduct underground tests with radioactive wastes in the WIPP facility, information regarding a compliance demonstration has not changed and this experimental data is being collected at the Idaho National Engineering Laboratory.

Upon a successful demonstration of compliance with applicable federal and state laws and regulations, and once the certification and approval requirements of the LWA are met, the WIPP facility will proceed through three other distinct phases: a disposal phase, a decommissioning phase, and a post-decommissioning phase. The disposal phase, projected to last 25 years, will consist of receiving, handling, and emplacing TRU and TRU-mixed waste in the repository for disposal. Additional scientific studies may continue during the disposal phase. The disposal phase will end when a decision is made to terminate further disposal activities or the repository has reached its capacity.

The decommissioning phase will follow the disposal phase. During the decommissioning phase the facility will be decontaminated and prepared for permanent closure. Closure of the HWMUs will be performed in accordance with the direction of Chapter I of the RCRA Part B Permit application. Surface facilities will be decontaminated and decommissioned, underground excavations will be closed, and shaft seals will be emplaced. This phase is projected to last eight years, with six years estimated for the RCRA closure portion.

The post-decommissioning phase will include the implementation of active and passive institutional controls. Active institutional controls may include activities such as long-term site access control and post-closure monitoring. Such controls will be implemented consistent with applicable regulations and permit conditions. Passive institutional controls will include notification devices such as permanent markers designed to reduce the likelihood of human intrusion, archival storage of WIPP

information off-site, and large earthen structures marking the repository footprint on the surface. The concept for permanently marking the WIPP, as required by Title 40 CFR 191.14(c), is described by a draft report listed in Attachment 3 (Reference 37).

1.2.2 Disposal Phase Operating History

As of this revision to the Conceptual Decontamination and Decommissioning Plan there is no disposal phase operating history.

1.3 Program Objectives

1.3.1 Decommissioning Objective

The main objective of decommissioning the WIPP site is to return the site to as close to the pre-construction condition, as reasonably possible, while protecting human health, the environment, and to meet NEPA and WIPP Land Withdrawal Act commitments.

1.3.2 Alternative Strategy

The decommissioning alternatives rejected in the Final Environmental Impact Statement included mothballing and in-place entombment.

These alternatives allowed for decommissioning the plant under the following credible situations:

- Decommissioning after the repository has been filled. The preferred methods would be in-place entombment of unusable underground structures, decontamination (as required), and dismantling of the surface structures.

- Decommissioning before the repository is filled, leaving open the possibility of later returning to fill it. Mothballing of the surface structures would be the preferred method for this situation. Due to creep closure the underground areas would require mining to obtain a safe work environment.

The present plan calls for decontaminating (as required) and dismantling surface facilities, entombing in the waste-disposal area all wastes generated in dismantling the surface facilities if they meet DD-WAC, close the remaining mine, and sealing the shafts and boreholes. Any wastes that do not meet the DD-WAC will be transported to an approved and permitted off-site facility.

Mothballing would consist of putting the plant into a state of protective storage for a few decades. This alternative would be selected if later repository operation or experiments were desired. It would require the eventual use of another alternative for the permanent decommissioning of the plant. The plant would be left generally intact except that all areas with hazardous levels of radiation would be isolated from the

public by suitable barriers and other means. Useful equipment could be decontaminated, if necessary, and removed from the site. Adequate radiation monitoring, environmental surveillance, and security procedures would be established to protect the health and safety of the public. The shafts and underground facilities would be left intact. This alternative was rejected.

Entombment applies mainly to the shafts and mine. Entombment of the surface facilities would be similar to mothballing except that the radioactive materials would be removed and placed in the mine or removed from the site. After the removal of usable equipment (and decontamination, if necessary), the vacated mine would be closed, and the shafts and boreholes would be sealed. In this alternative the mine and shafts would be permanently sealed; the surface facilities, however, would be available for some other use in the future. This alternative was rejected.

Decontamination and dismantling would involve the surface facilities, with the shaft and mine entombed as described above. Usable equipment would be decontaminated and removed; contaminated equipment and waste would be packaged and either placed in the mine or removed from the site if mine disposal were not feasible. Surface facilities would be demolished and debris removed or buried in the Construction and Demolition landfill. As nearly as possible, the surface would be returned to its original condition.

1.3.3 Cleanup Criteria

Criteria for the mixed waste decontamination is defined in 40 CFR 264, Subpart G—Closure and Post-Closure; WIPP RCRA Part B Permit Application, DOE/WIPP 91-005, Chapter I—Closure Plans, Postclosure Plans, and Financial Requirements, 20 New Mexico Administrative Code (NMAC) 4.1 Subpart V, Subparts G, I, and X, and DOE Order 5820.2A, Radioactive Waste Management.

Because of the type of waste management activities that will occur at the WIPP facility, waste residues that may be encountered during the operation of the facility and at closure may include waste generated as a result of the management of the waste containers (derived waste including rags and rubber gloves), waste generated as part of the closure activities (such as wipes used to sample the containers and equipment for potential radioactive contamination, solidified decontamination solutions, stabilized concrete dust from scabbler operations, equipment designed for disposal, contaminated salt that is excavated because of decontamination activities, etc.), and residues generated as a result of spill cleanup (rags, gloves, hazardous materials). All of the above wastes generated (derived wastes) during the operation and closure of the WIPP facility will be identified and managed as TRU mixed wastes.

Criteria for the radiological portion of the mixed waste decontamination is defined in DOE Order 5820.2A (Reference 22).

On the basis of "co-detection of hazardous and radioactive releases," decontamination will be considered complete for RCRA constituents when radiological decontamination has been accomplished. Radiological decontamination will be to less than or equal to:

	Loose	Fixed plus Removable
α	20 (dpm/100 cm^2)	500 (dpm/100 cm^2)
β-γ	200 (dpm/100 cm^2)	1000 (dpm/100 cm^2)

All surveys for contamination at the WIPP facility are based on the concept of co-detection. Co-detection is used to describe the detection of releases from containers by virtue of detection of radioactive contamination. Co-detection applies to all releases except the release of VOCs from TRU mixed waste containers. It provides the WIPP facility with a very sensitive method of detecting the release of non-VOC hazardous TRU constituents through the use of surface sampling (swipes) and radioactivity counting.

Decontaminated materials and equipment must be sampled in accordance with applicable procedures to assure that there are no RCRA constituents beyond the levels authorized for release. Items that are found to exceed the limits will be properly packaged and transferred to an appropriate treatment storage and disposal facility.

1.4 Program Management and Administration

1.4.1 Organization

A graphic representation of the management and operating contractor decontamination and decommissioning management organization is presented as Attachment 2.

1.4.2 Responsibilities

Decommissioning Project Manager - provides overall management of the decontamination and decommissioning effort. As the facility converts from the operational phase to the decommissioning phase, overall responsibility for the project management will shift to this individual.

Engineering Manager - provides engineering support for all D&D activities. Provides management oversight for licensing and regulatory compliance activities.

Construction Manager - provides control of maintenance activities, decommissioning utilities, structure removal, and shaft seal installation.

Operations Manager - provides management of radiological and chemical decontamination activities, mine closure process, facility operations, health physics, and environmental monitoring operations.

Administrative Manager - provides control of the budget and schedule, directs procurement activities, manages human resources, and manages training.

Safety/Security Manager - provides the overall safety oversight of the D&D activities. Provides for the physical security of the WIPP site.

QA Manager - identifies, develops and defines quality requirements applicable for the D&D process. Consults with line management in interpreting and implementing quality program elements, and provides performance-based independent assessment of quality affecting activities.

1.4.3 Decommissioning Project Team

The Decommissioning Project Team consists of the Department of Energy and the management and operating contractor.

1.4.4 Decommissioning Manpower

Decontamination and decommissioning process manpower will be developed from the WIPP workforce. As the operational phase is completed, personnel without proper job skills will be cross-trained for the new positions being created by the decommissioning phase. This process will reduce the need for layoffs, and provide a knowledgeable and experienced workforce.

1.4.5 Worker Health and Safety Training

Worker training for health and safety will be conducted in accordance with 29 CFR 1910.1200 and other applicable regulations. The basic training will be accomplished through the general employee training course administered to all new employees and with annual refresher training for all employees.

For further information on training policies refer to the current procedures listed in Attachment 3 of this plan (References 3, 83-85).

Personnel will continue to qualify and maintain qualification on the systems and equipment that they will operate.

1.4.6 Use, Control, and Management of Subcontractors

Current procurement policies and procedures for subcontractor interface are listed in Attachment 3 of this plan (References 65, 85-87).

1.5 Program Schedule and Cost

1.5.1 Major Milestone Schedule - Narrative

A schedule of the D&D process is included in this document as Attachment 1.

Acquire permits and approvals for D&D activities.

Removal of equipment and closure of the underground experimental areas may commence as soon as the area is no longer required.

As personnel downsizing takes place, temporary surface structures will become empty, and removal may commence.

Removal of temporary surface structures will be initiated prior to the projected emplacement of the last shipment of waste.

A site radioactivity characterization study will be performed to determine what areas of the site will require decontamination, to facilitate selection of an appropriate decontamination and decommissioning strategy, and after the decommissioning, demonstrate that the residual radioactive and/or hazardous materials satisfy criteria for unrestricted release.

Excess underground equipment will be decontaminated if required, moved to the surface, and disposed of in accordance with applicable federal property management regulations (41 CFR 101).

When economically feasible all usable equipment and materials will be decontaminated and removed from the site. Surface facilities will be decontaminated as required.

Contaminated structural debris, equipment, and decontamination wastes that meet the DD-WAC, will be packaged and placed in the mine in the last panel. Decontamination will be performed using technologies that do not add materials which would cause the derived waste to violate the DD-WAC. Liquids and fine particulate would require stabilization prior to disposal in the mine. Perform closure of the last HWMU in the same manner as the other panels. As the mine is closed the equipment will back out and be removed.

Shafts will be sealed in accordance with acceptable techniques.

Each Solid Waste Management Unit (SWMU) will be closed in accordance with all applicable regulations and requirements when it is no longer required.

Dismantling of surface facilities will commence upon vacancy and completion of radiological survey and, if required, decontamination.

Uncontaminated debris and unusable equipment will either be shipped away from the site for disposal or disposed of in the construction and demolition landfill.

Decommission the sewage system and the NPDES storm water evaporation basins. Close all SWMUs.

Excess salt will be disposed of per the Minerals Act of 1947.

Electrical power, telephone lines, water, railroad spurs, and roads will be removed, as required (electrical power, RR spurs and roads should remain to the degree necessary to support future construction of the Permanent Marker System and Permanent Marker testing).

The surface will be regraded to approximately its original contours.

Markers will be provided consistent with the approved passive control strategy.

Monitoring and active control will be established.

Unneeded environmental monitoring stations will be removed.

The underground storage tanks used for the storage of fuels will be removed in accordance with applicable regulations.

A final decommissioning report will be developed.

1.5.2 Cost Estimate - Narrative

A cost estimate will be developed for these activities for the Decontamination and Decommissioning Plan required by the Land Withdrawal Act. A conceptual cost estimate is available from the Waste Isolation Division Long-Term Regulatory Compliance group.

1.6 Decommissioning Activities

1.6.1 Plant Radiological Characterization

Extensive radiological contamination surveys of all areas of the WIPP site will be performed. The results of these surveys will provide the basis for selection of technology for decontamination and decommissioning of the WIPP facilities. Along with the historical records of surveys performed during the operational life of the facility, the contamination surveys will provide evidence for release of structures, equipment, and components.

Radiological Survey and Sampling Program

The radiological survey and sampling program will be accomplished using current procedures listed in Attachment 3 of this plan (Reference 74).

1.6.2 Physical Inventory

A complete inventory of all site facilities, equipment, and assets is to be performed so that disposition requirements may be determined prior to the items becoming excess. This inventory is standard practice for every major facility change.

Facility Physical Inventory

This inventory can be accomplished utilizing the WIPP Site Facility Master Plan (Reference 2). This is a controlled drawing, which coupled with outstanding Engineering Change Orders provides a complete listing of the site facilities.

Site Physical Inventory

Property Management maintains a database of all site equipment valued at $1000 or more, all real property regardless of value, and sensitive items valued at $200 and above. This database includes information such as the Manufacturer's nomenclature and model/serial number(s), the date the equipment was put into service, purchase order number and depreciable life, etc.

1.6.3 Facility and Site Preparation

Individual specifications will be developed for each structure prior to removal. These specifications will include a statement of work, as-built drawings, construction specifications, disposition of materials, required worker training and qualifications, etc. Specific instructions can be found in current WIPP procedures listed in Attachment 3 of this plan (References 86, 87).

Temporary Structures

Temporary structures such as the trailers used for offices will be prepared for disposal following vacancy and radiological clearance. Utilities (power, telephone, water, sewage, computer network, alarms, etc.) will be removed by site personnel. Office equipment and furniture removal may be contracted. The removal of skirting, reinstallation of axles, and towing may be performed under contract.

Laydown Areas

Laydown areas will be designated for radiologically contaminated materials, hazardous waste, solid waste, and scrapped or salvaged equipment/materials. These areas should be located centrally to where the majority of work is to be performed. Hazardous waste will be collected, accumulated, and disposed in accordance with applicable regulations.

Support Services

- Power will be maintained from the SPS feed east of the site. No conversion to construction power will be necessary to perform structure removal.

- Telephone service will continue through the telephone hut until the size of the site makes it no longer economical to maintain the hut, at which time the GTE telephone service will be transferred to individual feeds.

- Water is supplied by the Double Eagle Water Line, owned by the City of Carlsbad, through their wells located approximately 30 miles north of the WIPP. Water is supplied by gravity flow through a 24-inch diameter pipeline to a junction point about 13 miles north of the site at U. S. Highway 62/180. This line is sized to provide 6000 gal/min for use by

others in addition to the peak flow rate required by the WIPP facility. Controls at the junction point give the WIPP facility priority over flows to all other users. A 10-inch diameter pipeline supplies 375 gal/min water flow from the tie in point to the WIPP facility by gravity flow.

The water supply to the site will continue until such time that the domestic and fire water requirements no longer exist. At that time the pipeline will be capped. Ownership of the waterline will be transferred to the City of Carlsbad. The portion of the pipeline that the City does not want, will be decommissioned and removed.

- Refuse removal will continue with contractor support until the facility is taken into the post-decommissioning long-term monitoring phase.

- Sewage treatment is currently performed in a series of settling treatment and evaporation ponds south of the site. When the number of personnel has decreased enough that the need for these ponds is no longer necessary, and may be supplanted by portable facilities, the ponds will be closed in accordance with applicable regulations.

1.6.4 Decontamination

The "Start Clean - Stay Clean" operating philosophy of the WIPP site will decrease the need for decontamination during the Decommissioning phase. However, the need for decontamination technology may arise.

Chemical Cleaning

Detergents - no detergents are currently planned for use in decontamination activities.

Solvents

Water in limited quantities (e.g. dampened rags) - is the primary solvent used for decontamination

Windex® - may be used on a limited basis

Radiacwash® - may be used only if water, Windex®, etc. are not effective in reducing contamination to acceptable release levels.

Nonchemical Decontamination

Polyvinyl Alcohol - is used to remove radiological contamination from smooth surfaces such as the waste handling building floor. The residue from this process is a solid plastic contaminated with radioactive material and hazardous waste. The residue of the Polyvinyl Alcohol may be disposed of in the underground as a mixed waste.

Sandblasting - this method of decontamination would create large quantities of contaminated waste for disposal and is not recommended.

Grinding - this method would create a smaller quantity of contaminated waste than sandblasting, and might be used in limited applications.

High-Pressure Water Spray - this method could create large volumes of water that would need to be treated or stabilized before disposal and is not recommended.

Scabbler Pistons and Needle Scalers - this method utilizes pneumatically operated reciprocating scabbler pistons and needle scalers to remove up to 3/16 inch of the concrete surface which is filtered and stored in the vacuum system prior to solidification and disposal.

Ice-blast Technology - uses compressed air and ice chips to remove loose or fixed plus removable radioactive contamination, with only 24 gallons of waste water per hour of operation.

Dry Ice Blasting - on impact, dry ice pellets sublimate from their solid state into gas, leaving only the removed contaminant for disposal. The process is practically non-abrasive on all surfaces, inert and non-conductive.

Partial Removal of Components

Partial removal of components will be performed when it is radiologically safe to remove a section of pipe, ventilation ducting, bracket, etc., when the larger component is not contaminated, and when the removal of a portion of the whole will significantly reduce the volume to be emplaced in the last panel.

Cost/Benefit Analysis

A cost/benefit analysis will be necessary for evaluation of the decontamination options in the event that the need for this technology arises. It is, however, too early as of this writing to make an estimate of the necessity for decontamination technology beyond that currently available at the WIPP site.

1.6.5 Rigging of Heavy Components

The Department of Energy Hoisting and Rigging Manual, DOE/ID-10500 (Reference 20), will be utilized in all hoisting and rigging operations conducted at the WIPP site during decommissioning. The manual quotes verbatim or paraphrases the requirements of the Occupational Safety and Health Administration and the American National Standards Institute. It was developed to encompass, under one cover, hoisting and rigging requirements, codes, standards, and regulations. In doing so, it eliminates the need to maintain extensive (and often incomplete) libraries of hoisting and rigging standards throughout the DOE.

1.6.6 Liquid Radwaste Processing

Present Capacity and Capability

There is currently no large scale capability for liquid radwaste processing at the WIPP facility. Depending on the type of decontamination equipment selected and the quantity of waste liquid created by that equipment, a decision will have to be made at a later date for this system's specifications.

Small quantities of liquid radwaste can be solidified using Aquaset® or an equivalent grade absorbent material.

Services to be Added

No new services are anticipated. Due to the small quantities of liquid waste that is anticipated during the decontamination and decommissioning of the WIPP, no additional equipment is deemed necessary at this time. If quantities should be greater than currently anticipated, then the following technologies may be utilized.

- Mobile Evaporators
- Demineralizers
- Mobile Solidification System

1.6.7 Solid Radwaste Handling, Packaging and Emplacement

Containers

Waste containers for emplacement in the WIPP shall be noncombustible and meet all applicable requirements of 49 CFR §173.412 for Type A packaging. Waste containers of various sizes, shown to meet Department of Transportation Type A requirements by methods detailed in DOE Evaluation Document for DOT 7A Type A Packaging, DOE/DP/00058-H1;MLM 3245 are acceptable at the WIPP.

Packaging

Waste packaging is included in the information for containers in the above subsection.

Emplacement

Decommissioning waste will be emplaced in the underground, utilizing approved waste handling operations procedures, in the last HWMU prior to closure of the unit. Containers that are not the standard waste box or 55-gallon drums, will require separate procedures to ensure that the containers are loaded into the panel in a safe and coordinated manner.

Interim Storage/Staging

No areas within the facility are being permitted as interim storage areas. Satellite accumulation area regulations will apply. See 40 CFR 262.34 for limitations on quantities, time, and methodology for accumulation of hazardous waste at the decommissioning site. Waste containers with radioactive mixed waste will remain at the location of decontamination effort until the container is filled or the decontamination at that location is completed. As decontamination progresses beyond the surface, the waste containers will be directly emplaced in the panel. Once a container of waste is filled, it will be moved to the storage area and emplaced in a prompt manner.

1.6.8 Nonradioactive Hazardous Waste Handling and Disposal

The handling and disposal of nonradioactive hazardous waste will be performed in accordance with applicable regulations and approved WIPP hazardous waste management procedures. There are approved procedures in place at this time (References 46, 55, 57).

Waste Packaging Process

Current WIPP procedures listed in Attachment 3 of this plan delineate the responsibilities and handling requirements for site generated nonradioactive hazardous waste at the WIPP (References 46, 55, 57). The waste packaging process is designed to protect human health and the environment from negative effects of hazardous waste by ensuring that hazardous waste is properly handled, accumulated, and transported to an approved off-site treatment/storage/disposal facility in accordance with all applicable local, state and federal regulations, DOE Orders and WID policies and procedures.

Transportation

Current WIPP procedures as listed in Attachment 3 of this plan delineate the responsibilities and requirements that provide for the shipment of nonradioactive hazardous materials by the Waste Isolation Division (WID) from the WIPP, in compliance with the DOE requirement for management of materials transportation as specified in DOE Order 1540.1A, and applicable laws and regulations related to the shipment of hazardous materials (References 21, 55).

Instructions for the on site transportation of hazardous material, hazardous waste and non-RCRA regulated material are provided in current WIPP procedures listed in Attachment 3 of this plan (Reference 57).

1.6.9 Solid Waste Handling and Disposal

Guidelines for the operation of the construction and demolition landfill in a manner which is protective of human health and the environment and ensures compliance with applicable local and state laws and regulations are contained in current WIPP procedures listed in Attachment 3 of this plan (Reference 56).

Identification of Laydown Areas

The primary laydown area for solid waste (other than construction landfill debris) will be designated on the asphalt pad southeast of the Waste Handling Building. Construction and demolition debris will be moved directly to the construction landfill.

Traffic Management of Waste Site

No scavenging will be allowed at the waste site. Prior to loading of vehicles for transport to the landfill, the waste will be characterized by process knowledge or sampling to not contain any hazardous wastes.

Local Registered Sanitary Landfill Site

The registered sanitary landfill site utilized by the WIPP site is currently located near Hobbs, NM. The landfill is not currently permitted, but will have a permit hearing in January 1995, permit submittal in June 1995, and approval is expected eighteen months following submittal.

Compaction

There is currently no requirement for compaction of the solid waste.

1.6.10 Removal of Radioactive Equipment

All equipment will be checked for the presence of radioactive contamination. If radioactive contamination is detected, the contaminated equipment will be assumed to be contaminated with the hazardous waste constituents of the waste in the containers that the equipment contacted. Contaminated equipment will be decontaminated to the clean limits specified in Section 1.3.3 of this document or placed in containers and managed as derived TRU mixed waste.

Isolation of System and Cutting of Pipe

The WIPP does not have piping systems that will carry radioactive materials. The closest approximation would be possible contamination of the air handling ductwork in the waste handling building. In the event that the site radioactive characterization or a routine survey detects contamination in any of the ductwork, specific work instructions will be developed for the decontamination and removal of that ductwork. Those instructions will be based on the level and extent of contamination found, using standard industry practices.

Exhaust Filter Building and HEPA Filters

The Exhaust Filter Building (EFB) and HEPA Filters associated with the EFB must be operable during underground ventilation. Emplacement of contaminated EFB HEPA filters requires underground ventilation.

Procedures will be developed to ensure that the following steps will be performed:

a. Underground operation will be halted

b. the EFB HEPA filters will be removed

c. If the EFB HEPA filters are contaminated beyond acceptable criteria, they will be packaged for emplacement in the underground

d. A radiological survey will be performed on the EFB and associated equipment

e. Decontamination will be performed on all EFB equipment that is contaminated

f. HEPA filters will be installed

g. The EFB ventilation systems will be tested to meet surveillance requirements

h. Underground operations will recommence

Performance of these steps will decrease the potential for TRU or TRU mixed waste being generated during the decommissioning of the EFB. In the unlikely event that there is radiologically contaminated waste generated during the EFB decommissioning, it may be designated as low level radioactive waste and shipped to a licensed disposal facility.

Sampling and Characterization

Radioactivity - Methods for assuring that equipment is not contaminated and ready for free release are listed in Attachment 3 of this plan (Reference 78).

Equipment decontaminated will require a verification survey before release for disposition.

Size/Volume Reduction

There is currently no requirement for size/volume reduction. However, the WIPP has an active waste minimization and pollution prevention plan which applies both size and volume reduction where possible. This technology will be considered during decommissioning and utilized if technically and economically feasible, or necessary for emplacement of this waste into the last HWMU.

Removal and Packaging

Removal of radioactive equipment will be performed under strict health physics control following the procedures specified in documents listed in Attachment 3 of this plan, and approved work instructions (Reference 74).

The waste will be packaged in approved containers as specified in Section 1.6.8 of this plan.

Emplacement

Decontamination wastes will be emplaced in the last HWMU as derived mixed waste.

1.6.11 Removal of Nonradioactive Equipment

Isolation of System and Cutting of Pipe

System isolation and pipe cutting is marginally applicable to the WIPP facilities. Separate work instructions will be developed for the removal of closed systems using standard industry practices.

Verification of Noncontaminated Condition

All systems external to the Waste Handling and Storage areas will have been declared clean to the limits specified in Section 1.3.3 of this document during the site radiological characterization survey. Systems within those areas will require health physics surveys prior to removal. All systems that contained or may have contained hazardous materials will require sampling and possible flushing prior to removal.

Removal and Packaging

Removal of nonradioactive equipment will be performed following approved work instructions which will be developed by Work Control.

Holding Area

Location - The asphalt pad southeast of the waste handling building will be designated as the primary holding area for nonradioactive equipment.

Traffic Management - Equipment awaiting disposition will be segregated from access by non-authorized personnel.

Disposition

Retired - Nonradioactive equipment that is not scrap or salvage will be placed on the excess property list.

Disposal - Nonradioactive equipment that cannot be retired will be dispositioned as scrap or salvage.

1.6.12 Removal of Power and Control Systems

Circuits will be de-energized and removed as equipment and facilities are made available for disconnect. The diesel generators will be maintained until all vital loads are removed. After all site loads are removed, the utility will be notified to remove their site feed.

Removal of the uninterruptable power supplies (UPS) will present no additional problems. All batteries will be removed and excessed.

Operations Interface

Close coordination between the operations and construction managers will be required to assure that necessary circuits for the remaining facility are maintained as the circuits are removed.

Switch-over to Construction Power

Primary power will be utilized until all its electrical systems are completely removed. Construction power is not required during the decommissioning of the site.

Disposition

Where economically feasible based upon the criteria of cost, condition, etc. electrical equipment will be retired or declared excess as appropriate.

1.6.13 Removal of Contaminated Surfaces

Potentially Contaminated Areas

Walls, Floors, and Structures - Surfaces that will be potentially contaminated are in the Waste Handling Building CH Bay, Overpack and Repair Room, RH Bay, Cask Unloading Room, Hot Cell, Cask Transfer Shuttle car, Shaft Access, Waste Handling Building Ventilation system, and Exhaust Filter Building.

Shafts and Drifts - The Waste Handling Shaft, Exhaust Shaft, exhaust drift, and the underground drift from the Waste Station to the waste panel are areas of potential contamination. The Exhaust Shaft and the E-300 drift from S-1600 to S-400 have the potential for contamination if an emplaced container is breached.

The waste packages are surveyed prior to downloading, and therefore the potential for waste shaft contamination is limited to waste conveyance accident scenarios, which are deemed incredible events. The Waste Shaft will be a part of the site radiological characterization survey, but it is not anticipated that any decontamination will be required in the shaft. All shafts and drifts will be surveyed for the site radiological survey, but it is anticipated that the need for decontamination, if any, will be confined to the access drifts from the waste station to the entrance to the final panel.

Removal Controls

Decontamination will commence at the areas farthest from the waste shaft and proceed to the shaft access, and recommence from the shaft waste station south to the last panel. The minimum volume of material should be removed to control the storage volume needed in the underground.

Removal Methods

Applicable methods of contamination removal are listed in Section 1.6.4.

1.6.14 Closure of Last Hazardous Waste Management Unit

Closure Survey

A radiological closure survey will be performed in accordance with approved procedures. RCRA closure will be performed in accordance with the specifics defined in Chapter I of the RCRA Part B Permit Application.

1.6.15 Closure of Mine Underground

Equipment Removal

Equipment and materials will be removed from the mine to the extent practicable.

Electrical Systems - Electrical systems will be removed as the closure progresses out of the mine.

Mining Equipment - As the mining equipment is no longer needed it will be removed through the waste handling shaft. Some pieces of the equipment may require disassembly or cutting to fit into the shaft.

Support Equipment - Support equipment such as golf carts, ambulance, fire truck, portable offices, etc. will be removed from the mine and dispositioned as they become excess.

1.6.16 Shaft Sealing and Plugging

Shafts will be plugged in accordance with acceptable sealing techniques.

Shaft Seals - An essential task during the decommissioning of the waste repository will be sealing the remaining holes and shafts. Shaft seal design alternatives have been studied for several years. A reference design is available.

1.6.17 Demolition and Removal of Structures

Criteria

All site structures with the possible exception of the Hot Cell portion of the Waste Handling Building are to be removed during the decommissioning. The Hot Cell in the RH portion of the Waste Handling Building may remain as part of the permanent marker system. Criteria for free release of structures is delineated in Section 1.3.3 of this document.

Removal of Contamination

Appropriate techniques will be applied for the conditions of the contamination including quantity of contaminant, location, worker health and safety, fixed or loose, surface to be decontaminated, etc.

Removal Techniques

Applicable methods of contamination removal are listed in Section 1.6.4.

Verification of Noncontaminated Status

Structures that were shown noncontaminated by the site radiological and hazardous constituent characterization and historical records may be removed when there is no further use for them. Structures that indicated radiological contamination, will require a verification survey after decontamination. Those structures that are then shown clean will be removed as the schedule permits.

Disposition

Transferred - Structures will be declared excess in accordance with applicable Federal and DOE Property Management Regulations.

1.6.18 Final Radiological Survey and Hazardous Constituent Analyses

The final radiological survey and hazardous constituent analyses will encompass the entire WIPP site.

Sampling and Statistical Analysis

Approved procedures will be utilized to perform the final radiation survey and swipe or material sampling.

Environmental Monitoring

A final environmental monitoring survey will be performed to assure that the facility has not created any environmental hazards. Environmental monitoring will continue after decommissioning concurrent with long-term monitoring.

Survey Plan

Surveys will be performed in accordance with approved procedures.

Confirm Structures Meet Disposition Objectives

All structures with the possible exception of the Hot Cell portion of the Waste Handling Building will have been removed. The final radiological survey of the Hot Cell will verify meeting disposition objectives.

1.6.19 Restoration of Site

Decommissioning of Solid Waste Management Units

There are 13 discernable groups of SWMU at the WIPP site. The following table lists those groups and their descriptions. All SWMUs will be characterized and closed in accordance with applicable federal and state regulations. Recontoured sites will be reclaimed in accordance with the WIPP Land Management Plan.

SWMU No.	Unit Type	Unit Description	Waste Description
001 a - ab	Mud Pits	Approximately 46 decommissioned mud pits are located on 28 drill pads, which were used for settling drill cuttings out of the drilling fluids being used in drilling holes to support hydrologic testing and monitoring, potash evaluation, and drilling for hydrocarbons.	Sodium- and potassium chloride saturated brine; starch; bentonite gel; diesel fuel; drill cuttings; metal cuttings; grease; hydraulic fluid; motor oil.

002 a - d	Salt and Top Soil Storage Areas	A total of four areas ranging in size from 3 to 15 acres used for salt and topsoil storage.	Salt; topsoil; traces of hydraulic oil; motor oil; diesel fuel; and scrap steel.
003 a - b	Landfills	Two landfills used for disposal of construction debris.	Foundation excavation soils; concrete; scrap wood; and metal.
004 a - c	Storage Yards	Three yards used for storage of construction and maintenance materials, wastewater, and used oils or materials that can be reclaimed or recycled.	Water contaminated with motor oil, hydraulic oil, and diesel fuel; used hydraulic oil, motor oil, antifreeze, glycol-based oils, chemical grout; used lead acid batteries; scrap metal. Used hydrocarbons are collected in containers.
005 a - c	Concrete Batch Plants	Three areas used as temporary locations for concrete batch plants.	Concrete; trace amounts of motor oil and grease.
006* a - b	Holding Ponds	Two ponds used to hold brine drilling fluid from the drilling of the salt handling and waste handling shafts.	Saturated brine; bentonite; drill cuttings; hydraulic oil and grease.
007 a - c	Evaporation Ponds	Three ponds used for the evaporation of water.	Water; soap; nonhazardous cleaning solutions; oil; unsaturated salt brine.
008 a - r	Surface Satellite Accumulation Areas	Ten hazardous waste or used petroleum product satellite accumulation areas; two hazardous waste staging areas.	Nonradioactive, site-generated wastes, collected in containers including spent solvents, aerosol cans, oily rags, expired chemicals, and paint products.
009 a - l	Underground Satellite Accumulation Areas	Ten hazardous waste or used petroleum product satellite accumulation areas.	Nonradioactive, site-generated wastes, including spent solvents, aerosol cans, oily rags, used oils, spent lead acid batteries, grout, and cement. Hazardous waste and used petroleum products are collected in containers.

010 a - d	Shaft Sumps**	An area at the bottom of each of the four WIPP shafts that collected construction debris or accumulated brine.	Welding residue; scrap wood and metal; salt; Class C cement; chem-seal; bentonite; grease and oil; cement and chem grout; Rustler formation brine; washwater.
011 a - e	Sewage Treatment Facility	Five ponds used for WIPP sewage treatment.	Sanitary waste; neutralized film developer, and oil.
012	Nonhazardous Solid Waste Collections Bins	Twenty portable bins used for solid waste collection.	Nonhazardous solid waste including nonliquid sanitary waste and industrial waste.
013	TRU Mixed Waste Management Units	Areas where transuranic (TRU) mixed waste was managed during the Disposal Phase. Includes contact and remote handled TRU areas of the Waste Handling Building and Panels 1 through 8 in the underground. Waste will be in approved containers.	Radioactive mixed waste consisting of TRU waste that is co-contaminated by various listed solvents, or which contain characteristic waste consisting mostly of metals.

*Both holding ponds designated as 006a and 006b have been remediated.

** The AIS & ES terminate at the storage horizon, but are designated as sumps for the RCRA Part B Permit application.

Removal of Site Boundary Structures

Fences - Fences around the surface facilities will be removed and either retired or transferred. A fence line shall be established to control access to the repository footprint area (the waste disposal area projected to the land surface.) for the active controls after closure. A standard five-strand barbed wire cattle guard fence shall be erected along the perimeter of the repository surface footprint. The fence shall have gates placed approximately mid-way along each of the four sides.

Guardhouse - Structures will be declared excess in accordance with applicable federal and DOE property management regulations.

Grading

Following removal of all structures and surfaces, as well as buried piping, conduit, and wiring, the surface will be graded to near the original contour.

Revegetation

Following closure of the WIPP site, the area will be replanted in accordance with applicable regulations and agreements.

Facility and Site Closeout

A final inspection of the facility will be conducted to ensure that the area has been returned to as close as reasonably possible to the surrounding landscape. Monitoring for assurance that the vegetation and animal populations are returning to normal will be accomplished within the Post-Closure Monitoring Program.

1.6.20 Facility Release and Reporting

Certification of Unrestricted Level for Release

Certification of unrestricted level for release will involve the evidence of historical reports of surveys and the results of the site radiological characterization survey conducted at the start of the decontamination and decommissioning effort, and the final radiological survey and hazardous constituent analysis.

Release of Site and Structures

Individual structures will be released as excess property as they are found free of contamination, as specified in Section 1.6.4 of this plan, and there is no further use for them at the site.

Final Program Report

A final program report will be issued for the decontamination and decommissioning program to summarize the decommissioning process and the steps taken to obtain closure status.

1.7 Facility Modification

1.7.1 Material Staging/Storage Facility

Laydown, staging, and storage areas will be designated for use during the decommissioning process. These areas will require the same level of survey and cleanup as the other portions of the site for free release and closeout.

It is anticipated that a staging area will be required for oils and ethylene glycol waste. There is an anticipated 1500 gallons of waste ethylene glycol with 3000 gallons of flush water waste. Drum storage or a roll-off tank (preferred method), will be required for the ethylene glycol waste. All ethylene glycol will be surveyed and sampled. Once a determination is made that the material is not radiologically contaminated, all ethylene glycol will be sent off-site to be recycled.

1.7.2 Liquid Treatment Facility

There is currently no requirement for a liquid treatment facility at the WIPP. However, all liquid site derived wastes will be solidified per current WIPP procedures and disposed of in the repository.

1.8 Waste Management

1.8.1 Radioactive Materials

Types

All radioactive waste generated will be designated as "derived" waste. The waste will not contain any constituents that would prevent it from meeting the DD-WAC, and will be emplaced in the last HWMU.

Quantities

The quantities of radioactive mixed waste that will be emplaced into the last HWMU at decommissioning of the WIPP facility is expected to be low due to the "start-clean, stay-clean" operating philosophy. All contamination events during the life of the facility will be controlled and cleaned immediately.

Dose Rates

To meet the criteria for contact handled waste, the dose rates must not exceed 200 millirem per hour (mrem/hr).

1.8.2 Hazardous Wastes

Types

The WIPP facility controls the types and amounts of hazardous materials that are brought onto the site. Polychlorinated biphenyls and asbestos are excluded from use on the site. This process reduces the potential for hazardous wastes to be generated during D&D.

Quantities

The quantities of hazardous waste that will be generated during decommissioning of the WIPP facility is expected to be low due to the "start-clean, stay-clean" operating philosophy. All contamination events during the life of the facility will be controlled and cleaned before further work may continue in the area.

Disposition

Hazardous materials will be characterized and dispositioned utilizing the current WIPP procedures listed in Attachment 3 of this plan (References 33, 46, 51, 52, 55).

Packaging - Packaging will meet all applicable requirements.

On Site Storage - Nonradioactive hazardous materials will be stored in satellite waste accumulation areas, and transferred to the staging area in accordance with procedures listed in Attachment 3 of this plan.

Transportation - Nonradioactive hazardous materials will be shipped in accordance with procedures listed in Attachment 3 of this plan.

Disposal - Nonradioactive hazardous materials disposal will be at a permitted treatment, storage, or disposal facility.

1.9 Licensing and Regulatory Issues

1.9.1 Regulatory Compliance

Because of the stringent requirements for managing radioactive materials, the closure of the WIPP facility will require longer than the 180 days allowed in the regulations. Therefore, an extension to the 180 days must be requested for the closure in the permit application. If, for some unforeseen reason, closure cannot be completed within the time(s) specified, the DOE will request an extension to the closure time. This request will be submitted to the NMED in writing, at least 30 days before the expiration of the time allowed in the closure plan, and will describe the reason the extension is needed and estimate the amount of additional time needed to complete the closure. During the extended closure period, the DOE will continue to demonstrate compliance with applicable permit requirements and that all steps will be taken to prevent threats to human health and the environment as a result of TRU mixed waste management at the WIPP facility.

No later than the submission of the certification of closure of each hazardous waste disposal unit, the owner or operator must submit to the local zoning authority, or the authority with jurisdiction over local land use, and to the Regional Administrator, a survey plat indicating the location and dimensions of hazardous waste disposal units with respect to permanently surveyed benchmarks. This plat must be prepared and certified by a professional land surveyor. The plat filed with the local zoning authority,

or the authority with jurisdiction over local land use, must contain a note, prominently displayed, which states the owner's or operator's obligation to restrict disturbance of the hazardous waste disposal unit in accordance with the applicable regulations.

The Final Safety Analysis Report will require modification to meet the requirements of the Consultation and Cooperation agreement between the State of New Mexico and the U. S. Department of Energy.

A WIPP specific closure and post closure NEPA document will be developed prior to initiating the final closure phase.

1.9.2 Permit Modifications

Current Facility Status

The facility is currently awaiting authorization to receive TRU mixed waste for disposal.

Permit modifications may be necessary for decommissioning. Direction on this subject can be found in 40 CFR 270.41, 270.42, and 270.43.

40 CFR §270.41 Modification or Revocation and Reissuance of Permits, §270.42 Permit Modification at the request of the Permittee, and §270.43 Termination of Permits, are detailed in the Code of Federal Regulations.

Revisions to the FSAR will be required to incorporate the D&D changes in work scope, direction, organization, etc.

Development of an appropriate NEPA document, possibly a supplemental environmental impact statement will be necessary to address environmental changes resulting from substantial changes in the WIPP mission.

Prevention of Criticality

Adherence to the waste acceptance criteria for waste received at the site and for derived waste will assure that criticality is not an issue during the decontamination and decommissioning phase.

Release Prevention

Maintenance of the negative pressure in the waste handling areas and adherence to the applicable procedures will prevent the release of contaminants.

Decommissioning Activities Safety Analysis

DOE Order 5480.21, Unreviewed Safety Questions, Section 10, Program Requirements, requires that a contractor authorized to operate DOE nuclear facilities shall perform safety evaluations for all changes in facility and procedures as described

in the existing safety analyses and tests or experiments not described in the existing safety analyses.

Decommissioning is described in the Final Safety Analysis Report (FSAR), and this plan does not change the facility or procedures beyond that described in the FSAR.

The need for a decommissioning activities safety analysis will be evaluated prior to initiation of the decontamination and decommissioning plan. If a safety analysis is required for decommissioning activities, it will be documented through the FSAR update.

Changes to Operational Safety Requirements (OSR)

Decommissioning of WIPP is not expected to require a change in operational safety requirements. The requirements will need to be individually inactivated (as an unresolved safety question) as each of those systems covered by the OSRs are removed from service.

1.9.3 Residual Radioactivity

Post-Decommissioning Radiation Survey Program

Following decontamination (which will ensure the removal of waste residues at background levels) and decommissioning of the WIPP site, there will be no need for a radiation survey program. This may change in the final version of the Post-Closure Monitoring Plan.

Certification Requirements

Certification of post-decommissioning radiation levels will be provided in the post-closure notification to the State of New Mexico.

1.10 Records Disposition

Quality records generated during the decommissioning process will be identified on the decontamination and decommissioning section records inventory and disposition schedule. Following review of the records by cognizant personnel the records will be transmitted to Project Record Services.

A copy of records of waste disposal locations and quantities specified under 40 CFR §264.73(b)(2) will be submitted to the regional administrator and local land authority within 60 days of closure of the facility.

2.0 Supporting Documents

These documents are required to support the overall decommissioning program. This section provides a brief overview of the documents and document control numbers. Several of these documents will also address the requirements of the long-term protection plan for acceptable cleanup levels, sampling and analysis plans, and QA/QC specifications.

The documents listed below that are designated as "currently in place" are reviewed and updated periodically to ensure correctness with the current facility configuration and operational status.

2.1 Detailed Implementation Plan

A detailed implementation plan is not credible at this time for the completion of the decommissioning of the Waste Isolation Pilot Plant. Processes that are in current use and will be utilized for decontamination and decommissioning are detailed in procedures that are currently in place. New systems that are procured for the decontamination and/or decommissioning will require separate process specific procedures for operation. Prior to final waste emplacement a detailed implementation plan will be developed.

2.2 Engineering Plan

Procedures are currently in place which will direct engineering activities during the decommissioning process and are listed in Attachment 3 of this plan (References 58-70).

2.3 Cost, Schedule, and Financing Plan

Procedures are currently in place for financial aspects of decommissioning and are listed in Attachment 3 of this plan (References 86, 87).

At this date cost and schedule estimates are of little true value in predicting the actual numbers and timelines for 28 years in the future. A conceptual cost estimate is available from the Waste Isolation Division Long-Term Regulatory Compliance Group. A cost, schedule, and budget will be developed prior to final waste emplacement.

2.4 Solid Waste Management Unit Closure Plan

A plan will be developed for closure of the solid waste management units. The plan will be developed to accomplish the closures of the separate SWMUs in accordance with applicable regulations.

2.5 Health and Safety Plan

Procedures are currently in place to ensure the health and safety of workers and the public. These procedures are listed in Attachment 3 of this plan (Reference 72).

2.6 Quality Assurance Plan

Procedures are currently in place in to meet the requirements of DOE Order 5700.6C. These procedures are listed in Attachment 3 of this plan (Reference 82).

10 CFR 830.120 is implemented through DOE Order 5700.6C.

2.7 Emergency Plan

Emergency procedures are currently in place. These procedures are listed in Attachment 3 of this plan (Reference 76).

2.8 Environmental Report/NEPA Documentation

Procedures are currently in place for environmental reporting and NEPA documentation and are listed in Attachment 3 of this plan (References 47, 48, 50).

2.9 Radiological Protection Plan

Policies are currently in place for assuring that worker exposures to radiological and chemical hazards are kept low. These policies are listed in Attachment 3 of this plan (References 72, 73, 81).

2.10 Physical Security Plan

Procedures are currently in place for physical security. These Procedures are listed in Attachment 3 of this plan (Reference 71).

2.11 Environmental Monitoring Plan

Procedures are currently in place for environmental monitoring and are listed in Attachment 3 of this plan (References 44, 45, 52, 53).

2.12 Supplemental Environmental Impact Statement

Development of a Supplemental Environmental Impact Statement will be necessary to address environmental issues resulting from substantial changes in the WIPP mission.

Attachment 1 Schedule

23JUL20*	07JUN23	REMOVE TEMPORARY STRUCTURES
23JUN22	07JUN23	UPDATE SITE D & D PLAN
	08JUN23	FINAL WASTE EMPLACEMENT
08JUN23	04DEC23	SITE RADIATION CHARACTERIZATION
08JUN23	03JUN24	SURFACE DECONTAMINATION
08JUN23	03JUN24	REMOVE BUILDINGS 450, 450A, 453, 454, 455
04JUN24	28AUG24	UNDERGROUND DECONTAMINATION
04JUN24	22NOV27	DECOMMISSION WHB
04JUN24	28MAY25	REMOVE BUILDING 412
29AUG24	24FEB25	HWMU 510 CLOSURE
29AUG24	22FEB27	DECOMMISSION UNDERGROUND
25FEB25	23FEB26	REMOVE BUILDING 413
31MAR25*	24SEP26	CLOSE WASTE STORAGE AREA
29MAY25	27MAY26	REMOVE BUILDING 459
25MAR25*	20SEP27	SEAL EXHAUST SHAFT
26SEP25*	23MAR28	SEAL WASTE SHAFT
30JUN27*	27JUN28	REMOVE BUILDING 449
24MAR26*	18SEP28	SEAL AIS
27DEC27*	25JUN29	REMOVE BUILDING 451
26SEP26*	22MAR29	SEAL IH SHAFT
28JUN29	21JUN30	REMOVE BUILDING 489
24JUN30	20JUN31	REMOVE BUILDINGS 486 AND 452
20SEP30*	17OCT30	REMOVE SITE BOUNDARY FENCE

DECOMMISSIONING & DECONTAMINATION

Attachment 2 Decontamination and Decommissioning Management

Decontamination and Decommissioning Management

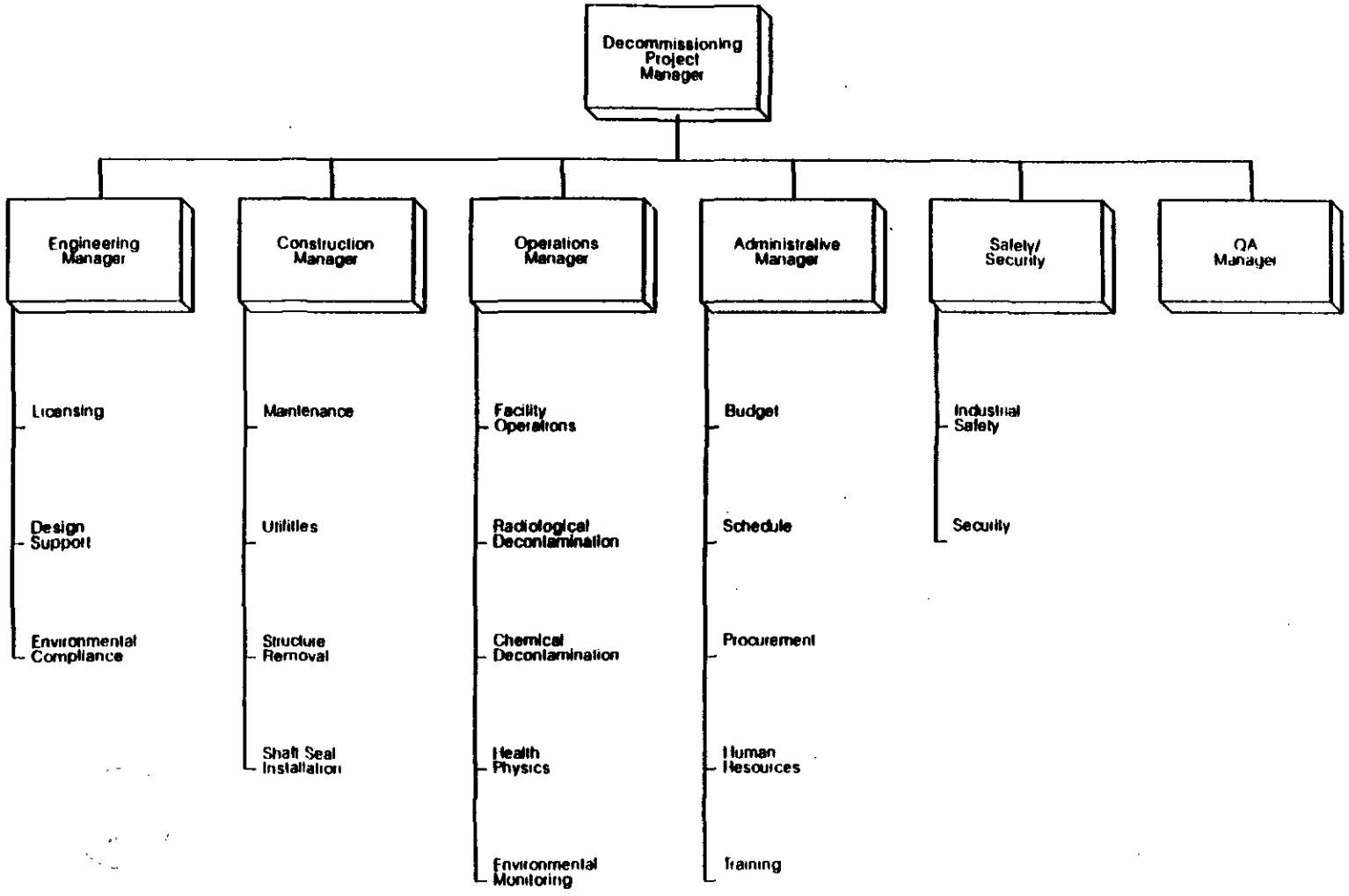

Attachment 3 References

1. 10 CFR 830.120, Quality Assurance requirements
2. 24-C-022-W, WIPP Site Facility Master Plan
3. 29 CFR 1910.1200, Hazard Communication
4. 40 CFR 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes
5. 40 CFR 194, Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes
6. 40 CFR 261, Identification and Listing of Hazardous Waste
7. 40 CFR 264, Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities
8. 40 CFR 268, Land Disposal Restrictions
9. 40 CFR 270, EPA Administered Permit Programs: The Hazardous Waste Permit Program
10. 40 CFR 280, Underground Storage Tanks
11. 41 CFR 101, Federal Property Management Regulations
12. 41 CFR 109, Department of Energy Property Management Regulations
13. 49 CFR 100 THROUGH 199, Research and Special Programs Administration, Department of Transportation
14. ANSI/ANS-15.10-1981, American National Standard for Decommissioning of Research Reactors
15. ASTM E1167 87, Standard guide for Radiation Protection Program for Decommissioning Operations
16. ASTM E1278 88, Standard Guide for Radioactive Pathway Methodology for Release of Sites Following Decommissioning
17. ASTM E1281-89, Standard Guide for Nuclear Facility Decommissioning Plans
18. CAO QAPD (Quality Assurance Program Description)
19. DOE/EIS-0026, Final Environmental Impact Statement
20. DOE/ID-10500, Department of Energy Hoisting and Rigging Manual, April 1993, Assistant Secretary for Environment, Safety and Health, Washington, DC 20585
21. DOE Order 1540.1A, Materials Transportation and Traffic Management
22. DOE Order 5820.2A, Radioactive Waste Management
23. DOE Order 5820.2B, Draft (4/29/93) - Decontamination and Decommissioning of Radioactively Contaminated Facilities
24. DOE Order 5700.6C, Quality Assurance Program Implementation Guide
25. DOE/CAO-94-2003, WIPP Regulatory Compliance Strategy and Management Plan for Demonstrating Compliance to Long-Term Disposal Standards
26. DOE/WIPP 87-016, Draft Rev. 1, A Plan for the Implementation of Assurance Requirements in Compliance with 40 CFR 191.14 at the Waste Isolation Pilot Plant
27. DOE/WIPP 91-005, Waste Isolation Pilot Plant RCRA Part B Permit Application
28. DOE/WIPP 93-029, Waste Isolation Pilot Plant Repository Monitoring Program Strategic Plan

29. DOE/WIPP 94-024, Waste Isolation Pilot Plant 1994 Environmental Monitoring Plan
30. EIB/SWMR-4, *New Mexico Solid Waste Management Regulations*
31. General Plant Design Description (GPDD) Revision 0
32. HA:94:6528, Revision 2 to WIPP Active Controls after Closure Design Criteria, R. J. Rodriguez, 9/14/94
33. 20 New Mexico Administrative Code 4.1 Subpart V
34. IAEA Safety Series No. 105, The Regulatory Process for the Decommissioning of Nuclear Facilities
35. Minerals Act of 1947, (Act of July 31, 1947, 30 U.S.C. 602, 603.)
36. NUREG-0586, Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities
37. Permanent Marker Conceptual Design Report, Draft, Revision 2, November 1994
38. PL 96-164, Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980
39. PL 102-579, Waste Isolation Pilot Plant Land Withdrawal Act
40. Waste Isolation Pilot Plant Project Technical Baseline for Regulatory Compliance.
41. Radiological Environmental Surveillance Air Sampling and Analysis at the WIPP Site, Carter, M. W., May 26, 1994, Westinghouse, Waste Isolation Division, Carlsbad, NM
42. WIPP-DOE-069, Waste Acceptance Criteria for the Waste Isolation Pilot Plant
43. *Working Agreement for Consultation and Cooperation*, Rev. 1, Section N (DOE, 1981)
44. WP 02-14 WIPP National Pollutant Discharge Elimination System Storm Water Pollution Prevention Plan
45. WP 02-2, Environmental Compliance Assessment Program (ECAP) Plan
46. WP 02-601, Nonradioactive Hazardous Waste Management
47. WP 02-801, National Environmental Policy Act Compliance
48. WP 02-802, NEPA Evaluation, Tracking, and Monitoring
49. WP 02-9, WIPP Final Safety Analysis Report
50. WP 02-EC, National Environmental Policy Act Compliance Plan for the Waste Isolation Pilot Plant
51. WP02-EM1, WIPP Quality Assurance Project Plan for WIPP Site Effluent and Hazardous Materials Sampling
52. WP02-EM2, The WIPP Site Effluent and Hazardous Materials Sampling Plan
53. WP02-EM1001, Sewage System Discharge Monitoring and Compliance
54. WP 02-RC1, Draft Waste Isolation Pilot Plant Project Technical Baseline for Regulatory Compliance
55. WP 06-101, Shipping of Nonradioactive Hazardous Materials
56. WP 06-108, Construction Landfill Operation
57. WP 06-HM3108, Request for Disposal
58. WP 09, Engineering Conduct of Operations and Procedures Manual
59. WP 09-CN3022, Engineering Document Control and Distribution
60. WP 09-007, Engineering and Design Document Preparation and Change Control

61. WP 09-024, Configuration Management Board/Engineering Change Proposal (ECP)
62. WP 09-025, Engineering Data Transmittal/Design Input
63. WP 09-029, Cognizant Engineer Responsibilities
64. WP 09-031, Engineering Calculations
65. WP 09-033, Construction Labor Services
66. WP 09-034, Configuration Management Determination
67. WP 09-035, Site Development Planning and Project Authorization Process
68. WP 09-8, Specification Preparation Style Guide
69. WP 09-9, Configuration Management Plan
70. WP 09-CN3003, As Built Drawings: Process and Control
71. WP 11-7, WIPP Security Manual
72. WP 12-1, WIPP Safety Manual
73. WP 12-2, WIPP ALARA Manual
74. WP 12-5, WIPP Radiological Control Manual
75. WP 12-6, VOC Monitoring Plan
76. WP 12-9, WIPP Emergency Plan and Administrative Procedures Manual
77. WP 12-10, Emergency Services Program Plan
78. WP 12-HP, WIPP Operational Health Physics Procedures Manual
79. WP 12-HP1100, Monitoring and Surveys
80. WP 12-HP3200, Radioactive Material Control
81. WP 12-RE3000, Radiological Control Program
82. WP 13-1, WID Quality Assurance Program Description
83. WP 14-TR3402, WIPP Training Policies
84. WP 14-TR3501, General Employee Training
85. WP 14-TR3502, Training Requirements for Subcontractor Personnel
86. WP 15-6, Purchasing Policies and Procedures Manual
87. WP 15-605, Award and Administration of Construction Work

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix DEF

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Deformation

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ACRONYMS

AEC	Atomic Energy Commission
DOE	U.S. Department of Energy
EEG	Environmental Evaluation Group
ERDA	U.S. Energy Research and Development Administration
MB	marker bed
OD	outer diameter
ORNL	Oak Ridge National Laboratory
SHS	salt-handling shaft
SNL	Sandia National Laboratories
SPIV	Site and Preliminary Design Validation
TD	total depth
WIPP	Waste Isolation Pilot Plant

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APPENDIX DEF

DEF.1 Introduction

The Salado Formation in which the Waste Isolation Pilot Plant (WIPP) is located is an evaporite unit comprised primarily of halite and anhydrite interbeds. The Castile Formation which underlies the Salado is also comprised of halite and anhydrite interbeds. Above the Salado, the Rustler Formation includes halitic mudstones, carbonate units, and anhydrite beds. Two processes are of concern in the assessment of a site in this type of geological environment: the rheological properties of halite allow it to deform at lower stresses than other rock types, and the solubility of halite and other evaporite minerals can lead to dissolution. Because of these concerns, the U.S. Department of Energy (DOE) has undertaken a site characterization program to assess the extent of any deformation in the region of the WIPP, and to determine the potential for dissolution to affect the performance of the disposal system.

This document describes the structural features of the Castile (Section DEF.2), the extent of dissolution in the region around the WIPP (Section DEF.3), and identifies the boreholes in the vicinity of the WIPP that have penetrated the Salado (Section DEF.4).

DEF.2 Gravity-Driven Structure in The Castile

This section describes the structural features in the Castile Formation that are commonly attributed to gravity-driven deformation. To properly present this subject, the data will first be shown in a general historical overview, permitting the reader to understand the sequence of investigations. The known extent of deformation in the Castile, how these structures are likely to develop in the future, how well they can be predicted, and the potential impact of these structures on the WIPP will also be discussed. Apart from the general geological impact, the performance of the WIPP as it might be affected by such structures is not specifically assessed here.

DEF.2.1 Background Information

For a number of years, it has been known that parts of the Castile Formation are deformed. Cross-sections of the basin geology through its margins have shown some evidence of deformation. Jones et al. (1973) provided a map of the isopachs of part of the Castile that clearly show much thicker portions in some areas along the northwestern to northern Delaware Basin, just inside the margin of the Capitan Reef. Very little information had been collated concerning deformation within the Delaware Basin until studies were initiated of the Delaware Basin as a possible site for radioactive waste disposal. Jones et al. (1973) is probably the clearest early presentation of this information, though the dissertation by Snider (1966) and the paper by Anderson et al. (1972) also reflect thicker sections in some Castile units adjacent to the reef.

In 1975, Sandia National Laboratories (SNL) drilled a third borehole, called U.S. Energy Research and Development Administration (ERDA)-6, at a site (Figure DEF-1) that had been partially investigated by Oak Ridge National Laboratories (ORNL) during 1974. Two boreholes Atomic Energy Commission ((AEC)-7 and AEC-8) were drilled in 1974 by ORNL before SNL was assigned to carry out the task of investigating this site for radioactive waste disposal under programs that preceded WIPP. Formation boundaries and marker beds in ERDA-6 were structurally high compared to AEC-7 and 8, and the degree of deformation increased downward. At about 2,711-feet (826-meters) depth, ERDA-6 began to produce pressurized brine and gas. The hole was tested extensively to determine the nature and origin of the brine. Beds within the Castile were displaced structurally upward, apparently by hundreds of feet (Jones 1981; Anderson and Powers 1978), and some of the lower units may have actually pierced upper units (Anderson and Powers 1978). Because of the desire for structurally uncomplicated units to simplify mining for a repository, the site under investigation at ERDA-6 was abandoned in 1975, and in 1975-76 the current site was initially selected and investigations began (Powers et al. 1978). As part of the selection criteria, a zone about 6 miles (10 kilometers) wide inside the Capitan Reef was avoided because it included known deformed Castile and Salado (Griswold 1977). This is the first instance in which the site investigations were directly influenced by discovery of deformation in the Castile and lower Salado.

The present site for the WIPP was selected and initially investigated in 1976 to determine if the desired characteristics for the preliminary site selection were present (Griswold 1977; Powers et al.1978). As the general criteria appeared to be met during this phase, the site and surrounding areas were characterized much more extensively and intensively beginning in 1977. Extensive new seismic reflection data were collected in 1977 and 1978 that began to reveal the deformed Castile north of the center of the site (Figure DEF-1). Because the principal effect was that the good quality Castile reflectors from the area south of the site center were disturbed, the area to the north was dubbed the disturbed zone. It also became known as the area of anomalous seismic reflectors or zone of anomalous seismic reflection data. The boundary of the disturbed zone was variously described as being from about 0.5 to 1 mile (0.8 to 1.6 kilometers) north of the center of the site, depending on the criteria to define the disturbed zone. Powers et al. (1978) generally defined the disturbed zone beginning about 1 mile (1.6 kilometers) north of the site center, where the seismic reflector character was poor to uninterpretable, or anomalous (Borns et al. 1983). About 0.5 mile (0.8 kilometer) north of the site center, it appeared that beds within the Castile Formation began to steepen in gradient, dipping to the south from a higher area to the north. The Environmental Evaluation Group (EEG) summarized various map limits to the disturbed zone, including the area where the Castile dip begins to steepen (Neill et al. 1983). Borns et al. (1983) included two separate areas south of the site as part of the disturbed zone based on seismic character.

The first new drillhole within the area encompassed by the disturbed zone was WIPP-11, and it was located about 3 miles (5 kilometers) north of the center of the WIPP site. Long and Associates (1977) examined proprietary petroleum company data in 1976, and identified

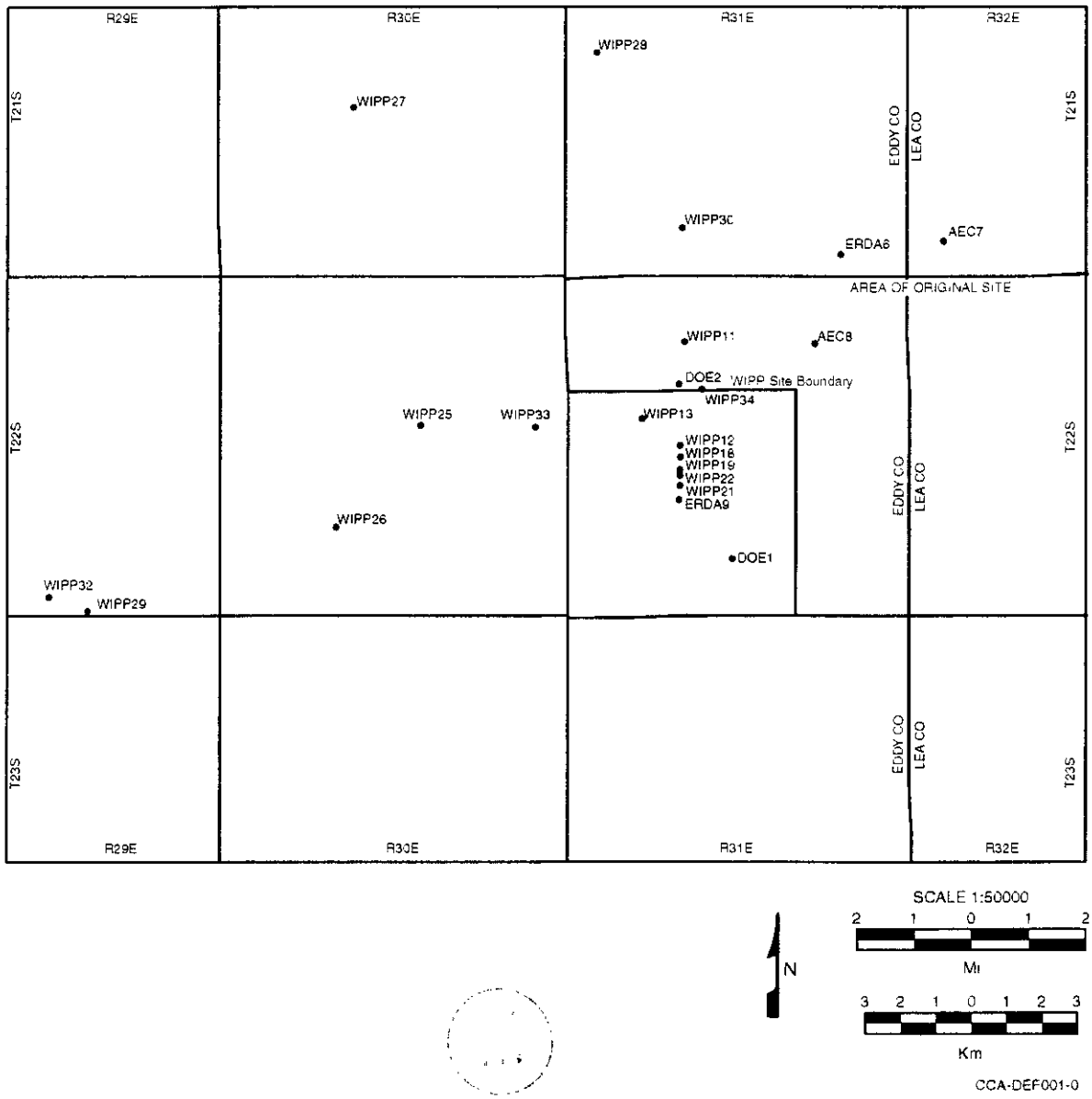

Figure DEF-1. Location of Main Stratigraphic Drillholes

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anomalous areas around the WIPP site, including the structural anomaly at the WIPP-11 location. Seismic reflection data acquired in 1977 indicated possible salt flowage within the Castile and a structure that could be similar to that at ERDA-6 (Sandia National Laboratories and U.S. Geological Survey 1979). WIPP-11 was drilled early in 1978, demonstrating the extensive deformation within the Castile and extending upward into the Salado. WIPP-11 did not encounter any brine or gas flows.

Seismic reflection data acquired in 1977 not only showed a zone of steepened dip of the Castile north of the site center, it also showed a possible fault offsetting parts of the Salado and Rustler Formations. A series of five boreholes was planned to provide detailed information on the structure of the Rustler/Salado contact. Four boreholes (WIPP 18, 19, 21, and 22) were required to demonstrate that there was no detectable offset on that contact in the area interpreted from 1977 seismic reflection data (Figure DEF-2). Later epochs (1978 and 1979) of seismic data in the same area, along with the drilling, continued to show generally poor resolution or uninterpretable data in the area of the disturbed zone. These studies generally showed that the acoustic velocity of the upper section changes laterally, complicating further the interpretation of the deeper Castile structure. Through the WIPP 18-22 drilling program, the upper Salado and Rustler were determined to be fundamentally undisturbed over the southern margin of the disturbed zone where the Castile appears to dip to the south (Sandia National Laboratories and U.S. Geological Survey 1979).

WIPP-12 was located approximately 1 mile (1.6 kilometers) north of the site center to test the amount the Castile was elevated (Figures DEF-1, DEF-2). It was drilled late in 1978 to the top of the Castile and detected approximately 160 feet (50 meters) of structural elevation compared to ERDA-9 and the center of the site (Sandia National Laboratories and D'Appolonia Consulting Engineers 1982c). The amount of disturbance of the Salado was not considered an impediment to underground development, though the underground storage facility was later reoriented from this northern area to an area south of the site center (see Section DEF.2.1). From drilling WIPP-12 and the WIPP 18-22 series, the southern margin of the disturbed zone was considered to be much more gentle in structure, while the seismic character and WIPP-11 indicated much more severe deformation of the Castile farther to the north.

Two additional phases of seismic reflection data were acquired in 1978 and 1979. These data mainly concerned the immediate site area (about 4 square miles [10 square kilometers]) and the southern edge of the disturbed zone. They indicated much the same problems and margins associated with the disturbed zone from the 1977 data. The latest seismic data (1979) were principally acquired to facilitate construction and Site and Preliminary Design Validation (SPIV) activities. As the project moved into SPIV activities, the disturbed zone was little investigated directly during the period from about late 1979 until mid-1981.

A microgravity survey of the site area was conducted to determine if the structure within the disturbed zone could be partially resolved by that method (Barrows et al. 1983; Barrows and Fett 1985). The large differences in density of halite and anhydrite might cause detectable

differences in the gravity field locally if the units were displaced and/or thickened relative to the surrounding areas. The microgravity survey covered an area of normal stratigraphy from south of the WIPP site center to the area of WIPP-11 (Figure DEF-3). As interpreted by Barrows et al. (1983), the microgravity does not resolve the larger scale deformation within the Castile Formation. Based on the interpretation of probable shallow disturbance of the gravity field, WIPP-14 and WIPP-34 were drilled about 2 miles (3 kilometers) north and about 0.5 mile (0.8 kilometer) east of the site center (Figure DEF-1). These boreholes encountered normal stratigraphy within the Rustler and upper Salado; Sandia National Laboratories and U.S. Geological Survey 1981) with some slight structural depression made apparent mainly by the deformation northeast of this area around ERDA-6 (Holt and Powers 1988). Barrows et al. (1983) attributed the gravity anomaly around WIPP-14 to decreased density within parts of the Rustler Formation, mainly from the difference in density due to anhydrite versus gypsum in WIPP-14. The overall difference in mass was attributed to karst processes by Barrows et al. (1983), rather than to deformation of any of the units associated with the disturbed zone.

During the mapping of the first shaft drilled at the WIPP site Salt Handling Shaft (SHS), Marker Bed (MB)139 was observed to have a few inches of relief on the basal contact and 2 to 3 feet (0.6 to 0.9 meter) of relief on the upper surface. Jarolimek et al. (1983) interpreted the internal structure on these high points of MB139 as showing a radial structure due apparently to gypsum growth textures and subsequent crushing, indicating a fundamentally depositional origin to the relief, rather than any structural disturbance related to the disturbed zone. Borns (1985) conducted an investigation of additional cores and holes drilled through MB139, because EEG was concerned that the apparent structure was related to the disturbed zone. Borns (1985) also concluded that the relief was not due to structural deformation, but mainly to erosion processes that carved part of the relief found on the top of the marker bed. From either point of view, the difference in relief on the upper and basal contacts of MB139, in such a thin unit, were convincing evidence that a form of tectonic deformation was not involved.

In late 1981, WIPP-12 was deepened to test for the possible presence of brine and/or pressurized gas within the structure in the Castile Formation (D'Appolonia Consulting Engineers, Inc. 1982). The probability of producing brine and/or gas from WIPP-12 was considered reasonably low at the time, because most known pressurized brine and/or gas was associated with much more deformed units than the Castile at WIPP-12. Fractured anhydrite in the upper Castile did begin to yield pressurized brine and gas when intercepted late in 1981, and WIPP-12 and ERDA-6 were further tested. Later geophysical work (Earth Technology Corporation 1987) suggests that the brine may underlie part of the WIPP facility, beyond the area usually included in the disturbed zone.

Though the DOE and EEG agreed that neither brine nor structure constituted a threat to health and safety, the proposed underground facilities were reoriented south of the site center, avoiding longer haulage and the slight structure encountered at the facility horizon (see

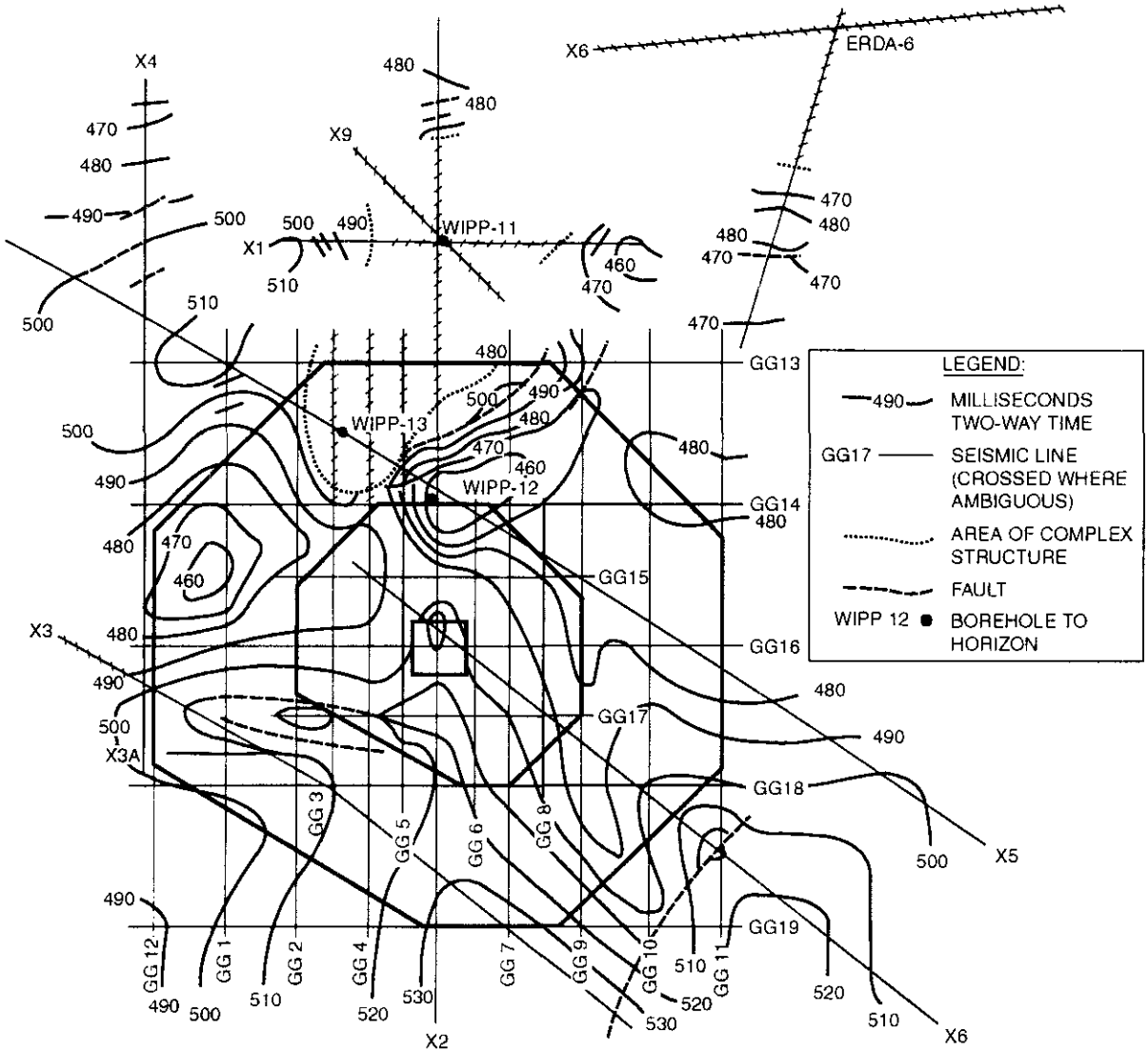

NOTES:

1. CONTOUR INTERVAL 10 MILLISECONDS. DATUM 3350 FEET ABOVE SEA LEVEL.
2. CONTOUR INTERVAL IN FEET WOULD BE APPROXIMATELY 75 FEET BASED ON AN AVERAGE SEISMIC VELOCITY OF 7620 FT./SEC. AVERAGED OVER THE ENTIRE STRATIGRAPHIC INTERVAL FROM GROUND SURFACE TO THE MIDDLE OF THE CASTILE FORMATION.

Source: Borns et al. 1983

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Figure DEF-2. Seismic Time Structure Middle Castile Formation

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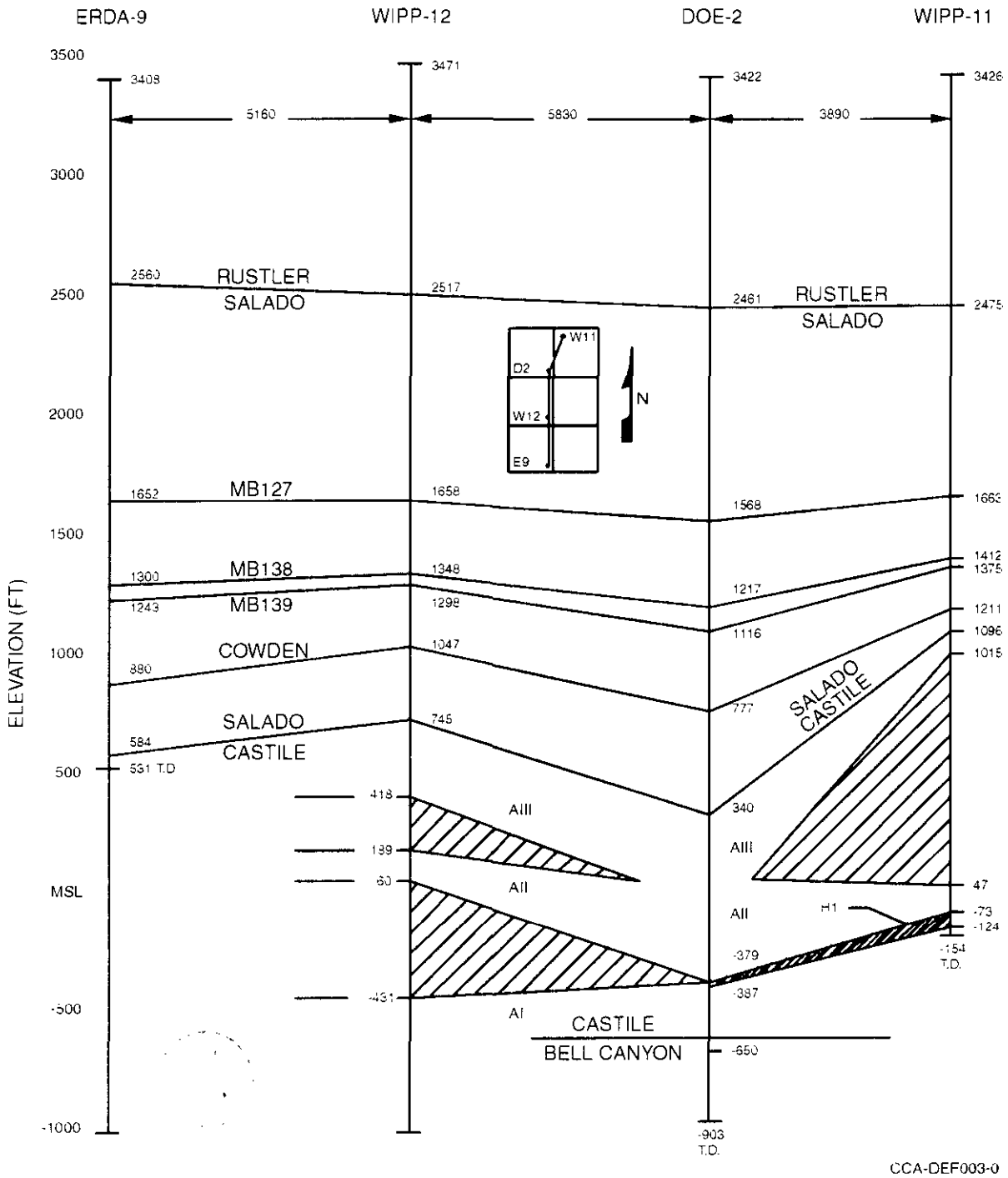

Figure DEF-3. Fence Diagram Using DOE-2 and Adjacent Holes

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Section DEF.2.1). As a consequence of the deepening and testing of WIPP-12, the link between structure and pressurized brine and gas was strengthened.

The last direct investigation of the disturbed zone was a by-product of another investigation. DOE-2 was drilled approximately 2 miles (3 kilometers) north of the center of the WIPP site to investigate the origin of a modest depression on MB124 (Griswold 1977; Powers et al. 1978) that was detected in a corehole drilled by a potash company. DOE-2 was principally a test of the hypothesis that the depression was caused by ductile flow of halite in response to deep dissolution of halite by water from the Bell Canyon Formation (Mercer et al. 1987).

Halite layers in the lower Salado were thicker than usual, indicating that part of the sequence had not been dissolved, and the Castile was very deformed. The Castile stratigraphy was not normal; the second halite was apparently squeezed out of the area during deformation. The stratigraphy in DOE-2 is apparently the result of processes that caused the disturbed zone and is not the result of any dissolution (Borns 1987; Mercer et al. 1987).

The preceding paragraphs describe most of the direct investigations of the disturbed zone and place them in their historical context. In the next few sections, more of the specific features of the disturbed zone will be described, interpreted, and discussed to indicate the significance of the structures and processes of formation for the WIPP.

DEF.2.2 Specific Features of the Disturbed Zone

The first specific feature of the disturbed zone is its boundary. In Section DEF.2.1, the different concepts of the boundary depended on ideas of where the Castile began to change and steepen dip (about 0.5 mile (0.8 kilometer) north of the site center, or where the various epochs of seismic data became unreliable to uninterpretable). Borns et al. (1983) present one diagram (Figure DEF-2) of the seismic time structure for the top of the Castile Formation that illustrates the variously defined boundaries as well as any diagram. The principal part of the disturbed zone is defined by a lobate area (Figure DEF-2) shown as an area of complex structure where the seismic data are considered ambiguous. The structurally-deformed area clearly includes an area about halfway between boreholes WIPP-12 and ERDA-9, as well as a larger area to the northeast. The two-way travel time contoured on the map is a function of depth; as the reflector is nearer the surface, the travel time to the reflector and back to the surface decreases. Thus, the areas enclosed with contours of smaller values should be structurally higher. (The top of Castile in WIPP-12 was 160 feet [50 meters] higher than it is in ERDA-9). The map was not directly converted to depth because the seismic reflection and borehole geophysical logging programs demonstrate clearly that there are also lateral velocity variations within the upper part of the rock section, especially within the Rustler and Dewey Lake Formations. These velocity variations cannot be adequately extracted from the travel times to permit converting the travel time to depth. Nonetheless, the map demonstrates the general best information about the extent of the disturbed zone. The central and southern part of the WIPP site area displays relatively uniform seismic travel time structure and nothing within the geological data contradicts that information to date.

The broad forms of the structures within the disturbed zone are generally anticlinal and synclinal (Borns 1987), though they are not necessarily regular shapes. The best known shape for part of the disturbed zone is between WIPP-12 and ERDA-9, where seismic information and several drillholes constrain part of the stratigraphy. There the structure tends to be a gently dipping limb of a anticlinal structure. Most of the remaining shapes attributed to the Castile within the disturbed zone or related area are based more on one drillhole or a few drillholes that somewhat constrain the structure. WIPP-11, WIPP-13, DOE-1, and ERDA-6 are all examples. A generalized cross-section of the structure at ERDA-6 (Anderson and Powers 1978) shows a piercement structure and a regular shape; the piercement is based on stratigraphic inferences, but the shape is fundamentally uncontrolled by closely spaced data. WIPP-11 and WIPP-12 are both believed to penetrate anticlinal forms, though the structure is only partially known from drilling and seismic reflection data. DOE-2 is believed to lie in a synclinal structure, and contacts on various units show a nested series of depressions in the upper Salado (Borns 1987). There are too few drillholes into the Castile to reconstruct the detailed shapes of Castile structures. The seismic data are not well enough constrained to calculate depths to reflectors, and most reflectors are too disturbed to interpret in this area. The specific shapes of individual structures are unlikely to be defined in the near future.

Anderson and Powers (1978) contoured several structures within the Delaware Basin, including structures at Poker Lake at least grossly similar to ERDA-6. Borns and Shaffer (1985) reexamined the information from Poker Lake and concluded that the actual shape is poorly constrained. Outside of the area on the north side of the current WIPP site, the information available is too sparse to define the individual shapes of structural features on borehole data.

It is important to note that, to date, none of the structures are demonstrably associated with comparable structure on the underlying Delaware Mountain Group. Snyder (in Borns et al. 1983) does show an upthrown block (hoist) through WIPP-11 on the top of the Bell Canyon Formation that is based on his projection of the thickness of the lower Castile; WIPP-11 did not penetrate the complete Castile section. Other areas, such as the Poker Lake structures, may display some relief on the top of the Delaware Mountain Group, but Borns and Shaffer (1985) do not attribute the relief to faulting. They believe the relief existed before and during deposition of the overlying Castile units. The underlying units to the Castile Formation are, for the most part, uninvolved in the structures displayed by the Castile.

Structure contour and isopach maps of the Salado and Rustler over areas of complicated Castile structure also show that the overlying units are successively less involved in the structure (for example, Section 7.2; Borns and Shaffer 1985; Borns et al. 1983; Holt and Powers 1988). Lower units that are thicker and deformed are overlain by units that are thinner and less structurally involved in the deformation. Under normal geological circumstances, for example, dealing with a rock sequence of carbonates or siliciclastics, the deformation would be considered completed by the time of deposition of the lowermost undeformed rock unit. Here, within a much more plastic set of rocks, the same geological reasoning is of less value,

as the rocks may compensate laterally for late deformation effects and produce the same results as seen here.

Borns (1983, 1987; Borns et al. 1983) has extensively examined the macroscopic to microscopic features from cores taken within the structurally deformed areas. These studies follow earlier, broader studies of macroscopic features from the state line outcrop (Kirkland and Anderson 1970) and ERDA-6 (Anderson and Powers 1978). Kirkland and Anderson (1970) reported that small-scale folding within the Castile outcrops is oriented consistently along the general north-south strike of beds in the Delaware Basin. From this, they concluded that the deformation was related to tilt of the basin, generally believed to be Cenozoic in age (for example, Anderson 1978; King 1948; Borns et al. 1983), though authors differ in opinions of when this took place by tens of millions of years. Anderson and Powers (1978) used this apparent relationship to estimate that folding at ERDA-6 took place after the tilt of the basin. Jones (1981) estimated that deformation took place before the Ogallala Formation was deposited, because that unit is undeformed at the location of ERDA-6. Bachman (1980) and Madsen and Raup (1988) are among investigators who interpret angular relationships between various formations of the Ochoan Series, beginning with the Castile-Salado contact. These relationships require tilting of the existing beds to the east, as the angular unconformities are always placed on the west side of the basin. Tilting of the basin may well have occurred through much of the time when the Ochoan Series was being deposited, as Holt and Powers (1988) present evidence that the depocenter for the Rustler Formation was displaced eastward from the Castile and Salado patterns and overlies part of the Capitan Reef on the northeast side of the Delaware Basin. The Delaware Basin appears to have tilted at various times from the late Permian to at least the Cenozoic, and the conditions for deformation may well have existed since the late Permian. Direct evidence of the time of deformation has been difficult to obtain, and tilting of the basin, as a condition for the deformation, appears to have occurred at times beginning in the late Permian. Jones (1981) argues that the structure at ERDA-6 must be, in part, younger than Triassic, because Triassic rocks are also deformed over the deformed evaporites. He further believes that the structure must be older than late Cenozoic, because the Ogallala Formation over part of the structure is undeformed and erosionally truncates the upper part of the Triassic rocks. This may be the most conclusive age relationship demonstrated for any of these related structures. Conventional relationships with beds overlying deformed evaporites, such as that cited by Jones (1981) for the Ogallala, are suspect if the deformation ends or dies out vertically within the evaporites because of the potential for compensating deformation in evaporites (for example, Borns 1983).

Borns (1983, 1987) reexamined the state line outcrop, as well as the cores from various boreholes, and concluded that the styles of deformation present in these cores indicate a very complicated history, including episodes of deformation that are probably synsedimentary. The folding may, for example, display disharmonic or opposing styles that would not normally be attributed to a single episode of strain in a pervasive stress field. If all the deformation occurred in response to a single event, such as the tilting of the Delaware Basin, the folds and other strain indicators should all have a common orientation. Isoclinal folding may be very

early, while asymmetric folding is often penetrative, indicating later time of origin. Fractures in more brittle units, such as the Castile anhydrites, are often very high angle to vertical and are considered one of the late deformation features in cores. These fractures in the larger anticlinal structures of the disturbed zone are apparently the proximate source of pressurized brines and gases. Borns (1985, 1987) recognized that tilting of the basin, among other possible sources of stress, may have occurred at several different times and is not limited to a single Cenozoic event.

DEF.2.3 Hypotheses of Formation of Deformation in Castile

Several hypotheses have been advanced for the formation of the Castile structures in the disturbed zone and other parts of the Delaware Basin (Borns et al. 1983). The five principal processes hypothesized as causes of the disturbed zone are gravity foundering, dissolution, gravity sliding, gypsum dehydration, and depositional processes (Borns et al. 1983). Each of these hypotheses will be briefly summarized, though gravity foundering due to density differences between halite and anhydrite is considered the leading hypothesis (Borns 1987).

Gravity foundering is based on the fact that anhydrite (about 2.9 gm/cc) is much more dense than halite (about 2.15 gm/cc). When anhydrite beds overlie halite, there is considerable potential for the anhydrite to sink and the halite to rise. This potential exists throughout much of the Delaware Basin in the Castile. Mathematical and centrifuge models of similar systems confirm the potential for such deformation and even suggest that the rate of deformation is about 0.02 inch per year (0.05 centimeter per year) (Borns et al. 1983). At such a rate, the disturbed zone could be inferred to develop over about 700,000 years (Borns et al. 1983). The principal difficulty with this hypothesis is that there are large areas of the Delaware Basin that remain undeformed, though the stratigraphy is similar to that within the disturbed zone. The potential for gravity foundering exists over most of the basin, yet only a small part actually manifests such deformation. A special condition, localized higher water content, or an anomalous distribution of water, is hypothesized to explain why deformation is localized despite the pervasive density inversion (Borns et al. 1983). Pressurized brine and gas associated with some of these structures is at least consistent with this explanation.

Halite could potentially be removed from the evaporite section by dissolution and change the form of the evaporites. The density structure could be changed by removing salt near the surface, causing collapse and fill with sediment that is more dense than the removed salt (Anderson and Powers 1978). Borns et al. (1983) reviewed some of the evidence that evaporites were deformed near surficial sinks and concluded that there was certainly some association, but that the pattern of deformation did not match the shallow dissolution. If salt is dissolved from the lower Salado or Castile, then overlying beds should deform in response to the removal of mass. DOE-2 was drilled to test that hypothesis. Recrystallized halite has been offered as evidence of the passage of fluids, but there appears to be no unique relationship between recrystallized halite and deformation. In addition, certain halite sections appear much overthickened, which is clearly not directly due to halite removal. These features generally indicate that the halite can be squeezed and will move laterally. The fact

that the Rustler shows no discernible overall structural lowering over the disturbed zone (Holt and Powers 1988) suggests that dissolution of the lower Salado or Castile is not the origin of the deformation. The one area in which the Rustler is structurally affected is around ERDA-6, and there it is warped upward as noted by Jones (1981). Borns et al. (1983) do not believe that the Bell Canyon has been a source for brines in the Castile because of the chemistry (Lambert 1978, 1983) and the small volume.

Gravity sliding in the Delaware Basin could be driven by two physical situations: the general eastward dip, and the dip off the Capitan Reef and forereef into the basin. In contrast to the gravity foundering mechanism, where movement is dominantly vertical, gravity would result in sliding blocks moving mainly laterally as well as downslope in this mechanism. Some of the deformation is adjacent to the reef (Jones et al. 1973), lending some substance to the hypothesis that the reef-forereef slope and facies changes could cause such sliding. Some deformation is in somewhat isolated portions of the basin (for example, Poker Lake; Anderson and Powers 1978; Borns and Shaffer 1985), and these structures were originally interpreted to align along the strike of the basin (Anderson and Powers 1978). Borns and Shaffer (1985) conclude that the data do not uniquely support that interpretation, and these structures may or may not support the concept of gravity sliding within the basin. Borns et al. (1983) also concluded that the timing of the various structures is an important factor in evaluating this hypothesis. As discussed above, neither the age of the various structures, nor the timing of the basin tilt, is well constrained. If tilting of the basin is an important event in forming these structures, the various macro- to microstructures should probably be consistently related. As in gravity foundering, much of the basin area has not reacted to what appears to be widespread similar stresses. Special circumstances, such as an anomalous distribution of water, may be necessary to overcome a threshold for deformation to occur.

In general, as temperature and pressure increase, gypsum dehydrates to form anhydrite and release free water. Borns et al. (1983) discuss the effects this process has on experiments in weakening the anhydrite. Borns et al. (1983) suggest, however, that a major difficulty with this hypothesis is that there should remain relicts of the original gypsum within the sedimentary column and these are not observed. Borns et al. (1983) suggest that mostly anhydrite was deposited in the Castile, and, as a consequence, the dehydration hypothesis has little observable support. Pseudomorphs after gypsum have been recorded in every major anhydrite of the Castile; Sandia National Laboratories and D'Appolonia Consulting Engineers 1982). Gypsum certainly has been present in the Castile, though anhydrite cannot be dismissed as a possibly important primary mineral. Delicate forms of original gypsum crystals are sometimes preserved and pseudomorphed by anhydrite or halite. Each requires volume-for-volume replacement, probably through dissolution and crystallizing the replacement mineral. There are no observed fluid escape paths, and the gypsum may have been replaced very early in the sedimentary history. The additional major drawback of this hypothesis is that the process should be pervasive, while the deformation is localized. Special pleading for an additional factor is necessary in this process as in some other hypotheses.

Depositional or syndepositional processes have been invoked for some of the deformation in the Castile Formation. Borns et al. (1983) list four main mechanisms that have been suggested: penecontemporaneous folding, resedimentation, slump blocks off reef margins, and sedimentation on inclined surfaces. Penecontemporaneous folding requires consolidation of the units over relatively short times. Borns et al. (1983) also cite the lack of observed features that indicate the rocks were reexposed. Evaporite units in the Mediterranean contain resedimented material: turbidites, slumping, and mudflows with other clastic sediment. Borns et al. (1983) report that the units of the WIPP area show little chaotic or clastic structures. They also apply the same argument of Kirkland and Anderson (1970) that the deformed units would have to be consolidated by the time of resedimentation.

In a more recent study of cores from the western part of the Delaware Basin, Robinson and Powers (1987) report a lobate unit of resedimented Castile anhydrite clasts overlying both the lower anhydrite and halite of the Castile and underlying the second anhydrite. The apparently unconformable contact with both anhydrite I and halite I lies across the extension of the Huapache monocline that appears to have been still active during the time part of the Castile was deposited. Polyclasts within some beds of this unit demonstrate that the original anhydrite was partially consolidated and that a unit of clasts was also at least partially consolidated to provide the polyclasts. These units were consolidated early between the time halite I was deposited and anhydrite II began to be deposited.

In the rest of the basin, there is no apparent interval between the end of halite and beginning of the anhydrite deposition. The relationship clearly indicates that the western margin was an area of sulfate clast formation, deposition, and lithification over a very short interval of geologic time. Hovorka (personal communication 1988) indicates that similar clastic deposits occur in cores from nearer the eastern margin of the Delaware Basin. Snider (1966) proposed much earlier that sedimentation caused anomalous thickness of Castile units near the basin margin, and Billo (1986) presented a similar conclusion. Neither reported any textural evidence to support their conclusions.

Clearly, Castile rock has been resedimented, but in the area where textural data are available, only modest deformation appears to be present (Robinson and Powers 1987). At this time, there is little to suggest that such sedimentation resulted in the deformation in the disturbed zone. There is also no direct evidence from the WIPP area that suggests slump blocks off the reef margin moved into the area, causing deformation. The high inferred slopes of some of these structures argues strongly against sedimentation on inclined surfaces (Borns et al. 1983).

The concept that deformation was syndepositional or penecontemporaneous with deposition appears mainly to be driven by the fact that deformation decreases upward through successive units. Normal geologic reasoning would support penecontemporaneous deformation, but does not take into account the rather plastic behavior of halite, allowing flow over high areas to move halite into low areas. Overlying units, such as the Rustler, are made of much less plastic material and do not respond as the Salado does. The deformation appears to be compensated in overlying units through deposition.

Overall, both gravity-driven mechanisms require some special additional conditions restricting deformation to small areas though most of the basin appears to be equally susceptible. Dissolution permits a more localized effect, but there does not appear to be an overall loss of mass in these areas and the chemistry of the fluids and hydrology of the units do not readily support the concept. Most of the syndepositional processes have no evidence to support them in the area of the disturbed zone. Currently, the most favored hypothesis is gravity foundering, with a yet undetected anomalous distribution of fluid lowering the viscosity of halite locally to permit deformation.

DEF.2.4 Timing of Deformation

Most of the arguments about timing of deformation have already been discussed. Standard geologic arguments about relative timing, based on involvement of the overlying units, is unlikely to hold for the evaporite units. Jones (1981) notes that uplifted and arched Triassic rocks near the ERDA-6 borehole are truncated by the flat-lying, undeformed Pliocene Ogallala Formation. He interpreted this as an indication that salt movement was complete before deposition of the Ogallala. However, he does not explain either how the Triassic structure relates to the deeper disturbed zone or how it is distinguished from near-surface dissolution effects (Borns et al. 1983). Castile rocks may have been deformed during any time period from Permian to the present. More to the point, for some hypotheses, the general conditions thought necessary to deform the Castile and Salado are still present, and mechanisms, such as gravity foundering, are potentially active (Borns et al. 1983).

An additional piece of data is relevant. Brines from ERDA-6 and WIPP-12 were analyzed, and the brines were calculated to have moved last about 800,000 years ago (Lambert and Carter 1984; Barr et al. 1979). One set of reasonable assumptions about brine chemistry and interactions with the rock leads to calculated residence times of about 25,000 to 50,000 years for these brines. This may relate to the last time that deformation was active on this structure, though it is not uniquely an indicator of deformation. The interaction between rock and water may have been strictly hydrologically driven, and may not require deformation at that time.

The second point of interest is that some modeling calculations indicate, as stated above, that the kinds of structures observed in the disturbed zone may require periods on the order of 700,000 years to form. This calculation gives no indication of when the structures formed, but it is relevant to timing and assessing how these structures might affect the WIPP.

DEF.2.5 Importance to the WIPP

The structures interpreted from core retrieved from WIPP-12 and ERDA-6 serve as possible analogs to effects of deformation on the WIPP. The DOE and EEG have analyzed the effects of brine and structure at WIPP-12 and the southern portion of the site and concluded the geologic conditions represent no threat to health and safety (see Section DEF.2.1). In addition, both boreholes encountered brine only within the anhydrite units, and that is the experience of all other encounters of these larger brine inflows (Popielak et al. 1983).

Anhydrite supports the fractures that provide porosity for the brine, and the anhydrite/halite units form an effective seal, as the pressurized brines and gas did not escape upward. The principal concern for isolation would be that the deformation, and its associated phenomena, such as pressurized brine and gas, could cause breaching of the repository and provide or make a pathway for the escape of the waste constituents. The period of time expected for development of the structure (700,000 years) is well beyond periods of regulatory concern. In addition, the evidence of the pressurized brine and gas occurrences is that they are confined to these Castile anhydrite layers and do not breach the lower Salado to reach the stratigraphic level of the repository. There is nothing at present to indicate that these features will form in the time period of concern or that they can directly cause a breach of the repository.

DEF.3 Dissolution

The Permian rocks of the Delaware Basin in which the WIPP is located are dominated by evaporites, and there is a potential for dissolution to change the properties of these rocks. Dissolution will initially enhance porosities, but continued dissolution may lead to compaction of the affected units with a consequent reduction in porosity. Compaction may result in fracturing of overlying brittle units and increased permeability. Extensive dissolution may create cavities and result in the collapse of overlying units. Dissolution has taken place at several stratigraphic levels in the Permian rocks, and has occurred over several periods between deposition and the present-day.

This section describes dissolution features in the region of the WIPP and in other areas of the Delaware Basin. Three broad styles of dissolution have been identified: **deep dissolution**, taking place in the Castile and the base of the Salado; **lateral dissolution**, involving dissolution at the top of the Salado and within the Rustler; and **shallow dissolution**, involving percolation of groundwater and mineral dissolution in the Rustler and overlying units. The known extent of each dissolution style is described, together with an assessment of possible future development and potential impact on the WIPP. A brief history of the investigations undertaken prior to and as part of the WIPP site characterization program is also presented.

DEF.3.1 Deep Dissolution

Several domal surface features (Hills A-D) are present at the northern end of Nash Draw (Figure DEF-4). These were mapped during investigations for Project Gnome, but were not identified as deep-seated structures at that time (Vine 1960). As part of the early investigations of southeastern New Mexico as a potential site for radioactive waste disposal, geophysical studies were undertaken to test the theory that these domes resulted from salt diapirism. Magnetic studies were not conclusive, but gravity surveys suggested that salt diapirism was unlikely to be the cause (Gera 1974). As a result, Gera interpreted the domes to be the result of shallow dissolution processes.

At the time of the early investigations, potash mining near the northern end of Nash Draw had not encountered any disturbed regions in the Salado. In 1975, however, continued mining

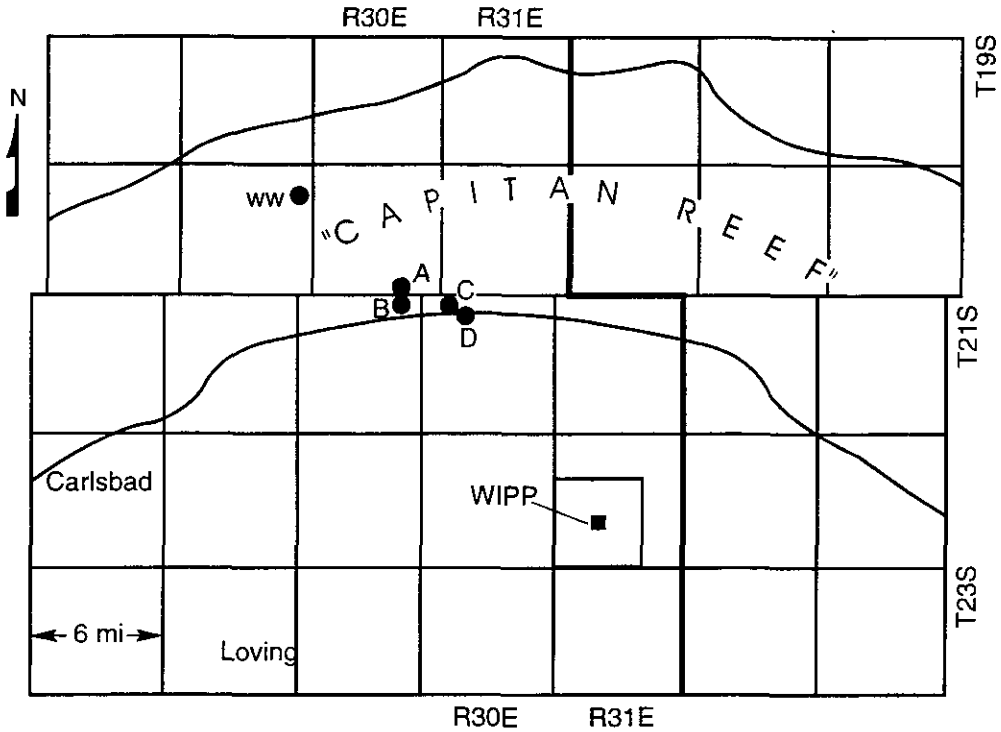

Generalized Location Map

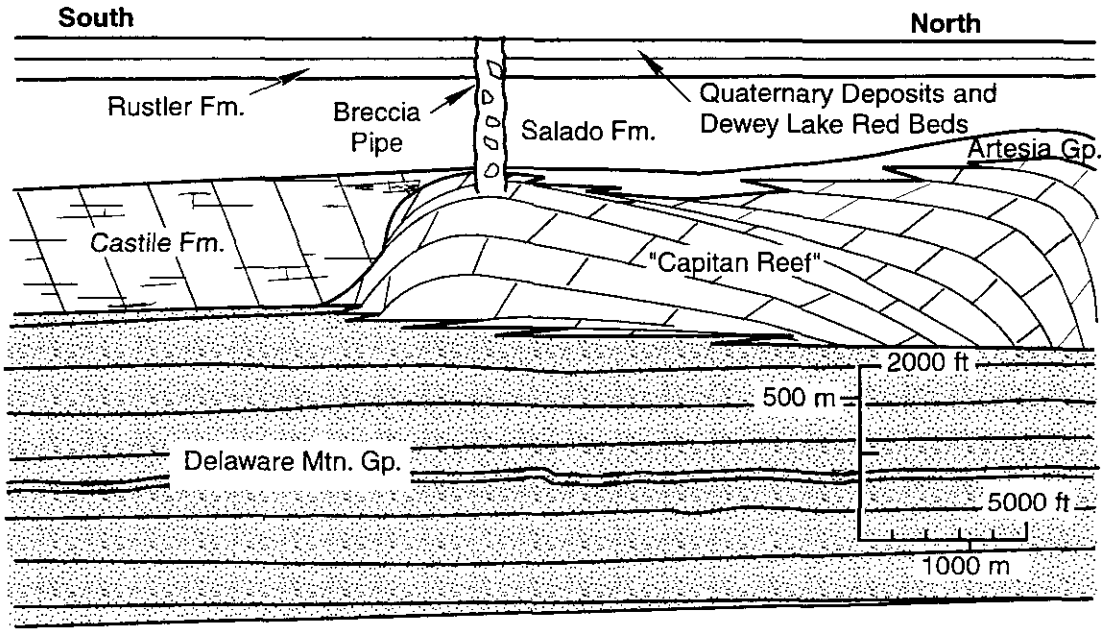

Generalized Cross Section

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Figure DEF-4. Location and Generalized Cross-Section of Localized Deep Dissolution Features

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intersected disrupted beds beneath Hill C, and the domal features were recognized as the surface expression of breccia pipes that affected the Salado.

Although these breccia pipes were some distance from the potential disposal site, there was concern that unidentified pipes elsewhere in the Delaware Basin could pose a threat to a repository. A series of geophysical investigations of the features known to be related to pipes was therefore undertaken to establish a reconnaissance tool for use in other areas. Seismic, electrical, and gravity methods were considered, of which electrical, and specifically resistivity, proved to be most effective in providing consistent indicators over breccia pipes (Elliot, 1976). Based on these results, a large resistivity field program was undertaken in 1977 over an area of about 37 square miles around the WIPP, with a resolution sufficient to identify features similar in size to Hills A-D (Elliot 1977a,b).

The resistivity survey identified an anomaly in Section 17, T.22S., R.31E., with characteristics and an apparent size similar to those of the known breccia pipes. This anomaly was investigated by drilling WIPP 13 in 1978, but no breccia was encountered in this borehole. Mapping of surficial features, conducted during 1978 and 1979, identified an area characterized by unusually thick fill and internal drainage in Section 13, T.22S., R.30E. This area was also characterized by low resistivity, although not by the type of localized anomaly associated with known breccia pipes. WIPP-33, drilled in 1979, showed recognizable marker beds within the upper Salado below this feature, confirming the absence of a breccia pipe. WIPP-32 was also drilled in 1979, in Section 33, T.22S., R.29E., to investigate a possible breccia pipe, but did not encounter displaced or brecciated horizons in the Rustler or Salado.

In parallel to the field studies investigating anomalies, studies of known breccia pipes were undertaken to help develop an understanding of the mechanisms leading to their formation. This work included the drilling of WIPP-31 at Hill A in 1978, and drilling WIPP-16 at Hill C and deepening WIPP-31 in 1980. As expected, these two boreholes encountered brecciated and displaced rocks in the Rustler and Salado.

As a contribution to the Geological Characterization Report (Powers et al. 1978), Anderson summarized the then available information on dissolution in the Delaware Basin (Anderson 1978), and described a generalized theory for deep dissolution developed from work in Texas and other areas of New Mexico as well as the Delaware Basin. This hypothesis included the concept of brine density flow which allows upward flow of water through an overlying fractured unit, dissolution of evaporites, and subsequent downward flow of the ensuing, more dense brine. Overlying rocks may then collapse into the resulting solution cavity. Anderson postulated that this type of localized deep dissolution had resulted not only in the features at Hills A-D but also other domes, mounds and depressions in the area. He considered that dissolution at depth on a regional scale had removed significant volumes of halite from the Salado and Castile during the Cenozoic in areas along the western and eastern boundaries of these formations (Figure DEF-5).

Surface mapping of features in the region of the WIPP, and the subsequent drilling of WIPP-16, WIPP-31, WIPP-32, and WIPP-33 led Bachman (1980) and Snyder and Gard (1982) to differentiate between surficial features formed by deep collapse and those formed by shallow dissolution (karst). Bachman supported Anderson's theory of brine density flow, and Snyder and Gard showed that the breccia pipes were related to deep-seated collapse within the Capitan Reef limestones around the northern boundary of the Delaware Basin (Figure DEF-4). There are no known breccia pipes which are not underlain by the Capitan Limestone. The breccia pipes have a positive relief because the cemented breccia is resistant to erosion, and lateral dissolution in Nash Draw has resulted in a lowering of the surrounding beds. San Simon Swale and the enclosed San Simon Sink are features with a negative relief that are also related to collapse within the Capitan Reef limestones, with subsidence occurring as recently as 1927.

Breccia pipes can form above the Capitan Limestone because the hydraulic conductivity of this unit is sufficient to allow significant groundwater flow and transport of dissolved material, thereby allowing the formation of solution cavities. Away from the reef, hydraulic conductivities in other units, such as the Castile anhydrites and the Bell Canyon, have been interpreted by some as too low to allow transport of any brines formed by dissolution (Lambert, 1983; Mercer 1983). However, in a review of the hydrogeology of the Bell Canyon, Davies (1983) calculated that hydraulic conductivities in sandstone channels are sufficient to allow regional groundwater flow and transport of brines from this unit into the Capitan Limestone. Brine density flow through fractures above the Bell Canyon could therefore lead to localized deep dissolution in areas of the Delaware Basin not underlain by the Capitan Reef. If such dissolution took place rapidly then brittle failure of overlying units would be expected, but if dissolution were slow then ductile behavior rather than collapse and brecciation could occur. Davies (1984) identified an area about 2 miles north of WIPP where structural depressions in the Salado suggested slow removal of salt at depth. Borehole DOE-2 was drilled in 1984 to study this feature. Beds in the lower Salado and Castile were found to differ in thickness from the equivalent beds in nearby boreholes: these variations were interpreted to result from deformation rather than dissolution (Borns 1987). Thus there is no unequivocal information that supports the possibility of localized deep dissolution occurring anywhere other than at the edges of the Capitan Reef.

Lambert (1983) examined Anderson's hypothesis that deep dissolution during the Cenozoic has removed as much as 50 percent of the original volume of halite in the western part of the Delaware Basin (Anderson 1978). This hypothesis is based on a correlation between widely spaced boreholes and between cores and wireline logs, and also on the assumption that all the halite units were of uniform thickness across the Delaware Basin at the time of deposition. Lambert called into question the correlations used by Anderson to infer dissolution, and also noted that the present-day, nonuniform thickness of halite beds could well arise from nonuniform deposition of halite, or from removal of halite by subaerial dissolution or erosion soon after deposition. Either of these mechanisms would result in missing halite interbeds among the anhydrite interbeds of the lower Salado.

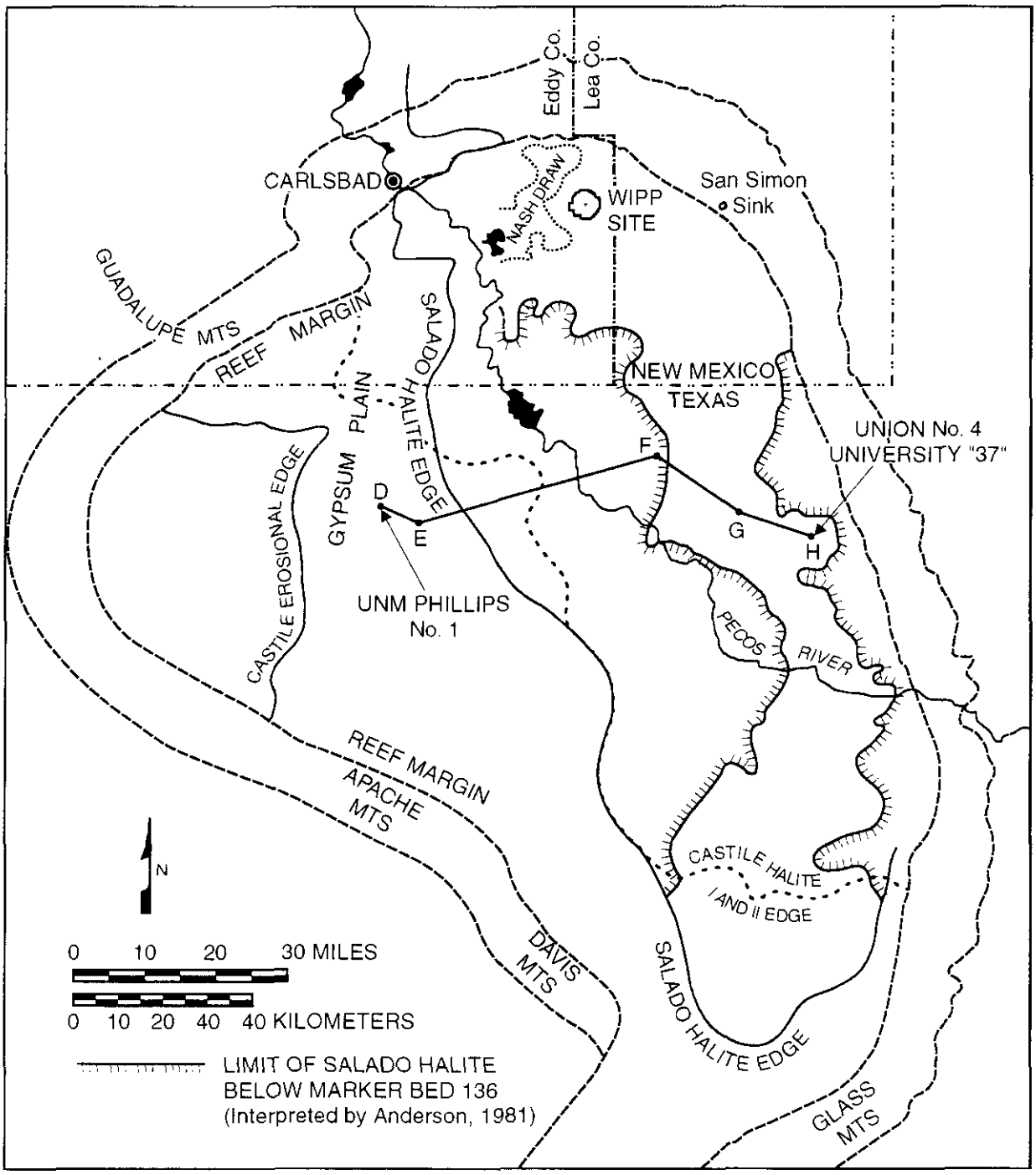

A: Map showing surface projections or outcrop of limits of Castile Formation, Halite I and II, Salado halite, and lower Salado halite (between marker bed 136 and Cowden anhydrite).

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Figure DEF-5. Distribution of Regional Deep Dissolution in Ochoan Evaporites Interpreted by Anderson (1978)

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Bachman (1980) described the Castile as a series of interfingering, discontinuous beds of halite and anhydrite that were deposited in individual pans within the Castile basin. Furthermore, geochemical evidence suggests (Adams 1969) that the halite beds may have formed during periodic influxes of brines derived from preexisting evaporites, rather than simply from evaporation of seawater. In such a basin, the distribution and thickness of the halite interbeds would be independent of the anhydrite formed from seawater, and there would be a tendency for halite beds to thin towards the margins. Anderson (1978) cited the presence of anhydrite breccias near the basin margin as evidence of later dissolution. Lambert (1983) noted that this type of breccia could also arise from syndepositional slumping along basin margins, leading to anhydrite mounds and consequent thinning of any overlying halites. ERDA-10 was drilled south of the WIPP in an area where Anderson's hypothesis would indicate that significant amounts of halite have been dissolved in the Cenozoic, with consequent collapse and brecciation of the anhydrite units. The absence of an intraformational breccia in ERDA-10 suggests, however, that any dissolution must have taken place relatively soon after deposition.

In summary, Anderson based his conclusions on the significance of regional deep dissolution on the existence of dissolution wedges along the margins of the Salado and Castile. More recent interpretations have questioned the basis for the identification of these wedges and therefore the significance to the WIPP of regional deep dissolution. Localized deep dissolution and collapse features are only known to be present along the margin of the Delaware Basin above the Capitan Reef. Theoretical considerations indicate that localized deep dissolution could occur away from the margin, but extensive geophysical surveys, field mapping, and drilling in the vicinity of the WIPP have failed to confirm that breccia pipes or slow dissolution pose a threat to the WIPP.

DEF.3.2 Lateral Dissolution

Dissolution of the upper Salado and Rustler has been recognized since the earliest studies in the Delaware Basin, and the extent of this dissolution in the region of the WIPP has been a focus for mapping and drilling programs since 1970 because of the influence that dissolution can have on hydrogeological properties. Near-surface dissolution processes, particularly the development of karst, are discussed in the following section. This section describes dissolution resulting from groundwater flow within the affected units. This is termed lateral dissolution because it can lead to lateral variations in porosity and permeability. It is equivalent in large part to the stratabound dissolution described by Lambert (1983).

Eastward tilting of the Delaware Basin during the Tertiary has exposed the Salado and Rustler in the western part of the basin, and infiltration of groundwaters during the Cenozoic has led to dissolution at various horizons in these formations. Nash Draw, some 5 miles (8 kilometers) to the west of the WIPP site, is the most prominent result of such lateral dissolution in the region, formed by collapse of the overlying Rustler where halite has been dissolved at the top of the Salado. Shallow dissolution within the disrupted units of the

Rustler has led to further development of this feature. Lateral dissolution of the Salado has also taken place to the west of Nash Draw.

The extent of dissolution at the top of the Salado was established by a series of boreholes drilled in 1978 (WIPP-25 to WIPP-30). Each borehole was drilled to a recognizable stratigraphic horizon within the upper Salado; in the eastern part of Nash Draw a complete Salado succession below MB103 is present, whereas to the west the succession is complete below the Vaca Triste bed (near MB116). The dissolved units are now represented by an unstructured solution residue comprising gypsum, clay, and sand up to 100 feet (33 meters) thick at WIPP-29. This residue has yielded brine in a number of boreholes and has been termed the brine aquifer. The eastern limit of lateral dissolution in the Salado is to the east of Livingston Ridge, with boreholes drilled close to the WIPP showing a complete stratigraphic section without a solution residue.

A tributary of the Pecos River flowed across the area of Nash Draw in Gatuña times (Figure DEF-6), depositing beds of gravel, which are now exposed on both sides of Nash Draw up to 200 feet (67 meters) above the floor. These gravels are dated at about 0.6 million years from included volcanic glass. The Mescalero caliche, dated at 420,000 to 570,000 years old from included ash layers, is present in collapse blocks along the eastern edge of Nash Draw, indicating some growth of Nash Draw in the late Pleistocene. Bachman (1974) provided initial estimates of dissolution rates at the top of the Salado based on the assumption that all dissolution occurred during the Quaternary. However, it is now recognized that some dissolution was pre-Cenozoic, and thus lateral dissolution has taken place at a slower rate (Bachman 1980; Szabo et al. 1980; Lambert 1983). In any event, the calculated rates are too slow for lateral dissolution to reach the controlled area during the period of regulatory concern.

In the vicinity of Nash Draw, halite is absent from all the units of the Rustler. Further east, towards the WIPP site, halite progressively appears in younger units. This has led many investigators to conclude that halite has been dissolved from the Rustler by groundwater in a process akin to lateral dissolution at the top of the Salado (see, for example, Lambert 1983, Bachman 1984, and Lowenstein 1987). However, a detailed hydrogeological model to explain the cross-stratal distribution has not been formulated.

An alternative interpretation of the distribution of halite within the Rustler was presented by Holt and Powers (1988) following detailed mapping of the Rustler exposed in the WIPP ventilation and exhaust shafts in 1984. Fossils, sedimentological features, and bedding relationships were identified in units that had previously been interpreted from boreholes as dissolution residues. Cores from existing boreholes, outcrops, geophysical logs and petrographic data were also reexamined to establish facies variability across the area. As a result of these studies, the Rustler was interpreted to have formed in variable depositional environments, including lagoon and saline playas, with two major episodes of marine flooding to produce the carbonate units. Sedimentary structures were interpreted to indicate synsedimentary dissolution of halite from halitic mudstones around a saline playa and fluvial

System	Series	Group	Formation	Member
Recent	Recent		Surficial Deposits	
Quaternary	Pleistocene		Mescalero Caliche	
			Gatuña	
Tertiary	Mid-Pliocene		Ogallala	
Triassic		Dockum	Santa Rosa	
Permian	Ochoan		Dewey Lake	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				lower
			Salado	upper
				McNutt Potash
				lower
			Castile	
	Guadalupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

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Figure DEF-6. Site Geologic Column

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transport of more distal clastic sediments. The halite in the Rustler, by this interpretation, has a distribution similar to that at the time the unit was deposited; some localized, marginal solution of halite may have occurred, but not over large areas.

The reanalysis of the Rustler by Holt and Powers (1988) has not led to significant changes in the interpreted distribution of halite in the Rustler in the region of the WIPP. This reinterpretation does not therefore influence the conceptual model for the hydrogeology of the present-day system, and neither interpretation of the Rustler would appear to predict threats to the integrity of the disposal system over the regulatory period.

DEF.3.3 Shallow Dissolution

The term shallow dissolution has been used in a variety of ways by different authors. It is used here in the sense of solution-and-fill as discussed by Lambert (1983), and excludes lateral or stratabound dissolution which is discussed in the previous section.

Much of the early work on the effects of dissolution in the region of the WIPP focused on deep dissolution and the potential for this to disrupt the integrity of the repository. When it was established that localized deep dissolution was restricted to units above the Capitan Reef, and that regional deep dissolution had not taken place to the extent envisaged by Anderson, the focus changed to shallow dissolution. In particular, the possibility that karst features had developed at or near the WIPP site was of interest because of the significant effects that such karst could have on the hydrogeology of units overlying the Salado. In some release scenarios, these overlying formations could provide a potential pathway for radionuclide transport to the accessible environment.

The geomorphology of the region around the WIPP, and particularly around Nash Draw, is clearly influenced by shallow dissolution, and this has been recognized in all geological studies of the region. The first specific studies were those conducted in relation to Project Gnome, in which Vine (1960) mapped a variety of geomorphological features. Bachman continued the mapping of the region in the early 1970s, and a number of boreholes were drilled to investigate features of uncertain origin. A synthesis of this work (Bachman 1980) differentiated between those surficial features formed by deep collapse (for example, Hills A-D) and those formed by shallow dissolution. Anderson (1978) compiled information on dissolution in the region as a contribution to the Geological Characterization Report, but did not focus on shallow dissolution.

A gravity survey was conducted in the northern part of the WIPP site in 1980 and showed anomalies consistent with shallow density changes (Barrows et al. 1983). Some of these anomalies corresponded to known surficial features such as dolines, or to other karst features known from borehole data or other geophysical data. Barrows et al. (1983) extended the interpretation of karst to encompass all of the gravity anomalies, inferring that the site is located in karst terrain and neglecting other mechanisms to explain apparent mass loss.

The concerns raised by the interpretation of the WIPP region as a karst terrain led the EEG to commission a study by LeGrand (reported in Chaturvedi and Channel, 1985). LeGrand concluded that – in the region of the WIPP – there were similarities and important differences to classical karst terrain. In particular, he distinguished between Nash Draw, where karst features are developed, and a more easterly region, including the WIPP site, where there is no significant shallow dissolution of halite, anhydrite or dolomite. These two regions are separated by a transition zone which includes a prong of dissolution extending from Nash Draw towards the site of WIPP-14.

Bachman (1985) also reexamined the evidence for karst features in the vicinity of the WIPP. He provided a useful summary of the main surficial and underground karst features. The former include dolines, collapse sinks, karst valleys, swallow holes, solution-subsidence troughs, blind valleys, karst plains, and a variety of minor surface features. All of these features have been identified in Nash Draw, along the Pecos drainage north of Carlsbad or on the Gypsum Plain to the southwest of the Pecos River. Only a few small clusters of shallow dolines on the Mescalero caliche have been identified on the Los Medaños plateau east of Livingstone Ridge (Figure DEF-7).

Karstic features, such as collapse sinks and swallow holes, are common within Nash Draw, and the depression itself is an example of a karst valley. Some of these karstic features might have developed if the Rustler had remained unfractured, but collapse of the Rustler beds through dissolution at the top of the underlying Salado has caused extensive fracturing and brecciation and allowed more extensive percolation of groundwater. East of Livingstone Ridge there is a decrease in the extent of Salado dissolution and a consequent decrease in the extent of fracturing of the Rustler. The extent of dissolution of primary minerals and fracture infills also decreases eastward from Livingstone Ridge.

Dissolution and fracturing are important controls on the hydraulic conductivity of the Rustler, and an understanding of these processes is important to understanding the future evolution of this unit. The discussion of lateral dissolution above concludes that the edge of halite dissolution at the top of the Salado will not reach the controlled area until well after the period of regulatory concern. The present-day pattern of secondary gypsum in fractures is the result of changes in rainfall and percolation over many climate cycles during the past 500,000 years or more. There is no evidence for a progressive change in this pattern across the area and, although some dissolution and precipitation of gypsum as fracture infills will inevitably occur in the next 10,000 years. Significant lateral changes in hydraulic conductivity are not expected to occur over the next few climate cycles.

DEF.3.4 Importance to the WIPP

In summary, early investigations in the region of the WIPP identified several styles of dissolution as of potential importance to the performance of the disposal system. Each of these dissolution styles was methodically and intensively examined by the DOE and other investigators as part of site characterization. Although there is not complete agreement on all

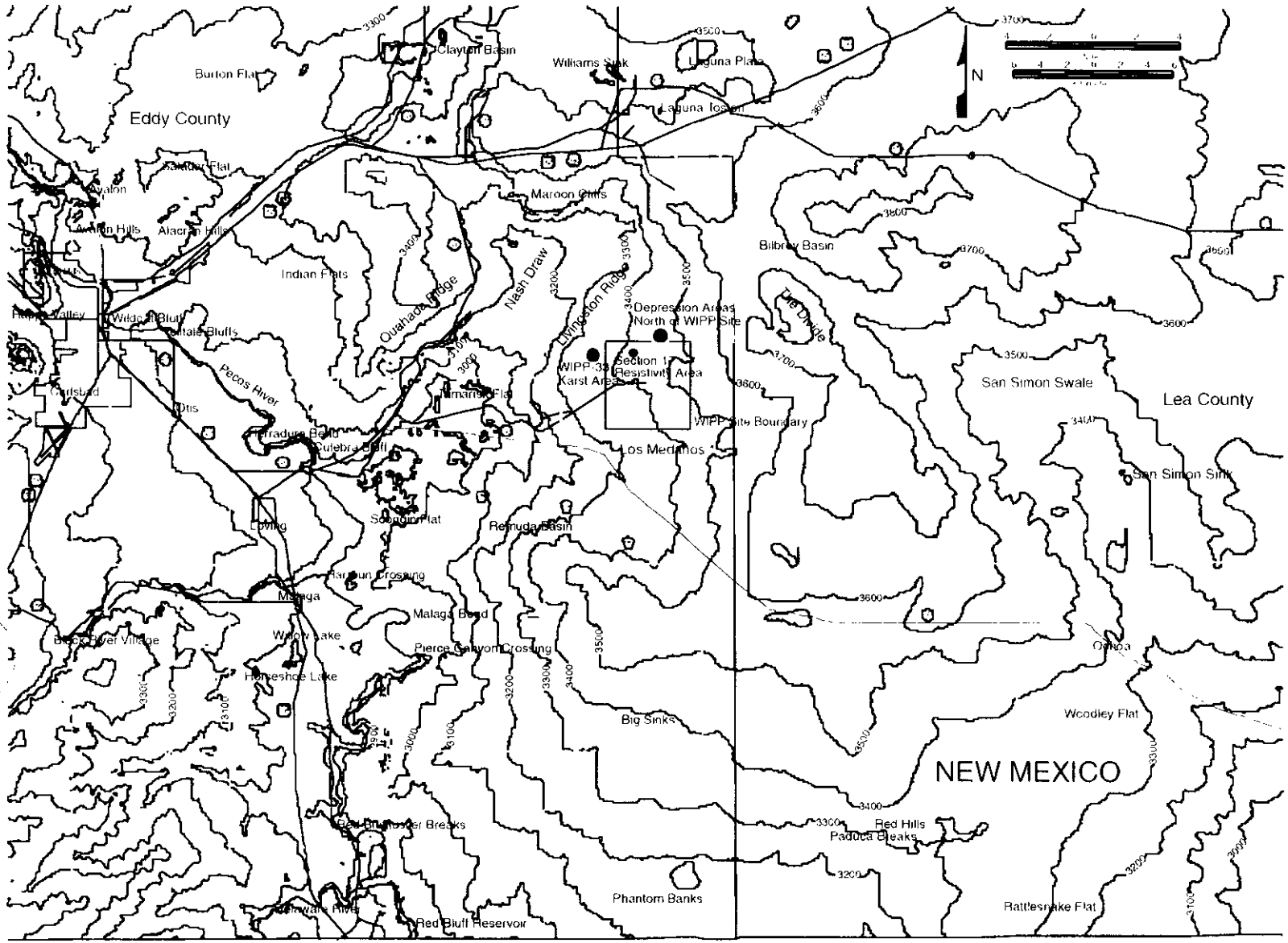

Figure DEF-7. Topographic Map of the Area Around the WIPP Site

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aspects of the possible extent and timing of the different types of dissolution, there is a high level of confidence that dissolution sufficient to affect the performance of the disposal system is physically unreasonable and will not occur over the regulatory timeframe.

DEF.4 Salado Penetrations

Within the 16-square miles (41-square kilometers) WIPP site boundary, 36 boreholes have been identified as penetrating into the Salado (Figure DEF-8; Table DEF-1). Thirty of these boreholes terminate near the top of the Salado; the remaining six boreholes were completed through the Salado to deeper formations. These boreholes have either been plugged and abandoned, or recompleted for use as hydrologic monitoring wells.

The six wells that penetrate through the Salado are two exploration wells and four drilled in support of the WIPP. Two hydrocarbon exploration wells, Clayton Williams #1 Badger Unit and Michael Grace #1 Cotton Baby, were drilled within the WIPP site boundary. The location of these wells is shown on Figure DEF-8, and the construction information is provided in Table DEF-1. These wells did not produce economical quantities of hydrocarbons and were plugged and abandoned in accordance with the state of New Mexico plugging criteria. The four additional deep boreholes, WIPP-12, WIPP-13, DOE-1, and ERDA-9, were drilled as stratigraphic holes for geologic site characterization (Figure DEF-8; Table DEF-1). These four boreholes have been recompleted and are currently used for hydrologic testing and sampling.

Most of the 30 boreholes completed near the top of the Salado were drilled in support of the WIPP. Seven of the boreholes (designated with an "H" prefix on Figure DEF-8) were drilled to just below the Rustler/Salado contact and were completed as hydrologic exploration wells. These wells were completed with the section in the Salado either left as an open hole or, in some cases, a cement plug was installed to prevent mixing of groundwater between the Rustler and Salado. Five boreholes were drilled within the boundary to characterize the site stratigraphy. Four of these boreholes (WIPP-18, WIPP-19, WIPP-21, and WIPP-22) were subsequently recompleted for hydrological testing and sampling purposes and are currently in use. The remaining stratigraphic borehole, B-25, was drilled as part of the geotechnical foundation analysis program. This borehole was plugged, as described in Table DEF-1. Industry potash and WIPP potash assessment boreholes (designated as D, I, or P, respectively, in Figure DEF-8) were drilled within the site boundary. These boreholes were plugged with cement and abandoned, except for borehole P-15. This borehole was plugged as described in Table DEF-1 and recompleted as a hydrologic test well.

Table DEF-1. Information for Boreholes Within the 16-Square Mile (41-Square Kilometer) WIPP Boundary

Borehole No.	Location T/R/SEC.	Completion Date	Total Depth (ft)	Purpose	Comments
B-25	22S/31E/20	2/13/79	902	Stratigraphy	Plugged and abandoned; cement plug from 902 feet to 461 feet, sand from 461 feet to 5 feet, cement plug from 5 feet to surface
CW#1	22S/31E/15	9/13/93	15,225	Hydrocarbon Explor.	Plugged and abandoned, 9/17/93
Cotton Baby	22S/31E/34	6/16/75	6,700	Hydrocarbon Explor.	Plugged and abandoned, 12/22/75
DOE-1	22S/31E/28	7/28/82	4,057	Stratigraphy	Converted to hydrologic monitoring
D-123	22S/31E/34	--	1,880	Potash Exploration	Plugged and abandoned
D-207	22S/31E/19	--	1,613	Potash Exploration	Plugged and abandoned
ERDA-9	22S/31E/20	6/26/76	2,875	Geo. Exploration	Converted to hydrologic monitoring
H-1	22S/31E/29	6/10/76	856	Hydro. Exploration	7 inches OD casing to 848 feet, cement plug to 831 feet
H-2c	22S/31E/29	2/5/77	795	Hydro. Exploration	6-5/8 inches OD casing to 742 feet, open hole to TD
H-3B1	22S/31E/29	8/12/76	902	Hydro. Exploration	6-5/8 inches OD casing to 891 feet, cement plug to 864 feet
H-5c	22S/31E/15	6/3/78	1,076	Hydro. Exploration	5-1/2 inches OD casing to 1,024, open hole to TD
H-6c	22S/31E/18	6/26/78	741	Hydro. Exploration	5-1/2 inches OD casing to 699 feet, open hole to TD
H-16	22S/31E/20	8/-/87	851	Hydro. Exploration	7 inches OD casing to 469 feet, open hole to TD
H-18	22S/31E/20	10/-/87	831	Hydro. Exploration	7 inches OD casing to 673 feet, cement plug to 766 feet
I-374	22S/31E/30	--	1,538	Potash Exploration	Plugged and abandoned

OD - Outer Diameter
TD - Total Depth

Table DEF-1. Information for Boreholes Within the 16-Square Mile (41-Square Kilometer) WIPP Boundary (Continued)

Borehole No.	Location T/R/SEC.	Completion Date	Total Depth (ft)	Purpose	Comments
I-375	22S/31E/33	--	1,746	Potash Exploration	Plugged and abandoned
I-376	22S/31E/20	--	1,702	Potash Exploration	Plugged and abandoned
I-377	22S/31E/22	--	1,876	Potash Exploration	Plugged and abandoned
I-456	22S/31E/27	--	1,975	Potash Exploration	Plugged and abandoned
I-457	22S/31E/27	--	1,885	Potash Exploration	Plugged and abandoned
P-1	22S/31E/29	9/2/76	1,591	Potash Exploration	Plugged and abandoned; 4-1/2 inches OD casing from 591 feet to 974 feet, plugged with cement
P-3	22S/31E/20	9/7/76	1,676	Potash Exploration	Plugged and abandoned; 4-1/2 inches OD casing from 490 feet to 826 feet, plugged with cement
P-4	22S/31E/28	9/4/76	1,857	Potash Exploration	Plugged and abandoned; recovered all casing, plugged with cement
P-5	22S/31E/17	9/21/76	1,830	Potash Exploration	Plugged and abandoned; 4-1/2 inches OD casing from 435 feet to 1,003 feet, plugged with cement
P-6	22S/31E/30	9/16/76	1,573	Potash Exploration	Plugged and abandoned; recovered all casing, plugged with cement
P-9	22S/31E/33	9/25/76	1,796	Potash Exploration	Plugged and abandoned; recovered all casing, plugged with cement
P-13	22S/31E/18	9/23/76	1,576	Potash Exploration	Plugged and abandoned; recovered all casing, plugged with cement

OD - Outer Diameter
TD - Total Depth

Table DEF-1. Information for Boreholes Within the 16-Square Mile (41-Square Kilometer) WIPP Boundary (Continued)

Borehole No.	Location T/R/SEC.	Completion Date	Total Depth (ft)	Purpose	Comments
P-15	22S/31E/18	10/15/76	1,465	Potash Exploration	Converted to hydrologic monitoring, cement plug from 1465 to 620 ft
P-21	22S/31E/15	10/26/76	1,915	Potash Exploration	Plugged and abandoned; recovered all casing, plugged with cement
WIPP-12	22S/31E/17	12/7/78	3,928	Geo. Exploration	9-5/8 inches OD casing to 1,001 feet; cement plug to 2,784 feet; converted to hydrologic monitoring
WIPP-13	22S/31E/17	8/6/78	3,856	Geo. Exploration	9-5/8 inches OD casing to 1,023 feet; open hole to TD, converted to hydrologic monitoring
WIPP-18	22S/31E/20	4/3/78	1,060	Stratigraphy	5-1/2 inches OD casing to 1,050 feet; cement plug to 1,050 feet; converted to hydrologic monitoring
WIPP-19	22S/31E/20	5/8/78	1,040	Stratigraphy	5-1/2 inches OD casing to 1,035 feet; cement plug to 1,035 feet; converted to hydrologic monitoring
WIPP-21	22S/31E/20	5/27/78	1,045	Stratigraphy	5-1/2 inches OD casing to 1,014 feet; cement plug to 1,014 feet; converted to hydrologic monitoring
WIPP-22	22S/31E/20	5/24/78	1,452	Stratigraphy	5-1/2 inches OD casing to 950 feet; cement plug to 941 feet; converted to hydrologic monitoring

OD - Outer Diameter
TD - Total Depth

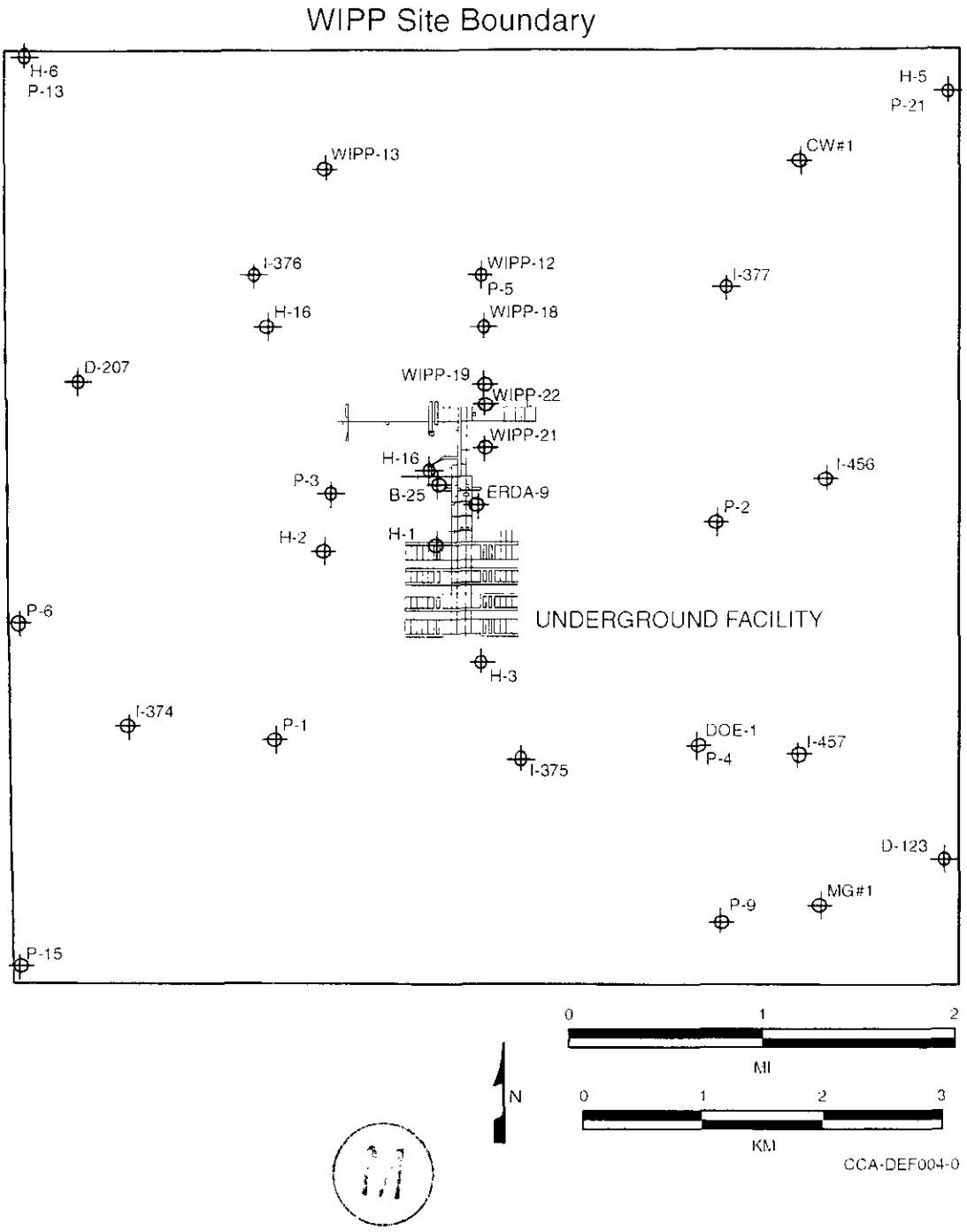

Figure DEF-8. Salado Drillhole Locations Within WIPP Site Boundary

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REFERENCES

Adams, S.S., 1969. "Bromine in the Salado Formation, Carlsbad Potash District, New Mexico," *NM Bureau of Mines and Mineral Resources Bulletin,* 93.

Anderson, R.Y., W. E. Dean, D.W. Kirkland and H.I. Snider. 1972. "Permian Castile Varied Evaporite Sequence, West Texas and New Mexico," *Bulletin of the Geological Society of America*, Vol. 83, pp. 59-86.

Anderson, R.Y. 1978. "Deep Dissolution of Salt, Northern New Mexico." Report for Sandia National Laboratories, Albuquerque, New Mexico. WPO 29527 - WPO 29530.

Anderson, R.Y. and D.W. Powers. 1978. "Salt Anticlines in the Castile-Salado Evaporite Sequence, Northern Delaware Basin, New Mexico," in *Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas*, Circular 159, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico.

Bachman, G.O. 1974. "Geological Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico," *Open File Report 74-194*, U.S. Geologic Survey, p. 81.

Bachman, G.O. 1980. "Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico," *Open File Report 80-1099*, U.S. Geologic Survey.

Bachman, G.O. 1984. *Regional Geology of Ochoan Evaporites, Northern Part of Delaware Basin.* Circular 184, pp. 1–22. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Bachman, G.O. 1985. *Assessment of Near-Surface Dissolution at and near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND84-7178. Sandia National Laboratories, Albuquerque, NM.

Barr, G.E., S.J. Lambert and J.A. Carter. 1979. "Uranium Isotope Disequilibrium in Groundwaters of Southeastern New Mexico and Implications Regarding Age-Dating of Waters," in *Proceedings of the International Symposium on Isotope Hydrology*, International Atomic Energy Agency, Vol. 2, pp. 645-660.

Barrows, L.J., S-E. Shaffer, W.B. Miller and J.D. Fett. 1983. *Waste Isolation Pilot Plant Site - Gravity Survey and Interpretation.* SAND82-2922. Sandia National Laboratories, Albuquerque, New Mexico.

Barrows, L., and J.D. Fett. 1985. "A High-Precision Gravity Survey in the Delaware Basin of Southeastern New Mexico," *Geophysics,* Vol. 50, pp. 825-833.

Billo, S. M. 1986. *Petroleum Sedimentology of the Ochoan Group, Texas and New Mexico.* Abstracts. *12th International Sedimentological Congress*, Canberra, Australia, pp. 30-31.

Borns, D.J. 1983. *Petrographic Study of Evaporite Deformation Near the Waste Isolation Pilot Plant (WIPP).* SAND83-0166. Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D.J., L.J. Barrows, D.W. Powers and R.P. Snyder. 1983. *Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site.* SAND82-1069, Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D.J. 1985. *Marker Bed 139: A Study of Drillcore from a Systematic Array.* SAND85-0023. Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D.J. and S-E. Shaffer. 1985. *Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin.* SAND83-1798. Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D.J. 1987. *The Geologic Structures Observed in Drillhole DOE-2 and Their Possible Origins: Waste Isolation Pilot Plant.* SAND86-1495. Sandia National Laboratories, Albuquerque, New Mexico.

Chaturvedi, L. and J.K Channell. 1985. "The Rustler Formation as a Transport Medium for Contaminated Groundwater," EEG-32. Environmental Evaluation Group, Santa Fe, NM.

D'Appolonia Consulting Engineers, Inc. 1982. "Data Field Report - ERDA-6 and WIPP-12 Testing," report prepared for Westinghouse Electric Corporation and the U.S. Department of Energy, Albuquerque, New Mexico, 7 volumes.

Davies, P.B. 1983. "Assessing the Potential for Deep-Seated Salt Dissolution and Subsidence at the Waste Isolation Pilot Plant (WIPP)," *State of New Mexico Environmental Evaluation Group Conference: WIPP Site Suitability for Radioactive Waste Disposal, Carlsbad, NM, May 12-13, 1983.*

Davies, P.B. 1984. "Deep-Seated Dissolution and Subsidence in Bedded Salt Deposits," [Ph.D. Thesis]. Stanford University, Palo Alto, CA.

Earth Technology Corporation. 1987. *Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP.* SAND87-7144. Sandia National Laboratories, Albuquerque, New Mexico.

Elliot, C.L. 1976. "An Experimental Detailed Resistivity Survey of Known or Suspected Breccia Pipes and Sinkholes, Eddy County, New Mexico." Tucson, AZ: Elliot Geophysical Company.

Elliot, C.L. 1977a. "Evaluation of the Proposed Los Medaños Nuclear Waste Disposal Site by Means of Electrical Resistivity Surveys, Eddy & Lea Counties, New Mexico." Tucson, AZ: Elliot Geophysical Company.

Elliot, C.L. 1977b. "Maps to Accompany Evaluation of the Proposed Los Medaños Nuclear Waste Disposal Site by Means of Electrical Resistivity Surveys, Eddy & Lea Counties, New Mexico." Tucson, AZ: Elliot Geophysical Company.

Gera, F. 1974. "On the Origin of the Small Hills in Nash Draw and Clayton Basin, Southeastern New Mexico," ORNL 74-2-29, Oak Ridge, TN: Oak Ridge Natioanl Laboratory.

Griswold, G.B. 1977. *Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, New Mexico.* SAND77 0946. Sandia National Laboratories, Albuquerque, New Mexico.

Holt, R.M. and D.W. Powers. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP-88-004. U.S. Department of Energy, Carlsbad, New Mexico.

Jarolimek, L., M.J. Timmer and D.W. Powers. 1983. *Correlation of Drillhole and Shatt Logs, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME-3179, U.S. Department of Energy, Albuquerque, New Mexico.

Jones, C.L. 1981. "Geologic Data tor Borehole ERDA-6, Eddy County, New Mexico," *Open File Report 81-468,* U.S. Geological Survey, Denver, Colorado.

Jones, C.L., M.E. Cooley and G.O. Bachman. 1973. "Salt Deposits of Los Medaños Area, Eddy and Lea Counties, New Mexico, *Open File Report 4339-7,* U.S. Geological Survey, p. 67.

King, P.B. 1948. *Geology of the Southern Guadalupe Mountains, Texas.* Professional Paper 215. U.S. Geological Survey, Washington, DC.

Kirkland, D.W. and R.Y. Anderson. 1970. "Microfolding in the Castile and Todilto Evaporites, Texas and New Mexico," *Geological Society of America Bulletin*, Vol. 81, pp. 3259-3282.

Lambert, S.J. 1983. *Dissolution of Evaporites In and Around the Delaware Basin, Southeastern New Mexico and West Texas.* SAND82-0461. Sandia National Laboratories, Albuquerque, New Mexico.

Lambert, S.J. 1978. "Geochemistry of Delaware Basin Ground Water," Circular 159, New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico, pp. 33-38.

Lambert, S.J. and J.A. Carter. 1984. *Uranium-Isotope Disequilibrium in Brine Reservoirs of the Castile Formation, Northern Delaware Basin, Southeastern New Mexico, l: Principles and Methods.* SAND-830144. Sandia National Laboratories, Albuquerque, New Mexico.

Long, G.J. and Associates, Inc. 1977. "Final Report, Waste Isolation Pilot Plant (WIPP), Los Medaños Area, Eddy and Lea Counties, New Mexico," report submitted to Sandia National Laboratories, Albuquerque, New Mexico.

Lowenstein, T.K. 1987. "Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico." EEG-36, New Mexico Health and Environment Department, Santa Fe, New Mexico.

Madsen, B.M. and O.B. Raup. 1988. "Characteristics of the Boundary Between the Castile and Salado Formations Near the Western Edge of the Delaware Basin, Southeastern New Mexico," *New Mexico Geology*, Vol.10, No.1, pp.1-6, 9.

Mercer, J.W. 1983. "Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area, Southeastern New Mexico." Water Resources Investigation Report 83-4016. U.S. Geological Survey, Albuquerque, NM.

Mercer, J.W., R.L. Beauheim, R.P. Snyder and G.M. Fairer. 1987. *Basic Data Report for Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-0611. Sandia National Laboratories, Albuquerque, New Mexico.

Neill, R.H., J.K. Channell, L., Chaturvedi, M.S. Little, K. Rehfeldt, and P. Speigler. 1983. "Evaluation of the Suitability of the WIPP Site," EEG-23, Environmental Evaluation Group, Santa Fe, New Mexico.

Popielak, R.S., R.L. Beauheim, S.R. Black, W.E. Coons, C.T. Ellingson and R.L. Olsen. 1983. *Brine Reservoirs in the Castile Formation, Southeastern New Mexico.* TME-3153, Department of Energy, Albuquerque, New Mexico.

Powers, D.W., S.J. Lambert, S-E. Shaffer, L.R. Hill, and W.D. Weart, eds. 1978. *Geological Characterization Report for the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND78-1596, Volumes I and ll, Sandia National Laboratories, Albuquerque, New Mexico.

Robinson, J.Q. and D.W. Powers. 1987. "A Clastic Deposit Within the Lower Castile Formation, Western Delaware Basin, New Mexico," *Guidebook 18,* El Paso Geological Society, pp. 69-79.

Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982. *Basic Data Report for Drillhole AEC-7 (Waste Isolation Pilot Plant - WIPP).* SAND82-0268. Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories and U.S. Geological Survey. 1979. *Basic Data Report for Drillhole WIPP-11 (Waste Isolation Pilot Plant - WIPP).* SAND79-0272. Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories and U.S. Geological Survey. 1981. *Basic Data Report for Drillhole WIPP-34 (Waste Isolation Pilot Plant - WIPP).* SAND81-2643. Sandia National Laboratories, Albuquerque, New Mexico.

Snider, H.I. 1966. "Stratigraphy and Associated Tectonics of the Upper Permian Castile-Salado-Rustler Evaporite Complex, Delaware Basin, West Texas and Southeast New Mexico," Ph.D. Dissertation, University of New Mexico, Albuquerque, New Mexico.

Snyder, R.P., and Gard, Jr., L.M. 1982. "Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, with Section on Drill-Stem Tests." *Open-File Report 82-968.* U.S. Geological Survey, Denver, CO.

Szabo, B.J., W.C. Gottschall, J.N. Rosholt, and C.R. McKinney. 1980. "Uranium Series Disequilibrium Investigation Related to the WIPP Site, New Mexico. Part I: A Preliminary Study of Uranium-Thorium Systematics in Dissolution Residues at the Top of Evaporites of the Salado Formation, Implications to Process and Time. Part II: Uranium Trend Dating of Surficial Deposits and Gypsum Spring Deposits Near WIPP Site, New Mexico." *Open-File Report 80-879.* Denver, CO: U.S. Geological Survey.

Vine, J.D. 1960. "Recent Domal Structures in Southeastern New Mexico," *Am. Assoc. Petroleum Geologists Bull.*, v. 44, no. 12, p. 1903-1911, 7 figs.

BIBLIOGRAPHY

Sandia National Laboratories and University of New Mexico. 1979. *Basic Data Report for Drillhole WIPP15 (Waste Isolation Pilot Plant - WIPP).* SAND79-0274. Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1982. *Basic Data Report for Drillhole WIPP-12 (Waste Isolation Pilot Plant - WIPP).* SAND82-2336. Sandia National Laboratories, Albuquerque, New Mexico.

Vine, J.D. 1963. "Recent Domal Structures in Southeastern New Mexico." *American Association of Petroleum Geologists Bulletin.* Vol. 44, no. 12, 1903-1911.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix DEL

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Delaware Basin Study

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ACRONYMS

BLM	Bureau of Land Management
CAD	Computer Aided Drafting
CCA	Compliance Certification Application
CFR	Code of Federal Regulations
CRA	Carlsbad Resource Area (BLM)
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EA	environmental assessments
EPA	U.S. Environmental Protection Agency
FR	*Federal Register*
FY	Fiscal Year
IIAP	Inadvertent Intrusion Advisory Panel
IM	Instruction Memorandum
INC	Incident(s) of Noncompliance
KPLA	Known Potash Leasing Area
LMR	Life-of-the-Mine Reserves
LWA	Land Withdrawal Act
MOU	Memorandum of Understanding
NEPA	National Environmental Policy Act
NMAC	New Mexico Administrative Code
NMBMMR	New Mexico Bureau of Mines and Mineral Resources
NMOCC	New Mexico Oil Conservation Commission
NMOCD	New Mexico Oil Conservation Division
NMSA	New Mexico Statutes Annotated
NOS	Notice of Staking
NTL	Notice to Lessee
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RMP	Resource Management Plan (BLM)
RRC	Railroad Commission (Texas)
TDS	total dissolved solids
TRU	transuranic
USDW	underground source of drinking water
WIPP	Waste Isolation Pilot Plant

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APPENDIX DEL

This report discusses factors that are pertinent to determining and evaluating inadvertent and intermittent intrusion into the U.S. Department of Energy (DOE) Waste Isolation Pilot Plant (WIPP) site boundary by oil, gas, and other resource-related drilling. It summarizes the most relevant provisions of the applicable laws and regulations pertaining to compliance by the DOE at the WIPP with U.S. Environmental Protection Agency (EPA) regulations for disposal of radioactive transuranic (TRU) wastes.

DEL.1 Purpose and Scope

The purpose of this investigation is to research and present information relevant to a certification of WIPP compliance with the EPA TRU waste disposal requirements in 40 Code of Federal Regulations (CFR) Part 191 and the relevant certification criteria of 40 CFR Part 194. This information serves as one of several assessments necessary to support the WIPP Compliance Certification Application required by 40 CFR Part 194, Subpart B (61 *Federal Register* [FR] 5224, February 9, 1996). It also supports the performance assessment and compliance assessment required to comply with the EPA environmental standards for disposal in 40 CFR Part 191, Subpart B and the environmental standards for groundwater protection in 40 CFR Part 191, Subpart C.

This report characterizes resource drilling historically accomplished in the Delaware Basin, which is in southeastern New Mexico and southwestern Texas. This report also describes resources in the basin (Section DEL-4), the historic nature, extent, and frequency of drilling for oil, gas, potash, sulfur, and water resources as well as the development and use of the most prevalent oil and gas well drilling technology (Section DEL-5), and federal and state of New Mexico regulations, policies, and problems related to drilling and plugging of oil and gas wells and potash coreholes (Section DEL-6). In addition, the projected rates for potential inadvertent and intermittent intrusion for exploratory oil and gas wells and other types of boreholes over a 10,000-year period are calculated and presented in Section DEL-7.

DEL.2 Regulatory Context

This section provides a context for the inadvertent and intermittent drilling intrusion discussion in the following sections. It summarizes provisions of the EPA radiation protection standards in 40 CFR Part 191, requirements of the WIPP Land Withdrawal Act (LWA), and provisions of the WIPP compliance certification criteria in 40 CFR Part 194 as they pertain to this investigation.

DEL.2.1 EPA Radiation Protection Standards (40 CFR Part 191)

In 1985, the EPA promulgated its radiation protection standards for managing and disposing of spent nuclear fuel, high-level and transuranic wastes,,which apply to management, storage, and disposal of TRU wastes at facilities operated by the DOE, including WIPP (40 CFR Part

191; 50 FR 38084, September 19, 1985). Initially, the standard consisted of two subparts: Subpart A, Environmental Standards for Management and Storage; and Subpart B, Environmental Standards for Disposal. A third subpart was added in 1993: Subpart C, Environmental Standards for Ground-Water Protection (58 FR 66414; December 20, 1993). All three subparts apply to WIPP, although only Subparts B and C are subject to EPA certification, as specified in the WIPP LWA.

Subparts B and C apply to radioactive materials that may be released into the accessible environment resulting from the disposal of TRU wastes; radiation doses received by members of the public as a result of such disposal; and radiation contamination of certain sources of groundwater (40 CFR § 191.11). The containment requirements in 40 CFR § 191.13 provide as follows:

> Disposal systems for . . . transuranic radioactive wastes shall be designed to provide a reasonable expectation, *based upon performance assessments*, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from *all significant processes and events that may affect the disposal system* shall [not exceed certain specified quantities]. (Emphasis added.)

Performance assessments that form the basis for determining compliance with the EPA containment requirements include the following:

(1) identification of processes and events that might affect the disposal system;

(2) examination of the effects of these processes and events on the disposal system; and

(3) estimation of the cumulative releases of radionuclides to the accessible environment over the 10,000-year regulatory period (40 CFR § 191.12).

(The processes and events analyzed in this report are those associated with drilling for resources.) As noted in 40 CFR § 191.13(b), because of the substantial uncertainties involved in projecting how the disposal system will perform in the long-term, performance assessments need not provide absolute proof that containment requirements will be met but only that a reasonable expectation of compliance will be achieved.

Part 191 also includes requirements pertaining to individual (40 CFR § 191.15) and groundwater (Subpart C) protection. Analyses performed to assess compliance with these provisions are called compliance assessments and are limited to the undisturbed performance of the disposal system. Compliance assessment analyses need not include an assumption that someone will intrude into the repository at some future time, but impacts of existing and near future drilling activities must be considered.

TRU waste disposal must also be conducted according to a number of assurance requirements (40 CFR § 191.14). These include but are not limited to the following: maintaining active institutional controls for as long as is practicable (but assuming no more than 100 years in the

performance assessment); designating disposal sites with permanent markers, records, and other passive institutional controls; and using the concept of multiple barriers to isolate the wastes. Active institutional controls include disposal site access control, maintenance and remedial action, release control and cleanup, and monitoring. Passive institutional controls include: permanent disposal-site markers; public records and archives; and government ownership and regulations regarding land or resource use (40 CFR § 191.12). No time limit is imposed in 40 CFR § 191.14 on how long passive institutional controls (including government ownership and resource-related regulations) can be expected to endure.

DEL.2.2 WIPP Land Withdrawal Act

The WIPP LWA (Pub. L. 102 – 579) withdrew 16 sections (10,240 acres; 4,144 hectares) of land from operation under public land laws and transferred administrative jurisdiction from the Department of the Interior (DOI), Bureau of Land Management (BLM) to the DOE for operation of the WIPP disposal facility (Figures DEL-1 and DEL-2). Under §7(b) of the Act, the DOE is prohibited from disposing TRU waste in the WIPP repository until EPA certifies that the facility is in compliance with the 40 CFR Part 191 final disposal standards (Subparts B and C) discussed in Section DEL.1.2.1. Under §8(f) of the act, the DOE must document and the EPA must recertify continued compliance with the disposal standards every five years until the end of the decommissioning phase. Section 8(c) of the WIPP LWA requires the EPA to issue criteria for certification of compliance with the disposal standards in 40 CFR Part 191.

DEL.2.3 EPA WIPP Compliance Certification/Determination Criteria (40 CFR Part 194)

In response to the LWA requirements, the EPA issued criteria for certification and recertification of the WIPP's compliance with the 40 CFR Part 191 disposal regulations. These criteria were published on February 9, 1996 as 40 CFR Part 194 (EPA 1996a; 61 FR 5224). All of the terms (for example, active and passive institutional controls) used in the criteria have the same definitions as those found in the Part 191 regulations. In addition to the Part 194 compliance criteria, the EPA issued a report on March 29, 1996, entitled *Compliance Application Guidance Document for 40 CFR Part 194* (EPA 1996[b]).

The documentation that must be submitted to the EPA by the DOE is in the form of a compliance certification application, the contents of which are specified in 40 CFR § 194.14. This application must include information on the presence and characteristics of potential pathways for transport of waste from the disposal system to the accessible environment including, but not limited to, existing boreholes and other potentially permeable features (40 CFR § 194.14[a][3]).

The 40 CFR Part 194 rule clarifies, for the purposes of certification, the 40 CFR Part 191 definition of performance assessments by stating that the DOE consider both natural processes and events, mining, deep drilling, and shallow drilling that may affect the disposal system during the regulatory time frame (40 CFR § 194.32[a]). Deep drilling is defined as drilling

events in the Delaware Basin that reach or exceed a depth of 2,150 feet (655 meters) (the WIPP disposal horizon) while shallow drilling refers to drilling depths of less than 2,150 feet (655 meters) (40 CFR § 194.2). The following process and assumptions, specified in 40 CFR § 194.33, are to be used in assessing the likelihood and consequences of drilling events.

- Assume that inadvertent and intermittent drilling for resources is the most severe (worst case) human intrusion scenario.

- In the performance assessment, assume that drilling for resources occurs at random intervals in time and space over the 10,000-year time frame.

- Calculate the deep drilling frequency by identifying the drilling that has occurred for each resource in the Delaware Basin over the past 100 years. The total drilling rate is to be derived by summing the drilling rates for each resource.

- Calculate the shallow drilling frequency by identifying the drilling that has occurred for each resource in the Delaware Basin over the past 100 years, considering only the resources of similar type and quality to those in the controlled area. The total drilling rate is to be derived by summing the drilling rates for each resource.

The analysis of the frequency and the consequences of resource-related drilling events over a 10,000-year period is dependent on future state assumptions (40 CFR § 194.25). To foreclose speculation, the EPA requires that compliance applications assume that characteristics of the future remain what they are at the time the compliance application is prepared (40 CFR § 194.25). This assumption applies to human existence and societal conditions and not to geologic, hydrologic, or climatic changes. This means that, for purposes of the 40 CFR Part 194 compliance evaluation, the DOE can assume current drilling technologies, drilling practices, and regulatory requirements will remain consistent with practices in the Delaware Basin at the time this application is prepared (40 CFR § 194.33[c][1]). The assumed future drilling practices include, but are not limited to: types and amounts of drilling fluids; borehole depths, diameters, and seals (plugs); and the fraction of boreholes sealed (plugged) by humans. Although assumptions concerning drilling and plugging regulations are not specified in 40 CFR § 194.33(c)(1), it is apparent that future drilling practices and technologies are in part dependent on and interrelate with federal and state regulations. Regulations are a societal condition under 40 CFR § 194.25(a) and are, therefore, assumed to remain the same.

In addition, provisions applicable to compliance assessment analyses, for the evaluation of compliance with the individual and groundwater protection requirements, are defined in 40 CFR § 194.54. The rule specifies that

> (b) Compliance assessments of undisturbed performance shall include the effects on the disposal system of:

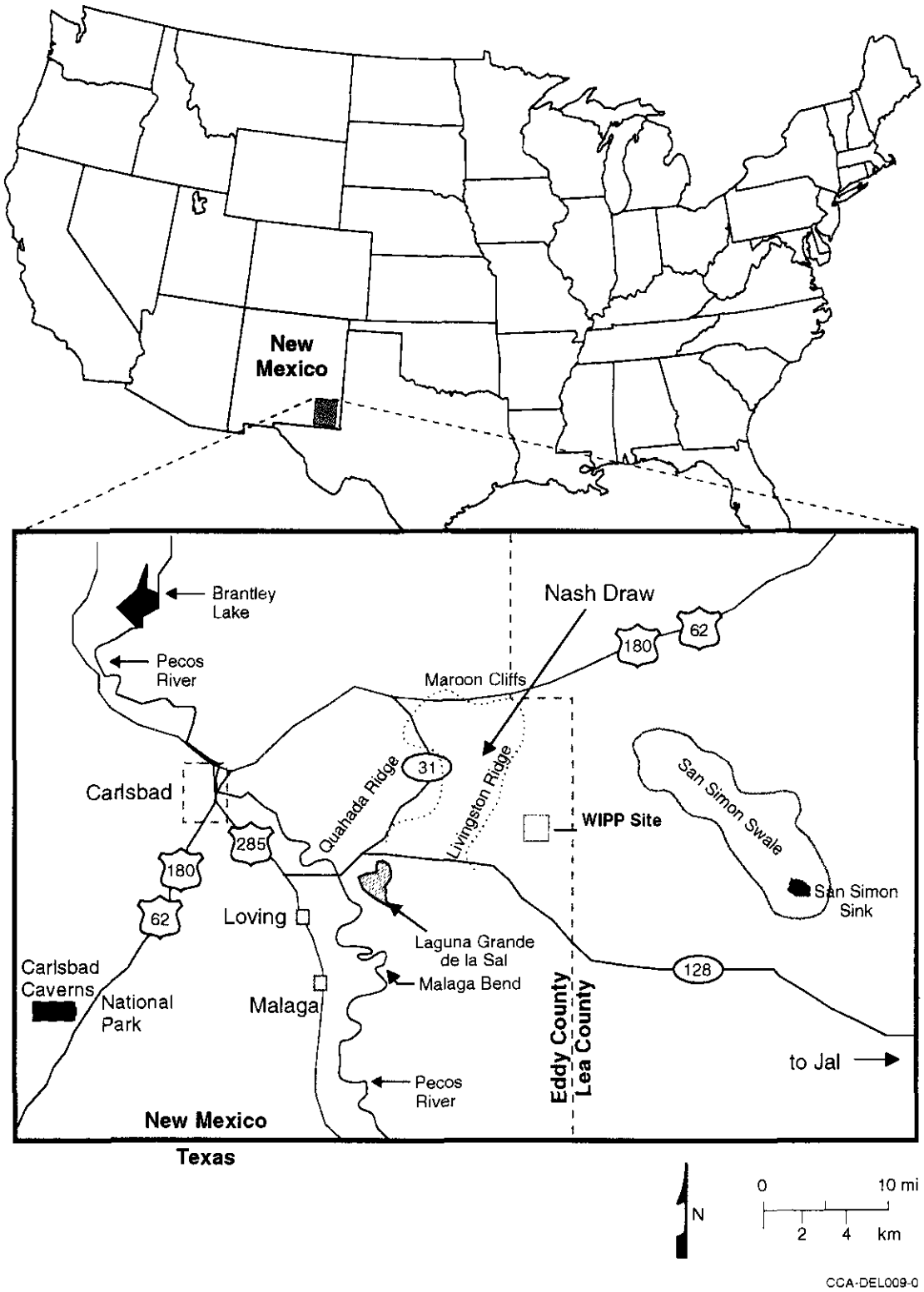

Figure DEL-1. General Location of the WIPP Land Withdrawal Area

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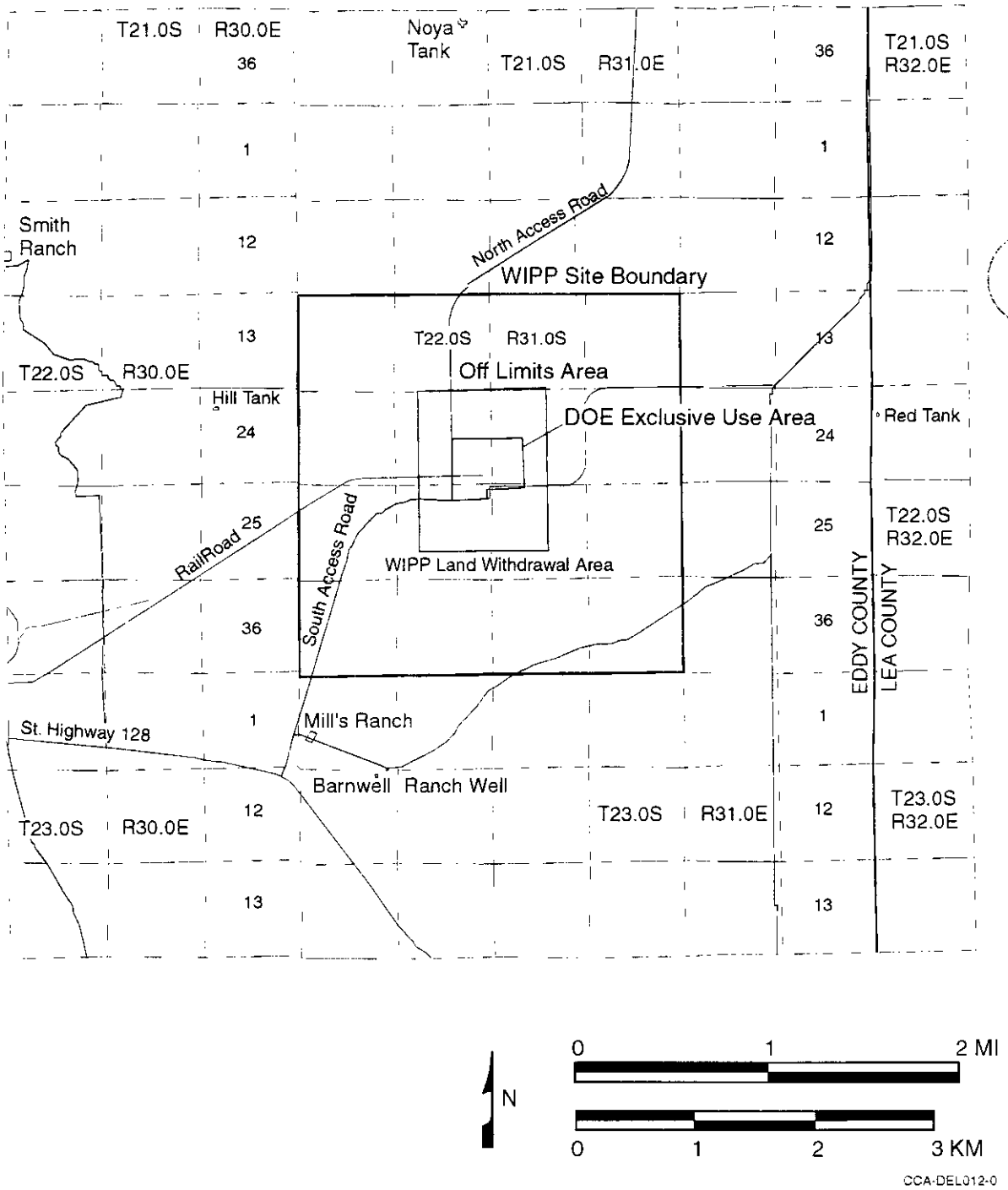

Figure DEL-2. WIPP Land Withdrawal Area

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(1) Existing boreholes in the vicinity of the disposal system, with attention to the pathways they provide for migration of radionuclides from the site; and

(2) Any activities that occur in the vicinity of the disposal system prior to or soon after disposal. Such activities shall include, but shall not be limited to: existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities.

The scope of compliance assessments is addressed by the EPA in its preamble to the 40 CFR Part 194 Final Rule:

> Section 194.54 defines the scope of compliance assessments. Compliance assessments should be conducted of the undisturbed performance of the disposal system, which, by the definition in section 12 of 40 CFR Part 191, denotes that the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.
>
> The Agency recognizes, however, that resource extraction and fluid injection activities which are currently performed in the Delaware Basin can alter the hydrogeologic properties of the initial state of the disposal system. The final rule requires that performance assessments and compliance assessments analyze the effects of all types of fluid-injection and all boreholes which can have an effect on the disposal system and which have been or will have been drilled prior to or soon after disposal. These boreholes shall be assumed to affect the properties of the disposal system for the entire 10,000-year regulatory time frame. Predictions about such future activities shall be strictly limited to the expected use of existing leases.

Compliance assessments of undisturbed conditions for 40 CFR Part 191 Section 15 and Subpart C must consider the effects on the disposal system over the long-term of any borehole drilling activities that are occurring in the vicinity of the disposal system today. Continued occurrence or initiation of new occurrences of the same activities must also be considered, if expected to occur on existing leases given today's conditions, up until the time of shaft sealing. Activities under way at the time of shaft sealing should be assumed to continue to their planned completion. Activities initiated after shaft sealing should not be considered in analyses of undisturbed conditions.

DEL.3 Definitions of Key Terms

The oil and gas industry, and the regulations that govern its activities, have specific terminology which is included as a glossary of terms in this document. Key EPA regulatory terms are also included.

DEL.4 The Delaware Basin and Its Economic Resources

Significant economic resources in the Delaware Basin consist primarily of oil, gas, potash, sulfur, and groundwater. The location of the basin and resources exploration and development activities in the basin are described in this section.

DEL.4.1 Delaware Basin Definition and Location

The Delaware Basin covers 8,920 square miles (23,100 square kilometers). The greatest north-south distance is about 143 miles (231 kilometers) and the east-west distance is about 108 miles (174 kilometers). The basin is shown in Figure DEL-3; it is defined in 40 CFR § 194.2 as follows:

> *Delaware Basin* means those surface and subsurface features which lie inside the boundary formed to the north, east and west of the [WIPP] disposal system, by the innermost edge of the Capitan Reef, and formed, to the south, by a straight line drawn from the southeastern point of the Davis Mountains to the most southwestern point of the Glass Mountains.

The Delaware Basin includes all or part of Brewster, Culberson, Jeff Davis, Loving, Pecos, Reeves, Ward, and Winkler Counties in Texas, and portions of Eddy and Lea Counties in New Mexico (Figure DEL-3).

DEL.4.2 Resources Within the Delaware Basin

Several natural resources are found within the basin, the most notable of which are oil, natural gas, potash, sulfur, and groundwater. The basin's hydrocarbon resources have been the source of successful exploration for over eighty years. Potash and sulfur are present in quantities large enough to be mined profitably. Caliche, gypsum, and halite are also present within the basin, but of these, only caliche is economically extracted at this time.

The New Mexico Bureau of Mines and Mineral Resources (NMBMMR) in its report, *Evaluation of Mineral Resources at the Waste Isolation Pilot Plant* (NMBMMR 1995), evaluated the resources within the Delaware Basin, with the primary area of focus being the area within one mile of the WIPP-site boundary.

DEL.4.2.1 Oil and Natural Gas Resources of the Delaware Basin

Since the first oil well was drilled in the Delaware Basin in 1909, the basin has been a continual source of oil and natural gas. There have been over 11,000 wells drilled for oil or gas in the Delaware Basin in the last 87 years. Exploration within the basin continues (Figure DEL-4).

The hydrocarbon resources of the Delaware Basin consist mostly of oil and associated gas found in the Permian strata and gas condensate in the Pennsylvanian strata. These strata exist beneath the WIPP site and immediately surrounding areas (Figure DEL-5). The majority of oil and gas production around WIPP has been from the following:

- sandstone reservoirs in the Delaware Mountain Group at 7,000 to 8,000 feet (2,134 to 2,438 meters),

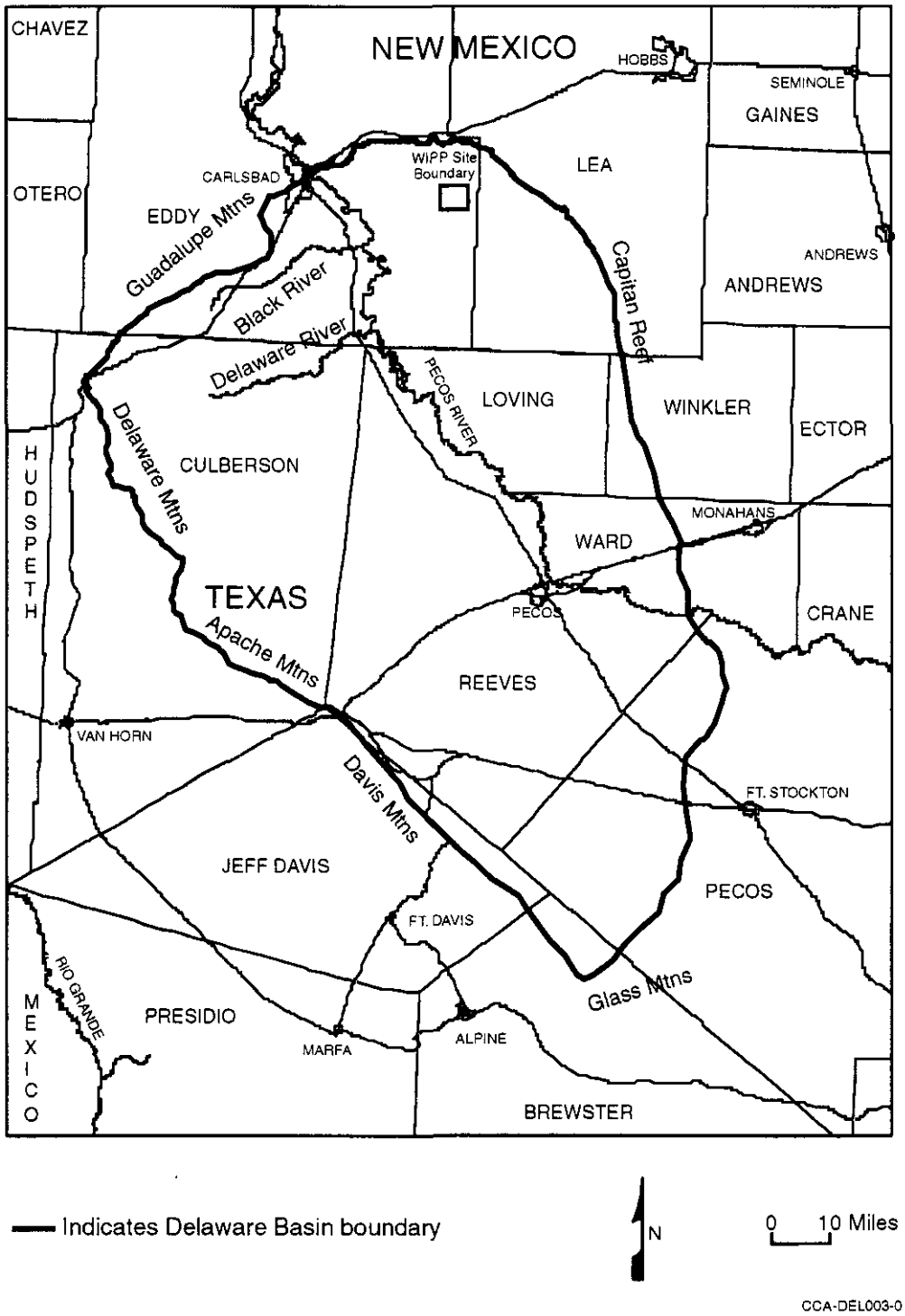

Figure DEL-3. Delaware Basin Boundary

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Figure DEL-4. Oil and Gas Wells Drilled in the Delaware Basin

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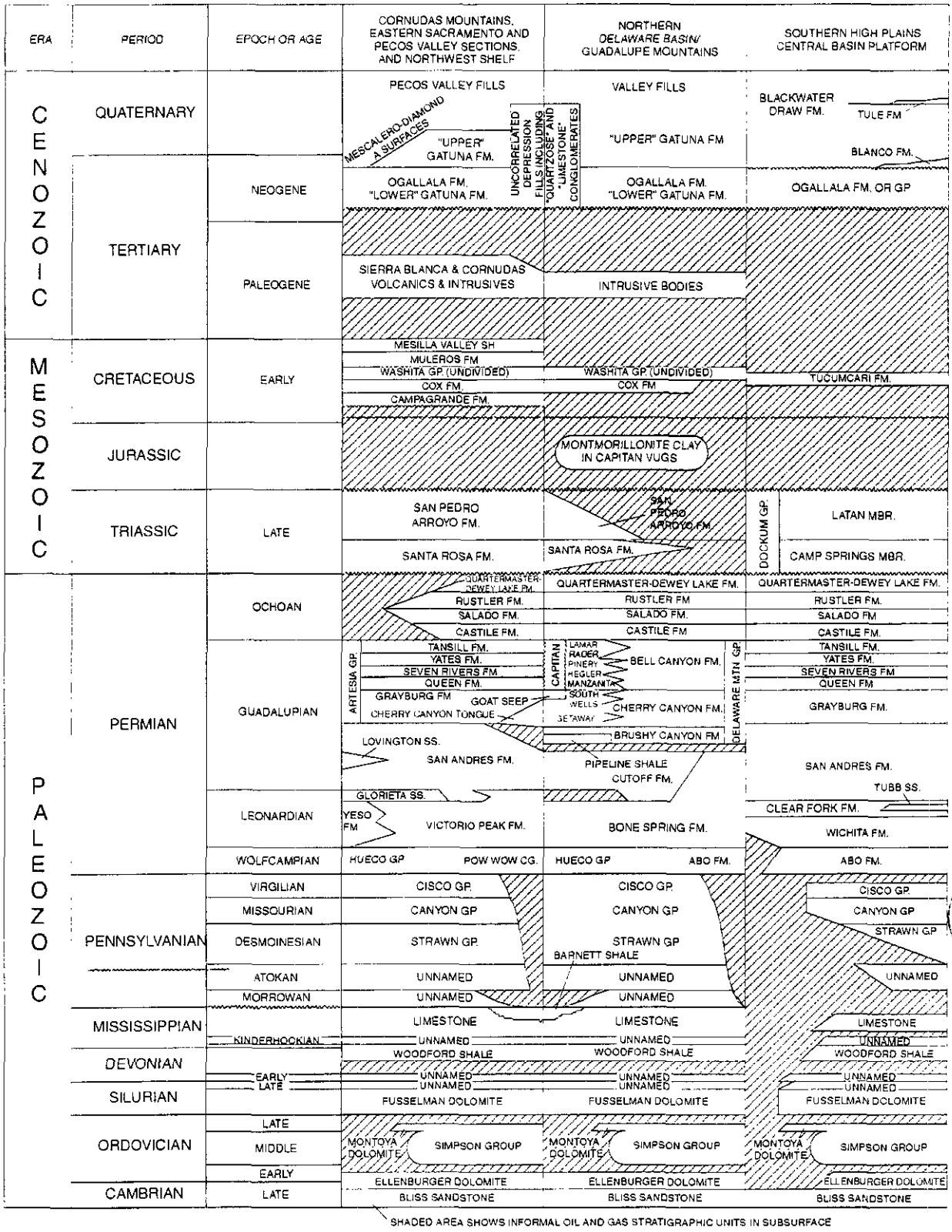

Figure DEL-5. Stratigraphic Nomenclature Chart of the Delaware Basin

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- sandstone and carbonates in the Bone Spring Formation from 8,000 to 11,000 feet (2,438 to 3,353 meters),

- carbonates from the Wolfcamp Group at approximately 12,000 feet (3,658 meters) (secondary oil reservoirs),

- carbonates in the Strawn Group at a depth of approximately 13,000 feet (3,963 meters) (secondary reservoirs of gas and light oil or condensate), and

- sandstone reservoirs of the Atoka and Morrow Groups. These groups are found at 13,000 to 14,000 feet (3,963 to 4,267 meters) and have been the source of most non-associated gas and condensate.

DEL.4.2.2 Oil and Gas Producing Formations of the Delaware Basin

Oil and gas resources occur at various depths within the Delaware Basin. To adequately address these resources and their relationship to the WIPP, it is necessary to discuss each resource as it is found and in which formations each resource is located. Figure DEL-5 provides a generalized stratigraphic cross-section of the oil- and gas-producing formations of the Delaware Basin. The following formation descriptions are from the oldest to the youngest sediments.

DEL.4.2.2.1 The Morrow Group

The Morrow Group is known primarily for production of gas and condensate and is found throughout the Delaware Basin. The Morrow is divided into two sections, the Morrow lime, which is approximately 650 feet (198 meters) thick and the Morrow clastic interval, which is 600 feet (183 meters) to 700 feet (213 meters) thick. Nearly all production in the Delaware Basin comes from the clastic section of the Morrow. Wells within the Morrow, immediately west of the WIPP area, give mixed information regarding the potential for future production of natural gas. The complex nature of Morrow sandstone deposition and trapping mechanisms makes it difficult to determine the probability and quality of any production. It is not uncommon for a Morrow gas well within the Delaware Basin to produce at a relatively high rate for a short period of time and then show dramatically reduced production due to depletion of the gas reservoir. This has been observed in Morrow wells near the WIPP (NMBMMR 1995).

DEL.4.2.2.2 The Atoka Group

The Atoka Group produces both oil and gas. The Atoka is composed of interbedded limestone, sandstone, and shale and is very similar to the Strawn Group in its configuration. Production within the Atoka is well established in the Delaware Basin in both limestone and sandstone reservoirs. All of the productive wells near the WIPP site produce primarily from one narrow and thin sandstone channel. Seven wells located adjacent to WIPP have produced

or are currently producing oil and gas. Estimated production from these seven wells is eight billion cubic feet (2.3×10^8 cubic meters) and 70 thousand barrels (11.1 million liters) condensate. Based on subsurface mapping of the reservoir, it appears that there is excellent production potential near the WIPP (NMBMMR 1995).

DEL.4.2.2.3 *The Strawn Group*

The Strawn Group is a gas producer. Four wells have been completed in this group, three of which appear to be economic producers. They have produced significant amounts of gas and condensate. A new well drilled in late 1993 has revealed what appears to be a significant new Strawn reservoir directly adjacent to the west edge of the WIPP land withdrawal area. With only limited exploration of this group, production capability cannot be accurately calculated, but based on drill stem tests it should be capable of producing similarly to other Strawn wells.

DEL.4.2.2.4 *The Canyon, Cisco, and Wolfcamp Groups*

The Wolfcamp Group produces both oil and gas. The Cisco and the Canyon Groups have been included in the Wolfcamp group following the common oil-field usage of the Wolfcamp sequence (Foster 1974). Wolfcamp pools are producers of non-associated gas in the Delaware Basin and oil and associated gas on the Northwest Shelf and Central Basin Platform. Two oil and gas pools have been discovered within the nine-township area surrounding the WIPP site (See Figure DEL-6). Uneconomic volumes of oil and gas have been recorded from three additional wells. Within the Wolfcamp Group, the Bilbrey Wolfcamp gas pool was discovered in 1985, during a re-entry into an abandoned Morrow gas well. At a depth of from 12,100 feet (3,689 meters) to 12,138 feet (3,701 meters), perforation was completed and the well was acidized. As of December 31, 1993, the well had produced 9,884 million cubic feet (2.8×10^8 cubic meters) of gas and 11,683 barrels (1.9 million liters) of condensate. The Diamondtail Wolfcamp pool was discovered in 1981 by a wildcat well during an unsuccessful attempt to drill for gas in the Morrow and Atoka. The well was perforated, acidized, and fractured between 12,181 feet (3,713 meters) and 12,193 feet (3,717 meters). After completion, it was producing 38 barrels (6,041 liters) of oil per day. The true potential of this pool has not been evaluated by further testing.

DEL.4.2.2.5 *Bone Spring Formation*

The Bone Spring Formation is also an oil-producing unit. Numerous Bone Spring pools in the Delaware Basin have been discovered by re-entering old gas wells in which production from the Atoka or Morrow has declined to subeconomic levels. Many of the exploratory wells leading to the discovery of oil in the Bone Spring Formation had originally targeted structural traps in deeper formations. With the exception of the Red Tank pool, development of known pools within the nine-township area surrounding the WIPP has been limited and is incomplete because operators have concentrated on drilling for deeper gas in the Morrow and Atoka or for shallower oil in the Delaware Mountain Group. Therefore, stratigraphic traps and stratigraphic trends have not been fully defined and the Bone Spring remains inadequately

explored and developed in the area. It is highly likely that numerous significant commercial accumulations of oil and associated gas remain to be found.

DEL.4.2.2.6 The Delaware Mountain Group

The Delaware Mountain Group is an oil-producing unit near the WIPP site. It is subdivided into three formations: Brushy Canyon, Cherry Canyon, and Bell Canyon. In areas adjacent to the WIPP site, production is obtained from the Cherry Canyon and Brushy Canyon Formations with most production coming from the Brushy Canyon (NMBMMR 1995).

The Brushy Canyon Formation has also been a producer of oil and associated gas in oil pools adjacent to the WIPP land withdrawal area. The oil traps are largely stratigraphic sandstones that are the major producers of all the Delaware oil pools adjacent to the WIPP site. The Cherry Canyon Formation wells have been drilled since 1970 and several producing fields exist within the Delaware Basin. The more productive Cherry Canyon wells have estimated recoveries of more than 180,000 barrels (2.86×10^5 hectoliters) of oil per well. The Bell Canyon Formation has been the zone most frequently drilled near the WIPP site. The majority of exploratory oil and gas wells were drilled before 1965 and were in the upper or middle part of the Bell Canyon Formation. Although a large number of these wells had positive oil shows through drill stem or core testing, they were never completed as production wells.

DEL.4.2.2.7 Brushy Canyon Formation

The Brushy Canyon is considered to have five main areas of deposition of oil and gas. The units of this formation have been carefully correlated and mapped. The Livingston Ridge Delaware was discovered in 1988 and the Lost Tank Delaware in 1992. Resources in these pools have been developed rapidly, averaging 25 wells per year since 1991. The Los Medanos Complex was discovered in 1991. Since its discovery, 99 wells have been drilled at depths ranging from 7,900 feet (2,409 meters) to 8,100 feet (2,470 meters). The Cabin Lake Pool was discovered in 1986 and has been developed at an average rate of seven wells per year. The Quahada Ridge Southeast Pool, the most recently discovered, began development in 1993. Development of this pool has been relatively slow with only three wells drilled in 1993 and two more in 1994.

DEL.4.2.3 Oil and Gas Exploration and Production Near the WIPP Site

As late as 1974, the WIPP site and the area within one mile (1.6 kilometers) of the site boundary was not thought to have large petroleum resources located within its boundaries. However, since 1974, successful completion of exploratory wells has demonstrated that profitable quantities of resources are present beneath the WIPP site. Comprehensive well records on file at the New Mexico Oil Conservation Division (NMOCD) show that 532 wells have been drilled in the nine-township area centered around the WIPP site as of 1993, with a large number of these completed after 1974 (Figure DEL-6). Few wells were drilled in the area before 1960. From 1960 to 1989, drilling activity increased but was sporadic, although it

exceeded 20 wells per year. In 1990, however, drilling increased markedly. Annual totals increased to a maximum of 140 wells per year during 1993. Increases in well completions during the 1990s can partially be attributed to the opening to drilling of previously restricted potash areas. The status of oil and gas wells within the WIPP withdrawal area and within 1 mile (1.6 kilometers) of the WIPP site boundary as of April 6, 1994, is shown in Figure DEL-7.

Lower parts of the Delaware Mountain Group were not generally recognized as exploratory and development targets until the late 1980s and early 1990s. Prior to that time, they were bypassed during drilling with little or no thought that they might contain economic oil reservoirs. In the years prior to 1970, the majority of wells drilled near the WIPP were for shallow oil 4,000 feet (1,220 meters) to 4,500 feet (1,372 meters) in the Bell Canyon Formation (NMBMMR 1995). Although these wells were considered exploratory and most were plugged and abandoned, there were many indications of oil in cores and drill-stem tests. Interest in gas wells was limited due to a lack of accessible pipelines and low well head prices. There was some limited success in the Bell Canyon area at Triste Draw, although none of the wells was drilled deep enough to reach either the Cherry Canyon or Brushy Canyon reservoirs which are now productive. Wells drilled after the 1970s and into the early 1980s were for natural gas from the much deeper Morrow and Atoka formations.

Drilling within the 10,240-acre (4,147-hectare) WIPP land withdrawal area has been extremely limited. Only three wells have been drilled for oil and gas within or below the area that was withdrawn for the WIPP site (Figure DEL-7). Two of the three wells drilled during the 1970s were abandoned without ever establishing production. The third well, drilled in 1982, reached the Atoka sandstone reservoir and gas production was established. This well, the Perry R. Bass No. 13 James Ranch Unit, remains productive and to date has produced 4.664 billion cubic feet (1.3×10^8 cubic meters) of natural gas and 27,500 barrels (4.4 million liters) of condensate from a total depth of 13,466 feet (4,105 meters). This well was directionally drilled from a surface location outside the WIPP land withdrawal area to a bottom hole location within the WIPP land withdrawal area. The drilling of this well was allowed as the result of the final judgement on the condemnation of land within Township 22 South, Range 31 East, Section 31.

In 1977, the United States, at the request of the Acting Administrator of the Energy Research and Development Administration, entered into condemnation actions (77-071-B and 77-776-B) for the acquisition of land within Township 22 South, Range 31 East, Section 31, Eddy County, New Mexico. The final judgment of the condemnation hearing allowed the U.S. to acquire the mineral rights for the surface and the underlying 6,000 feet (1,829 meters). The mineral rights below 6,000 feet (1,829 meters) were retained by the leaseholders. The mineral rights to the upper 6,000 feet (1,829 meters) were acquired to ensure that the bedded salt would remain intact and undisturbed by drilling.

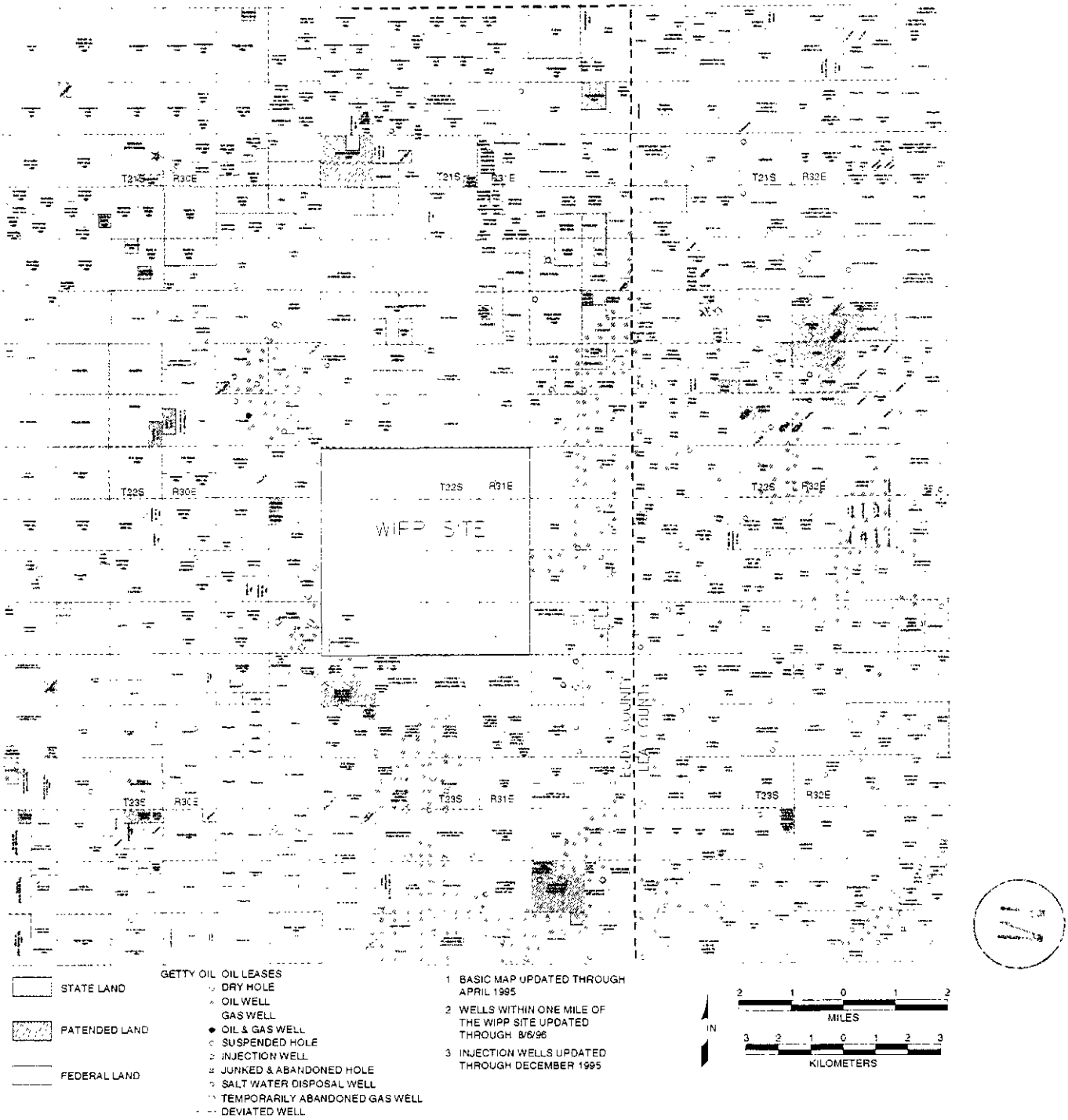

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Figure DEL-6. Oil and Gas Wells in the Nine-Townships Study Area Surrounding the WIPP Site

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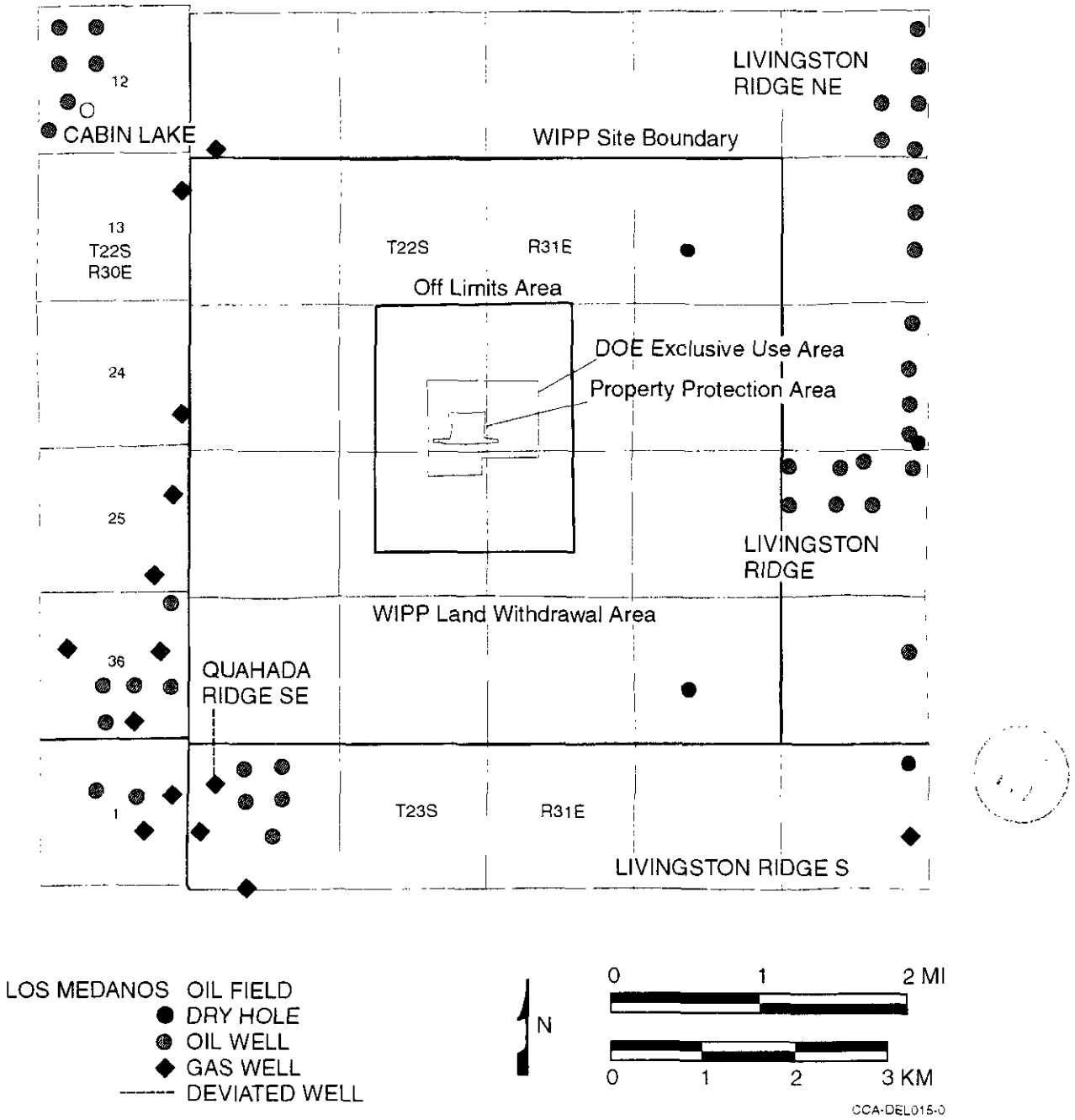

Figure DEL-7. Oil and Gas Wells Within One Mile of the WIPP Site Boundary

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DEL.4.2.4 Potash

Potash was discovered in Eddy County, New Mexico, in 1925 in the Snowden McSweeney Well No. 1 near the center of what is now called the Know Potash Lease Area (KPLA) (Figure DEL-8). The first potash coreholes were drilled in 1926. Potash is second in economic importance among the resources found in the Delaware Basin. It is found primarily in Eddy and Lea Counties of New Mexico which produced 83 percent of the nation's domestic potash in 1992. The BLM Carlsbad Mining District in southeastern New Mexico contains the largest domestic potash reserves (Figure DEL-8). The potash industry of New Mexico produces sylvite and langbeinite.

In March 1995, the NMBMMR completed a comprehensive reevaluation of potash resources within the WIPP land withdrawal area and the area within one mile (1.6 kilometer) of the land withdrawal area. The re-evaluation was based on an examination of 40 existing boreholes in the 36-square-mile (93-square-kilometer) area. This investigation indicated that economically attractive potash reserves are contained within the study area. However, of the 11 recognized potash zones, only the 4th and 10th zones within the area investigated contain economically attractive potash reserves (see Figure DEL-9). Even though these potash reserves have been identified as being present in the WIPP land withdrawal area, the repository itself is located in an area that is either barren of potash or has only minor potash mineralization (BLM 1993). Figure DEL-8 shows the distribution of potash leases within and outside of the Delaware Basin.

DEL.4.2.5 Sulfur

Sulfur appears in the Delaware Basin approximately 50 miles (81 kilometers) south of the WIPP in significant quantities and is considered an economically important resource at that location. There is no sulfur mining activity in the BLM Carlsbad Mining District or in NMOCD Districts 1 and 2.

DEL.4.2.6 Groundwater

The northern portion of the Delaware Basin, where the WIPP site is located, is surrounded by the Capitan Reef Complex which is of Permian age. The inner margin of the Capitan Reef serves as the boundary of the Delaware Basin (Section DEL.4.1 and Figure DEL-3). Within the Basin, a thick sequence of Permian rocks and a thin layer of Triassic rock contain six units that are important to the hydrogeology of the area: Bell Canyon, Castile, Salado, Rustler, Dewey Lake, and Santa Rosa (Figure DEL-5). Of these six units, only the Rustler, Dewey Lake, and Santa Rosa contain groundwaters that can be characterized as an economic resource. A discussion of the occurrence of underground sources of drinking water near the WIPP is provided in Appendix USDW.

DEL.4.2.6.1 Rustler Formation

The Rustler contains the most significant water-bearing zone in the northern Delaware Basin in the Culebra and Magenta Dolomite Members (Figure DEL-5). The groundwater chemistry of the Culebra is extremely variable with total dissolved solids (TDS) concentrations ranging from less than 5,000 milligrams per liter to greater than 200,000 milligrams per liter east of the WIPP site. The use of water from the Culebra is limited due to its varying yields and salinity. Useable water from the Culebra occurs several miles southwest of the WIPP site where the salinity is low enough to provide water for livestock.

The groundwater chemistry of the Magenta is also highly variable, ranging in TDS concentrations from 5,460 milligrams per liter to 270,000 milligrams per liter. Although, within the WIPP land withdrawal area, the general water quality of the Magenta is better than that of the Culebra, its use is very limited near the WIPP site.

DEL.4.2.6.2 Dewey Lake Formation

The Dewey Lake Redbeds overlie the Rustler Formation and underlies the Triassic Dockum Group (Figure DEL-5). Although the Dewey Lake has not normally been found to yield water, there are wells that will produce water in the southwestern to south-central portion of the WIPP site. Wells on the J.C. Mills and Twin Wells ranches south of the site produce water for both domestic and livestock use.

DEL.4.2.6.3 Santa Rosa Formation

The Santa Rosa Formation, which is present over the eastern half of the WIPP site, ranges in thickness from 0 to 300 feet (91 meters) (Figure DEL-5). Water occurrences in the Santa Rosa are very limited (DOE 1991 and DOE 1993).

DEL.5 Well Drilling, Plugging, and Abandonment Practices

This section discusses the current state of drilling technology for oil, gas, potash, and water, with primary emphasis directed at oil and gas well drilling technology. New and evolving drilling technologies are described where they apply. The intent of this section is to describe the current practices within the industry, within the Delaware Basin.

DEL.5.1 Oil and Gas Well Drilling Technology

Various types of drilling rigs, drill bits, and drilling fluids are discussed in this section. New drilling technologies, a typical drilling plan, and drill site preparation are also addressed. A typical oil and gas drilling sequence that might potentially occur in the New Mexico portion of the Delaware Basin is included in Attachment 1.

Figure DEL-8 is a large foldout
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Figure DEL-8. Potash Leases Within and Outside the Delaware Basin

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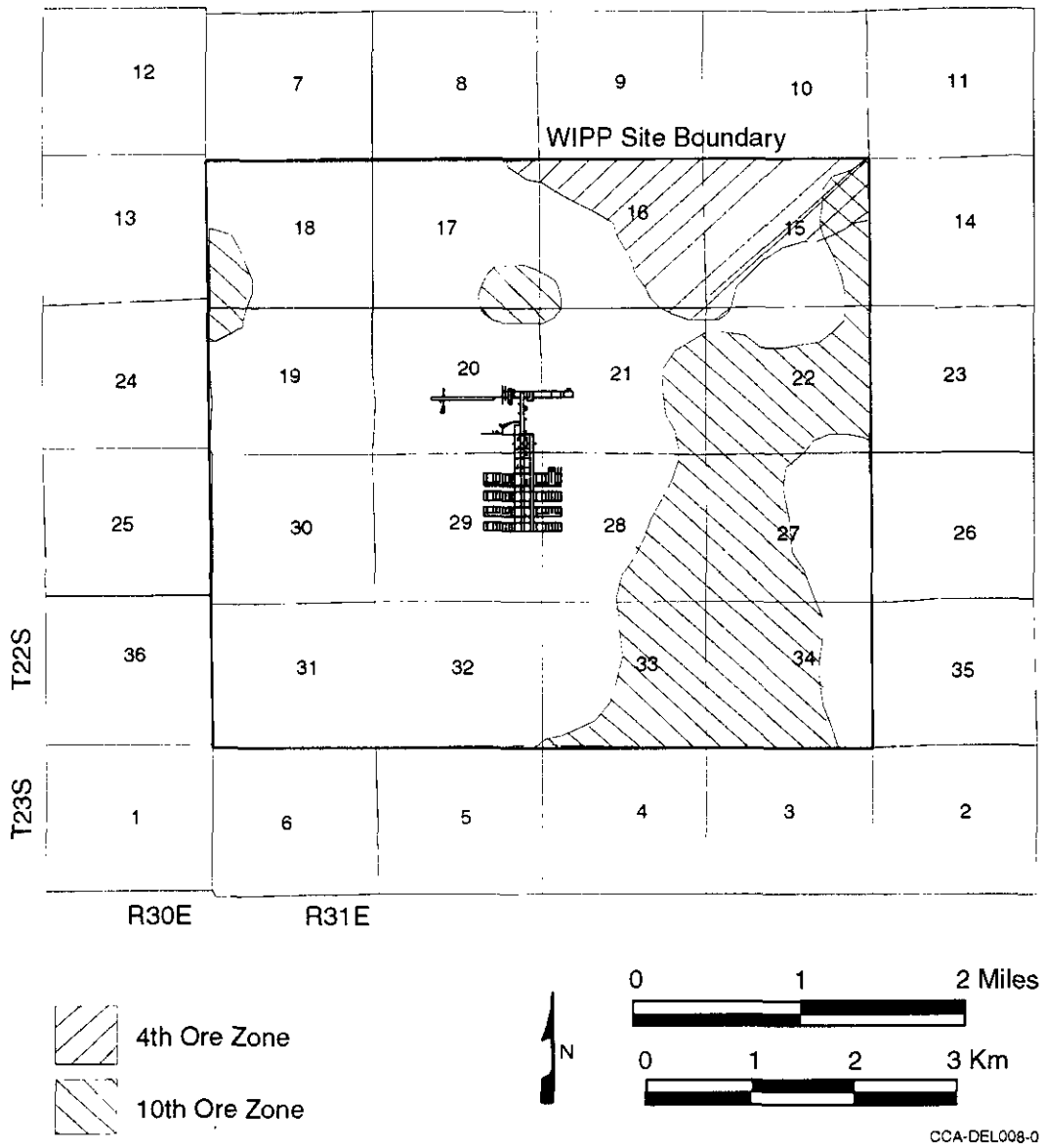

Figure DEL-9. Extent of Economically Minable Reserves of Potash Inside the Site Boundary (Based on NMBMMR Report)

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DEL.5.1.1 Cable Tool Rig

Cable tool rigs were used in early exploration for oil and gas in the Delaware Basin and were the workhorses of the industry in the early years. Cable tool drilling operates on a combination hammer-suction principle. A heavy, sharp-pointed bit is raised and dropped continuously into the hole, so that it chips and breaks the rock away. The bottom of the hole is kept full of mud and water, and the motion of the bit is regulated so that the moment it hits bottom it starts up again, adding the effect of suction to the pounding. Cable tool drilling has been substantially replaced by rotary drilling rigs. Diagrams of both types of rigs are provided in Figure DEL-10.

DEL.5.1.2 Rotary Drilling Rig

The cable tool rig was replaced in the early 1900s by the rotary drilling rig. Rotary rigs make a hole with a boring action rather than punching a hole, as is the case with the cable tool rig. The bit rotates while in constant contact with the rock at the bottom of the hole. Part of the weight of the drill pipe above the bit rests on the rotating bit. This pressure forces the bit into the rock as it turns. Fluid is pumped down the drill pipe and back to the surface to remove rock cuttings produced by the drill bit (Kennedy 1983).

The basic idea of rotary drilling has not changed significantly in more than 75 years, although there have been many improvements in the equipment comprising these rigs. Improvements have brought greater efficiency, greater depth capability, increased safety, and more control over hole conditions and reservoir fluids. The dual-speed top drive drilling rigs were introduced in the early 1980s. Demand for this type of rig has increased worldwide. One of the new dual-speed top drives is rated at 650 tons (590 metric tons). It can handle larger bit sizes and larger drill-string diameters, and reach greater drilling depths. This type of drilling rig offers greater personnel safety because it eliminates the rotary table. Other new tools have been developed to supplement the basic rotary drilling machinery.

DEL.5.1.3 Drilling Fluids

Drilling fluids are an integral part of every drilling program. Rotary drilling rigs and drill bits would not be able to function without drilling fluids, or mud as it is most commonly referred to in the oil and gas industry. The drilling fluids are circulated continuously through the drill pipe, down hole to the bit nozzles, and back up the annulus to the mud tanks on the surface. The drilling fluids pumped through the bit nozzles cause the bit cutters to turn and cut the hole. As the fluid moves out through the drill bit, it carries the cuttings made by the bit to the surface.

Drilling fluids serve several other functions as well. They lubricate and cool the bit, assist in bringing heavier cuttings to the surface, aid in controlling pressures that may exist in formations that are penetrated by the bit, and serve as a source of downhole information.

There are a variety of drilling fluids used in Delaware Basin drilling. Most rotary drilling operations use saturated brine (10 to 10.5 pounds per gallon) as a drilling fluid until reaching the Bell Canyon Formation, where intermediate casing is set. The brine has most often been manufactured by injecting fresh water into the Salado Formation and then pumping the water back to the surface. This process enables drillers to have a constant source of quality brine water. Saturated brine is used heavily in drilling because the intermediate string passes through the Salado Formation, which is salt. Fresh water will cause washout of the salt. Once drilling is continued in harder rock formations, such as the Bell Canyon Formation, materials such as bentonite, barite, or attapulgite are often added to the drilling fluid. All of these materials will increase viscosity and add weight to the drilling fluid column.

In recent years, the increased capacities of circulating systems and improvements in pumping technology have resulted in greater precision in controlling mud flow. Present day drilling fluids have been formulated using complex chemistry to combat specific downhole problems. These additions to fluid technology allow the driller to vary chemical and physical properties of the drilling fluid many times if necessary while drilling an oil or gas well.

DEL.5.1.4 Well Control and Safety

Well control and safety are two of the major concerns related to drilling. Because they are so closely interrelated, one cannot exist without the other. Maintaining a constant downhole pressure during drilling operations is a key factor in controlling an oil or gas well. Detailed well planning is the first step in preventing well control problems. Constant monitoring of drilling variables, use of appropriate equipment, and employment of well-trained drilling crews can significantly reduce the chances of losing control of a well.

Failure to control well pressures can cause major impediments to drilling progress. Loss of control over formation pressures can lead to loss of life, destruction of equipment, and abandonment of the well. Also, a well that has blown out may cause damage to the surrounding environment. These potential consequences have resulted in great emphasis being placed on the design and use of blowout control equipment, personnel training in well control, and regulations aimed at reducing the probability of well blowouts. (Note: A well blowout occurs when an uncontrolled flow of gas, oil, or other well fluids escapes into the atmosphere or an underground formation which is not the source of the pressurized fluid. It occurs when the pressure in an underground formation exceeds the pressure being applied by the column of drilling fluid. [The University of Texas 1991])

DEL.5.1.5 Directional and Horizontal Drilling

Directional, or deviated, drilling has been practiced in the petroleum industry for many years, however, the vast majority of wells are drilled vertically. Drilling rig personnel almost continually monitor drilling activity to maintain a vertical borehole. Occasions arise that call for the borehole to deviate in a direction that may be controlled by the driller. Methods to change direction of the borehole while drilling have changed from the conventional

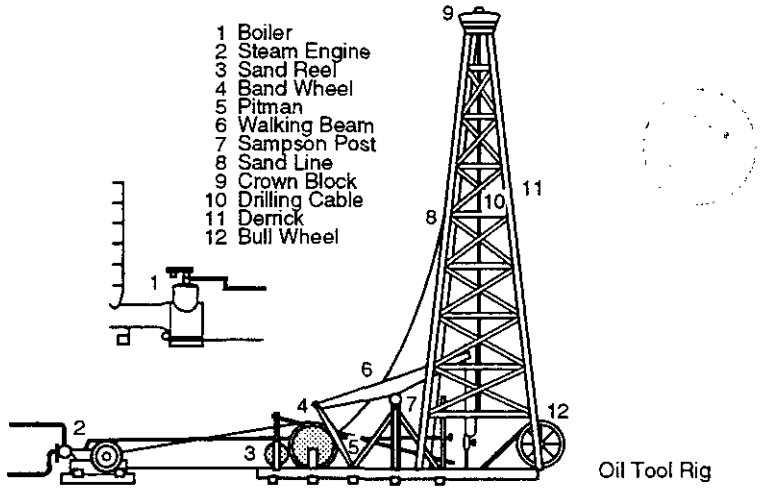

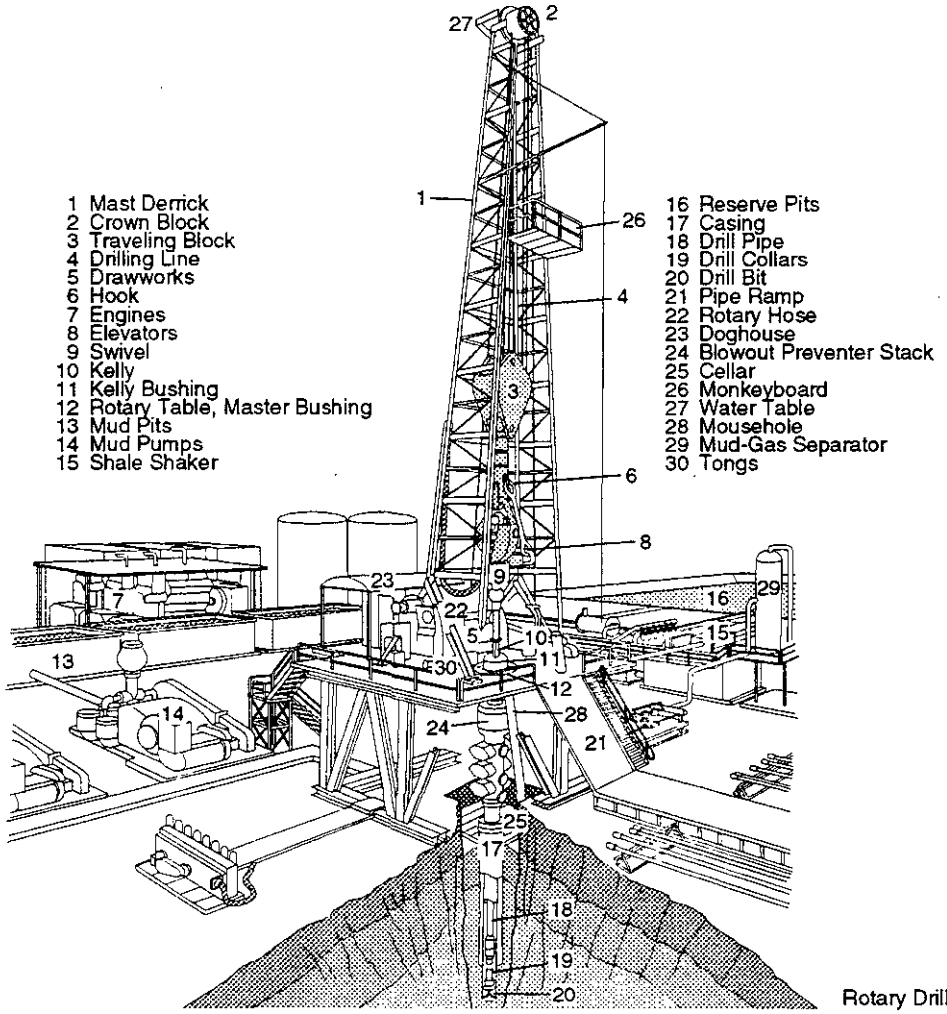

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Figure DEL-10. Cable Tool and Rotary Drilling Rigs

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whipstocking of the 1960s and 1970s to new and more efficient methods. Technical developments since the mid-1980s have made it possible to complete wells that could not have been completed earlier, either for technical or economic reasons. The petroleum industry has placed much emphasis on the drilling, completion, and stimulation of wells through directional drilling. Directional drilling has improved as the result of the development of downhole motors with improved control capabilities that may be steered from the surface. Communication between the downhole and the surface using telemetry allows the driller to know exactly where the bit is and how drilling is progressing. This information is available almost immediately to the driller, whereas before, drilling was delayed until drilled materials were circulated to the surface. This technology makes it possible for the driller to make more accurate adjustments in order to follow the planned pathway to the drilling target.

Horizontal drilling is a new technology that allows a driller to not only directionally drill a well but also to be able to drill horizontally into the chosen drilling horizon thereby exposing more of the formation to production. This technique evolved in the 1980s and has been improved upon since. The ability to open more of the paying zones of a formation allows the producing company to bring more oil or gas to the surface and do so more quickly. Directional and horizontal drilling is not widely practiced, however, as directional drilling may increase the cost of drilling by 50 to 60 percent, while horizontal drilling could double the cost of the well (NMBMMR 1995).

DEL.5.1.6 Other Recent Drilling Technologies

Recent innovations in drilling technologies are important to the understanding of the future states concept in the compliance evaluations; the same drilling techniques used today will be assumed to be used in the future. Several recent developments are summarized below.

- **Measurement and Logging While Drilling.** Measurement while drilling and logging while drilling are two of the fastest growing new technologies and are currently used in the Delaware Basin. These new technologies are capable of providing continuous sampling of data through downhole sensors positioned close to or at the bit. The data collected downhole are then transmitted to the surface through the drilling fluid, inside the drill string, using pressure impulses. Impulses are analyzed at the surface. Recorded parameters can be monitored at the surface for better control of operating conditions and wellbore direction as well as lithological information. Measurement while drilling data are collected to ensure continuous surveying, monitoring, and control. Logging while drilling collects data on porosity, resistivity, gamma ray, and caliper measurements to ensure better control of the drilling zone and wellbore status. This information can be combined into an excellent guiding tool.

- **Oil and Gas Well Cementing.** Improvements have been implemented in recent years in well cementing, particularly with regard to the use of cement additives. The use of additives has reduced the permeability of the cement behind the well casing. Gas migration in the annulus between the casing and the formation has been eliminated as

a result of the addition of four new cement additives: ironite sponge, XC-polymer, synthetic rubber, and Anchorage clay. Ironite sponge eliminates the micro-annulus between the casing and cement body by magnetically bonding the casing with the sponge. XC-polymer is a filtrate control agent. Anchorage clay reduces the permeability of cement by blocking pores. The addition of synthetic rubber compensates for the expansion and contraction cycles that are set in motion during the setting of the cement.

These improvements in cementing technology have a positive impact on wells completed in the Delaware Basin. The use of impermeable cement minimizes the threat of gas leaks. Cement with low permeability eliminates the formation of both micro-cracks and a micro-annulus. When used with dual-wall casing, it significantly reduces gas migration.

Drill pipe metallurgy has also improved, effectively combating corrosion and enabling the pipe to withstand the stresses resulting from extreme temperatures, pressures, and depths. Pipe handling tools and downhole equipment have been developed to meet specific needs.

Several changes in rotary drilling have been studied and some have been field tested. Currently, none of these new ideas has been competitive with conventional drilling techniques. Two new techniques that have been tested, high-pressure water jetting and abrasive jetting, still use mechanical energy to remove rock from the bottom of the hole. These new methods are significant departures from the conventional rotary method because of the need for specially-designed equipment. Successful field testing of these new techniques has been conducted but neither method is used routinely.

DEL.5.1.7 Developing a Drilling Plan

A typical scenario for an oil or gas well in the WIPP area would begin with a well planning process that would forecast the potential production zones encountered along with their expected depths (see Section DEL.6.1.1 for additional details). The forecast would be prepared using the results of gravity, magnetic or seismic surveys, or data obtained from offset wells. Commercial companies as well as the NMOCD and BLM would be consulted for information. Records maintained by drilling companies would be reviewed for information on hole and casing size, setting depth, formation pressures, mud types and weights, general characteristics, and any drilling problems that had been observed at previous wells in the area.

Once this stage of well planning was completed, the selection of hole and casing sizes and setting depths would be determined. A typical well completion is shown in Figure DEL-11. A well drilled in the Delaware Basin would have the first casing string set and cemented above the projected top of the salt section. Surface casing would typically be set and cemented from the surface to a depth of 400 feet (122 meters) to 800 feet (244 meters). The second (intermediate) casing string would be set and cemented below the base of the salt. Near the WIPP, this interval would be from the surface down to between 3,800 feet

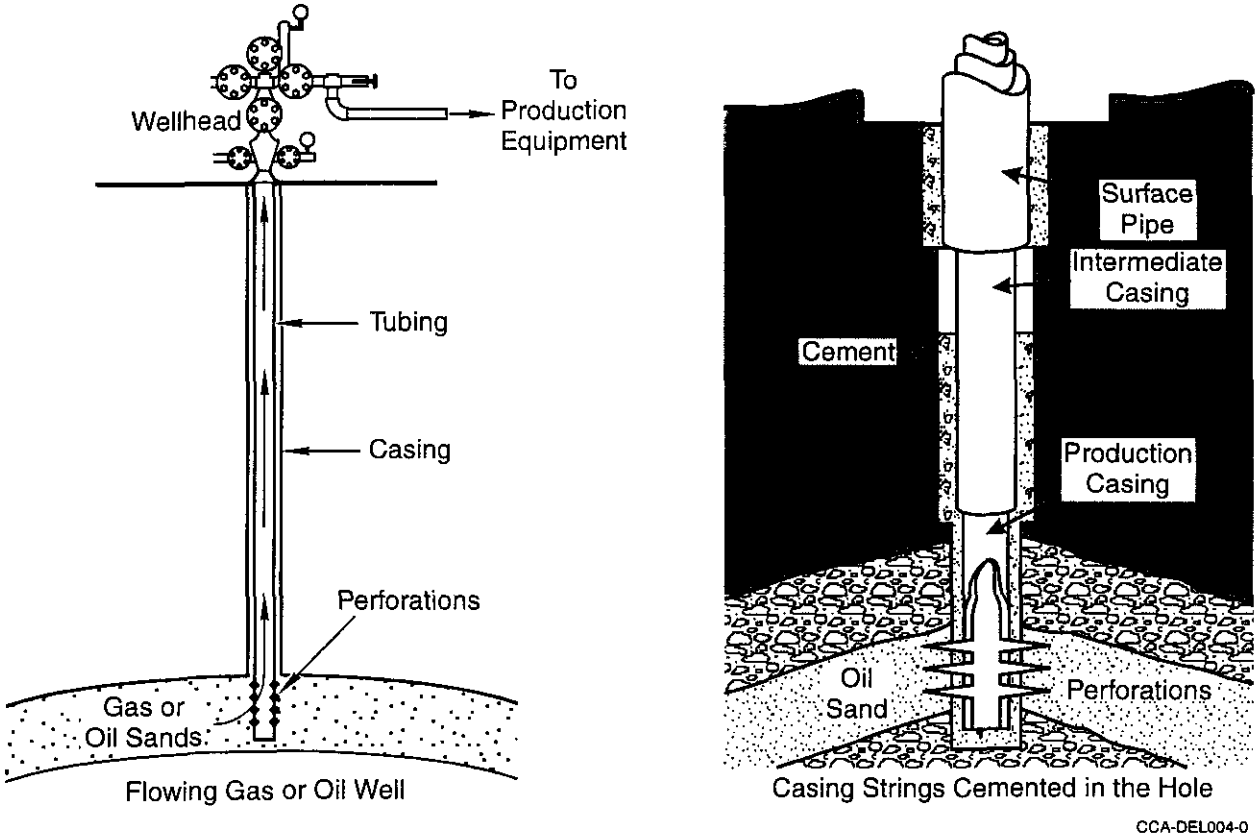

Figure DEL-11. Typical Well Completion

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(1,159 meters) and 4,200 feet (1,280 meters). The production casing string would be run from the surface to the total depth once drilling was completed.

Selection of the proper well casing weights and grades for the well is based on several considerations. The casing pipe must have sufficient wall thickness and steel strength to support the weight of the pipe as it is run into the hole. A safety factor must be added to both pipe and the pipe connections because of the possibility of the pipe sticking while it is being run into the hole. Pressure burst and collapse ratings must be calculated for the hole as they bear on the selection of casing weight and grade.

The type of cement, additives, and volumes must be selected for each casing string. Each casing string must be considered separately. The volume of cement for the intermediate and production string would be based upon bonding to the cement of the preceding casing string. The well plan would also include a cement bond log to indicate the effectiveness of the cementing of the casing strings.

The selection of a drilling mud system is critical to the drilling plan. Factors that must be considered include

(1) counterbalancing formation fluid pressures;

(2) efficient removal of rock fragments from the hole, including suspension of rock fragments when circulation stops;

(3) cooling, lubrication, and prevention of corrosion of the drill pipe and bit; and

(4) minimizing formation damage during the drilling process so that maximum information may be obtained from the formations as they are penetrated.

DEL.5.1.8 Drill Site Preparation

Following the completion of a drilling plan, a drilling site is selected by the operator. Upon final approval to drill, the location is surveyed and staked, and the drilling contractor is authorized to initiate construction. Information critical to construction of the drilling site (for example, location, dimensions, placement of the cellar, locations of the mouse and rat holes, and the layout of the reserve pit) is collected.

The size of a typical oil or gas well drilling pad is 300 feet by 260 feet (91 meters by 79 meters) with an additional 150 feet by 150 feet (46 meters by 46 meters) area for the reserve pit. Once the location of the pad is established, it is excavated to the underlying caliche layer and leveled. Caliche is hauled to the site by truck and compacted as necessary to establish a stable base. When the drilling pad is completed, a cellar is constructed over the intended wellbore. The cellar is excavated with final dimensions of about 8 feet by 8 feet by 6 feet (2.4 meters by 2.4 meters by 1.8 meters) and lined with either concrete or heavy wooden

timbers. An auger contractor then drills a starter hole to a depth of 40 to 80 feet (12 to 24 meters). A conductor pipe ranging in diameter from 20 to 30 inches (50.8 to 76.2 centimeters) is then set and cemented in place. The diameter of the conductor pipe is determined by the casing size selected for the well.

Reserve pits are then constructed at a point adjacent to the cellar. The reserve pits are excavated to a depth of from 4 to 6 feet (1.2 to 1.8 meters) with a berm constructed around the outside of the pit. The reserve pits are lined with 0.2 to 0.5 mil (0.005 to 0.0127 millimeters) plastic. The plastic liner is required by the NMOCD to prevent possible contamination of groundwater by drilling fluids that are circulated into the pit during the drilling operations.

At this stage, the location is ready for the drilling rig to arrive and be set up for drilling operations. The rig size and type selected to drill the well is determined based on hole size and anticipated total depth of the well. Factors considered in the selection of the appropriate rig are horsepower, hoisting capability, derrick and substructure capacity and height, pumps, and well control equipment. The rig size normally selected for drilling in the WIPP area is one with a drilling depth capacity of 7,000 to 15,400 feet (2,134 to 4,695 meters). After selection of the proper drilling rig, the drilling contractor moves onto the location and begins drilling operations. A typical oil or gas drilling sequence for drilling that might occur in the Delaware Basin in the future is included as Appendix A.

DEL.5.1.9 Well Completion

The final stage of the oil or gas drilling process is completion of the well (Figure DEL-11). A pulling-unit is moved onto the location and set up over the wellbore. An engineering completion company runs a cased hole log of the well. This log is compared to the open hole log and areas within the selected formation are selected for perforation. In most instances, standard 4-inch (10-centimeter) perforation guns are loaded at a shot-density determined by the completion engineer. The perforation guns are then run into the hole to the depth selected for perforation. (Note: Perforation involves puncturing or piercing the casing wall and cement in a wellbore to provide holes through which formation fluids may enter the wellbore. It is accomplished by lowering a perforating gun into the well which fires electrically detonated bullets or shaped charges.)

When the completion company is confident that the perforation guns are at the correct depth, casing perforation is completed. After perforation of the casing, the well could receive further stimulation by fracturing or acidizing the wellbore at the site of the perforations to begin or improve production. During these operations, sand and acid are pumped under high pressures through the perforations into the formation. Sand pumping and acidizing cause fracturing of the formation and can increase porosity and permeability, thereby enhancing the production of oil or gas.

DEL.5.2 Drilling of Potash Coreholes

Potash coreholes are drilled for the purpose of locating potash reserves. Diesel-powered wireline and conventional core drill rigs are used for potash exploration. With this equipment, conventional rotary drilling procedures are used to bore to the top of the potash-bearing section. Cores are then cut with a face-discharge bit that is set with diamonds. Cores are typically 2.25 inches (6 centimeters) in diameter. A double-tube core barrel through which drilling fluid is circulated between the inner and outer tubes is used to core the desired areas. The drilling fluid is usually composed of saturated sodium and potassium chloride brine to which starch, gel, and diesel fuel is added. Cores are usually cut in 10 or 20 feet (3 or 6 meter) lengths. These cores provide the potash industry with valuable data in determining the presence of mineable potash as well as the type and grade of the potash.

Before potash coreholes are drilled, the mining company must contact the State Land Office and secure a right-of-way if the cores are to be taken from land currently held by the mining company through a lease. If the land that the mining company plans to core drill is not held by lease, a prospecting permit must be obtained from the State Land Office. Once the permit is obtained, the mining company must then submit a sundry notice of intent to drill to the State Engineer's Office. This notice is usually accompanied by a second notice of intent to plug or abandon. Both of these notices are required by the State Engineer. The mining company submits both forms before drilling any coreholes.

When the corehole has been drilled and all cores removed, the corehole is usually filled with cement before the drilling rig is moved to the next coring site. As a result of this, potash coreholes are expected to have no effect on the performance of the WIPP.

DEL.5.3 Drilling of Water Wells

Water wells must be drilled by a company or individual licensed by the State Engineer's Office. The driller is required to post a bond.

The typical sequence of activities for drilling a water well is initiated with the construction of a drilling pad with two pits, a mud pit, and a settling pit. A truck-mounted rotary drilling rig or a cable tool rig is then moved in and set up over the selected drilling site, after which drilling with mud or air is initiated.

When mud is selected as the drilling medium, the mud pit is filled with the appropriate drilling fluid. The mud is then pumped from the mud pit through the bit. The mud serves to drive the drill bit rotary cutters, cool the drilling bit, and circulate cuttings through the annulus to the surface and into the settling pit. Upon hitting water, the mud is used to flush cuttings from the hole. The well is then completed.

In drilling with air, the air performs the same function as mud. Air cools the bit and moves cuttings to the settling pit. The mud pit, however, is left dry until water is hit. Once water has

been encountered, the mud pit is filled and the mud is used to flush cuttings from the hole. The well is then completed.

Well completion typically consists of placing a 25-foot (8-meter) length of steel well screen casing at the base of the well within the area where water is found. The steel screen is slotted, with the slots usually being 0.02 inch (0.05 centimeter) wide. This size is used because the casing is packed internally with gravel; the slots must not be large enough to allow the gravel to pass through. The remaining wellbore is cased and cemented to the surface with 3 feet (1-meter) of casing above ground level. A 10-foot (3-meter) layer of sand is deposited on top of the gravel inside the casing; this sand filters water as it rises in the well. Depending upon the depth of the water well, either polyvinyl chloride (PVC) or steel casing is installed to the surface.

Water wells that exceed 500 feet (152 meters) must be cased with steel because PVC is not sufficiently strong to withstand the weight of the casing. Also, the pressures become too great at that depth. Further, the bottom hole temperatures at that depth, combined with heat generated through hydration of cement used in casing the well, may actually melt the PVC. After cementing and packing, a submersible pump is installed in the well to allow water to be pumped to the surface for its intended use. When water wells are abandoned, the State Engineer's Office designates how the well will be plugged and witnesses the plugging activities.

DEL.5.4 Development of Injection and Secondary Recovery Wells

A permit is required from the NMOCD for any well used to inject gas, air, or water for secondary recovery or for water disposal. The regulation of injection wells is discussed in Section DEL.6.3. When injection well permits are granted, the NMOCD maintains close control over each well by requiring that annual casing-integrity testing be conducted and tracer surveys run to ensure that injected fluids are being pumped into the proper formations and they are not endangering any underground source of drinking water.

The most common type of injection well is for brine produced from the producing formation in oil and gas wells. Salt water disposal wells have become necessary as a result of the EPA's ruling that formation water may no longer be disposed of on the surface. All producing oil and gas wells produce water along with oil or gas. This water is now disposed of by injecting it into approved salt water disposal wells.

Waterflooding is the most common form of secondary recovery. This method involves the pumping of water through the existing perforations in a well in which production has decreased sufficiently to merit stimulation. As the water is pumped into a formation, it stimulates production of oil or gas in other nearby wells. This is a proven method of recovering hydrocarbons that otherwise would be unretrievable.

Waterflooding has been a popular form of secondary recovery for over 40 years. In its early stages, there was little or no monitoring of this process. More recently, it has been determined that waterflooding is responsible for a number of environmental problems related to groundwater. Since the late 1970s, strict control of waterflooding has been enforced. Section DEL.6.3.3.4 provides information on the regulation of waterflooding in the Delaware Basin.

DEL.5.5 Well Plugging and Abandonment Practices

This section addresses the technology associated with well plugging and abandonment. While the focus is on oil and gas wells, the plugging of potash coreholes and water wells is also described.

DEL.5.5.1 BLM Oil and Gas Plugging and Abandonment

The BLM regulations on oil and gas plugging and abandonment in 43 CFR § 3162.3-4 and Oil and Gas Order No. 2 are discussed in detail in Section DEL.4.1.2.2. This section serves as a supplement to that discussion.

DEL.5.5.1.1 Oil and Gas Well Plugging Sequence

The first step in plugging and abandoning a well is the submission of the Sundry Notice (Form 3160-5, Attachment 2) that informs the BLM of the operator's intent to abandon the well. This form must include a plan by the operator detailing exactly how the well will be plugged. BLM inspectors will review and approve the plan as presented or make modifications which the operator must follow.

The operator must provide a 24-hour notice to the BLM before beginning abandonment operations in order to allow BLM personnel an opportunity to witness the operation. BLM does not consider the plugging and abandonment procedure completed until a surface cap has been welded on the opening to the casing, a 4-inch (10 centimeter)-diameter pipe, 10 feet (3 meters) long, has been embedded in cement and extended 4 feet (1 meter) above ground level, and the cellars have been filled to the surface. When all phases of the abandonment are complete and have been inspected, the well plugging bond may be released (see Section DEL.6.1.5).

Plugging operations are typically carried out using a pulling unit (a truck with a large mounted derrick). The pulling unit sets up over the wellbore and is used to complete the plug and abandonment operation. The first step in the plugging process is to set the required cast iron bridge plug at the depth shown in the plugging plan as approved by the BLM. The point of placement for the bridge plug is just above the uppermost production perforations in the casing. Once the bridge plug is in place, the pulling unit operator will tag the bridge plug (touch the top of the plug with the tubing) to make certain that it is set at the correct depth as specified on the plugging plan contained in Form 3160-5 (Attachment 2).

When the proper depth is confirmed, a minimum of 25 feet (8 meters) of cement is placed on top of the bridge plug. The operator will then fill the borehole with at least nine-pound mud or brine water, filling the borehole to the site of the next plug location. The viscosity of the mud allows the operator to then pump a type C or H cement through the tubing to its correct depth on top of the mud. The mud column will support the weight of the cement until it sets up. The operator, if required by the BLM, will again tag the top of the cement to verify both the position and length of the plug.

While the NMOCD has inspection personnel on site in every instance to verify this process, the BLM elects to witness only selected plugging operations. The process of setting plugs will continue in the same manner until each of the plugs identified on the plugging plan has been properly placed. At this point, plugging operations are complete. The only remaining requirement to complete the plug and abandonment operation is that of returning the drill pad to a near-original state. This process may be completed in only a few days or possibly up to several months after plugging has been completed.

DEL.5.5.1.2 *Plugging of Temporarily Abandoned Wells*

Wells may be temporarily abandoned for up to five one-year periods with BLM approval (see Section DEL.6.1.2.3). A Sundry Notice must be submitted requesting temporary abandonment (Form 3160-5, Attachment 2). The notice must include a description of the abandonment procedure, a complete wellbore diagram, and the anticipated date the operations will occur. As with plugging and abandonment, this plan must be reviewed and approved by BLM inspectors. Once approved, a 48-hour notice must be given to BLM to allow an opportunity for the plugging inspection. Operators must install a bridge plug or a cement plug 50 to 100 feet (15 to 30 meters) above the perforations. If a cement plug is chosen, it must be tagged to make certain it is at the proper depth. Bridge plugs are set using a wireline with the proper depth being verified before the plug is set.

The integrity of the casing must be also be verified. If testing indicates problems with the casing, repairs must be made before the well may be temporarily abandoned.

DEL.5.5.1.3 *Plugging in the Potash Resource Area*

BLM requirements for plugging and abandonment in the potash areas are the same as in non-potash areas. Although the BLM has not overseen the plugging of any oil or gas wells in the potash area in a number of years, the requirements of the New Mexico Oil Conservation Commission (NMOCC) Order R-111-P (see Section DEL.6.2.4) will be considered at the appropriate time (Personal Communication 1996a). According to the Secretary of the Interior Order of October 28, 1986 (51 FR 39425), on oil, gas, and potash leasing, the BLM will cooperate with the NMOCD in implementing state rules and regulations although the BLM will make the final decision.

DEL.5.5.1.4 Most Common Technical Violations

Large national oil companies and large independent companies normally comply strictly with the oil and gas well plugging requirements. Large businesses, which have the necessary resources to properly plug and abandon their wells, typically contract with other large businesses to perform their plugging operations. It has been BLM's experience that these companies follow sound business practices and wish to remain in good standing with the BLM. Smaller independent operators are more likely to lack resources to respond as quickly to the BLM and may not plug a well with the same expertise that a larger established company might have. The BLM is aware of situations that pose a potential for improper plugging. If the agency has a concern regarding a contractor's methods, BLM personnel are present during the entire plugging operation (Personal Communication 1996b).

Plugging bonds are required to ensure that wells are plugged and abandoned properly and within a reasonable time frame (see Sections DEL.6.1.5 and DEL.6.2.1). Both NMOCD and BLM have experienced higher rates recently of what they refer to as orphan wells. These are wells that should be plugged and abandoned, but owners of these wells cannot be located. When this occurs, plugging of these wells becomes the responsibility of the agency upon whose land they are located. Both agencies have orphan well plugging funds that are funded partially through plugging bonds that have not been returned and money from their operating budgets. These orphaned wells are a matter of concern to both agencies and they are working to conserve financial resources for plugging.

DEL.5.5.2 State of New Mexico Oil and Gas Well Plugging and Abandonment

The NMOCD regulations on well plugging and abandonment are discussed in Sections DEL.6.2.2 and DEL.6.2.3. They are similar in many respects to the BLM requirements.

DEL.5.5.2.1 Plugging Outside the Potash Resource Area

The major distinction between NMOCD and BLM practices is that NMOCD witnesses every well plugging and abandonment operation on state and private land, whereas the BLM is only able to witness approximately 50 percent of the plugging operations on federal leases. Both agencies require sundry notices to be filed with an abandonment plan and both agencies review and approve or modify those plans.

DEL.5.5.2.2 Plugging Within the Potash Resource Area (R-111-P)

Operators must follow the same procedures within the potash enclave as they do in other areas, with the exception that the NMOCD requires the operator to run a solid cement plug through the entire salt section and water bearing zones in addition to installing a bridge plug above the perforations. Installing a solid cement plug through the salt provides additional assurance that no fluids or gases escape through the casing into potash mining areas or fresh water formations. (See Section DEL.6.2.3 on NMOCC Order R-111-P.)

DEL.5.5.2.3 Most Common Technical Violations

Because NMOCD inspectors are able to witness 100 percent of the plugging and abandonment operations, technical violations are very rare. NMOCD inspectors are present for each step in the plugging operation. Operators are informed that plugging operations are not to begin before NMOCD inspectors are on site. If NMOCD inspectors are not present when plugging operations begin, the operator may be required to remove everything from the well and start over. The NMOCD also requires plugging bonds to be secured by the operator before plugging and abandonment are carried out (see Section DEL.6.2.1). The bond is not released until all requirements for plug and abandonment have been properly completed (Personal Communication 1996c).

DEL.5.5.3 Plugging of Oil and Gas Service Wells

Oil and gas operators are required to follow NMOCD Rule 705 on commencement, discontinuance, and abandonment of injection operations when plugging an injection well. This rule requires operators to file a Notice of Discontinuance when a decision has been made to cease injection operations. The rule forbids temporary abandonment of service wells. Plugging requirements are the same as when plugging oil and gas wells or dry holes.

DEL.5.5.4 Plugging of Potash Coreholes

In June 1975, the land that is now the WIPP land withdrawal area became part of the Carlsbad Underground Water Basin. This placed potash coreholes under the jurisdiction of the State Engineer. A review of the records maintained by BLM on commercial potash coreholes indicates that, since 1975, 155 coreholes have been drilled and plugged in the New Mexico portion of the Delaware Basin. Of the 155 coreholes, 151 were plugged from bottom to top with solid cement while four were plugged with a mixture of mud and cement. As indicated by this review, the current plugging practice is to fill potash coreholes with a cement slurry from the bottom of the hole to the surface.

DEL.5.5.5 Plugging of Water Wells

The State Engineer has authority for all water wells. The State Engineer must be notified when a well is to be plugged and he designates how it is to be plugged. The method typically used in the Carlsbad Underground Water Basin is to remove all casing from the hole, clean the hole to the bottom using a sand pump or a cable tool drilling rig with a bailer, and fill the hole with red clay. The red clay is compacted as the hole is filled. Another method of filling the hole is to circulate the hole full of cement. This method is more expensive and is not typically used.

DEL.6 Regulations, Practices, and Problems Associated With Oil and Gas Well and Other Drill Hole Drilling, Plugging, and Abandonment

This section describes BLM (Section DEL.6.1) and NMOCD (Section DEL.6.2) regulatory requirements pertaining to the drilling and plugging of oil and gas wells. Requirements related to drilling and plugging of drill holes (coreholes) associated with exploration for potash resources are also briefly discussed. While the emphasis is on plugging of oil and gas or other types of boreholes, drilling requirements are discussed insofar as they may relate to inadvertent intrusion at the WIPP site. Enforcement actions, incidents of non-compliance with regulations, and other problems associated with drilling or plugging as they may relate to the integrity of the WIPP site are also identified.

The entire 10,240-acre (4,144-hectare) WIPP site (Figure DEL-2) is withdrawn from all forms of oil and gas, potash, and other mineral leasing and appropriation under §3(a)(1) of the Waste Isolation Pilot Plant Land Withdrawal Act of 1992 (U.S. Congress 1992). WIPP activities related to the management and disposal of TRU wastes are given priority although the WIPP site may continue to be used for wildlife habitat, livestock grazing, and hunting subject to conditions imposed by the DOI and applicable grazing laws and policies (LWA § 4[b]). With the exception of two existing oil and gas leases (which can be acquired by the DOE if deemed necessary), the LWA prohibits all surface and subsurface mining or oil and gas production on land on or under the WIPP site (LWA § 4[b][5]). Slant drilling from outside the boundaries of the WIPP site that would intrude into the withdrawal is also prohibited.

DEL.6.1 Bureau of Land Management (BLM)

Leasing of oil and gas resources under federal ownership in the WIPP area is conducted for the Carlsbad Resource Area (CRA) (Figure DEL-12) by the BLM Roswell District Office. Leasing has most recently been conducted under the 1988 Carlsbad Resource Management Plan and site-specific environmental assessments prepared to meet the requirements of the National Environmental Policy Act (NEPA). Leasing of oil and gas is authorized by the Mineral Leasing Act of 1920 and subsequent federal legislation.

The CRA encompasses approximately 6.4 million surface acres (2.6 million hectares) in Eddy and Lea Counties and the southwest portion of Chaves County (Figure DEL-12). The federal government owns both the surface estate and subsurface oil and gas resources on approximately 2.2 million acres (0.9 million hectares). On another 1.9 million acres (0.8 million hectares), the subsurface oil and gas is under federal ownership while the surface is either owned by non-federal surface owners or not administered by the BLM. Thus, federal oil and gas resources underlie approximately 4.1 million surface acres (1.7 million hectares) of the CRA. The CRA, within which the WIPP site is located, occupies only a small portion of the northern part of the Delaware Basin (Figure DEL-3).

DEL.6.1.1 Steps Involved in Oil and Gas Resource Development on Federal Lands

The steps involved in exploration, development, and production of oil and gas, as well as eventual plugging and abandonment, are similar on federal and State-regulated lands although BLM and NMOCD regulatory requirements differ. The major steps on BLM lands are as follows.

1. **Screening of Parcels Proposed for Leasing.** Screening is conducted according to a number of primarily environmental criteria and leasing requirements of other surface management agencies.

2. **Leasing of Parcels.** Leasing is authorized by the Mineral Leasing Act of 1920 (and subsequent legislation) and conducted according to BLM regulations in 43 CFR Part 3100, Subpart 3101. A lessee has the right to use as much of the leased land as is necessary for exploratory drilling and development of the oil or gas resources. Leasing applies to the federal mineral estate whether the surface is administered by the BLM, a private individual or company, or some other government agency.

3. **Geophysical Exploration.** Prospecting using seismic reflection surveys is the prevalent method used in the Roswell BLM District. Operators are required to file with the BLM Area Manager a notice of intent to conduct oil and gas exploration operations (Sundry Notice Form 3160-5; Attachment 2) accompanied by evidence of adequate bonding. When exploration activities are completed, the operator must file with the BLM a notice of completion of oil and gas exploration operations (Sundry Notice Form 3160-5; Attachment 2). The BLM may impose certain terms and conditions on exploration activities and notify the operator, following an inspection, if the terms and conditions have been met. If they have not been met, the surety bond required cannot be released. During the period of 1986 through 1992, the BLM approved 369 geophysical exploration notices of intent for the CRA.

4. **Drilling Permitting.** The lessee or operator must submit to BLM either a notice of staking (NOS) or an application for a permit to drill (Form 3160-3; Attachment 2). This is followed by a BLM field inspection to assess possible surface and subsurface impacts and specify, as necessary, site-specific mitigation measures. Before approving the application for a permit to drill, the BLM must prepare the required NEPA documentation. A number of environmental and other conditions and stipulations are attached to all drilling permits.

5. **Drilling Operations.** Applications for a permit to drill are approved for a one-year period and may receive a one year extension if drilling is not started during the first year. Drilling methods and technology are discussed in Section DEL.5.0. BLM drilling regulations are discussed in Section DEL.6.1.2.1.

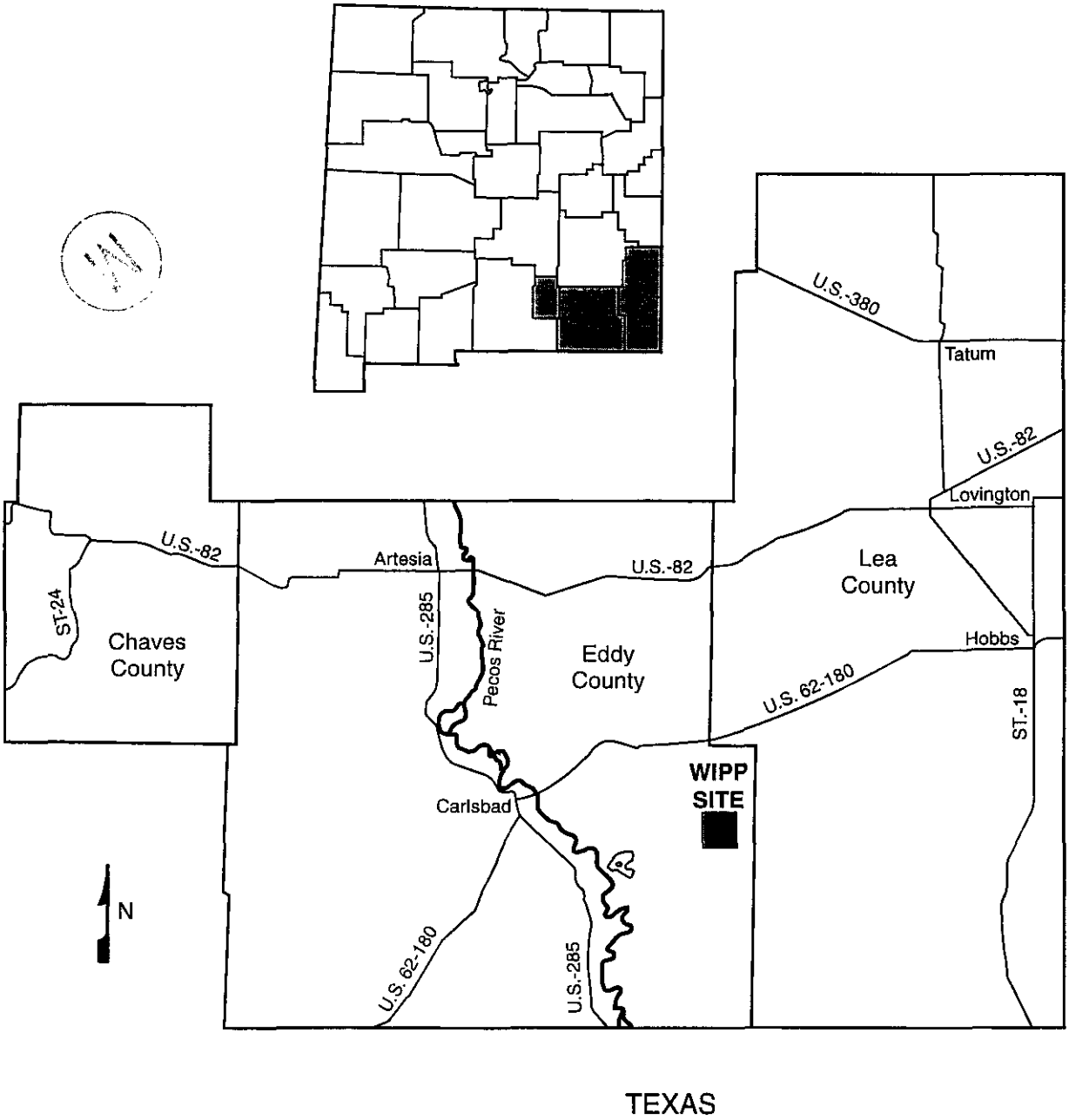

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Figure DEL-12. Carlsbad Resource Area

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6. **Development and Production.** Wells are completed and production equipment installed only when it is determined that oil or gas can be recovered in commercial quantities. A well completion or recompletion report and log, BLM Form 3160-4, is included in Attachment 2.

7. **Well Plugging and Abandonment.** BLM regulatory requirements governing well plugging and abandonment are discussed in Section DEL.6.1.2.2. Plugging of an abandoned well is required to prevent migration of fluids between underground zones, protect other resources (for example, potash and useable water), and reclaim the surface. A correlative purpose of plugging is to prevent waste of oil and gas resources.

DEL.6.1.2 BLM Regulation of Onshore Oil and Gas Operations

Exploration, development, and production of oil and gas from federal leases administered by the BLM are governed by comprehensive regulations for onshore oil and gas operations in 43 CFR Part 3160. Under the regulations, the term federal lands means all lands and interests in lands owned by the United States which are subject to the mineral leasing laws, including mineral resources or mineral estates reserved to the United States in the conveyance of a surface or nonmineral estate (§ 3160.0-5[c]). Thus, the regulations are not limited to oil and gas recovered from lands where the surface is administered by the BLM.

The BLM is authorized to require that

> [All] operations be conducted in a manner which protects other natural resources and the environmental quality, protects life and property and results in the maximum ultimate recovery of oil and gas with a minimum of waste and with minimum adverse effect on the ultimate recovery of other mineral resources (43 CFR § 3161.2).

The BLM regulations in 43 CFR are implemented and supplemented by various onshore oil and gas orders which are periodically issued under Subpart 3164 of the regulations. Onshore Oil and Gas Order No.1 (48 FR 48916) was issued on October 21, 1983, and covers many of the same topics as the regulations, some in more detail. Onshore Oil and Gas Order No. 2 (53 FR 46798, November 18, 1988) applies particularly to drilling operations including well abandonment and plugging requirements, and it expands on the 43 CFR regulations. BLM inspections and enforcement activities rely more on the oil and gas orders than on the regulations (Personal Communication 1996a).

DEL.6.1.2.1 Well Drilling

The BLM has authority to approve and monitor drilling and production, impose assessments or penalties, issue notices to lessees (NTLs), and suspend operations. No drilling operations or related surface disturbances can be commenced without approval of an application for a permit to drill (43 CFR § 3162.3-1[c]). The application for a permit to drill (Form 3160-3; Attachment 2) must include a drilling plan for a single well or several wells, a surface use plan, and evidence of bond coverage. A proposal to conduct well operations other than

drilling (for example, redrill, deepen, perform casing repairs, plug-back, and alter casing) must also be submitted to BLM for approval on Form 3160-3 (Attachment 2). Before approving an application for a permit to drill, the BLM must prepare an environmental review or an environmental assessment. These documents are used to determine if an environmental impact statement is required and to identify drilling approval terms and conditions (43 CFR § 3162.5-1[a]).

During the drilling and completion of a well, the operator is required to conduct tests, run logs, and make other necessary surveys (43 CFR § 3162.4-2). The operator is also required to determine the amount and direction of any deviation of the well from vertical. Results of such tests and surveys must be made available to the BLM.

Onshore Oil and Gas Order No. 2 details BLM's uniform national standards for minimum levels of performance for conducting drilling operations as well as for plugging and abandonment (53 FR 46798, November 18, 1988). Highly technical requirements are included for well control, well casing and cementing, drilling mud and related drilling procedures, drill stem testing, and special drilling operations. Casing and cementing programs are to be conducted to protect and isolate usable water zones, potentially productive zones, lost circulation zones, abnormally pressured zones, and any prospectively valuable mineral deposits. Drilling mud characteristics, use, and testing and implementation of related drilling procedures must be designed to prevent loss of well control.

DEL.6.1.2.2 *Well Abandonment and Plugging*

The BLM requirements pertaining to plugging and abandonment of oil and gas wells are contained in 43 CFR § 3162.3-4 and Section III.G of Onshore Oil and Gas Order No. 2. The regulations in 43 CFR Part 3160 provide as follows:

> The operator shall promptly plug and abandon, in accordance with a plan first approved in writing or prescribed by the authorized officer, each newly completed or recompleted well in which oil or gas is not encountered in paying quantities or which, after being completed as a producing well, is demonstrated to the satisfaction of the authorized officer to be no longer capable of producing oil or gas in paying quantities (43 CFR § 3162.3-4[a]).

There is an exception to this requirement if the BLM approves the use of the well as an injection well to recover additional oil or gas (enhanced recovery) or for subsurface disposal of produced water. Also, completion of a well as plugged or abandoned may include using the well as a water supply source, provided that the party using the well accepts responsibility for all costs over and above the normal plugging and abandonment expenses.

No well can be temporarily abandoned for more than 30 days without approval of the BLM, although permanent abandonment may be delayed for a period of up to 24 months. A temporarily abandoned well is defined as a completed well that is not capable of production in paying quantities but which may be used as a service well. Drilling or production equipment

must be removed from a well site that is to be permanently abandoned and the land surface reclaimed in accordance with an approved plan.

Oil and Gas Order No. 2 provides as follows:

> All formations bearing useable-quality water, oil, gas, or geothermal resources, and/or a prospectively valuable deposit of minerals shall be protected . . . . Failure to obtain approval [following an oral request and a written notice of intent] prior to commencement of abandonment operations shall result in immediate assessment of [$500] . . . . Within 30 days of *completion of abandonment, a subsequent report of abandonment shall be filed (53 CFR at* 46810).

Oil and Gas Order No. 2 prescribes the following method of plugging either open holes (that is, those holes in which no casing has been emplaced) or cased holes.

Open Hole:

- For an open hole, a cement plug must be placed to extend at least 50 feet (15 meters) below the bottom (except as limited by total depth or plugged back total depth) to 50 feet (15 meters) above the top of any zone encountered during drilling that contains fluid or gas with a potential to migrate or any prospectively valuable mineral deposits.

- All cement plugs, except the surface plug, must have sufficient slurry volume to fill 100 feet (30 meters) of hole plus an additional 10 percent of slurry for each 1,000 feet (305 meters) of depth.

- No plug, except the surface plug, can consist of less than 25 sacks of cement without approval from the BLM. (A sack of cement weighs 94 pounds [43 kilograms] and produces between 1 and 2 cubic feet [0.03 and 0.06 cubic meters] of slurry volume, depending on the quantity of additives used.)

- Extremely thick sections of a single formation (for example, salt sections) may be secured by placing 100-foot (30-meter) plugs across the top and bottom of the formation.

- Unless there are zones containing fluids or gas with the potential to migrate or potentially valuable mineral deposits (which require their own plugs 50 feet [15 meters] above and 50 feet [15 meters] below), long sections of open hole must be plugged at least every 3,000 feet (915 meters).

Cased Hole:

- For a cased hole, a cement plug must be placed opposite all perforations (holes made in the casing to allow formation fluids to enter the wellbore) and extend at least 50 feet (15 meters) below to 50 feet (15 meters) above the perforated interval. All cement

plugs, except the surface plug, have the same slurry volume requirements as those for an open hole. A bridge plug (see glossary) is also acceptable provided certain conditions are met.

- If any casing is cut and removed from the hole, a cement plug must be placed to extend at least 50 feet (15 meters) above and below the stub (the cut end of the casing). Plugging of the exposed hole resulting from casing removal must follow the procedure described above for plugging an open hole.

- An additional cement plug must be placed to extend at least 50 feet (15 meters) above and below the surface casing shoe (see glossary).

- No annular space (the space or annulus surrounding the pipe or casing in the wellbore) extending to the surface can be left open to the hole drilled below. If such a condition exists, at least the top 50 feet (15 meters) of annulus must be plugged with cement.

- Any cement plug which is the only isolating medium for a fresh water interval or a potentially valuable mineral deposit must be tested by tagging with the drill string. (Tagging refers to touching a downhole object.) If any plugs are placed where the fluid level will not remain static, they must be tested either by tagging with the casing string or establishing a pumping pressure of 1,000 pounds per-square-inch (pounds per square inch) (6,895,000 pascals). The purpose is to determine the integrity of the plug.

- If temperatures at the bottom of the hole exceed 230° F (110° C), silica sand or flour must be added to the slurry to prevent heat degradation of the cement.

- A cement surface plug at least 50 feet (15 meters) thick must be placed across all of the annuli.

- Each of the intervals between plugs must be filled with mud of sufficient density to exert hydrostatic pressure exceeding the greatest encountered during drilling. In the absence of other information, a minimum mud weight of nine pounds per gallon is required.

- A surface cap (in addition to a surface plug) is required. The surface cap is a metal plate at least .25 inch (0.6 centimeters) thick welded in place or a 4-inch (10-centimeter) diameter pipe 10 feet (3 meters) long embedded in cement and extending 4 feet (1.2 meters) above ground level. Prior to emplacing the surface cap, the casing must be cut off at the base of the cellar (a pit in the ground under the well rig floor) or 3 feet (1 meter) below final restored ground level (whichever is deeper). The cellar is then filled with suitable material and the surface restored.

The drilling of oil or gas wells in the potash area (Figure DEL-8) has not occurred in many years. However, when such wells need to be plugged, the BLM will consider the NMOCD

requirements in Order R-111-P (see Section DEL.6.2.3 below). The current plugging procedure followed in the CRA is illustrated in Figures DEL-13 and DEL-14.

DEL.6.1.2.3 BLM Policy on Temporarily Abandoned and Shut-In Wells

A temporarily abandoned well is a completed well that is not capable of producing oil or gas in commercial quantities but may have value as a service well (for example, injection or water disposal well). A shut-in well is a completed well capable of producing in commercial quantities or being used as a service well. A well cannot be temporarily abandoned for more than 30 days without prior BLM approval. Similarly, BLM approval is required if a well is to have shut-in status for a year or longer. Extensions of time are available in both cases under the regulations.

On December 16, 1994, the BLM New Mexico State Office issued Instruction Memorandum (IM) No. NM-95-022 pertaining to a testing and review policy for both producing and non-producing wells (Attachment 3). The IM requires the following considerations when BLM reviews applications for temporary abandonment or continued shut-in status.

- An operator requesting temporary abandonment for a particular well (on Sundry Notice Form 3160-5; Attachment 2) must

  (1) justify why the well should be temporarily abandoned,

  (2) describe the temporary abandonment procedure to be followed, and

  (3) demonstrate the mechanical integrity of the well casing.

  Specific plugging requirements for a well being temporarily abandoned are set forth in the IM.

- (Attachment 3). The pressure test required to demonstrate the mechanical integrity of the casing is also specified in the IM.

- While a well cannot be temporarily abandoned for more than 30 days without prior BLM approval, permanent abandonment can be delayed for up to 24 months (see 43 CFR § 3262.3-4[c]).

- An operator requesting shut-in approval for a particular well (also on Form 3160-5) must demonstrate that the well is capable of producing oil or gas in paying quantities. The operator must justify why the well should receive shut-in (inactive) status rather than being activated as a producing well or service well. Shut-in approval is granted for a one-year period, renewable for up to five years if justified. This policy provides the operator with a grace period of a least a year to do something with the well (for example, reestablish production, plug and abandon, or convert to a service well). As

> with temporary abandonment, the operator must demonstrate the mechanical integrity of the well casing through testing procedures specified in the IM (Attachment 3).

This BLM policy and its implementation has minimized the number of inactive and unplugged wells in the New Mexico portion of the Delaware Basin.

The BLM CRA office in Carlsbad, New Mexico, has been making a concerted effort to force operators to produce or plug inactive wells by reviewing the actual status of wells classified by operators as shut-in or temporarily abandoned. Through these reviews, the BLM can determine if these wells have further economic use. If not, the operators are directed to permanently plug and abandon them.

DEL.6.1.2.4 Well Records and Reports

The BLM regulations require the operator to keep accurate and complete records on standard forms of all lease operations including, but not limited to, drilling, production, redrilling, deepening, repairing, plugging back, and abandonment (43 CFR § 3162.4-1[a]). All records and reports must be maintained for at least six years.

DEL.6.1.3 Agreement Between DOE and BLM on Oil and Gas Activities Affecting WIPP

The DOE and the BLM executed a Memorandum of Understanding (MOU) on July 19, 1994, directed at establishing cooperative arrangements and procedures for land and resource management within the WIPP withdrawal area (see Attachment 4). The MOU supplements the WIPP Land Management Plan (DOE/WIPP 93-004). The MOU provides as follows:

> It is the intent of the DOE to ensure that mining and gas and oil activities do not encroach upon the withdrawal area. Adherence to this MOU is crucial to protecting the repository from inadvertent human intrusion . . . . In accordance with Section 4(b)(5)(A) of the LWA (WIPP Land Withdrawal Act), no surface or subsurface mining or oil and gas production, including slant drilling from outside the boundaries of the withdrawal, shall be permitted at any time (including after decommissioning) on lands on or under the withdrawal (MOU Section VI.E; emphasis added).

Exceptions to the LWA prohibition against resource extraction are for existing rights under two existing oil and gas leases in the WIPP withdrawal area, unless the EPA determines that acquisition of these leases is needed for WIPP to comply with the 40 CFR Part 191 disposal requirements or the Resource Conservation and Recovery Act (RCRA) (LWA § 4[b][5][B]).

Under the MOU, the DOE agrees to coordinate with the BLM regarding BLM permits for oil and gas drilling (or other mining activity) on BLM lands within one mile of the WIPP site boundary. DOE also agrees to interpret, review, and verify oil and gas activity calculations performed by the BLM. The BLM agrees to allow the DOE to review and comment on any applications for a permit to drill for oil and gas resources within one mile of the WIPP site boundary. Any DOE comments must be resolved before an application for a permit to drill can be approved by the BLM.

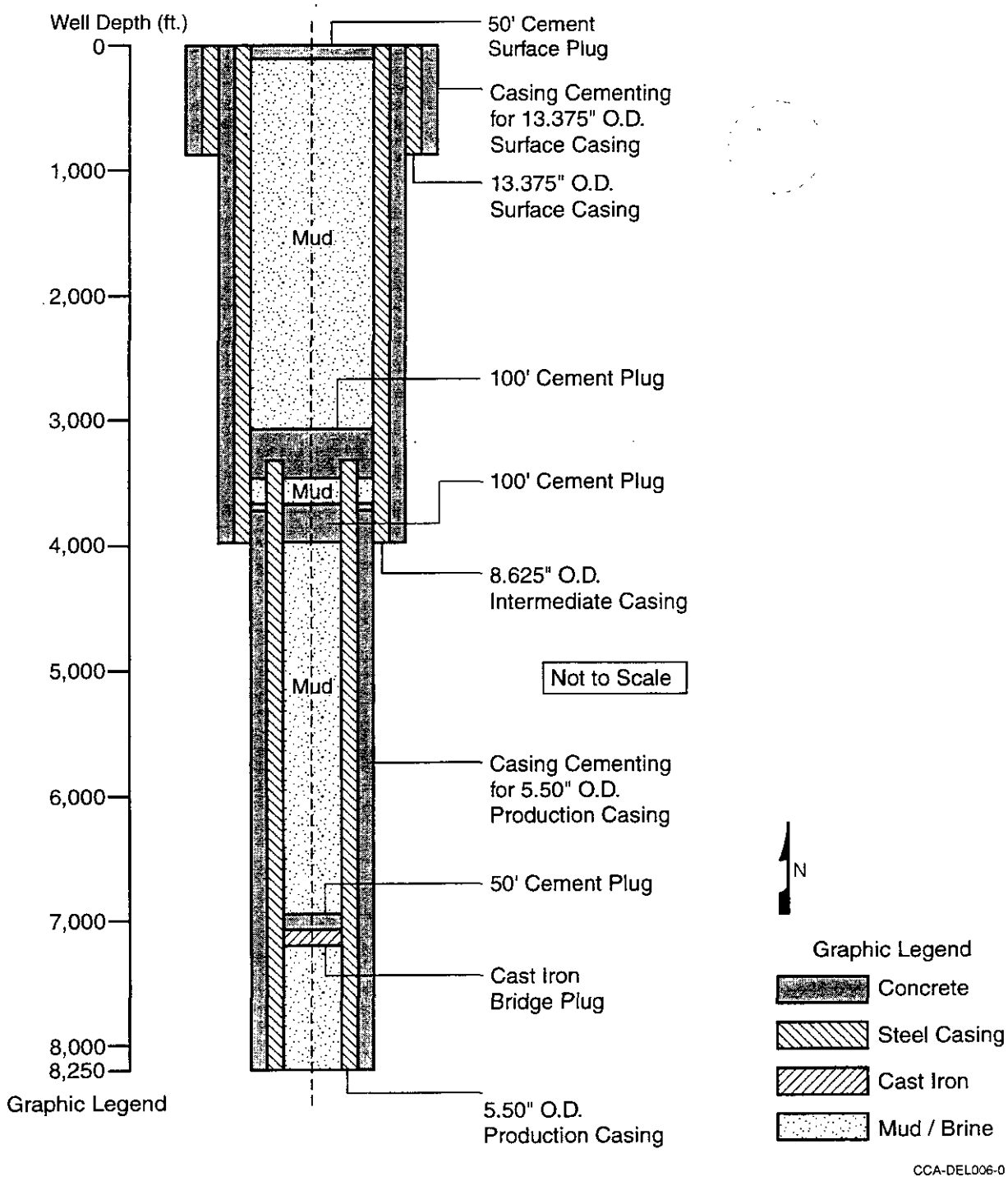

Figur DEL-13. Minimum Oil and Gas Well Plugging Requirements in the Delaware Basin

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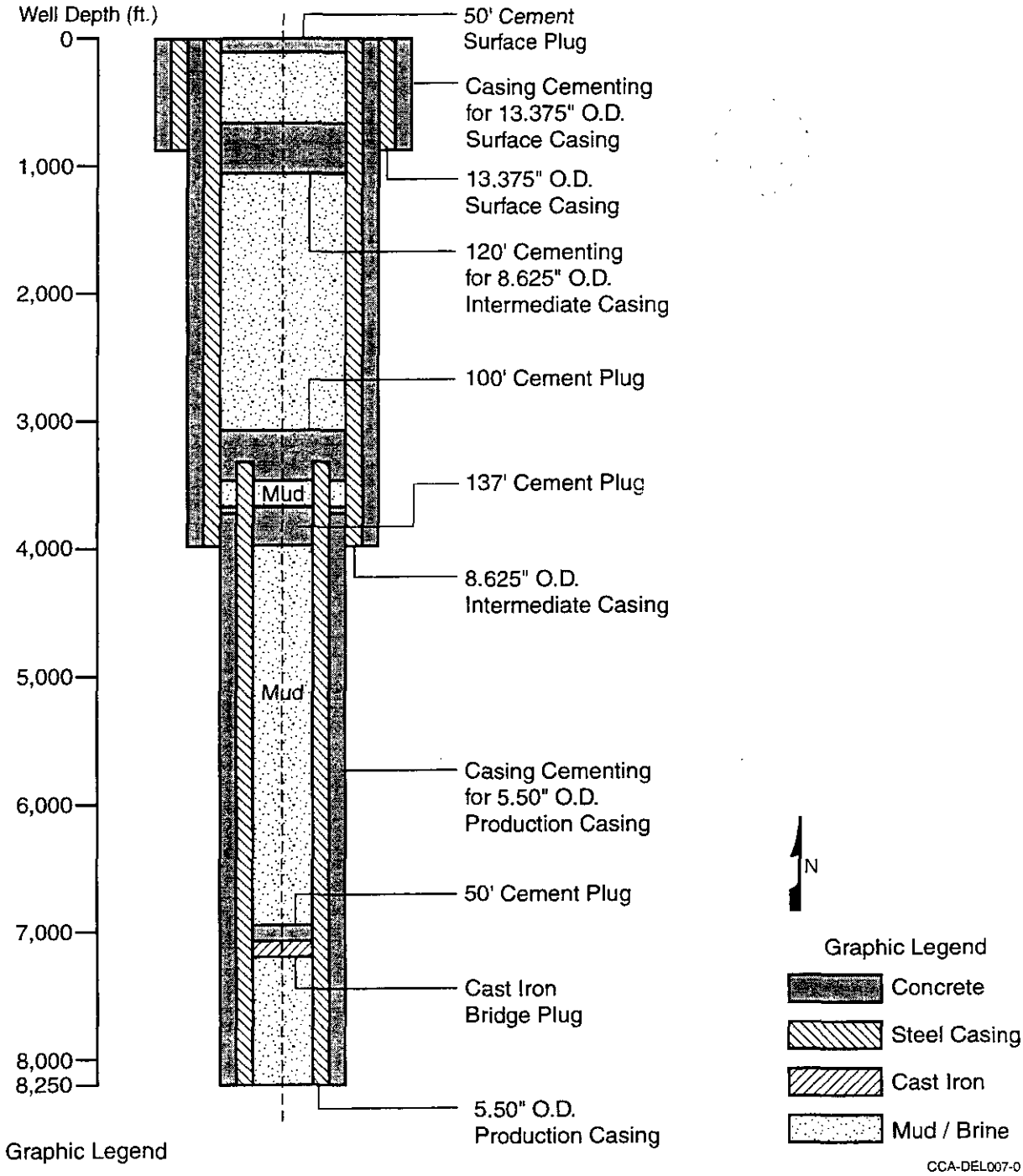

Figure DEL-14. Standard Oil and Gas Well Plugging Practices in the Potash Resource Area of the Deleware Basin

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BLM further agrees to the following as a special condition of approval for oil and gas activity within 330 feet (100 meters) of or closer to the WIPP boundary:

- Ensure that the operator provides the BLM with drill site vertical deviation surveys for each 500-foot (152-meter) drilling interval,

- Provide (BLM) technical expertise for calculating wellbore deviation and forward the results to DOE for review,

- Require the operator, in accordance with NMOCD Rule 111 (see Section DEL.6.2.1) to provide BLM with a directional survey to establish bottom hole location for wellbores with deviation angles of more than five degrees from vertical in any 500-foot (152-meter) interval,

- Require the operator to provide the BLM with a directional survey to establish the bottom hole location when it is indicated that the wellbore could deviate to within 100 feet (30 meters) of the WIPP withdrawal boundary, and

- Provide the DOE with directional survey results when it is indicated that the bottom hole location will deviate more than five degrees from vertical in any 500-foot (152-meter) interval, as well as survey results on wellbores that could deviate to within 100 feet (30 meters) of the withdrawal boundary.

The BLM also agrees to provide the DOE with well completion, alternate use, and plugging and abandonment reports related to drilling, production, injection, and mining activity on federal lands within one mile of the WIPP boundary.

DEL.6.1.4 Protection of Potash Resources

On October 28, 1986, the Secretary of the Interior issued an order entitled *Oil, Gas and Potash Leasing and Development Within the Designated Potash Area of Eddy and Lea Counties, New Mexico* (51 FR 39425). The order addressed the revision of earlier rules related to concurrent prospecting for, development, and production of oil and gas and potash resources within the Secretary's designated potash area (the legal description of which is contained in the order and shown in Figure DEL-8).

What BLM refers to as the Secretary's potash area is defined in 51 FR 39427 and encompasses approximately 497,000 acres (201,000 hectares). The NMOCD Order R-111-P potash area, which is the same as the KPLA, encompasses approximately 425 square miles (272,000 acres; 110,077 hectares) and lies within the Secretary's potash area (Figure DEL-8). The WIPP site is situated on the southeastern edge of the KPLA.

The 1986 Secretarial order reaffirmed the DOI policy of requiring that the following lease stipulations adequately protect the rights of oil and gas and potash leaseholders and operators.

- Oil and gas drilling will be permitted only if the lessee can assure the BLM that the drilling will not interfere with the mining and recovery of potash deposits.

- No oil and gas wells can be drilled at a location which would result in undue waste of potash deposits, pose a hazard to, or unduly interfere with potash mining.

- If the BLM determines that unitization (combining leased tracts on a fieldwide or reservoir-wide scale to facilitate recovery) is necessary for orderly oil and gas development and protection of potash resources, no oil and gas wells can be drilled unless they comply with the unit plan.

- The drilling or abandonment of any oil and gas well must comply with the BLM regulations in 43 CFR Part 3160 (see Sections DEL.6.1.2.1 and DEL.6.1.2.2 above) including any BLM requirements prescribed to prevent the infiltration of oil, gas, or water into potash deposits, mines, or workings.

As a reciprocal requirement, all potash permits and leases are subject to the stipulation that no mining or exploration operations be conducted that, in BLM's opinion, would constitute a hazard to oil or gas production or unreasonably interfere with orderly development and production under any oil and gas lease issued for the same (potash) lands.

The order imposes requirements on potash lessees to delineate on maps

(1) areas of current mining activity,

(2) areas where operations have been completed,

(3) areas containing minable reserves, and

(4) and areas believed to be barren of commercial ore (Figure DEL-8).

The order establishes a policy of denying oil and gas well applications for a permit to drill within these areas except for barren enclaves. In certain circumstances (for example, where the oil and gas formation cannot be reached within a barren area), the BLM may establish an oil and gas drilling island. No such island can be established within one mile of any area where potash mining will be conducted within three years.

The order requires the BLM to cooperate with the NMOCD in implementing the state regulations. Specifically, federal potash leaseholders may protest to the NMOCD the drilling of oil and gas wildcat wells on federal lands located within the State's oil-potash area as defined by Order No. R-111-P (see Section DEL.6.2.4). However, BLM has the prerogative to make the final decision. Although NMOCD oil and gas regulations, including Order No. R-111-P, do not legally apply to federal lands, the requirements for concurrent oil and gas and potash development are given due deference by the BLM.

DEL.6.1.5 Bonds, Penalties, and Enforcement

Prior to commencing any surface-disturbing activities related to drilling operations, the lessee or operator must post a surety or cash bond in an amount not less than $10,000 per lease to assure compliance with all the BLM lease terms

> . . .including complete and timely plugging of well(s), reclamation of the lease area(s), and the restoration of any lands or surface waters adversely affected . . . (43 CFR § 3104.1 and 3104.2).

Statewide bonds and nationwide bonds are established at minimums of $25,000 and $150,000, respectively, to cover all leases and operations by the same owner statewide or nationwide.

Noncompliance with the BLM regulations, terms of any lease or permit, or a BLM notice or order is subject to both civil and criminal penalties. Assessments run from $250 for a minor violation to $500 per day for such violations as failure to install blowout prevention equipment or drilling without approval (43 CFR § 3163.1). Civil penalties range from $500 to $5,000 per violation per day depending on the amount of time the violation goes uncorrected. Where public health and safety, the environment, or certain economic factors are threatened, the BLM can order an immediate shutdown of operations. Criminal penalties can be as severe as a $50,000 fine and/or imprisonment for up to two years.

According to the CRA office, the BLM rarely needs to impose civil or criminal penalties (Personal Communication 1995). Most noncompliance incidents involve surface uses rather than well drilling or plugging. There are very few violations of application for a permit to drill conditions due to BLM on-the-ground inspections and the self-interest of operators who find enforcement delays costly. Drilling permit violations involve probably not more than one in 100 wells (Personal Communication 1995).

Potentially, well plugging has more noncompliance problems than drilling because the owner/operator has no profit potential in plugging. To avoid noncompliance, well plugging has the highest inspection rate by BLM and NMOCD.

There were 788 incidents of noncompliance (INCs) involving improper drilling or production activities during fiscal years 1991 through 1996. INCs involve noncompliance with BLM regulations, orders, or instructions. Violation codes are assigned to each type of INC. The number of INCs associated with production and drilling for five selected violation codes are displayed in Table DEL-1. INCs for FYs earlier than FY 1991 have not been compiled from individual well records. As can be seen, almost all of the INCs are for surface violations associated with oil or gas production and not for well drilling or plugging.

The number of INCs has increased dramatically since FY 1993 because the BLM CRA office has greatly increased the number of inspections as a result of environmental concerns. There is increasing emphasis on such matters as surface reclamation, fencing of mud pits, removal of surface hydrocarbons to protect waterfowl, and protection of groundwater from surface

seepage. The total assessments levied during FY 1991 through FY 1996 (to date) period were in the range of $20,000 to $25,000 (Personal Communication 1996a). There were no civil or criminal penalties assessed and there were no bond forfeitures.

Table DEL-1 does not reflect any INCs for improper plugging because BLM inspections require that any plugging violation be corrected immediately. Certain wells are assigned inspection priority with regard to drilling, casing, cementing, and plugging. BLM has had to compel the proper plugging of only one well in the past six years (Personal Communication 1996a).

DEL.6.2 State of New Mexico

The NMOCD, as part of the New Mexico Energy, Minerals and Natural Resources Department, is responsible for issuing permits pertaining to drilling, development, and production of oil and natural gas resources under the authority of the Oil and Gas Act (§§ 70-2-1 through 70-2-36 NMSA 1978) and the New Mexico Water Quality Act (§ 74-6-4E NMSA 1978). The overall purpose of the NMOCD regulatory program is to protect oil, gas, potash, geothermal resources, and useable water. Special requirements pertaining to the protection of potash resources potentially impacted by oil and gas drilling activities are contained in Order R-111-P discussed in Section DEL.6.2.4.

Although the Oil and Gas Act creates the NMOCC, it delegates to the NMOCD the jurisdiction and authority over all matters relating to the conservation of oil and gas and the prevention of waste of potash as a result of oil and gas operations in this state (§ 70-2-6 NMSA 1978). The NMOCD has a day-to-day, hands-on administrative authority while the NMOCC has a quasi-judicial function in that it can hold hearings, subpoena witnesses, and implement rulemaking and enforcement functions. The NMOCD is authorized to collect data, conduct investigations, inspect properties, promulgate rules and regulations, and issue orders. It is also authorized to

- require dry or abandoned wells to be plugged in a way that confines crude petroleum oil, natural gas, or water in the strata in which it is found and prevent it from escaping to other strata;

- require a cash or surety bond in a sum not to exceed $50,000 to assure compliance with plugging and other oil and gas regulations;

- prevent drowning by water of any stratum capable of producing oil or gas;

- prevent fires, blowups, and caving; and

- spend the oil and gas reclamation fund and perform all acts necessary to plug dry and abandoned oil and gas wells.

Table DEL-1. BLM Oil and Gas Well Drilling, Production, and Abandonment Incidents of Noncompliance, FYs 1991 to 1996 According to Violation Code for the Carlsbad Resource Area

Fiscal Year	Activity Type	Violation Code 2[1]	Violation Code 3	Violation Code 6	Violation Code 50	Violation Code 53	Total
FY 91	Production	60	35	7	7	0	109
	Drilling	0	0	0	1	0	1
FY 92	Production	3	4	0	1	1	9
	Drilling	0	0		0	0	0
FY 93	Production	1	9	0	0	0	10
	Drilling	0	0			0	0
FY 94	Production	270	181	8	1	11	471
	Drilling	0	0	0	0	0	0
FY 95	Production	23	158	1	3	0	185
	Drilling	0	1	0	0	0	1
FY 96	Production	4	47	2	1	1	55
	Drilling (to 1/96)	0	1	0	0	0	1
Totals	Production	361	434	18	13	13	839
	Drilling	0	2	0	1	0	3

[1]Violation codes associated with oil or gas production, with examples, are as follows:

Code 2. Well equipment not satisfactory. Could include leaking wellhead or stuffing box (a device that prevents leakage of oil around a piston, rod, or other moving part) leaks.

Code 3. Environmental protection not satisfactory. Could include trash on location, previous oil spills not cleaned up, or pits containing fluids like oil or water.

Code 6. Surface use not in accordance with approved plan. Unauthorized pits or surface disturbance.

Code 50. Failure to comply with a BLM notice, written order, or instruction. The violation could result from the operator's failure to comply with any of the BLM regulations or orders related to INCs. Failure to correct INCs results in a money assessment or civil penalty.

Code 53. Failure to obtain approval of specific operations such as changing downhole production zones or commingling of production.

Violation codes associated with drilling or plugging, with examples, are as follows:

Code 2. Drill site not properly identified according to BLM requirements.

Code 3. Operations not conducted in a workmanlike manner or working outside of required safety guidelines.

Code 6. Downhole drilling deviation is not within the approved tolerance.

Code 50. Same as Code 50 as applied to drilling INCs.

The first comprehensive oil and gas regulations for New Mexico were issued by the NMOCC in 1935. The current rules and regulations, dated March 1, 1993 (plus some recent revisions), follow the same numbering system as those made effective on January 1, 1950. However, the

NMOCD is in the process of reformatting its rules in order to comply with the New Mexico Administrative Code (NMAC). Under this reformatting, the NMOCD regulations on petroleum, oil and gas storage and handling will be contained in NMAC Title 19 (Natural Resources and Wildlife), Chapter 15. Section letters in the 1993 rules will also be used. Thus, the former rule 101 on plugging bonds contained in Section C on drilling will become 19 NMAC 15.C.101. The rule numbers will be the same, although they will be preceded by the remainder of the NMAC citation.

All regulations promulgated by the NMOCD must be adopted by the NMOCC. The NMOCD has divided the state into four districts, each with a district supervisor, an oil and gas inspector, or a deputy oil and gas inspector. Eddy County, where the WIPP site is located, is in District 2 which also includes Otero, Dona Ana, Luna, Hildago, Grant, Sierra, Lincoln, and De Baca Counties and a portion of Chaves County. The District Office is in Artesia. District 1, immediately east of District 2, is headquartered in Hobbs and includes Lea, Roosevelt, and Curry Counties and a portion of Chaves County. Because of the geologic, hydrologic, climatic, economic, and mineralization differentiations among all or portions of the four NMOCD districts, district supervisors have considerable flexibility; the rules are often applied on a case-by-case basis. However, rule interpretations that involve fundamental property rights are the responsibility of the NMOCC.

The NMOCD regulations apply to oil and gas operations on private and state-owned lands. With a few exceptions (as agreed to by the BLM), they do not apply to BLM lands or other lands where oil and gas resources are reserved to the United States. In NMOCD Districts 1 and 2, a large percentage of the oil and gas resources are subject to federal leasing and are under BLM jurisdiction.

DEL.6.2.1 Well Drilling Requirements

The NMOCD regulations applicable to the drilling or acquisition of oil, gas, or associated service wells are contained in Rules 101 through 118 (now 19 NMAC 15.C.101 to 118). The following discussion summarizes the key provisions of selected rules that may potentially bear on the effects of future oil and gas drilling at the WIPP site. Numerous other drilling requirements are not directly relevant to human intrusion scenarios.

- **Rule 101 - Plugging Bond.** Anyone who has drilled or acquired, or is proposing to drill or acquire, an oil, gas, or service well on private or state-owned lands must supply a surety or cash bond to assure that the well is plugged and abandoned in compliance with the NMOCD rules. Plugging bonds are of two types: (1) a blanket bond in the amount of $50,000 covering all wells drilled in the state by the same owner/operator; and (2) a one-well plugging bond in an amount determined by well depth and location. For example, one-well plugging bonds in Eddy and Lea Counties are established by well depth as follows: less than 5,000 feet, $5,000; 5,000 to 10,000 feet, $7,500; and more than 10,000 feet, $10,000. When approved by the NMOCD District Office, a well can be drilled 500 feet deeper than the maximum depth covered by the bond. For

a deviated well, the bond is determined by the measured depth, not the vertical depth. The bond is not released until the plugging and abandonment of the well has been approved by the NMOCD. If the operator fails to properly plug and abandon the well(s) covered by the bond, the NMOCD may require that the bond be forfeited. Also, the NMOCD may take legal action to recover any additional costs.

- **Rule 102 - Notice of Intent to Drill.** Before commencing operations, the operator must notify the NMOCD of its intent to drill an oil, gas, or injection well on Form C-101, the application for a permit to drill, reenter, deepen, plugback, or add a zone (Attachment 5). Information supplied on Form C-101 includes well surface location, bottom hole location, and the proposed casing and cementing program.

- **Rule 104 -Well Spacing Acreage Requirements.** A well location and acreage dedication plat must be filed by the operator on Form C-102 (Attachment 5). Wildcat gas wells drilled in Eddy and Lea Counties must be located on 160-acre (65-hectare) tracts at least 660 feet (183 meters) from the tract's outer boundary and at least 330 feet (101 meters) from any quarter-quarter section (40-acre; 16-hectare) inner boundary. However, if a wildcat well is proposed to be drilled in the Wolfcamp or older formations, the drilling tract must consist of two contiguous quarter sections (360 acres; 146 hectares). (The rule defines a side boundary and an end boundary.) Wildcat oil wells must be located on tracts of approximately 40 acres (quarter-quarter sections), at least 330 feet (101 meters) from the tract boundary. All well tracts should be essentially square in shape and capable of being identified as legal subdivisions established by U.S. Public Land Surveys. Development oil wells in all New Mexico counties must be located on 40-acre (16-hectare) tracts at least 330 feet (101 meters) from the tract boundary and at least the same distance from the closest well capable of producing from the same pool. (Note: More than one well can be drilled on 40-acre [16-hectare] spacing if the wells are producing from different pools.) Development gas wells in Eddy and Lea Counties must be located on 160-acre (65-hectare) drilling tracts (with the same boundary distances as for wildcat wells) and at least 1,320 feet (402 meters) from the nearest gas well capable of producing from the same pool. Under the rather complex requirements of Section F of Rule 104, the NMOCD may approve oil or gas wells in unorthodox locations based on topographical or geological conditions. The NMOCD well spacing requirements are also applied by the BLM.

- **Rule 105 - Pit for Drilling Fluid and Drill Cuttings.** Before drilling is commenced, operators must provide a pit adequate for the disposal of drilling fluids and drill cuttings in a manner protective of surface or subsurface waters. Removal of the pit contents for offsite disposal is not permitted unless approved by the NMOCD. (Note: There is no current requirement for sampling or testing mud pit contents for hazardous or radioactive characteristics.)

- **Rule 106 - Sealing Off Strata.** During the drilling of an exploration, production, injection, or service well, all oil, gas, and water strata above the producing and/or

injection horizon must be sealed or separated to prevent their contents from migrating into other strata. Groundwater valuable for domestic, commercial, or livestock purposes must be confined to their respective strata and protected by methods approved by the NMOCD. Shut-off of water from oil- and gas-bearing strata is generally accomplished by cementing the well casing into the wellbore.

- **Rule 107 - Casing and Tubing.** All wells drilled for oil or gas must be equipped with surface and intermediate casing strings and associated cement as are necessary to seal off and isolate all water-, oil-, and gas-bearing strata encountered in the well. Production wells must be equipped with a string of properly cemented production casing at sufficient depth to protect all oil- and gas-bearing strata encountered in the well, including those from which the well is producing. Sufficient cement must be used around the surface casing to fill the annular space (or annulus, the space between the outside of the casing and the side of the wellbore). With certain exceptions, all cementing must be accomplished with hard setting cements which have been mixed with the appropriate additives. All casing strings must be pressure-tested after cementing and proved satisfactory before any other operations can proceed. The casing must remain stationary and under pressure for a least 8 hours following cementing. In Eddy and Lea Counties, casing strings my be allowed to stand until the compressive strength has reached 500 pounds per square inch before testing commences. All producing oil and gas wells with casing larger than 2.9-inch (7.3-centimeter) diameter casing must be tubed (running a small-diameter pipe through the casing to serve as a conduit for the passage of oil or gas).

- **Rule 109 - Blowout Prevention.** A blowout or gusher can occur when the underground formation pressure exceeds the pressure applied to it by the column of drilling fluid. This results in an uncontrolled flow of gas, oil, or other well fluids into the atmosphere or another underground formation. Under this rule, operators are required to install blowout preventers on all drilling rigs operating in areas of known high pressures (at or above the projected depth of the well) and in all areas where underground pressures are unknown. For any drilling operation requiring blowout prevention equipment, the operator must submit a blowout prevention program on Form C-101 (Attachment 5).

- **Rule 111 - Deviation Tests and Directional Drilling.** This rule is particularly relevant to inadvertent intrusion into the WIPP site. It was extensively revised on June 13, 1995. It requires that any well drilled or deepened must be tested at reasonably frequent intervals to determine the deviation of the drilling from vertical. Such tests must be made at least once every 500 feet (152 meters) or at the first bit change succeeding 500 feet (152 meters). All deviation tests must be tabulated, notarized, and submitted to the NMOCD on Form C-104 (Attachment 5). If the deviation averages more than five degrees in any 500-foot (152-meter) interval, the operator must calculate the maximum possible horizontal deviation of the wellbore. The

NMOCD can then require a directional survey to establish the location of the producing interval.

The appropriate NMOCD District Office may approve the drilling of a deviated wellbore, the deviation of an existing wellbore to straighten a crooked hole, side track junk in the hole, or side track an existing wellbore when the operator follows specified procedures. The bottomhole location will be considered acceptable if the actual subsurface location is no more than 50 feet (15 meters) from the approved subsurface location. The director of the NMOCD has authority to approve a directional wellbore project when a number of conditions are met. The major requirement is that the wellbore be totally confined to a producing area.

- **Rule 116 - Notification of Fire, Breaks, Leaks, Spills, and Blowouts.** The NMOCD must be notified by the owner/operator of any fire, break, leak, spill, or blowout occurring at any injection or disposal facility or at any oil or gas drilling, producing, transporting, or processing facility. Notification must be immediate, as soon as possible after discovery either in person or by telephone to the NMOCD District Office. (See the notification of fire, breaks, spills, leaks, and blowouts form in Attachment 5.) A written report of the incident must be submitted to the NMOCD within 10 days following discovery.

DEL.6.2.2 Well Plugging and Abandonment Requirements

Abandonment and plugging of wells are covered in Section D of the NMOCD regulations, Rules 201 through 204 (now 10 NMAC 15.D.201 to 204). These rules are included in their entirety in Attachment 6. Under Rule 201, the operator is responsible for plugging not only oil, gas, and injection wells but also seismic, core, or other exploration or service well. (Note: A service well is a nonproductive well used for injecting liquids or gas to enhance recovery, disposing of salt water, or producing a fresh water supply.) The well must be plugged and abandoned, or temporarily abandoned, within (a) 150 days following the suspension of drilling operations, (b) a determination that the well can no longer be put to beneficial use, or (c) a period of one year of continuous inactivity.

DEL.6.2.2.1 Plugging and Permanent Abandonment - Rule 202

Under Rule 202, a notice of intention to plug must be filed with the NMOCD on Form C-103, Sundry Notices and Reports on Wells (Attachment 5), by the operator before plugging operations commence. The notice must identify the well and the proposed plugging procedures, and provide a wellbore plugging diagram (see examples in Attachment 5). Under Rule 1103 on sundry notices, the plugging notice must also contain a detailed statement of the proposed work and plans for pulling casing, mudding, cementing (including the number of sacks of cement and depths of plugs), and the time and date of the proposed plugging operations. If not filed previously, a complete log of the well on Form C-105 (Attachment 5) must accompany the notice to plug. In the case of a newly-drilled dry hole, the operator is

allowed to plug after obtaining verbal approval from the NMOCD District Supervisor. However, written notice must be filed within 10 days of the verbal approval.

Before any well is abandoned, it must be plugged in a manner which will permanently confine all oil, gas and water in the separate strata in which they are originally found (Rule 202.B[1]). This can be accomplished by using mud-laden fluid, cement, and a single plug or a combination of plugs. The exact method employed must be approved by the NMOCD as based on the notice of intention to plug. Minimum plugging requirements and standard plugging practice in the potash resource area are shown in Figures DEL-13 and DEL-14.

Within a year following completion of plugging, the operator must accomplish the following:

(1) fill all pits,

(2) level the location,

(3) remove deadmen (buried anchors to steady the derrick) and all other junk, and

(4) take whatever measures are necessary to restore the site to a safe and clean condition.

When plugging and cleanup have been completed, the operator must contact the NMOCD and arrange for an inspection. The NMOCD will not approve the record of plugging until all necessary reports (Forms C-103 and C-105; Attachment 5) have been filed and the location has been inspected and approved.

Well marking requirements are specified in Rule 202.B(2). All plugged and abandoned wells must be marked with a 10-foot (3-meter) long steel marker at least 4 inches (10 centimeters) in diameter, set in cement, and extending at least 4 feet (1 meter) above mean ground level. The name of the operator, lease name, well number, and legal location (section, range, and township) must be welded, stamped or otherwise permanently engraved on the marker.

An exception is made for wells that can safely be used as a fresh water source. In such a case, the well need not be plugged above the sealing plug that is set below the fresh water formation. When this plugging has been completed, the operator seeking a bond release must file with the NMOCD a written agreement under which the landowner agrees to assume responsibility for the well.

DEL.6.2.2.2 Temporary Abandonment - Rule 203

A well can be temporarily abandoned for up to five years, during which period it must either be permanently plugged and abandoned or returned to beneficial use. After five years, an operator can apply for a new temporary abandonment approval. (Compare with BLM policy on temporarily abandoned and shut-in wells as discussed in Section DEL.6.1.2.3.) In order to receive NMOCD approval, the operator must submit a notice of intent to temporarily abandon

on Form C-103 (Attachment 5). A well cannot be temporarily abandoned unless the casing is mechanically sound and in good enough condition to prevent

(1) damage to the producing zone,

(2) migration of hydrocarbons or water,

(3) contamination of fresh water or other resources, and

(4) leakage of any substance to the surface.

If the well cannot meet the required mechanical integrity test, it must be plugged and abandoned or the casing problem must be corrected and confirmed by retesting. Methods of testing are detailed in Rule 203.C (Attachment 6).

DEL.6.2.3 Incidence of Unplugged Oil and Gas Wells

Criteria in 40 CFR Part 194 include the following:

> Performance assessments shall document that in analyzing the consequences of drilling events, the Department assumed that:
>
> (1) Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared. Such future drilling practices shall include . . . the fraction of such boreholes that are sealed by humans . . . (40 CFR § 194.33[c]).

Following these criteria, it was concluded that the fraction of boreholes that have been sealed by humans should be determined by evaluating all wells in the New Mexico portion of the Delaware Basin that were drilled and plugged since 1988 (the date the current plugging regulations became effective). Texas wells were not considered because a well drilled at the WIPP site would not subject to Texas regulations. The total number of hydrocarbon boreholes in the New Mexico portion of the Delaware Basin with completion dates from 1988 to 1995, as taken from the Petroleum Information Corporation database, is 875. The NMOCD records for each of these 875 wells were examined to determine the current status of each well.

Wells plugged or scheduled to be plugged on federal land were examined in detail. There were 47 wells found in this category. NMOCD records contain final plugging records for 43 of these wells and intent-to-plug notices for the remaining four wells.

A field verification for these four wells was conducted on March 14, 1996. Two of these wells were plugged, one was being plugged on that date, and one well was unplugged. The intent-to-plug notice for the unplugged well was approved on December 4, 1995, and, according to the Carlsbad, New Mexico, BLM office, the company responsible for this well was currently processing the appropriate paperwork to plug the well.

Based on this information, it is proposed that the performance assessment incorporate the assumption that no oil and gas wells would be left unplugged.

DEL.6.2.4 Oil and Gas Development in Potash Areas - NMOCC Order R-111-P

The New Mexico Oil and Gas Act declares as waste

> [D]rilling or producing operations for oil or gas within any area containing commercial deposits of potash where such operations would have the effect unduly to reduce the total quantity of such commercial deposits of potash which may reasonably be recovered -- or where such operations would interfere unduly with the orderly development of such potash deposits [§ 70-2-3(F) NMSA 1978].

Both the BLM (see Section DEL.6.1.4) and the NMOCD have been dealing with conflicts between the potash industry and oil and gas drilling and production operations for many years. The first NMOCC order addressing oil and gas drilling and potash mining activities in areas where leaseholds are overlapping was Order No. R-111-A of July 14, 1955.

On April 21, 1988, the NMOCC issued a major revision to Order No. R-111-A: Order No. R-111-P (now 19 NMAC 15.R.111). The objective of this order, which is still in effect, is to prevent waste, protect correlative rights (rights of an owner of an oil and gas property to produce his or her equitable share without waste), and ensure maximum conservation of New Mexico oil, gas, and potash resources. The key provisions of Order No. R-111-P are as follows:

- No oil and gas wells can be drilled so as to result in an undue waste of potash deposits, pose a hazard to, or unduly interfere with potash mining.

- No potash mining can be conducted which will pose a hazard to oil or gas production or unreasonably interfere with orderly oil or gas development.

- The intermediate string and production string of well casing must meet certain cementing requirements.

- A salt protection string of casing must be installed at least 100 feet (30 meters) below and not more than 600 feet (183 meters) below the base of the salt section. Cementing requirements for both shallow wells (above 5,000 feet [1,524 meters]) and deep wells (below 5,000 feet [1,524 meters]) above or below the Delaware Mountain Group are specified.

- All oil and gas wells drilled within the potash area (same as the KPLA) must provide a solid cement plug through the salt section and any water-bearing horizon and prevent liquids or gases from entering the hole above or below the salt section.

- The fluid used to mix the (plugging) cement must be saturated with salts common to the salt section penetrated but not more than three percent of calcium chloride by weight of cement wherever possible.

- Regardless of whether the potash lease is on federal or state lands, each potash lessee must file with the BLM and the State Land Office a designation of potash deposits considered by the lessee to be its life-of-the-mine reserves (LMR). LMRs are deposits believed to be economically minable using present mining methods and technology. Information on LMRs filed with the BLM and the State Land Office is considered proprietary and cannot be released to the general public.

- Before commencing oil or gas drilling operations within the potash area, the well operator must forward a map showing the location of the proposed well to every potash operator holding potash leases within a radius of one mile of the proposed well.

Permit applications for oil or gas well drilling on federal lands in the KPLA are processed by BLM while those on state or private lands are processed by the NMOCD. If State lands are involved, the State Land Office enters the picture because the NMOCD must determine from either the BLM or the State Land Office if the proposed well location is within a potash LMR area. Any application to drill in a potash LMR area must be approved by the lessor and lessees of both the potash and the oil and gas interests.

DEL.6.2.5 Bonds, Penalties, and Enforcement

Criminal and civil penalties for violations of the New Mexico Oil and Gas Act and related NMOCD rules and regulations are governed by §§ 70-2-28 through 70-2-32 NMSA 1978. Suits brought by the NMOCD through the State Attorney General may result in obtaining injunctions or temporary restraining orders. Knowing and willful violations can result in a $1,000 per day fine for each violation. Criminal violations (for example, fraudulent representations) are subject to a fine of up to $5,000, imprisonment up to three years, or both.

It is the bonding requirement that provides the teeth for the plugging requirements (see the discussion of NMOCD Rule 101 on plugging bonds in Section DEL.6.2.1). The NMOCD can order any well to be plugged and abandoned. Because failure to plug or improper plugging can result in pollution of both surface and underground water, well plugging and its enforcement would normally also be under the jurisdiction of the New Mexico Water Quality Control Commission. However, the Commission has delegated water quality matters related to oil and gas development to the NMOCD to prevent duplication of effort. The delegation of authority is authorized by the New Mexico Water Quality Act (§ 74-6-4E NMSA 1978).

A summary of oil and gas well data is provided in Table DEL-2 for the period 1971 through 1995. The table shows wells completed, wells plugged and abandoned, number of active wells, the number of regulatory cases docketed, and the number of cases pertaining to compulsory plugging.

DEL.6.3 Regulation of Injection Wells

This section discusses the regulation of injection wells (which are often included in the definition of service wells) by the BLM and the NMOCD. Injection wells located near the WIPP are shown in Figure DEL-6.

DEL.6.3.1 Definitions

BLM onshore oil and gas operations regulations and related orders do not define either injection or service wells. The NMOCD rules define an injection or input well as any well used for the injection of air, gas, water, or other fluids into any underground stratum (Rule 0.1). The NMOCD rules do not define the term service well. *The Dictionary for the Petroleum Industry* (University of Texas 1991) defines injection well as

> a well through which fluids are injected into an underground stratum to increase reservoir pressure and to displace oil.

The same source defines service well as

> a well used for injecting liquid or gas into a reservoir for enhanced recovery as well as saltwater disposal wells and water wells.

For the purpose of this analysis, injection well is defined broadly to mean wells used for injecting liquids or gases into a reservoir for enhanced (or secondary) recovery, wells used to dispose of saltwater, and wells used for underground storage of hydrocarbons. It does not include wells that are initially drilled for oil or gas exploration or production but are later used as water supply wells.

Most injection wells used in the oil and gas industry are not drilled only for injection purposes. In most cases, exploratory wells or producing wells that have reached an advanced state of depletion are converted to injection wells, either for water disposal or enhanced production purposes. Thus, the same drilling and plugging requirements that apply to oil and gas wells also apply to injection wells (see Sections DEL.6.1 and DEL.6.2).

DEL.6.3.2 Bureau of Land Management

The BLM does not have specific requirements that apply only to injection wells. Injection wells are not addressed in either the 43 CFR Part 3160 regulations on onshore oil and gas operations or the various onshore oil and gas orders. The requirements for drilling and plugging of oil and gas wells described in Section DEL.6.1.2 apply equally to injection wells.

Instead of having its own regulations governing injection wells, the BLM defers to the NMOCD (or Texas Oil and Gas Division) requirements. In other words, the BLM requires oil and gas operators to abide by the applicable state requirements and procedures. Of course, BLM would still issue the drilling permit on federal lands.

Table DEL-2. New Mexico and SE New Mexico Oil and Gas Well Data, 1971 to 1996 [1]

Year	Wells Completed [3]	Wells Abandoned [4]	Active Wells [5]	Docketed Cases [6]	Compulsory Plugging [7]
1996[2]	1200	400	29,690	300	25
1995	1139	342	29,172	283	19
1994	897	335	28,663	322	2
1993	916	357	28,163	371	0
1992	797	348	27,671	314	1
1991	929	284	27,461	383	2
1990	832	264	27,117	592	0
1989	668	272	26,965	457	3
1988	803	274	26,928	432	0
1987	770	313	26,664	302	2
1986	868	307	26,486	346	7
1985	1272	349	26,103	430	11
1984	1197	212	25,190	525	6
1983	1212	344	24,641	326	6
1982	1573	180	24,124	342	18
1981	1419	118	23,137	399	7
1980	1221	159	22,365	410	16
1979	997	155	21,671	383	12
1978	999	126	21,062	346	29
1977	849	204	20,515	335	15
1976	784	309	20,171	264	15
1975	794	264	20,170	258	10
1974	901	241	20,127	262	18
1973	600[8]	207	19,952	276	18
1972	666[9]	295	19,845	302	3
1971	NA	NA	NA	169	4

Notes on following page.

[1] The first three columns of data are for southeastern New Mexico. The remaining columns show statewide data. Southeastern New Mexico includes NMOCD District 1 (Lea, Roosevelt, Curry, and a portion of eastern Chaves Counties) and District 2 (Eddy, most of Chaves, DeBaca, Lincoln, Otero, and Dona Ana Counties).
[2] Numbers for 1996 were estimated by E. Martin, NMOCD, Santa Fe, New Mexico, on March 12, 1996.
[3] Includes oil, gas, dry hole, and service wells for NMOCD Districts 1 and 2.
[4] Includes oil, gas, and service wells abandoned in NMOCD Districts 1 and 2.
[5] Includes oil, gas, and injection wells for NMOCD Districts 1 and 2.
[6] Docketed cases are those enforcement actions set for a hearing. They result in various types of hearing orders. The numbers are for cases statewide, not only for NMOCD Districts 1 and 2. Docketed cases are categorized into 16 different subjects. Compulsory plugging was selected as the subject most relevant to inadvertent drilling into the WIPP.
[7] These numbers are statewide and not only for NMOCD Districts 1 and 2. Compulsory plugging refers to wells not totally in compliance with plugging requirements. The term does not refer to wells left unplugged.
[8] No service wells are included in this number for 1972 and 1973.
[9] This number for 1972 is for wells drilled, not wells completed.

DEL.6.3.3 State of New Mexico

The NMOCD regulations applicable to injection wells are contained in Rules 705 through 708 (19 NMAC 15.I.705-708). The rules apply to injection used for secondary or other enhanced recovery, pressure maintenance, salt water disposal, and underground storage. The rules apply to the injection of both fluids and gases. A permit is required from the NMOCD for the injection of gas, air, water, or any other medium into any oil or gas reservoir in order to maintain pressure for secondary or other enhanced recovery (Rule 701-A). A permit is also required for injection of water for disposal or for underground storage. The permit will be granted only after notice and hearing unless otherwise provided by the NMOCD rules. Because applications for underground storage are rare in New Mexico, storage injection well requirements are not discussed in this section.

DEL.6.3.3.1 Injection Application

Application for an injection permit (authorization to inject) must be made on NMOCD Form C 108 (Attachment 5) and contain the following information:

- complete well data for each proposed injection well,
- map identifying all wells and leases within two miles of each proposed injection well with a one-half mile radius circle showing the well's area of review,
- tabulation of data (well type, location, depth, and plugging detail if plugged) for all wells within the one-half mile area of review that penetrate the proposed injection zone,
- detailed data on the proposed injection well operation (volume of injection fluids, injection pressure, and chemical analyses of injection fluid),

- geological data including lithologic detail, thickness and depth of injection zone, and location of all underground sources of drinking water (USDW),

- well logging and test data (if not previously submitted),

- chemical analysis of fresh water from two or more existing and producing water wells within one mile of any injection or disposal well, and

- statement to the effect that available geologic and engineering data do not indicate the existence of open faults or other hydrologic connections between the disposal zone and any USDW.

One of four purposes for which the injection project requires a permit from the NMOCD is specified on Form C-108: secondary recovery, pressure maintenance, disposal, or storage.

Injection well permit applicants must provide, by certified or registered mail, a copy of the application to the surface landowner where the well is to be located and to each oil or gas lease operator within one-half mile of the proposed well location. (In actual practice, the NMOCD determines if all wells within a one-half mile radius of the proposed injection well are cased and cemented across the injection zone). If the application is for administrative approval without a hearing, the applicant must publish notice in a newspaper of general circulation in the county in which the proposed injection well will be located. If a written objection is filed with the NMOCD within 15 days of the filing of the application, a hearing must be held (Rule 701-D).

DEL.6.3.3.2 *Salt Water Disposal Wells*

The injection of water into any formation for the purpose of water disposal is permitted by the NMOCD only after notice and hearing (Rule 701-A). However, under Rule 701-E, an exception may be made for water disposal wells only when the waters to be disposed of are mineralized to such a degree as to be unfit for domestic, stock, irrigation, or other general use and when the waters are disposed of into a formation older than the Triassic (in Lea County only), provided there are no objections. Water disposal is not permitted into zones containing waters with TDS concentrations of 10,000 milligrams per liter or less, except after notice and hearing. Nevertheless, the NMOCD can authorize water disposal in such zones (TDS of 10,000 milligrams per liter or less) if the water to be disposed of is of higher quality than the water in the disposal zone. These restrictions do not apply to exempted aquifers which the NMOCD may establish.

DEL.6.3.3.3 *Pressure Maintenance Projects*

In pressure maintenance projects, fluids are injected into the oil- or gas-producing horizon in order to increase or maintain reservoir pressure in an area which has not reached the stripper well degree of depletion. All injection well permit applications for pressure maintenance

projects require both notice and a hearing unless the NMOCD grants an exception under certain circumstances (Rule 701-F). Although not prescribed by rule, the NMOCD practice is to limit all injection well pressures to 0.2 pounds per square inch (1,379 pascals) for each foot of well depth to the top of the injection zone.

DEL.6.3.3.4 Water Flood Projects

In water flooding, water is injected into a producing horizon in sufficient quantities and pressure to stimulate production from other wells in the area. It is limited under Rule 701-G to areas in which the wells have reached an advanced or stripper well state of depletion. All applications for water flood projects require a hearing. However, if there are no objections, a hearing is not required to permit additional injection wells that may be necessary to develop or maintain a thorough and efficient water flood injection for any authorized project (Rule 701-G [7]).

DEL.6.3.3.5 Casing and Cementing of Injection Wells

NMOCD Rule 702 requirements for casing and cementing of injection wells are, for all practical purposes, the same as for exploration and production wells. Wells must be cased with safe and adequate casing or tubing to prevent leakage and movement of either formation or injected fluid from the injection zone into any other zone or to the surface.

DEL.6.3.3.6 Injection Well Operation and Maintenance

NMOCD Rule 703-A provides as follows:

> Injection wells shall be equipped, operated, monitored, and maintained to facilitate periodic testing and to assure continued mechanical integrity which will result in no significant leak in the tubular goods and packing materials and no significant fluid movement through vertical channels adjacent to the wellbore.

Any injection project must be operated so as to prevent surface damage or pollution resulting from leaks, breaks, or spills. The failure of any injection well which may endanger a USDW must be reported immediately (that is, as soon as possible after discovery) to the appropriate NMOCD District Office under the procedures specified in Rule 116. Detailed injection well testing and monitoring requirements are outlined in NMOCD Rule 704.

DEL.6.3.3.7 Commencement, Discontinuance, and Abandonment

The operator of any injection well must immediately notify the NMOCD of the date when injection operations commenced (Rule 705-B). The operator must also notify the NMOCD within 30 days of the operations being discontinued and for what reasons. An injection well cannot be temporarily abandoned longer than six months unless the injection interval has been isolated by installing a cement plug or a bridge plug. Plugging requirements may be delayed if there is a continuing need for the well, it is mechanically sound, and its temporary

abandonment will not endanger a USDW. When injection operations have ceased for a continuous period of six months, the well will be considered abandoned; the permit will terminate automatically.

DEL.6.3.3.8 *Records and Reports*

The operator of an injection well must keep accurate records and make monthly reports to the NMOCD regarding the volumes of gas or fluids injected, stored, or produced. Various forms (C-115, C-120-A, and C-131-B) are available for this purpose.

DEL.7 Inadvertent and Intermittent Intrusion by Drilling

Information pertinent to the assessment of the likelihood of inadvertent intrusion into the repository is presented in this section.

DEL.7.1 Regulatory Context

The EPA criteria for certification of WIPP's compliance with the 40 CFR Part 191 disposal regulations state that performance assessments examine deep and shallow drilling that may potentially affect the disposal system during the 10,000-year regulatory time frame (40 CFR § 194.33[a]). Deep drilling is defined by the criteria as drilling events that reach or exceed 2,150 feet (655 meters) below the surface while shallow drilling means drilling events that do not reach a depth of 2,150 feet (655 meters) (40 CFR § 194.2). The total rate of deep drilling must be calculated as the sum of the rates of deep drilling for each resource in the Delaware Basin over the past 100 years. The total rate of shallow drilling must be calculated as the sum of the rates of shallow drilling over the same time period for each resource in the Delaware Basin that is of similar type and quality as the resources in the WIPP controlled area.

DEL.7.2 Shallow Drilling Events

The majority of shallow holes are composed of water wells, potash coreholes, and sulfur coreholes. The identification, location, and depth of the shallow boreholes in the Delaware Basin have been taken from existing commercial databases and maps. The data gathered on shallow boreholes was taken directly from commercial databases and BLM records as described below.

DEL.7.2.1 Water Wells

Information on water wells in the Delaware Basin was obtained from a commercial database developed by Whitestar Corporation of Englewood, Colorado.

DEL.7.2.2 Potash Coreholes

Information on potash coreholes in the Delaware Basin was compiled from BLM records.

DEL.7.2.3 Sulfur Coreholes

Sulfur corehole information was obtained from a commercial database developed by Whitestar Corporation of Englewood, Colorado, and the Petroleum Information Corporation of Denver, Colorado.

DEL.7.3 Deep Drilling Events

Only the drilling of a deep well could result in inadvertent human intrusion into the WIPP repository. Information on the identification, location, and depth of the deep boreholes in the Delaware Basin has been derived from existing commercial databases and maps. The data gathered on the deep oil and gas boreholes are available from several commercial sources. To assure the accuracy of these commercial databases and maps, and obtain the best possible count of deep wells in the basin, these commercial sources were verified against one another.

The data sources selected for determining the number of oil and gas wells in the Delaware Basin were maps obtained from the Midland Map Company and a database obtained from the Petroleum Information Corporation. Both the Midland Map Company and Petroleum Information Corporation obtained well records from the NMOCD and the Railroad Commission of Texas Oil and Gas Division. These companies have a reputation for data reliability; the information they provide is regarded as a standard within the industry. However, these companies do not provide any warranty on the accuracy or the completeness of the data.

It is not considered economically feasible to validate these data. The process of validating the data would require field verification of wells in an area covering approximately 8,910 square miles (23,077 square kilometers) as well as a comparison of NMOCD and BLM records with the private records of the various oil and gas companies.

While it was not considered feasible to validate the original data, it was considered reasonable to determine a verifiable deep well count. By comparing the two selected commercial sources of data, a count of deep wells in the Delaware Basin has been prepared. In comparing the Petroleum Information Corporation database to the Midland Map Company maps, some wells were found to be identified either in the database or on the maps, but not in both sources. The well count presented here was derived using all wells in the Petroleum Information Corporation database plus the wells identified on the Midland Map Company maps that were not in the Petroleum Information Corporation database.

DEL.7.4 Rate of Drilling in the Basin

The number of boreholes listed in the Petroleum Information Corporation database and the number of boreholes shown on the Midland Map Company map but not listed in the Petroleum Information Corporation database are provided in Table DEL-3. In addition, the number of shallow and deep boreholes created in the Delaware Basin over the past 100 years is shown by type of borehole in Table DEL-4.

In the case of water wells, the available data do not include the depths of all of the water wells shown in the database. To arrive at an estimate of the total number of deep and shallow water wells, the ratio of known deep wells (that is, those 2,150 feet [656 meters] or greater) versus known shallow water wells was calculated and applied to the total number of water wells shown in the database.

The intrusion rate for boreholes drilled per square kilometer (0.39 square mile) over 10,000 years has been calculated using the borehole counts listed in Tables DEL-4, DEL-5, and DEL-6. The calculated rates suggested for use in the performance assessment are shown in Table DEL-7. As provided by 40 CFR § 194.33(b)(4)(iii), the calculated rate for shallow boreholes excludes sulphur holes because no economically extractable sulphur is located within the WIPP land withdrawal area (NMBMMR 1995). In addition, consistent with EPA guidance in the EPA 1996 *Response to Comments Document For 40 CFR Part 194,* page 12-8, last paragraph, both shallow and deep holes created as part of WIPP site characterization efforts have been excluded from the count. Based on the data provided in these tables, the calculated rates are 21.821 shallow holes per square kilometer (0.39 square mile) and 46.765 deep holes per square kilometer (0.39 square mile) over 10,000 years.

DEL.7.5 Pressurized Brine Encounters Within the Delaware Basin

Some of the human intrusion scenarios evaluated in the WIPP performance assessment include the assumption that a borehole results in the establishment of a flow path between the repository and a pressurized brine pocket that could be located beneath the repository in the Castile. To identify reasonable assumptions for use in the performance assessment, commercial drillers and operators with experience in the Delaware Basin were surveyed to determine the frequency of occurrence and typical depths of abnormally pressurized brine zones within the Delaware Basin (Personal Communication 1996d; Personal Communication 1996e; Personal Communication 1996f; Personal Communication 1996g).

For the purpose of this investigation, abnormally pressurized brine zones are defined as those that exhibit pressures exceeding the hydrostatic pressure of the column of drilling fluid in the hole. Consistent with this definition, any brine encounter having pressure exceeding hydrostatic pressure is considered abnormally pressurized. Flow to the surface driven by differential pressures just above hydrostatic pressure, however, would typically not be noticed by a driller, and is expected to be of little impact to performance assessment.

Table DEL-3. Boreholes Within the Delaware Basin

Borehole Type	Boreholes Listed in the PI Database	Boreholes Shown on the Midland Map But Not Listed in the PI Database	Total Number of Boreholes by Type
	Hydrocarbon Boreholes		
Oil Well	5,728	37	5,765
Gas Well	1,569	2	1,571
Oil/Gas Well	14	0	14
Abandoned Wells	167	1	168
Dry Hole	3,453	56	3,509
Injection Well	72	2	74
Service Well	147	0	147
Total Hydrocarbon Boreholes	11,150	98	11,248
	Other Resource, Exploratory, or Test Boreholes		
Sulphur Corehole	584	0	584
Potash Corehole	925	0	925
Stratigraphic and Core Test Hole [1]	1,271 [1]	0	1,271 [1]
Water Well	2,311	0	2,311
Brine Well (Solution Mining)	1	0	1
Total Other Boreholes	5,092	0	5,092

[1] Excluding boreholes drilled as part of WIPP site characterization programs.

When asked how often abnormally pressurized brine zones are encountered, each of the drillers surveyed stated that it was an uncommon occurrence in the Delaware Basin, and that they believe the actual frequency to be less than five percent. This estimate captures those occurrences where the differential pressure could be great enough to drive a noticeable quantity of drilling fluid to the surface. The drillers reported that these zones are most frequently encountered in the Castile Formation in the Delaware Basin.

The Castile Formation within the land withdrawal area is approximately 1,250 feet (381 meters) thick. It is primarily an anhydrite formation and has been found to have isolated areas that hold quantities of brine. Based on observed Castile porosity (amount of space in the

Table DEL-4. Number of Shallow and Deep Boreholes Within the Delaware Basin, by Resource or Type

Borehole Type	Shallow Borehole [1]	Deep Borehole [2]
Hydrocarbon Borehole	608	10,640
Sulphur Corehole	495	89
Potash Corehole	906	19
Stratigraphic and Core Test Hole [3]	1,215 [3]	56 [3]
Water Well	2,311	0
Brine Well (Solution Mining)	1	0
Total Boreholes, by Depth	5,536	10,804

[1] Equal to or less than 2,150 feet (655 meters).
[2] Greater than 2,150 feet (655 meters).
[3] Excluding boreholes drilled as part of WIPP site characterization programs.

Table DEL-5. Number of Shallow Boreholes Per Square Kilometer in the Delaware Basin, by Resource or Type [1]

Borehole Type	Shallow Boreholes [2]	Boreholes Per Square Kilometer
Hydrocarbon Borehole	608	2.632
Sulphur Corehole	495	2.143
Potash Corehole	906	3.922
Stratigraphic and Core Test Holes [3]	1,215 [3]	5.259 [3]
Water Wells	2,311	10.003
Brine Well (Solution Mining)	1	0.004
Total Shallow Boreholes	5,536	23.963

[1] The area of the Delaware Basin is 23,102.1 square kilometers (14,356 square miles). The number of holes per square kilometer is calculated as follows: (number of holes) × 10,000 years / area / 100 years.
[2] Equal to or less than 2,150 feet (655 meters).
[3] Excluding boreholes drilled as part of WIPP site characterization programs.

Table DEL-6. Number of Deep Boreholes Per Square Kilometer in the Delaware Basin, by Resource or Type [1]

Borehole Type	Deep Boreholes [2]	Boreholes Per Square Kilometer
Hydrocarbon Borehole	10,640	46.056
Sulphur Corehole	89	0.385
Potash Corehole	19	0.082
Stratigraphic and Core Test Holes [3]	56 [3]	0.242 [3]
Water Well	0	0
Brine Well (Solution Mining)	0	0
Total Deep Boreholes	10,804	46.765

[1] The area of the Delaware Basin is 23,102.1 square kilometers (14,356 square miles). The number of holes per square kilometer is calculated as follows: (number of holes) × 10,000 years / area / 100 years.
[2] Greater than 2,150 feet (655 meters).
[3] Excluding boreholes drilled as part of WIPP site characterization programs.

Table DEL-7. Number of Boreholes Per Square Kilometer to be Used in Performance Assessment Calculations

Type of Borehole	Number of Boreholes	Boreholes Per Square Kilometer
Shallow Borehole	5,041 [1]	21.821
Deep Borehole	10,804 [2]	46.765

[1] Excluding sulphur coreholes and boreholes drilled as part of WIPP site characterization programs.
[2] Excluding boreholes drilled as part of WIPP site characterization programs.

formation to store brine) and permeability (ability of the formation to conduct fluids), brine present in the unit may be released into an intersecting uncased wellbore. This brine may be normally or abnormally pressured.

Hydrostatic pressure at any depth in the wellbore is calculated using the following formula:

$$Pm = MW \times D \times 0.052 \qquad (1)$$

where
Pm = ressure (pounds per square inch),
MW = mud weight (pounds per gallon),
D = depth (feet), and
0.052 = a conversion factor representing mud density.

For example, at 3,000 feet (915 meters), the hydrostatic pressure is calculated at 1,560 pounds per square inch (1.08×10^7 pascals) based upon the use of a 10-pounds-per-gallon saturated brine as the drilling fluid. In this example, brine flow to the surface would be possible only if the brine source is pressurized greater than 1,560 pounds per square inch.

Typically, the driller would become aware of abnormally pressurized brine only if the pressure of the brine encounter is sufficient to cause a noticeable gain of fluid in the mud pit. When this occurs and the flow is not great enough to cause immediate concern, drilling will typically continue, but the driller will calculate the rate of brine flow. This is accomplished by shutting off the pumps and using a bucket of known capacity to catch the free-flowing brine and noting the time that it takes to fill the bucket. From this measurement, the driller can determine the rate of flow in barrels-per-minute. If the flow rate is not so great as to cause concern of over-filling the reserve pit, drilling would continue until the hole reaches the Bell Canyon Formation. The intermediate casing would then be run and cemented. Once in place, the casing string would isolate the overpressurized zone and prevent further flow to the surface.

A very heavy brine flow, however, such as one that could potentially fill the pit within one-to-two hours, would not be allowed to continue. Corrective action would be taken in the form of killing the flow of brine. This is accomplished in the field by shutting in the blowout preventor and calculating the downhole pressure. Using this pressure, the driller then determines the quantity of barite (the mud additive most often used) that must be added to the drilling fluid to sufficiently increase the hydrostatic pressure exerted by the column, so that the differential pressure results in downward flow from the drilling fluid column into the formation. When brine flow to the surface has stopped, drilling continues to the depth originally determined in the well plan. Once this depth is reached, intermediate casing is run and cemented in place.

The drillers reported that measures to kill pressure-driven flow to the surface are required only rarely. They are generally able to drill through the Castile Formation while brine is flowing and successfully set the intermediate string in the Bell Canyon Formation (the usual drilling horizon).

Using a typical drilling scenario based on a pressurized zone at a depth of 3,000 feet (915 meters) with a hydrostatic pressure of 1,560 pounds per square inch (1.08×10^7 pascals), flow rates necessary to fill the pit at one-and-two-feet-per-hour increments have been calculated. This calculation is provided below.

Assume:

A. Well Depth, ΔZ :	3,000 feet
B. Mud Pit Volume:	125 feet * 125 feet * 6 feet = 93,750 cubic feet = 701,298.701 gallons
C. Casing Weight:	32 pounds per foot
D. Casing Inner Diameter	8.625 inches
E. Open Hole Inner Diameter	11.5 inches = 0.958 feet
F. Unit Volume:	15,625 cubic feet per foot of vertical height
G. Unit Volumetric Flow Rate:	4.34 cubic feet per second
H. Drilling Fluid:	Case 1: 10.25 pounds per gallon brine Case 2: barite

I.	Density (ρ):	Case 1: 76.68 pounds per cubic foot ^{3} Case 2: 263.3 pounds per cubic foot
J.	Friction Factor (f):	0.06 for coated casing/open hole
K.	Internal Casing Pipe Area (A):	$\pi d^2/4 = \pi(0.958)^2/4 = 0.721$ square feet
L.	Gravity (g):	32.17 feet per square second
M.	Velocity (1 ft/ hr Brine Pit Disp.):	V = Q/A = 4.34*1/0.721 = 6.017 feet per second
N.	Velocity (2 ft/ hr Brine Pit Disp.):	V = Q/A = 4.34*2/0.721 = 12.034 feet per second

Equation:

$$\frac{\Delta P}{\rho} = \frac{\Delta V^2}{2g} + \Delta Z + E_{12} \qquad (2)$$

$$\Delta P = \rho \left[\frac{\Delta V^2}{2g} + \Delta Z + \frac{fLV^2}{2gd} \right] \qquad (3)$$

Derived from Gieck (1987)

For the case of 1 ft/hr brine pit displacement: ΔP = 1,654.099 pounds per square inch (1.14046×10^7 pascals) gauge

For the case of 2 ft/hr brine pit displacement: ΔP = 1,823.784 pounds per square inch (1.25745×10^7 pascals) gauge

The calculation shows that a one-foot-per-hour pit level increase would be possible only if encountering bottom-hole pressures of at least 1,654 pounds per square inch gauge. A two-foot-per-hour increase in the pit level would require a pressure of 1,824 pounds per square inch (1.25745×10^7 Pa) gauge. Those surveyed indicated that pressures of this magnitude are seldom experienced in the Delaware Basin, and that both one- and two-foot-per-hour pit level rises would be noticed by the driller.

The low rate of occurrence of abnormally pressured brine has been further supported by information documented in the drilling records. Using databases assembled by Petroleum Information Corporation and Midland Map Company, which provide well name, operator, location, total depths, casing sizes, and dates of drilling and completion, the DOE has developed a list of all oil and gas wells that have been drilled within the New Mexico portion of the Delaware Basin. Wells on this list are located in the southern portions of Eddy and Lea Counties, which are the only New Mexico counties within the Delaware Basin.

The well files at the Oil Conservation Division offices in Artesia and Hobbs, New Mexico, (the NMOCD maintains the records of wells drilled on both state and federal leases in Eddy and Lea Counties) were also reviewed. The files record activities entered by the drillers from initiation of drilling to completion of a particular well. Drillers note in these reports any unusual occurrences such as abnormally pressured brine. Incidents of this type are reported in the form of daily reports. Although there is no requirement that they do so, drillers may include pressurized brine encounters in their daily reports, even if there has been no effect on drilling activities. The Texas portion of the Delaware Basin was not evaluated. The rationale

for not including the Texas portion is that wells nearer the WIPP land withdrawal area are of greatest interest in determining the presence of brine within the Castile.

Of a total of 3,406 well files reviewed, 28 were found to have notations by the driller indicating the encounter of pressurized brine. (See Figure DEL-15.)

Another factor influencing performance assessment analyses is the time that flow from a pressurized zone to the surface would continue prior to the installation of the intermediate casing string. As stated previously, the intermediate casing is typically run when the Bell Canyon Formation is reached, which is approximately 4,000 feet (1,220 meters) in depth near the WIPP site. At this time, the drill string is removed from the hole and intermediate casing is run and cemented from 4,000 feet (1,220 meters) to the surface. After cementing is completed, the driller is required by regulation to wait 24 hours for the cement to set before drilling resumes.

Drilling time from the repository depth at 2,150 feet (656 meters) through the remaining portion of the Salado and all of the Castile (an additional 1,250 feet; 381 meters) is calculated to be 54 hours. This number is based on drilling rates of 50-to-60 feet (15-to-18 meters) per hour from the base of the surface casing at 800 feet (244 meters), to the top of the Castile at 2,750 feet (838 meters) (New Mexico Junior College 1995). The drilling rate is expected to slow to 30-to-40 feet (9-to-12 meters) per hour through the Castile (New Mexico Junior College 1995). Once the Bell Canyon has been entered, an additional 14 hours are typically required to remove the drill string from the hole and run and cement the 3,200 feet (976 meters) of casing.

In the majority of drilling operations, the driller will be able to safely drill ahead, reach the Bell Canyon, and complete the intermediate casing, without having to resort to killing the pressure. However, if pressures encountered are great enough that the driller is forced to engage the blowout preventer and add weight to the drilling fluid, the maximum time that flow to the surface would occur is one to two hours. Therefore, two hours represents a reasonable lower bound duration and is derived from high pressure situations where the blowout preventer would be used to stop the flow to the surface and control the pressure by adding weight to the drilling fluids.

DEL.7.6 Borehole Permeability Assessment

Human intrusion scenarios evaluated in the WIPP performance assessment assume that one or more boreholes intercept the repository and that the boreholes are subsequently plugged. To support the evaluation of the potential consequences of scenarios of this type, the DOE has assessed the permeabilities that may be expected in plugged boreholes in the Delaware Basin. The permeability of the borehole plugs is important because this is a measure of the quantity of contaminated fluids that could hypothetically flow through the borehole plug.

Results of this work are reported in *Inadvertent Intrusion Borehole Permeability*, included as Attachment 7. The DOE report summarizes plugging practices in the Delaware Basin and identifies three plugging configurations typically used in the basin:

- a single continuous plug through the evaporite sequence,
- a two-plug configuration that contains one plug in the Bell Canyon Formation (below the depth of potential brine reservoirs) plus one plug in the Rustler Formation (between the Culebra aquifer and the repository), and
- a three-plug configuration that contains the two plugs described for the two-plug configuration, plus an additional plug in the Salado Formation.

Conclusions presented in the DOE report for each of these configurations include the following:

- In the case of the single continuous plug, the permeability of the plug is expected to remain at 5×10^{-17} square meters for the entire 10,000-year period of interest.
- For the two-plug configuration, the permeability between the repository and the surface is expected to be 5×10^{-17} square meters for a period of 200 years and 10^{-11} square meters to 10^{-14} square meters after that. The plug between the Castile and the repository is expected to have a very high permeability for 200 years and values of 10^{-11} to 10^{-14} square meters up to 1,200 years, and 10^{-12} to 10^{-15} square meters after that.
- With the three-plug configuration, the permeability between the intermediate plug and the surface is expected to be 5×10^{-17} square meters for 200 years and 10^{-11} to 10^{-14} square meters after that. The intermediate plug is expected to have a permeability of 5×10^{-17} square meters for a median time of 5,000 years, and the borehole between the Castile and the repository is expected to have values ranging from 10^{-11} to 10^{-14} square meters for 1,000 years more, and 10^{-12} to 10^{-15} square meters after that.

Under all scenarios considered in the report, the permeability of the borehole plug systems never exceed that of silty sand (10^{-11} to 10^{-14} square meters).

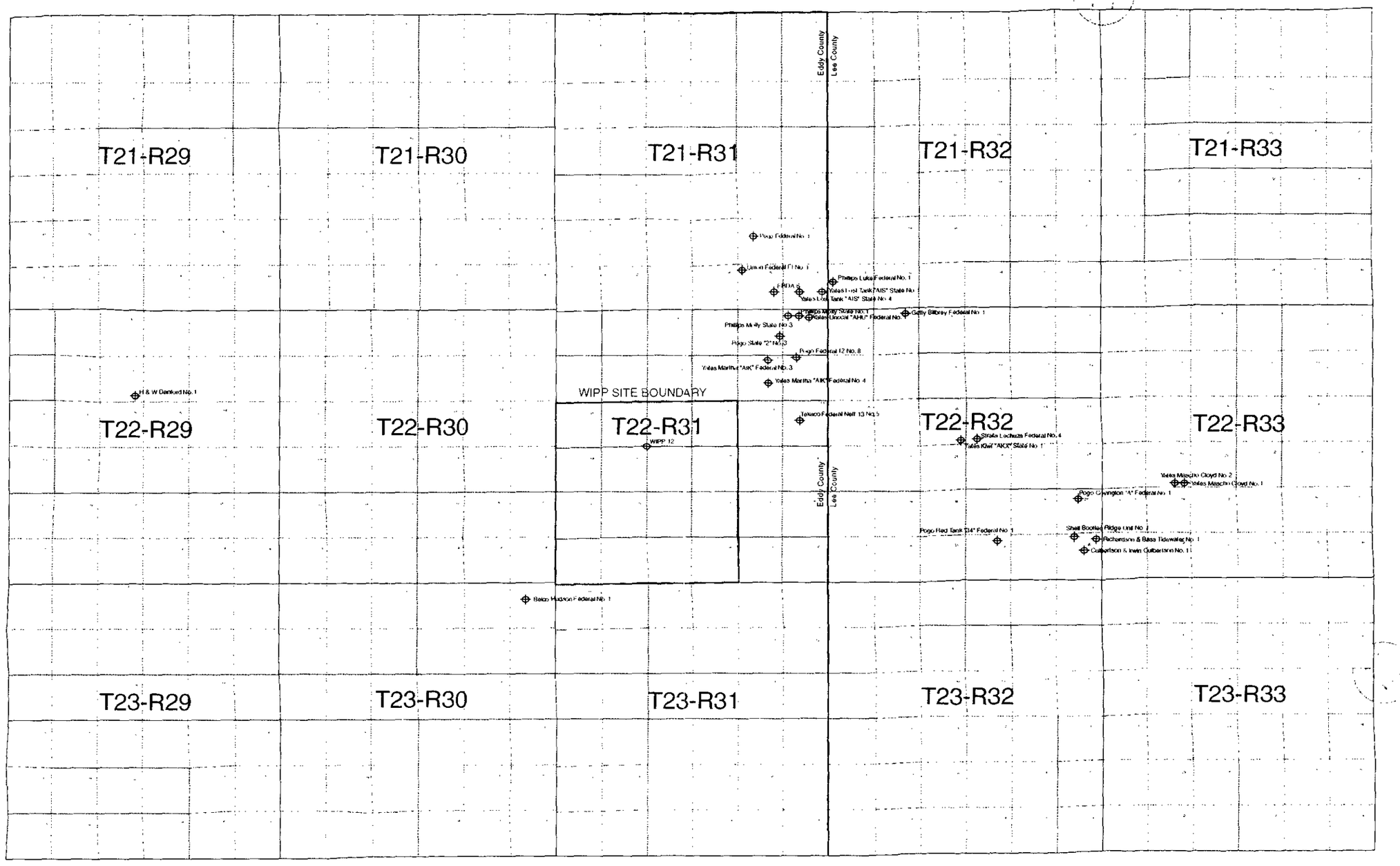

Note: A full-sized map of this figure is in a pocket at the end of Volume I, labeled Figure 2-28

Figure DEL-15. Recent Occurrences of Pressurized Brine in the Castile

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REFERENCES

Gieck, K., 1987. *Engineering Formulas*, 5th edition, McGraw Hill Publishers, Heilbronn/N, West Germany.

Kennedy, J.L., 1983. *Fundamentals of Drilling*, Penn Well Publishing.

New Mexico Bureau of Mines and Mineral Resources, 1995. *Evaluation of Mineral Resources at the Waste Isolation Pilot Plant,* Final Report, Vols. I-IV.

New Mexico Junior College, 1995. *Analytical Study of an Inadvertent Intrusion of the WIPP Site*, Hobbs, New Mexico.

Personal Communication, 1995. J. Amos, R. Manus, S. Shaw, T. O'Brian, and C. Cranston, U.S. Bureau of Land Management (BLM) and Roger Hansen, John Hart and Associates, P.A.

Personal Communication, 1996a. J. Amos, U.S. Bureau of Land Management (BLM) and Roger Hansen, John Hart and Associates, P.A. (JHA).

Personal Communication, 1996b. S. Shaw, U.S. Bureau of Land Management (BLM) and Jim Johns, Westinghouse Electric Corporation.

Personal Communication, 1996c. J. Sexton, New Mexico Oil Conservation Division (NMOCD) and Jim Johns, Westinghouse Electric Corporation.

Personal Communication, 1996d. Ted McVey, President, McVey Drilling Company, Hobbs, NM and Jim Johns, Westinghouse Electric Corporation, April 24, 1996.

Personal Communication, 1996e. Larry Scott, President, Lynx Petroleum Company, Hobbs, NM and Jim Johns, Westinghouse Electric Corporation, April 24, 1996.

Personal Communication, 1996f. Derald Roberts, Drilling Superintendent, Santa Fe Energy Corporation, Midland, TX and Jim Johns, Westinghouse Electric Corporation, April 23, 1996.

Personal Communication, 1996g. Mike Stubblefield, Field Engineer, New Mexico Oil Conservation Division, Artesia, NM and Jim Johns, Westinghouse Electric Corporation, April 24, 1996.

The University of Texas, Petroleum Extension Service, Division of Continuing Education, 1991. *A Dictionary for the Petroleum Industry*, First Edition.

U.S. Department of Energy (DOE), 1991. *Waste Isolation Pilot Plant Environmental Report for Calendar Year 1991,* DOE/WIPP 92-007, Appendix 4.

U.S. Department of Energy (DOE), 1993. *Resource Conservation and Recovery Act Part B Permit Application,* DOE/WIPP 91-005, Vol. XI, Appendix D7.

U.S. Department of Energy (DOE), 1996. *Inadvertent Intrusion Borehole Permeability,* Prepared by T.W. Thompson, W.E. Coons, J.L. Krumhansl and F.D. Hansen.

U.S. Environmental Protection Agency (EPA), 1996a. 40 CFR Part 194, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations.*

U.S. Environmental Protection Agency (EPA), 1996b. *Compliance Application Guidance for 40 CFR Part 194*, EPA 402-R-95-014, Washington, D.C.

U.S. Environmental Protection Agency (EPA), 1996c. *Response to Comments Document for 40 CFR Part 194*, EPA 402-R-96-001, Office of Air and Radiation, Washington, D.C.

U.S. Environmental Protection Agency (EPA), 1993. 40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes.*

WIPP Inadvertent Intrusion Advisory Panel (WIIAP) and New Mexico Junior College, 1995. *Analytical Study of An Inadvertent Intrusion of the WIPP Site,* Westinghouse Electric Corporation, September 5, 1995.

BIBLIOGRAPHY

Foster, R.W., 1974. *Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Wastes*, ORNL/SUB-4423/1, New Mexico Bureau of Mines and Mineral Resources (NMBMMR), Socorro, NM, New Mexico Institute of Mining and Technology. Open-File Report, Contract No. AF(40-1)-4423. Oak Ridge National Laboratory, Oak Ridge, TN.

Guzowski, R.V., and Gruebel, M.M., eds., 1991. *Background Information Presented to the Expert Panel on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*, SAND91-0928, Sandia National Laboratories, Albuquerque, New Mexico.

Hiss, W.L., 1976. *Structure of the Permian Ochoan Rustler Formation, Southeast New Mexico and West Texas,* New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Resource Map 7, 1976.

Midland Map Company, 1995. Copyrighted Ownership Maps, Midland, Texas.

Petroleum Information Corporation, 1995. Well Data Manager, a confidential and proprietary software product, Denver, Colorado.

S.M. Stoller Corporation and Merrick and Company, 1995. *Investigation of Borehole Brine Migration in Potash Mines - Phase II,* Carlsbad, New Mexico.

Sylvan Ascent, Inc., 1995. *CD/MAPS*, Toolbox Instructions and Data Definitions, Sylvan Ascent Software, Sylvan Ascent Inc., P.O. Box 4792, Santa Fe, New Mexico 87502.

Underhill, P.T., 1996. *Naturally Occurring Radioactive Materials Principals and Practices*, St. Lucie Press, Delray Beach, FL.

U.S. Bureau of Land Management (BLM), 1993. *Preliminary Map Showing Distribution of Potash Resources, Carlsbad Mining District, Eddy & Lea Counties, New Mexico,* BLM, Roswell District.

U.S. Congress, 1992. Waste Isolation Power Plant Land Withdrawal Act. Public Law 102–579, October 1992. 102nd Congress, Washington, DC.

Whitestar Corporation, Digital Mapping Specialists, Englewood Colorado.

GLOSSARY OF TERMS

accessible environment — The atmosphere, land surface, surface waters, oceans, and all of the lithosphere that is beyond the controlled area. (40 CFR § 191.12)

acidize — Treat oil-bearing formations with acid in order to increase production. This is accomplished by injecting hydrochloric or other acid into the formation under pressure. The acid etches the rock, enlarging the pore spaces for increased flow of reservoir fluids.

active institutional control — (1) Controlling access to a disposal site by any means other than passive institutional controls; (2) performing maintenance operations or remedial actions at a site; (3) controlling or cleaning up releases from a site; or (4) monitoring parameters related to disposal system performance. (40 CFR § 191.12)

annulus — The annular space surrounding the pipe in the wellbore.

blowout preventer — Also blowout preventer, this is one of several valves installed at the wellhead to prevent the escape of pressure in the annular space between the casing and the drill pipe or in an open hole with no drill pipe.

bottomhole — The lowest or deepest part of a well. Pertains to the bottom of the wellbore.

cast iron bridge plug — A metal plug with large rubber o-rings that is mechanically set against the interior casing wall in an oil or gas well. The plug is placed above the perforations in an oil or gas well that is to be plugged and abandoned.

casing shoe — A metal device attached at the base of the first casing joint that is placed into the borehole of a well. The shoe acts as a guide to divert cement into the casing annulus during the process of cementing the casing string.

cellar — A pit usually lined with concrete or steel pipe that provides space between the drilling rig floor and the wellhead to accommodate other functions or equipment. It also collects drainage water and other fluids for disposal.

certification — The EPA is required by §8(d)(1)(B) of the WIPP Land Withdrawal Act to certify whether the facility will comply with the disposal regulations in 40 CFR Part 191, Subpart B. Under §7(b)(1) of the act, the DOE may commence emplacement of TRU waste in the repository only after EPA certification has been granted. Certification criteria are contained in 40 CFR Part 194.

compliance assessment — The analysis conducted to determine compliance with 40 CFR § 191.15 and Part 191, Subpart C (40 CFR § 194.2).

controlled area — (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location (40 CFR § 191.12). The WIPP controlled area is the 16-square mile area withdrawn by the WIPP Land Withdrawal Act for use by the DOE for the WIPP project.

cuttings — Fragments of rock dislodged by the drilling bit and brought to the surface in the drilling fluids. These are often washed, dried, and analyzed to obtain information about the formations through which the drill bit is passing.

deep drilling — For purposes of this report, deep drilling is oil or gas well drilling to a depth of 2,150 feet (655 meters) or greater.

disposal system — Any combination of engineered and natural barriers that isolate radioactive waste after disposal (40 CFR § 191.12). The WIPP disposal system includes the controlled area.

downhole — Downward, as pertaining to a wellbore or borehole.

drilling fluids — Circulating fluids which lift drill cuttings out of the wellbore, cool the drilling bit, and counteract downhole formation pressure. Such fluids commonly consist of a mixture of brine, barite, clay, water, and chemical

additives. However, air, gas, water, or oil-based drilling muds are also used.

drill stem All of the machinery and equipment assembled together for rotary drilling.

drill string The column or string of drill pipe with attached tools for transmitting fluids and rotational power.

future state assumptions The EPA WIPP compliance certification rule assumption that all present day conditions will continue to exist in their present state for the entire 10,000-year regulatory time frame. The only exception is that geologic, hydrogeologic, and climatic processes and events are assumed to evolve (change) over the same time period. (40 CFR § 194.25)

kelly A length of pipe or hollow forging with shoulders on the outside that make it square or hexagonal. The kelly fits into a matching shouldered hole in the rotary table of the drill rig and is screwed into the top of the drill string.

land withdrawal area The 16 sections of land (10,240 acres; 4,144 hectares) approximately 33 miles east-southeast of Carlsbad, New Mexico withdrawn under the WIPP Land Withdrawal Act of 1992 (Pub. L. 102 – 579) from jurisdiction of the U.S. Department of Interior, Bureau of Land Management and transferred to the DOE for operation of the WIPP disposal site.

mousehole A 20-to-30 feet (6-to-9 meter) deep hole, usually 12 inches (30 centimeters) or more in diameter, located in the cellar adjacent to the borehole. The mousehole, as with the rathole, serves as a place to put the drillstem when the drillstem in not in the main borehole.

passive institutional controls (1) Permanent markers placed at a disposal site; (2) public records and archives; (3) government ownership and regulations regarding land or resource use; and (4) other methods of preserving knowledge about the location, design, and contents of the disposal system.

perforation A hole or holes made in the casing, the cement, or the rock formation through which formation fluids can enter

the wellbore. Holes are usually made with a perforating gun.

performance assessment An analysis that (1) identifies the features, events and processes that might affect the disposal system, (2) examines their effects on the performance of the disposal system, and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties. These estimates must be incorporated into an overall probability distribution of cumulative releases to the extent practicable. (40 CFR § 191.12)

permeability The resistance offered by a material to the movement of fluids, measured in darcies. In geoscience, permeability is a property which indicates the relative ease with which a specified fluid will flow through rock, soil, or an engineered material such as a borehole plug.

pipe A long, hollow cylinder (usually steel) through which fluids are conducted. Pipe can refer to casing, drill pipe, tubing, or line pipe.

porosity The relative volume of pore spaces between mineral grains as compared to the total rock volume. Porosity measures the capacity of rock to hold oil, gas, water, and other fluids. The usual porosity range is 15 to 20 percent.

rathole A 20-to-30 foot (6-to-9-meter) deep hole, usually 12 inches (30 centimeters) or more in diameter. It is located adjacent to the cellar and serves to hold the kelly when the kelly is not in the main borehole.

regulatory time frame The time period beginning when shafts are sealed and ending 10,000 years after disposal.

reserve pit Can be either a mud pit for storage of drilling fluid or a waste pit. It is usually lined with plastic or other material to prevent soil contamination.

rig up To install the tools and machinery necessary for preparing the drilling rig. Rig down means to dismantle the drilling rig following completion of drilling operations.

shallow drilling	For purposes of this report, shallow drilling is drilling to a depth of 2,150 feet (655 meters) or less.
transuranic (TRU) wastes	Wastes containing more than 100 nanocuries per gram of alpha-emitting transuranic isotopes with half-lives greater than 20 years except for (1) high-level radioactive wastes, (2) wastes that do not need the degree of isolation required by 40 CFR Part 191, or (3) wastes that the Nuclear Regulatory Commission has approved for disposal under 10 CFR Part 61. (40 CFR § 191.02[i])
trip in/trip out	To go into or enter the drill hole or wellbore, as with a drill pipe. Come out of the hole.
wellbore	A borehole or hole drilled by a bit. It may be cased, uncased, or partly cased.
well completion	The activities and techniques employed to prepare a well for production of oil or gas or for some other function, such as underground injection of fluids.
well logging	The recording of information about subsurface geologic conditions as well as data concerning drilling fluids, cuttings, drill stem conditions, drill cores, radioactivity, and other factors.
wellhead	The equipment installed at the surface of the wellbore.
zone	A rock stratum that is different from another rock stratum. Often the drilling zone or production zone.

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Attachment 1	Typical Oil or Gas Drilling Sequence in the Delaware Basin
Attachment 2	U.S. Bureau of Land Management Forms
Attachment 3	U.S. Bureau of Land Management Instruction Memorandum No. NM-95-022 on Temporarily Abandoned Wells (September 30, 1996)
Attachment 4	Memorandum of Understanding Between the U.S. Department of Energy and the U.S. Department of the Interior Bureau of Land Management and Waste Isolation Pilot Plant Statement of Work for the U.S. Department of the Interior Bureau of Land Management
Attachment 5	State of New Mexico Energy, Minerals, and Natural Resources Department Oil Conservation Division Forms
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	Appendix A Regulatory Basis for Consequence Analysis of Boreholes
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	Appendix C Degradation of Concrete
	Appendix D Creep Closure of Boreholes

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix DVR

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Design Validation Report

U.S. DEPARTMENT OF ENERGY

DOE-WIPP-86-010

WASTE ISOLATION PILOT PLANT

DESIGN VALIDATION
FINAL REPORT

JOB 12484

OCTOBER 1986

BECHTEL NATIONAL, INC.
SAN FRANCISCO, CALIFORNIA

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor its Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

FOREWORD

The reference design for the underground facilities at the Waste Isolation Pilot Plant was developed using the best criteria available at initiation of the detailed design effort. These design criteria are contained in the U.S. Department of Energy document titled Design Criteria, Waste Isolation Pilot Plant (WIPP), Revised Mission Concept-IIA (RMC-IIA), Rev. 4, dated February 1984. The validation process described in the Design Validation Final Report has resulted in validation of the reference design of the underground openings based on these criteria. Future changes may necessitate modification of the Design Criteria document and/or the reference design. Validation of the reference design as presented in this report permits the consideration of future design or design criteria modifications necessitated by these changes or by experience gained at the WIPP. Any future modifications to the design criteria and/or the reference design will be governed by a DOE Standard Operation Procedure (SOP) covering underground design changes. This procedure will explain the process to be followed in describing, evaluating and approving the change.

The Department of Energy wishes to acknowledge the following for their contributions to the design validation program:

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WASTE ISOLATION PILOT PLANT
DESIGN VALIDATION
EXECUTIVE SUMMARY

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is being developed by the U.S. Department of Energy (DOE) as a research and development facility to demonstrate the safe disposal of radioactive waste from U.S. defense programs. The facility is located in southeastern New Mexico, about 25 miles east of the city of Carlsbad. Underground development is at a depth of about 2,150 feet in thick deposits of bedded salt. The facility operation will include in situ experiments addressing technical issues for defense waste programs and storage of defense related contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste.

In 1979, the DOE established a Site and Preliminary Design Validation (SPDV) Program to provide additional confidence in the siting and design of the WIPP facility. On July 1, 1981, the DOE entered into an agreement with the State of New Mexico whereby the DOE would perform certain work to validate the reference design of the WIPP underground openings. The results of the site validation portion of the program are presented in the report titled Results of Site Validation Experiments, Volumes I and II, TME document 3177, dated March 1983. The results of the preliminary design validation portion of the program are presented in the report titled Waste Isolation Pilot Plant Preliminary Design Validation Report, dated March 30, 1983.

Design validation of the WIPP is defined as the process by which the reference design of the underground openings is confirmed by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. The design validation process consists of an assessment of the condition and behavior of shafts, drifts and a full-sized, four-room test panel

excavated during the SPDV Program and full WIPP construction. Based on this assessment of these excavations, and on predictions of their future behavior, any modifications to the design criteria, design bases or design configurations required to achieve a validated reference design will be developed. In addition, the validated reference design may be modified in the future as still more data and experience are gained during a 5-year demonstration period (period during which all waste must be retrievable) and permanent storage operations.

The WIPP Preliminary Design Validation Report was an interim report prepared as part of the overall validation of the WIPP underground opening reference design. The WIPP Design Validation Final Report contains additional information gathered after completion of the SPDV Program. This information has been analyzed and evaluated to complete the design validation process for the WIPP.

Four types of information were gathered for the WIPP Design Validation Final Report:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during underground construction;

(3) descriptions of core samples from instrumentation and other holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

The design validation process provides for the collection, analysis and evaluation of in situ data. This process is designed to permit determination of the need to modify elements of the underground opening reference design so that construction and operation of the full facility can proceed in a timely, safe, environmentally acceptable and cost effective manner. Observation and instrumentation data have been

collected and evaluated for each of the underground design elements. Tables I through VI at the end of this summary present the evaluation results for the design criteria, design bases and design configurations of the shafts and horizontal openings.

BACKGROUND OF UNDERGROUND DESIGN

Geologic characterization of the site began with a literature review and continued with the collection of field data. Special emphasis was placed on correlating data obtained from seismic reflection and resistivity surveys and borehole drilling. Design information regarding site stratigraphy from the ground surface to about 250 feet below the underground facility level was developed from geologic data obtained from drill holes ERDA-9, WIPP-12 and DOE-1, and from the SPDV exploratory and ventilation shafts.

The engineering designs for the WIPP surface and underground facilities began with the conceptual design, initiated in 1975 and completed in 1977. The conceptual design provided the basis for the development of the preliminary design of both the surface and underground facilities, which was completed in January 1980. The preliminary design incorporated the conventional room and pillar method for underground development.

Design of the WIPP provided for the access and storage openings to remain stable and provide minimum clearance for equipment during waste emplacement and the 5-year demonstration period, even though these openings will eventually close due to salt creep. Modeling techniques were used to estimate the geomechanical behavior and structural stability of the openings. The preliminary design included numerical modeling of the selected underground opening configurations. These models were used to predict opening closures and augmented other conventional mining industry methods of stability evaluation.

UNDERGROUND FACILITIES

Seven stratigraphic horizons were identified in 1979 as potential locations for the facility level. These horizons were chosen from examinations of available geotechnical data and on horizon selection criteria established by the WIPP project participants. Selection of the final underground development level was made by the DOE following the recommendation of WIPP project participants.

The WIPP facility is composed of three shafts connected to a single underground facility level. The C & SH shaft provides the principal means of access and also serves as the primary air intake opening. The waste shaft is designed to permit the transport of radioactive waste between the surface waste-handling facilities and the underground storage area. The exhaust shaft is the primary opening for exhaust air from the underground facility. All three shafts have three principle constituents: a lined section penetrating the rock overburden; an unlined section penetrating the salt; and a key at the rock/salt contact to act as a transition from the lined section to the unlined section.

The storage level contains all of the underground facilities for waste handling, waste storage, operations and maintenance. All of the underground horizontal openings are rectangular in cross section. The drift configurations range from 8 feet to 12 feet high and 12 feet to 25 feet wide.

Underground construction was accomplished in two phases. The initial (SPDV) phase was conducted from May 1981 through March 1983. The second phase, full construction, was accomplished from October 1983 through February 1985. Both phases included the excavation and outfitting of shafts, drifts and rooms.

SUPPORTING VALIDATION DOCUMENTS

The primary documents supporting design validation are the WIPP Preliminary Design Validation Report and quarterly geotechnical field data reports (GFDR).

The objective of preliminary design validation was to provide initial evaluation of the design criteria and design bases, and initial confirmation of the underground reference design. Geologic mapping, core drilling and logging, and geomechanical instrumentation data were assimilated to provide an early, short-term evaluation. The preliminary conclusions presented in the WIPP Preliminary Design Validation Report stated that the shafts and underground openings were performing as expected and were stable. In addition, gas had not been encountered in any significant quantity during excavation and no brine pockets had been encountered.

The GFDRs were initiated by the DOE to provide data from the SPDV Program and full construction in a timely manner. The GFDRs were intended to present in situ data on the geomechanical behavior of the strata surrounding the underground openings along with visual observations of opening behavior and analyses of selected underground design elements.

METHODOLOGY

Design validation is accomplished by determining the compatibility of the design criteria, design bases and reference design using site specific information. The design validation process consists of three major steps: data collection; analysis and evaluation; and prediction of future behavior.

The data collection program was designed to provide information on the geologic conditions encountered throughout the underground facility and on the structural behavior of the underground openings. The program

included geologic mapping, core drilling and logging, laboratory testing, visual inspections, and geomechanical instrumentation measurements. The data collected from these activities were analyzed and evaluated to determine the behavior of the various components of the underground facility and predict their future behavior by projecting the results of both finite element model and regression analyses.

The geomechanical instrumentation measurements provided in situ data on the behavior of the underground openings. These data were then used in empirical equations relating time and closure. Laboratory test results were used to calculate the salt creep and elastic parameters. Salt creep parameters were also determined by the regression analysis of in situ data. Long-term behavior of the underground openings was predicted by extrapolation of the results of the regression analysis.

GEOLOGIC CHARACTERIZATION

Geologic characterization of the WIPP underground openings began in June 1981. Data collection activities included geologic mapping, core drilling and logging, and fluid measurements. The SPDV exploratory shaft was mapped prior to selecting the storage horizon. The waste shaft was mapped, first as the SPDV ventilation shaft and again after it was enlarged to its final diameter. Geologic mapping was also conducted in the exhaust shaft.

Geologic mapping of the horizontal openings was conducted during design validation. This mapping was performed primarily to determine stratigraphic continuity. Mapping was conducted along one wall of the drifts to the northern extent of the facility and along the full length of the south exploratory drift. Geologic mapping was also conducted to the east and west facility boundaries in the experimental area and in the test rooms.

Geologic mapping confirmed the continuity of the stratigraphy within the horizontal openings to the facility boundaries. Core drilling and logging confirmed this stratigraphic continuity for a distance of 50 feet above and below the facility level. The geologic mapping and core logging did not detect any significant geologic structures. Data from the core holes were also used to establish the WIPP reference stratigraphy.

Fluid inflow measurements were obtained by various activities designed to characterize the two water-bearing dolomite members of the Rustler formation and the potential for the occurrence of gas and brine at the facility level. Measurements in the three shafts showed that water inflow from the Rustler formation is essentially negligible due to liner and seal performance.

Small amounts of pressurized gas have been encountered by some underground core holes. Brine has also been encountered in small quantities and is sometimes associated with gas occurrences. There has been no occurrence of gas or brine in quantities significant enough to jeopardize the stability or safety of the facility. Two programs, the brine testing program and the gas testing program, are being conducted to further characterize these occurrences. Neither program is associated with design validation.

Subsidence monuments have been installed on the surface over the shaft pillar area. The design criteria require that subsidence due to underground excavation not exceed 1 inch within a 500-foot radius of the waste shaft. It is not possible at this time to determine actual subsidence; this will occur over the next 25 years. Subsidence calculations used in the reference design indicate that the criteria limits will not be exceeded.

C & SH SHAFT

The C & SH shaft consists of a lined section, a shaft key, an unlined section and a shaft station. The shaft liner is made of structural steel that increases in thickness with depth to withstand increasing hydrostatic pressure. The reinforced concrete shaft key serves as a transition between the lined and unlined sections of the shaft. Chemical water seals behind the concrete key are designed to prevent ground water from flowing behind the key, into the unlined section of the shaft. The shaft station is excavated near the bottom of the unlined section.

Validation of the C & SH shaft reference design was accomplished by acquiring a variety of geotechnical data for analysis, evaluation and prediction of future behavior. The condition of the shaft liner and key are monitored by geomechanical instrumentation and visual inspections. Convergence points measure diametric closure; piezometers monitor ground-water pressures; strain gauges and pressure cells monitor the effect of salt creep on the concrete key. Telltale pipes in the shaft key provide information on the effectiveness of the chemical water seals. The unlined section of the shaft is monitored by extensometers and convergence points and is visually inspected for fracturing and rock slabbing. The shaft station has an extensive geomechanical instrumentation monitoring system and is inspected regularly.

The design basis hydrostatic pressure is suitable. Piezometer measurements indicate that the hydrostatic pressure is currently much less than the design pressure. Analysis of the shaft key indicates that lateral pressure on the key at the end of the operating period will be much less than the design basis lateral pressure requirement. Diametric closure of the key will be minimal. Computational analyses of stresses and strains indicate that the shaft will be stable and remain within the required safety limits during its operating life. Analysis of computed diametric closure near the bottom of the shaft

indicated that, while the closure will be within the design criteria and design basis limits, the lower buntons will be impacted.

The shaft design complies with the design criteria requirements for ground-water control. Regular inspections of shaft conditions show no signs of deterioration or instability.

The C & SH shaft station exhibits the highest degree of deterioration in the underground facility. The fracturing and separation observed has been stabilized, but will continue to develop. Closure during the 25-year operating life of the station will be on the order of 8 feet vertically and 5 feet horizontally. These conditions will require maintenance to ensure safety and to maintain the required minimum clearances for equipment and operations.

WASTE SHAFT

The waste shaft also consists of a lined section, a key, an unlined section and a shaft station. The shaft is lined with unreinforced concrete from the surface to the top of the Salado formation. The shaft liner terminates with a reinforced concrete key at the Rustler/Salado formation contact. The shaft is unlined, except for wire mesh, from the key to the bottom of the shaft.

Data collection activities in the waste shaft have consisted of geologic mapping, ground-water inflow measurements, geomechanical instrumentation measurements and periodic visual inspections. Except for convergence points, the geomechanical instruments are monitored remotely by the datalogger.

The waste shaft data was analyzed with respect to design parameters for each component of the shaft. As part of the engineering analysis, predictions of future behavior were made for each of the components.

Stability of the shaft liner has been confirmed. The water pressure exerted on it is significantly below the design hydrostatic pressure. If the pressure should reach the design hydrostatic pressure, the liner will still be stable. The shrinkage cracks in the liner do not present a structural problem.

The shaft key was designed to withstand a lateral pressure due to salt creep equivalent to 50 percent of the vertical overburden pressure. A numerical analysis was utilized to simulate the long-term effect of salt creep on the concrete key. It showed that the computed lateral pressure at the end of the operating period will be slightly higher than the design lateral pressure, but well below the total lateral pressure capacity of the key.

Observations of the waste shaft key have determined that only one minor seep occurs in the key and that no water seepage is occurring from the base of the key. This supports the conclusion that the water seals are functioning, that no water is seeping along the concrete/salt contact, and that salt dissolution is not occurring behind the key.

The design criteria require that no uncontrolled ground water reach the facility level through the shafts. Although minor amounts of fly water do reach the facility, this water has a negligible impact on operations and does not affect validation of this criterion.

The unlined section of the shaft was designed to be stable and maintain a diameter adequate for the operating life of the facility. The structural behavior of this section was analyzed using a finite element model and creep parameters determined from the C & SH shaft in situ data. The results indicate that the maximum stress occurred immediately after excavation and will decrease with time. Stress behavior will not cause a stability problem. Diametric closure due to salt creep will not exceed the design limits.

The design of the waste shaft station is based primarily on operational parameters. The closure and stability of the station was evaluated using in situ data from the C & SH shaft station. The estimated vertical closure rate will result in a total closure of over 7 feet during the 25 year operating life of the station. Actual closure may be less, but remedial work will still be required to maintain the proper clearances.

EXHAUST SHAFT

The exhaust shaft is constructed similarly to the waste shaft. It consists of a concrete lined section, a shaft key and an unlined section. The lined section is constructed of unreinforced concrete and the shaft key of reinforced concrete. The unlined section contains only rock bolts and wire mesh.

Data collection in the exhaust shaft has been on a much smaller scale than in the other two shafts. Geomechanical instrumentation was not required by the original shaft design because geologic and structural conditions were assumed to be similar to the other two nearby shafts. However, remotely monitored instrumentation has been installed to provide shaft-specific information for use in the sealing program. Geologic mapping and visual inspections have confirmed that the geologic and geohydrologic environment is similar to that of the other two shafts. Data from these two shafts have been used to predict the future performance of the exhaust shaft.

Geohydrologic and geomechanical data from the C & SH shaft and the waste shaft have been compared to model simulations for each section of the exhaust shaft. These models, field observations and instrumentation data confirm that the exhaust shaft reference design is suitable for its 25 year operating life.

The shaft liner is stable and has a water pressure against it that is less than the design basis hydrostatic pressure. If the pressure

increases, the liner will remain stable. Shrinkage cracks will not result in structural instability.

As with the waste shaft, an analysis of the exhaust shaft key indicates that the lateral pressure calculated for 25 years will slightly exceed the design lateral pressure, but will be well below the maximum allowable lateral pressure. Computational analyses of the stresses and strains indicate that the unlined section of the shaft will be stable and remain within safety limits during its operating life. The computed diametric closure will be within design criteria and design basis limits.

Water is entering the exhaust shaft through cracks and construction joints in the concrete liner. A small amount of water still reaches the shaft even after a remedial grouting program. When the exhaust fans are on, this water evaporates before reaching the facility. The water seals in the key appear to be functioning and there is no evidence of salt dissolution behind the key.

DRIFTS

The discussion of drifts contained in this section pertains to all horizontal underground openings except the shaft stations, test rooms, and storage area rooms and their associated drifts. The drifts were designed in accordance with the design criteria and design bases. The largest drifts were initially excavated 8 feet high and 25 feet wide. These drifts have been or will be enlarged to 12 feet high. This drift height is dictated by the minimum 11-foot operating clearance required for the waste storage equipment.

A variety of geotechnical activities were conducted to evaluate the behavior of the excavated drifts. These activities included geologic mapping, core drilling and logging, visual inspections, and geomechanical instrumentation measurements.

Visual inspections consisted of qualitative observations and documentation of various aspects of drift behavior. These observations are divided into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor fracturing, displacements and separations.

Deformational behavior consisting of spalling from the roof and walls of the drifts and fracturing and spalling at pillar corners has occurred. Separations and lateral displacements have been detected in the halite above the roof, primarily at clay seams. These types of behavior are expected and will continue to occur, but can be controlled by scaling and rock bolting.

Fracturing has occurred in marker bed 139 (MB-139) and in the overlying halite beneath the floor of the drifts. The fracturing is not well developed and occurs primarily beneath large intersections. Based on experience in local potash mines, this fracturing is not expected to cause stability or operational problems.

The comparison of measured closure behavior in drifts with different dimensions indicates that the maximum closure and closure rate will occur in 12 x 25-foot drifts. The closure rates are affected by the presence of nearby parallel drifts and crosscuts as well as differences in salt properties. Based on available measurement data and the results of modeling analyses, the closure rate in the 13 x 25-foot storage area drifts may be 30 percent greater than that of a single, infinitely long drift with the same dimensions.

Analyses of salt behavior around the 25-foot wide drifts has determined both the redistribution of stresses due to creep and the locations of effective creep strain concentrations. The stresses which develop immediately after excavation relax with time due to creep behavior and will not cause future stability problems. The strain will remain within the limit required for structural stability with respect to catastrophic failure.

The evaluation of field observations and analytical results have shown that the design criteria were appropriate for design of the horizontal openings. The criteria identified as requiring specific evaluation were determined to be suitable. The reference design for the horizontal openings is therefore validated.

Based on the results of design validation of the drifts, it is recommended that all drifts be inspected frequently for operational clearance and safety. If the clearance is insufficient, the drifts must be trimmed to the required dimensions. Scaling and rock bolting should be performed where necessary for safety purposes.

TEST ROOMS

The test rooms comprise a panel of four rooms having a similar configuration as the planned storage rooms. They have been instrumented, observed and analyzed to evaluate the behavior of the future storage rooms. Data collection activities have consisted of geologic mapping, core drilling and logging, visual inspections and geomechanical instrumentation measurements. The instrumentation includes borehole extensometers, inclinometers, convergence points, convergence meters and rigid-inclusion, vibrating-wire stressmeters.

Room deterioration has been minimal and consists of spalling from the roof and walls, vertical fracturing in the pillars, minor displacements and separations above the roof and beneath the floor, and fracturing beneath the floor. Areas of drummy rock detected by roof and wall inspections immediately following excavation were scaled and rock bolted. These areas have not increased noticeably in size since the test rooms were excavated, over 3 years ago.

Subhorizontal fracturing has developed beneath the test room floors. Separations and fractures are on a small scale except for one isolated location beneath Test Room 3. Fracturing in this area is well developed and occurs in two distinct zones. Studies have not shown

fracturing of this magnitude to occur anywhere else within the underground WIPP facility.

The analysis of closure of the test rooms using creep constants derived from laboratory data underestimate actual closure. The design criteria closure of 12 inches in 5 years has been exceeded within 3 years. Strains measured in the test rooms compare well with strains computed by numerical modeling.

STORAGE AREA

The storage area rooms and drifts are designed to permit the permanent storage of defense-related CH and RH TRU waste. The storage area is composed of eight panels consisting of seven rooms each. Each room is 13 feet high, 33 feet wide and 300 feet long. The storage area, including all rooms and drifts, is designed to provide storage space for 6,330,000 cubic feet of CH TRU waste and 1,000 canisters of RH TRU waste.

Validation of the storage room reference design depends primarily on the analysis of data from the four test rooms. Evaluation of the storage rooms was based on the results of a finite element model analysis using creep parameters determined from the test room analyses. The results of this analysis provided determinations of horizontal and vertical stresses, effective stresses, effective creep strains, principal stresses, room deformation and closure, and intersection closure.

The analyses show that the stress arch around the opening migrates away with time. The maximum stress occurs immediately after excavation and is reduced as the opening deforms over time due to salt creep. These stresses will therefore not cause a stability problem in the future. However, MB-139, the anhydrite bed approximately 4 feet below the floor, is expected to be subjected to gradually increasing stress and may exhibit local failure.

Effective creep strains will intensify and concentrate at some locations around the opening. While minor spalls and failures are expected to occur on the excavation surfaces, the rooms will remain structurally stable.

The storage room reference design of 13 feet high and 33 feet wide was based on calculations using laboratory-derived average creep parameters. This design allowed for 12 inches of vertical closure and 9 inches of horizontal closure 5 years after excavation. This accommodates the design bases requirements for a minimum of 16 inches of ventilation space above the stored waste and a 12-foot minimum height for storage equipment. The current predicted vertical closure at 5 years is about 22 inches. For permanent storage, the additional 10 inches of closure can be accommodated by excavating the storage rooms to a height of 13 feet 10 inches.

If a decision is made to retrieve the stored waste, the design criteria assumed, using a one-shift-per-day basis, that a room may be as much as 15 years old before removal of all of the waste is completed. A 15-year old room has a predicted vertical closure of 54 inches. This closure is 14 inches greater than the maximum acceptable closure and would result in crushing and possible breaching of the waste containers. Because this is not in compliance with the design criteria, other alternatives must be considered.

A 10 year maximum for retrieval is conservative. If three shifts per day were utilized, no room would be older than 7 years by the time its waste was removed. A 7 year old room would have 28 inches of vertical closure. Additional closure benefits can be gained by excavating a room to is maximum dimensions and then trimming the room to those maximum dimensions after 1 year of closure. This will allow the room to close at the rate determined by secondary creep and will result in 21 inches of vertical closure 7 years after trimming. This will meet the design criteria requirements.

The design bases provide for 9 inches of horizontal closure in the first 5 years after room excavation. The current prediction, based on in situ data, is 15 inches of closure in the 33- to 34-foot wide rooms. If the rooms are excavated 34-feet wide and backfilled with loose salt, this closure will be suitable for permanent storage.

For retrieval, the horizontal closure 15 years after excavation will be approximately 36 inches. This closure will result in some crushing and possible breaching of the waste containers. Even if retrieval is effected within 7 years, some containers may still be crushed and breached.

The timing of retrieval operations and two-stage excavation can be used to reduce wall-to-wall closure. Using a three-shift-per-day basis, a 7 year old room would close approximately 20 inches. If a first in/first out storage and retrieval operations is utilized, and waste is removed before a room reaches an age of 6 years, horizontal closure will be reduced to 18 inches. Both these changes would decrease the possiblity of crushing or breaching the containers. If a 34-foot wide room is trimmed after 1 year to its initial full dimensions, the horizontal closure at 7 years will be about 14 inches. This will further minimize crushing or breaching of the containers. The extent to which crushing will be minimized is unknown. This is because the space between the waste canisters and the room wall will be filled with loose salt. The load transferring capabilities of the backfill is not known at the present time.

The reference design also provides for permanent waste storage in all of the storage area drifts. Fifteen years after excavation a 13 x 25-foot drift is predicted to have a vertical closure of about 25 inches and a horizontal closure of about 20 inches. This is suitable for waste storage but trimming will be required for equipment clearance.

The storage area entry drifts will contain plugs for the isolation of the storage panels. The final design of these plugs is not yet

complete. However, the conceptual design envisions a multiple-component plug approximately 100 feet long.

The reference design for the storage rooms will be considered to be validated when any of the following recommended alternative modifications, or combination of these modifications, are incorporated:

(1) Maintain the reference design storage room dimensions of 13 to 14 feet high and 33 to 34 feet wide and maintain the salt backfill, but reduce the volume of waste to be stored and modify the container stacking configuration for the 5-year demonstration period. Revise the design criteria to require that waste be retrieved before a room exceeds an age of 7 years. This will meet the criteria that the waste containers not be crushed or breached, but it will require a significant number of additional storage rooms.

(2) Maintain the reference design storage room dimensions and maintain the planned waste volume. Revise the design criteria to delete the requirement for salt backfill and to require that waste be retrieved before a room exceeds an age of 7 years. This will meet the criteria that the waste containers not be crushed or breached without requiring additional storage rooms.

(3) Maintain the reference design storage room dimensions, planned waste volume, and salt backfill requirement. Revise the storage operations so that the first-emplaced waste is the first-retrieved waste with retrieval effected before the room exceeds 6 years of age. Excavate the room to 14 x 34 feet, then, 1 year later, trim the room to its initial 14 X 34 foot dimensions. This will minimize container crushing and breaching. More storage rooms will be utilized during the 5-year demonstration period, but the total number of rooms will remain the same as provided by the reference

design. This modification will require changing the design criteria to allow crushing and breaching of the CH waste containers prior to retrieval and to require a demonstration of the retrieval and handling of crushed and breached containers.

(4) Reduce the reference design storage room width from 33 feet to 28 feet, maintain the room height at 13 to 14 feet, and reduce the pillar width to 84 feet. Maintain the first room for RH waste emplacement at the original reference design dimensions. Reduce the planned waste volume and maintain the salt backfill requirement. Excavate the rooms to 14 x 28 feet, then trim them to this dimension after 1 year. Use a first-in/first-out storage operation. This will reduce the creep to approximately that of a 13 x 25-foot drift. Stability will be enhanced and crushing and breaching will be minimized. The volume of excavation will be approximately the same as for the reference design storage rooms, but with the advantage of a lower creep rate. If this alternative is selected, additional engineering evaluation will be required.

(5) Maintain the reference design storage room dimensions, the planned waste volume, the salt backfill requirement, and the reference design optimized excavation and storage plan. Revise the design criteria, as in alternative number 3, to allow crushing and breaching of the CH waste containers prior to their retrieval. Require a demonstration of the retrieval and handling of crushed and breached containers prior to the receipt of waste. This will not only demonstrate the safe retrieval of waste during the 5-year demonstration period, but also during permanent storage.

In addition to these recommended alternative modifications, the following modifications are recommended:

(6) The drifts used for storage will require maintenance and trimming to accommodate the required equipment and storage clearances. Their closure rates are not critical for storage because they will be used only for permanent storage near the end of the permanent storage period.

(7) Add additional rooms to compensate for the space occupied by the plugs in the storage area entry drifts.

(8) Install instrumentation in the storage rooms to obtain in situ data to monitor storage room behavior.

Table I

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Facility design	
a. Designed for an operating life of 25 years.	*
b. Underground facilities and equipmentshall be designed to be compatible with retrieval operations for all contact-handled (CH) and remote-handled (RH) TRU waste, with a retrieval decision to be made within 5 years after the intial emplacement of each species.	Suitable 12.3.3
c. The facility will be decommissioned after it has fulfilled its intended purposes. This will include backfilling the underground facilities, sealing the shafts and decommissioning the surface facilities.	*
(2) CH TRU waste **	
a. Estimated annual volume is 500,000 cubic feet.	*
b. Estimated volume at the end of the 5 year retrieval decision period is 1,410,000 cubic feet.	*
c. Estimated total storage capacity is 6,330,000 cubic feet.	*
d. Heat generated from the waste is negligible; it will be less than 10 milliwatts for average drums, less than 20 milliwatts for average boxes, and 10 watts for few drums containing heat source plutonium.	*

* Indicates element for which evaluation is not required.
** See Foreword.

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
e. Estimated annual quantities are 9,616 six-packs and 2,404 modular steel boxes.	*
f. Estimated total quantities are 121,700 six-packs and 30,430 modular steel boxes.	*
g. Underground facilities and equipment shall be designed to provide for a determination to effect retrieval of waste stored for a period up to 5 years after the initial emplacement and for a target of 5 to 10 years to reach the waste and retrieve it after the decision is made.	Suitable 12.6.1 12.6.2
(3) RH TRU waste **	
a. Assumed total receipt of 1,000 cansisters.	*
b. Assumed maximum receipt rate of two canisters per day and 250 canisters per year.	*
c. If assumed quantities are insufficient, additional RH waste storage will be accommodated within existing storage rooms.	*
d. Heat generated from the waste is on the order of 60 watts per canister.	*
e. Access shall be available to all emplacement positions throughout the retrievability period.	Suitable 12.3.3

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
f. When both CH and RH waste are scheduled for the same room, the RH waste shall be emplaced first. After the 5 year retrievability period has terminated, CH waste may be emplaced in that room.	*
(4) Shaft design	
a. Shafts shall be designed to be structurally stable throughout the operating life of the underground facility and the decommissioning period.	Suitable 7.4.1 8.4.1 9.4.1
b. Time-dependent closure of shafts due to salt creep shall be considered. Shafts shall be designed so that minimum dimensions required for shaft functions are maintained during design life.	Suitable 7.4.1 8.4.1 9.4.1
c. Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the storage horizon via the shafts.	Suitable 7.4.1 8.4.1 9.4.1
(5) Shaft liner design	
a. Help ensure that dimensions remain within limits required for shaft functions.	*
b. Prevent ground-water flow into the shaft.	Suitable 7.4.1 8.4.1 9.4.1
c. Protect wall rock from deterioration.	*

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
d. Preclude risk of rock fall from shaft wall.	*
(6) Mine design	
a. The underground openings shall be designed so that deformation of excavations and pillars will remain within limits required for structural function, ventilation and safety.	Suitable 7.4.1 8.4.1 10.4.1
b. Rock bolts shall be used where necessary to provide positive support of roof and walls.	*
c. Surface subsidence resulting from underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft.	Suitable 6.5
d. Excavations and pillars shall be located and dimensioned to avoid geologic discontinuities. If discontinuities are encountered, remedial action shall be engineered to correct the problem.	Suitable 3.4 6.3.1.2 6.3.3
e. Design shall be based on established mining procedures.	*
f. Predicted behavior of the salt shall be verified by in situ testing (SPDV) before proceeding with construction of the storage area.	*
g. Designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening.	Suitable 10.4.1 12.6.1

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
h. Creep closure rates used for design shall be confirmed by instrument observations in the excavations.	Suitable 11.3.2 12.3.2
i. Excavation dimensions shall include allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period.	Suitable 12.6.1 12.6.2
j. Minimize the potential for repository rock fracturing.	Suitable 11.4.1
k. Underground waste storage procedures shall include a designed backfill plan for fire protection. The backfill thickness shall be 1 to 2 feet.	Suitable 12.6.1
l. Permit isolation of panels of rooms with plugs after storage and backfilling are completed.	Suitable 12.6.1
m. Air locks, dampers, regulators and doors shall be designed and installed in such a manner that they can accommodate creep without impairment to their ability to maintain ventilation separation.	*
(7) Emplacement criteria	
a. The underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with waste container sizes, shapes, weights and stacking configurations, and with waste emplacement equipment.	Suitable 12.6.1

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
b. Provisions shall be made to accommodate backfilling over and around CH waste containers.	Suitable 12.6.1
c. Each storage panel shall have provisions for being isolated from other panels upon completion of storage operations in that panel.	Suitable 12.6.1
(8) Retrievability	
a. All wastes placed into the WIPP are retrievable, with retrievability to be demonstrated, until such time as the pilot plant is converted to an operational repository for permanent disposal of wastes.	Suitable 12.6.1 12.6.2
b. Each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years.	Suitable 12.6.1 12.6.2
(9) Underground excavation and haulage	
a. Mining shall be performed with continuous miners or equivalent machine type devices. Drill and blast-type mining shall be prohibited except where authorized.	*
b. Underground design shall provide maximum stability for excavated rooms and entries.	Suitable 7.4.1 8.4.1 10.4.1 11.4.1 12.6.1

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
c. Meet or exceed the intent of the applicable requirements of the MSHA in 30 CFR 57.9 and the New Mexico Mine Safety Code for All Mines.	*

Table II

EVALUATION RESULTS FOR C & SH SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
a. Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 7.4.1
b. Water shall be prevented from flowing down the unlined shaft from behind the liner.	Suitable 7.4.1
(2) Shaft key	
a. Key shall be designed to resist the lateral pressure from the salt. (Assumed to be 75 percent of the overburden pressure.)	Suitable 7.4.1
b. Key shall be designed to resist the hydrostatic pressure from above the salt.	Suitable 7.4.1
(3) Unlined section	
Provide 11-foot 8-inch diameter to allow for future salt creep deformation.	Suitable 7.4.1

Table III

EVALUATION RESULTS FOR WASTE SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 8.4.1
(2) Shaft key	
Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.	Suitable 8.4.1
(3) Unlined section	
Provide 20-foot diameter to allow for future salt creep deformation.	Suitable 8.4.1

Table IV

EVALUATION RESULTS FOR EXHAUST SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 9.4.1
(2) Shaft key	
Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.	Suitable 9.4.1
(3) Unlined section	
Provide 15-foot diameter to allow for future salt creep deformation.	Suitable 9.4.1

Table V

EVALUATION RESULTS FOR STORAGE AREA DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Operational requirements	
a. The storage area rooms, drifts and crosscuts shall be designed to allow for retrieval of all CH and RH waste stored for a period of up to 5 years after the initial emplacement of each waste species.	Suitable 12.6.1 12.6.2
b. Excavation dimensions in the waste storage area shall be to a uniform height of 13 feet.	Suitable 12.6.1 12.6.2
(2) Essential features	
Provide 1 foot vertical and 9 inches horizontal allowance for creep closure to maintain the minimum design dimensions up to 5 years after initial emplacement.	Suitable 12.6.1 12.6.2
(3) Safety design requirements	
A minimum opening of 16 inches shall be left at the top of the rooms and drifts for air passage above the waste and backfill.	Suitable 12.6.1 12.6.2

Table VI

EVALUATION RESULTS FOR DESIGN CONFIGURATIONS

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) C & SH shaft	
a. Provide 5/8 to 1 1/2-inch thick and 10-foot I.D. stiffened steel liner in upper 846 feet.	Suitable 7.3.2.1 7.3.3.1
b. Provide 30-inch thick, 10-foot I.D. and 39-foot long concrete key at rock/salt interface.	Suitable 7.3.2.2 7.3.3.2
c. Provide 11-foot 10-inch diameter unlined shaft below the key.	Suitable 7.3.2.3 7.3.3.3
d. Provide 17-foot high and 32-foot wide station.	Suitable 7.3.2.4 7.3.3.4
(2) Waste shaft	
a. Provide 10 to 20-inch thick and 19-foot I.D. concrete liner in upper 837 feet.	Suitable 8.3.2.1 8.3.3.1
b. Provide 51-inch thick, 19-foot I.D. and 63-foot long concrete key at rock/salt interface.	Suitable 8.3.2.2 8.3.3.2
c. Provide 20-foot diameter unlined shaft below the key.	Suitable 8.3.2.3 8.3.3.3
d. Provide 17-foot high and 30-foot wide station.	Suitable 8.3.2.4 8.3.3.4
(3) Exhaust shaft	
a. Provide 10 to 16-inch thick and 14-foot I.D. concrete liner in upper 844 feet.	Suitable 9.3.2.1 9.3.3.1

Table VI (continued)

EVALUATION RESULTS FOR DESIGN CONFIGURATIONS

ELEMENT	RESULT AND CHAPTER REFERENCE
b. Provide 42-inch thick, 14-foot I.D. and 63-foot long concrete key at rock/salt interface.	Suitable 9.3.2.2 9.3.3.2
c. Provide 15-foot diameter unlined shaft below the key.	Suitable 9.3.2.3 9.3.3.3
(4) Storage area	
a. Provide 13-foot high and 25-foot wide or smaller drifts.	Suitable 12.6.1 12.6.2
b. Provide 13-foot high and 33-foot wide storage rooms.	Suitable 12.6.1 12.6.2

CHAPTER 1
INTRODUCTION

1.1 PURPOSE

This report presents the results of validation of the underground opening reference design for the Waste Isolation Pilot Plant (WIPP). The basis for the report is defined in the Design Validation Plan (ref. 1-1) which, in part, includes certain data requirements defined in the Stipulated Agreement (ref. 1-2) reached between the U.S. Department of Energy (DOE) and the State of New Mexico on July 1, 1981.

Design validation of the WIPP is defined as the process by which the reference design of the underground openings is confirmed by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. The design validation process consists of an assessment of the condition and behavior of shafts, drifts and a full-sized, four-room test panel excavated during an initial stage known as the Site and Preliminary Design Validation (SPDV) Program and during full WIPP construction. Based on this assessment of these excavations, and on predictions of their future behavior, any modifications to the design criteria, design bases or design configurations required to achieve a validated reference design will be developed. In addition, the validated reference design may be modified in the future as still more data and experience are gained during a 5-year demonstration period (period during which all waste must be retrievable) and permanent storage operations.

In fulfilling the data requirements for design validation, this report provides documentation of actual underground conditions encountered as they relate to the design criteria, design bases and design configurations for the reference design of the underground openings. The contents of this report include all relevant data and field observations acquired for design validation. The underground openings excavated to date provide a firm basis for evaluation of the current and expected future behavior of the underground development.

The purpose of design validation is to:

- o validate the underground reference design, thus providing confidence in the safety and stability of the WIPP underground openings;

- o confirm the suitability of the design criteria, design bases and design configurations established specifically for the reference design of the underground openings;

- o re-confirm and expand upon the conclusions of the SPDV Program; and

- o comply with the DOE agreement with the State of New Mexico to validate the reference design of the WIPP underground openings.

This process was initially described in the WIPP Preliminary Design Validation Report (ref. 1-3) issued in March 1983. That report presented the results of a preliminary evaluation of the underground opening reference design based on activities conducted during the SPDV phase of underground development. That initial report was prepared in response to conditions contained in the Stipulated Agreement (Appendix A) between the DOE and the State of New Mexico which permitted a preliminary evaluation of design considerations at an early stage in underground development and allowed for any reference design modifications deemed necessary for full WIPP construction. The WIPP Design Validation Final Report (this report) is an extension of the preliminary report and presents further confirmation of the reference design based on additional data collected since completion of the SPDV Program in both old and new areas of underground excavation.

The WIPP Design Validation Final Report presents:

- o a summary of the background and development of the WIPP reference design;

- the design criteria and design bases used to develop the reference design for the underground openings;

- geologic characterizations of the shafts, drifts and test rooms;

- the methodology used for data collection, its analysis and evaluation, and the predictions of future behavior of the underground openings;

- the description of data collection activities in the shafts, drifts and test rooms;

- analyses and evaluations of the geologic behavior of the rock strata surrounding the shafts, drifts and test rooms based on visual inspections and geomechanical instrumentation measurements;

- predictions of expected future conditions of the underground openings based on model simulations using in situ data;

- an assessment of the suitability of the design criteria and design bases and validation of the reference design configurations, with recommendations for design modifications, if any;

- recommendations for operation and maintenance of the underground facility as they pertain to design validation; and

- all data and reference sources that support design validation.

1.2 SCOPE

Design validation of the WIPP underground openings has been accomplished through an assessment of their safety, stability and predicted future behavior. Observation and instrumentation data consistent with the Design Validation Plan objectives have been

collected and evaluated for each of the major design elements: shafts, drifts and test rooms.

Initial analyses and evaluations of the underground data obtained for design validation were provided in the WIPP Preliminary Design Validation Report. The WIPP Design Validation Final Report presents the results of activities whose objectives are outlined in the Design Validation Plan. These activities included field data collection and analyses of these data to determine the validity of the reference design.

Basically, four types of information were gathered for design validation. These are:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during underground construction;

(3) descriptions of core samples from instrumentation and other holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

Field tasks performed to gather this information included the following:

- establishment of survey control for underground excavations and reference points for geologic mapping;

- development of procedures and standards for activities such as geologic mapping/logging of underground excavations;

- geologic mapping in the shafts and horizontal openings;

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- examination and logging of rock cores from boreholes to obtain geologic information;

- observation and measurement of ground-water flow into the shafts;

- measurement of hydrostatic and lateral pressures on the shaft liner and shaft key;

- monitoring the floor height of horizontal openings above the top of marker bed 139 (MB-139) and the height of clay seams above the roofs using core hole data;

- measurement of closure in the shafts and horizontal openings;

- determination of the presence of gases and fluids;

- survey of shaft verticality; and

- examination of all surfaces of underground openings for displacement of clay seams, fracturing, roof sagging, floor heaving, or other occurrences that may indicate unstable conditions.

1.3 HISTORICAL BACKGROUND

The WIPP is being developed by the DOE as a research and development (R & D) facility to demonstrate the safe disposal of radioactive waste from U.S. defense programs. The facility is located in southeastern New Mexico, about 25 miles east of the city of Carlsbad (Figure 1-1). The underground development level is at a depth of approximately 2,150 feet in thick deposits of bedded salt. The facility will include space for the permanent storage of defense related transuranic (TRU) waste and for in situ experiments addressing technical issues for high-level defense waste programs. The WIPP's phased design and construction resulted in initial confirmation of the underground opening reference design through the SPDV Program. Design

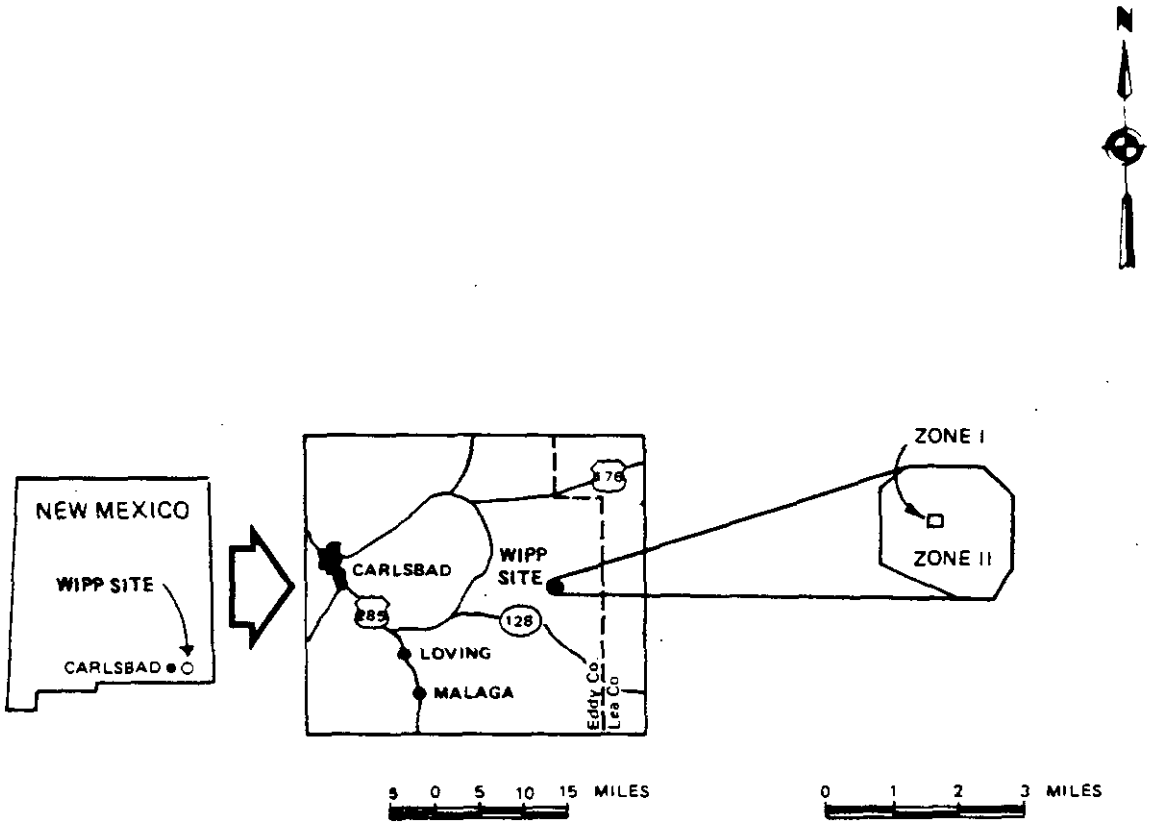

ZONE DESCRIPTION

ZONE I Surface Facilities Area
ZONE II Underground Storage Limits

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Figure 1-1

LOCATION OF THE WIPP

validation will provide confirmation of the decision to continue facility construction with subsequent in situ experiments and defense TRU waste storage.

The WIPP project is the result of waste management program efforts that were started by the U.S. government as long ago as 1955 when the U.S. Atomic Energy Commission (AEC) requested that the National Academy of Sciences (NAS) evaluate methods for disposing of radioactive waste in geologic formations. The NAS recommended bedded salt as the geologic formation providing the highest confidence for long-term isolation of waste from the biosphere. As a result of these efforts, the DOE (formerly the AEC) initiated the WIPP program in 1975. The major accomplishments of the program are listed in Table 1-1.

Assessments that pertain to design of the WIPP include extensive analyses of the impact of the facility on present and future environments. A Final Environmental Impact Statement (FEIS) (ref. 1-4) was prepared which provides information about the environmental and safety consequences of the WIPP project. A Safety Analysis Report (SAR) (ref. 1-5) was also prepared to support construction and operation of the WIPP. The SAR addresses all aspects of industrial and nuclear safety of the project and is updated periodically.

The WIPP is being developed in phases. At the time this report was prepared, most of the site characterization, design and supporting technological development had been done. The engineering design of the underground openings began with a conceptual design followed by a preliminary design and finally a detailed reference design. Facility development at the site began with the SPDV Program which allowed direct observation of the underground facility geology through two shafts and associated underground drifts. This program provided data for preliminary evaluation and confirmation of the reference design of the proposed underground excavations. Design and construction of the surface facilities have proceeded virtually independent of the underground opening design validation and are not addressed in this report.

Table 1-1

MAJOR ACCOMPLISHMENTS OF THE WIPP PROGRAM

	ITEM	DATE STARTED	DATE COMPLETED
(1)	National Academy of Sciences recommends salt as best geologic formation for disposal of nuclear waste.	-	1957
(2)	Salt deposit studies conducted in New Mexico by U.S. Geological Survey and Sandia National Laboratories.	1972	1975
(3)	Conceptual design of the WIPP.	1975	1977
(4)	Characterization of the WIPP site.	1975	1983
(5)	Public law authorizes capital funding for the WIPP.	-	1977
(6)	Title I - Preliminary design of the WIPP.	1/78	1/80
(7)	Safety Analysis Report issued for the WIPP.	-	2/80
(8)	Final Environmental Impact Statement issued for the WIPP.	-	10/80
(9)	SPDV Preliminary Design Validation Program.	7/79	3/83
(10)	Detailed design for Site and Preliminary Design Validation (SPDV).	7/79	10/80
(11)	SPDV Site Validation Experiments Program.	8/80	3/83
(12)	Title II - Detailed design of the WIPP.	2/81	2/84
(13)	Construction of SPDV shafts.	5/81	3/82
(14)	Design validation.	4/81	10/86
(15)	SPDV shaft outfitting and test room development.	10/81	7/83
(16)	Authorization for full WIPP construction.	-	7/83

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1.4 THE WIPP MISSION

The authorized mission for the WIPP emphasizes its role as an R & D facility to demonstrate safe disposal of radioactive waste from U.S. defense programs. Its mission is also to provide information from site characterization, laboratory experiments, geomechanical instrumentation and in situ tests which can be used to develop performance-assessment models for technological applications. Figure 1-2 shows the underground layout of the three R & D areas at the WIPP.

The WIPP R & D Program consists of three major program areas:

(1) site characterization and evaluation;

(2) repository development and operation; and

(3) waste package interactions.

In addition to providing for the permanent storage of defense related TRU waste, these program areas include technology development in waste isolation, in situ tests without radioactive material, and in situ tests with radioactive material. The WIPP will also serve as a laboratory for experiments with high-level defense waste. All high-level wastes will be removed from the WIPP at the conclusion of the testing period. These in situ waste experiments and associated activities are not part of design validation and, therefore, are not discussed in this report. An initial description of the in situ testing plan for the WIPP R & D Program was provided in Sandia National Laboratories' (SNL) Report 2628 (ref. 1-6).

1.5 DESIGN VALIDATION PROGRAM

Validation of the WIPP facility underground reference design is based on a strategy consisting of a detailed plan and approach for validating major reference design elements. A description of this strategy is

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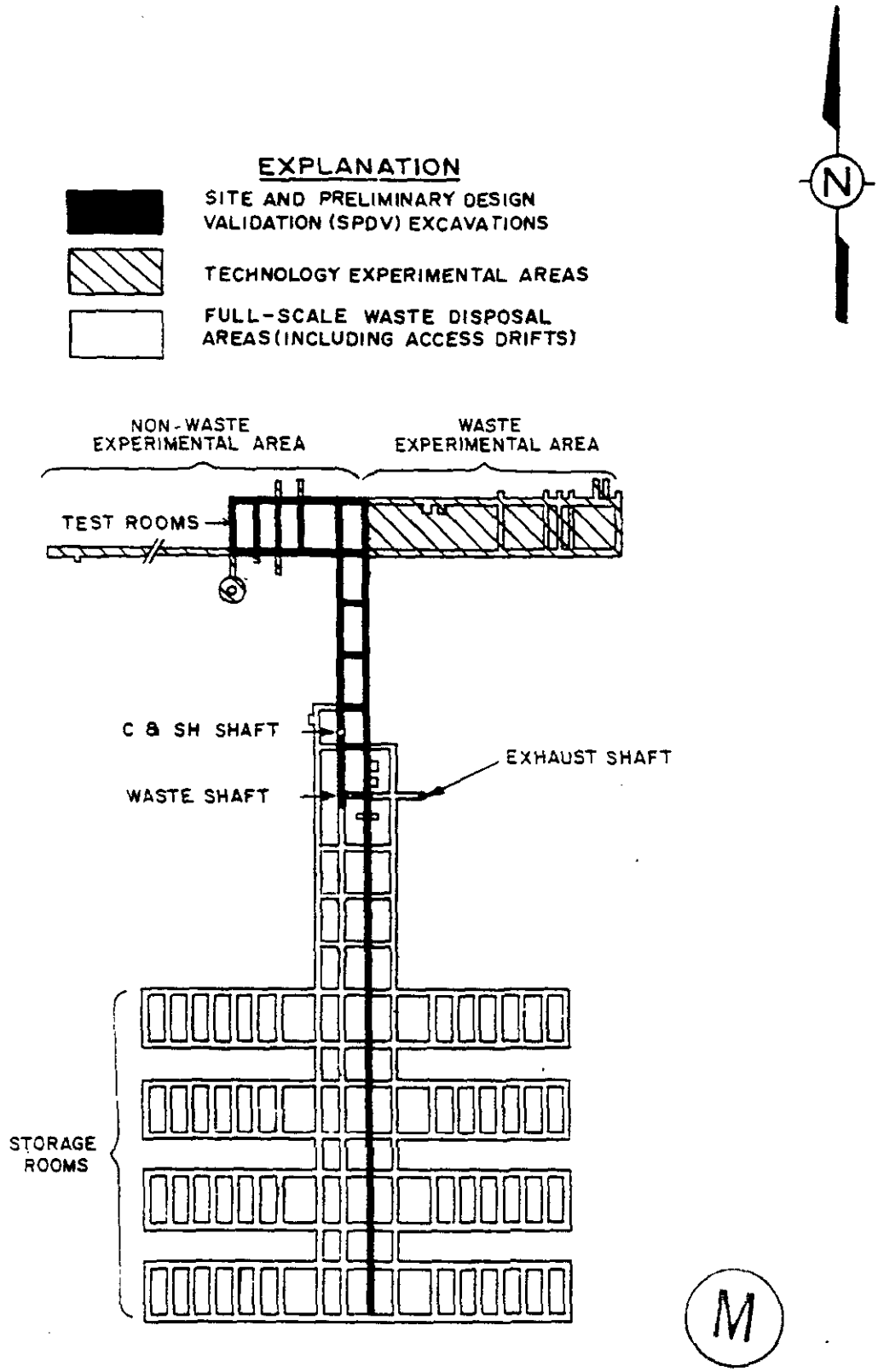

Figure 1-2

PLAN VIEW OF UNDERGROUND FACILITY

contained in the document titled Design Validation Strategy (ref. 1-7). The elements comprising the strategy for design validation are:

(1) Identify the design approaches and construction activities for the underground openings.

(2) Identify the design criteria, design bases and design configurations to be validated.

(3) Develop the methodology for validation.

(4) Acquire data on the underground development level from core samples, geologic mapping, laboratory tests, in situ tests, visual observations and mines in similar geologic formations.

(5) Synthesize the data obtained from the activities in element 4 to define the geologic environment of the facility level.

(6) Evaluate in situ geomechanical instrument measurements and visual observations to determine the response of the geologic materials to changes resulting from excavation or other disturbances.

(7) Predict the future behavior of the underground openings and salt surrounding the openings based on current in situ measurements, visual observations and computational analyses.

(8) Provide for comparisons of predicted and existing conditions at regular time intervals.

(9) Document design validation results and conclusions.

(10) Provide recommended design modifications as required.

(11) Provide data and reference sources to support the performance of the above activities.

Design validation efforts for the WIPP began with the SPDV Program. This program involved the excavation of underground openings, shafts, drifts and test rooms, representative of the full WIPP facility. These underground openings permitted the direct examination of geologic features and material behavior at the facility level. Additional observations and geomechanical instrumentation measurements were obtained following completion of the SPDV Program to complete the design validation program. A brief description of the design validation program is presented in the following subsections.

1.5.1 Site and Preliminary Design Validation (SPDV)

The SPDV Program was designed to further characterize and validate the WIPP site geology and provide preliminary validation of the underground opening reference design. The SPDV Program was composed of two integrated parts:

(1) site validation (ref. 1-8) to increase confidence in the process of site characterization and qualification; and

(2) preliminary design validation to assess the condition and behavior of excavated shafts, drifts and a full-sized, four-room test panel similar to those planned for the waste storage area.

The general SPDV underground layout is shown on Figure 1-3. The underground development level is located in Zone II, a WIPP site control zone that delineates the limits of underground storage. A preliminary design validation report was issued on March 30, 1983. This report presented the results of early observations and analyses of the condition and behavior of the SPDV excavations and is discussed in Chapter 4.

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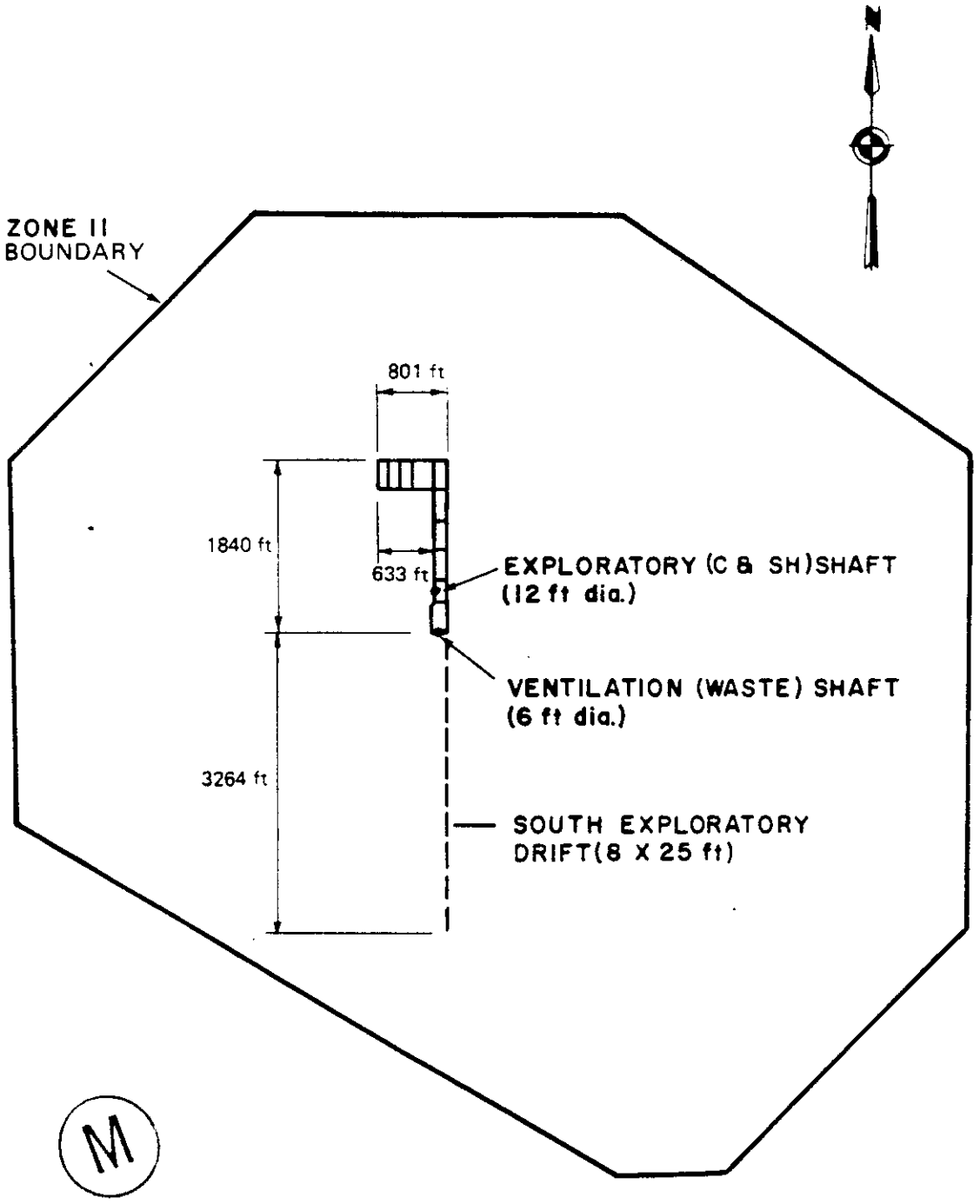

Figure 1-3

THE SPDV UNDERGROUND LAYOUT

1.5.2 Design Validation

Major activities related to design validation are cited in Table 1-2. As indicated by this table, field data collection activities that began with the SPDV Program were continued beyond the end of the program to provide additional data for design validation. The design validation process includes the evaluation and analysis of data obtained by these activities. The results of these evaluations and analyses have been presented in quarterly geotechnical field data reports (GFDR), each of which presents a discussion of different selected elements of the WIPP underground development. These reports provide supporting documentation for the WIPP Design Validation Final Report and are discussed in Chapter 4.

Some of the field data collection activities shown in Table 1-2 will continue after submittal of the WIPP Design Validation Final Report and beyond the completion of full WIPP construction. Collection of this data will provide additional information on the behavior of the underground openings through the 5-year demonstration period and through permanent storage operations. The data will also permit continuous monitoring of the safety of the openings. Underground facility reference design modifications will be made as required by an evaluation and analysis of these data. The data obtained will be periodically distributed to the project participants, the State of New Mexico, and will be placed in WIPP public reading rooms.

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Table 1-2

DESIGN VALIDATION ACTIVITY SCHEDULE

ACTIVITY	RESPONSIBILITY	SCHEDULE
(1) Prepare and issue Design Validation Plan	B/DOE	7/82 - 1/83
(2) Field data collection:		
a. Geologic mapping of vertical and horizontal underground excavations	TSC/B	3/82 - 3/83
b. Geomechanical instrumentation measurements and visual observations in shafts, drifts, and test rooms	TSC/B	4/82 - 3/83
c. Log core from holes in horizontal underground openings	TSC/B	10/82 - 3/83
d. Fluid inflow measurements	TSC/B	9/81 - 3/83
e. Shaft verticality surveys	DOE/TSC	1/82 - 3/83
(3) Evaluate field data; prepare Preliminary Design Validation Report	B	10/82 - 3/83
(4) Issue Preliminary Design Validation Report	DOE	3/83
(5) Continue with (2a), (2b), (2c), and (2d) above	TSC/B	3/83 - 7/86
(6) Evaluate/analyze field data; prepare Design Validation Final Report	B	3/83 - 5/86
(7) Design Validation Final Report review by Peer Review Panel	B	5/86 - 6/86
(8) Issue Design Validation Final Report	DOE	10/86

B = Bechtel National, Inc.; DOE = U.S. Department of Energy; TSC = Technical Support Contractor (Westinghouse Electric Corp.)

CHAPTER 2

BACKGROUND OF UNDERGROUND DESIGN

2.1 SITE CHARACTERIZATION AND EVALUATION

WIPP site characterization programs have consisted of geologic and hydrologic studies as well as biologic, meteorologic and economic studies. Geologic and geohydrologic characterization of the site, which started with surveys of literature and existing data, continued with the collection of new data and had the greatest degree of influence on design of the underground facility. Special emphasis was placed on correlating data obtained by geophysical techniques and borehole drilling. The geophysical techniques most widely used were seismic reflection and resistivity. Borehole drilling programs included holes drilled primarily for stratigraphic information on or near the site and holes drilled at the edge of, or away from, the site to study salt dissolution. Three holes, WIPP-11, WIPP-12 and DOE-1, were drilled through the Salado formation to acquire geologic data on deeper strata outside the Zone II boundaries of the site (refs. 2-1, 2-2 and 2-3). Within Zone II, the drilling of deep exploratory holes, i.e., to the depth of the WIPP facility level, was restricted by siting criteria. Prior to the drilling of the SPDV exploratory and ventilation shafts (subsequently known as the C & SH and waste shafts, respectively), ERDA-9 was the only borehole within Zone II that extended below the facility level.

The generalized stratigraphic relationship of the geologic formations of interest beneath the WIPP site is shown on Figure 2-1. Siltstone and fine-grained sandstone are the main rock types forming the Dewey Lake red beds. The Rustler formation, composed primarily of anhydrite and fine-grained sandstone, siltstone and mudstone, contains two water-bearing dolomite beds. Saline water is found in these beds, the Magenta and Culebra members, and at the contact between the Rustler and Salado formations. The Salado formation consists largely of halite containing thin beds of anhydrite and polyhalite with occassional thin clay seams. The Castile is a thick anhydrite and halite formation

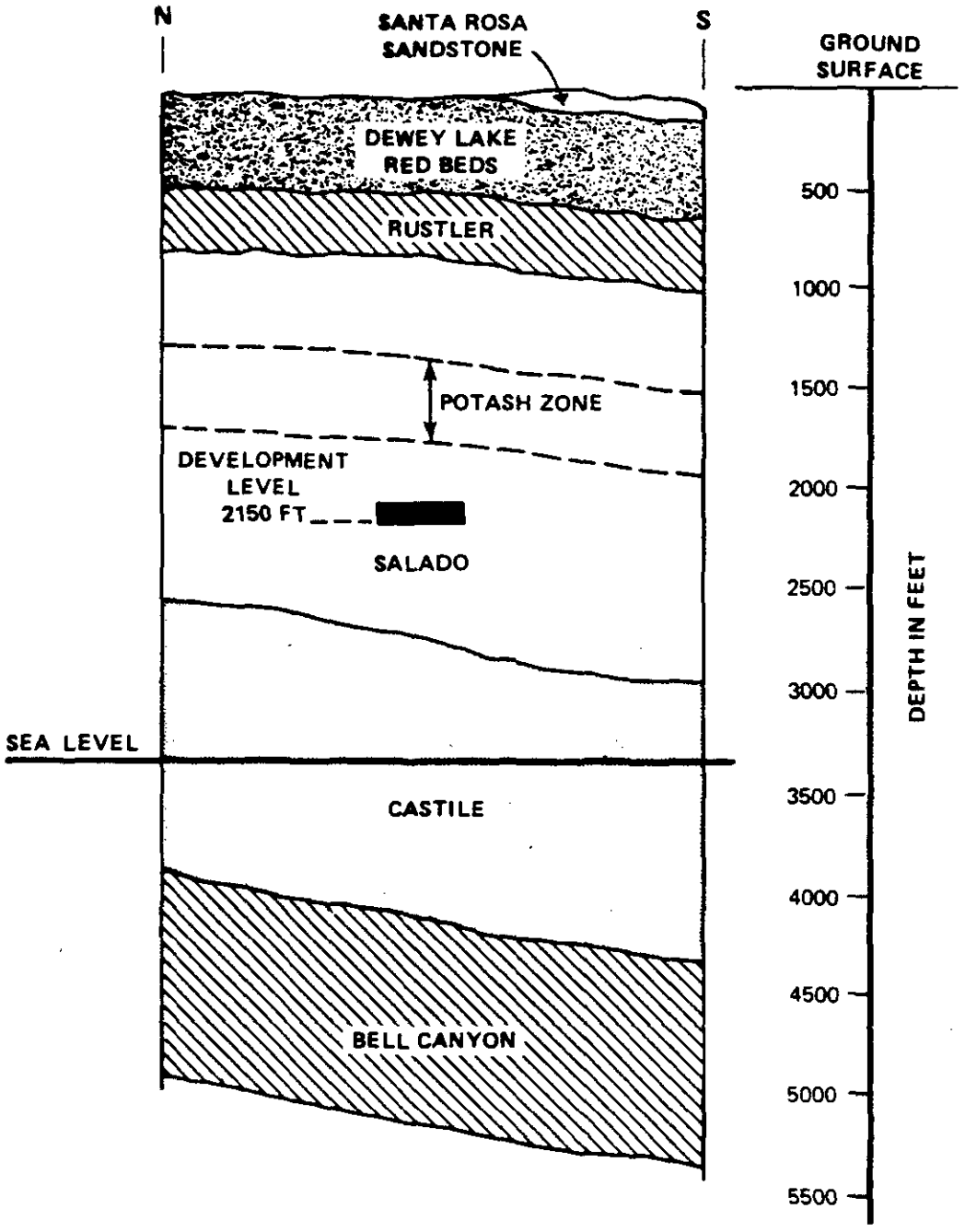

Figure 2-1

GENERAL SITE STRATIGRAPHY

underlying the Salado. The Bell Canyon formation consists primarily of sandstone, limestone and shale. No aquifers are present in the Salado or Castile formations beneath the site.

Site stratigraphy from the ground surface to about 250 feet below the underground facility level is presented in Appendix B, Figure B-1, Sheets 1 through 5. The stratigraphy shown is based on geologic data obtained from boreholes WIPP-12, ERDA-9 and DOE-1, and from the C & SH and waste shafts. An analysis of these data shows a strong correlation of the stratigraphy between the boreholes and shafts from the ground surface to below the underground facility level. This correlation is based primarily on the geophysical logs because core sample logging or "hands-on" mapping was not always carried out through the entire interval. Where possible, graphic lithologic descriptions based on logging or mapping of the rock strata have been included on Figure B-1 in Appendix B. This helps to more fully define the stratigraphic relationships shown by the geophysical logs.

The analysis between boreholes WIPP-12 to the north and DOE-1 to the south resulted in correlation of the major formation contacts and most marker beds in the Salado formation. Due to a lack of distinctive stratigraphic changes, the Dewey Lake red beds exhibit a relatively uniform profile in both the lithologic and geophysical logs. The Rustler formation, however, exhibits a much greater fluctuation in its geophysical profile as a result of the anhydrite, dolomite and fine-grained clastic beds it contains. Figure B-1 in Appendix B shows that the Rustler thickens slightly to the north with a slight rise in formation contacts occurring in the area of the WIPP facility.

Correlation of the Salado formation stratigraphy between WIPP-12 and DOE-1 verifies the consistency of most of the marker beds. The geophysical logs shows distinct breaks where polyhalite and anhydrite beds occur in the largely halitic rock strata. The major stratigraphic occurrence, in that portion of the Salado formation shown on Figure B-1 in Appendix B, is a thinning of strata to the north. This thinning

becomes apparent below marker bed 124 (MB-124) and is relatively well pronounced in the underground facility horizon. The effect of this thinning is to produce a reversal in the direction of dip of the strata above and below MB-124 between WIPP-12 and DOE-1. Above this marker bed the strata dip to the north, while below the marker bed the strata dip to the south. This thinning of strata controls the slope of the facility level excavation because the excavation must avoid encroachment on any stratigraphic horizons that could affect the stability or safety of the underground openings.

The figures in Appendix B show the continuity of rock strata across the WIPP site and in the area of underground excavation. These figures are intended to show that the major design assumptions which were made based on data from boreholes ERDA-9 and WIPP-12 remain valid, based on additional data obtained from geologic mapping of the underground openings and logging of underground core holes. Therefore, correlation of the site stratigraphy from the ground surface to below the underground facility level confirms the macroscopic continuity of stratigraphy beneath the WIPP site. Geologic characterization at the WIPP underground facility level is presented in Chapter 6.

Geohydrologic data pertaining to the site were obtained from conventional and special-purpose tests in many boreholes (ref. 1-5). Geophysical logging of these holes provided hydrogeologic information on the rock strata encountered. Pressure measurements, fluid samples and ranges of rock permeability were obtained for selected formations. Also, potentiometric surfaces of major aquifer systems were contoured by using measured water level elevations in boreholes.

Evaluation of data obtained from early site selection studies indicated that the current WIPP site was a suitable candidate for the establishment of a facility to demonstrate the safe disposal of radioactive waste. Additional studies have resulted in the issuance of numerous reports regarding the suitability of the WIPP site, including the Geological Characterization Report, Waste Isolation Pilot Plant

(WIPP) Site, Southeastern New Mexico (ref. 2-4), Final Environmental Impact Statement: Waste Isolation Pilot Plant (ref. 1-4), and the Waste Isolation Pilot Plant Safety Analysis Report (ref. 1-5). Final site validation was achieved in 1983 by an evaluation of the data contained in a report titled Results of Site Validation Experiments, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico (ref. 2-5) which presented the results of studies performed to fully satisfy all site qualification criteria. This report was followed by a confirmation of overall site suitability in a report titled Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability (ref. 2-6).

2.2 DESIGN CRITERIA

The Design Criteria, Waste Isolation Pilot Plant (WIPP), Site and Preliminary Design Validation (SPDV) (ref. 2-7), and the Design Criteria, Waste Isolation Pilot Plant (WIPP), Revised Mission Concept-IIA (RMC-IIA) (ref. 2-8) were used as guides by the Architect-Engineer (Bechtel National, Inc.) in developing the reference design for the WIPP underground openings. The documents contain general requirements which were addressed in the reference design. The Design Criteria, RMC-IIA, is the highest level design document for the project. All other design documents, such as design bases, drawings and specifications, were required to be in compliance with this document.

The design criteria also stipulate the type and estimated or assumed rate of waste to be received at the WIPP. The majority of the criteria presented in the RMC-IIA document are requirements which do not need evaluation as to their suitability and have no impact on validation considerations for the underground opening reference design. The major criteria that governed development of the reference design are presented in Table 2-1. Although some of the criteria in this table are elements which cannot be evaluated, they are included because of their influence on the reference design configurations. Those criteria that can be evaluated are discussed in later chapters of this report as

Table 2-1

ABRIDGED WIPP DESIGN CRITERIA

(1) Facility design

a. Designed for an operating life of 25 years.

b. Underground facilities and equipment shall be designed to be compatible with retrieval operations for all contact-handled (CH) and remote-handled (RH) TRU waste, with a retrieval decision to be made within 5 years after the initial emplacement of each species. (Chapter 12)

c. The facility will be decommissioned after it has fulfilled its intended purposes. This will include backfilling the underground facilities, sealing the shafts and decommissioning the surface facilities.

(2) CH TRU waste *

a. Estimated annual volume is 500,000 cubic feet.

b. Estimated volume at the end of the 5 year retrieval decision period is 1,410,000 cubic feet.

c. Estimated total storage capacity is 6,330,000 cubic feet.

d. Heat generated from the waste is negligible; it will be less than 10 milliwatts for average drums, less than 20 milliwatts for average boxes, and 10 watts for few drums containing heat source plutonium.

e. Estimated annual quantities are 9,616 six-packs and 2,404 modular steel boxes.

f. Estimated total quantities are 121,700 six-packs and 30,430 modular steel boxes.

g. Underground facilities and equipment shall be designed to provide for a determination to effect retrieval of waste stored for a period up to 5 years after the initial emplacement and for a target of 5 to 10 years to reach the waste and retrieve it after the decision is made. (Chapter 12)

(3) RH TRU waste *

a. Assumed total receipt of 1,000 canisters.

b. Assumed maximum receipt rate of two canisters per day and 250 canisters per year.

* See Foreword.

c. If assumed quantities are insufficient, additional RH waste storage will be accommodated within existing storage rooms.

d. Heat generated from the waste is on the order of 60 watts per canister.

e. Access shall be available to all emplacement positions throughout the retrievability period. (Chapter 12)

f. When both CH and RH waste are scheduled for the same room, the RH waste shall be emplaced first. After the 5 year retrievability period has terminated, CH waste may be emplaced in that room.

(4) Shaft design (Chapters 7, 8 and 9)

a. Shafts shall be designed to be structurally stable throughout the operating life of the underground facility and the decommissioning period.

b. Time-dependent closure of shafts due to salt creep shall be considered. Shafts shall be designed so that minimum dimensions required for shaft functions are maintained during design life.

c. Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the storage horizon via the shafts.

(5) Shaft liner design

a. Help ensure that dimensions remain within limits required for shaft functions.

b. Prevent ground-water flow into the shaft. (Chapters 7, 8 and 9)

c. Protect wall rock from deterioration.

d. Preclude risk of rock fall from shaft wall.

(6) Mine design

a. The underground openings shall be designed so that deformation of excavations and pillars will remain within limits required for structural function, ventilation and safety. (Chapters 7, 8 and 10)

b. Rock bolts shall be used where necessary to provide positive support of roofs and walls.

c. Surface subsidence resulting from underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft. (Chapter 6)

d. Excavations and pillars shall be located and dimensioned to avoid geologic discontinuities. If discontinuities are encountered, remedial action shall be engineered to correct the problem. (Chapters 3 and 6)

e. Design shall be based on established mining procedures.

f. Predicted behavior of the salt shall be verified by in situ testing (SPDV) before proceeding with construction of the storage area.

g. Designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening. (Chapters 10 and 12)

h. Creep closure rates used for design shall be confirmed by instrument observations in the excavations. (Chapters 11 and 12)

i. Excavation dimensions shall include allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period. (Chapter 12)

j. Minimize the potential for repository rock fracturing. (Chapter 11)

k. Underground waste storage procedures shall include a designed backfill plan for fire protection. The backfill thickness shall be 1 to 2 feet. (Chapter 12)

l. Permit isolation of panels of rooms with plugs after storage and backfilling are completed. (Chapter 12)

m. Air locks, dampers, regulators and doors shall be designed and installed in such a manner that they can accommodate creep without impairment to their ability to maintain ventilation separation.

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Table 2-1 (continued)

ABRIDGED WIPP DESIGN CRITERIA

(7) Emplacement criteria

a. The underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with waste container sizes, shapes, weights and stacking configurations, and with waste emplacement equipment. (Chapter 12)

b. Provisions shall be made to accommodate backfilling over and around CH waste containers. (Chapter 12)

c. Each storage panel shall have provisions for being isolated from other panels upon completion of storage operations in that panel. (Chapter 12)

(8) Retrievability

a. All wastes placed into the WIPP are retrievable, with retrievability to be demonstrated, until such time as the pilot plant is converted to an operational repository for permanent disposal of wastes. (Chapter 12)

b. Each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years. (Chapter 12)

(9) Underground excavation and haulage

a. Mining shall be performed with continuous miners or equivalent machine type devices. Drill and blast-type mining shall be prohibited except where authorized.

b. Underground design shall provide maximum stability for excavated rooms and entries. (Chapters 7, 8, 10, 11 and 12)

c. Meet or exceed the intent of the applicable requirements of the MSHA in 30 CFR 57.9 and the New Mexico Mine Safety Code for All Mines.

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indicated in the table.

2.3 DESIGN BASES

The design bases identify the detailed design requirements for the WIPP underground facilities. They are derived from the more general concepts presented in the design criteria. The design bases cover all aspects of the design and facility operations. Design bases applicable to design validation are listed in references 2-9 through 2-20. The essential elements of the design bases pertaining to design validation of the C & SH shaft, waste shaft, exhaust shaft, drifts and storage area are discussed in Chapters 7 through 10 and Chapter 12. The discussions cover only those bases that require evaluation. All other bases are requirements determined during design reviews and need not be evaluated for their suitability.

2.4 DESIGN CONFIGURATIONS

The reference design configurations are the engineered facilities designed to comply with the design criteria and design bases. They are described in various contract drawings and specifications. The essential elements of the design configurations are discussed in Chapters 3 and 12.

2.5 DESIGN DEVELOPMENT

Design of the WIPP surface and underground facilities consisted of three stages:

(1) the conceptual design;

(2) the preliminary design; and

(3) the detailed design, including the underground opening reference design.

At both the conceptual and preliminary design stages, an extensive, independent review of the underground layout and design was made by the

DOE and its consultants, SNL and Westinghouse Electric Corporation. The review included assessment of the underground design concept and consultation with Carlsbad area potash mine operators to obtain information from their experience. The preliminary design was also reviewed by other Federal agencies, the State of New Mexico and the NAS.

From these reviews and consultations, the DOE concluded that the detailed design, based on the current state of the art, was sound. However, for further confirmation, it was decided that the impact of site-specific geologic conditions on the underground opening reference design should be verified by direct observation. Consequently, the DOE initiated the SPDV Program described in Chapter 1. The SPDV Program provided in situ data on the local geology and on the geomechanical response of the strata to the underground openings.

2.5.1 Conceptual Design

Design of the WIPP surface and underground facilities began with the conceptual design, initiated in 1975 and completed in 1977 (ref. 2-21). The conceptual design provided the basis for development of the preliminary design of both the surface and underground facilities.

2.5.2 Preliminary Design

The WIPP preliminary design was begun in 1978 and completed in 1980 (ref. 2-22). The preliminary design (Figure 2-2) was based on empirical methods and local mining practices, incorporating the conventional room and pillar method for underground development. It included analytical evaluations of underground openings in bedded salt using the finite element method and laboratory test data (refs. 2-23 and 2-24). The roof and floor of the rooms and entries were checked for stability by methods described in the SME Mining Engineering Handbook (ref. 2-25). In addition to Bechtel, SNL performed confirming numerical analyses (refs. 2-26 and 2-27). These analyses predicted short- and long-term stress distributions around the selected openings as well as elastic and creep deformations.

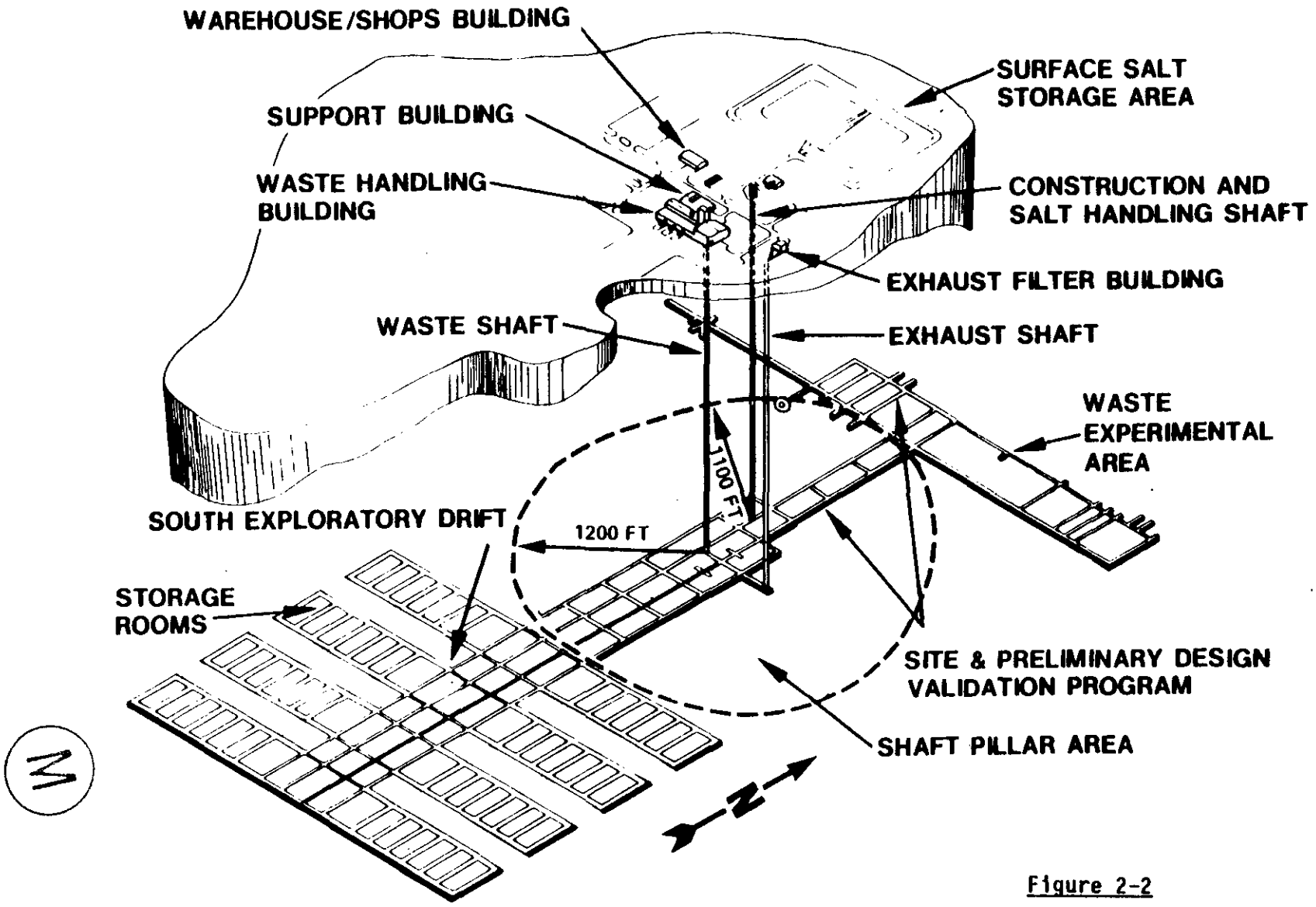

Figure 2-2

PERSPECTIVE VIEW OF THE WIPP

2.5.3 Detailed Design

Detailed design of the WIPP, begun in 1981 and completed in 1984, included design of the surface and underground facilities and the reference design for the underground openings. This was based on an extensive amount of data derived from the site characterization, including information from boreholes, surface geophysical measurements and laboratory tests. These data were used to establish the facility level and the design parameters. The number of holes drilled to the proposed facility level was restricted in order to retain its isolation from the surface. The layout and configuration of the underground openings were based mainly on empirical data which incorporates the room and pillar concept utilized in existing potash mines in Carlsbad and other mining areas, and on storage efficiency. The design was also based on mining and engineering standards universally applied to underground projects.

Analyses were performed to evaluate the stability of underground openings using material properties obtained from laboratory tests of core samples (ref. 2-28). Validation of the underground opening reference design with respect to the actual underground environment requires direct observation of geologic conditions at the facility level and the behavior of the underground openings. This interaction between observation of underground excavation and development of design is consistent with engineering practice for underground construction and with achieving the most cost-effective facility configuration.

Detailed design of the WIPP had sufficient flexibility to allow the incorporation of initial information obtained from excavation during the SPDV Program. This design flexibility was necessary for construction of the underground facilities. Calculations that applied material properties and analytical models developed from laboratory tests were performed to evaluate the behavior of the underground openings. Information obtained from the design validation program was used to confirm, refine, or alter the underground opening reference design as required to accommodate in situ conditions. The detailed

design included the development of construction details for the experimental areas and the full-scale waste storage area. It also included design of the surface facilities but this is not included in the design validation program.

2.6 DESIGN METHODS

Practical experience in the safe construction of salt and potash mines extends over many years. Empirical knowledge on the safe sizes of openings and pillars has been documented (ref. 2-29) and performance records of openings in salt are available. Different methods of analysis are required to determine the stability of openings in salt for different conditions of potential failure. The normal safety concepts of engineering, which relate a factor of safety to loads or stresses, cannot be transferred directly to the analysis of underground openings in salt. Therefore, postulated failure conditions were analyzed by other appropriate methods. In general, an opening in salt can be considered stable when the following two basic requirements are satisfied:

(1) the deformation of the opening conforms to the clearance envelope allowed for safe operation of the workings during design life; and

(2) the load bearing capacity of the salt around the opening is adequate to prevent sudden structural failure of the opening.

Subsections 2.6.1 through 2.6.3 discuss the empirical methods, closed form solutions and model simulations used for the reference design of the WIPP underground openings.

2.6.1 Empirical Method

Most of the seven potash mines in the Carlsbad area were visited by project participants on several occasions as the design evolved. The preliminary room and pillar configurations, including the width and

spacing of the rooms, drifts and pillars, were based primarily on experiences gained from general mining practices in those mines in areas with similar geology. The extraction ratio at the WIPP facility horizon is significantly less than that used in potash mines of similar depth in the Carlsbad area and in other parts of North America.

2.6.2 Closed Form Solutions

Closed form solutions in the SME Mining Engineering Handbook were used to check the design of the room-and-pillar system, including room dimensions, room spacing, pillar stresses and pillar width-to-height ratios. These types of solutions were also used to check room stability, including the stresses on the roof beams, and to estimate surface subsidence (ref. 2-30). Closed form solutions for steel and concrete structural design were used for design of the shaft liners and keys.

2.6.3 Model Simulation

To determine the geomechanical and structural behavior around the underground openings, mathematical models of the openings were generated and preliminary finite element analyses were performed to simulate this behavior. These analyses used material properties obtained from laboratory tests of drill core samples to estimate closure of the openings. In order to maintain the operational capability of the underground facility during its design life, allowances for roof, floor and wall closures were added to the operational clearance envelope of the underground openings. The design criteria require confirmation or modification of the estimated closure based on geomechanical instrument measurements obtained in the excavations.

Preliminary analyses were only considered parametric studies since important feedback from the design validation program observations and geomechanical instrument measurements was required to complete the understanding of the mechanism of creep deformation in the salt at the WIPP site.

CHAPTER 3

UNDERGROUND FACILITIES

3.1 INTRODUCTION

This chapter presents a brief history of the underground development level selection process. It also describes the configurations of the WIPP shafts, drifts and rooms, and summarizes their excavation history. The discussion of excavation history includes those details pertaining to the "as-built" openings which are considered significant with respect to the reference design. The reference design of the underground openings was based on requirements contained in the Design Criteria (refs. 2-7 and 2-8) and Design Bases (refs. 2-9 through 2-20) documents.

The WIPP underground facility is divided into three general areas (Figure 3-1). The northern portion is the experimental area containing the design validation test rooms and technology experiments. The central area is the shaft pillar. The number of drifts in this area is restricted to minimize subsidence around the shafts. This portion of the facility will primarily contain shops and personnel areas. The southern portion of the facility is the waste storage area. Although some mining has been conducted in this area, it remains largely unexcavated at the time of publication of this report.

3.2 SELECTION OF THE UNDERGROUND DEVELOPMENT LEVEL

Selection of the WIPP underground development level evolved over several years and various facility design concepts. Seven stratigraphic horizons were identified in 1979 as potential locations for the facility level and ranked in order of their preference. These seven horizons were chosen based on an examination of available borehole data, primarily geologic and geophysical logs from borehole ERDA-9, and on horizon selection criteria established by the WIPP project participants. The selection criteria consisted of recommended distances between the underground opening surfaces and the nearest overlying or underlying clay seams or partings.

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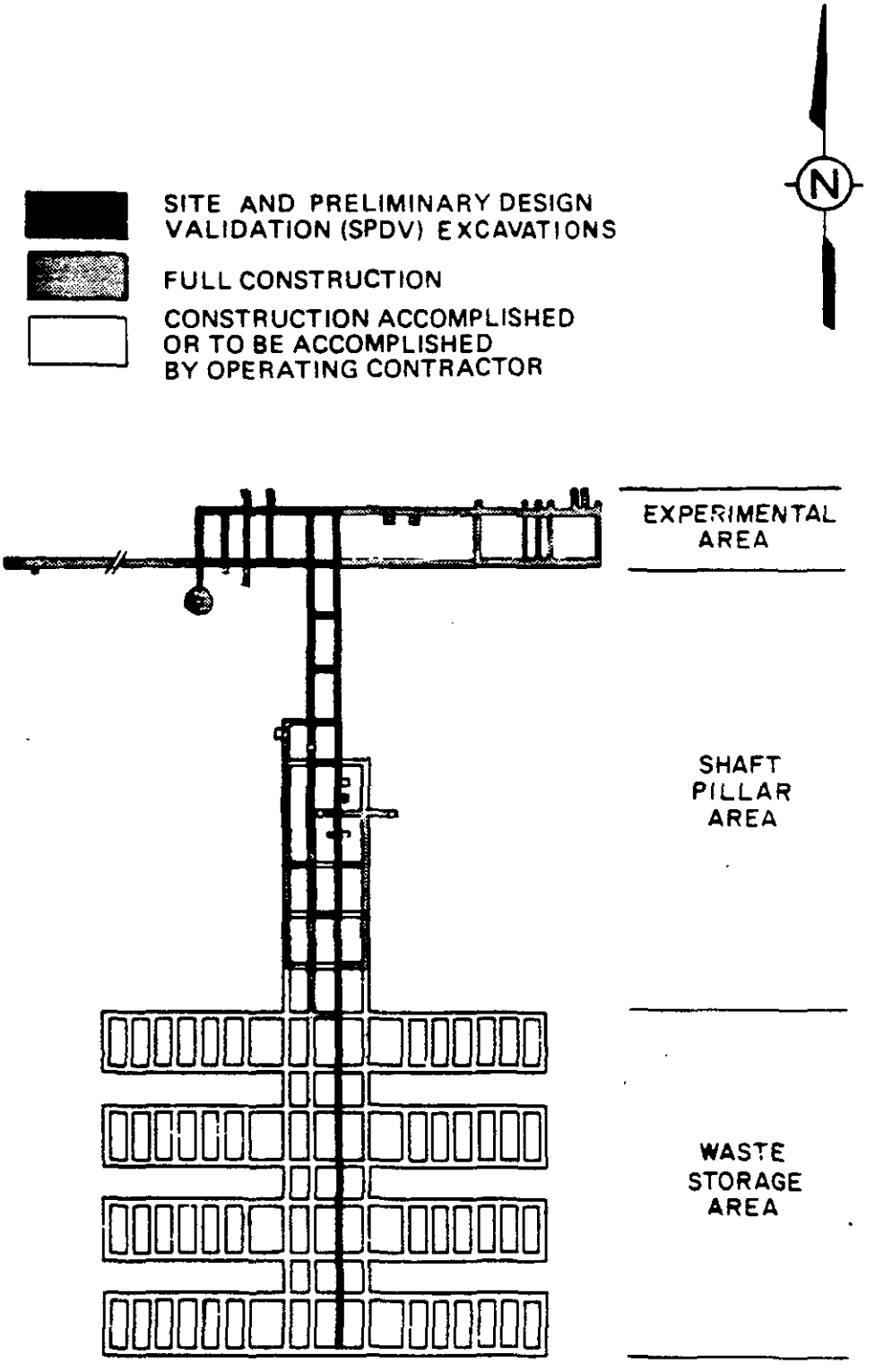

Figure 3-1

FUNCTIONAL AREAS OF THE UNDERGROUND FACILITY

Geologic mapping of the SPDV exploratory shaft in April and May 1982 permitted an assessment of the suitability of those intervals in the area of MB-139 preferred for the location of the facility level. This assessment included an evaluation of the intervals of interest against a modified version of the 1979 horizon selection criteria. These modified criteria were a result of changes to the initial WIPP facility concept, consisting of a reduction from two levels to one and alterations in the room size. The modified criteria were as follows:

(1) The rock comprising the underground facility horizon should contain no significant dissolution features, faults, or fractures. If any such features are noted, a detailed investigation must be conducted. (This element was not explicitly stated in the 1979 criteria.)

(2) There should be a minimum 4-foot thickness of halite between the top of MB-139 and the facility floor. The undulatory upper contact of MB-139 shall be considered in the selection of the facility floor level. (The 1979 criteria required a 5-foot thickness between the facility floor and the first underlying clay seam or parting.)

(3) There should be a minimum 14 1/2-foot section of halite for construction of nominal 13-foot high rooms. Minor impurities, such as argillaceous halite and polyhalite, may be acceptable. (The facility design in 1979 called for 12-foot high rooms.)

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(4) There should be a minimum of 5 feet of halite between the facility roof and the first overlying clay seam (defined as 1/4 inch thick or greater) for purposes of roof stability. (This criterion was adjusted at the site to a 5- to 10-foot thickness at the verbal request of SNL personnel.)

(5) Horizons containing substantial amounts of polyhalite should be avoided. The minimum thickness of halite defined in the

third criterion listed above was increased from 14 1/2 feet to 17 feet or more to accommodate the 17-foot high SPDV exploratory shaft station.

Selection of the final underground development level was made following a series of meetings in which the interval ranked first was evaluated for its ability to satisfy these criteria. The selection was based primarily on the results of detailed geologic shaft mapping from a depth of 2,080 feet to 2,185 feet. A meeting, attended by representatives from the DOE, Westinghouse, SNL and Bechtel, was held on May 2, 1982, to discuss the results of the selection process and to present a recommendation for the facility level location to the DOE. The final level selected for the facility floor was at a preliminary depth of 2,149 feet (elev. 1258.4 feet). The recommendation was accepted by the DOE and later reviewed and concurred in by a representative of the New Mexico Environmental Evaluation Group (EEG).

Geologic mapping of the SPDV exploratory shaft and subsequent evaluation by the project participants showed that, as anticipated, the geology was similar to that encountered in borehole ERDA-9. One exception was the discovery of an additional anhydrite bed, anhydrite "b", and its underlying clay seam. Figures 3-2 and 3-3 show the preliminary design (pre-SPDV) of the shaft station and storage rooms. This preliminary design was based on the stratigraphy at the first-ranked alternative horizon. Figures 3-2 and 3-3 show that only one anhydrite layer and clay seam were expected above the facility level at this horizon, based on the interpretation of ERDA-9 core. This would have produced 12 feet of uninterrupted halite above the shaft station and 16 feet above the storage rooms. However, shaft mapping revealed an intermediate bed, anhydrite "b", approximately 7 feet below the known bed, anhydrite "a". This reduced the uninterrupted halite thickness above the facility level roof to 3.5 to 5 feet at the shaft station and 7 to 8.5 feet in the waste storage area. Despite this finding, the underground facility horizon chosen was judged to adequately meet all of the established criteria.

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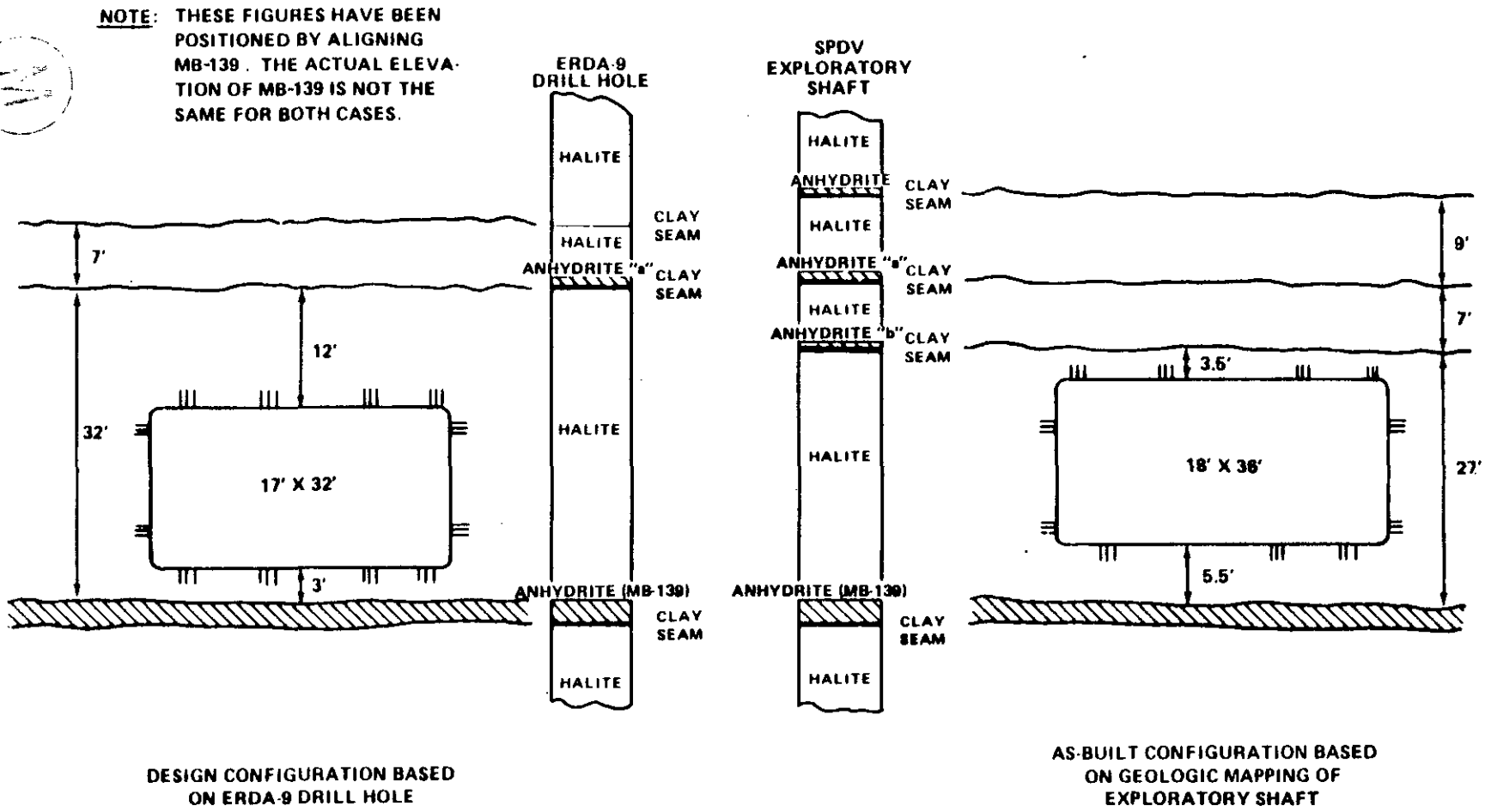

DESIGN CONFIGURATION BASED ON ERDA-9 DRILL HOLE

AS-BUILT CONFIGURATION BASED ON GEOLOGIC MAPPING OF EXPLORATORY SHAFT

Figure 3-2

SPDV EXPLORATORY SHAFT STATION
DESIGN VERSUS AS-BUILT CONFIGURATION

NOTE: THESE FIGURES HAVE BEEN POSITIONED BY ALIGNING MB-139. THE ACTUAL ELEVATION OF MB-139 IS NOT THE SAME FOR BOTH CASES.

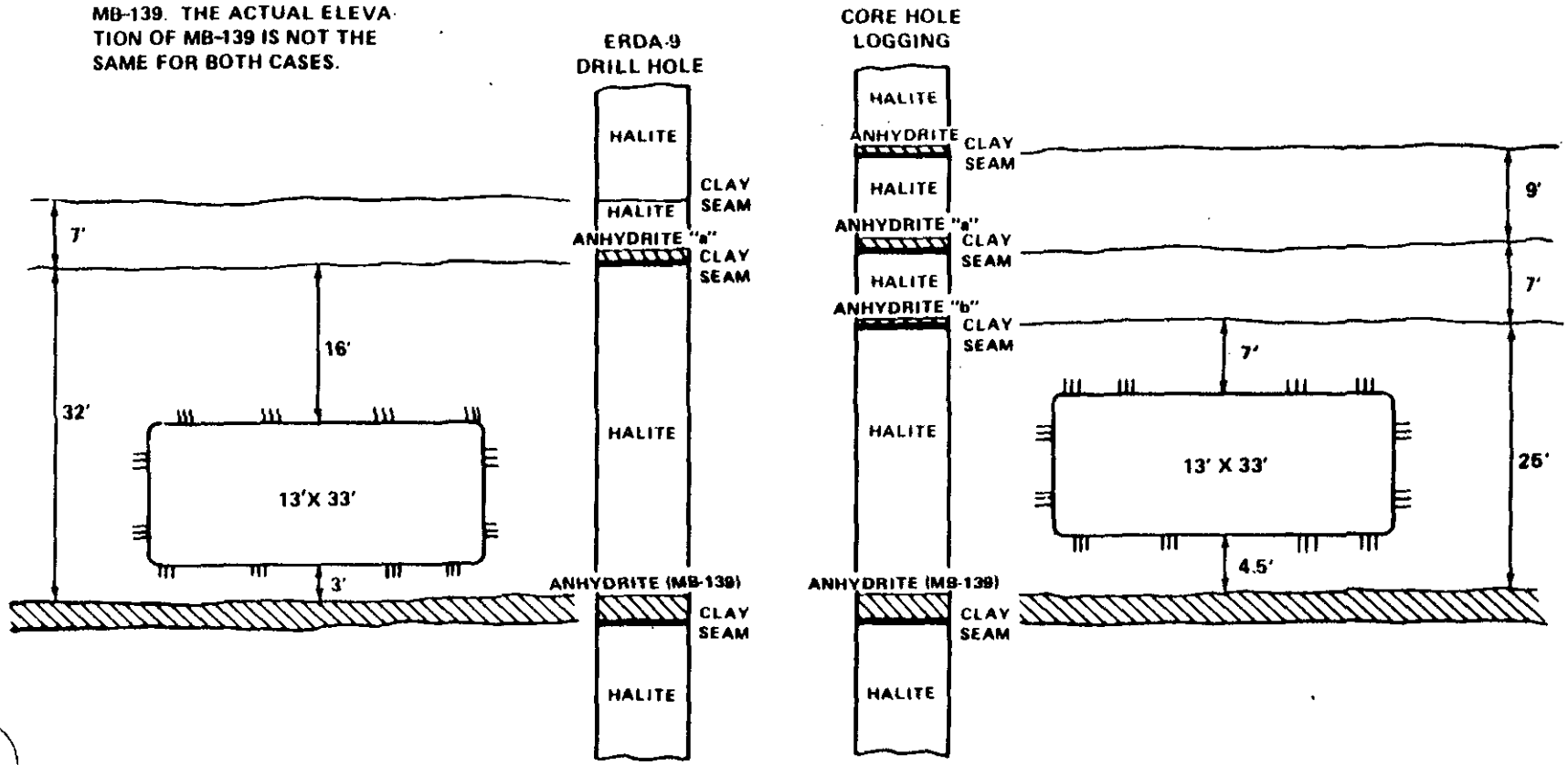

DESIGN CONFIGURATION BASED ON ERDA-9 DRILL HOLE

REVISED CONFIGURATION BASED ON CORE HOLE DATA

Figure 3-3

STORAGE ROOM
DESIGN VERSUS REVISED CONFIGURATION

At a meeting held on February 13, 1986, consideration was given to the desirability of relocating the facility level to a different stratigraphic horizon (ref. 3-2). The discussion was prompted by the following observations of the behavior of the underground openings:

(1) The effect of excavation on the strata surrounding the underground openings are being investigated by gas permeability testing. These tests indicate that zones of increased permeability due to fracturing, and proportional to the size of the opening, have developed between the floor of the openings and the base of MB-139 in the test rooms. These zones have also developed at intersections and other locations in the N1420 drift. Increased permeability has also been detected within anhydrite "b" above the roof of the test rooms. (Additional permeability testing is being conducted by SNL. The final results from this program are not yet available.)

(2) Fracturing has been encountered both within and above MB-139. It is especially well developed in the southern half of Test Room 3 (Room T). This fracturing is discussed in Chapter 10, subsection 10.3.2.1, and in Chapter 11, subsection 11.3.2.1.

(3) Both horizontal displacements and vertical separations have been observed above the roof of the underground openings. These occur primarily at anhydrite "b" and are associated with the underlying clay seam. This is discussed in Chapter 10, subsection 10.3.2.1, and in Chapter 11, subsection 11.3.2.1.

(4) In situ closure rates are almost three times greater than the rates originally predicted from laboratory test data. This is discussed in Chapters 10, 11 and 12.

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The underground opening behavior occurring at the WIPP is similar to that of other openings excavated in areas with similar geologic formations. The conditions are understood and any problems encountered can be adequately mitigated using standard mining engineering procedures. The behavior experienced at the present facility level is likely to occur to some extent at any alternate horizon selected. These conclusions, and the fact that the behavioral characteristics and geologic environment at the existing level are known, resulted in a decision by the WIPP project participants to keep the facility level at its present location. Studies of the behavior of the rooms and drifts will continue beyond design validation as discussed in Chapter 1, subsection 1.5.2.

3.3 DESCRIPTION OF UNDERGROUND FACILITIES

3.3.1 C & SH Shaft

The construction and salt handling (C & SH) shaft is the principal means of access to the underground WIPP facility and is the primary fresh-air intake for the underground ventilation system. It was originally designated the exploratory shaft during the SPDV Program. The shaft provides a means of access for personnel and materials to and from the facility, and for the removal of excavated salt. Geomechanical instrumentation installed in the shaft provides important data for monitoring the behavior of the liner and key, the salt strata surrounding the shaft. and ground-water pressures.

The shaft is lined with steel casing having a 10-foot inside diameter from the ground surface to a depth of 846 feet. The 10-foot diameter extends through the concrete shaft key to a depth of 880 feet. From the key to the bottom of the shaft at 2,298 feet the shaft is a nominal 12 feet in diameter and is unlined.

The steel liner was designed to retain the rock formations above the salt and to prevent water seepage into the shaft. The liner was designed for both construction and permanent loads. The construction load was considered to be the hydrostatic pressure exerted on the liner

by the fluid used to "float" it into place for installation. The permanent load is the hydrostatic pressure exerted on the liner by ground water under artesian conditions in the water-bearing zones. Rock pressure was not used in design due to the controlling influence of the hydrostatic pressure. Since hydrostatic pressure increased with depth, the steel liner thickness was also increased. The liner is 5/8 inch thick at the top and increases to 1 1/2 inches thick at the bottom. The liner is held in place with cement grout.

The C & SH shaft key is a 37 1/2-foot long reinforced-concrete structure at the base of the steel liner. The key serves two important functions. First, it provides a transition from the lined to the unlined sections of the shaft. Second, as an integral part of the liner, it prevents ground water from the upper water-bearing members from dissolving the salt around and beneath the key. This water movement is obstructed primarily by two water seals installed behind the concrete. A third seal, installed at the interface of the steel liner and concrete key, prevents water from flowing out at the interface and down the inner surface of the key. A gravel-filled trench was constructed behind the concrete above the lower of the two seals to intercept water migration past the upper seal. This water is drained through four pipes, called "telltales", to the key surface and into a water collection ring at the base of the key.

The shaft is unlined below the concrete key. Excavation by the rotary drilling method has resulted in shaft walls that are smooth and undamaged. No support or protective wire mesh was required.

3.3.2 Waste Shaft

The waste shaft serves to connect the waste handling building on the ground surface with the WIPP underground facility. The shaft's primary function is to permit the transfer of radioactive waste from the surface to the underground storage area. It will also serve as an intake shaft for small volumes of air during storage operations and as an emergency escape route. The waste shaft was initially excavated as

a 6-foot diameter ventilation shaft, which was the primary exhaust route during the SPDV phase of construction. As in the C & SH shaft, geomechanical instruments installed in the waste shaft provide important geotechnical data with which to monitor the behavior of the shaft and its surrounding geologic environment.

The waste shaft is lined with unreinforced concrete from the ground surface to the top of the key at a depth of 837 feet. The purpose of the liner is to retain the surrounding rock and to prevent ground water from entering the shaft. The lined section of the shaft has a finished inside diameter of 19 feet. The liner thickness increases with depth from 10 inches at the surface to 20 inches at the key. A water collection ring was incorporated into the liner immediately beneath both the Magenta and Culebra water-bearing members. These rings are connected to another ring at the base of the key.

The waste shaft key is similar in construction to the C & SH shaft key. It serves as a transition from the concrete-lined section to the exposed salt section of the shaft and it prevents ground water from reaching the salt via the shaft opening. The key is 63 feet long, 4 1/4 feet thick and constructed of reinforced concrete. The bottom of the key is at a depth of 900 feet. In contrast to the C & SH shaft key, the waste shaft key has only two water seals.

A water collection ring at the base of the key collects water trickling down the surface of the key and conducts it, as well as water from the two upper rings, to the shaft station via a 2-inch diameter PVC pipe. Two guide pipes, consisting of 2-inch diameter polyvinyl chloride (PVC) pipe, were also installed in the concrete key at a depth of 843 feet at the request of SNL to serve as guides for drilling test holes across the contact of the Rustler formation with the Salado formation.

The section of the shaft below the key is 20 feet in diameter and consists of exposed salt lined with wire mesh anchored by rock bolts. The 20-foot diameter shaft enlarges to 23 feet just above the waste

shaft station. This 23-foot diameter extends to the bottom of the shaft, approximately 122 feet below the facility level.

3.3.3 Exhaust Shaft

The exhaust shaft is the primary ventilation exhaust for the underground facilities. It is designed as a duct to remove air from the underground areas up through the exhaust filter building at the ground surface. In addition, the exhaust shaft will serve as a backup escape route during emergencies. This shaft is also used to carry an auxiliary 15 kV power cable and signal cables underground. These redundant cables serve as emergency alternates should the primary cables in the C & SH shaft become inoperative. The exhaust shaft, like the C & SH and waste shafts, contains a suite of geomechanical instruments.

The exhaust shaft is lined with unreinforced concrete from the ground surface to the top of the shaft key at a depth of 844 feet. The purpose of the liner is the same as that in the other two shafts. The liner has an inside diameter of 14 feet. The liner thickness increases from 10 to 16 inches with depth.

The exhaust shaft key serves the same function as the keys in the other two shafts. It is a transition element between the concrete liner in the upper section of the shaft and the exposed salt in the lower section. It is also designed to prevent ground water in the upper water-bearing members from reaching the salt section of the shaft. The key is 63 feet long and 3 1/2 feet thick. The key contains eight telltale drains at a depth of 857 feet and nine drains each at 855 feet and 870 ft. The key also contains two water seals, a water collection ring, and two guide pipes for drilling test holes. The bottom of the key is at a depth of 907 feet.

The exhaust shaft below the key is 15 feet in diameter. It is lined with wire mesh anchored by rock bolts. The exhaust shaft terminates at the facility level; there is no shaft sump.

3.3.4 Drifts

The underground shaft stations and drifts have been designed to facilitate the handling and transport of radioactive waste. They also provide access for construction operations and experimental activities. The drifts are designed to provide adequate ventilation supply and exhaust for all areas of the underground facility.

All drifts are rectangular in cross section with typical dimensions that range from about 8 to 12 feet high and 14 to 25 feet wide. Access drifts serve as the main haulageways between the shafts and the experimental and waste storage areas. Cross-cut drifts (crosscuts) are designed to accommodate equipment, shops and traffic flow. The crosscuts are generally smaller in cross-sectional dimensions than the access drifts. The excavated dimensions of major drifts and rooms are presented in Table 3-1. The horizontal underground openings are oriented either north-south or east-west and are labeled based on a grid system having the centerline of the C & SH shaft as its origin. For example, the E0 drift runs north-south in line with the C & SH shaft and the N1100 drift is an east-west drift 1100 feet north of the C & SH shaft.

The northern part of the facility contains the experimental areas. Four test rooms were excavated west of the E0 drift as part of the SPDV Program. These rooms are discussed in subsection 3.3.5. The remaining experimental areas have been excavated for long-term experimental programs to be conducted under the direction of SNL. These experiments are not part of design validation and are addressed in this report only when necessary to clarify the discussion.

The shaft pillar area (Figure 3-1) is designed to protect the surface structures and shafts from settlement resulting from the natural closure of underground openings. The shaft pillar dimensions were derived in accordance with standard analyses developed by the U.S. Bureau of Mines (ref. 2-30). Excavation within the shaft pillar area was designed to maintain an extraction ratio of less than 15 percent.

Table 3-1

FACILITY LEVEL CONFIGURATIONS
NOMINAL EXCAVATED DIMENSIONS OF MAJOR DRIFTS AND ROOMS

Drift or Room					Width (ft)	Height (ft)
E0	From	N35	To	N1420	25	12
E140	From	N140	To	N1420	14	8
E140	From	N140	To	S2210	25	12
E140	From	S2210	To	S3264 (Exploratory Drift)	25	8
E300	From	S90	To	S1980	14	12
W30	From	S90	To	S700	20	12
W30	From	S700	To	S1950	14	12
W170	From	N140	To	S1300	14	12
N140	From	E0	To	E140	12	12/19
N140	From	E0	To	W170	12	12/19
N460	From	E0	To	E140 (Conference Room)	20	8
N780	From	E0	To	E140	12	12
N1100	From	E0	To	E1546	14	9
N1100	From	E0	To	W667	20	12
N1100	From	W667	To	W1800 (Room G Entry Drift)	20	9
N1100	From	W1800	To	W2990 (Room G)	20	10
N1420	From	E140	To	E1546	14	12
N1420	From	E140	To	W647	20	12
S90	From	E0	To	E140	12	12
S90	From	E140	To	E300	14	12
S400	From	E60	To	E140	20	12
S400	From	E140	To	E300	14/18	12/17
S400	From	E300	To	E500	20	12
S700	From	W170	To	W30	20/25	12
S700	From	W30	To	E140	20	12
S700	From	E140	To	E300	20/35	12
S1000	From	W170	To	W30	20	12
S1000	From	W30	To	E140	25	12
S1000	From	E140	To	E300	20	12
S1300	From	W170	To	W30	20	12
S1300	From	W30	To	E140	20	12
S1300	From	E140	To	E300	20	12
S1600	From	W170	To	W30	20	12
S1600	From	W30	To	E140	20	12
S1600	From	E140	To	E300	20	12
S1600	From	E300	To	E520	14	12
S1950	From	W30	To	E140	14	12
S1950	From	E140	To	E300	20	12
S2180	From	E140	To	E300	14	12

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Table 3-1 (continued)

FACILITY LEVEL CONFIGURATIONS
NOMINAL EXCAVATED DIMENSIONS OF MAJOR DRIFTS AND ROOMS

Drift or Room	Width (ft)	Height (ft)
Test Rooms 1, 2, 3 & 4 (300 feet long)	33	13
Experimental Rooms A1, A2, A3, B & D (306 feet long)	18	18
Alcove I1 (43 feet long)	24	12
Alcoves I2, I3, I4, I5, I6 & I7 (33 feet long)	33	12
Rooms C1 & C2 (98 and 102 feet long)	18	18
Room J (98 feet long)	33	12
Rooms L1 & L2 (98 feet long)	33	12
Room H Entry	12	10
Room H (outside radius = 54 feet)	36	10

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A geomechanical instrumentation program was implemented to gather geotechnical data from the underground drifts. The program was designed to monitor the stability of the openings, to assess deformational characteristics of the salt, and to measure closure rates of typical drifts, rooms and intersections. In addition, an extensive program of geologic mapping, core drilling, laboratory testing and visual observations has been conducted. The methodology used and the results of these programs are discussed in other chapters of this report.

3.3.5 Test Rooms

Four test rooms were excavated in the northern section of the facility during the SPDV phase of construction. These rooms represent full-scale models of the future waste storage rooms and have the same dimensions, 13 feet high, 33 feet wide and 300 feet long, as the planned storage rooms.

The test rooms are designed to permit an assessment of deformation and closure rates due to salt creep as well as the stability of the future storage rooms. This has been accomplished by evaluations and analyses of geotechnical data gathered from geomechanical instruments installed in each room and the results of geologic mapping, core drilling, laboratory testing of samples from the surrounding strata, and qualitative visual observations by project geotechnical personnel. The results of these evaluations and analyses are presented in Chapters 11 and 12.

3.3.6 Waste Storage Area

The waste storage area will be developed in the southern portion of the facility (Figure 3-1). The reference design for this area includes a series of eight panels with seven storage rooms in each panel. The room dimensions are 13 feet high, 33 feet wide and 300 feet long. The width of the pillars between rooms is 100 feet. This configuration results in a storage area extraction ratio of less than 25 percent based on a line 100 feet beyond the storage area excavation neat line.

Full development of the waste storage area will eventually encompass about 140 acres. The reference design is based on the assumption that the storage rooms and panels will be excavated in stages coordinated with the scheduled arrival of waste. Waste storage is designed not only for the rooms but also for all drifts and crosscuts in the waste storage area (south of the S1600 drift).

3.4 UNDERGROUND CONSTRUCTION

The existing WIPP underground facility was constructed in two phases. The first phase, SPDV (Figure 3-1), was conducted from 1981 to 1983 and consisted of the excavation of the exploratory and ventilation shafts as well as several drifts and a panel of four test rooms. SPDV accomplished two objectives: (1) it permitted the completion of experiments and geotechnical activities required for the Site Validation Program (ref. 2-5); and (2) it provided for the initial in situ confirmation of the underground facility reference design. This allowed construction of the underground facility to proceed in a timely and cost-effective manner.

Excavation associated with the second phase of underground construction was accomplished from October 1983 through February 1985 and is designated as full construction on Figure 3-1. This excavation included enlarging the ventilation shaft for its conversion to the waste handling shaft, constructing the exhaust shaft, and mining additional underground drifts and test rooms for conducting R & D experiments. The operational name of the exploratory shaft changed to the C & SH shaft during this period. Design validation has been an integral part of this construction activity.

A third phase of underground construction is currently in progress. This is the initial operations phase during which excavation of the storage rooms will occur concurrently with waste emplacement. Mining for this phase started in June 1985 with the excavation of crosscuts for the installation of shops in the shaft piller area. Partial excavation of some storage rooms will follow. However, initial waste

emplacement is currently not scheduled to begin until late 1988. No discussion of the operations phase is presented in this report, although it will be strongly affected by the design validation results presented herein.

3.4.1 C & SH Shaft

C & SH shaft construction was performed during 1981 and 1982. Construction started in May 1981 with the excavation of a 98-foot deep pilot hole. The pilot hole was augered using a crane-mounted drilling unit. Steel surface casing with an interior diameter of 12 feet was grouted into place to a depth of 93.4 feet.

Shaft drilling started on July 4, 1981, and was completed 112 days later. The drilling was performed using a jacknife derrick with draw works capable of supporting a suspended load of 500 tons. The drilling method used consisted of air-lifted reverse circulation performed through double-walled drill pipe. The drilling fluid (brine) was maintained at a relatively constant level above the drill bit. The drill bit consisted of a 142-inch diameter full-face rolling cutter head. Shaft drilling was completed to a depth of 2,298 feet on October 24, 1981. Table 3-2 contains an abridged history of the C & SH shaft drilling program.

Liner installation began on November 12, 1981, and was completed on December 3, 1981. A steel liner was installed in 20- and 40-foot sections in the shaft above the salt formation. The steel sections were connected during installation using full-penetration bevel welds. Nondestructive radiographic examination was performed on each welded section. The liner was partially floated into place by filling the shaft with brine and adding brine to the inside of the liner to overcome the effect of buoyancy. Additional support for installation was provided by the drilling derrick and draw works. After the liner was in place, the annular space was grouted by the tremmie method. The grouting was completed on December 8, 1981.

Table 3-2

C & SH SHAFT - ABRIDGED DRILLING HISTORY

Location:		Eddy County, New Mexico; New Mexico Grid Coordinates X 666894.89, Y 499687.23
Elevation:		Ground Surface = 3410.5 ft MSL
Drilling Contractors/Rig Types:		Meredith Drilling Company/Auger (11.0 ft to 97.5 ft*); Challenger Drilling Company/ National 125 Jacknife Rotary (97.5 ft to 2,298 ft)
Drilling Data	Augered:	May 18 to June 17, 1981
	Spudded:	July 4, 1981
	Completed:	October 24, 1981
	Casing:	180-in. corrugated metal pipe, ground surface to 11 ft; 144-in. steel casing, ground surface to 93.4 ft; 120-in. steel liner, ground surface to 846 ft
	Drill Hole:	142-in. (nominal) diameter uncased borehole to a total depth of 2,298 ft
	Drilling Fluid:	Brine
Directional Survey Contractor:		Sperry-Sun (Gyroscopic Multishot Surveys)
Bottom Hole Coordinates:		X 666893.45, Y 499686.56 at 2,276 ft
Horizontal Displacement:		1.59 ft S 65.03° W at 2,276 ft

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Table 3-2 (continued)

C & SH SHAFT - ABRIDGED DRILLING HISTORY

Geophysical Logging Contractors:	Birdwell(B) and Dresser Atlas(D)
Geophysical Logs:	October 16 to December 17, 1981
Fluid Density (D)	1,200 ft to 550 ft
Fluid Density (B)	750 ft to 20 ft
Density (B)	2,294 ft to 50 ft
Caliper (3-diameter/aver.) (B)	2,294 ft to 50 ft
Epithermal Neutron (B)	2,294 ft to 50 ft
Gamma Ray (B)	2,300 ft to 0 ft
Fluid Density (B)	400 ft to 100 ft
Nuclear Cement Top Locator (NCTL) (B)	827 ft to 0 ft
Nuclear Annulus Investigation Log (NAIL) (B)	839 ft to 0 ft
Fluid Density (D)	2,250 ft to 2,003 ft

* All depths measured from ground surface.

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A key was constructed at the base of the steel liner during March and April 1982. The key is 37 1/2 feet long and constructed of reinforced concrete. Key construction required additional excavation in the salt below the liner to enlarge the shaft diameter. After the installation of reinforcing steel, drains, geomechanical instruments, grout pipes and block-outs for the injection of chemical seals, concrete was placed in several lifts from the bottom of the key to the bottom of the liner. Finally, the chemical seals were placed by injection.

3.4.2 Waste Shaft

Drilling of the SPDV ventilation shaft started on December 24, 1981, and was completed to a depth of 2,196 feet on March 10, 1982. The drilling operation was performed with the same drill rig used to drill the C & SH shaft. The drill bit was a 72-inch diameter full-face rolling cutter head. An abridged history of the shaft drilling is presented in Table 3-3. Except for a 97-foot long surface casing, the ventilation shaft was unlined. The ventilation shaft, and later the waste shaft, served as the exhaust for the underground facility until excavation of the permanent exhaust shaft was completed.

Enlargement of the SPDV ventilation shaft to become the waste shaft began in October 1983 (Table 3-3). This enlargement was performed from the top to the bottom of the shaft using the smooth-wall drill and blast method. The blasting was accomplished in 10-foot rounds that permitted the muck to fall down the 6-foot diameter shaft to the facility level. The muck was removed from the waste shaft station and hauled to the surface via the salt-handling skip in the C & SH shaft.

Construction of the unreinforced concrete liner closely followed this excavation. Typically, the shaft crew would take out three rounds (30 feet) of rock before placing one 24-foot section of concrete. This arrangement normally left no more than 6 feet of unlined shaft below the concrete.

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Table 3-3

WASTE SHAFT - ABRIDGED CONSTRUCTION HISTORY

Location:	Eddy County, New Mexico; New Mexico Grid Coordinates X 666920.76, Y 499286.92
Elevation:	Ground Surface = 3407.5 ft MSL Shaft Collar = 3407.9 ft MSL (ventilation shaft) Shaft Collar = 3409.0 ft MSL (waste shaft)
Ventilation Shaft	
Drilling Contractors/Rig Types:	Meredith Drilling Company/Auger (8.0 ft to 98.2 ft*); Challenger Drilling Company/ National 125 Jacknife Rotary (98.2 ft to 2,196 ft)
Drilling Data — Augered:	June 13 to 17, 1981
Spudded:	December 24, 1981
Completed:	March 10, 1982
Casing:	108-in. corrugated metal pipe, ground surface to 8 ft; 74-in. steel casing, 0.5 ft above ground surface to 96.9 ft
Drill Hole:	72-in. (nominal) diameter uncased borehole to a total depth of 2,196 ft
Drilling Fluid:	Brine
Directional Survey Contractor:	Sperry-Sun (Gyroscopic Multishot Surveys)
Bottom Hole Coordinates:	X 666918.81, Y 499285.81 at 2,177 ft
Horizontal Displacement:	2.25 ft S 60.2° W at 2,177 ft

Table 3-3 (continued)

WASTE SHAFT - ABRIDGED CONSTRUCTION HISTORY

Shaft Survey Contractor:	Cementation West, Inc.
Horizontal Displacement:	1.37 ft SW at 2,150 ft
Geophysical Logging Contractor:	Birdwell
Geophysical Logs:	March 8 to 10, 1982
Caliper (3-diameter/aver.)	2,190 ft to 0 ft
Epithermal Neutron	2,190 ft to 0 ft
Density	2,190 ft to 0 ft
Gamma Ray	2,100 ft to 0 ft
Fluid Density	2,191 ft to 1,800 ft
Waste Shaft	
Excavation Contractor:	Ohbayashi Corporation
Excavation Method:	Smooth-wall drill and blast
Finished Shaft Diameter:	Lined = 19 ft Unlined = 20 ft minimum
Shaft Collar Excavation Began:	October 11, 1983
Liner Plate and Concrete Backfill Completed:	November 12, 1983
Collar Pads and Sinking Headframe Foundations Poured:	November 14, 1983
Concrete Liner Constructed: (including key)	November 30, 1983, to April 3, 1984
Liner Plate at Magenta Dolomite Grouted:	March 8 to 10, 1984
Liner Plate at Culebra Dolomite Grouted:	April 3 to 5, 1984
Salt Section Excavated:	April 7 to June 11, 1984
Sump Excavated:	June 20 to August 8, 1984
Liner Grouted:	August 11 to 25, 1984

* All depths measured from ground surface.

As part of the shaft design, both the Magenta and Culebra dolomite members of the Rustler formation were overexcavated and covered with steel liner plate prior to concrete placement. The space between the liner plate and the rock provided room for water from these water-bearing zones to accumulate. This allowed the concrete liner to reach full strength without damage from hydrostatic pressure buildup. After the concrete liner had reached full strength, this annular space was grouted with Portland cement grout at a 1:1 cement-to-water ratio.

Construction of the waste shaft key was nearly identical with that of the C & SH shaft key. The key is 63-feet long and composed of reinforced concrete. The shaft was overexcavated and the reinforcing steel, drainpipes, geomechanical instruments and chemical seal blockouts were installed. Unlike in the C & SH shaft, the chemical seals were placed between lifts of concrete. Concrete was placed from the bottom of the key to the top in several lifts, with construction joints at the top of each lift and at each chemical seal blockout. At the chemical seal locations the seal material was placed into the blockout prior to placing the next lift of concrete. Construction of the shaft liner and key was completed on April 3, 1984.

Excavation of the shaft to its 20-foot finished diameter below the key began on April 7, 1984. This section of the shaft is lined with wire mesh anchored by 3-foot long rock bolts. Mesh installation, like liner installation, was accomplished concurrently with excavation. The shaft enlargement reached the facility level on June 11, 1984. The shaft sump was excavated between June 30 and August 8, 1984. The sump extends approximately 122 feet below the facility level.

The concrete liner and grouting at both water-bearing zones did not completely prevent water from entering the shaft. Water seeped through the liner at construction joints and some cracks from a depth of about 560 feet to 835 feet. A grouting program was undertaken to seal these leaks in August 1984. A total of 628 bags of Portland Type V cement, 103 bags of MC-500 microfine cement, and 76 gallons of Scotch-brand

5600 foam chemical grout were injected into 293 drilled holes (ref. 3-3). The grouting significantly reduced, but did not eliminate, water seepage through the concrete liner.

3.4.3 Exhaust Shaft

The exhaust shaft was constructed in two phases over a 16 month period. The first phase was the excavation of a 6-foot diameter pilot shaft using upreaming techniques. The second phase consisted of enlargement of this shaft by conventional drill and blast methods and lining of the upper 907 feet. The construction history is summarized in Table 3-4.

Shaft excavation began on September 22, 1983, with the drilling of a pilot hole. The pilot hole was a 7 7/8-inch diameter hole drilled from the ground surface to intersect with the S400 drift at a depth of about 2,150 feet. Therefore, directional control of the hole was critical. The upper 80 feet of the pilot hole was augered, then lined with a surface casing. Drilling progressed to a depth of 744 feet using a tri-cone roller bit and compressed air. A "Dynadrill" was then used to correct hole alignment from 735 to 1,183 feet based on the results of gyroscopic hole surveys. The circulating medium was also changed at this time from air to brine. The tri-cone bit was used to complete the pilot hole. The hole diameter was then reamed to 11 inches from the surface to the facility level, again using a tri-cone roller bit. Pilot hole drilling was completed on December 16, 1983.

Excavation of the pilot shaft was performed by reaming the 11-inch diameter pilot hole to a diameter of 6 feet. This was accomplished by the raise-bore method. Reaming was performed from the facility level to the ground surface. The raise-boring operation was conducted from December 31, 1983, to February 10, 1984, using a Robbins series 61R1131 raise-bore machine. This machine utilizes a full-face rolling cutter head pulled to the surface with hydraulic jacks. Drill cuttings fell to the facility level and were hauled to the surface via the C & SH shaft.

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Table 3-4

EXHAUST SHAFT - ABRIDGED CONSTRUCTION HISTORY

Location:	Eddy County, New Mexico; New Mexico Grid Coordinates X 667370.39, Y 499287.23
Elevation:	Shaft Collar = 3411.5 ft MSL Shaft Reference = 3409.0 ft MSL
Excavation Contractor:	Ohbayashi Corporation
Excavation Method:	Raise-bore 6-ft diameter pilot shaft; smooth-wall drill and blast to final dimensions
Subcontractors for Raise-Bore Excavation:	Raisebore, Inc., and J. S. Redpath Co.
Finished Shaft Diameter:	Lined = 14 ft Unlined = 15 ft
Pilot Hole Drilled:	September 22 to December 16, 1983
Raise-Bore Excavation:	December 31, 1983, to February 10, 1984
Shaft Collar Excavation Began:	July 15, 1984
Liner Plate and Concrete Backfill Completed:	July 17, 1984
Concrete Liner Constructed: (including key)	July 18 to November 29, 1984
Liner Plate at Culebra Dolomite Grouted:	December 2 to 4, 1984
Liner Plate at Magenta Dolomite Grouted:	December 4 to 5, 1984
Salt Section Excavated:	December 7, 1984, to January 17, 1985
Liner Grouted:	June 1 to July 31, 1985

Enlargement of the pilot shaft from 6 feet to the final exhaust shaft diameter of 15 feet began on July 15, 1984, and was accomplished by drilling and blasting in 10-foot rounds. Excavation was performed from the ground surface to the facility level. The rock was blasted into the open pilot shaft so that it fell to the facility level where it could be removed and hauled to the surface via the C & SH shaft.

The upper 844 feet of the exhaust shaft is lined with unreinforced concrete. As in the waste shaft, construction of the exhaust shaft liner occurred concurrent with the drill and blast excavation. Concrete placement for the liner was completed on November 29, 1984. The two water-bearing zones in the Rustler formation, the Magenta and Culebra dolomites, received the same special treatment that was performed in the waste shaft. Each zone was overexcavated and covered with steel liner plate prior to placing the concrete liner. After the liner had cured, grout was injected behind the liner plates.

Exhaust shaft key construction, similar to that in the waste shaft, was performed in November 1984. The key consists of reinforced concrete and extends from a depth of 844 to 907 feet. It initially contained 2 chemical seals, 8 telltale drains, 2 guide pipes for test hole drilling, and geomechanical instrumentation. Placement of the concrete and chemical seal material was identical to that performed in the waste shaft. Two additional sets of telltale drains were installed in the key by drilling after its construction. Each set contains nine drains. One set was installed above and one set below the initial eight-drain set.

The exhaust shaft is 15 feet in diameter from the bottom of the key to the facility level. For safety, the walls are covered with wire mesh anchored by rock bolts. Excavation of the shaft to its final dimensions was completed on January 17, 1985.

As in the waste shaft, water began seeping through the exhaust shaft liner at construction joints and small cracks. Total water inflow

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through the liner was measured at 0.35 gallons per minute in January 1985. A grouting program, using Portland cement and chemical grout, was conducted from June 1 through July 31, 1985, to seal these leaks and to ensure that the integrity of the shaft key was maintained. A total of 164 bags of Class C cement and 826.9 gallons of Terragel 5531 chemical grout were used. The total water inflow was reduced by this grouting to an essentially non-measureable quantity.

3.4.4 Drifts

The exploratory (C & SH) shaft station was the first underground horizontal opening excavated after completion of the SPDV exploratory and ventilation shafts. The initial shaft station excavation was performed from May 2 to June 3, 1982, using the drill and blast method. The station was trimmed to its final dimensions using the Dosco continuous mining machine discussed later in this subsection. The station area north of the shaft is 32 feet long, 32 to 35 feet wide and 12 feet high. South of the shaft, the station is 90 feet long and 32 to 38 feet wide. The height of the station south of the shaft is 18 feet for a distance of 54 feet and 14 feet for the remaining 36 feet. Cartridge water-gel explosives detonated by electric detonators were used for the drill and blast excavation. A detailed description of the SPDV exploratory shaft station excavation is presented in the WIPP Preliminary Design Validation Report (ref. 1-3).

Following the initial excavation of this station, the drill and blast method was used to excavate a drift southward to provide a connection between the two shafts so ventilation could be established. This drift was approximately 310 feet long, 18 feet wide and 9 feet high. Excavation of the drift was accomplished from June 3 to June 13, 1982.

The only other major use of the drill and blast method at the facility level was for construction of the loading pocket in the SPDV exploratory shaft. This pocket was constructed from June 1 through 30, 1982, on the north side of the shaft below the facility floor level.

It was later outfitted with a steel hopper and other equipment associated with the salt handling system.

The initial (SPDV) underground construction phase was conducted by Cementation West, Inc., of Tucson, Arizona. A British-made Dosco LH 1300, boom-type continuous mining machine was mobilized underground to the SPDV exploratory shaft station during late summer of 1982. This machine was used to excavate the remaining horizontal underground openings during the SPDV Program. The Dosco was capable of excavation rates of 1,000 to 1,200 tons per 24 hours (excavation was conducted on a three-shifts-per-day, seven-days-per-week basis). However, the excavation rate was often much less due to numerous construction and engineering related constraints. The mining machine was demobilized in May 1983 at the completion of the SPDV Program.

A second underground construction contract for full WIPP construction was awarded to Ohbayashi Corporation of South San Franicsco, California. During this phase of construction, two Japanese Mitsui Miike, boom-type continuous mining machines were used for excavation of the underground horizontal openings. Each of these machines excavated at a rate of 300 to 400 tons per 24 hours. These machines were mobilized to the underground facility in October 1983 and demobilized in April 1985.

A summary of the excavation sequence for the underground horizontal openings is presented on Figure 3-4. This figure shows the mining progress on a daily basis from October 14, 1982, through March 31, 1986. The underground mining operation was performed in the same manner during both construction phases regardless of the type of mining machine being used. The rotating head on the boom of the mining machine cut the salt away from the working face. The "muck" was pulled through the machine on a conveyor and deposited in one of several types of haul vehicles. Typically, the haul vehicles were underground trucks capable of carrying about 5 tons of muck. Other vehicles used included LHDs (Load-Haul-Dump, a type of front-end loader) and a telescoping-bed haul truck. The trucks carried the muck to the C & SH shaft station

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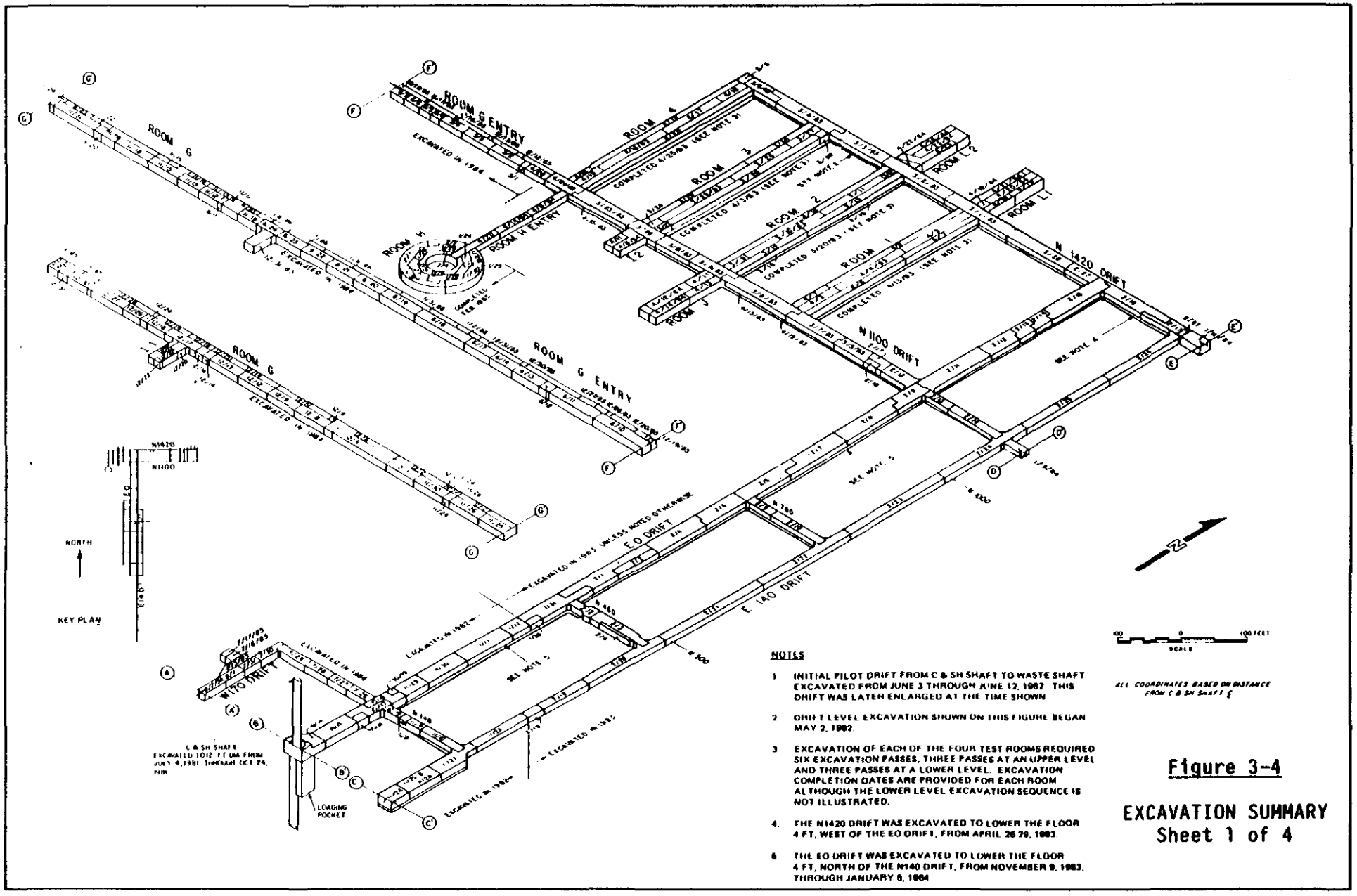

NOTES

1. INITIAL PILOT DRIFT FROM C & SH SHAFT TO WASTE SHAFT EXCAVATED FROM JUNE 3 THROUGH JUNE 12, 1982. THIS DRIFT WAS LATER ENLARGED AT THE TIME SHOWN.
2. DRIFT LEVEL EXCAVATION SHOWN ON THIS FIGURE BEGAN MAY 2, 1982.
3. EXCAVATION OF EACH OF THE FOUR TEST ROOMS REQUIRED SIX EXCAVATION PASSES, THREE PASSES AT AN UPPER LEVEL AND THREE PASSES AT A LOWER LEVEL. EXCAVATION COMPLETION DATES ARE PROVIDED FOR EACH ROOM ALTHOUGH THE LOWER LEVEL EXCAVATION SEQUENCE IS NOT ILLUSTRATED.
4. THE N1420 DRIFT WAS EXCAVATED TO LOWER THE FLOOR 4 FT, WEST OF THE E0 DRIFT, FROM APRIL 26-29, 1983.
5. THE E0 DRIFT WAS EXCAVATED TO LOWER THE FLOOR 4 FT, NORTH OF THE N140 DRIFT, FROM NOVEMBER 9, 1983, THROUGH JANUARY 8, 1984

Figure 3-4

EXCAVATION SUMMARY
Sheet 1 of 4

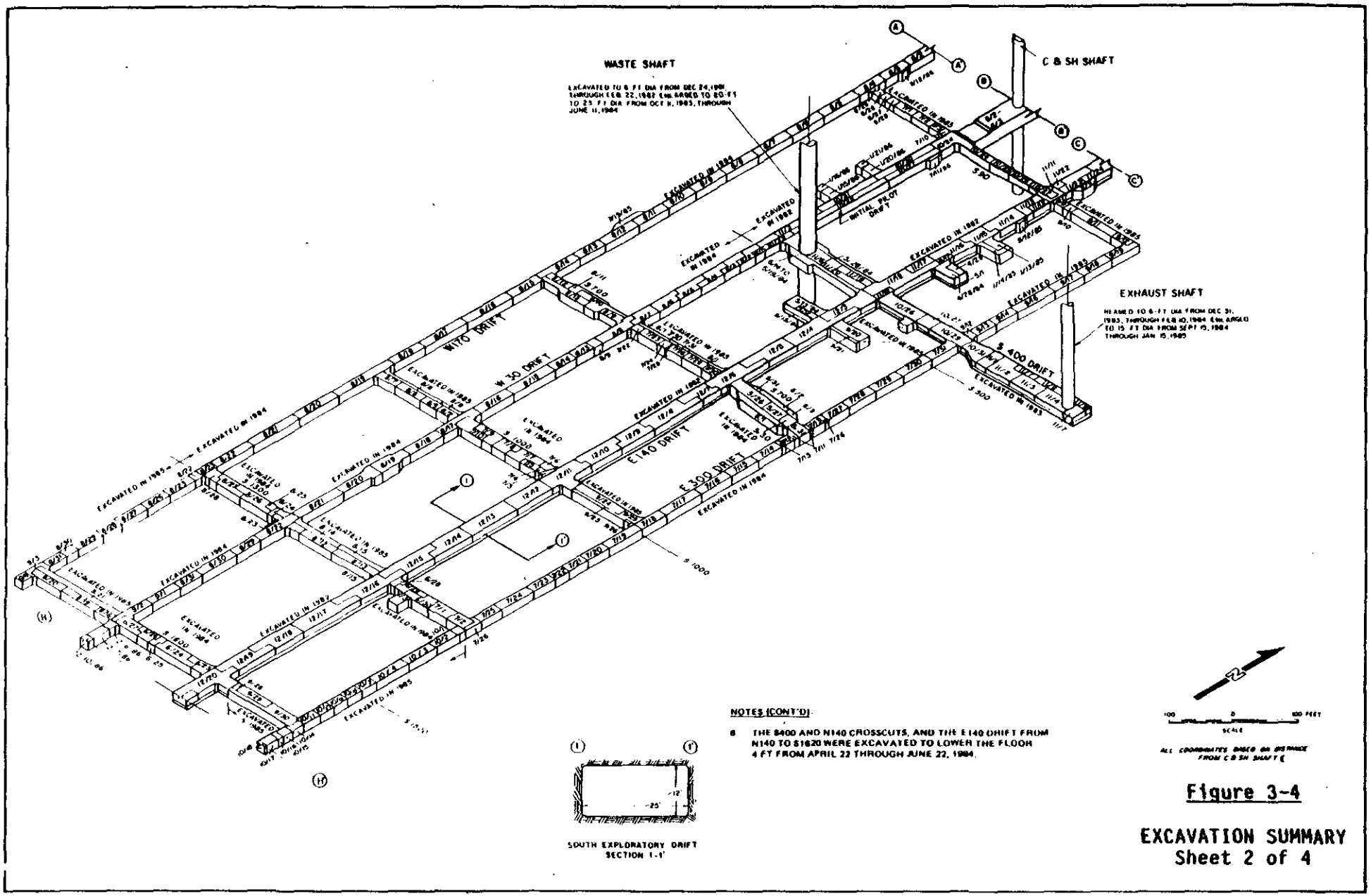

Figure 3-4

EXCAVATION SUMMARY
Sheet 2 of 4

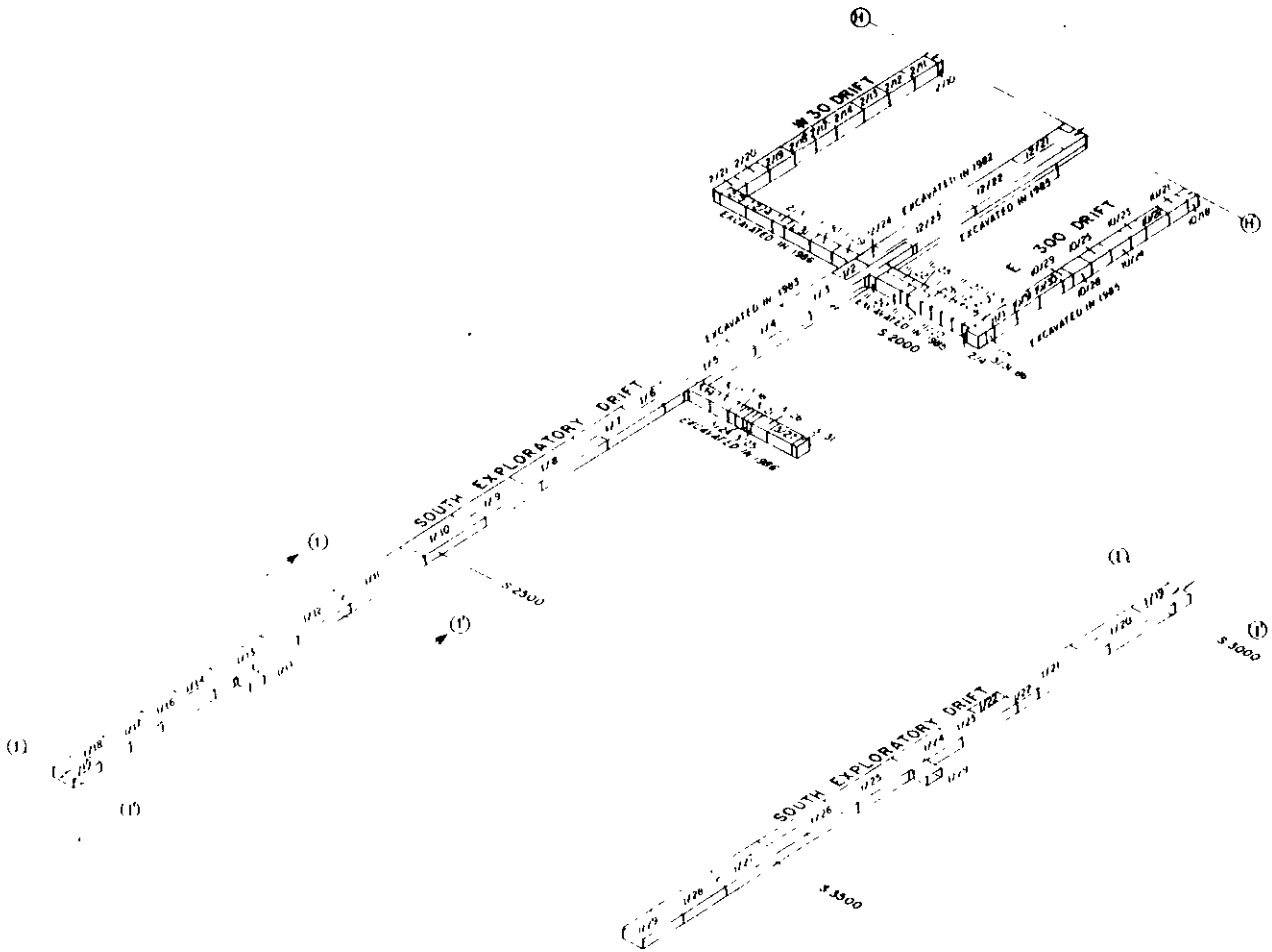

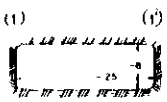

SOUTH EXPLORATORY DRIFT
SECTION I-I'

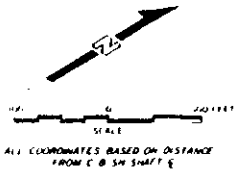

Figure 3-4

EXCAVATION SUMMARY
Sheet 3 of 4

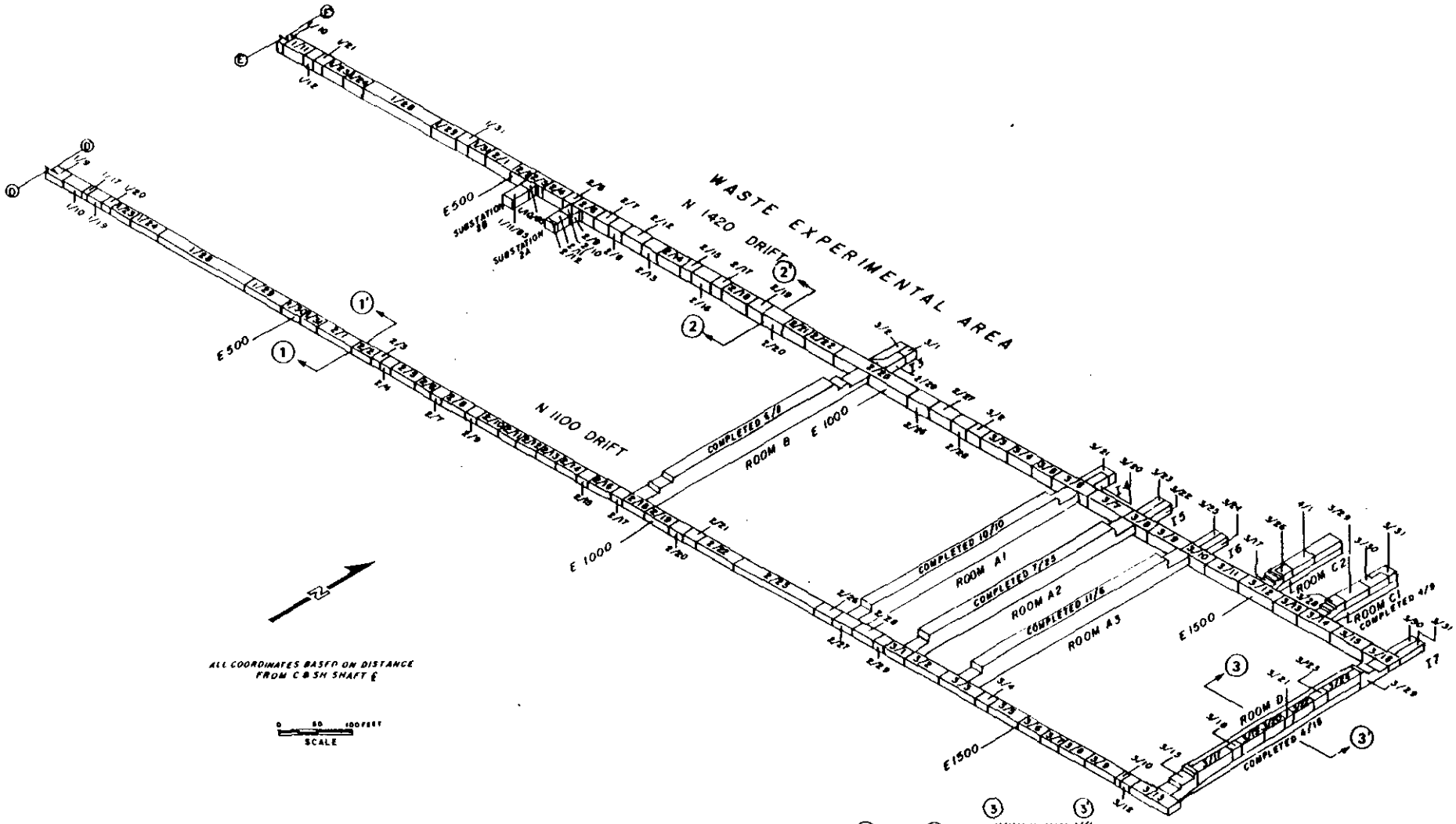

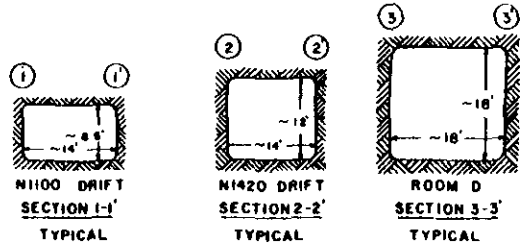

NOTES:

1. EXCAVATION SUMMARY FOR ROOMS A1, A2, A3, AND B ARE NOT PRESENTED
2. ALL EXCAVATIONS SHOWN ON THIS SHEET WERE MADE IN 1984, EXCEPT FOR SUBSTATION 2B

Figure 3-4

EXCAVATION SUMMARY
Sheet 4 of 4

and dumped it into the loading pocket. From there, the muck was carried to the surface in 7- to 8-ton loads in the skip. The skip dumped the muck at the surface into 50-ton Caterpillar or Euclid haul trucks which then carried the muck to the surface salt storage area.

During and immediately after excavation, a sounding survey of the roofs in the horizontal openings was made using a scaling bar to identify areas of drummy or slabby rock which could pose safety or stability problems. Remedial work was performed immediately after sounding in any areas identified as potentially unstable. This work consisted of hand-scaling thin drummy areas, removing larger drummy areas up to 18 inches thick with the mining machine, or rock bolting. In addition, two follow-up surveys were made of the roofs in all of the horizontal openings excavated at the time of the survey. The first survey was completed in July 1983 and the second in November 1984. Remedial work was performed on problem areas identified during these surveys. This work consisted of scaling, excavation, or rock bolting. It should be noted that the drummy areas identified during the July 1983 survey were sounded again in the November 1984 survey and did not show any noticeable enlargement.

Rock bolts are used selectively throughout the underground drifts for both remedial work and safety. The roofs of many high-traffic personnel areas are pattern bolted and covered with wire mesh as an additional safety precaution.

The C & SH shaft station has presented the majority of problems associated with roof stability. Due to its initial excavation by the drill and blast method, and the proximity of overlying clay seams, the roof in the station has required support by a large number of rock bolts. The method of rock bolting has evolved through several phases due to the effect of salt creep on roof separation along the clay seams.

Rock bolts were initially installed in the C & SH shaft station roof

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from May 9 to June 20, 1982. These bolts were 1 inch in diameter, 8, 10 or 12 feet in length, and made of grade 60 steel. They were anchored using resin cartridges.

These resin-anchor bolts began failing at the head assemblies shortly after their installation was completed. The failed bolts were replaced with 8-foot long, 5/8-inch diameter mechanical-anchor bolts with 2 x 12 x 12-inch wooden blocks installed between the steel head assembly plate and the salt. A total of over 400 resin-anchor and mechanical-anchor bolts were installed in the shaft station roof through April 1983.

During December 1983 and January 1984, 146 additional mechanical-anchor bolts, 5/8 inch in diameter and 8 feet long, were installed in the C & SH shaft station roof. In May 1984, another 91 similar anchor bolts were installed. After the mechanical-anchor bolts were installed, the nut and head assembly plate were cut off those older resin-anchor bolts showing evidence of excessive deformation. This was to prevent injury to personnel from falling nuts and plates should these resin-anchor bolts fail.

From mid-April through early August 1985, approximately 133 3/4-inch diameter mechanical-anchor bolts, 6 and 8 feet long, were installed in the station roof on approximately 3 1/2-foot centers. In addition, 245 resin-anchor bolts, 1 inch in diameter, were anchored above anhydrite "b" and across anhydrite "a". These bolts were 12 and 14 feet in length. The entire station roof was covered at this time with wire mesh secured with 2-foot long, 5/8-inch diameter mechanical-anchor bolts. Approximately 750 of the 2-foot long bolts were installed.

Although some resin-anchor bolts were used in the SPDV drifts and test rooms excavated in 1982 and 1983, mechanical-anchor bolts have been used in all subsequently excavated areas. Bolt lengths vary from 2 to 8 feet in the drifts and rooms. Wire mesh secured by 2-foot long mechanical-anchor bolts has been installed on the roofs of all high-traffic personnel areas. This includes instrument-shed and

electrical alcoves, many of the shop areas, and some of the brows above the entries to the waste experimental rooms. Rock bolts and wire mesh have also been installed in the roof of the N140 crosscut.

Rock bolts and wire mesh have been installed for roof support in the waste shaft station waste transfer area. The bolts, 3/4 inch in diameter and 12 feet long, are mechanical-anchor steel bolts set on nominal 4-foot centers.

3.4.5 Test Rooms

As part of the SPDV Program, four test rooms were excavated at the north end of the underground facility (Figure 3-4) by Cementation West, Inc., using the Dosco mining machine. The test room excavation was conducted from March 9 to April 25, 1983. Test Room 2 was excavated first, followed by Test Rooms 3, 1 and 4, in that order. Each room was excavated in a series of six passes along its longitudual axis (Figure 3-5). The first pass was the largest in cross section and was conducted down the center of the planned room along its roof. This pass was approximately 15 feet wide and 8 feet high. The second and third passes were conducted on either side of the first pass. Each of these passes were about 9 feet wide and 8 feet high. The last three passes lowered the floor 5 feet to complete the room excavation to its design height and width of 13 x 33 feet.

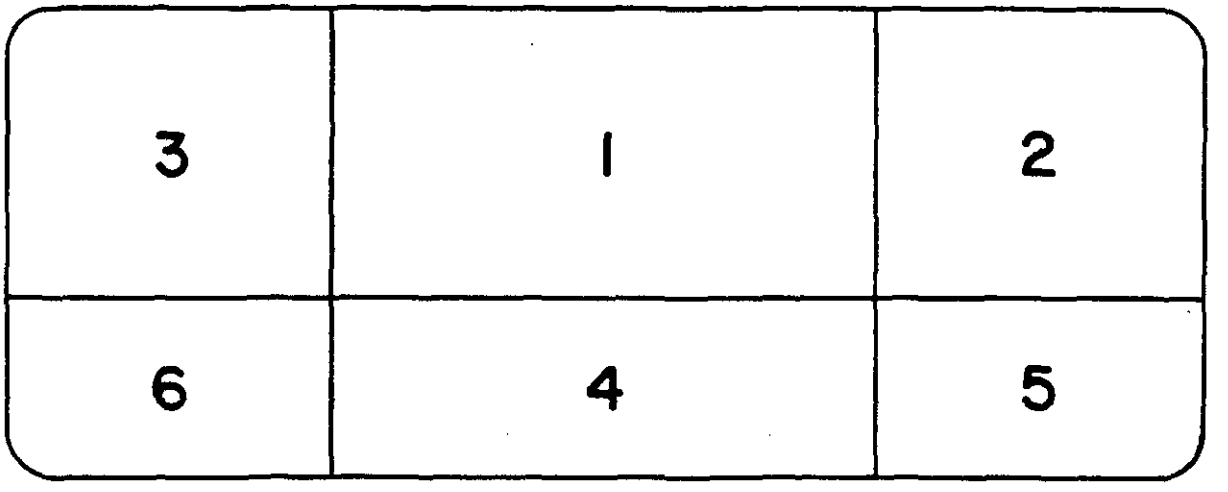

Figure 3-5

TEST ROOM EXCAVATION SEQUENCE

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CHAPTER 4

SUPPORTING VALIDATION DOCUMENTS

4.1 INTRODUCTION

This chapter discusses the principle documents containing information used to support design validation. These documents are the Waste Isolation Pilot Plant Preliminary Design Validation Report (ref. 1-3) and geotechnical field data reports (refs. 4-1 thru 4-19). These documents contain all of the data which has been collected, analyzed and evaluated for design validation since site construction activities began in July 1981. Other documents pertaining to design and site characterization are referenced throughout this report. However, they are considered peripheral documents not directly related to the design validation process and, therefore, are not described in this report. Because these other reports are public documents, they are available to anyone interested in obtaining additional background information or detailed data on the WIPP project.

4.2 PRELIMINARY DESIGN VALIDATION REPORT

The following subsections present a summary of the WIPP Preliminary Design Validation Report produced for the SPDV Program described in Chapter 1.

4.2.1 Purpose and Objectives

The purpose of the WIPP Preliminary Design Validation Report was to provide documentation on the behavior of the initial underground openings. Four types of information were gathered for this purpose:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during SPDV underground construction;

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(3) descriptions of core samples from instrumentation and exploratory holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

The objective of the report was to provide initial evaluations of the suitability of the design criteria and design bases and initial confirmation of the underground opening reference design in order to permit full facility construction. This initial confirmation was based on data obtained from geologic field activities and geomechanical instrumentation which were subjected to preliminary analysis and evaluation.

4.2.2 Data Acquisition Program

The preliminary design validation data acquisition program consisted of geologic field activities which provided information for initial validation of the WIPP underground opening reference design. Data was obtained from three principal activities:

(1) geologic mapping;

(2) vertical core hole logging; and

(3) geomechanical instrument measurements.

All of the data collected was verified at the site field office, then sent to the DOE/Technical Support Contractor (TSC) offices in Albuquerque, New Mexico, for preparation and inclusion into the GFDRs and other reports. Due to the qualitative nature of the geologic mapping and core hole data, efforts for preparation of this material generally required only limited evaluation, editing and drafting. The geomechanical instrumentation data, however, required more extensive preparation and analysis due to its applications to various aspects of underground opening behavior and the calculation of in situ salt properties.

4.2.3 Geomechanical Instrumentation

The SPDV geomechanical instrumentation program for the WIPP was designed to provide empirical data on the behavior of the salt around the underground openings and on the pressure developed behind the exploratory shaft liner and key by ground water and salt creep. The objective of the geomechanical instrumentation program for SPDV was to provide:

(1) short-term in situ measurements for assessment of the preliminary design performance of the underground openings;

(2) early detection of conditions that could affect the safety of personnel during construction; and

(3) data on adverse ground conditions that may be developing, in order to identify potential problems and plan and implement remedial measures.

Instruments were initially installed in the SPDV exploratory shaft, exploratory shaft station, ventilation shaft station, the E0, E140 and N1100 drifts, and the S90 crosscut to provide data input for the WIPP Preliminary Design Validation Report. The exploratory drift extending south of the ventilation shaft was added to the SPDV Program to provide additional information on the geology in the area proposed for excavation of the waste storage rooms. Geomechanical instruments were installed at several locations in this drift.

For the WIPP Preliminary Design Validation Report, borehole extensometer and convergence point data from the SPDV exploratory shaft, as well as data from the ventilation shaft station and drifts, were insufficient to estimate long-term closure rates. Most drift extensometers and convergence points had been installed only a relatively short time before the report was prepared. A period of 1 year or more was thought to be required before a relatively steady closure rate could be established. The data were useful in

demonstrating short-term stability of the excavations and for developing cumulative closure amounts. Instruments with the most extensive data typically showed a maximum of only 3 or 4 months of regular monitoring since installation.

4.2.4 Preliminary Conclusions

Preliminary conclusions presented in the WIPP Preliminary Design Validation Report were:

(1) The walls of the finished shafts are stable, both in the overburden and salt formations. The mapped shaft stratigraphy is generally comparable to the stratigraphy used in the design. Ground-water control is satisfactory. The shaft liner and shaft key are performing as expected. No major revision of design elements or parameters is foreseen for future WIPP shafts as a result of the findings of preliminary design validation.

(2) The underground horizontal openings are also stable. After excavation, repeated inspections of the exploratory and ventilation shaft stations, entry drifts, crosscuts and the south exploratory drift revealed essentially no deterioration in rock stability. The underground drifts and shaft stations are stable and provide safe working conditions.

(3) Encounters of gas were expected and are typical of nearby potash mines. The small amount of gas encountered is well below the limit permitted in the underground facility by MSHA regulations. No brine pockets have been encountered or detected during excavation of the shafts and underground openings.

4.3 GEOTECHNICAL FIELD DATA REPORTS

4.3.1 Background

The compilation of GFDRs was initiated by the DOE to provide geotechnical and related information from the WIPP underground activities to interested persons or groups in a timely manner. These reports provided data from the two major phases of WIPP development: SPDV and full construction. As discussed previously, SPDV was established as an early construction phase to permit validation of the WIPP site and preliminary validation of the reference design of the underground openings. The full construction phase following SPDV was utilized to continue visual inspections of the underground openings, monitoring and interpretation of data from geomechanical instruments, and evaluations and computational analyses of the behavior of the underground openings for design validation.

The GFDRs were eventually produced on a quarterly basis. These quarterly reports contain an evaluation of selected aspects of the WIPP underground environment based on preliminary interpretation and analyses of data collected from the above activities. The analyses and evaluations contained in the GFDRs provide the supporting documentation required for design validation.

4.3.2 Objectives

As stated in the GFDRs, the geomechanical instrumentation program for SPDV and design validation was designed and implemented to provide in situ data on the behavior of the rock (primarily salt) around the shafts and horizontal underground openings. More specifically, the instrumentation program was designed to provide:

(1) early detection of conditions that could affect operational safety;

(2) monitoring of closure rates to allow evaluation of waste storage and retrievability;

(3) a greater understanding of the in situ behavior of bedded salt by comparison of observed response with current facility reference design calculations; and

(4) measurements of salt deformation and stresses to confirm or indicate the necessity for revisions to the opening configuration and the parameters used in underground facility design based on clearance requirements.

4.3.3 Geomechanical Instrumentation

An extensive geomechanical instrumentation program was implemented to provide in situ data on the shafts and horizontal underground openings as part of the investigations performed at the WIPP site. These instruments have been providing data on deformation, pressure, loads and stress on a regular basis for analysis and evaluation. Instruments for measuring the geomechanical response of the shafts and horizontal underground openings include convergence points, convergence meters, multiple-point and single-point borehole extensometers, load cells, pressure cells, stressmeters, strain gauges, inclinometers, piezometers and lateral movement gauges.

Data from these geomechanical instruments are read remotely by an automatic datalogger system and/or collected manually. All data obtained are entered on magnetic tape for data reduction, tabulation, analysis and archiving. Data collected from the geomechanical instruments have been documented in the GFDRs. These data are the basis for analysis and evaluation by the project participants and other interested groups. The geomechanical instruments provide data for the analysis and evaluation of several phenomena at various locations, including strain in the C & SH shaft key, water pressure behind the C & SH and waste shaft liners, radial closure of shafts, pressures between shaft keys and wall rock, roof-to-floor and wall-to-wall closure in the shaft stations, drifts and rooms, and displacements at depth into the walls, roof and floor of shaft stations, drifts and rooms.

The frequency of data collection is determined on a per instrument basis and is dependent upon instrument location, method of instrument reading (manual or datalogger), and the number of days elapsed since excavation at the instrument location. After installation, the instrument is read frequently, but with time this reading frequency is decreased since the rate at which the salt mass responds following excavation also decreases with time.

The geomechanical instrumentation data are presented graphically in the GFDRs and represent readings collected from the WIPP site since April 1982. The data plots in the reports are grouped by areas within the underground facility and also by instrument type. The data plots are updated as new data become available. Summary tables of the instruments, with the latest readings and the operating histories, are also presented in the reports.

4.3.4 Geologic Data

Geologic data presented in the GFDRs have included the results of geologic mapping activities, core hole logging, and observations of the condition and behavior of underground opening surfaces. Geologic maps of the shafts and representative horizontal opening surfaces have been presented periodically in the GFDRs or in topical reports issued separately. Geologic logs containing descriptions of core samples obtained from core holes in the underground openings were presented in the GFDRs as they became available.

Frequent observations by project geotechnical personnel have provided qualitative determinations of the condition of the underground openings. These assessments were presented in the GFDRs to document changes in the condition of the underground openings and in salt behavior on a regular basis. Observations such as the condition of the roof and rock bolts in shaft stations, fractures in pillar corners at drift intersections and in the salt surrounding the drifts and rooms, behavior of the roof and walls of the drifts and rooms, and horizontal displacements, vertical separations and fracturing detected in open

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boreholes were documented. This information has provided important input for design evaluation and safety assessments.

4.3.5 Geomechanical/Structural Analyses

The quarterly GFDRs contain sections on both geotechnical and computational analyses. These sections present analyses of various elements of the underground excavations. The analyses are updated periodically to include the most current data available at the time the reports are published. They have provided a significant amount of information related to the geomechanical and structural behavior of the underground openings.

CHAPTER 5
METHODOLOGY

5.1 INTRODUCTION

Design validation of the WIPP underground openings is accomplished by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. Design validation also allows for the development of recommendations to improve or optimize the reference design. The methods used to validate the reference design may also be used to validate any recommended design modifications. Mathematical models containing the modifications can be generated and analyses performed to predict the future behavior of the modified reference design.

The design validation process consists of three major steps:

(1) data collection;

(2) analysis and evaluation; and

(3) prediction of future behavior.

Sections 5.2 through 5.4 present the methods used for data collection, analysis and evaluation, and prediction of future behavior.

5.2 DATA COLLECTION

One of the principal areas of effort in support of design validation was the compilation of geotechnical data. This data formed the basis for later analysis and evaluation and for predictive modeling. Data collected from geologic mapping, core drilling and logging, laboratory testing, geomechanical instrumentation and field observations have provided information for validation of the underground opening reference design. These data can be categorized based on their relationship to observations of geologic conditions or to structural behavior. Geologic observations include an assessment of the rock

characteristics; stability of the openings in rock; reaction of the rock to excavation; and movements along clay seams. Structural behavior is the development or modification of stresses and strains in the salt created by excavation of the underground openings, and the pressures occurring at rock/structure interfaces.

5.2.1 Geologic Mapping

Geologic mapping of the shafts, drifts and test rooms was conducted by site geologists. The objectives of the mapping were:

(1) provide confirmation and documentation of the continuity of the stratigraphy, lithology and structure above and below the facility horizon;

(2) evaluate any geologic conditions which may affect the excavation, stability, or safety of the horizontal openings;

(3) support field adjustments and modifications to the reference design based on the geologic conditions encountered; and

(4) finalize geomechanical instrument locations.

5.2.2 Core Drilling and Logging

Information on stratigraphy and lithology was obtained from core holes drilled into the floor and roof of the underground openings. The objectives of the core drilling program were:

(1) confirm the thickness, lateral extent, mineralogy and stratigraphic continuity of the host rock beyond the limits of the excavations;

(2) confirm the continuity of the geologic structure and the absence of any unusual features within the immediate zone of influence of the excavations; and

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(3) obtain stratigraphic information in order to determine extensometer anchor depths.

Details of the core drilling program are discussed in Chapter 6.

5.2.3 Laboratory Testing

Initial laboratory tests were performed on core samples of evaporite minerals and clay from exploratory boreholes AEC-7 and ERDA-9. These tests were performed by RE/SPEC, Inc., of Rapid City, South Dakota, and by SNL (refs. 5-1 and 5-2). The evaporite samples were tested in triaxial vessels at both room and elevated temperatures. Quasi-static compression tests were performed under different constant confining pressures and variable axial loads in steps, each load step being maintained for about 10 minutes. Quasi-static compression tests were considered as constant stress-rate tests for all practical purposes. Direct shear tests were performed on samples of clay to determine the coefficient of sliding friction.

5.2.4 Geomechanical Instrumentation

Geomechanical instruments in the WIPP underground facility provide data on deformation, pressure, loads and stress. Instruments for measuring the geomechanical response of the shafts and other underground openings include convergence points, convergence meters, multiple-point and single-point borehole extensometers, load cells, pressure cells, stressmeters, strain gauges, inclinometers, piezometers and lateral movement gauges. Data from the geomechanical instruments are collected manually as well as read remotely by an automatic datalogger system at the surface. All data are entered on magnetic tape for data reduction, tabulation, analysis and archiving. These data are a basis for the analysis and evaluation of underground opening behavior.

The geomechanical instrumentation program for design validation was designed and implemented to provide in situ data on the behavior of the

rock (primarily salt) around the shafts and underground openings. More specifically, the instrumentation program was designed to provide:

(1) early detection of conditions that could affect construction and operational safety;

(2) closure monitoring for evaluation of the ability of the underground openings to permit waste storage and retrieval;

(3) a greater understanding of the in situ behavior of bedded salt by a comparison of the observed responses with underground opening reference design calculations; and

(4) measurements of salt deformation to permit confirmation or revision of the opening configurations and the parameters used in the underground opening reference design based on clearance requirements.

Tables 5-1 through 5-5 present information on the distribution of geomechanical instruments installed at the WIPP. The instruments provide data for the evaluation and analyses of several phenomena at various locations, including strain in the C & SH shaft key, water pressure behind the C & SH and waste shaft liners, radial closure of the shafts, pressures between the concrete shaft keys and wall rock, roof-to-floor and wall-to-wall closure in the shaft stations, drifts and rooms, and displacements at depth into the walls, roof and floor of shaft stations, drifts and rooms.

Data from the geomechanical instruments are collected manually or read remotely by an automatic datalogger system. The datalogger is a computer system that automatically collects and records output from instruments at specified polling times. The signals from the instruments are first sent to local termination cabinets (LTC) where the signal is digitized and then transmitted to the datalogger for disk storage. Manual readings are manually entered into the computer system. Changes from initial readings and rates of change are

Table 5-1

C & SH SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Convergence points	Measure wall-to-wall closure of shaft
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Welded strain gauge	Measures strain in reinforcing steel of shaft key
Embedment strain gauge	Measures strain in concrete of shaft key
Unlined Section	
Multiple-point extensometer	Measures salt creep deformation
Convergence points	Measure wall-to-wall closure of shaft
Station	
Convergence points (includes permanent and temporary convergence points and wall shortening points)	Measure roof-to-floor and wall-to-wall closure of openings and pillar shortening
Extensometer (single-point and multiple-point)	Measures salt creep deformation in roof, floor and walls
Rock bolt load cell	Measures tensile loads on rock bolts
Lateral movement gauge	Measures lateral movement in roof

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Table 5-2

WASTE SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Unlined Section	
Convergence points	Measure wall-to-wall closure of shaft
Multiple-point extensometer	Measures salt creep deformation
Station	
Convergence points (includes permanent and temporary points)	Measure roof-to-floor and wall-to-wall closure of openings
Multiple-point extensometer	Measures salt creep deformation in roof, floor and walls

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Table 5-3

EXHAUST SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Unlined Section	
Multiple-point extensometer	Measures salt creep deformation

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Table 5-4

DRIFTS
INSTRUMENTS

Location and Type	Purpose
Convergence points (includes permanent and temporary convergence points and wall shortening points)	Measure roof-to-floor and wall-to-wall closure of openings and pillar shortening
Extensometer (single- and multiple-point)	Measures salt creep deformation in roof, floor and walls of openings

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Table 5-5

TEST ROOMS
INSTRUMENTS

Location and Type	Purpose
Convergence points	Measure roof-to-floor and wall-to-wall closure
Multiple-point extensometer	Measures salt creep deformation in roof, floor and walls
Inclinometer	Measures direction and amount of salt movement above the roof, below the floor, and in the walls
Rigid-inclusion stressmeter	Monitors changes in stress within anhydrite
Convergence meter	Measures vertical closure

calculated and stored in the computer. The data is transferred monthly to magnetic tapes which are made available to project participants.

Instruments connected to the datalogger include extensometers, piezometers, strain gauges, pressure cells, convergence meters and stressmeters. All convergence points, inclinometers, rock bolt load cells, lateral movement gauges and some extensometers must be read manually. Strain gauges, piezometers and pressure cells have been read manually at times.

The frequency of data collection is determined on a per instrument basis and is dependent upon instrument location, method of instrument reading (manual or datalogger). and the number of days elapsed since excavation at the instrument location. After installation the instrument is read frequently, but with time this reading frequency is decreased since the rate at which the salt mass responds following excavation also decreases with time.

The frequency of readings has been influenced by access limitations caused by construction operations and by the volume of data to be collected. At a few convergence point stations in newly excavated areas, readings were taken frequently to record the early rock response. Monitoring periods in these instances were typically every 4 to 12 hours for 24 hours, then once daily. Most manually read instruments were initially read weekly, then once every 2 weeks, and then once every month. Instruments connected to the datalogger were initially read at 24-hour intervals, then several times per week, and then once every 2 weeks. The current schedule for obtaining readings is shown in Table 5-6. Each instrument's range, sensitivity, resolution and precision are also presented in this table. These parameters are important when interpreting and evaluating the data, especially those readings which reflect changes that are close to the resolution, sensitivity, or precision limits of the instrument.

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Table 5-6

GEOMECHANICAL INSTRUMENTATION SPECIFICATION SUMMARY

Location	Instrument Type	Phenomenon Monitored	Parameters to be Evaluated	Scheduled Frequency of Readings as of this Report	Instrument Specifications: Range (R), Sensitivity (S) Resolution (E), Precision (P)
C&SH shaft	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
C&SH shaft key	Strain gauges	Strain	ΣStrain*	As accessible (M)	(R): 0-3000 μin./in.-embedded (R): 0-2500 μin./in.-spot welded (S): 1 μin./in.
C&SH shaft key	Pressure cells	Pressure	ΣPressure*	As accessible (M)	(R): 0-1000 psi (S): 1 psi
C&SH shaft liner & key	Piezometers	Water pressure	ΣPressure*	Monthly (M)	(R): 0-500 psig (E): ±0.5 psi
C&SH shaft	Convergence points	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	As accessible (M)	(R): 2-50 ft (P): ±0.005 in.
Waste shaft	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	As accessible (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Waste shaft Key	Pressure cells	Pressure	ΣPressure*	Weekly (D)	(R): 0-1000 psi (S): 1 psi
Waste shaft liner & key	Piezometers	Water Pressure	ΣPressure*	Weekly (D)	(R): 0-500 psig (E): ±0.5 psi
Waste shaft	Convergence points	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	As accessible (M)	(R): 2-50 ft (P): ±0.005 in.
Exhaust shaft	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Exhaust shaft liner & key	Piezometers	Water pressure	ΣPressure*	Monthly (M)	(R): 0-500 psig (E): ±0.5 psi
Exhaust shaft key	Pressure cells	Pressure	ΣPressure*	As accessible (M)	(R): 0-1000 psi (S): 1 psi
Drifts	Rockbolt load cells	Load	ΣLoad*, $\frac{\Delta p}{\Delta t}$**	Monthly (M)	(R): 0-300 kips (S): 16 lb
Drifts	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Weekly (D)/ Monthly (M)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Drifts	Convergence points	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Monthly to every 2 months (M)(1)	(R): 2-50 ft (P): ±0.005 in.
Drifts	Lateral movement gauges	Deformation	$\Sigma\delta$	No longer read	(R): 0-5 in. (E): 1/64 in. (P): ±1/64 in.
Test rooms	Vertical inclinometers	θ_x, θ_y	$\Sigma\delta_x$*, $\Sigma\delta y$*, $\Sigma\delta_{xy}$*, Azimuth*, $\frac{\Delta\Sigma w_x}{\Delta t}$, $\frac{\Delta\Sigma w_y}{\Delta t}$, $\frac{\Delta\Sigma\delta_{xy}}{\Delta t}$	Every 2 months (M)	(R): 0-30° (P): ±0.3 in./100 ft of casing (E): ±0.001 in./2 ft of casing (S): ±0.001 ft/2 ft of casing
Test rooms	Horizontal inclinometers	θ_z	$\Sigma\delta w_z$*, $\frac{\Delta\Sigma w_z}{\Delta t}$	Every 2 months (M)	(R): 0-30° (P): ±0.3 in./100 ft of casing (E): ±0.001 in./2 ft of casing (S): ±0.001 ft/2 ft of casing
Test rooms	Vibrating wire stressmeters	Stress	ΣS*, $\frac{\Delta S}{\Delta t}$*	Weekly (D, M)	(R): 12,000-44,000 psi wire stress
Test rooms	Convergence meters	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Weekly (D)	(R): Approximately 2.5 ft (S): ±0.001 in.
Test rooms	Convergence points	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Monthly (M)	(R): 2-50 ft (P): 0.005 in.
Test rooms	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$*	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.

Notes:

(D) = read through datalogger
(M) = read manually
$\Sigma\delta$ = total change from t = 0
θ = angle
ΔL = change from last reading
Δt = elapsed time since last reading

(1) New convergence points are read weekly for the first month after installation.
*Design/validation parameter
**Safety/operational parameter

5.2.5 Field Observations

The determination of underground conditions includes a qualitative assessment based on frequent observations by WIPP site geotechnical personnel. Changes in rock conditions and in the behavior of the underground openings have been observed and documented on a regular basis in the GFDRs. In addition, quarterly inspections have been made by Bechtel home office design engineering personnel. These inspections augmented the site geologists' observations and helped highlight those changes which occurred so slowly that they were difficult to detect on a daily basis.

Periodic inspections of the C & SH shaft have been made since the shaft was completed. Conditions of the shaft walls, liner and key have been observed in addition to any water flow into the shaft. Similar inspections of the waste and exhaust shafts have also been made but less frequently due to limited accessibility.

Observations of the horizontal openings include such items as the condition of their roofs and walls; fracturing in pillar corners at drift and room intersections and in roofs and floors; and horizontal displacements and vertical separations measured in open boreholes. This information has provided important input for design and safety evaluations.

5.3 ANALYSIS AND EVALUATION

Data collected at the WIPP site have been analyzed and evaluated by qualified engineers and scientists. Engineering experience and judgement were used in the evaluation of field observed conditions. Laboratory tests were performed on core samples to determine the constitutive equations for the host rocks. Theoretical and applied aspects of measurements, statistics and physics were utilized to analyze and evaluate geomechanical instrument data.

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5.3.1 Observations

The observations of geologic conditions documented during visual inspections are used to evaluate the performance of the underground openings. These evaluations are made in conjunction with the analytical techniques. The evaluations are qualitative, however, and are subjective assessments of the behavior of the salt surrounding the excavations.

5.3.2 Laboratory Tests

The results of the laboratory testing described in subsection 5.2.3 on samples of halite, argillaceous halite, anhydrite, polyhalite and clay from the facility level were evaluated and statistically analyzed to determine elastic and creep constants. Constitutive equations for each of these materials were established and their material property constants were determined (ref. 5-3). The material property constants based on the laboratory test results are presented in Chapter 6.

5.3.3 In Situ Measurements

Statistical and numerical methods were used to analyze in situ data and to evaluate the physical behavior of salt. Numerical models were used to compute creep parameters from the in situ data.

In situ measurement data from selected geomechanical instruments in the drifts and test rooms were fitted with analytical equations using regression procedures. Since early data are lacking for most of the instruments, one approach was to calculate the closure rates and fit an equation to the closure rate versus elapsed time relationship. An estimate of the early closure not measured by the instruments was independently derived.

5.4 PREDICTION OF FUTURE BEHAVIOR

Validation of the underground opening reference design requires predicting the future behavior of the openings. This was achieved by collecting in situ data consisting of field observations and

geomechanical instrument measurements. Statistical methods were then used to extrapolate the data obtained from the geomechanical instruments. Selected in situ data were fitted to analytical curves and predictions were made based on the extrapolated results. Closed form solutions and engineering experience were also utilized to substantiate the adequacy of the facility. A model simulation method was used to verify the creep model of salt based on creep constants derived from data obtained from laboratory material tests. After the determination of creep parameters using a statistical technique, the numerical model for simulating the facility was also utilized to predict and evaluate future behavior. This includes the closures, strain distributions and stress distributions over the operating life of the facility.

Design reviews were performed as required during design of the WIPP underground facility. Experience and judgment were an important adjunct in predicting the future behavior of the underground openings. More than 3 years of continuous data collection and analysis and evaluation have provided an adequate data base for predicting future behavior.

Subsections 5.4.1 through 5.4.3 describe the methods used for predicting the future behavior of the underground openings.

5.4.1 Extrapolation of In Situ Data

Selected in situ closure data were analyzed and fitted by analytical curves for extrapolation of future responses. Regression analyses by the Gauss-Newton or Marquardt compromise techniques were performed to determine the regression parameters. These regression parameters were assumed to be valid for the future behavior of the opening, and the equations were used to predict the future closure rate. To estimate the additional closure that could occur, the equation was integrated over the required time interval.

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5.4.2 Closed Form Solutions

Closed form solutions provided in the SME Mining Engineering Handbook (ref. 2-25) were used to evaluate the selected room and pillar sizes and their stability. Closed form solutions for steel and concrete structural design were also used to substantiate the adequacy of the shaft liners and keys (refs. 5-4 thru 5-7).

5.4.3 Model Simulations

Numerical analyses were performed to compute the predicted responses of the underground openings. The constitutive laws discussed in Appendix C were used in these analyses. However, yield or failure criteria developed for halite and non-halitic materials based on the results of laboratory tests were not incorporated in the numerical modeling. Due to the idealization of the real system in a mathematical model, the uncertainty of in situ auxiliary conditions corresponding to the mathematical model, and deviations in the material properties obtained from the laboratory tests, analyses using laboratory test data did not provide suitable results for design validation. Therefore, an engineering approach using curve fitting methods was employed. Creep parameters computed by the following procedure were used for the analyses. Additional information pertaining to material property deviations based on laboratory tests is presented in Chapter 6.

Numerical models were generated for the locations of specific instruments to simulate the instrument response and compute the creep parameters.

After generating the numerical models for these locations, their creep parameters were computed and the structural behavior was simulated by performing an analysis using the statistical method presented in Appendix C and the following procedures:

(1) At the initial stage, the surface of the openings were restrained to simulate the unexcavated condition.

(2) An internal stress was applied at each element to represent the initial lithostatic stress state, which is defined as:

$$\delta_{xx} = \delta_{yy} = \delta_{zz} = -\int_0^y pgdy \qquad (5\text{-}1)$$

where: p is the rock mass per unit volume;
g is the gravitational constant; and
y is the depth.

(3) The overburden and support pressures at the boundaries and the weight of the rock were applied to compute the static solution.

(4) The restraints at the surface of the openings were then removed to simulate the excavation.

(5) The structural responses were computed using a time step integration scheme. Normalized time steps were used throughout the analysis. At the first time step, the time increment was calculated by an iterative scheme using a predetermined initial time increment.

(6) In subsequent time steps, the time increment for each time step was calculated based upon the previous time steps and the specified maximum tolerances of stress and strain increments at the previous and current time steps. The structural responses were computed at each normalized time step.

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CHAPTER 6
GEOLOGIC CHARACTERIZATION

6.1 INTRODUCTION

Geologic characterization of the underground excavations for design validation of the WIPP began in June 1981. Initial characterization activities consisted of monitoring the drilling and geophysical logging of the SPDV exploratory shaft. As shaft outfitting and underground excavation progressed, the geologic work evolved into mapping of the shafts and underground horizontal openings, performing ground-water inflow tests, monitoring geomechanical instrumentation installations and taking subsequent readings or measurements, logging underground core hole samples, and performing other tasks related to defining the geologic integrity of the WIPP site. Data from these activities were evaluated in conjunction with information from previous site studies to more accurately define site geologic conditions as they related to design validation of the WIPP underground facility.

6.2 DATA COLLECTION ACTIVITIES

6.2.1 Geologic Mapping

An important aspect of validating the WIPP underground opening reference design included geologic mapping of the shafts and drifts. The objectives of this mapping were discussed in Chapter 5.

6.2.1.1 C & SH Shaft

Geologic characterization of the C & SH shaft began in late June 1981 with the drilling of the SPDV exploratory shaft (see Chapter 3, subsection 3.3.1, for an explanation of the two shaft names). The initial activity conducted to develop this characterization consisted of logging the drill cuttings at periodic intervals to permit a determination of rock types and to provide a description of the geologic formations penetrated (Appendix D, Figure D-1). These formations included, in descending order, the Dewey Lake red beds, the Rustler formation and the Salado formation.

After completion of the drilling operation, geophysical logging was performed in the shaft to determine the condition of the shaft wall and to more accurately define the stratigraphy penetrated. These logs were the caliper, gamma ray, density and epithermal neutron. The logs were analyzed to better determine the depths to various stratigraphic horizons and correlate them with those found in holes drilled during previous site investigation phases (Appendix B, Figure B-1).

Reconnaissance and detailed geologic mapping of the C & SH shaft was performed between March 31, 1982, and May 2, 1982, from a depth of about 846 feet (elev. 2564 feet) near the Rustler/Salado formation contact to a depth of 2,193 feet (elev. 1217 feet). Mapping above the 846-foot depth could not be performed due to the presence of the permanent steel liner, while drilling fluid and muck prevented mapping below the 2,193-foot depth. The results of this mapping, combined with criteria established as a result of previous site investigations, were used to select the final depth for the underground development level (Chapter 3, Section 3.2). The mapping results are shown in Appendix D, Figures D-2 through D-4. A detailed discussion of the mapping is contained in reference 3-1.

Vertical control for the shaft mapping was established by tape measure from a known elevation provided by the SPDV underground excavation contractor at the shaft collar. The scope of work and methodology for the shaft geotechnical activities are contained in reference 6-1.

Reconnaissance geologic mapping of the shaft from a depth of about 920 feet (elev. 2490 feet) to 2,083 feet (elev. 1327 feet) was accomplished after construction of the shaft key. The mapped area was limited to a strip 1 to 5 feet wide along the south side of the shaft. One interval from about 1,832 feet (elev. 1578 feet) to 1,892 feet (elev. 1518 feet) was not mapped due to the interference of shaft outfitting activities.

Detailed circumferential geologic mapping was performed in the key area from the base of the steel liner to a depth of about 920 feet.

Detailed mapping was also performed from a depth of about 2,083 feet to about 2,193 feet. Detailed mapping was carried out through this interval to obtain sufficient geologic information for use in making the final facility level selection. The facility level selection mapping was performed by several teams of geologists working over a 3-day period from April 30 to May 2, 1982. The detailed mapping was generally performed independently of shaft outfitting activities to permit better observation and interpretation of the shaft geologic characteristics.

Representative samples of the geologic strata surrounding the shaft were obtained during mapping for later, more detailed classification. Photographs were taken at various locations along the shaft wall for verification of the mapping results and record-keeping purposes. As mapping progressed, observations of the shaft wall were also made to determine the condition of the salt as a result of its behavior following excavation.

Based on the data obtained from the above activities, characterizations were made of the geologic formations penetrated by the C & SH shaft. The characterizations consisted primarily of descriptions of the stratigraphy, lithology and structure of the formations. Other detailed data were included, where relevant, to more accurately characterize the salt strata in areas of primary concern to the design of the WIPP underground facility.

The C & SH shaft geologic activities served to further refine and confirm the data obtained from previous site investigations. The geologic conditions observed in the C & SH shaft within the mapped interval corresponded to the conditions expected from previous investigations. Borehole ERDA-9, in particular, showed conditions similar to the C & SH shaft. Although some variation was observed, it was attributed to core loss in ERDA-9 which prevented the early detection of these conditions.

Only minor modifications to the reference design of the C & SH shaft key structure and the geomechanical instrumentation levels were made to accommodate the observed geology.

6.2.1.2 Waste Shaft

Drilling of the initial 6-foot diameter SPDV ventilation shaft (later to be enlarged to the waste shaft) was conducted from December 1981 to February 1982. Samples of the drill cuttings were obtained at periodic intervals from the drilling fluid to permit monitoring of the stratigraphy being penetrated. After the drilling was completed, a set of geophysical logs was run to determine the shaft wall conditions and to further define the boundaries of the rock strata penetrated.

Geologic mapping of the 6-foot diameter shaft began in July 1982 in conjunction with the initiation of shaft outfitting. Initially, five areas of weaker rock which had been washed out by the drilling operation were mapped between July and September 1982 before steel liner plate was placed over these areas for safety purposes. Geologic mapping of the SPDV ventilation shaft from the bottom of the steel surface casing at 97 feet (elev. 3312 feet) to the bottom of MB-139 was conducted during September and October 1982.

Both reconnaissance and detailed geologic mapping were performed in the 6-foot diameter shaft. The mapping extended from a depth of 97 feet below the ground surface to a depth of about 2,170 feet (elev. 1239 feet). The results of this mapping are shown in Appendix E, Figures E-1 through E-6. In addition, a lithologic log, based on the geologic mapping, and a geophysical density log are shown in Appendix B, Figure B-1, for correlation with the C & SH shaft and boreholes WIPP-12, ERDA-9 and DOE-1. A detailed description of the SPDV ventilation shaft geotechnical activities is contained in reference 4-3.

Mapping of the SPDV ventilation shaft was generally performed by a team of two geologists. Depth control was maintained by hanging a tape down the shaft wall at 100- to 200-foot intervals from the top of the

surface casing. Orientation in the shaft was maintained by following a steel guide installed on the southwest wall to control movement of the work platform used in the shaft. Most of the shaft was mapped in a strip about 2 to 3 feet wide along the steel guide. Although only a portion of the shaft wall was mapped, visual examination was made of the entire wall to determine if any geologic abnormalities existed. Below a depth of about 1,180 feet (elev. 2229 feet), mapping was performed on a limited basis due to salt incrustation on the shaft wall. This crust was apparently the result of dust from the facility level that was exhausting through the shaft and depositing on the wet shaft wall. Representative samples of the rock strata were collected to permit a more detailed description. Photographs were taken at various locations along the shaft wall for verification of the mapping results and record-keeping purposes. In addition to providing a description of the rock strata, observations of the shaft wall were made to determine, where possible, the reaction of the rock to excavation.

Detailed mapping around the full circumference of the 6-foot diameter shaft was performed at the following five intervals:

(1) Magenta dolomite member,
(2) Culebra dolomite member,
(3) Rustler formation fracture zone;
(4) Rustler/Salado formation contact; and
(5) MB-139.

Because of salt incrustation on the shaft wall immediately above the facility level, detailed circumferential mapping could not be performed in this area. However, two opposing strips about 1 foot wide were cut through the crust to permit mapping of the shaft wall for a distance of about 50 feet above the facility level. Depths in the facility level area were verified by a separate survey utilizing elevation points established in the C & SH shaft station.

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The enlargement of the SPDV ventilation shaft into the waste shaft began in October 1983 and was completed in August 1984. Additional geologic mapping and visual inspections were conducted concurrently with this excavation. Mapping was conducted from December 9, 1983, to August 10, 1984. Visual inspections of the shaft surface were performed throughout the shaft enlargement operations. The lithology of the exposed shaft stratigraphy was described and compared with the description of the same stratigraphic interval mapped in the SPDV ventilation shaft. Any differences or additional detail were noted and the SPDV ventilation shaft geologic map was modified accordingly.

In the lined section of the waste shaft, the depth to the base of each successive concrete segment was provided by the shaft excavation contractor. Vertical control for mapping was then established from the base of the previous segment. During enlargement of the unlined section of the shaft, vertical control was established from occasional survey control points installed by the contractor and from the previously mapped SPDV ventilation shaft geology. In the shaft sump, vertical control was based on a contractor survey point installed at a depth of 2,167 feet (elev. 1242 feet).

Detailed, full circumference geologic mapping was performed in areas of specific geologic interest. These areas were selected because of their poor exposure in the SPDV ventilation shaft, the possible occurrence of dissolutioning, or their hydrologic significance. These areas of detailed mapping were:

(1) the Forty-niner member claystone;
(2) the Magenta dolomite member;
(3) the Tamarisk member claystone;
(4) the Culebra dolomite member;
(5) the upper portion of the unnamed lower member of the Rustler formation; and
(6) the Rustler/Salado formation contact and key area.

The detailed mapping in the waste shaft was generally conducted as outlined in reference 6-1. Mapping was conducted by teams of four to six people. Once vertical control was established by the contractor from the base of the previous concrete segment, a 5 x 5-foot grid was painted on the shaft surface around its circumference to permit the accurate location of any lithologic contacts and geologic features.

Reconnaissance geologic mapping was performed in the waste shaft sump. A vertical strip, approximately 5 feet wide, was cleaned and mapped along the entire length of the sump.

A detailed description of the geotechnical activities conducted in the waste shaft is contained in reference 6-2. The results of the mapping are shown in Appendix E, Figure E-1.

The geologic mapping and visual inspections of the SPDV ventilation/waste shaft has provided additional documentation of the strata above and below the WIPP underground development level. Based on the data obtained from the shaft mapping activities, a general characterization of the stratigraphy, lithology and structure of the geologic formations penetrated by the waste shaft was made.

The waste shaft penetrates five formations. In descending order, they are the Gatuna formation of Quaternary age, the Santa Rosa sandstone of Triassic age, and the Dewey Lake redbeds, Rustler formation and Salado formation, all of Permian age. In addition, the waste shaft also penetrates thin surficial Quaternary dune sands and the Mescalero caliche. In the WIPP site area, the Santa Rosa sandstone and the Gatuna formation are represented by thin layers of sandstone (ref. 6-3). They were not mapped in the waste shaft due to installation of the shaft collar facilities.

The results of the geologic mapping of the waste shaft correlate well with the SPDV ventilation shaft mapping results. The stratigraphic units penetrated by the waste shaft are the same as those encountered by the C & SH shaft.

Post-depositional dissolution features were not observed in any stratigraphic horizons in the waste shaft. Several zones previously identified as containing dissolution residues in borehole ERDA-9 are now considered to contain pronounced primary sedimentary features.

6.2.1.3 Exhaust Shaft

The exhaust shaft was enlarged from a 6-foot diameter raise-bored shaft to its finished 14- to 15-foot diameter using conventional drill and blast methods from July 1984 to January 1985. Geologic mapping of the shaft wall was conducted concurrently with excavation and construction activities.

Reconnaissance geologic mapping was performed along the entire length of the shaft with the exception of selected areas where detailed mapping was performed. A vertical strip, approximately 5 feet wide, was cleaned and mapped. The procedures used for the reconnaissance mapping are contained in reference 6-1.

Detailed circumferential mapping of specific areas of geologic interest was also performed. These areas included those previously described in the C & SH and waste shafts and four additional areas within the Dewey Lake redbeds, three of which contain gypsum filled fractures. The areas of detailed mapping in the exhaust shaft were:

(1) gypsum-filled fractures at a depth of 195.0 to 210.0 feet;
(2) gypsum-filled fractures at a depth of 269.0 to 280.5 feet;
(3) gypsum-filled fractures at a depth of 353.5 to 375.0 feet;
(4) the Dewey Lake/Rustler formation contact (546.4 feet);
(5) the Forty-niner member claystone (575.5 to 586.5 feet);
(6) the Magenta dolomite member (602.5 to 627.0 feet);
(7) the Tamarisk member claystone (689.0 to 695.5 feet);
(8) the Culebra dolomite member (713.5 to 736.0 feet);
(9) the upper portion of the unnamed lower member (736.0 to 800.0 feet); and
(10) the Rustler/Salado formation contact and key (845.0 to 912.0 feet).

The detailed geologic mapping was performed in a manner similar to that in the waste shaft, using a 5 x 5-foot grid. Vertical survey control was provided by the shaft excavation contractor. As the shaft liner was constructed, the depth to the base of each successive concrete segment was provided by the contractor. Vertical control for mapping was then established from the base of the previous segment. During excavation of the unlined section of the shaft, vertical control was established with survey chains suspended from contractor-installed survey control points.

The results of the exhaust shaft mapping are shown in Appendix F, Figure F-1. A detailed description of the geotechnical activities in the exhaust shaft are included in the report titled Geotechnical Activities in the Exhaust Shaft (ref. 6-4).

In general, the exhaust shaft mapping results correlate well with the results from the waste shaft. Slight lateral variations in the geology produce minor exceptions. The exhaust shaft geologic mapping activities have produced additional confirmation of data obtained from previous site investigations. This mapping confirms the suitability of the shaft reference design, with some minor modifications, based on the original design parameters.

6.2.1.4 Drifts and Test Rooms

Geologic mapping of the drifts and test rooms was performed to characterize the facility level geology, demonstrate its continuity, and provide permanent documentation of the geology exposed in the underground excavations. Those drifts and rooms that were not mapped were visually inspected by site geologists to verify that the stratigraphy is laterally continuous and similar to that exposed in the mapped areas of the facility. No unusual geologic features were observed.

Geologic mapping was conducted in accordance with the procedures established in reference 6-1. A horizontal level-line referenced to

the C & SH shaft station floor elevation was established in the drifts and rooms using an engineer's tripod level. All stratigraphic contacts and geologic features were referenced to this level-line datum. Horizontal distances were measured with an engineer's tape using the C & SH shaft centerline as the zero reference point. Detailed mapping was performed at 10-foot intervals along one wall of the drifts. Between these intervals, the continuity of the stratigraphic contacts and the nature of the individual units were observed and noted on the map. The mapped drifts were the E140 drift, the E0 drift, the N1100 drift and the N1420 drift. Selected figures showing the megascopic results of this mapping are contained in Appendix B.

Geologic Mapping in the test rooms consisted of describing a 6- to 10-foot wide strip surrounding the instrument array in the center of each room. Both walls and the roof in each room were mapped. The remainder of the room was carefully inspected to confirm lateral continuity of the stratigraphic units. The strip maps from the test rooms are presented in Appendix G, Figures G-1 through G-4.

6.2.2 Core Drilling

6.2.2.1 Purpose

Vertical core holes were drilled into the floor and roof of the underground openings to provide geologic information for design validation. The objectives of the vertical core holes are described in Supporting Document 3 of reference 2-5. The purpose of the program was discussed in Chapter 5 of this report.

6.2.2.2 Summary of Drilling

A total of 124 vertical core holes have been drilled and logged in the underground drifts and in the SPDV test rooms, excluding those drilled as part of SNL's in situ tests. This number includes 16 holes drilled to replace holes that had poor core recovery and four holes drilled to obtain information on non-cored sections in the original holes. The

holes were generally drilled in pairs, one hole drilled vertically into the roof and one hole drilled vertically into the floor. Core was obtained in each hole to a nominal depth of 50 feet. Table 6-1 presents a summary of the core hole data. A map showing the core hole locations is presented on Figure 6-1. Geologic cross sections at selected core hole locations in the drifts are contained in Appendix H. Geologic drill logs of all of the core holes are contained in Appendix I.

Drilling was performed by the underground excavation contractor. The drill rig was set up by the driller and the attitude of the core hole was checked by site geotechnical personnel. Logging and handling of the core were performed by geotechnical personnel in conformance with the procedures outlined in Supporting Document 3 of reference 2-5.

All core holes were drilled using rotary equipment and compressed air or saturated brine as the circulating medium. The holes were drilled with a diamond impregnated bit which produced 2-inch or 2 3/8-inch diameter core. A 5-foot long double-tube or split double-tube core barrel was used to retain the core.

The core was logged underground as it was removed from the core barrel or after the drilling of the hole was completed. Logging was generally performed by the same geologist to maintain consistency in the descriptions of the geologic materials. The following data are recorded on each log:

(1) location of core hole and direction of drilling (up or down);
(2) beginning and completion dates of drilling;
(3) length and number of core run;
(4) amount and percentage of core recovery;
(5) stratigraphic and lithologic descriptions (color descriptions are based on the Geological Society of America (GSA) Rock-Color Chart);
(6) graphic lithologic profile; and

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Table 6-1

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (ft-MSL)	Approximate Station (ft)		Facility Coordinates (ft)		Depth/ Penetration (ft)	Instrument Designation
MB-139-1	Down	1264.1	N79	W6	N9766	E6888	10.0	None
MB-139-2	Down	1251.2	S410	E150	N9277	E7044	15.7	None
MB-139-3	Down	1260.5	S101	E157	N9586	E7051	16.0	None
MB-139-4	Down	1258.7	S99	W17	N9588	E6877	16.2	None
DH-01	Up	1318.2	N1424	E439.5	N11110.9	E7335.5	50.8	None
DH-02(1)	Down		N1424	E440	N11110.9	E7336.06	50.2	None
DH-02A(1)	Down		N1424	E435	N11110.9	E7331.29	49.2	None
DH-02B	Down	1306.3	N1424	E442	N11110.9	E7337.29	53.0	None
DH-03	Up	1318.1	N1112	E444	N10799.2	E7335.4	48.8	None
DH-03A	Up	1317.4	N1112	E450.5	N10779.2	E7341.92	49.9	None
DH-04	Down	1309.6	N1112.5	E444	N10799.2	E7335.4	45.8	None
DH-04A(1)	Down	1309.6	N1113	E446			11.2	None
DH-04B	Down	1309.7	N1112	E450.5	N10799.70	E7341.85	51.4	None
DH-05	Up	1329.9	N1463	E972	N11149.6	E7865.0	51.0	None
DH-06	Down	1317.9	N1463	E972	N11149.7	E7864.9	49.75	None
DH-07	Up	1326.7	N1112	E976.5	N10799.3	E7870.8	49.8	None
DH-08	Down	1318.8	N1112	E976.5	N10799.4	E7870.9	38.3	None
DH-08A(1)	Down	1318.7	N1112	E975			50.7	None
DH-08B	Down	1318.0	N1112	E979.5	N10799.47	E7866.66	51.4	None
DH-09	Up	1324.5	N1432	E1332.5	N11108.71	E8227.11	51.1	None
DH-10	Down	1312.1	N1432	E1332.5	N11106.70	E8227.09	52.0	None
DH-11	Up	1320.5	N1112	E1332.5	N10799.8	E8227.3	50.9	None
DH-12	Down	1311.1	N1112	E1332.5	N10799.4	E8227.2	51.3	None
DH-13	Up	1311.4	N1424	E1690	N11112	E8585	13.8	None
DH-13A	Up	1311.5	N1424.5	E1691	N11112	E8586	49.0	None
DH-13B	Up	1311.4	N1425	E1695	N11112.6	E8590.1	21.0	None
DH-14	Down	1299.5	N1425	E1695	N11112.6	E8590.1	49.1	None
DH-15	Up	1308.9	N1104	E1688.5	N10793.26	E8589.96	51.0	None
DH-16	Down	1300.3	N1104	E1688	N10792.89	E8589.39	51.0	None
DH-17	Up	1316.5	N1427	E178	N11114.2	E7071.8	52.0	None
DH-18	Down	1305.1	N1429	E181	N11114.2	E7071.8	50.8	None
DH-19	Up	1314.7	N1107	E206.5	N10794.2	E7101.7	51.6	None
DH-20	Down	1306.2	N1109	E206	N10794.2	E7101.7	51.1	None
DH-21	Up	1331.0	N1421	E786	N11109.1	E7680.9	50.4	None
DH-22	Down	1318.8	N1421.5	E785.5	N11109.2	E7680.9	51.0	None
DH-23	Up	1328.0	N1112	E781	N10799.2	E7679.9	51.0	None
DH-24	Down	1319.5	N1112	E781	N10799.2	E7679.8	49.4	None
DH-24A	Down	1319.5	N1112	E780	N10799.08	E7678.59	50.4	None
DH-25	Up	1318.8	N1422	E1510	N11109.7	E8403.8	51.8	None
DH-26	Down	1307.2	N1427	E1510	N11114.3	E8403.8	53.0	None
DH-27	Up	1300.8	N1107	W682	N10793.7	E6218.4	50.5	None
DH-28	Down	1289.9	N1107	W682	N10793.8	E6218.3	50.5	None
DH-29	Up	1298.3	N1099	W982	N10785.4	E5932.4	50.4	None
DH-29A	Up	1298.1	N1099	W987	N10786.1	E5927.3	35.0	None
DH-30	Down	1289.2	N1099	W982	N10785.5	E5932.2	50.1	None
DH-31	Up	1298.5	N1099	W1282	N10784.9	E5632.3	50.5	None
DH-31A	Up	1298.5	N1099	W1280	N10784.8	E5630.5	49.2	None
DH-31B	Up	1298.5±	N1099	W1261	N10786.7	E5652.2	4.9	None
DH-32	Down	1289.6	N1099	W1282	N10784.9	E5632.2	50.0	None
DH-32A	Down	1289.5	N1099	W1261	N10786.7	E5652.2	5.5	None
DH-33	Up	1298.6	N1099	W1582	N10786.0	E5331.1	50.5	None
DH-33A	Up	1297.4	N1099	W1570	N10786.8	E5342.0	4.1	None
DH-34	Down	1289.4	N1099	W1582	N10786.5	E5331.7	51.5	None
DH-34A	Down	1289.2	N1099	W1570	N10786.8	E5341.9	3.6	None
DH-35	Up	1294.4	N1102	W1882	N10789.4	E5032.2	52.0	None
DH-36	Down	1284.6	N1102	W1882	N10789.4	E5032.2	51.5	None
DH-37	Up	1297.4	N1101	W2182	N10788.9	E4732.0	51.5	None
DH-38	Down	1287.0	N1101	W2182	N10788.8	E4731.9	47.5	None
DH-39	Up	1296.0	N1101	W2482	N10789.2	E4430.7	50.7	None
DH-40	Down	1286.1	N1101	W2482	N10789.2	E4431.0	51.0	None
DH-41	Up	1295.8	N1101	W2782	N10789.0	E4132.6	49.9	None
DH-42	Down	1285.9	N1101	W2782	N10789.0	E4132.4	51.2	None
DH-42A	Down	1285.7	N1101	W2789	N10789.2	E4125.5	40.5	None

(1) Survey data not available.

Table 6-1 (continued)

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (ft-MSL)	Approximate Station (ft)		Facility Coordinates (ft)		Depth/ Penetration (ft)	Instrument Designation
DH-207	Up	1259.8	S697	E155	N8989.7	E7049.1	53.0	GE-246
DH-208	Down	1251.6	S698	E150	N8988.8	E7044.0	49.2	None
DH-211	Up	1270.5	S1320	E163	N8366.5	E7057.1	50.0	None
DH-212	Down	1261.7	S1320	E163	N8366.5	E7057.1	52.1	None
DH-215	Up	1272.0	S1960	E153	N7727.2	E7046.9	52.0	GE-247
DH-216	Down	1262.6	S1960	E153	N7727.2	E7046.9	54.2	GE-248
DH-219	Up	1266.3	S2422	E162	N7264.9	E7056.6	51.0	None
DH-219A	Up	1266.1	S2418	E162	N7268.5	E7056.2	11.3	None
DH-220	Down	1257.4	S2421	E162	N7265.5	E7055.9	51.8	None
DH-223	Up	1255.1	S3079	E154	N6607.2	E7048.5	52.6	GE-249
DH-224	Down	1246.6	S3079	E154	N6607.5	E7048.5	52.5	None
DH-227	Up	1247.0	S3656	E147	N6030.7	E7041.2	51.7	None
DH-228	Down	1237.8	S3656	E147	N6030.7	E7041.2	50.4	None
DH-301	Up	1276.9	N150	W170	N9830.5	E6724.5	50.75	None
DH-302	Down	1264.9	N150	W170	N9830.5	E6724.5	50.6	None
DH-303	Up	1267.2	S400	W170	N9282.3	E6726.1	51.4	None
DH-304	Down	1254.3	S400	W170	N9282.5	E6726.1	50.5	None
DH-306	Down	1244.1	S400	E140	N9287.3	E7049.9	52.0	None
DH-306A	Down	1244.0	S400	E125	N9287.9	E7034.6	8.5	None
DH-307	Up	1262.6	S400	E300	N9286.7	E7194.2	52.0	GE-263
DH-309	Up	1259.8	S700	E220	N8987.1	E7123.0	52.3	GE-265
DH-311	Up	1264.4	S1000	E300	N8686.3	E7194.9	52.0	GE-264
DH-313	Up	1270.6	S1300	E300	N8385.9	E7190.6	19.6	None
DH-313A	Up	1270.9	S1300	E299	N8386.6	E7189.5	50.2	None
DH-314	Down	1258.3	S1300	E300	N8386.5	E7189.5	50.75	None
DH-315	Up	1272.1	S1300	W170	N8387.3	E6725.5	50.3	None
DH-316	Down	1259.9	S1300	W170	N8387.2	E6725.3	50.1	None
DH-317	Up	1271.3	S1600	W33	N8077.4	E6875.9	50.1	None
DH-317A	Up	1271.2	S1600	W30	N8077.5	E6879.5	5.0	None
DH-317B	Up	1271.2	S1597	W30	N8080.3	E6881.0	51.0	None
DH-318	Down	1258.5	S1600	W30	N8077.3	E6876.1	50.0	None
DH-319	Up	1260.0	S700	E300	N8988.1	E7191.6	51.05	None
DH-321	Up	1261.4	S400	E0	N9792.0	E6891.8	52.0	GE-268
DH-323	Up	1261.2	S400	E55	N9291.7	E6952.5	52.5	GE-267
DO-45	Up	1285.5	N254	E147	N9941.0	E7041.3	52.4	GE-230
DO-46	Down	1276.5±	N254	E147	N9941.0	E7041.3	51.5	None
DO-52	Up	1280.4	N146	W4	N9832.5	E6890.5	51.6	GE-226
DO-53	Down	1266.6	N146	W4	N9832.5	E6890.5	49.2	None
DO-56	Up	1296.8	N621	E0	N10311.8	E6892.3	52.1	GE-234
DO-57	Down	1288.1	N621	E0	N10311.8	E6892.4	52.1	None
DO-63	Up	1310.6	N1110	E0	N10796.0	E6891.9	52.8	GE-243
DO-64	Down	1301.5	N1110	E0	N10796.0	E6891.6	52.8	GE-221
DO-67	Down	1296.8	N1265	W231.5	N10952.1	E6662.9	51.7	GE-220
DO-69	Up	1310.1	N1265	W231.5	N10951.9	E6662.5	51.4	GE-218
DO-77	Down	1294.6	N1270	W364.5	N10962.5	E6529.6	53.4	GE-216
DO-79	Up	1307.7	N1270	W364.5	N10962.6	E6529.5	51.8	GE-214
DO-88	Up	1305.9	N1265	W497.5	N10952.8	E6396.5	52.7	GE-212
DO-90	Down	1292.1	N1265	W497.5	N10952.6	E6396.4	53.6	GE-210
DO-91	Down	1292.1	N1275	W630.5	N10961.5	E6263.9	51.8	GE-209
DO-93	Up	1304.9	N1275	W630.5	N10961.1	E6263.9	52.0	GE-207
DO-201	Up	1262.2	S406	W19	N9280.6	E6874.9	51.7	None
DO-202	Down	1248.6	S406	W19	N9280.6	E6874.9	51.4	None
DO-203	Up	1298.2	N624	E140	N10308.6	E7041.7	52.0	GE-235
DO-204	Down	1290.5	N640	E140	N10308.5	E7041.5	51.6	None
DO-205	Up	1316.5	N1410	E0	N11095	E6892	50.7	None
DO-206	Down	1308.0	N1410	E0	N11095	E6892	50.6	None
DO-229	Up	1259.8	S401	E153	N9287	E7049	50.6	None
OH-9	Up	1310	N1433	W231.5	N11125.6	E6662.9	15.4	None
OH-11	Up	1308	N1433	W364.5	N11125.6	E6529.6	19.7	None
OH-13	Down	1298	N1433	W231.5	N11125.6	E6662.9	9.5	None
OH-14	Down	1296	N1433	W364.5	N11125.6	E6529.6	9.7	None

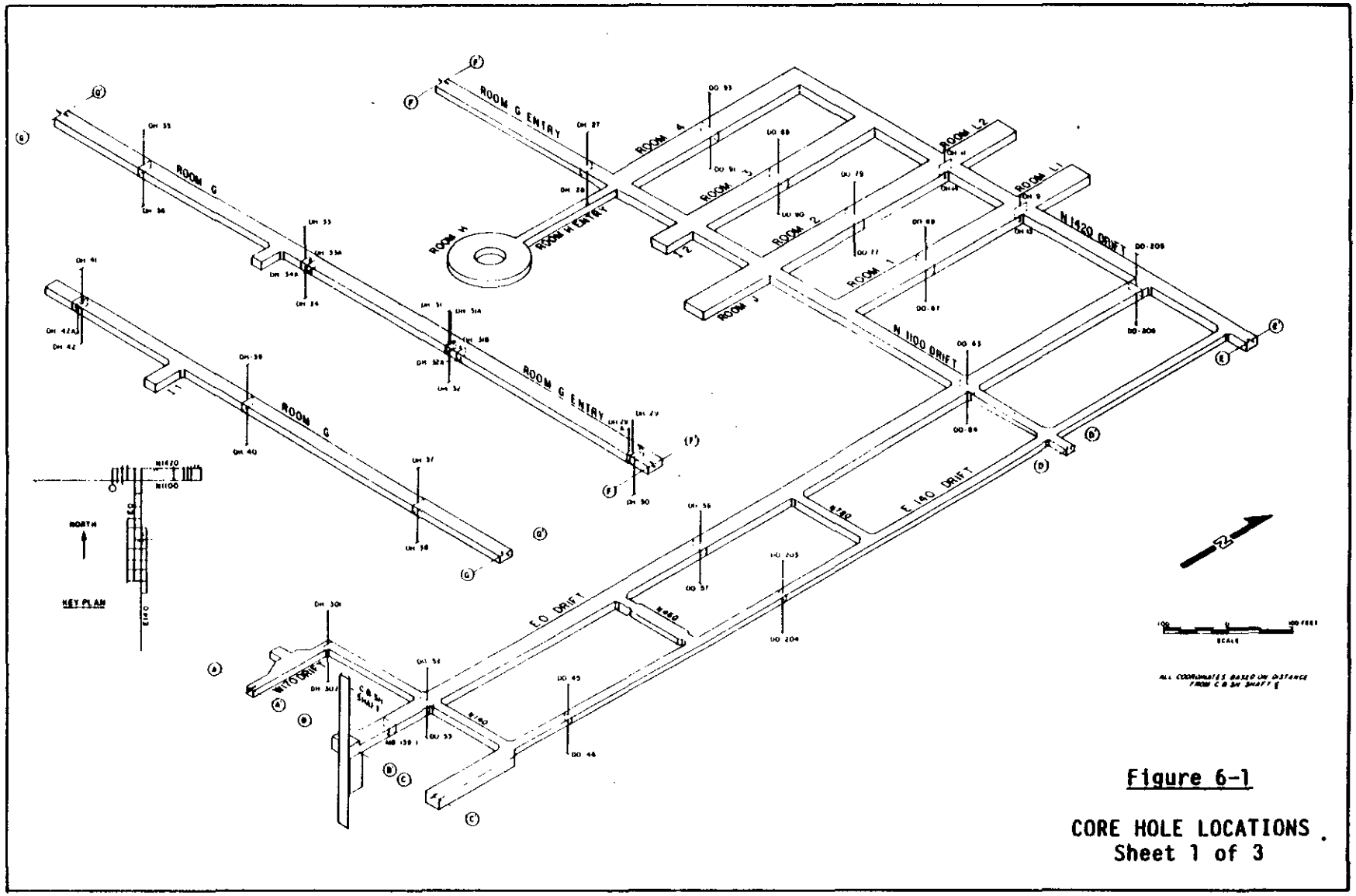

Figure 6-1

CORE HOLE LOCATIONS
Sheet 1 of 3

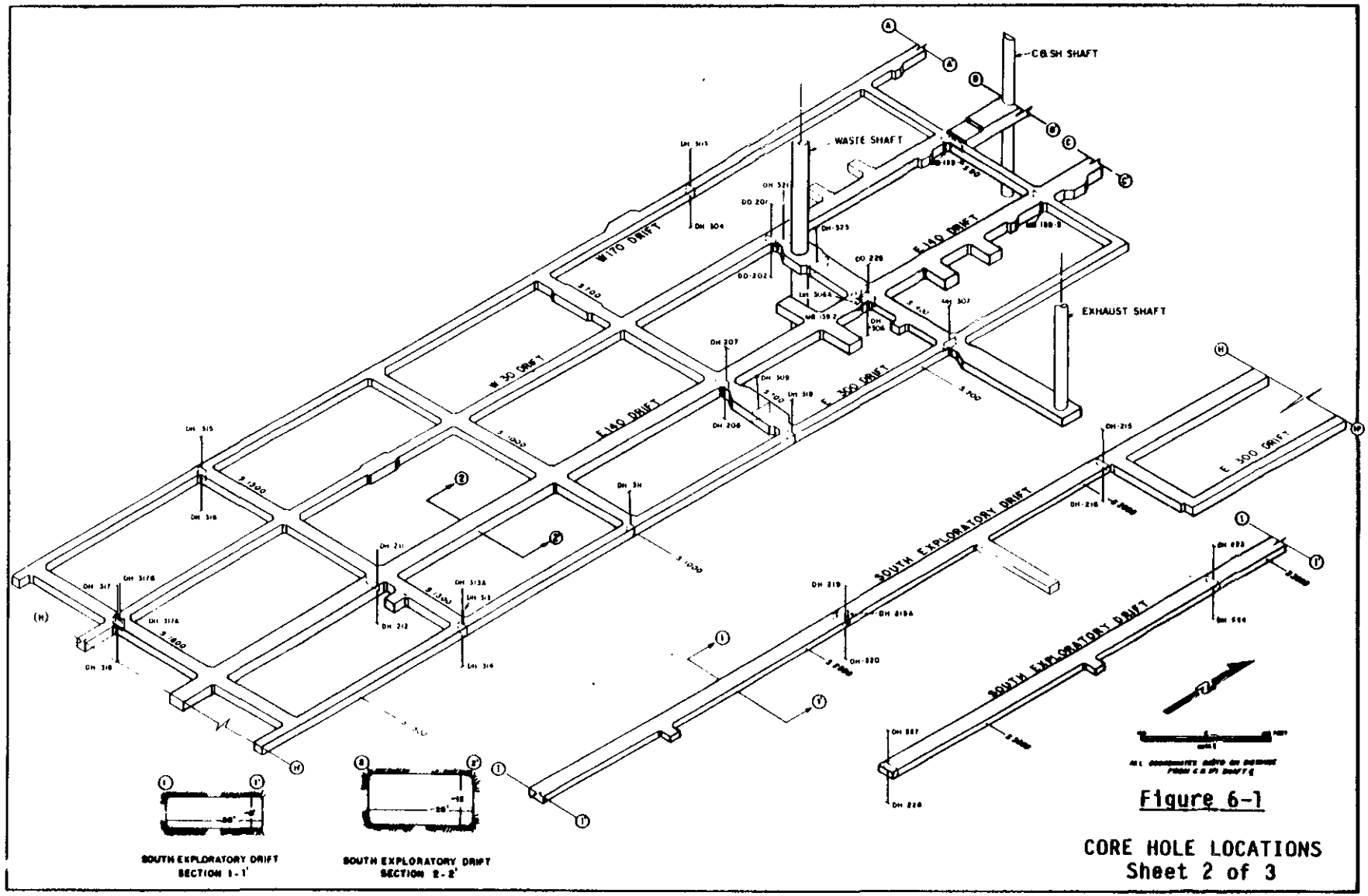

Figure 6-1

CORE HOLE LOCATIONS
Sheet 2 of 3

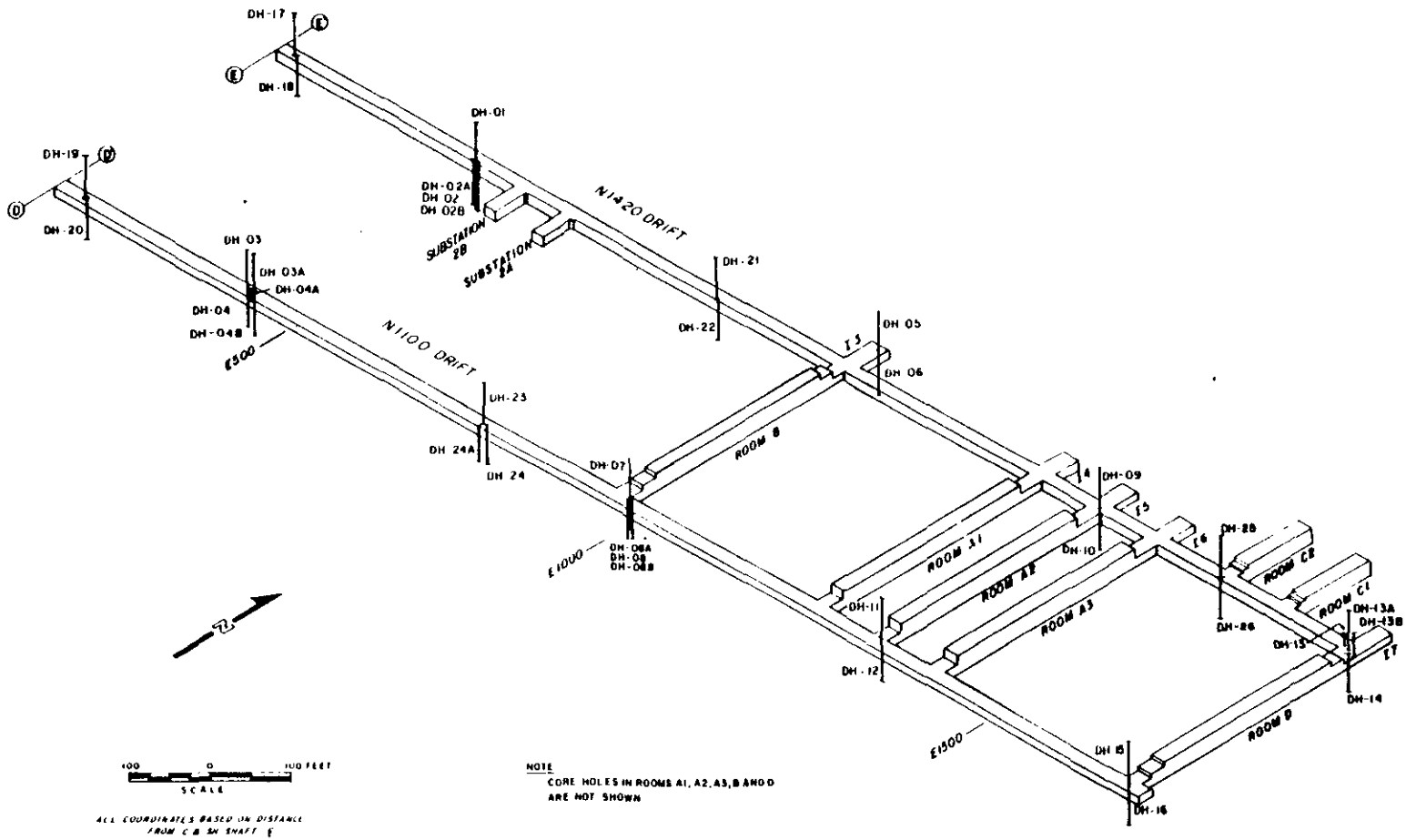

Figure 6-1

CORE HOLE LOCATIONS
Sheet 3 of 3

(7) other pertinent information related to core conditions and observations made during drilling.

Included on the logs of many of the core holes is a core sample reference number for each distinguishable stratigraphic unit (except anhydrite). This number (in some cases several numbers) is shown in brackets at the end of the unit description. The number identifies a specific core sample that has undergone a laboratory analysis to determine its percentage of insolubles (clay/polyhalite). A listing of the reference core samples and their laboratory test results for insoluble residues are presented in Table 6-2. The reference sample system was used to provide uniformity in the logging of the core and to facilitate the comparison of unit descriptions with samples having a known insoluble content. The sample number or numbers which appear on the log are those which are visually most similar to the overall unit. The crystal size in the reference samples may not be the same as in the units with which they are correlated.

Each box of core was photographed and then stored in the WIPP core library. After data from several of the core holes was collected, correlations between the holes were developed.

6.2.2.3 Summary of Results

The underground core drilling program has demonstrated the lateral continuity of stratigraphy throughout the underground facility horizon. Three anhydrite units were identified in the upholes and two anhydrite units were identified in the downholes. These units are consistently underlain by clay seams. In addition, a clay seam designated clay I was found in most of the upholes and a clay seam designated clay D was found in many of the downholes. Anhydrite is commonly associated with these two seams. The remaining units consist of halite with varying amounts of argillaceous material and polyhalite. Individual units vary slightly from hole to hole in thickness, crystal size, and the percentage of accessory constituents such as argillaceous material and polyhalite. The stratigraphy

Table 6-2

INSOLUBLE RESIDUES OF REFERENCE CORE SAMPLES
SANDIA NATIONAL LABORATORIES

Reference Sample Number	Hole Number	Depth Interval (feet)	Water-Insoluble Sample Weight (grams)	Water-Insoluble Residue Weight (grams)	Water-Insoluble Percent Weight	EDTA-Insoluble (1) Sample Weight (grams)	EDTA-Insoluble (1) Residue Weight (grams)	EDTA-Insoluble (1) Percent Weight
1	DO-52	9.0 - 9.7	451.09	0.03	0.01			
2	DO-52	39.4 - 40.0	336.10	0.11	0.03			
3	DO-52	14.3 - 15.0	415.57	2.15	0.52	1.61	0.72	44.72
4	DO-53	14.1 - 14.5	251.72	0.40	0.16	0.36	0.14	38.89(2)
5	DO-53	4.0 - 4.3	206.53	1.28	0.62	0.80	0.28	35.00(2)
6	DO-53	23.7 - 24.1	155.36	1.26	0.81	0.96	0.59	61.46
7(3)	DH-4B	18.0 - 18.35			0.22			
8	DO-52	2.0 - 2.75	436.67	2.16	0.49	1.32	0.91	68.94
9(3)	DH-12	28.15- 28.6			0.75			57.1
10(3)	DH-11	46.5 - 46.9			3.85			39.2
11(3)	DH-12	50.05- 50.4						
12(3)	DH-11	32.8 - 33.35			2.36			50.0
13	DO-53	36.1 - 36.7	364.13	1.89	0.52	1.47	1.17	79.59
14	DO-52	42.6 - 43.5	543.62	17.97	3.31	5.13	4.58	89.28
15	DO-52	33.8 - 34.7	538.73	20.28	3.76	5.05	3.98	78.81
16	DO-52	48.7 - 49.2	315.06	16.59	5.27	5.31	4.33	81.54
17(3)	DH-10	43.3 - 43.6			0.52			49.2

Notes:

(1) For description of sample preparation see Results of Site Validation Experiments, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, Section 5.4 (ref. 2-5).

(2) Small sample volume may have produced inaccurate result.

(3) Reference sample used for visual comparison is identical to the sample tested in the laboratory, but is from different interval within the same unit.

encountered in the core holes was used to prepare the reference stratigraphic column discussed in subsection 6.3.1.3.

The presence of any gas or brine detected during drilling is recorded on the drill logs. Usually within 2 weeks of completing an air-drilled uphole, brine weeps or moisture halos appear at the collar of the hole. Brine has also collected in some downholes which were dry during drilling. Observations of gas and brine occurrences are discussed in the following subsection.

6.2.3 Fluid Measurements

6.2.3.1 General Description

Ground-water inflow measurements were taken in both the SPDV exploratory and ventilation shafts as part of the geologic field activities for the SPDV Program. In addition, measurements in the waste shaft and exhaust shaft were taken as part of design validation. Gas and brine have been encountered in boreholes and at excavation faces in the facility level drifts and rooms. Studies are being performed by other WIPP project participants to further investigate and evaluate these occurrences.

6.2.3.2 C & SH Shaft

Measurements of fluid inflow were taken during the SPDV exploratory shaft drilling operation when the drill tools were out of the hole for a bit change. The measurements were taken by monitoring changes in the drilling fluid level over a period of several hours. These data were then used to estimate approximate ground-water flow rates into the shaft.

6.2.3.3 Waste Shaft

Ground-water inflow measurements were taken in the 6-foot diameter SPDV ventilation shaft during shaft outfitting. These measurements were taken in the shaft sump and at the base of the Rustler formation. The measurements in the shaft sump were used to determine total flow into

the shaft from all ground-water sources penetrated. Periodic measurements to determine water level rise with respect to a known point at the top of the sump were obtained during test intervals ranging from about 1.5 to 90 hours. The data obtained from these measurements were used to calculate approximate ground-water flow rates into the shaft ranging from 0.3 to 0.9 gallons per minute (gpm). The average flow rate was determined to be about 0.6 gpm.

An attempt to measure ground-water inflow from the rock strata above the Salado formation was only partially successful. A collection system to retain ground-water inflow was constructed at the base of the Rustler formation by placing plastic sheeting across the shaft and attaching it to the wall. The quantity of water collected in the sheeting and drained into a graduated container was calculated to accumulate at a rate of approximately 0.3 to 0.4 gpm from all sources above the Salado formation.

No direct inflow from the Magenta or Culebra dolomite members or at the Rustler/Salado formation contact was measured. The Magenta dolomite did not exhibit measurable flow. Ground water from this member resulted in the wetting of the wall below the dolomite for a distance of about 20 feet. Below this distance the shaft wall was essentially dry. Therefore, it was concluded that the Magenta was making no contribution to the collection system at the base of the Rustler formation. Visual inspection of the Rustler/Salado formation contact, and shaft wall conditions immediately above and below this contact, suggested that the zone was making little, if any, contribution to the water accumulating in the sump. Based on these results, it was concluded that the Culebra dolomite member was contributing the majority of ground water reaching the SPDV ventilation shaft sump.

The 6-foot diameter SPDV ventilation shaft was later enlarged to become the waste shaft for the WIPP facility. Of the three formations observed during geologic mapping activities in the enlarged shaft, only the Magenta and Culebra dolomite members of the Rustler formation were

obvious fluid-bearing zones. The Magenta exhibited only a few weeps and generally produced very little water. The entire Culebra section, however, was wet, but no obvious local concentrations of water inflow were observed. Wherever a ledge was present, a steady dripping of water occurred. The Rustler/Salado formation contact, often considered a fluid-producing zone, did not contain any observable fluid except for some dampness around rock bolts.

After the waste shaft liner was constructed, ground water was observed seeping through cracks and construction joints in it. These observations are discussed in Chapter 8, subsection 8.3.1.1.

6.2.3.4 Exhaust Shaft

A water inflow measurement of approximately 0.4 gpm into the 7 7/8-inch diameter pilot hole for the exhaust shaft was taken on December 1, 1983. On December 21, 1983, a water inflow of 0.47 gpm was measured after the pilot hole was enlarged to 11 inches in diameter.

After the shaft was excavated to its finished dimensions, water inflow through cracks and construction joints in the liner was measured. Measurement was made from the 2-inch drainpipe that connects the three water collection rings in the shaft. The measured flow was 0.35 gpm in January 1985. A grouting program, conducted in June and July 1985 within the lined section of the shaft, reduced this inflow to a non-measurable quantity.

6.2.3.5 Drifts and Test Rooms

Small amounts of gas under pressure have been encountered by some underground boreholes and at the working face of underground horizontal excavations. Brine is observed to weep locally from walls and into some boreholes. The brine occurrences are visible during or immediately after excavation or drilling and remain moist or produce fluid for a period of from several weeks to more than 3 years. The formation of salt blisters on walls and salt straws and precipitate at

M

hole collars are common. Salt incrustations forming on the roof are being monitored at three locations: W30/S1600, E140/S2190 and E140/S2740.

The gas occurrences encounterd by boreholes are indicated on the geologic drill logs. Pressure transient testing and gas sampling were performed in several holes in the roof and floor of the facility as reported in reference 4-11. Only two occurrences of gas at the working face were documented prior to the end of December 1985. In both cases, degassing could be heard at the face for short periods of time.

The locations of major weeps occurring on walls that were geologically mapped are indicated on the maps and a discussion of their occurrence and structure is presented in reference 4-10. Sampling of brine from weeps for chemical analysis is currently being conducted. A preliminary inventory of brine occurrences at accessible locations is presented in reference 4-15.

The flow of gas from monitored holes has been low and erratic. It appears to be associated with clay seams or a result of fracture permeability in anhydrite beds. The spatial distribution of brine occurrences is also undefined. Although very few weeps have been observed on the roof surface, boreholes in the roof sometimes weep brine. The amount and duration of flow from boreholes and wall areas varies considerably. Based on observations made during preliminary gas testing, the brine appears to be associated primarily with anhydrite beds and their underlying clay seams. However, brine can also weep directly from halitic units, as observed on the walls and roof of drifts and in the drum durability test pit in Room J.

Two program plans have been developed to investigate gas and brine occurrences in the WIPP underground facility. The programs will investigate the origin, migration, volume and composition of the occurrences. Work on the Brine Testing Program (BTP) is presently

being conducted and will continue through 1987. The Gas Testing Program (GTP) is also currently in progress.

As part of the BTP, 36 accessible boreholes containing brine have been monitored. These holes include the shallow holes for the Material Interface-Interactions Test (MIIT) in Room J, inclinometer holes in Test Rooms 1 and 2 (51X-IG-00201 and 51X-IG-00202), an abandoned stressmeter hole (51X-NG-00252) in Test Room 2, hole L1-X00 in Room L1, nine stratigraphic core holes in Room G (DH-35 through DH-42A), and eight stratigraphic core holes in experimental Rooms A1, A2, A3 and B (A1X01, A1X02, A2X01, A2X02, A3X01, A3X02, BX01 and BX02). The static level of any brine in the holes is measured and recorded on a regular basis. The brine is then evacuated from the hole and its volume measured.

The BTP monitoring of brine occurrences in the MIIT holes in Room J was suspended at the end of April 1985 due to interference with experimental activities in the room. Monitoring of the remainder of the boreholes listed above continues. As new monitoring locations for the BTP are identified, they will be added to the program.

An inventory of all boreholes drilled in the underground facility has been assembled. Data contained in the inventory include hole location, diameter, depth, present status, drilling fluid used, and any observations on the occurrence of gas or brine. Over 1400 holes are presently listed, most of which contain geomechanical instruments or are otherwise inaccessible. The list will be used to locate accessible boreholes that may be suitable for use in the gas and brine testing programs.

6.3 DESCRIPTION OF FACILITY GEOLOGY

6.3.1 Stratigraphy

The stratigraphy within the WIPP underground facility horizon has been determined through vertical core hole drilling and geologic mapping of

the excavation walls. A description of the generalized stratigraphy and evidence for stratigraphic continuity is presented in the following subsections. Figures showing the stratigraphy within the WIPP underground facility horizon are presented in Appendix B.

6.3.1.1 Generalized Stratigraphy

The WIPP underground facility horizon consists primarily of halite containing varying amounts of polyhalite and clay. This halite is interrupted by 5 anhydrite beds, 12 clay seams and 6 argillaceous layers. Figure 6-2 contains a generalized stratigraphic column showing the relationship of these materials. Detailed descriptions of the individual units (except clay seams) are presented in Table 6-3. Figure 6-3 shows the individual clay seams and their descriptions.

Because of the difference in the behavior of halite and anhydrite, the five anhydrite beds represent significant boundaries above and below the horizontal underground openings. Three of the beds, abouth 1 1/2 to 12 inches thick, occur approximately 7, 14 and 35 feet above the roof of the storage level drifts and rooms. The remaining two beds occur beneath the floor of the drifts and rooms. The most significant of these two beds is MB-139 which occurs approximately 3 1/2 to 4 1/2 feet below the floor of the storage level and varies from 2.5 to 4 feet in thickness. The remaining bed occurs about 32 feet below the storage level and is approximately 4 inches thick. Thin clay seams underlie all of the anhydrite beds.

Fifteen lithologic units have been identified during geologic mapping within the facility level drifts, rooms and waste experimental area. The majority of these units are halite containing varying amounts of polyhalite and argillaceous material, usually less than 2 percent. The remaining units consist of 2 anhydrite beds, 2 argillaceious halite units and 1 polyhalitic halite unit. Each of the 15 mapped units has been assigned a numerical designation as shown on Figure 6-2 and contained in Table 6-3.

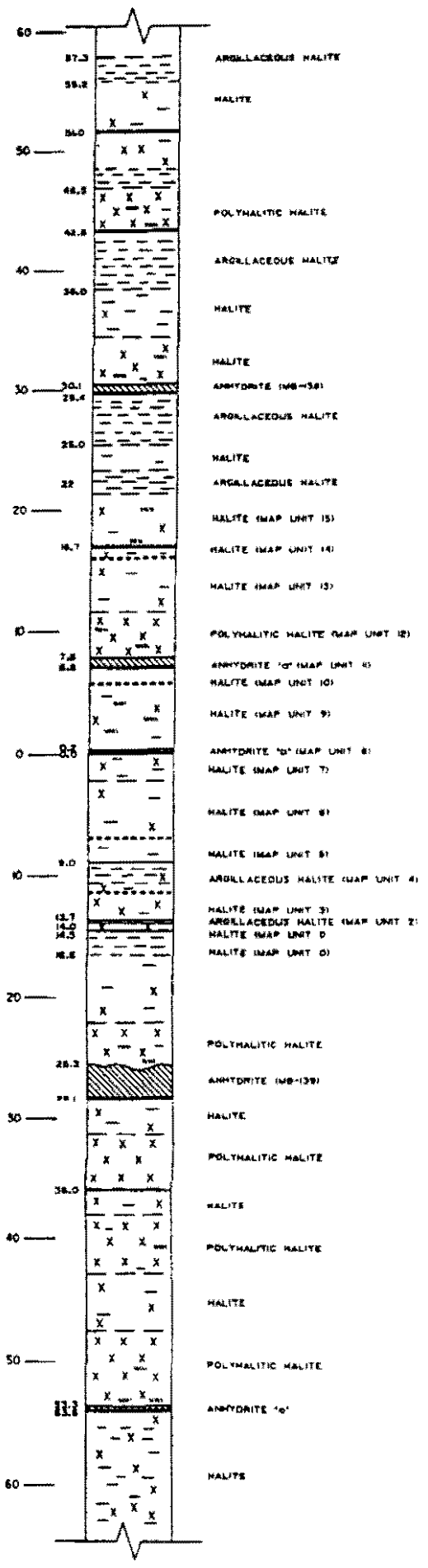

(SEE TABLE 6-3 FOR DETAILED DESCRIPTIONS OF UNITS)

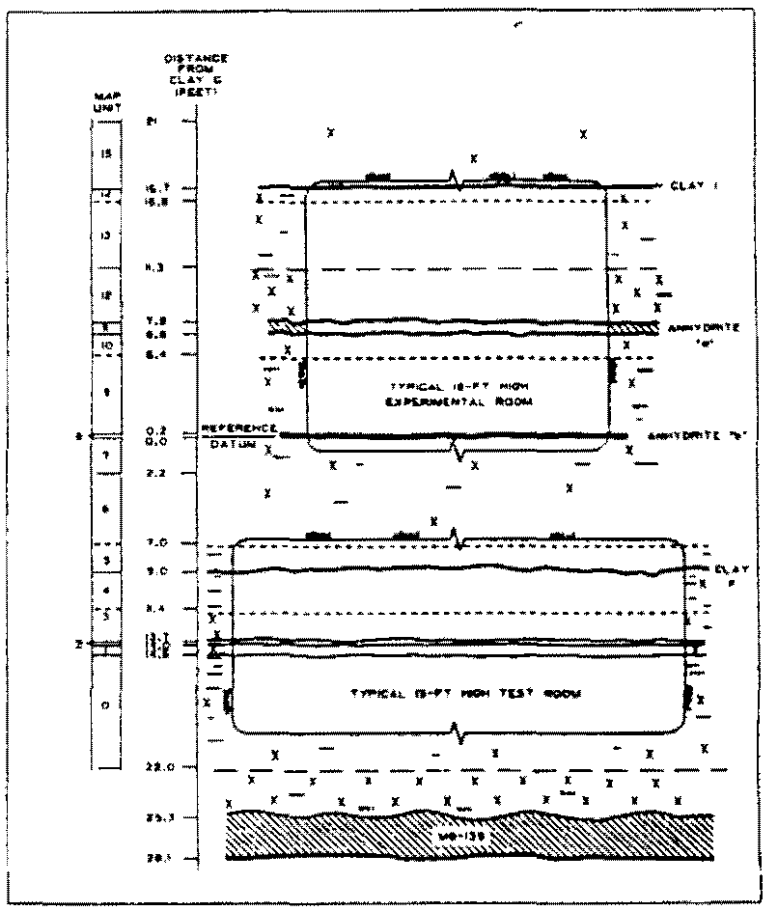

EXPLANATION

ROCK TYPE

HALITE — ANHYDRITE — POLYHALITIC HALITE — ARGILLACEOUS HALITE

ACCESSORY CONSTITUENTS

POLYHALITE — LAMINAR FEATURES: CLAY SEAM >1/16 IN. THICK

ARGILLACEOUS MATERIAL

ANHYDRITE STRINGERS

LITHOLOGIC CONTACTS

SHARP (IDENTIFIABLE WITHIN 0.05 FT.) — GRADATIONAL (IDENTIFIABLE WITHIN 0.05 TO 0.2 FT.) — DIFFUSE (IDENTIFIABLE WITHIN 0.2 TO 0.5 FT.)

NOTES:

1. DISTANCES ARE MEASURED FROM THE BASE OF ANHYDRITE 'b' (CLAY G) AND ARE AVERAGED FROM REPRESENTATIVE CORE HOLE LOGS, SHAFT AND TEST ROOM MAPPING. ACTUAL DISTANCES AND UNIT THICKNESSES MAY VARY LOCALLY FROM THOSE SHOWN.
2. DESCRIPTIONS OF UNITS ARE BASED ON CORE HOLE DATA, SHAFT MAPPING AND VISUAL INSPECTION OF EXPOSURES IN UNDERGROUND DRIFTS AND ROOMS.
3. DETAILED DESCRIPTIONS OF CLAY SEAMS ARE PRESENTED ON FIGURE 6-4.
4. PERCENTAGES OF ARGILLACEOUS MATERIAL AND POLYHALITE ARE BASED ON VISUAL ESTIMATES FROM EXAMINATION OF DRILL CORE AND EXPOSURES IN THE UNDERGROUND EXCAVATIONS. SANDIA NATIONAL LABORATORIES' MEASUREMENTS OF INSOLUBLES FROM SELECTED CORE WERE USED AS A POINT OF REFERENCE.

Figure 6-2

WIPP GENERALIZED STRATIGRAPHIC COLUMN

Table 6-3

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
55.2 to 57.3	Argillaceous halite	Clear to moderate brown, medium to coarsely crystalline. <1 to 3% brown clay. Intercrystalline and discontinuous breaks. In one core hole, consists of a 1 in. thick clay seam. Unit can vary up to 4 ft thickness. Contact with lower unit is gradational.
46.5 to 55.2	Halite	Clear to moderate reddish orange and moderate brown, coarsely crystalline, some medium. ≤1% brown clay, locally argillaceous (clays M-1 and M-2). Scattered anhydrite stringers locally.
42.8 to 46.5	Polyhalitic halite	Clear to moderate reddish orange, some moderate brown, coarsely crystalline. <1 to 3% polyhalite. None to 1% brown and some gray clay. Scattered anhydrite locally. Contact with unit below is fairly sharp.
38.0 to 42.8	Argillaceous halite	Clear to moderate brown, medium to coarsely crystalline, some fine. <1 to 5% brown clay. Locally contains 10% clay. Intercrystalline and scattered breaks. Locally contains partings and seams. Contact with lower unit is gradational based on increased clay content. Average range of unit is 38.0 to 42.8 ft above clay G but does vary from 33.8 to 46 ft.
34.0 to 38.0	Halite	Clear to moderate brown, some moderate reddish brown, coarsely crystalline, some fine and medium. ≤1% brown clay, trace gray clay locally. Scattered breaks. Locally argillaceous. <1% polyhalite. Contact with unit below is gradational based on clay and polyhalite content.
30.1 to 34.0	Halite	Clear to moderate reddish orange, coarsely crystalline. <1 to 3% polyhalite. Commonly polyhalitic. Scattered anhydrite stringers with anhydrite layers up to 1/2 in. thick locally. Scattered brown clay locally. Contact with MB-138 below is sharp.
29.4 to 30.1	Anhydrite (MB-138)	Light to medium gray, microcrystalline. Partly laminated. Scattered halite growths. Clays seam K found at base of unit.
25.0 to 29.4	Argillaceous halite	Clear to moderate brown, some light moderate reddish orange. Medium to coarsely crystalline. <1 to 3% brown clay, some gray. Locally up to 5% clay. Clay is intercrystalline with scattered breaks and partings present. < 1/2% dispersed polyhalite. Contact with lower unit is gradational based on clay content. Upper contact is sharp with clay K.
23.0 to 25.0	Halite	Clear, some light moderate brown, coarsely crystalline. <1/2% brown clay. Contact with clay J below varies from sharp to gradational depending if clay J is a distinct seam or merely an argillaceous zone.
21.0 to 23.0	Argillaceous halite	Usually consists of scattered breaks or argillaceous zone containing <1 to 3% brown clay. In C & SH shaft, it is a 1/2 in. thick brown clay seam.
16.7 to 21.0	Halite (Map Unit 15)	Clear, coarsely crystalline, scattered medium. None to <1% dispersed polyhalite and brown clay. Scattered anhydrite. Lower contact is sharp with clay I.
15.8 to 16.7	Halite (Map Unit 14)	Clear to grayish orange-pink, coarsely crystalline, some medium. <1/2% dispersed polyhalite. Scattered discontinuous gray clay stringers. Clay I is along upper contact. Contact with lower unit is diffuse.
11.5 to 15.8	Halite (Map Unit 13)	Clear to moderate reddish orange and moderate brown, medium to coarsely crystalline, some fine. ≤1% brown clay, locally up to 3%. Trace of gray clay. Scattered discontinuous breaks. <1% dispersed polyhalite and polyhalite blebs. Contact with unit below is gradational based on clay and polyhalite content.

Table 6-3 (continued)

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
7.5 to 11.5	Polyhalitic halite (Map Unit 12)	Clear to moderate reddish orange, coarsely crystalline. <1 to 3% dispersed polyhalite and polyhalite blebs. Scattered anhydrite stringers. Contact is sharp with unit below.
6.8 to 7.5	Anhydrite "a" (Map Unit 11)	Light to medium gray, light brownish gray and sometimes light moderate reddish orange. Microcrystalline. Halite growths within. Partly laminated. Clear, coarsely crystalline halite layer, up to 2 in. wide, found within exposures in waste experimental area. Thin gray clay seam H at base of unit.
5.5 to 6.8	Halite (Map Unit 10)	Clear to moderate reddish orange/brown, fine to coarsely crystalline. <1% brown and/or gray clay and dispersed polyhalite. Discontinuous clay stringers locally. Contact with lower unit is diffuse based on crystal size and varying amounts of clay and polyhalite.
0.2 to 5.5	Halite (Map Unit 9)	Clear to light moderately reddish orange, coarsely crystalline, some medium. None to <1% polyhalite. Trace of gray clay locally. Scattered anhydrite stringers. Contact with unit below is sharp.
0.0 to 0.2	Anhydrite "b" (Map Unit 8)	Light to medium gray, microcrystalline anhydrite. Scattered halite growths. Thin gray clay seam G at base of unit.
0.0 to -2.2	Halite (Map Unit 7)	Clean to light/medium gray, some moderate reddish orange/brown. Coarsely crystalline, some fine and medium. <1 brown and gray clay. Locally up to 2% clay. <1% dispersed polyhalite. Upper contact is sharp with clay G. Contact with lower unit is gradational.
-2.2 to -7.0	Halite (Map Unit 6)	Clear, some moderate reddish orange, coarsely crystalline, some fine to medium locally. <1/2% gray clay and polyhalite. Contact with lower unit gradational and/or diffuse.
-7.0 to -9.0	Halite (Map Unit 5)	Clear coarsely crystalline. <1/2% gray clay. Contact with lower unit is usually sharp with clay F.
-9.0 to -11 4	Argillaceous halite (Map Unit 4)	Clear to moderate brown and moderate reddish brown, coarsely crystalline. <1% polyhalite. <1 to 5% argillaceous material; predominantly brown, some gray, locally. Intercrystalline and discontinuous breaks and partings common in upper part of unit. Decreasing argillaceous content downward. Contact with lower unit is gradational.
-11.4 to -13.7	Halite (Map Unit 3)	Clear to moderate reddish orange, coarsely crystalline. <1% dispersed polyhalite and polyhalite blebs. Locally polyhalitic. Scattered gray clay locally. Contact with lower unit is sharp.
-13.7 to -14.0	Argillaceous halite (Map Unit 2)	Moderate reddish brown to medium gray, medium to coarsely crystalline. <1 to 3% argillaceous material. Contact with lower unit is usually sharp.
-14.0 to -14.5	Halite (Map Unit 1)	Light reddish orange to moderate reddish orange, medium to coarsely crystalline. <1% dispersed polyhalite. Contact with lower unit is sharp.
-14.5 to -22.0	Halite (Map Unit 0)	Clear to moderate reddish orange/brown, moderate brown and grayish brown. Medium to coarsely crystalline. <1 to 5% argillaceous material. Predominantly brown, some gray, intercrystalline argillaceous material and discontinuous breaks and partings. Upper two feet of unit is argillaceous halite decreasing in argillaceous material content downward. None to <1% polyhalite. Contact with lower unit is gradational based on polyhalite content.

Table 6-3 (continued)

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
-22.0 to -25.3	Polyhalitic halite	Clear to moderate reddish orange. Coarsely crystalline, some medium locally. <1 to 3% polyhalite. Scattered anhydrite. Scattered gray clay locally. Contact with lower unit (MB-139) is sharp, but commonly irregular and undulating. Trace of gray locally present along this contact.
-25.3 to -28.1	Anhydrite (MB-139)	Moderate reddish orange/brown to light and medium gray, microcrystalline anhydrite. "Swallowtail" pattern, consisting of halite growths within anhydrite, common in upper part of unit. Locally, hairline, clay-filled, low-angle fractures found in lower part of unit. Thin halite layer common close to lower contact. Clay seam E found at base of unit. Upper contact is irregular, undulating and sometimes contains <1/16 in. gray clay.
-28.1 to -31.2	Halite	Clear to moderate reddish orange, and light gray. Coarsely crystalline, some fine and medium. ≤1% polyhalite and intercrystalline gray clay. Contact with lower unit is gradational based on increased polyhalite content.
-31.2 to -36.0	Polyhalitic halite	Clear to moderate reddish orange, coarsely crystalline. < 1 to 3% polyhalite. Contact with lower unit is usually sharp along clay D.
-36.0 to -37.8	Halite	Clear to moderate reddish orange, some light gray. Medium to coarsely crystalline. ≤1% polyhalite and gray clay. Contact with lower unit is gradational based on increased polyhalite content.
-37.8 to -42.7	Polyhalitic halite	Clear to moderate reddish orange/brown, coarsely crystalline. < 1 to 3% polyhalite. Trace of clay locally. Scattered anhydrite locally. Contact with lower unit is gradational, based on decreased polyhalite content.
-42.7 to -47.3	Halite	Clear to moderate reddish orange, medium to coarsely crystalline. < 1% dispersed polyhalite. < 1% brown and/or gray clay. Contact with lower init is gradational and/or diffuse.
-47.3 to -53.3	Polyhalitic halite	Clear to moderate reddish orange. Coarsely crystalline with some medium sometimes present close to lower contact. <1 to 3% polyhalite. Scattered anhydrite especially common close to anhydrite "c". Lower contact is sharp with anhydrite "c".
-53.3 to -53.5	Anhydrite "c"	Light to medium gray, microcrystalline anhydrite. Scattered halite growths. Faintly laminated locally. Clay seam B found at base of unit.
-53.5 to -65.7	Halite	Clear to medium gray and moderate brown. Medium to coarsely crystalline, some fine locally. ≤1% polyhalite, locally polyhalitic. <1 to 3% clay, both brown and gray. Intercrystalline clay with discontinuous breaks and partings. Zones of argillaceous halite found within unit. Seams of clay mixed with halite crystals present locally. Upper contact of this unit is sharp with clay B.

* Descriptions are based on examination of drill core and exposures of units in shafts and other underground openings.

Map units 1 through 6 occur within the storage level drifts and rooms. Unit 1 is a distinct, relatively thin, orange-colored unit commonly referred to as the "orange marker bed". This unit is continuous throughout the facility level excavations. During excavation, it was used as a marker to help keep the underground openings within the proper stratigraphy. The descriptions for map units 7 through 15 represent the lithology most frequently encountered in the drifts and rooms in the waste experimental area. Minor variations in these lithologies occur at various locations but they are not of sufficient difference to justify their inclusion in the generalized descriptions.

6.3.1.2 Stratigraphic Continuity

The results of geologic mapping and core hole drilling in the underground facility have confirmed the lateral extent and stratigraphic continuity of the geologic units within the underground facility horizon. Strata exposed in the drifts have been traced continuously for 4,500 feet in an east-west direction and more than 5,000 feet in a north-south direction. North-south and east-west correlations between the vertical core holes have also demonstrated the continuity of the stratigraphic units above and below the facility level. Figures B-4 through B-9 in Appendix B show the correlations of stratigraphic horizons that have been made based on core hole data. These figures also demonstrate the slight southern dip of the units. Figure B-5 shows a slight thinning of units to the south by about 5 percent. Figures B-1 and B-2 show a larger correlation of stratigraphic horizons between boreholes WIPP-12 to the north and DOE-1 to the south. The five anhydrite beds shown on Figure 6-2 are laterally continuous across the WIPP site.

Although the general character of each stratigraphic unit remains constant throughout the underground facility horizon, minor variations occur. Some thin clay seams are discontinuous and some halite units thin locally or pinch out. The disruptions of some of these units are localized phenomena thought to result from syndepositional processes. Both lateral and vertical variations in the argillaceous and polyhalite

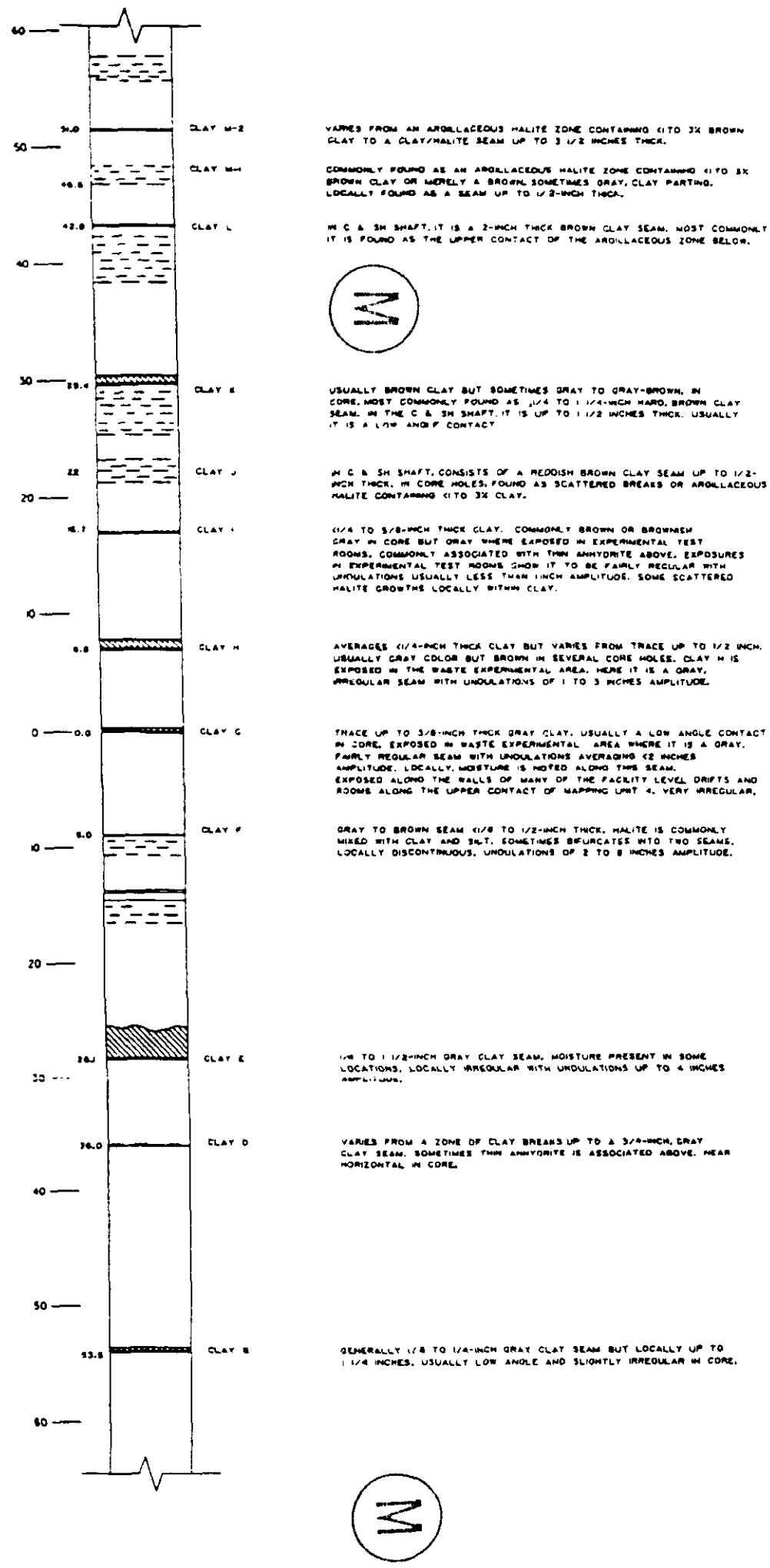

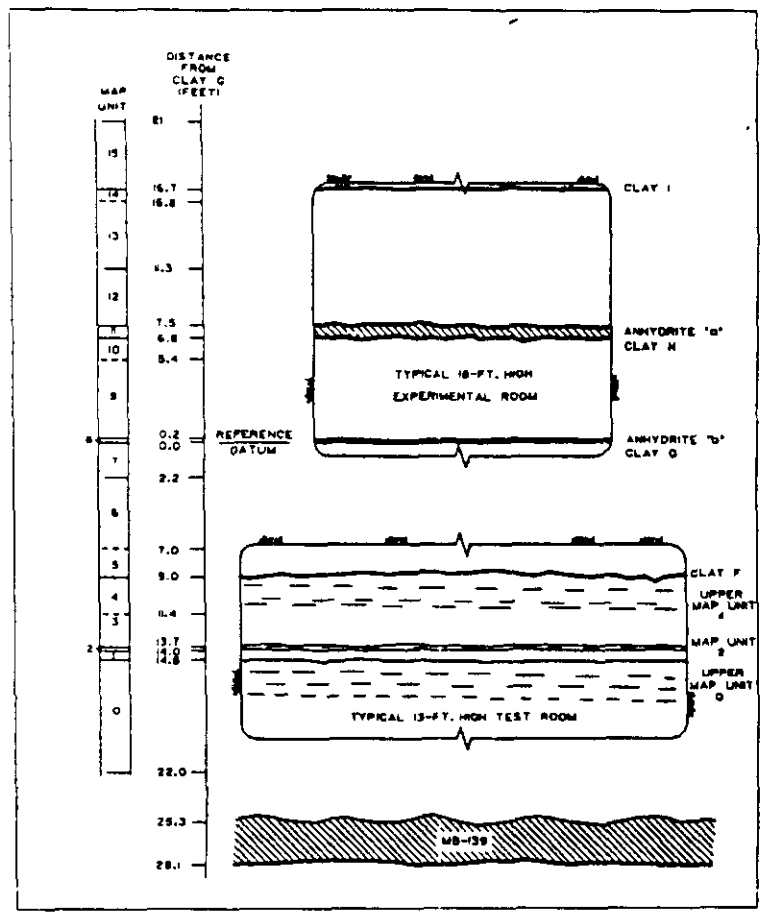

EXPLANATION

ROCK TYPE

ANHYDRITE

ARGILLACEOUS HALITE

ACCESSORY CONSTITUENTS

ANHYDRITE STRINGERS

LAMINAR FEATURES

CLAY SEAM 1/4 IN. THICK

LITHOLOGIC CONTACTS

SHARP

IDENTIFIABLE WITHIN 0.05 FT.

NOTES:

1. DISTANCES ARE MEASURED FROM CLAY G AND ARE AVERAGED FROM REPRESENTATIVE CORE HOLE LOGS AND SHAFT MAPPING.
2. DESCRIPTIONS OF CLAY SEAMS ARE BASED ON CORE HOLE DATA, SHAFT MAPPING AND VISUAL INSPECTION OF EXPOSURES IN UNDERGROUND DRIFTS AND ROOMS.
3. ONLY CLAY SEAMS ARE SHOWN ON THIS FIGURE. ALL OTHER UNITS ARE SHOWN ON FIGURE 6-2 AND DESCRIBED IN TABLE 6-3.

Figure 6-3

CLAY SEAMS

content of the halite units are common. The size of halite crystals varies from fine to coarse both laterally and vertically within inidvidual units. Although the anhydrite is microcrystalline, the beds vary laterally in color, thickness and polyhalite or halite content. The upper surface of MB-139 is undulatory with amplitudes of up to 12 inches.

The halite around the underground openings exhibits slightly varied behavior in response to excavation at different locations. This may be due to minor variations in crystal size or clay content. The clear halite in the roof of the E140 drift south of the waste shaft exhibits more spalling than is apparent in similar halite in other areas of the underground openings. Spalling along the upper portion of map unit 4 occurs in many of the facility level drifts and rooms. In the locations where this unit contains abundant argillaceous material, the spalling appears to be more pronounced. This behavior is discussed in Chapters 10 and 11.

6.3.1.3 Reference Stratigraphy

A meeting was held on November 15, 1979, to determine a reference stratigraphy for the WIPP site. This was titled the "November '79 Reference Stratigraphy" and was based on data obtained from exploratory boreholes. The purpose of the reference stratigraphy was to provide input data for thermal/structural analyses of shafts, drifts and rooms at the WIPP that could be referenced by all structural analysts and updated as more data became available.

The "November '79 Reference Stratigraphy" was revised in July 1981 and again in September 1983 as more data were collected from construction activities and underground core holes. The 1983 revision was titled "September '83 Reference Stratigraphy". This revision was based on the evaluation of 39 core hole logs and the geologic mapping performed in the SPDV exploratory and ventilation shafts.

The evaluation determined that the strata are fairly horizontal but dip slightly to the south. Based on a statistical analysis, the entire stratigraphic section was found to vary in elevation in a regular manner, but individual unit thicknesses and the relative separation between units were found to have no statistically significant variation between the northern and southern limits of the underground facility horizon (ref. 5-3).

Figure 6-4 shows the reference stratigraphy developed by this statistical analysis. This stratigraphy consists of 1 polyhalite bed, 2 argillaceous halite units, 7 anhydrite beds, 12 clay seams, and halite as the remaining constituent. This reference stratigraphy extends approximately 165 feet above and below the facility level. The location and thickness of the various units were adjusted by averaging values determined from the core holes. Geologic maps of the SPDV exploratory and ventilation shafts and the log of borehole ERDA-9 were used for units outside the WIPP underground facility horizon. The uniformity of the rock in the core holes and shafts, the lack of a statistically significant variation in unit thicknesses and elevation, and the expected small influence of any differences on structural behavior resulted in a decision to use the same reference stratigraphy throughout the site.

Subsequent to the development of the September 1983 reference stratigraphy, additional core holes were drilled and logged, the ventilation shaft was enlarged to the waste shaft, the exhaust shaft was completed, and both of these shafts were geologically mapped. Based on additional data from these activities, a generalized stratigraphic column of the underground facility horizon was developed (Figure 6-2 and Table 6-3). This stratigraphic column does not vary significantly from the earlier 1983 reference stratigraphy. Therefore, the 1983 reference stratigraphy continued to be used for model calculations.

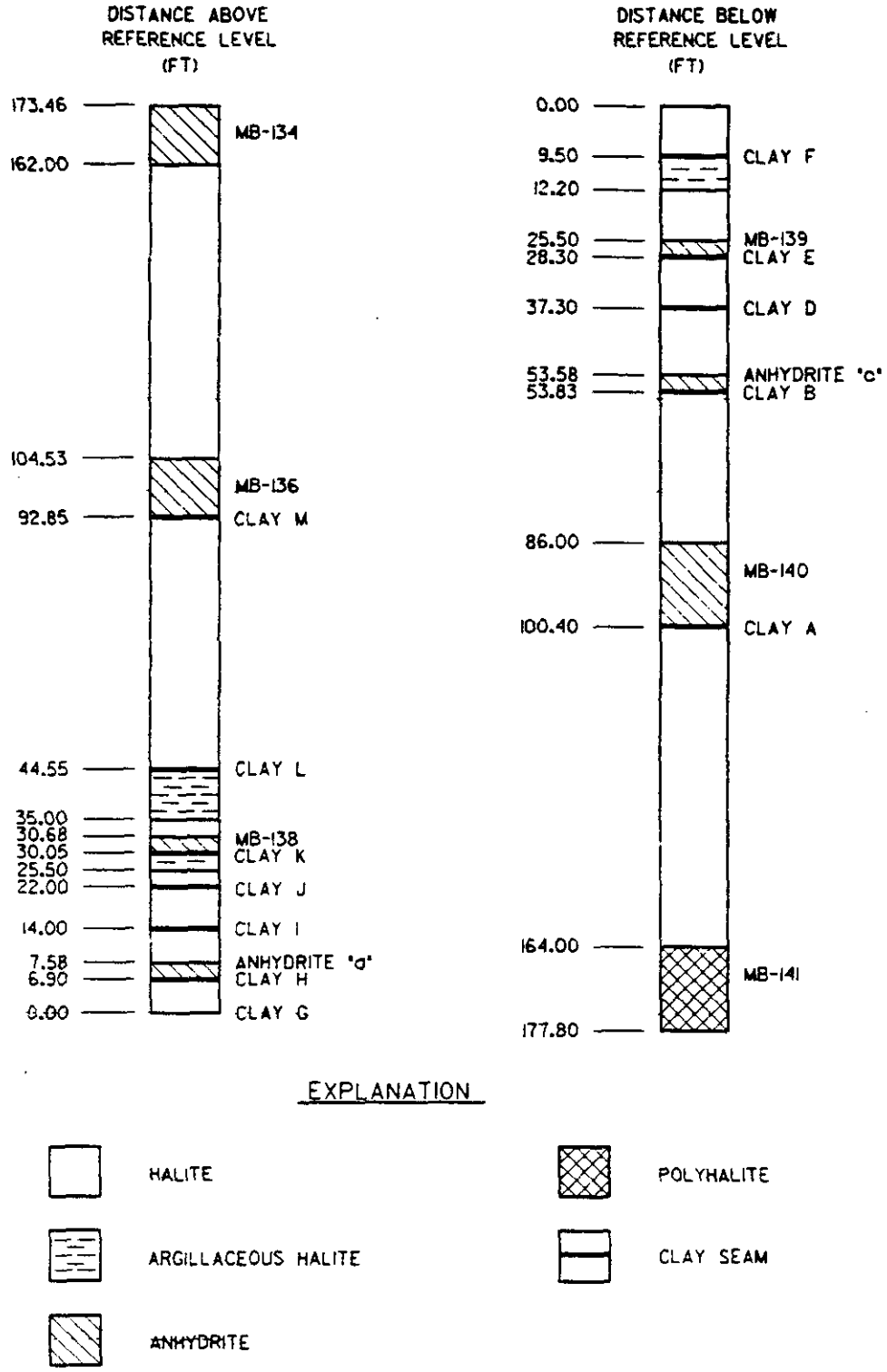

Figure 6-4

REFERENCE STRATIGRAPHY

6.3.2 Lithology

The Salado formation is predominantly halite, but other evaporite minerals and argillaceous materials are present that may locally compose up to 50 percent of the salt. Anhydrite, an early-precipitated evaporite mineral, is found in beds (usually less than 5 feet thick) which are typically underlain by a clay seam (1/16 to 3/4 inch thick). Polyhalite, a late-forming evaporite mineral, is commonly found as an accessory mineral in the Salado formation. Clay and silt may be found disseminated through the halite or in thin seams, partings, or breaks. Following is a description of the major lithologies occurring within the underground facility horizon.

Clear Halite. These units consist of halite with only trace amounts of impurities. The halite is predominantly medium to coarsely crystalline and clear to very light gray or moderate reddish orange. Less commonly, it occurs as finely crystalline, opaque, very light gray halite with a sucrose texture. Trace impurities of clay and/or polyhalite are generally dispersed in the halite. Scattered very light gray to white anhydrite or magnesite stringers may be present.

Polyhalitic Halite. These units are composed mainly of medium to coarsely crystalline halite with accessory amounts of polyhalite. As the polyhalite content increases, the color of the rock changes from transparent light orange-pink to translucent moderately reddish orange/brown or dark reddish brown. The polyhalite occurs primarily as interstitial blebs or patches and, less commonly, in stringers about 1/4 to 3/4 inch thick.

Argillaceous Halite. Six argillaceous halite units, three above and three below clay G, occur within the underground facility horizon. Generally, these units consist of medium to coarsely crystalline and some finely crystalline halite with from less than 1 to as much as 5 percent silty clay. The clay is predominantly brown in color with some gray. It is commonly intercrystalline or forms scattered breaks or partings. Discontinuous clay seams are present locally. The percent

of clay is a visual estimate; laboratory measurements of insolubles (ref. 6-5) were used as a reference.

The contacts between these units and the surrounding materials vary from gradational to distinct. Clays F, K and L occur at the upper contact of three of these argillaceous units. The three units below clay G are exposed in the underground drifts and rooms. These are geologic map units 2 and 4 and the upper portion of map unit 0 (Figure 6-2). They are exposed continuously throughout the openings except in the waste experimental area which is stratigraphically higher. Map unit 2 is very thin and absent in places.

No significant moisture is associated with these argillaceous halite layers. Commonly, they are slightly moist immediately after excavation and locally develop brine blisters on the walls of the underground openings.

Anhydrite. These beds range in thickness from a few inches to a few feet. Because they are readily identified, the anhydrite beds in the vicinity of the facility level have served as reference units.

Three anhydrite beds, 0.15 to 1.05 feet thick, are present above and two beds, 0.3 and 2.5 to 4 feet thick, are present below the facility level (Figure 6-2). All of the beds are laterally continuous and each is underlain by a thin clay seam. Locally, very thin anhydrite seams are associated with identified clay seams and scattered anhydrite stringers are common in several of the halite units. The anhydrite is microcrystalline and commonly ranges from a very light gray to medium gray-green color, although it is sometimes a moderate reddish to pinkish color. Halite growths are common, especially within MB-139. Anhydrite "a" commonly contains a clear halite seam up to 1 1/2 inches thick.

MB-139 is the thickest anhydrite unit within the underground facility horizon and is the most variable in color and composition. It is

described here in detail because of its importance in the deformational behavior of the underground openings, particularly the test rooms (Chapter 11).

MB-139 ranges from 2.5 to 4 feet thick. For mapping purposes, it has been divided into two subunits (Appendix G, Figures G-10 through G-34). Subunit A corresponds to Zones I, II and III described in reference 6-6. This subunit consists predominantly of reddish polyhalitic anhydrite and anhydrite mixed with light to medium gray anhydrite. Pods, lenses and seams of light to very light gray anhydrite are commonly scattered throughout the subunit. Irregular halite growths, ranging from less than 1/16 to more than 25 square inches, are common, especially in the upper half of subunit A. Commonly, a 1- to 2-inch thick seam of moderately reddish-orange to gray polyhalitic anhydrite with scattered halite and polyhalitic halite growths occurs along the upper contact. This corresponds to Zone I described in reference 6-6. Swallowtail growth patterns and hopper crystals are occasionally present in the upper 12 inches of subunit A, commonly within an upward undulation of the marker bed. Halite-filled fractures are found in places within the undulations. Scattered within the reddish polyhalitic anhydrite is an irregular and sometimes discontinuous layering of light gray anhydrite, which varies from less than 1/8 inch to 1/2 inch thick. Pods and lenses of gray anhydrite are often faintly aligned, although discontinuously, with the general trend of the layering. These pods and lenses are most prevalent in the lower half of subunit A.

Subunit B corresponds to Zones IV and V in reference 6-6. Its contact with subunit A is diffuse and based mainly on a change in color. Subunit B consists of light to medium gray anhydrite. Some core samples exhibit layering which faintly follows the general trend of the layering in subunit A. Halite growths are present, but to a much lesser degree than in subunit A. Usually the lower 4 to 8 inches of the subunit is faintly laminated and contains a few halite growths. A subhorizontal halite layer, usually less than 1/8 inch thick, is occassionally present close to the lower contact.

The upper contact of MB-139 is undulatory. The lower contact is underlain by clay E. This clay ranges from 1/4 inch to 1 1/2 inches thick. It is often slightly moist and sometimes wet.

Clay Seams. Characteristics of the clay seams within the underground facility horizon are shown on Figure 6-3 and summarized in Table 6-4. These include qualitative and/or quantitative characterizations and descriptions of the clay seams in terms of the following:

(1) color;
(2) thickness;
(3) moisture;
(4) grain size;
(5) consistency/plasticity;
(6) planar trend; and
(7) continuity/uniformity.

This information has been gathered through a review of core hole logs, geologic mapping and inspection of existing exposures.

The clay seams underlying anhydrite beds usually vary from less than 1/8 inch to 3/4 inch in thickness but may range up to 1 1/2 inches thick, as is common for clay E. The other, less continuous seams are usually less than 3/4 inch thick but may be as much as 2 inches thick, as is clay L in the C & SH shaft. Clay M-1 was as much as 3 1/2 inches thick in one hole but it consisted of a mixture of clay and halite crystals at this location.

Generally, the seams consist of clay with some silt. The clay varies from gray to brown in color. Only field classifications of the clay in core and underground exposures have been performed. These classifications indicate that the seams generally consist of soft to hard, medium plastic material. Locally, fine to coarse halite crystals are present in some of the seams. Clays F and M-1 commonly contain

Table 6-4

CLAY SEAM CHARACTERISTICS

Seam	Rating[1]	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
B	1	Gray	<1/8 to 1/4 in. average; locally up to 1 1/4 in.	Dry to slightly moist.	Passes #200 sieve.	Generally hard.	Slightly irregular; generally low angle in core but locally up to 35°.	Continuous.	Present in core holes and C & SH and waste shaft mapping.
D	2	Gray	≤3/4 in.	Dry except hole DO-57 where clay is moist; hole drilled with fluid.	Passes #200 sieve.	Hard to medium soft; medium to highly plastic.	Near horizontal in core.	Varies from zone of breaks to seam with associated anhydrite.	Present in many core holes and in C & SH shaft mapping
E	1	Gray	1/4 to 1 1/2 in.	Locally moist to wet.	Passes #200 sieve.	Soft to hard; medium plastic	---	Continuous.	Present in many core holes and in C & SH and waste shaft mapping.
F	2	Gray, sometimes brown.	<1/8 to 1/2 in.	Slight.	Passes #200 sieve. Commonly mixed with halite crystals.	Slightly plastic.	Very irregular; undulations of 2-in. to 8-in. amplitude.	This is at the upper contact of map unit 4; locally discontinuous; sometimes bifurcates into two seams.	Exposed along walls of many of the facility level drifts and rooms.
G	1	Gray	Trace up to 3/8 in.	Slightly to moderately moist; weeps along exposures in underground excavations.	Passes #200 sieve.	Soft to hard; medium plastic.	Fairly regular; undulations average <2-in. amplitude.	Continuous.	Found in most core holes, shaft mapping and underground waste experimental area excavation.
H	1	Gray; brown in several core holes.	Average ≤1/4 in. but ranges from trace up to 1/2 in.	Slightly to moderately moist.	Passes #200 sieve.	Medium plastic.	Fairly irregular; undulations of 1-in. to 3-in. amplitude.	Continuous.	Found in most core holes, shaft mapping and underground waste experimental area excavation.

Table 6-4 (continued)

CLAY SEAM CHARACTERISTICS

Seam	Rating (1)	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
I	1	Brown-brownish gray in core; gray where exposed in waste experimental rooms.	<1/4 to 5/8 in.	Slightly moist.	Passes #200 sieve; some scattered halite crystals locally.	Hard in some core holes; medium plastic.	Regular; undulations generally <1-in. amplitude.	Fairly continuous.	Commonly found in core holes, C & SH and exhaust shafts; also exposed in waste experimental room excavation.
J	3	Reddish-brown	1/2 in. in C & SH Shaft only.	---	Passes #200 sieve; trace silt, trace to some halite crystals.	---	---	Generally found as scattered breaks or localized argillaceous zone.	Found in C & SH shaft as 1/2 in. seam; not found in other shafts; in core holes, found as scattered breaks or localized argillaceous zone; absent in many core holes.
K	1	Brown, sometimes gray to gray-brown.	3/4 to 1 1/2 in.	Dry to moist; locally wet.	Passes #200 sieve; claystone in exhaust shaft.	Hard to medium hard; medium plastic.	Generally low angle contact in core; fairly regular.	Continuous.	Present in many core holes and shafts.
L	3	Brown	Up to 2 in. in C & SH shaft; usually found only as top of argillaceous unit.	---	Passes #200 sieve; some halite crystals.	---	---	Not a continuous seam; it is found generally as the top of argillaceous zone throughout core holes and shafts.	Exposed in C & SH shaft as seam; otherwise only noted as top of argillaceous unit.

Table 6-4 (continued)

CLAY SEAM CHARACTERISTICS

Seam	Rating (1)	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
M-1	4	Brown	<1/16 to 1/2 in.	Dry	Passes #200 sieve.	---	---	Unknown.	These two layers found in core holes in waste experimental area; not noted in shaft mapping.
M-2	4	Brown	Up to 3 1/2 in.	Dry	Clay mixed with halite crystals.	---	---	Unknown.	

Notes:

(1) Key to "Rating": 1 - continuous throughout facility level;
2 - generally continuous, but varies in character and regularity;
3 - discontinuous and not always well developed;
4 - continuity unknown.

(2) Clays B, E, G, H and K are sometimes noted as only a trace or not at all on core logs. This is usually because core grinding or washing during drilling removed evidence of clay.

(3) Some core logs note clay layers are moist. In holes drilled with brine, this may be due to drilling fluid. Many layers are dry in holes drilled with air. These may actually be slightly moist in the in situ state, but dried out by the drilling process.

(4) Clays B, E, G, H and K always underly continuous anhydrite layers. Clays I and D are commonly associated with thin anhydrite layers.

(5) Plasticity and consistency based on evaluation of in situ condition.

more halite mixed with the clay/silt fraction. Clay F also appears to be more silty and less plastic than the other seams.

Generally, the clay seams are slightly moist in their in situ state. However, some of the seams are wet and exhibit some brine weeping in places. This was observed for clays E, G, H and K in some core holes. The clay seams in some of the holes where brine was used as a drilling fluid were observed to be moist. This was probably due in part to the drilling fluid. In contrast, clay seams were observed to be dry in many of the core holes drilled using air circulation. It is expected that, in the in situ state, these seams contain a slight amount of moisture which was evaporated as a result of the drilling method. Some moisture can be seen along exposures of clay H and clay G in the waste experimental area. More moisture is evident along clay G and some salt blisters have accumulated locally along this seam. The clay seams exposed in the underground openings are generally slightly moist during and immediately after excavation. Some seams have continued to expel moisture long after excavation. Often, however, they dry out at the surface within a few days after their exposure.

Clays G, H and I, exposed in the waste experimental area, commonly contain white specks which may be salt resulting from the air drying of the clay. The clay usually has a slightly salty taste. These white specks are soft, can be easily crushed between the fingers, and have a slightly bitter taste.

The consistency of the clay encountered in the core holes and excavations is related to its moisture content. When wet or moist, the clay is generally soft to medium stiff and can be picked out with the fingers and molded into a ball in the hand. When the clay is only slightly moist or dry, it is stiff to hard and is difficult to work in the hand.

6.3.3 Structure

Geologic mapping of the underground openings has not identified any faults, joints, significant folds, or other structural disruptions that could affect the suitability of the WIPP facility for storing radioactive waste. Very small scale (approximately 1 foot), localized disruptions of the bedding have been encountered. These are attributed to penecontemporaneous processes.

Detailed correlations between vertical core holes, combined with the results of geologic mapping in the drifts and test rooms, indicate that the strata within the underground facility horizon are deformed slightly into a sinusoidal shape. Figure B-4 in Appendix B depicts this shape, but greatly exaggerates the amplitude of the deformation. The amplitude of the fold is approximately 10 to 15 feet and its wavelength is approximately 2,000 to 3,000 feet. The fold is superimposed on a gentle southward dip.

The deformation of the strata is post-depositional in origin. While undulations of depositional surfaces are common, all of the strata in the interval from 50 feet above to 50 feet below the facility level exhibit parallel undulations. This consistency in folding over a relatively large interval containing numerous depositional sequences suggests that the beds were deformed after deposition. The folding is a minor feature which does not adversely affect the suitability of the facility for waste storage.

6.4 PROPERTIES OF HOST ROCKS

As discussed in subsection 6.3.2, the underground facility horizon is composed of halite containing beds of argillaceous halite, anhydrite, polyhalite and thin clay seams. Laboratory tests were performed to determine the constitutive equations and material property constants for these host rocks (ref. 5-3). Subsections 6.4.1 and 6.4.2 present the properties of the host rocks based on laboratory and in situ data. In situ closure measurments were also used to "back calculate" the creep parameters for halite.

6.4.1 Laboratory Tests

Laboratory tests were performed on core samples from surface boreholes at the WIPP site prior to the initiation of underground excavation (ref. 5-3). Material property constants determined from the laboratory tests are presented in Tables 6-5 through 6-7. Table 6-5 shows the elastic constants for halite, argillaceous halite, anhydrite and polyhalite.

The failure criteria for both anhydrite and polyhalite were defined based on the results of the laboratory tests. One such criterion is Mohr-Coulomb, which defines failure in terms of friction and cohesion. Failure means that the material is unable to hold a deviatoric stress beyond a certain value. Once this value is reached, the material starts yielding. However, the Mohr-Coulomb criterion ignores the effect of intermediate principal stress on failure. In terms of principal stresses at failure,

$$(\sigma_3 - \sigma_1) = 2\Theta_o \cos\beta - (\sigma_3 + \sigma_1) \sin\beta \qquad (6\text{-}1)$$

where: Θ_o and β are Mohr-Coulomb parameters; and

σ_1 and σ_3 are principal stresses that are positive in tension.

Because the process of yield must be independent of the choice of axes, the failure criterion must be independent of the choice of axes and should be expressed in terms of stress invariants. The Drucker-Prager yield criterion is expressed as follows:

$$\sqrt{J_2'} = c - aJ_1 \qquad (6\text{-}2)$$

where: $\sqrt{J_2'}$ is the second stress invariant and is equal to $\bar{\sigma}/\sqrt{3}$; and

J_1 is the first stress invariant:

$$J_1 = \sigma_1 + \sigma_2 + \sigma_3 \qquad (6\text{-}3)$$

$$\bar{\sigma} = \frac{1}{\sqrt{2}} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2} \qquad (6\text{-}4)$$

Table 6-5

ELASTIC CONSTANTS DETERMINED FROM LABORATORY TESTS

MATERIAL	E (ksf)	ν
Halite	647,450.	0.25
Argillaceous halite	647,450.	0.25
Anhydrite	1,568,500.	0.35
Polyhalite	1,155,000.	0.36

Note:

E = elastic modulus

ν = Poisson's ratio

Table 6-6

FAILURE CONSTANTS DETERMINED FROM LABORATORY TESTS

	ULTIMATE				YIELD			
MATERIAL	Θ_0 (ksf)	β (°)	a	c (ksf)	Θ_0 (ksf)	β (°)	a	c (ksf)
Anhydrite	627.	37.0	0.279	752.	564.	29.0	0.226	689.
Polyhalite	395.	51.0	0.395	414.	359.	46.5	0.361	403.

Table 6-7

CREEP CONSTANTS DETERMINED FROM LABORATORY TESTS

	PRIMARY CONSTANTS			SECONDARY CONSTANTS		
MATERIAL	A	B	$\dot{\varepsilon}^*$ (sec^{-1})	D ($ksf^{-4.9}$ sec^{-1})	n	Q (kcal/mole)
Halite	4.56	127	5.39×10^{-8}	4.96×10^{-13}	4.9	12.0
Standard Error				1.05×10^{-13}	0.27	0.65
Argillaceous Halite	4.56	127	5.39×10^{-8}	1.49×10^{-12}	4.9	12.0

For anhydrite, however, the ultimate strength decreases somewhat with the change in strain rate. That is, a 10 percent decrease occurs as the strain rate is decreased from 10^{-4} sec^{-1} to 10^{-6} sec^{-1}. For polyhalite, the ultimate strength is assumed to be independent of the strain rate. Table 6-6 shows the failure constants for anhydrite and polyhalite.

Table 6-7 shows the creep constants for halite and argillaceous halite. Although the data for most individual creep tests are internally consistent, steady-state creep rates obtained from different specimens tested under the nominally same conditions may scatter by an order of magnitude. Nevertheless, statistical analysis has resulted in a "best fit" to the data. Table 6-7 also shows the deviation of the secondary creep constants for halite. It was concluded that when such large deviations or uncertainty exist, calculations using mean values are apt to be meaningless and the design process requires considerable judgement (ref. 6-7).

Based on laboratory tests, the failure criterion of halite can be described using a failure function ø, such that when ø becomes positive, halite no longer supports any deviatoric stress. The function ø is assumed to be:

$$\phi = \bar{\varepsilon} - 0.023 - f(p) \qquad (6\text{-}5)$$

where: $\bar{\varepsilon}$ is the effective creep strain (see Appendix C) and the function f(p) is expressed as:

$$f(p) = \begin{cases} 0.132 & \text{for } p \geq 125.26 \text{ ksf} \\ p(a - bp) & \text{for } p \leq 125.26 \text{ ksf} \end{cases} \qquad (6\text{-}6)$$

where: p, the pressure in ksf, is expressed as

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$$p = -\frac{\sigma_1 + \sigma_2 + \sigma_3}{3} \qquad (6\text{-}7)$$

and is positive in compression; and

a and b are equal to 2.122×10^{-3} ksf^{-1} and 8.487×10^{-6} ksf^{-2}, respectively (ref. 5-3).

Equation 6-5 indicates that if $\bar{\epsilon} \geq 0.023 + f(p)$ at any point in the halite, yielding will be initiated at that point. For p greater than 120 ksf, the failure effective strain is about 0.16.

Laboratory test results have also shown that a clay seam will be active for a frictional coefficient of 0.4, and that clay seam separation is unlikely unless the seam is very near the opening.

The average unit weight of the salt within the reference stratigraphy interval was determined to be 143.6 pounds per cubic foot (pcf) (ref. 5-3).

6.4.2 In Situ Data

In situ data was gathered from geomechanical instruments at various underground locations. The creep law shown by equation C.4-1 in Appendix C was used to fit the in situ data and to determine the creep parameters. The MARC General Purpose Finite Element Program (ref. 6-8) was used for the numerical computation based on the theory discussed in Appendix C. Table 6-8 shows the primary and secondary creep parameters determined from test room in situ data. Chapter 11 presents a more detailed discussion of the procedures used for computing these parameters.

Secondary creep parameters were also computed using in situ data from the C & SH shaft. The secondary creep parameters computed from horizontal deformations in the C & SH shaft and in the test rooms are reasonably close. The parameter based on test room wall-to-wall

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Table 6-8

CREEP PARAMETERS DETERMINED FROM IN SITU DATA

MATERIAL	PRIMARY PARAMETERS A	PRIMARY PARAMETERS z (sec^{-1})	SECONDARY PARAMETER C ($ksf^{-4.9}$ sec^{-1})
Halite			
Roof-to-Floor	1.774	5.573×10^{-8}	2.588×10^{-21}
Wall-to-Wall	1.618	4.757×10^{-8}	1.361×10^{-21}

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closure is 1.36×10^{-21} $ksf^{-4.9}$ sec^{-1} while the parameter based on extensometer measurements in the C & SH shaft is 1.30×10^{-21} $ksf^{-4.9}$ sec^{-1}.

6.5 SURFACE SUBSIDENCE MONITORING

The design criteria state that subsidence due to underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft. The layout of the underground excavation and the extraction ratio requirements were established to comply with this criteria. Subsidence monuments have been installed on the ground surface above the shaft pillar area (Chapter 2, Figure 2-2). Additional subsidence monuments are scheduled to be installed above the storage area in mid-1986. These monuments will be used to determine surface subsidence during the 25-year facility operating life.

Because the storage area has not yet been excavated, actual subsidence cannot be measured. This subsidence will occur over the next 25 years. The calculations used for the reference design indicate that subsidence is not likely to exceed the criteria limit. Therefore, the reference design subsidence criteria is considered validated on a computational basis rather than on actual measurement data. A review of this conclusion may be required later when a history of actual subsidence is available.

CHAPTER 7

C & SH SHAFT

7.1 INTRODUCTION

This chapter presents the results of the design validation program for the C & SH shaft. Included are discussions of the design criteria, design bases and design configurations pertaining to the C & SH shaft. This is followed by information and data from the design validation process including the data collected, its analysis and evaluation, and predictions regarding future behavior of the shaft liner and key and the rock strata surrounding the shaft. Conclusions and recommendations are presented based on a comparison of the results of the design validation process with the reference design.

7.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the C & SH shaft. The configuration of the shaft is discussed in Chapter 3, subsection 3.3.1.

7.2.1 Design Criteria

The Design Criteria document (ref. 2-8) contains the general concepts that were used as a guide for design of the WIPP underground openings. Table 2-1 summarizes those design criteria elements that are to be evaluated by the design validation process. The following discussion provides a summary of the elements that pertain to validation of the C & SH shaft reference design.

The design criteria specify that all shafts shall be designed for structural stability over an operating life of 25 years. The design shall also consider the requirements for shaft decommissioning and sealing. Shaft design shall prevent wall deformations which would interfere with shaft functions or affect the safety of operations within the shafts. Rock support shall be used as required to limit rock deformations and to prevent loosening and fallout of wall rock.

The time-dependent diametric closure of the shafts due to creep shall be considered in their design. The shafts shall be designed so that the minimum dimensions required for shaft functions are maintained throughout the operating life of the facility. Provisions for instruments to measure closure shall be included in the design.

Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the facility level via the shafts. Ground-water pressures and inflows shall be measured throughout the construction period and operating life of the shaft.

Shaft design shall consider the requirements of decommissioning and backfilling upon termination of operations. The design shall accommodate the need to ultimately seal potential pathways between the storage facility and the biosphere.

The shaft liner shall be designed to help ensure that the shaft dimensions remain within the limits required for shaft functions, prevent ground-water flow into the shaft, protect wall rock from deterioration, and preclude the risk of rockfall from the shaft walls.

The shaft stations shall be designed to provide structurally stable excavations and pillars. Deformations of excavations and pillars shall remain within the limits required for structural functions, ventilation and safety. The excavation design shall maintain the minimum dimensions required for the operating life of the opening by accommodating closure. Closure rates used for design shall be confirmed or modified by instrument observations in the excavations. Rock bolts shall be used where necessary to provide support of the roof and walls.

7.2.2 Design Bases

The Design Basis, Exploratory Shaft (ref. 2-10) and the Design Basis, Exploratory Shaft Geomechanical Instrumentation (ref. 2-12) were the primary documents used as a basis for design of the C & SH shaft. These documents, described in Chapter 2, provided the detailed design

requirements for the C & SH shaft. Table 7-1 summarizes those design basis elements which are to be evaluated by the design validation process. The following discussion provides a summary of the major design bases for the C & SH shaft. Not all of these bases require evaluation as seen by comparing the discussion with Table 7-1.

The design bases specify that the C & SH shaft shall be designed to provide access for personnel and equipment to excavate and operate the underground facility and to provide a means by which the excavated salt can be transported to the surface. It shall also serve as the ventilation intake shaft.

The shaft liner shall be made of structural steel and have an inside diameter of 10 feet. The remainder of the shaft shall be unlined and have an approximate diameter of 11 feet 8 inches. The steel liner shall extend from 1 foot above the ground surface to the top of the salt formation at a depth of approximately 850 feet. The primary materials used to line the shaft shall be cement grout, steel casing, corrugated metal pipe, structural steel and reinforced concrete.

The liner shall protect against sloughing, fallout and deterioration of the rock formations and shall prevent water seepage into the shaft. It shall have a smooth inner surface to reduce air friction. The liner shall be designed for temporary installation loads and permanent loads. The permanent load shall consist of a hydrostatic lateral pressure starting 250 feet below the ground surface and extending to approximately 837 feet below the surface. Rock pressure shall not be used as a factor in the design analysis. Installation loads to be considered shall be the compressive and tensile forces resulting from lateral pressure due to unequal heights of drilling fluid during the various stages of installation.

During shaft drilling, ground-water flow into the shaft shall be determined. If the amount of ground water entering the shaft is determined to be unacceptable by the DOE Contracting Officer, approved

Table 7-1

VALIDATION ELEMENTS OF C & SH SHAFT DESIGN BASES

(1) Shaft Liner

a. Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.

b. Water shall be prevented from flowing down the unlined shaft from behind the liner.

(2) Shaft Key

a. Key shall be designed to resist the lateral pressure from the salt. (Assumed to be 75 percent of the overburden pressure.)

b. Key shall be designed to resist the hydrostatic pressure from above the salt.

(3) Unlined Section

Provide 11-foot 8-inch diameter to allow for future salt creep deformation.

corrective action shall be taken to control the water inflow. The basis for determining if the amount of ground water flowing into the shaft is unacceptable shall be if the inflow exceeds an amount which can be tolerated without appreciably altering the drilling fluid characteristics as approved by the DOE Contracting Officer.

The shaft key shall be constructed using reinforced concrete and will serve as the transition element between the lined and the unlined sections of the shaft. It shall retain the rock formation and shall be provided with chemical water seals and a water collection ring with drains to prevent water from flowing from behind the liner down the unlined shaft. The key shall be designed to resist lateral pressure generated by salt creep, rock and soil overburden, and by hydrostatic pressure from above the salt. The design lateral pressure was selected as 75 percent of the overburden pressure based on the configuration of mine shafts in the vicinity of the WIPP. These shafts generally have a concrete liner that is thinner and that extends to a greater depth than the shaft key at the WIPP. Most of these shafts are at least 25 years old and show no significant deterioration or structural instability.

No liner or wire mesh is planned for the section of the shaft in the Salado formation. However, if field conditions require, rock bolts and wire mesh may be installed in zones of fractured salt.

The shaft station excavation shall be the minimum required to meet the operational and safety requirements in the shaft pillar area of the waste storage level. Supports of underground workings shall comply with Federal and New Mexico codes. The use of rock bolts and wire mesh in specific areas shall be determined by excavation conditions and code requirements. The roof, walls and floor shall be checked periodically for loose salt in accordance with applicable codes.

The bottom of the shaft shall extend below the facility level to accommodate the salt handling equipment and a sump to collect water that might enter the shaft. Should the stratigraphy of the facility

level be unsuitable for waste storage, the shaft bottom may be lowered to reach a more suitable stratigraphy.

Geomechanical instruments shall be provided to measure radial convergence (closure) of the shaft, water pressure behind the liner, salt creep, forces on the concrete key, and the variation of load on rock bolts. The type of instruments installed shall be strain gauges, pressure cells, piezometers, stressmeters, extensometers, load cells and radial convergence points.

The shaft liner, key, unlined section and furnishings shall be inspected at approximately 1 month intervals, or lesser intervals as required, to detect cracking, corrosion, deterioration and water intrusion.

7.3 DESIGN VALIDATION PROCESS

The design validation process for the C & SH shaft consists of data collection, analysis and evaluation, and predictions of future behavior. The following discussions of each of these activities have been divided into four sections: the lined section of the shaft; the shaft key; the unlined section; and the shaft station. This division is based on the different in situ and design conditions in each of these areas.

7.3.1 Data Collection

Data collection in the C & SH shaft has consisted of geologic mapping, visual inspections and geomechanical instrument measurements. The results of shaft mapping have been discussed in Chapter 6. Field observations and the geomechanical instrumentation program are discussed in the following subsections.

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7.3.1.1 Lined Section

Field Observations. The C & SH shaft has been inspected on a regular basis since its construction. During the facility level construction

phase, the mining contractors conducted weekly shaft inspections for safety and shaft maintenance. These weekly inspections are being continued by the facility operator.

Site geologists inspect the shaft at approximately 6-month intervals. These inspections provide geotechnical evaluations of the condition of the shaft, and of instrument conditions and their performance. Shaft inspections were performed on the following dates: August 29, October 1, October 5, October 22, November 19 and December 3, 1983; June 2, June 21, October 13 and November 12, 1984; and April 9 and December 9, 1985. The results of these inspections are presented in the GFDRs.

Geomechanical Instrumentation. Nine sets of radial convergence points were installed in the C & SH shaft between July 7 and 17, 1982. Two additional sets were installed on October 8, 1982. Five of these 11 sets were installed in the lined section of the shaft (Figure 7-1). Plots of the convergence point data from the lined section are presented in Appendix J, Figures J-205 through J-209.

Ten piezometers were installed in the lined section of the C & SH shaft above the shaft key between July 10 and 17, 1982 (Figure 7-1). Two piezometers each are at elevations of 2830, 2790, 2719, 2684 and 2608 feet. All of these piezometers are in the Rustler formation. The piezometers at elevations of 2790 and 2684 feet are in the water-bearing dolomite members, the Magenta and Culebra, respectively. Graphic plots of piezometer data are presented in Appendix J, Figures J-34 through J-44. The piezometers are dual-component instruments containing a vibrating-wire gauge and a pneumatic gauge. The vibrating-wire gauge is the principal instrument used to measure water pressure. The pneumatic gauge is used for initial calibration and periodic performance checks on the vibrating-wire units. The vibrating-wire piezometers were connected to the datalogger on October 30, 1982. The pneumatic units can only be read manually at the instrument location; however, most of the pneumatic units are no longer functioning.

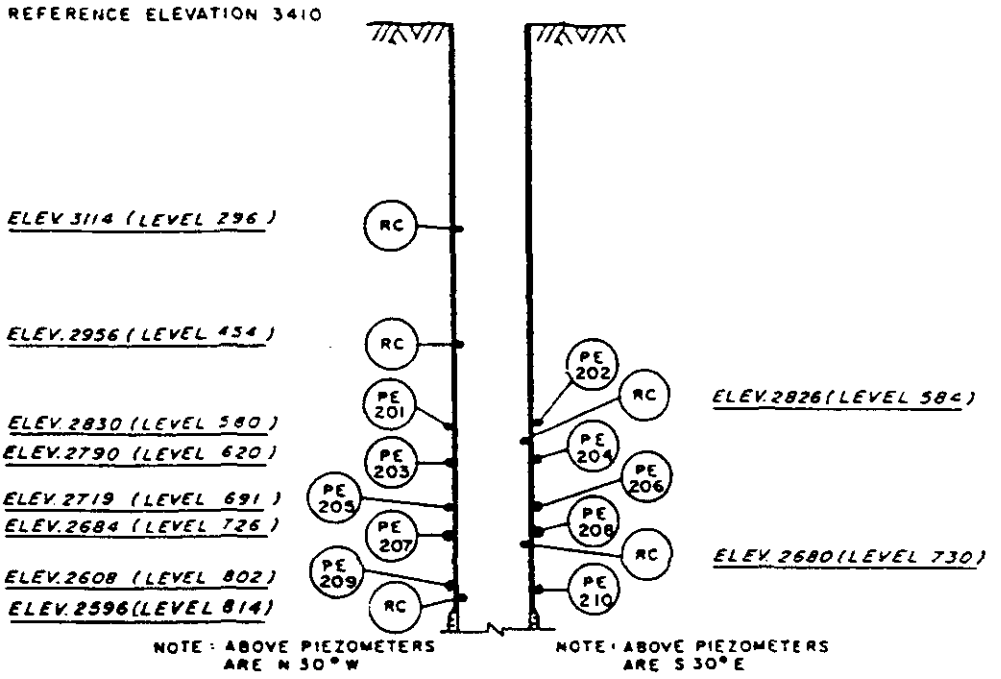

LEGEND

- (PE) PIEZOMETER
- (RC) RADIAL CONVERGENCE POINTS
- (GE) EXTENSOMETER

NOT TO SCALE

NOTES

1. RC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE TOP OF THE SHAFT BUNTON AT ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.

Figure 7-1

C & SH SHAFT LINER INSTRUMENTATION

The shaft instrumentation has had a history of damage. Convergence points and especially piezometers are susceptible to damage from falling objects and construction activities. Damage in the lined section of the shaft has generally consisted of sheared data cables, sheared or bent convergence points, broken junction boxes and water damage.

Water intrusion has been a major problem with most of the shaft instruments and control systems. One water source has been the holes drilled into the steel liner for piezometer installation. The bushing in the liner through which the piezometer was installed did not have tapered threads, making it difficult to seal the hole in the liner. Leakage through these holes has generally occurred at some time in their history. It was especially difficult to effect a seal when a piezometer was reinstalled after being repaired due to other damage.

Water trickling down the liner from around these bushings has sometimes entered damaged fiberglass junction boxes and terminal boxes through cracks. Water has also seeped into the conduit connecting piezometers with the nearest junction box. This water has corroded terminal blocks and seeped down cables connecting lower terminal boxes.

A second water source has been rainfall. During periods of heavy rain, water runs down the shaft along the surface of the liner. This water can enter terminal boxes broken by impact or construction activities. Once in the boxes, it causes corrosion and cable damage.

A great deal of effort has been exerted correcting these problems. Shields were placed over boxes, cables were replaced and rerouted, and piezometers were repaired and sealed as well as possible. These measures improved performance somewhat, but problems still exist. The data acquired from the instruments is considered valid, but must be interpreted in light of the various interruptions in data monitoring. The specific details of instrument damage are updated in every GFDR, particularly in the tables of operating histories.

7.3.1.2 Shaft Key

Field Observations. The shaft inspections conducted on October 1 and November 19, 1983, June 2 and October 13, 1984, and April 3 and December 9, 1985, paid particular attention to the shaft key. The design of the key provides a means to determine if any water from the water-bearing zones in the Rustler formation is flowing behind the key. This situation, if it existed, could cause dissolution of the salt around the key resulting in eventual structural instability.

During inspection of the shaft key, the condition of four telltale drains that connect to a French drain behind the key is observed. Any moisture in the drains is noted. Similarly, other capped pipes (those for possible future injection of grout and those originally used for chemical seal injection) are checked for accumulated water. The interface between the salt and the bottom of the key receives particular attention.

The latest geotechnical inspection of the shaft key was made on December 9, 1985. The four telltale drains at the key were inspected and cleaned. Only the hole on the northwest side of the shaft was weeping, resulting in salt accumulation on the terminal box below. After chipping off this salt, a small amount of liquified chemical seal material began oozing out of the telltale. Inspection of the bottom of the key showed no evidence of seepage below the concrete.

Geomechanical Instrumentation. Twenty-four embedment strain gauges, 16 spot-welded strain gauges, and 4 pressure cells were installed in the C & SH shaft key from April 11 to 17, 1982. Two piezometers were installed in the shaft key on July 10, 1982. The locations of these instruments are shown on Figure 7-2. All instruments were read manually until they were connected to the datalogger system on October 30, 1982. Appendix J contains plots of the data from these instruments. Piezometer data are presented on Figures J-44 and J-45. Figures J-54 through J-57 present pressure cell data. The strain gauge data are presented on Figures J-58 through J-97.

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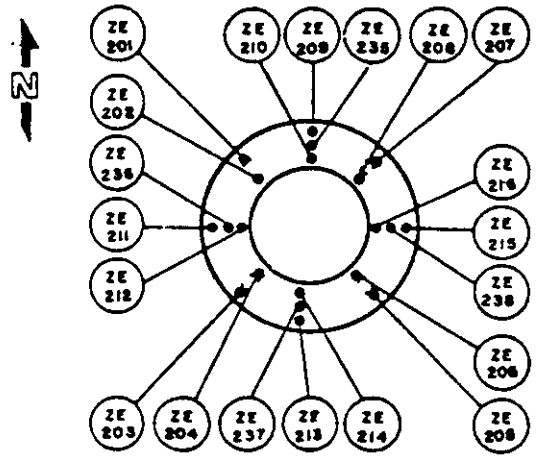

STRAIN GAUGE LOCATIONS
AT ELEV. 2553.7 FT (LEVEL 856.3 FT)

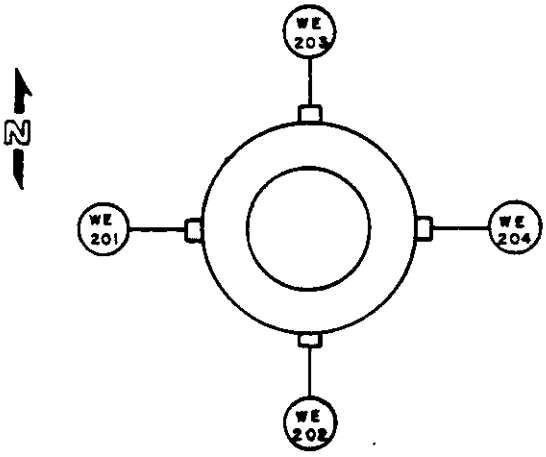

PRESSURE CELL LOCATIONS
AT ELEV. 2550.0 FT (LEVEL 860.0 FT)

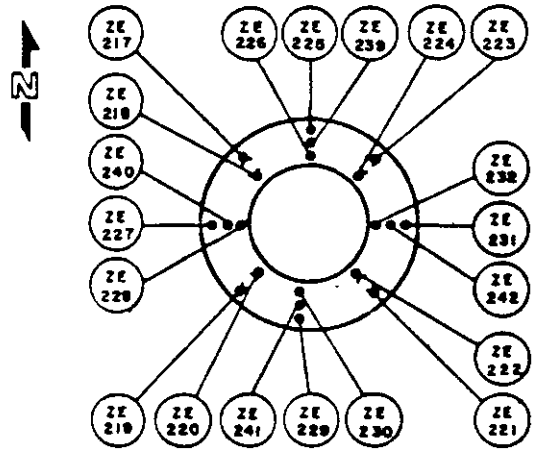

STRAIN GAUGE LOCATIONS
AT ELEV. 2547.6 FT (LEVEL 862.4 FT)

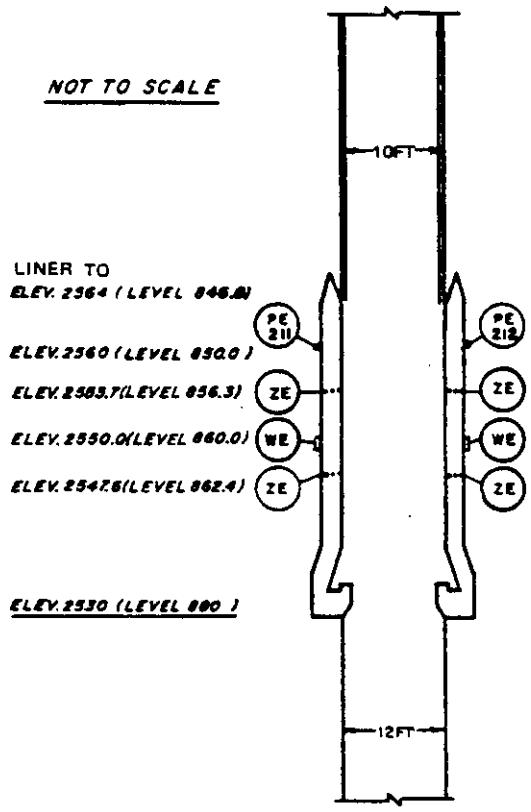

SHAFT KEY (PROFILE)

LEGEND

- ZE STRAIN GAUGE
- WE PRESSURE CELL
- PE PIEZOMETER

NOTES:

1. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH FROM THE TOP OF THE SHAFT BUNTON AT AN ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.
2. STRAIN GAUGES ARE ORIENTED HORIZONTALLY AND TANGENTIAL TO SHAFT CIRCUMFERENCE.
3. STRAIN GAUGES SHOWN AS ⊕ ARE SPOT WELDED TO REINFORCING STEEL.

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Figure 7-2

C & SH SHAFT KEY
INSTRUMENTATION

The instruments for monitoring the shaft key, and especially their electrical boxes and cables, have had the same performance problems as the piezometers and convergence points in the lined section above. The two key piezometers have been damaged and repaired repeatedly.

The major problem in the key has been water damage inside the various electrical boxes. The worst damage was in termination cabinet LTC-1. Water seeping down inside cables connected to water-damaged boxes in the lined section of the shaft corroded the terminals in the LTC. LTC-1 links the piezometers, strain gauges and pressure cells to the surface datalogger. Several attempts were made to repair the LTC components. The components were permanently removed in October 1984 in order to avoid further damage. The shaft instrumentation system is scheduled for an overhaul during a future construction contract. Meanwhile, all LTC-1-controlled instruments are read manually during shaft inspections.

The terminal boxes for the pressure cells and strain gauges have also been damaged. Initial damage was to the fiberglass boxes and data cables as they were struck by falling objects and construction materials traveling on the shaft conveyance. Subsequent damage was by water seeping into the boxes. The boxes and cables have been repaired numerous times.

Detailed accounts of instrument damage are presented in the GFDRs, particularly in the tables of operating histories. The GFDRs also discuss data collection, data plots and interpretative problems with the C & SH shaft key instruments.

7.3.1.3 Unlined Section

Field Observations. Shaft inspections include observations of the unlined section of the C & SH shaft. This section of the shaft consists of exposed salt forming a smooth wall. The inspections consist primarily of determining if any spalling or fracturing of the salt is occurring.

The unlined section was inspected to a depth of 2,057 feet (elev. 1353 feet) on December 9, 1985. One near-vertical fracture was observed on the west side of the shaft between a depth of 1,021 feet and 1,043 feet (elev. 2389 feet and 2367 feet). It ranged from closed to less than 1/4-inch wide at the wall surface and extended about 10 feet in length. It did not appear on the east side of the shaft. Previous shaft mapping showed the presence of halite-filled vertical fractures in anhydrite from a depth of approximately 1,023 feet to 1,038 feet (elev. 2387 feet to 2372 feet). The fracture observed appears to be one of those previously mapped. Salt blisters and precipitate were noted in various areas commonly associated with clay layers. The most notable area was a 4-foot zone around the entire shaft circumference from a depth of approximately 1,038 feet to 1,042 feet (elev. 2372 feet to 2368 feet).

Geomechanical Instrumentation. Nine borehole extensometers were installed in the unlined section of the C & SH shaft between July 6 and 8, 1982. These extensometers are arranged in three-instrument arrays at elevations of 2337 feet, 1846 feet and 1353 feet (Figure 7-3). Readings were taken manually until the extensometers were connected to the datalogger system in October 1982.

The extensometers are the multiple-point, sonic-probe type consisting of four anchors. The anchors for each extensometer were set at depths of 4, 9, 18 and 36 feet. The collar of the extensometers was recessed 1 foot into the salt. Data plots for the extensometers are presented in Appendix J, Figures J-116 through J-124.

The extensometers have not been damaged as much as the other instruments in the shaft. Their operating histories rarely show any interruption in the data. This lack of damage is a result of several factors. The diameter of the unlined shaft is 2 feet greater than that of the key or lined section. The instruments are recessed and therefore not susceptible to damage from falling objects. The extensometers are connected to LTC-2 and LTC-3, which are not directly

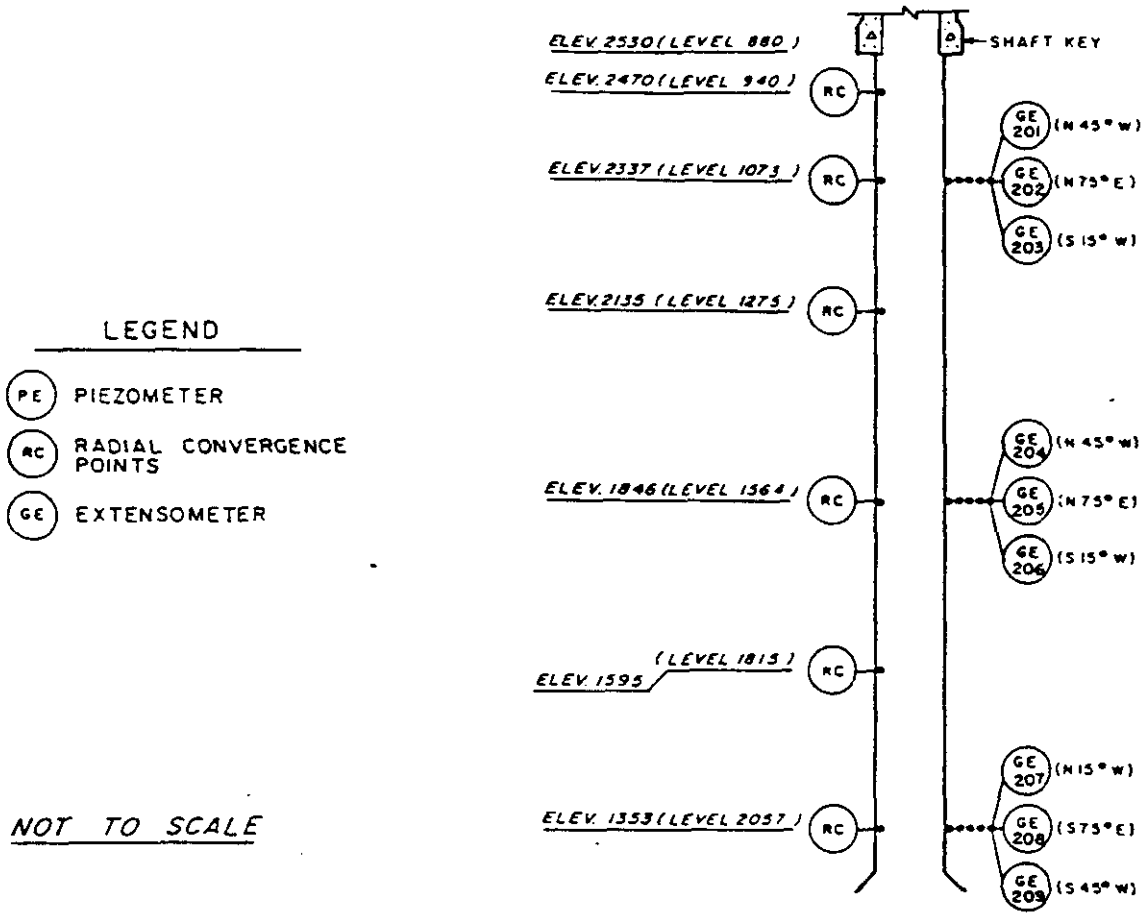

NOTES

1. RC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE TOP OF THE SHAFT BUNTON AT ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.

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Figure 7-3

C & SH SHAFT UNLINED SECTION INSTRUMENTATION

linked to LTC-1 and the piezometers. Thus, water damage has not been a problem.

Six sets of radial convergence points are located in the unlined section of the shaft. These points have a history of damage and replacement similar to that of the other convergence points. This history is discussed in the GFDRs. Plots of the convergence point data from the unlined section are presented in Appendix J, Figures J-210 through J-214. Only five plots are presented since damage to the set of points at elevation 1595 feet prevented the obtaining of reliable readings.

7.3.1.4 Shaft Station

Field Observations. Site geologists monitor the deformational behavior of the C & SH shaft station on a regular basis. Particular attention is given to four aspects of movement or failure: roof and wall spalling; fracturing at pillar corners; roof displacements and separations; and floor displacements, separations and fracturing. The observations are recorded at least every 3 months and have been published in each GFDR since the February 1984 issue.

A description of the C & SH shaft station excavation and roof support methods were presented in Chapter 3. The failure of resin-anchored rock bolts installed initially in the shaft station roof has been attributed to a combination of the following factors:

(1) the resin firmly held the bolt shank in place and salt creep caused failure at the first weak point;

(2) improper bolt installation resulted in damage to the threaded section of the bolt (improper torque and lack of beveled or spherical washers); and

(3) contributing factors such as corrosion and hydrogen embrittlement.

Rock bolts installed to replace the failed bolts, and subsequent bolt installations, used mechanical anchors. As the load on these bolts increases due to salt creep, the anchor yields by slipping in the hole. Although this slipping is not desirable for the roof support of underground openings in hard rock, it provides more control than rigid anchors that do not yield but instead produce sudden bolt failure as a result of the stress created by creeping salt. The slipping reduces the load on the bolt, thus reducing the potential for bolt failure, but allows continued roof support and prevents sudden roof falls. Each mechanical-anchor rock bolt supports a load that is less than its capacity, but the aggregate support provided by all of the rock bolts in a pattern is more than adequate for positive ground control. The experience at WIPP shows that the mechanical-anchor rock bolts perform well in creeping salt if periodically inspected and maintained.

The station roof and walls have exhibited continual slabbing and spalling which has required periodic scaling. Wire mesh has been installed over the entire station roof to contain any small, loose salt fragments.

Vertical fractures have developed in the pillar corners at the S90 crosscut. The condition of these fractures has been monitored and the results reported on a regular basis in the GFDRs. A discussion of fracturing at pillar corners is presented in Chapters 10 and 11.

Displacements, separations and fractures have been detected in boreholes drilled into the station roof and minor separations have been detected in some holes drilled into the station floor. Separations and fracturing at clay G and in the underlying halite were detected shortly after the initial station excavation. Horizontal displacements have been observed in various boreholes during the past 2 years.

In May and June 1986, 20 boreholes were drilled in four arrays in the shaft station to further investigate the extent of separations and fracturing in the roof and floor. This drilling was conducted as part

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of a program to characterize excavation effects in the salt surrounding the openings and particularly in MB-139. This program is discussed more fully in Chapters 10 and 11.

The new boreholes were inspected for the existence of separations and fractures. Existing holes were inspected for horizontal displacements. The probe used for this inspection consisted of an aluminum rod with a 1/16-inch thick nail attached perpendicular to one end. When applying moderate pressure, the nail snags on the borehole wall if a separation, fracture, or clay seam is encountered. The separation is considered to be less than 1/16 inch wide if the nail catches on, but does not penetrate the hole wall. If the separation at the wall surface is at least the nail width (approximately 1/16 inch) there will be a slight penetration. If the separation is larger, the nail penetrates its entire 1/2-inch length into the wall. When the probe catches on the hole wall, the feature is probed on all sides of the hole. This ensures that it is a continuous feature and not a clay pocket or an imperfection caused by the drilling.

Fracture zones, anhydrite beds, or clay seams were sometimes identified by picking out pieces of the material with the probe nail. An estimate of their vertical dimension was made by moving the probe rod up and down within the limits of the feature. Occassionally a slight penetration occurred at the clay seams due to a very small separation or penetration into the softer clay.

In the array of holes drilled north of the shaft, no separations or fractures were detected in the roof. In the two arrays drilled south of the shaft, multiple separations and fractures, ranging from approximately 1/16 inch to 4 inches wide, were found in most of the roof holes within the halite below clay G. Many of the fractures occur within 3 feet of the roof. Some separation and fracturing appears to be associated with clay G based on data from other holes in the station area and from the central roof holes in the two arrays, but no significant occurrence appears to have developed in the holes closest

to the station walls. A separation, less than 1/16 inch wide was detected in only one roof hole beyond a depth of 4 feet.

Only a few separations or fractures, less than 1/8 inch wide, were detected in the central floor hole of the hole array drilled north of the shaft. Some separations and fractures, less than 1/16 inch to 1 inch wide, were detected in the two floor hole arrays drilled south of the shaft. These occurrences were in MB-139 and the overlying halite. Essentially no separation was encountered at clay E at the base of MB-139. Holes drilled around the edge of the electrical substation concrete base slab foundation to investigate a potential source of its tilting encountered only small scattered separations. The total accumulated vertical separation is estimated to be less than 1/2 inch.

Geomechanical Instrumentation. As in other areas of the underground facility, a suite of geomechanical instruments was installed in the C & SH shaft station (Figure 7-4). The original instrumentation design consisted of 6 rock bolt load cells, 3 borehole extensometers, and 2 sets of convergence points. These instruments were installed between June 30 and November 16, 1982. Subsequently, 4 extensometers, 4 lateral movement gauges, 3 convergence point sets, and 1 set of wall shortening points were installed between January 8 and February 3, 1983. The purpose of this second suite of instruments was primarily to monitor any vertical or lateral movement of the immediate roof in the C & SH shaft station. The immediate station roof consists of a "beam" of salt resulting from separation along the thin clay seam beneath anhydrite "a". South of the shaft this beam is about 3 to 4 1/2 feet thick, while north of the shaft it is about 7 feet thick. Chapter 3, Section 3.2, presents a brief discussion of the underground facility horizon selection and the resulting location of the station with respect to overlying and underlying clay seams and anhydrite layers.

The data plots for the C & SH shaft station are presented in Appendix J. Figures J-146, J-147, J-163, and J-170 through J-173 show

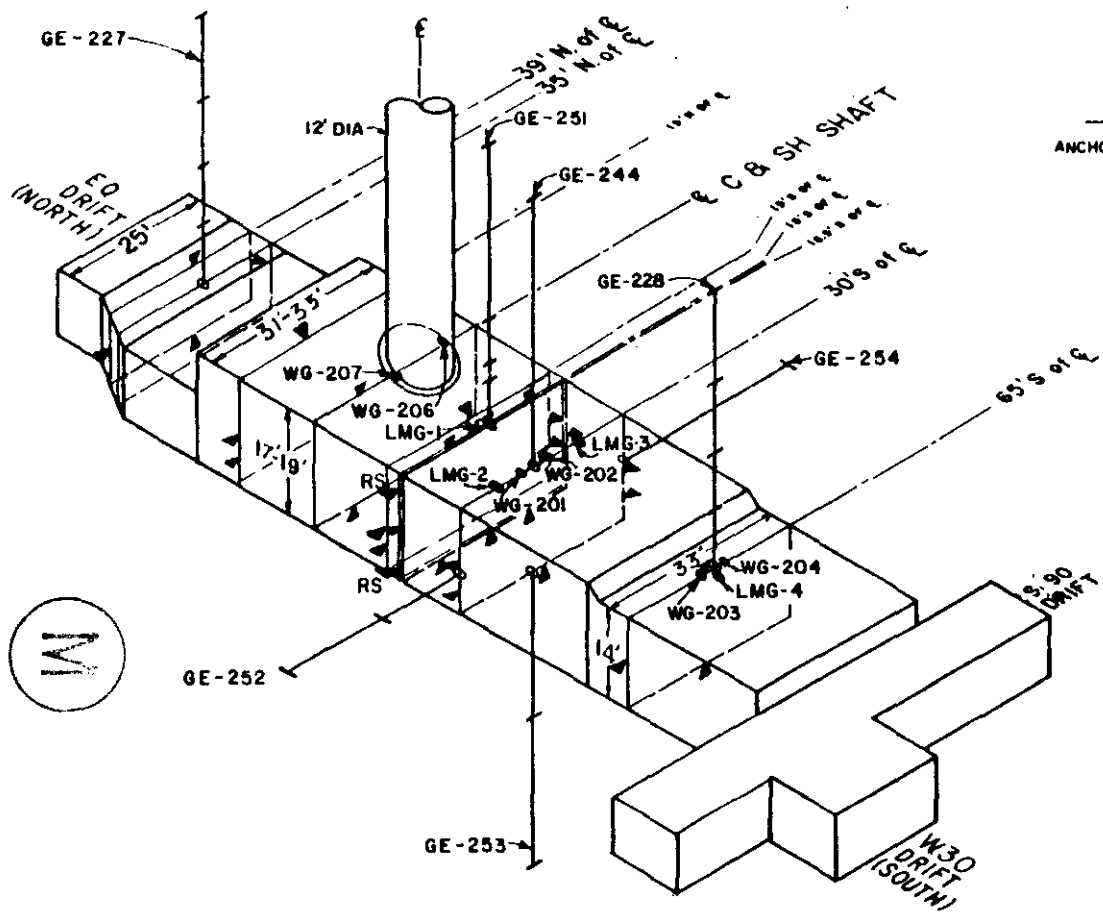

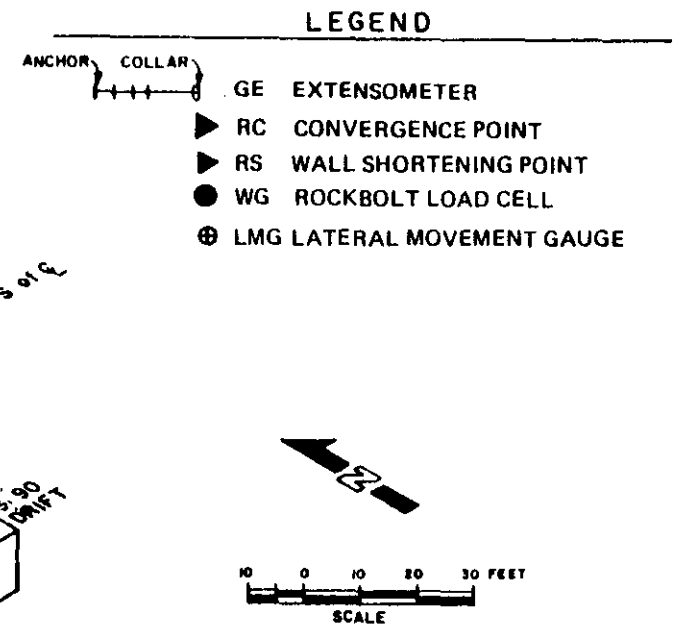

Figure 7-4

C & SH SHAFT STATION INSTRUMENTATION

the extensometer data. Convergence point data are presented on Figures J-188 through J-194 and rock bolt load cell data are shown on Figures J-192 through J-197.

Four lateral movement gauges were installed in the roof of the station. These were intended to measure lateral displacement of the salt above anhydrite "b". However, the lateral movement measurements were distorted by the vertical movement of the roof and a meaningful trend or pattern in the relative direction of horizontal movement did not develop. Therefore, reading of the lateral movement gauges was discontinued and the data are not presented in this report.

7.3.2 Analysis and Evaluation

The data collected from the C & SH shaft have been reviewed and subjected to statistical analysis, closed form solution and model simulation techniques for evaluation against the reference design parameters. The following subsections present discussions of these analyses and evaluations for the four sections of the shaft.

7.3.2.1 Lined Section

Observed Conditions. Observations of the steel liner during shaft inspections have detected no signs of deterioration. There is no indication of any liner instability due to shaft deformation. Water seepage has occurred only through the previously discussed piezometer bushings.

Structural Analysis. As a result of increasing hydrostatic pressure with depth, the thickness of the C & SH shaft steel liner and the size and spacing of its stiffener rings vary accordingly. The stiffener rings are 3-inch thick steel rings welded to the outer face of the liner. The thickness of the liner and the width and spacing of the stiffener rings for various depths are:

Depth (feet)	Plate Thickness (inches)	Stiffener Width (inches)	Stiffener Spacing (feet)
0.00 to 182.45	5/8	7-1/2	10
182.45 to 362.45	1	12	10
362.45 to 542.45	1	11	5
542.45 to 642.45	1-1/4	10-1/2	5
642.45 to 742.45	1-3/8	9	4
742.45 to 842.45	1-1/2	10-1/2	4

A structural analysis was performed for the shaft liner based on these depths and dimensions. The liner and stiffeners were made of A-441 steel fabricated into 20-foot sections by full penetration bevel welds between the liner sections and by fillet welds between the liner and the stiffeners. Radiographic acceptance examinations were performed on all welds in accordance with the American Welding Society (AWS) (ref. 7-1) and the ASME Boiler and Pressure Vessel Code, Sections VIII and IX (ref. 7-2).

A computer program was used to design the steel liner against elastic buckling between the stiffeners, elastic buckling of the combined liner and stiffener, and the yielding of the liner. This program was developed jointly by Fenix & Scisson and Southwest Research Institute and was based on Theory of Plates and Shells by S. P. Timoshenko and S. Woinowsky-Krieger (ref. 7-3).

The computational results of the analysis of the liner, based on the depths and dimensions presented above, show that the external pressure capacities and corresponding closure limits (maximum diametric changes) at the midpoint of a stiffener and at the midpoint between stiffeners are:

Depth (feet)	Pressure Capacity (psi)	Closure Limit at Stiffener (inches)	Closure Limit Between Stiffeners (inches)
0.00 to 182.45	139	0.007	0.054
182.45 to 362.45	281	0.010	0.069
362.45 to 542.45	434	0.019	0.108
542.45 to 642.45	518	0.030	0.104
642.45 to 742.45	595	0.043	0.112
742.45 to 842.45	684	0.043	0.118

In situ hydrostatic pressures determined from piezometer readings at elevations of 2830, 2790, 2719, 2684 and 2608 feet (Figure 7-1) were compared with design pressures and the pressure capacity of the liner as discussed below.

Measured Water Pressure. Piezometers are used to monitor the hydrostatic pressure exerted on the steel liner by water from the two water-bearing zones in the Rustler formation. Selected water pressure measurements are presented in Table 7-2. Because of the piezometer history of damage and leakage, the data must be used with caution. However, as expected, the data show a general trend of increasing pressure (Figure 7-5). The exceptions, 37X-PE-00211 and 37X-PE-00212, are discussed in the next subsection.

As indicated in Table 7-1, the design basis hydrostatic pressure is assumed to begin at a depth of 250 feet below ground level. This corresponds to the potentiometric surface of the water-bearing members in the Rustler formation. The hydrostatic design pressure gradient of the liner in the Rustler formation is shown on Figure 7-5. Piezometer reading data from June 1986 indicate pressures significantly less than the design hydrostatic pressure. This can be explained by a combination of the following conditions:

(1) drawdown of the potentiometric surface in the vicinity of the shafts;

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Table 7-2

C & SH SHAFT LINER AND KEY
SUMMARY OF MEASURED WATER PRESSURES (psi)

Date of Reading	PIEZOMETER NO. 37X-PE-00											
	201	202	203	204	205	206	207	208	209	210	211	212
	Elev. 2830		Elev. 2790		Elev. 2719		Elev. 2684		Elev. 2608		Elev. 2560	
Pressure capacity of liner	518		518		595		595		684			
Jun. 20,'83	112	111	108	108	86	86	110	104	140	142	6	12
Dec. 3,'83	96	96	100	101	84	84	98	100	137	139	13	9
Jun. 5,'84	90	93	-	-	79	-	90	96	127	129	5	1
Dec. 27,'84	93	95	119	119	102	100	105	116	-	152	3	0
Feb. 8,'85	98	100	131	130	109	105	107	117	-	157	10	7
May 21,'85	90	93	84	81	61	44*	105	-**	146*	137*	5	6
Jun. 29,'85	89	92	91	-**	97	-**	104	-**	-**	-**	4	7
Dec. 9,'85	90	91	108	104	100	-**	108	-**	-**	-**	-1	-1
Mar. 24, '86	101	102	-	134	107	-**	104	-**	-**	-**	-2	-4
Jun. 02, '86	89	91	104	-	100	-**	108	-**	-**	-**	-	-2

NOTE: All piezometers have leaked or suffered damage at one time or another.

* Piezometer leaking.

** Piezometer removed for repair.

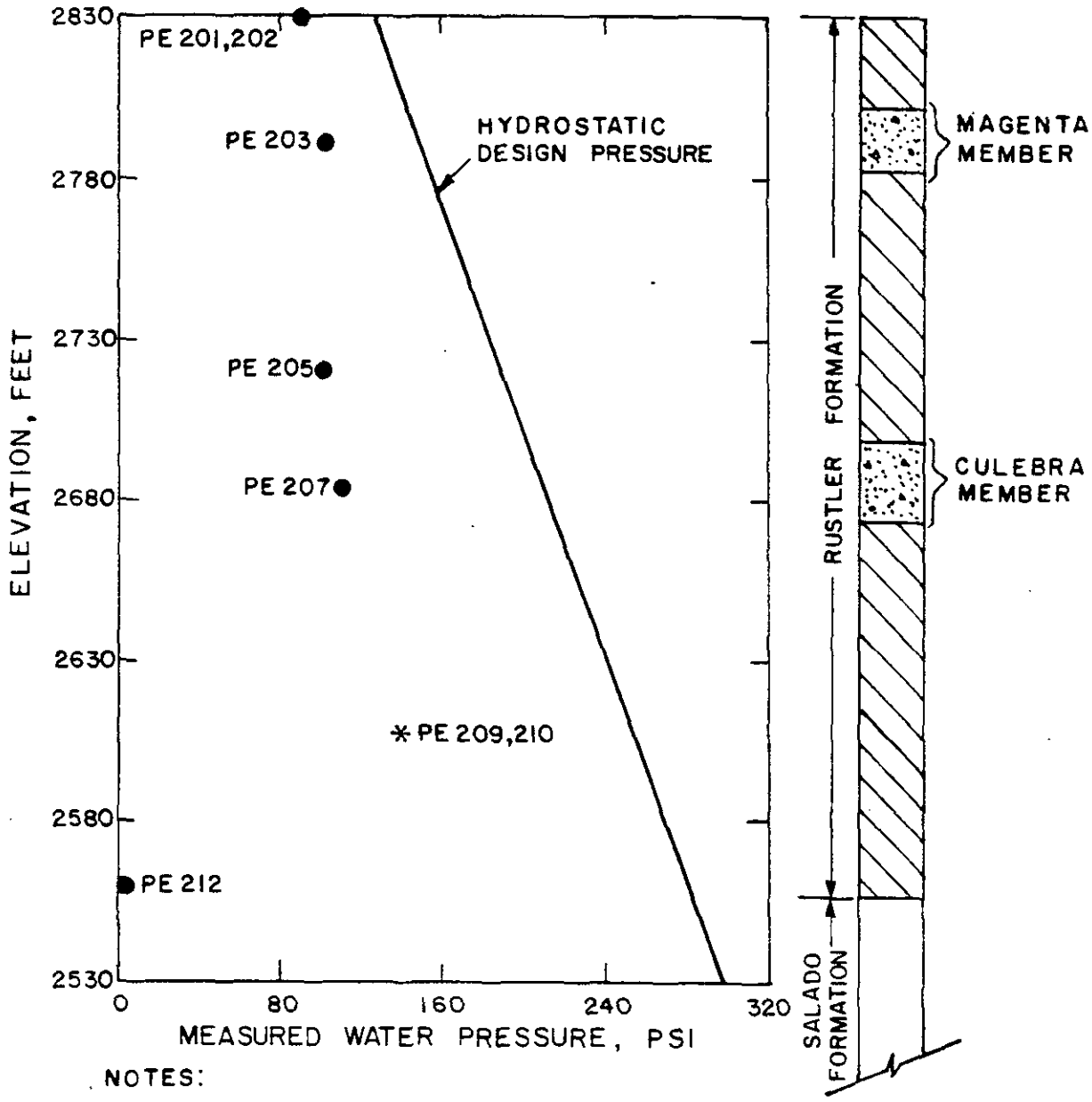

NOTES:

● READINGS TAKEN ON JUNE 2, 1986

* READING TAKEN ON MAY 21, 1985

Figure 7-5

C & SH SHAFT LINER AND KEY
WATER PRESSURE DISTRIBUTION

(2) incomplete hydraulic continuity behind the liner;

(3) water leakage through the piezometer bushings and telltales; and

(4) partial plugging of the piezometer filters.

Lowering of the potentiometric surface is primarily the result of water flowing into the unlined SPDV ventilation shaft and later through cracks in both the waste and exhaust shaft liners. Hydrologic testing at the site by SNL has also contributed to lowering the potentiometric surface.

The annular space between the steel liner and the rock was filled with grout during liner installation (Chapter 3). In addition to supporting the liner, the grout was intended to help prevent water in the water-bearing zones from contacting the salt in the key area. The variations in water pressure at the different piezometer elevations, and especially the lack of a linear increase with depth, suggests that this objective has been at least partially achieved. The absence of hydraulic continuity along the rock/liner interface could prevent the water at individual piezometer elevations from achieving the anticipated pressures.

Most of the piezometers have developed leaks at some time in their history. This leakage would result in a drop in water pressure at the affected piezometer. The piezometer would then measure a water pressure that is lower than anticipated. The influence of the leaks on piezometer readings is considered to be minor because, as individual piezometers are repaired or bushings are sealed, the data plots do not show a significant change from the normal variation within the data.

The fourth cause of variation in the pressure readings could be a result of partially-plugged filters. Each piezometer contains a stainless steel, porous stone filter. It has been noted during their

repair that some filters are partially covered with salt deposits and corrosion. It is not clear how much of an effect this may have on the piezometer readings. It is possible that there is no effect if the corrosion and salt deposition occurred after the filter was exposed to the atmosphere during piezometer removal.

Closure. Closure data show the in situ diametric changes in the liner based on radial convergence point measurements at elevations of 3114, 2956, 2826 and 2680 feet (Figure 7-1). These data are considered a lower bound because the in situ readings represent only relative closures since the first readings were taken 329 days after excavation. In addition to the effect of hydrostatic pressure, the closure data are also affected by variables such as temperature and lithostatic pressure.

Radial convergence point measurements in the lined section of the shaft indicate that the maximum diametric closure is less than 0.10 inch. Since the shaft is used for ventilation purposes and is open to the atmosphere, changes in ambient temperature from around 0°F in the winter to over 100°F in the summer may affect the diametric closure by approximately 0.075 inch. Consequently, only closure data recorded at approximately the same temperature should be used for analysis.

7.3.2.2 Shaft Key

Observed Conditions. Shaft key inspections indicate that the key is stable. Certain observations, however, dictate that continuous monitoring of the key will be required. The telltale drains, connected to a French drain behind the key, drip intermittently. Several other capped pipes typically produce small amounts of water when opened after being closed for several weeks.

No water has been observed bypassing the lower chemical water seal. During the June 2, 1984, inspection, liquified chemical seal material was observed in two chemical seal injection pipes. It is likely that chemical seal material is migrating behind the key since small amounts

were observed dripping from the northwest telltale drain and from piezometer 37X-PE-00211. These fluid observations do not present any immediate cause for concern. However, the key should be monitored on a regular basis and appropriate actions taken if required to mitigate any significant increase in fluid discharge.

Inspection of the bottom of the key has revealed no evidence of seepage below the concrete. Some salt stalactites have been observed hanging from the concrete but these originate from brine dripping from the leaking piezometers or telltale drains above.

Model Simulation. The long-term impact of C & SH shaft salt creep on the concrete key was evaluated by a nonlinear computational analysis using the finite element method (ref. 7-4). The objective of the analysis was to determine the structural adequacy of the shaft key based on the appropriate ACI Codes (ref. 7-5). Site stratigraphy was considered in the analysis. The creep behavior of the salt was incorporated into the material properties used in the finite element model. The shrinkage of the concrete during initial curing was also simulated in the computation (ref. 7-6).

From the shaft geologic mapping, it was determined that the stratigraphy in the shaft key area consists of horizontal layers of halite, argillaceous halite, anhydrite and siltstone, with clay seams between some of these layers (Figure 7-6). This stratigraphy was used as the basis in modeling.

The properties for the host rock are based on laboratory test results (refs. 5-3 and 7-7) as described in Appendix C. Because the analysis was performed early in design validation, before the methods of computing primary creep and using in situ material properties were developed (ref. 5-1), the analysis included only the secondary creep of salt based on laboratory test data.

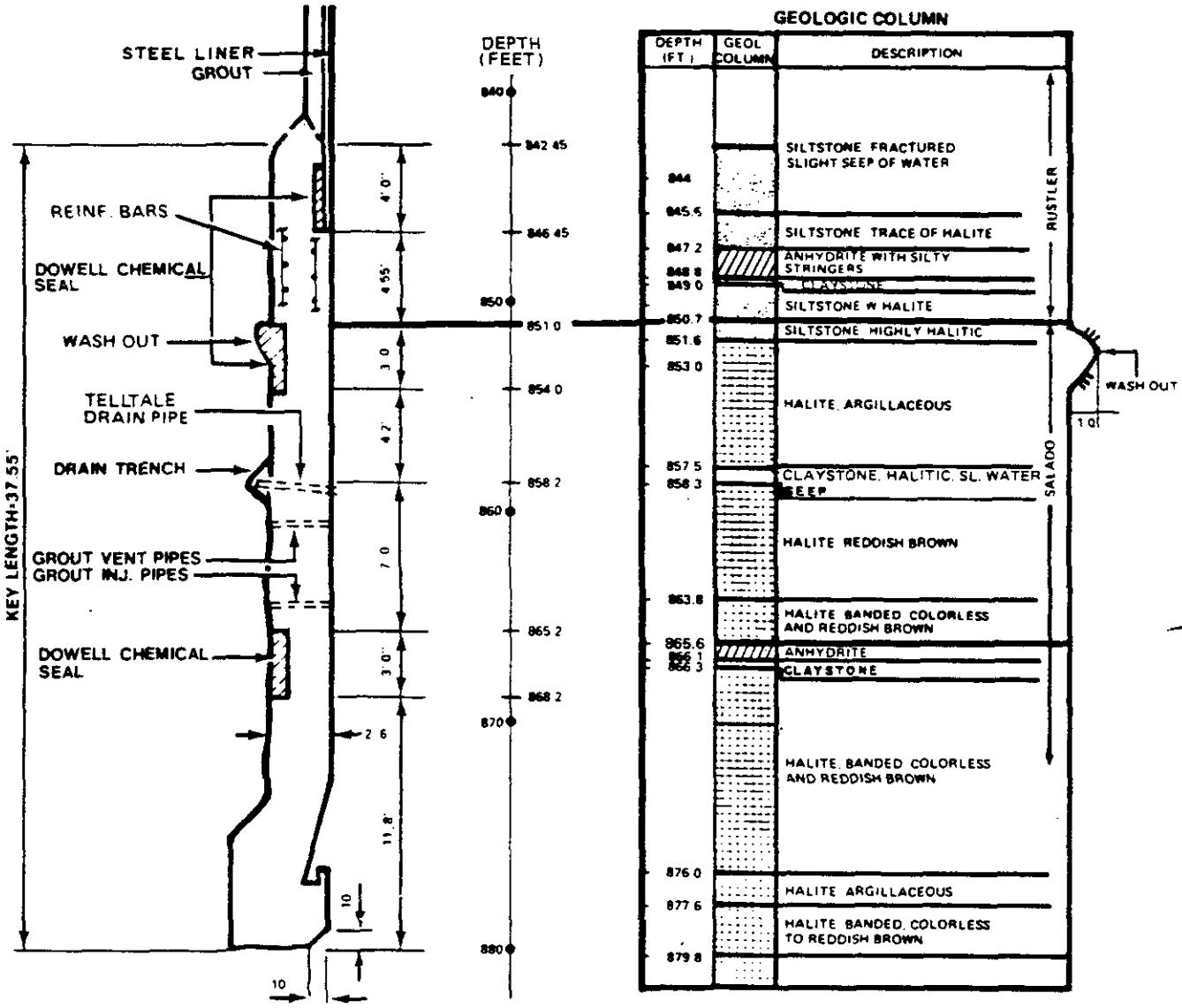

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Figure 7-6

C & SH SHAFT KEY
STRATIGRAPHY

The relationship for concrete shrinkage (ref. 7-8) can be expressed as:

$$\varepsilon_{sh} = \frac{t}{35 + t} \varepsilon_{shu} C_{the} C_h C_s C_{cem} C_{fa} \qquad (7\text{-}1)$$

for t in days, or:

$$\varepsilon_{sh} = \frac{t}{3{,}024{,}000 + t} \varepsilon_{shu} C_{the} C_h C_s C_{cem} C_{fa} \qquad (7\text{-}2)$$

where: t is the shrinkage time in seconds;

ε_{shu} is the ultimate shrinkage strain, taken to be 0.0008;

C_{the} is the correction factor for thickness (1.17 - 0.029T);

C_h is the correction factor for humidity (1.40 - 0.010H);

C_s is the correction factor for slump (0.89 + 0.041S);

C_{cem} is the correction factor for cement content (0.75 + 0.034B); and

C_{fa} is the correction factor for percent fines and air content, taken to be 1.0.

The thickness T of the key wall is 30 inches; the humidity H is very low in the region of the key and is assumed to be 50 percent; the slump S of 4 inches is taken as the average value for 5,000 psi concrete; and B is the number of sacks of cement per cubic yard of concrete, considered to be equal to seven. The values of the correction factors C_{the}, C_h, C_s and C_{cem}, as calculated from the equations above, are 0.3, 0.90, 1.05 and 0.99, respectively.

Figure 7-7 shows the finite element model for the creep analysis. Since the structure is symmetrical about the centerline of the shaft, the shaft key and the area around it were modeled using 196 quadrilateral ring finite elements representing 18 distinct geologic layers. The MARC General Purpose Finite Element Analysis Program (ref. 6-8) was used for the analysis. To reduce the computation time, the stress and strain were computed at the centroid of each element. Four clay seams, at depths of 848.9, 857.9, 866.2 and 900.9 feet, were considered as active slip planes, represented by 25 friction and gap link elements with a coefficient of friction equal to 0.4. The outside

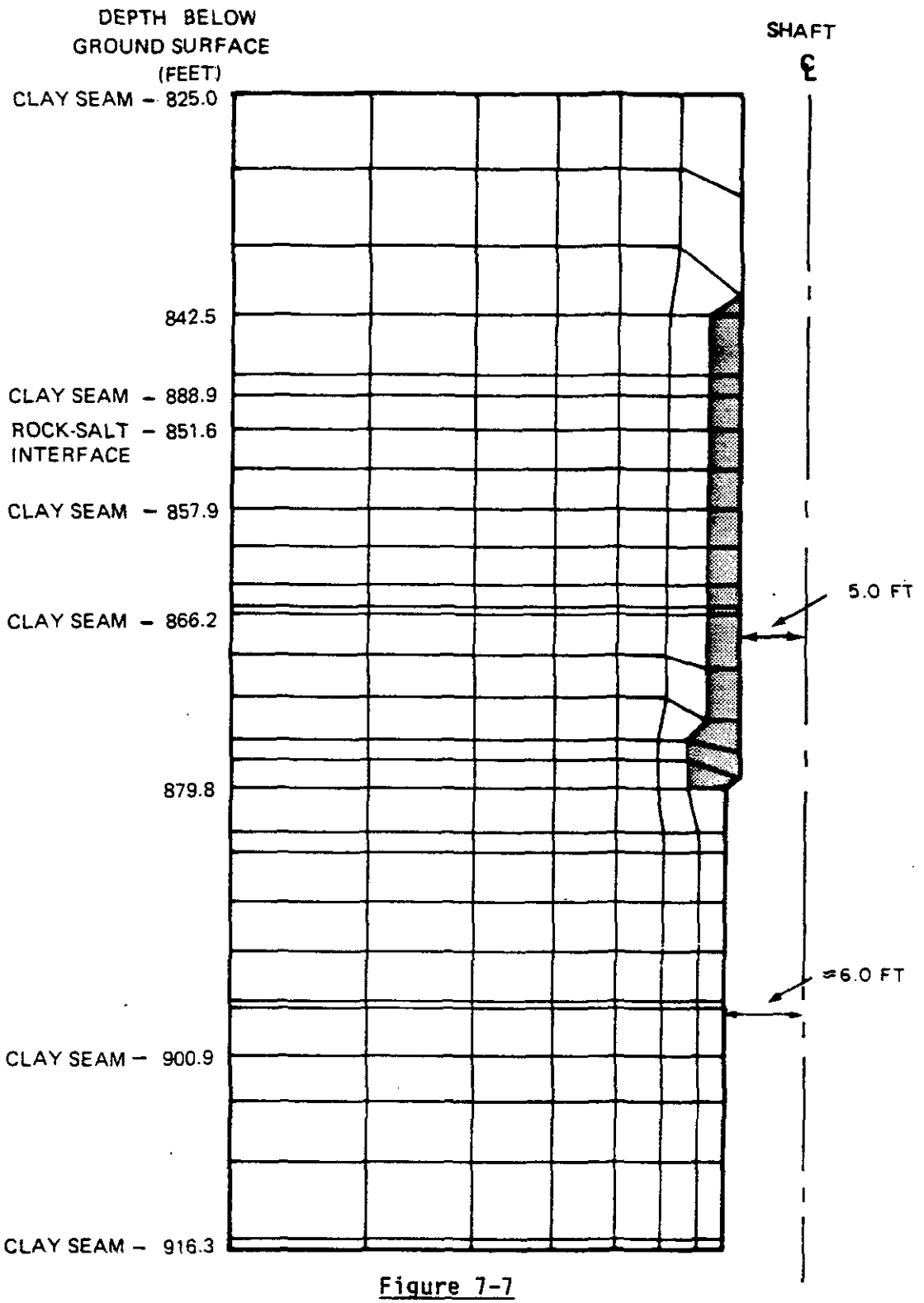

Figure 7-7

C & SH SHAFT KEY
FINITE ELEMENT MODEL

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vertical boundary had zero horizontal displacement and the bottom boundary had zero vertical displacement. The boundary conditions at the top of the model were uniform calculated pressures based on the mass density of the geologic formation from the ground surface to the elevation of the boundaries. The lithostatic stress state was defined as described in Chapter 5, equation 5-1.

Creep analysis was performed on the mathematical model by using the procedures described in Chapter 5. The analysis was carried out for a 5-year interval without the key and a comparison was made of the corresponding radial deformations to determine the time when creeping salt would come into contact with the shrinking concrete key. The times computed for various layers behind the key were between 1.6 and 3.9 years with an average value of 2.7 years after excavation of the shaft (or 2 years after construction of the shaft key). To simulate contact of the shaft wall with the concrete key, the elements of the key were tied to the proper locations on the shaft wall and the analysis was continued for a total of 27 years (refs. 7-4 and 7-6).

Deformation. Readings from the strain gauges embedded in the concrete key show a range of strains from approximately 0.00014 in compression to 0.00021 in tension with an average compressive strain of 0.00004 through December 9, 1985. The readings from the strain gauges welded to the reinforcing steel show a range of approximately 0.00031 in compression to 0.00054 in tension with an average tensile strain of 0.00006.

Table 7-3 summarizes the changes in readings of the embedment and welded gauges at a depth of 856 feet (elev. 2554 feet) since April 22, 1982, immediately after concrete was placed for the shaft key. The trend of the change in strain readings indicates that the salt had not made contact with the key by June 1985.

Water Pressure. Figure 7-5 shows water pressure readings from piezometers 37X-PE-00211 and 37X-PE-00212. These piezometers have

Table 7-3

C & SH SHAFT KEY
SUMMARY OF STRAIN GAUGE READINGS AT ELEVATION 2554 FEET

Strain Gauge No.	Change in strain x 10^{-6} since April 22, 1982				Remarks
	Jun. 5, 1984	Feb. 8, 1985	Jun. 29, 1985	Dec. 9, 1985	
37X-ZE-209	-63	-59	-81	-9.5	Embedment
211	-23	-16	-34	-51	strain gauges
213	-133	-104	-139	-144	14.5 inches
215	-82	-67	-99	-111	from inner surface
235	-12	16	-23	-47	Embedment
236	56	88	37	16	strain gauges
237	-18	35	-23	-8	9 inches from
238	-63	-23	-81	-99	inner surface
210	-110	-71	-123	-154	Embedment
212	178	272	201	215	strain gauges
214	58	128	65	79	3.5 inches
216	-53*	-7	-61	-76	from inner surface
201	-93	-100	-102	-138	Strain gauges
203	-	-	444*	-	welded to the
205	-235	-286	-352	-371	outer rein-
207	-102	-127	-142	-95	forcing bar
202	-43	-	-61	-58	Strain gauges
204	443	2066	1056	541	welded to the
206	-193	-147	-230	-246	inner rein-
208	-	-	-1659**	-	forcing bar

NOTE: Negative strain change indicates compression.

* Reading taken on May 3, 1984.
** Reading taken on Dec 30, 1982.

shown a range of readings from a maximum of 30 psi in 1982 to a current reading of 2 psi. As shown on the figure and in Table 7-2, the readings of these two piezometers are consistently lower than the readings from the upper piezometers. These lower piezometers are at a depth of 850 feet (elev. of 2560 feet), just above the chemical water seal at a depth of 851 feet (elev. 2559 feet). It appears that this seal may be breached and that water is able to bypass it and exit through the French drain and telltales. Piezometers 37X-PE-00211 and 37X-PE-00212 may also be isolated from the upper piezometers by the grout that was injected behind the steel liner at a depth of 843 feet (elev. 2567 feet).

The assumption that the chemical water seal just below the piezometers may be breached is based on observations of piezometer behavior during the October 1983 inspection. As discussed in subsection 7.3.1.2, several capped pipes in the key were found to contain small amounts of water during this inspection and were drained. Prior to this, piezometers 37X-PE-00211 and 37X-PE-00212 indicated pressures of around 6 to 8 psi. After draining the pipes, both piezometers showed a drop to 2 psi within 2 days. This indicates a hydraulic connection across the water seal.

It is unlikely that water in the key originates from higher in the shaft. Detailed mapping in the shaft key noted weeps from claystone and siltstone beds at depths of 842. 846 and 858 feet. This is probably the source of the water seen in the French drain telltales and other pipes in the key. The fact that the key piezometers have had consistently lower readings than the upper piezometers indicates that there is probably no hydraulic connection with the water-bearing members higher in the shaft. The draining of water from the grout pipes influenced only those piezometers in the key; none of the upper piezometers showed any pressure drop. The existence of a source of water in the key area provides a better explanation of the dripping from the telltales and the performance of the key piezometers than does the migration of water from the water-bearing members higher in the shaft.

Salt Pressure. The four earth pressure cells installed between the concrete of the shaft key and the salt have a combined average reading of less than 10 psi in compression. These four cells, located 90 degrees apart at elevation 2550 feet (Figure 7-2), are intended to register changes in lateral pressures on the shaft key exerted by the creeping salt. Table 7-4 shows that the pressure cells have not registered any significant change in readings for a period of over 3 years since construction of the concrete key.

If we assume that the pressure cells are functioning properly, then the halite between a depth of 858 feet and 863 feet (elev. 2552 feet and 2547 feet) had not made contact with the pressure cell diaphragms as of December 9, 1985. According to the results of computational analyses, the contact between the salt and concrete will be reestablished at different elevations at different times between 1984 and 1986.

7.3.2.3 Unlined Section

Observed Conditions. The unlined section of the shaft appears to be stable with no evidence of rock spalling, wall deterioration, or dissolution by water.

Closure. Figure 7-8 compares average diametric closure readings at six elevations on December 9, 1985. The readings reflect only relative closure since the initial readings were taken nearly 1 year after completion of shaft excavation. Thus, the maximum diametric closure at a depth of 2,057 feet (elev. 1353 feet), near the bottom of the shaft, will be more than 1.0 inch. At higher elevations in the shaft, the actual diametric closure over the same period will, likewise, be higher than those shown on the figure.

Deformation. The radial deformation of salt behind an opening can be determined from the measurements of movements of borehole extensometers with multiple anchor points.

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Table 7-4

C & SH SHAFT KEY
PERFORMANCE HISTORY OF PRESSURE CELLS

Description	Pressure Cell Reading (psi) WE-201	WE-202	WE-203	WE-204	Date of Reading
Initial Irad Gage Co calibration	+1	+2	+6	+13	Feb. 3,'82
Initial SRI calibration	+8	+7	+8	+8	Feb. 16,'82
Site received, inspection	-1	+1	0	-2	Mar. 30,'82
Pre-installation, surface	-1	+1	-5	-2	Apr. 4,'82
Pre-installation, in shaft	0	-1	-2	-2	Apr. 15,'82
After plaster of paris	-2	-2	0	-2	Apr. 15,'82
After concrete placement	0	0	0	0	Apr. 15,'82
Initial installed reading	0	0	0	0	Apr. 16,'82
Time after installation:					
7 days	+2	-1	+2	+17	Apr. 22,'82
107 days	-1	-3	-2	0	Jul. 31,'82
529 days	-2	-5	-31	+1	Sep. 26,'83
530 days	+1	-3	0	-2	Sep. 27,'83
544 days	-4	-8	-32	-3	Oct. 11,'83
597 days	-4	-7	-	0	Dec. 3,'83
797 days	-1	-7	-38	0	Jun. 20,'84
938 days	-12	-11	-27	0	Nov. 8,'84
1030 days	-12	-30	-	-2	Feb. 8,'85
1140 days	-6	-10	-25	+3	May 21,'85
1179 days	-6	-11	-25	+5	Jun. 29,'85
1342 days	-14	-10	-25	-2	Dec. 9,'85

NOTE: Negative sign indicates tension.

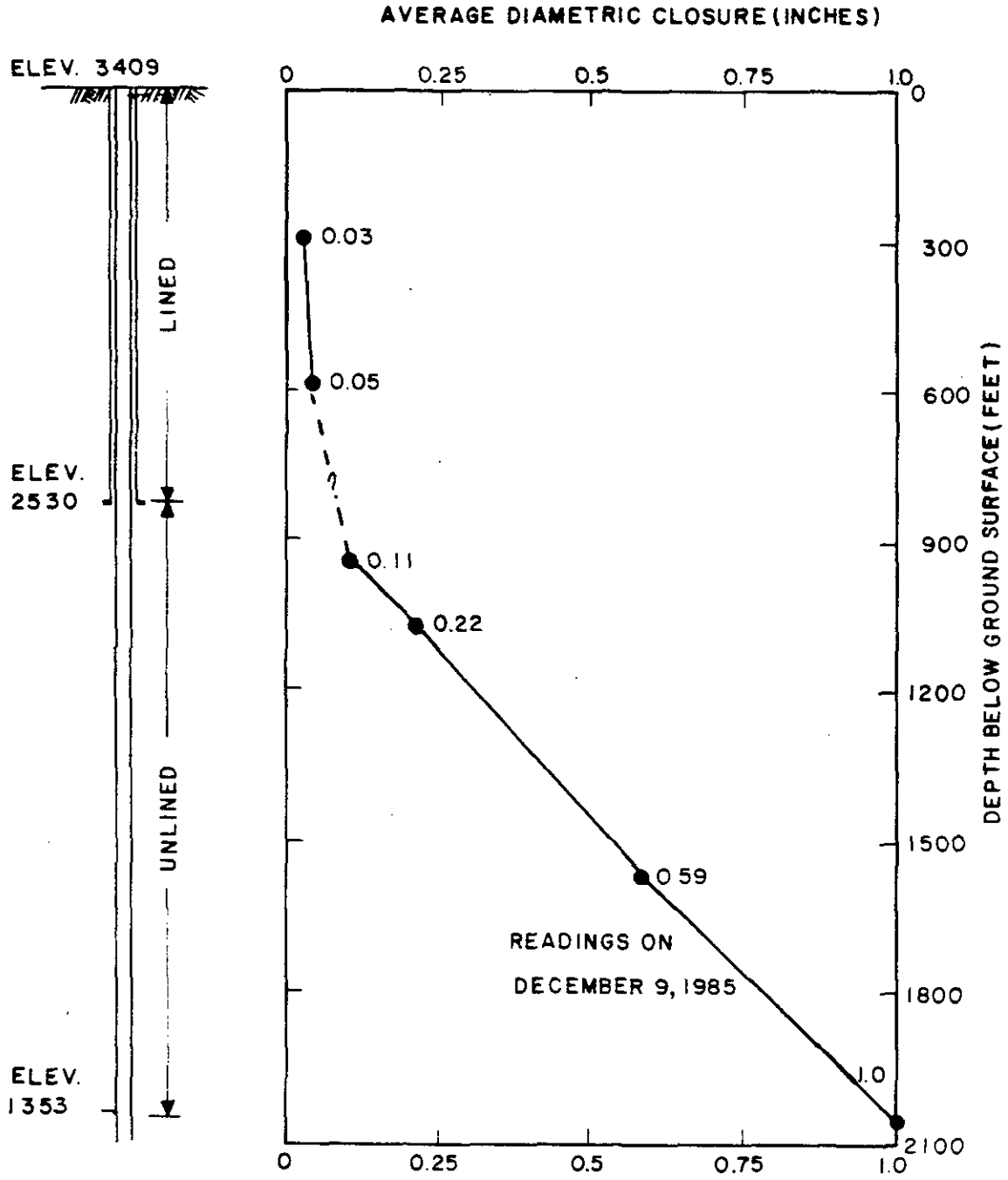

NOTES:

1. SHAFT WAS EXCAVATED FROM JULY THROUGH OCTOBER 1981
2. CONVERGENCE POINTS WERE INSTALLED FROM JULY THROUGH OCTOBER 1982.

Figure 7-8

C & SH SHAFT UNLINED SECTION
AVERAGE DIAMETRIC CLOSURE

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According to extensometer readings on September 16, 1985, the total average collar displacements at elevations 1846 feet and 1353 feet (Figure 7-3) were 0.19 inches and 0.235 inches, respectively. However, the extensometers were installed nearly 7 1/2 months after the completion of shaft excavation.

Figure 7-9 shows the collar movement time histories for multiple-point borehole extensometers 37X-GE-00202, 37X-GE-00205 and 37X-GE-00208 relative to their deepest anchor. The undulating shape of the curves appears to reflect the influence of seasonal temperature changes on the extensometers. The effect of temperature changes is more pronounced on the instrument behavior than on the salt surrounding the instrument. Figure 7-10 shows the change in calculated rates of collar movement with time for the extensometer time histories on Figure 7-9. The maximum rates coincide with the hottest months while during mid-winter the rates are close to, or slightly less than, zero. Because the time interval chosen for calculating the rate of collar movement is much less than the total observation period of 2 years, these rates are probably very close to the actual rates.

Comparison of the extensometer collar movements with convergence point readings suggests that the salt in the vicinity of the deepest anchor may also be moving. Thus collar movement does not reflect the true radial closure of the shaft. The amount of movement of the deepest anchor for any extensometer of given length can be estimated so that the collar displacement provides absolute radial closure. The diametric closure can be computed by model simulation as described below, by curve fitting as described in reference 4-19, or by closed form solution, also described in reference 4-19. Based on this analysis, the absolute movements of the collar and intermediate anchors for the 36-foot long shaft extensometers will deviate from the measured values by only 0.03 inch.

Model Simulation. The structural behavior of the unlined section of the C & SH shaft was analyzed by a nonlinear creep analysis using the

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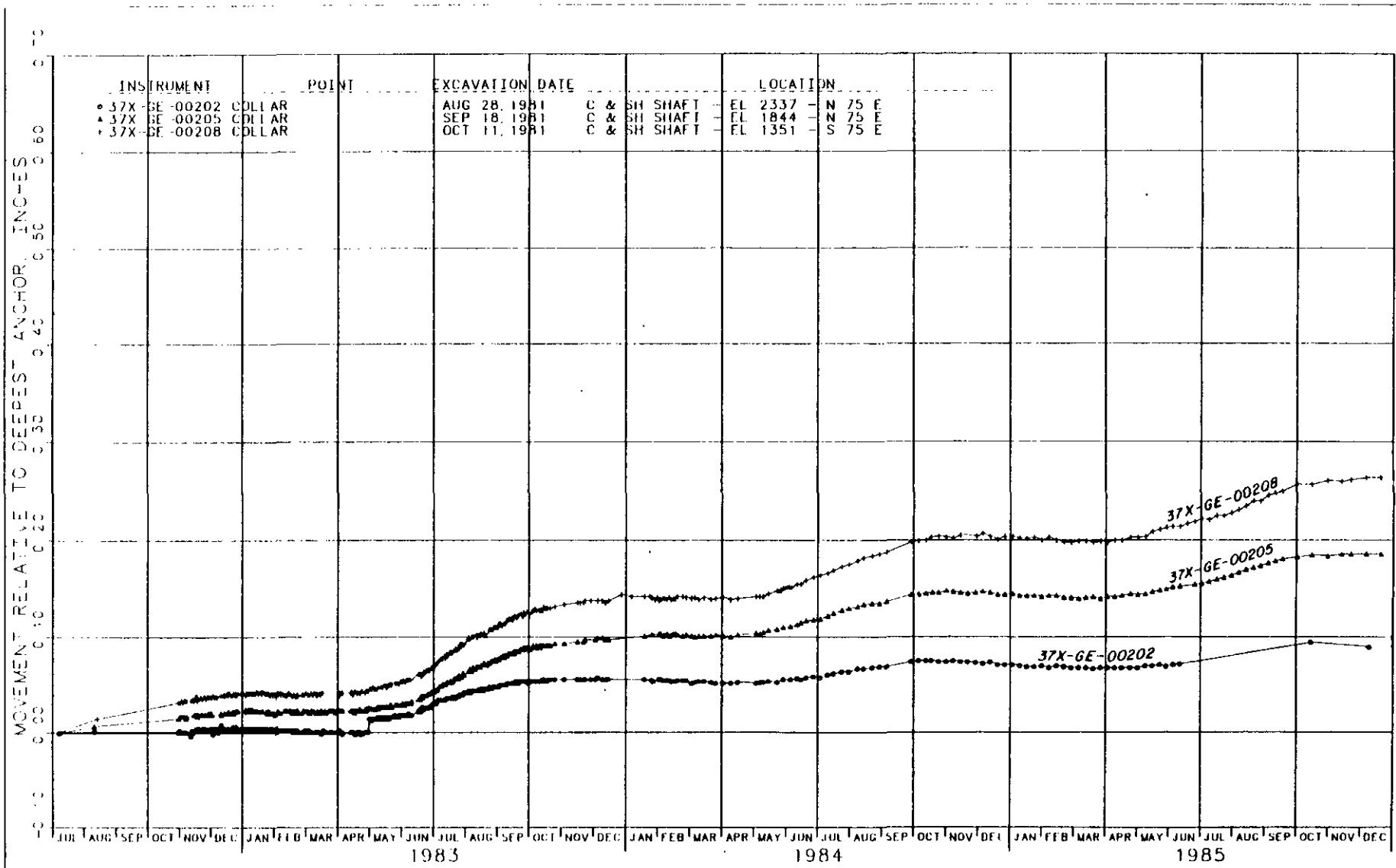

Figure 7-9

C & SH SHAFT UNLINED SECTION
COLLAR MOVEMENT TIME HISTORY

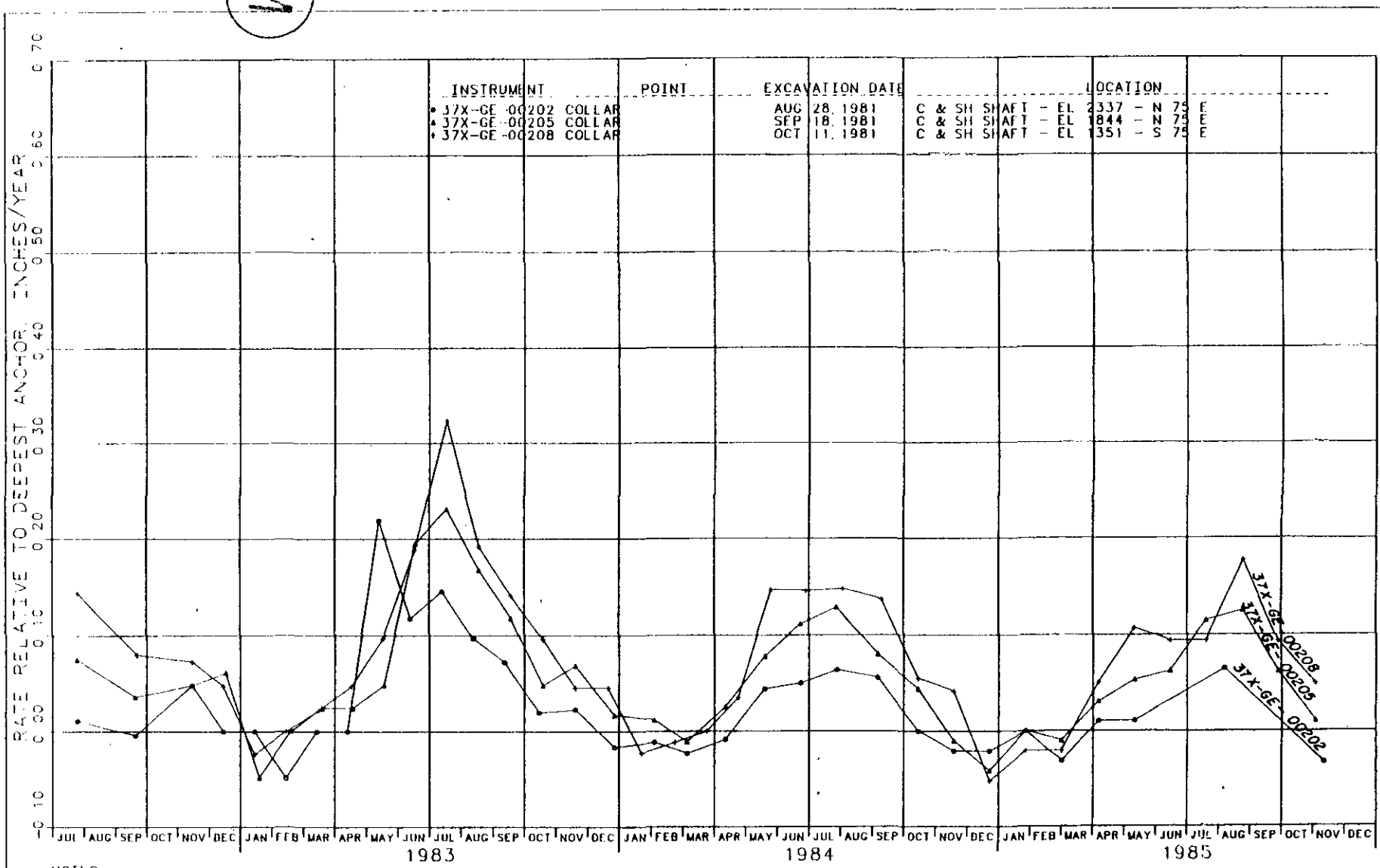

NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

Figure 7-10

C & SH SHAFT UNLINED SECTION
RATE OF COLLAR MOVEMENT VERSUS TIME

MARC General Purpose Finite Element Program (ref. 6-8). The objective of the analysis was to compute actual structural behavior by utilizing available in situ data, thereby verifying the design adequacy of the unlined section of the shaft.

The finite element model used for the analysis utilizes a single horizontal plane of quadrilateral ring elements with the upper and lower horizontal boundaries restrained against vertical displacement. This model is shown on Figure 7-11. The outside vertical boundary was given a constant uniform pressure based upon the lithostatic stress state defined in Chapter 5, equation 5-1. The inside boundary was also given a uniform pressure based upon the same lithostatic stress assumption; however, the pressure was removed in a step-wise fashion over a period of approximately 1 day. This was done to simulate the excavation of the drilled shaft, which results in a gradual relief of overburden pressure on the shaft interior and affects structural behavior in the early stage of excavation.

The secondary creep parameter C in Chapter 6, Table 6-8, was determined based on extensometer data at a depth of 2,057 feet (elev. 1353 feet). The value of C can be computed for each extensometer location using the analytical results and in situ data from the extensometer. Because C, determined from each extensometer, may vary, predicted diametric closures along each extensometer will vary accordingly. Using the diametric closures predicted at different directions on the horizontal plane, the principal directions of the strain on the horizontal plane can be determined. Consequently, closure along two horizontal principal directions can be predicted. Based on the predicted diametric closures at a depth of 2,057 feet in the N15°W, S75°E and S45°W directions, the major axis was found to be N17°40'W and the minor axis N72°20'E.

Closure predictions were made for two principal directions on the horizontal plane. Because the stress and strain distributions are not sensitive to the value of the secondary creep parameter, except during

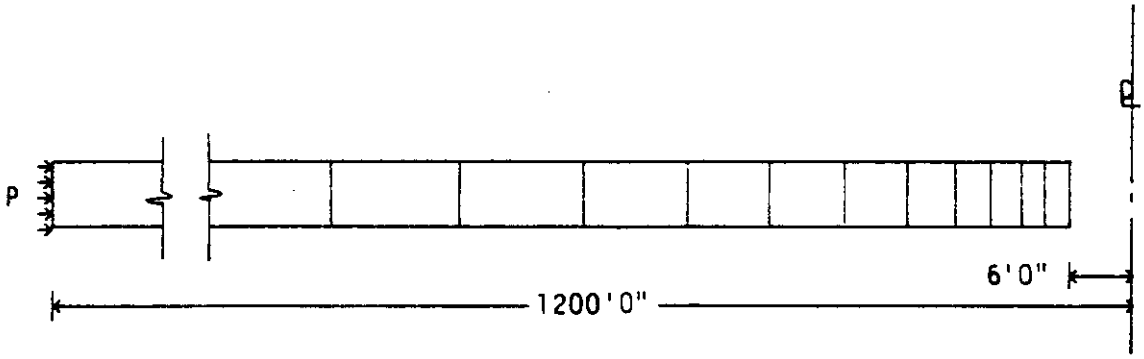

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Figure 7-11

C & SH SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

the initial stages of creep, the stress and strain distributions were computed based on the average values of the creep parameter C determined from three different directions.

7.3.2.4 Shaft Station

Observed Conditions. The C & SH shaft station exhibits spalling from both the roof and wall surfaces that requires continual routine maintenance. Displacements, separations and fracturing occuring above the roof at clay G and in the underlying halite were expected.

Data from the Excavation Effects Program indicate that the halite from 4 to 10 feet above the roof contains essentially no separations or fracturing. Floor heave is evident at the electrical substation where the concrete base slab has tilted several degrees, but holes drilled into the station floor encountered only minor separations and fracturing. Extensometer 51X-GE-00253, in the station floor, does not show any significant increase in collar movement that would be expected if floor heave and fracturing is occurring. Although the C & SH shaft station is the oldest and largest horizontal opening, the extent of separations and fracturing beneath the floor is very small relative to the fracturing found in the floor beneath Test Room 3 (Chapter 11).

The observed behavior in the station is apparently due in large part to its initial excavation by blasting. No other underground area has exhibited the degree of spalling that has occurred in the station. The blasting is thought to have accelerated separations at clay G and in the underlying halite in the main station area south of the shaft. However, the extensive rock bolting in the roof appears to have effectively controlled these separations.

Fracturing in the pillar corners at the S90 crosscut has continued to evolve as the salt responds to stresses produced by the station excavation. Changes in the fracturing are exhibited primarily by the appearance of new vertical fractures and by the elongation and widening of existing fractures. Minor spalling has also occurred, particularly

at the roof and wall intersection in the upper portion of geologic map unit 4.

Closure. Figure 7-12 shows closure rates calculated from the readings of roof-to-floor convergence points. The maximum rate appears to have occurred during the early part of August 1984.

The closure rates shown on Figure 7-12 cannot be directly compared without considering the differences in dimensions at the locations shown, as well as differences in the thickness of the roof beam below clay G, and the number of rock bolts in the vicinity of the respective convergence measurement stations.

Figure 7-13 compares the central vertical closure readings at stations S18.5 and N39. Although the closure measurements are very close at both stations, actual total closure at the S18.5 station will be greater since the initial reading at this station was taken nearly 261 days after the completion of excavation, compared to only 35 days at the N39 station. In addition, the larger opening dimensions at the S18.5 station will also result in more rapid closure. Even though the density of rock bolts is greater south of the C & SH shaft than north of it, the roof-to-floor closure is greater to the south. This is probably because the roof beam below clay G is thinner and longer to the south.

Figure 7-14 shows the collar movements of multiple-point borehole extensometers 51X-GE-00227 and 51X-GE-00228 in the station roof, 35 feet north and 65 feet south of the C & SH shaft, respectively. The average collar movement rate of 51X-GE-00228 is higher than that of 51X-GE-00227, as determined from Figure 7-14. The roof closure rate south of the shaft is currently more than the rate north of the shaft.

A double-point borehole extensometer (51X-GE-00253) was installed in the floor of the C & SH shaft station. The initial reading from this extensometer was taken nearly 238 days after the completion of

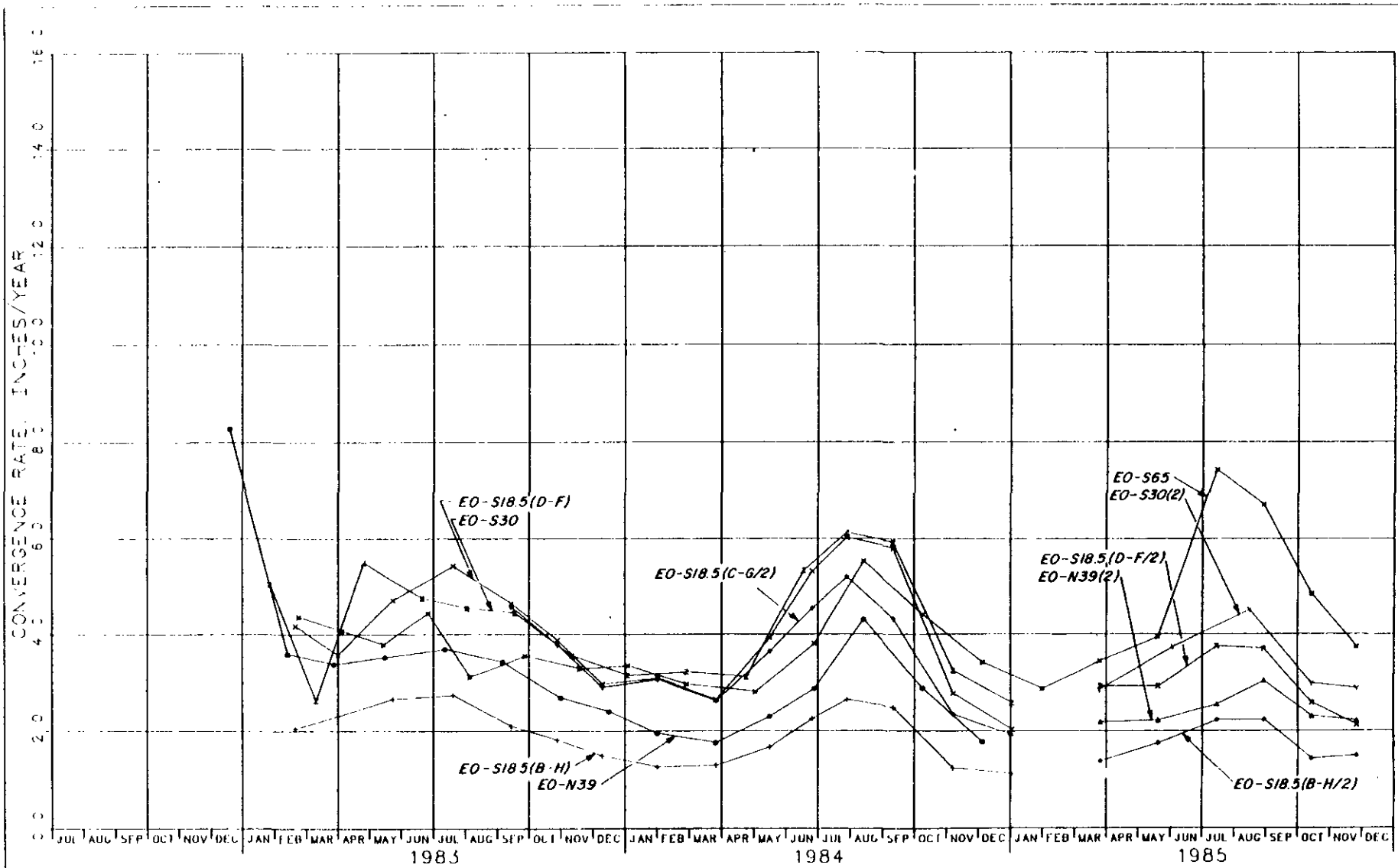

NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

Figure 7-12

C & SH SHAFT STATION
CALCULATED ROOF-TO-FLOOR CLOSURE RATES

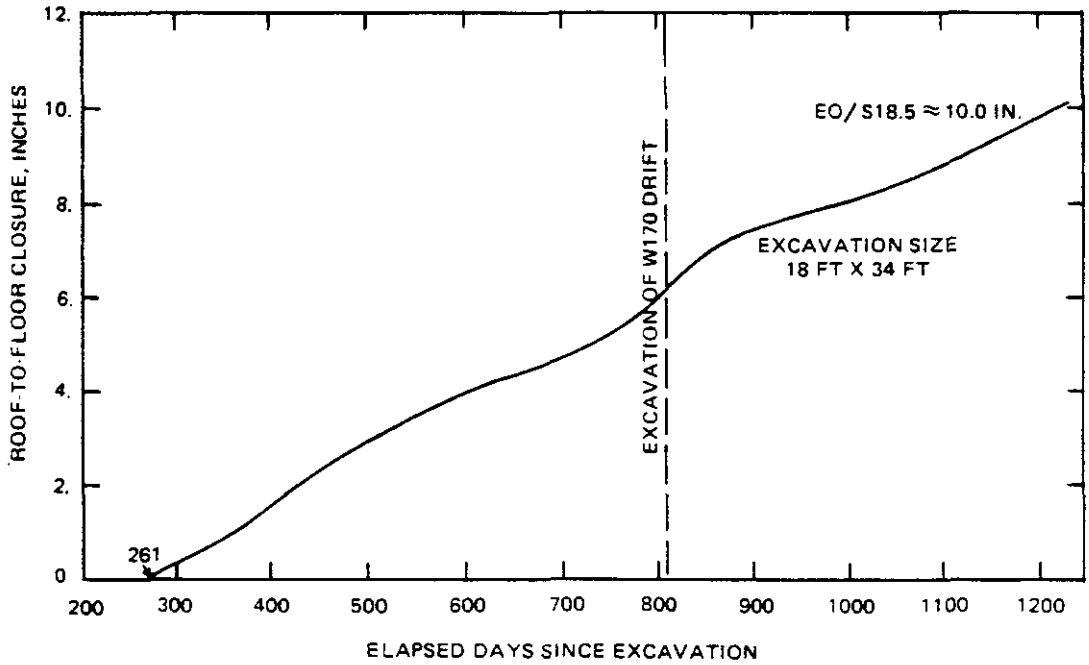

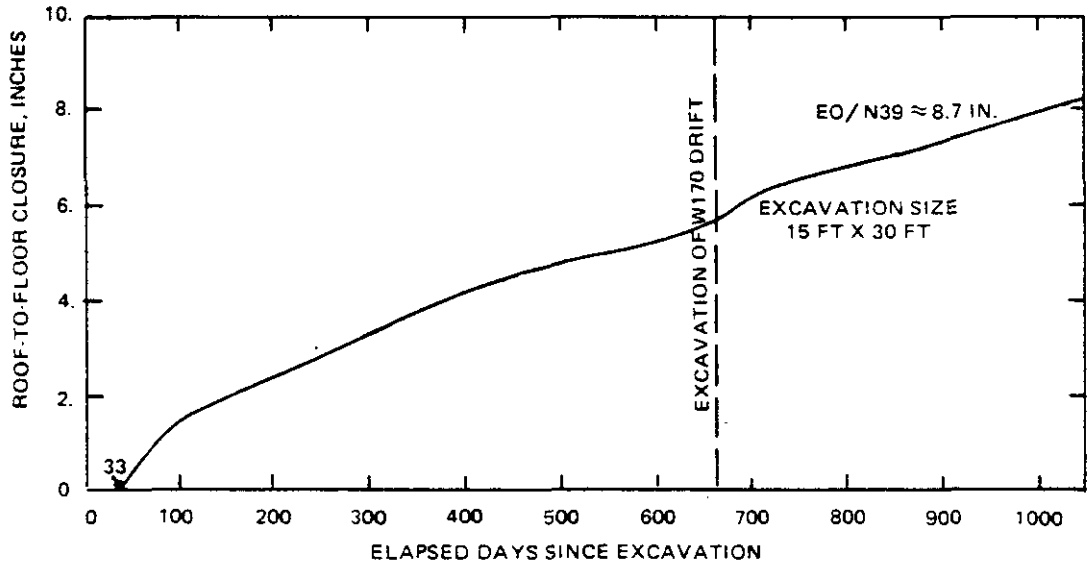

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Figure 7-13

C & SH SHAFT STATION
TYPICAL ROOF-TO-FLOOR CLOSURE HISTORY

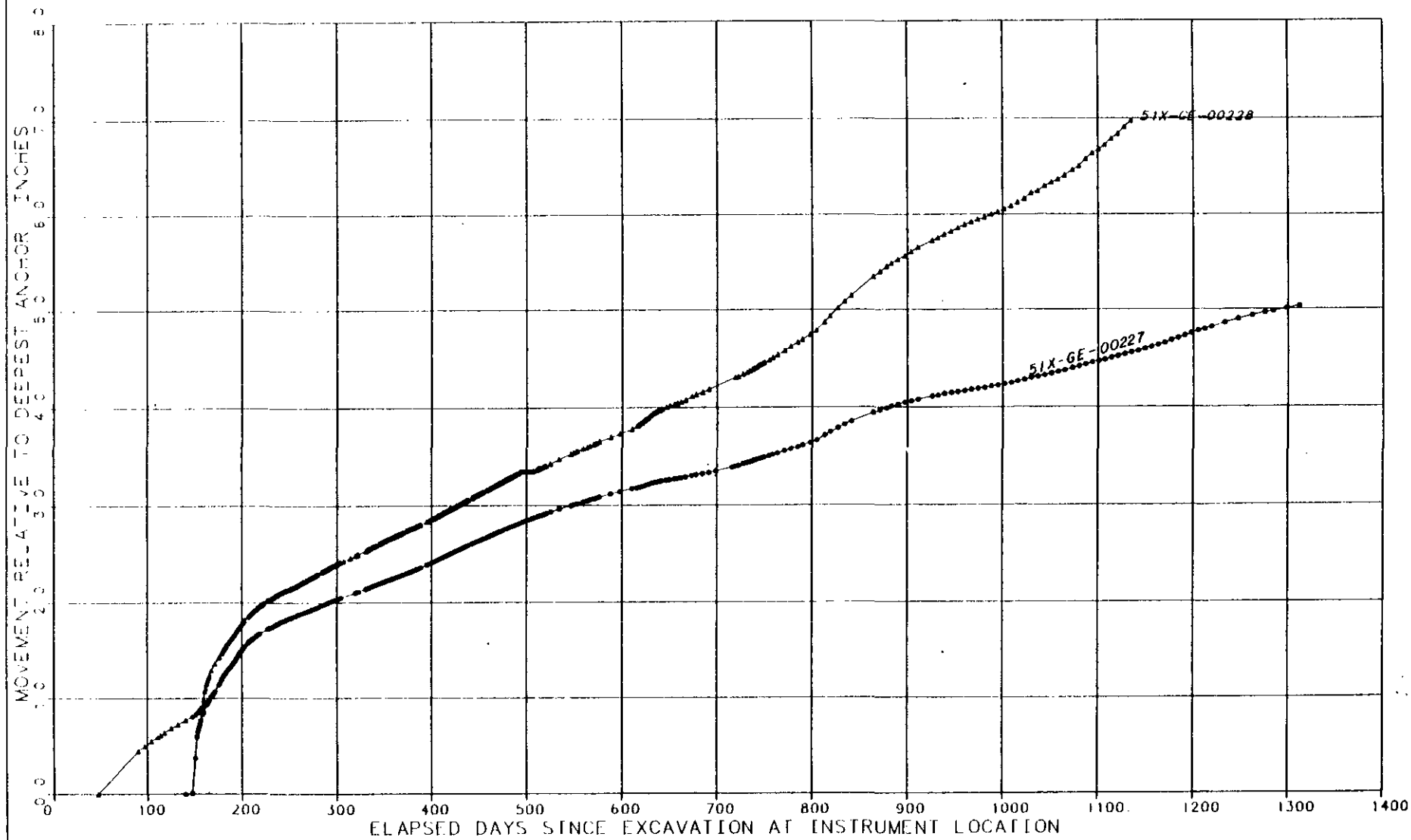

Figure 7-14

C & SH SHAFT STATION
HISTORY OF COLLAR MOVEMENTS - ROOF EXTENSOMETERS

excavation at the instrument location (Appendix J, Figure J-172). The measured collar movement relative to the deepest anchor was 3.26 inches on December 20, 1985. Actual floor heave will be higher as a result of the time-lag between the end of excavation and the initial reading date. There was a slight increase in the collar movement rate due to excavation of the nearby W170 drift, but the rate has since become steady.

Roof Stability. Figure 7-15 shows the distribution of measured movements along roof extensometer 51X-GE-00251, 18 1/2 feet south of the C & SH shaft, for the readings taken on September 18, 1985. The magnitudes shown are cumulative between the initial reading date of January 11, 1983, and September 18, 1985. The movements are also expressed as percentages of the collar reading. Sixty-one percent of the relative movement has taken place between the collar and anchor A. This has remained practically constant since December 1983 and is an indirect indication that there is no accelerating trend in the rate of opening at clay G in the vicinity of this extensometer. For comparison, the distribution of measured movement along roof extensometer 51X-GE-00227, 35 feet north of the C & SH shaft, is shown on Figure 7-16. The relative movement between the collar and anchor A has remained constant at 52 percent through December 1985. Based on these measurements, there is no indication that clay G is parting at an accelerating rate either north or south of the shaft.

7.3.3 Prediction of Future Behavior

This subsection presents the results of the analysis and evaluation of the finite element modeling and the data collected in the C & SH shaft. These results are presented in the form of predictions for future behavior of the constructed shaft elements (liner and key) and of the salt surrounding the unlined section of the shaft and the shaft station.

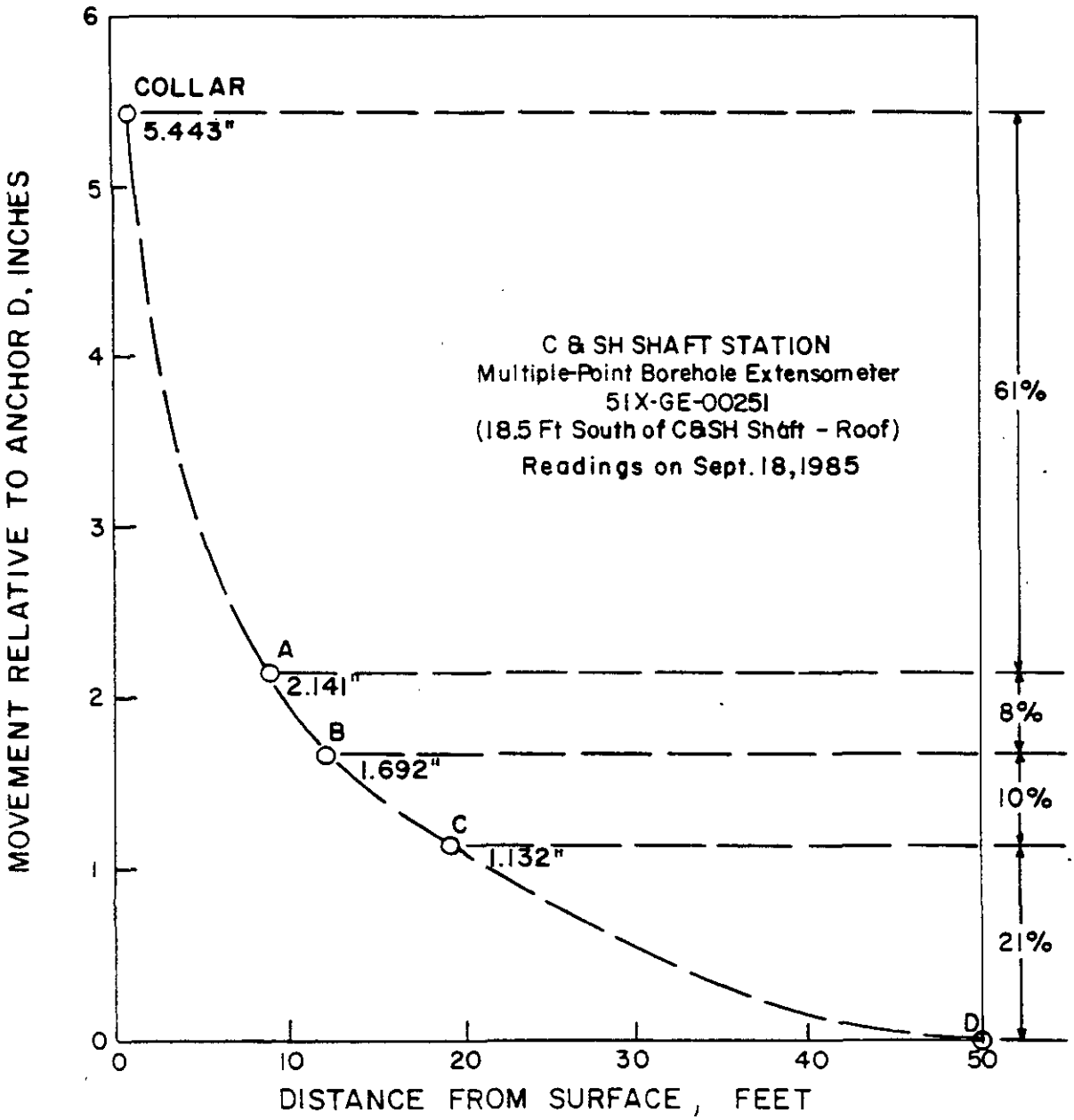

Figure 7-15

C & SH SHAFT STATION
MOVEMENT DISTRIBUTION ALONG ROOF EXTENSOMETER 51X-GE-00251

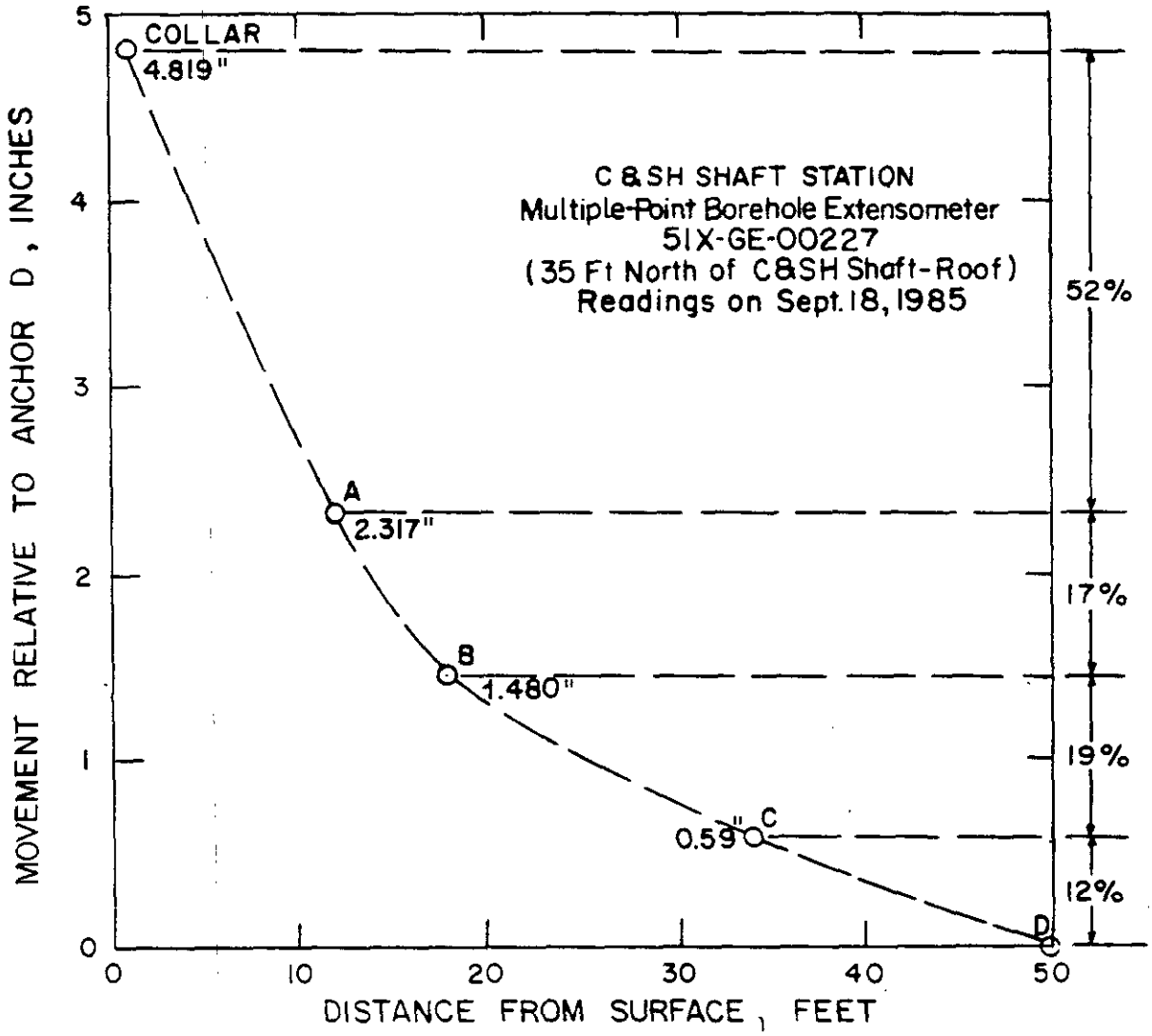

Figure 7-16

C & SH SHAFT STATION
MOVEMENT DISTRIBUTION ALONG ROOF EXTENSOMETER 51X-GE-00227

7.3.3.1 Lined Section

The water pressure on the shaft liner to date has been less than the hydrostatic design pressure. The prediction of future water pressures behind the liner is difficult due to the reasons discussed in subsection 7.3.2.1. The lower potentiometric surface and lack of hydraulic continuity along the rock/liner interface may prevent the ground water from reaching the design hydrostatic head. In addition, leaks around the piezometers and possibly obstructed filters may cause the measurements to be somewhat less than the actual pressure conditions.

Figure 7-17 shows that if the water pressure does reach the design hydrostatic pressure, the liner will remain stable based on its design factor of safety. The figure shows that the pressure capacity of the liner far exceeds the design hydrostatic pressure. This pressure was determined based on water level data obtained at the site during preliminary design activities. The data indicated that the highest potentiometric surface in the Rustler formation beneath the site occurred at a depth of approximately 250 feet below the ground surface. This data was later confirmed by investigations conducted in the site vicinity by the U.S. Geological Survey (USGS) (ref. 7-9). It is not expected that this potentiometric surface will be exceeded during the 25-year operating life of the facility. If any external water were to infiltrate along the rock/liner interface to form a column of water that would exceed the hydrostatic head contained in the design bases, the stability and safety of the steel liner would still not be compromised based on the design factor of safety.

7.3.3.2 Shaft Key

The results of the shaft key analysis indicate that after concrete is placed against the shaft wall it shrinks away from the wall at a rate greater than the rate of salt creep, resulting in a separation between the concrete and the salt. The rate of concrete shrinkage decreases with time and continuous salt creep eventually results in the salt

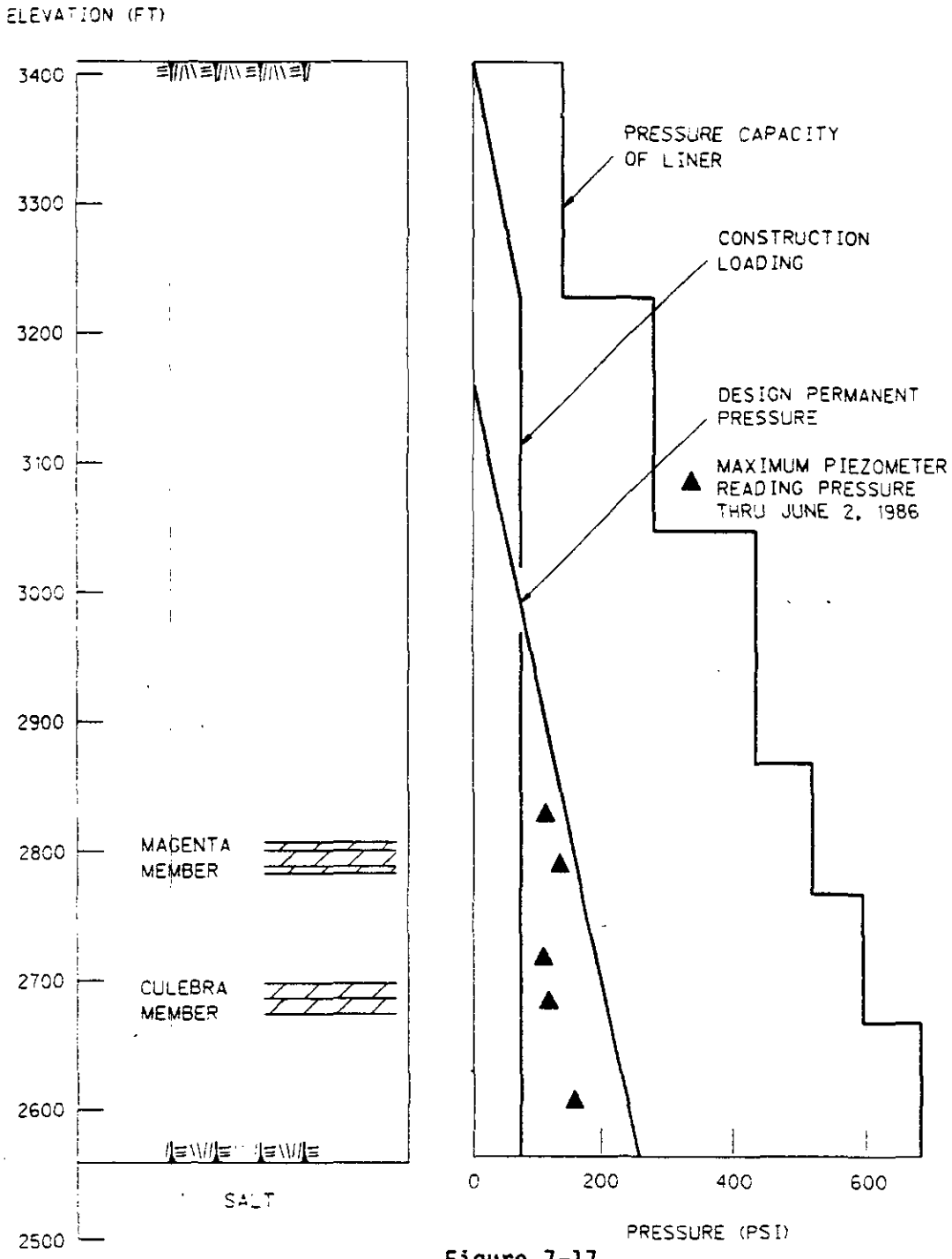

Figure 7-17

C & SH SHAFT LINER
LATERAL PRESSURE COMPARISON

contacting the concrete again. The interactive pressure between the concrete and the salt will then gradually increase due to continuous salt creep.

In the key area, the shaft wall radial and tangential stresses (Figures 7-18 and 7-19, respectively) were plotted as a function of distance from the centerline of the shaft for a typical section immediately after excavation of the shaft and for 1 year and 25 years after concrete placement. As expected, the radial stresses in the salt are initially relieved near the opening but begin increasing after the salt comes in contact with the concrete. Further away from the opening, the stresses trend toward the overburden pressure.

The tangential stresses in the salt 3 days after excavation show an elastic response which gives very high values near the opening. The stresses are relieved near the opening from the time the salt starts to creep until it contacts the concrete. After contact is made, and for the remainder of the 25 year analysis period, the stresses in the salt and concrete key increase. There exists a discontinuity of stress at the concrete/salt interface which is primarily due to differences in their material properties. Like the radial stresses, the tangential stresses approach the overburden pressure with increasing distance from the opening.

At 25 years, the radial stresses, which are equal to the lateral pressures on the salt face of the key, will increase to an average value of 275 psi. At the same time, the maximum hoop stress at the inside face of the concrete key has an approximate value of 1,000 psi, with an average value across the key of about 825 psi. Figures 7-20 and 7-21 show the predictions for average lateral pressures and average hoop stresses, respectively. A lateral pressure capacity in the key of 833 psi, based on an allowable hoop stress controlled by a concrete compression of 3,000 psi, results in a factor of safety of approximately three.

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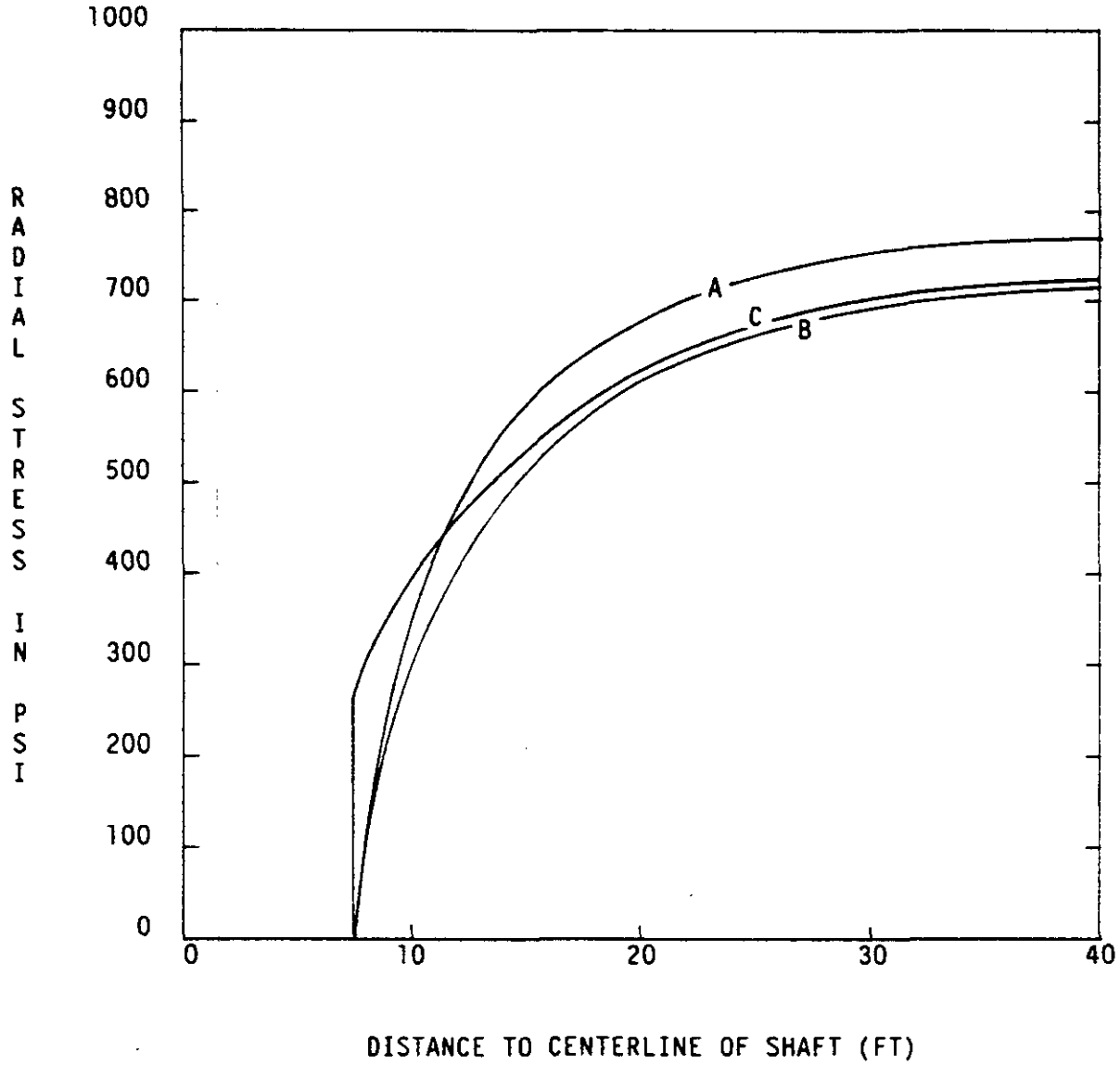

A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER CONCRETE PLACEMENT
C – 25 YEARS AFTER CONCRETE PLACEMENT

Figure 7-18

C & SH SHAFT KEY
RADIAL STRESS DISTRIBUTION

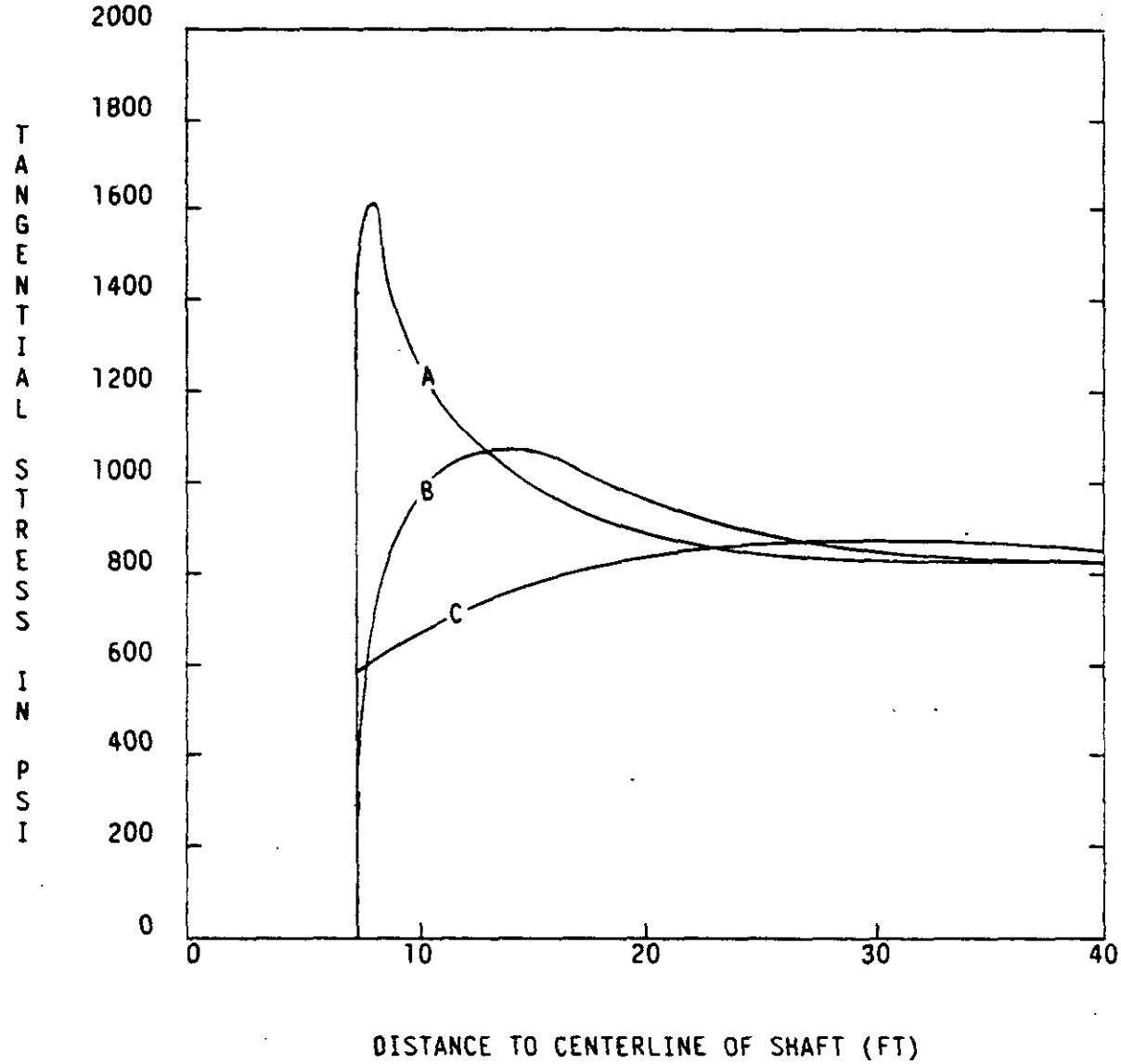

A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER CONCRETE PLACEMENT
C – 25 YEARS AFTER CONCRETE PLACEMENT

Figure 7-19

C & SH SHAFT KEY
TANGENTIAL STRESS DISTRIBUTION

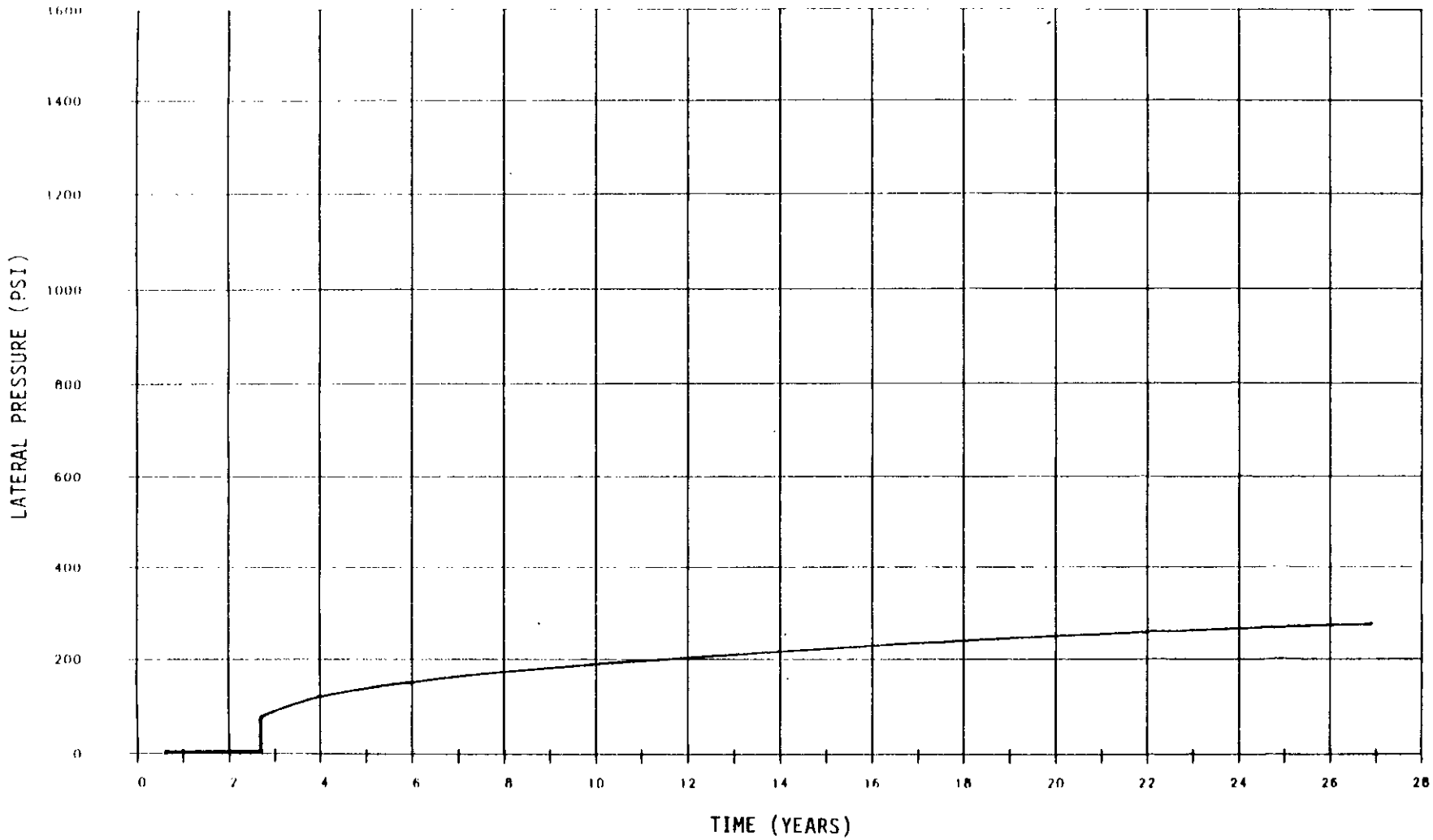

Figure 7-20

C & SH SHAFT KEY
LATERAL PRESSURE PREDICTION

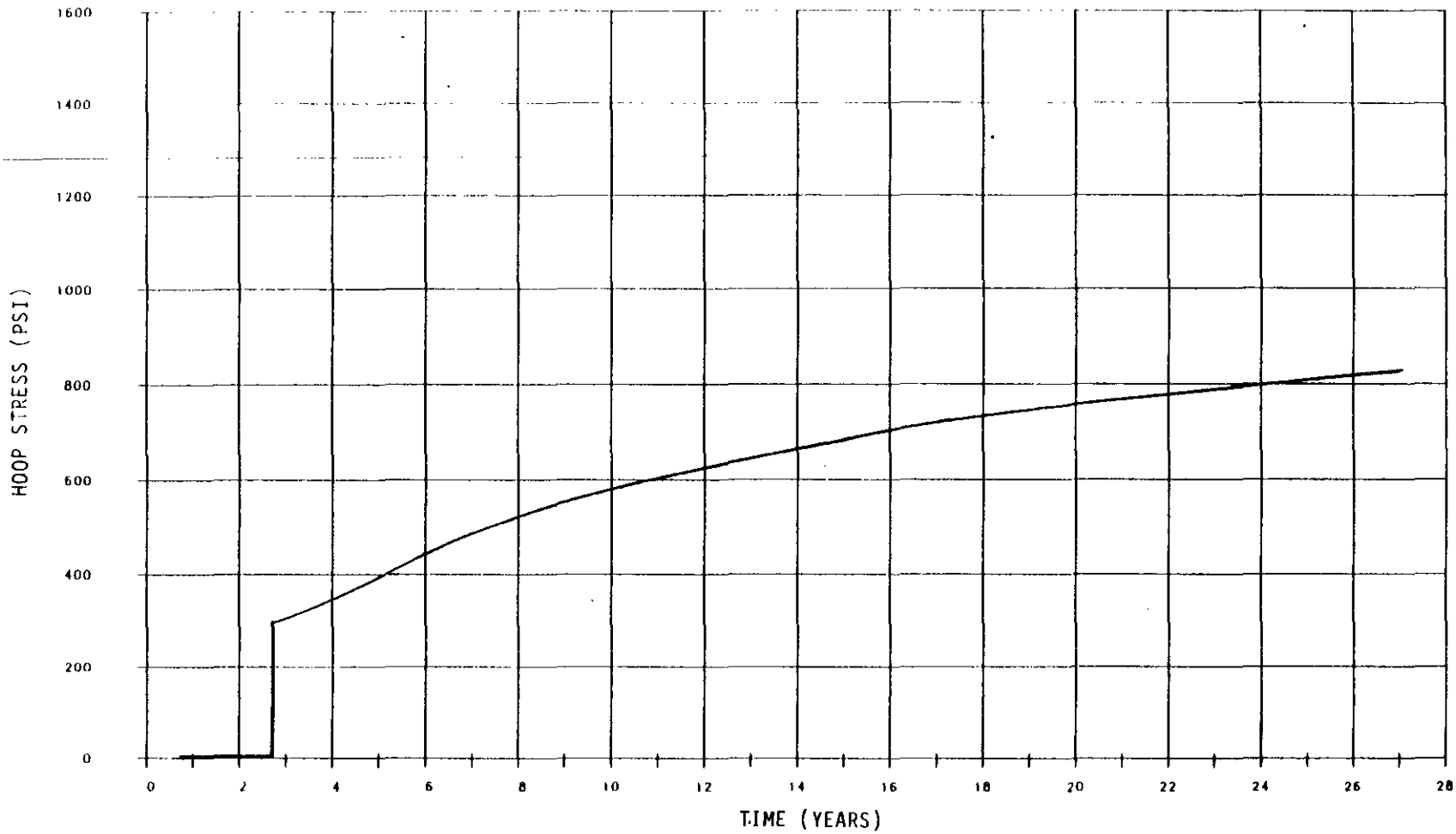

Figure 7-21

C & SH SHAFT KEY
HOOP STRESS PREDICTION

The average diametric closure of the key at 27 years is expected to be about 0.1 inch with a maximum value of 0.175 inch, or about half the predicted value for the salt in the unlined section immediately below the key (Figure 7-22). The average diametric closure of the unlined section immediately below the key at 27 years varies from 0.03 inch for the anhydrite bed to 0.38 inch for the argillaceous halite layer. Figure 7-23 shows the diametric closure predictions for both the concrete key and the salt in the adjacent shaft wall.

7.3.3.3 Unlined Section

Extrapolation of In Situ Responses. Convergence point measurements are too few to be used for the extrapolation of future in situ responses in the unlined section of the shaft. Thus, the readings of collar movements of multiple-point borehole extensometers must be used for this extrapolation. Because the extensometer collars are recessed 1 foot into the wall, and the readings are referenced to the deepest anchor which is also moving, extrapolation of collar movement will not produce an exact estimate of the movement of the shaft surface.

The maximum collar movement occurs at multiple-point borehole extensometer 37X-GE-00208 at a depth of 2,057 feet (elev. 1353 feet) (Figure 7-3). As discussed earlier, and as shown on Figure 7-9, the collar movement is affected by seasonal temperature fluctuations. However, if we consider only the later portion of the curve, its slope is approximately 0.125 inch/year between June 1984 and June 1985. Assuming this rate to be constant for another 22 years, the additional radial movement of the collar will be nearly 3 inches. Thus, the effective diameter of the unlined shaft will be reduced by nearly 6 inches.

Replication of In Situ Responses. Figures 7-24 and 7-25 show the radial and tangential stress distributions relative to the overburden stress at different times. Figure 7-24 indicates that the zone where radial stresses are affected increases in size with time while Figure 7-25 indicates that tangential stresses are only affected within an approximately constant radius of 60 feet.

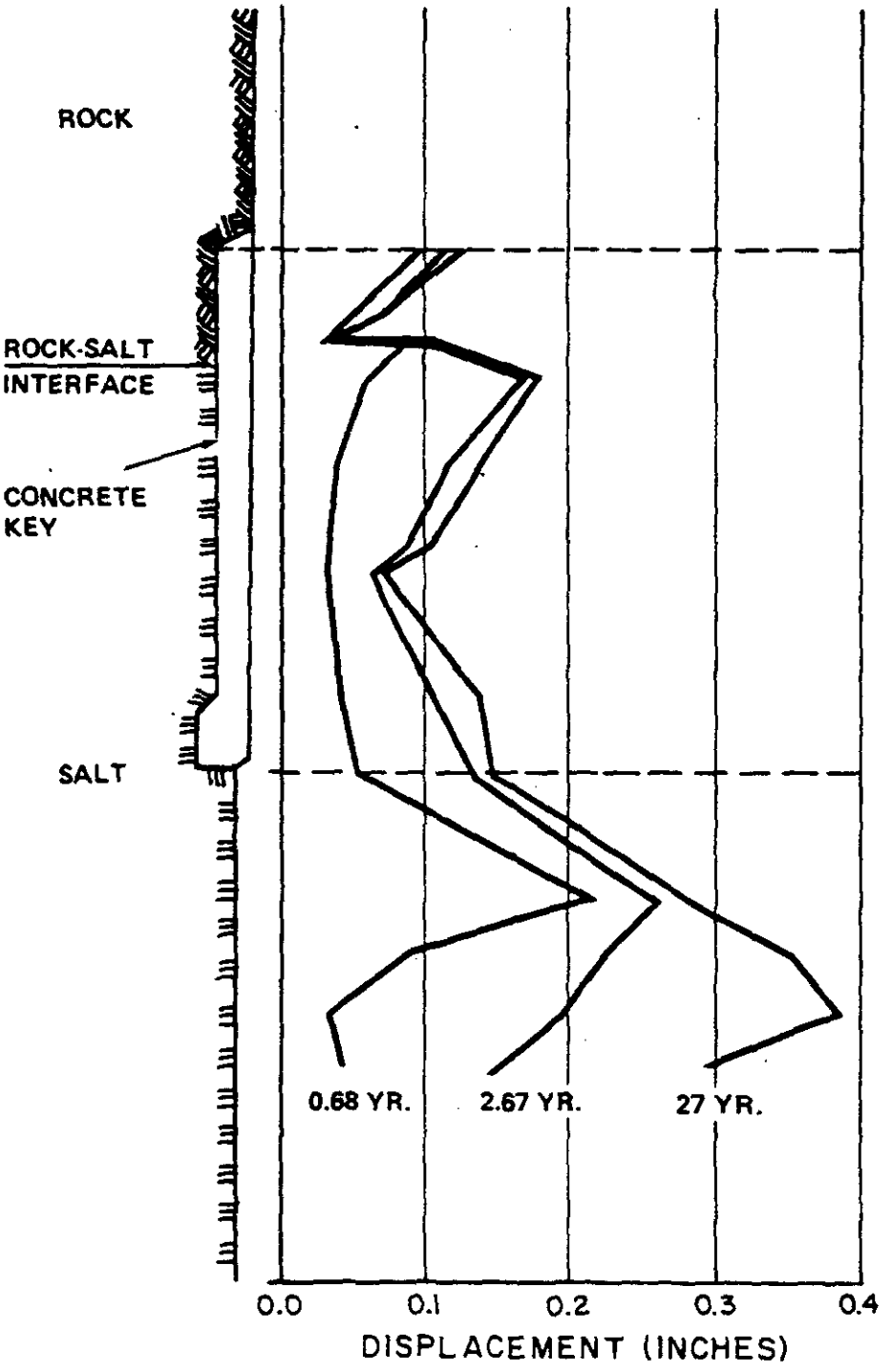

Figure 7-22

C & SH SHAFT KEY
DIAMETRIC CLOSURE

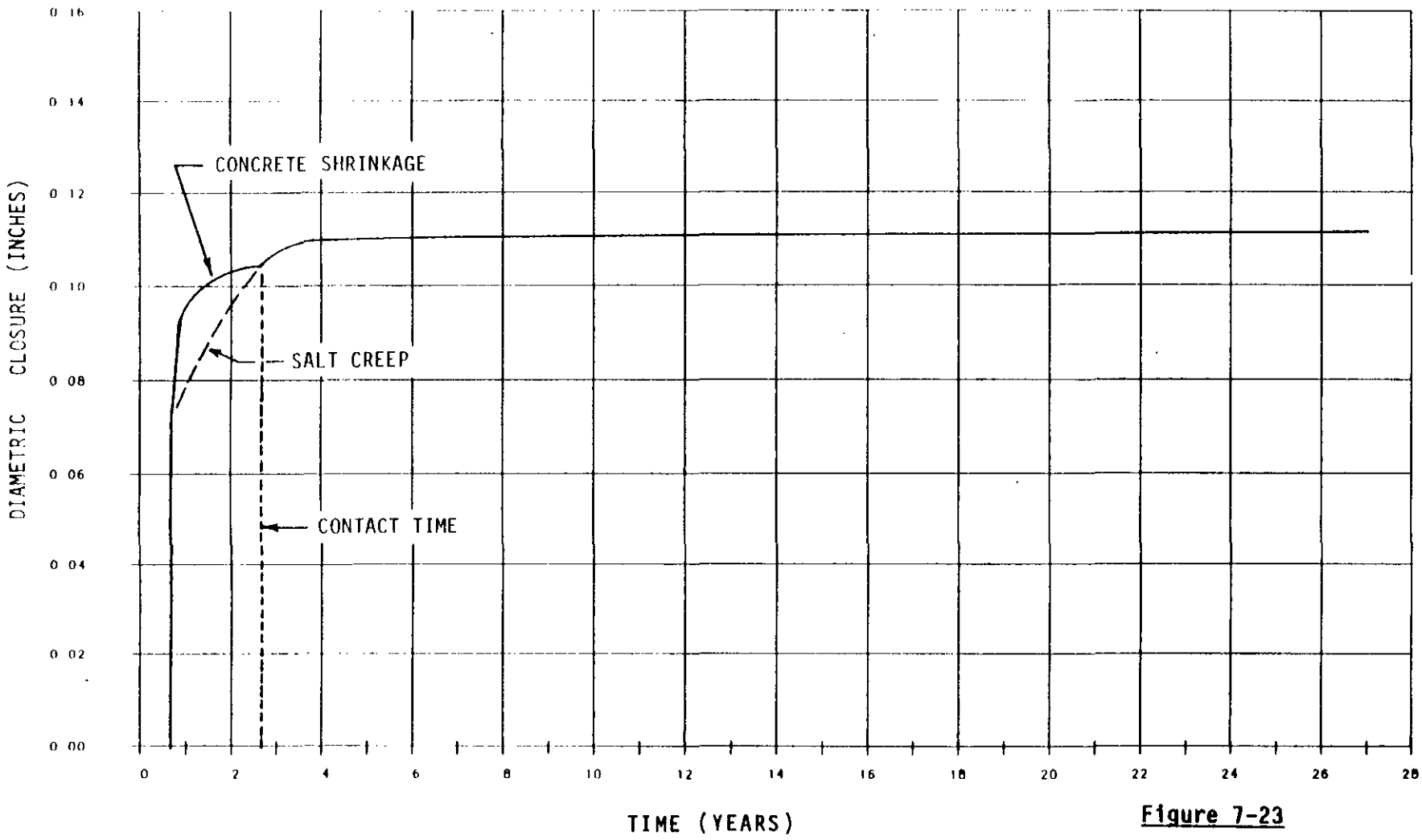

Figure 7-23

C & SH SHAFT KEY
DIAMETRIC CLOSURE PREDICTION

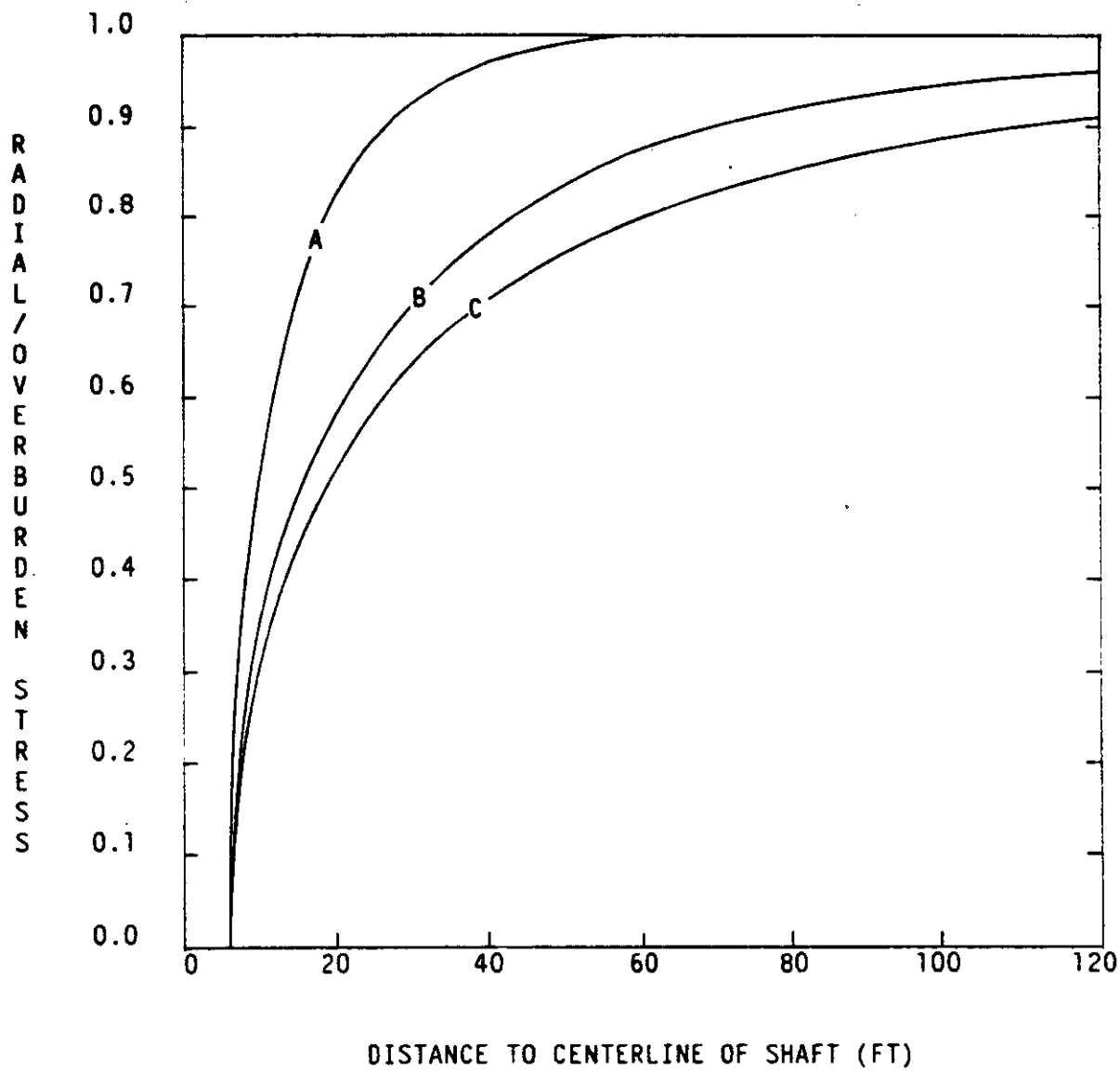

A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-24

C & SH SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1353

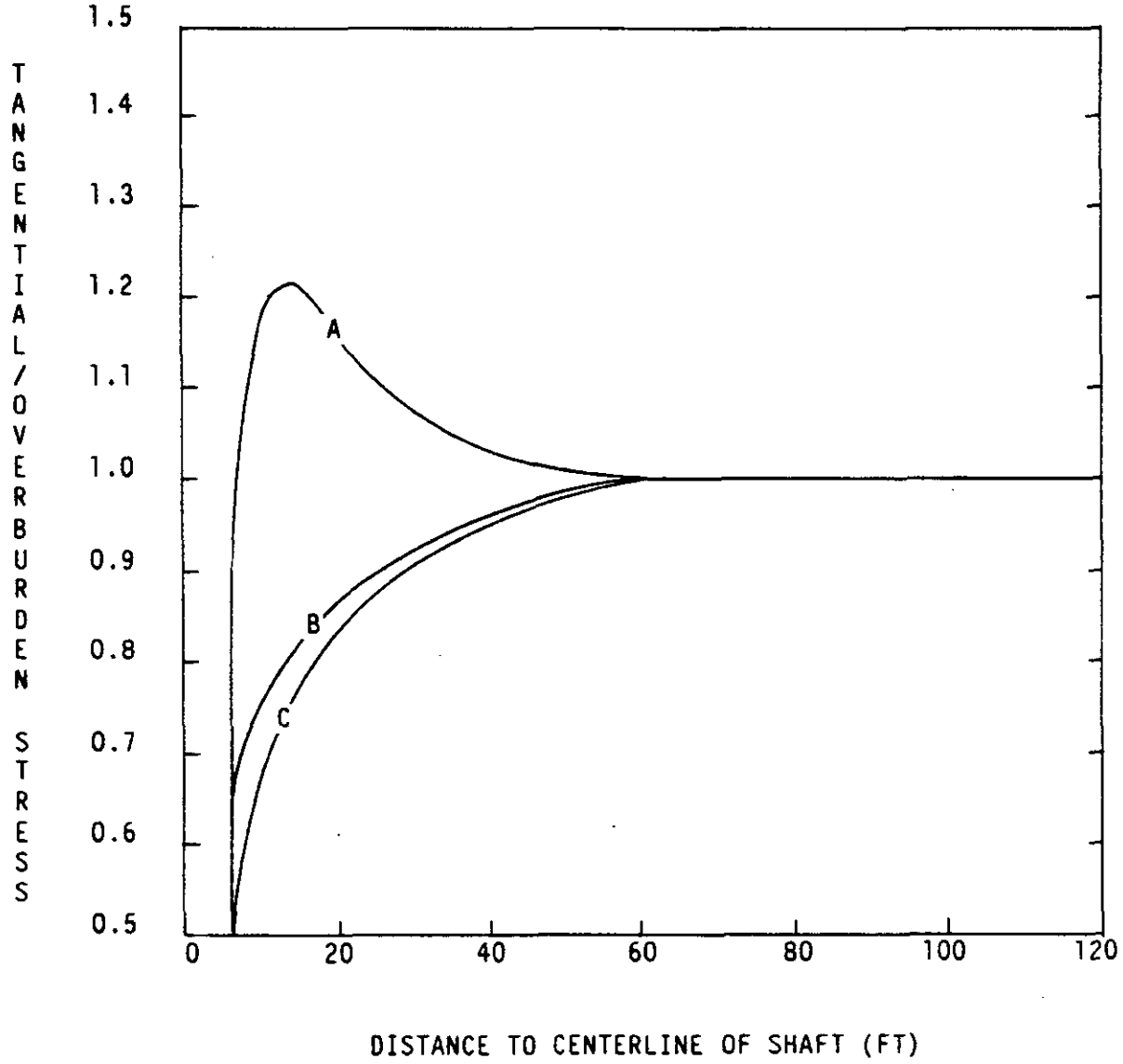

A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-25

C & SH SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1353

Figure 7-26 shows the ratio of radial displacements at various distances from the shaft centerline relative to the radial displacement of the shaft wall at different times. Based on this figure, the ratio of the displacements between each extensometer anchor point and the shaft wall can be determined. This figure indicates that the extensometer collar readings relative to the deepest anchor will reach about 84 percent of the actual radial displacement of the shaft wall 15 years after excavation.

Figure 7-27 illustrates the effective creep strain distribution in the shaft at a depth of 2,057 feet (elev. 1353 feet) at selected times after excavation. The magnitude of effective strain at the shaft wall at 15 years approaches a value of approximately 0.03.

Figure 7-28 shows diametric closure versus depth at different times. The response curves are drawn relative to the time the initial instrument readings were made. The response indicated by the curve to the left of the vertical axis corresponds to the computed response which took place between excavation and the initial instrument reading. The relative response between October 1982 and June 1984 is correct regardless of the time offset. Varying the time offset in effect shifts the position of all other response curves relative to the vertical axis. The diametric closure prediction at a depth of 2,057 feet is shown on Figure 7-29.

7.3.3.4 Shaft Station

Figure 7-15 shows that, for roof extensometer 51X-GE-00251 in the C & SH shaft station, the relative movement between the collar and anchor A, expressed as a percentage of the collar reading, has remained practically constant for the last 2 years. Thus, provided that no failure of the mechanical-anchor rock bolts occurs, the closure rate of the roof is expected to stabilize. It is assumed that no new excavation will occur close to the station. If additional excavation is performed, the rate of closure between the roof and floor and between the walls may be accelerated.

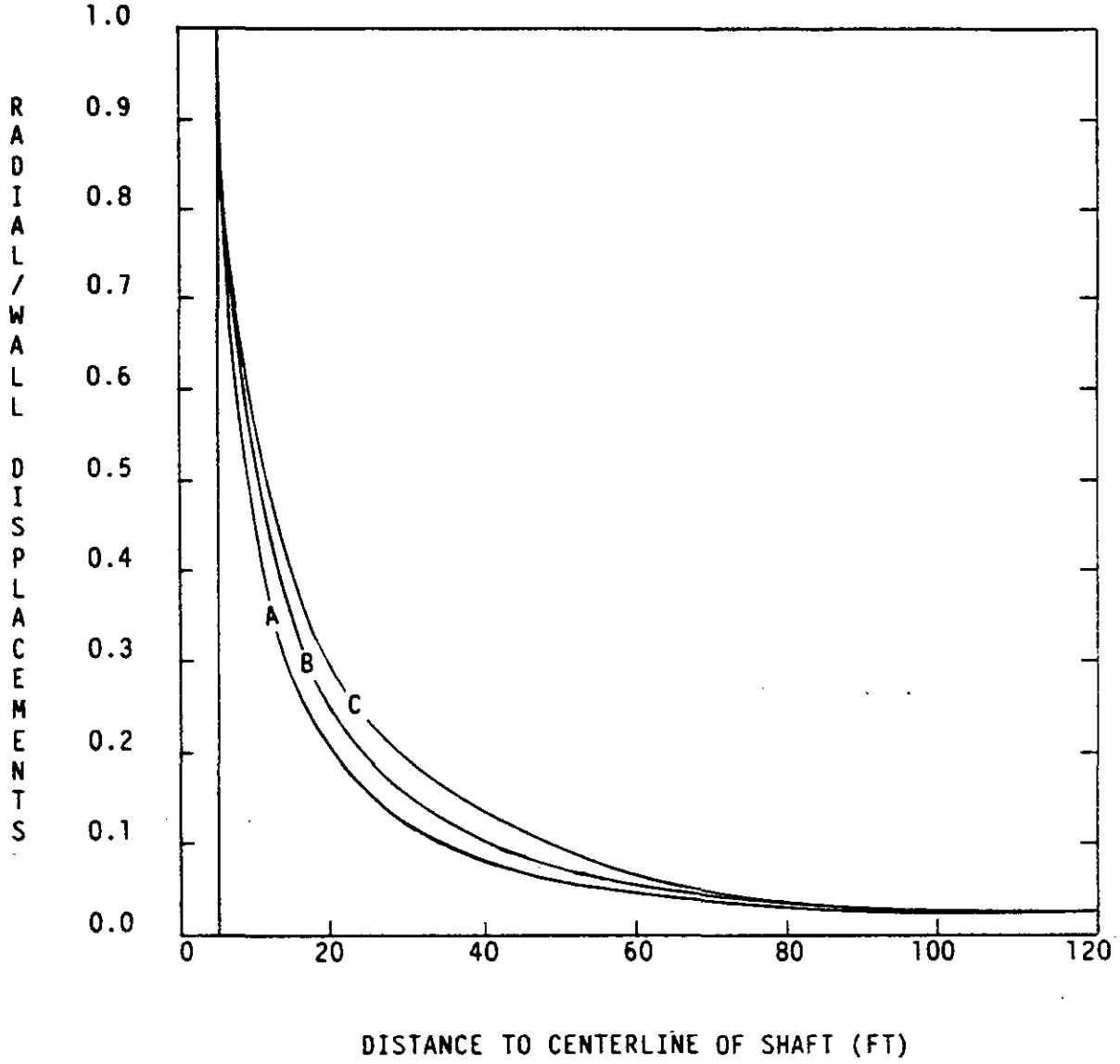

A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-26

C & SH SHAFT UNLINED SECTION
RADIAL DISPLACEMENT DISTRIBUTION AT ELEVATION 1353

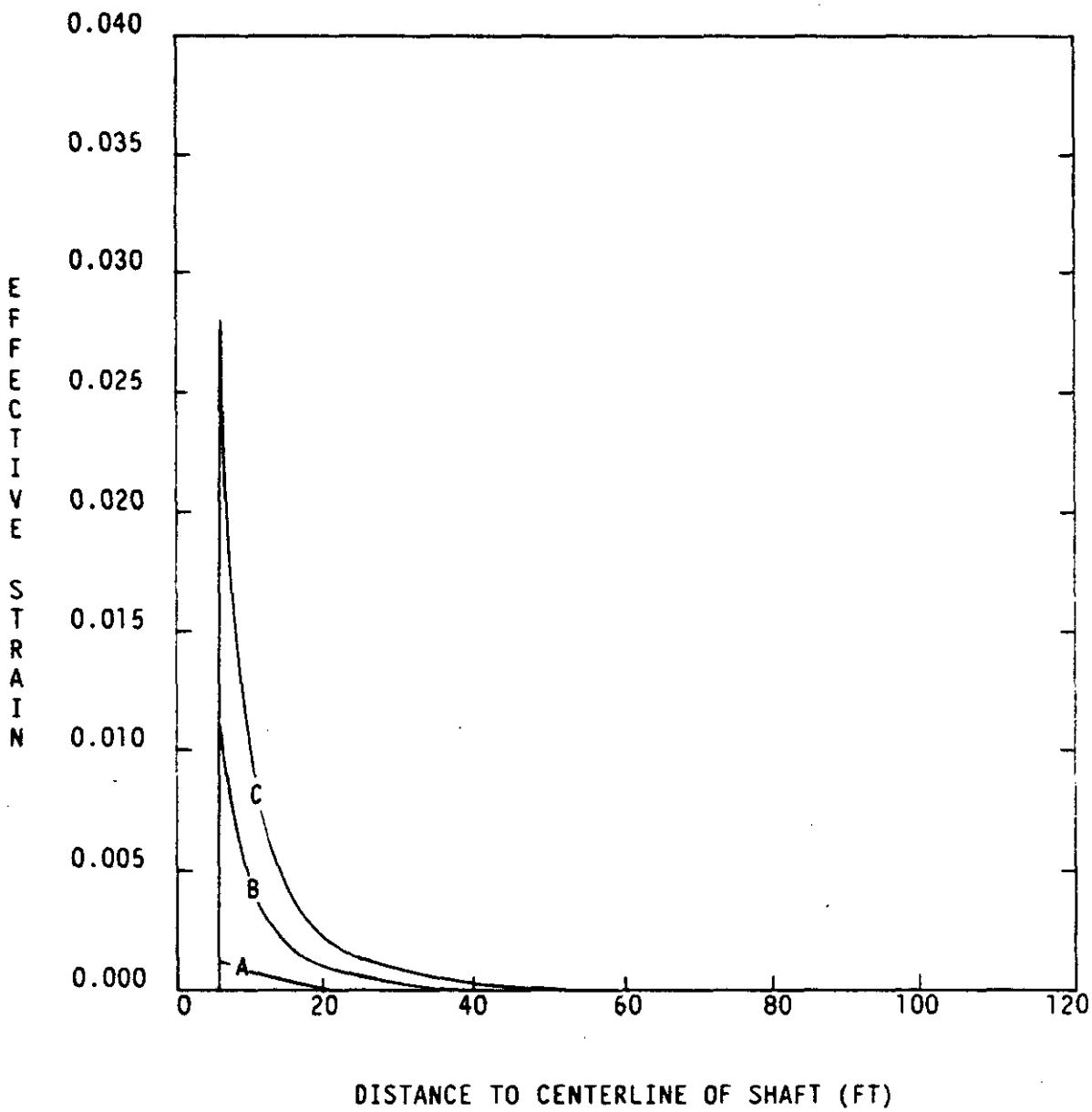

A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-27

C & SH SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1353

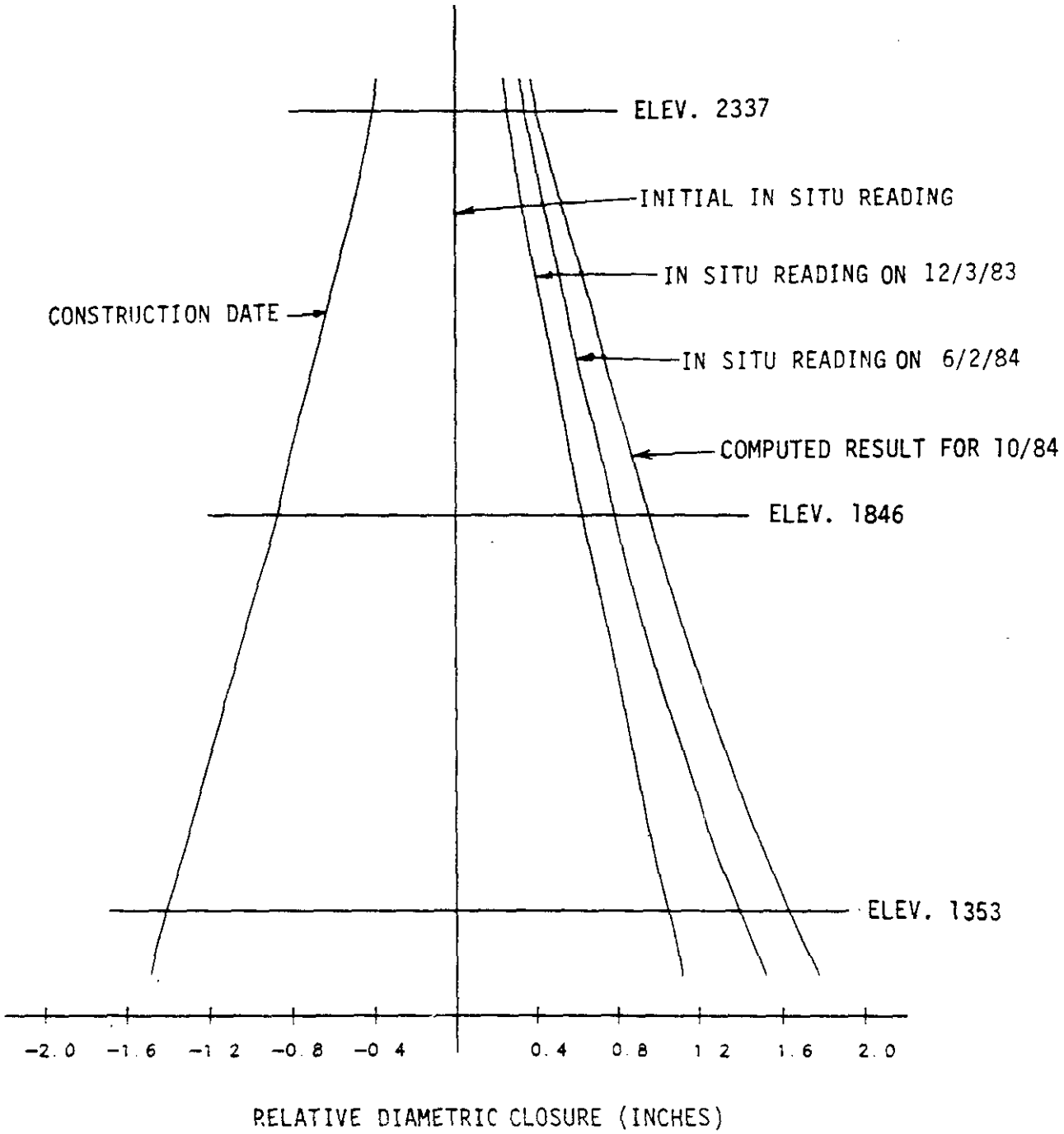

Figure 7-28

C & SH SHAFT UNLINED SECTION
RELATIVE DIAMETRIC CLOSURE

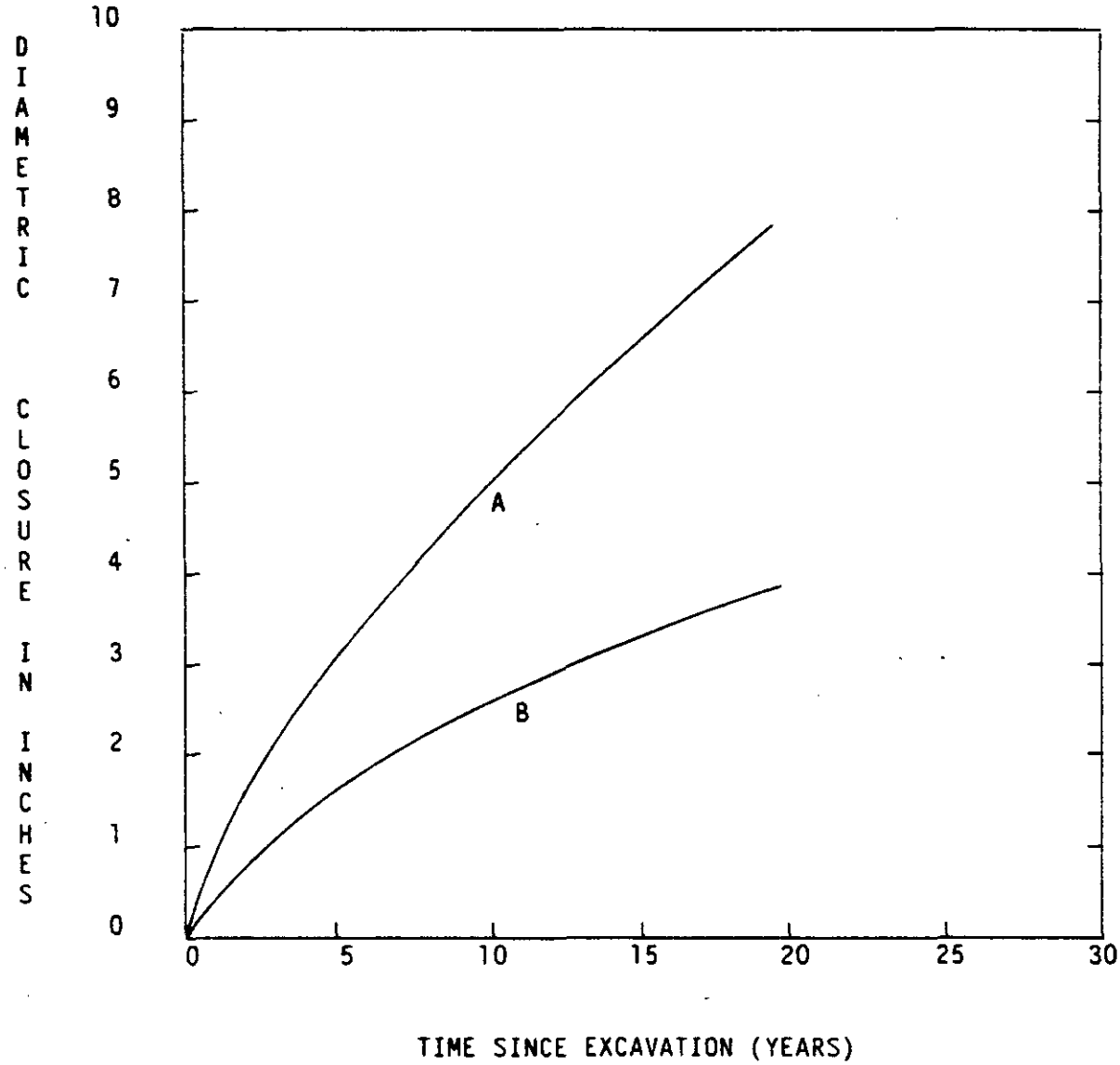

A – NORTH 17°40' WEST- MAJOR AXIS
B – NORTH 72°20' EAST- MINOR AXIS

Figure 7-29

C & SH SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1353

The rock bolts and wire mesh in the station roof will control spalling and stabilize the roof to provide a safe working environment but will not control salt creep. Although separations and fracturing have developed in the salt surrounding the shaft station, they exist on a much smaller scale than those observed in Test Room 3. They are expected to continue to develop throughout the operating life of the facility.

The total measured roof-to-floor closure in the C & SH shaft station was approximately 10 inches on September 16, 1985, nearly 3 1/4 years after the completion of excavation. The measured wall-to-wall closure over the same period was about 6 inches. Actual closure values are higher because the initial readings were taken nearly 260 days after the station was excavated. The average rate of roof-to-floor closure over the measurement period is approximately 3.89 inches/year. Assuming this rate will be constant throughout the operating life of 25 years, an additional roof-to-floor closure of about 8 feet is expected. Since the wall-to-wall closure is approximately 60 percent of the roof-to-floor closure, the additional wall-to-wall closure is expected to be nearly 5 feet.

7.4 CONCLUSIONS AND RECOMMENDATIONS

Design validation requires a determination of the compatibility of the design criteria, design bases and design configurations used in the reference design. Therefore, the following conclusions and recommendations address those criteria identified as applicable to the C & SH shaft in Chapter 2, Table 2-1, and the design basis elements presented in this chapter, Table 7-1. Other conclusions and recommendations that are a product of the design validation process are also presented.

7.4.1 Conclusions

Validation of the C & SH shaft reference design is based on a comparison of the applicable elements contained in the Design Criteria

and Design Bases documents with in situ conditions. These documents contain the requirements that the C & SH shaft must meet in terms of shaft stability, deformation, water pressure, water control, and shaft station stability and deformation.

Observations made during shaft inspections have not detected any signs of deterioration or instability. Due to its design pressure capacity, the liner is expected to remain stable even if the water pressure exceeds the design hydrostatic pressure.

The design basis assumption that the hydrostatic pressure begins 250 feet below the ground surface is suitable. Piezometer measurements indicate that the hydrostatic pressure is currently much less than the design basis pressure. These measurements are of sufficient accuracy to indicate that an anomalously high hydrostatic condition does not exist.

The design basis requirement that the key be designed to resist lateral pressure from the salt equal to 75 percent of the overburden pressure, approximately 640 psi, is suitable. The shaft key analysis indicates that the lateral pressure on the key at the end of 25 years will be approximately 275 psi. The lateral pressure capacity of the key is 833 psi. This provides for a factor of safety of about three. The analysis further shows that the maximum diametric closure expected for the key at the end of the operating period is only 0.175 inch. If the plastic flow or creep properties of the concrete were included in the analysis, the results would indicate that the design pressure would not be reached until after the 25-year operating life of the facility.

Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases with time as the stress arch around the opening migrates away. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. The stresses will, therefore, not cause a future stability problem in the unlined section of the C & SH shaft.

The analyses show the locations of effective creep strain concentrations in the unlined section of the shaft at different times. It is predicted that the maximum effective creep strain will not exceed 0.05 at the end of the operating life of the shaft. Based on the effective creep strain limit discussed in Chapter 6, the structural stability of the C & SH shaft will remain within required safety limits during its operating life.

The analyses also predict that the diametric closure near the bottom of the shaft at the end of its operating life will be approximately 10 inches along the major axis of principal strain, approximately 18 degrees from the longitudinal direction of the shaft tubular steel supports (buntons). Based on the predicted deformations and closures, the unlined section of the shaft will meet the requirements stated in the design criteria. The diameter of approximately 12 feet in the unlined section will allow for salt creep over the operating life, as required by the design bases. However, based on the design configuration of the C & SH shaft, the connections at both ends of some buntons do not provide sufficient allowance for longitudinal adjustment.

The C & SH shaft reference design complies with the criteria that require control of ground-water flow. This conclusion is made despite the fact that considerable instrumentation damage has been caused by water flow. This water has seeped into the shaft through holes cut in the liner for piezometer installation or is a result of direct rainfall. The piezometer leakage problem has been addressed and will receive additional corrective attention during a future shaft renovation. The rainwater does not reach the facility level in any significant or measureable quantity.

The chemical water seal just below the key piezometers is probably breached. The lowest water seal in the key is functioning properly. The water draining from the telltale drains has a local source. Therefore, it is concluded that there is no solutioning of the salt behind the key.

The C & SH shaft station exhibits the highest degree of deterioration in the underground facility. This is considered to be the result of the effects of blasting for initial excavation of the station. The station roof has been stabilized by rock bolting and no further significant deterioration is expected. However, removal of the 3-foot thick salt beam between the roof and clay G may be required for safety reasons in the future. Closure will continue at a rate of 3.89 inches/year vertically and 2.33 inches/year horizontally. Total closure after 25 years will be on the order of 8 feet vertically and 5 feet horizontally. This closure will require that the station roof or floor, and walls be trimmed periodically to maintain the design dimensions.

Separation and fracturing in the salt is expected to continue in the station roof and beneath the floor. Both closure and fracturing in the station will necessitate periodic maintenance during its operating life in order to maintain safety as well as the required clearances for equipment and operations.

The reference design for the C & SH shaft is validated based on the preceding discussions. The reference design complies with the design criteria and design bases. Except for instrument repair and maintenance, no modifications are required to the shaft reference design. The C & SH shaft will perform its functions as required during the operating life of the facility.

7.4.2 Recommendations

Based on the results of design validation, the following recommendations are made with respect to the C & SH shaft:

(1) Water behind the shaft key is undesirable and should be monitored carefully. If the volume of water behind the key increases, or if water starts flowing from beneath the key, past the lower water seal, it may become necessary to inject grout above the top water seal in the key. Grout should not

be placed behind the key (below the top seal) unless absolutely necessary. If this cannot be avoided, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the Plugging and Sealing Program requirements.

(2) Based on the results of design validation of the C & SH shaft, it is recommended that, during inspection of the shaft furnishings, the bunton connections should be inspected for closure allowance. If the allowance is insufficient, corrective action should be taken to provide for additional closure.

(3) The observation holes drilled in the roof of the shaft station to monitor displacements and separations, and in the floor to monitor fracturing, should be maintained. Continued observations of conditions in these holes will be valuable in assessing the safety and stability of the station.

CHAPTER 8

WASTE SHAFT

8.1 INTRODUCTION

The waste shaft provides the connection between the surface waste handling facilities and the underground storage level. A discussion of shaft construction was presented in Chapter 3 and geologic characterization of the shaft stratigraphy was presented in Chapter 6. This chapter presents discussions of the design criteria and design bases pertaining to the waste shaft. It documents the collection of waste shaft geotechnical data, its analysis and evaluation, and presents predictions of future shaft behavior. Conclusions and recommendations are presented based on a comparison of the results of the design validation process with the shaft reference design.

8.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the waste shaft. The design configuration of the shaft is discussed in Chapter 3, subsection 3.3.2.

8.2.1 Design Criteria

The design criteria for the waste shaft are the same as those for the C & SH shaft. The criteria requiring validation are indicated in the listing of abridged criteria presented in Chapter 2, Table 2-1, and are discussed in Chapter 7.

The design criteria requiring evaluation for design validation of the waste shaft are:

(1) shaft shall be designed to be structurally stable;

(2) shaft shall be designed to accommodate salt creep;

(3) ground-water flow into the shaft shall be controlled;

(4) underground openings (i.e. waste shaft station) shall be designed to accommodate deformation; and

(5) underground openings shall be stable.

8.2.2 Design Bases

The Design Basis, Waste Shaft (ref. 2-15) was the primary document used as a guide for waste shaft design. The major elements of this basis are summarized in this subsection. Only a few of these elements must be evaluated or have a direct impact on design validation. These particular elements are presented in Table 8-1.

The design bases specify that the waste shaft shall be designed to transport personnel, materials and radioactive waste. It shall also serve as an intake shaft for a small volume of air during normal operations and as an escape route during emergency operations.

The shaft shall be lined with unreinforced concrete from the bottom of its collar in the waste handling building to the top of the shaft key at the rock/salt interface. The liner shall be permanent and shall protect against spalling, fallout and deterioration of the rock in the shaft wall. It shall also prevent water seepage into the shaft.

The shaft liner shall be designed in compliance with applicable ACI Codes. A load factor of 1.4 shall be used for designing the concrete liner. The specified concrete compressive strength shall be 5,000 psi. No lateral rock pressure shall be assumed for design of the shaft liner. Hydrostatic pressure shall be considered to start at 250 feet below the ground surface and extend to the rock/salt interface at the top of the key. The water pressure shall be considered to increase 0.437 pounds per square inch (psi) for each foot of depth.

At water-bearing zones, the shaft shall be enlarged and liner plate installed to provide pressure relief and drainage space behind the liner during concrete placement and curing. Drainage pipes and

Table 8-1

VALIDATION ELEMENTS OF WASTE SHAFT DESIGN BASES

(1) Shaft liner

Hydrostatic pressure is considered to start at 250 feet below the ground surface and extend to the top of the key.

(2) Shaft key

Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.

(3) Unlined section

Provide 20-foot diameter to allow for future salt creep deformation.

temporary hoses shall be installed to control water inflow prior to placement of the concrete liner. When the concrete liner has attained adequate strength, the area behind the liner plate shall be grouted to preclude deterioration of the dolomite and mudstone in the water-bearing zones.

The shaft key at the bottom of the concrete liner shall be constructed of reinforced concrete keyed into the rock and salt strata. A chemical water seal shall be placed behind the top and bottom of the key to prevent the migration of water. After the completion of shaft excavation and construction of the concrete liner and key, permanent piping from water collection rings to the shaft station shall be installed. Water from the collection rings shall be piped to a tank in the shaft station and then transported to the surface. The piping shall include inspection and clean-out fittings. Inspection and cleaning of the water collection rings and drainage piping shall be performed as necessary.

A load factor of 1.7 shall be applied to the design loading used for the concrete in the shaft key. The key shall be designed to resist lateral pressure generated by salt creep. The design lateral pressure shall be 50 percent of the total vertical pressure due to the soil, rock and salt overburden.

Below the key, the shaft shall be excavated 20 feet in diameter to allow for future salt creep deformation. Rock bolts and wire mesh shall be installed in this unlined section of the shaft in order to provide a structurally stable salt surface.

A shaft station shall be excavated at the storage level. The shaft shall extend below the storage level to such a depth as required by the hoisting equipment and sump. The use of rock bolts and wire mesh shall be dictated by the condition of excavated surfaces as well as code requirements. The roof, walls and floor shall be checked periodically for loose salt in accordance with applicable codes. The tolerance for

excavation of roof, floor and wall surfaces shall be no greater than plus 6 inches. In no case shall the finished cross section dimensions be less than the design dimensions.

Geomechanical instruments shall be installed to measure water pressure behind the shaft liner, salt creep pressure behind the key, and radial convergence in the unlined section of the shaft. The types of instruments installed shall be piezometers, pressure cells, radial convergence points and extensometers.

The shaft, including the liner, key, unlined section, station and furnishings, shall be inspected at 1 month intervals, or as required by applicable codes, to detect cracking, corrosion, deterioration and water intrusion.

8.3 DESIGN VALIDATION PROCESS

The design validation process for the waste shaft consists of analytical calculations, finite element modeling, and the analysis of data collected from geomechanical instruments installed in the C & SH and waste shafts. The in situ material parameters of salt determined from C & SH shaft instrumentation data were used to analyze the closure behavior of the waste shaft. For the shaft station, the in situ measurement data obtained from the C & SH shaft station were used to predict future closure behavior. The following subsections present information pertaining to validation of the waste shaft reference design.

8.3.1 Data Collection

Data collection in the waste shaft has consisted of geologic mapping, visual observations and geomechanical instrumentation measurements. Data obtained from the geologic mapping were presented in Chapter 6. The following subsections discuss the field observations and the geomechanical instrumentation in the shaft.

8.3.1.1 Field Observations

Waste shaft inspections have been concerned primarily with water seepage through the concrete liner, salt incrustation on the surface of the liner, dissolution in the shaft sump and the results of the liner grouting program.

Water seepage through the waste shaft liner has occurred since construction. As discussed in Chapter 3, subsection 3.4.2, grouting during construction behind the steel liner plate at both the Magenta and Culebra members did not completely prevent water from entering the shaft. It was estimated that the total water seepage through the liner was approximately 0.5 gallons per minute (gpm). A remedial grouting program (ref. 3-3), conducted from August 11 through August 25, 1984, reduced the seepage to about 0.015 gpm as measured in October 1984. Subsequent inspections in February and June 1985 determined that fresh water had begun seeping through cracks and construction joints in the liner from zones within and above the grouted area. The highest level of water seepage was occurring at a depth of only 60 feet below the shaft collar. Because this is higher than the potentiometric surface of ground water in the Magenta and Culebra members, the source of the seepage was probably rainwater and construction water contained in the backfill around the shaft collar and in the underlying Gatuna sandstone. This is based on the fact that heavy rains in the late summer of 1984 left substantial quantities of water ponded in the waste-handling building excavations and in the remnant of the SPDV ventilation shaft drilling fluid reserve pit.

The initial rate of this renewed seepage could not be measured because the PVC drainpipe had been broken in several places. Subsequent repair of the drainpipe has permitted the rate of water inflow to be measured on a regular basis. The measurements are obtained by timing the flow of water from the drainpipe into a calibrated bucket. These measurements do not consider the small amount of uncontrolled "fly water" that falls down the inside of the shaft. The initial measurement, in January 1986, was 0.47 gpm. The measurements, are

plotted on Figure 8-1 and show a generally decreasing trend in the flow rate. This trend may be influenced by three factors. First, the water contained in the backfill and sandstone has slowly drained into the shaft. Second, the rate of evaporation increases as the outside air temperature increases, thus reducing the amount of water reaching the drains. Both of these conditions are temporary. A series of rainstorms could recharge the backfill and sandstone, and evaporation will decrease with cooler winter temperatures. Heavy rains in June 1986 may have been responsible for the increased flow detected by the late June reading. The third factor influencing the flow trend is the possibility that the water collection rings and the drainpipe may be partially blocked by debris. This would result in reduced water flow through the drainpipe and an increase in the amount of unmeasureable fly water.

Although there has been limited access to the waste shaft since August 1984, several inspections of the shaft and sump have been made. One inspection was made on February 21, 1985, at which time some instrumentation damage was observed. In addition, the PVC drainpipe was observed to have been broken in several locations. Appreciable salt incrustation was noted on the surface of the concrete liner and on many of the instrumentation boxes and cables. This incrustation was primarily attributed to salt dust from the underground excavation adhering to the damp shaft walls during the period since September 1984 when the waste shaft was used as an exhaust shaft. A small percentage of this salt incrustation was also attributed to water seepage through the liner.

On June 16, 1985, another inspection of the waste shaft was made to within 60 feet of the shaft station. The shaft ventilation had been changed from upcast to downcast after the February inspection. Very little salt incrustation was present on the concrete liner and only a small amount was present in places on the wire mesh. Fresh water entering the shaft through the liner, from approximately 60 feet below the collar, was running down the liner. Although much of the liner was

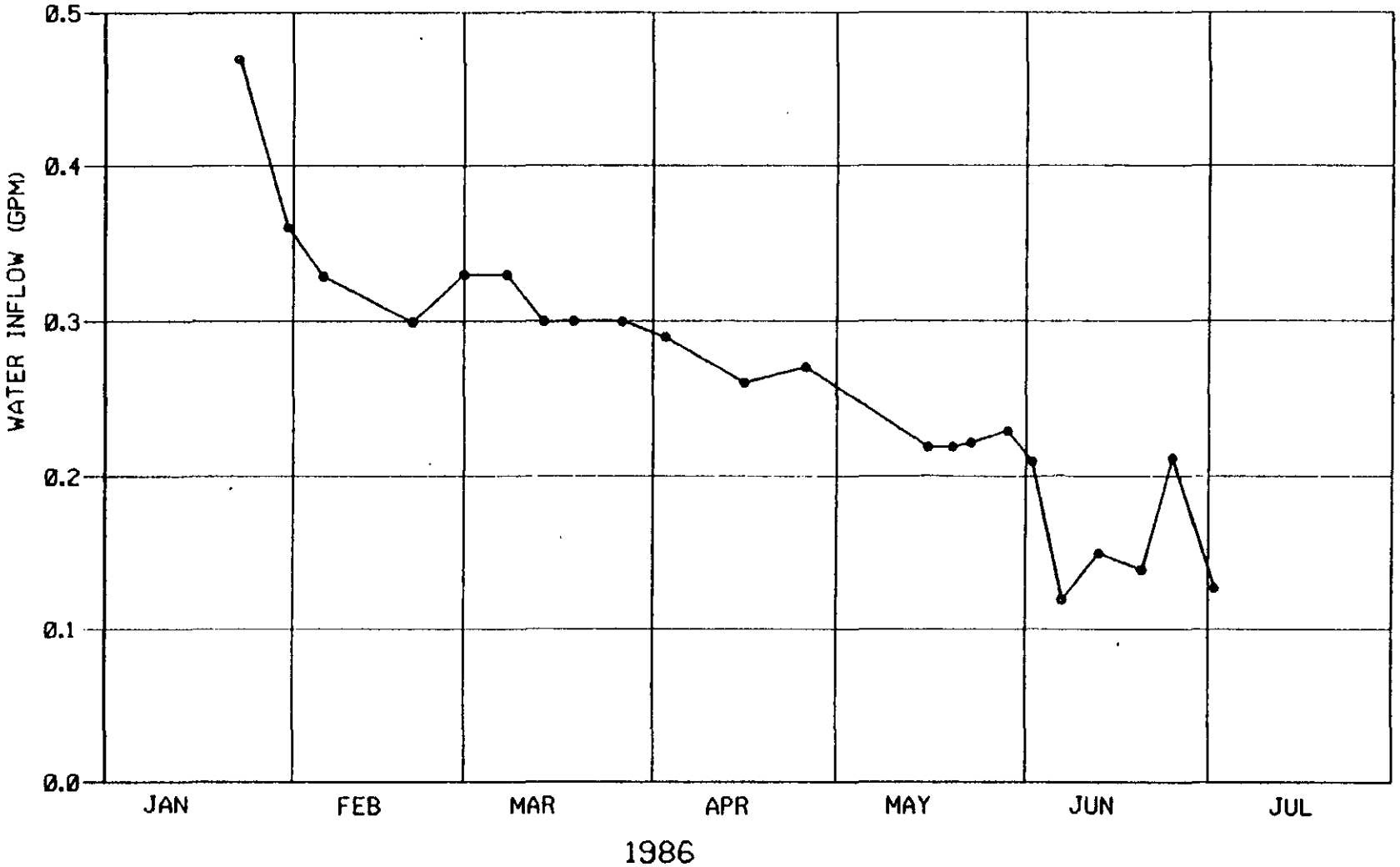

Figure 8-1

WASTE SHAFT
WATER INFLOW MEASUREMENTS

observed to be wet, the water rings were not full. This water appeared to have dissolved the salt incrustation observed in the February 1985 inspection. Cracks were common in the liner to within 60 feet of the collar. The PVC drainpipe damage had not been repaired. No water was seen draining from below the concrete key. The shaft sump contained water to within 60 feet of the shaft station floor. This water was a combination of rainwater, construction water and ground water. It was pumped out in September 1985.

On December 1, 1985, another inspection of the waste shaft was made. The PVC drainpipe was still broken or disconnected at several levels. The water rings were plugged and overflowing. There appeared to be an increase in water flow into the shaft, most noticeably at the Culebra member. An approximately 1/8- to 1/4-inch thickness of salt had been deposited on the liner below the Culebra.

On December 11, 1985, an inspection of the waste shaft sump was made. During this inspection, and a subsequent inspection on December 12, 1985, MB-139 was observed closely. The clay along the lower contact was distinct and no separations were noted. Although the upper contact could not be distinguished behind a covering of wire mesh, MB-139 could be seen quite well and appeared to be intact and undisturbed. One small fracture, approximately 2 feet long and 1/2 inch wide was observed on the west side of the shaft approximately 1 foot above the lower contact.

An anhydrite bed 61 to 66 feet below the station floor was also observed during this inspection. A zone of dissolution was present along the upper contact of this layer in the northwest to southeast half of the shaft. The dissolution occurred partially within the anhydrite bed. The maximum void width of approximately 0.7 foot occurred on the south-southwest side of the shaft and extended approximately 18 feet south into the salt. The zone of dissolution pinched out going around the shaft in either direction away from the area of maximum opening. There did not appear to be any disturbance of

the strata overlying or underlying this zone anywhere around the shaft and no voids or disturbance of the anhydrite existed on the opposite side of the shaft. The upper contact of the anhydrite with the overlying halite did not exhibit any irregularities. From the physical evidence available, it appeared that this feature was the result of localized dissolution. No dissolution of the anhydrite was observed. The dissolved material was probably a soluble evaporite mineral representing a facies change within the Salado formation. The dissolution appeared to have resulted from the previously discussed water which had been standing in the sump. The level of this water was measured at 60 feet from the shaft station floor prior to its being pumped out in September 1985. The shaft wall below the water line exhibited no significant deterioration due to the standing water. However, some sloughing of an anhydrite layer 71 to 75 feet below the shaft station floor and widening of the shaft near the bottom of the sump was evident. The shaft wall exhibited a glazed surface which probably resulted from minor dissolution of the salt surface.

A shaft inspection was conducted on July 24, 1986. The inspection team mapped the location of cracks in the concrete liner and any associated seepage. They also mapped the location of leaking construction joints. This mapping indicates that additional cracks have developed in the liner since mapping was conducted prior to the August 1984 grouting program. The shaft was found to be considerably drier than during the 1984 mapping program. Many of the new cracks mapped may have existed in 1984 but were masked by the water on the shaft walls. Also, salt precipitates now enhance the outline of the cracks. The inspection also revealed that recent construction work inside the shaft has resulted in some instrument cable and junction box damage and in breakage of the previously repaired PVC drainpipe.

The waste shaft station has shown little deterioration since it was enlarged from the SPDV ventilation shaft station dimensions. Visual surveys are performed approximately every 3 months by site geologists. The results of these inspections are documented in the GFDRs. Only

minor spalling along the station walls has occurred. Vertical fractures similar to those found in the drifts and test rooms have developed at intersection corners. The roof, although showing no visible evidence of deterioration, has been covered by wire mesh and rock bolts for safety purposes. During the July 1986 shaft inspection, some separation at clay G was observed on the east and west sides of the shaft. The separation was a maximum of 3/4 inch wide at the shaft surface and decreased away from the shaft. No separation was observed at clay H.

Minor separations and fracturing in MB-139 and in the overlying halite have been observed in the station floor. A dish-like fracture zone similar to that found in Test Room 2 is present, but has developed on a much smaller scale. Inspection of MB-139 in the shaft sump, and evidence from boreholes drilled in the station floor, show that the marker bed and the overlying halite are, for the most part, intact.

8.3.1.2 Geomechanical Instrumentation

The waste shaft geomechanical instrumentation is similar in design to that of the C & SH shaft. The shaft contains 12 vibrating-wire piezometers, 4 pressure cells, 9 multiple-point borehole extensometers, and 3 sets of radial convergence points. Figure 8-2 shows the instrument locations in the waste shaft and Figure 8-3 shows details of the key instrumentation.

As in the C & SH shaft, all of the geomechanical instruments, except the convergence points, are monitored remotely. The instruments are connected to the surface datalogger that polls all of the remotely-read underground instruments on a scheduled basis.

The 12 piezometers were installed on September 7 and 8, 1984, after the 6-foot diameter SPDV ventilation shaft had been enlarged to become the 20-foot to 23-foot diameter waste shaft. The water that could exert pressure on the liner is expected to come from the two water-bearing members in the Rustler formation. The Magenta dolomite member occurs

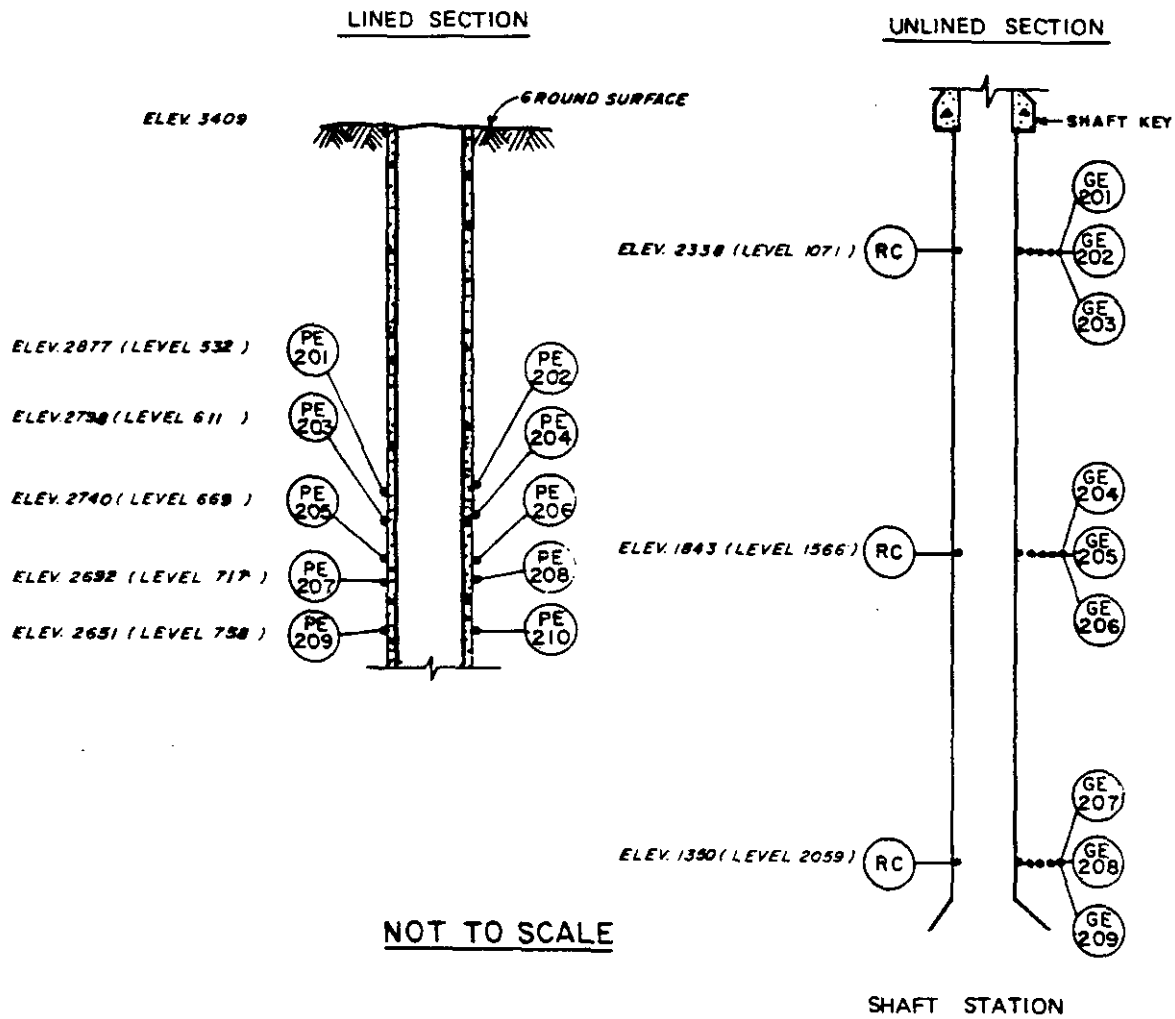

LEGEND

(PE) PIEZOMETER

(RC) CONVERGENCE POINTS

(GE) EXTENSOMETER

NOTES

1. PC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE SHAFT COLLAR AT ELEVATION 3409 FT MSL
3. SEE FIGURE 8-2 FOR DETAILS OF SHAFT KEY INSTRUMENTATION.

Figure 8-2

WASTE SHAFT INSTRUMENTATION

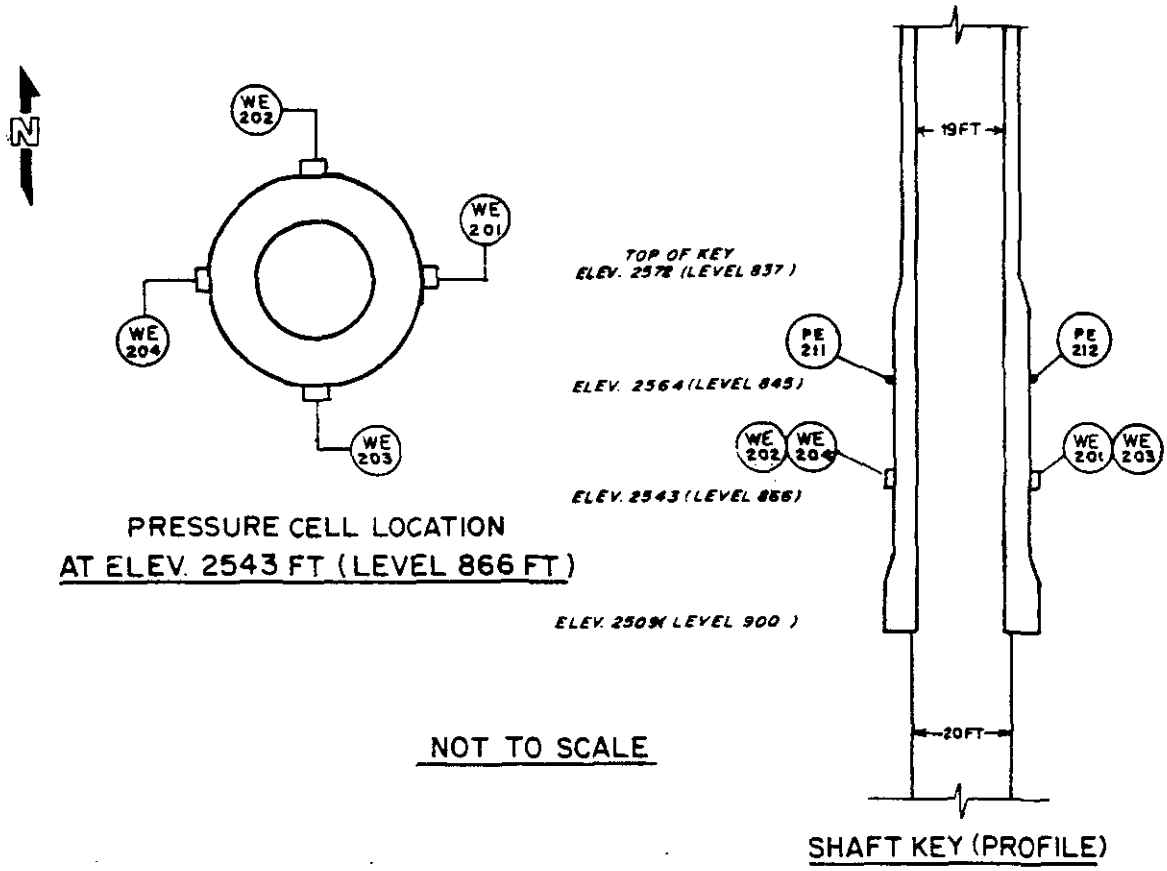

LEGEND

(WE) - PRESSURE CELL

(PE) - PIEZOMETER

NOTES:

1. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE SHAFT COLLAR AT ELEVATION 3409 FT MSL
2. PRESSURE CELLS LOCATED AT CONCRETE-ROCK INTERFACE.

Figure 8-3

WASTE SHAFT KEY
INSTRUMENTATION

from a depth of 596 feet to 621 feet (elev. 2813 to 2788 feet) and the Culebra dolomite member from a depth of 706.5 feet to 728.5 feet (elev. 2702.5 to 2680.5 feet). Two piezometers are at each of the following elevations: 2877, 2798, 2740, 2692, 2651 and 2564 feet (Figures 8-2 and 8-3). The piezometers are located on opposite sides of the shaft, one at N60°E and the other at S60°W. Piezometer readings are shown on the data plots in Appendix J.

The four pressure cells are located in the waste shaft key between the salt of the shaft wall and the concrete comprising the key. The pressure cells were installed at a depth of 866 feet (elev. 2543 feet). The four cells are spaced 90 degrees apart around the shaft at the north, east, south, and west positions (Figure 8-3). Initial pressure cell readings were taken on April 6, 1984. The waste shaft key concrete was placed between March 23 and April 3, 1984. Pressure cell data plots are also presented in Appendix J.

The extensometers and convergence points were installed only in the unlined section of the shaft below the key. These instruments, whose locations are shown on Figure 8-2, were installed after enlargement of the shaft to its final dimensions.

The nine multiple-point borehole extensometers were installed between August 31 and September 5, 1984, 3 to 5 months after the completion of shaft enlargement. Three extensometers each are located at three elevations in the unlined section of the shaft: 2338, 1843 and 1350 feet (Figure 8-2). The extensometers are spaced 120 degrees apart around the shaft. Plots of the readings are presented in Appendix J.

A set of radial convergence points, consisting of four points each, is located at each of the same elevations as the extensometers. The convergence points were installed immediately after enlargement of the shaft. Due to interference by shaft furnishings, it was not possible to set the convergence points at 90 degrees from each other. The set of convergence points at a depth of 1,071 feet consists of two points

on each side of the shaft conveyance furnishings. The two points were set 44 degrees apart. At the other two depths the two points on each side of the shaft are set 53 degrees apart. Convergence point readings were obtained from April through June 1984 and are plotted in Appendix J. However, their performance is considered poor and erratic. The readings have been affected by salt incrustation on the convergence point eyebolts and extensions. Convergence point readings were discontinued when the temporary waste shaft hoist was decommissioned on September 12, 1984. The convergence points will be inaccessible until approximately December 1986, when the permanent waste shaft hoist is installed.

Geomechanical instruments were installed in the SPDV ventilation shaft station in late 1982. The instrumentation consisted of three multiple-point borehole extensometers and two sets of convergence points as shown on Figure 8-4. When the shaft was enlarged to become the waste shaft, the station was also enlarged and the original instruments were destroyed. Two extensometers were then installed in the enlarged shaft station. Both of these extensometers are in the roof, one on either side of the waste shaft (Figure 8-5).

8.3.2 Analysis and Evaluation

Analysis of the waste shaft data and its evaluation against reference design parameters has been divided into four elements: the concrete-lined section of the shaft; the shaft key; the unlined section; and the shaft station. This division is based on the different in situ and design conditions in each of these areas.

8.3.2.1 Lined Section

Engineering mechanics principles were used to design the concrete liner against elastic buckling. Both axial and flexural stresses were considered in the design. Permissible stress values were those used for structural plain concrete (ref. 8-1) utilizing the ultimate strength design method. Since there are no significant salt strata in

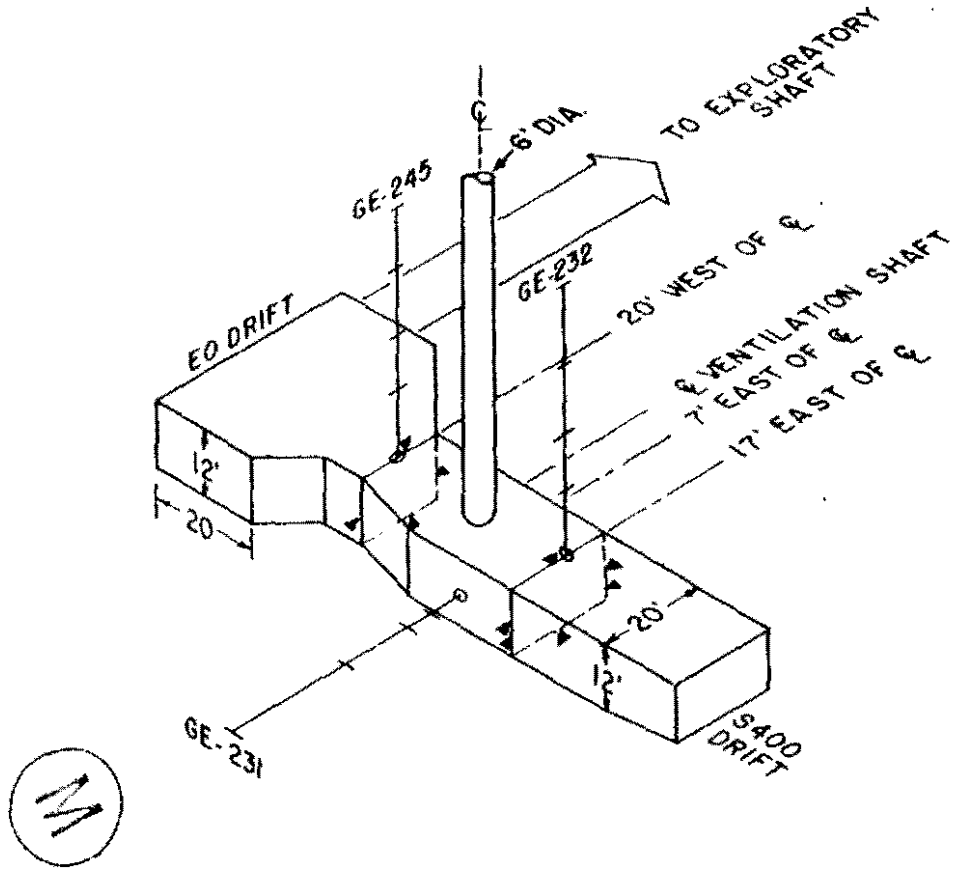

EXPLANATION

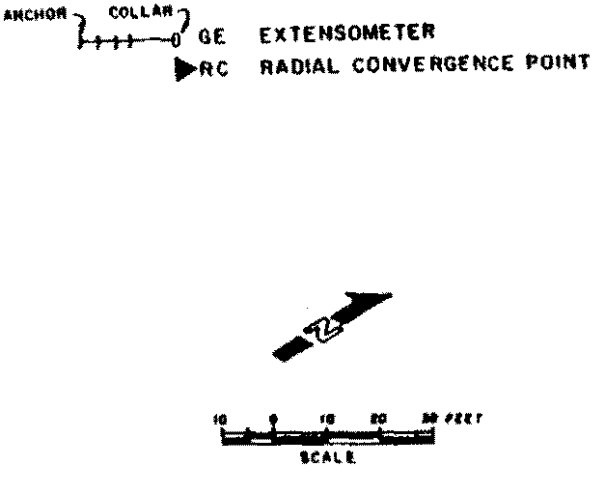

Figure 8-4

SPDV VENTILATION SHAFT STATION INSTRUMENTATION

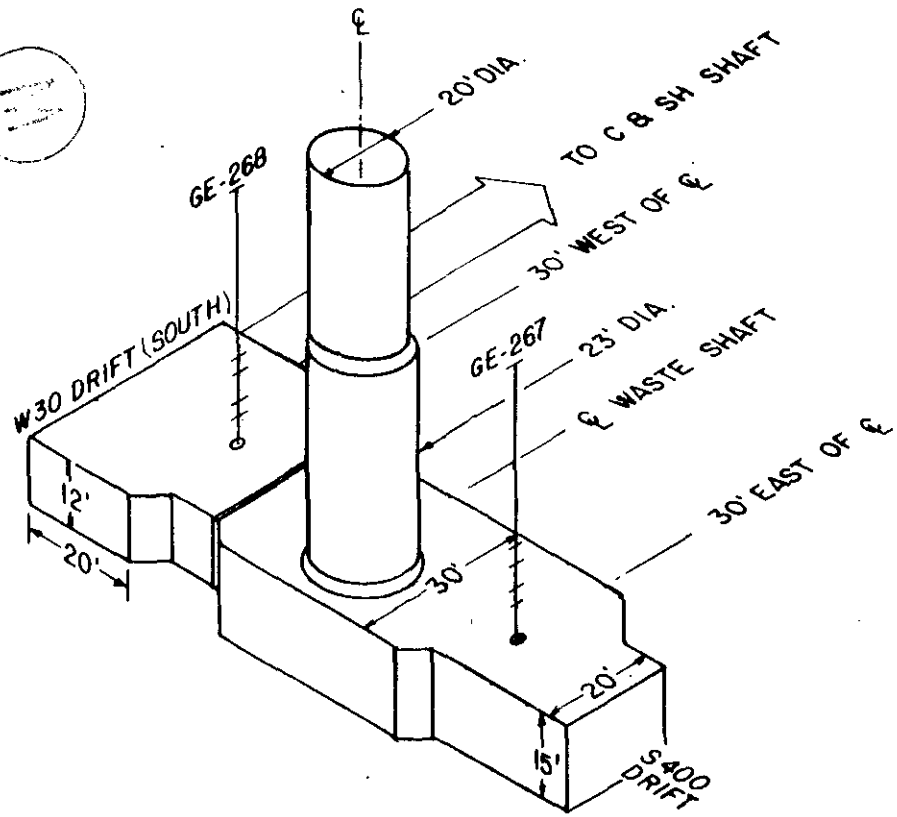

EXPLANATION

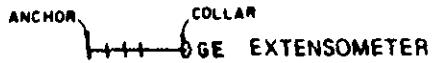

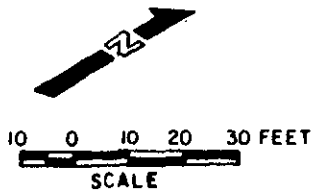

NOTES:

1. PREVIOUSLY IDENTIFIED AS THE SPDV VENTILATION SHAFT STATION.
2. INITIAL INSTRUMENTATION WAS DESTROYED IN JUNE 1984. EXTENSOMETERS GE-267 AND GE-268 WERE INSTALLED AFTER STATION ENLARGEMENT.

Figure 8-5

WASTE SHAFT STATION INSTRUMENTATION

the rock surrounding the liner, rock creep and the resulting rock pressure against the liner were assumed to be negligible. Hydrostatic pressure acting from a depth of 250 to 844 feet was used in the design based on the applicable design basis element (Table 8-1).

Additional stresses in the liner due to initial imperfections in roundness and grouting pressures were also considered. For stress calculations, an initial imperfection of 1 inch was assumed in the roundness of the liner. In place of the local water pressures, grouting pressures 1.3 times the ground-water pressure were assumed to act over one-sixth of the circumference of the liner. Due to localized effects, a 20 percent increase in the allowable concrete stress was assumed due to the short-term loading of the grouting pressure.

The external pressure capacities and corresponding closure limits (maximum diametric changes) for different thicknesses of the liner are:

Depth (feet)	Liner Thickness (inches)	Pressure Capacity (psi)	Closure Limit (inches)
27 to 462	10	216	0.165
462 to 580	14	370	0.215
580 to 762	18	523	0.251
762 to 837	20	598	0.266

The intent of the shaft piezometers is to monitor the pressure exerted on the liner by water from the Rustler formation. These data would indicate if the design hydrostatic pressure from the design basis was suitable.

Table 8-2 summarizes the variation in measured water pressures behind the liner at different times. Figure 8-6 shows the average reading on September 18, 1985, for each piezometer pair plotted against shaft depth. For comparison, the hydrostatic design pressure for the liner through this interval is also shown.

The measured pressures at this time are lower than the design pressure for two apparent reasons. First, water seepage through cracks and

Table 8-2

WASTE SHAFT LINER AND KEY
SUMMARY OF MEASURED WATER PRESSURES (psi)

PIEZOMETER NO. 31X-PE-00

Date of Reading	201	202	203	204	205	206	207	208	209	210	211	212
	Elev. 2879		Elev. 2798		Elev. 2740		Elev. 2692		Elev. 2651		Elev. 2564	
Dec. 26, 1984	-1	0	16	20	-7	-8	77	93	65	76	13	11
May 16, 1985	-2	0	11	16	12	-15	79	95	58	84	8	10
June 27, 1985	*	0	13	19	*	-16	78	95	*	91	11	12
Sep. 18, 1985	*	1	17	26	*	-14	99	115	*	107	19	22
Dec. 18, 1985	*	-3	-3	-2	*	-3	47	51	*	27	4	8
Mar. 16, 1986	*	-3	2	6	*	-13	*	63	*	47	5	12
June 13, 1986	*	0	10	15	*	-20	*	85	*	74	18	19

* Piezometer not functioning.

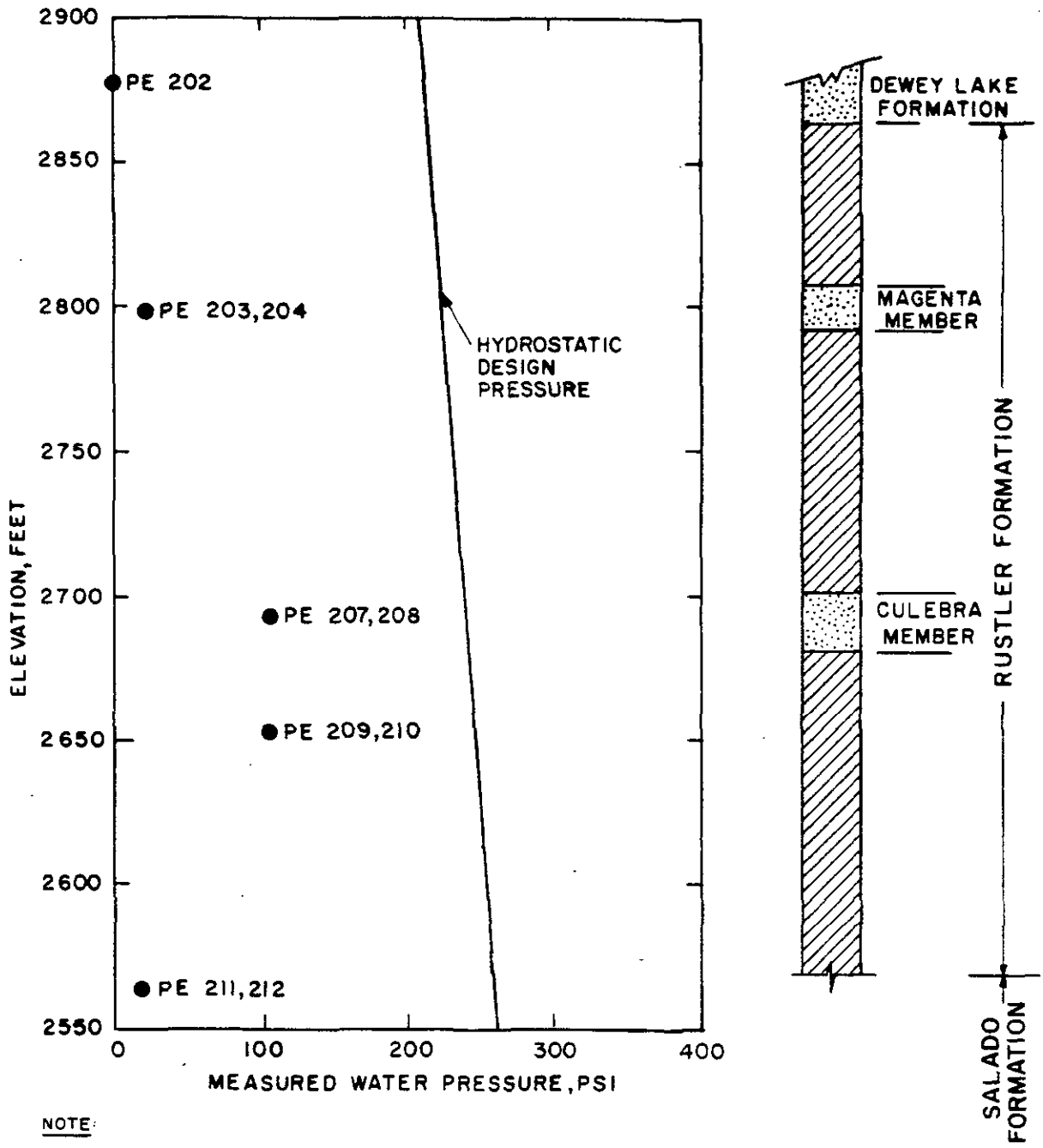

NOTE:

● AVERAGE OF READINGS TAKEN ON SEPT. 18, 1985

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Figure 8-6

WASTE SHAFT LINER
WATER PRESSURE MEASUREMENTS

construction joints in the liner has not allowed the water to build up to its full hydrostatic head. This means that the piezometers are not measuring the full pressure that might be expected against the liner if the leaks were sealed. Second, the low pressure readings, and especially the variation in readings, suggest that hydraulic continuity is incomplete along the rock/liner interface. It is possible that water from the Culebra has been isolated, or at least restricted, in its vertical extent. This is suggested by the distribution of pressures shown on Figure 8-6.

The pressure distribution of the piezometers is also shown on Figure 8-7. These readings, however, are the maximum pressure values measured for each piezometer elevation. The figure also shows the design hydrostatic pressure distribution for the entire liner and its pressure capacity. The pressure capacity provides a significant factor of safety over the design hydrostatic pressure.

8.3.2.2 Shaft Key

Due to lithostatic pressure, the salt formation behind the shaft key tends to creep over time. The result is a buildup of inward pressure against the concrete key. The concrete key was designed to withstand a lateral pressure equal to 50 percent of the vertical overburden pressure (approximately 60 ksf) for at least 25 years after its construction. This reduction in lateral pressure from 75 percent of the overburden pressure for the C & SH shaft to 50 percent for the waste shaft was based on the results of the analysis of data obtained from the C & SH shaft (Chapter 7).

A nonlinear finite element analysis was utilized to simulate the long-term creep interaction of the salt and the concrete key. The analysis was performed using the MARC Finite Element Program discussed in Chapter 6. The material properties of the finite element model simulated the creep behavior of the salt via a power law (equation C.4-6 in Appendix C) provided in the analysis.

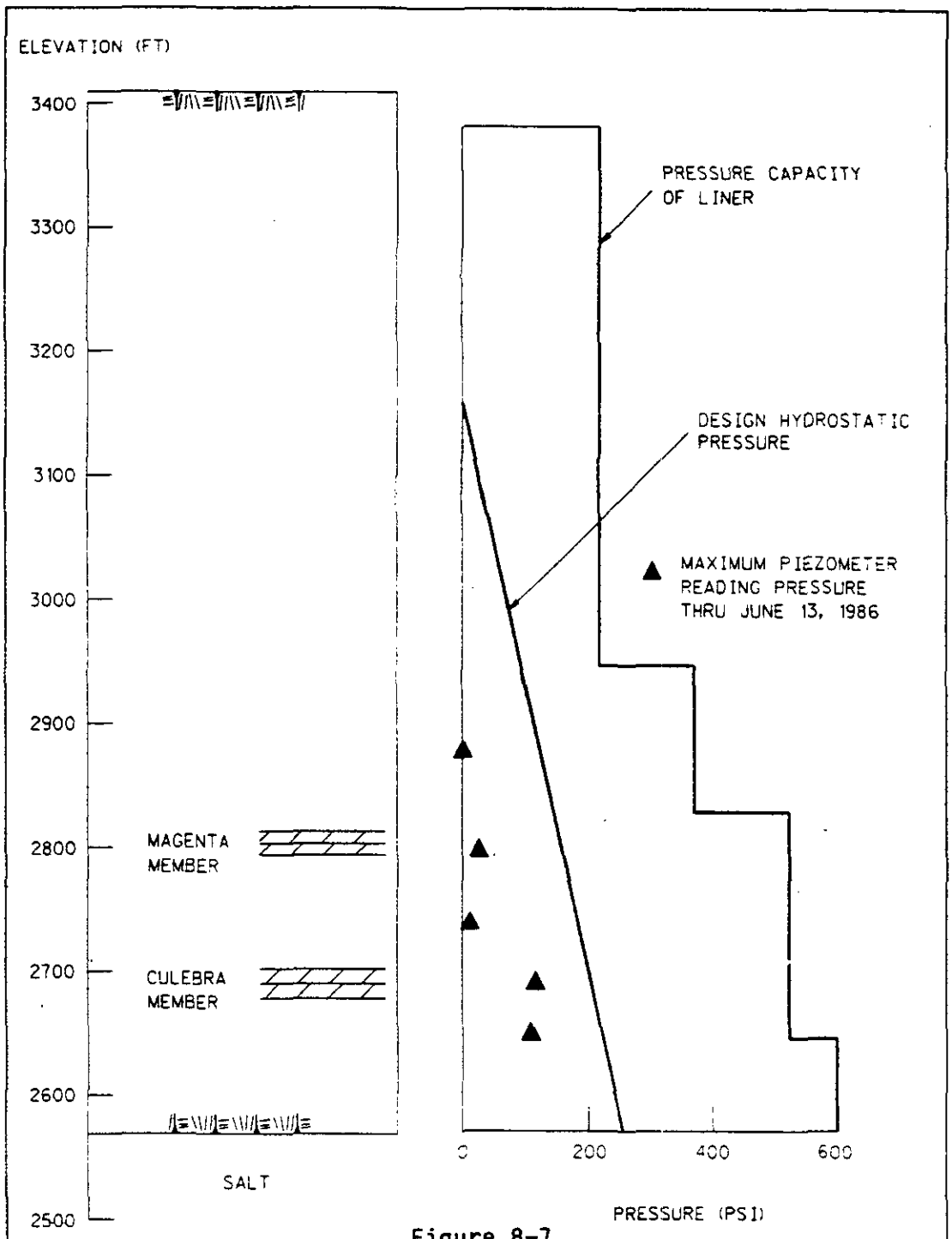

Figure 8-7

WASTE SHAFT LINER
LATERAL PRESSURE COMPARISON

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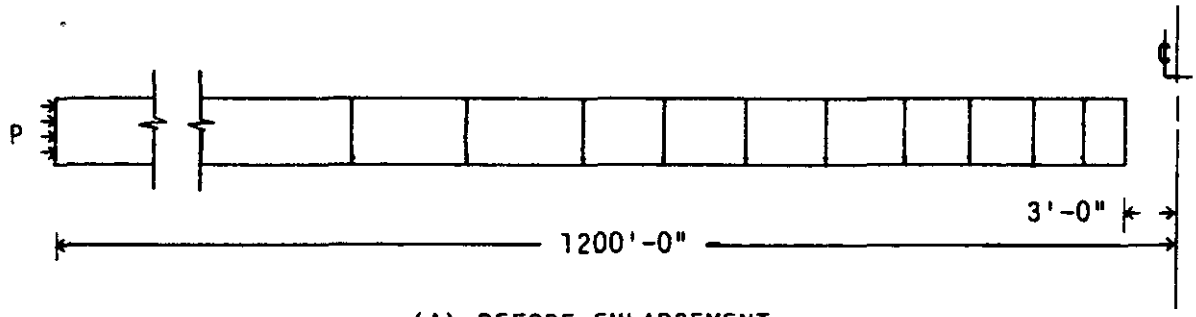

(A) BEFORE ENLARGEMENT

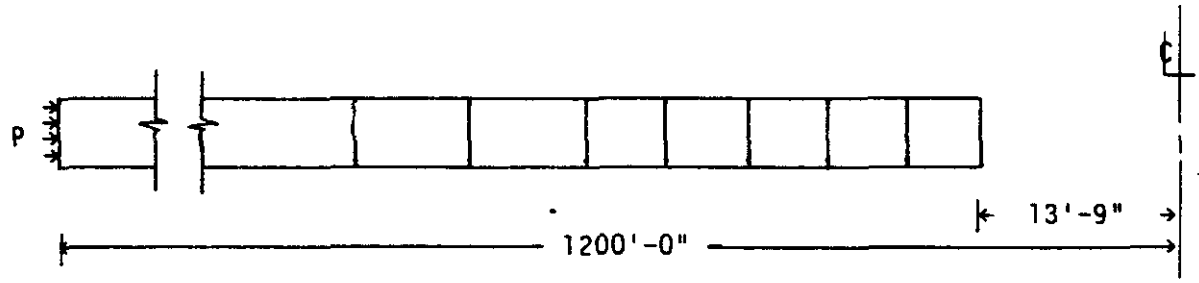

(B) AFTER ENLARGEMENT

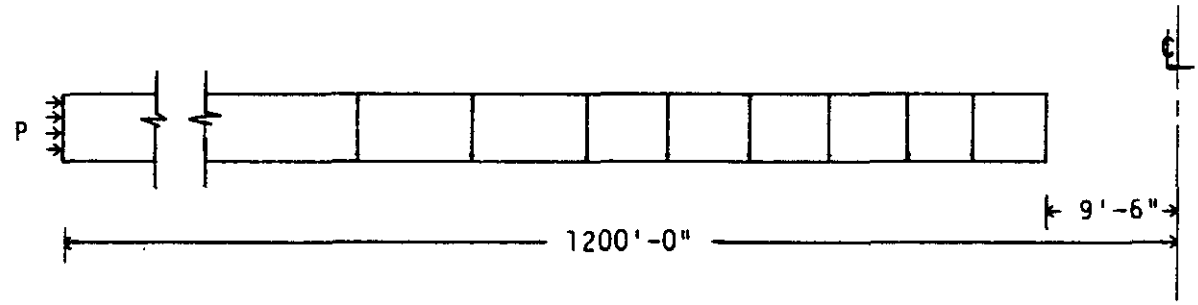

(C) AFTER CONCRETE CONSTRUCTION

Figure 8-8

WASTE SHAFT KEY
FINITE ELEMENT MODEL

Model Simulation. Unlike the more sophisticated analysis of the C & SH shaft key (which employed a multi-layered, axisymmetric finite element model), the finite element model for the waste shaft key and surrounding salt consists of a single layer of quadrilateral, axisymmetric ring elements as shown on Figure 8-8. Because only the lateral flexural stiffness of the shaft key was considered in the finite element model, and not its longitudinal flexural stiffness, the analysis provides conservative results. Also for conservatism, the shrinkage effect of the concrete was not taken into account in this analysis.

An inner element of the model, shown on Figure 8-8, represents a segment of the concrete key. In order to simulate the time interval between shaft excavation and concrete placement for the key, this element was not tied to the surrounding salt deposits. All depth-dependent input values, such as overburden stresses, were computed for a depth of 892 feet, low in the key, where such values are at a maximum. Because halite is the most dominant material in the rock around the shaft key, its properties were used for the model elements. Halite is also the material at the base of the shaft key where lateral pressure is at a maximum.

The following analytical procedure was used to perform a creep analysis of the waste shaft key:

(1) Initially, lateral forces were applied outwardly against the inside surface of the shaft. This simulates the condition prior to excavation of the original 6-foot diameter shaft.

(2) Lateral forces were applied inwardly against the outer vertical boundary of the model. The magnitude of these forces were based on the lateral earth pressure, equal to 892 feet of overburden, computed for the key elevation of 2517 feet.

(3) Internal stresses were applied in each element to represent the initial lithostatic stress state.

(4) All nodes of the model were restrained against vertical displacement.

(5) Subsequently, outward lateral forces against the inside surface of the shaft were removed to simulate excavation of the original 6-foot diameter shaft.

(6) A creep analysis was performed on the salt deposits surrounding the 6-foot diameter shaft until that time when the shaft diameter was enlarged and the concrete for the key was placed (795 days).

(7) The three innermost ring elements were detached (tie constraints removed) from the model to represent the enlargement of the shaft. A concrete ring element (tie constraints added to the model) then replaced the three salt elements just removed to model the concrete key.

(8) A second creep analysis was performed using this new model and a creep time representing 28 years after placement of the concrete key.

The stratigraphy in the upper section of the waste shaft is similar to that in the C & SH shaft. The creep parameters determined from in situ salt behavior in the C & SH shaft were, therefore, assumed to be valid for correlating analytical results of the waste shaft from normalized time to real time. The secondary creep parameter C was found to equal 5.70×10^{-21} $ksf^{-4.9}$ sec^{-1}. Because early in situ measurements were not available for the C & SH shaft, the primary creep parameters A and z were determined from in situ data from the horizontal drifts and were found to be 3.2 and 1.1×10^{-7} sec^{-1}, respectively.

Seepage Evaluation. The structural integrity of the shaft key is not totally dependent upon salt creep. The stability of the key, and consequently the shaft liner, can be compromised by water dissolving the salt surrounding the key. Water is prevented from seeping from the upper water-bearing zones down into the salt around the key primarily by two chemical water seals. The key configuration, including the seals, is described in Chapter 3.

The number of piezometers in the key are not sufficient to conclusively support an evaluation of seepage. However, the distribution of water pressure behind the liner and key provides an indication that there is probably no hydraulic continuity along the rock/liner interface. This is especially evident at the lowermost water-bearing zone at a depth of 717 feet (elev. 2692 feet). Here, water pressures are over 100 psi. The next lower level of piezometers, at a depth of 758 feet (elev. 2651 feet), also indicate pressures of about 100 psi. However, the lowest level of piezometers, in the shaft key, reflect pressures of less than 25 psi.

The telltale drains in the waste shaft key could not be located during the July 1986 inspection. Assuming they were constructed as designed, they may be covered by a thin veneer of concrete formed during concrete placement. A seep was noted on one side of the shaft at the approximate design level of the telltales. Inspection of the base of the key determined that no water was seeping from behind the key. This indicates that ground water is not bypassing the lower water seal between the key and the surrounding halite.

8.3.2.3 Unlined Section

The structural behavior of the unlined section of the waste shaft was also computed by a nonlinear creep analysis using the MARC Finite Element Program (ref. 6-8). The objective of the analysis was to compute the actual structural behavior by utilizing applicable in situ data from the C & SH shaft and the horizontal drifts, and to verify the design adequacy of the unlined section of the shaft.

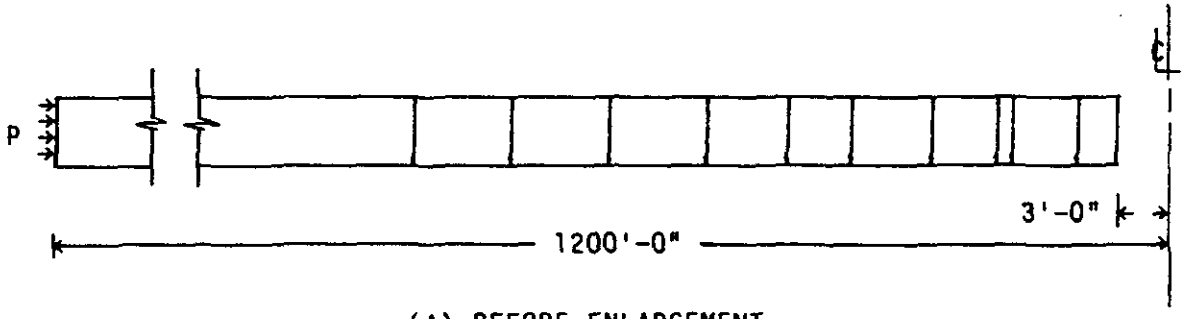

(A) BEFORE ENLARGEMENT

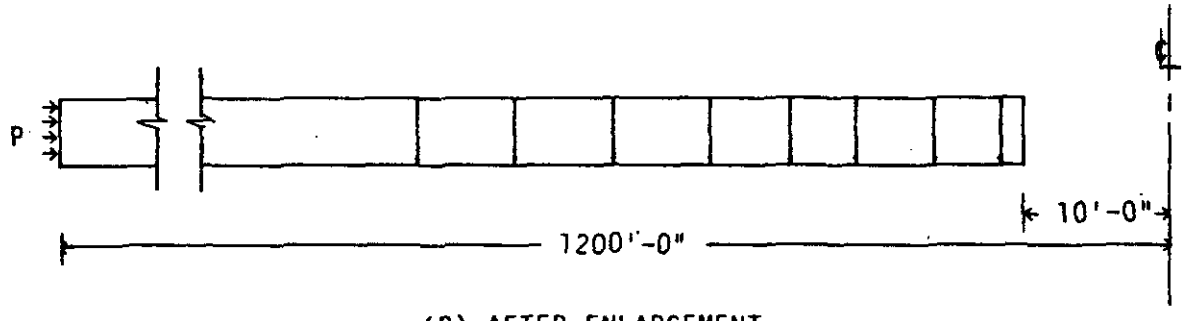

(B) AFTER ENLARGEMENT

Figure 8-9

WASTE SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

Model Simulation. The finite element model used for the unlined section of the waste shaft utilizes a single horizontal row of 70 quadrilateral axisymmetric ring elements. The model, shown on Figure 8-9, has its upper and lower horizontal boundaries restrained against vertical movement and a constant uniform lithostatic pressure, equal to 2,059 feet of overburden, applied to its outside vertical boundary. The same lithostatic pressure was initially applied to the inside vertical boundary as well; however, that pressure was later removed from the inside boundary to simulate the drilling of the original 6-foot diameter shaft.

The analysis simulates the salt creep until that time when the 6-foot diameter shaft was enlarged to its present 20-foot diameter. The shaft enlargement was simulated in the model by removing those ring elements that were located within the 20-foot diameter shaft opening. With the enlarged shaft configuration, simulated salt creep for another 28 years was analyzed.

Determination of Creep Parameters. Because the stratigraphy beneath the WIPP site is fairly uniform, the values of the creep parameters for the unlined section of the waste shaft were assumed to be identical to those values calculated at the corresponding elevations of the C & SH shaft. In addition, the C & SH shaft was drilled at a much earlier date than was the waste shaft; therefore, more in situ geomechanical instrument measurements were available for the C & SH shaft. The values of the creep parameters for the C & SH shaft were determined by correlating analytical results with extensometer readings obtained from a depth of 2,057 feet (elev. 1353 feet) in the shaft. The creep parameters C, A and z for the C & SH shaft were found to be 1.30×10^{-21} $ksf^{-4.9}$ sec^{-1}, 3.2 and 1.1×10^{-7} sec^{-1}, respectively. Chapter 7 presents specific details on how the creep parameters were evaluated for the C & SH shaft.

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8.3.2.4 Shaft Station

The analysis of closure and stability of the waste shaft station is based upon closure measurements in the C & SH shaft station. This is due to the limited amount of geomechanical instrumentation data available from the waste shaft station for the reasons discussed in subsection 8.3.1. The following discussion presents a brief comparison of the two shaft stations.

The waste shaft station cross-section dimensions are 15 feet high and 30 feet wide. These dimensions are comparable to those of the C & SH shaft station. However, the C & SH shaft station was excavated by drilling and blasting while the waste shaft station was excavated using a mining machine. The density of rock bolts in the roof of the C & SH shaft station is much greater than that in the waste shaft station. Also, the roof of the C & SH shaft station close to the shaft is approximately 3 feet below clay G, while clay G at the waste shaft station is nearly 8 feet above the roof. Thus, closure analysis of the waste shaft station using measurement data from the C & SH shaft station will be conservative.

The dimensions of the waste shaft station are also comparable to those of the test rooms and storage rooms. Computational analysis of the storage rooms (Chapter 12) predicts that failure will occur in MB-139, below the floor, due to gradual stress buildup. Similar behavior is expected to occur in MB-139 beneath the waste shaft station.

8.3.3 Prediction of Future Behavior

This subsection presents predictions of future behavior for the various elements of the waste shaft including the lined section, the shaft key, the unlined section and the shaft station.

8.3.3.1 Lined Section

The cracks in the concrete-lined section of the shaft are primarily the result of normal tension cracking occurring during the restrained

shrinkage of plain concrete. The cracks are not detrimental to the liner's structural integrity but sealing by grouting will be required to meet the design criteria regarding ground-water control.

Although the rate of water flowing into the waste shaft has been minor, the total volume of flow has resulted in the lowering of the potentiometric surface around the shaft. Other activities have also affected the potentiometric level in the vicinity of the shafts. Most notably, SNL pumping tests in borehole H-3 in late 1985 lowered the potentiometric surface approximately 40 feet (A.R. Lappin, SNL, personal communication). Due to the unknown effect of current and future hydrologic studies at the WIPP, it is difficult to predict the magnitude of future water pressure on the liner. However, two statements can be made concerning this water pressure:

(1) The piezometer data present a valid indication of water pressures behind the liner. Although this data cannot be used for predicting future pressures, continuous monitoring of these instruments will reflect current pressures and indicate short-term trends. This information can be compared with the design basis pressure distribution (Figures 8-6 and 8-7) to evaluate liner stability.

(2) Following the next grouting program in the waste shaft, if all water seepage through the liner has been stopped, it is possible that the potentiometric surface could return to its highest level determined during preliminary design activities. Assuming complete hydraulic continuity behind the liner, this condition would result in a pressure distribution equal to that of the hydrostatic pressure used for liner design. This condition would be within the design limits.

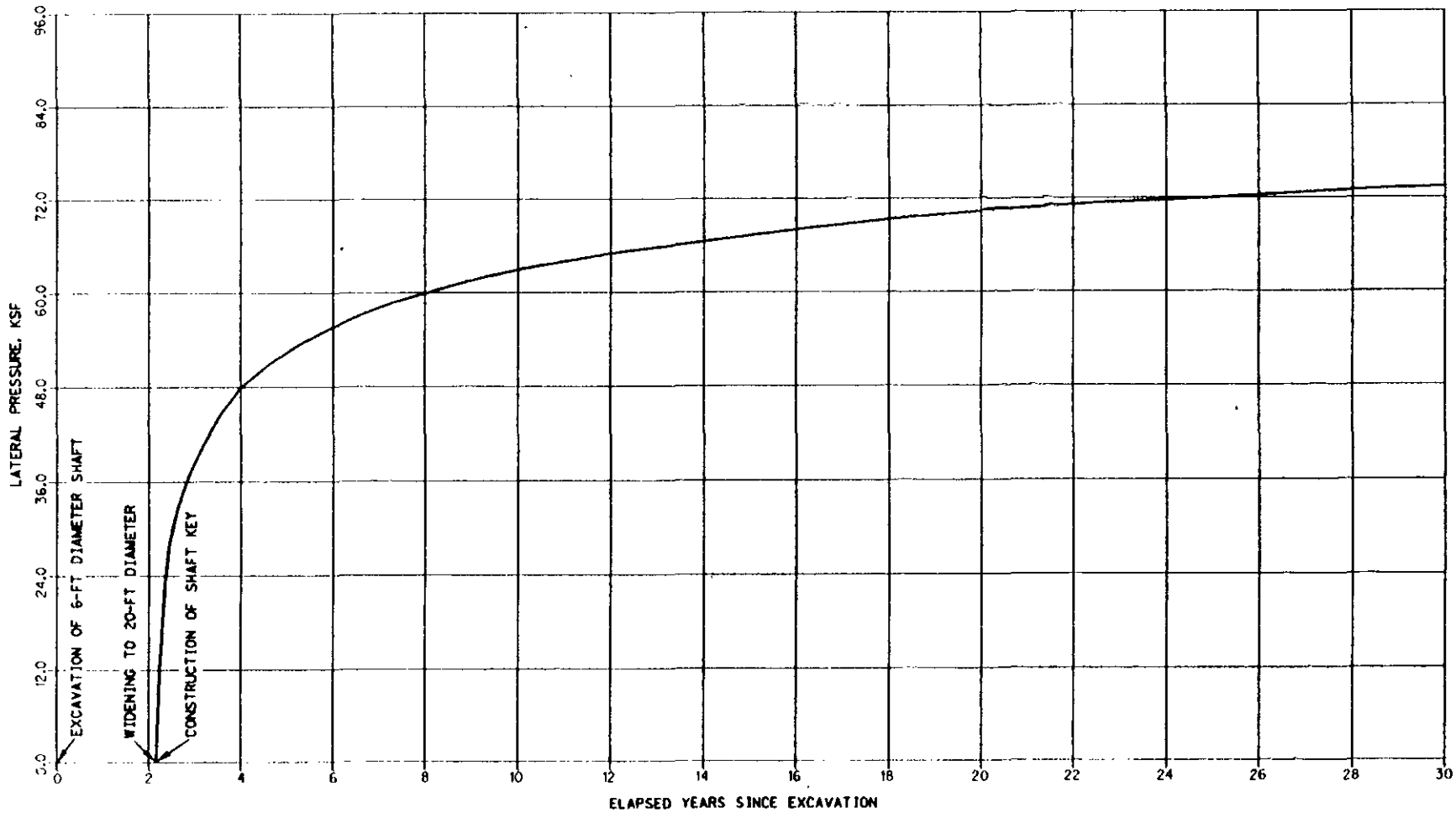

Figure 8-10

WASTE SHAFT KEY
LATERAL PRESSURE PREDICTION

8.3.3.2 Shaft Key

Figure 8-10 shows the predicted lateral pressure curve for the concrete key based on the finite element analysis. The key was designed as a compression cylinder in accordance with the strength design method for reinforced concrete (ref. 7-5) using an ultimate hoop stress of 4.25 ksi (0.85 f'_c). Using the design basis load factor of 1.7 for lateral loads, the maximum allowable hoop stress in the concrete key is 2.50 ksi, which results in an allowable lateral rock pressure of 148 ksf based on the diameter of the key. The design basis lateral pressure design requirement is approximately 60 ksf. Figure 8-10 shows a lateral pressure on the shaft key of approximately 72 ksf at the end of the 25-year shaft operating life. If the shrinkage and creep properties of the concrete were taken into account in the finite element analysis, the lateral pressure would actually be less than 72 ksf at 25 years.

The reinforced concrete of the shaft key is expected to exhibit cracks due to shrinkage. These are tensile cracks due to the reinforcement restraining the concrete from shrinking. The cracks are not considered significant because they are common to most reinforced concrete structures.

8.3.3.3 Unlined Section

Figures 8-11 and 8-12 show the radial and tangential (hoop) stress distributions relative to the overburden stress for different times in the unlined section of the waste shaft. Figure 8-11 shows the zone around the shaft opening where radial stresses are affected and indicates a decrease in magnitude over time. The computational results depicted on Figure 8-12 indicate that tangential stresses are only affected within a radius of approximately 120 feet.

Figures 8-13 and 8-14 show the effective stress and effective creep strain distributions in the unlined section of the waste shaft. The effective stress in the shaft wall at 25 years is approximately 140 ksf

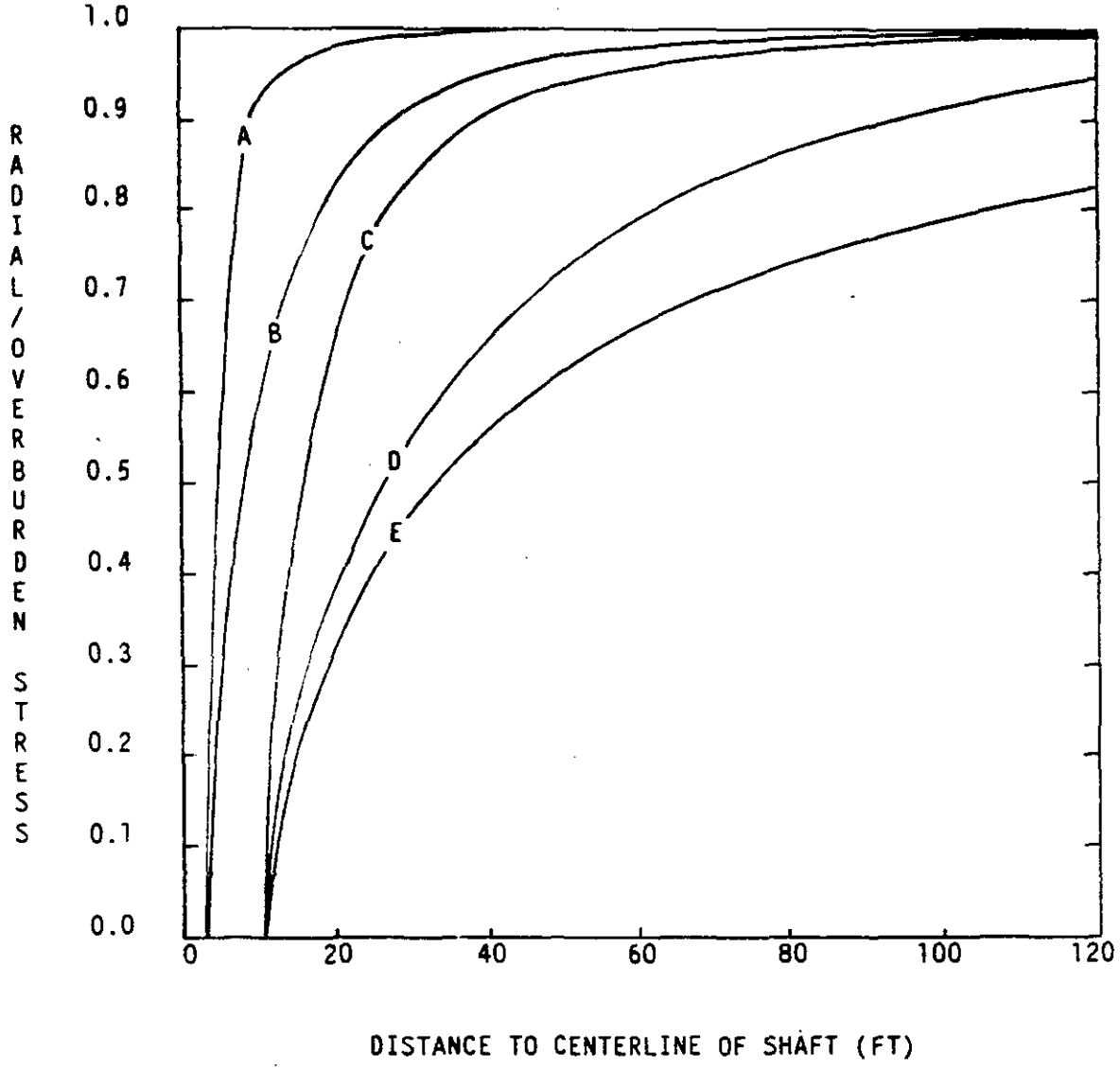

A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 8-11

WASTE SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1350 FEET

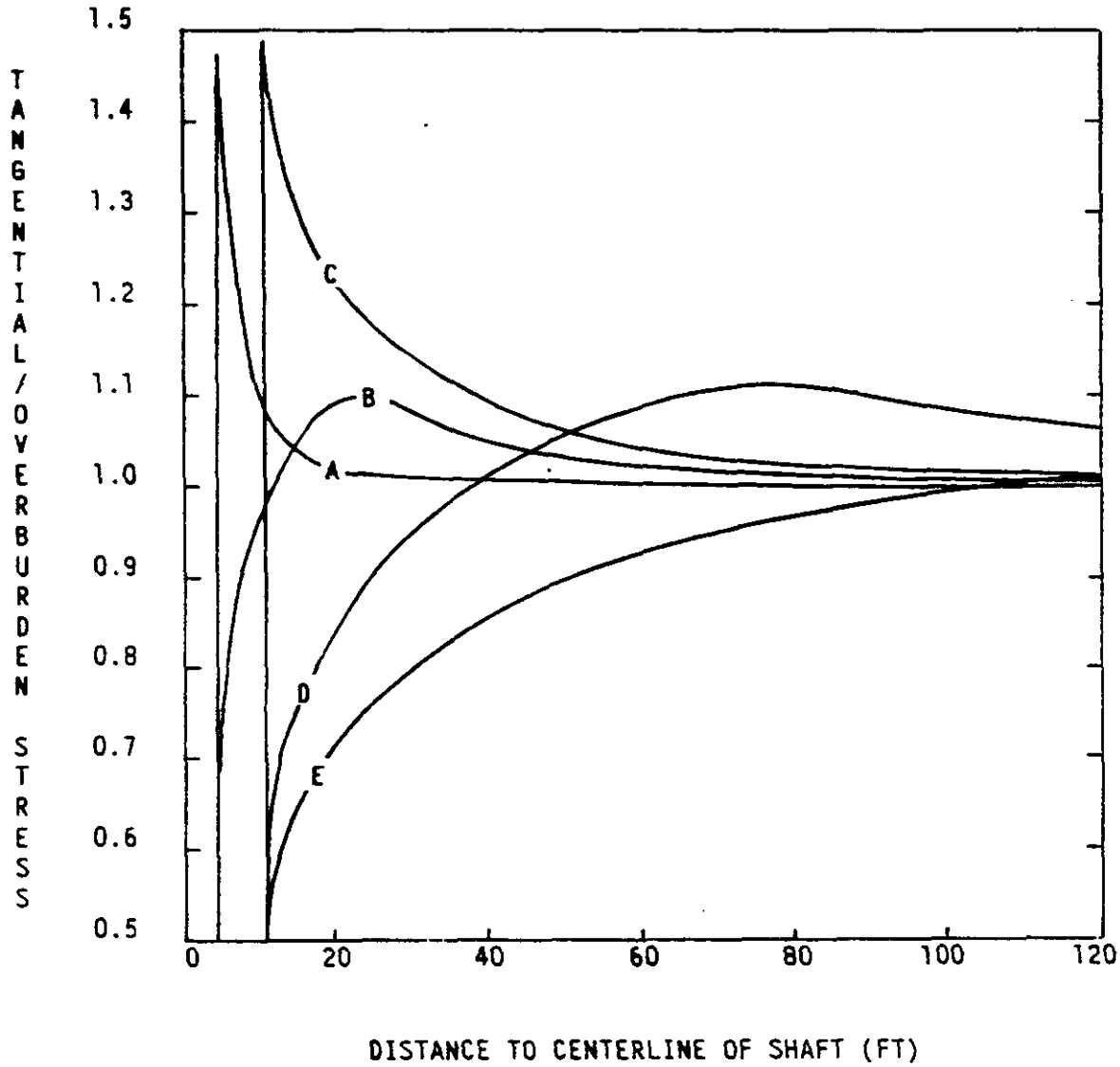

A - IMMEDIATELY AFTER EXCAVATION OF 6 FT-DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20 FT-DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20 FT-DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

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Figure 8-12

WASTE SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1350 FEET

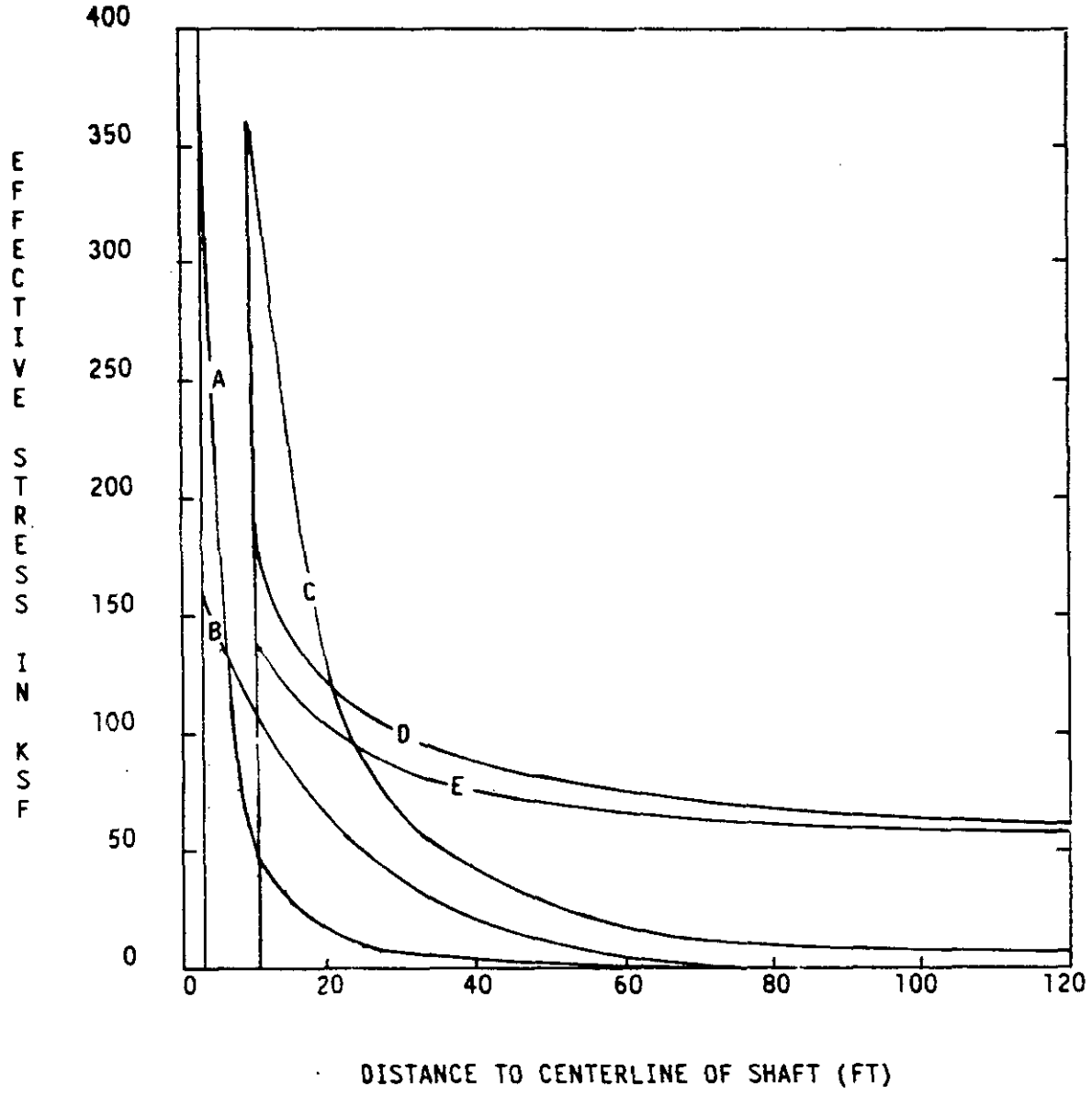

A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 8-13

WASTE SHAFT UNLINED SECTION
EFFECTIVE STRESS DISTRIBUTION AT ELEVATION 1350 FEET

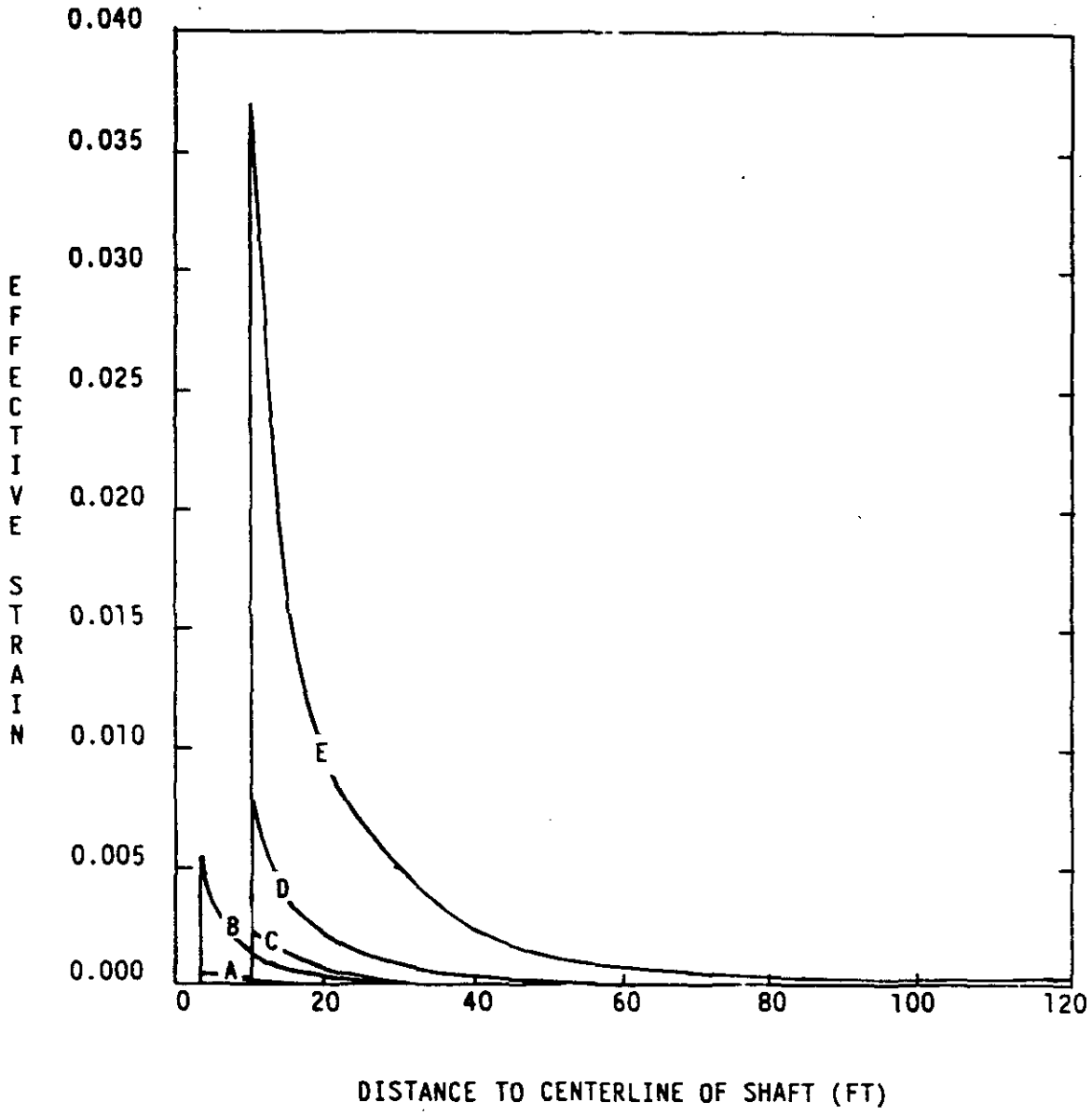

A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

M

Figure 8-14

WASTE SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1350 FEET

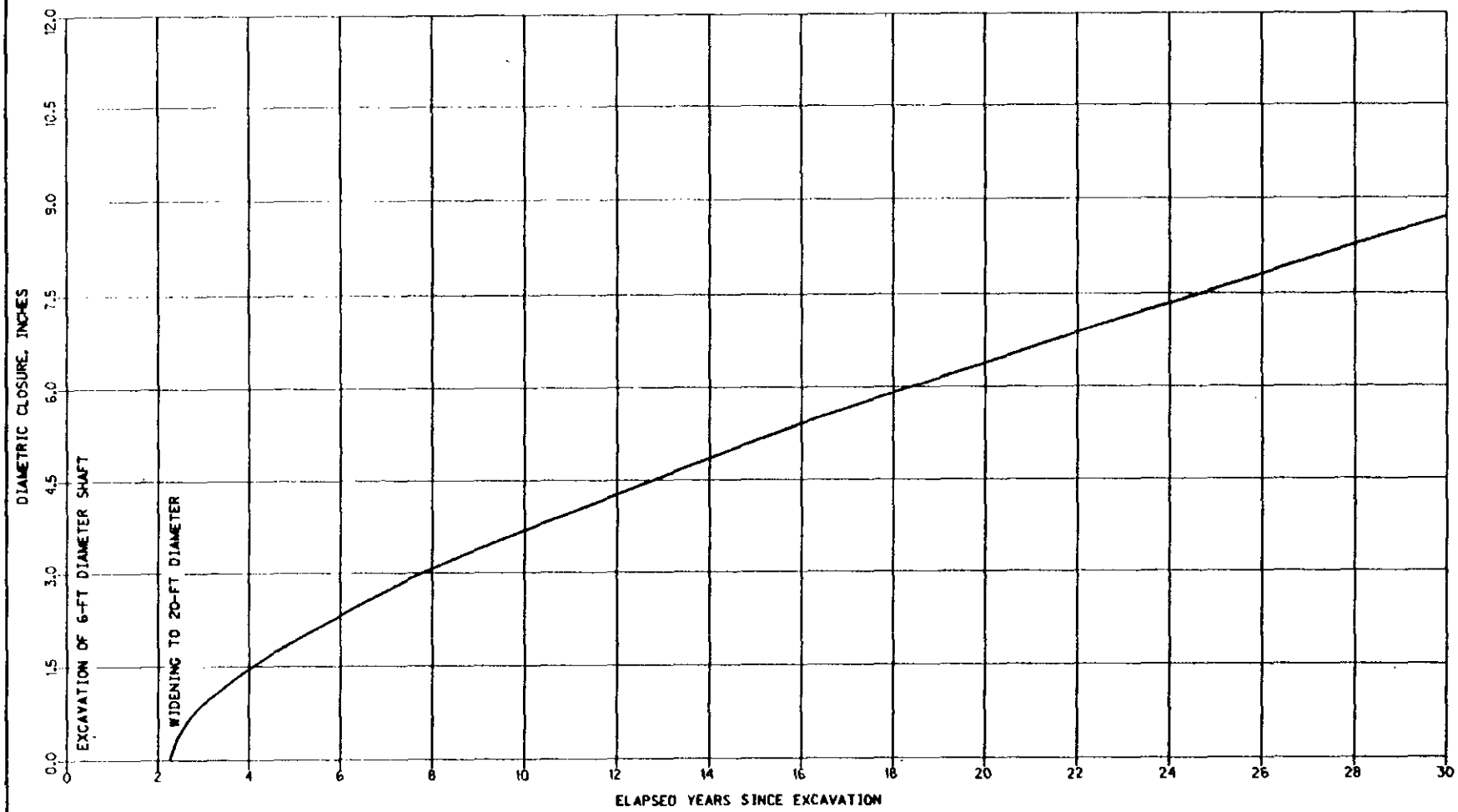

Figure 8-15

WASTE SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1350 FEET

while the effective creep strain in the shaft wall at 25 years reaches a value of approximately 0.037.

Figure 8-15 contains the prediction of diametric closure for the unlined section of the waste shaft at a depth of 2,059 feet (elev. 1350 feet). This figure shows a diametric closure of approximately 7 1/2 inches over the 25-year operating life of the shaft.

8.3.3.4 Shaft Station

Closure in the waste shaft station is predicted using measurement data from the C & SH shaft station. The measured roof-to-floor closure in the C & SH shaft station was approximately 10 inches on September 16, 1985, over 3 years after the completion of excavation. The measured wall-to-wall closure is greater than 6 inches over the same time period. However, the initial readings were taken nearly 260 days after the station was excavated; therefore, the actual closure magnitudes will be higher. The average rate of roof-to-floor closure over the measurement period was approximately 3.89 inches/year. Using this value as a constant closure rate over the plant operating life of 25 years, an additional roof-to-floor closure of about 8 feet is expected to occur. The wall-to-wall closure over the same period is expected to be approximately 60 percent of the roof-to-floor closure, or about 5 feet. Actual closure may be lower as discussed in subsection 8.3.2.4.

8.4 CONCLUSIONS AND RECOMMENDATIONS

Design validation requires an assessment of the compatibility of the design criteria, design bases and design configurations used for the reference design. The following conclusions and recommendations address those design elements identified in Section 8.2. Other conclusions and recommendations resulting from the design validation process are also presented.

8.4.1 Conclusions

The design criteria require that all of the shafts are to be stable. Shaft stability has been evaluated using analytical calculations,

finite element modeling and in situ data analysis. The shaft liner is considered stable because the water pressure exerted on it has remained significantly below the design hydrostatic pressure. If the water pressure increases to the design hydrostatic pressure, as may be expected if the leaks are sealed by additional grouting, liner stability will not be compromised. The pressure capacity of the liner sufficiently exceeds the design hydrostatic pressure.

Based on existing evidence, the cracks in the liner and key do not present a structural problem. The unreinforced concrete liner is expected to function as intended, provided that the existing cracks and construction joints are grouted and contact grouting is performed at the rock/liner interface. Consolidation grouting of the surrounding rock may also be necessary to achieve a dry shaft.

The shaft key was designed to withstand a design basis lateral pressure equal to 50 percent of the overburden pressure (approximately 60 ksf). The finite element analysis determined that the lateral pressure on the key at the end of the facility operating life will be approximately 72 ksf. Although this value is higher than the design lateral pressure, the key is expected to remain stable throughout its operating life because the allowable lateral rock pressure is 148 ksf. This is twice the lateral pressure predicted and provides a sufficient margin of safety. Furthermore, if the shrinkage and creep properties of the concrete were taken into account in the analysis, the lateral pressure would be less than 72 ksf.

The analytical results for the waste shaft, presented in Section 8.3, show the calculated redistribution of stresses around the shaft due to the effects of creep. Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases with time as the stress arch around the opening migrates away. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability

problem in the waste shaft except in the anhydrite bed (MB-139) below the floor of the shaft station. Gradual buildup of stress in this bed may result in floor heave and fracturing.

The analysis shows the locations of effective creep strain concentrations for selected times in the unlined section. Based on these predicted values of effective creep strain and the strain limit discussed in Chapter 6, the waste shaft will remain structurally stable over its planned 25-year operating life.

The analysis predicts that diametric closure in the unlined section of the waste shaft will be approximately 7 1/2 inches over its 25-year operating life. Based on the predicted deformations and closures, the waste shaft will meet the requirements stated in the design criteria and the 20-foot diameter unlined section will provide sufficient operating clearance to allow for salt creep.

The design criteria requires that no uncontrolled ground water reach the facility level via the shafts. The majority of water seeping through cracks and construction joints in the liner is collected in three water-collection rings and directed to the underground facility where it is disposed. Only minor amounts of uncontrolled fly water reach the facility level. This water has a negligible impact and does not affect validation of the criterion regarding ground water reaching the facility level.

Shaft inspections have determined that only one minor seep occurs in the key and that no water seepage occurrs from the base of the key. This supports the conclusion that the water seals are functioning, that no water is seeping along the concrete/salt interface, and that no salt dissolution is occurring behind the concrete key. The installation technique for the waste shaft water seals was improved over that used for the C & SH shaft water seals (Chapter 3).

The zone of dissolution observed in the shaft sump wall is not considered to be detrimental to the operation of the facility. The

material was dissolved differentially by standing water in the sump resulting from construction activities. It is not the result of any geologic discontinuity or process. This zone will not produce any structural problems in construction of the waste shaft facilities.

The waste shaft station is expected to undergo roof-to-floor closure at a rate of 3.89 inches/year. However, this rate has been obtained by using the C & SH shaft station instrument data. The actual closure rate may be lower. Additional heave and fracturing in the salt beneath the floor, as well as in MB-139, is expected to occur. Some remedial work will be required to maintain the required roof-to-floor clearance for operational equipment and activities.

The reference design for the waste shaft is considered to be validated in accordance with the objectives of the design validation program based on the analyses, evaluations and predictions of future behavior presented in this chapter. With one exception, the waste shaft reference design complies with the design criteria and the design bases. The criterion that stipulates that shaft liner design shall prevent ground-water flow into the shaft has not been met. The rate of water currently seeping into the waste shaft is not considered to be detrimental to the stability of the shaft or to its functional purpose. However, the criteria will be satisfied when additional remedial grouting has been performed. No modifications to the shaft reference design will be required.

8.4.2 Recommendations

Based on the results of design validation, the following recommendations with respect to the waste shaft are made:

(1) Due to the limited in situ data base, validation of the waste shaft key and unlined section relies on numerical modeling utilizing creep parameters derived from the C & SH shaft in situ data. It is recommended that the modeling be repeated, prior to the first receipt of waste, using the latest in situ

data from the waste shaft. This analysis should be repeated periodically for comparison and verification of in situ data against design parameters.

(2) Grouting should be performed to completely seal the waste shaft liner. This should include contact grouting behind the liner and grouting of shrinkage cracks and construction joints. Consolidation grouting may also be required. Qualified personnel should inspect the shaft at regularly scheduled intervals. The liner should be checked for leaks after grouting has been completed. The key should be checked for water seeping from behind the key at its base. If any seepage is detected it may become necessary to grout the area above the upper water seal. If possible, grout should not be placed behind the key below the upper seal. However, should grouting behind the key become necessary, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the requirements of the Plugging and Sealing Program.

(3) The dissolution zone in the waste shaft sump should be filled with a salt-compatible cement mortar.

(4) Because waste shaft station closure is based on C & SH shaft station data, and because of the importance of the waste shaft station in general, vertical convergence points or meters should be installed at selected locations and measurements taken periodically. These data should then be analyzed to obtain better estimates of station closure.

CHAPTER 9
EXHAUST SHAFT

9.1 INTRODUCTION

This chapter presents information on design validation of the exhaust shaft. Included are discussions of its design, the design validation process, and conclusions and recommendations pertaining to validation of the reference design.

9.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the exhaust shaft. The design configuration of the shaft is discussed in Chapter 3, subsection 3.3.3.

9.2.1 Design Criteria

The design criteria for the exhaust shaft are identical to those for the other two shafts. The criteria requiring validation are indicated in the listing of abridged criteria presented in Chapter 2, Table 2-1, and are discussed in Chapter 7.

The design criteria requiring evaluation for design validation of the exhaust shaft are:

(1) shaft shall be designed to be structurally stable;

(2) shaft shall be designed to accommodate salt creep; and

(3) ground-water flow into the shaft shall be controlled.

9.2.2 Design Bases

The design bases are the detailed design requirements developed from the design criteria. The primary design basis document for the exhaust shaft is the Design Basis, Exhaust Shaft (ref. 2-16). The major elements of the design bases are the same as those for the waste shaft,

except for the items discussed in the next paragraph. The elements that require evaluation or that have a direct impact on design validation are presented in Table 9-1.

In addition to adhering to the design basis elements discussed previously for the waste shaft, the exhaust shaft shall be designed to connect the facility level with the exhaust filter building at the ground surface. The exhaust shaft shall be used to remove air from the underground development level during construction and storage operations. The entire shaft shall be inspected utilizing a closed-circuit television camera that shall be lowered from the top of the shaft. Unlike the design bases for the other two shafts, the exhaust shaft design basis does not require the installation of geomechanical instrumentation.

9.3 DESIGN VALIDATION PROCESS

As discussed in Chapter 5, design validation of the exhaust shaft has been achieved by data collection, its analysis and evaluation, and the prediction of future behavior. Data collection activities have included geologic mapping and visual observations of the exhaust shaft wall. Although geomechanical instruments have been installed in the shaft, no data was available for design validation due to the late date of installation.

Computational analyses for the exhaust shaft were performed in the same manner as those for the waste shaft. The finite element analyses of the shaft key and unlined section used the material parameters for salt obtained from the C & SH shaft and horizontal drift analyses. The results of the analyses were then used to predict future behavior.

9.3.1 Data Collection

Data collection in the exhaust shaft was on a much smaller scale than in the other two shafts. Geologic mapping was conducted in the shaft to verify the stratigraphy. This mapping is discussed in detail in Chapter 6. Visual inspections and observations in the shaft were

Table 9-1

VALIDATION ELEMENTS OF EXHAUST SHAFT DESIGN BASES

(1) Shaft liner

Hydrostatic pressure should be considered to start at 250 feet below the ground surface and extend to the top of the key.

(2) Shaft key

Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.

(3) Unlined section

Provide 15-foot diameter to allow for future salt creep deformation.

sporadic due to limited access. The following discussion presents those observations which affect design validation.

9.3.1.1 Field Observations

Exhaust shaft construction was completed on January 15, 1985. Initial of the lined section of the shaft was performed on January 30, 1985. At that time water seepage through cracks and construction joints in the liner was observed. Seepage into the shaft was measured at 0.35 gallons per minute (gpm).

Subsequent inspections of the exhaust shaft liner were made in February and May 1985 to observe its condition and to evaluate the need for grouting to reduce water seepage. The first occurrence of moisture on the liner was observed 25 feet below the shaft collar. The majority of water seepage was occurring between approximate depths of 569 feet and 759 feet (elev. 2840 feet and 2650 feet). Below a depth of 759 feet the entire shaft liner was wet, making it difficult to determine the exact source of seepage. Some salt accumulation was observed on the liner below the Culebra water-bearing member. The May 1985 inspection generally revealed a 1/4- to 3/8-inch thickness of salt incrustation in this area with some local accumulation up to 4 inches in thickness.

Salt accumulation at two telltale drain holes, at a depth of 857 feet (elev. 2552 feet) on the northeast and east sides of the shaft key, had resulted in the almost complete plugging of these holes. The six other drain holes had minor salt accumulation. The bottom of the key had salt stalactites hanging from the concrete but no flow of water under the concrete was observed. There was no evidence of any dissolution of salt at the concrete/salt contact.

A cement/chemical grouting program was conducted in the exhaust shaft from June 1 through July 31, 1985. An inspection of the exhaust shaft liner was made on July 30, 1985. The liner was appreciably drier than it had been prior to grouting, especially below the Culebra member. One collar pipe, for future piezometer installation at a depth of 616

feet (elev. 2793 feet), was weeping and one pipe, at a depth of 722 feet (elev. 2687 feet), was dripping. This water constituted the majority of the total seepage into the shaft. Weeping from random cracks above a depth of 617 feet appeared to be of the same magnitude as before grouting. The water ring at the base of the shaft key was relatively dry. New telltale drain holes at a depth of 870 feet (elev. 2539 feet) were all dry. Several of the original drain holes, at 857 feet, and several new holes, at a depth of 855 feet (elev. 2554 feet), were weeping slightly. No evidence of seepage at the concrete key/salt contact was observed. The grouting program reduced water seepage into the exhaust shaft to an essentially non-measurable quantity.

Cursory inspections of the exhaust shaft made during the installation of geomechanical instruments in November and December 1985 indicated no appreciable change in the condition of the shaft liner since the July 1985 inspection.

A second grouting program was conducted in the exhaust shaft during August, September and October, 1986. The program was performed at this time to reduce the possible need for grouting in the future when shaft access will be limited. The grouting was conducted on a smaller scale than in the earlier program. It consisted of injecting grout through existing sleeves from the top of the salt in the key are to the top of the Magenta member. Grouting was also performed, as required, above the Magenta through sleeves in the liner. The results of the grouting were not available at the time of publication of this report.

9.3.1.2 Geomechanical Instrumentation

The original exhaust shaft design contained no provision for the installation of geomechanical instrumentation based on the assumption that rock behavior would be similar to that in the waste shaft. However, it was subsequently decided that geomechanical instrumentation should be installed to obtain shaft-specific behavior information for later use in the shaft sealing program.

Instrument locations in the exhaust shaft were based on waste shaft instrument locations. Twenty-one piezometers, 4 pressure cells and 9 extensometers have been installed in the exhaust shaft. The instrument installation was completed on December 27, 1985, 385 days after the completion of shaft excavation. All exhaust shaft instruments are monitored remotely by the datalogger.

9.3.2 Analysis and Evaluation

The analysis and evaluation of the constructed exhaust shaft has been performed using direct observation data and geomechanical instrumentation readings from the C & SH and waste shafts. This analysis and its evaluation against reference design parameters was performed for the three major sections of the shaft: the lined section; the shaft key; and the unlined section.

The adequacy of the exhaust shaft reference design was evaluated based on a complete spectrum of geomechanical behavior including stress, strain and deformation over the planned operating life of 25 years. The analyses used creep parameters computed from the C & SH shaft and the 8 x 25-foot drifts as well as hydrostatic pressures from the waste shaft.

9.3.2.1 Lined Section

Analyses were performed for the unreinforced concrete liner in the exhaust shaft. However, because no instrumentation data from this shaft were available, the analyses were based on data obtained from the C & SH and waste shafts.

The structural analysis and design of the exhaust shaft were performed using engineering mechanics principles and design bases similar to those used for the waste shaft as described in Chapter 8. For example, both axial and flexural stresses were considered in the design of the concrete liner, with permissible stress values taken as those used for structural unreinforced concrete (ref. 8-1) utilizing the ultimate

strength design method. Loads considered in the design of the concrete liner included a hydrostatic pressure assumed to act from a depth of 250 to 844 feet; a grouting pressure equal to 1.3 times the ground-water pressure acting over one-sixth of the circumference of the liner; and stresses due to an initial imperfection of 1 inch in the roundness of the liner. Since there is no major salt strata surrounding the liner, no significant creep will occur and rock pressures against the liner were assumed to be negligible.

Based on its finished dimensions, the computational results show that the external pressure capacities and corresponding closure limits (maximum diametric changes) for different thicknesses of the exhaust shaft liner are:

Depth (feet)	Liner Thickness (inches)	Pressure Capacity (psi)	Closure Limit (inches)
15 to 500	10	320	0.140
500 to 740	14	513	0.175
740 to 844	16	611	0.190

Since no measurements of the finished liner diameter were taken during construction, the actual closure is not available for comparison.

Figure 9-1 shows the relationship between the hydrostatic design pressure and the pressure capacity of the liner. The hydrostatic pressure is identical to that used for design of the waste shaft. Because the exhaust shaft liner also has water seeping through cracks and construction joints, the hydrostatic pressure is expected to behave in the same manner as discussed for the waste shaft in Chapter 8. That is, the design hydrostatic pressure is not expected to be reached until the shaft liner is completely sealed. When the design hydrostatic pressure is reached, the liner will have a factor of safety greater than two, based on the liner pressure capacity.

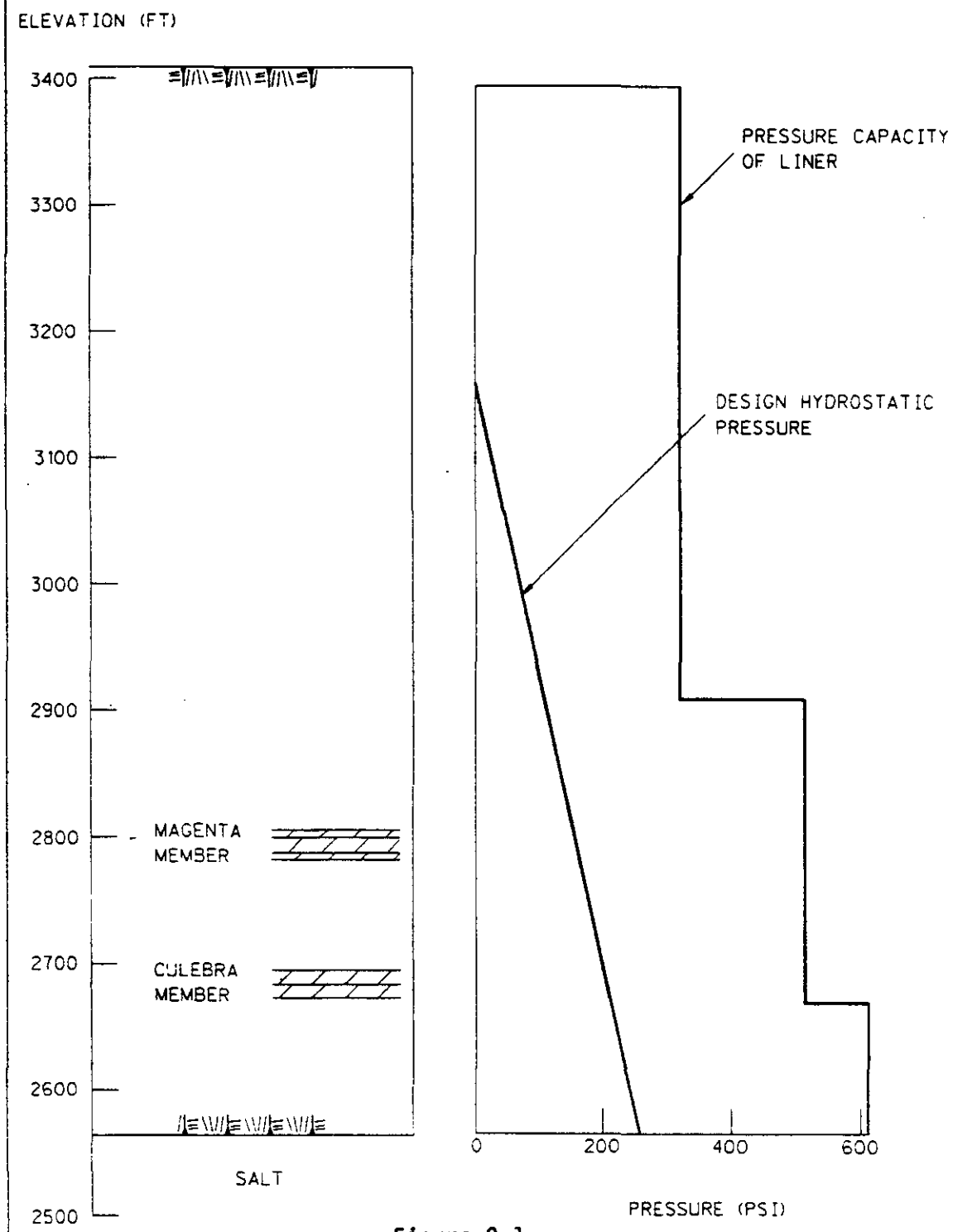

Figure 9-1

EXHAUST SHAFT LINER
LATERAL PRESSURE COMPARISON

9.3.2.2 Shaft Key

The exhaust shaft key was designed to withstand a lateral pressure equal to 50 percent of the vertical overburden pressure or about 60 ksf. A nonlinear finite element analysis, similar to that performed for the waste shaft key described in Chapter 8, was used to simulate the long-term creep interaction of the salt and the concrete key. The creep behavior of the salt was simulated using a power law (equation C.4-6 in Appendix C). For conservatism, the shrinkage effects and creep of the concrete were not taken into account in the analysis.

Model Simulation. The finite element model for the exhaust shaft key and surrounding salt consists of a single layer of quadrilateral axisymmetric ring elements as shown on Figure 9-2. An inner element of the model represents a segment of the concrete key; however, this element is not tied to the surrounding salt deposits until that time when the concrete for the shaft key is actually placed. All depth dependent input values, such as overburden stresses, initial lithostatic state, etc., were computed based on a depth of 891.5 feet, low in the key, where such values are at a maximum. Halite is the prevalent material present at the base of the shaft key and its properties were used for the parameters modeling the salt deposits surrounding the key.

The analytical procedure used to perform the creep analysis for the exhaust shaft key was similar to that used for the waste shaft key analysis described in Chapter 8. However, in the finite element model for the exhaust shaft, the key diameter was enlarged to 21 feet with a finished inside diameter of 14 feet.

9.3.2.3 Unlined Section

The structural behavior of the unlined section of the exhaust shaft was also computed using the MARC Finite Element Program discussed in Chapter 6. The analysis computed the actual structural behavior by utilizing applicable in situ data from the C & SH shaft and the horizontal drifts.

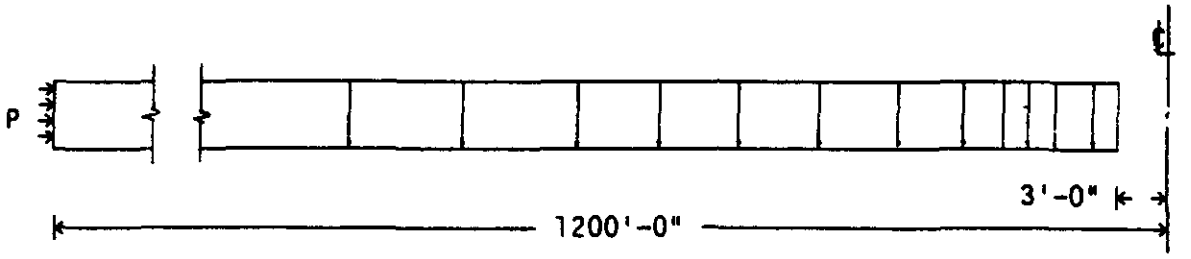

(A) BEFORE ENLARGEMENT

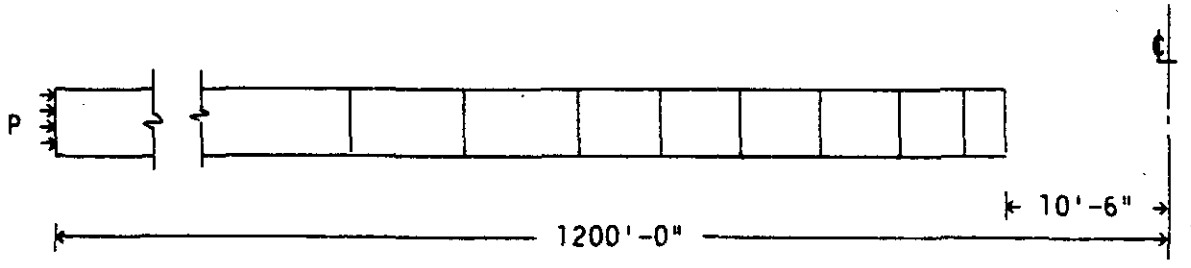

(B) AFTER ENLARGEMENT

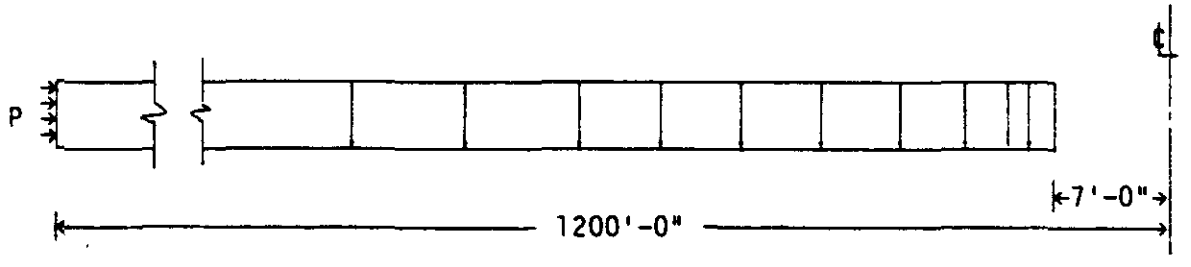

(C) AFTER KEY PLACEMENT

Figure 9-2

EXHAUST SHAFT KEY
FINITE ELEMENT MODEL

Model Simulation. The finite element model used for the unlined section of the exhaust shaft utilizes a single horizontal row of 70 quadrilateral axisymmetric ring elements. The model, shown on Figure 9-3, has its upper and lower horizontal boundaries restrained against vertical movement and has a constant lithostatic uniform pressure, equal to 2,066 feet of overburden, applied to its outside vertical boundary. The same lithostatic pressure was initially applied to the inside vertical boundary; however, that pressure was later removed from the inside boundary to simulate the drilling of the 6-foot diameter pilot bore.

The analysis simulates the salt creep until that time when the 6-foot diameter hole was enlarged to its present 15-foot diameter. The shaft enlargement is simulated in the model by removing those ring elements which are located within the newly-excavated 15-foot diameter. With the enlarged shaft configuration, simulated salt creep for another 25 years was analyzed.

Determination of Creep Parameters. Since the stratigraphy surrounding the C & SH shaft is similar to that surrounding the exhaust shaft, the creep parameters determined from the in situ salt behavior in the C & SH shaft were assumed to be valid for correlating analytical results for the exhaust shaft from normalized time to real time. The secondary creep parameter C for the C & SH shaft was found to equal 5.70×10^{-21} $ksf^{-4.9}$ sec^{-1}. Since early in situ measurements were not available for the C & SH shaft, the primary creep parameters A and z were determined from in situ data from the horizontal drifts and were found to be 3.2 and 1.1×10^{-7} sec^{-1}, respectively.

Chapter 7 presents specific details on the computation of the secondary creep parameter C from the C & SH shaft. Chapter 10 presents the computation of the primary creep parameters A and z from the drifts.

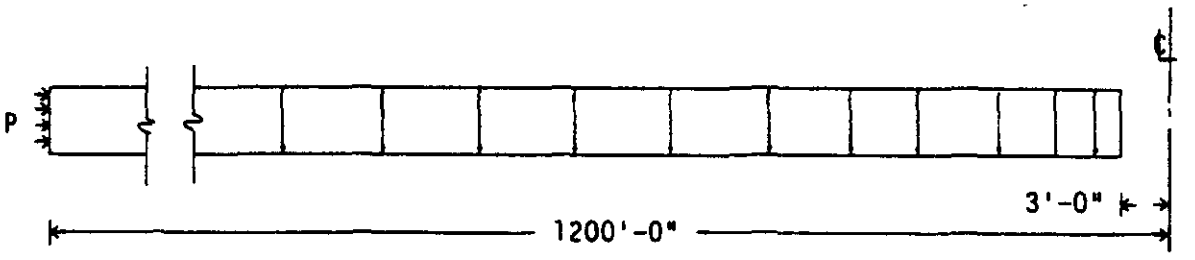

(A) BEFORE ENLARGEMENT

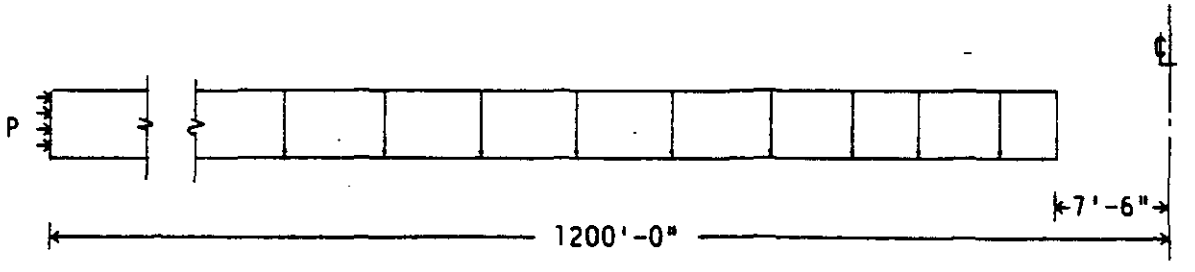

(B) AFTER ENLARGEMENT

Figure 9-3

EXHAUST SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

9.3.3 Prediction of Future Behavior

This subsection presents the results of the analysis and evaluation of the exhaust shaft. Predictions of future behavior for the lined section, key and unlined section are discussed.

9.3.3.1 Lined Section

The cracks in the concrete liner of the exhaust shaft are primarily tension cracks formed during restrained shrinkage we described in Chapter 8 with respect to the waste shift liner. These are neither unusual nor unexpected. Grouting of the cracks, as well as the leaking construction joints, will be required to meet the design criteria regarding ground-water control.

As discussed in Chapter 7, subsection 7.3.3.1, there is no reason to expect that the potentiometric surface at the WIPP site will exceed the design basis depth of 250 feet below the ground surface over the operating life of the facility. In the future, the recently installed piezometers will permit monitoring of the actual water pressure on the liner. Even if the water pressure rises to the design pressure, the pressure capacity of the liner will provide a sufficient margin of safety.

9.3.3.2 Shaft Key

The elapsed time from the drilling of the 6-foot diameter pilot bore to its widening to 21 feet in the key area and construction of the concrete key was approximately 316 days. Figure 9-4 shows the predicted lateral pressure curve for the concrete key based on the finite element analysis. The key was designed as a compression cylinder in accordance with the strength design method for reinforced concrete (ref. 7-5) using an ultimate hoop stress of 4.25 ksi. Using a load factor of 1.7 for lateral loads, the maximum allowable hoop stress in the key is 2.50 ksi. This hoop stress results in an allowable lateral rock pressure of 154 ksf based on the diameter of the key. Figure 9-4 shows a lateral pressure on the key of approximately 72 ksf

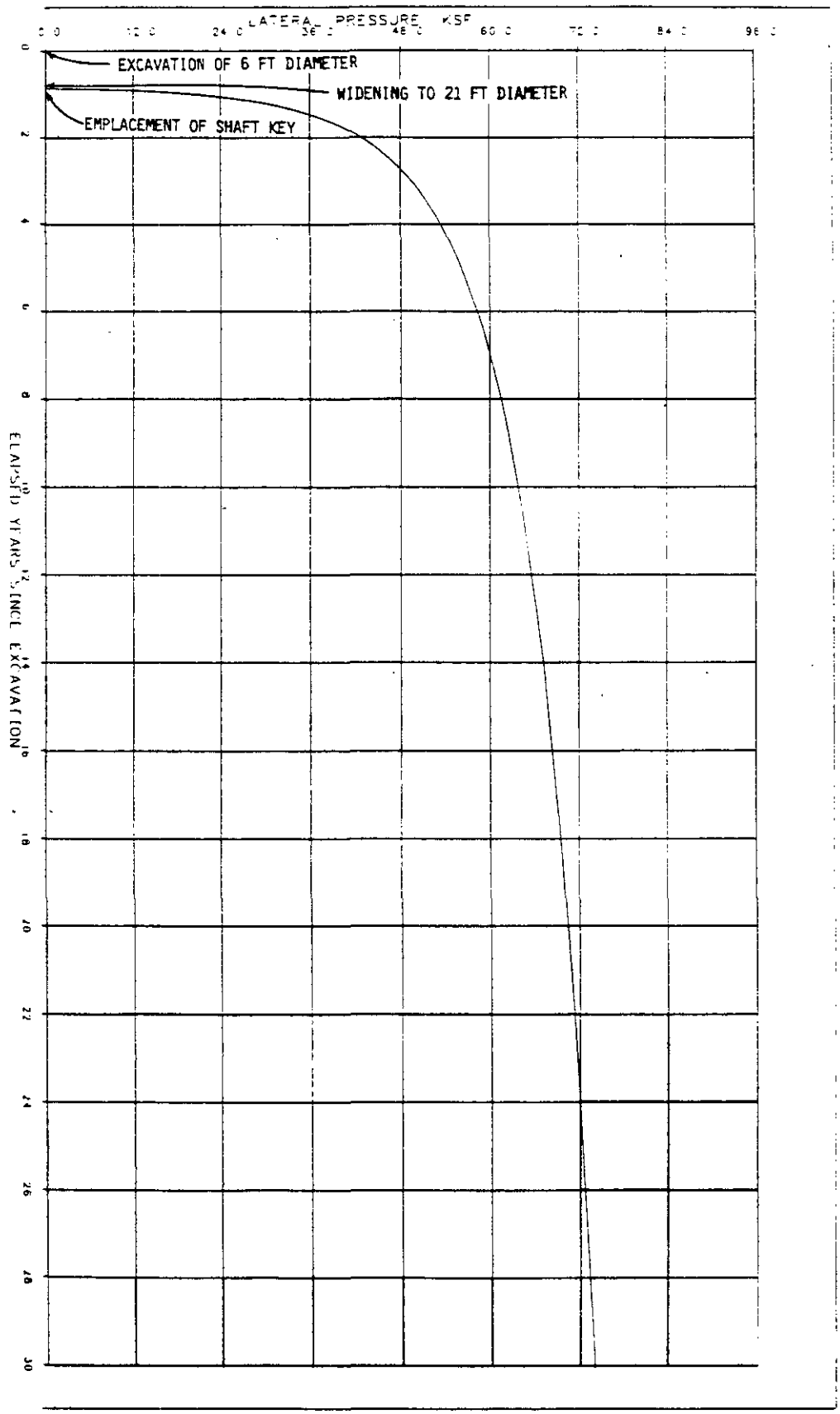

Figure 9-4

EXHAUST SHAFT KEY
LATERAL PRESSURE PREDICTION

at 25 years. Although higher than the design basis lateral pressure of 60 ksf, this value is about 50 percent of the allowable lateral pressure. In addition, the lateral pressure would actually be less than 72 ksf if concrete shrinkage and creep were taken into account in the finite element analysis.

Although no shrinkage cracks have been found in the reinforced concrete in the key, their presence would not be unexpected. They are common to most reinforced concrete structures and should not be of major concern.

9.3.3.3 Unlined Section

Figures 9-5 and 9-6 show predictions for radial and tangential (hoop) stress distributions relative to the overburden stress at different times for the unlined section of the exhaust shaft. Figure 9-5 shows the zone around the shaft opening where radial stresses are affected and their decrease in magnitude over time. The computational results indicate that tangential stresses are affected only within a radius of approximately 120 feet.

Figures 9-7 and 9-8 show predictions of the effective stress and effective creep strain distributions in the unlined section of the exhaust shaft. The magnitude of the effective stress in the shaft wall at 25 years approaches 140 ksf while the effective creep strain reaches a value of approximately 0.037.

Figure 9-9 shows approximately 6 inches of diametric closure in the unlined section of the exhaust shaft at a depth of 2,066 feet (elev. 1343 feet) over the 25-year operating life of the shaft.

9.4 CONCLUSIONS AND RECOMMENDATIONS

Design validation of the exhaust shaft requires an assessment of the compatibility of the design criteria, design bases and design configurations used for the reference design. The following discussion presents conclusions and recommendations regarding validation of the

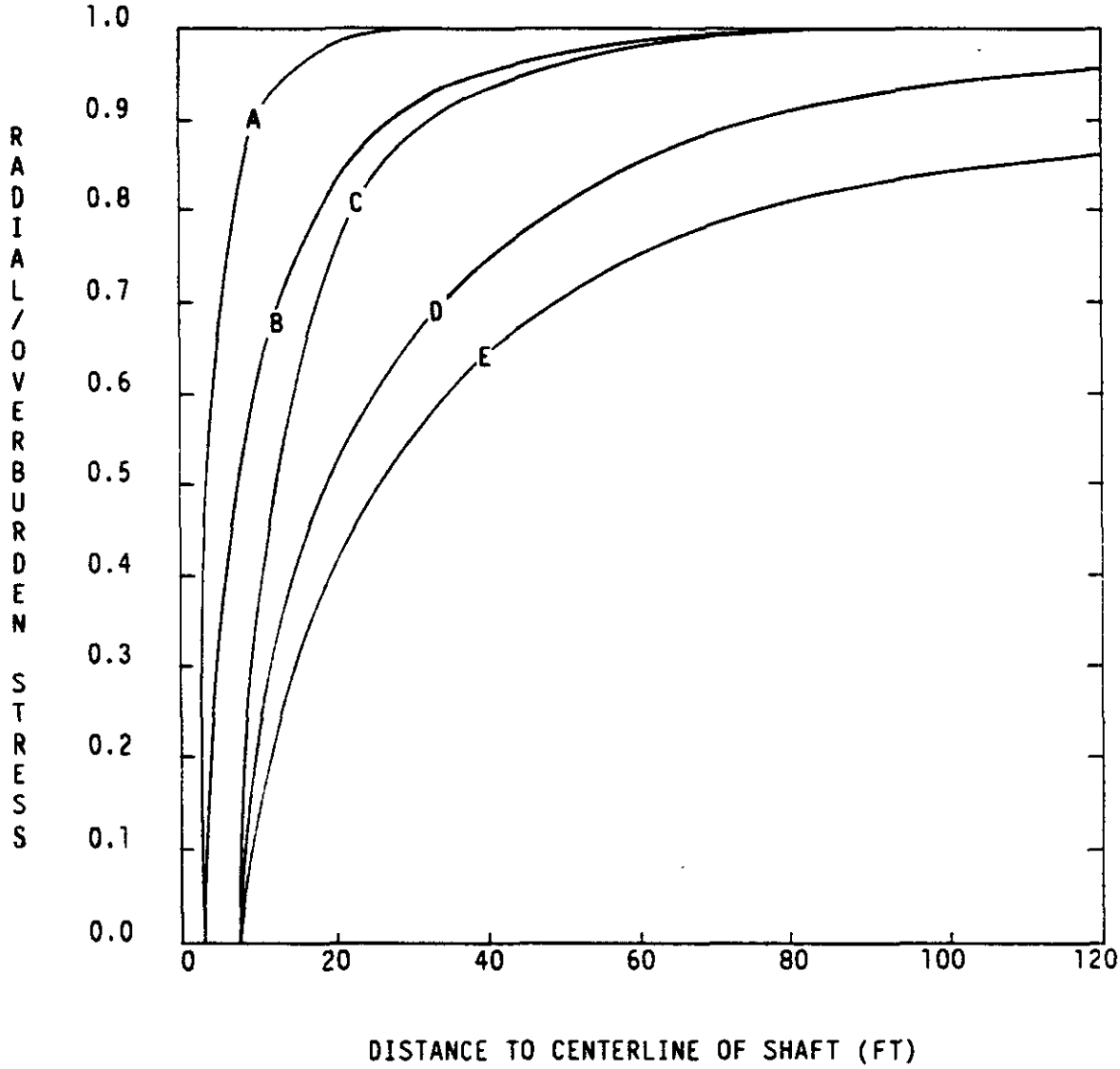

A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

M

Figure 9-5

EXHAUST SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1343 FEET

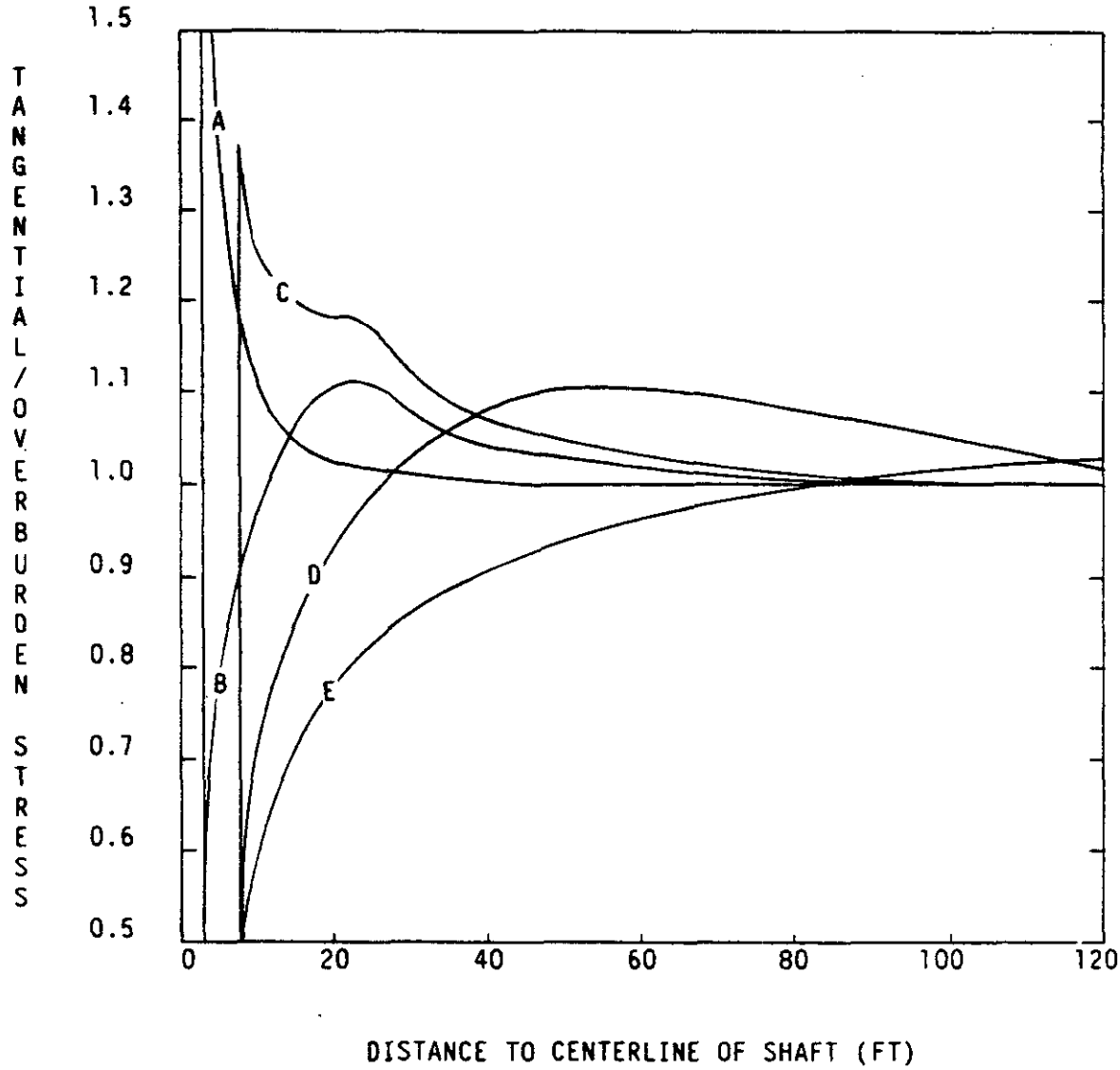

A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-6

EXHAUST SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1343 FEET

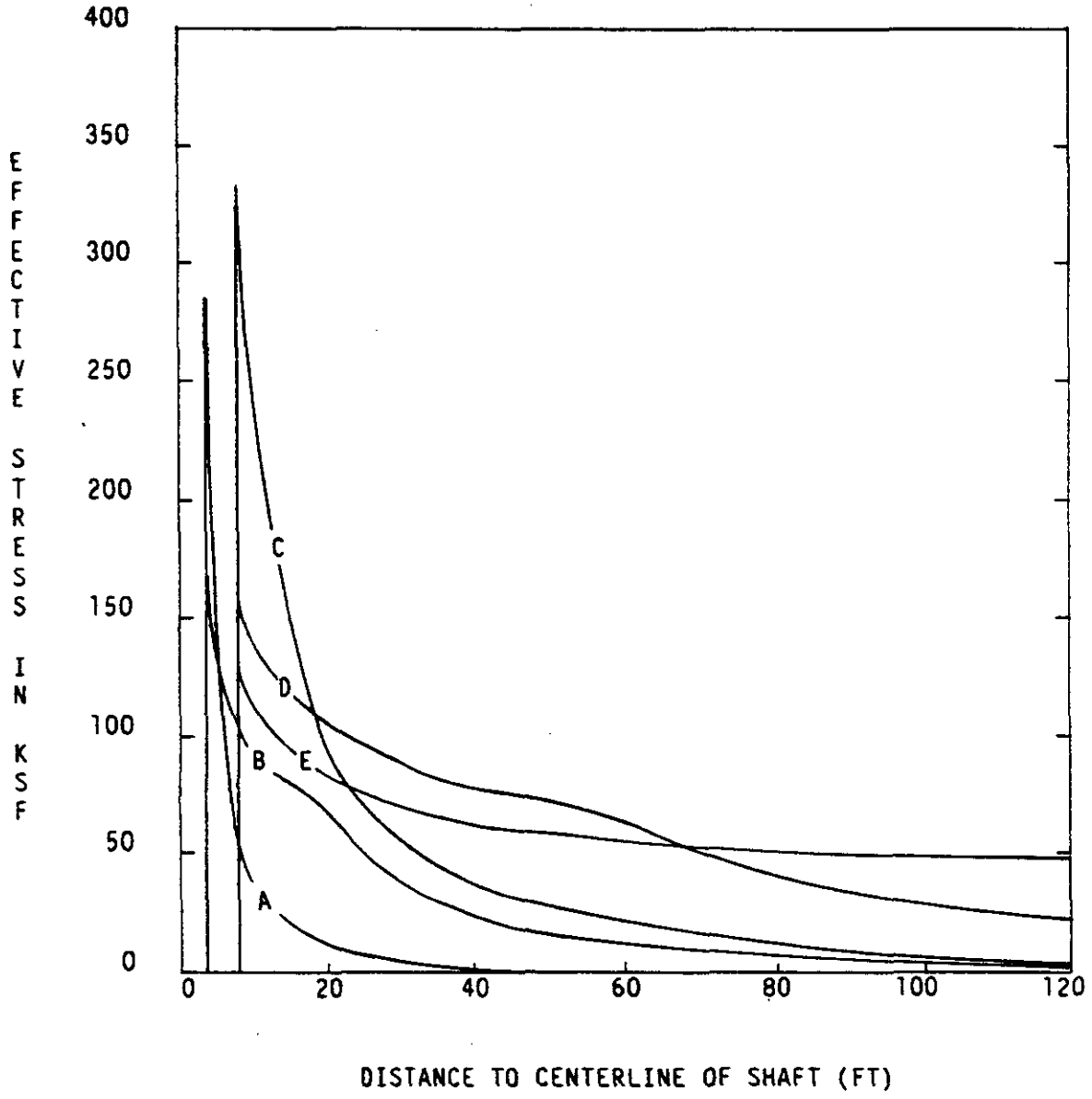

A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-7

EXHAUST SHAFT UNLINED SECTION
EFFECTIVE STRESS DISTRIBUTION AT ELEVATION 1343 FEET

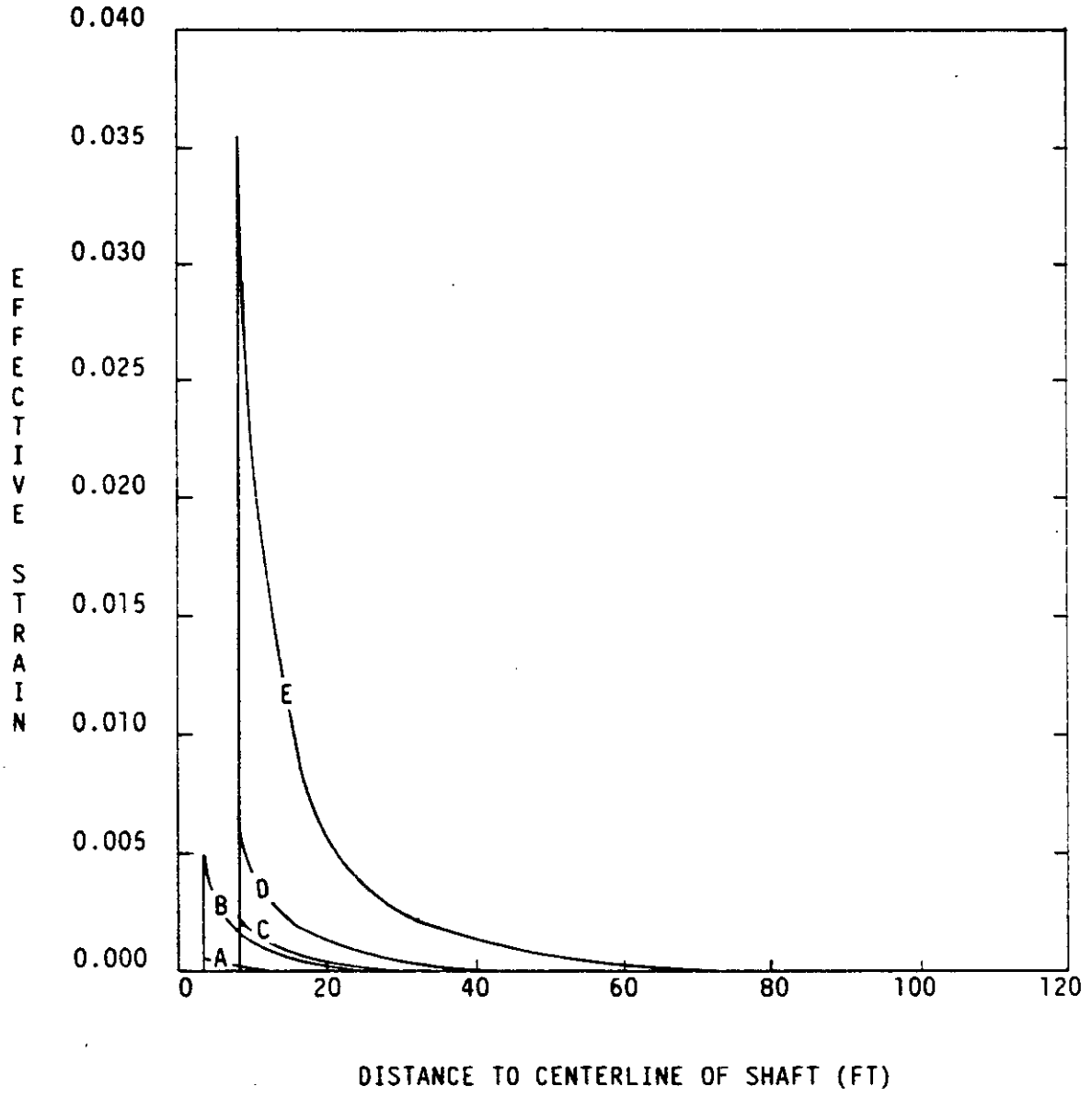

A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-8

EXHAUST SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1343 FEET

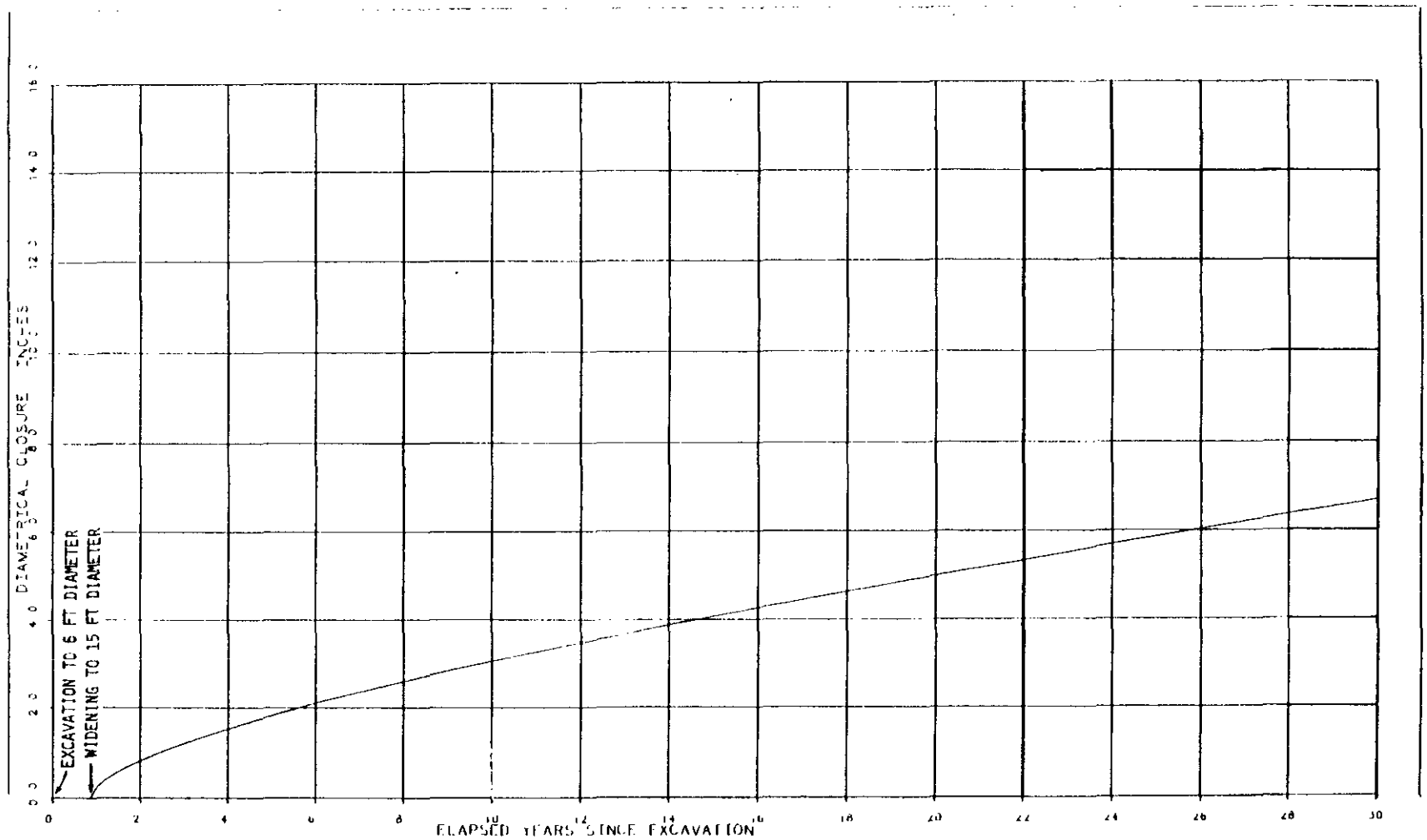

Figure 9-9

EXHAUST SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1343 FEET

exhaust shaft design as they pertain to the design elements identified in Section 9.2. These design elements stipulate the requirements that the exhaust shaft must meet in terms of shaft stability, deformation, water pressure and water control. Other conclusions and recommendations that are a product of the design validation process are also presented.

9.4.1 Conclusions

The stability of the exhaust shaft has been evaluated using analytical calculations, finite element modeling and analysis of data from the C & SH and waste shafts. The conclusions regarding shaft stability are the same as those for the waste shaft. The water pressure exerted on the shaft liner is currently less than the design hydrostatic pressure. If the hydrostatic pressure increases to its design limit, the liner will remain stable because its pressure capacity exceeds the design hydrostatic pressure by a factor greater than two. The cracks in the liner are not expected to result in any structural instability.

Analytical results show that the lateral pressure on the shaft key at the end of the 25-year operating life will be approximately 72 ksf. Although this pressure exceeds the design basis lateral pressure of 60 ksf, the allowable lateral pressure on the key is 154 ksf, or more than twice the predicted lateral pressure at 25 years. This provides a sufficient margin of safety against failure. If concrete shrinkage and creep were taken into account in the analysis, the margin of safety would be even greater.

The analytical results also show the redistribution of stresses around the unlined section of the shaft due to the effects of salt creep. Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases and the stress arch around the opening migrates away with time. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability problem in the unlined

section of the shaft. The analysis shows the locations of effective creep strain concentrations at different times around the opening in the unlined section. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, the exhaust shaft will remain structurally stable within the limits required for safety during its operating life.

The analysis also predicts that the maximum diametric closure in the unlined section at the end of the operating period will be approximately 6 inches. Based on the predicted deformations and closures, the exhaust shaft will meet the requirements stated in the design criteria. The design basis requirement that the 15-foot diameter unlined section allow for salt creep over its operating life will be met.

As in the waste shaft, water is entering the exhaust shaft through cracks and construction joints in the concrete liner. The amount of water seepage was greatly reduced by grouting conducted after construction. The small amount of water still reaching the open shaft quickly evaporates in the upcast flow of exhaust air. While the exhaust fans are operating, no water reaches the underground facility level. The water seals behind the shaft concrete key appear to be functioning as intended at the bottom of the key. No water is seeping from the concrete/salt interface. There is no evidence of salt dissolution behind the key.

The reference design for the exhaust shaft has been validated in accordance with the objectives of the design validation program, based on the analyses, evaluations and predictions of future behavior presented in this chapter. With one exception, the exhaust shaft reference design complies with the design criteria and the design bases. The criterion that the liner shall prevent ground-water flow into the shaft has not been met. However, the water currently seeping into the shaft is not considered to be detrimental to shaft stability or function. No modifications to the exhaust shaft reference design are required.

9.4.2 Recommendations

Based on the results of design validation, recommendations similar to those for the waste shaft are made for the exhaust shaft:

(1) Validation of the exhaust shaft key and unlined section relied on analysis and modeling using in situ data from the C & SH and waste shafts. It is recommended that the numerical modeling be repeated, prior to the first receipt of waste, using in situ data from the exhaust shaft instruments. This analysis should be repeated periodically for the comparison of in situ data against design parameters.

(2) The exhaust shaft should be inspected by qualified personnel at regularly scheduled intervals. The liner should be inspected for renewed seepage and grouting performed if an amount of water considered sufficient to affect the liner's stability or functional purpose is observed. The key should be inspected for water seeping from behind the key at its base. If any is detected, grout should be injected above the top water seal. Grout should not be placed behind the key below the top seal. If this cannot be avoided, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the requirements of the Plugging and Sealing Program.

CHAPTER 10

DRIFTS

10.1 INTRODUCTION

This chapter presents the results of validation of the reference design for the underground drifts. Discussions are presented on the reference design, data collected from the openings, its analysis and evaluation, and predictions of future behavior. Conclusions and recommendations pertaining to the reference design are presented based on the results of the validation process.

The term drifts includes all horizontal underground openings except the shaft stations, test rooms, and storage area rooms and their associated drifts. Discussions of the shaft stations are presented in Chapters 7 and 8. Discussions of the test rooms, storage rooms and storage area drifts are presented in Chapters 11 and 12.

The largest drifts planned for the underground facility were initially excavated 8 feet high and 25 feet wide. These drifts have been or will be enlarged to 12 feet high. The present 12-foot high, 25-foot wide drifts were excavated earlier than most of the smaller drifts and, therefore, have the longest history of in situ data collection. Because these 12 x 25-foot drifts are the largest to be excavated, they also have the most critical dimensions. Consequently, the analyses, evaluations and predictions are based primarily on these larger drifts. The smaller drifts and rooms are, therefore, considered to be validated as a result of the validation of the larger 12 x 25-foot drift reference design.

10.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design of the drifts.

10.2.1 Design Criteria

The design criteria established for the design of the WIPP underground facility are discussed in Chapter 2 and summarized in Table 2-1. Table 2-1 presents the major criteria affecting underground design, including such items as waste receipt rate, type of waste, backfill requirement, etc. Those criteria requiring evaluation of their suitability for design validation are indicated in Table 2-1. The remaining criteria contained in the Design Criteria document (ref. 2-7) do not require evaluation.

Three of the indicated criteria pertain directly to the drift reference design. The first criterion states that the underground openings shall be designed to provide structurally stable excavations and pillars. "Stable" is defined in the criteria document to mean that deformations of excavations and pillars are to remain within the limits required for structural function, ventilation and safety. The second criterion states that the underground opening reference design shall provide maximum stability for the excavated rooms and drifts. The third criterion stipulates that the underground excavation shall be designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening. Not only are these criteria to be evaluated for their suitability, but the reference design configurations based on them must also be evaluated. These reference design configurations were discussed in Chapter 3.

10.2.2 Design Bases

The design bases comprise the second level of the design documents. They outline specific design requirements that were followed in designing the final drift configurations. Only those design bases that apply directly to the underground drift configurations are discussed in this subsection. The Design Basis, Underground Excavations (refs. 2-9 and 2-18), Design Basis, Underground Shops and Facilities (ref. 2-20), and Design Basis, Geomechanical Instrumentation (ref. 2-17) should be referred to for details of the appropriate design bases used for the underground drifts. None of these design bases contained elements

pertaining specifically to the drifts that required evaluation during the validation program. Those bases that required evaluation for validation pertain only to the storage area drifts and are discussed in Chapter 12.

The design bases specify that excavation within the shaft pillar area shall be the minimum required to meet the operational and safety requirements of the waste storage level. The area extraction ratio was, therefore, kept below 15 percent in this area.

The maximum tolerance for excavation of the roof, floor and walls shall be plus six inches. In no case shall the finished dimensions be less than those specified by the design. The minimum vertical dimension for equipment clearances used to meet this basis was 11 feet.

Supports for underground workings shall comply with Federal and New Mexico codes. The use of rock bolts and wire mesh in specific areas shall be determined by mine conditions and code requirements. Entry roofs, walls and floors shall be checked periodically for loose salt in accordance with applicable codes. Methods of locating gas or brine accumulations shall be implemented, such as drilling holes ahead of the excavation and testing for the presence of gas.

A geomechanical instrumentation system shall be installed to provide in situ measurement data for design verification or modification and for subsequent operational planning. In addition, the instrumentation system shall monitor stress change, closure and creep to provide a record of the structural stability of the drifts and to provide early warning of abnormal conditions for operational safety.

Deformation measurements in the drifts shall be measured as a function of horizontal and vertical closure. Salt creep and stress distributions around the drifts and at intersections shall also be measured.

The instrumentation shall provide the primary detection of changes in structural behavior. Visual observations shall follow any detected abnormal strain, pressure or deformation for evaluation of the safety of the underground working places. In addition, a program shall be provided for periodic visual inspection of all underground working places.

10.3 DESIGN VALIDATION PROCESS

Validation of the reference design of the underground drifts includes the collection of data and the presentation of results based on its analysis and evaluation. The results of the design validation process are used to present conclusions regarding the compatibility of the design criteria, design bases and design configurations, and recommendations for modifications, if any. This section presents the data collected and predictions of future drift behavior based on analysis and evaluation of the data.

10.3.1 Data Collection

Data pertaining to the underground drifts was collected from various sources. Geologic data was acquired from geologic mapping and core drilling. These data verified the stratigraphic continuity at the facility level and are discussed in detail in Chapter 6. Data were also acquired from periodic visual inspections and from geomechanical instrumentation. Collection of these data are described in the following subsections.

10.3.1.1 Field Observations

Various aspects of underground behavior are evaluated by qualitative observations and documentation. Visual inspections of the drifts include observations of their general surface conditions in response to stress redistribution and creep. These conditions include shallow spalls from the roof and walls, especially at their intersection; and vertical fracturing in the pillars, both at corners and parallel to the walls. In addition to visual inspections, other techniques are used. Boreholes are surveyed using video cameras and displacements,

separations and fracturing of geologic strata surrounding the boreholes are detected using a simple probe. Surveys of underground conditions have been performed at least once every 3 months. Each survey is documented in a GFDR beginning with the February 1984 edition (refs. 4-12 through 4-19).

Recently, a special program was conducted to determine the effect of excavation induced deformation on the salt strata surrounding the facility level. An array of boreholes was drilled into the roof and floor at 30 locations in the drifts and test rooms during May through July 1986. These arrays are shown on Figure 10-1. These boreholes were used to locate separations and fractures in the halite and anhydrite near the horizontal underground openings. This Excavation Effects Program was instigated after the discovery of significant fracturing beneath the southern half of Test Room 3 (Room T). The objectives of this excavation effects study were to determine if fracturing of this magnitude has occurred anywhere else and to investigate existing conditions at selected localities throughout the facility.

The documented field observations can be separated into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor displacements, separations and fracturing.

Roof and Wall Spalling. During and immediately after excavation, a sounding survey of the roofs of all drifts was performed. Each survey identified areas of potential instability, such as drummy or slabby salt. Remedial work was accomplished immediately and included scaling, additional excavation, or rock bolting. Comprehensive sounding surveys were also performed in every underground opening in July 1983 and November 1984. The behavior of the roof and walls is documented in the table entitled "Condition of Roof and Walls" in each GFDR.

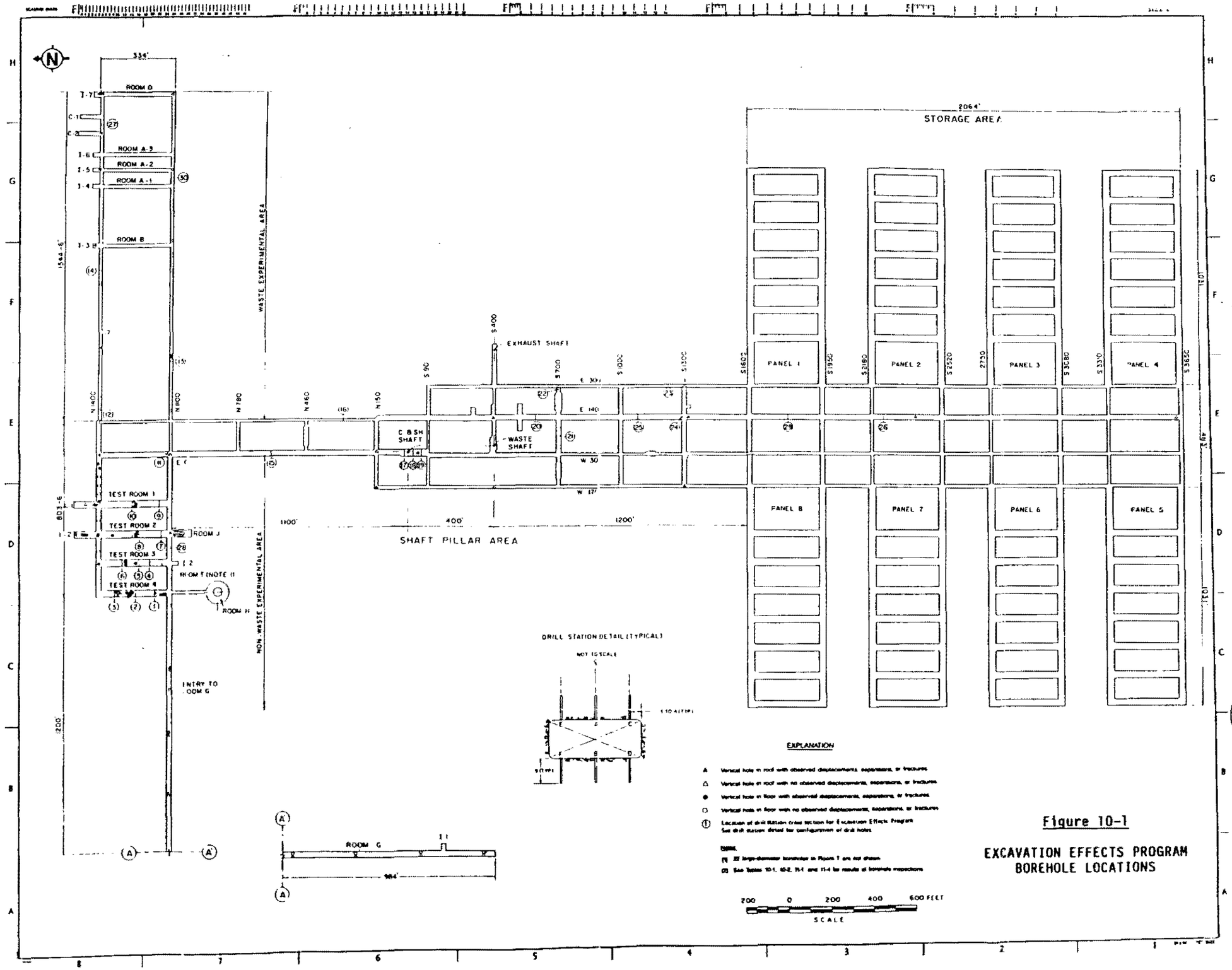

Figure 10-1

EXCAVATION EFFECTS PROGRAM
BOREHOLE LOCATIONS

Pillar Fracturing. Vertical fractures have developed in the corners formed by drift intersections. These fractures began appearing about 3 to 6 months after excavation. Site geologists have monitored the growth of these fractures and have included their observations in the GFDRs.

Vertical fractures parallel to the drift walls have been detected in several horizontal boreholes. These fractures were not present at the time of drilling. They were first observed in May 1986 and occur within 1 to 2 feet of the wall surface.

Roof Displacements and Separations. Horizontal displacements and vertical separations have been detected in some open boreholes in the drifts during the past 2 years. Periodic inspections of all accessible boreholes in the drifts have been made since September 1985. The results of these inspections in the roof holes are presented in Table 10-1.

Visual inspections were conducted directly or remotely using a video camera and/or probe. The probe used was described in Chapter 7, subsection 7.3.1.4. Depths to displacements and separations were measured with a tape measure. Relative horizontal displacements were measured where possible or estimated.

The recently conducted Excavation Effects Program consisted of drilling numerous arrays of 1 7/8-inch and 3-inch diameter holes at selected locations along the drifts (Figure 10-1). The holes were drilled approximately 9 feet into the roof and floor and inspected using a probe. The results of the inspection of these holes are presented in Table 10-2.

The N1100 and N1420 drifts were excavated eastward to E1680 in early 1984. These drifts incline upward to the experimental area. The roofs of both drifts intersect anhydrite beds "a" and "b". Slabby rock at the intersection was removed by the mining machine and rock bolts

Table 10-1

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-01	2-10-84	3	50.8	N1424/E439.5	None
DH-03	2-7-84	3	48.8	N1112/E444	D
DH-03A	3-12-84	3	49.9	N1112/E450.5	D
DH-05	3-9-84	3	51.0	N1463/E972	D
DH-07	2-22-84	3	49.8	N1112/E976.5	None
DH-09	3-14-84	3	51.1	N1432/E1332.5	None
DH-11	3-6-84	3	50.9	N1112/E1332.5	None
DH-13	3-28-84	3	13.8	N1424/E1690	D, S
DH-13A	3-29-84	3	49.0	N1425/E1691	D, S
DH-13B	4-5-84	3	21.0	N1425/E1695	D, S
DH-15	3-21-84	3	51.0	N1104/E1688.5	None
DH-17	1-19-84	3	52.0	N1104/E1688	None
DH-19	1-21-84	3	51.6	N1107/E206.5	None
DH-21	2-27-84	3	50.4	N1421/E786	None
DH-23	2-15-84	3	51.0	N1112/E781	None
DH-25	3-30-84	3	51.8	N1422/E1510	D, S
DH-27	7-27-84	3.5	50.5	N1107/W682	None
DH-29	7-25-84	3.5	50.4	N1099/W982	None
DH-29A	9-12-84	3.5	35.0	N1099/W987	None
DH-31	7-19-84	3.5	50.5	N1099/W1282	None

* D = displacement; S = separation; F = fracturing

Table 10-1 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-31A	7-24-84	3.5	49.2	N1099/W1280	None
DH-31B	9-12-84	3.5	4.9	N1099/W1261	None
DH-33	7-18-84	3.5	50.5	N1099/W1582	None
DH-33A	9-13-84	3.5	4.1	N1099/W1570	None
DH-35	1-27-85	3.5	52.0	N1102/W1882	None
DH-37	1-26-85	3.5	51.5	N1101/W2182	None
DH-39	1-24-85	3.5	50.7	N1101/W2482	None
DH-41	1-24-85	3.5	49.9	N1101/W2782	None
DH-205	2-18-83	3	50.7	N1410/E0	None
DH-211	12-19-82	3	50.0	S1320/E163	None
DH-219	1-14-83	3	51.0	S2422/E162	None
DH-227	1-28-83	3	51.7	S3656/E147	None
DH-301	8-30-84	3.5	50.8	N150/W170	D
DH-303	9-4-84	3.5	51.4	S400/W170	None
DH-313	7-10-84	3	19.6	S1300/E300	None
DH-313A	7-12-84	3	50.2	S1300/E299	None
DH-315	9-6-84	3.5	50.3	S1300/W170	D
DH-317	7-6-84	3	50.1	S1600/W33	None
DH-317A	7-6-84	3	5.0	S1600/W30	None
DH-317B	9-7-84	3.5	51.0	S1597/W30	None
DH-319	9-10-85	3.5	51.1	S700/E300	None

Table 10-1 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
OH-2	8-83	4	20	S410/E147	None
OH-3	8-83	4	20	Room 2 centerline	S, F
OH-4	8-83	4	20	N1110/W365	S
OH-6	8-83	4	20	N1110/W5	None
OH-7	8-83	4	20	S70/E0	D, S, F
OH-8	8-83	4	20	N140/E0	None
OH-9	2-84	4	15.4	N1433/W232	S, F
OH-10	2-84	4	21.0	N1420/W218	D
OH-11	2-84	4	19.7	N1433/W365	None
-	-	5	10	Room L1 centerline	None
L2PU-02	-	5	9.2	Room L2 centerline	None

Table 10-2

EXCAVATION EFFECTS PROGRAM

BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (HxW-FT)	EXCAVATION - DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
11	12x25	2/83 (FLOOR LOWERED 4 FT 12/83)	N110, W02	5/30/86	6/02/86	C	NONE	C (POSSIBLY CLAY G)	C	S, C	C
12	12x14	2/83	N1430, E140	6/05/86	6/10/86	S, C	C	C	S, C	S	S(?), C
13	8x14	1/84	N110, E439	6/20/86	6/30/86	D *	NONE	NONE	NONE	NONE	NONE
14	12x14	2/84	N1430, E875	6/06/86	6/10/86	S	S(?)	S	S(?)	C	S(?)
15	12x25	2/83 (FLOOR LOWERED 4 FT 12/83)	N626, W02	6/20/86	6/30/86	NONE	C	S, C	C	S, C	C
16	8x14	2/83	N305, E147	7/15/86	7/18/86	NO ROOF HOLES			NONE	C	C
17	12x32	10/82	C&SH SHAFT STATION - N028	5/30/86	6/02/86	C	NONE	F	NONE	S, F	NONE
18	17x35	6/82	C&SH SHAFT STATION - S024	6/04/86	6/04/86	C	S, F	F	S	NONE	S
19	15x35	6/82	C&SH SHAFT STATION - S056	6/03/86	6/04/86	F, C	F	F	F, C	C	C
20	14x25	12/82 (FLOOR LOWERED 5/84)	S592, E155	7/10/86	7/11/86	NONE	NONE	NONE	S, C	NONE	NONE
--	15x35	6/82	C&SH SHAFT STATION - ELECTRICAL SUBSTATION	6/05/86	6/06/86					X S, C	Y S, C
21	12x20	7/85	S700, E66	7/08/86	7/09/86	NONE	NONE	NONE	NONE	S	C (POSSIBLY CLAY E)
22	12x14	5/84; 7/84	S700, E300	7/08/86	7/09/86	NONE	NONE	NONE	C	NONE	NONE
23	12x14	7/84	S1190, E229	7/09/86	7/10/86	NONE	NONE	C	NONE	C	C
24	12x20	12/82; 6/85; 6/84	S1300, E155	7/09/86	7/10/86	NONE	NONE	NONE	NONE	NONE	NONE

Table 10-2 (continued)

EXCAVATION EFFECTS PROGRAM

BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (HxW-FT)	EXCAVATION DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
25	12x25	12/82 (FLOOR LOWERED 5/84)	S1129, E155	7/9/86	7/10/86	NONE	NONE	NONE	C	C	C
26	8x25	1/83	** S2205, E154	7/16/86	7/18/86	NO ROOF HOLES			NONE	NONE	C
27	12x14	3/84	** N1430, E1555	7/11/86	7/18/86	NO ROOF HOLES			NONE	NONE	C
28	12x20	3/83 (FLOOR LOWERED 4/83)	** N110, W432	7/16/86	7/18/86	NONE	NO HOLE	NONE	NONE	NO HOLE	C
29	12x25	12/82 (FLOOR LOWERED 11/85)	** S1700, E155	7/10/86	7/11/86	C	NONE	NONE	NO FLOOR HOLES		
30	8x14	2/84	** N110, E1303	7/11/86	7/18/86	C	NO HOLE	NONE	C	NO HOLE	NONE

* EXISTING HOLE.
** LOCATION APPROXIMATE. NOT SURVEYED.

EXPLANATION

D = HORIZONTAL DISPLACEMENT. FOUND ONLY IN PREVIOUSLY DRILLED HOLES. DISPLACEMENT APPEARS TO DEVELOP WITH TIME FOLLOWING HOLE DRILLING.

S = VERTICAL SEPARATION. PROBE NAIL PENETRATES HOLE WALL SURFACE. VERTICAL SEPARATIONS RANGE FROM APPROXIMATELY 1/16 INCH TO 6 INCHES.

F = FRACTURE ZONE. PIECES OF HALITE COMMONLY PICKED OUT OF ZONE BY PROBE NAIL.

C = PROBE NAIL CATCHES ON HOLE WALL SURFACE BUT DOES NOT PENETRATE. INDICATES POSSIBLE SEPARATION OF LESS THAN 1/16 INCH. OCCURENCES AT KNOWN CLAY LAYERS ARE NOT INDICATIVE OF SEPARATION AND ARE NOT INCLUDED IN THIS TABLE.

NOTES:

1. SECTION LOCATIONS AND HOLE CONFIGURATIONS ARE SHOWN ON FIGURE 10-1.
2. HOLES WERE DRILLED VERTICALLY USING A JACK-LEG DRILL.
3. NOMINAL HOLE DEPTH IS 9 FEET BUT SOME HOLES ARE SHORTER DUE TO LOW DRIFT ROOF OR DRILLING DIFFICULTIES.
4. ONE ROOF AND ONE FLOOR HOLE OF EACH ARRAY WERE GENERALLY DRILLED 3 INCHES IN DIAMETER TO ACCOMODATE USE OF BOREHOLE CAMERA IF DESIRED. OTHER HOLES WERE DRILLED 1-7/8 INCHES IN DIAMETER. EXISTING HOLES WERE USED WHERE POSSIBLE.
5. OBSERVATIONS WERE MADE USING A PROBE CONSISTING OF A NAIL ATTACHED PERPENDICULAR TO THE END OF A ROD.
6. HOLES AT SECTION 13 WERE DRILLED TO ONLY 6- OR 6.5-FT DEPTH DUE TO LOW DRIFT ROOF. NO ROOF HOLES WERE DRILLED AT SECTIONS 16 OR 26 DUE TO LOW DRIFT ROOF.
7. POSSIBLE SEPARATIONS IN FLOOR HOLES AT SECTION 25 ARE PROBABLY AT CLAY E.

and wire mesh were installed. Several fractures in the roof brow at these anhydrites have been observed.

A portion of the N140 crosscut between W170 and E140 has been excavated above clay G. An inspection of this area in June 1986 showed some minor vertical separation, on the order of 1/8 inch, as well as some squeezing out of clay G. No fractures in the underlying halite were observed.

Floor Displacements, Separations and Fracturing. Fracturing has developed beneath the floor in some locations. These fractures occur in the halite above MB-139 and sometimes extend into MB-139. The most prominent fracturing at present is beneath Test Room 3, as discussed in Chapter 11.

As with the roof boreholes, observations were accomplished using both video equipment and a probe. The results of floor hole inspections conducted through July 1986 in accessible boreholes are presented in Table 10-3. Results of the Excavation Effects Program are included in Table 10-2.

10.3.1.2 Geomechanical Instrumentation

An extensive system of geomechanical instruments has been installed in the underground drifts (Figure 10-2) to provide in situ data on the deformational behavior of these openings. The majority of the instruments were installed during the SPDV Program and therefore have been monitored for over three years. Additional instrumentation was installed after the SPDV program was completed.

Instrumentation in the drifts consists of radial convergence points and multiple-point borehole extensometers. The convergence points consist of pairs of eyebolts anchored in the salt of the roof, floor and walls of the drifts as well as at corners of intersections. The closure of the opening is measured between a pair of convergence points using a tape extensometer. The borehole extensometers are the sonic-probe type

Table 10-3

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOORS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-36	1-26-85	3.5	51.5	N1102/W1882	None
DH-38	1-26-85	3.5	47.5	N1101/W2182	None
DH-40	1-25-85	3.5	51.0	N1101/W2482	None
DH-42	1-23-85	3.5	51.2	N1101/W2782	None
DH-42A	1-25-85	3.5	40.5	N1101/W2789	None
DH-228	1-28-83	3	50.4	S3656/E147	None
OH-13	2-84	4	9.5	N1433/W232	S, F
OH-14	2-84	4	9.7	N1433/W365	D, S, F
JV-01	9-85	36	8	Room J	None
JV-02	9-85	36	8	Room J	None
JV-03	9-85	36	8	Room J	None
JV-04	9-85	36	8	Room J	None
JV-05	9-85	36	8	Room J	None
JV-06	9-85	36	8	Room J	None
JV-07	9-85	36	8	Room J	None
JV-08	9-85	36	8	Room J	F
JV-09	9-85	36	8	Room J	None
L2X-01	1-85	30	12	Room L2	None
L2PD-01	-	5	13.0	Room L2 centerline	D, S, F
-	-	5	11.3	Room L2 centerline	S, F

* D = displacement; S = separation; F = fracturing

Table 10-3 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOORS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
-	-	16	10.3	Room L2 centerline	D, S
NPD-03	1-86	5	9.3	N1420, east of Test Room 1	None
NPD-04	1-86	5	9.5	N1420, east of Test Room 1	None
NPD-05	1-86	5	9.6	N1420/Room L1	None
NPD-06	1-86	5	9.5	N1420/Room L1	None
NPD-07	1-86	5	9.0	N1420/Room L2	S, F
NPD-08	1-86	5	12.0	N1420, east of Test Room 1	S
NPD-11	1-86	5	8.9	N1420, between Test Rooms 2 and 3	None
NPD-12	1-86	5	9.0	N1420, between Rooms L1 and L2	None

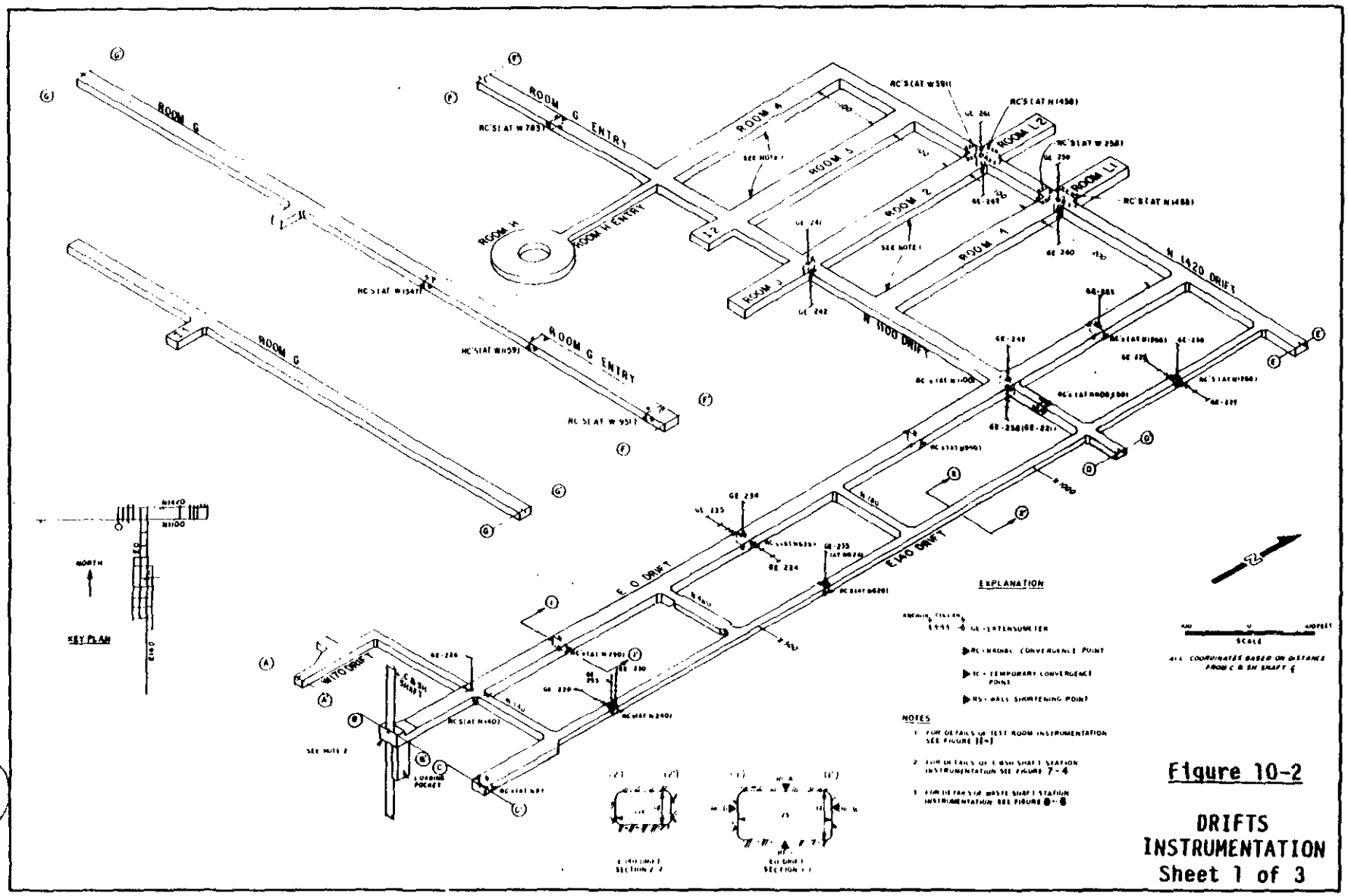

Figure 10-2

DRIFTS INSTRUMENTATION Sheet 1 of 3

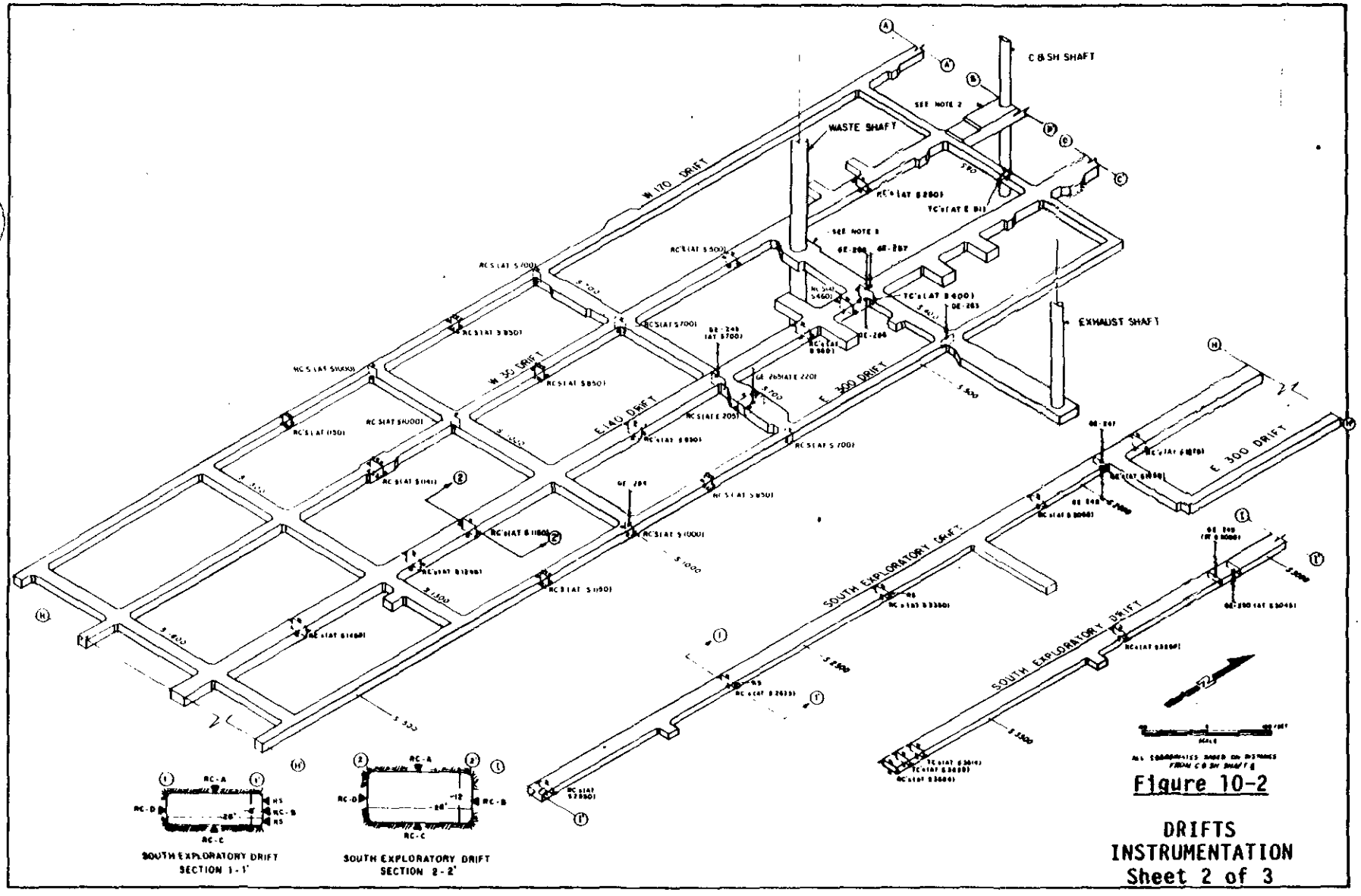

Figure 10-2

DRIFTS
INSTRUMENTATION
Sheet 2 of 3

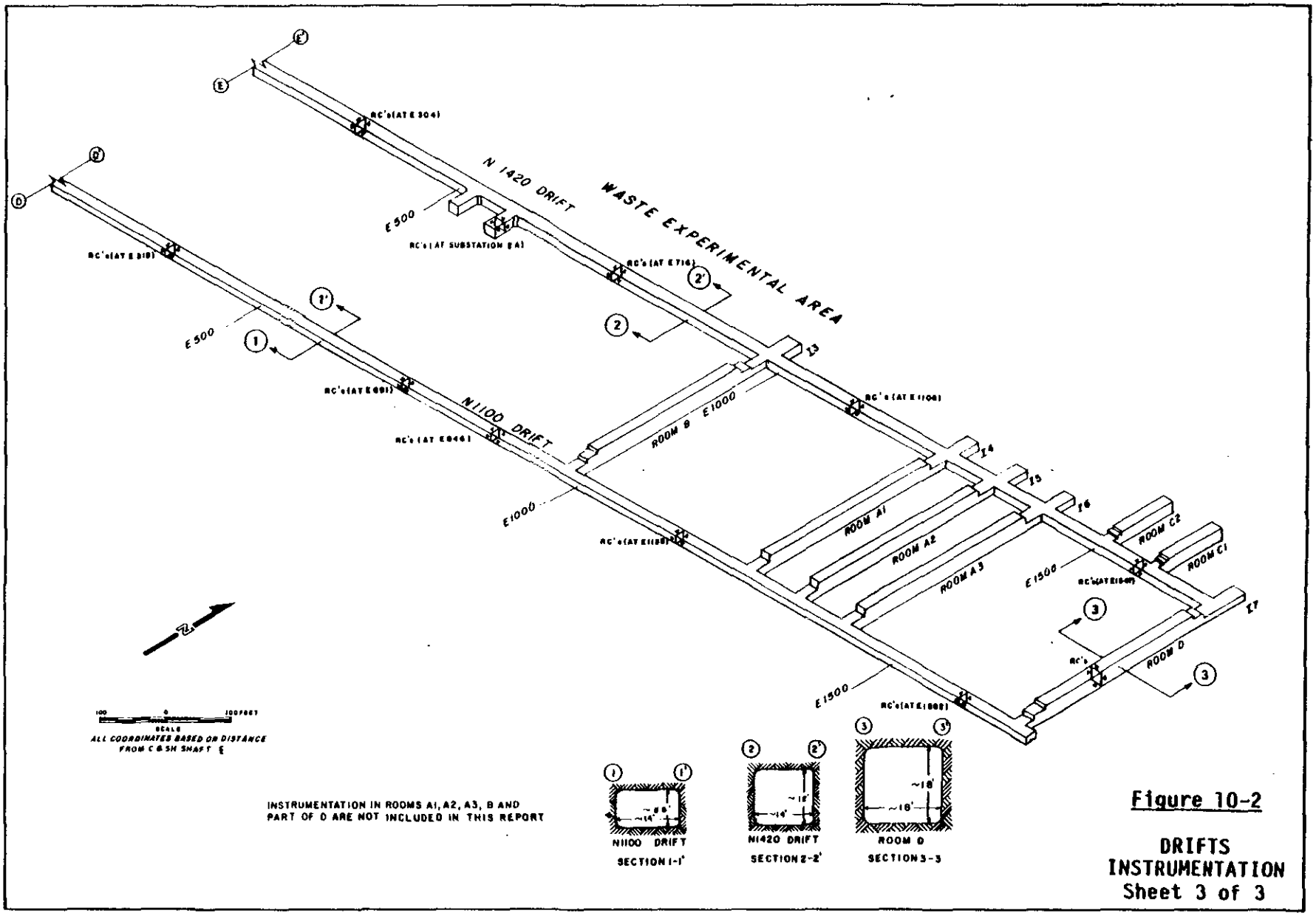

Figure 10-2

DRIFTS INSTRUMENTATION Sheet 3 of 3

with stainless steel anchor rods and expansion-ring anchors. Two-anchor, four-anchor and five-anchor extensometers have been installed. Anchor depths vary with locality and site-specific stratigraphy. Recent data plots for the drift instruments are presented in Appendix J.

No stressmeters were installed in either the halite or anhydrite surrounding the drift openings. A program to develop reliable stressmeters for use in halite was begun but abandoned when other WIPP participants initiated similar programs. The results of their programs indicate that measurements using modified stressmeters are not yet sufficiently reliable to be considered for design validation. Therefore, numerical modeling was relied upon to analyze stress changes with time in the halite and anhydrite around the openings. The reliability of the readings from the two stressmeters installed in MB-139 beneath Test Room 2 is discussed in Chapter 11.

The underground instrumentation system has had a complex history. All extensometers have been reset at least once because salt creep moved the anchor-rod magnets beyond the initial 2-inch measurement limit. Convergence points were frequently damaged by construction activities and were regularly replaced. Extensometers were also damaged during construction; some were replaced and others were abandoned. The operational history of the instruments is presented in each issue of the GFDRs.

10.3.2 Analysis and Evaluation

The in situ data collected and observations made during the design validation process were analyzed and evaluated to determine the effects of salt behavior on the drift excavations. Closure data were analyzed and a model simulation was performed for a typical 8 x 25-foot wide drift. An option for lowering the floor 5 feet was incorporated into the model for subsequent analysis of the drifts in the storage area. The results of the analysis of the larger drifts are presented in Chapter 12.

10.3.2.1 Observed Conditions

Evaluation of observed conditions is a qualitative process. It represents the assessment of qualified geologists and engineers and is an important component of the analysis and evaluation of measured responses and structural calculations.

Roof and Wall Spalling. Changes in roof and wall conditions occur slowly. Drummy areas detected during the original soundings have not enlarged significantly. These drummy areas occur in clear halite and are not associated with any noticeable clay deposits. Separations occur along planes of weakness, probably created by the orientation of crystal faces. Few new slabby areas have developed. For an unknown reason, more slabby areas developed in the roof of the E140 drift south of the waste shaft during excavation than in any other underground area. These areas have shown little, if any, growth.

Wall spalling is even more subdued. The most noticeable spalling occurs in the argillaceous halite unit and associated clay seam (geologic map unit 4 and clay F) near the intersection of the wall and roof. This area has exhibited slowly deteriorating conditions and requires occasional scaling. This spalling of map unit 4 and the squeezing out of associated clay F is most noticeable in the N1420 drift north of the test rooms and along the E140 drift south of the waste shaft. Spalling results from room closure and is related to the percentage of argillaceous material in the halite and to the proximity of the roof intersection. Similar behavior associated with anhydrite "b", anhydrite "a" and clay I has been observed in the walls of the drifts and test rooms in the waste experimental area. Some minor squeezing of clay G, clay H and clay I has occurred where these clays are exposed along drift walls. Relative motion along these clays similar to clay F is exhibited by the lower section of the wall moving into the excavation relative to the upper section. Some spalling of map unit 0 has also been noted along the E140 drift south of approximately S2500.

Pillar Fracturing. The vertical fractures that have developed in the pillar corners occur throughout the underground facility. They are particularly prominent in corners that were not beveled during excavation. The fractures range in width from closed to about 2 inches and extend into the salt essentially perpendicular to the surface.

The fractures grow steadily with time as the halite responds to deformation around the opening. Pillar corner fractures are the most obvious manifestation of pillar shortening in the drifts and rooms. These fractures will continue to grow and the corners will continue to deteriorate, with increasing spalling as a result. This behavior is expected and poses no stability problems, but it will require monitoring and maintenance throughout the operating life of the facility.

Vertical fractures have developed in the walls of the drifts parallel to the longitudinal drift axis. The fracture openings range from closed to 1/16 inch in width. The fractures have been detected in some boreholes where they occur within 2 feet of the wall surface. This type of fracturing is typical of underground excavations and probably represents tension fractures developed due to stress relief.

Roof Displacements and Separations. Clay G and clay H, above the roof of the facility level drifts, and clay I, above the roof of the drifts in the experimental area, have exhibited displacements and separations. Table 10-1 presents the results of observations made through July 1986 in 58 open boreholes. Twenty of these holes exhibited positive evidence of the occurrence of displacements and/or separations. Sixteen of these holes are at intersections. The vertical separations range from closed to 1/4 inch in width, and the horizontal displacements are up to 1 inch wide.

An additional 32 holes in 11 arrays were drilled in the roof at various facility level drift locations during the Excavation Effects Program (Figure 10-1). Of these, four arrays were drilled at intersections. Three additional arrays were drilled in the roof of drifts in the waste experimental area.

Inspection of the recently drilled holes using a probe indicate that minimal separation has occurred at the intersections and along the drifts. The size of the opening as well as the elapsed time since its excavation do not appear to have a significant effect on this phenomenon. Although the E140 drift south of the waste shaft was excavated early in construction and has the largest opening dimensions (12 x 25 feet), only minimal separations, less than 1/16 inch wide, were detected.

No separations were detected at clay G in the drift hole arrays, and the separations in the halite were usually less than 1/16 inch. There appears to be about 1/8 inch of separation at clay I in the array at E875 in the N1420 drift. This is consistent with observations made in previously drilled holes in the waste experimental area.

The observed displacements and separations immediately above the facility drifts appear to be normal deformational behavior. As the deviatoric stress around the underground openings increases following excavation, the surrounding salt will deform. The clay seams are zones of weakness that provide slip planes for salt movement during lateral loading. Movement is generally represented by the halite section below the clay seams moving into the excavation relative to the section above.

Floor Displacements, Separations and Fracturing. Minor displacements, separations and fracturing have occurred beneath the floor of the drifts. Table 10-3 presents the results of observations made in 34 open boreholes through July 1986. Ten of these holes exhibited displacements, separations or fracturing. Displacements up to 3/4 inch wide and separations up to 1/2 inch wide have been observed in boreholes at the intersection of Test Room 1 and Room L1, as well as at the intersection of Test Room 2 and Room L2. These are large, four-way intersections with 20 x 33-foot dimensions. Some displacements, separations and fracturing were also detected in three open boreholes in Room L2. Only two holes in the N1420 drift east of Test Room 1 exhibited separations, less than 1/8 inch wide. No other separations

have been detected in any other open boreholes in the N1420 drift or Room G. Only closed fractures were observed in the 30-inch diameter hole (L2X-01) in Room L2 (Figure 10-3). These fractures, many coated with clay, appeared to have originated prior to room excavation.

Nine small-diameter holes were drilled in the floor of the 35-foot wide S700 crosscut and inspected using a probe. These holes were drilled to determine the depth to MB-139 as well as to determine if any fractures were present. Fracture zones up to 1 inch wide were encountered in two locations in the halite above MB-139. Only one borehole contained a hairline fracture within MB-139.

During September 1985, nine 36-inch diameter holes were drilled in the floor of Room J, a 33-foot wide room, to accommodate structural steel columns. Only one near-horizontal fracture, less than 1/32 inch wide, was encountered in the halite above MB-139 in hole JV-8. No fractures were found in the other holes in Room J.

One fracture has been detected in the floor of the E140 drift south of the waste shaft. This fracture was observed while the drift was being enlarged from 8 feet to 12 feet high from April through June 1984. The fracture was about 18 inches below the original floor in halite and extended from approximately S1859 to S1871. Separation ranged from 1/16 inch to 1/2 inch and was associated with some clay. It curved upwards toward the floor at its northern and southern limits.

The results of the Excavation Effects Program indicate that minimal separations occur beneath the floor of the drifts and intersections. As determined from the roof holes, the size of the opening and elapsed time since excavation do not appear to have any effect on the occurrence of separations in the salt beneath the floor. No fracture zones were detected in any of the holes and separations where encountered, ranged from less than 1/16 inch to 1/8 inch wide. As with the older open boreholes, the Excavation Effects Program holes show evidence of separations within MB-139, at clay E and in the overlying halite.

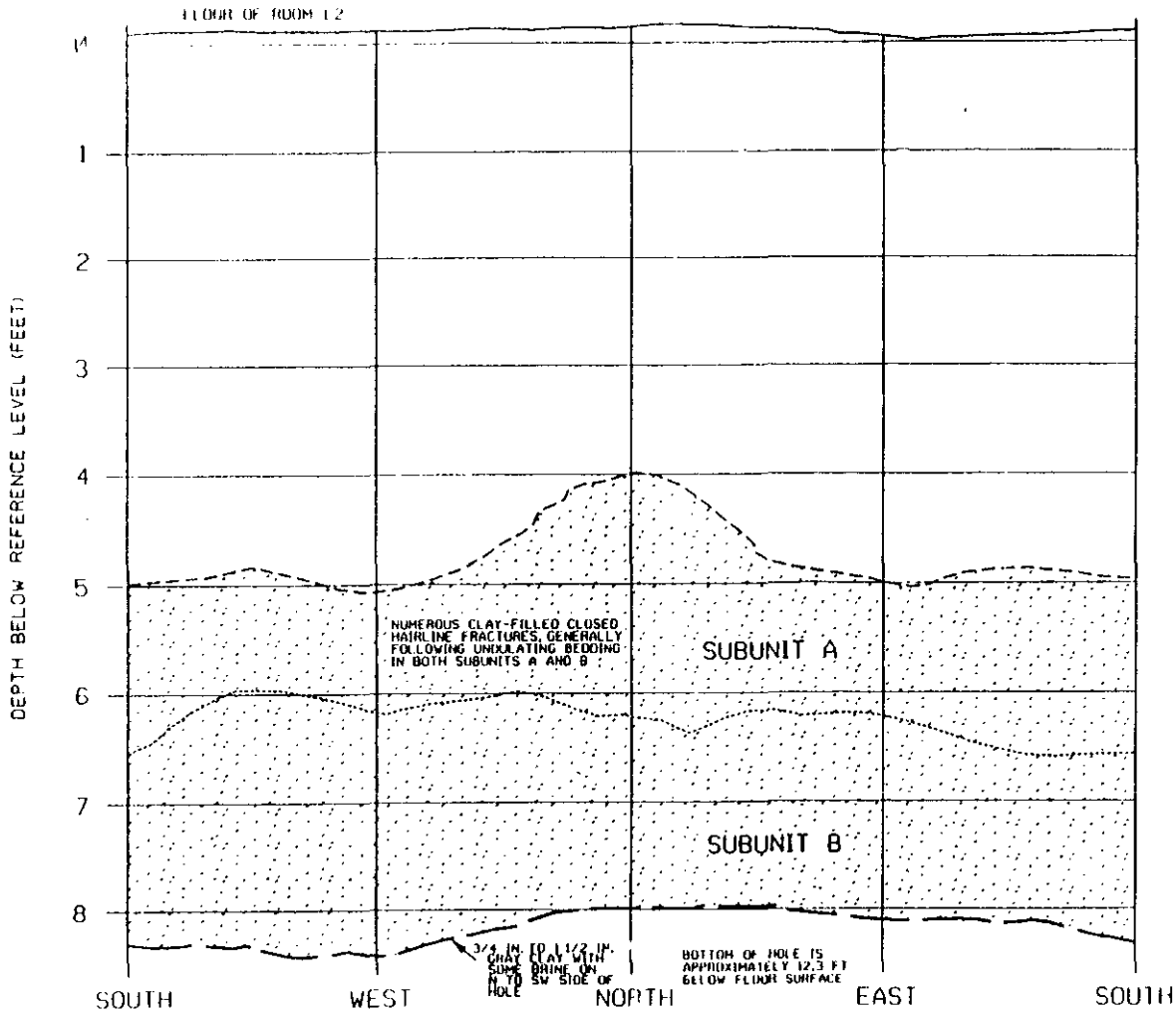

DATE MAPPED: 10/11/85

MAPPED BY: J.E. GALLERANI

0 1 2

SCALE IN FEET

EXPLANATION

- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  - DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE BOREHOLE WALL.
- FRACTURE ZONE
  - ZONE OF FRACTURED SALT BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  - CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE WIDTH OF SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE OPENING, 12 INCHES FROM BOREHOLE WALL.

NOTES:

1. BOREHOLE IS 30 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM AN UNSURVEYED REFERENCE LINE.
3. MAPPING WAS PERFORMED AT A SCALE OF 1 INCH EQUALS 1 FOOT.

Figure 10-3

DRIFTS
GEOLOGIC LOG OF HOLE L2X-01

The floor hole array in the N1420 drift at E875 encountered a slight separation of approximately 1/16 inch, coincident with a clay seam at a depth of about 8 1/2 feet. MB-139 at this location is about 22 feet below the floor.

Brine was encountered during the drilling of the central hole in the array at S700/E66 and continued to flow from the hole for several days after the completion of drilling. The hole encountered several separations up to 1/16 inch wide between a depth of 7.4 and 7.7 feet. No separations were detected in the other holes of this array. Brine has been encountered at several other hole array locations but no significant separations were detected in the holes.

The observations made to date indicate that fracturing in the drift floors is minimal. This includes observations of the E140 drift, which was one of the earliest excavations made during the SPDV Program. No fractures of the magnitude found in Test Room 3 (Chapter 11) have been detected in any of the drifts. Displacements, separations and fracturing beneath the floor is expected to continue in the future.

10.3.2.2 Closure Behavior at Selected Stations

Analyses were performed at selected stations to study roof-to-floor and wall-to-wall closure. Analysis was also performed to study the effect of floor lowering on closure.

Roof-to-Floor Closure. Until May 1984, the E140 drift south of the waste shaft was unique in that there were neither crosscuts nor nearby parallel drifts. However, in May and June 1984 the floor of the drift was lowered by 4 feet and new drifts and crosscuts were added between stations N140 and S1620. These two operations have resulted in an increase in closure rates for this portion of the drift. Since both operations occurred concurrently, it is difficult to isolate their effects on closure. However, it has generally been observed that any far field disturbance has only a short-term effect on the closure, and

that the closure rate, after a momentary increase, decays to its pre-perturbation rate pattern.

If we assume that the closure at station E140/S1879 is not measurably affected by the additional excavations performed north of station S1620, this station can then represent the closure of an infinitely long opening in a geologically uniform formation. However, because the convergence points were installed nearly 4 days after the completion of excavation, the roof-to-floor closure versus elapsed time curve was extrapolated backwards by fitting an equation in the form of

$$t = t_1 \, (1 + R(t)/R_1)^3 \qquad (10\text{-}1)$$

where: $R(t)$ is the instrument reading at elapsed time t since the end of excavation; and

R_1 is the regression parameter, equal to total closure at elapsed time t_1 since the end of excavation.

This equation indicates that at t equal to 0, the slope of the closure curve is infinite. This is not true because the slope at t equal to 0 is finite but large.

Based on the results of the regression analysis, the value of R_1 was determined to be 1.97 inches. However, the curve-fitting was not very good, probably because excavation at the instrument location was done in two stages making it difficult to assign the value for t_1. Because the shape of the early part of the closure versus time curve is not smooth, the estimated value of t_1 is approximate.

Figure 10-4 compares the measured closure with the adjusted curve at station E140/S1879 using the results of the regression analysis. The reading of roof-to-floor closure on August 26, 1985, was 5.84 inches and the adjusted value is 7.81 inches. Note that this station is nearly 230 feet from the boundary location north of which the floor was lowered 4 feet. It is likely that the excavation had some effect on

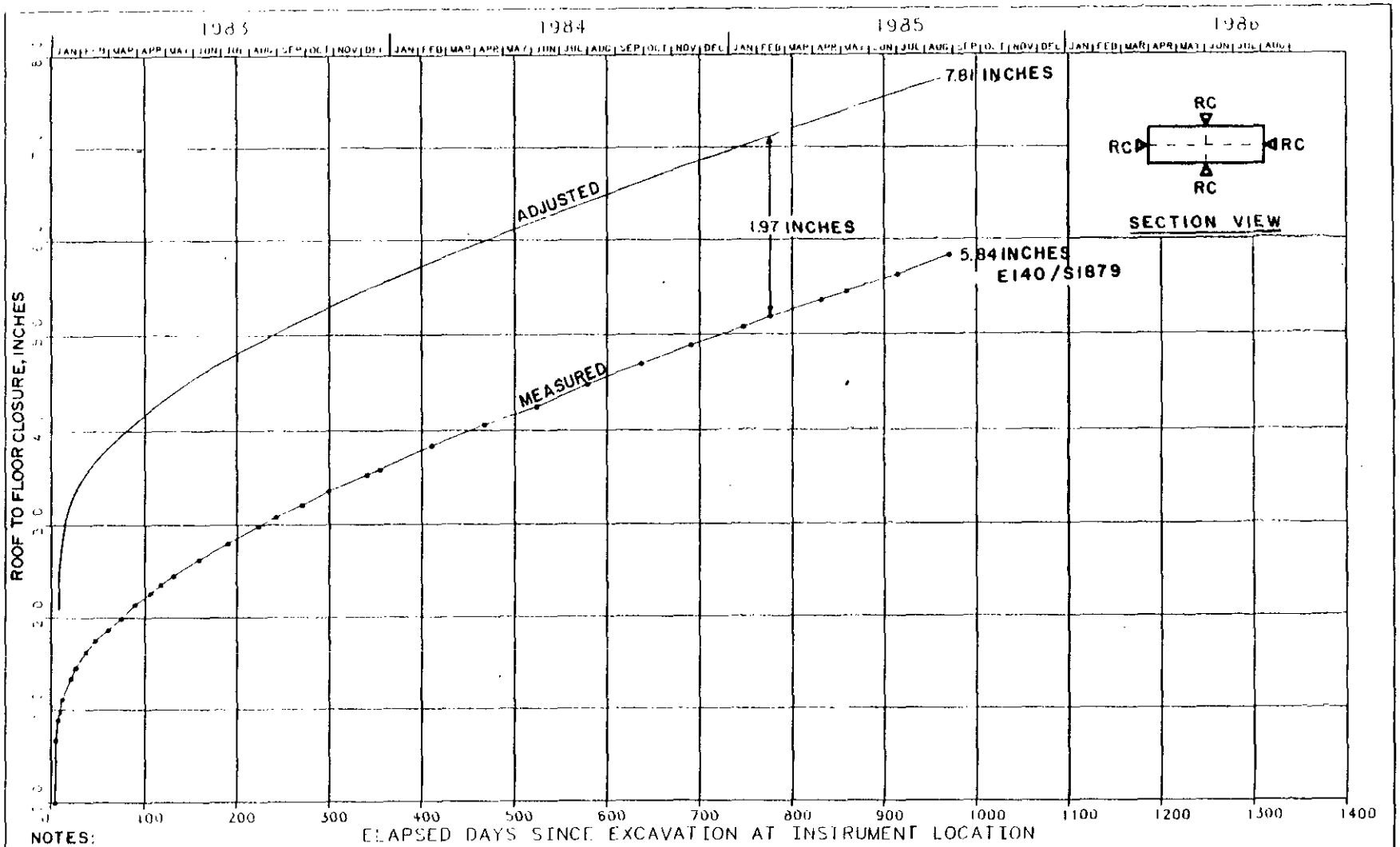

NOTES:

1. EXCAVATION DIMENSIONS = 8FT X 25FT
2. ADJUSTED CURVE OBTAINED USING THE RESULTS OF REGRESSION ANALYSIS

Figure 10-4

DRIFTS
COMPARISON OF MEASURED CLOSURE WITH REGRESSION CURVE AT E140/S1879

the closure at this station, although Figure 10-4 does not clearly show such an effect. The convergence points at this location have since been destroyed.

Figure 10-5 shows the central roof-to-floor closure at E140/S1246. The roof-to-floor convergence points were installed nearly 14 days after excavation at this location. This figure shows the effect that lowering the floor 4 feet has on the closure. In addition, the E300 drift excavation passed this location on August 21 and 22, 1984. The effect of lowering the floor, though, masks the effects of the adjacent excavation. As of August 26, 1985, the roof-to-floor closure of the 12 x 25-foot drift was 4.18 inches. The initial reading was taken on July 11, 1985, 1 day after the floor was lowered. Because the closure rate is very high at the early stages, actual roof-to-floor closure is greater than 4.18 inches.

Relationship Between Roof-to-Floor Closure and Drift Dimensions. Convergence points have been installed at various stations in underground drifts having different cross section dimensions. Some of the drifts, especially the E140 drift south of S1600, are isolated, while most of the other drifts have nearby parallel drifts and crosscuts. The closure behavior of these drifts is affected not only by the opening dimensions but also by the presence of adjacent openings. Differences in creep properties of the salt may also be responsible for differences in creep behavior. In addition, the closure behavior is affected by the 4- to 5-foot lowering of the drift floor.

Figure 10-6 shows measured roof-to-floor closure at selected stations in drifts with different cross section dimensions. Because measurements were not made immediately after the opening was excavated, the closure values were normalized to the values at approximately 10 days after the completion of excavation at the respective instrument station. As shown on this figure, the maximum closure and closure rate occur in drifts with opening dimensions of 12 x 25-feet. Because the

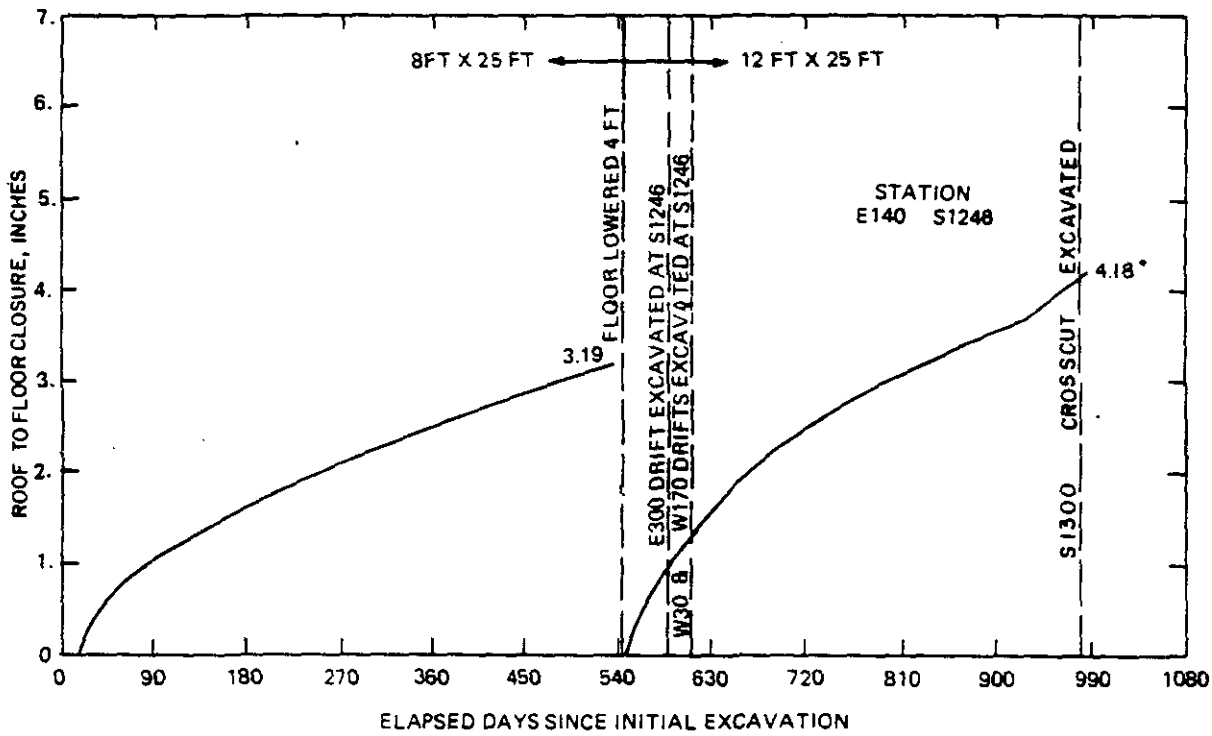

*MEASUREMENT ON AUGUST 26, 1985.

Figure 10-5

DRIFTS
EFFECT OF FLOOR LOWERING AND ADJACENT EXCAVATIONS
ON CLOSURE AT E140/S1246

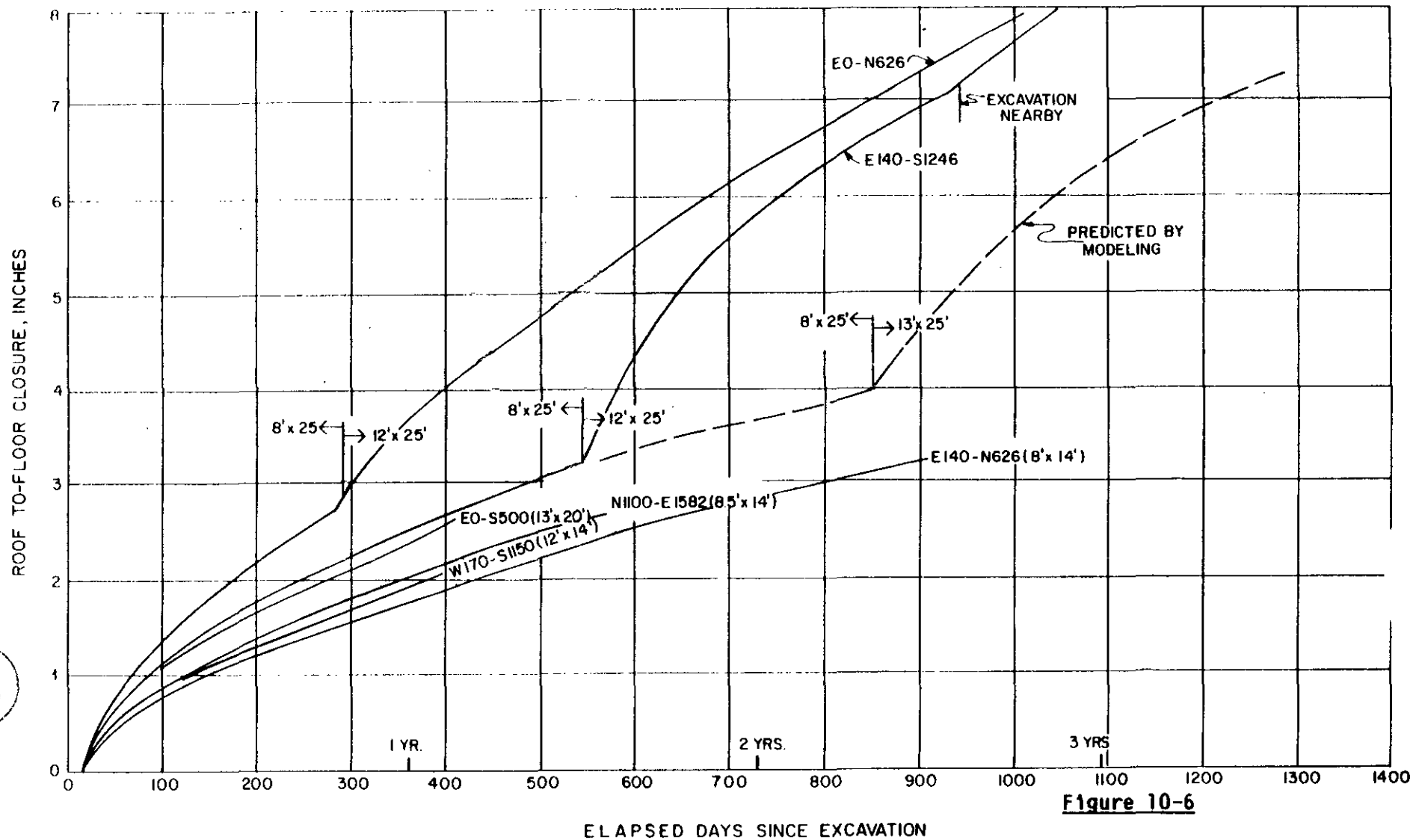

Figure 10-6

DRIFTS
COMPARISON OF ROOF-TO-FLOOR CLOSURE IN DRIFTS WI
DIFFERENT DIMENSIONS

drifts in the storage area will have cross section dimensions of 13 x 25 feet, the modeling analysis discussed in this chapter and in Chapter 12 focuses on predicting the behavior of the 13 x 25-foot drift opening for the operating life of 25 years.

The effect of lowering the floor 4 feet at instrument stations E0/N626 and E140/S1246 is to increase the closure rate permanently. Although the floor lowering was performed at different times at these stations, the steady state rate after excavation appears to be nearly the same. However, if the floor lowering is performed at a much later date following the initial excavation, it is likely that the total closure may be somewhat decreased. The closure behavior at these two stations is influenced by the presence of nearby parallel drifts and crosscuts, as well as likely differences in the creep properties of the salt.

Figure 10-6 also shows the predicted roof-to-floor closure of an infinitely long, single drift with cross section dimensions of 13 x 25 feet. This closure was obtained by modeling and is discussed in Chapter 12. The approximate steady state closure rate at E0/N626 and E140/S1246 is 2.00 inches/year. The steady state closure rate predicted for the infinitely long, single drift is 1.60 inches/year. The nearly 25 percent difference in these rates is probably due to the presence of adjacent drifts and crosscuts. This value compares well with the value of 30 percent obtained from modeling as discussed in subsection 10.3.3.3.

Figure 10-7 presents a comparison of the predicted closure of a 13 x 25-foot drift with the observed behavior of a 12 x 25-foot drift at E0/N626. The closure for the 13 x 25-foot drift was obtained by increasing the closure rate obtained from modeling the infinitely long, single drift by 30 percent. The roof-to-floor closure at E0/N626 does not include the values before the floor was lowered by 4 feet. This comparison indicates that it is reasonable to increase the closure rate of a single, infinitely long, 13 x 25-foot drift by 30 percent to account for the presence of adjacent parallel drifts and crosscuts.

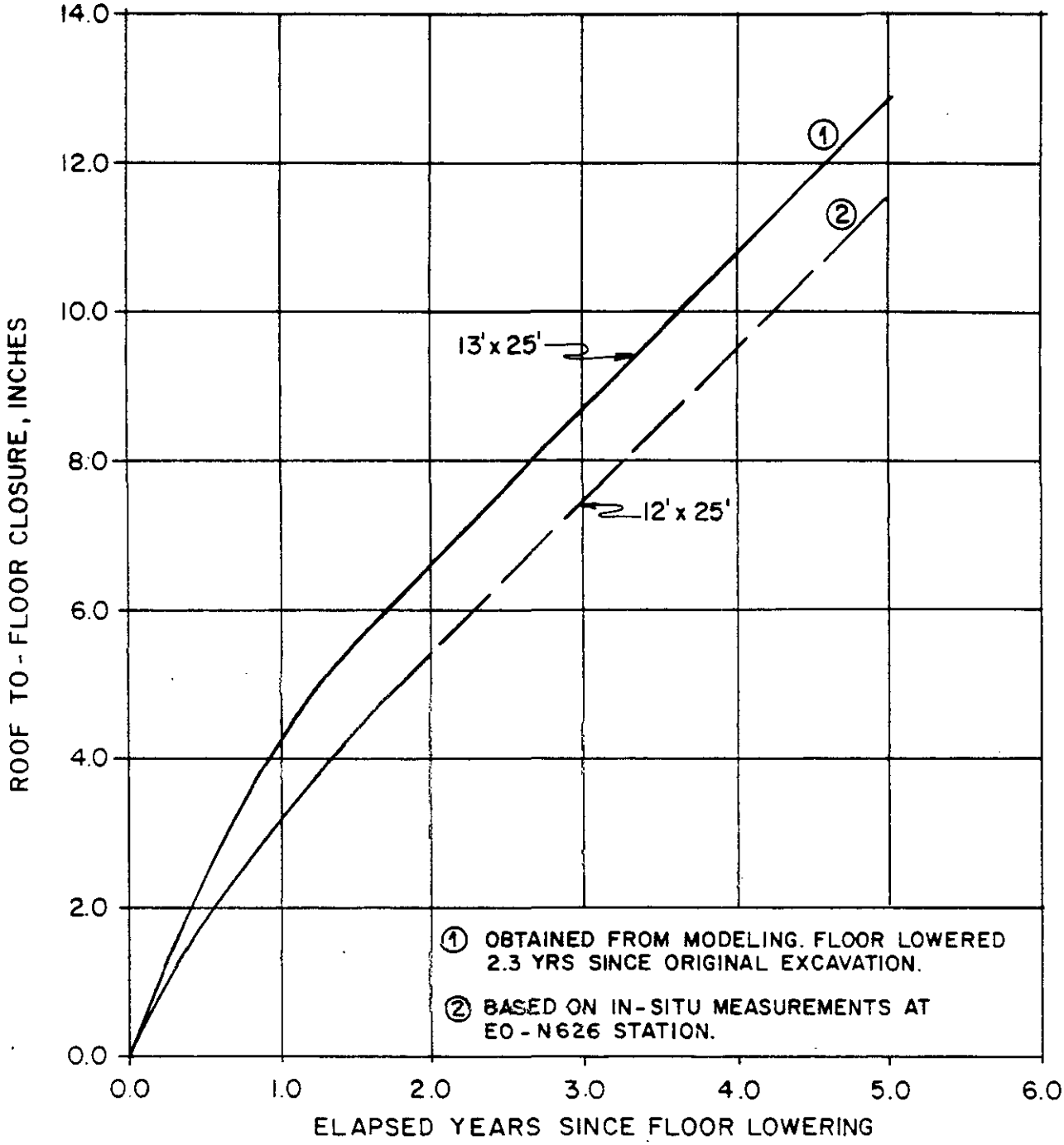

Figure 10-7

DRIFTS
COMPARISON OF PREDICTED AND OBSERVED
ROOF-TO-FLOOR CLOSURE

Wall-to-Wall Closure. The wall-to-wall convergence points at the S1246 station were installed immediately after the original excavation at this location was completed. When the cross section dimensions were 8 x 25 feet, the measurements were close to the true wall-to-wall closure at midheight of the instrument location. On June 30, 1984, the wall-to-wall closure was 5 inches for an elapsed time period of 564 days. After the floor was lowered, a new set of wall-to-wall convergence points was installed. The additional wall-to-wall closure was 3.31 inches through August 26, 1985.

Comparison of Roof-to-Floor to Wall-to-Wall Closures. Table 10-4 summarizes the closure of the E140 drift for locations south of S1620. Until August 1985, these locations were unique in that there were no crosscuts and no nearby parallel drifts at the time of the analysis. The cross section dimension was 8 x 25 feet. The maximum measured roof-to-floor closure of 5.19 inches was at station S1879. Stations S3614, S3639 and S3664 are influenced by the end constraints of the drift which terminates at about S3664.

Effect of Adjacent Drifts. Table 10-5 compares closure in the drifts at S1150. Because the initial readings were not taken immediately after the station location was excavated, the comparison is approximate. Note that, for the E140/S1150 station, the original cross section dimensions were 8 x 25 feet until June 8, 1984, and that no convergence points existed at this location prior to lowering the floor. The closure values at E140/S1150 are the maximum, not only because the opening dimensions are the largest, but also because the opening had already existed for nearly 550 days before the floor was lowered 4 feet. It is also likely that there is mutual influence between the openings.

Effect of Floor Lowering. The E0 drift between N140 and N1420 was increased in height from 8 feet to 12 feet (by lowering the floor) from November 9, 1983, through January 9, 1984. The closure readings increased rapidly as excavation approached the measurement stations but

Table 10-4

E140 DRIFT SOUTH OF S1620
SUMMARY OF MEASURED CLOSURE
(CROSS SECTION DIMENSIONS = 8 x 25 feet)

Instrument Location	Time-lag between end of excavation and initial reading (days) R-T-F*	W-T-W*	Convergence point reading (inches) Feb. 12, 1985 R-T-F*	W-T-W*
E140/S3664	14	0	1.70	1.48
E140/S3639	0	0	4.07	3.24
E140/S3614	0	0	4.49	3.72
E140/S3250	11	11	4.13	2.97
E140/S2950	10	10	4.19	3.18
E140/S2625	6	6	4.43	3.59
E140/S2350	9	9	4.33	3.44
E140/S2066	8	8	4.32	3.40
E140/S1879	4	2	5.46	4.00

* R-T-F = roof-to-floor
W-T-W = wall-to-wall

Table 10-5

COMPARISONS OF CLOSURE IN DRIFTS AT S1150

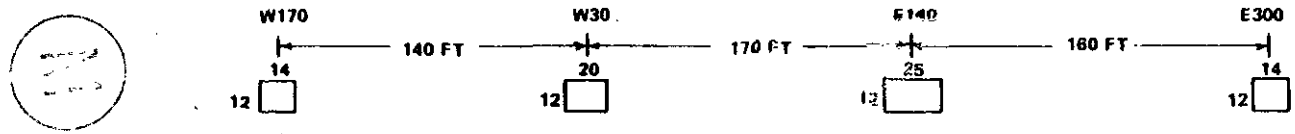

	W170	W30	E140	E300
INSTRUMENT LOCATION	W170/S1150	W30/S1141	E140/S1150	E300/S1150
DATE OF EXCAVATION	AUGUST 21, 1984	AUGUST 21, 1984	JUNE 8, 1984*	JULY 23, 1984
DATE OF INITIAL READING				
CENTRAL ROOF-TO-FLOOR	AUGUST 23, 1984	AUGUST 22, 1984	JUNE 14, 1984	JULY 26, 1984
CENTRAL WALL-TO-WALL	AUGUST 23, 1984	AUGUST 22, 1984	JUNE 14, 1984	JULY 26, 1984
DATE OF LATEST READING FOR BOTH ROOF-TO-FLOOR AND WALL-TO-WALL CONVERGENCE POINTS	SEP. 16,1985	SEP. 16, 1985	AUG. 26, 1985	SEP. 30, 1985
CLOSURE (IN.)				
CENTRAL ROOF-TO-FLOOR	2.46	3.10	3.61	2.18
CENTRAL WALL-TO-WALL	2.62	2.76	3.03	2.35

* FLOOR LOWERED BY 4 FT ON JUNE 8, 1984. DIMENSIONS WERE 8 FT X 25 FT BEFORE JUNE 8, 1984. CROSS DRIFTS S1100 AND S1300 EXCAVATED IN AUGUST, 1985.

dropped rapidly to, or slightly above, the pre-excavation rate. The floor lowering has affected the salt material above the roof of the openings to distances of at least 30 feet.

Figure 10-8 shows the relationship of the movement rates for the collar and two intermediate anchors of roof extensometer 51X-GE-00243 at the E0/N1100 intersection. The figure shows that the movement rate of the collar and these anchors increased due to floor lowering but then began decreasing until March 1984 (about 400 days after the initial excavation). The rate then began increasing again from March until August 1984 (about 550 days after the initial excavation). Because excavation activities were performed in the area of this instrument at this time, it is possible that parting at the clay seams above the roof was occurring at an increasing rate.

Figure 10-9 shows the movement rates of the collar and anchors of roof and wall extensometers at E0/N626. The collar movement rate of the east wall extensometer appears to be somewhat less than that of the west wall extensometer. It was also observed that floor lowering has affected the closure behavior of pillars as far as 25 feet from the opening. Similarly, roof behavior has been affected, probably up to at least 30 feet above the roof.

The height of the E140 drift remained at 8 feet during floor lowering in the E0 drift between N140 and N1420. However, excavation performed in the E0 drift appears to have affected the closure behavior of the E140 drift. Figure 10-10 shows the movement rates of the collar and anchor A for roof extensometer 51X-GE-00235 at E140/N624. The collar movement rate was decreasing monotonically until late December 1983. However, it appears to have increased around January 1984. Assuming the instrument was functioning properly and there was no anomalous behavior of clay seams in the roof of the E140 drift, excavation in the E0 drift may have influenced salt behavior as much as 150 feet from the E0 drift.

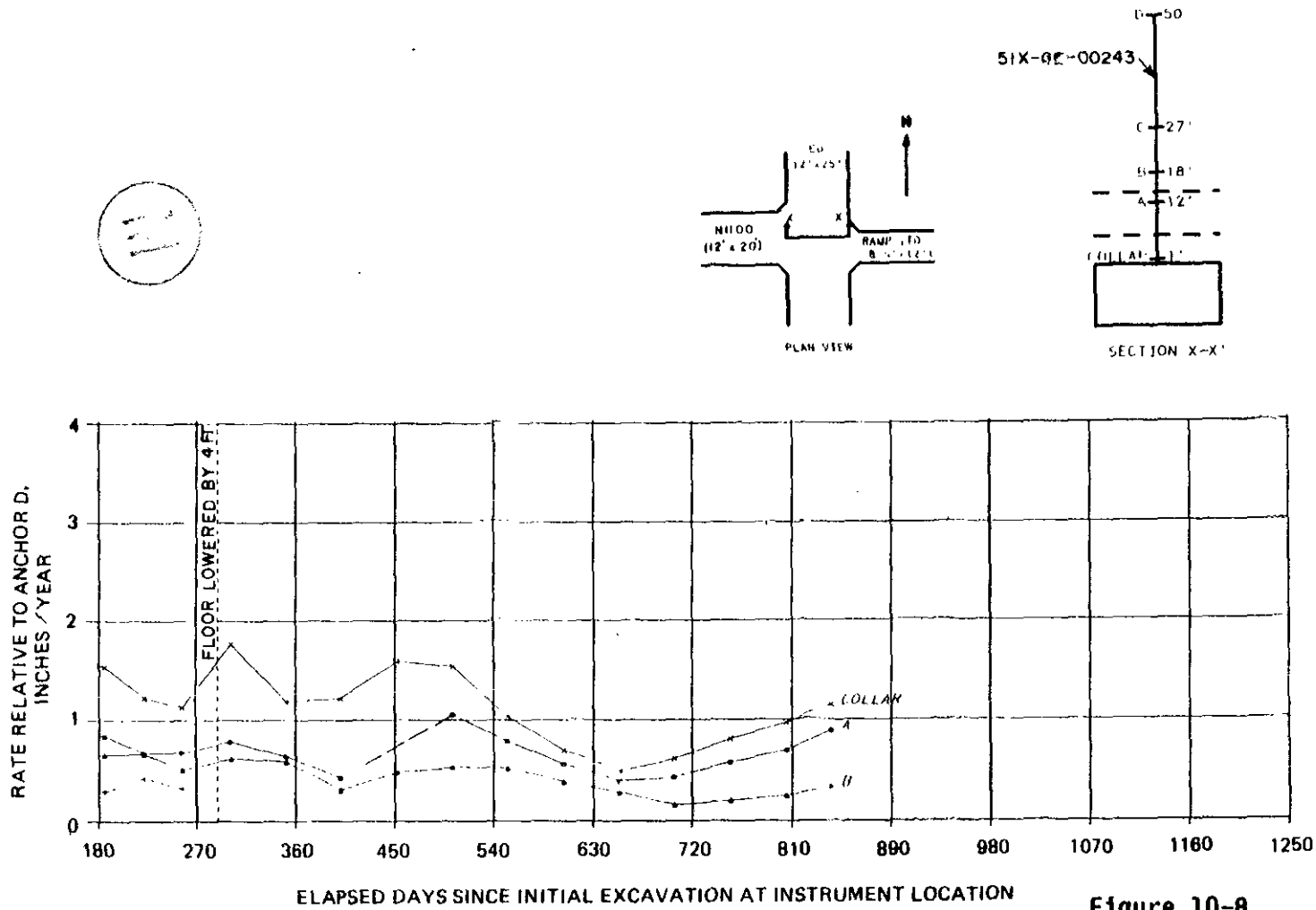

Figure 10-8

DRIFTS
EFFECT OF FLOOR LOWERING ON ROOF BEHAVIOR AT EO/N1100 INTERSECTION

NOTE: RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

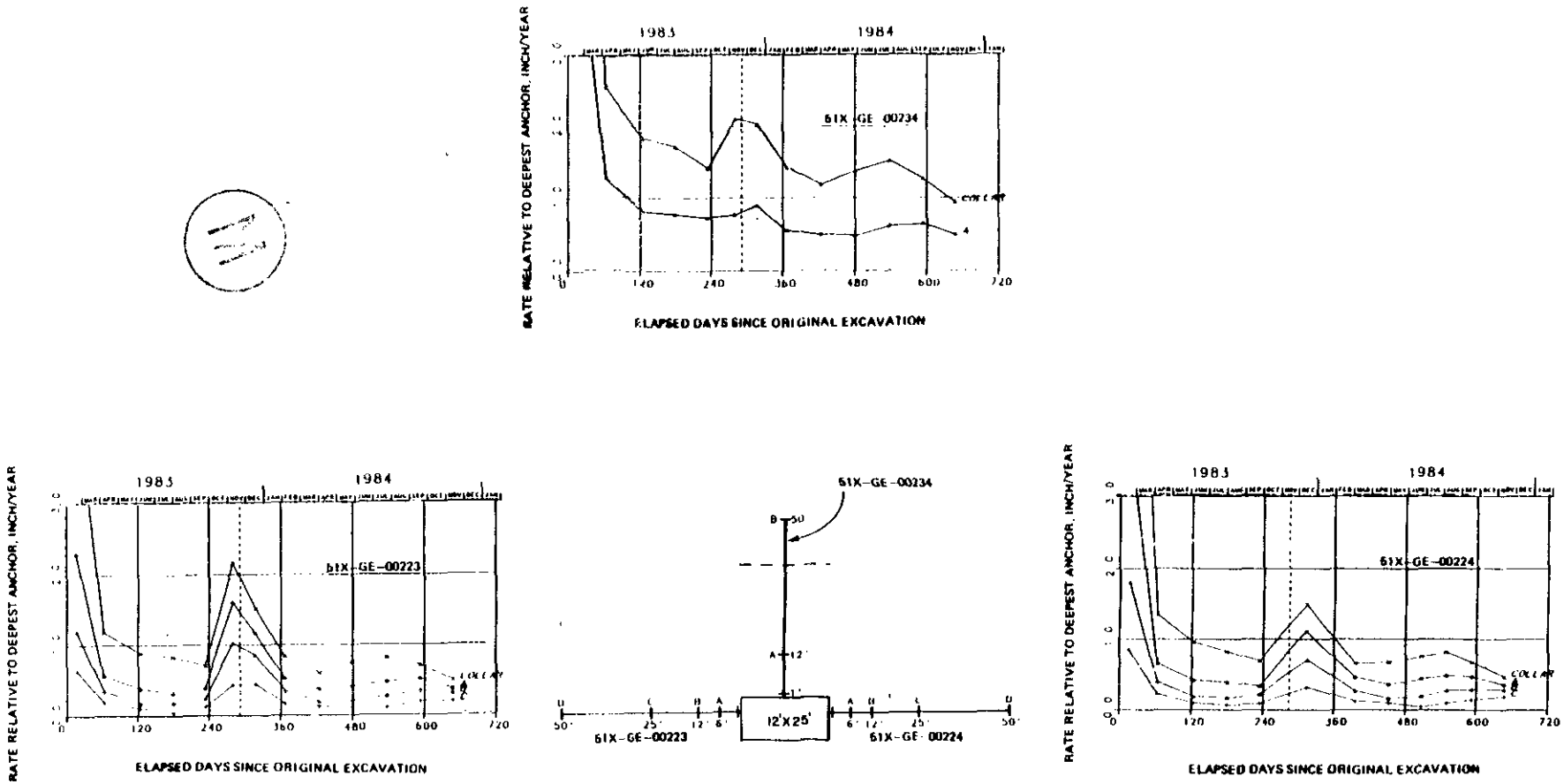

NOTE

VERTICAL DASHED LINE INDICATES TIME WHEN THE FLOOR WAS EXCAVATED FOUR FEET.

Figure 10-9

DRIFTS
EFFECT OF FLOOR LOWERING ON CLOSURE AT EO/N626

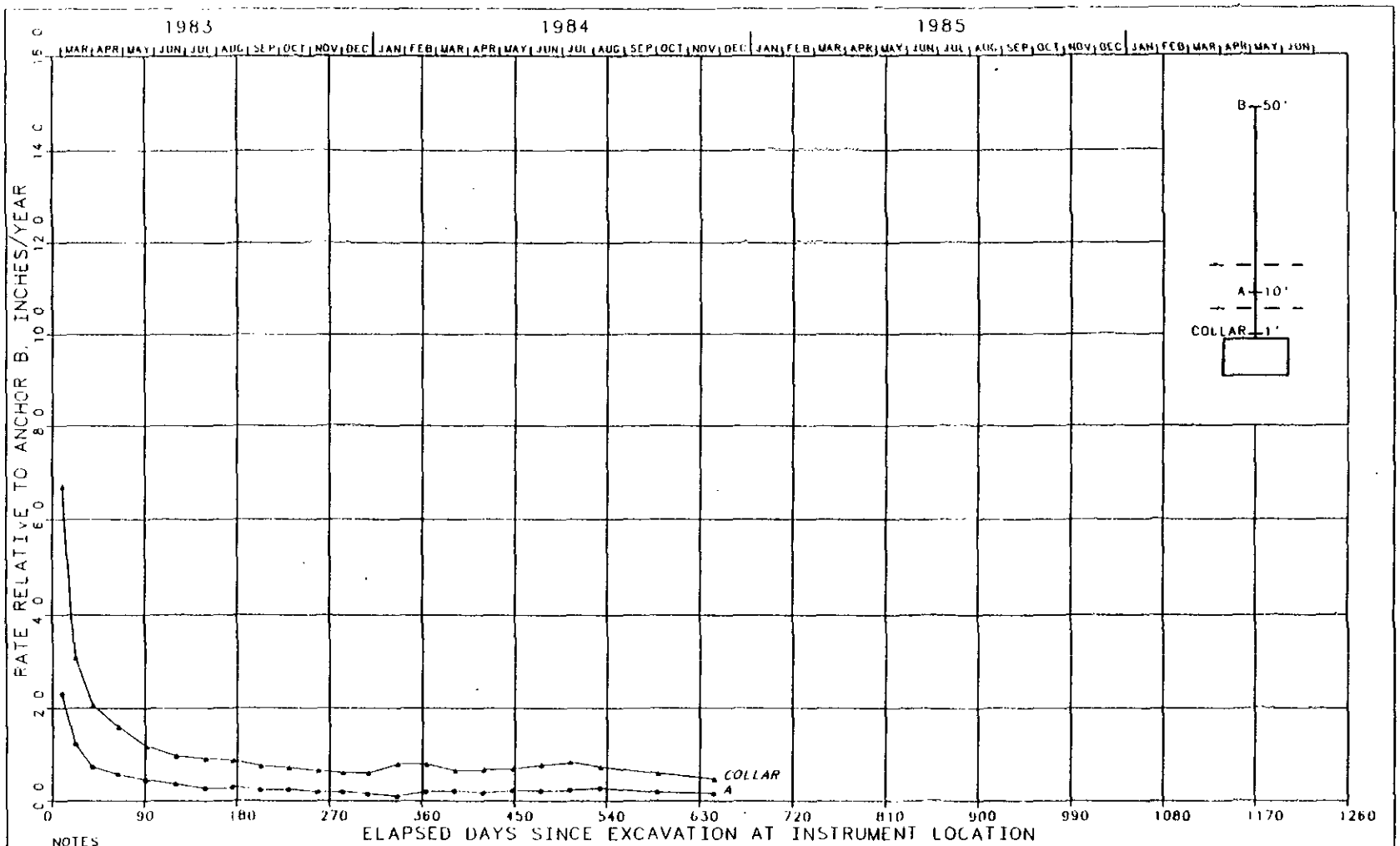

NOTES
1 RATE CALCULATED FOR MINIMUM INTERVALS OF 7 DAYS
2 SIZE OF EXCAVATION 8 FT X 14 FT

Figure 10-10

DRIFTS
EFFECT OF FLOOR LOWERING ON CLOSURE AT E140/N624

Observations of the effect of floor lowering on closure behavior are summarized below:

(1) The closure reading at an instrument station increases rapidly as floor excavation approaches the station and decreases rapidly to, or slightly above, the pre-excavation closure rate as excavation passes the instrument station.

(2) Floor lowering affects creep behavior of the salt above the roof of the openings to depths of at least 30 feet. This effect is short-lived, however, extending over a period of only a few months.

(3) Although the floor of the E140 drift north of the C & SH shaft was not lowered for most of its length, excavation performed in the E0 drift appears to have affected the E140 drift closure.

The movement rates of the anchors of extensometer 51X-GE-00243 at the E0/N1100 intersection increased and then decreased between March and August 1984. Because no excavation activity took place at this time in the vicinity of the instrument station, it was assumed that the clay seams above the roof may have been parting at an increasing rate. Figure 10-8 shows the variation in closure rates for the collar and anchor points with time. The rates of the collar and anchor movements have subsided and are probably returning to their pre-perturbation values. For comparison, the rates of collar and anchor movements of floor extensometer 51X-GE-00258 are shown on Figure 10-11. The rates of movements of the collar and intermediate anchors have a similar trend as the roof extensometer over the same time period. However, this extensometer was damaged due to mining operations on February 8, 1985. Since then, the readings have remained anomalous.

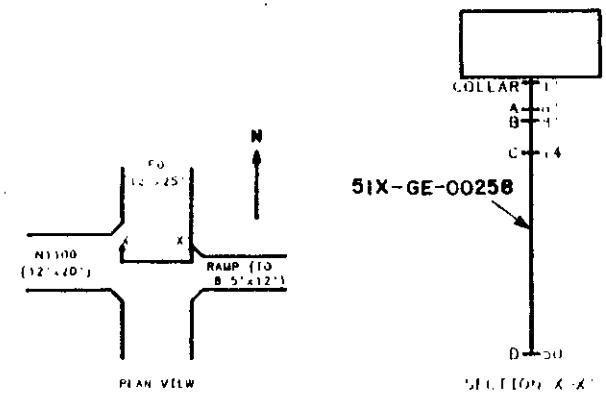

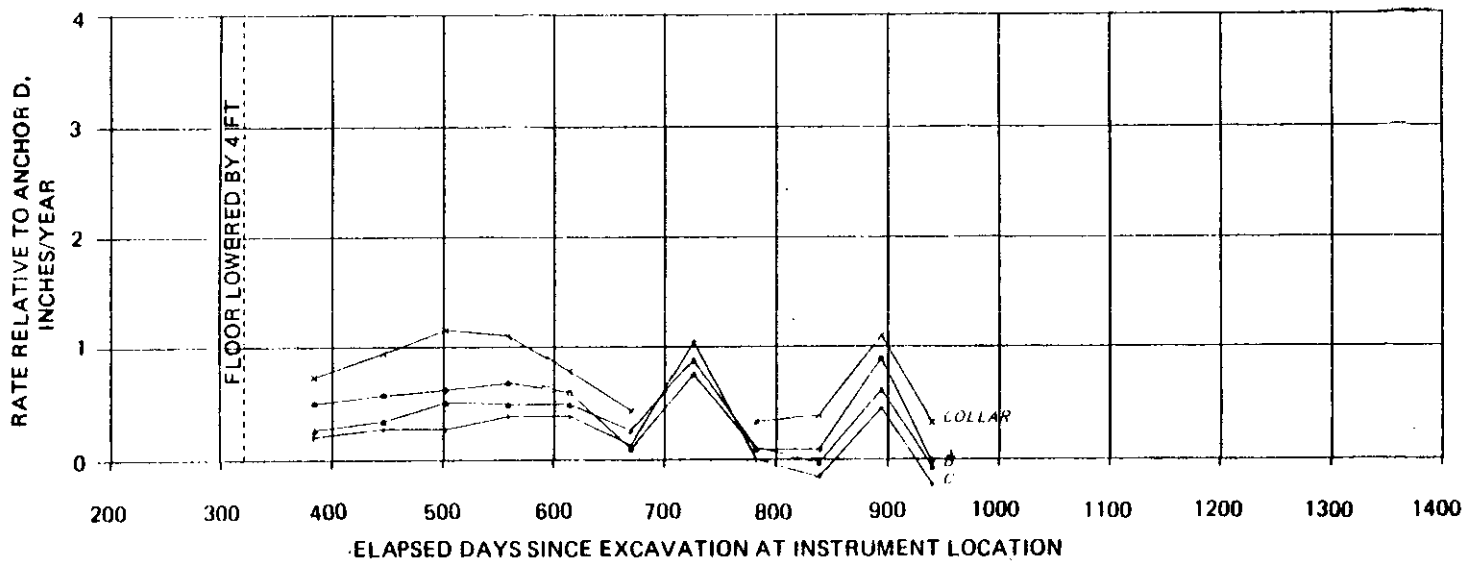

NOTE: RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

Figure 10-11

DRIFTS
RATE OF FLOOR HEAVE AT E0/N1100

10.3.2.3 Model Simulation

A finite element model utilizing an engineering approach was used to simulate the behavior of an 8 x 25-foot drift. The method described in Appendix C was used to mathematically simulate the in situ behavior of the drifts by determining the creep parameters C, A, and z. The following discussion describes the numerical modeling and the utilization of in situ data for the drifts. Also discussed are simulations of the effect of adjacent parallel and perpendicular drifts.

Utilization of Reference Stratigraphy. The reference stratigraphy described in Chapter 6 was used in the analysis. The reference level representing the elevation of clay G is 2,129.40 feet below the ground surface, based on the core hole log at station E140/S1960. Because the finite element method lends itself well to multiple layer analysis in which distinct material properties can be accounted for, the MARC General Purpose Finite Element Program (ref. 6-8) was used.

Structural Characterization. Figure 10-12 shows the finite element model used to predict closures, stresses and deformed shapes as a function of time for an 8 x 25-foot opening. The model consists of 122 plane strain elements with 21 gap/friction link elements modeling the clay seams and an option for lowering the floor 5 feet. The top and bottom boundaries of the model are at depths of 2,045.00 feet and 2,245.00 feet, respectively, below the ground surface. The drift roof, drift floor before lowering, and drift floor after lowering are at depths of 2,128.70, 2,136.70, and 2,141.70 feet, respectively, below the ground surface. The roof beam is 8.10 feet thick and the final floor level is 4.39 feet above MB-139.

Only anhydrite layers with thicknesses greater than 1 foot were included in the model. Calculations showed that most anhydrite layers less than 1 foot thick failed at vertical stresses less than 1 percent of the overburden pressure. Therefore, because their contribution to the stiffness of the model would be insignificant, they were not included.

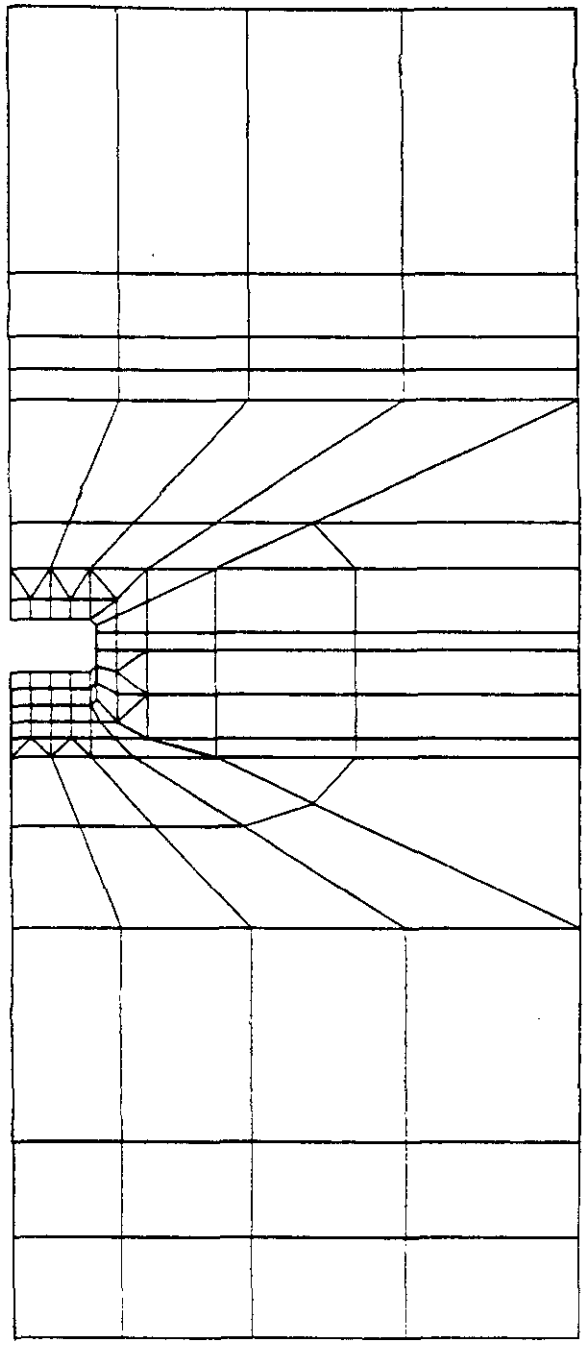

Figure 10-12

DRIFTS
FINITE ELEMENT MODEL - BEFORE FLOOR LOWERING

Clay seams in the model were limited to two above and two below the drift opening. The justification for this is twofold: first, reference 5-4 states that "90 percent of the drift closure measured with ten active slidelines could be captured with four slidelines, two directly above and two directly below the drift"; second, previous analyses have shown that, at locations representative of the more distant clay seams, the shear force is considerably less than the normal force; therefore, any slippage along these clay seams would be negligible compared to that along seams closer to the opening and they need not be included in the model. To simplify the analysis of this model, a coefficient of friction equal to 0.0 was assumed for the gap/friction elements modeling the clay seams.

The lateral boundaries of the model are 82 feet apart and were established based upon vertical axes of symmetry with regard to adjacent drifts. The upper and lower boundaries of the model were based upon experience from previous analyses and were extended far enough in both directions so that the difference between vertical and horizontal stresses at each point of the boundaries would be within 10 percent of the vertical stresses. Horizontal restraints were assumed for the lateral boundaries while vertical restraints were assumed for the lower boundary of the model. Stress boundary conditions were utilized for the upper boundary.

Element sizes were established to make them proportional in size to the estimated stress gradient across each element. In addition, the orientations of the elements were established in order to have the radiating mesh coincide with the assumed principal stress axes. These aspects of the model were designed to enhance the overall efficiency of the analysis.

Consideration of Drift Opening. The drift openings were originally excavated to 8 x 25 feet. Further development trimmed an additional 4 feet from the floor to provide a 12 x 25-foot opening in the shaft pillar area. To provide continuous response histories from initial

excavation through the floor lowering period, special considerations were provided for modeling the opening.

Determination of Creep Parameters. Data from ten different locations along the E140 drift from S550 to S3250 were reviewed and one representative location was selected to calculate creep parameters for the drifts and for use in predicting closures and stress distributions.

Figure 10-13 shows the correlated roof-to-floor and wall-to-wall in situ data curves from the selected location, as well as the predicted closure based on the calculated creep parameters.

Transformation of Time Domains. Having determined the values of C, A and z to be 1.40×10^{-21} $ksf^{-4.9}$ sec^{-1}, 3.2 and 1.1×10^{-7} sec^{-1}, respectively, the normalized time at which the floor lowering was scheduled to take place was determined by transforming 7.25×10^{7} sec (or 2.3 years) to normalized time using equation C.4-17 in Appendix C.

The normalized time which corresponds to the scheduled real time for drift floor lowering was determined to be 1.4205×10^{-13} $ksf^{-4.9}$ or 418 time increments from the start of the program. Accordingly, the drift height was changed at the end of increment 418, and the analysis continued until a total real time of approximately 5 years was reached.

Effect of Parallel Drifts. The extraction ratio at a particular location is dependent upon the arrangement of the drifts and pillars. Therefore, the effect that the extraction ratio has on structural responses can be determined by considering the effect of adjacent drifts. Two different cases were considered in the analysis. One case assumes the adjacent drifts are parallel to the drift being analyzed while the other case assumes adjacent drifts are perpendicular to the drift being analyzed.

To simplify and minimize the computational effort, a multiple drift model was used for the analysis of the 8 x 25-foot drift. For this

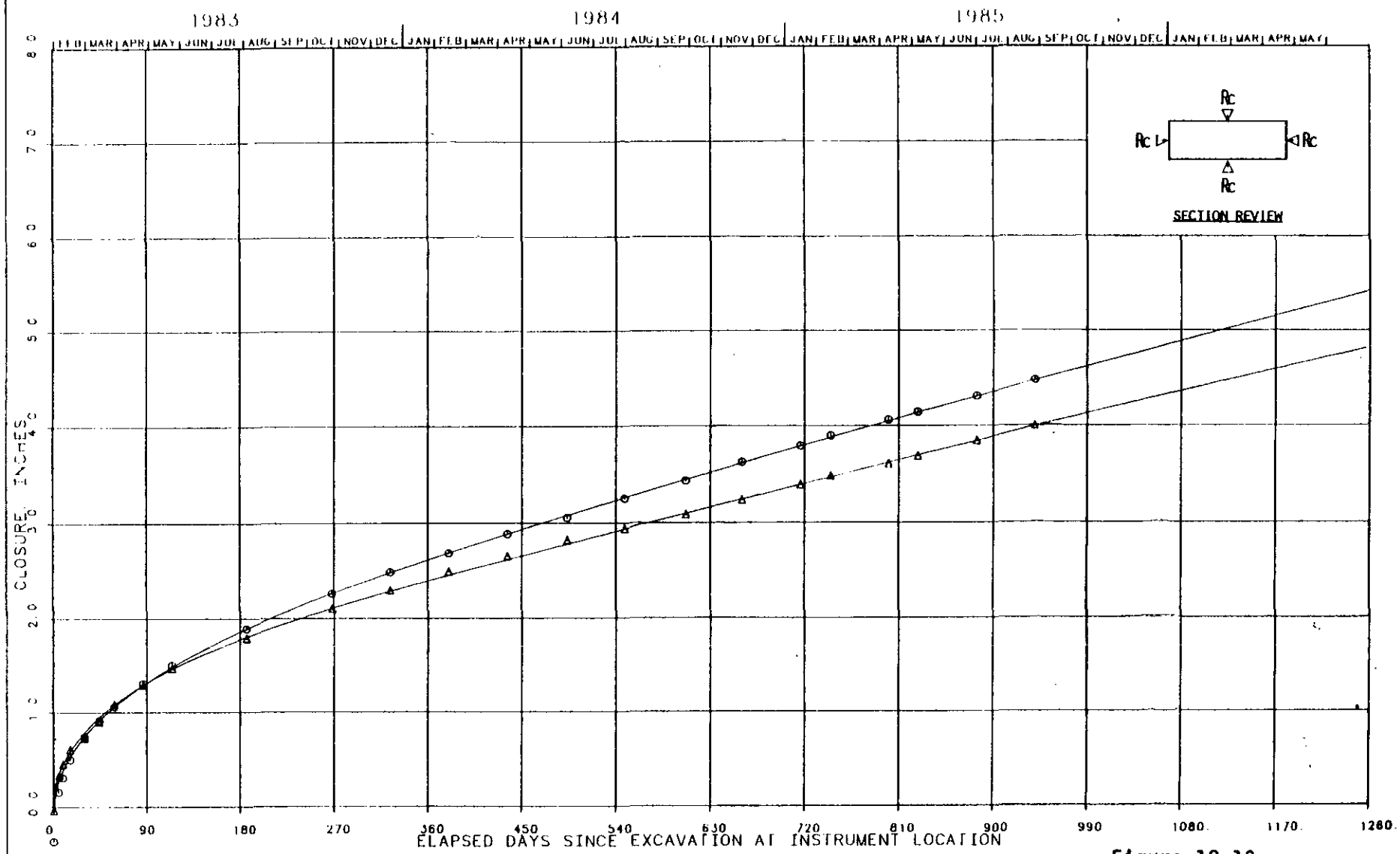

ROOF-TO-FLOOR IN SITU DATA
WALL-TO-WALL IN SITU DATA
COMPUTATIONAL DATA

Figure 10-13

DRIFTS
CORRELATED CLOSURE HISTORIES

model, the drift was assumed to be located between an infinite number of parallel drifts, with each having identical cross sections and pillar widths. Two-dimensional analyses using this model were performed assuming a state of plane strain. The boundary displacement conditions at the centerline of the pillar were assumed to be restrained in the horizontal direction but free in the vertical direction. Under these assumptions, this mathematical model can more accurately simulate the geologic conditions in the future when adjacent drifts will exist rather than at the present time when only a single drift exists. Computational results for the parallel drifts are presented in subsection 10.3.3. Parallel drifts with different dimensions and spacings can be incorporated into the present mathematical model and corresponding structural responses can be computed.

Effect of Perpendicular Drifts. Ideally, a three-dimensional analysis is required for the case when the drifts are not parallel to each other. However, the structural responses can be approximated based on the two-dimensional analysis described in this section.

Additional drifts which intersect perpendicular to the drift in question increase the average overburden pressure in the pillar. The two-dimensional analysis of parallel drifts has indicated that the vertical stresses initially increase sharply in the pillar area adjacent to the opening. Over time, salt creep reduces this stress peak as the stresses are redistributed over the width of the pillar. Eventually, the vertical stress level becomes nearly uniform over most of the pillar width.

The total overburden load in the pillar is equal to the average vertical stress multiplied by the pillar support area. Because this total overburden load remains constant before and after the excavation of perpendicular drifts, the average vertical pressure is inversely

proportional to the support area. This increased average vertical stress can, therefore, be expressed as:

$$\bar{\sigma}_r = \bar{\sigma}_i \, W_t/W_2 \qquad (10\text{-}2)$$

where: $\bar{\sigma}_r$ is the average vertical stress of a rectangular pillar, i.e., pillar within a gridwork of intersecting drifts;

$\bar{\sigma}_i$ is the average vertical stress of an infinitely long pillar, i.e., pillar without the perpendicular drifts;

W_t is the distance between the center lines of the perpendicular drifts; and

W_2 is the pillar width in the perpendicular direction, i.e., W_t minus the width of the perpendicular drift.

After the excavation of additional drifts in the perpendicular direction, the restraints at the new wall boundaries are released. Consequently, the distribution of effective stress in the pillar changes. Actual distribution of the effective stresses can be obtained through a three-dimensional computational analysis. However, a two-dimensional analysis can be used to estimate the stress distribution.

A two-dimensional analysis can neither model the restraint conditions nor predict out-of-plane displacements that occur at the boundary of the perpendicular drifts. As a result, the vertical stress distribution from the two-dimensional analysis is assumed to represent a plane some distance from the perpendicular drifts where the actual behavior more closely represents the plane strain condition. The accuracy of this assumption depends upon the distance between the plane being analyzed and the perpendicular drift. In all cases, the results of a two-dimensional analysis represent a lower bound on the effects of perpendicular drifts.

The pillar dimensions are identified as W_1 for the width of the pillar between parallel drifts and W_2 for the width of the pillar

between perpendicular drifts. For an infinitely long pillar, which can be considered as a rectangular pillar with W_1/W_2 equal to zero, the vertical stress distribution of the drift to the center of the pillar can be determined from a two-dimensional analysis. The distribution of the vertical stress $\sigma_i(y)$, shown at the top of Figure 10-14, is symmetrical with respect to the centerline of the pillar and stabilizes within several months after excavation.

For a square pillar, which can be considered as a special case of the rectangular pillar with W_1/W_2 equal to one, the vertical stress distribution should be symmetrical with respect to the two centerlines and two diagonals of the pillar. This is shown graphically in the middle of Figure 10-14, where the x-axis is assumed to be along the drift axis. Assuming the vertical stress distribution $\sigma_s(x,y)$ from the center of the pillar to any of the four walls is the same as the stress distribution $\sigma_i(y)$ across the width of the infinite pillar, the ratio of the average vertical stresses between the square and the infinite pillars can then be estimated from equation 10-3:

$$\frac{\bar{\sigma}_s}{\bar{\sigma}_i} = \frac{\int_0^{W/2} \int_{-x}^{+x} \sigma_s(x,y)\, dydx}{\int_0^{W/2} \int_0^{W/2} \sigma_i(y)\, dydx} \qquad (10\text{-}3)$$

where: $\bar{\sigma}_i$ is the average vertical stress for the infinitely long pillar;

$\bar{\sigma}_s$ is the average vertical stress for the square pillar;

$\sigma_i(y)$ is the vertical stress distribution for the infinitely long pillar; and

$\sigma_s(x,y)$ is the vertical stress distribution for the square pillar.

Based on the computational results from the previous analyses, the average vertical stress of a square pillar is estimated to be 15 percent higher than that for the infinitely long pillar. At the WIPP

facility level, most of the pillars have a rectangular shape. As shown at the bottom of Figure 10-14, a rectangular pillar can be separated into regions which are assumed to act either as an infinite or square pillar. By using a weighted area method, the following equation expresses the effect of varying the pillar's aspect ratio on the average vertical stress:

$$\bar{\sigma}_r = (1 + 0.15 \frac{W_1}{W_2}) \bar{\sigma}_i \qquad (10\text{-}4)$$

where: $\bar{\sigma}_r$ is the average vertical stress for the rectangular pillar.

The corresponding change in pillar shortening is proportional to the ratio of $\bar{\sigma}_r$ to $\bar{\sigma}_i$, raised to some power, with an exponent not exceeding n, where n is the exponent in the power law expression for the creep behavior. Subsection 10.3.3.3 presents the results using equation 10-4.

10.3.2.4 Bay Strains

Strains around an opening in salt vary with space and time. Although, it is difficult to measure these strains directly, they can be inferred from the measurements of anchor displacements of multiple-point borehole extensometers. Relative movements between anchors will provide an approximate distribution of strain along the axis of the extensometer. If these relative displacements are normalized over the spacing between the anchors, then these normalized relative displacements are termed "bay strains". The bay strain will be closer to the true strain provided that the spacing between anchors is small and that the deformation varies linearly with spacing between anchors. Bay strains are useful in detecting any anomalous behavior in salt around an opening such as that influenced by discontinuities, clay seams, or the effect of local stress concentrations.

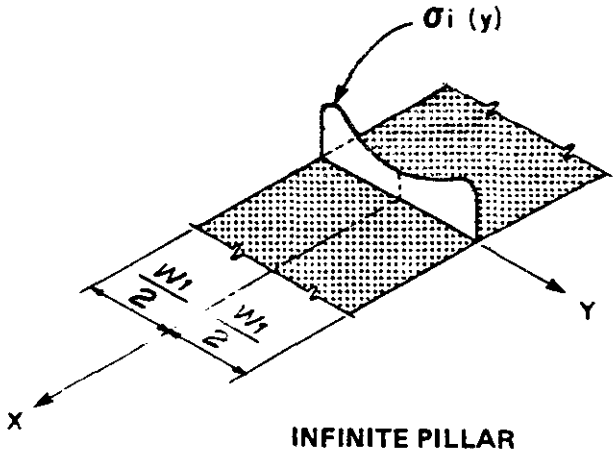

INFINITE PILLAR

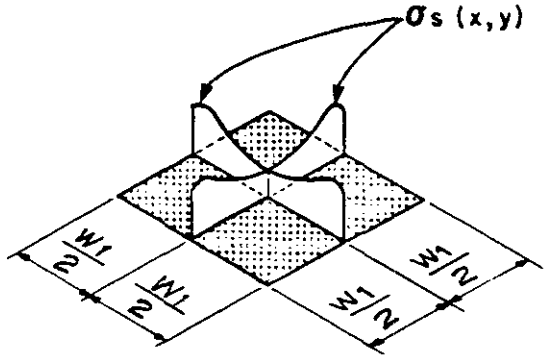

SQUARE PILLAR

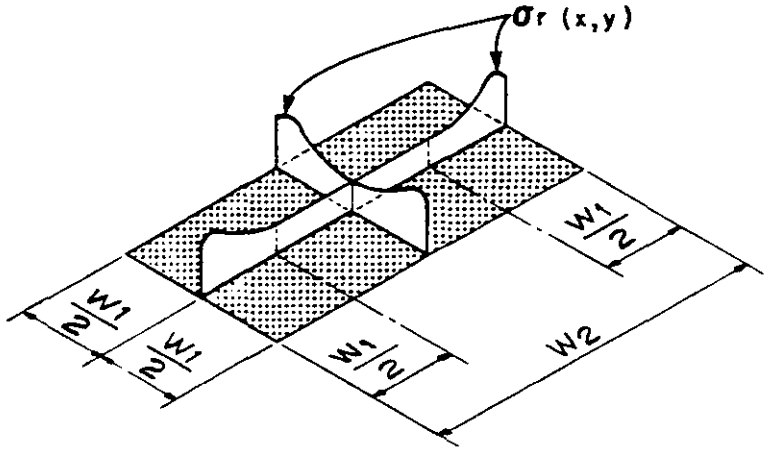

RECTANGULAR PILLAR

Figure 10-14

DRIFTS
VERTICAL STRESS DISTRIBUTIONS IN VARIOUS PILLARS

Figure 10-15 shows the variation of bay strains with elapsed time since completion of excavation for floor extensometer 51X-GE-00242. This extensometer is located at the intersection of Test Room 2 and the N1100 drift. The sudden increase in the bay strains may not be related to salt behavior and is apparently related to system measurement. Thus, it is likely that the maximum average bay strain in the first 6 feet of salt in the floor is no more than 1 percent. The analysis of bay strains in the floor of the drifts in other locations indicates that the maximum average bay strain generally occurs in the first 6 feet (collar to anchor A) in either the roof or the floor. Figures K-36 to K-45 in Appendix K show the variation of bay strains with elapsed time since excavation.

Figure 10-16 shows the rate of bay strains for extensometer 51X-GE-00242. The overall trend is that the rates decrease with time and are currently less than 0.5 percent/year. Figures K-46 to K-55 in Appendix K summarize the variation of strain rates with time.

The decreasing trend in the rates of bay strain with time is an indication that the salt in the roof and floor of the drifts is currently stable.

10.3.3 Prediction of Future Behavior

The results of the analysis of the 8 x 25-foot drift have been categorized as follows:

(1) Effective stresses and effective creep strains immediately after initial excavation; immediately before and after floor lowering; and 5 years after initial excavation.

(2) Principal stresses immediately after initial excavation; immediately before and after floor lowering; and 5 years after initial excavations.

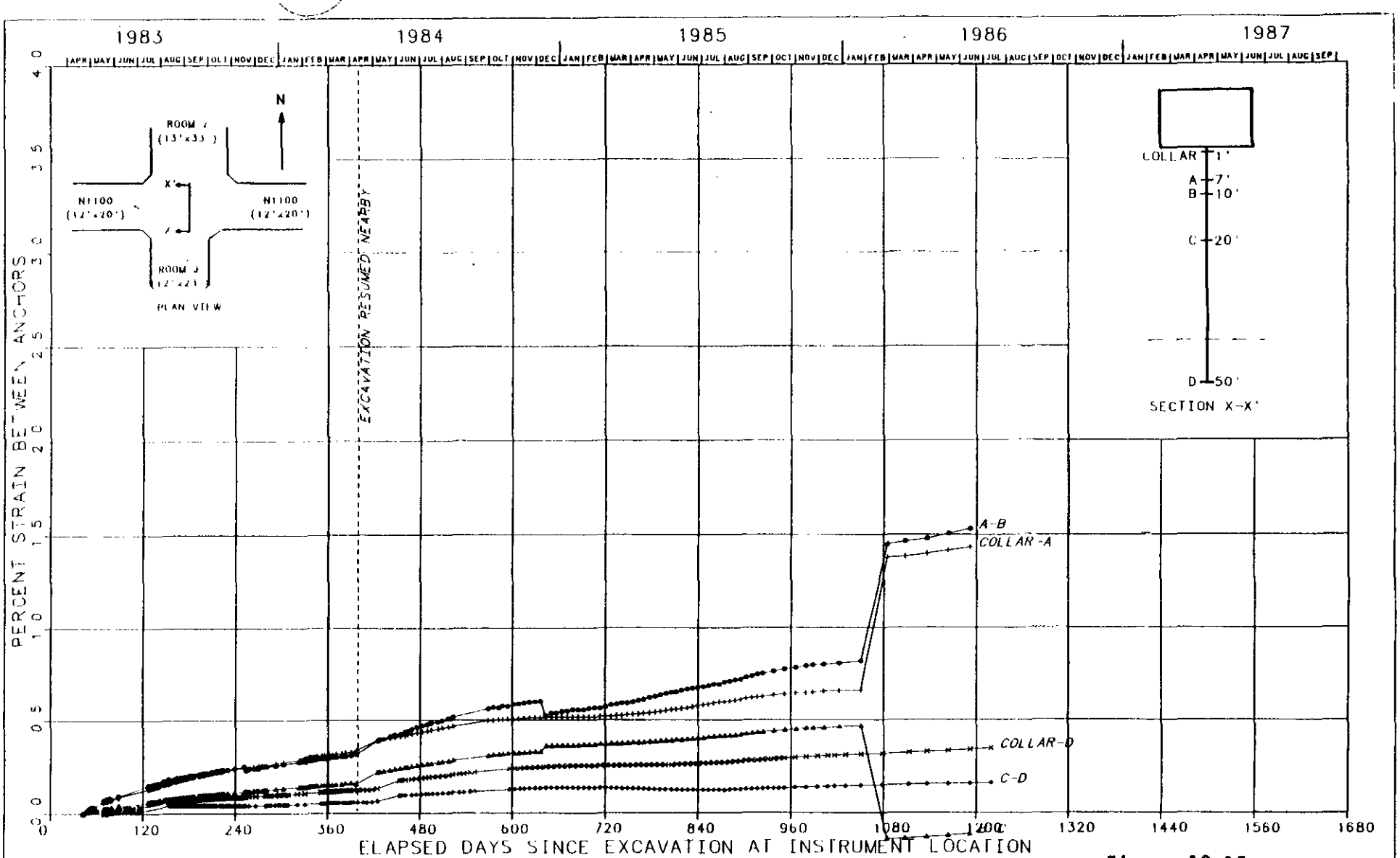

Figure 10-15

DRIFTS
STRAIN VERSUS TIME SINCE EXCAVATION
N1100/TEST ROOM 2 INTERSECTION

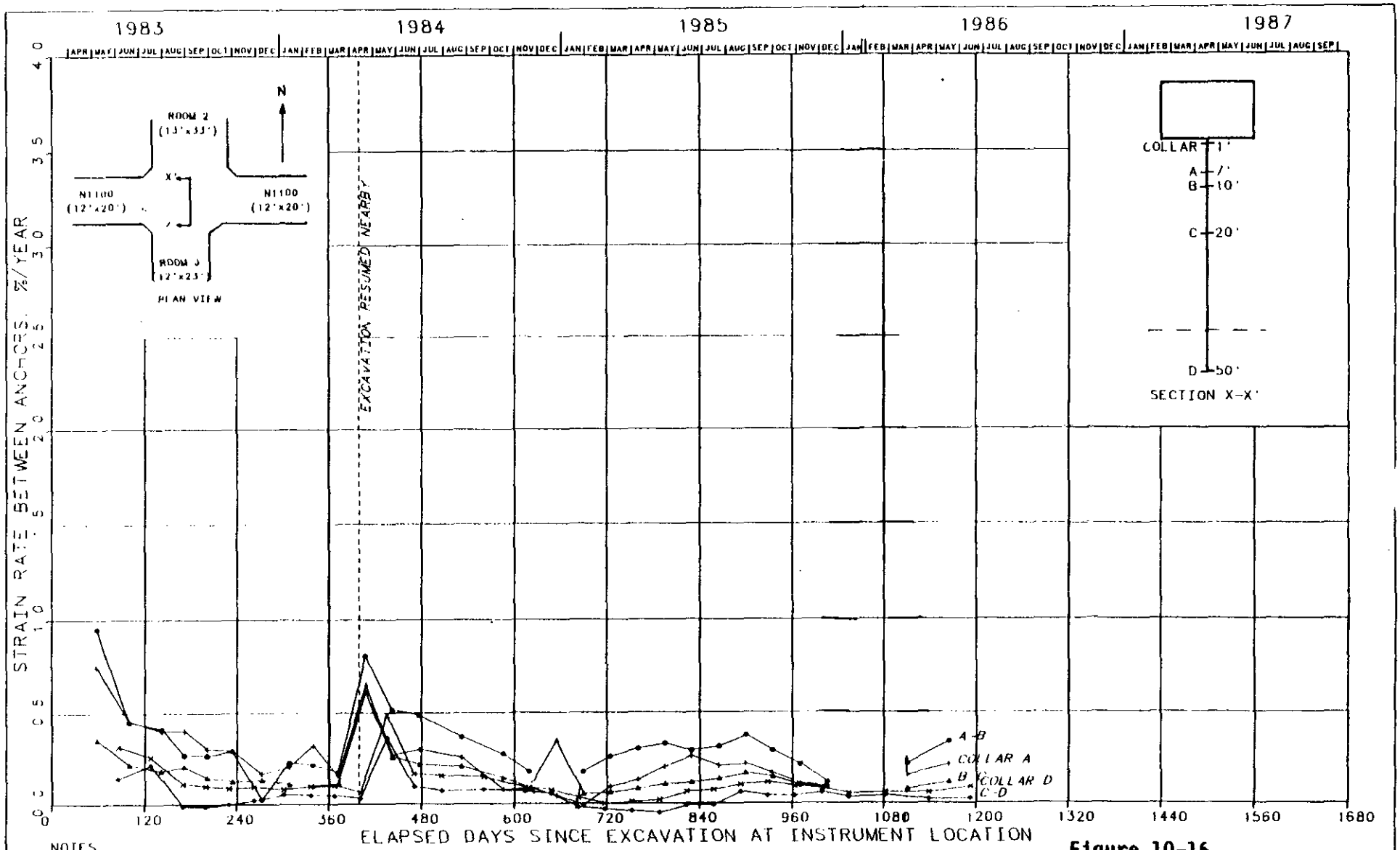

NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

Figure 10-16

DRIFTS
STRAIN RATE VERSUS TIME SINCE EXCAVATION
N1100/TEST ROOM 2 INTERSECTION

(3) Deformed drift shapes immediately before floor lowering and 5 years after initial excavation.

10.3.3.1 Effective Stresses

Figures 10-17 and 10-18 show the distribution of effective stresses in each of the elements of the mesh located near the midheight of the finite element model. The contours are numbered with integers from 1 to 10 with each contour interval representing an effective stress increment of 100 ksf. As time passes, the plots show the effective stresses becoming more concentrated in the anhydrite layer. That is, more energy in the form of strain energy is transferred from the creeping halite and argillaceous halite layers to the anhydrite.

10.3.3.2 Principal Stresses

The principal stress plots (Figures 10-19 and 10-20) show that, immediately after excavation, the magnitudes of the predicted principal stresses are relatively large in the corners of the drift and in the anhydrite layer. As the salt creeps, the principal stresses concentrate in the anhydrite layer near the centerline of the drift.

10.3.3.3 Deformation and Closure

A mesh showing the deformed drift shape is presented on Figure 10-21. This mesh shows the outline of the original, undeformed drift in dashed lines while the deformed shape at the corresponding creep time is shown in solid lines.

The deformed shape immediately before floor lowering shows significant vertical deflection (downward) in the roof area of the drift. The drift floor has heaved upward only slightly and the walls have begun to creep inward.

Effects Due to Extraction Ratio. An analysis was performed to simulate the effect on the response of the drift due to a change in the extraction ratio. A change in the extraction ratio is caused by

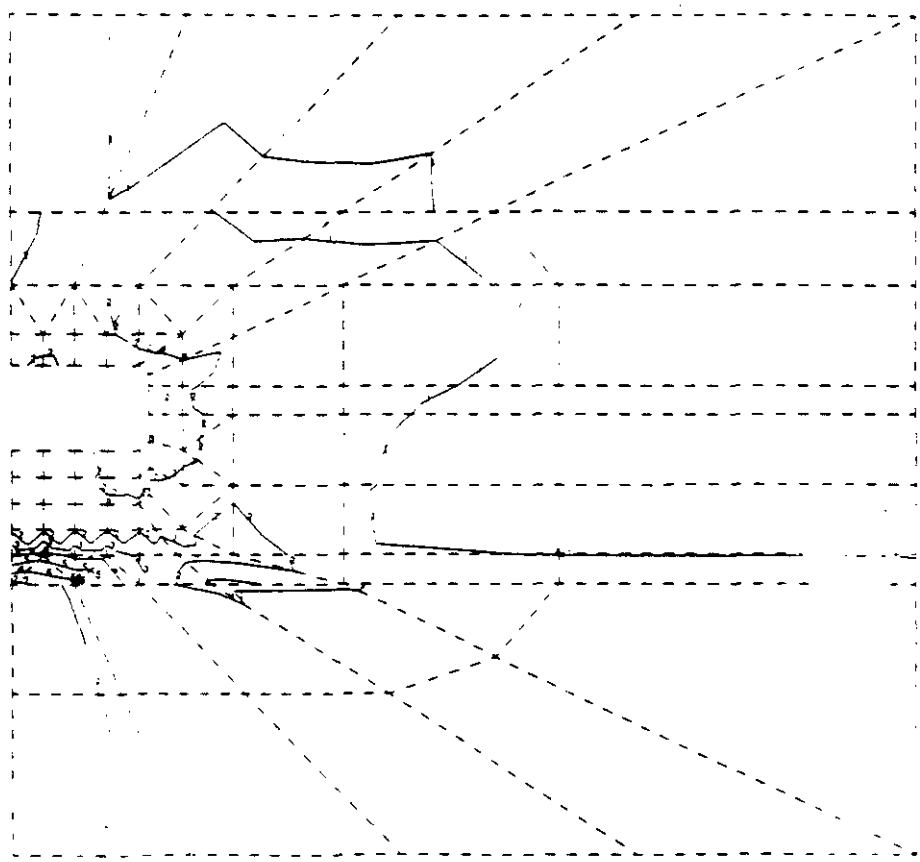

EXPLANATION OF CONTOUR LINES

1 = 100 KSF
2 = 200 KSF
3 = 300 KSF
4 = 400 KSF
5 = 500 KSF
6 = 600 KSF
7 = 700 KSF
8 = 800 KSF
9 = 900 KSF
10 = 1000 KSF

NOTE:
KSF = Kips per square foot.

Figure 10-17

DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION

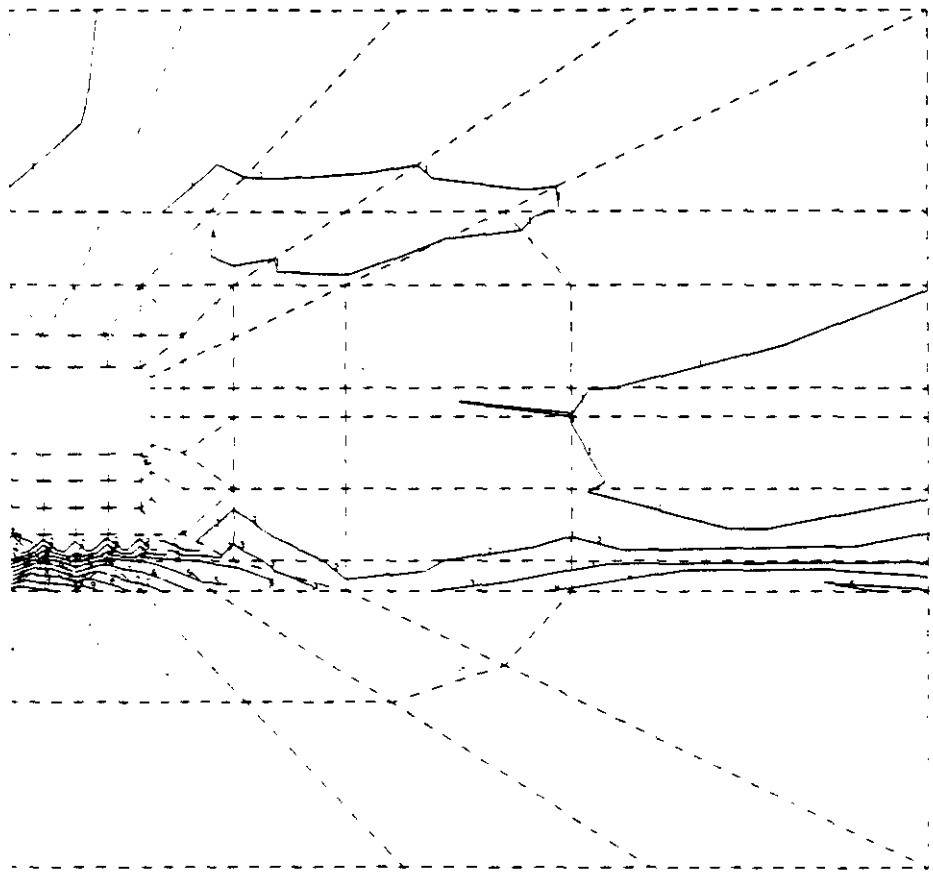

EXPLANATION OF CONTOUR LINES

1 = 100 KSF
2 = 200 KSF
3 = 300 KSF
4 = 400 KSF
5 = 500 KSF
6 = 600 KSF
7 = 700 KSF
8 = 800 KSF
9 = 900 KSF
10 = 1000 KSF

NOTE:
KSF = Kips per square foot

Figure 10-18

DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY BEFORE FLOOR LOWERING

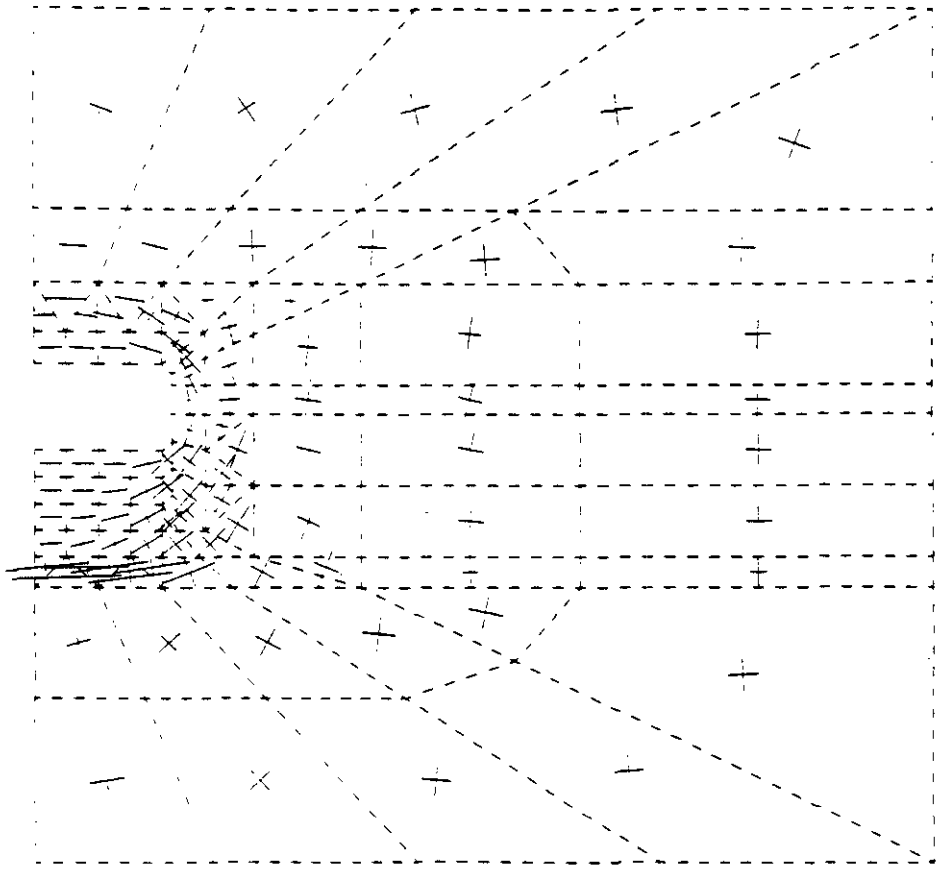

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Figure 10-19

DRIFTS
PRINCIPAL STRESSES IMMEDIATELY AFTER EXCAVATION

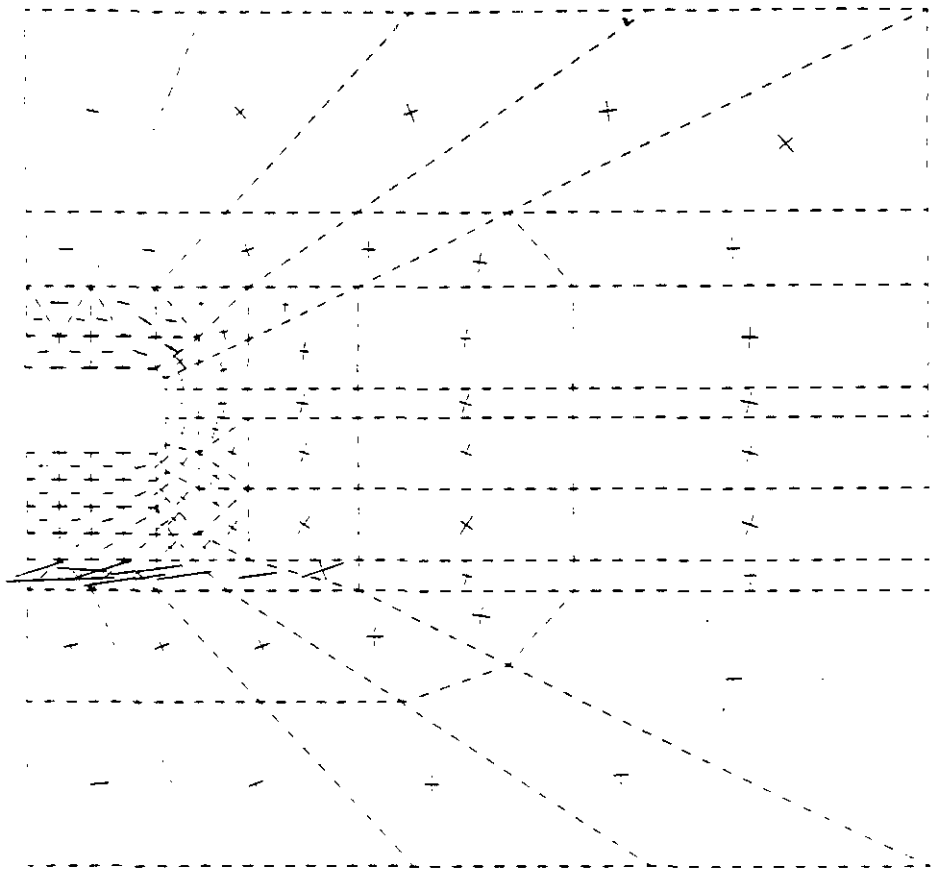

Figure 10-20

DRIFTS
PRINCIPAL STRESSES IMMEDIATELY BEFORE FLOOR LOWERING

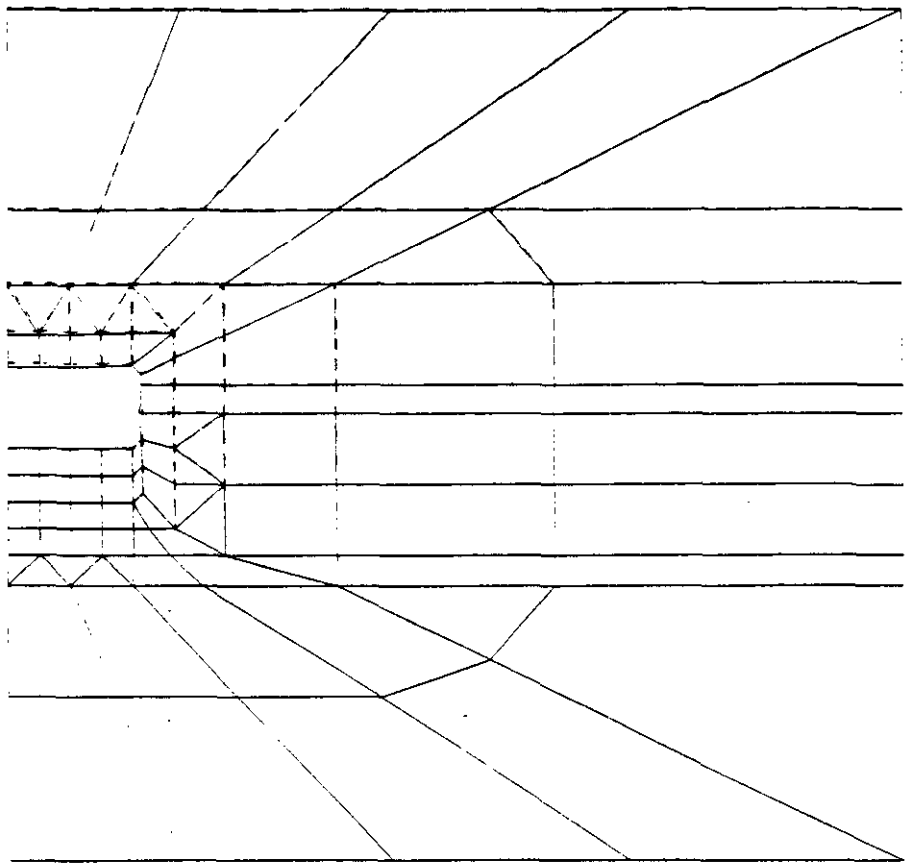

Figure 10-21

DRIFTS
DEFORMED SHAPE IMMEDIATELY BEFORE FLOOR LOWERING

excavation in adjacent or remote areas. The effect due to excavation in adjacent areas was simulated by modifying the finite element model used in the analysis. The difference is essentially a comparison of a single drift to a set of intersecting multiple drifts. Developing a single drift model which accurately represents the behavior of the infinite pillar requires assuming a width for the model. Therefore, to examine the effect of pillar width on analytical results, a 139-foot wide model similar to the one shown on Figure 10-12 was used as a base case and was later widened to 278 feet. Each model consists of an 8 x 25-foot drift.

Figures 10-22 and 10-23 show comparisons of the closure behavior for the two different pillar widths. Because the width of the model is expected to affect the vertical stresses, both the pillar shortening and roof sag components of closure are included. The top graph in both figures indicates that by halving the pillar width to that of the northern area spacing the roof-to-floor closure increases by about 15 percent.

The effects on pillar shortening due to increased overburden stress from the perpendicular drifts can be seen on the middle graph in Figure 10-22. Comparison of the infinite pillar with and without perpendicular drifts indicates a 15 percent increase in pillar shortening due to the presence of the intersecting drifts. Comparing the curves for the narrow pillar in the top two graphs indicates that pillar shortening contributes approximately half of the total closure response. The 15 percent increase in the pillar shortening then corresponds to a 7 1/2 percent contribution in total closure. This is also true for the total closure rate. The combined effects of single versus multiple drifts and multiple parallel drifts versus an intersecting gridwork account for about a 24 percent difference in the total closure rate.

The effects of releasing the boundary constraints at the perpendicular drift wall can be estimated by the use of equation 10-4. For the

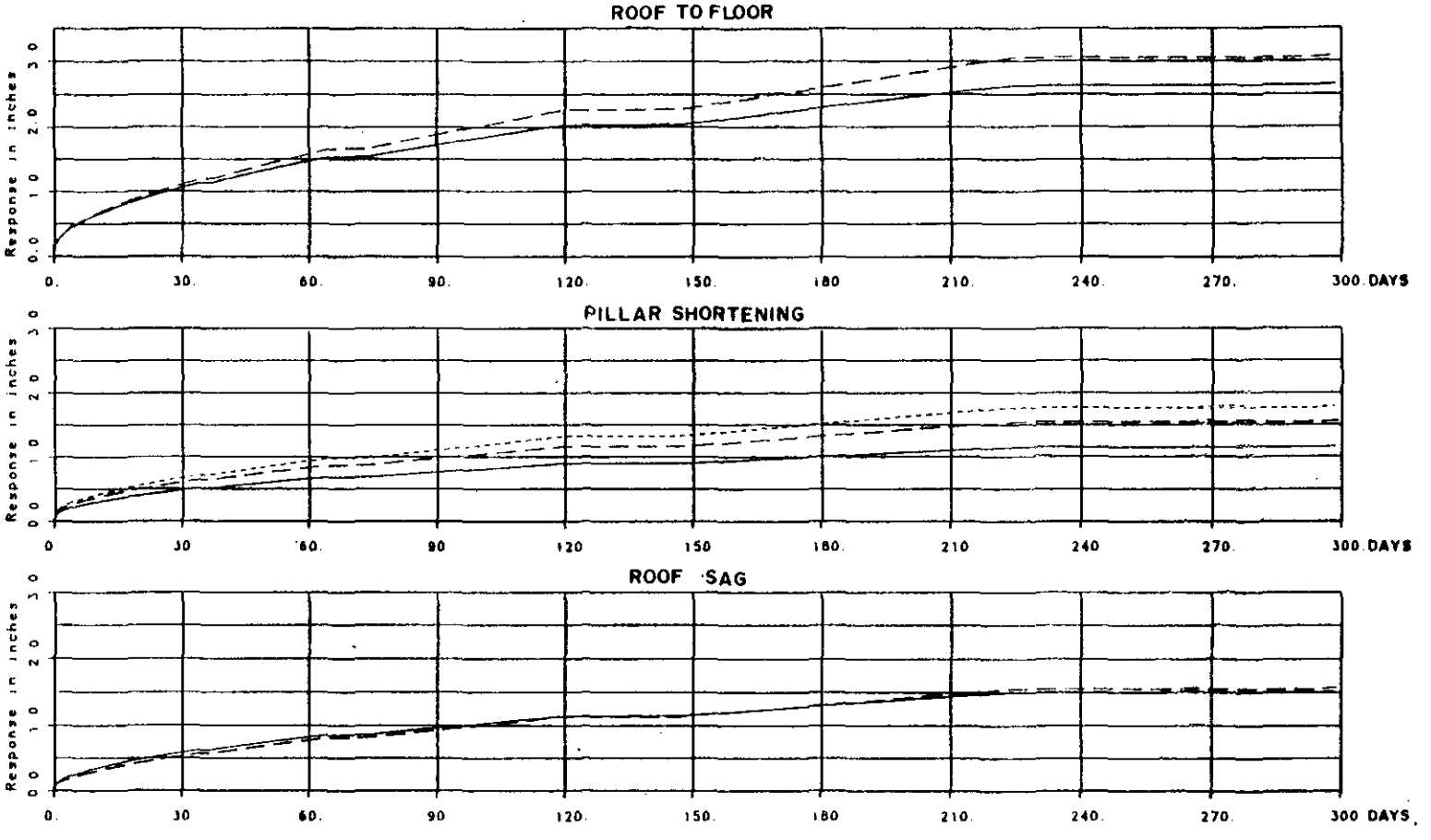

Wide Pillar
Narrow Pillar
Narrow Pillar with Perpendicular Drift

Figure 10-22

DRIFTS
COMPARISON OF CLOSURE COMPONENT RESPONSES

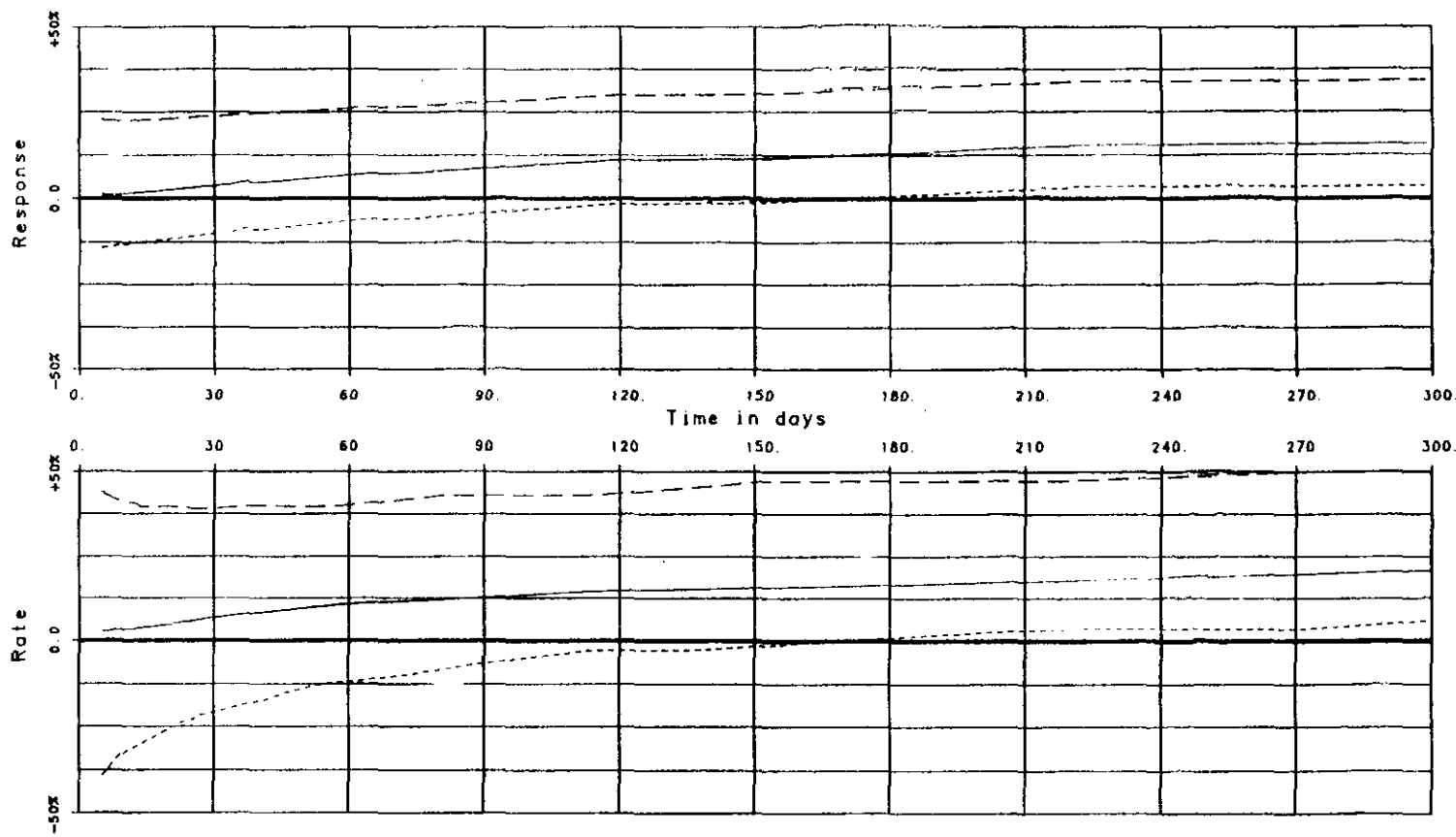

Roof-to-Floor
Pillar Shortening
Roof Sag

Figure 10-23

DRIFTS
CLOSURE EFFECTS DUE TO PILLAR WIDTH

northern area where the W_1/W_2 ratio is approximately 0.4, the average effective stress is increased by about 6 percent. If the pillar shortening rate is proportional to the square of the increase in average effective stress in the pillar, the boundary release accounts for a 12 percent increase in pillar shortening. As described in the previous paragraph, this 12 percent increase in pillar shortening rate corresponds to about a 6 percent increase in the total closure rate. This factor, combined with the previously described effects, yields about a 30 percent difference in the total closure rate. This compares well with the value presented in subsection 10.3.2.2.

The roof sag component of closure is shown in the bottom graph of Figure 10-23. Figure 10-22 shows the comparison of the closure components of the narrow model relative to the wide model which is equivalent to comparing multiple parallel drifts to a single drift. As this figure indicates, the behavior differences appear to stabilize after about 200 days.

10.3.3.4 Effectiveness of Numerical Modeling

The creep parameters C, A and z were determined using roof-to-floor and wall-to-wall closure data. The effectiveness of the numerical modeling which uses one set of measured data to predict with reasonable accuracy other variables such as stress and strain needs to be verified to infuse confidence in the numerical modeling procedure. Besides, such a comparison will enable testing the adequacy of the basic creep level as well as assumptions regarding the statigraphy assumed for the model.

The 8 x 25-foot drift south of S2180 was isolated until July 1986 and different sets of creep parameters were determined by numerical modeling using roof-to-floor closure data from various convergence point measurements. In situ roof-to-floor closure data for stations south of S2180 indicate that the drift behaves essentially like an infinitely long isolated opening except at the very end of the E140 drift. This affords an opportunity to compare the measured relative displacements in the roof as well as in the floor at one instrument

location with the values obtained from numerical modeling which used roof-to-floor closure data from measurements at some other instrument location to "back calculate" the creep parameters.

Figure 10-24 compares the measured relative displacement between the collar and anchor D of extensometer 51X-GE-00247, in the roof at E140/S1950, with the values obtained from the numerical modeling. The calculated value is the relative vertical displacement of two nodes comparable to the positions of the collar and anchor D of the extensometer. The parameters C, A and z were obtained using roof-to-floor closure data from the instrument location at E140/S1879. The agreement is reasonable because the slopes of both the measured and calculated relative displacements are nearly identical. Figure 10-25 similarly compares the measured relative displacement in floor extensometer 51X-GE-00248 at E140/S1950 with the calculated values from the same numerical modeling. The slope of the in situ curve is 28 percent steeper than the calculated value. This is probably because the numerical model assumes that the anhydrite layer in the floor of the drift as linearly elastic with infinite strength. This may not be true if the anhydrite has pre-existing fractures, and thus may not be able to absorb the heave from the salt below.

Figure 10-26 compares the measured wall-to-wall closure at E140/S1879 with the calculated wall-to-wall closure from the results of the same numerical modeling. The average slope of the curve from numerical modeling is nearly 43 percent steeper than the slope of the curve from measurement data.

10.4 CONCLUSIONS AND RECOMMENDATIONS

The following subsections present conclusions pertaining to validation of the drift reference design and recommendations for design modifications. These are based on a comparison of the design criteria, design bases and reference design configurations with the results of the analysis and evaluation of data collected during the design validation process.

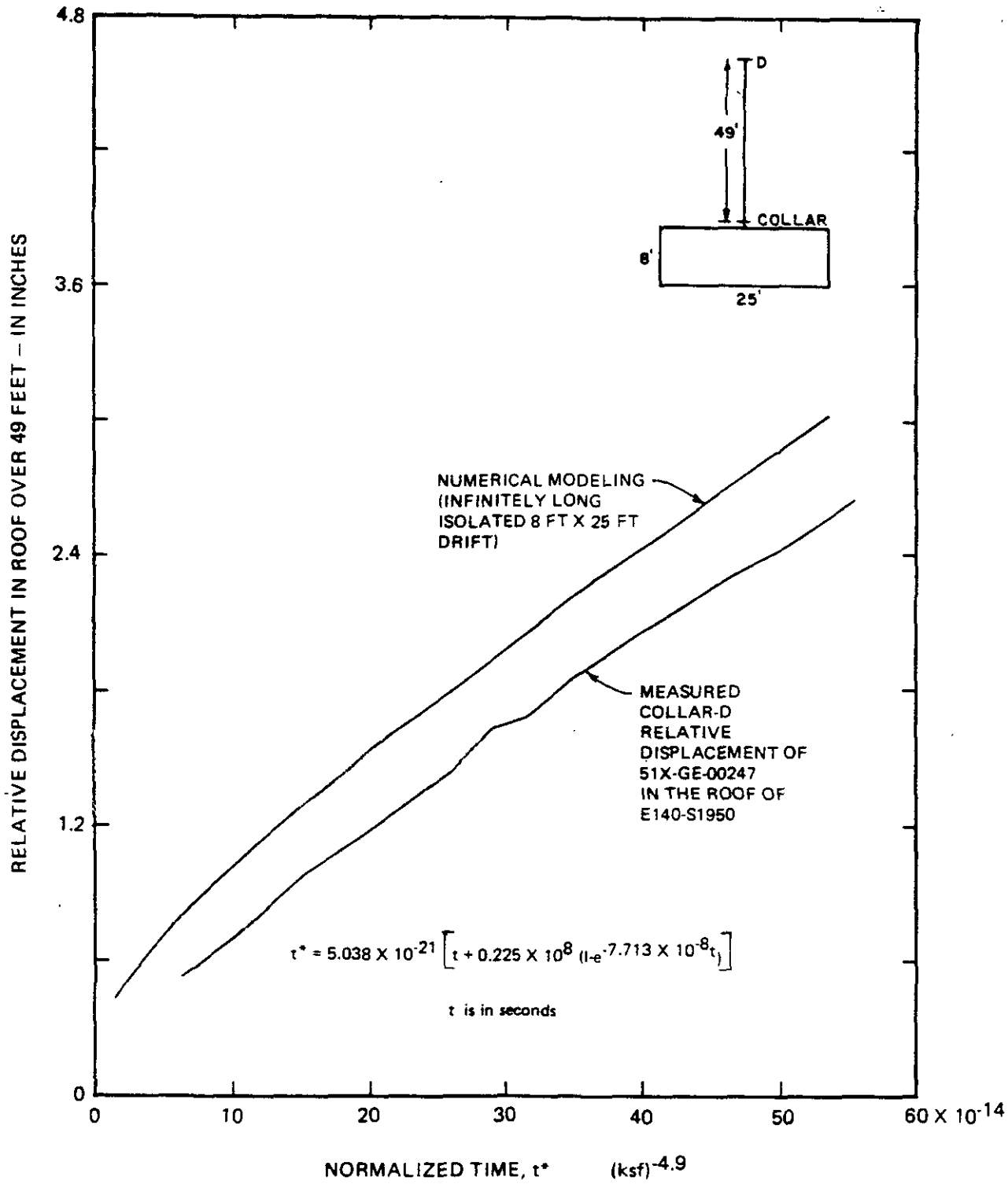

Figure 10-24

DRIFTS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT
DATA FROM ROOF EXTENSOMETER

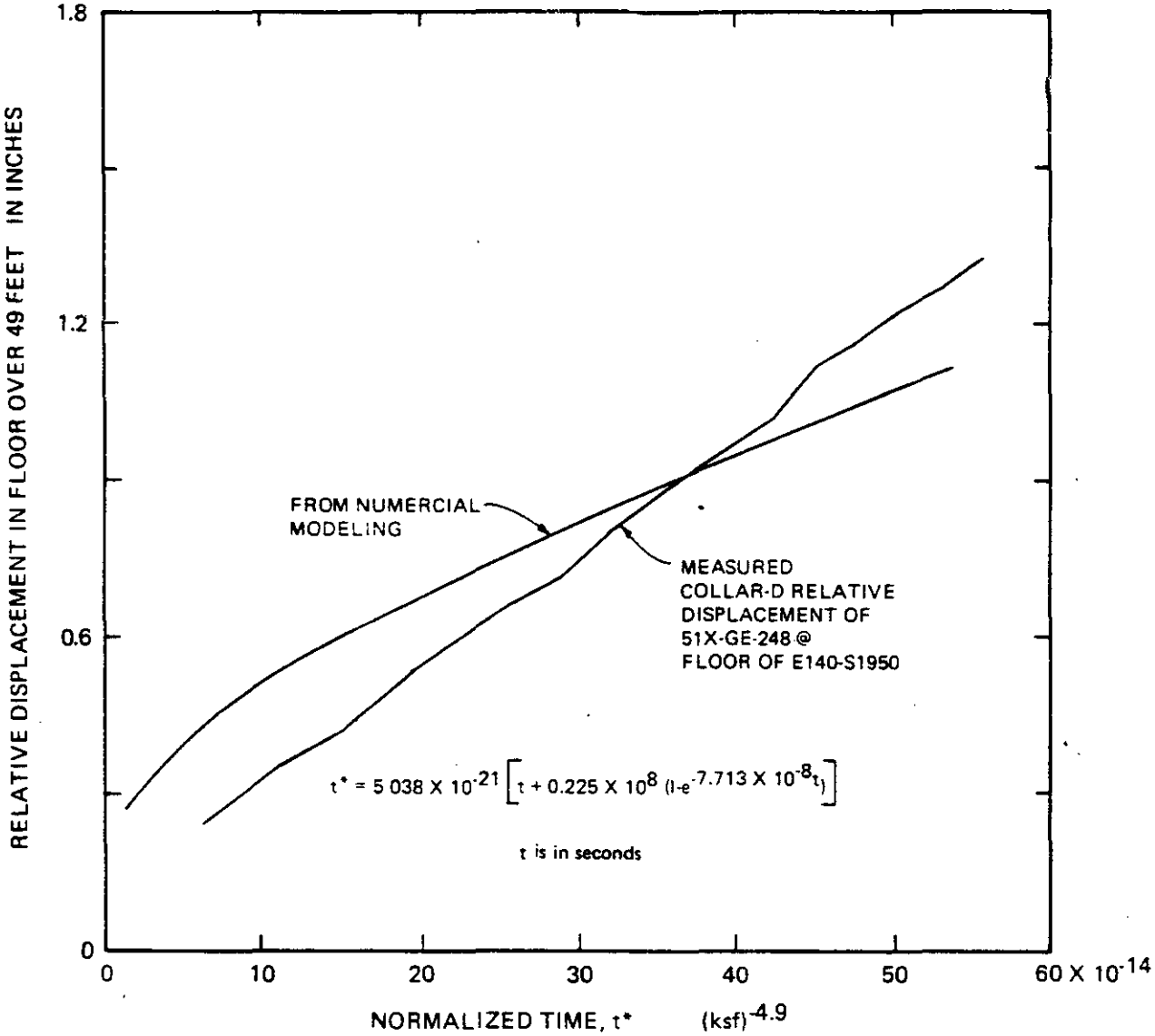

Figure 10-25

DRIFTS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT
DATA FROM FLOOR EXTENSOMETER

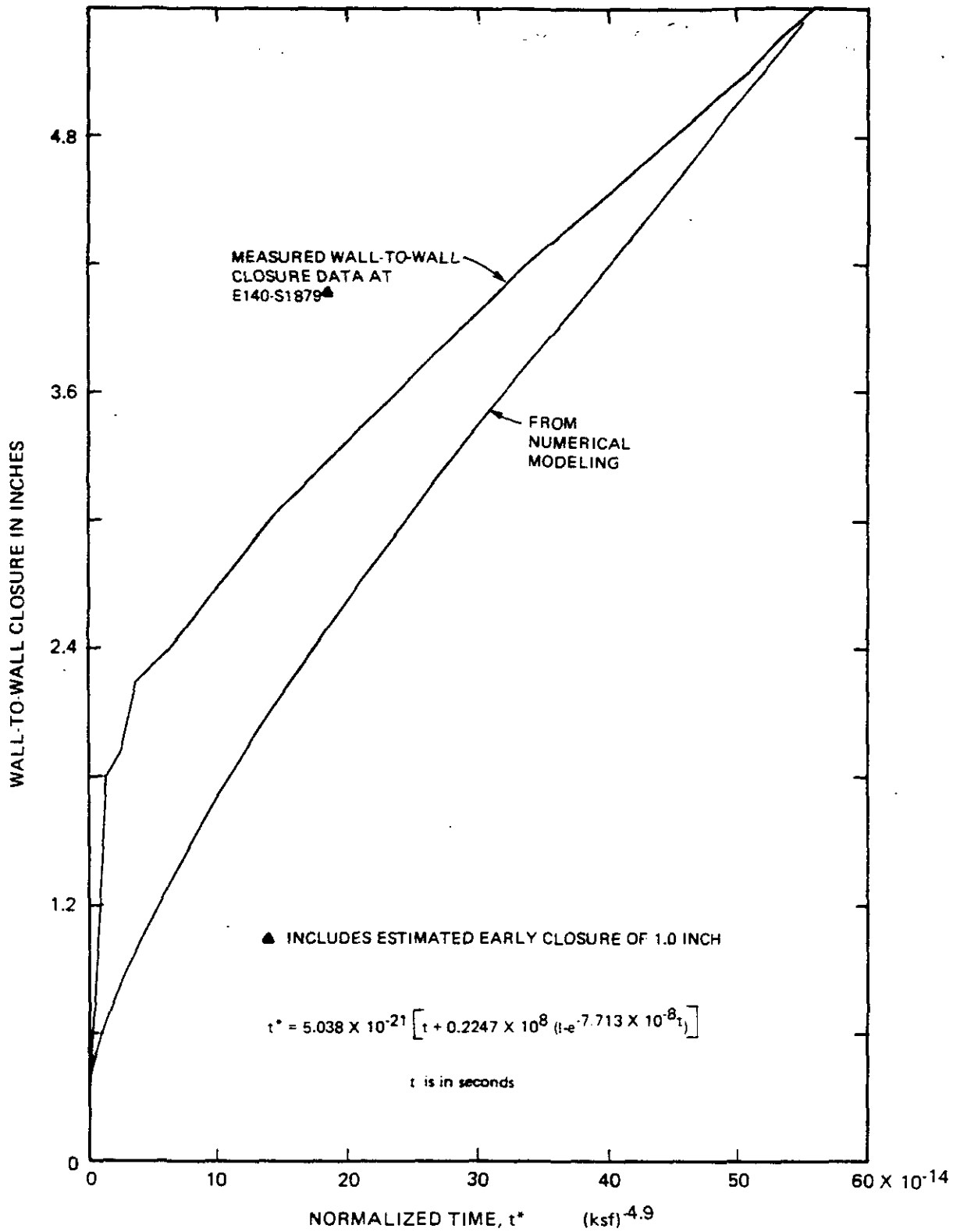

Figure 10-26

DRIFTS
NUMERICAL MODELING VERSUS MEASURED WALL-TO-WALL CLOSURE
AT E140/S1879

10.4.1 Conclusions

The evaluation of field observations and analytical results shows that the design criteria were appropriate for design of the horizontal openings. The three criteria identified as requiring specific evaluation, that the drifts remain within the required structural limits, provide maximum stability, and maintain the minimum required dimensions, were determined to be suitable. The reference design for the horizontal openings is therefore validated.

Spalling from the roof and walls of the drifts and fracturing and spalling at pillar corners will continue. Displacements and separations at clay seams above the roof may slowly increase. This deformational behavior is expected and can be controlled by scaling and rock bolting as necessary.

The average bay strains determined from the relative displacements of extensometer anchors 3 years after drift excavation are within 1 percent. The strain rates as well as the closure rates decrease with time indicating that the drifts are stable. Based on the projections of closure rates, the drifts will continue to be stable.

Fracturing beneath the floor of the drifts is minor and has nowhere developed to near the degree as that beneath the floor of Test Room 3. If additional fracturing develops in the future beneath the drifts, it is also expected to be minor. Based on experience in local potash mines, this type of fracturing is not expected to cause stability or operational problems.

The comparison of measured closure behavior in drifts with different dimensions indicates that the maximum closure and closure rate will occur in 12 x 25-foot drifts. The closure rates are affected by the presence of nearby parallel drifts and crosscuts as well as differences in salt properties. Based on available measurement data and the results of modeling analyses, the closure rate in the 13 x 25-foot

storage area drifts may be 30 percent greater than that of a single, infinitely long drift with the same dimensions (Chapter 12).

Analyses of salt behavior around the 25-foot wide drifts has determined the redistribution of stresses due to the effect of creep. Based on the computed vertical, horizontal and effective stresses, the stress which develops immediately after excavation is followed by relaxation due to creep behavior. According to the analyses, stress should not cause future stability problems in the drifts.

The analyses have also determined the locations of effective creep strain concentrations around the drifts at different times. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, the drifts will remain within the structural stability limits required, with respect to catastrophic failure, during the facility operating life. Minor spalls from the roof and wall surfaces are expected to occur. Analysis of observations in mines and discussion with mine personnel indicates that the surfaces of the drifts may start to deteriorate more rapidly after about 15 years. Increased maintenance will then be required.

10.4.2 Recommendations

Based on the results of design validation of the drifts, it is recommended that all drifts be inspected frequently for operational clearance and safety. If the clearance is insufficient, the drifts must be trimmed to the required dimensions. Trimming the floor to increase drift height is preferred over trimming the roof. Over the 25 year operating life, the roof should not be trimmed more than 12 inches for drifts 25 feet wide or less. Trimming the roof more than 12 inches would make the beam of salt too thin and increase the possiblity of a roof fall. Further trimming must be accomplished from the floor even though this will decrease the thickness of the salt above MB-139. Scaling and rock bolting should be performed where

necessary for safety purposes. Periodic inspection of accessible open boreholes should be performed to monitor the occurrence and behavior of displacements, separations and fracturing in the salt above the roof and beneath the floor of the drifts.

CHAPTER 11

TEST ROOMS

11.1 INTRODUCTION

The four test rooms comprise a panel with a configuration similar to that designed for the waste storage area. The test rooms were instrumented, observed and analyzed in order to evaluate the potential behavior of the storage rooms. This chapter presents the results of data collection activities in the test rooms and the analysis and evaluation of the data with respect to the behavior of the excavated rooms. The information presented here will be used in Chapter 12 to predict the future behavior of the storage rooms and to validate their reference design.

11.2 DESIGN

The test rooms represent a portion of the storage room reference design configuration. The purpose of the test rooms is to provide geotechnical information that can be used to predict the potential behavior of the storage rooms. Because they were excavated to permit validation of the storage room reference design, and will not be used for permanent storage, the test rooms were not specifically addressed in the Design Criteria document. The design criteria apply to the configuration of the storage rooms and, therefore, only indirectly to the configuration of the four-room test panel.

No Design Basis documents were developed specifically for the test rooms. Only two Design Basis documents (refs. 2-9 and 2-18) contain elements pertaining to the test rooms. These elements specify that test rooms shall be provided to verify underground conditions as required by the SPDV Program and that their dimensions shall be 33 feet wide, 13 feet high and 300 feet long. All other design bases that require evaluation are applicable to the storage rooms rather than to the test rooms.

The test room panel is the experimental model for the storage [illegible]. Validation of the test panel reference design configuration is not required. The test room data and analyses presented in this chapter are the bases for validation of the storage rooms. Predictions of the future behavior of the storage rooms based on these data analyses are presented in Chapter 12.

11.3.1 Data Collection

Data collection in the test rooms consisted of the accumulation of geotechnical data from geologic mapping, core drilling, observations of deformational behavior and geomechanical instrument measurements. Geologic mapping and core drilling were performed in the four test rooms. The stratigraphy defined by the mapping and core logging is discussed in Chapter 6. Observations of in situ behavior and data from the geomechanical instrumentation program are presented in the following subsections.

11.3.1.1 Field Observations

Some aspects of test room behavior can only be evaluated by visual observation. Visual inspections of the rooms include observations of their general surface conditions in response to stress redistribution and salt creep. These conditions include small spalls from the roof and walls, especially at their intersection, and vertical fracturing at pillar corners and along the walls in response to pillar shortening.

Field observations include other qualitative and quantitative techniques in addition to visual inspections of excavation surfaces. Boreholes are surveyed using video cameras. Horizontal displacements and vertical separations of the geologic strata surrounding boreholes are determined using a probe, as described in Chapter 7, subsection 7.3.1.4. Wall surfaces of large diameter holes are mapped by a geologist.

A qualitative determination of the conditions of the test rooms is made

by site geologists during an inspection of the rooms at least once every 3 months. These inspections have been documented in each GFDR starting with the February 1984 edition (refs. 4-12 through 4-19). Detailed descriptions of observed test room behavior are contained in each of these reports.

As discussed in Chapter 10, an Excavation Effects Program was conducted throughout the underground facility during May through July 1986. This program was conducted to further characterize near-field deformation above and below the facility level. Ten arrays of boreholes were drilled in the roof and floor of the test rooms. The locations of the arrays are shown on Figure 10-1 in Chapter 10.

The results of some of these observations are used in conjunction with the results of numerical analysis and in situ measurement data to quantify the structural behavior of the test rooms. The documented field observations can be separated into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor displacements, separations and fracturing.

Roof and Wall Spalling. A sounding survey of the roof of each test room was conducted during and immediately after excavation. Only a few areas of drummy rock were discovered and these were either removed or rock bolted.

The rooms have exhibited only minimal spalling over a period of 3 years since their excavation. The drummy areas originally found in the roofs have not grown noticeably, but some additional areas have been discovered by subsequent roof soundings. Additional scaling and rock bolting have been performed in most of these areas. The most noticeable spalling is associated with the argillaceous halite unit (geologic map unit 4, Appendix G, Figures G-1 through G-4) high on the test room walls. This spalling is generally continuous but shallow. Some spalling from the roof close to the walls has also been observed within the past year that has required support by rock bolts in selected areas.

fracturing. [illegible] formed by the intersection of drifts with [illegible] the fractures have separations that range from essentially closed to about 2 inches wide. They generally extend into the rock perpendicular to the rock surface for an unknown distance. All corners of the test rooms show fracturing and consequent spalling. The fractures first appeared in the pillar corners about 3 to 6 months after excavation. They started as thin, hairline fractures and have steadily grown in length, width and presumably depth. Each of the GFDRs document this gradual development of the fractures. Scaling of these corners has been performed periodically.

Vertical fracturing has developed in the pillars parallel to the room walls. This fracturing is relatively minor and, to date, has been observed only in Test Rooms 3 and 4. The fracturing has been detected in horizontal boreholes drilled into the walls and occurs within approximately 2 feet of the wall surface. The fractures range from closed to about 1/32 inch wide.

Roof Displacements and Separations. Inspections of open boreholes in the test room roofs were conducted using a video camera and/or probe. The video camera produces high-resolution, color videotapes that are useful in identifying horizontal displacements and vertical separations. The probe is used in conjunction with a tape measure to determine the location and amount of movement in the boreholes. As in other areas of the underground facility, expected horizontal and vertical movements of the geologic strata surrounding the boreholes have been observed or measured in the test rooms. These observations are summarized in Table 11-1.

Ten arrays of boreholes were drilled in the test rooms in May 1986 as part of the Excavation Effects Program. These holes were used for additional investigation of test room roof displacements and separations. Each hole was inspected using a probe. Table 11-2 presents a summary of the results of this study.

Table 11-1

TEST ROOMS 1 THROUGH 4
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
IG-205	4-17-83	3	56	Room 1; 1 ft from west wall	D
IG-206	4-15-83	3	52	Room 1; 1 ft from east wall	D
IG-203	3-26-83	3	52	Room 2; 1 ft from west wall	D
IG-204	3-83	3	52	Room 2; 1 ft from east wall	D
OH-3	8-83	4	20	Room 2 centerline	S, F
P4X-26	10-83	5	52.1	Room 4; N1360/W630	None
P4X-30	12-83	4	50.9	Room 4; N1360/W630	S
-	-	6	8	Room 4; N1360/W639	D, F
-	-	5	9±	Room 4 center; N1176	S(?)

* D = Displacement; S = Separation; F = Fracturing

Table II-2

EXCAVATION EFFECTS PROGRAM
BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (HxW-FT)	EXCAVATION DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
1	13x33	4/83	ROOM 4, N1175	5/15/86	5/15/86	C	S(?) *	C(?)	D, S *	C	S, C
2	13x33	4/83	ROOM 4, N1264	5/16/86	5/16/86	C(?)	NONE	C	NONE	C	S
3	13x33	4/83	ROOM 4, N1361	5/16/86	5/16/86	NONE	D *	NONE	NONE	D, S, F *	S
4	13x33	4/83	ROOM 3, N1198	5/15/86	5/15/86	NONE	NONE	S	NONE	S	S
5	13x33	4/83	ROOM 3, N1243	5/15/86	5/15/86	NONE	NONE	NONE	S, F (USED ROOM 3 LARGE DIAMETER HOLES)		
6	13x33	4/83	ROOM 3, N1312	5/15/86	5/15/86	S	C	NONE	D, S, F (USED PREVIOUSLY DRILLED HOLES MB-F1-01 THROUGH 03)		
7	13x33	3/83	ROOM 2, N1147	5/21/86	5/22/86	NONE	NONE	C	C	F, C	NONE
8	13x33	3/83	ROOM 2, N1231	5/21/86	5/22/86	F	F	NONE	S	S, F, C	F
9	13x33	4/83	ROOM 1, N1159	5/21/86	5/22/86	C	F	NONE	C	S, C	NONE
10	13x33	4/83	ROOM 1, N1275	5/21/86	5/22/86	F	S, F, C	NONE	C	S	S, C

* EXISTING HOLE.

EXPLANATION

D = HORIZONTAL DISPLACEMENT. FOUND ONLY IN PREVIOUSLY DRILLED HOLES. DISPLACEMENT APPEARS TO DEVELOP WITH TIME FOLLOWING HOLE DRILLING.

S = VERTICAL SEPARATION. PROBE NAIL PENETRATES HOLE WALL SURFACE. VERTICAL SEPARATIONS RANGE FROM APPROXIMATELY 1/16 INCH TO 6 INCHES.

F = FRACTURE ZONE. PIECES OF HALITE COMMONLY PICKED OUT OF ZONE BY PROBE NAIL.

C = PROBE NAIL CATCHES ON HOLE WALL SURFACE BUT DOES NOT PENETRATE. INDICATES POSSIBLE SEPARATION OF LESS THAN 1/16 INCH. OCCURENCES AT KNOWN CLAY LAYERS ARE NOT INDICATIVE OF SEPARATION AND ARE NOT INCLUDED IN THIS TABLE.

NOTES:

1. SECTION LOCATIONS AND HOLE CONFIGURATIONS ARE SHOWN IN CHAPTER 10, FIGURE 10-1.
2. HOLES WERE DRILLED VERTICALLY USING A JACK-LEG DRILL.
3. NOMINAL HOLE DEPTH IS 9 FEET BUT SOME HOLES ARE SHORTER DUE TO LOW DRIFT ROOF OR DRILLING DIFFICULTIES.
4. ONE ROOF AND ONE FLOOR HOLE OF EACH ARRAY WERE GENERALLY DRILLED 3 INCHES IN DIAMETER TO ACCOMODATE USE OF BOREHOLE CAMERA IF DESIRED. OTHER HOLES WERE DRILLED 1-7/8 INCHES IN DIAMETER. EXISTING HOLES WERE USED WHERE POSSIBLE.
5. OBSERVATIONS WERE MADE USING A PROBE CONSISTING OF A NAIL ATTACHED PERPENDICULAR TO THE END OF A ROD.

Floor Displacements, Separations and Fracturing. Horizontal displacements, vertical separations and fracturing have been observed beneath the floor of the test rooms in boreholes. They have been observed to occur in MB-139 and in the overlying halite. Geologic maps of Test Room 3 (Room T) boreholes are presented in Appendix G, Figures G-10 through G-31. A summary of the results of the inspection of all small-diameter boreholes drilled in the floor of the test rooms is presented in Table 11-3. The inspections were accomplished using video equipment and/or a probe.

The only prominent exposure of floor fracturing is in the 36-inch diameter boreholes drilled in the floor of the south half of Test Room 3 (Room T). A total of 22 holes were drilled in this area during September and November 1985 for the erection of structural steel columns. A drilling summary is presented in Table 11-4. The holes are approximately 7.2 feet deep. The bottom of many of the holes coincides with the occurence of clay E at the base of MB-139. The remaining holes were terminated above the base of the marker bed.

The holes were logged on a 360 degree foldout at a scale of 1 inch to 1 foot. All features were measured from a level reference line which was later surveyed to determine elevations. Fracture traces, fracture zones and hairline fractures, in addition to lithologic contacts, were logged. A fracture trace is a distinct fracture surface exposed on the wall of the borehole. Fracture traces shown on the logs, unless otherwise noted, are closed within a few inches of the wall surface. A fracture zone is an area on the wall bounded by distinct fractures. Rock within the zone is broken by numerous smaller fractures spaced less than 1 inch apart. The fractured rock is commonly broken out very close to the wall surface of the borehole due to drilling, but becomes closed within 1/2 to 2 inches of the wall surface. Locally, the zone is open or partially filled with drill cuttings. At a distance of 12 inches from the borehole, the cumulative vertical separation measured over the length of the hole varies from less than 1/4 inch to 6 inches. The hairline fractures are closed fractures usually found

THROUGH 4

RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOOR

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
IG-202	4-18-83	3	52	Room 1; 1 ft from west wall	D
GE-269	1-86	3	55	Room 1 centerline	S, F
IG-201	3-26-83	3	52	Room 2; 1 ft from west wall	D
NG-254	3-84	6	7	Room 2 centerline	None
GE-270	1-86	3	55	Room 2 centerline	S, F
2NPD-01	2-86	5	8.9	Room 2; N1370	S, F
MB-FI-01	12-85	4	12.0	Room 3; N1309	D, S, F
MB-FI-02	12-85	4	12.0	Room 3; N1309	D, S, F
MB-FI-03	12-85	4	12.0	Room 3; N1309	D, S, F
GE-271	1-86	3	55	Room 3 centerline	S, F
P4X-06	1983	5	9.0	Room 4; N1369/W625	D, S, F
P4X-25	10-83	5	50.2	Room 4; N1360/W630	D, S, F
P4X-27	10-83	5	51.1	Room 4; N1360/W630	D, S, F
P4X-29	10-83	5	49.5	Room 4; N1360/W630	D, S, F
P4X-31	11-83	5	50.4	Room 4; N1360/W630	D, S, F
P4X-81	11-83	16	-	Room 4	D, S, F
P4X-83	12-83	16	6.1	Room 4	S, F
P4X-84	1-84	36	9.5	Room 4	D, S, F

* D = Displacement; S = Separation; F = Fracturing

Table 11-4

TEST ROOM 3 (ROOM T)
SUMMARY OF DRILLING

Hole	Date Completed	Drilling Fluid	Communication During Drilling*
TV-01	10-25-85	Brine**	---
TV-02	10-28-85	Air	---
TV-03	11-05-85	Air	TV-07, TV-14 through 75° dipping fracture. TV-15 through fractures in halite close to surface on east side. Surface fracture close to east wall 25 feet south of TV-03. No communication to TV-13. TV-17, TV-12.
TV-04	11-08-85	Air	---
TV-05	11-20-85	Air	---
TV-06	11-13-85	Air	---
TV-07	10-29-85	Air	TV-12
TV-08	11-19-85	Air	---
TV-09	11-21-85	Air	---
TV-10	11-14-85	Air	TV-13, TV-14, TV-17, TV-15, TV-06, TV-11
TV-11	11-11-85	Air	---
TV-12	9-17-85	Air	---
TV-13	10-09-85	Air	TV-12, TV-15
TV-14	10-11-85	Air	TV-15
TV-15	9-23-85	Air	TV-19
TV-16	9-30-85	Air	TV-19, TV-20

TEST ROOM 3 (ROOM T)
SUMMARY OF DRILLING

Hole	Date Completed	Drilling Fluid	Communication During Drilling*
TV-17	10-15-85	Air	---
TV-18	10-02-85	Air	---
TV-19	9-20-85	Air	---
TV-20	9-25-85	Air	TV-19 along main fracture zone on north-northeast side.
TV-21	10-18-85	Air	---
TV-22	10-19-85	Air	TV-19 along main fracture zone on north-northeast side. TV-20 along main fracture zone on west side.

* Communication is indicated by drilling dust emanating from connected holes and detected by driller or geologist.

** Source of brine encountered in TV-01 is clay E at base of MB-139. Driller noted that this clay and about 4 inches of the overlying anhydrite were moist in many holes.

within fracture zones less than 1 inch wide. Some of these appear to be pre-excavation features within MB-139.

Additional small-diameter boreholes were drilled into the test room floors as part of the Excavation Effects Program. The 10 arrays summarized in Table 11-2 include three floor holes at each array. These holes were drilled primarily to determine if the fracturing observed in the 22 large-diameter holes in Test Room 3 extends to other areas beneath the test rooms.

11.3.1.2 Geomechanical Instrumentation

Geomechanical instrumentation in Test Rooms 1 through 4 initially consisted of 19 borehole extensometers, 16 horizontal inclinometers, 6 vertical inclinometers, 4 sets of convergence points, 2 convergence meters, and 2 rigid-inclusion vibrating-wire stressmeters (Figure 11-1). These instruments, with the exception of the inclinometers and convergence points, were connected to the datalogger system on May 13, 1983.

Due to failure for various reasons, some instruments in the test rooms had to be replaced. Those instruments replaced include both stressmeters in Test Room 2 and the extensometers in the floor of Test Rooms 1, 2 and 3. The history of instrument performance and maintenance is discussed in the GFDRs.

Figure 11-2 shows the instruments in each test room and the excavation dates at the instrument locations. Because the excavation of each test room required about 10 days to complete, it was difficult to assign a single date of excavation for some instrument locations. Table 11-5 presents the dates of excavation used for plotting and analysis of the test room data.

11.3.2 Analysis and Evaluation

This section discusses the analysis and evaluation of the results of

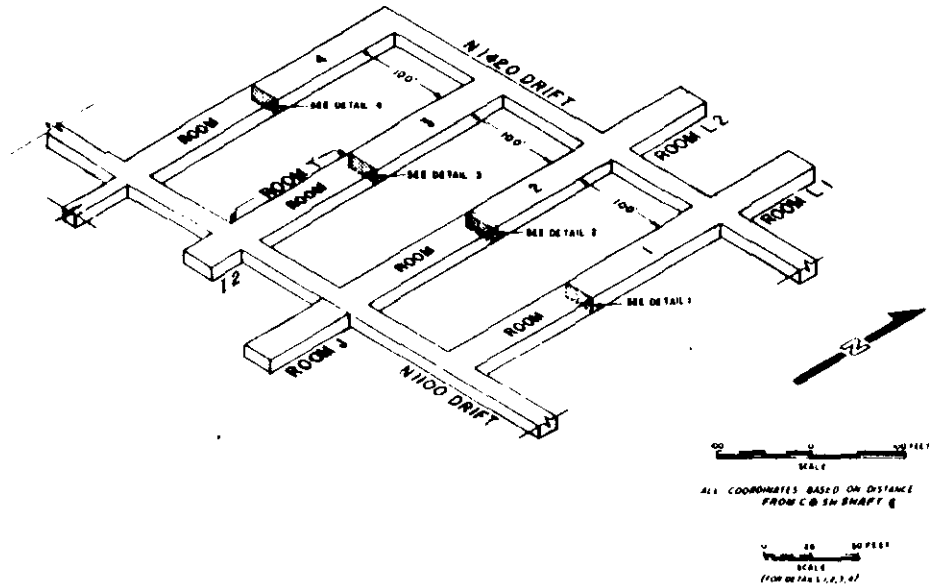

EXPLANATION

- IG INCLINOMETER
- CE CONVERGENCE METER
- GE EXTENSOMETER
- RC RADIAL CONVERGENCE PI
- SG STRESSMETER (RIGID INCLU

NOTE

1. EXTENSOMETERS GE 269, GE 270 AND GE 271 REPLACED GE-230, GE-218 AND GE-210, RESPECTIVELY.

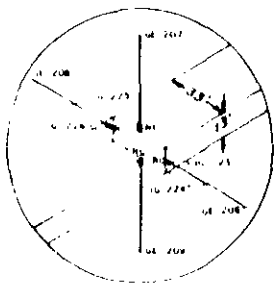

ROOM 4
INSTRUMENTATION LOCATION
DETAIL 4

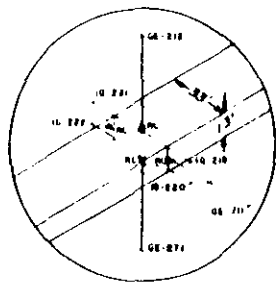

ROOM 3
INSTRUMENTATION LOCATION
DETAIL 3

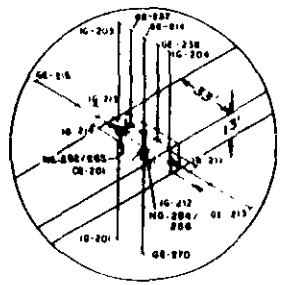

ROOM 2
INSTRUMENTATION LOCATION
DETAIL 2

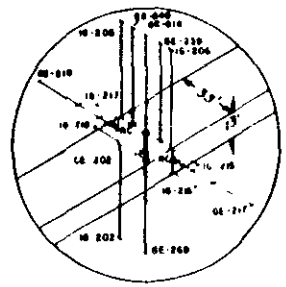

ROOM 1
INSTRUMENTATION LOCATION
DETAIL 1

Figure 11-1

TEST ROOMS INSTRUMENTATI

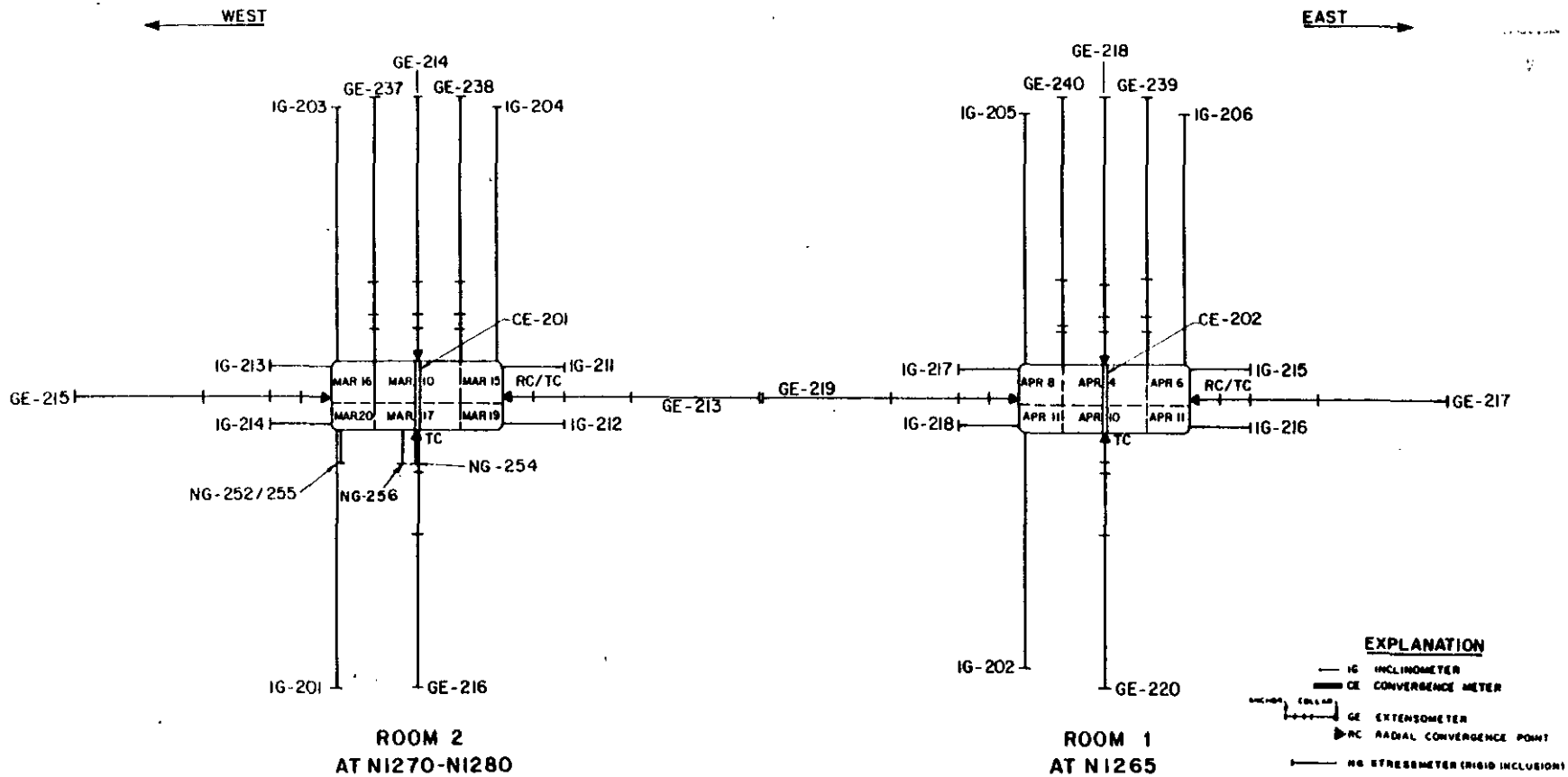

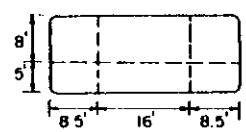

DIMENSIONS OF PASSES

NOTE: EXCAVATION OF THE TEST ROOMS WAS PERFORMED IN 1983.

Figure 11-2

TEST ROOMS
EXCAVATION SEQUENCE AT INSTRUMENT LOCATIONS
Sheet 1 of 2

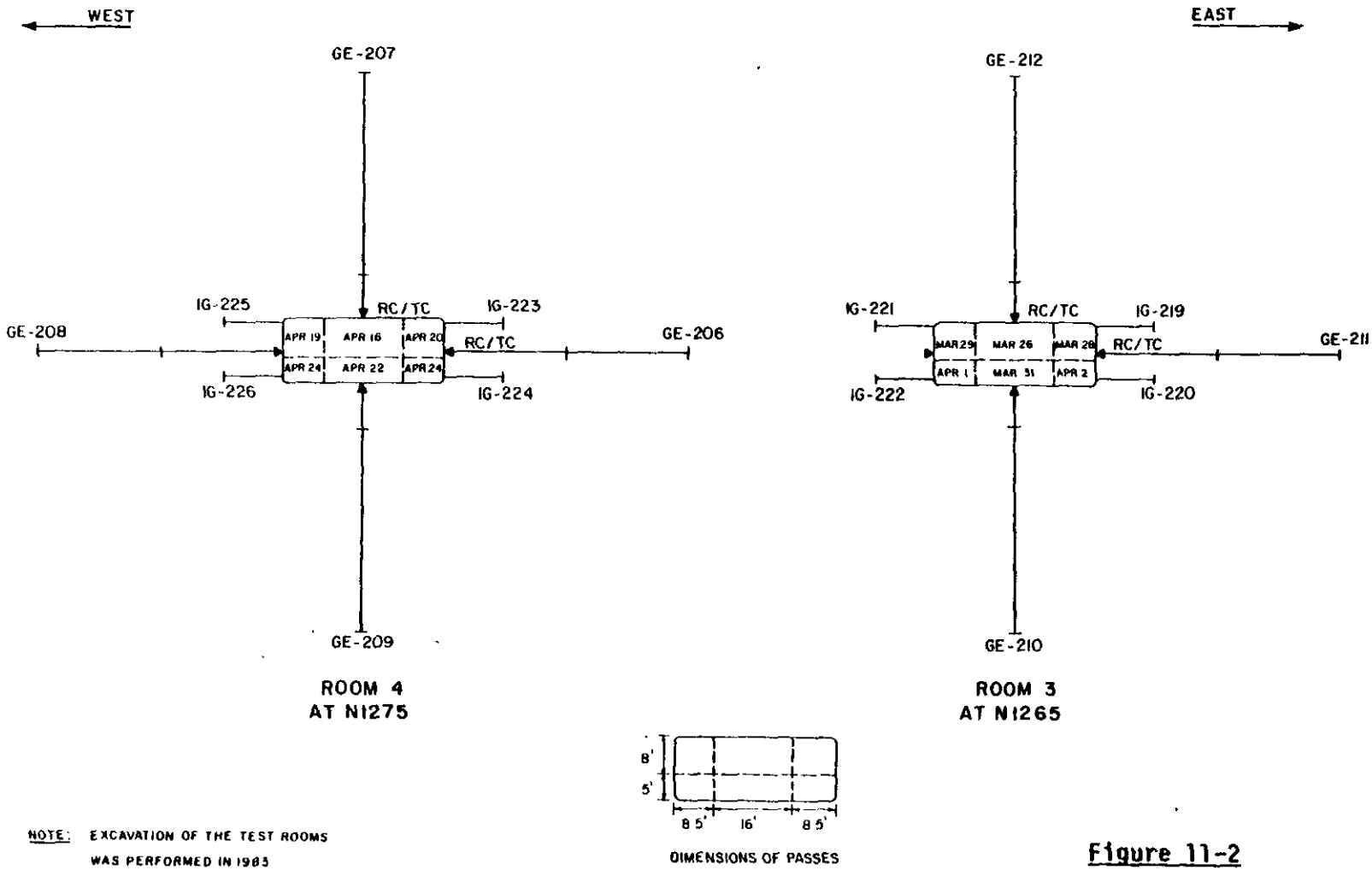

NOTE: EXCAVATION OF THE TEST ROOMS WAS PERFORMED IN 1983

Figure 11-2

TEST ROOMS
EXCAVATION SEQUENCE AT INSTRUMENT LOC.
Sheet 2 of 2

Table 11-5

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation Room 1	Room 2	Room 3	Room 4	Basis for Selection
Convergence meters	51X-CE-00202 51X-CE-00201	Apr. 7, 1983	Mar. 13, 1983			Average of dates for upper and lower center passes.
Roof extensometers - center	51X-GE-00218 51X-GE-00214 51X-GE-00212 51X-GE-00207	Apr. 4, 1983	Mar. 10, 1983	Mar. 26, 1983	Apr. 16, 1983	Date for upper center pass.
Floor extensometers - center	51X GE-00220 51X-GE-00216 51X-GE-00210 51X-GE-00209	Apr. 10, 1983	Mar. 17, 1983	Mar. 31, 1983	Apr. 22, 1983	Date for lower center pass.
Roof extensometers - east side	51X-GE-00239 51X-GE-00238	Apr. 5, 1983	Mar. 13, 1983			Average of dates for upper center and upper east passes.
Roof extensometers - west side	51X-GE-00240 51X-GE-00237	Apr. 6, 1983	Mar. 13, 1983			Average of dates for upper center and upper west passes.
Wall extensometers - east side	51X-GE-00217 51X-GE-00213 51X-GE-00211 51X-GE-00206	Apr. 6, 1983	Mar. 15, 1983	Mar. 28, 1983	Apr. 20, 1983	Date for upper east pass.
Wall extensometers - west side	51X-GE-00219 51X-GE-00215 51X-GE-00208	Apr. 8, 1983	Mar. 16, 1983		Apr. 19, 1983	Date for upper west pass.

Table II-5 (continued)

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation Room 1	Room 2	Room 3	Room 4	Basis for Selection
Wall shortening points - east side	IG 215-216 RS IG 211-212 RS IG 219-220 RS IG 223-224 RS	Apr. 8, 1983	Mar. 17, 1983	Mar. 30, 1983	Apr. 22, 1983	Average of dates for upper and lower east passes.
Wall shortening points - west side	IG 217-218 RS IG 213-214 RS IG 221-222 RS IG 225-226 RS	Apr. 9, 1983	Mar. 18, 1983	Mar. 30, 1983	Apr. 21, 1983	Average of dates for upper and lower west passes.
Wall-to-Wall convergence points - near roof	IG 211-213 TC IG 219-221 TC		Mar. 15, 1983	Mar. 28, 1983		Average of dates for upper east and west passes.
Wall-to-Wall convergence points - near floor	IG 212-214 TC IG 220-222 TC		Mar. 19, 1983	Apr. 1, 1983		Average of dates for lower east and west passes.
Wall-to-Wall permanent convergence points - center	Room 1 RC Room 2 RC Room 3 RC Room 4 RC	Apr. 7, 1983	Mar. 15, 1983	Mar. 29, 1983	Apr. 19, 1983	Average of dates for upper east and west passes.
Roof-to-Floor permanent convergence points - center	Room 3 RC Room 4 RC			Mar. 28,1983	Apr. 19, 1983	Average of dates for upper and lower center passes.

Table 11-5 (continued)

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation Room 1	Room 2	Room 3	Room 4	Basis for Selection
Wall-to-Wall temporary convergence points - center	Room 1 TC Room 2 TC Room 3 TC Room 4 TC	Apr. 7, 1983	Mar. 15 1983	Mar. 29, 1983	Apr. 19, 1983	Average of dates for upper east and west passes.
Roof-to-Floor temporary convergence points - center	Room 1 TC Room 2 TC Room 3 TC Room 4 TC	Apr. 7, 1983	Mar. 13, 1983	Mar. 28, 1983	Apr. 19, 1983	Average of dates for upper and lower center passes.
Floor stressmeters - west corner	51X-NG-00252 51X-NG-00255		Mar. 20, 1983 Mar. 20, 1983			Date for lower west pass. Date for lower west pass.
Floor stressmeters - center	51X-NG-00254 51X-NG-00256		Mar. 17, 1983 Mar. 17, 1983			Date for lower center pass. Date for lower center pass.

Notes:

(1) The "Elapsed Days Since Excavation" shown on the data plots in Appendix J were calculated using this "Assumed Date of Excavation".

(2) See Figure 11-2 for the excavation sequence at the center of the test rooms.

(3) The dates of excavation for individual inclinometers were not used for plotting.

field observations and numerical modeling of the test rooms using in situ measurement data are also presented. In addition, regression analyses of the closure rate obtained from the closure measurements were also performed. The fitted equations were used to supplement the prediction of closure behavior in the storage rooms and are discussed in Chapter 12.

11.3.2.1 Observed Conditions

Roof and Wall Spalling. Minor spalling from the roof in the test rooms, resulting in shallow drummy areas, has occurred as expected. Drummy areas usually occur within 3 to 6 inches of the roof in areas of clear halite not associated with any noticeable clay. Separations occur along local planes of weakness in the halite, probably created by the orientation of crystal surfaces. This same phenomenon occurs in the drifts. Drummy areas have been identified immediately after excavation and additional areas have developed since that time. These later-occurring drummy areas appear to develop primarily along the roof within several feet of the walls.

Spalling along the walls of the test rooms is a result of local stress concentrations and the low tensile properties of salt. It is also related to the percentage of argillaceous material in the halite and to the proximity of floor and roof intersections. The squeezing of clay F at the upper contact of geologic map unit 4 is associated with the spalling phenomenon. Minor spalling is also associated with map unit 0, near the floor.

Pillar Fracturing. Vertical fracturing in the pillars is the expected result of room deformation and stress concentrations. The fractures that have developed in the walls of the test rooms, parallel to the rooms, are considered to be tension fractures resulting from stress relief. Fractures detected in boreholes drilled in the upper portion of geologic map unit 4 are related to the spalling occurring in this unit.

Horizontal inclinometers in the test room walls show both upward and downward vertical movement toward the center of the wall (Appendix J, Figures J-320 through J-335). Although no displacements have been observed, the inclinometer data indicate that the salt has moved toward the central horizontal axis of the room. This movement, due to vertical compressive stress and salt creep, is discussed further in subsection 11.3.2.2. Tensile stresses resulting from this salt creep and pillar shortening have caused fractures to lengthen and widen and new fractures to develop. Fracturing is more prominent at pillar corners that were not beveled to the 4 x 4-foot design.

Fracturing parallel to the room walls will continue to occur. Spalling and local failure will also continue at pillar corners and will require periodic maintenance.

Roof Displacements and Separations. The displacements observed in various open boreholes in the test room roofs are the result of deformation around the openings. The halite at the storage horizon is interrupted by anhydrite beds and thin clay layers. These layers, particularly anhydrite "b" and the underlying clay G, are directly associated with the displacements observed in the test room roofs.

Lateral displacement in the salt above the test rooms is similar to that detected above the drifts. The halite bounded by the roof and clay G moves toward the room center relative to the upper layers of salt. The movement is, however, not exactly symmetrical about the room centerline. This is confirmed by inclinometer readings in the roof of Test Rooms 1 and 2 which show that the lateral movement of the salt close to the roof is greater to the west than to the east (Appendix J, Figures J-316 through J-319). However, this trend is reversed at about 32 feet above the roof of the test rooms. The halite comprising the lower roof beam is subjected to horizontal compressive stresses resulting in shear along clay G and possible vertical separation as the beam moves downward. Some casing deformations have also been observed within 1 foot of the hole collar of the roof inclinometers. The

re[illegible]ve [illegible] and is probably due to the near surface halite resisting the shear movement along clay G.

Movement within the halite below clay G, opposite to that found elsewhere, has been observed in one borehole in Test Room 4. This may be the result of movement along existing planes of weakness in the halite or of the resistance of the halite to shear movement along clay G.

The current results of the Excavation Effects Program indicate that minimal separation or fracturing has occurred at clay G or in the underlying halite above the test room roofs. In Test Rooms 3 and 4, separations less than 1/16 inch wide have been observed. No separation has been observed at clay G. In the array of holes comprising Section 5 in Table 11-2, above the 36-inch diameter holes in the floor of Test Room 3 (Room T), no separations or fracturing were detected. In hole C of Section 4 in Test Room 3, two 1/4-inch vertical separations were found within 1 foot of the roof. These fractures resulted from roof spalling.

Similar small separations were observed in the roof of Test Rooms 1 and 2. Also, fracture zones (in one case 2.4 inches wide) were detected in the halite below clay G in the center hole of three of the four arrays.

<u>Floor Displacements, Separations and Fracturing</u>. The only prominant display of fracturing observed throughout the entire WIPP underground facility during design validation has been in the area of the 36-inch diameter holes drilled in the floor in the south half of Test Room 3 (Room T). Cross sections of the room floor through these holes are presented in Appendix G, Figures G-33 and G-34. Two distinct fracture zones are evident. The first is a dish-shaped zone that angles 10 to 20 degrees downward from near the room walls, intersects MB-139, and flattens near the room center. This zone is most pronounced along the series of holes shown on Figure G-34. In the

northern cross section (Figure G-33), this fracture zone is evident in the holes west of the room centerline but is not present in the holes east of the centerline. In both sections, this upper fracture zone "daylights" at the floor surface or pinches out before reaching the room pillars.

A second fracture zone, dipping approximately 50 to 60 degrees from horizontal and exposed in the holes closest to the room walls, occurs below the upper fracture zone. This lower zone is more regular and planar than the upper zone. With the exception of one hole, this lower zone occurs entirely within MB-139 and is more developed on the west side of the room.

In addition to the two major fracture zones, some subhorizontal fracturing is present just above clay E at the base of MB-139. This fracturing is most evident in the holes closest to the room centerline. No separations along clay E were observed in any of the holes.

Communication between holes during drilling was observed and is described in Table 11-3. During the drilling of hole TV-03, drilling dust was observed coming up through a surface fracture close to the east wall, 25 feet south of the hole location.

A series of measuring pins were installed in two open holes, TV-03 and TV-19, in late January 1986 to monitor movements within the holes. The pins were installed in MB-139 and in the overlying halite and straddle the fracture zones. Measurements taken until the holes became inaccessible in June 1986 indicated that some small-scale dilation was occurring in both of the holes.

The fractures observed beneath the floor of Test Room 3 are directly related to the excavation geometry and the stratigraphy. Some fractures within MB-139 may have been pre-existing but have opened since room excavation.

[illegible] inch diameter holes [illegible] north half of Test Room [illegible] fracturing is occuring there. These holes were drilled to a nominal depth of 12 feet below the floor. A thin fracture zone was detected within 1 1/2 feet of the floor in two of the holes and minor fracturing was detected in MB-139 in all of the holes. This fracturing is significantly less developed than that observed in the south half of Test Room 3.

The 22 large-diameter holes in Test Room 3 were drilled late in 1985. They are, therefore, too recent to document any lateral displacements along the observed fractures. However, other older floor boreholes do indicate relative displacement. In Test Room 4, boreholes P4X-06, P4X-25, P4X-27, P4X-29 and P4X-31 all show multiple displacements and vertical separations (Table 11-2). These are primarily within MB-139 and exhibit up to 2 inches of lateral displacement and up to 1/2 inch of vertical separation. These five holes are near the room centerline. The relative movement of the multiple displacements observed is complicated and does not follow the simpler interpretation of the roof displacements. The most significant displacements in all of the holes have taken place closest to the floor surface and, in all cases, the salt above the fracture has moved east relative to the underlying salt. Inclinometers IG-202 and IG-201, in Test Rooms 1 and 2, also exhibit similar relative displacement. Both of these inclinometers are on the west side of their respective test rooms. The marker bed and the overlying salt have moved east towards the room centerline relative to the underlying salt. Movement is apparently along clay E and is approximately 3/4 inch.

Although no detailed investigation of the salt beneath the test room pillars has been performed, the Test Room 3 fracture mapping indicates that it is unlikely that fractures extend beneath them to any significant extent. Neither of the two fracture zones identified can be traced into the pillars. The upper fracture zone pinches out prior to reaching the walls or daylights at the floor surface. The lower fracture zone cannot be traced beyond the hole walls, but it is not

suspected of continuing beneath the pillars. One small diameter hole was drilled at an angle into each of the walls of Test Room 3 in May 1986. Except for a localized clay break at a depth of 3.2 feet, there was no evidence of separation.

Fractures and separations have been observed in four large-diameter holes drilled in the floor in the south end of Test Room 4. Fractures were observed in these holes during drilling in November 1983 and January 1984. The fracturing was minor, however, with no separations observed. One hole became inaccessible soon thereafter. Fractures in the other holes have been observed to increase in number and to exhibit separation (Table 11-2). Fractures occur in the marker bed and in the overlying halite. Because two of the holes have restricted access, monitoring of the fractures is difficult. Borehole P4X-84, in the southwest corner of Test Room 4, was mapped in February 1986 and the results are shown in Appendix G, Figure G-32. The separations and displacements in P4X-84 over the 2 year period since excavation are small in comparison to those in the floor holes in the south half of Test Room 3.

A low-angle fracture in the floor of Test Room 2 was observed in August 1985. An inspection in June 1986 showed that it extended from approximately N1242 to N1208. This fracture daylights at the floor surface, 1.5 feet to 6 feet from the west wall, and extends 2 feet below the floor surface toward the east. Approximately 8 to 10 inches of separation is present along this fracture, and approximately 25 square feet of floor in the vicinity of this fracture sounds drummy.

As part of the Excavation Effects Program, a series of holes were drilled in each of the test rooms to determine the extent of floor fracturing and for future monitoring of this phenomenon. Existing boreholes, such as those in Test Rooms 3 and 4, were utilized where possible. The locations of the holes are shown on Figure 10-1 in Chapter 10. These holes were inspected using a probe and the results are summarized in Table 11-2. The holes exhibited some fractures and

[illegible] The dish-[illegible] profile observed in the holes in [illegible] was also found in some of the hole arrays, although [illegible] much smaller scale. It was most pronounced in several of the holes close to the room walls where separations were estimated to be a maximum of 6 inches. In other locations, the separation ranged from 1/8 inch to 3 inches. Within MB-139, fractures and separations found in the central holes of the Test Room 1 array ranged from approximately 1/8 inch to 3 inches. For other hole arrays, the maximum separations were 1/2 inch and, again, these were found in the central holes.

Horizontal displacements and vertical separations have been observed in various small-diameter boreholes in the test room floors. Horizontal displacements up to 2 1/2 inches and vertical separations estimated to be up to 1/2 inch wide were present in some of these holes. Multiple displacements in single boreholes were also present. The horizontal displacements and vertical separations found in many of the holes are within MB-139 or coincide with the lower contact of this unit. These displacements and separations have developed since room excavation, although some of them may have developed along pre-existing planes of weakness in the marker bed.

In addition to observations made in open boreholes, ground-penetrating radar and gas permeability testing have been conducted in some of the test rooms. A radar survey was conducted in Test Rooms 2 and 3. The radar method has some limitations. It appears to be effective in locating the first reflector such as a fracture or clay seam beneath the floor, but the structure below this is not easily distinguished. MB-139 is readily defined on the records but fractures within it cannot be discerned.

Zones of relatively high permeability have been found to develop immediately beneath the floor of the test rooms and beneath the intersections of Test Rooms 1 and 2 with the N1420 drift. There also appears to be a slight increase in permeability, relative to background values, within MB-139 and immediately beneath the floor of the N1420

drift between Test Rooms 1 and 2. Some increase in permeability also appears to occur in MB-139 near the center of the pillar between Test Rooms 2 and 3. This data is only preliminary, however, because only one hole intersecting MB-139 beneath the pillar has been drilled and tested for permeability.

Gas tracer measurements performed along the centerline in the north half of Test Room 2 and across the N1420 drift to Room L2 indicate the existence of fracturing beneath the floor. A video survey of the boreholes used for the tracer tests shows the presence of fracture zones and separations mainly within MB-139. Holes tested along the N1420 drift, except at intersections, show little increase in background permeability. A video survey of these holes did not show any separations or fracturing.

In summary, subhorizontal fracturing has developed beneath the test room floors. The majority of this fracturing occurs as single fractures or thin fracture zones within MB-139 and the overlying halite. Horizontal displacements ranging up to 2 inches and separations generally ranging up to 1/2 inch have been measured in small diameter boreholes. Separations up to 6 inches have been observed locally. Only the south half of Test Room 3 (Room T) in the WIPP underground facility has exhibited extensive fracturing beneath the floor.

The Excavation Effects Program was designed in part to determine if fracturing similar to that occurring beneath the floor of Test Room 3 has developed in other areas of the facility. The results of this program show that, although small-scale fracturing is occurring beneath all of the test rooms, no other areas of fracturing have developed on the same order of magnitude as that in Test Room 3. The fracturing occurring beneath the floor of Test Room 3 appears to have existed prior to drilling. The stress changes induced by the size and number of holes drilled in this area probably exacerbated the existing fractures.

Roof-to-Floor Closure. Figure 11-3 shows the re[illegible] between measured roof-to-floor closure and the elapsed time since excavation of the four test rooms, as determined from convergence meter and convergence point data. Because of differences in time-lag between the end of excavation and the time of the initial readings, the relative positions of these curves are deceptive. For analysis purposes, the roof-to-floor closure that occurred before installation of the convergence instruments was determined using equation 10-1 in Chapter 10.

In addition, part of the measurement data from the temporary convergence points were added to the permanent convergence instrument data to obtain approximate values of the actual roof-to-floor closure. Table 11-6 shows roof-to-floor convergence point readings and adjusted closure magnitudes for the test rooms. Item 7 in this table shows the approximate roof-to-floor closure obtained by adding suitable portions of the temporary convergence point readings to the readings of the permanent convergence instruments.

It is apparent that the fracturing observed in the floor of the test rooms, and vertical separations in the roof, have contributed to the total roof-to-floor closure. However, based on measured cumulative vertical separations in September 1985, the contribution of floor fracturing to the total roof-to-floor closure is not more than 1 inch.

The total estimated closure (item 9 in Table 11-6) includes the values of early closure estimated by using equation 10-1 in Chapter 10. Based on the indicated additive values, the maximum roof-to-floor closure of approximately 16 1/2 inches through June 1986 occurs in Test Rooms 2 and 3. Test Room 4 has undergone the least roof-to-floor closure. Figure 11-4 shows the adjusted roof-to-floor closure values as a function of time.

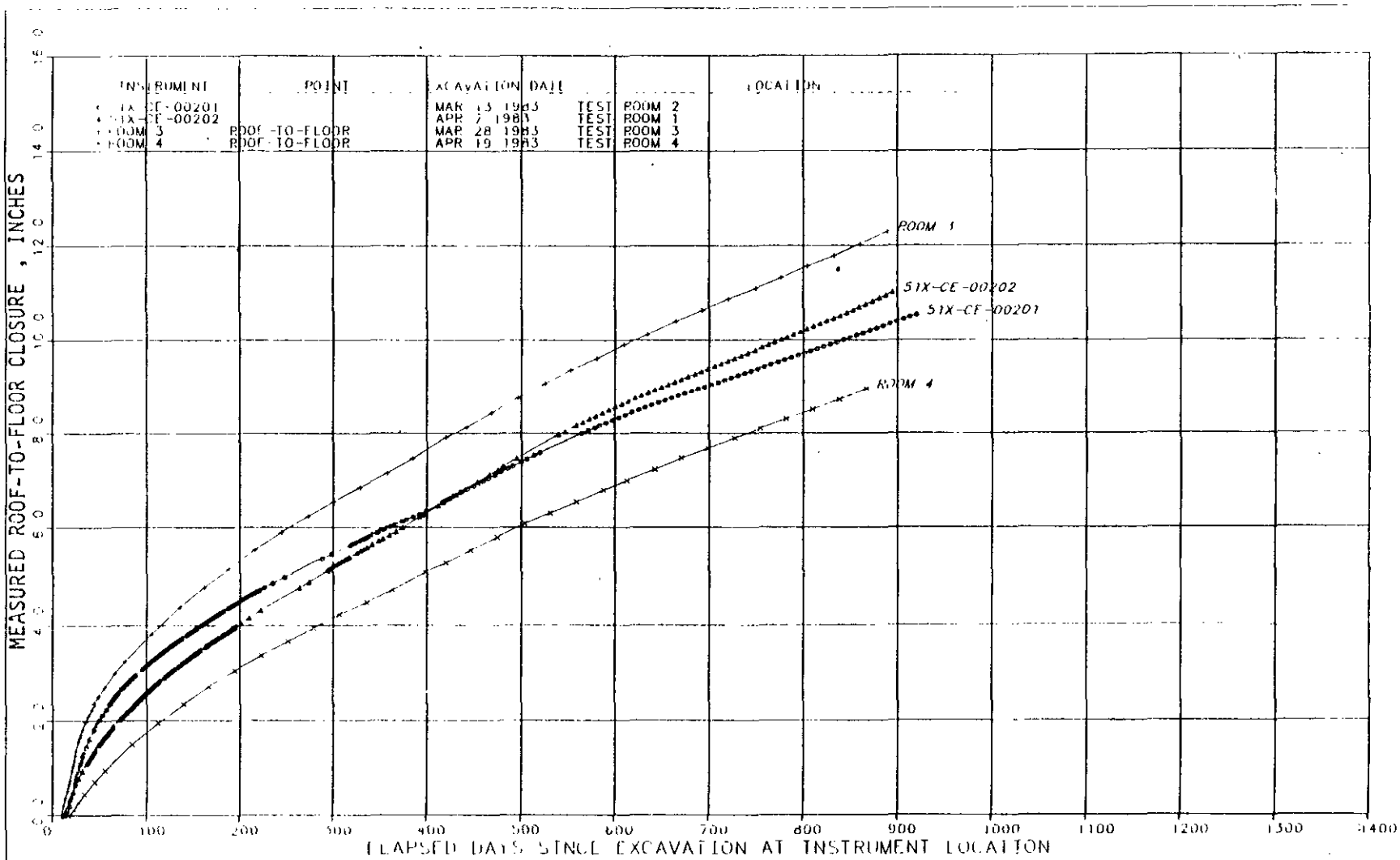

Figure 11-3

TEST ROOMS
MEASURED ROOF-TO-FLOOR CLOSURE COMPARISON

Table 11-6

TEST ROOMS
ROOF-TO-FLOOR CLOSURE COMPARISONS

Description	Test Room 1	Test Room 2	Test Room 3	Test Room 4
(1) Excavation period	April 3-13 1983	March 9-20 1983	March 24-April 3 1983	April 15-25 1983
(2) Date of first reading of temporary convergence (TC) points	April 12, 1983	March 21, 1983	April 4, 1983	April 26, 1983
(3) Date of first reading of permanent convergence (RC and CE) instruments	April 20, 1983	March 29, 1983	April 7, 1983	May 6, 1983
(4) Reading of TC points (inches) on date indicated	0.84 April 20, 1983	0.88 March 28, 1983	0.40 April 7, 1983	0.45 May 5, 198[illegible]
(5) Reading of RC and CE instruments (inches) on date indicated	13.11 June 13, 1986	12.20 June 13, 1986	13.83 April 28, 1986	10.62 April 28
(6) Total elapsed days of combined TC and RC measurements [Date for (5) - Date for (2)]	1157	1179	1120	1098
(7) Total measured closure (inches) [(4) + (5)]	13.95	13.08	14.23	11.0[illegible]
(8) Estimated closure (inches) by regression analysis for the period of (2) - (1)	2.39	3.72	2.17	1.32
(9) Total estimated closure (inches) [(7) + (8)]	16.34	16.80	16.40	12.39

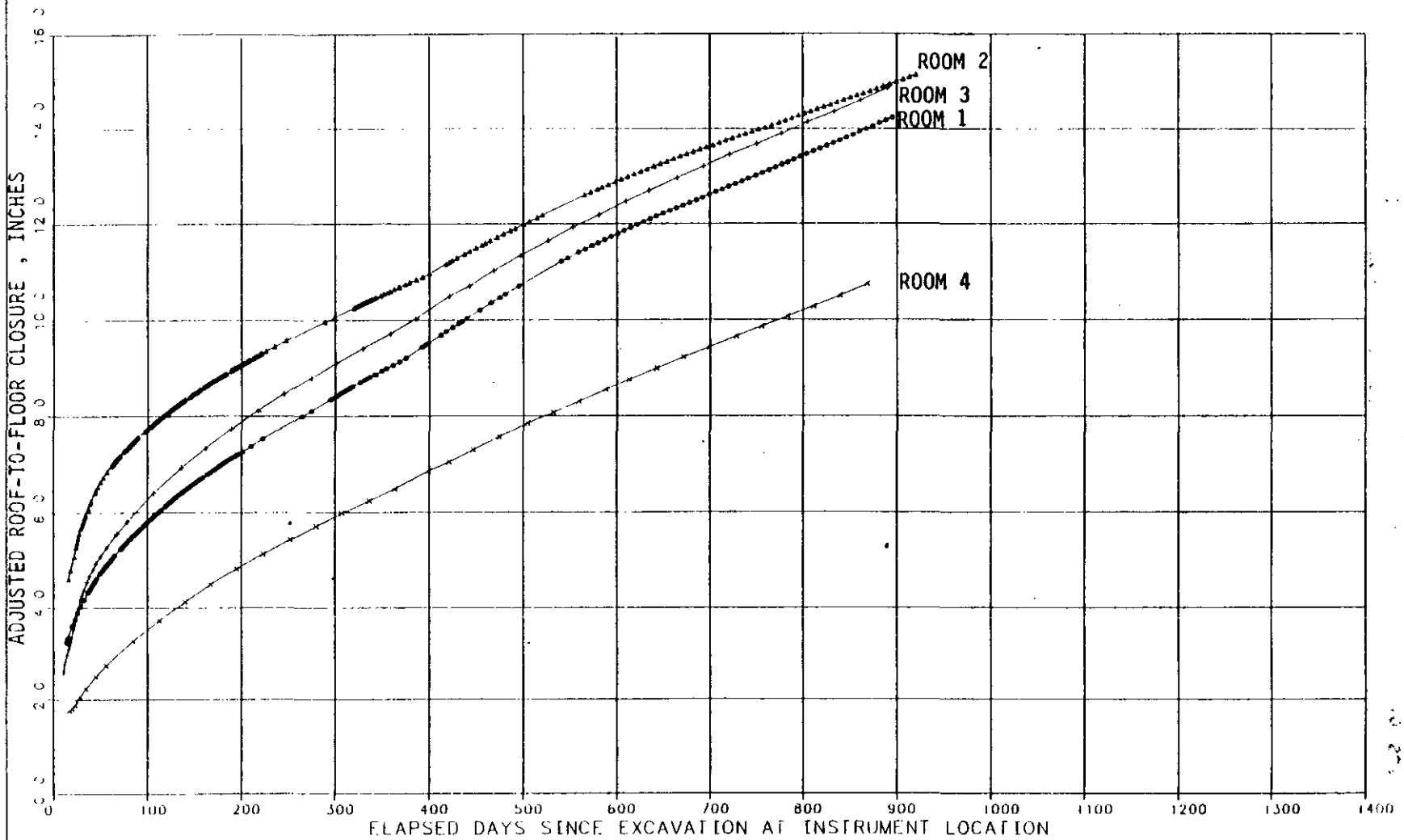

Figure 11-4

TEST ROOMS
ADJUSTED ROOF-TO-FLOOR CLOSURE

Figure 11-4 shows that the [illegible] except for occasional [illegible] disturbances from nearby excavations. Provided there are no additional perturbations in and around the test rooms, it is likely that the rate of closure will reach a steady state value. It is possible to get an estimate of the rate of closure using either a phenomenological rheological model or an empirical model that is essentially a curve-fitting procedure. Both methods have been attempted. Numerical methods using the phenomenological approach are discussed in Chapter 5.

Closure rates rather than measured closure are used in the empirical approach because measured closure is not absolute. Early closure measurements are not available because the instruments could not be installed immediately after excavation. However, the calculation of closure rates is not affected by the lack of early measurements. The closure rates are calculated by assuming a linear relationship between closure and elapsed time over a short interval. This time interval has been arbitrarily chosen as a minimum of 7 days.

Because it is expected that the closure rate will initially be relatively high and then decrease to a steady rate, the following equation was used:

$$C(t) = \frac{A}{t^n} + C_c(1 - e^{-at}) \qquad (11\text{-}1)$$

where: $C(t)$ is the closure rate at elapsed time t after excavation;
A, a and n are constants which depend upon the deformation characteristics of the salt, initial stress regime and dimensions of the opening; and
C_c is the steady state closure rate.

The value of C(t) is obtained by arbitrarily choosing a time interval of not less than 7 days. If R_i is the closure reading at calendar time t_i and R_{i+1} is the closure reading at t_{i+1}, then

$$C(t) = \frac{R_{i+1} - R_i}{\Delta t} \tag{11-2}$$

where: $\Delta t = (t_{i+1} - t_i) \quad \geq 7 \text{ days}$ (11-3)

The value of t is defined as:

$$t = \frac{t_i + t_{i+1}}{2} \tag{11-4}$$

A regression analysis, which is the fitting of an equation like 11-1 to the set of [C(t),t] data points, was performed using NLIN, a commercially available statistical software package (ref. 11-1). The general method used to estimate the constants, herein called the regression parameters, was to minimize the sum of the squares of the differences between the actual measured values and the values predicted by the proposed equation.

Equation 11-1, a nonlinear equation, cannot be converted into linear form. The statistical software NLIN employs iterative methods that attempt to find least-square estimates for nonlinear models. The methods commonly employed are the Gauss-Newton technique and the Marquardt compromise technique (ref. 11-2). However, the requisite partial derivatives of the equation with respect to the parameters must be specified. In many cases, the Marquardt compromise, which is considered to work well in many circumstances, gives a better estimate and provides quicker convergence of the values of the regression parameters. However, nonlinear regression analyses may not always result in good estimates of the regression parameters. In addition, the analysis tacitly assumes that the regressor variables are measured without error. Thus, the observations, which in this case are the values of C(t), were not weighted.

Fig[illegible] [illegible]-to-floor closure rates for Test Room 1 calculated by equation 11-1 to the values calculated using the fitted equation 11-2. The data used was obtained during the first year following the completion of excavation. The regression analysis showed that, for all practical purposes, equation 11-1 could be simplified as

$$C(t) = \frac{A}{t^n} + C_c \qquad (11\text{-}5)$$

because the value of 'a' obtained from the regression analysis was large enough to make the term e^{-at} comparatively negligible. The fitted equation for the roof-to-floor closure data in Test Room 1 has the form

$$C(t) = \frac{206.58}{t^{0.84}} + 2.24(1-e^{-5.27t}) \text{ inches/year} \qquad (11\text{-}6)$$

where: t is the elapsed time in days since excavation.

However, as shown by equation 11-5, equation 11-6 can be approximated as

$$C(t) = \frac{206.58}{t^{0.84}} + 2.24 \text{ inches/year} \qquad (11\text{-}7)$$

The method used was the Marquardt compromise technique. The coefficient of determination is 0.99.

The analysis was repeated later using roof-to-floor closure data at 980 days (2.68 years) after the completion of excavation. The regression equation was

$$C(t) = \frac{211.16}{t^{0.85}} + 2.44 \text{ inches/year} \qquad (11\text{-}8)$$

The steady state closure rate determined using the first year of data only is 9 percent less than the rate determined by using 2.68 years of

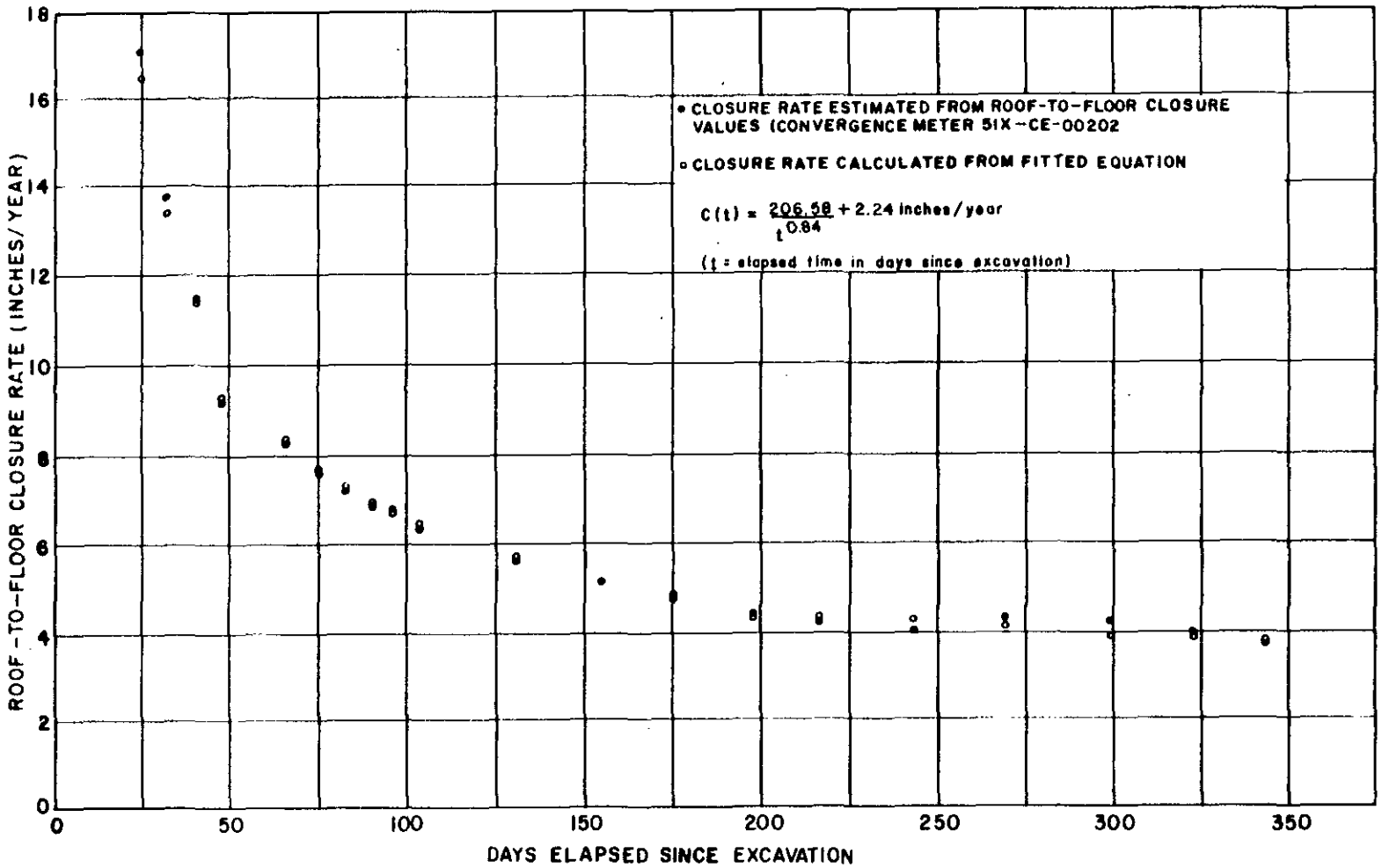

Figure 11-5

TEST ROOM 1
REGRESSION ANALYSIS OF ROOF-TO-FLOOR CLOSURE

measurement data, up to 1986, gave

$$C(t) = \frac{208}{t^{0.85}} + 2.40 \text{ inches/year} \qquad (11\text{-}9)$$

Equations 11-7, 11-8 and 11-9 show the consistency of the regression parameters for different input data sets.

Figure 11-6 shows the predicted roof-to-floor closure rate for Test Room 1 as a function of elapsed time in years using equation 11-9. Based on equation 11-7, the roof-to-floor closure rate at the end of 25 years is expected to be approximately 2.34 inches/year. Using equation 11-8, it will be 2.53 inches/year or 2.49 inches/year using equation 11-9.

Figures 11-7 through 11-10 show the fitted curves based on roof-to-floor closure rates calculated from equation 11-2, using data up to June 1986. To get an approximate idea of the roof-to-floor closure for periods of time greater than 1 year since the completion of excavation, equation 11-7 was integrated with respect to time between the limits of 1 year and time t_2 (in years) to yield

$$R(t) = 0.78(t_2^{0.147} - 1) + 0.20(t_2 - 1) \qquad (11\text{-}10)$$

Figure 11-11 shows the predicted roof-to-floor closure in feet for Test Room 1 (excluding that which has occurred in the first year after excavation) as a function of time in years. According to this prediction, 25 years after excavation this value will be 5.34 feet. A similar analysis using equation 11-9 gave a value of 5.3 feet.

Table 11-7 is a summary of the results of the nonlinear regression analyses for the roof-to-floor closure rates in the test rooms using 3 years of measurement data. The parameters contained in this table are applicable for an elapsed time expressed in years. For Test Room 4, the regression analysis using only the permanent convergence point data did not produce satisfactory results. The analysis was

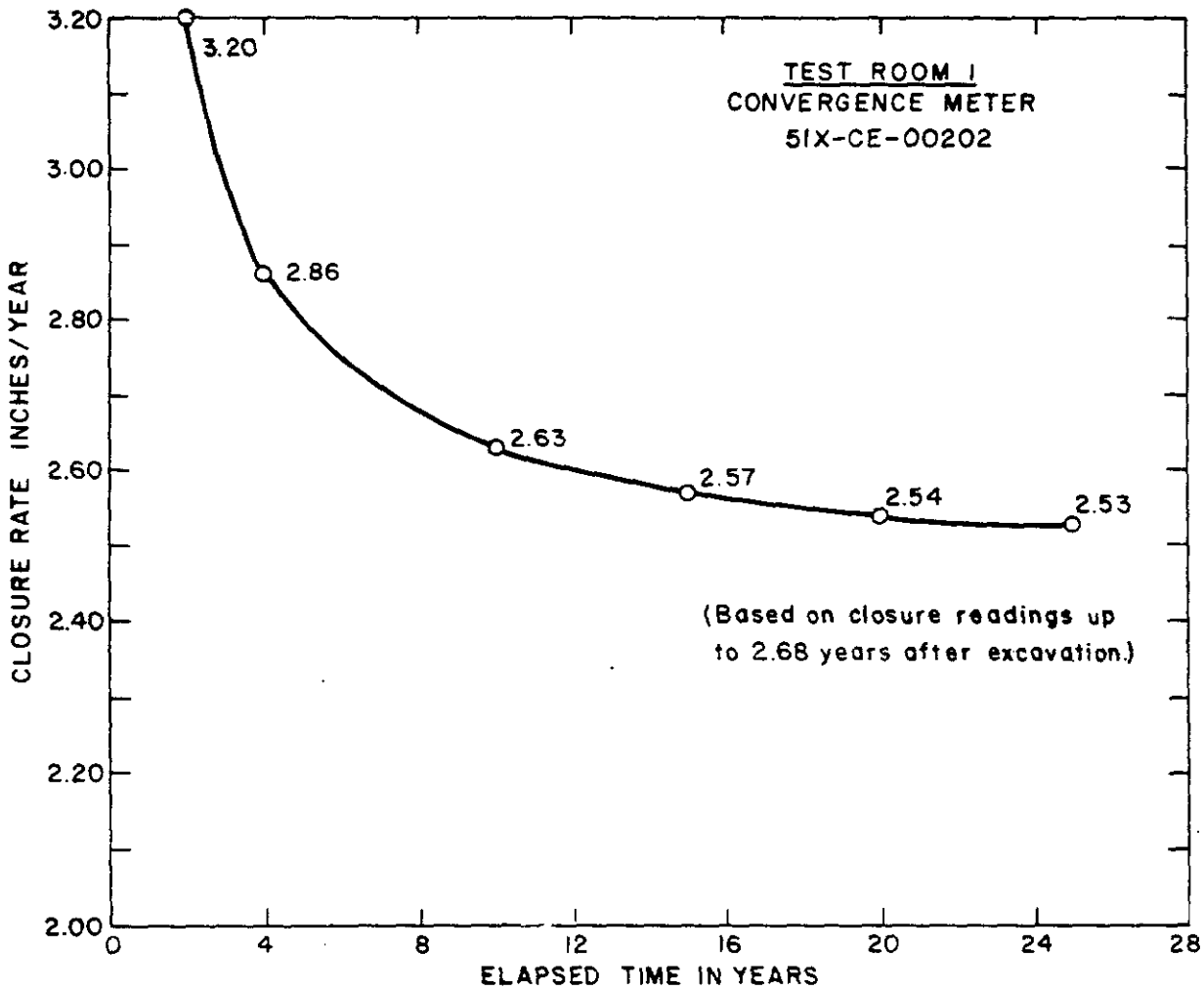

Figure 11-6

TEST ROOM 1
PREDICTED ROOF-TO-FLOOR CLOSURE RATE

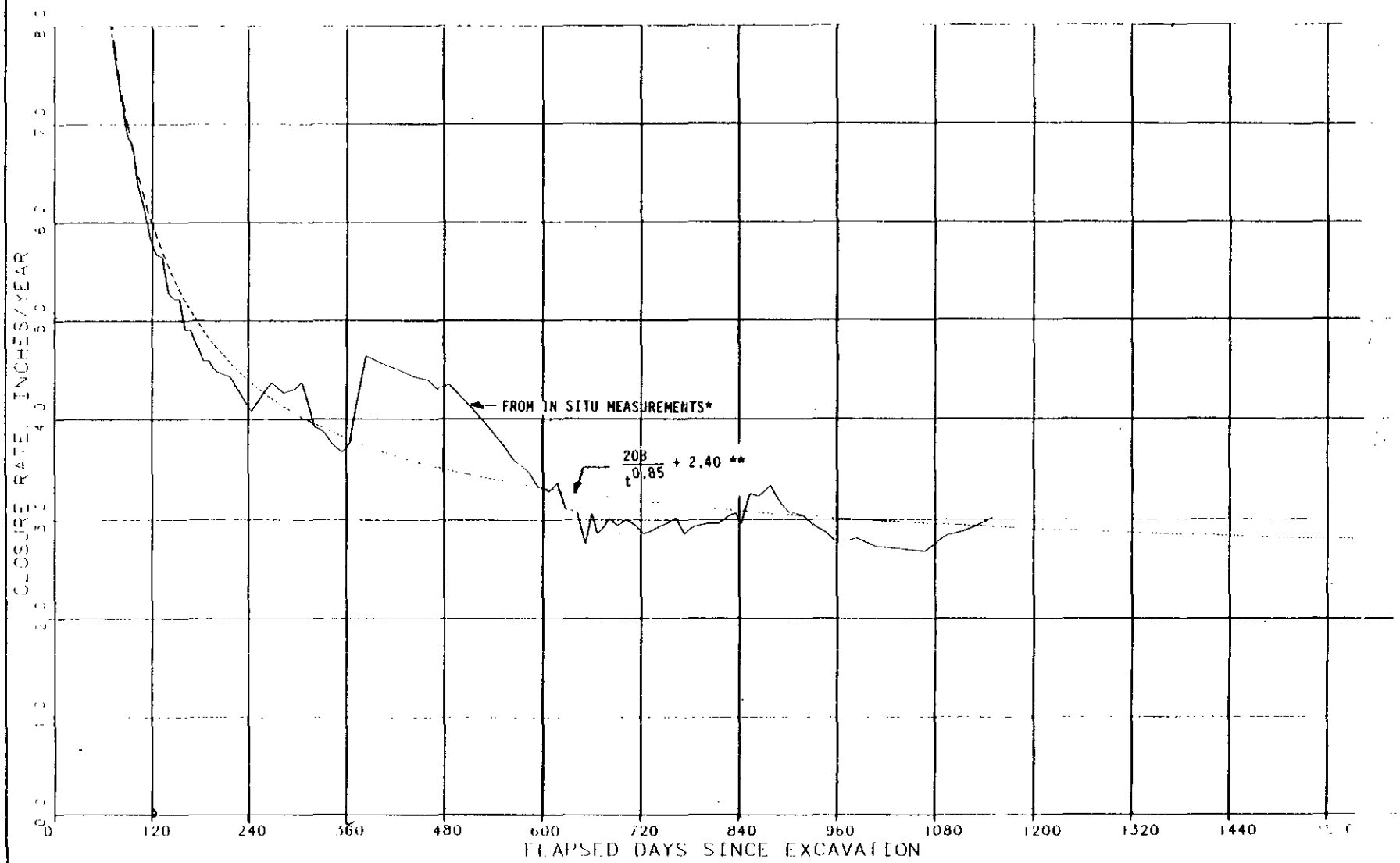

* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-7

TEST ROOM 1 ROOF-TO-FLOOR CLOSU
RESULTS OF REGRESSION ANALY

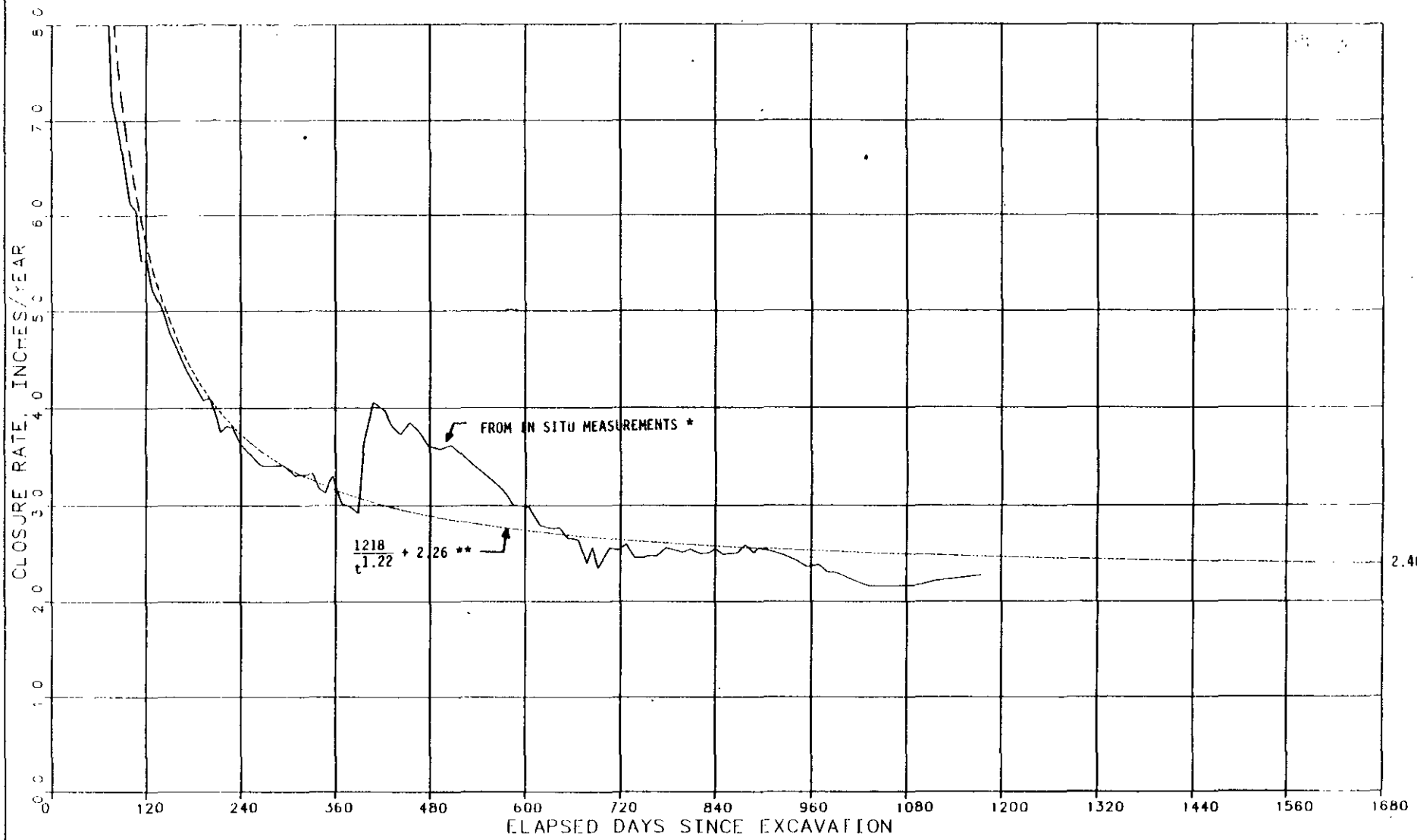

* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-8

TEST ROOM 2 ROOF-TO-FLOOR CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

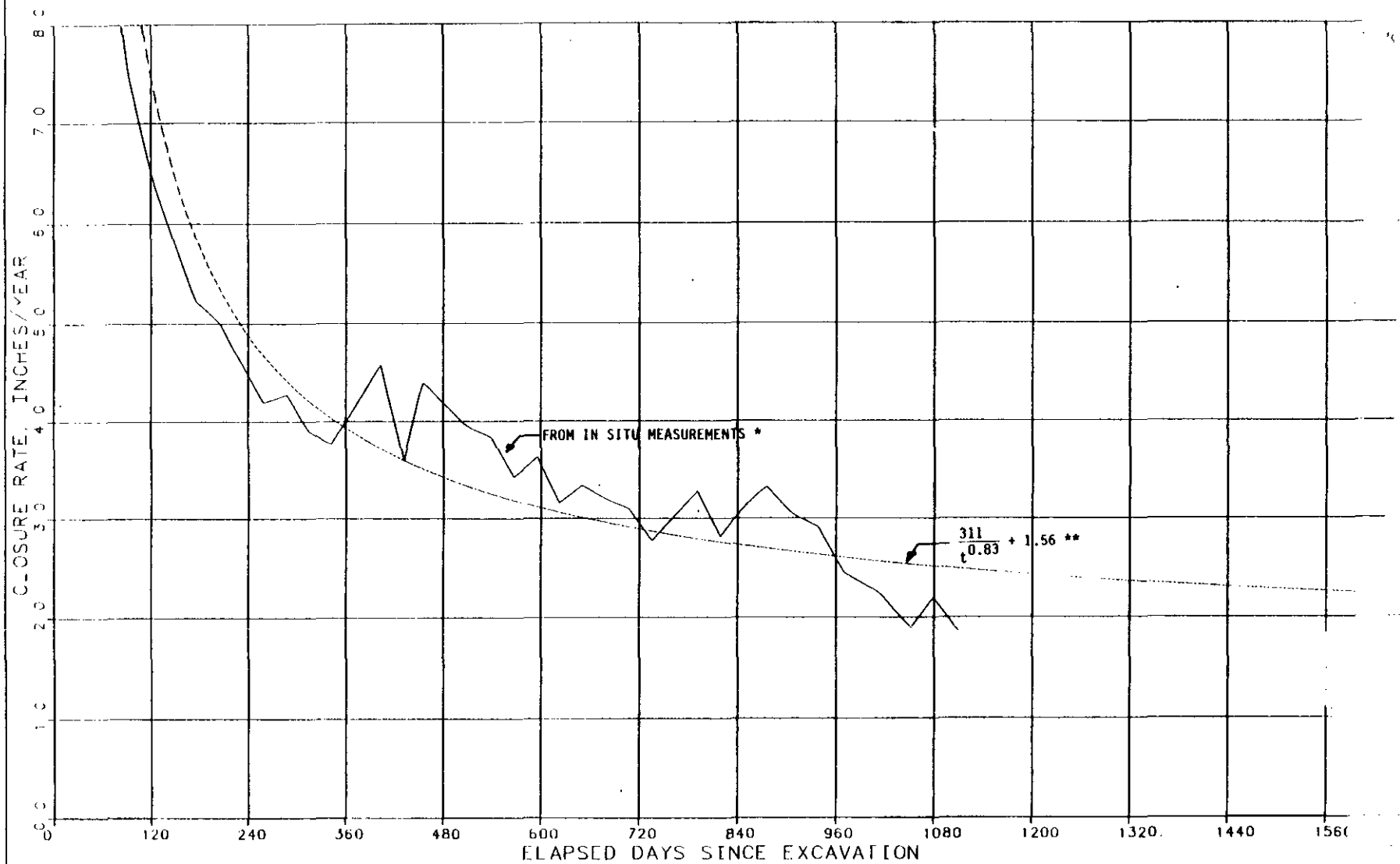

* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-9

TEST ROOM 3 ROOF-TO-FLOOR CLOSURE RESULTS OF REGRESSION ANALYSIS

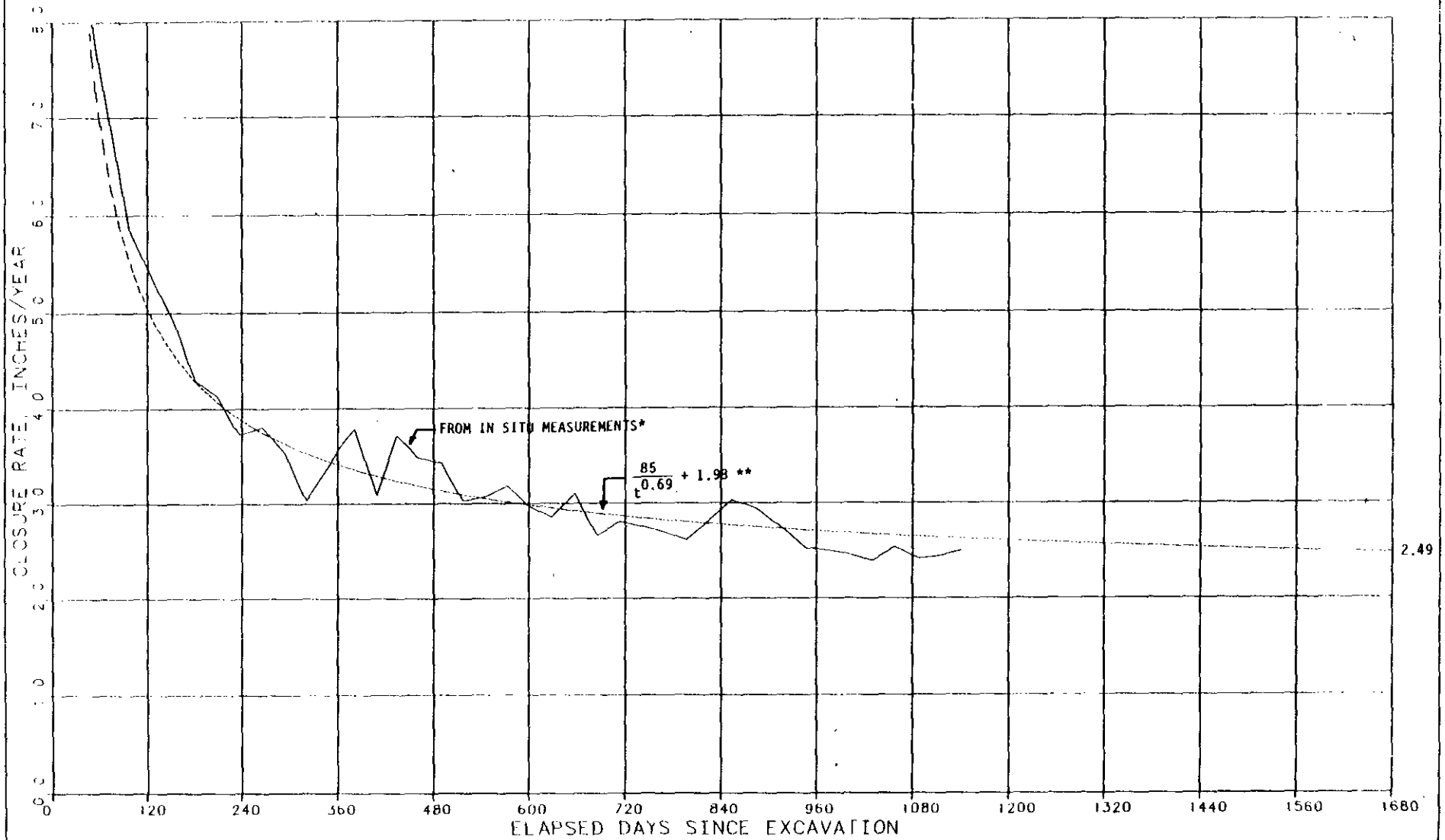

* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-10

TEST ROOM 4 ROOF-TO-FLOOR CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

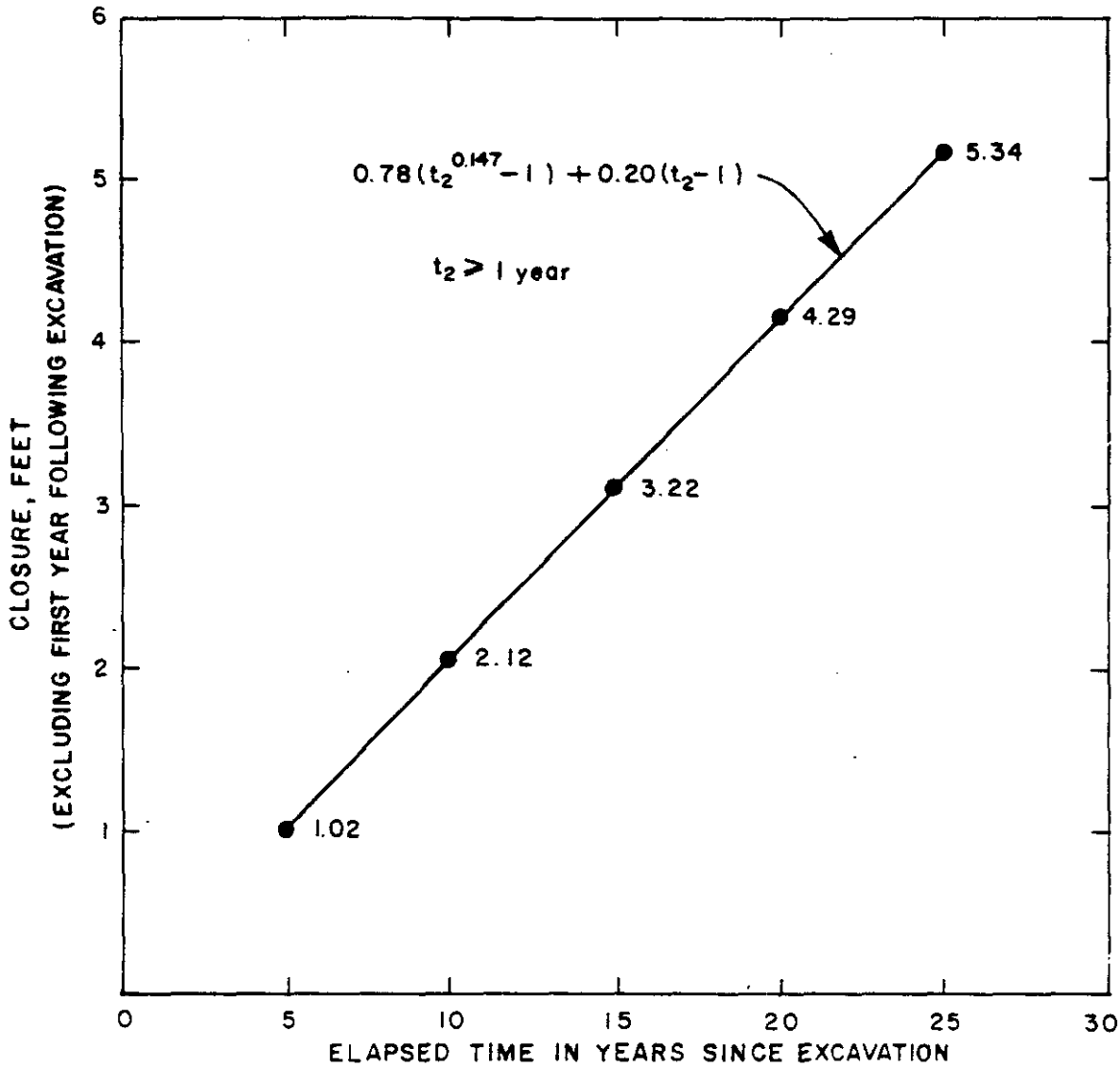

Figure 11-11

TEST ROOM 1
PREDICTED ADDITIONAL ROOF-TO-FLOOR CLOSURE

TEST ROOMS
SUMMARY OF RESULTS OF REGRESSION ANALYSES
FOR ROOF-TO-FLOOR CLOSURE RATES

Description	Test Room 1	2	3	4*
Regression Parameters**				
A	208	1218	311	85
n	0.85	1.22	0.83	0.69
C_c	2.40	2.26	1.56	1.98
r^2	0.99	0.98	0.94	0.97

Note: Analyses based on data obtained through June 1986.

* Data used for regression analysis includes data from temporary convergence points.

** Equation is: $C(t) = \frac{A}{t^n} + C_c$

where: C(t) is closure rate in inches/year;
A and n are constants;
t is elapsed time in days; and
C_c is steady state closure rate.

r^2 is the coefficient of determination.

repeated with [illegible] produced good results. The [illegible] of the regression analysis of roof-to-floor closure rates discussed in this subsection are used in Chapter 12 to define the bounds on the roof-to-floor closure rates for the storage rooms.

Wall-to-Wall Closure. Figure 11-12 summarizes the measured wall-to-wall closure magnitudes for the test rooms. Because of the lack of early measurements, the relative positions of the individual curves are not absolute. Table 11-8 presents an estimate of the actual wall-to-wall closure for the four test rooms. The approach is similar to the one used for estimating the actual roof-to-floor closure values. The maximum wall-to-wall closure occurs in Test Room 3 and is about 13 inches. The minimum wall-to-wall closure is about 9 inches in Test Room 4.

The regression analysis of wall-to-wall closure rates for Test Room 1, using measurement data up to June 1986, shows that the equation has the form

$$C(t) = \frac{202}{t^{0.94}} + 1.75 \text{ inches/year} \qquad (11\text{-}11)$$

where: t = elapsed time in days since excavation.

Comparing equation 11-11 with equation 11-9, the long-term wall-to-wall closure rate will be 73 percent of the roof-to-floor closure rate.

Table 11-9 is a summary of the results of the regression analyses for the wall-to-wall closure rates in Test Rooms 1 through 4. The closure rate values determined from temporary convergence point readings were included in the analysis of Test Room 2. The fitted curves for Test Rooms 2 and 3 are relatively poor. Figures 11-13 through 11-16 show the fitted equations for the wall-to-wall closure rate versus elapsed time curves for Test Rooms 1 through 4.

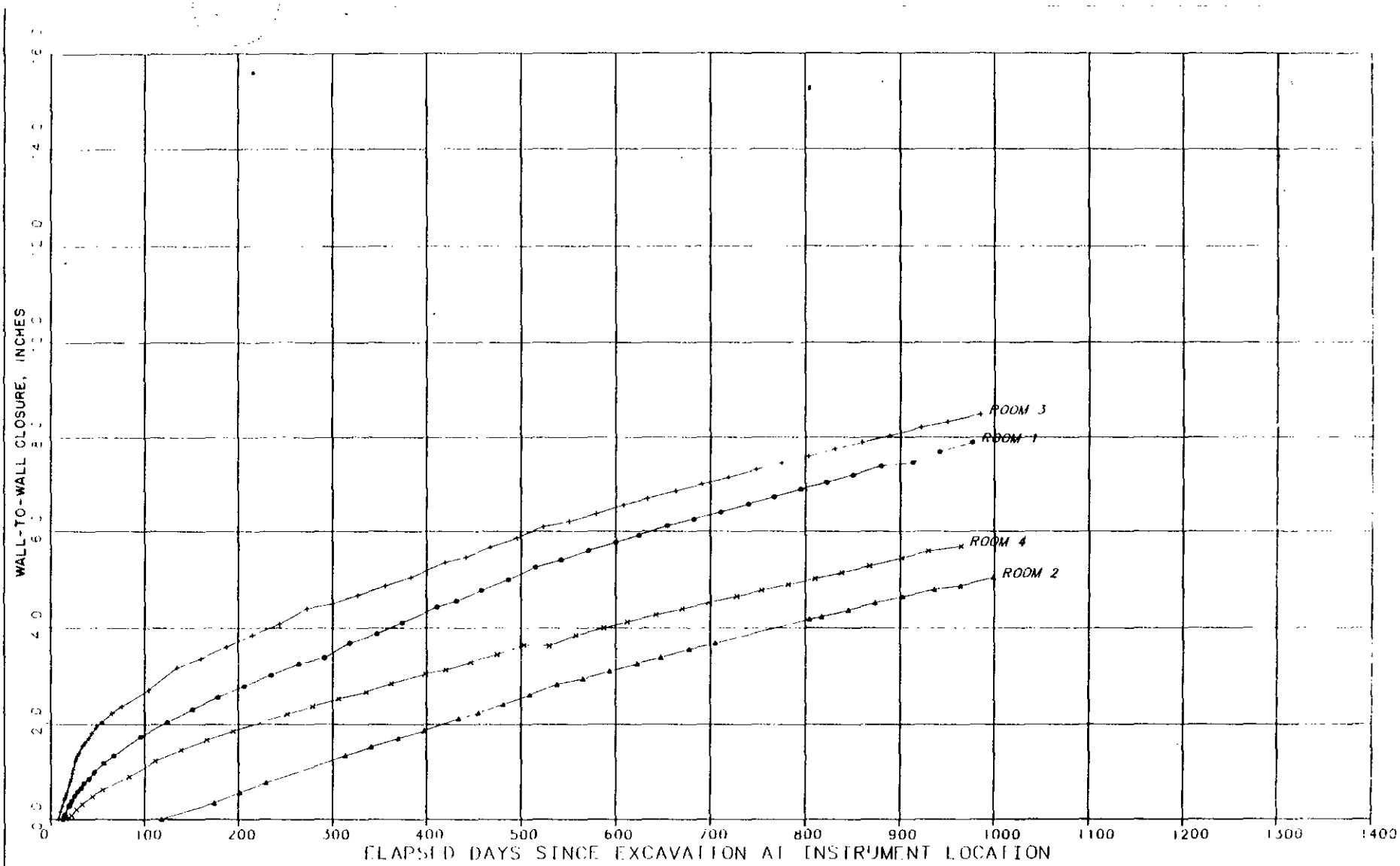

Figure 11-12

TEST ROOMS
WALL-TO-WALL CLOSURE COMPARISON

Table 11-8

TEST ROOMS
WALL-TO-WALL CLOSURE COMPARISONS

Description	Test Room 1	Test Room 2	Test Room 3	Test Room 4
(1) Excavation period	April 3-13 1983	March 9-20 1983	March 24-April 3 1983	April 15-25 1983
(2) Date of first reading of temporary convergence (TC) points	April 9, 1983	March 21, 1983	March 31, 1983	April 21, 1983
(3) Date of first reading of permanent convergence (RC) points	April 20, 1983	July 12, 1983	April 7, 1983	May 6, 1983
(4) Reading of TC points (inches) on date indicated	1.58 April 20, 1983	3.36 July 12, 1983	1.42 April 7, 1983	1.48 May 5, 1983
(5) Reading of RC points (inches) on date indicated	8.82 June 16, 1986	5.82 June 16, 1986	9.24 June 16, 1986	6.39 June 16, 1986
(6) Total elapsed days of combined TC and RC measurements [Date for (5) - Date for (2)]	1166	1151	1176	1151
(7) Total measured closure (inches) [(4) + (5)]	10.40	9.18	10.66	7.87
(8) Estimated closure (inches) by regression analysis for the period of (2) - (1)	1.79	2.51	2.16	1.42
(9) Total estimated closure (inches) [(7) + (8)]	12.19	11.69	12.82	9.29

Table 11-9

TEST ROOMS
SUMMARY OF RESULTS OF REGRESSION ANALYSES
FOR WALL-TO-WALL CLOSURE RATES

Description	Test Room 1	2*	3	4
Regression Constants**				
A	202	222	231	1766
n	0.94	0.79	0.83	1.81
C_c	1.75	0.30	0.74	1.88
r^2	0.96	0.95	0.92	0.99

Note: Analyses based on data obtained through June 1986.

* Data used for regression analysis includes data from temporary convergence points.

** Equation is: $C(t) = \frac{A}{t^n} + C_c$

where: C(t) is closure rate in inches/year;
A and n are constants;
t is elapsed time in days; and
C_c is steady state closure rate.

r^2 is the coefficient of determination.

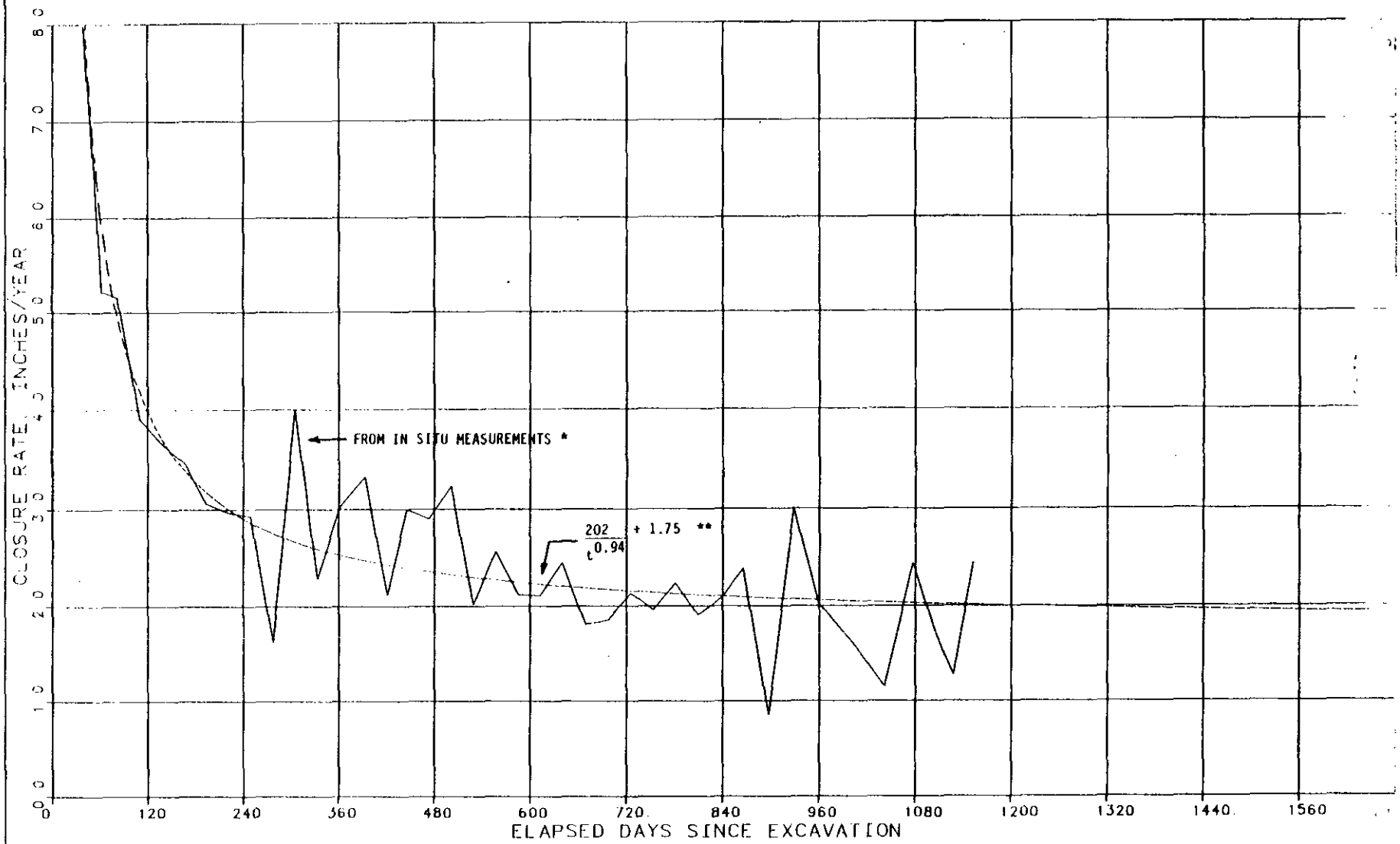

* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-13

TEST ROOM 1 WALL-TO-WALL CLOSURE RESULTS OF REGRESSION ANALYS

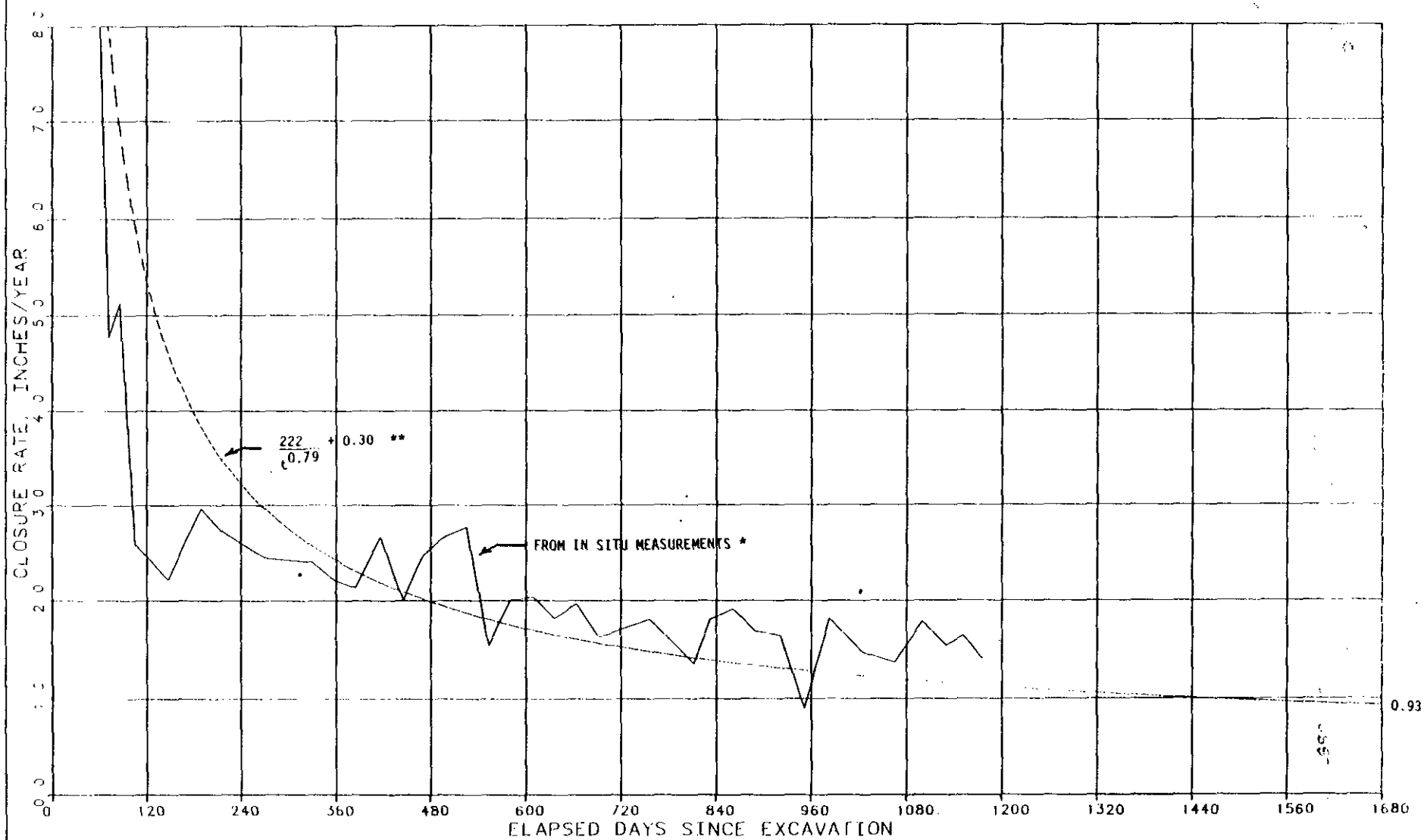

* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-14

TEST ROOM 2 WALL-TO-WALL CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

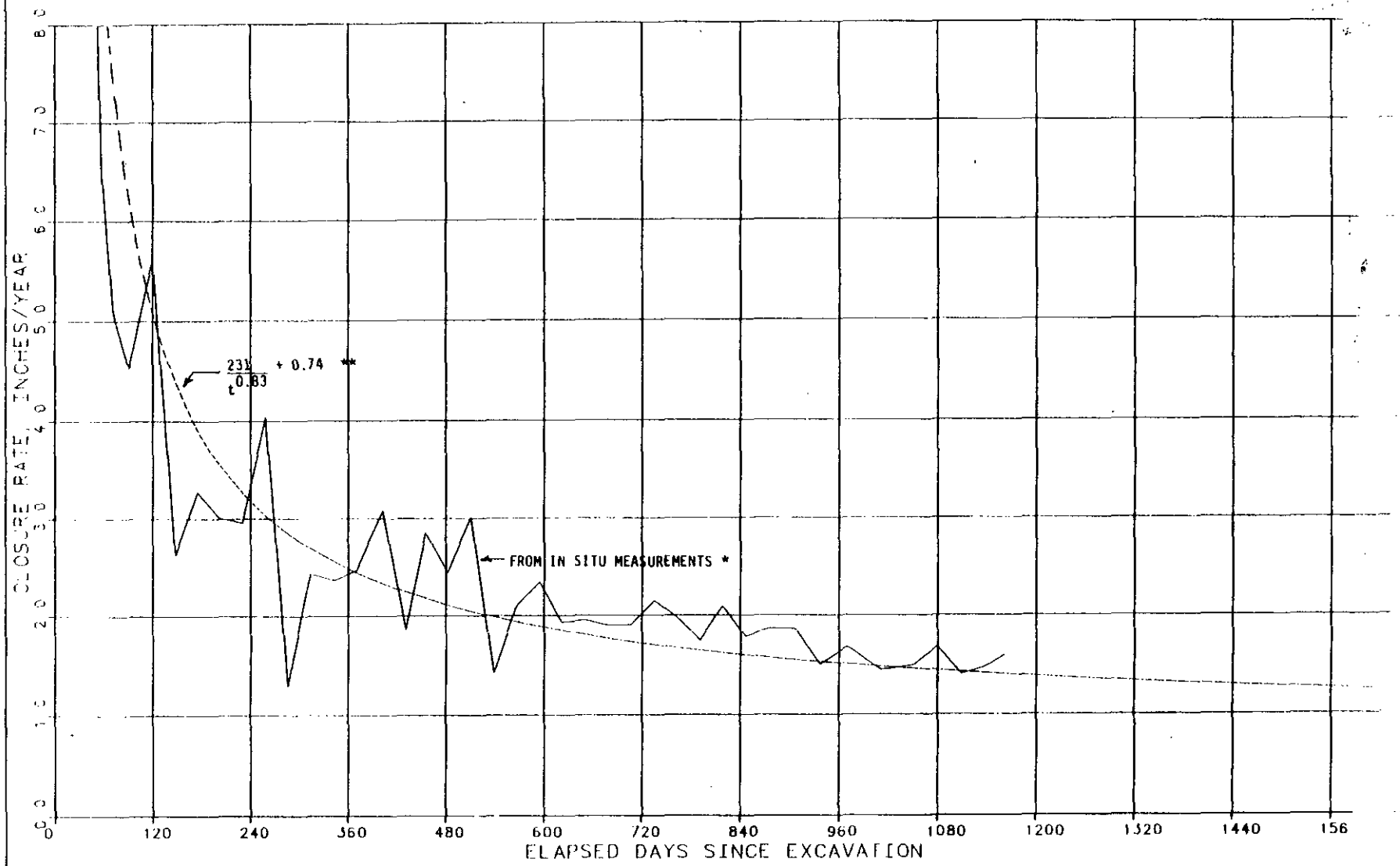

* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-15

TEST ROOM 3 WALL-TO-WALL CLOS
RESULTS OF REGRESSION ANAL

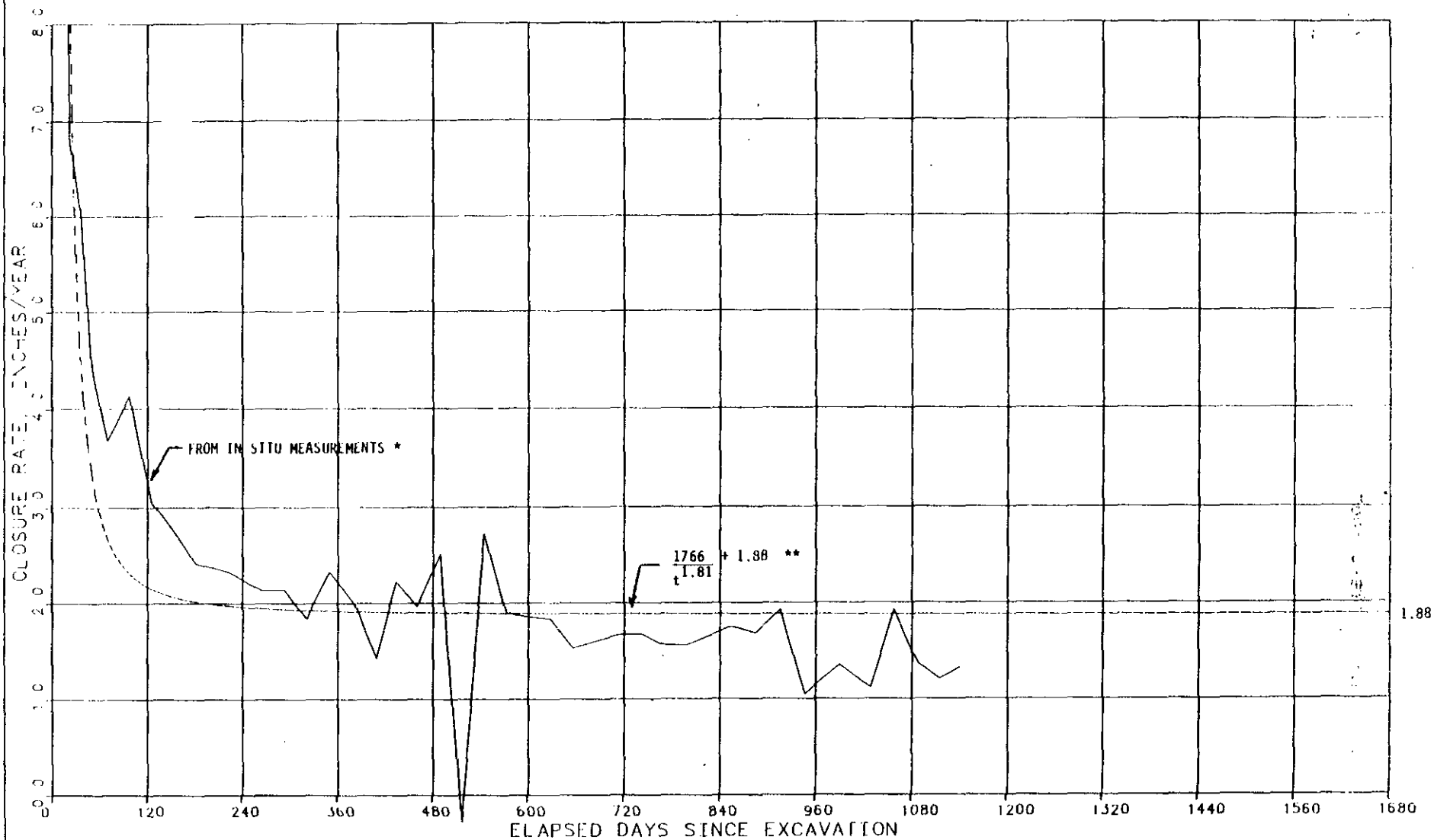

* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-16

TEST ROOM 4 WALL-TO-WALL CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

Summary of the collar multiple-point borehole extensometers in the test rooms. Because the extensometers could not be installed as soon as the excavation was completed, the collar readings do not reflect absolute closure. The table also shows the sum of the collar movements from both the east and west walls in each of the rooms except Test Room 3, which has no extensometer in the west wall. The last two columns of this table permit a comparison of the sum of the collar movements with wall-to-wall convergence point readings. Ideally, providing the salt is homogeneous, the central vertical lines of the pillars between Test Rooms 1 and 2 and Test Rooms 2 and 3 should be lines of symmetry with zero lateral strain. The deepest anchor at 50 feet for extensometers 51X-GE-00213 and 51X-GE-00215 should be expected to undergo negligible displacement. Therefore, the sum of the collar movements for Test Rooms 2 and 3 should be approximately the same as the wall-to-wall convergence point readings. As shown in Table 11-10, this is the case for Test Room 2. Exact equivalence is difficult to obtain because the collars of the extensometers are recessed into the wall by variable amounts and the time-lag between the end of excavation and the date of initial reading is not the same for the extensometers and the convergence points.

Comparison of Roof-to-Floor to Wall-to-Wall Closure Rates. Table 11-11 presents recent roof-to-floor and wall-to-wall closure rates for the test rooms. The rates were calculated using convergence point readings with a time interval of approximately 1 month. Based on these readings, the average wall-to-wall closure rate is approximately 68 percent of the roof-to-floor closure rate.

11.3.2.3 Deformation

An indication of the deformation of the salt around the test rooms may be obtained by comparing inclinometer measurements around a room. Figure 11-17 shows the cumulative measurements from the four wall inclinometers located around Test Room 3 through March 6, 1985. The inclinations are measured along the plane of the cross section.

Table 11-10

TEST ROOMS
WALL EXTENSOMETER COLLAR MOVEMENTS VERSUS CONVERGENCE POINT READINGS

Test Room	Extensometer	Location	Readings on June 13, 1986 (inches)	Sum of East & West Readings (inches)	Wall-to-Wall Convergence Point Readings on June 16, 1986 (inches)
1	51X-GE-00217	East wall	3.16	7.36	8.82*
	51X-GE-00219	West wall	4.20		
2	51X-GE-00213	East wall	4.95	9.52	9.18**
	51X-GE-00215	West wall	4.57		
3	51X-GE-00211	East wall	4.17	-	9.24*
	-	West wall	-		
4	51X-GE-00206	East wall	3.26	5.95	6.39*
	51X-GE-00208	West wall	2.69		

* From (5) in Table 11-8.
** From (7) in Table 11-8.

Table 11-11

TEST ROOMS
CLOSURE RATE COMPARISONS

Description of Closure Location	Test Room 1	2	3	4
Roof-to-Floor				
Reading/Date	12.88/May 16, 1986	12.03/May 16, 1986	13.65/Mar. 24, 1986	10.39/Mar. 24, 19[illegible]
Reading/Date	13.11/June 13, 1986	12.20/June 13, 1986	13.83/Apr. 28, 1986	10.62/Apr. 28, 19[illegible]
Difference in readings	0.23 inch	0.17 inch	0.18 inch	0.23 inch
Time interval	28 days	28 days	27 days	27 days
Rate ($\dot{V}$)	3.00 inch/yr	2.22 inch/yr	2.43 inch/yr	3.10 inch/yr
Wall-to-Wall				
Reading/Date	8.63/May 19, 1986	5.72/May 19, 1986	8.90/Mar. 24, 1986	6.09/Mar. 24, 1[illegible]
Reading/Date	8.82/June 16, 1986	5.82/June 16, 1986	9.03/Apr. 28, 1986	6.22/Apr. 28, 19[illegible]
Difference in	0.19 inch	0.10 inch	0.13 inch	0.13 inch

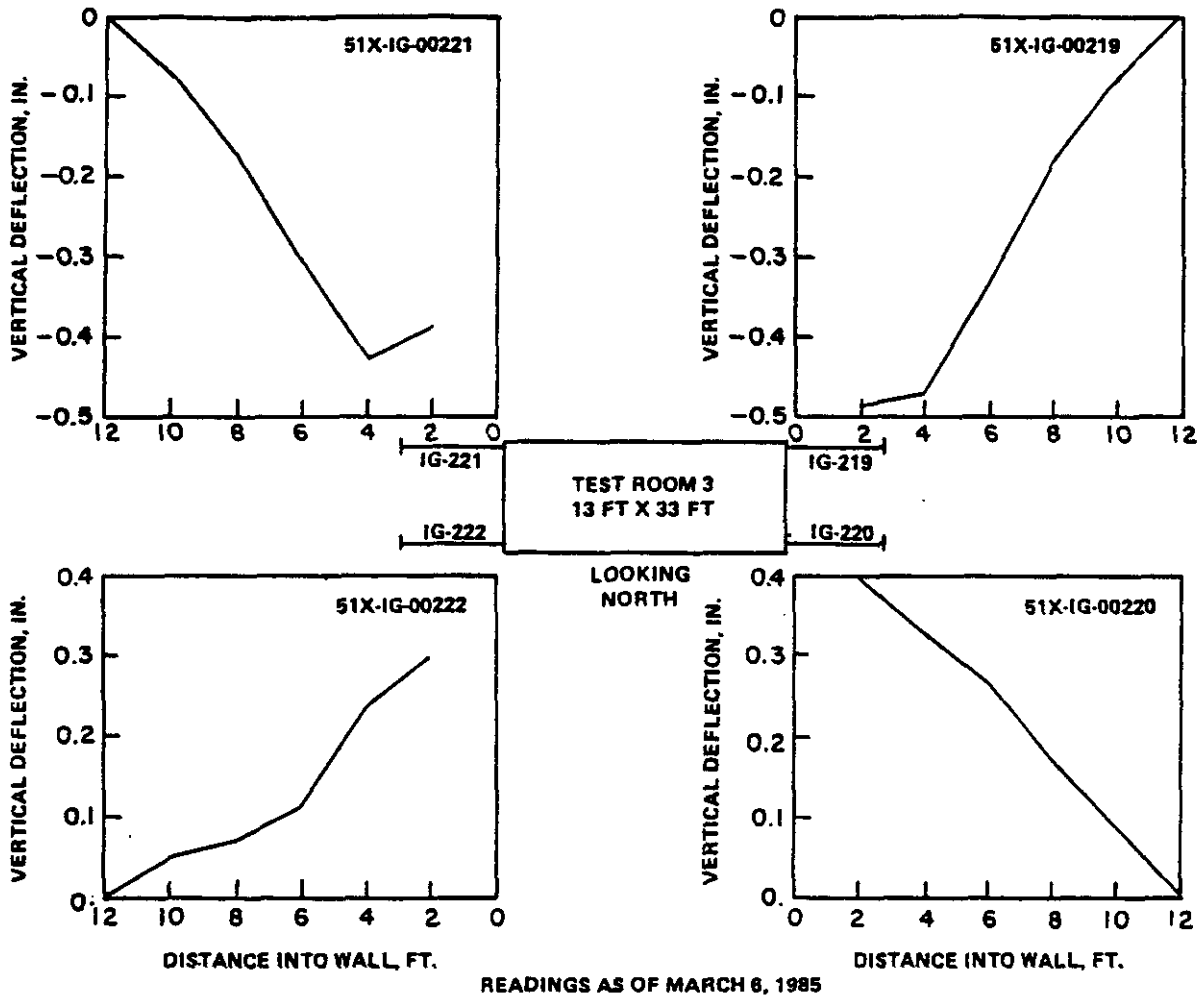

Figure 11-17

TEST ROOM 3
WALL INCLINOMETER BEHAVIOR

Figure 11-[illegible] show[illegible] [illegible] March 6, 1985. The in[illegible]ings from these inclinometers were taken 9 to 15 days after the completion of excavation in the test room. The current readings indicate that the maximum relative vertical deflection is on the order of 1 inch over a length of 12 feet.

The inclinometers near the roof show vertical downward deflection while those near the floor indicate upward deflection. This indicates that the central multiple-point borehole extensometers located in the walls of the test rooms probably undergo negligible vertical deflection.

11.3.2.4 Bay Strains

Relative movements between anchors of the multiple-point borehole extensometers will provide an approximate distribution of salt deformation around the excavated openings. The relative displacements are normalized over the spacing between anchors and are termed "bay strains". The bay strain is approximately the average axial strain between any two anchor points and will be closer to the true strain provided that the spacing between the anchors is small and that the deformation varies linearly with the spacing between the anchors. Bay strains are useful in detecting any anomalous behavior in the salt around an opening, such as that influenced by discontinuities, clay seams, or the effect of local stress concentrations.

Figure 11-19 shows the strain between the collar and anchor A for the roof extensometers in Test Room 1. The distance between the collar and anchor A is 5 feet. The maximum strain occurs at the east and west sides of the roof of the test room and is equal to approximately 4 percent through June 1986. Although the roof sag, as depicted by collar movement, is higher at the center of the rooms than at the sides, the bay strain is higher at the sides than at the center. As discussed in subsection 11.3.2.5, the numerical modeling also indicates higher strain at the roof and wall intersections. Figure 11-20 shows the vertical strain rates for these same extensometers. The rates are

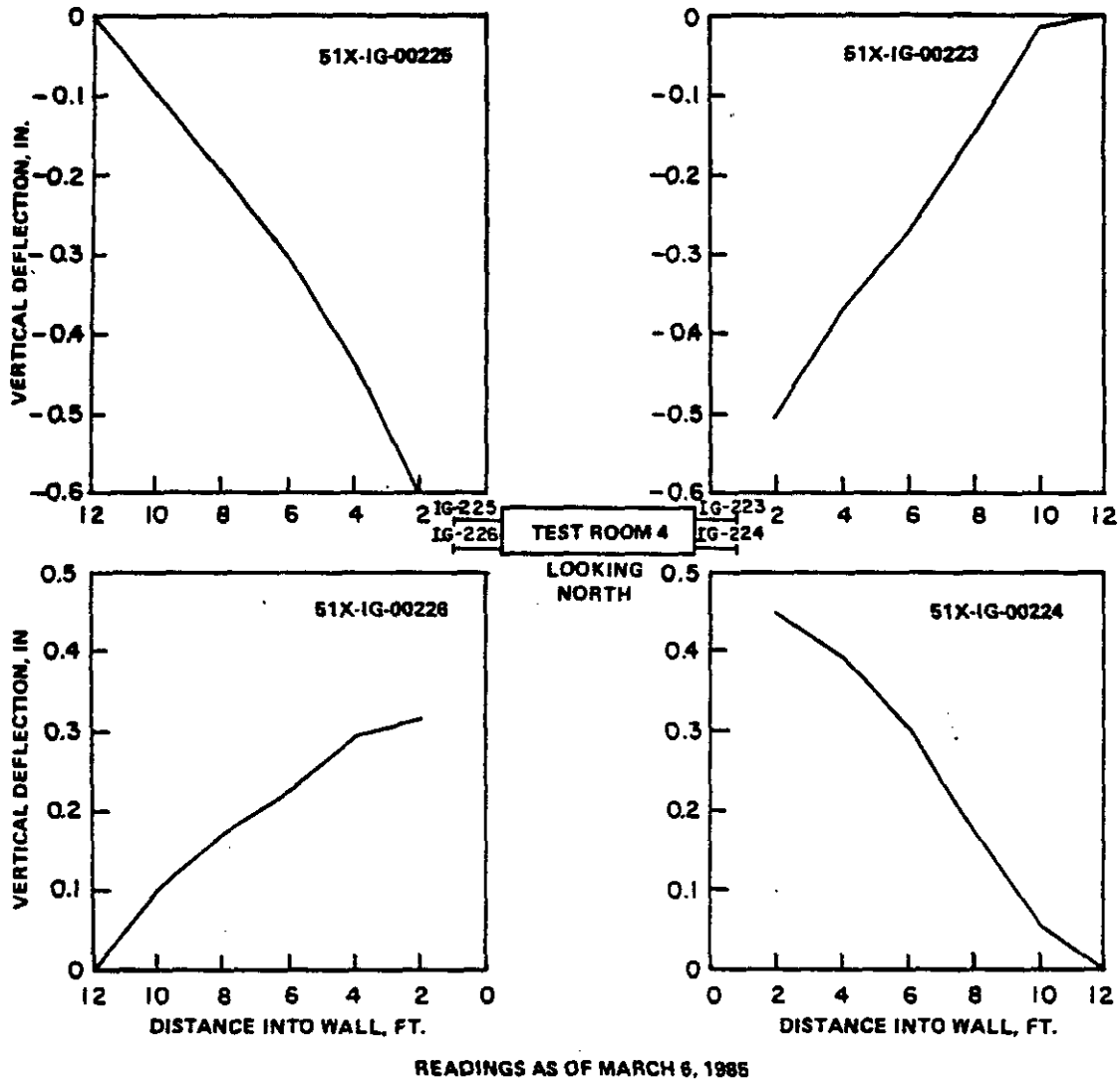

Figure 11-18

TEST ROOM 4
WALL INCLINOMETER BEHAVIOR

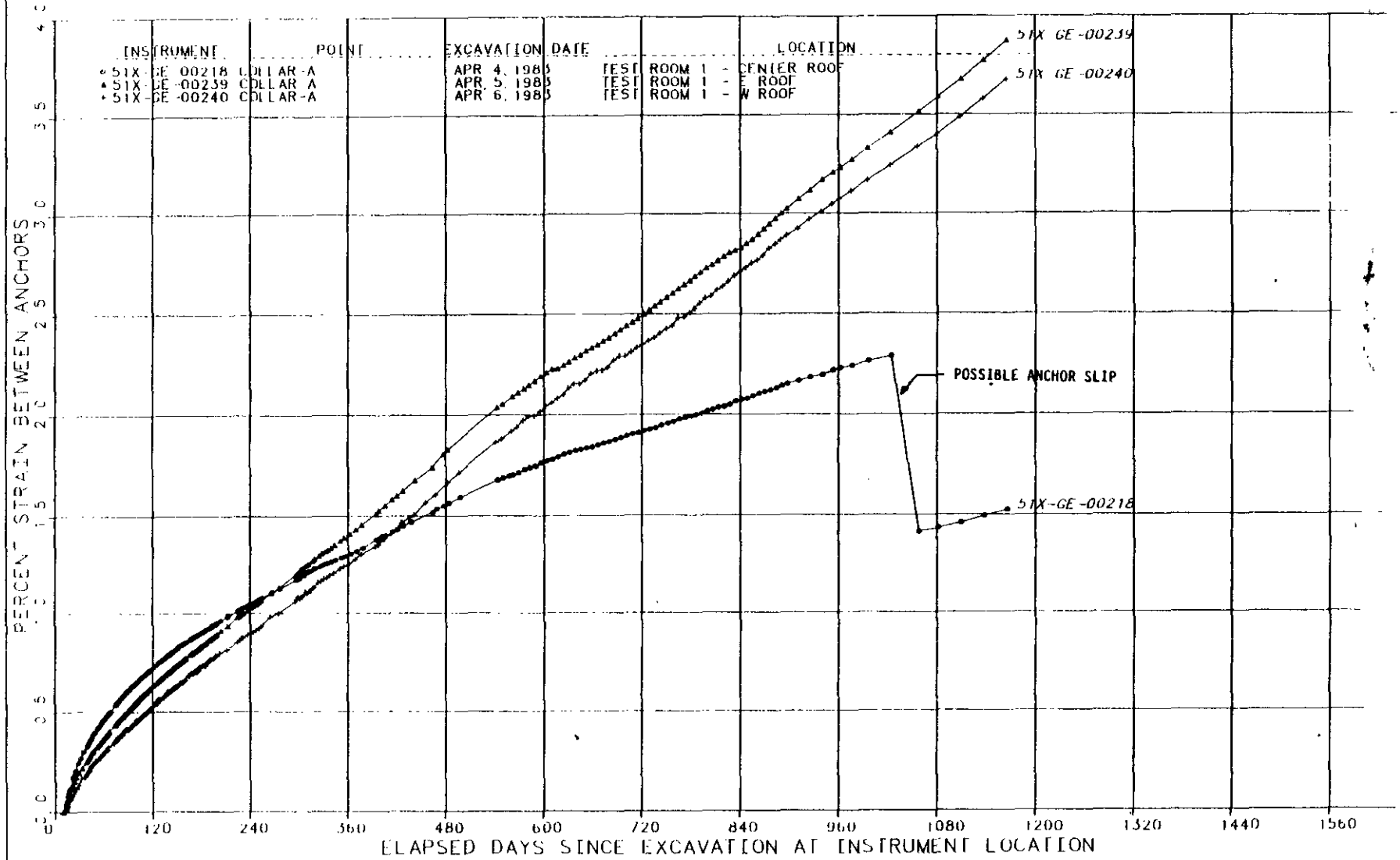

Figure 11-19

TEST ROOM 1 ROOF EXTENSOMETER STRAIN VERSUS TIME SINCE EXCAV

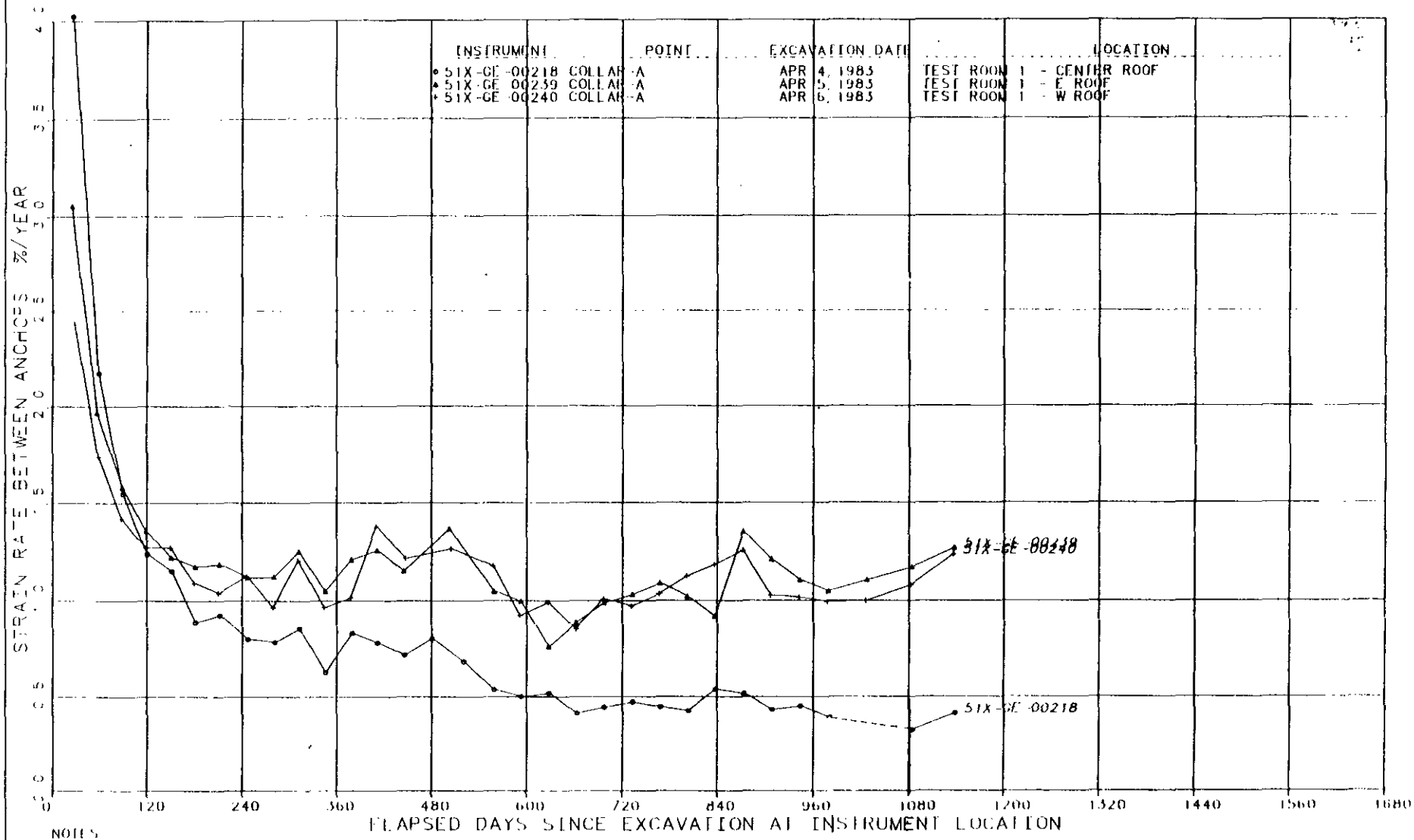

NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

Figure 11-20

TEST ROOM 1 ROOF EXTENSOMETERS
STRAIN RATE VERSUS TIME SINCE EXCAVATION

[illegible] the strains, the [illegible] are higher close to the pillars.

Figures K-37 through K-46 in Appendix K show the bay strains in percent as a function of elapsed time since excavation for all of the test rooms. To monitor more closely the separation across the clay seam at the base of anhydrite "b", the spacing between anchors A and B in Test Rooms 1 and 2 is 1 foot. Currently, the maximum strain occurs between anchors A and B on the west side and central part of the roof in Test Room 1, and is on the order of 5 percent. Because the anchors are not equally spaced, and the deformation varies nonlinearly with the distance along the anchor, a comparison of bay strain between successive anchors may be misleading.

Figures K-47 through K-56 in Appendix K show the strain rate plots for all of the roof and floor extensometers. In general, the strain rate is decreasing with time, except for floor extensometer 51X-GE-00210 in Test Room 3 where, for anchor A, the strain rate increased with time until the extensometer failed (Figure K-42). The decreasing trend in the strain rates is an indication that the salt above the roof and below the floor is currenty stable and will remain stable based on the projected decreasing rate.

11.3.2.5 Model Simulation

As discussed in Chapter 5, Section 5.3, numerical analyses using creep constants obtained from laboratory tests did not provide a good correlation with in situ measured closure. Therefore, an engineering approach using curve fitting methods was employed. The finite element method was used to simulate the behavior of the test rooms and to determine stress distributions. The effects of material properties and the proximity to other rooms were considered for incorporation into the model. The reference stratigraphy used in the model and the material properties of the geologic layers are described in Chapter 6. The constitutive equations used in the analyses, particularly the governing creep equations, are presented in Appendix C. Using the procedures

described in Chapter 5, Section 5.4, in situ roof-to-floor closure data through June 30, 1985, were correlated with the finite element responses to determine the values of creep parameters C, A and z for each test room. In order to eliminate the effect of excavation sequence on computation of the creep parameters, only in situ data taken after the completion of all test room excavation activities were utilized. The average values of these parameters for the four test rooms were then used to predict the responses of the future storage rooms as described in Chapter 12.

Figure 11-21 shows the finite element model for the test room panel based on the reference stratigraphy. The model has 363 nodes and consists of 270 plane strain elements, with gap/friction link elements modeling a clay seam at a depth of 2,104.87 feet. A friction coefficient of 0.4 was used for a member property of the gap/friction link elements. MB-139 was modeled as an elastic layer from a depth of 2,130.36 to 2,133.18 feet. The top and bottom boundaries of the model are at depths of 1,978.5 feet and 2,250.0 feet, respectively. The roof and floor of the room are at depths of 2,112.56 feet and 2,125.56 feet, respectively.

Two openings were incorporated in the finite element model to simulate differences resulting from the proximity of inner and outer rooms. These openings were modeled using height and width dimensions of 13 feet and 33 feet respectively. The boundary on one side of the model was taken as the vertical axis of symmetry for the center pillar and consists of horizontal restraints. The boundary on the other side of the model also utilized horizontal restraints. These boundaries were established based on experience from previous analyses and were extended far enough so that the effects of the boundaries on the structural responses were minimal. Stress boundary conditions were used at the top and bottom of the finite element model. A single vertical restraint at the lower left corner of the model was used to eliminate any rigid body modes in the model.

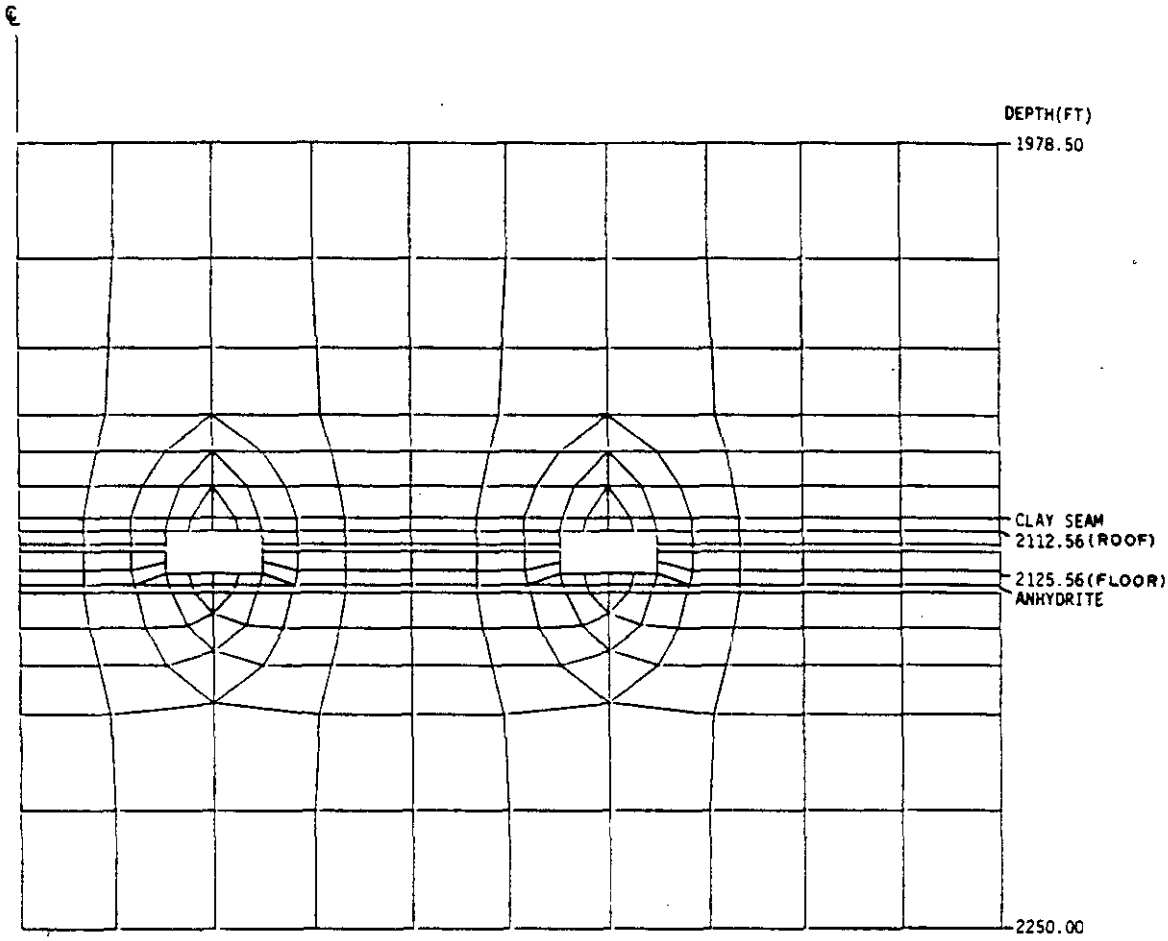

Figure 11-21

TEST ROOMS
FINITE ELEMENT MODEL

Element sizes were proportioned to minimize the stress gradients across each element. In addition, elements were oriented to have the mesh radiating from the opening of the model to be commensurate with estimated orientations of the principal stress axes. These aspects of the model were designed to increase the overall efficiency of the analyses.

Computation of In Situ Responses and Creep Parameters. The test room analyses were performed using the procedures described in Chapter 6 and the MARC General Purpose Finite Element Program (ref. 6-8). Time steps used in the analyses were within the specified tolerances recommended by the MARC Program. The analysis was performed in several stages with each stage containing between 50 and 100 integration steps. After completing each stage, the corresponding real time was computed to determine the required number of integration steps for the subsequent runs.

Figures 11-22 through 11-25 show the correlations of in situ and analytical roof-to-floor closures for Test Rooms 1 through 4. The in situ roof-to-floor closure data for Test Rooms 1 and 2 are from convergence meter readings while the measurements for Test Rooms 3 and 4 are from convergence points. Table 11-12 shows the individual creep parameters C, A and z for all four test rooms determined by numerically correlating the in situ roof-to-floor closure data. The table also shows the mean values of the creep parameters for three test room combinations.

Similarly, Figures 11-26 through 11-29 show the correlations of in situ and finite element wall-to-wall closures for Test Rooms 1 through 4. The in situ wall-to-wall closure data for Test Rooms 1, 3 and 4 are from permanent convergence points while the data from Test Room 2 consists of both temporary and permanent convergence point measurements. Table 11-13 shows the individual creep parameters C, A and z for all four test rooms determined by numerically correlating the in situ wall-to-wall closure data. The table also shows the mean values of the creep parameters for three test room combinations.

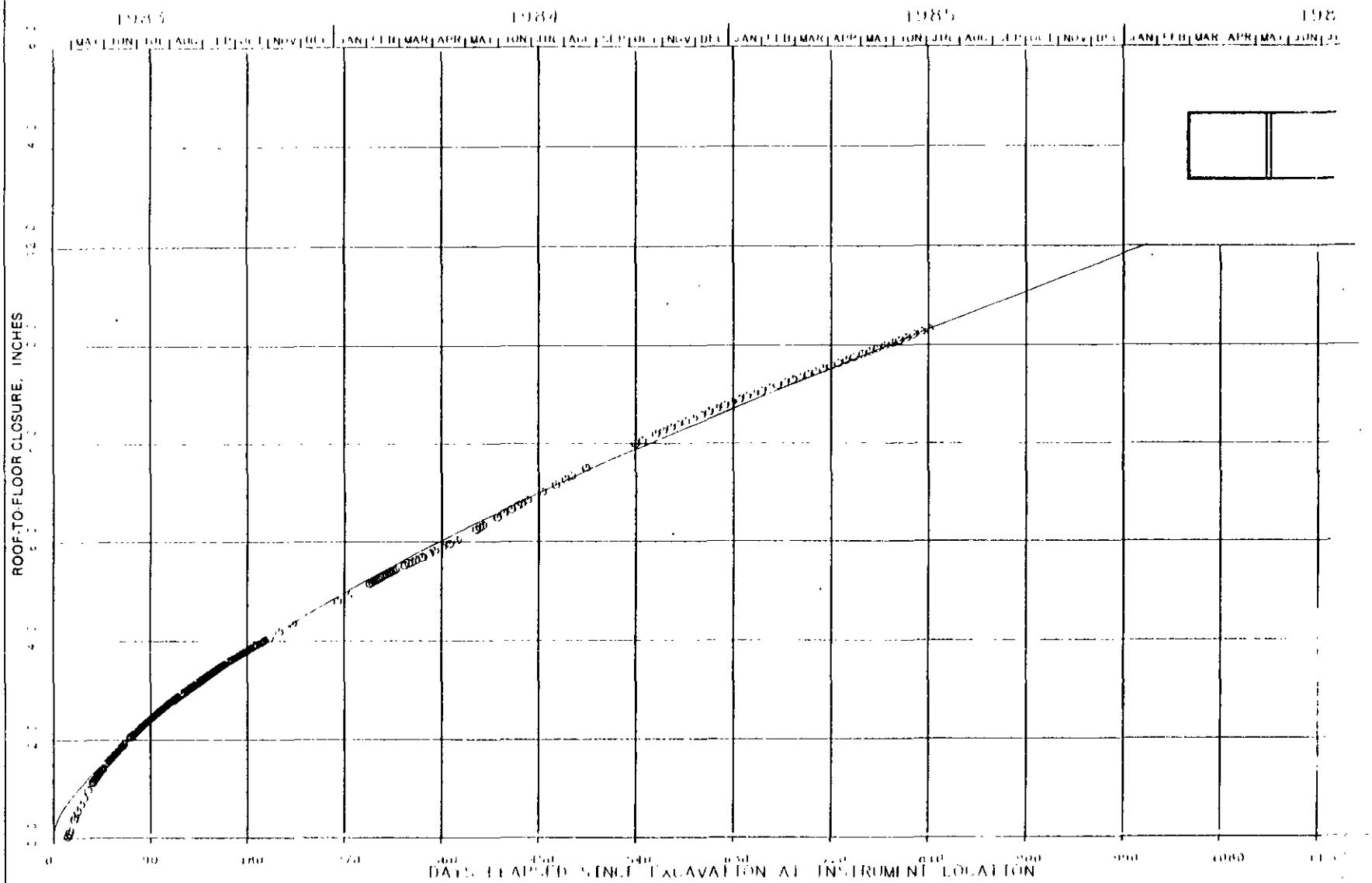

Figure 11-22

TEST ROOM 1
ROOF-TO-FLOOR CLOSURE HISTORY

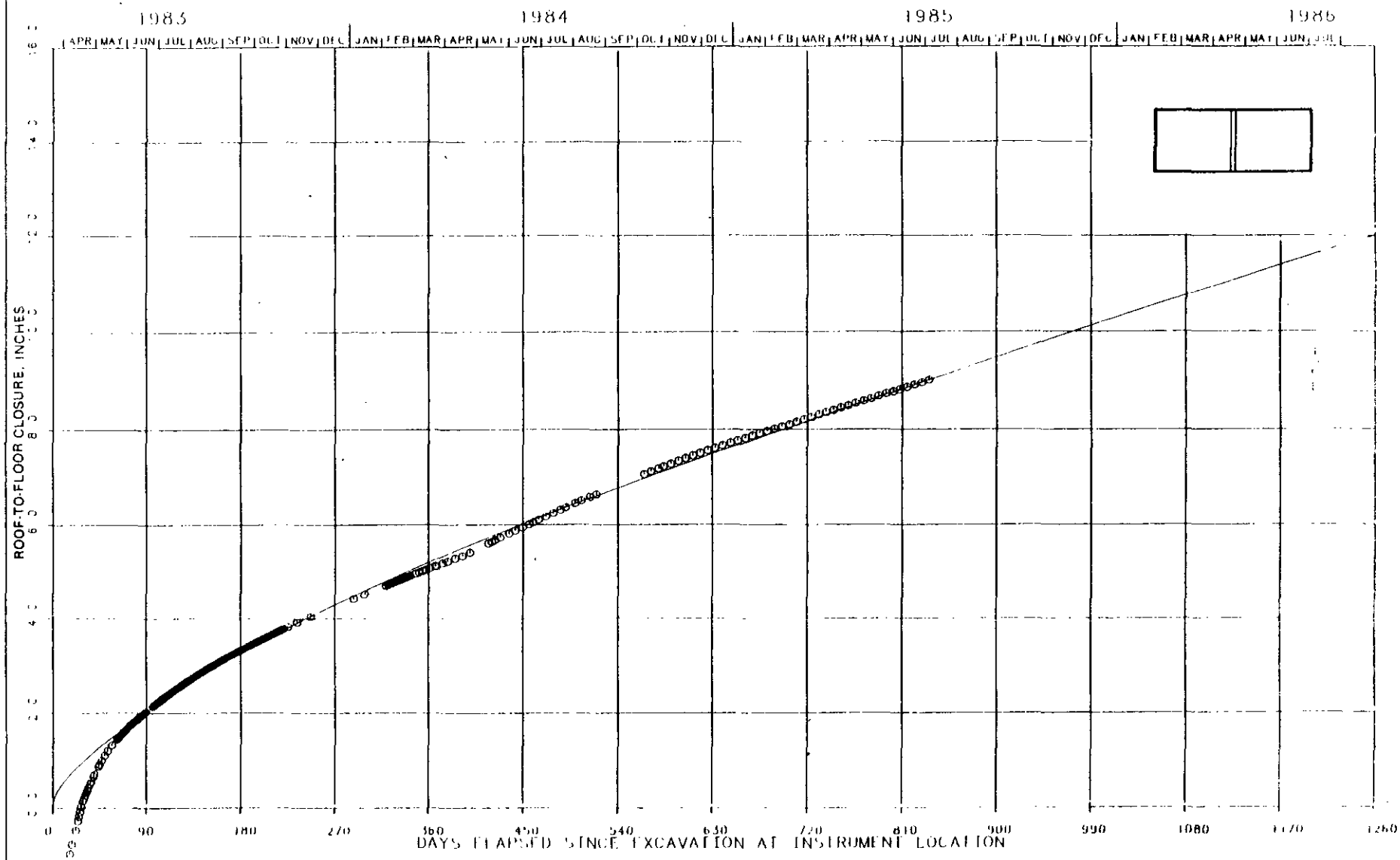

IN-SITU DATA

COMPUTATIONAL DATA

Figure 11-23

TEST ROOM 2
ROOF-TO-FLOOR CLOSURE HISTORY

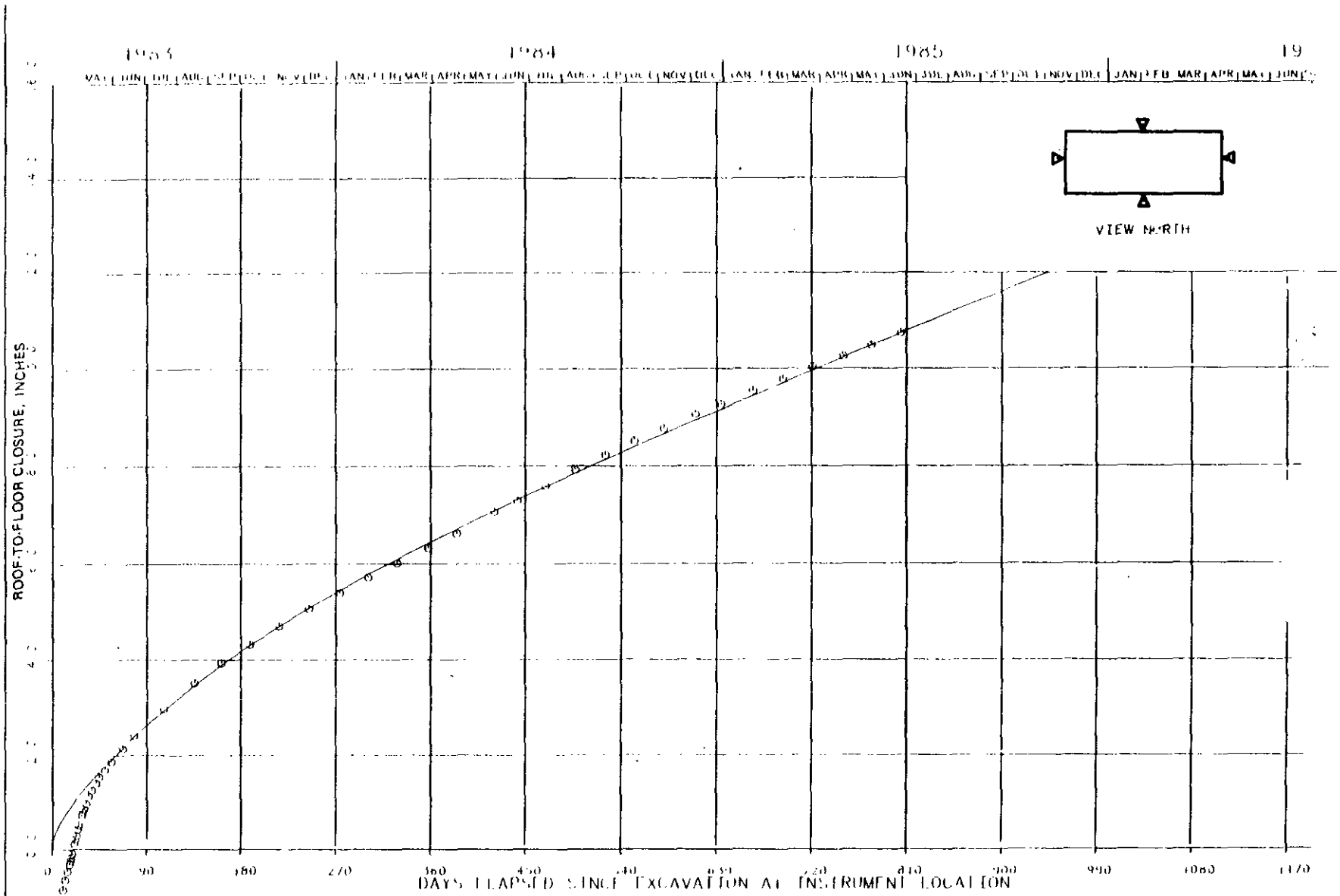

Figure 11-24

TEST ROOM 3
ROOF-TO-FLOOR CLOSURE HISTO

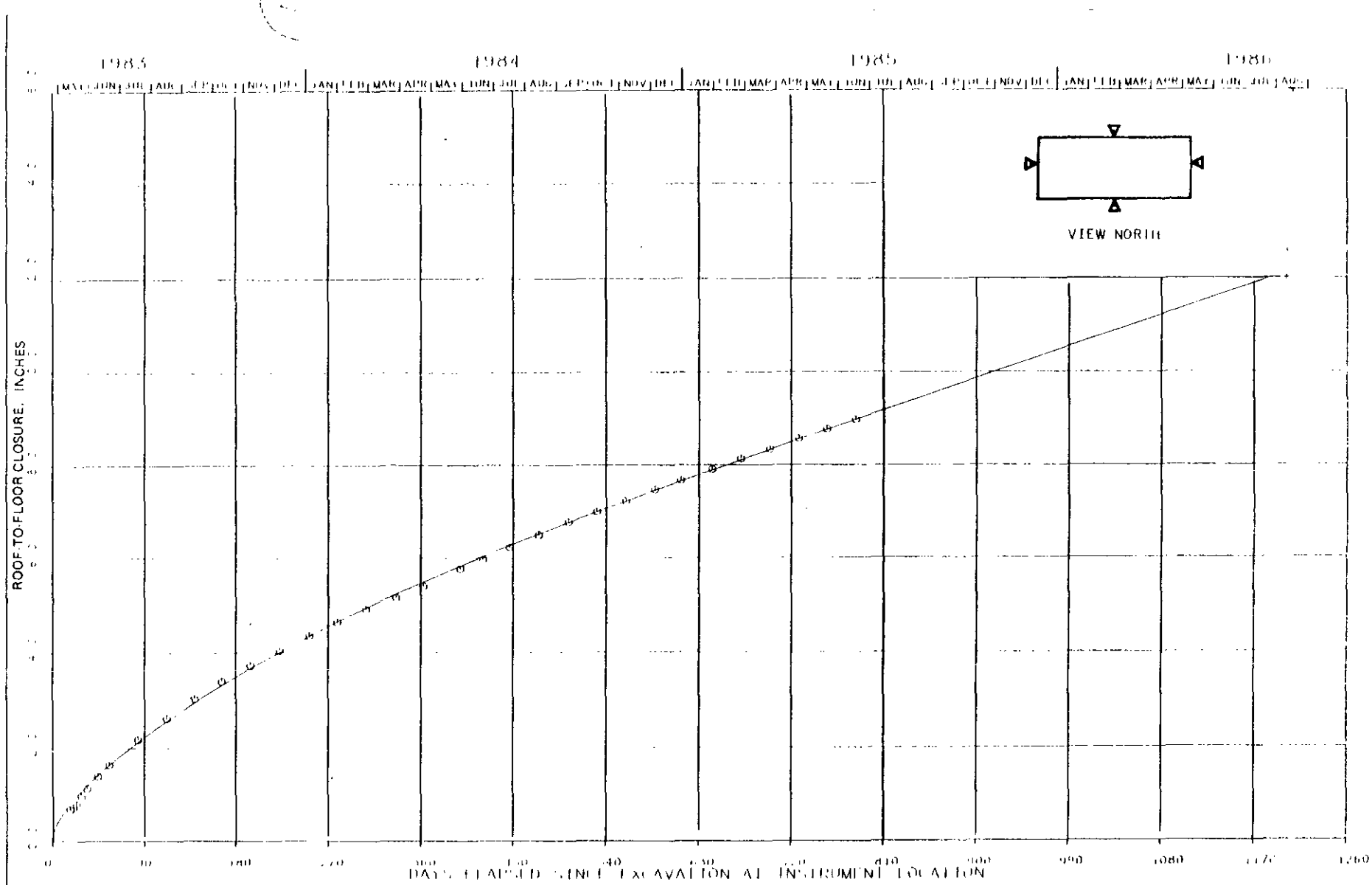

Figure 11-25

TEST ROOM 4
ROOF-TO-FLOOR CLOSURE HISTORY

TEST ROOM CREEP PARAMETERS
DETERMINED FROM ROOF-TO-FLOOR CLOSURES

Test Room	C ($ksf^{-4.9}sec^{-1}$)	A	z (sec^{-1})
1	3.103×10^{-21}	1.593	4.670×10^{-8}
2	1.919×10^{-21}	1.712	4.782×10^{-8}
3	2.516×10^{-21}	2.077	7.268×10^{-8}
4	2.813×10^{-21}	1.712	5.572×10^{-8}
Mean $\bar{X}$ (Rooms 1 thru 4)	2.588×10^{-21}	1.774	5.573×10^{-8}
Mean $\bar{X}$ (Rooms 1 & 4)	2.958×10^{-21}	1.653	5.121×10^{-8}
Mean $\bar{X}$ (Rooms 2 & 3)	2.218×10^{-21}	1.895	6.025×10^{-8}

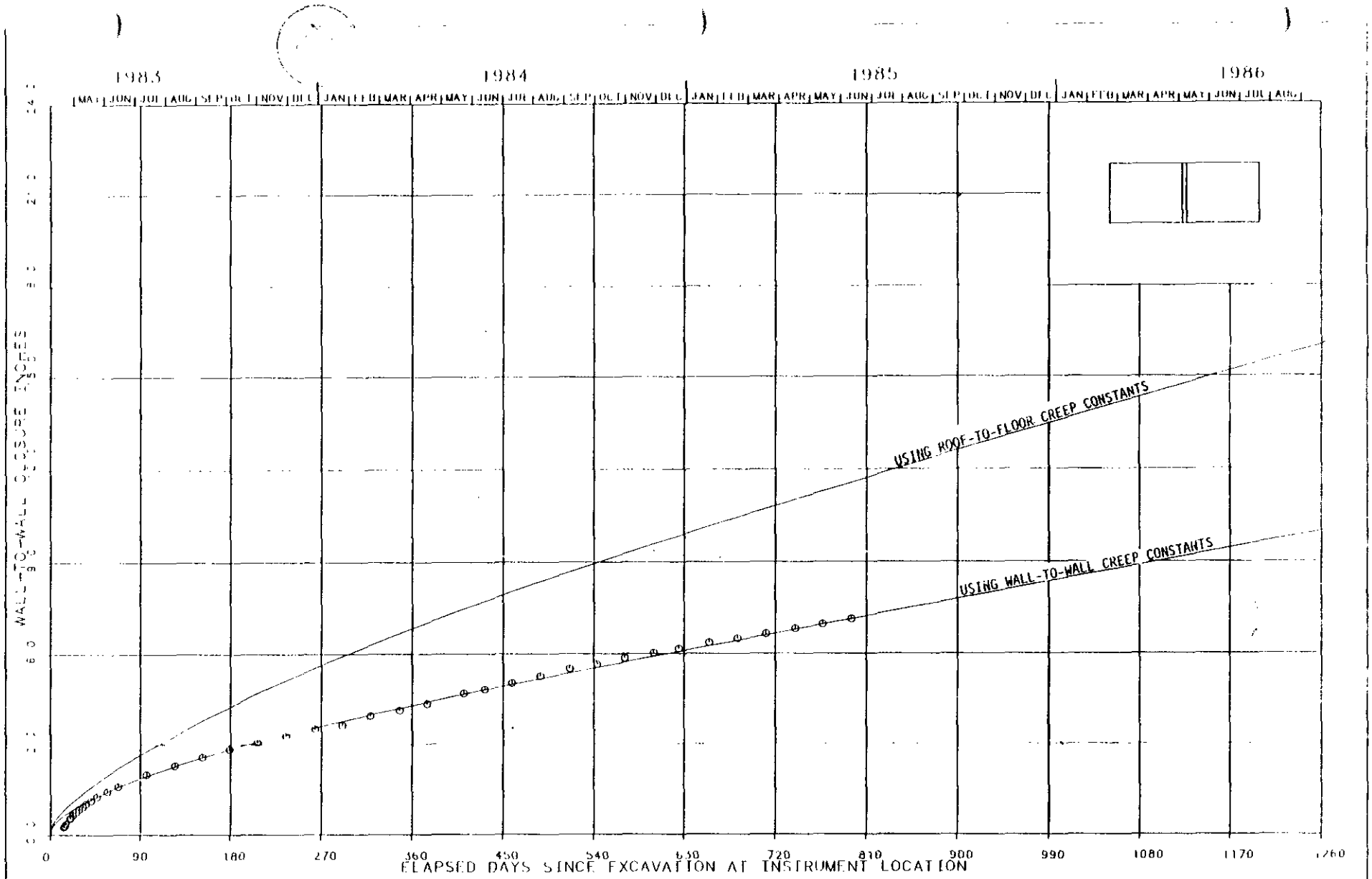

IN-SITU DATA

COMPUTATIONAL DATA

Figure 11-26

TEST ROOM 1
WALL-TO-WALL CLOSURE HISTORY

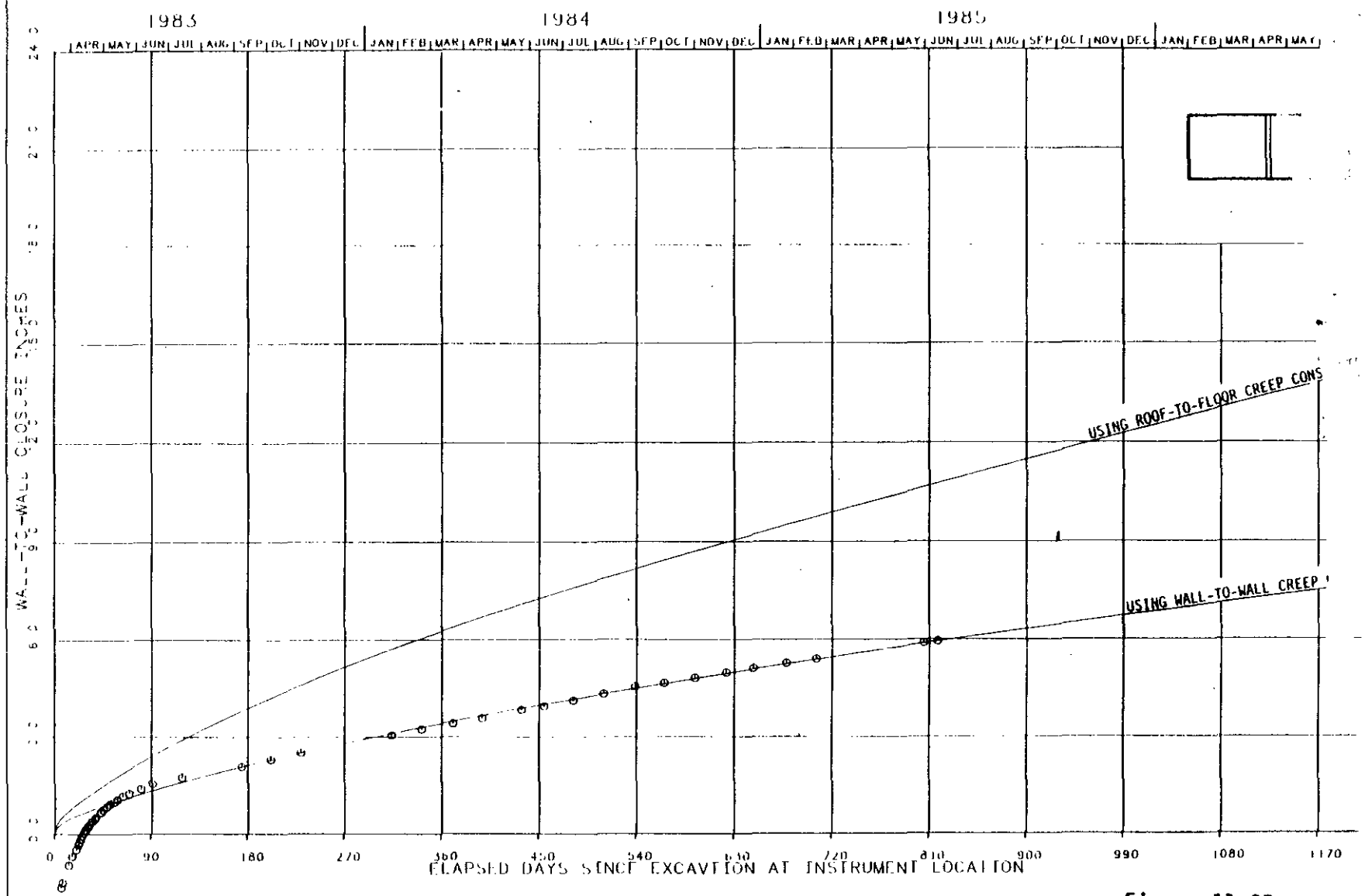

IN SITU DATA

COMPUTATIONAL DATA

Figure 11-27

TEST ROOM 2
WALL-TO-WALL CLOSURE HIST

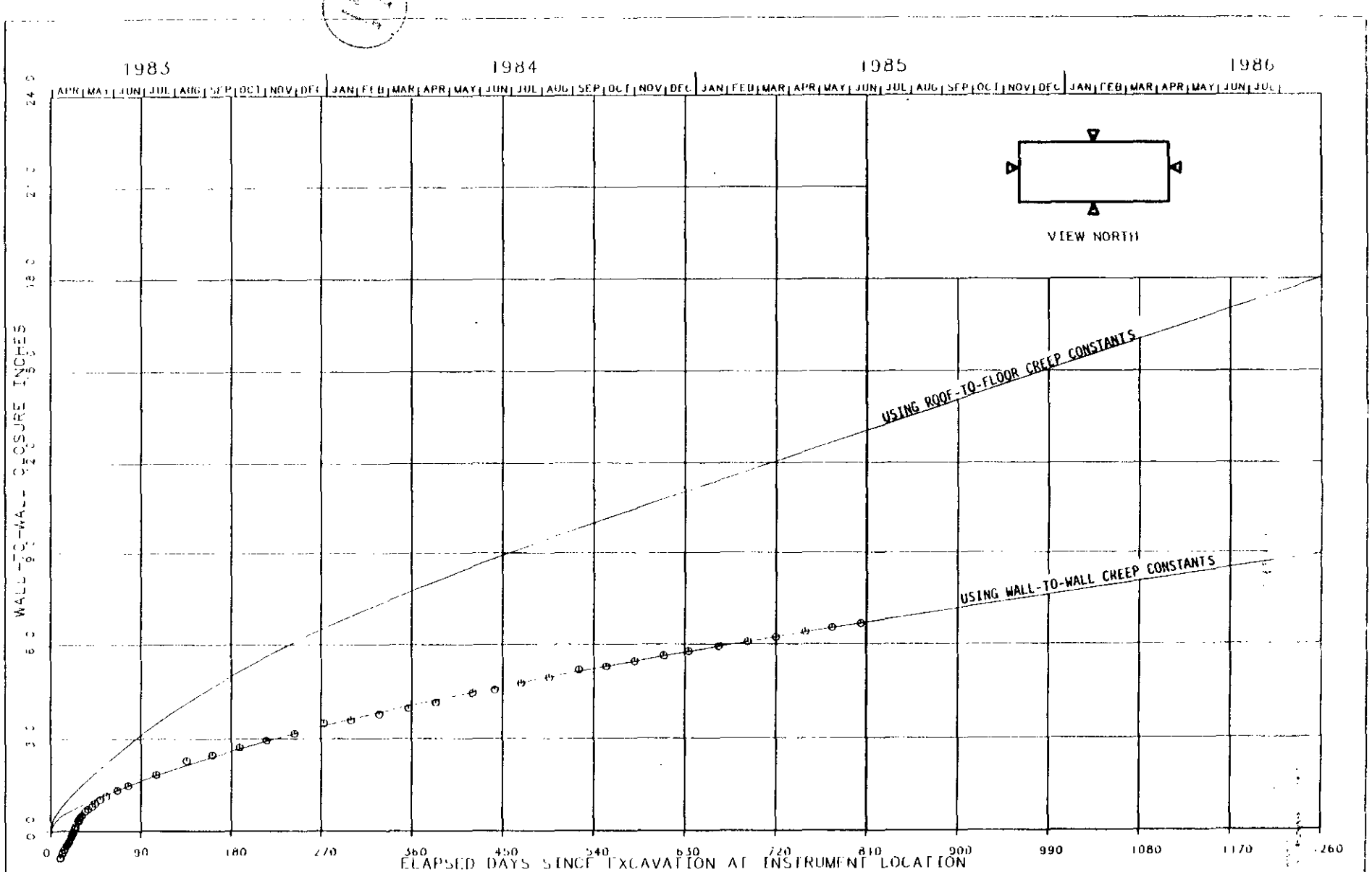

Figure 11-28

TEST ROOM 3
WALL-TO-WALL CLOSURE HISTORY

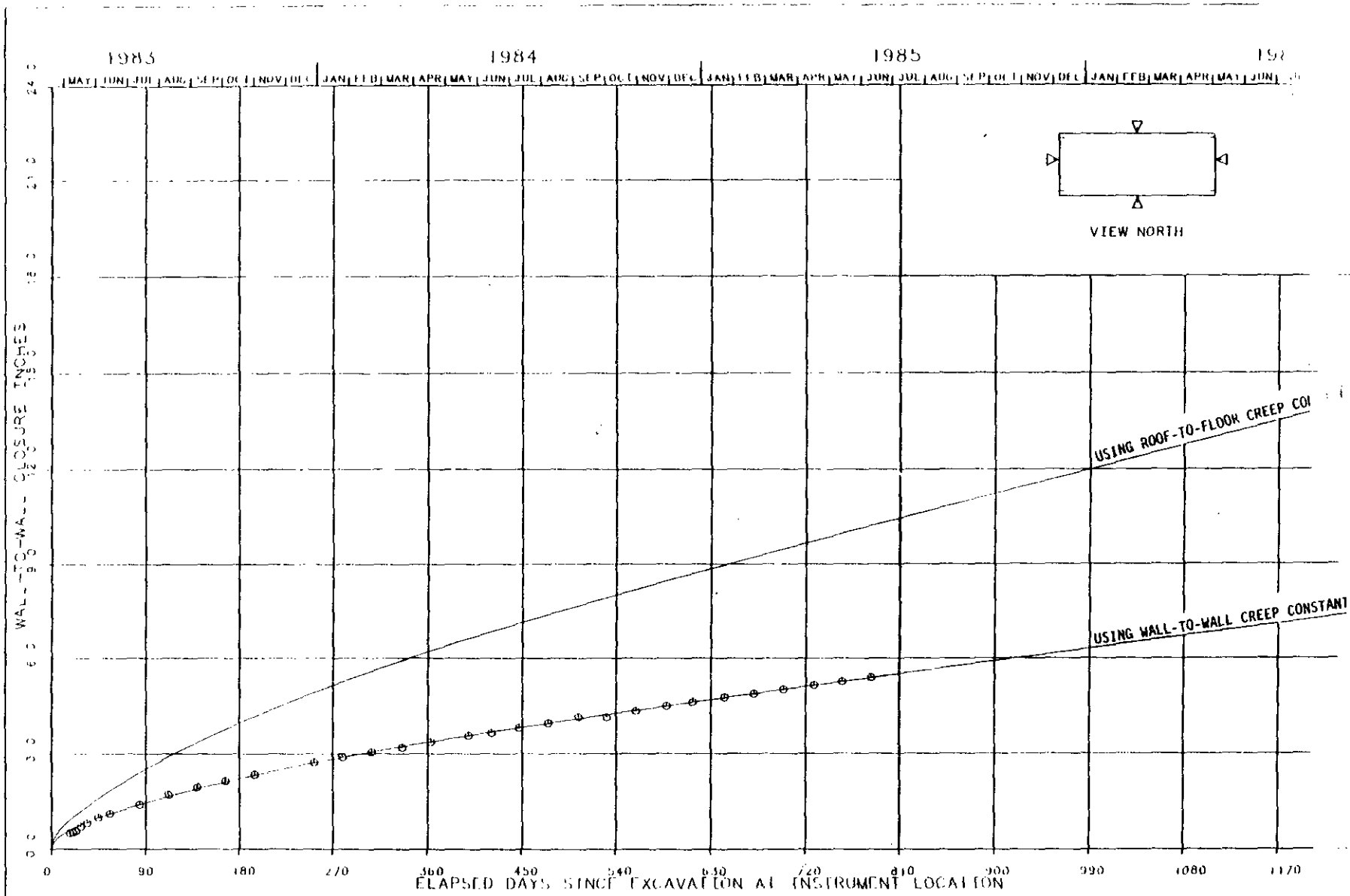

Figure 11-29

TEST ROOM 4
WALL-TO-WALL CLOSURE HIST

Table 11-13

TEST ROOM CREEP PARAMETERS
DETERMINED FROM WALL-TO-WALL CLOSURES

Test Room	C ($ksf^{-4.9}sec^{-1}$)	A	z (sec^{-1})
1	2.054×10^{-21}	1.502	6.810×10^{-8}
2	0.850×10^{-21}	1.630	2.476×10^{-8}
3	1.095×10^{-21}	1.920	4.464×10^{-8}
4	1.444×10^{-21}	1.419	5.276×10^{-8}
Mean $\bar{X}$ (Rooms 1 thru 4)	1.361×10^{-21}	1.618	4.757×10^{-8}
Mean $\bar{X}$ (Rooms 1 & 4)	1.749×10^{-21}	1.461	6.043×10^{-8}
Mean $\bar{X}$ (Rooms 2 & 3)	0.973×10^{-21}	1.775	3.470×10^{-8}

[illegible] and 11-10, the [illegible] the test rooms using roof-to-floor closure values va[illegible] from the values obtained using wall-to-wall closure values. To illustrate these variations, the upper curves on Figures 11-26 through 11-29 show the wall-to-wall finite element responses using creep parameters determined from roof-to-floor numerical correlations. The discrepancy may be partly due to material anisotropy of the salt which is not taken into account in the constitutive relationship for the salt. However, the most important contributor to the discrepancy may be the behavior of the clay seams and anhydrite beds. The model also does not include the complete effects of anisotropic creep behavior due to the combination of different layers in the actual stratigraphy. This behavior, due to anisotropic geometry, can be shown using a simple one-dimensional model similar to the one used by Branstetter et. al. (ref. 11-3). Consider a block of halite containing N horizontal layers with equal thickness. The creep law for each of the layers is assumed to be

$$\dot{\varepsilon}_c = f_i(t)\sigma^{-n} \qquad i = 1, 2, \ldots\ldots N \qquad (11\text{-}12)$$

The equivalent vertical creep function computed by considering only the creep relation in the vertical direction can be expressed as

$$f_v(t) = \frac{\sum_{i=1}^{N} f_i(t)}{N} \qquad (11\text{-}13)$$

However, the equivalent horizontal creep function computed by considering only the horizontal direction becomes

$$f_h(t) = \left[\sum_{i=1}^{N} f_i(t)^{-\frac{1}{n}} \right]^{-n} N^n \qquad (11\text{-}14)$$

It was found that, for any problem in which $f_i(t)$ varies, the value of the equivalent creep function in the horizontal direction, based on

equation 11-14, is lower than the value in the vertical direction, based on equation 11-13.

Replication of in situ creep behavior by the finite element model would require extensive research into the existing constitutive equations and perhaps modification of the MARC Finite Element Program. It is believed that the present methodology can adequately predict the roof-to-floor and wall-to-wall closures within acceptable engineering accuracy and that further work into anisotropic creep behavior is not justified for design validation.

One method of determining the structural adequacy of the salt is by using the effective strain. Model simulation of Test Room 2 behavior showed that the effective strain reached a maximum value at the intersections of the walls with the roof and floor. As discussed in subsection 11.3.2.4, bay strains in the vertical direction, determined from roof and floor extensometer data, are on the order of 5 percent through June 1986. Field observations of the test room walls have not found any structural failure at these strain values. Occasional minor, shallow spalls are a continuing occurrence, especially along the upper portion of geologic map unit 4.

Based on the results of the model simulation of Test Room 2, the maximum effective strain at the roof and wall intersection will be 6 percent about 15 years after excavation. The corresponding average vertical strain over a 2-foot thickness of salt will be 15 percent. However, effective strain is not directly measurable. At best, only vertical or horizontal strains can be determined from multiple-point borehole extensometer measurements. A comparison of the predicted vertical strain with the vertical strain determined from the relative displacement between the collar and anchor A of the roof extensometers has been made. Because the collar and anchor A are 5 feet apart, the strain calculated from the relative displacements will be an average value. Similarly, the strain from three elements spanning the collar to anchor A interval were summed and averaged for comparison.

shows the [illegible] the roof and wall intersection. Althougi [illegible] is expressed in terms of t*, the relationship between t* and the real time t is approximately linear. The strain determined from the collar to anchor A readings indicates that the rate is currently decreasing with time.

Figure 11-31 shows the relationship for the center of the roof. This rate is also decreasing with time, even though the numerical analysis shows a constant rate.

11.3.2.6 Effectiveness of Model Simulation

The procedure discussed in the previous subsection and in Chapter 5 used roof-to-floor closure data for the test rooms to calculate the creep parameters C, A and z. Extrapolation of creep behavior was then accomplished using these derived creep parameters.

The numerical analysis gives the displacements of nodal points and stresses within the elements. The effectiveness of the model used can be checked by comparing measurement data other than roof-to-floor closure with the magnitude predicated by the model. For example, relative displacements between anchor points in multiple-point borehole extensometers may be compared with predicted relative displacements between appropriate nodes of the model. Such a comparison will be helpful to assess the effectiveness of model simulation.

Because a symmetrical two-room model representing four rooms was used for model simulation, the relative displacement between the collar and the deepest anchor of the central roof extensometers in Test Rooms 1 and 4 were calculated for an interval of 60 days, and the average value determined. The real time t was converted to the normalized time t* using equation C.4-17 in Appendix C. This is because the numerical analysis was performed in terms of the normalized time. The vertical displacements of appropriate nodes in the finite element model, which approximately duplicate the collar and the deepest anchor of the roof extensometers, were compiled. If the nodes did not exactly match the

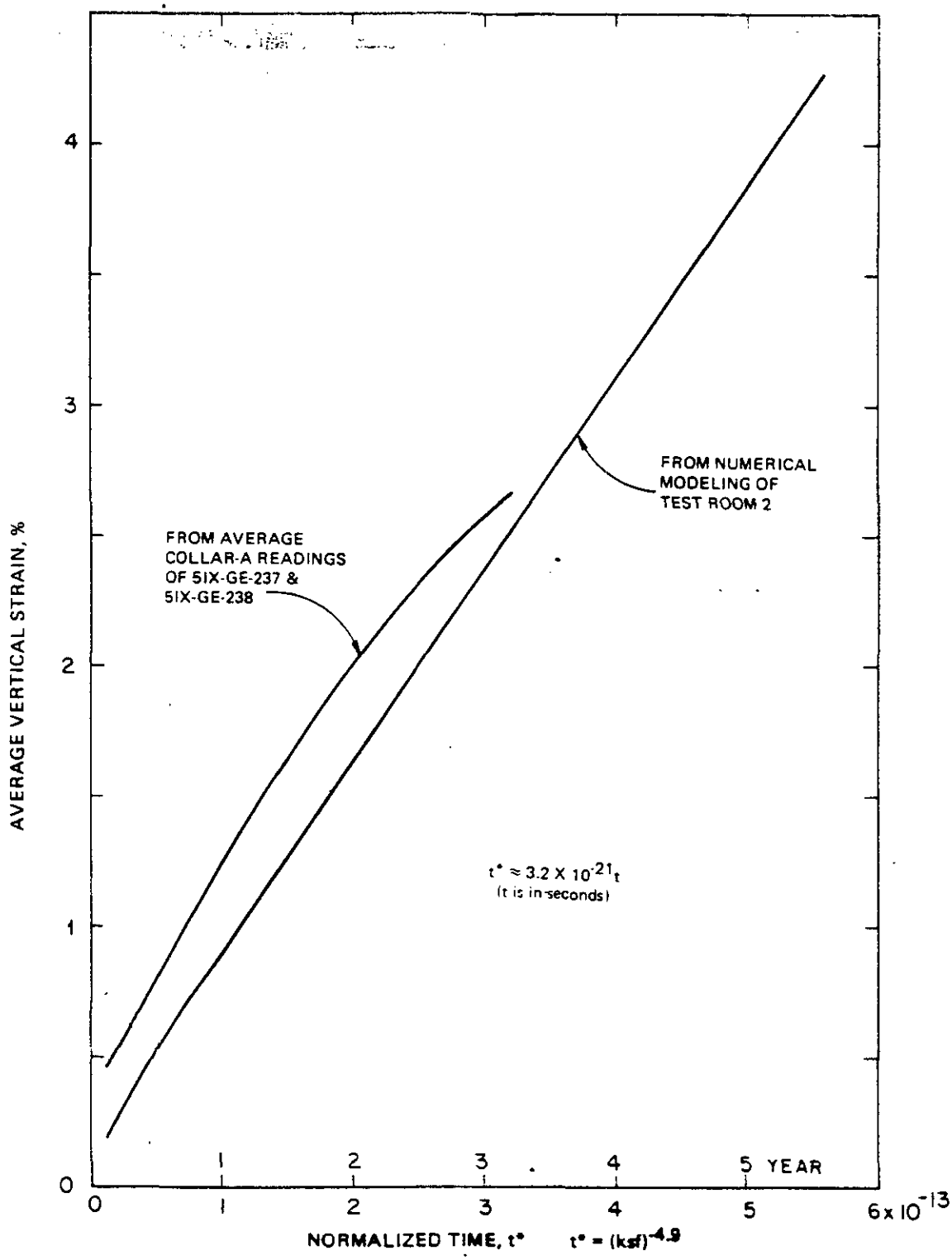

Figure 11-30

TEST ROOM 2
VERTICAL STRAIN AT ROOF AND PILLAR CORNER

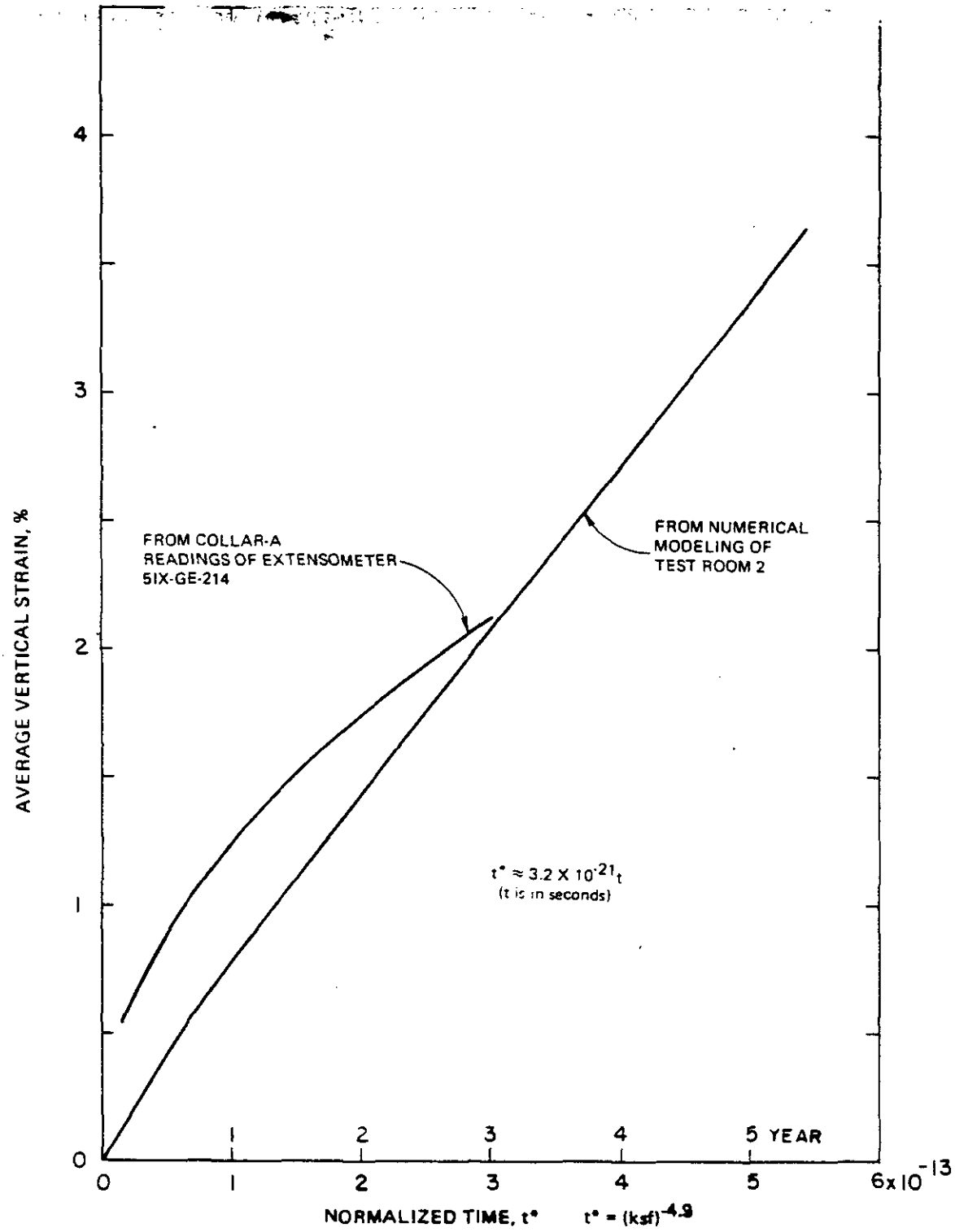

Figure 11-31

TEST ROOM 2
VERTICAL STRAIN AT ROOF CENTER

location of the deepest anchor, then linear interpolation was used to determine the displacement of salt at the required location.

Figure 11-32 compares the average relative displacement between the collar and the deepest anchor for the central roof extensometers 51X-GE-00207 and 51X-GE-00218, with the relative displacement between appropriate nodal points computed from the numerical model. A normalized time t* of 37.07×10^{-14} is equivalent to an elapsed time of nearly 3 years since the completion of excavation at the instrument location. The discrepancy between the measured and calculated relative movements is nearly 2 inches in 3 years.

For large values of t, the normalized time is approximately proportional to the real time, since the exponential term in equation C.4-17 in Appendix C approaches unity. For large values of t* (and t), the calculated relative displacement rate will be approximately 44 percent higher than the measured relative displacement rate if the current rate is maintained. A similar analysis was made for Test Rooms 2 and 3. Figure 11-33 compares the measured values with the values obtained from numerical modeling. The discrepancy in this case is 27 percent with respect to the measured value at nearly 3 years of elapsed time.

A comparison of salt heave measurement data from a floor extensometer in Test Room 4 was made with the values computed from numerical modeling. Figure 11-34 shows the results of this comparison. The numerical model underestimates the salt heave in the floor by approximately 70 percent of the measured value. This discrepancy is probably due to the assumption in the model that MB-139, 4.8 feet below the floor, is elastic and has infinite strength. Measurements from the floor extensometer and observations of fracturing indicate that MB-139 cannot be strictly considered as elastic. As discussed in subsection 11.3.2.1, borehole P4X-84 indicates the presence of lateral displacements and vertical separations in MB-139 beneath the floor of Test Room 4. This indicates that stresses in parts of the anhydrite bed may have reached the failure state.

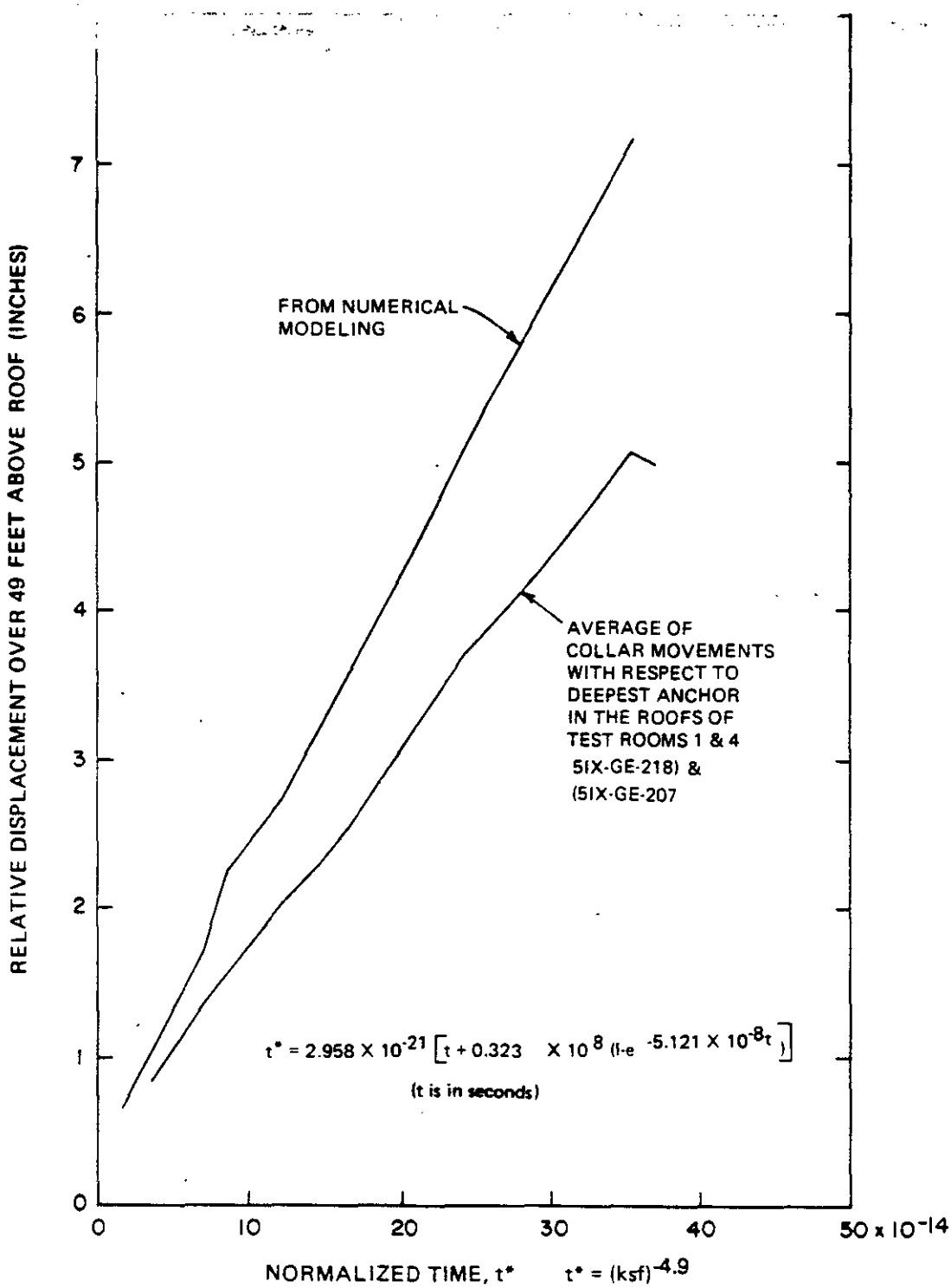

Figure 11-32

TEST ROOMS 1 AND 4 ROOF EXTENSOMETERS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

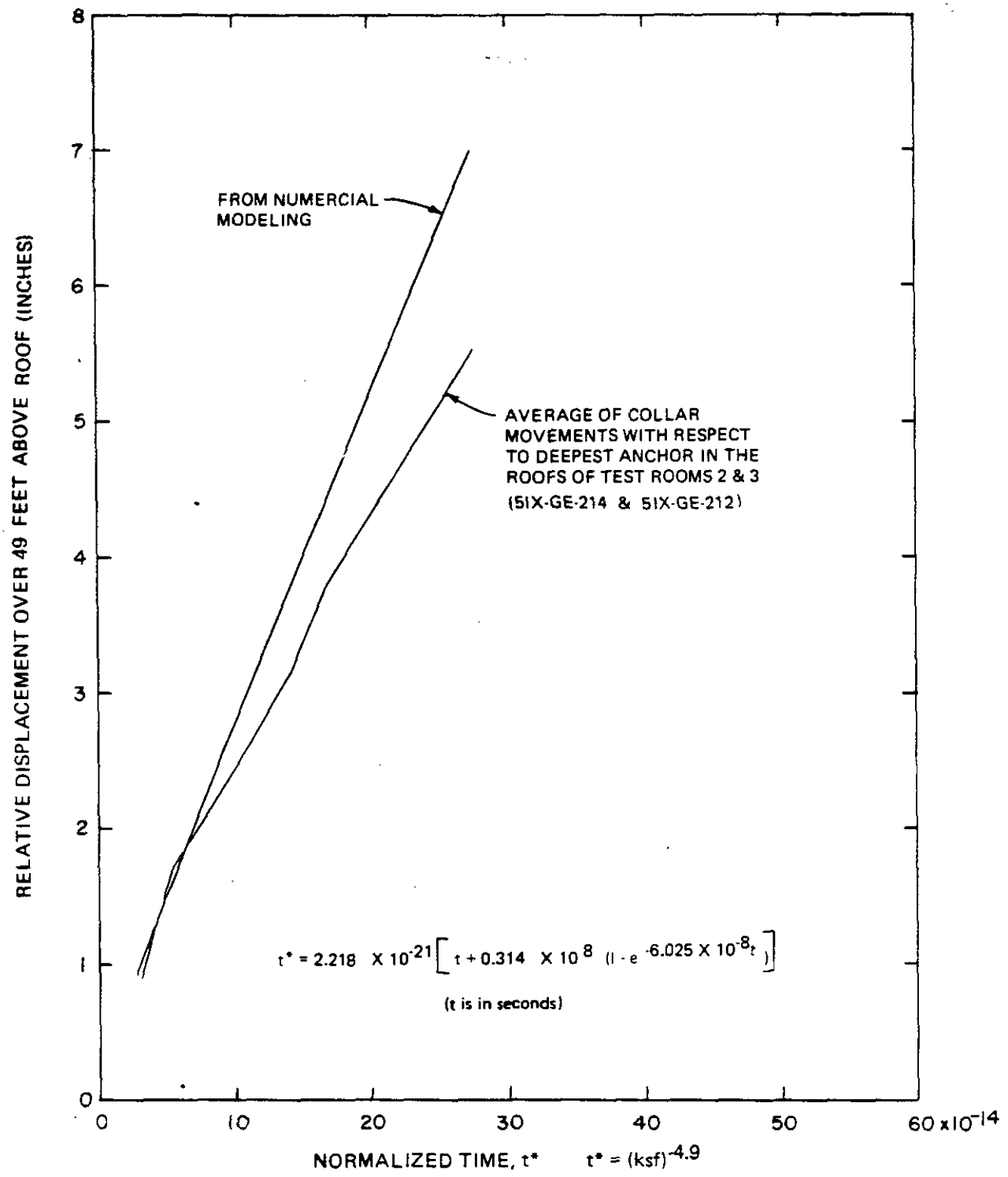

Figure 11-33

TEST ROOMS 2 AND 3 ROOF EXTENSOMETERS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

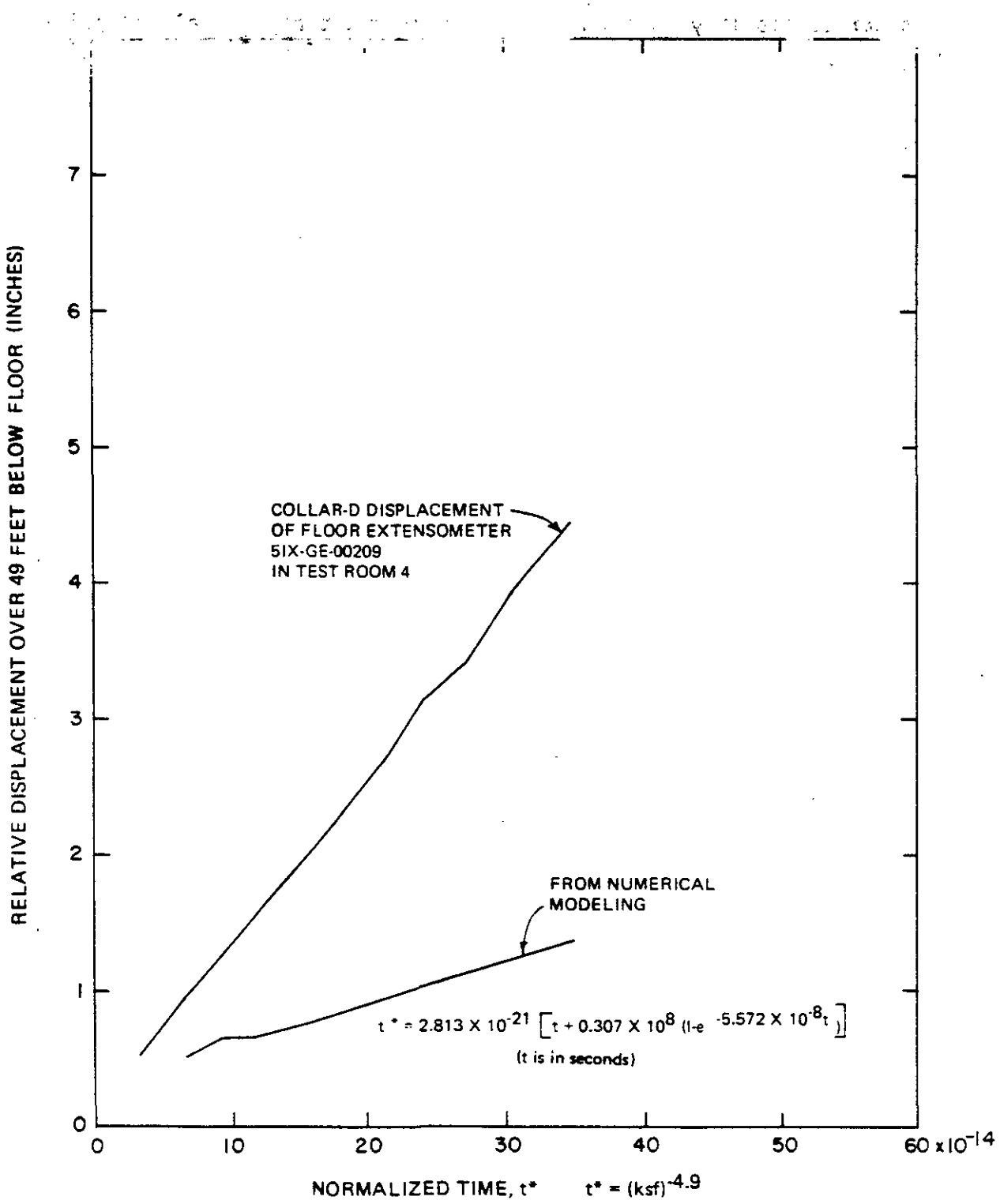

Figure 11-34

TEST ROOM 4 FLOOR EXTENSOMETER
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

Another possibility is that the fractures might have developed prior to excavation of the test rooms (ref. 6-6). In either case, assumptions of linear elasticity for the anhydrite bed become untenable. Modifications to the material characterization of this anhydrite material will be required to better represent its deformational behavior.

The basic philosophy of the model simulation developed in this report is that in situ measurement data are utilized to back calculate the creep parameters of the salt mass with the attendant discontinuities such as clay seams and anhydrite beds. For the model simulation technique, the in situ roof-to-floor closure data have been used to extract the creep parameters and predict future behavior using these creep parameters. This is because the roof-to-floor closure is deemed critical to evaluate the adequacy of the room dimensions for the effective storage and retrieval of waste. The discussions in the previous paragraphs indicate that there are discrepancies between measured and predicted quantities for variables other than roof-to-floor closure, such as deformations within the salt mass. Such discrepancies are not due exclusively to any inadequacy of the numerical modeling procedure but are also due to differences in the actual and assumed stratigraphy, variations in creep parameters with space and time, and inadequate representation of the stress-strain behavior of the anhydrite bed. However, it has been demonstrated that the model can predict, with sufficient accuracy for engineering purposes, the roof-to-floor closure behavior of the test rooms. A similar model simulation analysis was made for wall-to-wall closure and independent creep parameters were developed. Extrapolation of wall-to-wall closure with time was achieved using these creep parameters. This model simulation technique using in situ data was employed because the more detailed approach using material properties derived from laboratory tests may not produce more accurate results, as discussed in Chapter 5, subsection 5.4.3.

The reference design was based on computations for a single room rather than for multiple rooms. It was assumed that, with a low extraction ratio, the rooms with 100-foot pillars would not have as much early interaction as that which has developed in the four-room test panel. In Figure 11-35 the two lower curves show the computational results of roof-to-floor closure predictions for a 13 x 33-foot room using creep constants obtained from laboratory tests. The bottom curve represents the computational results from reference 11-4, dated August 1982, while the middle curve represents the updated result from reference 11-5, dated March 1985, which used revised creep parameters and an updated reference stratigraphy. In situ closure data for all four test rooms, including adjustments for their early closure, are plotted on the same figure for comparison. Interaction effects may be partly responsible for the discrepancy.

11.4 CONCLUSIONS AND RECOMMENDATIONS

11.4.1 Conclusions

The determination of the closure behavior of the WIPP underground openings using creep constants derived from laboratory experiments underestimated the actual closure. The measured roof-to-floor closure in the test rooms has exceeded 12 inches in the 3 years since the end of their excavation. This does not comply with the design criteria vertical closure allowance of 12 inches in 5 years.

Average vertical strains at roof and wall intersections, as determined from extensometer readings, were close to 3 percent in June 1986 and the strain rate was decreasing. Maximum vertical strain by numerical modeling occurs at roof and wall intersections and compares well with the value determined from in situ measurements.

Spalling from the roofs and walls, and fractures in the pillars and at pillar corners have been observed. Displacements and minor separations have been observed at clay seams and in the underlying halite in

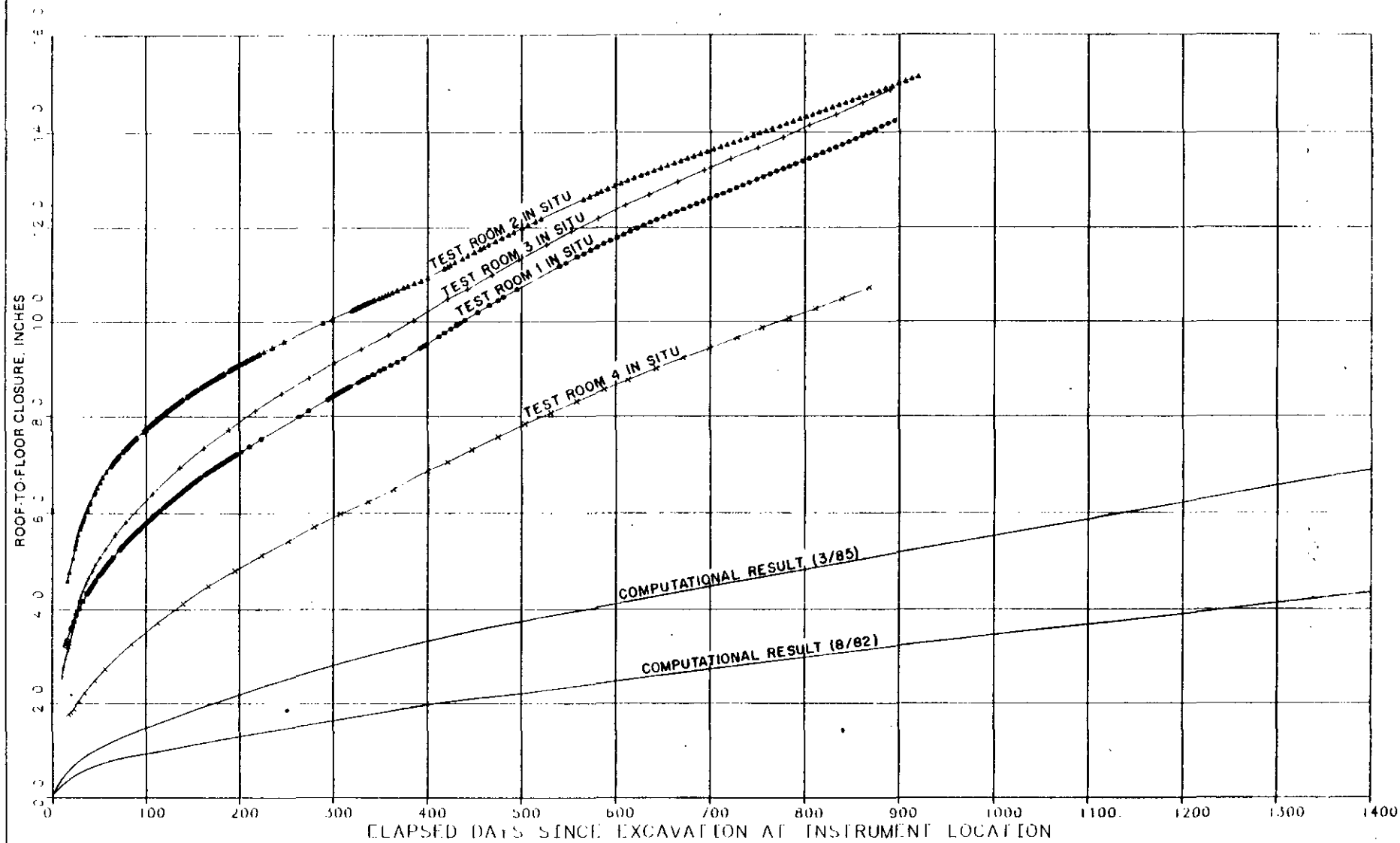

Figure 11-35

TEST ROOMS
COMPARISON OF LABORATORY VERSUS IN SITU DATA

[illegible] trate the roofs. hese [illegible] continue. Periodic maintenance of the roof and wall surfaces will be required.

Floor fracturing is well developed in the south half of Test Room 3 (Room T). Floor fracturing also occurs to a minor degree in the other test rooms and in a few areas in the drifts. Because the prominent floor fracturing occurring in Test Room 3 has not been found in any other rooms or drifts, it is considered to be anomalous to the underground facility. It is possible that the number and size of the 22 large-diameter holes in Test Room 3 exacerbated the pre-existing fractures. If floor fracturing occurs in the storage rooms, it is not expected to cause any operational or storage problems. As discussed in Chapter 3, Section 3.2, the WIPP project participants agreed, in a meeting on February 13, 1986, that the underground conditions do not require moving the facility level (ref. 3-2).

11.4.2 Recommendations

Observations and geomechanical instrumentation measurements should continue in the test rooms. Because they are the models for the determination of storage room behavior, trimming, rock bolting and other maintenance in the test rooms should be kept to the minimum required for safety, and the rooms allowed to deform.

It is recommended that Test Room 2, in particular, be preserved. It is the only test room that has not been physically altered. This room will then serve as a model for the storage rooms as they will exist prior to waste emplacement. Test Room 2 should not be trimmed or supported except as anticipated for the storage rooms. Additional instrumentation may be installed and small-diameter holes should be drilled in the roof and floor to observe the development of displacements, separations and fracturing. Large-diameter drilling should be prohibited and the room should be closed to all other activities. Continued observations of Test Room 2 behavior will

provide valuable data on anticipated storage room performance for the period between room excavation and the emplacement of waste.

A program of drilling, testing and geologic mapping should be continued to determine the development and extent of fracturing beneath the test room floors. When this has been determined, several monitoring stations should be established to document the behavior of the fractures. This program should also include monitoring roof displacements and separations. Arrays of small-diameter holes should be drilled in a few locations in each test room as soon as possible to document movement above the roof. However, drilling in Test Room 2 should be kept to a minimum.

Additional efforts are needed to refine constitutive laws for the creep behavior of salt as well as the representation of stratigraphy. The stress-strain-time behavior of anhydrite beds should be more accurately represented.

CHAPTER 12
STORAGE AREA

12.1 INTRODUCTION

The storage area encompasses all rooms, drifts and crosscuts that will be used for the permanent storage of CH and RH TRU wastes. The storage area is located south of the waste shaft station, from S1600 to S3664 (see Chapter 1, Figure 1-2, and this chapter, Figure 12-1, for location and layout). The storage area is arranged to provide a system in which CH and RH TRU wastes can be efficiently and safely handled and stored. A panel of four full-scale test rooms was excavated to determine the adequacy of the opening configuration and dimensions (Chapter 11). Evaluation of in situ data from these test rooms were utilized to predict the closures of, and stresses and strains around, the future storage area rooms and drifts.

This chapter presents information on the reference design of the storage area rooms and drifts, the design validation process, conclusions regarding the suitability of the reference design based on the findings of the validation process, and recommendations for modifications to the storage area design configurations that will, if implemented, result in a validated reference design.

12.2 DESIGN

This section presents the design criteria, design bases and reference design configurations that were used for the WIPP storage area rooms and drifts.

12.2.1 Design Criteria

The Design Criteria, RMC-IIA, for the storage area (ref. 2-8) is summarized in Chapter 2, Table 2-1. This table presents the major criteria that governed the WIPP underground opening reference design, including those criteria that require evaluation as part of the design validation process. The following discussion presents a description of

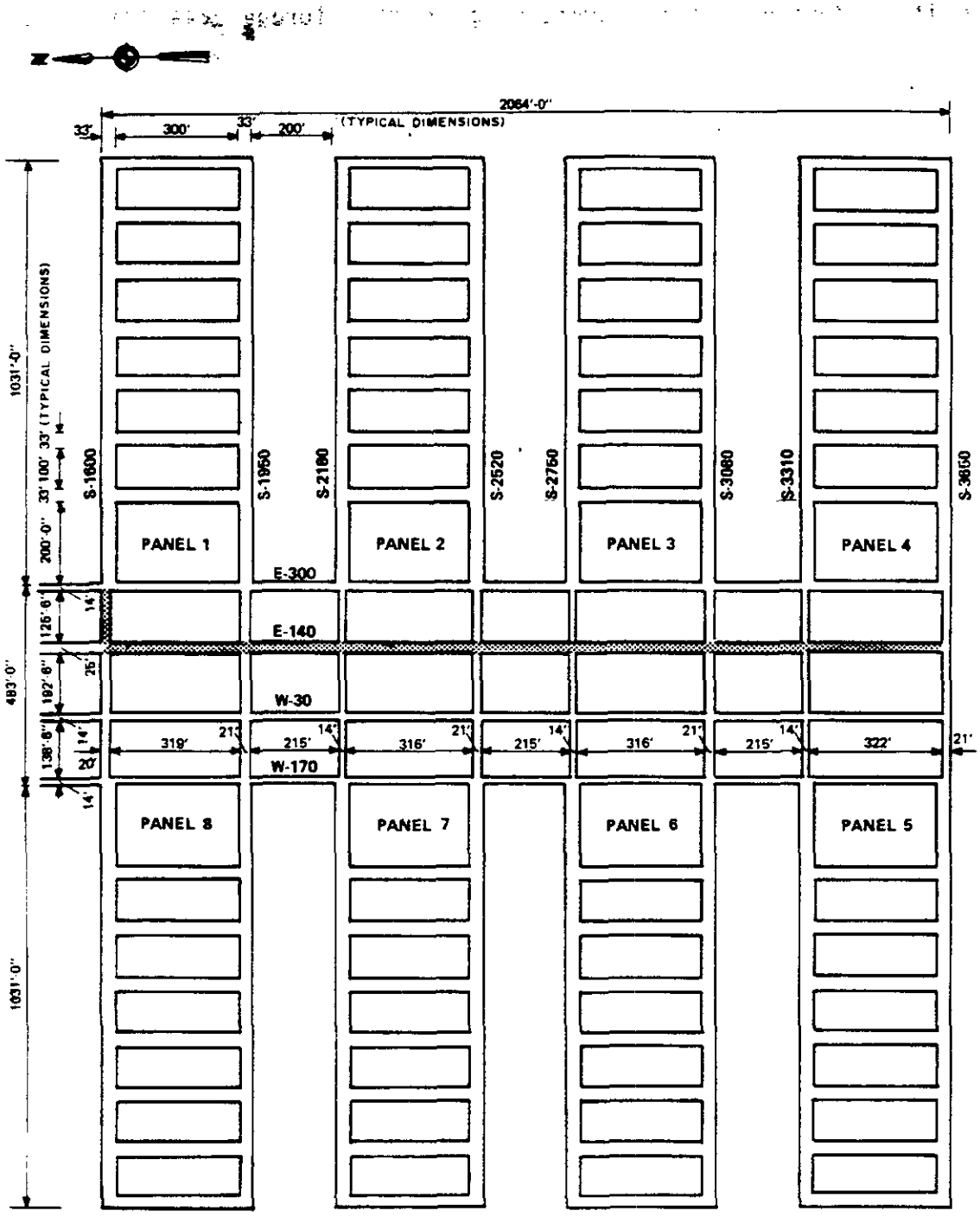

Figure 12-1

STORAGE AREA
REFERENCE DESIGN PLAN

the three design criteria pertaining to the storage area that require evaluation for validation of the reference design.

The first criterion requires that the excavation dimensions of the storage area rooms and drifts include an allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period. The second criterion states that each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years. The third criterion states that the underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with the waste container sizes, shapes, weights, and stacking configurations, and with the waste handling and backfilling equipment requirements.

Other criteria that apply to the storage area reference design also apply to the drifts and were discussed in Chapter 10.

12.2.2 Design Bases

The design bases describe the specific dimensional requirements used to develop the reference design for the storage area drift and room configurations (Figures 12-2 and 12-3). The Design Basis, Underground Excavations (ref. 2-18) contains the bases used for the storage area reference design. The major elements from this Design Basis document are summarized in the following discussion. Although other design bases were also used, they did not have a direct impact on design validation. The specific design bases requiring evaluation during the validation process are presented in Table 12-1.

The design bases specify that the reference design shall provide an underground storage area in which CH and RH TRU wastes can be efficiently handled and stored. The reference design of the waste storage area shall permit simultaneous storage of CH and RH TRU wastes. To the extent possible, the configuration of the storage area shall minimize haulage distances for excavated salt and waste storage.

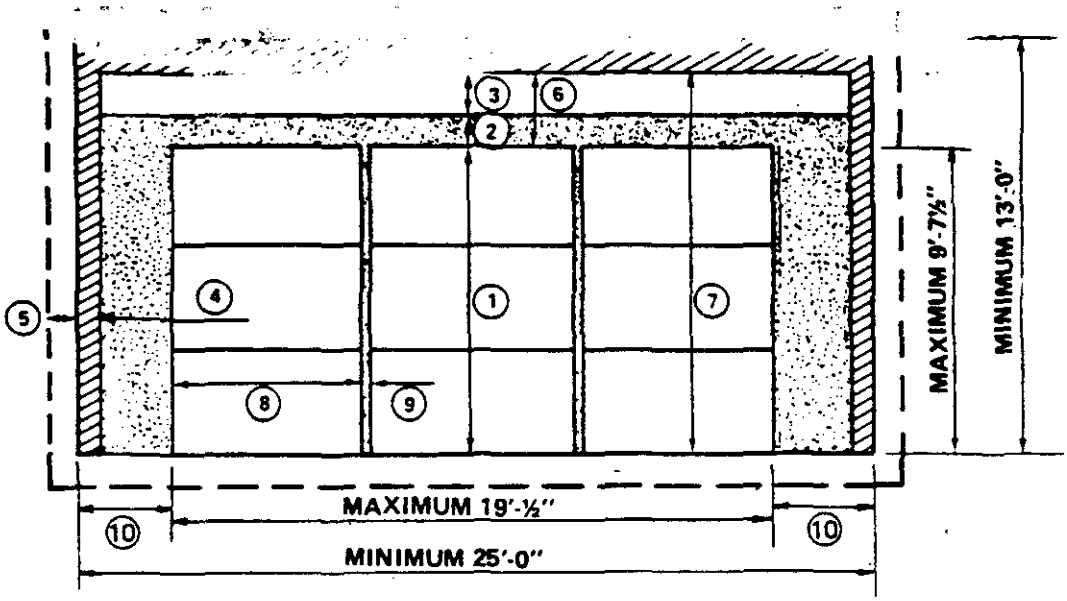

EXPLANATION

(1) HEIGHT OF WASTE PACKAGES STACKED THREE HIGH: 9'-7 1/2" FOR BOXES; 9'-0" FOR SIX PACKS.

(2) SALT COVER: 1' TO 2'; LEVEL OF SALT IS MAINTAINED AT 10'-8" ABOVE THE FLOOR.

(3) VENTILATION SPACE: 1'-4" MINIMUM UNTIL ROOM OR PANEL IS FILLED AND PLUGGED.

(4) SALT CREEP ALLOWANCE: 1'-0" ROOF; 4 1/2" EACH WALL (ASSUMED TO BE ADEQUATE FOR 5 YEARS).

(5) CONSTRUCTION TOLERANCE: +6". THE CONTRACTOR MUST MAINTAIN THE MINIMUM ROOM DIMENSIONS.

(6) BACKFILLING CONVEYOR CLEARANCE: 2'-4" ABOVE WASTE PACKAGES.

(7) HEADROOM: 12'-0" FOR CH BOXES AND RH TRANSPORTER.

(8) WASTE PACKAGE WIDTH: 6'-2 1/2" FOR BOXES; 6'-1 1/2" FOR SIX PACKS.

(9) STACKING TOLERANCE: 2 1/2" BETWEEN WASTE PACKAGES.

(10) SALT BACKFILL: 3'-0" BETWEEN WASTE PACKAGES AND WALL.

Figure 12-2

STORAGE AREA
DRIFT REFERENCE DESIGN DIMENSIONS

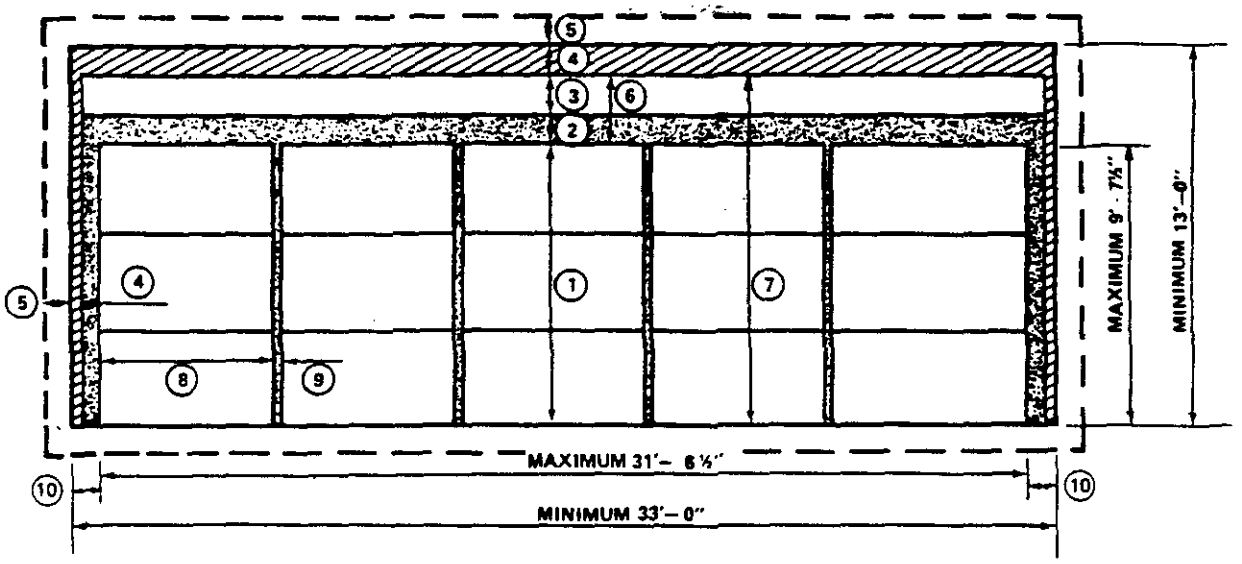

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(8) WASTE PACKAGE WIDTH: 6'-2 1/2" FOR BOXES; 6'-1 1/2" FOR SIX PACKS.

(9) STACKING TOLERANCE: 2 1/2" BETWEEN WASTE PACKAGES.

(10) SALT BACKFILL: 8 3/4" BETWEEN WASTE PACKAGES AND WALL.

Figure 12-3

STORAGE AREA
ROOM REFERENCE DESIGN DIMENSIONS

ELEMENTS OF STORAGE AREA DESIGN BASES

(1) Operational requirements

a. The storage area rooms, drifts and crosscuts shall be designed to allow for retrieval of all CH and RH waste stored for a period of up to 5 years after the initial emplacement of each waste species.

b. Excavation dimensions in the waste storage area shall be to a uniform height of 13 feet.

(2) Essential features

Provide 1 foot vertical and 9 inches horizontal allowance for creep closure to maintain the minimum design dimensions up to 5 years after initial emplacement.

(3) Safety design requirements

A minimum opening of 16 inches shall be left at the top of the rooms and drifts for air passage above the waste and backfill.

Construction and storage operations shall be physically separated and performed during different shifts.

Each storage room is to be filled with waste containers consisting of six-packs of CH TRU waste storage drums and/or boxes of CH TRU waste. The containers shall be stacked three high and five wide, stored with their longest dimension across the opening. A 2 1/2-inch stacking tolerance shall be allowed between waste packages. All rooms, drifts and crosscuts in the storage area may be used to store CH waste containers stacked three high. For this reason, excavation shall be to a uniform height of 13 feet throughout the waste storage area.

The underground storage area shall provide for the horizontal emplacement of 1,000 RH canisters. The RH canisters, nominally 10 feet long and 26 inches in diameter, shall be stored in the salt pillars. Emplacement holes shall be perpendicular to the walls, approximately midway between the floor and ceiling and evenly spaced laterally. Canister spacing shall be based on the assumption that the average heat output per canister will be 60 watts or less. Thermal loading in the RH waste storage area shall not exceed 10 kilowatts (kw) per acre. Allowing 12 inches for salt creep, RH waste emplacement machinery shall be designed to operate in an effective room height of 12 feet, including all required clearances.

The storage area floor shall be approximately 2,150 feet below the ground surface. The final level of the excavations shall be as determined by the DOE Contracting Officer.

Four parallel entries shall be provided from the shafts to the waste storage area. These entries shall provide separate channels for air intake and exhaust, salt removal, and waste storage.

Excavation dimensions shall include an allowance for salt creep of 1 foot in the vertical direction and 9 inches in the horizontal direction for all rooms for up to 5 years. The tolerance for excavation of roof,

[illegible] the finished cross section dimensions be less than design dimensions.

Provision shall be made for the expansion of the storage area within the boundaries of Zone II (Chapter 1, Figure 1-1) if required in the future. The area extraction ratio in the storage area shall not exceed 25 percent.

The stored CH TRU waste packages shall be covered with a layer of salt backfill (3/8 inch or less in grain size) for fire protection. The volume of stored CH TRU waste in any one compartment without a vertical fire barrier shall be limited to a maximum of 500,000 cubic feet. For ventilation above the backfilled waste, a minimum opening of 16 inches shall be provided.

No personnel may work in air that has passed over the stored CH TRU waste. However, personnel may work in air that has passed through an opening where RH TRU waste has been emplaced provided that canister holes have been sealed with plugs. Personnel may not work in air that has passed through openings where RH TRU waste is being emplaced.

12.2.3 Design Configuration

The reference design of the storage area was developed in accordance with the design criteria and the design bases. The design configuration is based on the stratigraphy determined from borehole ERDA-9 and on salt creep performance determined from laboratory tests on core extracted from ERDA-9. The ERDA-9 exploratory hole was the only hole within the underground development area which was permitted to penetrate the Salado formation to the underground facility horizon.

The storage area reference design configuration (Figures 12-1, 12-2 and 12-3) consists of eight panels with seven rooms each. The rooms are 13 feet high, 33 feet wide and 300 feet long. The panel entries are also 13 feet high and 33 feet wide. The rooms are separated in each panel

by 100-foot wide pillars and the panels are separated by 200-foot wide pillars. The test rooms discussed in Chapter 11 were designed to be the same size as the storage rooms. The test rooms were constructed to monitor salt performance, permit observations of opening stability, and to permit validation of the storage room reference design.

The reference design provides for the storage of CH waste in one room while RH waste is stored in another room. Emplacement of RH waste canisters into horizontal holes is depicted on Figure 12-4. After the RH waste canisters are emplaced in the walls of the storage room a shield plug is placed in the wall sleeve. When the emplacement of RH waste canisters is completed in the storage room, CH waste can be stored in the same room. During the 5-year demonstration period, the RH waste canisters are stored in steel sleeves in the first room of Panel 1. During permanent storage, they are emplaced in pillars throughout the storage area as dictated by the receival rate of the waste.

The RH waste canisters (with a heat output of 60 watts or less) are placed in horizontal holes spaced so that the local storage area thermal loading does not exceed the design basis limit of 10 kw/acre. For the reference design, and for this report, the thermal effects on storage room behavior were not considered significant. The reference design for RH waste is subject to the results of the ongoing WIPP experimental program.

The reference design configuration also defines stacking configurations and tolerances for ventilation, backfill and salt creep. These tolerances are shown on Figures 12-2 and 12-3 for the storage area drifts and rooms, respectively. In order to meet these requirements, the reference design configuration incorporates a reference operating procedure. This procedure is based on the waste receipt rates, emplacement rates, and retrieval rates stipulated by the design criteria. This operating procedure is part of the storage room reference design and is incorporated in construction package EP-01X.

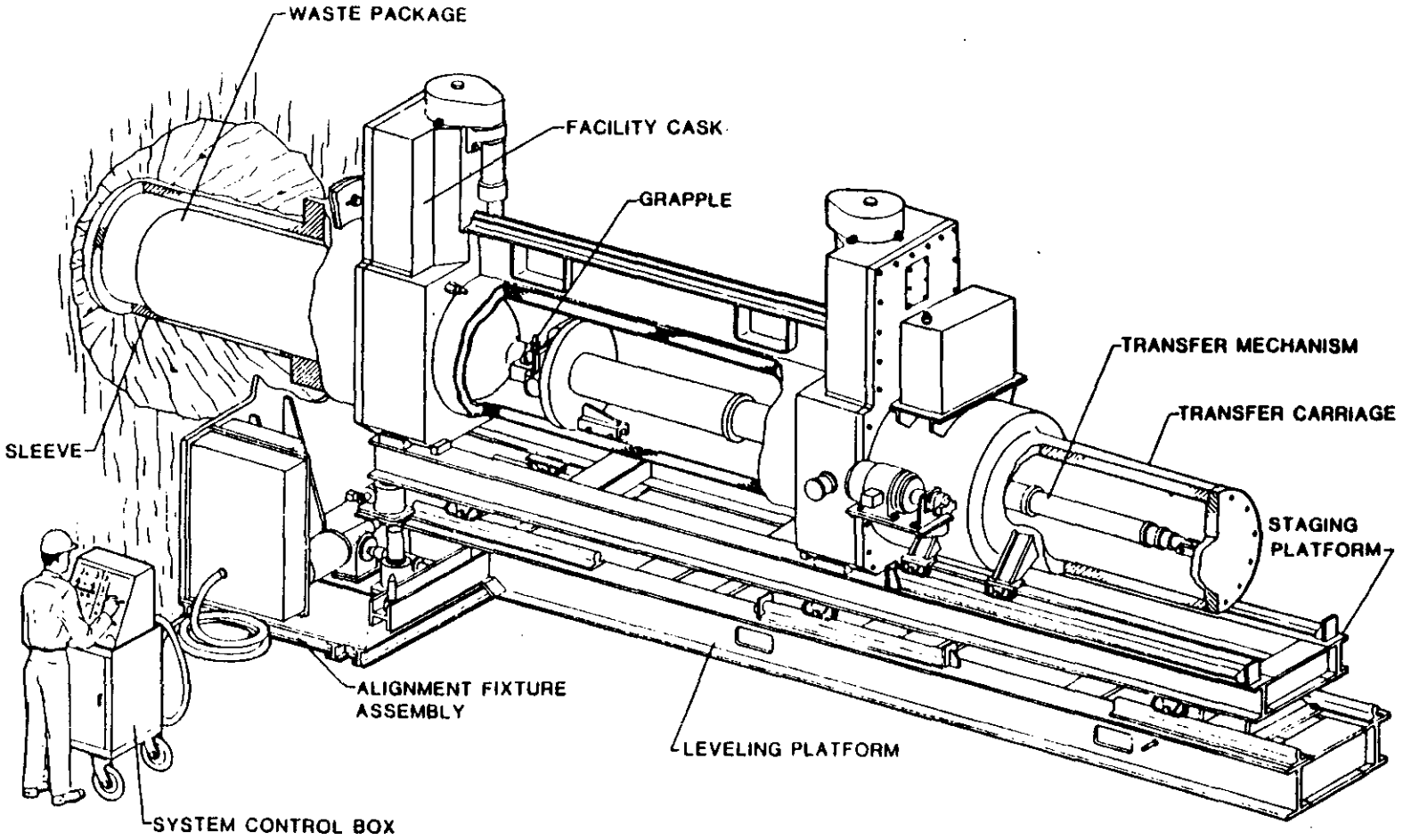

Figure 12-4

STORAGE AREA
HORIZONTAL EMPLACEMENT OF RH WASTE

This package contains the design documents that will be used to operate the WIPP.

12.3 DESIGN VALIDATION PROCESS

The design validation process for the storage area consists of the evaluation of numerical modeling and data analysis from the drifts and test rooms (Chapters 10 and 11) and its application to the reference design of the storage area drifts and rooms. The predicted future performance of the storage area openings was compared to the performance of existing openings having comparable dimensions. This was then used as the upper bound for validating the reference design.

12.3.1 Data Collection

Geomechanical instrumentation data collected from the test rooms were used to compute the creep parameters of the surrounding salt. Geologic mapping and drill cores from the underground facility were used to confirm the stratigraphy of the storage area. Test room instrumentation data and the computation of creep parameters are presented in Chapter 11. Chapter 6 presents information on the geologic mapping, drill cores and development of the reference stratigraphy.

The geomechanical instruments in the test rooms have provided deformation measurements and response data on the excavated openings. Periodic visual inspections of the rooms have provided observational data with which to further evaluate the response of the surrounding salt. Geologic mapping and core drilling in the E140 drift south of the waste shaft have provided information on the stratigraphy in the storage area.

12.3.2 Analysis and Evaluation

12.3.2.1 Storage Rooms

Analysis and evaluation of the storage room reference design have been performed using data collected from the test rooms. The adequacy of

[illegible] design wa[illegible] [illegible] behavior, including stress, strain an[illegible], which could be expected to occur over the operating life of each room. The operating life is defined as the period of time from initial excavation of the room until retrieval operations are completed, if the decision to retrieve is made, or until the storage operation for each panel is completed.

Evaluation of the geologic mapping and drill cores from the E140 drift south of the waste shaft has confirmed the continuity of the stratigraphy 50 feet above and below the storage area (refs. 4-1 and 4-2).

Based on an engineering approach (Chapter 5), numerical analyses were performed based on creep parameters determined from test room data and the stratigraphy surrounding the facility level. Because the extrapolation of the in situ closure data for the drifts and test rooms indicates that more than four rooms in a storage panel could influence the total closure and overall creep rate, a mathematical model was developed to estimate the upper bound responses. This requires assuming an infinite array of equally spaced storage rooms such that the centerline of a typical room and the centerline of any one of its pillars form axes of symmetry. In addition, the rooms were assumed to be infinitely long.

Figure 12-5 shows the finite element model that was used to determine the responses for an infinite array of infinitely long storage rooms. The model has 94 nodes and consists of 59 plane strain elements, with gap/friction link elements having a friction coefficient of 0.4 to model a clay seam. Because test room creep parameters are used in predicting the responses of the storage rooms, this model uses the same comparative element sizes and external loads as those used in the test room model described in Chapter 11, Section 11.3. The boundaries on both sides of the model were taken as vertical axes of symmetry to represent the pillar centerlines and consist of horizontal restraints.

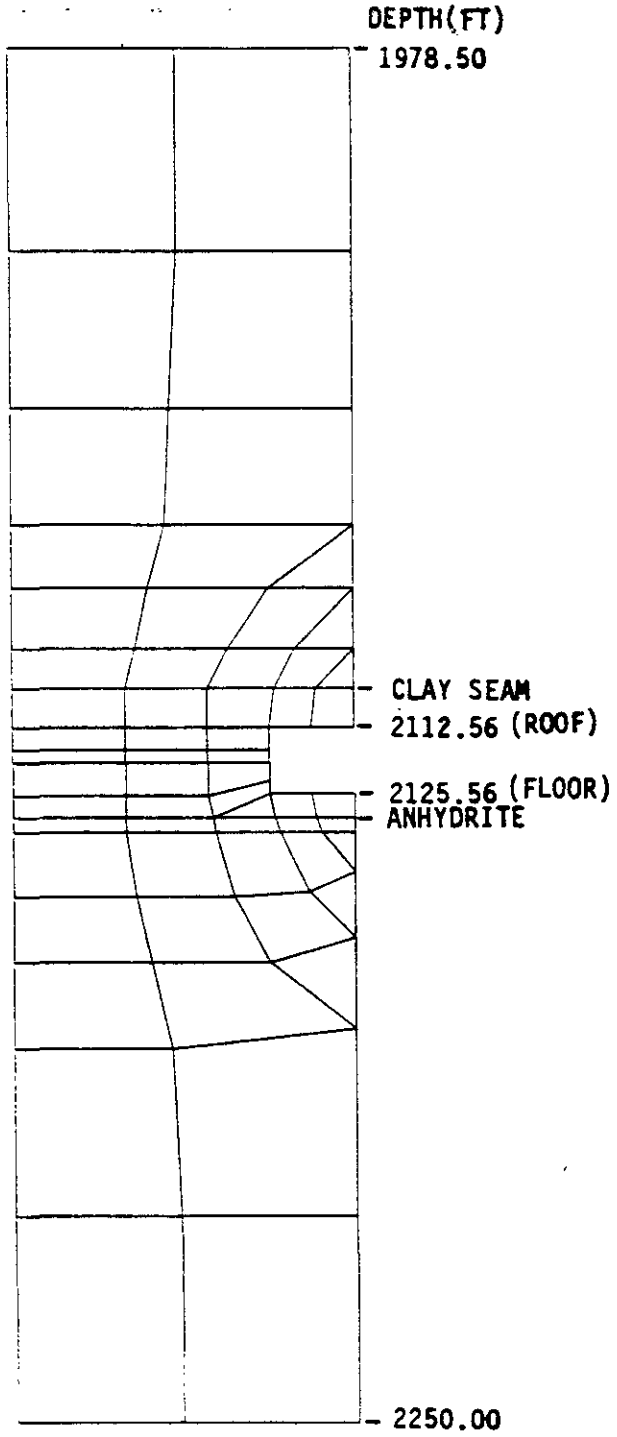

Figure 12-5

STORAGE AREA
ROOM FINITE ELEMENT MODEL

[illegible] anhydrite bed, and the [illegible] the room are based on the reference stratigraphy and are identical to those used in the test room finite element model.

The analyses were performed using the MARC General Purpose Finite Element Program discussed in Chapter 6. The average values of the creep parameters were derived from test room roof-to-floor and wall-to-wall in situ closure data. Using these computed creep parameters, previously presented in Chapter 11, Tables 11-10 and 11-11, the predicted future responses of the storage rooms were computed. The results of the analyses are presented below.

12.3.2.2 Storage Area Drifts

Analysis and evaluation of the 13 x 25-foot drift design for the storage area have been performed using data collected from the existing 8 x 25-foot drifts. The same finite element model used for the 8 x 25-foot drifts (Chapter 10) was used for the larger drifts. A removable floor section extending 5 feet vertically downward from the original floor level was integrated into the model so that this group of elements could be removed at the appropriate stage in the analysis to simulate floor excavation. A coefficient of friction of 0.0 was assumed for the gap/friction elements to model a clay seam. The time between initial excavation and the subsequent floor excavation was assumed to be 2 years. Therefore, all results presented in the following subsection are directly affected by these assumptions. Figure 12-6 shows the model after removal of the floor elements.

12.3.3 Prediction of Future Behavior

12.3.3.1 Storage Rooms

Because the room size and panel configuration of the four test rooms is similar to the design of the proposed storage rooms, the behavior of the storage rooms was computed using the measured data from the test rooms, as presented in Chapter 11. The results of the storage room

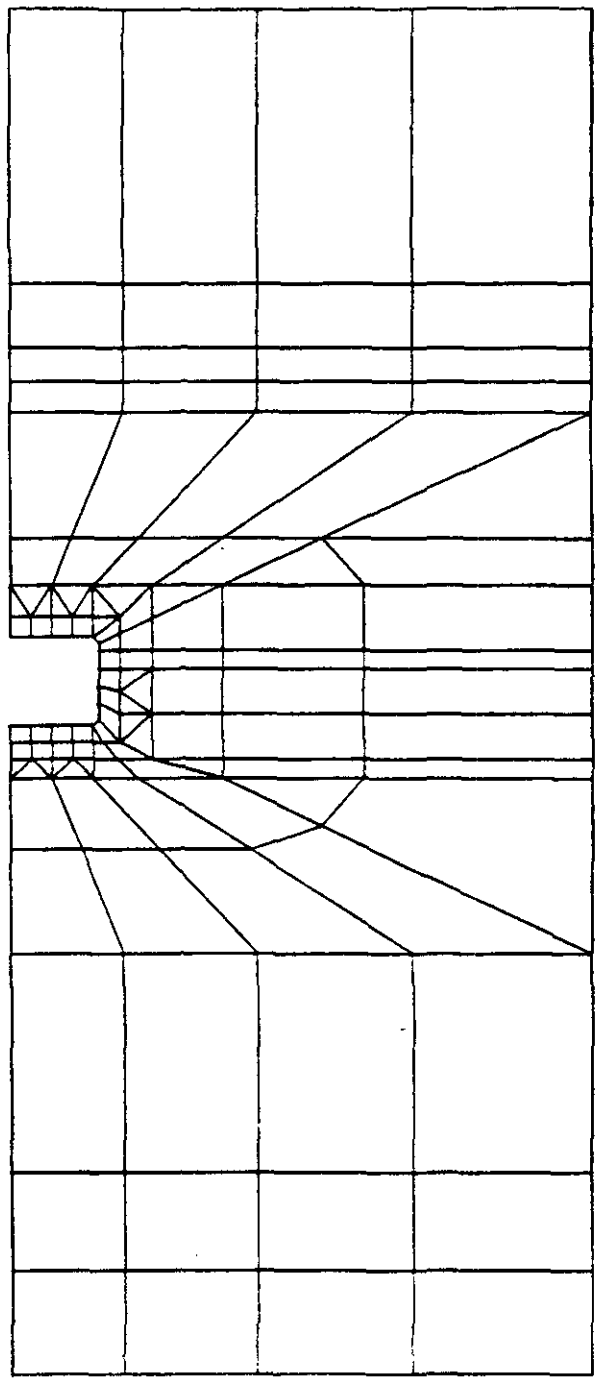

Figure 12-6

STORAGE AREA
DRIFT FINITE ELEMENT MODEL - AFTER FLOOR LOWERING

alys[illegible] [illegible] [illegible] [

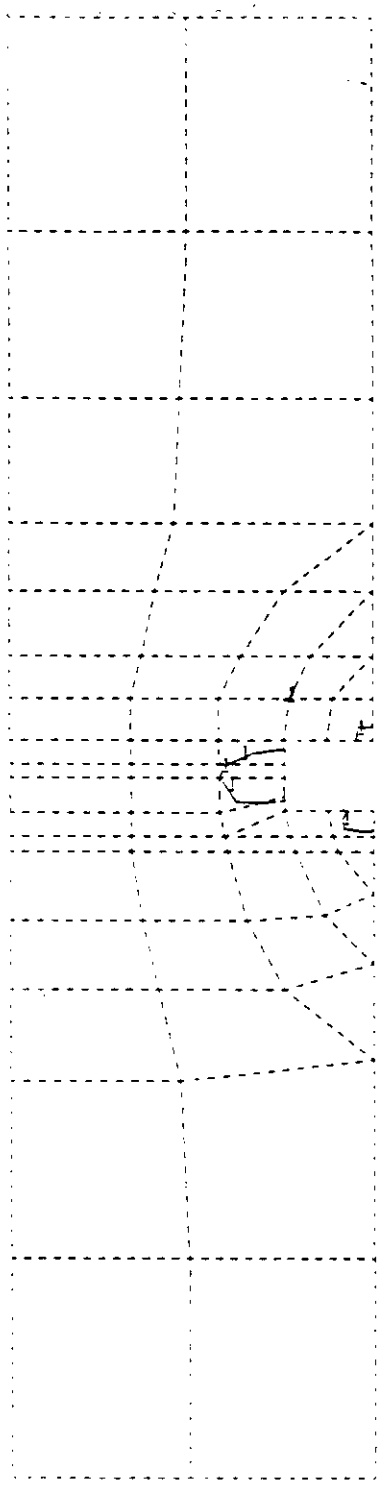

CONTOUR	σ_h(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-7

STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION

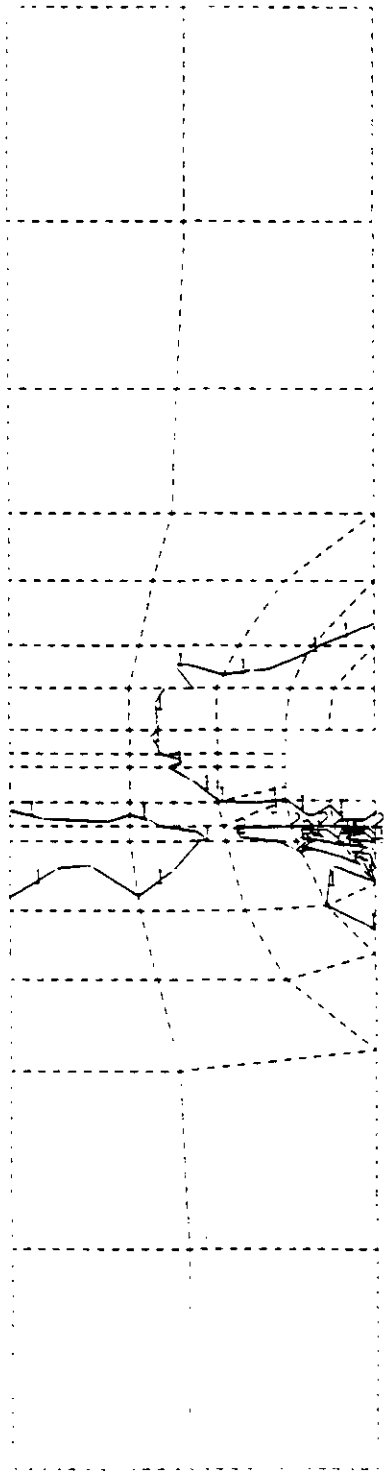

CONTOUR	σ_h(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-8

STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION

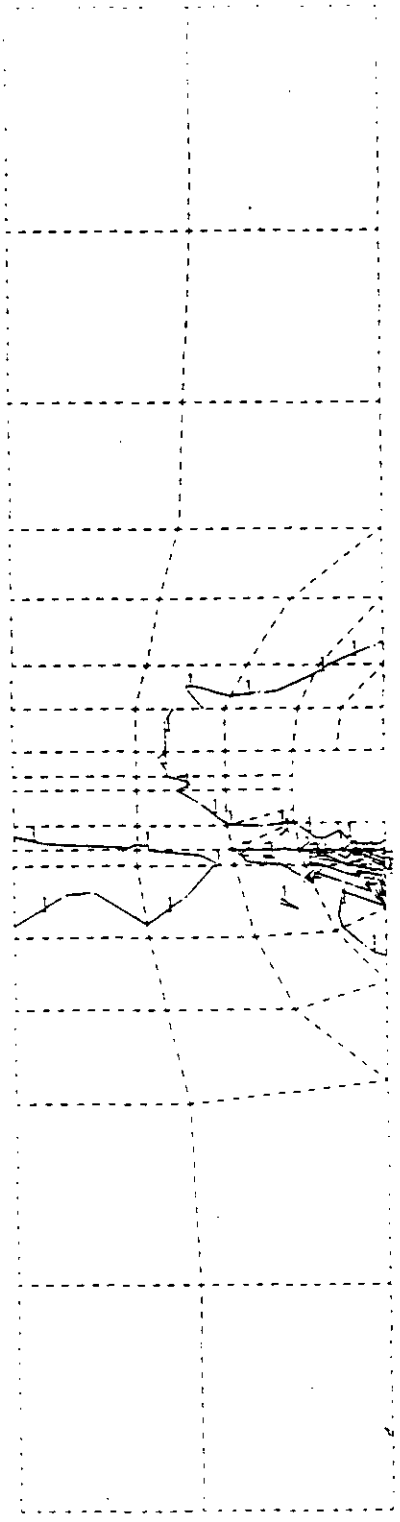

CONTOUR	σ_h(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-9

STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION

[illegible] in the wa[illegible]

[illegible]ately after excavation of between 500 and 750 ksf com[illegible]
This stress is approximately twice the original lithostatic stress before excavation and clearly shows the expected stress concentrations around the opening immediately after excavation. As the opening deforms, the vertical stress is redistributed around the opening and reduced to between 250 and 500 ksf compression.

Figures 12-11 and 12-12 show very small differences from 1 year through 10 years after excavation. That is, the vertical stress is relatively constant throughout that period with most of the halite roof beam having low stress in the vertical direction. Likewise, the uppermost level of elements in the room's floor has relatively low stress in the vertical direction due to its lack of vertical confinement.

The anhydrite bed (MB-139) below the storage room is, in general, subjected to low vertical stresses; however, some compressive vertical stress is indicated under the pillars.

Effective Stresses and Effective Creep Strains. Figures 12-13 through 12-15 show the computed effective stress distribution in those elements of the finite element model near the room opening. Ten contour increments, each having an interval of 250 ksf, were chosen to span a stress range from 0 to 2,500 ksf. The effective stress plot immediately after excavation shows a relatively low stress concentration in the anhydrite bed below the floor and no stresses greater than 500 ksf in the halite beds.

At 1 year and 6.5 years after excavation, the computed effective stresses have increased and concentrated in the anhydrite bed and overlying halite. Because the anhydrite was modeled as being elastic until failure and stiffer than halite, it supports more stress, which results in a large effective stress gradient in the anhydrite. The maximum computed effective stress is 2,600 ksf, concentrated in the anhydrite bed near the room centerline.

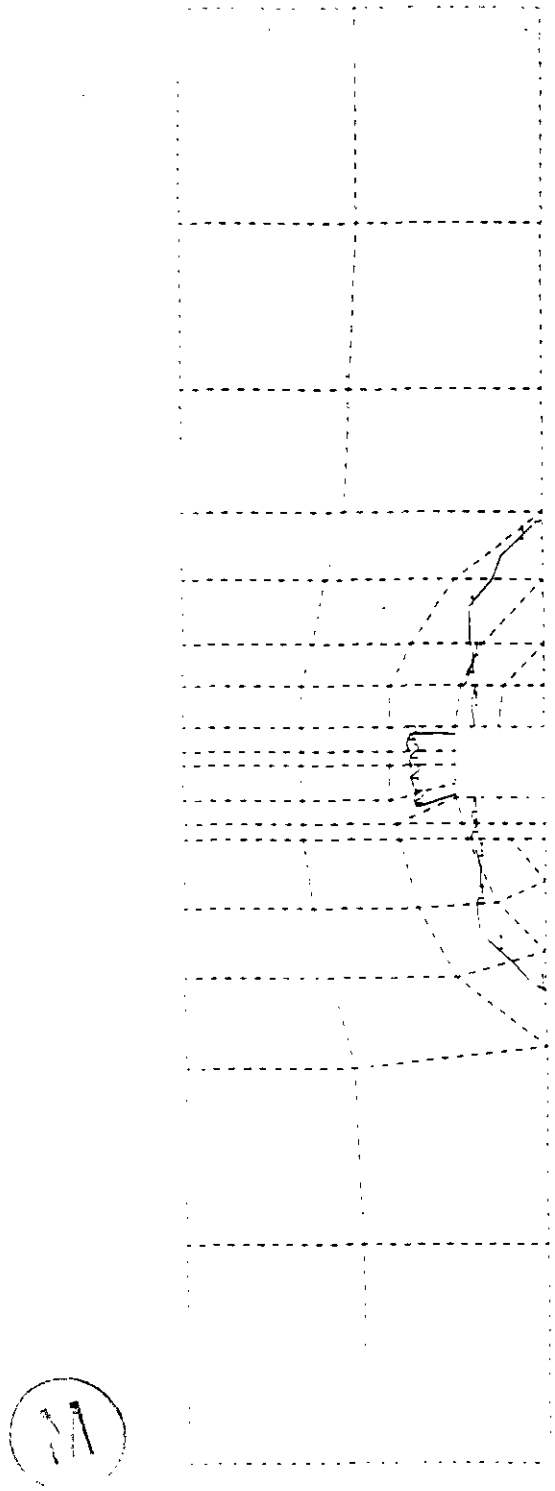

CONTOUR	σ_v(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-10

STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION

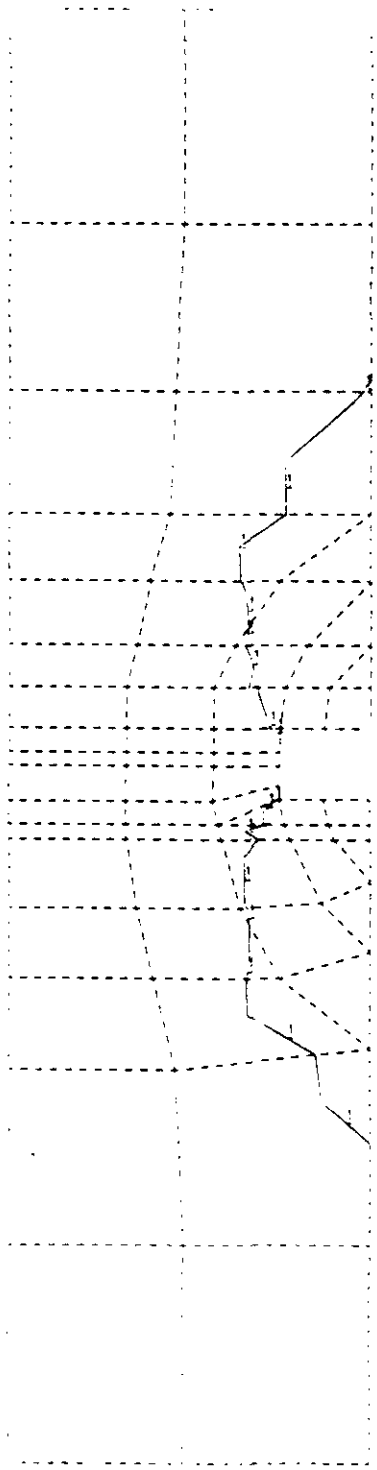

CONTOUR	σ_v(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-11

STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION

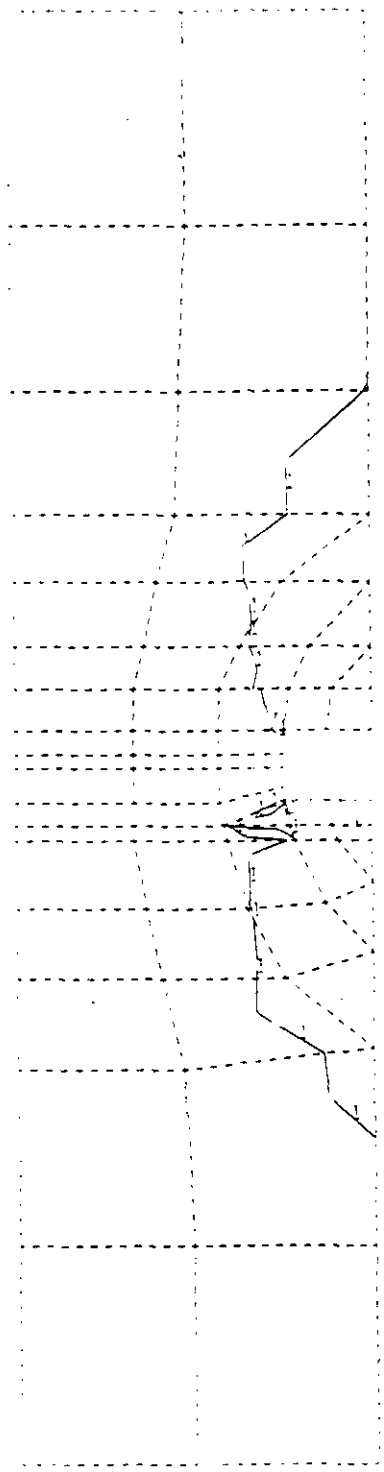

CONTOUR	σ_v(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-12

STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION

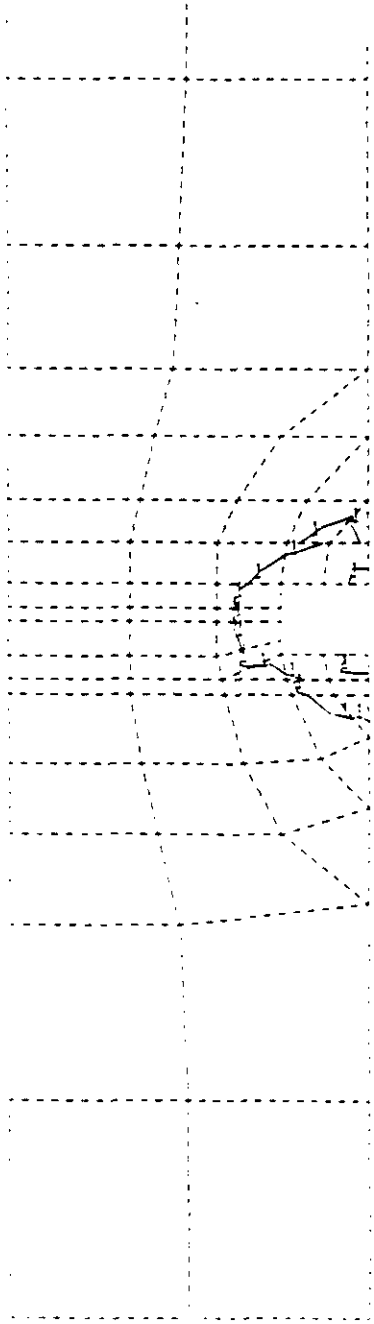

CONTOUR	$\bar{\sigma}$(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-13

STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION

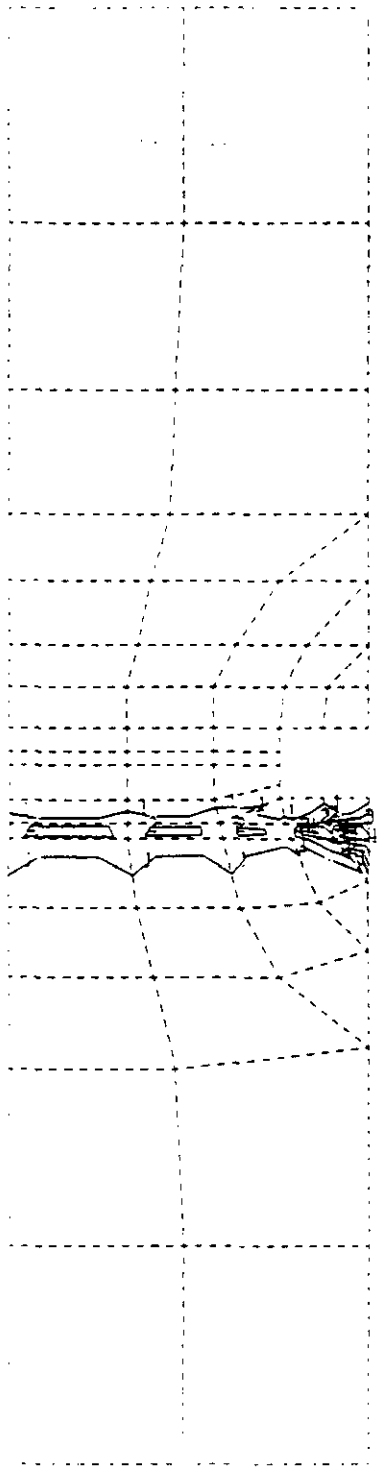

CONTOUR	$\bar{\sigma}$(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-14

STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION

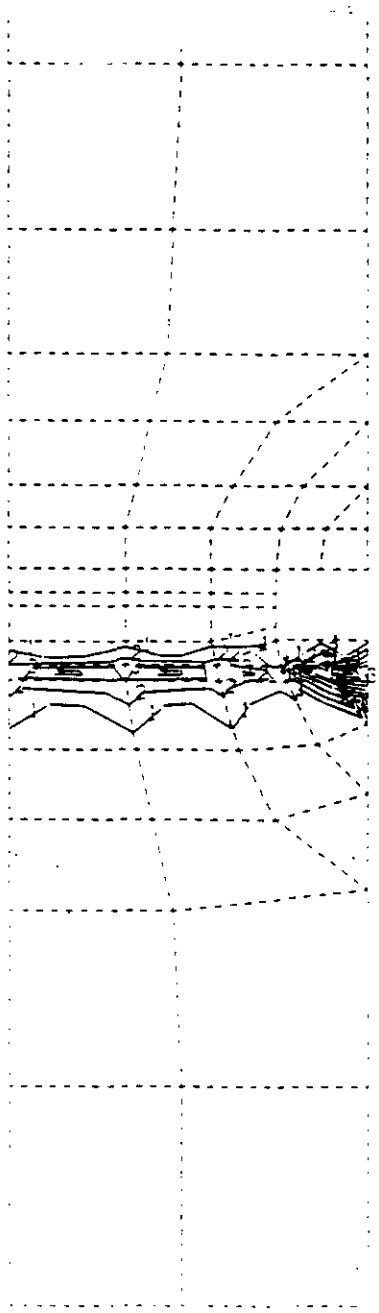

CONTOUR	$\bar{\sigma}$ (ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-15

STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION

Because the model does not include failure criteria for the anhydrite bed, an analysis for potential failure in this bed was performed separately. In Chapter 6, the failure criterion

$$\sqrt{J_2'} = 752 - 0.279J_1 \quad \text{(stress in ksf)} \qquad (12\text{-}1)$$

was defined for the anhydrite bed based on laboratory tests. Rewriting this equation in terms of the effective stress at failure $\bar{\sigma}_f$ and the first stress invarient at failure $(J_1)_f$:

$$\bar{\sigma}_f(\text{ksf}) = 1302.5 - 0.483\ (J_1)_f \qquad (12\text{-}2)$$

From the results of the numerical modeling, the average effective stress stress at a point close to the center of the room exceeds $\bar{\sigma}_f$ at about 8.5 years since excavation. This does not mean catastrophic failure will occur. Instead, there will be a redistribution of stress in the anhydrite bed which the model cannot consider.

Computed effective creep strain distributions were plotted on selected elements of the deformed mesh at 1 year and 6.5 years after excavation (Figures 12-16 and 12-17). Ten strain increments with an interval of 0.01 were used to span a strain range from 0 to 0.100.

At 1 year after excavation, effective creep strains have concentrated in the region around the room opening. At 6.5 years after excavation, the effective creep strains have further intensified around the room opening and in the region above the anhydrite bed near the room centerline.

Based on laboratory creep tests on samples of halite, a failure criterion has been proposed (equation 6-5 in Chapter 6). Based on this criterion, the failure effective strain for halite is a function of the mean normal stress intensity and reaches a maximum magnitude of nearly 16 percent at a mean stress intensity of 125 ksf.

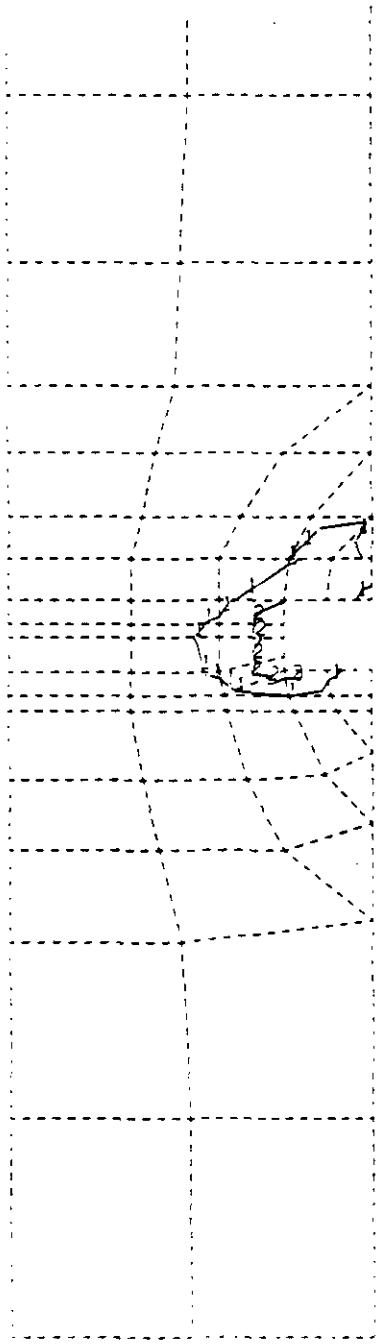

CONTOUR	$\bar{\epsilon}$
1	0.01
2	0.02
3	0.03
4	0.04
5	0.05
6	0.06
7	0.07
8	0.08
9	0.09
10	0.10

M

Figure 12-16

STORAGE ROOMS
EFFECTIVE CREEP STRAIN DISTRIBUTION 1 YEAR AFTER EXCAVATION

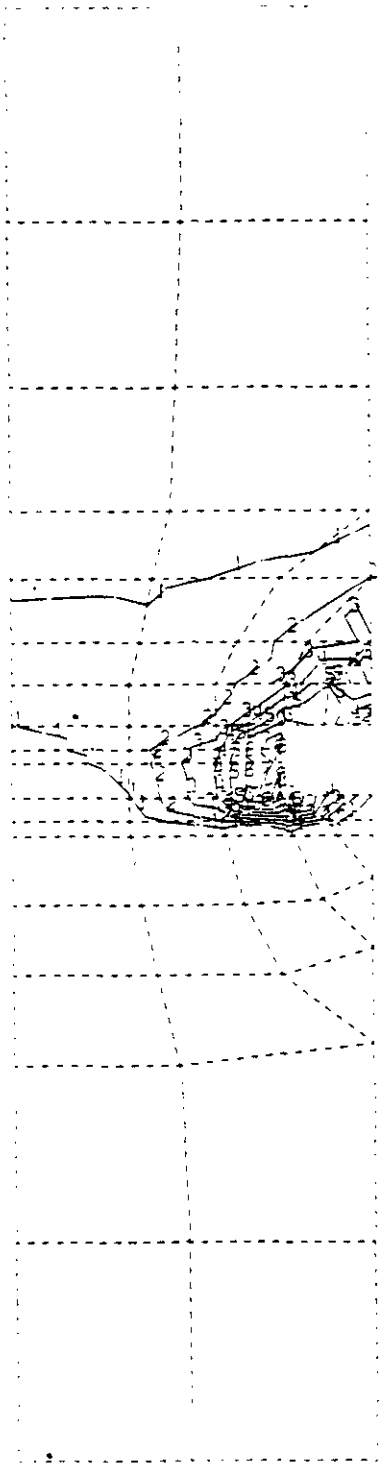

CONTOUR	$\bar{\epsilon}$
1	0.01
2	0.02
3	0.03
4	0.04
5	0.05
6	0.06
7	0.07
8	0.08
9	0.09
10	0.10

Figure 12-17

STORAGE ROOMS
EFFECTIVE CREEP STRAIN DISTRIBUTION 10 YEARS AFTER EXCAVATION

[illegible] creep strain [illegible], and by linear extrapolation beyond 6.5 years, failure will be initiated in the halite about 12 years after the completion of excavation. The failure will be initiated at floor and wall intersections.

However, the numerical modeling also shows that effective strain decreases rapidly with distance away from the opening. Thus, the failure is expected to be confined very close to the opening. This will require periodic scaling and trimming.

Principal Stresses. The computed principal stresses on the plane of a section across the storage rooms are presented in a qualitative manner on Figures 12-18 through 12-20. The magnitudes of the two principal stresses are proportional to the lengths of the corresponding lines which are plotted, perpendicular to each other, at the centroid of each of the elements.

Immediately after excavation, the magnitudes of the principal stresses are relatively large in the corners of the room and in the anhydrite bed. As the room opening deforms, the principal stresses concentrate in the anhydrite bed near the room centerline.

The plots of the principal stresses also show the stress arch which forms around the room due to the transfer of loads around the room opening. The stress arch tends to become enlarged with time and migrates away from the room.

Deformation and Closure. Figures 12-18 through 12-20 also show the predicted deformed shapes of a typical storage room at different times. The dashed lines represent the outline of the deformed shape of the storage room.

Immediately after excavation, deformation starts around the opening. After 1 year of creep, the halite roof beam deforms noticeably at its

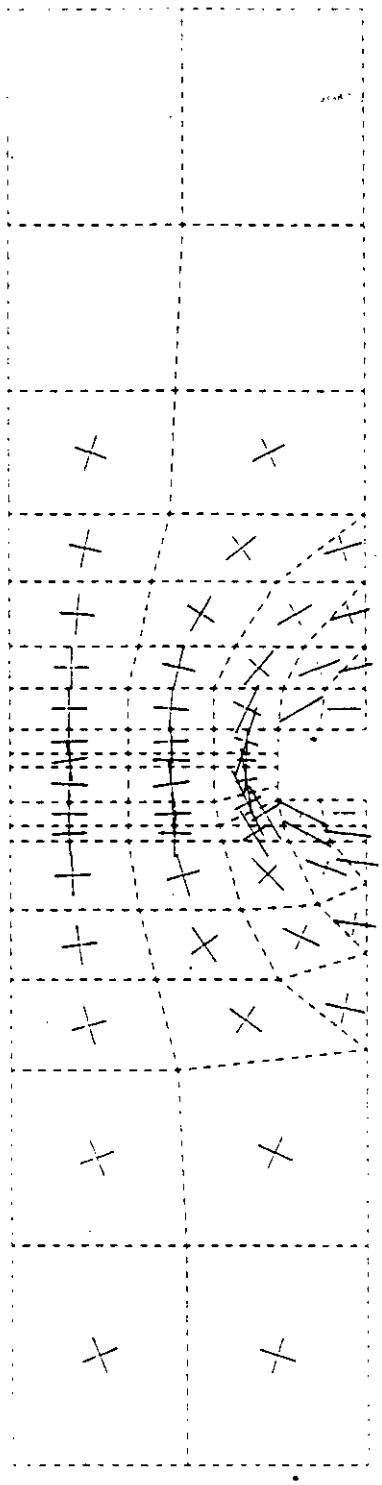

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Figure 12-18

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
IMMEDIATELY AFTER EXCAVATION

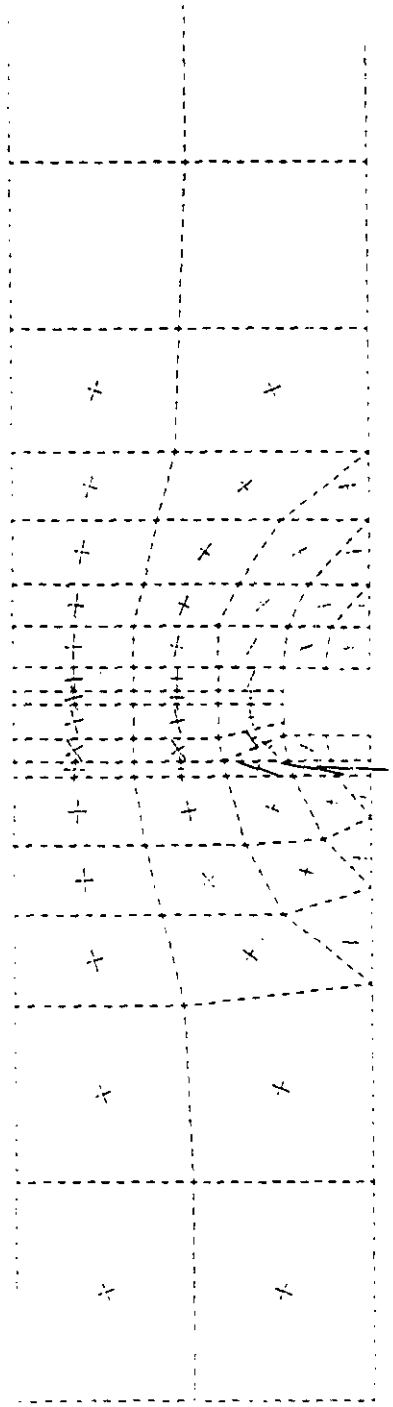

Figure 12-19

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
1 YEAR AFTER EXCAVATION

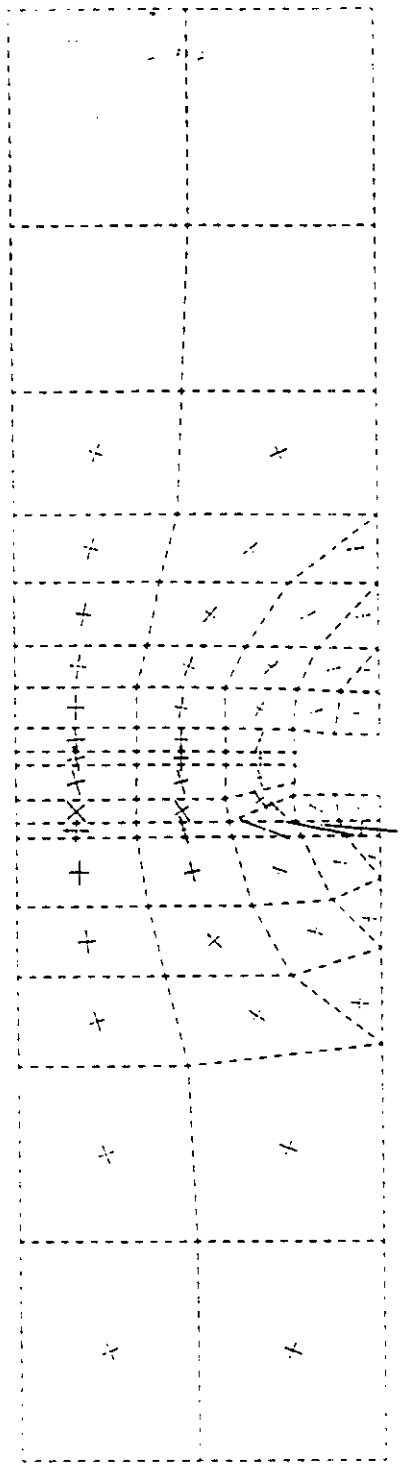

Figure 12-20

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
10 YEARS AFTER EXCAVATION

the predicted all

However, the floor heave is still very small , some slippage has occurred along the clay seams. This is graphically depicted as a slight horizontal disjointing of the lines that form the element boundaries along a clay seam.

At 6.5 years after excavation, the predicted deformed shape of the storage room shows much downward deformation in the roof beam at its centerline. The floor has heaved slightly upward, with the upward displacement being somewhat more noticeable in the center of the room. The analysis shows very little deformation in the anhydrite bed even after 10 years. Based on the small amount of floor heave, it appears that the stiff anhydrite bed diminishes the amount of floor creep by supporting a large amount of lateral pressure. However, because there is a potential for the anhydrite bed to fail locally at about 8.5 years after excavation, it may not be able to support this large amount of lateral pressure. This may result in a higher creep rate in the floor than predicted by the model.

As discussed in Chapter 11, laboratory derived creep constants underpredicted actual closure in the test rooms. Thus, back calculation of average creep parameters was made using either measured roof-to-floor or wall-to-wall closure data. The effectiveness of the model simulation techniques used to derive the creep parameters and extrapolate closure behavior were discussed in detail in Chapter 11, subsection 11.3.2.5. Because MB-139 was assumed to be linearly elastic with infinite strength, the numerical modeling underpredicted floor heave but overpredicted roof sag. However, the overall roof-to-floor closure is reasonably well predicted by the model.

In order to show the effect of geometry and extraction on the closure rate, extrapolations of the in situ closure histories for the test rooms and various size drifts, as well as the calculated roof-to-floor and wall-to-wall closures for the storage rooms were plotted for comparison (Figures 12-21 and 12-22). Similar calculations were made using the

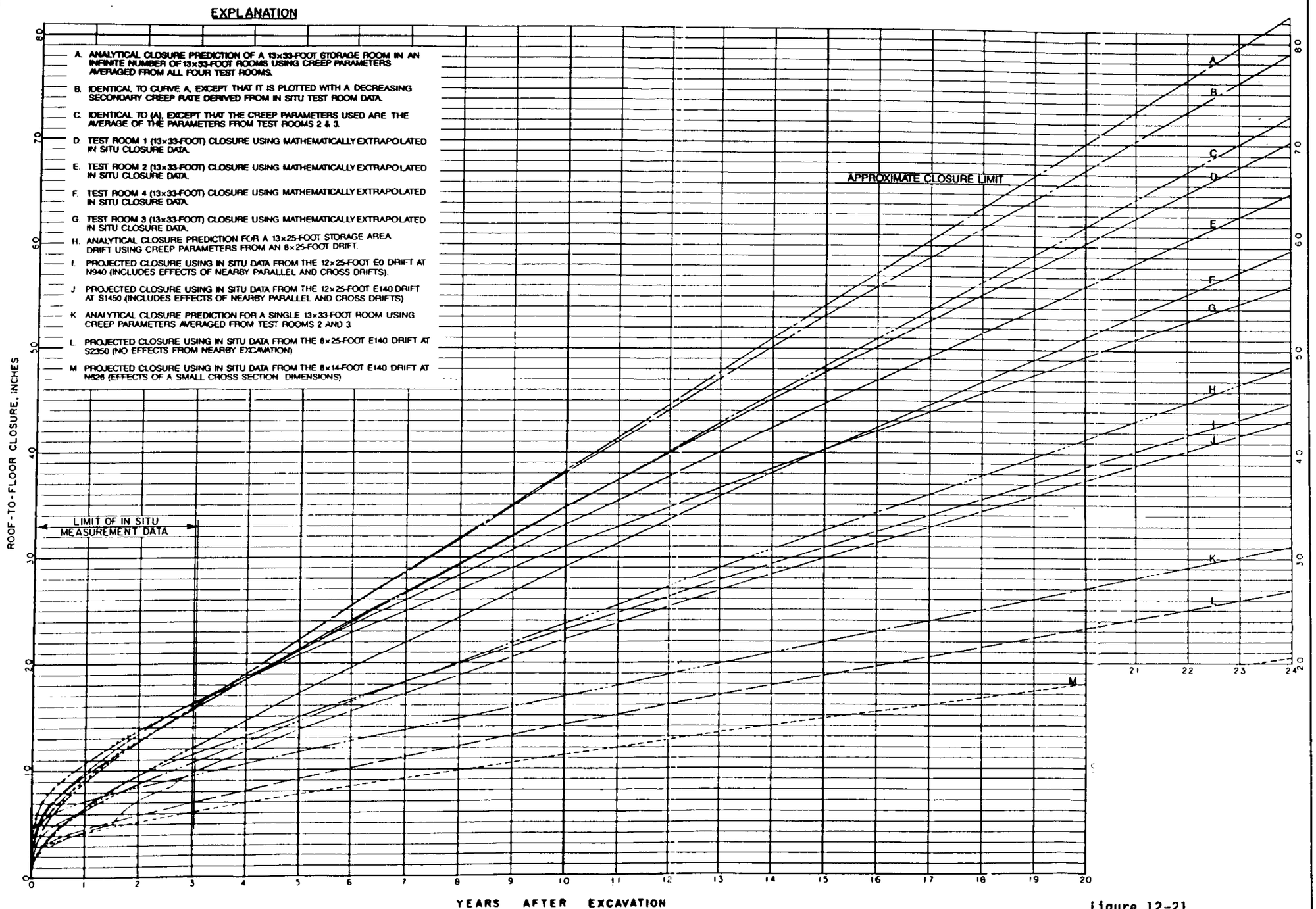

Figure 12-21

ROOF-TO-FLOOR CLOSURE
GEOMETRY AND EXCAVATION EFFECTS

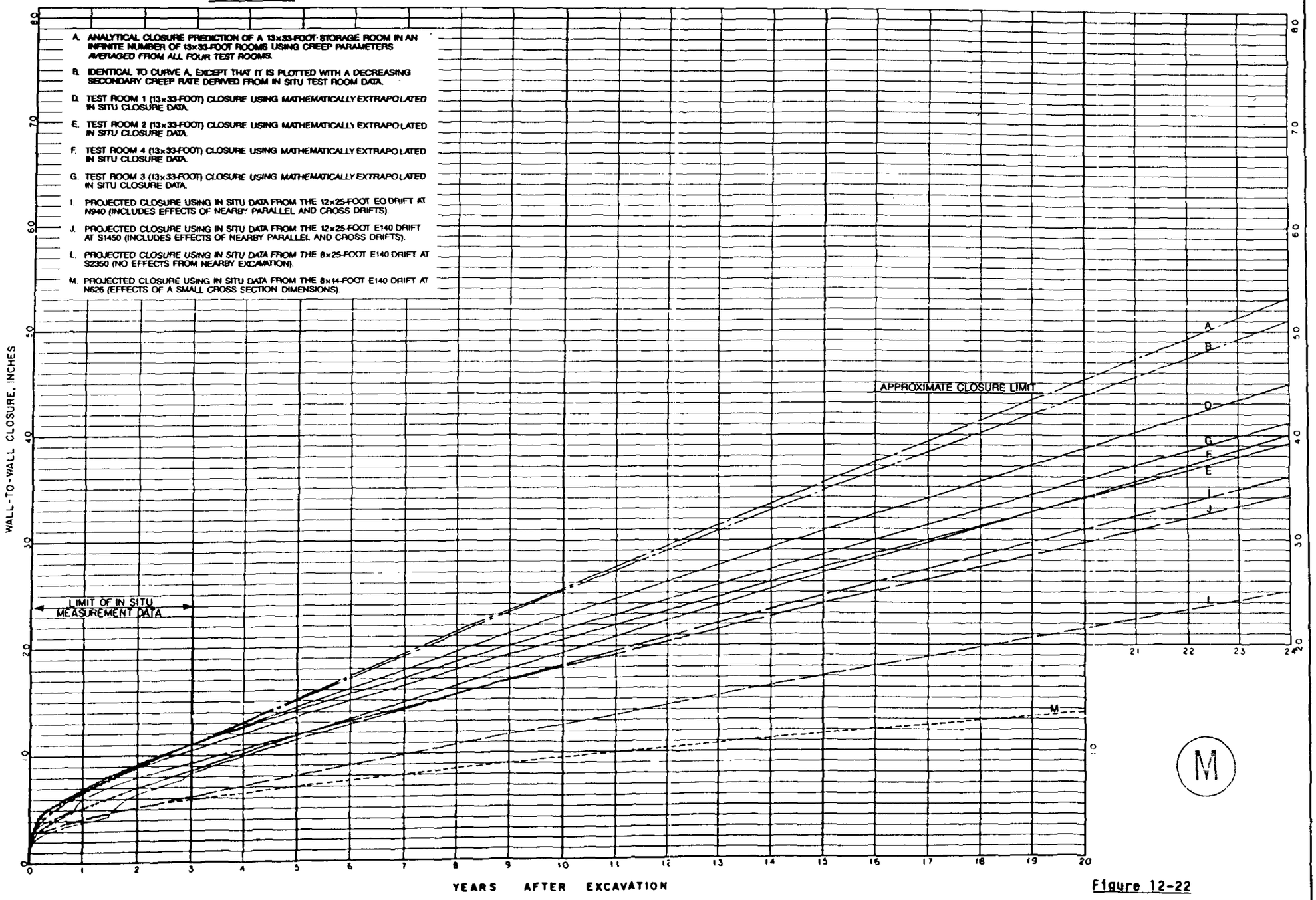

Figure 12-22

WALL-TO-WALL CLOSURE
GEOMETRY AND EXCAVATION EFFECTS

average creep parameters for the two interior 13 x 33-foot test rooms and using an infinite array of rooms to indicate the sensitivity of the value of the parameters. The same parameters were also used in the calculations of a single 13 x 33-foot room model to determine the effects of extraction on the number of rooms in an array. The descriptions of the closure curves plotted on Figures 12-21 and 12-22 are as follows:

(A) Analytical closure prediction of a 13 x 33-foot storage room in an infinite number of 13 x 33-foot rooms using creep parameters averaged from all four test rooms.

(B) Identical to curve A, except that it is plotted with a decreasing secondary creep rate derived from in situ test room data.

(C) Identical to curve A, except that the creep parameters used are the average of the constants from Test Rooms 2 and 3.

(D) Test Room 1 closure using mathematically extrapolated in situ closure data.

(E) Test Room 2 closure using mathematically extrapolated in situ closure data.

(F) Test Room 4 closure using mathematically extrapolated in situ closure data.

(G) Test Room 3 closure using mathematically extrapolated in situ closure data.

(H) Analytical closure predicted for a 13 x 25-foot storage area drift using creep parameters from an 8 x 25-foot drift.

(I) Projected closure [illegible] 25 [illegible] EO drift at N940 ([illegible] of nearby parallel and cross drifts).

(J) Projected closure using in situ data from the 12 x 25-foot E140 drift at S1450 (includes effects of nearby parallel and cross drifts).

(K) Analytical closure prediction for a single 13 x 33-foot room using creep parameters averaged from Test Rooms 2 and 3.

(L) Projected closure using in situ data from the 8 x 25-foot E140 drift at S2350 (no effects from nearby excavation).

(M) Projected closure using in situ data from the 8 x 14-foot E140 drift at N626 (effects of small cross section dimensions).

As expected, the two interior test rooms (Test Rooms 2 and 3) had more closure and higher closure rates during the first year than the outer rooms (Test Rooms 1 and 4). This is due to the fact that Test Rooms 2 and 3 were excavated before Test Rooms 1 and 4. However, Test Rooms 1 and 4 exhibit higher closure rates during the secondary creep stage. This is consistent with the stress arch principle.

An evaluation of these 13 closure curves indicates that geometry and extraction ratio strongly impact the total closure in a seven-room panel within an eight-panel storage area and that the rate of closure will be faster than the extrapolated curves for a test room within the four-room test panel. For conservatism, Curve A (Figures 12-21 and 12-22) is used for storage room analysis, prediction and validation.

Curve A on Figure 12-21 represents the roof-to-floor closure prediction using the average creep parameter values for Test Rooms 1 through 4. These values were previously presented in Chapter 11, Table 11-12. In

the first year following excavation, the roof-to-floor closure curve is non-linear. The primary creep closure rate is very fast, as shown by the steeply sloped region in the first 3 months. Two and one half inches were added to the measured closure values to compensate for the lack of early closure data (Chapter 11). During secondary creep, the curve flattens and becomes approximately linear with a closure rate of approximately 3 inches per year. This closure prediction shows a closure of approximately 22 inches at 5 years after excavation and 54 inches at 15 years after excavation.

Curve A on Figure 12-22 represents the wall-to-wall closure prediction using the average creep parameter values for Test Rooms 1 through 4. These values were previously presented in Chapter 11, Table 11-13. As with the roof-to-floor closure, the wall-to-wall closure is non-linear in the first year following excavation. Again, the closure rate due to primary creep is initially very fast in the first 3 months as shown by the steep slope of the curve. Two inches were added to the measured closure values, as discussed in Chapter 11, to compensate for the lack of early closure data. The curve eventually flattens during the secondary creep phase and becomes approximately linear with a closure rate of about 2 inches per year. The wall-to-wall closure prediction shows a closure of approximately 15 inches at 5 years after excavation and 36 inches at 15 years after excavation.

When the storage rooms are fully occupied by waste and backfill material, the closure of the room will be limited by the ability of the contents to be compacted. Assuming that the volume of the waste container can be compacted by 40 percent and the volume of the backfill material by 15 percent, the roof-to-floor closure is predicted to have a maximum value of 66 inches and the wall-to-wall closure a maximum value of 44 inches. This maximum closure would occur after about 18 years for vertical closure and 19 years for horizontal closure (Figures 12-21 and 12-22). A reduction in the closure rate after the wall and roof surfaces begin compacting the backfill material and exerting pressure on the waste containers has not been considered.

Curve A [illegible] conservative estimates of storage room closure. Therefore, values from these curves were used in evaluating the reference design against the design criteria and design bases requirements. The design bases allow up to 12 inches of closure in the first 5 years after excavation in order to maintain a 16-inch space for ventilation and backfill equipment and to maintain a 12-foot minimum clearance for storage equipment. The estimated vertical closure in 5 years using curve A is about 22 inches. This 10 inch increase over the design basis limit could be accommodated by increasing the reference design room height from 13 feet to 13 feet 10 inches. This would be satisfactory for permanent storage. Another way to accommodate the increased closure and still maintain the 16-inch ventilation space (Figure 12-3) is to eliminate the backfill or reduce its thickness covering the CH containers to 6 inches or less. Deleting the salt backfill would require a change in the design criteria.

The solution to the increased vertical closure is not so simple for permanent storage, however. If at the end of the 5-year demonstration period, a decision is made requiring the stored waste to be retrieved, the design criteria assume that it will take twice as long to retrieve waste as it took to store it. This would result in a room being an additional 10 years old before retrieval is completed. Under these circumstances, a 15-year old room would have a closure of 54 inches, based on Curve A. Assuming that a storage room was excavated to the maximum allowable height of 14 feet, the closure would be 14 inches more than could be accommodated (24 inches for closure allowance, including 12 inches allowed by the design basis and 12 inches for the increase in room height from 13 feet to 14 feet, and 16 inches for ventilation space). This would result in the backfill being compressed and in the possible crushing and breaching of the waste containers. Because this scenario does not comply with the design criteria requirements, other alternatives must be considered.

These alternatives, including modification of the design criteria, are presented in subsection 12.6.2. Two considerations must be addressed here, however, to support the recommendations. First, the 10 year maximum retrieval period assumed by the design criteria is very conservative. Should retrieval be conducted on a three shifts per day basis, rather than the assumed one shift per day, no room would be older than 7 years by the time its waste was retrieved. Based on Curve A, a 7 year old room, from the time of initial excavation, would have a closure of about 28 inches. Assuming a room was excavated to the 14-foot high maximum and allowing 24 inches for closure, the waste containers will not be crushed or breached. However, the ventilation space will be reduced to 12 inches. This could be tolerated because the maximum 28-inch closure will be at the room centerline; additional ventilation space will be gained closer to the room walls. Alternatively, the thickness of the salt backfill over the containers could be reduced or eliminated to maintain the ventilation.

The second consideration supporting the recommendations is that a reduction in room closure can be gained by modifying the excavation technique. A panel of rooms could be excavated to the reference design dimension of 13 to 14 feet high. After a year of closure, these openings will be closing at the rate determined by secondary creep. At this time the rooms could be trimmed to 14 feet high. Trimming will remove the salt that has moved into the room during the year and provide a full dimensioned room that will close at the rate determined by secondary creep. Based on an average secondary creep closure rate of 3 inches per year, the rooms would have the following predicted closures after trimming:

5 years	15 inches
7 years	21 inches
10 years	30 inches
15 years	45 inches

Should the retrieval be effected within 7 years after trimming, a

[illegible] would meet all of the retrieval requirements without further modification. [illegible]

In order to gain the reduced closure benefits of secondary creep, the amount of trimming must be kept to a minimum. The rooms should initially be excavated as close to the 14-foot high maximum dimension as possible. The trimming operation a year later should remove no more salt from the floor than necessary to enlarge the room height to 14 feet. This small amount of trimming will minimize the increase in closure that typically follows major re-excavation, as has already been experienced at the WIPP during floor lowering in some drifts (Chapter 10, Figure 10-6, and this chapter, Figure 12-21, Curve J). This is discussed in detail in the next subsection.

The width of the storage rooms presents similar problems. The reference design specifies a minimum room width of 33 feet and a maximum width of 34 feet. Again, Curve A on Figure 12-22 represents the most conservative estimate of horizontal closure. The design basis allows 9 inches of horizontal closure in the first 5 years (4 1/2 inches for each wall). The space between the wall and the waste containers (Item 10, Figure 12-3), for the storage area reference design, will be backfilled with loose salt.

The predicted wall-to-wall closure in 5 years, using Curve A, is about 15 inches. This closure will result in compaction of the salt backfill and possibly in the crushing and breaching of some containers. This condition is suitable for permanent storage. Should retrieval be required, the predicted closure for a 15-year old room would be 36 inches. If it is assumed that the room is excavated to its maximum dimensions, as discussed earlier, the room would be 34 feet wide with the waste containers 15 inches from each wall. This 30 inches of horizontal clearance is not adequate to meet the design criteria requirements for the crushing and breaching of containers, even if backfill were not required. In order to meet the intent of the design criteria, the reference design must be modified. The five alternatives presented in subsection 12.6.2 include modifications to accommodate this horizontal closure.

As is the case with vertical closure in the storage rooms, timing of retrieval operations and two-stage excavation can be used to reduce the wall-to-wall closure. Should three shifts per day be used during retrieval and if the rooms are a maximum of 7 years old, then wall-to-wall closure would be about 20 inches. If the storage operation is conducted on a first emplaced/first retrieved basis and retrieval is effected before a room exceeds an age of 6 years, horizontal closure would be further reduced to 18 inches. Both of these operational changes would decrease the possiblity of crushing or breaching the waste containers.

Two-stage excavation gains additional closure benefits. If a room is initially excavated to the maximum design width of 34 feet and after a year of closure trimmed to 34 feet, closure would be controlled by secondary creep. Based on a wall-to-wall secondary creep closure rate of 2 inches per year, the rooms would have the following predicted closures after trimming:

5 years	10 inches
7 years	14 inches
10 years	20 inches
15 years	30 inches

This will further minimize crushing or breaching of the waste containers.

It is expected that increasing the distance between the waste canisters and the wall by increasing the room to the maximum design width of 34 feet, thereby increasing the amount of loose salt backfill in this space, will increase the time it takes for horizontal closure to consolidate the backfill and transfer sufficient load to crush the waste canisters. This, coupled with the faster retrieval schedules discussed previously and the fact that the backfill will not be completely confined, will minimize crushing and breaching of the canisters as required by the criteria. How much it will be minimized

[illegible] from in situ [illegible] consoldiation and container stability become available.

12.3.3.2 Storage Area Drifts

The results of the analysis of the storage area drifts with dimensions of 8 x 25 feet were plotted at various integration time steps. These integration steps correspond to real times immediately after floor lowering and 5 years after initial excavation. The effective stress and effective creep strain, principal stresses, and deformed shape were plotted at these times based on the roof-to-floor creep parameters for a representative station (Chapter 10).

Effective Stresses and Effective Creep Strains. Figures 12-23 and 12-24 show the calculation for effective stress distribution in those elements of the finite element model near the drift opening. As with similar plots for the 8 x 25-foot drifts discussed in Chapter 10, each contour increment represents an effective stress interval of 100 ksf.

The plot of effective stress immediately after floor lowering shows the impact on the stress distribution as a result of the drift height modification. This change in effective stress precipitates a concomitant increase in the creep rate. This appears as a sharp but short increase in slope on the roof-to-floor closure versus time curve (Chapter 10, Figure 10-6, and this chapter, Figure 12-21, Curve J).

At the end of 5 years, the anhydrite bed shows a very large effective stress gradient from top to bottom in the vicinity of the drift floor due to the stiffness of the bed. Maximum effective stresses are in excess of 1,000 ksf.

The effective creep strains have concentrated in the region around the drift opening and intensify with time. A rough linear extrapolation of effective creep strain beyond 5 years indicates that the maximum

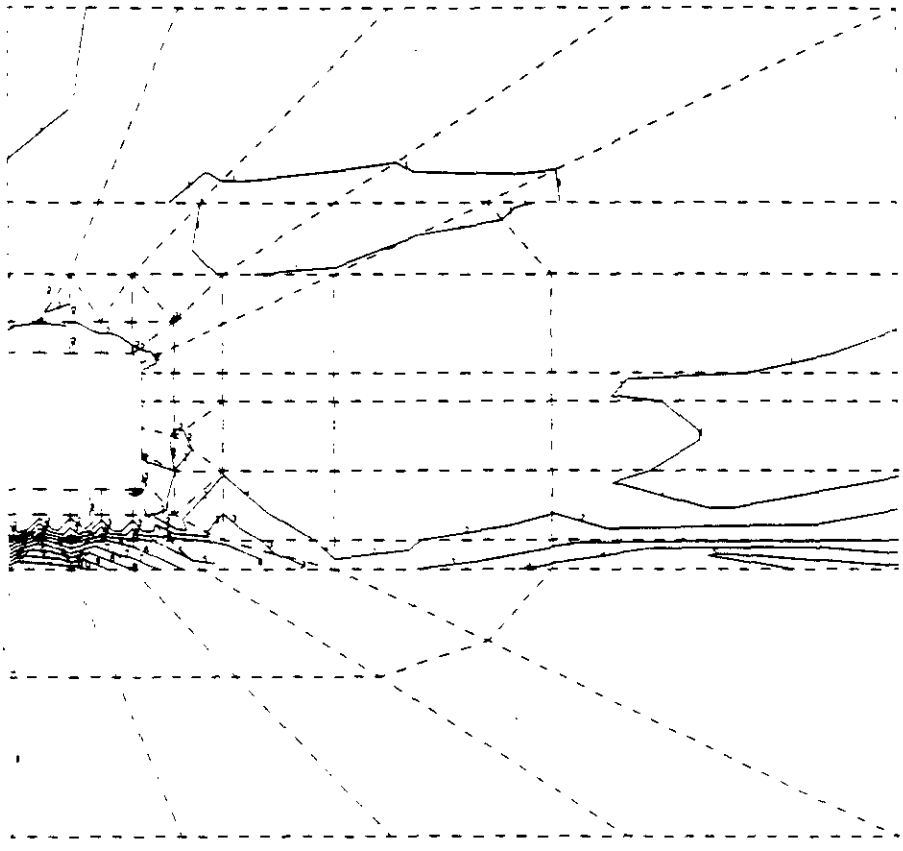

CONTOUR	$\bar{\sigma}$(ksf)
1	100
2	200
3	300
4	400
5	500
6	600
7	700
8	800
9	900
10	1000

Figure 12-23

STORAGE AREA DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER FLOOR LOWERING

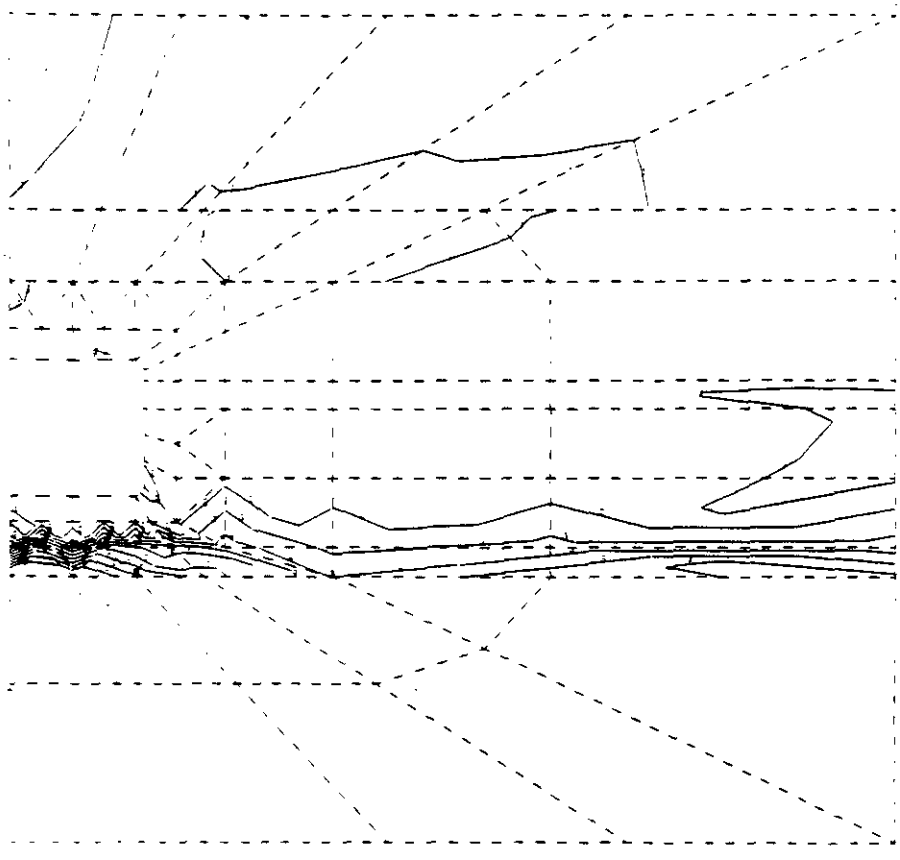

CONTOUR	$\bar{\sigma}$(ksf)
1	100
2	200
3	300
4	400
5	500
6	600
7	700
8	800
9	900
10	1000

Figure 12-24

STORAGE AREA DRIFTS
EFFECTIVE STRESS DISTRIBUTION 5 YEARS AFTER EXCAVATION

average effective creep strain may reach 16 percent at about 20 years after excavation. Based on failure criteria for halite obtained from laboratory test data (Chapter 6), failure in halite may start at about 15 percent. However, the numerical modeling indicates that the effective creep strain drops off sharply away from the opening. It is therefore expected that high effective strain would not result in a large scale failure in halite.

Principal Stresses. The plots of principal stresses (Figures 12-25 and 12-26) consistently show the "arch" pattern which develops around the drift in order to transfer loads past the drift opening. The arch is shown to migrate away from the opening with time. As expected, the magnitude of major principal stress is greater in the corners of the drift and in the underlying anhydrite bed. The anhydrite in particular is subjected to large stresses because it is the only material that has been assumed in the model to not creep; it therefore "stores" a large amount of energy in the form of elastic strain.

Deformation and Closure. Figure 12-27 shows the deformed shape 5 years after drift excavation, or approximately 3 years after floor lowering. It should be noted that, while both the roof and walls are creeping inward, the upward floor heave is small by comparison. This phenomenon is due to the stiffening effect of the underlying anhydrite bed.

The stress redistribution that occurs as a result of modifying the drift height is the driving force behind the large roof and wall deflections that are the most prominent features of the plot at 5 years. A close examination of the 5-year deformed plot shows that clay seam slippage has occurred. The most noticeable slippage has occurred in the clay seam located about 8 feet above the existing roof. Here, the maximum horizontal relative displacement across the seam is approximately 3 1/2 inches. Actual relative displacement will be lower because the clay seams have a finite friction coefficient.

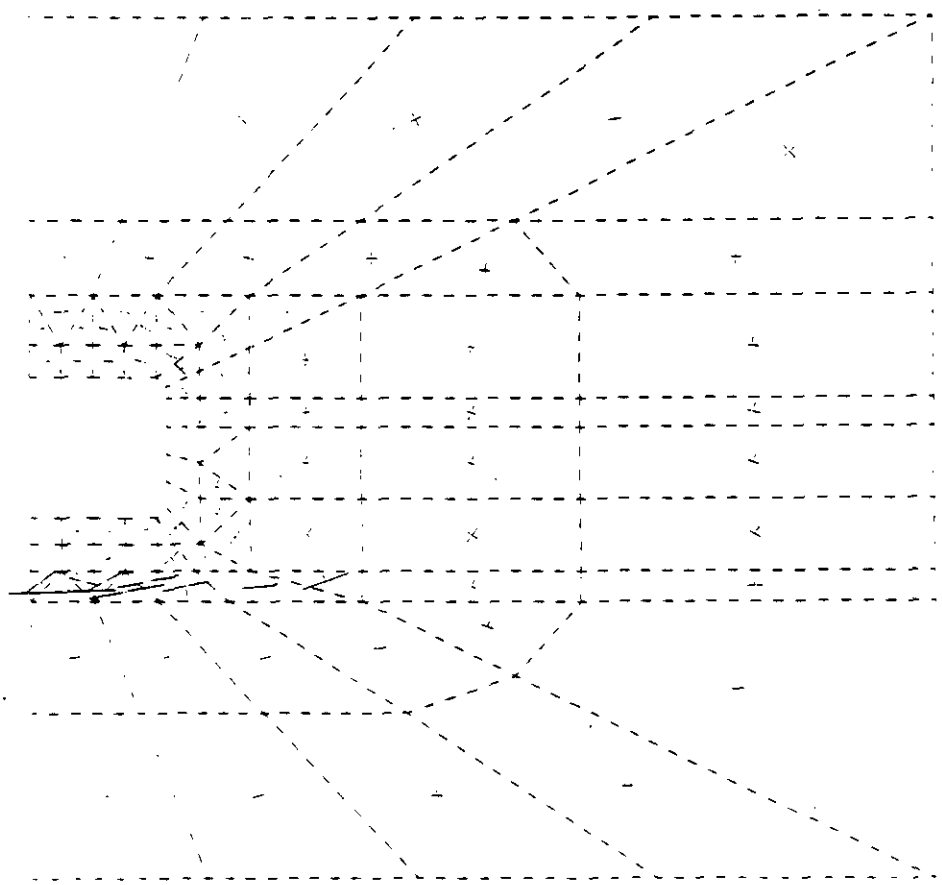

Figure 12-25

STORAGE AREA DRIFTS
PRINCIPAL STRESSES IMMEDIATELY AFTER EXCAVATION

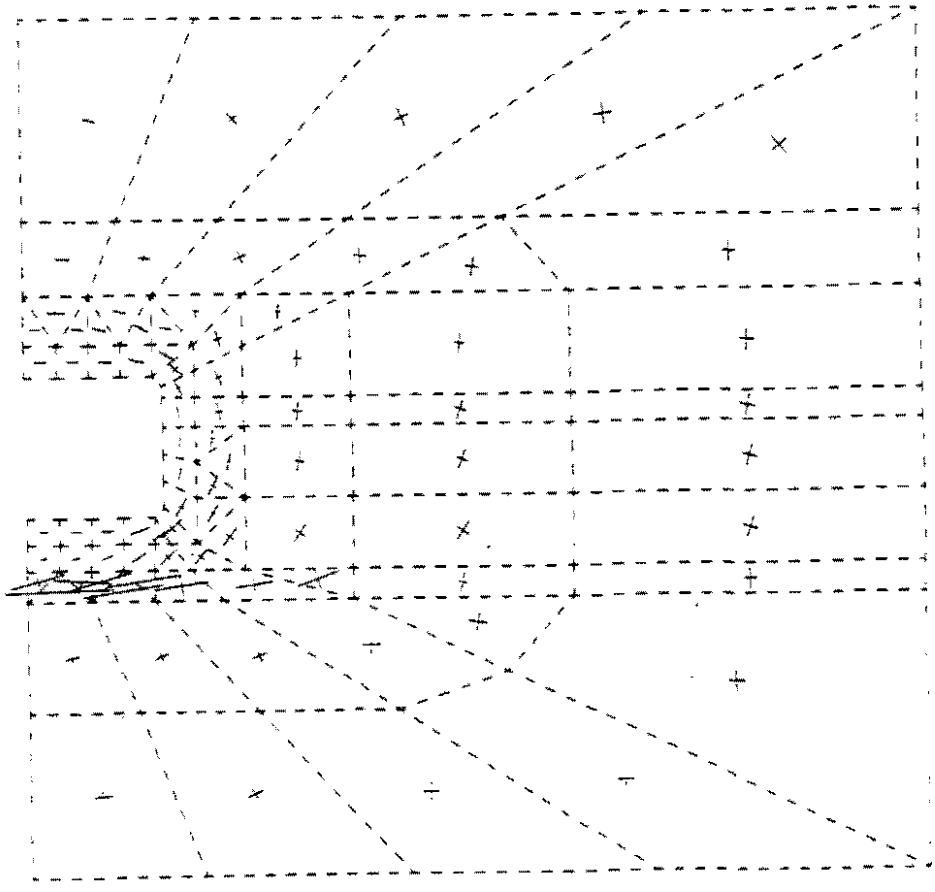

Figure 12-26

STORAGE AREA DRIFTS
PRINCIPAL STRESSES 5 YEARS AFTER EXCAVATION

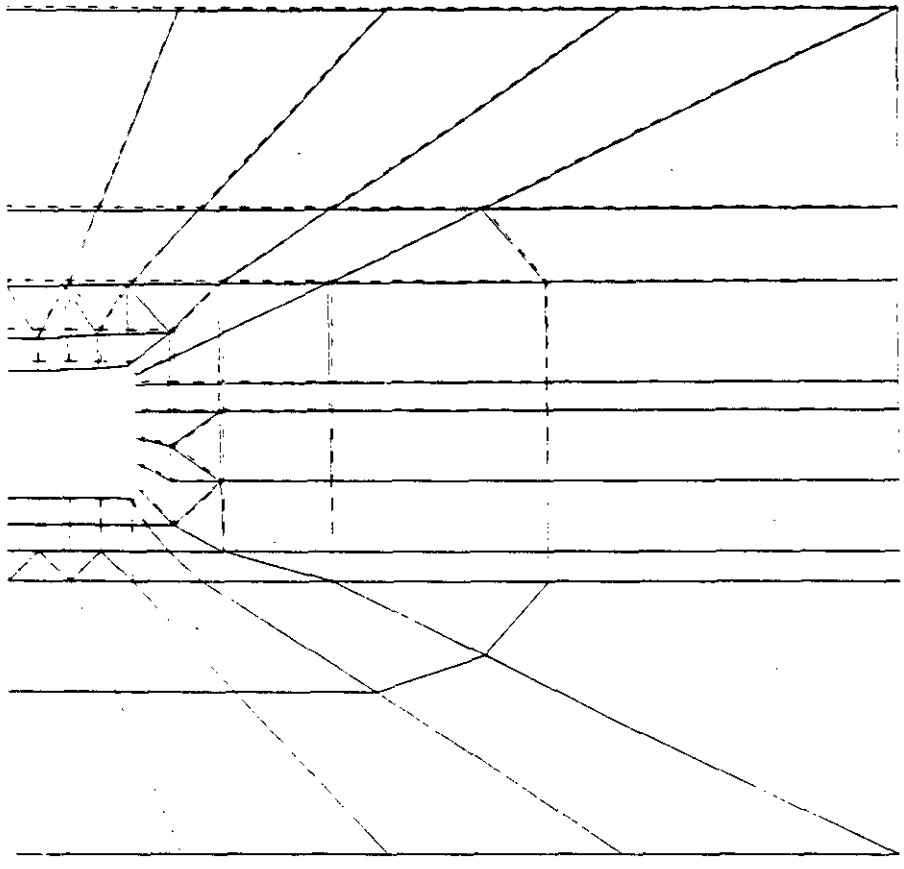

Figure 12-27

STORAGE AREA DRIFTS
DEFORMED SHAPE 5 YEARS AFTER EXCAVATION

Figure 12-28 demonstrates the effect of increasing the vertical dimension of a storage area drift at some point after initial excavation. The finite element model is calibrated with in situ data. It models an 8 x 25-foot drift that has its height increased to 13 feet by excavating an additional 5 feet from the floor. The 8 x 25-foot drift exhibits typical closure; that is, the curve shows high rate of closure during primary creep and a nearly constant closure rate during secondary creep. When the floor is lowered (in this case 2.3 years after excavation), primary creep is temporarily reinitiated. The secondary creep phase is eventually re-established, but with some difference. The slope of the curve during secondary creep after floor lowering is slightly steeper than the secondary creep prior to floor lowering. The rate of closure does not return to the initial rate, but rather reflects the new, larger dimension of the drift. In this model, the modified drift has 11 inches of vertical closure 5 years after initial excavation.

The same computation included wall-to-wall closure. The effects of floor lowering were the same as for roof-to-floor closure. After floor lowering, primary creep was reinitiated and followed by a new secondary creep phase with a slightly higher closure rate. Five years after initial excavation, the predicted horizontal closure is about 8 inches.

A rough extrapolation of the predicted roof-to-floor and wall-to-wall closures based on model simulation and resulting secondary creep closure indicates the following:

Time (Years)	Roof-to-Floor Closure at 2.0 inches/year (inches)	Wall-to-Wall Closure at 1.6 inches/year (inches)
10	20	16
15	30	24
20	40	32
25	50	40

The maximum effective strain around the drift opening reaches 6 percent about 8 years after excavation. Based on in situ observations and the

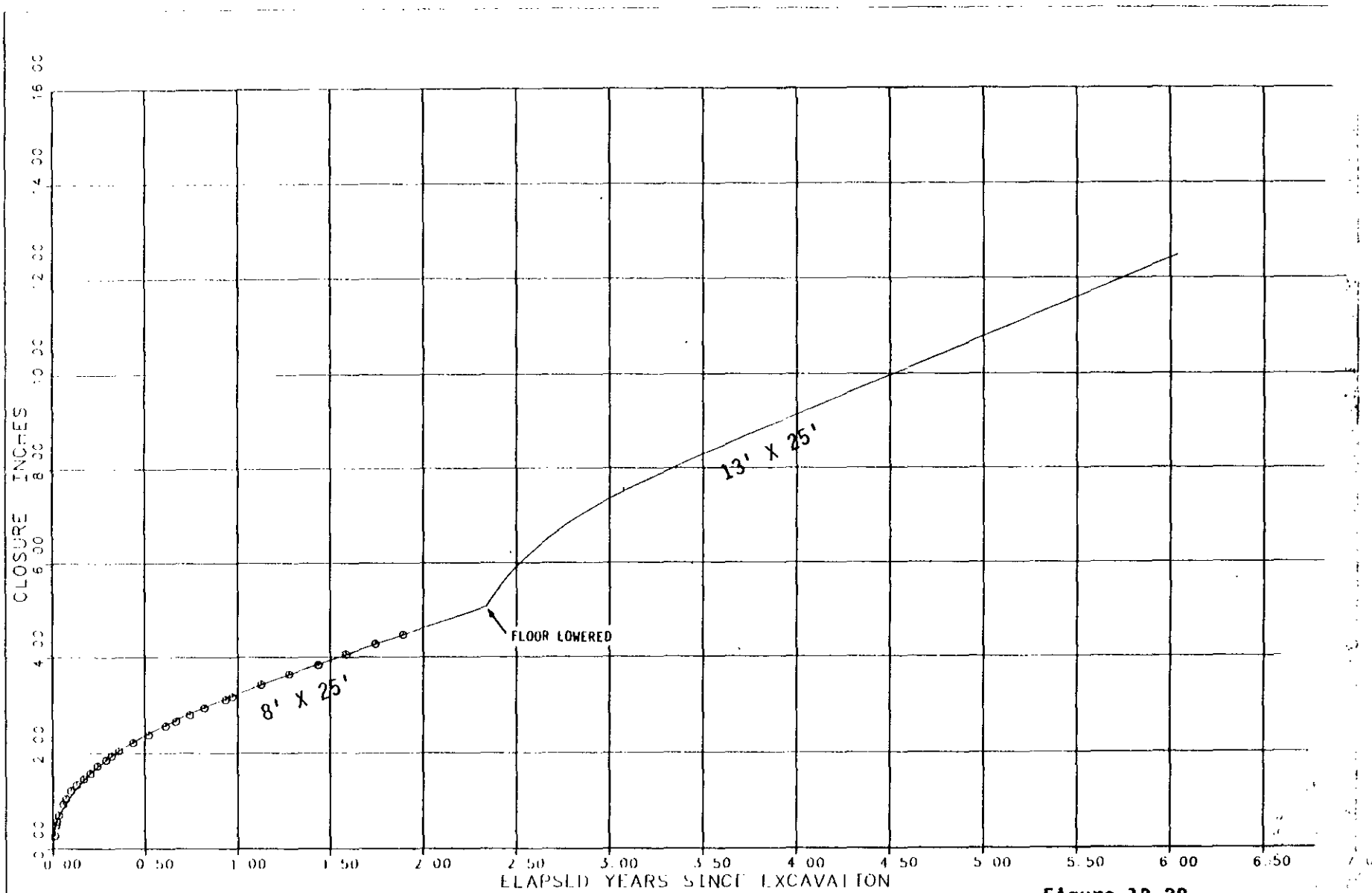

Figure 12-28

STORAGE AREA DRIFTS
ROOF-TO-FLOOR CLOSURE PREDICTION

results of modeling the test rooms, this effective strain of 6 percent may not result in instability of the drifts. However, in 15 years the effective strain at the excavation surface will exceed 10 percent locally and the roof-to-floor closure will be nearly 30 inches. According to the failure criterion, based on laboratory tests on samples of halite (Chapter 6), the halite is supposed to fail at about 16 percent effective strain. Therefore, minor surface deterioration can be expected and some trimming will be required to permit operation of the waste storage equipment. Because the effective strain decreases rapidly within the salt, trimming on the order of only a few feet may be needed after 20 years.

The storage drifts, as with the storage rooms, must accommodate greater than predicted closure. The reference design provides for waste storage in the storage area drifts only after all of the main storage rooms are filled. Since this would occur toward the end of the operating phase, waste in these drifts would not be subject to retrieval under the provisions governing the 5-year demonstration period. Waste stored in the drifts would be on a permanent basis.

Increased closure does impact waste emplacement and emplacement machinery. In the reference design, the greatest age a drift would reach before waste was emplaced would be about 15 years. At this age, based on the calculated closure for a 13 x 25-foot drift, the predicted roof-to-floor closure would be about 25 inches and the predicted wall-to-wall closure would be about 20 inches. The storage drifts would have to be trimmed to permit proper storage and equipment clearance. Similarly, the storage drifts and crosscuts less than 25 feet wide would also require trimming.

12.3.3.3 Intersections

The modeling of intersections is an expensive, three-dimensional analysis. However, to estimate closures at a storage room intersection, a simplified method can be utilized in place of a

[illegible] analysis [illegible] develops the mathematical relationship [illegible] floor closure at the intersections.

When normalized time is sufficiently large, analytical results have consistently shown that room closure in the normalized time domain can be estimated by the following equation:

$$u = u^*_o + \dot{u}^*_f \, t^* \qquad \text{when: } t^* > 1\text{x}10^{-11} \text{ ksf}^{-4.9} \qquad (12\text{-}3)$$

where: $t^* = C[t + \frac{A}{z}(1 - e^{-zt})]$ is the normalized time;

u^*_o is a constant; and

$$\dot{u}^*_f = \lim_{\Delta t \to 0} \frac{\Delta u}{\Delta t^*}$$

Closure for the storage room intersections, in normalized time, was calculated using the creep parameters discussed in Chapter 11 and in situ data collected near the intersections of the N1420 drifts with Rooms L1 and L2. As expected, the closure history follows equation 12-3 when the normalized time is greater than $8.0\text{x}10^{-12}$ ksf$^{-4.9}$. The average values of u^*_o and $\dot{u}^*_f$ for Rooms L1 and L2 were calculated to be 0.0450 feet and $1.967\text{x}10^{12}$ ksf$^{-4.9}$, respectively.

After determining the values of u^*_o and $\dot{u}^*_f$, equation 12-3 can be utilized for computing the closure at a storage room intersection. Figure 12-29 shows the roof-to-floor closure prediction at a storage room intersection.

12.4 STORAGE AREA PLUGS

The design criteria require that the storage area reference design contain provisions for the isolation of the waste storage panels from each other. The reference design contains recommended locations for plugs which would provide this isolation. It does not, however,

provide a specific design for the plugs. The design of the plugs is currently under investigation by SNL (ref. 12-8).

The recommended locations for the plugs are shown on Figure 12-30. The plugs will be constructed in the entry drifts to each panel. The four main access drifts to the storage area will also contain plugs. The section of the entry drifts leading from the access drifts to the first storage room is 200 feet long. The reference design contains provisions for the construction of approximately 100-foot long plugs centered in this 200-foot section of each entry drift.

Originally, the reference design contained entry drift cross section dimensions of 13 feet high and 33 feet wide. These dimensions are the same as those for the storage room reference design and were chosen based on waste container stacking considerations. This design was modified as the result of a meeting between the DOE and all project participants (ref. 3-2). The reference design modification was based on the necessity to minimize the cross section area of the plugs while maintaining sufficient room for the excavation and waste storage equipment.

The reference design modification for the entry drifts is shown on Figure 12-31. The 100-foot long section containing the plug has been reduced in cross section to 13 feet high and 14 feet wide for the exhaust drift and 20 feet wide for the intake drift. However, the operating contractor may further modify these dimensions to accommodate equipment. The four main access drifts will retain their original cross section dimensions in the areas of the planned plugs.

The plug shown on Figure 12-31 would consist of multiple components as described in reference 12-8. These components include a central core of bentonite or bentonite-based mix, salt-brick bulkheads, and cement-based bulkheads. Prior to constructing the multiple-component plug in an entry drift, the operating contractor must investigate the disturbed zone surrounding the drift. In particular, the occurrence of any fractures within and above MB-139, beneath the floor, and any

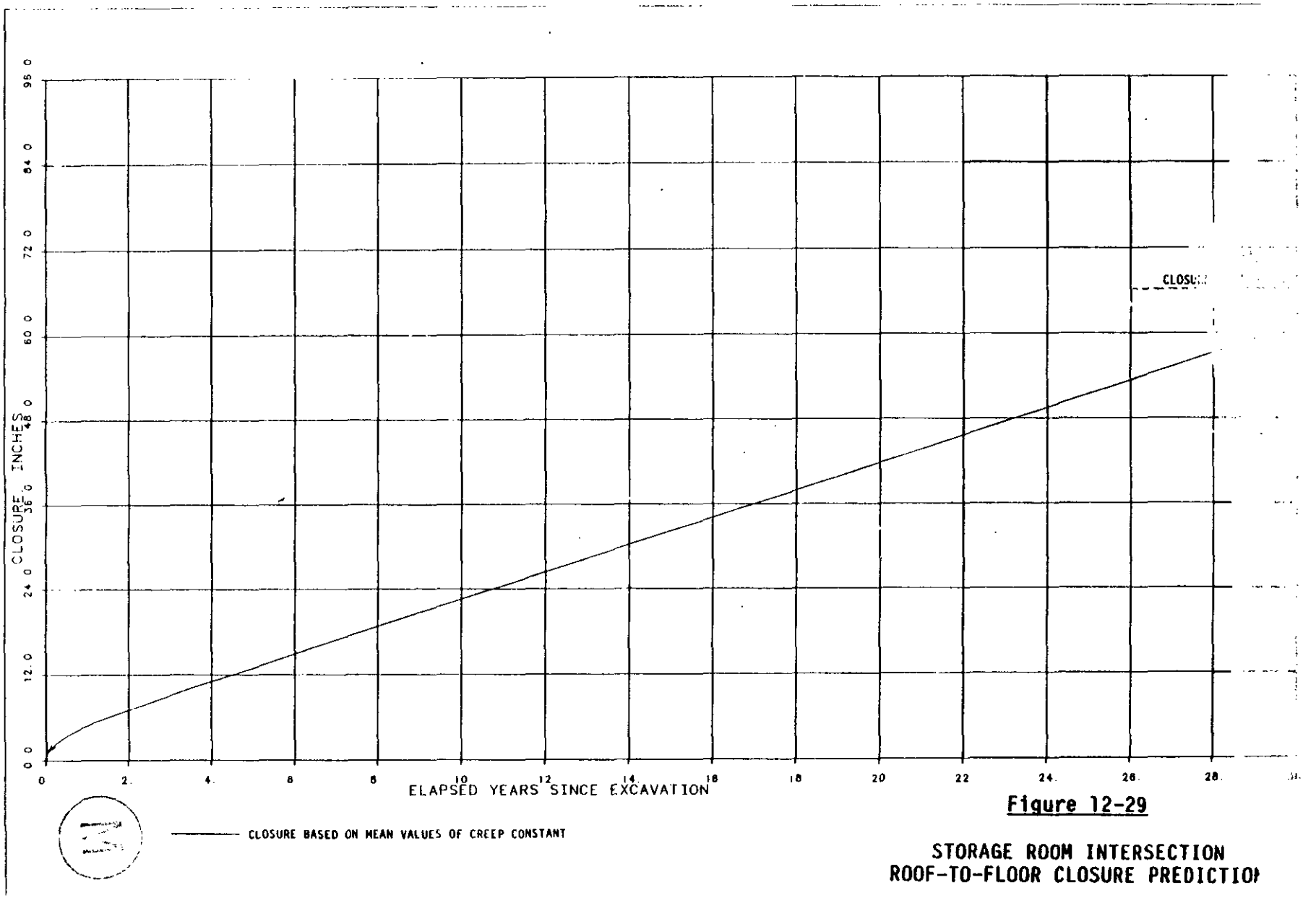

Figure 12-29

STORAGE ROOM INTERSECTION
ROOF-TO-FLOOR CLOSURE PREDICTIO

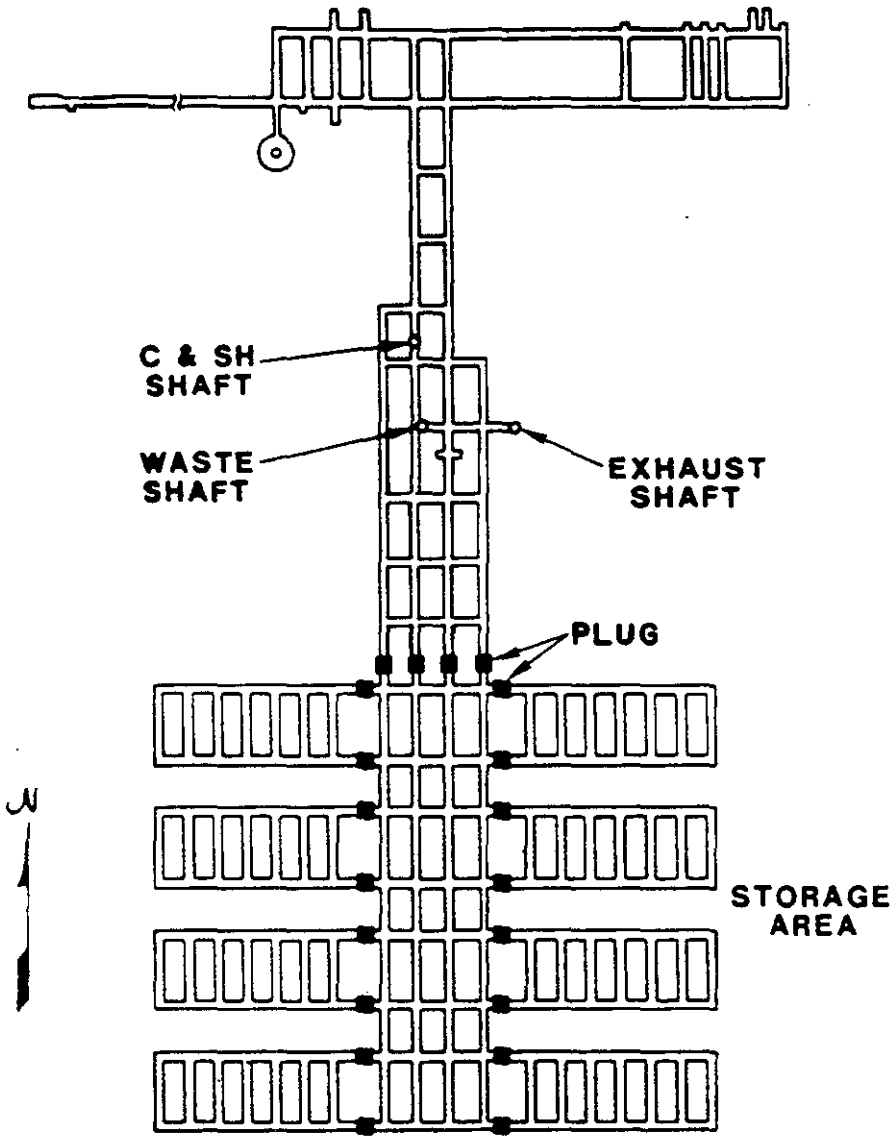

Figure 12-30

STORAGE AREA
PLUG LOCATIONS

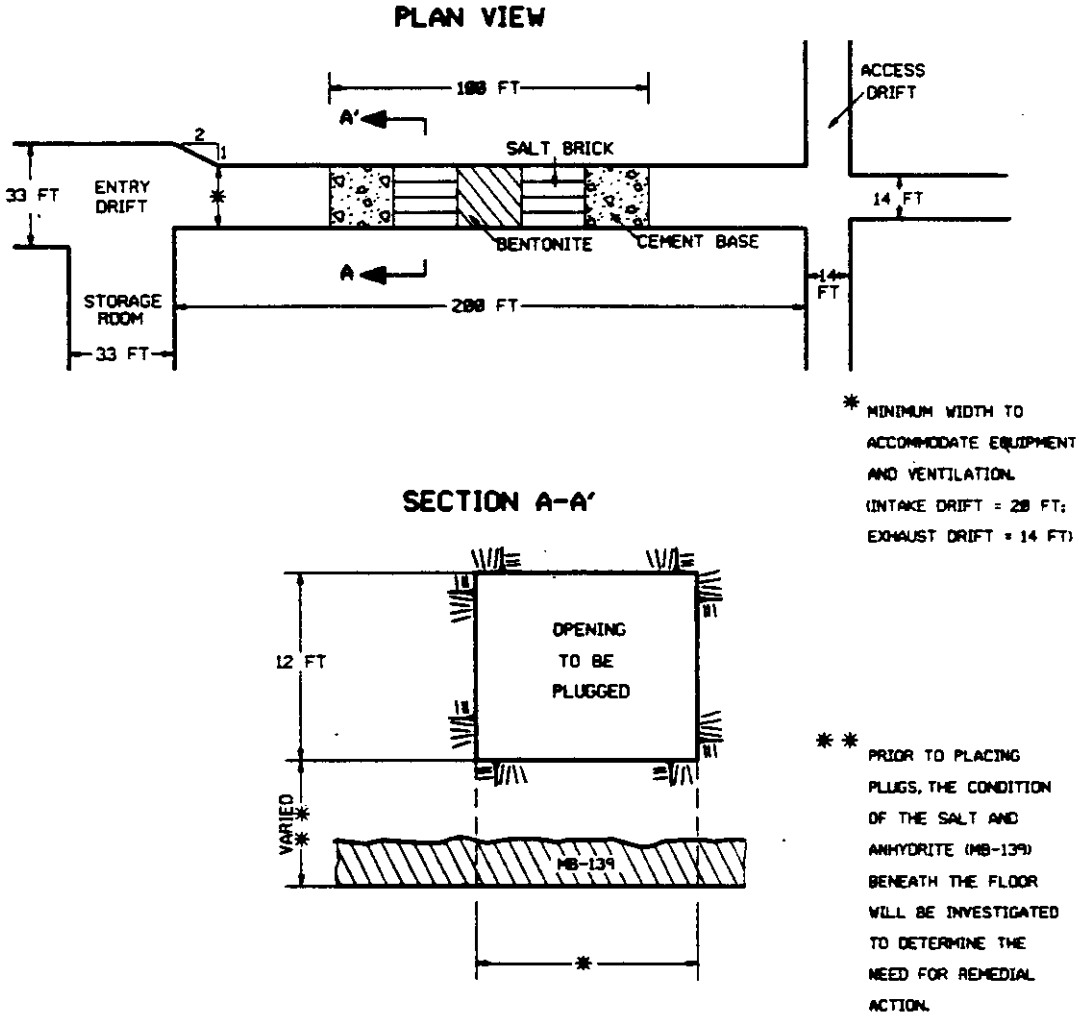

Figure 12-31

STORAGE AREA
PROPOSED PANEL PLUG REFERENCE DESIGN

separations at clay seams above the roof will need to be evaluated. If zones of unacceptable permeability are detected in the floor, the plug area should be lowered to remove the fractured zone and MB-139. Similarly, should any separations be found at clay seams above the entry drift, the roof should be excavated up through the highest seam exhibiting separation.

If the disturbed zone effects are not substantial, low-pressure grouting may be considered as an alternative remedial action. This would permit retention of the minimum cross section for the plug area. In addition, pressure grouting could be used in conjunction with excavation to treat deeper fractures, if present.

12.5 STORAGE ROOM BACKFILL

In accordance with the design criteria, the storage room reference design includes backfilling the rooms with crushed salt after waste emplacement. The storage area drift and room dimensional requirements are shown on Figures 12-2 and 12-3. The thickness of the salt backfill covering the waste packages shown on these figures is 1 to 2 feet. This is to be the thickness of the salt after placement and does not take into account backfill consolidation during room closure.

The only purpose for backfilling presented in the criteria is to provide fire protection in the storage rooms based on an accident scenario in which spontaneous ignition of the contents of a CH TRU waste container results in fire propagation to adjacent containers. Recent studies concerning the potential for spontaneous ignition in CH TRU waste containers have indicated that this is not a credible scenario. Although backfill is a design criteria requirement and therefore must be incorporated into the reference design, the results of these studies indicate that backfill will not be necessary for fire protection.

The following subsections present conclusions pertaining to validation of the WIPP storage area reference design and recommendations for design modifications to achieve validation of the reference design. These are based on a comparison of the design criteria, design bases and reference design configurations with the results of the analysis and evaluation of data collected during the design validation process.

12.6.1 Conclusions

The most significant finding of the design validation program is the difference between closure predicted from laboratory test data and the closure actually occurring in the underground facility. The storage area reference design configurations were designed before long-term in situ data were available. Closure rates were estimated using creep constants derived from the laboratory analyses of salt cores from borehole ERDA-9. These estimates resulted in the establishment of a closure limit of 12 inches in the first 5 years following excavation. Evaluation of the in situ data demonstrates that this closure limit is insufficient. The predicted closure based on laboratory analyses underestimates the actual closure at 3 years by about a factor of three (Figure 11-35). Establishing the causes for this underprediction of closure requires additional study and research and is beyond the scope of this report.

Vertical and horizontal closure demonstrated by the in situ data will not allow the reference design to meet the design criteria requirements. The waste containers will most likely be crushed and breached. Furthermore, because of the in situ closure the waste container stacking configurations and transport vehicle would not be compatible with the reference design room and drift configurations. In order for the reference design to comply with the design criteria, the storage area design configurations or the design criteria will have to be modified. Five alternative modifications are presented in the next subsection.

The analytical results for the storage area show the redistribution of stresses around the openings due to the effects of creep. Based on the computed vertical, horizontal and effective stresses, the magnitude of stresses immediately adjacent to the openings decreases and the stress arch around the openings migrates away with time. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability problem in the storage area except in MB-139, where a gradual buildup of stress may cause local failure of the anhydrite. This failure is expected to be in the form of floor slabbing and should not affect the structural performance of the openings nor hinder the waste storage operations. Investigations of the test room floors indicate that major fracturing has occurred only in the south half of Test Room 3 (Room T). All other floor fracturing has been minor.

The analysis shows the locations of effective creep strain concentrations at different times around the openings. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, effective creep strain may locally exceed the critical strain which is based on laboratory test data. However, this is not expected to disturb the overall structural stability within the limits required for safety during the 5-year demonstration period and permanent storage. Minor spalls and failures on the wall surfaces, similar to the ones discussed in Chapter 11, are expected to occur and can be easily identified and monitored. Scaling of these minor failures, when necessary, is considered a normal maintenance operation.

The facility stratigraphy is continuous and uniform. No anomalous conditions have been encountered that would jeopardize facility operations or waste storage integrity. The fracturing that is occurring beneath the test room floors may develop to some degree beneath the storage rooms. These fractures are not considered to be deleterious to storage room performance. There have been no occurrences of gas or brine in quantities that would adversely affect waste storage operations.

[illegible] plugs as [illegible]. The referenc desi[illegible] drifts contains a reduced cross section in the plug area. The minimum dimensions for the plug area will be dictated by operating requirements. The dimensions may also require alteration if disturbed zone effects are present that necessitate additional excavation.

An independent study has concluded that spontaneous combustion in the waste containers is not a credible event. In this case, crushed salt backfill will not be required for fire protection. Because it has been determined that the storage rooms will close at a rate faster than originally anticipated, deletion of the backfill requirement will provide additional allowance for vertical closure. This has favorable implications in terms of recommended modifications discussed in the next subsection.

12.6.2 Recommendations

The reference design will be validated when any of the following alternative modifications or combinations thereof are incorporated:

(1) Maintain the reference design room dimensions (13 to 14 feet high and 33 to 34 feet wide), retain the salt backfill but reduce the volume of waste to be stored and modify the waste stacking configuration in each room and entry drift (Figure 12-32). These changes would be required only during the 5-year demonstration period. Revise the criteria to require that retrieval operations be accomplished within 7 years of excavating each room. This will assure that the waste containers will not be crushed or breached. However, it will require a significant number of additional rooms during and after the demonstration period.

(2) Maintain the reference design room dimensions and the waste storage volume. Revise the criteria to delete the requirement for salt backfill and to require that if the

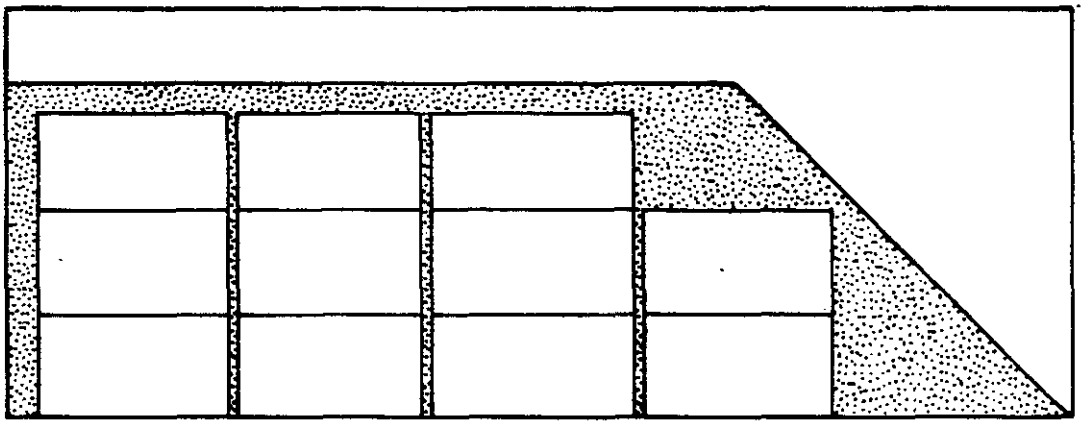

Figure 12-32

STORAGE AREA
MODIFIED WASTE STACKING CONFIGURATION

[illegible] waste [illegible] any room in which waste [illegible] years. This will preclude the possibility of crushing and/or breaching any waste containers and will make retrieval easier and more rapid. No additional rooms will be required.

(3) Maintain the reference design room dimensions, the waste storage volume, and the salt backfill. Revise the storage operations during the 5-year demonstration period so that the waste stored first can be retrieved first. Excavate the rooms to 14 x 34 feet initially and then trim them to 14 x 34 feet a year later. Rooms having waste retrieved will not be older than 6 years and the wall-to-wall closure will be approximately 12 inches. This would minimize the crushing and breaching of the waste containers. The criteria are to be revised as stated under (5) of these recommendations. However, due to the first-in/first-out recommendation, more rooms will be required during the 5-year demonstration period to accommodate the expected volume of waste. Trimming to the final dimensions will also increase operating costs. The total number of rooms required will be the same as provided by the reference design.

(4) For the 5-year demonstration period, reduce the storage room width from 33 feet to 28 feet, maintain the 13 to 14-foot height, and reduce the pillar width to 84 feet. Maintain the first room for RH emplacement at 33 feet to 34 feet wide and 13 feet to 14 feet high as provided in the reference design. Reduce the volume of waste to be stored in each room and maintain the salt backfill. Excavate the rooms to 14 x 28 feet then, after approximately 1 year, trim them to 14 x 28 feet again. Provide for first-in/first-out emplacement and retrieval during the 5-year demonstration period. This will reduce the rate of creep to approximately

the rate for the 13 x 25-foot drifts. The potential for crushing and breaching of the waste containers will be minimized and the stability should be better than that for a 33-foot wide room. The total volume of excavation will be approximately the same. If this alternative is selected, additional engineering evaluation will be required.

(5) Maintain all of the features of the reference design. That is, maintain the storage room configuration of 13 feet high and 33 feet wide, maintain the salt backfill, maintain the planned volume of waste to be stored in each room and drift, and maintain the same optimized excavation plan for the 5-year demonstration period and permanent storage. Revise the design criteria to allow crushing and breaching of the CH waste containers during the 5-year demonstration period as well as during permanent storage. Also, revise the criteria requiring a demonstration of waste package handling to include a demonstration of the retrieval of crushed and breached containers prior to receiving waste. This alternative will not only demonstrate the safe retrieval of waste if required during the 5-year demonstration period but also at any time during permanent storage.

In addition to these recommended alternative modifications, the following modifications are recommended:

(6) The drifts used for storage will have to be maintained and trimmed to provide the required equipment and storage clearances. The closure rates are not critical for storage because these drifts will be used only for permanent storage near the end of the permanent storage period.

[illegible]

the plugs in the [illegible]

(8) Install instrumentation in the storage rooms to obtain in situ data to monitor storage room behavior.

GLOSSARY

G.1 TERMINOLOGY

Back - The roof of underground horizontal openings.

Bunton - Horizontal, tubular steel section installed in the C & SH shaft to support the wood guide rails which center the shaft conveyance as they travel in the shaft.

CH TRU waste - Contact-handled transuranic waste that is packaged so that the dose rate at the surface of the waste package is not greater than 200 millirem/h.

Closure - The gradual decrease in distance between two opposing points in an underground opening as a result of rock or salt movement.

Convergence - See "closure".

Datalogger - Computer system that collects and records the output of geomechanical instrumentation.

Design bases - Detailed requirements established from the design criteria to provide additional direction in development of the engineering design of the WIPP underground facilities.

Design configuration - Engineered design dimensions of underground facility openings based on requirements of design criteria and design bases.

Design criteria - General requirements established to govern the engineering design of the WIPP underground facilities.

Design validation - The process of confirming the WIPP underground opening reference design by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. Validation is achieved through an assessment of the condition and behavior of the underground openings, and on predictions of their future behavior, based on in situ observations and measurements.

Drummy - Term used to describe rock that sounds hollow or loose when tapped with a solid object; used especially in relation to a mine roof.

Facility level - The underground horizontal portion of the WIPP facility developed for waste storage purposes.

Floor/roof beam - The rock thickness between the floor or roof of an excavated opening and the first underlying or overlying clay seam.

Galloway - A multi-decked steel platform suspended in a shaft and raised or lowered by means of a cable hoist. It is used to transport material and personnel in the shaft, particularly during shaft outfitting.

Guide - Vertical shaft member of steel or wood which is used to center the conveyance equipment as it travels in the shaft.

Long-term monitoring - The extended acquisition and evaluation of data to determine the geomechanical response of the rock/salt to excavation. These data will supplement the R & D program.

Muck - The broken rock and other material that is removed during shaft or horizontal opening excavation.

Penecontemporaneous - Term used to indicate a geologic process that occurs concurrent with or after sediment deposition but before lithification.

Potash - Any potassium-rich rock mined and refined to produce products used in agriculture or industry.

Preliminary design validation - The process of achieving a preliminary evaluation of the underground design criteria, design bases and design configurations early in construction, primarily by visual observations of the underground openings and geomechanical instrumentation measurements.

R & D Program - The WIPP mission designed to provide a technical understanding of systems design, safety and environmental assessments for the disposal of radioactive waste from U.S. defense programs. The program includes technology development through laboratory testing of theoretical analysis and in situ testing to evaluate the techniques used to monitor the responses of materials and facility systems.

RH TRU waste - Remote-handled transuranic waste that is packaged so that the dose rate at the surface of the package is greater than 200 millirem/h but less than 100 rem/h.

Rib - The vertical wall of underground horizontal openings.

Scaling - The removal of loose rock from underground opening surfaces.

Shaft outfitting - The process of installing shaft furnishings (utilities, buntons, guides, conveyance equipment, etc.), as well as stabilizing the wall by means of rock bolts, wire mesh or lining.

Short-term monitoring - The acquisition and evaluation of data to determine the initial geomechanical response of the rock/salt to excavation.

Site and Preliminary Design Validation (SPDV) - A WIPP program consisting of two integrated subprograms, Site Validation and Preliminary Design Validation, that are defined in their individual listings.

Site characterization - The process of obtaining geotechnical data and conducting experiments to determine the suitability of the WIPP site for a research and development facility to demonstrate the safe disposal of defense-related nuclear waste.

Site validation - The process of achieving the highest practicable level of confidence in the site's suitability and overall qualification through subsurface investigations.

Slabbing - The weakening of rock fragments or segments along fractures parallel to the excavation surface.

Spud - To begin drilling a well, hole or shaft.

Spalling - The breaking loose of chips, thin slabs, or fragments from the outer surface of a rock mass.

Telltale pipe - A pipe used to monitor the effectiveness of the chemical water seals in the shaft keys. The pipe provides a pathway for water to flow through the concrete beneath the seals from the salt/concrete interface to the inside face of the concrete key.

Transuranic (TRU) waste - Radioactive waste containing transuranic elements created by the absorption of neutrons into uranium atoms.

Underground development level - See "facility level".

Underground facility horizon - The stratigraphic interval within the Salado formation, from a depth of approximately 2,100 to 2,170 feet (elev. 1240 to 1310 feet), which was selected for testing and storage of low-level nuclear waste.

G.2 ACRONYMS

ACI	American Concrete Institute
AEC	Atomic Energy Commission
BNI	Bechtel National, Incorporated
BTP	Brine Testing Program
C & SH	Construction and salt handling
CH TRU	Contact-handled transuranic
DOE	U.S. Department of Energy
FEIS	Final Environmental Impact Statement
GFDR	Geotechnical Field Data Report
GSA	Geological Society of America
GTP	Gas Testing Program
LTC	Local termination cabinet
MIIT	Material Interface-Interactions Test
MOC	Management and Operating Contractor
MSHA	Mine Safety and Health Administration
NAS	National Academy of Sciences
R & D	Research and development
RH TRU	Remotely-handled transuranic
RMC-IIA	Revised Mission Concept IIA
SAR	Safety Analysis Report
SME	Society of Mining Engineering
SNL	Sandia National Laboratories
SPDV	Site and Preliminary Design Validation
TRU	Transuranic
TSC	Technical Support Contractor
USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant

REFERENCES

1-1 Waste Isolation Pilot Plant, Design Validation Plan, January 27, 1983, Document No. 76B510AB-000, Rev. 6, U.S. Department of Energy, WIPP Project Office, Albuquerque, New Mexico.

1-2 Letter, D.T. Schueler (DOE) to G.S. Goldstein (State of New Mexico), August 31, 1981, "Cost and Merit Evaluation for Stipulated Agreement Activities".

1-3 Waste Isolation Pilot Plant Preliminary Design Validation Report, March 30, 1983, prepared for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

1-4 Final Environmental Impact Statement: Waste Isolation Pilot Plant, 1980, DOE/EIS-0026, U.S. Department of Energy, Washington, D.C.

1-5 Waste Isolation Pilot Plant Safety Analysis Report, 1980, U.S. Department of Energy, WIPP Project Office, Albuquerque, New Mexico.

1-6 Matalucci, R.V., C.L. Christensen, T.O. Hunter, M.A. Molecke, and D.E. Munson, 1982, WIPP Research and Development Program: In Situ Testing Plan, SAND81-2628, Sandia National Laboratories, Albuquerque, New Mexico.

1-7 Waste Isolation Pilot Plant, Design Validation Strategy, 1986, U.S Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

1-8 Site Validation Program, 1982, WIPP-DOE-116, Rev. 1, prepared for the U.S. Department of Energy by the Technical Support Contractor, Albuquerque, New Mexico.

2-1 Seward, Paul D., compiler, 1982, Abridged Borehole Histories for the Waste Isolation Pilot Plant (WIPP) Studies, SAND82-0080, Sandia National Laboratories, Albuquerque, New Mexico.

2-2 U.S. Department of Energy, 1982, Basic Data Report, Borehole WIPP-12 Deepening, TME 3148, Albuquerque, New Mexico.

2-3 _____, 1982, Basic Data Report for Borehole DOE-1, TME 3159, Albuquerque, New Mexico.

2-4 Powers, D.W., S.J. Lambert, S.E. Shaffer, L.R. Hill, and W.D. Weart, editors, 1978, Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, SAND78-1596, Sandia National Laboratories, Albuquerque, New Mexico.

2-5 Results of Site Validation Experiments, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, 1983, Vols 1 and 2, TME 3177, prepared for the U.S. Department of Energy by the Technical Support Contractor, Albuquerque, New Mexico.

2-6 Weart, W.D., March 1983, Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability, SAND83-0450, Sandia National Laboratories, Albuquerque, New Mexico.

2-7 Design Criteria, Waste Isolation Pilot Plant (WIPP), Site and Preliminary Design Validation (SPDV), October 1981, WIPP-DOE-72, Rev. 1, prepared for the U.S. Department of Energy by the Technical Support Contractor, Albuquerque, New Mexico.

2-8 Design Criteria, Waste Isolation Pilot Plant (WIPP), Revised Mission Concept-IIA (RMC-IIA), February 1984, WIPP-DOE-71, Rev. 4, prepared for the U.S. Department of Energy by the Technical Support Contractor, Albuquerque, New Mexico.

2-9 Waste Isolation Pilot Plant, Design Basis, SPDV Underground Excavations, November 21, 1980, D-51-W-02, Rev. 3, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-10 Waste Isolation Pilot Plant, Design Basis, Exploratory Shaft, December 16, 1980, D-31-R-03, Rev. 2, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-11 Waste Isolation Pilot Plant, Design Basis, Exploratory Shaft Furnishings and Station, December 12, 1980, D-37-S-02, Rev. 2, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-12 Waste Isolation Pilot Plant, Design Basis, Exploratory Shaft Geomechanical Instrumentation, December 3, 1980, D-32-X-01, Rev. 2, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-13 Waste Isolation Pilot Plant, Design Basis, Underground Experimental Areas, October 20, 1982, D-52-K-04, Rev. 2, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-14 Waste Isolation Pilot Plant, Design Basis, WIPP-RMC IIA (General), May 14, 1983, D-76-K-01, Rev. 7, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-15 Waste Isolation Pilot Plant, Design Basis, Waste Shaft, September 21, 1983, D-31-R-01, Rev. 8, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-16 Waste Isolation Pilot Plant, Design Basis, Exhaust Shaft, September 21, 1983, D-35-R-01, Rev. 1, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-17 Waste Isolation Pilot Plant, Design Bases, Geomechanical Instrumentation, September 1983, D-76-X-01, Rev. 6, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-18 Waste Isolation Pilot Plant, Design Basis, Underground Excavations, October 14, 1983, D-51-W-01, Rev. 6, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-19 Waste Isolation Pilot Plant, Design Basis, Design Classification, November 30, 1983, D-76-K-03, Rev. 9, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-20 Waste Isolation Pilot Plant, Design Basis, Underground Shops and Facilities, January 17, 1984, D-54-E-01, Rev. 6, prepared for the U.S. Department of Energy by Bechtel National, Inc.

2-21 WIPP Conceptual Design Report, 1977, SAND77-0274, prepared for the U.S. Department of Energy by Sandia National Laboratories, Albuquerque, New Mexico.

2-22 WIPP Title I Design Report, and supplements, 1979 and 1980, prepared for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

2-23 Stability Analysis of Underground Openings, RMC-II, 1981, Study Report No. 51-R-510-04, Rev. 0, prepared for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

2-24 Li, W.T., and C.L. Wu, May 1983, Analysis of Creep for a Nuclear Waste Storage in Salt Formation, Nuclear Technology.

2-25 Society of Mining Engineers of The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 1973, SME Mining Engineering Handbook, 2 Volumes, Port City Press, Baltimore, Maryland.

REFERENCES (continued)

2-26 Morgan, H.S., R.D. Krieg, and R.V. Matalucci, November 1981, Comparative Analysis of Nine Structural Codes Used in the Second WIPP Benchmark Problem, SAND81-1389, Sandia National Laboratories, Albuquerque, New Mexico.

2-27 Miller, J.D., C.M. Stone, and L.J. Branstetter, August 1982, Reference Calculations for Underground Rooms of the WIPP, SAND82-1176, Sandia National Laboratories, Albuquerque, New Mexico.

2-28 Memo from W.D. Weart (Sandia) to Distribution, July 31, 1981, "Reference Creep Law and Material Properties for WIPP".

2-29 Empirical Design Basis of Underground Salt Openings in the WIPP Project, November 12, 1979, Document No. DR-51-R-1, prepared for Bechtel National, Inc., by Shosei Serata.

2-30 U.S. Bureau of Mines, 1973, Subsidence Due to Underground Mining, Information Circular 8571.

3-1 Geotechnical Activities in the Exploratory Shaft - Selection of the Facility Interval, March 1983, TME 3178, prepared for the U.S. Department of Energy by the Technical Support Contractor, Albuquerque, New Mexico.

3-2 U.S. Department of Energy, June 30, 1986, "Project Position Regarding Subhorizontal Floor Fracturing", DOE Memo-WIPP:RAC 86:2003.

3-3 Grouting Report, Waste Shaft Lining, January 1985, Bechtel Document 31D510AA, prepared for the U.S. Department of Energy.

4-1 Geotechnical Field Data Report No. 2, November 9, 1982, "Exploratory Shaft, Exploratory Shaft Key, and Exploratory Shaft Station Instrumentation", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-2 Geotechnical Field Data Report No. 3, December 15, 1982, "Underground Excavation Field Instrumentation Data (shaft data not updated)", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-3 Geotechnical Field Data Report No. 4, January 8, 1983, "Geologic Mapping and Water Inflow Testing in the SPDV Ventilation Shaft", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-4 Geotechnical Field Data Report No. 5, January 18, 1983, "Geologic Mapping of Access Drifts 'Double Box' Area", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-5 Geotechnical Field Data Report No. 6, January 17, 1983, "Underground Excavation Field Instrumentation Data", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-6 Geotechnical Field Data Report No. 7, January 17, 1983, "Geologic Mapping of Exploratory Drift", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-7 Geotechnical Field Data Report No. 8, January 17, 1983, "Underground Excavation Field Instrumentation Data", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

REFERENCES (continued)

4-8 Geotechnical Field Data Report No. 9, February 18, 1983, "Logging of Vertical Coreholes 'Double Box' Area and Exploratory Drift", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-9 Geotechnical Field Data Report No. 10, March 18, 1983, "Underground Excavation Field Instrumentation Data", compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-10 Quarterly Geotechnical Field Data Report, July 1983, WIPP-DOE-163, compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-11 Quarterly Geotechnical Field Data Report, October 1983, WIPP-DOE-177, compiled for the U.S. Department of Energy by TSC-D'Appolonia, Albuquerque, New Mexico.

4-12 Quarterly Geotechnical Field Data Report, February 1984, WIPP-DOE-196, compiled for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

4-13 Quarterly Geotechnical Field Data Report, May 1984, WIPP-DOE-199, compiled for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

4-14 Quarterly Geotechnical Field Data Report, August 1984, WIPP-DOE-200, compiled for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

4-15 Quarterly Geotechnical Field Data Report, November 1984, WIPP-DOE-202, compiled for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

4-16 Quarterly Geotechnical Field Data Report, March 1985, WIPP-DOE-210, compiled for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

4-17 Quarterly Geotechnical Field Data Report, June 1985, WIPP-DOE-213, compiled for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

4-18 Quarterly Geotechnical Field Data Report, September 1985, WIPP-DOE-218, compiled for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

4-19 Quarterly Geotechnical Field Data Report, December 1985, WIPP-DOE-221, compiled for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

5-1 Hansen, Francis D., November 1979, Triaxial Quasi-Static Compression and Creep Behavior of Bedded Salt from Southeastern New Mexico, SAND79-7045, Sandia National Laboratories, Albuquerque, New Mexico.

5-2 Nawcrock, W.R., and D.W. Hannum, May 1979 (revised), Intern Summary of Sandia Creep Parameters on Rock Salt from the WIPP Study Area, Southeastern New Mexico, SAND79-0115, Sandia National Laboratories, Albuquerque, New Mexico.

5-3 Krieg, R.D., January 1984, Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project, SAND83-1908, Sandia National Laboratories, Albuquerque, New Mexico.

5-4 Herrmann, W., W.R. Wawersik, and H.S. Lauson, November 1980, A Model for Transient Creep of Southeastern New Mexico Salt, SAND80-2172, Sandia National Laboratories, Albuquerque, New Mexico.

5-5 Jaegar, J.C., and N.G.W. Cook, 1976, Fundamentals of Rock Mechanics, Second Edition, Chapman and Hall, London.

5-6 Li, W.T., C.L. Wu, and N. Antonas, November 1982, "Salt Creep Design Consideration for Underground Nuclear Waste Storage", Proceedings of MRS 6th Int. Sym. on Scientific Basis for Nuclear Waste Management.

5-7 Primary Creep of Rock Salt, November 8, 1983, Bechtel Report 76-D-540AD-01.

6-1 McKinney, R.F., and R.S. Newton, January 3, 1983, Site Validation Field Program Plan, Rev. 1.2, prepared for the U.S. Department of Energy by the Technical Support Contractor, Albuquerque, New Mexico.

6-2 Geotechnical Activities in the Waste Handling Shaft, October 1984, WTSD-TME-038, prepared for the U.S. Department of Energy by the Technical Support Contractor, Albuquerque, New Mexico.

6-3 Jones, C.L., 1981, Geological Data for Borehole ERDA-9, Eddy County, New Mexico, U.S. Geological Survey Open-file Report 81-469.

6-4 Holt, R., and D. Powers, 1986, Geotechnical Activities in the Exhaust Shaft, DOE-WIPP-86-008, prepared for the U.S. Department of Energy by the Technology Development Department of the Management and Operating Contractor, Carlsbad, New Mexico.

6-5 Stein, C.L., September 1985, Mineralogy in the Waste Isolation Pilot Plant (WIPP) Facility Stratigraphic Horizon, SAND85-034, Sandia National Laboratories, Albuquerque, New Mexico.

6-6 Borns, D.J., September 1985, Marker Bed 139: A Study of Drillcore from a Systematic Array, SAND85-0023, Sandia National Laboratories, Albuquerque, New Mexico.

6-7 Herrmann, W., W. R. Wawersik, and H.S. Lauson, March 1980, Analysis of Steady State Creep of Southeastern New Mexico Bedded Salt, SAND-80-0558, Sandia National Laboratories.

6-8 MARC Analysis Research Corp., 1980, MARC General Purpose Finite Element Program User Information Manual, Rev. J.2-1.

7-1 American Welding Society, 1980, Structural Welding Code - Steel, AWS D1.1.

7-2 ASME Boiler and Pressure Vessel Code, 1980, Sections V, VIII and IX, American Society of Mechanical Engineers.

7-3 Timoshenko, S., and S. Woinowsky-Krieger, 1959, Theory of Plates and Shells, McGraw-Hill, New York.

7-4 Li, W.T., N. Antonas, C.L. Wu, and K. Mark, February 1983, "Salt Structural Interaction of Underground Nuclear Waste Storage", Proceedings of the Waste Management '83 Symposium, Tucson, Arizona.

7-5 American Concrete Institute, 1977, Building Code Requirements for Reinforced Concrete, ACI-318.

7-6 Antonas, N., W. T. Li, K. Mark, and C. L. Wu, May 1983, "Creep Interaction of Salt and a Concrete Ring Structure", Proceedings of ASME EMD Specialty Conference.

7-7 Geology Laboratory Results of Rock Testing, 1979, Document No. 22-4-510-04, Rev. 2, prepared for the U.S. Department of Energy by Bechtel National, Inc., San Francisco, California.

7-8 Designing for Effects of Creep, Shrinkage, Temperature in Concrete Structures, 1971, ACI Publication SP-27, American Concrete Institute, Detroit, Michigan.

7-9 Mercer, J. W., 1983, Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico, USGS Water-Resources Investigations Report 83-4016, Albuquerque, New Mexico.

8-1 American Concrete Institute, 1972, Building Code Requirements for Structural Plain Concrete, ACI-322.

11-1 SAS Institute, Inc., 1985, SAS, Release 5.03, Cary, North Carolina.

11-2 SAS Institute, Inc., 1985, User's Guide: Statistics; Version 5 Edition, Chapter 25, The NLIN Procedure, Cary, North Carolina.

11-3 Branstetter, L.J., R. D. Krieg, and C.M. Stone, October 1982, The Effect of a Random Variation of Rock Salt Creep on Calculations of Storage Room Closure for the WIPP Project, SAND82-0024, Sandia National Laboratories, Albuquerque, New Mexico.

11-4 Miller, J. D., C. M. Stone, and L. J. Branstetter, August 1982, Reference Calculations for Underground Rooms of the WIPP, SAND82-1176, Sandia National Laboratories, Albuquerque, New Mexico.

11-5 Branstetter, L. J., March 1985, Second Reference Calculations for the WIPP, SAND83-2461, Sandia National Laboratories, Albuquerque, New Mexico.

12-1 General Design Criteria Manual for Department of Energy Facilities, June 10, 1981, draft, DOE 6430.

12-2 Physical Protection of DOE Property, September 29, 1977, IMD 6105.

12-3 Standard for Protection Against Radiation, Code of Federal Regulations, 10 CFR 20.

12-4 Requirements for Radiation Protection, Chapter 11, DOE 5480.1A.

12-5 A Guide to Reducing Radiation Exposure to As Low As Reasonably Achievable, DOE/EV/1830-T5.

12-6 Mine Safety and Health Standards - Metal and Non-Metal Underground Mines (MSHA), Code of Federal Regulations, 30 CFR 57.

12-7 New Mexico Mine Safety Code, 1981.

12-8 Stormont, J. C., November 1984, Plugging and Sealing Program for the Waste Isolation Pilot Plant (WIPP), SAND 84-1057, Sandia National Laboratories, Albuquerque, New Mexico.

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WASTE ISOLATION PILOT PLANT

DESIGN VALIDATION
FINAL REPORT

APPENDICES

JOB 12484

OCTOBER 1986

BECHTEL NATIONAL, INC.
SAN FRANCISCO, CALIFORNIA

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DOE STIPULATED AGREEMENT WITH STATE OF NEW MEXICO (PARTIAL)

APPENDIX A

STIPULATED AGREEMENT (PARTIAL)

The Department of Energy (DOE) and the State of New Mexico on July 1, 1981, entered into a Stipulated Agreement to perform certain work to validate the design of the WIPP underground facilities. Proposals for performing this work were identified in two parts: 1) tasks necessary to detail plans and rationale for the proposed design validation assessment, and 2) tasks necessary to prepare a report providing data, analysis and interpretation of the results of design validation assessment. The scope of work associated with these two DOE proposals included in the Stipulated Agreement are given below:

DOE Proposal to Prepare the Plan for Design Validation

1. Assumptions

The following assumption was made to define the tasks necessary to fulfill the requirements of this request.

a) The plan will primarily focus on the development of test panels for observing rock mechanics behavior.

2. Proposed Work

The tasks to be completed to provide the required plan include:

a) Review of the current test plans.

b) Establishment of objectives and needs of the test plan, based on past analysis, material property data, uncertainty in design assumptions, the behavior, time period for test, etc.

c) Establishment of the rational behind the test plan.

d) Establishment of priorities for various components of the test.

e) Preparation of the steps in design, analysis, monitoring and review of the test program.

f) Review of the consistency of the proposed plan with the objectives and rationale for the test.

g) DOE will provide an individual to coordinate communications on test planning and experiment progress with the state.

3. Expected Results

The anticipated results include a more detailed test plan with appropriate technical rationale, and justification to perform to construct a test panel within the non-waste experimental area. The test panel may consist of four rooms separated by pillars. The dimensions of each will be similar to those to be used in the WIPP waste storage area. The results from the test should validate key assumptions for design regarding rock mass behavior. The test results will be of particular interest for predicting long term behavior of room closures.

4. Merits of the Proposed Plan

The proposed plan will provide a defensible, rational plan for the design test panel. The actual tests should significantly enhance the level of confidence and credibility in the resulting design.

5. Schedule

The draft of the proposed plan will be submitted to the State of New Mexico by the end of November 1981. [Revised to the end of October 1982 at a joint meeting on September 21, 1982, between DOE, EEG, et al]

DOE Proposal for the Proposed Report

1. Assumptions

The following assumption was made with regard to the proposal to provide the subject report:

a) The impact of SPDV Design Validation Experiment results on basic design assumptions will be the focus of this report, and validity of the actual designs in all its aspects will not be emphasized.

b) If all the tests can not be completed within the present schedule, an interim report summarizing the status of experiments may be provided.

2. Proposed Work

The following tasks will be undertaken as a part of the proposed work.

a) The experimental data will be obtained and deciphered.

b) A basic data package will be prepared.

c) Anaylsis of data for the rock mechanics parameters will be made.

d) The results will be evaluated against the basic design assumptions.

e) An overall evaluation of the impact of any differences between the assumed and observed design parameters will be made.

f) A report summarizing the above steps will be prepared.

3. Work Not Proposed

The proposed work will not include validation/verification of the designs, since the verification/validation would require further steps being carried out separately such as checking of the design calculations and drawings.

4. Expected Results

Results of the experiments will likely demonstrate the validity of the basic design assumptions regarding rock mechanics parameters. It could also possibly suggest a review of these assumptions and their overall impact on the design development.

5. Schedule

A draft of the proposed topical report will be provided by the end of March 1983*. If significant experimental results are not available prior to that time, an interim status report will be provided, and a draft of the entire report will follow as soon as reasonably possible.

*Revised to the end of March 1983 at a joint meeting on September 21, 1982, between DOE, EEG, et al.

APPENDIX B

GEOLOGIC CORRELATIONS

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B-9	Geologic Correlation East-West Section, N1100 Drift Station W682 to W2782 (2 Sheets)

M

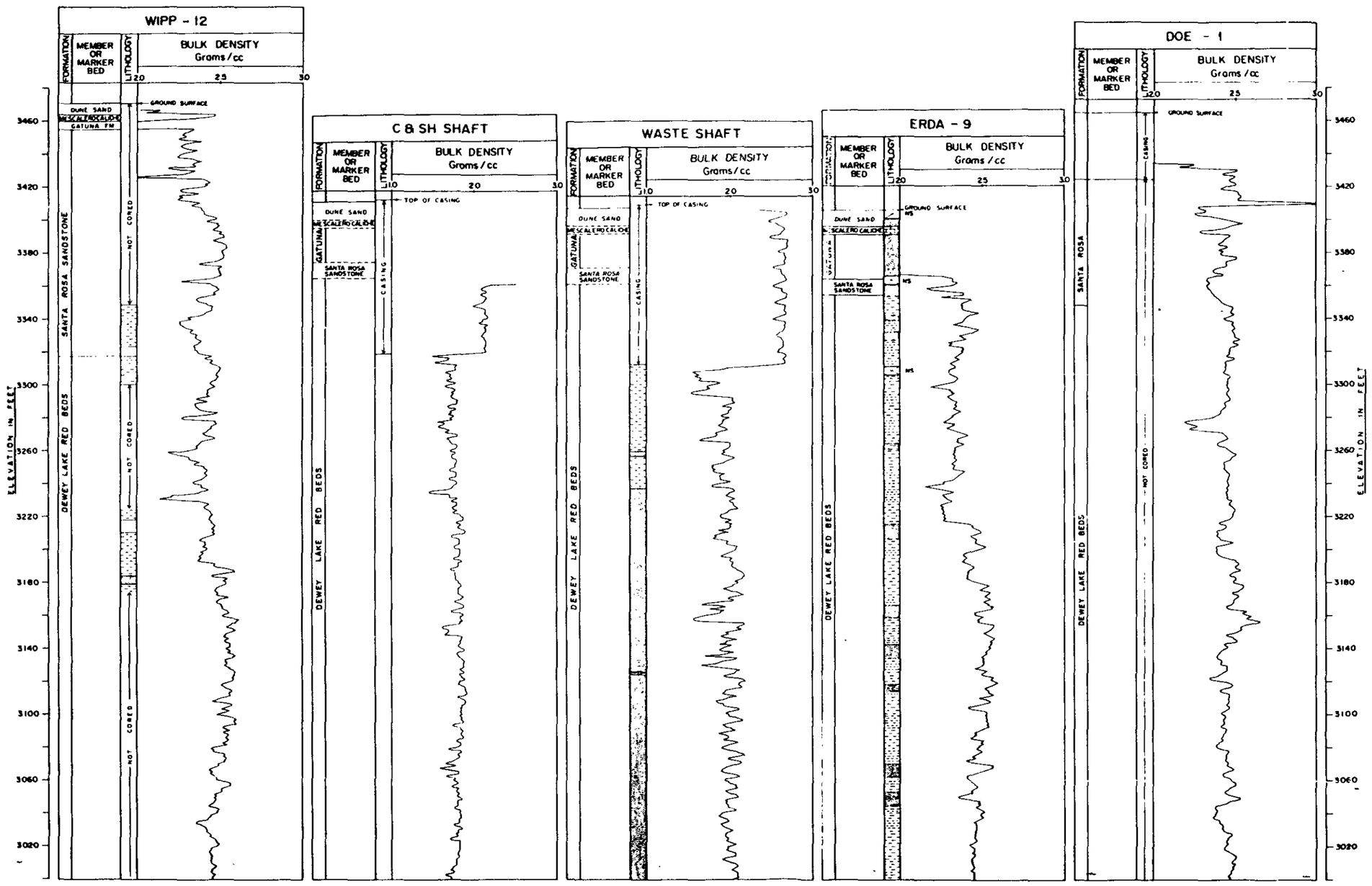

EXPLANATION

- Sandstone
- Caliche
- Siltstone
- Mudstone
- Anhydrite
- Gypsum
- Dolomite
- Halite
- Argillaceous Halite
- Polyhalite

NC = Not Cored
NR = No Recovery
NS = No Sample
MB = Marker Bed

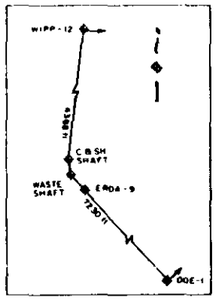

KEY PLAN

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 1 OF 5

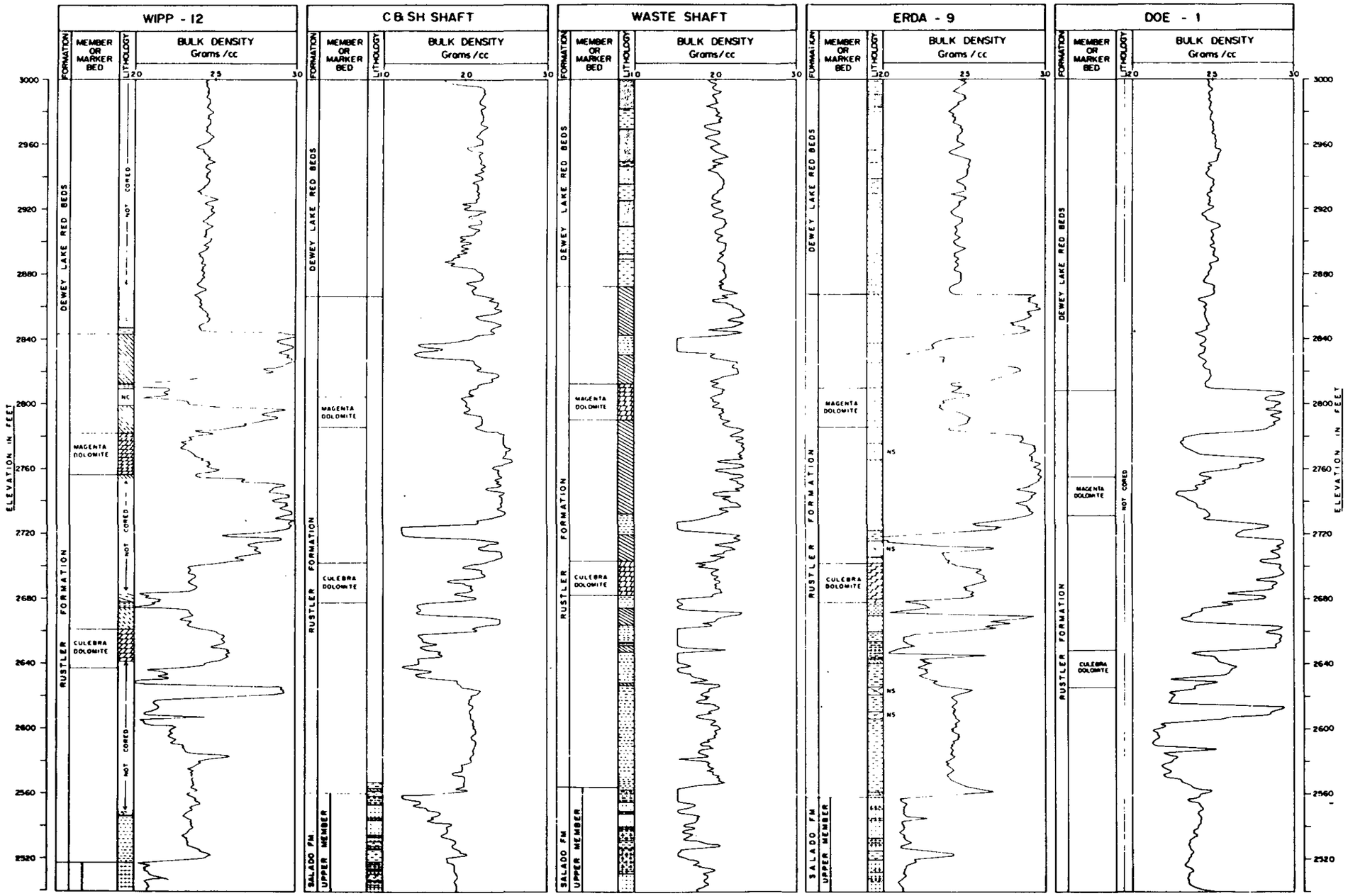

NOTE

See sheet 1 for explanation and key plan

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 2 OF 5

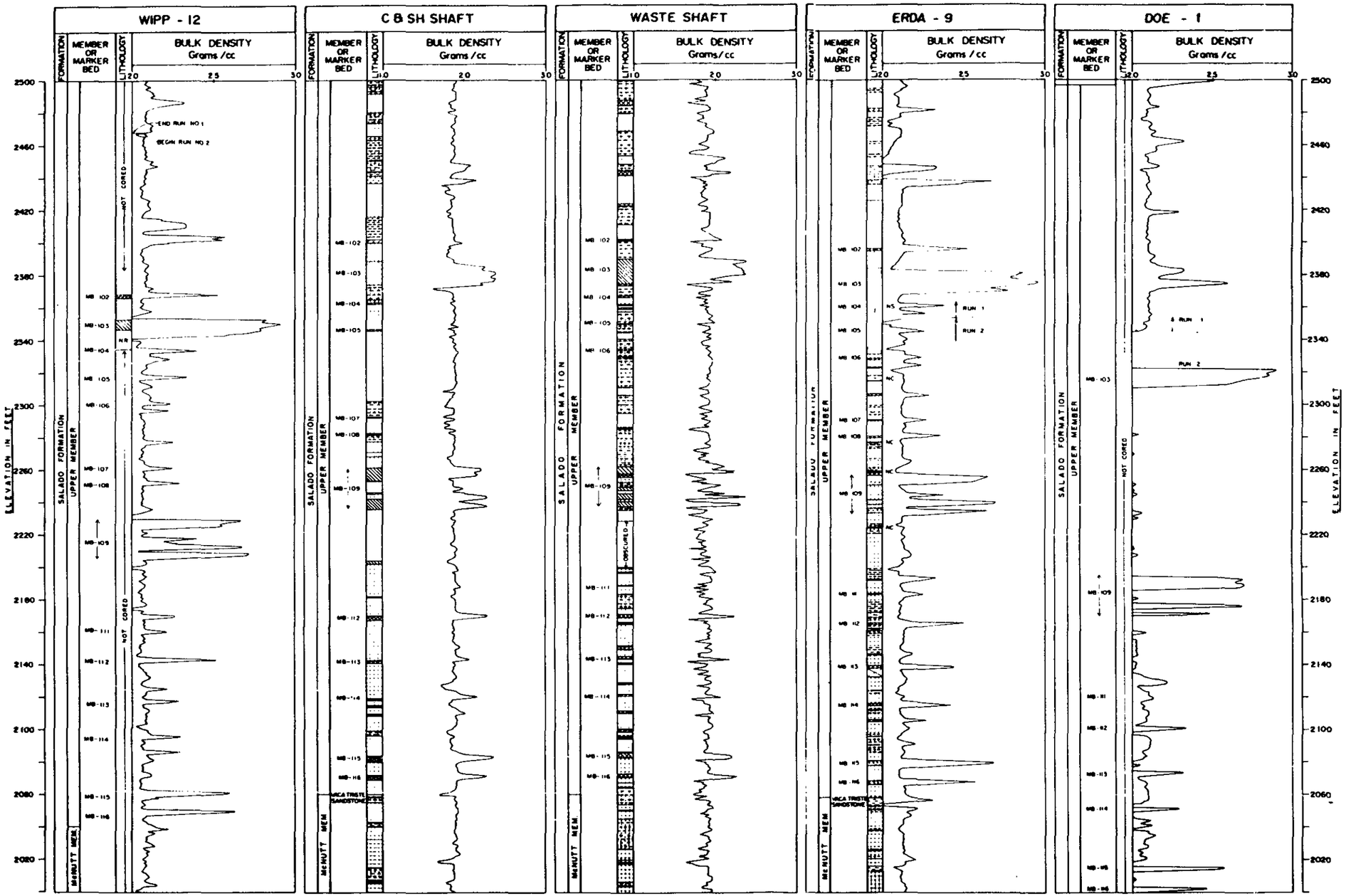

NOTE

See sheet 1 for explanation and key plan

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 3 OF 5

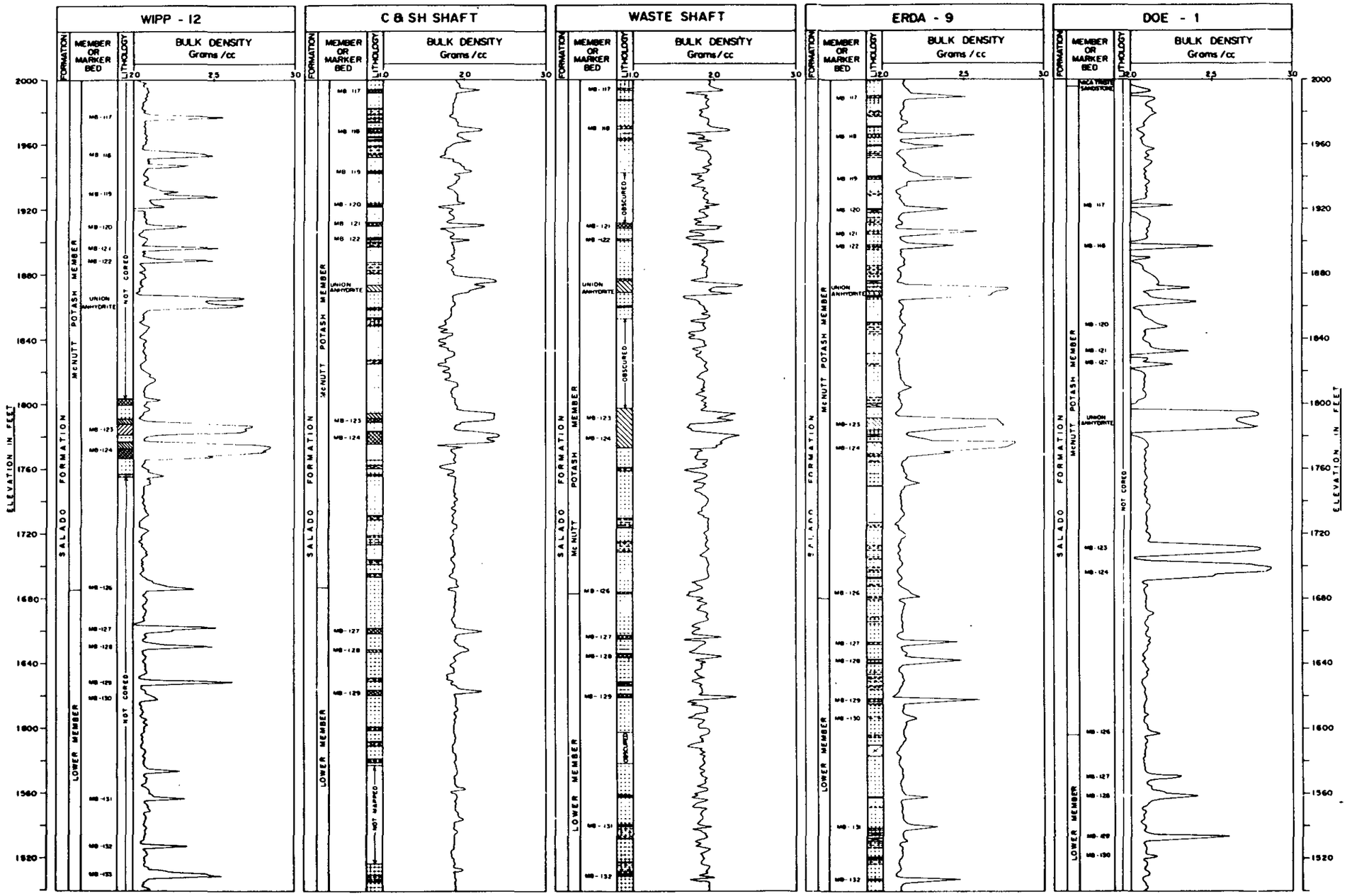

NOTE

See sheet 1 for explanation and key plan

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 4 OF 5

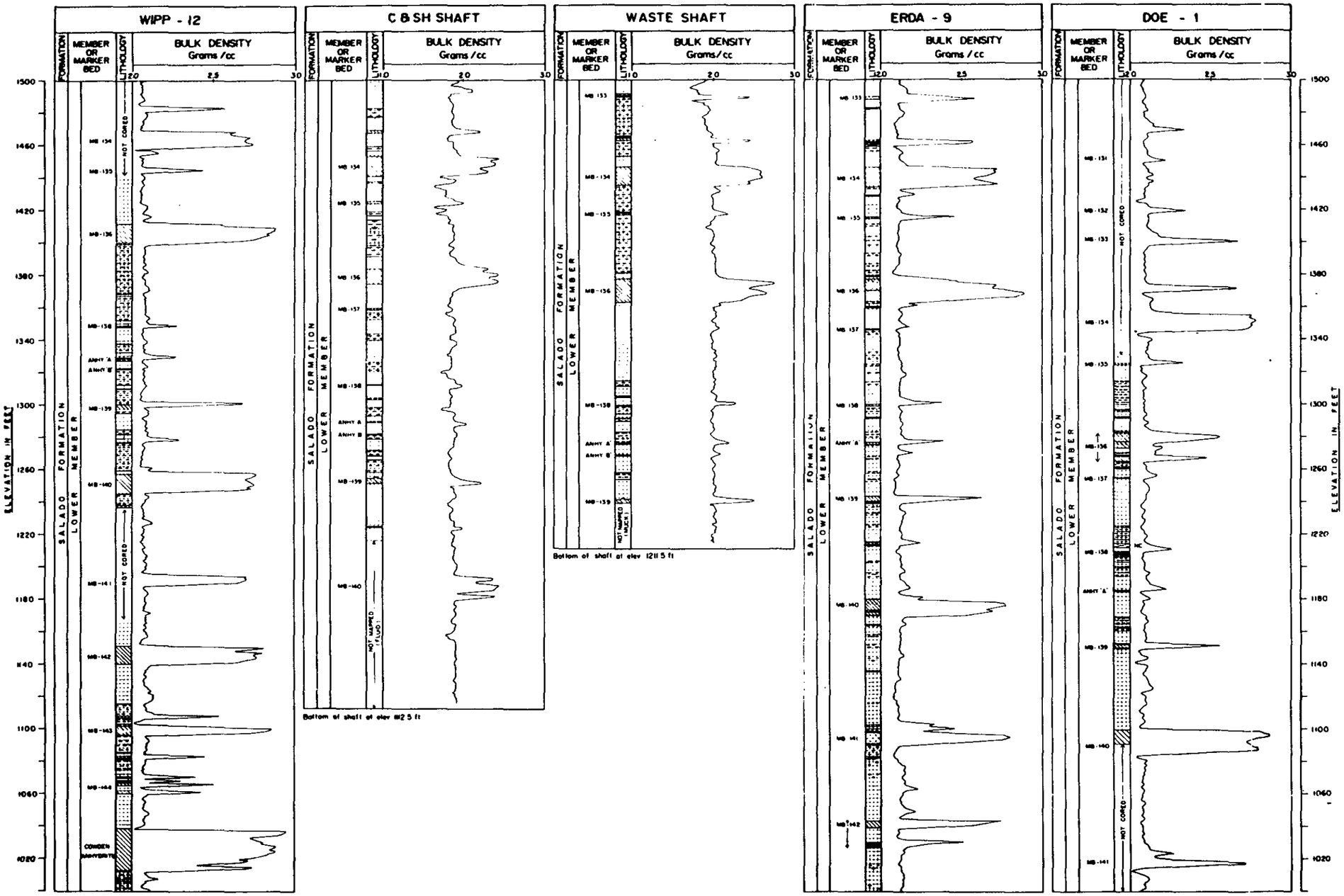

NOTE

See sheet 1 for explanation and key plan

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 5 OF 5

5

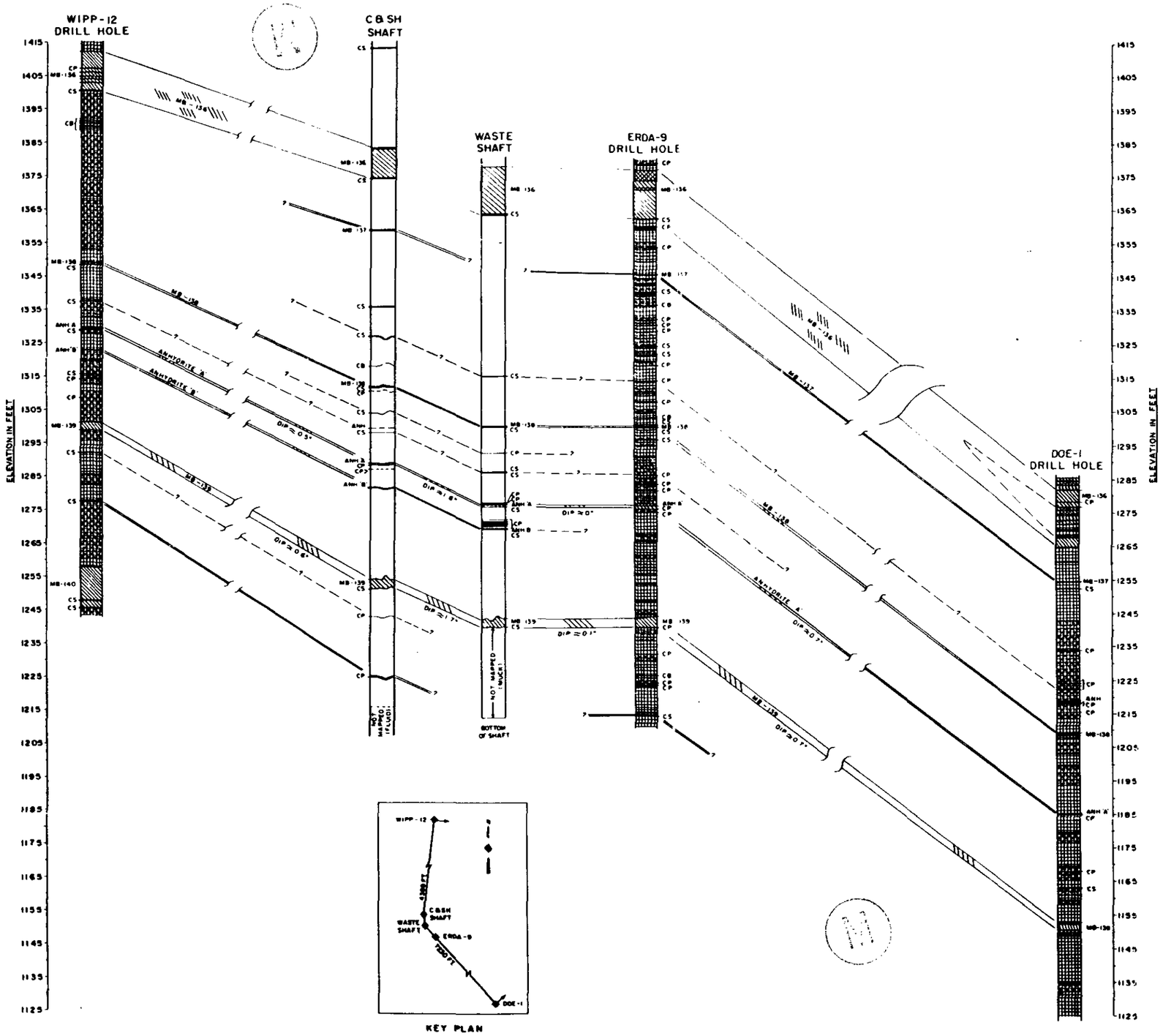

EXPLANATION

- Halite
- Argillaceous Halite
- Anhydrite
- Polyhalite
- Anhydritic Halite
- Clay Seam (CS)

CP = Clay Parting
CB = Clay Break
MB = Marker Bed
ANH = Anhydrite

NOTES:

1. Stratigraphic and lithologic descriptions for WIPP-12, ERDA-9, and DOE-1 based on geologic logging of rock core Descriptions for C&SH and waste shafts based on geologic mapping of shaft walls.
2. See Figure B-3 for detailed lithology of C&SH and waste shafts.
3. Polyhalite content of halite not shown
4. Dips shown are apparent and not true dips

REFERENCES:

1. Jones, C. L., Geologic Data for Borehole ERDA-9, 1981
2. U.S. Dept. of Energy, Basic Data Report for Borehole DOE-1, 1982.

FIGURE B-2

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1
FACILITY HORIZON AREA

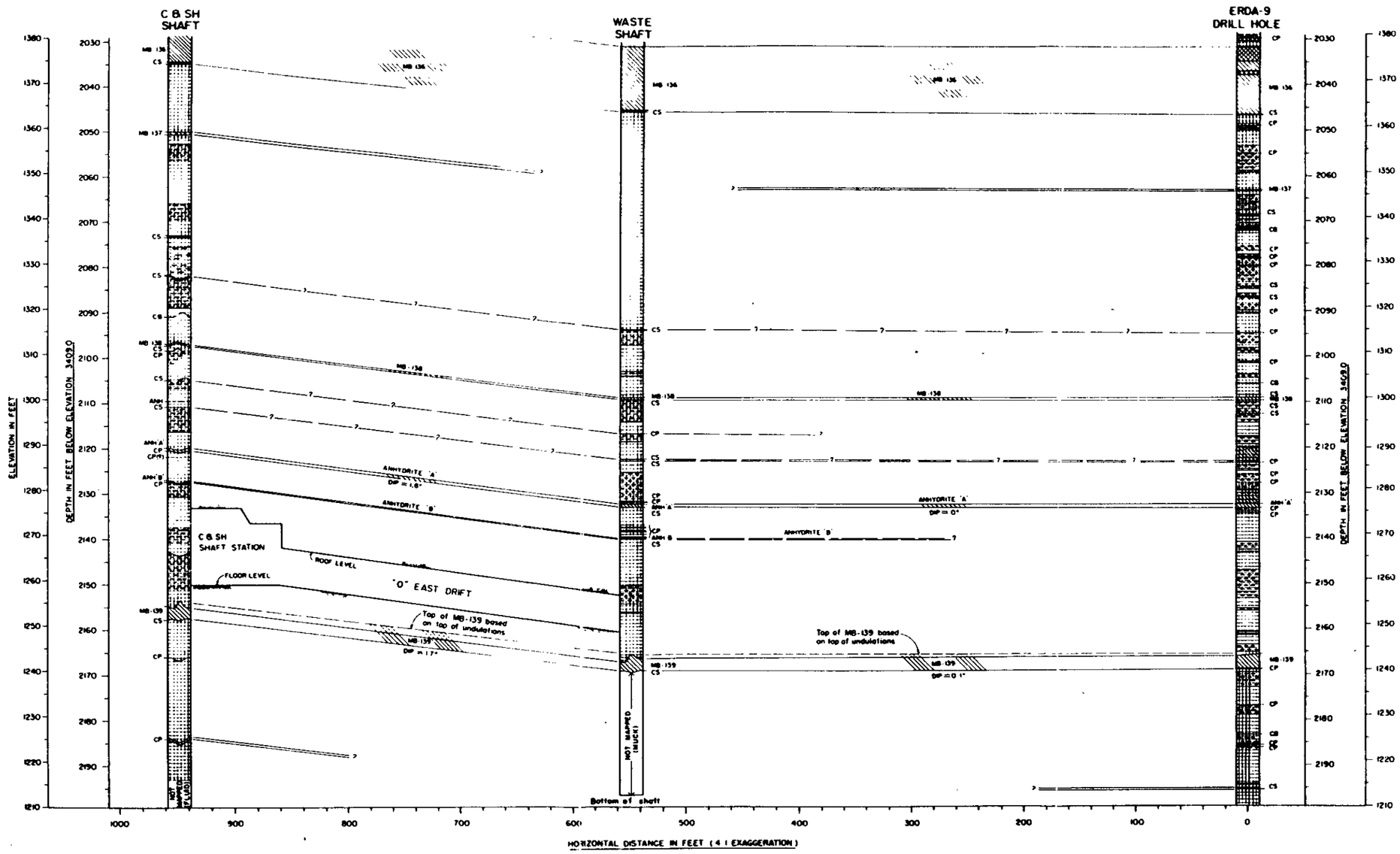

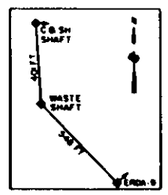

KEY PLAN

NOTES

1. Stratigraphy and lithologic descriptions for ERDA-9 based on geologic logging of rock core. Descriptions for C & SH and waste shafts based on geologic mapping of shaft walls.
2. See Figure B-2 for explanation of symbols and references
3. Polyhalite content of halite not shown
4. Dips shown are apparent and not true dips

FIGURE B-3

GEOLOGIC CORRELATION
C&SH SHAFT TO ERDA-9
FACILITY LEVEL AREA

The following descriptions pertain to the geologic map units shown in the drifts on Figures B-4, B-5 and B-8:

UNIT DESCRIPTIONS

UNIT 6[1] Halite: colorless with grayish orange-pink (1 OR 8/2)[2] tint; transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; unit extends into the roof; lower contact with Unit 5 is gradational and/or diffuse.

UNIT 5 Halite: colorless; transparent to translucent; coarsely crystalline; trace of bluish-white (5B 9/1) to light bluish-gray (5B 7/1) argillaceous material occurring as pods (1/2-inch diameter) and discontinuous laminations or filling interstices; lower contact with Unit 4 is generally sharp and based on prominent color change in argillaceous material (gray to red-brown) from Unit 5 to Unit 4.

UNIT 4 Argillaceous halite: colorless to moderate reddish-brown (1 OR 4/6), less frequently light bluish-gray (5B 7/1); transparent; coarsely crystalline; trace of dispersed polyhalite; trace to abundant argillaceous material (decreasing downward) consisting of clay containing a trace of silt and fine crystals of halite, occurring as discontinuous laminations in upper half of unit and interstitially in lower half; lower contact with Unit 3 is gradational and based on absence of argillaceous material in Unit 3.

UNIT 3 Halite: colorless to moderate reddish-orange (1 OR 6/6); transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; polyhalite content commonly increases downward; lower contact with Unit 2 is sharp.

UNIT 2 Argillaceous halite: moderate reddish-brown (1 OR 5/5), less frequently light bluish-gray (5B 7/1); medium to coarsely crystalline; argillaceous material primarily occurs interstitially or as discontinuous laminations; lower contact with Unit 1 is generally sharp, less frequently gradational.

UNIT 1 Halite: light reddish-orange (1 OR 8/6) to moderate reddish-orange (1 OR 6/6), less frequently colorless; translucent to transparent; medium to coarsely crystalline; trace of dispersed polyhalite; lower contact with Unit 0 is sharp.

UNIT 0 Argillaceous halite: colorless to moderate reddish-orange (1 OR 6/6) and moderate reddish-brown (1 OR 4/6); medium to coarsely crystalline; trace of dispersed polyhalite; some argillaceous material occurs as discontinuous laminations and blebs or fills interstices (decreasing downward); contains finely crystalline halite; unit extends into the floor.

NOTES:

(1) Units listed in descending order from roof to floor.

(2) Alpha-numeric color designations are based on Geological Society of America Rock Color Chart.

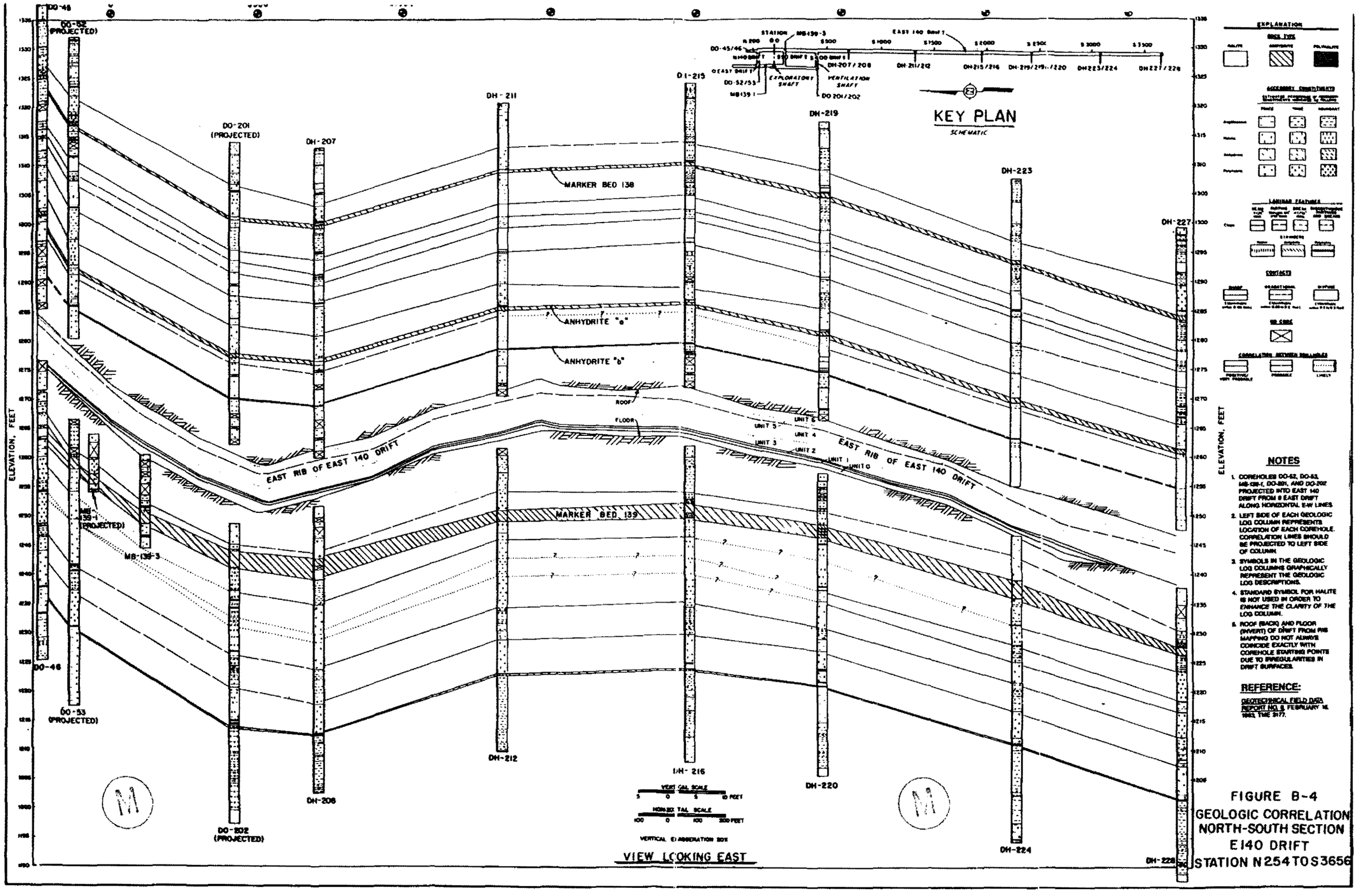

FIGURE B-4
GEOLOGIC CORRELATION
NORTH-SOUTH SECTION
E140 DRIFT
STATION N254 TO S3656

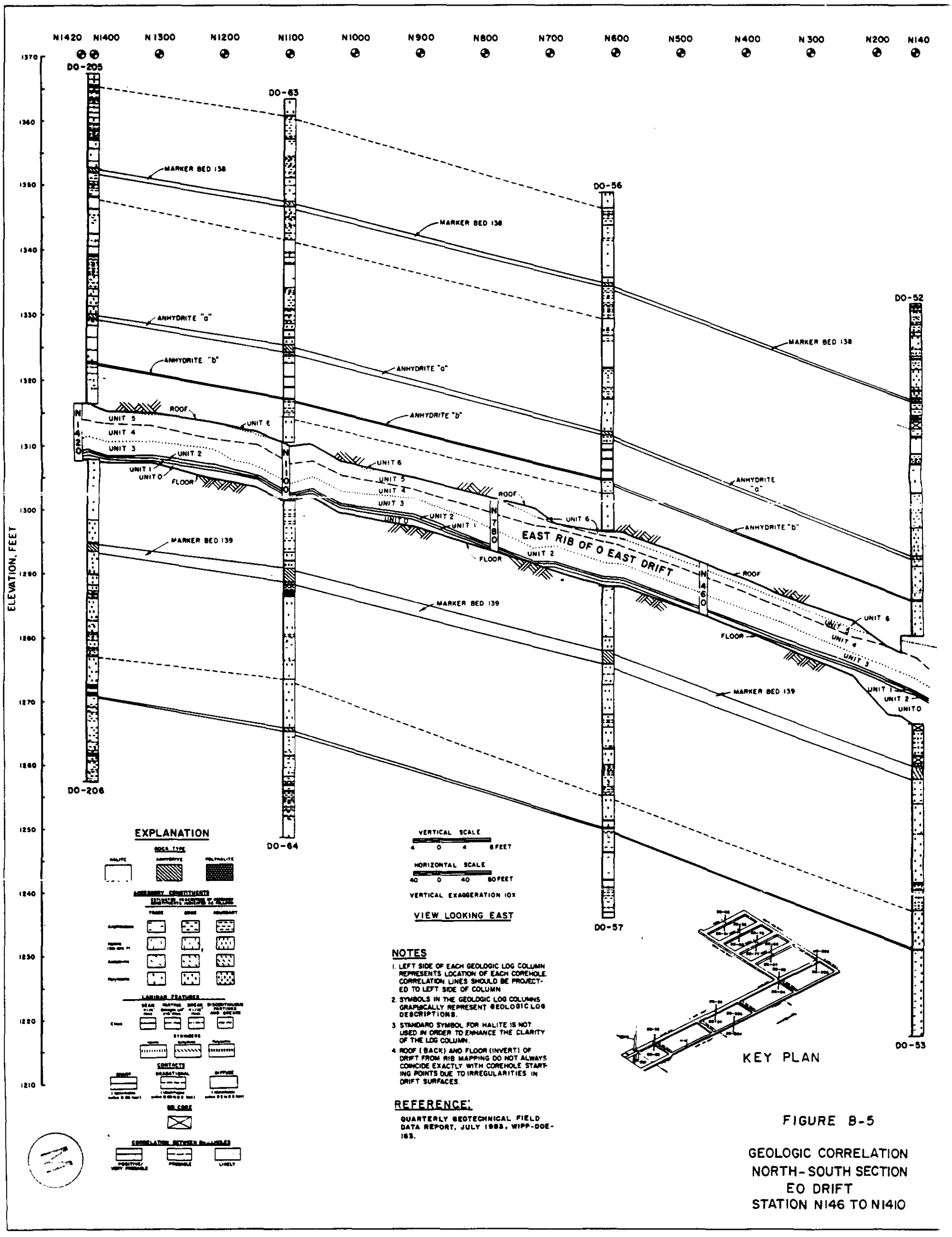

NOTES

1. LEFT SIDE OF EACH GEOLOGIC LOG COLUMN REPRESENTS LOCATION OF EACH COREHOLE. CORRELATION LINES SHOULD BE PROJECTED TO LEFT SIDE OF COLUMN
2. SYMBOLS IN THE GEOLOGIC LOG COLUMNS GRAPHICALLY REPRESENT GEOLOGIC LOG DESCRIPTIONS.
3. STANDARD SYMBOL FOR HALITE IS NOT USED IN ORDER TO ENHANCE THE CLARITY OF THE LOG COLUMN.
4. ROOF (BACK) AND FLOOR (INVERT) OF DRIFT FROM RIB MAPPING DO NOT ALWAYS COINCIDE EXACTLY WITH COREHOLE STARTING POINTS DUE TO IRREGULARITIES IN DRIFT SURFACES.

REFERENCE:

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-183.

FIGURE B-5

GEOLOGIC CORRELATION
NORTH-SOUTH SECTION
EO DRIFT
STATION N146 TO N1410

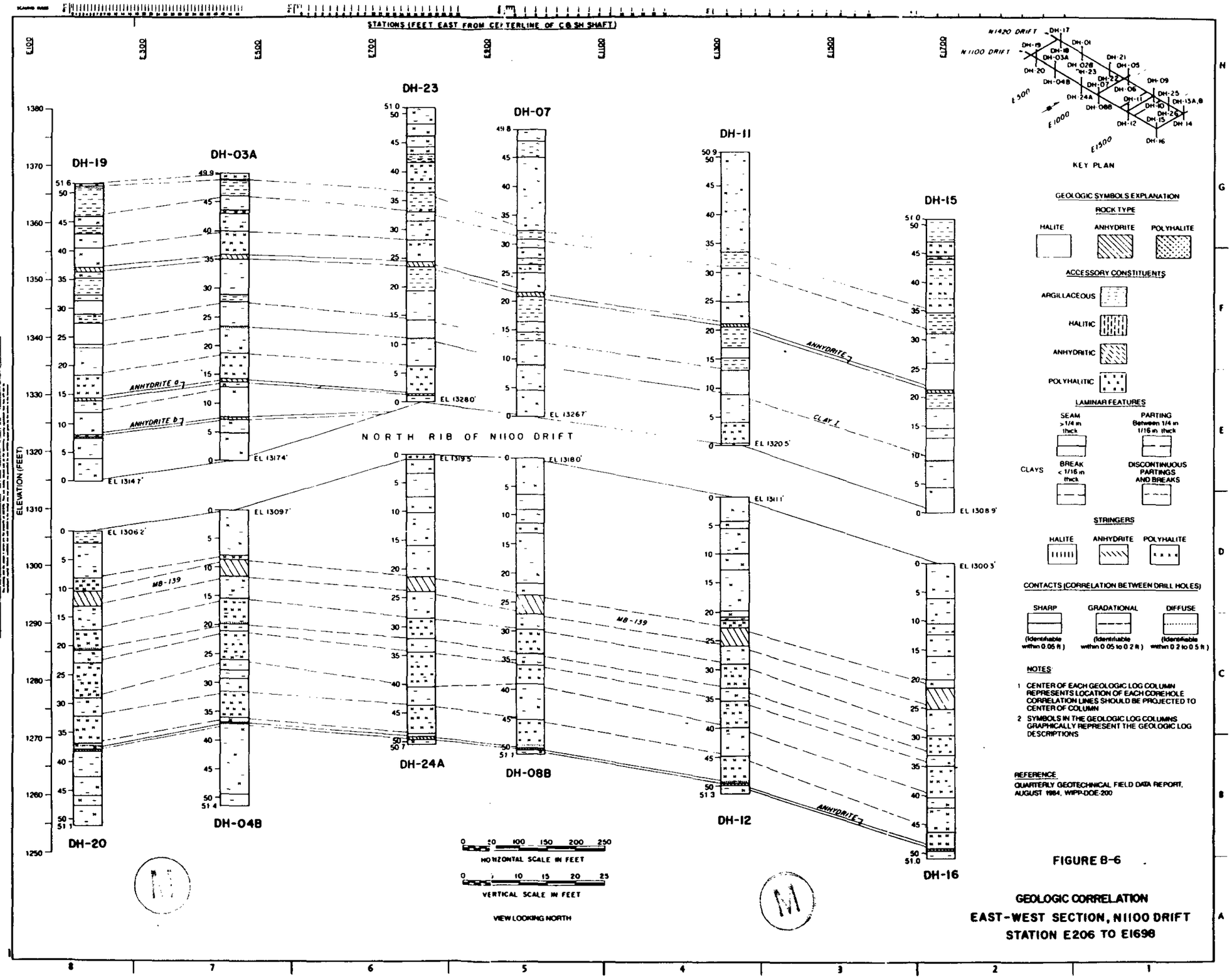
STATIONS (FEET EAST FROM CENTERLINE OF C&S SH SHAFT)
E100
E300
E500
E700
E900
E1100
E1300
E1500
E1700
ELEVATION (FEET)
1380
1370
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
DH-19
DH-03A
DH-23
DH-07
DH-11
DH-15
DH-20
DH-04B
DH-24A
DH-08B
DH-12
DH-16
ANHYDRITE a
ANHYDRITE b
MB-139
ANHYDRITE
CLAY I
EL 1314.7'
EL 1317.4'
EL 1328.0'
EL 1326.7'
EL 1320.5'
EL 1308.9'
EL 1306.2'
EL 1309.7'
EL 1319.5'
EL 1318.0'
EL 1311.1'
EL 1300.3'
NORTH RIB OF N1100 DRIFT
HORIZONTAL SCALE IN FEET
0 50 100 150 200 250
VERTICAL SCALE IN FEET
0 5 10 15 20 25
VIEW LOOKING NORTH
N1420 DRIFT
N1100 DRIFT
E500
E1000
E1500
KEY PLAN
GEOLOGIC SYMBOLS EXPLANATION
ROCK TYPE
HALITE
ANHYDRITE
POLYHALITE
ACCESSORY CONSTITUENTS
ARGILLACEOUS
HALITIC
ANHYDRITIC
POLYHALITIC
LAMINAR FEATURES
SEAM >1/4 in thick
PARTING Between 1/4 in 1/16 in thick
CLAYS
BREAK < 1/16 in thick
DISCONTINUOUS PARTINGS AND BREAKS
STRINGERS
HALITE
ANHYDRITE
POLYHALITE
CONTACTS (CORRELATION BETWEEN DRILL HOLES)
SHARP (Identifiable within 0.05 ft)
GRADATIONAL (Identifiable within 0.05 to 0.2 ft)
DIFFUSE (Identifiable within 0.2 to 0.5 ft)
NOTES:
1 CENTER OF EACH GEOLOGIC LOG COLUMN REPRESENTS LOCATION OF EACH COREHOLE CORRELATION LINES SHOULD BE PROJECTED TO CENTER OF COLUMN
2 SYMBOLS IN THE GEOLOGIC LOG COLUMNS GRAPHICALLY REPRESENT THE GEOLOGIC LOG DESCRIPTIONS
REFERENCE
QUARTERLY GEOTECHNICAL FIELD DATA REPORT, AUGUST 1984, WIPP-DOE-200
FIGURE 8-6
GEOLOGIC CORRELATION
EAST-WEST SECTION, N1100 DRIFT
STATION E206 TO E1698

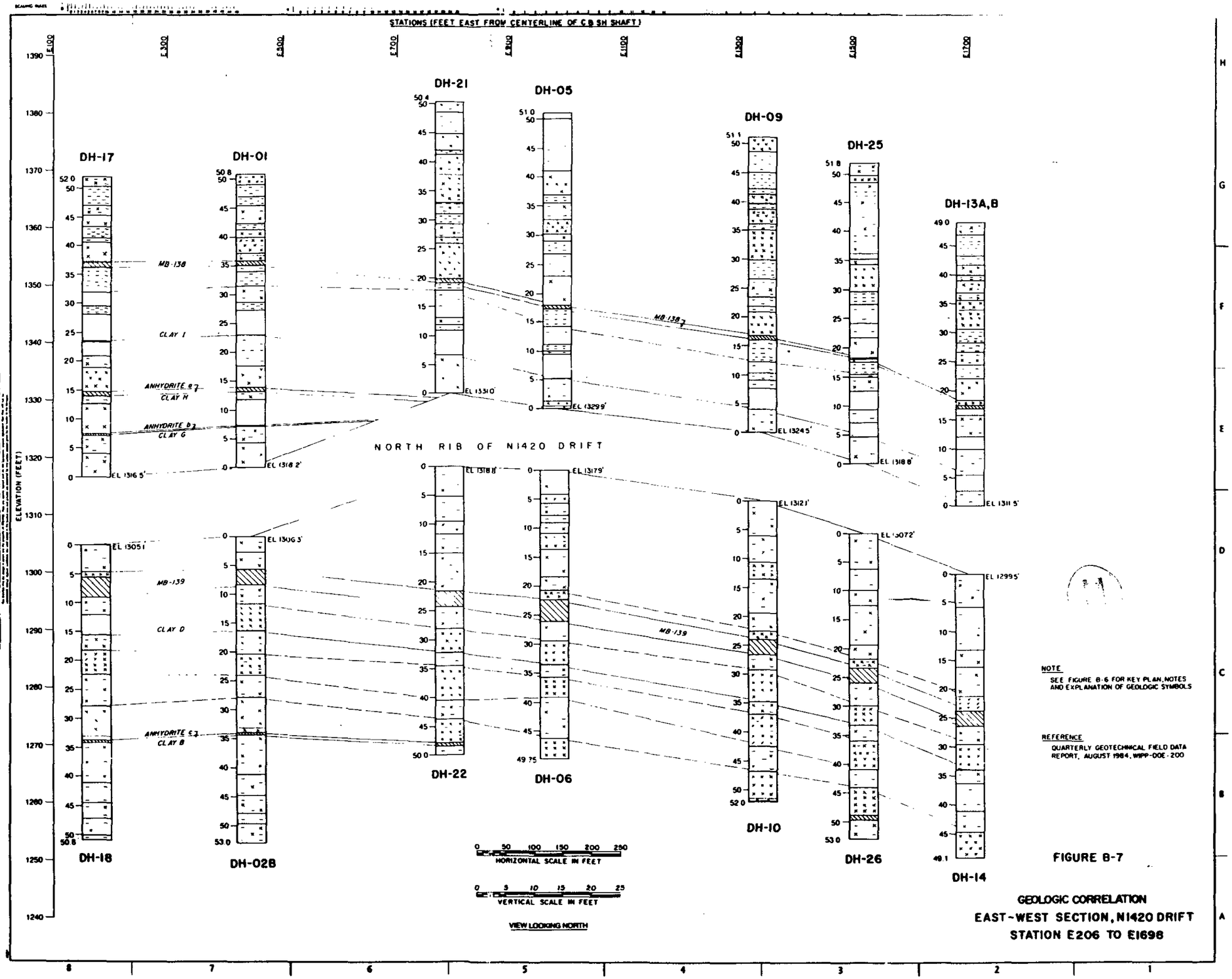
STATIONS (FEET EAST FROM CENTERLINE OF C & SH SHAFT)
E100
E300
E500
E700
E900
E1100
E1300
E1500
E1700
ELEVATION (FEET)
1390
1380
1370
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
1240
DH-17
DH-01
DH-21
DH-05
DH-09
DH-25
DH-13A,B
DH-18
DH-02B
DH-22
DH-06
DH-10
DH-26
DH-14
MB-138
CLAY I
ANHYDRITE a
CLAY H
ANHYDRITE b
CLAY G
MB-139
CLAY D
ANHYDRITE c
CLAY B
EL 1316.5'
EL 1318.2'
EL 1310'
EL 1329.9'
EL 1324.5'
EL 1318.8'
EL 1311.5'
EL 1305.1'
EL 1306.3'
EL 1318.8'
EL 1317.9'
EL 1312.1'
EL 1307.2'
EL 1299.5'
NORTH RIB OF N1420 DRIFT
0 50 100 150 200 250
HORIZONTAL SCALE IN FEET
0 5 10 15 20 25
VERTICAL SCALE IN FEET
VIEW LOOKING NORTH
NOTE
SEE FIGURE B-6 FOR KEY PLAN, NOTES AND EXPLANATION OF GEOLOGIC SYMBOLS
REFERENCE
QUARTERLY GEOTECHNICAL FIELD DATA REPORT, AUGUST 1984, WIPP-DOE-200
FIGURE B-7
GEOLOGIC CORRELATION
EAST-WEST SECTION, N1420 DRIFT
STATION E206 TO E1698

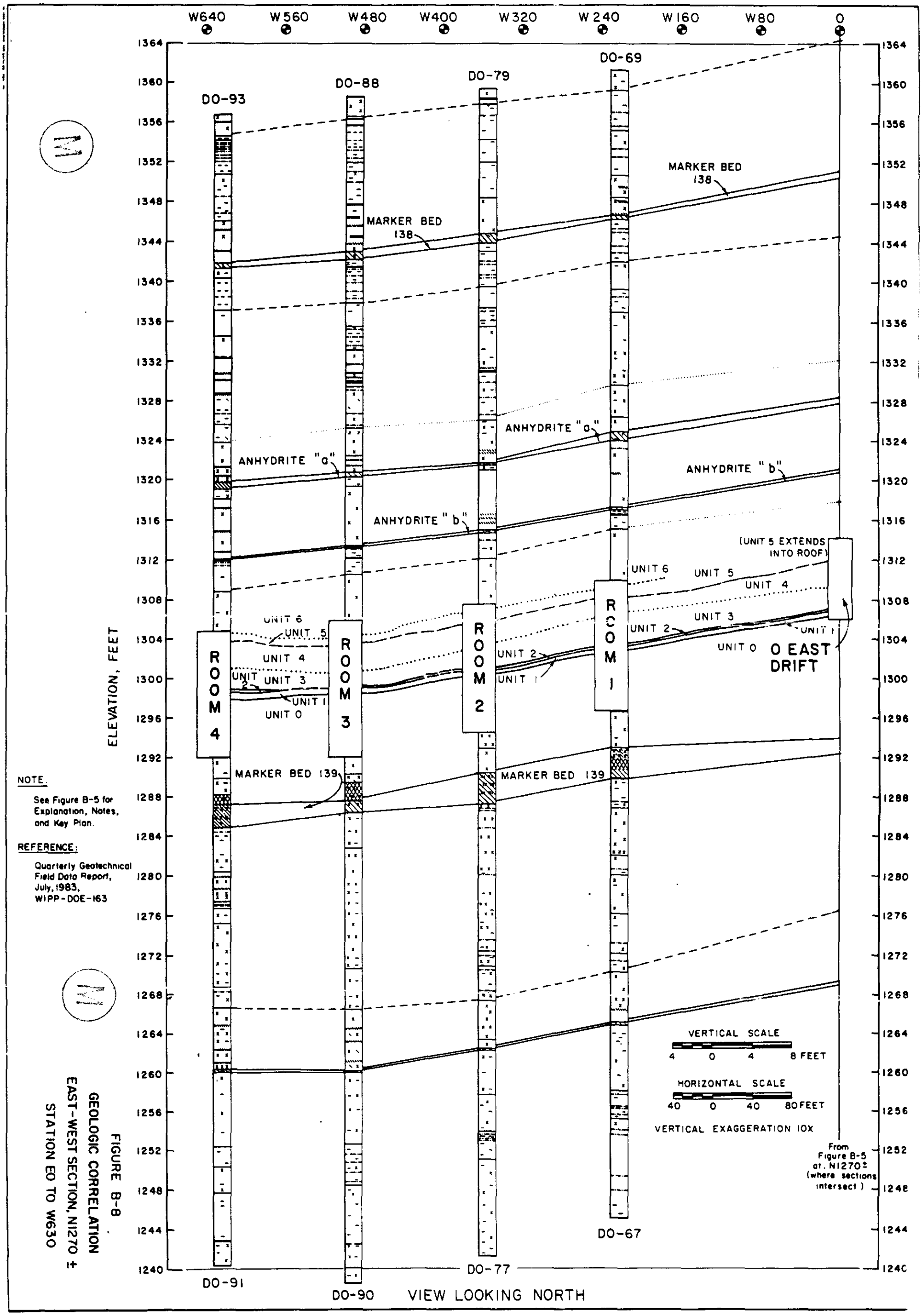

NOTE:

See Figure B-5 for Explanation, Notes, and Key Plan.

REFERENCE:

Quarterly Geotechnical Field Data Report, July, 1983, WIPP-DOE-163

FIGURE B-8

GEOLOGIC CORRELATION

EAST-WEST SECTION, N1270 ±

STATION E0 TO W630

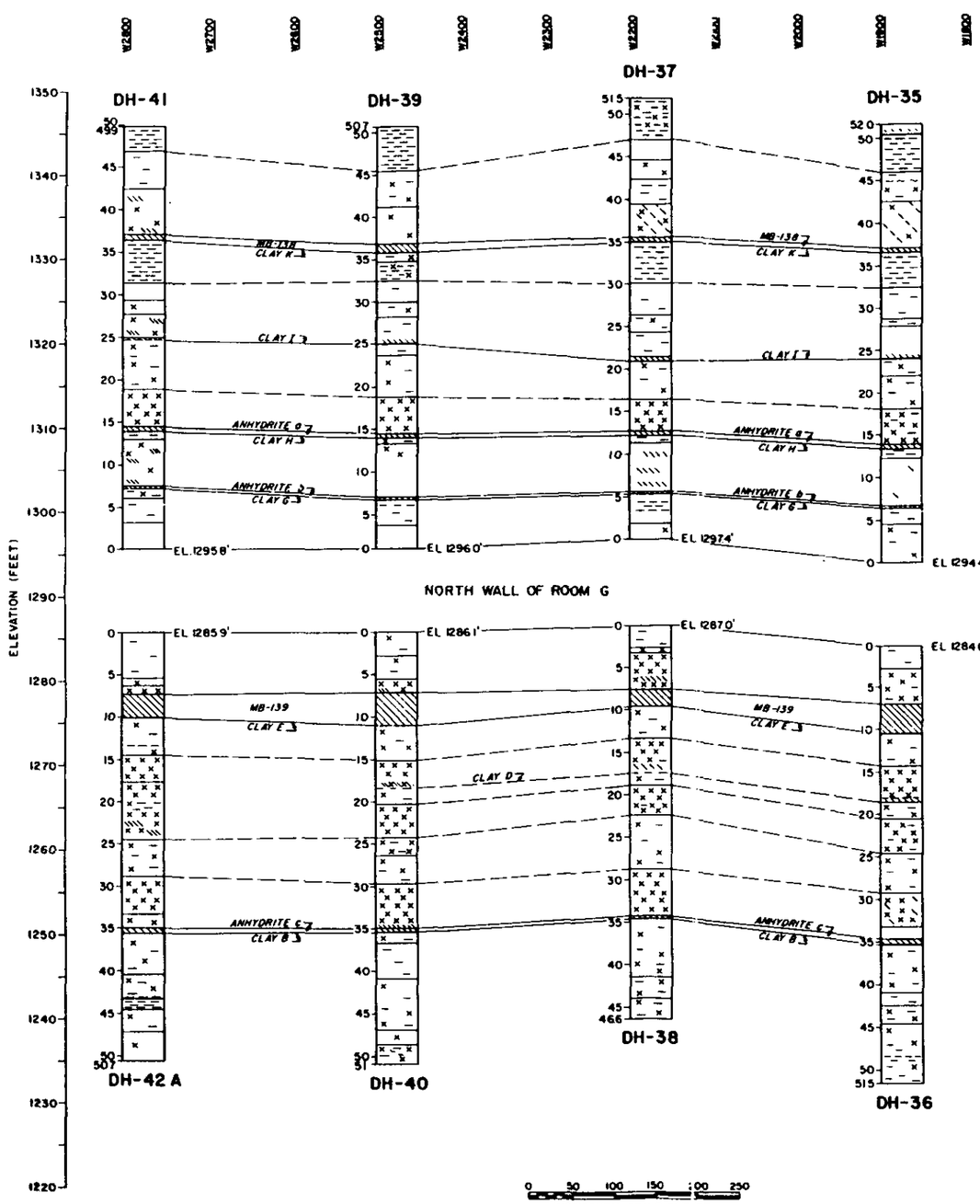

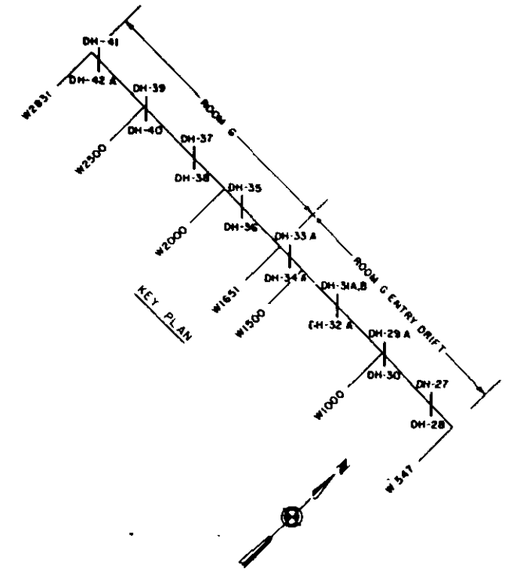

GEOLOGIC SYMBOLS EXPLANATION

ROCK TYPE

HALITE — ANHYDRITE

ACCESSORY CONSTITUENTS

ARGILLACEOUS

ANHYDRITIC

POLYHALITIC

LAMINAR FEATURES

DISCONTINUOUS PARTINGS AND BREAKS

STRINGERS

ANHYDRITE

CONTACTS (CORRELATION BETWEEN DRILL HOLES)

SHARP (identifiable within 0.05 ft.)

GRADATIONAL (identifiable within 0.05 to 0.2 ft.)

DIFFUSE (identifiable within 0.2 to 0.5 ft.)

NOTES:

1. CENTER OF EACH GEOLOGIC LOG COLUMN REPRESENTS LOCATION OF EACH COREHOLE. CORRELATION LINES SHOULD BE PROJECTED TO CENTER OF COLUMN
2. SYMBOLS IN THE GEOLOGIC LOG COLUMNS GRAPHICALLY REPRESENT THE GEOLOGIC LOG DESCRIPTIONS

REFERENCE:

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JUNE 1985, WIPP-DOE-213.

FIGURE B-9

GEOLOGIC CORRELATION EAST-WEST SECTION, N 1100 DRIFT STATION W682 TO W2782

SHEET 1 OF 2

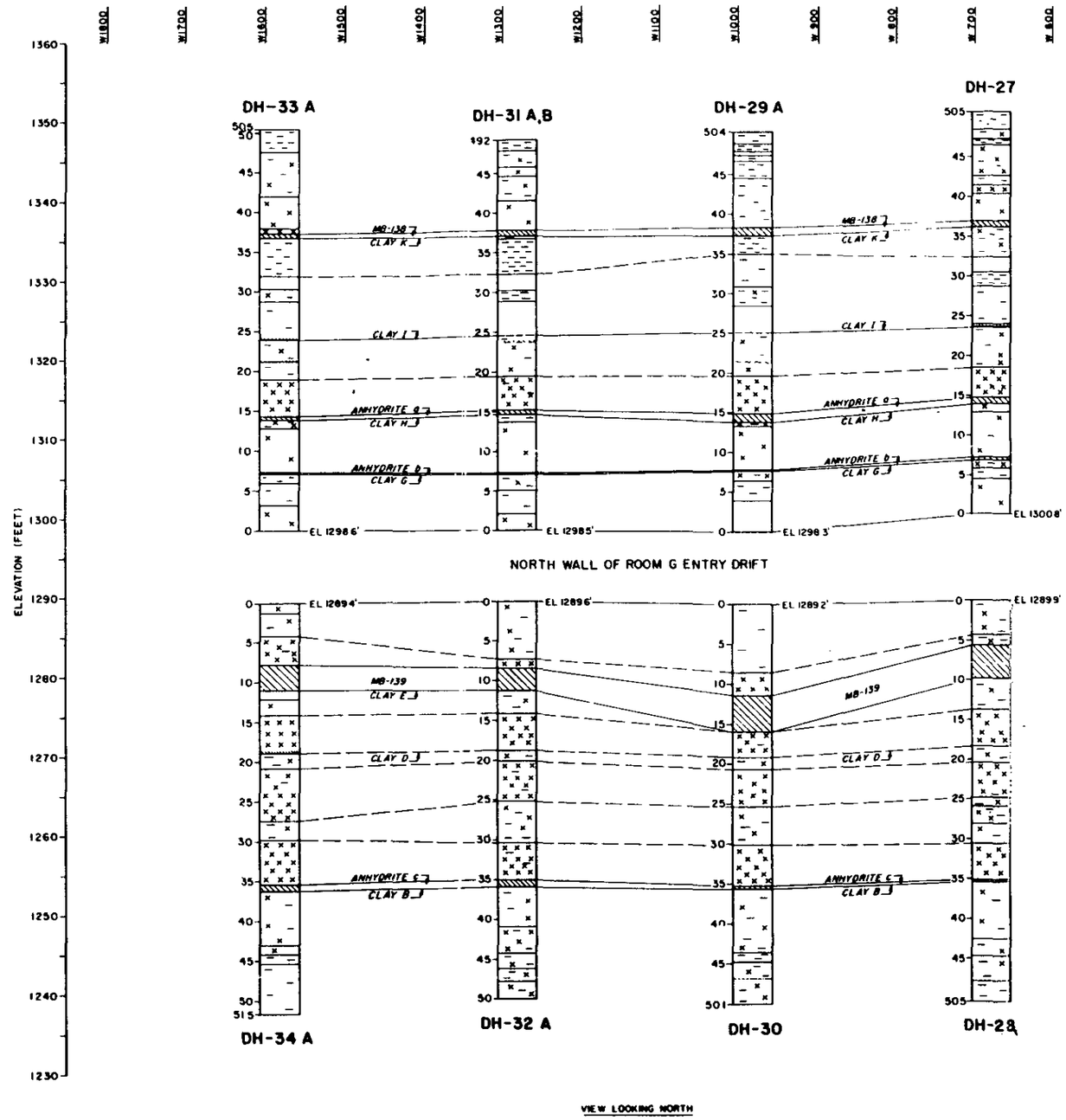

NOTE:
SEE SHEET 1 FOR NOTES AND EXPLANATION OF GEOLOGIC SYMBOLS

REFERENCE
SEE SHEET 1

0 50 100 150 200 250
HORIZONTAL SCALE IN FEET

0 5 10 15 20 25
VERTICAL SCALE IN FEET

FIGURE B-9

GEOLOGIC CORRELATION
EAST-WEST SECTION, N1100 DRIFT
STATION W682 TO W2782

SHEET 2 OF 2

APPENDIX C

MATHEMATICAL SIMULATION OF UNDERGROUND IN SITU BEHAVIOR

CONTENTS

Section	Title
C.1	INTRODUCTION
C.2	MATERIAL BEHAVIOR OF HOST ROCKS
C.3	FORMULATION OF GOVERNING EQUATIONS
C.4	NORMALIZATION OF GOVERNING EQUATIONS
C.5	DETERMINATION OF CREEP CONSTANTS
C.6	PREDICTION OF STRUCTURAL BEHAVIOR
C.7	CONCLUSIONS

Figure No.	Title/Description
C-1	Time Response Relationship of the Normalized Creep Analysis Method
C-2	Graphical Representation of Creep Constants Relating Time Domains
C-3	Comparison of Analytical Results and In Situ Responses for Various Data Point Sets
C-4	Comparison of Analytical Results and In Situ Response for Various Instrument Offset Values

APPENDIX C

MATHEMATICAL SIMULATION OF UNDERGROUND IN SITU BEHAVIOR

C.1 INTRODUCTION

The methodology described in the following sections presents analytical techniques for simulating underground behavior in salt formations. Consideration is given to time-dependent non-linear material behavior and incorporation of in situ measurements to predict structural responses. The theoretical background and procedures presented by this methodology are explained.

C.2 MATERIAL BEHAVIOR OF HOST ROCKS

The most significant physical property of halite is that it creeps. Its creep behavior is dependent upon the variations of stress and temperature with respect to time. The creep phenomenon is also affected by the physical properties of the geologic strata adjacent to the halite and by discontinuities in the geologic layers. Therefore, non-halitic interbeds and clay seams should also be considered when modeling and simulating the structural behavior of salt formations. The following subsections summarize the material behavior of various host rocks (ref. C-1).

C.2.1 Halitic Materials

The constitutive equation for halitic materials can be expressed as:

$$\dot{\varepsilon}_{ij} = -\frac{\nu}{E}\dot{\sigma}_{kk}\,\delta_{ij} + \frac{1+\nu}{E}\,\dot{\sigma}_{ij} + \dot{\varepsilon}^{c}_{ij} \qquad \text{(C.2-1)}$$

where: $\dot{\varepsilon}_{ij}$ are the components of the strain tensor;

ν is Poisson's ratio;

E is Young's modulus;

δ_{ij} is the Kronecker delta;

$\dot{\sigma}_{ij}$ are the components of the stress tensor; and

the creep strain rate, $\dot{\varepsilon}^c_{ij}$, is given by:

$$\dot{\varepsilon}^c_{ij} = |\dot{\varepsilon}^c_{kl}| \frac{\sigma'_{ij}}{|\sigma'_{mn}|} \qquad \text{(C.2-2)}$$

where: σ'_{ij} are the components of the deviatoric stress tensor.

The magnitude of the creep strain rate can be expressed in terms of the effective creep strain rate, ε, or the effective stress, σ. Thus,

$$|\dot{\varepsilon}^c_{ij}| = \sqrt{1.5}\ \dot{\bar{\varepsilon}} \qquad \text{(C.2-3)}$$

where the effective strain rate $\dot{\bar{\varepsilon}}$ is defined as:

$$\dot{\bar{\varepsilon}} = \left(\frac{2}{3} \dot{\varepsilon}^c_{ij}\ \dot{\varepsilon}^c_{ij} \right)^{1/2} \qquad \text{(C.2-4)}$$

which is the sum of the primary and secondary creep strain rates, namely

$$\dot{\bar{\varepsilon}} = \dot{\varepsilon}_p + \dot{\varepsilon}_s \qquad \text{(C.2-5)}$$

where the primary creep strain rate is defined as:

$$\dot{\varepsilon}_p = (A - B\ \varepsilon_p)\ \dot{\varepsilon}_s \qquad \text{for } \dot{\varepsilon}_s \geq \dot{\varepsilon}^*$$

and (C.2-6)

$$\dot{\varepsilon}_p = (A - B\ \frac{\dot{\varepsilon}^*}{\dot{\varepsilon}_s} \varepsilon_p)\ \dot{\varepsilon}_s \qquad \text{for } \dot{\varepsilon}_s < \dot{\varepsilon}^*$$

where $\dot{\varepsilon}_s$ can be defined by an exponential law

$$\dot{\varepsilon}_s = D\ \sigma^{-n}\ e^{-Q/R\Theta} \qquad \text{(C.2-7)}$$

and $\bar{\sigma} = \left(\frac{3}{2} \sigma'_{ij}\ \sigma'_{ij} \right)^{1/2}$ is the effective stress;

$\dot{\varepsilon}^*$, A and B are primary creep constants;

D and n are secondary creep constants;

Θ is temperature in Kelvin;

Q is the effective activation energy in cal/mole; and

R is the universal gas constant, 1.987 cal/mole-K.

C.2.2 Non-halitic Materials

In the underground facility horizon at the WIPP site, certain portions of the rock are non-halitic. The stress-strain relationship for non-halitic materials is assumed to follow the Prandtl-Reuss constitutive equation:

$$\dot{\varepsilon}_{ij} = -\frac{\nu}{E}\dot{\sigma}_{kk}\delta_{ij} + \frac{1+\nu}{E}\dot{\sigma}_{ij} + \dot{\varepsilon}^{P}_{ij} \qquad \text{(C.2-8)}$$

The plastic behavior is defined by the two-dimensional Mohr-Coulomb criterion:

$$\sigma_3 - \sigma_1 = 2\Theta_0\cos\beta - (\sigma_3 + \sigma_1)\sin\beta \qquad \text{(C.2-9)}$$

and the Drucker-Prager criterion, which is the generalized form of the Mohr-Coulomb criterion:

$$\sqrt{J_2'} = c - aJ_1 \qquad \text{(C.2-10)}$$

where: σ_3 and σ_1 are the two principal stresses, which are positive in tension;

Θ_0, β, c and a are the plastic constants;

$\sqrt{J_2'}$ is the second deviatoric stress invariant; and

J_1 is the first stress invariant.

The numerical modeling does not include failure criterion for the non-halitic materials. Anhydrite is assumed to be linearly elastic.

C.2.3 Clay Seams

Thin seams of clay are present between some of the rock layers. These clay seams can allow relative slippage and separation of the layers across the clay seams. The slippage of the clay seams follows a dry friction law:

$$\sigma_{12} = \mu \, |\sigma_{11}| \qquad \text{(C.2-11)}$$

where: μ is the frictional coefficient; direction 1 of the stress is normal to the plan of the seam; and direction 2 of the stress is in the direction of motion or incipient motion.

C.3 FORMULATION OF GOVERNING EQUATIONS

The underground behavior of salt can be determined by solving the following governing equations:

(1) Equation of equilibrium:

$$\sigma_{ij,j} + X_i = 0 \qquad \text{(C.3-1)}$$

where: σ_{ij} is the stress tensor; and

X_i is the body force vector.

(2) Strain-rate velocity relation:

$$2\dot{\varepsilon}_{ij} = \dot{u}_{i,j} + \dot{u}_{j,i} \qquad \text{(C.3-2)}$$

where: $\dot{\varepsilon}_{ij}$ is the strain rate tensor;

$\dot{u}_i$ is the velocity vector; and

$(\dot{\ })$ represents the derivative of ( ) with respect to time t.

(3) Stress strain relations:

<u>halitic materials</u>

$$\dot{\varepsilon}_{ij} = -\frac{\nu}{E}\dot{\sigma}_{kk}\delta_{ij} + \frac{1+\nu}{E}\dot{\sigma}_{ij} + \dot{\varepsilon}^{c}_{ij} \qquad \text{(C.3-3)}$$

where: $\dot{\varepsilon}^{c}$ is defined in subsection C.2.1.

<u>non-halitic materials</u>

$$\dot{\varepsilon}_{ij} = -\frac{\nu}{E}\dot{\sigma}_{kk}\delta_{ij} + \frac{1+\nu}{E}\dot{\sigma}_{ij} + \dot{\varepsilon}^{P}_{ij} \qquad \text{(C.3-4)}$$

(4) Boundary conditions:

$$\dot{u}_i = \dot{U}_i \qquad \text{over } S_u \qquad \text{(C.3-5)}$$

$$\sigma_{ij} n_j = T_i \qquad \text{over } S_\sigma \qquad \text{(C.3-6)}$$

where: S_u is the surface on which $\dot{u}_i$ is specified as U_i and S_σ is the surface on which the traction vector $\sigma_{ij} n_j$ is specified as T_i where n_j is the component of the outward-pointing unit normal vector.

C.4 NORMALIZATION OF GOVERNING EQUATIONS

In order to determine the creep properties of halite, the governing equations in Section C.3 need to be solved before knowing the values of the creep constants. This can be achieved by normalizing the governing equations to the creep function and solving the normalized equations. The creep constants can then be determined by correlating the analytical results with in situ data.

Consider the creep behavior of halitic material follows a power law:

$$\dot{\varepsilon} = F\,\sigma^{-n} \qquad \text{(C.4-1)}$$

where: F is a creep function.

The governing equations in Section C.2 can be normalized to F by transforming to a normalized time domain in terms of time t* such that:

$$dt^* = F\,dt \qquad \text{(C.4-2)}$$

By substituting equation (C.4-2) into equations (C.3-1) through (C.3-6), a system of normalized equations can be formed:

(1) Equation of equilibrium:

$$\sigma_{ij,j} + X_i = 0 \qquad \text{(C.4-3)}$$

(2) Strain-rate velocity relation:

$$2\dot{\varepsilon}^*_{ij} = \dot{u}^*_{i,j} + \dot{u}^*_{j,i} \qquad \text{(C.4-4)}$$

where: $(\dot{\ }^*)$ represents the derivative of ( ) with respect to the normalized time t*.

(3) Stress strain relations:

<u>halitic materials</u>

$$\dot{\varepsilon}^*_{ij} = -\frac{\upsilon}{E}\,\dot{\sigma}^*_{kk}\,\delta_{ij} + \frac{1+\upsilon}{E}\,\dot{\sigma}^*_{ij} + \dot{\varepsilon}^{*c}_{ij} \qquad \text{(C.4-5)}$$

$$\text{where:}\quad \dot{\varepsilon}^*_s = \sigma^{-n} \qquad \text{(C.4-6)}$$

<u>non-halitic materials</u>

$$\dot{\varepsilon}^*_{ij} = -\frac{\upsilon}{E}\,\dot{\sigma}^*_{kk}\,\delta_{ij} + \frac{1+\upsilon}{E}\,\dot{\sigma}^*_{ij} + \dot{\varepsilon}^{*p}_{ij} \qquad \text{(C.4-7)}$$

(4) Boundary conditions:

$$\dot{u}^*_i = \dot{U}^*_i \qquad \text{over } S_u \qquad \text{(C.4-8)}$$

where: $\dot{U}^*_i$ is computed as $\dot{U}^*_i = U_i/F$

$$\sigma_{ij}n_j = T_i \qquad \text{over } S_\sigma \qquad \text{(C.4-9)}$$

The above normalized governing equations are similar to the governing equations before normalization, except that the time derivatives in the normalized equations are taken with respect to normalized time t*, and the creep function F has been eliminated. Since the normalized governing equations have the same form as the governing equations before normalization, a conventional method such as the finite element technique can be used to solve the normalized governing equations for the analytical results in terms of normalized time t*, without knowing the creep function F.

After obtaining the normalized analytical result, the creep function F can be determined for establishing the relationship between the real and the normalized time domains. From Equations (C.2-5) through (C.2-7), the function F can be expressed as:

$$F = [f(\varepsilon_p, \dot{\varepsilon}_s) + 1]C \qquad \text{(C.4-10)}$$

where: $C = D\, e^{-Q/R\Theta}$; *A is defined in equation (C.2-6); D, Q, R and* Θ are defined in equation (C.2-7); and $f(\varepsilon_p, \varepsilon_s)$ represents the portion inside the parentheses of equation (C.2-6), which is expressed as:

$$f(\varepsilon_p, \dot{\varepsilon}_s) = A - B\,\varepsilon_p \qquad \text{for } \dot{\varepsilon}_s \geq \dot{\varepsilon}^*$$

and (C.4-11)

$$f(\varepsilon_p, \dot{\varepsilon}_s) = A - B\,\frac{\dot{\varepsilon}^*}{\dot{\varepsilon}_s}\varepsilon_p \qquad \text{for } \dot{\varepsilon}_s < \dot{\varepsilon}^*$$

From equation (C.4-11), it can be found that at time $t = 0$, $\varepsilon_p = 0$, which provides an initial condition:

$$f(\varepsilon_p, \dot{\varepsilon}_s) = A \qquad \text{for } t = 0 \qquad \text{(C.4-12)}$$

When the time t approaches the steady state stage t_s, primary creep is no longer active. Therefore:

$$f(\varepsilon_p, \dot{\varepsilon}_s) \rightarrow 0 \qquad \text{for } t \rightarrow t_s \qquad \text{(C.4-13)}$$

since the primary creep decreases exponentially with time (ref. C-1). Based on the auxiliary conditions (C.4-12) and (C.4-13), the function f can be expressed as an exponential function:

$$f = A\, e^{-zt} \qquad \text{(C.4-14)}$$

By substituting equation (C.4-14) into equation (C.4-1), function F can be written as:

$$F = [A\ e^{-zt} + 1]C \qquad \text{(C.4-15)}$$

where: the constants C, A and z can be determined from in situ data.

The relationship between the real time domain and the normalized time domain can then be obtained by integrating equation (C.4-2):

$$t^* = \int_0^t F\ dt \qquad \text{(C.4-16)}$$

Substituting equation (C.4-15) into equation (C.4-16) and using the initial condition $t^* = 0$, when $t = 0$, equation (C.4-16) becomes:

$$t^* = C\ [t + A/z\ (1 - e^{-zt})] \qquad \text{(C.4-17)}$$

After determining the creep constants, the analytical results can then be mapped from the normalized time domain to the real time domain using equation (C.4-17).

C.5 DETERMINATION OF CREEP CONSTANTS

The computational method can also be considered as a two-phased process which allows structural responses to be determined for any time in question. The first phase is a transformation from the real to the normalized time domain by use of parametric equations containing creep constants. The second phase is relating a structural response to that the normalized time by performing a structural analysis. The fundamental relationship can be represented graphically as shown on Figure C-1. The upper curve indicates the expression relating the two time domains which depends on the creep constants C, A and z. The double vertical axes represent the relationship between the normalized time t* and response as indicated by the results of the structural analysis.

The terms A and z represent primary creep constants that can be viewed in a number of ways. By themselves, 'A' relates the ratio of initial to steady-state creep rates and 'z' corresponds to the primary creep decay constant. A simplified relationship can be used utilizing only the ratio of A to z when the term inside the parentheses in equation (C.4-15) approaches unity in the steady-state period. As Figure C-2 indicates, the value of A/z (also identified as t_o) represents a real time offset such that the following equation can be used:

$$t^* = C\ (t + A/z) \qquad \text{(C.5-1)}$$

A Salt Creep Constant Evaluation computer program (SCCE, Bechtel computer program CE 465) was developed for the purpose of evaluating the creep constants from in situ data.

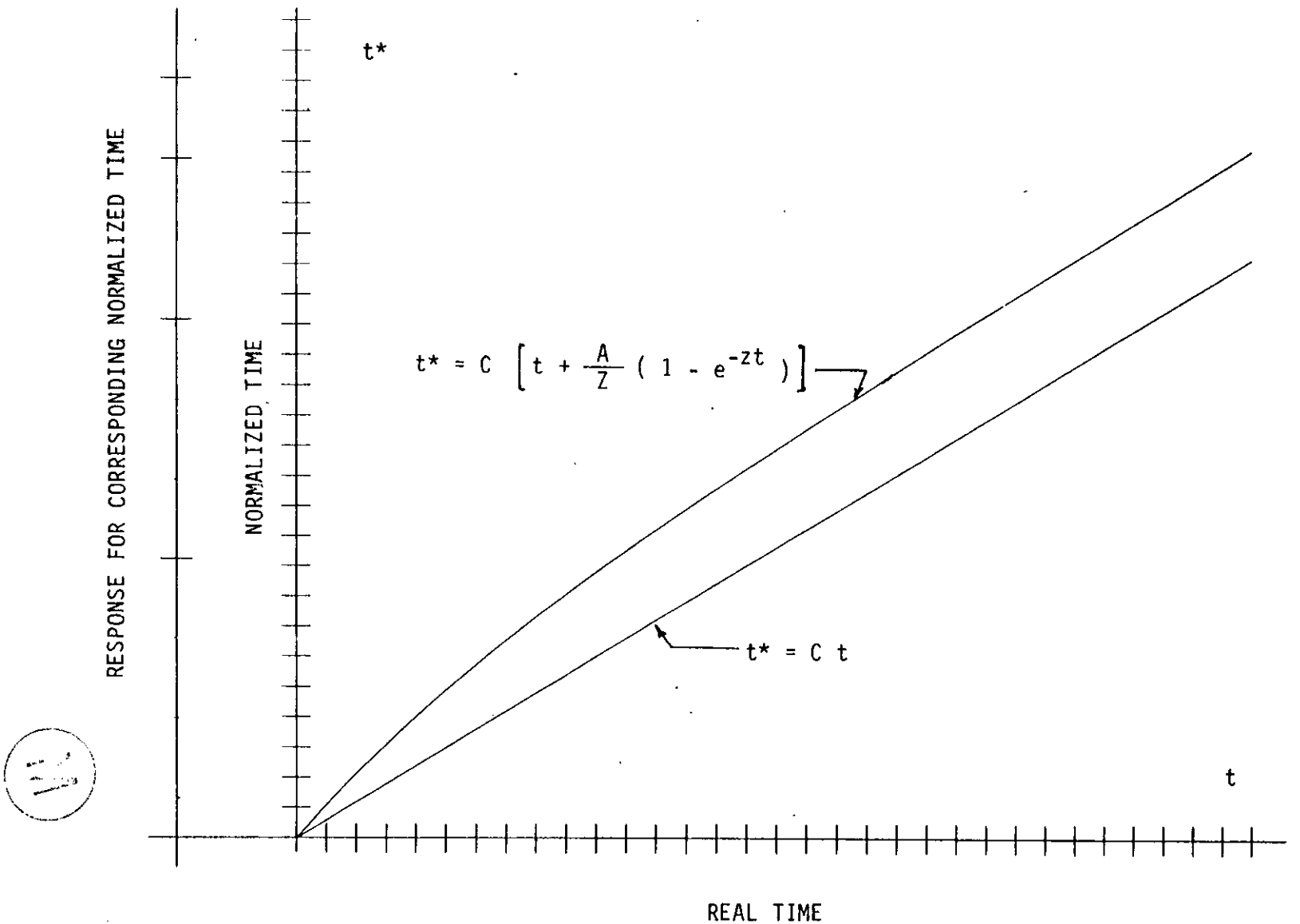

FIGURE C-1

TIME RESPONSE RELATIONSHIP OF THE NORMALIZED CREEP ANALYSIS METHOD

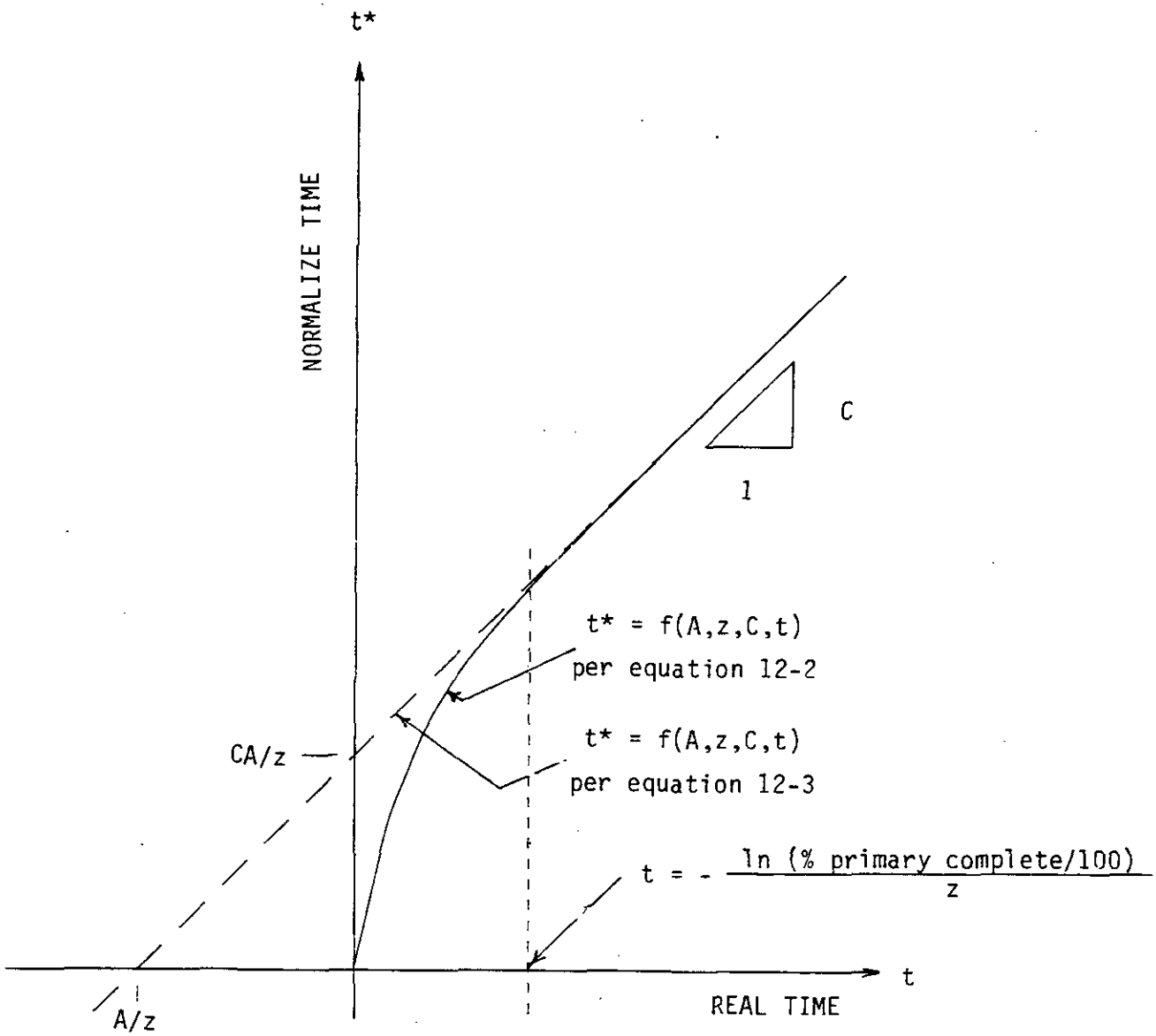

FIGURE C-2

GRAPHICAL REPRESENTATION OF

CREEP CONSTANTS RELATING TIME DOMAINS

The link between real time and response is completed by relating the normalized time to the response determined from the structural analysis. In brief, if the creep constants are known, the normalized time associated with any real time can be determined from equation (C.4-17) and the response corresponding to this time is found from the analysis results. Conversely, if in situ data which relates real time to response is available, this two-phased process can be worked backwards to evaluate the creep constants.

Because the response in both the in situ measurements and the structural analysis must be consistent, the displacements caused by creep are related.

In the analysis, the total response is an accumulation of elastic and creep responses,

$$R_t(t^*) = R_c(t^*) + R_e(t^*) \qquad \text{(C.5-2)}$$

where: R_t is the total response;
R_c is the creep response; and
R_e is the elastic response.

In as much as the total response at time $t^* = 0$ consists of elastic response only, and the elastic response $R_e(t^*)$ is always approximately equal to $R_t(0)$, the following equation can be used in lieu of equation (C.5-2):

$$R_c(t^*) = R_t(t^*) - R_t(0) \qquad \text{(C.5-3)}$$

The in situ readings represent the response relative to the time when the instrument was installed. In order for an actual creep response to be determined, the creep response which takes place between the time the excavation was made and the time when the instrument was installed must be found. Theoretically, if an instrument had been installed very shortly after excavation, this difference between measured and actual creep responses would be negligible. In reality, the excavation of all material contributing to the support of a specific location in an opening cannot be completed within a few days. As a result, the measured response from an instrument installed immediately after excavation would be a combination of initial creep and elastic responses. The term "instrument offset" is introduced to identify the difference between the actual creep response and the measured response starting at time t_1 when nearby excavations no longer introduce initial creep and elastic responses. This relationship is shown below:

$$R_I(t) = R_M(t) + R_I(t_1) \qquad \text{(C.5-4)}$$

where: R_I is the actual in situ response;
R_M is the measured response; and
$R_I(t_1)$ is the instrument offset.

Determination of the constant C, which represents the steady state creep rate, requires that the in situ readings are well into the steady state range. If this is the case, the relationship

$$dt^* = F\ dt \qquad \text{(C.5-5)}$$

can be used to determine the value of C since C equals F at very large values of t. The expression for C is:

$$C = (t^*_n - t^*_m) / (t_n - t_m) \qquad \text{(C.5-6)}$$

If t_m and t_n represent the times at which instrument readings are taken and $R_I(t_m)$ and $R_I(t_n)$ are the actual creep responses at these times, then the values of t^*_m and t^*_n can be found by relating these actual in situ creep responses with the analytical creep responses.

Assuming for the moment that the true value of instrument offset is known, equation (C.4-15) can be written for two time-response situations to produce two simultaneous equations which contain only the two remaining creep constants, A and z. By cancelling out the A term, the solution of the following equation provides the value of z.

$$\frac{1 - e^{-zt_n}}{1 - e^{-zt_m}} - \frac{t^*_n/C - t_n}{t^*_m/C - t_m} = 0 \qquad \text{(C.5-7)}$$

Once the value of z is found to satisfy the expression, A can be found from the following equation:

$$A = z\,(t_m^*/C - t_m)\ /\ (1 - e^{-zt}) \qquad \text{(C.5-8)}$$

Graphically this method determines constants which force the analytical curve to match the in situ data at the two time-response situations used in calculating the constants. Each different set of data points yields different values of A and z. Figure C-3 compares analytical and in situ responses for a few different sets of data points. Whereas creep behavior is history dependent, matching the last available data point is advantageous in predicting future responses. The determination of best values of A and z is done by minimizing the area between in situ and analytic response histories. The least area yields the best values. The SCCE program can be set up to search for this optimal condition.

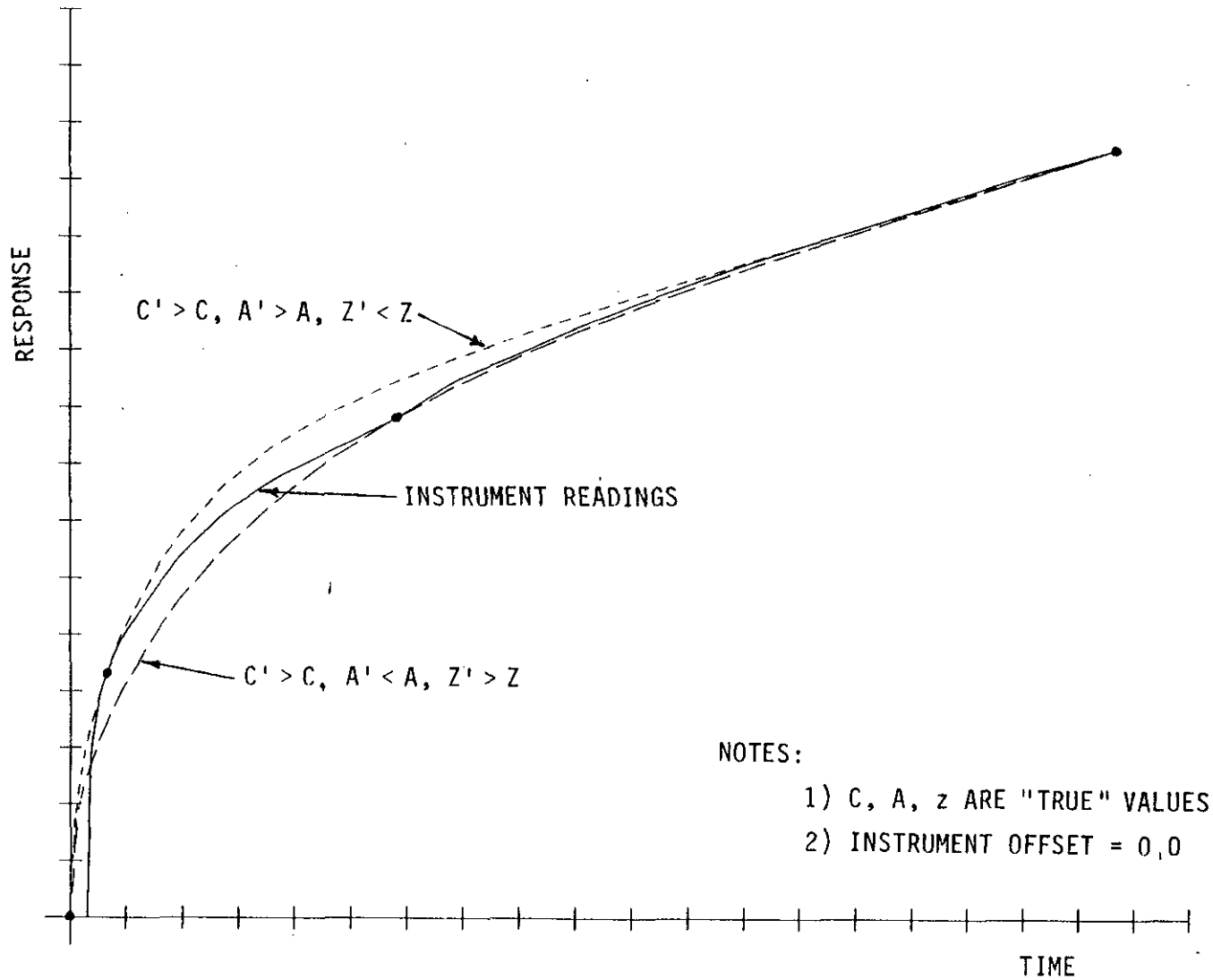

FIGURE C-3

COMPARISON OF ANALYTICAL RESULTS AND IN-SITU RESPONSES FOR VARIOUS DATA POINT SETS

The point which must be kept in perspective is that the determination of the constants A and z are dependent on both the instrument offset and the steady-state creep constant C. The effects of uncertainty in C can be minimized by assuring that no extraneous data are used in the solution of equation (C.5-6). The appropriate value of the instrument offset can only be found from minimizing the response deviation as was described in the previous paragraph. Figure C-4 shows how analytical and in situ responses compare for a few different values of the instrument offset. The curves in Figures C-3 and C-4 were generated through use of the SCCE program.

The SCCE computer program provides an effective means of determining salt creep properties by being able to process the large volume of in situ data and analytical results for design validation.

C.6 PREDICTION OF STRUCTURAL BEHAVIOR

After the creep constants C, A and z are determined, the structural response history can then be mapped from the normalized time domain into the real time domain using equation (C.4-15). Utilizing the in situ creep constants, additional mathematical models can also be used to predict the future structural responses for various facilities.

C.7 CONCLUSIONS

By normalizing the time in the governing equations to the creep function, the structural responses can be computed as functions of normalized time. This computation is performed without knowing the creep constants. After correlating the response history obtained from the analysis to the corresponding one measured from the site, the creep constants can be determined. Consequently, the relationship between the normalized and real time can be established, and the analytical responses can be mapped from the normalized time domain to the real time domain. Predicted results can therefore be provided for validating the adequacy of the underground behavior in the salt formation.

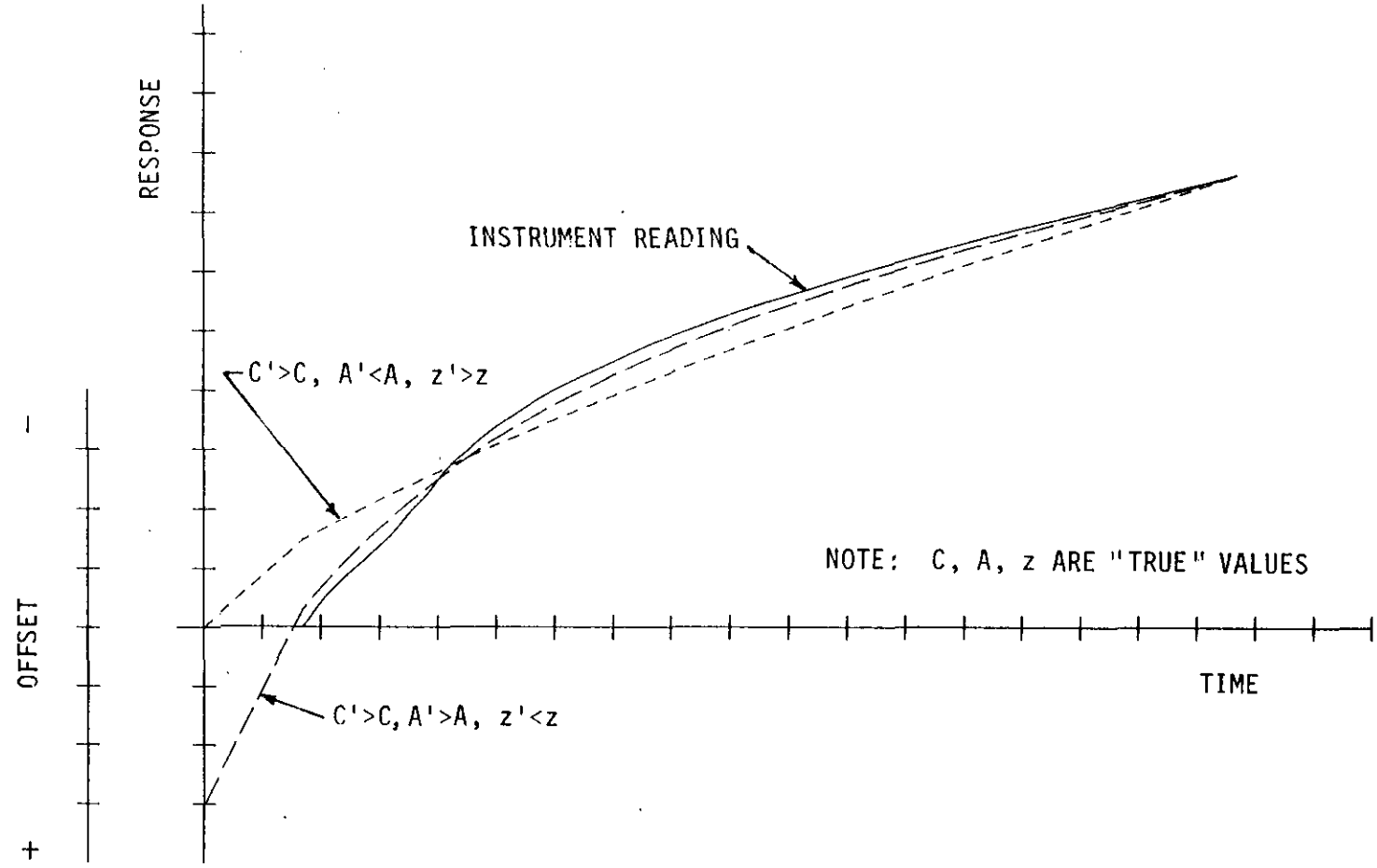

FIGURE C-4

COMPARISON OF ANALYTICAL RESULTS AND IN-SITU RESPONSE FOR VARIOUS INSTRUMENT OFFSET VALUES

REFERENCES

C-1 Krieg, R. D., January 1984, Reference Stratigraphy and Properties for the Waste Isolation Pilot Plant Project, SAND83-1908, Sandia National Laboratories, Albuquerque, New Mexico.

APPENDIX D

C & SH SHAFT
GEOLOGIC LOGS AND MAPS

CONTENTS

Figure No.	Title/Description
D-1	Geologic Drill Log 0 to 850 feet (11 Sheets)
D-2	Key Area Geology Bottom of casing to 920 feet
D-3	Lithologic Log Showing Sample and Instrument Locations Bottom of casing to 2200 feet (3 Sheets)
D-4	Facility Level Area Geology 2080 to 2192 feet

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	1 OF 11	EXPLORATORY SHAFT (SPDV)

SITE	COORDINATES (PLANT GRID)	ANGLE FROM HORIZ.	BEARING
WIPP EDDY CO., NEW MEXICO	N 9687.23 E 6894.89	90°	N. A.

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
7-4-81	10-24-81	CHALLENGER DRILLING CO.	NATIONAL 125	142 IN.	16	2282	(FROM G.S.) 2298 FT.

CORE RECOVERY (FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK
N. A.	N. A.	172	N.A.	3410.5	NOT DETERMINED	(FROM GROUND SURFACE) 16 FT./3394.5

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
N. A.	180 IN./11FT. 144 IN./93.4 FT. 120 IN./843FT.	R.M. BEATHARD, R.C. KISER, J.L. MATTHEWS

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K. B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3417.5	0				Rig depths measured from kelly bushing approx. 7 ft. above ground surface.
							3410.5				GROUND SURFACE	
BACKHOE								10			0-11' DUNE SAND, Reddish brown	NOTES: 1. Stratigraphic description from 0 to 103 ft. based on geologic log of boring B-25. 2. 168 in. dia. pilot hole augered from 0-97.5 ft. by Meredith Drilling Co. prior to setting and cementing 144 in. dia. surface casing. 3. All depths given are from ground surface except for those shown in depth column.
							3399.5	20			11-16' CALICHE, White	
							3394.5				16-36.5' GATUNA FORMATION, Sandstone, reddish brown, fine to medium grained	
								30				
								40				
							3374.0				36.5-46.5' SANTA ROSA FORMATION, Sandstone, gray and reddish brown, fine grained	CASING: 0-11 ft. = 180 in. dia CMP 0-93.4 ft. = 144 in. dia. surface casing 0-843 ft. = 120 in. dia. steel liner (installed after completion of shaft drilling)
								50				
							3364.0				46.5-538' DEWEY LAKE FORMATION, Siltstone and sandstone, reddish brown, whitish veins of gypsum interspersed throughout	
								60				
168 IN. DIA. AUGER FROM 11 TO 97.5 FT		NO SAMPLES TAKEN FROM GROUND SURFACE TO 103 FT.					3347.5	70				

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-1

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO
WIPP	12484	2 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3347.5	70				
168 IN. DIA. AUGER		NO SAMPLES TAKEN									DEWEY LAKE FORMATION, Siltstone and sandstone, reddish brown, whitish veins of gypsum interspersed throughout	
								80				
								90				
								100				Horizontal displacement at 99 ft. was 0.01 ft. S27°06'W
								110		1	Siltstone, dark reddish brown, moderately weak, thinly bedded	Cuttings samples collected from discharge end of blooie-line unless otherwise indicated. Sample depths shown are approximate
142 IN. DIA. ROTARY CUTTER BIT FROM 97.5 TO 2298 FT.		CUTTINGS SAMPLES TAKEN FROM 103 TO 2298 FT.						120		2	Sandstone, dark reddish brown, fine grained, well sorted, sub-rounded grains, weakly cemented	
								130		3	Sandstone, silty, very fine grained, grading into siltstone in places	Drilling rate from 122 to 148 ft. was 1.4 ft/hr
								140		4	As above	
							3267.5	150		5	Siltstone, sandy, dark reddish brown	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	3 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3267.5	150				
											Siltstone, sandy, dark reddish brown, moderately weak, thin bedded, grading into sandstone in places	Horizontal displacement at 143 ft. was 0.02 ft. S 04°07'W
								160		6	Clay, dark reddish brown, some siltstone (dark reddish brown and greenish gray, moderately weak), clay probably occurs as claystone interbedded with siltstone	Drilling rate from 148 to 158 ft. was 3.3ft./hr.
								170		7	Siltstone, sandy, dark reddish brown, moderately weak, little clay	Drilling rate from 158 to 194 ft. was 12 ft./hr.
								180		8	As above	
								190		9	Clay and Siltstone, dark reddish brown	Horizontal displacement at 183 ft. was 0.01 ft. S17°47'W
								200		10	Sandstone, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted	Drilling rate from 194 to 203 ft. was 1.3 ft./hr.
								210		11	Siltstone, dark reddish brown, moderately weak, gypsum fragments	Drilling rate from 203 to 217 ft. was 1.2 ft./hr.
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						220		12	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted	Drilling rate from 217 to 245 ft. was 1.4 ft./hr.
							3187.5	230		13	Siltstone, dark reddish brown	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	4 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3187.5	230			Siltstone, dark reddish brown, moderately weak, gypsum fragments, little clay	
												Horizontal displacement at 229 ft. was 0.02 ft. S43°30'W
								240		14	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted, some siltstone, abundant gypsum fragments	
								250		15	As above, much less gypsum	
										16		S#16 taken from drill bit - no formal description
								260		17	As above (sample No. 14)	Drilling rate from 245 to 262 ft. was 1.0 ft./hr.
								270		18	As above, abundant gypsum and greenish sandstone fragments	Drilling rate from 262 to 276 ft. was 0.6 ft./hr.
								280		19	As above	Horizontal displacement at 271 ft. was 0.03 ft. S19°29'W
								290		20	As above	Drilling rate from 276 to 299 ft. was 1.2 ft./hr.
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						300		21	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, well sorted, and Siltstone, dark reddish brown, moderately weak, some gypsum fragments	Drilling rate from 299 to 309 ft. was 1.3 ft./hr.
							3107.5	310		22	Sandstone, as above, some lt. green color	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	5 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3107.5	310				
										23		S# 23 taken from drill bit - no formal description
								320		24	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, well sorted, and Siltstone, dark reddish brown, moderately weak	Horizontal displacement at 313 ft. was 0.04 ft. S 0° 03'E
												Drilling rate from 309 to 322 ft. was 1.9 ft./hr.
								330		25	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted, some gypsum fragments	Drilling rate from 322 to 336 ft. was 1.6 ft./hr.
								340		26	Siltstone, clayey, dark reddish brown, moderately weak, and Sandstone, dark reddish brown, moderately weak, very fine grained, trace of clay	Drilling rate from 336 to 375 ft. was 2.1 ft./hr.
								350		27	Siltstone, sandy, dark reddish brown and greenish gray, moderately weak	
								360		28	Siltstone, sandy, dark reddish brown, moderately weak, grades into Sandstone, dark reddish brown, moderately weak, very fine grained	Horizontal displacement at 357 ft. was 0.06 ft. S01° 10'E
								370		29	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted	
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						380		30	As above, with gypsum fragments	Drilling rate from 375 to 433 ft. was 2.0 ft./hr.
							3027.5	390		31	Sandstone, as above, and Siltstone	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	6 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3027.5	390			Sandstone, as above, and Siltstone, sandy, dark reddish brown, some greenish gray frags., moderately weak, abundant gypsum fragments	
								400		32	As above	
								410		33	Sandstone, as sample No. 29, abundant gypsum fragments	← Horizontal displacement at 401 ft. was 0.08 ft. S08° 13'W
								420		34	As above	
								430		35	As above	
								440		36	As above, some gray green color	Drilling rate from 433 to 464 ft. was 1.6 ft./hr.
								450		37	Sandstone and Siltstone, as sample No. 32	← Horizontal displacement at 445 ft. was 0.10 ft. S18° 50'W
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						460		38	As above	
							2947.5	470		39	Sandstone, as sample No. 29	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	7 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT. BELOW K.B.)	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							2947.5	470				Drilling rates: 464-490 ft. = 1.5 ft./hr. 490 - 502 ft. = 0.8 ft./hr. 502 - 506 ft. = 0.7 ft./hr.
								480		40	Siltstone, dark reddish brown, moderately weak, gypsum fragments, trace of sandstone	
								490		41	Sandstone, silty, dark reddish brown, moderately strong to moderately weak, very fine grained, abundant greenish gray reduction spots	
												Horizontal displacement at 489 ft. was 0.14 ft. S28°17'W
								500		42	As above	
								510		43	As above, subrounded, well sorted, gypsum fragments	
												Drilling rates: 506 - 510 ft. = 1.3 ft./hr. 510 - 513 ft. = 0.5 ft./hr. 513 - 527 ft. = 0.6 ft./hr. 527 - 538 ft. = 0.5 ft./hr. 538 - 548 ft. = 0.4 ft./hr.
								520		44	As above	
								530		45	As above, moderately weak, some greenish gray reduction spots	
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						540		46	As above	Horizontal displacement at 533 ft. was 0.18 ft. S35° 10'W
										47	As above	
							2872.5			48	As above	
											538 - 850' RUSTLER FORMATION, primarily anhydrite, dolomite, and mudstone	
							2867.5	550		49	Anhydrite, white to light brownish gray	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	8 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							2867.5	550			Anhydrite, white to light brownish gray, hard, finely crystalline, some gypsum fragments	
												Drilling rates: 548-554 ft. = 0.5 ft./hr. 554-561 ft. = 0.7 ft./hr.
								560		50	As above	
								570		51	As above, light gray to light brownish gray	
								580		52	Clay, dark brown, high plasticity, some silt	
												← Horizontal displacement at 577 ft. was 0.24 ft. S40° 12'W
								590		53	Siltstone, medium gray, moderately weak, some very fine sand and minor clay	
							2817.5	600		54	Anhydrite, very lt. gray to med. dk. gray, moderately hard	
											593 - 628' MAGENTA DOLOMITE MEMBER	
								610		55	Siltstone, calcareous, med. olive gray to olive gray, strong, mod. hard, mod. to well cemented, sparse gypsum crystals	
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						620		56	As above	
							2795.5				? — — — — — — — — — — — — — — — ?	
							2787.5	630		57	Dolomite, olive gray	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	9 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							2787.5	630				
							2782.5				Dolomite, olive gray, mod. strong, mod. hard, sugary texture w/small silver blebs (mica?), evidence of lamella, powdered sample reacts slightly w/HCl acid	
								640		58	Anhydrite, very light gray to brownish gray, mod. strong, mod. hard, well cemented, possibly gypsiferous	
								650		59	As above	
								660		60	As above	
								670		61	As above, contains minor amt. of small black grains w/resinous luster, pulverized grains have earthy to sandy appearance & small reaction w/HCl acid	
								680		62	As above (sample No. 58), lighter in overall color and larger fragments	
								690		63	As above, lighter in overall color, smaller fragments than above	
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						700		64	Anhydrite, mot. pale yellow brn. overall, some pale reddish brn. frags. (polyhalite), stronger and harder than previous samples, trace translucent to white, fibrous satinspar gypsum, trace gray clay frags.	
							2707.5	710		65	Anhydrite, slightly mot. med. to lt. gray	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	10 OF 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							2707.5	710			Anhydrite, slightly mot. med. to lt. gray overall, trace gypsum	
							2699.5					
								720		66	711-740' CULEBRA DOLOMITE MEMBER Dolomite, crystalline, lt. olive gray, mod. strong, well cemented, sugary texture, powdered sample reacts slightly w/HCl acid, trace transparent gypsum crystals	
								730		67		
								740		68	As above	
							2670.5					
								750		69	Anhydrite, crystalline, variegated color (primarily grayish pink, pale red, and light gray), strong, hard, sugary texture, blebs of grayish red (polyhalite?)	
							2658.5					
								760		70	Halite, pale reddish brn., strong, hard, dissolves slowly in hot water, few transparent frags. exhibiting cleavage faces, trace argillaceous material	← Horizontal displacement at 753 ft. was 0.49 ft. S51° 15'W
								770		71	As above, more abundant crystals, some mudstone (clay to fine sand particles, grayish red, poor to mod. cementation, crumbles easily)	
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						780		72	As above, trace anhydrite (yellow gray, strong, mod. hard)	
							2627.5	790		73	Mudstone, moderate brown	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	11 of 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	PRESSURE P.S.I.	TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							2627.5	790			Mudstone, primarily silt w/clay and fine sand particles, mod. brn., strong, hard, well cemented, trace transparent halite crystals	
								800		74	As above, less halite, trace anhydrite	
								810		75	Mudstone, primarily silt w/fine sand & minor clay particles, olive gray, strong, hard, mod. cemented, mica flakes present	
								820		76	As above (sample No. 73), trace gypsum crystals and olive gray mudstone	
								830		77	As above (sample No. 75), trace brn. mudstone	
								840		78	As above	
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						850		79	As above, larger frags.	← Horizontal displacement at 841 ft. was 0.59 ft. S54°18'W
										80	As above, brown and olive gray, trace anhydrite	
							2560.5	860		81	850-2298' SALADO FORMATION Note: *For description of Salado Formation stratigraphy and lithology see geologic map of shaft*	
							2547.5	870		82		

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

NOTES:

1) ELEVATIONS REFER TO BOTTOM OF CONCRETE AT ELEVATION OF 2530.38 WHICH WAS TIED TO CWI BENCHMARK NO. CW-1 (BRASS CAP OUTSIDE THE C & SH SHAFT) AT ELEVATION 3410.080 ON DECEMBER 2, 1982.

2) DEPTHS ARE RELATED TO THE TOP OF FIRST BUNTON AT ELEVATION 3410.0 FT. MSL.

3) PRELIMINARY DEPTHS WERE CORRECTED BY THE ADDITION OF A -0.2 FT. CORRECTION FACTOR.

4) STANDARD GEOLOGIC SYMBOL FOR HALITE IS NOT USED IN ORDER TO ENHANCE THE CLARITY OF THE LOG COLUMN.

REFERENCE:

GEOTECHNICAL ACTIVITIES IN THE EXPLORATORY SHAFT-SELECTION OF THE FACILITY INTERVAL, MARCH 1983, TIME 3178.

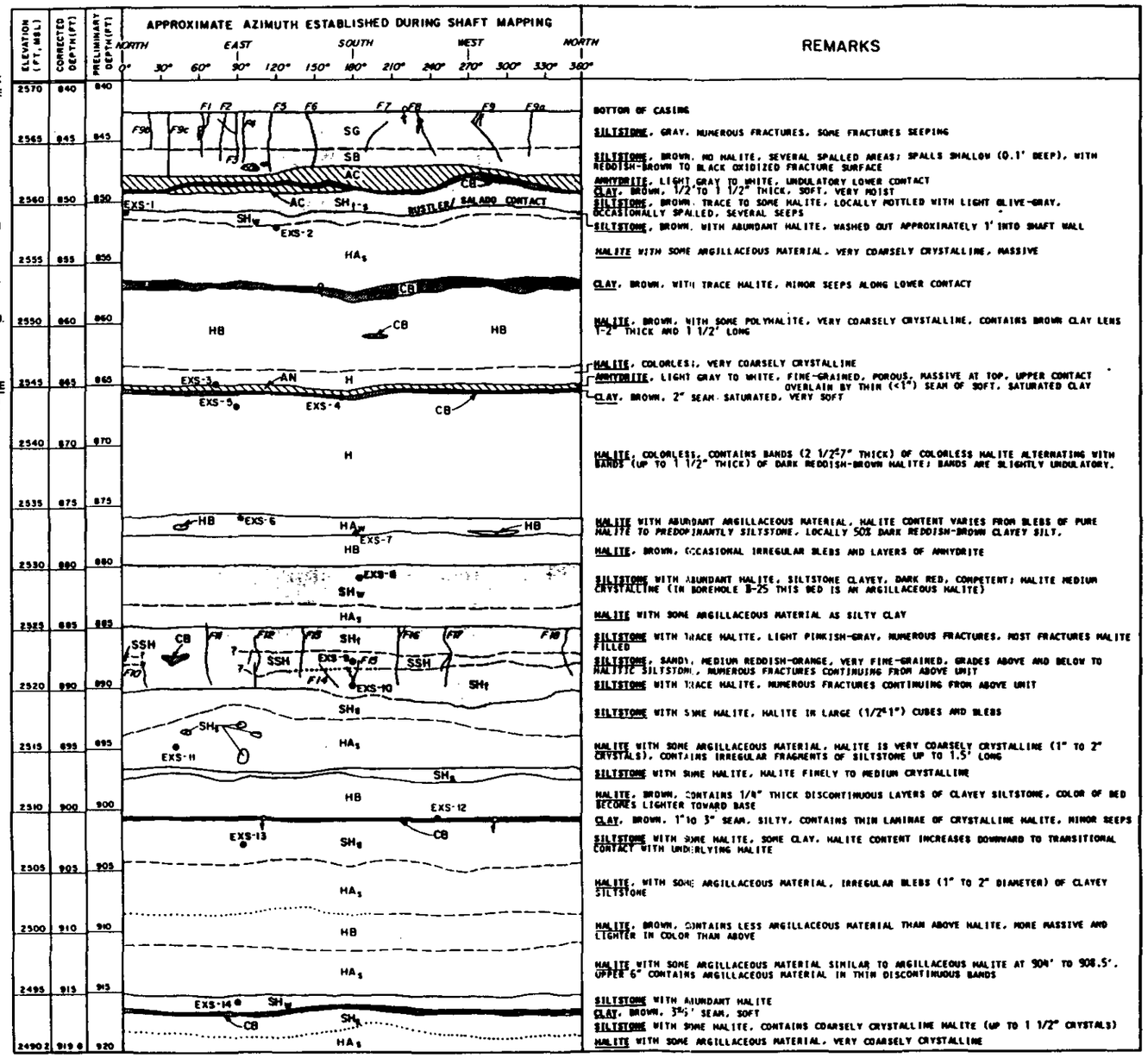

EXPLANATION

ROCK TYPE

SILTSTONE — HALITE (See note 4) — ANHYDRITE

CONTACTS

SHARP (Identifiable within 0.05 feet) — GRADATIONAL (Identifiable within 0.05 to 0.2 feet) — DIFFUSE (Identifiable within 0.2 to 0.5 feet)

F1 FRACTURE — EXS-5 ROCK SAMPLE LOCATION AND NUMBER

SEEP — CLAY LAYER (See note 5)

SPALLED AREA

GEOLOGIC UNIT SYMBOLS AND DESCRIPTIONS *

A — ARGILLACEOUS MATERIAL, GENERALLY FOUND AS AN INTERGRANULAR ACCESSORY CONSTITUENT, LIGHT GRAY (N7) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY MOIST TO MOIST, TRACE TO SOME SILT.

AN — ANHYDRITE, LIGHT GRAY (N7) TO WHITE (N9), MODERATE ORANGE-PINK (10R 7/4) TO PALE REDDISH-BROWN (10R 5/4), FINELY CRYSTALLINE.

AC — ANHYDRITE, LIGHT GRAY (N7) TO GRAYISH-ORANGE (10YR 7/4) TO WHITE (N9), WITH SEVERAL SOFT 1/2- TO 1 1/2-INCH CLAY STRINGERS WITH TRACE OF SILT.

CB — CLAY, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6) WITH TRACE TO SOME SILT, TRACE TO SOME HALITE.

HA** — HALITE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6) TO MODERATE REDDISH-ORANGE (10R 6/6), LOCALLY MEDIUM LIGHT GRAY (N7), MEDIUM TO COARSELY CRYSTALLINE, ARGILLACEOUS.

HB — HALITE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY TRANSLUCENT, MEDIUM TO COARSELY CRYSTALLINE.

H — HALITE, COLORLESS (TRANSPARENT TO TRANSLUCENT) TO GRAYISH-ORANGE-PINK (5YR 7/2), MEDIUM TO COARSELY CRYSTALLINE, MAY BE BANDED.

SB — SILTSTONE, DARK REDDISH-BROWN (10R 3/4), TRACE TO NO HALITE, TRACE FINE-GRAINED SAND.

SG — SILTSTONE, LIGHT OLIVE-GRAY (5Y 6/1), TRACE FINE-GRAINED SAND, TRACE TO NO HALITE.

SH** — SILTSTONE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), HALITIC, TRACE TO SOME CLAY, LOCALLY CONTAINS VERY FINE TO FINE-GRAINED SAND.

SSH — SILTSTONE, MODERATE REDDISH-ORANGE (10R 6/6), WITH VERY FINE-GRAINED SAND, TRACE HALITE; LOCALLY GRADES TO A VERY FINE TO FINE-GRAINED SANDSTONE, MODERATE REDDISH-BROWN (10R 4/6) TO MEDIUM LIGHT GRAY (N7), TRACE TO SOME SILT.

* SLIGHT VARIATIONS FROM THESE GENERAL DESCRIPTIONS MAY EXIST. THE EXCEPTIONS ARE NOTED IN THE REMARKS COLUMN.
** ESTIMATED CONTENT OF ACCESSORY CONSTITUENTS IS INDICATED BY A MODIFIER: T = TRACE
S = SOME
W = WITH OR ABUNDANT

SCALE 5 0 5 10 FT

FRACTURE NOTES:

FRACTURES DESIGNATED F1 TO F9C REFER TO THOSE IN A SILTSTONE BED AT DEPTHS 842.5 TO 847 FEET. FRACTURES F10 TO F18 ARE IN A SILTSTONE BED AT DEPTHS 875 TO 880 FEET.

F1 — OPEN TO 1/4-INCH WIDE ABOVE CONTACT, CLOSED BELOW CONTACT; VERY MINOR SEEPAGE.

F2 — FILLED WITH WHITE PRECIPITATE (SALT?); 1/8-INCH WIDE IN UPPER EXTENT, CLOSED IN LOWER EXTENT.

F3 — BIFURCATION FORMS POTENTIAL SPALL AREA.

F4 — VERY MINOR SEEPAGE; OPEN.

F5 — OXIDIZED MATERIAL IN FRACTURE BELOW CONTACT; 1/8-INCH MAXIMUM WIDTH.

F6 — TRENDS N20°E; 1/4-INCH WIDE; OPEN.

F7 — CLOSED ABOVE CONTACT, OPEN TO 1/4-INCH WIDE BELOW CONTACT.

F8 — OPEN 1/16- TO 1/2-INCH WIDE ABOVE CONTACT, CLOSED BELOW CONTACT; PARTIALLY FILLED WITH SILT; MINOR SEEPAGE.

F9 — 1/8- TO 1/4-INCH WIDE.

F9a — ESTIMATED STRIKE N60°W.

F9b — OPEN 1/4-INCH WIDE.

F9c — CLOSED TO OPEN 1/4-INCH WIDE.

F10 — HALITE FILLED, STRIKE E-W.

F11 — VERTICAL FRACTURE WITH MAXIMUM WIDTH OF 1 INCH; HALITE FILLED; MODERATE REDDISH-BROWN COLOR; ESTIMATED STRIKE N30°E; MATCHES WITH F15.

F12 — FRACTURE PARTIALLY FILLED WITH HALITE; STRIKE N88°E; MATCHES WITH F17.

F13 — NO SPECIFIC DATA.

F14 — ESTIMATED STRIKE N60°W, DIPPING 40°SW.

F15 — POSSIBLY MATCHES F11?; STRIKE N30°E.

F16 — VERTICAL FRACTURE 3/4-INCH WIDE; HALITE FILLED; PROBABLY MATCHES F18; STRIKE N11°E.

F17 — VERTICAL FRACTURE 1/2-INCH WIDE; HALITE FILLED; MATCHES F12; STRIKE N88°E.

F18 — ESTIMATED STRIKE N10 TO 20°E; FRACTURE F18 MATCHES F16; HALITE FILLED.

FIGURE D-2
C & SH SHAFT
KEY AREA GEOLOGY
BOTTOM CASING TO 920 FEET

M

16

NOTES:

1) ELEVATIONS REFER TO BOTTOM OF CONCRETE AT ELEVATION OF 2530.38 WHICH WAS TIED TO CWI BENCHMARK NO. CW-1 (BRASS CAP OUTSIDE THE C & SH SHAFT) AT ELEVATION 3410.080 ON DECEMBER 2, 1982.

2) DEPTHS ARE RELATED TO THE TOP OF FIRST BUNTON AT ELEVATION 3410.0 FT. MSL.

3) PRELIMINARY DEPTHS WERE CORRECTED BY THE ADDITION OF A CORRECTION FACTOR.

4) STANDARD GEOLOGIC SYMBOL FOR HALITE IS NOT USED IN ORDER TO ENHANCE THE CLARITY OF THE LOG COLUMN.

REFERENCE:

GEOTECHNICAL ACTIVITIES IN THE EXPLORATORY SHAFT-SELECTION OF THE FACILITY INTERVAL, MARCH 1983, TME 3178.

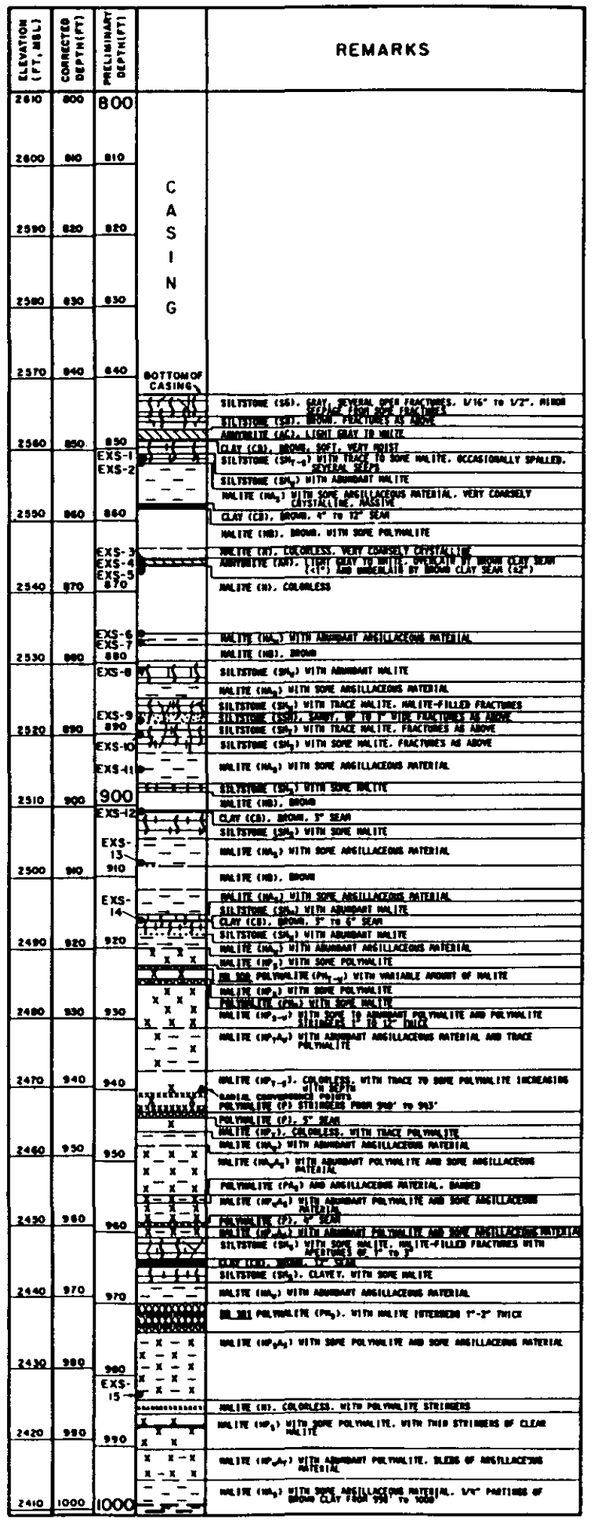

GEOLOGIC UNIT SYMBOLS AND DESCRIPTIONS*

A — **ARGILLACEOUS** MATERIAL, GENERALLY FOUND AS AN INTERGRANULAR ACCESSORY CONSTITUENT, LIGHT GRAY (N7) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY MOIST TO MOIST, TRACE TO SOME SILT.

AC — **ANHYDRITE**, LIGHT GRAY (N7) TO WHITE (N9) TO GRAYISH-ORANGE (10YR 7/4), FINELY CRYSTALLINE TO MICROCRYSTALLINE, SEVERAL SOFT 1/2- TO 1 1/2-INCH CLAY STRINGERS WITH TRACE SILT.

AH — **ANHYDRITE**, MEDIUM DARK GRAY (N4) TO LIGHT GRAY (N7) TO WHITE (N9), MODERATE ORANGE-PINK (10R 7/4) TO PALE REDDISH-BROWN (10R 5/4), FINELY CRYSTALLINE TO MICROCRYSTALLINE.

CB — **CLAY**, DARK REDDISH-BROWN (10R 3/4), TRACE TO SOME SILT, TRACE TO SOME HALITE.

CG — **CLAY**, MEDIUM LIGHT GRAY (N6) TO MEDIUM DARK GRAY (N4) TO LIGHT OLIVE-GRAY (5Y 6/1), TRACE TO SOME SILT, TRACE TO SOME HALITE.

H — **HALITE**, COLORLESS (TRANSPARENT TO TRANSLUCENT) TO GRAYISH-ORANGE-PINK (5YR 7/2), MEDIUM TO COARSELY CRYSTALLINE, MAY BE BANDED.

HA** — **HALITE**, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), MEDIUM TO COARSELY CRYSTALLINE, ARGILLACEOUS.

HB — **HALITE**, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY TRANSLUCENT.

HP** — **HALITE**, TRANSLUCENT TO MODERATE REDDISH-ORANGE (10R 6/6) TO MODERATE REDDISH-BROWN (10R 4/6), POLYHALITIC.

HPA** — **HALITE**, MODERATE REDDISH-ORANGE (10R 6/6) TO MODERATE REDDISH-BROWN (10R 4/6), POLYHALITIC AND ARGILLACEOUS.

P — **POLYHALITE**, MODERATE REDDISH-BROWN (10R 4/6) TO MODERATE REDDISH-ORANGE (10R 6/6), FINELY CRYSTALLINE TO MICROCRYSTALLINE.

PA** — **POLYHALITE**, MODERATE REDDISH-BROWN (10R 4/6), FINELY CRYSTALLINE TO MICROCRYSTALLINE, ARGILLACEOUS.

PH** — **POLYHALITE**, MODERATE REDDISH-BROWN (10R 4/6) TO MODERATE REDDISH-ORANGE (10R 6/6), FINELY CRYSTALLINE TO MICROCRYSTALLINE, HALITIC.

SB — **SILTSTONE**, DARK REDDISH-BROWN (10R 3/4), TRACE HALITE, TRACE FINE SAND.

SG — **SILTSTONE**, LIGHT OLIVE-GRAY (5Y 6/1), TRACE HALITE, TRACE FINE-GRAINED SAND.

SH** — **SILTSTONE**, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), HALITIC, TRACE TO SOME CLAY, LOCALLY CONTAINS VERY FINE-GRAINED SAND.

SSH — **SILTSTONE**, MODERATE REDDISH-ORANGE (10R 6/6), WITH VERY FINE-GRAINED SAND, TRACE HALITE; LOCALLY GRADES TO VERY FINE TO FINE-GRAINED SANDSTONE, MODERATE REDDISH-BROWN (10R 4/6) TO MEDIUM LIGHT GRAY (N6) TRACE TO SOME SILT.

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* SLIGHT VARIATIONS FROM THESE GENERAL DESCRIPTIONS MAY EXIST. THE EXCEPTIONS ARE NOTED IN THE REMARKS COLUMN.

**ESTIMATED CONTENT OF ACCESSORY CONSTITUENTS IS INDICATED BY A MODIFER:
T = TRACE
S = SOME
W = WITH OR ABUNDANT

EXPLANATION

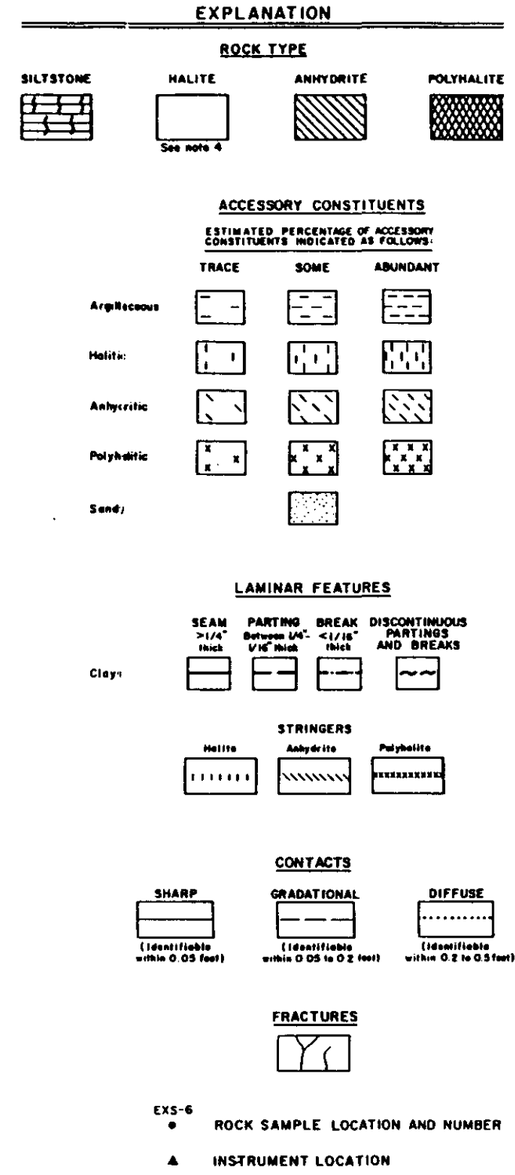

FIGURE D-3

C & SH SHAFT
LITHOLOGIC LOG SHOWING
SAMPLE AND INSTRUMENT LOCATIONS
BOTTOM OF CASING TO 2200 FEET

SHEET 1 OF 3

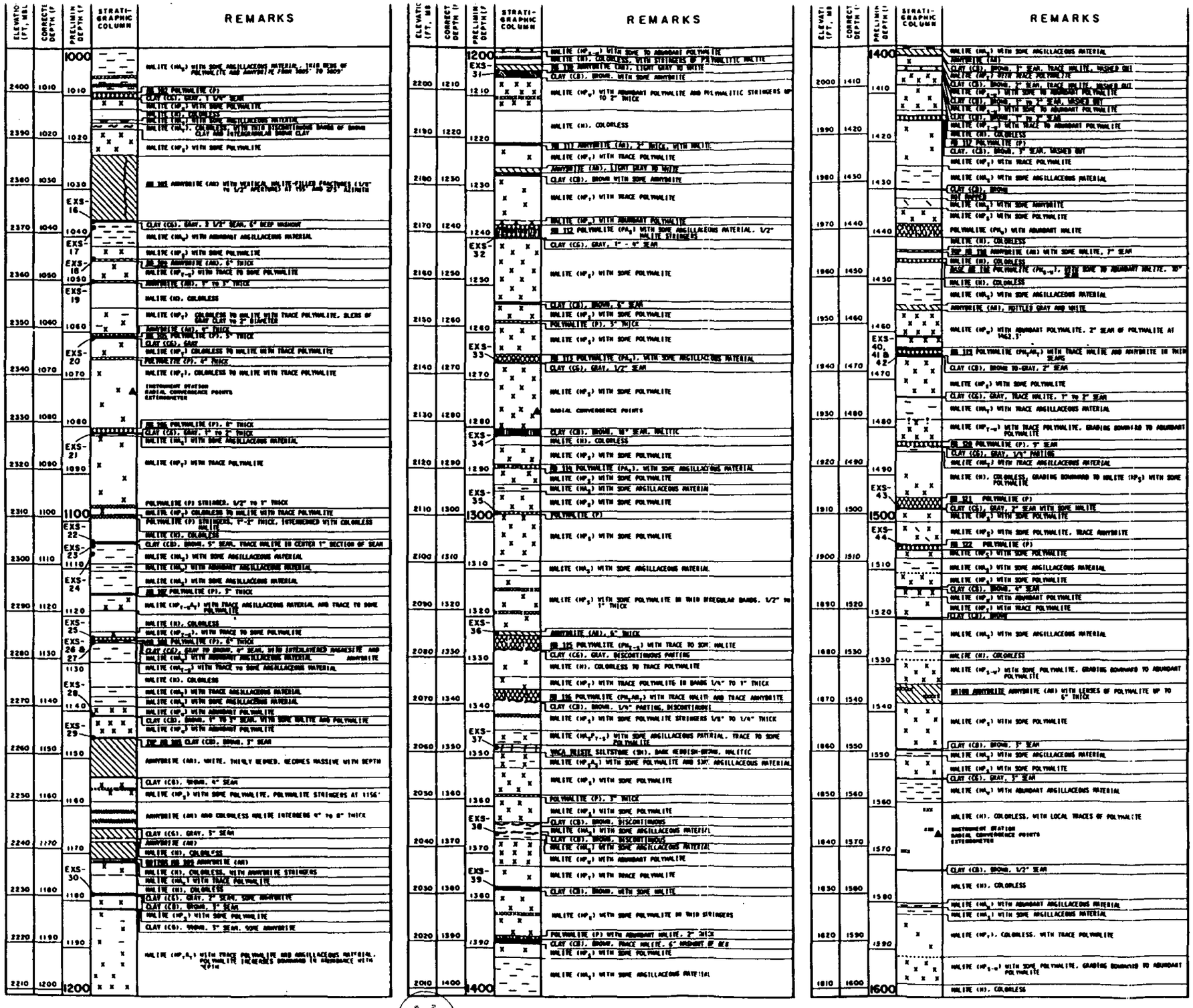

Figure D-3
C & SH SHAFT
LITHOLOGIC LOG SHOWING
SAMPLE AND INSTRUMENT LOCATIONS
BOTTOM OF CASING TO 2200 FEET

SHEET 2 OF 3

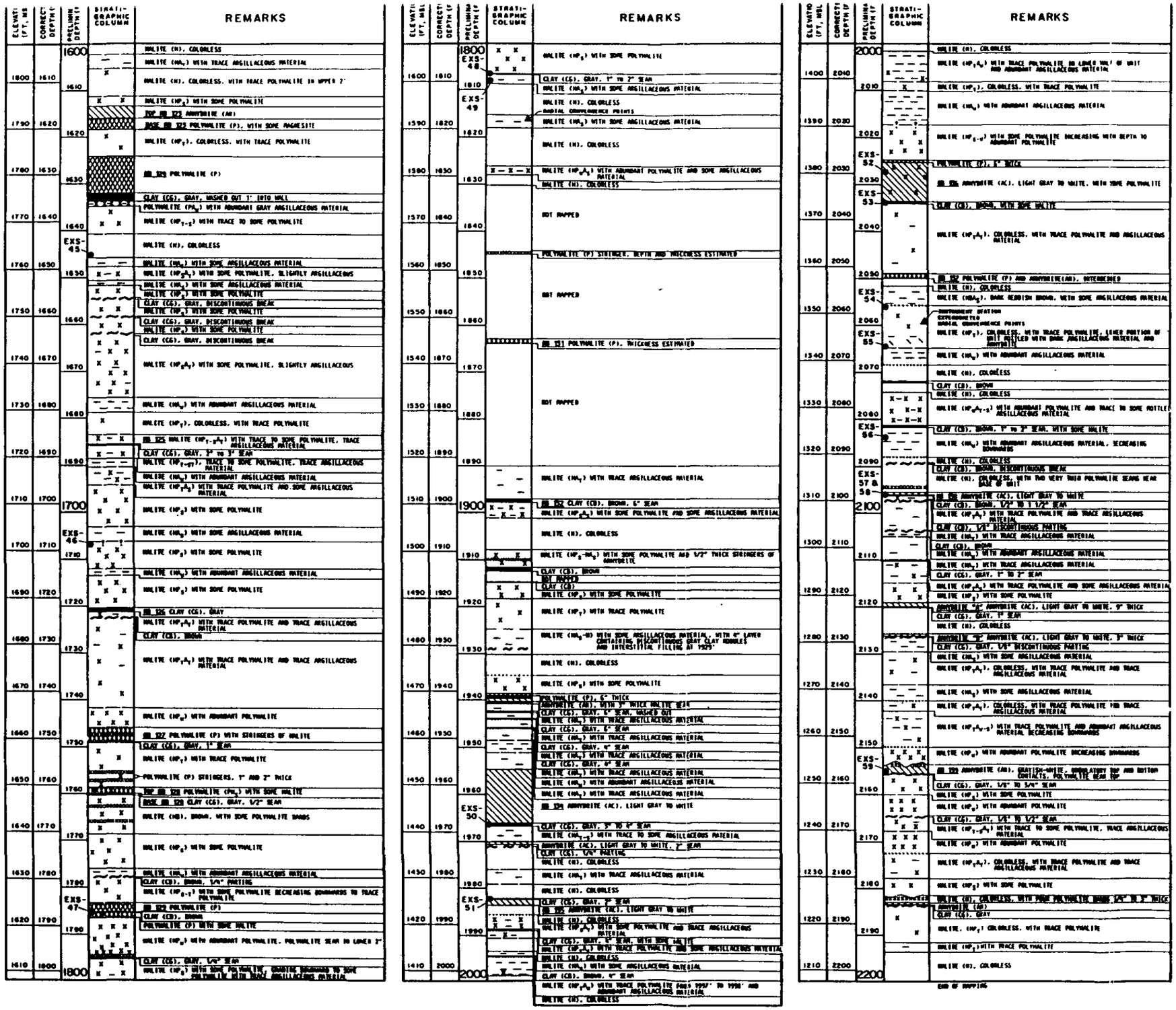

FIGURE D-3

C & SH SHAFT
LITHOLOGIC LOG SHOWING
SAMPLE AND INSTRUMENT LOCATIONS
BOTTOM OF CASING TO 2200 FEET

SHEET 3 OF 3

NOTES:

1) ELEVATIONS REFER TO CWI BENCHMARK NO. 82-D (BRASS CAP ON N.W. CORNER OF THE UNDERGROUND POWER CENTER FOUNDATION) AT ELEVATION 1258.58 WHICH WAS TIED TO CWI BENCHMARK NO. CWI (BRASS CAP OUTSIDE THE C & SH SHAFT) AT ELEVATION 3410.080 ON DECEMBER 2, 1982. BENCHMARK NO. 82-D IS WITHIN THE ZONE OF DEFORMATION OF THE STATION AND CANNOT BE CONSIDERED STABLE.

2) DEPTHS ARE RELATED TO THE TOP OF FIRST BUNTON AT ELEVATION 3410.0 FT. MSL.

3) PRELIMINARY DEPTHS WERE CORRECTED BY THE ADDITION OF A +2.8 FT. CORRECTION FACTOR.

4) STANDARD GEOLOGIC SYMBOL FOR HALITE IS NOT USED IN ORDER TO ENHANCE THE CLARITY OF THE LOG COLUMN.

REFERENCE:

GEOTECHNICAL ACTIVITIES IN THE EXPLORATORY SHAFT-SELECTION OF THE FACILITY INTERVAL, MARCH 1983, TME 3178.

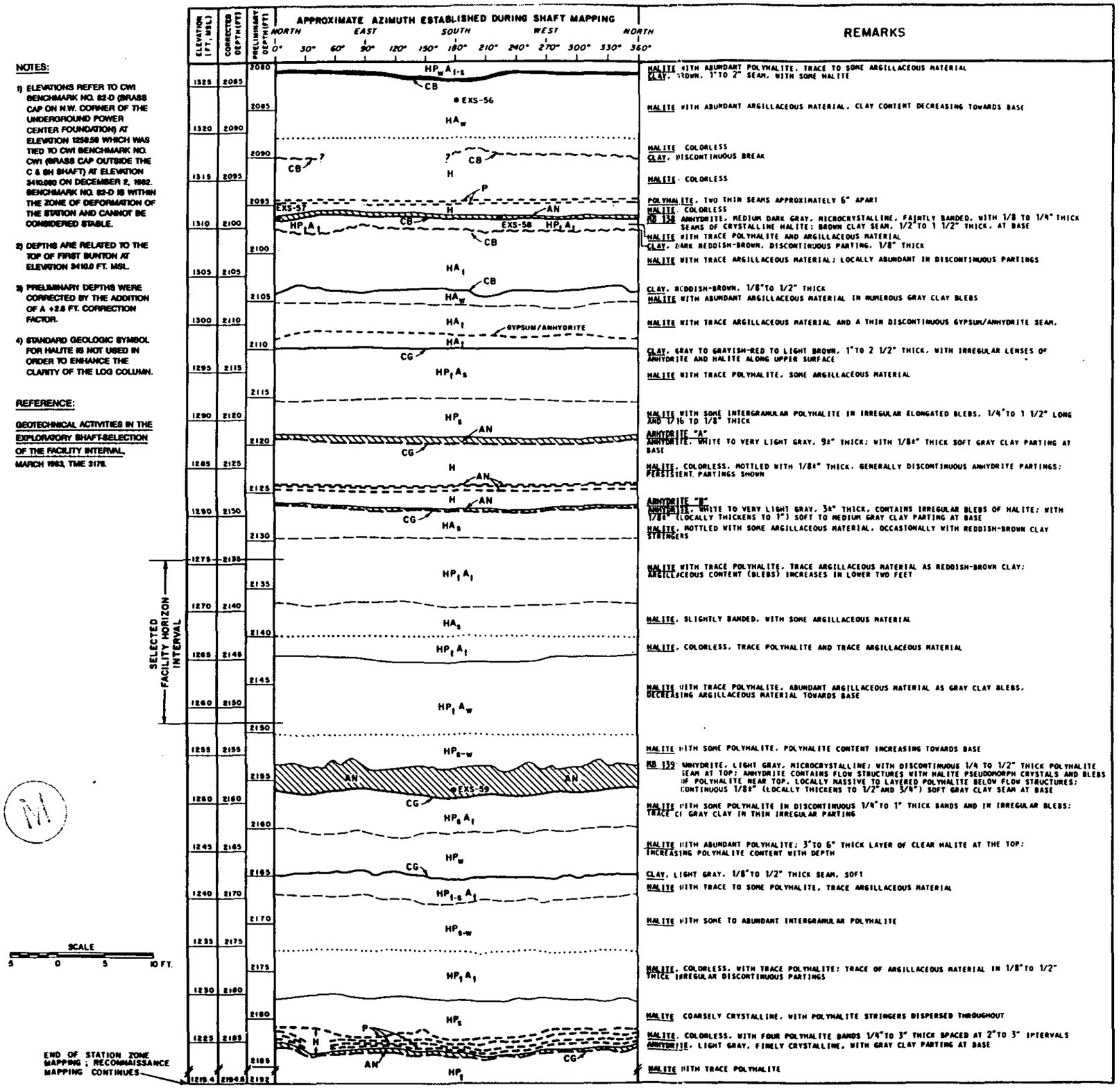

EXPLANATION

ROCK TYPE

HALITE — See note 4

ANHYDRITE

LAMINAR FEATURES

MISCELLANEOUS (AS LABELED)

CLAY: SEAM >1/4" thick; PARTING Between 1/4" 1/16" thick; BREAK <1/16" thick; DISCONTINUOUS PARTINGS AND BREAKS

CONTACTS

SHARP (Identifiable within 0.05 feet)

GRADATIONAL (Identifiable within 0.05 to 0.2 feet)

DIFFUSE (Identifiable within 0.2 to 0.5 feet)

EXS-56 ROCK SAMPLE LOCATION AND NUMBER

CLAY LAYER

GEOLOGIC UNIT SYMBOLS AND DESCRIPTIONS *

A** ARGILLACEOUS MATERIAL, GENERALLY FOUND AS AN INTERGRANULAR ACCESSORY CONSTITUENT, LIGHT GRAY (N7) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY MOIST TO MOIST, TRACE TO SOME SILT.

AN ANHYDRITE, MEDIUM DARK GRAY (N4) TO LIGHT GRAY (N7) TO WHITE (N9), MODERATE ORANGE-PINK (10R 7/4) TO PALE REDDISH-BROWN (10R 5/4), FINELY CRYSTALLINE TO MICROCRYSTALLINE.

CB CLAY, DARK REDDISH-BROWN (10R 3/4), TRACE TO SOME SILT, TRACE TO SOME HALITE.

CG CLAY, MEDIUM LIGHT GRAY (N6) TO MEDIUM DARK GRAY (N4) TO LIGHT OLIVE-GRAY (5Y 6/1), TRACE TO SOME SILT, TRACE TO SOME HALITE.

HA** HALITE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), MEDIUM TO COARSELY CRYSTALLINE, ARGILLACEOUS.

H HALITE, COLORLESS (TRANSPARENT TO TRANSLUCENT) TO GRAYISH-ORANGE-PINK (5YR 7/2), MEDIUM TO COARSELY CRYSTALLINE, MAY BE BANDED.

HP** HALITE, TRANSLUCENT TO MODERATE REDDISH-ORANGE (10R 6/6) TO MODERATE REDDISH-BROWN (10R 4/6), POLYHALITIC.

HPA** HALITE, MODERATE REDDISH-ORANGE (10R 6/6) TO MODERATE REDDISH-BROWN (10R 4/6), POLYHALITIC AND ARGILLACEOUS.

P POLYHALITE, MODERATE REDDISH-BROWN (10R 4/6) TO MODERATE REDDISH-ORANGE (10R 6/6), FINELY CRYSTALLINE TO MICROCRYSTALLINE.

* SLIGHT VARIATIONS FROM THESE GENERAL DESCRIPTIONS MAY EXIST. THE EXCEPTIONS ARE NOTED IN THE REMARKS COLUMN.

** ESTIMATED CONTENT OF ACCESSORY CONSTITUENTS IS INDICATED BY A MODIFIER: T = TRACE; S = SOME; W = WITH OR ABUNDANT

FIGURE D-4

C & SH SHAFT
FACILITY LEVEL AREA GEOLOGY
2080 TO 2192 FEET

20

APPENDIX E

WASTE SHAFT
GEOLOGIC LOGS AND MAPS

CONTENTS

Figure No.	Title/Description
E-1	Lithologic Log 97 to 2286 feet (26 Sheets)
E-2	Magenta Dolomite 597 to 620 feet
E-3	Culebra Dolomite 705 to 727 feet
E-4	Rustler Formation Fracture Zone 779 to 843 feet
E-5	Rustler/Salado Formation Contact 840 to 930 feet (2 Sheets)
E-6	Facility Level Area 2100 to 2170 feet (2 Sheets)

EXPLANATION

ROCK TYPE

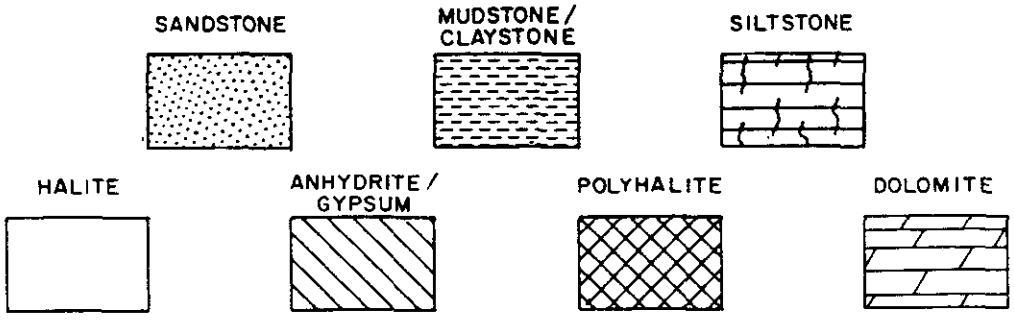

ACCESSORY CONSTITUENTS

ESTIMATED PERCENTAGE OF ACCESSORY CONSTITUENTS INDICATED AS FOLLOWS

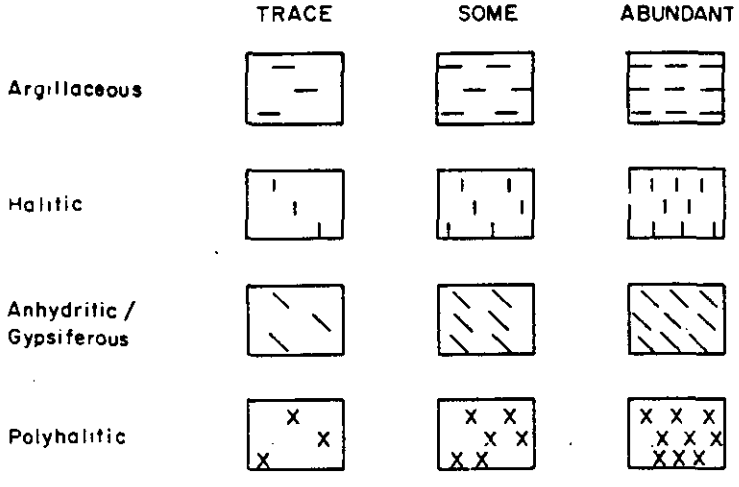

LAMINAR FEATURES

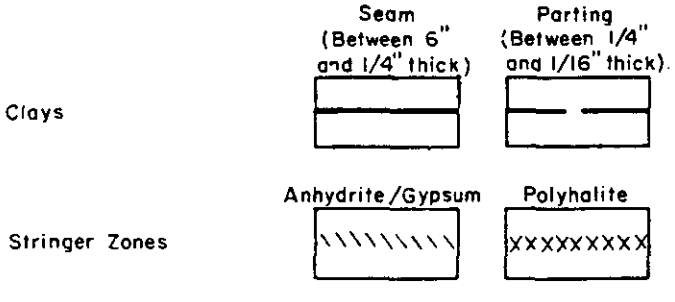

CONTACTS

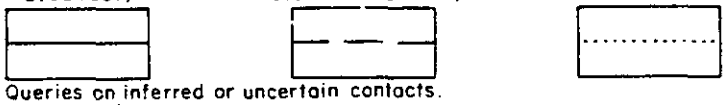

Queries on inferred or uncertain contacts.
"Obscured" where lithologic and stratigraphic details are uncertain in the interval between contacts shown.
See "remarks" for complete description of units.

REFERENCE:

Geotechnical Activities in the Waste Handling Shaft, October 1984, WSTD-TME-038.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 1 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3310	100		Dewey Lake Redbeds Silty fine sandstone and siltstone, reddish-brown, thinly bedded (<4") to laminated; contains local interbeds of fine sandstone and siltstone.
3300	110		Silty fine sandstone and siltstone, reddish-brown; green-gray reduced zones occur as discontinuous bands (<2"), nodules, and lenses.
			As above, without greenish-gray reduced zones.
3290	120		As above, with greenish-gray reduced zones.
			As above, vuggy, particularly 122.6'-122.7'; vugs 1"-2" diameter, up to 5" deep; local sandy zones, especially in greenish-gray reduced zones.
		CONCRETE LINER	Siltstone, reddish-brown, laminated.
3280	130		Siltstone, greenish-gray.
			Siltstone, reddish-brown.
			Alternating layers of fine sandstone and siltstone, 2"-18" each; soft sediment deformation structures; vugs.
3270	140		Silty fine sandstone and siltstone, reddish-brown, thin bedded (<4") to laminated; local interbeds of fine sandstone and siltstone.
			Silty fine sandstone and siltstone, greenish-gray.
3260	150		Silty fine sandstone and siltstone, reddish-brown, thin bedded to laminated.
3250	160		Silty fine sandstone and siltstone; green-gray reduced zones in 1/8"-1/4"-thick, approximately horizontal bands; closed fractures, <1/8", calcite filled, random orientation, few intersect.
			Sandstone, light gray, approximately horizontal; some dark grains.
3240	170		Siltstone, reddish-brown; few, gray, spherical reduced zones (~1/2" diameter); calcareous cement.
3230	180		Sandstone, reddish-brown, silty, very fine grained, non-calcareous; upper contact (4") is light gray; joints/fractures (1/8"-1/2") filled with gypsum, most are subhorizontal, discontinuous, irregular, 1"-1' spacing and offset by high angle fractures.

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FIGURE E-1

WASTE HANDLING SHAFT LITHOLOGIC LOG SHEET 2 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)		STRATIGRAPHIC COLUMN	REMARKS
	180			As above.
				Sandstone, light gray, hard, non-calcareous, fine-grained; irregular, subhorizontal, discontinuous gypsum layers (1/8" - 1/2" thick), 2" - 6" spacing
3220	190			Sandstone, reddish-brown, silty, very fine grained, non-calcareous; gradational contact; gypsum layers; intermittent laminae and cross-bedding.
				As above, without gypsum layers, laminated, cross-bedded near base.
3210	200			Sandstone, reddish-brown, silty, minor cross-bedding and laminations; gypsum layers occur 196.9' downward, greenish-gray, irregular, subhorizontal layers: 196.7'-196.9'; 203.9'-204.1'; ~211.8'; 230.5'; 243.6'-243.8'; 249.3'; 253.1-253.2; 253.8'-255.1'; 265.1'-265.2', gypsum layers less abundant below 221', average spacing >1'.
3200	210			
		CONCRETE LINER		
3190	220			
3180	230			
3170	240			
				Discontinuous, reddish-brown siltstone lenses at 243.3', 249.4'-249.9, 251.5'-253.0'
3160	250			
3150	260			
				Gypsum layer, 1 1/2" maximum thickness, crenulated, with local bifurcations, subhorizontal.
				Sandstone as above, gypsum layers increase in frequency downward, mostly subhorizontal, up to 1" thick; high angle layers are thinner
3140	270			Siltstone, reddish-brown, hard.
				Sandstone, reddish-brown, silty, cross-bedded, and laminated.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 3 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	270	CONCRETE LINER	As above
			Siltstone, reddish-brown, 271.6'-271.7'
3130	280		Sandstone, reddish-brown, silty; greenish-gray layers at 272.8' 272.9', 279.1'-279.3', 284.0'-284.2' gypsum layer decreases downward from 281.1' to 320.1'.
			Siltstone, reddish-brown, sandy.
3120	290		Sandstone, reddish-brown, silty; siltstone layers with underlying gypsum at 305.6'-305.9', 307.6'-307.7', 311.7'-311.8', 312.6'-312.9', 315.2'-316.0', 317.7'-317.9', (*without gypsum*), 318.6'-318.8', (without gypsum); 319.3'-319.4' (without gypsum); irregular greenish-gray layers at 315.9'-316.1', 317.5', 321.9'-322.2', 326.0'-326.4'; gypsum layer frequency increases downward from 321.1' to 326.1'.
3110	300		
3100	310		
3090	320		
3080	330		As above, with dark reddish-brown, sandy siltstone layers at 336.7'-337.0', 343.4'-344.2' (with underlying gypsum layer) greenish-gray, reduced layers at 337.0'-337.4', 343.8'-343.9' 351.3'-351.4, 359.3-359.7', 361.1'-361.2', local increase in subhorizontal and subvertical gypsum layers (335.1'-337.1', 348.1'-362.6').
3070	340		
3060	350		
3050	360		

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FIGURE E-1

WASTE HANDLING SHAFT LITHOLOGIC LOG SHEET 4 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	360		As above
3040	370		Sandstone, reddish-brown, as above, except finely laminated, silty; numerous thin gypsum layers along bedding planes (<1/8"), some subvertical; at 416.1', laminae (1-10mm) grade to more massive bedding, soft sediment deformation structures at 391.1'-393.1' and 401.1'-409.1'
3030	380		
3020	390		
3010	400		
3000	410		
			As above, except massively bedded.
2990	420		Sandstone, occasionally cross laminated; gray-green reduced zone in irregular bands, nodules, and swirls; some beds of reddish-brown mudstone; lens of white sand at 420'.
2980	430		Siltstone, reddish-brown, some very fine sand, hard, massive, occasional thin subhorizontal gypsum partings; spotty gray-green reduced zones (1/8"-1" diam); locally gypsiferous.
2970	440		Sandstone and siltstone interbedded; numerous greenish-gray reduced zones
2960	450		Sandstone, reddish-brown, silty, thin, discontinuous gypsum layers, subhorizontal to subvertical, massive, hard, very fine grained; contains siltstone bed, reddish-brown, moderately hard, somewhat friable (447.4'-447.7'); reduced zone, greenish-gray, silty, discontinuous blebs in horizontal band (458.5'-459.5')

CONCRETE LINER

FIGURE E-1

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WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 5 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	450		As above
2950	460		
			Siltstone or very silty sandstone, hard, massive; abundant reduced spots at base.
2940	470		Sandstone, reddish-brown; gypsum layers abundant and prominent, 467.1'-473.1'; sparse greenish-grey reduced spots near top.
2930	480		Siltstone or silty sandstone, reddish-brown; fewer gypsum layers 473.6'-492.1'
2920	490		Sandstone, reddish-brown; increasing frequency of gypsum layers; few high angle gypsum layers; siltstone lens at 497.7-497.8 containing a greater percentage of horizontal gypsum layers; occasional greenish-grey reduced spots.
2910	500		
2900	510		Siltstone, reddish-brown, sandy, gradational contact, massive, finely bedded at base, hard; thin gypsum layers; sand content *increases below about 511.1'*
2890	520		*Sandstone, reddish-brown, massive, silty to very silty, hard;* thin gypsum seams; occasional reduced spots of varying size; contacts gradational.
2880	530		Siltstone, reddish-brown, sandy, massive, hard, very fine sand; thin gypsum layers; At basal contact gypsum layers surround clasts of siltstone; basal 4" to 6" aquires a purplish hue; basal 1" is reduced; basal contact contains soft sediment deformation features.
2870	540		RUSTLER FORMATION FORTY-NINER MEMBER *See description next sheet.*

CONCRETE LINER

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 6 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	540	CONCRETE LINER	Anhydrite, light gray, hard, finely crystalline; massive in upper part, grading to banded light-dark on a 1/2" scale;upper contact undulates up to 8"; 1/2" to 1" wide gypsum filled fractures occur through out, spacing of 9" to 18"; gypsum filled fractures 1/8" to 1/2" wide occur through out, spacing of 1" to 6"; basal 6" is dark brown, coarse crystalline gypsum.
2860	550		As above, with 3"-4" vugs filled with well developed gypsum crystals, at 557.6'.
2850	560		
2840	570		Claystone, silty.
2830	580		Anhydrite, gray or grayish-white, hard, finely crystaline, gypsum-filled fractures and gypsum stringers, banded near 588.0'
2820	590		
2810	600		MAGENTA DOLOMITE MEMBER Dolomite, with disseminated gypsum (FigureE-2)
2800	610		
2790	620		TAMARISK MEMBER Anhydrite, gray, coarsely crystalline, gypsum occurs in upper part; increasing hardness downward; some high angle gypsum layers ; transition to less gypsiferous anhydrite.
2780	630		Anhydrite, gray, finely crystalline, hard; with gypsum stringers, most sub-horizontal, 1"-2" thick; banding appears light and dark gray, below 651.1' banding replaced by mottled gray coloration; becomes slightly argillaceous toward the base.

FIGURE E-1

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WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 7 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	630		As above
2770	640		
2760	650		
2750	660		Continuous gypsum layer (3/8") with black clay parting (1/8") above and seam (1/4") below at 657.3'-658.0'; white gypsum, soft clay; locally displaced by small fractures with a thrust component of movement.
2740	670		As above, except unmottled, sugary, hard, uniformed
2730	680		Anhydritic claystone
			Anhydrite
2720	690		Claystone, silty
			Anhydrite, light gray, finely crystalline; banded; local black clay laminae; upper 1' gypsiferous, whitish-gray.
2710	700		Clay seam, dark gray, soft, up to 6"; includes thin, discontinuous gypsum seam Anhydrite, as above.
2700	710		CULEBRA DOLOMITE MEMBER Dolomite, contains abundant gypsum filled vugs. (See Figure E-3)
2690	720		

CONCRETE LINER

FIGURE E-1

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WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 8 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	720		Dolomite, contains abundant gypsum filled vugs (See Figure E-3)
2680	730		UNNAMED LOWER MEMBER Claystone
2670	740		Anhydrite
			Argillaceous siltstone and halitic mudstone.
2660	750		Argillaceous halite or halitic mudstone.
2650	760		Halite, argillaceous
			Anhydrite
			Halite
2640	770		Halite, Argillaceous and silty
2630	780		Siltstone, sandy
			Siltstone (See Figure E-4)
		Obscured Contact	Siltstone, sandy
2620	790		Mudstone, reddish-brown, finely laminated with some dark brown laminae and grayish-brown laminae; small cross-laminations and trough cross-laminations; also, some soft sediment deformation features. Sandstone, reddish-brown, silty, upper part finely laminated with small cross-laminations; trough cross-laminated at the base.
2610	300		Claystone, gray, finely laminated, laminae are occasionally terminated erosionally and lensoid in shape; near the base, cross-laminations occur.
2600	810		Mudstone, gray, banded or locally reddish-brown, finely laminated, local cross-laminations; grading to a siltstone at the base.

CONCRETE LINER

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 9 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	810		As above
2590	820		
2580	830		
2570	840		Argillaceous siltstone
			Silty claystone, anhydrite, and anhydritic siltstone.
			SALADO FORMATION
			Claystone, halitic (See Figure B-5)
2560	850	Contact Obscured	Halite
			Halite, argillaceous
			Halite
2550	860		Anhydrite, halitic
			Halite
2540	870		Halite, argillaceous
			Halite
2530	880		Halite, argillaceous
			Halite
2520	890		Halite, argillaceous
			Halite, some argillaceous material; transition to clear halite with trace polyhalite, trace argillaceous material, underlain by 1" seam gray green clayey silt.
			Halite, with abundant argillaceous material.
2510	900		Halite, clear; polyhalite and argillic content increase downward; argillaceous zone (898.2'- 898.3'), with reddish-brown clay blebs and stringers.

CONCRETE LINER

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 10 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	900		As above
			Halite, clear, massive, moderately soft; trace polyhalite
			Halite, argillaceous; trace polyhalite.
			Halite, clear; trace polyhalite.
2500	910		Halite, argillaceous; includes clay seam at 906.1' dipping few degrees NE.
			Halite, clear.
			Halite, reddish-brown, argillaceous and silty; soft gray-green band near upper contact.
2490	920		Halite, less argillaceous than above; trace to some polyhalite; blebs of gray-green siltstone; layers (>1') of clear halite with trace argillaceous material and polyhalite (914.0'-915.0', 916.7'-917.7'); clear halite with white claystone parting (1/8") (919.8'-921.6').
			Polyhalite, red-orange; halitic (921.6'-921.9'); halite, argillaceous, trace polyhalite, soft (921.9'-922.2'); polyhalite, light-orange, medium soft to hard (922.2'-922.8'); halite, clear, and polyhalite in alternating layers (1/4"-1") (922.8'-924.7').
2480	930		Halite; argillaceous content increases downward; trace polyhalite; gray-green siltstone blebs or layers, reduced zones.
			Halite, clear, trace argillaceous material and siltstone; argillic content increases downward between 936.3'-940.4'.
2470	940		Halite, clear, very argillaceous, brown-red; gray-green siltstone at lower contact; undulatory upper contact.
			Halite, brown-red; trace polyhalite, lower argillaceous content than above; gradational contacts.
			Halite, brown-red, very argillaceous; many thin (<1/4") polyhalite stringers.
2460			Halite, red-brown, very argillaceous, soft.
	950		Halite, clear to pale pink, coarse crystals; trace polyhalite increases downward; layer of polyhalite (953.0'-953.2').
			Halite, red to brown red, abundant polyhalite; argillaceous content increases downward, especially 955.6'-955.9'.
2450			Mudstone, silty or siltstone, brown-red, trace halite; massive, medium soft to soft, harder at upper contact and very hard 2"-3" inside wall; fractures.
	960		As above, except light gray.
			Halite, clear to red-brown, some to abundant argillaceous material; some polyhalite, orange to red-brown.
			Polyhalite, reddish-orange, massive, medium soft to medium hard.
2440			Interbedded polyhalite and halite, hard; massive polyhalite; lower portion contains 2"-3" bed of anhydrite.
	970		Halite, red-brown, argillaceous; argillic content decreases with depth and is largely absent below 972.1'; trace polyhalite, increases downward; clear halite alternates with polyhalite and halitic polyhalite in 12"-14" beds near lower contact; hard where argillic content is low.
2430	980		
			Anhydrite, with halite, fine-grained, gray, hard.
2420	990		Halite, clear, high argillic content, red-brown; some discontinous argillaceous stringers and disseminated along crystal boundaries and in crystals; medium to large halite crystals; trace disseminated polyhalite; polyhalitic in lower 1'; some gray-green clay stringers

WIRE MESH

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 11 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	990		As above
2410	1000		Halite, clear; trace polyhalite and argillaceous material in 0.3' bands alternating with discontinuous argillaceous, polyhalitic halite bands, 0.01'; at 999.6', halite bands thicken to ~1'; argillaceous content increases downward in halite bands; polyhalite occurs in layers (up to 1") downward.
			Polyhalite, reddish-orange, thickness ranges 9"-19"; underlain by gray clay seam (1/4") and gray anhydrite and polyhalite (1"-4").
2400	1010		Halite, some argillaceous material; argillic content decreases downward; thin (1/4") clay partings at 1010.6' (gray) and at 1012.1' (reddish brown); argillaceous bed (1010.5'-1011.3').
			Halite, some argillaceous material; argillaceous material evenly disseminated, decreases slightly below 1016.1', wavy, irregular (1/8"-1"), reddish-brown clay seam at 1016.1'.
2390	1020		Anhydrite, dark gray, or banded light and dark gray; halite-rich lenses near upper contact; several subvertical, open (1/4"-1/2") or tight fractures; some halite fracture filling (1031.6'-1033.6').
			Clay, moderate gray and reddish-brown, soft; halite-filled fractures.
			Halite, some argillaceous material, disseminated trace polyhalite; decreasing argillaceous material below about 1038.1'; occasional gray blebs in lower portion
2380	1030	WIRE MESH	Anhydrite, light gray, hard; vuggy and dissolved near upper contact.
			Halite, clear, coarsely crystalline; trace argillaceous material; thin discontinuous anhydrite bands up to 1/2" thick; trace polyhalite at base.
			Polyhalite, reddish-orange, medium soft, some anhydrite.
2370	1040		Halite, clear, coarsely crystalline; trace argillaceous material and polyhalite.
			Halite; some argillaceous material.
			Halite, clear; trace argillaceous material; thin discontinuous polyhalite stringers.
			Halite; some argillaceous material, disseminated; gray clay parting (up to 1/4"), soft, discontinuous (1052.4'); gray and reddish-brown clay parting (up to 1/8"), discontinuous (1054.3'); gray clay stringers and blebs (up to 1/8") (1057.8'-1058.9'); disseminated polyhalite below 1055.1'.
2360	1050		
			Polyhalite, up to 18"; underlain by gray anhydrite (1") and gray and reddish-brown clay (2").
			Halite, some disseminated argillaceous material and trace polyhalite.
2350	1060		Halite; some argillaceous material; some polyhalite in discontinuous stringers; gray clay blebs (up to 1") at 1062.8'.
			Halite, coarse crystalline; trace argillaceous material and polyhalite
			Halite, trace to some argillaceous material; trace polyhalite; polyhalite both disseminated and in discontinuous stringers; polyhalite increases 1074.3' to 1075.1'.
2340	1070		Polyhalite; continuous, irregular layer (3"-4" thick) underlain by soft gray clay at lower contact.
			Halite; some to abundant argillaceous material, decreases downward; few red-brown clay blebs (3"-4" diam.); trace polyhalite.
			Polyhalite; continuous, irregular contacts, 4"-6" thick; immediately overlain by gray clay blebs and underlain by red-brown and gray clay seam (1"-2").
2330	1080		Halite; some to abundant argillaceous material; trace polyhalite.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 12 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1080		As above
			Halite, argillaceous; argillic content decreases downward; gray and red-brown clay blebs at 1085.6'-1087.9'; discontinuous polyhalite stringer at lower contact (1087.9').
2320	1090		Halite, medium to coarse crystalline, trace to some argillaceous material; occasional gray clay blebs; argillic content decreases toward 1091.8', increases toward base; contains polyhalite stringers, blebs, and beds (1"-3" thick) at 1095.9'-1096.0' and 1098.0'-1098.3'.
2310	1100		Halite, clear; trace argillaceous material and polyhalite.
2300	1110		Halite; abundant argillaceous material and gray clay blebs at contact and in upper 1'; trace to some argillaceous material at bottom; trace polyhalite below 1104.1', increases to some downward to 1111.1'; polyhalite bed and stringers, reddish-orange, moderately soft (1113.8'-1114.2').
2290	1120		Halite, clear, trace argillaceous material and polyhalite.
			Halite; trace argillaceous material; polyhalite.
			Halite; argillaceous material; trace polyhalite in continuous stringers (up to 1/2").
2280	1130	WIRE MESH	Polyhalite, reddish-orange to pale-orange; underlain by reddish-brown clay seam (3"-5"), soft.
			Halite; argillaceous with red-brown and gray clay blebs; argillaceous content decreases to trace amount by 1129.1'; halite, clear, at 1133.1' and below.
			Halite, some argillaceous material with few clay blebs; polyhalite-rich zone with trace argillaceous material at 1138.7'.
2270	1140		Halite; some argillaceous material and polyhalite; polyhalite decreases to trace amount below 1142.9'.
			Halite; abundant argillaceous material; with anhydrite blebs and stringers.
			Anhydrite, gray, dense.
			Polyhalite, orange-red, medium hard.
			Anhydrite; gray clay bed (3") underlies anhydrite.
2260	1150		Halite; some (10%) interstitial polyhalite.
			Halite; with anhydrite and some polyhalite in stringers (1/4"-1") at 1156.8', 1157.2', 1157.9', 1159.1', 1159.3', and several discontinuous stringers
			Anhydrite.
			Halite, clear; trace polyhalite.
2250	1160		Anhydrite; layer (2"), underlain by clear halite, with two anhydrite layers (1/4") at 1161.2'-1161.3'; underlain by anhydrite layer (2").
			Halite, clear; two anhydrite layers at 1162.6' (1/4", discontinuous) and at 1163.0' (1/2", continuous).
			Anhydrite, gray, dense; lower 0.2' is polyhalite; clay-rich seam (1164.6'-1165.6').
			Halite; some (~20%) polyhalite
2240	1170		Anhydrite, gray, dense.

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FIGURE E-1

WASTE HANDLING SHAFT LITHOLOGIC LOG SHEET 13 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1170		As above
			Halite; trace to some argillaceous material, dark gray clay; trace polyhalite
2230	1180		Halite, argillaceous, decreasing toward base; trace to some polyhalite, layers (1/2") at 1176.1' and 1176.6' continuous gray-reddish-brown clay seam (~5") at 1178.2'-1178.6'.
			Halite, trace polyhalite, disseminated argillaceous material.
2220	1190		Halite, argillaceous, reddish-brown; trace polyhalite; argillaceous content decreases toward the base.
			Halite, trace to some argillaceous material, trace polyhalite.
2210	1200		Polyhalite; has irregular contacts; underlain by 1"-2" thick gray clay seam.
			Halite; trace polyhalite.
			Polyhalite; irregular anhydrite layers with halite crystals.
2200	1210		Halite; trace to some polyhalite.
			Halite; some argillaceous material; polyhalite bands ≤1/4" thick
			Polyhalite.
			Halite, clear; trace argillaceous material and polyhalite.
			Halite, clear.
2190	1220		Halite, some argillaceous material.
			Anhydrite, gray, dense.
			Halite, clear, thin; discontinuous polyhalite bands, 0.2'-0.4' apart.
			Halite; some polyhalite.
			Halite; trace argillaceous material, with gray clay stringers.
2180	1230		Halite; abundant argillaceous material; nodules (1/2") of reddish-brown clay; argillaceous content decreases to some (1227.8'-1234.7').
			Halite, clear.
			Halite; some polyhalite.
2170	1240		Polyhalite; undulatory upper contact, 0.7' relief; gray clay seam (1"-2" thick) underlies polyhalite.
			Halite; trace to some (≤10 %) polyhalite.
			Halite, some (~10-15%) argillaceous material, discontinuous stringers and disseminated gray clay; trace polyhalite.
2160	1250		Halite, some (10-20%) polyhalite in thin, discontinuous stringers, and interstitially.
			Halite, trace polyhalite in thin, relatively continuous stringers; polyhalite blebs and irregular masses (2"-3" diam.) (1250.9'-1257.5').
			Polyhalite, thickness varies 2"-6", underlain by gray clay seam (1/4"-1/2"); contacts undulatory.
2150	1260		Halite, clear; trace polyhalite.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 14 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1260		As above
			Polyhalite, 16"-18" thick; thin halite layers at 1265.4'; underlain by gray clay seam (1/2").
			Halite, clear.
2140			Halite, clear; trace polyhalite
	1270		Halite; some argillaceous material, gray clay.
			Halite; some (10-20%) polyhalite interstitially, in stringers and scattered blebs; continuous band of polyhalite stringers (1272.4'-1272.8').
			Halite, clear; trace to some polyhalite.
			Halite; trace argillaceous material, gray clay.
2130	1280		Halite, clear; trace polyhalite.
			Halite, some to abundant argillaceous material, reddish-brown clay; reddish-brown clay seam up to 3" thick (1282.4'-1282.5').
			Halite, clear; trace polyhalite in discontinuous layers (<2") at 2187.5' and 2187.8'.
2120			Polyhalite.
	1290		Halite, clear; trace argillaceous material and polyhalite; banded halite and polyhalite near upper contact (1289.6'-1290.1').
			Halite, clear; diffuse contact.
2110	1300		Polyhalite; in stringers (1298.5'-1298.9', 1299.4'-1299.5') and layers (2"-6") (1298.9'-1299.4').
			Halite, clear; trace polyhalite.
			Halite; trace to some polyhalite; several polyhalite layers at 1304.1' (up to ~1/4"), 1304.6' (~1/4"), and 1305.1' (2").
2100	1310		Halite, clear; gradational upper contact.
			Halite; trace to some argillaceous material, reddish-brown.
			Halite, clear; trace polyhalite.
			Polyhalite; some halite.
			Halite, argillaceous; or halitic clay, gray.
2090	1320		Halite, clear; polyhalite blebs.
			Anhydrite; in bands (~1/2") at 1324.0', 1324.2', 1324.4'.
			Polyhalite; anhydrite in lower 3" (1327.4'-1327.8').
			Halite, clear; trace polyhalite.
2080	1330		Halite; some to abundant polyhalite.
			Halite, clear; polyhalite stringers and blebs (1333.6'-1336.6'); distinct polyhalite layers (1/4"-1") at 1336.9', 1337.1'.
			Polyhalite; clear halite layer (~4") at 1339.0'-1339.3'; underlain by gray clay seam (1/4").
2070	1340		Halite, clear; trace polyhalite.
			Mc Nutt Potash Zone Halite; trace to some polyhalite.
			Halite; some argillaceous material and polyhalite.
			Halite; abundant argillaceous material; trace to some polyhalite with large polyhalite blebs.
2060	1350		Halite; some to abundant argillaceous material, reddish-brown, including irregular clay masses and clayey silt.

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FIGURE E-1

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WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 15 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1350		As above
			Halite; trace argillaceous material; some polyhalite.
2050			
	1360		Polyhalite
			Halite; trace to some polyhalite, with stringers in upper 4" (1359.6'-1360.0'); trace polyhalite below 1360.0').
2040	1370		Halite, clear; trace to some polyhalite in stringers.
2030	1380		Halite, some argillaceous material, red-brown, stringer and blebs of polyhalite.
			Halite, polyhalitic, with dark gray clay stringers.
			Polyhalite; 1"-3" thick.
2020	1390		Halite; trace to some polyhalite; trace argillaceous material to 1388.1' only, polyhalite parting (1/8") at 1389.9'.
			Clay, red-brown, gray, halitic, silty.
			Halite; some argillaceous material, trace polyhalite.
2010	1400		Halite, clear; trace polyhalite.
			Clay, gray, reddish-brown to grayish-brown.
			Halite, argillaceous, polyhalitic.
2000	1410		? Halite, clear; trace polyhalite; 1"-2" diam. clay blebs; argillaceous and polyhalite layer (1/2") at 1413.5'.
			Halite, clear; trace to some polyhalite; polyhalite layers (1/16"-2") at 1414.1'-1414.3' and at 1415.5' (1/8").
			Polyhalite; clay seam (1 1/2"-3" thick), gray, with halite stringer underlying.
1990	1420		Halite, clear; trace to some polyhalite.
			Polyhalite; irregular (1/4"-3").
1980	1430		Halite, clear; trace to some polyhalite; at about 1425.6' trace gray clay and polyhalite layer; 1" argillaceous halite layer at 1438.0'.
1970	1440		Polyhalite; underlain by 1/2" gray clay seam.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 16 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1440		As above
			Halite, clear; trace to some polyhalite; polyhalite layers at 1444.9'-1445.0' and 1442.2'-1442.4', locally bifurcate and pinch and swell.
			Polyhalite.
1960	1450		Halite, argillaceous, red brown.
1950	1460		Halite, clear; some polyhalite.
1940	1470		Halite, argillaceous; argillaceous content decreases to base.
1930	1480		Halite, clear; trace to some polyhalite, slightly argillaceous.
1920	1490		Halite, clear; some polyhalite.
1910	1500		Polyhalite; undulatory upper contact (> 6" relief); clay, gray, underlying (~2").
			Halite, clear to white; trace to some polyhalite.
1900	1510		Polyhalite.
			Halite, clear; trace polyhalite.
			Halite, argillaceous, reddish-brown.
			Halite, gray, locally argillaceous.
1890	1520		Halite, argillaceous, reddish-brown.
			Halite, locally argillaceous.
1880	1530		Halite, argillaceous; argillaceous content decreases to base.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 17 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1530		Polyhalite blebs within 6" above contact.
			Polyhalite; with localized halite lenses.
1870	1540		Anhydrite, gray, abundant polyhalite; several horizontal fractures (?); clay-filled lenses parallel bedding plane (≤ 1 1/2"); halite-filled vertical fractures at 1537.3' and 1538.0'; clay seam (1/2"), gray, underlying; undulatory lower contact, 1' relief.
1860	1550		Halite, trace to some (10-25%) polyhalite.
			Halite, some (~10%) argillaceous material, gray.
			Halite, trace to some polyhalite.
			As above; trace gray clay.
			As above; no clay.
1850	1560		Clay, gray seam (3"); halite.
			Halite, argillaceous, some polyhalite; local masses of clear halite.
			Halite; some polyhalite.
1840	1570		Halite, slightly argillaceous; some polyhalite.
1830	1580		Halite; argillaceous zones parallel to bedding.
1820	1590		Halite, clear to white; trace polyhalite; locally argillaceous.
1810	1600		
1800	1610		
			Anhydrite and halite, banded; 1"-3" anhydrite bands.
1790	1620		Anhydrite, gray, hard.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 18 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1620		As above
			Polyhalite, underlain by 1" gray clay seam.
			Halite, clear; trace polyhalite.
1780	1630		
			Anhydrite, gray, finely crystalline; clay partings and seams, gray at 1635.6'(1/4"), 1636.0'-1636.7' (with anhydrite and polyhalite stringer and bands), 1637.3'-1637.4' (soft); polyhalite at 1636.7'-1637.6'.
1770	1640		Halite; trace polyhalite; polyhalite band, 1639.9'; clay seam, gray, at 1643.0'.
			Halite, clear; polyhalite increases to trace amounts below 1646.1'; clay parting, gray, discontinuous, and blebs (1/8"-1/4") at 1650.1'.
1760	1650		Halite, clear; argillaceous (1650.1'-1650.5'); trace polyhalite and argillaceous material (1650.5'-1651.9'); argillaceous, with gray clay blebs (1651.9'-1652.1').
			Halite, clear; trace to some polyhalite; polyhalite decreases downward to 1675.1' before increasing at 1678.1'; possible clay zones between 1652.1'-1675.1'.
1750	1660	WIRE MESH	
1740	1670		
1730	1680		
			Halite, argillaceous; trace polyhalite; clay blebs, gray, upper 1"; red-brown clay blebs below; contacts uncertain.
1720	1690		Halite, clear; trace to some polyhalite.
			Halite, with red-brown clay blebs; (?) clay seam (1/4"-1/2") with polyhalite at 1694.8'.
1710	1700		Halite, clear; trace to some argillaceous material.
1700	1710		Halite, clear; trace polyhalite and argillaceous material.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 19 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1710		As above
1690	1720		
			Halite, coarse (1") crystalline; abundant (~50%) polyhalite.
			Polyhalite, halite.
1680	1730		Clay seam, gray, (4"); underlain by halite, clear; trace polyhalite in halite.
			Halite; discontinuous clay stringers and blebs, reddish-brown (1728.7'-1729.1'); trace polyhalite (1729.1'-1739.1').
1670	1740		Halite clear. (Shaft walls obscured by ~1/2" crust).
			Halite, clear; trace polyhalite.
1660	1750	WIRE MESH	
			Halite; polyhalite stringers.
			Polyhalite, reddish-orange, uniform.
			Halite, clear; trace polyhalite.
			Polyhalite, reddish-orange; underlain by clay seam (1/16"-1").
1650	1760		Halite, clear; trace polyhalite.
			Halite, clear; polyhalite in bands (1/8"-2").
			Polyhalite, pale orange to reddish-brown, anhydritic, halite layers at 1765.4'-1765.6' (thinning to 1/2"), 1766.0'-1766.1'.
1640	1770		Halite, clear; trace polyhalite.
1630	1780		
			? Halite, argillaceous.
			? Halite, polyhalite.
1620	1790		Polyhalite, reddish-orange; 1' gray clay seam at lower contact.
			Halite, clear; trace polyhalite and argillaceous material.
1610	1800		

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 20 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1800		Halite, clear; grading downward to polyhalitic halite; polyhalite layer 1801.6'-1801.7'; halite, clear; trace polyhalite (1801.7'-1802.1'); underlain by gray clay seam (1802.1'-1802.3').
			Halite, clear; trace to some polyhalite.
1600	1810		Halite, clear, coarsely crystalline; stringers or blebs of polyhalite.
1590	1820		Halite, clear; gray clay stringers.
1580	1830		
1570	1840		Halite; trace polyhalite.
1560	1850		Polyhalite; reddish-orange.
			Halite; trace polyhalite; gray clay seam (~2") at 1852.2', contains halite crystals, grading downward to argillaceous halite.
1550	1860		Halite, clear; trace polyhalite.
			Halite, clear; trace to some polyhalite in stringers.
			Halite, clear; polyhalite bands, pale orange to light orange.
1540	1870		Polyhalite.
			Clay, gray, very stiff, with halite crystals.
			Halite; abundant argillaceous material; trace polyhalite.
1530	1880		Polyhalite; clear halite above and below polyhalite.
		(Obscured)	Halite, clear, slightly argillaceous.
1520	1890		Halite, clear; trace polyhalite.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 21 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1890		As above
			Halite, polyhalitic, argillaceous.
1510	1900		Halite, clear.
			Polyhalite; slightly undulatory lower contact; with clay seam (1/4"-1/2") at base.
			Halite, clear; trace polyhalite.
1500	1910		
			Halite, clear; polyhalite increasing downward.
			Halite, polyhalitic halite, and polyhalite, in alternating bands.
1490	1920		Polyhalite, reddish-orange; with discontinuous halite layers at 1920.3'-1920.4'
			Anhydrite, gray, finely crystalline; trace polyhalite; underlain by gray clay and reddish-orange polyhalite layer (1921.4'-1921.6').
			Halite; some polyhalite; slightly argillaceous.
			Halite; argillaceous; some polyhalite.
1480	1930		Halite, slightly argillaceous; some polyhalite.
			Halite; argillaceous (gray); slightly polyhalitic.
1470	1940		Halite; argillaceous (gray), content decreases to base.
			Polyhalite.
			Anhydrite, light orange to gray, polyhalitic; grades downward to gray, with trace polyhalite.
			Halite, clear.
1460	1950		Anhydrite, gray, hard.
			Clay, gray (0.1'), hard.
			Halite, argillaceous in bands and stringers.
1450	1960		Halite, clear; trace polyhalite; at lower contact becomes polyhalitic and anhydritic.
1440	1970		Anhydrite, gray, hard; weathered anhydrite or anhydritic clay (4") at lower contact.
1430	1980		Halite; locally argillaceous in bands, content decreases to base.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 22 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	1980		As above
1420	1990		Halite, clear to white; local argillaceous stringers.
			Halite, anhydritic; alternating beds.
			Anhydrite, gray, hard; slightly undulatory lower contact; underlain by clay parting (~1/8")
1410	2000		Halite, clear to white, argillaceous in stringers and bands; some polyhalite near the base.
1400	2010		Halite, clear, trace of gray argillaceous stringers becoming more argillaceous toward the base.
1390	2020		
1380	2030		Halite, polyhalite; uncertain contact.
			Anhydrite, gray, hard; undulatory upper contact.
1370	2040		Polyhalitic anhydrite, fine crystalline.
			Anhydrite, gray, fine crystalline; clay seam, gray, at 2045.1'-2045.3
1360	2050		Halite, clear; trace to some polyhalite; locally argillaceous in stringers.
1350	2060		Halite, clear.
1340	2070		Halite, clear; trace argillaceous material; trace polyhalite.

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 23 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	2070		As above
1330	2080		
			Halite, clear; some polyhalite.
			Anhydrite, halite, gray, finely crystalline; 2" thick; both contacts undulatory.
			Halite, clear; some polyhalite; slightly argillaceous.
1320	2090		Halite, white to clear, coarse crystalline; some polyhalite; argillaceous at top.
1310	2100		Halite, argillaceous; trace polyhalite; clear halite occurs in pods; argillaceous content decreases toward the base.
			Halite, clear; trace polyhalite.
1300	2110	WIRE MESH	Anhydrite, very light gray, hard, dense; gray and brown clay at 2110.1' - 2110.2'.
			Halite, argillaceous, medium soft to medium hard.
			Halite, clear; trace to some argillaceous material.
			Halite, clear.
1290	2120		
1280	2130		
			Halite, clear; some polyhalite; anhydrite layer (1/2") at 2131.6'.
			Anhydrite, light gray, hard, dense; underlain by clay seam (1/4").
			Halite, argillaceous; trace polyhalite.
1270	2140		Halite, clear; polyhalite increases downward to trace amounts; argillaceous material increases downward to trace to some; anhydrite layer (1/4") at 2140.4'; anhydrite, light gray, dense, hard (2140.6' - 2140.8'); underlain by clay parting (1/8"-1/4").
			Halite; trace polyhalite.
1260	2150		End of reconnaissance mapping.
			FACILITY LEVEL (See Figure E-6)
1250	2160		

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FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 24 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	2160	As above	Start of sump mapping. Halite, white to reddish orange, coarse to very coarsely crystalline, polyhalitic; undulatory basal contact.
1240	2170		Anhydrite, with polyhalite, medium gray to very light pink, finely crystalline to sugary texture; thinly laminated to banded (horizontal to subhorizontal); anhydrite color banded white to medium gray in lower 2'; basal 4" is dark gray claystone; basal contact undulates 4" - 5", wavelength 3".
			Halite, white to clear with thin seams or gray clay/anhydrite and irregular seams to clots of orange polyhalitic halite, medium to coarse crystalline, structureless; polyhalite and clay/anhydrite seams content decreases toward base; basal contact gradational.
1230	2180	WIRE MESH	Halite, light pink to orange, medium to coarsely crystalline, polyhalitic; thin (1" - 1.5") polyhalite seam at base, polyhalite dark orange and contains large halite crystals; 1.5' wide shallow dissolution pit at base; basal contact sharp.
			Halite, white to light gray with local orange areas, coarse to very coarse crystalline, faintly bedded to structureless; irregular gray clay seams at top and through-out; basal contact gradational.
1220	2190		Halite, with some clay/anhydrite; orange to white near top, orange and medium brown near base, coarsely to very coarsely crystalline, faint bedding, polyhalitic; clay/anhydrite becomes more abundant near base; basal contact irregular (2" - 5" vertical variations) and gradational.
			Halite, white to orange with some clear halite masses, coarsely to very coarsely crystalline, broadly banded (2" - 4"), trace polyhalite; basal contact irregular over 2" and diffuse.
1210	2200		Halite, orange to white with clear irregular masses, coarsely to very coarsely crystalline, trace polyhalite; crudely color banded; poorly defined subhorizontal bedding; basal contact based on color and is gradational.
			Halite, white to slightly pink, medium to coarsely crystalline, trace polyhalite; gray 2" - 4" anhydrite bed with underlying gray clay seam (1/8") near top; 3" deep, 8" - 16" wide dissolution pit into the underlying unit occurs at the basal contact; over dissolution pit, anhydrite bed is downwarped 4" - 6"; basal contact gradational.
1200	2210		Halite, anhydritic and argillaceous; light gray with white and clear zones, crudely bedded; becomes less anhydritic and argillaceous with depth; basal contact gradational.
			Halite, white to light brown, finely to medium crystalline, sugary texture; contains 1/8" beds of anhydrite spaced 2" - 4", content decreases toward the base; basal contact gradational.
			Halite, white to very light orange, medium to coarsely crystalline, structureless, sugary texture; basal contact gradational.
1190	2220		Halite, orange and white, finely to medium crystalline at top grades to medium to coarse crystalline at base, indistinct bedding, polyhalitic; horizontal to subhorizontal light gray bands of anhydrite near top; lower 20" - 40" contains masses of coarsely crystalline halite; polyhalite content increases toward base; basal contact sharp.
1180	2230		Anhydrite, gray, very finely crystalline, crudely bedded at top, finely bedded at base.
			Polyhalite, pink, structureless at top grading to crudely bedded at base.
			Clay/anhydrite, gray; basal contact sharp.
			Halite, white to light orange, medium to coarsel crystalline; basal contact slightly irregular; sharp.
1170	2240		Anhydrite, very dark brownish-gray with thin layers (1/5" - 2/5") of light gray to white, microlaminated to thinly bedded; occasionally, white bands are closely spaced and lenticular; 1" - 6" thick bed of gray clay occurs at base; basal contact irregular (erosional ?), sharp.
			Halite, white to slightly pink; upper 12" - 16" contains gray clay-rich anhydrite in large clots (8" - 12" diameter), smaller clots (< 2" diameter), and in thin interbeds; remainder is halite, medium to coarsely crystalline, weakly bedded; lower 1" - 2" is reddish-brown to gray clay; basal contact sharp, undulatory (2" - 4"), slightly periodic (3" - 6"), and truncates bedding in underlying unit.
1160	2250		Halite, argillaceous/anhydritic in upper part, lower 20" polyhalitic; thin to medium bedded in upper part; bedding truncated at upper contact.

FIGURE E-1

PREPARED BY RMH DATE 9/13/84
CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 25 OF 26

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
	2250	XXXXXXXXXXXX	As above
			Halite, argillaceous and anhydritic, orange to reddish-brown, medium to coarsely crystalline, bedded; upper 1"-6" reddish-brown to gray halitic claystone; basal contact gradational.
		X	Halite, white to very light orange with discontinuous orange bedding; trace polyhalite; basal contact undulatory (8") and gradational.
1150	2260	XXXXXXXXXXXX	Halite, light pink to orange to light brown; upper part, irregular alteration of pink and brown; lower 3', massive and brown; basal contact gradational to diffuse.
			Halite, light orange to orange to light brown, coarsely to very coarsely crystalline; discontinuous 1"-2" subhorizontal polyhalite layers at and near base; basal contact slightly irregular, sharp.
1140	2270		Anhydrite, with some polyhalite, gray to orange; occassionally continuous with overlying polyhalite, very thin gray clay bed at base; basal contact slightly undulatory (4"), sharp.
			Halite, similar to halite overlying the above unit; includes irregular zones of clear halite; basal contact sharp.
1130	2280		Halite, argillaceous and anhydritic, white to very light orange to reddish-brown; clay content decreases toward base; upper 2"-3" contains discontinuous reddish-brown mudstone that is disrupted by dissolution pits filled with clear halite; clay rich zones are tabular clots occassionally arranged in crude layers; basal contact gradational to diffuse.
			Halite, similar to above.
			Halite, similar to above.
			Bottom of waste shaft sump
1120	2290		

FIGURE E-1

PREPARED BY RMH DATE 9/13/84
CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 26 OF 26

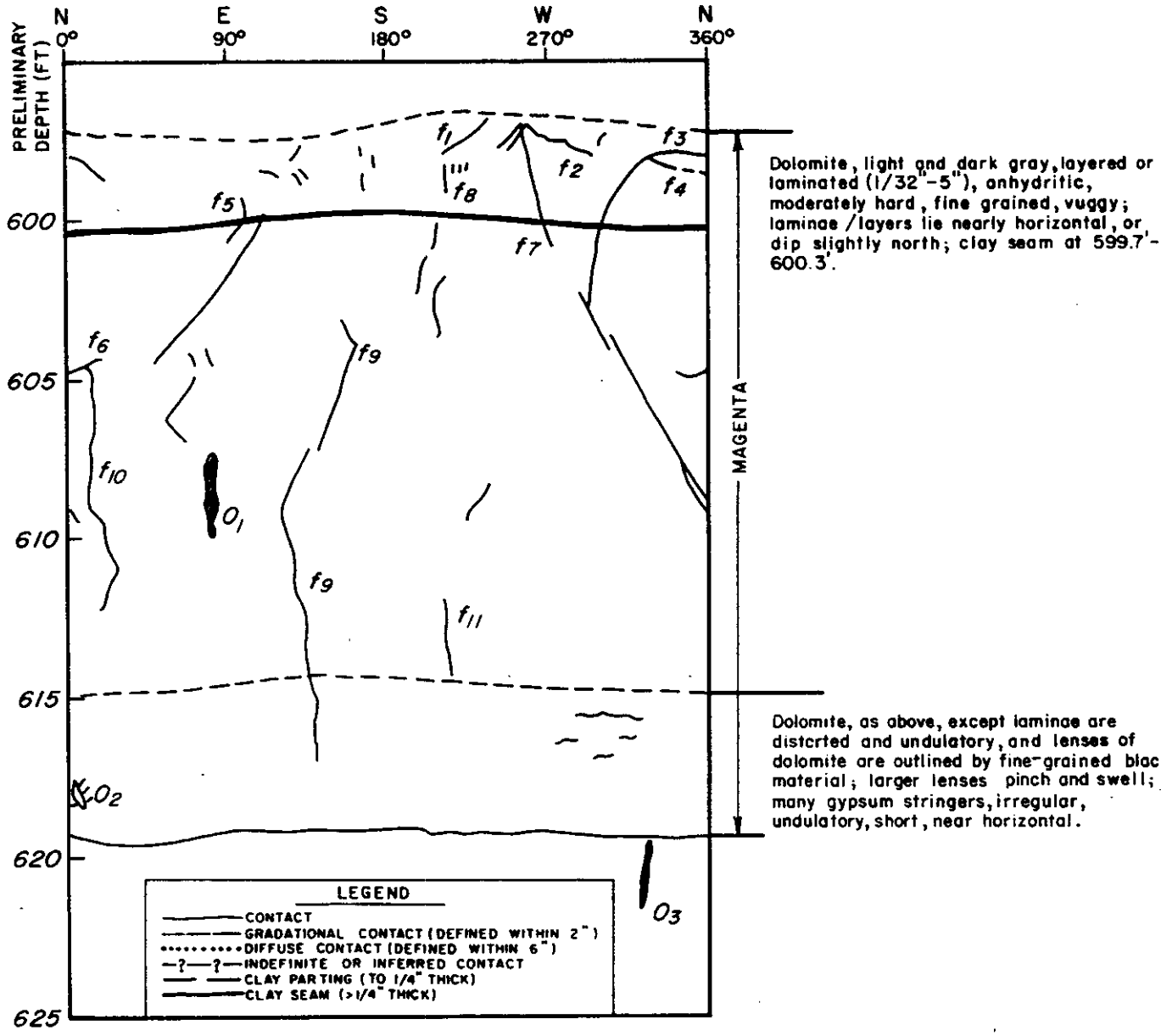

FRACTURE NOTES

f1 Open.

f2 Open.

f3 Gypsum filled near the north extent, open (1/2") or accompanied by gypsum dissolution on west wall.

f4 Open (1/32").

f5 Open (1/32"); gypsum filled at depth, appears to offset laminae in dolomite.

f6 Open (1/32") near upper terminus; filled near 604'; open (1/16"-1/2") toward lower terminus; composed of several small fractures.

f7 Open (1/16").

f8 Fracture connects vuggy or leached zone to the west.

f9 Open (up to 1/4"), some gypsum fill has been leached.

f10 As *f9*

f11 Open (1/16"); small amount of gypsum fill.

OTHER NOTES

O1 Iron oxide (red) stain.

O2 Large dolomite clast embedded in laminated dolomite; laminae distorted downward around clast.

O3 Solution feature in underlying Rustler Formation (anhydrite)

REFERENCE:

Geotechnical Field Data Report No. 4, 1983, Geologic Mapping & Water Inflow Testing in SPDV Ventilation Shaft.

Figure E-2
WASTE SHAFT
MAGENTA DOLOMITE
597 TO 620 FEET

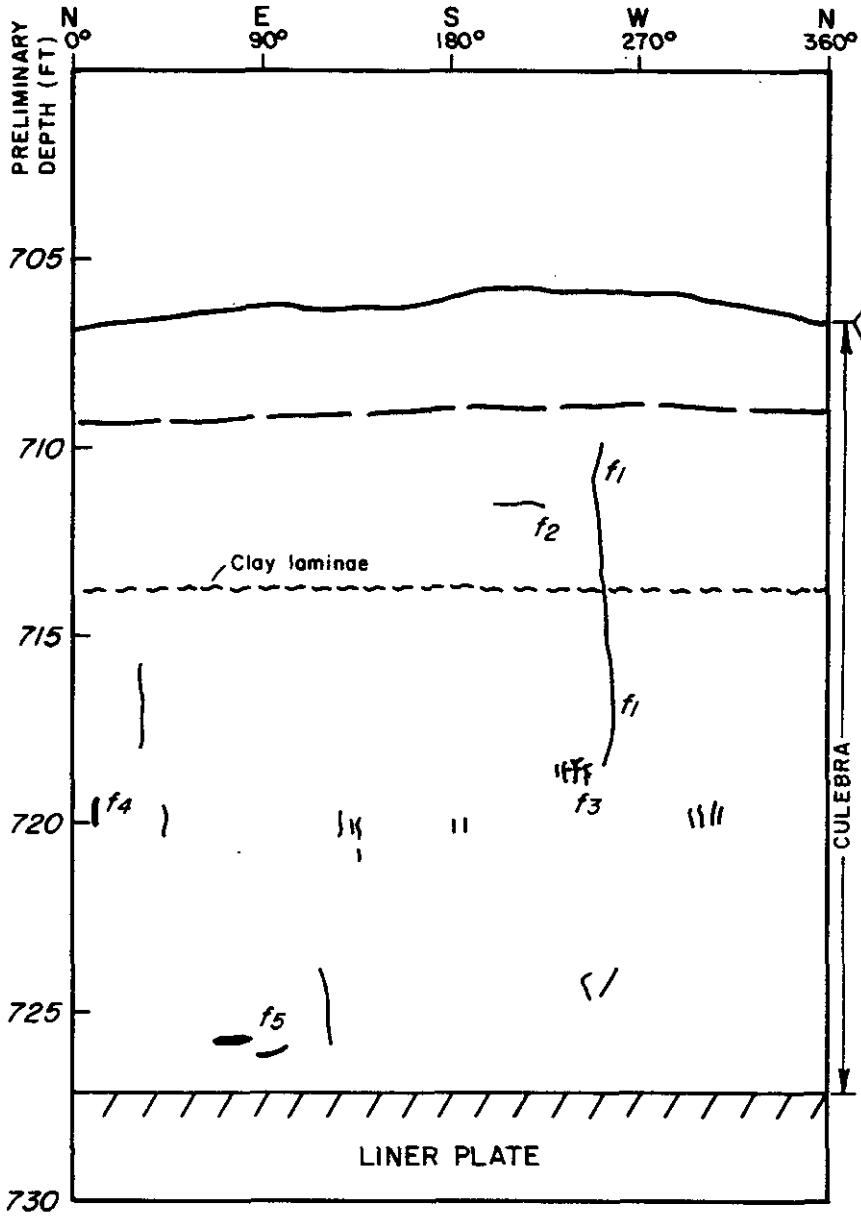

Anhydrite, gray, banded, sandy or silty, calcareous, laminated, with laminae finer downward; near lower contact, laminae are distorted.

Clay, black seam (1"), soft where exposed, stiff to hard, dry inside shaft wall

Dolomite, light gray, hard, fine-grained, vuggy; clay, black-gray parting (1/16") at 709.0', dipping slightly north; large vugs (1"-2" deep) in 1'-2' zone at 712.0'; series of clay laminae, black, dip slightly to north at ~ 714.5'-714.8'.

REFERENCE:

Geotechnical Field Data Report No. 4, 1983, Geologic Mapping and Water Inflow Testing in SPDV Ventilation Shaft.

FRACTURE NOTES

f1 Closed, tight, clay fill.

f2 Closed, tight.

f3 Series of short, hairline fractures; at 718.0' hairline fracture density increases.

f4 Open, up to 1/8", filled with soft erodable material (clay?).

f5 Sparry calcite or dolomite, may be fracture fill.

LEGEND

- CONTACT
- GRADATIONAL CONTACT (DEFINED WITHIN 2")
- DIFFUSE CONTACT (DEFINED WITHIN 6")
- —?—?— INDEFINITE OR INFERRED CONTACT
- CLAY PARTING (TO 1/4" THICK)
- CLAY SEAM (> 1/4" THICK)

Figure E-3
WASTE SHAFT
CULEBRA DOLOMITE
705 TO 727 FEET

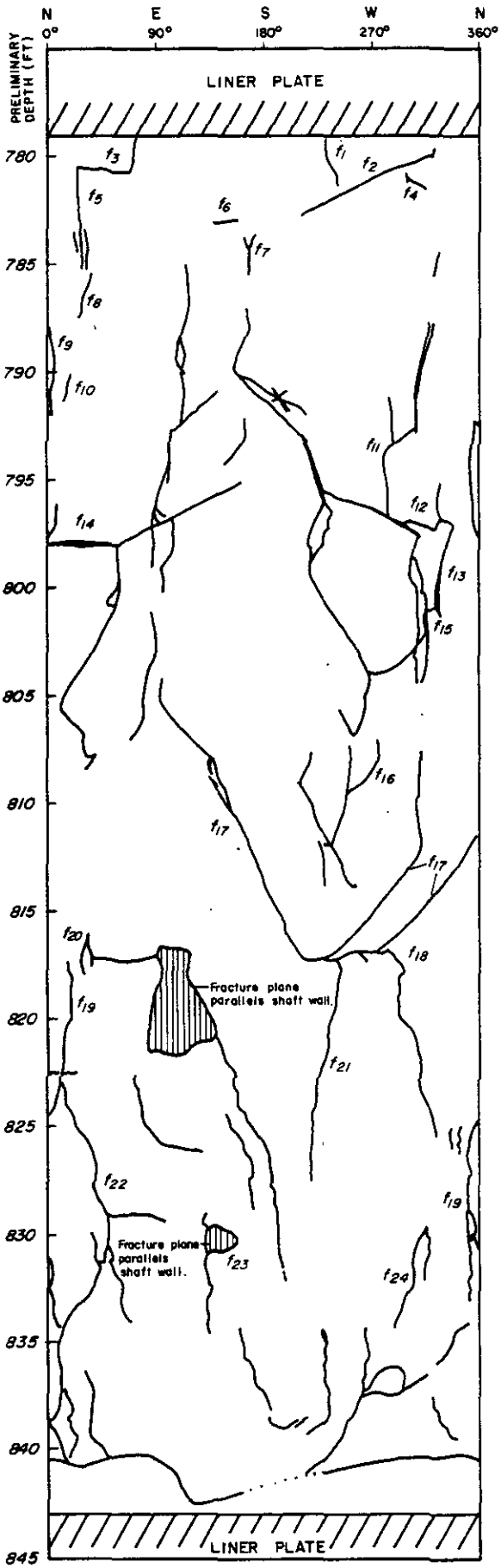

Host rock is dark reddish-brown mudstone.

FRACTURE NOTES

f_1	Open (1/4"-1").
f_2	Open (1/4"-1/2").
f_3	Open (1/4"-1").
f_4	Open.
f_5	Open (1/4").
f_6	Open (1"), 1 1/2" deep into shaft wall.
f_7	Open (1/4").
f_8	Open (1/2")
f_9	Open (1/8"-1"), polyhalitic halite fill.
f_{10}	Open (1/8")
f_{11}	Open (1/16") to closed.
f_{12}	Open (2"); polyhalite and halite fill actively dissolving.
f_{13}	Open (3/4"); polyhalite and halite fill
f_{14}	Open (1/8"- 2 1/2"), up to 1' deep in shaft wall
f_{15}	Open (1"); polyhalite fill.
f_{16}	Open (1/16").
f_{17}	Open (1/4"-3/4"); halite fill remnants.
f_{18}	Open (1/4") to closed.
f_{19}	Open (1/4") to closed
f_{20}	Open (1/4"-1"); halite fill remnants; curved fracture strikes S5E to S25E.
f_{21}	Open (1/4") to closed.
f_{22}	Closed; below 830', open (1/8"-1/4"); probable halite fill.
f_{23}	Fracture plane roughly parallels wall, strike N80E.
f_{24}	Closed.

REFERENCE:

GEOTECHNICAL FIELD DATA REPORT NO. 4, 1983, GEOLOGIC MAPPING AND WATER INFLOW TESTING IN SPDV VENTILATION SHAFT.

FIGURE E-4

WASTE SHAFT
RUSTLER FORMATION FRACTURE ZONE
779 TO 843 FEET

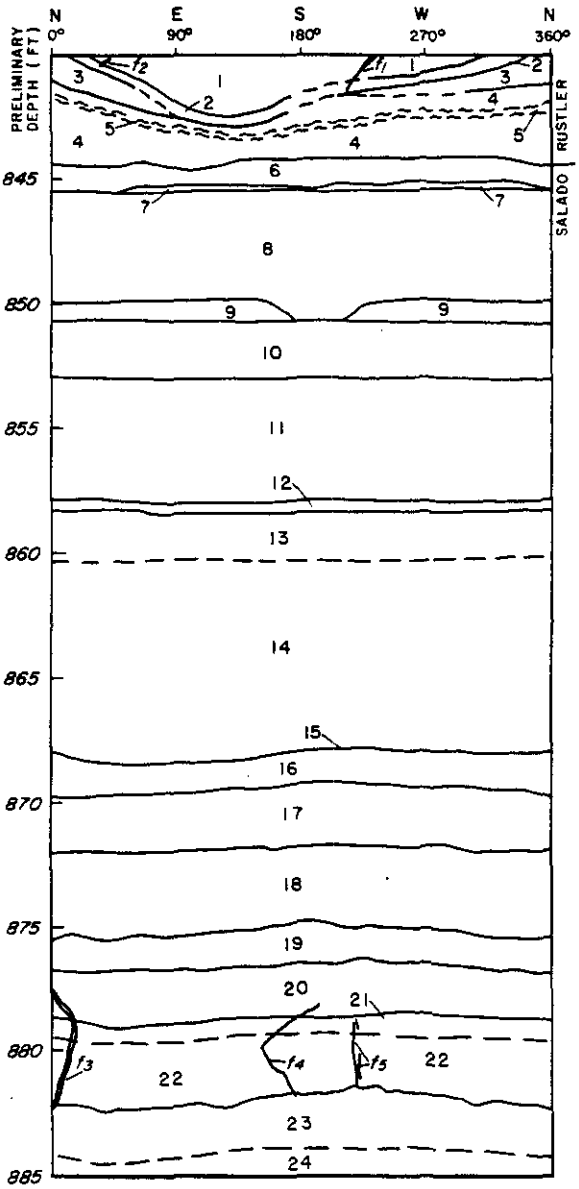

EXPLANATION

1 Mudstone, light gray to reddish-brown, silty.

2 Mudstone, dark reddish-brown, silty (clay siltstone), 3"-6" thick; finer grained than 1; minor deformations due perhaps to dissolution below

3 Mudstone or siltstone, banded dark and light gray, silty, fine sand.

4 Mudstone or siltstone, reddish-brown, fine-grained, and softer than 3.

5 Anhydrite, light gray; bands (1/8"-1/2") in an ~2" thick zone in unit 4

6 Dissolution residue, granular, soft, loose material, dark reddish-brown.

7 Polyhalite, moderate reddish-orange; pinch and swell (0--5"); locally underlain by dissolution residue.

8 Halite, light reddish-brown to reddish-orange; polyhalite disseminated in upper 1', locally rich polyhalite pockets, trace disseminated elsewhere, polyhalite-rich at lower 1'; argillaceous material as surface residue (clay).

9 Clayey mudstone or silty claystone, dark reddish-brown, 0-12" thick.

10 Halite, dark reddish-brown; some argillaceous material.

11 Halite, light reddish-brown to clear; trace polyhalite; argillaceous in upper 1'-11/4'.

12 Anhydrite and polyhalite, light gray to light reddish-orange, fine granular, 6" thick, underlain by seam (1"-2") of clay, dark reddish-brown, soft.

13 Halite, dark to moderate reddish-brown; some polyhalite and argillaceous material.

14 Halite, clear to light reddish-brown, banded, trace polyhalite, in stringers and bands (3"-6").

15 Siltstone or mudstone, gray-green, sandy; anhydrite blebs, variable thickness (1/8"-1").

16 Halite, reddish-brown, argillaceous; clayey residue on shaft wall.

17 Halite, polyhalitic; indistinct banding; polyhalite veinlets along crystal boundaries; polyhalite content increases downward.

18 Halite, argillaceous material, reddish-brown; clayey residuum on shaft surface.

19 Halite; trace polyhalite, trace argillaceous material; irregular upper contact.

20 Mudstone, reddish-brown, gray-green mottling with higher silt content, soft where weathered.

21 Mudstone, gray-green, sandy to silty, hard.

22 Mudstone, reddish-brown, hard.

23 Halite, reddish-brown, argillaceous; clay residuum on shaft surface.

24 As above; transition to lower argillaceous content.

LEGEND

- CONTACT
- GRADATIONAL CONTACT (DEFINED WITHIN 2")
- DIFFUSE CONTACT (DEFINED WITHIN 6")
- ?—?— INDEFINITE OR INFERRED CONTACT
- CLAY PARTING (TO 1/4" THICK)
- CLAY SEAM (>1/4" THICK)

FRACTURE NOTES

f1 Open (up to 1/4") to closed; ends with depth

f2 Open (up to 1/16") to closed, nearby vertical fractures are general closed and discontinuous.

f3 Strike ~ N 45° E; halite fill, 1/2" wide, increases downward to 1-1/2" to 2"

f4 Strike ~ N 30° E

f5 Strike N 60° E; uncertain upward extent

REFERENCE:

GEOTECHNICAL FIELD DATA REPORT NO 4, 1983, GEOLOGIC MAPPING AND WATER INFLOW TESTING IN SPDV VENTILATION SHAFT

FIGURE E-5

WASTE SHAFT
RUSTLER/SALADO FORMATION CONTACT
840 TO 930 FEET

SHEET 1 OF 2

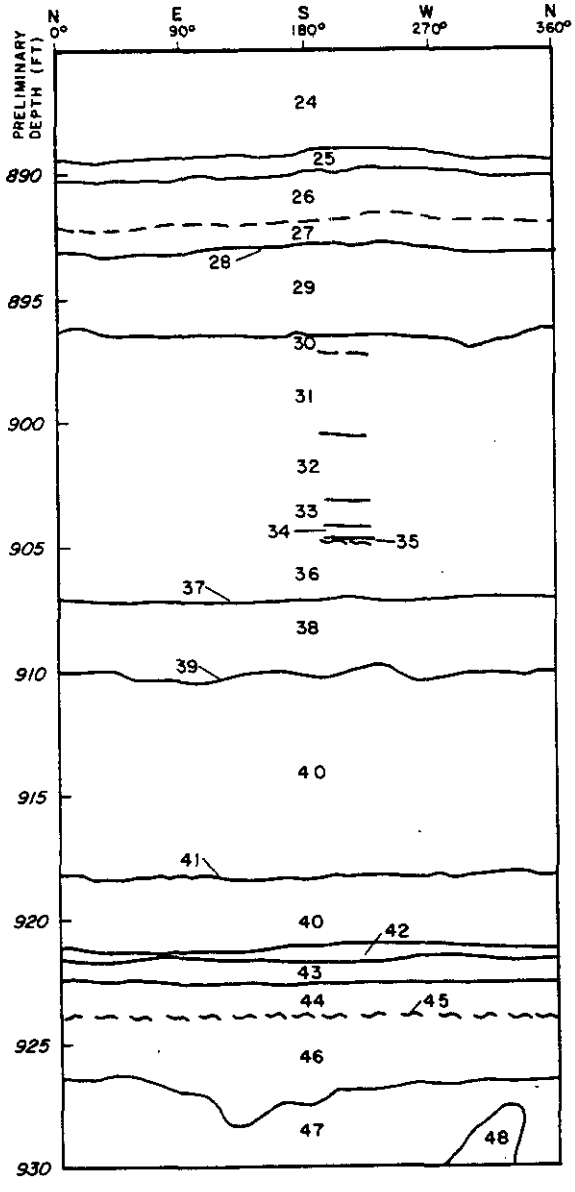

EXPLANATION

25 *Halite; argillaceous content higher than 24.*

26 Halite; some argillaceous material.

27 Halite, clear; trace polyhalite and argillaceous material; transition from 26.

28 Silt, gray-green, clayey, ~1".

29 Halite; some to abundant argillaceous material; clayey residuum on shaft surface.

30 Halite, clear.

31 Halite, polyhalitic.

32 *Halite, clear.*

33 Halite, polyhalitic, argillaceous.

34 Halite, clear.

35 Clay, gray thin seam (~ 1/8").

36 Halite, polyhalitic, argillaceous.

37 Clay, gray and reddish-brown seam (0.1'-0.3').

38 Mudstone, halite and/or very argillaceous halite; stiff clay; halite crystals up to 1'.

39 Clay, gray and reddish-brown seam (0.1'-0.3').

40 Halite; some argillaceous material.

41 Clay, gray and reddish-brown; and polyhalite, reddish-orange seam (1/4"-1/2"), soft.

42 Polyhalite, pale orange; underlain by anhydrite, gray, dense, 1/4".

43 Halite, polyhalite; thinly interbedded.

44 Halite, clear; trace polyhalite.

45 Clay parting, gray.

46 Halite, abundant argillaceous material, reddish-brown with gray blebs; grades to halitic mudstone; halite crystals up to 1/2".

47 Halite; some to abundant argillaceous material.

48 Clay, reddish-brown, few gray blebs; inclusion in 47; disseminated halite.

LEGEND

CONTACT
GRADATIONAL CONTACT (DEFINED WITHIN 2")
DIFFUSE CONTACT (DEFINED WITHIN 6")
INDEFINITE OR INFERRED CONTACT
CLAY PARTING (TO 1/4" THICK)
CLAY SEAM (>1/4" THICK)

FIGURE E-5
WASTE SHAFT
RUSTLER/SALADO FORMATION CONTACT
840 TO 930 FEET

SHEET 2 OF 2

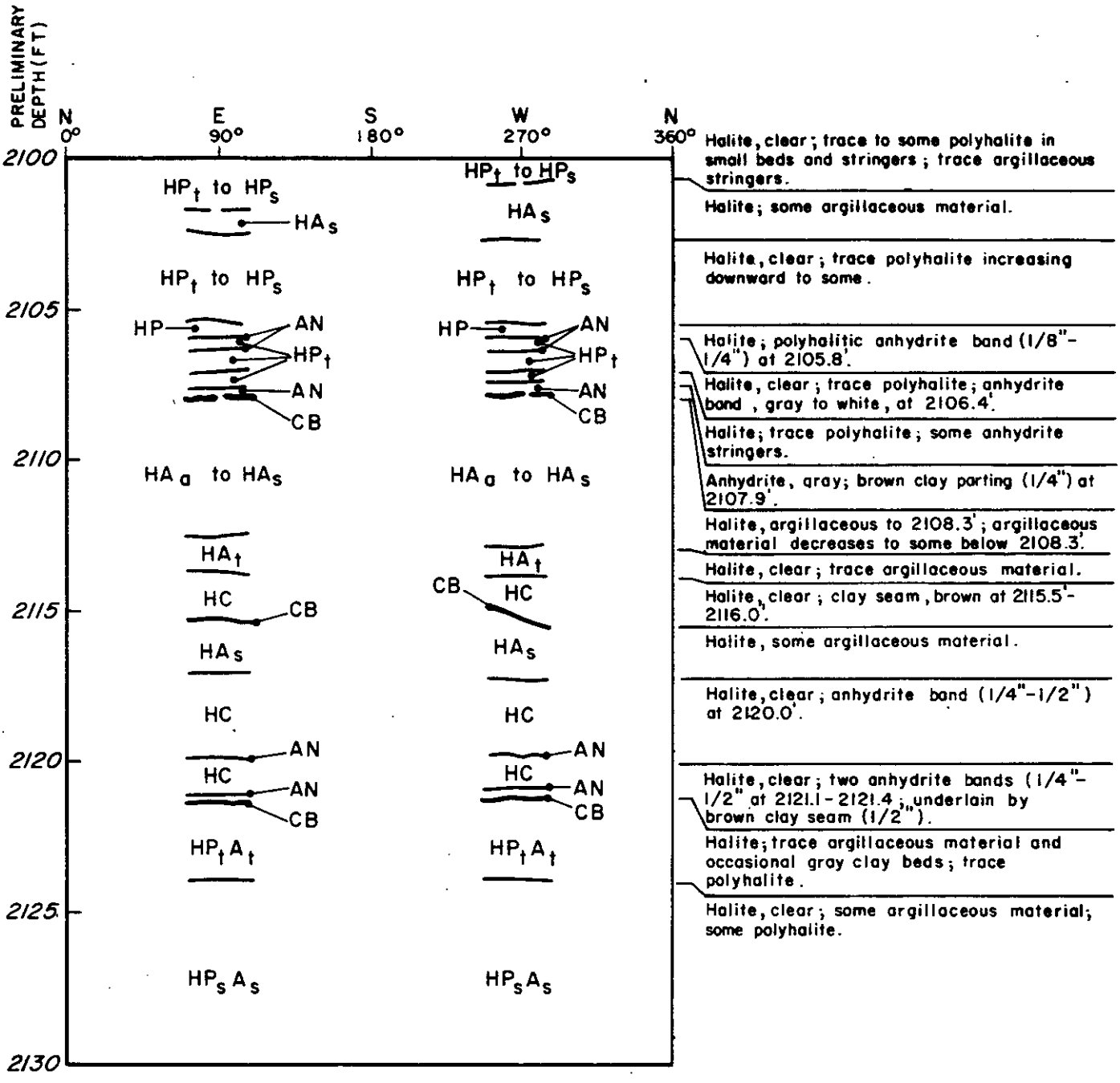

LEGEND

- ——— CONTACT
- ——— GRADATIONAL CONTACT (DEFINED WITHIN 2")
- •••••••••• DIFFUSE CONTACT (DEFINED WITHIN 6")
- —?—?— INDEFINITE OR INFERRED CONTACT
- — — — — CLAY PARTING (1/4" TO 1-1/16" THICK)

REFERENCE:

GEOTECHNICAL FIELD DATA REPORT NO. 4, 1983, GEOLOGIC MAPPING AND WATER INFLOW TESTING IN SPDV VENTILATION SHAFT.

FIGURE E-6
WASTE SHAFT
FACILITY LEVEL AREA
2100 TO 2170 FEET

SHEET 1 OF 2

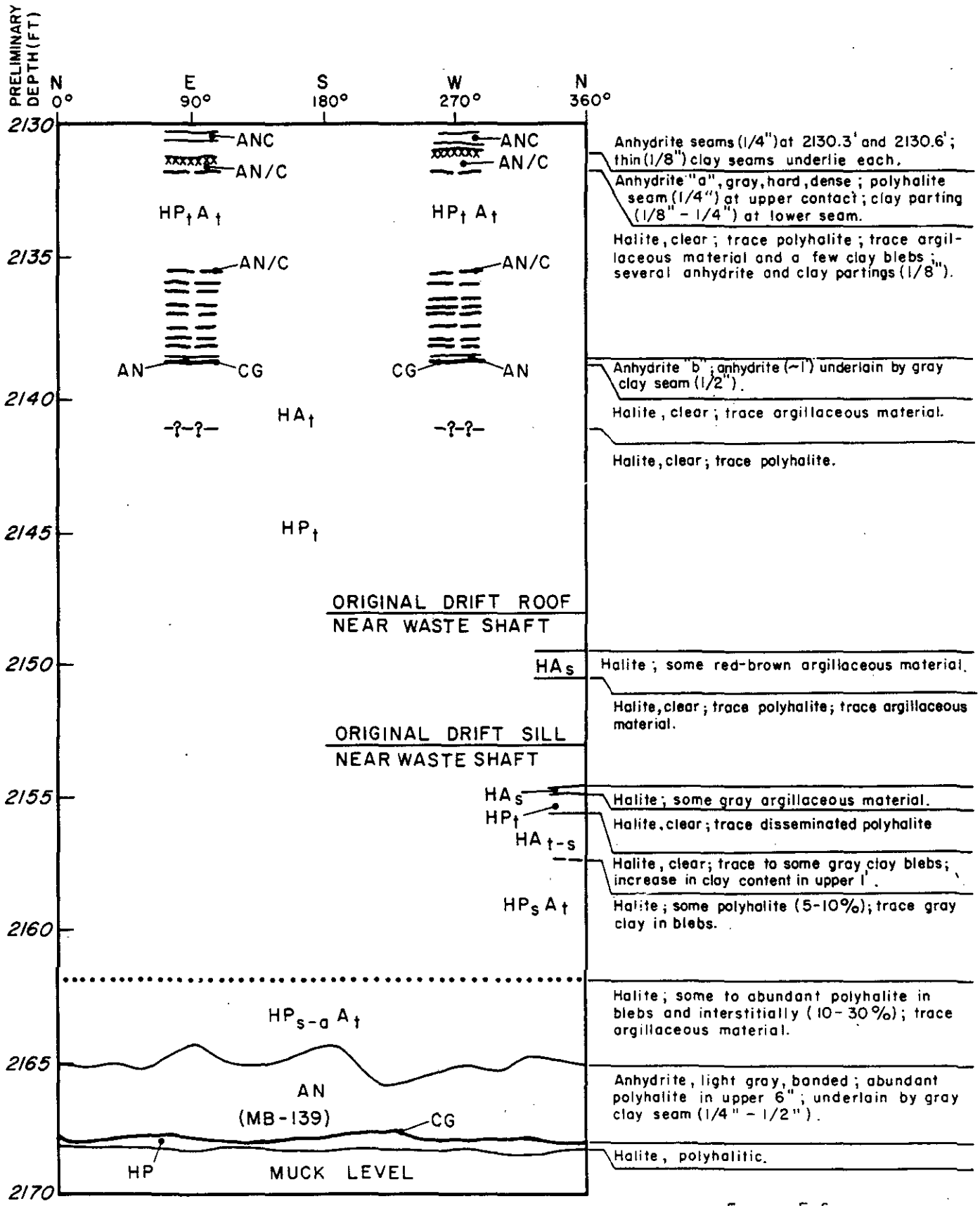

FIGURE E-6

WASTE SHAFT
FACILITY LEVEL AREA
2100 TO 2170 FEET

SHEET 2 OF 2

APPENDIX F

EXHAUST SHAFT
GEOLOGIC LOG

CONTENTS

Figure No.	Title/Description
F-1	Exhaust Shaft Geologic Log (49 Sheets)

EXPLANATION

ROCK TYPE

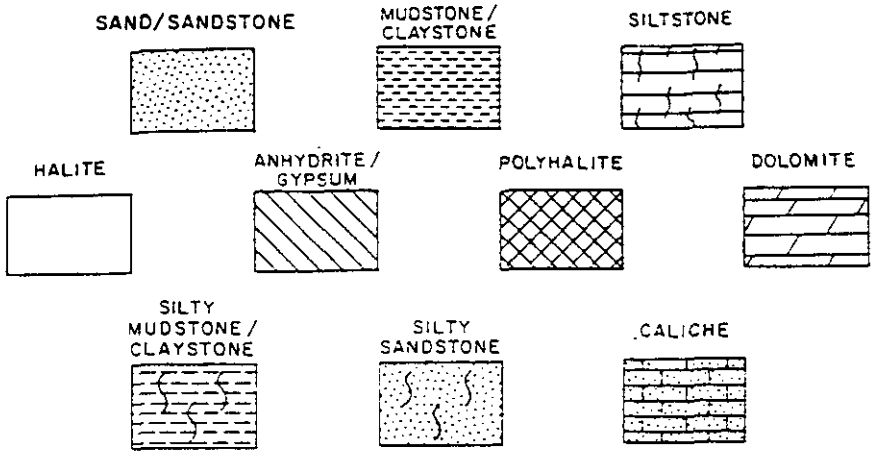

ACCESSORY CONSTITUENTS

ESTIMATED PERCENTAGE OF ACCESSORY CONSTITUENTS INDICATED AS FOLLOWS

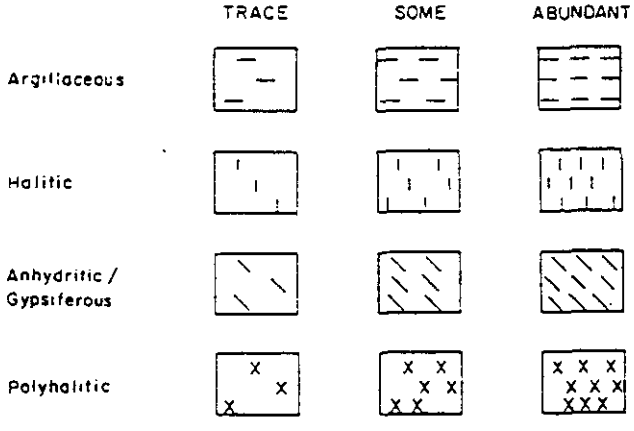

LAMINAR FEATURES

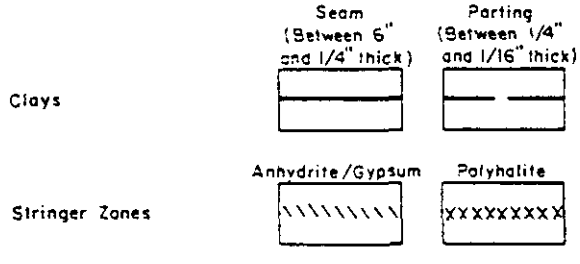

CONTACTS

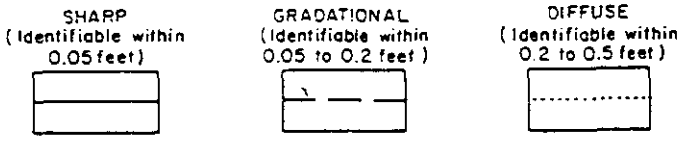

SALADO MARKER BEDS ARE IDENTIFIED BY NUMBER IN THE STRATIGRAPHIC COLUMN

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3411.5			
3410			COLLAR PAD
3409	0		QUATERNARY DUNE SAND. SAND, SILTY, REDDISH-BROWN, POORLY SORTED, SUBANGULAR GRAINS, A FEW MAFIC GRAINS (LESS THAN 10%); WEAKLY CONSOLIDATED.
3404	5		
3399	10		MESCALERO CALICHE. CALICHE, WHITE TO TAN, NODULAR, SIZE AND QUANTITY OF NODULES INCREASING WITH DEPTH; CARBONATE CONTENT HIGHEST IN LIGHT COLORED SUBHORIZONTAL STRINGERS; UPPER 1.0' HARD, HARDNESS DECREASING TOWARD BASE; MOIST; CONTAINS LOCAL CONCENTRATIONS OF SILTSTONE AND SANDSTONE; COLOR BECOMES REDDISH-BROWN TOWARD BASE; IRREGULARLY-SHAPED DISCONTINUOUS BEDS OF SILTSTONE, CHERT AND SANDSTONE PEBBLE CONGLOMERATE MIGRATE VERTICALLY AND LATERALLY; THICK DISCONTINUOUS BEDS OF ORANGISH-BROWN SAND OCCUR NEAR BASE; BASAL CONTACT DIFFUSE.
3394	15		
3389	20		GATUNA FORMATION. SANDSTONE, FINE TO VERY FINE GRAINED, REDDISH-BROWN, POORLY SORTED, CALCAREOUS, FRIABLE, DRY; BASAL 1.5' IS SANDSTONE, COARSE TO FINE GRAINED, POORLY SORTED, ROUNDED, CONTAINING ANGULAR DEBRIS FROM UNDERLYING REDBEDS; BASAL CONTACT SHARP, EROSIONAL, SLIGHTLY UNDULATORY.
3384	25		
3379	30		
3374	35		SANTA ROSA FORMATION. SILTSTONE AND VERY FINE GRAINED SANDSTONE, SILT TO VERY FINE SAND-SIZED GRAINS, REDDISH-BROWN, CALCAREOUS, POORLY SORTED, CONTAINS PEBBLES OF CHERT AND MAFIC GRAINS; UPPER 1.0' CONTAINS CALICHE IN SUBHORIZONTAL STRINGERS; BASAL CONTACT DIFFUSE.
3369	40		

EXHAUST SHAFT

LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3369	40	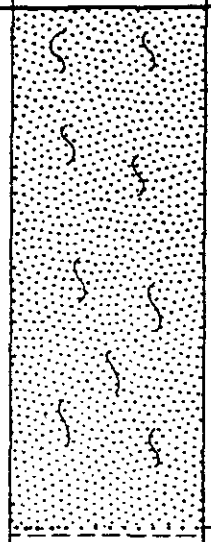	AS ABOVE
3364	45		
3359	50		
3354	55	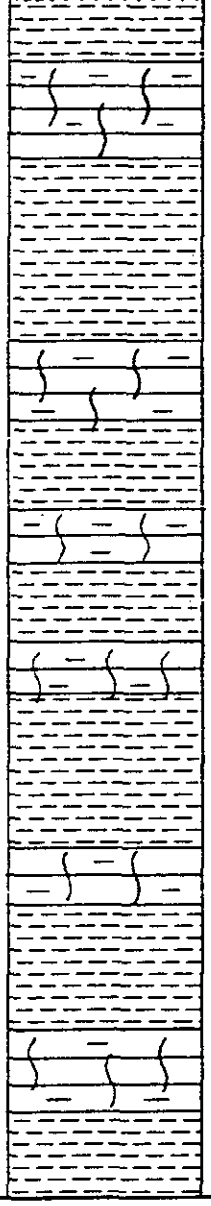	DEWEY LAKE REDBEDS MUDSTONE INTERBEDDED WITH ARGILLACEOUS SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO THINLY BEDDED (1/8" TO 1"), BEDDING SLIGHTLY UNDULATORY, HARD; SEDIMENTARY STRUCTURES INCLUDE: SMALL TABULAR RIP-UP CLASTS (<1/4") ALIGNED IN THIN BEDS, CROSS LAMINATIONS, LOAD STRUCTURES, FILLED DESICCATION CRACKS; OCCASIONAL 1-1/2" INTERBEDS OF GRAY SILTSTONE; RARE GREENISH-GRAY REDUCTION SPOTS (<1/16" DIAMETER); BASAL CONTACT GRADATIONAL.
3349	60		
3344	65		
3339	70		
3334	75		
3329	80		
3324	85		

EXHAUS SHAFT
LITHOLOGIC LOG
SHEET 3 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3324	85		AS ABOVE
3319	90		MUDSTONE, REDDISH-BROWN, THINLY LAMINATED TO THINLY BEDDED, HARD; CONTAINS THIN BEDS (1/2" TO 1") OF GRAY SILTY MUDSTONE; FRACTURES PARALLEL TO BEDDING, SPACED 3"; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/4" TO 1/2" DIAMETER); CONTAINS OCCASIONAL LOAD STRUCTURES; BASAL CONTACT DIFFUSE.
3314	95		SILTY MUDSTONE INTERBEDDED WITH ARGILLACEOUS SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO THINLY BEDDED (<1/32" TO 2-1/2"); OCCASIONAL GREENISH-GRAY SILTSTONE INTERBEDS; OCCASIONAL LOAD STRUCTURES; SMALL OPEN FRACTURES PARALLEL TO BEDDING, SPACED 1" TO 2-1/2"; FEW SUBVERTICAL FRACTURES, SPACED 1' TO 2.5'; BASAL CONTACT DIFFUSE.
3309	100		
3304	105		SANDSTONE, VERY FINE GRAINED, REDDISH-BROWN, THINLY LAMINATED TO CROSS-LAMINATED, HARD TO SOFT, RARE INTERBEDS OF SILTY MUDSTONE (1/2" TO 1" THICK); THIN (<1/32") SUBHORIZONTAL FRACTURES PARALLEL TO BEDDING, SPACED 3" TO 9"; TWO 1/2" THICK PARALLEL HORIZONTAL FRACTURES FILLED WITH CARBONATE OCCUR AT 108.0' AND 108.5'; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS; BASAL CONTACT DIFFUSE.
3299	110		
3294	115		SILTY MUDSTONE INTERBEDDED WITH MUDSTONE, REDDISH-BROWN, THINLY LAMINATED TO CROSS-LAMINATED, HARD; RARE GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1/2" DIAMETER); OCCASIONAL 1/4" TO 2" THICK GREENISH-GRAY INTERBEDS; OCCASIONAL SOFT SEDIMENT DEFORMATION FEATURES; HORIZONTAL FRACTURES PARALLEL TO BEDDING, SPACED 1" TO 4"; BASAL CONTACT SHARP.
3289	120		SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO CROSS-LAMINATED; OCCASIONAL INTERBEDS OF SILTY MUDSTONE; LOAD STRUCTURES, MUDSTONE RIP-UP CLASTS; MODERATELY ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1/4" DIAMETER); OCCASIONAL GREENISH-GRAY BEDS (1/2" TO 2" THICK); THIN HORIZONTAL FRACTURES (<1/32") WITH GYPSUM FILLING BELOW 121.5', SPACED 2" TO 1.5'; BASAL CONTACT SHARP.
3284	125		
3279	130		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3279	130	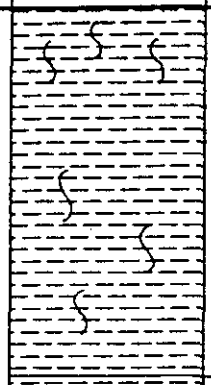	SILTY MUDSTONE, REDDISH-BROWN, THINLY LAMINATED (<1/32"), LOCALLY INTERBEDDED WITH SILTSTONE; CONTAINS CROSS-LAMINATIONS, FILLED DESICCATION CRACKS; SUBVERTICAL CLAY-FILLED FRACTURES OCCUR NEAR TOP, SPACED 3" TO 4"; LOCALLY, BEDDING MAY BE GREENISH-GRAY IN COLOR; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER); SUBHORIZONTAL GYPSUM-FILLED FRACTURES, SPACED 3" TO 6"; SUBVERTICAL FRACTURES SPACED 3" TO 12"; IN LOWER 3', 1/8" TO 3" THICK HORIZONTAL GREENISH-GRAY REDUCTION ZONES OCCUR IN GROUPS, INDIVIDUAL ZONES SPACED 1/2", GROUPS SPACED 0.8' TO 1.5'; BASAL CONTACT SHARP, MARKED BY 2" BED OF WHITISH-GRAY SILTSTONE WITH A GREENISH-GRAY REDUCTION ZONE ABOVE AND BELOW.
3274	135		
3269	140	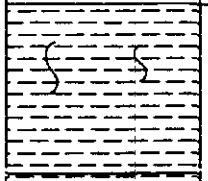	MUDSTONE, DARK REDDISH-BROWN, INTERBEDDED WITH SILTY MUDSTONE, LIGHT REDDISH-BROWN, THINLY LAMINATED TO BEDDED (<1/32" TO 1/2"), LOCALLY FISSILE, OCCASIONALLY CROSS-LAMINATED, BEDDING MAY TERMINATE EROSIONALLY, STRUCTURES BECOMES LESS FINE BELOW 148.0'; RARE SUBVERTICAL TO HIGH ANGLE FRACTURES WITH GRANULAR GYPSUM FILLING (<1/8" THICK); FROM 132.5' TO 147.5', ABUNDANT SUBHORIZONTAL FRACTURES, SPACED 1'; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/32" TO 2" DIAMETER); BASAL CONTACT GRADATIONAL.
3264	145		
3259	150	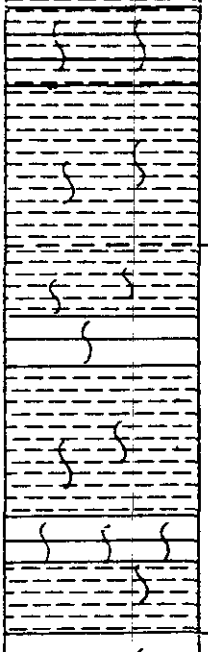	SILTY MUDSTONE, DARK REDDISH-BROWN, INTERBEDDED WITH SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO BEDDED (1/32" TO 1-1/2"), SOFT; OCCASIONALLY CROSS-LAMINATED, CONTAINS LOAD STRUCTURES, OVERALL SEDIMENTARY STRUCTURES ARE LESS FINE THAN OVER-LYING UNIT, GRAIN SIZE COARSENS DOWNWARD; 1" TO 2" THICK HORIZONTAL GREENISH-GRAY REDUCED ZONES, SPACED 3" TO 5"; FRACTURES OCCUR BELOW 154.5', 1/8" THICK, FILLED WITH GYPSUM; SUBVERTICAL FRACTURES SPACED 2' TO 3', SUBHORIZONTAL FRACTURES SPACED 0.5' TO 1.5'; BASAL 2' CONTAINS GREENISH-GRAY AND REDDISH-BROWN INTERBEDDED MUDSTONE; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/32" TO 1" DIAMETER); BASAL CON-TACT SHARP.
3254	155		
3249	160		
3244	165	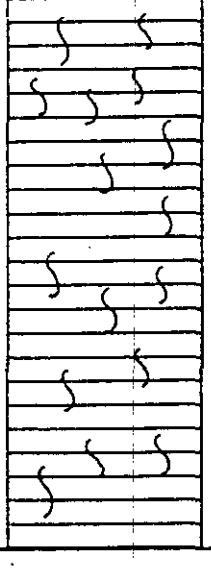	SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO STRUCTURELESS; BEDDING THICKENS AND THINS (1/2" TO 2"); OCCASIONAL GREENISH-GRAY BEDS 1/8" TO 1/2" THICK, SPACED 3.0'; ONLY A FEW HIGH ANGLE FRACTURES 1/8" THICK, GYPSUM-FILLED, STRIKING N60°W; AT 167.5' CHANNEL LAG CONGLOMERATE OCCURS CONTAINING SILTSTONE PEBBLES; THINLY LAMINATED SILTY MUDSTONE FROM 170.5' TO 171.3' WITH GREENISH-GRAY REDUCTION ZONES 1" TO 3" THICK, SPACED 4"; NEAR 171.3' BECOMES POORLY SORTED; THINLY LAMINATED WITH CROSS-LAMINATIONS AND EROSIONAL TERMINATIONS NEAR BASE; CONTAINS GREENISH-GRAY REDUCTION SPOTS UP TO 2" DIAMETER; BASAL CONTACT GRADATIONAL.
3239	170		
3234	175		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3234	175		AS ABOVE
3229	180		
3224	185		MUDSTONE, REDDISH-BROWN, THINLY LAMINATED TO BEDDED (1/32" TO 1/2" THICK), SOFT; BEDDING INDISTINCT; RARE GREENISH-GRAY REDUCTION SPOTS TO 1" DIAMETER, REDUCTION SPOTS CONCENTRATED AROUND REDUCED, GREENISH-GRAY, 1" WIDE HORIZONTAL BAND AT 191.7', VERY FEW FRACTURES; BASAL 1.5' BECOMES SILTY; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, OVERLYING BEDS DRAPE OVER CONTACT, EROSIONAL.
3219	190		
3214	195		SANDSTONE, VERY FINE GRAINED, GRAYISH-WHITE, HARD TO SOFT; TROUGH CROSS-BEDDING BECOMES APPARENT NEAR BASE; CONTAINS FIBROUS GYPSUM-FILLED FRACTURES WITH VARIABLE ORIENTATION, 1/4" TO 1" THICK; BASAL CONTACT SHARP.
3209	200		SANDSTONE AT TOP GRADING TO SILTSTONE, REDDISH-MAROON, LAMINATED TO BEDDED, OCCASIONALLY CROSS-LAMINATED, HARD; COLOR BECOMES WHITISH-MAROON TOWARD BASE; LOWER 1.3' IS SANDSTONE, STRUCTURELESS EXCEPT FOR OCCASIONAL INTERBEDS OF REDDISH-BROWN SILTSTONE; ABUNDANT FRACTURES, MOST HORIZONTAL TO SUBHORIZONTAL AND SLIGHTLY UNDULATORY, FILLED WITH FIBROUS GYPSUM, THICKNESS 1/16" TO 2", SPACED 1/8" TO 6"; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
3204	205		CLAYSTONE, REDDISH-BROWN, THINLY LAMINATED; CROSS-LAMINATED, SETS 1/2" ACROSS, BEDDING EROSIONALLY TERMINATED, CONTAINS SOFT SEDIMENT DEFORMATION FEATURES; BECOMES SILTY TOWARD BASE; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS TO 1/2" DIAMETER, SPOTS OCCASIONALLY BROKEN BY GYPSUM-FILLED FRACTURES; SEE FIGURE 6 FOR FRACTURE NOTES; BASAL CONTACT GRADATIONAL.
3199	210		MUDSTONE WITH INTERBEDDED SILTSTONE, DARK REDDISH-BROWN, THINLY LAMINATED, ABUNDANT CROSS-LAMINATIONS, BEDDING OFTEN TERMINATED EROSIONALLY; ABUNDANT SUBHORIZONTAL GYPSUM-FILLED FRACTURES, SPACED 6", 1/8" TO 3" THICK; VERTICAL AND SUBVERTICAL FRACTURES RARE; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS; BASAL CONTACT GRADATIONAL.
3194	215		
3189	220		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3189	220		SILTSTONE INTERBEDDED WITH VERY FINE SANDSTONE, REDDISH-BROWN, THINLY LAMINATED TO BEDDED, CROSS-LAMINATED, BEDS OFTEN EROSIONALLY TERMINATED, HARD; CROSS-LAMINATIONS INCREASE BELOW 223.0', HORIZONTAL EROSIONAL PLANES OCCUR BELOW 223.0', SPACED 1.0' TO 2.0'; SUBHORIZONTAL GYPSUM-FILLED FRACTURES ABUNDANT, 1/16" TO 1/4" THICK; RARE SUBVERTICAL FRACTURES; BASAL CONTACT GRADATIONAL.
3184	225		
3179	230		
3174	235		SANDSTONE, REDDISH-BROWN, SILTY, THINLY LAMINATED TO BEDDED, OCCASIONALLY CROSS-LAMINATED; ABUNDANT SUBHORIZONTAL GYPSUM-FILLED FRACTURES, 1/16" TO 1" THICK, SPACED 2" TO 1.0', FRACTURES BIFURCATE LOCALLY; RARE SUBVERTICAL GYPSUM-FILLED FRACTURES; BASAL CONTACT SHARP.
3169	240		
3164	245		
3159	250		SANDSTONE, REDDISH-BROWN, SILTY, STRUCTURELESS EXCEPT RARE CROSS-LAMINATIONS AND HORIZONTAL LAMINATIONS; FEWER GYPSUM-FILLED FRACTURES THAN OVERLYING UNIT, FRACTURES TO 2" THICK; BASAL CONTACT GRADATIONAL.
3154	255		
3149	260		SANDSTONE, REDDISH-BROWN, SILTY, LOCALLY LAMINATED AND CROSS-LAMINATED; OCCASIONAL SUBHORIZONTAL GYPSUM-FILLED FRACTURES, 1/4" TO 1/2" THICK, SPACED 2.8' TO 3.4'. FRACTURES BIFURCATE LOCALLY; SUBVERTICAL FRACTURES RARE; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS TO 1" DIAMETER; BASAL 1.0' CONSISTS OF REDDISH-BROWN SILTSTONE; BASAL CONTACT GRADATIONAL.
3144	265		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3144	265		AS ABOVE
3139	270		SANDSTONE, REDDISH-BROWN, SILTY, MOSTLY MASSIVE WITH SOME LOCAL LAMINATIONS AND CROSS-BEDDING; SUBHORIZONTAL AND SUBVERTICAL GYPSUM-FILLED FRACTURES, SUBHORIZONTAL MORE ABUNDANT, SEE FIGURE 7; BASAL CONTACT GRADATIONAL.
3134	275		
3129	280		
3124	285		ARGILLACEOUS SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO LAMINATED (1/16" TO 1/4" THICK); ABUNDANT SEDIMENTARY STRUCTURES INCLUDING: TROUGH CROSS-LAMINATIONS, EROSIONAL SURFACES TRACEABLE AROUND CIRCUMFERENCE OF SHAFT, SOFT SEDIMENT DEFORMATION FEATURES; CROSS-LAMINATION SETS ARE 1" TO 4" ACROSS, INCREASING TO 2.0' TO 3.0' ACROSS NEAR BASE; LOWER 1.0' CONTAINS 1/4" THICK BEDS OF CLAYSTONE; HORIZONTAL AND SUBHORIZONTAL GYPSUM-FILLED FRACTURES 1/4" TO 1" THICK, SPACED 0.5' TO 2.0'; VERTICAL AND SUBVERTICAL GYPSUM-FILLED FRACTURES 1/8" TO 1/4" THICK, SPACED 3.0' TO 5.0'; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS TO 1" DIAMETER; BASAL CONTACT SHARP, MARKED BY OCCURRENCE OF A MUDSTONE BED.
3119	290		
3114	295		MUDSTONE INTERBEDDED WITH SILTY CLAYSTONE, REDDISH-BROWN, THINLY LAMINATED TO VERY THINLY BEDDED (<1/16" TO 1/2" THICK); ABUNDANT SETS OF TROUGH CROSS-LAMINATIONS 1" TO 4" ACROSS, CLAY DRAPE OVER RIPPLE CROSS-LAMINATIONS; OCCASIONAL SOFT SEDIMENT DEFORMATION; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1/2" DIAMETER); UNIT BOUNDED BY HORIZONTAL GYPSUM-FILLED FRACTURES, 1" THICK AT TOP GRADING TO 1/2" THICK AT BASE; BASAL CONTACT SHARP.
3109	300		MUDSTONE AT TOP GRADING TO SILTSTONE AT BASE, REDDISH-BROWN, THINLY LAMINATED TO THINLY BEDDED (1/6" TO 1" THICK); ABUNDANT FINE STRUCTURES INCLUDING: FLASER BEDDING, CROSS-LAMINATIONS, TROUGH CROSS-LAMINATIONS, FILLED DESICCATION CRACKS, LOAD STRUCTURES, ABUNDANT EROSIONAL CONTACTS; GYPSUM-FILLED FRACTURES ARE MODERATELY ABUNDANT, 1/16" TO 1-1/2" THICK, HORIZONTAL AND SUBHORIZONTAL FRACTURES SPACED 1.0' TO 4.0', VERTICAL AND SUBVERTICAL FRACTURES SPACED 3.0' TO 5.0'; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER); RARE 2" THICK, SUBHORIZONTAL, GREENISH-GRAY REDUCED ZONES; BASAL CONTACT SHARP.
3104	305		
3099	310		AS BELOW

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3099	310		MUDSTONE AT TOP, GRADING TO SILTSTONE, DARK REDDISH-BROWN TO REDDISH-BROWN, WITH MINOR INTERBEDDED MUDSTONE, THINLY LAMINATED TO LAMINATED (<1/32" TO 1/8"), HARD; CROSS-LAMINATED, BECOMING MORE ABUNDANT WITH DEPTH; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1/4" DIAMETER); FIBROUS GYPSUM-FILLED FRACTURES BECOME LESS ABUNDANT WITH DEPTH; HORIZONTAL AND SUBHORIZONTAL FRACTURES 1/16" TO 1" THICK, SPACED 2" TO 2.0'; VERTICAL AND SUBVERTICAL FRACTURES 1/16" TO 1/4" THICK, SPACED 2" TO 2.0'; BASAL CONTACT SHARP.
3094	315		MUDSTONE AT TOP, GRADING TO SILTSTONE WITH DEPTH, DARK REDDISH-BROWN TO REDDISH-BROWN, UNIT SIMILAR TO ABOVE EXCEPT FOR A 3" THICK BED OF MUDSTONE WHICH OCCURS AT 316.2' AND HAS A SHARP UPPER CONTACT AND GRADES TO SILTSTONE WITH DEPTH, HARD; MUDSTONE: STRUCTURELESS; SILTSTONE: FINELY LAMINATED TO CROSS-LAMINATED; FRACTURES SIMILAR TO OVERLYING UNIT; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS TO 1" DIAMETER; BASAL CONTACT MARKED BY 3" THICK SUBHORIZONTAL GREENISH-GRAY ZONE AND DARK REDDISH-BROWN MUDSTONE, SHARP.
3089	320		MUDSTONE, REDDISH-BROWN, STRUCTURELESS; FRACTURES SIMILAR TO OVERLYING UNIT; BASAL CONTACT GRADATIONAL.
3084	325		CLAYSTONE, DARK REDDISH-BROWN, INTERBEDDED WITH SILTSTONE, LIGHT REDDISH-BROWN, MICRO-LAMINATED TO VERY THINLY BEDDED (<1/32" TO 1/2"); SILTSTONE: CROSS-LAMINATED; CLAYSTONE: STRUCTURELESS; ABUNDANT GREENISH-GRAY REDUCTION SPOTS; GRADES TO SILTSTONE AT BASE; ALL FRACTURES FILLED WITH FIBROUS GYPSUM; HORIZONTAL AND SUBHORIZONTAL FRACTURES 1/8" TO 1" THICK, SPACED 3" TO 2.0'; VERTICAL AND SUB-VERTICAL FRACTURES 1/16" TO 1/4" THICK, SPACED 2.0' TO 3.0'; BASAL CONTACT SHARP.
3079	330		
3074	335		CLAYSTONE, DARK REDDISH-BROWN, MICRO-LAMINATED TO THINLY LAMINATED (<1/32" TO 1/16"), STRUCTURE POORLY DEFINED DUE TO ABUNDANT FRACTURING, OCCASIONAL CROSS-LAMINATIONS, BEDDING OFTEN CONVOLUTED AND EROSIONALLY TERMINATED; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER); ABUNDANT GYPSUM-FILLED FRACTURES, ~90% HORIZONTAL AND SUBHORIZONTAL; TWO SCALES OF SPACING: MINOR - 1/8" TO 2", MAJOR - 2" TO 6". FRACTURE DENSITY INCREASES TOWARD BASE, THICKNESS VARIES FROM 1/16" TO 1.0'; REMAINING ~10% VERTICAL AND SUBVERTICAL FRACTURES, SPACED 2" TO 2.5', THICKNESS 1/16" TO 1/4"; BASAL CONTACT SHARP.
3069	340		
3064	345		SILTSTONE, REDDISH-BROWN, LAMINATED TO BEDDED, CROSS-LAMINATED, SOFT SEDIMENT DEFORMATION FEATURES, HARD; ALL FRACTURES FILLED WITH FIBROUS GYPSUM; SUBHORIZONTAL AND HORIZONTAL FRACTURES 1/16" TO 1" THICK, SPACED 1" TO 1.0'; VERTICAL AND SUBVERTICAL FRACTURES 1/8" TO 1/2" THICK, SPACED 6" TO 2.0'; ABUNDANT GREENISH-GRAY REDUCTION SPOTS 1/16" TO 1" DIAMETER; BASAL CONTACT SHARP.
3059	350		
3054	355		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3054	355	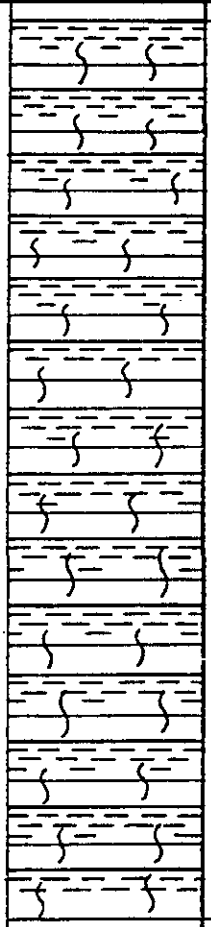	MUDSTONE GRADING TO SILTSTONE IN VERTICAL GRADATIONAL SEQUENCES 1.0' TO 3.0' THICK, REDDISH-BROWN (SILTSTONE) AND DARK REDDISH-BROWN (MUDSTONE), EACH SEQUENCE CONSISTS OF STRUCTURELESS MUDSTONE AT TOP GRADING TO THINLY LAMINATED TO BEDDED SILTSTONE AT BASE; AMOUNT OF SEDIMENTARY STRUCTURES INCREASE TO BASE OF EACH SEQUENCE, THESE STRUCTURES INCLUDE: CROSS-LAMINATIONS, TROUGH CROSS-LAMINATIONS, EROSIONAL SURFACES, OCCASIONAL SOFT SEDIMENT DEFORMATION FEATURES; UPPER CONTACT OF EACH SEQUENCE IS EROSIONAL; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER); ALL FRACTURES GYPSUM-FILLED; VERTICAL AND HIGH ANGLE FRACTURES APPEAR YOUNGER THAN HORIZONTAL AND SUBHORIZONTAL FRACTURES; SUBHORIZONTAL FRACTURE FILLING OCCASIONALLY SIGMOIDAL AND/OR TILTED; FILLING IN VERTICAL AND HIGH ANGLE FRACTURES HAVE A COMPONENT OF THRUST; THREE TYPES OF HORIZONTAL AND SUBHORIZONTAL FRACTURES; THICK - 1/2" TO 1", SPACED 1.0' TO 2.0'; MODERATELY THIN - 1/8" TO 1/2:, SPACED 1" TO 1.5'; THIN - <1/8", SPACED 1/4" TO 1"; BASAL CONTACT SHARP.
3049	360		
3044	365		
3039	370		
3034	375		
3029	380	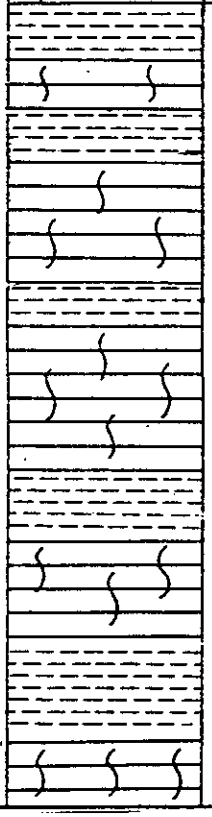	SILTSTONE, REDDISH-BROWN, WITH INTERBEDDED CLAYSTONE, DARK REDDISH-BROWN, 1" TO 4" THICK FINING UPWARD SEQUENCES, THINLY LAMINATED TO THINLY BEDDED (1/16" TO 2" THICK), HARD; SEDIMENTARY STRUCTURES INCLUDE: CROSS-LAMINATIONS, SOFT SEDIMENT LOAD STRUCTURES, EROSIONAL CONTACTS AT TOP OF EACH FINING UPWARD SEQUENCE; LOCALLY ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER), SOME OCCUR IN ALIGNED ZONES; OVERALL GRAIN SIZE INCREASES TO BASE; ABUNDANT HORIZONTAL, FIBROUS GYPSUM-FILLED FRACTURES OCCUR IN TWO SIZE GROUPS: 0" TO 1/4" THICK, SPACED 1/4" TO 1"; 1/4" TO 1/2" THICK, SPACED 0.5' TO 2.0'; VERTICAL AND HIGH ANGLE FIBROUS GYPSUM-FILLED FRACTURES ARE MODERATELY ABUNDANT, 1/16" TO 1/2" THICK, SPACED 2.5' TO 5'; BASAL CONTACT SHARP, UNDULATORY, POSSIBLY EROSIONAL.
3024	385		
3019	390		
3014	395		
3009	400		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3009	400	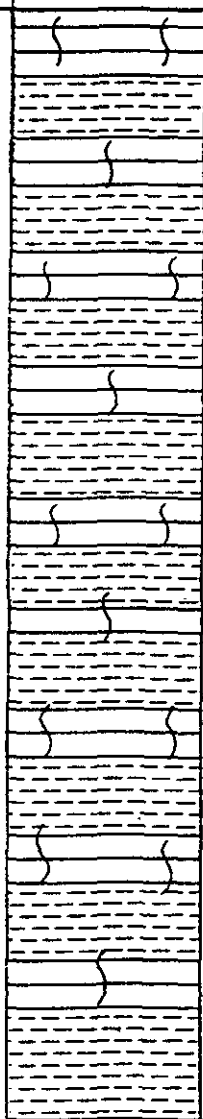	SILTSTONE, REDDISH-BROWN, WITH INTERBEDDED CLAYSTONE, DARK REDDISH-BROWN, 1" TO 4" THICK FINING UPWARD SEQUENCES, THINLY LAMINATED TO THINLY BEDDED (1/16" TO 2" THICK), HARD; SEDIMENTARY STRUCTURES INCLUDE: CROSS-LAMINATIONS, SOFT SEDIMENT LOAD STRUCTURES, EROSIONAL CONTACTS AT TOP OF EACH FINING UPWARD SEQUENCE; LOCALLY ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER), SOME OCCUR IN ALIGNED ZONES; OVERALL GRAIN SIZE INCREASES TO BASE; ABUNDANT HORIZONTAL, FIBROUS GYPSUM-FILLED FRACTURES OCCUR IN TWO SIZE GROUPS: 0" TO 1/4" THICK, SPACED 1/4" TO 1"; 1/4" TO 1/2" THICK, SPACED 0.5' TO 2.0'; VERTICAL AND HIGH ANGLE FIBROUS GYPSUM-FILLED FRACTURES ARE MODERATELY ABUNDANT, 1/16" TO 1/2" THICK, SPACED 2.5' TO 5'; BASAL CONTACT SHARP, UNDULATORY, POSSIBLY EROSIONAL.
3004	405		
2999	410		
2994	415		
2989	420		
2984	425		
2979	430	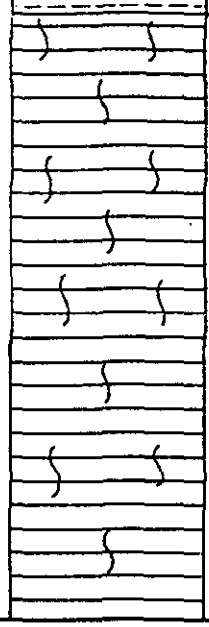	SILTSTONE AT TOP, GRADING TO CLAYSTONE AT BASE, REDDISH-BROWN TO DARK REDDISH-BROWN, TRACE OF BEDDING AT TOP GRADING TO STRUCTURELESS AT BASE, HARD; CONTAINS OCCASIONAL CLAYSTONE CLASTS <1/8" DIAMETER; RARE INTERBEDS OF CLAYSTONE, 1/16" THICK; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 2" DIAMETER) OCCUR IN ZONES; ABUNDANT HORIZONTAL AND SUBHORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES, MAJORITY 1/16" THICK, SPACED 1" TO 2"; MODERATELY ABUNDANT VERTICAL AND SUBVERTICAL FIBROUS GYPSUM-FILLED FRACTURES UP TO 1/4" THICK, SPACED 1.0' TO 3.0'; BASAL CONTACT OBSCURED.
2974	435		
2969	440		
2964	445		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2964	445		AS ABOVE
2959	450		
2954	455		
		OBSCURED	
2949	460		SLIGHTLY SANDY SILTSTONE, REDDISH-BROWN, INTERBEDDED WITH SILTY-MUDSTONE, DARK REDDISH-BROWN, 1" THICK FINING UPWARDS SEQUENCES, THINLY BEDDED (1"); MINOR EROSIONAL CONTACTS AT TOP OF EACH FINING UPWARD SEQUENCE; HORIZONTAL AND SUBHORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES <1/8" THICK, SPACED 0" TO 6"; SUBVERTICAL AND VERTICAL FIBROUS GYPSUM-FILLED FRACTURES ARE LESS ABUNDANT AND CROSS-CUT HORIZONTAL AND SUBHORIZONTAL FRACTURES; BASAL CONTACT SHARP.
2944	465		SILTSTONE AT TOP GRADING TO CLAYSTONE AT BASE, REDDISH-BROWN TO DARK REDDISH-BROWN, TRACE OF BEDDING AT TOP GRADING TO STRUCTURELESS AT BASE, HARD; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 2" DIAMETER); HORIZONTAL AND SUBHORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES <1/8" THICK; SUBVERTICAL AND VERTICAL GYPSUM-FILLED FRACTURES ARE LESS ABUNDANT AND CROSS-CUT HORIZONTAL AND SUBHORIZONTAL FRACTURES; BASAL CONTACT SHARP.
2939	470		
2934	475		
2929	480		
2924	485		MUDSTONE, SILTY, DARK REDDISH-BROWN, STRUCTURELESS; NO HORIZONTAL OR SUBHORIZONTAL GYPSUM-FILLED FRACTURES; RARE SUBVERTICAL AND VERTICAL FRACTURES PRESENT, 0" TO 1/2" THICK; BASAL CONTACT GRADATIONAL.
2919	490		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2919	490		AS ABOVE
2914	495		
2909	500		CLAYSTONE GRADING TO SILTSTONE WITH DEPTH, REDDISH-BROWN TO DARK REDDISH-BROWN, THIN 1" TO 3" THICK FINING UPWARDS SEQUENCES, THINLY BEDDED; CONTAINS MINOR EROSIONAL CONTACTS AT TOP OF EACH FINING UPWARDS SEQUENCE; ABUNDANT HORIZONTAL AND SUBHORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES 0" TO 1/8" THICK, SPACED 0" TO 6"; MODERATELY ABUNDANT VERTICAL AND SUBVERTICAL FIBROUS GYPSUM-FILLED FRACTURES 1/8" TO 1/2" THICK; BASAL CONTACT SHARP.
2904	505		
2899	510		
2894	515		
2889	520		
2884	525		SILTSTONE, (FIGURE 9).
2879	530		
2874	535		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2874	535		
2869	540		
2864	545		SILTSTONE
2859	550		RUSTLER FORMATION FORTY-NINER MEMBER ANHYDRITE, FINELY CRYSTALLINE, GRAY TO GRAYISH-BROWN, WHITE AT UPPER CONTACT, BANDED TO OCCASIONALLY LAMINATED, SPACED 1/16" TO 1"; BANDS AND LAMINAE UNDULATORY UP TO 1/4" AND OCCASIONALLY TERMINATE ABRUPTLY, GRAY BANDS USUALLY THICKEST, BECOME STRUCTURELESS WITH DEPTH, LOCALLY NODULAR; UPPER 3.0' CONTAINS INTERBEDDED CLAY LAMINAE, CONTENT DECREASING WITH DEPTH; LOCALLY GYPSIFEROUS IN UPPER 6"; NEAR TOP, HORIZONTAL AND SUBHORIZONTAL GYPSUM-FILLED FRACTURES ARE ABUNDANT, 1/8" TO 1/2" THICK, SPACED 1" TO 3"; BEDDING TERMINATED EROSIONALLY AT UPPER CONTACT; HORIZONTAL AND SUBHORIZONTAL GYPSUM-FILLED FRACTURES SPACED 1" TO 2.0', 1/16" TO 1/4" THICK; RARE VERTICAL AND SUBVERTICAL GYPSUM-FILLED FRACTURES, 1/8" TO 1/4" THICK, SPACED 2.0' TO 6.0'; BASAL CONTACT SHARP.
2854	555		
2849	560		
2844	565		
2839	570		
2834	575		ANHYDRITE
2829	580		SILTY CLAYSTONE

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 14 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2829	580		
2824	585		
			ANHYDRITE
2819	590		
2814	595		
2809	600		
			MAGENTA DOLOMITE MEMBER DOLOMITE, GYPSIFEROUS
2804	605		
2799	610		
2794	615		
2789	620		
2784	625		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2784	625		
2779	630		TAMARISK MEMBER ANHYDRITE, FINELY CRYSTALLINE, GRAY TO LIGHT BROWNISH-GRAY TO TAN WITH DEPTH, LAMINATED TO NODULAR, HARD; LOCALLY GYPSIFEROUS AT UPPER CONTACT; CONTAINS INTERBEDS OF LAMINATED CARBONATE LOCALLY AND NEAR BASE; LAMINAE MAY LOCALLY BE TERMINATED EROSIONALLY; 1" TO 2" THICK ORGANIC (?) BLACK CLAYSTONE AT 665.9', CONTAINS FIBROUS GYPSUM-FILLED FRACTURES, FIBERS ORIENTED VERTICALLY, 1/32" TO 1" THICK, DISCONTINUOUS, LOCALLY BIFURCATING; HORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES THROUGHOUT WITH SPACING 0.5' TO 1.5', 1/32" TO 1/16" THICK; RARE SUBVERTICAL FRACTURES; BASAL CONTACT GRADATIONAL.
2774	635		
2769	640		
2764	645		
2759	650		
2754	655		
2749	660		
2744	665		
2739	670		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2739	670		AS ABOVE
2734	675		
2729	680		
			ANHYDRITE
			ANHYDRITE
2724	685		
			CLAYSTONE
			ANHYDRITE, ARGILLACEOUS
2719	690		SILTY CLAYSTONE
2714	695		
			ANHYDRITE
2709	700		
			CLAYSTONE
			ANHYDRITE
2704	705		
2699	710		
			CULEBRA DOLOMITE MEMBER
2694	715		DOLOMITE, GYPSIFEROUS

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 17 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2694	715		AS ABOVE
2689	720		
2684	725		
2679	730		
2674	735		
			UNNAMED LOWER MEMBER SILTY CLAYSTONE
2669	740		
2664	745		ANHYDRITE
2659	750		
2654	755		SANDY MUDSTONE
			HALITIC MUDSTONE OR ARGILLACEOUS HALITE
2649	760		

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 18 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2649	760		AS ABOVE
2644	765		HALITE
			ANHYDRITE
2639	770		HALITE, ARGILLACEOUS HALITE
2634	775		ARGILLACEOUS HALITE AND HALITIC MUDSTONE
2629	780		ARGILLACEOUS HALITE AND HALITIC MUDSTONE
2624	785		
2619	790		SANDY HALITIC SILTSTONE
2614	795		SILTSTONE AND SANDY SILTSTONE, LIGHT BROWN TO REDDISH-BROWN WITH THIN LAYERS OF MEDIUM GRAY CLAYSTONE AND MUDSTONE, THINLY BEDDED TO LAMINATED, DIVISIBLE INTO UNITS 8" TO 20" THICK; BEDDING AND LAMINATIONS GENERALLY HORIZONTAL TO SUBHORIZONTAL, SOME WAVY BEDDING, SOME MICRO CROSS-LAMINATIONS; FROM 792.0' TO 795.0' LARGER CROSS-CUTTING RELATIONSHIPS WITH SOME UNITS PARTIALLY TO WHOLLY EROSIONALLY REMOVED, UNITS GENERALLY DOWN-CUT TO EAST AND SOUTHEAST; SMALL-SCALE CROSS-BEDDING HAS VARIABLE CURRENT DIRECTIONS WITH DEPTH, MOST SOUTH; AT 794.0' SYMMETRICAL RIPPLES WITH CLAY DRAPE; RIPPLE SETS 1/4" TO 1/2" THICK; MINOR SOFT SEDIMENT DEFORMATION, LOCAL FINING UPWARDS SEQUENCES; BASAL CONTACT GRADATIONAL.
2609	800		
2604	805		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2604	805		SILTSTONE AND ARGILLACEOUS SILTSTONE INTERBEDDED WITH CLAYSTONE, GRAY AND DARK GRAY, THINLY LAMINATED (1/32" TO 1/8"); ABUNDANT FINE STRUCTURES INCLUDING HORIZONTAL LAMINATIONS, LOW-ANGLE CROSS-LAMINATION SETS OF VARYING SIZE (2" TO 3.0'); CURRENT DIRECTIONS IN SMALLER SETS VARY, CURRENT DIRECTIONS IN LARGER SETS MOSTLY NORTHEAST; RARE LOAD STRUCTURES, EROSIONAL SCOUR AND FILL; RARE HIGH-ANGLE HALITE-FILLED FRACTURES; FRACTURE OCCURRENCE INCREASES WITH DEPTH, NEAR BASE RARE HORIZONTAL AND SUBVERTICAL HALITE-FILLED FRACTURES 1/8" TO 3" THICK, SPACED 3.0' TO 8.0'; SOME LARGER SUBHORIZONTAL FRACTURES EXHIBIT AN EAST (TOP) WEST (BOTTOM) SHEAR; CONTAINS DARK GRAY SPOTS AND BLEBS (BIOTURBATION), CONTENT INCREASING WITH DEPTH; BECOMES ARGILLACEOUS SILTSTONE WITH DEPTH; GRAY WITH LOCAL REDDISH-BROWN AREAS, THINLY LAMINATED AND CONTAINS BROWNISH CLASTS OF ANHYDRITE (1/8" TO 1-1/2" DIAMETER) ROUNDED AND OCCASIONALLY FLATTENED PARALLEL TO BEDDING; CLASTS RANDOMLY SCATTERED THROUGHOUT; RARE LOW-ANGLE CROSS-LAMINATION SETS; BASAL CONTACT GRADATIONAL OVER 1/2", IRREGULAR, MAPPED AS DIFFUSE DUE TO EXTREME CONTACT UNDULATIONS.
2599	810		
2594	815		
2589	820		
2584	825		
2579	830		
2574	835		
2569	840		
2564	845		
			SANDY SILTSTONE
			SILTSTONE
2559	850		POLYHALITE, ANHYDRITE, AND ARGILLACEOUS ANHYDRITE

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 20 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2559	850		
			SALADO FORMATION HALITIC MUDSTONE
2554	855		HALITE
2549	860		HALITE
2544	865		
			HALITIC CLAYSTONE
2539	870		HALITE
2534	875		
			HALITIC CLAYSTONE
2529	880		HALITE
			HALITIC CLAYSTONE
2524	885		ARGILLACEOUS HALITE
			CLAYSTONE, SLIGHTLY HALITIC
2519	890		HALITE, ARGILLACEOUS
2514	895		

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 21 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2514	895		
			ARGILLACEOUS HALITE
2509	900		HALITE
			ARGILLACEOUS HALITE
2504	905		HALITE, SLIGHTLY ARGILLACEOUS
2499	910		
			HALITE, COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, THINLY BEDDED WITH THIN SUBHORIZONTAL STRINGERS OF ANHYDRITE AND POLYHALITE; SLIGHTLY ARGILLACEOUS IN UPPER 0.5'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
2494	915		SILTY CLAYSTONE, BROWNISH-RED, VERY SOFT; HALITIC, HALITE OCCURS AS 1/4" TO 1" DISPLACIVE CRYSTALS; CONTAINS LOCALLY REDUCED CLAYSTONE; BASAL CONTACT DIFFUSE, GENETICALLY GRADATIONAL.
2489	920		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS INTERSTITIAL RED CLAY IN UPPER 3.0', CONTENT DECREASES WITH DEPTH; TRACE RANDOMLY ORIENTED STRINGERS OF POLYHALITE IN REMAINDER OF UNIT; BASAL CONTACT DIFFUSE.
2484	925		HALITE MIXED WITH POLYHALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; POLYHALITE CONTENT DECREASES WITH DEPTH, CONTENT GREATEST IN UPPER 0.5', OCCURS AS GROUPS OF SUBHORIZONTAL STRINGERS, BECOMING LESS ABUNDANT WITH DEPTH; SUBHORIZONTAL STRINGERS OF ANHYDRITE OCCUR WITH DEPTH, STRINGERS OF POLYHALITE AND ANHYDRITE BECOME RANDOMLY ORIENTED WITH DEPTH; BASAL CONTACT GRADATIONAL.
2479	930		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO ORANGE TO CLEAR; ABUNDANT POLYHALITE IN UPPER 3" TINTS HALITE ORANGE; SUBHORIZONTAL STRINGERS OF POLYHALITE AND ANHYDRITE SPACED 1" TO 3"; BED OF VERY POLYHALITIC HALITE OCCURS BETWEEN 729.4' AND 730.0', UNIDENTIFIED GAS ORIGINATES FROM THIS AREA ALONG FRACTURES; BASAL CONTACT DIFFUSE.
2474	935		ARGILLACEOUS HALITE, ARGILLACEOUS MATERIAL REDDISH-BROWN, HALITE WHITISH-GRAY TO CLEAR; HALITE OCCURS AS DISPLACIVE CRYSTALS AND AGGREGATES OF CRYSTALS; UNIT CONTAINS LOCAL GREENISH-GRAY REDUCTION ZONES; CLAY CONTENT DECREASES WITH DEPTH, DECREASES ABRUPTLY BELOW 937.0'; ROCK BELOW 937.0' CLASSIFIED AS: HALITE, WHITE, MEDIUM TO COARSELY CRYSTALLINE, SLIGHTLY ARGILLACEOUS, CLAY CONTENT DECREASING WITH DEPTH, TRACE POLYHALITE AND ANHYDRITE STRINGERS CONTENT INCREASING WITH DEPTH. STRINGERS RANDOMLY ORIENTED AT TOP, BECOMING SUBHORIZONTAL WITH DEPTH, SPACED 1" TO 3"; BASAL CONTACT GRADATIONAL, MARKED BY 1" THICK ZONE OF GRAYISH-WHITE HALITE.
2469	940		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2469	940		AS ABOVE
2464	945		
2459	950		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITISH-GRAY TO CLEAR, MASSIVE; HALITE OCCURS AS CRYSTAL AGGREGATES IN ZONES OR PODS; CLAY CONTENT DECREASES ABRUPTLY BELOW 949.0'; TRACE DISSEMINATED POLYHALITE BLEBS, CONTENT INCREASES WITH DEPTH; BECOMES BEDDED IN LOWER 2.0' WITH ALTERNATING POLYHALITIC HALITE AND CLEAR HALITE BEDS 2" TO 3" THICK; BASAL CONTACT SHARP, DISCONFORMABLE.
2454	955		
2449	960		ARGILLACEOUS HALITE IN UPPER 2.0', REDDISH-BROWN, CLAY CONTENT DECREASES WITH DEPTH, GRADES INTO POLYHALITIC HALITE; HALITE IS WHITE TO TINTED ORANGE TO CLEAR, MEDIUM TO COARSELY CRYSTALLINE; POLYHALITE OCCURS AS BLEBS AND STRINGERS, POLYHALITE BED AT 961.5'; CONTAINS LOCAL GREENISH-GRAY REDUCTION SPOTS IN ARGILLACEOUS MATERIAL NEAR THE BASE; BASAL CONTACT SHARP, MARKED BY 3" THICK HORIZONTAL FIBROUS HALITE-FILLED FRACTURE.
2444	965		SILTSTONE, REDDISH-BROWN, TRACE OF BEDDING; CONTAINS SMALL 1/4" IMBAYED DISPLACIVE HALITE CRYSTALS NEAR TOP; CONTAINS RARE SUBVERTICAL HALITE-FILLED FRACTURES; BECOMES ANHYDRITIC (GRAY) IN LOWER 2.0'; CONTAINS DISPLACIVE HALITE CRYSTALS <1/8"; BASAL CONTACT SHARP.
2439	970		ARGILLACEOUS HALITE, ARGILLACEOUS MATERIAL REDDISH-BROWN, HALITE CLEAR; BELOW 969.0' CLAY CONTENT DECREASES ABRUPTLY, UNIT BECOMES SLIGHTLY ARGILLACEOUS AND POLYHALITIC, CLAY AND POLYHALITE OCCUR AS RANDOMLY ORIENTED STRINGERS; OVERALL CLAY CONTENT DECREASES WITH DEPTH; POLYHALITE CONTENT INCREASES WITH DEPTH; BASAL CONTACT GRADATIONAL.
2434	975	MB 101	POLYHALITE, ANHYDRITIC, FINELY CRYSTALLINE, ORANGE, HARD; HALITIC, HALITE WHITE; ANHYDRITE GRAY; DISCONTINUOUS BEDS OF WHITE FINELY CRYSTALLINE HALITE NEAR TOP; AT 975.0', 1" THICK BED OF THINLY LAMINATED ANHYDRITE OCCURS; UNIT CONTAINS CLEAR DISPLACIVE HALITE CRYSTALS NEAR BASE; BASAL CONTACT SHARP.
			HALITE, POLYHALITIC, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, THIN TO MEDIUM BEDDED BY SUBHORIZONTAL STRINGERS OF POLYHALITE; BASAL CONTACT SHARP, MARKED BY A 2" THICK BED OF POLYHALITE.
2429	980		ARGILLACEOUS HALITE, REDDISH-BROWN, SLIGHTLY ANHYDRITIC, CLAY CONTENT DECREASES WITH DEPTH; NEAR TOP, HALITE OCCURS AS DISPLACIVE CRYSTALS; BECOMES THE DOMINANT MINERAL TYPE WITH DEPTH, BECOMES MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, THINLY BEDDED IN LOWER 2.0' WITH STRINGERS OF POLYHALITE SEPARATING BEDS; ARGILLACEOUS MATERIAL OCCURS AS MATRIX IN UPPER PART, STRINGERS IN LOWER PART; SOME GREENISH-GRAY REDUCTION SPOTS OCCUR NEAR TOP; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, DISCONFORMABLE.
2424	985		

EXHAUST SHAFT

LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2424	985		AS ABOVE
2419	990		ARGILLACEOUS HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; REDDISH-BROWN CLAY MATRIX IN UPPER 4"; POLYHALITIC; CLAY AND POLYHALITE OCCUR AS SUBHORIZONTAL STRINGERS SPACED 1" TO 4"; BASAL CONTACT SHARP.
2414	995		ARGILLACEOUS HALITE GRADING TO HALITE WITH DEPTH; CLAY OCCURS AS REDDISH-BROWN MATRIX AT TOP, HALITE OCCURS AS DISPLACIVE CRYSTALS AND CRYSTAL AGGREGATES ALIGNED IN ZONES, CLAY IN UPPER 1" GREENISH GRAY; CLAY CONTENT DECREASES WITH DEPTH, OCCURS AS SUBHORIZONTAL STRINGERS; HALITE BECOMES DOMINANT ROCK TYPE WITH DEPTH, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE POLYHALITE BLEBS AND RANDOMLY ORIENTED TO SUBHORIZONTAL STRINGERS; RARE ANHYDRITE STRINGERS; LOWER 3.0' TINTED ORANGE; BASAL CONTACT SHARP.
2409	1000		
2404	1005		
2399	1010		
2394	1015	M3 102	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; 1" THICK GRAY CLAYSTONE BEDS 3" ABOVE AND AT BASAL CONTACT; BASAL CONTACT SHARP.
			HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; TRACE POLYHALITE STRINGERS AND DISSEMINATED BLEBS; AT 1017.8', 1" THICK BED OF POLYHALITE OCCURS UNDERLAIN BY A 1/4" THICK BED OF GRAY CLAYSTONE; BASAL CONTACT SHARP, MARKED BY DISSOLUTION TROUGHS.
2389	1020		ARGILLACEOUS HALITE, WHITE TO CLEAR, MEDIUM TO COARSELY CRYSTALLINE; CLAY OCCURS AS BROWN SUBHORIZONTAL STRINGERS, SPACED 1" TO 2"; STRINGERS ARE TERMINATED EROSIONALLY AT UPPER CONTACT, CLAY CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE STRINGERS AND DISSEMINATED BLEBS, CONTENT INCREASES IN LOWER 3.0'; BASAL CONTACT SHARP, EROSIONAL, UNDULATORY UP TO 1.0'.
2384	1025		
2379	1030		AS BELOW

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2379	1030	MB 103	ANHYDRITE, FINELY CRYSTALLINE, ALTERNATING LIGHT AND DARK GRAY, LAMINATED TO VERY THINLY BEDDED; BEDDING UNDULATES SLIGHTLY, BEDS OFTEN CONTAIN ENTROLITHIC STRUCTURES: LOCAL <1/4" CRYSTALS OF HALITE; LIGHT BROWN CARBONATE (?) INTERBEDS; BASAL CONTACT GRADATIONAL.
2374	1035		CARBONATE (DOLOMITE?), FINELY CRYSTALLINE OR GRAINED, LIGHT BROWN WITH GRAYISH-BROWN LAMINAE, THINLY LAMINATED, LAMINAE OCCUR AS CONCAVE DOWNWARD SETS AVERAGING 4" TO 7" ACROSS: PROBABLE ALGAL STROMATOLITES; DARKER LAMINAE ORGANIC (?); BASAL CONTACT MARKED BY SUBHORIZONTAL GRAYISH-BROWN LAMINAE, GRADATIONAL.
2369	1040	MB 103	DOLOMITE, FINELY CRYSTALLINE, LIGHT BROWN, HINT OF BEDDING; BASAL CONTACT SHARP, EROSIONAL.
			ANHYDRITE, CARBONATE-RICH, FINELY CRYSTALLINE, ALTERNATING LIGHT GRAY AND GRAY, THINLY LAMINATED IN UPPER 0.9', REMAINDER STRUCTURELESS: BASAL CONTACT SHARP, EROSIONAL.
2364	1045		SILTY CLAYSTONE, GRAY, LOCALLY THINLY LAMINATED; CONTAINS DISPLACIVE HALITE CRYSTALS; BASAL CONTACT SHARP.
2359	1050	MB 104	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; CLAY MATRIX IN UPPER 1.0', HALITE OCCURS AS DISPLACIVE CRYSTALS, CLAY CONTENT DECREASES WITH DEPTH; CLAY MORPHOLOGY CHANGES FROM MATRIX TO SUBHORIZONTAL STRINGERS SPACED 1" TO 2", BELOW 1047.0' ARGILLACEOUS STRINGERS BECOME DISCONTINUOUS AND ORIENTED RANDOMLY; TRACE DISCONTINUOUS SUBHORIZONTAL STRINGERS AND PODS OF POLYHALITE, CONTENT INCREASES WITH DEPTH; AT 1050.0' A 0.3' THICK LAMINATED BED OF ANHYDRITE OCCURS, BELOW THIS BED CLAY CONTENT DECREASES MARKEDLY AND TRACE AMOUNTS OF POLYHALITE AND ANHYDRITE OCCUR IN DISCONTINUOUS STRINGERS; 2" THICK BED OF ANHYDRITE OCCURS AT 1055.0'; LOWER 1.0' IS VERY POLYHALITIC; BASAL CONTACT SHARP.
2354	1055		
2349	1060		ARGILLACEOUS HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, CLAY OCCURS IN RANDOMLY-ORIENTED STRINGERS: STRINGERS AND BLEBS OF POLYHALITE; BASAL CONTACT SHARP, UNDULATORY UP TO 1.0'.
2344	1065	MB 105	POLYHALITE, FINELY CRYSTALLINE, ORANGE, STRUCTURELESS EXCEPT NEAR BASE; LOCALLY HALITIC; THIN GRAY ANHYDRITE BED OCCURS AT BASE; BASAL CONTACT SHARP, MARKED BY A THIN BED OF GRAY CLAYSTONE.
2339	1070		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS AT TOP, REDDISH-BROWN, CONTENT DECREASES WITH DEPTH, CLAY OCCURS IN STRINGERS; TRACE POLYHALITE AS RANDOMLY-ORIENTED STRINGERS WHICH GRADE TO SUBHORIZONTAL WITH DEPTH, CONTENT INCREASES WITH DEPTH; AT 1071.6, 1" THICK BED OF POLYHALITE OCCURS UNDERLAIN BY 1" THICK GRAY CLAYSTONE BED; CLAY CONTENT INCREASES SLIGHTLY BELOW 1071.6', COLOR REDDISH-BROWN TO GRAY; BECOMES VERY POLYHALITIC IN LOWER 1.0'; BASAL CONTACT SHARP.
2334	1075		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2334	1075		AS ABOVE
2329	1080		
			POLYHALITE, FINELY CRYSTALLINE, ORANGE; UNDERLAIN BY 1/2" THICK GRAY CLAYSTONE BED; BASAL CONTACT SHARP.
2324	1085		HALITE, MEDIUM TO COARSELY CRYSTALLINE, CLEAR TO WHITE; UPPER 1.0' ARGILLACEOUS STRINGERS, CONTENT DECREASES WITH DEPTH; POLYHALITE STRINGERS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP.
			POLYHALITE, FINELY CRYSTALLINE, ORANGE, STRUCTURELESS; UNDERLAIN BY 1" THICK GRAY CLAYSTONE BED; BASAL CONTACT SHARP.
2319	1090		HALITE, MODERATELY ARGILLACEOUS AND POLYHALITIC, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; LOCAL REDDISH-BROWN CLAY MATRIX, HALITE OCCURS AS DISPLACIVE CRYSTALS, LOCAL GREENISH-GRAY REDUCTION ZONES; ARGILLACEOUS STRINGERS ABUNDANT IN UPPER 3.0', CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1103.0'; POLYHALITE OCCURS AS DISSEMINATED BLEBS AND STRINGERS, CONTENT INCREASING WITH DEPTH, 1" THICK POLYHALITE BED AT 1105.2'; BASAL CONTACT SHARP.
2314	1095		
2309	1100		
2304	1105		
2299	1110		
			HALITE, ARGILLACEOUS AND POLYHALITIC, COARSELY CRYSTALLINE, WHITE TO CLEAR; CLAY OCCURS AS STRINGERS; POLYHALITE OCCURS AS DISSEMINATED BLEBS AND STRINGERS, 6" THICK IRREGULAR BED OF POLYHALITE AT 1120.5', LOWER 6" VERY POLYHALITIC; BASAL CONTACT SHARP.
2294	1115		
2289	1120		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2289	1120	MB 107	AS ABOVE
2284	1125		POLYHALITE, FINELY CRYSTALLINE, ORANGE, STRUCTURELESS; UNDERLAIN BY 2" THICK GRAY CLAYSTONE BED; BASAL CONTACT SHARP.
2279	1130	MB 108	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; UPPER 4" VERY ARGILLACEOUS, CLAY OCCURS AS REDDISH-BROWN DISCONTINUOUS RANDOMLY-ORIENTED STRINGERS; REMAINDER CONTAINS TRACE CLAY STRINGERS, LOCALLY STRINGERS BECOME SUBHORIZONTAL AND DENSITY MAY INCREASE; CONTAINS TRACE POLYHALITE WITH DEPTH; BASAL CONTACT SHARP, DISCONFORMABLE.
2274	1135		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; UPPER 1" VERY ARGILLACEOUS, SLIGHTLY ARGILLACEOUS TO 1146.0'; MODERATELY ABUNDANT RANDOMLY-ORIENTED STRINGERS AND LARGE BLEBS OF POLYHALITE, CONTENT INCREASING WITH DEPTH, LOWER 1.5' VERY POLYHALITIC; BASAL CONTACT SHARP, DISCONFORMABLE.
2269	1140		ARGILLACEOUS HALITE. FINELY TO COARSELY CRYSTALLINE; LOCALLY INTERBEDDED WITH HALITIC MUDSTONE CONTAINING DISPLACIVE HALITE CRYSTALS; REDDISH-BROWN CLAY DISSEMINATED THROUGHOUT AS MATRIX, CONTENT INCREASES WITH DEPTH; IRREGULARLY SHAPED ZONES (1.0' x 2.0') OF PURE HALITE RANDOMLY SCATTERED THROUGHOUT UNIT; LOCAL SMALL ZONES OF REDUCED GREENISH-GRAY CLAY; DISSOLUTION PITS THROUGH UNIT FILLED WITH ARGILLACEOUS HALITE; POLYHALITIC, CONTENT INCREASES WITH DEPTH, DISCONTINUOUS 1" THICK POLYHALITE BED AT BASAL CONTACT; BASAL CONTACT GRADATIONAL, IRREGULAR WITH UP TO 1.0' OF RELIEF, LOCALLY SHARP, EROSIONAL.
2264	1145		ANHYDRITE, FINELY CRYSTALLINE, LIGHT GRAY TO LIGHT TANNISH-GRAY, THINLY LAMINATED TO THINLY BEDDED, BEDS SEPARATED BY DARK GRAY THIN LAMINAE; HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS BECOME ABUNDANT BELOW 1155.0', 1/16" TO 2" HIGH, BECOME MORE ABUNDANT AND LARGER WITH DEPTH, MOST OCCUR ALONG SUBHORIZONTAL BEDDING PLANES, OCCASIONALLY PSEUDOMORPHS LIE PARALLEL TO BEDDING; AT UPPER CONTACT DISSOLUTION PITS INTO ANHYDRITE OCCUR, FILLED WITH GRAY ARGILLACEOUS HALITE AND HALITIC MUDSTONE, 0.5' TO 2.0' DEEP INTO ANHYDRITE, BEDDING TERMINATED EROSIONALLY AT SIDES OF DISSOLUTION PITS; LOCALLY, POLYHALITE IS INCLUDED IN HALITE FILLING OF HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS, POLYHALITE ALSO OCCURS IN IRREGULARLY-SHAPED ZONES (2" x 3") AS REPLACEMENT OF ANHYDRITE; HALITE OCCURS ALONG BEDDING PLANES BELOW 1157.0'; LOWER 1" CONTAINS INTERBEDS OF POLYHALITE; BASAL CONTACT SHARP.
2259	1150		
2254	1155		POLYHALITE, SLIGHTLY HALITIC, FINELY CRYSTALLINE, REDDISH-ORANGE, HINT OF BEDDING IN UPPER 4", REMAINDER STRUCTURELESS EXCEPT FOR RARE HALITE PSEUDOMORPHS AFTER SWALLOWTAIL GYPSUM CRYSTALS; CONTAINS ABUNDANT IRREGULARLY-SHAPED CRYSTALS OF HALITE (1/32" TO 1/2"); LOWER 3" IS ANHYDRITIC OR CARBONATE-RICH, COLOR GRADES TO BROWN AT BASE; BASAL CONTACT SHARP, UNDULATORY ON TWO SCALES: MINOR - UP TO 3", MAJOR - UP TO 2.5', EXHIBITS SOFT SEDIMENT DEFORMATION DUE TO LOADING.
2249	1160	MB 109	CLAYSTONE, LIGHT GRAY AT TOP TO GRAY AT BASE, STRUCTURELESS EXCEPT FOR FLOWAGE STRUCTURES; THICKNESS RANGES FROM 0.2' TO 1.0'; LOCALLY BROKEN BY 0" TO 2" THICK FRACTURES FILLED WITH CLEAR TO ORANGE HALITE; BASAL CONTACT SHARP, UNDULATORY UP TO 2.0', DISCONFORMABLE.
2244	1165	MB 109	HALITE, COARSELY CRYSTALLINE, CLEAR TO WHITE; CONTAINS GRAY CLAY STRINGERS IN UPPER 2.0', CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS BLEBS, RANDOMLY-ORIENTED STRINGERS, AND AS THICK SUBHORIZONTAL STRINGERS 1/4" THICK; ANHYDRITE OCCURS WITH POLYHALITE STRINGERS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, UNDULATORY UP TO 1.0'.

EXHAUST SHAFT
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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2244	1165	MB 109	ANHYDRITE, FINELY CRYSTALLINE, GRAY TO LIGHT GRAY, HINT OF THIN LAMINATIONS; CONTAINS 1" THICK ANHYDRITE LOCAL ZONES OF MIXED HALITE AND FINELY CRYSTALLINE; BASAL CONTACT SHARP.
2239	1170		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS HORIZONTAL STRINGERS OF ANHYDRITE, 1" TO 3" THICK BEDS OF FINELY CRYSTALLINE ANHYDRITE WITH HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS AT 1167.3', 1168.4', 1169.4'; BASAL CONTACT SHARP.
2234	1175	MB 109	ANHYDRITE, FINELY CRYSTALLINE, LIGHT GRAY TO GRAY, FINELY LAMINATED; CONTAINS HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS, 1/4" TO 1-1/2" HIGH, OCCURRING PARALLEL TO BEDDING PLANES; BASAL CONTACT UNDULATORY DUE TO INFILLING OF SHALLOW CHANNEL FORMS IN UNDERLYING UNIT, SHARP, DISCONFORMABLE.
		MB 109	ANHYDRITE AND CLAYSTONE; ANHYDRITE OCCURS AS ISOLATED GRAY NODULES IN A POORLY INDURATED GRAY CLAYSTONE MATRIX; SIZE OF NODULES INCREASES WITH DEPTH; TEXTURE OF BASAL 1.0' DEFINED AS NODULAR; BASAL CONTACT SHARP, DISCONFORMABLE.
2229	1180		ANHYDRITE, HALITIC, FINELY CRYSTALLINE, GRAY TO BROWNISH-GRAY, MICRO TO THINLY LAMINATED, LAMINAE ALTERNATE LIGHT TO DARK; CONTAINS LOCAL HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS, < 1/8" HIGH; BASAL CONTACT SHARP, UNDULATORY, LOCALLY DISCONFORMABLE, MARKED BY DISCONTINUOUS 1" THICK POLYHALITE BED.
			HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; POLYHALITIC AT TOP, CONTENT DECREASES WITH DEPTH; BASAL CONTACT SHARP, DISCONFORMABLE.
2224	1185		POLYHALITE, FINELY CRYSTALLINE, PALE ORANGISH-BROWN, LOCALLY MICROLAMINATED TO BANDED (< 1/32" TO 1" THICK); LOCALLY 1/2" TO 1" THICK UNALTERED ANHYDRITE BEDS, NEAR TOP BEDS CONTAIN HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS 1/4" TO 1/2" HIGH; BASAL CONTACT SHARP, UNDULATORY UP TO 0.5', DISCONFORMABLE, MARKED BY THE OCCURRENCE OF 1" TO 2" THICK BED OF GRAY CLAYSTONE.
2219	1190		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; BLEBS AND SUBHORIZONTAL STRINGERS OF POLYHALITE TO 1/2" THICK; LOCAL GRAY SUBHORIZONTAL STRINGERS OF CLAY TERMINATED AT PENECONTEMPORANEOUS DISSOLUTION PITS; BASAL CONTACT SHARP, DISCONFORMABLE, UNDULATORY UP TO 0.4'.
2214	1195		HALITE AND ARGILLACEOUS HALITE; HALITE: WHITE TO CLEAR TO TINTED ORANGE; CLAY: REDDISH-BROWN; UPPER 0.5' VERY ARGILLACEOUS, CONTAINS DISPLACIVE HALITE CRYSTALS (< 1/4") IN MUDSTONE MATRIX, UPPER 3" GREENISH-GRAY IN COLOR, CLAY CONTENT DECREASES WITH DEPTH TO 1189.0', 0.5' THICK REDDISH-BROWN ARGILLACEOUS HALITE BED OCCURS BELOW 1189.0', CLAY CONTENT INCREASES ABRUPTLY, THEN DECREASES WITH DEPTH, CLAY MATERIAL OCCURS AS MATRIX MATERIAL OR AS RANDOMLY-ORIENTED STRINGERS, CLAY CONTENT LOCALLY INCREASES BELOW 1200.0'; TRACE POLYHALITE AT TOP, CONTENT INCREASING WITH DEPTH, AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED DISCONTINUOUS STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
2209	1200		
2204	1205		
2199	1210		

EXHAUST SHAFT
LITHOLOGIC LOG
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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2199	1210		
2194	1215	MB 110	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO ORANGISH-WHITE; UPPER 2.0' REDDISH-BROWN HALITIC MUDTONE CONTAINING DISPLACIVE HALITE CRYSTALS, GRADES INTO SLIGHTLY ARGILLACEOUS HALITE; REMAINDER CONTAINS GRAY CLAY DISSEMINATED THROUGHOUT AS INTER-CRYSTALLINE MATERIAL; POLYHALITE OCCURS AS RANDOMLY-ORIENTED STRINGERS AND DISSEMI-NATED BLEBS, BETWEEN 1217.0' AND 1219.0', 2" THICK POLYHALITE BEDS SPACED 0.5' TO 1.0' OCCUR, 3" THICK DISCONTINUOUS BED OF POLYHALITE UNDERLAIN BY A THIN BED OF GRAY CLAYSTONE OCCURS AT 1219.0', BED OF FINELY CRYSTALLINE ORANGISH-WHITE POLYHALITE OCCURS BETWEEN 1227.1' TO 1227.5'; 1/8" TO 1/4" THICK SUBHORIZONTAL STRINGERS OF POLYHALITE OCCUR IN THE INTERVALS FROM 1225.1' TO 1227.1' AND 1227.5' TO 1229.5'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
2189	1220		
2184	1225	MB 111	
2179	1230		
2174	1235		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; CLAY AND POLYHALITE OCCUR AS RANDOMLY-ORIENTED DISCONTINUOUS STRINGERS; UPPER 2.0' ARGILLACEOUS HALITE, HALITE OCCURS IN DISCONTINUOUS ZONES AND PODS OF CRYSTALS IN CLAY AND HALITE MATRIX, CLAY CONTENT DECREASES WITH DEPTH; BASAL CONTACT SHARP, UNDULATORY.
2169	1240		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; POLYHALITIC AND ARGILLACEOUS; ARGIL-LACEOUS HALITE OCCURS IN UPPER 0.5', CONTENT DECREASES WITH DEPTH; POLYHALITE OCCURS AS DISCONTINUOUS STRINGERS, BELOW 1243.0' POLYHALITE BECOMES ABUNDANT; BASAL CONTACT SHARP, UNDULATORY UP TO 1.0'.
2164	1245	MB 112	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, CONTAINS ZONES OF LIGHT ORANGE; APPEARS TO HAVE MOUND FORMS AT UPPER CONTACT; CONTAINS IRREGULARLY-SHAPED CRYSTALS OF HALITE (1/16" TO 3/4") DISSEMINATED THROUGHOUT; BASAL CONTACT SHARP, MARKED BY 1" TO 2-1/2" THICK GRAY CLAYSTONE CONTAINING HALITE.
2159	1250		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; TRACE GRAY CLAY, CONTENT DECREASES WITH DEPTH, BETWEEN 1255.8' AND 1257.0' SUBHORIZONTAL STRINGERS OF REDDISH-BROWN CLAY ARE CONTINUOUS AROUND THE CIRCUMFERENCE OF THE SHAFT; DISSEMINATED POLYHALITE BLEBS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP.
2154	1255		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2154	1255		AS ABOVE
2149	1260		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 0.5' ARGILLACEOUS, CLAY OCCURS WITH HALITE AS MATRIX, BELOW 1260.7' CLAY OCCURS AS STRINGERS, CONTENT DECREASES WITH DEPTH; DISSEMINATED POLYHALITE BLEBS; BASAL CONTACT SHARP.
			POLYHALITE, FINELY CRYSTALLINE, ORANGISH-RED, STRUCTURELESS; UNDERLAIN BY 1" THICK GRAY CLAYSTONE BED; BASAL CONTACT SHARP.
2144	1265		HALITE, WHITE TO CLEAR, COARSELY CRYSTALLINE, SLIGHTLY ARGILLACEOUS; CLAY OCCURS IN STRINGERS, CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1268.0'; TRACE POLYHALITE BLEBS; BASAL CONTACT SHARP.
2139	1270		
		MB 113	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, STRUCTURELESS; UNIT SPLIT BY 4" THICK CLEAR HALITE BED, OCCURS 3" BELOW UPPER CONTACT; BASAL CONTACT SHARP, MARKED BY 2" THICK GRAY CLAYSTONE BED.
2134	1275		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO ORANGE TO CLEAR; TRACE POLYHALITE, OCCURS AS DISCONTINOUS RANDOMLY-ORIENTED STRINGERS AND AS DISSEMINATED BLEBS; SLIGHTLY ARGILLACEOUS, GRAY CLAY STRINGERS TO 1276.0', ABSENT BETWEEN 1276.0' AND 1280.0', CLAY STRINGERS IN 1.0' THICK BAND BELOW 1280.0', BELOW 1284.0' CLAY CONTENT INCREASES AS SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
2129	1280		
2124	1285		
2119	1290		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS, UPPER 1.5' TO 2.0' ARGILLACEOUS HALITE WITH CLAY AND HALITE MATRIX, HALITE OCCURS AS ZONES AND PODS OF CRYSTALS AND DISPLACIVE CRYSTALS TO 1/2" ACROSS, CLAY CONTENT DECREASES WITH DEPTH; POLYHALITE OCCURS AS SUBHORIZONTAL STRINGERS AND DISSEMINATED BLEBS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, UNDULATORY.
			POLYHALITE, FINELY CRYSTALLINE, ORANGISH-RED, STRUCTURELESS EXCEPT FOR 1" THICK INTERBEDS OF HALITE; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
2114	1295	MB 114	HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS SUBHORIZONTAL CONTINUOUS STRINGERS OF POLYHALITE IN UPPER 0.5', IN THE REMAINDER OF THE UNIT POLYHALITE OCCURS AS RARE DISSEMINATED BLEBS; BASAL CONTACT SHARP.
2109	1300		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS AT TOP, CLAY OCCURS AS RANDOMLY-ORIENTED STRINGERS, CONTENT DECREASES WITH DEPTH; BASAL CONTACT GRADATIONAL.

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2109	1300		AS ABOVE
2104	1305		POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; CONTAINS IRREGULAR CRYSTALS AND BEDS OF HALITE; BASAL CONTACT SHARP, EXTREMELY IRREGULAR.
2099	1310		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; POLYHALITE OCCURS AS IRREGULAR RANDOMLY-ORIENTED AND SUBHORIZONTAL STRINGERS AND AS DISSEMINATED BLEBS, CONTENT INCREASES WITH DEPTH; BETWEEN 1307.0' AND 1308.0' HORIZONTAL AND SUBHORIZONTAL STRINGERS OF CLAY OCCUR; BASAL CONTACT DIFFUSE.
2094	1315		ARGILLACEOUS HALITE, REDDISH-BROWN CLAY, HALITE WHITE TO CLEAR; HALITE OCCURS IN PODS AND IRREGULARLY-SHAPED ZONES AND AS GROUPS OF CRYSTALS DISPERSED THROUGHOUT, BOTH CLAY AND HALITE OCCUR AS MATRIX; BASAL CONTACT GRADATIONAL.
2089	1320		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; SLIGHTLY ARGILLACEOUS, REDDISH-BROWN, CLAY CONTENT DECREASES WITH DEPTH; TRACE DISSEMINATED POLYHALITE BLEBS, CONTENT INCREASES WITH DEPTH, FROM 1320.4' TO 1320.9' A REDDISH-ORANGE, FINELY CRYSTALLINE POLYHALITE BED OCCURS; BASAL CONTACT SHARP.
2084	1325		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 4" ARGILLACEOUS, CLAY OCCURS AS FINE DISCONTINUOUS STRINGERS, CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1326.0'; BECOMES POLYHALITIC BELOW 1326.0', CONTENT INCREASES WITH DEPTH; BASAL CONTACT GRADATIONAL.
2079	1330		ANHYDRITE, FINELY CRYSTALLINE, LIGHT AND MEDIUM GRAY; INTERBEDS OF HALITE IN UPPER PART, CONTENT DECREASES WITH DEPTH; LOWER 1" CONTAINS NO INTERBEDS OF HALITE; BASAL CONTACT SHARP.
		MB 115	POLYHALITE, HALITIC, FINELY CRYSTALLINE, REDDISH-ORANGE; CONTAINS IRREGULAR DISCONTINUOUS BEDS OF CLEAR HALITE AND IRREGULARLY-SHAPED CRYSTALS OF HALITE 1/32" TO 1/8" ACROSS; OCCASIONAL HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS IN UPPER 1"; FROM 1331.5' TO 1331.8' OF GRAY FINELY CRYSTALLINE ANHYDRITE BED OCCURS; BASAL CONTACT SHARP, MARKED BY 1" THICK BED OF GRAY CLAYSTONE.
2074	1335		
2069	1340		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; VERY SLIGHTLY ARGILLACEOUS; TRACE POLYHALITE AND ANHYDRITE, IRREGULAR BLEBS OF POLYHALITE OCCURS ABOVE 1335.0', ANHYDRITE OCCURS AS CONTINUOUS AND DISCONTINUOUS STRINGERS BELOW 1335.0', BASAL 2.0' CONTAINS 1/4" THICK SUBHORIZONTAL STRINGERS OF ANHYDRITE; BASAL CONTACT SHARP.
2064	1345	MB 116	POLYHALITE INTERBEDDED WITH ANHYDRITE, FINELY CRYSTALLINE, LIGHT GRAY TO LIGHT GRAYISH-ORANGE, THINLY LAMINATED TO STRUCTURELESS; HALITE BED BETWEEN 1343.1' AND 1343.4'; BASAL CONTACT SHARP, MARKED BY 1" THICK GRAY CLAYSTONE BED.

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2064	1345		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; POLYHALITE OCCURS AS CONTINUOUS HORIZONTAL AND SUBHORIZONTAL STRINGERS AND AS IRREGULARLY-SHAPED BLEBS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP.
2059	1350		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, REDDISH-BROWN HALITIC CLAYSTONE MATRIX, HALITE CLEAR TO WHITE; HALITE OCCURS AS IRREGULARLY-SHAPED AGGREGATES OF CRYSTALS; CONTAINS 1/4" TO 2" THICK SUBHORIZONTAL HALITE-FILLED FRACTURES; BASAL CONTACT UNDULATORY UP TO 2.0', GRADATIONAL TO SHARP, DISCONFORMABLE.
2054	1355		McNUTT POTASH ZONE VACA TRISTA MARKER BED HALITIC SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO STRUCTURELESS; HALITE OCCURS AS ISOLATED DISPLACIVE CRYSTALS UP TO 1-1/2" ACROSS; LOCAL CHANNEL FILL STRUCTURES PRESENT; CONTAINS BOTH SUBVERTICAL AND SUBHORIZONTAL HALITE-FILLED FRACTURES 1/8" TO 2" THICK; CHANNEL INTO UNDERLYING UNIT 3.0' DEEP (EAST SIDE OF SHAFT); NUMEROUS FILLED CHANNELS THROUGHOUT UNIT; OCCASIONAL CROSS-LAMINATIONS; BASAL CONTACT GRADATIONAL TO LOCALLY SHARP, UNDULATORY UP TO 3.0'.
2049	1360		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS TO 1363.0', CLAY OCCURS AS REDDISH-BROWN MATRIX, CONTENT DECREASES WITH DEPTH, HALITE OCCURS AS IRREGULARLY-SHAPED CRYSTAL MASSES; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH AS SUBHORIZONTAL CONTINUOUS AND DISCONTINUOUS STRINGERS AND THIN BEDS, ALSO AS DISSEMINATED BLEBS; BELOW 1363.0' ARGILLACEOUS MATERIAL OCCURS AS LOCAL SUBHORIZONTAL STRINGERS; 1" THICK BED OF POLYHALITE OCCURS AT 1365.6'; FROM 1373.4' TO 1373.9' ARGILLACEOUS HALITE OCCURS; BASAL CONTACT SHARP, DISCONFORMABLE.
2044	1365		
2039	1370		
2034	1375		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, CRUDELY THIN TO MEDIUM BEDDED; POLYHALITE OCCURS AS SUBHORIZONTAL PARALLEL STRINGERS GROUPED IN UPPER 2.0', RANDOMLY-ORIENTED STRINGERS BELOW 1380.4', DISSEMINATED BLEBS, CONTENT DECREASES WITH DEPTH; LOCALLY SLIGHTLY ARGILLACEOUS, COLOR WHITISH-GRAY, SUBHORIZONTAL STRINGERS AND LOCAL IRREGULARLY-SHAPED ZONES OF CLAY, CONTENT DECREASES WITH DEPTH; 1/4" TO 1/2" THICK CLAYSTONE BED AT 1383.8'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
2029	1380		HALITIC CLAYSTONE AND ARGILLACEOUS HALITE, CLAY REDDISH-BROWN, HALITE WHITE TO CLEAR AND FINELY CRYSTALLINE; HALITE CONTENT INCREASES WITH DEPTH, OCCURS AS DISPLACIVE CRYSTALS (1/8" TO 1/2" ACROSS) AND PODS OF RELATIVELY PURE HALITE; LOCAL PODS OF POLYHALITE; BASAL CONTACT GRADATIONAL.
2024	1385		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; LOCALLY ARGILLACEOUS, REDDISH-BROWN CLAY OCCURS AS RANDOMLY-ORIENTED STRINGERS IN SUBHORIZONTAL ZONES, CONTENT DECREASES WITH DEPTH, DECREASES ABRUPTLY BELOW 1390.1'; TRACE POLYHALITE AS RARE DISSEMINATED RANDOMLY-ORIENTED STRINGERS AND BLEBS, CONTENT INCREASES WITH DEPTH, POLYHALITE BED OCCURS BETWEEN 1390.9' AND 1391.1', CONTENT INCREASES ABRUPTLY NEAR BASE; LOCAL ZONES AND STRINGERS OF ARGILLACEOUS HALITE CONTAINING GRAY CLAY; BASAL CONTACT SHARP, DISCONFORMABLE.
2019	1390		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2019	1390		AS ABOVE
2014	1395		HALITIC CLAYSTONE, UPPER 2" GRAY, REMAINDER REDDISH-BROWN, STRUCTURELESS EXCEPT FOR DISPLACIVE CRYSTALS (1/8" TO 1/2"); LOCAL GREENISH-GRAY REDUCTION SPOTS; HINT OF RELICT BEDDING; BASAL CONTACT GRADATIONAL, UNDULATORY.
2009	1400		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; VERY POLYHALITIC TO 1400.0', OCCURRING AS ABUNDANT RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS AND ZONES; BELOW 1400.0' RARE POLYHALITE AND SUBHORIZONTAL GRAY STRINGERS OF CLAY; BASAL CONTACT SHARP, DISCONFORMABLE.
2004	1405		ARGILLACEOUS HALITE; GRAY CLAY IN UPPER 1.0', REMAINDER REDDISH-BROWN; HALITE OCCURS AS WELL-ROUNDED PODS OR COBBLES (?) 1" TO 4" DIAMETER, FINE GRAINED OR CRYSTALLINE COARSENING TOWARD CENTER, WHITE TO CLEAR WITH RARE ORANGE TINT, PODS BREAK IN SPHERICAL PATTERN; LOCALLY HALITE OCCURS AS CLEAR TO WHITE IRREGULARLY SHAPED ZONES, HALITE ALSO OCCURS AS SMALL DISPLACIVE CRYSTALS <1/32" TO 1/8" ACROSS; LOCAL 1/8" TO 1/4" DISCONTINUOUS HALITE-FILLED (FIBROUS) FRACTURES; CONTAINS LOCAL POLYHALITE ZONES; BASAL CONTACT SHARP.
1999	1410		
1994	1415		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS AT TOP, CONTENT DECREASES WITH DEPTH, LOCAL DISCONTINUOUS IRREGULARLY-SHAPED ZONES OF CLAYSTONE, CLAY ALSO OCCURS AS RANDOMLY-ORIENTED AND SUBHORIZONTAL STRINGERS; MODERATELY ABUNDANT POLYHALITE, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL DISCONTINUOUS STRINGERS; CLAY ABSENT BELOW 1415.0'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY UP TO 4".
1989	1420	MB 117	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; THIN SUBHORIZONTAL HALITE-FILLED FRACTURES <1/16" THICK; CONTAINS RARE CRYSTALS OF HALITE 1/16" TO 1/4" ACROSS; LOWER 4" CONTAINS BLACK LAMINAE PARALLEL TO LOWER CONTACT; BASAL CONTACT SHARP, UNDULATORY ON TWO SCALES: MAJOR - 0.8', MINOR - 0.1', MARKED BY 1" THICK GREENISH-GRAY CLAYSTONE BED.
1984	1425		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE IRREGULAR DISCONTINUOUS STRINGERS AND BLEBS OF POLYHALITE; LOCAL TRACE AMOUNTS OF GRAY SUBHORIZONTAL STRINGERS OF CLAY; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
1979	1430		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; MODERATELY ARGILLACEOUS, CLAY REDDISH-BROWN TO GRAY WITH DEPTH, OCCURS AS INTER-CRYSTALLINE MATERIAL AND SUBHORIZONTAL TO RANDOMLY-ORIENTED STRINGERS, CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE BLEBS, CONTENT INCREASES WITH DEPTH, AT 1437.5' A 0.1' THICK BED OF REDDISH-ORANGE POLYHALITE OCCURS; BELOW POLYHALITE BED CLAY CONTENT INCREASES SLIGHTLY THEN DECREASES WITH DEPTH; BASAL CONTACT DIFFUSE, CONFORMABLE.
1974	1435		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1974	1435		AS ABOVE
1969	1440		
1964	1445	MB 118	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, STRUCTURELESS; HALITIC IN UPPER 1.5', HALITE OCCURS AS DISCONTINUOUS THIN BEDS AND IRREGULARLY-SHAPED ZONES, WHITE TO CLEAR; REMAINDER HALITE-FREE; BASAL CONTACT SHARP, MARKED BY 1" TO 2" THICK GREENISH-GRAY CLAYSTONE BED, DISCONFORMABLE.
1959	1450		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS RARE DISSEMINATED BLEBS AND SUBHORIZONTAL STRINGERS; TWO 3/4" THICK BEDS OF POLYHALITE NEAR 1450'; BASAL CONTACT SHARP.
			POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, STRUCTURELESS EXCEPT FOR RARE SUBHORIZONTAL AND SUBVERTICAL HALITE-FILLED FRACTURES < 1/8" THICK; BASAL CONTACT SHARP.
1954	1455		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE; TRACE SUBHORIZONTAL GRAY CLAY STRINGERS; RARE DISSEMINATED BLEBS AND SUBHORIZONTAL STRINGERS OF POLYHALITE, CONTENT INCREASES WITH DEPTH, INCREASES ABRUPTLY IN LOWER 4"; BASAL CONTACT SHARP.
			ARGILLACEOUS HALITE AND HALITIC CLAYSTONE; UPPER 0.5' TO 1.0' GRAY, REMAINDER REDDISH-BROWN; HALITE OCCURS AS IRREGULARLY-SHAPED ZONES, DISCONTINUOUS BEDS, DISPLACIVE CRYSTALS < 1/8" ACROSS; BASAL CONTACT DIFFUSE.
1949	1460		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; VERY ARGILLACEOUS TO 1459.0', CLAY CONTENT DECREASES WITH DEPTH, OCCURS AS IRREGULARLY-SHAPED ZONES OF HALITIC CLAYSTONE WITH DISPLACIVE HALITE CRYSTALS AND AS MATRIX AND RANDOMLY-ORIENTED STRINGERS OF CLAY IN ARGILLACEOUS HALITE, BELOW 1459.0' CLAY CONTENT DECREASES ABRUPTLY; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS, STRINGERS BECOME HORIZONTAL AND 1/4" THICK SPACED 2" TO 4" IN LOWER 5.0', 0.5' THICK BED OF POLYHALITE OCCURS AT 1469.0'; BASAL CONTACT GRADATIONAL.
1944	1465		POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE TO ORANGISH-RED; UPPER 0.5' CONTAINS DISCONTINUOUS BEDS OF IRREGULARLY-SHAPED PODS OF HALITE; BECOMES LAMINATED WITH CLAY PARTINGS BELOW 1470.0'; BASAL CONTACT SHARP, MARKED BY 1" TO 4" THICK BED OF GRAY CLAYSTONE SPLIT BY BIFURCATING HALITE-FILLED SUBHORIZONTAL FRACTURE, UNDULATORY UP TO 0.5'.
1939	1470	MB 119	HALITE, COARSELY CRYSTALLINE, WHITE, BEDDED WITH SUBHORIZONTAL CONTINUOUS STRINGERS AND BEDS OF POLYHALITE 1/4" TO 3/4" THICK; POLYHALITE CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1475.0'; BEDDED WITH SUBHORIZONTAL STRINGERS OF GRAY CLAY BELOW 1475.0'; BASAL CONTACT SHARP.
1934	1475		HALITE, FINELY TO MEDIUM CRYSTALLINE, WHITE TO CLEAR; GRAYISH-BLACK CLAY OCCURS AS INTERSTITIAL FILLING AND AS DISCONTINUOUS SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP.
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, BANDED BY ORANGE-TINTED HALITE SPACED 1" TO 2"; 1" THICK BED OF GREENISH-GRAY CLAYSTONE OCCURS 2" ABOVE LOWER CONTACT; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1929	1480		HALITIC CLAYSTONE AND ARGILLACEOUS HALITE, REDDISH-BROWN; HALITE OCCURS AS DISPLACIVE CRYSTALS AND SUBHORIZONTAL FRACTURE FILLINGS 1/4" THICK; UPPER 4" GREENISH-GRAY; BASAL CONTACT DIFFUSE.

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1929	1480		AS ABOVE
1924	1485		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; SLIGHTLY ARGILLACEOUS IN UPPER 2.0' AS DISCONTINUOUS RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE AT TOP, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND STRINGERS; BASAL CONTACT SHARP.
1919	1490	MB 120	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, STRUCTURELESS; BASAL CONTACT SHARP, MARKED BY 1/2" TO 1" THICK GRAY CLAYSTONE BED.
			HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS SUBHORIZONTAL STRINGERS OF BLACKISH-GRAY CLAY SPACED 2" TO 4"; BASAL CONTACT SHARP.
1914	1495		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, BANDED WHITE AND ORANGE, SPACED 1" TO 2", TRACE POLYHALITE; BASAL CONTACT GRADATIONAL.
1909	1500		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; HALITE OCCURS AS PODS AND IRREGULARLY-SHAPED ZONES OF CRYSTALS SURROUNDED BY REDDISH-BROWN CLAY MATRIX; CLAY CONTENT DECREASES WITH DEPTH; UPPER 4" CONTAINS SUBHORIZONTAL STRINGERS OF BLACKISH-GRAY CLAY SPACED 1"; BASAL CONTACT DIFFUSE.
1904	1505	MB 121	HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT SHARP, IRREGULAR, UNDULATORY UP TO 1", DISCONFORMABLE.
			POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; HALITIC, CONTAINS IRREGULARLY-SHAPED PODS OF HALITE TO 4" ACROSS; CONTAINS LOCAL ZONES RICH IN ANHYDRITE OR LANGBENITE (?); BASAL CONTACT SHARP, UNDULATORY, SLIGHTLY IRREGULAR.
1899	1510		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
		MB 122	POLYHALITE, FINELY CRYSTALLINE, BROWN TO TAN, STRUCTURELESS; BASAL CONTACT SHARP.
			HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS STRINGERS OF POLYHALITE AND GRAY CLAY SPACED 1" TO 2"; BASAL CONTACT SHARP.
1894	1515		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; UPPER 0.5' ARGILLACEOUS, REDDISH-BROWN, CONTENT DECREASES WITH DEPTH; TWO 3" THICK BEDS OF REDDISH-BROWN ARGILLACEOUS HALITE OCCUR AT 1519.8' AND 1520.2'; BASAL 0.5' CONTAINS SUBHORIZONTAL GRAY CLAY STRINGERS, SPACED 1" TO 3"; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
1889	1520		
1884	1525		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1884	1525		AS ABOVE
1879	1530		ARGILLACEOUS HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; CLAY REDDISH-BROWN, UPPER 1.0' TO 3.0' GRAY ARGILLACEOUS HALITE WITH RARE SMALL DISPLACIVE HALITE CRYSTALS < 1/16" ACROSS; HALITE OCCURS AS AGGREGATES OF CRYSTALS IN PODS OR ZONES; CLAY OCCURS AS MATRIX IN UPPER PART, OCCURS AS DISSEMINATED IRREGULARLY-SHAPED ZONES AND RANDOMLY-ORIENTED STRINGERS WITH DEPTH, CONTENT DECREASES WITH DEPTH; BASAL CONTACT SHARP.
1874	1535		UNION ANHYDRITE ANHYDRITE, ALTERNATES WHITISH-GRAY TO DARK GRAY, FINELY CRYSTALLINE, THINLY LAMINATED TO THINLY BEDDED; HALITIC, CONTAINS RARE 1/16" CRYSTALS OF HALITE; UPPER 2" TO 5" POLYHALITIC, DISCONTINUOUS POLYHALITE LENS OCCURS ON NORTHWEST SIDE OF SHAFT BETWEEN 1539.5' AND 1541.6'; LOWER 1.0' TO 2.0' CONTAINS WHITE LAMINAE INTERBEDDED WITH ANHYDRITE, POSSIBLY CARBONATE; BASAL CONTACT GRADATIONAL, ALTERNATION CONTACT, CONFORMABLE.
1869	1540		POLYHALITE, FINELY CRYSTALLINE, ORANGISH-RED TO REDDISH-ORANGE, THINLY LAMINATED TO THINLY BEDDED, LOCALLY STRUCTURELESS, LAMINAE OFTEN SLIGHTLY CONTORTED; LOCALLY ANHYDRITIC, OCCURS AS UNALTERED LAMINAE AND ZONES; BASAL CONTACT SHARP, MARKED BY LOAD CASTS INTO UNDERLYING UNIT (2" DEEP BY 1" TO 3" ACROSS) AND FLAME STRUCTURES.
1864	1545		ANHYDRITIC CLAYSTONE, FINELY LAMINATED, GRAY TO WHITISH-GRAY; CONTAINS LOCAL, SMALL ENTROLITHIC STRUCTURES; BASAL CONTACT GRADATIONAL TO DIFFUSE.
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, SLIGHTLY BEDDED BY DISCONTINUOUS SUBHORIZONTAL STRINGERS OF POLYHALITE AND BANDS OF POLYHALITIC HALITE; BASAL CONTACT SHARP, DISCONFORMABLE.
1859	1550		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, STRUCTURELESS; SLIGHTLY ARGILLACEOUS, MODERATELY ABUNDANT IN UPPER 1.0', CONTENT DECREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT GRADATIONAL.
1854	1555		
1849	1560		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS IN UPPER 1.5', GRAY, AS SUBHORIZONTAL STRINGERS AND BEDS, CONTENT DECREASES WITH DEPTH, 1.0' TO 2.0' THICK BED OF GRAY ARGILLACEOUS HALITE AT 1560.2'; BELOW 1560.2' CLAY CONTENT INCREASES AND BECOMES REDDISH-BROWN, OCCURS AS STRINGERS AND DISCONTINUOUS BEDS OF ARGILLACEOUS HALITE, CONTENT DECREASES WITH DEPTH, LOCALLY GRAY, CONTENT DROPS TO TRACE NEAR BASE; SOME POLYHALITE, CONTENT INCREASES TO 1560.2', BELOW WHICH IT DECREASES WITH DEPTH) OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, DISCONFORMABLE.
1844	1565		
1839	1570		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1839	1570		AS ABOVE
1834	1575		
1829	1580		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, STRUCTURELESS; UPPER 0.5' SLIGHTLY ARGILLACEOUS, REDDISH-BROWN, CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1582.0', OCCURS AS DISCONTINUOUS STRINGERS AND AS INTERCRYSTALLINE MATRIX; TRACE DISSEMINATED POLYHALITE BLEBS; BASAL CONTACT GRADATIONAL, HIGHLY IRREGULAR, MARKED BY THE OCCURRENCE OF ARGILLACEOUS HALITE.
1824	1585		
1819	1590		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 0.5' HAS REDDISH-BROWN CLAY MATRIX, CONTENT DECREASES SLIGHTLY WITH DEPTH, CLAY BECOMES BOTH GRAY AND REDDISH-BROWN, OCCURS AS RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND AS STRINGERS WITH DEPTH; BASAL CONTACT GRADATIONAL, DISCONFORMABLE.
1814	1595		
1809	1600		
1804	1605		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; SLIGHTLY ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, REDDISH-BROWN, OCCURS AS INTERCRYSTALLINE MATERIAL AND RANDOMLY-ORIENTED STRINGERS, LOCALLY OCCURS IN GREATER CONCENTRATIONS; TRACE POLYHALITE, CONTENT INCREASES SLIGHTLY WITH DEPTH, OCCURS AS DISSEMINATED BLEBS, BLEBS BECOME LARGER WITH DEPTH (UP TO 2" x 1"); BASAL CONTACT SHARP.
1799	1610		
1794	1615		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1794	1615	— X	
1789	1620	MB 123	ANHYDRITE, FINELY CRYSTALLINE, BROWNISH-GRAY TO ORANGISH-TAN, THINLY LAMINATED; LOCALLY ALTERED TO POLYHALITE; LAMINAE OFTEN CONTORTED AND SLIGHTLY HALITIC, LOCALLY NODULAR, STRUCTURE OFTEN ENTROLITHIC; BASAL CONTACT GRADATIONAL.
1784	1625	X XXXXXXXXXXXXXX X	HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; 3" THICK BED OF ORANGISH-RED POLYHALITE AT 1624.2'; TRACE POLYHALITE, OCCURS AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS AND AS DISSEMINATED BLEBS; THIN 1" THICK IRREGULAR BED OF ANHYDRITE AT 1628.3'; BASAL CONTACT SHARP, DISCONFORMABLE (?).
1779	1630	MB 124	ANHYDRITE, FINELY CRYSTALLINE, BROWNISH-GRAY TO TANNISH-GRAY, ENTROLITHIC TO NODULAR TO 1633.0', BELOW 1633.0', BECOMES LAMINATED TO THINLY BEDDED, LOCALLY CONTAINS ANHYDRITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS; LOCALLY POLYHALITIC; BASAL CONTACT SHARP, MARKED BY 2.0" TO 4.0" THICK GRAY THINLY LAMINATED CLAYSTONE BED CONTAINING SEVERAL SUBHORIZONTAL FIBROUS HALITE-FILLED FRACTURES 1/8" TO 1/4" THICK, SPACED 1" TO 2"; BASAL CONTACT GRADATIONAL.
1774	1635		
		MB 124	ARGILLACEOUS POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; POLYHALITE OCCURS AS REPLACEMENT OF ANHYDRITE OR GYPSUM NODULES IN GRAY CLAYSTONE MATRIX; NODULE CONCENTRATION INCREASES WITH DEPTH UNTIL MATRIX IS POLYHALITE; NODULE DIAMETER 1/8" TO 1/2"; UNDERLAIN BY 1" TO 2" GRAY CLAYSTONE BED; BASAL CONTACT SHARP, UNDULATORY, IRREGULAR.
1769	1640	X X X	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; POLYHALITIC, OCCURS AS DISSEMINATED BLEBS AND AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; GRAY CLAYSTONE BED OCCURS AT 1644.0'; POLYHALITE CONTENT TRACE BELOW 1644.0'; LOWER 1.5' CONTAINS TRACE AMOUNT OF CLAY STRINGERS; BASAL CONTACT SHARP, IRREGULAR WITH DISSOLUTION PITS 0.3' DEEP, MARKED BY 2" TO 3" THICK GRAY CLAYSTONE BED.
1764	1645	X X X	
1759	1650	—	
1754	1655	X X —	HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; POLYHALITIC, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; TRACE DISSEMINATED GRAY CLAY; BASAL CONTACT SHARP.
1749	1660	— X	AS BELOW

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1749	1660		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE REDDISH-BROWN AND GRAY CLAY, OCCURRING AS STRINGERS AND AS LOCALLY DISSEMINATED MATRIX, CLAY CONTENT INCREASES ABRUPTLY BELOW 1662.0' AS REDDISH-BROWN STRINGERS, CONTENT DECREASES WITH DEPTH, ARGILLACEOUS HALITE BED OCCURS WITH CLAY AS STRINGERS AND MATRIX BETWEEN 1673.0' AND 1673.8', LOWER 2.5' CONTAINS DISCONTINUOUS HORIZONTAL AND SUBHORIZONTAL STRINGERS OF GRAY CLAY; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS WITH SIZE INCREASING WITH DEPTH (1" DIAMETER); BASAL CONTACT SHARP, IRREGULAR, UNDULATORY TO 0.5'.
1744	1665		
1739	1670		
1734	1675		
1729	1680		
1724	1685		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS HALITE OCCURS BETWEEN 1681.4' AND 1682.6', GRAY CLAY; REDDISH-BROWN ARGILLACEOUS HALITE OCCURS BETWEEN 1682.6' AND 1684.1', CLAY OCCURS AS RANDOMLY-ORIENTED STRINGERS AND AS MATRIX; CLAY CONTENT DECREASES ABRUPTLY BELOW 1684.1'; TRACE POLYHALITE BELOW 1686.4', CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP.
1719	1690		
1714	1695		ARGILLACEOUS HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; VERY ARGILLACEOUS IN UPPER 0.5', CLAY REDDISH-BROWN, CONTENT DECREASES WITH DEPTH, OCCURS AS INTERCRYSTALLINE MATRIX AND RARE STRINGERS, CONTENT DECREASES ABRUPTLY BELOW 1704.0'; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT SHARP, IRREGULAR, DISCONFORMABLE.
1709	1700		
1704	1705		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1704	1705		AS ABOVE
1699	1710		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 0.3' TO 0.4' AND LOWER 0.7' PURE HALITE, REMAINDER SLIGHTLY ARGILLACEOUS, CLAY REDDISH-BROWN, BECOMING GRAY WITH DEPTH; BASAL CONTACT SHARP, IRREGULAR, DISCONFORMABLE.
1694	1715		
1689	1720		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; UPPER 1.0' ARGILLACEOUS, CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS. LOWER 1.0' VERY POLYHALITIC; BASAL CONTACT SHARP, IRREGULAR, UNDULATORY.
1684	1725		
			POLYHALITE, FINELY CRYSTALLINE, ORANGISH-RED, STRUCTURELESS; UNIT VERY UNDULATORY; BASAL 0.4' CONSISTS OF GREENISH-GRAY CLAYSTONE; BASAL CONTACT SHARP, UNDULATORY, DISCONFORMABLE.
1679	1730		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; LOCALLY ARGILLACEOUS, CLAY REDDISH-BROWN, CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT SHARP, IRREGULAR WITH DISSOLUTION PITS 1.0' DEEP INTO UNDERLYING UNIT.
1674	1735		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 2.0' SLIGHTLY ARGILLACEOUS, CLAY REDDISH-BROWN, OCCURS AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS AND DISSEMINATED INTERCRYSTALLINE MATERIAL; TRACE POLYHALITE AT TOP, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT GRADATIONAL.
1669	1740		
1664	1745		
1659	1750		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1659	1750	X	AS ABOVE
		MB 127	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, TRACE THIN LAMINATIONS; LOCALLY ANHYDRITIC; BASAL CONTACT SHARP.
		MB 127	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE OCCASIONALLY TINTED ORANGE; SUBHORIZONTAL POLYHALITE STRINGERS, 1/8" THICK; BASAL CONTACT SHARP, IRREGULAR.
1654	1755	X	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; BASAL CONTACT SHARP, MARKED BY 1" THICK GRAY CLAYSTONE BED.
		X	HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; POLYHALITIC, CONTENT DECREASES WITH DEPTH, OCCURS AS STRINGERS AND BLEBS; 0.1' TO 0.4' THICK ANHYDRITE BED OCCURS AT 1761.9'; BASAL CONTACT SHARP.
1649	1760	X	
		MB 128	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, THINLY LAMINATED; 0.3' THICK HALITE BED AT 1763.9', LOWER 0.1' TO 0.2' HALITIC GRAY CLAYSTONE; BASAL CONTACT SHARP.
1644	1765	— — —	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE OCCASIONALLY TINTED ORANGE, HINT OF BEDDING FROM SUBHORIZONTAL STRINGERS OF POLYHALITE SPACED 0.2'; 0.1' THICK BED OF ARGILLACEOUS HALITE OCCURS AT 1767.3'; POLYHALITE CONTENT INCREASES ABRUPTLY NEAR BASE; BASAL CONTACT SHARP, DISCONFORMABLE.
1639	1770	X X	
		— — —	ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; GRAY CLAY OCCURS AS MATRIX AND INTERCRYSTALLINE MATERIAL, CLAY BECOMES REDDISH-BROWN BELOW 1773.8', CLAY CONTENT DECREASES WITH DEPTH; CLAY-FREE POLYHALITIC HALITE OCCURS BETWEEN 1773.3' AND 1773.8'; POLYHALITE CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, IRREGULAR.
		X X X	
1634	1775	— —	
		—	
1629	1780	—	
		—	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS TO 1782.4', CONTENT DECREASES ABRUPTLY BELOW, CLAY OCCURS AS MATRIX; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT GRADATIONAL.
1624	1785	X	
			POLYHALITE, FINELY CRYSTALLINE, DARK REDDISH-ORANGE, HINT OF THIN LAMINATIONS; TRACE HALITE; BASAL CONTACT SHARP, MARKED BY 1" THICK GRAY CLAYSTONE BED, SLIGHTLY UNDULATORY, DISCONFORMABLE.
		MB 129	ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, CLEAR; GRAY CLAY AT TOP, GRADING TO REDDISH-BROWN WITH DEPTH, CONTENT DECREASES WITH DEPTH UNTIL ABSENT AT 1792.3'; CLAY CONTENT INCREASES AS INTERCRYSTALLINE MATERIAL AND STRINGERS BELOW 1792.3', CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1794.0'; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, MARKED BY 0.1' THICK BED OF POLYHALITE UNDERLAIN BY 1/4" THICK GRAY CLAYSTONE BED.
1619	1790	— —	
		—	
		X	
1614	1795	—	

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1614	1795		AS ABOVE
1609	1800	MB-130	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS SUBHORIZONTAL GRAY CLAY STRINGERS TO 1804.3', ABSENT BELOW 1804.3'; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, MARKED BY 3" ZONE OF GRAYISH HALITE UNDERLAIN BY 1" THICK GRAY CLAYSTONE.
1604	1805		
1599	1810		
1594	1815		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 1.8' ARGILLACEOUS, REDDISH-BROWN, CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS, BLEBS ALIGNED IN ZONES AND STRINGERS OCCUR BELOW 1817.6'; CONTAINS GRAY CLAY AS STRINGERS AND DISSEMINATED INTER-CRYSTALLINE MATERIAL BETWEEN 1819.2' AND 1819.9'; BASAL CONTACT SHARP, IRREGULAR, DISCONFORMABLE.
1589	1820		
1584	1825		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLA-CEOUS, REDDISH-BROWN, CLAY OCCURS AS INTERCRYSTALLINE MATRIX AND STRINGERS, CONTENT DECREASES WITH DEPTH, CONTENT DECREASES ABRUPTLY BELOW 1823.0'; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT GRADATIONAL.
1579	1830		
1574	1835		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; SLIGHTLY ARGILLACEOUS IN UPPER 4.0', CONTENT DECREASES WITH DEPTH, CLAY OCCURS AS STRINGERS AND INTERCRYSTALLINE MATRIX, CONTAINS RARE SMALL (<1/16") DISPLACIVE HALITE CRYSTALS; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT SHARP, MARKED BY DISSOLUTION PITS 6" TO 8" DEEP INTO UNDERLYING UNIT, IRREGULAR, UNDU-LATORY.
1569	1840		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS TO 1839.8', OCCURS AS GRAY STRINGERS; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT GRADATIONAL, HIGHLY IRREGULAR, SLIGHTLY UNDULATORY.

EXHAUST SHAFT

LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1569	1840		AS ABOVE
1564	1845		POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; HALITIC; BASAL CONTACT GRADATIONAL, VERY IRREGULAR, UNDULATORY.
1559	1850		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS, GRAY AT TOP GRADING TO REDDISH-BROWN WITH DEPTH, CONTENT DECREASES WITH DEPTH, CLAY OCCURS AS SUBHORIZONTAL STRINGERS AND AS MATRIX MATERIAL IN IRREGULARLY-SHAPED ZONES OF ARGILLACEOUS HALITE; POLYHALITIC, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED DISCONTINUOUS STRINGERS; CONTAINS LARGE IRREGULAR ZONES (SEVERAL SQUARE FOOT AREA) OF PURE WHITE HALITE WHICH ARE CONTINUOUS INTO UNDERLYING UNIT (DISSOLUTION PITS ?); BASAL CONTACT SHARP, IRREGULAR, DISCONFORMABLE.
1554	1855		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS AT TOP, CONTENT DECREASES WITH DEPTH, OCCURS AS RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; CONTAINS DISSOLUTION PITS 2.0' TO 3.0' DEEP, FILLED WITH WHITE COARSELY CRYSTALLINE HALITE; BASAL CONTACT SHARP TO ABSENT, MARKED BY 1" THICK GRAY CLAYSTONE BED.
1549	1860		HALITE, COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; POLYHALITIC, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL 1/4" THICK STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
1544	1865		
		MB 131	POLYHALITE, FINELY CRYSTALLINE, DARK REDDISH-ORANGE, STRUCTURELESS; HALITIC; UNDERLAIN BY 4" THICK BED OF GRAY HALITIC CLAYSTONE; BASAL CONTACT GRADATIONAL.
1539	1870		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; SLIGHTLY ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, OCCURS AS SUBHORIZONTAL STRINGERS; POLYHALITIC, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL STRINGERS, POLYHALITE BED 0.1' THICK AT 1875.7'; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1534	1875		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CLAY REDDISH-BROWN TO GRAY, OCCURS AS IRREGULAR SUBHORIZONTAL STRINGERS; HALITE OCCURS IN PODS OR ZONES OF CRYSTALS; TRACE POLYHALITE; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
1529	1880		HALITE, COARSELY CRYSTALLINE, WHITE; BECOMES SLIGHTLY ARGILLACEOUS WITH DEPTH; POLYHALITIC, OCCURS AS BLEBS AND SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1524	1885		ARGILLACEOUS HALITE, REDDISH-BROWN WITH TRACE OF GRAY; HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR, OCCURS AS IRREGULARLY-SHAPED BEDS AND PODS, LOCALLY POLYHALITIC AND FREE OF CLAY; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND IRREGULAR RANDOMLY-ORIENTED STRINGERS; 1/4" THICK BED OF POLYHALITE UNDERLAIN BY 1/4" THICK DISCONTINUOUS BED OF GRAY CLAYSTONE OCCURS AT 1898.2'; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.

EXHAUST SHAFT

LITHOLOGIC LOG

PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1524	1885		AS ABOVE
1519	1890		
1514	1895		
		MB 132	POLYHALITE, FINELY CRYSTALLINE, DARK REDDISH-ORANGE, STRUCTURELESS; UNDERLAIN BY 1" THICK GREENISH-GRAY CLAYSTONE; BASAL CONTACT SHARP.
1509	1900		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; TRACE ARGILLACEOUS MATERIAL BELOW 1901.0', CONTENT DECREASES WITH DEPTH, TOTALLY ABSENT BELOW 1904.8', OCCURS AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS BECOMING BLEBS WITH DEPTH; 1/4" THICK SUBHORIZONTAL STRINGERS OF ANHYDRITE OCCUR BELOW 1914.0'; AT 1916.5', A 0.2' THICK PINKISH-RED POLYHALITE BED OCCURS; BASAL CONTACT SHARP, SLIGHTLY IRREGULAR AND UNDULATORY.
1504	1905		
1499	1910		
1494	1915		
1489	1920	MB 133	POLYHALITE, FINELY CRYSTALLINE, DARK RED, STRUCTURELESS AT TOP GRADING TO LAMINATED AT BASE; HALITIC, BASAL CONTACT SHARP TO GRADATIONAL, MARKED BY 0.1' TO 0.2' THICK GRAY CLAYSTONE BED.
		X X X	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, SLIGHTLY ARGILLACEOUS, OCCURS AS RANDOMLY-ORIENTED STRINGERS; ABUNDANT POLYHALITE, OCCURS AS DISSEMINATED BLEBS; CONTAINS LOCAL ZONES OF PURE HALITE; BASAL CONTACT GRADATIONAL, IRREGULAR.
1484	1925	X	HALITE, MEDIUM TO COARSELY CRYSTALLINE, CLEAR TO WHITE; RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS OF BLACK CLAY OCCUR BETWEEN 1923.5' AND 1926.4'; POLYHALITIC, CONTENT INCREASES ABRUPTLY BELOW 1926.8', THEN DECREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT DIFFUSE.
1479	1930		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1479	1930		HALITE, FINELY TO COARSELY CRYSTALLINE, CLEAR TO WHITE; MODERATELY ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, OCCURS AS BLACK BLEBS AND STRINGERS; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISCONTINUOUS IRREGULAR RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS AND DISSEMINATED BLEBS; CONTAINS LOCAL BEDS AND ZONES OF CLAY-FREE HALITE; POLYHALITE CONTENT INCREASES ABRUPTLY NEAR BASE; BASAL CONTACT SHARP.
1474	1935		
1469	1940		
1464	1945		ANHYDRITE, FINELY CRYSTALLINE, LIGHT TO DARK GRAY, THINLY LAMINATED TO LAMINATED; UPPER 0 TO 0.5' POLYHALITIC; LOCALLY HALITIC, OCCURS AS DISCONTINUOUS BEDS AND PODS; SOME LAMINAE ORGANIC-RICH (?); LAMINAE UNDULATE SLIGHTLY; UNDERLAIN BY 0.1' TO 0.3' THICK GRAY HALITIC CLAYSTONE; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1459	1950		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, STRUCTURELESS; SLIGHTLY ARGILLACEOUS IN UPPER 5.0', OCCURS AS GRAY DISCONTINUOUS SUBHORIZONTAL STRINGERS, BELOW 1952.3' CONTENT INCREASES SHARPLY, THEN DECREASES WITH DEPTH, DISCONTINUOUS 1" TO 2" THICK IRREGULAR GRAY CLAYSTONE BED OCCURS AT 1952.3'; TRACE POLYHALITE, OCCURS AS LIGHT ORANGISH-WHITE DISSEMINATED BLEBS; IN BASAL 1.0' POLYHALITE AND ANHYDRITE OCCUR AS DISCONTINUOUS SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, IRREGULAR.
1454	1955		
1449	1960		
		MB 134	ANHYDRITE, FINELY CRYSTALLINE, GRAY ALTERNATING WITH DARK GRAY, THINLY LAMINATED; LOCALLY CONTAINS PODS OF HALITE AND HALITE-RICH LAMINAE; BASAL CONTACT SHARP, CONFORMABLE.
1444	1965	MB 134	ANHYDRITE, FINELY CRYSTALLINE, GRAY; HALITIC, OCCURS AS ABUNDANT HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS ALIGNED PARALLEL TO BEDDING, 1/8" TO 2" HIGH, MAJORITY ORIENTED VERTICALLY; LOCALLY, ANHYDRITE IS FREE OF PSEUDOMORPHS AND THINLY LAMINATED, LAMINAE ALTERNATE FROM LIGHT TO DARK GRAY; HALITE PSEUDOMORPHS ABSENT BETWEEN 1966.6' AND 1967.5'; BASAL CONTACT GRADATIONAL TO DIFFUSE.
1439	1970	MB 134	ANHYDRITE, FINELY CRYSTALLINE, ALTERNATING LIGHT AND DARK GRAY, THINLY LAMINATED TO LAMINATED; LAMINAE OFTEN CONTAIN INSIPIENT ENTROLITHIC STRUCTURES AND ANHYDRITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS; UNDERLAIN BY 0.4' TO 0.5' THICK BED OF MICROLAMINATED TO THINLY LAMINATED GRAY CLAYSTONE CONTAINING SUBHORIZONTAL BIFURCATING 0 TO 1" THICK HALITE-FILLED FRACTURES; BASAL CONTACT SHARP, IRREGULAR, UNDULATORY, DISCONFORMABLE.
1434	1975		

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LITHOLOGIC LOG

PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1434	1975		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, STRUCTURELESS; MODERATELY ARGILLACEOUS, GRAY, CONTENT DECREASES WITH DEPTH, OCCURS AS DISSEMINATED RANDOMLY-ORIENTED DISCONTINUOUS STRINGERS AND BLEBS; TRACE POLYHALITE BLEBS; CONTAINS INTER-UNIT DISSOLUTION PITS FILLED WITH RELATIVELY PURE HALITE; FREE OF GRAY CLAY FROM 1985.0' TO 1989.0'; THIN (<1/8") SUBHORIZONTAL STRINGERS OF ANHYDRITE OCCUR BELOW 1986.0'; IRREGULAR BED OF HALITIC ANHYDRITE IN LOWER 1" TO 3" OVERLIES HIGHLY UNDULATORY BASAL CONTACT, CONTACT MARKED BY GRAY CLAYSTONE IN CHANNEL TROUGHS, CONTACT EROSIONALLY TERMINATES UNDERLYING UNIT AT THE WEST SIDE OF SHAFT; BASAL CONTACT SHARP.
1429	1980		
1424	1985		
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE; CONTAINS DISCONTINUOUS SUBHORIZONTAL STRINGERS OF ANHYDRITE, <1/4" THICK; UNIT THICKNESS VARIES FROM 0 TO 1.5' AS IT IS EROSIONALLY TERMINATED AT UPPER CONTACT; SHAPE LENTICULAR (0 TO 1.5' X 6'); BASAL CONTACT SHARP.
1419	1990	MB 135	ANHYDRITE, FINELY CRYSTALLINE, LIGHT GRAY, LOCALLY THINLY LAMINATED; CONTAINS ABUNDANT HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS; BASAL CONTACT SHARP, MARKED BY 1/4" TO 1/2" THICK GRAY CLAYSTONE BED.
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED GRAY, BANDED, SPACED 1/2" TO 4", TRACE GRAY CLAY; CONTAINS CONTINUOUS IRREGULAR SUBHORIZONTAL STRINGERS OF GRAY CLAY; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY UP TO 4".
1414	1995		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED GRAY, BANDED ON 1/2" TO 2" SCALE, SLIGHTLY ARGILLACEOUS, OCCURS AS SUBHORIZONTAL STRINGERS AND LOCAL RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP.
1409	2000		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, STRUCTURELESS; SLIGHTLY ARGILLACEOUS IN UPPER PART, CONTENT DECREASES WITH DEPTH, OCCURS AS REDDISH-BROWN RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, SLIGHTLY IRREGULAR, SLIGHTLY UNDULATORY (3").
1404	2005		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; CLAY REDDISH-BROWN, CONTENT DECREASES WITH DEPTH, OCCURS AS INTERCRYSTALLINE MATRIX, GRADES TO SUBHORIZONTAL STRINGERS WITH DEPTH; HALITE OCCURS AS DISCONTINUOUS BEDS AND ALIGNED PODS; BASAL CONTACT SHARP, IRREGULAR, UNDULATORY.
1399	2010		
1394	2015		
1389	2020		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1389	2020	—	AS ABOVE
1384	2025	— X — X —	HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, OCCURS AS IRREGULAR DISCONTINUOUS BEDS 1/2" TO 2" THICK AT TOP, BECOMES MASSIVE WITH DEPTH; VERY ARGILLACEOUS AT TOP, CONTENT DECREASES WITH DEPTH, OCCURS AS INTERCRYSTALLINE MATRIX; ABUNDANT POLYHALITE AT TOP, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RARE SUBHORIZONTAL STRINGERS; CONTAINS ABUNDANT VERTICALLY-ORIENTED ELONGATE ZONES OF PURE AND POLYHALITIC HALITE WITH IRREGULAR EDGES, 1.0' TO 2.0' ACROSS, UP TO 3.0' DEEP; BASAL CONTACT EXHIBITS CHANNEL FORM, WITH HIGH SIDE OCCURRING ON WEST SIDE OF SHAFT AT 2032.0' AND LOW POINT OCCURRING ON EAST SIDE OF SHAFT AT 2036.3'; CHANNEL FILL CONSISTS OF HALITE AND POLYHALITIC HALITE BELOW 2032.0', A 0.5' THICK BED OF FINELY CRYSTALLINE ANHYDRITE OCCURS AT 2032.3' AND TERMINATES AGAINST UNDERLYING UNIT AT WEST SIDE OF SHAFT, FILL CONTAINS ABUNDANT SUBHORIZONTAL STRINGERS OF ANHYDRITE THAT TERMINATE AGAINST UNDERLYING UNIT AT WEST SIDE OF SHAFT; BASAL CONTACT SHARP.
1379	2030	— X	
1374	2035	—	
1369	2040	MB 136	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, STRUCTURELESS EXCEPT FOR LOCAL ZONES CONTAINING HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS AND LOCAL ZONES WITH NODULAR STRUCTURE, LOCALLY THINLY LAMINATED NEAR BASE; UPPER 2.0' ON WEST SIDE OF SHAFT CONSISTS OF THINLY LAMINATED ANHYDRITE; BASAL CONTACT GRADATIONAL, UNDULATORY.
1364	2045	MB 136	ANHYDRITE, FINELY CRYSTALLINE, ALTERNATING LIGHT AND DARK GRAY, THINLY LAMINATED, LAMINAE UNDULATE SLIGHTLY; 0.3' ABOVE LOWER CONTACT, 0 TO 1" THICK DISCONTINUOUS PURE HALITE BED OCCURS, CONTAINS ONE DISCONTINUOUS STRINGER OF POLYHALITE; BASAL CONTACT SHARP.
1359	2050	— X —	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; SLIGHTLY ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, OCCURS AS REDDISH-BROWN TO GRAY RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS WHICH BECOME SUBHORIZONTAL WITH DEPTH; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL STRINGERS NEAR BASE; 1" TO 2" THICK BED OF ANHYDRITE (NORTHWEST SIDE OF SHAFT) AND POLYHALITE (SOUTHEAST SIDE OF SHAFT) AT 2059.3'; SUBHORIZONTAL STRINGERS OF ANHYDRITE IN LOWER 5.0'; NO CLAY OCCURS BELOW 2059.3'; BASAL CONTACT SHARP, UNDULATORY TO 0.4', DISCONFORMABLE.
1354	2055	—	
1349	2060	— MB 137 —	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE AND GRAY, THINLY BEDDED TO GRAY ARGILLACEOUS HALITE WITH CLAY-FREE HALITE, BEDDING TERMINATED AT UPPER CONTACT; TRACE POLYHALITE AT TOP, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS; ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, GRAY AT TOP GRADING TO GRAYISH-BROWN WITH DEPTH, OCCURS AS DISCONTINUOUS RANDOMLY-ORIENTED STRINGERS AND LOCAL ZONES OF INTERCRYSTALLINE MATERIAL, BECOMES REDDISH-BROWN BELOW 2070.2', CONTENT DECREASES ABRUPTLY BELOW 2079.0', BASAL 2.0' SLIGHTLY ARGILLACEOUS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, IRREGULAR, MARKED BY DISCONTINUOUS IRREGULAR 2" THICK BED OF HALITIC ANHYDRITE.
		X	
1344	2065	— X	

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LITHOLOGIC LOG

PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1344	2065		AS ABOVE
1339	2070		
1334	2075		
1329	2080		
1324	2085		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; ARGILLACEOUS IN UPPER 1.2', OCCURS AS REDDISH-BROWN DISCONTINUOUS SUBHORIZONTAL STRINGERS AND MASSES OF HALITIC MUDSTONE, CONTENT DECREASES WITH DEPTH; BASAL CONTACT SHARP.
1319	2090		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS OF POLYHALITE; ARGILLACEOUS IN UPPER 1.0', CONTENT DECREASES WITH DEPTH; LOCAL ANHYDRITE STRINGERS OCCUR NEAR BASAL CONTACT; BASAL CONTACT SHARP, SLIGHTLY IRREGULAR AND UNDULATORY.
1314	2095		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE DISSEMINATED POLYHALITE BLEBS; ARGILLACEOUS AT TOP, CONTENT DECREASES WITH DEPTH EXCEPT FOR LOCAL INCREASES, CONTENT DECREASES ABRUPTLY BELOW 2101.5', OCCURS AS DISCONTINUOUS SUBHORIZONTAL STRINGERS; THIN DISCONTINUOUS STRINGERS OF ANHYDRITE AND POLYHALITE OCCUR IN LOWER 2.0'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
1309	2100		
1304	2105		ANHYDRITE, FINELY CRYSTALLINE, ALTERNATING LIGHT AND DARK GRAY, THINLY LAMINATED; UNDERLAIN BY 1/2" THICK GRAYISH-BROWN CLAYSTONE BED; BASAL CONTACT SHARP.
		MB 138	HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, BEDDED AT TOP WITH REDDISH-BROWN ARGILLACEOUS HALITE, SPACED 1" TO 2"; ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, OCCURS AS INTERCRYSTALLINE MATRIX IN ARGILLACEOUS HALITE BANDS AT TOP AND RANDOMLY-ORIENTED STRINGERS WITH DEPTH, CONTENT DECREASES ABRUPTLY BELOW 2111.3'; RARE DISSEMINATED BLEBS OF POLYHALITE; BASAL CONTACT DIFFUSE.
1299	2110		

EXHAUST SHAFT

LITHOLOGIC LOG

PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1299	2110		AS ABOVE
1294	2115		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE STRINGERS OF CLAY IN UPPER 1.7'; TRACE SUBHORIZONTAL TO HORIZONTAL CONTINUOUS STRINGERS OF ANHYDRITE BELOW 2117.0'; BASAL CONTACT SHARP.
1289	2120		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, RARE RANDOMLY-ORIENTED CLAY STRINGERS TO 2125.2'; UPPER CONTACT MARKED BY ANHYDRITIC CLAYSTONE CONTAINING DISPLACIVE HALITE CRYSTALS (<1/4"); TRACE POLYHALITE BLEBS; ANHYDRITE STRINGERS OCCUR BETWEEN 2128.1' AND 2128.5'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, IRREGULAR.
1284	2125		
1279	2130		ANHYDRITE (A), FINELY CRYSTALLINE, LIGHT GRAY, THINLY LAMINATED, LAMINAE SLIGHTLY CONTORTED; LOCALLY CONTAINS SMALL HALITE CRYSTALS (<1/16"); BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE CLAY STRINGERS TO 2131.5'; SUBHORIZONTAL STRINGERS OF ANHYDRITE SPACED 2" TO 4" OCCUR BELOW 2134.0'; BASAL CONTACT SHARP.
1274	2135		
			ANHYDRITE (B), FINELY CRYSTALLINE, LIGHT GRAY, HINT OF THIN LAMINATIONS; HALITIC, BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1269	2140		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE SUBHORIZONTAL CLAY STRINGERS AT TOP, CONTENT DECREASES WITH DEPTH; VERY RARE BLEBS OF POLYHALITE; BASAL CONTACT NOT OBSERVED.
1264	2145		
	2146.4	FACILITY LEVEL	

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LITHOLOGIC LOG

APPENDIX G

TEST ROOMS
GEOLOGIC MAPS AND SECTIONS

CONTENTS

Figure No.	Title/Description
G-1	Test Room 1 - Instrument Array Geologic Strip Map
G-2	Test Room 2 - Instrument Array Geologic Strip Map
G-3	Test Room 3 - Instrument Array Geologic Strip Map
G-4	Test Room 4 - Instrument Array Geologic Strip Map
G-5	Section Through Test Room 1
G-6	Section Through Test Room 2
G-7	Section Through Test Room 3
G-8	Section Through Test Room 4
G-9	Room T Large Diameter Drill Hole Location Plan
G-10	Geologic Map of Drill Hole TV-01
G-11	Geologic Map of Drill Hole TV-02
G-12	Geologic Map of Drill Hole TV-03
G-13	Geologic Map of Drill Hole TV-04
G-14	Geologic Map of Drill Hole TV-05
G-15	Geologic Map of Drill Hole TV-06
G-16	Geologic Map of Drill Hole TV-07
G-17	Geologic Map of Drill Hole TV-08
G-18	Geologic Map of Drill Hole TV-09
G-19	Geologic Map of Drill Hole TV-10
G-20	Geologic Map of Drill Hole TV-11
G-21	Geologic Map of Drill Hole TV-12
G-22	Geologic Map of Drill Hole TV-13
G-23	Geologic Map of Drill Hole TV-14
G-24	Geologic Map of Drill Hole TV-15
G-25	Geologic Map of Drill Hole TV-16
G-26	Geologic Map of Drill Hole TV-17
G-27	Geologic Map of Drill Hole TV-18
G-28	Geologic Map of Drill Hole TV-19
G-29	Geologic Map of Drill Hole TV-20
G-30	Geologic Map of Drill Hole TV-21
G-31	Geologic Map of Drill Hole TV-22
G-32	Section A Through Room T
G-33	Section B Through Room T
G-34	Geologic Map of Drill Hole P4X-84

The following descriptions pertain to the geologic map units shown on Figures G-1 through G-4:

UNIT DESCRIPTIONS

UNIT 6[1] Halite: colorless with grayish orange-pink (1 OR 8/2)[2] tint; transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; unit extends into the roof; lower contact with Unit 5 is gradational and/or diffuse.

UNIT 5 Halite: colorless; transparent to translucent; coarsely crystalline; trace of bluish-white (5B 9/1) to light bluish-gray (5B 7/1) argillaceous material occurring as pods (1/2-inch diameter) and discontinuous laminations or filling interstices; lower contact with Unit 4 is generally sharp and based on prominent color change in argillaceous material (gray to red-brown) from Unit 5 to Unit 4.

UNIT 4 Argillaceous halite: colorless to moderate reddish-brown (1 OR 4/6), less frequently light bluish-gray (5B 7/1); transparent; coarsely crystalline; trace of dispersed polyhalite; trace to abundant argillaceous material (decreasing downward) consisting of clay containing a trace of silt and fine crystals of halite, occurring as discontinuous laminations in upper half of unit and interstitially in lower half; lower contact with Unit 3 is gradational and based on absence of argillaceous material in Unit 3.

UNIT 3 Halite: colorless to moderate reddish-orange (1 OR 6/6); transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; polyhalite content commonly increases downward; lower contact with Unit 2 is sharp.

UNIT 2 Argillaceous halite: moderate reddish-brown (1 OR 5/5), less frequently light bluish-gray (5B 7/1); medium to coarsely crystalline; argillaceous material primarily occurs interstitially or as discontinuous laminations; lower contact with Unit 1 is generally sharp, less frequently gradational.

UNIT 1 Halite: light reddish-orange (1 OR 8/6) to moderate reddish-orange (1 OR 6/6), less frequently colorless; translucent to transparent; medium to coarsely crystalline; trace of dispersed polyhalite; lower contact with Unit 0 is sharp.

UNIT 0 Argillaceous halite: colorless to moderate reddish-orange (1 OR 6/6) and moderate reddish-brown (1 OR 4/6); medium to coarsely crystalline; trace of dispersed polyhalite; some argillaceous material occurs as discontinuous laminations and blebs or fills interstices (decreasing downward); contains finely crystalline halite; unit extends into the floor.

NOTES:

(1) Units listed in descending order from roof to floor.

(2) Alpha-numeric color designations are based on Geological Society of America Rock Color Chart.

The following legend and notes pertain to the geologic maps shown on Figures G-1 through G-4:

LEGEND:

CONTACTS

SHARP (LESS THAN 0.05 FEET)

GRADATIONAL (0.05 TO 0.2 FEET)

DIFFUSE (0.2 TO 0.5 FEET)

WEEP

DAMP AREA WITH 1/4" TO 3/4" DIAMETER KNOBS AND INCRUSTATIONS OF FINELY-CRYSTALLINE HALITE.

BREAKS IN BED CONTINUITY

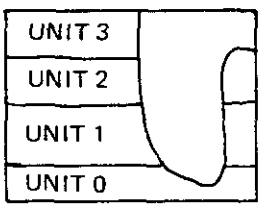

SYN- OR IMMEDIATELY POST-DEPOSITIONAL DISSOLUTION OR SCOUR CHANNELS FILLED WITH SEDIMENT FROM OVERLYING UNIT. (TYPICAL)

NOTES:

1. VERTICAL CONTROL FOR MAPPING IS MEAN SEA LEVEL (MSL) REFERENCED TO UNDERGROUND SURVEY POINTS ESTABLISHED BY CEMENTATION WEST, INC.
2. HORIZONTAL CONTROL FOR MAPPING REFERENCED TO ZERO POINT AT CENTER-LINE OF C&SH SHAFT.

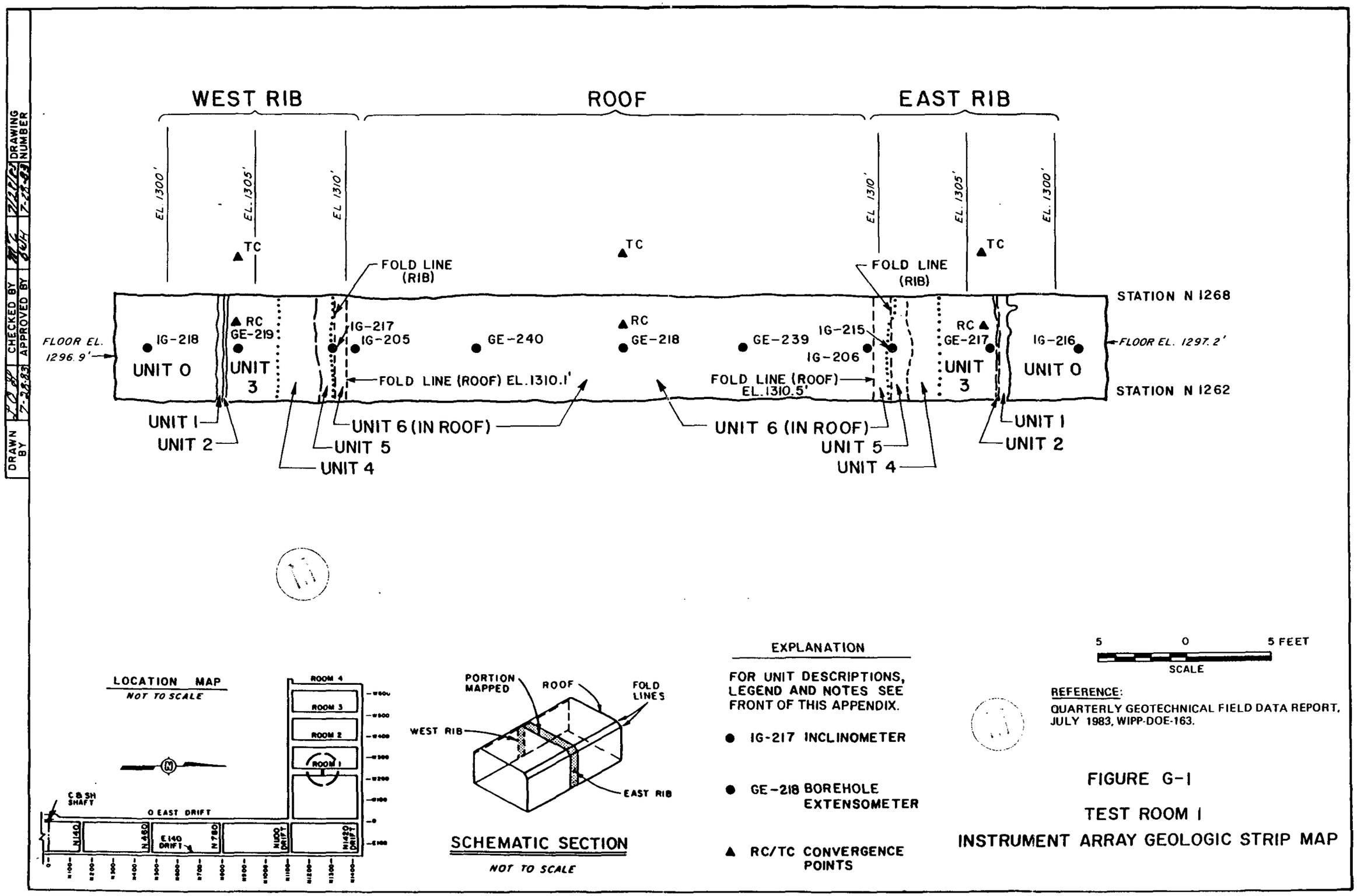

FIGURE G-1

TEST ROOM 1

INSTRUMENT ARRAY GEOLOGIC STRIP MAP

DRAWN BY	CHECKED BY	APPROVED BY	DRAWING NUMBER
[illegible] 7-28-83	[illegible]	RWH	1-28-83

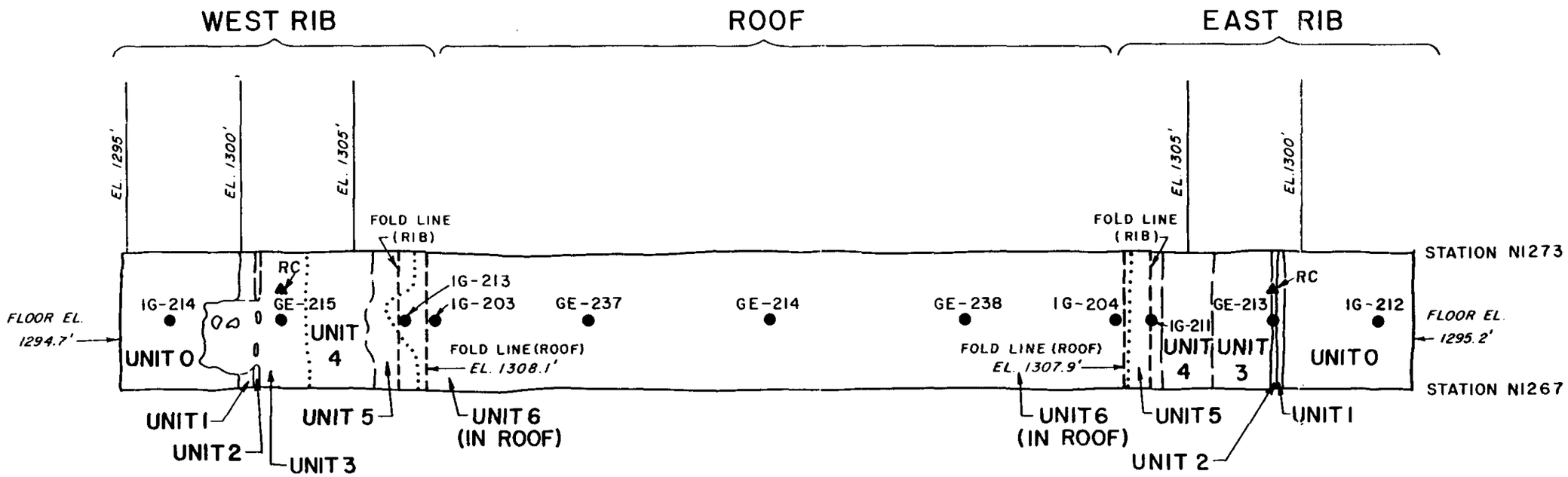

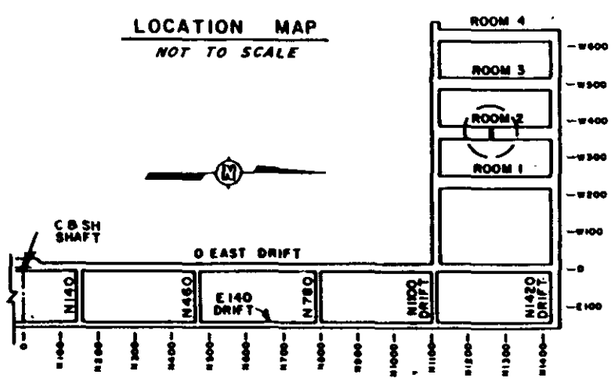

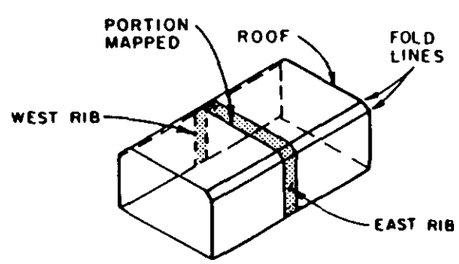

SCHEMATIC SECTION

NOT TO SCALE

EXPLANATION

FOR UNIT DESCRIPTIONS, LEGEND AND NOTES SEE FRONT OF THIS APPENDIX.

EAST RIB - MAPPING UNIT CONTACTS ARE OBSCURED BY GROUT TO 2' SOUTH AND 4' NORTH OF INSTRUMENT LINE. INDICATED CONTACTS ARE PROJECTED FROM THESE POINTS.

- ● IG-215 INCLINOMETER
- ● GE-214 BOREHOLE EXTENSOMETER
- ▲ RC/TC CONVERGENCE POINTS

5 0 5 FEET

SCALE

REFERENCE:

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-163.

FIGURE G-2

TEST ROOM 2

INSTRUMENT ARRAY GEOLOGIC STRIP MAP

DRAWN BY	CHECKED BY	DRAWING NUMBER
2-28-83	APPROVED BY	7-28-83

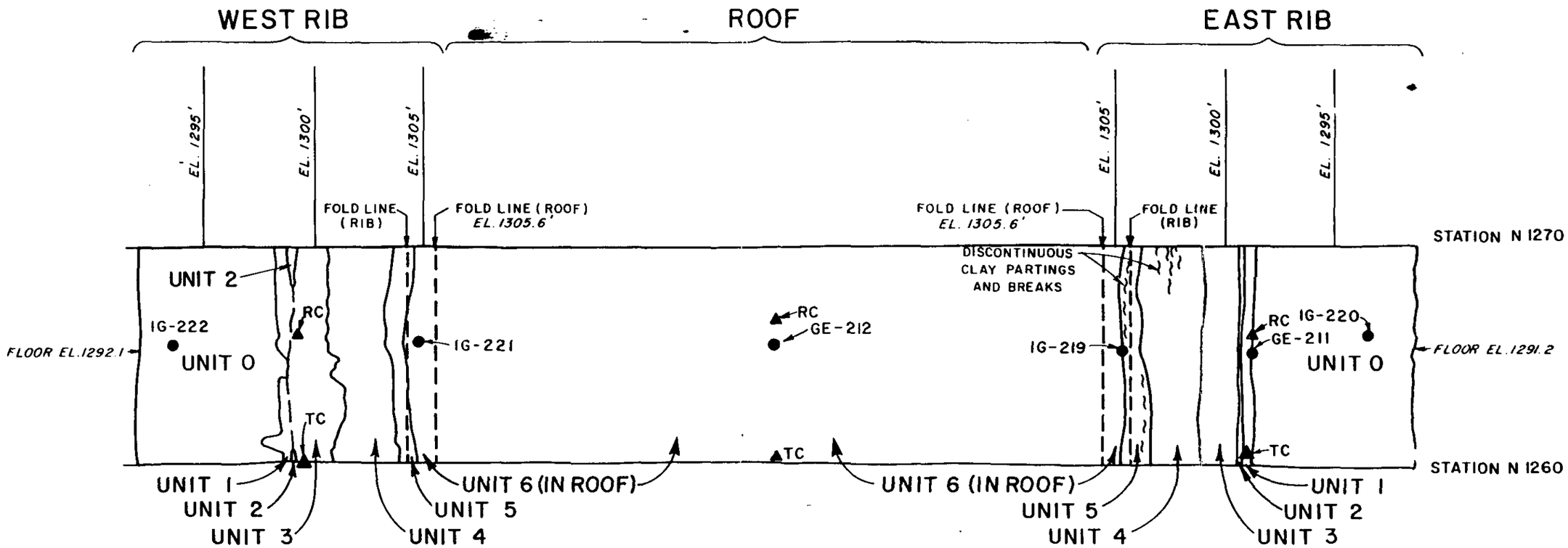

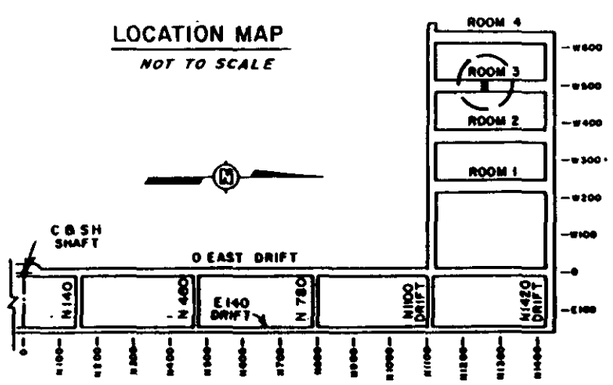

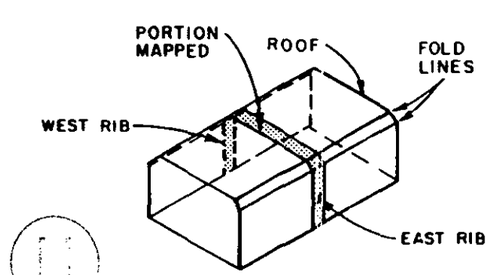

SCHEMATIC SECTION

NOT TO SCALE

EXPLANATION

FOR UNIT DESCRIPTIONS, LEGEND AND NOTES SEE FRONT OF THIS APPENDIX.

● IG-221 INCLINOMETER

● GE-211 BOREHOLE EXTENSOMETER

▲ RC/TC CONVERGENCE POINTS

5 0 5 FEET

SCALE

REFERENCE:

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-163.

FIGURE G-3

TEST ROOM 3

INSTRUMENT ARRAY GEOLOGIC STRIP MAP

DRAWN BY	L A 5/19/83	CHECKED BY	APPROVED BY	DRAWING NUMBER NM78-648-B

080-B

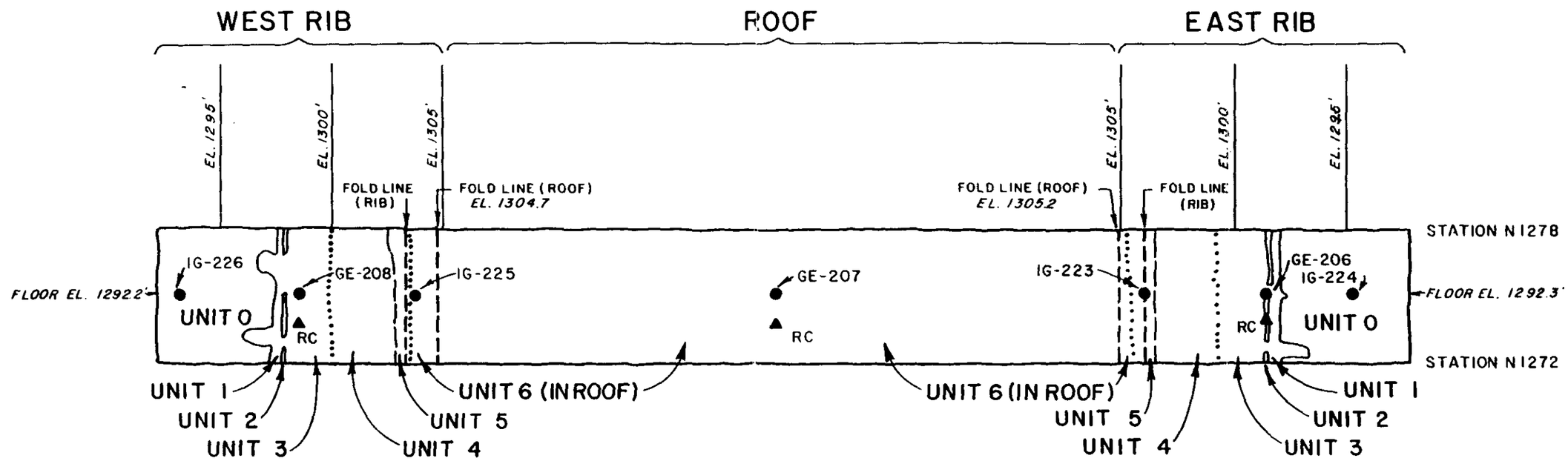

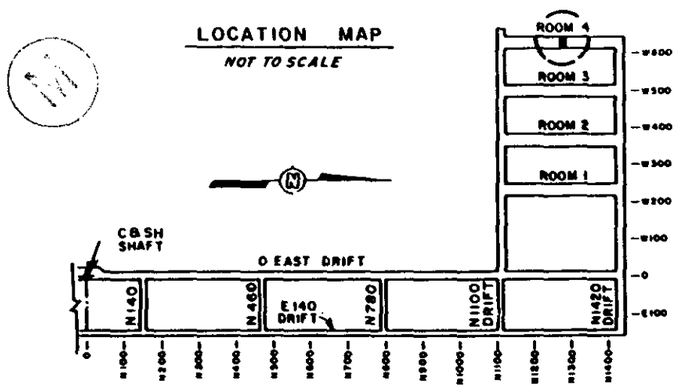

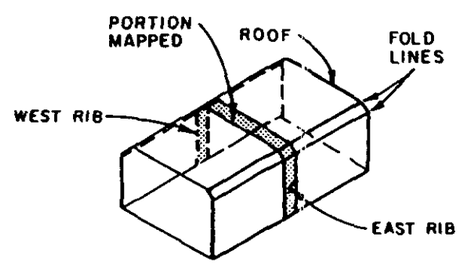

SCHEMATIC SECTION

NOT TO SCALE

EXPLANATION

FOR UNIT DESCRIPTIONS, LEGEND AND NOTES SEE FRONT OF THIS APPENDIX.

● IG-225 INCLINOMETER

● GE-207 BOREHOLE EXTENSOMETER

▲ RC/TC CONVERGENCE POINTS

5 0 5 FEET

SCALE

REFERENCE:

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-163.

FIGURE G-4

TEST ROOM 4

INSTRUMENT ARRAY GEOLOGIC STRIP MAP

24

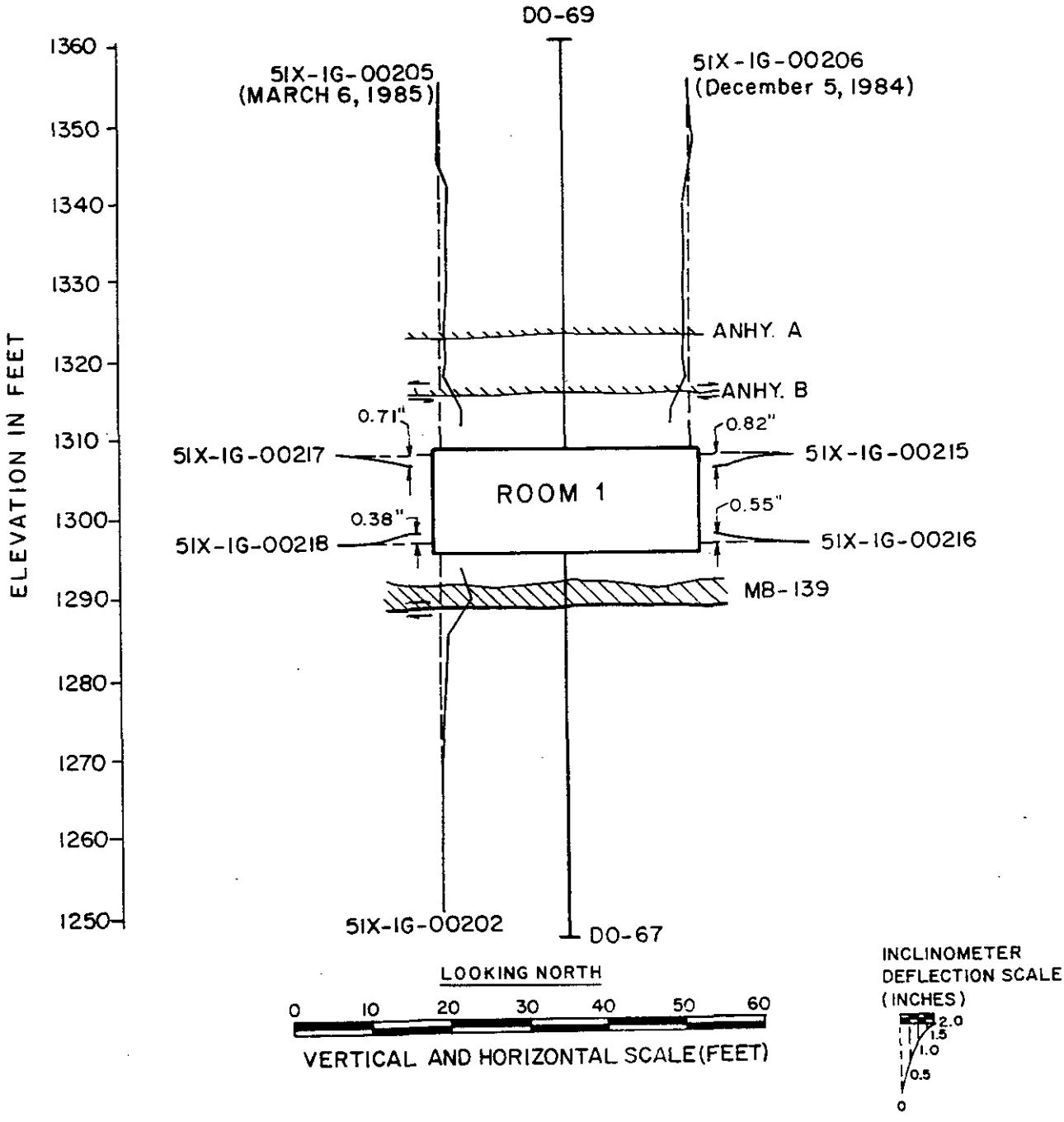

EXPLANATION

ANHYDRITE UNIT

CLAY, AT LOWER CONTACT OF MB-139.

ORIGINAL (DASHED LINE) AND DEFLECTED (SOLID LINE) POSITIONS OF INCLINOMETER. EXAGGERATED SCALE AS SHOWN.

BOREHOLE WITH OBSERVED OFFSET (NOT TO SCALE). SHOWING RELATIVE MOVEMENTS.

VERTICAL COREHOLE

DO-67

NOTES

1. INCLINOMETER DATA AS OF AUG. 20, 1985 UNLESS NOTED OTHERWISE.
2. OFFSETS IN BOREHOLES ARE NOT DRAWN TO SCALE; ONLY RELATIVE MOVEMENTS ARE SHOWN.

FIGURE G-5

SECTION THROUGH TEST ROOM 1

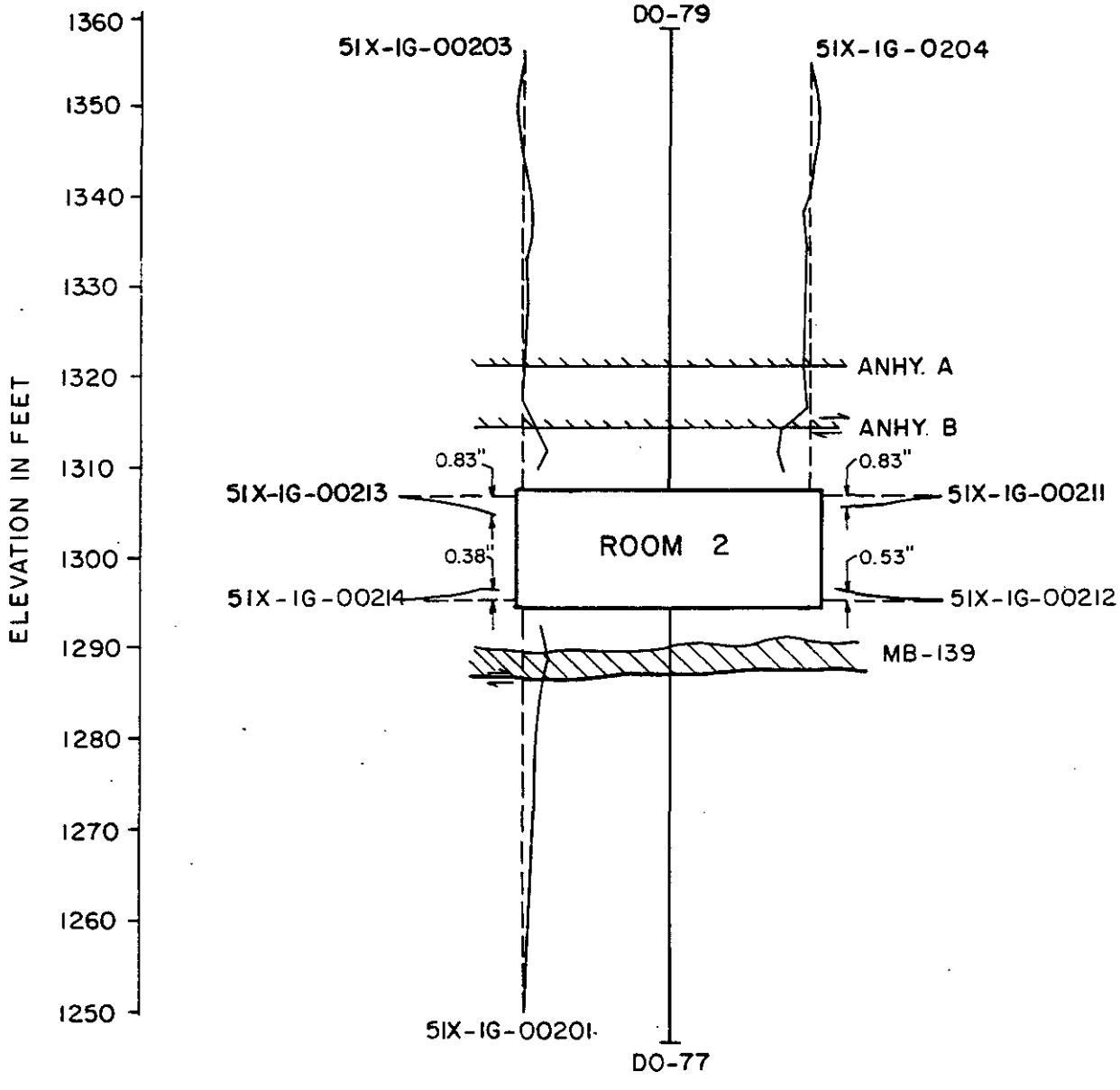

EXPLANATION

ANHYDRITE UNIT

CLAY, AT LOWER CONTACT OF MB-139.

ORIGINAL (DASHED LINE) AND DEFLECTED (SOLID LINE) POSITIONS OF INCLINOMETER. EXAGGERATED SCALE AS SHOWN.

BOREHOLE WITH OBSERVED OFFSET (NOT TO SCALE), SHOWING RELATIVE MOVEMENTS.

VERTICAL COREHOLE

DO-77

NOTES

1. INCLINOMETER DATA AS OF AUG. 20, 1985 UNLESS NOTED OTHERWISE.

2. OFFSETS IN BOREHOLES ARE NOT DRAWN TO SCALE; ONLY RELATIVE MOVEMENTS ARE SHOWN.

FIGURE G-6

SECTION THROUGH TEST ROOM 2

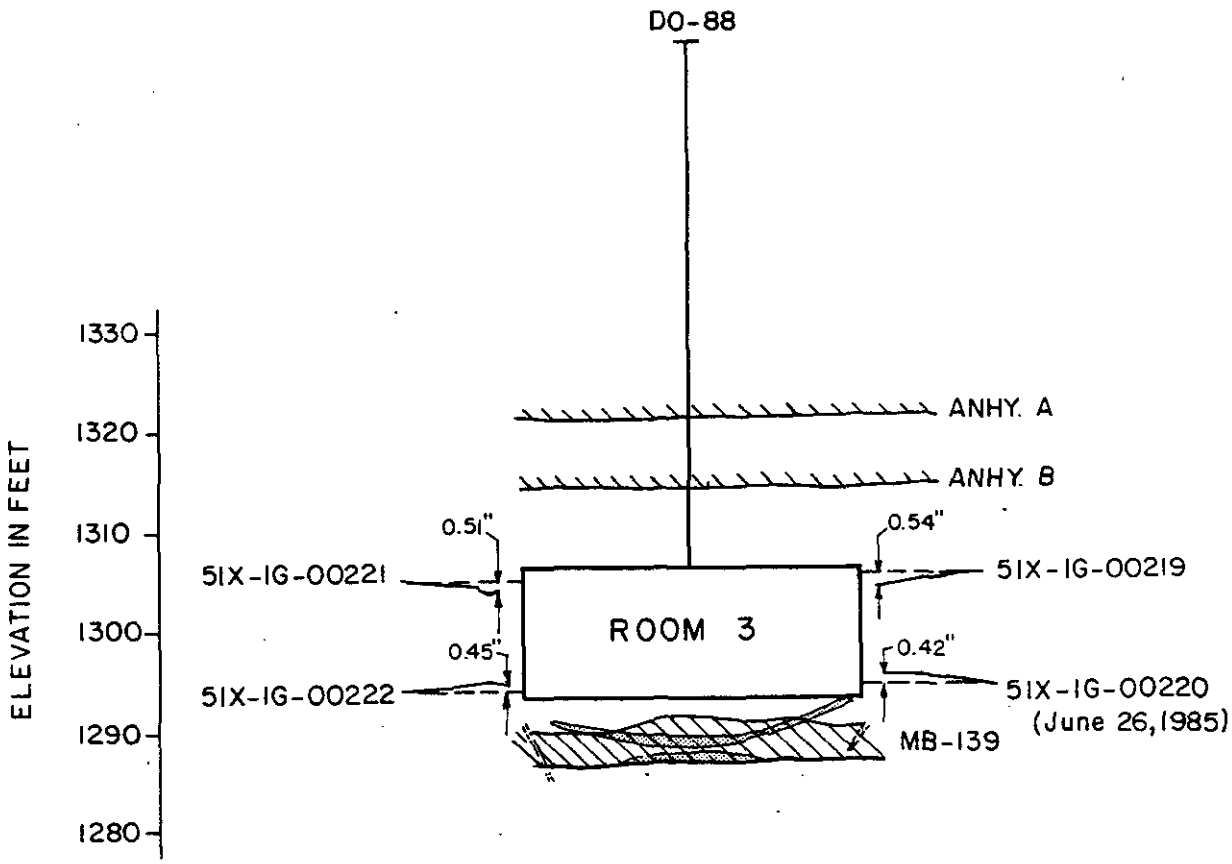

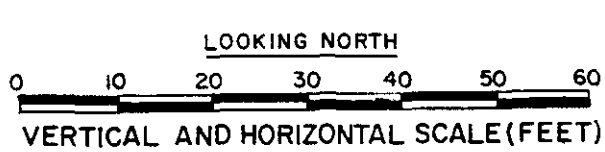

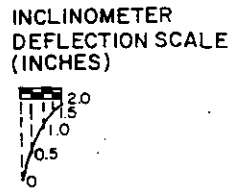

EXPLANATION

- ANHYDRITE UNIT
- FRACTURE ZONE
- CLAY, AT LOWER CONTACT OF MB-139.
- OPEN FRACTURE
- ORIGINAL (DASHED LINE) AND DEFLECTED (SOLID LINE) POSITIONS OF INCLINOMETER. EXAGGERATED SCALE AS SHOWN.
- BOREHOLE WITH OBSERVED OFFSET (NOT TO SCALE), SHOWING RELATIVE MOVEMENTS.
- DO-88 VERTICAL COREHOLE

NOTES

1. OPEN FRACTURES AND FRACTURE ZONES SHOWN BELOW ROOM 3 ARE GENERALIZED FROM GEOLOGIC MAPPING OF LARGE (36-INCH) DIAMETER BOREHOLES. INFORMATION ON FRACTURES BELOW OTHER ROOMS IS INCOMPLETE.
2. INCLINOMETER DATA AS OF AUG. 20, 1985 UNLESS NOTED OTHERWISE.
3. OFFSETS IN BOREHOLES ARE NOT DRAWN TO SCALE; ONLY RELATIVE MOVEMENTS ARE SHOWN.

FIGURE G-7
SECTION THROUGH TEST ROOM 3

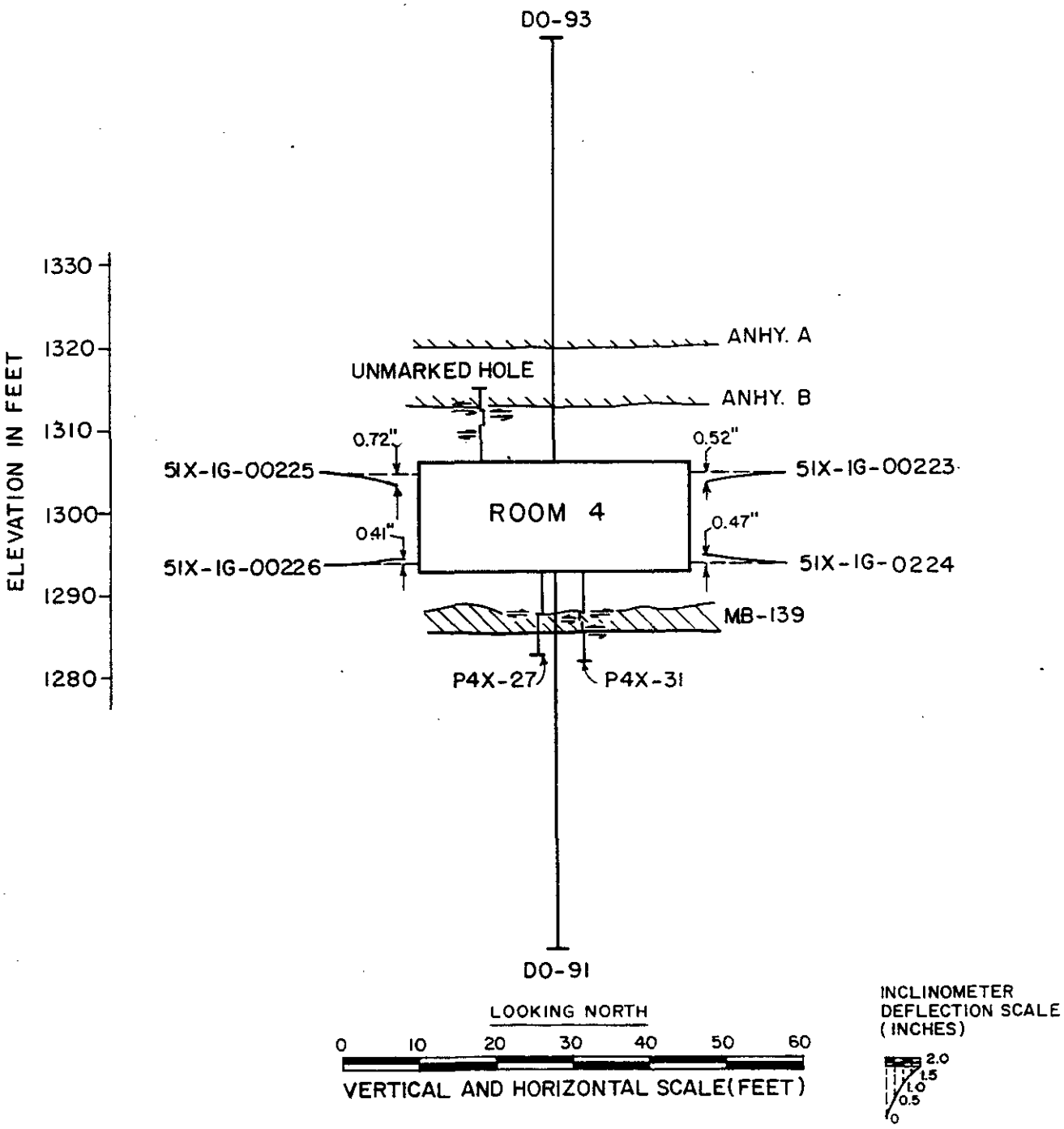

EXPLANATION

ANHYDRITE UNIT

CLAY, AT LOWER CONTACT OF MB-139.

ORIGINAL (DASHED LINE) AND DEFLECTED (SOLID LINE) POSITIONS OF INCLINOMETER. EXAGGERATED SCALE AS SHOWN.

BOREHOLE WITH OBSERVED OFFSET (NOT TO SCALE), SHOWING RELATIVE MOVEMENTS.

VERTICAL COREHOLE

DO-91

NOTES

1. INCLINOMETER DATA AS OF AUG. 20, 1985 UNLESS NOTED OTHERWISE.
2. OFFSETS IN BOREHOLES ARE NOT DRAWN TO SCALE; ONLY RELATIVE MOVEMENTS ARE SHOWN.

FIGURE G-8

SECTION THROUGH TEST ROOM 4

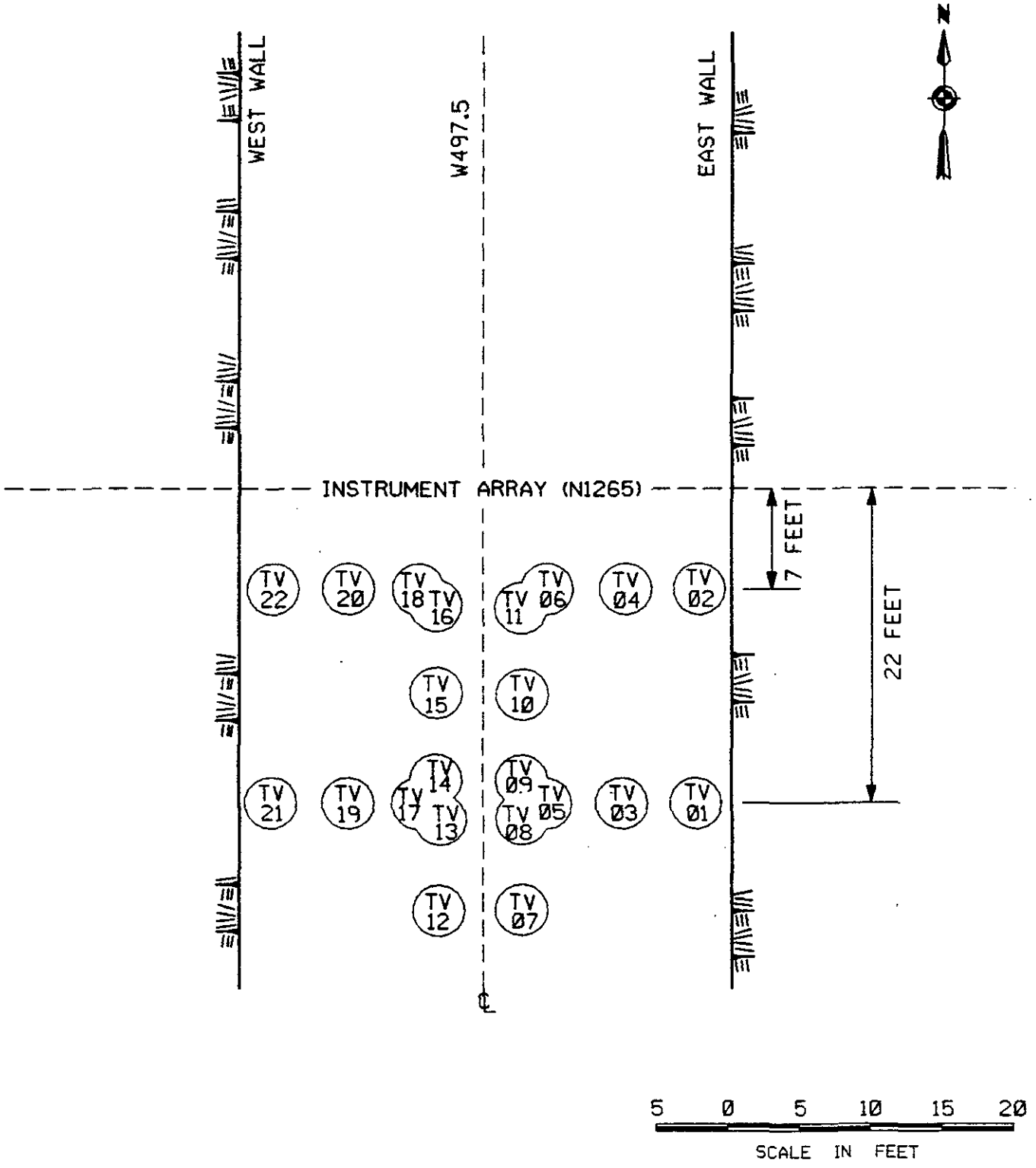

FIGURE G-9

ROOM T
LARGE DIAMETER DRILL HOLES
LOCATION PLAN

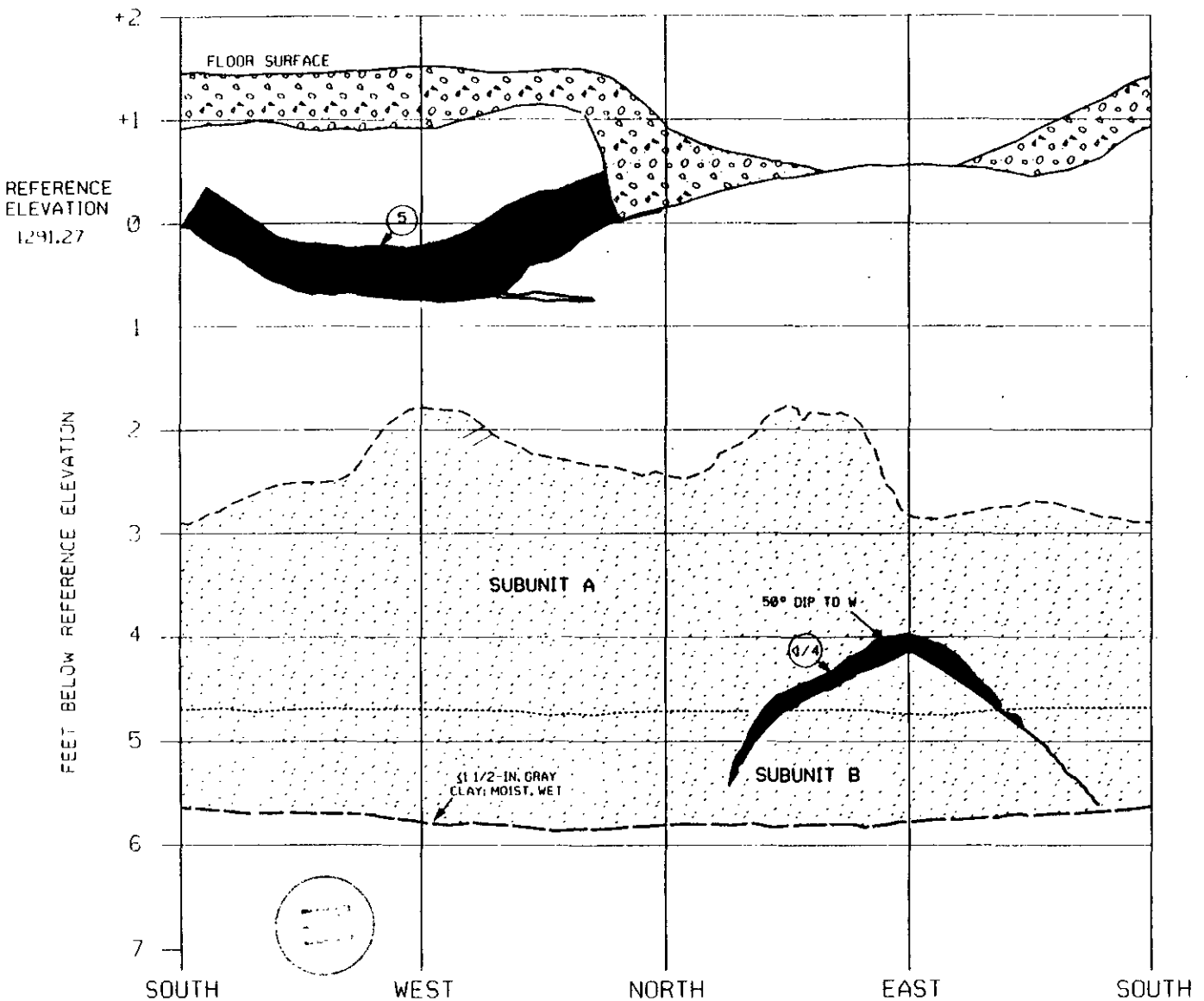

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 10/30/85
MAPPED BY: J.E. GALLERANI

FIGURE G-10

GEOLOGIC MAP OF DRILL HOLE TV-01

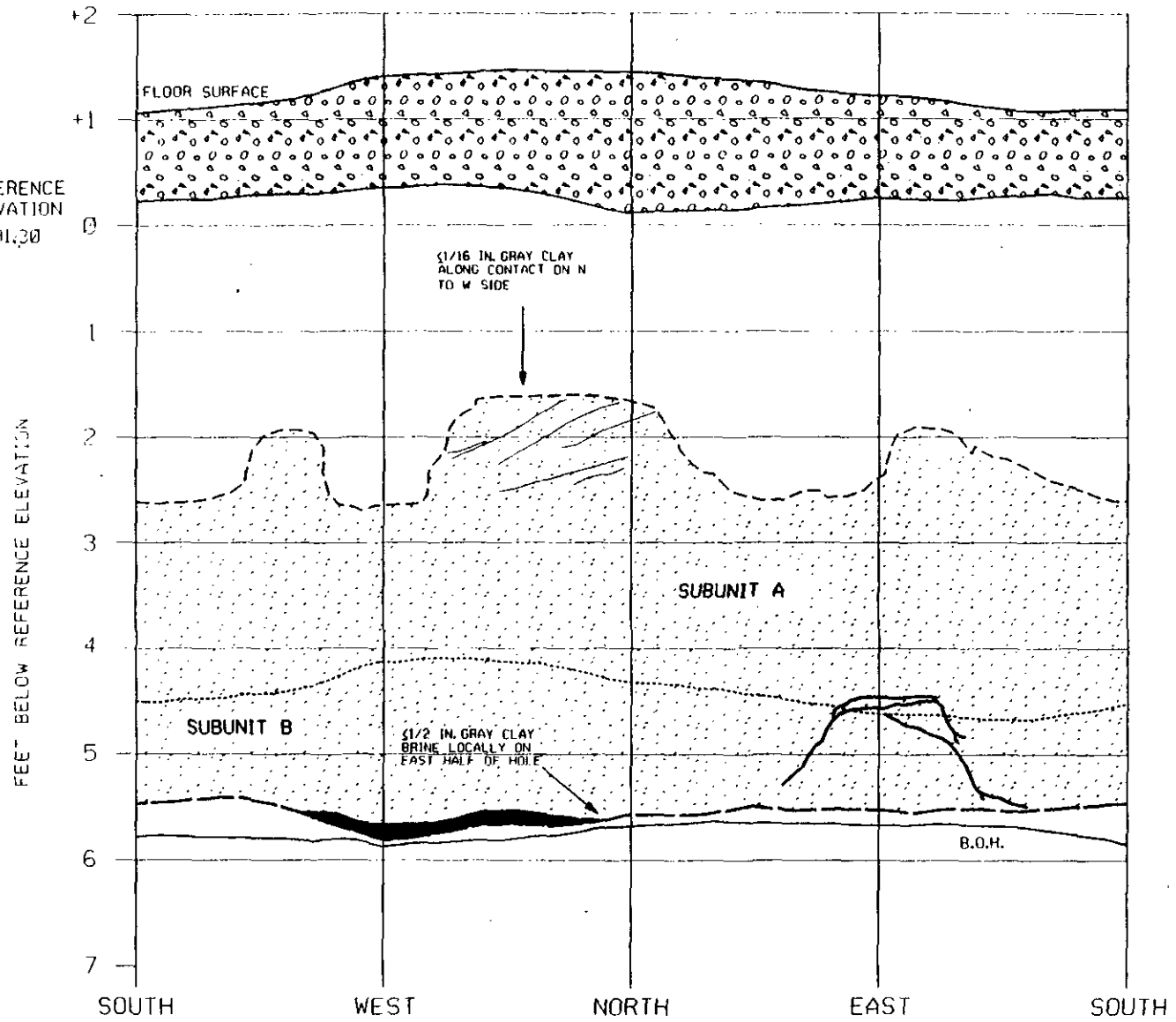

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 10/30/85
MAPPED BY: J.E. GALLERANI

FIGURE G-11

GEOLOGIC MAP OF DRILL HOLE TV-02

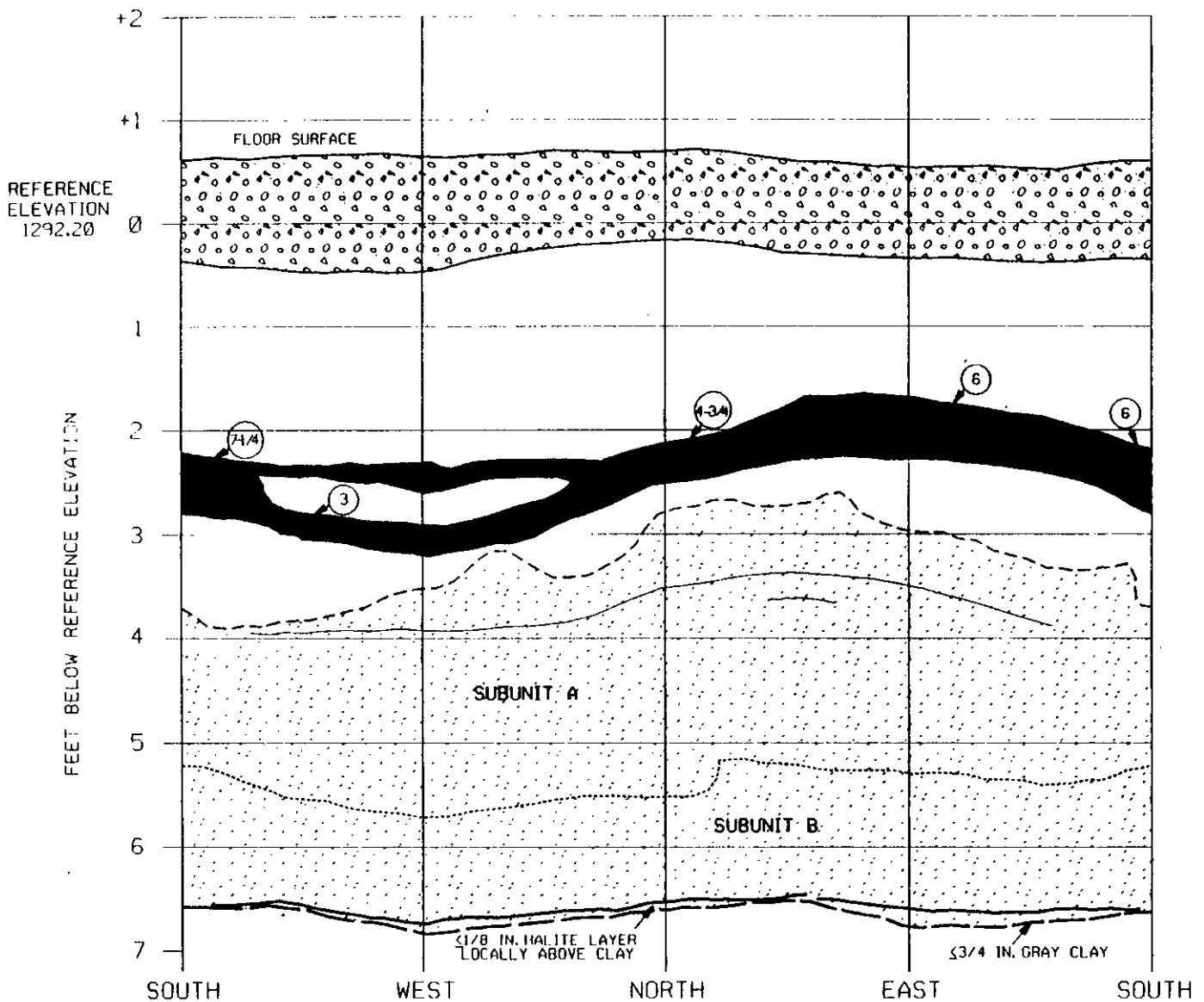

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

DATE MAPPED: 11/25/85
MAPPED BY: J.E. GALLERANI

0 1 2
SCALE IN FEET

FIGURE G-12

GEOLOGIC MAP OF DRILL HOLE TV-03

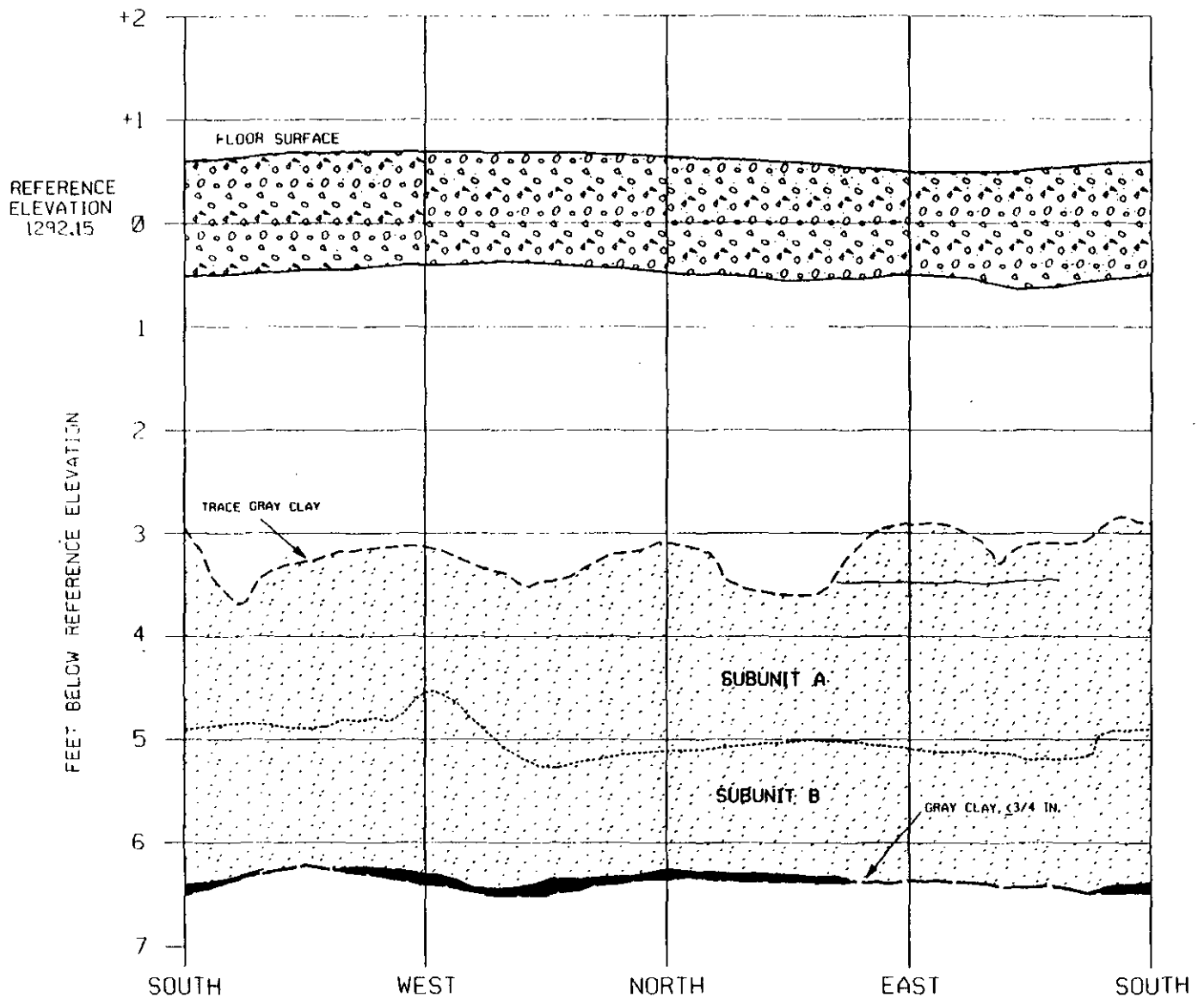

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 11/20/85
MAPPED BY: J.E. GALLERANI

FIGURE G-13

GEOLOGIC MAP OF DRILL HOLE TV-04

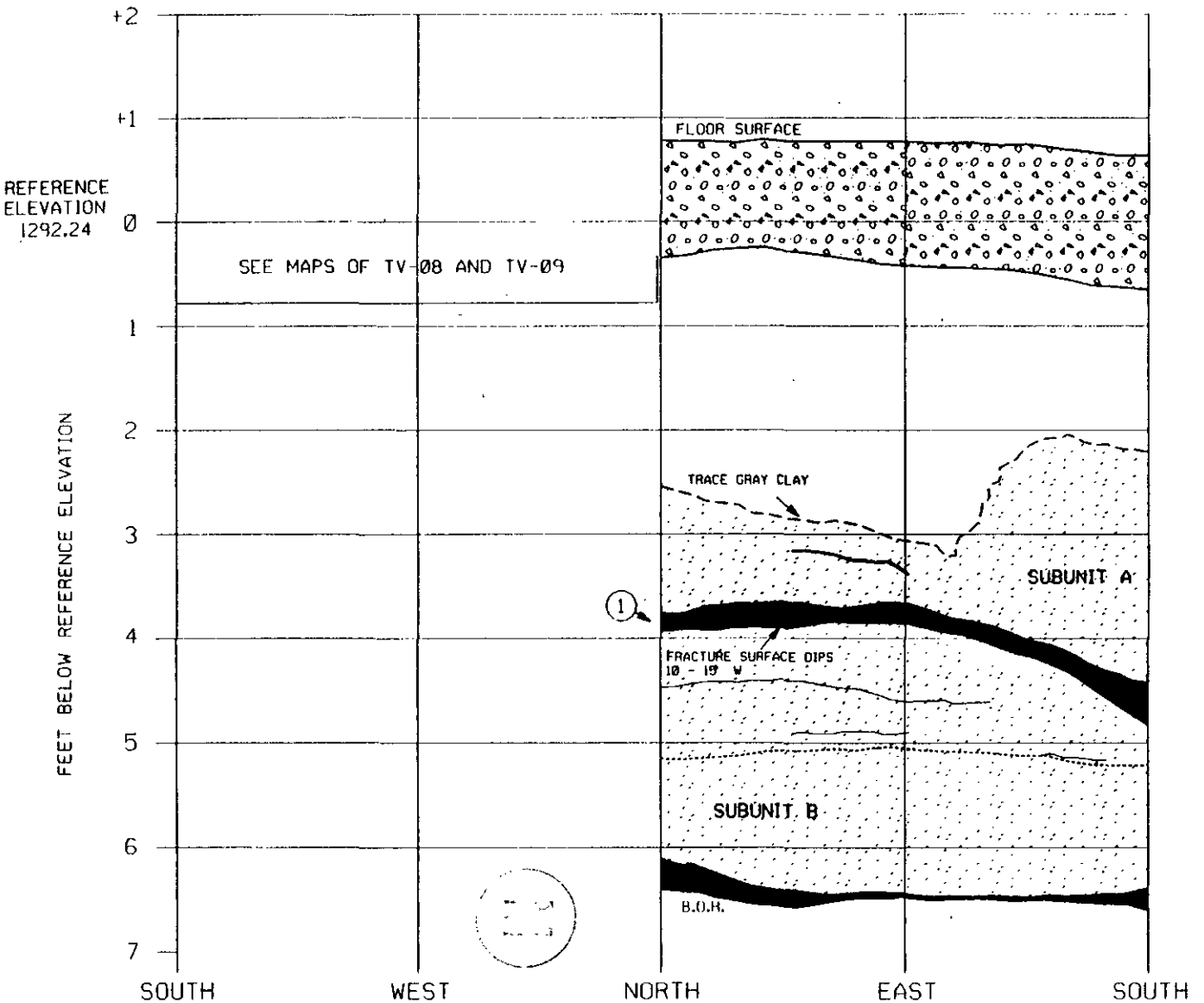

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 12/5/85
MAPPED BY: J.E. GALLERANI

FIGURE G-14

GEOLOGIC MAP OF DRILL HOLE TV-05

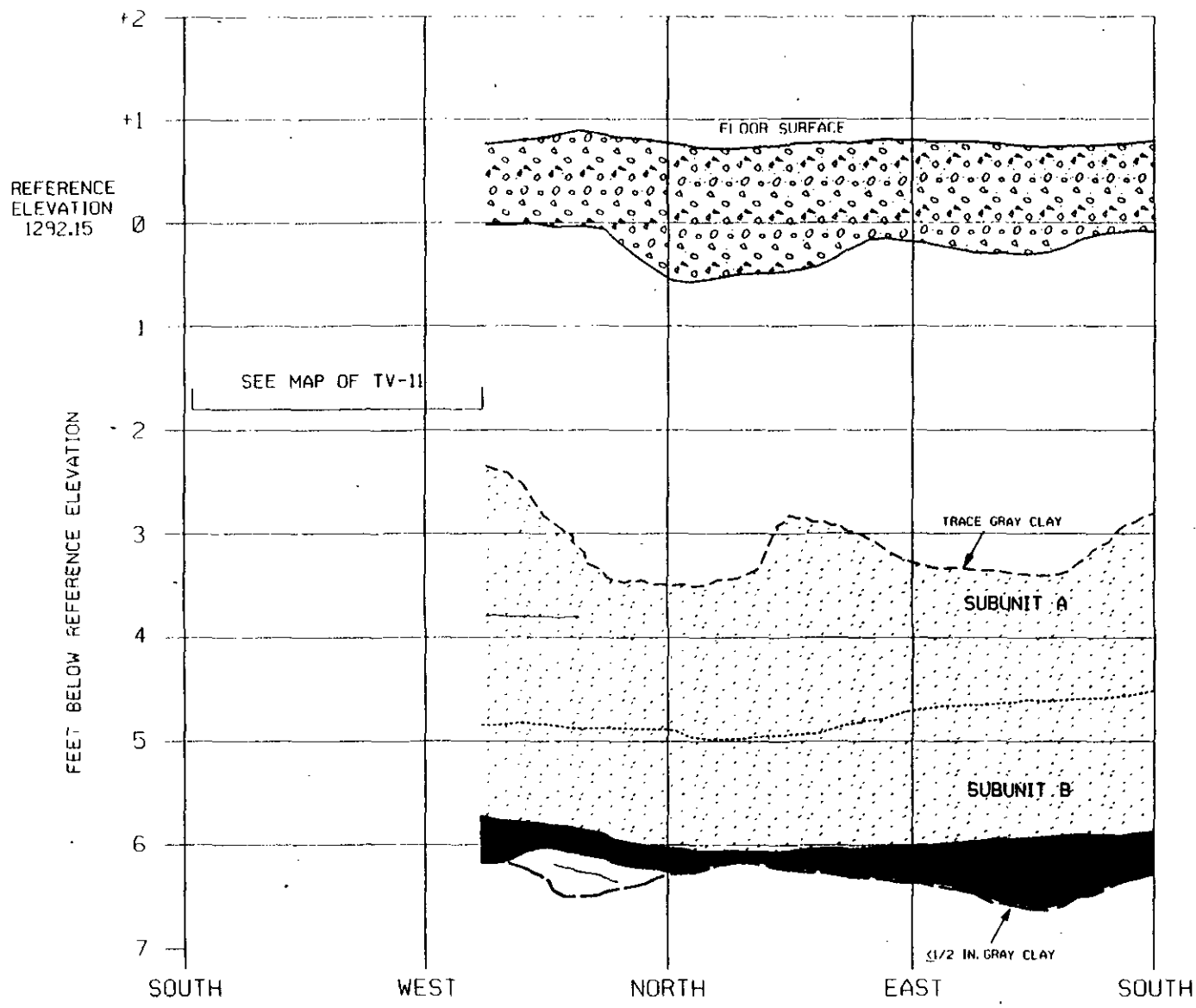

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 11/20/85
MAPPED BY: J.E. GALLERANI

FIGURE G-15

GEOLOGIC MAP OF DRILL HOLE TV-06

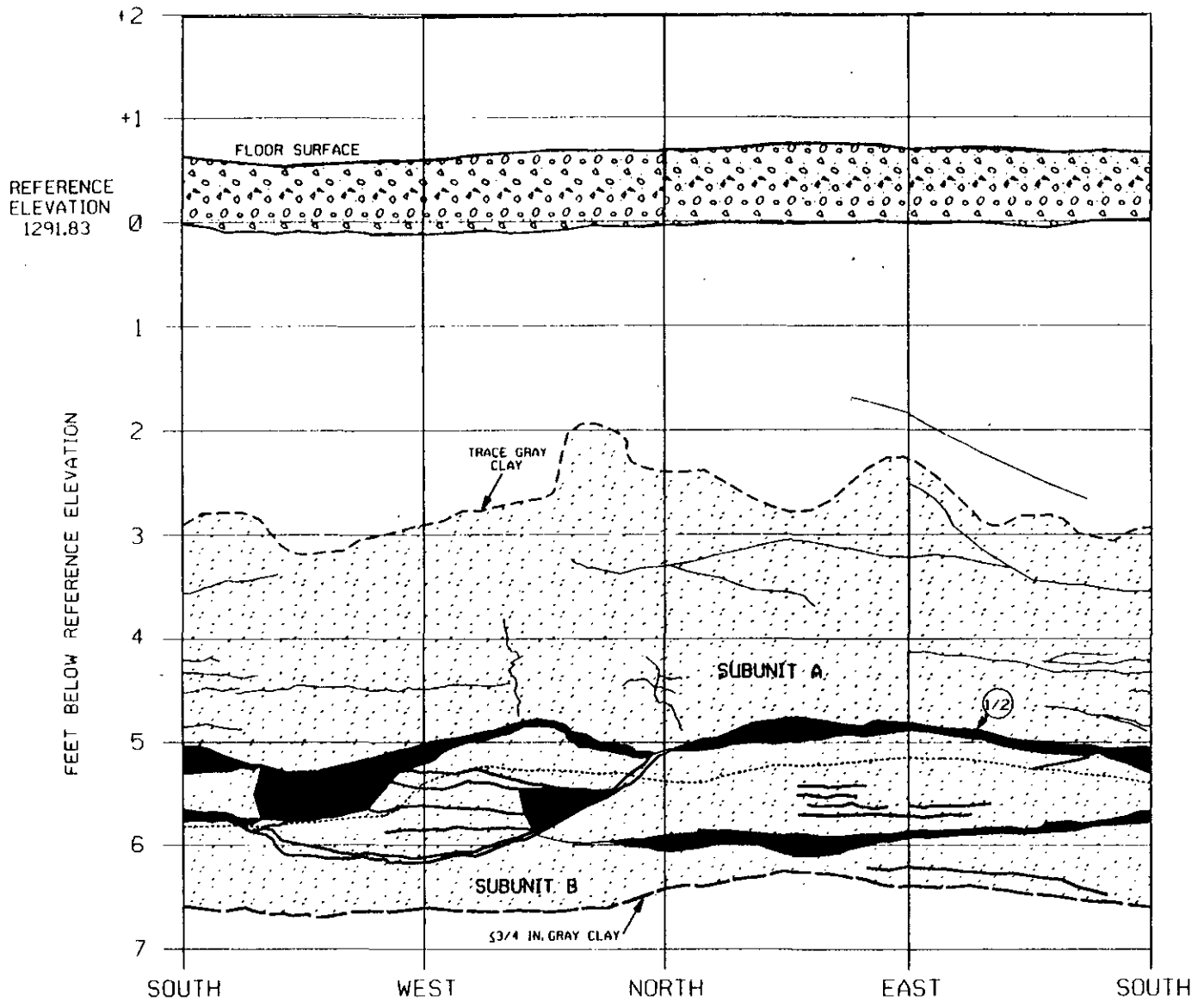

DATE MAPPED: 11/25/85
MAPPED BY: J.E. GALLERANI

0 1 2
SCALE IN FEET

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-16

GEOLOGIC MAP OF DRILL HOLE TV-07

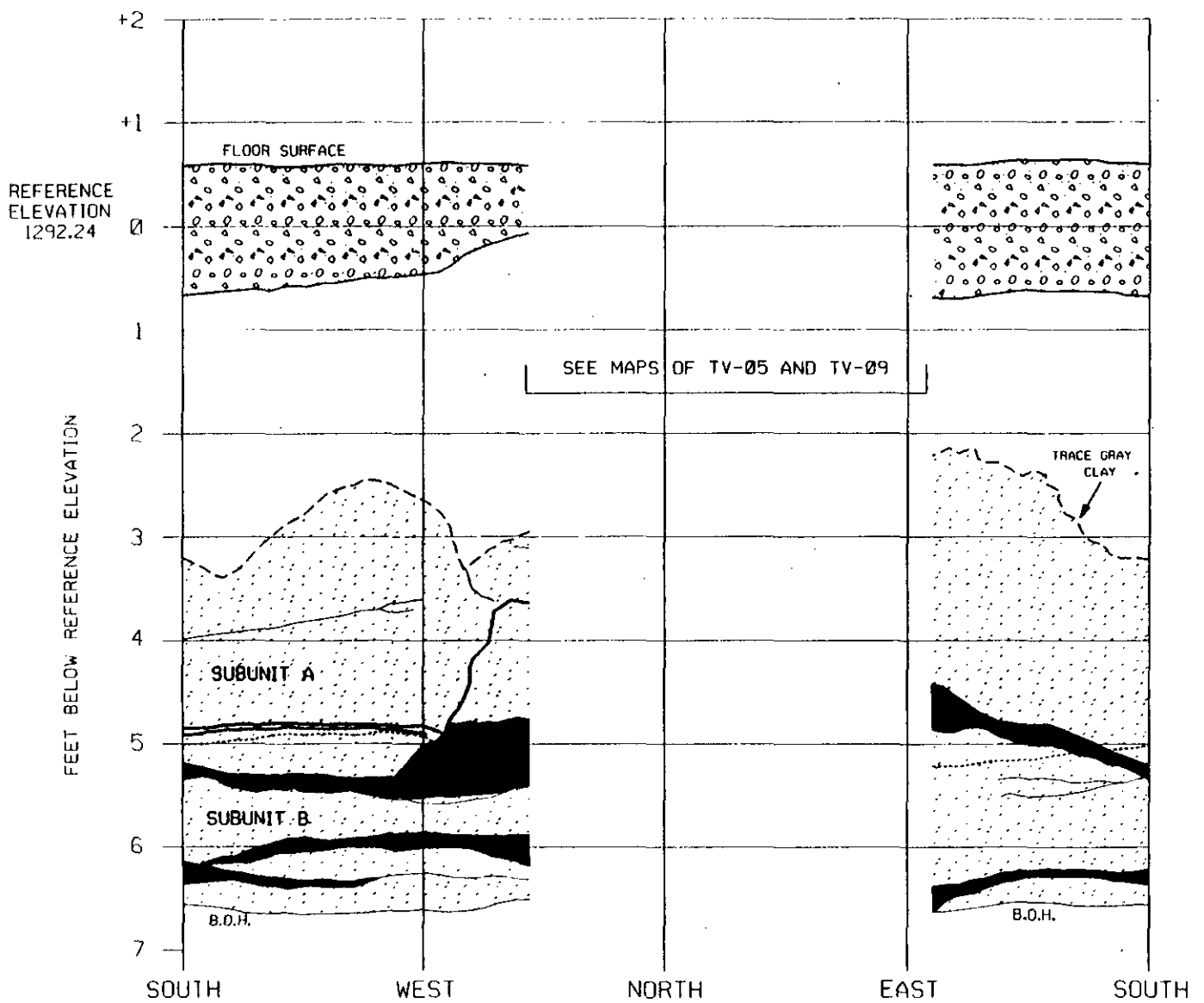

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 12/5/85
MAPPED BY: J.E. GALLERANI

FIGURE G-17

GEOLOGIC MAP OF DRILL HOLE TV-08

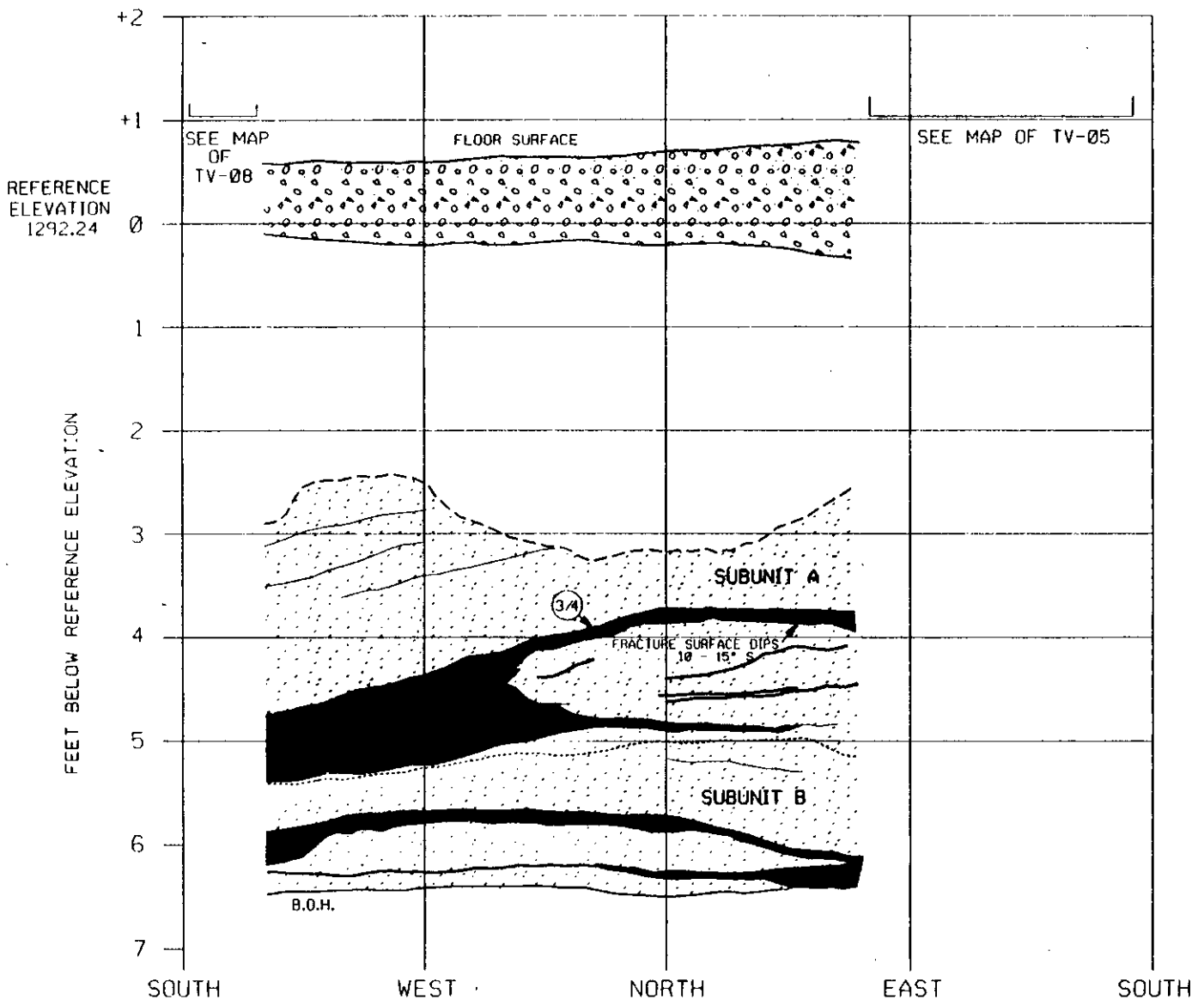

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 12/5/85
MAPPED BY: J.E. GALLERANI

FIGURE G-18

GEOLOGIC MAP OF DRILL HOLE TV-Ø9

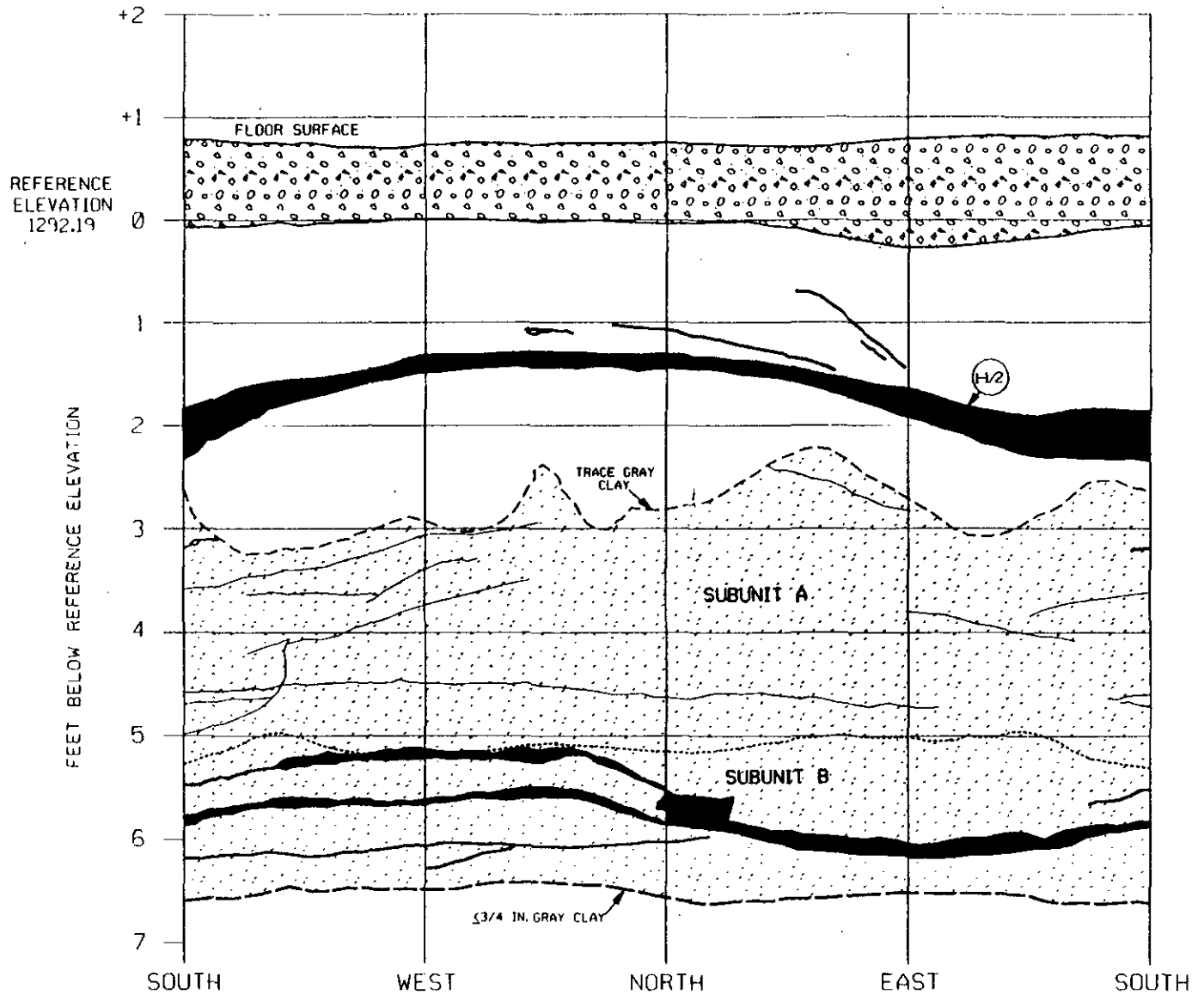

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 12/2/85
MAPPED BY: J.E. GALLERANI

FIGURE G-19

GEOLOGIC MAP OF DRILL HOLE TV-10

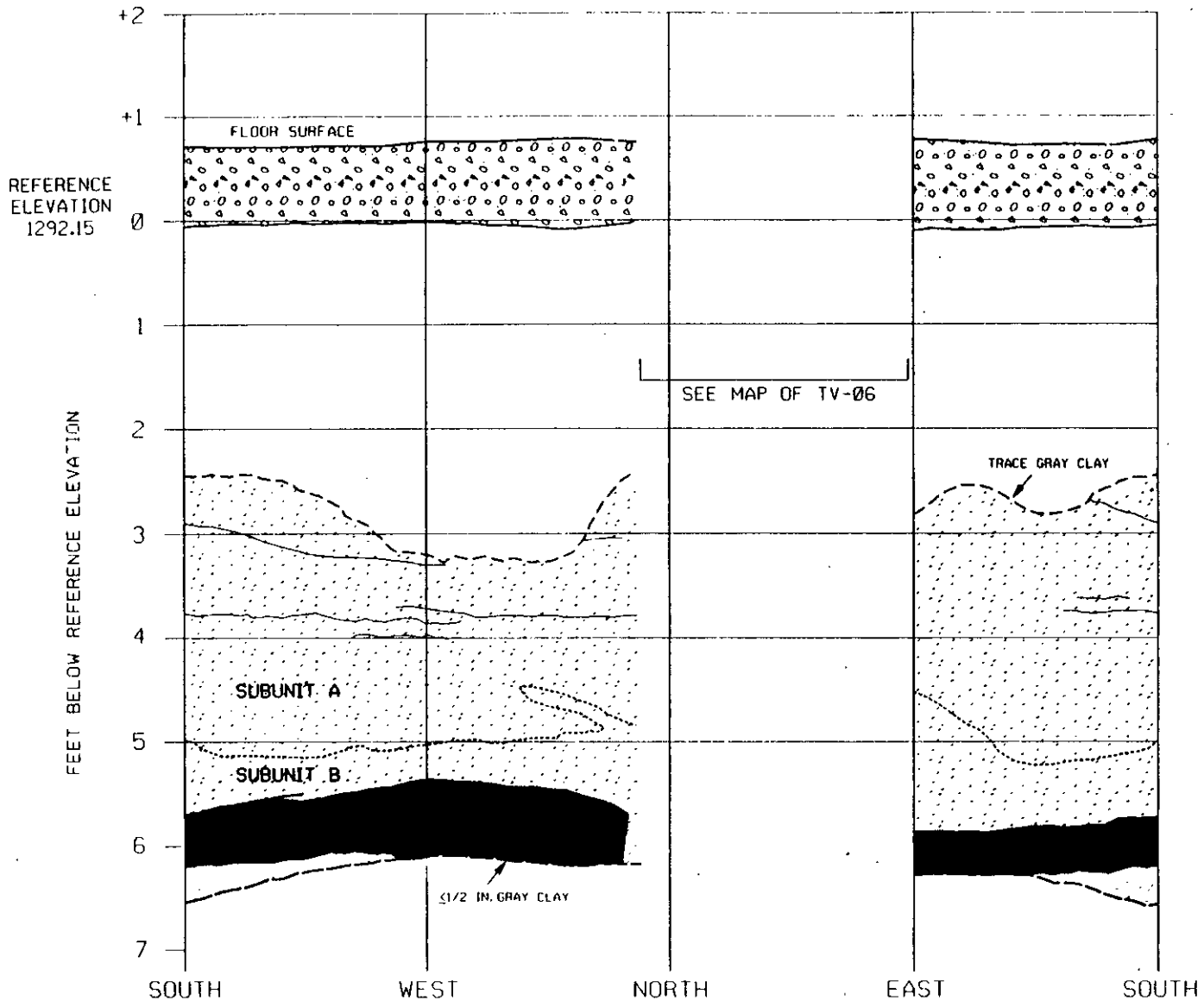

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 11/20/85
MAPPED BY: J.E. GALLERANI

FIGURE G-20

GEOLOGIC MAP OF DRILL HOLE TV-11

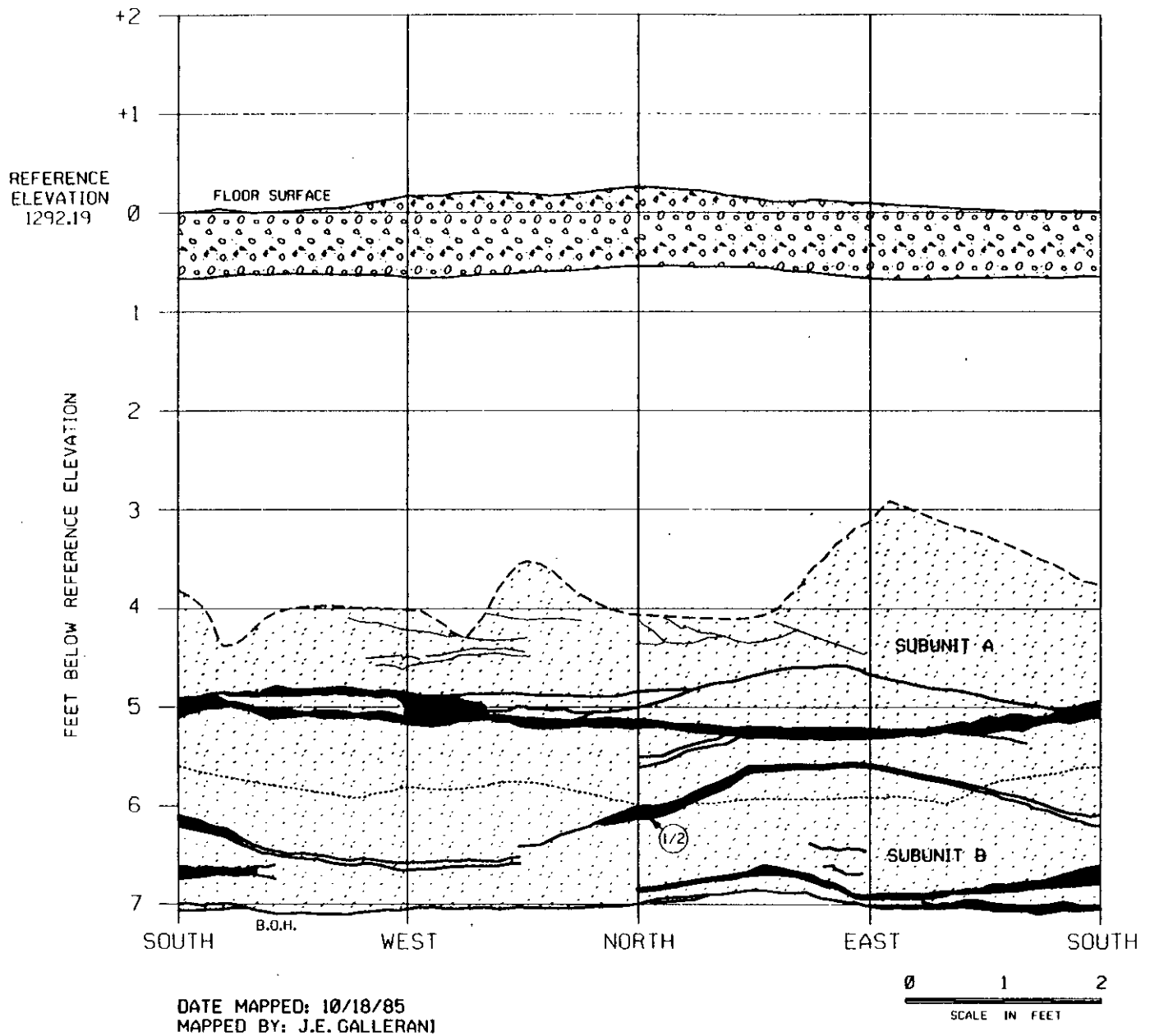

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

DATE MAPPED: 10/18/85
MAPPED BY: J.E. GALLERANI

FIGURE G-21

GEOLOGIC MAP OF DRILL HOLE TV-12

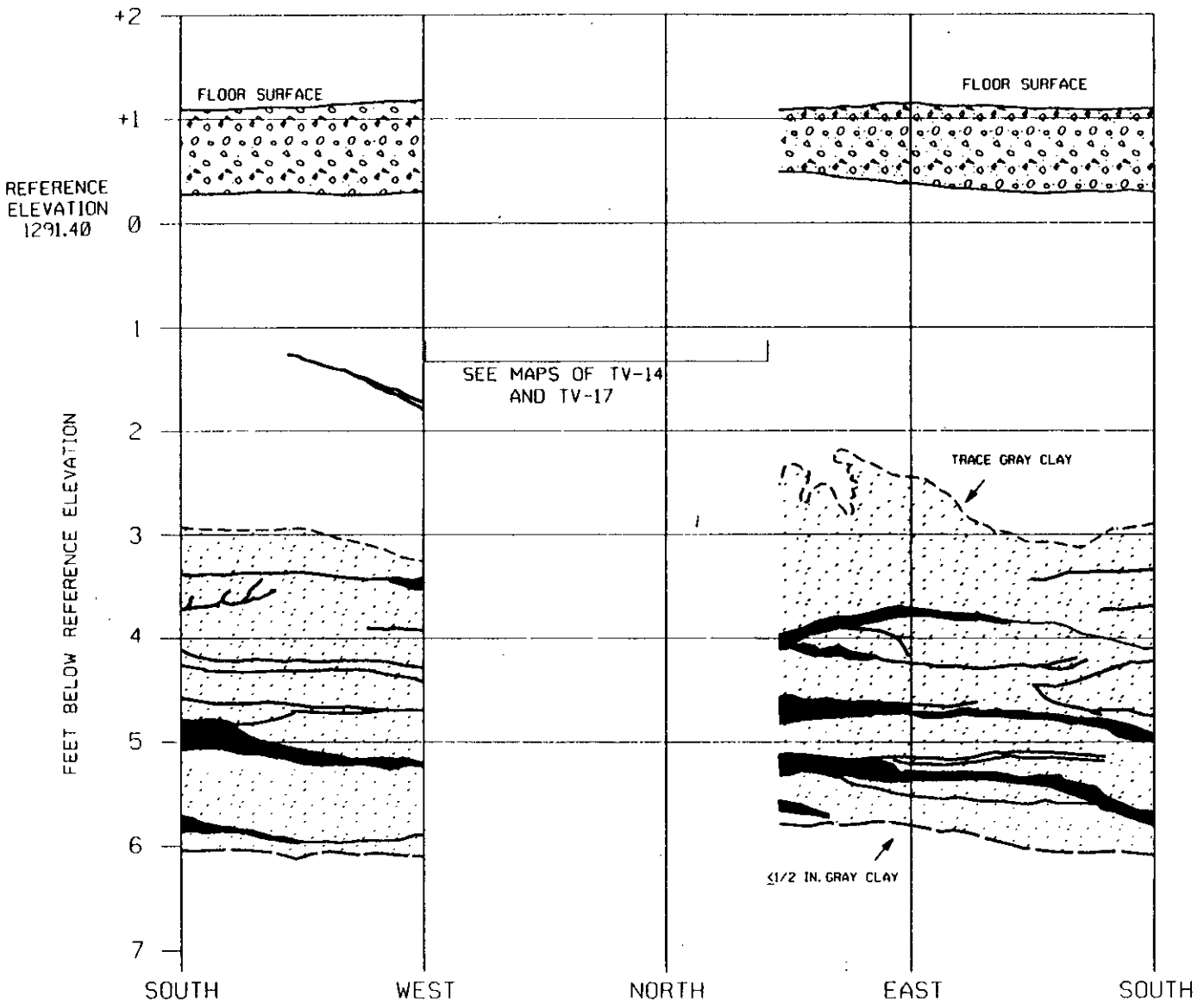

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 10/25/85
MAPPED BY: J.E. GALLERANI

FIGURE G-22

GEOLOGIC MAP OF DRILL HOLE TV-13

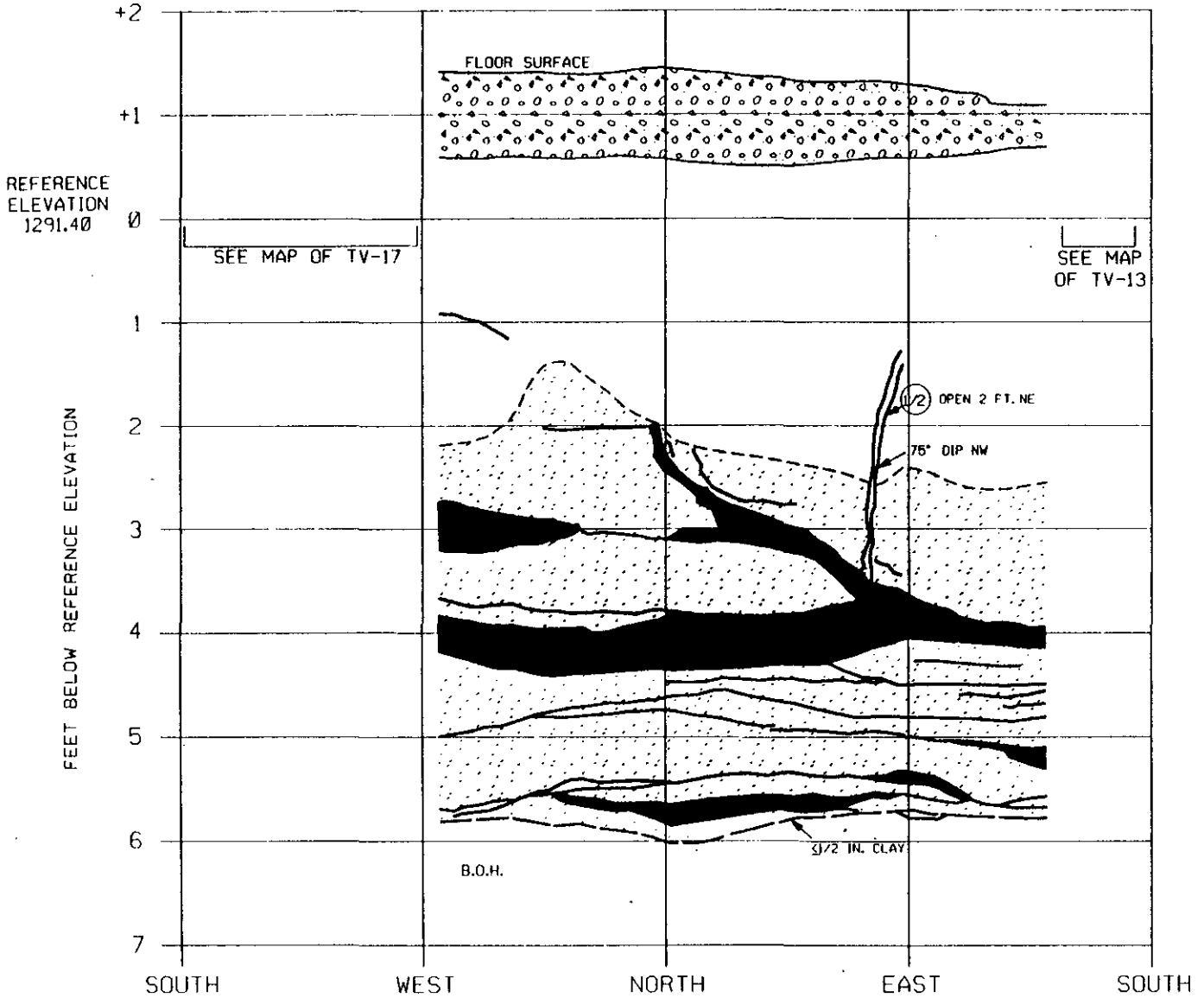

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 10/24/85
MAPPED BY: J.E. GALLERANI

FIGURE G-23

GEOLOGIC MAP OF DRILL HOLE TV-14

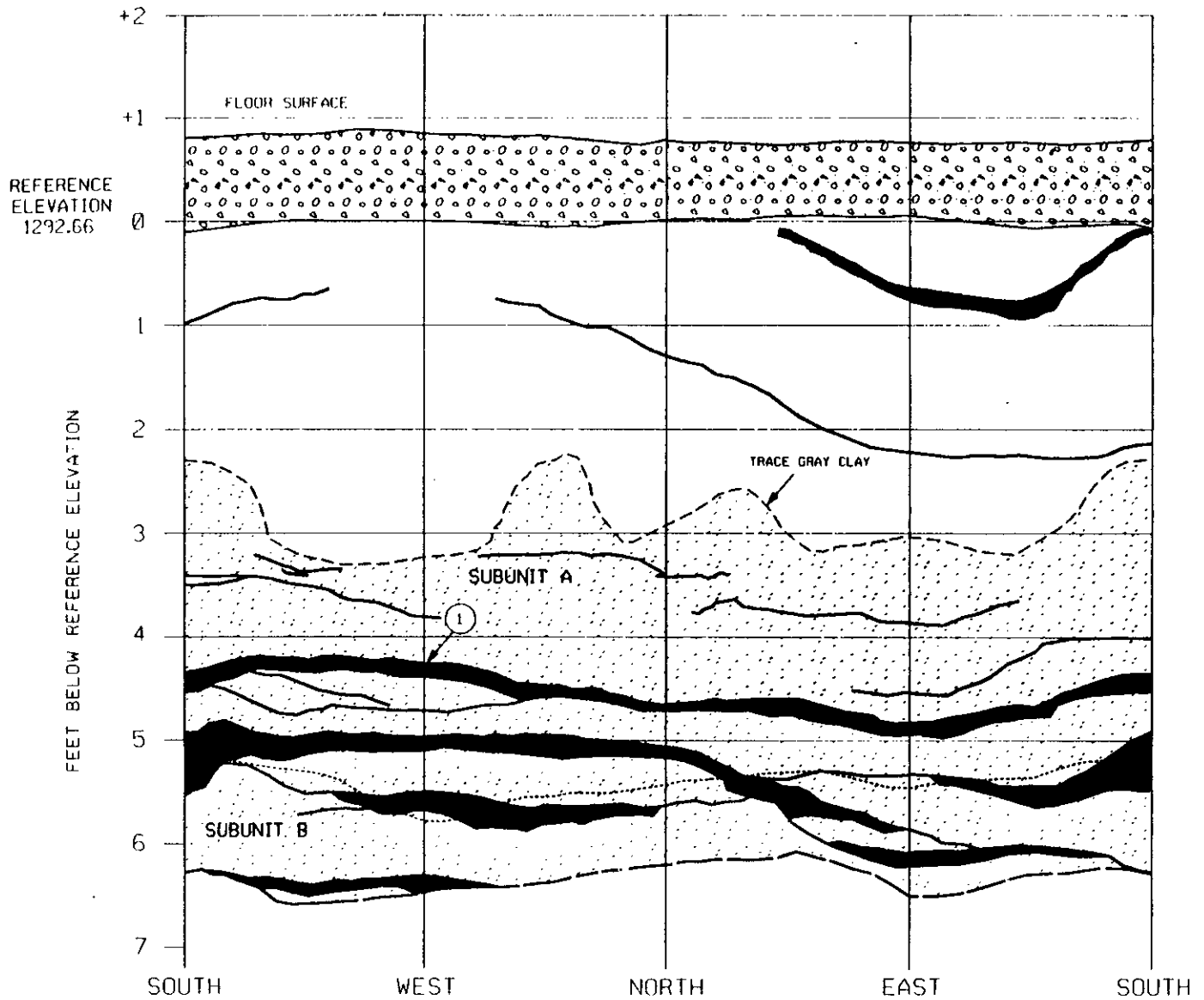

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 10/9/85
MAPPED BY: J.E. GALLERANI

FIGURE G-24

GEOLOGIC MAP OF DRILL HOLE TV-15

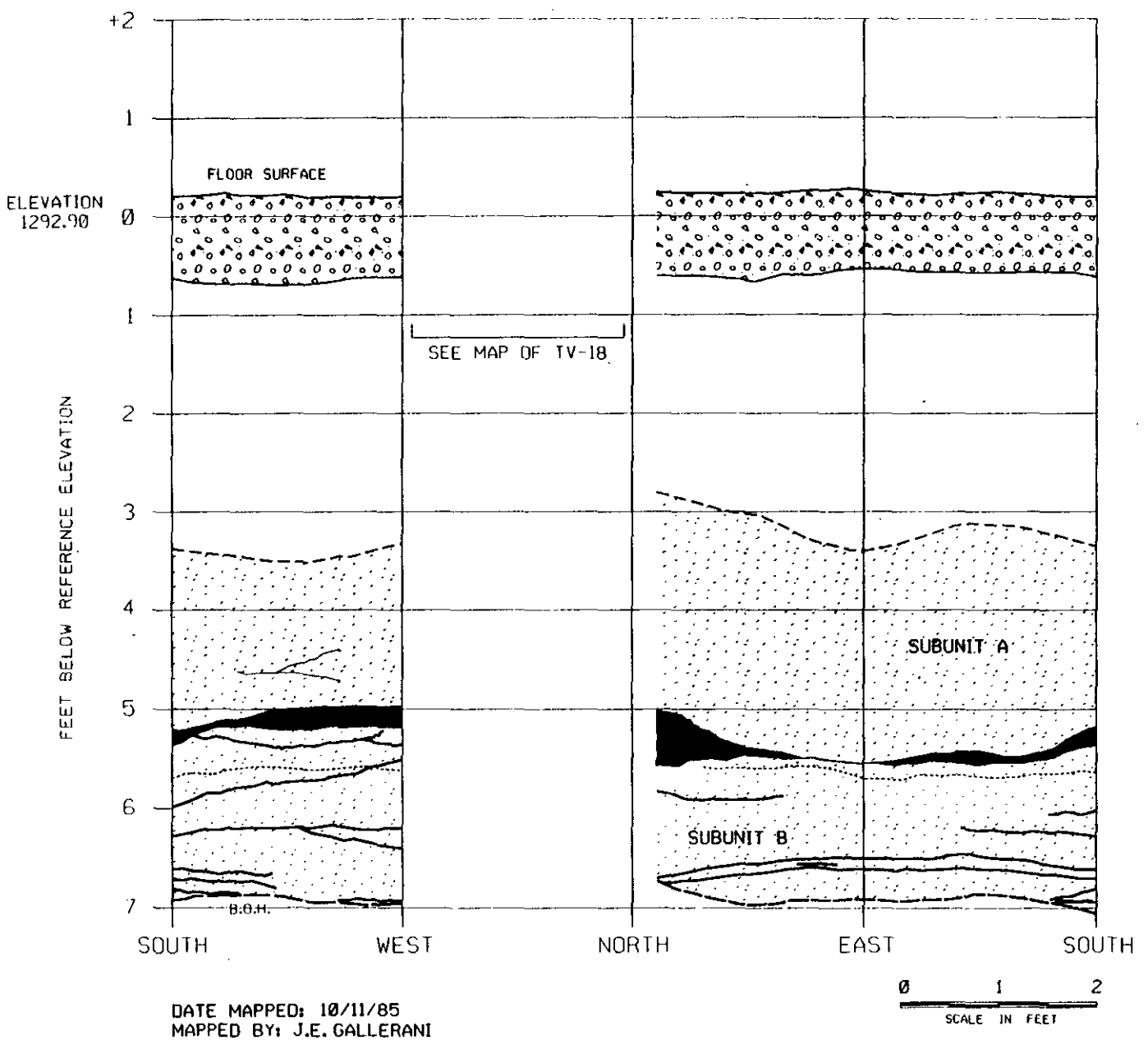

DATE MAPPED: 10/11/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-25

GEOLOGIC MAP OF DRILL HOLE TV-16

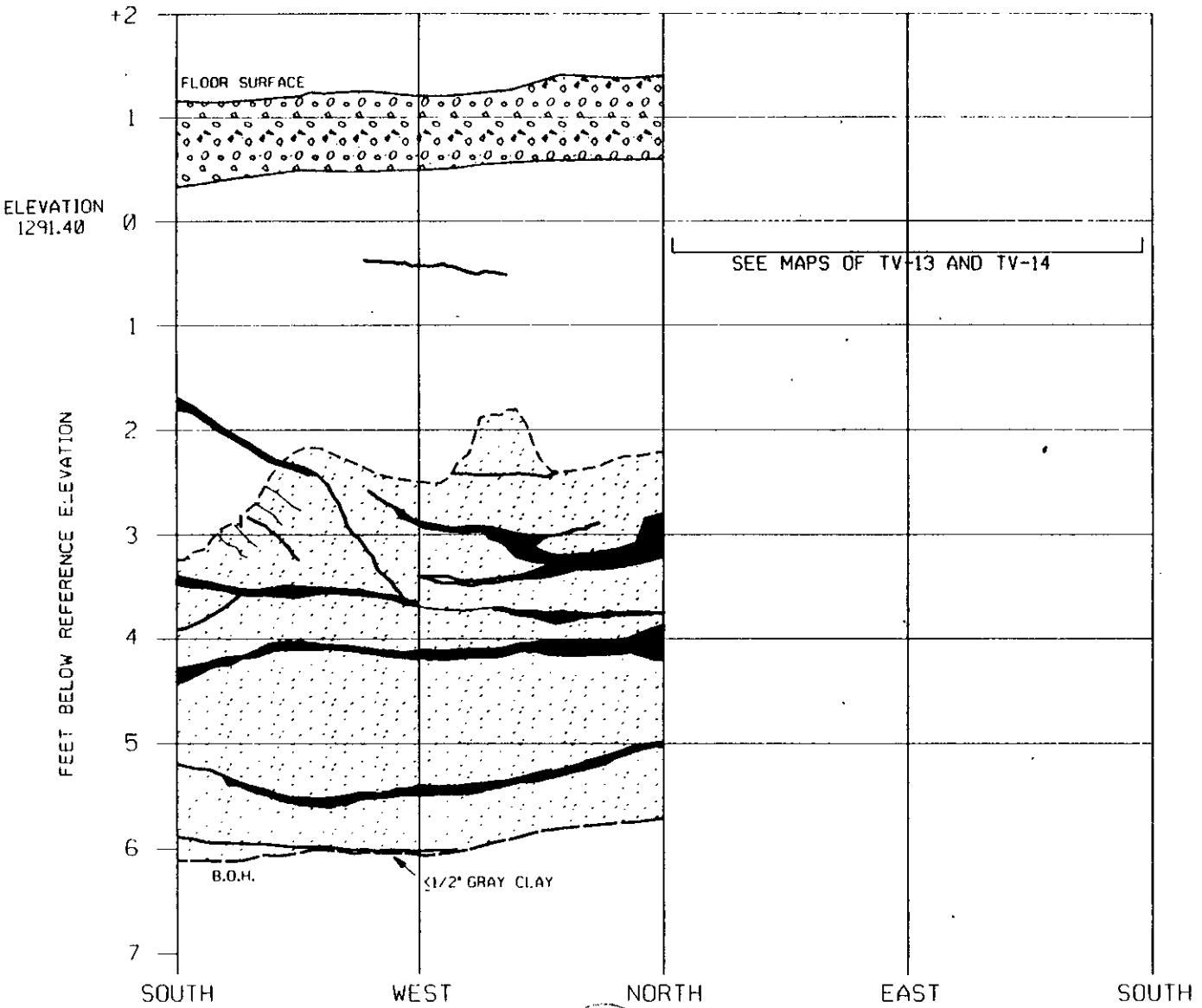

DATE MAPPED: 10/24/85
MAPPED BY: J.E. GALLERANI

0 1 2
SCALE IN FEET

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-26

GEOLOGIC MAP OF DRILL HOLE TV-17

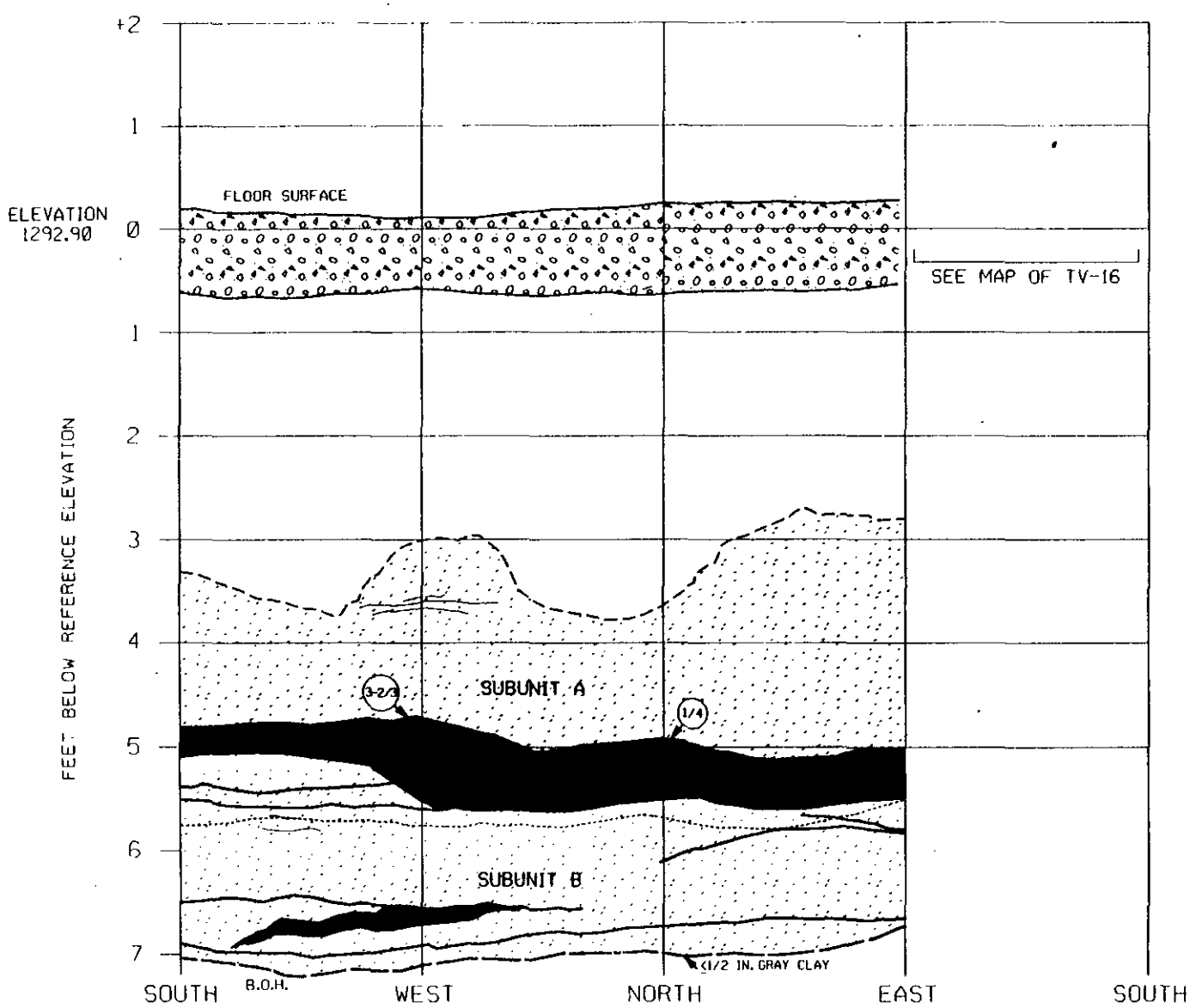

DATE MAPPED: 10/11/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-27

GEOLOGIC MAP OF DRILL HOLE TV-18

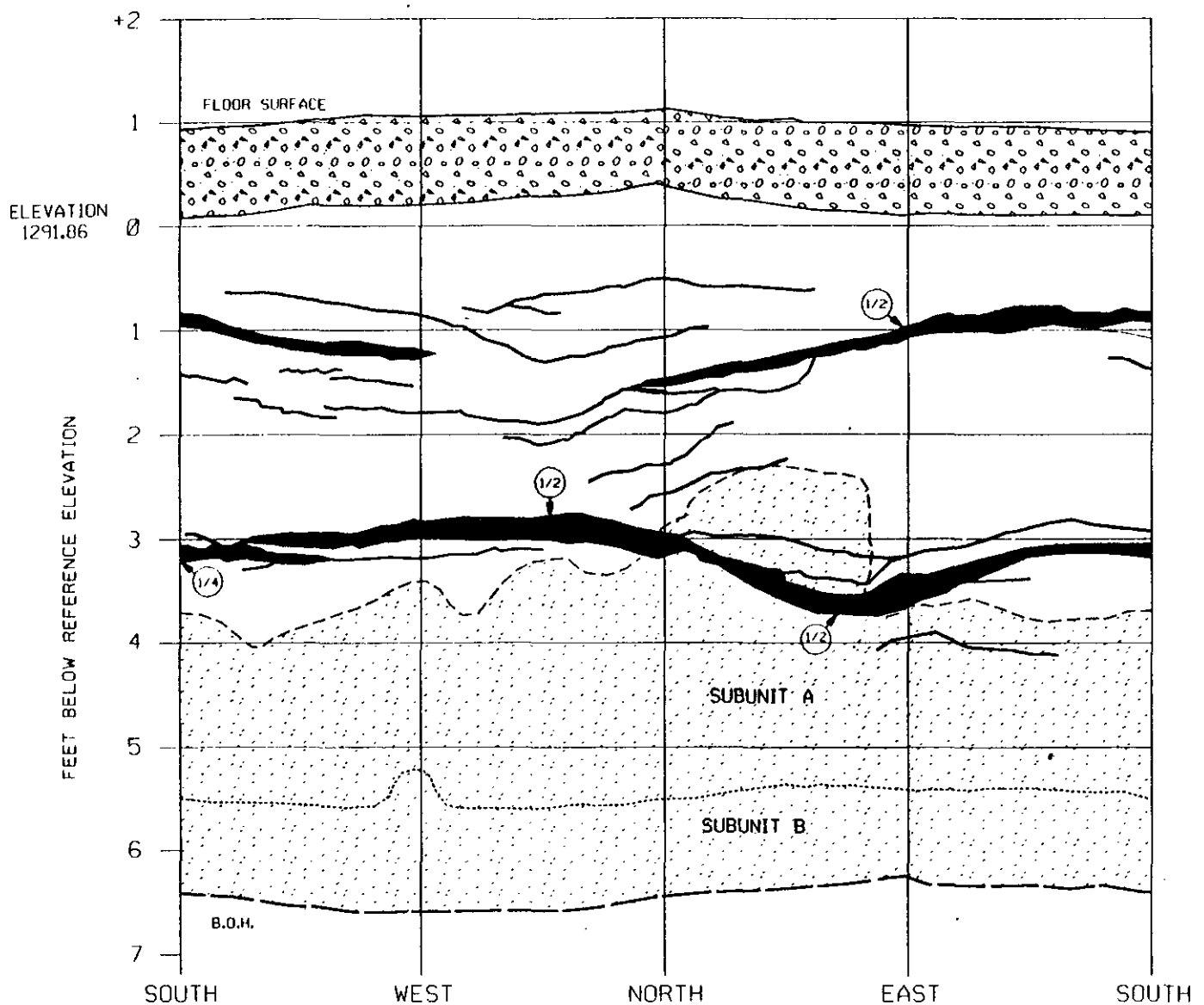

DATE MAPPED: 10/22/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-28

GEOLOGIC MAP OF DRILL HOLE TV-19

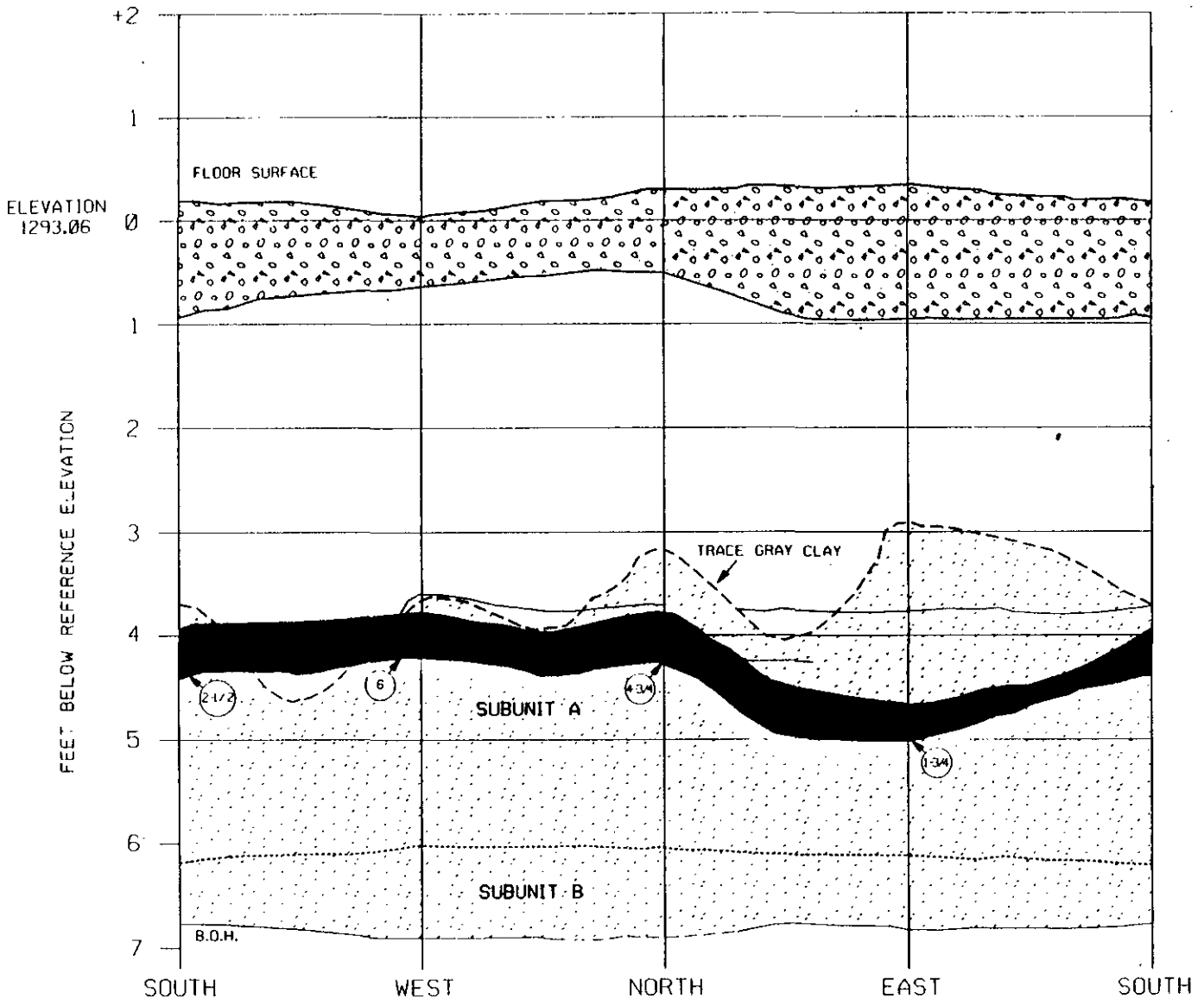

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 10/09/85
MAPPED BY: J.E. GALLERANI

FIGURE G-29

GEOLOGIC MAP OF DRILL HOLE TV-20

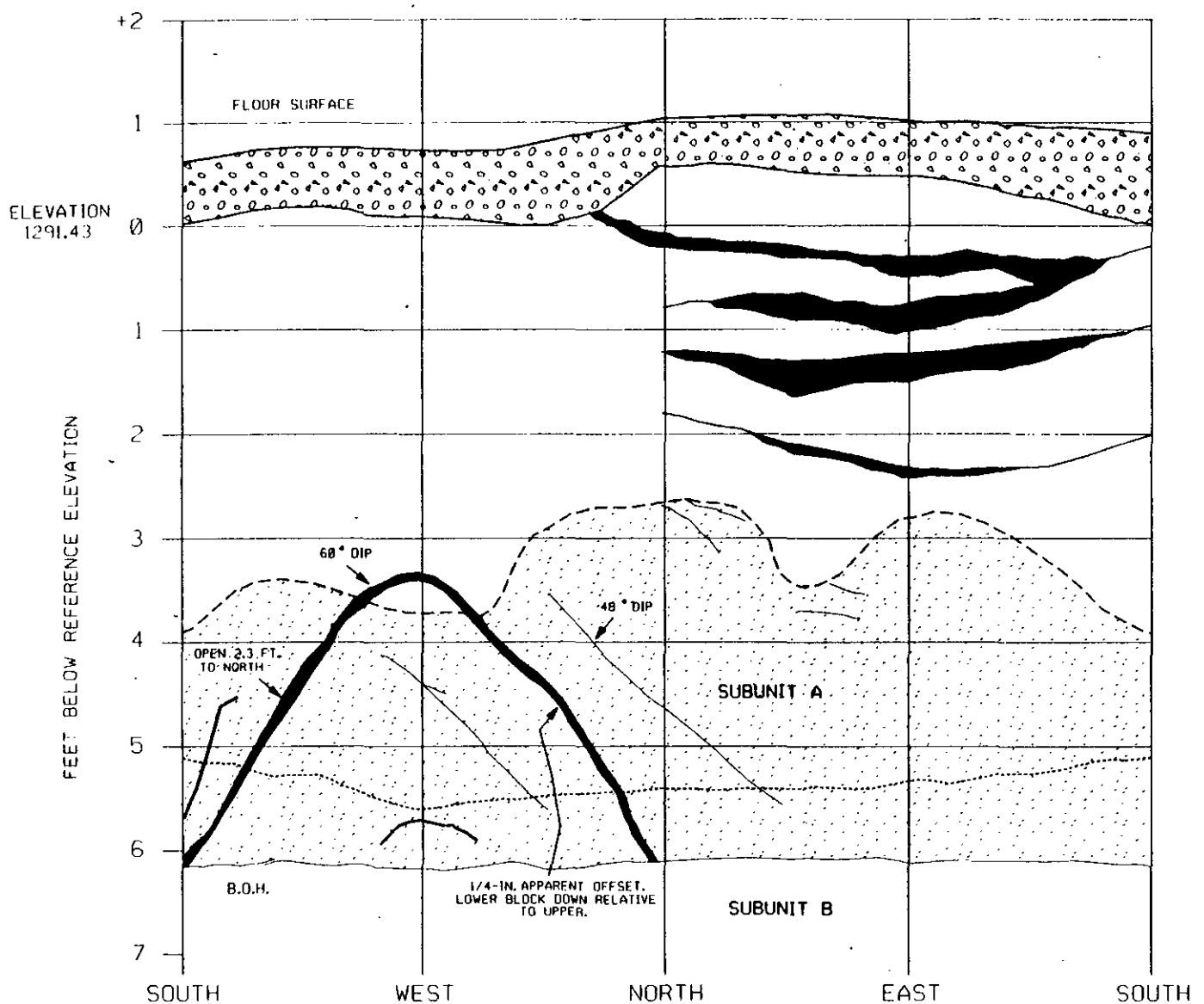

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

DATE MAPPED: 10/22/85
MAPPED BY: J.E. GALLERANI

0 1 2
SCALE IN FEET

FIGURE G-30

GEOLOGIC MAP OF DRILL HOLE TV-21

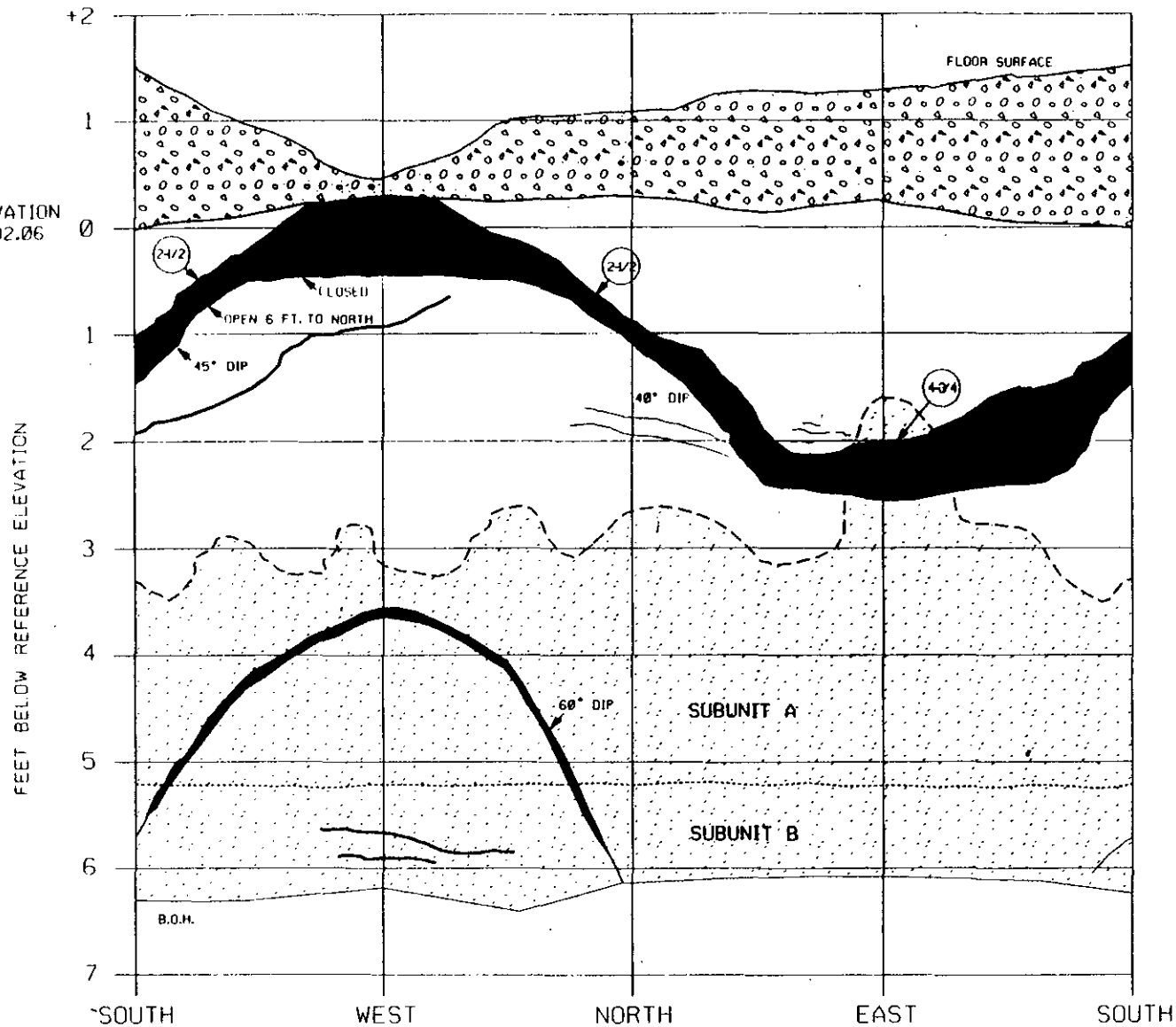

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

0 1 2
SCALE IN FEET

DATE MAPPED: 10/25/85
MAPPED BY: J.E. GALLERANI

FIGURE G-31

GEOLOGIC MAP OF DRILL HOLE TV-22

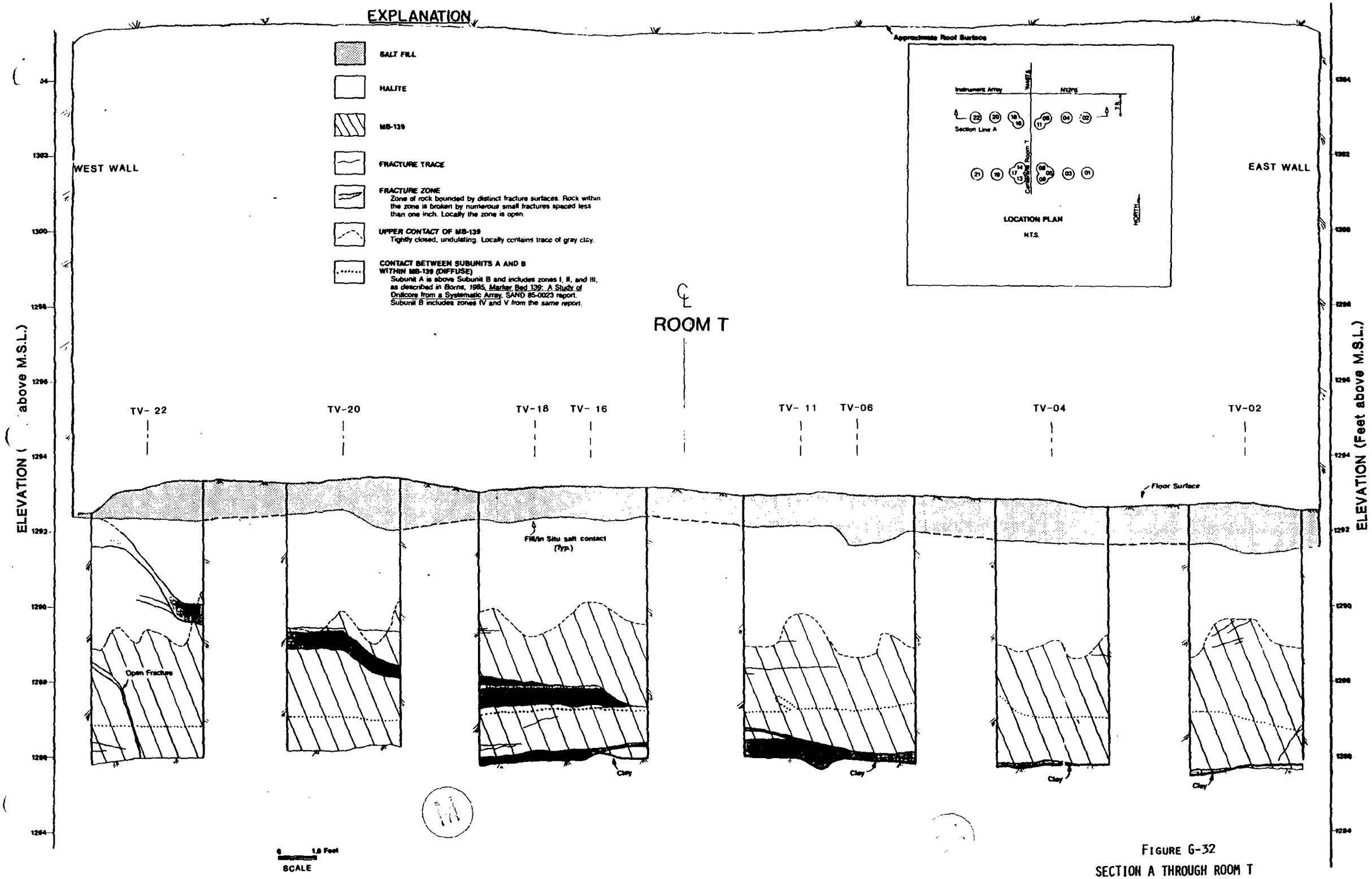

FIGURE G-32
SECTION A THROUGH ROOM T

25

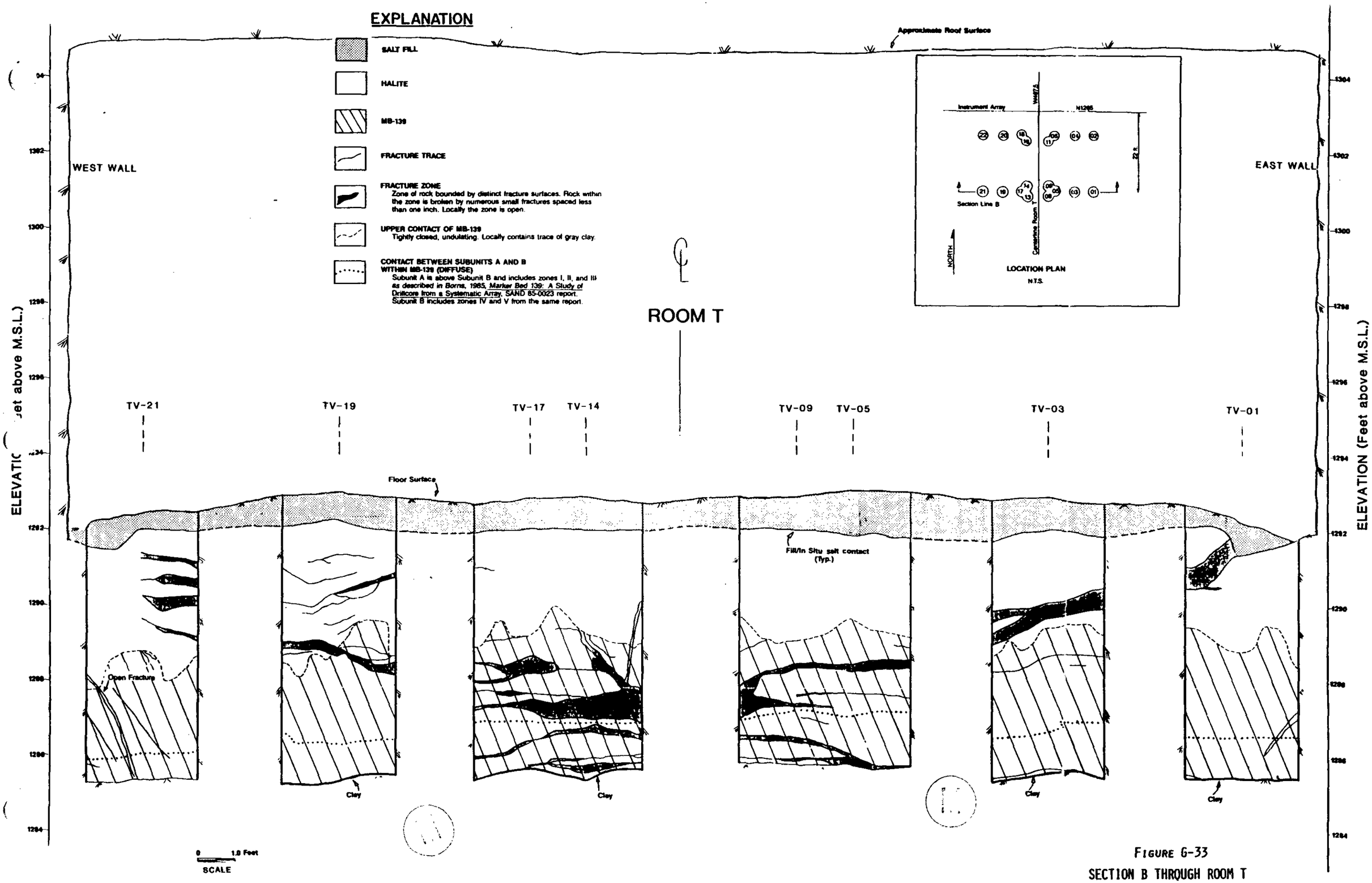

FIGURE G-33
SECTION B THROUGH ROOM T

21

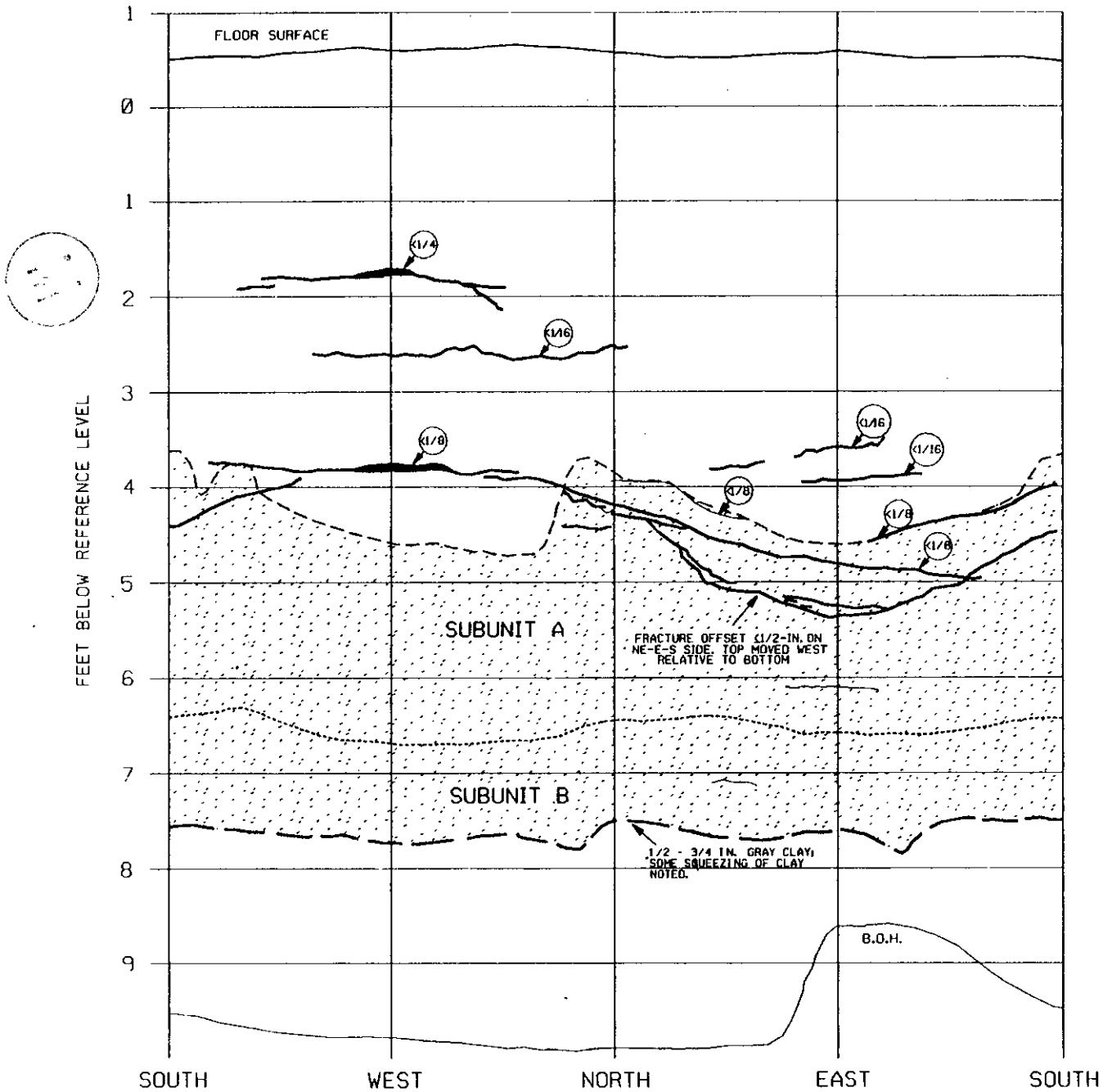

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS IN SOUTHWEST CORNER OF TEST ROOM 4 AND IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM AN UNSURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.
5. HOLE CONTAINS SALT FILL AT BOTTOM.

DATE MAPPED: 2/6/86

MAPPED BY: J.E. GALLERANI

0 1 2
SCALE IN FEET

FIGURE G-34

GEOLOGIC MAP OF DRILL HOLE P4X-84

APPENDIX H

DRIFT CROSS SECTIONS

CONTENTS

Figure No.	Title/Description
H-1	East-West Cross Section - E0 Drift at N1410
H-2	East-West Cross Section - E0 Drift at N1110
H-3	East-West Cross Section - E0 Drift at N621
H-4	East-West Cross Section - E0 Drift at N146
H-5	East-West Cross Section - W30 Drift at S406
H-6	East-West Cross Section - E140 Drift at S1320
H-7	East-West Cross Section - E140 Drift at S1960
H-8	East-West Cross Section - E140 Drift at S2421
H-9	East-West Cross Section - E140 Drift at S3079
H-10	East-West Cross Section - E140 Drift at S3656

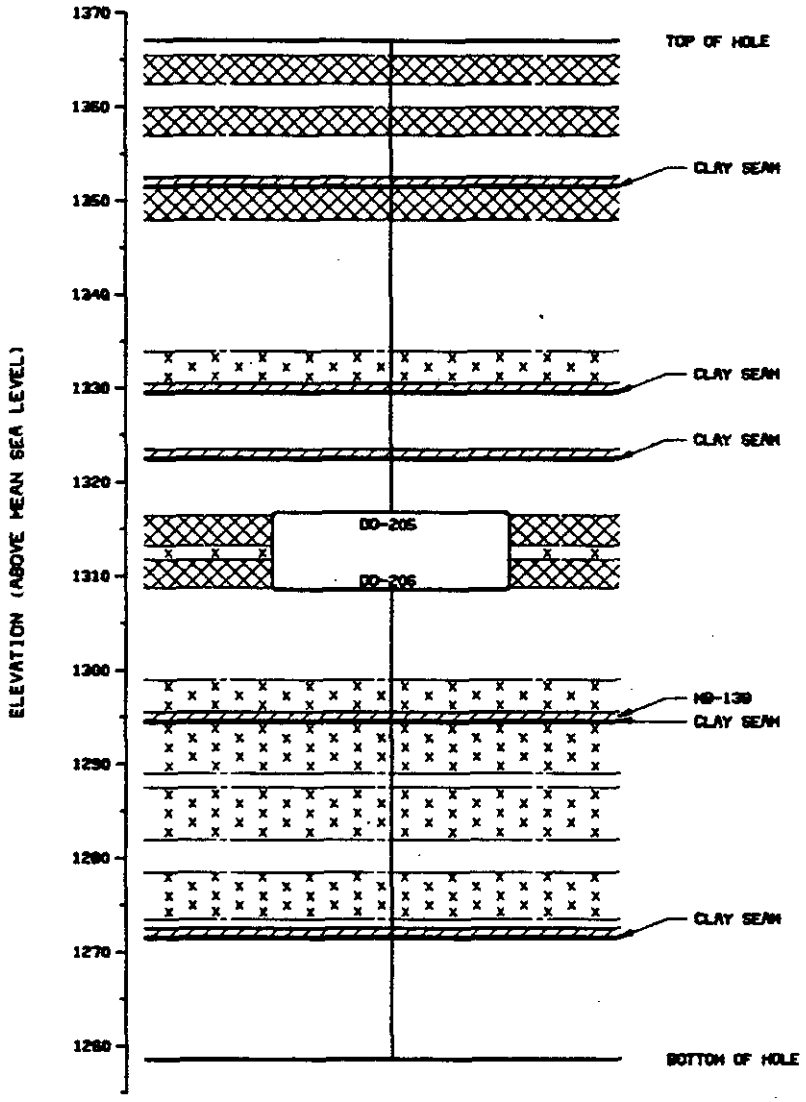

KEY PLAN

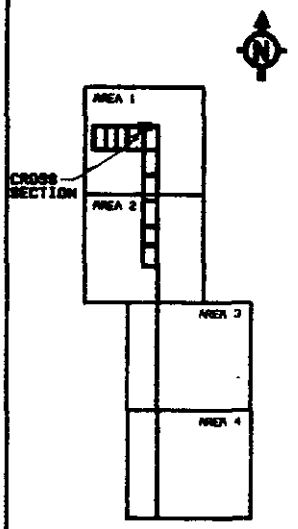

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DO - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST-WEST CROSS SECTION EO DRIFT AT N1410

FIGURE H-1

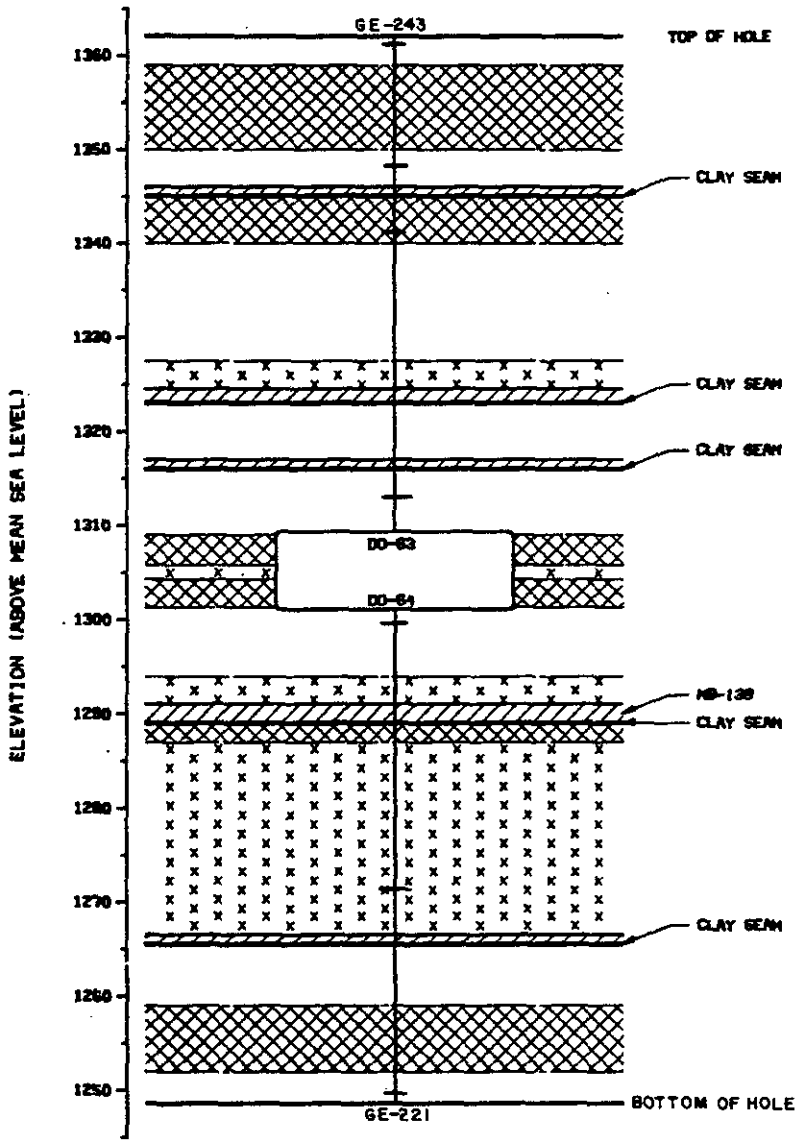

KEY PLAN

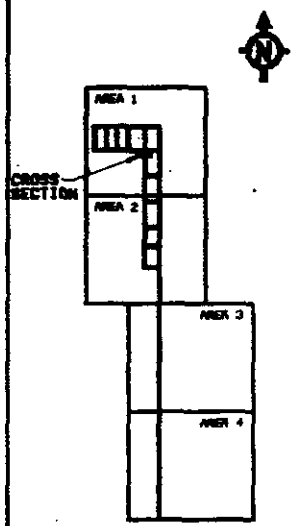

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DO - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST-WEST CROSS SECTION EO DRIFT AT N1110

FIGURE H-2

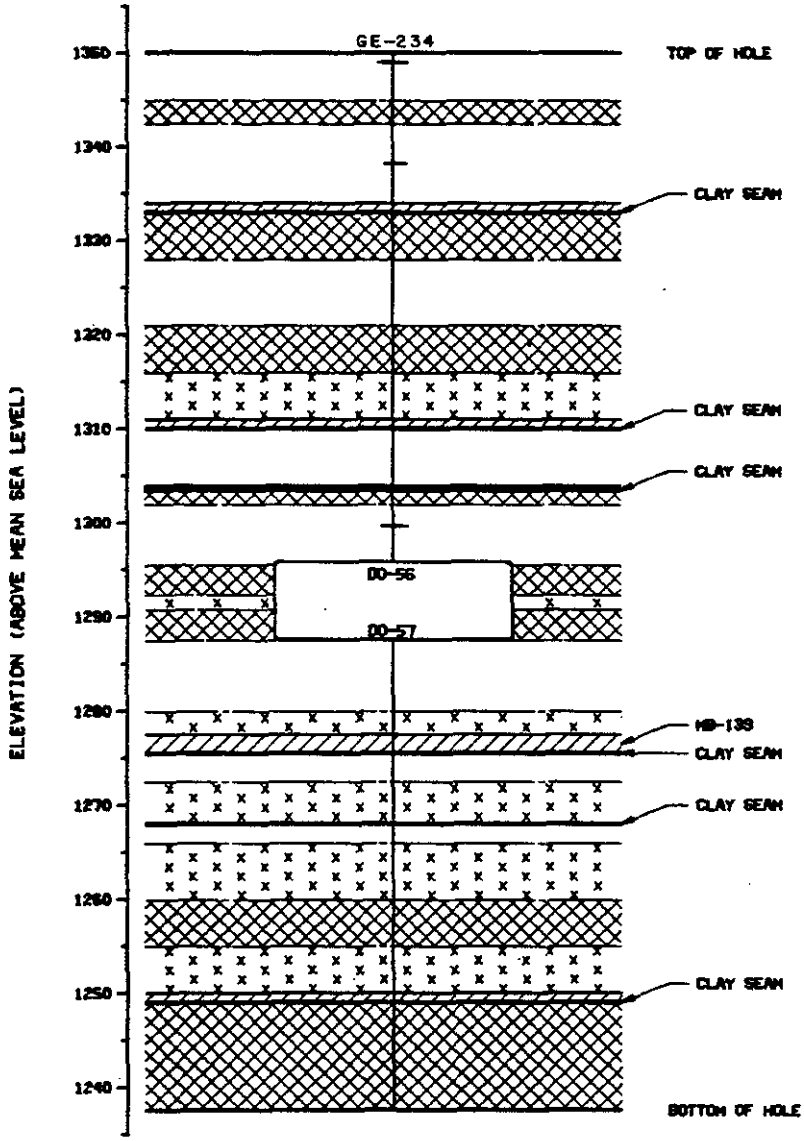

KEY PLAN

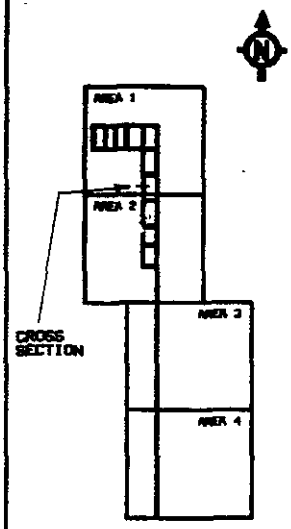

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DO - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST-WEST CROSS-SECTION EO DRIFT AT N621

FIGURE H-3

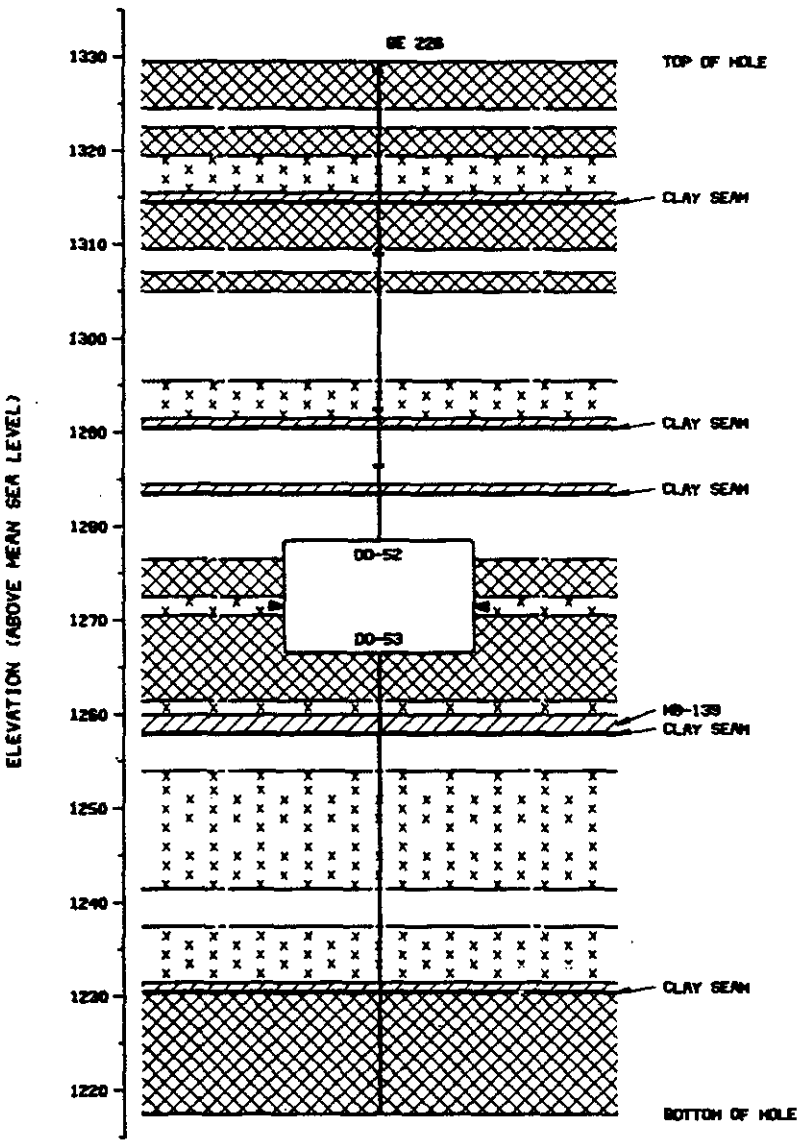

KEY PLAN

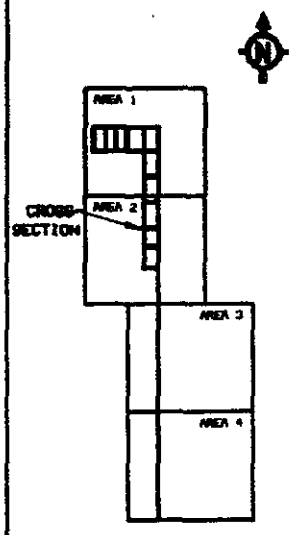

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DO - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST-WEST CROSS SECTION EO DRIFT AT N146

FIGURE H-4

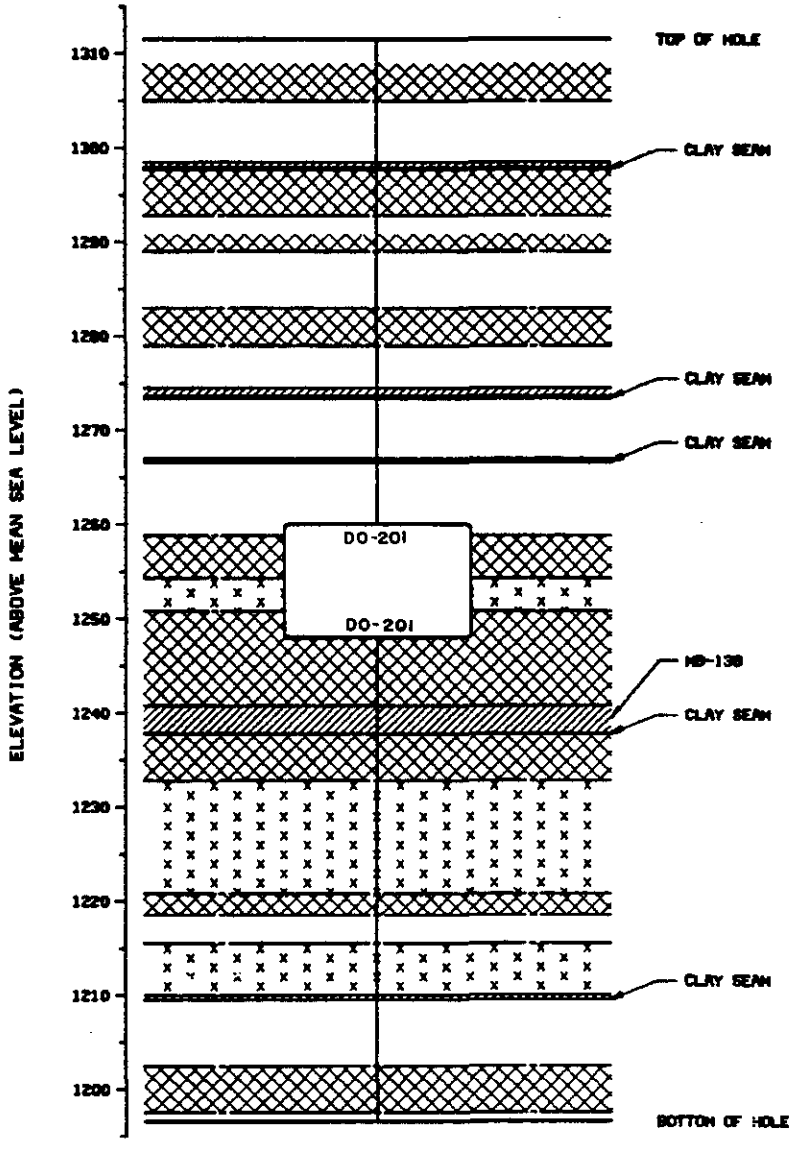

KEY PLAN

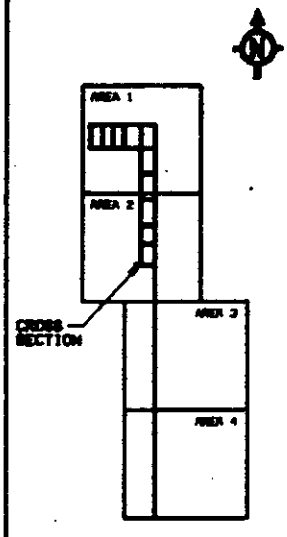

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DO - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST
CROSS SECTION
W30 DRIFT AT S406

FIGURE H-5

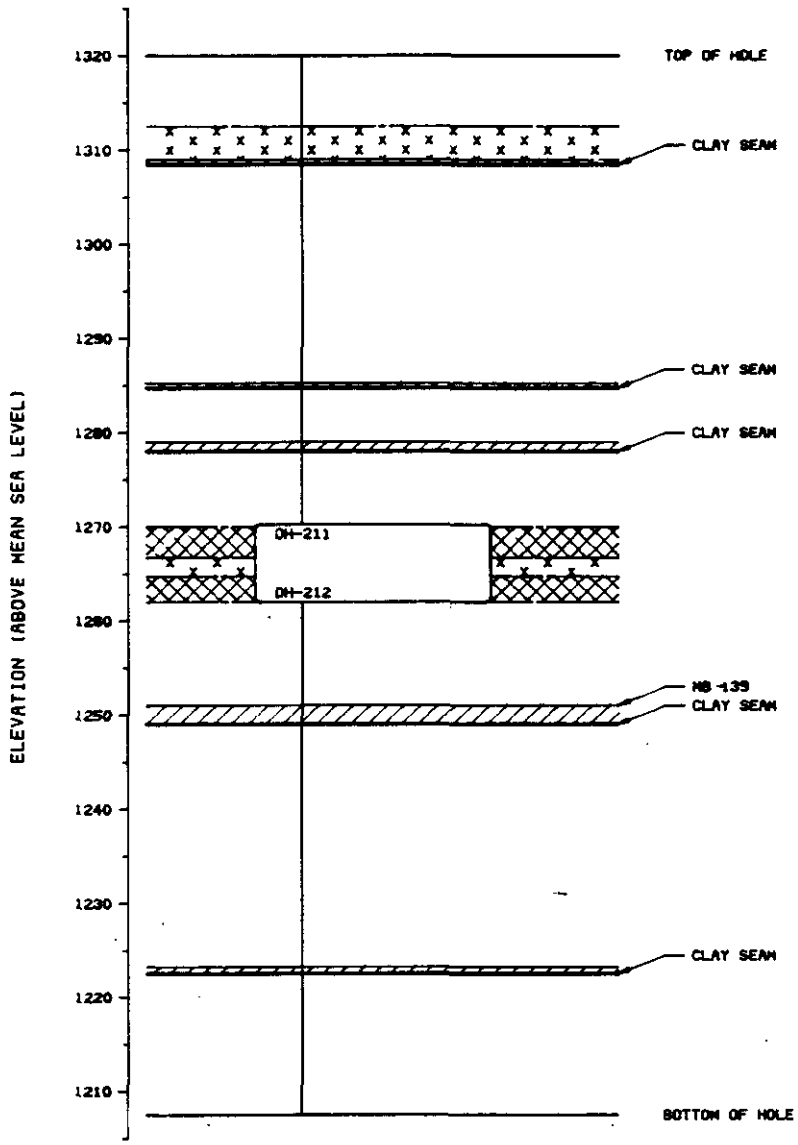

KEY PLAN

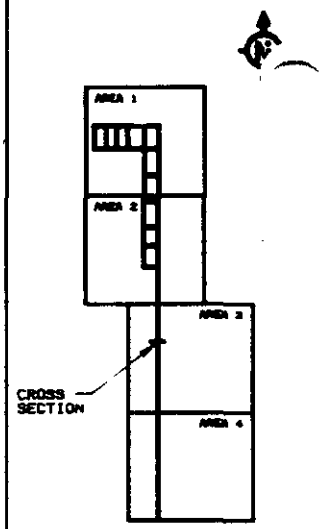

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DH - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST CROSS SECTION E140 DRIFT AT S1320

FIGURE H-6

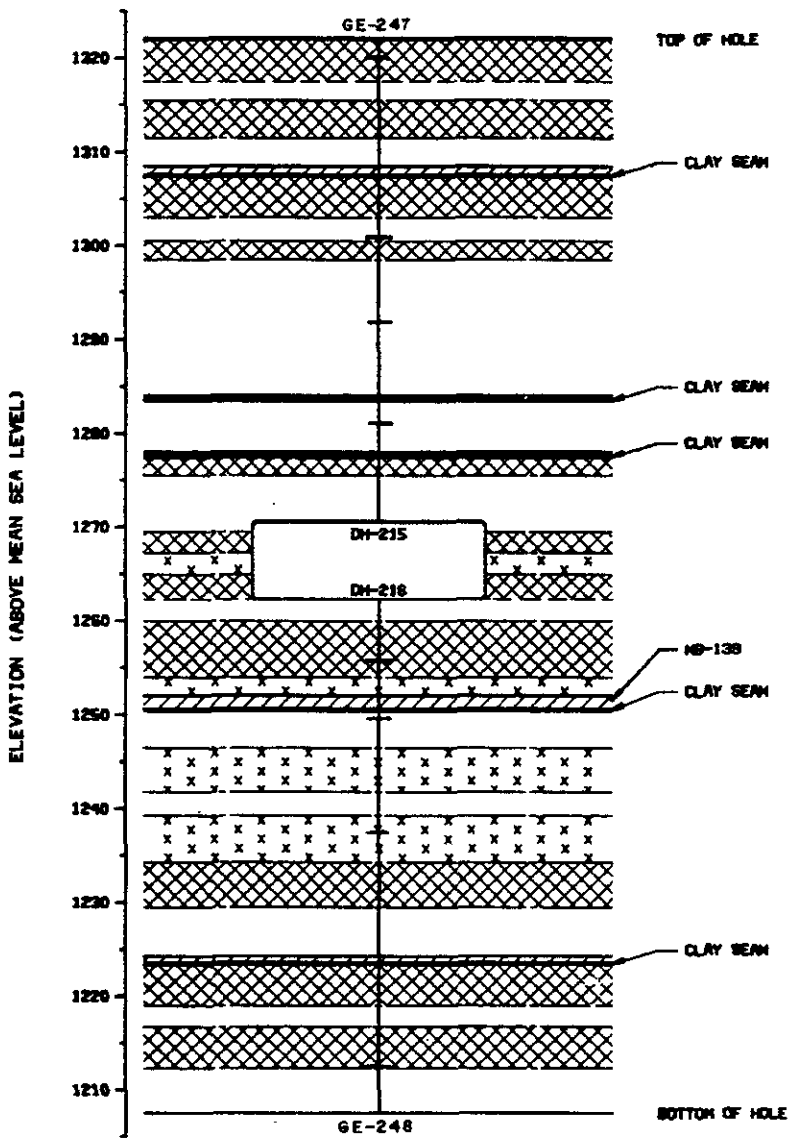

KEY PLAN

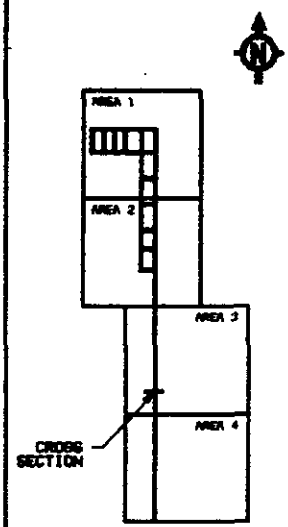

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DH - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST
CROSS SECTION
E140 DRIFT AT S1960

FIGURE H-7

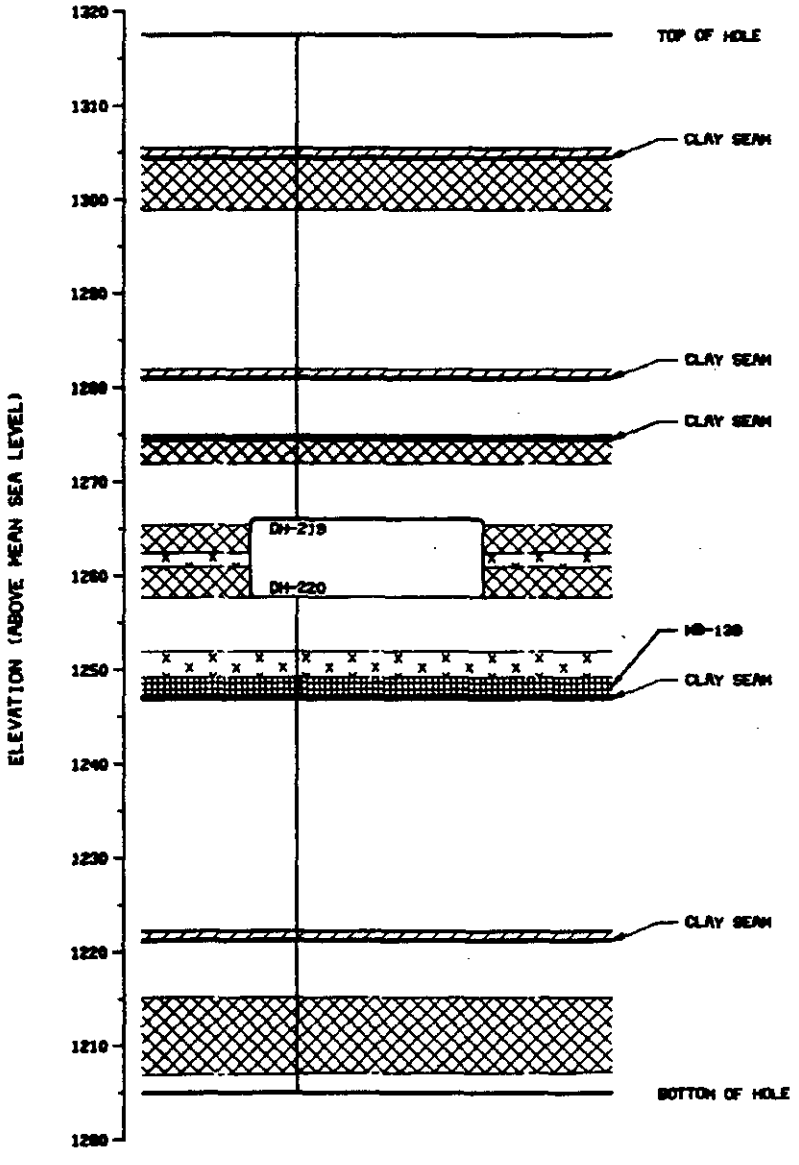

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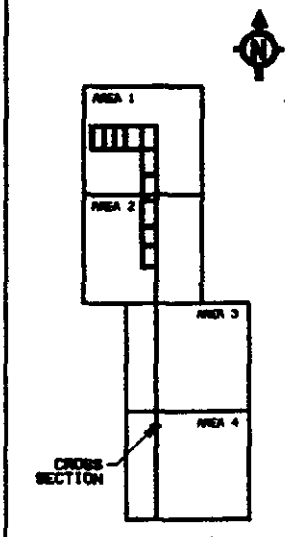

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DH - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST
CROSS SECTION
E140 DRIFT AT S242

FIGURE H-8

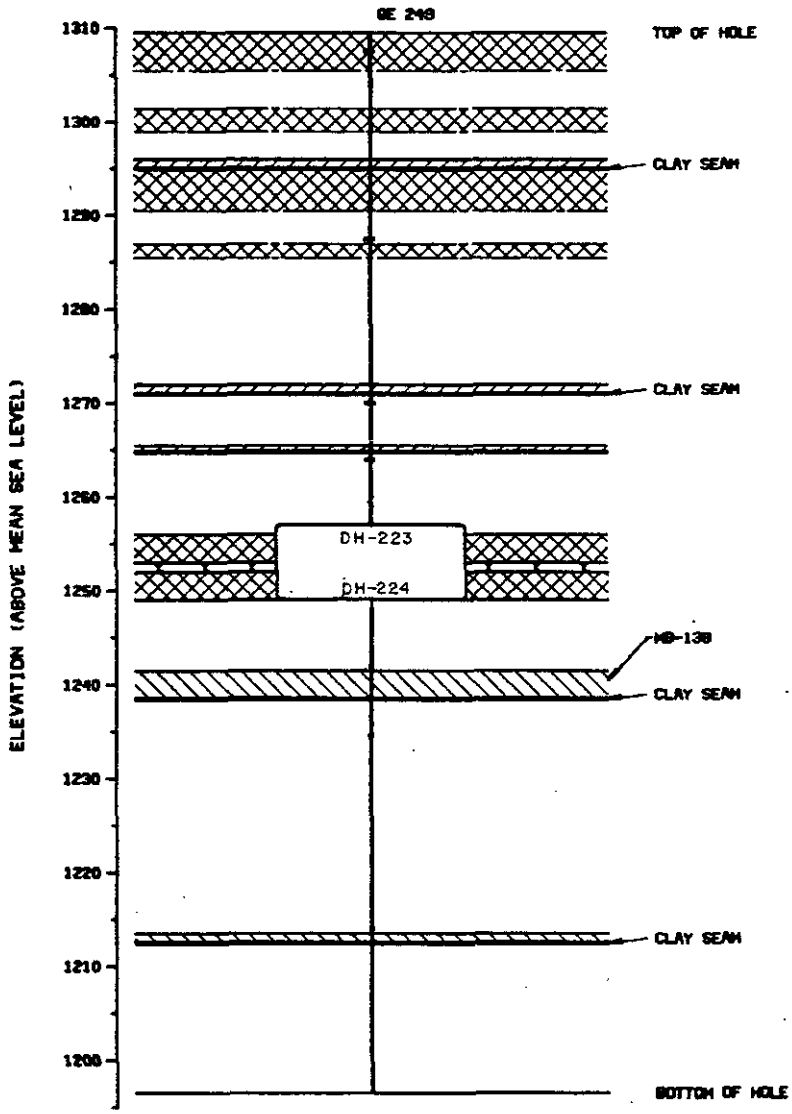

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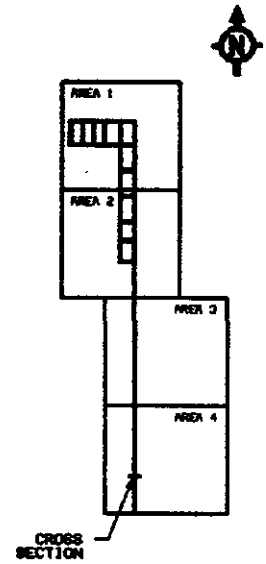

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DH - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST CROSS SECTION E140 DRIFT AT S3079

FIGURE H-9

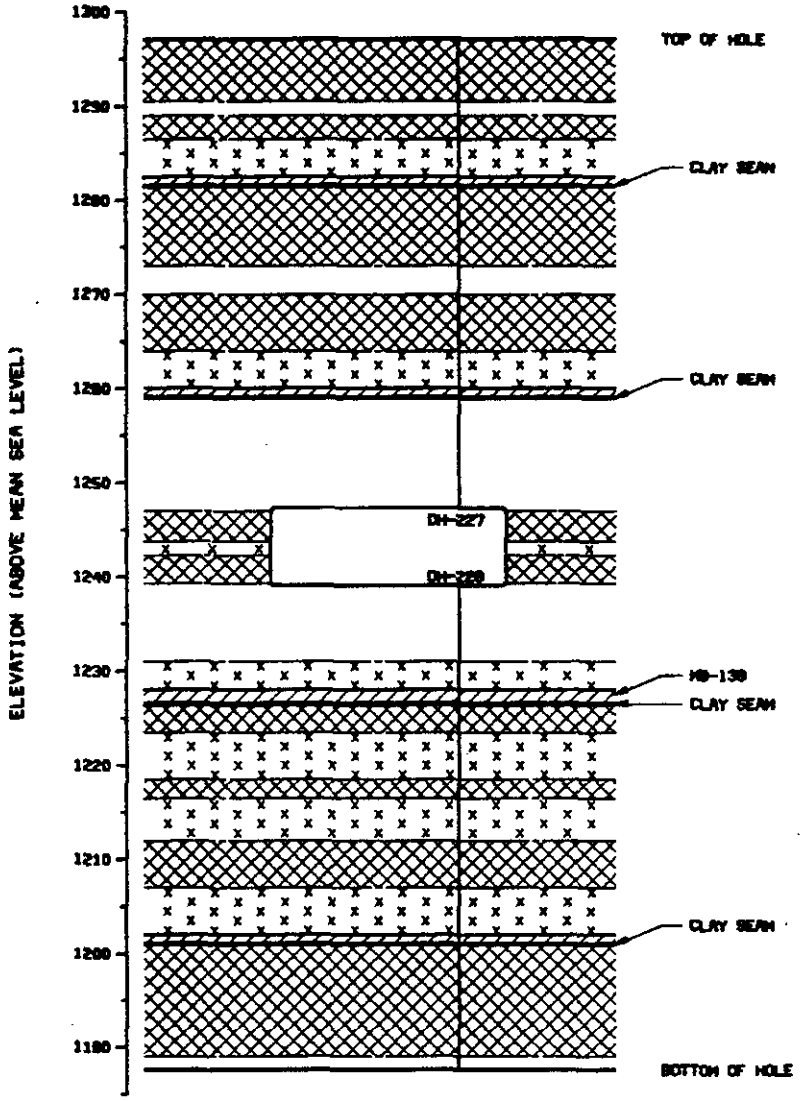

KEY PLAN

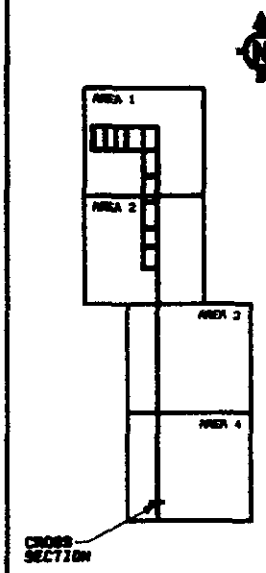

NOTES

LEGEND

INSTRUMENTS

- GE - EXTENSOMETER (MULTIPLE POINT)
- DH - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST CROSS SECTION E140 DRIFT AT S3656

FIGURE H-10

APPENDIX I

FACILITY LEVEL
GEOLOGIC CORE HOLE LOGS

CONTENTS

Table No.	Title/Description
I-1	Summary of Core Hole Data

Core Hole Logs

See Table I-1 for listing of enclosed logs.

Table I-1

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (Ft-MSL)	Approximate Station (Ft)		Facility Coordinates (Ft)		Depth/ Penetration (Ft)	Instrument Designation
MB-139-1	Down	1264.1	N79	W6	N9766	E6888	10.0	None
MB-139-2	Down	1251.2	S410	E150	N9277	E7044	15.7	None
MB-139-3	Down	1260.5	S101	E157	N9586	E7051	16.0	None
MB-139-4	Down	1258.7	S99	W17	N9588	E6877	16.2	None
DH-01	Up	1318.2	N1424	E439.5	N11110.9	E7335.5	50.8	None
DH-02(1)	Down		N1424	E440	N11110.9	E7336.06	50.2	None
DH-02A(1)	Down		N1424	E435	N11110.9	E7331.29	49.2	None
DH-02B	Down	1306.3	N1424	E442	N11110.9	E7331.29	53.0	None
DH-03	Up	1318.1	N1112	E444	N10799.2	E7335.4	48.8	None
DH-03A	Up	1317.4	N1112	E450.5	N10779.2	E7341.92	49.9	None
DH-04	Down	1309.6	N1112.5	E444	N10799.2	E7335.4	45.8	None
DH-04A(1)	Down	1309.6	N1113	E446			11.2	None
DH-04B	Down	1309.7	N1112	E450.5	N10799.70	E7341.85	51.4	None
DH-05	Up	1329.9	N1463	E972	N11149.6	E7865.0	51.0	None
DH-06	Down	1317.9	N1463	E972	N11149.7	E7864.9	49.75	None
DH-07	Up	1326.7	N1112	E976.5	N10799.3	E7870.8	49.8	None
DH-08	Down	1318.8	N1112	E976.5	N10799.4	E7870.9	38.3	None
DH-08A(1)	Down	1318.7	N1112	E975			50.7	None
DH-08B	Down	1318.0	N1112	E979.5	N10799.47	E7866.66	51.4	None
DH-09	Up	1324.5	N1432	E1332.5	N11108.71	E8227.11	51.1	None
DH-10	Down	1312.1	N1432	E1332.5	N11108.70	E8227.09	52.0	None
DH-11	Up	1320.5	N1112	E1332.5	N10799.8	E8227.3	50.9	None
DH-12	Down	1311.1	N1112	E1332.5	N10799.4	E8227.2	51.3	None
DH-13	Up	1311.4	N1424	E1690	N11112	E8585	13.8	None
DH-13A	Up	1311.5	N1424.5	E1691	N11112	E8586	49.0	None
DH-13B	Up	1311.4	N1425	E1695	N11112.6	E8590.1	21.0	None
DH-14	Down	1299.5	N1425	E1695	N11112.6	E8590.1	49.1	None
DH-15	Up	1308.9	N1104	E1688.5	N10793.26	E8589.96	51.0	None
DH-16	Down	1300.3	N1104	E1688	N10792.89	E8589.39	51.0	None
DH-17	Up	1316.5	N1427	E178	N11114.2	E7071.8	52.0	None
DH-18	Down	1305.1	N1429	E181	N11114.2	E7071.8	50.8	None
DH-19	Up	1314.7	N1107	E206.5	N10794.2	E7101.7	51.6	None
DH-20	Down	1306.2	N1109	E206	N10794.2	E7101.7	51.1	None
DH-21	Up	1331.0	N1421	E786	N11109.1	E7680.9	50.4	None
DH-22	Down	1318.8	N1421.5	E785.5	N11109.2	E7680.9	51.0	None
DH-23	Up	1328.0	N1112	E781	N10799.2	E7679.9	51.0	None
DH-24	Down	1319.5	N1112	E781	N10799.2	E7679.8	49.4	None
DH-24A	Down	1319.5	N1112	E780	N10799.08	E7678.59	50.4	None
DH-25	Up	1318.8	N1422	E1510	N11109.7	E8403.8	51.8	None
DH-26	Down	1307.2	N1427	E1510	N11114.3	E8403.8	53.0	None
DH-27	Up	1300.8	N1107	W682	N10793.7	E6218.4	50.5	None
DH-28	Down	1289.9	N1107	W682	N10793.8	E6218.3	50.5	None
DH-29	Up	1298.3	N1099	W982	N10785.4	E5932.4	50.4	None
DH-29A	Up	1298.1	N1099	W987	N10786.1	E5927.3	35.0	None
DH-30	Down	1289.2	N1099	W982	N10785.5	E5932.2	50.1	None
DH-31	Up	1298.5	N1099	W1282	N10784.9	E5632.3	50.5	None
DH-31A	Up	1298.5	N1099	W1280	N10784.8	E5630.5	49.2	None
DH-31B	Up	1298.5±	N1099	W1261	N10786.7	E5652.2	4.9	None
DH-32	Down	1289.6	N1099	W1282	N10784.9	E5632.2	50.0	None
DH-32A	Down	1289.5	N1099	W1261	N10786.7	E5652.2	5.5	None
DH-33	Up	1298.6	N1099	W1582	N10786.0	E5331.7	50.5	None
DH-33A	Up	1297.4	N1099	W1570	N10786.8	E5342.0	4.1	None
DH-34	Down	1289.4	N1099	W1582	N10786.5	E5331.7	51.5	None
DH-34A	Down	1289.2	N1099	W1570	N10786.8	E5341.9	3.6	None
DH-35	Up	1294.4	N1102	W1882	N10789.4	E5032.2	52.0	None
DH-36	Down	1284.6	N1102	W1882	N10789.4	E5032.2	51.5	None
DH-37	Up	1297.4	N1101	W2182	N10788.9	E4732.0	51.5	None
DH-38	Down	1287.0	N1101	W2182	N10788.8	E4731.9	47.5	None
DH-39	Up	1296.0	N1101	W2482	N10789.2	E4430.7	50.7	None
DH-40	Down	1286.1	N1101	W2482	N10789.2	E4431.0	51.0	None
DH-41	Up	1295.8	N1101	W2782	N10789.0	E4132.6	49.9	None
DH-42	Down	1285.9	N1101	W2782	N10789.0	E4132.4	51.2	None
DH-42A	Down	1285.7	N1101	W2789	N10789.2	E4125.5	40.5	None

(1) Survey data not available.

Table I-1 (continued)

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (Ft-MSL)	Approximate Station (Ft)		Facility Coordinates (Ft)		Depth/ Penetration (Ft)	Instrument Designation
DH-207	Up	1259.8	S697	E155	N8989.7	E7049.1	53.0	GE-246
DH-208	Down	1251.6	S698	E150	N8988.8	E7044.0	49.2	None
DH-211	Up	1270.5	S1320	E163	N8366.5	E7057.1	50.0	None
DH-212	Down	1261.7	S1320	E163	N8366.5	E7057.1	52.1	None
DH-215	Up	1272.0	S1960	E153	N7727.2	E7046.9	52.0	GE-247
DH-216	Down	1262.6	S1960	E153	N7727.2	E7046.9	54.2	GE-248
DH-219	Up	1266.3	S2422	E162	N7264.9	E7056.6	51.0	None
DH-219A	Up	1266.1	S2418	E162	N7268.5	E7056.2	11.3	None
DH-220	Down	1257.4	S2421	E162	N7265.5	E7055.9	51.8	None
DH-223	Up	1255.1	S3079	E154	N6607.2	E7048.5	52.6	GE-249
DH-224	Down	1246.6	S3079	E154	N6607.5	E7048.5	52.5	None
DH-227	Up	1247.0	S3656	E147	N6030.7	E7041.2	51.7	None
DH-228	Down	1237.8	S3656	E147	N6030.7	E7041.2	50.4	None
DH-301	Up	1276.9	N150	W170	N9830.5	E6724.5	50.75	None
DH-302	Down	1264.9	N150	W170	N9830.5	E6724.5	50.6	None
DH-303	Up	1267.2	S400	W170	N9282.3	E6726.1	51.4	None
DH-304	Down	1254.3	S400	W170	N9282.5	E6726.1	50.5	None
DH-306	Down	1244.1	S400	E140	N9287.3	E7049.9	52.0	None
DH-306A	Down	1244.0	S400	E125	N9287.9	E7034.6	8.5	None
DH-307	Up	1262.6	S400	E300	N9286.7	E7194.2	52.0	GE-263
DH-309	Up	1259.8	S700	E220	N8987.1	E7123.0	52.3	GE-265
DH-311	Up	1264.4	S1000	E300	N8686.3	E7194.9	52.0	GE-264
DH-313	Up	1270.6	S1300	E300	N8385.9	E7190.6	19.6	None
DH-313A	Up	1270.9	S1300	E299	N8386.6	E7189.5	50.2	None
DH-314	Down	1258.3	S1300	E300	N8386.5	E7189.5	50.75	None
DH-315	Up	1272.1	S1300	W170	N8387.3	E6725.5	50.3	None
DH-316	Down	1259.9	S1300	W170	N8387.2	E6725.3	50.1	None
DH-317	Up	1271.3	S1600	W33	N8077.4	E6875.9	50.1	None
DH-317A	Up	1271.2	S1600	W30	N8077.5	E6879.5	5.0	None
DH-317B	Up	1271.2	S1597	W30	N8080.3	E6881.0	51.0	None
DH-318	Down	1258.5	S1600	W30	N8077.3	E6876.1	50.0	None
DH-319	Up	1260.0	S700	E300	N8988.1	E7191.6	51.05	None
DH-321	Up	1261.4	S400	E0	N9792.0	E6891.8	52.0	GE-268
DH-323	Up	1261.2	S400	E55	N9291.7	E6952.5	52.5	GE-267
DO-45	Up	1285.5	N254	E147	N9941.0	E7041.3	52.4	GE-230
DO-46	Down	1276.5±	N254	E147	N9941.0	E7041.3	51.5	None
DO-52	Up	1280.4	N146	W4	N9832.5	E6890.5	51.6	GE-226
DO-53	Down	1286.6	N146	W4	N9832.5	E6890.5	49.2	None
DO-56	Up	1296.8	N621	E0	N10311.8	E6892.3	52.1	GE-234
DO-57	Down	1288.1	N621	E0	N10311.8	E6892.4	52.1	None
DO-63	Up	1310.6	N1110	E0	N10796.0	E6891.9	52.8	GE-243
DO-64	Down	1301.5	N1110	E0	N10796.0	E6891.6	52.8	GE-221
DO-67	Down	1296.8	N1265	W231.5	N10952.1	E6662.9	51.7	GE-220
DO-69	Up	1310.1	N1265	W231.5	N10951.9	E6662.5	51.4	GE-218
DO-77	Down	1294.6	N1270	W364.5	N10962.5	E6529.6	53.4	GE-216
DO-79	Up	1307.7	N1270	W364.5	N10962.6	E6529.5	51.8	GE-214
DO-88	Up	1305.9	N1265	W497.5	N10952.8	E6396.5	52.7	GE-212
DO-90	Down	1292.1	N1265	W497.5	N10952.6	E6396.4	53.6	GE-210
DO-91	Down	1292.1	N1275	W630.5	N10961.5	E6263.9	51.8	GE-209
DO-93	Up	1304.9	N1275	W630.5	N10961.1	E6263.9	52.0	GE-207
DO-201	Up	1262.2	S406	W19	N9280.6	E6874.9	51.7	None
DO-202	Down	1248.6	S406	W19	N9280.6	E6874.9	51.4	None
DO-203	Up	1298.2	N624	E140	N10308.6	E7041.7	52.0	GE-235
DO-204	Down	1290.5	N640	E140	N10308.5	E7041.5	51.6	None
DO-205	Up	1316.5	N1410	E0	N11095	E6892	50.7	None
DO-206	Down	1308.0	N1410	E0	N11095	E6892	50.6	None
DO-229	Up	1259.8	S401	E153	N9287	E7049	50.6	None
OH-9	Up	1310	N1433	W231.5	N11125.6	E6662.9	15.4	None
OH-11	Up	1308	N1433	W364.5	N11125.6	E6529.6	19.7	None
OH-13	Down	1298	N1433	W231.5	N11125.6	E6662.9	9.5	None
OH-14	Down	1296	N1433	W364.5	N11125.6	E6529.6	9.7	None

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. MB-139-1 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 79' N of Exploratory Shaft centerline, midspan

STATION N79,W6 COLLAR ELEV. 1264.1' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9766, E6888 DEPTH OF BOREHOLE 10.0'

DRILLING METHOD Air & Brine DRILL MAKE/MODEL Longyear 38

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

SHEET 1 OF 1

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.5	100	–		0.0' – 4.4' **HALITE:** clear halite, coarsely crystalline, 1-2% moderate reddish-orange (10R 6/6) polyhalite, 1-2% brown clay, ~1% gray clay, all in discrete blebs.	Hole was cored on 27 October 1982. The first 5' interval was drilled with air. Recovery was poor, and the core was covered with oil. At 5', drilling with brine commenced and continued to 10'. At 10', the water pump failed and the rods became stuck in the hole. Rods were pulled and drilling halted at 10'.
2		0.8	24	–		4.4' – 6.8' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 5% polyhalite in blebs above 6.0', in blebs and disseminated below 6.0', clay absent, 10-50% anhydrite from 6.7'-6.8'.	
3	5	1.0	100	–			
4		3.5	88	–		6.8' – 8.6' **ANHYDRITE:** (Marker Bed 139) light gray (N7), microcrystalline anhydrite, 5-50% polyhalitic halite from 6.8'-8.1' decreasing downward, gray clay parting at 8.6'.	
						8.6' – 9.5' **HALITE:** clear to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 1-2% mostly disseminated polyhalite, ~1% gray clay.	Total depth = 10.0'.
	10						
	15						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. MB-139-2 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION Intersection of South 400 and East 140 Drifts, 14.5' N of S rib of South 400 Drift, 18' W of E rib of East 140 Drift

STATION S410, E150 COLLAR ELEV. 1251.2' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9277, E7044 DEPTH OF BOREHOLE 15.7'

DRILLING METHOD Air and Brine DRILL MAKE/MODEL Longyear D-65

PREPARED BY RMB/Bechtel DATE 11/27/82 SHEET 1 OF 1

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.6	89	-		0.0' - 1.1' **HALITE:** clear halite, medium to coarsely crystalline, trace polyhalite, gray clay break at 0.4'.	Coring started at 12:00 hours on 27 November 1982.
2		1.9	90	-		1.1' - 2.8' **HALITE:** medium reddish-orange (10R 5/6), translucent halite, medium crystalline, moderately hard, 2 - 5% clay, ~5% polyhalite, gray clay parting at 1.1', brown clay parting at 1.4'.	
3	5	0.6	27	-		2.8' - 6.5' **HALITE:** predominantly clear halite, coarsely crystalline, trace polyhalite in places, trace gray clay blebs in places.	From ground surface to 8.7', core was recovered directly into drill rod without use of inner barrel. Inner barrel was used below 8.7'.
4		1.3	100	-		6.5' - 8.1' **HALITE:** medium reddish-orange (10R 5/6), translucent halite, medium crystalline, ~2% polyhalite, trace gray clay blebs in places, polyhalite absent from 7.4' - 8.1'.	
5		1.3	100	-		8.1' - 9.7' **POLYHALITIC HALITE:** medium reddish-orange (10R 5/6), translucent halite, medium to coarsely crystalline, moderately hard, 20 - 25% polyhalite.	
6	10	4.9	98	-		9.7' - 12.9' **ANHYDRITE:** (Marker Bed 139) medium light (N6) to very light gray (N8) to light brownish-gray (5YR 6/1) anhydrite, hard, dense, up to 50% halite from 9.7' - 10.5' in "mesh" network with anhydrite, some halite from 10.5' - 12.9', polyhalite band 9.7' - 9.75', 10.5' - 12.9' mostly broken into "poker chips".	At ~11'-12', brine drilling fluid started bubbling back out of hole. Hit trace pressurized gas.
7	15	1.9	95	-		12.9' - 13.7' **HALITE:** light gray (N7) mottled with medium reddish-orange (10R 5/6) translucent halite, clay occurs predominantly as closely-spaced breaks, 1" gray clay seam at 12.9', gray clay breaks at 13.1', 13.2', and 13.3'.	
						13.7' - 15.7' **HALITE:** brownish-gray and medium reddish-orange (10R 5/6) translucent halite, medium to coarsely crystalline, ~1% gray clay, trace polyhalite in places, especially 15.3' - 15.7', gray clay breaks at 13.9', 14.3', and 14.7'.	Finished coring at 14:15 hours, gas still evident in hole. Total depth = 15.7'.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. MB-139-3 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION Intersection of South 90 and East 140 Drifts, 1' N of S rib of the South 90 Drift, 14.5' E of W rib of the East 140 Drift

STATION S101,E157 COLLAR ELEV. 1260.5' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9586, E7051 DEPTH OF BOREHOLE 16.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JAK,RLB/TSC DATE 1/26/83 SHEET 1 OF 1

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.1	49	-		0.0' - 7.9' **HALITE:** clear to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, 1-5% polyhalite, 1-3% gray clay predominantly at top, 1-3% brown clay predominantly at bottom, 0.0'-0.6' has <1% polyhalite, ~1% disseminated polyhalite and no clay from 4.2'-4.8', otherwise polyhalite is in discrete blebs.	Hole cored on 28 December 1982.
2		0.75	45	-			
3	5	1.2	39	-			
4		1.8	83	-		7.9' - 9.6' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, 2-5% polyhalite disseminated and in blebs, <1% gray clay, brown clay absent.	
5	10	4.6	92	-		9.6' - 11.9' **ANHYDRITE:** (Marker Bed 139) light gray (N7) microcrystalline anhydrite, trace halite from 9.6'-11.2', gray clay seam at 11.9'.	Gas encountered while drilling through MB 139.
						11.9' - 16.0' **HALITE:** clear to moderate reddish-brown (10R 4/6) halite, finely to coarsely crystalline, 1-2% disseminated polyhalite, 1-2% gray clay above 14.3', 1-3% brown clay below 14.8', clay absent elsewhere, 14.3'-14.8' is relatively pure halite. pure halite.	
6	15	1.8	100	-			Total depth = 16.0'.
	20						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. MB-139-4 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION Intersection of O East and South 90 Drifts, 5' E of W rib of O East Drift, 3' N of S rib of South 90 Drift

STATION S99,W17 COLLAR ELEV. 1258.7' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9588, E6877 DEPTH OF BOREHOLE 16.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

SHEET 1 OF 1

RUN NUMBER	DEPTH (ft)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	0.5	25	–			Hole cored on 29 November 1982.
2	5	3.5	95	–		0.0' – 5.6' **HALITE:** mottled white to clear to dark reddish-brown (10R 3/4) halite, coarsely crystalline, 1 – 5% polyhalite and 1 – 5% brown clay, both concentrated in discrete blebs within otherwise clear halite.	Run 1 recovery seems to be from bottom of run.
3		3.5	95	–		5.6' – 8.5' **POLYHALITIC HALITE:** clear halite, coarsely crystalline, 5 – 10% moderate reddish-brown (10R 5/6) polyhalite in discrete blebs, <1% gray clay.	
4	10	4.6	97	–		8.5' – 11.9' **ANHYDRITE:** (Marker Bed 139) light gray (N7) anhydrite, 30 – 40% halite from 8.5' – 10.7, 5 – 10% halite from 10.7' – 11.1', gray clay seam at 11.9'.	Drilled with solution of vent shaft water and added salt.
5	15	2.1	100	–		11.9' – 16.2' **HALITE:** clear to moderate reddish-brown (10R 4/6) to light gray (N7) halite, finely to coarsely crystalline, 1 – 5% polyhalite and 1 – 2% gray clay in bands, ~1% brown clay.	Most core shows signs of dissolution by drilling fluid. Smooth, rounded features of halite, polyhalite and clay stand out in relief.
	20						Total depth = 16.2'.

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-01

LOCATION N 1420 DRIFT: ROOF

STATION N 1424 ± E 439.5 ± COLLAR ELEV. 1318.2 DIRECTION OF DRILLING VERTICAL-UP

MINE COORDINATES N 11,110.9 E 7335.5 DEPTH OF BOREHOLE 50.8 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/9/84 (SWING) DATE COMPLETED 2/10/84 (SWING) SHEET

LOGGED BY: J.E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 3.2	3.2	3.2	100		0.0'-4.4' HALITE: Clear with scattered moderate reddish orange (10R 6/6) polyhalite, coarsely crystalline with some fine to medium locally. (1,2)	Watson drill;AW rods, NX double tube core barrel. Run 1. Broken zone 2.5'-2.8' ±.
2	3.2 – 8.0	4.8	4.8	100		4.4'-7.05' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤1% gray clay and < 1/2% polyhalite. (11)	Drilling Time: 7 hrs ±.
						7.05'-7.2' ANHYDRITE b: Light gray (N7) to medium gray (N5) microcrystalline. ≤ 3/16" gray clay at 7.05'.	No gas; dry hole. Run 2. Broken up last 15" ± of run 2.
3	8.0 – 12.0	4.0	4.0	100		7.2'-11.8' HALITE: Clear, fine to coarsely crystalline to 8', then predominantly clear, coarsely crystalline. Slight moderate reddish orange color to 8'. (1,2)	Run 3. Broken last 6".
						11.8'-13.25' HALITE: Clear with some light moderate reddish brown (10R 4/6) and light gray (N7) medium to coarsely crystalline with fine locally. < 1/2% gray gray and dispersed polyhalite. (9)	
4	12.0 – 13.0	1.0	1.0	100			
5	13.0 – 17.2	4.2	4.2	100		13.25'-13.85' ANHYDRITE a: White to medium gray (N5) microcrystalline. Scattered halite growths especially from 13.5'. Trace of gray clay at 13.25': Some core grinding noted here.	Run 5. Broken up 16.0'-16.8' ±.
6	17.2 – 22.0	4.8	4.8	100		13.85'-17.6' HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 2% locally, polyhalite blebs. (2,3)	Run 6. Broken up last 4" of run.
						17.6'-22.9' HALITE: Clear, some light gray (N7); medium to coarsely crystalline. < 1% gray intercrystalline clay. Break at 20.1'. Gray clay break, trace of anhydrite at 22.9'. (1,9)	
7	22.0 – 25	5.3	4.9	92.5		22.9'-27.3' HALITE: Clear, coarsely crystalline, some medium. Scattered white anhydrite/magnesite? stringers. (1)	Run 7. Broken zones from 25'-27.3' within core.

BORING NO. DH-01

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-01

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	5.3	5.3	92.5		27.3'-28.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), fine to coarsely crystalline. < 1 to 3% clay, predominantly brown with trace of gray. Breaks at 27.9' and 28.35'. ≤5% brown clay from 28.35' to 28.6'. (17)	
8		4.7	4.7	100		28.6'-31.5' HALITE: Clear, coarsely crystalline ≤ 1/2% gray clay and polyhalite locally. (1)	Run 8. Broken up 30.2'- 32'±.
	30					31.5'-34.0' ARGILLACEOUS HALITE: Clear to medium brown (5YR 4/4) and dark reddish brown (10R 3/4) medium to coarsely crystalline. < 1 to 4% brown clay. Scattered breaks at 33.2'-34'. (10)	
9		5.0	5.0	100		34.0'-35.0' HALITE: Clear, coarsely crystalline. < 1/2% brown clay. (1,8)	Run 9. Broken up discs 33.8'-35' ±.
	35					35.0'-35.85' ANHYDRITE: Very light gray (N8) to medium gray (N5) microcrystalline anhydrite: partially laminated. Scattered halite growths, especially 35.55'-35.85'. ≤1/4" brown clay at 35.0'.	
10		4.3	4.3	100		35.85'-37.2' HALITE: Clear, coarsely crystalline. <1% polyhalite blebs and patches up to 1/2" white anhydrite layer at 36.7'. (1,2)	Run 10. Broken zones in core 38'-39.5' ±.
	40					37.2'-39.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline < 1 to 3% polyhalite blebs and patches. < 1/2% gray clay. (3,4,7)	
11		4.7	4.7	100		39.9'-42.3' HALITE: Clear to light brown (5YR 5/6), medium to coarsely crystalline. ≤ 1% brown intercrystalline clay. 1/2" brown clay seam at 41.3'. < 1% polyhalite. Argillaceous halite at 41.8' to 42.3'. (8,10)	Run 11. Small broken zones in core 45'-46' ±.
	45					42.3'-45.4' HALITE: Clear, coarsely crystalline. < 1% polyhalite and < 1/2% gray clay. (1,7)	
12		4.8	4.8	100		45.4'-47.0' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) (5YR 3/4) medium to coarsely crystalline. < 1 to 5% brown clay, intercrystalline and breaks. Breaks from 46.5' to 46.9'. (12)	
	50					47.0'-49.0' HALITE: Clear to medium brown (5YR 4/4) to moderate yellowish brown (104R 5/4) medium to coarsely crystalline, some fine. ≤ 1 to 2% brown clay. Up to 4% clay from 48.7'-49.0'. Scattered breaks here. 3/8" brown clay seam at 49.0'. (12,17)	
	55					49.0'-50.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% gray clay. (4,7)	

27.3 32.0 37.0 41.3 46.0 50.8

BORING NO. DH-01

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-02

LOCATION N1420 DRIFT - FLOOR

STATION N1424 ± E440 ± COLLAR ELEV. DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N11,110.9 E7336.06 DEPTH OF BOREHOLE 50.2'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/7/84 (SWING) DATE COMPLETED 2/8/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 4.5	4.5	4.5	100		0.0'-4.8' HALITE: Clear with some light gray (N7); coarsely crystalline, some medium. ≤1% gray intercrystalline clay and < 1/2% polyhalite blebs.	Watson drill NX double tube barrel, AW rods. Total time: 3-1/2 hours. Had to bolt machine to floor. Vibration of track boom is considerable
						4.8'-5.3' POLYHALITIC HALITE: Clear to moderate reddish orange; coarsely crystalline. < 1 to 3% polyhalite.	No gas; dry hole.
2	4.5 – 9.5	5.0	4.5	90		5.3'-8.5' MB-139: Moderate reddish orange anhydrite mixed with halite to 5.4', then predominantly white to medium light gray (N6) anhydrite. Some "swallowtail" pattern in upper part. Scattered halite growths throughout. Abundant polyhalitic halite mixed with the anhydrite from 7.25'-8.0'. < 1/4" gray clay at 8.5'.	Contacts below run 2 not able to be determined accurately due to core loss. Run 2. Core loss probably upper 1-1/2'.
3	9.5 – 14.8	5.3	4.6	86.8		8.5'-11.8' HALITE: Clear, medium to coarsely crystalline. <1% gray clay and polyhalite.	
						11.8'-15.7' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 2% polyhalite. <1/2% gray clay. Some anhydrite at 15.5 to 15.7'. Gray clay parting at 15.7'.	
4	14.8 – 20.0	5.2	3.3	63.5		15.7'-16.4' HALITE: Clear, medium to coarsely crystalline. <1% gray clay and dispersed polyhalite.	
						16.4'-25.0' ± POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. <1/2% gray clay below 22.5' ±.	
5	20.0 – 25.0	5.0	4.0	80		25.0'-30.0' ± HALITE: Clear, fine to coarsely crystalline. <1/2% clay and polyhalite.	

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-02

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25.0 – 30.0	5.0	2.7	54		30.0'-33.9' ± HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1/2% dispersed polyhalite. 1/2" anhydrite layer at 30'.	Run 7. Poor core recovery. Run 8. Poor core recovery. Took apart core barrel. Air ports were plugged. Cleaned up but still poor recovery.
7	30.0 – 33.9	3.9	1.0	25.6		33.9'-45.8' ± HALITE: Clear to light gray (N7) and medium light gray (N6); medium to coarsely crystalline, some fine. < 1% clay and < 1/2% dispersed polyhalite.	
8	33.9 – 39.5	5.6	1.2	21.4		45.8'-50.2' HALITE: Clear, medium to coarsely crystalline. None to < 1% gray clay. < 1/2% polyhalite from 49.3' to 50.2'.	
9	39.5 – 44.6	5.1	1.2	23.5		Note: Core recovery from 4.5' is below 95%. Unable to accurately determine contacts. Hole was redrilled twice. Refer to logs for DH-02A and DH-02B.	
10	44.6 – 50.2	5.6	4.5	80.4			

BORING NO. DH-02

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-02A

LOCATION N1420 DRIFT FLOOR

STATION N1424 ± E435 ± COLLAR ELEV. _____ DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N11,110.9 E7331.29 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/8/84 (SWING) DATE COMPLETED 2/9/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 I OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 5.0	5.0	5.0	100		0.0'-2.75' HALITE: Clear to light gray (N7) coarsely crystalline. <1% gray clay. <1/2% polyhalite.	Watson drill with NX double tube barrel. AW rods. Drilling time: 6 hours and 45 minutes. No gas/brine.
						2.75'-5.6' HALITE: Clear with some moderate reddish orange (10R 6/6); coarsely crystalline. <1% polyhalite.	
2	5.0 – 10.0	5.0	4.3	86		5.6'-8.2' MB-139: "Swallowtail" pattern of halite and anhydrite from 5.6' to 7.5'. 1" layer of clear halite at 7.2'. From 7.5' to 8.2' predominantly light gray anhydrite with scattered halite growths. Some irregular laminated present. No clay at 8.2' but core grinding evident.	Run 2. Loss appears to be at top of run. Run 4. Core looks good in run; loss possibly throughout.
						8.2'-11.8' HALITE: Clear with some light moderate reddish orange and light gray (N7). Medium to coarsely crystalline. <1% gray clay. Breaks at 10.75' to 11.05'.	
3	10.0 – 14.8	4.8	4.7	97.9		11.8'-13.0' HALITE: Clear, coarsely crystalline. <1% polyhalite. <1/2% gray clay.	
						13.0'-17.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. 1-1/2" anhydrite layer at 17'±. Core loss makes contacts ±8".	
4	14.8 – 20.1	5.3	3.8	71.7		17.2'-20.1' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay.	
5	20.1 – 25.0	4.9	4.9	100		20.1'-25.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1 to 3% polyhalite. <1% gray intercrystalline clay at 22.4' to 25'.	
						25.0'-28.6' HALITE: Clear, medium to coarsely crystalline. None to <1/2% dispersed polyhalite and gray clay.	

BORING NO. DH-02A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-02A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25.0 – 30.0	5.0	5.0	100		28.6'-33.6' HALITE: Clear to moderate reddish orange; coarsely crystalline. < 1 to 2% polyhalite. Scattered anhydrite stringers. < 1/2% gray clay locally.	Run 8. Broken zone 37.4'-37.7', ±
						33.6'-34/3' HALITE: Clear, coarsely crystalline. None to < 1/2% polyhalite.	Run 10. Broken up last 8" of Run 10. Core loss probably here.
7	30.0 – 35.0	5.0	5.0	100		34.3'-34.6' ANHYDRITE: V. light (N8) to medium light gray (N6) anhydrite. Faintly laminated scattered halite growths. Clay break at 34.6'.	Beyond 35', core is more broken up with evidence of more vibration damage.
						34.6'-41.4' HALITE: Clear, some light to medium light gray (N7 to N6); coarsely crystalline. < 1% gray clay. Core loss Runs 8, 9 make contact at 41.4' approximate.	Contacts at 5.6', 17.2'; 41.4' and 45.9' are approximate due to core loss.
8	35.0 – 39.2	4.2	1.5	35.7		41.4'-45.9' HALITE: Clear to moderate brown some fine. < 1 to 3" brown clay, intercrystalline and scattered breaks. Contacts approximate, due to core loss.	
9	39.2 – 44.2	5.0	3.8	76		45.9'-49.2' HALITE: Clear with some light gray (N7) and medium light gray (N6); medium to coarsely crystalline, some fine. < 1% gray clay.	
10	44.2 – 49.2	5.0	4.2	84		Note: Average core recovery for hole is less than 95% Some contacts not able to be determined accurately. Replacement hole DH-2B drilled. Refer to log for this hole.	

BORING NO. DH-02A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-02B

LOCATION N1420 DRIFT - FLOOR

STATION N1424 ± E442 ± COLLAR ELEV. 1306.3 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N11110.9 E7331.29 DEPTH OF BOREHOLE 53.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/22/84 (SWING) DATE COMPLETED 3/23/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/30/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.1	2.1	2.1	100		0.0'-2.7' HALITE: Clear, trace of light gray (N7); coarsely crystalline. <1/2% gray clay and scattered polyhalite blebs. [1, 2]	Watson post mounted drill NW split tube barrel. AW rods. Drilling Time: 5 hours
2	2.1 – 3.6	1.5	1.4	93		2.7'-5.7' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. 1/2% gray clay locally. <1% polyhalite. (2-4)	Core condition fair. Some discing and vibration damage noted.
3	3.6 – 5.3	1.7	0.4	24			
4	5.3 – 6.6	1.3	1.3	100		5.7'-8.3' MB-139: From 5.7' to 6.5' is a mixture of halite and anhydrite. Some "Swallowtail" pattern present. Below 6.5' mostly light gray (N7) to medium light gray (N6) anhydrite. Scattered halite growths. 3/16" halite layer at 8.15'. 3/8" hard gray clay at lower contact.	
5	6.6 – 8.1	1.5	1.5	100			
6	8.1 – 12.8	4.7	4.7	100		8.3'-11.7' HALITE: Clear to medium light gray (N6) and moderate reddish orange (10R 6/6); medium to coarsely crystalline <1% gray clay and <1/2% dispersed polyhalite. [2, 9]	
7	12.8 – 17.9	5.1	5.1	100		11.7'-16.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite. 1/2" anhydrite layer with irregular gray clay parting at 16.35-16.4'. [3, 4, 7]	
						16.4'-20.3' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1); trace of moderate reddish orange. Coarsely crystalline, some medium <1% gray clay and <1% polyhalite grades into unit below. [2, 9]	
8	17.9 – 22.9	5.0	5.0	100		20.3'-24.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1 to 3% polyhalitic. <1% gray clay locally. [2 - 4, 7]	
						24.0'-27.9' HALITE: Clear to light moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1/2% dispersed polyhalite and light gray clay. Break at 24.05'. [2, 9]	

BORING NO. DH-02B

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-02B

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
9	25	5.0	4.9	98		27.9'-33.9' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 2% polyhalite blebs and patches. Scattered anhydrite from 31'. Predominantly anhydrite at 33.05 to 33.2' with dark gray along core break in anhydrite. [2, 4]	
10	30	5.0	5.0	100		33.9'-34.3' ANHYDRITE: White to medium light gray (N6) microcrystalline. Scattered halite growths. Trace of gray clay at 34.4'.	
11	35	5.0	5.0	100		34.3'-41.2' HALITE: Clear with some medium light gray (N6), light bluish gray (5B 7/1) and moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% gray intercrystalline clay. <1/2% dispersed polyhalite. [2, 9, 11]	
12	40	5.0	5.0	100		41.2'-44.75' HALITE: Clear to moderate brown (5YR 4/4) and moderate reddish brown 10R 4/6). Medium to coarsely crystalline. <1 to 2% brown clay, trace of gray. <1/2% dispersed polyhalite. [13, 17]	
13	45	5.0	5.0	100		44.75'-47.9 HALITE: Clear, some medium light gray (N6); coarsely crystalline. ≤1% gray clay. <1/2% polyhalite. [2, 11]	
14	50	5.1	5.0	98		47.9'-49.6 HALITE: Clear, coarsely crystalline. <1/2% gray clay at 48.9' ±. [1]	
						49.6'-53.0' HALITE: Clear to light moderate reddish orange (10R 6/6); coarse, some medium crystalline. ≤1% polyhalite. <1/2% gray clay to 52.4', then increases to 1% clay. [2, 9 from 52.4'-53.0']	

27.9 32.9 37.9 42.9 47.9 53.0

BORING NO. DH-02B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-03

LOCATION N1100 DRIFT - FLOOR

STATION N 1112 ± E 444 ± COLLAR ELEV. 1318.14 DIRECTION OF DRILLING UP-VERTICAL

MINE COORDINATES N 10,799.2 E 7335.4 DEPTH OF BOREHOLE 48.8 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 2/6/84 (DAY) DATE COMPLETED 2/7/84 (DAY 11AM) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	1.3	1.3	100		0.0'-4.5' HALITE: Clear, coarsely crystalline, some medium from 3.9 to 4.5'. < 1% polyhalite blebs.	CP-65 drill, EW rods.
2	1.3	1.4	1.0	71	X		No gas or brine.
3	2.7	1.2	1.1	92	X	4.5'-8.2' HALITE: Clear to light gray medium to coarsely crystalline. ≤ 1% gray intercrystalline clay. < 1/2% polyhalite.	Run 1. 6" diameter core from 0-0 to 1.3'.
4	3.9	2.7	2.1	78	X	8.2'-8.4' ANHYDRITE b: white to light gray (N7) microcrystalline anhydrite with scattered halite growths. Trace of gray clay at 8.2'. < 1/2" halite layer, then trace of gray clay at 8.4'.	Because of poor core recovery, contacts at 4.8'; 22.9'; 26.0'; 30.75'; and 44.9' are approximate only.
5	6.6	4.1	4.1	100	X	8.4'-12.0' HALITE: Clear, coarsely crystalline. *Scattered white anhydrite?magnesite? Stringers.*	
6	10.7	5.1	4.9	96	X	12.0'-13.6' HALITE: Clear, some light moderate reddish orange, fine to medium, some coarsely crystalline. < 1% dispersed polyhalite and < 1/2% gray intercrystalline clay.	Run 6. Core broken up below anhydrite zone.
7	15.8	5.2	4.9	94	X	13.6'-14.3' ANHYDRITE a: White to light gray (N7) microcrystalline anhydrite. Scattered halite growths, *especially common 13.95'-14.3'. Thin halite layer at 13.85'-13.9'.* Trace of gray clay at 13.6'. Core grinding evident.	
8	21.0	5.0	3.1	62	X	14.3'-18.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite.	Run 8. Broken core zones.
	25				X	18.4'-22.9' HALITE: Clear with local zones of medium brown (5YR 3/4) medium to coarsely crystalline. 1% *predominantly brown clay. Local zones of* ≤ 2% clay at 19.8'-20.7'±; 21.0'-21.4'±. < 1/2% polyhalite. Brown clay break at 22.9'±. No anhydrite.	

BORING NO. DH-03

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-03

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25	5.0	3.1	62		22.9'-26.0' HALITE: Clear, coarsely crystalline. Scattered white anhydrite/magnesite stringers.	Run 10. Broken up core last 1/2 of run.
9		1.5	1.3	87			Run 12. Borrowed SNL stabilizer for KW rods. Tried it on Run 12.. Core much better.
10		2.5	1.0	40		26.0'-30.75' HALITE: Clear to medium brown (5YR 3/4), medium to coarsely crystalline. < 1/2% dispersed polyhalite <1 to 2% brown clay. Some core grinding noted.	Run 13. Discs of clear halite, some broke up.
11	30	3.0	1.5	50		30.75'-34.0' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4), medium to coarsely crystalline. < 1 to 3% brown clay. Break at 34'.	Run 14. Moved stabilizer 15' from barrel. Core broken up in clear halite and lower 6" of run. Drilling going slow. Much trouble with rod chatter.
12		2.1	2.0	95		34.0'-35.05' HALITE: Clear with some grayish brown, medium to coarsely crystalline. <1% brown clay, some gray.	Run 15. Core broken. Rods measured 48.8'. May have lost core in bottom of hole.
13	35	4.0	4.0	100		35.05'-35.7' ANHYDRITE: Light gray to medium gray (N5) anhydrite with scattered halite growths. Increase of halite from 35.5'-35.7: ≤1/16" brown clay at 35.05'. Some core grinding evident.	
14	40	4.4	4.4	100		35.7'-39.9' HALITE: Clear, coarsely crystalline, none to ≤1% moderate reddish orange polyhalite blebs and patches. Scattered white stringers.	
						39.9'-41.0' HALITE: Clear to moderate reddish brown (10R 4/6) coarsely crystalline ≤1% brown clay and polyhalite.	
15	45	5.3	4.5	85		41.0'-41.6' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4) coarsely crystalline <1 to 4% brown clay. Break at 41.5' ±.	
						41.6'-44.9' HALITE: Clear to moderate reddish brown (10R 4/6) coarsely crystalline. None to 2% polyhalite and < 1/2% clay.	
	50					44.9'-48.8' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4), medium to coarsely crystalline. < 1 to 4% brown intercrystalline clay. Breaks at 47.1'; 47.6' ±. Predominantly fine to medium crystalline at 47.8'-48.8'.	Measurements on Run 15 made from top of run.
						NOTE: Because of poor recovery, replacement hole DH-03A drilled later. Refer to log for DH-03A.	

26.0 27.5 30.0 33.0 35.1 39.1 43.5 48.8

BORING NO. DH-03

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-03A

LOCATION N1100 DRIFT - ROOF

STATION N1112± E450.5± COLLAR ELEV. 1317.4 DIRECTION OF DRILLING VERTICAL-UP

MINE COORDINATES N10,779.20 E7341.92 DEPTH OF BOREHOLE 49.9 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-10-84 (SWING) DATE COMPLETED 3-12-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-12-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.1	2.1	2.1	100	X	0.0'-4.9' HALITE: Clear, coarsely crystalline, some medium. < 1% polyhalite. [2]	Watson drill post mounted. AW rods. Used 2' double tube barrel to start hole. NW split tube core barrel from Run 2.
2	2.1 – 5.6	3.5	3.5	100	X	4.9'-7.3' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1); medium to coarsely crystalline < 1% gray clay. < 1% polyhalite at 6.6'-7.3'. [9, 11]	Drill time: 6 hours.
3	5.6 – 10.0	4.4	4.4	100	X	7.3'-7.55' ANHYDRITE b - White to light gray (N7) anhydrite with growths of halite trace of gray clay at 7.3'. Upper contact irregular tightly welded.	Run 3. Broken up 7.6'-10'. Run 4. Broken core.
						7.55'-12.8' HALITE: Clear, coarsely crystalline. ≤ 1% polyhalite at 11.8'-12.8'. [1, 2]	
4	10.0 – 10.9	0.9	0.9	100		12.8'-13.7' HALITE: Clear to light gray (N7), some moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Medium crystalline, some coarse. < 1% polyhalite and gray clay. [9]	Used piece of foam rubber in barrel to keep core from falling down in barrel. Drill has jerky motion.
5	10.9 – 15.5	4.6	4.6	100	X	13.7'-14.3' ANHYDRITE a: White to light gray (N7) anhydrite. Faintly laminated. Couple of very thin anhydrite layers at 13.9'-14'. Scattered halite growths increasing from 14.0'-14.3'. Trace of gray clay at 13.7'.	Core broken up. Vibration damage evident. Discing and broken up zones.
6	15.5 – 20.5	5.0	5.0	100	X	14.3'-18.65' *POLYHALITIC HALITE*: Clear to moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. < 1 to 3% polyhalite. Scattered white anhydrite stringers. [3, 4, 7]	Jerky drill motion is cause of core damage. No gas; dry hole. Run 5. Broken zone 14.3'-15'.
					X	18.65'-23.4' HALITE: Clear some light brownish gray (5YR 6/1); moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4) fine to coarsely crystalline. < 1% brown clay, some gray. < 1/2% polyhalite. Brown clay at 23.35' with anhydrite layer above it. [13, 17]	
7	20.5 – 24.9	4.4	4.4	100	X	23.4'-27.7' HALITE: Clear, coarsely crystalline. < 1% brown clay from 27.0'. [1]	Run 8. Broken up measured core in run rods.

BORING NO. DH-03A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-03A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25	2.7	2.7	100		27.7'-28.9' *ARGILLACEOUS HALITE:* Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. Scattered breaks. Parting at 28.85'. [12]	Run 9. Core broken up recovery difficult to measure.
9	30	4.0	4.0	100		28.9'-35.05' HALITE: Clear to moderate brown (5YR 4/4); coarsely crystalline. ≤ 1% brown clay, both intra and intercrystalline. Locally argillaceous. Scattered breaks. Clear halite at 34.7' to 35.05'. [1, 10]	Run 10. Broken zones of core.
10	35	3.5	3.5	100		35.05'-35.95' ANHYDRITE: White to light gray (N7), partially laminated. Scattered growths of halite 35.1' to 35.6' ±. Then becomes a mixture of anhydrite and polyhalitic halite grading upwards to less amount of anhydrite. 1/2" ± brown clay at 35.05'.	Run 11. Broken core last 3' of run. Run 12. Broken up last 2' of run.
11	40	4.9	4.9	100	X	35.95'-40.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite scattered white anhydrite to 37.3'. [2-4, 7]	
						40.0'-43.1' HALITE: Clear to moderate brown (5YR 4/4), some moderate reddish orange. Medium to coarsely crystalline, some fine ≤ 1% brown clay and < 1/2% dispersed polyhalite. [7?]	Run 13. Some broken core.
12	45	4.9	4.9	100	X	43.1'-43.6' *POLYHALITIC HALITE:* Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. [3, 4, 7]	
					X X	43.6'-46.1' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline. ≤ 1% brown clay blebs and patches. [8]	
13	50	5.0	5.0	100		46.1'-48.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) to moderate red (5R 4/6) and light moderate reddish orange (10R 6/6). Fine to coarsely crystalline. < 1 to 3% brown clay. Clear halite at 47.4'-47.7' ± 1" brown clay seam at 48.7'. Halite crystals within. [10, 12]	
					X X X	48.9'-49.9' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. < 1 to 3% polyhalite. [3, 4]	
	55						

27.6 — 31.6 — 35.1 — 40.0 — 44.9 — 49.9

BORING NO. DH-03A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-04

LOCATION N1100 DRIFT - FLOOR

STATION N1112.5 ± E444 ± COLLAR ELEV. 1309.56 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10,799.2 E7335.4 DEPTH OF BOREHOLE 45.8'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 2/2/84 (DAY) DATE COMPLETED 2/4/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	1.0	1.0	100		0.0'-4.5' HALITE: Clear to light gray (N7) coarsely crystalline. ≤1% gray intercrystalline clay. <1/2% polyhalite.	NW drill rods. 2' lengths. No gas. Dry hole.
2	1.0	1.8	1.8	100			
3	2.8	2.0	2.0	100		4.5'-8.1' HALITE: Clear, medium to coarsely crystalline. <1/2% polyhalite blebs and <1/2% gray clay locally.	Good core to 33.8' Then core recovery poor. Quality not good. Grinding, broken up core. Core barrel problems and rod chatter during drilling.
4	4.8	2.0	2.0	100		8.1'-9.25' POLYHALITIC HALITE: Clear to mod. reddish orange (10R 6/6) coarsely blebs and patches.	
5	6.8	2.0	2.0	100		9.25'-11.65' MB-139: Mixture of moderate reddish orange polyhalitic halite and anhydrite to 9.85'. Then predominantly white to light gray, microcrystalline anhydrite. Scattered halite growths. Some laminae in anhydrite. Up to 3/4" hard, dry gray clay at lower contact.	Run 1. 6" single tube 0.0' to 1.0' because 8-1/2' back of drift too low to start with NX barrel.
6	8.8	5.0	5.0	100		11.65'-13.6' HALITE: Clear to moderate reddish orange (10R 6/6) and some moderate brown (5YR 3/4), fine to coarsely crystalline. ≤1% brown clay and dispersed polyhalite.	
7	13.8	5.0	5.0	100		13.6'-15.35' HALITE: Clear to light gray (N7), some moderate reddish orange, fine to coarsely crystalline. ≤ 1% gray intercrystalline clay. Breaks at 14.1; 15.35'. < ½% polyhalite.	
8	18.8	5.0	5.0	100		15.35'-19.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. 1 to 3% polyhalitic. Scattered anhydrite in core mixture of anhydrite and halite at 19.75'-19.9'. Trace of gray clay at 19.9'.	
9	23.8	5.0	5.0	100		19.9'-21.1' HALITE: Clear to moderate reddish orange (10R 6/6), fine to medium crystalline. <1/2% dispersed polyhalite.	Run 9. Broken zones within polyhalitic halite. Core barrel stuck at 27' ± from 11:30 am to 2:10 pm. broken up 23.8'-26.3'.

BORING NO. DH-04

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-04

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
9	25	5.0	5.0	100		21.1'-27.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Clay break at 21.55'. < 1/2% gray intercrystalline clay from 25'-27.6'.	
28.8							
10	30	5.0	4.9	98		27.6'-30.2' HALITE: Clear to light gray (N7) to moderate reddish orange (10R 6/6), fine to coarsely crystalline. ≤ 1% gray clay. Breaks at 28.2', 28.45'. < ½% polyhalite.	Run 10. Core grinding.
						30.2'-35.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite.	Run 11. Core grinding throughout run. 0.8' of core left in hole at end of run.
33.8							Runs 12, 13, 14. Broken up core.
11	35	4.2	2.5	60		35.0'-35.6' ANHYDRITE: Moderate reddish orange to medium gray from 35'-35.3 ±. Then very light to medium gray. No clay at lower contact but core grinding evident.	Contacts from 35' are approximate due to core loss.
38.0						35.6'-43' HALITE: Clear mottled with some light gray (N7) and moderate reddish orange, medium to coarsely crystalline. < 1/2% gray clay and polyhalite.	Note: Hole beyond 33' not able to be logged accurately because of poor core recovery and quality. Replacement hole DH-04B drilled at later date. Refer to log for hole DH-04B.
12	40	5.0	1.4	28		43.0'- 45.8': Not able to classify due to poor quality and poor recovery of core.	
43.0							
13		1.8	0.4	22	NO LOG		
44.8							
14	45	1.0	0.3	30			
45.8							
	50						

M

BORING NO. DH-04

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-4A

LOCATION N1100 DRIFT; FLOOR

STATION N1113 ± E446 ± COLLAR ELEV. 1309.6± DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES _____ DEPTH OF BOREHOLE 11.2 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL BOYLES JVA

DATE STARTED 3-8-84 (SWING) DATE COMPLETED 3-9-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-9-84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	0						0.0' - 7.0' HALITE: Clear to moderate reddish orange; coarsely crystalline. ≤ 1% polyhalite. < 1% gray clay.	Used Boyles JVA screw feed drill.
0.6	1		1.7	1.5	88	X		Used roller bit to 0.6', then NX double tube core barrel.
2.3	2		1.8	1.5	83	X	7.0' - 8.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) to light brown (5YR 5/6). Coarsely crystalline. < 1 to 3% polyhalite.	No gas. Dry hole.
4.1	3	5	2.3	2.3	100	X	8.6' - 11.2' MB-139: From 8.6 to 9.6', mixture of halite and anhydrite. "Swallowtail" patterns. Then predominantly medium gray to very light gray (N8) anhydrite with scattered halite growths.	Driller stopped hole at 11.2' because of core loss. Drilled replacement hole DH-4B using Watson drill. Refer to log for DH-4B.
6.4	4	10	4.8	3.5	73	X X X X X X		
11.2		15						

BORING NO. DH-4A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-04B

LOCATION N1100 DRIFT; FLOOR

STATION N1112 ± E450.5 ± COLLAR ELEV. 1309.7 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10,799.70 E7341.85 DEPTH OF BOREHOLE 51.4 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-9-84 (SWING) DATE COMPLETED 3-10-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-24-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.0	2.0	2.0	100		0.0'-7.9' HALITE: Clear, some moderate reddish orange (10R 6/6) and medium bluish gray (5B 3/1) coarsely crystalline. < 1% gray clay and polyhalite blebs. [2, some 9]	Watson drill. Post mounted NW split tube core barrel. AW rods. Drilling time: 3-1/2 hours.
2	2.0 – 5.2	3.2	3.2	100		7.9'-8.55' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 2% polyhalite. [3, 7]	No brine or gas. Core coming out good.
3	5.2 – 7.9	2.7	1.0	37		8.55'-11.6' MB-139: From 8.55' to 9.85'± is a mixture of halite and anhydrite. From 9.85' is predominantly white to light gray (N7) anhydrite with growths of halite. Anhydrite is irregularly laminated. Upper contact is tightly closed and dips 25°±. Several tightly closed hairline fractures at 10.9' to 11.0'±. Gray clay at 11.6'.	NW core barrel has stepped diamond bit. Barrel made by Christensen. No gas; dry hole.
4	7.9 – 11.0	3.1	3.1	100		11.6'-15.45' HALITE: Clear to light gray (N7), moderate brown (5YR 4/4) and moderate reddish orange (10R 6/6); medium to coarsely crystalline; some fine. ≤ 1% gray clay, trace of brown. ≤ 1% polyhalite. Gray clay breaks at 12.5', 14.35', 14.6". [9]	
5	11.0 – 11.7	0.7	0.7	100			
6	11.7 – 16.0	4.3	4.3	100		15.45'-19.85' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) and brown (10R 4/6); coarsely crystalline. < 1 to 3% polyhalite. < 1/2% gray intercrystalline clay to 15.9'. Moderate reddish orange/brown anhydrite and some halite at 19.75' to 19.85'. Gray clay parting at 19.85'. [7]	
7	16.0 – 21.0	5.0	5.0	100		19.85'-21.0' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. ≤1% polyhalite and < 1% gray clay. [5, 9]	
8	21.0 – 25	5.1	5.1	100		21.0'-26.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), moderate reddish brown (10R 4/6); coarsely crystalline, some medium. < 1 to 3% polyhalite. < 1% brown clay at 21.0-21.6'. < 1/2% gray clay locally below 21.6'. [7]	

BORING NO. DH-04B

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-04B

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25	5.1	5.1	100		26.1'-27.8' HALITE: Clear with some light gray (N7) and moderate reddish orange (10R 6/6); coarsely crystalline with some medium. <1/2% polyhalite. <1% gray clay. Some of clay is medium plastic, moist. [9]	
9		5.1	5.1	100		27.8'-29.3' HALITE: Clear to moderate reddish orange (10R 6/6), brownish gray (5YR 4/1) and moderate brown (5YR 3/4). Medium to coarsely crystalline. < 1 to 2% brown clay, trace gray. Break at 28.95'. < 1% polyhalite. [12]	
10	30	5.0	5.0	100		29.3'-31.6' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% gray clay and polyhalite. Break at 29.55'. [9, 17]	
11	35	5.0	5.0	100		31.6'-36.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. Scattered anhydrite stringers. [3, 4, 7]	
12	40	5.1	5.1	100		36.1'-36.8' HALITE: Clear, some moderate reddish orange; medium to coarsely crystalline. < 1/2% polyhalite. Anhydrite stringers from 36.55' to 36.8'. [1]	
13	45	5.1	5.1	100		36.8'-37.0' ANHYDRITE: Very light (N8) to light gray (N7) anhydrite. Scattered halite growths, especially last 0.5'. Trace gray clay at 37.0'. Core grinding evident here. [8]	
	50					37.0'-49.35' HALITE: Clear with light bluish gray (5B 7/1), light gray (N7), moderate brown (5YR 4/4) and moderate reddish orange/brown (10R 6/6-10R 4/6). Medium to coarsely crystalline. ≤1% brown and gray clay. <1% polyhalite. Clear halite at 41.2' to 41.9'. Predominantly brown clay (≤1%) from 44.3' to 45.3' and 47.0' to 48.5'. [9, 11, 17]	
	55					49.35'-51.4' HALITE: Clear, coarsely crystalline <1/2% gray clay locally. [1, 8]	Several pieces in Run 13 are up to 1-1/2' long before taking out of tube.

26.1 31.2 36.2 41.2 46.3 51.4

BORING NO. DH-04B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. DH-05

LOCATION N1420 DRIFT IN ALCOVE AT RM. B INTERSECTION

STATION N1463 E972 COLLAR ELEV. 1329.9 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N11149.6 E7865.0 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 3/3/84 (DAY) DATE COMPLETED 3/9/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/14/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		3.3	3.2	97		0.0'-0.35' HALITE: Clear, some light moderate reddish orange (10R 6/6), medium-coarsely crystalline. < 1/2% dispersed polyhalite.	Hole drilled by SNL. Longyear 65 drill with 4" dia. masonry single thin wall core barrel. Diamond bit.
3.3						0.35'-1.25' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline < 1 to 2% polyhalite.	Run 2. Core grinding at anhydrite-clay layer.
2	5	3.35	3.35	100		1.25'-5.05' HALITE: Clear to light gray (N7), medium-coarsely crystalline. ≤ 1% intercrystalline gray clay. < 1/2% dispersed polyhalite. Breaks at 1.35', 4.8'. Very light gray anhydrite stringer at 2.6', 1/2" anhydrite, trace of clay at 5.0'. Some core grinding noted.	Some difficulty removing core from barrel. Possibly due to moisture in air line. This occurred to 23'±. Core trays hit by passing muck truck. Core partly disturbed in Runs 3, 4, 5.
6.65							
3		2.70	2.4	89			
9.35						5.05' -9.3' HALITE: Clear, coarsely crystalline. Scattered white magnesite? stringers.	
4	10	3.65	3.65	100		9.3'-9.95' HALITE: Clear with some light gray intercrystalline clay (≤ 1%). Medium-coarsely crystalline.	Run 5. Loss at 13'-14', some grinding.
13.0							
5	15	4.15	3.95	95		9.95'-11.0' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4) to moderate reddish orange (10R 6/6), fine-medium, some coarsely crystalline. < 1 to 3% brown clay. < 1/2% dispersed polyhalite coloration. Gray clay along tightly closed irregular upper contact.	
17.15							
6	20	4.0	4.0	100		11.0'-14.1' HALITE: Clear, coarsely crystalline. No clay to 12.9', From 12.9'-14.1', < 1/2% gray and brown clay.	Core quality improves beyond 10' depth; some grinding on ends of core pieces.
21.15						14.1'-17.15' ARGILLACEOUS HALITE: Clear to moderate reddish orange (10R 6/6) medium brown, fine to medium, some coarsely crystalline. < 1 to 4% brown clay, trace of gray. Irregular break at 16.35'.	
7		3.15	3.10	98			
24.3	25						

BORING NO. DH-05

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-05

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	26.6	2.3	2.3	100		17.15'-17.75' ANHYDRITE: Very light (N8) to light gray (N7) anhydrite to 17.4'. Then mixed with growths of halite. Tight welded irregular upper contact. Brown clay along lower contact. Core grinding evident here.	Run 8. Some grinding on core ends.
9	30.5	3.9	3.6	92		17.75'-22.7' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1% dispersed polyhalite and scattered blebs. White very light gray anhydrite stringer up to 1/2" thick at 19.25'.	
10	33.7	3.2	3.2	100		22.7'-26.6' HALITE: Clear, some moderate reddish brown (10R 4/6), coarsely crystalline with zones of fine-medium. < 1% polyhalite. ≤ 1% brown clay. Breaks at 23.15', 24.3', 26.1. Some core grinding evident.	Broken core 24' -25'.
11	36.9	3.2	3.2	100		26.6'-28.8' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4), coarsely crystalline. < 1 to 3% brown clay. Core broken 26.6'-27.9'.	Core barrel plugged off with clay at 26.6'. Driller stopped hole here on 3/8/84 continued with 4-½" ø roller bit to 26.6'. Then continued coring with 4" barrel.
12	40.6	3.7	3.7	100		28.8'-30.1' HALITE: Clear, coarsely crystalline. < 1/2% polyhalite.	
13	44.0	3.4	3.4	100		30.1'-32.5' POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. < 1/2% gray clay.	
14	47.75	3.75	3.75	100		32.5'-35.4' HALITE: Clear mottled with moderate brown (5YR 3/4) to dark reddish brown, coarsely crystalline. < 1 to 2% patches of brown clay. < 1/2% polyhalite. Parting at 35.4' ± dipping 30° ±.	
15	51.0	3.25	3.25	100		35.4'-36.8' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 2%, locally of dispersed polyhalite.	
						38.6'-40.9' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline ≤ 1% polyhalite. Moderate reddish brown, polyhalitic at 38.6'-39.0'. Anhydrite stringers at 38.7'-38.8'.	
						40.9'-51.0' HALITE: Clear to moderate reddish brown (10R 4/6) to medium brown (5YR 3/4) medium-coarsely crystalline. < 1 to 3% brown clay, intergranular and in patches. < 1/2% polyhalite. Breaks at 41.85', 44.0'-44.2'.	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4 INCH CORE BORING NO. DH-06

LOCATION I-3 ALCOVE - FLOOR

STATION N 1463 ± E 972 COLLAR ELEV. 1317.9 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 11,149.7 E 7864.9 DEPTH OF BOREHOLE 49.75 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 3-4-84 (DAY) DATE COMPLETED 3-7-84 (DAY) SHEET

LOGGED BY: J. F. GALLERANI DATE: 3-10-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0–2.1	2.1	2.1	100		0.0'-4.2' HALITE: Clear, coarsely crystalline. < 1/2% polyhalite from 3.4' ±.	Longyear 65 drill, EW rods; 4" diameter, 2' long core barrel with core catcher used.
2	2.1–4.15	2.05	2.05	100	X	4.2'-5.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6): coarsely crystalline. <1 to 2% polyhalite.	Some grinding noted on ends of core in most runs. Lengths of core pieces generally 1" to 11". Average 3" ±.
3	4.15–6.25	2.1	2.1	100	X X X	5.6'-7.8' HALITE: Clear with trace of light gray (N7). Coarsely crystalline. < 1/2% gray intercrystalline clay. < 1/2% polyhalite.	
4	6.25–8.0	1.75	1.75	100	—		Run 4. Grinding on some core ends.
5	8.0–9.85	1.85	1.85	100	— — —	7.8'-9.0' HALITE: Clear to light gray (N7); medium to coarsely crystalline, trace fine. ≤ 1% gray intercrystalline clay. ≤ 1/4" gray clay seam at 7.8' and 1/8" clay seam at 8.45' ±.	Run 5. Some grinding at 9.3'.
6	9.85–11.95	2.1	2.1	100	X X X X	9.0'-10.8' HALITE: Clear, coarsely crystalline locally some medium. < 1/2% gray clay and polyhalite.	
7	11.95–13.6	1.65	1.65	100	X X X	10.8'-13.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. No clay to 12.35'; then < 1% gray clay.	
8	13.6–15.2	1.6	1.6	100	— X		
9	15.2–16.85	1.65	1.65	100		13.6'-18.65' HALITE: Clear to light gray (N7); coarsely crystalline. ≤ 1% gray intercrystalline clay. None to < 1% polyhalite.	
10	16.85–18.65	1.8	1.8	100	— X		Run 10, 11, 12. Some grinding on core ends.
11	18.65–20.5	1.85	1.85	100	X — X	18.65'-20.6' HALITE: Clear, some moderate reddish orange (10R 6/6); coarsely crystalline. ≤ 1% polyhalite. < 1/2% gray clay.	No gas; dry hole.
12	20.5–23.0	2.5	2.5	100	X X X X X	20.6'-22.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline ≤ 1% to 3% polyhalite. < 1/2% gray clay.	
13	23.0–25.0	2.0	1.9	95			

BORING NO. DH-06

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-06

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
14	25	1.2	1.2	100		22.3'-26.1' MB-139: "Swallowtail" pattern of halite and anhydrite from 22.3' to 24.2'. Then predominantly very light (N8) to light gray (N7) and some moderate reddish orange (10R 6/6) anhydrite mixed with growths of halite. No clay at lower contact but some core grinding on ends of core throughout MB-139.	
15		1.3	1.3	100			
16		1.6	1.6	100		26.1'-29.4' HALITE: Clear to light moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% dispersed polyhalite and < 1/2% gray clay.	
17	30	1.9	1.9	100			
18		2.0	2.0	100		29.4'-33.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. Anhydrite mixed with halite at 33.2'-33.5'. Gray clay at 33.5'.	
19		2.0	2.0	100			
20	35	1.7	1.7	100		33.5'-35.6' HALITE: Clear to light gray (N7) and moderate reddish orange (10R 6/6); medium to coarsely crystalline. ≤ 1% gray clay and < 1/2% dispersed polyhalite.	
21		1.8	1.8	100		35.6'-39.1' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); coarsely crystalline. < 1 to 4% polyhalite.	
22		1.5	1.5	100			
23	40	2.0	2.0	100		39.1'-46.2' HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6) and grayish brown (5YR 3/2). Medium to coarsely crystalline. ≤ 1% brown clay, some gray. < 1% polyhalite. Core loss 42'-45'.	
24		3.0	0	0		46.2'-49.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. Scattered white stringers of anhydrite/magnesite.	
25	45	2.0	2.0	100			
26		2.75	2.75	100			
	50						
	55						

26.2 — 27.5 — 29.1 — 31.0 — 33.0 — 35.0 — 36.7 — 38.5 — 40.0 — 42.0 — 45.0 — 47.0 — 49.75

BORING NO. DH-06

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-07

LOCATION N1100 DRIFT AT RM. B INTERSECTION; ROOF

STATION N1112 E976.5 COLLAR ELEV. 1326.7 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N10,799.3 E7870.8 DEPTH OF BOREHOLE 49.8'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/21/84 (SWING) DATE COMPLETED 2/22/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/4/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0 – 0.9: 1		0.9	0.9	100	X	0.0'-4.6' HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline ≤ 1% polyhalite blebs and patches. Up to 2% polyhalite from 3.1'-4.6'. [1,3]	Watson drill.AW rods. NX double tube core barrel. Drill Time: 9 hours ±.
0.9 – 2.9: 2		2.0	2.0	100	X		
2.9 – 5.8: 3	5	2.9	2.9	100	X, X	4.6'-9.0' HALITE: Clear to light gray (N7), some moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. ≤ 1% gray clay. < 1/2% polyhalite. 1/2" gray clay at 8.85'. Anhydrite and halite 8.9'-9.0'. [9, 11]	Run 2. Some discing. No gas. Dry hole.
5.8 – 10.8: 4	10	5.0	5.0	100	X	9.0'-13.2' HALITE: Clear, coarsely crystalline, none to < ½% intercrystalline gray clay. [1] 13.2'-14.7' HALITE: Clear to moderate brown (5YR 3/4; 4/4). Medium-coarsely crystalline, some fine. < 1 to 3% brown clay. Locally zones of argillaceous halite. [12, 17]	Run 5. Broken up last 0.4'.
10.8 – 15.1: 5	15	4.3	4.3	100		14.7'-16.5' HALITE: Clear with some moderate brown (5YR 4/4); coarsely crystalline. None to ≤ 1% brown clay. [1, 8] 16.5'-20.85' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. < 1 to 4% brown intercrystalline clay, trace of gray. Breaks at 20.0', 20.5'. [10, 15]	Run 7. Broken zones in clear halite.
15.1 – 19.6: 6	20	4.5	4.5	100		20.85'-21.55' ANHYDRITE: White to light gray (N8), microcrystalline anhydrite with scattered halite growths. Up to 3/4" brown clay at 20.85'. 21.55'-24.9' HALITE: Clear, coarsely crystalline, < 1% polyhalite. [1]	Run 8. Broken zones last 1.5'.
19.6 – 24.0: 7	25	4.4	4.4	100	X, X	24.9'-26.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1% intercrystalline clay. < 1 to 3% polyhalite. [4,5]	Runs 9-11. Discing of core throughout.Discs 3/8-1" size.

BORING NO. DH-07

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-07

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
8		4.6	4.6	100		26.4'-27.5' HALITE: Clear to moderate brown (5YR 4/4); medium-coarsely crystalline, < 1 to 3% brown clay. Break at 27.2' ±. [17]	
9	28.6 / 30	4.0	4.0	100		27.5'-29.35' HALITE: Clear mottled with moderate reddish orange (10R 6/6) polyhalite blebs, coarsely crystalline. ≤ 1% polyhalite. [1-3] 29.35'-30.85 HALITE: Clear mottled with moderate brown (5YR 4/4); coarsely crystalline. ≤ 1% brown intercrystalline, intracrystalline blebs, pockets of brown clay. [8, 10]	Run 12. Broken and discing entire run. Core quality to 27' is fair. Able to determine depth to to clay/anhydrite at 8.85' accurately. Below 27', core is in discs 3/8 to 1" size. Scattered broken zones. Difficult to measure recovery accurately.
10	32.6 / 35	4.5	4.5	100		30.85'-32.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) coarsely crystalline. Brown clay < 1 to 5%, locally. 3/4" brown clay seam at 32.25'. [10, 15]	Run 13. Longest piece is 2".
11	37.1 / 40	4.0	4.0	100		32.3'-45.0' HALITE: Clear mottled with moderate reddish orange/brown (10R 6/6; 4/6) and moderate brown (5YR 3/4; 4/4). Coarsely crystalline. Core varies from zones containing mostly blebs and patches of modern reddish orange polyhalite, < 1 to 3%, to zones containing blebs and patches of brown clay < 1 to 2%. Reddish orange color, in part, probably due to iron staining. [3, 4, 10]	
12	41.1 / 45	4.3	4.3	100		45.0'-47.8' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium-coarsely crystalline. < 1 to 3% intercrystalline brown clay. Breaks at 45.6'; 46.4'. [15] 47.8'-49.8' HALITE: Clear with some moderate brown (10R 4/6); medium to coarsely crystalline. ≤ 1% brown clay, trace of gray. [17]	
13	45.4 / 50	4.4	4.4	100			
	49.8 / 55						

BORING NO. DH-07

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX CORE BORING NO. DH-08

LOCATION N1100 DRIFT AT RM. B INTERSECTION - FLOOR

STATION N1112 ± E976.5 ± COLLAR ELEV. 1318.80 DIRECTION OF DRILLING DOWN-VERTICAL

MINE COORDINATES N10,799.4 E 7870.9 DEPTH OF BOREHOLE 38.3 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/22/84 (SWING) DATE COMPLETED 2/23/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.2	2.2	2.2	100		0.0'-2.6' HALITE: Clear to light gray (N7) coarsely crystalline. < 1% intergranular gray clay. < 1/2% polyhalite blebs locally.	Watson post mounted, air drill; AW rods. NX double tube core barrel.
2	2.2 – 4.6	2.4	2.4	100		2.6'-5.85' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. < 1% polyhalite blebs and dispersed polyhalite.	Drilling time: 8 hours and 15 minutes. Mining while drilling.
3	4.6 – 5.7	1.1	1.0	90.9			Core condition is pretty good. Only a few broken up zones.
4	5.7 – 9.0	3.3	2.0	60.6		5.85'-10.1' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤ 1% intergranular gray clay. < 1% polyhalite blebs.	Run 4. Loss throughout. Core grinding bottom of run.
5	9.0 – 10.8	1.8	1.7	94.4		10.1'-12.8' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline, some fine to medium. < 1% polyhalite except 12.3'-12.5'. where core is polyhalitic, up to 3% polyhalite. Contact at 12.8' approximate due to core loss.	
6	10.8 – 15.8	5.0	4.5	90		12.8'-19.5' HALITE: Clear to light bluish gray (5B 7/1), light gray (N7) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray clay. Break at 14.7'.	Run 6. Broken up about 12.4' in run. Loss possibly here
						19.5'-23.0' HALITE: Clear mottled with some moderate reddish orange (10R 6/6) < 1% polyhalite. < 1/2% gray clay 23.0' contact measured from bottom of run 8.	
7	15.8 – 20.5	4.7	4.7	100		23.0'-26.6' MB-139: Upper 1.5' of MB-139 shows "swallowtail" pattern, a mixture of anhydrite and halite. Below this is light gray to white anhydrite with scattered halite growths. Some laminae within. Hairline, tightly closed low angle fractures. Trace gray clay at 26.6'.	Run 7. Broken top of run and at 18.5'-19.5' ±.
8	20.5 – 25.2	4.7	3.8	80.9			Run 8. Some grinding, broken up top of run. Most lost probably here. Some grinding at top and bottom of MB-139 also.

BORING NO. DH-08

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-08

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25.2 / 25						
9		5.2	4.1	78.8		26.6'-30.4' HALITE: Clear to moderate reddish orange 10R 6/6, some light gray, medium to coarsely crystalline. < 1% dispersed polyhalite and gray clay.	Run 9. Grinding at top of run.
	30 / 30.4					30.4'-33.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), some light gray, medium to coarsely crystalline. <1 to 3% polyhalite.	
10		3.0	3.0	100		33.4'-35.8' HALITE: Clear to light gray (N7), medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% dispersed polyhalite. Clay break at 34.6' ±.	
	33.4 / 35						
11		4.9	3.9	79.6		35.8'-38.3' HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline, some medium. ≤ 1% polyhalite. < 1/2% gray clay. Polyhalitic (1 to 3%) from 36.8'-38.3' ±.	Run 11. Loss throughout. Some grinding at top of run.
	38.3 / 40					Note: Hole stopped at 38.3' due to core loss. Replacement holes DH-8A and DH-8B drilled in same vacinity. Refer to these drill logs.	Following contacts are approximate due to core loss: 12.8' 23.0' -measured from bottom of run 8. 26.6' -assumed most loss was in MB-139. 35.8'-is ± 0.5'.
	45						
	50						

BORING NO. DH-08

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-08A

LOCATION N 1100 DRIFT; FLOOR

STATION N1112 ± E 975 ± COLLAR ELEV. 1318.7± DIRECTION OF DRILLING DOWN - VERTICAL

MINE COORDINATES _____ DEPTH OF BOREHOLE 50.7 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/24/84 (SWING) DATE COMPLETED 2/29/84 (SWING) SHEET

LOGGED BY: J.E. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		1.6	1.6	100		0.0'-6.6'± 0.4' HALITE: Clear to light (N7) gray coarsely crystalline. None to < 1% gray clay. < 1/2% polyhalite locally. Clear 3.4'-4.2'. Gray clay break at 6.6'.	Watson post mounted. AW rods. NX double tube core barrel.
1.6							
2		0.5	0.3	60			Drilling Time: 10 hours.
2.1							
3		2.1	2.1	100		6.6'-9.65' HALITE: Clear to light bluish gray (5B 7/1) and light gray (N7), medium-coarsely crystalline. ≤ 1% intergranular gray clay. < 1/2% dispersed polyhalite.	No gas; dry hole.
4.2							
4	5	3.6	2.8	78		9.65'-13.1' HALITE: Clear with some light moderate reddish orange (10R 6/6), coarsely crystalline. < 1% polyhalite. < 1/2% gray clay.	
7.8							
5	10	2.9	2.9	100		13.1'-15.8' HALITE: Clear to light gray (N7), coarsely crystalline. ≤ 1% gray intergranular clay and < 1% polyhalite blebs.	
10.7							
6	15	4.6	4.6	100		15.8'-20.95' HALITE: Clear to light bluish gray (5B 7/1) and light moderate, reddish orange (10R 6/6) medium-coarsely crystalline; scattered fine. <1/2% intergranular gray clay and < 1/2% dispersed polyhalite. Clay break at 20.8'.	
15.3						20.95'-23.15' HALITE: Clear, coarsely crystalline. < 1% polyhalite blebs.	
7	20	4.9	4.7	96		23.15'-26.4' MB-139: Very light gray (N7) to white anhydrite mixed with halite growths to 25.6'. Then mostly microcrystalline anhydrite partially laminated. Gray clay ≤ 1/8" at 26.4'.	Run 7. Loss probably top of run.
20.2							
8	25	4.9	4.9	100			
25.1							

BORING NO. DH-08A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-08A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
9	25.1 – 30.2	5.1	5.1	100		26.4'-29.5' HALITE: Clear to light bluish gray (5B 7/1) and light gray, medium to coarsely crystalline. < 1% dispersed gray clay. < 1/2% dispersed polyhalite. Break at 29.05'.	
						29.5'-33.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Anhydrite mixed with halite from 33.4'-33.6'. Gray clay break at 33.6'.	Overall core condition is fair. Scattered broken zones and discing shows vibration stress.
10	30.2 – 31.9	1.7	1.0	59		33.6'-35.6' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. < 1/2% gray clay. < 1% polyhalite.	Contact at 33.6' is ±0.35' due to core loss.
11	31.9 – 35.6	3.7	3.0	81		35.6'-40.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite.	
12	35.6 – 38.9	3.3	3.0	91		40.1'-44.5' HALITE: Clear with some moderate reddish orange and light gray (N7), medium to coarsely crystalline. ≤ 1% polyhalite and gray clay.	
13	38.9 – 41.0	2.1	1.1	52		44.5'-48.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite.	Run 13. Broken up at top.
14	41.0 – 45.7	4.7	4.7	100		48.75'-50.0' HALITE: Clear coarsely crystalline. < 1/2% polyhalite.	
						50.0'-50.3' ANHYDRITE: Very light (N8) to medium light gray (N6) to white microcrystalline anhydrite with scattered halite growths. Up to 1/2" halite layer at 50.1'. No clay at lower contact but possibly ground up.	
15	45.7 – 50.7	5.0	5.0	100		50.3'-50.7' HALITE: Clear to light gray (N7), medium to coarsely crystalline. < 1% gray intercrystalline clay.	Contact at 40.1' is ±0.5' due to core loss.
						Note: Core recovery is below 95%. Replacement hole DH-08B drilled later. Refer to log for DH-08B.	Run 15. Discing in run 15.

BORING NO. DH-08A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-08B

LOCATION N1100 DRIFT - FLOOR

STATION N1112± E979.5± COLLAR ELEV. 1318.00 DIRECTION OF DRILLING VERTICAL-DOWN

MINE COORDINATES N 10,799.47 E 7866.66 DEPTH OF BOREHOLE 51.4 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-16-84 (SWING) DATE COMPLETED 3-17-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-23-84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0.0						
0.9	0		0.9	0.0	0		0.0'-6.4' HALITE: Clear; medium to coarsely crystalline. <1/2% polyhalite blebs and <1/2% gray clay locally. (1,2)	Watson drill: post mounted. AW rods. NW split tube barrel.
1.3	1		0.4	0.3	75	X		
	2		2.7	2.7	100		6.4'-11.4' HALITE: Clear to medium bluish gray (5B 5/1) and medium gray (N5). Coarsely crystalline, some medium ≤1% gray clay. 1/4" ± gray clay seam at 8.9'. (11)	Drilling time: 6 hours ±.
4.0								
4.9	3		0.9	0.6	67			Core is fair. Some discing of coarse crystalline polyhalitic halite and chipping of outer surface of core due to vibration but pieces tend to fit together fairly well in barrel.
	4	5	1.5	1.5	100	X	11.4'-13.15' HALITE: Clear, some moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 2% polyhalite blebs and dispersed. (2,3)	
6.4								
	5		2.8	2.8	100		13.15'-21.75' HALITE: Clear to medium bluish gray (5B 5/1) and some moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1/2% dispersed polyhalite. ≤1% gray intercrystalline clay. (9)	Run 0. Salt loose and broke up, cased to 0.9'. No core.
9.2								
		10						Runs 2 & 3. Some discing of core.
	6		5.0	5.0	100	X	21.75'-23.75' HALITE: Clear, coarsely crystalline. None increasing to <1% polyhalite with depth. (1,2,)	
14.2								
	7	15	5.0	5.0	100	X	23.75'-26.9' MB-139: "Swallowtail" pattern of halite and anhydrite to 24.55'. Then predominantly very light (N8) to light gray (N7) to white, partially laminated, anhydrite with scattered halite growths. Several tightly closed hairline fractures at 26.7' to 26.9'. <1/8" gray clay along lower contact.	Run 7. Some chipping of outer surface of core due to vibration last 3' of the run.
19.2								
	8	20	5.1	5.1	100	X		
24.3		25						

BORING NO. DH-08B

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-08B

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
9	25	2.6	2.6	100		26.9'-29.6' HALITE: Clear to light gray (N7); light bluish gray (5B 7/1), and moderate reddish orange (10R 6/8). Medium to coarsely crystalline ≤1% gray clay and <1/2% dispersed. (9)	
10	30	4.5	4.5	100		29.6'-33.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline with some fine to 30.15'. <1 to 3% polyhalite. Anhydrite with halite from 33.75 to 33.8'. Clay break at 33.8'. (2-5,7)	Runs 10 thru 12. Discing in polyhalitic halite.
11	35	5.0	5.0	100		33.8'-35.8' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1). Medium to coarsely crystalline. <1% gray clay. <1/2% polyhalite. (9)	
12	40	5.0	5.0	100		35.8'-39.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) and some moderate reddish brown (10R 4/6). Coarsely crystalline. <1 to 3% polyhalite. (3.4,7)	
13	45	5.0	5.0	100		39.0'-45.2' HALITE: Clear to moderate reddish orange (10R 6/6); light gray (N7) and light bluish gray (5B 7/1). Medium to coarsely crystalline. ≤1% gray clay and <1 to 2% polyhalite. (2,9)	
						45.2'-50.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite 1" anhydrite/halite layer at 49.7'. (3,4,7)	
						50.2'-50.5' HALITE: Clear, coarsely crystalline, some medium. Scattered white anhydrite stringers at 50.2'-50.25' ±. (1)	
14	50	5.0	5.0	100		50.5'-50.8' ANHYDRITE: Very light gray (N8) to white anhydrite with scattered halite growths. ≤3/8" gray clay at 50.8'.	
						50.8'-51.4' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1) with some moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1/2% dispersed polyhalite. ≤1% gray clay. Break at 51.1'. (9)	Run 14. Discing, chipping of core most of run.
	55						

26.9 — 31.4 — 36.4 — 41.4 — 46.4 — 51.4

BORING NO. DH-08B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-09

LOCATION N1420 DRIFT; ROOF

STATION N1432± E1332.5± COLLAR ELEV. 1324.5 DIRECTION OF DRILLING VERTICAL-UP

MINE COORDINATES N11,108.71 E8227.11 DEPTH OF BOREHOLE 51.1'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-14-84 (SWING) DATE COMPLETED 3/14/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-15-84 1 OF 3

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0–2.75	2.75	2.75	100		0.0'–4.1' HALITE: Clear to light gray (N7) and medium light gray (N6), medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% polyhalite. 3/8" gray clay at 4.1'. Trace of anhydrite associated. [9,11]	Watson drill. AW rods. NW split tube barrel. Drill Time: 7 hours ±.
2	2.75–5.5	2.75	2.65	96		4.1'–7.7' HALITE: Clear, coarsely crystalline. Trace anhydrite at 4.6'. Scattered white stringers. [1]	No gas; dry hole.
3	5.5–8.4	2.9	2.2	76		7.7'–9.1' HALITE: Clear to light gray (N7); medium light gray (N6). Coarsely crystalline. ≤ 1% gray clay, trace brown. [11]	All core shows varying degrees of vibration damage. Jerky drill feed is cause for much of this.
4	8.4–13.0	4.6	3.8	83		9.1'–10.3' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. [13, 14] 10.3'–12.3' HALITE: Clear, some light gray (N7) coarsely crystalline. None to < 1% gray, some brown clay. [1, some 9]	Run 3. Much of core broken up. Run 4. Broken up badly last 2' ±.
5	13.0–16.1	3.1	3.1	100		12.3'–16.1' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 4% brown clay. Intercrystalline and scattered breaks. Parting at 14.75'. 1/2" brown clay seam at 16.05'. [14]	Run 6. Core loss probably above anhydrite. Run 7 thru 13. Broken zones and discing especially in the coarsely crystalline, polyhalitic halite.
6	16.1–20.4	4.3	3.8	88		16.1'–16.75' ANHYDRITE: White to light gray anhydrite mixed with halite to 16.45'. Then mostly laminated anhydrite. 16.75'–20.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. < 1% from 18.4'–20.4'. [2–4,7]	
7	20.4–25.2	4.8	4.8	100		20.9'–21.9' HALITE: Clear to light gray (N7); coarsely crystalline. ≤ 1% gray clay. [11]	

BORING NO. DH-09

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 3 — BORING NO. DH-09

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25.0						
8	25.2 – 28.8	3.6	3.6	100		21.9'-23.5' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline, some fine. <1 to 2% brown clay. [12, 13]	
						23.5'-26.7' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline. <1% brown clay. <1/2% polyhalite blebs. Increasing clay content from 26.1'. [2, 10]	
9	28.8 – 33.6	4.8	4.8	100		26.7'-29.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and moderate reddish brown (10R 4/6), medium to coarsely crystalline. <1 to 4% brown clay. Scattered partings. Breaks at 27.5';27.6'. 1/2" clay mixed with halite seam at 29.9' <1 to 2% clay from 27.8'-29.1'. [10, 16]	
10	33.6 – 36.1	2.5	2.5	100		29.9'-35.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. [3, 4, 7]	
11	36.1 – 41.1	5.0	5.0	100		35.1'-36.2' HALITE: Clear to moderate brown (5YR 4/4) to moderate reddish brown (10R 4/6). Coarsely crystalline. <1 to 2% brown clay. 3/8" clay seam at 35.2'. Breaks at 35.85' and 36.2'. [10]	
						36.2'-38.7' POLYHALITIC HALITE: Clear mottled with moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. <1 to 3% polyhalite blebs and patches. <1/2% blebs of brown clay. [3, 4, 7]	
12	41.1 – 46.2	5.1	5.1	100		38.7'-39.7' HALITE: Clear mottled with moderate brown (5YR 4/4) and moderate reddish brown (10R 4/6) clay. Coarsely crystalline. ≤1 to 2% clay. 1/2" seam at 39.5'. 3/4" anhydrite mixed with halite at 39.65'. [10]	
						39.7'-41.3' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 2% polyhalite. Polyhalite from 39.7' to 40.1'. [1-3]	
13	46.2 – 51.1	4.9	4.9	100		41.3'-42.3' HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. <1 to 2% brown clay. [8, 10]	
						42.3'-45.1' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. <1 to 3% brown clay. Scattered breaks. [10, 15]	
	55						

WIPP

WASTE ISOLATION PILOT PLANT SHEET 3 OF 3 BORING NO. DH-09

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
						45.1–48.6' HALITE: Clear mottled with moderate brown (5YR 4/4), coarsely crystalline. ≤1% brown clay, trace gray. Locally up to 2% clay. Scattered breaks last 1". [10, 12]	
						48.6'-51.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) and moderate reddish brown (10R 4/6); coarsely crystalline. <1 to 3% polyhalite. [3, 4, 7]	

BORING NO. DH-09

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-10

LOCATION N1420 DRIFT - FLOOR

STATION N1432± E1332.5± COLLAR ELEV. 1312.1 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 11,108.70 E 8227.09 DEPTH OF BOREHOLE 52.0 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-15-84 (SWING) DATE COMPLETED 3-15-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-17-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 0.5	0.5	0.5	100		0.0'-6.1' HALITE: Clear; coarsely crystalline, some fine. < 1% gray clay and 1/2% polyhalite locally. [1]	Watson drill. AW rods. 2' barrel for 1st run, then 5' NW split tube barrel used. No gas; dry hole. Drill Time: 5-1/2 hours
2	0.5 – 3.6	3.1	3.1	100		6.1'-10.6' HALITE: Clear mottled with medium dark gray (N4); coarsely crystalline, some medium locally. ≤ 1% gray clay. Dark gray clay break at 8.0'. < 1/2% polyhalite. [11]	Core is brittle and will break with low hand pressure into smaller discs and pieces. Jerky, surging feed on drill.
3	3.6 – 8.2	4.6	4.6	100		10.6'13.5' POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6). Coarsely crystalline. < 1 to 2% polyhalite blebs and patches. < 1/2% gray clay. [3, 4, 7]	Core shows chipping on surface.
4	8.2 – 13.3	5.1	5.1	100		13.5'-19.4' HALITE: Clear, some light gray (N7) and medium light gray (N6). Medium to coarsely crystalline. ≤ 1% gray intercrystalline clay. Breaks at 15.2'-15.3'. < 1/2% polyhalite. [2, 11]	Runs 2, 3. Some broken core, discing, vibration fractures. Run 4. Good core.
5	13.3 – 15.9	2.6	2.6	100		19.4'-22.6' HALITE: Clear mottled with some moderate reddish orange (10R 6/6); coarsely crystalline; some medium. ≤ 1% polyhalite blebs and patches. < 1/2% gray clay. [2, 5]	
6	15.9 – 20.9	5.0	5.0	100		22.6'-24.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. [3, 4]	
7	20.9 – 25	5.2	5.2	100		24.0'-26.65' MB-139: Moderate reddish orange (10R 6/6) to white anhydrite mixed with halite to 25.4'. Then predominantly light gray (N7) to white anhydrite with scattered halite growths faintly laminated. 1/2" clay seam at lower contact.	Runs 2, 3. Some broken core, discing, vibration fractures. Run 4. Good core.
						26.65'- 29.3' HALITE: Clear to medium light gray (N6) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤ 1% gray clay and dispersed polyhalite. Clay break at 27.95' and 29.3'. [2, 11]	

BORING NO. DH-10

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-10

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	5.2	5.2	100		29.3' -34.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline line. < 1 to 3% polyhalite. 1/2" anhydrite with gray clay break at 34.75'-34.8'. [3-5, 7]	Run 8. Barrel plugged because of clay seam. Run 9 thru 13. Core quality fair. Discing in some runs.
8 (26.1–26.8)		0.7	0.7	100			
9	30	4.7	4.7	100		34.8'-37.0' HALITE: Clear to moderate reddish orange (10R 6/6); some light gray (N7) and light bluish gray (5B 7/1). Medium to coarsely crystalline. ≤ 1% gray clay. < 1 to 2% polyhalite. [2, 11]	
10 (31.5–36.6)	35	5.1	5.1	100		37.0'-42.5' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6) coarsely crystalline. < 1 to 3% polyhalite. Trace brown and gray clay locally. [2-5]	
						42.5'-46.75 HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6) with some medium light gray (N6). Medium to coarsely crystalline. Up to 2% brown clay with some gray clay and polyhalite to 43.3'. Below this is < 1% clay and polyhalite. [1, 17]	
11 (41.8)	40	5.2	5.2	100		46.75'-51.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. Moderate reddish orange anhydrite at 51.5' to 51.6' ±. [2-4, 7]	
						51.8'-52.0' HALITE: Clear, coarsely crystalline. [1]	
12 (46.9)	45	5.1	5.1	100			
13 (52.0)	50	5.1	5.1	100			
	55						

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BORING NO. DH-10

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-11

LOCATION N1100 DRIFT AT ROOM A-2 CENTERLINE; ROOF

STATION N1112± E1332.5± COLLAR ELEV. 1320.5 DIRECTION OF DRILLING UP-VERTICAL

MINE COORDINATES N10,799.8 E8227.3 DEPTH OF BOREHOLE 50.9 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/5/84 (SWING) DATE COMPLETED 3/6/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0–0.4	0.4	0.4	100			
2	0.4–1.9	1.5	1.5	100		0.0'–0.5' HALITE: Clear, trace of moderate reddish orange. Coarsely crystalline. <1/2% polyhalite. [2]	Watson drill. AW rods NX double tube core barrel. Drilling Time: 7 hours. ±
3	1.9–3.8	1.9	1.7	90		0.5'–4.1' POLYHALITIC HALITE: Clear to moderate reddish orange; coarsely crystalline. <1 to 3% polyhalite. [3]	Throughout hole much discing and broken core. Quality poor. No gas; dry hole.
4	3.8–5.7	1.9	1.9	100			
5	5.7–10.2	4.5	4.5	100		4.1'–8.8' HALITE: Clear to light gray (N7) and medium light gray (N6), some moderate brown (5YR 4/4) medium to coarsely crystalline, some fine. ≤1% clay. [2,9] 8.8'–13.1' HALITE: Clear, coarsely crystalline. 1/2" ± gray anhydrite layer at 9.3' with trace of gray clay anhydrite stringers to 10.5' ±. [1]	
6	10.2–12.3	2.1	2.1	100		13.1'–15.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); fine to medium, some coarsely crystalline. <1 to 3% brown clay. [12]	
7	12.3–15.6	3.3	3.0	91		15.2'–17.0' HALITE: Clear, trace of light brown (5YR 6/4). Coarsely crystalline. [1]	
8	15.6–17.1	1.5	1.5	100		17.0'–20.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. <1 to 3% brown clay, intercrystalline and breaks. ≥10% clay at 20.5'–20.6'. [10, 15]	
9	17.1–20.6	3.5	3.5	100		20.6'–21.2' ANHYDRITE: White to light gray (N7) microcrystalline, partially laminated anhydrite. Scattered halite growths. 1/2" brown clay seam at 20.6'.	Run 10. Some core grinding evident here.
10	20.6–21.7	1.1	1.1	100			
11	21.7–23.8	2.1	2.1	100			

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-11

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
12	25	3.4	3.4	100		21.2'-24.9' HALITE: Clear, some light moderate reddish orange; coarsely crystalline. ≤ 1% polyhalite. [1,3]	
13	27.2	2.5	2.5	100		24.9'-30.7' HALITE: Clear, some moderate brown (5YR 4/4); coarsely crystalline except medium at 25.5' to 26.1'. < 1 to 2%, locally, brown clay. < 1/2% dispersed polyhalite. [2, 10]	
14	29.7	2.4	2.4	100		30.7'-33.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. Breaks at 31.5', 32.8'. [12, 14]	
15	30 32.1	3.9	3.9	100		33.5'-50.9' HALITE: Clear to moderate brown (5YR 3/4; 4/4) and mottled with moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. < 1 to 3% brown clay with trace of gray. < 1 to 2% polyhalite blebs and patches. Core varies from zones containing polyhalite blebs with no clay to zones with mixed clay and polyhalite and zones containing only patches of clay. [5, 10] Zones with polyhalite blebs and patches and only trace of clay are the following approximate depths: 33.5' -33.7', 40.4' -41.3', 43.1' -44.9', 49.2' -49.7'.	
16	35 36.0	4.5	4.5	100			
17	40 40.5	2.4	2.4	100			
18	42.9	4.7	4.7	100			
19	45 47.6	3.3	3.3	100			
	50 50.9						

BORING NO. DH-11

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-12

LOCATION N1100 DRIFT AT ROOM A-2 INTERSECTION, FLOOR

STATION N1112± E1332.5± COLLAR ELEV. 1311.1 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10,799.4 E 8227.2 DEPTH OF BOREHOLE 51.3'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-7-84 (SWING) DATE COMPLETED 3-7-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-24-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0–1.8	1.8	1.8	100		0.0–4.25' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1); coarsely crystalline. < 1% gray intercrystalline clay. < 1/2% polyhalite. [11]	Watson Drill. NW split tube core barrel. AW rods. Drill Time: 6-1/2 hours ±.
2	1.8–5.8	4.0	4.0	100		4.25'–5.55' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1% polyhalite. [3]	
3	5.8–11.1	5.3	5.3	100		5.55'–10.0' HALITE: Clear to light gray (N7) and medium light gray (N6); some moderate reddish orange and brown. Coarsely crystalline, some medium. < 1% gray clay. Partings at 7.4' and 8.55'. < 1% polyhalite. [11,2]	Core quality shows significant improvement over previously drilled core.
						10.0'–12.65' HALITE: Clear to moderate reddish orange, (10R 6/6) coarsely crystalline. ≤ 1% polyhalite. Gray clay break at 12.25'. [2]	
4	11.1–16.1	5.0	5.0	100		12.65'–19.8' HALITE: Clear to light bluish gray (5B 7/1) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤1% gray clay; trace brown < 1% polyhalite. [11.2]	
						19.8'–20.9' HALITE: Clear, some moderate reddish orange (10R 6/6). Coarsely crystalline. < 1% polyhalite. [1]	
5	16.1–21.2	5.1	5.1	100		20.9'–21.45' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤ 1% gray clay. [11]	
						21.45'–22.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline < 1 to 2% polyhalite blebs and patches. [1-3]	
6	21.2–25	5.1	5.1	100			

BORING NO. DH-12

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-12

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25					22.75'-25.9' MB-139: From 22.75' to 23.85' is a "swallowtail" pattern of halite and anhydrite. Below this is predominantly white to light gray (N7) to medium light gray (N6) microcrystalline anhydrite with scattered halite growths. Anhydrite is partially laminated. < 1/2" moist gray clay at lower contact.	
7	30	5.0	5.0	100		25.9'-29.0' HALITE: Clear to moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline. ≤ 1% gray clay and < 1% dispersed polyhalite. [9,11]	
8	35	5.0	5.0	100		29.0'-32.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 4% polyhalite. None to < 1% gray clay. [4-6]	
						33.2'-35.35' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% gray clay and dispersed polyhalite. [1,2]	
9	40	5.0	5.0	100		35.35'-39.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% gray clay locally. [2-4]	
						39.9'-44.8' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline, some medium. ≤ 1% gray clay and ≤ 1% polyhalite, locally up to 2%. [1, 10]	
10	45	5.0	5.0	100		44.8'-49.5' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); coarsely crystalline. < 1 to 4% polyhalite average ≤1 to 2%. < 1% gray clay. Moderate reddish orange/brown microcrystalline anhydrite/polyhalite at 49.1' to 49.3'. Lower surface is irregular and slightly polished. [2-4, 7]	
11	50	5.0	5.0	100		49.5'-49.8' ANHYDRITE: White to light gray (N7); microcrystalline, faintly laminaed anhydrite. Scattered halite growths. Trace of gray clay at 49.8'.	
	55					49.8'-51.3' HALITE: Clear, some light bluish gray (5B 7/1) and moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% polyhalite. [9, locally 2]	

26.3 31.3 36.3 41.3 46.3 51.3

BORING NO. DH-12

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-13

LOCATION N1420 DRIFT @ ROOM D INTERSECTION

STATION N 1424, E1690 COLLAR ELEV. 1311.4 DIRECTION OF DRILLING VERTICAL ~~UP~~

MINE COORDINATES N11 112, E8585 DEPTH OF BOREHOLE 13.8 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON MODEL 750

DATE STARTED 3/28/84 (SWING) DATE COMPLETED 3/28/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/30/84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	1		2.4	2.4	100	X	0.0'-3.9' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1% dispersed polyhalite. ~~<1/2% gray clay.~~ 1/2" anhydrite at 3.9'±. Gray clay below.	Watson drill, AW rods, NW split-tube barrel. Set-up time: 7 hrs. Drilling time: 2-1/2 hrs.
2.4	2	5	5.5	3.6	65.5	X	3.9'-8.7' HALITE: Clear, coarsely crystalline. None to <1% gray clay.	No gas. Dry hole.
							8.7'-9.4' HALITE: Clear to moderate brown (5YR 4/4); some light gray (N7). Medium to coarsely crystalline. ≤ 1% brown and gray clay.	Contacts approximate due to core loss.
							9.4'-13.8' HALITE: Clear, some light gray (N7); coarsely crystalline. <1% dispersed gray clay.	Run 2. Core broken-up much of run.
7.9	3		0.8	0.8	100			
8.7	4	10	5.1	4.1	80.4		Note: This hole was stopped at 13.8' due to core loss. Refer to drill logs for replacement holes DH-13A and DH-13B.	
13.8		15						
		20						
		25						

BORING NO. DH-13

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX CORE BORING NO. DH-13A

LOCATION 6" N.E. OF DH-13; N1420 DRIFT AT ROOM D INTERSECTION

STATION N 1424.5, E1691 COLLAR ELEV. 1311.5± DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11112, E8586 DEPTH OF BOREHOLE 49.0 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON MODEL 750

DATE STARTED 3/28/84 (SWING) DATE COMPLETED 3/29/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/30/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.5	2.5	2.5	100		0.0'-4.25' HALITE: Clear, some light gray (N7), medium to coarsely crystalline. < 1% dispersed gray clay. < 1/2% dispersed polyhalite. Break at 4.25'.	Watson drill, AW rods. Used NW double-tube barrel and split-tube barrel.
2	2.5 – 3.2	0.7	0.65	93		4.25'-6.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. 1/4" anhydrite layer at 4.55'.	Drilling time: 5 hrs. ± Run 2. Barrel plugged.
3	3.2 – 6.1	2.9	2.9	100		6.3'-10.6' HALITE: Clear to light moderate reddish orange (10R 6/6); some light bluish gray (5B 7/1). Medium to coarsely crystalline. ~~< 1/2% dispersed~~ polyhalite and gray clay.	Contacts at 6.3' and 10.6' are approximate due to core loss.
4	6.1 – 8.9	2.8	0.6	21		10.6'-13.4' HALITE: Clear to light gray (N7) and medium light gray (N6). Coarsely crystalline. None to < 1% gray clay. Upper 12" of recovered core is clear.	
5	8.9 – 10.9	2.0	2.0	100		13.4'-16.55' ARGILLACEOUS HALITE: Clear to medium brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. Scattered breaks.	
6	10.9 – 12.9	2.0	1.0	50		16.55'-17.25' ANHYDRITE: Light gray, microcrystalline; faintly laminated. Scattered halite growths, especially 16.75'-16.95'±. 2-1/2" gray clay seam at 16.55'-16.75', medium plastic. Contains scattered halite crystals.	Run 6. Much of core broken-up.
7	12.9 – 15.1	2.2	2.2	100		17.25'-22.2' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 2% polyhalite. Scattered anhydrite.	Run 7. Tried 3' NX double-tube barrel. Core OK.
8	15.1 – 16.7	1.6	1.6	100			Run 8. NW split-tube plugged-off at clay seam.
9	16.7 – 20.7	4.0	3.3	83		22.2'-24.5' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 2% brown clay. Breaks at 22.4' and 23.25'. [12,17] 24.5'-26.7' HALITE: Clear mottled with some moderate reddish orange (10R 6/6); coarsely crystalline. < 1/2% gray clay and < 1% polyhalite. [2 - 4, some 9]	Run 9. Core broken-up in polyhalitic halite.
10	20.7 – 24.0	3.3	3.3	100		26.7'-28.3' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 2% brown clay. [8, 10]	Runs 10-15. Used Sprague and Henwood double-tube core barrel. A piece of foam rubber was used inside barrel to prevent core from falling in barrel.
11	24.0 – 25	5.0	5.0	100			

BORING NO. DH-13A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-13A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
11	25	5.0	5.0	100		28.3'-30.6' ARGILLACEOUS HALITE:- Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. Break at 28.4'. 1-1/2" brown clay mixed with halite at 30.4'-30.6'±. [12]	
						30.6'-35.55' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. 1/2" gray clay seam at 33.9'. [2 - 5]	
12	30	4.9	4.9	100		35.55'-36.8' HALITE: Clear with some moderate brown (5YR 4/4); coarsely crystalline. < 1/2% polyhalite. ≤ 1% brown clay patches. Irregular break at 35.55'. [10, 17]	
						36.8'-39.0' HALITE: Clear mottled with some moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Coarsely crystalline < 1% brown clay blebs. ≤ 1 to 2% polyhalite blebs. [1 - 3, 8]	
13	35	5.0	5.0	100		39.0'-39.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4); medium to coarsely crystalline. Brown clay < 1 to 3%. Break at 39.6' and 1/2" seam at 39.85'. [12]	
						39.9'-41.7' HALITE: Clear mottled with moderate reddish orange; coarsely crystalline. ≤ 1% polyhalite. 1-1/2" anhydrite and halite at 39.9'-40.0'. [1, 2]	
14	40	5.1	5.1	100		41.7-43.3' HALITE: Clear with some moderate brown (5YR 4/4); coarsely crystalline, some medium. ≤ 1% brown clay. [8, 10]	
						43.3'-46.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4); medium to coarsely crystalline. < 1 to 3% brown clay. Parting at 43.3'. Breaks at 45.5'; 45.6'. [10]	
15	45	5.0	5.0	100		46.9'-49.0' HALITE: Clear to moderate reddish brown (10R 4/6) and moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤ 1% brown clay, trace of gray. < 1% polyhalite. [10]	
	50						
	55						

29.0 — 33.9 — 38.9 — 44.0 — 49.0

BORING NO. DH-13A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-13B

LOCATION N1420 DRIFT; ROOF AT RM. D INTERSECTION

STATION N1425, E1695 COLLAR ELEV. 1311.4 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11112.62, E8590.14 DEPTH OF BOREHOLE 21.0 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON MODEL 750

DATE STARTED 4-5-84 (SWING) DATE COMPLETED 4-5-84 (SWING) SHEET

LOGGED BY: J. F. GALLERANI DATE: 4-5-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	2.7	2.7	100		0.0'-2.7' HALITE: Clear to medium light gray (N6) and some light moderate reddish orange (10R 6/6). Coarsely crystalline. ≤ 1% gray clay. [9]	AW rods, S&H NX double-tube core barrel. Drilling time: 1 hr. ±
2	2.7	4.8	4.8	100		2.7'-5.5' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. < 1/4" gray clay seam at 5.5' with some anhydrite just above. [1]	
	5					5.5'-9.9' HALITE: Clear, trace of light gray (N7), medium to coarsely crystalline. < 1/2% clay. [1, 9]	
						9.9'-12.1' HALITE: Clear, coarsely crystalline. [1]	
3	7.5	4.9	4.9	100		12.1'-15.8' HALITE: Clear with some medium light gray (N6) and medium brown (5YR 4/4). Medium to coarsely crystalline, trace fine locally. < 1/2% dispersed polyhalite and ≤ 1% gray clay, some brown. Scattered discontinuous breaks. [9, 17]	
	10					15.8'-16.8' HALITE: Clear, coarsely crystalline. [1]	
4	12.4	4.5	4.5	100		16.8'-17.5' ANHYDRITE: Light gray (N7) to medium light gray (N6) microcrystalline anhydrite with scattered halite growths. Partially laminated. 1/2" layer of mostly halite at 17.4'. Tightly closed upper contact. Up to 1-1/4" hard gray clay at ~~16.8'-16.9'~~.	
	15					17.5'-18.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. [7]	
5	16.9	4.1	4.1	100		18.3'-21.0' HALITE: Clear with some moderate reddish orange. < 1% polyhalite locally. ≤ 1/2" white anhydrite layer at 18.9'±. [1, 2]	
	20						
	21.0						
	25						

BORING NO. DH-13B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX CORE BORING NO. DH-14

LOCATION N1420 DRIFT, FLOOR AT INTERSECTION OF RM. D

STATION N 1425, E 1695 COLLAR ELEV. 1299.5 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N11112.62, E8590.14 DEPTH OF BOREHOLE 49.1 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON MODEL 750

DATE STARTED 4/6/84 DATE COMPLETED 4/6/84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 4/27/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 3.2	3.2	3.2	100		0.0'-5.8' HALITE: Clear with some light gray (N7), coarsely crystalline. < 1% gray clay and polyhalite. [1, 11]	Watson drill, AW rods, NX double-tube core barrel.
2	3.2 – 8.1	4.9	4.9	100		5.8'-13.15' HALITE: Clear to medium light gray (N6), coarsely crystalline, some medium. ≤ 1% gray clay. < 1/2% dispersed polyhalite. [9, 11] 13.15'-16.2' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1% polyhalite. [1-3]	No gas. Dry hole. Core shows some discing and surface vibration damage.
3	8.1 – 13.1	5.0	5.0	100		16.2'-21.3' HALITE: Clear to light moderate reddish orange (10R 6/6) and light gray (N7), medium to coarsely crystalline. < 1/2% dispersed polyhalite. < 1% gray clay. [9, 11] 21.3'-23.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline. < 1 to 2% polyhalite. Scattered anhydrite. [3, 7]	
4	13.1 – 18.1	5.0	5.0	100		23.7'-26.45' MB-139: Light gray to moderate reddish orange mixture of predominantly anhydrite with some polyhalitic halite to 25.55'. Then light gray anhydrite with scattered halite growths and laminae. Trace of gray clay at 26.45'. 26.45'-29.5' HALITE: Clear to moderate reddish orange (10R 6/6) and some light gray (N7). Medium to coarsely crystalline. < 1/2% dispersed polyhalite and < 1% gray clay. [9]	
5	18.1 – 23.1	5.0	5.0	100		29.5'-33.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Anhydrite mixed with some halite from 33.75'-33.9'. Gray clay at 33.9' [7] 33.9'-36.25' HALITE: Clear to light moderate reddish orange (10R 6/6) and some light gray (N7). Medium to coarsely crystalline. < 1/2% dispersed polyhalite. < 1% gray clay. [9]	
6	23.1 – 25	5.0	5.0	100			

BORING NO. DH-14

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-14

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	5.0	100		36.25'-41.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. < 1/2% gray clay with up to 1% clay at 39.5'-40.3'. Break at 39.5'. [3, 4, 7]	
28.1						41.1'-44.7' HALITE: Clear to moderate reddish orange (10R 6/6) and some light gray (N7). Medium to coarsely crystalline, some fine. < 1/2% dispersed polyhalite. < 1% gray clay. [9]	
7	30	5.0	5.0	100		44.7'-49.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. [3, 7]	
33.1							
8	35	5.0	5.0	100			
38.1							
9	40	5.0	5.0	100			
43.1							
10	45	5.0	5.0	100			
48.1							
11		1.0	1.0	100			
49.1	50						
	55						

BORING NO. DH-14

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ - _____ HOLE TYPE/SIZE NX CORE BORING NO. DH-15

LOCATION N1100 DRIFT; ROOF

STATION N1104± E1688.5± COLLAR ELEV. 1308.9 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N10,793.26 E8589.96 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/20/84 (SWING) DATE COMPLETED 3/21/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/25/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.4	2.4	2.4	100	X	0.0'-4.5' HALITE: Clear, coarsely crystalline. < 1% polyhalite from 3.7'-4.5' ±. Scattered white anhydrite/magnesite? Stringers. [1 2]	Watson post mounted drill. AW rods. NW split tube barrel.
2	2.4 – 6.3	3.9	3.9	100	X	4.5'-9.2' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤ 1% gray clay. < 1/8" clay seam at 9.1'. From 9.1' to 9.2' anhydrite mixed with halite. [2,11]	Drilling Time: 6-1/2 hours.
3	6.3 – 7.5	1.2	1.2	100		9.2'-13.0' HALITE: Clear, coarsely crystalline. Scattered white stringers. [1]	Core generally all together in split tube. Tends to break up some when put in box.
4	7.5 – 11.7	4.2	4.2	100		13.0'-14.7' HALITE: Clear to light gray (N7) and moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. < 1% brown clay with trace gray. Sugary texture 14.1'-14.7'. [9,17]	Run 4. Discing of core in clear halite.
5	11.7 – 16.6	4.9	4.9	100		14.7'-18.1' HALITE: Clear, coarsely crystalline none to ≤ 1% gray clay. [1, some 11]	Run 5. Some broken core.
6	16.6 – 20.9	4.3	4.3	100		18.1'-20.85' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and grayish red (10R 4/2) medium to coarsely crystalline. < 1 to 3% brown clay. 1/2" ± brown clay seam at 19.6'. (12,16)	
7	20.9 – 25.4	4.5	4.5	100		20.85'-21.35' ANHYDRITE: Light (N7) to medium gray (N5) to white anhydrite. Scattered halite growths up to 1/2" brown clay seam at 20.85'.	
						21.35'-26.0' HALITE: Clear, coarsely crystalline. Stringers of anhydrite mixed with halite 21.35'-21.75'. Scattered white stringers throughout core. [1,2]	

BORING NO. DH-15

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-15

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25.4 – 29.9	4.5	4.5	100		26.0'-31.2' HALITE: Clear to dark reddish brown and moderate brown (5YR 4/4). Predominantly coarse with zones of fine-medium from 26.5'-26.9' ± and 28.0'-28.5' ±. < 1 to 2% brown clay. [8, 10, 12]	
9	29.9 – 34.8	4.9	4.9	100		31.2'-34.75' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and moderate reddish brown (10R 4/6); medium to coarsely crystalline. < 1 to 5% brown clay intercrystalline and breaks. From 34.45' to 34.65' clay ≥10%. (10,12)	
10	34.8 – 39.8	5.0	5.0	100		34.75'-43.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. 1" anhydrite layer at 37.25'. <1 to 3% brown clay at 40.25' -41.45. [3, 4, 7]	
11	39.8 – 44.6	4.8	4.8	100		43.2'-44.1' HALITE: Clear mottled with dark reddish brown and moderate brown (5YR 4/4). Coarsely crystalline. ≤ 1% brown clay. [8, 10]	Run 10. Some discing of core.
12	44.6 – 46.0	1.4	1.4	100		44.1"-44.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); fine to medium crystalline, some coarse. < 1 to 3% brown clay, intercrystalline and breaks. Anhydrite/halite at 44.4'-44.6'. [12, 17]	
13	46.0 – 51.0	5.0	5.0	100		44.6'-47.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. [3, 4, 7]	
						47.1'-51.0' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4); medium to coarsely crystalline. < 1 to 3% brown clay. [10, 12]	

Depth scale: 25, 30, 35, 40, 45, 50, 55

BORING NO. DH-15

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-16

LOCATION N1100 DRIFT - FLOOR

STATION N1104 ± E1588 ± COLLAR ELEV. 1300.3 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10792.89 E8589.39 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/19/84 (SWING) DATE COMPLETED 3/19/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/20/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	2.0	2.0	100	X	0.0'-6.1' HALITE: Clear, coarsely crystalline, some medium. < 1/2% polyhalite and gray clay. [1, 2]	Watson drill. Post mounted AW rods. NW split tube barrel. Drilling Time: 4-1/2 hours. No gas. Dry hole.
2	2.0	0.3	0.1	33			
3	2.3	1.1	1.1	100		6.1'-10.4' HALITE: Clear to light gray (N7); coarsely crystalline, some medium. ≤ 1% gray clay. < 1/2% dispersed polyhalite. [11]	
4	3.4	2.6	2.5	96	X	10.4'-12.35' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. < 1 to 2% polyhalite. < 1% gray clay at 11.85'-11.95'. [1-3]	Overall core quality is satisfactory. Can fit ends together fairly well. Some discing of core, especially in coarsely crystalline material.
5	6.0	5.1	5.1	100	X	12.35'-16.0' HALITE: Clear to light gray (N7); light bluish gray (5B-7/1) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤ 1% polyhalite and gray clay. [9]	Runs 4 and 5. Some discing of core.
6	11.1	4.9	4.9	100	X	16.0'-20.1' HALITE: Clear to light bluish gray (5B 7/1) and light gray (N7); coarsely crystalline. ≤ 1% gray clay. [11]	
7	16.0	5.1	5.1	100	X	20.1'-21.5' HALITE: Clear, scattered moderate reddish orange polyhalite blebs. Coarsely crystalline. < 1/2% polyhalite. [2, 3]	
8	21.1	4.9	4.9	100		21.5'-25.2' MB-139: Mixture of halite and anhydrite in "swallowtail" pattern from 21.5'-23.6'. From 23.6', predominantly anhydrite with some halite growths. Some laminae, especially noted from 24.5'. 1/2" ± clay at lower contact.	
						25.2'-29.6' HALITE: Clear, some moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline. < 1/2% polyhalite and gray clay. Coarsely crystalline with no clay from 29.2-29.6'. [9]	

BORING NO. DH-16

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-16

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25	4.9	4.9	100			
9	30	5.0	5.0	100		29.6'-33.05' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. 1/2" hard gray clay. Seam at lower contact. [3, 4, 7]	
10	35	5.0	5.0	100		33.05'-34.9' HALITE: Clear mottled with some moderate reddish orange polyhalite blebs. Coarsely crystalline, some medium. <1/2% polyhalite and gray clay. [2]	
11	40	5.0	5.0	100		34.9'-40.35' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline except some medium at 39.65' to 40.35'. <1 to 3% polyhalite <1/2% gray clay. [2-5, 9]	
12	45	5.1	5.1	100		40.35'-42.1' HALITE: Clear, coarsely crystalline. None to 1% gray clay and <1/2% dispersed polyhalite. [1, 2]	
13	50	4.9	4.9	100		42.1'-46.3' HALITE: Clear to moderate reddish orange/brown (10R 6/6;4/6) with some light gray (N7). Coarsely crystalline. ≤1% gray intercrystalline clay. <1 to 2% polyhalite. Locally polyhalitic. [9]	
	55					46.3'-49.15' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Moderate reddish orange anhydrite mixed with some halite at 48.95-49.05' ±. [2-4, 7]	
						49.15-49.45' ANHYDRITE: White to light gray (N7), microcrystalline. Scattered halite growths. ≤1/16" gray clay at 49.45'.	
						49.45'-51.0' HALITE: Clear, medium to coarsely crystalline. <1/2% clay at 50.8' to 51.0'. [2]	

26.0 31.0 36.0 41.0 46.1 51.0

BORING NO. DH-16

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-17

LOCATION N 1420 DRIFT: ROOF

STATION N1427 ± E178 ± COLLAR ELEV. 1316.45 DIRECTION OF DRILLING UP-VERTICAL

MINE COORDINATES N11114.2 E7071.8 DEPTH OF BOREHOLE 52.0 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 1/18/84 (DAY) DATE COMPLETED 1/19/84 (DAY) SHEET

LOGGED BY: J.E. GALLERANI DATE: 3/6/84 1 OF 3

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 3.7	3.7	3.7	100		0.0'-4.2' HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline, some medium. Scattered polyhalite < 1%. < 1/2% gray clay. [3,9]	Watson drill. AW rods. NX double tube core barrel.
2	3.7 – 8.7	5.0	5.0	100		4.2'-7.2' HALITE: Clear to light gray (N7) coarsely crystalline. ≤ 1% gray intercrystalline clay. < 1/2% polyhalite. [9,11]	Drilling time: 5 hours. Dry hole; no gas.
						7.2'-7.4' ANHYDRITE b: Very light (N8) to light gray (N7) microcrystalline anhydrite. Trace of dry gray clay at 7.2'. Some core grinding noted. Tightly closed irregular upper contact. Some halite growths 7.3'-7.4'.	Overall core condition good. Only several small broken up zones.
3	8.7 – 13.6	4.9	4.9	100		7.4'-12.8' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. ≤ 1% polyhalite 7.3'-7.7' and 12.0'-12.6'. [1,2]	
						12.8'-14.1' HALITE: Clear to light bluish gray (5B 7/1), fine to medium crystalline. ≤ 1% gray intercrystalline clay. Trace of dispersed polyhalite. (9)	
4	13.6 – 18.4	4.8	4.8	100		14.1'-14.8' ANHYDRITE a: White to medium light (N6) and very light (N8) gray microcrystalline anhydrite some laminae. Growths of halite present. < 1/32" halite laminate at 14.4'. Trace of gray clay at 14.1'.	Run 4. Core broken up last 6" of run.
						14.8'-19.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite blebs, patches. [3,4,7]	
5	18.4 – 23.4	5.0	5.0	100		19.0'-21.0' HALITE: Clear to light gray (N7), fine to medium crystalline with some coarse. < 1 to 2% gray clay. < 1/2% dispersed polyhalite. [1,2,9]	

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 3 BORING NO. DH-17

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	4.8	4.8	100		21.0'-23.6' HALITE: Clear, coarsely crystalline. Trace < 1% gray clay. fine-medium crystalline 22.4'-22.9'. < 1/2% polyhalite blebs. Clay parting at 23.5'. 3/4" anhydrite layer above this. [2,9)	
7	30	5.0	5.0	100		23.6'-28.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite/magnesite stringers from 23.6'-25.6'. [1)	Run 7. Core broken up zone 32.2'-32.7' ±
						28.3'-29.6' ARGILLACEOUS HALITE: Clear to grayish brown, fine to medium crystalline. < 1 to 2% brown and gray clay. Scattered breaks. (12,15)	
8	35	4.0	4.0	100		29.6'-32.0' HALITE: Clear, coarsely crystalline. [1,8)	Run 8. Bit plugged off went only 4' and pulled barrel.
						32.0'-36.3' HALITE: Clear to moderate brown (5YR 4/4) and grayish brown, coarsely crystalline, some medium. < 1% brown and gray clay to 33.1' ±. Core is argillaceous, 1 to 3% brown clay, from 32.9-35.2'. Clear from 35.8'-36.3'. [8,10)	
9	40	5.0	5.0	100	X		
					X	36.3'-37.2' ANHYDRITE: Very light (N8) to light gray (N7) microcrystalline anhydrite. Halite growths within 1" brown clay seam at 36.2'. Slightly plastic, low moisture.	
10	45	4.8	4.8	100		37.2'-40.7' HALITE: Clear mottled with moderate reddish orange (10R 6/6), coarsely crystalline. < 1% polyhalite blebs anhydrite mixed with halite from 37.2' to 37.6'. [2-4)	
					X		
					X	40.7'-41.5 HALITE: Clear to moderate brown (5YR 4/4) coarsely crystalline. ≤ 1% brown intercrystalline clay. [2,8]	
11	50	5.0	5.0	100		41.5'-43.4' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) coarsely crystalline. < 1 to 3% brown intercrystalline clay. Trace of Gray. Breaks at 41.5', 42.2'. (10,16)	
					X	43.4'-45.4' HALITE: Clear, coarsely crystalline. 1% polyhalite at 43.4'-44.0'. [2)	
	55						

28.2 33.2 37.2 42.2 47.0 52.0

BORING NO. DH-17

WIPP

WASTE ISOLATION PILOT PLANT SHEET 3 OF 3 BORING NO. DH-17

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
						45.4'-47.05' HALITE: Clear, coarsely crystalline. < 1% brown intercrystalline clay. < 1/2% polyhalite blebs. [8)	
						47.05'-50.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) medium to coarsely crystalline. < 1 to 5% brown clay, intercrystalline and breaks. 1" brown clay mixed with halite crystals at 50.2'. [16)	
						50.3'-52.0 POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6) coarsely crystalline. < 1%, locally 2% polyhalite. < 1/2% gray clay. [4, 7]	

BORING NO. DH-17

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-18

LOCATION N1420 DRIFT - FLOOR

STATION N1429± E181± COLLAR ELEV. 1305.1 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N11,114.2 E7071.8 DEPTH OF BOREHOLE 50.8'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 1/19/84 (SWING) DATE COMPLETED 1/20/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 5.1	5.1	5.1	100		0.0'-4.7' HALITE: Clear, coarsely crystalline. < 1% gray clay locally. < 1/2% polyhalite blebs. [1] 4.7'-5.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1% to 3% polyhalite. [7]	Watson drill. AW rods, NX double tube barrel. Drilling time: 5-1/2 hours. Dry hole. No Gas.
2	5.1 – 9.1	4.0	3.1	78		5.6'-9.1' MB-139: From 5.6' to 6.7' is light gray (N7) to moderate reddish orange (10R 6/6) mixture of halite, polyhalite and anhydrite. Shows "swallowtail" pattern. From 6.1' to 9.1' ± is white to medium gray (N5) anhydrite with scattered halite growths. Very thin layers of halite lower part of unit. Lower contact approximate because of core loss.	Run 1. Small broken zone 2.2'-2.4' ±. Run 2. Left some core in hole. Ground up in run 3.
3	9.1 – 13.6	4.5	4.5	100		9.1'-12.1' HALITE: Clear to light bluish gray (5B 7/1) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤ 1% polyhalite and intercrystalline gray clay. [9]	
4	13.6 – 18.3	4.7	4.7	100		12.1'-18.2' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite, locally 2%. 1" anhydrite layer at 15.6'. 1/2" clay and anhydrite at 15.8'. Dips at 10°±. < 1% gray clay at 15.8'-16.8'. < 1/2% polyhalite from 15.8'-18.2'. [7, 2] 18.2'-22.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, scattered medium < 1 to 4%. [3, 4, 7]	
5	18.3 – 23.1	4.8	4.8	100		22.4'-27.9' HALITE: Clear to light gray (N7) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. < 1% polyhalite and dispersed gray clay.	
6	23.1 – 25	5.2	5.2	100			

BORING NO. DH-18

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-18

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	5.2	5.2	100		27.9'-33.7' HALITE: Clear mottled with moderate reddish orange, coarsely crystalline. < 1 to 2% polyhalite with most concentration at 27.9' to 30.0'. 1" anhydrite layer at 33.0'. [7, 1]	
28.3							
7	30	4.8	4.8	100		33.7'-34.05' ANHYDRITE: Very light (N8) to medium gray (N5) microcrystalline anhydrite with scattered halite growths. Trace of dry gray clay at 34.05'.	
						34.05'-41.2' HALITE: Clear mottled with some light gray, fine to coarsely crystalline. ≤ 1% gray intercrystalline clay and polyhalite. Clear, fine to medium crystalline from 35.2' to 36.1'. [9, 4]	
33.1							
8	35	5.0	5.0	100		41.2'-44.6' HALITE: Clear to medium brown (5YR 4/4) to grayish brown (5YR 3/2) medium to coarsely crystalline. <1 to 2% brown, trace gray. [10]	
38.1						44.6'-47.2' HALITE: Clear to light gray (N7) coarsely crystalline. < 1% gray intercrystalline clay. < 1/2% dispersed polyhalite. [11]	
9	40	5.0	5.0	100		47.2'-50.1' HALITE: Clear, coarsely crystalline. 1/2% gray clay at 48.6' to 48.7'. < 1% dispersed polyhalite at 48.7' to 50.1'. [2]	Run 9. Small broken zone. 38.1'-38.4' ±.
43.1						50.1'-50.8' HALITE: Clear, with some light gray (N7), coarsely crystalline. < 1% gray intercrystalline clay. Break at 50.5'. [11]	Run 10-11. Time to put rods in hole, drill, and come out of hole and empty barrel and put rods back in hole: 43 minutes.
10	45	4.6	4.6	100			
47.7							
11	50	3.1	3.1	100			
50.8							

BORING NO. DH-18

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-19

LOCATION N1100 DRIFT - ROOF

STATION N 1107 ± E 206.5 ± COLLAR ELEV. 1314.7 DIRECTION OF DRILLING UP-VERTICAL

MINE COORDINATES N 10,794.2 E 7101.7 DEPTH OF BOREHOLE 51.6 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 1/20/83 (DAY) DATE COMPLETED 1/21/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 3

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1 (0.0–0.6)	0	0.6	0.6	100			
2 (0.6–5.0)	5	4.4	4.4	100		0.0'–4.0' HALITE: Clear, coarsely crystalline. < 1/2% gray intercrystalline clay and < 1% polyhalite blebs. (2) 4.0'–7.55' HALITE: Clear with some light gray (N7), medium to coarse crystalline. ≤ 1% gray, intercrystalline clay < 1/2% dispersed polyhalite. (2,9)	Watson drill. AW Rods; NW double tube barrel 6" diameter barrel used to start hole. Roof only 8-1/2' high so unable to get NX core barrel on drill. Drill Time: 7-1/2 hours. Dry hole; no gas.
3 (5.0–9.6)	10	4.6	4.6	100		7.55'–7.75' ANHYDRITE b: Very light (N8) to medium gray (N5) microcrystalline anhydrite. Scattered halite growths. Several near-horizontal hairline fractures with anhydrite. Trace clay at 7.55'.	
4 (9.6–13.2)		3.6	3.6	100		7.75'–8.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. 1 to 2% polyhalite. (7) 8.2'–12.1' HALITE: Clear, coarsely crystalline. <1/2% dispersed polyhalite locally. Very clear at 8.2' to 8.7' ±. (1)	
5 (13.2–17.0)	15	3.8	3.8	100		12.1'–13.9' HALITE: Clear to light gray (N7) coarsely crystalline to 13'; then fine to medium <1% gray intercrystalline clay. < 1% polyhalite to 13'. (2,9)	Run 5. Core broken in discs from 14.5 to 17' ±.
6 (17.0–21.6)	20	4.6	4.6	100		13.9'–14.5' ANHYDRITE a: Very light (N8) to medium gray (N5) microcrystalline anhydrite. Scattered halite growths. Thin, irregular halite layer at 14.3' ±. 14.5'–18.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. Scattered anhydrite to 16' ±. <1 to 3% polyhalite, dispersed and blebs. (3,4,7)	
7 (21.6–25)	25	4.4	4.4	100			Run 7. Core broken up last 2' of run in clear halite.

BORING NO. DH-19

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 3 — BORING NO. DH-19

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	4.4	4.4	100		18.5'-23.8' HALITE: Clear to grayish brown (5YR 3/2) fine to coarsely crystalline. ≤ 1% clay, predominantly brown with some gray. Brown break at 19.8' ±. Coarse crystalline from 22.9'. 3/4" anhydrite layer with grayish-brown clay break at 23.2'. Trace of dispersed polyhalite. (17)	
8		4.4	4.4	100	X	23.8'-27.5' HALITE: Clear, coarsely crystalline. Scattered irregular anhydrite laminae. (1, 8)	Run 8. Broken up last 3".
9	30	4.7	4.7	100		27.5'-29.2' ARGILLACEOUS HALITE: Clear to medium brown (5YR 4/4) fine to coarsely crystalline. < 1 to 3% brown intercrystalline clay. < 1/2% dispersed polyhalite. Trace of gray clay. (12)	Run 9. Core broken up last 2' of run but within one unit.
						29.2'-31.4' HALITE: Clear, coarsely crystalline. (1)	
10	35	4.2	4.2	100	X	31.4'-32.4' HALITE: Clear with some moderate brown (5YR 4/4, 3/4) coarsely crystalline < 1% brown clay. (8)	Run 10 & 11. Core broken up 38'-39.6'± all in clear halite.
					X	32.4'-35.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4) medium to coarsely crystalline. <1 to 4% brown clay. (10,16)	
11	40	4.8	4.8	100	X	35.3'-36.4' HALITE: Clear to moderate reddish orange 10R 6/6 and light gray (N7) fine to medium crystalline <1/2% dispersed polyhalite and < 1% gray clay. (9)	
						36.4'-37.1' ANHYDRITE: Very light to light gray microcrystalline anhydrite. Scattered halite growths. Some horizontal laminae 1/2" brown clay seam at 36.4'.	
12	45	3.0	3.0	100	X		Run 12. Some broken core last 1.5'.
13		4.5	4.5	100		37.1'-40.6' HALITE: Clear mottled with moderate reddish orange (10R 6/6) coarsely crystalline. ≤ 1% polyhalite blebs. Scattered white very light gray anhydrite/magnesite? (1,2)	
	50					40.6'-43.0' HALITE: Clear with some moderate brown (5YR 3/4; 4/4) and mottled with moderate reddish orange (10R 6/6) fine to coarsely crystalline. < 1% polyhalite. <1% clay. (2,17)	
	55				X		

26.0 30.4 35.1 39.3 44.1 47.1 51.6

BORING NO. DH-19

WIPP

WASTE ISOLATION PILOT PLANT SHEET 3 OF 3 BORING NO. DH-19

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
						43.0'-44.4' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4; 4/4) coarsely crystalline. <1 to 3% brown intercrystalline clay. (10)	
						44.4'-46.0' HALITE: Clear, coarsely crystalline. < 1% polyhalite blebs. (2)	
						46.0'-51.35' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4; 4/4) fine to coarsely crystalline. <1 to 3% brown clay, intercrystalline and scattered breaks. 3/8" brown clay seam at 51.0'. (12,16)	
						51.35'-51.6' HALITE: Clear, coarsely crystalline. ≤1% polyhalite blebs. (2)	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-20

LOCATION N1100 DRIFT; FLOOR

STATION N1109± E206± COLLAR ELEV. 1306.2 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10,794.2 E7101.7 DEPTH OF BOREHOLE 51.1'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 1/31/84 (DAY) DATE COMPLETED 1/31/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.3	2.3	2.3	100		0.0'-2.05' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. < 1 to 4% brown clay, intercrystalline. Break at 0.7'. [10]	Watson Drill. AW Rods. 3' single tube barrel to start hole from 0.0' to 4.6'. Then 5' NX double tube barrel.
2	2.3 – 4.6	2.3	2.3	100		2.05'-8.15' HALITE: Clear, medium to coarsely crystalline. ≤ 1% clay. Brown clay to 2.4', then gray. < 1/2% polyhalite. [2, 8]	Drill time: 5 hours. Dry; No gas.
3	4.6 – 8.6	4.0	4.0	100		8.15'-10.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 4% polyhalite. [7]	
4	8.6 – 13.6	5.0	5.0	100		10.4'-13.0' MB-139: From 10.4'-11.15' mixture of moderate reddish orange halite and anhydrite. From 11.15', predominantly white to light gray (N7) to medium gray (N5) microcrystalline anhydrite, some halite intergrowths. Tightly welded upper contact. Up to 1/2" gray, hard clay at lower contact dipping 15° ±. Halite laminae just above clay. Anhydrite is laminated. Near-horizontal, irregular tightly closed hairline fractures in core 12.2'-12.5'.	Core locally, broken up, disturbed due to drilling.
5	13.6 – 18.0	4.4	4.1	93.2		13.0'-17.15' HALITE: Clear to moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤ 1% polyhalite ≤ 1% gray and some brown clay. Break at 15.3'. [9, 17]	
6	18.0 – 22.9	4.9	4.5	91.8		17.15'-20.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 4% polyhalite increasing content 18.0'-20.7'. Gray clay < 1/16" at 20.7'. Some anhydrite mixed with halite 20.4'-20.7'. [3, 4, 7] 20.7'-22.85' HALITE: Clear mottled with moderate reddish orange and gray medium to coarsely crystalline. ≤ 1% polyhalite. ≤ 1% gray intercrystalline clay. Clear from 21.5'-21.9'. [9]	
7	22.9 – 25	5.0	4.9	98			

BORING NO. DH-20

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-20

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	5.0	4.9	98		22.85'-29.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. < 1% gray intercrystalline clay. Some anhydrite 28.35'-28.55'±. [3, 4, 7]	
8	30	4.9	4.9	100		29.0'-32.2' HALITE: Clear with some moderate reddish orange (10R 6/6) medium to coarsely crystalline. < 1/2% gray intercrystalline clay. < 1/2% dispersed polyhalite. [2,9]	
9	35	4.8	4.8	100		32.2'-36.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. < 1% polyhalite from 34'-35.05'. Scattered anhydrite stringers below 35'. [3, 4, 7] 36.8'-37.8' HALITE: Clear, coarsely crystalline. ≤ 1% polyhalite. Scattered anhydrite stringers. Mixture of halite and some anhydrite at 37.1' to 37.25'. [2]	
10	40	5.0	5.0	100		37.8'-38.3' ANHYDRITE: White to light gray (N7), microcrystalline. Growths of halite especially common to 37.95'. Hard gray clay parting at 38.3'. 38.3'-42.6' HALITE: Clear, some light gray (N7) to medium with some coarsely crystalline. ≤ 1% gray clay, locally up to 2%. Some brown clay present. Gray break at 39.25'. Brown colored break at 39.8'. [9, 11]	
11	45	5.0	5.0	100		42.6'-45.8' HALITE: Clear, coarsely crystalline. <1/2% gray intercrystalline clay and polyhalite blebs. Break at 45.45'. [2, 11] 45.8'-47.6' HALITE: Clear to grayish brown, medium to coarsely crystalline. ≤ 1% brown clay, trace of gray. < 1% polyhalitic. [17]	
12	50	3.5	3.5	100		47.6'-51.1' HALITE: Clear medium to coarsely crystalline. ≤ 1% dispersed gray clay and polyhalite. [9]	
	55						

27.9 32.8 37.6 42.6 47.6 51.1

BORING NO. DH-20

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-21

LOCATION N1420 DRIFT; ROOF

STATION N1421± E786± COLLAR ELEV. 1331.0 DIRECTION OF DRILLING VERTICAL-UP

MINE COORDINATES N11,109.1 E7680.9 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/26/84 (SWING) DATE COMPLETED 2/27/84 (SWING) SHEET

LOGGED BY: J. F. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0–2.3	2.3	2.3	100		0.0'-6.7' HALITE: Clear with some moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% polyhalite and < 1/2% intercrystalline gray clay. 1/2" gray clay seam at 6.7'. [3, 9]	Watson drill: AW rods; NX double tube core barrel. Drilling time: 8 hrs± No gas. Dry hole.
2	2.3–7.0	4.7	4.6	98		6.7'-11.0' HALITE: Clear, coarsely crystalline. Scattered white stringers of anhydrite/magnesite. [1]	Core shows discing, broken zones throughout.
						11.0'-11.8' HALITE: Clear to light gray (N7) coarsely crystalline, < 1% intercrystalline gray clay. [11]	
3	7.0–11.6	4.6	4.3	94		11.8'-13.1' HALITE: Clear, medium to coarsely crystalline. < 1/2% dispersed polyhalite and gray clay. [1, 9]	Run 2. Some broken core.
4	11.6–15.7	4.1	4.1	100		13.1'-17.9' HALITE: Clear to light gray (N7) and locally grayish brown. Coarsely crystalline. None to ≤1% intercrystalline gray clay. Trace brown clay at 17.3'-17.5'±. Clear halite at 13.1'-14.4' and 17.7'-17.9' ±. [11]	Run 3. Broken core, discing. Run 4. Discing throughout. Run 5. Broken core much of run.
						17.9'-19.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. < 1 to 3% intercrystalline brown clay, trace of gray. Break at 18.95'. [12, 17]	Run 6. Discing below anhydrite in this run.
5	15.7–18.7	3.0	2.7	90		19.2'-19.8' ANHYDRITE: White to light gray (N7) microcrystalline anhydrite to 19.6'. Then mixture of polyhalitic halite and anhydrite. Irregular laminae in some of the anhydrite. Up to 3/4" hard brown clay at 19.2'. Some core grinding noted.	
6	18.7–23.3	4.6	4.6	100		19.8'-26.0' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6 ; 10R 4/6). Coarsely crystalline. < 1/2% clay and anhydrite locally. [3-5, 7]	Contact at 26.0' is approximate due to broken up core.

BORING NO. DH-21

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-21

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	4.7	4.2	89		26.0'-27.0' HALITE: Clear to light moderate reddish orange (10R 6/6). Fine to medium, some coarsely crystalline. < 1% dispersed polyhalite.	Run 7. Much of the core is broken up.
28.0						27.0'-29.3' HALITE: Clear, mottled with moderate brown (5YR 3/4), and dark reddish brown (10R 3/4). Coarsely crystalline. < 1/2% polyhalite and < 1% brown clay. [2, 8]	Run 8. Discing, broken core in part of run.
8	30	5.0	4.7	94		29.3'-31.1' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and dark reddish brown (10R 3/4). Medium to coarsely crystalline. < 1 to 4% brown clay, intercrystalline and breaks throughout. [15]	Run 9. Discing, broken core in most of run. Runs 10, 11, 12. Discing in coarse crystalline halite.
33.0						31.1'-33.0' HALITE: Clear to moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6). Fine to coarsely crystalline. < 1/2% dispersed polyhalite. < 1% intercrystalline brown clay. Mostly brown clay mixed with some halite at 32.7-32.9'. Break at 33.0'. [12, 17]	
9	35	4.7	4.7	100			
37.7						33.0'-41.35' POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6), moderate reddish brown (10R 4/6), and moderate brown (5YR 3/4). Coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% brown intercrystalline and intra-crystalline clay. [4, 5, 7]. Mostly brown clay with some halite at 37.7-37.95'. ≥ 5% clay at 38.45-38.65'±. [10]	
10	40	4.3	4.3	100			
42.0						41.35'-42.0' ARGILLACEOUS HALITE: Moderate brown (5YR 3/4; 4/4) to reddish brown (10R 3/4), medium crystalline. < 3 to 10% brown clay. [10, 16]	
11	45	4.0	4.0	100		42.0'-44.9' HALITE: Clear mottled with moderate reddish orange/brown (10R 6/6; 4/6) polyhalite blebs and patches. Coarsely crystalline. ≤ 1% polyhalite. 1/2" anhydrite layer at 42.2'. No clay. This core is similar to some found from 33-35' but less polyhalite. [2-4]	
46.0							
12	50	4.4	4.4	100		44.9'-48.6' HALITE: Clear to moderate brown (5YR 3/4; 4/4), coarsely crystalline. < 1 to 2% brown inter-crystalline and intracrystalline clay. > 10% brown clay at 46.0-46.3'±. Break at 46.4'±. [10]	
50.4	55					48.6'-50.4' HALITE: Clear, some moderate brown (5YR 4/4), medium to coarsely crystalline. < 1% brown, trace gray, intercrystalline clay. < 1/2% polyhalite. [8]	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-22

LOCATION N1420 DRIFT - FLOOR

STATION N 1421.5 ± E 785.5 COLLAR ELEV. 1318.8 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N 11,109.2 E 7680.9 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/27/84 (SWING) DATE COMPLETED 2/29/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 4.8	4.8	4.8	100		0.0'-5.1' HALITE: Clear, coarsely crystalline. < 1% gray intercrystalline clay locally. < 1/2% polyhalite. [1)	Watson drill AW rods. NX double tube core barrel. Drilling time: 8-1/2 hours ± Overall core quality is good. Only a couple of broken zones. No gas. Dry hole.
						5.1'-9.5' HALITE: Clear to light and medium gray (N7, N5) coarsely crystalline. ≤ 1% gray intercrystalline clay. Steeply dipping, irregular break at 7.65'-7.8'. [11)	
2	4.8 – 8.8	4.0	4.0	100		9.5'-11.7' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite, blebs and dispersed. [3)	
3	8.8 – 10.5	1.7	1.7	100		11.7'-15.0' HALITE: Clear to light gray (N7), some moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% gray intercrystalline clay and < 1/2% dispersed polyhalite. [9)	
4	10.5 – 15.1	4.6	4.6	100		15.0'-21.55' HALITE: Clear, coarsely crystalline. None to < 1% polyhalite blebs. < 1/2% gray intercrystalline clay locally. [1.2)	Run 4. Broken up top 0.2' of run.
5	15.1 – 17.1	2.0	2.0	100		21.55'-24.3' MB-139: From 21.55' to 23.10' core shows "swallowtail" pattern a mixture of anhydrite and halite. Slight trace of gray clay on upper contact which dips 35°±. Predominantly halite from 23.10'-23.2'. Then mostly it gray (N7) to white anhydrite with scattered halite growths irregular laminae. Several hairline, tightly closed fractures at 23.9'-24.15' ±. Horizontal halite laminae at 23.2' ±. Trace of gray clay at 24.3'.	Run 5. Core spring worn out. Left 3' of core in hole.
6	17.1 – 21.0	3.9	3.1	79		24.3'-28.0' HALITE: Clear to light gray (N7), medium to coarsely crystalline. ≤ 1% gray intercrystalline clay. < 1/2% polyhalite. Break at 25.2'. [9)	Run 6. Broken up 17.5' - 18.5'.
7	21.0 – 25.1	4.1	4.1	100			

BORING NO. DH-22

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-22

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
25.1							
8		4.7	4.7	100		28.0'-32.25' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. Anhydrite mixed with halite at 32.0'-32.25'. (7)	
29.8	30					32.25'-34.5' HALITE: Clear with some light gray (N7), coarsely crystalline. ≤1% gray clay. Breaks at 33.85', 34.3'. (9,11)	
9		4.7	4.7	100		34.5'-40.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1% gray intercrystalline clay. Breaks at 38.0', 38.25'. <1 to 3% polyhalite. (3,4,7)	
34.5						40.5'-43.7' HALITE: Clear, medium to coarsely crystalline. <1% gray clay and<1/2% dispersed polyhalite. Break at 41.3'. (9)	
10	35	4.1	4.1	100		43.7'-47.85' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 4% polyhalite. < 1/2% gray clay locally. (7)	
38.6						47.85'-48.4' *ANHYDRITE: mixed halite and moderate* reddish brown (10R 4/6) anhydrite to 48.1'. From 48.1', mostly very light gray (N8) to white and moderate reddish brown (10R 4/6) anhydrite with scattered halite growths. <1/8" clay seam at 48.4'.	
11	40	5.1	5.1	100		48.4'-50.0' HALITE: Clear, coarsely crystalline. <1% gray intercrystalline clay. Break at 49.75'. (11)	
43.7							
12	45	2.0	2.0	100			
45.7							
13		4.3	4.3	100			Run 13. Broken up upper part of run.
50.0	50						

BORING NO. DH-22

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ - _____ HOLE TYPE/SIZE NX CORE BORING NO. DH-23

LOCATION N1100 DRIFT; ROOF

STATION N1112± E781± COLLAR ELEV. 1328.03 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N10,799.2 E7679.9 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/13/84 (SWING) DATE COMPLETED 2/15/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0–2.1	2.1	2.1	100		0.0'–1.2' HALITE: Clear to light moderate reddish orange (10R 6/6), fine to coarsely crystalline. <1/2% gray clay. Break at 0.25'. [2, 9]	NX Double tube core barrel. AW Rods. Watson drill mounted on single post jacked to floor/roof. Drilling time: 7 hours ±.
2	2.1–4.3	2.2	2.2	100		1.2'–1.9' ANHYDRITE a: White to medium light gray (N6) microcrystalline anhydrite. Growths of halite within. Gray clay seam <1/16" at 1.2'.	No gas. Dry hole.
3	4.3–6.3	2.0	2.0	100		1.9'–6.25' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. [3]	Core recovery difficult to measure because core is sometimes broken up into 1/2" to 1-1/2" discs and gravel size pieces.
4	6.3–8.0	1.7	1.7	100			
5	8.0–9.75	1.75	1.75	100		6.25'–11.05' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, some fine to medium. Brown and gray clay <1%. Brown clay seam ≤1/16" with some anhydrite at 11.05'. [9, 17]	
6	9.75–14.25	4.5	4.5	100		11.05'–14.25' HALITE: Clear, coarsely crystalline. Scattered white stringers of anhydrite/magnesite?. [1]	Run 2. Broken up last 0.6'. Run 3. Broken up some/discing. Run 6. Broken up 12-14'±.
7	14.25–15.7	1.45	1.45	100		14.25'–19.3' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. None to 2% brown clay. <1 to 2% clay from 14.25–15.7' and 18.5–19.3'. Clear from 17.0–18.5'. [8, 10]	Run 7. Zones of broken core. Run 8. Broken up last 0.6' of run.
8	15.7–17.7	2.0	2.0	100			
9	17.7–20.7	3.0	3.0	100		19.3'–23.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. Some fine to medium. <1 to 4% brown clay. [8, 10]	Run 10. Some broken zones above and below anhydrite.
10	20.7–25	4.75	4.75	100		23.5'–24.4' ANHYDRITE: White to very light gray (N8) microcrystalline anhydrite. Scattered polyhalitic halite growths, especially common 24–24.4'±. 3/4" brown clay seam at 23.5'.	

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-23

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
10	25.45 – 25	4.75	4.75	100		24.4'-28.15' HALITE: Clear, some moderate reddish orange, coarsely crystalline. < 1% polyhalite blebs. 1/2" white anhydrite layer at 25.1'±. Up to 3% polyhalite with trace gray clay at 27.45-27.95'. [2]	Run 11. Broken zones beyond 26.7'. Run 15. Broken up last 12"± of run.
11	29.75 – 30	4.3	4.3	100		28.15'-31.45' HALITE: Clear to moderate brown (5YR 4/4) and moderate reddish orange (10R 6/6), coarsely crystalline, some fine. Brown clay < 1 to 2%, locally. < 1 to 2% polyhalite blebs and patches. [17]	Contact at 28.15 is approximate due to broken core in Run 11.
12	34.0 – 35	4.25	4.25	100		31.45'-33.2' HALITE: Clear, coarsely crystalline. < 1% brown clay blebs. [8]	
13	38.4 – 40	4.4	4.4	100		33.2'-36.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and some moderate reddish orange (10R 6/6). Coarsely crystalline. < 1 to 3% brown clay, intercrystalline and breaks. 1/4"± brown clay seam at 33.8'±. ≤ 1/16" clay partings at 35.4' and 36.5'. [10]	
14	43.4 – 45	5.0	4.9	98		36.5'-38.1' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite blebs and patches. Scattered anhydrite stringers. [2, 3]	
15	47.8 – 50	4.4	4.4	100		38.1'-41.65' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% gray clay. Trace brown clay at 41.65'. [4, 5]	
16	51.0 – 55	3.2	3.2	100		41.65'-42.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline, some medium. < 1 to 5% brown clay. 1" brown clay seam with some halite at 42.7'. [12, 17]	
						42.9'-44.3' ANHYDRITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite. [2, 5]	
						44.3'-46.2' HALITE: Clear to moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Coarsely crystalline to 44.9', then fine to medium. ≤ 1% brown and gray clay. < 1% dispersed polyhalite. < 1/4" brown clay seam at 46.05'. Anhydrite at 46.05-46.2'. [9, 17]	
						46.2'-48.25' HALITE: Clear, coarsely crystalline. < 1% moderate reddish orange polyhalite blebs. [1]	
						48.25'-51.0' HALITE: Clear to moderate reddish brown (10R 4/6) coarsely crystalline. < 1 to 2% brown clay and ≤ 1% polyhalite blebs. [8, 10]	

BORING NO. DH-23

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-24

LOCATION N1100 DRIFT; FLOOR

STATION N 1112 ± E 781 ± COLLAR ELEV. 1319.51 DIRECTION OF DRILLING DOWN - VERTICAL

MINE COORDINATES N10,799.2 E7679.8 DEPTH OF BOREHOLE 49.4'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/15/84 (SWING) DATE COMPLETED 2/16/84 (DAY) SHEET

LOGGED BY: J.E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0.0					
1		1.6	1.5	94	X	0.0'-3.3' HALITE: Clear, coarsely crystalline. < 1/2% polyhalite blebs.	Watson drill. AW rods. NX double tube core barrel mounted on post jacked to floor/roof. Still vibration from drill motor, but post is stable.
1.6							
2		1.5	1.5	100	X	3.3'-5.2' HALITE: Clear, coarsely crystalline. < 1/2% gray clay and polyhalite blebs.	
3.1							
3	5	2.9	2.9	100	X	5.2'-7.15' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤1% gray clay, locally up to 2%. Breaks and intercrystalline. Breaks at 6.05'; 6.85'. < 1/2% polyhalite.	
6.0							
4	10	4.5	4.5	100	X X	7.15'-10.7' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline < 1% to 2% polyhalite blebs and dispersed increasing content from 9.1' to 10.7'. Gray clay break at 10.35'.	Run 5. Several broken zones in core. Loss throughout. Contacts at 10.7'; 12.6' approximate only.
10.5							
5	15	5.3	3.6	68	X	10.7'-12.6' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1) medium to coarsely crystalline. ≤ 1% gray intercrystalline clay. Break at 10.9'. 12.6'-20.8' HALITE: Clear, coarsely crystalline. 1/2% polyhalite blebs. None to < 1% gray intercrystalline clay. Break at 20.75'.	
15.8							
6	20	5.0	5.0	100	X	20.8'-24.0' MB-139: From 20.8' to 22.4' is mixture of anhydrite and halite. "Swallowtail" pattern. From 22.4 to 24.0' is white to medium gray (N5) microcrystalline anhydrite. Scattered halite growths. Irregular laminae in core. Tightly closed hairline fractures in core from 23.5' to 24.0'. Up to 3/4" gray clay.	
20.8							
7	25	5.0	5.0	100	X	24.0'-28.3' HALITE: Clear with some moderate reddish orange (10R 6/6) and light gray (N7), medium to coarsely crystalline, some fine. < 1/2% dispersed polyhalite and < 1% gray intercrystalline clay. Breaks at 24.4'; 24.8'.	

[redacted]

BORING NO. DH-24

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-24

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25.8	5.0	5.0	100		28.3'-31.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Up to 1" anhydrite layer in core.	
8	30 / 30.7	4.9	4.9	100		31.8'-34.2' HALITE: Clear with some light gray (N7), medium to coarsely crystalline < 1% gray intercrystalline clay. < 1/2% dispersed polyhalite. Core broken up in this section. Some core loss.	Run 9. Broken up last 1/2 of core. Probable loss from 32.1'-34.2'.
9	34.2	3.5	3.5	100		34.2'-35.2' HALITE: Clear, coarsely crystalline. < 1% polyhalite blebs.	
10	35 / 39.4	5.2	5.2	100		35.2'-38.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), some medium light gray (N6), coarsely crystalline. < 1 to 3%, locally to 5%, polyhalite. < 1/2% gray clay.	Run 11. Measured rods 42.4". Probable loss within last 2" of run.
						38.4'-43.0' HALITE: Clear with some light moderate reddish orange (10R 6/6) fine to coarsely crystalline. < 1/2% dispersed polyhalite and gray clay. 0.5' core loss within this zone.	
11	40 / 42.4	3.0	2.5	83		43.0'-44.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 5% polyhalite.	
12	45 / 47.7	5.3	5.3	100		44.4'-48.25' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite blebs, patches and dispersed. Predominantly polyhalite 47.35'-47.45'.	
						48.25'-48.6' ANHYDRITE: Very light gray (N8) to medium light gray (N6) microcrystalline anhydrite. Scattered halite growths. Up to 1" clear, coarsely crystalline halite from 48.3'-48.4' ±. < 1/16" gray clay at 48.6'. Some core grinding evident.	
13	49.4	1.7	1.7	100		48.6'-49.4' HALITE: Clear to light gray (N7); medium to coarsely crystalline. < 1 to 2% gray clay. Breaks at 48.7' and 49.0'.	
	50 / 55					Note: Overall recovery below 95%. Replacement hole DH-24A drilled later. Refer to the drill log for DH-24A.	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-24A

LOCATION N1100 DRIFT - FLOOR

STATION N1112 ± E780 ± COLLAR ELEV. 1319.49 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10799.08 E7678.59 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/21/84 (SWING) DATE COMPLETED 3/22/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/23/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.2	2.2	2.0	91		0.0'-0.1' FILL:	Watson Drill AW rods. Run 1. Used 3' double tube barrel first run to start hole. NW split tube barrel used after first run. Drill Time: 5 hours ±.
2	2.2 – 5.0	2.8	2.8	100		0.1'-3.3' HALITE: Clear to light moderate reddish orange (10R 6/6); coarsely crystalline. < 1/2% dispersed polyhalite. [1, 2]	
3	5.0 – 10.1	5.1	5.1	100		3.3'-7.4' HALITE: Clear to medium gray (N5); coarsely crystalline. ≤ 1% gray clay. [1, 11] 7.4'-10.2' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. ≤1% polyhalite, increasing content 9.2' to 10.2'. [2, 3]	
4	10.1 – 15.2	5.1	5.1	100		10.2'-15.9' HALITE: Clear to medium light gray (6); light bluish gray (5B-7/1) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray clay. Breaks at 10.95'; 11.85'. < 1/2% polyhalite. [11] 15.9'-21.3' HALITE: Clear with some light moderate reddish orange; coarsely crystalline, some medium. < 1/2% gray clay and polyhalite. [2]	
5	15.2 – 20.3	5.1	4.9	96		21.3'-23.95' MB-139: From 21.3' to 22.5' is mixture of anhydrite and halite partially in a "swallowtail" pattern. Upper contact dips 20° ± with tightly closed fracture along base. Below 22.5' is white to light gray (N7) to moderate reddish orange anhydrite scattered halite growths. 1/2" gray clay at lower contact.	
6	20.3 – 25.4	5.1	5.1	100		23.95'-28.6' HALITE: Clear to light moderate reddish orange 10R 6/6 and trace of light gray (N7) medium to coarsely crystalline. < 1% dispersed polyhalite and < 1/2% gray clay. [2, 3, 9]	

BORING NO. DH-24A

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-24A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25.4 / 25						
7		5.0	5.0	100		28.6'-32.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Irregular gray clay break at 32.1'. [2, 4, 7]	
	30 / 30.4					32.1'-34.4' HALITE: Clear to medium light gray (N6) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. < 1/2% dispersed polyhalite and < 1/2% gray clay. [9]	
8		5.0	5.0	100		34.4'-40.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline with some medium. None to 3% polyhalite. < 1/2% gray clay locally. [2-5, 7]	
	35 / 35.4					40.5'-43.7' HALITE: Clear to medium light gray (N6) and some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray intercrystalline clay and < 1/2% dispersed polyhalite. [9]	Run 9. Driller increased RPM's on last 2' of run.
9		5.0	3.0	60		43.7'-48.55' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. < 1/2% gray clay locally. [3, 4, 7]	
	40 / 40.4					48.55'-49.2' HALITE: Clear, coarsely crystalline, some medium. Scattered white anhydrite stringers. [1, 2]	
10		4.9	4.9	100		49.2'-49.5' ANHYDRITE: White to medium light gray (N6), microcrystalline. Scattered halite growths. Trace of gray clay at 49.5'.	
	45 / 45.3					49.5'-50.4' HALITE: Clear with some moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% polyhalite. < 1/2% gray clay. [1, 9]	
11		5.1	5.1	100			
	50 / 50.4						
	55						

BORING NO. DH-24A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX BORING NO. DH-25

LOCATION N1420 Drift at Room C-2 Intersection

STATION N 1422, E 1510 COLLAR ELEV. 1318.8 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N 11109.72, E 8403.78 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Rotary/Air DRILL MAKE/MODEL Watson Model 750

DATE STARTED 3/29/84 (swing) DATE COMPLETED 3/30/84 (swing) SHEET

LOGGED BY: J. E. Gallegani DATE: 4/18/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.5	2.5	2.5	100		0.0'-4.6' HALITE: Clear to light gray (N7) and light moderate reddish orange (10R 6/6), medium to coarsely crystalline. < 1% gray clay. < 1/2% dispersed polyhalite. [1, 9]	Watson drill, post-mounted, AW rods, S&H NX double-tube. Drilling time: 5 hrs. ±
2	2.5 – 6.9	4.4	4.4	100		4.6'-7.0' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. 1/2" gray anhydrite layer at 4.85'. Trace of gray clay at 4.85'. [1] 7.0'-9.3' HALITE: Clear to light gray (N7) and some moderate brown (5YR 4/4). Fine to coarsely crystalline. ≤ 1% gray clay. ≤ 1% brown clay from 8.5'-8.85'. Clay break at 8.6'. [11]	
3	6.9 – 10.9	4.0	4.0	100		9.3'-12.4' HALITE: Clear, coarsely crystalline. [1] 12.4'-15.4' HALITE: Clear to light gray (N7), medium light gray (N6), and locally some moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray clay. 1/2" clay and halite seam at 15'. < 1/2% dispersed polyhalite. [11]	
4	10.9 – 15.9	5.0	5.0	100		15.4'-16.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. < 1 to 3% brown clay, trace gray. [12, 16]	
5	15.9 – 16.9	1.0	1.0	100		16.9'-17.4' HALITE: Clear, coarsely crystalline. < 1/2% dispersed polyhalite. [2]	
6	16.9 – 20.5	3.6	3.6	100		17.4'-18.15' ANHYDRITE: White to medium light gray (N6), microcrystalline anhydrite. Faintly laminated. Growths of halite within. Trace of brown clay at 17.4'. Some polyhalite along upper contact. 18.15'-21.6' HALITE: Clear mottled with moderate reddish orange (10R 6/6), coarsely crystalline. None to 2% polyhalite. [1, 2]	Run 6: Broken-up last 12" of run. Run 7. Discing of core.
7	20.5 – 25	5.4	5.4	100			

BORING NO. DH-25

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-25

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
25.9	7	25	5.4	5.4	100		21.6'-27.4' HALITE: Clear to moderate brown (5YR 4/4), fine to coarsely crystalline. < 1 to 2% brown clay, locally argillaceous. Breaks at 21.8'±, 23.6'±, 24.0'±. Brown clay seam at 24.05'. Coarsely crystalline 24.1'-27.4'. [8, 10, 12]	
	8	30	5.0	5.0	100		27.4'-29.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline, some fine. < 1 to 4% brown clay, intergranular and scattered breaks. [12]	
30.9	9	35	4.4	4.4	100		29.6'-34.3' POLYHALITIC HALITE: Clear to moderate reddish orange, coarsely crystalline. < 1 to 3% polyhalite. Average < 2%. [3, 4] 34.3'-35.3' HALITE: Clear, coarsely crystalline. < 1/2% polyhalite blebs. [1]	Run 9. Broken-up core, discing.
35.3 36.2	10		0.9	0.9	100		35.3'-48.5' HALITE: Clear with patches of moderate brown (5YR 3/4; 4/4) and traces of moderate reddish orange (10R 6/6). Coarsely crystalline, some medium to 36.4'. < 1 to 2% brown clay. 1/2" brown clay seam with some halite at 36.25'. Mostly brown clay mixed with halite from 38.9-39.2'. > 30% clay here. ≤ 1% polyhalite blebs and patches. Clay breaks at 46.6'±, 46.8'±, 47.2'±, 48.5'. Argillaceous halite at 46.35'-47.2'. [1, 8, 10]	Run 10. Broken-up core.
	11	40	4.6	4.6	100		48.5'-49.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. [3, 4]	
40.8 42.1	12		1.3	1.3	100		49.7'-51.8' HALITE: Clear with some light gray (N7) and moderate reddish orange (10R 6/6). Coarsely crystalline. ≤ 1% gray clay and polyhalite blebs and patches. [9, 11]	Run 12. Broken-up core.
	13	45	4.7	4.7	100			
46.8	14	50	5.0	5.0	100			
51.8								

BORING NO. DH-25

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX Core BORING NO. DH-26

LOCATION N1420 Drift at Room C-2 Intersection

STATION N 1427, E 1510 COLLAR ELEV. 1307.2 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N 11114.32, E 8403.78 DEPTH OF BOREHOLE 53.0 Ft.

DRILLING METHOD Rotary/Air DRILL MAKE/MODEL Watson Model 750

DATE STARTED 3/30/84 (swing) DATE COMPLETED 3/30/84 (swing) SHEET

LOGGED BY: J. E. Gallerani DATE: 4/18/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 4.2	4.2	4.2	100		0.0'-6.2' HALITE: Clear, coarsely crystalline, some medium. < 1/2% gray intercrystalline clay. < 1/2% polyhalite. [1, 2]	Watson drill, AW rods, NX double-tube core barrel, except run 4 where NW split-tube barrel was used.
						6.2'-9.8' HALITE: Clear to medium light gray (N6), coarsely crystalline. ≤ 1% gray clay. Breaks at 7.75', 8.1', 9.6'. [11]	Drill time: 4 hrs. No gas. Dry hole.
2	4.2 – 7.5	3.3	3.3	100		9.8'-12.5' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite [1, 2]	Overall core is fair with some broken zones and discing.
3	7.5 – 12.1	4.6	4.6	100		12.5'-19.3' HALITE: Clear to medium light gray (N6) and light moderate reddish orange (10R 6/6). Fine to coarsely crystalline. ≤ 1% gray clay. < 1/2% polyhalite. [1, 9]	Run 2. Discing of core.
						19.3'-21.8' HALITE: Clear with some moderate reddish orange (10R 6/6), coarsely crystalline. None to < 1% polyhalite. [1, 2]	
4	12.1 – 13.5	1.4	0.85	61		21.8'-23.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Scattered anhydrite. < 1/2% gray clay. [4, 6]	Run 4. Tried split-tube core barrel but barrel plugged-off while drilling.
5	13.5 – 18.2	4.7	4.7	100		23.3'-25.9' MB-139: Very light gray (N8) to medium light gray (N6) anhydrite with scattered halite growths. Anhydrite is partly laminated. 1-1/2" hard gray clay seam at lower contact.	
						25.9'-29.8' HALITE: Clear to moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline. ≤ 1% gray clay and < 1% polyhalite. [2, 9]	
6	18.2 – 23.2	5.0	5.0	100		29.8'-33.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Gray clay break at 33.3'. Anhydrite mixed with halite from 33.05'-33.3'. [7]	
						33.3'-36.0' HALITE: Clear with some moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline. < 1/2% dispersed polyhalite. < 1% gray intercrystalline clay. [9]	

BORING NO. DH-26

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-26

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	5.0	5.0	100		36.0'-41.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline to 39.6', then medium to coarse. < 1 to 3% polyhalite blebs and dispersed. < 1/2% gray clay locally. Scattered anhydrite 39.6'-40.0'±. [3, 7]	
8	30	4.8	4.8	100		41.0'-44.0' HALITE: Clear to light bluish gray (5B 7/1) and light gray (N7) and some moderate reddish orange, medium to coarsely crystalline. ≤ 1/4" gray clay seams at 36.1'± and 41.7'±. ≤ 1% clay. [9] 44.0'-48.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. [7]	
9	35	5.0	5.0	100		48.8'-49.6' ANHYDRITE: Moderate reddish orange anhydrite to 49'. Then halite with some anhydrite from 49'-49.1'. Then medium light gray (N6) to light gray (N7) anhydrite. Trace of gray clay at 49.6'. 49.6'-53.0' HALITE: Clear to medium light gray (N6), medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% dispersed polyhalite. [1, 9]	
10	40	5.0	5.0	100			
11	45	5.0	3.6	72			Run 11. Discing of core. Run 12. Broken-up in upper one foot. Considerable chipping of core surface below the anhydrite.
12	50	5.0	5.0	100			
	55						

28.2 33.0 38.0 43.0 48.0 53.0

BORING NO. DH-26

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-27

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1107, W682 COLLAR ELEV. 1300.8 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10,793.7, E6218.4 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-26-84 DATE COMPLETED 7-27-84 SHEET

LOGGED BY: J. GALLERANI DATE: 7-28-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	3.0	3.0	2.8	93		0.0'-4.5' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% polyhalite. [1, 2]	NC double tube wireline core barrel. NC rods.
2	6.3	3.3	3.3	100		4.5'-5.8' HALITE: Clear to moderate brown (5YR 3/4), coarsely crystalline, some medium ≤1% to 2% locally, brown clay.. Parting @ 5.5'. [8, 10]	Note: Drilled 0.0-3.0' with 2-5/8" inside diameter single tube core barrel. Total drilling time: 13 hrs.
						5.8'-6.95' HALITE: Clear to moderate reddish brown (10R 4/6), grayish red (10R 4/2), medium to coarsely crystalline, some fine ≤1% to 2% dispersed polyhalite and <1% gray and brown clay.	
3	8.5	2.2	2.2	100		6.95'-7.20' ANHYDRITE b: Light (N7) to medium light gray (N6), microcrystalline anhydrite. Halite growths within, most common in middle of unit.	
4	13.0	4.5	4.5	100		7.20'-12.95' HALITE: Clear, coarsely crystalline, scattered white stringers of anhydrite. <1/2% polyhalite. Trace of gray clay @ 12.3'. [1]	
						12.95'-13.95' HALITE: Clear to moderate reddish orange (10R 6/6), fine to coarsely crystalline. ≤1% polyhalite and <1% gray clay. [9]	
5	18.0	5.0	5.0	100		13.95'-14.55' ANHYDRITE a: Very light (N8) to medium light gray (N6), microcrystalline anhydrite, irregular laminae. Scattered halite growths most common from 14.25 to 14.55'. Pinkish gray color here. Trace of gray clay @ 13.95'.	
						14.55'-18.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite. [4, 7]	
6	21.2	3.2	3.2	100		18.4'-23.9' HALITE: Clear to moderate brown (10R 4/6), some moderate reddish orange (10R 6/6), coarsely crystalline, some medium. None to 2% brown clay. ≤1% polyhalite from 22.1'-22.9' ±. Scattered anhydrite to 19.4' [8, 10]. ≤3/8" brown clay seam at 23.7'. 1/2" anhydrite above @ 23.85'.	
7	25	4.8	4.3	90		23.9'-28.6' HALITE: Clear, coarsely crystalline, trace brown clay from 27.2'± and some medium crystalline. [1] [8 from 27.2']	Runs 7-12: Broken core zones in coarsely crystalline, clear halite.

BORING NO. DH-27

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-27

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	4.8	4.3	90		28.6'-30.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4), fine to medium, some coarsely crystalline. <1% to 3% brown clay. [12]	
8	30	4.8	3.5	73		30.5'-32.4' HALITE: Clear, trace of light moderate brown, coarsely crystalline. <1/2% brown clay. Core broken up @ 30.8'-31.4'. [1, 8]	39% of core recovered was ≥2 inches in length.
						32.4'-36.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4), some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% to 3% brown clay. <1/2% dispersed polyhalite. Scattered breaks. [10, 12]	
9	35	3.8	3.7	97		36.2'-36.95' ANHYDRITE: Very light (N8) to light gray (N7), some moderate reddish orange anhydrite. Scattered halite growths within. 3/4" hard brown clay @ 36.2'.	
						36.95'-40.3' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline <1%, locally 2%, polyhalite, scattered white anhydrite stringers. [1, 3]	
10		3.4	2.9	85		40.3'-41.4' POLYHALITIC HALITE: Clear, to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite. [4, 7]	
11	40	4.5	3.9	87		41.4'-42.55' HALITE: Clear, some moderate brown (5YR 4/4) coarsely crystalline, some medium, <1% brown clay, break @ 42.5'. [1, 8]	
						42.55'-46.4' HALITE: Clear to moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Coarsely crystalline, some medium. ≤2% polyhalite to 43'±; then <1% [1, 2]. ≤2% brown clay at 43.65'-43.9' [12]. Break @ 44.3'.	
12	45	4.7	4.7	100		46.4'-47.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4), coarsely crystalline, <1% to 3% brown clay. Mixture of brown clay and halite seam at 47.1'-47.2'. [10]	
						47.2'-48.3' HALITE: Clear to moderate reddish orange/brown (10R 6/6, 4/6), medium to coarsely crystalline. ≤1% brown clay, <1% polyhalite. [17]	
13	50	3.3	3.3	100		48.3'-50.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline, some fine <2% to 5% brown clay. Scattered clay breaks [10, 15].	
	55						

Depth scale: 26.0, 30.8, 34.6, 38.0, 42.5, 47.2, 50.5

BORING NO. DH-27

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ - _____ HOLE TYPE/SIZE NC-CORE BORING NO. DH-28

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1107, W682 COLLAR ELEV. 1289.9 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10793.8, E6218.3 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-25-84 DATE COMPLETED 7-26-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-27-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 3.0	3.0	2.7	90		0.0'-4.2' HALITE: Clear, coarsely crystalline, some medium. <1% polyhalite, <1% clay, predominantly gray with trace of brown. [1, 2]	NC double tube wire-line core barrel with NC rods. Used 2-5/8" core bit, single tube barrel from 0.0'-3.0'. Total drilling time: 4.5 hrs. Core quality good, 75% of core recovered is ≥ 2" lengths.
2	3.0 – 7.8	4.8	4.75	98		4.2'-5.6' HALITE: Clear, mottled with some moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% polyhalite blebs. Trace of anhydrite. [2, 4] 5.6'-9.9' MB-139: Mixture of polyhalitic halite and anhydrite to 7.6'. Some "swallowtail" pattern. Then predominantly anhydrite with scattered halite growths. Light gray and moderate reddish orange to 8.4', then predominantly light (N7) to medium light (N6) gray. <1/8" gray clay at 9.9'.	
3	7.8 – 13.0	5.2	5.1	98		9.9'-13.65' HALITE: Clear to medium light gray (N6) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite. <1% gray clay. [9] 13.65'-18.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite. Anhydrite/halite @ 18.05'-18.25'. Irregular gray clay break at 18.3'. [4, 7]	
4	13.0 – 18.0	5.0	5.0	100		18.3'-20.4' HALITE: Clear to light gray (N7) and light moderate reddish orange (10R 6/6), medium to coarsely crystalline. ≤1% dispersed polyhalite and gray clay. [9] 20.4'-24.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite, trace of gray clay at 23.85'. [3, 4, 7]	
5	18.0 – 23.0	5.0	5.0	100		24.9'-25.9' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline, ≤1% dispersed polyhalite. [2] 25.9'-28.1' HALITE: Clear to moderate reddish brown (10R 4/6) and medium brown (5YR 3/4), medium to coarsely crystalline. <1% to 2% brown clay. ≤1% polyhalite. [17]	
6	23.0 – 25	5.1	5.1	100			

BORING NO. DH-28

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-28

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	5.1	100		28.1'-30.6' HALITE: Clear, medium to coarsely crystalline, <1/2% dispersed polyhalite, trace of gray clay locally. [2]	
						30.6'-35.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite [7]. Moderate reddish orange to light gray anhydrite, some halite, at 34.65'-34.9'.	
7	30	5.0	4.9	98		35.1'-35.35' ANHYDRITE: Light (N7) to medium light (N6) gray, microcrystalline. Scattered halite growths. ≤3/8" hard gray clay layer at lower contact.	
						35.35'-42.55' HALITE: Clear to light moderate reddish orange (10R 6/6) and medium gray (N5). Medium to coarsely crystalline. <1% dispersed polyhalite, ≤1% gray clay. [9, 11]	
8	35	5.0	5.0	100		42.55'-44.6' HALITE: Clear to moderate reddish brown (10R 4/6) and moderate brown (5YR 3/4). Medium to coarsely crystalline, <1% to 2% brown clay, some gray, <1% polyhalite dispersed. [17, some 9]	
						44.6'-47.9' HALITE: Clear to moderate reddish orange (10R 6/6), some medium gray (N5). Medium to coarsely crystalline, ≤1% polyhalite and ≤1/2% gray clay. [9]	
9	40	4.9	4.6	94		47.9'-50.5' HALITE: Clear, coarsely crystalline. [1]	
10	45	5.0	5.0	100			Core broken up at 39.6'-39.8'±.
11	50	2.5	2.5	100			

28.1 33.1 38.1 43.0 48.0 50.5

BORING NO. DH-28

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC-CORE BORING NO. DH-29

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W982 COLLAR ELEV. 1298.3 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10785.4, E5932.4 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-23-84 DATE COMPLETED 7-25-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-25-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	0						
1		2.2	2.2	100		0.0'-3.9' HALITE: Clear, coarsely crystalline. [1]	NC double tube wire line core barrel, NC stepped diamond bit. Used 2 ft starter barrel (2-5/8" core) from 0'-6.1' Total drilling time: 13½hrs.
2.2						3.9'-6.3' HALITE: Clear to moderate brown (5YR 3/4), coarsely crystalline, <1% to 2% brown clay.	
2		1.8	1.8	100		6.3'-7.55' HALITE: Clear to moderate brown (5YR 4/4) and grayish red. Fine to medium, some coarse, ≤1% clay, brown and gray. <1/2% dispersed polyhalite.	
4.0							
3	5	2.1	2.1	100		7.55'-7.75' ANHYDRITE b: Light gray (N7), microcrystalline, scattered halite growths. Trace of gray clay at 7.55'.	
6.1							Run 4: 6.1'-10.0', core not good, discing in clear halite.
4		4.6	4.6	100		7.75'-13.25' HALITE: Clear, coarsely crystalline. <1/2% polyhalite, Scattered white stringers.	Run 5: core not good, average length ~1" (discing).
	10					13.25'-14.3 HALITE: Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% gray clay. ≤1% to 2% polyhalite dispersed.	
10.7							
5		4.1	4.1	100		14.3'-14.8' ANHYDRITE a: Light gray to medium light gray microcrystalline anhydrite. Scattered halite growths. Trace of gray clay at 14.2'.	
						14.8'-19.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite.	
14.8							
6	15	4.7	4.7	100		19.6'-22.5' HALITE: Clear, some moderate brown, coarsely crystalline, some fine and medium. ≤1% brown clay. <1/2% dispersed polyhalite. Breaks at 20.75', 21.5'.	
						22.5'-24.4' HALITE: Clear, to moderate brown, fine to medium, some coarsely crystalline. <1% brown clay. <1/2% dispersed polyhalite.	
19.5							
7	20	4.9	4.9	100		24.4'-27.7' HALITE: Clear, coarsely crystalline. Scattered white anhydrite.	Run 7: bottomed in brown clay seam. Vibrated and broke core.
						27.7'-29.9' HALITE: Clear, mottled with moderate brown, coarsely crystalline, some medium. ≤1% to 2% brown clay. Core broken up to 29.2'.	
24.4	25						

M

BORING NO. DH-29

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-29

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					29.9'-31.7' HALITE: Clear, coarsely crystalline.	
8		4.8	4.8?	100?		31.7'-32.4 HALITE: Clear, some light moderate brown. Coarsely crystalline. <1/2% brown clay.	
						32.4'-37.35' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. <1% to 3% brown clay, scattered breaks.	Run 9: Very bad core 29.2'-33.0'.
29.2	30						
9		5.0	5.0	100		37.35'-38.25 ANHYDRITE: Light gray to medium light gray, microcrystalline anhydrite. Scattered halite growths. 1" hard brown clay layer at 37.35".	
						38.25'-44.4' HALITE: Clear, coarsely crystalline. None to <1% brown clay. Scattered white stringers. [1], [2]. Brown clay parting at 44.4'.	Circulation blocked @ 37.3'. Hit mud seam.
34.2	35						
10		5.0	5.0	100		44.4'-46.65 HALITE: Clear to moderate brown, coarsely crystalline, some zones of medium. <1% to 3%, locally, brown clay. Breaks at 46.35', 46.5' Argillaceous 44.4'-45.0' and 46.35'-46.5'.	
						46.65'-47.4' HALITE: Clear, coarsely crystalline. [1]	
						47.4'-47.9' HALITE: Clear, some moderate brown. Coarsely crystalline. ≤1% brown clay.	
39.2	40						Run 11: Some discing, broken in clear halite.
11		3.5	3.5	100		47.9'-48.9' ARGILLACEOUS HALITE: Clear to moderate brown, medium crystalline, some coarse. 3% brown clay. 1" halite and brown clay seam @ 47.9'.	
42.7						48.9'-50.4' HALITE: Clear, mottled with moderate brown clay, coarse, some medium. <1% to 2% brown clay, <1/2% dispersed polyhalite. [10]	
12	45	4.7	4.7	100			39% of recovered core was ≥2 inch length.
47.4							Interval from 20 to 35' was replaced with corehole DH-29A.
13		3.0	3.0	100	X		
50.4	50						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC-CORE BORING NO. DH-29A

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W987 COLLAR ELEV. 1298.1 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10,786.1 E5927.3 DEPTH OF BOREHOLE 35.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-12-84 DATE COMPLETED 9-12-84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 9-29-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0					0.0'-20.0' NON-CORE: Refer to log for DH-29.	NC double tube core barrel used. This hole was drilled to replace 20'-35' zone of poor quality core in DH-29. Refer to log for DH-29 for core descriptions at 0'-20' and 35'-50'
	5					20.0'-25.0' HALITE: Clear to moderate brown (5YR 4/4), some moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. <1% to 2% brown clay. <1% polyhalite locally. Anhydrite seam at 25'±. ≤1/4" hard brown clay associated. [12, 17]	
						25.0'-28.4' HALITE: Clear, coarsely crystalline. Scattered anhydrite stringers. [1]	
	10					28.4'-30.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline. <1% to 3% brown clay. <1/2% dispersed polyhalite. [10, 15, 17]	
						30.9'-35.0' HALITE: Clear, some moderate brown (5YR 3/4, 4/4), coarsely crystalline, some medium. ≤1% brown clay. [10]	
	15						
20.0	20						
1		5.0	4.6	92	X		
25.0	25						

BORING NO. DH-29A

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-29A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25.0 25						
2		5.0	4.7	94			
	30.0 30						
3		5.0	4.5	90			
	35.0 35						
	40						

M

BORING NO. DH-29A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NC CORE BORING NO. DH-30

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1099, W982 COLLAR ELEV. 1289.2 DIRECTION OF DRILLING ~~DOWN~~ VERTICAL

MINE COORDINATES N10785.5, E5932.3 DEPTH OF BOREHOLE 50.1'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-25-84 DATE COMPLETED 7-25-84 SHEET

LOGGED BY: L. GALLERANI DATE: 7-26-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 1.7	1.7	1.7	100		0.0'-8.6' HALITE: Clear, some light medium gray. Coarsely crystalline, some medium. ≤1% gray clay. Trace of brown at 1.0'-1.7'. [1, 11]	NC double tube wire-line core barrel. Used 2 ft single tube barrel from 0'-5.8'. Had to ream hole to 5.8 ft to accommodate NC core barrel. Total drilling time 5.5 hrs.
2	1.7 – 5.8	4.1	4.1	100		8.6'-11.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. [7]	
						11.5'-16.0' MB-139: Mixture of halite and anhydrite to 13'. Then predominantly very light to medium light gray anhydrite with scattered halite growths. Irregular hairline fracture at 14'±. Gray clay at lower contact.	
3	5.8 – 9.9	4.1	4.1	100		16.0'-19.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% gray clay. <1% to 3% polyhalite. Scattered anhydrite. [some 5]	
4	9.9 – 14.9	5.0	5.0	100		19.2'-20.7' HALITE: Clear, some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay.	
						20.7'-25.45' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [5, 7]	
						25.45'-30.1' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% polyhalite dispersed. ≤1% gray clay. [9]	66% of core recovered is ≥2 inch length.
5	14.9 – 19.9	5.0	5.0	100		30.1'-35.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite [5, 7]. Anhydrite/halite layer at 34.9'-35.1'±.	
						35.2'-35.6' ANHYDRITE: Light gray (N7) to medium light gray (N6), microcrystalline. Scattered halite growths. No clay.	
6	19.9 – 25.0	5.1	5.1	100		35.6'-43.75' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% dispersed polyhalite and gray clay [9]. Polyhalitic at 42.9'-43.5'±.	

M

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-30

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7		5.1	5.1	100		43.75'-44.8' HALITE: Clear to moderate reddish orange (10R 6/6), some moderate brown (10R 4/6). Medium to coarsely crystalline. <1% to 2% brown clay, some gray. Breaks at 44.35' and 45.10'± [14, 17].	Runs 7, 8, 9: Some breakage in medium to coarsely crystalline halite.
						44.8'-46.9' HALITE: Clear to light moderate reddish orange (10R 6/6), some bluish gray. Medium to coarsely crystalline. <1/2% dispersed polyhalite. <1% gray clay.	
	30						
8		5.1	5.1	100		46.9'-50.1' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite. <1/2% gray clay. 1% to 2% polyhalite at 46.9' to 47.7'±. [1, 2, 11]	
	35						
9		5.1	5.1	100			
	40						
10		5.1	5.1	100			
	45						
11		5.1	5.1	100			
	50						

M

BORING NO. DH-30

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NC-CORE BORING NO. DH-31

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W1282 COLLAR ELEV. 1298.5 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10,784.9, E5632.3 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-18-84 DATE COMPLETED 7-19-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-20-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	0						
0		Non-Core			Non-Core	0.0'-5.0' NON-CORE.	NC double tube wire line core barrel, NC stepped diamond bit. 2 ft starter barrel with impregnated bit caused too much vibration. Went to plugged diamond bit from 0.0 ft to 5.0 ft. Total drilling time 11.5 hrs.
						5.0'-7.25' HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline, some medium, ≤1% to 2% brown clay.	
						7.25'-7.5' ANHYDRITE b: Light gray microcrystalline anhydrite. Scattered halite growths. ≤1/4" gray clay at 7.25'.	
5.0	5						
1		2.7	2.65	98		7.5'-13.6' HALITE: Clear, some light moderate reddish orange, coarsely crystalline. <1/2% polyhalite. Scattered white stringers.	
7.7							
2	10	5.0	4.9	98		13.6'-14.4' HALITE: Clear to moderate reddish brown, medium to coarsely crystalline. ≤1% brown clay, some gray, and dispersed polyhalite.	
						14.4'-15.1' ANHYDRITE a: Light gray to medium light gray. Scattered halite growths. Trace gray clay at 14.4'. Core grinding evident.	
12.7						15.1'-19.05' POLYHALITIC HALITE: Clear to moderate reddish orange, coarsely crystalline. ≤1% to 2% polyhalite.	
3	15	4.8	4.8	100		19.05'-21.4' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline, <1% to 3% brown clay. <1% dispersed polyhalite.	28% of core recovered was ≥2 inch length.
						21.4'-23.95' HALITE: Clear to light moderate reddish orange, medium to coarsely crystalline. <1% polyhalite. <1/2% brownish gray clay. Brown clay seam at 23.9' with associated anhydrite to 23.95.	
17.5							
4	20	4.0	4.0	100		23.95'-27.9' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
						27.9'-29.65' HALITE: Clear to moderate brown, medium to coarsely crystalline. None to 3% brown clay.	
21.5							
5	25	4.5	4.2	95		29.65'-31.1' HALITE: Clear, coarsely crystalline.	

M

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-31

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					31.1'-32.7' HALITE: Clear, medium to coarsely crystalline. <1/2% brown clay.	Run 6: Core broken up. Difficult to measure recovery.
6	26.0 – 30.5	4.5	4.1	91		32.7'-33.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline. <1% to 3% brown clay. [10]	
						33.6'-34.5' HALITE: Clear, coarsely crystalline. <1/2% brown clay.	Run 7: Discing, some broken core.
7	30.5 – 35.5	5.0	4.7	94		34.5'-36.55' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. <1% to 3% brown clay.	
						36.55'-37.35' ANHYDRITE: Very light gray to medium light gray, scattered halite growths and irregular laminae. ≤1/8" brown clay at 36.55'.	Run 8: 1'± core is broken up.
						37.35'-41.5' HALITE: Clear to moderate reddish orange, coarsely crystalline. <1% to 2% polyhalite. Locally polyhalitic.	
8	35.5 – 40.5	5.0	4.8	96		41.5'-44.3' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. <1% to 3%, locally, brown clay, scattered breaks.	
						44.3'-45.5' HALITE: Clear, coarsely crystalline. <1% polyhalite. <1/2% clay.	
9	40.5 – 45.5	5.0	5.0	100		45.5'-47.0' HALITE: Clear, mottled with moderate brown (5YR 4/4), coarsely crystalline. <1% to 2% brown clay.	
						47.0'-50.5' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. <1% to 3% brown clay. Breaks from 47.5' to 50.5'.	
10	45.5 – 50.5	5.0	5.0	100		Note: Hole redrilled due to poor core quality. See log for hole DH-31A.	

BORING NO. DH-31

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NC-CORE BORING NO. DH-31A

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099 W1280 COLLAR ELEV. 1298.5 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10784.8, E5630.5 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-20-84 DATE COMPLETED 7-24-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-24-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	0					0.0'-5.1' NON-CORE: Used plugged diamond bit.	NC double tube wire-line core barrel. Wireline rod and stepped diamond bit. Total drilling time: 10.5± hrs. 46% of core recovered was ≥2 inch length.
0		Non-Core				5.1'-7.15' HALITE: Clear to moderate brown, some light to moderate reddish orange. Medium to coarsely crystalline. ≤1% brown clay with trace of gray. <1/2% dispersed polyhalite. [8, 17]	
						7.15'-7.35' ANHYDRITE b: Light gray (N7), micro-crystalline, partially laminated. Scattered halite growths. Gray clay at 7.15'. Contact dips 10°±.	Upper 4.9' of hole was replaced with corehole DH-32B.
.1	5						
1		4.9	4.8	97		7.35'-13.85' HALITE: Clear, some light to moderate reddish orange. Coarsely crystalline. <1/2% poly-halite. Scattered white stringers. [1, 2]	
						13.85'-14.65' HALITE: Clear to moderate brown. Fine to medium crystalline, some coarsely crystalline. ≤1% brown clay. [12]	
10.0	10					14.65'-15.3' ANHYDRITE a: Light to medium light gray microcrystalline. Scattered halite growths. ≤3/16" gray clay at 14.65. Vertical fracture noted from 14.35' to 14.85'.	
2		5.2	5.2	100		15.3'-19.5' POLYHALITIC HALITE: Clear to moderately reddish orange, (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. <1/2% gray clay locally. [5, 7]	Run 2: Several broken zones in clear halite.
15.2	15					19.5'-24.75' HALITE: Clear, some lightly moderate reddish orange. Medium to coarsely crystalline with with some fine crystalline. <1% brown with some gray clay and polyhalite dispersed. 1/2" grayish brown hard clay at 24.7'. Scattered halite within. [12, 17]	
3		5.1	5.1	100		24.75'-28.8' HALITE: Clear, coarsely crystalline. Scattered white anhydrite. 3/4" anhydrite layer at 26.4'±. Appears to be vertical fracture at 24.75'-25.15'±. Probably caused when banging end piece of core from barrel. [1]	
20.3	20					28.8'-30.3' ARGILLACEOUS HALITE: Clear to moderate brown. Fine to medium crystalline with some coarsely crystalline. ≤1% to 3% brown clay. Break at 30.3'. [12]	
4		5.0	5.0	100			
	25						

BORING NO. DH-31A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-31A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25.3					30.3'-32.4' HALITE: Clear, coarsely crystalline. [1]	Run 5: Badly broken by drilling.
5	25–30.1	4.8	4.8	100		32.4'-36.7' ARGILLACEOUS HALITE: Clear to moderately brown, medium to coarsely crystalline. ≤1% to 3% brown clay. Scattered breaks. [15]	
						36.7'-37.1' HALITE: Clear to coarsely crystalline. ≤1% brown clay. [8, 10]	Run 6: Badly broken to 33.3' in very coarse halite.
	30.1					37.1'-37.85' ANHYDRITE: Light to medium light gray, microcrystalline anhydrite. Partly laminated. Scattered halite growths. ≤3/4" hard brown clay seam at 37.1'.	
6	30–34.5	4.7	4.7	100		37.85'-41.5' HALITE: Clear, coarsely crystalline, scattered medium. ≤1/2% polyhalite. [1]	
	34.5					41.5'-44.6' HALITE: Clear to moderate brown. Medium to coarsely crystalline. <1% to 2% brown clay. <1% polyhalite blebs. Irregular 1" brown clay and halite seam at 44.5'±. [8, 17]	
7	35–39.5	4.7	4.7	100		44.6'-45.8' HALITE: Clear, coarsely crystalline. <1% polyhalite blebs. [2]	
						45.8'-47.8' HALITE: Clear, mottled with moderate brown, coarsely crystalline. ≤1% brown clay blebs. <1/2% polyhalite blebs. [8, 10]	
8	39.5–44.4	4.9	4.9	100		47.8'-49.2' ARGILLACEOUS HALITE: Clear to moderate brown. Fine to medium crystalline, some coarsely crystalline. <1% to 3% brown clay with scattered breaks. [12]	Run 9: Core disced from 45.5' to 48'.
9	44.4–49.2	4.8	4.8	100			
	49.2–50						

BORING NO. DH-31A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 2 3/4" CORE BORING NO. DH-31B

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W1261 COLLAR ELEV. 1298.5± DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10786.7 E5652.2 DEPTH OF BOREHOLE 4.9 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-12-84 DATE COMPLETED 9-12-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 9-29-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		4.9	4.9	100	X X	0.0'-2.4' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% to 2% polyhalite. Scattered anhydrite stringers. [2]	Single tube barrel used.
					— —	2.4'-4.9' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. ≤1% brown clay, trace of gray.[8, some 10].	
4.9	5						This hole drilled to replace non-core section of DH31A.

BORING NO. DH-31B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC-CORE BORING NO. DH-32

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1099, W1282 COLLAR ELEV. 1289.6 DIRECTION OF DRILLING VERTICAL ~~DOWN~~

MINE COORDINATES N10784.9, E5632.2 DEPTH OF BOREHOLE 50.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-19-84 DATE COMPLETED 7-20-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-20-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0	0 – 5.3	Non-Core				0.0'-5.3' NON-CORE: Used plugged bit. 5.3'-7.4' HALITE: Clear, mottled with some moderate reddish orange and brown. Coarsely crystalline. <1% polyhalite. <1/2% brown and gray clay 6.75'-7.05'. [3] 7.4'-8.5' POLYHALITIC HALITE: Clear to moderate reddish orange to coarsely crystalline. <1% to 2% polyhalite [3, 4].	NC double tube wire-line core barrel, NC rods and stepped diamond bit. Total drilling time: 6± hrs. Upper 5.5' of hole replaced with corehole DH-32A.
1	5.3 – 10.3	5.0	4.9	98		8.5'-11.3' MB-139: (upper contact dips 40°±). Mixture of halite and anhydrite to 9.6± with some "swallowtail" structure. From 9.6'±, predominently Light to light medium gray anhydrite with scattered halite growths @ 9.15' to 10.75'. Clear halite layers at 10.3'-10.4'. ≤3/16" gray clay @ 11.3'. Core grinding evident here. 11.3'-14.2' HALITE: Clear, some moderate reddish orange (10R 6/6), moderate brown, medium to coarse. ≤1% clay, gray to 12.7', then brown clay. Irregular brownish gray break @ 14.2'. <1/2% dispersed polyhalite. [9, 17]	
2	10.3 – 15.1	4.8	4.2	95		14.2'-18.85' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite. Gray clay parting @ 18.85'. [3, 5, 7]	56% of recovered core was ≥2 inch length.
3	15.1 – 20.1	5.0	4.8	96		18.85'-20.1' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay. [9] 20.1'-25.25' POLYHALITIC HALITE: Clear to moderate reddish orange and brown (10R 6/6, 4/6), coarse, some medium. <1% to 3% polyhalite. <1/2% brown and gray clay. Vertical fracture in core at 23.4'-23.8'. Looks like stress fracture. [4, 6, 7]	
4	20.1 – 25	4.9	4.9	100		25.25'-30.4' HALITE: Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% to 2% polyhalite. <1% gray clay, locally. <1% brown clay at 28.3'-29.9'. Vertical fractures in core at 27.35'-27.55' and 28.6'-29.2'±. [9, some 17]	Run 4: Vertical fracture at 20.1', 23.5' and 26.0'. Probably caused by overshot tool impact on barrel.

BORING NO. DH-32

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-32

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
5	25	5.2	4.9	94.5		30.4'-35.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. <1% gray clay to 31'. [7] 35.0'-35.9' ANHYDRITE: Moderate reddish orange (10R 6/6) to medium light gray (N6), microcrystalline anhydrite with scattered halite growths. Gray clay at 35.9'. Contact irregular, low angle here.	
6	30 (30.2)	5.0	5.0	100		35.9'-40.8' HALITE: Clear to light moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1/2% dispersed polyhalite. <1% clay, predominently gray. Brown clay at 37.3'-37.9' [9, 11, some 17] 40.8'-44.2' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 2% polyhalite, locally 3% from 43.0'-43.9'±. <1% gray clay [4, 9].	
7	35 (35.2)	4.8	4.7	97		44.2'-46.1' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. <1% brown clay. <1/2% dispersed polyhalite [17]. 46.1'-47.75' HALITE: Clear, some medium light gray. Medium to coarsely crystalline. <1% gray clay and <1/2% polyhalite [9]. 47.75'-50.0' HALITE: Clear mottled with moderate reddish orange (10R 6/6). Coarsely crystalline. <1% polyhalite. <1/2% gray clay locally. [2]	
8	40 (40.0)	5.1	5.1	100			
9	45 (45.1)	4.9	4.9	100			
	50 (50.0)						

M

BORING NO. DH-32

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 2 3/4" CORE BORING NO. DH-32A

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1099, W1261 COLLAR ELEV. 1289.5 DIRECTION OF DRILLING VERTICAL ~~DOWN~~

MINE COORDINATES N10 786.7 E5652.2 DEPTH OF BOREHOLE 5.5 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-13-84 DATE COMPLETED 9-13-84 SHEET

LOGGED BY: J. F. GALLERANI DATE: 9-29-84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	1	5	5.5	5.5	100	X X X	0.0'-5.5' HALITE: Clear, some moderate reddish orange, coarsely crystalline, some fine and medium, <1% to 2% locally polyhalite. <1% clay, gray except at 1.7'-2.6'± where it is brown. [2, 9]	Single tube barrel used.
5.5								45% of core recovered was ≥2 inch length.
								This hole was drilled to replace non-core section of DH-32.

BORING NO. DH-32A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC-CORE BORING NO. DH-33

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W1582 COLLAR ELEV. 1298.6 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10786.0, E5331.1 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-16-84 DATE COMPLETED 7-18-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-18-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0	0	Non-core				0.0'-4.0' NON-CORE: Roller bit to 4' in order to accommodate long core barrel.	NC double tube wire-line core barrel, NC rods and stepped diamond bit used from 4.0' depth. Upper 4.0' of hole replaced with corehole DH-33A. Total drilling time: 16* hrs.
						4.0'-5.9' HALITE: Clear with some moderate brown (5YR 4/4). Coarsely crystalline with some medium crystalline. <1% brown clay. [8, 13]	
1	4.0 5	5.0	4.9	98		5.9'-7.15' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline, <1% to 2% brown clay. Irregular break at 6.0'. [10]	
						7.15'-7.25' ANHYDRITE b: Light gray to medium gray (N7, N6). Microcrystalline. Gray clay ≤3/16" at 7.15'.	
2	9.0 10	4.0	4.0	100		7.25'-12.9' HALITE: Clear with some light to moderate reddish orange (10R 6/6). Coarsely crystalline. Scattered white stringers of anhydrite and/or magnesite. None to <1/2% polyhalite. [1]	
						12.9'-13.1' HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, ≤1% polyhalite, ≤1% brown clay. [17]	40% of recovered core was ≥2 inch length.
3	13.0 15	5.0	5.0	100		13.1'-13.85' HALITE: Clear to light moderate brown (5YR 4/4). Fine to medium crystalline with some coarse crystalline. <1/2% polyhalite and <1% clay, brown with some gray. [9]	
						13.85'-14.4' ANHYDRITE a: Light gray to light medium gray (N7, N6), microcrystalline anhydrite with scattered halite growths. ≤1/8" gray clay at lower contact.	
4	18.0 20	5.0	5.0	100		14.4'-19.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite with scattered anhydrite. [4, 7]	
						19.0'-21.25' HALITE: Clear with some lightly moderate brown (5YR 3/4), medium to coarsely crystalline with some fine crystalline. ≤1% brown clay and some gray clay with ≤1/8" anhydrite at 21.2'-21.25'. [9, 12]	M
5	23.0 25	5.0	5.0	100		21.25'-24.1' HALITE: Clear with some moderate brown (5YR 4/4), coarsely crystalline, some fine to medium crystalline, <1% brown clay, <1/2% polyhalite. 1/2" brown clay seam at 23.95' with associated halite/anhydrite to 24.1'. [8]	

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-33

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					24.1'-28.7' HALITE: Clear, coarsely crystalline, trace of brown clay locally. [1]	
						28.7'-30.3' HALITE: Clear to moderate brown (5YR 4/4). Fine to medium crystalline with some coarse crystalline. <1/2% dispersed polyhalite. <1% to 2% brown clay, some gray. [12]	
28.0 6	30	5.0	4.8	96		30.3'-32.0' HALITE: Clear, coarsely crystalline. [1]	
						32.0'-36.8' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. <1% to 3% brown clay. Scattered breaks. [15, 16]	
33.0 7	35	4.0	4.0	100		36.8'-37.3' ANHYDRITE: Light gray to light medium gray (N7, N6), microcrystalline anhydrite. Scattered halite growths. Brown clay at 36.8'. Core grinding here.	
						37.3'-38.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite. [5, 7]	
37.0 8	40	5.0	5.0	100		38.0'-42.0' HALITE: Clear with some light to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% polyhalite. [1, 2]	
						42.0'-47.5' HALITE: Clear to lightly moderate reddish orange and moderate brown (5YR 3/4, 4/4). Medium to coarsely crystalline. Some fine crystalline locally. ≤1% brown clay. <1% polyhalite. Fairly clear, coarsely crystalline between 45.3' and 46.3'±. [1] [10, 17]	
42.0 9	45	5.0	4.8	96		47.5'-50.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4), medium to coarsely crystalline. <1% to 3% brown clay with scattered breaks. [10, 14]	
47.0 10	50	3.5	3.5	100			
50.5							

BORING NO. DH-33

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 2 3/4" CORE BORING NO. DH-33A

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W1570 COLLAR ELEV. 1297.4 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10786.8 E5342.0 DEPTH OF BOREHOLE 4.1

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-13-84 DATE COMPLETED 9-13-84 SHEET

LOGGED BY: J. F. GALLERANI DATE: 9-29-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		4.1	4.1	100	X X	0.0'-3.2' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline, some medium from 2.3'±. ≤1% polyhalite. [1, 3] 3.2'-4.1' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline. <1% brown clay. [8]	Single tube barrel used.
4.1							
	5						
	10						51% of core recovered was ≥2 inch length. This hole was drilled to replace non-core section of DH-33.

BORING NO. DH-33A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-34

LOCATION ROOM G ACCESS DIRFT - FLOOR

STATION N1099, W1582 COLLAR ELEV. 1289.4 DIRECTION OF DRILLING ~~DOWN~~ VERTICAL

MINE COORDINATES N10786.5, E5331.7 DEPTH OF BOREHOLE 51.5±

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-16-84 DATE COMPLETED 7-17-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-18-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0	0.0 – 3.5	Non-core				0.0'-3.5' NON-CORE.	CP65 mounted on scissor lift. NW split tube core barrel, NW rods used plugged diamond bit to 3.5' because of low drift back. Unable to use longer core barrel. Upper 3.5' of hole replaced with corehole DH-34A. Total drill time: 13 hrs ±.
						3.5'-4.2- HALITE: Clear, some moderate brown (5YR 4/4) and moderate reddish orange (10R 6/6). Coarsely crystalline. <1% brown clay, some gray. Trace polyhalite. [8]	
1	3.5 – 5.9	2.5	2.3	92		4.2'-7.8' POLYHALITIC HALITE: Clear, mottled with moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite blebs and patches. ≤1% gray clay to 6.1', then no clay. Scattered anhydrite. [5, 7]	
2	5.9 – 9.3	3.4	3.4	100		7.8'-11.05' MB-139: Mixture of anhydrite and halite ("swallowtail" pattern) from 7.8' to 8.6'±. Then becomes mostly anhydrite. Moderate reddish orange with irregular patches of white and light gray to 9.7'±. Increase in halite content 9.8'-10.3'±. Below 10.3' is light gray anhydrite. Trace of gray clay at 11.05'. Core grinding evident.	
3	9.3 – 14.0	4.7	4.7	100		11.05'-12.1' HALITE: Clear, medium to coarsely crystalline. [1]	
						12.1'-14.2' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. [1]	
4	14.0 – 19.0	5.0	5.0	100		14.2'-18.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [5, 6, 7] Moderate reddish orange anhydrite mixed with halite from 18.65'-18.9'±. Break at 14.45'±.	40% of core recovered was ≥2 inch length.
						18.9'-20.95' HALITE: Clear to light moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay, trace of gray. ≤1% dispersed polyhalite. Break @ 20.75'. [17]	
5	19.0 – 24.0	5.0	4.75	95		20.95'-27.45' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Medium to coarsely crystalline from 25.2'±. Anhydrite-halite from 24.1'-24.2', ≤1% gray clay from 26.5'-26.8'±. [7]	
6	24.0 –	5.0	5.0	100			

BORING NO. DH-34

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-34

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					27.45'-29.9' HALITE: Clear, some moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6), medium to coarsely crystalline, some fine. ≤1% brown clay, some gray from 29.4'-29.9'. <1/2% dispersed polyhalite. [17, some 9]	
						29.9'-35.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. 2" anhydrite/halite layer at 35.15'-35.3'. [4, 7]	
29.0	30						
7		5.0	5.0	100		35.4'-36.15' ANHYDRITE: Light gray (N7) to moderate reddish orange (10R 6/6), microcrystalline. Halite growths within. Trace of gray clay at 36.15'.	Run 7: Some vibration this run. Tightened tie down bolts and feed beam.
						36.15'-43.0' HALITE: Clear, coarsely crystalline, some medium. <1/2% dispersed polyhalite. <1% gray clay. [9]	
34.0	35						
8		5.1	5.1	100		43.0'-44.2' HALITE: Clear, some moderate reddish orange, coarsely crystalline. <1/2% polyhalite. [2]	
						44.2'-45.4' HALITE: Clear with some moderate brown (5YR 4/4), coarsely crystalline. <1% brown clay. Break at 45.4'. [8, some 10]	
						45.5'-51.5' HALITE: Clear, coarsely crystalline, some medium, <1% gray clay, trace brown. [8, 11]	Run 9: Core barrel blocked up this run. Some brown clay on inner tube.
39.1	40						
9		3.9	1.8	46			
43.0							
10	45	5.0	5.0	100			Run 11: Dropped core barrel 4" when pulling rods. Day shift driller drilled over this run. Core broken up because of this.
48.0							
11	50	3.5	3.5	100			
± 51.5							

BORING NO. DH-34

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 2 3/4" CORE BORING NO. DH-34A

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1099, W1570 COLLAR ELEV. 1289.2 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10 786.8 E5341.9 DEPTH OF BOREHOLE 3.6'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-13-84 DATE COMPLETED 9-13-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 9-29-84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	1		3.6	3.6	100	X	0.0'-1.3' HALITE: Clear, coarsely crystalline, some medium, <1/2% polyhalite blebs. [1] 1.3'-3.6' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline. ≤1% brown clay. [8, 10]	Used single tube starter barrel. 94% of recovered core was ≥2 inch length. This hole was drilled to replace non-core section of DH-34.
3.6								

BORING NO. DH-34A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-35

LOCATION ROOM G - ROOF

STATION N1102, W1882 COLLAR ELEV. 1294.4 FT DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10789.4, E5032.2 DEPTH OF BOREHOLE 52.0 FT.

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-26-85 DATE COMPLETED 1-27-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-13-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.2	2.2	2.0	91		0.0'-4.4' HALITE: clear to moderate brown (5YR 4/4), coarsely crystalline. <1% brown clay. Scattered polyhalite blebs. [1,8]	NC single-tube barrel used for run 1. NC double-tube wireline barrel used for remainder of hole.
2	2.2 – 7.2	5.0	4.5	90		4.4'-6.2' HALITE: Clear to moderate brown (5YR 4/4; 3/4); fine to medium crystalline, some coarse. ≤1% brown clay, trace of gray. [8,10,12]	Partially broken core upper 2' of Run 2.
						6.2'-6.4' ANHYDRITE "b": Light medium to medium gray microcrystalline anhydrite with polyhalitic halite growths. Trace of hard gray clay at 6.2'. Anhydrite is laminated close to clay contact, low angle.	26% of core recovered was 2-inch lengths. Dry hole. No gas detected.
3	7.2 – 12.2	5.0	4.8	96		6.4'-12.1' HALITE: Clear, coarsely crystalline. Trace of anhydrite stringers. [1]	
						12.1'-13.2' HALITE: Clear to light moderate reddish orange (10R 6/6); fine to medium crystalline. < 1/2% dispersed polyhalite. ≤ 1% clay, brown and gray. Brown break at 12.35'. [9,12]	
						13.2'-13.85' ANHYDRITE "a": Very light to medium gray microcrystalline anhydrite. Irregular laminae. Scattered halite growths. From 13.6'. Up to 1/4" hard gray clay at 13.2'. Core grinding evident.	
4	12.2 – 17.2	5.0	4.9	98		13.85'-18.0' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6), coarsely crystalline. <1 to 3% polyhalite. [4,7]	
						18.0'-21.9' HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); fine to coarsely crystalline. ≤1% gray clay, some brown. < 1% polyhalite. [9, some 12]	Run 6 partially broken in clear halite. Run 7 broken most of run.
5	17.2 – 22.5	5.3	4.7	89		21.9'-24.05' HALITE: Clear, scattered moderate brown (5YR 4/4). Coarsely crystalline, some medium, <1/2% polyhalite. ≤1% brown clay. Up to 3/8" hard brown clay at 24.0'. Trace of anhydrite above. Near horizontal, irregular. [8,10]	
6	22.5 – 25	5.0	3.5	70			

BORING NO. DH-35

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-35

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					24.05'-27.8' HALITE: Clear, coarsely crystalline. [1]	
6		5.0	3.5	70		27.8'-28.7' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. ≤1 to 2% brown clay. [10]	Broken core in Run 9.
27.5							
						28.7'-32.5' HALITE: Clear, coarsely crystalline. None to <1% brown clay. [1, some 10]	
7	30	5.0	3.3	66		32.5'-36.5' ± 0.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4): medium to coarsely crystalline. <1 to 3% brown clay, trace brownish-gray locally scattered breaks. [10,15]	Broken zones throughout Run 10.
32.5							
8	35	5.0	4.3	86		36.5'-37.1' ANHYDRITE: Very light to light medium gray, microcrystalline anhydrite. Scattered small polyhalitic halite growths. Up to 1/2" hard brown clay at 36.5'. Near horizontal. Core grinding evident.	Broken zones, especially last 18" of Run 11.
						37.1'-42.6' HALITE: Clear, coarsely crystalline. <1/2% scattered polyhalite blebs. Scattered white anhydrite. [1]	
37.5							
9	40	5.0	3.2	64		42.6'-46.1' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, except fine to medium from 43.7' to 44.5'. <1/2% moderate reddish orange polyhalite here. <1% brown clay. Irregular break at 44.55'±.	
						46.1'-50.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4); medium to coarsely crystalline. <1 to 3% brown clay, up to 5% locally. Seam of clay mixed with halite crystals from 50.4' to 50.6'. [10,12,15]	
42.5							
10	45	5.0	5.0	100		50.6'-52.0' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); coarsely crystalline. <1 to 3% polyhalite. Moderate reddish brown polyhalite/anhydrite at 50.75' to 50.95'±.	
47.5							
11	50	4.5	4.5	100			
52.0							
	55						

BORING NO. DH-35

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE ~~NC CORE~~ BORING NO. DH-36

LOCATION ROOM G - FLOOR

STATION N1102, W1882 COLLAR ELEV. 1284.6 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10789.4, E5032.2 DEPTH OF BOREHOLE 51.5 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-26-85 DATE COMPLETED 1-26-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-27-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	2.0	2.0	100		0.0'-2.7' HALITE: Clear, some moderate brown, coarsely crystalline. <1% brown clay.	NC single-tube core barrel used for Runs 1 and 2. For remaining runs, NC double-tube wireline core barrel used.
2	2.0	1.5	1.4	93		2.7'-7.0' ± 0.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. Trace clay. [2,5,7]	Total drilling time: 6 hrs.
3	3.5	4.5	4.2	93		7.0'-10.4' ± 0.3' MB-139: Moderate reddish orange and medium gray to 8.7'±. From 8.7', predominantly light to medium gray anhydrite with halite growths. Gray clay, up to 1/2" at 10.4'.	43% of core recovered was ≥ 2-inch lengths.
	5						In salt, used second gear (74 rev./inch).
						10.4'-14.3' HALITE: Clear to light bluish gray; medium to coarsely crystalline. < 1/2% dispersed polyhalite. ≤1% gray clay. [9,11]	In anhydrite, used third gear (100 rev./inch).
4	8.0	3.2	2.5	78		14.3'-18.6' POLYHALITIC HALITE: Clear to moderate reddish orange/brown, coarsely crystalline. <1 to 3% polyhalite. Gray clay, some anhydrite at 18.3'-18.6'±. Irregular gray seam at 18.6'.	Dry hole. No gas detected.
	10						
5	11.2	5.0	5.0	100		18.6'-20.6' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% gray clay and polyhalite. [9]	
						20.6'-24.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. <1 to 3% polyhalite. Average is <2%. [2,4,7]	
	15						
6	16.2	5.0	5.0	100		24.7'-29.4' HALITE: Clear, some moderate reddish orange (10R 6/6); coarsely crystalline. ≤1% polyhalite. Locally polyhalitic. <1% gray clay. [9]	
						29.4'-33.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Trace anhydrite.	
	20					33.4'-34.9' HALITE: Clear, some light moderate reddish orange; coarsely crystalline. <1% polyhalite.	Core partly broken in Run 10.
7	21.2	5.3	5.3	100			
	25						

BORING NO. DH-36

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-36

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25					34.9'-35.5' ANHYDRITE: Moderate reddish orange microcrystalline anhydrite mixed with halite growths to 35.15'±. Very irregular upper contact. Consists of anhydrite intermixed with halite. From 35.15', light to light medium gray anhydrite with scattered halite growths. Some "swallowtail" pattern noted. 1/2" hard gray clay at lower contact. Dips 10"±.	
8	26.5	5.0	4.8	96		35.5'-41.2' HALITE: Clear, some light medium gray. Coarsely crystalline, some medium. <1% gray clay and <1/2% polyhalite blebs. [1,11]	
	30						
9	31.5	5.0	5.0	100		41.2'-42.7' HALITE: Clear, some moderate reddish orange. Coarsely crystalline. <1% gray clay. [9]	
						42.7'-44.9' HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); medium to coarsely crystalline. <1 to 2% polyhalite, locally polyhalitic. ≤1% brown clay. [17]	
	35						
10	36.5	5.0	5.0	100		44.9'-51.5' HALITE: Clear, coarsely crystalline, some medium. <1/2% dispersed polyhalite locally. <1% gray clay at 47'-47.3' and 48.5'-49.3'. Scattered breaks at 50.5'-51.2'. [1,11]	
	40						
11	41.5	5.0	4.5	90			
	45						
12	46.5	5.0	4.6	92			
	50						
	51.5						
	55						

BORING NO. DH-36

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-37

LOCATION ROOM G - ROOF

STATION N1101, W2182 COLLAR ELEV. 1297.4 FT DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10788.9, E4732.0 DEPTH OF BOREHOLE 51.5 FT.

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-25-85 DATE COMPLETED 1-26-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-26-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	2.2	2.2	100		0.0'-1.8' HALITE: Clear, some light moderate reddish orange (10R 6/6), coarsely crystalline. <1/2% polyhalite. [1]	NC single-tube core barrel used for Run 1. NC double-tube core barrel used for remainder of hole.
2	2.2	5.8	5.3	91		1.8'-5.3' ± 0.15' HALITE: Clear to moderate brown (5YR 3/4), medium to coarsely crystalline. None to 1% brown clay, some gray. Scattered breaks at 3.7', 4.0', 5.1'±.	42% of core recovered was was ≥ 2" lengths.
	5					5.3'-5.5' ANHYDRITE "b". Light to medium gray, microcrystalline anhydrite. Partially laminated. Trace of gray clay along irregular, low-angle surface at 5.3'. Core broken along this.	Dry hole. No gas detected.
	8.0					5.5'-11.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
3	10	3.5	3.2	91		11.3'-12.2' HALITE: Clear, some moderate brown (5YR 4/4). Fine to medium crystalline, some coarse. ≤1% brown clay.	Run 4: Some broken core.
	11.5					12.2'-12.7' ANHYDRITE "a": Light to medium gray microcrystalline anhydrite. Up to 1/8" brown clay along low-angle, smooth surface at 12.2'. Some core grinding evident.	First 1' of Run 5 broken.
4	15	5.0	4.8	96		12.7'-16.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite.	
	16.5					16.5'-21.6' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. ≤1% brown clay, trace of gray. <1/2% dispersed polyhalite. Up to 1/2" hard brown clay seam at 21.35'. Low-angle, irregular. Some anhydrite associated to 21.6'. [10, 17]	First 1' of Run 6 broken.
5	20	5.0	5.0	100		21.6'-24.5' HALITE: Clear, coarsely crystalline. <1/2% brown clay to 23'. [8 to 23'; then 1]	Broken zones through Run 7, especially first 18".
	21.5					24.5'-26.5' HALITE: Clear to light moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Fine to medium, crystalline, some coarse. <1% brown clay, trace gray. <1/2% dispersed polyhalite. [12]	
6	25	5.0	4.2	84			

BORING NO. DH-37

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-37

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25					26.5'-30.2' HALITE: clear, coarsely crystalline. <1/2% brown clay to 28'. [8,1]	Broken clear halite in Run 9.
7	26.5	5.0	5.0	100		30.2'-35.15' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. ≤1% brown clay to 31.5'; then 1 to 3%. Scattered breaks. [10,15]	
	30					35.15'-35.85' ANHYDRITE: Light to medium gray, microcrystalline anhydrite with scattered halite growths. Up to 1" hard brown clay at 35.15'. Low angle.	
8	31.5	5.0	4.5	90		35.85'-39.7' ± 0.7' HALITE: Clear, coarsely crystalline. <1/2% polyhalite. Scattered white anhydrite stringers.	
	35					39.7'-42.6' HALITE: Clear, some moderate brown (5YR 4/4); coarsely crystalline. ≤1% brown clay. Irregular break at 41.7'±. [10]	
9	36.5	1.5	1.5	100		42.6'-44.9' HALITE: Clear with <1% moderate reddish orange polyhalite blebs. Coarsely crystalline. [1]	
10	38.0	3.5	2.1	60		44.9'-47.25' HALITE: Clear to moderate brown (5YR 4/4); coarsely crystalline. ≤1% brown clay. [10]	
	40					47.25'-51.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. <1 to 3% brown clay, locally up to 5% from 49.8'-50.9'. Scattered breaks at 47.6'; 50.9', 51.2'±. <1/2% polyhalite. [15]	
11	41.5	4.5	4.5	100			
	45						
12	46.0	5.5	5.5	100			
	50						
	51.5						
	55						

BORING NO. DH-37

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-38

LOCATION ROOM G - FLOOR

STATION N1101, W2182 COLLAR ELEV. 1287.0 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10788.8, E4731.9 DEPTH OF BOREHOLE 47.5 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-25-85 DATE COMPLETED 1-26-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-26-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0 – 2.4	2.4	2.3	96		0.0'-2.5' HALITE: Clear to moderate brown (5YR 3/4); coarsely crystalline, some medium. ≤1% brown clay. [8,10]	NC double-tube wireline core barrel, except Run 1 where NC single-tube barrel was used
2	2.4 – 7.4	5.0	4.9	98		2.5'-3.1' HALITE: Clear, coarsely crystalline. <1/2% polyhalite blebs. [1,2] 3.1'-7.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Anhydrite mixed with halite from 5.4' to 7.4'. Some "swallowtail" structure evident. [4,7 to 5.4']	47% of core recovered was ≥ 2-inch lengths. Dry hole. No gas detected.
3	7.4 – 11.5	4.1	3.9	95		7.4'-9.45' MB-139: Gray anhydrite mixed with growths of polyhalitic halite/halite to 9'; then predominantly light to light medium gray anhydrite. Scattered halite growths. Gray clay at lower contact. Core grinding evident. 9.45'-13.2' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. ≤1% polyhalite and gray clay. [9]	
4	11.5 – 16.5	5.0	4.2	84		13.2'-17.35' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Some anhydrite and gray clay from 17.05' to 17.3'±. [7] 17.35'-18.8' HALITE: Clear to light moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1% polyhalite. < 1/2% clay, brown and gray. [8,9]	
5	16.5 – 21.5	5.0	4.7	94		18.8'-22.3' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); coarsely crystalline. <1 to 3% polyhalite. Trace gray clay at 21.5'. [7] 22.3'-28.7' HALITE: Clear to moderate reddish orange/brown (10R 6/6, 4/6). Coarsely crystalline, some medium. ≤1 to 2% polyhalite locally. ≤1% light bluish gray clay, slight trace of brown.	
6	21.5 – 25	5.0	5.0	100		28.7'-34.3' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6), coarsely crystalline. <1 to 3% polyhalite. Clear halite 34-34.3'. [7]	

BORING NO. DH-38

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-38

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25					34.3'-34.6' ANHYDRITE: Very light to light medium gray microcrystalline anhydrite. Scattered small halite growths common from 34.45'± with larger growths present above this. Some irregular laminae within anhydrite. 1/4" hard dry gray clay at lower contact. Low angle.	Dropped core barrel on last run. After retrieving barrel, did not continue drilling.
7	30	5.0	5.0	100		34.6'-41.55' HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6). Medium to coarsely crystalline with zones of fine to medium, sugary-textured halite. None to ≤1% polyhalite. <1% gray clay, some brown. Polyhalitic 41.2'-41.55'. [9, some 17]	Total time on hole was 12 hrs ±.
8	35	5.0	5.0	100		41.55'-44.1' HALITE: Clear to moderate brown (5YR 4/4; 3/4), coarsely crystalline, some medium. <1 to 2% brown clay. Trace of polyhalite. [10]	
9	40	5.0	5.0	100		44.1'-47.5' HALITE: Clear to light moderate reddish orange (10R 6/6); medium to coarsely crystalline, some fine. <1% polyhalite. ≤ gray clay. [2,9]	
10	45	6.0	5.1	85			
	50						
	55						

26.5 31.5 36.5 41.5 47.5

M

BORING NO. DH-38

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-39

LOCATION ROOM G - ROOF

STATION N1101, W2482 COLLAR ELEV. 1296.0 FT DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10789.2, E4430.7 DEPTH OF BOREHOLE 50.7 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-24-85 DATE COMPLETED 1-24-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-9-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	3.7	3.0	81		0.0'-3.6' HALITE: Clear, coarsely crystalline, some medium. [1]	Run 1 made with NC single-tube barrel. Remainder of hole with NC double-tube wireline core barrel.
						3.6'-6.6' ± 0.3' HALITE: Clear, some moderate brown (5YR 3/4), coarsely crystalline to 5', then medium to coarse. ≤ 1% clay, increasing content from 5'. Brown, some gray. Break at 5.9'±.	Dry hole. No gas detected.
2	3.7	5.0	4.3	86		6.6'-6.8' ANHYDRITE "b": Medium gray, microcrystalline. Gray clay at 6.6'. Core broken. Halite growths especially within 0.05' of lower contact.	30% of core recovered was ≥ 2-inch lengths. Core broken in parts of Runs 3 and 4.
	5					6.8'-13.2' HALITE: Clear, coarsely crystalline. <1/2% polyhalite from 12.2'. [1]	
3	8.7	5.0	4.8	96		13.2'-13.9' HALITE: Clear to moderate brown (5YR 3/4) and light moderate reddish orange. Fine to medium crystalline. ≤1% brown clay. <1/2% dispersed polyhalite. [9,17]	
	10					13.9'-14.45' ANHYDRITE "a": Light gray to light medium gray, microcrystalline anhydrite. Near-horizontal laminae. Scattered halite growths. 3/8" gray clay at 13.9'.	Last 0.2' of Run 5 broken.
4	13.7	5.0	5.0	100		14.45'-18.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite, average 2%. Anhydrite stringer at 15.8'. [2,3,5]	Run 6: Core broken; discing throughout.
	15					18.75'-23.7' HALITE: Clear to moderate brown (5YR 4/4) and some moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤1% brown clay, locally up to 2%. <1% polyhalite, dispersed and blebs. [10,17]	Run 8: Mostly broken zones. Run 9: Discing of core. Run 10: Several broken zones.
5	18.7½	5.0	4.8	96		23.7'-28.2' HALITE: Clear, coarsely crystalline. <1/2% brown clay to 25'. <1/4" brown clay at 25.0' with associated anhydrite layer to 25.15'. [1]	Runs 11 and 12: Broken core.
	20					28.2'-30.0' HALITE: Clear to moderate brown, some moderate reddish orange. Fine to medium, some coarse. ≤1 brown clay. <1/2% dispersed polyhalite. [12]	Run 13: Core is badly broken.
6	23.7	4.7	4.7	100			
	25						

BORING NO. DH-39

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-39

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	4.7	4.7	100		30.0'-32.6' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline. None to <1% brown clay. [1,8]	
						32.6'-34.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4; 4/4). Medium to coarsely crystalline. <1 to 3% brown clay. Trace of dispersed polyhalite.	
7	30	1.8	1.8	100		34.9'-35.9' HALITE: Clear to light moderate reddish orange; medium to coarsely crystalline. <1/2% dispersed polyhalite and gray clay [2,9].	
8		1.5	1.5	100			
9		1.4	1.4	100		35.9'-36.5' ANHYDRITE: Light gray to medium gray microcrystalline anhydrite. Some halite growth. Trace brown clay at 35.9'. Core grinding evident.	
10	35	2.8	2.8	100		36.5'-41.4' HALITE: Clear, some light moderate reddish orange (10R 6/6) coarsely crystalline. <1/2% polyhalite. [1,2]	
11		2.0	1.7	85		41.4'-45.7' ± 0.6' HALITE: Clear with some moderate brown and moderate reddish orange. Fine to medium crystalline to 43.5'±, then coarsely crystalline. <1/2% dispersed polyhalite. <1% brown clay.	
12	40	5.0	5.0	100		45.7'-50.7' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4). Medium to coarsely crystalline, some fine. <1 to 5% brown clay.	
13	45	4.0	2.5	62			
14	50	3.8	2.5	66			
	55						

28.4 — 30.2 — 31.7 — 33.1 — 35.9 — 37.9 — 42.9 — 46.9 — 50.7

M

BORING NO. DH-39

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-40

LOCATION ROOM G - FLOOR

STATION N1101, W2482 COLLAR ELEV. 1286.1 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10789.2, E4431.0 DEPTH OF BOREHOLE 51.0 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-24-85 DATE COMPLETED 1-25-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-25-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0 – 2.0	2.0	1.9	95		0.0'-2.6' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, some medium. <1/2% polyhalite. ≤1% brown clay, trace of gray. [8,10]	NC double-tube wireline core barrel, except for Runs 1 and 2 where NC single-tube barrel used.
2	2.0 – 2.7	0.7	0.7	100		2.6'-5.4' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% polyhalite blebs. Trace gray clay locally. [2,4]	Total drilling time: 8 hrs. ±.
3	2.7 – 6.5	3.8	3.7	97		5.4'-7.05' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, except fine to medium from 5.4' to 5.8'±. <1 to 3% polyhalite. Trace anhydrite from 6.55'. [4,7]	Dry hole. No gas detected.
4	6.5 – 11.5	5.0	5.0	100		7.05'-10.95' MB-139: Moderate reddish orange to light gray anhydrite and polyhalitic halite to 9.5'±. Then light to light medium gray anhydrite with scattered growths of halite within. 3/4" hard, gray, dry clay at lower contact.	74% of core recovered was ≥2-inch lengths. Good core.
						10.95'-15.1' HALITE: Clear with some light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1/2% dispersed polyhalite. <1/2% gray clay. [9]	
5	11.5 – 16.5	5.0	5.0	100		15.1'-18.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. Average 2%. 1-1/2" polyhalite/anhydrite at 18.25'. Gray clay parting at 18.4'. [7]	
						18.4'-20.2' HALITE: Clear to light moderate reddish orange (10R 6/6). Some light gray (N7). Medium to coarsely crystalline. <1% gray clay. <1/2 % polyhalite. [9]	
6	16.5 – 21.5	5.0	5.0	100		20.2'-24.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. [4,7]	
						24.3'-26.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, some medium. <1 to 3% polyhalite. ≤1% gray clay.	
7	21.5 – 25	5.1	5.1	100			

BORING NO. DH-40

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-40

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	26.6	5.1	5.1	100		26.4'-29.7' HALITE: Clear, some light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1/2% dispersed polyhalite and brown clay. Trace gray clay locally. [17, locally 9]	
8	31.5	4.9	4.9	100		29.7'-35.05' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. Moderate reddish orange polyhalite/anhydrite from 34.7'-34.95'. [4,7]	
	30					35.05'-35.4' ANHYDRITE: Light to very light (N7, N8) gray anhydrite to 35.15'. Then anhydrite with scattered halite growths throughout. 1/4" hard, dry gray clay at lower contact.	
9	36.0	4.5	4.5	100		35.4'-36.75' HALITE: Clear to light moderate reddish orange, fine to medium crystalline. <1/2% dispersed polyhalite and gray clay. [2,9]	
	35					36.75'-41.0' HALITE: Clear, trace of moderate brown, coarsely crystalline. <1% brown clay. [8]	
10	41.0	5.0	5.0	100		41.0'-47.0' HALITE: Clear to moderate reddish orange/brown (10R 6/6, 4/6). Coarsely crystalline, some medium. ≤1 to 2% polyhalite. <1% gray clay, some brown. Locally polyhalite. [2,4,6]	
	40					47.0'-48.8' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite. [1,2]	
11	46.0	5.0	5.0	100		48.8'-51.0' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. <1/2% polyhalite and gray clay locally. Break at 50.6'± which dips 45°±. Trace of gray clay along contact of fine-medium crystalline and coarse crystalline halite at 49'-50.5'±. [1,9]	
	45						
12	51.0	5.0	5.0	100			
	50						
	55						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-41

LOCATION ROOM G - ROOF

STATION N1101, W2782 COLLAR ELEV. 1295.8 FT DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10789.0, E4132.6 DEPTH OF BOREHOLE 49.9 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-23-85 DATE COMPLETED 1-24-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-24-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	3.0	1.1	37		0.0'-3.0' HALITE: Clear, coarsely crystalline, some medium. [1] 3.0'-5.9' HALITE: Clear, some light moderate brown, coarsely crystalline. <1/2% brown clay. [8]	NC single-tube core barrel for Run 1. All other runs used NC double-tube wireline core barrel. Total drilling time: 8 hrs ±.
2	3.0 5	4.0	3.3	82		5.9'-7.0' HALITE: Clear to moderate brown (5YR 4/4), fine to medium, some coarse crystalline. ≤1%, locally 2%, brown clay with trace of gray. <1/2% dispersed polyhalite.	Dry hole. No gas detected. 31% of recovered core was ≥2-inch lengths.
3	7.0 10	4.0	2.8	70		7.0'-7.3' ANHYDRITE "b": Light to light medium gray (N7, N6), microcrystalline anhydrite. Laminated to 7.1'. Scattered halite growths. ≤1/2" gray clay at 7.0'. Some core grinding evident. 7.3'-12.9'± 0.4' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. <1/2% polyhalite locally. [1]	Run 1: Some broken core. Run 3: Broken last 1/2'. Much of Run 5 broken.
4	11.0 15	5.0	4.2	84		12.9'-13.8'± 0.4' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. ≤1% brown clay, some gray. Only 0.4' core recovered. 13.8'± -14.4' ANHYDRITE "a": Light to light medium gray (N7, N6); microcrystalline anhydrite. Irregular dark/light laminae. Trace of brown clay at 13.8'. Low-angle contact.	Run 8: Zones of broken core.
5	16.0 20	5.0	3.4	68		14.4'-18.8'± POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 3% polyhalite. [5,7] 18.8'-25.0' HALITE: Clear to moderate brown (5YR 4/4), some moderate reddish orange. Medium to coarsely crystalline, some fine. ≤1% brown clay, trace of gray. <1/2% of polyhalite locally. Irregular, low-angle brown clay seam at 24.8'. Up to 1/4". Associated anhydrite to 25'. Core broken. [1,10]	Run 10: Some broken zones.
6	21.0 25	5.0	5.0	100		25.0'-27.7' HALITE: Clear, coarsely crystalline. Scattered polyhalite and anhydrite stringers.	Run 12: Partially broken last 3'.

N

BORING NO. DH-41

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-41

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	5.0	100		27.7'-29.4' HALITE: Clear, some moderate brown (5YR 4/4) and moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. ≤1% brown clay and <1/2% dispersed polyhalite locally. [12]	
7		1.5	1.5	100			
8	30	5.0	5.0	100		29.4'-31.4' HALITE: Clear, coarsely crystalline. [1]	
						31.4'-36.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4), fine to coarsely crystalline. <1 to 3% brown clay. Scattered breaks. [10,15]	
						36.5'-37.25' ANHYDRITE: Light to medium gray (N7,N5), microcrystalline anhydrite. Laminae most noticeable from 37.0'. Prominent halite growths to 36.75'. Up to 1/4" brown clay at 36.5' but core broken here.	
9	35	4.0	4.0	100		37.25'-42.55' HALITE: Clear, coarsely crystalline. None to 2% polyhalite. Scattered anhydrite. [1,2] ≤2% polyhalite from 38.9-41.1'. [4]	
						42.55'-47.0' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, some fine to medium locally. <1% brown clay. [8,10]	
10	40	4.6	4.6	100		47.0'-49.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4; 4/4). Medium to coarsely crystalline, some fine. <1 to 3% brown clay, locally up to 5%. Scattered breaks. [10,15]	
11		1.4	1.4	100			
12	45	4.4	4.4	100			
13		3.0	3.0	100			
	50						
	55						

26.0 — 27.5 — 32.5 — 36.5 — 41.1 — 42.5 — 46.9 — 49.9

M

BORING NO. DH-41

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-42

LOCATION ROOM G - FLOOR

STATION N1101, W2782 COLLAR ELEV. 1285.9 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10789.0, E4132.4 DEPTH OF BOREHOLE 51.2 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-23-85 DATE COMPLETED 1-23-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-14-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	3.6	3.6	100		0.0'-5.3' HALITE: Clear, some light moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% brown clay. [1,2,8]	2-3/4" I.D. single-tube barrel used for Run 1. NC rods and NC double-tube core barrel used from Run 2.
	3.6					5.3'-6.2' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite from 5.6'±. [1,2]	Dry hole. No gas detected. Total drilling time: 8 hrs ±.
2	5	5.0	5.0	100		6.2'-7.3' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6, 4/6). Coarsely crystalline. <1 to 3% polyhalite. [7]	45% of core recovered was ≥2-inch length.
	8.6					7.3'-10.1' MB-139: Mixture of halite/anhydrite with "swallowtail" pattern from 7.3' to 8.9'. Then predominantly light to medium gray (N7, N5) microcrystalline anhydrite. Scattered halite growths. Up to 1/2" dry gray clay at lower contact. Contact dips 20°±.	Interval 20'-40.5' replaced with hole DH-42A.
3	10	4.6	4.6	100		10.1'-14.5' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay. Brown clay at 12.9'-13.3'. [9]	
	13.2					14.5'-17.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. [7]	
4	15	5.0	5.0	100		17.6'-24.5'± 0.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. 1 to 3% polyhalite. ≤1% gray clay to 20.8'. Scattered anhydrite. [5,7]	Barrel plugged during Run 6. No core recovery in Run 7.
	18.2					24.5'-28.3' HALITE: Clear, some light moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay. <1/2% dispersed polyhalite.	Poor core quality in Runs 8 and 9.
5	20	4.8	4.8	100		28.3'-39.8' Unable to log due to poor recovery and quality.	
	23.0						
6	25	5.3	4.4	83			

M

BORING NO. DH-42

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-42

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	5.3	4.4	83		39.8'± -43.3' HALITE: Clear, some moderate brown (5YR 4/4); medium gray (N5) and moderate reddish orange. Coarsely crystalline. ≤1% clay, gray with some brown. ≤1% polyhalite. Bluish-gray break at 43.3'.	
7	30	5.0	0.0	0	Unable to log due to poor core recovery and quality.	43.3'-44.65' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), fine to medium crystalline, some coarse. <1/2% polyhalite. <1 to 3% brown clay. Scattered breaks.	
8	35	3.5	2.0	57		44.65'-47.2' HALITE: Clear, some moderate reddish orange (10R 6/6). Coarsely crystalline, some fine to medium. <1% gray clay. Predominantly brown clay to 46'. <1% polyhalite. [9,11, some 17]	
9		3.0	0.4	13		47.2'-51.2' HALITE: Clear, coarsely crystalline. <1/2% polyhalite. [1]	
10	40	3.1	3.1	100			
11	45	5.1	5.0	98			
12	50	3.2	2.0	63			
	55						

28.3 — 33.3 — 36.8 — 39.8 — 42.9 — 48.0 — 51.2

BORING NO. DH-42

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-42A

LOCATION ROOM G - FLOOR

STATION N1101, W2789 COLLAR ELEV. 1285.7 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10789.2, E4125.5 DEPTH OF BOREHOLE 40.5 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-25-85 DATE COMPLETED 1-25-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-25-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	0	No Core				0.0'-20.0' No core. Refer to DH-42 log.	Replacement hole for portion of core hole DH-42.
	5					20.0'-25.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. <1 to 3% polyhalite. <1% gray clay from 24.7-25.7'. Some brown clay. [7, some 9]	NC double-tube wireline barrel used. NC rods 20.0'-40.5'.
						25.7'-28.9' HALITE: Clear, some moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Medium to coarsely crystalline, some fine. ≤1% polyhalite and brown clay. Scattered breaks from 26.8'. [17]	58% of core recovered was ≥2-inch length.
						28.9'-33.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3%, average 2%, polyhalite. [4,7]	Total drilling time: 5 1/2 hrs ±.
	10					33.4'-35.0' HALITE: Clear, some light moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% polyhalite, locally 2%. Small moist vug in core. Gradational contact at 33.4'. [1,2,4]	Dry hole. No gas detected.
						35.0'-35.7' ANHYDRITE: Moderate reddish orange/brown (10R 6/6, 4/6), intermixed with polyhalitic halite to 35.3'. Then moderate reddish orange to light gray anhydrite. Scattered halite growths. Up to 3/4" gray clay at 35.7'. Irregular, low-angle contact.	Very good core.
	15					35.7'-40.5' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1/2% polyhalite. 0 to <1% gray clay. Breaks at 37.2' and 37.55'±. [9,11]	
20.0	20						
1		1.5	1.5	100	X X X X X X X X X X X X X X X X X X X X		
21.5							
2	25	5.0	5.0	100			

M

BORING NO. DH-42A

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-42A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
2	25	5.0	5.0	100			
3	30	5.0	5.0	100			
4	35	5.0	5.0	100			
5	40	4.0	3.6	90			
	45						
	50						
	55						

26.5

31.5

36.5

40.5

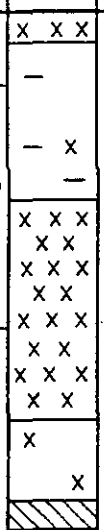

M

BORING NO. DH-42A

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-207 INSTRUMENT TYPE & NUMBER Extensometer GE-246 HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S697, E155 COLLAR ELEV. 1259.8' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N8989.7, E7049.1 BOREHOLE PENETRATION 53.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
9	25	5.0	100	—			
8	20	5.0	100	—		20.7' - 25.8' **HALITE:** mottled colorless to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, 0-1% polyhalite, 0-7% brown clay, banded clay/polyhalite appearance.	
7	15	4.7	92	—		16.4' - 20.7' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 5/6) halite, medium to coarsely crystalline, 10-20% polyhalite from 16.4'-17.2', 1-5% from 17.2'-20.7', clear, pure halite from 16.9'-17.0,' anhydrite stringer (~1/2") at 17.0', no clay, discontinuous anhydrite stringer (~1/16") at 18.1'.	
						15.7' - 16.4' **ANHYDRITE:** (Anhydrite "a") light gray (N7) microcrystalline anhydrite, 0-5% halite, no basal clay but core is badly broken and chipped up at bottom of anhydrite—clay may be washed away.	
6	10	4.2	84	—		8.9' - 15.7' **HALITE:** clear to colorless halite, medium to coarsely crystalline, <1% polyhalite from 8.8'-10.0' and 13.9'-15.3', absent elsewhere, ~1% gray clay from 13.9'-15.3', clay absent elsewhere, anhydrite stringer (1/16") at 9.0'.	Pressurized gas encountered at 11.9' pushed drill rods back slightly and blew water out of hole.
5		040	80	—		8.75' - 8.9' **ANHYDRITE:** (Anhydrite "b") light gray (N7), microcrystalline anhydrite, 8.8'-8.9' core lost.	Gas encountered at ~8.8'.
4	5	2.0	59	—		3.3' - 8.75' **HALITE:** colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upwards, 0-1% polyhalite, 1-5% brown clay locally concentrated, few blebs of gray clay, gray clay break at 8.75'.	Core runs 1 through 4 were drilled without inner barrel.
3		1.7	85	—			
2		0.7	88	—		0.0' - 3.3' **HALITE:** clear halite, coarsely crystalline, <1% polyhalite, <1% gray clay, <1% brown clay increasing upward, grades into next higher unit.	0' - 1' drilled with 6" single-tube core barrel.
1		0.8	67	—			Drilling started at 09:30 hours on 10 December 1982.
	0						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-207 INSTRUMENT TYPE & NUMBER Extensometer GE-246 HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S697, E155 COLLAR ELEV. 1259.8' DIRECTION OF DRILLING Vertical UP

MINE COORDINATES N8989.7, E7049.1 BOREHOLE PENETRATION 53.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
14	50	4.0	100	—		(see description on next sheet)	
13	45	46	92	—		**46.9' - 49.0' HALITE:** colorless halite, coarsely crystalline, <1% polyhalite, few blebs of clay 46.9'-48.0', increasing to 1-2% (total brown and gray) from 48.0'-49.0', grades into unit above.	
						43.0' - 46.9' HALITE: mottled colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1% polyhalite, 1-5% brown clay locally concentrated, brown clay parting at 43.5', 45.3'-46.6' is relatively pure halite with one brown clay seam impossible to locate because of condition of core.	
12	40	4.7	94	—		**39.9' - 43.0' HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1-3% *disseminated polyhalite, several anhydrite stringers* but core too broken to locate.	
						39.1' - 39.9' ANHYDRITE: (Marker Bed 138) light gray (N7) *microcrystalline anhydrite, moderate* (10R 4/6) to dark reddish-brown (10R 3/4) polyhalite band from 39.8'-39.9', 30-40% halite in upper 0.2'.	
11	35	4.6	92	—		**33.9' - 39.1' HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upward, few blebs of polyhalite except for 1-2% at 38.2', 5% brown clay, <1% gray clay, brown clay seams at 38.3' and 39.1', brown clay break at 37.6', 0.1' of clear halite with trace gray clay at top of unit.	
10	30	5.0	100	—		**31.4' -33.9' HALITE:** colorless halite, coarsely crystalline, <1% polyhalite.	
						29.4' - 31.4' ARGILLACEOUS HALITE: colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, few blebs of polyhalite, 1-2% brown and gray clay 29.4'-30.0', 10-20%, brown clay 30.0'-31.4', brown clay partings at 30.6', 30.8', 31.0', and 31.3', anhydrite stringer (<1/16") at 31.2'.	
9	25	5.0	100	—		**25.8'-29.4' HALITE:** colorless halite, coarsely crystalline, few blebs of polyhalite, brown *clay parting at 26.3', clay absent elsewhere,* anhydrite stringer zone 26.3'-26.7', anhydrite stringers (<1/16") at 26.9', 27.2', 27.6', and 28.3'.	
						(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-207 INSTRUMENT TYPE & NUMBER Extensometer GE-246 HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S697, E155 COLLAR ELEV. 1259.8' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N8989.7, E7049.1 BOREHOLE PENETRATION 53.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						Total penetration = 53.0'.
14	50	4.0	100	—		49.0' - 53.0' ARGILLACEOUS HALITE: mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upward, <1% polyhalite, 1-20% brown clay, increasing upward, brown clay partings at 50.1', 51.9', 52.6', and 52.9', brown clay seam at 50.2'.	Drilling completed on 11 December 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-208 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S698, E150 COLLAR ELEV. 1251.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8988.8, E7044.0 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12 B

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83

SHEET 1 OF 2

RUN NUMBER	DEPTH (ft)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.5	75	—	X		Drilling started 10:00 hours, 10 December 1982 RUN 1 - unclear where core loss occurred. No inner barrel used.
2	5	1.5	38	—	X	0.0' - 9.1' **HALITE:** clear to moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6) halite, moderately hard, medium to coarsely crystalline, scattered blebs of orange polyhalite throughout. Trace (<1/2%) of brown interstitial clay. Polyhalite content increases to ~2% below 8.0'. Clear halite from 6.5' to 8.0'.	RUN 2 - no inner barrel used.
3		4.2	100	—	X		
4	10	4.4	88	—	X	9.1' - 12.6' **ANHYDRITE:** (Marker Bed 139) light gray (N7) anhydrite, moderately hard, very finely crystalline, core broken into 1/4" to 3/4" pieces. 12.6' - 12.7' **CLAY:** medium light gray (N6) clay seam, stiff, moderately plastic. 12.7' - 16.9' **HALITE:** clear to mottled medium gray (N5) to pale reddish-brown (10R 5/4) halite, moderately hard, finely to coarsely crystalline. Clay comprises 3-5% with trace (2-3%) interstitial polyhalite and scattered polyhalite blebs. Clay breaks at 13.6', 13.9', 14.0', 14.4', 14.7', 15.5', 16.1', and 16.7'.	RUN 4 - MB 139 is broken up--core loss probably from this bed.
5	15 20	5.1	100	—	X	16.9' - 28.1' **HALITE:** clear halite with some moderate reddish-orange (10R 6/6) polyhalite zones, finely to coarsely crystalline, moderately hard. Trace (<1%) interstitial, light gray (N7) clay from 21.5'-23.8'. Polyhalite content ranges from 0 to 2% throughout and increases to 2-3% from 26.5'-28.1'. Clear halite from 24.7' to 26.0'.	
6	25	4.9	98	—	X		

M

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-208 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S698, E150 COLLAR ELEV. 1251.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8988.8, E7044.0 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY BGK, JPS/Bechtel DATE 1/26/83 SHEET 2 OF 2

RUN NUMBER	DEPTH (ft)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25–30	5.1	100	—		(as above)	
8	30–35	4.8	96	—		28.1' - 34.0' **HALITE:** clear to very light gray (N8) to light brownish-gray (5YR 6/1) halite, moderately hard, medium to coarsely crystalline, clay in part comprises up to 3% of core. Few polyhalite blebs throughout. Very light gray (N8) halite from 29.3'-30.2'. Clay breaks at 28.4', 29.3', 29.8', 30.9', and 32.0'.	Averaging 1 in approximately 2 1/2 minutes of drilling.
9	35–40	3.9	98	—		34.0' - 39.2' **HALITE:** polyhalitic, clear to moderate reddish-orange (10R 6/6) halite, moderately hard, coarsely crystalline. Polyhalite occurs as interstitial layers and scattered blebs and comprises 2-5% of core. Polyhalite lens from 38.5'-39.0'.	
10	40–45	5.0	100	—		39.2' - 39.4' **ANHYDRITE:** very light gray (N8) anhydrite, dense, hard, very finely crystalline, few blebs of clear halite.	
11	45–50	4.8	96	—		39.4' - 49.2' **ARGILLACEOUS HALITE:** clear to mottled medium dark gray (N4) to pale yellowish-brown (10YR 6/2), to pale red (10R 6/2) halite, moderately hard, finely to coarsely crystalline, clay content ranges from 0 to 10%. Scattered, near-horizontal clay breaks at 40.5', 40.7', 42.7', 42.9', 43.7', 47.6', 48.2', and 48.5'. Finely crystalline below 46.5'.	Drilling finished 14:30 hours, 10 December 1982. Total depth = 49.2'. Hole slowly discharging gas on 13 December 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-211 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930' S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1270.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N8366.5, E7057.1 BOREHOLE PENETRATION 50.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83 SHEET 1 OF 2

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
						(see description on next sheet)	
8	25	5.0	100	–		19.0' – 24.2' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upward, ≤ 1% polyhalite, 1-5% brown clay locally concentrated, <1% gray clay.	
7	20	4.6	100	–		15.1' – 19.0' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1-2% polyhalite, polyhalite stringers at 15.1'; anhydrite stringer zone from 15.1'-15.8', anhydrite stringers at 16.3' and 17.1'.	
6	15	4.9	98	–		14.5' – 15.1' **ANHYDRITE:** (Anhydrite "a") light gray (N7) microcrystalline anhydrite. 13.7' – 14.5' **HALITE:** mottled colorless to grayish-orange-pink (5YR 7/2) to moderate brown (5YR 3/4) halite, medium to finely crystalline, <1% polyhalite, 2-5% disseminated brown clay, <1% gray clay, gray clay parting at 14.5'.	Advancing 5' in 0.5 hr.
5	10	3.4	97	–		7.9' – 13.7' **HALITE:** colorless halite, coarsely crystalline, <1% polyhalite and clay, anhydrite stringers at 9.3' (0.5") and 10.0' (0.1"), gray clay increases from 0-1% from 13.3' – 13.7', grades into unit above.	
4		1.5	100	–		7.8' – 7.9' **ANHYDRITE:** (Anhydrite "b") light gray (N7), microcrystalline anhydrite, mixed with halite at upper contact.	Gas at about 8'. Flow rate measured for 30 seconds = 11.8 cfm.
3		2.0	100	–		5.0' – 7.8' **HALITE:** colorless to mottled moderate reddish-orange (10R 6/6) to medium light gray (N6) halite, medium to coarsely crystalline, <1-3% polyhalite locally concentrated, ~1% gray clay, gray clay break at 7.8'.	Gas at moderate pressure at just under 8'.
2	5	0.7	35	–		0.0' – 5.0' **HALITE:** colorless halite, coarsely crystalline, ≤ 1% polyhalite, few blebs of gray clay.	CORE LOSS: Run #1, at 1.6'-2.1' Run #2, throughout run
1		1.5	75	–			0' – 1.0' drilled with 6" single-tube core barrel. Drilling started at 13:45 hours on 18 December 1982.
	0						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-211 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930' S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1270.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N8366.5, E7057.1 BOREHOLE PENETRATION 50.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83 SHEET 2 OF 2

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	3.0	100	–		48.1' – 50.0' **HALITE:** mottled, clear/colorless to moderate brown (5YR 3/4) halite, coarsely to finely crystalline, fining upward, 1-2% disseminated polyhalite from 49.6'-50.0', few blebs elsewhere, 1-5% brown clay locally concentrated.	Total penetration = 50.0'. Finished at 15:00 hours on 19 December 1982.
12	45	5.1	100	–		46.2' – 48.1' **HALITE:** clear to colorless halite, coarsely crystalline, <1% polyhalite and brown and gray clay, brown clay increases upward to 1% as unit grades into unit above.	
						42.3' – 46.2' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1% polyhalite except 45.5'-45.9' where 1-2% disseminated, 1-5% brown clay locally concentrated, brown clay break at 46.0'.	
11	40	46	92	–		38.5' – 42.3' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 2-5% polyhalite with localized elongate blebs of polyhalite, anhydrite stringers 38.5'-38.7', 38.9', and 39.1', few blebs of clay, grades into unit above.	
						38.0' – 38.5' **ANHYDRITE:** (Marker Bed 138) light gray (N7) microcrystalline anhydrite.	
10	35	5.1	100	–		32.7' – 38.0' **HALITE:** mottled whitish to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, <1% polyhalite except 1-2% from 36.8'-37.1', 5% brown clay locally concentrated, brown clay break at 35.9', brown clay seam at 38.0'.	
						30.5' – 32.7' **HALITE:** clear halite, coarsely crystalline, <1% polyhalite and clay.	
9	30	5.2	100	–		28.5' – 30.5' **HALITE:** mottled whitish to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upward, <1% polyhalite, 1-5% brown clay locally concentrated, <1% gray clay, brown clay break at 29.4', brown clay parting at 30.5'.	
						24.2' – 28.5' **HALITE:** colorless halite, coarsely crystalline, <1% polyhalite and clay, anhydrite/gray clay parting at 24.6', anhydrite parting at 24.8', both ~0.5".	
8	25	5.0	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-212 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930' S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1261.7' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8366.5, E7057.1 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83

SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	5.6	80	–		0.0' – 4.3' **HALITE:** clear to medium gray (N5) halite, moderately hard, coarsely crystalline, 5% clay in part. Gray clay breaks at 2.0', 2.8', and 3.3'. Trace (<1/2%) polyhalite at 1.9'.	Started at 14:00 hours on 17 December 1982. Drilling rate is 20' per hour. Core loss in Run #1 from 0.0'-1.4'.
	5					4.3' – 10.7' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, moderately hard, finely to coarsely crystalline with trace of moderate brown (5YR 3/4) clay bands. 1% clay from 7.1'-7.7'. Polyhalite occurs as blebs and interstitially and ranges from <1% to 10%.	Brine saturation measured at 100%. Trace of gas detected in first 7'.
2	10	5.1	100	–		10.7' – 12.6' **ANHYDRITE:** (Marker Bed 139) banded, medium gray (N5) and very light gray (N8) anhydrite, hard, dense, finely crystalline. Core is broken into 1/4"-1/2" chips from 12.1' to 12.6'. Medium light gray (N6) clay seam at 12.6', moderately soft and plastic, ±1/2" thick.	
3	15	5.0	100	–		12.6' – 14.5' **HALITE:** clear, coarsely crystalline halite, moderately hard, <1% clay throughout. Medium light gray (N6) clay breaks at 13.0' and 13.2'.	
4	20	5.3	100	–		14.5' – 27.9' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline. Polyhalite is interstitial and occurs as blebs and ranges from 0% to 10%. Discontinuous, very thin clay breaks at 15.6', 18.8', 19.9', 21.6', 22.0', and 27.4'.	
5	25	5.1	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-212 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930' S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1261.7' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8366.5, E7057.1 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK, JPS/Bechtel DATE 1/26/83

SHEET 2 OF 3

RUN NUMBER	DEPTH (ft)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.1	100	-		(as above)	Drilling on 18 December 1982 started at 08:45 hours.
6	30	5.3	100	-		27.9' - 32.8' **HALITE:** argillaceous in part, clear to mottled grayish-red (5R 4/2) and medium light gray (N6) halite, moderately hard, finely to medium crystalline. Clay is interstitial and comprises up to 5%. Few medium light gray (N6) and moderate brown (5YR 3/4) clay breaks at 28.2', 28.4', 29.4', 29.7', 30.0', 30.1', and 31.3'. Trace (<1/2%) orange polyhalite blebs scattered from 31.2' to 32.8'.	
7	35	4.7	94	-		32.8' - 38.6' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6) halite, slightly banded in part, moderately hard, finely to coarsely crystalline. Polyhalite is interstitial and occurs as blebs and ranges from 2-5%.	Drilling stopped at 09:30 due to electrical problems with drill motor. Resumed at 11:30.
						38.6' - 38.9' **ANHYDRITE:** light gray (N7) anhydrite, dense, hard, very finely crystalline. At 38.9', trace of light gray (N7) clay on anhydrite fragments.	
8	40	4.1	100	-			
9	45	5.2	100	-		38.9' - 51.9' **ARGILLACEOUS HALITE:** clear to medium gray (N5) and pale yellowish-brown (10YR 6/2) halite, moderately hard, medium to coarsely crystalline, clay content from <1% to 10%. Few orange polyhalite blebs scattered throughout. Clay breaks at 43.0', 45.9', 48.1', 48.6', and 50.3'.	
10	50	4.8	96	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-212 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930" S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1261.7' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8366.5, E7057.1 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	4.8	96	-	X	(as above) 51.9' - 52.1' HALITE: clear halite, moderately hard, coarsely crystalline.	Finished hole at 12:45 hours on 18 December 1982. Total depth = 52.1'.
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-215 INSTRUMENT TYPE & NUMBER Extensometer GE-247 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1272.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7727.2, E7046.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY BWH/TSC//RMB,JPS/Bechtel DATE 1/5-6/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25	4.9	98	-		23.2' - 28.8' **HALITE:** clear, fine to coarsely crystalline halite, moderately hard, few white anhydrite seams. At 24.7', anhydrite seam, 0.1' with brown clay parting. At 25.6', 1/2" white anhydrite seam, near horizontal and irregular.	
						22.4' - 23.2' **HALITE:** clear, medium to coarsely crystalline halite. 1% to 2% polyhalite blebs. Trace of interstitial brown clay.	
6	20	4.3	86	-		18.0' - 22.4' **HALITE:** clear halite with 10-15% brown clay, coarsely crystalline. Clay breaks at 19.2', 19.7', and 20.3'. 2% interstitial polyhalite from 20.0' to 20.3'. At 20.6', anhydrite bleb.	
						14.5' - 18.0' **HALITE:** clear, coarsely crystalline halite, 5% polyhalite in blebs. At 14.8', 1/2" thick anhydrite seam, sub-horizontal, irregular surface. From 15.1' - 17.0' polyhalite reduced to 1%. From 17.0' - 18.0' trace of gray clay.	
5	15	5.0	100	-		14.0' - 14.5' **ANHYDRITE:** (Anhydrite "a") gray brown (5YR 3/2) to light gray, microcrystalline anhydrite.	
4	10	4.9	98	-		7.6' - 14.0' **HALITE:** clear to light brown (10YR 4/2), coarsely crystalline halite. Less than 5% polyhalite, trace (<5%) of interstitial light gray clay. Gray clay seam at 14.0'.	
						7.4' - 7.6' **ANHYDRITE:** (Anhydrite "b") gray (N4), hard anhydrite, gray halite, clay seam at 7.4'.	From 7.0' - 8.0', hit trace of pressurized gas.
3		1.7	85	-		5.5' - 7.4' **ARGILLACEOUS HALITE:** dark gray (N4) to brown (5YR 5/2), coarsely crystalline halite, 5-10% interstitial brown clay, trace of polyhalite.	
2	5	0.7	35	-		0.0' - 5.5' **HALITE:** clear coarsely crystalline halite, from less than 5% to 10% polyhalite.	
1		1.5	75	-			0' - 1.0' drilled with 6" single-tube core barrel.
	0						Set casing to 4.5" at 09:00 hr. Began NX coring with brine at 09:30 hrs, 5 January 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-215 INSTRUMENT TYPE & NUMBER Extensometer GE-247 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1272.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7727.2, E7046.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY BWH/TSC//RMB,JPS/Bechtel DATE 1/5-6/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	5.0	100	–		**42.0' - 52.0' ARGILLACEOUS HALITE:** halite with trace polyhalite, mottled grayish brown and reddish orange (10YR 6/5). From 42.0' - 45.4', 20-30% brownish clay, coarsely crystalline with less than 1% polyhalite. Clay breaks at: 42.6', 42.9', 44.0', 44.2', 44.5', and 45.3'. From 45.4' - 47.4', clear, medium to coarsely crystalline, trace of gray clay, less than 1% polyhalite. From 47.4' - 52.0', argillaceous with 10-15% clay, fine to coarsely crystalline, moderately hard. Clay breaks at: 48.2', 48.8', 49.3', 49.4', 49.5', 50.4', 50.7', 50.9', 51.1', and 51.4'. From 51.2' - 52.0', finely crystalline with less than 2% interstitial polyhalite.	
11	45	5.0	100	–		**38.4' - 42.0' HALITE:** polyhalitic (5-10%) halite, clear and mottled reddish-orange, polyhalite as blebs in part. Moderately hard, medium crystalline. Trace of gray clay throughout. At 38.7', thin <1/4" anhydrite stringer.	Stopped coring on 5 January 1983 at 15:30 hrs. at 42.0 ft.
10	40	5.0	100	–		**37.8' - 38.4' ANHYDRITE:** (Marker Bed 138) light gray (N5) anhydrite, hard, dense, with light and dark gray banding. At 37.8', 0.1' thick brown clay seam, moderately stiff.	
						36.6' - 37.8' HALITE: polyhalitic (25%) halite to 37.0', finely crystalline, mottled gray, brown, and reddish orange, moderately hard. Argillaceous (10-15%) to 37.8', finely to medium crystalline, gray brown.	
9	35	5.0	100	–		**32.8' - 36.6' ARGILLACEOUS HALITE:** dark grayish brown (5YR 3/2) halite with some clear halite. Moderately hard, medium to coarsely crystalline. Clay breaks at 33.2', 33.3', 34.1', 34.4', 34.6', 34.9', 35.0', 35.4', 35.8', 36.3', and 36.6'.	
						30.4' - 32.8' HALITE: clear halite, moderately hard, finely to medium crystalline.	
8	30	5.0	100	–		**28.8' - 30.4' ARGILLACEOUS HALITE:** brownish gray (5YR 4/1), finely to coarsely crystalline halite, moderately hard. Clay (10-20%) is dark brown with trace of gray. Polyhalite (1%) from 30.2' to 30.4'. At 29.6', brown clay break.	
7	25	4.9	98	–		(As below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-215 INSTRUMENT TYPE & NUMBER Extensometer GE-247 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1272.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7727.2, E7046.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY BWH/TSC//RMB,JPS/Bechtel DATE 1/5-6/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	75, 70, 65, 60, 55						
12	50	5.0	100	–	X X X	(As below)	Total penetration = 52.0'. Completed hole at 10:00 hours on 6 January 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-216 INSTRUMENT TYPE & NUMBER Extensometer GE-248 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1262.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7727.2, E7046.9 DEPTH OF BOREHOLE 54.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 1/8-10/83

SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0	0	0.7	70	-		0.0' - 2.0' **HALITE:** clear, fine to coarsely crystalline halite, trace of polyhalite.	NX coring began at 10:00 hours on 6 January 1983. From 0'-7', core loss due to grinding throughout runs 0 & 1.
1	5	4.8	80	-		2.0' - 8.0' **ARGILLACEOUS HALITE:** clear and medium gray (N5) halite, moderately hard, 10-20% gray interstitial clay throughout, medium to coarsely crystalline. Clay breaks at 3.5' and 3.6'. At 4.2', blebs and trace of polyhalite.	0' - 1' drilled with 6" single-tube core barrel.
2	10	4.0	100	-		8.0' - 9.2' **POLYHALITIC HALITE:** clear and medium reddish-orange (10R 6/5) halite, coarsely crystalline, hard, brittle. 30-50% finely crystalline polyhalite.	
						9.2' - 9.9' **POLYHALITE:** medium reddish-orange (10R 6/5) polyhalite, hard, finely crystalline, with 20-30% clear halite.	
						9.9' - 11.5' **ANHYDRITE:** (Marker Bed 139) light gray to pale brown (5YR 5/2) anhydrite, banded, hard, dense.	Trace of gas at 11:0'.
3	15	5.2	100	-		11.5' - 12.3' **POLYHALITE:** medium reddish-orange (10R 6/5) polyhalite, trace of light gray anhydrite partings.	
						12.3' - 12.5' **CLAY:** brownish-gray (5YR 4/1) clay seam, stiff to firm, subhorizontal with irregular lower contact.	
						12.5' - 15.6' **HALITE:** medium reddish-orange (10R 6/5) and mottled brownish-gray (5YR 4/1) halite, finely to coarsely crystalline, moderately hard, argillaceous in part (< 2%). 5% polyhalite in part. Clay breaks at 12.7', 13.1', 13.8', 14.8', 15.5'.	
4	20	5.3	100	-		15.6' - 27.8' **POLYHALITIC HALITE:** clear and medium reddish-orange (10R 6/5) halite, moderately crystalline, hard. 5-30% blebs of polyhalite. Polyhalite < 1% from 20.5'-23.0'. Gray clay break at 26.9'.	
5	25	5.2	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-216 INSTRUMENT TYPE & NUMBER Extensometer GE-248 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1262.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7727.2, E7046.9 DEPTH OF BOREHOLE 54.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 1/8-10/83

SHEET 2 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.2	100	–		(As above)	
6	30	5.3	100	–		27.8' - 32.4' **ARGILLACEOUS HALITE:** mottled brownish-gray (5YR 4/1) halite with trace of orange polyhalite. Moderately hard, finely to coarsely crystalline. Abundant interstitial clay at 30.9'. Clay breaks at 27.85', 28.1', 28.5', 29.2', 29.3', 29.9', 30.2', 30.6', 31.4'.	
7	35	5.2	100	–		32.4' - 38.2' **HALITE:** clear and medium reddish orange (10R 6/5) halite, finely to coarsely crystalline, moderately hard, few blebs of polyhalite throughout. Polyhalite generally less than 5%. At 37.2', sub-horizontal polyhalite seam.	
8	40	5.1	100	–		38.2' - 38.4' **ANHYDRITE:** medium light gray (N6) anhydrite, hard, dense, underlain by light gray clay parting of unknown thickness.	
						38.4' - 42.9' **ARGILLACEOUS HALITE:** mottled medium gray (N5) halite, finely to medium crystalline, 10% gray clay throughout. Clay breaks at: 39.4', 39.6', 40.2', 40.6', 41.8'. From 40.9' to 41.8', trace of polyhalite.	
9	45	5.3	100	–		42.9' - 45.2' **HALITE:** clear to moderate reddish-orange (10R 6/6) halite, finely to medium crystalline, trace of interstitial gray clay throughout.	
						45.2' - 49.7' **ARGILLACEOUS HALITE:** light grayish-brown halite, finely to medium crystalline, moderately hard, brown clay 2-5%. Clay breaks at: 45.7', 46.3', 46.7', 47.5', 49.0'. Trace of polyhalite.	
10	50	5.1	100	–		(see description on next sheet)	

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WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-216 INSTRUMENT TYPE & NUMBER Extensometer GE-248 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1262.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7727.2, E7046.9 DEPTH OF BOREHOLE 54.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 1/8-10/83

SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	5.1	100	-		49.7' - 54.2' HALITE: clear, medium to coarsely crystalline halite, moderately hard. Trace of gray clay throughout.	
11		1.5	100	-			Hole completed on 6 January 1983 at 15:00 hours. Total depth = 54.2'.
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-219 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2422' S of Exploratory Shaft centerline, 5' from E rib

STATION S2422, E162 COLLAR ELEV. 1266.3' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7264.9, E7056.6 BOREHOLE PENETRATION 51.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/18/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.1	100	—		24.0' - 28.8' **HALITE:** clear, medium to coarsely crystalline halite, moderately hard, few scattered white anhydrite blebs. At 24.3', 1/2" thick medium gray (N5) clay seam, dense, highly plastic.	
7	20	5.0	100	—		21.7' - 24.0' **HALITE:** clear to light brownish-gray (5YR 4/1) halite, finely crystalline, moderately hard. Trace (< 1%) of brown, interstitial argillaceous material throughout.	
						19.0' - 21.7' **HALITE:** argillaceous, clear to mottled brownish-gray (5YR 4/1) and moderate brown (5YR 3/4) halite, finely to medium crystalline, moderately hard. Light and dark brown interstitial argillaceous zones (5%) throughout. Clay breaks at: 19.0', 19.4', 19.9', 20.5', 20.7' and 21.5'.	
6	15	5.0	100	—		15.1' - 19.0' **HALITE:** clear, medium to coarsely crystalline halite, moderately hard. At 15.7', 45° dipping very light gray (N8) anhydrite seam, 1" thick. Few blebs of reddish-orange (10R 5/6) polyhalite throughout. Polyhalite content increases to 1/2% below 18.2'.	Trace of pressurized gas encountered at 15.0'.
						14.5' - 15.1' **ANHYDRITE:** (Anhydrite "a") banded light (N7) to dark (N3) gray anhydrite, hard, dense, trace of clear interstitial halite throughout.	
						14.4' - 14.5' **CLAY:** very light gray (N8) clay seam, subhorizontal, moderately soft.	
5	10	4.8	96	—		8.0' - 14.4' **HALITE:** clear to very pale orange (10YR 8/2) halite, finely to coarsely crystalline, moderately hard. From 13.0' to 14.4', argillaceous content up to 1%. Few polyhalite blebs at 14.2'.	
4		0.7	70	—			
3	5	2.1	52	—		5.8' - 8.0' **HALITE:** argillaceous, clear to mottled brownish-gray (5YR 4/1) to moderate brown (5YR 3/4) halite, moderately hard, slightly brittle, finely to coarsely crystalline.	
2		2.1	95	—		0.0' - 5.8' **HALITE:** clear halite, medium to coarsely crystalline, moderately hard, trace (<1%) of interstitial polyhalite and few scattered blebs of medium reddish-orange (10R 5/6) polyhalite throughout.	
1	0	1.1	85	—			NX coring began at 13:00 hours on 13 January 1983.

CORE LOSS:

RUN	WHERE LOST
1	0.0' - 0.2'
3	4.1' - 4.8'
	5.2' - 6.0'
	6.5' - 6.9'
4	7.9' - 8.2'

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-219 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2422' S of Exploratory Shaft centerline, 5' from E rib

STATION S2422, E162 COLLAR ELEV. 1266.3' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7264.9, E7056.6 BOREHOLE PENETRATION 51.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/18/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	50					(see description on next sheet)	
13		4.0	100	—		42.8' - 49.9' **HALITE:** argillaceous, clear to mottled grayish-brown (5YR 3/2) halite, moderately hard, finely to coarsely crystalline. Numerous scattered, brown clay breaks throughout. Argillaceous content ranges from 0% to 2%. Reduction in clay content from 46.8'-48.0'. Clay breaks at: 43.2', 43.8', 44.8', 44.9', 45.4', 45.9', 46.4', 46.5', 49.0', and 49.6'.	
12	45	3.1	100	—			
11		5.0	100	—		38.9' - 42.8' **HALITE:** clear, medium to coarsely crystalline halite, moderate hard. Few scattered stringers of light gray (N7) anhydrite throughout. Irregular anhydrite partings at: 39.0', 39.1', 39.7', and 40.2'.	
	40						
10		4.8	96	—	-X-	38.1' - 38.9' **ANHYDRITE:** (Marker Bed 138) white (N9) to very light gray (N8) anhydrite, dense, hard, finely crystalline.	
						38.0' - 38.1' **CLAY:** moderate brown (5YR 3/4) clay seam, moderately soft and plastic, subhorizontal contact with overlying anhydrite.	Trace of pressurized gas at 37.0'.
	35					32.5' - 38.0' **ARGILLACEOUS HALITE:** clear to mottled grayish-brown (5YR 3/2) halite, finely to medium crystalline, moderately hard. Argillaceous content 10-20%, but less than 5% from 32.5'-33.5'. From 37.3'-38.0', trace of interstitial dark yellowish-orange (10YR 6/6) polyhalite. Clay breaks at 34.0', 34.2', 34.4', 35.6', 36.2', 36.3', and 36.9'	
9		5.3	100	—		30.3' - 32.5' **HALITE:** clear, medium to coarsely crystalline halite, moderately hard.	
	30					28.8' - 30.3' **HALITE:** argillaceous, clear to brownish-gray (5YR 4/1) halite, finely crystalline. Argillaceous content 2-3% from 28.8' to 29.3' and < 1% from 29.3' to 30.3'.	
8		5.1	100	—		(As below)	
	25						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-219 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2422' S of Exploratory Shaft centerline, 5' from E rib

STATION S2422, E162 COLLAR ELEV. 1266.3' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7264.9, E7056.6 BOREHOLE PENETRATION 51.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/18/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
13	50	4.0	100	—	—	49.9' - 51.0' **HALITE:** argillaceous, clear, moderate brown (5YR 3/4) halite, very finely crystalline, sugary texture in part, moderately hard, 2-5% argillaceous content. Irregular, moderate brown (5YR 3/4) clay breaks at 50.0' and 50.2'.	Total penetration = 51.0'. Hole completed at 15:15 hours on 14 January 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-219A INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2418' S of Exploratory Shaft centerline, 5' from E rib

STATION S2418, E162 COLLAR ELEV. 1266.1' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7268.5, E7056.2 BOREHOLE PENETRATION 11.3'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/18/83 SHEET 1 OF 1

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	10					8.2' - 11.3' **HALITE:** clear halite, moderately hard, medium to coarsely crystalline. Few scattered hairline stringers of very light gray (N8) anhydrite at: 8.5', 8.8', 9.8', 10.0', 10.8' and 11.1'.	Total penetration = 11.3'.
5		5.3	100	—		8.2' **ANHYDRITE:** (Anhydrite "b") light gray (N7), very finely crystalline anhydrite, hard, dense, 3/8" thick.	Hole cored to determine exact location, thickness, and character of clay parting and anhydrite lens at 8.2' not recovered in DH-219.
4		0.3	100	—	X	5.5' - 8.2' **ARGILLACEOUS HALITE:** clear to mottled moderate brown (5YR 3/4) halite, medium to coarsely crystalline, moderately hard. Interstitial argillaceous material comprises 20% of core. Trace of grayish-orange (10YR 7/4) polyhalite (< 1%) from 7.0' to 7.3'. Brown clay break at 7.3' and gray clay parting at 8.2'.	
3	5	2.0	100	—	X		0' - 1.0' drilled with 6" single-tube core barrel.
2		1.7	100	—	X X X	0.0' - 5.5' **HALITE:** clear halite, finely to coarsely crystalline, moderately hard, trace of medium reddish-orange (10R 5/6) polyhalite and scattered polyhalite blebs.	RUN 1 core lost between 1.7' - 2.0'.
1		0.7	70	—	X		NX coring began at 10:00 hours and ended at 11:15 hours on 17 January 1983.
	0						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-220 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2421' S of Exploratory Shaft centerline, 5' from E rib

STATION S2421, E162 COLLAR ELEV. 1257.4' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7265.5, E7055.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/19/83

SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0 – 5	4.1	68	–		0.0' - 6.5' **HALITE:** clear, finely to coarsely crystalline halite, moderately hard. Trace (< 1%) of reddish-orange (10R 5/6) polyhalite blebs throughout. Few grayish-brown argillaceous zones, < 1%.	NX coring began at 08:30 hours on 15 January 1983.
2		0.9	90	–		6.5' - 8.8' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline. Polyhalite (5-10%) occurs as blebs and interstitial layers.	CORE LOSS: RUN / WHERE LOST: 1 — 1.3' - 1.4', 2.3' - 2.8', 3.3' - 4.0', 4.1' - 4.7'; 2 — 6.0' - 6.1'; 4 — 12.2' - 12.3'; 8 — 33.4' - 33.7'
3	10	5.2	100	–		8.8' - 11.0' **ANHYDRITE:** (Marker Bed 139) polyhalitic, pale reddish-brown (10R 5/4) and medium gray (N5) anhydrite, dense, finely crystalline, hard, numerous polyhalite seams and partings comprise up to 50% of core, slightly banded. Medium gray (N5) clay parting at 11.0'.	
4	15	4.9	98	–		11.0' - 19.9' **HALITE:** polyhalitic in part, clear halite, light gray (N7) and moderate reddish-orange (10R 6/6). Finely to coarsely crystalline, moderately hard. Interstitial gray clay at 12.2'. Polyhalite content 2% (3-5% from 16.0' to 19.9'). Scattered polyhalite blebs at 14.0', seam at 19.3'.	
5	20	5.3	100	–		19.9' - 22.0' **HALITE:** clear to light gray (N7) halite, medium to coarsely crystalline, moderately hard, trace clay (< 1%) in part. Gray clay break at 20.0'.	
						22.0' - 28.4' **HALITE:** polyhalitic, clear to moderate reddish-orange (10R 6/6) and light brownish-gray (5YR 6/1) halite, finely to coarsely crystalline, moderately hard, 2-3% polyhalite and trace (< 1%) clay from 26.8'-28.4'. Finely crystalline from 24.9'-27.0'. Polyhalite occurs as interstitial layers and irregular blebs. Below 26.8', 5% interstitial gray clay, with clay breaks at 26.8', 27.0' and 27.4'.	
6	25	5.0	100	–			

M

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-220 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2421' S of Exploratory Shaft centerline, 5' from E rib

STATION S2421, E162 COLLAR ELEV. 1257.4' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7265.5, E7055.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/19/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	100	-		(as above)	
7	30	5.0	100	-		28.4' - 30.4' **HALITE:** clear to light gray (N7) halite, medium to coarsely crystalline, soft* to moderately hard. Clay content < 1%.	*From 28.3' to 29.5' core is broken into very small 1/8"-1/16" fragments.
8	35	4.7	94	-		30.4' - 36.3' **HALITE:** polyhalitic, clear to moderate reddish-orange (10R 6/6) halite, moderately to coarsely crystalline, moderately hard. Blebs and interstitial polyhalite comprise 3-5% of core. Few scattered, discontinuous hairline breaks of white anhydrite. At 35.7', light gray horizontal anhydrite parting with irregular surfaces.	
						36.3' - 36.5' **ANHYDRITE:** light (N7) and dark (N3) gray anhydrite bands, dense, hard, very finely crystalline. At 36.5' light gray (N7) clay seam, firm to stiff, moderately plastic.	
9	40	5.3	100	-		36.5' - 42.6' **HALITE:** clear to light gray (N7) to light brownish-gray (5YR 6/1) halite, moderately to coarsely crystalline, moderately hard. Trace (< 1%) clay in part.	
10	45	5.1	100	-		42.6' - 50.5' **ARGILLACEOUS HALITE:** mottled medium light gray (N6) to grayish-brown (5YR 3/2) and clear, finely to coarsely crystalline halite, moderately hard. Clay content 10-20% with clay breaks at: 44.5', 44.6', 45.1', 45.4', 47.4', 47.8', 48.2' and 48.9'.	
11	50	3.9	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-220 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2421' S of Exploratory Shaft centerline, 5' from E rib

STATION S2421, E162 COLLAR ELEV. 1257.4' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7265.5, E7055.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/19/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	3.9	100	–		(As above) 50.5' - 51.8' HALITE: clear halite, moderately hard, moderately to coarsely crystalline.	Hole completed at 15:00 hours on 15 January 1983. Trace of gas encountered after completion of hole. Total depth = 51.8'.
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-223 INSTRUMENT TYPE & NUMBER Extensometer GE-249 HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1255.1' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6607.2, E7048.5 BOREHOLE PENETRATION 52.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 1/26/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.0	100	-		**19.2' - 28.9' HALITE:** argillaceous and polyhalitic in part; clear to mottled light gray (N7) and moderate brown (5YR 3/4) halite, moderately hard, finely to coarsely crystalline. Clay content <2%. Polyhalite <1% from 20.8' to 21.1'. Clay breaks at 19.3', 22.3', 23.1', 23.8', clay parting at 24.3'. At 24.3', anhydrite stringer, 1/8" thick, bluish-white (5B 9/1), hard, dense.	
7	20	5.2	100	-		**15.2' - 19.2' HALITE:** clear halite, medium to coarsely crystalline, moderately hard, trace (<1%) moderate reddish-orange (10R 5/6) polyhalite blebs throughout.	
6	15	4.9	98	-		**14.2' - 15.2' ANHYDRITE:** (Anhydrite "a") very light (N8) to light gray (N7) anhydrite, dense, hard, finely crystalline, faintly banded in part. Some interstitial clear halite from 14.8' to 15.2'.	Pressurized gas at 15' blew return line out of reserve pond.
5	10	5.3	100	-		**0.0' - 14.2' HALITE:** clear to medium gray (N5) halite, medium to coarsely crystalline, moderately hard. Core is moderately fractured and broken from 1.0' to 4.5'. Trace clay (<1%) from 5.0' to 8.3' and from 13.5' to 14.2'. Clay breaks at 5.0', 6.7', 6.9', 7.3', 8.1', and 13.4'. 1/4" clay seams at 8.2' and 14.2'. 1/2"-thick, hard, dense, medium dark gray (N4) anhydrite (Anhydrite "b") lens at 8.2'.	Trace of gas between 8' and 9'.
4	5	1.1	58	-			CORE LOSS:
3		1.2	80	-			RUN — WHERE LOST 2 — 1.0' - 1.3' 3 — Throughout run 4 — Throughout run
2		1.7	85	-			Core Run #1 was a 1' run with a 6" O.D. core barrel.
1	0	1.0	100	-			Drilling started 09:30 hours on 22 January 1983

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-223 INSTRUMENT TYPE & NUMBER Extensometer GE-249 HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1255.1' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6607.2, E7048.5 BOREHOLE PENETRATION 52.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 1/26/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	5.2	100	-		(see description on next sheet)	
12	45	5.0	100	-		44.9' - 48.6' **HALITE:** clear halite, moderately hard, coarsely crystalline. Trace interstitial dark reddish-brown (10R 3/4) clay from 44.9' - 45.4'.	
						42.0' - 44.9' **ARGILLACEOUS HALITE:** clear and dark reddish-brown (10R 3/4) halite, finely to coarsely crystalline, moderately hard. Clay content up to 30%, clay breaks at 42.0', 42.5', 42.9', 43.0', 43.25', 43.6', and 44.7'.	
11	40	5.2	100	-	X X	38.6' - 42.0' **HALITE:** clear halite, medium to coarsely crystalline, moderately hard, trace interstitial moderate reddish-orange (10R 6/6) polyhalite and medium gray (N5) clay. Very light gray (N8) anhydrite stringers at 39.0' and 39.5'.	
						37.9' - 38.6' **ANHYDRITE:** (Marker Bed 138) light gray (N7) anhydrite, dense, hard, very finely crystalline.	
10	35	5.1	100	-		33.5' - 37.9' **ARGILLACEOUS HALITE:** brownish-gray (5YR 4/1) to grayish-brown (5YR 3/2) halite, finely to coarsely crystalline, moderately hard, 15-30% interstitial clay with clear halite. Clay breaks at 34.6', 35.1', 35.5', 35.7', 35.9', 36.3', 37.0', 37.2', 37.3', and 37.8'. At 37.9', 3/4"-thick clay seam, grayish-brown (5YR 3/2), stiff, moderately plastic.	
						30.3' - 33.5' **HALITE:** clear halite, coarsely crystalline, moderately hard, trace (<1/2%) clay from 32.7' to 33.5'.	Pressurized gas encountered at ±30'.
9	30	5.2	100	-		28.9' - 30.3' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, moderately hard, finely to moderately crystalline, 10-15% clay. Clay breaks at 29.1', 29.9', 30.0'. Core is slightly vesicular at 30.0'. Clay seam, 1/4" thick, medium light gray (N6), stiff and moderately plastic at 30.2'.	
8	25	5.0	100	-		(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-223 INSTRUMENT TYPE & NUMBER Extensometer GE-249 HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1255.1' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6607.2, E7048.5 BOREHOLE PENETRATION 52.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 1/26/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
13	50	5.2	100	-		48.6' - 52.6' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, moderately hard, finely to coarsely crystalline. Clay comprises 20-35% in part. Finely crystalline from 50.8'-52.6'. Clay breaks at 48.8', 49.0', 50.1', 52.0', 52.3', and 52.6'.	Total penetration = 52.6'. Completed hole at 08:30 hours on 23 January 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-224 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1246.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6607.5, E7048.5 DEPTH OF BOREHOLE 52.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/25/83

SHEET 1 OF 3

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.0	100	–			Coring began at 08:40 hours on 23 January 1983. Core Run #1, from 0.0' to 1.0', using 6" single-tube core barrel.
2		1.7	40	–		0.0' – 7.6' **HALITE:** clear halite, moderately hard, medium to coarsely crystalline, trace clay (<1/2%) from 1.0'-3.0', few moderate reddish-orange (10R 6/6) polyhalite blebs.	
3	5	5.2	100	–		7.6' – 10.7' **ANHYDRITE:** (Marker Bed 139), banded light bluish-gray (5B 7/1) to medium light gray (N6) to moderate reddish-brown (10R 4/6) anhydrite, very finely crystalline, hard, dense slightly halitic and polyhalitic. Medium gray (N5) clay seam, moderately soft and plastic, ±1/2" thick at 10.7'.	CORE LOSS: RUN 2 Throughout run; RUN 4 10.2' – 10.3'
4	10	0.9	90	–			
5		5.3	100	–		10.7' – 15.2' **HALITE:** clear and mottled moderate reddish-orange (10R 6/6) to light gray (N7) to grayish-orange (10YR 7/4) halite, moderately hard, finely to medium crystalline. Polyhalite and clay content varies throughout from <1% to 3%. Polyhalite is interstitial with some blebs. Medium light gray (N6) clay breaks at 11.7', 12.0', and 14.5'.	
	15					15.2' – 18.6' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline, polyhalite content ranges from <1% to 10% in blebs and interstitially, clay-filled fracture at 15.25'.	
6		5.0	100	–		18.6' – 21.7' **HALITE:** clear and brownish-gray (5YR 4/1) halite with trace of moderate reddish-orange (10R 6/6), moderately hard, medium to coarsely crystalline, trace (<2%) clay in part with trace (<5%) interstitial polyhalite throughout, clay breaks at 18.75', 19.9', and 20.75'.	
	20						
7		5.2	100	–		21.7' – 25.0' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6) halite, moderately hard, coarsely crystalline, polyhalite occurs as blebs and interstitial layers, ranging from 3-5%.	
	25						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-224 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1246.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6607.5, E7048.5 DEPTH OF BOREHOLE 52.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/25/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25	5.2	100	-			
8	30	5.0	100	-		25.0' - 30.0' **HALITE:** clear to mottled pale reddish-brown (10R 5/4) to pale brown (5YR 5/2) halite, finely to medium crystalline, slightly argillaceous and polyhalitic in part, clay content about 2% with breaks at 25.1', 26.5', 26.7', and 27.4'.	
						30.0' - 35.4' **HALITE:** clear and moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline. Polyhalite (<3%) is interstitial or occurs as blebs. At 34.6', medium light gray (N6) anhydrite stringer 3/8" thick.	
9	35	5.3	100	-		35.4' - 35.7' **ANHYDRITE:** banded very light gray (N8) and dark gray (N1) anhydrite, hard, dense, very finely crystalline.	
						35.7' - 35.8' **CLAY:** medium dark gray (N4) clay seam, moist, soft, near horizontal.	
10	40	5.0	100	-		35.8' - 49.1' **ARGILLACEOUS HALITE:** clear to medium dark gray (N4) halite, finely to coarsely crystalline, moderately hard. Clay content ranges from <1% to 10% with few orange polyhalite blebs at 43.7'. Clay breaks at 36.6', 43.8', 44.3', and 44.4'.	
11	45	5.3	100	-			
12	50	5.2	100	-		(see description on next sheet)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-224 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1246.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6607.5, E7048.5 DEPTH OF BOREHOLE 52.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/25/83

SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	5.2	100	–	X	49.1' – 52.5' HALITE: clear and mottled pale reddish-brown (10R 5/4) to light gray (N7) halite, finely to coarsely crystalline, moderately hard. Trace (<1/2%) polyhalite and clay throughout. At 52.0', 3/8"-thick, light gray (N7) clay seam, firm, moderately plastic. Thin clay break at 52.3'.	Hole completed at 14:30 hours on 23 January 1983.
	55						Total depth = 52.5'.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-227 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1247.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6030.7, E7041.2 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/28/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
						(see description on next sheet)	
7	25	5.3	100	-		18.0' - 24.3' **ARGILLACEOUS HALITE:** clear and medium light gray (N6) halite with isolated bands of moderate reddish-orange (10R 6/6) polyhalite, finely to coarsely crystalline, moderately hard. Argillaceous content 5-10% with clay breaks at 18.1', 18.5', 19.0', 19.6', 20.2', 20.5', 21.5', 22.4', 22.6, and 23.3'. Isolated bands of polyhalite at 19.2', 19.9', and 20.9'.	
6	20	5.0	100	-			
					X X X X X	14.5' - 18.0' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, moderately hard. Polyhalite generally <2% and occurs as scattered blebs or interstitially.	
5	15	5.1	100	-		13.8' - 14.5' **HALITE:** clear halite, coarsely crystalline, moderately hard. At 14.5', very light gray (N8) anhydrite lens.	
					X	13.0' - 13.8' **ANHYDRITE:** (Anhydrite "a") banded very light gray (N8) and medium gray (N5) anhydrite, hard, dense, microcrystalline.	
						12.9' - 13.0' **CLAY:** light gray (N7) clay, moderately soft, moist.	
4	10	5.0	100	-		7.1' - 12.9' **HALITE:** clear halite, medium to coarsely crystalline, moderately hard. From 12.1'-12.9', few interstitial argillaceous and polyhalitic zones. Clay content about 1-2% from 12.1'-12.5', and polyhalite about 1% from 12.5'-12.9'.	Trace of gas at 7.0'.
3		1.0	100	-	X	0.0' - 7.1' **HALITE:** clear to medium gray (N5) halite, moderately hard, coarsely crystalline, slightly (<1/2%) argillaceous in part. Few discontinuous clay breaks throughout. Few orange polyhalitic blebs from 6.0'-6.5'. At 7.1', olive gray (5Y 4/1) anhydrite stringer (Anhydrite "b"), hard, dense, with trace of medium gray (N5) clay.	Core Loss: Run — Where Lost 1 — Throughout Run 2 — Throughout Run 12 — 46.7'-46.8' 0' - 1.0' drilled with 6" single-tube core barrel. Hole began at 13:00 hours on 28 January 1983.
2	5	0.5	25	-			
1		0.6	30	-			
0	0	1.0	100	-			

M

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-227 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1247.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6030.7, E7041.2 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/28/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	4.9	98	–		45.6' - 50.4' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2) halite, finely to coarsely crystalline, moderately hard, finely crystalline from 49.8'-50.6'. Clay content generally 0-15% and about 1% from 45.6'-47.4'. Clay breaks at 47.1', 47.4', 47.5', 47.8', 48.3', 48.5', 48.7', 49.3', 49.4', 49.5', and 50.2'. From 50.4' - 50.6', grayish-red (10R 4/2) clay seam, moderately soft, highly plastic.	
11	45	5.1	100	–		44.0' - 45.6' **HALITE:** clear halite, coarsely crystalline, moderately hard. 41.7' - 44.0' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2) halite, finely to coarsely crystalline, moderately hard. Argillaceous content ranges from 0-15% with clay breaks at 42.0', 42.9', 43.5', 43.7, and 43.9'.	
10	40	5.0	100	–		37.5' - 41.7' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, polyhalite occurs as isolated blebs or interstitially, and comprises about 5-8% of core. 36.6' - 37.5' **HALITE:** clear halite, coarsely crystalline, moderately hard, few isolated stringers of gray anhydrite.	
9	35	5.2	100	–		35.9' - 36.6' **ANHYDRITE:** (Marker Bed 138) olive gray (5Y 4/1) anhydrite, hard, dense, microcrystalline, core broken into 1/4" chips. 35.8' - 35.9' **CLAY:** pale brown (5YR 5/2) clay, moist, moderately soft, moderately plastic. 27.0' - 35.8' **ARGILLACEOUS HALITE:** clear to mottled pale brown (5YR 5/2) and moderate brown (5YR 4/4) halite, moderately hard, finely to coarsely crystalline. Argillaceous content ranges from 0 to 10%. Clear and clay-free from 29.0'-30.2'. Brown and gray clay partings and breaks at 27.9', 28.0', 28.2', 28.5', 28.8', 30.5' (gray), 30.6' (gray), 30.8' (gray), 32.4' 32.5', 33.0', 33.1', 33.5', 33.8', 34.4', 34.7', 34.9', 35.5', and 35.6'.	
8	30	5.0	100	–			
7	25	5.3	100	–		24.3' - 27.0' **HALITE:** clear halite, moderately hard, medium to coarsely crystalline, few scattered hairline breaks of light gray (N7) anhydrite.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-227 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1247.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6030.7, E7041.2 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/28/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
12	50	4.9	98	–	X X	50.6' – 51.7' HALITE: clear and moderate reddish-orange (10R 6/6) halite, moderately hard, coarsely crystalline. Polyhalite occurs as isolated blebs and comprises 2-3% of core.	Total penetration = 51.7'. Hole completed at 17:30 hours on 28 January 1983.
						(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-228 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S. of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1237.8' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6030.7, E7041.2 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/2/83

SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0 – 5	3.0	58	—		0.0' - 7.3' HALITE: clear and medium gray (N5) halite, coarsely crystalline, moderately hard with numerous gray clay-filled hairline breaks. Slightly (<1%) argillaceous in part. Few (1%) polyhalitic blebs and interstitial layers from 5.9'-6.2'.	Coring began at 17:45 hours on 28 January 1983 Hole cored from 0' to 5.2' without inner tube in drill rod. From 5.2' to 50.4', hole cored using NX double tube core barrel.
2	5 – 10	5.3	100	—		7.3' - 9.4' POLYHALITIC HALITE clear and moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline, few grayish-pink (5R 8/2) anhydrite stringers. Polyhalite comprises up to 15% of rock. 9.4' - 10.2' POLYHALITE: pale reddish-brown (10R 5/4) to moderate reddish-orange (10R 6/6) polyhalite, microcrystalline, moderately hard, grades into underlying anhydrite.	
3	10 – 15	5.2	100	—		10.2' - 11.5' ANHYDRITE: (Marker Bed 139) light gray (N7) anhydrite, dense, hard, microcrystalline, banded medium dark gray (N4) in part, core broken into 1/8"-1/16" chips. At 11.5', medium gray (N5) clay seam, 1/4" thick, soft, moist. 11.5' - 14.4' ARGILLACEOUS HALITE: clear and medium light gray (N6) halite, finely to coarsely crystalline with 5-15% argillaceous material. Gray clay breaks at 11.7', 12.0', 12.4', 13.5', 13.8', 14.2', and 14.4'.	
4	15 – 20	5.3	100	—		14.4' - 19.4' POLYHALITIC HALITE: clear and moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, moderately hard. Polyhalite comprises 10-15% of core and occurs as blebs or interstitial zones. 19.4' - 21.4' ARGILLACEOUS HALITE: clear and brownish-gray (5YR 4/1) halite, finely to coarsely crystalline, moderately hard, few clay breaks throughout. Clay content ranges from 0 to 5%. At 19.4', 1/2"-thick, very light gray (N8) anhydrite seam. At 19.5', medium gray (N5) clay parting, subhorizontal. Clay breaks at 20.7' and 21.3'.	
5	20 – 25	5.0	100	—		(see description on next sheet)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-228 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1237.8' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6030.7, E7041.2 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/2/83

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.0	100	–		21.4' – 25.7' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, moderately hard. Polyhalite content ranges from 0–10% and occurs as interstitial layers and scattered blebs.	
6	30	5.3	100	–		25.7' – 30.7' **HALITE:** argillaceous, clear and light gray (N7) halite, moderately hard, finely to coarsely crystalline. Clay content ranges from 2–5% with clay breaks at 27.7', 28.6', 29.5', 29.6', and 30.1'. Some (5%) interstitial polyhalite from 26.2' to 27.4' and at 28.8'.	
7	35	4.9	100	–		30.7' – 36.3' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6) halite, moderately hard, coarsely crystalline, 0–3% polyhalite. At 35.5', light gray (N7) 1/2" horizontal anhydrite seam.	
8	40	5.2	100	–		36.3' – 36.5' **ANHYDRITE:** banded medium dark gray (N4) and very light gray (N8) anhydrite, hard, dense, microcrystalline.	
9	45	5.0	100	–		36.5' – 49.1' **ARGILLACEOUS HALITE:** clear and medium light gray (N6) to grayish-orange (10YR 7/4) halite, finely to coarsely crystalline, moderately hard. Clay content about 5–10%, and clay breaks at 37.7', 38.2', 42.1', 43.3', 44.0', 45.0', and 47.0'. Finely crystalline from 44.1'–46.4'.	
10	50	4.0	85	–		49.1' – 50.4' **HALITE:** clear halite, moderately hard, coarsely crystalline.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-228 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1237.8' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6030.7, E7041.2 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/2/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	4.0	85	-		(as above)	Hole completed at 22:00 hours on 28 January 1983. Total depth = 50.4'.
	55						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-301

LOCATION INTERSECTION N150, W170 DRIFTS - ROOF

STATION N150, W170 COLLAR ELEV. 1276.9 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N9830.5, E6724.5 DEPTH OF BOREHOLE 50.75'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 8-29-84 DATE COMPLETED 8-30-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 8-31-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	2.0	2.0	100		0.0'-5.3' HALITE: Clear, mottled with blebs of moderate reddish orange polyhalite. Coarsely crystalline. ≤1% polyhalite. [1, 2]	NC double tube wireline core barrel. NC rods. Total drill time: 26 hrs ±.
2	2.0	5.0	5.0	100		5.3'-8.0' HALITE: Clear, some moderate brown (5YR 3/4, 4/4). Coarsely crystalline, ≤1% brown clay. [8, 17]	
	5					8.0'-8.9' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite and gray clay. [9]	No gas. Dry hole.
3	7.0	5.0	5.0	100		8.9'-9.15' ANHYDRITE b: Light gray (N7), microcrystalline, faintly laminated. Halite growths within. Trace of gray clay at 8.9'.	
						9.15'-14.3' HALITE: Clear, some light moderate reddish orange (10R 6/6). Coarsely crystalline. Scattered anhydrite. [1]	
	10					14.3'-15.65' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite and gray clay, trace of brown clay. [9]	39% of core recovered was ≥2 inch length.
4	12.0	4.6	4.6	100		15.65'-16.45' ANHYDRITE a: Light (N7) to medium light (N6), microcrystalline. Faintly laminated. Scattered halite growths, especially at 15.95'-16.45'. Trace of gray clay at 15.65'.	
	15					16.45'-20.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [7]	
5	16.6	5.0	5.0	100		20.4'-25.7' HALITE: Clear to moderate brown and reddish orange (10R 4/6, 6/6). Medium to coarsely crystalline. <1% brown clay. ≤1/2% polyhalite except at 20.4'-21.9' where polyhalite is 1% to 2%. [17]. 3/4" hard grayish-brown clay seam at 25.65'. Trace of associated anhydrite.	
	20					25.7'-29.4' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers.[1]	
6	21.6	5.0	5.0	100		29.4'-32.1' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, some fine to medium. ≤1% brown clay. [8, some 10]	
	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-301

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					32.1'-34.05' HALITE: Clear, coarsely crystalline. [1]	
26.6 / 7		2.0	2.0	100		34.05'-39.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline. <1% to 3% brown clay. Clear halite 36.0'-36.2'±. [10, 15]	
28.6 / 8	30	3.7	3.7	100		39.2'-39.7' ANHYDRITE: Light (N7) to medium light (N6) gray anhydrite, laminated. Scattered halite growths. Trace of grayish-brown clay at 39.2'.	
						39.7'-46.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, locally some fine to medium, <1% to 3% polyhalite to 40.5', <1% polyhalite at 40.5'-41.95' and 42.85' to 44.85'. Trace brown clay at 44.6'± [2, 5].	
32.3 / 9	35	5.0	4.9	98		46.75'-47.55' HALITE: Clear to moderate brown, some moderate reddish orange (5YR 4/4, 6/6). Medium to coarsely crystalline. ≤1% brown clay. Parting at 47.55'. [17]	
						47.55'-49.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, <1% to 3% polyhalite. [3, 5, 7]	
37.3 / 10	40	4.45	4.45	100		49.75'-50.75' HALITE: Clear mottled with moderate brown (5YR 4/4), coarsely crystalline. ≤1% brown clay. [8, 10]	
41.75 / 11		2.0	2.0	100			
43.75 / 12	45	4.0	4.0	100			
47.75 / 13	50	3.0	2.9	97			
50.75							

BORING NO. DH-301

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-302

LOCATION INTERSECTION N150, W170 DRIFTS - FLOOR

STATION N150, W170 COLLAR ELEV. 1264.9 DIRECTION OF DRILLING VERTICAL ~~DOWN~~

MINE COORDINATES N9830.5, E6724.5 DEPTH OF BOREHOLE 50.6'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 8-30-84 DATE COMPLETED 8-30-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 8-31-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	1.7	0.6	35.3		0.0'-2.8' HALITE: Clear, coarsely crystalline. <1/2% gray clay to 1.7'. <1/2% polyhalite from 1.7' to 2.8'. [1]	NC double tube core barrel. Set up time: 30 minutes. Total drill time: 6 hrs±. Run 1: Bit plugged. Core broken up badly.
2	1.7	4.9	4.8	97.9		2.8'-7.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [7]	
3	5 / 6.6	5.0	5.0	100		7.3'-9.6' MB-139: Mixture of halite and anhydrite to 8.1'±. Light gray to light moderate reddish orange. Some "swallowtail" pattern. From 8.1', very light (N8) to medium light (N6) gray anhydrite with scattered halite growths. Faintly laminated. Trace of gray clay at 9.6'.	No gas. Dry hole.
4	10 / 11.6	5.0	5.0	100		9.6'-12.9' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline, some fine. <1% gray clay and dispersed polyhalite. [9]	82% of core recovered is ≥2 inch length.
5	15 / 16.6	5.0	5.0	100		12.9'-17.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite [7]. Anhydrite/halite layer at 16.8'-17.0' with ≤1/4" gray clay @ 17'.	
						17.0'-19.3' HALITE: Clear, some moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% gray clay and dispersed polyhalite [9].	
						19.3'-25.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline to 23.5' then medium to coarse. <1% to 3% polyhalite locally up to 5%. ≤1% gray clay from 22.2'±. [5, 6, 7]	
6	20 / 21.6	5.0	5.0	100		25.6'-29.6' HALITE: Clear, some light bluish gray, medium to coarsely crystalline. ≤1% gray clay. <1% polyhalite dispersed. [9, some 11]	
						29.6'-34.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite [3, 7]. Anhydrite layers up to 3/4" thick at 34.4'-34.6'.	
	25	5.0	5.0	100		34.6'-35.7' HALITE: Clear, some light moderate reddish orange, coarsely crystalline. ≤1% polyhalite. Scattered anhydrite. [2]	

BORING NO. DH-302

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-302

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7	30	5.0	4.9	98		35.7'-35.9' ANHYDRITE: Light (N7) to very light (N8) gray microcrystalline anhydrite. Scattered small halite growths. Trace of gray clay at 35.9'.	
						35.9'-43.3' HALITE: Clear, some moderate reddish orange (10R 6/6) and medium light gray (N6). Coarsely crystalline, some medium and fine. ≤1% dispersed polyhalite to 38.2', then <1/2% dispersed and blebs. ≤1% gray clay. Low angle gray clay parting at 43.3'. [9, some 11]	
8	35	5.0	5.0	100		43.3'-47.4' HALITE: Clear to moderate reddish orange (10R 6/6). Some moderate brown (5YR 4/4) from 44.8'-45.5'±. Medium to coarsely crystalline. <1% to 2% polyhalite. <1% gray clay except 1% to 2% brown clay at 44.8' to 45.5'.	
						47.4'-50.6' HALITE: Clear, coarsely crystalline. <1% gray clay. Trace of polyhalite blebs. [1, 11]	
9	40	5.0	5.0	100			
10	45	5.0	5.0	100			
11	50	4.0	4.0	100			

26.6 — 31.6 — 36.6 — 41.6 — 46.6 — 50.6

M

BORING NO. DH-302

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-303

LOCATION W170 DRIFT - ROOF

STATION S400, W170 COLLAR ELEV. 1267.2 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N9282.3, E6726.1 DEPTH OF BOREHOLE 51.4'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-4-84 DATE COMPLETED 9-4-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 9-4-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	2.5	2.5	100		0.0'-5.45' HALITE: Clear, coarsely crystalline. <1/2% scattered polyhalite blebs. [1]	NC double tube wireline core barrel. NC rods.
2	5	5.0	5.0	100		5.45'-8.6' HALITE: Clear with some moderate brown (5YR 4/4). Medium to coarsely crystalline. <1% brown clay [8]. Break at 6.75'. <1/2% dispersed polyhalite at 7.5'-8.6'. [17]	No gas. Dry hole.
						8.6'-8.8' ANHYDRITE b: Light to light medium gray (N7, N6). Microcrystalline with scattered halite growths. Trace of gray clay at 8.6'.	
						8.8'-14.5' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	48% of recovered core is ≥2 inch length.
3	10	4.7	4.7	100		14.5'-15.75' HALITE: Clear with some light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% dispersed polyhalite. <1% gray clay. [9]	
						15.75'-16.45' ANHYDRITE a: Very light to light medium gray (N8, N6). Microcrystalline. Partially laminated, scattered halite growths. Trace of gray clay at 15.75'.	
4	15	5.0	5.0	100		16.45'-20.65' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3%, average 2% polyhalite. Scattered anhydrite. [2, 3, 5]	Run 4: Core broken last 6" of run.
						20.65'-26.4' HALITE: Clear to light moderate reddish orange (10R 6/6), some medium brown (5YR 4/4). Medium to coarsely crystalline with some fine crystalline. <1/2% dispersed polyhalite. ≤1% brown clay. <1/2" hard, dry brown clay seam at 26.3' with anhydrite associated to 26.4'. [8, 17]	
5	20	4.8	4.8	100		26.4'-30.7' HALITE: Clear, coasrsely crystalline with scattered anhydrite. [1]	Run 5: Some broken core in polyhalitic halite.
						30.7'-37.7' HALITE: Clear with some medium brown (5YR 3/4). Medium to coarsely crystalline with some fine. None to ≤1% brown clay with traces of gray. <1/2% polyhalite. [1, 8] with [12] at 30.7'-32.1'.	
6	25	5.0	5.0	100			

Depth scale: 2.5, 7.5, 12.2, 17.2, 22.1

BORING NO. DH-303

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-303

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					37.7'-39.5' ARGILLACEOUS HALITE: Clear to moderate brown 5YR 4/4, 3/4). Medium to coarsely crystalline with <1/2% dispersed polyhalite. <1% to 3% brown clay with a trace of gray clay. Brown break at 38.3'. [15, 17]	
27							
7						39.5'-40.15' ANHYDRITE: Very light to medium light gray (N8, N6). Scattered halite growths with irregular low angle laminae. ≤1/2" hard, dry brown clay at 39.5'.	
	30	4.9	4.9	100			
31.9						40.15'-44.2' HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline with scattered white anhydrite. ≤1% polyhalite [2, 3] except at 41.3'-42.9' *where there is >1% to 3% polyhalite.* [7]	*Run 8: isolated broken zones.*
8	35	5.0	5.0	100		44.2'-47.3' HALITE: Clear to moderate brown (5YR 4/4, 3/4). Coarsely crystalline with locally fine to medium crystalline. ≤ 1% brown clay with trace gray locally. Break at 47.2' with some thin anhydrite stringers at 47.2'-47.3'. [8, 10]	Run 9: Some broken core 39.5'-41.9 ft.
36.9						47.3'-49.6' HALITE: Clear, coarsely crystalline with < 1/2% polyhalite. Slight trace of very small brown clay blebs from 49'±.	
9	40	5.0	4.9	98		49.6'-51.4' ARGILLACEOUS HALITE: Clear to moderate brown ((5YR 3/4, 4/4). Coarsely crystalline with fine to medium crystalline from 51.3'. <1% to 3% brown clay, averaging 1% to 2%. Scattered clay breaks. [12, 15]	
41.9							
10	45	5.0	5.0	100			
46.9							
11	50	4.5	4.5	100			
51.4							

BORING NO. DH-303

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NC CORE BORING NO. DH-304

LOCATION S 400, W 170 DRIFT INTERSECTION - FLOOR

STATION S 400, W 170 COLLAR ELEV. 1254.3 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 9282.5,E6726.1 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 08/31/84 DATE COMPLETED 08/31/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 08/31/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	5.0	5.0	4.9	98		0.0'-4.0' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. <1% gray clay. <1/2% dispersed polyhalite. [9]	NC double tube wireline core barrel. NC rods. Total drill time: 6 hrs± 81% of core recovered is ≥2 inch length.
						4.0'-6.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [5, 7]	
2	6.9	1.9	1.9	100		6.1'-8.75' MB-139: Mixture of moderate reddish orange (10R 6/6) halite and anhydrite to 7.15'±. Then predominently light gray, microcrystalline anhydrite with scattered halite growths. Some near-horizontal lighter-darker gray laminae. Gray clay at 8.75'.	No gas. Dry hole.
3	11.9	5.0	5.0	100		8.75'-12.4' HALITE: Clear to light moderate reddish orange (10R 6/6), some light gray (N7). Medium to coarsely crystalline. <1/2% dispersed polyhalite. <1% gray clay. [9]	
						12.4'-16.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. Scattered anhydrite. <1% to 3% polyhalite. [5, 7] 1/4" gray clay seam at 16.5', dipping 40°±.	
4	16.9	5.0	5.0	100		16.5'-18.6' HALITE: Clear to light moderate reddish orange (10R 6/6), some light gray (N7). Medium to coarsely crystalline, some fine. <1% dispersed polyhalite and gray clay. [9]	
						18.6'-25.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. Scattered anhydrite. <1% to 3% polyhalite [3, 7]. <1% gray clay, some medium crystalline at 23.5'-25.5'.	
5	21.9	5.0	5.0	100		25.5'-29.05' HALITE: Clear, some light moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline, some fine. <1/2% polyhalite and <1% gray clay. Scattered anhydrite. [9]	
						29.05'-34.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. Scattered anhydrite from 33.8'. [3, 5, 7]	
6	25	5.0	5.0	100		34.7'-35.15' ANHYDRITE: Very light gray (N8) to light gray (N7) anhydrite with scattered halite growths. Gray clay parting at 35.15'.	

BORING NO. DH-304

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-304

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					35.15'-48.2' HALITE: Clear, some light moderate reddish orange (10R 6/6) and light medium bluish gray. Medium to *coarsely crystalline, some fine to 37.7'*, then predominently coarse, <1/2% dispersed polyhalite. ≤1% gray clay. [9, 11]	
26.9							
7		5.0	5.0	100		48.2'-50.5' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, ≤1% polyhalite and gray clay. [2, 9]	
	30						
31.9							
8		5.1	5.1	100			
	35						
37.0							
9	40	5.0	5.0	100			
42.0							
10	45	4.8	4.8	100			
46.8							
11		3.7	3.7	100			
	50						
50.5							

BORING NO. DH-304

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-306

LOCATION S 400, E 140 DRIFT INTERSECTION - FLOOR

STATION S 400, E 140 COLLAR ELEV. 1244.1 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N9287.3 E7049.9 DEPTH OF BOREHOLE 52.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/11/84 DATE COMPLETED 09/12/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/12/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		4.9	3.2	65		0.0'-1.9' HALITE: Some moderate reddish orange (10R 6/6). <1/2% gray clay and polyhalite. Recovery poor.	NW Split Tube Core Barrel. Total drill time: 13 hrs. Probed hole with "scratcher rod." Separation at 3.9' and 5' depth in hole.
						1.9'-2.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 2% polyhalite. [3, 4]	
4.9	5					2.9'-5.0'± MB-139: Mixture of some halite with anhydrite to 4'±. Then light gray to light medium gray (N7, N6) microcrystalline anhydrite. Scattered halite growths. Core moist from 4.6'±.	
2		3.5	2.5	71		5.0'±-8.7' HALITE: Clear to moderate reddish orange (10R 6/6), some light gray (N7). Medium to coarsely crystalline, some fine. <1/2% dispersed polyhalite. <1% gray clay, some brown locally.	
8.4							
3	10	2.2	2.2	100		8.7'-10.2' HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, ≤1% polyhalite. [2, 3]	Water encountered in hole at 2' ± depth. Noted inflow of water at 5' depth. Water level rose to 4'± from surface immediately after completing each drill run to 20' depth. Flow of water decreased significantly by 9-12-84. Source of this water appears to be simply from water dumped in area by contractor and is not natural brine water.
10.6							
4		5.0	4.2	84		10.2'-15.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline to 14'±, then medium to coarsely crystalline, some fine. <1% to 3% polyhalite. [3, 5, 7] <1/2% gray clay from 14'±.	
	15					15.6'-17.5' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% polyhalite blebs. [2, 3] Grades into unit below.	
15.6							
5		4.9	4.7	96		17.5'-20.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. [3, 5, 7]	
	20					20.7'-25.2' HALITE: Clear to light moderate reddish orange (10R 6/6). Coarsely crystalline with some medium. <1% dispersed polyhalite. <1% gray clay. Clear between 23.0' and 24.7'±. [1, 9]	
20.5							
6		4.0	4.0	100		25.2'-30.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3%, average <2% polyhalite. [3, 5, 7]. Moderate reddish orange polyhalite/anhydrite at 30.2'-30.5'±.	
24.5	25						

BORING NO. DH-306

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-306

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	5.0	5.0	100		30.6'-31.0' ANHYDRITE: Very light to light gray (N8, N7), microcrystalline. Scattered halite growths especially below 30.75'. No clay evident.	
						31.0'-39.7'± HALITE: Clear to lightly moderate reddish orange (10R 6/6). Coarsely crystalline, some medium. <1/2% dispersed polyhalite and gray clay. Anhydrite runs down to 31.5' within halite. [1, some 9, 11]	
8	30	5.0	4.6	92		39.7'-42.3' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay. [8, 10]	
						42.3'-44.9' HALITE: Clear, coarsely crystalline. <1% light bluish gray clay.	Had problems with core recovery in some runs. Core spring not holding core probably due to water in the hole. Had to adjust spring.
						44.9'-48.0' HALITE: Clear, coarsely crystalline. Slight trace of brownish clay to 45.5'±. [1]	
9	35	4.0	1.9	48		48.0'-49.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. Trace of anhydrite. [5]	
						49.6'-52.0' HALITE: Clear to lightly moderate reddish orange and some light bluish gray. Coarsely crystalline, some medium. <1/2% polyhalite dispersed and ≤1% bluish gray clay. [9]	35% of core recovered was ≥2 inch length.
10	40	3.0	1.8	60			
11		1.5	1.5	100			
12	45	5.0	5.0	100			Note: Drilled hole DH-306A approximately 15' west of DH-306 to replace upper 8.5' of DH-306 and to check for brine here. DH-306A was a dry hole drilled to 8.5' depth.
13	50	4.0	4.0	100			

29.5 — 34.5 — 38.5 — 41.5 — 43.0 — 48.0 — 52.0

BORING NO. DH-306

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-306A

LOCATION S 400 DRIFT - FLOOR

STATION S 400, E125 COLLAR ELEV. 1244.0 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N9287.9 E7034.6 DEPTH OF BOREHOLE 8.5

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/12/84 DATE COMPLETED 09/12/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/12/84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		4.6	4.6	100		0.0'-0.7' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. <1/2% dispersed polyhalite. [1, 2] 0.7'-2.1' POLYHALITIC HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite, average 2%. [3, 7]	NC double tube wireline core barrel. NC rods. No gas. Dry hole.
4.6	5						
2		3.9	3.9	100		2.1'-5.45' MB-139: Very light to medium light (N8, N6) gray microcrystalline anhydrite to 3.9'. Some "swallowtail" pattern in upper 1'. From 3.9' is partially laminated anhydrite. 1 in. hard gray clay seam at lower contact. Contact dips 10°±. Slight moisture along contact.	
8.5						5.45'-8.5' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline, <1% dispersed polyhalite. ≤1% clay, predominently gray with some brown locally at 6.9'-7.5'±. [9]	This is replacement hole for upper 8.5' of DH-306.

BORING NO. DH-306A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER GE-263 HOLE TYPE/SIZE NX CORE BORING NO. DH-307

LOCATION INTERSECTION OF E 300; S 400 DRIFTS - ROOF

STATION S 400, E 300 COLLAR ELEV. 1262.6 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N9286.7 E7194.2 DEPTH OF BOREHOLE 52.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 08/21/84 DATE COMPLETED 08/21/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 08/27/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 5.0	5.0	1.3	26		0.0'-4.7'± (Core Loss) HALITE: Clear, coarsely crystalline. [1] 4.7'-7.5' HALITE: Clear with some light moderate brown (5YR 4/4). Coarsely crystalline with fine to medium crystalline between 7'-7.5'± [9]. <1% brown clay with some gray clay at 7'-7.5'. [8]	NW split tube core barrel. NW rods. No gas. Dry hole.
2	5.0 – 8.0	3.0	3.0	100		7.5'-7.7' ANHYDRITE b: Very light to light gray (N8, N7). Microcrystalline with scattered halite. Gray clay at 7.5'. 7.7'-12.95' HALITE: Clear, coarsely crystalline with scattered anhydrite. <1/2% gray clay locally. [1]	Overall core quality not too good. Box #2 is good. Most other boxes show much discing. 21% of core recovered is ≥2 inch length.
3	8.0 – 9.0	1.0	1.0	100		12.95'-14.05' HALITE: Clear to lightly moderate reddish orange (10R 6/6) and light medium brown (5YR 4/4). Medium to coarsely crystalline. <1/2% dispersed polyhalite and <1% brown, gray clay. [9, 17]	
4	9.0 – 11.5	2.5	1.1	44		14.05'-15.0' ANHYDRITE a: Light to very light gray (N7, N8), microcrystalline anhydrite with scattered irregular laminae in light to darker gray. Halite growths common at 14.5'-15.0'. Trace of clay at 14.05'.	
5	11.5 – 16.5	5.0	5.0	100		15.0'-19.3' POLYHALITIC HALITE: Clear to moderate reddish orange, coarsely crystalline, <1% to 3% polyhalite, averaging <2%. Scattered anhydrite.	
6	16.5 – 21.5	5.0	5.0	100		19.3'-24.7' HALITE: Clear to moderate brown (5YR 3/4, 4/4) with light moderately reddish orange (10R 6/6). Medium to coarsely crystalline with some fine crystalline. <1/2% dispersed polyhalite. ≤1% brown clay with trace of gray locally. At 24.5'-24.7' hard, grayish brown clay associated with anhydrite. Core broken up here. [9, 17] 24.7'-27.1' HALITE: Clear, coarsely crystalline with scattered anhydrite stringers. [1]	
7	21.5 – 25	5.0	5.0	100		27.1'-30.0'± HALITE: Clear to medium brown (5YR 4/4). Coarsely crystalline, ≤2% brown clay to 27.9'± then <1%. [8, 10]	

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WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-307

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					30.0'-32.7' HALITE: Clear, coarsely crystalline. [1] (much discing)	
26.5							
8	30	5.0	5.0	100		32.7'-37.75'± HALITE: Clear to medium brown (5YR 4/4, 3/4) with some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline with some fine. Average ≤1% brown clay to 36.7'±, then gray. Argillaceous halite with 1% to 3% brown clay from 35'-36.8'±. [9, 12, 17]	
31.5						37.75'-38.5' ANHYDRITE: Light to very light gray (N7, N8). Microcrystalline with scattered halite growths. Up to 1" of hard brown clay at 37.75'.	
9	35	4.5	4.5	100	X	38.5'-40.1'± POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite with some anhydrite [4, 5]. Much discing.	
36.0						40.1'-42.0'± HALITE: Clear, coarsely crystalline with <1% moderate reddish orange polyhalite blebs. Much discing. [1, 2]	
10		2.5	2.5	100	X	42.0'-45.5'± POLYHALITIC HALITE: Clear, mottled with some moderate reddish orange (10R 6/6). Coarsely crystalline with some localized medium and fine crystalline. <1% to 3% polyalite blebs/patches. <1/2% gray clay locally. Brown clay parting at 44.5'± with some anhydrite above. [2, 3, 5]	
38.5							
11	40	4.9	4.9	100	X X X X X X X	45.5'-47.7' HALITE: Clear with some light to moderate brown (5YR 4/4). Coarsely crystalline. <1% brown clay. [8]	
					X X X X X	47.7'-51.7' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4). Medium to coarsely crystalline. <1% to 3% brown clay with scattered breaks and <1/2% dispersed polyhalite. [15, 17]	
43.4							
12	45	4.8	4.8	100	X X	51.7'-52.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. 1% to 3% polyhalite. [5]	
48.2							
13	50	3.8	3.8	100	X X X X X		
52.0							

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BORING NO. DH-307

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER GE-265 HOLE TYPE/SIZE NX CORE BORING NO. DH-309

LOCATION INTERSECTION OF E 300, S 700 DRIFTS - ROOF

STATION S 700, E 220 COLLAR ELEV. 1259.8 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8987.1, E7123.0 DEPTH OF BOREHOLE 52.3'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 08/23/84 DATE COMPLETED 08/23/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 08/28/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 4.0	4.0	3.4	85		0.0'-2.5' HALITE: Clear to light, moderately reddish orange (10R 6/6). Coarsely crystalline with some medium crystalline. <1/2% dispersed polyhalite. [1] 2.5'-8.95' HALITE: Clear to moderate brown (5YR 4/4) with some moderate reddish orange (10R 6/6). Coarsely crystalline with some medium crystalline. ≤1% brown clay. <1/2% polyhalite dispersed. [8, 17]	NW split tube core barrel. NW rods. 18% of recovered core is ≥2 inch length. Overall core quality is poor.
2	4.0 – 6.5	2.5	2.5	100		8.95'-9.1' ANHYDRITE b: Light to medium light gray (N7, N6). Microcrystalline with halite growths common between 9.0'-9.1'. Trace of gray clay at 8.95'.	
3	6.5 – 11.5	5.0	5.0	100		9.1'-14.7' HALITE: Clear, coarsely crystalline with scattered anhydrite. [1] 14.7'-15.75' HALITE: Clear to moderate brown (5YR 4/4). Medium with some coarse crystalline. ≤1% brown clay with a trace of gray. <1/2% dispersed polyhalite. Break at 15.05'±. 15.75'-16.35' ANHYDRITE a: Light to medium light gray (N7, NC), with scattered laminae. Scattered halite growths. Trace of gray clay at 15.75'.	
4	11.5 – 16.0	4.5	4.4	98		16.35'-20.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% (average ≤1%) polyhalite. Core broken up, disced. [3, 4]	Runs 4 to 11: Shows much discing between 12' and 45'±.
5	16.0 – 21.0	5.0	5.0	100		20.7'-25.5' HALITE: Clear to light moderate brown (5YR 4/4) with some light moderately reddish orange (10R 6/6). Medium to coarsely crystalline with some fine. ≤1% brown clay. <1/2% dispersed polyhalite. 3/4" brown clay seam at 25.45' with some anhydrite stringers above. [8, 10, 17] 25.5'-28.8' HALITE: Clear, coarsely crystalline with scattered anhydrite. [1]	Accurate logging was difficult where core was badly disced.
6	21.0 – 25	5.0	5.0	100		28.8'-35.7' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline with locally medium crystalline. ≤1% brown clay. Clear 32.1'-33'±. [1, 8, locally 10]	

BORING NO. DH-309

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-309

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					35.7'-39.1' HALITE: Clear to moderate brown (5YR 4/4, 3/4). Medium to coarsely crystalline. ≤1% brown clay locally argillaceous where 1% to 3% clay at 35.7'-37.3'±.	
7	30	5.0	4.5	90		39.1'-39.65' ANHYDRITE: Very light to light gray (N8, N7). Microcrystalline with scattered halite growths and light to dark laminae. Brown hard clay seam at 39.1'.	* Six gas flows were encountered during drilling at the following depths: 15.6', 20.6', 25.0', 25.6', 31.9' and 39.1'. Gas flows varied in duration from about 10 seconds to 5 minutes and smelled sweet. Dry hole.
8	35	5.0	3.2	64		39.65'-44.4' HALITE: Clear with some lightly moderate reddish orange (10R 6/6). Coarsely crystalline. <1/2% polyhalite. [1]	
9		1.1	1.1	100		44.4'-47.0' HALITE: Clear with some moderate brown (5YR 4/4). Coarsely crystalline ≤1% brown clay. Breaks at 45.4'-45.5'±. [8, some 10]	
10	40	3.6	3.6	100		47.0'-48.4' HALITE: Clear to lightly moderate reddish orange (10R 6/6) with some moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay. <1/2% dispersed polyhalite [17] Irregular break at 47.9'.	
11		3.4	2.8	82		48.4'-50.5' HALITE: Clear, mottled with some light moderate brown. Coarsely crystalline. <1% brown clay. [8]	
12	45	4.9	4.3	88		50.5'-52.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4). Coarse with some medium crystalline. <1% to 3% brown clay. >5% brown clay between 51.6' and 51.85'±. [10, 15]	
13	50	3.3	3.3	100			

26.0 — 31.0 — 36.0 — 37.1 — 40.7 — 44.1 — 49.0 — 52.3

BORING NO. DH-309

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER GE-264 HOLE TYPE/SIZE NX CORE BORING NO. DH-311

LOCATION E 300 DRIFT - ROOF

STATION E 300; S 1000 COLLAR ELEV. 1264.4 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8686.3, E7194.9 DEPTH OF BOREHOLE 52.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 08/24/84 DATE COMPLETED 08/24/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 08/27/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 1.6	1.6	1.6	100		0.0'-2.5' HALITE: Clear, coarsely crystalline. <1/2% gray clay. [1]	NW split tube core barrel. NW rods.
2	1.6 – 5.7	4.1	3.0	73		2.5'-8.4' HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. <1% to 2% brown clay. Becomes medium crystalline at 7.7'-8.4' with trace of polyhalite dispersed. [8, 10]	No gas. Dry hole.
3	5.7 – 8.8	3.1	3.1	100		8.4'-8.8' ANHYDRITE b: Very light gray (N8) to medium light gray (N6). Microcrystalline with scattered halite growths especially last 0.2'. Trace gray clay at 8.4'.	Overall core is poor quality. Much discing in halite. Only 8% of recovered core is ≥2 inch length.
4	8.8 – 11.0	2.2	1.6	73		8.8'-14.1' HALITE: Clear and coarsely crystalline with scattered white anhydrite/magnesite. [1]	
5	11.0 – 15.8	4.8	4.2	88		14.1'-15.1' HALITE: Clear to moderate brown and moderate yellowish brown (10YR 5/4).. Medium crystalline. <1% brown with a trace of gray clay. <1/2% dispersed polyhalite. [17]	
6	15.8 – 18.1	2.3	2.3	100		15.1'-15.8' ANHYDRITE a: Very light to medium light gray (N8, N6). Microcrystalline anhydrite, partially laminated. More halite pinkish color between 15.4'-15.8'. Trace of gray clay at 15.1'.	
7	18.1 – 18.4	.3	.3	100		15.8'-19.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. <1/2% gray clay locally. Traces of anhydrite locally. [3, 5, 7]	
8	18.4 – 21.5	3.1	3.1	100		19.5'-25.4' HALITE: Clear to moderate brown (5YR 3/4, 4/4) and light moderate reddish orange. Medium to coarsely crystalline with some fine. <1/2% dispersed polyhalite. ≤1% brown clay with trace of gray locally. Gray clay seam at 25.2'. Anhydrite laminae mixed with halite to 25.4'. [10, 17] - some [8]	
9	21.5 – 25	5.0	5.0	100		25.4'-29.7' HALITE: Clear, coarsely crystalline. [1]	
						29.7'-31.5' HALITE: Clear with some moderately brown (5YR 3/4). Coarsely crystalline with some medium to fine. <1% brown clay except at 30.2'-30.6'± where ≤2% brown clay. Break at 30.6'. [8, 17]	

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BORING NO. DH-311

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-311

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					31.5'-33.8' HALITE: Clear, coarsely crystalline with <1% brown clay. [1, 8]	
26.5							
10	30	5.0	5.0	100		33.8'-38.65' ARGILLACEOUS HALITE: Clear to moderately brown (5YR 3/4). Coarsely crystalline with scattered medium. <1% to 2%, locally 3% brown clay. [10, 15]	
						38.65'-39.3' ANHYDRITE: Very light to light gray (N8, N7), microcrystalline. Scattered lighter to darker gray laminae and scattered halite growths. 1" brown hard clay seam at 38.65'.	
31.5							
11	35	5.0	5.0	100		39.3'-43.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite with scattered anhydrite. [3, 5]	
						43.7'-48.6'± HALITE: Clear to light moderate brown and some moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% brown clay. <1% polyhalite. [10] <1% to 2% polyhalite blebs at 46.7'-47.7'. No clay. [3]	
36.5							
12		2.8	2.8	100		48.6'-51.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4). Medium to coarsely crystalline. <1% to 3% brown clay. [10, 15]	
39.3						51.2'-52.0' HALITE: Clear to moderate brown (5YR 3/4, 4/4), fine to medium crystalline. <1% to 2% brown clay. Trace of dispersed polyhalite. [12]	
13	40	2.8	2.8	100			
42.1							
14	45	5.0	4.0	80			
47.1							
15	50	4.9	4.5	92			
52.0							

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BORING NO. DH-311

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NW CORE BORING NO. DH-313

LOCATION INTERSECTION OF E 300; S 1300 DRIFTS - ROOF

STATION S 1300, E 300 COLLAR ELEV. 1270.6 DIRECTION OF DRILLING VERTICAL DIP

MINE COORDINATES N 8385.9, E 7190.6 DEPTH OF BOREHOLE 19.6'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/09/84 DATE COMPLETED 07/10/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/10/84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	0						
1		5.0	3.7	74		0.0'-7.9' (±0.6') HALITE: Clear and coarsely crystalline. <1/2% gray clay and polyhalite locally. From 6.5' (±0.6') ≤1% clay with some medium crystalline.	NW split tube core barrel and rods with diamond stepped bit.
						7.9'-8.1' ANHYDRITE b: Light gray (N7), microcrystalline. Halite growths with a trace of clay at lower contacts.	No gas. Dry hole.
5.0	5					8.1'-13.1' HALITE: Clear, coarsely crystalline.	
2		5.0	3.8	76		13.1'-14.0' HALITE: Clear, fine to medium crystalline with some coarsely crystalline. <1/2% light gray clay.	
						14.0'-14.85' ANHYDRITE a: Light gray (N7), microcrystalline with scattered halite growths. Trace of clay at 14.0'.	
10.0	10					14.85'-19.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite.	
3		2.1	2.0	95			
12.1						Stopped hole at 19.6 ft due to core loss and poor core quality. Refer to log for replacement hole DH-313A.	
4		3.2	3.2	100			
15.3	15						
5		4.3	3.3	77			14% of core recovered was ≥2 inch length.
19.6	20						

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BORING NO. DH-313

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NW CORE BORING NO. DH-313A

LOCATION INTERSECTION OF E 300; S 1300 DRIFTS - ROOF

STATION S 1300, E 299 COLLAR ELEV. 1270.9 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8386.6, E 7189.5 DEPTH OF BOREHOLE 50.2'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/10/84 DATE COMPLETED 07/12/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/12/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 1.8	1.8	1.8	100		0.0'-5.2' HALITE: Clear, coarsely crystalline with some fine to medium crystalline locally. <1/2% polyhalite blebs and gray clay. [1, 11]	NW split tube core barrel. NW rods.
2	1.8 – 3.4	1.6	1.6	100		5.2'-7.9' HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline <1% to 2% brown clay to 7.3', then <1% gray clay. [8, 10, 12]	
3	3.4 – 5.5	2.1	2.1	100		7.9'-8.05' ANHYDRITE b: Light gray microcrystalline. Trace of gray clay at 7.9'.	Total drill time: 12 hrs. Total down time: 5 hrs.
4	5.5 – 8.5	3.0	3.0	100		8.05'-13.3' HALITE: Clear and coarsely crystalline. <1/2% polyhalite with scattered white stringers of anhydrite/magnesite. [1]	No gas. Dry hole.
5	8.5 – 10.9	2.4	1.9	79		13.3'-14.0' HALITE: Clear with medium to coarsely crystalline. <1/2% gray clay. Gray break at 13.3'.	Down time due to power outage.
6	10.9 – 12.5	1.6	1.6	100		14.0'-15.0' ANHYDRITE a: Light gray microcrystalline anhydrite. Partially laminated. Halite growths increasing in percent from 14.4'. Trace of gray clay at 14.0'.	
7	12.5 – 15.85	3.35	3.0	90		15.0'-19.0' POLYHALITIC HALITE: Clear to moderately reddish orange. Coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite mixed with halite to 15.65'-15.85'. [3, 4]	Broken core, discing between 8.5' and 30.0'.
8	15.85 – 18.0	2.15	1.9	88		19.0'-24.5' HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay. <1/2% dispersed polyhalite. Clear halite at 21.9' to 22.35'±. [8, 17]	22% of total core recovered was ≥2 inch length.
						24.5'-27.3' HALITE: Clear and coarsely crystalline with scattered anhydrite. [1]	
9	18.0 – 20.85	2.85	2.85	100		27.3'-32.35' HALITE: Clear with some moderate brown (5YR 4/4). Coarsely crystalline except fine to medium crystalline between 29.2'-30.3'. <1% brown clay except 29.2'-30.3' where clay is ≤1%. [1, 8, 10] Graditional upper contact.	
10	20.85 – 23.5	2.65	2.65	100			
11	23.5 – 25	2.35	1.7	72			

BORING NO. DH-313A

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-313A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
12	25.85 – 28.5	2.65	2.1	79		32.35'-37.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline with some fine. <1% to 2% brown clay with trace of gray clay <1/2% dispersed polyhalite. [10, 15]	
13	28.5 – 30.85	2.35	1.75	74		37.5'-38.2' ANHYDRITE: Light to medium gray, microcrystalline anhydrite. Scattered halite growths especially common to 37.9'. 1/2" brown clay seam at 37.5'.	
14	30.85 – 33.5	2.65	2.65	100		38.2'-42.25' HALITE: Clear to light moderate reddish orange. Coarsely crystalline. ≤1% polyhalite with scattered anhydrite to 39.2'±. [2, 3]	
15	33.5 – 35.85	2.35	2.35	100		42.25'-45.7' HALITE: Clear to moderate brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay with ≤2% between 45.25'-45.7'±. [10]	
16	35.85 – 38.5	2.65	2.65	100		45.7'-47.15' HALITE: Clear coarsely crystalline 0% to 1/2% brown clay. [1, 8]	
17	38.5 – 40.85	2.35	2.35	100		47.15'-48.7' HALITE: Clear and coarsely crystalline with some medium. <1% brown clay. [10, 17]	
18	40.85 – 43.5	2.65	2.65	100		48.7'-50.2' HALITE: Clear to moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Medium to coarsely crystalline with some fine. <1/2% dispersed polyhalite. <1% to 2% locally brown clay. [12, 17]	
19	43.5 – 45.85	2.35	2.1	89			
20	45.85 – 48.5	2.65	2.65	100			
21	48.5 – 50.2	1.7	1.7	100			

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NW CORE BORING NO. DH-314

LOCATION INTERSECTION OF S 1300, E 300 DRIFTS - FLOOR

STATION S1300, E 300 COLLAR ELEV. 1258.3 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 8386.5, E 7189.5 DEPTH OF BOREHOLE 50.75'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/12/84 DATE COMPLETED 07/13/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/13/84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0						
	1		3.75	3.1	83		0.0'-1.5' HALITE: Clear, some moderate reddish orange (10R 6/6). Coarsely crystalline. <1/2% polyhalite. [1, 2]	NW split tube core barrel with NW rods.
							1.5'-4.55' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. <1/2% gray clay locally. [3, 6, 7]	
3.75	2		2.0	2.0	100		4.55'-7.6' MB-139: "Swallowtail" pattern to 5.45'±. Mixture of halite and anhydrite. Moderate reddish orange (10R 6/6) to light gray color. Then light to medium gray anhydrite with scattered halite growths. Scattered laminae. Trace of gray clay at 7.6'. Some grinding evident.	Total drill time: 7 hrs.
5.75		5						No gas. Dry hole.
	3		4.95	4.95	100		7.6'-10.3' HALITE: Clear to light moderate reddish orange (10R 6/6), some light gray (N7). Fine to medium crystalline with some coarse. <1% dispersed polyhalite. <1/2% gray clay. [9]	Core quality good.
		10						
10.7							10.3'-11.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Coarsely crystalline. <1% to 3% polyhalite. <1% brown clay. [some 17]	
	4		5.1	5.1	100		11.8'-16.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Anhydrite mixed with halite at 15.8'-16.1'. [7]	
		15						
15.8							16.1'-18.2' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. ≤1% brown and gray clay. <1% dispersed polyhalite. [9, 17]	46% of core recovered was ≥2 inch length.
	5		5.1	5.1	100		18.2'-22.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [7]	
		20						
20.9							22.5'-28.3' HALITE: Clear to lightly moderate reddish orange (10R 6/6), some light gray. Fine to coarsely crystalline, ≤1% dispersed polyhalite and gray clay. Some scattered anhydrite. [9]	
	6		5.1	5.1	100			
		25						

BORING NO. DH-314

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-314

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					28.3'-33.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite, generally dispersed. Moderate reddish orange (10R 6/6) anhydrite mixed with halite at 32.85'-33.05'. [7]	
26.0							
7		5.0	5.0	100		33.2'-33.65' ANHYDRITE: Very light to light gray (N8, N7). Microcrystalline anhydrite. Scattered halite growths throughout. No clay.	
	30						
31.0						33.65'-39.25' HALITE: Clear medium to coarsely crystalline. <1% gray clay. [9, 11]	
8		5.0	4.9	98		39.25'-41.15' HALITE: Clear, some lightly moderate reddish orange (10R 6/6). Coarsely crystalline with some fine to medium. <1% gray clay and dispersed polyhalite.	
	35					41.15'-43.45' HALITE: Clear, some lightly moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. ≤1% brown clay and 1/2% dispersed polyhalite. [17]	
36.0							
9		4.85	4.7	97		43.45'-48.25' HALITE: Clear, coarsely crystalline with some medium. <1% gray clay. Trace of polyhalite locally. [11]	
	40					48.25'-50.75' HALITE: Clear, coarsely crystalline. <1/2% polyhalite. Gray clay break at 50.25'. [1]	
40.85							
10		5.1	5.1	100			
	45						
45.95							
11		4.8	4.8	100			
	50						
50.75							

M

BORING NO. DH-314

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-315

LOCATION INTERSECTION OF W 170, S 1300 DRIFTS - ROOF

STATION S 1300, W 170 COLLAR ELEV. 1272.1 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8387.3, E 6725.5 DEPTH OF BOREHOLE 50.3'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/05/84 DATE COMPLETED 09/06/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/06/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 1.5	1.5	1.1	73		0.0'-7.0' HALITE: Clear, coarsely crystalline with some medium. <1/2% polyhalite. <1/2% gray clay locally. [1]	NC double tube wireline core barrel with NC rods. Run 1: Broken core.
2	1.5 – 6.5	5.0	4.5	90		7.0'-8.4' HALITE: Clear, some moderate brown (5YR 4/4) and light moderate reddish orange. Medium to coarsely crystalline. <1/2% dispersed polyhalite. <1% brown clay to 7.7'±, then gray. [9, 17] 8.4'-8.6' ANHYDRITE b: Very light to medium light gray (N8, N6) microcrystalline anhydrite. Scattered halite within. Hard, dry, gray clay at 8.4'	Run 2: Broken zones within run. No gas. Dry hole.
3	6.5 – 11.5	5.0	5.0	100		8.6'-14.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1] 14.3'-15.1' HALITE: Clear to lightly moderate brown (5YR 4/4), some lightly moderate reddish orange (10R 6/6). Fine to medium crystalline. <1/2% dispersed polyhalite. <1% brown clay. 15.1'-15.95' ANHYDRITE a: Very light to medium light gray (N8, N6), microcrystalline. Partially laminated. Scattered halite growths especially from 15.5'±. <1/4" gray clay at 15.1'.	
4	11.5 – 16.5	5.0	5.0	100		15.95'-20.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite, average <1% to 2%. [2, 4, 7] 20.0'-25.1' HALITE: Clear to light moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Medium to coarsely crystalline, some fine. ≤1% brown clay. <1/2% dispersed polyhalite. Some scattered breaks. [8, 17] <1/4" hard, dry, brown clay at 25.0' with associated anhydrite stringers to 25.1'	39% of recovered core was ≥2 inch length.
5	16.5 – 21.5	5.0	5.0	100		25.1'-29.8' HALITE: Clear, coarsely crystalline. Scattered anhydrite stringers.[1] 29.8'-31.5' ARGILLACEOUS HALITE: Clear to medium brown (5YR 4/4), fine to medium crystalline, some coarse. <1% to 3% brown clay.[12]	
6	21.5 – 25	4.8	4.8	100			

BORING NO. DH-315

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-315

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					31.5'-34.7' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline, <1% brown clay. [1, 8]	
26.3							
7		5.0	5.0	100		34.7'-39.0' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4), some light moderate reddish orange (10R 6/6). Fine to medium crystalline, some coarse. <1% to 3% brown clay. <1/2% dispersed polyhalite locally. Scattered breaks. [12, 15]	
	30					39.0'-39.45' ANHYDRITE: Very light gray to light medium gray (N8, N6). Microcrystalline, faintly laminated. Scattered small halite growths. 1/2" hard, dry, brown clay seam at 39.0'.	
31.3							
8		4.8	4.8	100		39.45'-40.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. [2, 7]	
	35					40.6'-43.7' HALITE: Clear, coarsely crystalline. Locally <1/2% polyhalite. Very clear to 41.6'±. [1]	
36.1							
9		5.0	5.0	100		43.7'-49.1' HALITE: Clear to moderate brown (5YR 4/4), scattered lightly moderate reddish orange (10R 6/6). Coarsely crystalline, some medium. Generally <1% brown clay with zones 1% to 3%. Break at 44.0'±; parting at 44.15±. Predominantly brown clay mixed with halite at 45.8'-46.0'±. Broken up here. [1, 8, 10, locally 12]. Trace of polyhalite.	Run 9: Broken between 40.0'-41.1'. Scattered broken zones throughout.
	40					49.1'-50.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4). Medium to coarsely crystalline. <1% to 5% brown clay. Break at 50.3' [15]	
41.1							
10		4.9	4.9	100			
	45						
46.0							
11		4.3	4.3	100			
	50						
50.3							

BORING NO. DH-315

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-316

LOCATION INTERSECTION S 1300, W 170 DRIFTS - FLOOR

STATION S 1300, W 170 COLLAR ELEV. 1259.9 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 8387.2, E6725.3 DEPTH OF BOREHOLE 50.1'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/06/84 DATE COMPLETED 09/06/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/06/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 1.6	1.6	1.6	100		0.0'-1.7' HALITE: Clear with some moderate reddish orange. (10R 6/6) Coarsely crystalline. <1/2% polyhalite and gray clay locally. [1, 2]	NC double tube wireline core barrel. NC rods. Total drill time: 7 hrs.
2	1.6 – 6.5	4.9	4.9	100		1.7'-5.0' POLYHALITIC HALITE: Clear to moderate reddish orange. (10R 6/6) Coarsely crystalline. <1% to 3% polyhalite with scattered anhydrite. [3, 7]	
						5.0'-7.65' MB-139: Mixture of very light to light medium gray anhydrite and moderate reddish orange halite (10R 6/6) to 6.25'±. Then predominently light gray and moderate reddish orange anhydrite mixed with some halite. Low angle irregular layering and laminae throughout. Dry hard gray clay at 7.65'.	No gas. Dry hole.
3	6.5 – 11.5	5.0	5.0	100		7.65'-11.85' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Medium to coarsely crystalline with some fine. <1/2% polyhalite dispersed and gray clay except locally at 9.2'-10.7' where polyhalite is 1% to 2%. [9]	
						11.85'-24.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline with some medium crystalline locally. Scattered anhydrite. <1% to 3% polyhalite, locally up to 5%. <1% gray clay below 15.8'. [3, 5, 7]	
4	11.5 – 16.5	5.0	5.0	100		24.0'-25.2' HALITE: Clear to moderate reddish brown (10R 6/6). Coarsely crystalline. ≤1% polyhalite and brown clay with a trace of gray.	79% of core recovered was ≥ 2 inch length.
						25.2'-26.95' HALITE: Clear with some moderate brown (5YR 4/4). Fine to medium, some coarsely crystalline. <1% brown clay. Breaks at 25.2' and 25.25', parting at 25.55'±. [8, 10]	
5	16.5 – 21.5	5.0	5.0	100		26.95'-33.05' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite with scattered anhydrite. 1"± irregular anhydrite layer at 33'±.	
6	21.5 – 25	5.0	5.0	100		33.05'-34.0' HALITE: Clear coarsely crystalline Scattered white anhydrite stringers. [1]	

BORING NO. DH-316

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-316

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
	26.5					34.0'-34.4' ANHYDRITE: Very light to light medium gray microcrystalline anhydrite. Scattered halite growths and pods, especially below 34.2'±. <1/4" gray clay at 34.4'.	
7		5.0	5.0	100		34.4'-39.1' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline with some fine. <1/2% dispersed polyhalite and gray clay. [1, 9]	
	30					39.1'-46.1' HALITE: Clear to moderate brown (5YR 4/4) with some lightly moderate reddish orange. Medium to coarsely crystalline. <1% brown clay. <1/2% polyhalite. [8, 10, 17]	
	31.5					46.1'-47.5' HALITE: Clear with some light bluish gray. Coarsely crystalline, some medium. <1/2% gray clay. <1/2% scattered polyhalite blebs.	
8	35	5.0	5.0	100		47.5'-49.7' HALITE: Clear, coarsely crystalline. <1/2% polyhalite blebs. [1]	
	36.5					49.7'-50.1' POLYHALITIC HALITE: Clear to moderate reddish orange. Coarsely crystalline. <1% to 3% polyhalite.[7]	
9	40	5.0	5.0	100			Run 9: First 2' of run contained locally broken zones.
	41.5						
10	45	5.0	5.0	100			
	46.5						
11		3.6	3.6	100			
	50.1						

M

BORING NO. DH-316

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-317

LOCATION INTERSECTION OF S 1600, W 30 DRIFTS - ROOF

STATION S 1600, W 33 COLLAR ELEV. 1271.3 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8077.4, E 6875.9 DEPTH OF BOREHOLE 50.1'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/05/84 DATE COMPLETED 07/06/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/06/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 4.8	4.8	3.2	66		0.0'-7.3' HALITE: Clear, coarsely crystalline to 5.0', then medium to coarsely crystalline. <1/2% polyhalite and gray clay locally. [1, 11] 7.3'-8.4' HALITE: Clear to moderate reddish orange (10R 6/6), some medium brown (5YR 4/4). Medium to coarsely crystalline. <1% brown/gray clay and polyhalite [17]	NW split tube core barrel and NW rods. Total drill time: 11 hrs. *Runs 1, 6, 7, 8, 10 and 11* contain broken zones.
2	4.8 – 9.8	5.0	5.0	100		8.4'-8.7' ANHYDRITE b: Very light to medium light gray (N8, N6). Microcrystalline anhydrite. Scattered halite growths. Trace of gray clay at 8.4' 8.7'-11.8' (±0.15') HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	No gas. Dry hole.
3	9.8 – 10.8	1.0	1.0	100		11.8'-12.65' HALITE: Clear, some medium brown (5YR 3/4) and moderate reddish orange (10R 6/6). Medium crystalline, some coarse. <1% brown to gray clay. <1% polyhalite. [9, 17]	
4	10.8 – 15.8	5.0	4.7	94		12.65'-13.15' ANHYDRITE a: Light gray to medium light gray (N7, N6). Microcrystalline. Scattered halite growths, trace of clay at 12.65'. 13.15'-19.2' HALITE: Clear, trace of medium reddish orange (10R 6/6). Coarsely crystalline. <1/2% polyhalite. [1, 2]	Runs 4 and 5 contain discing.
5	15.8 – 20.8	5.0	5.0	100		19.2'-22.9' (±0.5') HALITE: Clear, some moderate brown (5YR 4/4) to moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite and brown clay. [17] 22.9'-28.6' (±0.6') HALITE: Clear, coarsely crystalline. [1] <1/8" brown clay seam at 24.7' ±0.45'. 3/4" anhydrite at 24.75±.	18% of core recovered was ≥2 inch length.
6	20.8 – 25	5.0	4.1	82		28.6'±-30.6'± HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. <1% to 2% brown clay. <1% polyhalite. [10] ≤1/4" brown clay seam at 30.6', some anhydrite associated. 30.6'-35.6' HALITE: Clear, coarsely crystalline. <1% brown clay. [8, some 10]	

BORING NO. DH-317

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-317

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					35.6'-38.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. <1% to 3% brown clay, trace gray. [15]	
25.8							
7		5.0	3.9	78		38.2'-38.8' ANHYDRITE: Light gray (N7). Microcrystalline. Scattered halite growths. Trace brown clay at 38.2'.	
	30					38.8'-40.1' HALITE: Clear, coarsely crystalline. <1% polyhalite. [1]	
30.8							
8		4.8	4.0	83		40.1'-42.4' HALITE: Clear, some moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% polyhalite blebs, locally 2%. Gray clay break at 42.4'. [2, 4]	
						42.4'-44.0' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline. <1% brown clay. [8, 10]	
	35					44.0'-44.7' HALITE: Clear to moderate brown (5YR 3/4). Medium crystalline. <1% to 2% brown clay. <1/2% dispersed polyhalite. [17]	
35.6							
9		5.0	5.0	100		44.7'-49.2' HALITE: Clear, some medium brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay. Locally <1/2% polyhalite blebs. [10]	
	40					49.2'-50.1' HALITE: Clear to moderate reddish orange (10R 6/6), medium brown, medium to coarsely crystalline. ≤1% brown clay and polyhalite. [17]	
40.6							
10		5.0	5.0	100			Because of poor quality and recovery of core, holes DH-317A, 317B were drilled. Refer to logs for these holes.
	45						
45.6							
11		4.5	4.5	100			
50.1	50						

BORING NO. DH-317

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NW CORE BORING NO. DH-317A

LOCATION INTERSECTION OF S 1600, W 30 DRIFTS - ROOF

STATION S 1600, W 30 COLLAR ELEV. 1271.2 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8077.5, E 6879.5 DEPTH OF BOREHOLE 5.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/06/84 DATE COMPLETED 07/06/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/06/84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		2.0	2.0	100	—	0.0'-5.0' HALITE: Clear, coarsely crystalline. <1/2% polyhalite and gray clay. [1, 2]	NW split tube core barrel and NW rods. Drill time: 45 minutes. This hole was drilled to replace first run of hole 317.
2.0							
2		3.0	2.9	97	X		
5.0	5						No gas. Dry hole.

M

BORING NO. DH-317A

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-317B

LOCATION INTERSECTION OF W 30, S 1600 DRIFTS - ROOF

STATION S 1597, W 30 COLLAR ELEV. 1271.2 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N8080.3, E6881.0 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/07/84 DATE COMPLETED 09/07/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/08/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		1.75	1.4	80	X	0.0'-5.1' HALITE: Clear with some lightly moderate reddish orange (10R 6/6). Coarsely crystalline with some medium. <1/2% polyhalite.[1]	NC double tube wireline core barrel with NC rods. Total drilling time: 12 hrs ±. This is a replacement hole for 317 and 317A. Runs1, 2: broken core.
1.75							
2		4.65	4.65	100	X	5.1'-7.1' HALITE: Clear, medium to coarsely crystalline. <1% gray clay and dispersed polyhalite.[1, 11]	
	5				—	7.1'-8.1' HALITE: Clear to moderate brown (5YR 4/4) with some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% brown clay. Trace of polyhalite.	
6.4					X	8.1'-8.7' HALITE: Clear, some lightly moderate reddish orange (10R 6/6). <1/2% gray clay and polyhalite. [9]	
3		4.9	4.9	100	— X / X —	8.7'-8.9' ANHYDRITE b: Very light to medium light gray. microcrystalline anhydrite with growths of halite. ≤1/4" dry gray clay at 8.7'.	
	10					8.9'-13.9' HALITE: Clear, coarsely crystalline with scattered white anhydrite stringers. [1]	
11.3							
4		5.0	5.0	100	X / — X	13.9'-15.1' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Medium crystalline with some fine and coarsely crystalline. <1/2% polyhalite with ≤1% between 14.9' and 15.1'. ≤1% gray clay.	
	15					15.1'-15.85' ANHYDRITE a: Very light to lightly medium gray (N8, N6) anhydrite. Scattered halite growths. Trace of moist gray clay at 15.1'.	Run 4: Water seepage from hole after rods were broken at end of run. Probably from anhydrite a.
16.3							
5		5.0	5.0	100	X / X / X	15.85'-20.1' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Coarsely crystalline anhydrite mixed with halite between 16'-16.2'. Scattered white anhydrite stringers throughout core. ≤1% polyhalite blebs. [1, 2] Core broken up between 15.85'-16.05'±. Very clear.	
	20				—	20.1-26.0' HALITE: Clear, some moderate brown (5YR 4/4). Medium to coarsely crystalline, some fine. ≤1% brown clay. <1/2% dispersed polyhalite. 1/4" brown hard clay seam at 25.8' with associated anhydrite stringers to 26.0'.	
21.3							
6		5.0	4.7	94	X / — / —		
	25						

M

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-317B

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
	26.3					26.0'-30.1' HALITE: *Clear, coarsely crystalline.* Scattered white anhydrite stringers. [1]	
7		5.0	4.5	90		30.1'-33.8' HALITE: Clear with zones of moderate brown. Coarsely crystalline with some medium. ≤1% brown clay. [1, 8, some 10]	
	30					33.8'-39.6' ARGILLACEOUS HALITE: *Clear to moderate* brown (5YR 3/4, 4/4). Coarsely crystalline, some medium. <1% to 3% brown clay. <1/2% dispersed polyhalite. Scattered breaks. [8, 10, 15, 17]	Run 8: Broken zones of core.
	31.3					39.6'-40.2' ANHYDRITE: Very light to light medium gray (N8, N6), microcrystalline anhydrite. Faintly laminated, low angle. Scattered very small halite growths. ≤3/8" brown clay seam at 39.6'. Dips 15°±.	
8		5.0	4.6	92		40.2'-44.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite, average <2%. [3, 7]	
	35						
	36.3					44.3'-51.0' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline, locally fine to medium. ≤1% brown clay. <1/2% polyhalite patches, blebs, locally up to 2%. Scattered brown clay breaks 47.1'-47.7±. Clear halite, scattered polyhalite blebs at 48'-49.1'±. [1, 8, 10]	
9		5.0	4.6	92			
	40						
	41.3						Run 10: Broken core beyond 43 ft. Hit gas pocket at 45.9'. No reading on methane detection meter. No sound of gas leak.
10		5.0	5.0	100			34% of recovered core is ≥2 inch length.
	45						
	46.3						
11		4.7	4.7	100			
	50						
	51.0						

BORING NO. DH-317B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-318

LOCATION INTERSECTION OF S 1600, W 30 DRIFTS - FLOOR

STATION S 1600, W 30 COLLAR ELEV. 1258.5 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 8077.3, E 6876.1 DEPTH OF BOREHOLE 50.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/02/84 DATE COMPLETED 07/03/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/03/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	0						
1		4.2	4.2	100		0.0'-4.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. Scattered anhydrite. ≤1% to 3% polyhalite. [7]	NW split tube core barrel. NW rods. Scissor lift.
						4.75'-7.3' MB-139: From 4.75'-5.75'± is mixture of anhydrite and halite. Then predominantly anhydrite with scattered halite growths. Light gray with some moderate reddish orange. Gray clay parting at 7.3'.	
4.2							Total drill time: 7 hrs.
	5					7.3'-11.0' HALITE: Clear to light gray (N7) and light moderate reddish orange. Medium to coarsely crystalline. ≤1% gray clay. <1% dispersed polyhalite. Gray clay break at 9'. ≤3% polyhalite to 7.8'±. [9]	No gas. Dry hole.
2		5.3	5.3	100		11.0'-15.45' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 2% polyhalite dispersed. Scattered anhydrite. 3/4" anhydrite layer at 15.35'. Gray clay parting at 15.45'. [4, 7]	33% of core recovered is ≥2 inch length.
9.5							
	10					15.45'-17.2' HALITE: Clear, some light gray (N7) and moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤1% gray clay. <1/2% dispersed polyhalite. [9]	
3		5.2	5.2	100		17.2'-20.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% to 3% polyhalite. [5, 6, 7]	
14.7							
	15					20.5'-27.0' HALITE: Clear (some light gray (N7) to lightly moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤1% gray clay, some brown. <1% polyhalite dispersed. Breaks at 21.5' and 21.9'±. [9, 17]	
4		5.0	5.0	100		27.0'-32.7' HALITE: Clear to moderate reddish orange (10R 6/6). coarsely crystalline. <1% to 2% dispersed polyhalite. Trace of gray clay at 27.1'. Up to 1" anhydrite at 32.6'. Scattered anhydrite stringers between 31.6'-32.6'. [2, 4]	
19.7							
	20					32.7'-33.65' HALITE: Clear, medium to coarsely crystalline. <1/2% dispersed polyhalite. [1]	
5		5.1	5.1	100			
24.8	25						

BORING NO. DH-318

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-318

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
6		5.2	5.2	100		33.65'-33.95' ANHYDRITE: Very light to light gray (N8, N7). Microcrystalline. Scattered halite growths. 1/2" halite layer just below upper contact. ≤1/8" gray clay seam at lower contact. Core grinding here.	
						33.95'-40.3' HALITE: Clear, some moderate reddish orange (10R 6/6). <1/2% polyhalite. <1% gray clay to 34.95'±, then 0 - <1/2%. [2], [some 9]	
30.0	30						
						40.3'-44.2' HALITE: Clear, some medium brown (5YR 4/4). Coarsely crystalline, some medium. ≤1% brown clay. <1/2% polyhalite. [8, 10]	
7		5.0	5.0	100		44.2'-50.0' HALITE: Clear, coarsely crystalline, some medium. Zero to <1% gray clay. <1/2% polyhalite. [1, 11]	
35.0	35						
8		5.0	5.0	100			
40.0	40						
9		5.0	5.0	100			
45.0	45						
10		5.0	3.0	60			
50.0	50						

BORING NO. DH-318

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER: -

HOLE TYPE/SIZE: NC CORE

BORING NO.: DH-319

LOCATION: INTERSECTION OF S 700, E 300 DRIFTS -- ROOF

STATION: S 700, E 300

COLLAR ELEV.: 1260.0

DIRECTION OF DRILLING: VERTICAL UP

MINE COORDINATES: N8988.1 E7191.6

DEPTH OF BOREHOLE: 51.05'

DRILLING METHOD: ROTARY AIR

DRILL MAKE/MODEL: CP-65

DATE STARTED: 09/10/84

DATE COMPLETED: 09/10/84

SHEET 1 OF 2

LOGGED BY: J.E. GALLERANI

DATE: 09/10/84

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.0	2.0	2.0	100		0.0'-5.4' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Coarsely crystalline, some medium locally. <1/2% polyhalite. Trace brown clay from 4.7'. [1]	NC double tube wireline core barrel. NC rods.
2	2.0 – 6.6	4.6	4.6	100		5.4'-8.45' HALITE: Clear to moderate brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay, locally up to 2%. Gray clay from 5.05'. Scattered polyhalite. Some anhydrite close to contact at 8.45'. [8, 10]	No gas. Dry hole.
						8.45'-8.65' ANHYDRITE b: Very light to light medium gray (N8, N6). Microcrystalline. Trace gray clay at 8.45'.	
3	6.6 – 11.7	5.1	5.1	100		8.65'-14.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite. [1]	
						14.3'-15.65' HALITE: Clear, some lightly moderate reddish orange and moderate brown (5YR 4/4). Fine to coarsely crystalline. ≤1% polyhalite and gray, brown clay. [17]	
4	11.7 – 16.7	5.0	5.0	100		15.65'-16.35' ANHYDRITE a: Very light to medium light gray anhydrite. Scattered halite growths, especially from 16.15'. Trace gray clay at 15.65'. Core grinding evident here.	
						16.35'-20.85' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. Average 1% to 2%. [3, 4]	
5	16.7 – .7	5.0	4.9	98		20.85'-25.35' HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay, some gray. Trace dispersed polyhalite. [10, 17, some 12] 1/4" hard brown grayish clay seam at 25.3'± with associated anhydrite/halite to 25.35'.	
						25.35'-30.9' HALITE: Clear, coarsely crystalline. Slight trace clay. [1]	
						30.9'-32.7' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4). Medium to coarsely crystalline. Scattered breaks. <1% to 3% brown clay. [10, 15]	Run 5: Some broken core.
6	.7 – 25	4.7	4.7	100		32.7'-33.9' HALITE: Clear, coarsely crystalline. [1]	

BORING NO. DH-319

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-319

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					33.9'-36.55' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay. [8, 10]	
26.4							
7		4.9	4.9	100		36.55'-40.05' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4). Medium to coarsely crystalline. <1% to 3% brown clay. Scattered breaks. [15]	Run 7: Broken core.
	30					40.05'-40.6' ANHYDRITE: Very light to light medium gray (N8, N6). Microcrystalline. Scattered halite growths. Partially laminated. 1/2" halite layer at 40.4'±.	
31.3							
8		4.75	4.75	100		40.6'-48.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, some fine to medium between 45.8'-46.8'±. <1% to 3% polyhalite, locally 5%. Scattered anhydrite. Scattered brown clay 45.8'-46.8'±.	Run 8: Broken zones within run.
	35					48.3'-51.05' HALITE: Clear mottled with moderate brown (5YR 4/4). Coarsely crystalline. ≤1%, locally 2% brown clay. <1/2% polyhalite blebs.	
36.05							
9		5.0	5.0	100			
	40						
41.05							
10		5.0	5.0	100			40% of core recovered was ≥2 inch length.
	45						
46.05							
11		5.0	5.0	100			
	50						
51.05							

BORING NO. DH-319

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER GE-268 HOLE TYPE/SIZE NX CORE BORING NO. DH-321

LOCATION S 400 DRIFT JUST WEST OF WASTE SHAFT - ROOF

STATION S 400 E0 COLLAR ELEV. 1261.4 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N9792.0 E6891.8 DEPTH OF BOREHOLE 52.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/14/84 DATE COMPLETED 09/14/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/29/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 5.0	5.0	5.0	100		0.0'-4.3' HALITE: Clear, coarsely crystalline. <1/2% polyhalite and gray clay. [1] 4.3'-6.6' HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. ≤1% brown clay [10] 6.6'-7.8' HALITE: Clear to medium light gray (N6) and light moderate reddish orange (10R 6/6). Fine to medium, some coarsely crystalline. <1/2% dispersed polyhalite. ≤1% gray clay.	NW split tube core barrel with NW rods. Overall core quality good.
2	5.0 – 10.0	5.0	5.0	100		7.8'-8.05' ANHYDRITE b: Light gray (N7) microcrystalline, some laminae. Scattered halite growths. Trace of gray clay at 7.8'. 8.05'-14.0' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
3	10.0 – 15.0	5.0	5.0	100		14.0'-14.65' HALITE: Clear to moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6), medium crystalline. ≤1% brown clay. <1% dispersed polyhalite. 14.65'-15.5' ANHYDRITE a: Light to medium gray (N7, N5) microcrystalline anhydrite. Irregular laminae Scattered halite growths especially from 15.1'. Trace of gray clay at 14.65'.	
4	15.0 – 20.0	5.0	5.0	100		15.5'-19.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite, average ≤2% scattered anhydrite. [3, 4, 7] 19.9'-22.4' HALITE: Clear to moderate reddish orange (10R 6/6). Some moderate brown. Medium to coarsely crystalline. ≤1% polyhalite and brown clay. [17]	
5	20.0 – 25.0	5.0	5.0	100		22.4'-24.3' HALITE: Clear to light moderate reddish orange and some light bluish gray. Medium to coarsely crystalline. <1/2% polyhalite. <1% gray clay. [9] 24.3'-29.6' HALITE: Clear, coarsely crystalline. Scattered anhydrite. Up to 1/2" hard brown clay seam at 25.1' with trace of associated anhydrite. <1/2% polyhalite locally. [1]	M

BORING NO. DH-321

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-321

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6		5.0	5.0	100		29.6'-31.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline, some fine. <1% to 3% brown clay. [12]	
						31.2'-33.3' HALITE: Clear, coarsely crystalline. [1]	
						33.3'-35.2' HALITE: Clear, some moderate reddish brown (10R 4/6), coarsely crystalline. None to ≤2% brown clay [1, 10]	
30.0	30						
7		5.0	5.0	100		35.2'-38.7' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4), medium to coarsely crystalline. <1% to 3% brown clay, trace gray. 1/2" brown clay seam at 37.45'. <1/2% polyhalite dispersed. [14, 17].	
						38.7'-39.4' ANHYDRITE: Light to medium light gray (N7, N6) microcrystalline anhydrite. Partially laminated. 3/4" hard brown clay seam at 38.7'.	
35.0	35						
8		5.0	5.0	100		39.4'-40.2' HALITE: Clear, coarsely crystalline. <1/2% polyhalite, scattered anhydrite. [1]	
						40.2'-43.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [7]	
40.0	40					43.0'-47.0' HALITE: Clear to moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Coarsely crystalline with zones of fine-medium. <1% to 2% brown clay. <1% polyhalite. [8, 12]	
9		5.0	5.0	100		47.0'-48.9' HALITE: Clear mottled with some moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% polyhalite. <1/2% gray clay. [1, 3]	
						48.9'-52.0' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline. <1% to 3% brown clay. [10, 15]	
45.0	45						
10		5.0	5.0	100			
50.0	50						
11		2.0	2.0	100			
52.0	52						
	55						

BORING NO. DH-321

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER GE-267 HOLE TYPE/SIZE NX BORING NO. DH-323

LOCATION WASTE SHAFT STATION - ROOF - EAST OF WASTE SHAFT

STATION S400, E55 COLLAR ELEV. 1261.2 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N9291.7, E6952.5 DEPTH OF BOREHOLE 52.5 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 2-22-85 DATE COMPLETED 2-22-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-28-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	3.0	0.9	30		0.0'-3.6' HALITE: Clear, medium to coarsely crystalline. [1]	NX split-tube core barrel.
						3.6'-8.0' HALITE: Clear, some moderate brown (5YR 4/4); medium to coarsely crystalline. <1% brown clay. [8]	
2	3.0	1.3	1.2	92			8.7% of core recovered was ≥ 2-inch lengths.
3	4.3 5	2.7	2.7	100		8.0'-8.3' ANHYDRITE "b": Very light to medium gray anhydrite. Scattered halite growths. Up to 1/2" dark gray clay at 8.0'. Irregular, low angle.	
						8.3'-14.5' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	Poor core quality.
4	7.0 10	5.0	5.0	100		14.5'-15.6'± HALITE: Clear to moderate brown (5YR 4/4); fine to medium crystalline. ≤ 2% brown clay, some gray. <1/2% dispersed polyhalite. [12]	
						15.6'-16.25'± ANHYDRITE "a": Light to light medium gray anhydrite. 1/4" gray clay at 15.6'. Low angle.	
5	12.0 15	5.0	3.5	70		16.25'±-20.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Scattered anhydrite. [5,7]	
						20.5'-23.5' HALITE: Clear, some moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. ≤1% brown clay. Trace polyhalite. Up to 1" brown clay seam at 23.25'. Irregular, low angle. Some hairline halite-filled fractures in clay. Some associated anhydrite to 23.5'. [8,10]	
6	17.0	2.0	1.1	55		23.5'-30.4' HALITE: Clear, coarsely crystalline, some medium. [1]	
7	19.0 20	2.5	2.5	100		30.4'-35.4' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. ≤1% brown clay, locally 2%. Break at 31.7'±. [8,10]	
8	21.5	1.5	0.9	60		35.4'-37.8' ± 0.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4), fine to medium crystalline. <1 to 3% brown clay. [12,15]	
9	23.0 25	3.4	1.2	35		37.8'-38.8' ANHYDRITE: Light to medium gray, microcrystalline anhydrite. Up to 1" brown clay at 37.8'. Irregular, undulating surfaced core is disced.	

BORING NO. DH-323

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-323

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
9	26.4	3.4	1.2	35		38.8'-42.0' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. <1 to 3% polyhalite blebs and patches. Core broken.	Note: Core is badly disced from about Run 10. It is broken from about 33' to 52.5'. Difficult to log hole due to broken core and core loss.
10	27.2	0.8	0.6	75			
11	30.4	3.2	1.2	38		42.0'-50.5'± HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. ≤1% patches of brown clay, increasing to ≤2% beyond 48'±. Core badly disced. [8,10]	
12	35.4	5.0	2.6	52		50.5'-52.5' ARGILLACEOUS HALITE: Clear to moderate brown, fine to medium crystalline, some coarse. <1 to 3% brown clay.	
13	38.8	3.4	2.3	68			
14	42.0	3.2	2.0	62			
15	45.0	3.0	1.5	50			
16	47.5	2.5	1.0	40			
17	52.5	5.0	3.5	70			

M

BORING NO. DH-323

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-45 INSTRUMENT TYPE & NUMBER Extensometer GE-230 HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254,E147 COLLAR ELEV. 1285.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9941.0, E7041.3 BOREHOLE PENETRATION 52.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.0	100	–		21.8' - 26.9' **HALITE:** colorless to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, 1-2% polyhalite, 1-5% brown and gray clay. Clay is largely interstitial from 21.8'-24.0', in discontinuous partings and breaks from 24.0'-26.9', brown clay break at 25.9'.	Run 8 from 24.0'-29.0' is broken and separated along clay seams. Clay may be washed out.
7	20	5.0	100	–		16.6' - 21.8' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, ~2% dispersed polyhalite, two *undulatory anhydrite stringers* (~1/8") at 17.2'.	
6	15	4.0	78	–		16.0' - 16.6' **ANHYDRITE:** (Anhydrite "a") very light (N8) to medium gray (N5) microcrystalline anhydrite, 10-20% halite from 16.3'-16.6', light gray (N7) clay parting at 16.0'.	
						14.8' - 16.0' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium crystalline, 5% brown (and gray) clay, polyhalite band at 15.8'-15.9', otherwise polyhalite absent.	
5	10	3.3	66	–		7.9' - 14.8' **HALITE:** clear, colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, trace (1-2%) polyhalite from 7.9'-10.8' and 12.1'-14.8', undulatory very light gray (N8) anhydrite stringers at 11.1' (~1/16"), 11.35' (~1/16"), and 11.55' (<1/16").	
						7.0' - 7.9' **HALITE:** mottled colorless to medium gray (N5) to moderate reddish-orange (10R 6/6) halite, finely to medium crystalline, 5% gray and brown clay, 7.0'-7.1' is pure, medium to coarsely crystalline halite, brown clay break at 7.2', brown and gray clay break at 7.9', 1% polyhalite.	
4		2.0	100	–		6.9' - 7.0' **ANHYDRITE:** (Anhydrite "b") light (N7) to very light gray (N8) microcrystalline anhydrite, dense, ~20% halite.	
3	5	1.8	95	–		5.0' - 6.9' **HALITE:** mottled colorless to grayish-brown (5YR 3/2) halite, medium to coarsely crystalline, 2-3% interstitial grayish-brown and medium light gray (N6) clay, <1% polyhalite.	
2		0.8	40	–		3.8' - 5.0' Core lost.	
1	0	1.8	86	–		0.0' - 3.8' **HALITE:** colorless to clear halite, medium to coarsely crystalline, 0-3% moderate reddish-orange (10R 6/6) polyhalite dispersed, trace (1%) brown and gray clay from 3.0'-3.8'.	Runs 1 - 4 were not cored with the inner barrel. 0' - 0.9' drilled with 6" single-tube core barrel. Drilling started 09:45 hours, 3 December 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-45 INSTRUMENT TYPE & NUMBER Extensometer GE-230 HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254,E147 COLLAR ELEV. 1285.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9941.0, E7041.3 BOREHOLE PENETRATION 52.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	3.2	100	–		(see description on next sheet)	
12	45	5.0	100	–		44.8' - 49.3' **HALITE:** clear to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1-3% polyhalite, concentration (5-10%) of brown clay at 46.25'-46.5', brown clay break at 46.6', discontinuous break at 48.4', trace to absent clay elsewhere.	
						43.4' - 44.8' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, 5% brown clay locally concentrated, 1-2% polyhalite, brown clay parting at 43.4', break at 44.7'.	
11	40	4.8	100	–		40.0' - 43.4' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 5-10% polyhalite, clay is absent to 43.0', trace above, anhydrite stringers decreasing in frequency from 40.0'-41.0'.	
						39.4' - 40.0' **ANHYDRITE:** (Marker Bed 138) very light (N8) to medium gray (N5) microcrystalline anhydrite, 5-10% halite increasing upwards, grades into anhydritic halite above.	
10	35	4.5	83	–		35.6' - 39.4' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, coarsely to medium crystalline, fining upwards, 5-10% brown clay locally concentrated, <1% polyhalite, clay is ~1% from 38.7'-39.4' and polyhalite is ~2%, pale brown (5YR 5/2) clay parting at 39.4'.	Run 10 (34.0'-39.4') Bottom (around 34.0'-35.0') is more broken up. Core loss was assumed to be at 34.0'-35.0'.
						32.1' - 35.6' **HALITE:** clear, coarsely crystalline halite, few blebs of polyhalite, clay is absent 32.1'-33.0', ~1% from 33.0'-35.6', increasing upsection.	
9	30	4.4	88	–		30.6' - 32.1' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, coarsely crystalline at base, fining upwards to sugary texture, 5-10% clay (mostly brown), brown clay parting at 30.7', break at 32.1', trace polyhalite.	Run 9 (29.0'-34.0') is also very broken and clay may have been lost at breaks.
8	25	5.0	100	–		26.9' - 30.6' **HALITE:** clear, coarsely crystalline halite, few blebs of polyhalite, discontinuous anhydrite stringers (<1/16") at 27.1' and 28.1'.	
						(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-45 INSTRUMENT TYPE & NUMBER Extensometer GE-230 HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254,E147 COLLAR ELEV. 1285.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9941.0, E7041.3 BOREHOLE PENETRATION 52.4'

DRILLING METHOD Wet (Brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83

SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55					52.2' - 52.4' **HALITE:** clear, coarsely crystalline halite, 1% polyhalite.	
13	50	3.2	100	—	X — X — — X — — X —	49.3' - 52.2' **ARGILLACEOUS HALITE:** mottled clear to moderate brown (5YR 3/4) to moderate reddish-brown (10R 4/6) halite, finely to coarsely crystalline, 5-10% brown clay, 1-5% polyhalite, pale (10R 5/4) to moderate reddish-brown (10R4/6) clay seam at 52.1', brown clay break at 49.4'.	Total penetration = 52.4'. Hole finished at 15:00 hours, 4 December 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-46 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254, E147 COLLAR ELEV. ~1276.5' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9941.0, E7041.3 DEPTH OF BOREHOLE 51.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83

SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	3.2	64	—		0.0' - 7.0' **HALITE:** clear to brownish-gray (5YR 4/1) halite, medium to coarsely crystalline, trace (<1/2%) of moderate reddish-orange (10R 6/6) polyhalite. Clay content up to 5% occurring as diffuse zones or interstitially.	Drilling started 15:20 hours, 4 December 1982. Stopped at 15:40 hours, with 5.0' drilled. Run 1 - core loss seems to have occurred at top of core.
2	5	0.4	40	—			
3		5.0	100	—		7.0' - 8.9' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, coarsely crystalline, moderately hard. Polyhalite occurs interstitially and as scattered blebs from 0 to 10%. Light gray (N7) clay parting (1/8") at 7.8'.	
	10					8.9' - 13.0' **ANHYDRITE:** (Marker Bed 139) light gray (N7) anhydrite, microcrystalline, hard, zones of moderate reddish-orange (10R 6/6) polyhalite from 8.9'-9.5', hairline anhydrite breaks in clear halite matrix at top. Core broken into 1/2" chips from 11.0'-13.0'. Light gray (N7) clay seam, stiff, at 13.0'.	
4		4.3	86	—		13.0' - 16.4' **HALITE:** clear, medium to coarsely crystalline halite, with clay and polyhalite in discrete bands and interstitially. Several brown clay partings (1/16") at 13.4'-13.5', and a brown clay break (1/32") at ~15.2'. Light gray (N7) clay is less abundant and occurs interstitially. Clay content ranges from 0 to 3% and polyhalite content to 2%.	
	15						
5		5.1	100	—		16.4' - 27.9' **POLYHALITIC HALITE:** clear, medium to coarsely crystalline halite, with 5-10% moderate reddish-orange (10R 6/6) polyhalite, brown clay break (1/32") at 20.6', trace interstitial gray clay from 20.6'-21.8' and at 26.7'.	
	20						
6		4.7	94	—			
	25						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-46 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254, E147 COLLAR ELEV. -1276.5' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9941.0, E7041.3 DEPTH OF BOREHOLE 51.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK, JPS/Bechtel DATE 1/26/83

SHEET 2 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	4.7	94	—		(as above)	
7	30	5.2	100	—		27.9' - 32.6' **HALITE:** clear, mottled light gray (N7), light brown (5YR 6/4) to moderate reddish-orange (10R 6/6) halite, moderately hard, finely to coarsely crystalline. Orange interstitial polyhalite represents about 2% of unit, gray and brown clay about 2-3%. Brown clay breaks at 28.8', 29.2', 30.2', and 30.3'. Gray clay breaks at 27.9', 28.0', 28.3', 28.5', 29.8', and 30.0'.	
8	35	5.0	100	—		32.6' - 38.7' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, coarsely crystalline, with 2-5% polyhalite. Polyhalite is generally interstitial but also occurs as thin layers (1/16"-1/8"). Anhydrite layer (1/16") at 37.8'.	
9	40	5.1	100	—		38.7' - 38.9' **ANHYDRITE:** light bluish-gray (5B 7/1), microcrystalline anhydrite, with light gray (N7) clay parting (1/8") at 38.9'.	
10	45	4.7	94	—		38.9' - 51.5' **HALITE:** argillaceous, clear to mottled medium gray (N5) and pale yellowish-brown (10YR 6/2) halite, finely to coarsely crystalline, moderately hard. Clay content ranges from 0 to ±5%, with <1% interstitial polyhalite, clay breaks at 44.5', 47.5', 48.2', 48.4', 48.7', 48.8', and 50.8'. Clear halite lenses from 43.1'-43.7' and 48.9'-49.5'.	
11	50	5.1	100	—			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-46 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254, E147 COLLAR ELEV. -1276.5' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9941.0, E7041.3 DEPTH OF BOREHOLE 51.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.1	100	—	— X —	(as above)	Hole finished at 13:30 hours, 5 December 1982. Total depth = 51.5'.
	55						

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WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-52 INSTRUMENT TYPE & NUMBER Extensometer GE-226 HOLE SIZE NX

LOCATION 0 East Drift, 146' N of Exploratory Shaft centerline, midspan

STATION N146; W4 COLLAR ELEV. 1280.4' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9832.5, E6890.5 BOREHOLE PENETRATION 51.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.0	100	–		22.3' - 26.8' **HALITE:** clear to colorless halite, medium to coarsely crystalline, few blebs of polyhalite, trace disseminated clay at 25.9'-26.0', anhydrite stringers (~0.1") at 22.7' and 23.9'.	
4	20	6.0	100	–		16.8' - 22.3' **HALITE:** colorless to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, 5% brown and gray clay (mostly brown) locally concentrated, ~1% polyhalite, brown clay break at 19.2', anhydrite/clay zone at 22.2'-22.3'.	
3	15	5.0	100	–		12.5' - 16.8' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 2-10% polyhalite in bands, anhydrite stringer, somewhat diffuse, at 13.7'.	
						12.0' - 12.5' **ANHYDRITE:** (Anhydrite "a") light to very light gray (N7-8), microcrystalline anhydrite, 30-50% halite from 12.4'-12.5'.	
						10.8' - 12.0' **HALITE:** mottled clear to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium crystalline, 5% brown clay, 0-3% polyhalite increasing upward, light gray (N7) clay parting at 12.0'.	
2	10	4.9	98	–		5.5' - 10.8' **HALITE:** clear to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 0-2% polyhalite, anhydrite stringers (<1/16") at 5.6', 5.9', 6.7', 6.9', and 7.4'.	
						5.3' - 5.5' **ANHYDRITE:** (Anhydrite "b") light gray (N7), microcrystalline anhydrite, undulatory bedding, 20-30% halite.	Most core shows circumferential scoring.
1	5	5.0	100	–		0.0' - 5.3' **HALITE:** colorless to clear halite, medium to coarsely crystalline, 1-3% polyhalite, 0-5% brown clay increasing upward, light gray (N7) clay parting at 5.3'.	Drilling water was recycled through the drill in such a manner that previous cuttings are pushed back into the hole.
	0						Hole was cored from 2 - 4 November 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-52 INSTRUMENT TYPE & NUMBER Extensometer GE-226 HOLE SIZE NX

LOCATION 0 East Drift, 146' N of Exploratory Shaft centerline, midspan

STATION N146, W4 COLLAR ELEV. 1280.4' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9832.5, E6890.5 BOREHOLE PENETRATION 51.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12 B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.0	100	–		46.6' – 51.1' **ARGILLACEOUS HALITE:** colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, 1-2% polyhalite, 1-10% brown clay locally concentrated, brown clay partings at 47.2', 48.3', 48.7', 50.5' and 51.0', coarsely crystalline halite with <1% clay and polyhalite from 49.0'-49.3'.	
10	45	5.1	100	–		44.5' – 46.6' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1-3% polyhalite, few blebs of gray and brown clay.	
						41.5' – 44.5' **ARGILLACEOUS HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, ~1% polyhalite, 2-10% brown clay locally concentrated, 41.5'-41.9' is purer halite, with only trace brown and gray clay, brown clay partings at 43.0', 43.5', and 44.5', brown clay seam at 43.2'.	
9	40	5.0	100	–		36.9' – 41.5' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 1-10% polyhalite locally concentrated, polyhalite stringer zone from 38.15'-38.35', anhydrite stringers at 36.95', 37.2', 37.6', and 38.8'.	
						36.5' – 36.9' **ANHYDRITE:** (Marker Bed 138) light gray (N7), microcrystalline anhydrite, undulatory, halitic upper contact.	
8	35	3.9	78	–		31.0' – 36.5' **ARGILLACEOUS HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1% polyhalite, 2-10% brown clay locally concentrated, brown clay partings at 33.8', 34.1', 34.5', and 36.3', brown clay break at 35.4', gray clay seam at 36.5'.	
7		0.2	40	–			
6	30	5.0	100	–		28.5' – 31.0' **HALITE:** colorless halite, coarsely crystalline, few blebs of polyhalite, clay is absent to 30.0', increasing to 2% interstitial brown blebs at 31.0'.	Drill rods stuck at ~30' after being left in the hole overnight.
						26.8' – 28.5' **ARGILLACEOUS HALITE:** colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1% polyhalite in 1/8"-1/2" blebs, 5-10% brown clay, brown clay breaks at 27.1', 27.7', 27.8', and 28.4'.	
5	25	5.0	100	–		(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-52 INSTRUMENT TYPE & NUMBER Extensometer GE-226 HOLE SIZE NX

LOCATION 0 East Drift, 146' N of Exploratory Shaft centerline, midspan

STATION N146, W4 COLLAR ELEV. 1280.4' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9832.5, E6890.5 BOREHOLE PENETRATION 51.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55					51.1' - 51.6' HALITE: colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 1-2% polyhalite, <1% gray and brown clay, anhydrite stringer (0.1") at 51.25'.	Total penetration = 51.6'.
11	50	5.0	100	–		(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-53 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 146' N of Exploratory Shaft centerline, midspan

STATION N146, W4 COLLAR ELEV. 1266.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9832.5, E6890.5 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Longyear 38

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83 SHEET 1 OF 2

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	0						
1		3.1	78	–		**0.0' – ~4.9' ARGILLACEOUS HALITE:** clear, coarsely crystalline halite, with some moderate reddish-orange (10R 6/6) to moderate reddish-brown (10R 4/6) polyhalite, and some light gray (N7) clay that occurs in small patches, especially around 3.2'.	0' – 1.0' was drilled with 6" single-tube core barrel.
	5						
2		1.0	50	–		**~4.9' – 6.5' POLYHALITIC HALITE:** clear, coarsely crystalline halite, with abundant polyhalite.	RUN 1 core broken. Impossible to determine location of core loss.
3		5.0	100	–		**6.5' – 8.6' ANHYDRITE:** (Marker Bed 139) very light gray (N8), microcrystalline anhydrite, with clear, fine-grained halite. Anhydrite becomes purer with depth. Light gray (N7) clay parting (1/8"-1/4") at base of anhydrite.	
	10					**8.6' – 12.4' HALITE:** clear, white, and mottled pale red (10R 6/2) coarsely crystalline halite, with approximately 1% moderate reddish-orange (10R 6/6) polyhalite, and trace (<5%) moderate brown (5YR 4/4) interstitial clay.	Drilling was very slow due to problems with the Longyear drill. The first 7 core runs were relatively easy (relative to the last 4 runs). All later cores were completed with great difficulty. The vertical control for the drill was broken so there was no mechanical means of pulling the core barrel. The drilling brine is not filtered.
4		5.0	100	–			
	15						
5		4.9	100	–		**12.4' – 25.2' POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, moderately hard. Polyhalite represents 3-5% of core and occurs as scattered blebs or interstitially. Gray clay parting (1/8"-1/4") at 17.1'. Light gray (N7) clay seams at 24.8'-25.2'.	
	20						
6		5.0	100	–			
	25						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-53 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 146'N of Exploratory Shaft centerline, midspan

STATION N146, W4 COLLAR ELEV. 1266.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9832.5, E6890.5 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Longyear 38

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83 SHEET 2 OF 2

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	100	-		(as above)	
7	30	4.8	98	-		25.2' - 29.5' **HALITE:** clear, coarsely crystalline halite, with some (10-15%) interstitial moderate brown (5YR 4/4) clay, a light gray (N7) clay seam at 26.2', and some (10-15%) polyhalite. Laminations at 26.2' dip about 10°.	RUN 7 core lost from 26.8' - 26.9'.
8	35	5.0	100	-		29.5' - 35.5' **POLYHALITIC HALITE:** clear, coarsely crystalline halite, with 5-10% moderate reddish-orange (10R 6/6) polyhalite. Polyhalite occurs as discontinuous breaks, blebs or interstitially. Clear halite from 35.0'-35.5'.	
						35.5' - 35.7' **ANHYDRITE:** very light gray (N8), microcrystalline anhydrite, with gray clay parting (1/8") at base.	
9	40	5.0	100	-		35.7' - 49.2' **ARGILLACEOUS HALITE:** clear halite, finely to medium crystalline, moderately hard, with interbedded brown clay (5%) and polyhalite (1-5%). Color ranges from medium gray (N5) to light brown (5YR 6/4). Polyhalite occurs as interstitial layers.	
10	45	4.5	100	-			
11	50	2.9	100	-			Total depth = 49.2'.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-56 INSTRUMENT TYPE & NUMBER Extensometer Ge-234 HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft Centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N10311.8 E6892.3 BOREHOLE PENETRATION 52.1'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	100	–		20.2'-25.1' **ARGILLACEOUS HALITE:** clear to mottled pale brown (5YR 5/2) and brownish-gray (5YR 4/1), medium to coarsely crystalline and moderately hard. Clay occurs interstitially with some clay breaks and partings and represents from 0-10% of core. From 23.3'-24.1', zone of moderate reddish-orange (10R 6/6) interstitial polyhalite. Clay breaks at: 20.3', 20.5', 21.3', 22.0', and 24.5'. At 24.9', 1/4" thick brownish-gray (5YR 4/1) clay partings.	
5	20	5.0	100	–		15.3'-20.2' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), finely to coarsely crystalline, moderately hard. Finely crystalline from 19.5'-20.0'. Polyhalite occurs as isolated blebs or interstitially and comprises 5-10% of core.	
4	15	5.0	100	–		14.7'-15.3' **ANHYDRITE:** banded, very light gray (N8) and medium dark gray (N4), microcrystalline, hard, dense. Core broken into 1/2" chips. 13.5'-14.7' **HALITE:** argillaceous and polyhalite in part. Mottled pale brown (5YR 4/2) and moderate reddish-brown (10R 4/6) and brownish-gray (5YR 4/1). Finely crystalline, moderately hard. Clay and polyhalite comprise 5-10% of core.	Core Loss: Run — Where Lost 2 — 2.0'-6.0' 3 — 11.6'-11.7' 11 — 47.1'-47.2'
3	10	4.9	98	–		8.0'-13.5' **HALITE:** clear, medium to coarsely crystalline, moderately hard, few scattered, very light gray (N8) anhydrite stringers throughout. 7.8'-8.0' **ANHYDRITE:** medium gray (N5), hard, dense, microcrystalline.	
2	5	2.7	47	–		5.8'-7.8' **ARGILLACEOUS HALITE:** clear and brownish-gray (5YR 4/1), medium to coarsely crystalline, moderately hard. Argillaceous content up to 10%. 0.0'-5.8' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite occurs as isolated blebs and comprises up to 3% core.	
1		1.0	100	–			Hole begun at 13:00 hours on 2 February 1983. Cored from 0 to 1.0' using 6" diameter single tube barrel. Cored from 1.0'-52.1' using NX core barrel with brine.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-56 INSTRUMENT TYPE & NUMBER Extensometer GE-234 HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft Centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N10311.8 E6892.3 BOREHOLE PENETRATION 52.1'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.1	100	–		47.0'-49.5' **ARGILLACEOUS HALITE:** clear and moderate brown (5YR 3/4), finely to coarsely crystalline, moderately hard. Clay content ranges from 0 to 15%. Clay breaks at: 47.9', 48.5', 48.7', and 49.0'.	
10	45	5.0	100	–	X	38.0'-47.0' **HALITE:** clear with trace of moderate reddish-orange (10R 6/6) polyhalite blebs throughout. Finely to coarsely crystalline, moderately hard. Polyhalite occurs interstitially or as scattered blebs and comprises up to 5% of core. Anhydrite stringer, 1/2"-3/4" thick at 39.0'. Finely crystalline, sugary texture from 44.3'-45.0', and argillaceous (2-5%). Brown clay breaks at: 44.6', and 44.9'.	
9	40	5.0	100	–	X	37.5'-38.0' **ANHYDRITE:** light gray (N7) to medium dark gray (N4), dense, hard, microcrystalline.	
						37.5' **CLAY:** pale brown (5YR 5/2), moderately plastic, moderately soft, moist, 1/2" thick seam.	
8	35	5.1	100	–		32.5'-37.5' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2), finely to coarsely crystalline, moderately hard. Clay content ranges from 2-10% with clay breaks at: 33.0', 33.5', 33.7', 33.9', 34.2', 34.4', 35.0', 35.6', 36.0', 36.6', and 37.1'. Finely crystalline from 35.2'-37.5'.	
7	30	5.2	100	–		25.1'-32.5' **HALITE:** clear and slightly argillaceous in part. Finely to coarsely crystalline, moderately hard. From 29.0'-31.0' clay content ranges from 0 to 2% with brown clay breaks at: 29.1', 29.9', 30.0', 30.7', and 30.8'.	
6	25	4.9	98	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-56 INSTRUMENT TYPE & NUMBER Extensometer GE-234 HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft Centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N10311[illegible]6892.3 BOREHOLE PENETRATION 52.1'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
	50				X X X	49.5'-52.1' **HALITE:** polyhalite, clear and mottled reddish-orange (10R 6/6) and grayish-red (5R 4/2). Finely to medium crystalline, moderately hard. Polyhalite occurs interstitially and as blebs and comprises 0-10% of core. Sugary texture from 50.5'-51.2'.	Hole completed at 22:00 hours on 2 February 1983. Total Penetration = 52.1'

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. D0-57 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1288.1 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10311.8 E6892.4 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	5	1.2	17	-		0.0'-7.9' **HALITE:** clear to pale brown (5YR 5/2). Coarsely crystalline, moderately hard, trace of gray and brown clay throughout.	Hole begun at 09:30 hours on 3 February 1983. Hole cored from 0' to 7' using NX size drill rods without inner barrel.
2	10	4.7	94	-		7.9'-10.1' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), moderately hard, coarsely crystalline.	
						10.1'-12.2' **ANHYDRITE:** banded light gray (N7) to olive gray (5YR 4/1), hard, dense, microcrystalline.	
						12.2'-12.3' **CLAY:** medium gray (N5) moist, moderately soft, highly plastic.	
3	15	5.1	100	-		12.3'-15.5' **HALITE:** clear and mottled pale brown (5YR 5/2) and pale reddish-brown (10R 5/4), finely crystalline, moderately hard. Trace of clay and polyhalite throughout, up to 5%, locally. Brown clay break at 13.8'.	Core Loss:
						15.5'-20.2' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard.	
4	20	5.3	100	-		20.2' **CLAY:** medium gray (N5), moist, highly plastic, moderately soft, 1/2"-3/4" thick, sub-horizontal.	
						20.2'-22.1' **HALITE:** argillaceous, coarsely crystalline, moderately hard. Clay content is 3-5% and occurs interstitially. Clay breaks at: 21.0' and 21.4'. Halite is clear and pale brown (5YR 5/2).	
5	25	5.1	100	-		22.1'-28.0' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite comprises up to 10% of core and occurs as scattered blebs or interstitially. Few isolated seams of polyhalite throughout.	

Run	Where Lost
1	Throughout Run
2	7.0'-7.3'
7	33.6-33.7'
9	43.0'-43.1'

M

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-57 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1288.1 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10311.8 E6892.4 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 2 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.1	100	–		(as above)	
6	30	5.3	100	–		**28.0'-32.8' ARGILLACEOUS HALITE:** clear and mottled pale reddish-brown (10R 5/4) and medium light gray (N6), finely to coarsely crystalline, moderately hard. Clay content up to 10% with trace amounts of orange polyhalite throughout. Clay breaks at: 28.0', 28.4', 28.7', 29.2', 29.4', 29.7', 31.5', 32.0', and 32.4'.	
7	35	4.9	98	–		**32.8'-37.8' POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), finely to coarsely crystalline, moderately hard. Polyhalite comprises up to 15% of core and occurs as isolated blebs or interstitial layers. Polyhalite seam from 36.7'-36.9'.	
8	40	5.2	100	–		**37.8'-38.1' ANHYDRITE:** light gray (N7), hard, dense, microcrystalline. **38.1'-51.3' ARGILLACEOUS HALITE:** clear and mottled medium gray (N5), pale brown (5YR 5/2) and grayish-orange (10YR 7/4). Finely to coarsely crystalline, moderately hard, clay content varies from < 1% up to 10%. Clay breaks at: 38.5', 47.2', 47.3', 47.7', 48.2', 48.6', 50.0', and 50.6'. Few seams of interstitial, orange polyhalite. Clear halite from 42.6'-45.0'.	
9	45	4.9	98	–			
10	50	4.1	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-57 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1288.1 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10311.8 E6892.4 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	4.1	100	–		(as above)	Hole completed at 14:30 hours on 3 February 1983.
	52.1					51.3'-52.1' HALITE: clear, coarsely crystalline, moderately hard.	Total Depth = 52.1'

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-63 INSTRUMENT TYPE & NUMBER Extensometer GE-243 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1310.6' DIRECTION OF DRILLING vertical up

MINE COORDINATES N10796.0, E6891.9 BOREHOLE PENETRATION 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25	5.0	100	–		(see description on next sheet)	
6	20	5.0	100	–		**17.9'-23.4' HALITE:** argillaceous, moderately hard, finely to coarsely crystalline, clear to mottled grayish-brown (5YR 3/2) and pale yellowish-brown (10YR 6/2). Clay content up to 20% in part. Clay breaks at: 18.5', 19.2', 19.9', 20.2', 22.7', and 23.0'.	
5	15	5.2	100	–		**14.8'-17.9' POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), moderately hard, coarsely crystalline. Polyhalite content ranges from 2-15% with few polyhalite stringers and isolated blebs. **13.6'-14.8' ANHYDRITE:** very light gray (N8) to pinkish-gray (5YR 8/1) hard, dense microcrystalline with some interstitial clear halite. **12.0'-13.6' HALITE:** argillaceous, clear to mottled brownish-gray (5YR 4/1) to light gray (N7). Finely to coarsely crystalline, moderately hard. Clay content up to 15% and gray clay breaks at 13.0' and 13.1'. Trace of orange polyhalite from 13.3'-13.6'. Gray clay parting, moderately plastic at 13.6'.	
4		2.6	100	14			
3	10	4.6	92	–		**6.7'-12.0' HALITE:** clear, moderately hard, medium to coarsely crystalline, few white (N9) anhydrite stringers. **6.5'-6.7' ANHYDRITE:** very light gray (N8), hard, dense, microcrystalline. Core broken into 1/4" chips.	Core Loss: Run / Where Lost 2 / 3.0'-3.2' 4.2'-4.5' 5.1'-5.5' 3 / 6.9'-7.0' 7.5'-7.7' 8.0'-8.1'
2	5	1.9	68	–		**3.8'-6.5' HALITE:** argillaceous, medium light gray (N6) to light brownish-gray (5YR 6/1), moderately hard, finely to medium crystalline. Clay content ranges from 2-8%, with clay breaks at 4.4', 5.2', and 6.1'. Trace of interstitial polyhalite at 6.0'. Gray clay parting at 6.5'.	
1		2.0	100	–		**0.0'-3.8' HALITE:** polyhalitic in part, clear and moderate reddish-orange (10R 6/6) interstitial polyhalite. Moderately hard and medium to coarsely crystalline.	Began coring at 08:30 hours on 10 February 1983. Cored to 5.8' without inner barrel.
0	0	.85	83	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-63 INSTRUMENT TYPE & NUMBER Extensometer GE-243 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1310.6' DIRECTION OF DRILLING vertical UP

MINE COORDINATES N10796.0, E6891.9 BOREHOLE PENETRATION 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	4.0	100	60		40.6'-50.3' **ARGILLACEOUS HALITE:** clear to mottled medium gray (N5), moderate brown (5YR 3/4) to pale yellowish-brown (10YR 6/2), moderately hard, finely to coarsely crystalline. Finely crystalline from 41.6'-42.5' and from 47.0'-48.3'. Clear halite from 44.0'-45.3'. Clay content ranges from 0-20% with numerous clay breaks throughout. Clay breaks at: 41.4', 42.4', 43.3', 43.8', 46.5', 46.6', 47.0', and 49.5'. *Brown clay parting, moist, highly plastic at 50.3'.*	
11	45	5.1	100	-			
10	40	5.0	100	-	X	36.8'-40.6' **HALITE:** clear, moderately hard, medium to coarsely crystalline, few stringers of white anhydrite throughout. Slightly polyhalitic in part from 38.5'-40.0'.	
					X	36.1'-36.8' **ANHYDRITE:** light gray (N7) to medium dark gray (N4), hard, dense, microcrystalline, slightly banded in part. Trace of polyhalite at 36.5'.	
9	35	5.1	100	-	X	36.0'-36.1' **CLAY:** pale brown (5YR 5/2), moderately soft, moist, highly plastic near horizontal.	
					X	31.1'-36.0' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2), and moderate brown (5 YR 3/4), moderately hard, finely to coarsely crystalline; clay content ranges from 0 to 10%. Numerous clay breaks and partings and trace of polyhalitic halite at 35.5'. Clay breaks at: 32.0', 33.1', 33.3', 33.8', 34.2', and 35.0'. *Brown clay parting at 34.4'.*	
8	30	5.0	100	-			
					X	23.4'-31.1' **HALITE:** clear, coarsely crystalline, moderately hard, trace of white anhydrite in hairline stringers. From 27.3'-29.3' slightly argillaceous in part, finely crystalline and grayish-brown (5YR 3/2). Brown clay breaks at: 27.4', 27.6', and 29.1'. Trace of orange polyhalite from 28.6'-29.0'	
7	25	5.0	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-63 INSTRUMENT TYPE & NUMBER Extensometer GE-243 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1310.6' DIRECTION OF DRILLING vertical up

MINE COORDINATES N10796.0, E6891.9 BOREHOLE PENETRATION 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						Hole completed at at 14:45 hours on 10 February 1983.
12	50	4.0	100	–	X X X	50.3'-52.8' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite, which comprises about 0-10% of core, occurs interstitially and as isolated blebs.	Total Penetration = 52.8'

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-64 INSTRUMENT TYPE & NUMBER Extensometer GE-221 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1301.5' DIRECTION OF DRILLING vertical down

MINE COORDINATES N10796.0, E6891.6 DEPTH OF BOREHOLE 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 1 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0		1.0	100	–			
1	5	6.0	100	–		**0.0'-8.0'** **HALITE:** argillaceous and polyhalitic in part; clear to medium gray (N5) and moderate reddish orange (10R 6/6); moderately hard, finely to coarsely crystalline with few clay breaks. Clay and polyhalite up to 5% locally. Clay breaks at 1.5', 2.2', 2.5', 3.3', 3.7', 6.3', and 7.5'.	Hole began at 15:00 hours on 10 February 1983. Hole cored from 0' to 1' using a 6" core barrel. From 1' to 7' hole cored without inner core barrel.
2	10	4.9	98	–		**8.0'-10.6'** **POLYHALITIC HALITE:** clear and moderate reddish orange (10R 6/6). Polyhalite occurs as dense isolated stringers and blebs and comprises 15% of core. From 10.0'-10.6' polyhalite is finely crystalline, hard and comprises up to 100% of core.	Core Loss: Run 2 Where Lost 9.3'-9.4'; Run 8 40.8'-41.0'
						10.6'-12.8' **ANHYDRITE:** light gray (N7) to light olive-gray (5Y 6/1), moderately hard, microcrystalline, highly fractured. Core broken into 1/4'-1/2' chips.	
3	15	5.1	100	–		**12.8'-15.0'** **ARGILLACEOUS HALITE:** light gray (N7) to medium dark gray (N4), finely crystalline, moderately hard with clay content up to 20%. Gray clay breaks at 13.2', 13.3', and 13.7'. Numerous interstitial clay layers from 14.0'-15.0'. Gray clay parting at 12.8'.	
4	20	5.0	100	–		**15.0'-35.6'** **POLYHALITIC HALITE:** clear and moderate reddish orange (10R 6/6), moderately hard, medium to coarsely crystalline. Polyhalite ranges from 0-15% with polyhalite blebs and interstitial zones. Slightly gray and argillaceous from 20.9'-21.9' and from 27.9'-28.2'. Clay breaks at: 20.9', 21.3', and 28.0'. Clear halite from 29.2'-29.9' and from 31.5'-32.4'.	
5	25	5.2	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-64 INSTRUMENT TYPE & NUMBER Extensometer GE-221 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1301.5' DIRECTION OF DRILLING vertical down

MINE COORDINATES N10796.0, E6891.6 DEPTH OF BOREHOLE 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 2 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.2	100	—		(as above)	
6	30	5.1	100	—			
7	35	5.2	100	—		35.6'-36.2' **ANHYDRITE:** olive gray (5Y 4/1) highly fractured and broken, dense, microcrystalline. Core broken into 1/2" pieces. Gray clay seam 1/2" thick at 36.2'.	
8	40	4.8	96	—		36.2'-43.3' **HALITE:** argillaceous in part, clear and mottled medium gray (N5) to pale yellowish brown (10YR 6/2). Interstitial clay content up to 10% locally. Clay breaks at: 39.9' and 40.0'. Few zones of orange interstitial polyhalitic halite at: 37.5', 39.0', 40.1' and 42.7'.	
9	45	5.2	100	—		43.3'-50.0' **ARGILLACEOUS HALITE:** clear and mottled grayish brown (5YR 3/2) and medium gray (N5) moderately hard, finely to coarsely crystalline. Clay content ranges from <1% to 25%. Clay breaks at: 44.0', 44.7', 45.9', 46.5', 47.0', 47.3', 48.1', 48.6', and 49.4'. Few polyhalite stringers at 44.5' and 45.6'.	
10	50	5.2	100	—			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-64 INSTRUMENT TYPE & NUMBER Extensometer GE-221 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1301.5' DIRECTION OF DRILLING vertical down

MINE COORDINATES N10796.0, E6891.6 DEPTH OF BOREHOLE 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 3 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	5.0	100	–	X	50.0'-52.8' HALITE: clear, coarsely crystalline, moderately hard. Core broken into 1/4" pieces from 51.5'-52.0'. Slightly polyhalitic from 52.5'-52.8'.	Hole completed at 19:00 hours on 10 February 1983 Total Depth = 52.8'
	55						

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WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-67 INSTRUMENT TYPE & NUMBER Extensometer CE-220 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Down Vertical

MINE COORDINATES N10952.1, E6662.9 DEPTH OF BOREHOLE 51.7'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JFG DATE 5/5/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0	0	1.0	1.0	–		**0.0' - 3.7' POLYHALITIC HALITE:** Clear mottled with moderate reddish-orange (10R 6/6), coarsely crystalline, medium hard. Blebs of polyhalite <1 to 5%. Trace (<1%) gray clay.	Started Drilling at 09:45 hours on 18 April 1983.
1		3.3	87	–		**3.7' - 6.8' ANHYDRITE:** (Marker Bed 139) Very light gray (N8) anhydrite mixed with moderate reddish- orange (10R 6/6), and reddish-brown (10R 4/6) polyhalite and polyhalitic halite from 3.7' to 6.0', core hard. From 5.0 to 6.0', core is predominantly moderate reddish-brown (10R 4/6) polyhalite. Core broken into "disc-like" pieces as thin as 0.01'. Core medium hard. From 6.0' to 6.8', core is all anhydrite, microcrystalline; hard gray clay at 6.7' to 6.8'.	$5\frac{1}{2}$" single-tube barrel used to core 0.0 to 1.0'. NX single tube barrel used 1.0' to 4.8'. NX double tube barrel used 4.8' to 51.7'.
2	5	1.8	85	–			
3	10	4.8	100	–		**6.8' - 9.8' HALITE:** Clear to moderate reddish-orange (10R 6/6) and grayish-brown (5YR 4/1) medium to coarsely crystalline, medium hard. <1 to 3% polyhalite. <1 to 3% gray clay to 8.6', turning to brown clay. Clay parting at 9.1'. Numerous breaks throughout core.	Moderate gas flow at 6' to 7'. Flow for 3 to 4 minutes, then slowed down appreciably. Methane 3 to $4\frac{1}{2}$% at collar.
4	15	5.1	100	–		**9.8' - 14.7' POLYHALITIC HALITE:** Clear to moderate reddish-orange (10R 6/6), coarsely crystalline, hard polyhalite generally <1 to 5% with local zones >5%. From 14.3' to 14.7' polyhalite 20 to 60%.	
						14.7' - 16.6' HALITE: Clear to brownish-gray (5YR 4/1) with some moderate reddish-brown (10R 4/6), medium to coarsely crystalline, medium hard, trace (< 1%) of gray and brown clay. Trace (<1%) polyhalite. Clay breaks at 14.7' and 16.0'.	
5	20	4.8	100	–		**16.6' - 20.5' POLYHALITIC HALITE:** Clear to moderate reddish-orange (10R 6/6), coarsely crystalline, hard. <1 to 5% polyhalite. <1% gray clay.	
6	25	5.1	100	–		**20.5' - 26.5' HALITE:** Clear to moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6), medium to coarsely crystalline, medium hard. <1 to 2% polyhalite and 1 to 2% clay. Clay breaks at 20.5', 23.4', 24.4' and 25.2'.	

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO DO-67 INSTRUMENT TYPE & NUMBER Extensometer GE-220 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Down Vertica

MINE COORDINATES N10952.1, E6662.9 DEPTH OF BOREHOLE 51.7'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	100	–		As Above	
7	30	4.8	100	–		26.5' - 31.6' **HALITE:** Clear to moderate reddish-orange (10R 6/6), coarsely crystalline, hard blebs and patches of polyhalite <1 to 3%. Polyhalitic from 29.4' to 30.5'. Anhydrite stringers from 30.5' to 30.9'	
						31.6' - 31.9' **ANHYDRITE:** Very light (N8) to medium dark gray (N4), laminated, micro-crystalline, hard. Trace of clay at 31.9'. Some core grinding evident.	
8	35	4.95	99	–		31.9' - 38.7' **HALITE:** Clear to grayish brown (5Y 3/2) and moderate reddish-orange, fine to coarsely crystalline, medium hard. Contains <1 to 3% clay and <1% polyhalite. Argillaceous halite from 32.7' to 33.7'.	
9	40	5.0	100	–		38.7' - 41.5' **ARGILLACEOUS HALITE:** Clear to brownish gray (5YR 4/1), coarsely crystalline, medium hard. Gray and brown clay <1 to 5%. Breaks at 39.0', 40.3', 40.5' and 41.0'.	
10	45	5.2	100	–		41.5' - 51.7' **HALITE:** Clear to brownish-gray (5YR 4/1) to moderate reddish-orange, medium to coarsely crystalline, medium hard, <1% polyhalite. Clay, generally <1%. Zones from 42.4' to 43.3', 47.3' - 47.6' and 49.1' - 49.3' containing clay breaks and up to 5% clay. Core broken up at 46.8' to 47.1' due to extraction from core barrel. Core clear from 44.9' to 47.2'.	M
11	50	4.8	96	–			

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO DO-67 INSTRUMENT TYPE & NUMBER Extensometer CE-220 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Down Vertical

MINE COORDINATES N10952.1, E6662.9 DEPTH OF BOREHOLE 51.7'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (FT)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4.8	96	–		As Above	Completed drilling at 15:25 hours on 18 April 1983. Total penetration = 51.7 feet.
	55						

M

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-69 INSTRUMENT TYPE & NUMBER Extensometer GE-218 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1310.1 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10951.9, E6662.5 BOREHOLE PENETRATION 51.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/6/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	100	–		19.6' – 27.0' **HALITE:** Clear to brownish gray (5YR 4/1), medium to coarsely crystalline, medium hard to hard. Trace of polyhalite 20.6' to 20.8' and 22.4' to 23.0'. Trace (1-2%) gray clay at 19.6' to 22.4'. Brown clay (<3%) mixed with halite at 23.8' to 24.0'. Core broken up.	
5	20	4.9	100	–		16.4' – 19.6' **POLYHALITIC HALITE:** Clear mottled with moderate reddish orange (10R 6/6) and moderate reddish brown (10R 4/6) polyhalite, coarsely crystalline, medium hard to hard polyhalite <1 to 5%. Trace (<1%) clay.	
						14.9' – 16.4' **HALITE:** Clear mottled with moderate reddish orange (10R 6/6) polyhalite, coarsely crystalline, medium hard. Polyhalite <1%.	Light to moderate gas flow at 14'±. 1 to 3% methane at return line. Flow for approximately 10 minutes. Smell of "rotten egg" noted.
4	15	5.1	100	–		14.0' – 14.9' **ANHYDRITE:** (Anhydrite "a") white, very light (N8) to medium gray (N5), microcrystalline, hard. Trace of halite. Trace of clay at 14.0'.	
						7.27' – 14.0' **HALITE:** Clear, medium to coarsely crystalline, hard. Contains minute traces (<1%) of polyhalite, scattered irregular anhydrite stringers. Gray clay break at 13.25'.	
3	10	4.9	100	–		7.0' – 7.27' **ANHYDRITE:** (Anhydrite "b") Light gray (N7), microcrystalline, hard anhydrite mixed with some halite. Trace of gray clay at 7.0'.	Light-moderate gas flow at 7'±. Faint smell. Flow lasted several minutes. No methane measured at return line.
2	5	5.0	100	–		6.5' – 7.0' **ARGILLACEOUS HALITE:** Clear to grayish brown (5YR 3/2), medium crystalline, medium hard. Clay predominantly gray with some brown (<5%), clay breaks at 6.7' and 6.8'.	NX double-tube barrel used from 1.6' to 51.4'.
						5.1' – 6.5' **HALITE:** Clear to brownish gray (5YR 4/1) and medium gray (N5), medium to coarsely crystalline, medium hard. Trace of gray clay (<1% to 2%) throughout.	NX single-tube barrel used from 1.0' to 1.6'.
1		.33	60	–		0.0' – 5.1' **HALITE:** Clear to mottled with scattered medium reddish orange (10R 6/6) blebs of polyhalite, coarsely crystalline, medium hard to hard, polyhalite <1%.	5 1/2" single-tube barrel used from 0.0' to 1.0'.
0	0	1.0	100	–			Coring started at 11:45 hours, 12 April 1983.

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-69 INSTRUMENT TYPE & NUMBER Extensometer GE-218 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1310.1 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10951.9, E6662.5 BOREHOLE PENETRATION 51.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/6/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
					X	As Above	
11	50	5.1	100	–		**45.2' – 49.3' ARGILLACEOUS HALITE:** Clear to dark reddish brown (10R 3/4), medium to coarsely crystalline, medium hard. Brown clay <1 to 10%. Clay breaks throughout.	
10	45	4.8	100	–	X	**40.7' – 45.2' HALITE:** Clear to grayish brown (5YR 3/2) to moderate reddish brown (10R 4/6) and dark reddish brown (10R 3/4), fine to coarsely crystalline, medium hard. Trace (1%) polyhalite. Predominantly brown clay (<1%) with locally >3%. Clay breaks at 42.7' and 43.4'. Broken up at 42.3' to 42.6' probably during removal from barrel.	
9	40	5.0	100	–	X X X	**38.5' – 40.7' POLYHALITIC HALITE:** Clear mottled with moderate reddish orange (10R 6/6) and reddish brown (10R 4/6), coarsely crystalline, medium hard to hard. Polyhalite <1 to 5%. Scattered anhydrite stringers. **36.7' – 38.5' HALITE:** Clear to dark reddish brown (10R 3/4), coarsely crystalline, hard. Contains trace of polyhalite, generally <1% but locally >5%. Irregular anhydrite stringers scattered within core. Anhydrite >40% from 36.7' to 37.1'.	
8	35	5.0	100	–		**36.3' – 36.7' ANHYDRITE:** (Marker Bed 138) White to very light (N8) and medium gray (N5), microcrystalline, hard. **32.1' – 36.3' ARGILLACEOUS HALITE:** Clear to dark reddish brown (10R 3/4), medium to coarsely crystalline, medium hard. Brown clay 2 to 10%. Clay breaks throughout. 1" brown clay seam at 36.3'.	
7	30	4.9	100	–	X	**29.3' – 32.1' HALITE:** Clear, medium to coarsely crystalline, medium hard to hard. Trace (<1%) clay and polyhalite from 31.6'. **27.0' – 29.3' ARGILLACEOUS HALITE:** Clear to grayish brown (5YR 3/2), predominantly coarsely crystalline; fine-medium crystalline from 28.6' to 29.3', medium hard. Predominantly brown clay <1 to 5%. Clay breaks at 28.6' and 29.3'.	
6	25	5.1	100	–	X	As Below	

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-69 INSTRUMENT TYPE & NUMBER Extensometer GE-218 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1310.1 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10951.9, E6662.5 BOREHOLE PENETRATION 51.4'

DRILLING METHOD Rotary W/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/6/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
11	50	5.1	100	–	X	49.3' – 51.4' **POLYHALITIC HALITE:** Clear mottled with moderate reddish orange (10R 6/6) polyhalite, coarsely crystalline, medium hard to hard. Polyhalite averages 1 to 3%, locally up to 5%. Trace (<1%) gray clay.	Total penetration = 51.4'. Drilling completed at 12:30 hours, 13 April 1983.

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO DO-77 INSTRUMENT TYPE & NUMBER Extensometer GE-216 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270 in Floor 16.5 Feet From E and W Ribs.

STATION N1270, W364.5 COLLAR ELEV. 1294.6 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10962.5, E6529.6 DEPTH OF BOREHOLE 53.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/31/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (FT)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0		0.8	100	—		**0.0' - 1.7' POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) to moderate reddish brown (10R 4/6), coarsely crystalline, hard. Polyhalite comprises <5% to 15% of rock.	Started drilling 27 March 1983 at 9:10 a.m. 5 1/2" diameter single-tube core barrel used from 0.0' to 0.8'. NX single-tube core barrel used from 1.0' to 5.6'. NX double-tube core barrel used from 5.6' to 53.4'.
1		1.0	50	—		**1.7' - 4.1' HALITE:** clear, coarsely crystalline, moderately hard. Core is broken up, possible core loss. Trace (<2%) polyhalite blebs.	
2	5	1.9	68	—		**4.1' - 7.25' ANHYDRITE (Marker Bed 139):** moderate reddish-orange (10R 6/6) to moderate reddish-brown (10R 4/6) polyhalitic halite, medium to coarsely crystalline, mixed with very light (N8) to light gray (N7) anhydrite from 4.1' to 6.4'. Grades into medium (N5) to very light gray (N8) anhydrite at approximately 6.4'. Microcrystalline, hard, dense. Trace of gray clay at 7.25'. Core grinding evident within this zone.	
3		0.9	64	—			
4	10	5.0	100	—		**7.25' - 23.6' POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6), fine to medium crystalline, hard. Polyhalite averages <5% to 10% with <2% from 14.7' to 17.3'. Gray clay breaks at 7.8', 8.0', 9.8' and 14.5'. Scattered clay breaks at 21.0' to 22.5'. Core contains gray clay (2% to 4%) from 14.4' to 23.6'.	
5	15	5.3	100	—			Possible Core Loss Zones: Run 1: Throughout Run 2: From 2.8' to 4.1'. Run 3: Throughout
6	20	5.2	100	—			
7	25	5.2	100	—		**23.6' - 27.2' HALITE:** clear and brownish gray (5YR 4/1) to moderate reddish-brown (10R 4/6), fine to coarsely crystalline, hard. Gray clay (<1% to 4%). Polyhalite content <1% to 5%, generally increasing with depth from 26.0'. Scattered clay breaks within core.	

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-77 INSTRUMENT TYPE & NUMBER Extensometer GE-216 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270 in Floor 16.5 Feet from E and W Ribs.

STATION N1270, W364.5 COLLAR ELEV. 1294.6 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10962.5, E6529.6 DEPTH OF BOREHOLE 53.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/31/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (FT)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25	5.2	100	—		(as above)	
8	30	5.2	100	—		27.2' - 31.2' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) to moderate reddish brown (10R 4/6), coarsely crystalline, hard. Polyhalite occurs as blebs and irregular patches, generally <1% to 5% but locally >15%.	
						31.2' - 32.1' **HALITE:** clear, medium to coarsely crystalline, hard. Trace of polyhalite.	
9	35	5.2	100	—		32.1' - 32.3' **ANHYDRITE:** very light gray (N8) to medium light gray (N6), microcrystalline, banded. Trace of clear halite. Trace of clay at 32.3'. Some core grinding evident.	
						32.3' - 36.9' **HALITE:** clear to brownish gray (5YR 4/1), medium to coarsely crystalline, hard. Gray clay <1% to 3% scattered throughout. Trace of moderate reddish-orange (10R 6/6) polyhalite.	
10	40	5.1	100	—		36.9' - 43.5' **ARGILLACEOUS HALITE:** clear to brownish-gray (5YR 4/1), fine to coarsely crystalline, hard. Brown clay seam (1/4") at 40.8' and clay parting at 41.3'. Moderate reddish-orange (10R 6/6) polyhalite constitutes 1% to 2% of core. Several clay breaks from 41.0' to 41.7'.	
11	45	5.1	100	—		43.5' - 53.4' **HALITE:** clear to grayish red (10R 4/2), medium to coarsely crystalline, hard. Trace of gray clay and trace of polyhalite blebs. 1% to 2% gray clay from 51.0' to 52.15' and 52.75' to 53.1'.	
12	50	5.1	100	—			

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. D0-77 INSTRUMENT TYPE & NUMBER Extensometer GE-216 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270 in Floor 16.5 Feet From E and W Ribs.

STATION N1270, W364.5 COLLAR ELEV. 1294.6 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10962.5, E6529.6 DEPTH OF BOREHOLE 53.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/31/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	5.1	100	—	X	43.5' - 53.4' HALITE: clear to grayish red (10R 4/2), medium to coarsely crystalline, hard. Trace of gray clay and trace of polyhalite blebs. 1% to 2% gray clay from 51.0' to 52.15' and 52.75' to 53.1'.	Completed drilling 27 March 1983 at 2:00 p.m.
	55						Total Depth = 53.4'

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-79 INSTRUMENT TYPE & NUMBER Extensometer GE-214 HOLE SIZE NX

LOCATION Test Room 2. Centerline of Room at Station N1270 in Roof 16.5 Feet From E and W Ribs.

STATION N1270, W364.5 COLLAR ELEV. 1307.7 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10962.6, E6529.5 BOREHOLE PENETRATION 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/24/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.3	100	—	X	23.4'-27.9' **HALITE:** clear, medium crystalline, moderately hard. Obscure traces of polyhalite and argillaceous material. Core broken up from 27.4' to 27.6'. Irregular white anhydrite stringers at 23.7'.	
5	20	4.8	96	—	X	18.4'-23.4' **ARGILLACEOUS HALITE:** moderate brown (5YR 3/4) to moderate reddish-orange (10R 6/6) with some clear halite, medium to coarsely crystalline, hard. Scattered brown clay breaks. 1/4" brown clay seam at 23.3'. Trace polyhalite blebs (<1%) found locally. Argillaceous content varies from <1% to 5%.	
						14.1'-18.4' **POLYHALITIC HALITE:** clear to mottled with moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6) blebs of polyhalite. Medium to coarsely crystalline, hard. White anhydrite stringers from 15' to 15.1' and 15.2' to 15.3'. Polyhalite content varies from <2% to 5%. Scattered traces of argillaceous material from 17.1' to 18.4'.	
4	15	5.1	100	—	X	13.8'-14.1' **ANHYDRITE:** (Anhydrite "a") light gray (N7) to white, microcrystalline, hard, dense. Trace of gray clay at 13.8'. Some evidence of core grinding.	Trace of gas at 14'±. No methane at end of return line.
					X	13.3'-13.8' **HALITE:** grayish-red (5R 4/2) to clear, fine to medium crystalline, hard. Contains few gray clay breaks and trace of polyhalite.	
3	10	4.8	96	—		7.35'-13.3' **HALITE:** clear with scattered zones of moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6), medium to coarsely crystalline, moderately hard to hard. Thin, very light gray (N8) to white anhydrite stringers at 8.0', 8.5' and 8.8'.	Possible Core Loss Zones: Run 2: throughout Run 5: throughout Run 7: 27.9' to 29.8'.
						7.1'-7.35' **ANHYDRITE:** (Anhydrite "b") light gray (N7) to medium gray (N5), banded, microcrystalline, hard, dense. Trace of brown clay.	
2	5	4.5	96	—	X	4.5'-7.1' **ARGILLACEOUS HALITE:** grayish-brown (5YR 3/2), predominantly medium crystalline ranging to coarsely crystalline, moderately hard to hard. Trace of reddish-orange polyhalite throughout. Clay content <5%, predominantly gray ranging to brown. Gray clay break at 6.3'. Trace of gray clay at 7.1', with evidence of core grinding.	Hit gas at 7'. Measured < 2% methane at end of return line. Moderate gas flow. NX double-tube core barrel used from 2.4' to 51.8'. NX single-tube core barrel used from 1.0' to 2.4'.
1		1.4	100	—		0.0'-4.5' **HALITE:** clear to moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Trace of polyhalite blebs and brown argillaceous material found throughout.	0' - 1.0' drilled with 5 1/2" single-tube core barrel. Drilling began at 11:35 a.m. on 21 March 1983
0	0	1.0	100	—	X		

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-79 INSTRUMENT TYPE & NUMBER Extensometer GE-214 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270 in Roof 16.5 Feet From E and W Ribs

STATION N1270, W364.5 COLLAR ELEV. 1307.7 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10962.6, E6529.5 BOREHOLE PENETRATION 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/24/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.2	100	—		As Above	
10	45	5.1	100	—		44.4'-46.7' **HALITE:** clear mottled with some moderate reddish-brown (10R 4/6), medium to coarsely crystalline, hard. Trace of brown argillaceous material (<1%). 40.8'-44.4' **HALITE:** moderate reddish-brown (10R 4/6) to dark brown (10R 3/4) with some clear halite, fine to coarsely crystalline, moderately hard. Scattered zones of brown clay. Argillaceous content averages <2% but locally >5%.	
9	40	5.1	100	—	X X X	37.3'-40.8' **HALITE:** clear from 37.4' to 38.4'. Clear, mottled with moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6) comprises remaining portion of section; medium to coarsely crystalline, hard. Trace (2%) of polyhalite from 37.3' to 38.4' and 38.4' to 40.8'. Core broken up from 37.4' to 37.9' and 38.1' to 38.2'. 36.3'-37.3' **ANHYDRITE:** (Marker Bed 138) very light gray (N8) to medium dark gray (N4) to white, banded, microcrystalline, hard. Clear to reddish-orange (10R 6/6) halite is mixed with anhydrite from 36.9' to 37.3'.	
8	35	4.1	100	—		35.4'-36.3' **HALITE:** clear, coarsely crystalline, hard. Several scattered blebs of grayish-brown argillaceous material. 31.8'-35.4' **ARGILLACEOUS HALITE:** clear to dark reddish-brown (10R 3/4) to moderate brown (5YR 3/4) to brownish-gray (5YR 4/1) mottled, medium to coarsely crystalline, moderately hard. Brown and gray clay generally <2%. Numerous clay breaks.	
7	30	4.7	94	—	X	29.8'-31.8' **HALITE:** clear, medium to coarsely crystalline, moderately hard. Traces of brown clay (<1%). 27.9'-29.8' **HALITE:** clear to moderate brown (5YR 3/4), medium to coarsely crystalline, moderately hard. Trace of argillaceous material throughout. Contains thin (F 1/8 ") brown clay partings at 28.6', 29.5', and 29.8'.	
6	25	5.3	100	—		As Below	Air bubbles in return water continuously to 37'±. No methane at end of return line.

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-79 INSTRUMENT TYPE & NUMBER Extensometer GE-214 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270 in Roof 16.5 Feet From E and W Ribs

STATION N1270, W364.5 COLLAR ELEV. 1307.7 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10962.6, E6529.5 BOREHOLE PENETRATION 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/24/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55					50.3'-51.8' **POLYHALITIC HALITE:** clear mottled with moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6) polyhalite blebs and stringers; medium to coarsely crystalline, hard. Polyhalite content <5%.	
						46.7'-50.3' **ARGILLACEOUS HALITE:** clear to moderate reddish-orange (10R 6/6) mixed with moderate reddish-brown (10R 4/6), fine to coarsely crystalline, moderately hard. Argillaceous content typically < 3% but >5% from 46.7' to 47.8'; color of core through this interval mottled dark reddish brown (10R 3/4). Zone of fine crystalline halite mixed with argillaceous material from 49.7' to 50.0'. Clay breaks/partings from 49.1' to 49.2'.	Total Penetration = 51.8'
11	50	5.2	100	—	X		Hole completed at 5:30 p.m. on 21 March 1983.

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-88 INSTRUMENT TYPE & NUMBER Extensometer GE-212 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1305.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10952.8, E6396.5 BOREHOLE PENETRATION 52.7'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	100	–		See Above	
5	20	5.2	100	–		19.3' - 24.1' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4), medium to coarsely crystalline, hard. Trace of polyhalite. Anhydrite stringers at 23.4', 24.0' to 24.1' and scattered traces of anhydrite from 21.5' to 22.2'. Clay partings from 23.9' to 24.1'; clay breaks throughout. Clay content <3 to >5%.	
4	15	4.8	100	–		14.8' - 19.3' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6), medium to coarsely crystalline, hard. Blebs and irregular patches of polyhalite, up to 5%. Scattered anhydrite stringers from 15.4' to 16.6'.	
						14.3' - 14.8' **ANHYDRITE:** (Anhydrite "a") very light (N7) to medium gray (N5), micro-crystalline, hard. Trace of gray clay at 14.3'.	Gas hit again while drilling Anhydrite "a" (14.3' to 14.8'); 3 to 4% methane at end of return line. Strong flow to 15'± then slowed appreciably.
						13.4' - 14.3' **HALITE:** clear to dark reddish brown (10R 3/4), fine to medium crystalline, hard. Contains trace of brown and gray clay, locally up to 3%.	
3	10	5.3	100	–		7.55' - 13.4' **HALITE:** clear, medium to coarsely crystalline, hard, trace of polyhalite (<1%).	
						7.33' - 7.55' **ANHYDRITE:** (Anhydrite "b") very light (N7) to medium gray (N5), micro-crystalline, hard. Contains scattered polyhalitic halite. Gray clay parting at 7.33'.	Gas hit at 7.33'. 2% to 4% methane at end of return line. Moderate to strong gas flow for 3 to 4 minutes, decreasing to light flow with 1 1/2% methane. Gas gave off foul odor.
2		1.5	100	–		6.25' - 7.33' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2), fine to medium crystalline, hard. Contains brown and gray clay, up to 5%. Clay breaks at 6.3', 7.2', and 7.25'.	Drilled in low gear entire hole to minimize rod vibration.
1	5	5.3	100	–		4.7' - 6.25' **HALITE:** brownish-gray (5YR 4/1) to medium gray (N5), medium to coarsely crystalline, hard. Trace of gray clay scattered throughout.	NX double-tube core barrel used from 0.95' to 52.70'.
						0.0' - 4.7' **HALITE:** clear to moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Contains trace (<1%) polyhalite blebs. Slightly more polyhalite from 0.0' to 1.4'.	Drilling begun: 4 April 1983 at 11:00 a.m. 5 1/2" diameter single-tube core barrel used to core from 0.0' to 0.95'.
0	0	0.9	100	–			

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-88 INSTRUMENT TYPE & NUMBER Extensometer GE-212 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1305.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10952.8, E6396.5 BOREHOLE PENETRATION 52.7'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4-14-83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4.4	100	—		46.0' - 49.8' **ARGILLACEOUS HALITE:** clear to dark reddish-brown (10R 3/4), fine to coarsely crystalline, moderately hard. Brown argillaceous material generally <1% up to 5%. Clay seams and soft clay/halite mixture (clay >50%) from 47.6' to 47.7' and 49.5' to 49.8'. Scattered clay breaks throughout.	
10	45	5.0	100	—	X	41.8' - 46.0' **HALITE:** clear to grayish-brown (5YR 3/2) to moderate reddish-brown (10R 4/6) and dark reddish-brown (10R 3/4) fine to coarsely crystalline, hard. Predominantly brown argillaceous material <1% with >5% locally. Argillaceous halite from 41.8' to 42.7' and 43.8' to 44.6'. Brown clay partings from 44.0' to 44.2' and clay breaks at 44.2' to 46.0'. Trace of polyhalite.	
9	40	5.0	100	—		37.15' - 41.8' **HALITE:** clear with moderate reddish-orange (10R 6/8) blebs and irregular stringers of polyhalite. Coarsely crystalline, hard. Polyhalite <1% to 2%. Trace of argillaceous material (<1%) from 41.1' to 41.8'. Scattered irregular anhydrite stringers from 38.0' to 41.8'.	
8	35	5.2	100	—	X	36.3' - 37.15' **ANHYDRITE:** (Marker Bed 138) very light (N8) to medium gray (N6), micro-crystalline, hard. Trace (<1%) polyhalite.	
					X	35.5' - 36.3' **HALITE:** clear, coarsely crystalline, moderately hard. Trace of polyhalite blebs and trace of clay (<1%) from 36.1'. Brown clay parting at 36.3'.	
						31.9' - 35.5' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) coarsely crystalline, moderately hard. Generally 1 to 3% brown clay with some gray, but locally >5% clay. Clay breaks throughout.	
7	30	5.0	100	—		29.6' - 31.9' **HALITE:** clear, coarsely crystalline, hard. Trace (<1%) argillaceous material from 31.1'.	
						27.2' - 29.6' **ARGILLACEOUS HALITE:** dark reddish-brown (10R 3/4) to brownish-gray (5YR 4/1). Fine to medium crystalline, hard. Numerous clay breaks. Clay content <2 to >5%. Predominantly brown clay to 29.1', then mixed brown & gray.	
6	25	5.0	100	—	X	24.1' - 27.2' **HALITE:** clear, coarsely crystalline, hard. Slight trace of polyhalite. Anhydrite stringers from 24.3' to 25.0', and 25.8' to 25.85'.	

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-88 INSTRUMENT TYPE & NUMBER Extensometer GE-212 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs

STATION N1265, W497.5 COLLAR ELEV. 1305.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10952.8, E6396.5 BOREHOLE PENETRATION 52.7

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
11	50	4.4	100	–	X X X X	50.55' - 52.70' **POLYHALITIC HALITE:** clear mottled with moderate reddish-orange polyhalite, coarsely crystalline, hard. Polyhalite <1% to 5%. Brown clay breaks from 50.55' to 50.75'. 49.8' - 50.55' **HALITE:** clear, coarsely crystalline, hard.	Drilling completed: 5 April 1983 at 1:10 p.m. Total Drilling Time: 8 hrs Total Penetration = 52.70'

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-90 INSTRUMENT TYPE & NUMBER Extensometer GE-210 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10952.6, E6396.4 DEPTH OF BOREHOLE 53.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0	0	0.85	100	–	X	0.0' – 1.8' **HALITE:** clear, coarsely crystalline, hard. Trace (<1%) polyhalite.	Started drilling 5 April 1983 at 1:50 p.m. 5 1/2" diameter single-tube core barrel used to drill 0.0' – 0.85'.
1		1.3	100	–	X X	1.8' – 2.65' **POLYHALITIC HALITE:** clear, mottled with moderate reddish-orange (10R 6/6), coarsely crystalline, hard. Blebs of polyhalite <1% to 5%. Trace of anhydrite from 2.25' to 2.65'.	
2		1.35	100	–			
3		0.95	100				
4	5	0.90	82	–		2.65' – 4.45' **POLYHALITE:** moderate reddish brown (10R 4/6) polyhalite mixed with very light gray (N8) anhydrite. Fine to micro-crystalline, hard, dense.	NX single-tube core barrel used from 0.85' – 5.55'.
5		5.2	100	–	X –	4.45' – 5.7' **ANHYDRITE:** (Marker Bed 139) very light (N8) to medium gray (N6), micro-crystalline, hard, dense. Mixed with some polyhalite to 5'. Gray clay seam at 5.7'.	
					– X		
					X –		
	10				X X	5.7' – 9.25' **HALITE:** clear with scattered moderate reddish-orange (10R 6/6) medium crystalline, hard. Scattered polyhalite (<1%) and trace (<1%) gray clay.	
6		5.3	100	–	X	9.25' – 21.35' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) and grayish-brown (5YR 4/1), medium to coarsely crystalline, hard. Irregular patches and blebs of polyhalite 1% to 5%, locally >10%. Gray clay 1% to 2% from 13.7' to 16.0' and 20.35' to 21.35'.	
					X X		
					X –		
	15				X –		
					X –		
7		5.3	100	–	X		
					X X		
					X		
	20				X –		
					X –		
8		5.3	100	–	X –	21.35' – 25.75' **HALITE:** clear to grayish-red (5R 4/2) medium to coarsely crystalline, moderately hard. Trace of polyhalite. 1% to 2% gray clay with lesser amounts of brown clay.	
	25				– X		

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WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-90 INSTRUMENT TYPE & NUMBER Extensometer GE-210 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10952.6, E6396.4 DEPTH OF BOREHOLE 53.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.3	100	—		See Above	
9	30	5.2	100	—		25.75' - 31.95' **POLYHALITIC HALITE:** clear mottled with moderate reddish-orange (10R 6/6), coarsely crystalline, hard. 1% to 5% polyhalite. Scattered irregular blebs and stringers of very light gray (N8) anhydrite from 27.05' to 31.95', one-half inch wide irregular anhydrite seam at 31.0'.	
						31.95' - 32.10' **ANHYDRITE:** very light gray (N8) to medium gray (N6), microcrystalline, hard, dense. Trace of gray clay at 32.1'.	
10	35	5.1	100	—		32.10' - 39.5' **HALITE:** clear to medium gray (N6), fine to coarsely crystalline, hard. Contains trace (<1%) polyhalite locally. Breaks and patches of gray clay <1% to 3%. Core clear with no argillaceous material from 36.65' to 37.05' and from 39.0' to 39.5'.	
11	40	5.2	100	—		39.5' - 43.65' **ARGILLACEOUS HALITE:** clear to brownish-gray (5YR 4/1) medium to coarsely crystalline, moderately hard to hard. Contains <1% to 5% clay (average 2%), predominantly gray in color with lesser amounts of brown. Clay breaks throughout. Trace of polyhalite (<1%).	
12	45	5.25	100	—		43.65' - 49.50' **HALITE:** clear, coarsely crystalline, moderately hard. Trace of gray clay (<1%). Trace polyhalite from 44.45' to 44.65'.	
13	50	5.3	100	—		See below	

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-90 INSTRUMENT TYPE & NUMBER Extensometer GE-210 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10952.6, E6396.4 DEPTH OF BOREHOLE 53.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (FT)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	5.3	100	—	X —	49.50' - 52.10' **HALITE:** clear to moderate reddish-orange (10R 6/6) and brownish-gray (5YR 4/1). Contains trace of polyhalite (<1%) and <1% to 3% gray clay. Clay parting at 49.5' and scattered breaks within core.	
14		0.9	100	—	— X	52.10' - 53.6' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6), medium to coarsely crystalline, hard. Polyhalite 1% to 3%. Trace (<1%) of gray clay.	Drilling completed 7 April 1983 at 11:10 a.m. Total drilling time: 5.5 hours. Total Depth = 53.60'
	55						

M

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-91 INSTRUMENT TYPE & NUMBER Extensometer GE-209 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Station N1275, in Floor 16.5' From E and W Ribs.

STATION N1275, W630.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10961.5, E6263.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0	0	1.0	100	—	X	0.0' - 2.1' **HALITE:** Clear, coarsely crystalline, medium hard. Contains <1% polyhalite blebs and trace (<1%) gray clay.	Drilling started at 15:05 hours, 28 April 1983.
1		0.6	50	—	—		
2		0.7	100	—	X — X	2.1' - 3.8' **POLYHALITIC HALITE:** Clear mottled with moderate reddish orange (10R 6/6) polyhalite. Polyhalite <1 to 5%. Trace (<1%) gray clay.	5 1/2" single tube barrel used 0.0' to 1.0'. NX single tube barrel used 1.0' to 5.2'. NX double tube barrel used 5.2' to 51.8'.
3		1.75	76	—	X	3.8' - 4.8' **POLYHALITE:** Moderate reddish brown (10R 4/6), very fine to microcrystalline, hard. Trace of anhydrite.	
4	5	1.75	100	—	X X X	4.8' - 7.2' **ANHYDRITE:** (Marker Bed 139) Very light gray (N8), medium gray (N5) to moderate reddish brown (10R 4/6) and moderate reddish orange (10R 6/6) to approximately 6.5', with about 50% polyhalite. Then predominantly very light to medium gray anhydrite mixed with some polyhalite and polyhalitic halite. <1/8" gray clay parting at 7.2'. Core broken into disc-like pieces 5.2' to 6.2'.	Note: Run #3 originally drilled to 4.5'±. Core stayed in hole after pulling barrel. Had to redrill to 5.2' and retrieve core.
5		4.6	100	—	— — —		Run #6 - core stayed in hole after barrel pulled. Had to return barrel, drill and pull core.
	10				X X —	7.2' - 11.6' **HALITE:** Clear to moderate reddish orange (10R 6/6) to light gray (N7), fine to coarsely crystalline, medium hard. Contains <1% gray clay with up to 5% gray clay locally. Polyhalite <1% to 2%. Polyhalitic halite at 10.0' to 10.3'. Clay break at 7.7'.	Small gas flow at 7'±. Low flow. No methane. Very slight flow continued until entire hole was drilled.
6		5.2	100	—	X X	11.6' - 15.3' **POLYHALITIC HALITE:** Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline, medium hard to hard. Polyhalite 3% to >5%. Gray clay breaks at 14.9' and 15.0'. Irregular anhydrite stringers throughout.	Core Loss: Run 1, Throughout Run 3, Probably from 2.9' to 3.8'.
	15				X —	15.3' - 16.8' **HALITE:** Clear to light gray (N7) to moderate reddish orange (10R 6/6), medium to coarsely crystalline, medium hard. Polyhalite <1% to 2%. Gray clay <2%.	
7		5.0	100	—	X X X X —	16.8' - 23.2' **POLYHALITIC HALITE:** Clear to moderate reddish orange (10R 6/6), coarsely crystalline, hard. Polyhalite average <1 to 3%, locally up to 5%. Trace gray clay at 20.8' to 23.2'. Scattered clay breaks.	
	20				— X X —		
8		5.1	100	—	— X	23.2' - 25.4' **HALITE:** Clear, coarsely crystalline, hard. Trace (<1%) polyhalite and trace gray clay. Clay break at 23.7'.	
	25						

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-91 INSTRUMENT TYPE & NUMBER Extensometer GE-209 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Station N1275, in Floor 16.5' From E and W Ribs.

STATION N1275, W630.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10961.5, E6263.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
						As Above	
8	25	5.1	100	—			
9	30	4.9	100	—		25.4' - 31.8' **POLYHALITIC HALITE:** Clear to moderate reddish orange (10R 6/6) on moderate reddish brown (10R 4/6), coarsely crystalline, hard. Trace (<1%) gray clay. Polyhalite blebs and patches <1 to <5%, locally >5%. Scattered irregular anhydrite stringers from 27.2'. Polyhalite > 90% from 31.6' to 31.8'.	
						31.8' - 32.1' **ANHYDRITE:** Very light (N8) to medium gray (N5), microcrystalline, hard. Mixed with some halite from 31.8'. Trace of clay at 32.1'.	
10	35	4.9	100	—		32.1' - 39.7' **HALITE:** Clear to medium gray (N5) to grayish red (10R 4/2), medium to coarsely crystalline, medium hard. Gray clay <1 to 3%. Trace (<1%) polyhalite. Core broken up at 37.2' to 37.3'.	
11	40	5.1	100	—		39.7' - 41.8' ***ARGILLACEOUS HALITE:*** Clear to medium gray (N5), medium to coarsely crystalline, medium hard to soft. Some core can be broken in hand with low pressure. Gray clay 1 to 5%. Core broken up at 41.5' to 41.6'.	
12	45	5.1	100	—		41.8' - 44.4' **POLYHALITIC HALITE:** Clear to moderate reddish orange (10R 6/6), coarsely crystalline, medium hard. Polyhalite blebs and patches <1 to 5%. Trace of gray clay at 43.3'.	
13	50	4.9	100	—		44.4' - 49.3' **HALITE:** Clear, coarsely crystalline, medium hard to hard. Trace (<1%) gray clay. Core broken up with trace of clay at 45.5' - 45.8'. Clay parting at 49.3' with up to 3% clay at 48.9' to 49.3'.	M
						As Below	

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-91 INSTRUMENT TYPE & NUMBER Extensometer GE-209 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Stations N1275, in Floor 16.5' From E and W Ribs.

STATION N1275, W630.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10961.5, E6263.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	4.9	100	—	— X	49.3' – 51.8' HALITE: Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline, medium hard. Trace (<1%) gray clay. Polyhalite <1 to 3% dispersed throughout.	Hole completed at 14:50 hours, 29 April 1983. Total depth = 51.8'.
	55						

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-93 INSTRUMENT TYPE & NUMBER Extensometer GE-207 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Station N1275, in Roof 16.5 Feet From East and West Ribs

STATION N1275, W630.5 COLLAR ELEV. 1304.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10961.1, E6263.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
						As Above	
6	25	5.2	100	—		18.9' - 24.0' **ARGILLACEOUS HALITE:** Clear to dark reddish brown (10R 3/4) medium to coarsely crystalline, medium hard. Scattered traces of anhydrite. 1/4" layer anhydrite at 23.9'. Brown clay <1 to >5%. Scattered clay breaks. Parting at 23.9'.	
5	20	5.0	100	—	X X	14.9' - 18.9' **POLYHALITIC HALITE:** Clear mottled with medium reddish orange (10R 6/6) and medium reddish brown (10R 4/6) coarsely crystalline, hard. Scattered white anhydrite stringers to 16.4'. Polyhalite blebs and irregular patches average 1 to 5% with locally >10% from 14.9' to 16.7'.	
4	15	5.1	100	—	X X X X	14.2' - 14.9' **ANHYDRITE:** (Anhydrite "a") Very light (N8) to medium gray (N5), microcrystalline, hard. Some laminations noted. Some very finely crystalline halite mixed with anhydrite.	
					X	13.3' - 14.2' **ARGILLACEOUS HALITE:** Clear to medium reddish orange (10R 6/6) and dark reddish brown (10R 3/4), fine to medium crystalline, medium hard to hard. Brown clay <1 to >5%. Trace (<1%) polyhalite. Trace gray clay at 14.2'.	
3	10	4.9	97	—	X	7.3' - 13.3' **HALITE:** Clear, coarsely crystalline, hard. Scattered white anhydrite stringers. 1/8" anhydrite layer at 7.7'. Trace (<1%) polyhalite.	Drilling begun at 11:00 hours, 27 April 1983. Core loss: Run #1, Throughout #3, Throughout #8, Throughout
						7.15' - 7.3' **ANHYDRITE:** (Anhydrite "b") Medium light (N6) to medium gray (N5), microcrystalline, hard.	Moderate gas flow at 7'±. Flow for 5-10 minutes, H_2S - 0% and methane 1 to 3 1/2% measured at end of return line. Slight smell to gas. Low flow of gas to 16'±. No H_2S recorded.
2	5	4.95	100	—	X	4.05' - 7.15' **HALITE:** Clear to medium brown (5YR 4/4) to medium gray (N5), medium to coarsely crystalline, medium hard. Trace (1 to 2%) brown and gray clay. Breaks at 6.6' and 7.1'. Trace clay at 7.2'.	5 1/2" single tube barrel used to core 0.0' to 1.0'.
.1		0.65	81	—	X	0.0' - 4.05' **HALITE:** Clear with some grayish red (5R 4/2), coarsely crystalline, medium to medium hard. Trace (<1%) polyhalite blebs and clay.	NX single tube barrel used 1.0' to 1.8'. NX double tube barrel used 1.8' to 52.0'.
0	0	1.0	100	—	X		

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-93 INSTRUMENT TYPE & NUMBER Extensometer GE-207 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Stations N1275, in Roof 16.5 Feet From E and W Ribs

STATION N1275, W630.5 COLLAR ELEV. 1304.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10961.1, E6263.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 2 OF 3

As Above

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4.8	100	–		45.9' – 49.8' **ARGILLACEOUS HALITE:** Clear to medium brown (5YR 3/4), medium to coarsely crystalline, medium hard. Brown clay <1 to >5%. Clay breaks at 47.2', 47.4', 47.7', 48.3', 48.5', 48.9' and 49.3' to 49.4'. 3/4" clay seam at 49.7'.	
10	45	5.1	100	–	X	41.3' – 45.9' **HALITE:** Clear to dark reddish brown (10R 3/4), medium to coarsely crystalline, medium hard to hard. Trace polyhalite. Brown clay averages 1% with local zones >5%. Clay breaks at 41.9' and 43.7'. Argillaceous halite at 41.9' to 42.1', 42.4' to 43.0' and 44.1' to 44.3'.	
9	40	5.1	100	–	X X	37.0' – 41.3' **HALITE:** Clear, coarsely crystalline, hard. Scattered white anhydrite stringers. Trace (<1%) moderate reddish orange polyhalite blebs from 39.4' to 41.3'.	
						36.3' – 37.0' **ANHYDRITE:** (Marker Bed 138) Very light (N8) to medium gray (N5), microcrystalline, hard. Some <20% halite mixed with anhydrite 36.4' to 36.6'. Brown clay seam 36.3' to 36.4'.	
8	35	5.0	100	–	X	35.5' – 36.3' **HALITE:** Clear to medium reddish orange (10R 6/6), fine to medium crystalline, some coarse, medium hard. Trace polyhalite (<1%) and trace brown clay.	
						32.3' – 35.5' **ARGILLACEOUS HALITE:** Clear to medium brown (5YR 3/4), fine to medium crystalline, with some coarse. Soft to medium hardness. Core broken up approximately 32.6' to 33.2'. Brown clay generally 5 to 10% with zones <1%. Argillaceous >40% at 34.5' to 34.8'.	Can be combined in hand with low to moderate pressure due to grain size and clay content.
7	30	4.8	100	–	X	29.7' – 32.3' **HALITE:** Clear, coarsely crystalline, medium hard to hard. Trace (<1%) brown clay from 31.6'.	
						27.5' – 29.7' **HALITE:** Clear to medium brown (5YR 3/4) fine to coarsely crystalline, medium hard. Brown argillaceous <1 to 4%. Clay break at 27.6'. Trace (<1%) polyhalite from 29.2'-29.6'. Core medium reddish orange.	
6	25	5.2	100	–		24.0' – 27.5' **HALITE:** Clear, coarsely crystalline, hard. Few scattered white anhydrite stringers to 26.0'.	

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WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-93 INSTRUMENT TYPE & NUMBER Extensometer GE-207 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Stations N1275, in Roof 16.5 Feet From E and W Ribs

STATION N1275, W630.5 COLLAR ELEV. 1304.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10961.1, E6263.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEC DATE 5/5/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
11	50	4.8	100	–	X X	49.8' – 52.0' HALITE: Clear to medium reddish orange (10R 6/6). Coarsely crystalline, hard. Polyhalite blebs and patches <1 to 4%. Highest percentage is from 49.8' to 51.0'. A few scattered anhydrite stringers and blebs from 51.0' to 52.0'.	Hole completed at 11:15 hours, 28 April 1983. Total penetration = 52.0'.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-201 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1262.2' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9280.6, E6874.9 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JBM,RFM,RLB/TSC//DGK,RMB/Bechtel DATE 1/25/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.0	100	–		20.3' – 25.4' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, ~1% polyhalite, 1-5% brown and gray (mostly brown) clay, 5-10% polyhalite from 24.3'-24.5', anhydrite/clay zone 25.3'-25.4'.	
7	20	4.9	98	–		15.5' – 20.3' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 1-5% polyhalite, few blebs of clay, anhydrite stringers (<1/16") at 16.1', 16.3', 17.8', and 18.1'.	
6	15	4.6	92	–		14.8' – 15.5' **ANHYDRITE:** (Anhydrite "a") light to very light gray (N7-8), microcrystalline anhydrite, 20-30% halite in upper 0.1', trace polyhalite near upper contact. 14.0' – 14.8' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, 1-2% polyhalite, ~1% gray clay, 1-5% brown clay, gray clay parting at 14.8'.	
5	10	2.0	100	–		7.9' – 14.0' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 0-1% polyhalite, clay absent below 13.5', ~1% gray clay from 13.5'-14.0', anhydrite stringers (~1/16") at 9.5' and 9.8'.	
4	5	4.3	86	–		7.7' – 7.9' **ANHYDRITE:** (Anhydrite "b") light to very light gray (N7-8), microcrystalline anhydrite, 30-40% halite. 0.0' – 7.7' **HALITE:** clear to mottled colorless and moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 2% polyhalite, <1% gray clay, brown clay absent to 4.0', 1-2% from 4.0'-7.7', light gray (N7) clay seam at 7.7'.	
3		1.5	79	–			
2		1.15	96	–			Hole begun 23 November 1982.
1		.55	92	–			0' – 0.85' drilled with 6" single-tube core barrel.
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WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-201 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1262.2' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9280.6, E6874.9 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JBM,RFM,RLB/TSC//DGK,RMB/Bechtel DATE 1/25/83

SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	50					(see description on next sheet)	
13		5.0	100	–		46.3' – 49.4' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1-3% polyhalite, locally in blebs, <1% clay.	
12	45	5.0	96	–		44.4' – 46.3' **HALITE:** colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, ~1% polyhalite, 1-5% brown clay, brown clay break at 44.8'.	
						38.9' – 44.4' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1-7% polyhalite, 0-1% clay, anhydrite stringers at 39.0', 39.3', and 40.0'.	
11	40	5.0	100	–		38.3' – 38.9' **ANHYDRITE:** (Marker Bed 138) medium to light gray (N5-7), microcrystalline anhydrite, 10-20% halite in upper 0.05'.	
						33.2' – 38.3' **ARGILLACEOUS HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, <1% polyhalite, 1-10% brown clay locally concentrated, brown clay parting at 37.1', brown clay seam at 38.3'.	
10	35	5.0	100	–		31.4' – 33.2' **HALITE:** clear halite, coarsely crystalline, <1% polyhalite, <1% brown and gray clay.	
9	30	4.6	92	–		29.4' – 31.4' **ARGILLACEOUS HALITE:** colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, <1% polyhalite, 1-5% clay (mostly brown), anhydrite stringer (<1/16") at 31.4'.	
						25.4' – 29.4' **HALITE:** clear halite, medium to coarsely crystalline, <1% polyhalite, <1% brown and gray clay from 29.3'-29.4', absent elsewhere, anhydrite stringers at 25.6'-25.7', 26.0', and 26.6'.	
8	25	5.0	100	–		(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-201 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1262.2' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9280.6, E6874.9 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JBM,RFM,RLB/TSC//DGK,RMB/Bechtel DATE 1/25/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
13	50	50	100	—	— X	49.4' - 51.7' **ARGILLACEOUS HALITE:** colorless to moderate brown (5YR 4/6) halite, coarsely crystalline, 1-2% polyhalite, 1-5% brown clay to 50.7', 5-10% from 50.7'-51.7', brown clay breaks at 49.7', 50.6', 51.1', and 51.7'.	Total penetration = 51.7'. Hole finished at 13:30 hours, 24 November 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-202 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1248.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9280.6, E6874.9 DEPTH OF BOREHOLE 51.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 11/24/82

SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	14	70	—		**0.0' - 3.7'** **HALITE:** clear, medium to coarsely crystalline halite, with trace (<1%) polyhalite, and trace (<0.5%) gray clay blebs from 0'-2.0'.	Drilling started 14:00 hours, 24 November 1982. Coring with brine.
2	5	45	90	—		**3.7' - 4.8'** **POLYHALITIC HALITE:** moderate reddish-orange (10R 5/6), translucent, coarsely crystalline, medium hard halite. Gradational lower contact. Clay parting at 4.5' (washed out by drilling).	Core Run #1 - broken in small pieces and partially dissolved. Longest piece = 0.2'.
						4.8' - 7.6' **ANHYDRITE:** (Marker Bed 139) light gray (N7) hard, dense, very thinly bedded to laminated anhydrite. Core is broken "poker-chip" fashion along bedding. Medium light gray (N6), moderately stiff, anhydritic clay seam (~1/2") at 7.6'.	
3	10	4.9	98	—		**7.6' - 11.5'** **ARGILLACEOUS HALITE:** moderate reddish-orange (10R 6/6) translucent, medium crystalline halite, with some polyhalite (10-20%), some to abundant (about 25-30%) clay, and localized trace light gray (N7) clay blebs. Clay break at 7.8'. Clay parting at 11.1'.	Hit pressurized gas around 10'-12'. Drilling fluid bubbled at collar.
4	15	4.9	98	—		**11.5' - 24.3'** **POLYHALITIC HALITE:** clear, coarsely crystalline halite, with 35-40% polyhalite. Polyhalite bands at 13.1', 14.4', 21.8'. Relatively clear halite from 11.5'-12.1' and 15.5'-17.0' with some (10-15%) clay.	Drilling stopped at 16:00 hours and 12.0' 24 November 1982 for Thanksgiving Holiday. Resumed coring at 08:20 hours, 26 November 1982.
5	20	5.1	100	—		Argillaceous zone at 15.7'-15.85' Gray clay parting at 15.95' Gray clay break at 16.55' Brown clay break at 16.7' Argillaceous zone at 17.5' Gray clay break at 22.6' Gray clay parting at 23.0' Gray argillaceous zone (30-40% clay) at 23.1'-23.3'.	From 12' to 32', drilling averaged 0.2 ft./min.
6	25	5.1	100	—		(see description on next sheet)	Run 6 - longest piece = 1.3'.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-202 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1248.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9280.6, E6874.9 DEPTH OF BOREHOLE 51.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 11/24/82 SHEET 2 OF 3

RUN NUMBER	DEPTH (ft)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	100	—		24.3' - 28.0' **ARGILLACEOUS HALITE:** halite, with 20-25% clay, and 15-20% polyhalite. Gray-brown argillaceous zone at 24.4'-26.4', with clay breaks at 24.7', 25.1', 25.4', 25.6', 26.3'.	
7	30	5.2	100	—		28.0' - 34.6' **POLYHALITIC HALITE:** moderate reddish-orange (10R 6/6), translucent, medium crystalline halite, with 1% to 20% polyhalite, and localized trace gray clay blebs. Clear halite at 31.2'-31.7', 32.6'-32.7', and 33.8'-34.6'. Polyhalite bands at 33.6'-33.8' and 34.2'.	
8	35	5.0	100	—		34.6' - 35.0' **ANHYDRITE:** light gray (N7), hard, dense, halitic anhydrite. Gray clay parting at 35.0'.	Run 8 - Longest piece = 1.1'; average = 0.3'.
9	40	4.9	100	—		35.0' - 49.0' **ARGILLACEOUS HALITE:** translucent, finely to medium crystalline, medium hard halite, mottled light brown with some (10%) moderate reddish-orange (10R 6/6) polyhalite, and some (10-15%) light gray (N7) and moderate brown (5YR 3/4) clay as blebs. Clay breaks at 38.9', 39.2' (gray), 40.7' (gray), 41.1' (gray), 42.5' (gray), 42.7' (brown), 43.6' (brown), 43.7' (brown), 44.3' (brown), brown clay parting at 43.2', and trace polyhalite from 43.2' to 44.8'.	
10	45	5.0	100	—			M
11	50	4.1	100	—		49.0' - 51.4' **HALITE:** clear halite, moderately hard and coarsely crystalline.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-202 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1248.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9280.6, E6874.9 DEPTH OF BOREHOLE 51.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 11/24/82 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4 1	100	—		(as above)	Run 11 - pulled at 12:30 hours, 26 November 1982. Total depth = 51.4'.
	55						

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WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-203 INSTRUMENT TYPE & NUMBER Extensometer GE-235 HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline, 6.8' from W rib

STATION N624, E140 COLLAR ELEV. 1298.2 DIRECTION OF DRILLING vertical up

MINE COORDINATES N10308.6, E7041.7 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/23/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.2	100	–		*(see description on next sheet)*	Began coring at 10:15 hours on 23 February 1983. Cored from 0'-1.0' using 6" single tube barrel. Cored from 1.0'-5.8' without inner core tube.
5	20	5.1	100	–		20.6'-24.0' **HALITE:** argillaceous, clear to pale brown (5YR 5/2) and medium gray (N5), finely to coarsely crystalline, moderately hard. Clay content 0-5% and occurs interstitially. Clay breaks at 20.8', 22.2', 22.7', 23.4', and 23.9'. Irregular light gray (N7) anhydrite seam (1/2") at 24.0'.	
					X	15.0'-20.6' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite occurs as blebs and stringers and represents 0-5% of core. Clear halite from 19.8'-20.6'.	Core loss in Run #1 occurred throughout core run.
4	15	5.2	100	–	X	14.2'-15.0' **ANHYDRITE:** medium gray (N5) to very light gray (N8), hard, dense, microcrystalline.	
					X	13.1'-14.2' **HALITE:** argillaceous, mottled light brownish-gray (5YR 6/1) and pale yellowish brown (10YR 6/2), finely crystalline, moderately hard. Clay content 3-8%. Brown clay breaks at 13.5' and 14.2'.	Encountered trace of gas at 14.5'.
3		2.0	100	–	X	8.2'-13.1' **HALITE:** clear, medium to coarsely crystalline, moderately hard, trace of scattered blebs of orange polyhalite. Few hairline stringers of white (N9) anhydrite.	
2	10	5.2	100	–	X	8.0'-8.2' **ANHYDRITE:** medium gray (N5), hard, dense, microcrystalline.	
						5.5'-8.0' **HALITE:** argillaceous, clear to pale yellowish-brown (10YR 6/2) to brownish-gray (5YR 4/1). Finely to medium crystalline, moderately hard. Interstitial clay comprises 2-10% of core. Brown clay breaks at: 6.9', 7.1', 7.3'. Thin parting of gray clay at 8.0'.	
1	5	1.7	35	–	X	0.0'-5.5' **HALITE:** clear with trace of moderate reddish-orange (10R 6/6) polyhalite. Coarsely crystalline, moderately hard. Few isolated blebs of polyhalite.	
0	0	.9	90	–	X		

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-203 INSTRUMENT TYPE & NUMBER Extensometer GE-235 HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline, 6.8' from W rib

STATION N624, E140 COLLAR ELEV. 1298.2 DIRECTION OF DRILLING vertical up

MINE COORDINATES N10308.6, E7041.7 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/23/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	2.9	100	–			
10	45	5.2	100	–		42.4'-50.1' **ARGILLACEOUS HALITE:** clear and mottled pale brown (5YR 5/2), pale yellowish-brown (10 YR 6/2) and brownish-gray (5YR 4/1). Finely to coarsely crystalline, moderately hard. Clay content from 0 to 25% with brown clay breaks at: 42.5', 43.0', 45.3', 45.8', 46.2', 47.0', 47.2', 48.9', 49.3', and 49.6'. At 49.9', 1/2" thick, moist, brown clay seam.	
9	40	5.0	100	–		37.6'-42.4' **HALITE:** clear, medium to coarsely crystalline, moderately hard. Trace of moderate reddish-orange (10R 6/6) polyhalite stringers from 39.5'-42.0'.	
8	35	5.2	100	–		36.9'-37.6' **ANHYDRITE:** medium light gray (N6), very hard, dense, microcrystalline. Few clear halite stringers at 37.6'.	
						32.0'-36.9' **ARGILLACEOUS HALITE:** clear and mottled medium gray (N5), brownish-gray (5YR 4/1) and pale yellowish-brown (10YR 6/2). Finely to coarsely crystalline, moderately hard. Finely crystalline from 35.9'-36.9'. Clay content ranges from 0-15% with numerous discontinuous clay breaks throughout. Clay breaks at: 33.0', 33.5', 35.1', 35.6', 35.7'. At 36.9', 1/2" thick, grayish-brown (5YR 3/2) soft, moist clay seam.	
7	30	5.2	100	–		29.8'-32.0' **HALITE:** clear, coarsely crystalline, moderately hard.	
						28.2'-29.8' **ARGILLACEOUS HALITE:** clear and light brownish-gray (5YR 6/1), moderately hard, medium crystalline. Clay content ranges from 0 to 15% with clay breaks at: 29.0', 29.3' and 29.7'.	
6	25	5.2	100	–		24.0'-28.2' **HALITE:** clear, coarsely crystalline, moderately hard. Few scattered, white (N9) anhydrite stringers.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-203 INSTRUMENT TYPE & NUMBER Extensometer GE-235 HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline, 6.8' from W rib

STATION N624, E140 COLLAR ELEV. 1298.2 DIRECTION OF DRILLING vertical up

MINE COORDINATES N10308.6, E7041.7 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/23/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						Total Penetration = 52.0'
11	50	2.9	100	–	X	50.1'-52.0' HALITE: clear to moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Trace of orange polyhalite occurs as blebs and stringers	Hole completed at 19:00 hours on 23 February 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-204 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline 6.8' from W rib

STATION N640, E140 COLLAR ELEV. 1290.5 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10308.5, E7041.5 DEPTH OF BOREHOLE 51.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/24/83 SHEET 1 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	.7	35	–			Began coring at 18:45 hrs. on 23 February 1983. Cored from 0 to 0.3' with 6" single tube core barrel. Cored without inner tube from 0.3' to 6.4'.
2	5	1.9	46	–		0.0'-7.1' **HALITE:** argillaceous, clear and pale brown (5YR 5/2), coarsely crystalline, moderately hard. Interstitial brown clay content ranges from 0-3%. Clay breaks at: 3.0' and 5.0'.	
3	10	4.7	100	–		7.1'-8.9' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite occurs as scattered stringers and blebs and represents from 0-3% of core. Dense polyhalite seam (1/4") at 8.9'.	
4	15	5.0	100	–		8.9'-11.5' **ANHYDRITE:** very light gray (N8) to medium light gray (N6), hard to very hard, dense, microcrystalline. Core broken into 1/8"-1/4" chips throughout; slightly banded in part. 11.5'-11.6" **CLAY:** medium gray (N5), moist, soft, highly plastic. 11.6'-15.3' **HALITE:** argillaceous, clear and light gray (N7) to grayish orange-pink (5YR 7/2). Trace of polyhalite throughout. Medium to coarsely crystalline, moderately hard. Clay content ranges from 0 to 15% with gray clay breaks at: 11.7', 12.0', 13.0', 13.5', and 14.0'	Core Loss: Run — Where Lost 1 — Throughout Run 2 — Throughout Run 3 — 0.7' lost between 32.0' to 33.0'
5	20	5.1	100	–		15.3'-27.9' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6), and grayish-orange (10YR 7/4). Medium to coarsely crystalline, moderately hard, polyhalite content ranges from 0 to 20% locally and occurs interstitially and as isolated blebs and stringers. Trace of argillaceous halite from 19.0'-21.0'. Clay breaks at: 19.6', 19.7', and 20.0'.	
6	25	5.2	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. D0-204 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline 6.8' from W rib

STATION N640, E140 COLLAR ELEV. 1290.5 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10308.5, E7041.5 DEPTH OF BOREHOLE 51.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/24/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (')	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.2	100	–		(as above)	
7	30	4.9	100	–		27.9'-31.3' **HALITE:** argillaceous, clear and light gray (N7) to light brownish-gray (5YR 6/1), fine to medium crystalline, moderately hard. Clay content up to 5% with few isolated blebs of orange polyhalitic halite throughout. Gray clay breaks at 28.3', 30.0', and 31.1'.	
8	35	4.3	86	–		31.3'-37.2' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite occurs as dense stringers and isolated blebs and represents 0-10% of core. At 35.7', 1/2" thick, hard, dense polyhalite seam.	
9	40	5.2	100	–		37.2'-37.4' **ANHYDRITE:** medium light gray (N6), very hard, dense microcrystalline. At 37.4', medium gray (N5) clay parting.	
10	45	4.8	100	–		37.4'-49.8' **ARGILLACEOUS HALITE:** clear and mottled light gray (N7), to light brownish-gray (5YR 6/1) to pale yellowish-brown (10YR 6/2). Finely to coarsely crystalline, moderately hard. Clay content ranges from 0-25% with trace of interstitial orange polyhalite below 43.9'. Numerous brown and gray clay breaks throughout. Dominant clay breaks at: 37.6', 38.0', 40.1', 44.3', 45.4', 45.5', 45.7', 46.4', 47.0', and 48.9'.	
11	50	5.3	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-204 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline, 6.8' from W rib

STATION N640, E140 COLLAR ELEV. 1290.5 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10308.5, E7041.5 DEPTH OF BOREHOLE 51.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/24/83 SHEET 3 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.3	100	–	–	49.8'-51.6' HALITE: clear, coarsely crystalline, moderately hard, with trace gray clay in part.	Hole completed at 10:00 hours on 24 February 1983. Total Depth = 51.6'
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-205 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1316.5' DIRECTION OF DRILLING vertical up

MINE COORDINATES N11095, E6892 BOREHOLE PENETRATION 50.7'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/19/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	100	–		22.5'-31.5' **HALITE:** clear, coarsely crystalline, moderately hard, few isolated stringers of white (N9), anhydrite. At 22.7', 1/2" thick medium gray (N5) moist clay seam. From 27.5'-28.7', moderate brown (5YR 4/4), slightly argillaceous zone, medium crystalline. At 28.7' gray clay parting.	
5	20	5.2	100	–		17.4'-27.5' **HALITE:** argillaceous, clear to mottled dark gray (N4) to pale yellowish-brown (10YR 6/2). Finely to medium crystalline, moderately hard. Clay content ranges from 0 to 15%. Trace of orange polyhalitic halite from 19.3'-20.0'. Clay breaks at 18.3', 19.7', 20.0', 20.5', 21.0', 21.3', 21.9' and 22.3'.	
						13.5'-17.4' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), moderately hard, coarsely crystalline. Few very light gray (N8) hard, anhydrite stringers throughout. 1/8" thick anhydrite stringer at 14.7'. Polyhalite occurs interstitially and in isolated blebs in 5-8% of core.	
4	15	4.8	100	–		12.8'-13.5' **ANHYDRITE:** medium gray (N5) to very light gray (N8); hard, dense, microcrystalline, slightly banded in part. Moist, gray clay parting at 12.8'.	At 12.9' encountered gas. No detectable gas after 5 minutes.
3	10	3.0	97	–		6.3'-12.8' **HALITE:** clear, coarsely crystalline, moderately hard, few white (N9), hairline anhydrite stringers throughout. Trace polyhalite from 6.3'-7.1'. Finely crystalline above 12.0'. Trace of light gray (N7) interstitial clay above 12.0'. Gray clay breaks at 12.5' and 12.7'.	
						6.1'-6.3' **ANHYDRITE:** very light gray (N8), hard, dense, microcrystalline, broken into 1/8" chips. Soft, gray clay parting at 6.1'.	
2	5	3.0	97	–		0.0'-6.1' **HALITE:** argillaceous and polyhalitic in part. Clear to moderate reddish-orange (10R 6/6) to light brown (5 YR 6/4) to medium gray (N5). Finely to coarsely crystalline, moderately hard. Finely crystalline above 4.6'. Few gray clay breaks at 4.4', 5.4' and 5.9'. Clay and polyhalite represent from 0-3% of core.	Coring began at 09:00 hours on 18 February 1983.
1		2.0	100	–			Cored from 0'-1.0' with 6" core barrel. From 1.0'-6.1' cored without use of inner core barrel.
0	0	.9	90	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-205 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1316.5' DIRECTION OF DRILLING vertical up

MINE COORDINATES N11095, E6892 BOREHOLE PENETRATION 50.7'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/19/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4.1	100	-		46.1'-49.1' **ARGILLACEOUS HALITE:** clear to mottled brownish-gray (5YR 4/1) to medium light gray (N6) to moderate brown (5YR 3/4). Finely to coarsely crystalline, moderately hard. Numerous clay breaks and partings with clay composing 0-20% of core. Finely crystalline from 47.8'-48.9'. Brown clay breaks at 46.4', 46.7', 46.9', 47.4', 47.9', 48.0', 48.1', 48.5' and 48.7'. Clay partings at 46.8', 48.8' and 48.9'.	
10	45	5.0	100	-		43.1'-46.1' **HALITE:** clear, medium to coarsely crystalline, moderately hard, numerous blebs and stringers of very light gray (N7) anhydrite. Trace of orange polyhalite at 43.6'. Trace of brownish-gray (5YR 4/1) clay from 45.6'-45.8'.	
9	40	5.1	100	-		40.4'-43.1' **ARGILLACEOUS HALITE:** clear to mottled grayish-brown (5YR 3/2), pale yellowish-brown (10YR 6/2) and moderately reddish-orange (10R 6/6), finely to coarsely crystalline, moderately hard. Finely crystalline from 41.0'-43.0'. Clay content ranges from 0-15% with trace of interstitial polyhalite from 42.5'-43.0'. Clay breaks at 40.7', 40.8', 41.2', 41.4', 41.8', 42.0', 42.3' and 43.0'.	
8	35	5.1	100	-		36.2'-40.4' **HALITE:** clear, coarsely crystalline, moderately hard. Trace of polyhalite throughout. Some isolated stringers of very light gray (N8) anhydrite. 35.4'-36.2' **ANHYDRITE:** light gray (N7) to medium gray (N5), very hard, dense. 35.3'-35.4' **CLAY:** grayish brown (5YR 3/2), moist, firm to stiff, highly plastic, dense. Horizontal contact with anhydrite above.	
7	30	5.2	100	-		31.5'-35.3' **ARGILLACEOUS HALITE:** clear to pale yellowish-brown (10Y/R 6/2) and medium gray (N5), finely to coarsely crystalline, moderately hard, numerous brown clay breaks throughout; clay represents about 3-10% of core. Clay breaks at 31.5', 31.6', 32.9', 33.4', 33.6' and 34.0'.	
6	25	5.0	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-205 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1316.5' DIRECTION OF DRILLING vertical up

MINE COORDINATES N11095, E6892 BOREHOLE PENETRATION 50.7'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/19/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11		4.1	100	17	X	49.1'-50.7' **HALITE:** polyhalitic, clear and moderate reddish orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite comprises 0-3% of core and occurs as isolated blebs and stringers.	Total Penetration = 50.7' Completed hole at 15:00 hours on 18 February 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-206 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1308.0' DIRECTION OF DRILLING vertical down

MINE COORDINATES N11095, E6892 DEPTH OF BOREHOLE 50.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/22/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0–5	3.3	55	–		0.0'-9.5' **HALITE:** argillaceous and polyhalitic in part. Clear to moderate reddish-orange (10R 6/6) and light gray (N7), finely to coarsely crystalline, moderately hard. Interstitial clay composes up to 1% of core as does isolated blebs and stringers of orange polyhalite. Clear halite from 8.5'-9.5'.	Hole began at 09:30 hours on 21 February 1983. Cored from 0' to 6.0' without inner core barrel.
2	5–10	5.3	100	–			
3	10–15	1.7	55	–		9.5'-13.2' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite is interstitial and locally represents up to 25% of core. Hard polyhalite seam at 13.1'.	Core Loss: Run 1 Throughout Run; Run 3 11.3'-13.2'
						13.2'-14.4' **ANHYDRITE:** light gray (N7) to very light gray (N8), hard, dense, microcrystalline.	Encountered gas at 13.2'.
4	15–20	2.1	100			14.4'-20.6' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite ranges from 0-20% and occurs as blebs and stringers throughout. At 18.0', hard, dense, 1/4" thick polyhalite seam. Trace of clay from 19.5'-19.9' with 1/2" thick gray clay seam at 19.5'.	
5		5.0	100	–			
						20.6'-21.8' **HALITE:** argillaceous, clear and medium gray (N5), medium to coarsely crystalline, moderately hard. Clay content ranges from 0-5% and occurs interstitially. Gray clay breaks at 20.9', 21.1', 21.2' and 21.5'.	
6	20–25	5.2	100	–		(see description on next sheet)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-206 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1308.0' DIRECTION OF DRILLING vertical down

MINE COORDINATES N11095, E6892 DEPTH OF BOREHOLE 50.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/22/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.2	100	–		21.8'-27.3' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite comprises up to 25% of core in dense stringers and blebs with some interstitial halite. Trace of clay at 25.3' and 25.9' with gray clay parting at 25.3'.	
7	30	5.1	100	–		27.3'-30.9' **HALITE:** argillaceous and polyhalitic, clear and mottled medium gray (N5) to light gray (N7) to moderate reddish-orange (10R 6/6). Finely to medium crystalline, moderately hard. Gray clay represents 3-5% of core and orange polyhalite 1-2%. Clay and polyhalite occur interstitially throughout. Gray clay breaks at 27.3', 27.5', 27.8', 28.4', 29.5', 29.7', 30.0' and 30.7'.	
8	35	5.2	100	–		30.9'-35.9' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), medium crystalline, moderately hard. Polyhalite occurs interstitially and as isolated blebs and represents from 0-10% of core. 1/2" thick polyhalite seams at 35.4' and 35.8'.	
9	40	5.3	100	–		35.9'-36.9' **HALITE:** clear, medium to coarsely crystalline, moderately hard; very thin, hairline stringers of anhydrite at 36.5'.	
						36.9'-37.1' **ANHYDRITE:** light gray (N7), hard, dense, microcrystalline, with medium gray (N5) 1/8" thick, soft, moist, clay parting at 37.1'.	
10	45	5.3	100	–		37.1'-50.6' **HALITE:** argillaceous, clear to mottled brownish-gray (5YR 4/1), light gray (N7) and light brown (5YR 6/4). Medium to coarsely crystalline, moderately hard, trace polyhalitic halite from 45.2' to 46.3'. Clay content ranges from 0-15% and occurs interstitially. Clear halite from 37.5'-38.4', 41.0'-42.0', and 50.3'-50.6'. Gray or brown clay breaks at 38.9', 39.7', 44.3', 45.7', 46.0', 46.3', 46.4', 46.5', 47.3' and 49.0'.	M
11	50	3.0	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. D0-206 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1308.0' DIRECTION OF DRILLING vertical down

MINE COORDINATES N11095, E6892 DEPTH OF BOREHOLE 50.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/22/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11		3.0	100	–	– –		Total Depth = 50.6' Hole completed at 14:30 hours on 21 February 1983
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WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-229 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 401' S of Exploratory Shaft Centerline, 13.7' from E rib

STATION S 401, E 153 COLLAR ELEV. 1259.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N9287 E7049 BOREHOLE PENETRATION 50.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB/Bechtel DATE 3/4/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	4.0	80	–	X	(see description on next sheet) 20.8'-23.2' **ARGILLACEOUS HALITE:** (lower contact approximate) pale brown (5YR 5/2) to moderate brown (5YR 3/4), mottled, medium to coarsely crystalline, moderately hard. Contains 2-5% brown clay, trace only from 20.8'-21.5'. Contains several clay breaks.	Core Loss: Run 1 - at 1.4' Run 2 - throughout Run 6 - throughout Run 7 - intermittently between 16.4'-20.0' Run 8 - throughout
7	20	4.5	88	–	X	16.6'-20.8' **POLYHALITIC HALITE:** clear, mottled with moderate reddish-orange (10R 6/6) polyhalite, medium to coarsely crystalline. Polyhalite content varies from 1 to 5% and occurs as discrete blebs and stringers. Also contains 1-2% very light gray (N8), blebs and thin anhydrite stringers. Polyhalite absent from 18.6' to 19.3'.	
6	15	4.3	86	–	X	15.9'-16.6' **ANHYDRITE:** (Anhydrite "a") medium light gray (N6) to white, banded, microcrystalline, hard, dense. Trace of gray clay at 15.9'. 8.6-15.9' **HALITE:** clear, medium to coarsely crystalline, moderately hard. 8.7'-8.9': light gray anhydrite stringers and reddish-orange polyhalite blebs. Very thin light gray anhydrite stringers at 9.6'. 1/8" light gray anhydrite stringer at 10.4'. Light gray anhydrite bleb and small polyhalite blebs at 14.7' and at 15.5'-15.6'.	Stuffing box blown out of collar three times during Run #6, at approximately 12', 15', and 15.9'. Gas has high pressure but low volume. Flow lasted for about one minute in each case.
5	10	5.1	100	–	X	8.5'-8.6' **ANHYDRITE:** (Anhydrite "b") medium gray (N5), banded, hard, dense, microcrystalline. Trace of gray clay at 8.5'. 5.3'-8.5' **ARGILLACEOUS HALITE:** brownish-gray (5YR 4/1), medium crystalline, moderately hard. ≤2% clay from 5.3' to 6.8'. ±5% clay 6.8' to 8.5'. Brown clay breaks at 6.9', 7.1', 7.8', 7.9', 8.2', 8.3'.	Brief flow of gas at moderate pressure at 8.5'. Inner core barrel was used after 6.3'.
4		1.3	100	–			
3	5	2.4	100	–	X	0.0'-5.3' **HALITE:** clear to moderate reddish-orange (10R 6/6), locally light brownish-gray (5YR 6/1), medium to coarsely crystalline, moderately hard. Trace polyhalite blebs throughout. Argillaceous (±2%) from 0.0' to 0.5'.	Run #3 was dropped by drillers. Core was not necessarily boxed in order. Core Run #0 is a 5.5" diameter plug 1.0' long drilled out for stuffing box. Coring began at 10:00 hours, 2 March 1983.
2		0.6	50	–	X		
1		0.3	75	–			
0	0	1.0	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-229 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 401' S of Exploratory Shaft Centerline, 13.7' from E rib

STATION S 401, E 153 COLLAR ELEV. 1259.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N9287-E7049 BOREHOLE PENETRATION 50.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB/Bechtel DATE 3/4/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	50					(see description on next sheet)	
13		4.0	100	–		**45.2'-48.1' HALITE:** clear, mottled locally with moderate brown (5YR 3/4) clay, medium to coarsely crystalline, moderately hard. Clay content increases upward: trace brown clay 45.2'-47.0'; 2%± 47.0'-47.6'; 10%± with clay breaks 47.6'-48.0'. Trace polyhalite blebs 45.2'-47.0'.	
12	45	5.0	100	–		**40.4'-45.2' HALITE:** clear, mottled with moderate reddish-orange (10R 6/6) polyhalite, medium to coarsely crystalline, moderately hard. Contains 1-4% polyhalite as discrete blebs and stringers. Also contains trace very light gray anhydrite blebs.	
11	40	5.1	100	–		**39.9'-40.4' ANHYDRITE:** medium gray (N5), banded with very light gray (N8), microcrystalline, hard, dense. Underlain by 1/2" thick brown clay seam.	Hit strong flow of pressurized gas at about 38'. Flow continued at moderate rate until about 41.5' (approximate 5 minute duration).
10	35	4.0	80	–		**30.4'-39.9' ARGILLACEOUS HALITE:** pale brown (5YR 5/2) to moderate brown (5YR 3/4), locally clear mottled with moderate reddish-orange polyhalite, fine to coarsely crystalline, moderately hard. Clay content about 2-5%. Numerous brown clay breaks. Trace polyhalite without clay from 31.7'-32.2' and 38.8'-39.5'. Clear halite from 32.4'-34.0'.	Core Loss: Run 9 - intermittently between 26.5'-28.0' Run 10 -throughout.
9	30	4.8	96	–		**23.2'-30.4' HALITE:** clear, medium to coarsely crystalline, moderately hard. Traces of polyhalite and brown clay 23.2'-26.5'. Light gray anhydrite seam underlain by brown clay partings 26.5'-26.6'. Very light gray anhydrite seam, 1/8"-1/4", at 27.6', and a few hairline anhydrite stringers throughout.	Violent bursts of pressurized gas at about 20', and again at about 31'. Stuffing box blown out of collar both times. Very high flow for 30± seconds, then diminished to a strong flow for 2-5 minutes, then dissipated.
8	25	4.0	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-229 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 401' S of Exploratory Shaft Centerline, 13.7' from E rib

STATION S 401, E 153 COLLAR ELEV. 1259.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N9287 E7049 BOREHOLE PENETRATION 50.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB/Bechtel DATE 3/4/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	4.0	100	–	X –	48.1'-50.6' **HALITE:** predominately clear, locally mottled with moderate brown clay and moderate reddish-orange polyhalite, medium to coarsely crystalline, moderately hard. Contains trace polyhalite blebs throughout and trace brown clay 50.4'-50.6'. Possible clay break at 48.4'.	Hole completed at 11:30 hours on 3 March 1983.

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WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. OH-9

LOCATION CENTERLINE OF ROOM L-1; TEST ROOM 1 INTERSECTION; ROOF

STATION N1433 W231.5 COLLAR ELEV. 1310 ± DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11,125.6 E6662.9 DEPTH OF BOREHOLE 15.4 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 2-27-84 (DAY) DATE COMPLETED 2-28-84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-28-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		1.85	1.85	100	X	0.0' - 4.2' HALITE: Clear, coarsely crystalline. < 1% polyhalite. 1% from 1.0 to 2.0'±.	4" dia. thin wall masonry core barrel. Used with KW rods.
1.85							
2		3.7	3.7	100	X	4.2' - 7.3' HALITE: Clear, coarsely crystalline to 6.3'. Then medium to coarse. ≤ 1% gray inter-crystalline clay. < 1/2% dispersed polyhalite.	Hole drilled by SNL.
	5				—	7.3' - 7.45' ANHYDRITE b: Gray, microcrystalline anhydrite. Up to 1/2" halite layer at 7.4'. Trace of gray clay at 7.3'. Upper contact tightly welded. Intact core.	Dry hole. No gas. Core broken in several pieces at lower contact of anhydrite b. Unable to determine if any separation exists.
5.55					X —		
3		3.75	3.75	100		7.45' - 13.15' HALITE: Clear; coarsely crystalline. Scattered white stringers.	
9.3							
4	10	3.05	3.05	100		13.15' - 13.95' HALITE: Clear to light gray (N7); medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% dispersed polyhalite.	
12.35							
5		3.05	3.05	100	— X	13.95' - 14.45' ANHYDRITE a: Light gray to white anhydrite with scattered halite growths from 14.15'. Upper contact tightly welded. Lower contact has < 1/16" gray clay.	Core broken at 13.95'. Smooth, horizontal break. Unable to determine any separation from core here.
	15				X X X	14.45' - 15.4' POLYHALITIC HALITE: Clear to *moderate reddish orange (10R 6/6); coarsely* crystalline. < 1 to 3% polyhalite.	
15.4							

M

BORING NO. OH-9

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. OH-11

LOCATION CENTERLINE OF ROOM L-2 AND TEST ROOM 2 INTERSECTION; ROOF

STATION N1433 W354.5 COLLAR ELEV. 1308 ± DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11,125.6 E6529.6 DEPTH OF BOREHOLE 19.7 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 2-15-84 (DAY) DATE COMPLETED 2-16-84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-16-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		1.5	1.5	100		0.0' - 2.3' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 2% polyhalite blebs and patches.	Used 4" thin wall masonry core barrel with BW rods.
1.5							
2		3.1	3.1	100		2.3' - 5.2' HALITE: Clear, some moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1% polyhalite. Clay break at 3.0 - 3.2'.	Hole drilled by SNL. Drilling time: 8-1/2 hrs. ±.
4.6							
3	5	3.0	3.0	100		5.2' - 7.6' HALITE: Clear mixed with medium light gray (N6); medium to coarsely crystalline. <1% gray clay and polyhalite.	
7.6							
4		2.85	2.85	100		7.6' - 7.8' ANHYDRITE b: White to light gray (N7) anhydrite with scattered halite growths. Slight trace clay at 7.6'. Upper contact is tightly welded. Core intact.	Lower contact of anhydrite b shows some core grinding. Trace of gray clay.
10.45	10						
5		3.65	3.65	100		7.8' - 13.0' HALITE: Clear; coarsely crystalline. Scattered white stringers.	
						13.0' - 14.1' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1/2% dispersed polyhalite and gray clay.	
14.1							
6	15	3.7	3.7	100		14.1' - 14.8' ANHYDRITE a: White to light gray (N7) microcrystalline anhydrite with scattered halite growths, especially common from 14.6 - 14.8'. <1/32" gray clay at 14.1'. Upper contact is irregular; tightly welded. Core intact. Grades into polyhalitic halite above.	Core broken at lower contact of anhydrite a but pieces fit together fairly well.
17.8							
7		1.9	1.9	100		14.8' - 18.4' POLYHALITIC HALITE: Clear to moderate reddish orange; coarsely crystalline. <1 to 3% polyhalite. Anhydrite stringers at 15.9 and 16.05'.	
19.7	20					18.4' - 19.7' HALITE: Clear, medium to coarsely crystalline. <1% dispersed gray clay. Break at 18.4'.	

BORING NO. OH-11

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. OH-13

LOCATION CENTERLINE ROOM L-1 AND TEST ROOM 1 INTERSECTION; FLOOR

STATION N1433 W231.5 COLLAR ELEV. 1298 ± DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N11125.6 E6662.9 DEPTH OF BOREHOLE 9.5 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 2-28-84 (DAY) DATE COMPLETED 2-28-84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-28-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1		2.5	2.5	100		0.0'-0.15' FILL	4" dia. wall masonry core barrel used with EW rods.
2.5					X	0.15'-1.5' HALITE: Clear, coarsely crystalline. <1% gray intercrystalline clay.	
2		3.15	3.15	100	X	1.5'-4.4' HALITE: Clear with some moderate reddish orange (10R 6/6); coarsely crystalline. <1% polyhalite blebs and patches. Gray clay break at 2.5'.	Hole drilled by SNL.
	5						
5.65							
3		3.85	3.85	100	X	4.4'-4.6'± POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1% gray clay. 1 to 3% polyhalite. Some anhydrite present.	
9.5					X		
	10					4.6'-8.1' MB-139 : Upper contact, core is broken at 15"±,<1/32" gray clay along it. Mixture of anhydrite and halite to 7.3'. From 7.3' - 7.8' is light gray (N7) to white anhydrite. Irregular pattern of white and gray color. Near-horizontal laminae present. Hard, dry gray clay 7.8 to 8.1'± (lower contact dips from 7.95 to 8.1'). <1/16"halite layer at 7.85'.	20"± break in core at 5.65' but core pieces fit together very well. Core is broke at 7.9'± but core ends fit together. Below clay at lower contact, core is intact, and contact is tightly welded.
						8.1' - 8.6' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1/2% polyhalite. Steeply dipping, clean fracture extends from center of core at 8.0' to outer edge at 8.5'. Core not broken completely along this.	
						8.6' - 9.5' HALITE: Clear to light gray (N7), medium to coarsely crystalline, some fine. <1/2% polyhalite. ≤1% gray intercrystalline clay. Several steeply dipping, clean fractures in core. Core not broken completely along any fractures. Clay breaks at 8.6' and 9.3'.	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. OH-14

LOCATION CENTERLINE OF ROOM L-2 AND TEST ROOM 2 INTERSECTION; FLOOR

STATION N1433 W364.5 COLLAR ELEV. 1296 ± DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N11,125.6 E6529.6 DEPTH OF BOREHOLE 9.7 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 2-16-84 (DAY) DATE COMPLETED 2-17-84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-17-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		1.7	1.7	100	X —	0.0' - 1.9' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline with zones of fine to medium. ≤1% polyhalite. <1/2% gray intercrystalline clay.	4-inch thin wall masonry core barrel used with EW rods.
1.7							
2		1.8	1.8	100	X X X	1.9' - 4.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 4% polyhalite. Scattered anhydrite from 3.8 to 4.4'. Clean, irregular break in core at 3.55'.	Hole drilled by SNL. Dry hole. No gas. Separation noted in walls of hole at 3.55'.
3.5							
3	5	3.45	3.45	100	X X	4.4' - 6.95' MB-139: White to medium light gray (N6) with some moderate reddish orange (10R 6/6). Microcrystalline anhydrite from 4.4 - 5.4'. ≤1/16" halite layer at 6.75 - 6.8'. Continuous through core there is a hairline fracture 1/2" below this halite where core is broken along. Upper contact of MB-139 is tightly closed and dips 15°±. Less than 1/2" below is a parallel break in core. Core pieces fit tightly along this though 1/2 to 3/4" gray clay along lower contact.	While drilling hole, just below top of MB-139, had some air and drill cuttings coming out of 51X-GE-00262 hole. Coming out of extensometer hole at 4.8' depth. Core at lower contact of MB-139 is broken here. Difficult to determine any separation from looking at core.
6.95							
4		2.75	2.75	100	— X —	6.95' - 9.7' HALITE: Clear to light moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1% dispersed polyhalite. <1% gray clay, intercrystalline and scattered breaks.	Put water in OH-14 and it came out in 51X-GE-00262 at 4.8' depth.
9.7	10						

M

BORING NO. OH-14

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix EBS

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Engineered Alternatives Cost/Benefit Study

ENGINEERED ALTERNATIVES COST/BENEFIT STUDY

Prepared by:

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Prepared for:

U.S. Department of Energy-Carlsbad Area Office
Contract #DE-AC04-86AL31950

September 1995

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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is a United States Department of Energy (DOE) project designed to demonstrate the safe disposal of Transuranic (TRU) waste in deep, geologic, bedded salt. The WIPP site is located in southeastern New Mexico. By law (U.S. Congress, 1992) the WIPP site has been withdrawn from public use and has been set aside for use in the safe disposal of TRU waste. Also by law, disposal of TRU waste must comply with rules and regulations promulgated by the U.S. Environmental Protection Agency (EPA). The disposal system design consists of multiple barriers, both natural and man-made, located in a geologic salt deposit, 2,150 feet (655.3 meters) below ground. These barriers were selected because of their ability to permanently isolate the waste from the accessible environment as required to comply with subparts B and C of Title 40 Code of Federal Regulations Part 191 (40 CFR 191). As a part of the assurance requirements, 40 CFR §191.14 requires that barriers of different types shall be used to isolate the waste. The WIPP design uses both a geologic (natural) and engineered barriers for waste isolation as specified by these regulations. However, to provide additional confidence in containment prediction calculations used to demonstrate compliance with the containment requirements, Engineered Alternatives (EA) could be used as additional assurance measures beyond those used to meet the containment requirements. This report uses the term EA to represent engineered barriers that are technically feasible processes, technologies, methods, repository designs, or waste from modifications which make a significant positive impact on the disposal system in terms of reducing uncertainty in performance calculations or improving long-term performance. These EAs, if used, function as barriers to the release of radioactive material.

The DOE has initiated a cost/benefit study to evaluate EAs for potential use as assurance measures. The purpose of this report is to provide the DOE with cost and benefit information for use in the selection or rejection of EAs, specifically should it be determined that additional barriers are needed for assurance purposes. This study includes a qualitative assessment of estimated cost, potential risks, benefits, and relative repository performance impacts from the implementation of EAs, and where appropriate, the impact on the entire waste management complex (as a system) was considered. This report is entitled, the Engineered Alternatives Cost/Benefit Study (EACBS).

The EACBS evaluated EAs using the following assumptions and guidance.

- The present baseline design of the disposal system and its predicted performance meet the containment requirements of 40 CFR 191 without additional EAs. The baseline does not include waste processing above that required by the WIPP Waste Acceptance Criteria (WAC) and does not include backfill as an option.

- The information presented in this report is to be used to select or reject EAs for assurance purposes only and not for demonstrating compliance with the containment requirements.

- The results of the EACBS analysis are qualitative. However, both qualitative and quantitative methods are used to generate the output information.

- The output of the EACBS compares the results of the EA analysis with the baseline and not to each other. Numeric ranking of EAs is not provided.

- The EA analysis uses a multi-factor approach that evaluates the cost; the risk, both incidental and accidental; and the benefit and schedule impacts that could be expected from the implementation of each individual EA. The factors are not ranked or weighted.

- TRU waste destined for WIPP can be grouped into three basic waste forms, sludges, solid organics, and solid inorganic materials.

- All waste shipped to WIPP will meet the WAC. WAC requirements reflect any necessary waste treatment or processing restrictions.

The DOE has previously evaluated EAs. For example, the Engineered Alternatives Task Force (EATF) Final Report (DOE 1991a) contained analyses of EAs for use in meeting 40 CFR 191 containment requirements. The EATF focused the analysis on an EA's ability to reduce gas generation and its impact on human intrusion scenarios. The EACBS study differs from the EATF in that the EACBS analysis generates information to be used for meeting assurance requirements rather than to address compliance with containment requirements through their inclusion in the compliance baseline. The EACBS analysis also includes information on system wide cost, risks, and public confidence.

The approach used in the EACBS was to screen potential EAs compiled from previous studies, proposed regulations, and input elicited from stakeholders. The screening process used a working group composed of technical professionals from various fields to compare the proposed EAs to an EA definition and then to determine if those EAs that meet the definition also meet regulatory and technological feasibility criteria. The output of the screening process is a list of EAs that did not meet the definition and/or screening criteria along with the justification for their rejection, and a list of EAs retained for further consideration. This list of retained EAs was then optimized to determine which EAs would be further analyzed using a multi-factor approach.

The screening processes evaluated 111 proposed EAs and screened them to a field of 54. The 54 EAs retained were further screened by the DOE using feasibility and effectiveness criteria to provide the final set of 18 EAs used by the EACBS. The 18 EAs agreed upon by the DOE for the EACBS evaluation consisted of nine basic alternatives and nine variations. The variations originated in the screening process and are noted with a letter following the original ID number. The 18 final EAs along with a brief description of each EA are listed below. Complete details of the screening process can be found in Section 2.3.1 of this report.

Analyzed Engineered Alternatives

Baseline

For EA comparison, the baseline is considered to be the current WIPP disposal system design. For each EA and the baseline waste meeting the WAC is emplaced in rooms that are 13 feet (3.96 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long and access drifts in waste stacks of seven-pack drums (three high) and Standard Waste Boxes (three high). No backfill is included in the baseline.

#1—Supercompact Organics and Inorganics

Solid organic and inorganic wastes are sorted to remove items that cannot be compacted. Sorted waste is pre-compacted in 35-gallon (132.6 liters) drums and then supercompacted. Usually, the contents of four supercompacted drums are placed in a 55-gallon (208-liter) drum. Sludges are not processed.

#6—Shred and Compact Organics and Inorganics

Solid organics and inorganics are shredded and compacted in 55-gallon (208-liter) drums using a mechanical shredder and a low pressure compactor. Sludges are not processed.

#10—Plasma Processing of All Wastes

All wastes are processed through a mechanical shredder and the input waste stream is controlled to ensure a suitable metal to non-metal ratio. The waste is processed through a Plasma Arc Centrifugal Treatment System and placed into 55-gallon (208-liter) drums.

#33—Sand Plus Clay Backfill

A mixture of medium grained sand and granulated clay is used as backfill. The mixture is placed around the waste stack and between the drums filling the void space between drums and unmined host salt in waste emplacement panels. A 50 percent void space is assumed.

#35a—Salt Aggregate (Grout) Backfill

A salt aggregate grout mixture is used as backfill to fill the void spaces between drums and unmined host salt in waste emplacement panels. This backfill consists of a cementitious-based salt aggregate grout with crushed salt aggregate and is pumped around the waste stack and between the drums filling the void spaces. A 20 percent void space is assumed.

#35b—Cementitious Grout Backfill

A cementitious grout backfill consisting of ordinary Portland cement, sand and fresh water is pumped around the waste stack and between the drums filling the void space. A 20 percent void space is assumed.

#77a—Supercompact Organics and Inorganics, Salt Aggregate/Grout Backfill, Monolayer of 2000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long

Alternatives #1 and #35a are combined. The room height is lowered from 13 feet to 6 feet (3.96 meters to 1.83 meters) and only one layer of drums is emplaced in the room.

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#77b—Supercompact Organics and Inorganics, Clay-Based Backfill, Monolayer of 2000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long

Alternatives #1 and #111 are combined. The room height is lowered from 13 feet to 6 feet (3.96 meters to 1.83 meters) and only one layer of drums is emplaced in the room.

#77c—Supercompact Organics and Inorganics, Sand/Clay Backfill, Monolayer of 2000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long

Alternatives #1 and #33 are combined. The room height is lowered from 13 feet to 6 feet (3.96 meters to 1.83 meters) and only one layer of drums is emplaced in the room.

#77d—Supercompact Organics and Inorganics, CaO Backfill, Monolayer of 2000 drums in a room that is 6 feet (1.83 meters) high, 33 feet (10.06 meters) wide, and 300 feet (91.44 meters) long

Alternatives #1 and #83 are combined. The room height is lowered from 13 feet to 6 feet (3.96 meters to 1.83 meters) and only one layer of drums is emplaced in the room.

#83—Salt Backfill with CaO

A backfill of commercially available granulated lime (also called quick lime which consists of CaO) and crushed salt are placed around the waste stacks and between the drums filling the void space. A 50 percent void space is assumed.

#94a—Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, No Backfill

EA 94a includes two processes to treat the TRU waste. The first is an enhanced cementation process of previously solidified and "as generated" sludge. Existing sludges are fed into a mechanical crusher/shredder. The crushed waste is mixed with an enhanced cement and the product is poured into 55-gallon (208-liter) drums. Newly generated sludges are solidified with the enhanced cement. The second process shreds solid organic and inorganic wastes and adds clay to the shredded waste. This waste product is packaged in 55-gallon (208-liter) drums.

#94b—Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, Sand/Clay Backfill

Alternative #94a and #33 are combined.

#94c—Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, Cementitious Grout Backfill

Alternative #94a and #35b are combined.

#94d—Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, Salt Aggregate Grout Backfill

Alternative #94a and #35a are combined.

#94e—Enhanced Cement Sludges, Shred and Add Clay-Based Materials to Organics and Inorganics, Clay-Based Backfill

Alternative #94a and #111 are combined.

#94f—Enhanced Cement Sludges, Shred, and Add Clay-Based Materials to Organics and Inorganics, CaO/Salt Backfill

Alternative #94a and #83 are combined.

#111—Clay-Based Backfill

A backfill consisting of commercially available pelletized clay is placed around the waste stack and between the drums, filling the void space. A 50 percent void space is assumed.

Table E-1 lists the 18 alternatives with reference to specifications for waste form, backfill and room dimensions. The 18 EAs were analyzed with respect to the following eight factors as described in the proposed rule 40 CFR §194.44. For analytical consistency, Factors 1 and 9 from 40 CFR §194.44 have been combined in the EACBS.

1. Effects of EAs on long-term performance of the disposal system. This factor analyzes the EA's ability to limit water and radionuclide movement to the accessible environment and the potential consequences of human initiated processes or events.

2. The increased or reduced uncertainty in compliance assessment.

3. The impact on public and worker exposure to radiation (at WIPP and off-site) both during and after the incorporation of an EA.

4. The increased ease or difficulty in future removal of the waste from the WIPP disposal system.

5. The increased or reduced risk (incidental and accidental exposure) of transporting the waste to the WIPP.

6. The increased or reduced public confidence in the performance of the disposal system.

TABLE E-1

SUMMARY OF ENGINEERED ALTERNATIVES EVALUATED BY EACBS RELATIVE TO THE BASELINE

Identifier	Alternative	Sludges	Solid Organic	Solid Inorganic	Backfill	Facility Design
0	Baseline	As received	As received	As received	None	Baseline
1	Supercompact waste	As received	Supercompacted	Supercompacted	None	Baseline
6	Shred and compact	As received	Shred and Compact	Shred and Compact	None	Baseline
10	Plasma processing of all waste	Plasma Processed	Plasma Processed	Plasma Processed	None	Baseline
33	Sand plus clay backfill	As received	As received	As received	Sand Plus Clay Backfill	Baseline
35.a	Salt aggregate grout backfill	As received	As received	As received	Salt Aggregate Grout Backfill	Baseline
35.b	Cementitious grout backfill	As received	As received	As received	Cementitious Grout Backfill	Baseline
77.a	Supercompact organics and inorganics, clay-based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Salt Aggregate Grout Backfill	6'X33'X300'
77.b	Supercompact organics and inorganics, clay-based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Clay-based backfill	6'X33'X300'
77.c	Supercompact organics and inorganics, clay-based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Sand/clay backfill	6'X33'X300'
77.d	Supercompact organics and inorganics, clay-based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Salt plus CaO Backfill	6'X33'X300'
83	Salt backfill with CaO	As received	As received	As received	Salt plus CaO Backfill	Baseline
94.a	Enhanced cement sludges, shred and cement organics and inorganics, no backfill	Enhanced Cement	Shred and add clay	Shred and add clay	No backfill	Baseline

TABLE E-1 (Concluded)

SUMMARY OF ENGINEERED ALTERNATIVES EVALUATED BY EACBS RELATIVE TO THE BASELINE

Identifier	Alternative	Sludges	Solid Organic	Solid Inorganic	Backfill	Facility Design
94.b	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Clay/sand backfill	Baseline
94.c	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Cementitious Grout	Baseline
94.d	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Salt Aggregate Grout	Baseline
94.e	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Clay	Baseline
94.f	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Salt plus CaO Backfill	Baseline
111	Clay-Based Backfill	As received	As received	As received	Clay-Based Backfill	Baseline

7. The increased or reduced total DOE waste management system cost and schedule impacts.

8. The impact on other waste disposal programs.

The following discussions outlines the analysis and results for each EA with respect to the eight factors.

Factor 1—Effects of EAs on Long-Term Performance of the Disposal System

Factor 1 deals with the impacts that an EA is predicted to have on the long-term performance (not specific to the regulatory requirements) of the disposal system. Impacts are predicted using the Design Analysis Model (DAM), which considers the coupled processes of brine inflow, creep closure, gas generation, and radionuclide migration under undisturbed conditions. The consequences of three human intrusion scenarios are also considered. The DAM was originally developed by the EATF (DOE, 1991a). The three human intrusion scenarios postulate the existence of future boreholes that inadvertently penetrate the waste rooms and panels (waste horizon). These scenarios are the same as those considered in the 1992 Performance Assessment, and are fully described in SNL/NM (1993). These three scenarios are referred to in the EACBS as E1, E2, and E1E2. This factor is evaluated by considering the impacts of each EA on the following:

- Relative changes in the cumulative 10,000-year release of radionuclides based purely on the quantity of cuttings released to the surface from each of the three human intrusion scenarios

- Relative changes in the cumulative 10,000-year release of radionuclides into the overlying Rustler Formation from each of the three human intrusion scenarios.

The impacts of each EA are expressed as changes in the parameters described above relative to the baseline, which is defined as unprocessed waste emplaced in disposal panels with no backfill.

Although both disturbed and undisturbed conditions are simulated, the greatest consequences of releases are expected to occur as a result of human intrusion. Therefore, the study places emphasis on the effects of EAs on mitigating releases from the human intrusion scenarios.

Factor 2—The Increased or Reduced Uncertainty in Compliance Assessment

Factor 2 estimates the EAs ability to treat uncertainty relative to the quantity of radioactive materials that are expected to be transported to the accessible environment as a result of human intrusion scenarios. This factor estimates the uncertainties by systematically manipulating the DAM input parameters from the Factor 1 analyses using a Monte Carlo simulation for each EA analyzed. The results of Factor 2 are then used in conjunction with those of Factor 1 to characterize the potential for an EA to provide additional assurance in the performance of the disposal system.

Treatment of uncertainty in compliance assessment can be realized by reducing both the magnitude of radioactive materials released to the accessible environment and characterizing the

potential variability in that quantity. Factor 1 addresses the magnitude of reduction through a Measure of Relative Effectiveness (MRE) for cuttings removal to the surface and groundwater transport to the Culebra Dolomite via the borehole, given scenarios E1, E2, or E1E2 occur. A MRE is a unitless factor that expresses the change in the magnitude of releases with respect to the baseline disposal system design. Factor 2 addresses the ability of the EAs to treat the uncertainty about these estimates of release quantity by treating the uncertainty about predictions of quantities of radioactive material that might be released as a result of the intrusion scenarios. Therefore, increasing the confidence in the performance of the disposal system.

Factor 3—The Impact on Public and Worker Exposure to Radiation Both During and After the Incorporation of an EA

This factor characterizes the human-health risks (incidental and accidental exposure) associated with the implementation of an EA, including those impacts realized at the WIPP site and generator or disposal facilities that handle TRU or TRU-mixed waste. Potential impacts include radiation effects (both occupational exposures and the release of material resulting from an off-normal accident scenario), effects from the release of hazardous material, and, in the case of individuals within the facilities, ordinary industrial hazards. Impacts are considered for the following five groups of individuals at the WIPP and at the generator/disposal sites:

- Workers directly involved with handling, processing, or storing TRU waste (generally referred to as "workers")
- Other workers in the facility who are not directly involved with the TRU waste (referred to as "co-located workers")
- The co-located worker who receives the highest exposure to radiation or hazardous material from TRU waste activities
- All members of the public who live within 50 miles (80.5 kilometers) of the facility where the TRU waste is being handled, processed, or stored (generally referred to as "public")
- The member of the public located off-site who receives the highest exposure from activities associated with TRU handling, processing, or disposal (often called the Maximum Off-Site Individual or MOI).

Factor 4—The Increased Ease or Difficulty in Future Removal of the Waste from the WIPP Disposal System

For the purpose of this report, waste removal is defined as the activity involving recovery of the waste after repository closure. In assessing the waste removal activities, the waste inventory and physical properties for each EA determine the underground panel geometry that would in turn determine the time required for underground removal (mining of the waste). Underground waste removal considers the compressive strength and density of the waste form as well as the consolidation of the backfill expected to occur after a specified period of time (if applicable). The occupational hazards for industrial accidents include the conventional hazards due to underground mining accidents, hazardous waste exposure, and radioactive waste exposure.

Factor 5—The Increased or Reduced Risk of Transporting the Waste to the WIPP

The transportation risk factor consists of the human-health impacts due to radiation- and hazardous-material exposures that could potentially result from transporting CH- or RH-TRU waste. The risk factor is defined in terms of the radiological, chemical, and non-radiological/non-chemical impacts of either normal, incident-free transportation or transportation accidents. Not all of the EAs impact transportation; backfill only alternatives are not analyzed using this factor. The results break down the total number of shipments from each storage/generator site and present the exposures to the public and workers. Where applicable, reported transportation risks and exposures are in the same units used in Factor 3.

Factor 6—The Increased or Reduced Public Confidence in the Performance of the Disposal System

This study was conducted in two phases to identify both historic and current public concerns about WIPP's postclosure performance. During Phase 1, existing public commentary was examined to identify concerns about postclosure WIPP. These comments and concerns were further analyzed to determine the relative frequency of the concerns and the persistence of concerns over time. Data sources included:

- The WIPP FSEIS (DOE, 1990b)
- Response to Comments for Amendments to 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and TRU Radioactive Wastes (EPA, 1993)
- Public Hearings on EPA's Proposed Rule 40 CFR Part 194, Criteria for the Certification and Determination of the WIPP's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and TRU Radioactive Wastes, March 21-24, 1995 (EPA, 1995)

During Phase 2, comments were collected during a series of focus group discussions and interviews in which participants were invited to share their concerns.

The combined findings from Phase 1 and Phase 2 analyses serve as considerations for selecting engineered alternatives that would address expressed public concerns. A qualitative assessment is made using the comment categories (comments were segregated based on the general nature of the concern) and determining which EAs address the concerns within these categories.

Factor 7—The Increased or Reduced Total DOE Waste Management System Cost and Schedule Impacts

Factor 7 analyzed increased or reduced cost and schedule impacts from implementation of EAs on the total DOE waste management system. The cost consists of summarized waste processing, transportation, backfill, and emplacement handling for the selected alternatives. The analyzed costs include a comparative analysis of the incremental change in cost of the screened alternatives relative to the repository baseline. This analysis estimates the level of funding that must be appropriated, the estimated manpower for the activities, and a conceptual schedule that provides start and stop dates for each EA analyzed. Cost was analyzed by developing process

flow diagrams that segment the alternative into conceptual elements. The costs for the alternatives were developed on the basis of waste quantities and required throughput rates to meet the schedule constraints.

The schedule analysis provides a measure of the time required to implement an EA relative to the baseline. The schedule includes the incremental change of implementing an alternative on the baseline.

Factor 8—The Impact on Other Waste Disposal Programs

This factor includes an assessment of the impacts that the EAs will have on other DOE waste processing and disposal programs, including programs for LLW and low-level mixed waste (LLMW). Major impacts are assessed based on the additional volumes of waste that are projected to be generated by TRU waste processing with respect to each EA.

OVERALL CONCLUSION OF THE EACBS

After a decision is made concerning the use of EAs at WIPP for additional assurance purposes, any subsequent selection of EAs will be made using total disposal system knowledge. The EACBS provides comparative information concerning cost, schedule, worker and public radiological/chemical and accidental/incidental risks, disposal system performance impacts, public perception, waste removal impacts, and other waste disposal system impacts. The process for the selection or rejection of EAs will use this and other related information to weigh the relative importance and to determine which EAs will be implemented. The information in this report should not be used as the sole bases for the selection/rejection of any individual EA.

Table E-1 summarizes the 18 EAs analyzed in the EACBS. Each alternative was evaluated using the eight factors. The analysis results were compiled in a tabular summary and converted into quantifiable performance measures. Some factors were reported with one measure, while other factors could not be adequately expressed with a single measure. Table E-2 summarizes the performance measures and units presented for each factor. Table E-3 summarizes selected output information from the analysis of each EA and the baseline with respect to the eight factors.

The product from the evaluation of each factor was integrated into a qualitative result called a performance vector, that expresses the performance of an EA with respect to the baseline. As is the case for any analysis, these results are conditional on the models, data, and assumptions used in the analysis. Models, data and assumptions used in the analysis are described in Chapter 3.0. These models, data, and assumptions are based on the best available current information, and are considered to be appropriate for the purposes of this study. Technological understanding of many topics considered in this analysis is advancing rapidly, however, and it should be noted that changes in the modeling system or the model input, such as possible changes in our understanding of the future performance of specific EAs, could lead to somewhat different results. Table E-4 summarizes the results of the EACBS analysis and provides the performance vectors for each of the selected EAs plus the baseline repository design.

The EAs can be separated into three general categories, Waste Processing, Backfill, and Combination of these alternatives. The following observations were noted from the results of this analysis.

1

TABLE E-2

PERFORMANCE MEASURES REPORTED

EA FACTOR	PERFORMANCE MEASURE	UNITS
1) Long term Repository Performance	Measure of relative effectiveness (MRE) of repository performance compared to the baseline.	Ratio of the mean value EA performance to the baseline
2) Uncertainty in Compliance Assessment	Measure of the relative uncertainty (MRU) of repository performance compared to the baseline.	Ratio of the range factor for EA performance to the baseline
3) Worker & Public Risk[a]	Facility worker risk	FTE-rem excess fatalities, construction and operation injuries and fatalities
	Maximum co-located worker risk	rem, excess cancer fatalities
	Co-located worker collective risk	Person-rem excess fatalities[b]
	Maximum off-site individual risk	rem, excess cancer fatalities
	Collective off-site public risk	Person-rem excess fatalities[b]
4) Impact on Waste Removal	Measure of relative difficulty of waste removal compared to the baseline.	Qualitative ranking.
5) Transportation Risk[a]	Transport crew collective radiological, nonaccident risk	Person-rem, latent cancer fatalities
	Public collective radiological, nonaccident risk	Person-rem, latent cancer fatalities
	Public maximum individual radiological, nonaccident risk	rem, latent cancer fatalities
	Public and crew collective radiological, accident risk	Person-rem, latent cancer fatalities
	Public and crew collective chemical risk	EPRG-2 ratio
	Public and crew collective non-rad, non-chemical risk	injuries, fatalities
6) Public Confidence	Listing of citizen concerns about repository performance	Not applicable
7) System Cost & Schedule[a]	Waste storage costs	1994 dollars
	Waste treatment costs	1994 dollars
	Waste transportation costs	1994 dollars
	WIPP waste placement and backfill costs	1994 dollars
	Start of WIPP operations	Date of first waste placement
	Completion of WIPP operations	Date of closure
8) Impact on Other Disposal Systems	Secondary waste volumes	Percentage change in estimated secondary waste volumes relative to the DOE low level and low level mixed waste

[a]For EAs that involve waste treatment, results are reported separately for decentralized, regionalized and centralized locations.
[b]Other units of measure are also used for non-radiological risk.

TABLE E-3

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Waste Backfill Compressive Strength (MPa)	NA	25.2	24.5	25.1	24.1	15.2	21.1	21.1	19.4	12.2	12.2	18.3	20.1	24.7	14.7	20.6	20.6	14.7	19.7	15.2
Emplacement Volume Impact (% Emplaced or Amount not Emplaced m^3)	NA	100% emplaced	100% empleced	100% empleced	100% emplaced	100% emplaced	100% emplaced	100% emplaced	41,655	41,655	41,655	41,655	100% emplaced	27,177	27,177	27,177	27,177	27,177	27,177	100% emplaced
Backfill Properties -																				
Initial Density (Kg/m^3)	NA	NA	NA	NA	NA	1,590	1,884	1,884	1,884	1,000	1,590	1,193	1,193	NA	1,590	1,884	1,884	1,000	1,193	1,000
Initial Porosity (%)						40.0	31.3	31.3	31.3	62.5	40.0	44.8	44.8		40.0	31.3	31.3	62.5	44.8	62.5
Solid Density (Kg/m^3)						2,650	2,741	2,741	2,741	2,670	2,650	2,162	2,162		2,650	2,741	2,741	2,670	2,162	2,670
MRE (unitless)	1																			
E1		1.0	0.93	0.95	0.00078	0.74	0.40	0.40	0.44	0.56	0.73	0.79	0.83	0.69	0.66	0.45	0.45	0.53	0.67	0.54
E2		1.0	1.4	1.1	0.0093	2.0	1.1	1.1	0.56	2.3	2.1	0.30	0.30	1.1	0.86	0.46	0.46	0.88	0.30	2.1
E1E2		1.0	1.0	1.0	0.00076	0.99	0.04	0.04	0.083	0.93	0.98	0.032	0.050	1.0	0.99	0.089	0.089	0.49	0.012	0.56
Cuttings		1.0	.26	0.79	0.12	0.92	0.40	0.40	0.21	0.22	0.21	0.22	0.94	0.57	0.52	0.30	0.30	0.53	0.54	0.94
Uncertainty E1	2																			
5th Percentile		NA	0.92	0.92	0.0004	0.73	0.40	0.40	0.43	0.55	0.72	0.60	0.83	0.68	0.64	0.44	0.44	0.52	0.26	0.53
95th Percentile			0.94	0.96	0.0012	0.78	0.42	0.42	0.47	0.59	0.78	0.81	0.84	0.72	0.69	0.47	0.47	0.56	0.68	0.55
Uncertainty E2	2																			
5th Percentile		NA	0.61	0.75	0.0009	0.31	0.18	0.18	0.091	0.45	0.37	0.009	0.009	0.19	0.14	0.03	0.03	0.16	0.005	0.33
95th Percentile			2.08	1.75	0.0549	1.39	1.09	1.09	0.87	2.35	2.06	0.83	0.84	1.08	1.61	0.88	0.88	1.62	0.75	2.18
Uncertainty E1E2	2																			
5th Percentile		NA	1.0	1.0	0.0003	0.99	0.009	0.009	0.011	0.37	0.98	0.012	0.012	0.37	0.22	0.01	0.01	0.024	0.009	0.024
95th Percentile			1.0	1.0	0.0066	0.99	0.75	0.75	0.98	0.98	0.98	0.438	0.76	1.0	0.99	0.98	0.98	0.99	0.045	0.99
Uncertainty Cuttings	2																			
5th Percentile		NA	0.25	0.75	0.11	0.91	0.40	0.40	0.21	0.21	0.21	0.21	0.94	0.56	0.52	0.29	0.29	0.53	0.53	0.93
95th Percentile			0.26	0.80	0.18	0.92	0.40	0.40	0.21	0.22	0.21	0.22	0.94	0.57	0.52	0.30	0.30	0.53	0.54	0.94
WIPP Worker Rad Risk	3																			
FTE-Rem		322.85	322.85	322.85	322.85	345.27	357.23	357.23	342.07	340.15	343.99	338.23	339.29	322.85	346.77	366.20	343.78	342.28	339.29	342.28
Excess Fatalities		0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.14	0.15	0.14	0.14	0.14	0.14
WIPP Indust. Accidents	3																			
Injuries		53.63	44.05	44.05	33.20	64.50	70.81	70.81	55.53	49.80	51.77	51.06	66.45	53.63	67.04	69.14	69.56	61.83	63.25	62.53
Fatalities		0.16	0.13	0.13	0.10	0.29	0.30	0.30	0.15	0.15	0.15	0.25	0.28	0.16	0.39	0.21	0.49	0.18	0.28	0.18

TABLE E-3 (continued)

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Waste Processing Risk	3																			
Centralized Scenario																				
Off-site Population																				
Cancer Fatalities		1.94×10^{-4}	$4..24\times10^{-4}$	4.24×10^{-4}	8.99×10^{-1}	NA	NA	NA	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	NA	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	NA
Cancer Incidence		5.51×10^{-8}	5.74×10^{-7}	5.74×10^{-7}	3.39×10^{-7}				5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}		5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	
Workers																				
Cancer Fatalities		7.78×10^{-1}	$1.10\times10^{+0}$	$1.20\times10^{+0}$	$1.34\times10^{+0}$				$1.10\times10^{+0}$	$1.10\times10^{+0}$	$1.10\times10^{+0}$	$1.10\times10^{+0}$		$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	
Cancer Incidence		1.30×10^{-5}	3.49×10^{-5}	3.80×10^{-5}	1.69×10^{-4}				3.49×10^{-5}	3.49×10^{-5}	3.49×10^{-5}	3.49×10^{-5}		3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	
Construct/Op Fatalities		2.81	3.79	4.08	5.29				3.79	3.79	3.79	3.79		4.08	4.08	4.08	4.08	4.08	4.08	
Waste Processing Risk	3																			
Regionalized Scenario																				
Off-site Population																				
Cancer Fatalities		1.94×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	$4.79\times10^{+0}$	NA	NA	NA	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	NA	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	NA
Cancer Incidence		5.51×10^{-8}	3.69×10^{-7}	3.69×10^{-7}	3.19×10^{-7}				3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}		3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	
Workers																				
Cancer Fatalities		7.78×10^{-1}	9.92×10^{-1}	8.12×10^{-1}	9.10×10^{-1}				9.92×10^{-1}	9.92×10^{-1}	9.92×10^{-1}	9.92×10^{-1}		8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	
Cancer Incidence		1.30×10^{-5}	3.15×10^{-5}	2.58×10^{-5}	3.73×10^{-5}				3.15×10^{-5}	3.15×10^{-5}	3.15×10^{-5}	3.15×10^{-5}		2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	
Construct/Op Fatalities		2.81	3.83	3.45	7.18				3.83	3.83	3.83	3.83		3.45	3.45	3.45	3.45	3.45	3.45	
Waste Processing Risk	3																			
Decentralized Scenario																				
Off-site Population																				
Cancer Fatalities		1.94×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	$4.60\times10^{+0}$	NA	NA	NA	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	NA	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	NA
Cancer Incidence		5.51×10^{-8}	3.59×10^{-7}	3.59×10^{-7}	3.06×10^{-7}				3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}		3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	
Workers																				
Cancer Fatalities		7.78×10^{-1}	9.54×10^{-1}	7.91×10^{-1}	$1.17\times10^{+0}$				9.54×10^{-1}	9.54×10^{-1}	9.54×10^{-1}	9.54×10^{-1}		7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	
Cancer Incidence		1.30×10^{-5}	3.03×10^{-5}	2.51×10^{-5}	4.81×10^{-5}				3.03×10^{-5}	3.03×10^{-5}	3.03×10^{-5}	3.03×10^{-5}		2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	
Construct/Op Fatalities		2.81	4.05	3.78	9.73				4.05	4.05	4.05	4.05		3.78	3.78	3.78	3.78	3.78	3.78	
Mining Advance Rate (m/Shift)	4	1.8	1.8	1.8	1.9	2.0	1.9	1.9	4.2	4.5	4.5	4.2	1.9	1.8	2.0	1.9	1.9	2.0	1.9	2.0
Removal Risk	4																			
Fatal Accidents		0.58	0.58	0.58	0.58	0.53	0.56	0.56	0.26	0.24	0.24	0.25	0.56	0.58	0.53	0.56	0.56	0.53	0.55	0.53
Non-Fatal Accidents		11.74	11.66	11.73	11.62	10.74	11.31	11.31	5.15	4.83	4.83	5.09	11.22	11.69	10.69	11.26	11.26	10.69	11.17	10.74

TABLE E-3 (continued)

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Trans Rad Risk[1]	5																			
Decentralized (CH only)																				
Worker		$6.69x10^{+2}$	$5.81x10^{+2}$	$5.47x10^{+2}$	$7.16x10^{+2}$	$6.69x10^{+2}$	$6.69x10^{+2}$	$6.69x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$6.69x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$6.69x10^{+2}$
Person-Rem		$2.68x10^{-1}$	$2.32x10^{-1}$	$2.19x10^{-1}$	$2.86x0^{-1}$	$2.68x10^{-1}$	2.6810^{-1}	2.6810^{-1}	$2.32x10^{-1}$	$2.32x10^{-1}$	$2.32x10^{-1}$	$2.32x10^{-1}$	2.6810^{-1}	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	2.6810^{-1}
LCF																				
Public		$4.00x10^{+3}$	$3.47x10^{+3}$	$3.27x10^{+3}$	$4.27x10^{+3}$	$4.00x10^{+3}$	$4.00x10^{+3}$	$4.00x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$4.00x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$4.00x10^{+3}$
Person-Rem		$2.00x10^{+0}$	$1.74x10^{+0}$	$1.64x10^{+0}$	$2.14x10^{+0}$	$2.00x10^{+0}$	$2.00x10^{+0}$	$2.00x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$2.00x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$2.00x10^{+0}$
LCF																				
Accident		$8.01x10^{+1}$	$5.92x10^{+0}$	$7.59x10^{+1}$	$1.21x10^{+0}$	$8.01x10^{+1}$	$8.01x10^{+1}$	$8.01x10^{+1}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$8.01x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$8.01x10^{+1}$
Person-Rem		$4.01x10^{-2}$	$2.96x10^{-3}$	$3.80x10^{-2}$	$6.05x10^{-4}$	$4.01x10^{-2}$	$4.01x10^{-2}$	$4.01x10^{-2}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$4.01x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$4.01x10^{-2}$
LCF																				
Trans Chemical Risk	5																			
Decentralized																				
Max. Individual		$1.21x10^{+0}$	$1.80x10^{+0}$	$1.20x10^{+0}$	$2.10x10^{-5}$	$1.21x10^{+0}$	$1.21x10^{+0}$	$1.21x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.21x10^{+0}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$1.21x10^{+0}$
Trans Non-Rad/Chem Risk	5																			
Decentralized																				
Injuries		$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$
Fatalities		$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$
Percent of Comments Addressed by EA	6	NA	33%	33%	40%	31%	36%	36%	33%	33%	33%	33%	36%	42%	42%	42%	42%	42%	42%	36%
Total System Cost	7																			
Decentralized ($x10^6$)		4,483	5,219	4,955	6,704	4,538	4,569	4,569	5,280	5,250	5,257	5,255	4,536	7,624	7,675	7,703	7,703	7,667	7,673	4,529
Regionalized ($x10^6$)		4,335	4,824	4,607	5,742	4,391	4,421	4,421	4,884	4,855	4,861	4,859	4,388	6,835	6,886	6,913	6,914	6,877	6,883	4,381
Centralized ($x10^6$)		4,029	4,177	4,129	4,725	4,084	4,115	4,145	4,237	4,208	4,214	4,213	4,082	4,982	5,032	5,060	5,061	5,024	5,030	4,075
Schedule Impact - Delayed Emplacement Relative to Baseline Startup	7	No Delay	9yrs.	8yrs.	9yrs.	No Delay	No Delay	No Delay	9yrs.	9yrs.	9yrs.	9yrs.	No Delay	9yrs.	9yrs.	9yrs.	9yrs.	9yrs.	9yrs.	No Delay
Other Waste Generation	8																			
Secondary (m^3)		32,729	118,040	118,040	21,848	32,729	32,729	32,729	118,040	118,040	118,040	118,040	32,729	131,625	131,625	131,625	131,625	131,625	131,625	32,729
LLW/LLMW (m^3)		16,365	59,020	59,020	10,924	16,365	16,365	16,365	59,020	59,020	59,020	59,020	16,365	65,813	65,813	65,813	65,813	65,813	65,813	16,365

[1]Only the Decentralized scenario is shown here. The Centralized scenario results for all EAs are the same as the baseline reported here The Regionalized scenario analysis output is shown in Table 3-44.

- Waste Processing alternatives (EA # 1,6 & 10) were analyzed for the three processing scenarios (centralized, regionalized, and decentralized). Each scenario has inherent benefits and detriments. In general, processing alternatives impact the entire waste disposal system, involving the generator/storage sites, waste transportation, other waste disposal systems, and the WIPP waste handling system. Processing alternatives have higher cost, greater risks, and present increased schedule delays in comparison to baseline or backfill only EAs. In general, processing EAs have a marginal performance impact on the repository except for plasma processing (EA# 10) which shows a significant increase in repository impact, however, at the expense of the highest potential risk for all of the EAs analyzed.

  Centralized Processing—Since the centralized scenario processes all waste at one facility, the construction and operational costs are the lowest of the three waste processing scenarios. Operational and construction incidents and fatalities and public and worker chemical and radiological exposure risks are higher than the baseline. Transportation impacts are similar to the baseline. The centralized scenario has the highest potential to impact system wide disposal operations. Since one facility processes all waste, this facility becomes a potential choke point for the entire system.

  Regionalized Processing—The regionalized scenario processes waste at five generator/storage sites. The cost to implement regionalized EA scenarios are significantly higher than the centralized and slightly lower than the decentralized scenarios. In general, the worker and public radiological/chemical exposure risks are slightly higher than the centralized and lower than the decentralized scenarios. Transportation chemical exposure risks are slightly lower than the baseline since the waste is processed into a more inert matrix prior to shipment to WIPP. Accident and radiation risks are similar to the baseline.

  Decentralized Processing—For the scenario, processing is performed at the ten major generator/storage sites. The scenario has the highest cost of the three processing scenarios (as much as $1 billion difference between the centralized and decentralized for EA# 77a-d). The operation/construction incidents and fatality rates are generally higher than both the centralized and regionalized (baseline included).

- Backfill alternatives (EA# 33, 35a, 35b, 83 and 111) have the least impact on the entire waste disposal system. The WIPP waste handling system is impacted; waste transportation, generator/storage sites, and other waste disposal systems are not affected. Cost, schedule radiation and chemical exposure are similar to the baseline estimates. Backfill alternatives improve long-term disposal system performance.

- Combination alternatives contain both multiple processing alternatives and/or backfill alternatives. These alternatives (EA# 77a through 77d and 94a through 94f) have benefits and detriments associated with each individual alternative type. The overall cost and schedule impacts are the highest of the EAs. Transportation, worker and public risks (radiological, chemical accidental and incidental) are also the highest of all EAs. The overall impact of combination EAs on long-term disposal system performance are comparable to that associated with the backfill and processing only alternatives.

WIPP ENGINEERED ALTERNATIVES IMPACT VECTOR ELEMENTS

TRU WASTE DISPOSAL SCENARIO		LONG TERM COMPLIANCE CONFIDENCE		PUBLIC HEALTH RISK				WORKER HEALTH		DISPOSAL SYSTEM COSTS TRU WASTE					WIPP SCHEDULE			
						At WIPP						At WIPP						
Seq. No.	Engineered Alternative Case #	Cutings Scenarios	Water Scenarios	At Generator	In Transport	*Before Closure*	*After Closure*	At Generator	At WIPP	At Generator	In Transport	Storage & Treatment	Placement & Backfill	IMPACT ON OTHER WASTE DISPOSAL SYSTEMS	First Waste	Closure	WASTE REMOVAL CAPABILITY	PUBLIC ACCEPTANCE
1	Baseline-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
2	33-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	❑	▲	▲	▲	▲	▲
3	35a-1	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	❑	▲	▲	▲	▲	▲
4	35b-1	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	❑	▲	▲	▲	▲	▲
5	111-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	❑	▲	▲	▲	▲	▲
6	83-1	▲	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	❑	▲	▲	▲	▲	▲
7	1-1	○	▲	▲	▲	❑	▲	▲	■	▲	▲	■	○	❑	■	▲	○	▲
8	77a-1	○	▲	▲	▲	❑	▲	▲	■	▲	▲	■	▲	❑	■	▲	○	▲
9	77b-1	○	▲	▲	▲	❑	▲	▲	■	▲	▲	■	▲	❑	■	▲	○	▲
10	77c-1	○	▲	▲	▲	❑	▲	▲	■	▲	▲	■	▲	❑	■	▲	○	▲
11	77d-1	○	○	▲	▲	❑	▲	▲	■	▲	▲	■	▲	❑	■	▲	○	▲
12	6-1	▲	▲	▲	▲	❑	▲	▲	■	○	▲	■	○	❑	■	▲	▲	▲
13	94a-1	○	▲	▲	▲	❑	▲	▲	■	○	▲	■	▲	❑	■	▲	▲	▲
14	94b-1	○	▲	▲	▲	❑	▲	▲	■	○	▲	■	❑	❑	■	▲	▲	▲
15	94c-1	○	▲	▲	▲	❑	▲	▲	■	○	▲	■	❑	❑	■	▲	▲	▲
16	94d-1	○	▲	▲	▲	❑	▲	▲	■	○	▲	■	❑	❑	■	▲	▲	▲
17	94e-1	○	▲	▲	▲	❑	▲	▲	■	○	▲	■	❑	❑	■	▲	▲	▲
18	94f-1	○	○	▲	▲	❑	▲	▲	■	○	▲	■	❑	❑	■	▲	▲	▲
19	10-1	●	●	▲	▲	■	▲	▲	■	○	▲	■	○	○	■	▲	▲	▲

SCENARIO TREE LEGEND:

Super C: Supercompaction of all waste, except sludges
S&C: Shreding and compaction of all waste, except sludges
SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
SAG: Salt Aggregate Grout
CG: Cemenitious Grout

IMPACT VECTOR RANKING:

● Performance is significantly better than the corresponding baseline performance.
○ Performance is marginally better than the corresponding baseline performance.
▲ Performance is approximately the same as the corresponding baseline performance.
❑ Performance is marginally worse than the corresponding baseline performance.
■ Performance is significantly worse than the corresponding baseline performance.

[a] The Centralized Processing Scenario was selected because it generally produces the lowest increase in cost, schedule impacts, and health risks with respect to the baseline case–results for the regionalized and decentralized scenarios are found in Section 3.0.

Figure E-4
Summary of WIPP Engineered Alternative Evaluation Results for Centralized Processing Scenario[a]

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LIST OF ABBREVIATIONS/ACRONYMS

Am	americium
ANL-E	Argonne National Laboratory-East
ANL-W	Argonne National Laboratory-West
BIR	Baseline Inventory Report
CaO	calcium oxide
CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
CH	contact-handled
Ci	curie
CPLM	costs per loaded mile
CPM	critical path method
DAM	Design Analysis Model
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DOE-CAO	U.S. Department of Energy, Carlsbad Area Office
DOT	U.S. Department of Transportation
DRZ	disturbed rock zone
EA	*Engineered Alternative*
EACBS	Engineered Alternatives Cost Benefit Study
EAMP	Engineered Alternatives Multidisciplinary Panel
EASWG	Engineered Alternatives Study Working Group
EATF	Engineered Alternatives Task Force
EM-PEIS	Environmental Management Programmatic Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ERPG-2	Emergency Response Planning Guideline-2
ETEC	Energy Technology Engineering Center
FEIS	Final Environmental Impact Statement
FSEIS	Final Supplement Environmental Impact Statement
FTE	full-time equivalent
IDB	Integrated Data Base
INEL	Idaho National Engineering Laboratory
IR	incident rate(s)
KAPL	Knolls Atomic Power Laboratory
LANL	Los Alamos National Laboratory
lb/ft^3	pounds per cubic meter
LBL	Lawrence Berkeley Laboratory
LCF	latent cancer fatality
LESAT	Lockheed Martin Environmental Systems and Technologies Co.
LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
LOC(s)	level(s) of concern
LWA	Land Withdrawal Act
m^3	cubic meter
MB139	Marker Bed 139

LIST OF ABBREVIATIONS/ACRONYMS *(Continued)*

MEI	Maximum Exposed Individual
MOI	Maximum Off-Site Individual
MPa	megaPascals
m/s	meters per second
MRE	Measure of Relative Effectiveness
mrem/hr	millirem per hour
MU	Missouri University
MWIR	(Interim) Mixed Waste Inventory Report
NACEPT	National Advisory Council on Environmental Policy and Technology
nCi/g	nanoCuries per gram
NEPA	National Environmental Policy Act
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
OASIS	*Organic and Sludge Immobilization System*
O&M	operations and maintenance
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
PA	Performance Assessment
PACT	Plasma Arc Centrifugal Treatment
PDSTP	Preliminary Draft Site Treatment Plan
PEL	permissible exposure limit
PERT	Project Evaluation and Review Technique
PLCC	planning life cycle cost
PPE	personal protective equipment
preops	preoperations
psi	pounds per square inch
Pu	plutonium
QAPP	Quality Assurance Program Plan
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RH	remote-handled
SARF	Supercompaction and Repackaging Facility
SEIS	Supplement Environmental Impact Statement
SNL/NM	Sandia National Laboratories/New Mexico
SPM	System Prioritization Method
SRS	Savannah River Site
SVOC	semivolatile organic compound
SWB	standard waste box
Th	thorium
TI	Transport Index
TLV(s)	threshold limit value(s)
TRU	transuranic
TRUPACT-II	Transuranic Package Transporter-II
U	uranium

LIST OF ABBREVIATIONS/ACRONYMS *(Continued)*

VOC	volatile organic compound
WAC	Waste Acceptance Criteria
WID	Westinghouse Waste Isolation Division
WIPP	Waste Isolation Pilot Plant
WMFCITRUW	Waste Management Facility Cost Information for Transuranic Waste
WSRIC	(RFETS) Waste Stream and Residue Identification and Characterization

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1.0 INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

An Engineered Alternative (EA) is defined as a technologically feasible process, technology, method, repository design, or waste form modification which makes a significant positive impact on the disposal system, and in general terms, as an engineered barrier or group of engineered barriers. A "Barrier" is defined in Title 40, Code of Federal Regulations (CFR) Part 191 (40 CFR 191) as,

> "...any material or structure that prevents or substantially delays movement of water or radionuclides towards the accessible environment. For example, a barrier may be a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around the waste, provided that the material or structure substantially delays movement of water or radionuclides" (EPA, 1993a).

An engineered barrier is further defined in the Waste Isolation Pilot Plant (WIPP) Land Withdrawal Act (LWA) as,

> "...backfill, room seals, panel seals, and any other manmade barrier component of the disposal system" (U.S. Congress, 1992).

Both natural and engineered barriers are presently incorporated in the disposal system design of WIPP. EAs may be used to provide additional confidence that the WIPP disposal system will comply with the containment requirements in 40 CFR 191. This additional confidence measure defines the term assurance used throughout this report.

The Department of Energy (DOE) has initiated this EA cost benefit study (EACBS) to provide a technical basis for the selection and rejection of EAs for the WIPP should it be determined that additional barriers are needed for assurance purposes. This study includes a qualitative assessment of estimated costs, potential risks, benefits, and relative repository performance impacts resulting from the implementation of EAs. This assessment was made by first identifying candidate EAs and then screening alternatives using a defined process to determine which EAs should be retained for further detailed analysis. The detailed analyses were designed and conducted so as to determine the relative benefits and detriments on the DOE transuranic (TRU) waste management system. Performance related benefits at WIPP were considered, but were not the only impacts assessed. The results of the study will provide DOE with cost and benefit information for use in the selection of additional engineered barriers for the WIPP if it is determined to be desirable.

The selection/rejection of EAs for use at WIPP will be made using the best available information and will take into consideration the importance of many relevant factors. Examples of these factors are disposal system performance, cost, and risk to the public and workers from radiological/chemical and transportation related incidents and accidents. Since the relative benefit of an EA is dependent on those factors that carry the most importance, which are determined by the DOE decision maker, this study does not quantitatively rank nor recommend EAs for possible

use at WIPP. The EACBS provides non-weighted information and, where possible, qualitatively compares an EA's impact with respect to the existing baseline for WIPP.

1.2 BACKGROUND

1.2.1 WIPP Description and Mission Statement

The WIPP, a research and development facility of the DOE, is located in the Northern Delaware Basin in southeastern New Mexico (Figure 1-1). The WIPP is a proposed underground repository designed and constructed for the disposal of TRU radioactive wastes. TRU wastes are generated from DOE defense-related activities, including weapons production research, and development. Currently, the majority of these wastes are generated and/or stored at ten DOE sites across the country (DOE, 1994c).

The majority of TRU waste is material contaminated with alpha emitting radionuclides (e.g., plutonium-239) with half lives greater than 20 years and concentrations greater than 100 nanocuries per gram (nCi/g) of waste (DOE, 1994c). TRU wastes are classified as either contact-handled (CH) or remote-handled (RH) (DOE, 1994c), depending on the dose rate at the surface of the waste container. CH-TRU waste containers have an external dose rate less than 200 millirem per hour (mrem/hr) at the surface of the container. CH-TRU waste constitutes the vast majority (~97 volume percent) (DOE, 1995e) of the overall TRU waste inventory destined for WIPP. The WIPP repository and the waste to be stored at WIPP are described below.

1.2.1.1 The WIPP Repository

Detailed descriptions of the geology and hydrology of the WIPP site have been published in numerous documents (DOE, 1990b; Lappin, 1988; Lappin et al., 1989). The WIPP repository is located 2,150 feet below the surface in a bedded salt (halite) formation of Permian age known as the Salado Formation (Figure 1-2). The basis for the selection of the WIPP site and an analysis of its environmental impacts were presented in the WIPP Final Environmental Impact Statement (FEIS) (DOE, 1980) and supplemented with more current information in the Final Supplement Environmental Impact Statement (FSEIS) (DOE, 1990b). Figure 1-3 shows a three-dimensional layout of the repository in relation to the support facilities on the surface. The WIPP rooms and panels are excavated in the salt beds of the Salado. A panel consists of seven waste emplacement rooms and associated access drifts as shown in Figure 1-3.

After the waste is emplaced in the WIPP disposal rooms, natural closure occurs due to the creep (plastic flow) of the surrounding salt formation. This creep is in response to the pressure gradient that exists between the far-field pressure away from the repository (referred to as the lithostatic pressure or the pressure at the depth of the repository due to overlying rock) and the pressure in the repository (which, after excavation, is initially at atmospheric pressure). In a freshly excavated room under atmospheric pressure, this creep is of the order of a few inches per year. Under expected conditions, complete closure of the repository occurs, and the waste is safely and permanently isolated from the surrounding environment.

1.2.1.2 Waste Description

TRU waste to be disposed of at the WIPP consists of newly generated and/or retrievably stored waste in drums or boxes at major DOE facilities across the United States. Examples of

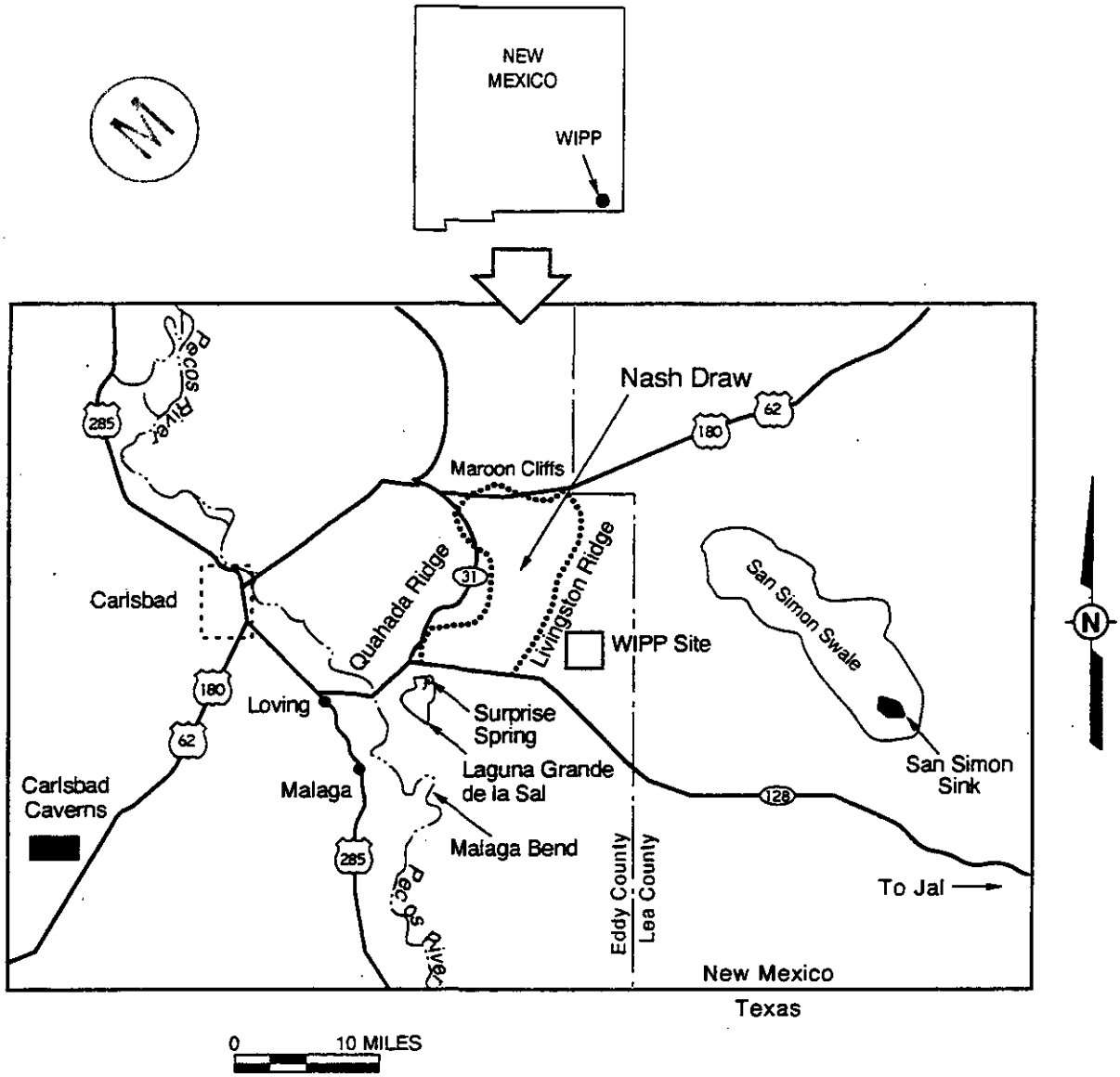

Figure 1-1
WIPP Location in Southeastern New Mexico (Rechard, 1989)

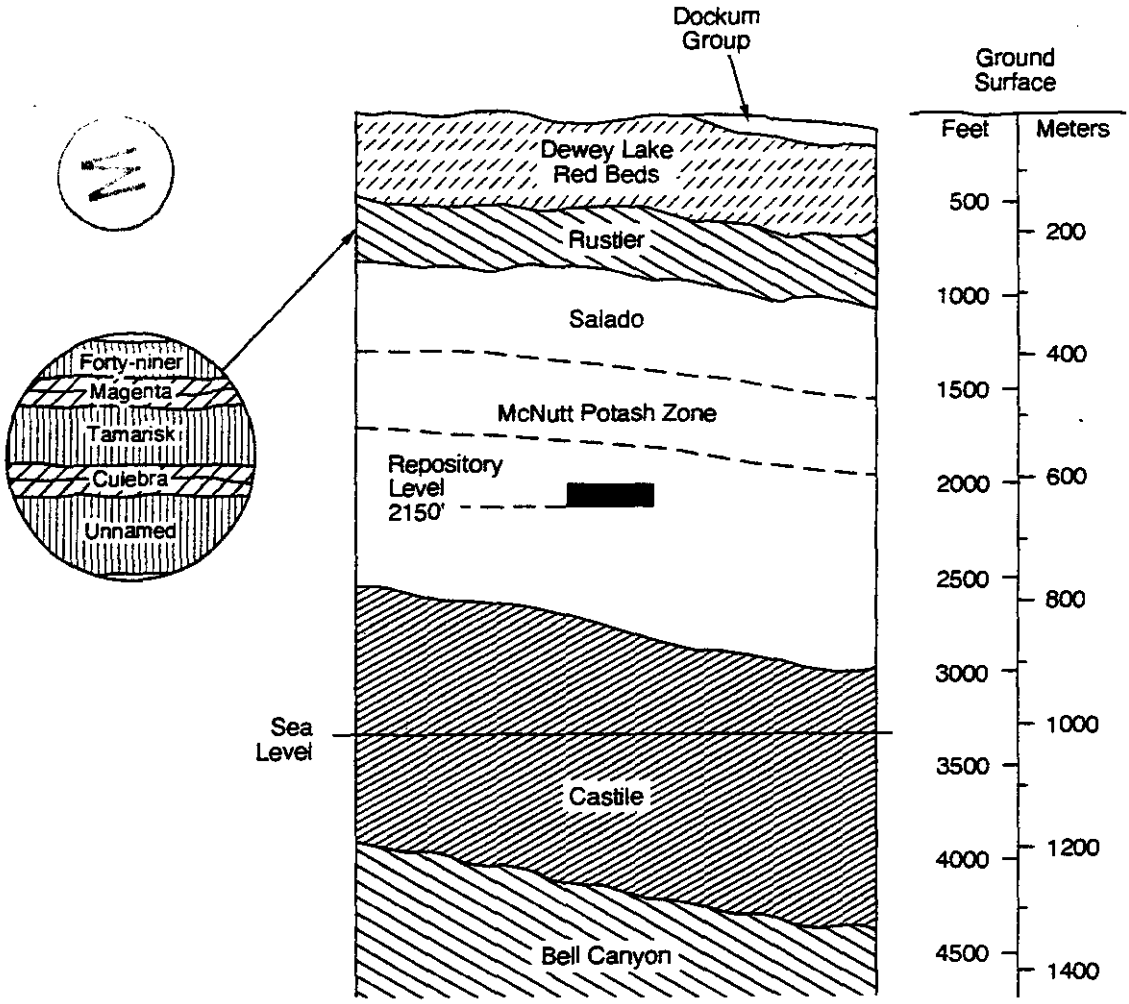

Figure 1-2

Level of WIPP Repository and Generalized Stratigraphic Column (Rechard, 1989)

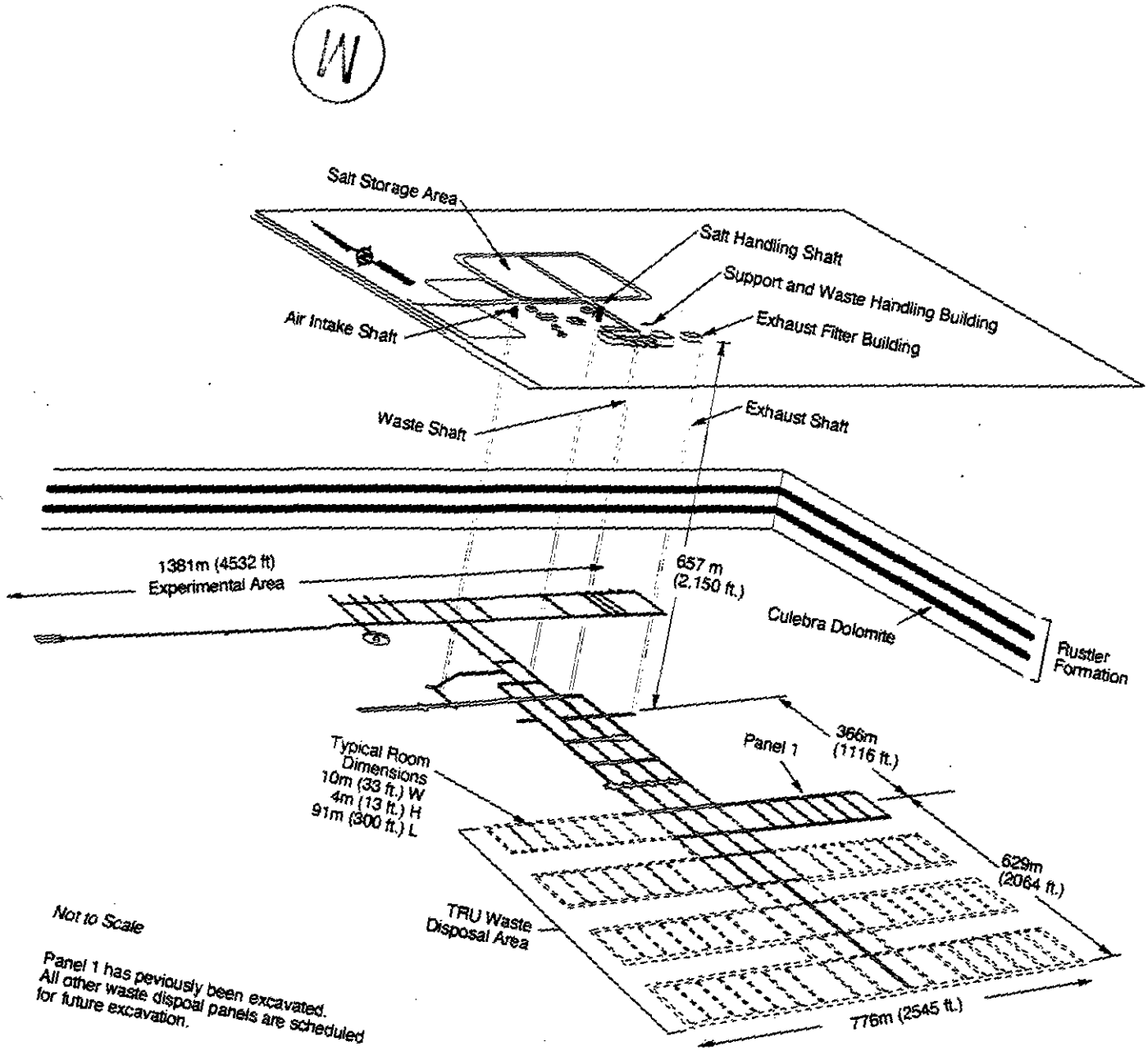

Figure 1-3
Proposed WIPP Repository Showing Both TRU Disposal Areas and Experimental Areas (Nowak et al., 1990)

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processes that generate the waste are plutonium recovery operations, glove box operations, and the operation of on-site analytical and research and development laboratories. The waste destined for the WIPP site is either solid or solidified material and can be grouped into three major waste forms:

- Sludges
- Solid organic (combustible) waste
- Solid inorganic (glass/metal, etc.) waste.

Sludges are predominantly inorganic solidified wastes with some form of solidifying or stabilizing agent, usually a cement-based material. A small percentage of sludges designated as "organic sludges" may contain organic solvents in greater than trace (>1 weight percent) quantities (DOE, 1994f). Solid organic waste consists of organic materials (sometimes referred to as "combustible" waste) such as paper, plastic, tissues, plywood, etc. Solid inorganic waste consists of metals, glass, and a small percentage of other noncombustible material. All waste types are in a chemically stable and nonreactive form (DOE, 1990c) and have been stored and handled at the waste generator and disposal sites for over four decades. The wastes generated at the different sites are generally comparable, and for the most part, can all be grouped under the three waste forms listed above (DOE, 1990c).

The waste is generally packaged in plastic bags (polyethylene and/or polyvinyl chloride) that are placed inside the waste containers (55-gallon steel drums or larger metal boxes) (DOE, 1994f). These different layers of confinement serve as barriers for radioactive materials in the waste. The waste containers are fitted with carbon composite filters to prevent the build-up of gas pressure in the containers, while retaining any particulates inside the containers (NRC, 1994).

Waste characterization (the constituents and properties) of TRU waste is based on process knowledge and records information, and information from past and current sampling programs in place at the DOE sites. The available waste characterization information has been comprehensively summarized in a number of documents (e.g., DOE, 1995e, DOE, 1994f; DOE, 1990c).

1.2.2 Past EA and Related Studies

Prior to the DOE initiating this cost benefit study, designed to provide additional information for use in selecting or rejecting EAs for the WIPP, Performance Assessment (PA) (SNL, 1993), EA effectiveness and feasibility studies (DOE, 1991a), and other repository performance studies have been conducted at WIPP.

Preliminary performance assessment analyses of the WIPP's long-term performance undertaken in the late 1980s indicated that two potential problems could lead to the inability of demonstrating compliance: (1) gas generation in the repository leading to excess pressure that could serve as a driving force for transport to the boundary, and (2) future inadvertent human intrusion events. The identification of these problems led to a list of associated performance parameters and an associated list of design enhancements including modifications to the facility, to the waste forms, and/or other design variations. These candidate design enhancements are referred to as engineered alternatives and were evaluated for their feasibility of reducing or eliminating gas generation and/or the consequences of human intrusion events. An evaluation of the risk to human health was not part of this PA assessment.

The DOE established the Engineered Alternatives Task Force (EATF) in September of 1989, and chartered it to identify and screen potential EAs with respect to both effectiveness and feasibility of implementation to address the concerns about gas generation and human intrusion. The EATF, in turn, chartered an Engineered Alternatives Multidisciplinary Panel (EAMP) which screened an initial 64 alternatives to 36. The EATF then combined these candidates into 14 logically consistent and potentially viable "engineered alternatives." These 14 candidates, plus a baseline, were evaluated with respect to relative effectiveness and feasibility in addressing gas generation and inadvertent human intrusion impacts. The EATF issued its final report in July 1991 (DOE, 1991a). In order to maximize the benefits of the EATF evaluations and to provide timely integration of EATF activities with SNL PA, these programs were conducted in parallel. The overall purpose of the alternatives evaluation by the EATF was to enhance performance of the WIPP to meet regulatory requirements for containment.

This EACBS differs from the EATF study in two fundamental ways. First, in the current study, EAs are assessed against eight specific factors (as prescribed in 40 CFR 194) that provide the data and information for use in selecting or rejecting an EA based on a set of screening criteria. Second, the 1991 EATF study was aimed at identifying alternatives which, if needed, would *improve disposal system performance to the point where compliance with quantifiable standards* was achieved. The current study begins with the assumption that regulatory compliance can be demonstrated with the current baseline and that these alternatives could be used to enhance the performance of the WIPP disposal system through treatment of the uncertainty about the qualitative performance predictions.

1.2.3 Regulatory Topics

The WIPP disposal system must demonstrate compliance with the requirements imposed by several regulations. The DOE must demonstrate compliance with Subparts B and C of 40 CFR 191. These regulations call for a PA to be used to predict the expected cumulative releases of radionuclides to the accessible environment over 10,000 years. The PA uses numerical modeling to predict whether the performance of the disposal system can reasonably be expected to meet the requirements of 40 CFR 191. The numerical modeling is supported by experimental programs and expert judgement as appropriate. Results of the PA are quantitative in nature and will indicate whether the WIPP design meets the numerical performance measures specified in the 40 CFR 191 standard. Therefore, the calculated results of a final PA can only be used to indicate that the disposal system does or does not comply. This point is important because the results of the EACBS are not in a form that will lend themselves to such comparative analysis using alternative PA results.

The 40 CFR 191 regulations also specify that assurance measures will be implemented at WIPP. These assurance measures provide additional confidence and thereby complement compliance *with the containment requirements of 40 CFR § 191.13. Assurance measures planned for the* WIPP include active institutional controls, monitoring, passive institutional controls, and both natural and engineered barriers. Natural and engineered barriers that are currently part of the baseline include the favorable geology; hydrology, and the shaft sealing system. The EACBS was designed to identify candidate EAs that could be used to address the assurance requirements by providing the information necessary to allow a decision for their use beyond that necessary to meet the regulatory containment requirements. As part of the assurance requirements, EAs may be complementary to the numerical performance predictions by adding

confidence to prediction of the disposal system performance through treatment of the uncertainty associated with the calculated performance prediction.

A distinction between compliance with the numerical requirements for containment and assurance must be maintained. Compliance relates to the regulatory performance limits applicable to the WIPP, whereas assurance relates to enhancing performance or reducing uncertainty associated with a compliance determination. This study assumes the baseline repository design is compliant with all 40 CFR 191 requirements. If an EA is selected by the DOE based on information in this report, utilization of the EA will be in addition to the engineered barriers already incorporated in the baseline.

1.3 PROGRAM DRIVERS

This study is intended to provide potential valuable measures to be used for enhancing repository performance or reducing uncertainty associated with a compliance determination should the DOE determine that such steps are justifiable. A proactive approach was used through the assessment of recent DOE, EPA, and NACEPT interactions that concluded that investigating the potential benefits and detriments of additional engineered barriers is a logical and responsible endeavor.

2.0 PROGRAM APPROACH

2.1 METHOD USED TO ANALYZE ENGINEERED ALTERNATIVES

The EACBS uses a multi-step process to assess and analyze EAs. The basic approach identifies EAs to be considered in the analysis, screens this list to determine that the EA meets specific criteria, and then analyzes each EA in a multifactor analysis producing cost, scheduling, and benefit/detriment information. This process is illustrated in Figure 2-1 and is described further in this section.

The EACBS is composed of these five basic components.

- Identify Potential Engineered Alternatives—A list of potential engineered alternatives is generated. The list is composed of potentially viable alternatives from previous studies and stakeholder input. This list is found in Appendix A.

- Screen Engineered Alternatives—EAs were screened to eliminate alternatives that did not meet a specified criterion for system benefit or detriment. A multidisciplinary working group was used to define the criteria and screen the alternatives. The result of the screening process was a list of potential EAs to include in the cost/benefit analysis and a list of EAs that were rejected from further evaluation. Those EAs that were rejected were qualified with the reason for rejection. The EAs and the reasons for rejection are found in Appendices B and C.

- Optimize Remaining Engineered Alternatives—The EAs that passed the screen were optimized based on technological feasibility and effectiveness to determine the set of EAs for use in the EACBS.

- Analyze Optimized EAs against Eight Factors—The optimized list of EAs were analyzed against the eight factors prescribed in Section 1.0. The output of the analysis was compiled and summarized. The methods, processes, and assumptions used in the analyses were documented.

- Summarize Results—A complete summary of the factor analysis output is presented. The output of the study compares the results from the EA analysis with respect to the baseline.

The EA screening and selection process was designed to allow EAs, from any source, to be considered and independently evaluated. If an EA was to be further analyzed, the EA was independently assessed and documented with respect to each of the eight factors. This approach was taken to ensure that the EACBS would not be influenced by the source of the EAs, the number of EAs analyzed, or their performance. It also ensures that the analysis would be repeatable which allows additional EAs to be analyzed in the future.

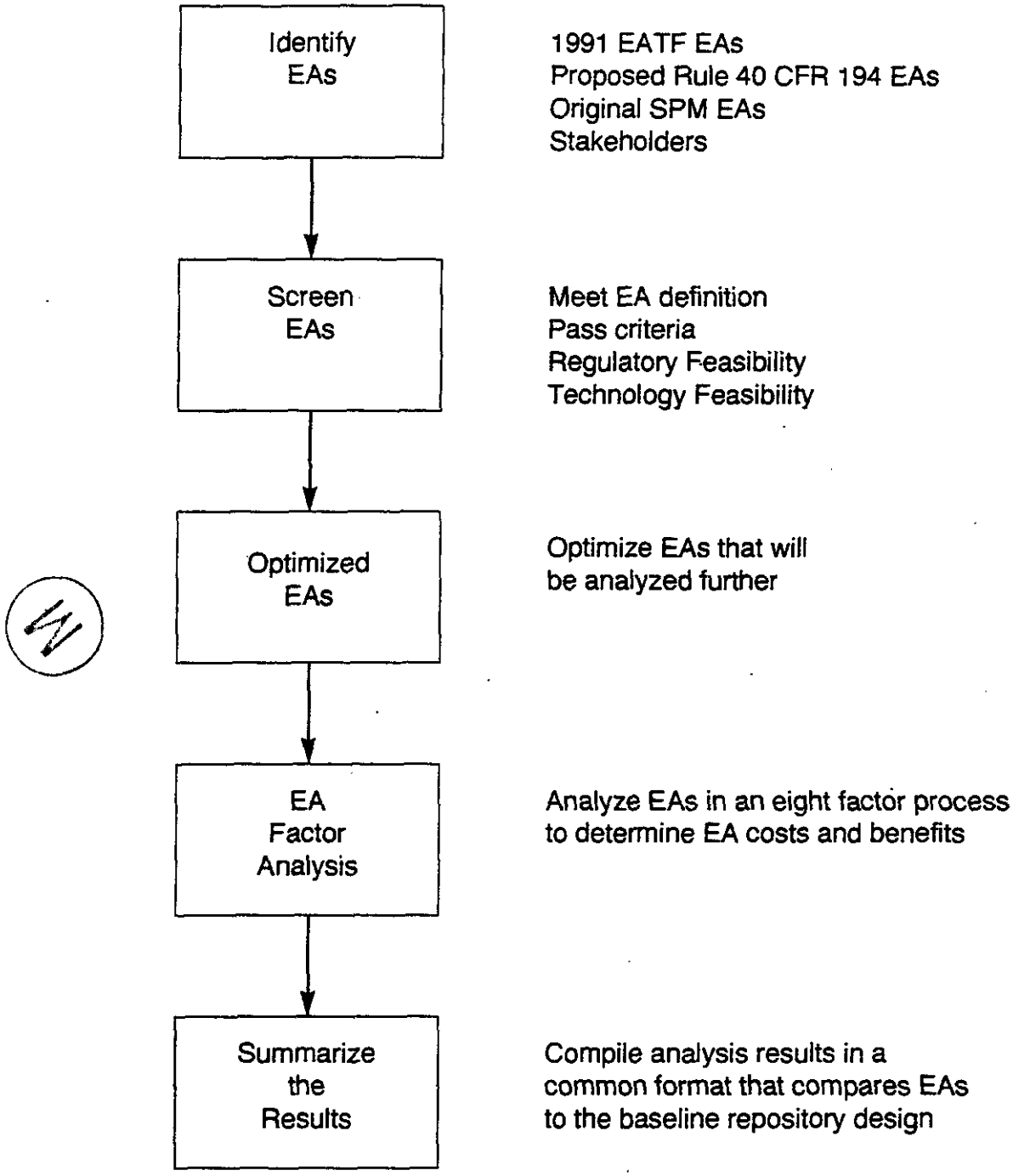

Figure 2-1
EACBS Program Flow Chart

The EACBS identifies potentially valuable measures by analyzing EAs with respect to the following factors:[1]

1. Effects of EAs on long-term performance of the disposal system—This factor analyzes the EA's ability to limit water and radionuclide movement towards the accessible environment and the consequences of human initiated processes or events (human intrusion).

2. The increased or reduced uncertainty in compliance assessment

3. Impact on public and worker exposures to radiation (at the WIPP and off site) both during and after incorporation of an EA

4. The increased ease or difficulty in future removal of the waste from the WIPP disposal system

5. The increased or reduced risk of transporting the waste to the WIPP (radiation and chemical exposures, incidental and accidental)

6. The increased or reduced public confidence in the performance of the disposal system

7. The increased or reduced total DOE waste management system cost and schedule impacts

8. The impact on other waste disposal programs from the incorporation of an EA.

In addition to the factors listed above, the EACBS includes analyses which evaluated:

- Existing waste that is already packaged
- Existing waste that is not yet packaged
- Existing waste that is in need of repackaging
- To-be-generated waste.

2.2 IDENTIFICATION AND SCREENING OF ENGINEERED ALTERNATIVES

2.2.1 Engineered Alternatives Identification

A list of candidates was compiled from the previous EA studies and the proposed rule 40 CFR 194. The list includes the following.

- Sixty-four individual EAs, 14 EA combinations and a baseline found in the Final Report of the Engineered Alternatives Task Force (DOE, 1991a). These are the individual technologies and combinations considered in the original EATF study.

[1]These evaluation factors are prescribed in the EPA proposed rule 40 CFR Part 194. However, Factors 1 and 9 as listed in 40 CFR 194 have been combined in the EACBS.

- Twenty EAs initially considered in the System Prioritization Methodology (SPM).
- Ten EAs found in the proposed rule 40 CFR §194.44.
- Stakeholder input from focus group and technical exchange meetings.

A complete list of the initial EAs can be referenced in Appendix A and was used as input for the screening process. Each EA is identified by a unique number that is used throughout the entire study. During the screening process, selected EAs were refined to allow more detailed evaluation of the results with respect to the technologies associated with the specific EA. These EAs used the same assigned number as the original but a lower case letter was added. This allowed changes to be tracked throughout the study. An example includes EA# 4—Wet Oxidation. The Engineered Alternatives Screening Working Group (EASWG) determined that wet oxidation alone was not a viable EA in and of itself because the resulting treated waste would need to be solidified to be shippable and accepted at WIPP. For this reason, EA # 4 was split into 4a—Wet Oxidation and Cement Solid Organics and 4b—Wet Oxidation and Vitrify Solid Organic Waste. In addition to those EAs passing the screening process, the EASWG added two EAs to the list.

Formal requests were made by the DOE to WIPP stakeholders to provide input into the screening process. During the development of the EACBS, stakeholders suggested EAs, such as vitrification and alternate container materials, for consideration in the EACBS. No new EAs were suggested by stakeholders that were not already being considered in the study.

2.2.2 Screening Process

A two-tiered approach was used to screen the initial list of EAs. The first tier consisted of qualitatively comparing conceptual technologies to a precise definition of an EA. The second tier consisted of qualitatively comparing those conceptual technologies that met the definition of an EA with a must satisfy criteria. One hundred and eleven EAs (109 plus 2 added by the EASWG), including combinations of EAs, were subjected to the screening process listed in Appendix A. Two lists were generated, one listing the EAs that passed, the other listing those rejected based on not meeting the definition of an EA. The screening process is illustrated in Figure 2-2.

2.2.2.1 Screening

The screening process conducted by the EASWG is described in detail in "Engineered Alternatives Cost Benefit Study Screening Report," Appendix D. The EASWG was comprised of a professional facilitator and technical professionals from the following fields:

- Waste management
- Waste processing
- Probabilistic risk assessment
- Transportation engineering
- Environmental engineering
- Mine engineering
- Radiation risk assessment
- Chemical engineering
- Cost/schedule assessment
- Public relations.

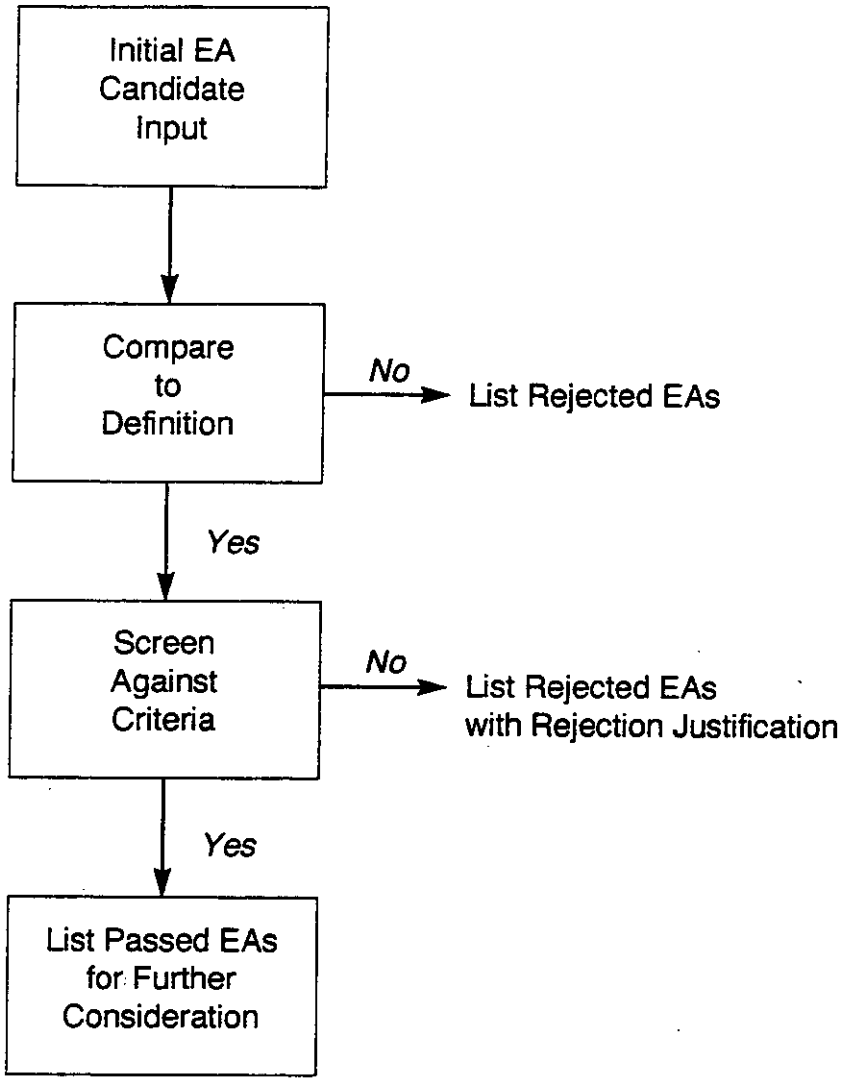

Figure 2-2
EACBS Screening Process

The individuals chosen to participate in the EASWG activities had technical experience in the fields listed and had direct knowledge of the WIPP project and/or other DOE waste management programs. Additional information regarding the details of the screening process, identification of the individuals assigned to the EASWG, and resumes of their experience can be found in Appendix D.

The EASWG met on April 24, 25, and 26, 1995 and again on May 1, 2, and 3, 1995.

From a review of the scoping report (Appendix D) the working group broke the screening process down into the following steps:

1. Review the definition of an EA.
2. Review the screening criteria.
3. Review the EA candidates and their definitions.
4. Outline the screening process.
5. Compare the EA candidates to the EA definition. Document the results.
6. Determine if the EAs that met the definition also meet the screening criteria.
7. Document the results.

The components of the EA screening process are discussed in the following sections.

2.2.2.2 Engineered Alternative General Definition

The EASWG first developed the definition of an EA for use at WIPP, this definition states:

> An EA is a technically feasible process, technology, method, repository design, or waste form modification which makes a significant positive impact on the disposal system in terms of reducing uncertainty or improving long-term performance. An EA must meet the definition of a "barrier" (engineered or man-made aspect of definition) as defined in 40 CFR 191 and the final waste form must meet the WIPP Waste Acceptance Criteria (WAC).

To meet the definition, an EA must satisfy at least one of the following conditions.

- Reduce permeability of the waste stack.
- Increase the shear strength of the waste form.
- Reduce the total gas produced from the waste form by:
  - Reducing corrosion potential or rate
  - Reducing microbial activity
  - Isolating or lowering available water/brine contact with the waste[2]
- Reduce the transport rate of radionuclides.
- Reduce the consequences of human initiated processes or events.

[2]Radiolysis gas generation is not a critical issue and is not a significant factor in gas generation (WID, 1995b).

- Reduce the solubility of the radionuclides.

2.2.2.3 Screening Criteria

The EASWG based the screening criteria on those used in the EATF. The EATF, in developing its final report (DOE, 1991a), used a process which subjected EAs to a "must satisfy" criteria consisting of three elements:

- Regulatory compliance and permitting
- Availability of technology
- Schedule of implementation.

In reviewing the criteria used previously, the EASWG concluded that the EATF criteria are based on feasibility and abbreviated two of the titles to Regulatory Feasibility and Technological Feasibility. The EASWG also noted that the scheduling criterion is inherent in each of the feasibility criteria and therefore did not consider schedule as a separate requirement.

Regulatory Feasibility requires that the technology of EAs being considered must be licensable or permittable in today's political climate. The EA or technology must have a likelihood to demonstrate regulatory compliance including local, state, or federal permits to operate. Technological Feasibility requires that the EA must have been demonstrated at a minimum of laboratory bench scale and must have the potential for full-scale implementation in the future (Appendix D). All EAs that were eventually analyzed in the EACBS contain technologies that were beyond bench scale.

2.2.2.4 Review Engineered Alternatives and their Definitions

The EASWG reviewed the EAs listed in Appendix A and made adjustments to the list, as appropriate. Some of the original titles were modified to expand on which waste types were used with the technologies. Some of the definitions were clarified or expanded to update advancements in technologies since 1991. The following summarizes these adjustments:

EA 4—Wet Oxidation

EA 4, Wet Oxidation, was divided into 4a (Wet Oxidation and Cement) and 4b (Wet Oxidation and Vitrify). Wet oxidation alone would not meet the WAC of no free liquids. Cementation and Vitrification represented two technologies for stabilizing the waste and meeting the criterion.

EA 11—Melt Metals

EA 11, Melt Metals, was divided into 11a (Melt Metals) and 11b (Melt Metals and Partition Actinides with Frit). EA 11a (Melt Metals) provides for casting the metals into ingots prior to disposal in the WIPP. EA 11b (Melt Metals and Partition Actinides with Frit) provides for adding glass frit to partition the radionuclides into slag, removing the slag for disposal at WIPP and casting the metal into ingots for disposal in an low-level waste (LLW) facility.

EA 16—Acid Digestion

EA 16, Acid Digestion, was divided into 16a (Acid Digestion and Cement) and 16b (Acid Digestion and Vitrify) for the same reasons that initiated dividing EA 4 into two separate EAs.

EA 110—Enhanced Solidification of Sludges

EA 110, Enhanced Solidification of Sludges, was developed when the EASWG recognized that cementation had been used along with other process enhancements for EAs but that no single EA employed an enhanced cementation process for sludges.

EA 111—Clay Base Backfill

EA 111, Clay Base Backfill, provides for using both swelling (i.e., bentonite) and non-swelling clays with or without other backfill additives (grout or salt).

2.2.2.5 Outline the Screening Process

The following outline was developed by the EASWG for screening EAs:

1. Compare EA to definition and determine if the EA is positive or detrimental to the disposal system.

2. Identify duplicate EAs and delete.

3. Compare remaining EAs to screening criteria
   a. Regulatory Feasibility
   b. Technological Feasibility.

This outline is illustrated in Figure 2-2.

2.2.2.6 Compare the Engineered Alternative Candidates to the EA Definition

The EASWG compared each of the EAs to the general definition of an EA. Two lists were developed based on this review. The "pass" list identified those EAs that met the definition. The "reject" list identified those EAs that did not meet the definition. The reject list documented the working group's rationale for determining why the specific EA did not met the general definition. The original reject list can be found in Appendix D. The pass list is addressed in more detail in Section 2.2.3 below.

2.2.2.7 Compare the Engineered Alternatives to the Screening Criteria

The Pass list EAs were then individually evaluated against the screening criteria defined as Regulatory Feasibility and Technological Feasibility. Some of the Pass list EAs where screened out as a result of evaluating their properties against these two criteria.

2.2.2.8 Description of Screening Output

The pass list described above is comprised of 54 total EAs. Appendix B contains a list of the EAs

which passed the EA definition and screening criteria. Included in Appendix B is a brief description of individual EAs and a justification for the EASWG's assigning each EA to the pass list.

None of the EAs identified in proposed rule 40 CFR 194 (EA 100 through EA 109) were assigned to the Pass List. The justifications for rejecting these EAs were either that the individual EAs where duplicate to EAs on the Pass List or that the EA was inherent in other EAs on the Pass List. For a detailed explanation of each EA that was rejected, see Appendix C.

2.2.3 Engineered Alternatives Optimization

The EACBS began with 111 potential EAs and used the screening process described in Section 2.2.2, Screening Methods, to screen this list down to 54. The initially screened EAs were further optimized to determine the optimal set of EAs to focus upon. The optimization of EAs was needed to determine which EAs should be included in the benefit/detriment analysis based on relative potential importance.

The optimization was done with two steps. First, an optimization method was developed and EA recommendation made. The DOE-CAO then used the optimization information to identify the final list of EAs to be considered in the EACBS analysis.

2.2.3.1 Initial Optimization

A method was developed to optimize the list of 54 screened alternatives found on the pass list. This method based EA selection on alternatives that were very feasible, very effective, or combinations of these attributes. The method selected EAs that addressed all disposal system performance parameters, both singly and in combinations. The method scored the 54 EAs in technological and regulatory feasibility categories, as well as effectiveness in the four general categories of performance; gas generation, actinide solubility, waste permeability, and waste shear strength. Once the qualitative assessments were completed by the EASWG, an objective statement was made and criteria developed. Based on the criteria and relative scores, a recommendation of EAs for further analysis was made. Appendix D describes the initial optimization process in detail and presents the qualitative assessment of EA feasibility and effectiveness along with the list of 14 optimized EAs.

2.2.3.2 Second Optimization

The list of 14 EAs was reviewed by DOE-CAO and further processed into a list of nine EAs plus nine EA variations. This process took into account recent SPM analysis results concluding that gas generation, a disposal system performance parameter, is not a critical issue for the WIPP repository. This method eliminated parameters that are primarily concerned with reduction in gas generation potential and added several alternatives that will provide benefit related to actinide solubility, waste strength, and waste permeability—issues that have been found to be critical performance parameters. The salt backfill alternative #12 was removed because salt is used in improving disposal system performance and in other selected EAs as a filler material.

During the DOE-CAO review, modifications were made to the nine selected EAs. These modifications considered other backfills in the combination EAs and modified some of the original backfills. Appendix A, Table A-3 details the changes made to the original list of 14 EAs and

briefly describes the modifications. The finalized list of 18 EAs used in the EACBS are referenced in Table 2-1. The results of the screening and optimization process are summarized in Figure 2-3. This figure illustrates the EAs that were selected for additional analysis after each round of evaluation.

2.2.3.3 Conclusion

Optimization of EAs initially assessed the technological and regulatory feasibility for the 54 EAs. A qualitative assessment was made on the effectiveness of each EA in addressing gas generation, actinide solubility, waste permeability, and waste strength. The EACBS chose not to include transportation and consequence of human intrusion in this assessment. The results of this assessment were used to recommend 14 initial EAs to the DOE-CAO. The DOE used the initial optimization information and recent information from the SPM and other related studies to further identify the EAs. This resulted in the 18 final EAs that were analyzed in the EACBS.

2.3 PROGRAM PARAMETERS AND GUIDING ASSUMPTIONS

The EACBS was performed using a well defined set of guiding assumptions, EA definitions, and parameter values. These values, assumptions, and definitions are discussed below.

2.3.1 Engineered Alternatives Definitions

The baseline and the 18 final EAs were evaluated by the EACBS and are described in detail in the following subsections. Table 2-2 summarizes and compares the characteristics of each of the EAs.

The 18 EAs are composed of nine basic EAs and nine variations of those basic EAs (see Table 2-1). Only the baseline and the nine basic EAs are described to preclude redundancy.

2.3.1.1 Baseline Treatment to the WIPP WAC

The baseline for managing TRU waste includes retrieving waste from earth-covered storage, characterizing the waste in accordance with the requirements of the Transuranic Waste Characterization Quality Assurance Program Plan (QAPP) (DOE, 1995d), treating and repackaging the waste only as necessary to meet the requirements of the WIPP WAC (DOE, 1991c), storing the waste, certifying that the waste meets WIPP WAC requirements, and shipping the waste to WIPP for disposal. Each of the DOE sites that stores and/or generates TRU waste will be responsible for developing the capabilities needed to characterize and ship its TRU waste. Smaller sites may send their waste to larger sites for treatment and interim storage pending shipment to WIPP.

Characterization of TRU waste packages includes:

- Nondestructive assay—Techniques used to identify and quantify radionuclides in TRU waste.

- Radiography—A nondestructive testing method that utilizes X-rays to inspect and determine the physical form of waste.

1

TABLE 2-1

EAS ANALYZED IN THE EACBS

ID Number	Description
#1	Supercompact Organics and Inorganics, no backfill, as received sludges.
#6	Shred and Compact Organics and Inorganics, no backfill, as received sludges.
#10	Plasma Processing of All Waste, no backfill.
#33	Sand Plus Clay Backfill, as received waste.
#35a	Salt Aggregate Grout Backfill Around Drums, as received waste.
#35b	Cementitious Grout Backfill, as received waste.
#77a	Supercompact organics and inorganics, salt aggregate/grout backfill, monolayer of 2000 drums in a 6- x 33- x 300-foot room.
#77b	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums in a 6- x 33- x 300-foot room.
#77c	Supercompact organics and inorganics, sand/clay based backfill, monolayer of 2000 drums in a 6- x 33- x 300-foot room.
#77d	Supercompact organics and inorganics, salt/CaO backfill, monolayer of 2000 drums in a 6x33x300 foot room.
#83	Salt backfill with CaO, as received waste.
#94a	Enhanced cement sludges, shred and add clay based material to organics and inorganics, no backfill.
#94b	Enhanced cement sludges, shred and add clay based material to organics and inorganics, sand/clay grout backfill.
#94c	Enhanced cement sludges, shred and add clay based material to organics and inorganics, cementitious grout backfill.
#94d	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.
#94e	Enhanced cement sludges, shred and add clay based material to organics and inorganics, clay based backfill.
#94f	Enhanced cement sludges, shred and add clay based material to organics and inorganics, CaO/Salt backfill.
#111	Clay Based Backfill, as received waste.
Baseline	Baseline disposal system design, no backfill, treatment to WIPP WAC.

Original List of Potential Engineered Alternatives

EATF-1	EATF-29	EATF-57	SPM-E
EATF-2	EATF-30	EATF-58	SPM IT-1
EATF-3	EATF-31	EATF-59	SPM IT-2
EATF-4	EATF-32	EATF-60	SPM IT-3
EATF-5	EATF-33	EATF-61	SPM IT-4
EATF-6	EATF-34	EATF-62	SPM IT-5
EATF-7	EATF-3 5	EATF-63	SPM IT-6
EATF-8	EATF-36	EATF-64	SPM IT-7
EATF-9	EATF-37	EATF-Baseline	SPM IT-8
EATF-10	EATF-38	EATF-Alt. 1	SPM IT-9
EATF-11	EATF-39	EATF-Alt. 2	SPM IT-10
EATF-12	EATF-40	EATF-Alt. 3	SPMEATF-8
EATF-13	EATF-41	EATF-Alt. 4	SPMEATF-9
EATF-14	EATF-42	EATF-Alt. 5	SPM DOE-1
EATF-15	EATF-43	EATF-Alt. 6	SPM DOE-2
EATF-16	EATF-44	EATF-Alt. 7	CFR-100
EATF-17	EATF-45	EATF-Alt. 8	CFR-101
EATF-18	EATF-46	EATF-Alt. 9	CFR-102
EATF-19	EATF-47	EATF-Alt. 10	CFR-103
EATF-20	EATF-48	EATF-Alt. 11	CFR-104
EATF-21	EATF-49	EATF-Alt. 12	CFR-105
EATF-22	EATF-50	EATF-Alt. 13	CFR-106
EATF-23	EATF-51	EATF-Alt. 14	CFR-107
EATF-24	EATF-52	SPM-Baseline	CFR-108
EATF-25	EATF-53	SPM-A	CFR-109
EATF-26	EATF-54	SPM-B	EASWG-110*
EATF-27	EATF-55	SPM-C	EASWG-111*
EATF-28	EATF-56	SPM-D	

Potential Engineered Alternatives After First Round of Screening

EATF-1	EATF-63
EATF-2	EATF-64
EATF-3	EATF-Alt. 1
EATF-4a	EATF-Alt. 2
EATF-4b	EATF-Alt. 3
EATF-5	EATF-Alt. 4
EATF-6	EATF-Alt. 5
EATF-7	EATF-Alt. 6
EATF-8	EATF-Alt. 7
EATF-9	EATF-Alt. 8
EATF-10	EATF-Alt. 9
EATF-11a	EATF-Alt. 10
EATF-11b	EATF-Alt. 11
EATF-12	EATF-Alt. 12
EATF-15	EATF-Alt. 13
EATF-16a	EATF-Alt. 14
EATF-16b	SPM-C
EATF-19	SPM IT-2
EATF-22	SPM IT-3
EATF-29	SPM IT-4
EATF-33	SPM IT-5
EATF-35	SPM IT-7
EATF-36	SPM IT-8
EATF-38	SPM IT-9
EATF-51	SPM IT-10
EATF-53	EASWG-110
EATF-60	EASWG-111

Potential Engineered Alternatives First Optimized List

EATF-10
EATF-12
EATF-33
EATF-35
EATF-53
EATF-60
EATF-63
EATF-Alt. 9
EATF-Alt. 10
SPM-C
SPM IT-4
SPM IT-9
SPM-IT-10
EASWG-110

Final List of Engineered Alternatives for the EACBS Analysis

EATF-1
EATF-6
EATF-10
EATF-33
EATF-35a
EATF-35b
EATF-Alt. 12a
EATF-Alt. 12b
EATF-Alt. 12c
EATF-Alt. 12d
SPM-C
SPM IT-9a
SPM IT-9b
SPM IT-9c
SPM IT-9d
SPM IT-9e
SPM IT-9f
EASWG-111

EATF = Engineered Alternative Task Force
CFR = Code of Federal Regulations
SPM = System Prioritization Method
EASWG = Engineered Alternatives Study Working Group
* = Added by the EASWG

Stake holder inputs not included, however all stateholder EAs were duplicates of those listed in this table. For additional detail see Section 2.2.1

Figure 2-3
Summary of Engineering Alternative screening Process Results

TABLE 2-2

SUMMARY OF ENGINEERED ALTERNATIVES EVALUATED BY EACBS RELATIVE TO THE BASELINE

Identifier	Alternative	Sludges	Solid Organic	Solid Inorganic	Backfill	Facility Design
0	Baseline	As received	As received	As received	None	Baseline
1	Supercompact waste	As received	Supercompacted	Supercompacted	None	Baseline
6	Shred and compact	As received	Shred and Compact	Shred and Compact	None	Baseline
10	Plasma processing of all waste	Plasma Processed	Plasma Processed	Plasma Processed	None	Baseline
33	Sand plus clay backfill	As received	As received	As received	Sand Plus Clay Backfill	Baseline
35.a	Salt aggregate grout backfill	As received	As received	As received	Salt Aggregate Grout Backfill	Baseline
35.b	Cementitious grout backfill	As received	As received	As received	Cementitious Grout Backfill	Baseline
77.a	Supercompact organics and inorganics, salt aggregate grout backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Salt Aggregate Grout Backfill	6X33X300
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Clay based backfill	6X33X300
77.c	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums	As received	Supercompact	Supercompact	Sand/clay backfill	6X33X300
77.d	Supercompact organics and inorganics, salt plus CaO backfill monolayer of 2000 drums	As received	Supercompact	Supercompact	Salt plus CaO Backfill	6X33X300
83	Salt backfill with CaO	As received	As received	As received	Salt plus CaO Backfill	Baseline
94.a	Enhanced cement sludges, shred and cement organics and inorganics, no backfill	Enhanced Cement	Shred and add clay	Shred and add clay	No backfill	Baseline

TABLE 2-2 (Concluded)

SUMMARY OF ENGINEERED ALTERNATIVES EVALUATED BY EACBS RELATIVE TO THE BASELINE

Identifier	Alternative	Sludges	Solid Organic	Solid Inorganic	Backfill	Facility Design
94.b	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Clay/sand backfill	Baseline
94.c	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Cementitious Grout	Baseline
94.d	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Salt Aggregate Grout	Baseline
94.e	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Clay	Baseline
94.f	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	Enhanced Cement	Shred and Add Clay	Shred and Add Clay	Salt plus CaO Backfill	Baseline
111	Clay Based Backfill	As received	As received	As received	Clay Based Backfill	Baseline

- Sampling and analysis of headspace gas—the collection and analysis of samples of headspace gas. Headspace gas will be analyzed to determine the quantities of hydrogen, methane, and listed volatile organic compounds (VOCs) in the gas.

- Sampling and analysis of homogenous solids and soil/gravel—the collection and analysis of representative samples of waste materials classified as homogenous solids and soil/gravel. The samples will be analyzed to quantify the amounts of VOCs, semi-volatile organic compounds (SVOCs) and metals in the samples.

- Visual examination—as a quality control check on radiography, a statistically selected portion of the waste containers must be opened and visually examined.

The WIPP WAC sets limits on the amounts of free liquids, particulates, and pyrophoric materials (pyrophoric radionuclides) that are acceptable in TRU waste packages, and identifies items that are prohibited from being in TRU waste packages, including explosives and compressed gasses. If waste packages contain items that do not meet the WIPP WAC, as determined by radiographic examination, then the waste packages will be opened and the nonconforming items will be removed and treated such that they will meet the WIPP WAC requirements (e.g., liquids will be solidified, particulates will be stabilized, and compressed gas containers will be punctured). Treatment and repackaging will only be done to the extent required to meet the requirements of the WIPP WAC. For this study, it was assumed that all newly generated sludges will be cemented, and that some of the stored sludges will require re-cementing to meet WIPP WAC requirements. Wastes will be stored and managed in accordance with site-specific requirements.

2.3.1.2 Alternatives #1 and #77—Supercompact Solid Organic and Solid Inorganic Wastes

For this study, the supercompaction process is modeled after the Supercompaction and Repackaging Facility (SARF) which is in operation at the Rocky Flats Environmental Technology Site (RFETS) (DOE, 1995c). The SARF is the only supercompaction facility in the United States specifically designed to treat TRU waste. Only solid organic and solid inorganic wastes are suitable for supercompaction. In this alternative, sludges will be solidified as in the baseline according to existing procedures to meet WIPP WAC requirements.

In the SARF process, waste is first emptied into a glovebox where it is sorted to remove items which cannot be supercompacted (e.g., unpunctured aerosol cans). The incompatible items will be either treated such that they can be supercompacted (e.g., puncturing the aerosol can), or packaged such that they meet WIPP WAC requirements and sent to WIPP for disposal without supercompaction. Items suitable for supercompaction are then compacted into a 35-gallon (132-liter) drum using a low-force (30 metric ton) compactor. The compacted 35-gallon (132-liter) drums are then transferred to the supercompactor. The supercompactor applies a high force (1,500 to 2,000 metric tons) to the 35-gallon (132-liter) drum to compact the waste material into a smaller volume. The compacted drum, called a "puck," is then transferred to a 55-gallon (208-liter) drum for final packaging to WIPP WAC requirements. On average, 4 pucks can be packaged into each 55-gallon (208-liter) drum. The volume reduction ratio for supercompaction is assumed to be 2.9:1. The final waste density is assumed to be 104.8 pounds (lb) (47.5 kg)/per cubic feet (ft^3), compared to an initial density of approximately 33.3 lb (15.1 kg)/ft^3. Density is increased over that resulting simply from the volume reduction ratio because of the additional metal from the compacted drums.

With the exception of adding supercompaction, all of the other elements of the baseline are part of this alternative, including waste retrieval, waste characterization, waste storage, waste certification, and transportation. The waste placed in the repository will be load managed such that the radionuclide inventory per panel will be identical to the baseline.

2.3.1.3 Alternative #6—Shred & Compact Solid Organic and Solid Inorganic Wastes

For this study, the shred & compaction process is modeled after commercially available techniques that have been successfully used for low-level waste and TRU waste (Moghissi et al., 1986; Owens, 1995). Only solid organic and solid inorganic wastes are suitable for shred and compaction. In this alternative, sludges will be solidified as in the baseline according to existing procedures to meet WIPP WAC requirements.

The initial waste processing step is size reduction, using a shredder, such that no individual waste item has a dimension greater than 4 inches. The shredded waste is then compacted into a 55-gallon (208-liter) drum using a low-force (30 metric ton) compactor. This process is repeated, adding more waste to the drum and compacting it, until the drum is full. Once the drum is full, a lid is installed and the drum is sent to storage. The volume reduction ratio for shred and compaction is assumed to be 1.3 : 1. The final waste density is assumed to be 48.3 lb (21.9 kg)/ft^3, compared to an initial density of approximately 33.3 lb (15.1 kg)/ft^3.

With the exception of shredding and compacting waste, all of the other elements of the baseline are maintained in this alternative, including waste retrieval, waste characterization, waste storage, waste certification, and transportation. The waste placed in the repository will be load managed such that the radionuclide inventory per panel will be the same as the baseline.

2.3.1.4 Alternative #10—Treat All Wastes in Plasma Melter

For this study, the plasma melting process is modeled after the Plasma Arc Centrifugal Treatment (PACT) system that has been developed by Retech, Inc., and will be used by Lockheed Martin Environmental Systems and Technologies Co. (LESAT) as part of the Pit 9 Comprehensive Demonstration (LESAT, 1995) at the Idaho National Engineering Laboratory (INEL). This treatment technology is applicable to all waste types, and to achieve optimum operations, it is desirable to process sludges, solid organic, and solid inorganic wastes simultaneously (Nielsen, 1995).

The first step in the plasma melter system is size reduction of the waste using a shredder, such that no individual waste item has a dimension greater than 4 inches. A magnetic separator then removes most of the iron and steel from the shredded waste so that the amount of iron in the final waste form can be controlled to be less than 30 weight percent. This control is important to assure a uniform final waste form. Shredded waste will then be transferred to 55-gallon (208-liter) drums and stored temporarily until it is sent to the PACT system for treatment. The iron and steel that was separated from the waste will also be packaged in 55-gallon (208-liter) drums and stored until it is sent to the PACT system for treatment.

The PACT process is a thermal process that treats waste materials using a rotating crucible into which waste material is introduced for treatment. Treatment of the material will be accomplished with the use of a transferred arc plasma torch operating in an oxygen-rich environment. The operation of the torch in this environment will bring the waste to a molten state, destroy any

organic materials, and oxidize or immobilize any heavy metals. The molten slag will then be poured into 55-gallon (208-liter) drums and allowed to cool. Upon cooling, the final molten slag becomes a non-leachable "glass". Plasma melting results in a volume reduction ratio of approximately 3 : 1 (Nielsen, 1995), and the final waste form is assumed to have a density of 100.5 lb (45.6 kg)/ft^3 compared to an initial average density of 33.1 lb (15 kg)/ft^3.

With the exception of adding the PACT system, all of the other elements of the baseline are maintained in this alternative, including waste retrieval, waste characterization, waste storage, waste certification, and transportation.

2.3.1.5 Alternative #33—Sand Plus Clay Backfill

For this alternative the waste is treated and emplaced in the same manner as for the baseline. A backfill consisting of a mixture of medium grained sand and granulated clay is placed around the waste stack and between the drums filling the void space within the rooms. The backfill is 70% sand and 30% clay by volume. The clay is commercially available granulated kaolinite or illite. The sand and clay are prepared in a hopper or drum mixer and are pneumatically placed around the waste stack after the waste is emplaced. Because of the inefficiencies associated with pneumatically placing a dry fine to medium grained material, a void space of 50% is assumed.

The clay is added to the sand to reduce the hydraulic conductivity of the backfill and impede the flow of brine and the mobility of radionuclides.

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM, 1991) and will fill the space between the waste drums and the room walls (approximately 1.64 ft [0.5 m]). The total volume of backfill material for the entire underground is approximately 3.7 million ft^3 (104,000 m^3). The hydraulic conductivity of the sand plus clay backfill is expected to range from 6 x 10^{-7} meter per second (m/s) at 0 psi stress to 9 x 10^{-9} m/s at 2,200 psi stress.

2.3.1.6 Alternative #35a—Salt Aggregate Grout Backfill

For this alternative the waste is treated and emplaced in the same manner as for the baseline. A cementitious based grout backfill using crushed salt as the aggregate and simulated WIPP brine as the added water, is pumped around the waste stack and between the drums filling the void space within the rooms. Some inefficiencies will occur in placing the grout backfill so a void space of 80% is used.

Crushed salt and simulated WIPP brine are used in the grout in order to reduce chemical incompatibilities that occur between WIPP brine and normal Portland cement based grouts and concretes (Gulick and Wakeley, 1989). The grout mix will be based on the BCT-1F mixture from Gulick and Wakeley (1989).

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM 1991) and will fill the space between the waste drums and the room walls (approximately 1.64 ft [0.5 m]). The total volume of backfill for the entire underground is approximately 5.9 million ft^3 (166,000 m^3) (calculated by 0.8 x 7,346,352 ft^3 [208,000 m^3]). The

hydraulic conductivity of the salt aggregate grout backfill is assumed to be constant throughout the range of expected stresses at 1.3×10^{-12} m/s.

2.3.1.7 Alternative #35b—Cementitious Grout Backfill

For this alternative the waste is treated and emplaced in the same manner as for the baseline. A cementitious grout backfill using ordinary Portland cement, sand aggregate, and fresh water, is pumped around the waste stack and between the drums filling the void space within the rooms. Some inefficiencies will occur in placing the grout backfill so a void space of 80% is assumed.

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM, 1991) and will fill the space between the waste drums and the room walls (approximately 1.64 ft [0.5 m]). The total volume of backfill for the entire underground is approximately 5.9 million ft^3 (166,000 m^3). The hydraulic conductivity of the cementitious grout backfill is assumed to be constant throughout the range of expected stresses at 1.3×10^{-12} m/s.

2.3.1.8 Alternative #83—CaO and Crushed Salt Backfill

For this alternative the waste is treated and emplaced in the same manner as for the baseline. A backfill consisting of commercially available granulated CaO (quick lime) and crushed salt aggregate is pneumatically placed around the waste stack and between the drums filling the void space within the rooms. The mixture consists of less than 10% CaO and 90% crushed salt aggregate. Because of the inefficiencies associated with pneumatically placing a dry material, a void space of 50% is assumed.

The lime is added to increase the pH of the brines in the repository environment and lower radionuclide solubility. At a pH of approximately 8.5 (30 grams CaO/liter of brine) the solubility and mobility of the radionuclides decreases significantly. Higher concentrations of CaO (higher than approximately 10%) will raise the pH of the brine above the optimum range (a pH of 10.0) at which point the solubility and mobility of the radionuclides begins to increase.

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM, 1991) and will fill the space between the waste drums and the room walls (approximately 0.5 m). The total volume of backfill for the entire underground is approximately 3.7 million ft^3 (104,000 m^3). The hydraulic conductivity of the CaO and crushed salt backfill is assumed to range from 7×10^{-2} m/s at 0 pound per square inch (psi) stress to 1×10^{-11} m/s at 2,200 psi stress.

2.3.1.9 Alternative #94—Enhanced Cementation of Sludges, Shred and Add Clay to Solid Organic and Solid Inorganic Wastes

This alternative includes two treatment techniques: (1) sludges will be solidified with engineered cement to improve performance as a waste form, and (2) the solid organic and solid inorganic wastes will be shredded and clay will be added to reduce the void space in the final waste form. For the purposes of this study, the enhanced cementation process will be modeled after existing facilities that solidify radioactive sludge wastes. No facility in the United States is known to shred waste and add clay before storage and/or disposal. However, the required technologies are commonly used in industry and it is anticipated that this treatment system could be developed with little difficulty. For this study, the shred/add clay process will be modeled after facilities that

shred and add cement-based grout to waste. The required equipment should be similar to that now used by shred/add grout and shred/add clay facilities, and the operating costs will be adjusted to account for the difference in materials costs between grout and clay.

The first step in the enhanced cementation process is size reduction of sludges that were previously solidified. Size reduction will be accomplished using a standard industrial crusher/shredder. The crushed waste will then be placed into transfer containers and loaded into a feed hopper. The waste will then be fed from the hopper and mixed with enhanced cement and placed into 55-gallon (208-liter) drums. Newly generated sludges would not be processed for size reduction but would go directly to the feed hopper, similar to the method currently being use to solidify sludges. The exact formula for the enhanced cement has not been determined, but possibilities include sulphur-polymer cement, portland cement with additives, and portland cement mixed with fiberglass. This process has a volume increase ratio of 2.5:1. The density of the final waste form is assumed to be 40.8 lb (18.5 kg)/ft^3 compared to an initial density of 32.3 lb (14.6 kg)/ft^3.

The first step for the shred/add clay process, is size reduction of the incoming waste stream using a shredder, such that no individual waste item has a dimension greater than 4 inches. The shredded waste will then be placed into transfer containers and loaded into a feed hopper. The waste will then be fed from the hopper and mixed with clay (e.g., kaolin) pellets and placed into 55-gallon (208-liter) drums. It is assumed that the clay will fill 80% of the initial void volume in the waste package. The final density of the waste is assumed to be 78.5 lb (35.6 kg)/ft^3 compared to an initial average density of 33.3 lb (15.1 kg)/ft^3. There is also assumed to be no net change to the waste volume (i.e., treatment of one drum of waste results in one drum of treated waste).

With the exception of adding the enhanced cementation and shred/add clay waste processing steps, all of the other elements of the baseline are maintained in this alternative, including waste retrieval, waste characterization, waste storage, waste certification, and transportation.

2.3.1.10 Alternative #111—Clay Based Backfill

For this alternative, waste is treated and emplaced in the same manner as for the baseline. A backfill consisting of commercially available pelletized kaolinite or illite clay (DOE, 1995a) is place pneumatically around the waste stack and between the drums filling the void space within the rooms. Pelletized clay is used to reduce potential dust inhalation safety issues. Because of the inefficiencies associated with pneumatically placing a dry material, a void space of 50% is assumed.

The clay is used to reduce the hydraulic conductivity of the backfill and impede the flow of brine and the mobility of radionuclides.

The backfill is placed to a height of about 1.96 ft (0.6 m) above the top of the waste stack (SNL/NM, 1991). The total volume of backfill for the entire underground is approximately 3.7 million ft^3 (104,000 m^3). The hydraulic conductivity of the clay based backfill is assumed to range from 1 x 10^{-10} m/s at 0 psi stress to 2 x 10^{-13} m/s at 2,200 psi stress.

2.3.2 Program Assumptions

Throughout the analysis of EAs many assumptions were made relative to waste inventory, waste processing, and waste characteristics. Assumptions were used in the basic program approach, the screening process and the actual analysis within the factors. Many of these assumptions are specific to the screening process or factor and are described in the respective screening and analysis factor sections (see Chapter 3.0). The following describes the common guiding assumptions used throughout the EACBS.

- The baseline repository design is in compliance with 40 CFR 191. EAs evaluated in this study will be used to provide additional assurance for a disposal system that is compliant with the containment requirements.

- The analysis is a tool to assess cost and benefit of EAs, not to recommend or rank alternatives. Weighting of factors was not performed as part of this study.

- The output of the EACBS will provide the DOE with information that will allow for the selection or rejection of an EA if additional engineered barriers are desirable.

- For waste processing EAs that increase the actinide concentration in the waste (i.e., volume reduction EAs), rooms and panels will be load managed to maintain the baseline actinide inventories for each room and panel. The waste containers are assumed to be evenly distributed throughout the rooms and panels.

- Schedule analysis was performed to determine the outer bound impact. Emplacement of waste would start only after processing/treatment facilities were on-line. No waste was assumed to be emplaced prior to this date even if the EA did not process all of the waste (i.e., sludges could be emplaced prior to the startup of a shred and grout facility). The baseline, however, did assume waste would be emplaced prior to completion of WIPP WAC treatment facilities. The baseline analysis reports the date processing facilities are on-line, however waste would be emplaced prior to this date.

- All waste processing EAs are performed on 100% of the affected wastes. No EA is assumed to be performed on a percentage of the waste available for processing by the EA. This represents the upper end impacts with the baseline being the lower end. Any variation in the processed waste percentage would fall between these bounds.

- The operational period is assumed to be at least 35 years. The waste processing facilities are assumed to operate for 20 years. These operational periods were assumed because most processing EAs have a nine year startup cycle. This assumes a startup and 20 year processing operation followed by decommissioning could be completed within a 35 year time frame.

- For the EACBS, the waste volume is assumed to be 6.2 million (M) ft^3 (0.175 M m^3). If an EA reduces the waste volume, only 6.2 M ft^3 (0.175 M m^3) of waste will be treated, not the amount that would produce 6.2 M ft^3 (0.175 M m^3) of treated waste. For EAs that increase the waste volume after treatment, only

6.2 M ft^3 (0.175 M m^3) of treated waste will be emplaced, the amount of waste generated in excess of 6.2 M ft^3 (0.175 M m^3) would not be emplaced.

- The reduction of the probability of human intrusion is not considered in the EACBS. Only the consequences of an intrusion event were analyzed. No EA was considered that may reduce the probability of human intrusion, since that type of assurance measure is being considered in passive marker studies.

2.3.3 Alternative Waste Processing Configurations

In addition to the screened EAs, three waste processing site configurations were analyzed. These configurations, called decentralized, regionalized, and centralized, are based on the Draft Environmental Management Programmatic Environmental Impact Statement (EM-PEIS) analysis, and vary by the number of installations at which the selected waste processing facilities would be located. Generally, those installations which have the largest volumes of waste were selected as the locations for treatment of waste under the decentralized and regionalized alternatives. Table 2-3 summarizes the site waste transfers for each of these configurations. RH-TRU waste was only analyzed for the decentralized case.

As shown in Figures 2-4 and 2-5, the decentralized configuration evaluated characterizing and packaging TRU waste at all sites where TRU waste is generated, and shipping CH-TRU waste from the sites with smaller amounts to the nearest of the 10 sites with the largest amounts of TRU waste for treatment and interim storage prior to shipping to WIPP. The RH-TRU waste will be stored at six sites.

As shown in Figure 2-6, the regionalized configuration analyzes the impacts of consolidating CH-TRU waste at the five sites with the largest inventories of waste, and treating the waste in accordance with the various engineered alternatives at these five sites prior to shipping to WIPP.

In the centralized configuration, CH-TRU waste is characterized and packaged at all generating sites and shipped to WIPP for treatment and disposal, as shown in Figure 2-7.

2.3.4 Baseline Definition

The baseline condition is defined as the current design and disposal scheme for the WIPP. The baseline disposal system is described in Section 1.2.1 of this report and the current Final Safety Analysis Report for the WIPP (DOE, 1991b). The baseline includes multiple barriers, both natural and engineered, that isolate the waste from the accessible environment and provide confidence that the performance predictions associated with the containment requirements of 40 CFR 191.13 are met.

2.3.4.1 Baseline Parameters

The WIPP baseline conditions important to the EACBS are:

- The WIPP capacity is 6.2 million ft^3 by volume. The baseline volumes of sludges, organics, and inorganics are projected from current waste inventories.

- No waste processing is required beyond that to meet the WAC.

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TABLE 2-3

WIPP ENGINEERED ALTERNATIVES SITE WASTE TRANSFERS

	Decentralized			
SITE	CH	RH	Regionalized	Centralized
ANL-E	WIPP		SRS	WIPP
Ames	ANL-E		SRS	WIPP
Battelle Columbus		ORR		WIPP
Bettis	Mound	ORR	SRS	WIPP
ETEC	NTS		INEL	WIPP
Hanford	WIPP	WIPP	WIPP	WIPP
INEL	WIPP	WIPP	WIPP	WIPP
KAPL	Mound	ORR	SRS	WIPP
LANL	WIPP	WIPP	WIPP	WIPP
LBL	LLNL		Hanford	WIPP
LLNL	WIPP		Hanford	WIPP
Mound	WIPP		SRS	WIPP
U. of Mo.	ANL-E		SRS	WIPP
NTS	WIPP		INEL	WIPP
ORR	WIPP	WIPP	SRS	WIPP
Paducah	ORR		SRS	WIPP
Pantex	LANL		LANL	WIPP
RFETS	WIPP		WIPP	WIPP
SNL/NM	LANL		LANL	WIPP
SRS	WIPP	WIPP	WIPP	WIPP

M

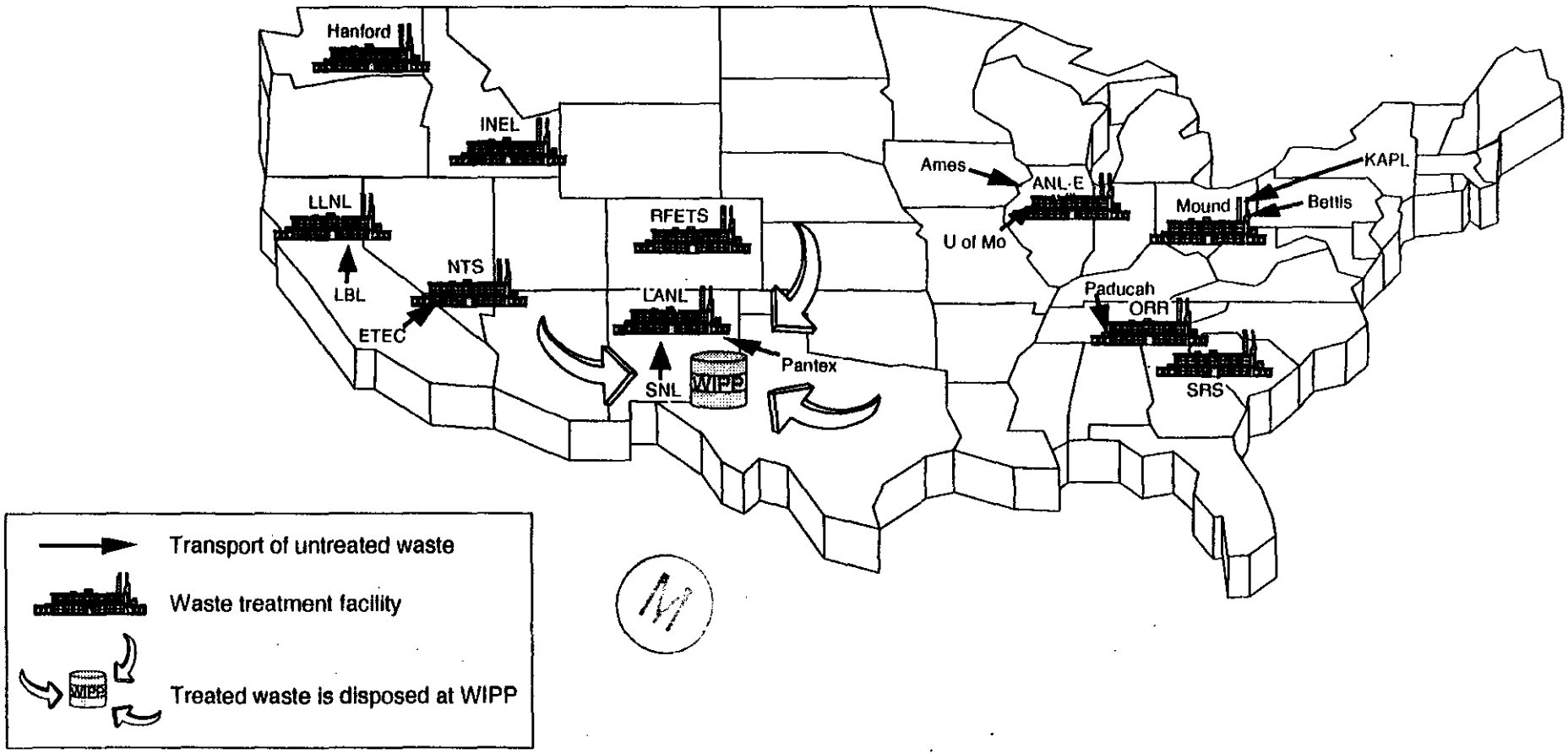

G95\EEC\Decent-1870.ppt

Figure 2-4
Decentralized Configuration for Contact-Handled Transuranic Waste Treatment

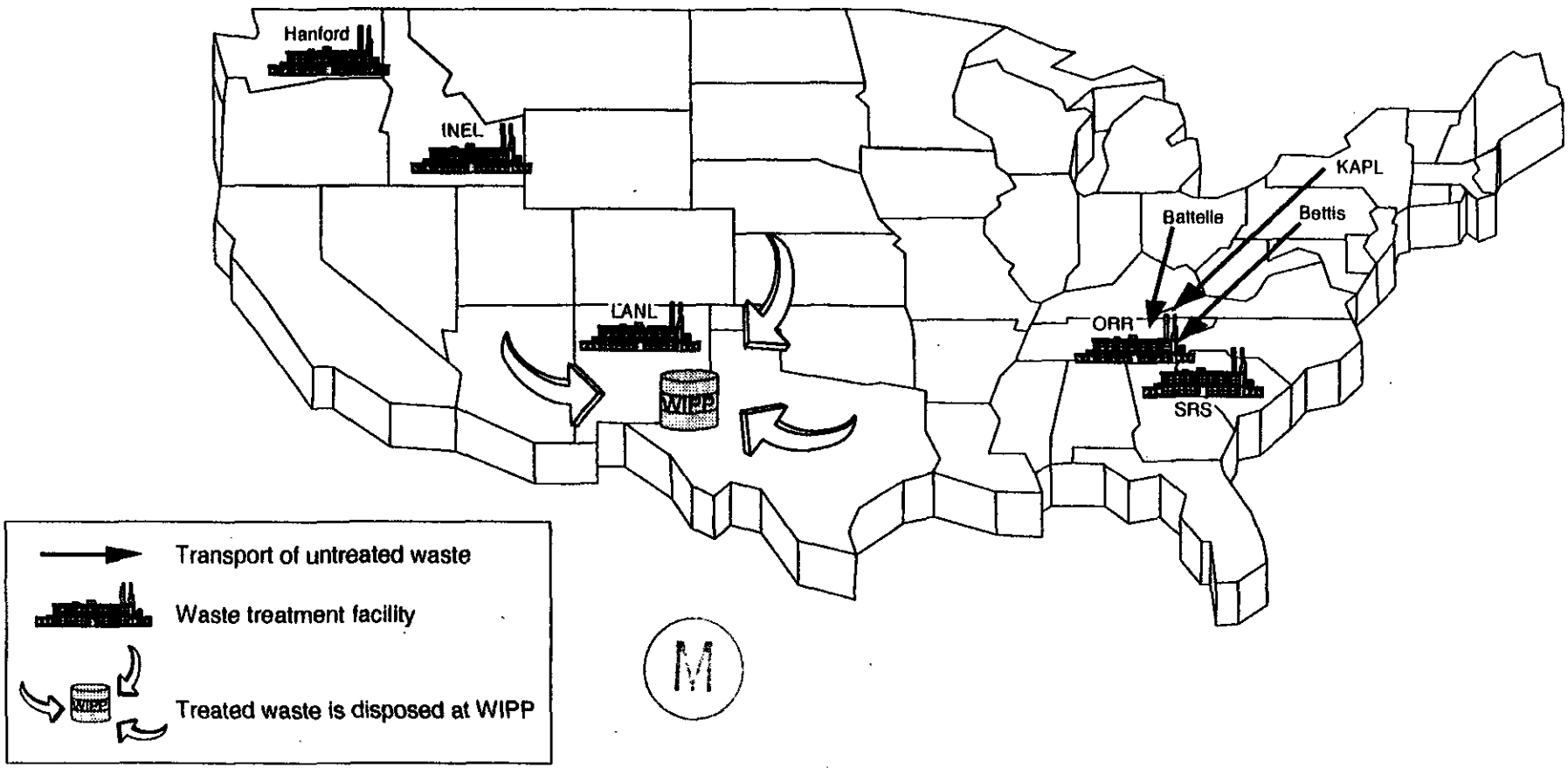

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Figure 2-5
Decentralized Configuration for Remote-Handled Transuranic Waste Treatment

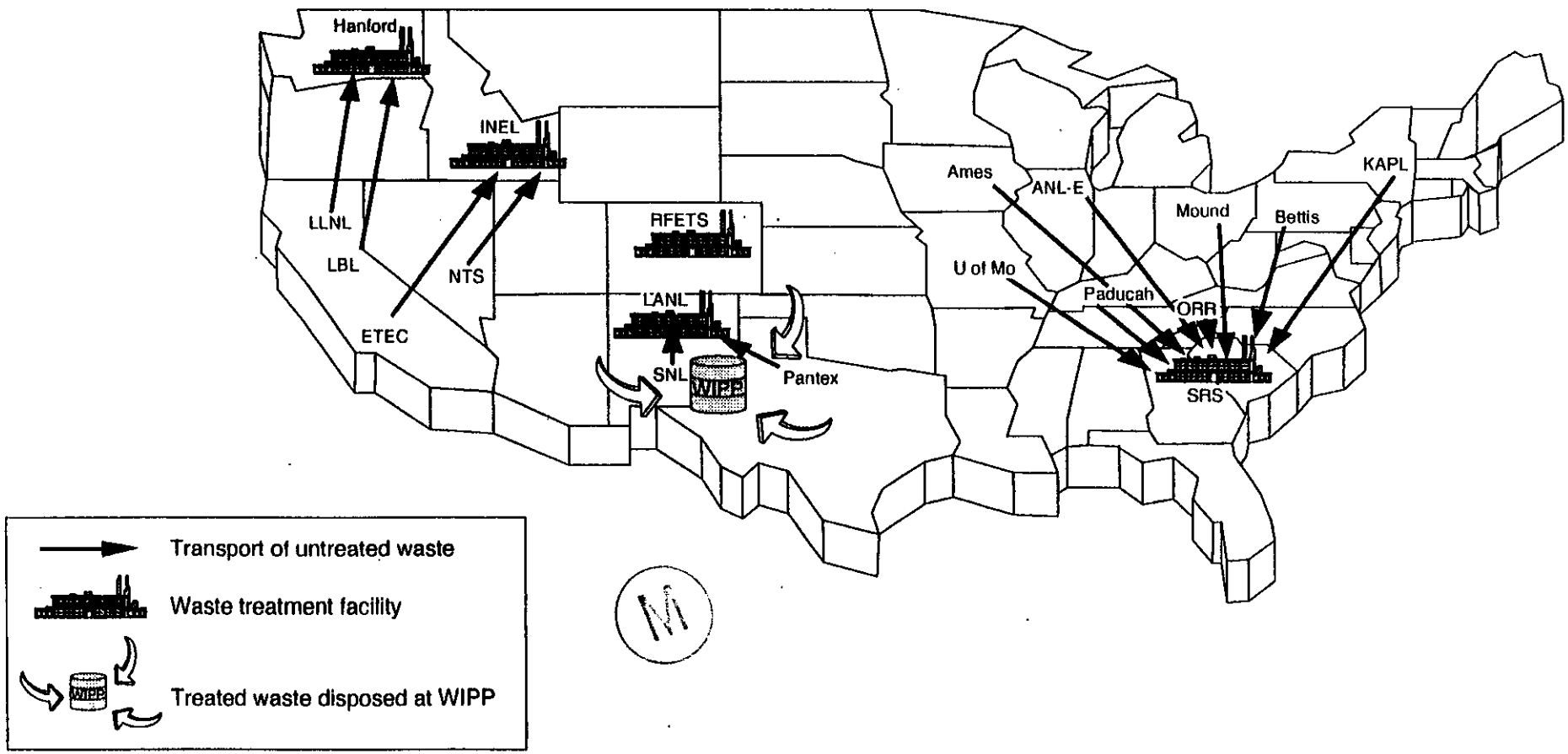

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Figure 2-6
Regionalized Configuration for Contact-Handled Transuranic Waste Treatment

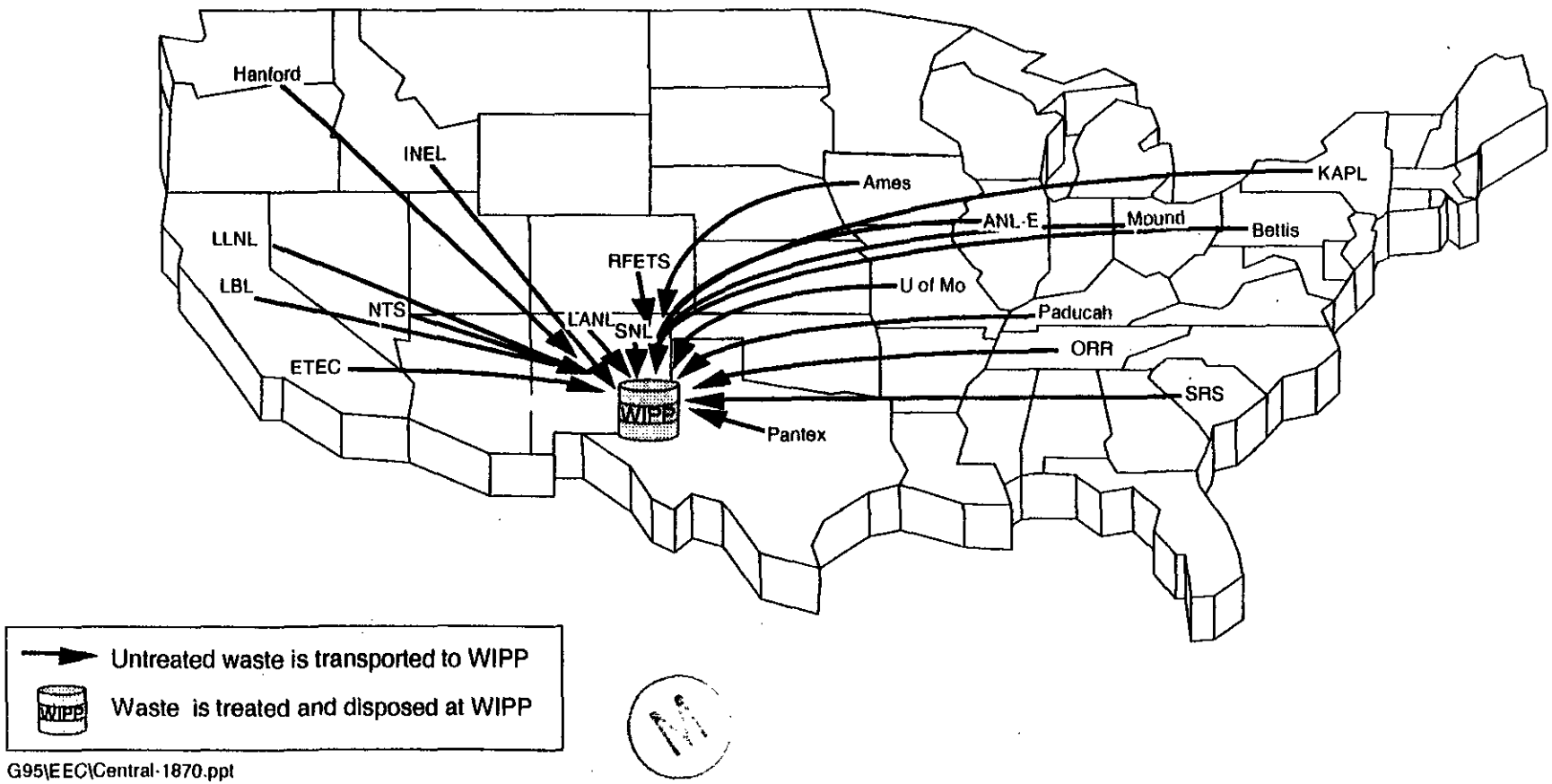

Figure 2-7

Centralized Configuration for Contact-Handled Transuranic Waste Treatment

- The WIPP will be ready to accept waste in 1998.
- No backfill is used in waste disposal areas.

The baseline for waste management is assumed to be decentralized. Processing and packaging of TRU waste to meet the WAC are performed at all 16 DOE sites where these wastes are currently stored or generated. Following processing and packaging, the waste would be shipped from sites with small amounts of waste to the 10 DOE sites with the largest amount of waste for interim storage. This strategy approximates the current DOE TRU waste management policy. The 10 major DOE waste sites are listed in Table 2-4.

TABLE 2-4

TEN MAJOR DOE WASTE GENERATOR/STORAGE SITES

1	Argonne National Laboratory-East (ANL-E)
2	Hanford Site
3	Idaho National Engineering Laboratory (INEL)
4	Lawrence Livermore National Laboratory (LLNL)
5	Los Alamos National Laboratory (LANL)
6	Mound Plant
7	Nevada Test Site (NTS)
8	Oak Ridge Reservation (ORR)
9	Rocky Flats Environmental Technology Site (RFETS)
10	Savannah River Site (SRS)

For waste to meet the WIPP WAC in the baseline, aqueous liquids must be stabilized and small particulates immobilized. Organic liquids will be stabilized by organic stabilization (use of a binding agent, such as calcium silicates, to form a solid). Solid process residue will be sorted for non-compliant items, corrosive and reactive materials will be neutralized and deactivated. Noncompliant particulates will be immobilized by solidification (i.e., cement). Sludges will be sorted and repackaged if they exceed wattage limits. Soils will be grouted if particulates exceed the WIPP WAC limits.

2.3.4.2 Common Analysis Parameters

There are many common parameters used throughout the analysis, such as waste inventories, masses, densities and forms for each EA, backfill volumes, emplacement geometries and physical properties, radionuclide inventories, waste emplacement work-off schedules, waste processing rates, and number of shipments and mileage for CH-TRU and RH-TRU waste. This information is shown in Tables 2-5 through 2-10, respectively.

TABLE 2-5

SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Total Backfill (m^3)	Excavated Area Volume (m^3)	Salt Volume (m^3)	No. of Panels
0	Baseline	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	0	207,406	289,814	10
1	Compact Waste	54,389	26,019	13,438	93,846	9,385	45,097	93,846	0	0	207,406	363,092	10
6	Shred and Compact	54,389	56,498	29,181	140,068	14,007	67,308	140,068	0	0	207,406	316,870	10
10	Plasma Processing of All Waste	10,767	24,532	12,671	47,970	4,797	23,051	47,970	0	0	207,406	408,968	10
33	Sand Plus Clay Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	103,703	207,406	82,408	10
35.a	Salt Aggregate Grout Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	165,925	207,406	82,408	10
35.b	Cementitious Grout Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	165,925	207,406	82,408	10
77.a	Supercompact organics and inorganics, salt-aggregate grout backfill, monolayer of 2,000 drums, in 6- x 33- x 300-ft rooms	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	93,604	117,006	41,697	10
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2,000 drums, in 6- x 33- x 300-ft rooms	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	58,503	117,006	41,697	10

Refer to footnotes at end of table.

TABLE 2-5 (Continued)

SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Total Backfill (m^3)	Excavated Area Volume (m^3)	Salt Volume (m^3)	No. of Panels
77.c	Supercompact organics and inorganics, sand plus clay-based backfill, monolayer of 2,000 drums, in 6- x 33- x 300-ft rooms	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	58,503	117,006	41,697	10
77.d	Supercompact organics and inorganics, CaO based backfill, monolayer of 2,000 drums, in 6- x 33- x 300-ft rooms	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	58,503	117,006	41,697	10
83	Salt Backfill with CaO	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	103,703	207,406	82,408	10
94.a	Enhanced cement sludges, shred and add clay to organics and inorganics, no backfill	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	0	0	289,814	10
94.b	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, sand plus clay backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	103,703	207,406	82,408	10

Refer to footnotes at end of table.

TABLE 2-5 (Continued)

SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Total Backfill (m^3)	Excavated Area Volume (m^3)	Salt Volume (m^3)	No. of Panels
94.c	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, cementitious grout backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	165,925	207,406	82,408	10
94.d	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, salt aggregate grout backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	165,925	207,406	82,408	10
94.e	Enhanced cement sludges, shred and add clay-based material to organics and inorganics, clay backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	103,703	207,406	82,408	10
94.f	Enhanced cement sludges, shred and add clay- based material to organics and inorganics, CaO backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	103,703	207,406	82,408	10
111	Clay Based Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	103,703	207,406	82,408	10

Refer to footnotes at end of table.

TABLE 2-5 (Concluded)

SUMMARY OF WASTE INVENTORIES

*Unaccepted Waste Volume is the volume of CH-TRU waste that will not fit in the WIPP underground with the present panel configuration and assumptions.

Assumptions:

- Backfill filling efficiency is assumed to be 80% for fluid backfill materials and 50% for dry backfill materials
- The allowable volume of waste per panel is 16,712 cubic meters
- There are 12.54 room equivalents per panel
- Available backfill volume per panel is 732,446 ft^3 = 20,741 m^3
- The backfill height for the 77 series alternatives is assumed to be ≈0.6 m over the top of the waste and the waste is ≈0.9 m high for a total height of 1.467 m (SNL SAND91-0893/3, page 3–13)
- The total available backfill volume per panel for 77 series alternatives is = 11,701 m^3
- The volume of a waste drum is 7.35 ft^3 = 0.21 m^3.

Source: DOE, 1995e (see Appendix O for additional details).

TABLE 2-6

WIPP ENGINEERED ALTERNATIVES MASS AND VOLUME OUTPUT

	Sludges			Solid Organics			Solid Inorganics		
Case #	Total Mass (kg)	Total Volume (m^3)	Density (kg/m^3)	Total Mass (kg)	Total Volume (m^3)	Density (kg/m^3)	Total Mass (kg)	Total Volume (cu.m)	Density (kg/cu.m)
Baseline	30,921,720	54,389	569	47,234,933	74,339	635	13,007,073	38,396	339
Alternative 1	30,921,720	54,389	569	51,958,427	26,019	1,997	14,307,781	13,438	1,065
Alternative 6	30,921,720	54,389	569	51,958,427	56,498	920	14,307.781	29,181	490
Alternative 10	16,929,945	10,767	1,572	47,234,933	24,532	1,925	13,007,073	12,671	1,027
Alternative 94	53,329,327	81,566	654	111,139,691	74,339	1,495	30,604,513	38,396	797

Source: DOE, 1995e (see Appendix O for additional details).

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TABLE 2-7

BACKFILL PROPERTIES FOR ENGINEERED ALTERNATIVES

Backfill Material (Alternatives Used)	Initial Density (kg/m^3)	Initial Porosity (%)	Solid[a] Density (kg/m^3)
70% Sand Plus 30% Clay (Alt. 33, 77c, 94b)	1,590[b]	40.0[b]	2,650[c]
Salt Aggregate Grout (Alt. 35a, 77a, 94d)	1,884[d]	31.3[d]	2,741[c]
Cementitious Grout (Alt. 35b, 94c)	1,884[d]	31.3[d]	2,741[c]
Clay Based (Alt. 111, 77b, 94e)	1,000[e]	62.5[f]	2,670[g]
Crushed Salt Plus CaO Backfill (Alt. 83, 77d, 94f)	1,193[h]	44.8[h]	2,162[h]

[a]Solid density is the density after consolidation to 0% porosity.
[b]Peck, R.B., W.E. Hanson, and T.H. Thornburn, 1974, *Foundation Engineering*, 2nd ed., John Wiley & Sons, New York, New York, 514 pp.
[c]Calculated from initial density and porosity.
[d]Coons, W., A. Bergstrom, P. Gnirk, M. Gray, B. Knecht, R. Pusch, J. Steadman, B. Stillborg, M. Tokonami, and M. Vaajasaari, 1987, "State-of-the-Art Report on Potentially Useful Materials for Sealing Nuclear Waste Repositories," *STRIPA Report 87-12*, prepared for the Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.
[e]Nowak, E.J., Sandia National Laboratories, 1990, Personal Communication.
[f]Calculated from initial density and solid density.
[g]Morris, D.A., and A.I. Johnson, 1967, "Summary of Hydrologic and Physical Properties of Rock and Soil Materials, as Analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948–60," *Geological Survey Water-Supply Paper 1839-D*, U.S. Government Printing Office, Washington, D.C.
[h]Case, J.B., P.C. Kelsall, and J.L. Withiam, 1987, "Laboratory Investigation of Crushed Salt Consolidation," *Proceedings of the 28th U.S. Symposium on Rock Mechanics*, June 1–July 1, 1987, Tucson, Arizona.

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TABLE 2-8

WIPP ACTINIDE INVENTORY (FROM DOE, 1995e)

Nuclide	CH (Curies)	RH (Curies)	Total (Curies)
Pu-238	$1.89 \times 10^{+06}$	$3.53 \times 10^{+03}$	$1.89 \times 10^{+06}$
Pu-239	$3.85 \times 10^{+05}$	$6.41 \times 10^{+03}$	$3.91 \times 10^{+05}$
Pu-240	$7.22 \times 10^{+04}$	$1.74 \times 10^{+02}$	$7.24 \times 10^{+04}$
Pu-241	$1.01 \times 10^{+06}$	$9.06 \times 10^{+02}$	$1.01 \times 10^{+06}$
Pu-242	$1.27 \times 10^{+03}$	1.48×10^{-02}	$1.27 \times 10^{+03}$
U-233	$1.38 \times 10^{+03}$	$8.57 \times 10^{+02}$	$2.24 \times 10^{+03}$
U-235	2.88	5.66	8.54
U-238	$1.88 \times 10^{+01}$	$1.31 \times 10^{+01}$	$3.19 \times 10^{+01}$
Am-241	$2.23 \times 10^{+05}$	$5.30 \times 10^{+02}$	$2.24 \times 10^{+05}$
NP-237	$8.82 \times 10^{+01}$	1.18×10^{-02}	$8.82 \times 10^{+01}$
Th-232	6.07×10^{-01}	7.09×10^{-03}	6.14×10^{-01}
Cf-252	$1.85 \times 10^{+02}$	$5.11 \times 10^{+01}$	$2.36 \times 10^{+02}$
Totals	$3.58 \times 10^{+06}$	$1.25 \times 10^{+04}$	$3.60 \times 10^{+06}$

Source: DOE, 1995e.

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TABLE 2-9

ENGINEERED ALTERNATIVES WASTE EMPLACEMENT WORK-OFF SCHEDULE FOR CH WASTE
(Only EAs with Waste Processing Shown)

EA#	Processing Scenario	Number of Shipments to WIPP[1]	Number of TRUPACTS Processed/Emplaced per Day[2]
Baseline, 33, 35 (a-b), 83, 111	Decentralized	19,944	7.12
	Regionalized	19,941	7.12
	Centralized	17,401	6.21
Alternative 1	Decentralized	19,571	6.94
(Compact)[3]	Regionalized	19,548	6.93
	Centralized	17,401	8.70
Alternative 6	Decentralized	18,794	8.52
(Shred & Compact)[3]	Regionalized	18,838	8.58
	Centralized	17,401	8.70
Alternative 10	Decentralized	17,174	5.72
(Plasma) Based on 25 yr. due to 100% waste being processed[3]	Regionalized	17,186	5.80
	Centralized	17,401	8.70
Alternative #77a	Decentralized	19,571	6.99
(Super Comp, monoL	Regionalized	19,548	6.93
6-ft rm, Salt Aggreg BF)[3]	Centralized	17,401	8.70
Alternative 77b	Decentralized	19,571	6.94
(Super Comp, monoL	Regionalized	19,548	6.93
6-ft rm, Clay BF)[3]	Centralized	17,401	8.70
Alternative 77c[3]	Decentralized	19,571	6.94
(Super Comp, monoL	Regionalized	19,548	6.93
6-ft rm, Clay BF)[3]	Centralized	17,401	8.70
Alternative 77d	Decentralized	19,571	6.94
(Super Comp, monoL	Regionalized	19,548	6.93
6-ft rm, CaO BF)[3]	Centralized	17,401	8.70

1 **TABLE 2-9 (Continued)**

ENGINEERED ALTERNATIVES WASTE EMPLACEMENT WORK-OFF SCHEDULE (Only EAs with Waste Processing Shown)

EA #	Processing Scenario	Number of Shipments	Number of TRUPACTS Processed/Emplaced per Day
Alternative 94a	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, no BF)[3]	Centralized	17,401	8.70
Alternative 94b	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized	17,401	8.70
Alternative 94c	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized	17,401	8.70
Alternative 94d	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized	17,401	8.70
Alternative 94e	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized[4]	17,401	8.70
Alternative 94f	Decentralized[4]	33,225	9.70
(Cement Sldg, shred	Regionalized[4]	33,214	9.70
& Clay, Sand/Clay BF)[3]	Centralized	17,401	8.70

[1]The number of shipments is based on the number of shipments to the WIPP only.
[2]The number of TRUPACTS is based on a 35 year operational life for WIPP.
[3]The emplacement activity is 25 years based on a 10 year lag for waste processing activities.
[4]The waste emplacement activity exceeds the 35 year operational due to 28.6 years for TRUPACT II processing.

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TABLE 2-10

ENGINEERED ALTERNATIVES WASTE PROCESSING RATES

(Only EAs with Waste Processing Shown)

Alternatives	Sludges (m^3)	Solid Organics (m^3)	Solid Inorganics (m^3)
Baseline	2,719	3,717	1,920
Alternative 1	2,719	1,301	672
Alternative 6	2,719	2,825	1,459
Alternative 10	538	1,227	634
Alternative 94	4,078	3,717	1,920

3.0 FACTORS ANALYSES

Chapter 3.0 is organized by subsections as a function of the analysis of each of the eight factors listed below. These eight factors were summarized from the nine evaluation factors prescribed in the proposed rule 40 CFR 194. For consistency in analyses, Factors 1 and 9 have been combined for use in the EACBS.

1. Effects of engineered alternatives on long-term performance of the disposal system.

2. The increased or reduced uncertainty in compliance assessment

3. Impact on public and worker exposures to radiation (at the WIPP and off site) both during and after incorporation of an EA

4. The increased ease or difficulty in future removal of the waste from the WIPP disposal system

5. The increased or reduced risk of transporting the waste to the WIPP (radiation and chemical exposure, both incidental and accidental)

6. The increased or reduced public confidence in the performance of the disposal system

7. The increased or reduced total DOE waste management system cost and schedule impacts

8. The impact on other waste disposal programs from the incorporation of an EA.

3.1 FACTOR 1: EFFECTS OF ENGINEERED ALTERNATIVES ON LONG-TERM PERFORMANCE OF THE DISPOSAL SYSTEM

3.1.1 Definition of Factor 1

Factor 1 deals with the impacts that an EA is predicted to have on the long-term performance of the disposal system. Impacts are predicted using the Design Analysis Model (DAM), which considers the coupled processes of brine inflow, creep closure, gas generation, and radionuclide migration under undisturbed conditions, and also considers the consequences of three human intrusion scenarios. The three human intrusion scenarios considered by the simulation postulate the existence of future boreholes that inadvertently penetrate the waste horizon and affect the containment and isolation characteristics of the TRU waste disposal system. These scenarios are the same as those considered in the PA conducted by SNL/NM, and are fully described in SNL/NM (1993) and Appendix E. These three scenarios are referenced in the EACBS as E1, E2, and E1E2. Section 2.1 specifies that this factor also analyzes the movement of water. This is indirectly addressed within the radionuclide movement analysis because radionuclide movement is partially driven by water/brine movement. Factor 1 is evaluated by considering the impacts of each EA on the following:

- Relative changes in the release of radionuclides in drill cuttings from each of the three human intrusion scenarios

- Relative changes in the cumulative 10,000-year release of radionuclides into the overlying Rustler formation from each of the three human intrusion scenarios

The impacts of each EA are expressed as changes in the above parameters relative to the baseline, which is defined as untreated waste (except as required by the WIPP WAC) emplaced in disposal panels with no backfill.

Although both disturbed and undisturbed conditions are simulated, the study places emphasis on the effects of EAs on mitigating releases from human intrusion scenarios. Releases to the accessible environment are not predicted to occur during undisturbed performance.

The following parameters are considered as part of the Factor 1 analysis.

Porosity and Permeability of the Waste/Backfill Composite Material

The permeability of the waste/backfill composite material in the room is a major factor in controlling the flow of contaminated brine in a waste disposal room toward a human intrusion drill hole that penetrates the room. In addition, a reduction in the initial porosity or void volume of the room will result in a faster approach to lithostatic pressure, due to a reduction in the volume available for gas expansion and a reduction of the time period over which brine can flow along a pressure gradient towards the disposal rooms.

Most EAs provide a moderate to large reduction in porosity of the waste/backfill composite material. Reductions in porosity translate into reductions in permeability in a non-linear manner. Supercompaction provides only a slight decrease in permeability, whereas plasma processing of the waste or addition of clay to the backfill provides a larger decrease in permeability.

Brine Inflow Rates

Limited amounts of brine have been observed to flow into the underground excavations in response to the transient pressure gradient imposed by the excavations (Deal et al., 1989). The undisturbed units of the Salado Formation within the repository horizon contain 0.60 percent by weight (1.56 percent by volume) brine (Deal et al., 1989). This source of this brine is probably Permian seawater that became trapped in the evaporite sequence at the time of deposition. The majority of the brine observed to seep into the underground excavations is predominantly local brine that became redistributed within the disturbed rock zone (DRZ) that forms around the excavations.

Brine inflow is a process of concern because it provides a medium for the potential transport of radionuclides. Human intrusion events can create a potential pathway for the migration of contaminated brine towards the accessible environment. Brine contacting the waste is assumed to dissolve the five actinide elements of concern (plutonium [Pu], neptunium [Np], uranium [U], thorium [Th], and americium [Am]) at concentrations equal to their respective solubility limits (reference Appendix G).

Brine inflow is also a process of concern because the water will react with steel drums, standard waste boxes, and iron and aluminum waste materials, to form iron and aluminum oxides plus hydrogen gas. The two likely reactions involving iron are predicted to be (SNL/NM, 1993):

$$3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2 \qquad 3.1$$

and

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2 \qquad 3.2$$

It is important to note that water (or brine) is required for this reaction to occur, and that water (or brine) is consumed by the reaction. The reaction is thus self-limiting because, as long as there is metal in the room, any brine that flows into a room will be converted into metal oxide plus hydrogen gas. Accumulation of brine in a room will only occur if the brine inflow rate is greater than the metal corrosion rate, or if all of the metals have already been completely corroded.

Shear Strength of the Waste/Backfill Composite

One significant pathway for the release of radionuclides in response to human intrusion events is the direct removal of drill cuttings to the surface. The total volume of waste (V) that is brought to the surface in response to a drilling event is calculated by:

$$V = \pi \bullet (\text{effective radius of borehole})^2 \bullet \text{height of waste} \qquad 3.3$$

The effective radius of the borehole is equal to the actual radius of the drill bit plus any waste surrounding the borehole that might spall or erode into the borehole in response to the action of the drill bit or the circulation of drilling mud. The actual radius of the drill bit is an assumed value that is based on current oil field drilling practices. The second component of the effective radius term is controlled in part by the shear strength of the waste/backfill composite. Alternatives that increase the shear strength of the waste (such as supercompaction or plasma processing) or backfill (such as grout) will result in the removal of a smaller volume of waste to the surface in response to a drilling event, reducing the radiological consequences of the intrusion event.

Radionuclide Solubility

One pathway considered for the release of radionuclides to the accessible environment is the dissolution of the radionuclides in brine that may come in contact with the waste, followed by transport of the contaminated brine to the accessible environment. Brine can be transported via fractures caused by excessive pressurization of the repository by gas generation, or by pathways created by future inadvertent human intrusions. A key factor controlling the release of radionuclides by these mechanisms is the solubility of the radionuclides in brine. For this study, solubility is defined in this case as the maximum mass of a given actinide element that can dissolve in a unit volume of brine of a specified composition. The solubilities of the relevant actinide elements are complex functions of several parameters, however, they all show similar behavior with respect to pH, showing a decrease in solubility as the pH is raised above neutrality, generally reaching a solubility minimum in the range of 8.5 to 10.

The ability of brine to transport radionuclides could be greatly reduced if the pH of any brine that accumulates in the repository is raised from the ambient value of around 6.1 to a value that is

closer to the solubility minimum range. Engineered alternatives that buffer the pH to a higher, more favorable value by the addition of lime (calcium oxide, or CaO) or portland-type cement (which contains a major percentage of hydrated lime [portlandite, or $Ca(OH)_2$]) to either the drum contents or backfill, are expected to result in improved performance because of lower actinide solubilities.

Sorption of Actinides on Backfill Material

Clay materials have a well known affinity under certain conditions to adsorb actinides. The net effect of this process is usually to either permanently immobilize the actinide, or retard the migration of the actinide relative to the average flow rate of a non-sorbing solute. In the repository, this retardation can provide additional time for radioactive decay to occur, thus reducing the total activity released.

A large amount of experimental data on sorption of radionuclides on clay minerals exists, however, most of this information is only applicable to dilute groundwater. Salado brines have extremely high concentrations of Mg^{+2}, K^+, Na^+, Cl^-, SO_4^{-2}, etc. Total dissolved solids in Salado brines are in the range of 370,000 mg/l compared to values in the range of 1,000 mg/l or less for drinking water. Sorption processes in the presence of these brines are quite different than processes occurring in dilute groundwater. No data was found to be available to simulate sorption of actinides on clay minerals in the presence of Salado brines, so this process was not considered. This approach is consistent with the SNL PA methodology which also concluded that "data to quantify actinide sorption on the various substrates under WIPP-specific physicochemical conditions are not available", and that "predicting sorption under WIPP-specific conditions is not feasible" (SNL, 1995).

The net effect of not considering this process is to minimize the predicted effectiveness of EAs that involve the addition of clay to the drums or backfill. The effects of clay on reducing initial void volume and decreasing the permeability of the waste/backfill composite are considered.

3.1.2 Methodology Used to Evaluate Factor 1

This section provides a description of the conceptual model of long-term repository performance that serves as the basis for the DAM. The numerical implementation of the conceptual model is described in Appendix E. The section concludes with a listing of the input parameter values and description of the criteria used to evaluate the effectiveness of alternatives during human intrusion events.

3.1.2.1 General Description of the Processes Simulated by the Design Analysis Model

The DAM was originally developed for the EATF (DOE, 1991a) and was subsequently updated for the EACBS. The DAM simulates processes occurring in the repository (rooms, panels, access drifts, and shaft seals) for the 10,000-year regulatory period defined in 40 CFR Part 191 (EPA, 1993) under both undisturbed and disturbed (human intrusion) conditions.

The behavior of the repository as simulated by the DAM is divided into the following time periods:

- Repository under Atmospheric Pressure—During this time atmospheric pressure is maintained within the repository.

- Repository Pressurization from Atmospheric to Peak Pressure—This phase is characterized by the processes associated with increasing gas pressure and presence of brine.

- Repository after Peak Pressure—This phase is characterized by the long-term processes that continue once peak pressures are reached in the repository, interrupted only by a human intrusion event.

The processes simulated by the DAM are discussed in detail in Appendix E.

Repository under Atmospheric Pressure

The excavation of underground openings at the WIPP horizon results in a predictable disturbance of the equilibrium state of the Salado. This deviation from equilibrium causes creep closure of the surrounding salt, resulting in the formation of a DRZ adjacent to surrounding openings. Creep closure is the viscoplastic response towards equilibrium by the rock under a deviatoric stress. Deviatoric stresses are the normal and shear stresses that remain after subtracting a hydrostatic stress, equal to the mean normal stress, from each normal stress component (Goodman, 1980).

The DRZ is defined as the zone of rock in which mechanical properties and hydrologic properties have changed in response to the excavation. The term "near-field" is used to describe the zone of rock within the DRZ, and the term "far-field" is used to describe the rock outside the DRZ in which intrinsic parameters such as porosity and permeability are undisturbed from pre-excavation values. Observations have defined a DRZ extending laterally throughout the excavation and varying in thickness from 1 to 5 meters, depending on the size and age of the opening. The "disturbed" zone exists above and below the repository (Figure 3-1), while the "intact" zone is undisturbed, and exists beyond the area affected by the excavations.

A panel, consisting of seven rooms and associated access drifts, will be filled with the waste containers (either drums or boxes). In most of the EAs that were evaluated, a backfill material (e.g., salt, clay, or grout) is used to fill the space around and between the waste containers. The waste and backfill material is referred to as "waste/backfill composite" or "composite". The purpose of adding the backfill varies depending on the alternative. Reasons for including backfill include: minimizing void volume in the room, reducing the permeability of the composite, increasing the shear strength of the composite, absorbing brine, and controlling the pH of any brine that may come in contact with the waste. Dry backfill is assumed to be emplaced at a 50 percent void space, and wet backfill (grout) is assumed to be emplaced at an 80 percent void space.

During excavations and waste emplacement, atmospheric pressure is maintained within the repository. Since the atmospheric pressure is substantially lower than the lithostatic pressure in the surrounding rocks, a depressurization of the Salado around the repository will occur. This will be manifested by a gradual decrease in pressure from the far-field pore pressure in the intact Salado to atmospheric pressure in a panel. Naturally occurring gas (nitrogen and methane) is present in brine from the Salado, and has been observed to exsolve from the brine in response to depressurization.

Underground experience at the WIPP with the presence and movement of brine within the Salado has yielded an understanding of brine movement in salt. The presence and movement of brine

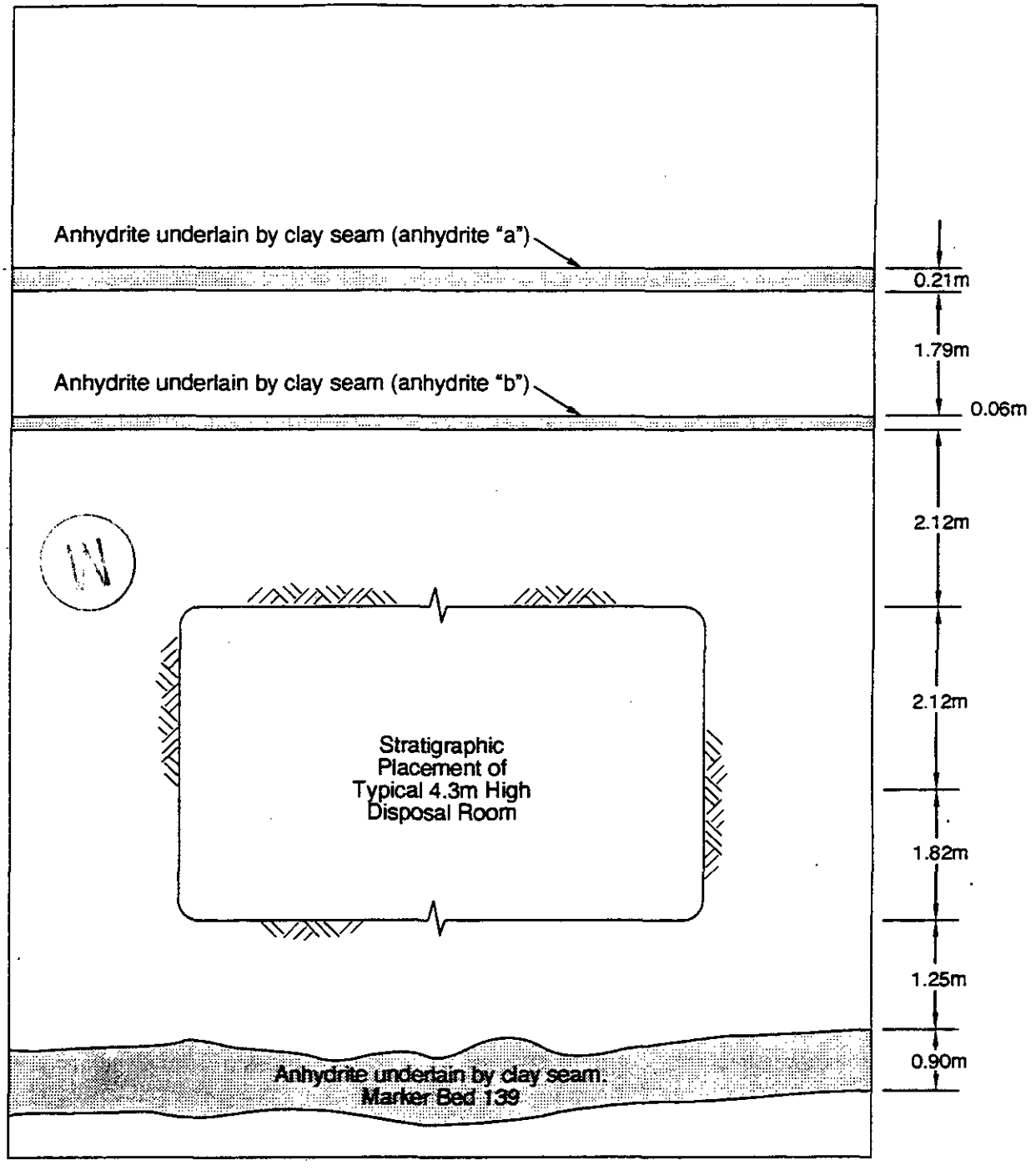

Figure 3-1

Stratigraphy at the Repository Horizon (Modified from Lappin et al. [1989])

in the Salado adjacent to the underground workings is evidenced by small "weeps" (brine encrustations) that commonly develop on the walls of an excavation shortly after it is mined. These "weeps" are a result of the difference in pressure between the surrounding halite and the atmospheric pressure within the rooms, and cease over time. In general, the brine inflow rate is less than the evaporation potential caused by mine ventilation, resulting in humid, but brine-free conditions in the repository.

In-situ brine flow experiments are used to measure the permeability of the Salado. The brine flow rates into sealed boreholes are in the range of 0.43 gallons (1.64 L)/yr to 0.792 gallons (3 L)/yr as steady states are approached. These rates have been used to calculate far-field Salado permeabilities that fall within the range of 10^{-21} to 10^{-20} m^2, using a poroelastic Darcy flow model (Lappin et al., 1989). On the basis of preliminary data, the far-field permeability of the anhydrites appears to be one to three orders of magnitude higher than that of the intact pure halite.

Emplacement of the waste within a panel is followed by closure of the access drifts and finally, sealing the shafts with a multi-component seal system. The goal of the sealing system is to limit groundwater from the overlying units from flowing down the shafts, and limit brine and/or gas from flowing up the shafts. This objective is accomplished by a combination of short-term seals in the form of concrete plugs, and long-term seals in the form of salt that has reconsolidated due to creep closure.

Repository Pressurization from Atmospheric to Peak Pressure

As long as the generated stress results in pressures below lithostatic within the repository, the Salado will continue to creep due to deviatoric stresses, thereby reducing the room dimensions.

The creep will continue and could eventually compact the waste/backfill composite. At some point the closure force will be resisted by the combination of two different mechanisms. The first of these is the ability of the particular waste/backfill composite to physically function to resist the force of compaction, manifested by its effective stress. A calculation of the effective stress and other properties is discussed in Appendix F. The effective stress is the stress that is transferred between the solid particles of the waste/backfill composite. The other mechanism is the effect of gas pressure within the void spaces. The increasing gas pressure provides a second component of internal stress resisting creep. As creep ceases, additional development of the DRZ will cease and may actually begin to reverse as fractures induced during the formation of the DRZ will begin to heal.

The small amounts of brine will continue to migrate toward the panels as long as there is an adequate pressure differential between the waste disposal panels and the undisturbed Salado. As described previously, corrosion of drums and metals in the waste under anoxic conditions will consume brine (if present), producing hydrogen gas in the process which contributes to pressurization. In addition, microbial activity is assumed to consume cellulosic materials (paper and wood), and perhaps other organic materials (plastic and rubber) in the waste as well, producing carbon dioxide and methane, and to a lesser extent nitrogen, hydrogen sulfide, hydrogen, and carbon monoxide. The hydrogen sulfide will probably be consumed by reacting with the metals or their corrosion products to form sulfide minerals. Radiolysis of brines, cellulosic materials, plastics, and rubbers will consume water and degrade the organics to produce limited amounts of hydrogen, oxygen, carbon monoxide gas, and carbon dioxide. Carbon dioxide may be removed from the gas phase by reacting with cementitious materials present as part of the

waste or backfill to form carbonate minerals (calcite, siderite, magnesite, etc.). The combination of gas generation due to the mechanisms described above, and the decrease in void volume due to creep closure, will result in pressurization of the panels.

Increased gas generation will increase the partial pressures of the gases and their solubilities in brine. This will cause additional gas to dissolve in the brine that may be present in the room. The increased concentration of gases in the brine will be the driving force for diffusion of gases into the intact Salado.

In addition to diffusion, advection into the Salado could occur as the gas pressure increases within the panel. This process involves the migration of gases under a pressure gradient from the room into the more permeable anhydrite units adjacent to the underground openings. The ability of these Salado units to advect gases will depend on: (1) the intrinsic permeability of each unit; (2) the relative brine and gas saturations of these units; (3) any capillary or threshold-pressure effects involved in gas displacement of brine already present; and (4) the amount of localized depressurization which exists due to the operational phase. Ongoing work suggests the threshold-pressure within the intact Salado halites may be as high as 8 megaPascal (MPa). Therefore, the sum total of the threshold pressure and the in-situ pore pressure will probably prevent gas advection into the halite. However, if some fractures exist within the DRZ that connect the panel to the anhydrite beds, gases will be dissipated due to the higher permeability (therefore lower threshold pressure) of the anhydrite units. Advective processes would allow some gas to escape from the panels, thus lowering the pressure in the disposal rooms.

The proposed short-term seals consisting of concrete plugs and possibly clay materials are designed to function for approximately 100 years after decommissioning. The long-term seals are made of crushed salt that is chemically and mechanically compatible with the host rock formation. Creep closure of the surrounding intact host rock consolidates and densifies the crushed salt to a condition comparable to the preexcavation intact salt.

Repository after Peak Pressure

No further brine inflow would take place once the pressures in the panel equal or exceed the far-field pressure of the Salado. Any brine accumulated in the panel would continue to be consumed at some rate by anoxic corrosion and would facilitate microbial degradation, assuming corrodible metals and organic materials are still present in the facility. These gas generation processes could, under some sets of conditions, create a peak pressure exceeding lithostatic. In addition, once the water present in the brine is consumed, reactions of carbon dioxide with cementitious materials would also cease, since these reactions require water.

The mechanical resistance to closure prevents further creep during the late phase, resulting in a cessation of waste/backfill compaction. This mechanical resistance is made up of two components: (1) the stress of compaction and (2) the interstitial fluid pressure. When the sum total of these components becomes greater than the lithostatic pressure, the deviatoric stresses are eliminated and creep ceases. At this point, the void volume becomes fixed at a constant value.

Gas advection will continue as long as the pressure within the panel is such that a driving force into the Salado is maintained. Once the pressure in the repository returns to lithostatic, the driving force is terminated and the system reaches a steady state condition.

Radionuclide Release Rate From Waste

A solubility-limited source term was assumed in the model. The assumption, which is consistent with the Sandia PA approach, presumes that any brine that contacts the waste immediately dissolves the five actinide elements at concentrations equal to their solubilities in brine, provided that sufficient actinide inventory is available. This is a reasonable assumption for untreated waste, because the actinides are mostly present as surface contamination, and are readily available for dissolution by intruding brine. The assumption may be less reasonable for plasma-processed waste because the actinide release rate from this waste form may be limited by the dissolution rate of the glass. The solubility-limited approach for the plasma processing alternative was still used because the leach rate of this waste form in WIPP brine is unknown.

Radionuclide Solubility

Solubility data on actinide-bearing solids were compiled for this study from published experimental investigations to estimate radionuclide concentrations in brine contacting TRU waste. Based on the most recent revision of the BIR for WIPP (DOE 1995e), actinides of interest that have isotopes with half-lives of 20 years or more are Th, U, Np, Pu, and Am, which occur in the waste primarily as oxides (Weiner, 1995). The remaining radionuclides summarized in the WTWBIR have very short half lives (less than 6 years) or are present in quantities insufficient to affect the release limits allowed under 40 CFR §191.13. Therefore, the radio-elements considered in the Factor 1 analysis are limited to Th, U, Np, Pu, and Am solids.

A discussion on radionuclide solubility is presented in Appendix G and Appendix H. This discussion is divided into two parts: 1) a summary of literature studies on the actinides of interest (Appendix G) and 2) a summary of the statistical approach used to select the mean solubility values and their 95 percent confidence intervals for Th, U, Np, Pu, and Am at the pH values of interest (Appendix H).

Two pH values are of interest for the EACBS solubility analysis: a pH of 6.1 (baseline), which corresponds to the average pH values observed in indigenous Salado brine, and a pH of 8.3, which is the approximate pH established in Salado brine by the brucite ($Mg(OH)_2$) buffer when a limited amount of lime is added to the backfill. Specific information on the effects of the addition of lime on the pH of Salado brine is presented in Appendix H.

3.1.2.2 Input Parameter Values Used in Factor 1 Analysis

This section provides listings of the input parameter values that were used in the DAM for the baseline case and each of the EAs. Table 3-1 is a list of input parameter values that are the same for each of the EAs. Table 3-2 is a list of parameter values that change for some or all of the EAs. The definition and unit of measure for each parameter in both tables are provided as footnotes at the end of each table.

3.1.2.3 Criteria Used to Evaluate Effectiveness of Alternatives

This section describes the criteria used to evaluate the effectiveness of alternatives in improving repository performance under human intrusion scenarios.

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TABLE 3-1

LIST OF CONSTANT PARAMETERS USED IN THE DESIGN ANALYSIS MODEL

Parameter[a]	Value	Parameter[a]		Value
CB	0.596875		Hydrogen	0
KANH	18		Nitrogen	0.25532
PANH	10.36		Oxygen	0
TEMP	300	RATIO	Carbon Dioxide	0.42553
PF	146.10		Carbon Monoxide	0
NU	4.95		Water	0
CW	0.5523E-18		Methane	0.31915
CH	0.1464E-18	RHTORW		0.7
HHUMRATE	0.0	RBOR		0.177500
HINURATE	0.6	TIMBORHOL		4,999
BHUMRATE	0.01	PTHL		91.440002
BINURATE	0.1			
BIOSTOIC	0.835			

[a]Footnotes:

CB = Brine inflow rate at atmospheric pressure (in cubic meters per panel per year).
KANH = Negative log of the permeability of anhydrite (in square meters).
PANH = Pore pressure in anhydrites (in kiloPascals).
TEMP = Room temperature (in Kelvin).
PF = Lithostatic pressure plus tensile strength of intact salt (in atmospheres).
NU = Stress constant (unitless).
CW = Horizontal strain rate (unitless).
CH = Vertical strain rate (unitless).
HHUMRATE = Rate of hydrogen gas generation due to anoxic corrosion of metals under humid conditions (in moles of hydrogen per drum of waste per year).
HINURATE = Rate of hydrogen gas generation due to anoxic corrosion of metals under inundated conditions (in moles of hydrogen gas per drum of waste per year).
BHUMRATE = Rate of microbial gas generation under humid conditions (in moles of biogas per kilogram of cellulosics per year).
BINURATE = Rate of microbial gas generation under inundated conditions (in moles of biogas per kilogram of cellulosics per year).
BIOSTOIC = Stoichiometry factor for microbial gas generation process (in moles of biogas generated per mole of cellulosics consumed).
RHTORW = Stoichiometry factor for anoxic corrosion process (in moles of hydrogen gas generated per mole of water consumed).
RBOR = Radius of borehole (in meters).
RATIO = Mole fraction of given gas generated microbially (unitless).
TIMBORHOL = Time of intrusion (in years).
PTHL = Distance between boreholes for the E1E2 intrusion scenarios (in meters).

TABLE 3-2

LIST OF VARYING PARAMETERS USED IN THE DESIGN ANALYSIS MODEL

	Parameter[a]									
EA	Width	Height	Length	VPNL	DENSINIT	VB	MOLCAOH2	WSTPOR	E0	ADIF
Baseline	10.05840	3.96240	91.44	45,700	0.01071	0.0	7.2E+05	0.90753	4.86848	31,756
1	10.05840	3.96240	91.44	45,700	0.02035	0.0	7.2E+05	0.82625	2.12332	31,756
6	10.05840	3.96240	91.44	45,700	0.01362	0.0	7.2E+05	0.88369	3.6656	31,756
10	10.05840	3.96240	91.44	45,700	0.03155	0.0	0.00	0.78524	1.52840	31,756
33	10.05840	3.96240	91.44	45,700	0.03248	0.0	7.2E+05	0.67661	1.65587	31,756
35a	10.05840	3.96240	91.44	45,700	0.04265	186.2	2.0E+08	0.58205	1.25758	31,756
35b	10.05840	3.96240	91.44	45,700	0.04265	186.2	2.0E+08	0.58205	1.25758	31,756
77a	10.05840	1.82880	91.44	21,093	0.05552	109.2	1.2E+08	0.45717	0.75743	27,077
77b	10.05840	1.82880	91.44	21,093	0.03237	0.0	402,053	0.68561	1.81487	27,077
77c	10.05840	1.82880	91.44	21,093	0.04465	0.0	402,053	0.55545	0.99069	27,077
77d	10.05840	1.82880	91.44	21,093	0.03640	0.0	2.2E+07	0.58309	1.12269	27,077
83	10.05840	3.96240	91.44	45,700	0.02658	0.0	3.4E+07	0.69637	1.82875	31,756
94a	10.05840	3.96240	91.44	45,700	0.01461	0.0	1.4E+07	0.87625	3.38930	31,756
94b	10.05840	3.96240	91.44	45,700	0.03567	0.0	1.4E+07	0.65108	1.46194	31,756
94c	10.05840	3.96240	91.44	45,700	0.04584	186.2	2.2E+08	0.55661	1.12818	31,756
94d	10.05840	3.96240	91.44	45,700	0.04584	186.2	2.2E+08	0.55661	1.12818	31,756
94e	10.05840	3.96240	91.44	45,700	0.02690	0.0	1.4E+07	0.74404	2.35614	31,756
94f	10.05840	3.96240	91.44	45,700	0.02978	0.0	4.7E+07	0.67082	1.60961	31,756
111	10.05840	3.96240	91.44	45,700	0.02370	0.0	7.2E+05	0.76966	2.72883	31,756

TABLE 3-2 (Continued)

LIST OF VARYING PARAMETERS USED IN THE DESIGN ANALYSIS MODEL

	Parameter[a]									
EA	Plutonium	Uranium	RADSOL Americium	Neptunium	Thorium	CLRNC	NDE	H2MAX	BIOMAX	RADFRAC
Baseline	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	1.29	80,519	7.0E+07	3.0E+06	3.00
1	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	2.46	45,194	8.2E+07	3.0E+06	1.50
6	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	1.72	67,478	8.2E+07	3.0E+06	2.60
10	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	3.08	26,585	3.7E+07	303.3	1.00
33	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	7.0E+07	3.0E+06	3.00
35a	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	7.0E+07	3.0E+06	2.00
35b	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	7.0E+07	3.0E+06	2.00
77a	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.36	25,080	4.6E+07	1.7E+06	1.50
77b	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.36	25,080	4.6E+07	1.7E+06	1.50
77c	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.36	25,080	4.6E+07	1.7E+06	1.50
77d	1.0E-07	3.98E-03	3.16E-04	1.99E-04	5.0E-08	0.36	25,080	4.6E+07	1.7E+06	1.50
83	1.0E-07	3.98E-03	3.16E-04	1.99E-04	5.0E-08	0.71	80,519	7.0E+07	3.0E+06	3.00
94a	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	1.29	80,519	9.5E+07	3.0E+06	2.30
94b	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	9.5E+07	3.0E+06	2.30
94c	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	9.5E+07	3.0E+06	1.75
94d	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	9.5E+07	3.0E+06	1.75
94e	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	80,519	9.5E+07	3.0E+06	2.30
94f	1.0E-07	3.98E-03	3.16E-04	1.99E-04	5.0E-08	0.71	80,519	9.5E+07	3.0E+06	2.30
111	5.0E-04	3.2E-02	4.0E-02	2.5E-02	7.9E-08	0.71	85,019	7.0E+07	3.0E+06	3.00

TABLE 3-2 (Continued)

LIST OF VARYING PARAMETERS USED IN THE DESIGN ANALYSIS MODEL

[a]Footnotes:

Width	=	Room width (in meters).
Height	=	Room height (in meters).
Length	=	Room length (in meters).
VPNL	=	Volume of panel (in cubic meters).
DENSINIT	=	Initial waste density (in pounds per cubic inch).
VB	=	Initial brine volume (in cubic meters).
MOLCAOH2	=	Moles of calcium hydroxide present in a panel (in moles of calcium hydroxide per panel).
WSTPOR	=	Porosity of the waste and backfill at zero stress (unitless).
E0	=	Initial void ratio (unitless).
ADIF	=	Total surface area for diffusion (in square meters).
RADSOL	=	Radionuclide solubility (in moles per liter).
CLRNC	=	Initial clearance between waste stack and roof of room (in meters of air gap).
NDE	=	Number of drum-equivalents per panel (unitless).
H2MAX	=	Maximum moles of hydrogen generated from anoxic corrosion (in moles of hydrogen).
BIOMAX	=	Maximum biogas potential based on amount of cellulosics present (in kilograms of cellulosics per panel).
RADFRAC	=	Erosion factor used to calculate the effective radius of a borehole as a means for determining quantity of waste in cuttings (unitless). RADFAC x RBOR = effective radius.

Describing the release of radionuclides from the disposal system can be complex because the five actinides of concern have different solubilities, and the specific isotopes of concern have different inventories and half-lives. A convenient method of describing release is through the use of an equation termed the "EPA sum rule". This equation can be expressed as:

$$Q = \Sigma \left[\frac{Q_i}{RL_i} \right], \qquad 3.5$$

where:

Q = Total normalized release
Q_i = Predicted release of isotope i
RL_i = Release limit for isotope i.

This equation expresses the combined normalized release of each isotope of concern as a single value, which is convenient for comparison of the various alternatives with the baseline. The release limit term RL_i is based on the individual isotope release limits provided in 40 CFR 191, which allows a certain number of "units" of release of each isotope normalized to the total inventory of alpha-emitting transuranic isotopes with half-lives greater than 20 years (EPA, 1985).

For each EA, separate Q values are calculated for the cuttings release and the groundwater pathway for each of the three scenarios, providing four Q values for each EA. The Q values for cuttings release are based on the volume of cuttings brought to the surface, and the activity of each radionuclide contained in that volume. The model considers the density of the exhumed waste, compaction of the waste from creep closure, radionuclide decay, and contributions from erosion of the waste surrounding the borehole by circulating drilling fluid.

Cuttings releases from each of the three scenarios are based on the assumption that each scenario occurs one time at 5,000 years after facility closure. These predicted releases cannot be directly compared to the EPA Standard because the results are not weighted by the probabilities of scenario occurrence as the Standard requires.

The Q values for the groundwater pathway are also based on a cumulative 5,000 year release, assuming that each scenario occurs one time at 5,000 years after facility closure. Releases are calculated from the cumulative flux of each radionuclide into the Culebra at the point of borehole intersection. These predicted releases to groundwater cannot be compared with the EPA Standard for two reasons. As is the case with the cuttings release, the results are not weighted by the probabilities of scenario occurrence. In addition, results are based on cumulative radionuclide flux into the Culebra, whereas the Standard considers cumulative radionuclide flux across the 16 square mile (41.42 square kilometer) land withdrawal boundary. Thus, any attenuation of radionuclides within the Culebra along a flow path from the point of borehole intersection to the land withdrawal boundary from processes including advection, dispersion, retardation, matrix diffusion, and decay, are not considered in the model.

A parameter called the "Measure of Relative Effectiveness" (MRE) was then defined using the DAM for each alternative, scenario, and mode of release (cuttings and groundwater pathway) in order to quantitatively compare the relative merits of each alternative with respect to human intrusion events. This factor is a measure of the relative improvement in the performance of the

alternative design, compared to the baseline design. The ratio of the cumulative release of radionuclides for an engineered alternative to the release under baseline conditions is the MRE for that particular alternative. In other words:

$$\text{Measure of Relative Effectiveness} = \frac{\text{Normalized Cumulative Release of Radionuclides Using the Alternative Design}}{\text{Normalized Cumulative Release of Radionuclides Using the Baseline Design}} \qquad 3.6$$

or

$$MRE = \frac{Q_{Alternative}}{Q_{Baseline}} \qquad 3.7$$

Six MREs are calculated for each scenario, consisting of cuttings and groundwater pathway releases for each of three scenarios (E1, E2, and E1E2). For the baseline, the MRE is equal to 1. The lower the value of this factor, less than 1, the more effective the alternative is in improving repository performance relative to the baseline. Values greater than 1 indicate that the alternative yields higher radionuclide releases than the baseline design.

The MREs provide an accurate measure of the relative changes in long-term performance, even though they are calculated from Q values that do not address EPA requirements for the consideration of the probability of release scenarios. The absolute Q values do not consider the probability of scenario occurrence, but none of the alternatives affect those probabilities. Since the MRE is calculated as a ratio of Q values, the effects of scenario probabilities cancel, yielding an accurate relative index. Likewise, the absolute Q values for the groundwater pathway do not consider the effects of radionuclide transport processes in the Culebra, but none of the EAs affect those processes. Since the MRE is calculated as a ratio of Q values, the effects of those Culebra transport processes cancel, yielding an accurate relative index.

3.1.2.4 Comparison between the SNL Performance Assessment Model and the Engineered Alternatives Design Analysis Model

Most of the conceptual models and input parameter values used in the EA study were based on the SNL performance assessment (PA) approach as documented in the SNL 1992 PA Update (SNL, 1992) and the SNL System Prioritization Method Position Papers. The majority of the differences between the EA and PA approaches are required by the relative nature of the EA approach compared to the absolute nature of the SNL PA model. The goal of the EA study is to quantify the relative differences in performance between the baseline case and the various alternatives. This is achieved by calculating a measure of relative effectiveness (MRE) for each alternative which is a measure of the extent to which the EA increases or decreases the cumulative 10,000-year radionuclide release relative to the baseline case.

The goal of the PA methodology is to quantify the predicted performance of the baseline case for comparison against the requirements of 40 CFR 191. This is achieved by calculating the cumulative 10,000 year radionuclide release.

Several processes simulated in the PA model have significant effects on absolute results but little to no effects on relative results. These processes have not been included in the DAM. Specific differences between the PA and EA models are discussed below.

Human intrusion probabilities—The PA model randomly selects intrusion times based on a general failure rate function that is described using a Poison distribution. This is required to quantify the absolute cumulative 10,000-year release. The DAM assumes that each of the three intrusion scenarios occur once at 5000 years after facility closure. None of the alternatives evaluated by the EA study affect the rate or frequency of intrusions, so the probability and rate of intrusion are considerations that can be neglected by the EA study (see Section 3.1.3.1). Doubling the rate of intrusion will roughly double the absolute predicted releases, but will not change the relative benefits offered by an EA.

Spatial domain—The PA model predicts the cumulative 10,000-year radionuclide release across the 16 square mile (41.42 square kilometer) land withdrawal boundary. This requires simulating groundwater flow and radionuclide transport process that will occur along potential flow paths through the Culebra Dolomite from the point of borehole intersection to the unit boundary. The DAM predicts the cumulative 10,000-year radionuclide release into the Culebra at the point of borehole intersection and does not consider processes in the Culebra. None of the alternatives evaluated by the EA study affect flow or transport in the Culebra so the attenuation of radionuclide within the Culebra does not change the relative benefits offered by an EA.

Gas generation rates—For gas generation rates, the "expected" values for humid and inundated conditions cited in the Gas Generation Position Paper (November 15, 1994 Draft) was used as the median values in the DAM but the ranges from the position paper were not. The range of values in the SNL Position Paper for microbial gas generation in an inundated environment is 0 to 5 moles/drum/yr (m/d/y). This range represent the possible range of values for an individual randomly selected drum. It is inappropriate to sample on this range if there are 85,000 drums in a panel that are in communication with each other. The probability of all 85,000 drums generating gas at a rate of 5 m/d/y is insignificant. In addition, the high generators will tend to cancel the low generators. Under these conditions, the appropriate range to sample on is a measure of the error of the mean rather than the full range of possible values for individual drums.

Radionuclide solubilities—For radionuclide solubilities, the Actinide Source Term Position Paper (March 31, 1995 draft) discusses several different conceptual models but recommends the *Inventory Limits with Realistically Conservative Maximum Concentrations Model*. This model assumes large arbitrary values and does not consider the effects of changing pH. Some of the alternatives utilize pH buffers (CaO or portland grout) to raise the pH of brine that may come in contact with the waste and thereby reduce actinide solubilities. The EA study requires a source term approach that can assess the effects of pH shifts on actinide solubilities. The selected approach was to base solubilities on published experimental values in brine or saline systems as a function of pH. A summary of the published experimental values is provided in Appendix G, and the statistical analysis and results of the experimental data evaluation is provided in Appendix H.

Release of drill cuttings during human intrusion events—One component of release during human intrusion events is the direct transport of waste to the surface by the action of an exploratory drill bit. The SNL PA methodology considers three separate physical processes that can influence the quantity of waste brought to the surface by drilling events. These processes are:

- Cuttings—waste contained in the cylindrical volume created by the cutting action of the drill bit passing through the waste
- Cavings—waste that erodes from the borehole wall in response to the upward-flowing drilling fluid within the annulus
- Spallings—waste introduced into the drilling fluid caused by the release of waste-generated gas escaping to the lower-pressure borehole.

The SNL PA model plans to considers all three of the above processes but currently only the first two are implemented (Butcher et al., 1995). The DAM also only considers the first two of the above processes.

3.1.3 Results of Analysis of Factor 1

Results of long-term performance are provided in Table 3-3.

Discussion and interpretation of the human intrusion results and their uncertainties is provided in detail in Section 3.2.

3.1.3.1 Effects of Intrusions at Times Other Than 5000 Years

The absolute quantitative releases from human intrusion events are dependent on the timing, probability, and frequency of the events. However, the relative benefits of the EAs (as calculated by the MREs) are not very sensitive to the timing of the EAs and are totally independent of the probabilities and frequencies of the events.

Comparisons of the alternatives are based on the assumption that each of the three human intrusion events occur once at 5000 years. The effects of this simplifying assumption was evaluated by performing additional simulations for the baseline and nine selected alternatives at 200, 2000, and 7000 years. The results of this limited sensitivity analysis on the effects of intrusion time are discussed below for each scenario.

Cuttings release—The calculated MREs from cuttings release is the same at 2000, 5000, and 7000 years. The MREs at 200 years differ by several percent from the MREs at later years because the composite material in the rooms at 200 years is still in the process of consolidating from creep closure, and this consolidation occurs at differing rates for each alternative. Consolidation of the composite material is complete by 2000 years, so the MREs remain constant thereafter.

E1 groundwater pathway scenario—The E1 (Castile brine) scenario MRE results are also sensitive to time in the early years because of on-going compaction and the effects of compaction on permeability. Once the composite material fully compacts, the permeability reaches a constant value and results are insensitive to time.

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TABLE 3-3

MEASURE OF RELATIVE EFFECTIVENESS FOR RELEASES TO THE CULEBRA DOLOMITE AND TO THE SURFACE UNDER THE THREE INTRUSION SCENARIOS

			Normalized Quantity Transported to Culebra Dolomite (by Intrusion Scenario)			Normalized Quantity of Radionuclides Released to Surface Through Cuttings for Each Intrusion Scenario
Waste Processing	Backfill	Engineered Alternative Number	E1	E2	E1E2	E1, E2, or E1E2
None	None	Baseline	1.0	1.0	1.0	1.0
	Sand & Clay	33	0.74	2.0	0.99	0.92
	SAG	35a	0.40	1.1	0.040	0.40
	CG	35b	0.40	1.1	0.040	0.40
	Clay	111	0.54	2.1	0.56	0.94
	CaO & Salt	83	0.83	0.30	0.05	0.94
Super C	None	1	0.93	1.4	1.00	0.26
	SAG	77a	0.44	0.56	0.083	0.21
	Clay	77b	0.56	2.3	0.93	0.22
	Sand & Clay	77c	0.73	2.1	0.98	0.21
	CaO & Salt	77d	0.79	0.30	0.032	0.22
S & C	None	6	0.95	1.1	1.0	0.79
EC/SC	None	94a	0.69	1.1	1.0	0.57
	Sand & Clay	94b	0.66	0.86	0.99	0.52
	CG	94c	0.45	0.46	0.089	0.30
	SAG	94d	0.45	0.46	0.089	0.30
	Clay	94e	0.53	0.88	0.49	0.53
	CaO & Salt	94f	0.67	0.30	0.012	0.54
Plasma	None	10	0.00078	0.0093	0.00076	0.12

LEGEND:

Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
EC/SC: Enhanced cementation of sludges. Shred and add clay based materials to organics and inorganics
SAG: Salt aggregate grout
CG: Cementitious grout

M

Consolidation of the composite material is complete by 2000 years, so the MREs remain constant thereafter.

E2 groundwater pathway scenario—No releases are predicted for the E2 scenario until the fluid pressure in the room is sufficient to transport brine to the level of the Culebra. At 200 years, the pressure is too low to drive releases, but by 2000 years, pressure is high enough to yield releases. MREs remain constant after that point.

E1E2 groundwater pathway scenario—All three of the scenarios evaluate flow releases over the time frame of intrusion until the 10,000-year regulatory limit. An intrusion at 5000 years allows 5000 years of flow to occur, but an intrusion at 7000 years allows only 3000 years of flow to occur. In the case of the E1E2 scenario, the flow occurs between two boreholes within a panel.

Depending on the cumulative volume of brine flow that occurs, the radionuclide releases from each alternative fall into two categories: inventory-limited releases and solubility-limited releases. Inventory-limited releases occur when a large enough cumulative volume of brine flows through the affected portion of waste to cause the release of the entire actinide inventory in the affected volume of waste over the regulatory period of performance. Solubility-limited releases occur when brine flow rates or radionuclide solubilities do not allow the entire inventory within the affected volume to be released over the regulatory period of performance.

Results for the baseline case at all times evaluated (200, 2000, 5000 and 7000 years) show inventory-limited releases. Results for some of the alternatives (33, 1, 6, and 94a) also show inventory-limited releases for the E1E2 scenario at all times evaluated. The MREs for these alternatives do not show a dependence on time of intrusion because an inventory-limited release for the alternative is divided by the inventory-limited release for the baseline, yielding a constant ratio that is independent of time.

Other alternatives (83 and 10) have MREs that show a sensitivity to time of intrusion because the releases for these alternatives are solubility-limited. When a release that is a function of brine flow or radionuclide solubility is compared to a release that is a function of inventory, the time over which the release takes place becomes a sensitive variable. Under these conditions, the MRE decreases (improved performance) at later years because the window of time over which cumulative releases are integrated is shorter.

The results of this sensitivity analysis show that in general, the MREs are insensitive to the time of intrusion once the physical properties (density and permeability) of the composite material in the room reaches a steady-state condition. This occurs sometime between 200 and 2000 years. One exception is the results of the E1E2 scenario for some alternatives. For these cases, the improvement offered by those alternatives relative to the baseline case increases when the intrusion event occurs at later years. Even for these alternatives, performing the comparisons at times other than 5000 years would not change the relative ranking of the MRE results.

3.2 FACTOR 2: UNCERTAINTY IN COMPLIANCE ASSESSMENT

3.2.1 Definition of Factor 2

Factor 2 estimates the EA's ability to treat uncertainty relative to the quantity of radioactive materials that will be transported to the accessible environment as a result of scenarios that intrude into the disposal system. The results of Factor 2 may then be used in conjunction with those of Factor 1 to characterize capability of an EA to provide additional assurance that the disposal system complies with the requirements of 40 CFR 191.13(a).

Treatment of uncertainty in compliance assessment can be realized by reducing both the quantity of radioactive materials released to the accessible environment and the statistical variability about that quantity. As described in Section 3.1, Factor 1 addresses the magnitude of reduction through the analysis of the MRE for cuttings removal to the surface and groundwater transport to the Culebra via the borehole, given scenarios E1, E2, or E1E2 occur. Factor 2 addresses the ability of the EAs to treat the uncertainty regarding these processes. By lowering the uncertainty of predictions of quantities of radioactive material that might be released as a result of an intrusion scenario, one can provide additional assurance in the prediction that the disposal system will perform as expected.

The EPA requires that the results of the formal performance assessment be incorporated, to the extent practicable, into a single complementary cumulative distribution function (CCDF) that indicates the probability of exceeding various levels of summed normalized releases (EPA, 1985). Several such CCDFs are provided in SNL, 1992. The mean MREs calculated by Factor 1 can be interpreted as the factor by which the entire group of CCDFs may shift to the left. The uncertainties calculated in Factor 2 relate to 1) the uncertainty in the mean MREs and 2) the degree to which the set of CCDFs may become less spread out. Because the largest improvement in assurance that adequate containment will be achieved derives from reducing the spread of large releases (which are closest to the EPA limit), the second measure calculates an MRE based on the factor by which the 95th percentiles of value of radionuclide transport are reduced by each EA.

3.2.2 Methodology Used to Evaluate Factor 2

A given EA might have an impact on one or more parameters that are important to repository performance. Because the physical processes expected to operate in the repository are nonlinear and interrelated, the impacts on uncertainty in the overall estimate of performance cannot be determined analytically by examining changes in the uncertainty assigned to any one input parameter. Therefore, the EACBS evaluation of uncertainty generates a series of input parameter sets using Monte Carlo techniques that randomly sample the parameters' probability distributions. The DAM then uses each set of input parameters to estimate the quantity of radioactive materials that will be transported across the immediate boundary of the WIPP repository, given each of the intrusion scenarios occur. The uncertainty results are then correlated to those for the baseline design so that comparisons can be made of the proposed EAs.

3.2.2.1 Uncertainty of Key Repository Performance Parameters

The analysis proceeds by first characterizing the uncertainty of important parameters of the waste and the disposal system that influence the long term performance of the repository. It then

estimates how each EA's estimated physical characteristics treat uncertainty through impacting these parameters.

The quantity and rate of radionuclide movement will depend on the conditions produced by the intrusion event, the driving forces available at or near the repository, and the mobility of the waste in response to the driving forces. Input parameter uncertainty that impacts these processes includes the natural variability of materials used in the disposal system and uncertainty produced by the lack of sufficient data used to determine parameter ranges. Uncertainty is expressed by establishing distributions of the possible values for each of the parameters. Once a value is randomly selected from the distribution for a given sample calculation, it is assumed to remain at that value for the 10,000-year period of repository performance as calculated by the DAM.

First, the uncertainty in the state-of-knowledge regarding these parameters is assessed and represented by probability distributions in the STADIC Code, which is described in Appendix J. The definition of the probability distributions is done within a FORTRAN subroutine of STADIC. By further programming the subroutine, the analyst can explicitly account for physical correlations between the parameters by establishing dependencies in the sampling of their associated uncertainty distributions. STADIC generates random numbers using Monte Carlo subroutines and samples each of the probability distributions in accordance with the dependency rules established by the user-defined subroutine to produce a set of input values to the DAM code.

Given a set of input parameter values, the DAM calculates the evolution of conditions within the repository and the resultant transport of radioactive materials outside the immediate boundary of the repository for each of the three intrusion scenarios. The output of the DAM calculation is then stored with its associated input set as one trial of the Monte Carlo simulation. When a reasonable number of trials are accomplished (1,000 for this analysis), uncertainties in repository performance resulting from the uncertainties in the input parameters can be observed and analyzed. For this evaluation, 1,000 trials was judged to be reasonable. This produced a spectrum of results that clearly indicated trends and produced no discontinuous gaps in output.

3.2.2.2 Changes in Uncertainties Produced by an Engineered Alternative

Distribution of Overall MRE

As discussed in Section 3.1.2.2, the increased confidence in compliance assessment that would be achieved through implementing an EA is estimated by calculating two MREs for each intrusion scenario. These ratios are calculated individually for the two major mechanisms of radionuclide transport:

- MRE_{cut} — Measure of Relative Effectiveness for cuttings releases on the surface
- MRE_{wat} — Measure of Relative Effectiveness for reducing waterborne transport to the Culebra at the point of borehole intrusion.

An MRE is obtained by calculating the ratio of the cumulative release of radionuclides using the EA divided by the cumulative release of radionuclides with the baseline design. Values of an MRE that are less than one indicate that an EA will improve the long term performance of the disposal system. The net impact on a graph of the CCDF of the PA will be to move the

consequences associated with intrusion scenarios to the left, thus reducing the impact of uncertainties in the assessment.

Using the Monte Carlo process, the physical parameters describing the baseline design and each of the EA's are each subjected to 1,000 performance calculations using the DAM computer code. To ensure that the comparisons will be based on the uncertainties in the anticipated changes in performance parameters and not differences in the random samples, the same random number seed is used to initialize the sampling of the input parameters of the baseline design and each of the EAs. The order in which random samples are taken remains constant across the baseline design and all EAs. The two MREs previously described are then calculated based on samples that used the same random numbers set in both the baseline and the EA. These calculations produce 1,000 values for each MRE. The distribution of these MRE values represents the uncertainties regarding the potential for performance improvement produced by each EA.

MRE for Reducing Larger Releases of Radioactive Materials

An MRE that relates an EA's effectiveness in addressing conditions that could produce larger releases from the repository is determined by comparing the 95th percentiles of the cumulative distributions results of the 1,000 random sample calculations for quantities of radioactive materials transported in reference to the EA and the baseline. In this case, the individual sample calculations are not directly correlated. The objective is to gain confidence that an EA may reduce the quantities of radioactive materials that could potentially be released under combinations of physical conditions particularly favorable for transport.

3.2.3 Assumptions and Input for Factor 2

3.2.3.1 Assumptions

The calculations conducted for evaluation of an EA assume that an intrusion event corresponding to the E1, E2, or E1E2 scenarios has occurred. The calculations do not address the frequency at which these intrusion events occur. They calculate only the consequences of a breach of repository containment as produced by the intrusion event.

Numerical model uncertainty is related to the inability to incorporate the actual physical complexity of the process into the model analysis. Factor 2 analysis assumes that no uncertainty is attributable to the computer models used. This assures that any uncertainty in modeling would impact both the performance of the baseline design and the EA in a similar manner, and thus not have a significant impact on the calculation of MREs.

3.2.3.2 Input Parameter Distributions

The distributions used for the uncertainty analysis were derived by interpretation of the evidence used to establish the point estimates for Factor 1. Only a limited amount of information was available regarding the uncertainty, mostly in the form of upper and lower bounds. Consequently, the uncertainty distributions were formulated using the combined judgement of both the Factor 1 and Factor 2 teams to best reflect the available evidence. Table 3-4 identifies the baseline physical parameters whose uncertainty has been judged to have a potential significant influence

TABLE 3-4

DEFINITION OF UNCERTAIN PARAMETERS IN THE DESIGN ANALYSIS MODEL

Parameters Having Uncertainty	Variable Description (units)	Is this Variable Changed by an Engineered Alternative?															
		1	6	10	33	35a,b	77a	77b	77c	77d	83	94a	94b	94c,d	94e	94f	111
BHUMRATE	Microbial gas generation rate under humid facility conditions (moles/kg cellulosics-yr)	No Change From Baseline															
BINURATE	Microbial gas generation rate from anoxic corrosion under inundated facility conditions (moles/kg cellulosics-yr)	No Change From Baseline															
BIOSTOIC	Ratio of moles of biogas generated to moles of cellulosics consumed (dimensionless)	No Change From Baseline															
CB	Brine inflow rate at a pressure difference of lithostatic minus atmospheric (m3/yr-panel)	No Change From Baseline															
H2MAX	Maximum hydrogen gas generation potential from anoxic corrosion (mol/panel)	Yes	Yes	Yes	No Change	Yes	Yes	Yes	Yes	No Change From Baseline							
HHUMRATE	Hydrogen gas generation rate from anoxic corrosion under humid facility conditions (moles/drum-yr)	No Change From Baseline															
HINURATE	Hydrogen gas generation rate from anoxic corrosion under inundated facility conditions (moles/drum-yr)	No Change From Baseline															
KPANH	Negative log of the permeability of the anhydrite beds (dimensionless)	No Change from Baseline															
RADFAC	Factor used to estimate the effective borehole radius during intrusion (dimensionless)	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
RADSOL (1)	Pu-240 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (2)	U-236 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (3)	Am-241 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (4)	Np-237 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (5)	U-233 solubility in brine (mol/l)	Completely Correlated With RADSOL(2)															
RADSOL (6)	Th-229 solubility in brine (mol/l)	No Change from Baseline								Yes	Yes	No Change from BL				Yes	No
RADSOL (7)	Pu-238 solubility in brine (mol/l)	Completely Correlated With RADSOL(1)															
RADSOL (8)	U-234 solubility in brine (mol/l)	Completely Correlated With RADSOL(2)															
RADSOL (9)	Th-230 solubility in brine (mol/l)	Completely Correlated With RADSOL(6)															
RADSOL (12)	Pu-239 solubility in brine (mol/l)	Completely Correlated With RADSOL(1)															
RBOR	Radius of borehole for intrusion scenarios (m)	No Change From Baseline															
RHTORW	Ratio of hydrogen gas generation rate to water consumption rate during anoxic corrosion (dimensionless)	No Change From Baseline															

on the assurance of compliance. Detailed documentation of the input parameter distributions can be found in Appendix J.

Dependencies and correlations among input parameters are modeled using the STADIC sampling subroutine by allowing the same random number to be used to generate the values for two or more physical parameters. Details of the specific variables for which dependencies are established are given in Appendix J. For example, they include dependencies between the inundated and humid gas generation rates for both anoxic and biodegradation conditions. The dependency reflects the similarity of the chemical conversion involved, with the differences in brine availability producing a different model for the rate of the process and reflects the judgement that the humid gas generation rate should never exceed the inundated gas generation rate, since the cumulative distribution of the humid process has lower values at all percentiles of the distribution.

3.2.4 Results of Analysis of Factor 2

The results of the uncertainty analysis are presented in a series of four tables that match the MREs for releases to both the surface and the Culebra assuming the three human intrusion scenarios, as defined in Section 3.2.2. The description of the variability within the 1,000 case-by-case calculations of the overall MRE is broken into three parts:

- The first column shows the percentage of cases that produced no transport of radioactive material from the repository. These cases reflect the combination of parameters values that produce conditions favorable for complete containment.

- The next four columns present the 5th, 50th (median) and 95th percentile distribution parameters and the mean value of the distribution of MRE for those cases that do not include zero transport in either the baseline design or the engineered alternatives. The percentage of cases that produce no transport can be read directly from the first column. Of this percentage, the cases that were zero for the baseline are indeterminate, with the remaining having an MRE of zero.

- The sixth column presents the percentage of cases that produced the same upper bound value of release. These cases reflect the combination of parameter values that produce conditions favorable for transport.

The last column of the table presents the MRE comparing the 95th percentiles of the CCDF of predicted cumulative release of radioactive materials released for each engineered alternative. This MRE is a single point value.

3.2.4.1 Release of Cuttings, All Scenarios

By definition, all baseline and EA calculations for the drill cuttings release scenario resulted in the release of radioactive material to the surface in the cuttings, since the material intersected by the borehole must be deposited on the surface. None of the EAs that passed the screening process change the horizontal footprint of waste that the drilling operation could intersect. Therefore, the major impact of an EA with respect to radionuclide releases is the reduction in the effective radius of the borehole due to the increased effective resistance of the waste material to erosion during the drilling process.

Table 3-5 shows the results of the uncertainty calculations for cuttings release by all scenarios. First, it can be seen that radioactive materials removed from the repository horizon with drill cuttings is not subject to lower or upper bounds. This is reasonable, since the drilling operation must pass through only a few meters of waste at most, with compaction making the layer thinner. Given even conservatively slow drilling rates, the borehole walls should not be subject to slurry erosion from the drilling process for more than a few hours. Thus, the enlargement of the borehole radius due to erosion of waste is expected to be between a Factor 1 and 3, as indicated in Table J-4 of Appendix J. Thus, the MRE predicted by the DAM for reduction in cuttings removal can vary at most by a factor of 9 across all alternatives, with each MRE being well defined.

Figures 3-2 and 3-3 illustrate the results given in Table 3-5 for ease of comparison. It can be seen from these figures that plasma processing produces the best MRE for reducing cuttings releases. In fact, the waste composite produced by plasma processing produces an approximate maximum possible improvement, because it is estimated that waste treated by plasma processing could make the effective radius of the eroded borehole very close to that of the drill bit. There are no other significant trends among the other alternatives.

3.2.4.2 Waterborne Transport, Scenario E1

Table 3-6 gives the results for waterborne transport of radioactive materials from the repository to the Culebra (Scenario E1). For all 1,000 trials the transported quantities of radionuclides fell in a narrow band of values, indicating that the processes modeled in the DAM may not be sensitive to the input parameters that were modeled with uncertainty. This result can be explained by the boundary conditions imposed upon the repository by the assumptions made about the Castile. In Scenario E1, a borehole completely penetrates the Salado salt formation and punctures the Castile approximately 656 feet (200 meters) below the level of the repository. The Castile is assumed to contain a brine reservoir that is an infinite source of salt-saturated fluid at high pressure, resulting in a continuous flow of brine up the borehole to the Culebra.

As the brine flows through the repository level via the borehole, it may also spread into a limited volume of the waste composite, termed the wash-through volume. As it passes through the waste composite, it dissolves radionuclides to the limit of their solubilities in brine. As indicated in Appendix E, the quantities of radionuclides transported to the Culebra as a result of E1 is a function of the quantity of water flowing from the Castile and the volume of the repository it washes through. If a sufficient quantity of this brine flows through some volume of the repository, radioactive material will be carried to the Culebra until the available inventory of radionuclides in the wash-through volume is completely depleted. The calculated results of the 1,000 uncertainty cases are insensitive to the solubility of radionuclides in brine, indicating that the 5,000 years available after the intrusion event is sufficient to produce this result. Consequently, transport of radioactive material to the Culebra in this scenario is primarily dependent on the magnitude of the wash-through volume and the radionuclide inventory within that volume.

An important parameter for determining both the rate of brine flow through the repository and the size of the wash-through volume is the hydraulic conductivity of the backfill/waste composite. Hydraulic conductivity of the backfill/waste composite is not derived by the DAM and is currently expressed as a ninth order polynomial of the effective stress level of waste compaction (Appendix F). Since specifying the uncertainty of the hydraulic conductivity correlation would require establishing a weighted set of polynomial expressions, each with its own set of nine

TABLE 3-5

UNCERTAINTY ANALYSIS OF MEASURE OF RELATIVE EFFECTIVENESS FOR RELEASE OF CUTTINGS TO THE SURFACE (ALL SCENARIOS)

TRU Disposal System Scenario					Variability in Case by Case Calculations of MRE						
						Distribution of MREs for Cases With No Zero Transport					
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Percent Runs Producing Zero Transport	5th Percentile (most benefit)	Median	Mean	95th Percentile (least benefit)	Percent Runs at Maximum Limit of Transport	MRE for 95th %-tiles of EA & Baseline Transport CCDFs
	None	None	1	Baseline	0%					0%	N/A
		Sand+Clay	2	33	0%	0.91	0.92	0.92	0.92	0%	0.92
		SAG	3	35a	0%	0.40	0.40	0.40	0.40	0%	0.40
		CG	4	35b	0%	0.40	0.40	0.40	0.40	0%	0.40
		Clay	5	111	0%	0.93	0.94	0.94	0.94	0%	0.94
		CaO + Salt	6	83	0%	0.94	0.94	0.94	0.94	0%	0.94
	Super C	None	7	1	0%	0.25	0.26	0.26	0.26	0%	0.25
		SAG	8	77a	0%	0.21	0.21	0.21	0.21	0%	0.21
		Clay	9	77b	0%	0.21	0.21	0.21	0.22	0%	0.21
		Sand+Clay	10	77c	0%	0.21	0.21	0.21	0.21	0%	0.21
		CaO + Salt	11	77d	0%	0.21	0.21	0.21	0.22	0%	0.22
	S&C	None	12	6	0%	0.75	0.79	0.78	0.80	0%	0.77
	SCC	None	13	94a	0%	0.56	0.57	0.57	0.57	0%	0.57
		Sand+Clay	14	94b	0%	0.52	0.52	0.52	0.52	0%	0.52
		CG	15	94c	0%	0.29	0.30	0.30	0.30	0%	0.30
		SAG	16	94d	0%	0.29	0.30	0.30	0.30	0%	0.30
		Clay	17	94e	0%	0.53	0.53	0.53	0.53	0%	0.53
		CaO + Salt	18	94f	0%	0.53	0.54	0.53	0.54	0%	0.54
	Plasma	None	19	10	0%	0.11	0.12	0.13	0.18	0%	0.12

LEGEND:
Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
EC/SC: Enhanced cementation of sludges. Shred and add clay based materials to organics and inorganics
SAG: Salt aggregate grout
CG: Cementitious grout

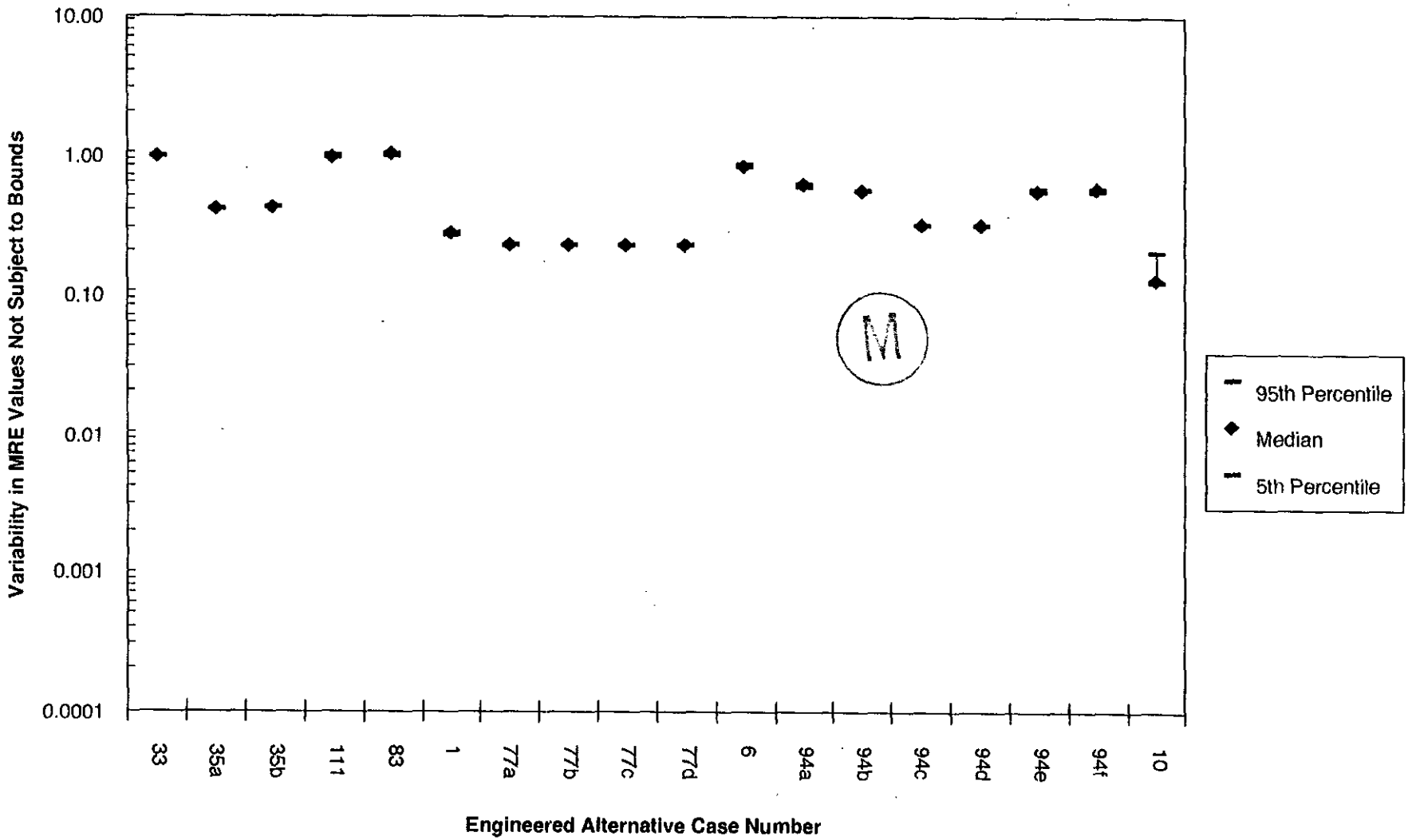

Figure 3-2

Uncertainty Analysis of Case-by Case Measure of Relative Effectiveness for Release of Cuttings to the Surface (all scenarios)

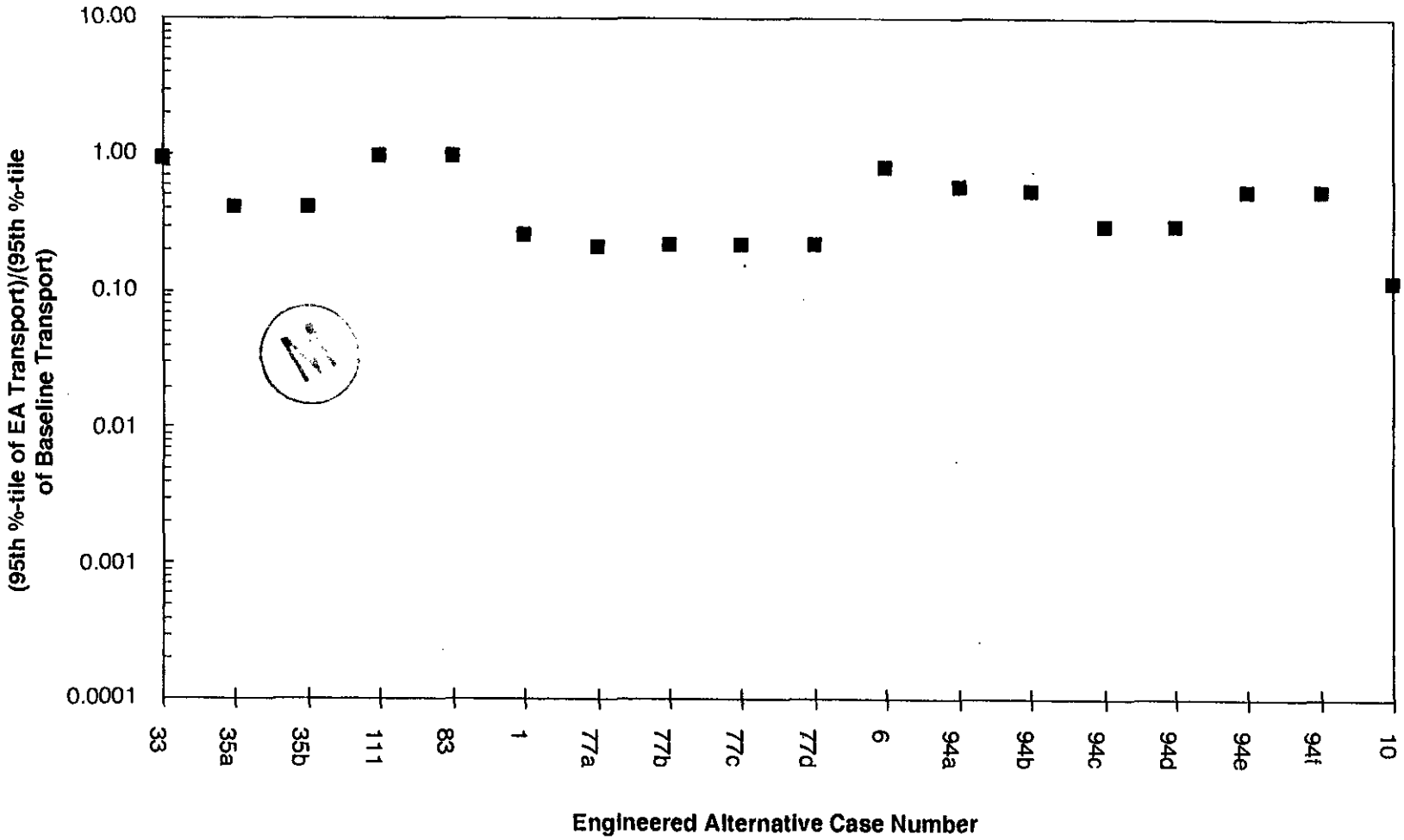

Figure 3-3

Measure of Relative Effectiveness for Reducing 95th Percentile of All Uncertainty Case Runs for Release of Cuttings to the Surface (all scenarios)

TABLE 3-6

UNCERTAINTY ANALYSIS OF MEASURE OF RELATIVE EFFECTIVENESS FOR WATERBORNE TRANSPORT TO CULEBRA DOLOMITE (SCENARIO E1)

TRU Disposal System Scenario					Variability in Case by Case Calculations of MRE						
						Distribution of MREs for Cases With No Zero Transport					
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Percent Runs Producing Zero Transport	5th Percentile (most benefit)	Median	Mean	95th Percentile (least benefit)	Percent Runs at Maximum Limit of Transport	MRE for 95th %-tiles of EA & Baseline Transport CCDFs
	None	None	1	Baseline	0%					0%	N/A
		Sand+Clay	2	33	0%	0.73	0.75	0.75	0.78	0%	0.73
		SAG	3	35a	0%	0.40	0.41	0.41	0.42	0%	0.40
		CG	4	35b	0%	0.40	0.41	0.41	0.42	0%	0.40
		Clay	5	111	0%	0.53	0.54	0.54	0.55	0%	0.53
		CaO + Salt	6	83	0%	0.83	0.83	0.81	0.84	0%	0.83
	Super C	None	7	1	0%	0.92	0.93	0.93	0.94	0%	0.94
		SAG	8	77a	0%	0.43	0.45	0.45	0.47	0%	0.43
		Clay	9	77b	0%	0.55	0.56	0.57	0.59	0%	0.55
		Sand+Clay	10	77c	0%	0.72	0.74	0.74	0.78	0%	0.72
		CaO + Salt	11	77d	0%	0.60	0.80	0.77	0.81	0%	0.78
	S&C	None	12	6	0%	0.92	0.94	0.94	0.96	0%	0.96
	SCC	None	13	94a	0%	0.68	0.69	0.70	0.72	0%	0.68
		Sand+Clay	14	94b	0%	0.64	0.66	0.66	0.69	0%	0.64
		CG	15	94c	0%	0.44	0.45	0.45	0.47	0%	0.44
		SAG	16	94d	0%	0.44	0.45	0.45	0.47	0%	0.44
		Clay	17	94e	0%	0.52	0.54	0.54	0.56	0%	0.52
		CaO + Salt	18	94f	0%	0.26	0.67	0.63	0.68	0%	0.66
	Plasma	None	19	10	0%	0.0004	0.0007	0.0008	0.0012	0%	0.0011

LEGEND:
Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
EC/SC: Enhanced cementation of sludges. Shred and add clay based materials to organics and inorganics
SAG: Salt aggregate grout
CG: Cementitious grout

coefficients, to express the range of potential relations, only a best estimate was used for EA comparison purposes. This explains the very narrow range of actinide activity transported and also the resultant overall MRE.

Figures 3-4a and 3-4b plot the results given in Table 3-6 for ease of comparison. It can be seen from this figure that plasma processing reduces transport following an E1 scenario by a factor of over 1,000, whereas all the other alternatives produce reductions of less than a factor of 10. This significant difference is attributed to the resulting very low hydraulic conductivity within the waste horizon for a vitrified waste/salt composite. This very low permeability greatly restricts the radius to which the wash-through volume extends into the waste horizon, compared to the baseline design and all other alternatives.

Of those involving backfill, the engineered alternatives that use either SAG or SG backfill provide the best performance for the E1 Scenario. These backfill options would tend to provide a consistently tough waste composite across the entire cross section penetrated by the borehole.

3.2.4.3 Waterborne Transport, Scenario E2

Of all the scenarios and mechanisms for transport investigated in this study, waterborne transport as a result of the E2 Scenario is the most dependent on the inflow of brine and the buildup of fluid pressure within the undisturbed repository. It does not have the assumed pressure and infinite source of brine available from the Castile as a driving force to move radionuclides to the Culebra, as is the case with the E1 scenario.

Because of the wide variation in the physical input parameters, there are random sample calculations in which the baseline design for the EA may produce waterborne radioactive transport to the Culebra of zero. For example, a combination of conditions that produce a low repository pressure may result in a hydraulic head too low for water to rise to the Culebra. In addition, low brine inflow and/or a high brine consumption rate from anoxic corrosion may simply not provide sufficient brine for any release. Conversely, there are a group of random sample calculations in which the baseline design or the EA produce waterborne radioactive transport to the Culebra at a bounding limit corresponding to the entire inventory of radioactive material available in a panel.

Table 3-7 shows that about 1 percent of cases for the baseline design produce zero releases, while 7% of the cases transport essentially all available radionuclides in a panel. Many of the EAs increase the percentage of cases that produce zero transport, but some also increase the number of cases that produce releases at the upper limit of waste that is available for hydraulic communication with the borehole. It should be noted that plasma processing produces the most improvement by far and also produces the least spread of MRE values. This indicates that the vitrified waste/salt composite has performance properties that are insensitive to the quantities that *were modeled with uncertainty for this analysis.*

Figures 3-5a and b plot the results given in Table 3-7 for ease of comparison. As with Scenario E1, plasma processing produces the most improvement of performance against E2 scenarios, for the same reason as stated in Section 3.2.4.3 for E1 scenarios. The backfill EAs that use lime (CaO) to reduce the actinide solubility also produces a very significant benefit because the limited availability of brine enhances the importance of actinide solubility. The SAG and CG backfill also add some benefit, although not as significant as lime. The waste processing options have little to no significant impact on performance. In Figure 3-5b, the large number of

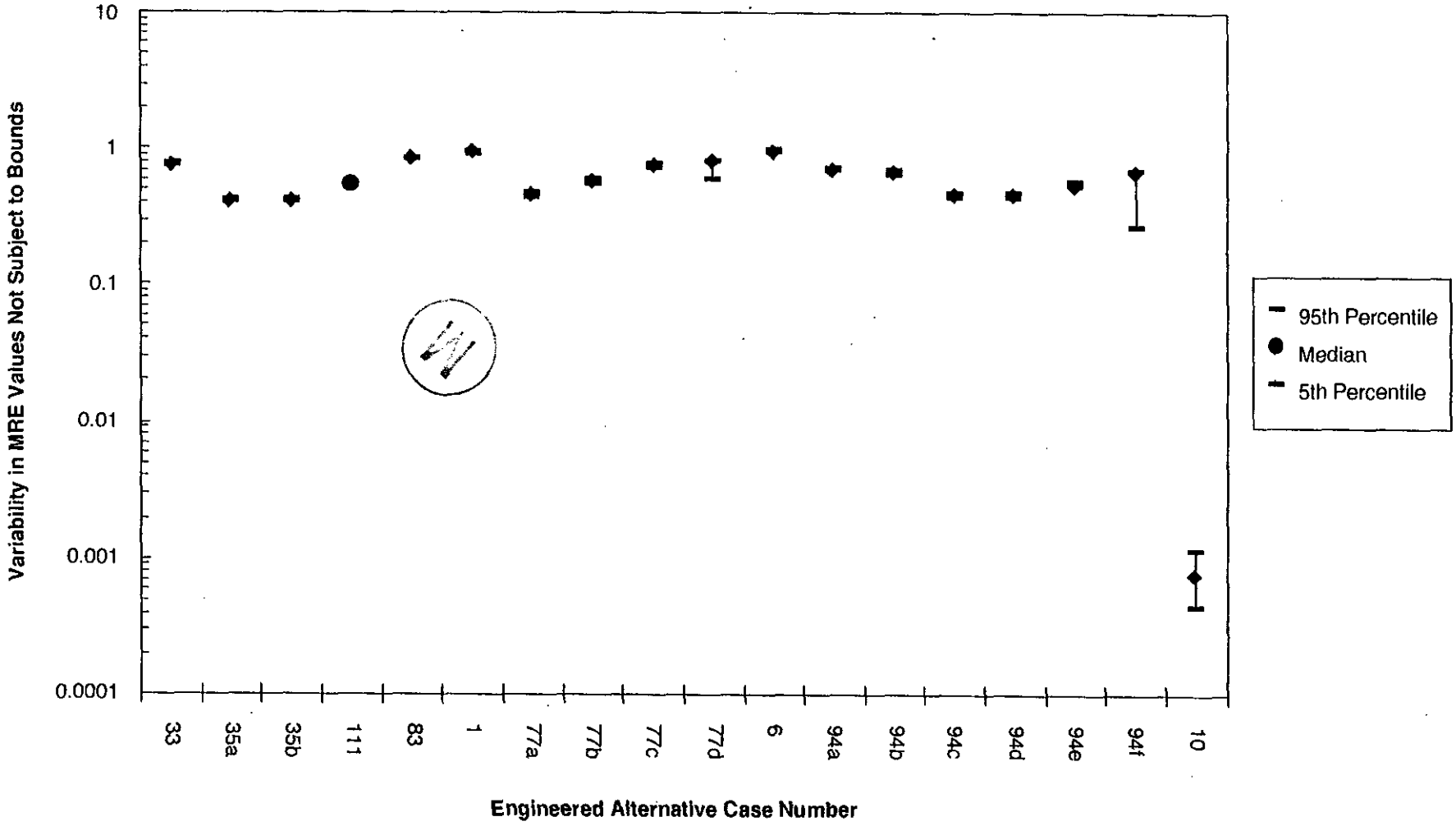

Figure 3-4a

Uncertainty Analysis of Case-by Case Measure of Relative Effectiveness for Waterborne Transport to Culebra Dolomite (Scenario E1)

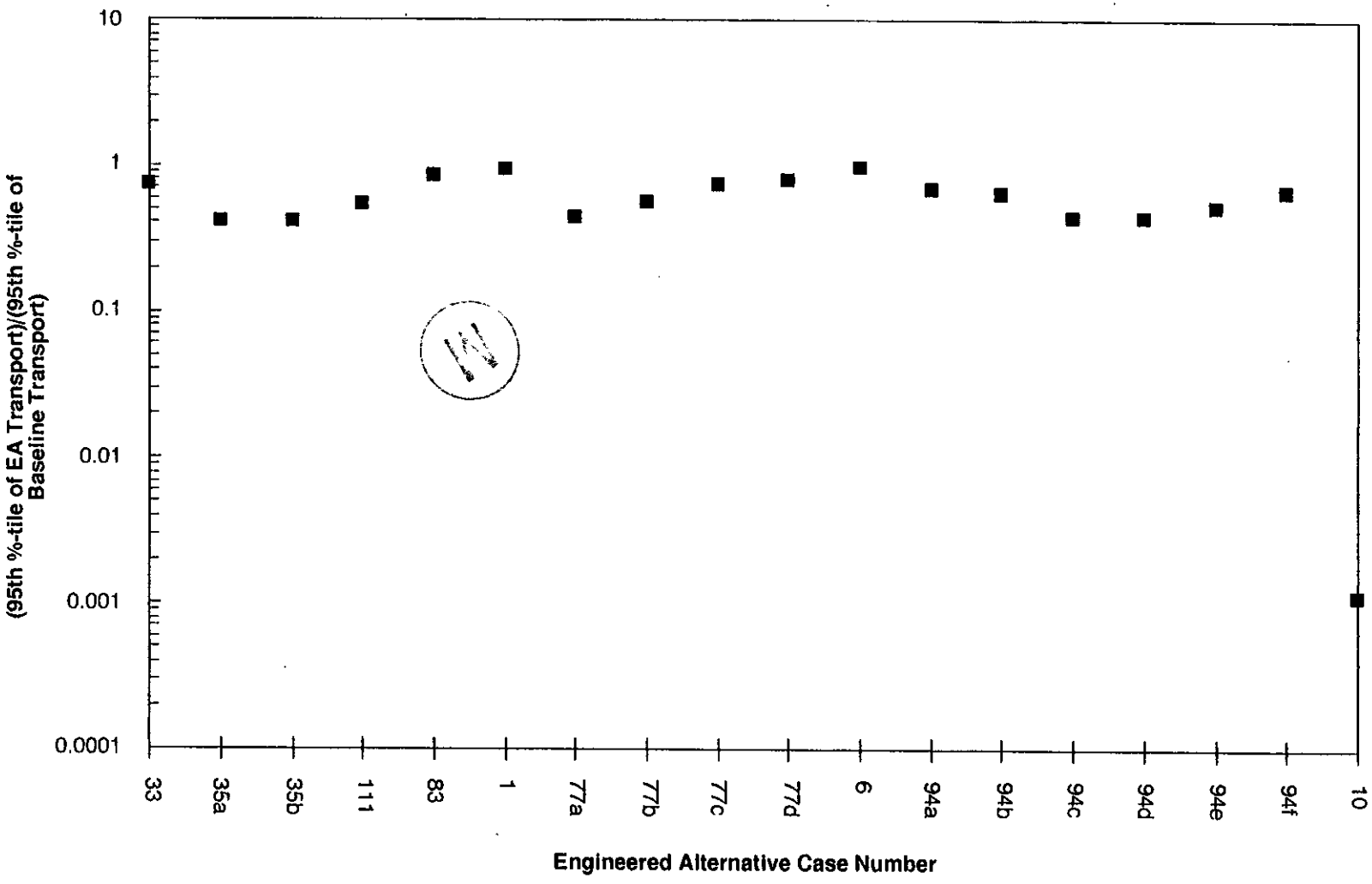

Figure 3-4b

Measure fo Relative Effectiveness for Reducing 95th Percentile of All Uncertainty Case Runs for Waterborne Transport to Culebra Dolomite (Scenario E1)

TABLE 3-7

UNCERTAINTY ANALYSIS OF MEASURE OF RELATIVE EFFECTIVENESS FOR WATERBORNE TRANSPORT TO CULEBRA DOLOMITE (SCENARIO E2)

TRU Disposal System Scenario					Variability in Case by Case Calculations of MRE						
						Distribution of MREs for Cases With No Zero Transport					
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Percent Runs Producing Zero Transport	5th Percentile (most benefit)	Median	Mean	95th Percentile (least benefit	Percent Runs at Maximum Limit of Transport	MRE for 95th %-tiles of EA & Baseline Transport CCDFs
	None	None	1	Baseline	1%					7%	N/A
		Sand+Clay	2	33	21%	0.31	1.07	1.11	1.99	7%	1.00
		SAG	3	35a	24%	0.18	0.71	0.68	1.09	3%	0.54
		CG	4	35b	24%	0.18	0.71	0.68	1.09	3%	0.54
		Clay	5	111	21%	0.33	1.14	1.20	2.18	7%	1.00
		CaO + Salt	6	83	7%	0.009	0.12	0.24	0.84	0%	0.009
	Super C	None	7	1	0%	0.61	1.08	1.28	2.08	8%	1.00
		SAG	8	77a	19%	0.091	0.31	0.37	0.87	1%	0.19
		Clay	9	77b	18%	0.45	1.11	1.23	2.35	8%	1.00
		Sand+Clay	10	77c	18%	0.37	1.06	1.15	2.06	8%	1.00
		CaO + Salt	11	77d	4%	0.009	0.119	0.235	0.83	0%	0.009
	S&C	None	12	6	0%	0.75	1.01	1.17	1.75	8%	1.00
	SCC	None	13	94a	24%	0.19	0.72	0.69	1.08	3%	0.57
		Sand+Clay	14	94b	56%	0.14	0.74	0.77	1.61	2%	0.25
		CG	15	94c	59%	0.03	0.37	0.41	0.88	1%	0.08
		SAG	16	94d	59%	0.03	0.37	0.41	0.88	1%	0.08
		Clay	17	94e	55%	0.16	0.75	0.78	1.62	2%	0.26
		CaO + Salt	18	94f	31%	0.005	0.09	0.19	0.75	0%	0.009
	Plasma	None	19	10	0%	0.0009	0.0088	0.0194	0.0549	0%	0.0018

LEGEND:
Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
EC/SC: Enhanced cementation of sludges. Shred and add clay based materials to organics and inorganics
SAG: Salt aggregate grout
CG: Cementitious grout

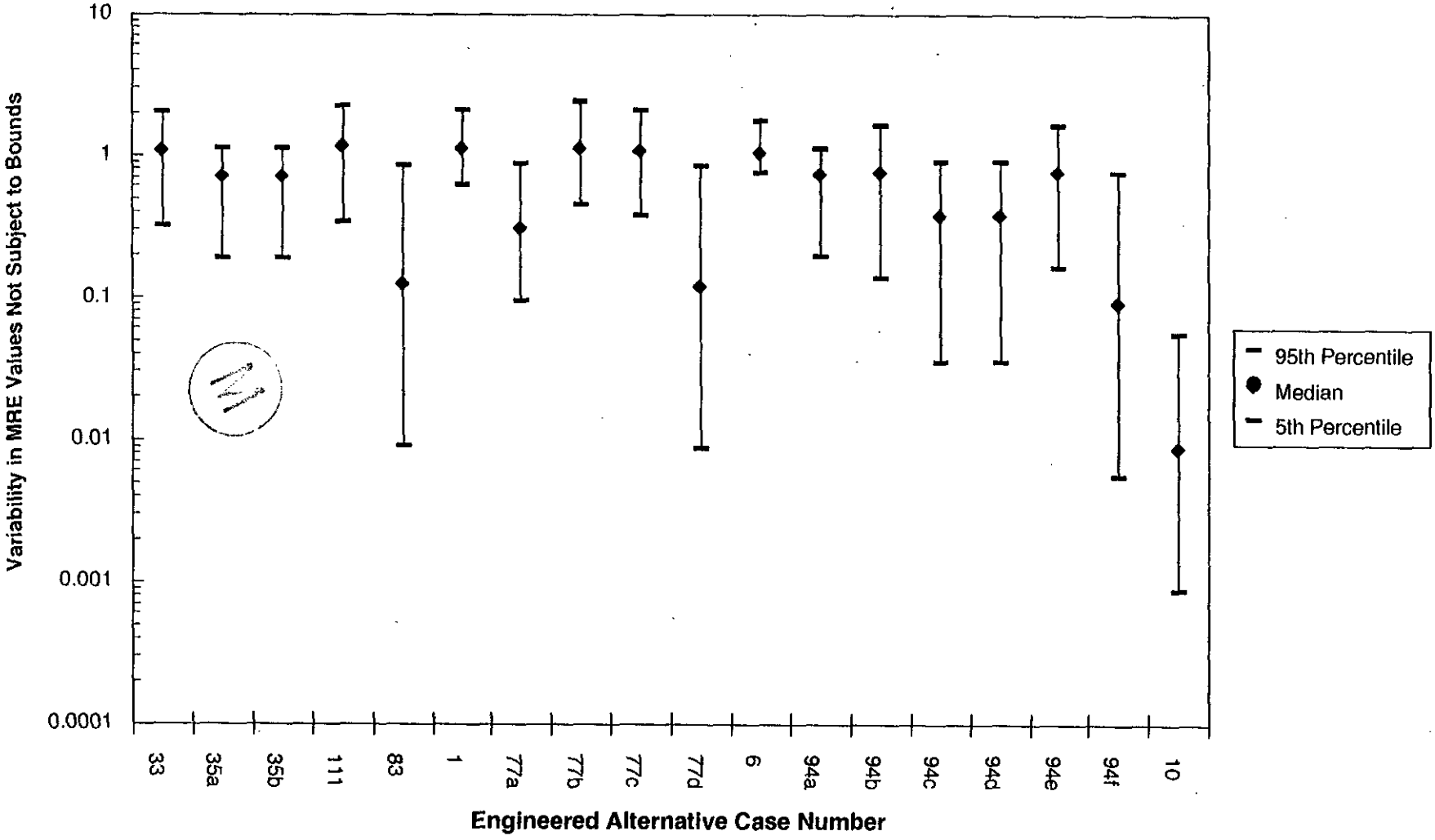

Figure 3-5a

Uncertainty Analysis of Case-by Case Measure of Relative Effectiveness for Waterborne Transport to Culebra Dolomite (Scenario E2)

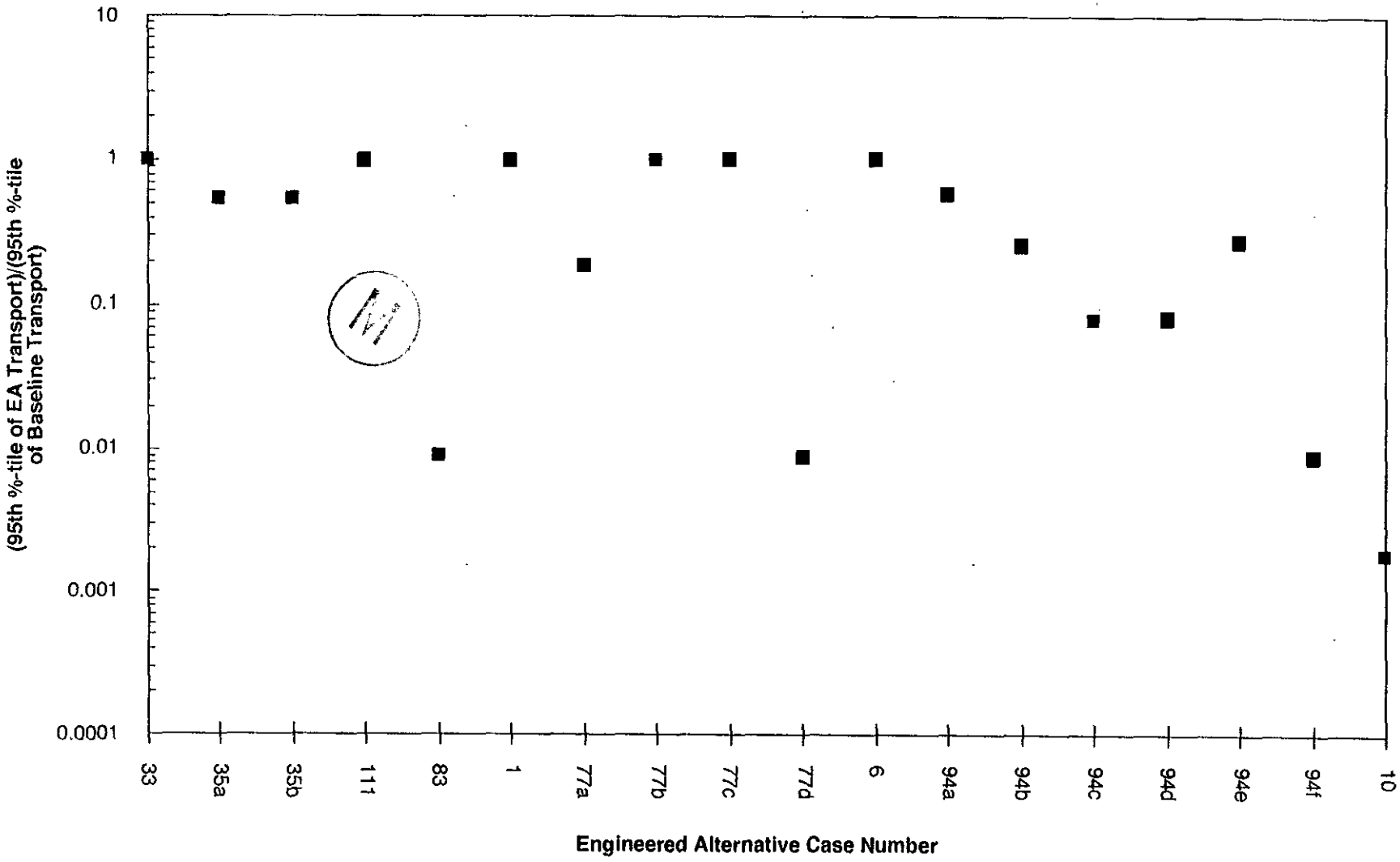

Figure 3-5b

Measure of Relative Effectiveness for Reducing 95th Percentile of All Uncertainty Waterborne Transport to Culebra Dolomite (Scenario E2)

values at 1.0 indicate that at least 5% of the cases are producing releases at the limit of available radionuclide inventory for both the baseline design and the EA. In these cases, the EA has no impact on the potential for the larger releases for this scenario.

3.2.4.4 Waterborne Transport, Scenario E1E2

The physical process of interest for the E1E2 Scenario involves saturated brine flowing through the repository horizon between two boreholes. One borehole permits Castile brine at high pressure to flow into the repository, but blocks the brine's path to the surface via that borehole. A second borehole then forms a path for flow in response to the pressure head to the Culebra. For comparison of EA performance, the two boreholes are assumed to be at opposite ends of a room, resulting in the wash-through volume being equal to the volume of one room at the time of the human intrusion event.

As with the E1 Scenario, the quantity of brine that flows through the room is dependent on the backfill/waste composite hydraulic conductivity; but if enough brine flows through the room, the radionuclide inventory in the room can be completely dissolved. Because of the hydraulic conductivity of the baseline design, high pressure, and unlimited supply of brine assumed to be available from the Castile, all the baseline calculations resulted in complete dissolution of the waste inventory of the room. The 1,000 random sample calculations for the E1E2 scenario for the baseline design all result in the same quantity of radionuclide transport.

Table 3-8 and Figure 3-6a and 3-6b show the results for waterborne transport due to the E1E2 Scenario. The EAs that are effective against Scenario E1E2 either alter the backfill/waste composite hydraulic conductivity or the actinide solubility along that path, which is assumed to consist of an entire room. Consistent with E1 and E2, plasma processing, which produces the greatest reductions in permeability, results in the best improvement. However, other EAs also produced good results. Those EAs that use either SAG or CG backfill significantly reduce permeability, which in turn reduces the backfill/waste composite hydraulic conductivity. This lowers the rate of brine flow, thus reducing the quantity of brine available to dissolve and transport actinides. The EAs that employ lime reduce solubility, thus lowering the quantity of actinides that a given amount of brine can dissolve.

TABLE 3-8

UNCERTAINTY ANALYSIS OF MEASURE OF RELATIVE EFFECTIVENESS FOR WATERBORNE TRANSPORT TO CULEBRA DOLOMITE (SCENARIO E1E2)

TRU Disposal System Scenario					Variability in Case by Case Calculations of MRE						
						Distribution of MREs for Cases With No Zero Transport					
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Percent Runs Producing Zero Transport	5th Percentile	Median	Mean	95th Percentile	Percent Runs at Maximum Limit of Transport	MRE for 95th %-tiles of EA & Baseline Transport CCDFs
	None	None	1	Baseline	0%					100%	N/A
		Sand+Clay	2	33	0%	0.99	0.99	0.97	0.99	96%	0.99
		SAG	3	35a	0%	0.009	0.036	0.129	0.75	4%	0.75
		CG	4	35b	0%	0.009	0.036	0.129	0.75	4%	0.75
		Clay	5	111	0%	0.024	0.476	0.53	0.99	35%	0.99
		CaO	6	83	0%	0.012	0.041	0.14	0.76	4%	0.76
	Super C	None	7	1	0%	1.00	1.00	1.00	1.00	100%	1.00
		SAG	8	77a	0%	0.011	0.075	0.224	0.98	10%	0.98
		Clay	9	77b	0%	0.037	0.825	0.63	0.98	48%	0.98
		Sand+Clay	10	77c	0%	0.98	0.98	0.96	0.98	96%	0.98
		CaO	11	77d	0%	0.012	0.027	0.094	0.438	2%	0.437
	S&C	None	12	6	0%	1.00	1.00	1.00	1.00	100%	1.00
	SCC	None	13	94a	0%	0.37	1.00	0.93	1.00	88%	1.00
		Sand+Clay	14	94b	0%	0.22	0.99	0.89	0.99	82%	0.99
		CG	15	94c	0%	0.01	0.08	0.23	0.98	11%	0.98
		SAG	16	94d	0%	0.01	0.08	0.23	0.98	11%	0.98
		Clay	17	94e	0%	0.024	0.44	0.52	0.99	34%	0.98
		CaO	18	94f	0%	0.009	0.012	0.020	0.045	1%	0.045
	Plasma	None	19	10	0%	0.0003	0.0009	0.0018	0.0066	0%	0.01

LEGEND:
Super C: Shredding and compaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
SAG: Salt Aggregate Grout
CG: Cementitious Grout

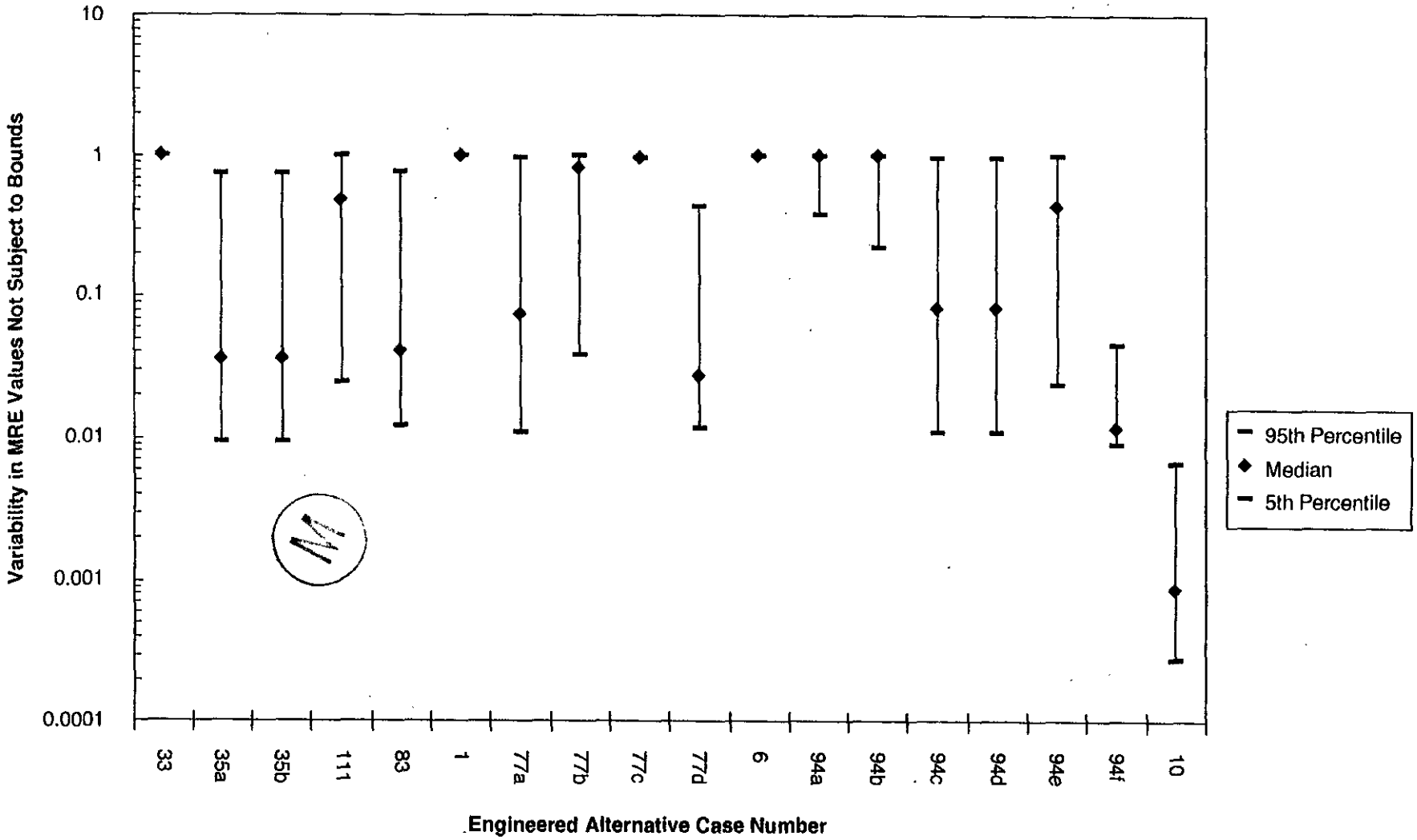

Figure 3-6a

Uncertainty Analysis of Case-by-Case Measure of Relative Effectiveness for Waterbourne Transport to Culebra Dolomite (Scenario E1E2)

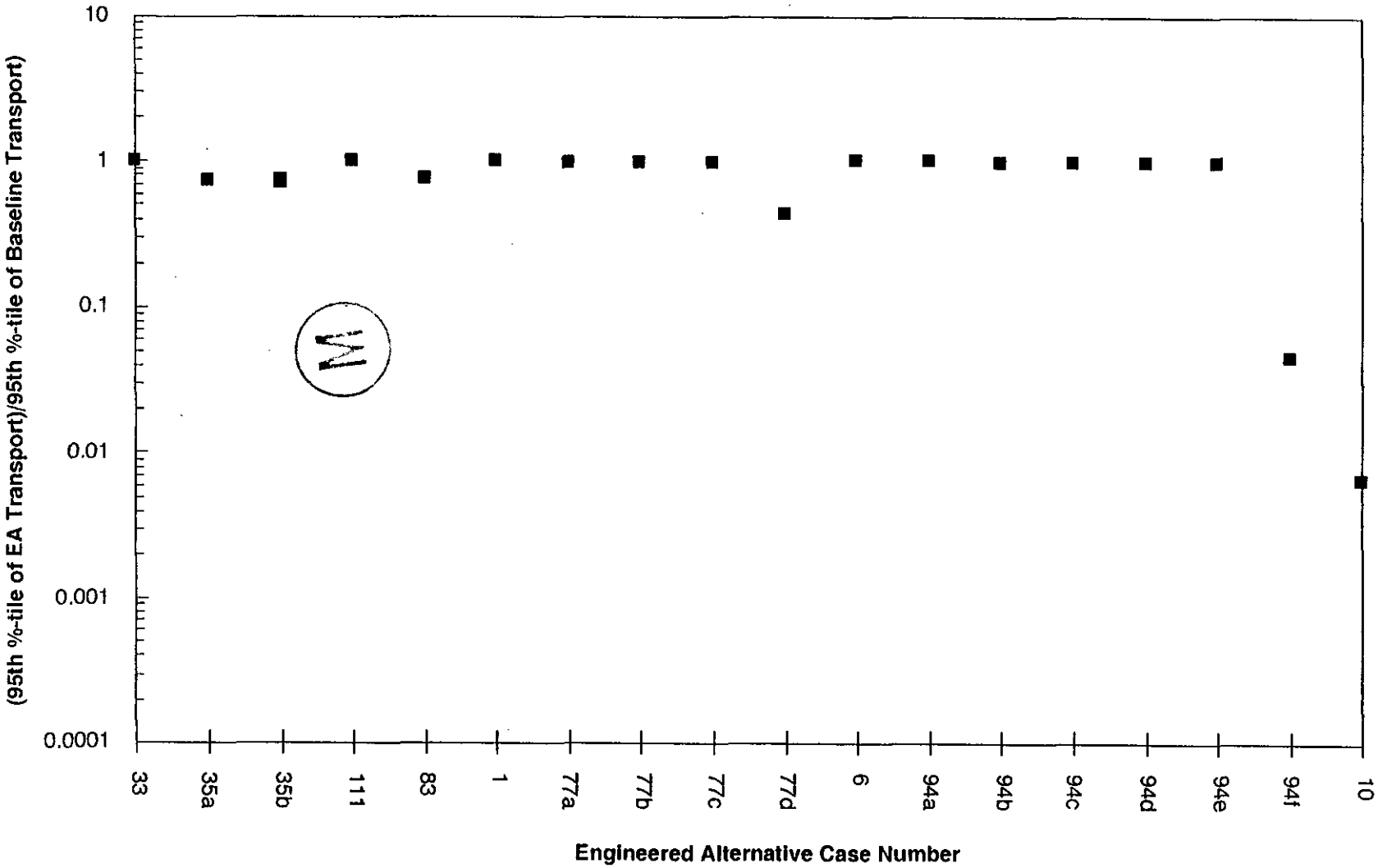

Figure 3-6b

Measure of Relative Effectiveness for Reducing 95th Percentile of All Uncertainty Waterborne Transport to Culebra Dolomite (Scenario E1E2)

3.3 FACTOR 3: IMPACT ON WORKER AND PUBLIC RISK

3.3.1 Definition of Factor 3

Discussion of the human health risks associated with adopting an EA includes impacts that may be realized at the WIPP site and generator or disposal facilities that are involved with TRU or TRU-mixed waste. Consideration of potential impacts includes radiation effects (both radiation emanating from waste or processing equipment and the release of radioactive material), effects from the release of hazardous material, and, in the case of individuals within the facilities, ordinary industrial hazards. Impacts are considered for the following five groups of individuals at the WIPP and at the generator/disposal sites:

- Workers directly involved with handling, processing, or storing TRU waste (generally referred to as "workers")
- Other workers in the facility who are not directly involved with the TRU waste (also referred to as "co-located workers")
- The co-located worker who receives the highest exposure to radiation or hazardous material from TRU waste activities
- All members of the public who live within 50 miles (80.5 km) of the facility where the TRU waste is being handled, processed, or stored (generally referred to as "public")
- The member of the public located off-site who receives the highest exposure from activities associated with TRU handling, processing, or disposal (often called the Maximum Off-Site Individual or MOI).

Radiation emanating from waste or processing equipment primarily affects workers. Because co-located workers and members of the public are much further from the source of radiation, the human health impacts on these groups are small and can be ignored in this analysis. Hazardous and toxic chemicals do not have human health impacts on any of the groups as long as the chemicals remain contained.

If radioactive material, hazardous material, or toxic chemicals do not remain contained within packaging, they may pose a hazard to workers, co-located workers, or the public, primarily by being taken into the body via numerous exposure processes. Such releases may result from faulty packaging, violation of the integrity of the packaging, or opening of the packaging during processing. To constitute a risk, however, the released materials must come in contact with an individual. To do that, the material must move through some pathway between the source of material and the exposed individual. The most frequent pathway involves some portion of the material becoming airborne, moving in air to the exposed individual, and being inhaled. Other pathways include contamination of water that is subsequently consumed by the exposed individual or used to water food crops or provide drinking water for animals; deposition from the air to food crops; and deposition on the ground where it may be taken up by plants, become a source for contaminating water, or be resuspended in the air. Exposure may also come from contact with or ingestion of soil or other materials contaminated by the waste.

Human health impacts are not generally measured the same way for radiation, toxic chemicals, carcinogenic chemicals, or industrial accidents. To facilitate comparison with other reported data, this document reports impacts in the units most commonly used in other studies. In addition, to the extent possible, the report also displays results in units that will facilitate comparing the impacts from the different types of hazards, recognizing that the endpoints are not identical. The following paragraphs describe significant differences between the endpoints reported.

Standard health and safety control practices include administrative control of exposures to radiation or hazardous material for workers as individuals and as groups. Workers are often rotated through hazardous and nonhazardous work to limit individual exposures. For this reason, the concept of the full-time equivalent (FTE) is used in relation to worker doses. An FTE is assumed to be commensurate to one individual working full time in a waste management facility even though it may actually represent a number of individuals, none of whom work full time in the facility. Rather than reporting maximum individual or average worker doses, the report uses collective dose for all workers. These doses will be expressed in FTE-rem rather than person-rem to emphasize that they are worker and not public doses.

The impacts of exposure to radiation and to carcinogenic chemicals may be reported as excess cancers. Unfortunately, most of the data reported in the literature relating radiation exposure and cancer are given in terms of cancer fatalities, and cancer incidence is usually reported for exposure to carcinogenic chemicals. Because cancer incidence is not synonymous with cancer fatalities, the units for radiation risk will be excess fatalities, and the units for carcinogenic compounds will be excess cancers.

Unlike carcinogenic hazardous chemicals, toxic chemicals do not have an apparent impact when present in less than a threshold concentration. Exposure to these types of chemicals is reported as a fraction of the applicable limit. For members of the public, the estimated long-term air concentration for each chemical is divided by the maximum level to which an individual may be exposed 24 hours a day for 70 years without developing adverse effects. The resulting fraction, called a hazard quotient, is totaled for all reported chemicals and the sum reported as a hazard index. The amount the hazard index exceeds 1.0 can serve as an indicator of relative potential for causing harm.

For workers, the exposure to toxic chemicals is reported as an exposure index. The exposure ratio is calculated similarly to the hazard quotient except that it is based on the maximum concentration that might be observed for each chemical which is divided by a threshold limit value based on safe exposure for a shorter time, typically an 8-hour day or 40-hour week. The sum of the exposure ratios for all chemicals of concern is called the exposure index. An exposure index of greater than 1.0 indicates an increased likelihood of adverse health effects in the workers.

Table 3-9 summarizes the types of human health risk analyses and the units in which the results are reported.

3.3.2 Methodology Used to Evaluate Worker and Public Risk

This section of the report describes the methodology used to produce estimates of worker and public risk. Details of the models and the way they were applied may be found in Appendix K.

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TABLE 3-9

REPORTING UNITS FOR HUMAN HEALTH RISK ANALYSIS

Exposure Group	Radiation Impacts	Carcinogenic Chemicals	Toxic Chemicals	Industrial Accidents
Workers (Collective)	FTE-rem Excess Fatalities	Excess Cancers	Exposure Index	Injuries Fatalities
Most Exposed Co-Located Worker	Rem Excess Risk	Excess Cancers	Hazard Index	Not Applicable
Co-Located Workers (Collective)	Person-rem Excess Fatalities	Excess Cancers	Not Applicable	Not Applicable
Most Exposed Off-site Individual	Rem Excess Risk	Excess Cancers	Hazard Index	Not Applicable
Collective Off-site (Public)	Person-rem Excess Fatalities	Excess Cancers	Not Applicable	Not Applicable

Many of the alternatives consist of a combination of a method of waste processing with a method of emplacement of the waste at the WIPP. For the sake of simplicity of presentation and flexibility in considering the impacts of the alternatives, the analysis of the treatment options has been performed separately from the analysis of the impacts of emplacement at the WIPP. With the exception of the data for the maximally exposed individuals, all the human health impacts may be considered additive, and thus, may be considered in multiple combinations.

All alternatives, including the baseline, have some activities in common. Those include retrieval, packaging, and certification of the waste to WIPP WAC standards. All of the alternatives may be considered as various combinations of four waste processes and five emplacement options. The four processing options follow:

- Compact (supercompact) all waste except sludges. This process is included in Alternatives 1 and 77(a–d).
- Shred and compact all waste except sludges, Alternative 6.
- Plasma processing, Alternative 10.
- Shred and add clay-based materials to organics and inorganics used in Alternatives 94(a–f).

The baseline involves no backfill during emplacement. The five emplacement options involve various types of backfill:

- Sand plus clay backfill, Alternatives 33, 77c, and 94b.
- Salt aggregate grout backfill, Alternatives 35a, 77a, and 94d.
- Cementitious grout backfill, Alternatives 35b and 94c.
- Clay-based backfill, Alternatives 77b, 94e, and 111.
- CaO backfill, Alternatives 83, 77d, and 94f.

Table 3-10 displays the processing and emplacement options used in each EA. The total impact of each alternative is the sum of the processing and emplacement impacts.

Because the WIPP is not now active for emplacement of TRU waste, and most of the facilities throughout the DOE system are not operating the types of waste processing specified in the alternatives, all analysis of EA performance must be performed using modeling techniques.

3.3.2.1 Methodology Used to Evaluate Waste Process Impacts

The impacts from each alternative are compared to the impacts from a baseline, which consists of the emplacement of waste certified to meet the WIPP WAC without any backfill of the rooms after emplacement. The baseline includes waste that is already packaged and complies with the WAC, waste that is not yet generated but will be packaged and certified to meet WAC, and waste that is not yet packaged or needs to be repackaged to meet the WAC or that requires some

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TABLE 3-10

HUMAN HEALTH ANALYTICAL COMPONENTS OF EACH ENGINEERED ALTERNATIVE

Engineered Alternative	Processing Analysis	Emplacement Analysis
1	Supercompaction	Same as Baseline
6	Shred and Compact	Same as Baseline
10	Plasma Processing	Same as Baseline
33	Same as Baseline	Sand plus Clay Backfill
35a	Same as Baseline	Salt Aggregate Grout Backfill
35b	Same as Baseline	Cementitious Grout Backfill
111	Same as Baseline	Clay-based Backfill
77a	Supercompaction	Salt Aggregate Grout Backfill
77b	Supercompaction	Clay-based Backfill
77c	Supercompaction	Sand plus Clay Backfill
77d	Supercompaction	CaO Backfill
83	Same as Baseline	CaO Backfill
94a	Shred and Add Clay	Same as Baseline
94b	Shred and Add Clay	Sand plus Clay Backfill
94c	Shred and Add Clay	Cementitious Grout Backfill
94d	Shred and Add Clay	Salt Aggregate Grout Backfill
94e	Shred and Add Clay	Clay-based Backfill
94f	Shred and Add Clay	CaO Backfill

processing to allow certification that it meets the WAC. The latter two situations will require operation of facilities that are considered part of the baseline. These activities are expected to take place at 10 major DOE facilities (see Table 2-4)[1]:

In considering waste processing, where the required waste handling facilities do not currently exist, worker exposures and airborne releases are estimated by assuming a generic facility located at the site. The analysis of these generic facilities is based on individual modules, each of which is designed to perform one specific and necessary part of the task. For example, most generic facilities require a module in which waste is received and inspected and another from which the final product is shipped or sent to a disposal location. Other modules might include repackaging or specific waste processing. Isotopic concentrations of the waste and physical configuration of each module (size and placement of tanks, etc.) are used to estimate worker dose rates. The operations performed in each module are analyzed and estimates of exposure rates, potential air concentrations in the workplace, releases from the vent system, and personnel requirements for operation and maintenance are made and reported on a normalized basis. For example, data on personnel doses are calculated on a per unit throughput basis. Multiplying by the projected annual throughput for a particular site yields an estimate of the annual dose to all the workers for that module. These types of data are then combined for all the necessary modules for a given facility to estimate the annual worker dose for the appropriate waste processing at that particular site. Finally, the data for operations at all waste processing facilities is combined to give a total for the DOE system for that particular alternative.

The impacts of material released to the environment are analyzed independently for each facility. The primary pathway for exposure involves air transport of the material. The impacts associated with the air releases are dependent on local meteorology, air dispersion, and the location of the individual(s) exposed relative to the release point. Thus details of local meteorology and population density and distribution are all inputs to the models for each individual storage or processing facility. In other words, an identical quantity and type of waste going through the same waste processing method may have different human health impacts at each facility.

Performing the analyses as described above involves the application of many very complex models and large data sets. Because performing this type of analysis for all possible combinations of each alternative and each configuration[2] is beyond the scope of this report, a method was developed that simplifies the modeling requirements while retaining adequate information to allow comparison of the many alternatives and configurations. This procedure consists of applying scaling factors to the results of a limited number of the complex analyses described above. The scaling factors are developed independently for each facility and combined to form a weighted scaling factor applied to the systemwide results of the selected fullscale analyses.

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[1]Almost all the waste is located at these 10 sites. Minor additional amounts of waste stored at other small DOE sites may be transported to one or more of these sites. These additional amounts of waste are insignificant and do not impact the human health analysis. DOE sites other than these 10 are currently generating small quantities of TRU waste.

[2]Configuration refers to the arrangement of location(s) at which waste processing is assumed to occur. In the 'Distributed' configuration, waste treatment occurs at the ten sites identified previously. In the 'Regional' configuration, waste is transported to five sites for treatment. In the 'Centralized' configuration, all waste is transported to the WIPP and is treated at a facility built for that purpose.

For a selected EA process, there are two primary considerations that would require scaling of human health impacts. One would be whether or not the selected process was performed at the particular facility. The other is the variation in waste throughput at each facility. The difference in throughput at any given facility may result from either changes to meet the WIPP design capacity or modifications in the system-wide configuration. Consider, for example, the Lawrence Livermore National Laboratory (LLNL), which would perform plasma processing of waste in the decentralized configuration but would only be involved in shipping waste to other facilities for the regional and centralized configurations. In addition to these considerations, the amount of waste assumed to be processed and/or shipped from LLNL must be adjusted, along with all other facilities, to match the design capacity of the WIPP.

Changes in process and throughput alter the human health impacts in two primary ways. Human health impacts are primarily due to materials released to the air to which individuals are subsequently exposed and radiation emitted from the waste exposing those in close proximity either to the waste processing equipment or to the waste in disposal. Exposure to radiation or hazardous materials released during transportation activities is considered in Section 3.5, Risk of Transportation. Changes in waste handling during processing and changes in the amount of waste processed change the amount of radioactive and/or hazardous material released to the air. These releases impact co-located workers and the public. Air releases for different waste processes are process-dependent rather than throughput-dependent. For a given waste process, however, the modeled amount of material released is a linear function of the amount of waste processed or the total throughput. Thus, at each facility, modeling must consider each process separately but may apply linear scaling factors to account for variations in waste throughput.

Impacts on workers are primarily time and process dependent for both exposure to radiation and to airborne contaminants in the workplace. The working time is dependent on the processes involved and the amount of waste processed. The variation between processes requires individual analyses for each process or combination of processes. The amount of time workers spend performing a particular waste process, expressed in full-time equivalents or FTEs, is a function of the amount of waste processed or the waste throughput but that function is not a linear function. Efficiencies of scale dictate that, as facility capacities increase, the number of FTEs required to process a given amount of waste decrease, often eventually reaching a point where increases in waste capacity do not increase FTE requirements to perform the activity. These effects may be plotted on graphs showing the number of FTEs required to process a given input capacity. The shape of these graphs depends on not only the process but also the activities within the process and the range of input capacities considered. To facilitate incorporating these data into the modeling, polynomial equations were generated to match the curves for each process considered which included FTE requirements for pre-operational, construction, operation and maintenance (O&M), and decontamination and decommissioning (D&D) activities. Scaling factors for worker impacts were then generated based on the change in the number of FTEs required at each facility for changes in process and throughput. Construction activities and O&M were considered individually since exposure to radiation and air contaminants would not be expected during construction activities.

3.3.2.2 Methodology Used to Evaluate Waste Emplacement and Backfill Impacts

The amount of waste assumed as the input to all treatment processes was based on the amount of waste that would meet the WIPP design limit for the baseline. The output volume for different alternatives varies depending on the processes used to treat the waste. With the exception of

alternatives involving plasma processing, scaling factors for the off-site impacts of changing emplacement options are based on the changes in total volume of waste emplaced. The releases of hazardous material from waste treated with the plasma process reflects the expectation that all volatile hazardous material is either destroyed in the plasma process or immobilized in the final waste form.

Although different treatments would produce waste forms that vary in both radioactivity concentration levels and total volume, the potential increase in surface radiation levels is offset by both increased self-shielding and decreased volume of waste handled. The modeling reflects this by retaining a scaling factor of one for worker exposure to all waste forms. Scaling factors for worker impacts, based on changes in the numbers of FTEs for emplacement, are applied only for those alternatives that vary the amount of underground work because of changes in the placement or backfill options. These scaling factors are modeled as linear functions of the number of FTEs because the size of the WIPP facility does not vary in a manner that would affect efficiencies of scale.

The analyses for worker injuries and fatalities are performed by applying statistical data from industry operational experience to the number of affected workers for a particular operation. The operation data that most closely approximates the underground mining activities involved in emplacement and backfilling are those gathered for underground salt mining. Accident statistics are typically represented in terms of incident rates (IR). The incident rate is calculated as the number of occurrences divided by a multiple of the numbers of employee hours worked such as injuries per million person-hours worked. The impacts of accidents are modeled by multiplying the IR by the number of person-hours for the particular activity and alternative. The impacts for above ground waste handling, underground emplacement, and backfill activities are summed to represent the total impact for each alternative.

3.3.3 Assumptions and Input for Factor 3

The DOE Office of Environmental Management is developing extensive analyses of waste processing options at fixed locations for the EMPEIS (DOE, 1994b) consistent with the analytical techniques described in Section 3.3.2. The following alternatives were analyzed for CH-TRU waste:

- No Action (Case 1). CH-TRU waste removal, packaging, certification to WIPP acceptance criteria, and indefinite interim storage at all generator sites.

- Decentralized Alternative (Case 4). CH-TRU waste removal, packaging, certification to WIPP acceptance criteria, and stored at ten installations. CH-TRU waste from smaller sites shipped to one of the ten identified sites for processing and storage.

- Regionalized Alternative (Case 5). CH-TRU waste is consolidated, treated to minimize gas generation, and stored at five installations. Treatment involves shredding of appropriate waste and grouting of all waste.

- Regionalized Alternative 2 (Case 6). CH-TRU waste is consolidated, treated to meet RCRA land disposal restrictions, and stored at five installations. Treatment involves incineration and grouting of ash.

- Regionalized Alternative 3 (Case 8). CH-TRU waste is consolidated, treated to meet RCRA land disposal restrictions, and stored at three installations. Treatment involves incineration and grouting of ash.

- Centralized Alternative (Case 9). CH-TRU waste is consolidated, treated to meet RCRA land disposal restrictions, and disposed of at one installation, the WIPP site. Treatment involves incineration and grouting of ash.

The alternatives analyzed in the EMPEIS are not identical to those selected for analysis by the EACBS, but the similarities are sufficiently close to allow selective use of the EMPEIS results as the basis of the analysis for the four processing options for the alternatives. A discussion of some general observations common to the processing options and a description of the basis for the analysis of each of the processing options follows.

3.3.3.1 General Observations on Processing Options

With the exception of the high temperature treatment of the waste, the processing step with the highest potential for contamination release to the work area and through the facility ventilation and discharge filtration system occurs during opening of waste containers and handling of the waste. This opening and handling of waste is a necessary part of sorting the waste prior to shredding or compacting or grouting organics and inorganics. This tends to make releases from all waste processes that incorporate such activities similar in magnitude for the same throughput of waste. Only those processes that involve high temperatures or other actions that would drive off contaminants in the waste would be expected to show a very significant difference in air releases.

Similarly, except for processes that strongly concentrate the contaminants, the highest dose rates to which workers would be exposed would normally occur when they are handling the waste or waste containers. Manual activities such as emptying and sorting waste from waste containers or waste streams tend to be labor-intensive, leading to increased worker exposures for a given quantity of waste processed.

3.3.3.2 Baseline

The alternative baseline is modeled using the results from the EMPEIS Case 4. Both operations consist of retrieval, packaging, and certification to the WIPP WAC at 10 selected facilities. The modeling accounts for the small amounts of waste shipped from smaller generators to one of the ten processor facilities as well as the increase in throughput required to fill the WIPP to design capacity.

3.3.3.3 Shred and Compact

The alternatives that involve shred and compact of everything but sludges are modeled using the results from the EMPEIS shred and grout process, EMPEIS Case 5. Both waste processing methods involve opening, sorting, and shredding the waste. The compacting and grouting are performed remotely and have similar potential for airborne releases and worker exposures. The releases and exposures for either compacting or grouting are expected to be small compared to opening, sorting, and shredding the waste.

3.3.3.4 Shred and Add Clay-based Materials to Organics and Inorganics

The differences between the addition of grout material to drums of waste, as is done in EMPEIS Case 5, and the addition of clay-based material in the alternatives are negligible both for worker exposures and airborne releases. The shred and add clay EA is modeled after the EMPEIS Case 5 scenario.

3.3.3.5 Supercompaction

The processes used in supercompaction of wastes other than sludges is very similar to shred and compact with the addition of a step following the initial compaction in which the normally compacted drum is compressed in a high pressure hydraulic press. The initial steps do not require shredding but do require opening the waste drums and sorting to assure noncompressible materials are not included in the initial drum loading. Supercompaction is modeled using the results of the EMPEIS shred and grout combined with data on the supercompaction module taken from the environmental assessment of the supercompactor at the RFETS (DOE, 1990a).

3.3.3.6 Plasma Process

Plasma Processing is significantly different from EMPEIS Cases 6 and 9, incineration and grouting of the ash. However, from the standpoint of potential airborne releases, the two are similar in that both are high temperature processes which would drive off and/or destroy organic hazardous contaminants. The results from EMPEIS Cases 6 and 9 were used as the basis for impacts involving airborne releases. Worker exposure rates would be expected to be similar, and process modeling was performed to account for differences in total operational FTEs.

3.3.3.7 Emplacement Activities

The basis numbers for impact estimates of emplacement activities were taken from the WIPP FSEIS (DOE, 1990b). Industrial accident estimates, which were not available in the FSEIS, were calculated from estimates of FTEs required to perform waste handling, emplacement, and backfill activities and incident rates for salt mine operation from nationwide reported industry experience from 1978 through 1993 (U.S. Department of Labor, 1978-1993). Some types of accidents that contribute heavily to the incident rates for ordinary salt mining would not be involved in WIPP operations. Data on the contribution of types of accidents to the numbers of incidents (D'Appolonia Consulting Engineers, Inc., 1976) were used to refine the estimate of the number of incidents at the WIPP. The following assumptions were made in the analysis of the impacts of accidents involved in waste handling at the WIPP, emplacement, and backfill activities:

- The WIPP operational life is assumed to be 35 years, and emplacement operations will continue over the entire lifetime.

- Waste receipt and emplacement is based on 2 shifts per day, 5 days per week, 20 days per month for the 35 years of operational life of the WIPP.

- Based on industry experience (Hartman, 1992) backfill operations are expected to be performed as a batch operation functioning an average of 4 hours per day, 5 days per week, 20 days per month for the 35 years of operational life.

- Because of the differences between salt mining and WIPP emplacement and backfill activities, the following types of accidents are assumed not to be significant sources of accidental injuries or fatalities: falls of the roof, face, or sides of panels; explosives handling, fires, and explosions.

- Worker risk at the WIPP analyzed in this section does not include mining of panels or associated activities.

- Above-ground support activities not associated with waste handling are not included in this impact analysis.

3.3.3.8 Other Data

The polynomial equations used to estimate FTEs as a function of process throughput were created from manpower curves developed for the EMPEIS facility cost estimates (Feizollahi and Shropshire, 1994).

The estimates for waste process throughput volumes were taken from data developed for Section 3.8.

3.3.3.9 Sources of Uncertainty

Most of the estimates for human health impacts are based on numbers reported in the EMPEIS. These are based on generic designs for hypothetical facilities, not on measured dose or release rates of currently constructed and operating facilities. The use of those results includes uncertainty associated with those estimates, including uncertainties from definition of the physical setting; model applicability and assumptions; fate, transport, and exposure parameters; and toxicity and risk characterization. Other data used in the analysis, such as the waste quantities and FTE estimates, have uncertainties associated with them.

While the modeling process in the EMPEIS was refined as much as possible for individual facilities, the estimates were not intended to indicate absolute risks for any alternative or facility. The intent of the analysis in the EMPEIS and also in this document was to provide estimates of relative risks between alternatives. Because of that, any systematic errors in the modeling would tend to be diminished in the final analysis since the same errors would be applied to each case.

The largest single source of uncertainty in this analysis arises from applying the EMPEIS models to the alternatives. Two extensions have been made, which are potential sources of error. There are no adequate data available to allow the estimation of how much error may be involved in applying results from the analysis of processes selected in the EMPEIS to those selected in this report. Because this report also considers a complete set of configurations for each waste handling process, there are additional uncertainties involved in the extension of EMPEIS alternative data to additional configurations.

Other potential sources of uncertainty are listed below. These, however, are considered of minor consequence compared to those mentioned above. It is unlikely that any of these uncertainties have any measurable impact on the final results but are listed primarily for thoroughness.

- The EMPEIS calculations include adjustments for the isotopic mixtures expected at each facility based on available radionuclide inventories. As wastes from different sites were combined to allow analysis of configurations not analyzed in the EMPEIS, no adjustment was made to account for changes in the resulting radionuclide inventories.

- The EMPEIS analysis addressed how much of the waste from each site was readily retrievable, how much would require potentially difficult retrieval (such as retrieval of buried waste for which container integrity may have been compromised), and how much was newly generated. Each of these sources of waste yields different values for airborne releases and potential worker exposures. Individual site scaling factors were developed using the differences between the waste inventory used in the EMPEIS and the more current inventory figures used by the EACBS in this report. Thus the scaling factors use an inherent assumption that the ratio of retrieved waste to newly generated waste does not change. Actual increases in waste throughput at each facility would result from changes in the quantity of newly generated waste rather than changes in the quantity of retrieved waste.

- Model adjustments were performed for changes in total waste volumes on a site-by-site basis. Although changes in the organic:inorganic:sludge ratios would affect both worker doses and airborne releases, available data were insufficient to allow accounting for those differences.

- The EMPEIS does not assume any storage at the WIPP. All EMPEIS alternatives for TRU waste include storage at the location where the waste is processed. Storage does not increase airborne releases but does increase worker doses from required inspections and maintenance. However, these doses would be expected to be directly proportional to waste volume and relatively unaffected by waste form. In-storage inspection does not benefit from efficiencies of scale. Although different waste forms may be expected to have different dose rates, any increases in dose rates are offset by decreases in the total volume requiring inspection and emplacement. Thus, while the EMPEIS worker doses on which the alternatives are based include doses from long-term waste storage, the effect is applied to all processes and configurations and does not change the relative assessment of those alternatives.

3.3.4 Results of Analysis

Tables 3-11 through 3-28 contain the results of the human health impact analysis for processing and emplacing CH-TRU waste. RH-TRU waste was not evaluated for human health impacts as part of the EACBS. All impacts are expressed as impacts accumulated over a 20-year operating lifetime of the waste processing facilities.

System-wide human health impacts for the baseline and four processing options described in Section 3.3.2 and the three processing configurations are shown in Tables 3-11 through 3-23. Each table displays the impacts as detailed in Table 3-9 for a single processing option and configuration. The injuries and fatalities from industrial accidents are further divided into impacts associated with construction and operations activities. Each table also lists the waste processing facility associated with the most exposed individual impacts reported in the body of the table.

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TABLE 3-11

SYSTEM-WIDE HUMAN HEALTH IMPACTS PREPARE AND CERTIFY WASTE TO WIPP ACCEPTANCE CRITERIA AT 10 LOCATIONS BASELINE

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	3.73×10^{-02}			
	Excess Fatalities	1.78×10^{-05}			
	Excess Cancers		5.51×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	1.54×10^{-05}			
	Excess Risk	7.78×10^{-09}			
	Excess Cancers		1.44×10^{-11}		
	Hazard Index			2.27×10^{-09}	
Off-site Population	Dose (Person-rem)	3.89×10^{-01}			
	Excess Fatalities	1.94×10^{-04}			
	Excess Cancers		2.11×10^{-07}		
Most Exposed Off-site Individual	Dose (Rem)	2.14×10^{-05}			
	Excess Risk	1.11×10^{-08}			
	Excess Cancers		5.44×10^{-12}		
	Hazard Index			2.92×10^{-10}	
Workers	Dose (FTE-rem)	$1.94 \times 10^{+03}$			
	Excess Fatalities	7.78×10^{-01}			
	Excess Cancers		1.30×10^{-05}		
	Exposure Index			4.02×10^{-05}	
	Construction Fatalities				9.92×10^{-01}
	Construction Injuries				$8.52 \times 10^{+02}$
	Operations Fatalities				$1.81 \times 10^{+00}$
	Operations Injuries				$7.65 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1

TABLE 3-12

SYSTEM-WIDE HUMAN HEALTH IMPACTS SUPERCOMPACTION OF WASTE AT 10 LOCATIONS ALTERNATIVE CASES 1 AND 77(a–d)

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.00×10^{-01}			
	Excess Fatalities	2.50×10^{-05}			
	Excess Cancers		9.06×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.34×10^{-05}			
	Excess Risk	1.20×10^{-08}			
	Excess Cancers		2.34×10^{-11}		
	Hazard Index			3.90×10^{-09}	
Off-site Population	Dose (person-rem)	5.31×10^{-01}			
	Excess Fatalities	2.65×10^{-04}			
	Excess Cancers		3.59×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	5.29×10^{-05}			
	Excess Risk	2.61×10^{-08}			
	Excess Cancers		1.82×10^{-11}		
	Hazard Index			8.32×10^{-10}	
Workers	Dose (FTE-rem)	$2.42 \times 10^{+03}$			
	Excess Fatalities	9.54×10^{-01}			
	Excess Cancers		3.03×10^{-05}		
	Exposure Index			4.69×10^{-05}	
	Construction Fatalities				$1.47 \times 10^{+00}$
	Construction Injuries				$1.28 \times 10^{+03}$
	Operations Fatalities				$2.57 \times 10^{+00}$
	Operations Injuries				$1.14 \times 10^{+03}$

The most exposed off-site individual is associated with Los Alamos National Lab

1

TABLE 3-13

SYSTEM-WIDE HUMAN HEALTH IMPACTS SUPERCOMPACTION OF WASTE AT FIVE LOCATIONS ALTERNATIVE CASES 1 AND 77(a–d)

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.13×10^{-01}			
	Excess Fatalities	2.57×10^{-05}			
	Excess Cancers		9.30×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.41×10^{-05}			
	Excess Risk	1.24×10^{-08}			
	Excess Cancers		2.41×10^{-11}		
	Hazard Index			4.01×10^{-09}	
Off-site Population	Dose (person-rem)	5.45×10^{-01}			
	Excess Fatalities	2.73×10^{-04}			
	Excess Cancers		3.69×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	2.72×10^{-05}			
	Excess Risk	1.34×10^{-08}			
	Excess Cancers		9.33×10^{-12}		
	Hazard Index			4.28×10^{-10}	
Workers	Dose (FTE-rem)	$2.52 \times 10^{+03}$			
	Excess Fatalities	9.92×10^{-01}			
	Excess Cancers		3.15×10^{-05}		
	Exposure Index			4.88×10^{-05}	
	Construction Fatalities				$1.16 \times 10^{+00}$
	Construction Injuries				$1.00 \times 10^{+03}$
	Operations Fatalities				$2.68 \times 10^{+00}$
	Operations Injuries				$1.18 \times 10^{+03}$

The most exposed off-site individual is associated with Los Alamos National Lab

1

TABLE 3-14

SYSTEM-WIDE HUMAN HEALTH IMPACTS SUPERCOMPACTION OF WASTE AT ONE LOCATION ALTERNATIVE CASES 1 AND 77(a–d)

			Hazardous Chemicals		Physical
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Hazards
Co-located Workers	Dose (person-rem)	7.99×10^{-01}			
	Excess Fatalities	3.99×10^{-05}			
	Excess Cancers		1.45×10^{-07}		
Most Exposed Co-located Individual	Dose (rem)	3.74×10^{-05}			
	Excess Risk	1.92×10^{-08}			
	Excess Cancers		3.74×10^{-11}		
	Hazard Index			6.24×10^{-09}	
Off-site Population	Dose (person-rem)	8.49×10^{-01}			
	Excess Fatalities	4.24×10^{-04}			
	Excess Cancers		5.74×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	3.17×10^{-04}			
	Excess Risk	1.56×10^{-07}			
	Excess Cancers		1.09×10^{-10}		
	Hazard Index			4.98×10^{-09}	
Workers	Dose (FTE-rem)	$2.79 \times 10^{+03}$			
	Excess Fatalities	$1.10 \times 10^{+00}$			
	Excess Cancers		3.49×10^{-05}		
	Exposure Index			5.41×10^{-05}	
	Construction Fatalities				8.18×10^{-01}
	Construction Injuries				$7.11 \times 10^{+02}$
	Operations Fatalities				$2.97 \times 10^{+00}$
	Operations Injuries				$1.31 \times 10^{+03}$

The most exposed off-site individual is associated with WIPP

1

TABLE 3-15

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND COMPACT WASTE AT 10 LOCATIONS
ALTERNATIVE CASE 6

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.00×10^{-01}			
	Excess Fatalities	2.50×10^{-05}			
	Excess Cancers		9.06×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.34×10^{-05}			
	Excess Risk	1.20×10^{-08}			
	Excess Cancers		2.34×10^{-11}		
	Hazard Index			3.90×10^{-09}	
Off-site Population	Dose (person-rem)	5.31×10^{-01}			
	Excess Fatalities	2.65×10^{-04}			
	Excess Cancers		3.59×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	5.29×10^{-05}			
	Excess Risk	2.61×10^{-08}			
	Excess Cancers		1.82×10^{-11}		
	Hazard Index			8.32×10^{-10}	
Workers	Dose (FTE-rem)	$2.01 \times 10^{+03}$			
	Excess Fatalities	7.91×10^{-01}			
	Excess Cancers		2.51×10^{-05}		
	Exposure Index			3.89×10^{-05}	
	Construction Fatalities				$1.65 \times 10^{+00}$
	Construction Injuries				$1.43 \times 10^{+03}$
	Operations Fatalities				$2.13 \times 10^{+00}$
	Operations Injuries				$9.41 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1

TABLE 3-16

SYSTEM-WIDE HUMAN HEALTH IMPACTS SHRED AND COMPACT WASTE AT FIVE LOCATIONS ALTERNATIVE CASE 6

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.13×10^{-01}			
	Excess Fatalities	2.57×10^{-05}			
	Excess Cancers		9.30×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.41×10^{-05}			
	Excess Risk	1.24×10^{-08}			
	Excess Cancers		2.41×10^{-11}		
	Hazard Index			4.01×10^{-09}	
Off-site Population	Dose (person-rem)	5.45×10^{-01}			
	Excess Fatalities	2.73×10^{-04}			
	Excess Cancers		3.69×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	2.72×10^{-05}			
	Excess Risk	1.34×10^{-08}			
	Excess Cancers		9.33×10^{-12}		
	Hazard Index			4.28×10^{-10}	
Workers	Dose (FTE-rem)	$2.06 \times 10^{+03}$			
	Excess Fatalities	8.12×10^{-01}			
	Excess Cancers		2.58×10^{-05}		
	Exposure Index			4.00×10^{-05}	
	Construction Fatalities				$1.26 \times 10^{+00}$
	Construction Injuries				$1.09 \times 10^{+03}$
	Operations Fatalities				$2.19 \times 10^{+00}$
	Operations Injuries				$9.67 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1

TABLE 3-17

SYSTEM-WIDE HUMAN HEALTH IMPACTS SHRED AND COMPACT WASTE AT ONE LOCATION ALTERNATIVE CASE 6

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	7.99×10^{-01}			
	Excess Fatalities	3.99×10^{-05}			
	Excess Cancers		1.45×10^{-07}		
Most Exposed Co-located Individual	Dose (rem)	3.74×10^{-05}			
	Excess Risk	1.92×10^{-08}			
	Excess Cancers		3.74×10^{-11}		
	Hazard Index			6.24×10^{-09}	
Off-site Population	Dose (person-rem)	8.49×10^{-01}			
	Excess Fatalities	4.24×10^{-04}			
	Excess Cancers		5.74×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	9.29×10^{-05}			
	Excess Risk	4.58×10^{-08}			
	Excess Cancers		3.18×10^{-11}		
	Hazard Index			1.46×10^{-09}	
Workers	Dose (FTE-rem)	$3.04 \times 10^{+03}$			
	Excess Fatalities	$1.20 \times 10^{+00}$			
	Excess Cancers		3.80×10^{-05}		
	Exposure Index			5.90×10^{-05}	
	Construction Fatalities		M		8.44×10^{-01}
	Construction Injuries				$7.35 \times 10^{+02}$
	Operations Fatalities				$3.23 \times 10^{+00}$
	Operations Injuries				$1.43 \times 10^{+03}$

The most exposed off-site individual is associated with WIPP

1

TABLE 3-18

SYSTEM-WIDE HUMAN HEALTH IMPACTS
PLASMA PROCESSING OF WASTE AT 10 LOCATIONS
ALTERNATIVE CASE 10

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	$9.61 \times 10^{+02}$			
	Excess Fatalities	4.73×10^{-01}			
	Excess Cancers		7.80×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	6.82×10^{-01}			
	Excess Risk	3.34×10^{-04}			
	Excess Cancers		2.09×10^{-11}		
	Hazard Index			1.81×10^{-07}	
Off-site Population	Dose (person-rem)	$9.33 \times 10^{+03}$			
	Excess Fatalities	$4.60 \times 10^{+00}$			
	Excess Cancers		3.06×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	4.92×10^{-01}			
	Excess Risk	2.54×10^{-04}			
	Excess Cancers		1.82×10^{-11}		
	Hazard Index			4.17×10^{-08}	
Workers	Dose (FTE-rem)	$2.88 \times 10^{+03}$			
	Excess Fatalities	$1.17 \times 10^{+00}$			
	Excess Cancers		4.81×10^{-05}		
	Exposure Index			1.65×10^{-03}	
	Construction Fatalities				$4.73 \times 10^{+00}$
	Construction Injuries				$3.94 \times 10^{+03}$
	Operations Fatalities				$5.00 \times 10^{+00}$
	Operations Injuries				$2.12 \times 10^{+03}$

The most exposed off-site individual is associated with Los Alamos National Lab

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TABLE 3-19

SYSTEM-WIDE HUMAN HEALTH IMPACTS
PLASMA PROCESSING OF WASTE AT FIVE LOCATIONS
ALTERNATIVE CASE 10

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	$1.00 \times 10^{+03}$			
	Excess Fatalities	4.93×10^{-01}			
	Excess Cancers		8.13×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	7.11×10^{-01}			
	Excess Risk	3.48×10^{-04}			
	Excess Cancers		2.18×10^{-11}		
	Hazard Index			1.89×10^{-07}	
Off-site Population	Dose (person-rem)	$9.72 \times 10^{+03}$			
	Excess Fatalities	$4.79 \times 10^{+00}$			
	Excess Cancers		3.19×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	2.53×10^{-01}			
	Excess Risk	1.30×10^{-04}			
	Excess Cancers		9.34×10^{-12}		
	Hazard Index			2.14×10^{-08}	
Workers	Dose (FTE-rem)	$2.24 \times 10^{+03}$			
	Excess Fatalities	9.10×10^{-01}			
	Excess Cancers		3.73×10^{-05}		
	Exposure Index			1.28×10^{-03}	
	Construction Fatalities				$3.31 \times 10^{+00}$
	Construction Injuries				$2.75 \times 10^{+03}$
	Operations Fatalities				$3.88 \times 10^{+00}$
	Operations Injuries				$1.64 \times 10^{+03}$

The most exposed off-site individual is associated with Los Alamos National Lab

1

TABLE 3-20

SYSTEM-WIDE HUMAN HEALTH IMPACTS
PLASMA PROCESSING OF WASTE AT ONE LOCATION
ALTERNATIVE CASE 10

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	$1.46 \times 10^{+02}$			
	Excess Fatalities	7.37×10^{-02}			
	Excess Cancers		9.73×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	5.60×10^{-01}			
	Excess Risk	2.80×10^{-04}			
	Excess Cancers		2.21×10^{-11}		
	Hazard Index			6.78×10^{-07}	
Off-site Population	Dose (person-rem)	$1.77 \times 10^{+03}$			
	Excess Fatalities	8.99×10^{-01}			
	Excess Cancers		3.39×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	4.72×10^{-01}			
	Excess Risk	2.36×10^{-04}			
	Excess Cancers		7.07×10^{-12}		
	Hazard Index			1.12×10^{-07}	
Workers	Dose (FTE-rem)	$3.34 \times 10^{+03}$			
	Excess Fatalities	$1.34 \times 10^{+00}$			
	Excess Cancers		1.69×10^{-04}		
	Exposure Index			2.16×10^{-03}	
	Construction Fatalities				$1.75 \times 10^{+00}$
	Construction Injuries				$1.61 \times 10^{+03}$
	Operations Fatalities				$3.54 \times 10^{+00}$
	Operations Injuries				$1.55 \times 10^{+03}$

The most exposed off-site individual is associated with WIPP

1

TABLE 3-21

SYSTEM-WIDE HUMAN HEALTH IMPACTS SHRED AND ADD CLAY TO WASTE AT 10 LOCATIONS ALTERNATIVE CASES 94(a–f)

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.00×10^{-01}			
	Excess Fatalities	2.50×10^{-05}			
	Excess Cancers		9.06×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.34×10^{-05}			
	Excess Risk	1.20×10^{-08}			
	Excess Cancers		2.34×10^{-11}		
	Hazard Index			3.90×10^{-09}	
Off-site Population	Dose (person-rem)	5.31×10^{-01}			
	Excess Fatalities	2.65×10^{-04}			
	Excess Cancers		3.59×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	5.29×10^{-05}			
	Excess Risk	2.61×10^{-08}			
	Excess Cancers		1.82×10^{-11}		
	Hazard Index			8.32×10^{-10}	
Workers	Dose (FTE-rem)	$2.01 \times 10^{+03}$			
	Excess Fatalities	7.91×10^{-01}			
	Excess Cancers		2.51×10^{-05}		
	Exposure Index			3.89×10^{-05}	
	Construction Fatalities				$1.65 \times 10^{+00}$
	Construction Injuries				$1.43 \times 10^{+03}$
	Operations Fatalities				$2.13 \times 10^{+00}$
	Operations Injuries				$9.41 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1

TABLE 3-22

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND ADD CLAY TO WASTE AT FIVE LOCATIONS
ALTERNATIVE CASES 94(a–f)

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	5.13×10^{-01}			
	Excess Fatalities	2.57×10^{-05}			
	Excess Cancers		9.30×10^{-08}		
Most Exposed Co-located Individual	Dose (rem)	2.41×10^{-05}			
	Excess Risk	1.24×10^{-08}			
	Excess Cancers		2.41×10^{-11}		
	Hazard Index			4.01×10^{-09}	
Off-site Population	Dose (person-rem)	5.45×10^{-01}			
	Excess Fatalities	2.73×10^{-04}			
	Excess Cancers		3.69×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	2.72×10^{-05}			
	Excess Risk	1.34×10^{-08}			
	Excess Cancers		9.33×10^{-12}		
	Hazard Index			4.28×10^{-10}	
Workers	Dose (FTE-rem)	$2.06 \times 10^{+03}$			
	Excess Fatalities	8.12×10^{-01}			
	Excess Cancers		2.58×10^{-05}		
	Exposure Index			4.00×10^{-05}	
	Construction Fatalities				$1.26 \times 10^{+00}$
	Construction Injuries				$1.09 \times 10^{+03}$
	Operations Fatalities				$2.19 \times 10^{+00}$
	Operations Injuries				$9.67 \times 10^{+02}$

The most exposed off-site individual is associated with Los Alamos National Lab

1

TABLE 3-23

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND ADD CLAY TO WASTE AT ONE LOCATION
ALTERNATIVE CASES 94(a–f)

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	7.99×10^{-01}			
	Excess Fatalities	3.99×10^{-05}			
	Excess Cancers		1.45×10^{-07}		
Most Exposed Co-located Individual	Dose (rem)	3.74×10^{-05}			
	Excess Risk	1.92×10^{-08}			
	Excess Cancers		3.74×10^{-11}		
	Hazard Index			6.24×10^{-09}	
Off-site Population	Dose (person-rem)	8.49×10^{-01}			
	Excess Fatalities	4.24×10^{-04}			
	Excess Cancers		5.74×10^{-07}		
Most Exposed Off-site Individual	Dose (rem)	9.29×10^{-05}			
	Excess Risk	4.58×10^{-08}			
	Excess Cancers		3.18×10^{-11}		
	Hazard Index			1.46×10^{-09}	
Workers	Dose (FTE-rem)	$3.04 \times 10^{+03}$			
	Excess Fatalities	$1.20 \times 10^{+00}$			
	Excess Cancers		3.80×10^{-05}		
	Exposure Index			5.90×10^{-05}	
	Construction Fatalities				8.44×10^{-01}
	Construction Injuries				$7.35 \times 10^{+02}$
	Operations Fatalities				$3.23 \times 10^{+00}$
	Operations Injuries				$1.43 \times 10^{+03}$

The most exposed off-site individual is associated with WIPP

TABLE 3-24

SUMMARY OF ENGINEERED ALTERNATIVES HUMAN HEALTH IMPACTS CONTACT-HANDLED TRU WASTE RISKS TO TOTAL POPULATIONS BY WASTE TREATMENT AND CONFIGURATION

EA Number	Treatment Process	Configuration	Off-site Population		Co-located Workers		Workers		C&OF[3]
			CF[1]	CI[2]	CF	CI	CF	CI	
0	Baseline	Ten sites	1.94×10^{-04}	5.51×10^{-08}	1.78×10^{-05}	1.44×10^{-11}	7.78×10^{-01}	1.30×10^{-05}	2.81
1	Supercompaction	Ten sites	2.65×10^{-04}	3.59×10^{-07}	2.50×10^{-05}	9.06×10^{-08}	9.54×10^{-01}	3.03×10^{-05}	4.05
1	Supercompaction	Five sites	2.73×10^{-04}	3.69×10^{-07}	2.57×10^{-05}	9.30×10^{-08}	9.92×10^{-01}	3.15×10^{-05}	3.83
1	Supercompaction	One site	4.24×10^{-04}	5.74×10^{-07}	3.99×10^{-05}	1.45×10^{-07}	$1.10 \times 10^{+00}$	3.49×10^{-05}	3.79
6	Shred and Compact	Ten sites	2.65×10^{-04}	3.59×10^{-07}	2.50×10^{-05}	9.06×10^{-08}	7.91×10^{-01}	2.51×10^{-05}	3.78
6	Shred and Compact	Five sites	2.73×10^{-04}	3.69×10^{-07}	2.57×10^{-05}	9.30×10^{-08}	8.12×10^{-01}	2.58×10^{-05}	3.45
6	Shred and Compact	One site	4.24×10^{-04}	5.74×10^{-07}	3.99×10^{-05}	1.45×10^{-07}	$1.20 \times 10^{+00}$	3.80×10^{-05}	4.08
10	Plasma Processing	Ten sites	$4.60 \times 10^{+00}$	3.06×10^{-07}	4.73×10^{-01}	7.80×10^{-08}	$1.17 \times 10^{+00}$	4.81×10^{-05}	9.73
10	Plasma Processing	Five sites	$4.79 \times 10^{+00}$	3.19×10^{-07}	4.93×10^{-01}	8.13×10^{-08}	9.10×10^{-01}	3.73×10^{-05}	7.18
10	Plasma Processing	One site	8.99×10^{-01}	3.39×10^{-07}	7.37×10^{-02}	9.73×10^{-08}	$1.34 \times 10^{+00}$	1.69×10^{-04}	5.29
94	Shred and Add Clay	Ten sites	2.65×10^{-04}	3.59×10^{-07}	2.50×10^{-05}	9.06×10^{-08}	7.91×10^{-01}	2.51×10^{-05}	3.78
94	Shred and Add Clay	Five sites	2.73×10^{-04}	3.69×10^{-07}	2.57×10^{-05}	9.30×10^{-08}	8.12×10^{-01}	2.58×10^{-05}	3.45
94	Shred and Add Clay	One site	4.24×10^{-04}	5.74×10^{-07}	3.99×10^{-05}	1.45×10^{-07}	$1.20 \times 10^{+00}$	3.80×10^{-05}	4.08

[1]CF—cancer fatality.
[2]CI—cancer incidence.
[3]C&OF—fatalities from physical hazards during construction and operating activities.

TABLE 3-25

SUMMARY OF ENGINEERED ALTERNATIVES HUMAN HEALTH IMPACTS CONTACT-HANDLED TRU WASTE RISKS TO OFF-SITE AND CO-LOCATED WORKERS BY WASTE TREATMENT AND CONFIGURATION

EA Number	Treatment Process	Configuration	Most Exposed Off-site Individual			Most Exposed Co-located Worker			Associated Site
			CF[2]	CI[2]	HI[3]	CF	CI	HI	
0	Baseline	Ten sites	1.11×10^{-08}	5.44×10^{-12}	2.92×10^{-10}	7.78×10^{-09}	1.44×10^{-11}	2.27×10^{-09}	Los Alamos National Lab
1	Supercompaction	Ten sites	2.61×10^{-08}	1.82×10^{-11}	8.32×10^{-10}	1.20×10^{-08}	2.34×10^{-11}	3.90×10^{-09}	Los Alamos National Lab
1	Supercompaction	Five sites	1.34×10^{-08}	9.33×10^{-12}	4.28×10^{-10}	1.24×10^{-08}	2.41×10^{-11}	4.01×10^{-09}	Los Alamos National Lab
1	Supercompaction	One site	1.56×10^{-07}	1.09×10^{-10}	4.98×10^{-09}	3.99×10^{-05}	3.74×10^{-11}	6.24×10^{-09}	WIPP
6	Shred and Compact	Ten sites	2.61×10^{-08}	1.82×10^{-11}	8.32×10^{-10}	1.20×10^{-08}	2.34×10^{-11}	3.90×10^{-09}	Los Alamos National Lab
6	Shred and Compact	Five sites	1.34×10^{-08}	9.33×10^{-12}	4.28×10^{-10}	1.24×10^{-08}	2.41×10^{-11}	4.01×10^{-09}	Los Alamos National Lab
6	Shred and Compact	One site	4.58×10^{-08}	3.18×10^{-11}	1.46×10^{-09}	1.92×10^{-08}	3.74×10^{-11}	6.24×10^{-09}	WIPP
10	Plasma Processing	Ten sites	2.54×10^{-04}	1.82×10^{-11}	4.17×10^{-08}	3.34×10^{-04}	2.09×10^{-11}	1.81×10^{-07}	Los Alamos National Lab
10	Plasma Processing	Five sites	1.30×10^{-04}	9.34×10^{-12}	2.14×10^{-08}	3.48×10^{-04}	2.18×10^{-11}	1.89×10^{-07}	Los Alamos National Lab
10	Plasma Processing	One site	2.36×10^{-04}	7.07×10^{-12}	1.12×10^{-07}	2.80×10^{-04}	2.21×10^{-11}	6.78×10^{-07}	WIPP
94	Shred and Add Clay	Ten sites	2.61×10^{-08}	1.82×10^{-11}	8.32×10^{-10}	1.20×10^{-08}	2.34×10^{-11}	3.90×10^{-09}	Los Alamos National Lab
94	Shred and Add Clay	Five sites	1.34×10^{-08}	9.33×10^{-12}	4.28×10^{-10}	1.24×10^{-08}	2.41×10^{-11}	4.01×10^{-09}	Los Alamos National Lab
94	Shred and Add Clay	One site	4.58×10^{-08}	3.18×10^{-11}	1.46×10^{-09}	1.92×10^{-08}	3.74×10^{-11}	6.24×10^{-09}	WIPP

[1]CF—cancer fatality.
[2]CI—cancer incidence.
[3]HI—hazard index.

1

TABLE 3-26

SUMMARY OF HUMAN HEALTH IMPACTS ASSOCIATED WITH CH-TRU WASTE EMPLACEMENT AT THE WIPP RADIATION IMPACTS

		Workers		Most Exposed Off-site		Collective Off-site	
EA Number	Case Description	Doses (FTE-rem)	Excess Fatalities	Doses (rem)	Excess Risk	Doses (person-rem)	Excess Fatalities
0	Baseline	322.85	0.13	6.65×10^{-05}	3.32×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
1	Supercompaction	322.85	0.13	6.65×10^{-05}	3.32×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
6	Shred and Compact	322.85	0.13	3.73×10^{-05}	1.87×10^{-08}	1.75×10^{-02}	8.75×10^{-06}
10	Plasma Processing	322.85	0.13	5.57×10^{-05}	2.79×10^{-08}	6.00×10^{-03}	3.00×10^{-06}
33	Sand plus Clay Backfill	345.27	0.14	1.91×10^{-05}	9.54×10^{-09}	2.09×10^{-02}	1.04×10^{-05}
35a	Salt Aggregate Grout Backfill	357.23	0.14	6.65×10^{-05}	3.32×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
35b	Cementitious Grout Backfill	357.23	0.14	6.65×10^{-05}	3.32×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
111	Clay Based Backfill	342.28	0.14	6.65×10^{-05}	3.32×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
77a	Supercompact with Salt Aggregate Grout	342.07	0.14	6.65×10^{-05}	3.32×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
77b	Supercompact with Clay Based Backfill	340.15	0.14	3.73×10^{-05}	1.87×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
77c	Supercompact with Sand and Clay Backfill	343.99	0.14	3.73×10^{-05}	1.87×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
77d	Supercompact with Cao Backfill	338.23	0.14	3.73×10^{-05}	1.87×10^{-08}	1.17×10^{-02}	5.87×10^{-06}
83	Cao Backfill	339.29	0.14	3.73×10^{-05}	1.87×10^{-08}	2.09×10^{-02}	1.04×10^{-05}
94a	Shred and Add Clay to Waste	322.85	0.13	6.65×10^{-05}	3.32×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94b	Shred and Add Clay, Clay/sand Backfill	346.77	0.14	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94c	Shred and Add Clay, Cementitious Grout	366.20	0.15	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94d	Shred and Add Clay, Salt Aggregate Grout	343.78	0.14	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94e	Shred and Add Clay to Waste, Clay Backfill	342.28	0.14	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}
94f	Shred and Add Clay to Waste Cao Backfill	339.29	0.14	7.73×10^{-05}	3.86×10^{-08}	2.43×10^{-02}	1.21×10^{-05}

TABLE 3-27

SUMMARY OF HUMAN HEALTH IMPACTS ASSOCIATED WITH CH-TRU WASTE EMPLACEMENT AT THE WIPP HAZARDOUS AND TOXIC CHEMICAL IMPACTS

EA Number	Case Description	Carcinogenic Chemicals (Excess Cancers)			Toxic Chemicals (Hazard Index)		
		Workers	Most Exposed Co-located	Most Exposed Off-site	Workers	Most Exposed Co-located	Most Exposed Off-site
0	Baseline	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
1	Supercompaction	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
6	Shred and Compact	1.03×10^{-05}	2.55×10^{-10}	2.15×10^{-10}	1.43×10^{-03}	3.58×10^{-08}	6.61×10^{-09}
10	Plasma Processing	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$	$0.00 \times 10^{+00}$
33	Sand plus Clay Backfill	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
35a	Salt Aggregate Grout	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
35b	Cementitious Grout	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
111	Clay Based Backfill	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
77a	Supercompact with	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
77b	Supercompact with	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
77c	Supercompact with	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
77d	Supercompact with	6.93×10^{-06}	1.71×10^{-10}	1.44×10^{-10}	9.60×10^{-04}	2.40×10^{-08}	4.43×10^{-09}
83	Cao Backfill	1.23×10^{-05}	3.04×10^{-10}	2.56×10^{-10}	1.71×10^{-03}	4.27×10^{-08}	7.88×10^{-09}
94a	Shred and Add Clay to	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94b	Shred and Add Clay,	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94c	Shred and Add Clay,	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94d	Shred and Add Clay,	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94e	Shred and Add Clay to	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}
94f	Shred and Add Clay to	1.44×10^{-05}	3.53×10^{-10}	2.98×10^{-10}	1.99×10^{-03}	4.97×10^{-08}	9.16×10^{-09}

1

TABLE 3-28

SUMMARY OF HUMAN HEALTH IMPACTS ASSOCIATED CH-TRU WASTE EMPLACEMENT AT THE WIPP WORKER INDUSTRIAL ACCIDENTS

EA Number	Case Description	Injuries	Fatalities
0	Baseline	53.63	0.16
1	Supercompaction	44.05	0.13
6	Shred and Compact	44.05	0.13
10	Plasma Processing	33.20	0.10
33	Sand plus Clay Backfill	64.50	0.29
35a	Salt Aggregate Grout Backfill	70.81	0.30
35b	Cementitious Grout Backfill	70.81	0.30
111	Clay Based Backfill	62.53	0.18
77a	Supercompact with Salt Aggregate Grout	55.53	0.15
77b	Supercompact with Clay Based Backfill	49.80	0.15
77c	Supercompact with Sand and Clay Backfill	51.77	0.15
77d	Supercompact with Cao Backfill	51.06	0.25
83	CaO Backfill	66.45	0.28
94a	Shred and Add Clay to Waste	53.63	0.16
94b	Shred and Add Clay to Waste Clay and Sand Backfill	67.04	0.39
94c	Shred and Add Clay to Waste Cementitious Grout Backfill	69.14	0.21
94d	Shred and Add Clay to Waste Salt Aggregate Grout Backfill	69.56	0.49
94e	Shred and Add Clay to Waste Clay Based Backfill	61.83	0.18
94f	Shred and Add Clay to Waste Cao Backfill	63.25	0.28

Table 3-24 shows a summary of the system-wide cumulative impacts on workers, co-located workers, and the off-site population for all combinations of waste processes and configurations. The impacts included in this table are the excess cancer fatalities from radiation exposure, excess cancer incidence from hazardous chemical exposure, and worker fatalities from industrial accidents. Table 3-25 contains similar data for the most exposed off-site individual and most exposed co-located worker. The impacts of industrial accidents from handling CH-TRU waste are not applicable to co-located workers and off-site individuals and are not included on Table 3-25. The table does add the Hazard Index for the most exposed individuals as well as the facility at which the highest individual impact was determined.

Tables 3-26 through 3-28 show summaries of the impacts on workers, co-located workers, and the off-site population from emplacement activities at the WIPP. Each combination of waste processing and emplacement backfill are represented because the waste processes generate different waste forms and quantities for equivalent inputs. Differing backfill options affect the amount of time and effort required to complete the emplacement of the waste. Table 3-26 shows the impacts, in terms of both dose and excess fatalities, from collective doses to workers and the off-site population and the total dose to the most exposed off-site individual. Table 3-27 shows the impacts of both carcinogenic and toxic chemicals on workers, the most exposed co-located worker, and the most exposed off-site individual. Table 3-28 shows the injuries and fatal accidents at the WIPP estimated to involve workers over the period analyzed for waste emplacement at the WIPP.

As discussed in Section 3.3.3.9, there are a number of sources of uncertainty, but the largest single source of uncertainty arises from applying EMPEIS models to the alternatives. The equivalence of the scenarios in the EMPEIS and the alternatives vary from very close, such as using the shred and grout from the EMPEIS to simulate shred and add clay in the alternatives, to much more tenuous, such as simulating the plasma processing in the alternatives by the EMPEIS incinerate-and-grout process. The information available is insufficient to allow a numerical estimate of how much uncertainty is introduced by these assumptions, but it is expected that nonsystemic uncertainties should not exceed plus or minus 100 percent of the risk estimates.

The conclusions in the following bullet list may be inferred from the data in Tables 3-11 through 3-28.

- The differences in cancer incidence for workers, co-located workers, and off-site populations are within a factor of two for all processes and configurations. The cancer incidence for the alternatives are the same as for the baseline for workers but four orders of magnitude higher than the baseline for co-located workers and about one order of magnitude for off-site populations. This probably results from adequate control of worker exposure to volatile chemicals in the waste by ventilation controls during waste processing, but vent releases increase with any processing. The baseline does not require opening the waste drums, but all the analyzed waste processes do require some opening of the waste, thus releasing volatile chemicals to be exhausted from the facility vents.

- Cancer fatalities for workers are also within a factor of two for all processes and configurations and for the baseline. The same is true for co-located workers and

off-site populations except that cancer fatalities are about four orders of magnitude higher for plasma processing than for the baseline or any other process.

- Cancer fatalities show a general increase with increased consolidation, although differences are less than a factor of two. Only plasma processing does not follow the trend, with centralized impacts showing a slight decrease for off-site populations and co-located workers but an increase for workers.

- Physical hazards show very little difference between process or configurations, including the baseline, except for plasma processing where distributed and regional processing show an increase of two to three times other processes and configurations.

- Somewhat greater differences between configurations might have been expected than were observed for those impacts most affected by the change in FTEs (cancer fatalities and physical hazard fatalities). However, the improvements expected to be provided by the efficiencies of scale are offset by the double handling required to prepare waste at nonprocessing facilities followed by additional handling to receive that waste at the processing site.

- For individuals, risk values of less than 10^{-6} for cancer fatalities or incidence or hazard index values less than one are not considered significant. With the exception of cancer fatalities for plasma processing, none of the impacts to most exposed individuals are considered significant. The variations between processes and configurations do not show variations greater than a factor of two to five except for plasma processing which shows the same four orders of magnitude increase observed in cancer fatalities in groups. Even for cancer fatalities for plasma processing, the annualized risks are between 7×10^{-6} and 2×10^{-5}, just slightly greater than the level of insignificance.

- Impacts for emplacement of the waste at WIPP show only about a factor of two or three between the various alternatives for either radiation or chemical hazard exposure. Plasma processing shows a decrease of approximately five for off-site population risks from radiation, primarily because most of the radioactive material is retained in the waste form. No risks are shown for chemical impacts of emplacement of plasma-processed waste because all the volatile chemicals have either been removed from the waste during processing or are tightly bound within the waste form.

- Fatalities from physical accidents are no more than 1 for the 35-year operational period for any of the alternatives. Both injuries and fatalities for each alternative are within 25 percent of the baseline.

3.4 WASTE REMOVAL IMPACT

3.4.1 Definition of Factor 4

Waste removal is defined as the activity involving recovery of the waste after repository closure. In assessing the waste removal activities, the waste inventory and physical properties for each engineered alternative determine the underground panel geometry that would in turn determine the time required for underground removal. Underground removal considers the compressive strength and density of the waste form as well as the consolidation of the backfill expected to occur after a specified period of time. The occupational hazards for industrial accidents include the conventional hazards due to underground mining accidents, hazardous waste exposure, and radioactive waste exposure.

After waste emplacement, the surrounding salt will be subject to creep with encroachment of the waste occurring after a period of 10 to 20 years. As encroachment occurs, the waste and backfill (if present) consolidate with a reduction of void space. This reduction affects the physical characteristics of the waste with time. The degree of difficulty in removing waste depends on the degree of consolidation at the time of removal, and the physical properties that in turn affect underground waste removal operations. The room geometry and repository layout also affect underground waste removal operations. The evaluation of this factor considers these waste and backfill (if present) properties for the baseline and each alternative at some future point in time when waste removal would be accomplished. This factor determines the impact on the ability to remove waste. No provisions are made with any of the EAs that specifically facilitate removal. Such provisions are not required by the disposal standard.

3.4.2 Methodology Used to Evaluate the Mine Waste Removal Factor (Factor 4)

The main objective of mine waste removal evaluation is to assess the degree of difficulty in extracting waste and backfill and how each of the alternatives influences the associated risk and detriments for each alternative. The factor components include (1) the waste volume and repository layout for each alternative that would determine the number of panels for waste disposal; and (2) the unconfined compressive strength of the waste/backfill that affect the mining advance rate. If a waste form/backfill were selected that would have desirable characteristics for long term isolation (such as a high compressive strength that reduces the release of drill cuttings), it might be undesirable from the mine waste removal in that there would be increased hazards regarding removal.

The baseline for waste removal is evaluated by defining the physical layout for underground waste removal activities. The analysis of industrial hazards suggests that the number of accidents is related to the time required for underground waste removal, and that in turn relates to the underground continuous mining time. Each of the alternatives can be ranked with regard to waste removal subjecting workers to risk. For waste forms exhibiting higher compressive strength (grouted waste, etc.), more time is required for mining and removal with the occurrence of a larger number of nonradiological and radiological accidents and doses.

The unconfined compressive strengths of various waste forms are evaluated using the relationships of compressive strength to porosity. For crushed salt backfill, cementitious materials, and earthen materials, test data were compiled and relationships developed as illustrated in Figure 3-7 (Nelson et al., 1981; Mindess and Young, 1981; U.S. Bureau of

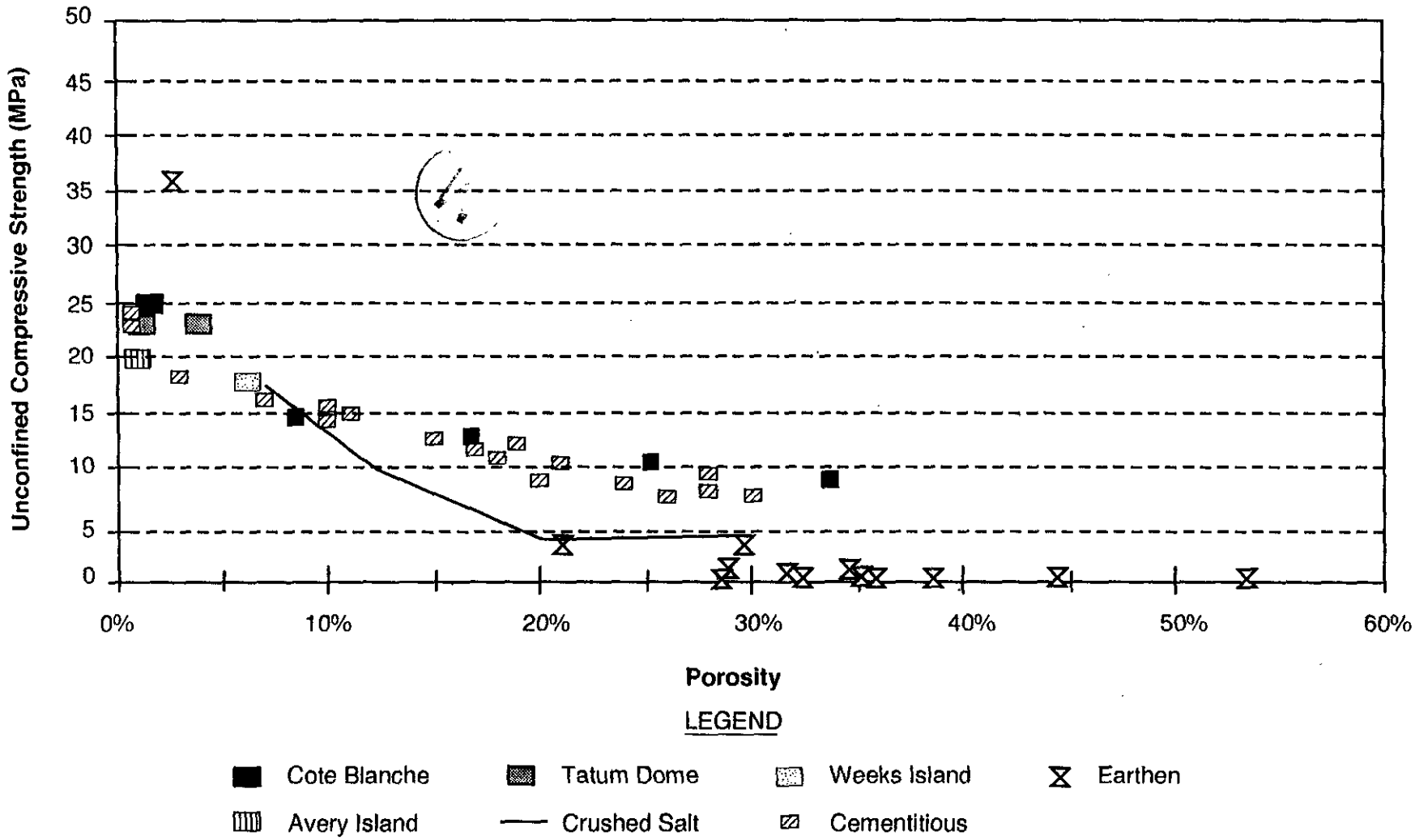

Figure 3-7
Relationship of Unrestricted Compressive Strength to Porosity

Reclamation, 1974; and Winterkorn and Fang, 1977). The test data from these sources show that cementitious materials exhibit a range of low to high porosities with higher compressive strengths, earthen materials (clay, sand) exhibit higher porosities with lower compressive strengths, and that crushed salt exhibits compressive strengths intermediate to these materials. The inorganic or metallic waste would exhibit a much higher compressive strength; yet the effective porosity would be much higher. As discussed subsequently, the mining advance rate was selected to be about one-half of the rate for other waste forms and backfill.

After approximately 100 years, the waste and backfill (if present) would consolidate to a value near lithostatic stress. As stresses buildup on the waste form and backfill, the secondary creep rate would reduce. If waste removal is assumed to occur when the waste compressive stress has reached 90 percent of lithostatic stress (14 MPa), the porosity can be determined for the various materials. The porosity of the various materials at this stress level is presented in Table 3-29. Note that the same relationships for porosity with stress level as used for Factor 1 were considered here. From the unconfined compressive strength vs. porosity relationship presented in Figure 3-7, the approximate compressive strengths can be determined, and then averaged on the basis of volume for each of the materials.

The mining advance rate as a function of compressive strength is determined by relating the specific energy to compressive strength from laboratory disc cutting studies for rocks of various compressive strengths from 50 to 350 MPa (Temporal et al., 1983), and then relating the specific energy to excavation rate (McFeat-Smith and Powell, 1979). In laboratory disc cutting studies, the specific energy in cutting is determined, and then correlated to compressive strength as presented in Figure 3-8. The laboratory procedure was to make a series of cuts on a rock surface to simulate an excavated face, make cuts with the disc cutter on the simulated rock surface while recording the tool force, and length of cut, measure the cut volume, and then determine the specific energy as the tool force times the length of cut divided by the excavation volume. The relationship in Figure 3-8 can then be related to other combined laboratory and field studies where specific energy is determined, and then related to field cutting rates for a typical medium weight roadheader as shown in Figure 3-9. Although other operational parameters such as depth of cut, cutting geometry, line spacing and the degree of wear of the cutting tool, the use of a standard cutting test ensures that variation in specific energy can be directly attributed to the cutting characteristics tested. If consideration is given to a 13 ft by 33 ft (3.96 by 10.06 m) or a 6 ft by 33 ft (1.83 by 10.06 m) room size, the mining advance rate as a function of unconfined compressive strength can be determined as shown in Figure 3-10.

For metallic waste, steel exhibits a high average compressive strength of approximately 30,000 psi (206 MPa).

From the above discussion, the mining advance rate would be smaller than normal mining advance rates. From Temporal, et al., 1983, the specific energy is about 30 MJ/m^3. From McFeat-Smith and Powell, 1979, the mining rate is about 177 ft^3 (5 m^3) per hour. This results in a mining advance rate of 3.3 ft (1 m) per shift, which is about one-half the mining advance rate for other materials.

TABLE 3-29
SUMMARY OF POROSITIES AND COMPRESSIVE STRENGTHS

Identifier	Alternative	Porosity at Lithostatic Pressure				Unconfined Compressive Strength					Average Waste/ Backfill Composite (MPa)
		Sludges[1]	Solid Organic	Solid Inorganic Metals	Backfill	Sludges (MPa)	Solid Organic (MPa)	Solid Inorganic (MPa)	Backfill (MPa)	Host Salt (MPa)	
0	Baseline	12.21%	15.42%	41.72%	—	16	7	75	—	25	25.2
1	Compact Waste	12.21%	15.42%	41.72%	—	16	9	75	—	25	24.5
6	Shred and Compact	12.21%	13.15%	39.16%	—	16	9	75	—	25	25.1
10	Plasma Processing of All Waste	12.21%	12.21%	12.21%	—	16	16	16	—	25	24.1
33	Sand Plus Clay Backfill	12.21%	15.42%	41.72%	33.60%	16	7	75	3	25	15.2
35.a	Salt Aggregate Grout Backfill	12.21%	15.42%	41.72%	31.30%	16	7	75	16	25	21.1
35.b	Cementitious Grout Backfill	12.21%	15.42%	41.72%	31.30%	16	7	75	16	25	21.1
77.a	Supercompact organics and inorganics, salt-aggregate grout backfill, monolayer of 2,000 drums, in 6X33X300	12.21%	24.00%	39.16%	31.30%	16	9	75	16	25	19.4
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums, in 6X33X300	12.21%	13.15%	39.16%	40.50%	16	9	75	3	25	12.2
77.c	Supercompact organics and inorganics, sand plus clay based backfill, monolayer of 2,000 drums, in 6X33X300	12.21%	13.15%	39.16%	33.60%	16	9	75	3	25	12.2
77.d	Supercompact organics and inorganics, CaO based backfill, monolayer of 2,000 drums, in 6X33X300	12.21%	13.15%	39.16%	10.10%	16	9	75	14	25	18.3
83	Salt Backfill with CaO	12.21%	15.42%	41.72%	10.10%	16	7	75	14	25	20.2

TABLE 3-29 (Continued)
SUMMARY OF POROSITIES AND COMPRESSIVE STRENGTHS

Identifier	Alternative	Porosity at Lithostatic Pressure				Unconfined Compressive Strength					Average Composite Waste/ Backfill (MPa)
		Sludges[1]	Solid Organic	Solid Inorganic Metals	Backfill	Sludges (MPa)	Solid Organic (MPa)	Solid Inorganic (MPa)	Backfill (MPa)	Host Salt (MPa)	
94.a	SPM IT-4 Enhanced cement sludges, shred and add clay organics and inorganics, no backfill	20.0%	24.00%	41.30%	—	16	7	75	0	25	24.7
94.b	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, sand plus clay backfill.	20.0%	24.00%	41.30%	33.60%	16	7	75	3	25	14.7
94.c	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, cementitious grout backfill.	20.0%	24.00%	41.30%	31.30%	16	7	75	16	25	20.6
94.d	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.	20.0%	24.00%	41.30%	31.30%	16	7	75	16	25	20.6
94.e	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, clay backfill.	20.0%	24.00%	41.30%	40.50%	16	7	75	3	25	14.7
94.f	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, CaO backfill.	20.0%	24.00%	41.30%	10.10%	16	7	75	14	25	19.7
111	Clay Based Backfill	12.21%	15.42%	41.72%	40.50%	16	7	75	3	25	15.2

[1]Porosity for enhanced cementation is estimated at 20% at 2000 psi stress. The enhanced cemented sludge is assumed to have a compressive strength of greater than 2000 psi. The 20% pore space is assumed to be from entrained air during mixing and does not change with increased pressure up to 2000 psi.

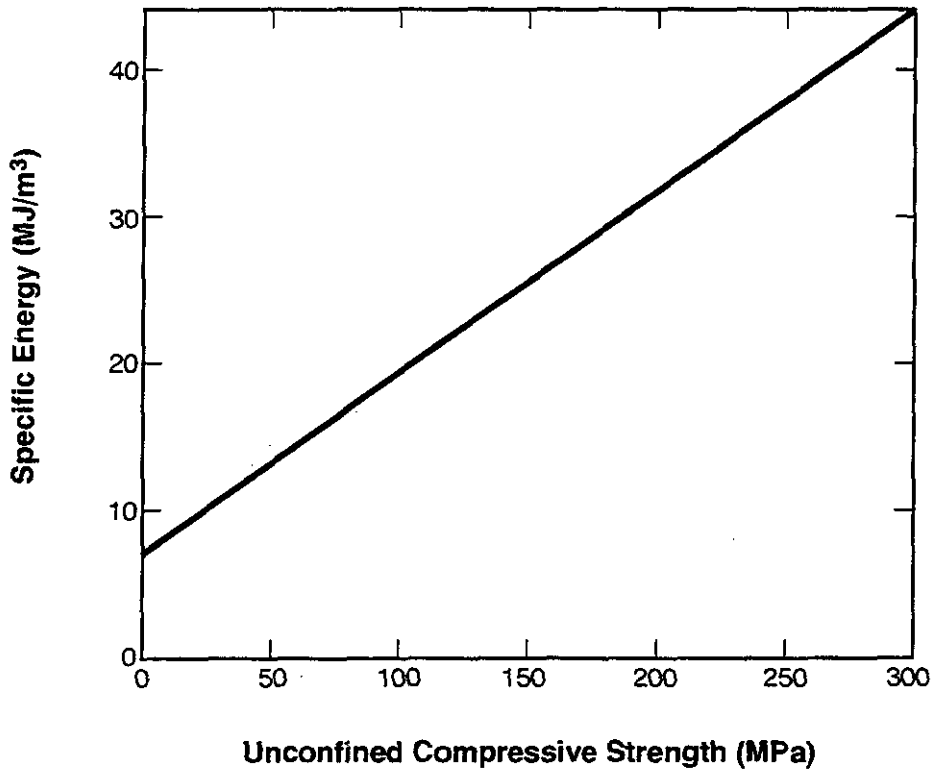

Figure 3-8
Mining Advance Rate Mine Waste Removal Evaluation

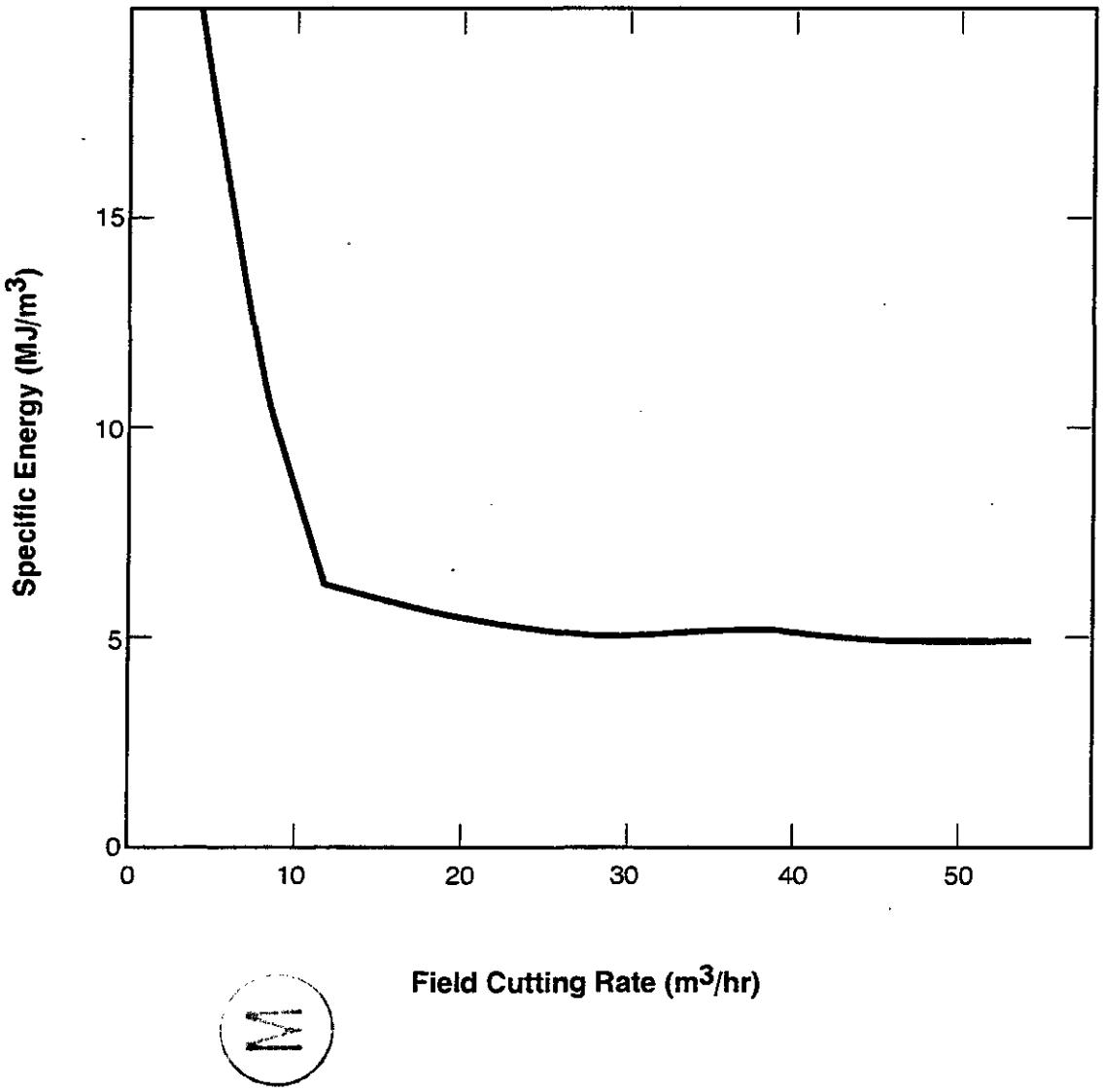

Figure 3-9
Relationship of Specific Energy to the Field Cutting Rate

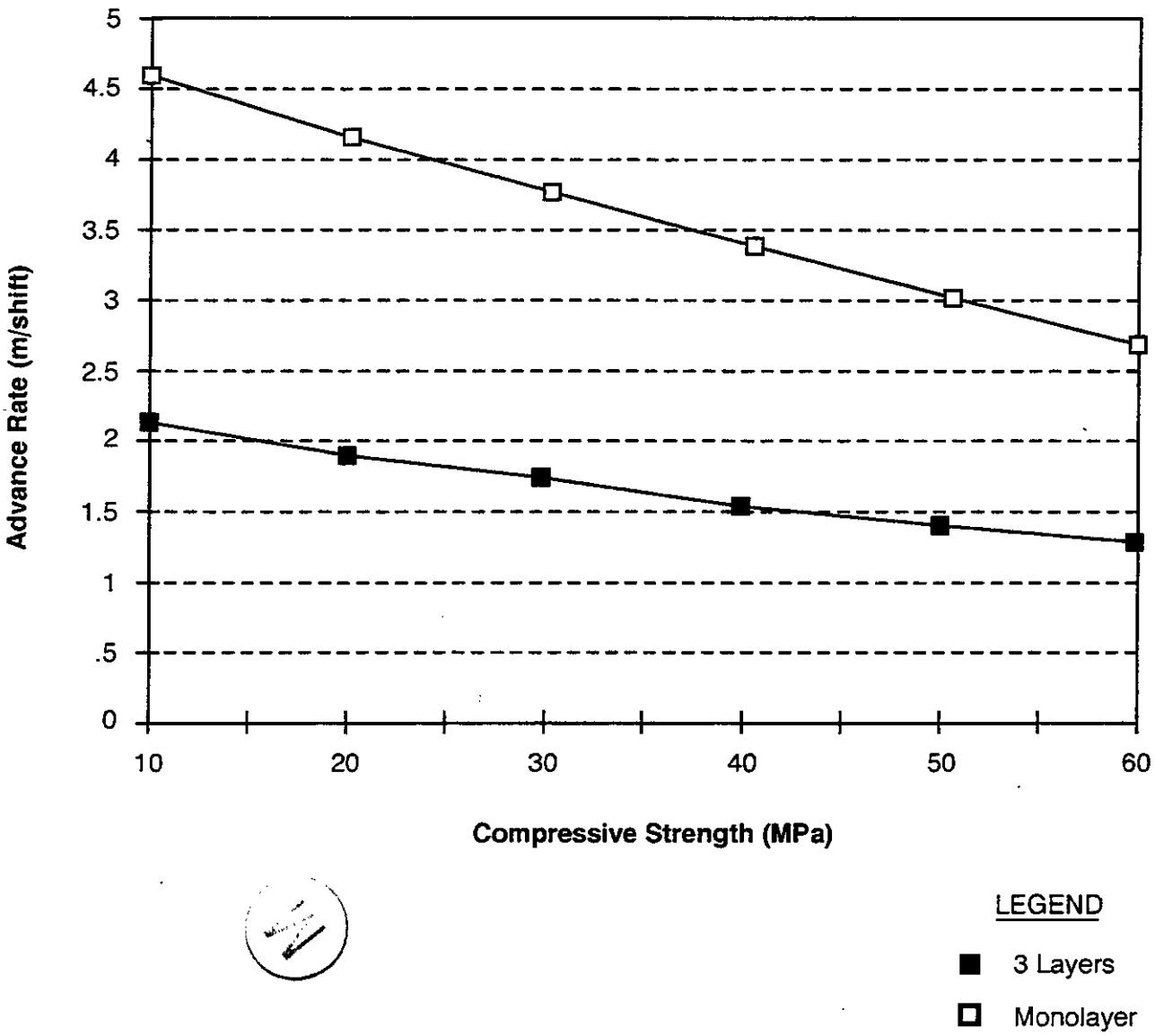

Figure 3-10
Relationship of Mining Advance Rate to Compressive Strength

3.4.3 Assumptions and Data for Factor 4

Data sources for assessing the unconfined compressive strength and the mining advance rate have been described previously. The baseline operational parameters for waste removal is defined by the following assumptions:

- Waste will be placed in the eight panels plus their associated access drifts giving the waste disposal volume of 10 panel equivalents.

- Underground excavation and waste removal occurs at some future time when the waste consolidate to near lithostatic stress after decommissioning and sealing of the facility. Waste recovery is by continuous mining using available technology.

- The underground waste removal activities require continuous mining and re-excavation of the ten equivalent panels. Each panel equivalent will hold approximately 80,000 drums of contact handled waste for a total waste inventory of approximately 800,000 drums. The waste inventory for the baseline consists of sludges, solid organic waste and solid inorganic waste. No backfill is considered, but overexcavation of the waste stack would be necessary to assure complete removal of the waste stack. For purposes of analysis, it is assumed that the dimensions of the rooms excavated equals the initial dimensions. The dimensions of the rooms for the baseline analysis are 13 ft by 33 ft by 300 ft (3.96 by 10.06 by 91.43 m) (Case et al., 1991). There are 12.54 room equivalents per panel, and 10 equivalent panels for all EAs. The WIPP design includes eight panels, with the associated panel access drifts providing an additional two panel equivalents.

- RH TRU waste is not considered in this analysis. The comparison of RH waste baseline with the EAs shows no difference. The analysis of baseline conditions with respect to EA related cost, time, and risk values shows no variability in results.

- Mining advance rates will be developed from the estimated strength and density of the waste forms after consolidation to near lithostatic stress. At this point in time, each waste form will have a certain density and porosity. The porosity is estimated from porosity versus stress relationships developed, and then related to the compressive strength for each waste form. The mining advance rate is inversely proportional to the compressive strength and density of the waste form.

- Performance studies have been performed by the mining industry for mining advance rates using continuous mining equipment relative to various rock types and rock strengths (e.g., McFeat-Smith and Powell, 1979). Mining advance rates at the WIPP will be estimated from these performance studies. Mined waste handling is scheduled at the same rate as excavation. The amount of time required for mining is determined from the panel entry lengths divided by the mining advance rate.

- Following excavation, the CH-TRU waste will be emplaced in waste containers similar to the standard waste boxes used by the project by a Load-Haul-Dump operation. Waste transporters move the material to the ground surface. The material disposition of the waste after this point in time is beyond the scope the EACBS.

- After completion of waste removal activities in a panel, the panel will be closed and isolated from the other panel by the construction of panel ventilation barriers. Underground ventilation will then be established to the next panel for waste removal activities.

- Based upon the above assumptions for underground mining and removal operations, a schedule is developed for waste removal, the number of man hours determined, and the occupational hazards assessed for the removal period. The occupational hazards for industrial accidents include the conventional hazards due to underground mining accidents, hazardous waste exposure during an accident, and radiation exposure during an accident.

For each of the alternatives, additional operational parameters are defined regarding repository geometry, and backfill emplacement. These include:

- For plasma processing with a single layer of drums per room, an initial void space 8.2 ft (2.5 meters) high above the waste stack would exist. This results in the excavation of salt that affects the mining time.

- For the 77 series of EAs involving the monolayer of waste containers, the initial room dimensions are 6 ft X 33 ft X 300 ft (1.83 X 10.06 X 91.44 m).

- The radionuclide inventory per panel remains the same for each of the alternatives. For alternatives involving the 77 and 94 series, less waste is placed per room under this assumption and the WIPP cannot accommodate the total waste inventory.

- The thickness of the backfill layer around the drums is 0.5 m between the room sidewall and the waste stack, and about 2 ft (0.6 m) above the waste stack. The void space between the waste drums is 80 percent for the "wet" backfill alternatives involving grout, and 50 percent for the "dry" backfill alternatives.

The volumes of backfill have been calculated and are presented in Table 3-30. The salt volume excavated to the initial room dimensions considers the total volume for 10 panel equivalents that are mined out equal to 16,138,593 ft^3 (456,938 m^3) for a 13 ft (3.96 m) high drift and 7,448,565 ft^3 (210,894 m^3) for a 6 ft (1.83 m) high drift minus the volume for the waste and the emplaced backfill. The total backfill volume is based on the geometry of the backfill, and the void space.

The average mining advance rate is determined from the average compressive strength in Table 3-29 and the relationships in Figure 3-10 for either the 6 ft (1.83 m) high or the 13 ft (3.96 m) high entry. The number of shifts is determined by the entry length divided by the average mining advance rate (Table 3-31). The subtotal manning table for mining excavation during waste removal is determined by multiplying the number of shifts by 24 with 8 persons working at any given time. The subtotal manning for materials handling during waste removal is determined by the number of workers per shift (assumed to be 30 with 10 working at any given time). The total man hours available for accidents to occur is equal to 18 workers per shift times 8 hours per shift times the number of shifts. The industrial accident estimates are taken from (D'Appolonia Consulting Engineers, Inc., 1976) for salt. The rates are 39.7 injuries per 3.04 million man-hours worked for nonfatal accidents, and 1.97 fatalities per 3.04 million man-hours worked for fatal

TABLE 3-30
SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Backfill Material Volume (m^3)	Backfill Emplaced Volume (m^3)	Salt Volume (m^3)	No. of Panels
0	Baseline	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	0	—	289,814	10
1	Compact Waste	54,389	26,019	13,438	93,846	9,385	45,097	93,846	0	0	—	363,092	10
6	Shred and Compact	54,389	56,498	29,181	140,068	14,007	67,308	140,068	0	0	—	316,870	10
10	Plasma Processing of All Waste	10,767	24,532	12,671	47,970	4,797	23,051	47,970	0	0	—	408,968	10
33	Sand Plus Clay Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	154,500	207,370	82,444	10
35.a	Salt Aggregate Grout Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	186,220	207,370	82,444	10
35.b	Cementitious Grout Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	186,220	207,370	82,444	10
77.a	Supercompact organics and inorganics, salt-aggregate grout backfill, monolayer of 2,000 drums, in 6X33X300	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	109,220	117,000	41,703	10
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2,000 drums, in 6X33X300	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	97,540	117,000	41,703	10
77.c	Supercompact organics and inorganics, sand plus clay based backfill, monolayer of 2,000 drums, in 6X33X300	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	97,540	117,000	41,703	10

Refer to footnotes at end of table.

TABLE 3-30 (Continued)
SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Backfill Material Volume (m^3)	Backfill Emplaced Volume (m^3)	Salt Volume (m^3)	No. of Panels
77.d	Supercompact organics and inorganics, CaO based backfill, monolayer of 2,000 drums, in 6X33X300	54,389	26,019	13,438	93,846	5,219	25,080	52,191	41,655	97,540	117,000	41,703	10
83	Salt Backfill with CaO	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	154,500	207,370	82,444	10
94.a	SPM IT-4 Enhanced cement sludges, shred and add clay organics and inorganics, no backfill	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	0	0	289,814	10
94.b	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, sand plus clay backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	154,500	207,370	82,444	10
94.c	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, cementitious grout backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	186,220	207,370	82,444	10

Refer to footnotes at end of table.

TABLE 3-30 (Continued)
SUMMARY OF WASTE INVENTORIES

Identifier	Alternative	Sludges Volume (m^3)	Solid Organic Volume (m^3)	Solid Inorganic Volume (m^3)	Total Waste Volume (m^3)	Total Waste per Panel (m^3)	Total Drums per Panel	Total Allowable Waste Volume (m^3)	Unaccepted Waste Volume* (m^3)	Backfill Material Volume (m^3)	Backfill Emplaced Volume (m^3)	Salt Volume (m^3)	No. of Panels
94.d	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	186,220	207,370	82,444	10
94.e	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, clay backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	154,500	207,370	82,444	10
94.f	SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, CaO backfill.	81,566	74,339	38,396	194,301	16,712	80,309	167,124	27,177	154,500	207,370	82,444	10
111	Clay Based Backfill	54,389	74,339	38,396	167,124	16,712	80,309	167,124	0	154,500	207,370	82,444	10

*Unaccepted Waste Volume is the volume of waste generated by a treatment process that is in excess of the WIPP design volume.

Source: DOE, 1995e, Baseline Inventory Report, See Appendix O for Waste Inventory Details.

TABLE 3-31
MINING ADVANCE RATE AND TIME

Identifier	Alternative	Average Advance Rate m/shift	No. of Shifts	Mining Excavation Man-Shifts	Materials Handling Man-Shifts	Total Man-Shifts	Man Hours	Fatal Accidents	Nonfatal Accidents
0	Baseline	1.8	6,243	149,835	187,294	337,129	899,010	0.58	11.74
1	Compact Waste	1.8	6,202	148,842	186,052	334,894	893,051	0.58	11.66
6	Shred and Compact	1.8	6,240	149,753	187,192	336,945	898,521	0.58	11.73
10	Plasma Processing of All Waste	1.9	6,177	148,246	185,307	333,553	889,474	0.58	11.62
33	Sand Plus Clay Backfill	2.0	5,710	137,042	171,303	308,345	822,254	0.53	10.74
35.a	Salt Aggregate Grout Backfill	1.9	6,013	144,324	180,404	324,728	865,941	0.56	11.31
35.b	Cementitious Grout Backfill	1.9	6,013	144,324	180,404	324,728	865,941	0.56	11.31
77.a	Supercompact organics and inorganics, salt-aggregate grout backfill, monolayer of 2,000 drums, in 6X33X300	4.2	2,733	65,591	81,988	147,579	393,544	0.26	5.14
77.b	Supercompact organics and inorganics, clay based backfill, monolayer of 2000 drums, in 6X33X300	4.5	2,569	61,648	77,060	138,708	369,887	0.24	4.83
77.c	Supercompact organics and inorganics, sand plus clay based backfill, monolayer of 2,000 drums, in 6X33X300	4.5	2,569	61,648	77,060	138,708	369,887	0.24	4.83
77.d	Supercompact organics and inorganics, CaO based backfill, monolayer of 2,000 drums, in 6X33X300	4.2	2,706	64,952	81,189	146,141	389,709	0.25	5.09
83	Salt Backfill with CaO	1.9	5,965	143,153	178,942	322,095	858,921	0.56	11.22

TABLE 3-31 (Continued)
MINING ADVANCE RATE AND TIME

Identifier	Alternative	Average Advance Rate m/shift	No. of Shifts	Mining Excavation Man-Shifts	Materials Handling Man-Shifts	Total Man-Shifts	Man Hours	Fatal Accidents	Nonfatal Accidents
94.a	Enhanced cement sludges, shred and add clay organics and inorganics, no backfill	1.8	6,215	149,154	186,442	335,596	894,921	0.58	11.69
94.b	Enhanced cement sludges, shred and add clay based material to organics and inorganics, sand plus clay backfill.	2.0	5,686	136,472	170,590	307,062	818,832	0.53	10.69
94.c	Enhanced cement sludges, shred and add clay based material to organics and inorganics, cementitious grout backfill.	1.9	5,987	143,691	179,614	323,305	862,147	0.56	11.26
94.d	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.	1.9	5,987	143,691	179,614	323,305	862,147	0.56	11.26
94.e	Enhanced cement sludges, shred and add clay based material to organics and inorganics, clay backfill.	2.0	5,686	136,472	170,590	307,062	818,832	0.53	10.69
94.f	Enhanced cement sludges, shred and add clay based material to organics and inorganics, CaO backfill.	1.9	5,939	142,531	178,164	320,695	855,188	0.55	11.17
111	Clay Based Backfill	2.0	5,710	137,042	171,303	308,345	822,254	0.53	10.74

accidents. The radiation exposure would be no different between alternatives based upon the assumption that the radionuclide inventory per panel remains the same for each of the alternatives. For hazardous organic materials, plasma processing would eliminate hazardous waste exposure.

3.4.4 Results of Analysis for Factor 4

The results show that among the alternatives, the placement of the waste in a single monolayer in a 6 ft by 33 ft (1.83 by 10.06 m) room would reduce mining excavation substantially, and would reduce the number of underground mining accidents substantially. The results show little difference among the other alternatives since the mining advance rate is nearly the same at 6.56 ft (2 m) per shift for nonmetallic waste, and 3.28 ft (1 m) per shift for metallic waste. The use of clay or sand backfill would exhibit a slightly lower strength, and result in a reduced waste removal time. Yet, these effects are secondary since the waste stack would need to be overexcavated to assure removal of the waste.

3.5 IMPACT ON TRANSPORTATION RISK

Transportation risks are evaluated based on the number of CH- and RH-TRU waste shipments required to dispose of the WIPP authorized waste volume of 6.2 million cubic feet. This provides a reasonably conservative analysis which is consistent with prior waste shipment studies for the WIPP. In general, this volume basis analysis approach involves more shipments than would be required to ship the EA final waste form quantities identified in Table 2-6. Based on estimated final waste form densities, some shipments may be weight limited and may not be able to fully utilize the volume capacity of a TRUPACT-II. With the current level of available information and to meet the objectives of the current study as discussed in Section 1.1, this study retains the use of WIPP's authorized waste volume and the volume capacity of a TRUPACT-II to estimate the number of waste shipments.

Four transportation configurations are considered in the analysis: the baseline and decentralized, regionalized, and centralized configurations. The baseline is defined as shipment of WIPP WAC-certified TRU waste from all generator/storage sites to WIPP (Figure 3-11). In the decentralized case (also shown on Figure 3-11), most waste processing required to enhance repository performance would occur at the generator/storage sites, but some of the small-quantity generators would ship waste to one of the large-quantity generators for processing. In the regionalized case, waste would be shipped to Hanford Site, Idaho National Engineering Laboratory, Savannah River Site, or Los Alamos National Laboratory for processing (Figure 3-12). The centralized case would consist of shipment of all waste from the generator/storage sites to a processing facility located at WIPP (Figure 3-13).

Approximately 98 percent of the CH- and RH-TRU waste shipments will originate from six major generator/storage facilities. The remaining shipments originate from approximately 14 minor facilities. The major/minor facilities, shown on Figures 3-11 through 3-13, are as follows:

Facilities	CH-TRU	RH-TRU
Hanford	Major site	Major site
INEL	Major site	Minor site
LANL	Major site	Minor site
RFETS	Major site	Minor site
SRS	Major site	Minor site
ORNL	Minor site	Major site
AMES	Minor site	Not generated or stored
ANL/E	Minor site	Not generated or stored
Battelle	Not generated or stored	Minor site
Bettis	Minor site	Minor site
ETEC	Minor site	Not generated or stored
KAPL	Minor site	Minor site
LBL	Minor site	Not generated or stored
LLNL	Minor site	Not generated or stored
Mound	Minor site	Not generated or stored
MU	Minor site	Not generated or stored

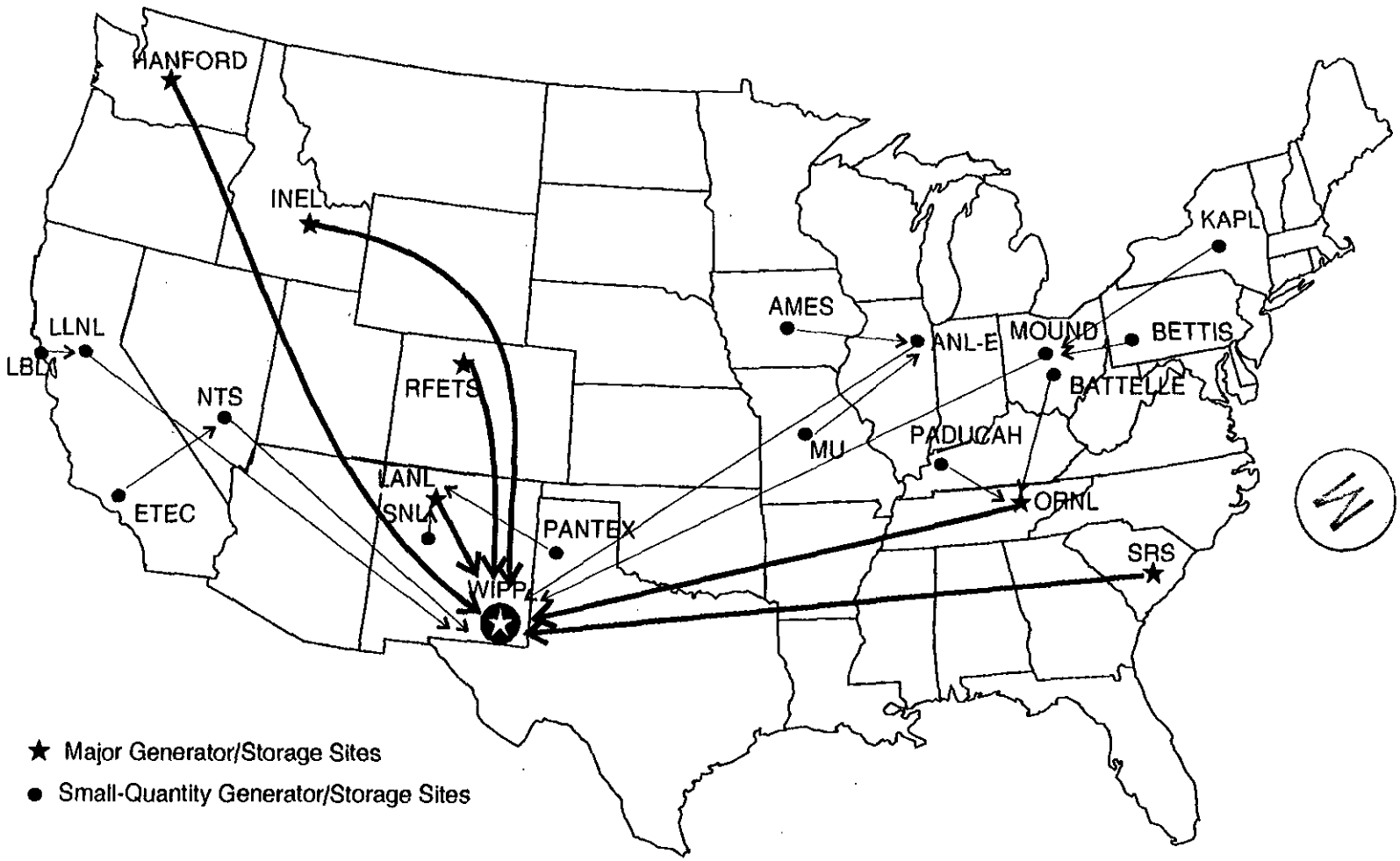

Figure 3-11

Transportation Configuration for Generator/Storage Site Base Case & Decentralized Configuration

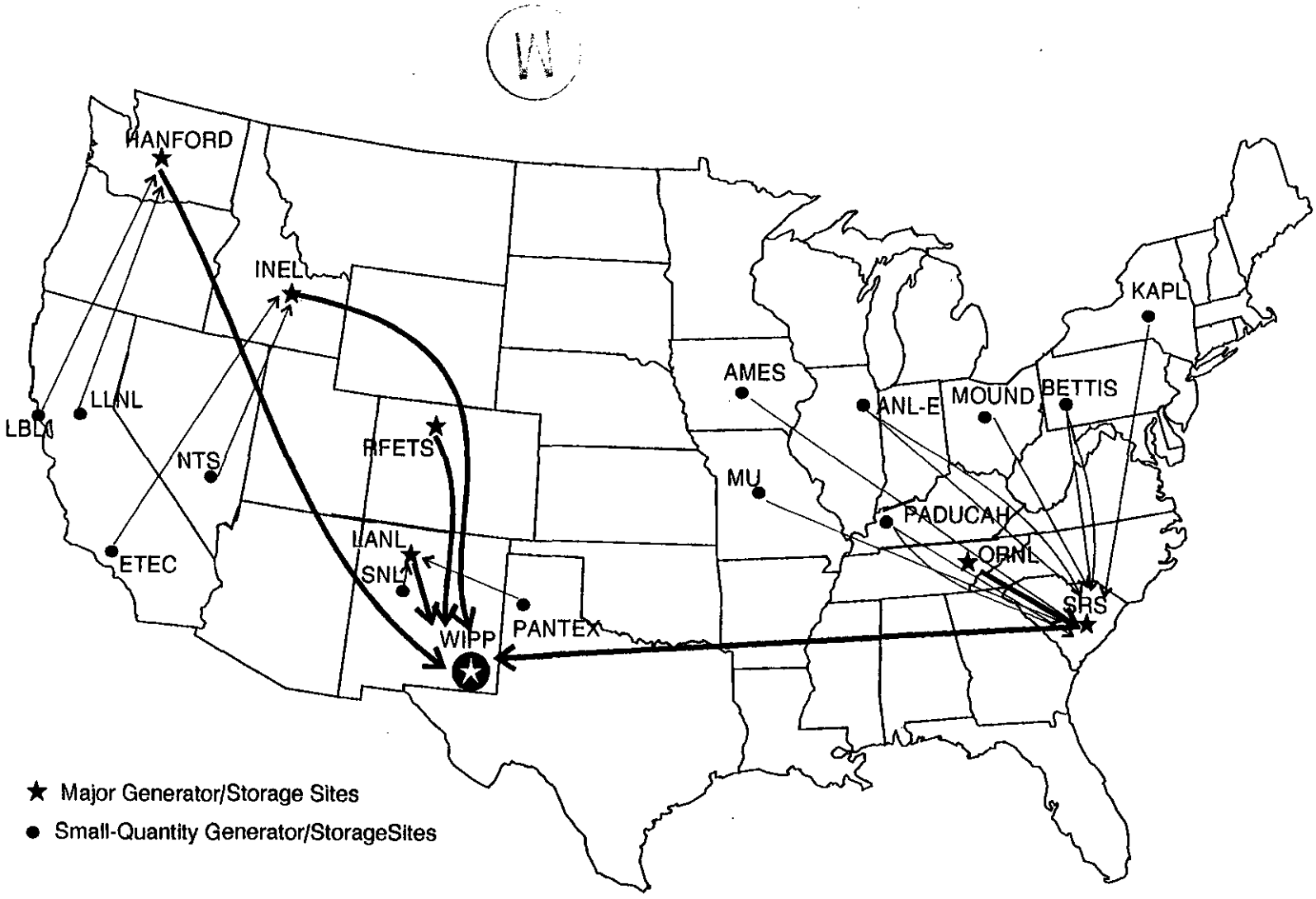

Figure 3-12
Transportation Configuration for Generator/Storage Site Regionalized Configuration

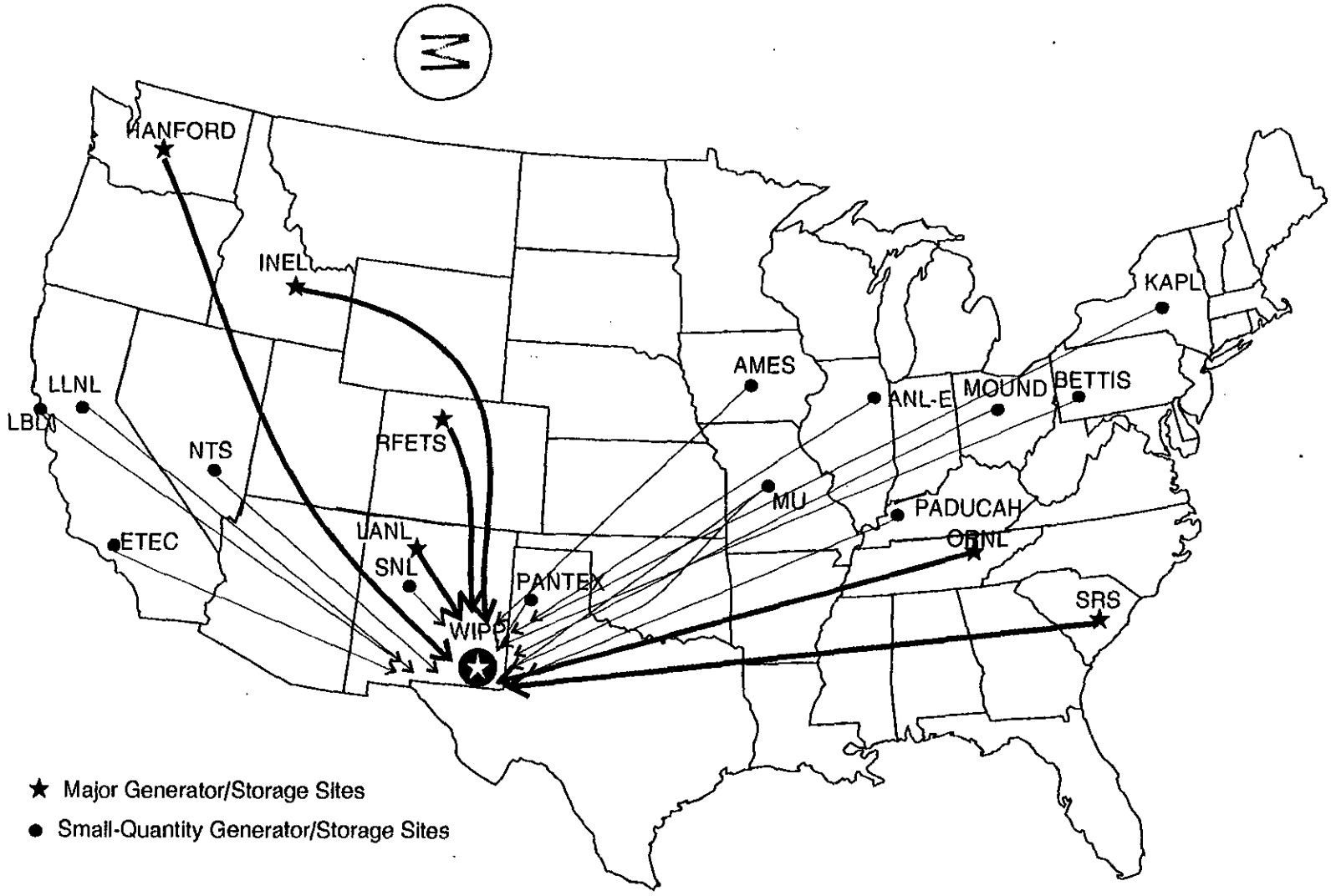

Figure 3-13
Transportation Configuration for Generator/Storage Site Centralized Configuration

NTS	Minor site	Not generated or stored
Paducah	Minor site	Not generated or stored
Pantex	Minor site	Not generated or stored
SNL	Minor site	Not generated or stored

The engineered alternatives that are being analyzed for their impact on transportation risk are:

No. 1: Compact waste

No. 6: Shred and compact

No. 10: Plasma processing

No. 77: Supercompact organics and inorganics (solid waste)

No. 94: Enhanced cementation of sludges, shred and add clay based materials to organics and inorganics.

All CH- and RH-TRU waste that is transported either for processing or disposal will be shipped in Type B transportation packages. CH-TRU waste will be placed either in 55-gallon (208-liter) drums or standard waste boxes (SWBs) and transported in a Transuranic Package Transporter-II (TRUPACT-II) (Figure 3-14). RH-TRU waste will be in either 30-gallon (113.6-liter) or 55-gallon (208-liter) drums placed in a RH-TRU waste canister and transported in an RH-72B cask. The TRUPACT-II has been certified by the U.S. Nuclear Regulatory Commission (NRC) and has been used by the DOE for intrasite CH-TRU waste transportation. The RH-72B cask (Figure 3-15) has yet to be NRC certified, but is scheduled to be available for RH-TRU waste transportation when WIPP is ready for waste emplacement.

3.5.1 Definition of the TRU Waste Transportation Risk Factor

The transportation risk factor consists of the human health impacts that could potentially result from transporting CH- or RH-TRU waste. The risk factor is defined in terms of the radiological, chemical, and non-radiological/non-chemical impacts of either normal, incident-free transportation or transportation accidents.

3.5.2 Methodology Used to Evaluate the Transportation Risk Factor

The transportation analysis presented in this chapter was conducted similarly to assessments such as NUREG-0170 (NRC, 1977), the WIPP FEIS (DOE, 1980), the WIPP FSEIS (DOE, 1990b), and the Comparative Study of Waste Isolation Pilot Plant (WIPP) Transportation Alternatives (DOE, 1994a). Since 1980, computer models and basic assumptions have been refined, but the approach to estimating the consequences and risks has remained the same. This methodology has proven to be accurate, reliable, and technically acceptable. The analytical codes or models used for this analysis have been extensively documented in the WIPP FSEIS (DOE, 1990b). Methods and assumptions used are provided in the following subsections.

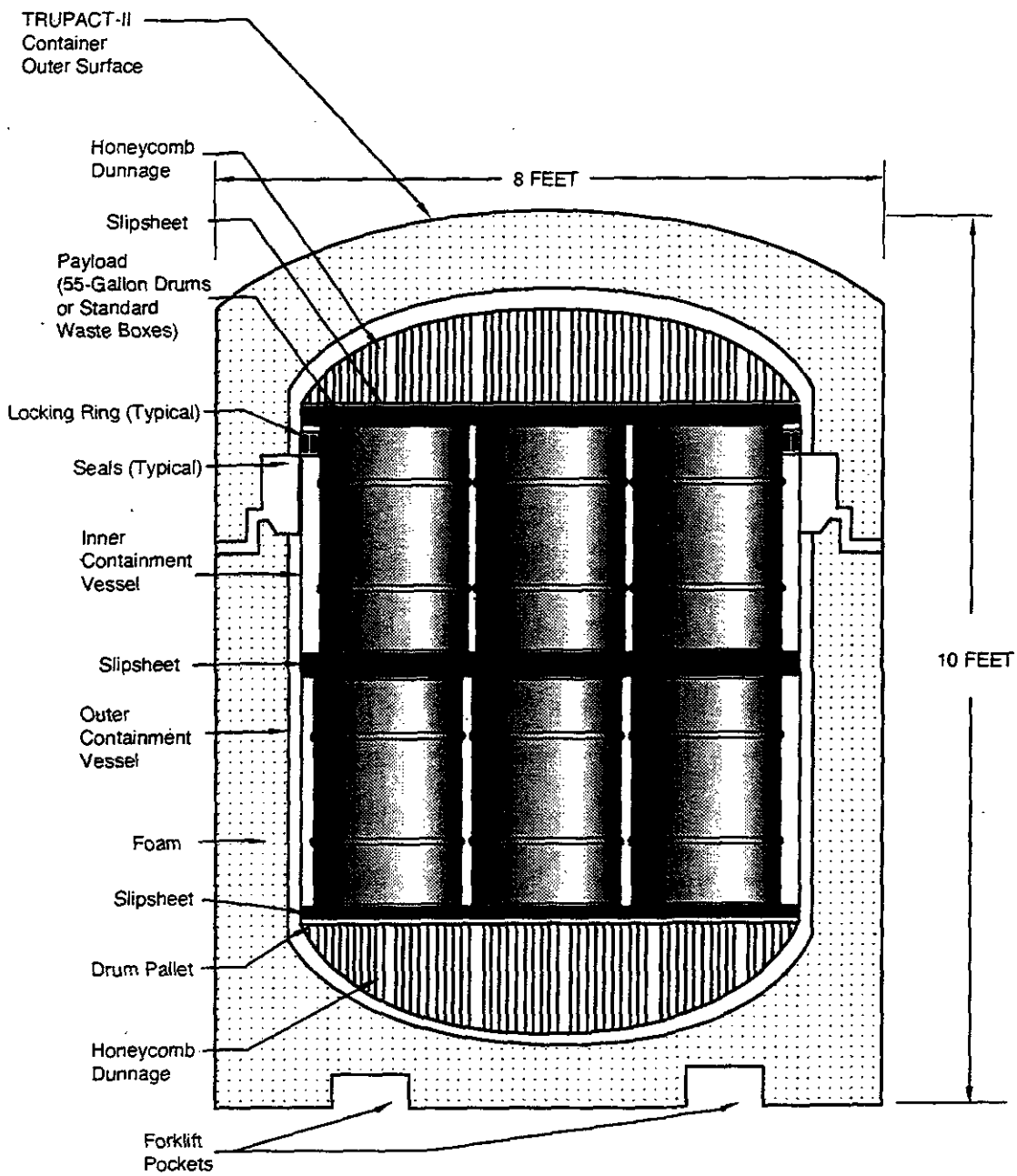

Figure 3-14
TRUPACT-II Shipping Container For CH-TRU Waste (Schematic)

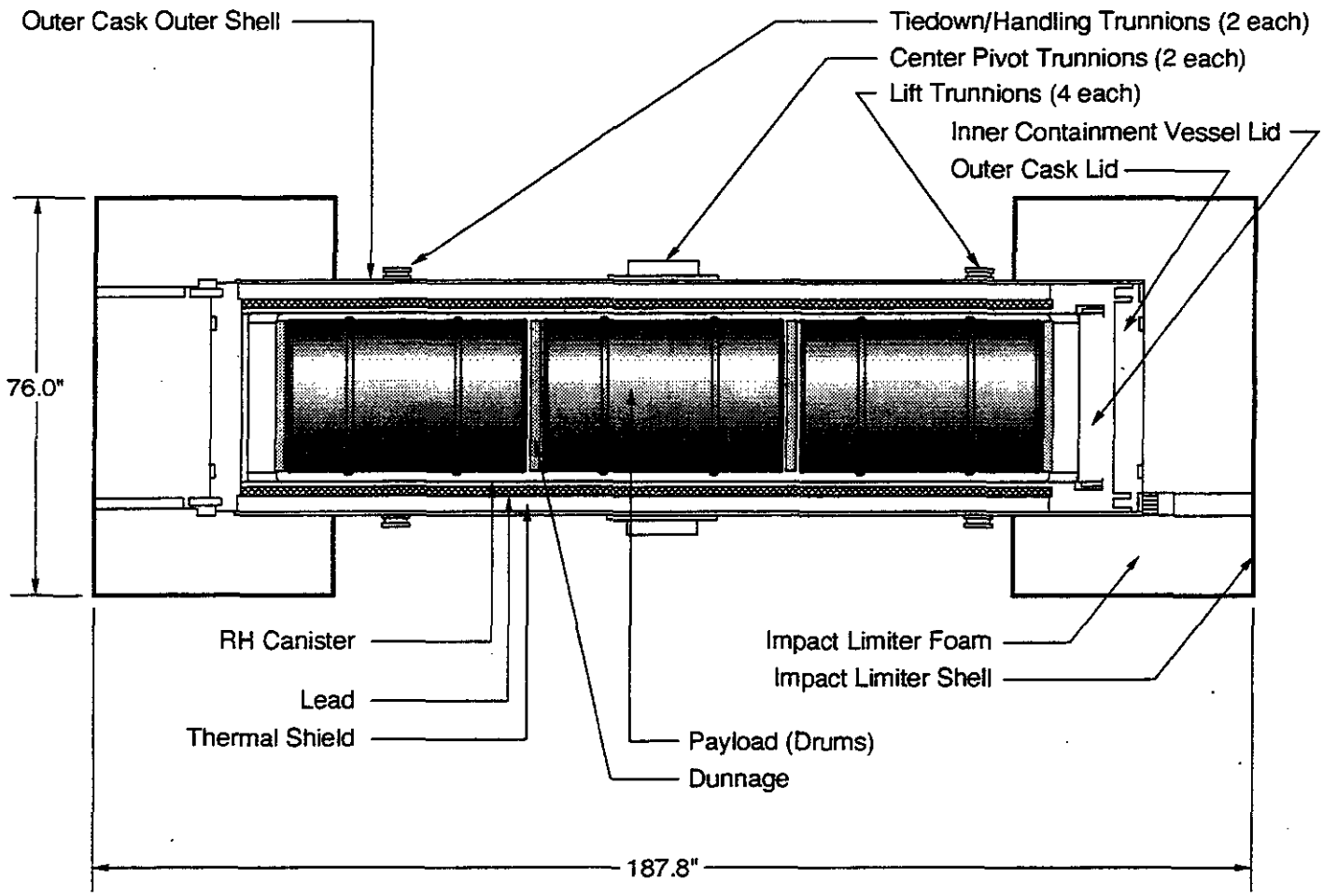

Figure 3-15
RH-72B Shipping Cask for RH-TRU Waste (Schematic)

3.5.2.1 Evaluation Methods Used

3.5.2.1.1 Transportation Routes

The CH- and RH-TRU waste shipments will travel routes as specified in 49 CFR 177.825, which regulates highway and state-approved non-interstate segments between shipment origin sites and the WIPP. Tables 3-32 through 3-35 present origin/destination, total one-way mileage, and fraction of travel in various population zones. These tables also summarize the number of shipments for the transportation configurations for each engineered alternative considered.

3.5.2.1.2 Radiological Exposures

The RADTRAN computer code was used to calculate radiological risks. RADTRAN was originally developed by Sandia National Laboratories to support preparation of NUREG-0170, Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes (NRC, 1977). This code has undergone over 18 years of development and is continuing to be refined. RADTRAN 4 (version 4.0.17) (Neuhauser and Kanipe, 1992) was used for the current analyses and was accessed using TRANSNET, an SNL/NM centralized MICRO VAX II computer system. The TRANSNET system incorporates transportation models and data bases that may be accessed via a modem-equipped personal computer.

RADTRAN calculates doses for various population subgroups (e.g., workers, the public) for normal transportation conditions. For the public, it calculates doses to people

- In the vicinity of the transportation vehicle while it is stopped
- Surrounding the transportation route
- Sharing the transportation route with the vehicle.

The dose assessment incorporates a point-source approximation for distances between the receptor and the source of more than twice the largest physical dimension of the source. A line-source approximation is applied for exposure distances less than twice the largest package dimension. The RADTRAN code incorporates features to take credit for shielding for typical structures in urban and suburban settings. RADTRAN also calculates a hypothetical maximum exposure to an individual who resides along the surface transportation route. The model assumes that the individual lives approximately 100 feet (30 meters) from the surface transportation link and that the vehicle passes by at approximately 40 miles per hour (64 kilometers per hour). RADTRAN incorporates algorithms to predict radiological impacts from accidents exceeding transportation package performance conditions. The code evaluates both internal exposure pathways (i.e., inhalation, resuspension, and ingestion) and external exposure pathways (i.e., cloudshine, groundshine) to project potential accident consequences and risks (probability x consequence) to the general public.

Low levels of penetrating radiation from radioactive material shipments pose an external exposure pathway to transportation workers and the public during normal (incident-free) transportation conditions. Shipment external radiation levels are regulated by the U.S. Department of Transportation (DOT) and the NRC on the basis of the Transport Index (TI). The TI represents

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TABLE 3-32

NUMBER OF SHIPMENTS AND MILEAGE FOR CH-TRU WASTE BASELINE

Waste Origin Site	To Route Destination	Total[1] Shipments	Rural	Suburban	Urban	Total One-Way Mileage
Major CH-TRU Waste Sites						
HANFORD	WIPP	5,712	1,645.3	144.4	18.1	1,808.0
INEL	WIPP	4,974	1,262.5	114.1	15.4	1,392.0
LANL	WIPP	2,839[2]	318.4	21.4	2.1	342.0
RFETS	WIPP	931	618.6	71.1	14.1	704.0
SRS	WIPP	2,827	1,184.2	304.8	19.8	1,509.0
Small CH-TRU Waste Sites						
AMES	ANL-E	1	300.7	50.2	2.1	353.0
ANL-E	WIPP	7[3]	1,237.7	203.0	13.8	1,455.0
BETTIS	MOUND	17	155.0	113.8	20.0	289.0
ETEC	NTS	2	269.1	61.3	44.6	375.0
KAPL	MOUND	1	381.8	291.2	20.6	694.0
LBL	LLNL	1	19.9	31.8	23.2	75.0
LLNL	WIPP	137[4]	1,303.6	100.4	47.9	1,452.0
MOUND	WIPP	47[5]	1,301.3	234.3	20.8	1,557.0
MU	ANL-E	1	294.8	89.0	9.2	393.0
NTS	WIPP	68[6]	1,136.7	63.8	13.4	1,214.0
ORNL	WIPP	120[7]	1,317.6	182.1	21.1	1,521.0
PADUCAH	ORNL	1	251.0	61.7	4.4	317.0
PANTEX	LANL	1	314.2	16.9	3.8	335.0
SNL	LANL	3	82.1	16.7	5.2	104.0
	TOTAL SHIPMENTS	17,690				

[1]The total number of shipments is based on 60% of the waste being shipped in 55-gallon (208-liter) drums and 40% of the waste being shipped in standard waste boxes. It is also assumed that any site with three or less shipments will make all shipments in *55-gallon (208-liter) drums.*
[2]This total includes one shipment from PANTEX to LANL and three shipments from SNL to LANL.
[3]This total includes one shipment from AMES to ANL-E and one shipment from MU to ANL-E.
[4]This includes one shipment from LBL.
[5]This total includes 17 shipments from BETTIS to MOUND and one shipment from KAPL to MOUND.
[6]This total includes two shipments from ETEC.
[7]This total includes one shipment from PADUCAH.

Source: Waste Quantity Throughput and Shipments from Wagner, 1995; mileage data from the Highway Computer Code, Johnson et al., 1993.

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TABLE 3-33

NUMBER OF SHIPMENTS AND MILEAGE FOR RH-TRU WASTE BASELINE AND DECENTRALIZED CONFIGURATION

Waste Origin Site	To Route Destination	Total Shipments	Rural	Suburban	Urban	Total One-Way Mileage
Major RH-TRU Waste Sites						
HANFORD	WIPP	5,176	1,645.3	144.4	18.1	1,808.0
ORNL	WIPP	2,185[1]	1,317.6	182.1	21.1	1,521.0
Small RH-TRU Waste Sites						
BATTELLE	ORNL	123	242.6	151.4	14.9	409.0
BETTIS	ORNL	3	414.2	180.1	12.6	607.0
INEL	WIPP	109	1,262.5	114.1	15.4	1,392.0
KAPL	ORNL	57	588.6	285.5	9.8	884.0
LANL	WIPP	249	318.4	21.4	2.1	342.0
SRS	WIPP	56	1,184.2	304.8	19.8	1,509.0
TOTAL SHIPMENTS		7,958				

[1]Total includes 123 shipments from Battelle to ORNL, 3 shipments from Bettis to ORNL, and 57 shipments from KAPL to ORNL.

Source: Waste Quantity Throughput and Shipments from Wagner, 1995; mileage data from the Highway Computer Code, Johnson et al., 1993.

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TABLE 3-34

NUMBER OF SHIPMENTS AND MILEAGE FOR CH-TRU WASTE REGIONAL CONFIGURATION

Waste Origin Site	Route Destination	Total[1] Shipments	Rural	Suburban	Urban	Total One-Way Mileage
Major CH-TRU Waste Sites						
HANFORD	WIPP	5,849[2]	1,645.3	144.4	18.1	1,808
INEL	WIPP	5,042[3]	1,262.5	114.1	15.4	1,392
LANL	WIPP	2,839[4]	318.4	21.4	2.1	342
RFETS	WIPP	931	618.6	71.1	14.1	704
SRS	WIPP	3,001[5]	1,184.2	304.8	19.8	1,509
Small CH-TRU Waste Sites						
AMES	SRS	1	881.9	292.3	15.7	1,190
ANL-E	SRS	5	587.3	265.9	23.7	877
BETTIS	SRS	17	485	188.4	12.4	686
ETEC	INEL	2	754.7	141.5	61.7	958
KAPL	SRS	1	641.3	295.2	11.7	949
LBL	HANFORD	1	667.7	167.1	35.2	870
LLNL	HANFORD	136	675.1	183.9	30.8	890
MOUND	SRS	29	424.2	206.4	10.4	641
MU	SRS	1	604.3	231.3	27.2	863
NTS	INEL	66	600.3	92.3	20.3	713
ORNL	SRS	119	244.6	110.4	3	358
PADUCAH	SRS	1	380.1	171.1	17.6	569
PANTEX	LANL	1	314.2	16.9	3.8	335
SNL	LANL	3	82.1	16.7	5.2	104
TOTAL SHIPMENTS		18,045				

[1]The total number of shipments is based on 60% of the waste being shipped in 55-gallon (208-liter) drums and 40% of the waste being shipped in Standard Waste Boxes. It is also assumed that any site with three or less shipments *will make all shipments in 55-gallon (208-liter) drums.*
[2]This total includes 136 shipments from LLNL to HANFORD and one shipment from LBL to HANFORD.
[3]This total includes 66 shipments from NTS to INEL and two shipments from ETEC to INEL.
[4]This total includes one shipment from PANTEX to LANL and three shipments from SNL to LANL.
[5]This total includes five shipments from ANL-E to SRS; one shipment from AMES to SRS; 17 shipments from BETTIS to SRS; one shipment from KAPL to SRS; 20 shipments from MOUND to SRS; one shipment from MU to SRS; 119 shipments from ORNL to SRS; one shipment from PADUCH to SRS.

Source: Waste Quantity Throughput and Shipments from Wagner, 1995; mileage data from the Highway Computer Code, Johnson et al., 1993.

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TABLE 3-35

NUMBER OF SHIPMENTS AND MILEAGE FOR CH-TRU WASTE CENTRALIZED CONFIGURATION

Waste Origin Site	Route Destination	Total[1] Shipments	Rural	Suburban	Urban	Total One-Way Mileage
Major CH-TRU Waste Sites						
HANFORD	WIPP	5,712	1,645.3	144.4	18.1	1,808.0
INEL	WIPP	4,974	1,262.5	114.1	15.4	1,392.0
LANL	WIPP	2,835	318.4	21.4	2.1	342.0
RFETS	WIPP	931	618.6	71.1	14.1	704.0
SRS	WIPP	2,827	1,184.2	304.8	19.8	1,509.0
Small CH-TRU Waste Sites						
AMES	WIPP	1	1,121.4	117.8	15.7	1,255.0
ANL-E	WIPP	5	1,237.7	203.0	13.8	1,455.0
BETTIS	WIPP	17	1,452.7	318.3	31.4	1,803.0
ETEC	WIPP	2	754.7	141.5	61.7	958
KAPL	WIPP	1	1,679.6	495.7	31.9	2,208.0
LBL	WIPP	1	1,320.2	130.5	71.0	1,522.0
LLNL	WIPP	136	1,303.6	100.4	47.9	1,452.0
MOUND	WIPP	29	1,301.3	234.3	20.8	1,557.0
MU	WIPP	1	1,017.5	109.5	17.9	1,145.0
NTS	WIPP	66	1,136.7	63.8	13.4	1,214.0
ORNL	WIPP	119	1,317.6	182.1	21.1	1,521.0
PADUCAH	WIPP	1	1,174.1	171.4	13.9	1,360.0
PANTEX	WIPP	1	412.6	26.7	3.6	443.0
SNL	WIPP	3	288.3	18.7	3.9	311.0
	TOTAL SHIPMENTS	17,662				

[1]The total number of shipments is based on 60% of the waste being shipped in 55-gallon (208-liter) drums and 40% of the waste being shipped in Standard Waste Boxes. It is also assumed that any site with three or less shipments will make all shipments in 55-gallon (208-liter) drums.

Source: Wagner, 1995, mileage data from the Highway Computer Code, Johnson et al., 1993.

the radiation dose rate (in mrem/hr) at 3.3 feet (1 meter) from the surface of the shipping package. Calculated TI values are dependent on:

- Distribution and quantity of radionuclides per shipment
- Self-shielding characteristics of the waste
  - Waste configuration
  - Bulk density
  - Whole-atom ratios of chemical composition
- Configuration and shielding characteristics of the shipment packages.

Calculated TI values are key inputs to the RADTRAN code to evaluate normal transportation impacts.

Shipment TI values were determined using the Microshield Code (Version 3.13, Groves Engineering Inc.) Microshield incorporates libraries of radionuclide kinetics and energies, material absorption coefficients, buildup factors, and dose integration options. TI values were calculated using a cylindrical source/shield model. The calculations took credit for the shelf-shielding characteristics of the waste and for the packaging design. While the TRUPACT-II is not designed specifically to provide shielding, its materials of construction provide some shielding benefits. Pacific Nuclear Systems Dwg No. 2077-500SNP (Rev. K) was used to establish the packaging configuration and material thickness (NRC, 1994). The RH-72B cask is designed to provide shielding and was modeled using Pacific Nuclear Systems Dwg No. X-106-500SNP (Rev. none).

Other key inputs to assess normal transportation impacts are the shipment route length and the fraction of travel in urban, suburban, and rural zones. These zones were determined using the HIGHWAY model (Johnson et al., 1993). Routes were selected for analysis based on 49 CFR 177.825, for truck, which regulates highways and state-approved, non-interstate segments between the shipment origin sites and the WIPP. Exposures to individuals residing or working in buildings along the route were determined using RADTRAN Shielding Option 2. This option estimates exposures to individuals in buildings at reduced rates and takes representative credit for shielding benefits afforded by typical building structures found in the three population areas.

Primary RADTRAN input parameters are summarized in Table 3-36 and are representative of CH-TRU and RH-TRU waste truck shipment modes analyzed in this study. Route-specific population densities were used as determined by the HIGHWAY model. Calculated TRU waste truck shipment TI values are presented in Table 3-37 and were estimated using the Microshield code as discussed above. For engineered alternatives and system configurations requiring waste processing at another location, the TI for the origin/treatment location route segment differs from the TI for the treatment location/WIPP route segment, as determined by how the treatment process affects the final waste form mass (kg/m^3) and radionuclide (Ci/m^3) densities. Radionuclides evaluated and their associated RADTRAN input parameters are summarized in Table 3-38.

A screening analysis was performed to select the radionuclides for evaluation, as summarized in Table 3-38. The BIR identifies approximately 139 radionuclides in the WIPP disposal inventory

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TABLE 3-36

RADTRAN INPUT DATA

Parameter	CH-TRU Waste	RH-TRU Waste
Configuration Data		
Transport Mode	Truck	Truck
Package Type	TRUPACT-II	72B Cask
Packages/Shipment	3[1]	1
Package Characteristic Dimension, m	7.39	3.6
Movement Data		
Shipment distance, km	(site/alternative-specific)	
Population density, people/km	(route/alternative-specific per Highway Routing Model)	
Shipment speed, km/hr		
- Urban population zone	24.16	24.16
- Suburban population zone	40.32	40.32
- Rural population zone	88.56	88.56
Stop time per kilometer, hr/km	0.011	0.011
Other normal input	(RADTRAN 4 default values)	
Normal Exposure Data		
Transport Index (TI), mrem/hr	(site/alternative-specific, see Table 3-37)	
Number of crew members	2	2
Effective distance from source to crew,[2]	10	19
Number of people per public vehicle	2	2
Number of people exposed while stopped	50	50
Exposure distance while stopped, m	20	20
Accident Exposure Data		
Number of accident severity categories[3]	8	8
Accident severity category frequency	(NUREG-0170 values)	
Radioactive contents/parameters	(see Table 3-38)	
Release fractions	(See Table 3-39)	
Other accident inputs	(RADTRAN 4 and default values)	
Accident rates,[4] accidents/km		
- Urban population zone	1.60×10^{-05}	1.60×10^{-05}
- Suburban population zone	3.00×10^{-06}	3.00×10^{-06}
- Rural population zone	1.37×10^{-07}	1.37×10^{-07}

[1]Treated in RADTRAN model as one effective package.
[2]Accounts for RADTRAN simplified exposure model.
[3]Based on NUREG-0170, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes" (NRC, 1977).
[4]Based on *Comparative Study of Waste Isolation Pilot Plant (WIPP) Transportation Alternatives* (DOE, 1994a).

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TABLE 3-37

CALCULATED TRU WASTE TRUCK SHIPMENT TI VALUES[1,2,3,4]

		CH-TRU					RH-TRU
Waste Origin Site	To Route Segment Destination	Baseline	Alternative No. 1 & 77	Alternative No. 6	Alternative No. 10	Alternative No. 94	Baseline
AMES	ANL-E	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	
	SRS		$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	
	WIPP	$1.0x10^{+00}$	$9.0x10^{-01}$	$8.7x10^{-01}$	$1.2x10^{+00}$	$5.1x10^{-01}$	
ANL-E	SRS		$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	
BATTELLE	ORNL						$3.8x10^{-01}$
	WIPP						$3.8x10^{-01}$
BETTIS	MOUND	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	
	ORNL						$3.2x10^{-01}$
	SRS		$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	
	WIPP	$1.0x10^{+00}$	$9.0x10^{-01}$	$8.7x10^{-01}$	$1.2x10^{+00}$	$5.1x10^{-01}$	$3.2x10^{-01}$
ETEC	INEL		$5.6x10^{+00}$	$5.6x10^{+00}$	$5.6x10^{+00}$	$5.6x10^{+00}$	
	NTS	$5.6x10^{+00}$	$5.6x10^{+00}$	$5.6x10^{+00}$	$5.6x10^{+00}$	$5.6x10^{+00}$	
	WIPP	$5.6x10^{+00}$	$1.3x10^{+01}$	$7.4x10^{+00}$	$1.4x10^{+01}$	$1.0x10^{+01}$	
HANFORD	WIPP	$9.3x10^{+00}$	$8.0x10^{+00}$	$7.5x10^{+00}$	$9.8x10^{+00}$	$5.9x10^{+00}$	$6.9x10^{+01}$
INEL	WIPP	$1.0x10^{+00}$	$9.0x10^{-01}$	$8.7x10^{-01}$	$1.2x10^{+00}$	$5.1x10^{-01}$	$2.4x10^{+00}$
KAPL	MOUND	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	
	ORNL						$7.1x10^{-01}$
	SRS		$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	
	WIPP	$1.0x10^{+00}$	$9.0x10^{-01}$	$8.7x10^{-01}$	$1.2x10^{+00}$	$5.1x10^{-01}$	$7.1x10^{-01}$
LANL	WIPP	$4.8x10^{-01}$	$6.8x10^{-01}$	$6.6x10^{-01}$	$1.0x10^{+00}$	$4.3x10^{-01}$	$1.3x10^{+00}$
LBL	HANFORD		$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	LLNL	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	

Refer to footnotes at end of table.

TABLE 3-37 (Continued)

CALCULATED TRU WASTE TRUCK SHIPMENT TI VALUES[1,2,3,4]

		CH-TRU					RH-TRU
Waste Origin Site	To Route Segment Destination	Baseline	Alternative No. 1 & 77	Alternative No. 6	Alternative No. 10	Alternative No. 94	Baseline
	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	
LLNL	HANFORD		$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	
MOUND	SRS		$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	
MU	ANL-E	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	SRS		$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	
NTS	INEL		$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	$1.0x10^{+00}$	
	WIPP	$1.0x10^{+00}$	$9.0x10^{-01}$	$8.7x10^{-01}$	$1.2x10^{+00}$	$5.1x10^{-01}$	
ORNL	SRS		$2.2x10^{+02}$	$2.2x10^{+02}$	$2.2x10^{+02}$	$2.2x10^{+02}$	
	WIPP	$2.2x10^{+02}$	$1.1x10^{+02}$	$1.3x10^{+02}$	$1.2x10^{+02}$	$6.9x10^{+01}$	$2.0x10^{+01}$
PA	ORNL	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	SRS		$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	
PANTEX	LANL	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	
RFETS	WIPP	$1.3x10^{-02}$	$9.3x10^{-03}$	$9.2x10^{-03}$	$1.8x10^{-02}$	$7.8x10^{-03}$	
SNL	LANL	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	$1.0x10^{-02}$	
	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	
SRS	WIPP	$1.0x10^{-02}$	$1.1x10^{-02}$	$1.0x10^{-02}$	$1.2x10^{-02}$	$7.7x10^{-03}$	$1.6x10^{+01}$

[1]Tabulated TI values have units of mrem/hr.
[2]Tablulated shipment TI values for route segments to treatment/storage considered under the decentralized and regional treatment configuration are the same as the baseline values.
[3]Tablulated shipment TI values for the WIPP route segments are for the treated waste forms considered under the respective engineered alternatives.
[4]Shipment TI values to WIPP under the centralized treatment configuration are the same as the baseline values for all engineered alternatives.

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TABLE 3-38

SELECTED RADIONUCLIDES FOR TRANSPORTATION ANALYSIS AND ASSOCIATED RADTRAN INPUTS

Radionuclide	Half-life (days)	Photon Energy (MeV)	Cloudshine Dose Factor (rem-m^3/Ci-sec)	Inhalation Dose Factor (rem CEDE/Ci)	Lung Type	1-yr Lung Dose for Inhalation (rem/Ci)	1-yr Marrow Dose for Inh (rem/Ci)
AC-227	$7.29\times10^{+03}$	2.31×10^{-04}	1.99×10^{-05}	$7.70\times10^{+09}$	3	$2.30\times10^{+09}$	$4.30\times10^{+08}$
AM-241	$1.58\times10^{+05}$	3.24×10^{-02}	3.01×10^{-03}	$5.90\times10^{+08}$	3	$1.20\times10^{+08}$	$1.70\times10^{+07}$
AM-243	$2.70\times10^{+06}$	5.59×10^{-02}	8.11×10^{-03}	$5.90\times10^{+08}$	3	$1.10\times10^{+08}$	$1.60\times10^{+07}$
BA-137m	Accounted for by RADTRAN with parent nuclide (CS-137)						
CE-144	$2.84\times10^{+02}$	5.25×10^{-02}	2.88×10^{-03}	$6.30\times10^{+05}$	1	$3.60\times10^{+06}$	$4.20\times10^{+03}$
CF-252	$9.64\times10^{+02}$	1.20×10^{-03}	1.19×10^{-05}	$2.40\times10^{+08}$	3	$8.60\times10^{+08}$	$2.30\times10^{+06}$
CM-243	$1.04\times10^{+04}$	1.34×10^{-01}	2.02×10^{-02}	$4.00\times10^{+08}$	3	$1.20\times10^{+08}$	$1.70\times10^{+07}$
CM-244	$6.62\times10^{+03}$	1.70×10^{-03}	1.33×10^{-05}	$3.10\times10^{+08}$	3	$1.20\times10^{+08}$	$1.70\times10^{+07}$
CM-245	$3.10\times10^{+06}$	9.55×10^{-02}	1.13×10^{-02}	$6.20\times10^{+08}$	3	$1.10\times10^{+08}$	$1.60\times10^{+07}$
CO-60	$1.93\times10^{+03}$	$2.50\times10^{+00}$	4.12×10^{-01}	$2.80\times10^{+05}$	2	$7.90\times10^{+05}$	$3.80\times10^{+04}$
CS-134	$7.53\times10^{+02}$	$1.55\times10^{+00}$	2.54×10^{-01}	$4.60\times10^{+04}$	2	$4.10\times10^{+04}$	$3.90\times10^{+04}$
CS-137	$1.10\times10^{+04}$	5.96×10^{-01}	$0.00\times10^{+00}$	$3.20\times10^{+04}$	2	$3.10\times10^{+04}$	$2.60\times10^{+04}$
EU-152	$4.87\times10^{+03}$	$1.14\times10^{+00}$	1.87×10^{-01}	$2.60\times10^{+05}$	2	$0.00\times10^{+00}$	$0.00\times10^{+00}$
EU-154	$3.21\times10^{+03}$	$1.22\times10^{+00}$	2.06×10^{-01}	$3.10\times10^{+05}$	2	$0.00\times10^{+00}$	$0.00\times10^{+00}$
EU-155	$1.81\times10^{+03}$	6.05×10^{-02}	9.10×10^{-03}	$4.80\times10^{+04}$	2	$0.00\times10^{+00}$	$0.00\times10^{+00}$
NB-95	$3.52\times10^{+01}$	7.66×10^{-01}	1.26×10^{-01}	$7.30\times10^{+03}$	1	$5.30\times10^{+04}$	$2.40\times10^{+03}$
NP-237	$7.82\times10^{+08}$	3.43×10^{-02}	3.64×10^{-03}	$5.60\times10^{+08}$	3	$1.00\times10^{+08}$	$1.50\times10^{+07}$
PR-144	Accounted for by RADTRAN with parent nuclide (CE-144)						
PU-238	$3.21\times10^{+04}$	1.81×10^{-03}	1.40×10^{-05}	$5.30\times10^{+08}$	3	$4.50\times10^{+08}$	$1.10\times10^{+06}$
PU-239	$8.79\times10^{+06}$	7.96×10^{-04}	1.30×10^{-05}	$5.70\times10^{+08}$	3	$4.20\times10^{+08}$	$1.10\times10^{+06}$
PU-240	$2.39\times10^{+06}$	1.73×10^{-03}	1.37×10^{-05}	$5.70\times10^{+08}$	3	$4.20\times10^{+08}$	$1.10\times10^{+06}$
PU-241	$5.26\times10^{+03}$	2.54×10^{-06}	0.00×10^{-00}	$9.90\times10^{+06}$	3	$3.60\times10^{+05}$	$1.30\times10^{+03}$
PU-242	$1.37\times10^{+08}$	1.44×10^{-03}	1.16×10^{-05}	$5.30\times10^{+08}$	3	$4.00\times10^{+08}$	$1.00\times10^{+06}$
RH-106	3.46×10^{-04}	2.01×10^{-01}	3.33×10^{-02}	$2.20\times10^{+00}$	1	$4.30\times10^{+06}$	$4.00\times10^{+04}$
SB-125	$1.01\times10^{+03}$	4.30×10^{-01}	6.75×10^{-02}	$1.70\times10^{+04}$	2	$4.40\times10^{+04}$	$5.50\times10^{+02}$

1

TABLE 3-38 (Continued)

SELECTED RADIONUCLIDES FOR TRANSPORTATION ANALYSIS AND ASSOCIATED RADTRAN INPUTS

Radionuclide	Half-life (days)	Photon Energy (MeV)	Cloudshine Dose Factor (rem-m^3/Ci-sec)	Inhalation Dose Factor (rem CEDE/Ci)	Lung Type	1-yr Lung Dose for Inhalation (rem/Ci)	1-yr Marrow Dose for Inh (rem/Ci)
SR-90	$1.06x10^{+04}$	$0.00x10^{+00}$	$0.00x10^{+00}$	$2.40x10^{+06}$	2	$4.50x10^{+06}$	$3.80x10^{+03}$
TE-125m	$5.80x10^{+01}$	$3.55x10^{-02}$	$1.53x10^{-03}$	$1.00x10^{+04}$	1	$0.00x10^{+00}$	$0.00x10^{+00}$
TH-228	$6.98x10^{+02}$	$3.03x10^{-03}$	$3.14x10^{-04}$	$5.80x10^{+08}$	3	$2.20x10^{+09}$	$1.20x10^{+08}$
TH-229	$2.68x10^{+06}$	$9.54x10^{-02}$	$1.37x10^{-02}$	$2.90x10^{+09}$	3	$2.40x10^{+09}$	$1.40x10^{+08}$
TH-231	$1.06x10^{+00}$	$2.55x10^{-02}$	$1.85x10^{-03}$	$1.00x10^{+03}$	1	$5.10x10^{+03}$	$6.70x10^{+01}$
TL-208	$2.13x10^{-03}$	$3.36x10^{+00}$	$6.28x10^{-01}$	$8.00x10^{+00}$	1	$5.70x10^{+01}$	$1.10x10^{+00}$
U-232	$2.63x10^{+04}$	$2.19x10^{-03}$	$4.22x10^{-05}$	$1.10x10^{+09}$	3	$8.30x10^{+08}$	$5.20x10^{+05}$
U-233	$5.79x10^{+07}$	$1.31x10^{-03}$	$3.80x10^{-05}$	$2.40x10^{+08}$	3	$4.00x10^{+08}$	$6.10x10^{+03}$
U-234	$8.90x10^{+07}$	$1.73x10^{-03}$	$2.43x10^{-05}$	$2.30x10^{+08}$	3	$3.90x10^{+08}$	$3.10x10^{+05}$
U-238	$1.63x10^{+12}$	$1.36x10^{-03}$	$1.65x10^{-05}$	$2.20x10^{-08}$	3	$3.50x10^{+08}$	$6.30x10^{+03}$
Y-90	$2.67x10^{+00}$	$1.69x10^{-06}$	$0.00x10^{+00}$	$9.90x10^{+03}$	1	$5.90x10^{+04}$	$7.40x10^{+02}$

for CH-TRU and RH-TRU waste. Radionuclides were ranked as to their potential significance in determining the Transportation Risk Factor using a relative hazard value. The relative hazard value for each radionuclide was calculated by multiplying the anticipated inventory activity fraction of each radionuclide by a dose factor index and a photon energy index and summing the products. The dose factor index for each radionuclide was determined by summing its ingestion and inhalation dose factors (rem/Ci) and dividing by the Pu-239 dose factor sum. Similarly, the photon energy index for each radionuclide was determined by dividing its average photon energy by the maximum photon energy of the radionuclides in the inventory. In this manner, a relative measure of internal and external exposure hazards for each radionuclide could be assessed. Those radionuclides having relative hazard values within four orders of magnitude of the highest value were selected for analysis.

To predict potential radiological impacts from accidents, this analysis uses an accident severity classification scheme and associated probabilities of occurrence derived from NUREG-0170 (NRC, 1977) and the WIPP FSEIS (DOE, 1990b). Accident severity categories define the seriousness of an accident in terms of mechanical and thermal (fire) loads and influence the potential amount of radioactive material released during an accident. Most accidents are unlikely to cause any release, but very severe accidents (much more severe than represented by NRC certification standards for Type B containers) may cause some of the radioactive material to escape. NUREG-0170 defined eight accident severity categories. The first two accident categories were defined to be less serious than the hypothetical accident conditions specified in 10 CFR Part 71 for testing Type B packaging and were retained in this analysis. Thus, use of the TRUPACT-II container and RH-72B cask would be very unlikely to result in any releases to the environment for severity category I or II accidents. NUREG-0170 defined the remaining six categories to postulate increasingly severe, but less likely, accidents resulting in a release of radioactive materials from Type B packages.

A key parameter for analyzing postulated accidents is the estimated release fraction of radioactive material escaping to the environment. Particulates can result from impacts that fracture or suspend the radioactive material or from fires that can entrain impact-generated particulates, cause off-gassing of volatile fission products, or thermally degrade and then entrain particulates from previously intact material. Inhalation is a primary internal exposure pathway for people that results from breathing respirable (<10 microns), aerosolized particulates. As the particulates move downwind, some settle out onto the ground where they can expose people to penetrating radiation. This constitutes the "groundshine" exposure pathway. After settling, some fraction of the particles can also be resuspended into the air due to wind or other surface disturbances. These particulates can then be inhaled by people as were those in the initial plume and constitute the source term for the resuspension dose pathway. Finally, particles in the air can also expose people to penetrating radiation; this constitutes the "cloudshine" exposure pathway. For this analysis, the ingestion pathway (through which particles settle on crops and are subsequently consumed by the public) was not assessed. Reasons for not incorporating the ingestion pathway were that (1) any accident resulting in contamination of crops would result in interdiction of those crops prior to any significant consumption by the public, (2) based on dose conversion factors for the radionuclides of interest, inhalation exposures result in doses typically one to two orders of magnitude greater than those from ingestion for equal uptakes of radioactive material, and (3) the RADTRAN model has not formally adopted radionuclide ingestion parameters (i.e., soil or food transfer factors).

This analysis uses the release fractions developed in Appendix D of the WIPP FSEIS (DOE,

1990b) for postulated accidents involving baseline CH-TRU and RH-TRU waste shipments. The release fraction analysis determined how much radioactive material could be potentially released to the environment in a respirable, airborne form for accident severity categories III through VIII. Larger particle sizes (greater than 10 microns) were not analyzed, as they tend to be eliminated by the body and consequently are not as significant in estimating health effects.

Calculation of respirable release fractions for engineered alternatives No. 1 and No. 77 (supercompacted waste) followed the WIPP FSEIS methodology. The fraction of material released from failed containers was reduced by one third for severity categories III through VII, reflecting greater crush resistance of the drums (less void space) and that there will typically be four supercompacted pucks in each drum. Additionally, the fraction of material aerosolized from impact was reduced by an order of magnitude to reflect reduced aerosolization of the supercompacted waste form by impact forces. Similarly, the fraction of material entrained to the environment was reduced by an order of magnitude to represent the supercompacted waste form. Finally, the fraction of material aerosolized by the postulated thermal event was also reduced by an order of magnitude to account for the reduced surface area of the supercompacted waste form.

Calculation of respirable release fractions for engineered alternative No. 6 (compacted/shredded waste) also followed the WIPP FSEIS methodology. The fraction of material released from failed containers was reduced by one third (assumed same as supercompacted waste) for the lower accident severity categories (III, IV, and V). This accounts for the increased crush resistance of the drums due to compaction but recognizes that it is not as great as with supercompaction. The fraction of material aerosolized by the thermal event was increased by an order of magnitude to reflect the increased surface area of the shredded material. It was assumed that engineered alternative No. 94 waste forms would have similar release fractions because they have essentially the same treated waste matrices, except that clay is added to enhance repository performance.

Calculation of release fractions for engineered alternative No. 10 waste forms required the use of alternative analysis methodologies. The products of plasma processing are vitrified glasses and solid metals and are anticipated to be able to withstand severe temperatures. Respirable impact releases were determined using impact test data for vitrified materials (Pacific Northwest Laboratories, 1975). The amount of material fractured at an impact velocity of 66 feet per second ranged from 0.013 to 0.15 percent. The upper value of this range was used as the amount of material released for accident severity category VIII. RADTRAN default values for an immobile material for the aerosol fraction and the respirable fraction were applied to the estimated material released to quantify the respirable impact release. This value was conservatively applied to accident severity categories III through VIII. Under thermal accident conditions, vitrified materials are anticipated to behave like refractory brick. The primary release mechanism is expected to be the aerosolization of material from contaminated surfaces. Any such releases are anticipated to occur only at the more severe accident categories involving a prolonged fire (category IV through VIII). The Nuclear Fuel Cycle Facility Accident Analysis Handbook (Ayer et al., 1988) recommends a thermal suspension factor of 2.5×10^{-5}/s. This analysis assumed that there is an effective thermal suspension duration of one hour and that 10 percent of the material fractured is available for release under severity category VIII accident conditions. Additionally, a decontamination factor of 5×10^{-2} was used for releases from the package cavity to the environment. This is consistent with values used in Transportation—Accident Scenarios for Commercial Spent Fuel (Wilmot, 1981) and takes credit for mitigation processes reducing radioactive material releases such as particulate settlement, plateout, and filtration effects along

the leak path. The resulting respirable thermal release fraction was conservatively applied to accident severity categories IV through VIII. The total respirable release fraction was determined by summing the impact and thermal release components.

Table 3-39 summarizes the resulting radioactive material release fractions for postulated accidents for the baseline and engineered alternatives evaluated in this study. Radiological exposures to internal and external doses of radiation are reported in units of rem (individual dose) or person-rem (collective dose to a group of individuals). The average annual dose of ionizing radiation to a member of the U.S. population is estimated to be 0.36 rem (National Council on Radiation Protection and Measurements, 1987). This includes both natural sources (e.g., radon) and artificial sources (e.g., diagnostic x-rays). Principal adverse effects from human exposure to low-level ionizing radiation are carcinogenicity (ability to cause cancer), mutagenicity (ability to cause inheritable defects), and teratogenicity (ability to cause noninheritable birth defects). For low-level exposures, the most significant risk is that of latent (delayed) cancers. The summation of radiation doses (collective dose) to a group of individuals may be multiplied by a dose-to-risk conversion factor to estimate the number of incremental latent cancer fatalities (LCFs) associated with the postulated exposure. Use of a dose-to-risk conversion factor of 500 LCFs per million person-rem (5.0×10^{-4} LCFs/person-rem) for the general population and of 400 latent cancer fatalities per million person-rem (4.0×10^{-4} LCFs/person-rem) for workers are currently accepted values (NRC, 1991). This difference in dose-to-risk conversion factors for the two population groups is attributable to the presence of children in the general population.

3.5.2.1.3 Hazardous Chemical Exposures

The hazardous chemical analysis is based on the methodology presented in the Transportation Alternatives report (DOE, 1994a). As the scope of the current chapter and above-mentioned report is limited to the analysis of transportation impacts from the gate of the shipment origin site to the gate of the treatment or disposal site, no handling of waste containers is considered. Additionally, the hazardous chemical constituents of the waste are completely contained within the shipment package (i.e., TRUPACT-II or RH-72B cask). Because of the integrity and leak tightness of these Type B packages, it can be concluded that the shipment of hazardous chemical waste constituents presents an insignificant hazard to workers and the public under incident-free transportation conditions.

While it is very unlikely that an accident will breach a Type B package, such an accident is credible and constitutes a potential chemical exposure source to the public. Comparison of resulting airborne chemical concentrations to an accepted level of protection is used as the basis for determining the chemical component of the Transportation Risk Factor. Because predicted airborne chemical concentrations are determined by the waste form (i.e., untreated, supercompacted, vitrified) and associated release mechanisms, the chemical component of the Transportation Risk Factor is affected by the engineered alternative considered and not by the decentralized, regionalized, or centralized configurations to be evaluated. Thus, each engineered alternative considered will have one chemical risk factor, which will be the same for all configurations.

The chemical assessment was performed based on a very severe shipment accident. Maximum impacts were evaluated by assuming a severity VIII category accident and associated releases. The risk factor was evaluated by comparing maximum airborne chemical concentrations for a member of the public with concentrations based on Emergency Response Planning Guideline 2

1

TABLE 3-39

TRU WASTE TRUCK SHIPMENT RELEASE FRACTIONS FOR POSTULATED ACCIDENTS[1]

	Accident Severity Category							
Scenario	I	II	III	IV	V	VI	VII	VIII
Baseline[2]								
CH-TRU Waste	$0x10^{-00}$	$0x10^{-00}$	$8x10^{-09}$	$2x10^{-07}$	$8x10^{-05}$	$2x10^{-04}$	$2x10^{-04}$	$2x10^{-04}$
RH-TRU Waste	$0x10^{-00}$	$0x10^{-00}$	$6x10^{-09}$	$2x10^{-07}$	$1x10^{-04}$	$1x10^{-04}$	$2x10^{-04}$	$2x10^{-04}$
CH-TRU Waste Engineered Alternatives[3]								
Alternative No. 1 & 77	$0x10^{-00}$	$0x10^{-00}$	$8x10^{-09}$	$2x10^{-08}$	$2x10^{-06}$	$5x10^{-06}$	$7x10^{-06}$	$2x10^{-05}$
Alternative No. 6	$0x10^{-00}$	$0x10^{-00}$	$1x10^{-08}$	$2x10^{-06}$	$3x10^{-05}$	$2x10^{-04}$	$2x10^{-04}$	$2x10^{-04}$
Alternative No. 10	$0x10^{-00}$	$0x10^{-00}$	$8x10^{-11}$	$7x10^{-08}$	$7x10^{-08}$	$7x10^{-08}$	$7x10^{-08}$	$7x10^{-08}$
Alternative No. 94	$0x10^{-00}$	$0x10^{-00}$	$1x10^{-08}$	$2x10^{-06}$	$3x10^{-05}$	$2x10^{-04}$	$2x10^{-04}$	$2x10^{-04}$

[1]Tabulated release fractions are for the final waste form.
[2]Baseline release fractions based on the WIPP FSEIS (Appendix D, TABLES D.3.21 and D.3.22) (DOE, 1990b).
[3]See Section 3.5.2.1.2 text for basis of engineered alternative release fractions.

(ERPG-2). An ERPG-2 is defined as the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action (AIHA, 1989). This is an appropriate exposure level for the public and is consistent with the recommendations in the DOT 1990 Emergency Response Guidebook (DOT, 1990).

ERPG-2 values are developed based on an anticipated one-hour exposure. To address a postulated two-hour exposure, the ERPG-2 value was halved to provide an adjusted ERPG-2 value. This is a more stringent exposure level for comparing two-hour release concentration values with calculated chemical airborne concentrations. This comparison was accomplished by dividing the maximum calculated receptor concentrations for each chemical by the adjusted ERPG-2 value. Ratios smaller than unity indicate that exposures fall within health-based reference levels. Additionally, the individual chemical ratios were summed and compared to unity. This provides an indication of potential cumulative effects for exposure to multiple chemicals even though it does not take into consideration possible synergistic effects among the chemicals.

Based on the relative shipment capacity of the TRUPACT-II (308.7 cubic feet per drum shipment and 389.1 cubic feet (11.02 cubic meters) per SWB shipment) versus the relative shipment capacity of the RH-72B (31.4 cubic feet [0.89 cubic meters]) and the chemical characterization data presented in the Interim Mixed Waste Inventory Report (DOE, 1993a), it is concluded that hazardous constituent accident analyses for CH-TRU waste baseline shipments are bounding for RH-TRU waste baseline shipments.

An initial screening analysis was performed to identify potential chemicals for analysis under accident conditions. Table C-1 of the WIPP RCRA Part B Permit Application (DOE, 1993b) and the TRUPACT-II List of Chemical Compounds in Each Content Code in TRUCON (DOE, 1994g) were reviewed to identify chemicals found in CH-TRU waste streams for INEL, Hanford Site, RFETS, and Savannah River Site. Waste streams from these sites are currently projected to constitute 82 percent of the CH-TRU waste to be emplaced at the WIPP. Chemicals were retained as candidates for analysis if an airborne concentration limit could be found for the chemical of interest. Concentration limits considered included:

- The EPA list of acutely hazardous substances having levels of concern (LOCs)
- Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) values
- American Industrial Hygiene Association Emergency Response Planning Guideline (ERPG) values
- American Conference of Governmental Industrial Hygienists Threshold Limit Values (TLVs)

Following the initial screening analysis, chemicals were further ranked as to their potential health significance using a relative hazard value. The relative hazard value for each chemical was determined by dividing the hazard value for a given chemical by the maximum hazard value for all the chemicals in the respective table. The hazard value was calculated as the fraction (concentration) of the chemical in the waste matrix divided by the airborne concentration limit of

the subject chemical. Thus, the higher a chemical concentration in a waste matrix or the lower its airborne concentration limit, the greater its potential hazard. All substances having a relative hazard value within 1 percent of the maximum relative risk value were retained for final analysis. The 20 chemicals that fell within 1 percent of the maximum hazard value and that were selected for further analysis are presented in Table 3-40.

Chemical concentrations in the waste matrix were estimated using Table C-1 of the WIPP RCRA Part B Permit Application (DOE, 1993b) and the TRUPACT-II list of chemical compounds in each content code in TRUCON (DOE, 1994g). These documents provide concentration values for chemicals in the various waste matrices. Chemicals were typically reported as either dominant (>10 weight percent), minor (1-10 weight percent), trace (<1 weight percent), trace 1 (< 0.1 weight percent), trace 2 (low parts per million [ppm] range), or trace 3 (<1 ppm by weight). The following concentration values were assigned for each category (fraction by weight):

Dominant	(D)	–	0.3
Minor	(M)	–	0.10
Trace	(T)	–	0.01
Trace 1	(T1)	–	0.001
Trace 2	(T2)	–	0.0001
Trace 3	(T3)	–	no chemicals passing the initial screening were in this category.

The analysis used the highest reported nominal concentration for a given chemical, with the exception of cadmium, due to the variability of its concentration in the waste forms considered (maximum reported value is "D," value utilized is "M").

Airborne chemical concentrations for the maximally exposed member of the public were determined using the Gaussian Dispersion Plume equation of Pasquill as modified by Gifford (1961) for ground-level concentrations at the centerline of the plume:

$$\chi = [Q/(\pi\ \sigma_y \sigma_z\ \mu)]\ \exp\ [-.5\ (H/\sigma_z)^2], \qquad 3.8$$

where

χ = contaminant airborne concentration at x meters downwind, mg/m^3
Q = contaminant release rate, mg/s
μ = mean wind speed, m/s
σ_y = horizontal dispersion coefficient, m
σ_z = vertical dispersion coefficient, m
H = effective release height, m.

The above equation does not incorporate plume depletion effects from particulate settlement (by gravitational or chemical effects) and thus will overstate air concentrations and resulting inhalation exposures. Additionally, each accident was postulated to occur during a period having very stable atmospheric meteorological conditions (Pasquill Stability Class F, wind speed of 1 m/s). Use of these unfavorable meteorological conditions introduces additional conservatism into the analysis.

The following short-term dispersion coefficients (Slade, 1968) were incorporated in the Gaussian Plume Dispersion equation:

1

TABLE 3-40

SELECTION OF CHEMICAL CONSTITUENTS IN CH-TRU WASTE FOR FURTHER ANALYSIS

Chemical Name	CAS Number	Quantity Code[1]	Fraction in Waste Matrix[2]	ERPG-2 (ppm)	ERPG-2 Source[3]	Hazard Value	Relative Hazard Value
Beryllium	7740-41-7	T	0.01	0.01	c	$1.00x10^{+00}$	$2.33x10^{-01}$
Bromine	7726-95-6	T	0.01	1.00	c	$1.00x10^{-02}$	$3.33x10^{-02}$
Cadmium (fume)	7440-43-9	D	0.3	0.07	b	$4.29x10^{+00}$	$9.99x10^{-01}$
Carbon tetrachloride	56-23-5	D	0.3	25.00	b	$1.20x10^{-02}$	$4.00x10^{-02}$
Cellulose	9004-34-6	D	0.3	25.00	a	$1.2x10^{-02}$	$4.00x10^{-02}$
Chloroform	67-66-3	D	0.3	100.00	d	$3.00x10^{-03}$	$1.00x10^{-02}$
Chlorosulfonic acid	7790-94-5	T	0.01	2.10	c	$4.76x10^{-03}$	$1.59x10^{-02}$
Chromium VI compounds,as Cr		T	0.01	0.10	a	$1.00x10^{-01}$	$2.33x10^{-02}$
Copper (fume)	7440-50-8	M	0.1	0.40	a	$2.50x10^{-01}$	$5.83x10^{-02}$
Hydrazine	302-01-2	T	0.01	0.80	c	$1.25x10^{-02}$	$4.17x10^{-02}$
Lead	7439-92-1	D	0.3	0.09	a	$3.33x10^{+00}$	$7.77x10^{-01}$
Mercury (inorganic)	7439-97-6	T	0.01	0.01	b	$1.00x10^{+00}$	$2.33x10^{-01}$
Oxalic acid	144-62-7	T	0.01	1.50	a	$6.67x10^{-03}$	$2.22x10^{-02}$
Platinum	7440-06-4	M	0.1	0.50	a	$2.00x10^{-01}$	$4.66x10^{-02}$
Phosphoric acid	7664-38-2	T	0.01	1.50	a	$6.67x10^{-03}$	$2.22x10^{-02}$
Silver	7440-22-4	T	0.01	0.10	a	$1.00x10^{-01}$	$2.33x10^{-02}$
Sodium hydroxide	1310-73-2	T	0.01	1.20	b	$8.33x10^{-03}$	$2.78x10^{-02}$
Tributyl phosphate	126-73-8	D	0.3	1.00	a	$3.00x10^{-01}$	$1.00x10^{+00}$
Tungsten (sol. Compounds as W)	7440-33-7	M	0.1	0.50	a	$2.00x10^{-01}$	$4.66x10^{-02}$
Uranium	7440-61-1	T	0.01	0.10	a	$1.00x10^{-01}$	$2.33x10^{-02}$

[1]D = Dominant; M = Minor; T = Trace
[2]Chemical concentrations in the waste matrix are conservatively estimated based on the assigned quantity codes for use in the risk analysis and are not representative of average TRU waste characteristics.
[3]a. TLV-TWA X5; b. PEL-C; c. ERPG-2; d. LOC

$\sigma_y = 0.02\ (x)^{.89}$
$\sigma_z = 0.05\ (x)^{.61}$
x = downwind distance, m

The effective height (H) of the accident plume was estimated as approximately 69 feet (21 meters). This takes into consideration the buoyancy rise associated with the thermal effects from the accident. Thermal effects (e.g., hydrocarbon fuel fire) are expected to play a major role in any loss-of-containment scenario. The buoyancy rise was determined using a heat emission of $8.3 \times 10^{+4}$ watts/m^2, based on hydrocarbon fuel fire tests (Gregory et al., 1987).

The resulting maximum receptor concentration for a member of the public was calculated as:

$$\text{Receptor concentration (maximum individual)} = \chi/Q\ \text{(maximum individual)} \times \text{Release Rate (mg/s)} \qquad 3.9$$

where:	χ/Q (maximum individual)	=	1.13×10^{-04} s/m^3
	Release Rate	=	Release Quantity (mg)/7200 (s) (assumes a two-hour release)
	Release Quantity	=	Release fraction x fraction of waste chemical is present x chemical fraction in waste x weight of waste/shipment.

Thus, receptor chemical concentrations for postulated accidents will vary by engineered alternative as determined by how the final waste form affects the release fraction, the chemical fraction in the waste, and the density of the waste matrix.

Quantities of hazardous constituents released during the maximum accident were determined using the following bases:

- A severity category VIII accident occurs, resulting in a breach of all three TRUPACT-II packages, and involves both impact and thermal release mechanisms.
- The CH-TRU waste matrix form and density vary by engineered alternative.
- Chemicals released as respirable particulate matter will have a release fraction as determined for the radiological analysis.
- Chemicals released as vapors will have a release fraction dependent on their vapor pressure at the elevated temperature conditions of the TRUPACT-II under accident conditions.
- The fraction of a TRU waste shipment containing the hazardous chemicals of interest was determined on a systemwide-average basis.

- The Interim Mixed Waste Inventory Report (DOE, 1993a) (Chapter 4.0, Table 4-1, and site waste profile sheets) was used to estimate the fraction of CH-TRU waste volume (or shipment) for which each hazardous constituent of interest is present.

3.5.2.1.4 Nonradiological/Non-chemical Risks

The methodology presented in the WIPP FSEIS (DOE, 1990b) was used to estimate the range of non-radiological and non-chemical risks, which involve traumatic injuries and fatalities that are independent of the characteristics of the cargo (Table 3-41).

The HIGHWAY model (Johnson et al., 1993) was used to determine truck travel mileages and travel distance in rural, suburban, and urban population zones. The model incorporates updated 1990 census data.

Estimates of per-shipment risk include accident-related injuries and fatalities of a single TRU waste shipment (round trip) to the WIPP. Cumulative risk estimates were determined by multiplying per-shipment risks by the total number of shipments.

3.5.3 Assumptions and Data Used

3.5.3.1 Number of Waste Shipments

Number of waste shipments is dependent on a site-by-site volume. The analysis in this chapter assumes that a total volume of 6.2 million cubic feet (0.17 million cubic meters) of TRU waste will be emplaced at WIPP. This total includes 5.95 million cubic feet (0.16 million cubic meters) of CH-TRU waste and 250,000 cubic feet (7078.3 cubic meters) of RH-TRU waste. Tables R-20 and R-21 in Appendix R ("Waste Volumes and Inventories") present the CH-TRU and RH-TRU waste volumes for each site. The volumes have been scaled up to reach repository emplacement limits.

The following assumptions were used to estimate the site-by-site shipment volume for TRU waste (Wagner, March 1995):

CH-TRU waste
- 7.35 cubic feet (0.208 cubic meters) per drum
- 64.85 cubic feet (1.836 cubic meters) per SWB
- 14 drums per TRUPACT-II
- 2 SWBs per TRUPACT-II
- 3 TRUPACT-IIs per shipment
- 308.7 cubic feet (8.74 cubic meters) per drum shipment
- 389.1 cubic feet (11.02 cubic meters) per SWB shipment

RH-TRU waste
- 31.4 cubic feet (0.89 cubic meters) per RH-72B cask
- one RH-72B cask per shipment
- 31.4 cubic feet (0.89 cubic meters) per shipment

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TABLE 3-41

NONRADIOLOGICAL AND NONCHEMICAL UNIT RISK FACTORS

Mode	Zone	Injuries/Mile	Fatalities/Mile
Truck	Rural	1.33×10^{-06}	1.09×10^{-07}
	Suburban	6.32×10^{-07}	2.69×10^{-08}
	Urban	6.16×10^{-07}	1.54×10^{-08}

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3.5.3.2 Waste Characteristics

Baseline waste characteristics were primarily established using two information resources: (1) the Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report (DOE, 1995e) and (2) the Comparative Study of Waste Isolation Pilot Plant (WIPP) Transportation Alternatives (DOE, 1994a), which was prepared to meet requirements of the LWA. In subsequent discussions, these reports are referred to as the BIR and the Transportation Alternatives report, respectively. The BIR was used to establish waste forms and densities and their corresponding radionuclide content and distribution. Average sitewide information was incorporated into the analysis. The Transportation Alternatives report was used to quantify hazardous chemical concentrations in the TRU waste matrices. The information presented in the Transportation Alternatives report was derived from (1) the U.S. Department of Energy Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capabilities and Technologies (DOE, 1993a); (2) Table C-1 of the Waste Isolation Pilot Plant Resource Conservation and Recovery Act (RCRA) Part B Permit Application (DOE, 1993b); and (3) the Waste Isolation Pilot Plant, TRUPACT-II List of Chemical Compounds in Each Content Code in TRUCON (DOE, 1994g).

Final waste forms and associated characteristics for the engineered alternatives were determined using the program information presented in Section 2.3 and supporting appendices. As with the baseline analysis, waste form characteristics were evaluated on an average sitewide basis.

As previously discussed in Section 3.5.2.1.2, a screening analysis was performed to identify the radionuclides of primary concern for the transportation risk assessment. The disposal radionuclide inventory presented in Chapter 4.0 of the BIR identifies approximately 139 radionuclides in the CH-TRU and RH-TRU waste. These radionuclides result from the varied waste operations throughout the DOE complex and the ingrowth of daughter products during the radioactive decay process. Based on the screening analysis, a manageable and representative evaluation was possible with the inclusion of 36 of the radionuclides.

3.5.4 Results of the Analysis of the Transportation Risk Factors

3.5.4.1 Radiological Exposures

Appendix L, "Transportation Risk," provides tables of data that are the outcome of the analysis of transportation risk factors. The following subsections discuss key aspects of these data as they apply to risks of radiological and hazardous chemical exposures and to nonradiological/ nonchemical risks.

3.5.4.1.1 Baseline

The detailed results of the radiological Transportation Risk Factor analysis for baseline CH-TRU and RH-TRU waste shipments are presented in Tables L-1 through L-4 in Appendix L. Risk factor values are provided on a per-shipment basis and for cumulative/lifetime shipments for each applicable route segment. As discussed in the methodology section, incident-free risk factor doses are determined for the truck crew, the public, and the maximum member of the public residing or working along the transportation route corridor. The accident risk dose factor provides a probabilistic measure of doses to the public resulting from a spectrum of postulated accidents ranging from minor incidents (no radiological material released) to very severe accidents (incident exceeds Type B packaging test conditions).

Major CH-TRU sites (Hanford, INEL, LANL, RFETS, and SRS) involve almost 98 percent of all CH-TRU waste shipments and account for a comparable percentage of total radiological doses (incident-free and accident risks) to the public. Similarly, major RH-TRU sites (Hanford and ORNL) comprise 90 percent of all RH-TRU waste shipments and account for almost 99 percent of incident-free public doses and 96 percent of accident risk doses to the public for RH-TRU waste shipments. It is noted that while the number of RH-TRU waste shipments equals approximately 45 percent of the number of CH-TRU waste shipments, total RH-TRU incident-free public doses are projected to equal almost 83 percent of the total CH-TRU value. Also, calculated maximum individual doses are anticipated to be greater for RH-TRU waste shipments. This results from the higher TI values for RH-TRU waste shipments. The hypothetical maximum individual exposed to every TRU waste shipment is predicted to receive a cumulative dose of 1.7×10^{-2} rem over the lifetime of WIPP operations.

It is observed that Hanford RH-TRU waste constitutes the large majority of RH-TRU shipment radiological risks. Additionally, this site was estimated to have a shipment TI value (69 mrem/hr; Table 3-37) exceeding regulatory limits for exclusive-use vehicles. RADTRAN dose calculations were performed using regulatory limit values; however, the analysis suggests that proper load management, additional waste shielding, or reduced payload capacity options may need to be addressed.

3.5.4.1.2 Engineered Alternatives Nos. 1 and 77

As discussed in Section 3.5.2, engineered alternatives No. 1 and No. 77 have similar final waste forms and, as such, have similar Transportation Risk Factors. Both incident-free risk factor doses and accident risk doses were determined. Predicted values are summarized in Appendix L Tables L-5 through L-10 for the decentralized, regionalized, and centralized configurations. Per-shipment and cumulative WIPP lifetime risk factors are tabulated for each configuration.

As with the baseline analysis, major CH-TRU sites comprise the large majority of waste shipments and account for a comparable percentage of total radiological risks. Population risks (i.e., crew, public) are greatest for the centralized configuration and lowest for the decentralized configuration; however, all configuration values are within 16 percent of each other. Maximum hypothetical individual doses are highest for the regionalized configuration and lowest for the decentralized configuration. This is largely due to the increased number of shipments associated with the regionalized configuration (approximately 355 more shipments than the decentralized configuration). With this difference, maximum hypothetical individual doses vary by 38 percent.

Comparing baseline with engineered alternative No. 1 and No. 77 radiological risk factors, it can be concluded that:

- There are no significant differences in the extent of radiological risks.
- The decentralized and regionalized configurations for the engineered alternatives result in nominal reductions in population radiological risks.
- The centralized configuration for the engineered alternatives has essentially the same level of risk as the baseline, as expected, because shipment waste forms and movements are comparable.

3.5.4.1.3 Engineered Alternative No. 6

Predicted radiological Transportation Risk Factors for engineered alternative No. 6 are presented in Appendix L Tables L-11 through L-14 for the decentralized and regionalized configurations. Risk factors are provided on a per-shipment and cumulative WIPP lifetime basis for each configuration. As with the foregoing analyses, both incident-free doses and accident risk doses are tabulated. Radiological risk factors for the centralized configuration are identical to those presented in Table L-9 (per shipment) and Table L-10 (cumulative WIPP lifetime). In fact, all engineered alternatives will have the same radiological risk factors for the centralized configuration because all have identical shipment waste forms and movements.

As with the other engineered alternatives, major CH-TRU waste shipment sites account for the large majority of radiological risks. All three configurations for the engineered alternative result in comparable levels of risk. Incident-free population doses are projected to be the highest for the centralized configuration and comparable for the decentralized and regionalized configurations. Maximum hypothetical individual doses are highest for the regionalized configuration and lowest for the decentralized configuration. This will tend to be true for all engineered alternatives due to the previously noted increase in the number of shipments associated with the regionalized configuration. Accident risk doses for the centralized configuration are predicted to be nominally higher (approximately 5 percent) than the decentralized and regionalized configurations.

Comparison of engineered alternative No. 6 radiological risk factors with those for the baseline results in conclusions similar to those derived for alternative No. 1 and No. 77; namely, there are no significant differences in the extent of radiological risks.

3.5.4.1.4 Engineered Alternative No. 10

The results of the radiological Transportation Risk Factor analysis for engineered alternative No. 10 are summarized in Appendix L Tables L-15 through L-18. Risk factor values for the decentralized and regionalized configurations are tabulated. As discussed in Section 3.5.4.1.3, all engineered alternatives will have identical radiological risk factors for the centralized configuration as listed in Tables L-9 and L-10.

All three configurations for the engineered alternative result in comparable incident-free population doses to the crew members and the public. All values are within approximately 7 percent of each other. As previously observed, the regionalized configuration results in the highest dose for the hypothetical maximum individual and is approximately 32 percent higher than the decentralized value (lowest maximum individual dose). The accident risk doses for the decentralized and regionalized configurations are over an order of magnitude lower than the centralized configuration value. These reduced accident risks result from the reduced release fraction estimates for the engineered alternative vitrified waste form.

There are no significant differences between engineered alternative No. 10 and the baseline for incident-free doses. However, the subject alternative does provide significantly reduced accident risk doses (by over an order of magnitude) due to the reduced released fractions associated with the immobilized waste form for postulated accidents.

3.5.4.1.5 Engineered Alternative No. 94

Appendix L Tables L-19 through L-22 present calculated radiological risk factors for engineered alternative No. 94. Risk factors are provided on a per-shipment and cumulative WIPP lifetime basis for the decentralized and regionalized configurations. Centralized configuration risk factors are summarized in Tables L-9 and L-10.

Radiological Transportation Risk Factors are comparable for all three configurations. The treated waste form for this alternative is similar to that for engineered alternative No. 6, with the exception that clay is added to the shredded waste matrix. This has the effect of reducing the average radionuclide density and increasing the mass density of the treated waste matrix. Both effects tend to reduce the shipment TI value for the treated waste form. Consequently, incident-free doses for engineered alternative No. 94 are approximately 32 percent less than those for engineered alternative No. 6.

Radiological risk factors for the three configurations are comparable with those for the baseline, although it can be concluded that the decentralized and regionalized configurations provide risk reductions ranging from 28 percent to 46 percent, depending on the specific risk parameter considered (i.e., crew, public, or maximum individual doses or accident risks).

3.5.4.2 Hazardous Chemical Exposures

3.5.4.2.1 Baseline

The results of the baseline chemical exposure analysis are presented in Table L-23 of Appendix L. As described in Section 3.5.2.1.3, the analysis postulates that a very severe accident occurs and compares the predicted receptor (maximum member of the public) airborne concentrations with adjusted ERPG-2 values. This was done by dividing the calculated receptor concentration by the adjusted ERPG-2 value for each hazardous chemical. Ratios smaller than one indicate that exposures fall within health-based reference levels.

Table L-23 of Appendix L shows that all individual chemical concentration/ERPG-2 ratios for the postulated maximum exposed individual are acceptable. The combined chemical exposure ratio exceeds a value of one (1.2). This suggests that irreversible or other serious health effects cannot be excluded from occurring; however, the conservatisms incorporated into the analysis (as discussed in Section 3.5.2.2) make it highly likely that the occurrence of any such postulated event would fall within health-based reference levels and would be acceptable.

Based on the relative shipment capacity of the TRUPACT-II and the RH-72B cask and on current chemical characterization data, it can be concluded that hazardous chemical accident analyses for CH-TRU waste shipments bound RH-TRU waste shipments.

3.5.4.2.2 Engineered Alternatives

Chemical airborne releases for engineered alternatives No. 1, 6, 10, 77, and 94 are summarized in Table L-24 of Appendix L for a postulated very severe accident. The release form, release fraction, and receptor concentration/ERPG-2 ratios are tabulated for each engineered alternative.

Engineered alternatives No. 1 and 77 have the highest combined chemical exposure hazard,

followed by engineered alternative No. 6. Engineered alternatives No. 10 and 94 have combined chemical exposure ratios that fall within health-based reference levels and for which it can be concluded that no irreversible or other serious health effects are expected to occur. For all engineered alternatives, individual chemical exposure ratios for engineered alternatives No. 1, 6, and 77 exceed one, indicating that irreversible health effects cannot be excluded from occurring. As noted in Section 3.5.3.2.1, the analysis incorporates several conservatisms. It can be concluded that the levels of exposure would not result in any fatalities.

3.5.4.3 Non-radiological/Non-chemical Risks

The non-radiological and non-chemical impacts of transporting TRU waste to the WIPP are the same as those resulting from transporting non-nuclear and non-hazardous materials. The risks involve traumatic injuries and fatalities from transportation accidents. Non-radiological and non-chemical impacts are independent of the characteristics of the cargo and therefore totally unrelated to radiological and hazardous chemical risks resulting from projected accidents. The non-radiological/non-chemical risks are also therefore independent of impacts from waste processing engineered alternatives.

Calculated per-shipment non-radiological and non-chemical risks for CH-TRU and RH-TRU shipments to the WIPP are summarized in Appendix L Table L-25. These risks include the impact of the return trip by truck from the WIPP to the generator or storage facility.

Total cumulative non-radiological and non-chemical CH-TRU and RH-TRU transportation risks are summarized in Appendix L Tables L-26 through L-29 for the entire life of the disposal phase.

3.5.4.4 Uncertainties

The transportation risks estimated in this chapter are affected by a number of uncertainties. For example:

- Waste Volume vs. Waste Mass—Waste volume limited shipments were analyzed to provide an upper bound for the transportation risks. The risks associated with waste mass limited shipments would fall below this upper bound.

- Waste volumes and locations—The risks will either increase or decrease depending on the volume of waste shipped and the distance to WIPP.

- Waste form—The risks in an accident will decrease if the waste is solidified, incinerated, vitrified, etc., because less material would be released. The non-radiological/non-chemical risks will increase if more shipments occur.

- Waste mass—The TRUPACT-IIs and RH-72B casks are weight limited. The waste mass could be such that many shipments could consist of just a few drums, thus increasing the number of shipments.

- TRU waste from environmental restoration activities—To date, the TRU waste volumes for environmental restoration activities have not been factored into WIPP operations.

- Mode of shipment—The analysis presented here is based on all shipments being made by truck. All previous transportation risk assessments for WIPP have analyzed rail shipments as well.

3.5.4.5 Summary of Results

As defined in Section 3.5.1, the Transportation Risk Factor is comprised of three risk components: radiological, chemical, and non-radiological/non-chemical. The radiological risk component is expressed in both doses (person-rem for collective exposures or rem for individual exposures) and health effects (incremental LCFs). These risks result from both incident-free transportation activities and postulated accidents. The chemical risk component provides a measure of the level of hazard for the maximally exposed member of the public for a postulated very severe accident. It is expressed as a unitless number and is calculated as the sum of each airborne chemical concentration divided by its respective ERPG-2 value. Chemical risk component values below 1.0 suggest that nearly all individuals could be exposed without experiencing or developing irreversible or serious health effects which could impair an individual's ability to take protective action. The non-radiological/non-chemical risk component results from non-cargo-related accident impacts and is expressed as traumatic injuries and fatalities.

A summary of the results of the transportation risk analysis is presented in Tables 3-42, 3-43, and 3-44. Table 3-42 summarizes the Transportation Risk Factor for baseline CH-TRU and RH-TRU waste shipments and for CH-TRU waste shipments for the centralized configuration. Tables 3-43 and 3-44 summarize the Transportation Risk Factor for CH-TRU waste shipments for the decentralized and regionalized configurations, respectively. As previously discussed, only five engineered alternatives affect the Transportation Risk Factor (Nos. 1, 6, 10, 77, and 94). Of these, two (Nos. 1 and 77) have the same risk factor values. The remaining engineered alternatives have the same Transportation Risk Factor as the baseline. To quantify the total Transportation Risk Factor for all TRU waste shipments, the baseline RH-TRU waste Transportation Risk Factor must be added to the risk factor for the CH-TRU engineered alternative of interest.

The chemical risk component is not affected by transportation movements and thus varies by engineered alternative but not by transportation configuration. The non-radiological/non-chemical risk component is affected by transportation movements but not by the nature of the waste cargo, and thus varies by transportation configuration but not by engineered alternative. The radiological risk component is affected by both transportation movements and the nature of the cargo and thus varies by both the engineered alternative and the transportation configuration evaluated.

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TABLE 3-42

SUMMARY OF CUMULATIVE/LIFETIME TRANSPORTATION RISK FACTOR BASELINE AND CENTRALIZED CONFIGURATION

	Baseline		Centralized Configuration
	CH-TRU Waste	RH-TRU Waste	All Engineered Alternatives for CH-TRU Waste
Radiological Risk Component			
Crew[1] - person-rem (LCFs)	$6.69 \times 10^{+02}$ (2.68×10^{-01})	$6.38 \times 10^{+02}$ (2.55×10^{-01})	$6.69 \times 10^{+02}$ (2.68×10^{-01})
Public[1] - person-rem (LCFs)	$4.00 \times 10^{+03}$ ($2.00 \times 10^{+00}$)	$3.32 \times 10^{+03}$ ($1.66 \times 10^{+00}$)	$4.00 \times 10^{+03}$ ($2.00 \times 10^{+00}$)
Max Individual[1,2,3] - rem (LCFs)	4.99×10^{-03} (2.50×10^{-06})	1.20×10^{-02} (6.00×10^{-06})	4.99×10^{-03} (2.50×10^{-06})
Accident Risk - person-rem (LCFs)	$8.01 \times 10^{+01}$ (4.01×10^{-02})	6.52×10^{-01} (3.26×10^{-04})	$8.01 \times 10^{+01}$ (4.01×10^{-02})
Chemical Risk Component			
Max Individual[4] - Total Airborne Concentration/ Adj'd ERPG-2	$1.2 \times 10^{+00}$	$1.2 \times 10^{+00}$[5]	Varies by alternative; same as shown on Table 3-42 or 3-43
Non-radiological/Non-chemical Risk Component			
Injuries	$6.61 \times 10^{+01}$	$3.35 \times 10^{+01}$	$7.06 \times 10^{+01}$
Fatalities	$4.87 \times 10^{+00}$	$2.63 \times 10^{+00}$	$4.71 \times 10^{+00}$

[1]Results from incident-free transportation activities.
[2]RADTRAN calculated maximum individual who is exposed to every shipment.
[3]LCF for the maximum individual estimated using the collective dose risk factor for a population exposure.
[4]Assumes a severity category VIII accident occurs.
[5]Bounding CH-TRU waste value used.

1

TABLE 3-43

SUMMARY OF CUMULATIVE/LIFETIME CH-TRU WASTE TRANSPORTATION RISK FACTOR DECENTRALIZED CONFIGURATION

	Engineered Alternative			
	No. 1 & 77	No. 6	No. 10	No. 94
Radiological Risk Component				
Crew[1] - person-rem (LCFs)	$5.81 \times 10^{+02}$ (2.32×10^{-01})	$5.47 \times 10^{+02}$ (2.19×10^{-01})	$7.16 \times 10^{+02}$ (2.86×10^{-01})	$4.25 \times 10^{+02}$ (1.70×10^{-01})
Public[1] - person-rem (LCFs)	$3.47 \times 10^{+03}$ ($1.74 \times 10^{+00}$)	$3.27 \times 10^{+03}$ ($1.64 \times 10^{+00}$)	$4.27 \times 10^{+03}$ ($2.14 \times 10^{+00}$)	$2.55 \times 10^{+03}$ ($1.28 \times 10^{+00}$)
Max Individual[1,2,3] - rem (LCFs)	3.80×10^{-03} (1.90×10^{-06})	3.81×10^{-03} (1.91×10^{-06})	4.61×10^{-03} (2.31×10^{-06})	2.68×10^{-03} (1.35×10^{-06})
Accident Risk - person-rem (LCFs)	$5.92 \times 10^{+00}$ (2.96×10^{-03})	$7.59 \times 10^{+01}$ (3.80×10^{-02})	$1.21 \times 10^{+00}$ (6.05×10^{-04})	$5.76 \times 10^{+01}$ (2.88×10^{-02})
Chemical Risk Component				
Max Individual[4] - Total Airborne Concentration/ Adj'd ERPG-2	$1.80 \times 10^{+00}$	$1.20 \times 10^{+00}$	2.10×10^{-05}	8.10×10^{-01}
Non-radiological/Non-chemical Risk Component				
Injuries	$6.61 \times 10^{+01}$	$6.61 \times 10^{+01}$	$6.61 \times 10^{+01}$	$6.61 \times 10^{+01}$
Fatalities	$4.87 \times 10^{+00}$	$4.87 \times 10^{+00}$	$4.87 \times 10^{+00}$	$4.87 \times 10^{+00}$

[1]Results from incident-free transportation activities.
[2]RADTRAN model calculated maximum individual who is exposed to every shipment.
[3]LCF for the maximum individual estimated using the collective dose risk factor for a population exposure.
[4]Assumes a severity category VIII accident occurs.

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TABLE 3-44

SUMMARY OF CUMULATIVE/LIFETIME CH-TRU WASTE TRANSPORTATION RISK FACTOR REGIONALIZED CONFIGURATION

	Engineered Alternative			
	No. 1 & 77	No. 6	No. 10	No. 94
Radiological Risk Component				
Crew[1] - person-rem (LCFs)	$5.87 \times 10^{+02}$ (2.35×10^{-01})	$5.53 \times 10^{+02}$ (2.21×10^{-01})	$7.22 \times 10^{+02}$ (2.88×10^{-01})	$4.31 \times 10^{+02}$ (1.72×10^{-01})
Public[1] - person-rem (LCFs)	$3.50 \times 10^{+03}$ ($1.75 \times 10^{+00}$)	$3.28 \times 10^{+03}$ ($1.64 \times 10^{+00}$)	$4.30 \times 10^{+03}$ ($2.16 \times 10^{+00}$)	$2.58 \times 10^{+03}$ ($1.29 \times 10^{+00}$)
Max Individual[1,2,3] - rem (LCFs)	5.30×10^{-03} (2.65×10^{-06})	5.32×10^{-03} (2.66×10^{-06})	6.11×10^{-03} (3.06×10^{-06})	4.19×10^{-03} (2.10×10^{-06})
Accident Risk - person-rem (LCFs)	$6.71 \times 10^{+00}$ (3.36×10^{-03})	$7.65 \times 10^{+01}$ (3.83×10^{-02})	$1.96 \times 10^{+00}$ (9.80×10^{-04})	$5.86 \times 10^{+01}$ (2.93×10^{-02})
Chemical Risk Component				
Max Individual[4] - Total Airborne Concentration/ Adj'd ERPG-2	$1.80 \times 10^{+00}$	$1.20 \times 10^{+00}$	2.10×10^{-05}	8.10×10^{-01}
Non-radiological/Non-chemical Risk Component				
Injuries	$5.98 \times 10^{+01}$	$5.98 \times 10^{+01}$	$5.98 \times 10^{+01}$	$5.98 \times 10^{+01}$
Fatalities	$4.76 \times 10^{+00}$	$4.76 \times 10^{+00}$	$4.76 \times 10^{+00}$	$4.76 \times 10^{+00}$

[1]Results from incident-free transportation activities.
[2]RADTRAN calculated maximum individual who is exposed to every shipment.
[3]LCF for the maximum individual estimated using the collective dose risk factor for a population exposure.
[4]Assumes a severity category VIII accident occurs.

3.6 IMPACT ON PUBLIC CONFIDENCE IN THE PERFORMANCE OF THE DISPOSAL SYSTEM

3.6.1 Definition of Factor 6

Identifying and understanding public concern about real or perceived risks associated with WIPP in its postclosure state provide important information that can assist the DOE in:

- Planning and executing sound engineered alternatives to eliminate potential postclosure risks and address public concerns.
- Providing credible scientific bases and data to assist the public in understanding risk probabilities as related to posed concerns and comments.
- Actively involving the general public in the WIPP development process to ensure a two-way flow of information that fosters openness and credibility.

This study was conducted in two phases to identify both historic and current public concerns about WIPP's postclosure performance. During Phase 1, some significant existing public commentary was examined to identify concerns about postclosure WIPP. These comments and concerns were further analyzed to determine the relative frequency of the concerns, the persistence of concerns over time, and the geographic source of concerns. Data sources included:

- The WIPP FSEIS (DOE, 1990b).
- Response to Comments for Amendments to 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (EPA, 1993)
- Public Hearings on EPA's Proposed Rule 40 CFR Part 194, Criteria for the Certification and Determination of the WIPP's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes, March 21-24, 1995 (EPA, 1995).

During Phase 2, comments were collected during a series of focus group discussions and interviews held in Carlsbad, Albuquerque, and Santa Fe, New Mexico, in which participants were invited to share their concerns about postclosure WIPP. These cities were selected as sites for the meetings because they were communities which have major population centers with residents that have shown interest in WIPP. Focus group discussions were held in Carlsbad on June 26, 1995; Albuquerque, on June 27, 1995; and Santa Fe on June 28, 1995. Additionally, interviews were held with three individuals who were invited but unable to participate in the focus group discussions. The Carlsbad interviews were held on July 6 and July 10, 1995, and the Santa Fe interview was conducted on June 28, 1995.

The combined findings from Phase 1 and Phase 2 analyses serve as considerations for selecting EAs that would address expressed public concern.

3.6.2 Methodology Used to Evaluate the Public Confidence Factor (Factor 6)

The data sources used as a source of public comments for the Phase I portion of this study were selected for several reasons:

- There are well-organized and published records of extensive public comments in the WIPP FSEIS. The FSEIS provided a wealth of commentary for developing a taxonomy of public postclosure concerns.

- The series of public hearings held in Carlsbad, Albuquerque, and Santa Fe during the period March 22-24, 1995, regarding EPA's Proposed Rule 40 CFR Part 194, *provided an excellent opportunity for collection of contemporary public concerns* about postclosure WIPP.

- The six years of elapsed time between the comments documented in the WIPP SEIS and those collected in March 1995 provide an opportunity to examine public concerns over a period of time. A comparison between the two, allowed analysts to identify possible shifts in public concerns since the oral and written comments were made as contained in the FSEIS.

The focus group discussions held in Carlsbad, Albuquerque, and Santa Fe, New Mexico were composed of community and business leaders, public opinion leaders, and advocacy group leaders. A proposed list of stakeholders to be asked to participate in the focus group discussions was developed for each location and was presented to Westinghouse Waste Isolation Division (WID) and the DOE-CAO for review and approval. This list was developed (1) by reviewing the EA stakeholder list, (2) through discussions with WIPP personnel, (3) from team knowledge of local communities and stakeholders, and (4) by reviewing the lists of attendees at the EPA 40 CFR Part 194 public hearings. Criteria for selection of focus group discussion participants included the following:

- Demonstrated long-term and abiding interest in the WIPP

- Business and community leaders who represent more than just a singular point of view

- Interest in the WIPP demonstrated by providing oral and/or written comments at public hearings on WIPP.

These selection criteria were developed to ensure that a diverse group, representative of New Mexico, was selected and that focus group participants had some knowledge about WIPP before the meeting. The final list of proposed participants for each location was presented to WID and DOE-CAO for review and approval. No participant attended more than one focus group discussion.

3.6.2.1 Data Collection and Formatting

Development of a Comment Taxonomy for Phase 1

The WIPP FSEIS represents the most comprehensive collection of formally organized public commentary about the WIPP Project. Published in 1990, the FSEIS records 1591 oral and 4948 written comments that express a wide range of public concerns. For example, there are comments related to potential economic and social impacts, comments on the geologic characteristics of the underground site, and comments on the possible risks to endangered species. In short, the comments are wide-ranging in content and depth.

For purposes of this study, a comment classification scheme was developed by identifying within the FSEIS those comments relating to issues about postclosure WIPP. This classification system was refined into the taxonomy of public concerns shown on Figure 3-16, WIPP Postclosure Concerns Phase 1 Taxonomy, which presents the relative frequency of public comments by category and are described below.

Phase 1 Comment Taxonomy

1.0 Conditions—Conditions seen as potential causes for undesirable outcomes. This category of comment is broken down further into three subcategories.

1.1 Waste Characteristics—Attributes (e.g., origin, volume, quantity) of the waste proposed for disposal at the WIPP facility.

1.1.1 Characterization/identification—Radioactivity level of waste (e.g., curie level), commercial waste, hazardous wastes, hazardous chemical constituents, etc.

1.1.2 In-storage reactions—Gas generation, heat generation.

1.1.3 Treatment—Vitrification, cementation, etc.

1.2 Waste Repository Technology Applied—Aspects, appropriateness, and nature of technologies to be used at the WIPP.

1.2.1 Siting—Geological, hydrological aspects of the WIPP site itself.

1.2.2 Design—Plugs and seals, backfill, etc.

1.3 Disposal Period Events—Outcomes regardless of cause that could introduce adverse risk to the environment.

1.3.1 Human-caused intrusion—Mining, drilling, sabotage, terrorism

1.3.2 Intrusion due to natural causes—Seismic, climatic changes (e.g., substantially increased precipitation), tornadoes.

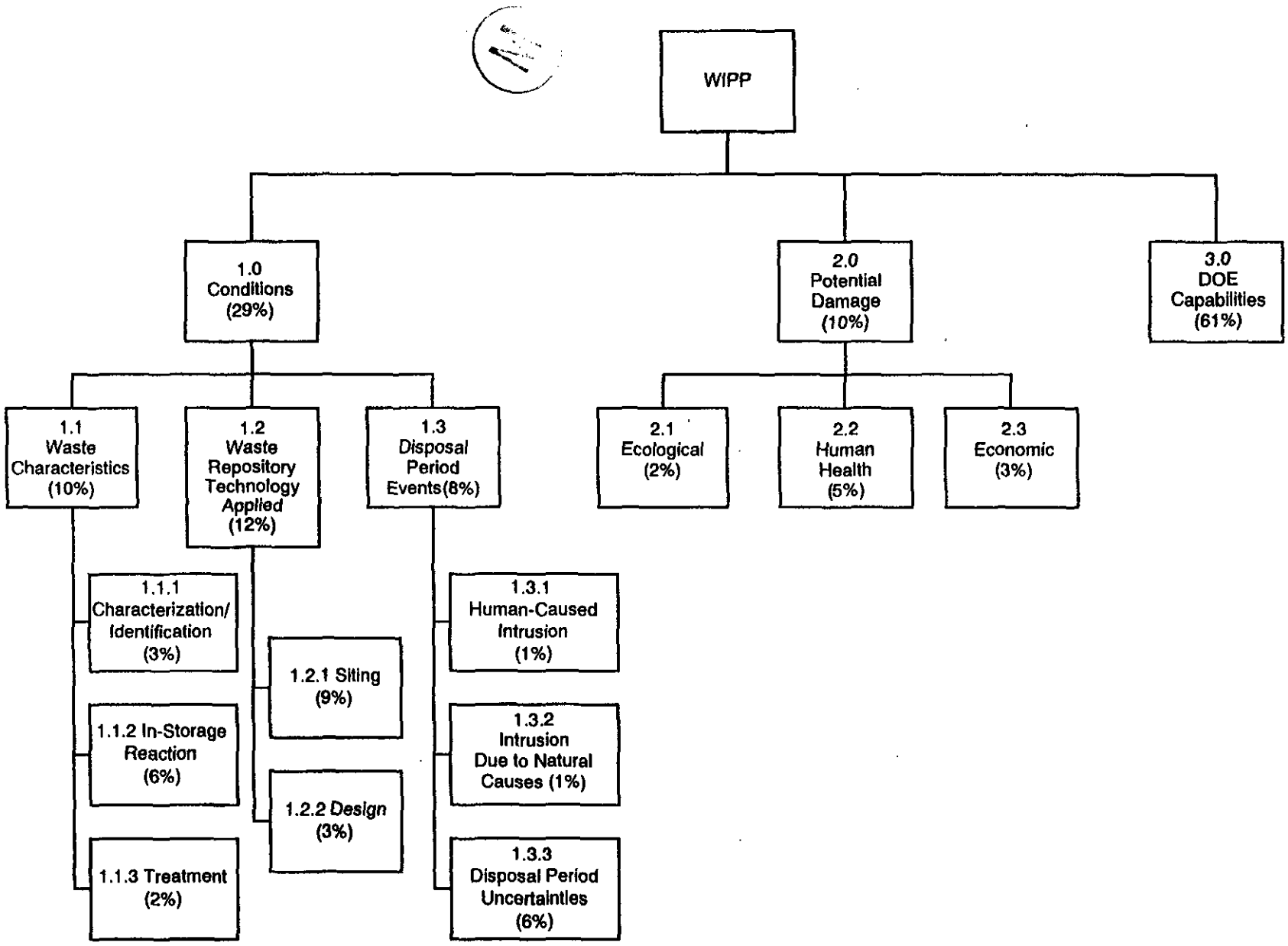

Figure 3-16
WIPP Postclosure Concerns Phase 1 Taxonomy

1.3.3 Disposal period uncertainties (10,000 years)—Standards, technology obsolescence, changes in cultural/social norms and practices, shifts in language use and meaning, unpredictable events

2.0 Potential Damage—Issues and conditions pertaining to environmental and human health and safety.

2.1 Ecological—Indigenous flora and fauna, groundwater contamination, effects on the Pecos and Rio Grande Rivers.

2.2 Human Health—Psychological impacts, medical services, radiation dose limits, radiation protection standards, exposure to plutonium.

2.3 Economy—Business development, tourism, property values, financial responsibility in event of accidental release.

3.0 DOE Capabilities—Public perceptions of DOE and its ability to manage the WIPP (e.g., credibility, impartial scientific review, needs for review and oversight).

Modifying the Comment Taxonomy for Phase 2

Focus group results indicated a need for extending and modifying the Phase 1 taxonomy so that suggested contemporary stakeholder concerns could be more adequately categorized. The original taxonomy was extended into seven major categories as shown on Figure 3-17, WIPP Postclosure Concerns Phase 2 Taxonomy, and discussed below. All Phase 1 categories are represented in the Phase 2 taxonomy. Percentages reflect relative frequency of comment by category.

Phase 2 Comment Taxonomy

1.0 Waste Conditions—Conditions seen as potential causes for undesirable outcomes.

1.1 Characterization/Identification -Radioactivity level of waste (e.g., curie level), commercial waste, hazardous wastes, hazardous chemical constituents.

1.2 In-Storage Reaction—Gas generation, heat generation.

1.3 Treatment—Vitrification, cementation.

1.4 Characteristics—Attributes (e.g., origin, volume, quantity) of the waste proposed for disposal at the WIPP facility.

2.0 Technology Applied—Aspects, appropriateness, and nature of technologies to be used at the WIPP.

2.1 Siting—Geological, hydrological aspects of the WIPP site itself.

2.2 Site Design—Plugs and seals, backfill.

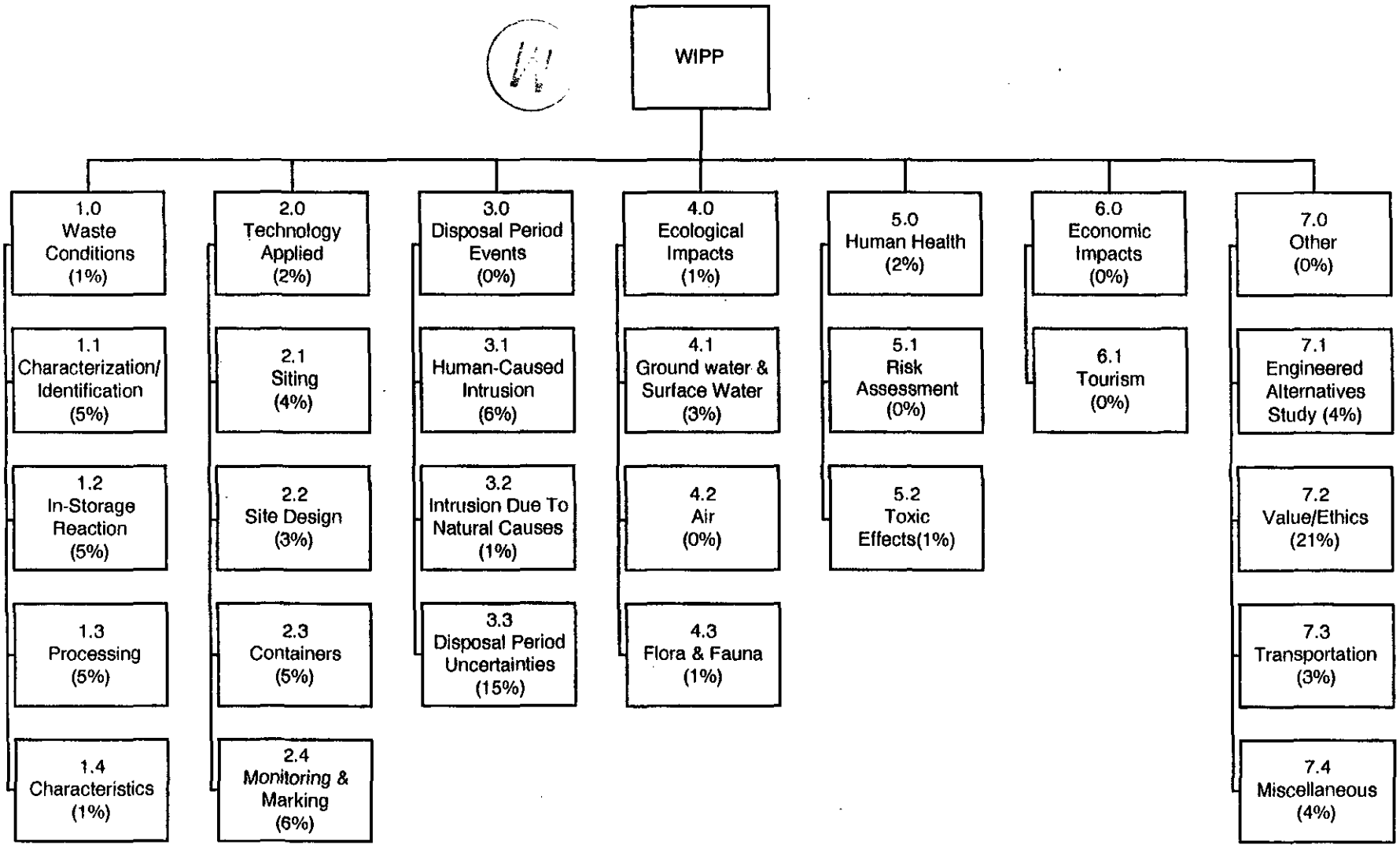

Figure 3-17
WIPP Postclosure Concerns Phase 2 Taxonomy

2.3 Containers—Permanent and temporary waste storage devices, e.g., drums, TRUPACT.

2.4 Monitoring and Marking—Matters pertaining to the short and long-term monitoring of the WIPP and/or its contents. Concerns about how WIPP can be marked such that future generations comprehend its location and purpose.

3.0 Disposal Period Events—Outcomes, regardless of cause, that could introduce adverse risk to the environment.

3.1 Human-Caused Intrusion—Planned and unplanned mining, drilling, sabotage, terrorism events.

3.2 Intrusion Due to Natural Causes—Seismic, climatic changes (e.g., substantially increased precipitation, tornadoes).

3.3 Disposal Period Uncertainties—Standards, technology obsolescence, changes in cultural/social norms and practices, shifts in language use and meaning, unpredictable events.

4.0 Ecological Impacts—Events which could result in damage to the environment, including groundwater, surface water, and plant and animal life.

5.0 Human Health—Psychological impacts, medical services, radiation dose limits, risk assessments, radiation protection standards, exposure to nuclear materials, and toxic effects.

6.0 Economic Impacts—Business development, tourism, property values, financial responsibility in event of accidental release.

7.0 Other

7.1 EA Study—Matters relating directly to this study, e.g., concerns about whether the regulations require the use of engineered alternatives.

7.2 Value/Ethics—Public perceptions of, individuals, society, and its institutions as they relate to motives, values, and actions pertaining to the public good. (e.g., credibility, impartial scientific review, need for review and oversight).

7.3 Transportation—Topics concerning the movement of waste materials via public roadways and/or other routes by motorized conveyance prior to WIPP closure.

7.4 Miscellaneous—Comments not readily associated with any other taxonomic category.

Formatting Comment Data in Phase 1

Each comment was tagged with a unique identifier. For example, "roll-up" comments from the WIPP FSEIS were already numbered. If a particular comment published in the FSEIS was identified as pertaining to postclosure WIPP, then the number of that comment was placed into one of the comment categories as defined by the taxonomy discussed above. Other comment sources were handled similarly by using either existing comment identification codes or by creating new ones when necessary. This system allows traceability from data back to the original comment as published or collected from oral presentation.

In some instances, a single recorded comment may have been made many times by different individuals. In such cases, the frequency of comment occurrence has been recorded as ***the total number of times the comment was made.*** This allows the same comment to be examined against time and frequency of occurrence. All raw data have been retained on file and may be accessed as required.

Additionally, comments have been coded by location source. For example, comment category 5.1-2 (a roll-up comment from the FSEIS) pertains to waste characterization and identification. There are 19 individual comments that form the basis for this roll-up. Fifteen of these comments were from New Mexico sources and four from outside the state. Further, data have been collected for this study that documents that fourteen of the fifteen New Mexico comments were from Santa Fe sources and one from an Albuquerque source. Geographic source data are on file.

Formatting Comment Data in Phase 2

Verbatim transcripts of the meetings were not prepared. Instead, notes were recorded on flip charts. As completed, individual sheets of notes were posted around the room. Additionally, notetakers were provided to record information to supplement that recorded on the charts. After the meeting, the meeting notes were finalized and sent to each participant for review and comment. Focus group comments are included as Appendix M.

Written comments for each meeting were analyzed and were sorted into specific taxonomic categories. In many instances, a "single" comment made by an individual at the focus group meeting consisted of comments on several subjects. For example, a participant might begin commentary by talking about perceived risks associated with groundwater intrusion into the repository, transition to a remark about how future generations might know about WIPP, and close with a statement concluding that, in the speaker's opinion, WIPP was well engineered, scientifically thorough, and ready to be put to use. Comments such as this are related to several taxonomic categories and were so recorded. When all comments had been categorized, they were then examined to determine whether they reflected a concern about postclosure WIPP or a more general concern not directly pertinent to postclosure WIPP (e.g., transportation of waste via TRUPACT-II).

3.6.2.2 Data Reduction

The number of comments occurring in each taxonomic category was converted to a percent of the total number of comments from a single source. Data in tabular form are provided in

Appendix N. Phase 1 data were combined to yield a composite of all original data sources. Phase 2 data were similarly combined for a composite view.

Phase 1 data include only comments pertaining to postclosure WIPP. Phase 2 data include more general comments about WIPP that extend beyond concerns about the postclosure period. These additional data are included to give a more accurate impression of actual focus group commentary. While the purpose of the focus group meeting was clearly stated by group leaders at the beginning of each session, discussion quite naturally extended beyond concerns about postclosure WIPP to other topics. The ratio of postclosure-specific to WIPP-general comments is perhaps a useful index of the intensity of public concern with postclosure WIPP in relation to concern about more current WIPP-related issues.

All data are presented in the body of this report as exploded pie charts. This format allows easy comparison of one data set to another. Changes were made to all sections of the Phase 1 taxonomy to accommodate specific concerns presented at the focus group discussions. Additionally, the focus group discussions concentrated on WIPP postclosure concerns. Therefore, Phase 1 and Phase 2 data are not directly comparable on a category-to-category basis. Nonetheless, trend comparisons can be made easily. Data presented in chart form have been intentionally limited in level of detail (this allows easier interpretation); a detailed accounting of frequency counts and percentages by category and subcategories is available in Appendix N.

3.6.2.3 Data Analysis

Raw data have been arrayed in similar formats such that major comparisons and trends may be identified. For example, much data reduction has been in terms of "percent." This practice allows rapid comparison of data sets of unequal size. There has been no attempt to apply formal analytic tools for the purpose of testing the statistical significance of this study's preliminary findings. Nonetheless, it is useful to note highly visible trends as a means for further thought and investigation.

Data were examined systematically to determine:

1. Which area is the most frequent comment category?

2. What are the sources of comments? (By state, city, etc.)

3. Have the relative frequency of comments changed over time?

4. How are public concerns about postclosure WIPP proportional to more general, contemporary WIPP issues?

5. Are there differences in comment frequencies related to geographic origin of comments?

3.6.2.4 Matching EAs to Noted Public Concerns About Postclosure WIPP

An interdisciplinary Working Group (the EASWG) of technical professionals who participated in the development of the EACBS was assembled to examine each EA and assess whether the alternative could address noted postclosure concerns. The Phase 2 taxonomy was used for this assessment as all concerns categorized in the Phase 1 taxonomy are addressed in the Phase 2

taxonomy. To ensure the Working Group understood the postclosure concerns present by the focus groups, a review was made of all notes for the focus group discussions and interviews. The Working Group did not assess the importance of the concerns, only whether the EAs could address or mitigate the noted postclosure concerns. Several assumptions were used by the Working Group in this assessment. The assumptions that were used are presented below.

- All waste processing EAs will require some level of postprocessing waste characterization.
- All waste will be assayed prior to disposal or shipment to WIPP.
- EAs were only matched to postclosure concerns.
- Sampling and analysis of headspace gas will be performed for all drums to determine the quantities of hydrogen, methane, and listed volatile organic compounds.
- All drums will undergo real-time-radiography which is a nondestructive test used to X-ray and inspect waste containers to determine the physical form of the waste and identify the presence or absence of free liquids.
- Using a statistically valid sample, a visual inspection will be performed of waste containers to ensure the level of quality for the real-time radiography inspections.

The results of this assessment are presented below. For each EA evaluated in the Cost/Benefit Study, a brief description of the alternative is presented, along with a statement of how the alternative would augment current baseline conditions/or programs for the WIPP. Many of the EAs in the Cost/Benefit Study are different combinations of waste processing techniques and/or backfill measures. For the purposes of this assessment, the waste processing techniques and types of backfills are addressed separately. The public postclosure concerns that could be addressed by the alternative are then presented by category and the total percentage of the comments that pertain to that concern are noted.

3.6.2.4.1 Supercompact Waste [Alternatives #1 and #77(a-d)]

Solid organic and inorganic wastes are sorted to remove items that cannot be compacted. The sorted waste is precompacted into 35-gallon drums and the supercompacted sludges are not processed.

Public Concerns Which May Be Addressed by this Alternative

This EA cannot be used for all waste streams. Some sorting and visual inspection of the waste is performed for this alternative which will augment the waste characterization process that is used to ensure that waste meets the WIPP WAC. Therefore, concerns regarding waste characterization/identification (5%), could be addressed by this alternative. Additionally, as the alternative would increase the density and strength of the waste form that would be emplaced in the repository, the potential release of hazardous and radioactive materials that could result from human-caused intrusions would be mitigated. Public concerns regarding human-caused

intrusions (6%), disposal period uncertainties (15%), ecological impacts (1%), engineered alternatives (4%), and human health (2%) could therefore be mitigated by this alternative.

3.6.2.4.2 Shred and Compact Solid Organic and Solid Inorganic Waste (Alternative #6)

Solid organic and inorganic wastes are shredded and compacted into 55-gallon (208-liter) drums using a lower pressure compactor than in supercompaction. Sludges are not processed.

Public Concerns Which May Be Addressed by this Alternative

This EA cannot be used for all waste streams. Some sorting and visual inspection of the waste is performed for this alternative which will augment the waste characterization process that is used to ensure that waste meets the WIPP Waste Acceptance Criteria. Therefore, concerns regarding waste characterization/identification (5%) could be addressed by this alternative. Additionally, as the alternative would increase the density and strength of the waste form that would be emplaced in the repository, the potential release of hazardous and radioactive materials that could result from human-caused intrusions would be mitigated. Public concerns regarding human-caused intrusions (6%), disposal period uncertainties (15%), ecological impacts (1%), engineered alternatives (4%), and human health (2%) could therefore be mitigated by this alternative.

3.6.2.4.3 Treat All Waste in a Plasma Melter (Alternative #10)

All wastes are processed through a shredder and the input waste stream is regulated to ensure a suitable metal to waste ratio. The waste is processed through a Plasma Arc Centrifugal Treatment system and poured into 55-gallon (208-liter) drums.

Public Concerns Which May Be Addressed by this Alternative

This EA can be used for all waste streams. In addition to the waste characterization that will be performed for all WIPP waste, some sorting and visual inspection of the waste is performed for this alternative. Therefore, concerns regarding waste characterization/identification (5%), could be addressed by this alternative. Additionally, as the alternative would destroy the hazardous organic constituents in the waste, concerns pertaining to the release or migration of hazardous constituents would be addressed. The alternative would also increase the density and strength of the waste form that would be emplaced in the repository, thus the potential release of hazardous and radioactive materials that could result from human-caused intrusions would be reduced. Thus, public concerns regarding waste processing (6%), waste characteristics (1%), human-caused intrusions (6%), disposal period uncertainties (15%), ecological impacts (1%), engineered alternatives (4%), and human health (2%) could be mitigated by this alternative.

3.6.2.4.4 Sand Plus Clay Backfill (Alternative #33)

A mixture of medium grained sand and granulated clay is used as a backfill for this alternative. The mixture is placed around the waste stack and between the drums filling the void space in the rooms within the repository.

Public Concerns Which May Be Addressed by this Alternative

This sand/clay backfill will lower the permeability and porosity of the waste, thus reducing the potential for release of contaminated brine through a drilling event. It will also limit brine inflow, thus reducing gas generation. Therefore, this alternative addresses concerns regarding in-storage reactions (5%), human-caused intrusions (6%), site design (3%), disposal period uncertainties (15%), engineered alternatives (4%), ecological impacts (1%), and human health (2%).

3.6.2.4.5 Salt Aggregate Grout Backfill (Alternative #35a)

This EA uses a salt aggregated grout mixture as backfill to fill the void spaces within a room in the repository after the waste is emplaced. This backfill consisting of a cementitious-based grout (which uses crushed salt as the aggregate and simulated WIPP brine as the added water), is pumped around the waste stack and between the drums filling the void space within the rooms.

Public Concerns Which May Be Addressed by this Alternative

Salt aggregate grout backfill increase the pH of any brine that may come in contact with the waste, thereby reducing gas generation and radionuclide solubility and mobility. This backfill also lowers the permeability and porosity of the waste, which minimizes brine inflow. Public concerns which may be mitigated by this alternative include those regarding in-storage reactions (5%), human-caused intrusions (6%), site design, (3%), disposal period uncertainties (15%), engineered alternatives (4%), ecological impacts (1%), and human health (2%).

3.6.2.4.6 Cementitious Grout Backfill (Alternative #35b)

A cementitious based grout backfill consisting of ordinary Portland cement, sand aggregate, and fresh waster is used for this alternative. The backfill is pumped around the waste stack and between the drums filling the void space within the room.

Public Concerns Which May Be Addressed by this Alternative

This backfill will increase the pH of any brine that may come in contact with the waste, thereby reducing gas generation and radionuclide solubility. This backfill also lowers the permeability and porosity of the waste, which minimizes brine inflow. Public concerns which may be mitigated or addressed by this alternative include those regarding in-storage reactions (5%), human-caused intrusions (6%), site design (3%), disposal period uncertainties (15%), engineered alternatives (4%), ecological impacts (1%), and human health (2%).

3.6.2.4.7 Lime (CaO) and Crushed Salt Backfill (Alternative #83)

This backfill consists of a commercially available granulated lime (quick lime) and crushed salt aggregate which is pneumatically placed around the waste stack and between the drums, filling the void space in the rooms. The mixture consists of less than 10% lime and 90% crushed salt aggregate.

Public Concerns Which May Be Addressed by this Alternative

The introduction of lime to the backfill increases the pH of any brine that may come in contact with the waste in the repository, thereby reducing radionuclide solubility and mobility. Lime backfill also lowers the permeability and porosity of the waste, which minimizes brine inflow. Public concerns which may be mitigated or addressed by this alternative include those regarding in-storage reactions (5%), human-caused intrusions (6%), site design, (3%), engineered alternatives (4%), disposal period uncertainties (15%), ecological impacts (1%), and human health (2%).

3.6.2.4.8 Enhanced Cementation of Sludges, Shred and Add Clay to Solid Organic and Solid Inorganic Wastes [Alternatives #94(a-f)]

This alternative includes two processes to treat the waste: (1) enhanced cementation of previously solidified and as generated sludges and (2) shredding solid organic and inorganic waste and adding clay to the shredded waste. Existing sludges are fed into a crusher/shredder. The crushed waste is mixed with an enhanced cement and is poured into 55-gallon (208-liter) drums. Newly generated sludges that are not dried will be solidified with the enhanced cement.

Solid organics and inorganics are shred and clay is added to the waste. This waste is packaged in 55-gallon (208-liter) drums.

Public Concerns Which May Be Addressed by this Alternative

This EA can treat both sludges and solid inorganic and organic waste. In addition to the waste characterization that is performed to meet the WIPP Waste Acceptance Criteria, some sorting and visual inspection of the waste is performed prior to shredding. Therefore, noted public concerns regarding waste characterization/identification (5%) could be mitigated by this alternative. This alternative will also reduce the generation of gas by increasing the pH of brine that may come into contact with the waste form. Thus, concerns about in-storage reactions (5%) would be mitigated by this alternative. Additionally, the alternative will reduce brine inflow through the addition of clay-based materials to the waste, therefore, the potential release of hazardous and radioactive materials that could result from human-caused intrusions would be reduced. Thus, public concerns regarding waste processing (5%), waste characteristics (1%), human-caused intrusions (6%), disposal period uncertainties (13%), ecological impacts (1%), engineered alternatives (4%), and human health (2%) could be addressed or mitigated by this alternative.

3.6.2.4.9 Clay-based Backfill (Alternative #111)

A backfill consisting of commercially available pelletized clay will be used for this alternative. The clay backfill will be placed around the waste stack and between the drums filling the void pace within the rooms.

Public Concerns Which May Be Addressed by this Alternative

The clay backfill will reduce the hydraulic conductivity of the backfill and impede the flow of brine and the mobility of radionuclides. This alternative may therefore address or mitigate public concerns regarding in-storage reactions (5%), human-caused intrusions (6%), site design (3%),

disposal period uncertainties (15%), ecological impacts (1%), engineered alternatives (4%), and human health (2%).

3.6.2.4.10 Public Concerns That Could Not be Addressed by an EA

The EAs that are assessed in this Cost/Benefit Study could not address all postclosure concerns that were noted during this study. The categories of public concerns that could not be addressed or reduced by an EA include siting (4%), containers (5%), monitoring and marking (6%), intrusion due to natural causes (1%), economic impacts (0%), values and ethics (21%), and miscellaneous (4%).

3.6.3 Results of Analysis

3.6.3.1 Comments on the WIPP FSEIS, 1990

Figure 3-18, Relative Frequency of Comments by Category for the WIPP FSEIS, is a graphical representation of the comments by category.

1. *Most comments fell into the "DOE Capabilities" category.*

   Sixty-three percent (4,154 out of 6,539) of all postclosure WIPP comments pertained to perceptions of DOE as they related to DOE's ability to manage the WIPP (Figure 3-18). Comments included concerns about credibility, scientific impartiality, and need for proper review and oversight. The percentage of comments falling into this category decreases in other comment sources made at later dates.

2. *The majority of comments were from New Mexico residents.*

   Of the 1,591 total postclosure oral comments on the WIPP FSEIS, 1,417 (89%) were comments made by New Mexicans. Total written comments on the WIPP SEIS numbered 4,948 with 4,412 (89%) being from New Mexicans.

3. *The rank ordering of comment categories and subcategories by number of comments recorded reveals that New Mexican and non-New Mexican commenters alike tended to place importance on the same issues.*

   A comparison of total comment frequency to comment frequency attributed to New Mexicans showed no rank order position differing by more than one.

4. *Public concerns are approximately equally balanced among the categories within "Conditions."*

   Concerns about "Waste Characteristics" total 10% while concerns about "Waste Repository Technology Applied" total 12% and concerns expressed about "Disposal Period Events" total 8%.

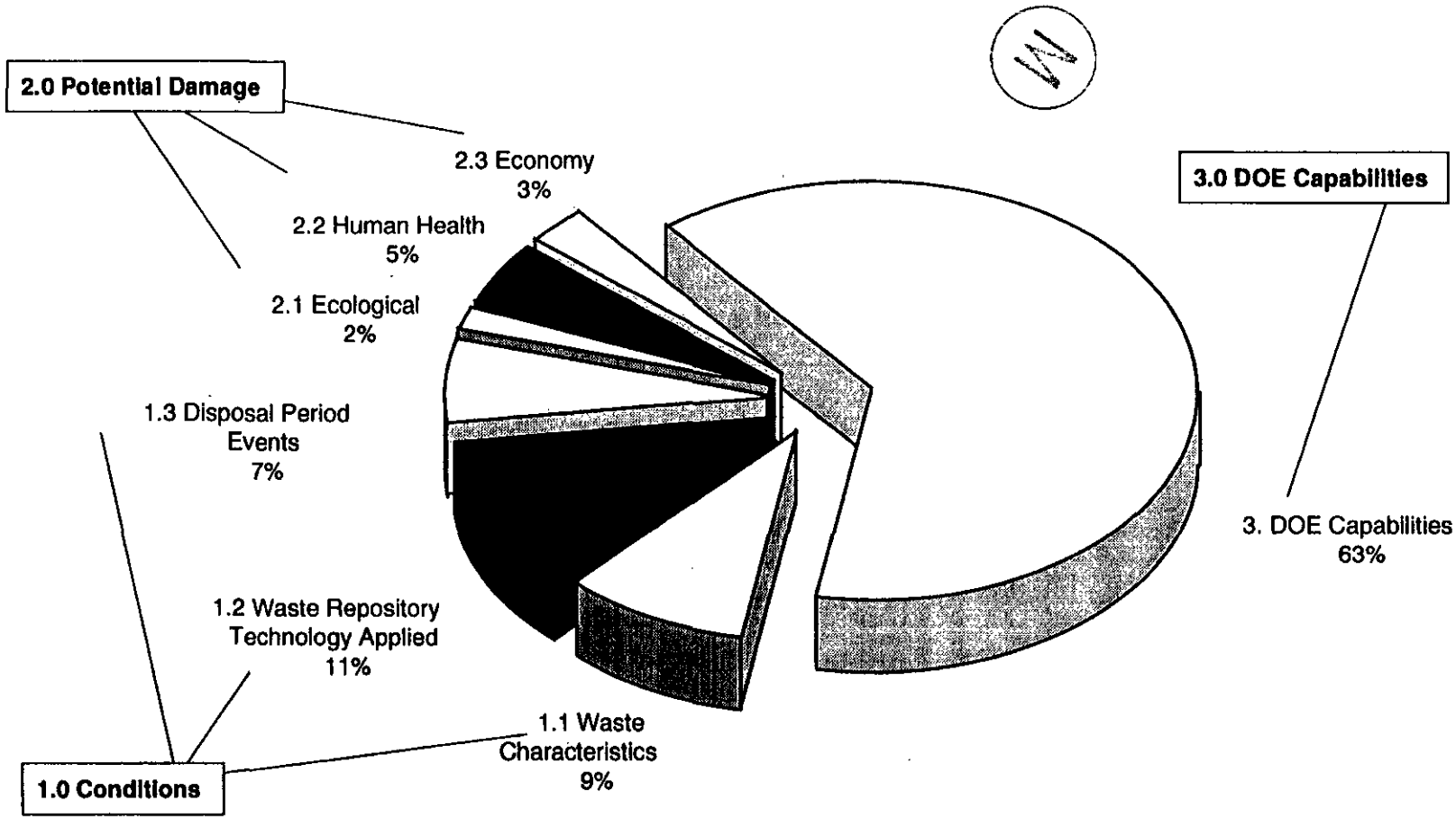

Figure 3-18
Relative Frequency of Comments by Category
WIPP Supplement Environmental Impact Statement
n = 6,539

3.6.3.2 Comments on 40 CFR Part 191, December 1993

Figure 3-19 illustrates relative frequency of comments by category for the December 1993 responses to the Amendments for 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Wastes.

1. *Comments directly related to DOE capabilities were 2% of the total.*

2. *The comment category of more frequent concern was "Conditions" (85%).*

3. *The most frequent comment category within "Potential Damage" pertained to potential human health effects of the repository (10% of a total 13%).*

3.6.3.3 Comments on Proposed Rule 40 CFR Part 194, March 21-24, 1995

Figure 3-20 shows the relative frequency of comments by category for the March 21-24, 1995, public hearing on the EPA's Proposed Rule 40 CFR Part 194.

1. *The majority of comments pertained to "Conditions" (81%).*

2. *Within the category "Conditions," most comments were directed toward applied waste repository technology and disposal period events (38% and 26% respectively). The third subcategory, "Waste Characteristics," accounted for 17% of the total.*

3. *Comments regarding potential damage (human health, ecological, and economic) accounted for a total of 13% of all comments.*

3.6.3.4 Comments from Carlsbad Focus Group Discussion and Interviews

Figure 3-21 provides the relative frequency of comments for the focus group discussions held in Carlsbad, New Mexico.

1. *The largest percentage of comments fell under "Other." By reference to Appendix N, the single largest subcategory of comments is "Value/Ethics."*

2. *"Economic Impacts" had the least number of total comments (2%).*

3. *Comments pertaining to "Disposal Period Events" constitute 12% of all comments.*

3.6.3.5 Comments from Albuquerque Focus Group

Figure 3-22 illustrates the relative frequency of comments for the Albuquerque focus group.

1. *As with the Carlsbad focus group, Albuquerque results show the majority of comments (34%) falling into the category "Other." Again, the data in Appendix N help clarify this finding. Within this category, comments concerning "Value/Ethics" dominate (19%), with the remaining portion mostly concerning the EA Study (10%).*

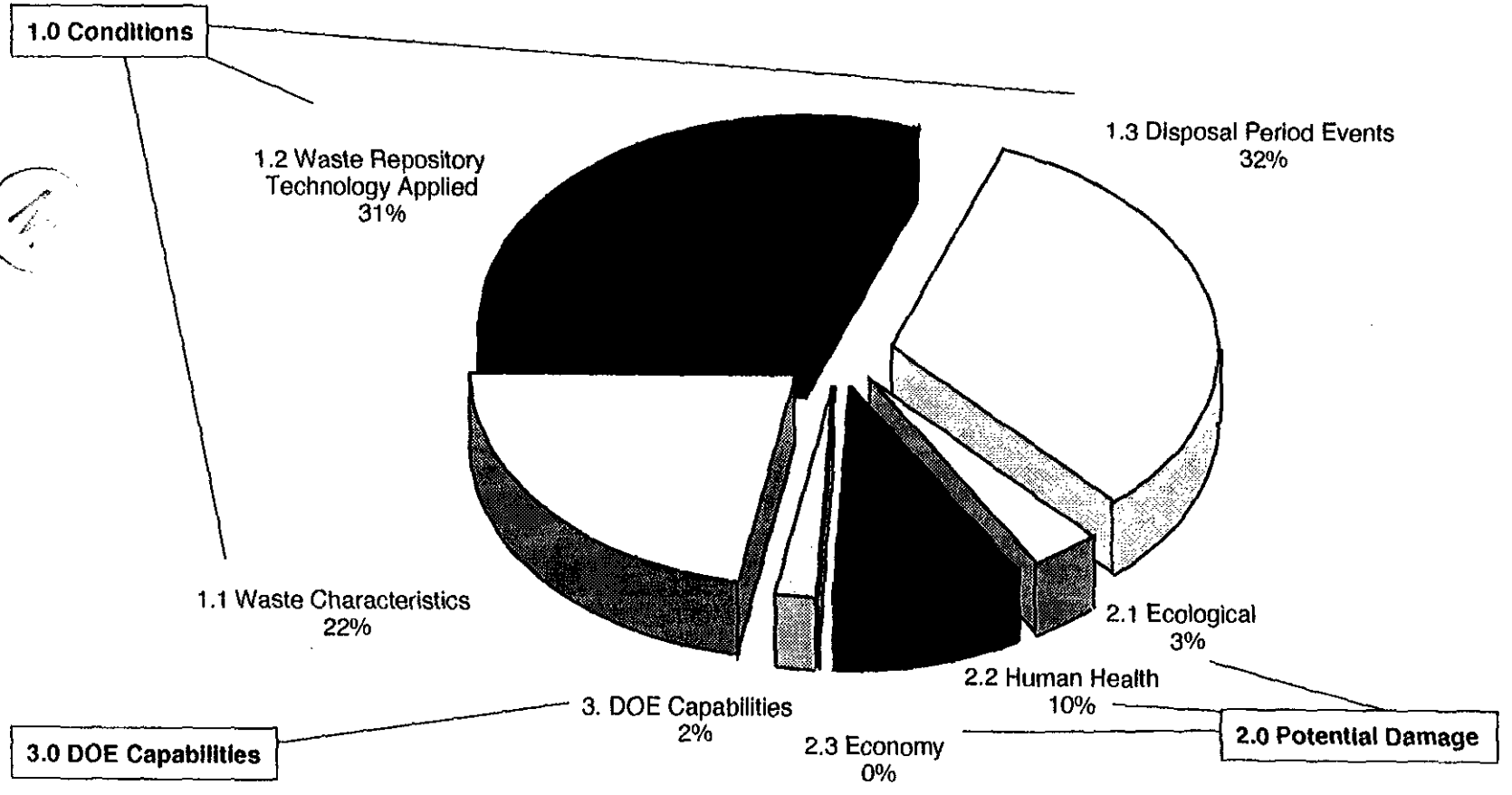

Figure 3-19
Relative Frequency of Comments by Category
Response to Amendments for 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes, December 1993
n = 157

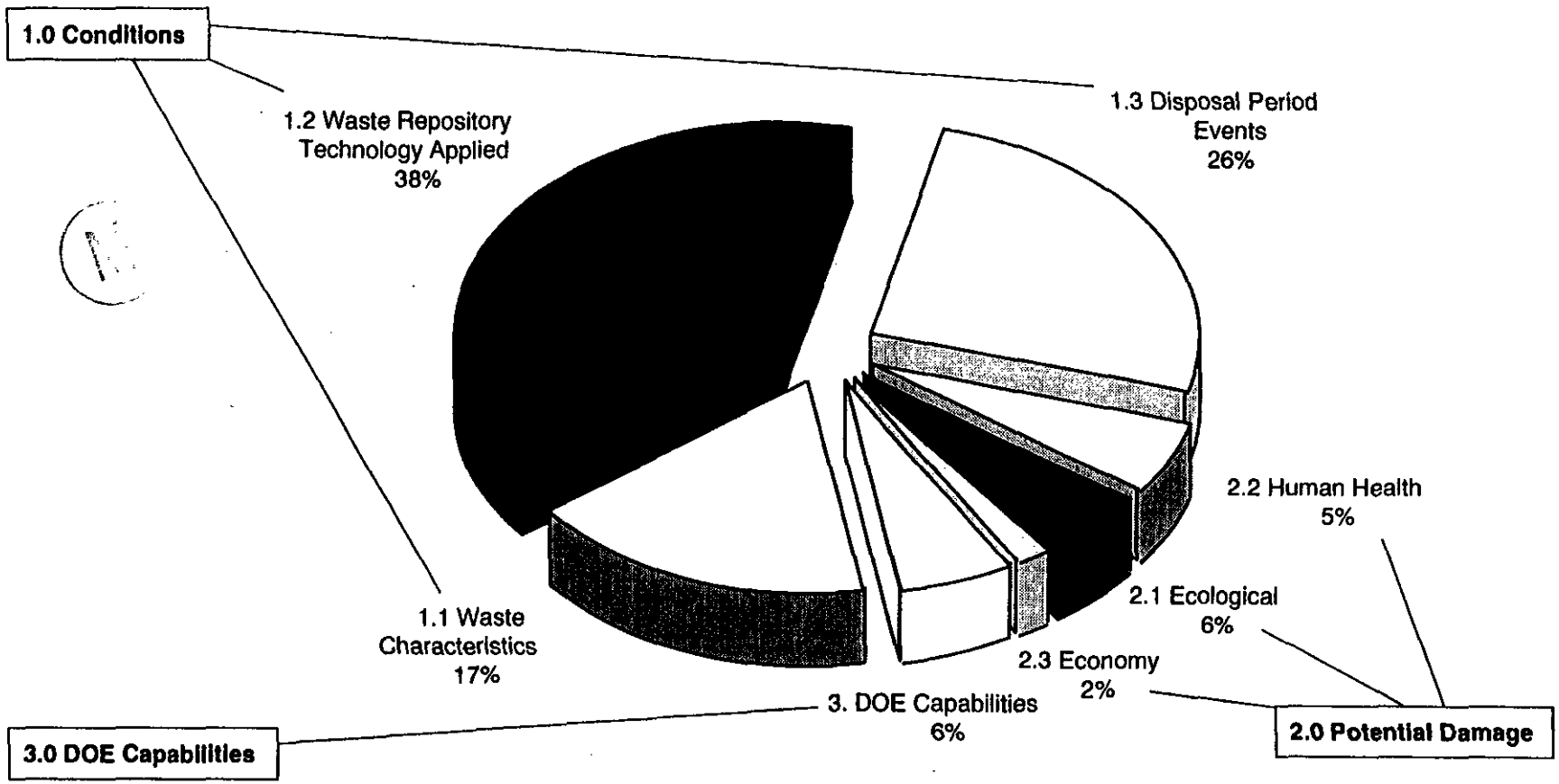

Figure 3-20
Relative Frequency of Comments by Category
Public Hearings on EPA's Proposed Rule 40 CFR Part 194, March 21-24, 1995
n = 181

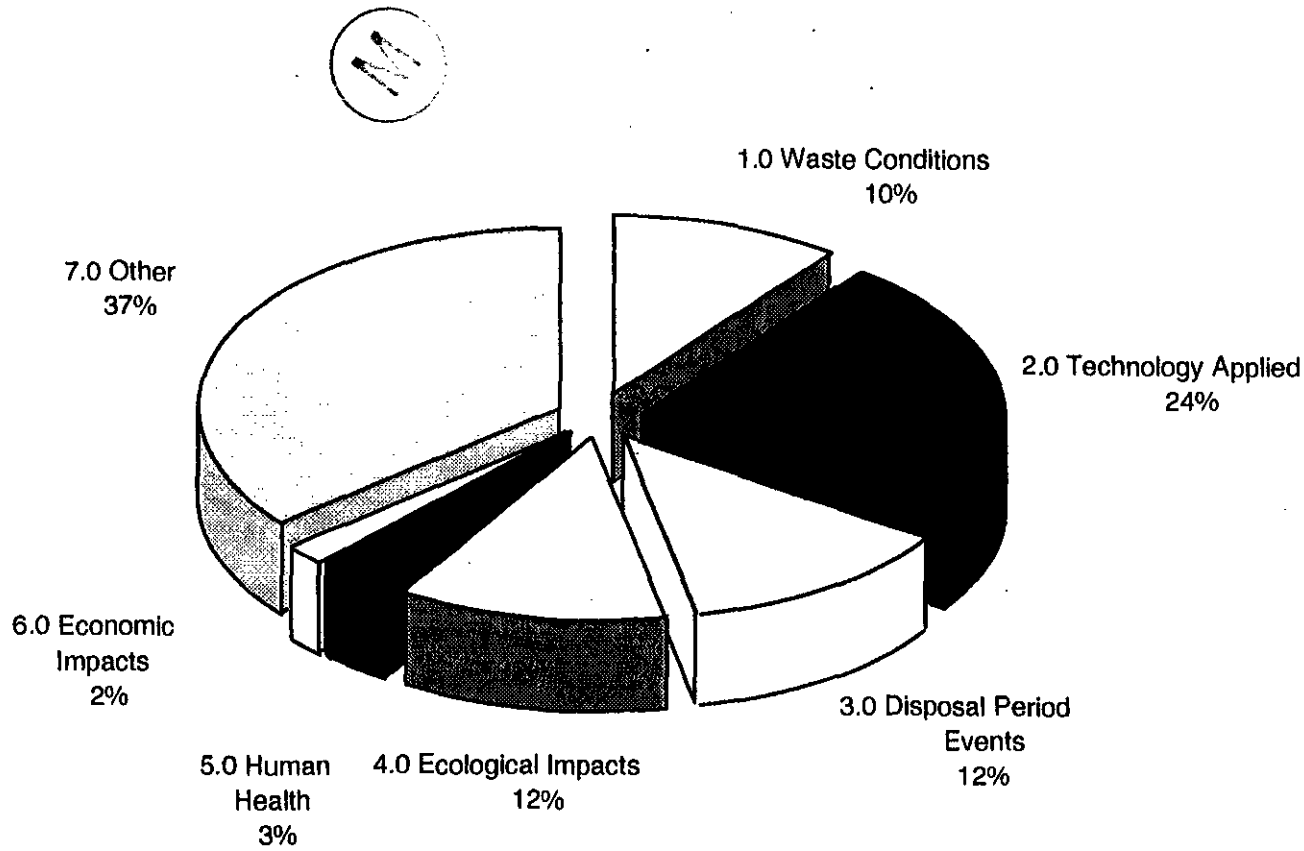

Figure 3-21
Relative Frequency of Comments by Category
Focus Group Meetings – June 1995
Carlsbad
n = 58

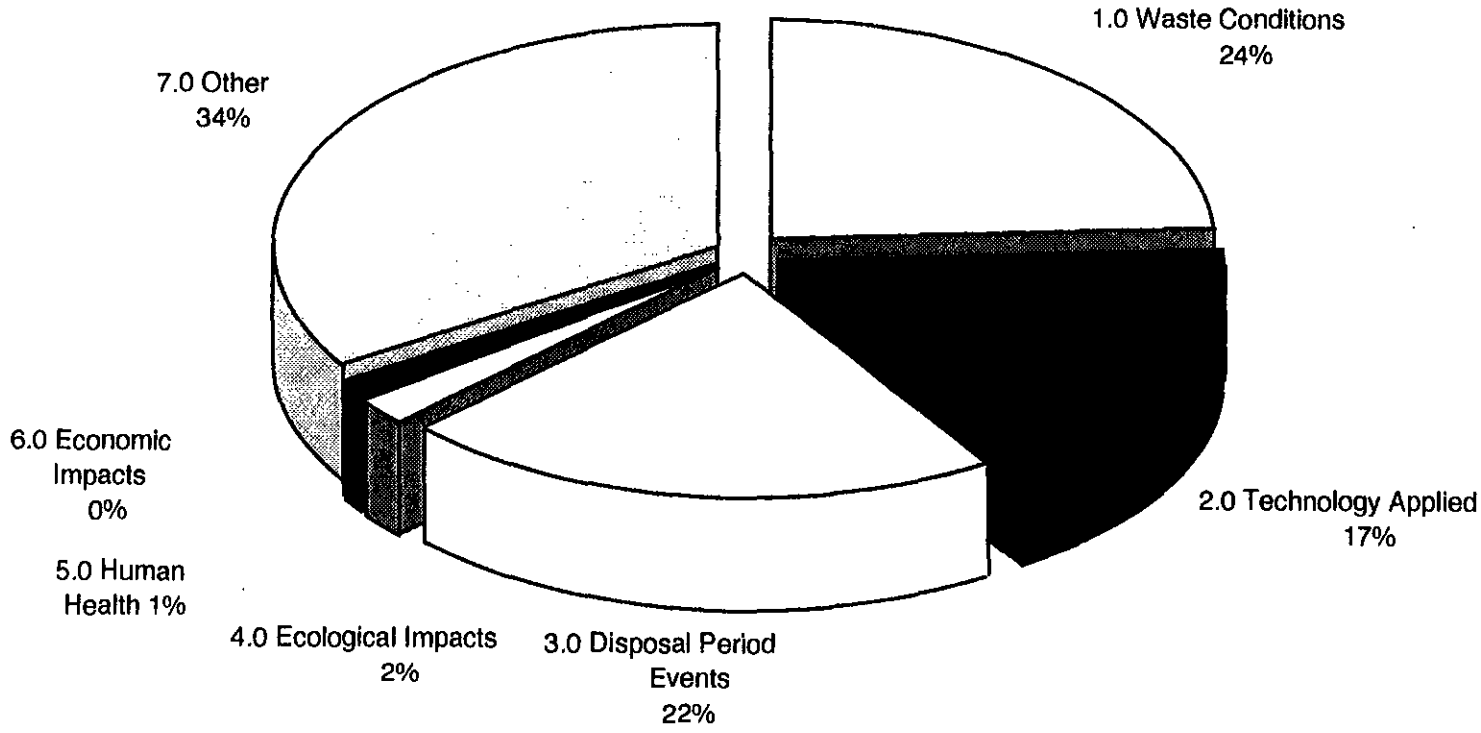

Figure 3-22
Relative Frequency of Comments by Category
Focus Group Meetings – June 1995
Albuquerque
n = 105

2. *Twenty-two percent of all comments were related to issues surrounding disposal period events, with 11% relating to "Disposal Period Uncertainties" and 11% concerned with "Human-Caused Intrusion."*

3.6.3.6 Comments from Santa Fe Focus Group Discussion and Interview

Figure 3-23 illustrates the relative frequency of comments for the focus group discussions held in Santa Fe, New Mexico.

1. *The majority of comments are again in the category of "Other" (28%). Examination of detail data in Appendix N reveals that 22% of the comments pertained to "Value/Ethics" with the remaining 5% fairly evenly distributed over the remaining three subset categories, "Engineered Alternatives Study," "Transportation," and "Miscellaneous.".*

2. *Comments pertaining to "Waste Conditions," "Technology Applied," and "Disposal Period Events" constitute 60% of all comments made during the focus group discussion. A review of actual comments in Appendix M helps to further explain the concerns.*

3.6.3.7 Data Comparison for Phase 1 Data

Figure 3-24, Relative Frequency of Comments by Category, Total All Comments, graphically represents the combined Phase 1 public concerns.

1. *Comment frequencies tend to follow the same pattern from one comment source to another.*

   The highest percentage of comments fell into the "Conditions" category (e.g., comments concerning "Waste Characteristics, Waste Repository Technology, and Disposal Period Events"). The range for this category was 58 percentage points (with a maximum value of 83% and a minimum of 25%), and the mean was 58%. A visual examination of the charts makes this observation more apparent. Other categories also tend to conform to this observation.

2. *The percentage of comments pertaining to Category 3 ("DOE Capabilities") has dropped markedly over time.*

   The 1990 SEIS recorded 4,154 comments pertaining to issues related to DOE capabilities. This represented 64% of the total 6539 comments recorded in the SEIS. The percentage of comments from other, more recent, Phase 1 sources ranged from 2% to 6%. Even though the number of comments from the other two sources totaled only 338 in comparison to the 6,539 comments from the SEIS, there seems to be a definite downward trend in this category.

3.6.3.8 Data Comparison for Phase 2 Data

Figure 3-25, Relative Frequency of Comments by Category, Focus Group Discussions and Interviews, is a composite pie chart illustrating the combined results for the focus group discussions and interviews held at Carlsbad, Santa Fe, and Albuquerque.

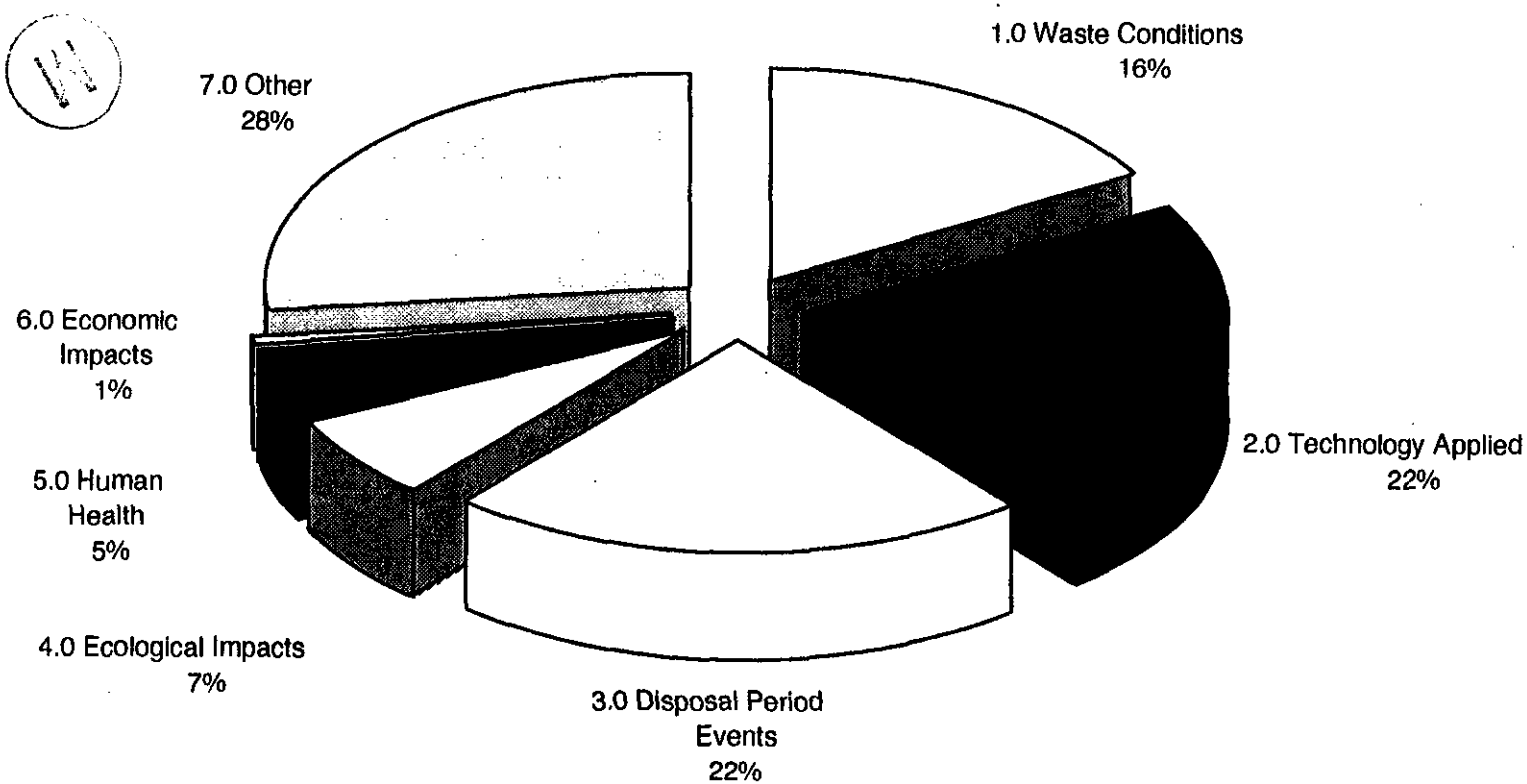

Figure 3-23
Relative Frequency of Comments by Category
Focus Group Meetings – June 1995
Santa Fe
n = 178

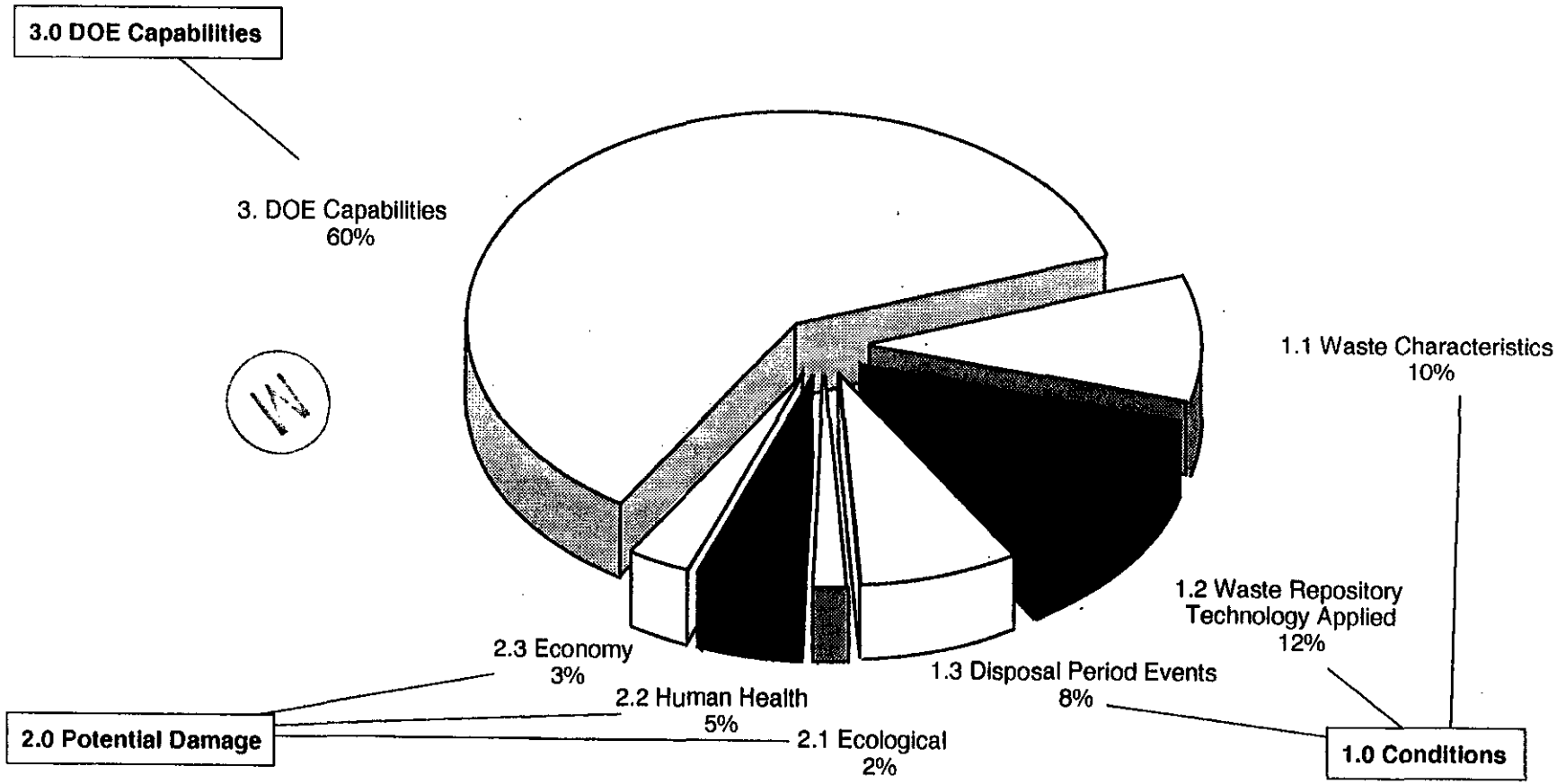

Figure 3-24
Relative Frequency of Comments by Category
Total All Comments
n = 6,877

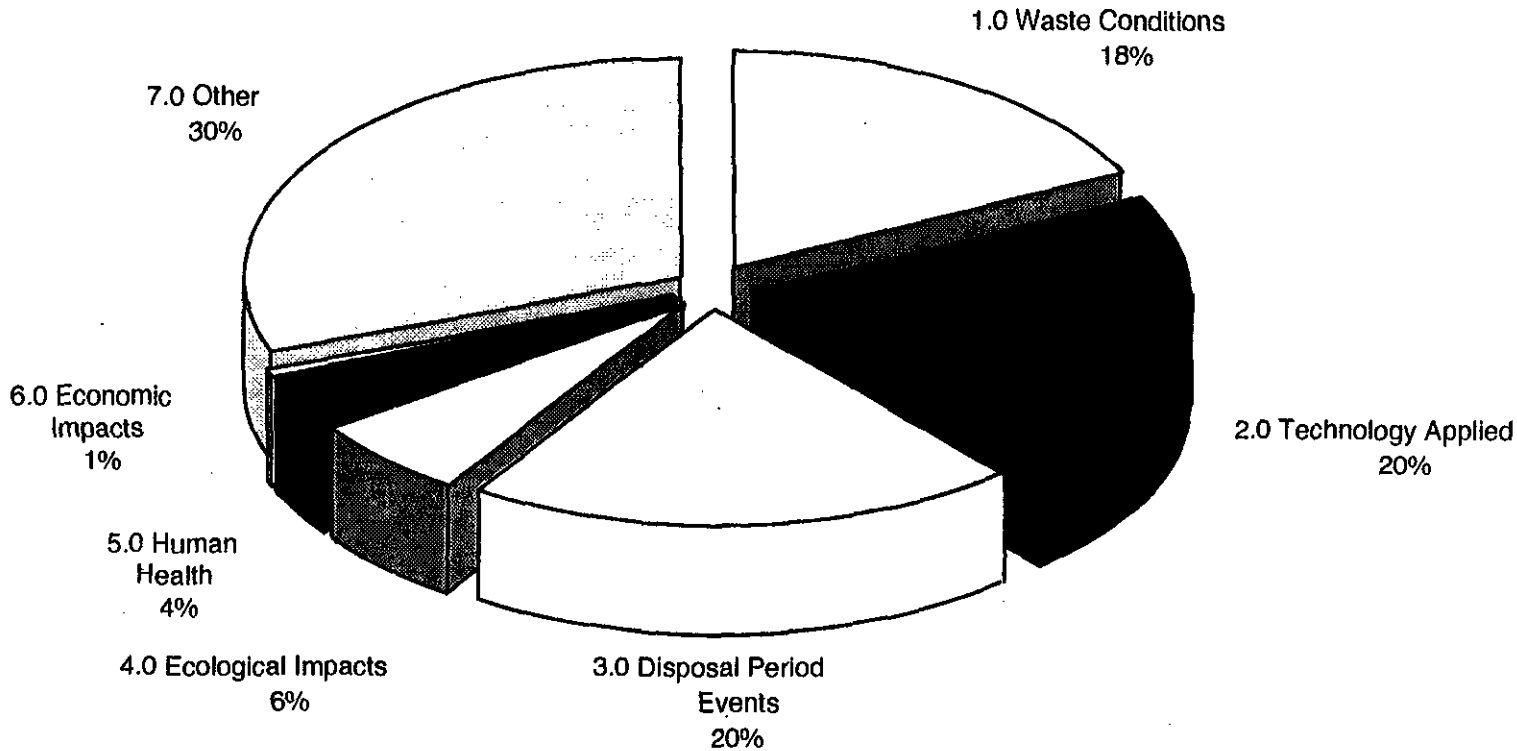

Figure 3-25
Relative Frequency of Comments by Category
Focus Group Discussions and Interviews
Composite: Carlsbad + Santa Fe + Albuquerque
n = 341

1. *Every comment made during a focus group discussion was categorized as either pertinent or not pertinent to postclosure WIPP. Interestingly, most comments made were pertinent to postclosure WIPP (ranging from 83% of all comments made on human health to 95% of all comments concerning disposal period events). The two taxonomic categories having the least percentage of comments that related directly to postclosure WIPP were "Economic Impacts" (0%) and "Other" (48%). The low percentage of postclosure-related comments in the "Economic Impact" category has little or no significance because there were only two comments made during the entire series of focus group sessions. The lower percentage of comments relevant to postclosure WIPP in the category "Other" is attributable to a host of comments made about values and ethics directed at matters of trust (see "DOE Capabilities" in the Phase 1 taxonomy). In any case, almost half of the comments included in the "Other" category cannot be regarded as comments directed specifically at postclosure WIPP. See Appendix N for detailed information on how comments were classified as pertinent or not pertinent.*

2. *"Disposal Period Events" received 20% of total comments. The very long safekeeping period required for wastes emplaced at the WIPP is a time period well beyond the predictive range commonly used by most people.*

3. *A total of only 11% of comments were classified into the categories "Economic Impacts," "Human Health," and "Ecological Impacts."*

4. *Next to concerns about "Disposal Period Uncertainties," "Technology Applied" (20% of all focus group comments) and "Waste Conditions" (18% of all comments) gathered the most comments. These comments included concerns about waste containers, the types of waste to be accepted at WIPP, waste characterization, and the technologies appropriate for long-term isolation of the waste.*

3.6.3.9 Concluding Remarks

While not a statistically pure undertaking, results of this study are several:

- The majority (78%) of the concerns presented during the focus group discussions pertained to postclosure WIPP.

- The majority of the categories of concerns can be addressed or mitigated by an EA. Only seven of the eighteen categories of concern cannot be addressed or mitigated by an EA.

- The largest single category of concern for all focus group discussions was value/ethics. Comments in this category include concerns about how decisions are made and whose values are used by the government in its decision-making practices.

- Tabular frequency analysis allows traceability of study results back to the original source of comment.

- The raw data offer expanded opportunity for more detailed examination as interest and need dictate (e.g., geographic source of comments).

Anecdotal results include the fact that each focus group discussion varied in the expressed concerns. Most of the stakeholders who participated in the Carlsbad discussions expressed their confidence in the long-term ability of the WIPP to isolate hazardous wastes from the environment. Several of the Carlsbad participants stated that they didn't really have any serious postclosure concerns about WIPP but were mildly concerned about issues such as long-term record keeping and permanent site markers. Many of the Albuquerque participants commented on the regulatory requirements for EAs, human-caused intrusion, and disposal period uncertainties. The Santa Fe participants commented on waste processing, disposal period uncertainties, monitoring and marking of the site, and how and whose values are used by the government in its decision-making practices.

There were also several comments presented during each focus group discussion which expressed concern about the adequacy of 55-gallon (208-liter) drums as waste containers, and the ecological impacts of water breaching the site, becoming contaminated, and migrating to the surface or to the overlying water-bearing strata.

3.7 FACTOR 7: DOE TOTAL SYSTEMS COST AND SCHEDULE ESTIMATES

3.7.1 Definition of Factor 7

The impact of cost and schedule for each alternative will be an important tool for planning the implementation of an alternative. Cost and schedule will typically determine the level of funding that must be appropriated, the required manpower for the activities, and a schedule that provides conceptual start and stop dates.

The total cost will be composed of waste processing, transportation, repository backfill, and emplacement handling costs for the selected alternatives in different configurations. Processing cost are estimated by first developing process flow diagrams that segment the alternative into functional elements. The costs for the alternatives are developed on the basis of waste quantities and throughput rates required to meet schedule constraints. The throughputs for each element are used to determine costs for each element, and total processing costs consist of a summation of each appropriate element cost. Other cost elements (transportation, backfill, and emplacement handling) will be estimated using accepted departmental methods. The presentation of total costs will include a comparative analysis of the incremental change of the screened alternatives relative to the repository baseline cost.

The schedule for each alternative will provide a measure of the alternative's desirability. An alternative with an excessive implementation schedule may be deemed undesirable. The schedule analysis provides a measure of time required to implement an EA relative to the baseline. The schedule will include a baseline and the incremental change of an alternative to the baseline.

Both cost and schedule impacts will be based on an approach consistent with current departmental methodologies and assumptions. The results of the analysis are presented according to key elements and summarized according to each alternative.

3.7.2 Methodology Used to Evaluate Factor 7

Costs estimates for implementing the individual EAs in the different facility configurations were composed of four major elements:

- Waste processing costs (Section 3.7.2.1)
- Transportation costs (Section 3.7.2.2)
- Backfill emplacement costs (Section 3.7.2.3)
- Waste emplacement handling costs (Section 3.7.2.4).

Each of these elements was summed to arrive at a total system cost.

3.7.2.1 Process Costing Methodology

The waste processing costs were estimated using information contained in "Interim Report: Waste Management Facilities Cost Information for Transuranic Waste" (WMFCITRUW) (Feizollahi and Shropshire, 1994). The cost estimating method used by Feizollahi and Shropshire involves segmenting waste management facilities into discrete modules which are used to estimate the costs for building and operating facilities to perform various waste management functions. Cost

estimates for different types of integrated TRU waste facilities are created by linking modules for different functions together in such a way that they closely approximate an actual waste management facility. This methodology provides the flexibility to estimate the costs many different sized facilities with many different functions without having to perform a rigorous conceptual design and cost estimate for each facility configuration.

Figure 3-26 shows the information flow diagram used to develop waste processing cost estimates. Information from process flow diagrams and mass flow rates are required as input to the cost modules. A combination of data sources were used to develop this information, including existing waste inventories and waste generation projections (Appendix O), processing schedules (Appendix Q), a listing of EAs that require waste processing (Section 2), and the system configuration for the waste processing facilities (i.e., centralized, regionalized, or decentralized) (Section 2).

Process flow diagrams were developed for each alternative in each configuration (see Figures 3-27 to 3-37). These flow schemes were based on the DOE "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force" (DOE, 1991a), the Draft EM-PEIS report, and the WMFCITRUW report (Feizollahi and Shropshire, 1994). Information from these sources were used to connect each of the modules and to construct a visual description of mass and volume flow through each treatment process.

The modules are described below:

- Front End: Front-end support facilities consist of all administrative and laboratory buildings required for the waste management support functions. Front-end support functions include security, personnel decontamination (radioactive and hazardous), maintenance of noncontaminated areas and equipment, health physics, radiation badges, facility access control, sanitary facilities, work control and personnel support, internal and external communications, spill or emergency response provisions (hazardous and radioactive), analytical laboratory, environmental field sampling, environmental regulatory reporting, and records management.

- Retrieval: This module consists of all-weather excavation, inspection, and repackaging of bermed waste. The module includes three principal unit operations: earthen-cover extraction and decontamination, waste-container retrieval and inspection, and packaging and staging for shipment.

- Waste Characterization: This module is a self-contained facility in which waste characterization is performed. Activities include extracting physical samples of waste; conducting chemical, physical, and radiological analysis of waste samples; and repackaging drums and boxes to remove and stabilize noncompliant waste.

- Maintenance: A maintenance facility is used in conjunction with treatment facilities. It consists of a failed-equipment receiving and repair building housing machinery and tools.

- Treatment: The treatment module varies based on the alternative being considered. Treatment options include grouting, supercompacting, shredding and

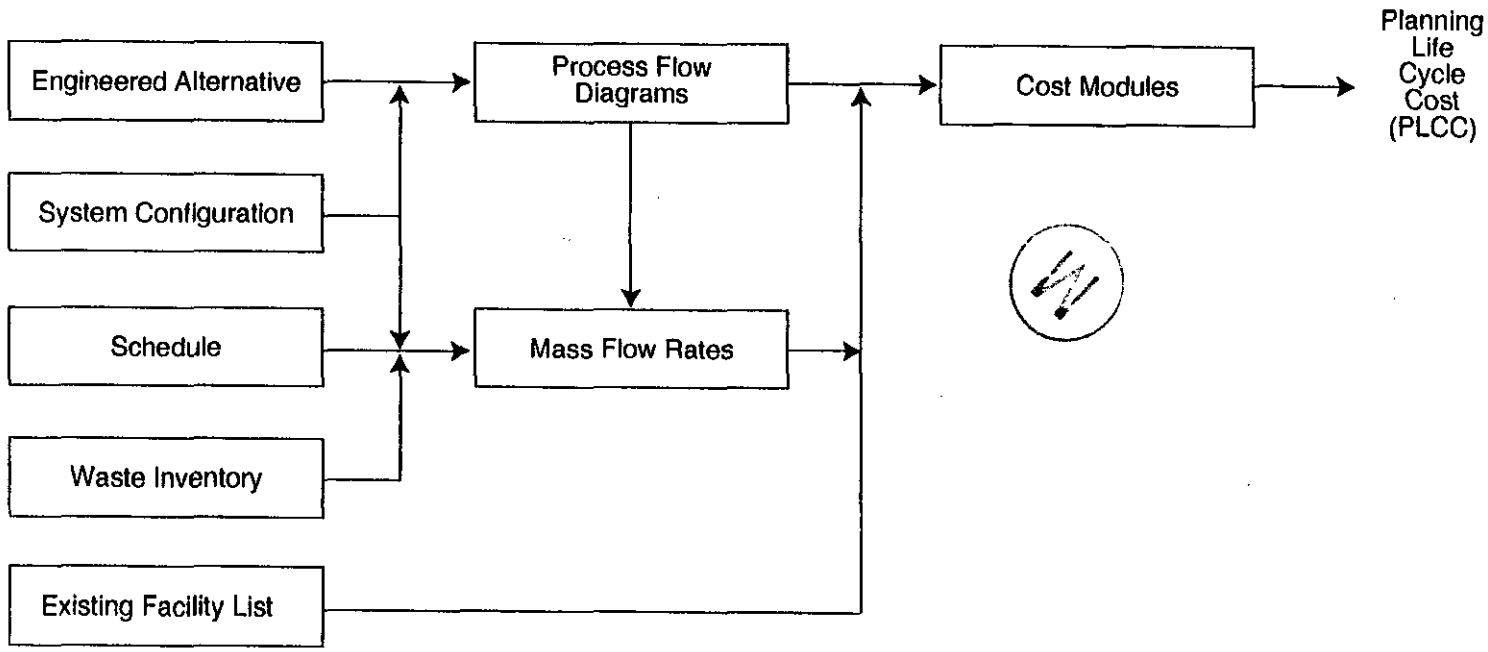

Figure 3-26
Process Costing Methodology Flow Diagram

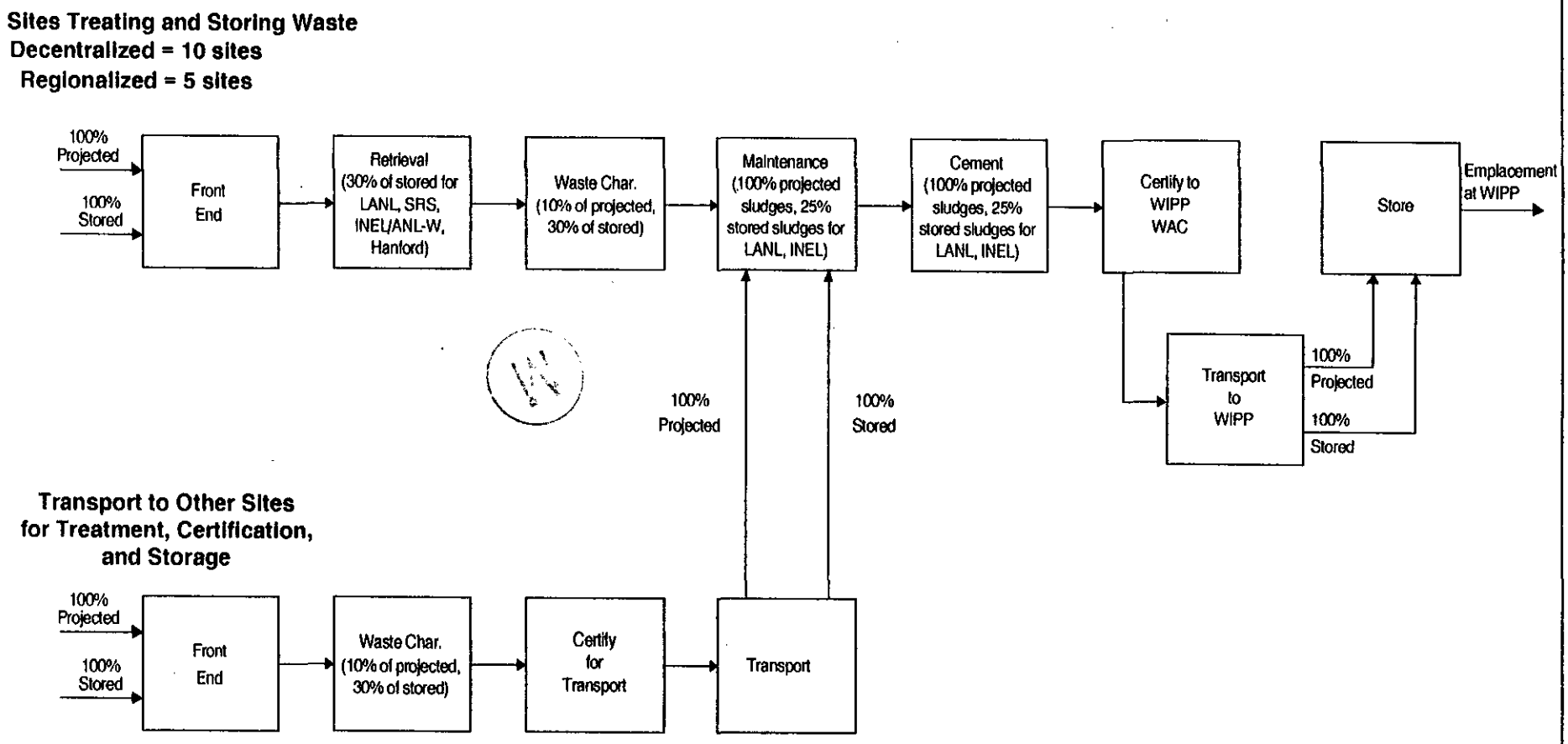

Figure 3-27

Decentralized and Regionalized Base Cases and Alternative ID #s 33, 35(a&b), 83, and 111 Contact Handled Process Flow Diagram A

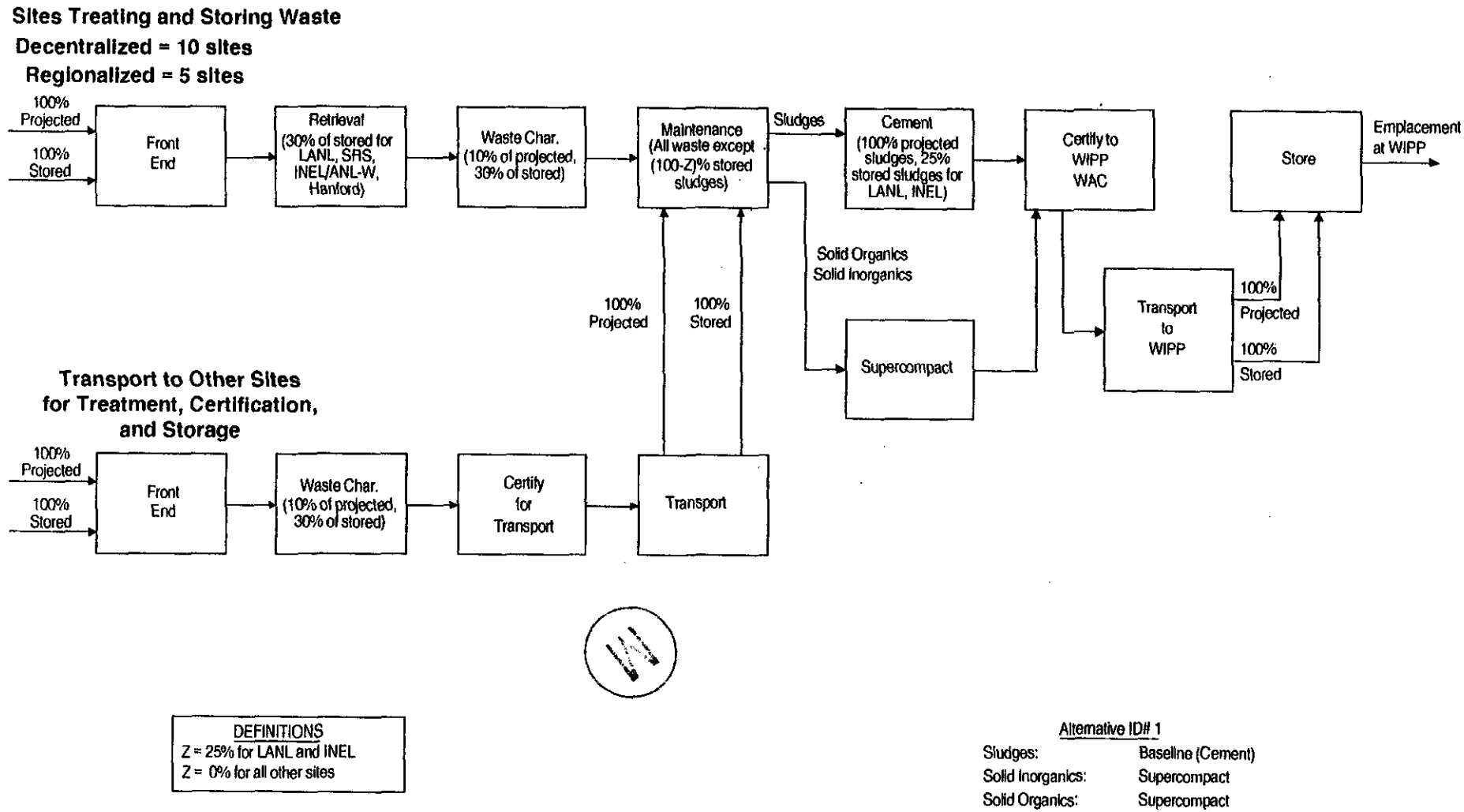

Figure 3-28

Decentralized and Regionalized Alternative ID #s 1 and 77(a-d) Contact Handled Process Flow Diagram B

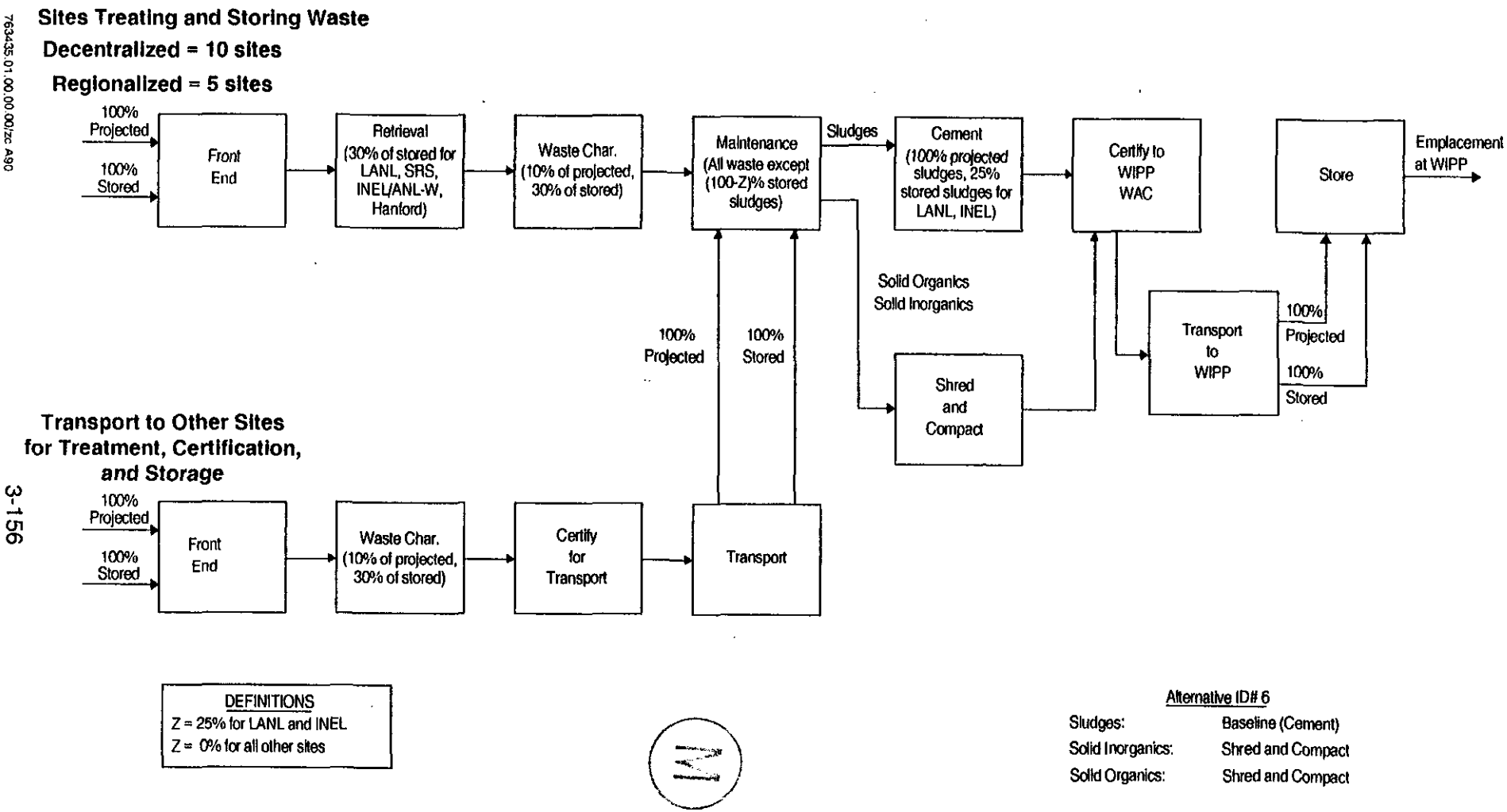

Figure 3-29
Decentralized and Regionalized Alternative ID# 6 Contact Handled Process Flow Diagram C

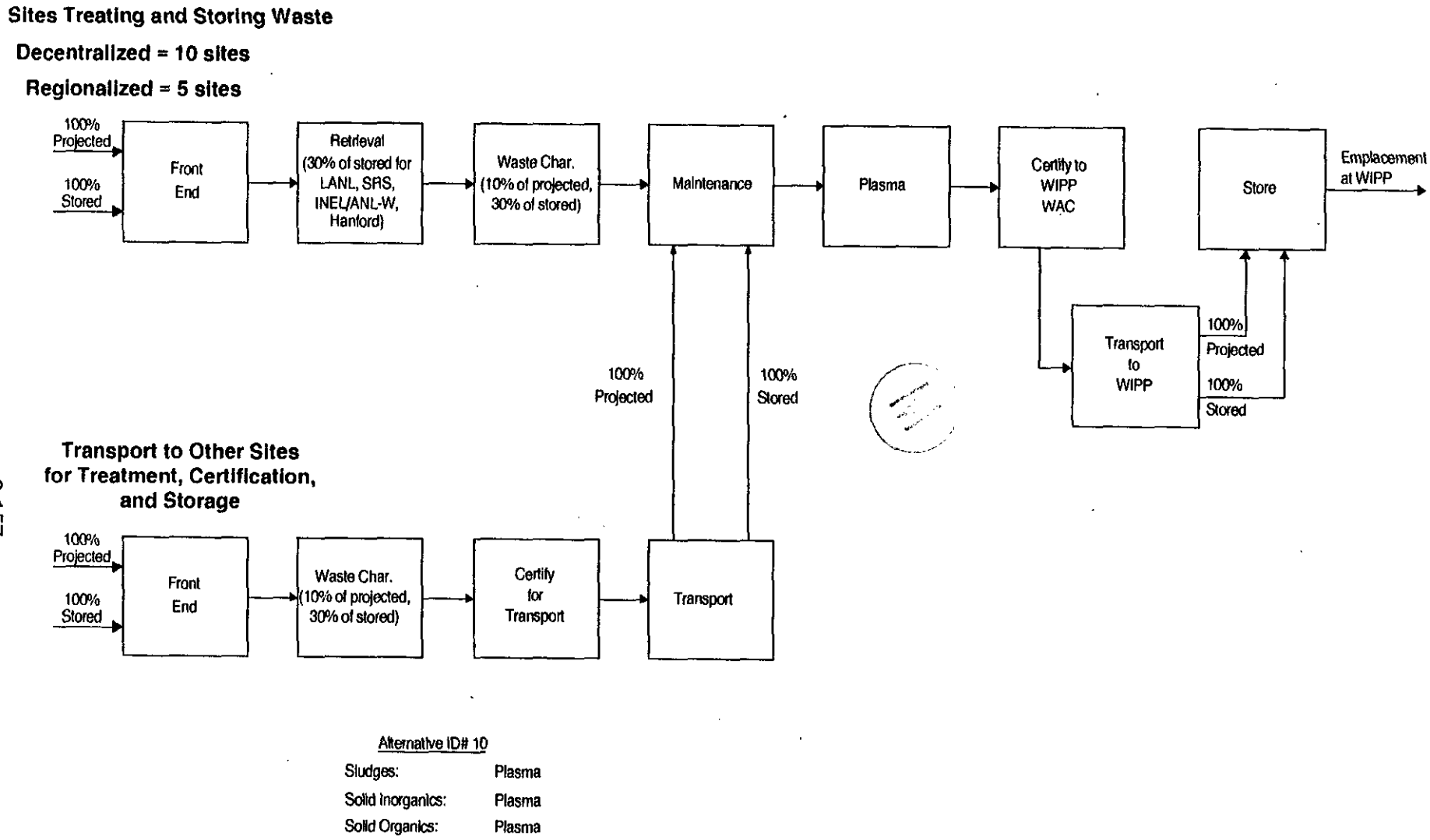

Alternative ID# 10

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure 3-30

Decentralized and Regionalized Alternative ID# 10 Contact Handled Process Flow Diagram D

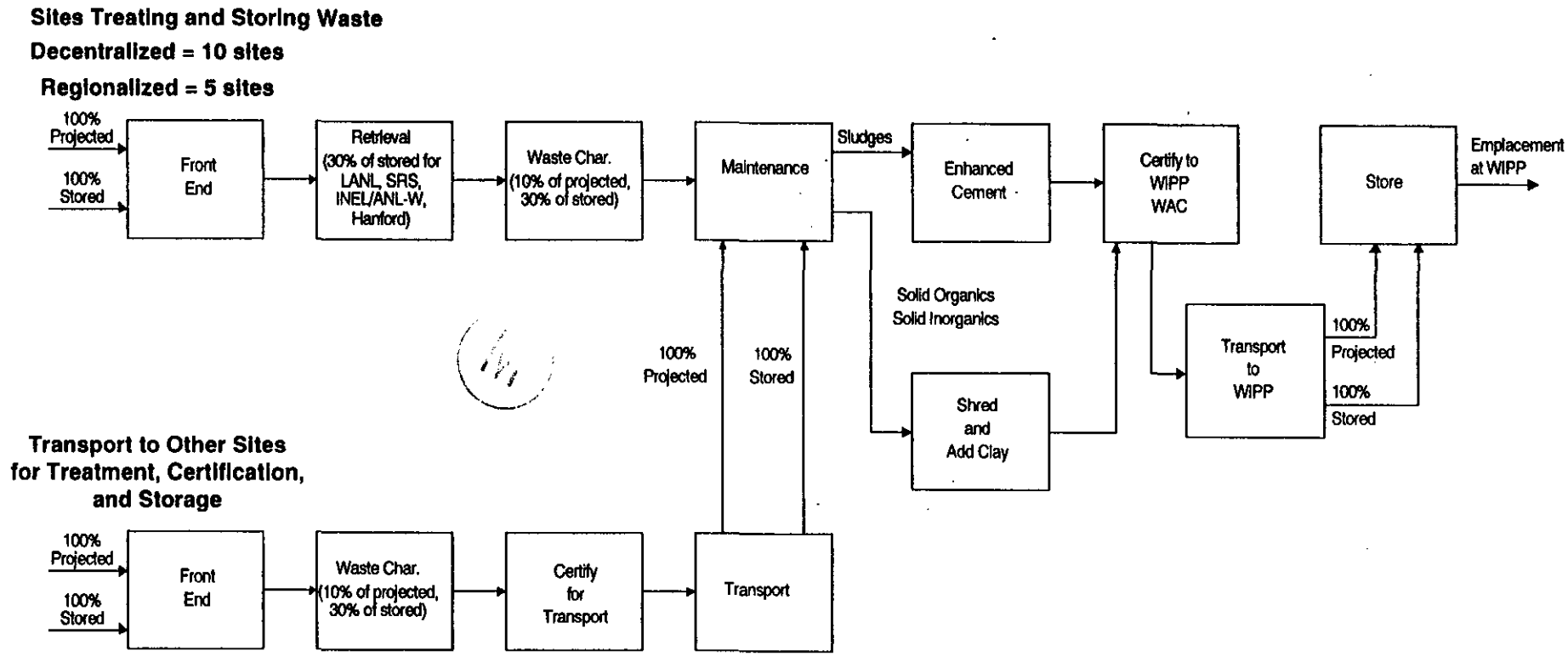

Alternative ID# 94(a-f)

Sludges:	Enhanced Cement
Solid Inorganics:	Shred and Add Clay
Solid Organics:	Shred and Add Clay

Figure 3-31
Decentralized and Regionalized Alternative ID# 94(a-f) Contact Handled Process Flow Diagram E

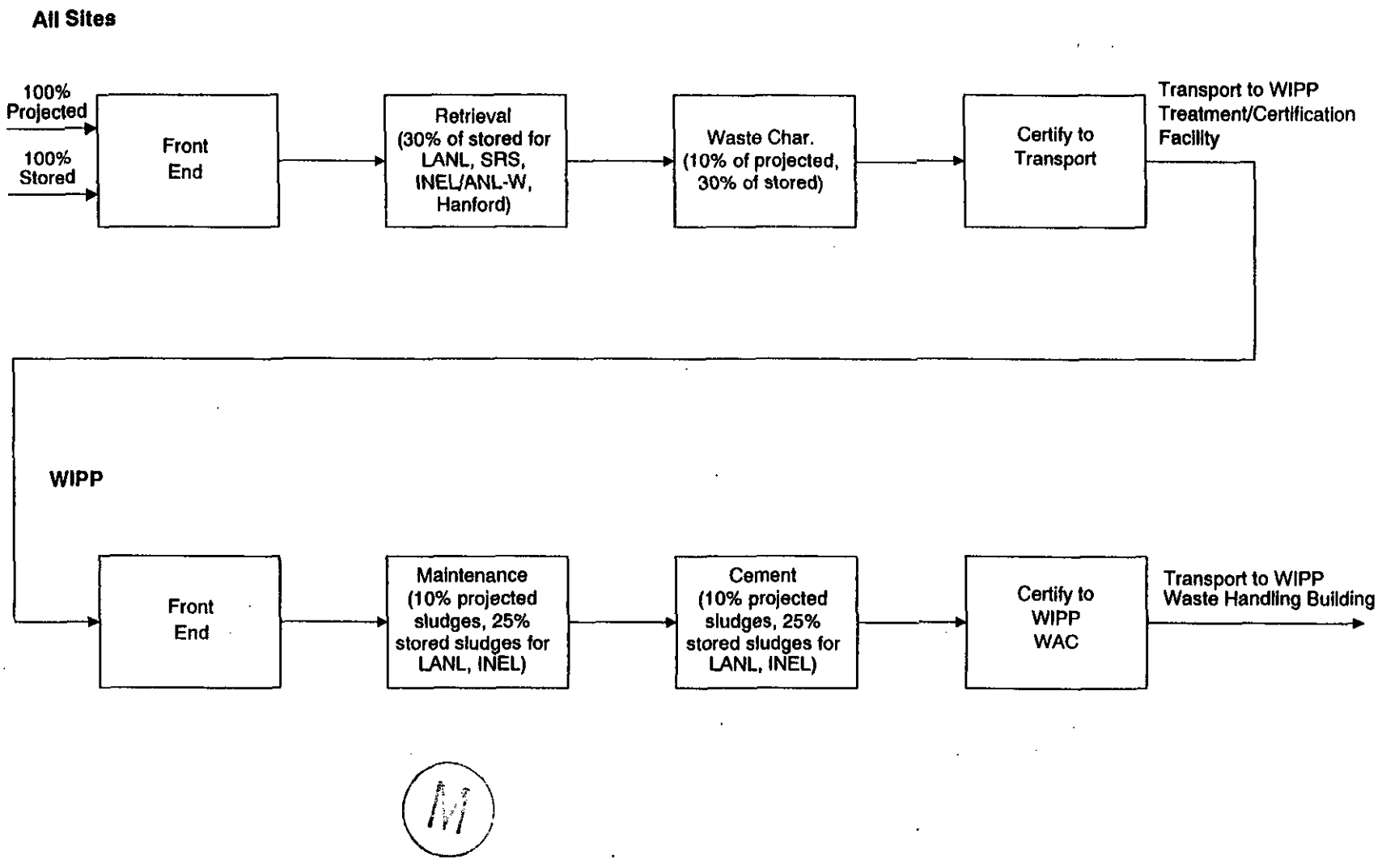

Figure 3-32

Centralized Base Case and Alternative ID #s 33, 35(a&b), 83, and 111 Contact Handled Process Flow Diagram F

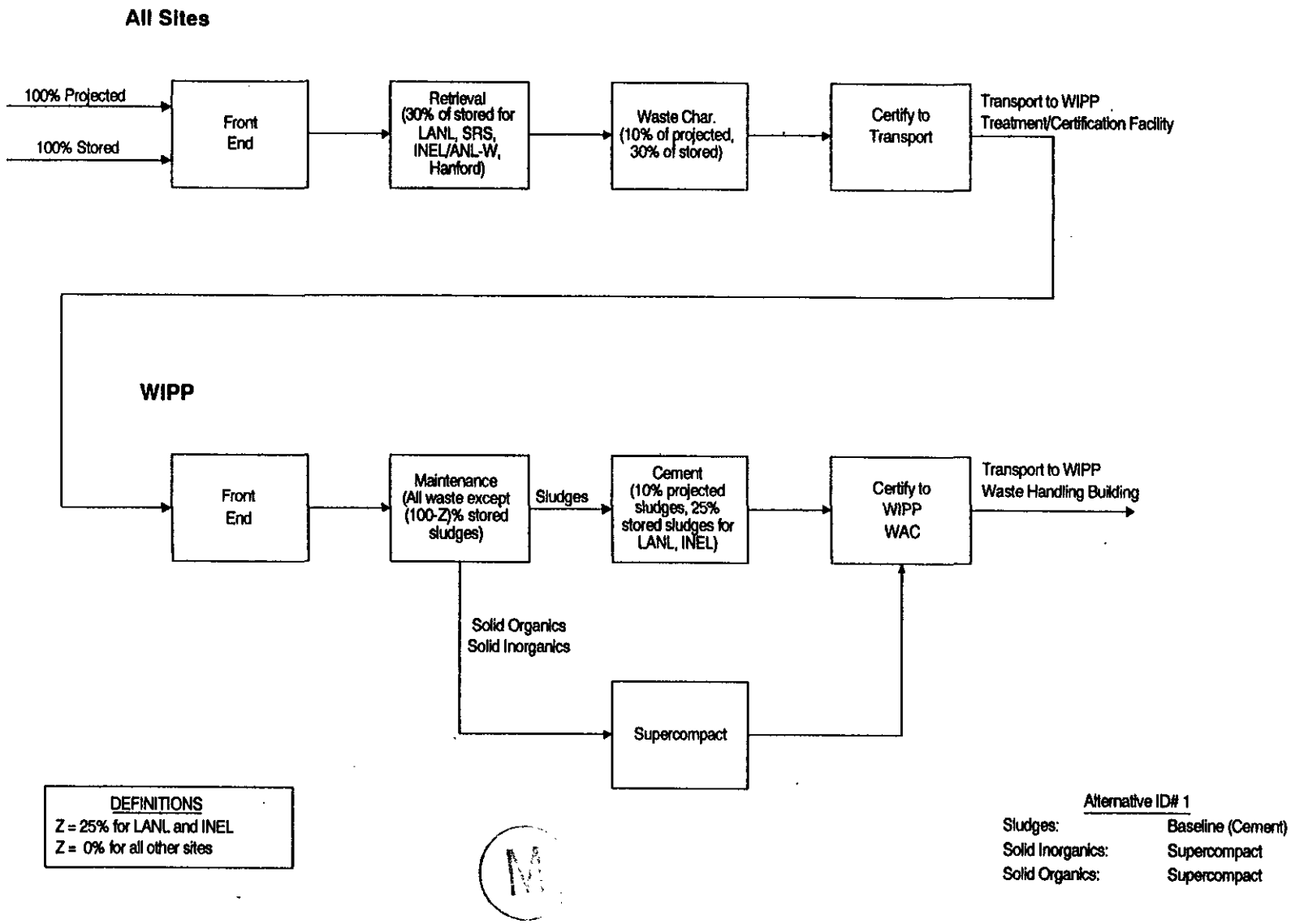

Figure 3-33
Centralized Alternative ID#s 1 and 77(a-d) Contact Handled Process Fl Diagram G

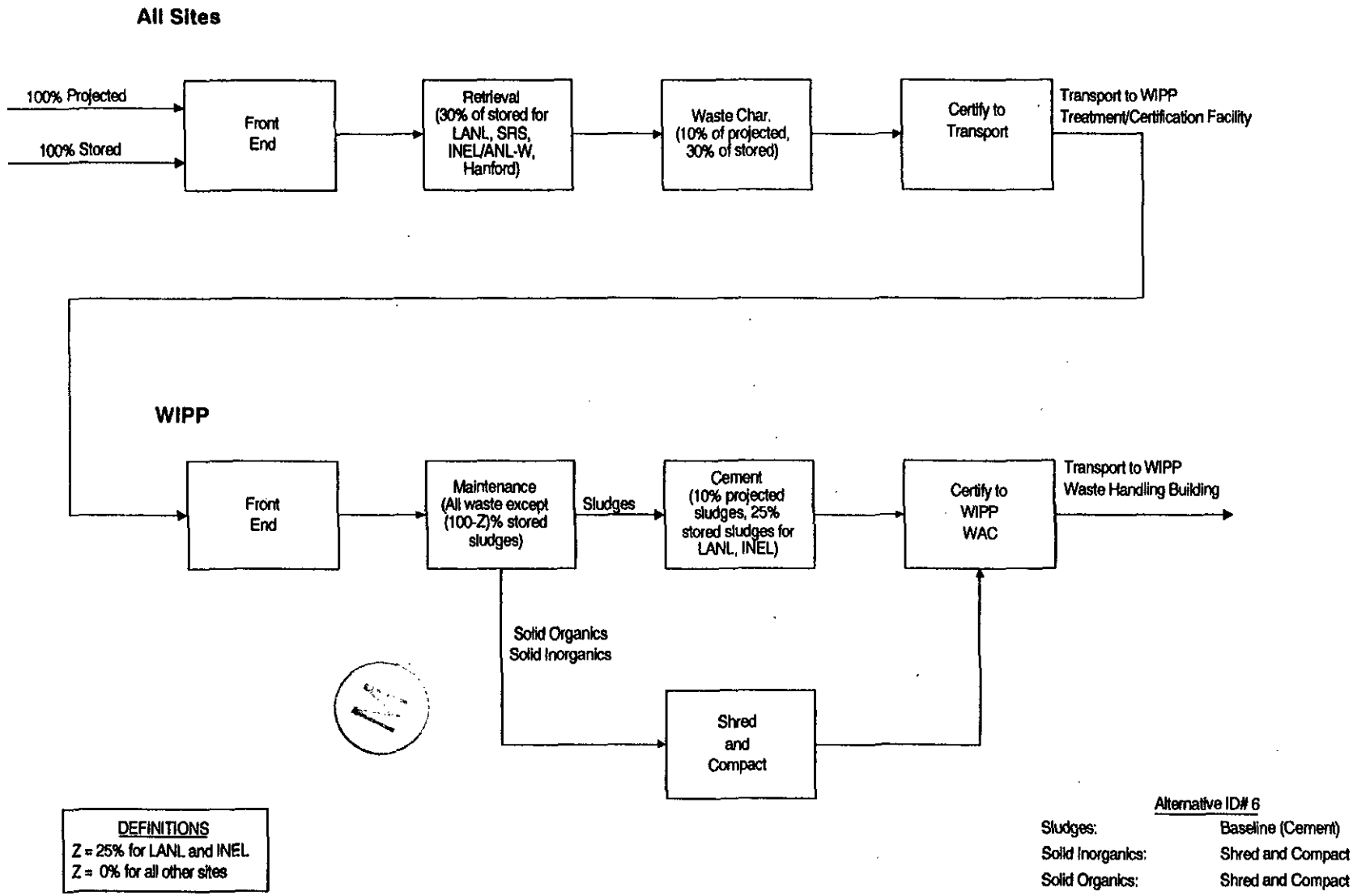

Figure 3-34

Centralized Alternative ID# 6 Contact Handled Process Flow Diagram H

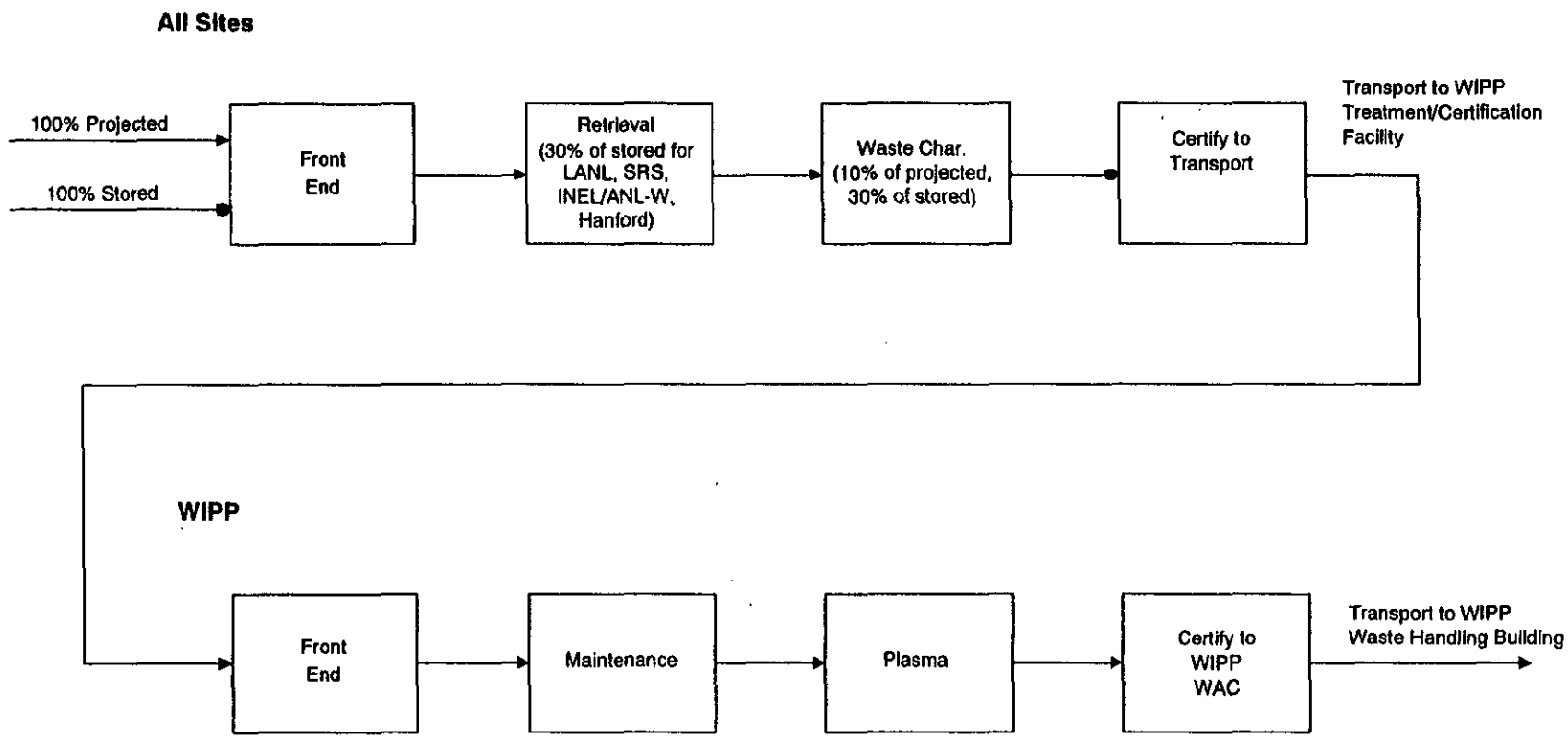

Alternative ID# 10

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure 3-35
Centralized Alternative ID# 10 Contact Handled Process Flow Diagram I

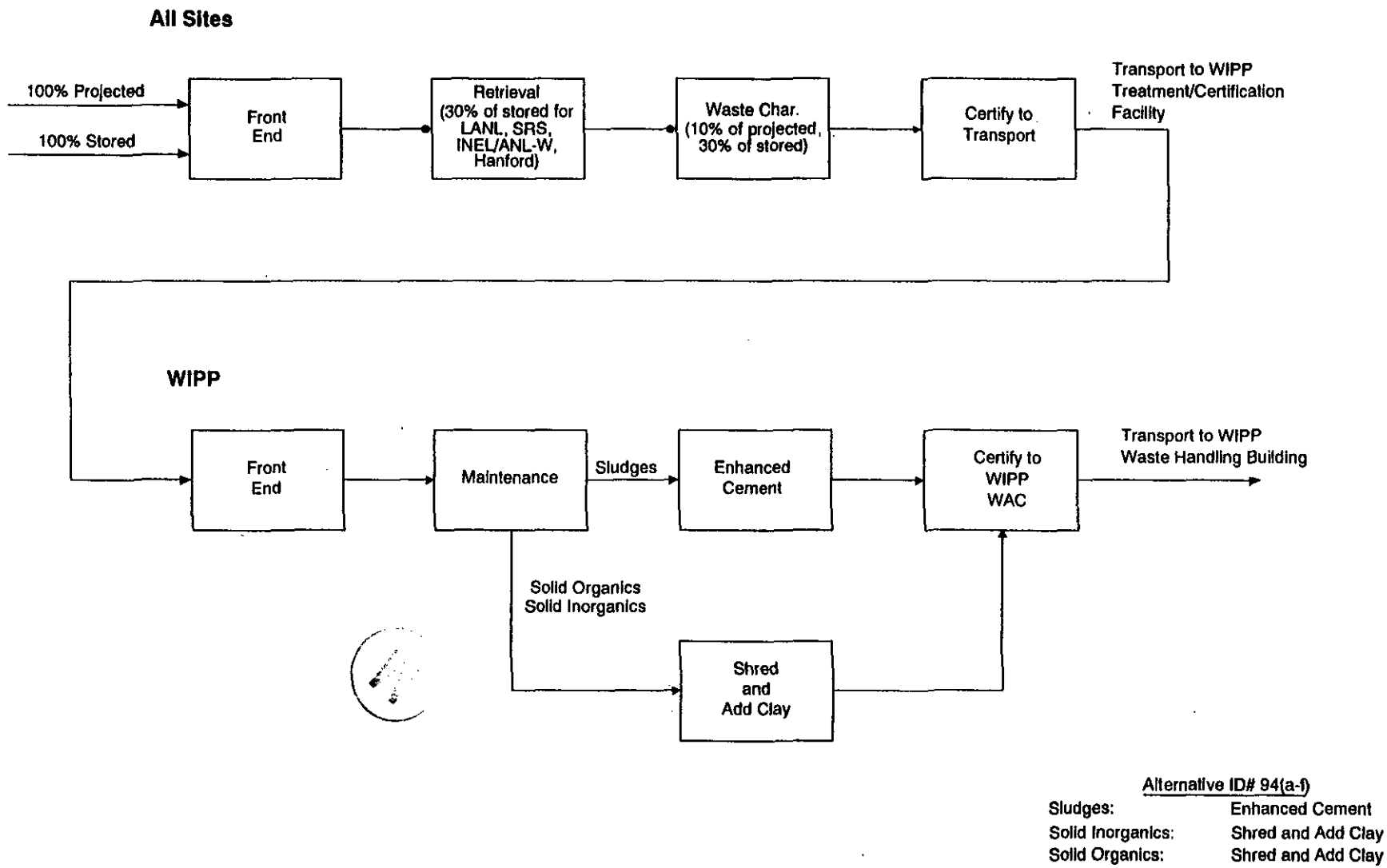

Figure 3-36
Centralized Alternative ID# 94(a-f)
Process Flow Diagram J

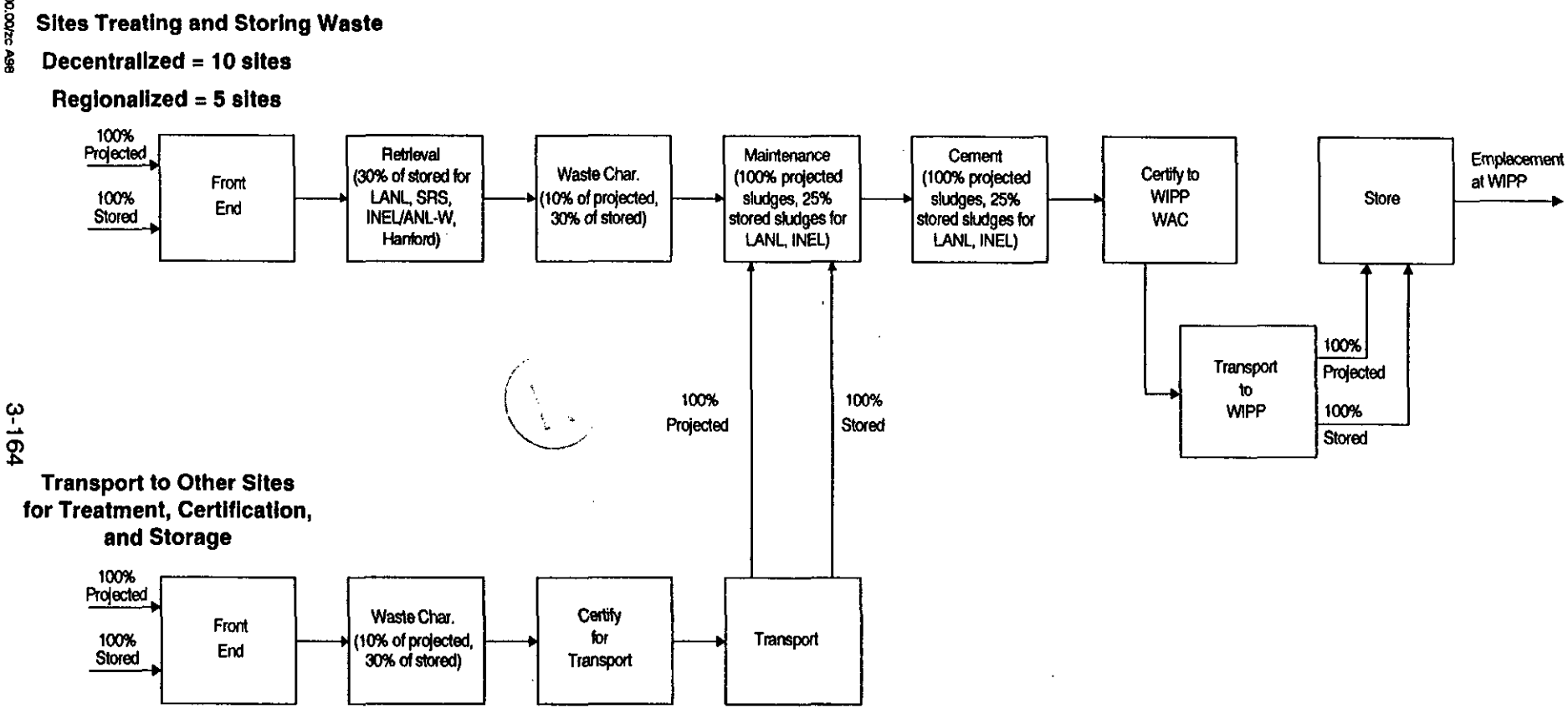

Figure 3-37
Decentralized Base Case Remote Handled Process Fl Diagram K

compacting, plasma melting, enhanced-cement processing, and shredding and adding clay.

- Storage: This module consists of a RCRA-compliant storage building sized to accommodate an accumulation of up to 20 years' volume of waste input from treatment modules. Storage area features include spill collection, sloping floors, sumps, and concrete berms. Monitoring is included for both gamma and alpha radiation control.

- Certification: Certification consists of storage of incoming material, assay and certification, and truck loading. The facility is equipped with a bridge crane and a forklift. It is assumed that certification operations will take place indoors.

- Transportation: Transportation consists of truck shipments. Equipment includes a tractor and trailer transporting three TRUPACT-IIs for CH waste or one RH cask (RH-72B) (a cylinder consisting of a separate inner canister within an outer cask protected by impact limiters at each end) for RH waste.

The process flow diagrams are developed from multiple data sources, and TRU waste processing knowledge from various sources; therefore, the uncertainty of the process flow diagrams cannot be quantified, but should be in the same order of magnitude as the documents used as guidelines for this study. The process flow diagrams developed for this study were designed mostly in accordance with the EM-PEIS and the WMFCITRUW report, however, not every module recommended in the WMFCITRUW report was included in this study. The reasons for deviating from the recommended WMFCITRUW guidance include 1) minimizing the costs of duplicate equipment contained in more than one module, and 2) more accurately representing the functions in existing and planned TRU waste facilities.

Mass and volume throughput are calculated using data from the WIPP BIR (DOE, 1995e). These rates are calculated using a 20-year processing period and a 4,032-hour working year. The mass or volume input to each of the individual modules is shown in Appendix O and is used as the basis for the module throughput which is the primary data used to estimate the cost of the module.

"The TRU waste disposal inventory in the BIR is derived from existing information on waste, which has been provided by DOE TRU waste generator/storage sites and is predominately based on process knowledge" (DOE, 1995e). Any uncertainty within the BIR is carried into this EA study. Calculated processing rates using a 20-year period and 4,032-hour working year may also introduce a level of uncertainty in estimating the costs. Many of the calculated processing rates were below or beyond the range of processing rates listed in the WMFCITRUW report and may cause the calculated costs to be skewed.

Numerical data values for cost versus flow rate information were obtained from the authors of the WMFCITRUW and used to construct approximate relations or curve fits for cost versus mass or volume throughput for a specific processing module. Cost data are available in the WMFCITRUW report according to specific project activities including pre-operations (pre-ops), planning life cycle cost (PLCC), construction, O&M, and D&D. Appendix P provides additional information on the method for establishing the modules. The PLCC is the summation of pre-ops, construction, O&M and D&D cost.

The WMFCITRUW was developed specifically to calculate facility costs in the EM-PEIS. Neither the WMFCITRUW nor the EM-PEIS provide a quantitative uncertainty of the costing data. From the costing categories listed in Plant Design and Economics for Chemical Engineers (Peters et al., 1991), the WMFCITRUW study cost estimates fall into the Study Estimate cost category where the probable accuracy of the estimate is plus or minus 30 percent.

To ensure that the waste processing cost estimates presented in this study account for those facilities that currently exist, a list of existing facilities was assembled from information gathered from several sources, including personal communications (Bjotued, 1995; George, 1995) and preliminary information being developed by the DOE National TRU Program Office (NTPO). Data from these sources were consolidated into a single list used to describe existing TRU waste processing facilities for this study, as shown in Table 3-47. All of the information sources have not been subject to extensive review, thus uncertainty of the data arises from the uncertainties associated with the sources themselves, and any changes that have occurred between the current time and the time these sources were compiled.

The existing facility list was used to adjust process cost estimates. O&M and D&D costs were added and applied to facilities that had current existing TRU waste processing facilities for a specific module, while the PLCC was applied to facilities that did not have existing processing capabilities for a specific module.

Combining all of the information gathered, computer cost-model programs have been developed using Visual Basic computer programming language and cost equations were applied based on a calculated mass or volume throughput for a specific module. These programs were implemented using a computer spreadsheet with mass and volume throughput data. The computer cost model programs calculate the cost for each processing module for each alternative in each configuration. Summary results for process costs are presented in Section 3.7.4.1 of this report.

3.7.2.2 TRU Waste Transportation Cost Estimation Methodology

This section presents the information sources and assumptions used to complete transportation cost estimations for the various alternatives.

The guidance chosen for development of transportation cost estimates comes from "Waste Management Facilities Cost Information for Transportation of Radioactive and Hazardous Materials," (Feizollahi et al., 1994). This report was also used as guidance for development of transportation cost estimation in the Draft EM-PEIS. The report also covers the procedure for estimating the costs of various types of wastes, including an entire section on RH and CH TRU waste transportation. The report includes only guidance for estimating the cost of transportation of waste; loading and unloading operations are included in the facility operating and maintenance costs.

It is assumed that all CH TRU waste will be shipped by truck in TRUPACT-II containers, which have mass, volume, and radionuclide restrictions that limit the amount of waste transported in one shipment. Using volume and mass data for waste at each of the sites, both mass-limited and volume-limited cases were developed (Appendix P), but radionuclide content was not considered a limiting factor for CH-TRU waste. For RH-TRU waste, however, radionuclide limitations were important, and the volumes had to be further reduced to meet container and shipping

1

TABLE 3-45

EXISTING TRU FACILITIES

	Waste Processing Functions								
								Treatment[b]	
Site	Retrieve	Waste Char	Front End	Certify/ Ship	Maint	Storage	Grout	Super Cmpct	Plasma
Major Generator/Storage Sites									
ANL-E	–		X		X	X			
Hanf		X	X	X	X	X			
INEL/ ANL-W		X	X	X	X	X			X[c]
LANL		X	X		X	X	X		
LLNL	–	X	X	X	X	X			
Mound	–		X		X				
NTS	–		X		X	X			
ORNL	–	X	X	X	X	X			
RFETS	–	X	X	X	X	X	X	X	
SRS			X		X	X			
Small Quantity Sites									
Ames	–	P	[a]	P	–	–	–	–	–
BCLDP	–	P	[a]	P	–	–	–	–	–
BT	–	P	[a]	P	–	–	–	–	–
ETEC	–	P	[a]	P	–	–	–	–	–
KAPL	–	P	[a]	P	–	–	–	–	–
LBL	–	P	[a]	P	–	–	–	–	–
Pad	–	P	[a]	P	–	–	–	–	–
Pantex	–	P	[a]	P	–	–	–	–	–
SNL	–	P	[a]	P	–	–	–	–	–
U Mo	–	P	[a]	P	–	–	–	–	–
WVDP	–	P	[a]	P	–	–	–	–	–

Notes:
X = Site has existing facilities to perform this function. No credit was given for planned facilities. Costs only include 20 years of O&M and D&D.
– = Site will not require this function.
P = This function will be accomplished utilizing portable equipment.
[a]For sites which will use portable equipment for waste characterization and certification and shipment, it is assumed that existing facilities will be sufficient for administrative purposes.
[b]No facilities exist to treat TRU waste using shred/compact, shred/add clay, or enhanced cement.
[c]It is assumed that the INEL Pit 9 treatment facility will be available to treat stored waste.

specifications. Appendix P shows how the number of shipments was derived for each EA and each configuration. The number is drums allowable in a TRUPACT II shipment is dependent on the density of the waste. Shipments may include as many as 42 drums of low density waste or as little as 14 drums of high density waste. It should be noted that the number of shipments used to calculate transportation costs differs from the number of shipments used to estimate transportation risks. Transportation risk methodology (Section 3.5.2) adjusts the number of shipments so that they represent a conservative bounding case. Transportation costs were based on less conservative estimates as shown in Appendix P.

The planned route and total mileage traveled for each of the shipments was determined by the HIGHWAY 3.3 Routing Model. The model is an extensive computerized atlas that determines the optimum route for a given origin and destination. The DOE sites that produce and treat TRU waste are all included, as is the WIPP repository. The program allows the user to place constraints on route choices, and several were invoked in order to choose the most preferred route for TRU waste transportation. Route constraints include the barred use of roads that prohibit truck use, the preferred use of routes already designated for hazardous waste transportation, and the use of roads in New Mexico designated as preferred shipment routes to the WIPP. The model is described in Section 3.5.2, Methodology Used to Evaluate Factor 5 (Risk of Transportation).

There are three types of costs associated with transportation. Carrier costs and hardware costs are functions of a moving vehicle and are combined to make up the "costs per loaded mile" (CPLM). Carrier costs include tractor, fuel, labor, insurance, security escort, taxes, tools, permit fees, and related costs incurred during waste transportation. Hardware costs are associated with maintenance of the specialized trailers and railroad cars used to transport waste. Fixed costs are independent of the distance traveled and considered separately. Fixed costs include demurrage costs of the carrier and the hardware used in the shipment. The total cost for a single shipment can be determined by adding the fixed costs to the product of the CPLM and the number of miles traveled. It should be noted that the CPLM unit rate is based on one-way mileage from origin to destination, but that the total cost for one shipment includes the return trip (see Section 3.5.3.5).

Finally, the process of estimating the costs is a straightforward analysis (Appendix P). The costs are derived from the number of shipments, taking into consideration the volume of drums or standard waste boxes, waste density, and the radionuclide inventory of the waste. The number of shipments are applied to the CPLM and the round-trip mileage, and the fixed costs are added to determine the total transportation costs for each individual site. Transportation cost estimations were performed for the decentralized and regionalized cases and each alternative therein. An estimation was also made for the centralized baseline. Since the centralized transportation configuration requires that all waste be treated at the WIPP, all the centralized alternatives are similar from a transportation point of view. Results are discussed in Section 3.7.4.2.

There are relatively few sources of uncertainty in the development of the transportation cost estimations. Included in these are the uncertainty of the waste inventory requiring transportation and the uncertainty in the numbers provided in the report used as guidance for estimate development. The level of uncertainty is discussed in Section 3.7.4.2.

3.7.2.3 Backfill Emplacement Cost Estimation Methodology

Backfill emplacement costs were developed by analyzing a logical approach to emplacing material into a panel. The approach was generic in nature to accommodate the fact that an exact method of emplacement has not been developed. The approach for estimating the costs of emplacement are generated by applying mine development data sources to an activity that is not characteristic to the mining industry (Appendix P). The backfilling of waste emplaced in a mine has not been an activity that is common practice for the DOE or mining industry.

The cost estimation of a backfill operation had to be developed based on the rate at which backfill would be emplaced. The assumptions for this estimation are listed in section 3.7.3. Once the capacity of the equipment requirement is determined a cost model determines the cost requirement for backfill.

The primary source of costing information is the SME Mining Engineering Handbook (Hartman, 1992) which provides a logical approach to the activities that would be performed. Assumptions had to be made in order to provide some logical data points for performing a backfill activity. An estimation of this type would be categorized as a Study Estimate where the uncertainty of the estimate is plus or minus 30 percent.

Data for the estimate is dependent on the mass and volume of backfill material. The backfill is emplaced daily as a batch and would not interrupt the waste emplacement activities. The working rate for backfill emplacement is assumed to be 960 hours per year for 35 years.

Calculation of the cost estimation is developed utilizing a spreadsheet format that applied the cost equations to the rate at which the backfill would be emplaced. The spreadsheet calculated the cost for each alternative that had a backfill associated with it.

3.7.2.4 WIPP Waste Operations Emplacement Cost Estimation Methodology

The cost estimation for the impacts associated with the WIPP operations only analyzed the incremental costs to the actual activities associated with waste handling and emplacement. These impacts provide a measure of the planning necessary to implementing an alternative.

For each of the alternatives and configuration (decentralized, regionalized, centralized) the throughput of the waste is determined in order to handle and emplace the waste at WIPP. The throughput rate is based on the number of transported waste shipments to be handled at WIPP (see Appendix P). The waste work-off and repository configuration is analyzed against the baseline to determine additional equipment requirements or modifications. The next parameter is to determine the manpower necessary to handle the waste was also determined. Guidance was provided in order to determine the size of a crew and the waste handling capacity.

The number of waste shipments to the WIPP is determined based on the methodology for transportation (see section 3.7.2.2). The throughput rate is calculated by applying the number of shipments to the operational period of the WIPP. The manpower requirements for the waste handling operations are given as three possible crews based on the throughput rate. The capital equipment requirement is estimated and totaled for the applicable alternative.

Calculation of the WIPP handling cost estimation was developed utilizing a spreadsheet format that applied the capital requirements and the throughput rate of the waste to the manpower requirement. The cost was calculated for each alternative and case. A comparative analysis was performed to the baseline decentralized alternative.

3.7.2.5 Schedule Methodology

The EA analysis included developing a permitting, construction, and operating schedule for each alternative and the baseline. Schedules are developed for each treatment option and then combined as appropriate to determine a schedule for each alternative. For example, the schedule for Alternative 94 incorporates the schedules for treatment scenarios of Enhanced Cement and Shred and Add Clay. The schedules will not be affected by the different site configurations, so these are not included.

For each treatment option, several steps are followed in order to arrive at a schedule. It was assumed that these treatment units would be capital projects, so a generic "Capital Project Logic Flow Diagram," developed for RFETS capital projects, was modeled to determine the major activities and their logical relationship to the other major activities (Appendix Q). To arrive at meaningful time estimates, it was necessary to develop some schedule detail, which was based on previous experience at RFETS, INEL, and Hanford. For some of the tasks, a deterministic approach was used, also referred to as Critical Path Method (CPM) scheduling, based on similar or identical work performed previously. For other tasks, a Program Evaluation and Review Techniques (PERT) analysis was applied to arrive at a probable duration estimate. PERT uses three time estimates for each activity: an optimistic or minimum time T_o, a most likely or modal time T_m, and a pessimistic or maximum time T_p. This probabilistic approach lends itself well to activities for which there is little historical record. PERT analysis was applied to the Plasma alternative, whereas a CPM analysis was applied to the Shred and Compact alternative. Once the task durations were determined, the activities were loaded into PRIMAVERA with the appropriate logic ties, and the system was allowed to perform the schedule calculations. Table 3-46 presents the results of a PERT analysis that was used as a starting point for estimating activity durations for several of the major activities.

The operational life for the WIPP site was constrained to be 35 years. This provides the basis for the operational and backfill activities to be performed within the limitation of time. Therefore, the backfill and waste emplacement operations do not have any significant schedule impact.

Schedule scenarios for each treatment option are developed relative to the baseline and Shred and Compact to have a reference point for subsequent schedule development. The primary differences between the schedules for each treatment option are the durations estimated for the design, construction, and D&D activities. The more complex the treatment process, the longer the durations for each of these activities. The baseline and Shred and Compact scenarios are assumed to have the shortest schedules because they employ the simplest technologies, followed in order of complexity by Shred and Compact, Enhanced Cement, Supercompact, and Plasma. For the Plasma Melter scenario, the RCRA permitting and National Environmental Policy Act (NEPA) documentation durations are also increased because of the likelihood of significant public and agency comments.

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TABLE 3-46

PERT ANALYSIS TIME ESTIMATES

Major Activities[a]	To	Tm	Tp	Te	Te in Days
Preliminary Safety Analysis	.890	1.000	2.250	1.190	298
Final Safety Analysis Report	1.420	2.000	4.440	2.310	578
Title I Design	.375	.500	1.250	.604	151
Title II Design	.738	.860	2.810	.998	250
Construction	1.910	2.000	3.160	2.178	545
NEPA	1.781	2.120	7.632	2.982	746
Prevention of Significant Deterioration Preparation	.840	1.000	2.250	1.182	295
Prevention of Significant Deterioration Approval	.335	.830	2.330	.998	249
NESHAPS	.750	1.000	2.500	1.208	302
Resource Conservation & Recovery Act Permit Preparation	.269	.320	.720	.378	95
Operations Readiness Review	1.840	1.840	4.287	2.248	562
Te=New Estimated Duration in Years	$Te=\frac{To+Tm(4)+TP}{6}$				

[a]Some major activities may be performed in parallel.
*Values are approximate.

3.7.3 Assumptions and Data for Factor 7

Two major sources of data are used for the analysis of cost and schedule:

- The initial retrievable and projected waste volumes are obtained from the WIPP BIR (DOE, 1995e) (see Appendix O).
- Guidance for process flow diagrams and costing and cost curves are obtained from the WMFCITRUW report.

The major assumptions follow:

- Mass and volume changes occur during certain processing activities. A summary of the mass and volume changes is presented in Table 3-47.
- The volume of waste categorized as "unknown" is processed the same as solid organics and inorganics. However, the mass of unknown waste is assumed to be zero because no information is available regarding the density of the unknown waste and the volume of this waste is small compared to the total volume of waste destined for WIPP.
- Thirty percent of the stored waste at Los Alamos National Laboratory (LANL), Savannah River Site (SRS), INEL/Argonne National Laboratory-West (ANL-W), and Hanford requires retrieval.
- Twenty-five percent of stored sludges at LANL and INEL requires re-grouting, and all of the stored sludges at ORNL require grouting.
- Waste is treated and or stored according to the site configurations denoted in Table 3-48.
- Waste is processed 4,032 hours per year over a 20-year waste processing facility operating life.
- All waste within a major waste form category (i.e., sludges, solid organic, solid inorganic) can be treated using a specified technology.
- The supercompaction module does not include shredding.
- Costs for a vitrification unit are considered adequate for the costs for a plasma melter.
- Costs for enhanced cement processing are identical to costs for grouting except for material costs.
- Costs for shredding and adding clay are identical to costs for grouting except for material costs.

TABLE 3-47

MASS AND VOLUME CHANGES FOR WASTE TREATMENT/PROCESSING MODULES

Module	Mass Ratio (Output/Input)	Volume Ratio (Output/Input)
Front End	1.0[a]	1.0[b]
Retrieval	1.1[a]	1.1[b]
Waste Characterization	1.0[b]	1.0[b]
Maintenance	1.0[b]	1.1[b]
Grout	3.15[a]	2.5[b]
Supercompact	1.1[a]	0.35[b]
Shred and Compact	1.1[a]	0.76[b]
Shred and Add Clay	2.35[b]	1.0[b]
Plasma	1.0[a]	0.33[b]
Certification	1.0[b]	1.0[b]
Storage	1.0[b]	1.0[b]

[a]Source (Feizollahi and Shropshire, 1994)
[b]Values derived from engineered calculations.

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TABLE 3-48

SITE TRANSFERS FOR THE DECENTRALIZED, REGIONALIZED, AND CENTRALIZED CONFIGURATIONS

Decentralized			Regionalized			Centralized		
Site	CH	RH	Site	CH	RH	Site	CH	RH
ANL-E*	WIPP	ORNL+	ANL-E	SRS	ORNL	ANL-E	WIPP	WIPP
Ames	ANL-E#		Ames	SRS		Ames	WIPP	
BCLDP		ORNL+	BCLDP		ORNL	BCLDP		WIPP
BT	Mound	ORNL+	BT	SRS	ORNL	BT	WIPP	WIPP
ETEC	NTS		ETEC	INEL/ ANL-W		ETEC	WIPP	
INEL/ ANL-W*	WIPP	WIPP	INEL/ ANL-W*	WIPP	Hanford	INEL/ ANL-W	WIPP	WIPP
KAPL	Mound	ORNL+	KAPL	SRS	ORNL	KAPL	WIPP	WIPP
LANL*	WIPP	WIPP	LANL*	WIPP	Hanford	LANL	WIPP	WIPP
LBL	(LLNL)		LBL	Hanford		LBL	WIPP	
LLNL*	WIPP		LLNL	Hanford		LLNL	WIPP	
Mound*	WIPP		Mound	SRS		Mound	WIPP	
MU	ANL-E#		MU	SRS		MU	WIPP	
NTS*	WIPP	WIPP	NTS	INEL/ ANL-W	Hanford	NTS	WIPP	WIPP
ORNL*	WIPP	WIPP	ORNL* (rh)	SRS	WIPP	ORNL	WIPP	WIPP
PA	ORNL		PA	SRS		PA	WIPP	
Pantex	LANL		Pantex	LANL		Pantex	WIPP	
RFETS*	WIPP		RFETS*	WIPP		RFETS	WIPP	
Hanford*	WIPP	WIPP	Hanford*	WIPP	WIPP	Hanford	WIPP	WIPP
SNL/NM	LANL		SNL/NM	LANL		SNL/NM	WIPP	
SRS*	WIPP	WIPP	SRS*	WIPP	ORNL	SRS	WIPP	WIPP

Notes:

* Denotes a processing site.

ORNL+ *Remote handled wastes from BCLDP, BT, KAPL, (these are not discussed in the EM-PEIS) and ANL-E* should be processed at ORNL instead of Mound because Mound currently does not process or store RH waste.

ANL-E# The EM-PEIS discusses that ANL-E will process and ship their own CH waste, but does not cover Ames and MU, which are closer to ANL-E than ORNL.

(LLNL) EM-PEIS indicates LBL waste will be shipped to Hanford. LBL waste should be shipped to LLNL because it is much closer.

- Costs for shredding and compacting are analyzed as a modified cost module for supercompaction.
- Funding is unconstrained for the purposes of developing schedules.
- Costs are in 1994 dollars and do not take into account escalation or the time value of dollars.
- The operations at WIPP are 35 years.
- The waste emplacement operations at WIPP consists of two eight hour shift operations five days a week.
- Both waste handling and backfill are completed in the 35 year operational period.
- Waste emplacement is dependent upon the number of TRUPACT-IIs per day.
- Backfill costs are based on a batch per day (tons) of material that would be emplaced each day.
- Backfill of the rooms does not impact operations.

3.7.4 Results of Analysis for Factor 7

3.7.4.1 Process Costing Results

As described in Section 3.7.2.1, process costs are calculated using computer program cost models developed for this study (Appendix P). Costs are calculated for each alternative in each configuration for CH waste and for decentralized baseline for RH waste. Cost values are based on 1994 cost data and do not take into consideration time value of money or escalation for expenditures occurring during the planning life cycle (Feizollahi and Shropshire, 1994). Summaries of these costs are presented in Tables 3-49 and 3-50. These tables present the summary of process costs for the baseline and each of the different alternatives in each of the configurations for CH waste and for the decentralized baseline for RH waste. Processing schemes for Alternatives 33, 35(a&b), 83, and 111 are identical to the processing schemes for the baseline for each of the configurations, therefore their processing costs are assumed to be identical to the processing costs for the baseline. The processing scheme for Alternative 77 (a-d) is the same as the processing scheme for Alternative 1 for each of the configurations; therefore, its processing costs are identical to the process costs for Alternative 1. Alternative 33, 35(a-b), 77(a-d), 83, and 111 will be omitted from further discussion in this section because they are not unique with respect to processing cost.

The range of processing costs for CH waste varies between $3.2 billion for the centralized baseline and $6.3 billion for decentralized Alternatives 94(a-f). The process costs for the decentralized alternatives are the highest for a specific alternative; the process costs for the centralized configuration are the lowest. This was expected due to process costs for treatment

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TABLE 3-49

CH WASTE PROCESSING COST GRAND TOTALS ($K)

Alternative ID #	Decentralized	Regionalized	Centralized
Baseline	3,576,954	3,418,650	3,202,376
1	4,379,357	3,974.696	3,411,991
6	4,117,678	3,757,294	3,329,333
10	5,966,427	4,992,885	3,960,139
33	3,576,954	3,418,650	3,202,376
35 (a&b)	3,576,954	3,418,650	3,202,376
77(a-d)	4,379,357	3,974,696	3,411,991
83	3,576,954	3,418,650	3,202,376
94 (a-f)	6,301,672	5,502,932	4,217,091
111	3,576,954	3,418,650	3,202,376

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TABLE 3-50

RH CENTRALIZED BASELINE COST PER SITE ($K)

Site	Cost
BCLDP	0
BT	0
HANFORD	173,279
INEL/ANL-W	170,849
KAPL	0
LANL	206,932
ORNL	339,190
SRS	121,730
GRAND TOTAL	1,011,980

(maintenance and specific alternative treatments) being applied to a larger number of sites in the decentralized (10 sites) and regionalized (5 sites) configuration as compared to the centralized (1 site) configuration.

The processing costs for the baseline are least expensive when compared to the alternatives; processing costs for Alternative 94 are most expensive. This results from a combination of effects. One explanation for this is that the treatment module throughput values for the baseline are lowest; treatment module throughput values for Alternative 94 (a-f) are highest. The baseline consists of treating to the WIPP-WAC (DOE, 1991c). Treatment to WAC entailed shredding and grouting a portion of the existing sludges and all of the projected sludges, along with repackaging waste as necessary to meet transportation and WIPP requirements. In Alternative 94(a-f) all of the waste is treated in some way by either repackaging, enhanced-cement processing, or shredding and adding clay. Thus, the "waste treatment" processing throughput for Alternative 94 (a-f) is higher than the baseline.

The second explanation is that for the shred-and-add-clay and, enhanced-cement cost modules, it is assumed that there are currently no facilities that had these processing capabilities. The result is that the PLCC is applied to all appropriate sites (decentralized, regionalized and centralized configurations) making Alternative 94 (a-f) more costly than other alternatives (e.g Alternative 1, etc.) where some facilities currently do have a specific processing capability.

Another observation from the information presented in Table 3-49 is that after taking the level of uncertainty of the cost estimations plus or minus 30 percent (Section 3.7.2.1), that the centralized alternative processing costs are approximately the same as compared to the decentralized baseline. The decentralized baseline represents the current strategy for managing CH waste.

The RH process costs for the baseline decentralized configuration is $1.0 billion.

3.7.4.2 TRU Waste Transportation Cost Estimation Results

This section provides information on the results of the transportation cost estimations for the various alternatives. For information regarding the sources and assumptions used to complete transportation cost estimations, refer to Section 3.7.2.2 and Appendix P.

Transportation cost estimations are performed for each configuration and alternative. Within the centralized, regionalized, and decentralized configurations, some of the alternatives are identical from a transportation standpoint, making the transportation costs for these alternatives the same. For example, the centralized configuration provides only one set of transportation requirements because all treatment occurs at the WIPP, making the transportation costs for all centralized alternatives the same. Similarly, the regionalized and decentralized alternatives that vary backfill options do not provide unique situations to transportation, so these cases have transportation costs equal to those of other alternatives. Alternatives that present transportation with a unique scheme include the baseline and Alternatives 1, 6, 10, and 94(a-f).

Shipments being limited by both mass and volume has a significant effect on the transportation costs for alternatives that result in a more dense waste form, especially supercompaction (alternatives 1 and 77), plasma melting (alternative 10), and shred/add clay (alternatives 94 a-f). In the case of supercompaction and plasma melting, the final waste volumes were significantly reduced, but the transportation costs for the decentralized configurations only reduced by less

than 1 percent and less than 13 percent, respectively. In the case of alternative 94, the final waste volume was not decreased and the waste density was significantly increased, causing many of the shipments to become mass-limited. In the decentralized configuration, this had the effect of increasing the transportation costs by more than 66 percent. It is clear increasing waste density plays a key role in reducing the benefits derived from waste treatments that result in a volume reduction.

The transportation costs range from a minimum of $603.4 million for decentralized Alternative 10, which has the largest degree of waste volume reduction at the most number of sites, to a maximum of $1.2 billion for regionalized Alternative 94(a-f), which not only increases the original volume of waste by the largest percentage, but also increased the density of the final waste, thus causing mass-limited shipment, and also has the highest percentage of "double handled" waste. An estimate to handle RH waste for the decentralized baseline is also prepared. In addition to the $690.9 million estimated to transport CH waste for this alternative, $318.3 million is estimated to transport RH waste. Even though the volume of RH waste is significantly smaller than CH waste, to avoid exceeding radionuclide content limitations during transportation, a much smaller volume is carried by each shipment. The Transportation Cost Estimation Summary, Table 3-51 presents the estimated transportation costs for each alternative. The level of uncertainty in the cost estimates comes from two sources. One, the level of uncertainty in the stored and projected waste volumes in the BIR (DOE, 1995e) and two, the level of uncertainty in the studies used as guidance to develop the transportation cost estimates. For guidance in estimating transportation costs, a report titled "Waste Management Facilities Cost Information for Transportation of Radioactive and Hazardous Materials" (Feizollahi et al., 1994), was contracted by the DOE, and Revision 1 was completed in September 1994. A report of this nature would be classified as a "study estimate" (Peters and Timmerhaus, 1991), and would have a probable accuracy only within plus or minus 30 percent.

3.7.4.2.1 Backfill Emplacement Cost Results

Backfill emplacement costs are determined for each of the alternatives that specified backfill. The cost for emplacement activities is independent to the case of the alternative (decentralized, regionalized, centralized) and is only affected by the mass and volume of the backfill. Thus, costs for the alternatives are dependent only upon the amount and type of backfill that is to be utilized. Table 3-52 provides a summary of the estimated cost total for each alternative. The lowest cost for backfill are alternatives 77(b-d) which consists of the least amount of backfill material due to the reduced room height for waste. The highest cost for backfill are alternatives 35(a-b) and 94d, respectively. This is due to the increased complexity of emplacing a wet (grout) backfill.

Cost of backfill is categorized as a planning cost estimate and has an uncertainty of plus or minus 30 percent. In addition the estimation does not include the cost of the material to be utilized for backfill. It is assumed that backfill materials consisting of salt would utilize the existing mined materials.

3.7.4.2.2 WIPP Waste Operations Emplacement Cost Results

Cost information for the emplacement activities associated with the waste handling at the WIPP are discussed in this section. The discussion includes the assumptions and limitations of the results. The comparative analysis of the WIPP waste handling and emplacement activities is discussed is shown in Table 3-53. The cost of WIPP handling and emplacing the waste is

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TABLE 3-51

TRANSPORTATION COST GRAND TOTAL SUMMARY

	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
CH Centralized Baseline	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 1	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 6	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 10	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 33	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 35	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 77	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 83	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 94	17,401	47,883,104	161,133	449,956	611,089
CH Centralized Alternative 111	17,401	47,883,104	161,133	449,956	611,089
CH Regionalized Baseline	20356	54,395,038	188,497	512,795	701,291
CH Regionalized Alternative 1	19948	54,214,868	184,718	510,549	695,268
CH Regionalized Alternative 6	19253	51,234,016	178,283	483,104	661,387
CH Regionalized Alternative 10	17627	47,954,934	163,226	451,451	614,677
CH Regionalized Alternative 33	20356	54,395,038	188,497	512,795	701,291
CH Regionalized Alternative 35	20356	54,395,038	188,497	512,795	701,291
CH Regionalized Alternative 77	19948	54,214,868	184,718	510,549	695,268
CH Regionalized Alternative 83	20356	54,395,038	188,497	512,795	701,291
CH Regionalized Alternative 94	33598	89,825,730	311,117	845,163	1,156,280
CH Regionalized Alternative 111	20356	54,395,038	188,497	512,795	701,291
CH Decentralized Baseline	19974	53,744,480	184,959	505,929	690,888
RH Decentralized Baseline	7958	26,210,998	73,691	244,610	318,301
CH Decentralized Alternative 1	19602	53,672,290	181,515	504,689	686,204
CH Decentralized Alternative 6	18831	50,447,700	174,375	474,981	649,356
CH Decentralized Alternative 10	17203	47,259,152	159,300	444,134	603,433
CH Decentralized Alternative 33	19974	53,744,480	184,959	505,929	690,888
CH Decentralized Alternative 35	19974	53,744,480	184,959	505,929	690,888
CH Decentralized Alternative 77	19602	53,672,290	181,515	504,689	686,204
CH Decentralized Alternative 83	19974	53,744,480	184,959	505,929	690,888
CH Decentralized Alternative 94	33290	89,202,790	308,265	838,670	1,146,935
CH Decentralized Alternative 111	19974	53,744,480	184,959	505,929	690,888

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TABLE 3-52

BACKFILL EMPLACEMENT COST TOTALS SUMMARY

Alternative ID#	Total Cost ($K)
33	55,527
35a	86,139
35b	86,141
77a	60,394
77b	31,299
77c	37,487
77d	35,894
83	53,146
94b	50,707
94c	78,536
94d	79,057
94e	42,262
94f	48,533
111	46,272

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TABLE 3-53

WIPP WASTE HANDLING COSTS

Alternative	Configuration	Cost ($K)
Baseline[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040
1[b]	Decentralized	153,600
	Regionalized	153,600
	Centralized	153,600
6[b]	Decentralized	188,160
	Regionalized	188,160
	Centralized	188,160
10[b]	Decentralized	134,400
	Regionalized	134,400
	Centralized	153,600
33[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040
35 (a,b)[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040
77 (a-d)[b]	Decentralized	153,600
	Regionalized	153,600
	Centralized	153,600
83[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040
94 (a-f)[c]	Decentralized	175,718
	Regionalized	175,718
	Centralized	153,600
111[a]	Decentralized	215,040
	Regionalized	215,040
	Centralized	215,040

Notes
[a]These alternatives involve only treating waste to WIPP WAC. WIPP emplaces waste for 35 years.
[b]These alternatives involve building new treatment facilities. WIPP emplaces waste for 25 years.
[c]This alternative involves building new treatment facilities. WIPP emplaces waste for 28.6 years for the decentralized and regionalized configurations, 3.6 years longer than the assumed operating life.

primarily independent of the cases (decentralized, regionalized, centralized) for this cost estimate study. For this estimate there were three waste handling/emplacement crew configuration that are utilized as input for the alternatives. The crew sized was dependent upon the number of TRUPACT-IIs that are processed per day. The number of TRUPACT-IIs that are processed based on the number of waste shipment and the limiting factor of a 35 year operational life for WIPP.

Baseline cost is established based on the required labor to handle and emplace the waste. The alternatives 33, 35(a-b), and 111 have the same comparable cost as the baseline. The alternative with the highest handling savings are number 10 and 94(a-f). This is due to a decrease in emplacement activities for 25 years rather than 35 years. Alternatives 1 and 6 have the same handling savings. Alternative 77(a-d) has a reduced savings as compared to alternative 1. This is due to the reduced room height but does not accommodate the current remote handled underground handling equipment or emplacement configuration. The limitation of this estimate is that the total WIPP budget is not included in this estimate. The only costs included are labor and anticipated capital equipment or modifications. Additional cost not included in this comparative analysis is the required budget that would be needed to manage and operate the WIPP, departmental management, and any additional research and development. This estimate is only intended to provide a measure of the relative cost savings or burden for an alternative.

3.7.4.3 Total Cost Summary

The total costs for implementing various alternatives are shown in Table 3-54. Total costs range from $4.0 billion for centralized treatment to WIPP WAC, to $7.7 billion for alternative 94c. Waste processing is by far the largest cost element, accounting for approximately 80 percent of the total cost.

3.7.4.4 Schedule Results

The results of the schedule development for the baseline and each of the different alternatives are presented in Figures 3-38 through 3-42. These schedules represent a "worst case" scenario where facilities needed to implement the baseline or alternatives are not currently available. It is assumed that where facilities currently exist, waste would be available for emplacement at WIPP in 1998. These figures present summary level schedules that include major activities and durations. Detailed schedules that list intermediate steps for each major activity and include all assumptions are included in Appendix Q, the schedule appendix.

Table 3-55 presents a summary comparison of the major activities and their associated start and finish dates for the baseline and each alternative. There is only a two year increase in total project duration between the baseline and the alternative with the longest duration (plasma). Operations are projected to begin in 11 to 12 years for alternatives that require new treatment facilities. Those facilities already available could begin treating waste immediately. For all alternatives, the treatment operations are projected to be completed within the anticipated operational lifetime of the WIPP facility. Based on schedules alone, no alternative presents significant benefits or detriments relative to the baseline.

Three major uncertainties associated with the schedules include:

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TABLE 3-54

TOTAL COST SUMMARY

Alternative	Configuration	Costs ($K) Process[a]	Transportation	Backfill	Handling	Total
Baseline	Decentralized	3,576,954	690,888	0	215,040	4,482,882
	Regionalized	3,418,650	701,291	0	215,040	4,334,981
	Centralized	3,202,376	611,089	0	215,040	4,028,505
1	Decentralized	4,379,357	686,204	0	153,600	5,219,161
	Regionalized	3,974,696	695,268	0	153,600	4,823,564
	Centralized	3,411,991	611,089	0	153,600	4,176,680
6	Decentralized	4,117,678	649,356	0	188,160	4,955,194
	Regionalized	3,757,294	661,387	0	188,160	4,606,841
	Centralized	3,329,333	611,089	0	188,160	4,128,582
10	Decentralized	5,966,427	603,433	0	134,400	6,704,260
	Regionalized	4,992,885	614,677	0	134,400	5,741,962
	Centralized	3,960,139	611,089	0	153,600	4,724,828
33	Decentralized	3,576,954	690,888	55,527	215,040	4,538,409
	Regionalized	3,418,650	701,291	55,527	215,040	4,390,508
	Centralized	3,202,376	611,089	55,527	215,040	4,084,032
35a	Decentralized	3,576,954	690,888	86,139	215,040	4,569,021
	Regionalized	3,418,650	701,291	86,139	215,040	4,421,120
	Centralized	3,202,376	611,089	86,139	215,040	4,114,644
35b	Decentralized	3,576,954	690,888	86,141	215,040	4,569,023
	Regionalized	3,418,650	701,291	86,141	215,040	4,421,122
	Centralized	3,202,376	611,089	86,141	215,040	4,114,646
77a	Decentralized	4,379,357	686,204	60,394	153,600	5,279,555
	Regionalized	3,974,696	695,268	60,394	153,600	4,883,958
	Centralized	3,411,991	611,089	60,394	153,600	4,237,074
77b	Decentralized	4,379,357	686,204	31,299	153,600	5,250,460
	Regionalized	3,974,696	695,268	31,299	153,600	4,854,863
	Centralized	3,411,991	611,089	31,299	153,600	4,207,979
77c	Decentralized	4,379,357	686,204	37,487	153,600	5,256,648
	Regionalized	3,974,696	695,268	37,487	153,600	4,861,051
	Centralized	3,411,991	611,089	37,487	153,600	4,214,167
77d	Decentralized	4,379,357	686,204	35,894	153,600	5,255,055
	Regionalized	3,974,696	695,268	35,894	153,600	4,859,458
	Centralized	3,411,991	611,089	35,894	153,600	4,212,574
83	Decentralized	3,576,954	690,888	53,146	215,040	4,536,028
	Regionalized	3,418,650	701,291	53,146	215,040	4,388,127
	Centralized	3,202,376	611,089	53,146	215,040	4,081,651
94a	Decentralized	6,301,672	1,146,935	0	175,718	7,624,325
	Regionalized	5,502,932	1,156,280	0	175,718	6,834,930
	Centralized	4,217,091	611,089	0	153,600	4,981,780
94b	Decentralized	6,301,672	1,146,935	50,707	175,718	7,675,032
	Regionalized	5,502,932	1,156,280	50,707	175,718	6,885,637
	Centralized	4,217,091	611,089	50,707	153,600	5,032,487
94c	Decentralized	6,301,672	1,146,935	78,536	175,718	7,702,861
	Regionalized	5,502,932	1,156,280	78,536	175,718	6,913,466
	Centralized	4,217,091	611,089	78,536	153,600	5,060,316

TABLE 3-54 (Continued)

TOTAL COST SUMMARY

		Costs ($K)				
Alternative	Configuration	Process[a]	Transportation	Backfill	Handling	Total
94d	Decentralized	6,301,672	1,146,935	79,057	175,718	7,703,382
	Regionalized	5,502,932	1,156,280	79,057	175,718	6,913,987
	Centralized	4,217,091	611,089	79,057	153,600	5,060,837
94e	Decentralized	6,301,672	1,146,935	42,262	175,718	7,666,587
	Regionalized	5,502,932	1,156,280	42,262	175,718	6,877,192
	Centralized	4,217,091	611,089	42,262	153,600	5,024,042
94f	Decentralized	6,301,672	1,146,935	48,533	175,718	7,672,858
	Regionalized	5,502,932	1,156,280	48,533	175,718	6,883,463
	Centralized	4,217,091	611,089	48,533	153,600	5,030,313
111	Decentralized	3,576,954	690,888	46,272	215,040	4,529,154
	Regionalized	3,418,650	701,291	46,272	215,040	4,381,253
	Centralized	3,202,376	611,089	46,272	215,040	4,074,777

[a]Process costs only represent those costs to process CH waste. Decentralized processing of RH waste costs approximately $1.0 billion.

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,451*	14JUL88A	13JUL29
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
190	ISSUE FINAL DRAFT ENVIR. IMPACT STATEMENT	0	12AUG97	11AUG97
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	881*	10MAR98	21AUG01
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		19JAN99
501	NESHAPS DETERMINATION COMPLETE	0		28AUG00
504	PSD PERMIT COMPLETE	0		21AUG01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	29AUG00	26SEP02
339	BEGIN RCRA PERMIT MOD	0	29AUG00	
430	PERMIT APPROVAL	0		26SEP02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,571*	25SEP98	22NOV04
266	TITLE II DESIGN COMPLETE	0		23FEB01
285	RCRA HOLD	0		26SEP02
289	BEGIN CONSTRUCTION	0	27SEP02	
291	CONSTRUCTON COMPLETE	0		01JUL04
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	02JUL04	17MAR05
TESTING				
507	TESTING	460*	28SEP04	18JUL06
530	ORR COMPLETE	0		19MAY06
OPERATIONS				
539	OPERATIONS	5,100*	19JUL06	21JUL26
560	IMPLEMENT SYSTEM USAGE	0	19JUL06	
565	FACILITY ACCEPTANCE	0	12OCT06	
567	OPERATIONS COMPLETE	0		21JUL26
D&D				
574	D&D	760*	22JUL26	13JUL29

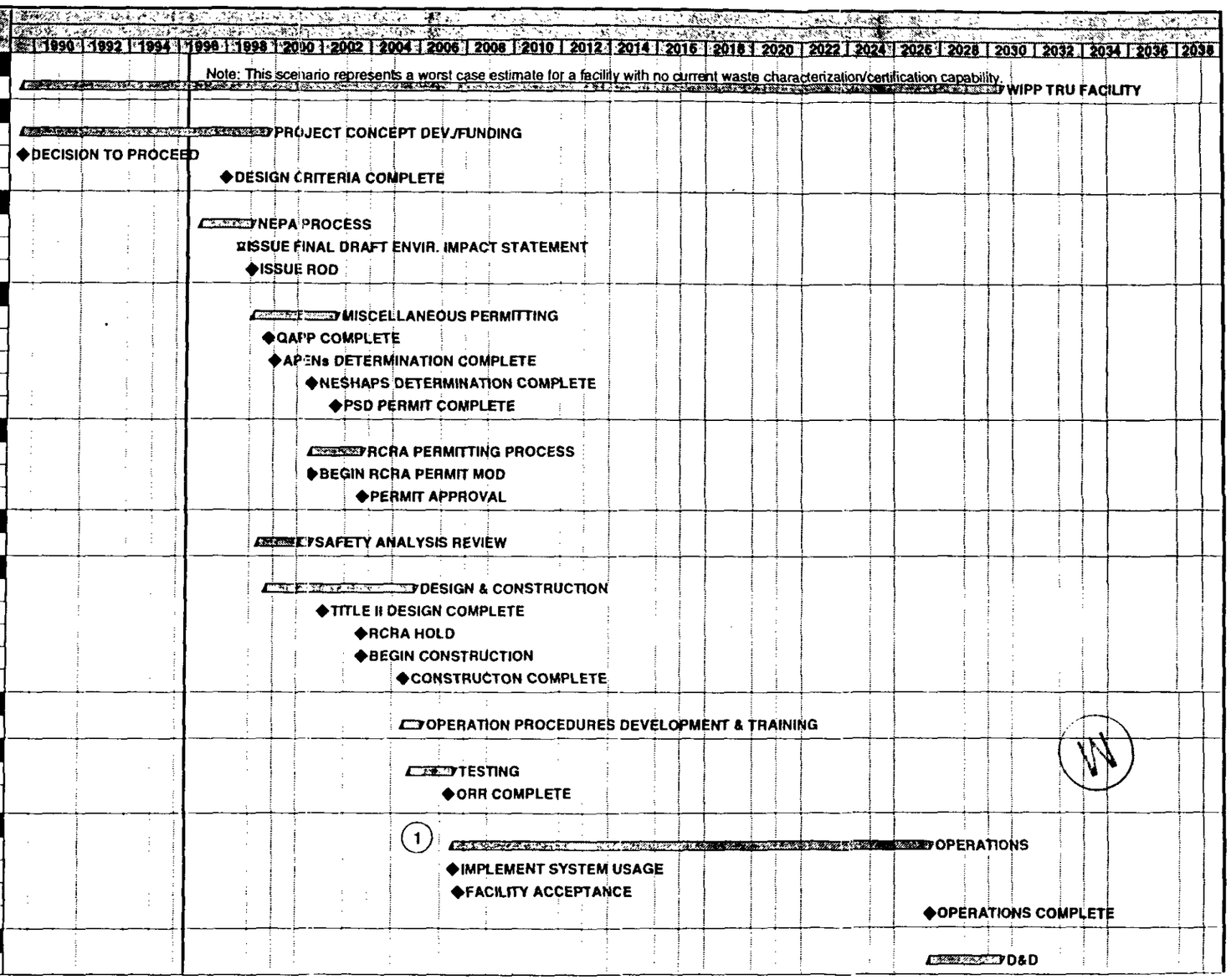

* *Represents a calculated time duration based on estimated scheduling values*

(1) *Baseline waste emplacement starts after WIPP is declared operational, the start date shown here represents the point in time when all WIPP WAC processing facilities are operational*

Figure 3-38
Basecase Scenario Summary

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,681*	14JUL88A	07JUN30
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	899*	10MAR98	17SEP01
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		19JAN99
501	NESHAPS DETERMINATION COMPLETE	0		22SEP00
504	PSD PERMIT COMPLETE	0		17SEP01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	28NOV00	26DEC02
339	BEGIN RCRA PERMIT MOD	0	28NOV00	
430	PERMIT APPROVAL	0		26DEC02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,744*	25SEP98	28JUL05
266	TITLE II DESIGN COMPLETE	0		23MAY01
285	RCRA HOLD	0		26DEC02
289	BEGIN CONSTRUCTION	0	27DEC02	
291	CONSTRUCTION COMPLETE	0		08MAR05
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	09MAR05	18NOV05
TESTING				
507	TESTING	460*	02JUN05	22MAR07
530	ORR COMPLETE	0		25JAN07
OPERATIONS				
539	OPERATIONS	5,100*	23MAR07	25MAR27
560	IMPLEMENT SYSTEM USAGE	0	23MAR07	
565	FACILITY ACCEPTANCE	0	18JUN07	
567	OPERATIONS COMPLETE	0		25MAR27
D&D				
574	D&D	817*	26MAR27	07JUN30

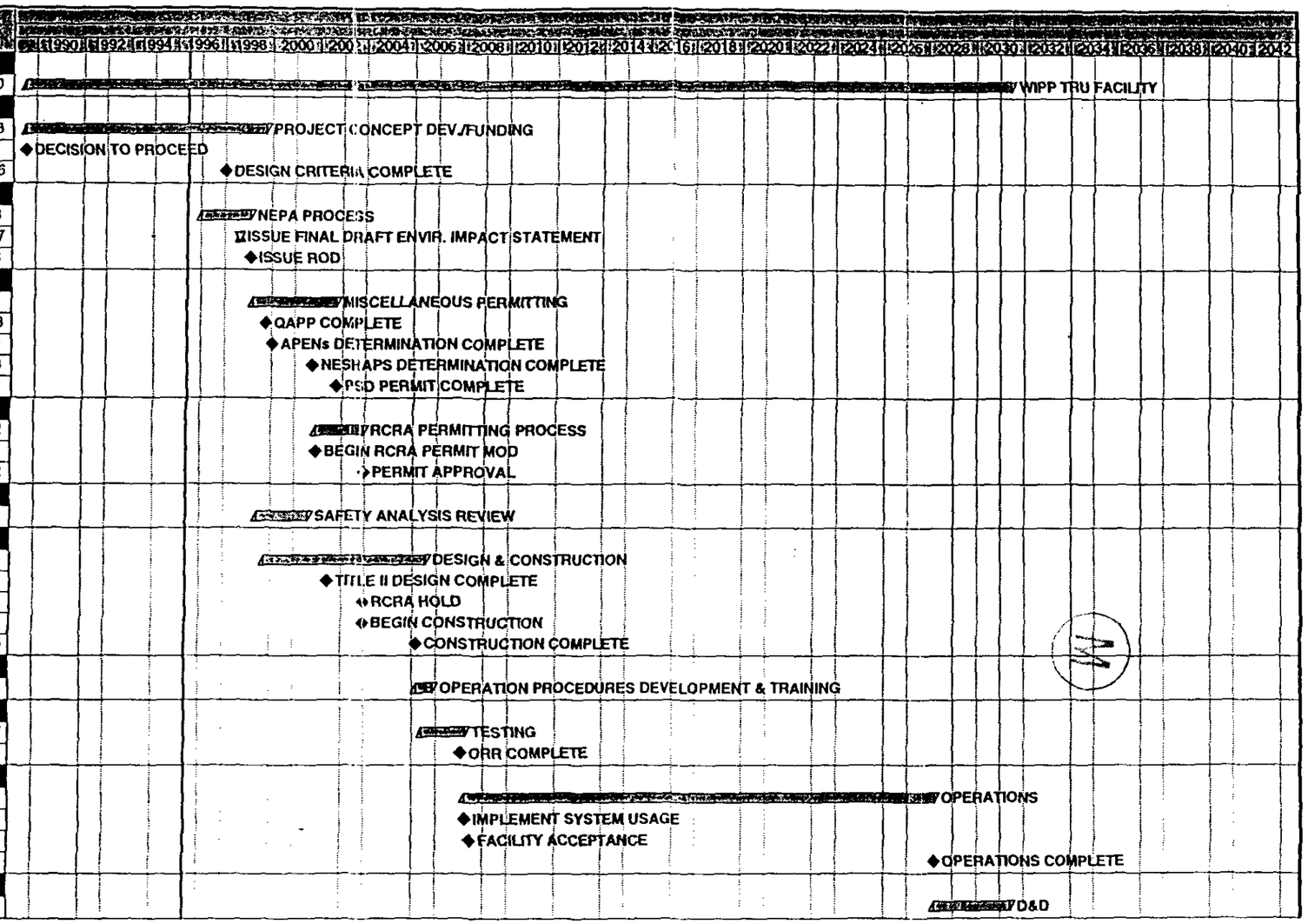

* *Represents a calculated time duration based on estimated scheduling values*

Figure 3-39
Supercompaction Scenario Summary

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,529*	14JUL88A	01NOV29
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	881*	10MAR98	21AUG01
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		19JAN99
501	NESHAPS DETERMINATION COMPLETE	0		28AUG00
504	PSD PERMIT COMPLETE	0		21AUG01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	29AUG00	26SEP02
339	BEGIN RCRA PERMIT MOD	0	29AUG00	
430	PERMIT APPROVAL	0		26SEP02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,621*	25SEP98	03FEB05
266	TITLE II DESIGN COMPLETE	0		23FEB01
285	RCRA HOLD	0		26SEP02
289	BEGIN CONSTRUCTION	0	27SEP02	
291	CONSTRUCTION COMPLETE	0		13SEP04
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	14SEP04	26MAY05
TESTING				
507	TESTING	460*	08DEC04	27SEP06
530	ORR COMPLETE	0		01AUG06
OPERATIONS				
539	OPERATIONS	5,100*	28SEP06	30SEP26
560	IMPLEMENT SYSTEM USAGE	0	28SEP06	
565	FACILITY ACCEPTANCE	0	22DEC06	
567	OPERATIONS COMPLETE	0		30SEP26
D&D				
574	D&D	788*	01OCT26	01NOV29

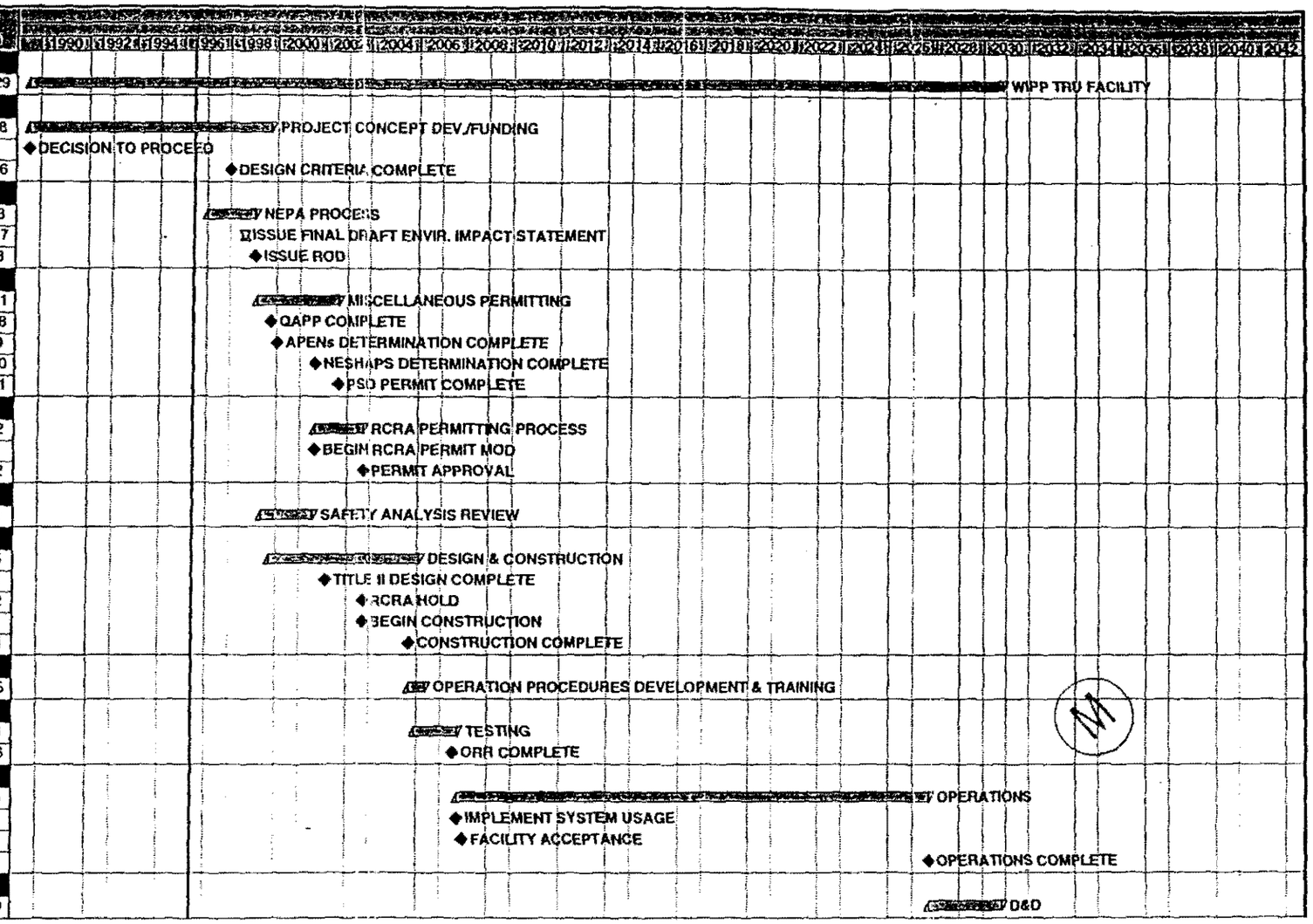

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Figure 3-40
Shred & Compact Scenario Summary

* *Represents a calculated time duration based on estimated scheduling values*

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,903*	14JUL88A	22APR31
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	680*	04JAN96	01SEP98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	16MAR98	13MAR98
205	ISSUE ROD	0		01SEP98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	1,138*	10MAR98	23AUG02
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		15OCT99
501	NESHAPS DETERMINATION COMPLETE	0		30AUG01
504	PSD PERMIT COMPLETE	0		23AUG02
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	700*	22SEP00	20JUN03
339	BEGIN RCRA PERMIT MOD	0	22SEP00	
430	PERMIT APPROVAL	0		20JUN03
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,933*	25SEP98	25APR06
266	TITLE II DESIGN COMPLETE	0		28AUG01
285	RCRA HOLD	0		20JUN03
289	BEGIN CONSTRUCTION	0	23JUN03	
291	CONSTRUCTION COMPLETE	0		02DEC05
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	05DEC05	17AUG06
TESTING				
507	TESTING	460*	01MAR06	18DEC07
530	ORR COMPLETE	0		22OCT07
OPERATIONS				
539	OPERATIONS	5,100*	19DEC07	21DEC27
560	IMPLEMENT SYSTEM USAGE	0	19DEC07	
565	FACILITY ACCEPTANCE	0	14MAR08	
567	OPERATIONS COMPLETE	0		21DEC27
D&D				
574	D&D	850*	22DEC27	22APR31

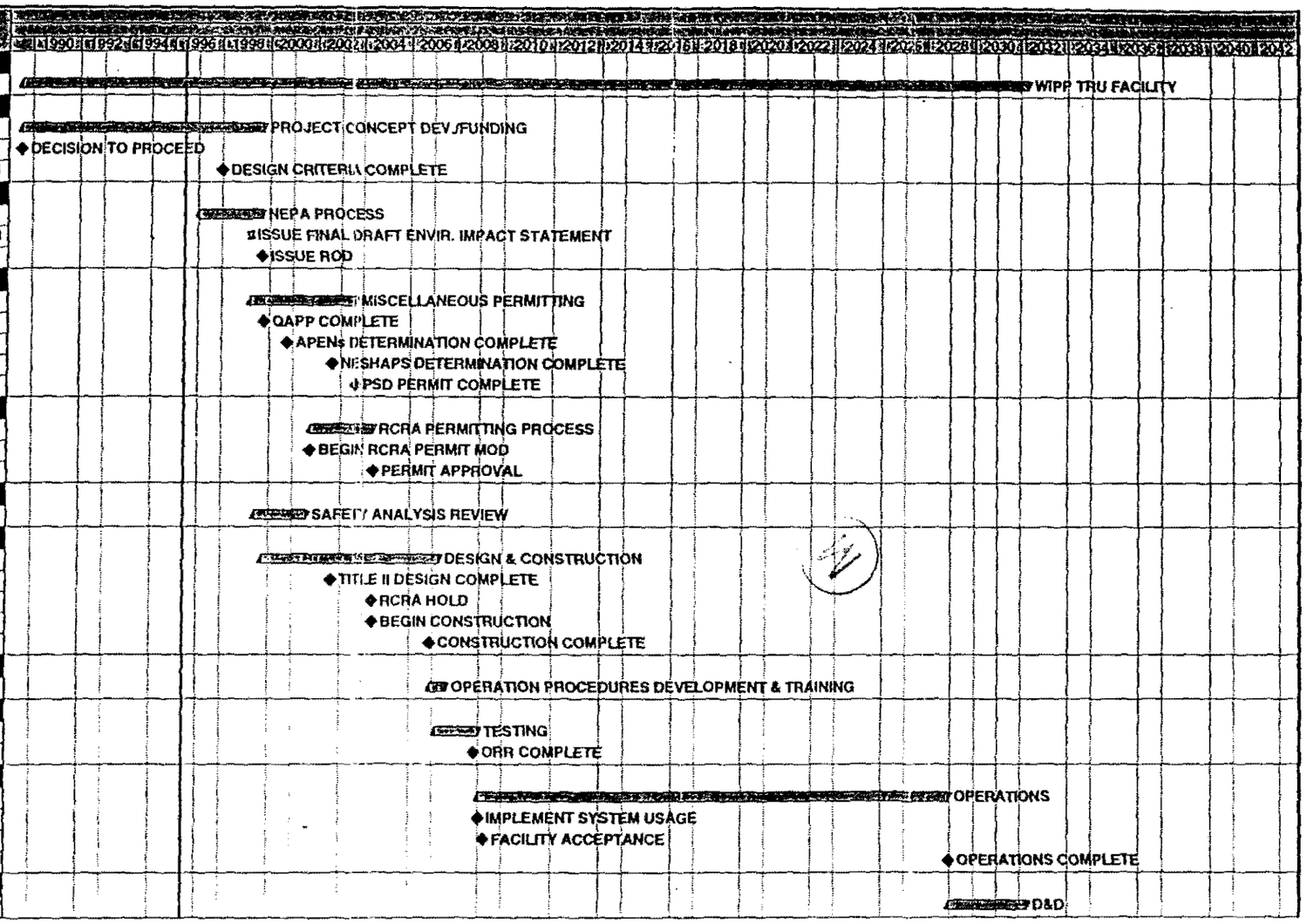

Figure 3-41
Plasma Scenario Summary

* *Represents a calculated time duration based on estimated scheduling values*

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,618*	14JUL88A	11MAR30
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
15	DECISION TO PROCEED	0	14JUL88A	
51	DESIGN CRITERIA COMPLETE	0		20DEC96
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	896*	10MAR98	12SEP01
486	QAPP COMPLETE	0		08OCT98
451	APENs DETERMINATION COMPLETE	0		19JAN99
501	NESHAPS DETERMINATION COMPLETE	0		19SEP00
504	PSD PERMIT COMPLETE	0		12SEP01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	20SEP00	17OCT02
339	BEGIN RCRA PERMIT MOD	0	20SEP00	
430	PERMIT APPROVAL	0		17OCT02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,686*	25SEP98	05MAY05
266	TITLE II DESIGN COMPLETE	0		08MAY01
285	RCRA HOLD	0		17OCT02
289	BEGIN CONSTRUCTION	0	18OCT02	
291	CONSTRUCTION COMPLETE	0		14DEC04
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	15DEC04	29AUG05
TESTING				
507	TESTING	460*	11MAR05	29DEC06
530	ORR COMPLETE	0		01NOV06
OPERATIONS				
539	OPERATIONS	5,100*	02JAN07	04JAN27
560	IMPLEMENT SYSTEM USAGE	0	02JAN07	
565	FACILITY ACCEPTANCE	0	27MAR07	
567	OPERATIONS COMPLETE	0		04JAN27
D&D				
574	D&D	812*	05JAN27	11MAR30

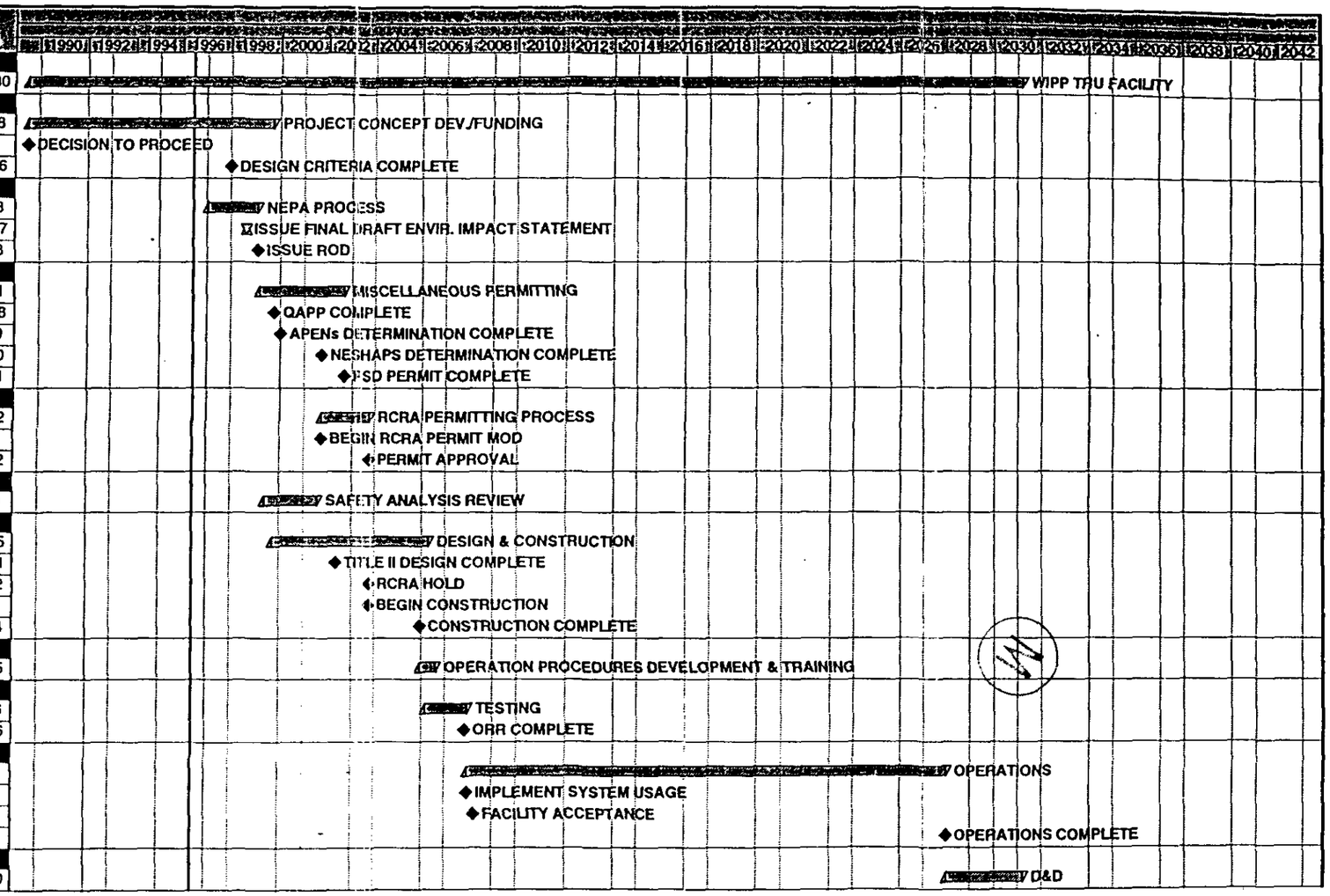

* *Represents a calculated time duration based on estimated scheduling values*

Figure 3-42
Cementation/Shred/
Add Clay Scenario

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TABLE 3-55

PROCESSING SCHEDULE SUMMARY

Alternative	Description	Start	Finish	Years
6	Shred and Compact	1/4/96	11/1/2029	34
94	Cementation/Shred and Add Clay	1/4/96	3/11/2030	35
1	Supercompact	1/4/96	6/7/2030	35.5
10	Plasma	1/4/96	4/22/2031	36
N/A	Baseline	1/4/96	7/13/2029	33.5

- Availability of funding. Lack of funding could result in schedule delays.

- Ability of sites to obtain RCRA permits and other approvals and permits. For instance, it is anticipated that obtaining a RCRA permit for a plasma melter may be more difficult than obtaining one for some of the other processes. Additionally, there may be resistance at a given location to accepting waste from off-site, making it difficult to permit alternatives associated with the regionalized or centralized alternatives.

- Political climate, which could vary on a state-by-state basis.

These uncertainties are not quantified.

3.8 IMPACT ON OTHER WASTE DISPOSAL PROGRAMS

3.8.1 Definition of Factor 8

This factor includes an assessment of the impacts that the EAs will have on other waste processing and disposal programs, including programs for LLW and low-level mixed waste (LLMW). Major impacts are assessed based on additional volumes of waste that are projected to be generated by the TRU waste processing as analyzed for each waste processing based EA. EAs that do not process waste, such as backfill only EAs, are not considered in this analysis.

3.8.2 Methodology Used to Evaluate Factor 8

Data from four TRU waste cementation treatment processes at RFETS were analyzed, and the low-level secondary waste stream volumes were summed for each treatment process. The four waste generation rates, calculated as volume of low-level secondary waste generated per volume of cemented (output) waste, were then averaged (Appendix R). This average is 0.3 drums of secondary waste generated per drum of output cemented waste. The percents of the total secondary waste generated as LLW and LLMW are also averaged for the four treatment processes, and the average was approximately fifty percent LLW and fifty percent LLMW.

Because data are not available for other treatment processes, it is assumed that the other waste processes being evaluated (with the exception of plasma melting) generate similar volumes of secondary LLW as the cementation process, on a waste input basis. To convert the cementation data from an output basis to an input basis, the volume increase factor for cementation of 1:2.5 was used (see Table 3-47). This waste input basis factor, calculated to be 0.75 drums of secondary waste per drum of input waste, is then applied to each treatment process to calculate the volume of secondary LLW generated. The scaled volumes of sludges, solid organics, and solid inorganics that are used as inputs in the EA cost analysis were also used in this analysis (Section 2.3).

For the plasma melting process, the secondary low-level waste generation is assumed to be zero because the treatment process is designed such that secondary waste feeds back through the plasma melter. The volume reduction achieved in the plasma process for typical secondary wastes such as personal protective equipment (PPE), filters, and combustibles, is very high, so the volume of secondary wastes generated from the treatment process will be negligible. However, secondary waste will still be generated in the waste characterization step.

The waste characterization step is shown in the process flow diagrams in Section 3.7.2.1. The waste characterization module, as defined in the EM-PEIS, includes opening and sorting drum contents, collecting waste samples, and repackaging, if necessary, to remove and stabilize noncompliant waste. This operation, which occurs in a glovebox, is assumed to generate secondary low-level waste at the same rate (input basis) as the treatment processes. The secondary waste generated is calculated only for the portion of the waste inventory that passes through the waste characterization step (assumed to be 30 percent of stored waste and 10 percent of projected waste, as shown on the process flow diagrams in Section 3.7.2.1. Secondary waste generated from waste characterization is the same for the baseline and all EAs.

The calculated generation rates of LLW and LLMW for each EA were then compared to current and projected total DOE inventories of LLW and LLMW to determine impact in terms of percentage increase over current levels for each EA (Appendix R).

3.8.3 Assumptions and Data for Factor 8

The data analyzed for this factor comes from the RFETS Waste Stream and Residue Identification and Characterization report (WSRIC) (EG&G Rocky Flats, Inc., 1995), version 5.0. Four treatment processes are reviewed:

Building 774: Organic and Sludge Immobilization System (OASIS)
Building 774: Miscellaneous Waste Handling
Building 774: Precipitation/Filtration
Building 374: Sludge Solidification

All of these processes involve cementation of TRU waste and occur in gloveboxes. It is assumed that the RFETS data would generally be representative of TRU waste cementation processes at any DOE facility. Several other assumptions were made in assembling and compiling the data:

- All secondary waste characterized as "TRU or LL" is assumed to be LL, to estimate conservatively the potential impacts on the LL waste program. Likewise, waste characterized as "TRUM or LLM" is assumed to be LLM, and waste characterized as "LLM or HAZ" is assumed to be LLM.

- Several waste streams listed generation rates as "variable" or "insufficient data." Generation rates for these waste streams are estimated based on other similar processes and wastes.

- Most generation rates are provided on a volume basis. Those that are presented on a mass basis were converted to volume basis using assumed densities based on other RFETS data and the Baseline Inventory Report.

Other TRU waste processes at RFETS that parallel treatment options being evaluated in this study, such as the supercompactor, did not have secondary waste estimates provided in the WSRIC report. Because other data were not readily available, it is assumed that the other waste processes being evaluated (with the exception of plasma melting) generate similar volumes of secondary LLW as the cementation process, on a waste input basis.

Data for total DOE waste inventories and projections for LLW and LLMW are obtained from the 1993 Integrated Data Base Report (IDB) (DOE, 1994c) and the 1994 Mixed Waste Inventory Report (MWIR) (DOE, 1994d), respectively.

3.8.4 Results of Analysis of Factor 8

Table 3-56 presents the estimated volumes of secondary waste that are projected for each EA, including the amount calculated from the waste characterization and treatment steps. The annual waste generation shown is based on a 20-year treatment operation period for EA treatments. As explained in the methodology section, the secondary waste is assumed to be comprised of 50 percent LLW and 50 percent LLMW. Alternative 94 is projected to generate the most secondary

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TABLE 3-56

SECONDARY WASTE VOLUMES
(cubic meters)

	Secondary Waste		LLW/LLMW (Each)	
Alternative	**Total**	**Annual[1]**	**Total**	**Annual[1]**
Baseline	32,729	1,636	16,365	818
1 and 77 (Supercompact)	118,040	5,902	59,020	2,951
6 (Shred and compact)	118,040	5,902	59,020	2,951
10 (Plasma)	21,848	1,092	10,924	546
94 (Enhanced cement/ shred and add clay)	131,625	6,581	65,813	3,291

[1]Based on a 20-year treatment operation period.

waste (three times more than the baseline), with Alternative 10 generating the least (one-third less than the baseline). Alternatives 1 and 6 generate 2.6 times more secondary waste than the baseline.

Table 3-57 shows a summary of LLMW impacts from each waste processing EA, expressed as percentages of total DOE LLMW (stored-plus-projected) and annual DOE LLMW generation. The annual DOE rate is taken as an average of projected generation rates for 1993 through 1997 from the MWIR. Projected generation rates beyond 1997 are not consistently provided in the MWIR. Alternative 10 (plasma) will generate less LLMW than the baseline, making this an attractive alternative in terms of impacts on other waste disposal programs. Compared to total DOE stored-plus-projected LLMW, the other alternatives will generate 14 to 16 percent more LLMW. The range for the annual generation basis is 10 to 12 percent more LLMW. This could have an impact on available permitted RCRA storage and treatment capacity at some sites.

Table 3-58 presents a summary of LLW impacts from each EA, expressed as percentages of total DOE LLW (buried-plus-projected) and annual DOE LLW generation. The annual DOE rate is taken as an average of projected generation rates for 1993 and 1994 from the IDB (the only years with annual generation rates projected). Again, Alternative 10 (plasma) generates less LLW than the baseline, making it an attractive alternative in terms of impacts on other waste disposal programs. Compared to total DOE LLW (buried-plus-projected), the other alternatives generate about one percent more LLW. The range for the annual generation basis is eight to nine percent more LLW. Because LLW can generally be shipped for disposal as it is generated, this increase is not expected to have as significant an impact on DOE's LLW program as the LLMW increase.

Uncertainties associated with this analysis of impacts on LLW and LLMW programs result from uncertainties in the source documents (WSRIC, MWIR, and IDB) as well as uncertainties introduced in this analysis. The IDB states that waste characterization is underway at many DOE sites, which may cause the classification of the waste to change in the future. In addition, the MWIR includes some waste from environmental restoration and D&D programs, while the IDB does not appear to. In this analysis, all EA treatments were assumed to generate secondary waste at the same rate (on an input basis) as four cementation processes at RFETS, which is felt to be a reasonable estimate for purposes of this analysis but which may require further study to reduce uncertainties.

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TABLE 3-57
LOW-LEVEL MIXED WASTE IMPACTS

Alternative	% of Total DOE LLMW (Stored + Projected)[1]	% of Annual LLMW Generation[2]
Baseline	3.8	2.9
1 (Supercompact)	13.9	10.4
6 (Shred and compact)	13.9	10.4
10 (Plasma)	2.6	1.9
94 (Enhanced cement/shred and add clay)	15.5	11.6

[1]Based on stored and projected volumes from MWIR through 2022 (total = 425,932 m^3).

[2]Based on average of annual projected volumes from MWIR for 1993 to 1997 (average = 28,420 m^3/yr).

TABLE 3-58

LOW-LEVEL WASTE IMPACTS

Alternative	% of Total DOE LLW (Buried + Projected)[1]	% of Annual LLW Generation[2]
Baseline	0.29	2.2
1 (Supercompact)	1.03	7.8
6 (Shred and compact)	1.03	7.8
10 (Plasma)	0.19	1.4
94 (Enhanced cement/shred and add clay)	1.15	8.7

[1]Based on historical and projected buried waste volumes from IDB through 2022 (total = 5,722,000 m^3).

[2]Based on average of annual projected volumes from IDB for 1993 to 1994 (average = 37,895 m^3/yr).

4.0 QUALITY ASSURANCE

4.1 QUALITY ASSURANCE APPROACH

The DOE-CAO has developed a quality assurance (QA) program in the CAO Quality Assurance Program Description (CAO-QAPD; CAO-94-1012). The program meets the applicable requirements of the American Society of Mechanical Engineer's (ASME) "Quality Assurance Program Requirements for Nuclear Facilities" (NQA-1-1989 Edition), ASME's "Quality Assurance Requirements of Computer Software for Nuclear Facility Applications" (NQA-2a-1990 addenda, part 2.7 to ASME NQA-2-1989 edition), and ASME's "Quality Assurance Program Requirements for the Collection of Scientific and Technical Information on Site Characterization of High-Level Nuclear Waste Repositories" (NQA-3-1989 edition).

The ASME NQA-1-1989 edition sets forth requirements for the "establishment and execution of quality assurance programs for the siting, design, construction, operation, and decommissioning of nuclear facilities." For the purpose of this project, the NQA-2a-1990 addenda to ASME NQA-2-1989 edition standard applies to computer software "used to produce or manipulate data which are used directly in the design, analysis, and operation of structures, systems, and components." The NQA-3-1989 edition standard sets forth quality assurance requirements which apply to "activities which could affect the quality of scientific and technical information collected as part of the site characterization phase of high-level nuclear waste repositories."

The QA program implemented in support of the EACBS address elements such as calculations, models, and data collection used to perform the EA analysis. Documentation that details quality indicators such as data accuracy, precision, representativeness, completeness, comparability, and reproducibility has been compiled for the record, as appropriate. Appendix S details specific QA procedures used in most of the factors.

Computer models developed in support of the analyses in this study are based upon appropriate conceptual, mathematical, and numerical models. Program verification and validation methods were applied to ensure the desired performance of these models. Verification is the process by which the output (e.g., numerical results) of a computer program are determined to be "correct". Verification implies that the program solves the numerical problem as intended by the program author. Validation implies that the theory and assumptions used in constructing the program logic constitute a correct representation of the process or system being simulated by the program. Verification was performed by one, or more of the following methods, depending on the intended use of the program:

- Independent manual calculations are performed to verify the program algorithms.
- The results produced by the program are compared to the results from an "independently developed" program (e.g., a program developed outside the company or by an independent working group).
- The program results are compared to analyses published in textbooks and journals or, to the results of applicable experiments.

- Previous Validation. Models that have been previously used and approved in other DOE program will not be revalidated unless the model is modified or used for other purposes than their intended design.

Validation documentation, as necessary, consist of published conclusions comparing model predictions with data from laboratory experiments, field experiments, natural analogues, and published conclusions made by external review groups.

Many aspects of the EACBS are qualitative in nature. The methods used to analyze the EAs within the factors used many quantitative tools such as computer models and spreadsheet calculations (see appendices for details). However the results from these quantitative tools are qualitative since the input parameters and assumptions are based on qualitative estimates and judgements. The quality assurance program used in this report mostly centers around hand checking calculations from spreadsheets, computer models and validating changes made to these models.

5.0 INTEGRATION AND SUMMARY OF ANALYSIS RESULTS

5.1 OVERVIEW OF THE INTEGRATION PROCESS

The EAs proposed in this study are intended to reduce the estimated risks to future populations from waste disposal at WIPP and to provide additional confidence in the performance of the disposal system. EA evaluation factors 1 and 2 address these issues. The additional handling and processing of wastes required to implement the EAs may, however, impose additional near-term costs and health risks beyond those involved in the WIPP baseline design. These potential concerns are addressed by evaluation factors 3 through 8. This section integrates the results from all the evaluation factors into a form that will assist decisionmakers and other stakeholders in assessing the costs and benefits of EA adoption for both short and long-term impacts.

The next subsection reviews the TRU waste disposal program scenarios evaluated in detail for this study. Next, the quantitative performance measures used to document waste system performance against the evaluation factors found in Chapter 3 are described and organized for integrated results presentation. Finally, integrated results are presented in a form that allows the overall performance of the EAs to be compared to the baseline WIPP design.

5.2 SUMMARY OF EAs EVALUATED

The identification and screening of EAs is documented in Chapter 2. Out of 111 EA concepts screened for this analysis, 18 specific alternatives were selected for further evaluation. The 18 EAs represent a complete spectrum of EAs ranging from those believed to be narrowly effective in one impact area to those with broad effectiveness plus EAs judged to have high feasibility. Summary descriptions of the EAs selected for evaluation are presented in Section 2.2.1.

EAs involving additional waste processing were further evaluated under three separate configurations:

- Waste processing is decentralized at 10 generator sites.
- Waste is processed at 5 regional generator sites.
- Waste is centrally processed at WIPP.

This consideration of waste processing location expanded the number of EA scenarios to be evaluated to 44 plus the baseline case.

The EAs can be uniquely defined by the following three parameters:

- Combination alternatives
- Waste processing alternatives
- Waste backfill provisions

Figure 5-1 presents a scenario tree constructed using these parameters to organize the baseline and 44 evaluated EAs in a logical order . The scenario tree organization starts at the top with the baseline TRU disposal system. Next follows those EAs that involve only backfill external to the waste drums. EAs that use increasingly aggressive processing technologies are found by descending down the scenario tree.

TRU Disposal System	Additional Waste Processing?	Processing Facilities Location?	Waste Backfill?	Seq. No.	Engineered Alternative Case #
	None*	N/A	None	1	Baseline
			Sand+Clay	2	33
			SAG	3	35a
			CG	4	35b
			Clay	5	111
			CaO	6	83
	Super C	WIPP	None	7	1-1
			SAG	8	77a-1
			Clay	9	77b-1
			Sand+Clay	10	77c-1
			CaO	11	77d-1
		5 Sites	None	12	1-5
			SAG	13	77a-5
			Clay	14	77b-5
			Sand+Clay	15	77c-5
			CaO	16	77d-5
		10 Sites	None	17	1-10
			SAG	18	77a-10
			Clay	19	77b-10
			Sand+Clay	20	77c-10
			CaO	21	77d-10
	S&C	WIPP	None	22	6-1
		5 Sites	None	23	6-5
		10 Sites	None	24	6-10
	SCC	WIPP	None	25	94a-1
			Sand+Clay	26	94b-1
			CG	27	94c-1
			SAG	28	94d-1
			Clay	29	94e-1
			CaO	30	94f-1
		5 Sites	None	31	94a-5
			Sand+Clay	32	94b-5
			CG	33	94c-5
			SAG	34	94d-5
			Clay	35	94e-5
			CaO	36	94f-5
		10 Sites	None	37	94a-10
			Sand+Clay	38	94b-10
			CG	39	94c-10
			SAG	40	94d-10
			Clay	41	94e-10
			CaO	42	94f-10
	Plasma	WIPP	None	43	10-1
		5 Sites	None	44	10-5
		10 Sites	None	45	10-10

LEGEND:

Super C: Supercompaction of all waste, except sludges
S&C: Shredding and compaction of all waste, except sludges
SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
SAG: Salt Aggregate Grout
CG: Cemenitious Grout
* Baseline assumes processing to meet WIPP WAC is performed.

Figure 5-1
Engineered Alternatives Scenario Tree

5.3 PERFORMANCE MEASURES FOR RESULTS INTEGRATION

The baseline TRU waste disposal system and the 18 EAs defined in Chapter 2 were evaluated against each of the eight factors discussed in Chapter 3. In Chapter 3, analysis results were presented for each factor using quantifiable performance measures identified for each factor. While some factors were characterized by a single performance measure, others required several different performance measures to adequately describe the results. Table 5-1 summarizes the performance measures reported for each factor.

To facilitate the integration of results, the performance measures reported in Chapter 3 were organized and condensed to define a multi-element "impact vector" describing the complete analysis results for each EA for all factors. Special attention was given in constructing the impact vector to communicate the phase of the TRU disposal program being impacted by an EA and the location (at WIPP, at generator sites) of the risk or cost impact. The relationships between the eight assessment factors and the elements of the impact vector are shown in Figure 5-2.

5.4 SUMMARY OF ANALYSIS RESULTS FOR EVALUATED ALTERNATIVES

5.4.1 Approach to Results Integration

Figure 5-3 combines the EA scenario tree from Figure 5-1 and the impact vector from Figure 5-2 to form a matrix for integrating and summarizing the results of the EA analyses. To facilitate comparison of the EAs to the baseline WIPP design, the quantitative results from each factor analysis, expressed in the different units of measure as summarized in Table 5-1, are translated into a common qualitative scale that compares the EA to the baseline in general terms. Table 5-2 below shows the five categories that are used to represent the results of each impact vector element.

The term "significant" refers to the overlap in the range of performance predicted for the EA verses the baseline. Interpretation of these categories varies with the relative magnitude and uncertainty of the performance measures. For example, a factor of two difference between the predicted point estimates for total cost of alternatives may be very significant with essentially no overlap in the distributions of the two predictions. A factor of two difference in predicted point estimates for latent cancer fatalities may, by comparison, be less significant with a considerable overlap in the distributions of the two predictions. This concept is similar to the idea of statistical significance, however, it is assigned judgmentally in this report since we are addressing a state of knowledge rather than the results of controlled experiments.

Figure 5-4 presents the same qualitative ratings shown in Figure 5-3, only condensed down to the eight top level elements of the impact vector.

A summary of selected analysis results from each of the eight factors are presented in Table 5-3. Table 5-3 contains an overview of the analysis results for each EA and the baseline case. Supportive data for the results are also included.

The remainder of this chapter discusses how the quantitative evaluation results from Chapter 3 were interpreted for each of the major impact categories for presentation in Figure 5-3.

1

TABLE 5-1
PERFORMANCE MEASURES REPORTED

EA FACTOR	PERFORMANCE MEASURE	UNITS
1) Long term Repository Performance	Measure of relative effectiveness (MRE) of repository performance compared to the baseline.	Ratio of the mean value EA performance to the baseline
2) Uncertainty in Compliance Assessment	Measure of the relative uncertainty (MRU) of repository performance compared to the baseline.	Ratio of the range factor for EA performance to the baseline
3) Worker & Public Risk[a]	Facility worker risk	FTE-REM excess fatalities, construction and operation injuries and fatalities
	Maximum co-located worker risk	REM, excess cancer fatalities
	Co-located worker collective risk	Person-REM excess fatalities[b]
	Maximum off-site individual risk	REM, excess cancer fatalities
	Collective off-site public risk	Person-REM excess fatalities[b]
4) Impact on Waste Removal	Measure of relative difficulty of waste removal compared to the baseline.	Qualitative ranking.
5) Transportation Risk[a]	Transport crew collective radiological, nonaccident risk	Person-REM, latent cancer fatalities
	Public collective radiological, nonaccident risk	Person-REM, latent cancer fatalities
	Public maximum individual radiological, nonaccident risk	REM, latent cancer fatalities
	Public and crew collective radiological, accident risk	Person-REM, latent cancer fatalities
	Public and crew collective chemical risk	EPRG-2 ratio
	Public and crew collective non-rad, non-chemical risk	injuries, fatalities
6) Public Confidence	Listing of citizen concerns about repository performance	Not applicable
7) System Cost & Schedule[a]	Waste storage costs	1994 dollars
	Waste treatment costs	1994 dollars
	Waste transportation costs	1994 dollars
	WIPP waste placement and backfill costs	1994 dollars
	Start of WIPP operations	Date of first waste placement
	Completion of WIPP operations	Date of closure
8) Impact on Other Disposal Systems	Secondary waste volumes	Percentage change in estimated secondary waste volumes relative to the DOE low level and low level mixed waste

[a]For EAs that involve waste treatment, results are reported separately for decentralized, regionalized and centralized locations.
[b]Other units of measure are also used for non-radiological risk.

EA FACTORS	WIPP ENGINEERED ALTERNATIVES IMPACT VECTOR ELEMENTS																
	LONG TERM COMPLIANCE CONFIDENCE		PUBLIC HEALTH RISK				WORKER HEALTH		DISPOSAL SYSTEM COSTS					WIPP SCHEDULE			
					At WIPP				TRU WASTE		At WIPP						
	Cutings Scenarios	Water Scenarios	At Generator	In Transport	*Before Closure*	*After Closure*	At Generator	At WIPP	At Generator	In Transport	Storage & Treatment	Placement & Backfill	OTHER WASTE	First Waste to WIPP	Closure	WASTE REMOVAL CAPABILITY	PUBLIC ACCEPTANCE
1) Long Term Repository Performance						X											
2) Uncertainty in Compliance	X	X															
3) Worker & Public Risk			X		X		X	X									
4) Waste Removal Capability																X	
5) Transportation Risk				X													
6) Public Confidence																	X
7) System Cost & Schedule									X	X	X	X		X	X		
8) Other Disposal Systems													X				

Figure 5-2
Relationship of EA Factors and Impact Vector

TRU WASTE DISPOSAL SCENARIO					WIPP ENGINEERED ALTERNATIVES IMPACT VECTOR ELEMENTS																
					LONG TERM COMPLIANCE CONFIDENCE		PUBLIC HEALTH RISK				WORKER HEALTH		DISPOSAL SYSTEM COSTS					WIPP SCHEDULE			
													TRU WASTE								
									At WIPP						At WIPP						
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Cuttings Scenarios	Water Scenarios	At Generator	In Transport	*Before Closure*	*After Closure*	At Generator	At WIPP	At Generator	In Transport	Storage & Treatment	Placement & Backfill	OTHER WASTE	First Waste	Closure	WASTE REMOVAL CAPABILITY	PUBLIC ACCEPTANCE
	None	None	1	Baseline-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
		Sand+Clay	2	33-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	❒	▲	▲	▲	▲	▲
		SAG	3	35a-1	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	❒	▲	▲	▲	▲	▲
		CG	4	35b-1	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	❒	▲	▲	▲	▲	▲
		Clay	5	111-1	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	❒	▲	▲	▲	▲	▲
		CaO	6	83-1	▲	○	▲	▲	▲	▲	▲	▲	▲	▲	▲	❒	▲	▲	▲	▲	▲
	Super C	None	7	1-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	❒	▲	❒	■	▲	○	▲
		SAG	8	77a-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	❒	❒	❒	■	▲	○	▲
		Clay	9	77b-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	❒	❒	❒	■	▲	○	▲
		Sand+Clay	10	77c-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	❒	❒	❒	■	▲	○	▲
		CaO	11	77d-1	○	○	▲	▲	❒	▲	▲	■	▲	▲	❒	❒	❒	■	▲	○	▲
	S&C	None	12	6-1	▲	▲	▲	▲	❒	▲	▲	■	▲	▲	❒	▲	❒	■	▲	▲	▲
	SCC	None	13	94a-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	■	▲	❒	■	▲	▲	▲
		Sand+Clay	14	94b-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	■	❒	❒	■	▲	▲	▲
		CG	15	94c-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	■	❒	❒	■	▲	▲	▲
		SAG	16	94d-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	■	❒	❒	■	▲	▲	▲
		Clay	17	94e-1	○	▲	▲	▲	❒	▲	▲	■	▲	▲	■	❒	❒	■	▲	▲	▲
		CaO	18	94f-1	○	○	▲	▲	❒	▲	▲	■	▲	▲	■	❒	❒	■	▲	▲	▲
	Plasma	None	19	10-1	●	●	▲	▲	■	▲	▲	■	▲	▲	■	▲	○	■	▲	▲	▲

SCENARIO TREE LEGEND:

Super C: Supercompaction of all waste, except sludges
S&C: Shreding and compaction of all waste, except sludges
SCC: All wastes other than sludges are shredded and repackaged with clay. Sludges are cemented.
SAG: Salt Aggregate Grout
CG: Cemenitious Grout

IMPACT VECTOR RANKING:

● Performance is significantly better than the corresponding baseline performance.
○ Performance is marginally better than the corresponding baseline performance.
▲ Performance is approximately the same as the corresponding baseline performance.
❒ Performance is marginally worse than the corresponding baseline performance.
■ Performance is significantly worse than the corresponding baseline performance.

[a] The Centralized Processing Scenario was selected because it generally produces the lowest increase in cost, schedule impacts, and health risks with respect to the baseline case–results for the regionalized and decentralized scenarios are found in Section 3.0.

Figure 5-3
Summary of WIPP Engineered Alternative Evaluation Results for Centralized Processing Scenario[a]

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TABLE 5-2

QUALITATIVE IMPACT VECTOR RESULT CATEGORIES

SYMBOL	DESCRIPTION
●	Performance is significantly better than the corresponding baseline performance.
○	Performance is marginally better than the corresponding baseline performance.
▲	Performance is approximately the same as the corresponding baseline performance.
□	Performance is marginally worse than the corresponding baseline performance.
■	Performance is significantly worse than the corresponding baseline performance.

TRU DISPOSAL SYSTEM SCENARIO					WIPP ENGINEERED ALTERNATIVES IMPACT VECTOR ELEMENTS								
TRU Disposal System	Additional Waste Processing?	Waste Backfill?	Seq. No.	Engineered Alternative Case #	Cutings Scenarios Confidence	Water Scenarios Confidence	PUBLIC HEALTH RISK	WORKER HEALTH RISK	DISPOSAL SYSTEM COSTS	OTHER DISPOSAL SYSTEM IMPACTS	WIPP SCHEDULE	WASTE REMOVAL CAPABILITY	PUBLIC ACCEPTANCE
	None	None	1	Baseline-1	▲	▲	▲	▲	▲	▲	▲	▲	▲
		Sand+Clay	2	33-1	▲	▲	▲	▲	▲	▲	▲	▲	▲
		SAG	3	35a-1	○	▲	▲	▲	▲	▲	▲	▲	▲
		CG	4	35b-1	○	▲	▲	▲	▲	▲	▲	▲	▲
		Clay	5	111-1	▲	▲	▲	▲	▲	▲	▲	▲	▲
		CaO	6	83-1	▲	○	▲	▲	▲	▲	▲	▲	▲
	Super C	None	7	1-1	○	▲	▲	□	□	□	■	○	▲
		SAG	8	77a-1	○	▲	▲	□	□	□	■	○	▲
		Clay	9	77b-1	○	▲	▲	□	□	□	■	○	▲
		Sand+Clay	10	77c-1	○	▲	▲	□	□	□	■	○	▲
		CaO	11	77d-1	○	○	▲	□	□	□	■	○	▲
	S&C	None	12	6-1	▲	▲	▲	□	□	□	■	▲	▲
	SCC	None	13	94a-1	○	▲	▲	□	■	□	■	▲	▲
		Sand+Clay	14	94b-1	○	▲	▲	□	■	□	■	▲	▲
		CG	15	94c-1	○	▲	▲	□	■	□	■	▲	▲
		SAG	16	94d-1	○	▲	▲	□	■	□	■	▲	▲
		Clay	17	94e-1	○	▲	▲	□	■	□	■	▲	▲
		CaO	18	94f-1	○	○	▲	□	■	□	■	▲	▲
	Plasma	None	19	10-1	●	●	■	□	■	○	■	▲	▲

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IMPACT VECTOR RANKING:

● Performance is significantly better than the corresponding baseline performance.
○ Performance is marginally better than the corresponding baseline performance.
▲ Performance is approximately the same as the corresponding baseline performance.
□ Performance is marginally worse than the corresponding baseline performance.
■ Performance is significantly worse than the corresponding baseline performance.

[a] The Centralized Processing Scenario was selected because it generally produces the lowest increase in cost, schedule impacts, and health risks with respect to the baseline case–results for the regionalized and decentralized scenarios are found in Section 3.0.

Figure 5-4
Condensed Summary of WIPP Engineered Alternative Evaluation Results for Centralized Processing Scenario[a]

TABLE 5-3

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Waste Backfill Compressive Strength (MPa)	NA	25.2	24.5	25.1	24.1	15.2	21.1	21.1	19.4	12.2	12.2	18.3	20.1	24.7	14.7	20.6	20.6	14.7	19.7	15.2
Emplacement Volume Impact (% Emplaced or Amount not Emplaced m^3)	NA	100% emplaced	100% empleced	100% empleced	100% emplaced	100% emplaced	100% emplaced	100% emplaced	41,655	41,655	41,655	41,655	100% emplaced	27,177	27,177	27,177	27,177	27,177	27,177	100% emplaced
Backfill Properties -																				
Initial Density (Kg/m^3)	NA	NA	NA	NA	NA	1,590	1,884	1,884	1,884	1,000	1,590	1,193	1,193	NA	1,590	1,884	1,884	1,000	1,193	1,000
Initial Porosity (%)						40.0	31.3	31.3	31.3	62.5	40.0	44.8	44.8		40.0	31.3	31.3	62.5	44.8	62.5
Solid Density (Kg/m^3)						2,650	2,741	2,741	2,741	2,670	2,650	2,162	2,162		2,650	2,741	2,741	2,670	2,162	2,670
MRE (unitless)	1																			
E1		1.0	0.93	0.95	0.00078	0.74	0.40	0.40	0.44	0.56	0.73	0.79	0.83	0.69	0.66	0.45	0.45	0.53	0.67	0.54
E2		1.0	1.4	1.1	0.0093	2.0	1.1	1.1	0.56	2.3	2.1	0.30	0.30	1.1	0.86	0.46	0.46	0.88	0.30	2.1
E1E2		1.0	1.0	1.0	0.00076	0.99	0.04	0.04	0.083	0.93	0.98	0.032	0.050	1.0	0.99	0.089	0.089	0.49	0.012	0.56
Cuttings		1.0	.26	0.79	0.12	0.92	0.40	0.40	0.21	0.22	0.21	0.22	0.94	0.57	0.52	0.30	0.30	0.53	0.54	0.94
Uncertainty E1	2																			
5th Percentile		NA	0.92	0.92	0.0004	0.73	0.40	0.40	0.43	0.55	0.72	0.60	0.83	0.68	0.64	0.44	0.44	0.52	0.26	0.53
95th Percentile			0.94	0.96	0.0012	0.78	0.42	0.42	0.47	0.59	0.78	0.81	0.84	0.72	0.69	0.47	0.47	0.56	0.68	0.55
Uncertainty E2	2																			
5th Percentile		NA	0.61	0.75	0.0009	0.31	0.18	0.18	0.091	0.45	0.37	0.009	0.009	0.19	0.14	0.03	0.03	0.16	0.005	0.33
95th Percentile			2.08	1.75	0.0549	1.99	1.09	1.09	0.87	2.35	2.06	0.83	0.84	1.08	1.61	0.88	0.88	1.62	0.75	2.18
Uncertainty E1E2	2																			
5th Percentile		NA	1.0	1.0	0.0003	0.99	0.009	0.009	0.011	0.37	0.98	0.012	0.012	0.37	0.22	0.01	0.01	0.024	0.009	0.024
95th Percentile			1.0	1.0	0.0066	0.99	0.75	0.75	0.98	0.98	0.98	0.438	0.76	1.0	0.99	0.98	0.98	0.99	0.045	0.99
Uncertainty Cuttings	2																			
5th Percentile		NA	0.25	0.75	0.11	0.91	0.40	0.40	0.21	0.21	0.21	0.21	0.94	0.56	0.52	0.29	0.29	0.53	0.53	0.93
95th Percentile			0.26	0.80	0.18	0.92	0.40	0.40	0.21	0.22	0.21	0.22	0.94	0.57	0.52	0.30	0.30	0.53	0.54	0.94
WIPP Worker Rad Risk	3																			
FTE-Rem		322.85	322.85	322.85	322.85	345.27	357.23	357.23	342.07	340.15	343.99	338.23	339.29	322.85	346.77	366.20	343.78	342.28	339.29	342.28
Excess Fatalities		0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.13	0.14	0.15	0.14	0.14	0.14	0.14
WIPP Indust. Accidents	3																			
Injuries		53.63	44.05	44.05	33.20	64.50	70.81	70.81	55.53	49.80	51.77	51.06	66.45	53.63	67.04	69.14	69.56	61.83	63.25	62.53
Fatalities		0.16	0.13	0.13	0.10	0.29	0.30	0.30	0.15	0.15	0.15	0.25	0.28	0.16	0.39	0.21	0.49	0.18	0.28	0.18

M

M

TABLE 5-3 (continued)

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Waste Processing Risk	3																			
Centralized Scenario																				
Off-site Population																				
Cancer Fatalities		1.94×10^{-4}	$4..24\times10^{-4}$	4.24×10^{-4}	8.99×10^{-1}	NA	NA	NA	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	NA	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	$4..24\times10^{-4}$	NA
Cancer Incidence		5.51×10^{-8}	5.74×10^{-7}	5.74×10^{-7}	3.39×10^{-7}				5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}		5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	5.74×10^{-7}	
Workers																				
Cancer Fatalities		7.78×10^{-1}	$1.10\times10^{+0}$	$1.20\times10^{+0}$	$1.34\times10^{+0}$				$1.10\times10^{+0}$	$1.10\times10^{+0}$	$1.10\times10^{+0}$	$1.10\times10^{+0}$		$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	$1.20\times10^{+0}$	
Cancer Incidence		1.30×10^{-5}	3.49×10^{-5}	3.80×10^{-5}	1.69×10^{-4}				3.49×10^{-5}	3.49×10^{-5}	3.49×10^{-5}	3.49×10^{-5}		3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	3.80×10^{-5}	
Construct/Op Fatalities		2.81	3.79	4.08	5.29				3.79	3.79	3.79	3.79		4.08	4.08	4.08	4.08	4.08	4.08	
Waste Processing Risk	3																			
Regionalized Scenario																				
Off-site Population		1.94×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	$4.79\times10^{+0}$	NA	NA	NA	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	NA	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	2.73×10^{-4}	NA
Cancer Fatalities		5.51×10^{-8}	3.69×10^{-7}	3.69×10^{-7}	3.19×10^{-7}				3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}		3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	3.69×10^{-7}	
Cancer Incidence																				
Workers		7.78×10^{-1}	9.92×10^{-1}	8.12×10^{-1}	9.10×10^{-1}				9.92×10^{-1}	9.92×10^{-1}	9.92×10^{-1}	9.92×10^{-1}		8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	8.12×10^{-1}	
Cancer Fatalities		1.30×10^{-5}	3.15×10^{-5}	2.58×10^{-5}	3.73×10^{-5}				3.15×10^{-5}	3.15×10^{-5}	3.15×10^{-5}	3.15×10^{-5}		2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	2.58×10^{-5}	
Cancer Incidence		2.81	3.83	3.45	7.18				3.83	3.83	3.83	3.83		3.45	3.45	3.45	3.45	3.45	3.45	
Construct/Op Fatalities																				
Waste Processing Risk	3																			
Decentralized Scenario																				
Off-site Population		1.94×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	$4.60\times10^{+0}$	NA	NA	NA	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	NA	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	2.65×10^{-4}	NA
Cancer Fatalities		5.51×10^{-8}	3.59×10^{-7}	3.59×10^{-7}	3.06×10^{-7}				3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}		3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	3.59×10^{-7}	
Cancer Incidence																				
Workers		7.78×10^{-1}	9.54×10^{-1}	7.91×10^{-1}	$1.17\times10^{+0}$				9.54×10^{-1}	9.54×10^{-1}	9.54×10^{-1}	9.54×10^{-1}		7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	7.91×10^{-1}	
Cancer Fatalities		1.30×10^{-5}	3.03×10^{-5}	2.51×10^{-5}	4.81×10^{-5}				3.03×10^{-5}	3.03×10^{-5}	3.03×10^{-5}	3.03×10^{-5}		2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	2.51×10^{-5}	
Cancer Incidence		2.81	4.05	3.78	9.73				4.05	4.05	4.05	4.05		3.78	3.78	3.78	3.78	3.78	3.78	
Construct/Op Fatalities																				
Mining Advance Rate (m/Shift)	4	1.8	1.8	1.8	1.9	2.0	1.9	1.9	4.2	4.5	4.5	4.2	1.9	1.8	2.0	1.9	1.9	2.0	1.9	2.0
Removal Risk	4																			
Fatal Accidents		0.58	0.58	0.58	0.58	0.53	0.56	0.56	0.26	0.24	0.24	0.25	0.56	0.58	0.53	0.56	0.56	0.53	0.55	0.53
Non-Fatal Accidents		11.74	11.66	11.73	11.62	10.74	11.31	11.31	5.15	4.83	4.83	5.09	11.22	11.69	10.69	11.26	11.26	10.69	11.17	10.74

TABLE 5-3 (continued)

SUMMARY OF ANALYSIS RESULTS

Factor Output	Factor Number	Baseline	EA 1 Supper-compact	EA 6 Shred and Compact	EA 10 Plasma	EA 33 Sand & Clay BF	EA 35a Salt Agg. BF	EA 35b Cement Grout BF	EA 77a SuperC Salt Agg. BF	EA 77b SuperC Clay Base BF	EA 77c SuperC Sand Clay BF	EA 77d SuperC CaO BF	EA 83 CaO BF	EA 94a Shrd/Cly Sludge No BF	EA 94b 94 a + Clay Sand BF	EA 94c 94a + Cement Grout BF	EA 94d 94a + Salt Agg. BF	EA 94e 94a + Clay Base BF	EA 94f 94a + CaO BF	EA 111 Clay Based BF
Trans Rad Risk[1]	5																			
Decentralized (CH only)																				
Worker		$6.69x10^{+2}$	$5.81x10^{+2}$	$5.47x10^{+2}$	$7.16x10^{+2}$	$6.69x10^{+2}$	$6.69x10^{+2}$	$6.69x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$5.81x10^{+2}$	$6.69x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$4.25x10^{+2}$	$6.69x10^{+2}$
Person-Rem		$2.68x10^{-1}$	$2.32x10^{-1}$	$2.19x10^{-1}$	$2.86x0^{-1}$	$2.68x10^{-1}$	2.6810^{-1}	2.6810^{-1}	$2.32x10^{-1}$	$2.32x10^{-1}$	$2.32x10^{-1}$	$2.32x10^{-1}$	2.6810^{-1}	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	$1.70x10^{-1}$	2.6810^{-1}
LCF																				
Public		$4.00x10^{+3}$	$3.47x10^{+3}$	$3.27x10^{+3}$	$4.27x10^{+3}$	$4.00x10^{+3}$	$4.00x10^{+3}$	$4.00x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$3.47x10^{+3}$	$4.00x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$2.55x10^{+3}$	$4.00x10^{+3}$
Person-Rem		$2.00x10^{+0}$	$1.74x10^{+0}$	$1.64x10^{+0}$	$2.14x10^{+0}$	$2.00x10^{+0}$	$2.00x10^{+0}$	$2.00x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$1.74x10^{+0}$	$2.00x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$1.28x10^{+0}$	$2.00x10^{+0}$
LCF																				
Accident		$8.01x10^{+1}$	$5.92x10^{+0}$	$7.59x10^{+1}$	$1.21x10^{+0}$	$8.01x10^{+1}$	$8.01x10^{+1}$	$8.01x10^{+1}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$5.92x10^{+0}$	$8.01x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$5.76x10^{+1}$	$8.01x10^{+1}$
Person-Rem		$4.01x10^{-2}$	$2.96x10^{-3}$	$3.80x10^{-2}$	$6.05x10^{-4}$	$4.01x10^{-2}$	$4.01x10^{-2}$	$4.01x10^{-2}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$2.96x10^{-3}$	$4.01x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$2.88x10^{-2}$	$4.01x10^{-2}$
LCF																				
Trans Chemical Risk	5																			
Decentralized																				
Max. Individual		$1.21x10^{+0}$	$1.80x10^{+0}$	$1.20x10^{+0}$	$2.10x10^{-5}$	$1.21x10^{+0}$	$1.21x10^{+0}$	$1.21x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.80x10^{+0}$	$1.21x10^{+0}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$8.10x10^{-1}$	$1.21x10^{+0}$
Trans Non-Rad/Chem Risk	5																			
Decentralized																				
Injuries		$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$	$6.61x10^{+1}$
Fatalities		$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$	$4.87x10^{+0}$
Percent of Comments Addressed by EA	6	NA	33%	33%	40%	31%	36%	36%	33%	33%	33%	33%	36%	42%	42%	42%	42%	42%	42%	36%
Total System Cost	7																			
Decentralized ($x10^6$)		4,483	5,219	4,955	6,704	4,538	4,569	4,569	5,280	5,250	5,257	5,255	4,536	7,624	7,675	7,703	7,703	7,667	7,673	4,529
Regionalized ($x10^6$)		4,335	4,824	4,607	5,742	4,391	4,421	4,421	4,884	4,855	4,861	4,859	4,388	6,835	6,886	6,913	6,914	6,877	6,883	4,381
Centralized ($x10^6$)		4,029	4,177	4,129	4,725	4,084	4,115	4,145	4,237	4,208	4,214	4,213	4,082	4,982	5,032	5,050	5,061	5,024	5,030	4,075
Schedule Impact - Delayed Emplacement Relative to Baseline Startup	7	No Delay	9yrs.	8yrs.	9yrs.	No Delay	No Delay	No Delay	9yrs.	9yrs.	9yrs.	9yrs.	No Delay	9yrs.	9yrs.	9yrs.	9yrs.	9yrs.	9yrs.	No Delay
Other Waste Generation	8																			
Secondary (m^3)		32,729	118,040	118,040	21,848	32,729	32,729	32,729	118,040	118,040	118,040	118,040	32,729	131,625	131,625	131,625	131,625	131,625	131,625	32,729
LLW/LLMW (m^3)		16,365	59,020	59,020	10,924	16,365	16,365	16,365	59,020	59,020	59,020	59,020	16,365	65,813	65,813	65,813	65,813	65,813	65,813	16,365

[1]Only the Decentralized scenario is shown here. The Centralized scenario results for all EAs are the same as the baseline reported here. The Regionalized scenario analysis output is shown in Table 3-44.

In order to simplify the summary, only results for centralized processing scenarios from the Figure 5-1 EA scenario tree are included in Figure 5-3. This was done because, among the three processing facility schemes studied, centralized processing at WIPP generally produced the lowest increases in cost and schedule along with approximately comparable health risks. The impacts of regionalized and decentralized processing on cost are discussed in section 5.4.5.

5.4.2 Long-term Compliance Confidence

Chapters 3.1 and 3.2 report the evaluation of potential material releases from WIPP, given human intrusion into the repository in the distant future. These chapters discuss the impact of the EAs on the best estimate of WIPP performance and our confidence in the best estimate predictions, respectively.

The evaluations in chapters 3.1 and 3.2 focus on the possible transport of waste material from WIPP via direct removal by drilling and indirect removal via the transport of contaminated brine. Because the drilled material is removed from the bore hole directly into the above ground environment, while contaminated brine is subject to dilution and retention in the water bearing strata between the repository and the surface, evaluation results for these two release mechanisms are reported separately. Ongoing performance assessment work is now in progress that may produce conclusions on the relative importance of these release mechanisms.

Figures 5-5a and 5-5b show the predicted performance for all EAs relative to the baseline for direct material releases and the three brine transport scenarios. Figure 5-5a compares the median value results and Figure 5-5b compares the 95th percentile results.

Since no EA alters the footprint of the disposal area of the repository, EAs that reduce the effective diameter of the borehole through the waste should show the best improvement in predicted performance for direct drilling releases. The effective diameter of the borehole can, in theory, be reduced from the baseline conditions by increasing the shear strength of the waste bearing material, thereby causing the drill to cut a "cleaner" hole through the waste. Following this line of reasoning, EAs involving cement backfills and the supercompacting or plasma processing of waste should be expected to produce improved performance. This prediction was confirmed by the analysis results in Section 3.2. The reduction shown for plasma processing (approximately a factor of 9) was near the maximum achievable, considering the assumed increase in the effective borehole radius for unprocessed waste was a factor of 3. As stated in Section 3.1.1, it was not feasible to consider the impacts of actinide sorption on clays, EAs that employ clay based materials may exhibit better performance than the results presented in this report.

Repository performance with respect to brine transport is a much more complex question than direct material removal and was found to be dependent on the particular release scenario modeled. For the case where drilling passes through the repository and into the Castile brine reservoir below WIPP, plasma processing (EA#10) and EAs using cementitious backfills (EAs 35a, 35b, 77a, 94c, and 94d) produced a notable improvement over the baseline case.

For release scenarios where brine was modeled to pass through the waste horizontally before exiting (scenarios E2 and E1E2), the solubility of radionuclides and permeability of the waste were shown to be important. For release scenario E2, EAs using CaO backfill (EA#77d, 83 and 94f) produced marginally improved performance over the baseline. For release scenario E1E2, both

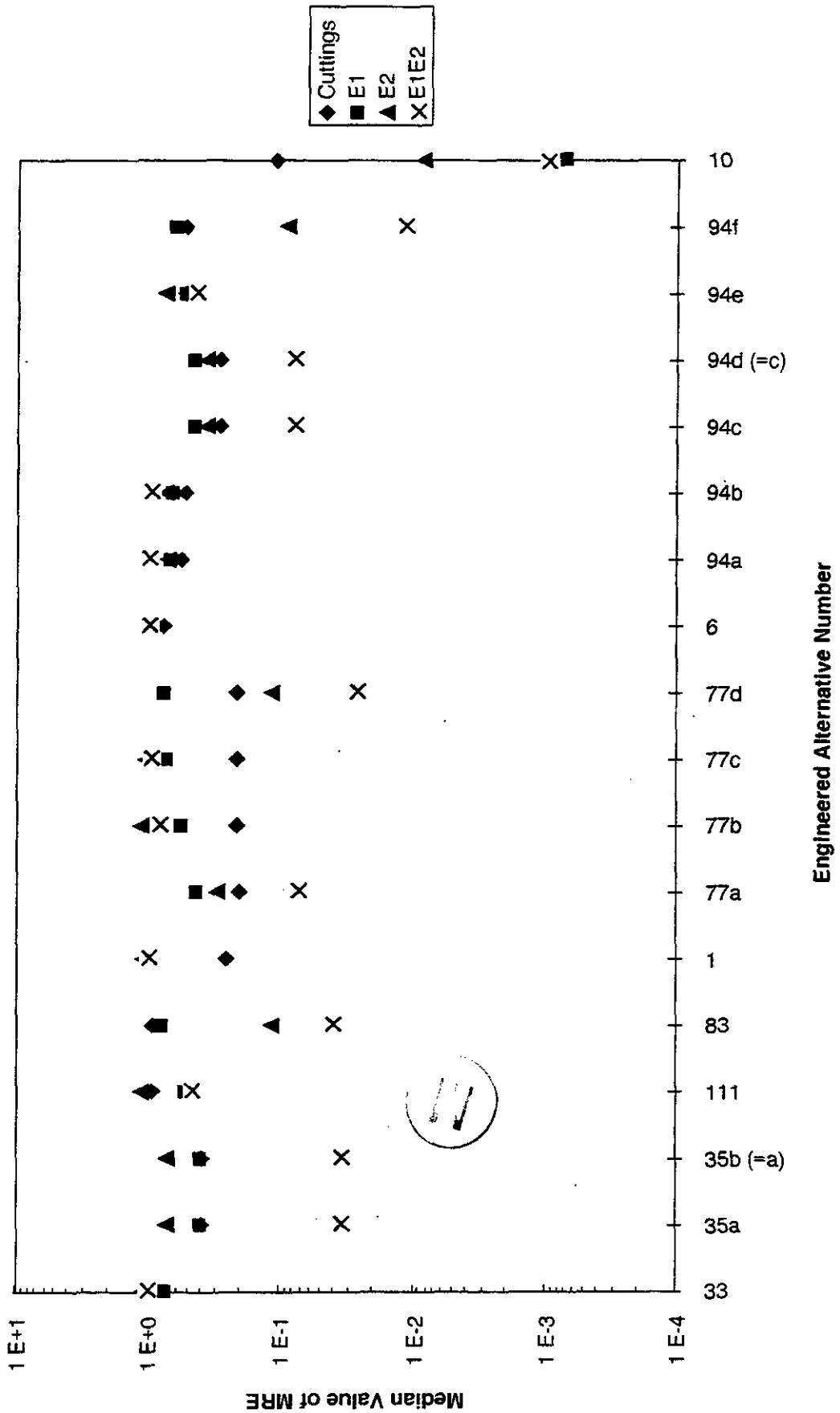

Figure 5-5a
Comparison of Medians of Case-by-Case MREs Across All Scenarios

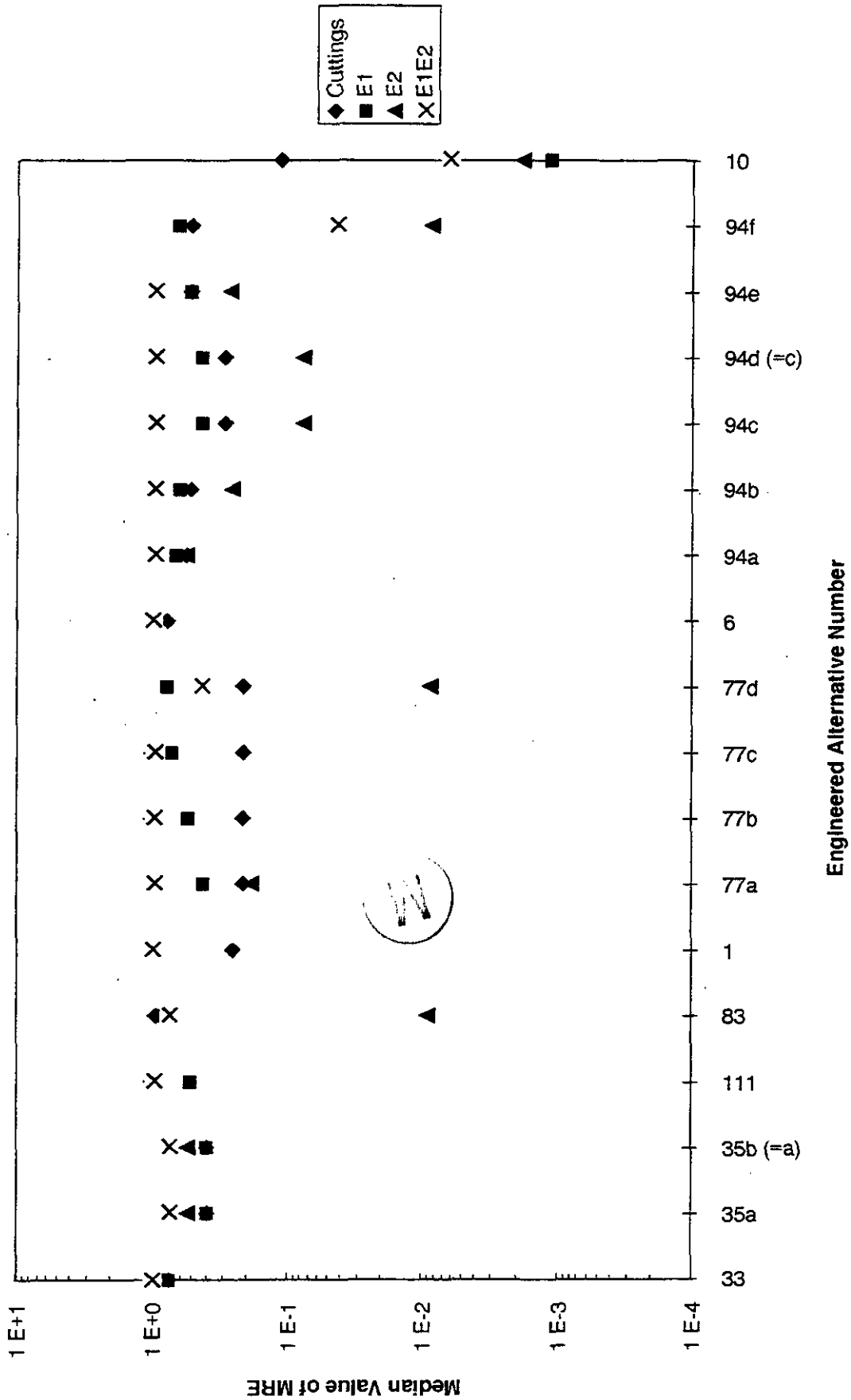

Figure 5-5b
Comparison of 95th Percentiles of the CDFs Across All Scenarios

CaO and cementitious backfills (EA#35a 35b, 77a, 77d, 83, 94c, and 94f) produced significant performance improvements. Plasma processing showed increased performance for both the E2 and E1E2 scenarios.

The qualitative performance rankings for brine transport scenarios in Figure 5-3 were assigned based on a combination of the results across the three brine transport scenarios. Based on the above discussion, Plasma Processing (EA#10) was given a "significant" rating because of its improvement in performance for all three brine transport scenarios. CaO backfill options (EA#77d, 83, and 94f) were given a "marginal" rating based on their improvements in both E2 and E1E2 release scenarios. All other EAs were rated generally unchanged from the baseline.

5.4.3 Public Health Risk

5.4.3.1 Public Health Risk Before Closure

Off-site public health risk from potential exposure to radionuclides and hazardous chemicals before WIPP closure was estimated for the baseline WIPP design and each EA. Calculations were performed to estimate added risks for both a hypothetical maximum exposed individual (MEI) and the collective off-site population. Relative risk indications among the EAs were consistent using either of these measures.

Total public health risk results for all EAs except those involving plasma waste processing were found to be quite close to the baseline predictions. Plasma waste processing (EA#10) public risk was found to be approximately four orders of magnitude greater than that for the other TRU processing options.

Public health risks at the generator sites were found to be relatively consistent across all scenarios (except plasma processing) due to the fact that processing risks added only marginally to the risk involved in waste handling and packaging found in the baseline alternative.

Public health risks at WIPP were higher, compared to the baseline, for scenarios requiring centralized waste processing at WIPP. This would be expected because the baseline has very minimal above ground waste handling at WIPP, while centralized processing will require extensive new treatment and disposal facilities at WIPP. This increased health risk at WIPP is partially offset, however, by lower risk at the generator sites, because the handling and packaging requirements for pre-treatment waste transfer are less than for direct placement at WIPP. The resulting total public risk across all sites for the centralized processing scenarios was generally found to be higher than for regionalized or 10-site processing. Based on the above findings, the results reported in Figure 5-3 show public health risk at the generator sites to be essentially unchanged for all EAs. Public health risks at WIPP are unchanged for the backfill only scenarios and marginally higher for all processing options, except plasma, which is significantly higher. These indicated increases in risk at WIPP are for the centralized processing options shown. For regionalized and decentralized cases, overall public health risks are marginally higher than that for the baseline.

Public health risk results are presented graphically in Figure 5-6 for all waste processing EAs. Backfill EAs (EA Nos. 33, 35a, 35b, 83, and 111) have the same risk as the baseline case. In this display, the total additional point estimate fatality risks from Tables 3-9 to 3-21 are summed

to form the midpoints shown and the high and low values estimated by assigning a range factor of 2 to the distribution of possible outcomes around the point estimate values.

5.4.3.2 Transportation Risk

Transportation risks reported in Chapter 3.5 included the potential consequences to both the transport crew and the public from both radiological and nonradiological sources. Differences among the EAs were found for radiological and hazardous chemical exposure risks. However, these risks were dominated by nonradiological/nonchemical risks and the results for total excess fatalities showed only minor variations from the baseline (less than 8%) across all EA scenarios. Thus, transportation risks prior to WIPP closure are indicated as unchanged from the baseline for all EAs in Figure 5-3.

Transportation risk results are presented graphically in Figure 5-7. In this display, the total additional point estimate fatality risks from Tables 3-42, 3-43, and 3-43 are summed to form the best estimate values shown.

5.4.3.3 Public Health Risk After Closure

Estimates of the impact of the EAs on predicted long-term public heath risk, presented in Chapter 3.1, mirror the compliance results discussed in section 5.4.2. However, the magnitude of long-term health risks predicted for the baseline and all EAs are exceedingly small. Therefore, long-term public health risks for all EAs are classified as essentially the same as the baseline.

5.4.4 Worker Health Risk

Worker risks were estimated for both facility workers directly involved in handling and processing TRU wastes and for co-located workers not directly involved with the wastes.

Health risks to both facility and on-site co-located workers from potential exposure to radionuclides and hazardous chemicals was estimated for the baseline WIPP design and each EA. Calculations were performed to estimate added risks for both a hypothetical MEI and the collective on-site population. Relative risk indications among the EAs were consistent using either of these risk measures. Risks to facility workers from standard industrial hazards involved in facility construction and operation were also calculated. For all scenarios, standard industrial risks outweighed risks from exposure to radionuclides or hazardous chemicals.

Total worker health risk results for all EAs involving all types of waste processing were found to be higher than for nonprocessing scenarios. These higher risks were incurred at the processing sites, that is the generators for distributed or regionalized processing and at WIPP for centralized processing. As a result, the centralized processing cases reported in Figure 5-3 show unchanged risks for the generator sites and significantly higher risks at WIPP for all processing options.

Worker health risk results are presented graphically in Figure 5-8. In this display, the total additional point estimate fatality risks from Tables 3-9 to 3-21 are summed to form the midpoints shown and the high and low values are estimated by assigning a range factor of 2 to the distribution of possible outcomes around the point estimate values.

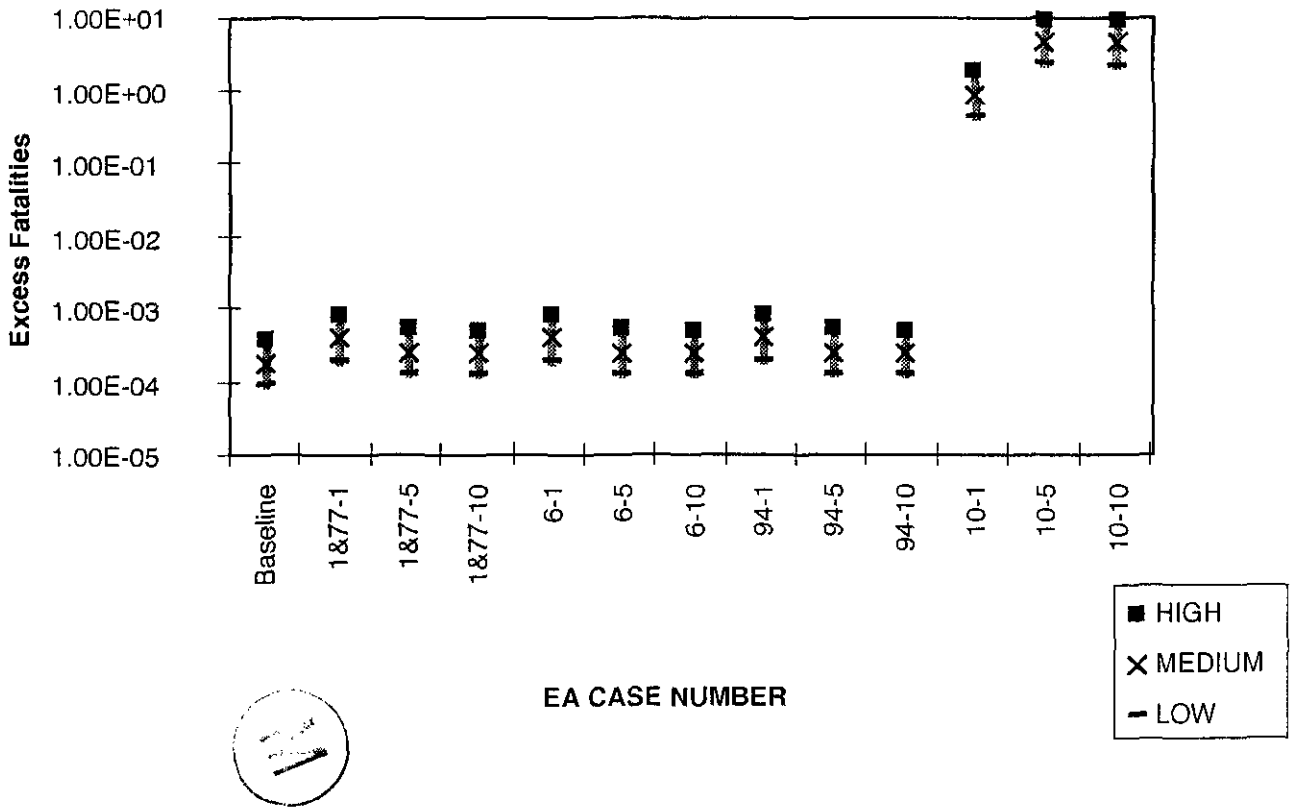

Figure 5-6
Offsite Public Risk

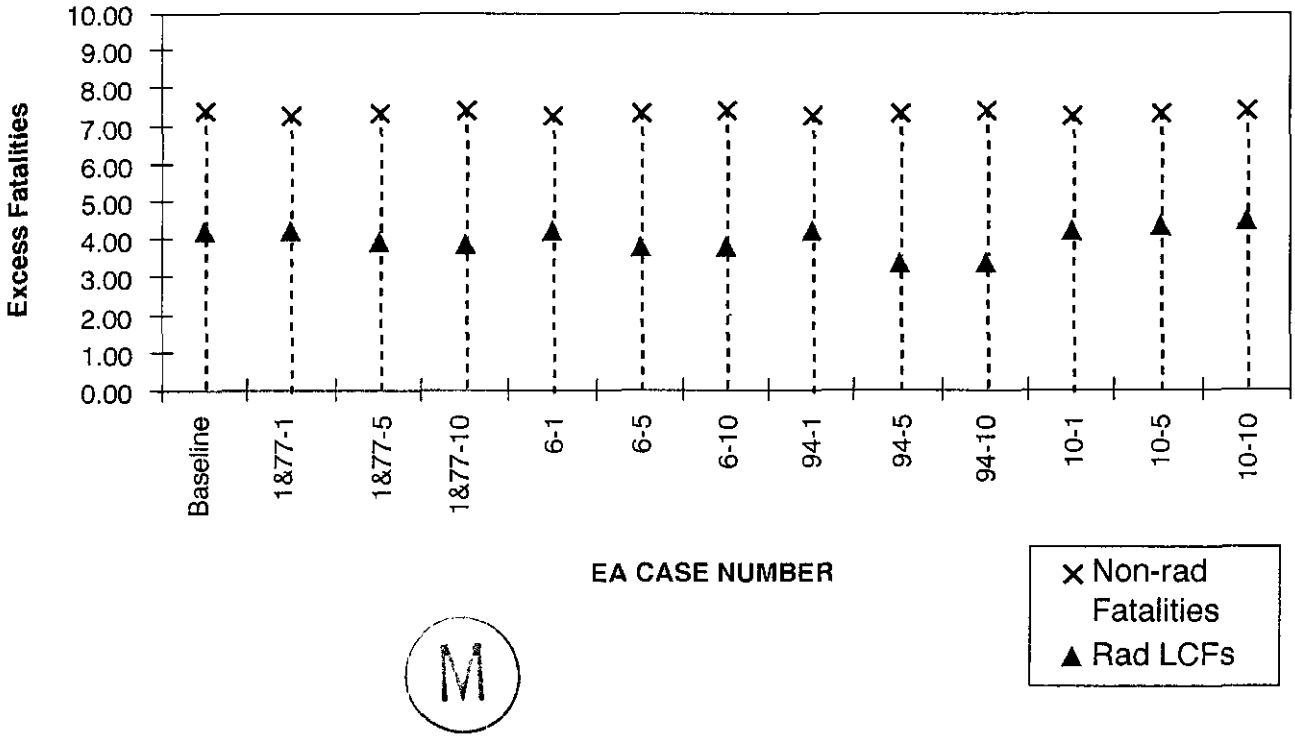

Figure 5-7
Transportation Risk

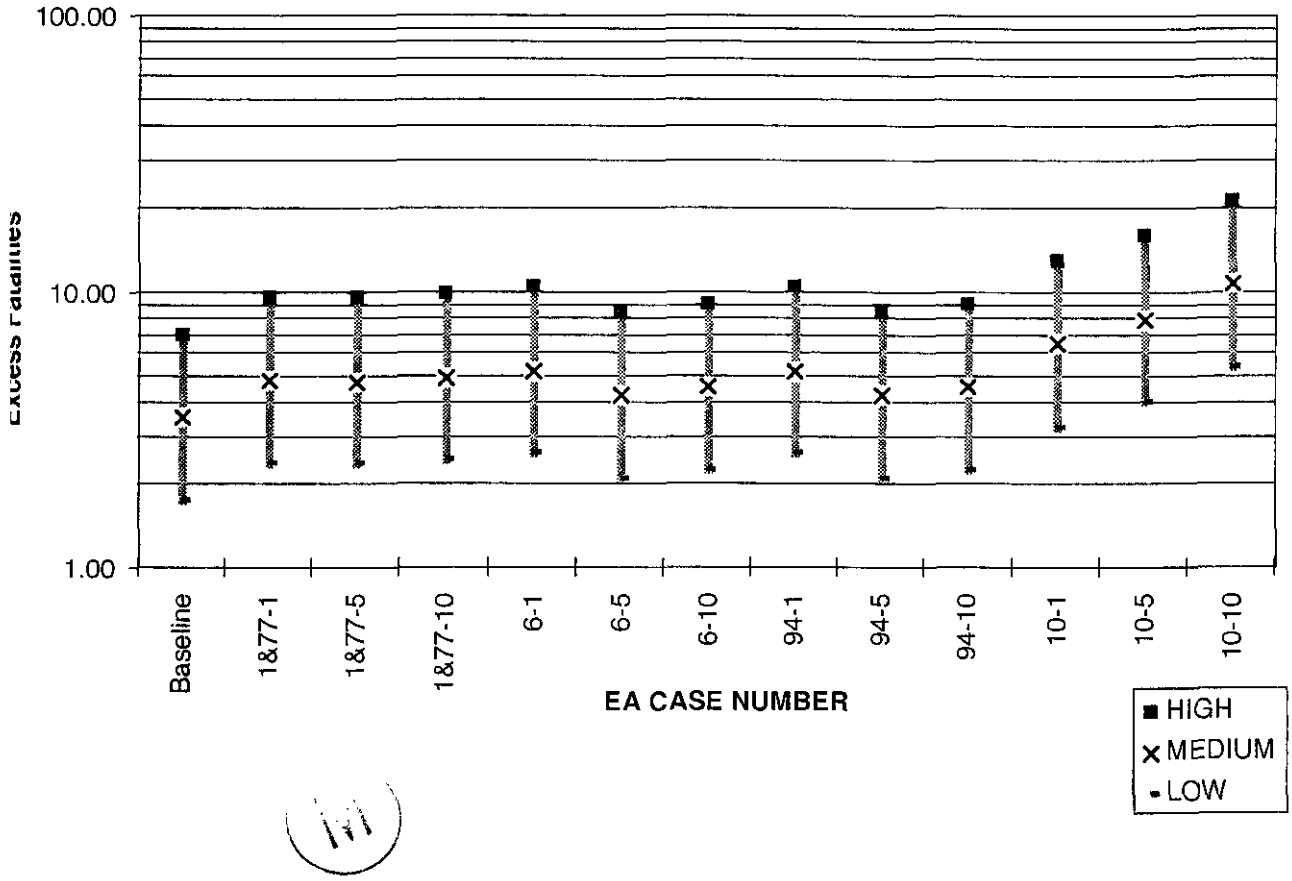

Figure 5-8
Worker Risk

5.4.5 Disposal System Cost

5.4.5.1 Waste Processing Cost

Estimated costs for waste processing summarized in Chapter 3.7.4.1.1 were found to increase substantially over the baseline for the more extensive processing methods. Overlaid on this trend, powerful economies of scale are predicted for accomplishing the processing centrally at WIPP rather than regionally or at each waste generation site. Centralized processing at WIPP, while potentially reducing overall costs, would result in significantly increased expenditures at WIPP. This shift is estimated to total between 15% and 34% of total processing costs or $500 million to $1.5 billion.

5.4.5.2 Transportation Cost

Waste transportation costs were found to be essentially the same for all centralized and backfill only EAs. These costs were estimated to be the same as the baseline centralized transportation costs. The decentralized and regionalized baseline costs were the same for the corresponding EAs except for the 94 series which had a significantly higher cost.

5.4.5.3 Waste Placement and Backfill Cost

Cost impacts for waste placement and backfill are estimated to total between $30 and $80 million or less than 1.5% of the total disposal system costs. The cost additions indicated on Figure 5-3 are incurred for the placement of wet cement backfills, while potential savings are shown for EA Nos. 1, 6, 10, 77 all, and 94 all processing options.

5.4.5.4 Total TRU Disposal System Cost

By combining the costs from the previous subsections, the combined influences of processing method and processing location on the total TRU waste disposal system costs can be seen. The impact of processing costs on the total TRU system is seen in Figure 5-9. This Figure shows the total TRU system costs, with uncertainty for all processing options performed centrally at WIPP. Supercompaction with backfill EAs (EA#77 all) and the shred and add clay alternatives (EA#94) show significant cost increases over the baseline. This conclusion is valid, however, only for the centralized processing results shown. Figure 5-10 shows that economies of scale are much stronger for the more aggressive processing methods than for the baseline. Thus, while centralized shred and add clay (EA#94) and plasma processing (EA#10) appear competitive with lesser processing alternatives, a decentralized approach for the same processes is significantly more costly.

5.4.6 Impact on Other Waste Programs

In general, only the additional waste processing activities associated with the WIPP EAs have the potential to impact other waste systems. The assessment of other waste system impacts reported in Chapter 3.8 found that all processing techniques evaluated, except plasma processing, significantly increased the LLW and LLMW volumes generated from the TRU waste disposal system. Plasma processing (EA#10) actually reduces somewhat the volumes of other waste from the base since all contaminated materials are recycled into the final product.

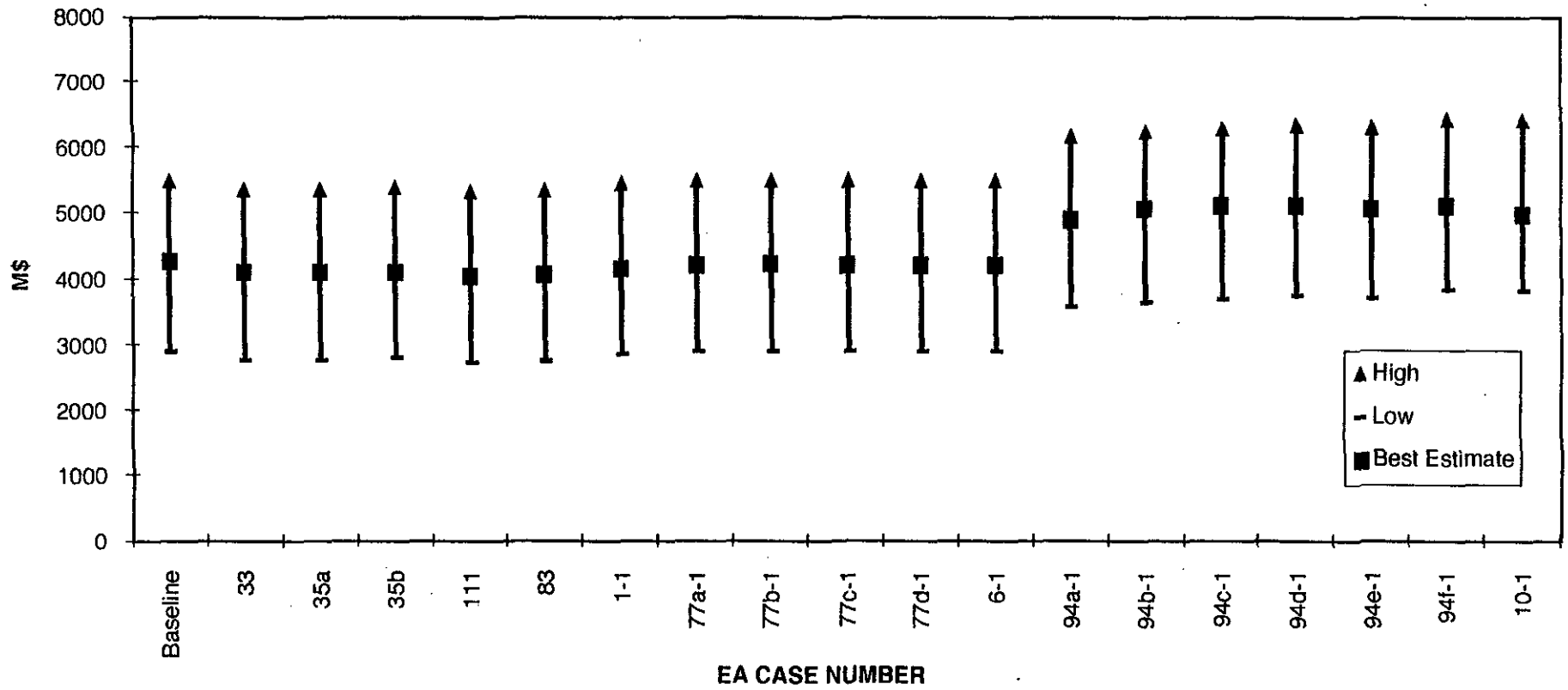

Figure 5-9

Impact of Processing Method on Total TRU Waste System Cost (for Centralized Processing Cases)

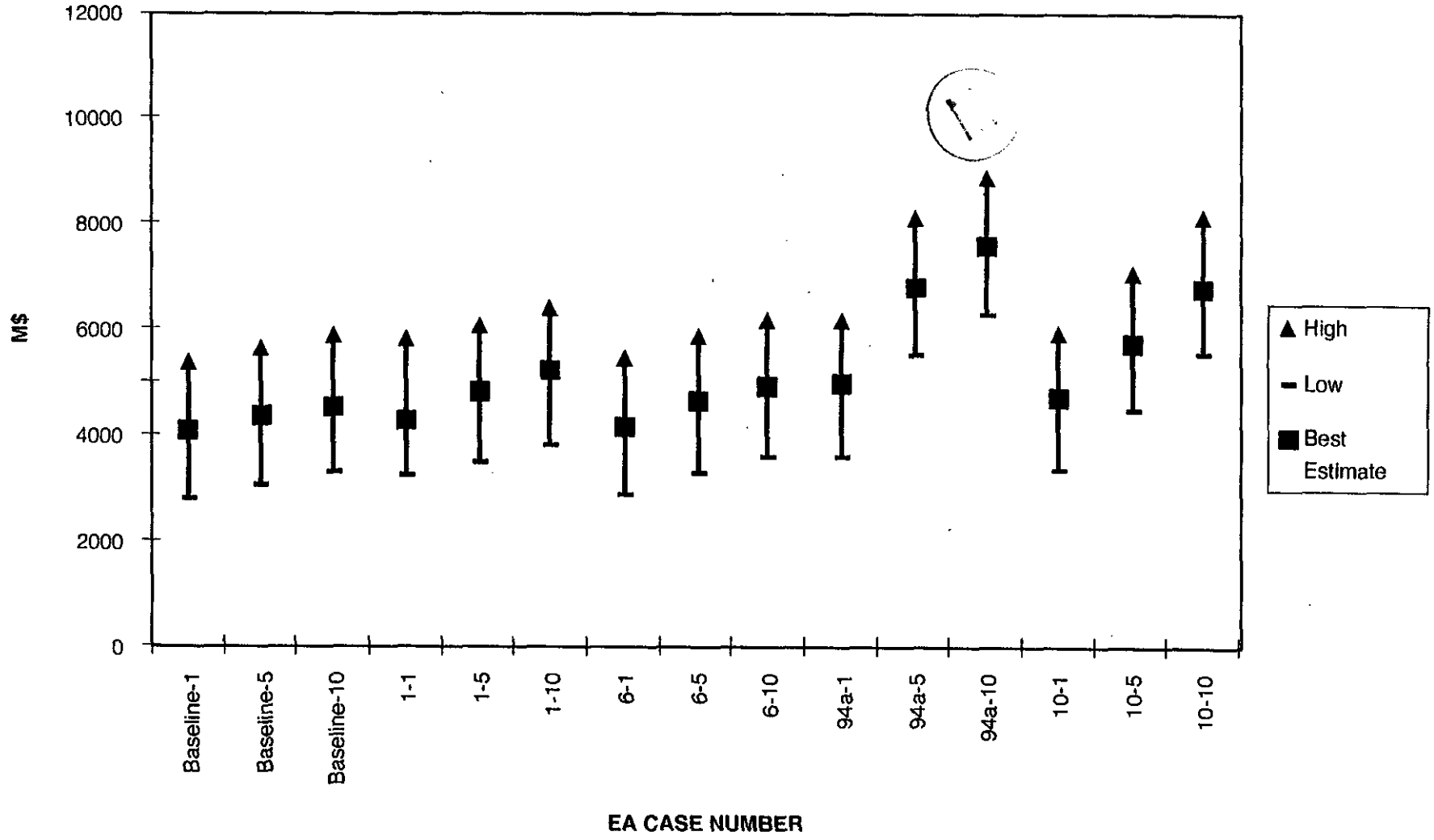

Figure 5-10
Impact Of Processing Location On Total TRU Waste System Cost

Even though the volumes of other waste produced from the TRU program would be increased by processing, the volumes generated were found to be small compared to those coming from other sources. Therefore, the impact on the overall volumes of LLW and LLMW requiring disposal is minor. Thus, the impacts on other waste disposal systems for processing alternatives #1, 6, 77 and 94 are indicated as marginal in Figure 5-3.

5.4.7 WIPP Schedule

Analyses of the potential impacts of EAs on the WIPP operating schedule presented in Chapter 3.7.2 show that the waste processing, placement and backfill activities included in any of the evaluated EAs can be accomplished within a 35 year operational life for WIPP. Underlying this broad conclusion, however, it is also acknowledged that the placement of wastes requiring additional processing may be delayed 12 years or more while the facilities needed to perform the processing are licensed and built. Because of this, the WIPP schedule impacts shown on Figure 5-3 for the first placement of wastes requiring additional processing are indicated to be significantly later than the baseline.

5.4.8 Waste Removal Capability

Table 3-31 summarizes the person-hour effort and associated risks for the hypothetical removal of wastes from WIPP for the baseline and all EAs. This evaluation shows that all EAs except those involving supercompaction of wastes, would require essentially the same effort to remove. EAs that limit the total emplacement volumes below the baseline case (EA#1 and 77 all), reduce the waste removal effort by approximately 50 percent. Thus, EAs 1 and 77a-d are shown as marginally better than the baseline in Figure 5-3.

5.4.9 Public Confidence

Chapter 3.6 documents the potential for selected waste processing and backfill actions to address public concerns expressed about long-term WIPP performance. The evaluated processing and backfill actions were found to have a possible impact on 31% to 42% of the public concerns registered to date. Potential concerns about additional public health risks or TRU disposal system costs prior to WIPP closure have not yet been investigated.

Because of the nature of public opinion and the qualitative analysis used to assess public confidence, measurement of public confidence in the performance of the disposal system was taken as the percentage of comments that could be addressed by an EA. The overall spread of the results were such that they do not lend to differentiation. Therefore, all EAs are indicated as unchanged from the baseline for this impact vector element (Figure 5-3).

5.5 Summary of Observations and Conclusions

Each EA was analyzed in the EACBS and the results are presented in Chapter 3. These results were integrated into a summary presented in Sections 5.1 through 5.4. comparing the results to the baseline. The following sections provide an overview of the limitations of the study and present some observations that were apparent from the evaluation of the results.

Engineered Alternatives analyzed in the EACBS can be categorized into the following three groups.

- Processing Alternatives—Processing alternatives (EA# 1,6 & 10) were analyzed for three processing scenarios, centralized, regionalized and decentralized. The three scenarios have inherent benefits and detriments independent of the EAs. In general, processing alternatives impact the entire waste disposal system, involving the generator/storage sites, waste transportation, other waste disposal systems, and the WIPP waste handling system. Processing alternatives have higher cost, risks and schedule delays than the baseline and backfill only EAs. Processing EAs have a marginal performance impact on the repository excluding plasma processing (EA# 10) which showed a significant increase in repository impact at the expense of having the highest potential risk of all EAs analyzed.

- Backfill Alternatives—Backfill alternatives (EA# 33, 35a, 35b, 83 & 111) have the least impact on the entire waste disposal system. The WIPP waste handling system is impacted; waste transportation, generator/storage sites, and other waste disposal systems are not affected. Cost, schedule radiation and chemical exposure are all similar to the baseline estimates. All backfill alternatives improve long-term disposal system performance.

- Combination Alternatives—Combination alternatives contain both multiple processing and/or backfill alternatives.[1] These alternatives (EA# 77a through 77d and 94a through 94f) have benefits and detriments associated with each alternative type. The overall costs and schedule impacts on the EAs are the highest of all and the transportation, worker and public risks (radiological, chemical accidental and incidental) are also the highest of the alternatives. The overall impact on long-term disposal system performance for combination EAs is comparable to the performance associated with the single backfill and processing alternatives.

5.5.1 Limitations of the Study

- The EAs considered in this study were restricted to waste treatment, backfill, and minor facility design modification such as changes in room dimensions to accommodate treated waste forms. The definition of an EA used in this study does not include processes that would reduce the probability of an intrusive event.

- Assessment of the frequency of human intrusion and any active or passive features that might impact the intrusion frequency were outside the scope of this evaluation. Since any changes affecting the frequency of intrusion would impact both the baseline and each EA equally, those effects cancel when the measures of relative effectiveness are calculated.

- No releases to the accessible environment of radionuclides are predicted to occur under undisturbed performance. Therefore, this analysis focused on EAs that could mitigate the consequences of human intrusion events.

- This study calculated releases to the Culebra; transport processes in the Culebra were not simulated as part of the long-term performance modeling. Since none of

[1]One combination EA contains "Enhanced Cementation of Sludges," a processing EA, that was not one of the individual processing EAs but will be detailed in the Combination EA section.

the EAs evaluated in this study affect those transport processes, the effects of those processes cancel when the measures of relative effectiveness are calculated.

- The actinide sorption properties of clays were not included in the EACBS analysis, impacting the results for EAs that included clay materials. The performance of these EAs may be higher all for radionuclide transport scenarios.

- The cost models used in the EACBS analysis originated in the EMPEIS. The accuracy of the results presented here are a function of the accuracy of the models.

5.5.2 Benefits and Detriments of Processing Alternatives

All EAs involving waste processing were analyzed for three separate scenarios related to where the waste would be processed and how many facilities are to be used. These scenarios have inherent benefits and determents that are independent of the EA. These benefits and determents are discussed below.

5.5.2.1 Centralized Cases

Detriment

The centralized case processes all waste at one processing facility, the WIPP. All generators retrieve, package and certify the waste prior to shipment to the one processing facility. The risks and costs for these operations are the same as baseline, however the overall worker and public risks are higher since all the waste is handled twice, once at the generator and again at the processing facility. Since a majority of the off-site risks are associated with opening of the drums, and the generators and processing facility both perform this operation, the off-site and on-site radiological and health risks are highest for the centralized scenario.

The centralized scenario has the highest potential to impact system wide disposal operations. Since one facility is used to process the waste, it must be fully operational on schedule and must operate as designed without failures. The processing facility is the bottleneck of the disposal system since delays impact the total disposal operation. Success or failure of the centralized processing scenario is dependent on the functional design, siting, permitting, construction, schedule, and functionality of one facility.

WIPP currently has no facilities or capabilities to process the waste. All centralized EAs will require the construction of new facilities to process the waste at WIPP.

Benefit

The centralized scenario has the lowest implementation cost to of the three scenarios (baseline not included). The cost of building one facility will be lower than building five or ten smaller facilities (Figure 5-10). With respect to the baseline, the generator/storage sites incur the same general costs as the baseline, and may be slightly lower. The EACBS assumed that less certification will be required to ship the waste to the processing facility since the shipped waste is not the final waste form emplaced in WIPP. The waste would not need to meet the WIPP WAC, only DOT transportation requirements.

The operational/construction incidental/fatalities are lower than the decentralized scenario and are either better or worse than the regionalized scenario, depending on the particular EA (baseline not included).

All transportation risks are unchanged from the baseline configuration; the transportation scenario for the centralized case is identical to the baseline.

5.5.2.2 Regionalized

Detriments

The regionalized scenario processes waste at five generator sites. The sites are selected such that a majority of the waste is presently stored at those sites, requiring only a small amount of waste to be transported from the other five generator/storage sites. The waste must be retrieved, packaged and certified prior to shipment to the five processing facilities. The five processing sites must also retrieve and handle their waste. Therefore, the total off-site and on-site risks are similar to but slightly higher than the baseline (Table 3-24). This is because the small quantities of waste from the sites shipped to the five processing facilities are handled twice.

For most of the EAs, the cost for the regionalized scenario is significantly higher than the centralized scenario and lower than the decentralized scenario (Figure 5-10). The cost differences between the EAs are due to the current capabilities of the generator storage sites; some sites will require minor modifications to process the waste for the minor processing EAs such as Shred and Compact (#77EAs).

Benefits

The regionalized processing scenario is more flexible than the centralized case. Since five facilities are required, the impact of failure at one facility will not severely impact the total disposal system operations. Failures at sites prior to completion operation of that facility may be overcome by the success of the other facilities; contingencies could include designs that are capable of processing more than would be required for five sites. Schedule impacts and processing rates can be adjusted to compensate for deficiencies at other facilities.

The operational/construction indecent/fatalities are lower than the decentralized scenario and are better or worse than the centralized scenario depending on the particular EA (baseline not included).

Since most of the waste is processed at the five sites, and most processing modifies the waste into a safer form for transportation, a reduction in transportation chemical risk is gained. The radiation risks are assumed to be the same as the baseline except for EAs that reduce the overall waste volume shipped to WIPP.

5.5.2.3 Decentralized

Detriments

The decentralized scenario builds and operates ten processing facilities at the major sites. The cost of this scenario is the highest of all three. The EACBS takes into account the current capabilities of the sites and factors in cost reductions where site capabilities and existing

structures for the processing facilities can be utilized. However, not all EAs can utilize current site facilities or capabilities.

The operational/construction indecent/fatalities are generally higher than both the centralized and regionalized scenarios (baseline included).

Benefits

A reduction in the transportation radiation and chemical risks for accident scenarios occurs for most processing EAs because the waste form has been modified. Since all waste is processed prior to shipment to WIPP, all accident scenarios occur with the improved waste form. This reduction is related to the EAs final waste characteristics and is dependent on the particular EA.

5.5.3 Conclusion

The conclusions of this report do not recommend, select or reject EAs based on the results of the EACBS analysis. The results and observations are intended to be used by a DOE decision maker for consideration regarding the potential use of EAs at WIPP for additional assurance. If a decision is made to select an EA for WIPP, it will be made with full system wide knowledge and best available information for which the EACBS provides only a part. The risk cost benefits and overall disposal system impacts must be considered along with the potential benefits if an EA is selected. The EACBS was conceived to provide information regarding these impacts and benefits.

6.0 REFERENCES

AIHA, see American Industrial Hygiene Association.

American Industrial Hygiene Association, 1989, "Concepts and Procedures for the Development of Emergency Response Planning Guidelines (ERPGs)," American Industrial Hygiene Association ERPG Committee, December, Akron, Ohio.

Ayer, J. E., et al., 1988, "The Nuclear Fuel Cycle Facility Accident Analysis Handbook," *NUREG-1320*, May, U.S. Nuclear Regulatory Commission, Washington, D.C.

Bjotvedt, L., MACTEC, 1995, Personal Communication.

Brush, L. H., 1995, "Position Paper on Gas Generation in the Waste Isolation Pilot Plant," Sandia National Laboratories, Albuquerque, New Mexico.

Case, J. B., C. A. Givens, and J. R. Tyburski, 1991, "The Geotechnical Effects of Alcove Excavation on Panel 1," *DOE/WIPP 91-017,* U.S. Department of Energy, Carlsbad, New Mexico.

Case, J. B., P. C. Kelsall, and J. L. Withiam, 1987, "Laboratory Investigation of Crushed Salt Consolidation," *Proceedings of the 28th U.S. Symposium on Rock Mechanics*, June 1–July 1, 1987, Tucson, Arizona.

Coons, W., A. Bergstrom, P. Gnirk, M. Gray, B. Knecht, R. Pusch, J. Steadman, B. Stillborg, M. Tokonami, and M. Vaajasaari, 1987, "State-of-the-Art Report on Potentially Useful Materials for Sealing Nuclear Waste Repositories," *STRIPA Report 87-12*, prepared for the Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.

D'Appolonia Consulting Engineers, Inc., 1976, "Preliminary State-of-the-Art Survey: Mining Techniques for Salt and Other Rock Types," Report to Office of Waste Isolation, Nuclear Division, D'Appolonia Consulting Engineers, Denver, Colorado.

Deal, D. E., R. J. Abitz, D. S. Belski, J. B. Case, M. E. Crawley, R. M. Deshler, P. E. Drez, C. A. Givens, R. B. King, B. A. Lauctes, J. Myers, S. Niou, J. M. Pietz, W. M. Roggenthen, J. R. Tyburski, and M. C. Wallace, 1989, "Brine Sampling and Evaluation Program 1988 Report," *DOE-WIPP-89-015*, U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

DOE, see U.S. Department of Energy.

DOT, see U.S. Department of Transportation.

EG&G Rocky Flats, Inc, 1995, "Waste Stream and Residue Identification and Characterization," Buildings 374 and 774, Version 5.0.

EPA, see U.S. Environmental Protection Agency.

Feizollahi, F., and Shropshire, D., 1994, "Interim Report: Waste Management Facilities Cost Information for Transuranic Waste," *EGG-WM-11274*, Idaho Falls, Idaho.

Feizollahi, F., D. Shropshire, and D. Burton, 1994, "Waste Management Facilities Cost Information for Transportation of Radioactive and Hazardous Materials," *EGG-WM-10877*, Rev. 1, EG&G Idaho, Inc., Idaho Falls, Idaho.

Freeze, R. A., and J. A. Cherry, 1979, *Groundwater*, Prentice Hall, Englewood Cliffs, New Jersey.

George, D., The S. M. Stoller Corporation, 1995, Personal Communication.

Gifford, F. A., Jr., 1961, "Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion," *Nuclear Safety*, 2:4,47–57.

Goodman, R. E., 1980, *Introduction to Rock Mechanics*, John Wiley & Sons, New York, New York, p. 62.

Gregory, J. J., R. Mata, and N. R. Keltner, August 1987, "Thermal Measurements in a Series of Large Open Pool Fires," *SAND85-0196*, Sandia National Laboratories, Albuquerque, New Mexico.

Gulick, C. W., and L. D. Wakeley, 1989, "Reference Properties of Cement-Based Plugging and Sealing Materials for the Waste Isolation Pilot Plant (WIPP)," *Technical Report SL-89-17*, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

Hartman, Howard L., 1992, Society of Mining Engineers, *Mining Engineering Handbook*, 2nd ed., Society of Mining Engineers.

ICRP, see International Commission on Radiological Protection.

International Commission on Radiological Protection, 1990, *1990 Recommendations of the International Commission on Radiological Protection*, Pergamon Press, New York, New York.

Johnson, P. E., D. S. Joy, D. B. Clarke, and J. M. Jacobi, 1993, "HIGHWAY 3.1—An Enhanced Highway Routing Model: Program Description, Methodology, and Revised User's Manual," *ORNL/TM-12090*, Oak Ridge, Tennessee.

Lappin, A. R., 1988, "Summary of Site-Characterization Studies Conducted from 1983 through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico," *SAND88-0157*, Sandia National Laboratories, Albuquerque, New Mexico.

Lappin, A. R., R. L. Hunter, eds., D. P. Garber, P. B. Davies, assoc. eds., March 1989, "Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989," *SAND89-0462*, Sandia National Laboratories, Albuquerque, New Mexico.

LESAT, see Lockheed Environmental Systems & Technologies Co.

Lide, D. R., ed., 1991, *CRC Handbook of Chemistry and Physics*, 71st ed., CRC Press, Boca Raton, Florida.

Lockheed Environmental Systems & Technologies Co. (LESAT), 1995, "Pit 9 Comprehensive Demonstration Phase II Preliminary Safety Analysis Report draft", *LAE-0001* Draft, under Subcontract No. C91-133136 to the U.S. Department of Energy.

McFeat-Smith, I., and R. J. Powell, 1979, "The selection and Application of Roadheaders for Rock Tunnelling," *Proceedings of the 1979 Rapid Excavation and Tunnelling Conference,* Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, New York.

Mindess, S., and J. F. Young, 1981, *Concrete,* Prentice-Hall, Englewood Cliffs, New Jersey.

Moghissi, A. A., Godbee, H. W., and Hobart, S. A., 1986, *Radioactive Waste Technology*, American Society of Mechanical Engineer, New York, New York.

Morris, D. A., and A. I. Johnson, 1967, "Summary of Hydrologic and Physical Properties of Rock and Soil Materials, as Analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948–60," *Geological Survey Water-Supply Paper 1839-D*, U.S. Government Printing Office, Washington, D.C.

National Council on Radiation Protection and Measurements, 1987, *Ionizing Radiation Exposures of the Population of the United States*, Report No. 93.

Nelson, J., P. C. Kelsall, J. B. Case, and J. G. Franzone, 1981, "Assessment of Crushed Salt Consolidation and Fracture Healing Processes in a Nuclear Waste Repository in Salt," D'Appolonia Topical Report, D'Appolonia Consulting Engineers, Albuquerque, New Mexico.

Neuhauser, K. S. and F. L. Kanipe, 1992, "RADTRAN 4: Volume 3, User Guide," *SAND89-2370, TTC-0943*, Sandia National Laboratories, Albuquerque, New Mexico.

Nielsen, T. J., Lockheed Martin Environmental Systems and Technologies Co., 1995, Personal Communications.

Nowak, E. J., J. R. Tillerson, and T. M. Torres, 1990, "Initial Reference Seal System Design: Waste Isolation Pilot Plant (WIPP)," *SAND90-0355*, Sandia National Laboratories, Albuquerque, New Mexico.

Nowak, E. J., Sandia National Laboratories, 1990, Personal Communication.

Nowak, E. J., D. F. McTigue, and R. Beraun, 1988, "Brine Inflow to WIPP Disposal Rooms: Data, Modeling, and Assessment," *SAND88-0112*, Sandia National Laboratories, Albuquerque, New Mexico.

NRC, see U.S. Nuclear Regulatory Commission.

Owens, C. B., Scientific Ecology Group, Inc., 1995, Personal Communication.

Pacific Northwest Laboratories, 1975, "Impact Testing of Vitreous Simulated High Level Waste in Canisters," *BNWL-1903*.

Peck, R. B., W. E. Hanson, and T. H. Thornburn, 1974, *Foundation Engineering*, 2nd ed., John Wiley & Sons, New York, New York, 514 pp.

Peters, M. S., and K. D. Timmerhaus, 1991, *Plant Design and Economics for Chemical Engineers*, 4th ed., McGraw Hill, Inc., New York, New York.

Peters, R. D., D. N. Berger, and W. A. Ross, 1991, "Design and Development of a Plasma Furnace to Treat Radioactive Wastes," Presented at the Spectrum '90 Nuclear and Hazardous Waste Management International Topical Meeting, Knoxville, Tennessee, September 30 to October 4, 1990.

Rechard, R. P., 1989, "Review and Discussion of Code Linkage and Data Flow in Nuclear Waste Compliance Assessments," *SAND87-2833*, Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories/New Mexico, 1995, "Systems Prioritization Method—Iteration 2 Baseline Position Paper: Actinide Source Term," C. F. Novak, N. J. Dhooge, H. W. Papenguth, and R. F. Weiner, Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories/New Mexico, 1993, "Preliminary Performance Assessment for the Waste Isolation Pilot Plant," December 1992, *SAND92-0700*, Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories/New Mexico, December 1991, "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991," Vol. 3: Reference Data, WIPP Performance Assessment Division, *SAND91-0893/3*, Sandia National Laboratories, New Mexico.

Slade, D. H., ed., 1968, "Meteorology and Atomic Energy—1968," *TID-24190*, Division of Technical Information, U.S. Atomic Energy Commission.

SNL/NM, see Sandia National Laboratories/New Mexico.

Temporal, J., R. A. Snowdon, and W. P. O'Reilly, 1983, "Laboratory Disc Cutting Studies in Medium and Hard Rocks," *Proceedings of the 1983 Rapid Excavation and Tunnelling Conference*, Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York.

U.S. Bureau of Reclamation, 1974, "Design of Small Dams," A Water Resources Technical Publication, U.S. Government Printing Office, Washington, D.C.

U.S. Congress, October 30, 1992, "Waste Isolation Pilot Plant Land Withdrawal Act," *Public Law 102-579*, Washington D.C.

U.S. Department of Energy, 1995a, "Clay Information for Engineered Alternatives Cost/Benefit Study," Memorandum from James Maes, Regulatory Engineer, DOE/CAO, to Jonathan Myers, IT Corporation.

U.S. Department of Energy, 1995b, "Environmental Restoration and Waste Management Programmatic Environmental Impact Statement," Appendix D, March 7, 1995, draft.

U.S. Department of Energy, 1995c, "State RCRA Permit Modification Request #33 for the Supercompactor," *State RCRA Permit No. 91-02-30-01 CO 7890010526*, Rocky Flats Environmental Technology Site, Golden, Colorado.

U.S. Department of Energy, 1995d, "Transuranic Waste Characterization Quality Assurance Program Plan," *DOE/CAO-94-1010*, Rev. 0, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy, 1995e, "Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report," *CAO-94-1005*, Rev. 1, Carlsbad, New Mexico.

U.S. Department of Energy, 1994a, "Comparative Study of Waste Isolation Pilot Plant (WIPP) Transportation Alternatives," *DOE/WIPP 93-058*, Carlsbad, New Mexico.

U.S. Department of Energy, 1994b, "Draft Environmental Management Programmatic Environmental Impact Statement," *DOE/EIS-0200*.

U.S. Department of Energy, 1994c, "Integrated Data Base Report 1993: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," *DOE/RW-0006*, Rev. 10, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

U.S. Department of Energy, 1994d, "National Data Base System for the Final Mixed Waste Inventory Report, Draft User's Guide," (includes data diskette, Version 1.0).

U.S. Department of Energy, 1994e, "Office of Environmental Management Programmatic Environmental Impact Statement," *DOE/EIS-0200*, Vol 2, draft.

U.S. Department of Energy, 1994f, "TRUPACT-II Content Codes (TRUCON)," *DOE/WIPP 89-004*, Rev. 8, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

U.S. Department of Energy, 1994g, "TRUPACT-II List of Chemical Compounds in Each Content Code in TRUCON," Rev. 7, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy, 1993a, "Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capacities and Technologies," *DOE/NBM-1100*, WIPP Project Integration Office, Albuquerque, New Mexico.

U.S. Department of Energy, 1993b, "Resource Conservation and Recovery Act Part B Permit Application," *DOE/WIPP 91-005*, Rev. 3, WIPP Project Site Office, Carlsbad, New Mexico.

U.S. Department of Energy, 1991a, "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force," *DOE/WIPP 91-007*, Vol. 1, Rev. 0, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy, 1991b, "Final Safety Analysis Report," *WP-02-7*, Rev. 4, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy, 1991c, "Waste Acceptance Criteria for the Waste Isolation Pilot Plant," *WIPP-DOE-069*, Rev. 4, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy, 1990a, "Environmental Assessment of Supercompactor and Repackaging Facility and TRU Waste Shredder," *DOE/EA-0432*, Golden, Colorado.

U.S. Department of Energy, 1990b, "Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant," *DOE/EIS-0026-FS*, Office of Environmental Restoration and Waste Management, Washington, D.C.

U.S. Department of Energy, 1990c, "Waste Isolation Pilot Plant No-Migration Variance Petition," *DOE/WIPP 89-003*, U.S. Department of Energy, Waste Isolation Pilot Plant Project Office, Carlsbad, New Mexico.

U.S. Department of Energy, 1980, "Final Environmental Impact Statement, Waste Isolation Pilot Plant," *DOE/EIS-0026*, Washington, D.C.

U.S. Department of Labor, 1978–1993, "Injury Experience in Nonmetallic Mineral Mining (Except Stone and Coal), 19[78–93]," Mine Safety and Health Administration, Division of Mining Information Systems, Denver Safety and Health Technology Center Technical Support, Denver, Colorado.

U.S. Department of Transportation, 1990, "Research and Special Programs Administration, Department of Transportation, Carriage by Public Highway," Title 49 CFR Part 177 (49 CFR 177), U.S. Department of Transportation, Washington, D.C.

U.S. Department of Transportation, 1990, *1990 Emergency Response Guidebook*, Research and Special Administration, Office of Hazardous Materials Transportation, Washington, D.C.

U.S. Environmental Protection Agency, 1995, Proposed Rule, "Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes," Title 40, Code of Federal Regulations, Part 194, (40 CFR 194), U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, 1993a, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes," Title 40, Code of Federal Regulations, Part 191, (40 CFR 191), U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, 1993b, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes," *EPA/WIPP 402-R-93-072*, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Nuclear Regulatory Commission Docket No. 9218, 1994, "Safety Analysis Report for the TRUPACT-II Shipping Package," Rev. 14, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

U.S. Nuclear Regulatory Commission, 1991, "Preamble to Standards for Protection Against Radiation," *56 FR 23363, Federal Register.*

U.S. Nuclear Regulatory Commission, 1977, "Final Environmental Statement on The Transportation of Radioactive Material by Air and Other Modes," *NUREG-0170*, Office of Standards Development, Washington, D.C.

Wagner, S., Westinghouse Waste Isolation Division, March 1995, Personal Communication.

Weiner, R., June 9, 1995, *Planned activities for the actinide source term and chemical retardation programs*, Enclosure to Letter for Professor Charles Fairhurst, University of Minnesota, Chairman, National Research Council Committee on the Waste Isolation Pilot Plant, letter from E. J. Nowak, Manager, Chemical and Disposal Room Processes Project Management Department, Sandia National Laboratories.

Westinghouse Electric Corporation, Waste Isolation Division, 1995, "Engineered Alternatives Cost/Benefit Study Scoping Report," *WID/WIPP 95-2093*, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

WID, see Westinghouse Electric Corporation, Waste Isolation Division.

Wilmot, E. L., 1981, "Transportation—Accident Scenarios for Commercial Spent Fuel," *SAND80-2124*, Sandia National Laboratories, Albuquerque, New Mexico.

Winterkorn, H. F., and Hsai-Yang Fang, 1977, *Foundation Engineering Handbook*, Van Norstand, New York, New York.

APPENDIX A
INITIAL ENGINEERED ALTERNATIVES SCREENING CANDIDATES

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TABLE A-1
INITIAL ENGINEERED ALTERNATIVES SCREENING CANDIDATES

The individual Engineered Alternatives (EA) found in the 1991 Engineered Alternatives Task Force (EATF) Final Report (DOE, 1991), #1 through #64, are as follows:

1. Compact Waste
2. Incinerate and Cement
3. Incinerate and Vitrify
4. Wet Oxidation
5. Shred and Bituminize
6. Shred and Compact
7. Shred and Cement
8. Shred and Polymer Encapsulation
9. Shred add Salt and Compact
10. Plasma Processing
11. Melt Metals
12. Add Salt Backfill
13. Add other Sorbents
14. Add Gas Suppressant
15. Shred and Add Bentonite
16. Acid Digestion
17. Sterilization
18. Add Copper Sulfate
19. Add Gas Getters
20. Add Fillers
21. Segregate Waste Forms
22. Decontaminate Metals
23. Change Waste Generation Process
24. Add Anti-Bacterial Material
25. Accelerate Waste Digestion Process
26. Alter Corrosion Environment
27. Alter Bacterial Environment in WIPP
28. Transmutation of Radionuclides
29. Vitrify Sludges
30. Salt Backfill Only
31. Salt Backfill Plus Gas Getters
32. Compact Backfill
33. Salt Plus Brine Sorbents
34. Preformed Compacted Backfill
35. Grout Backfill
36. Bitumen Backfill
37. Add Gas Suppressant
38. Minimize Space Around Waste Stack
39. Segregate Waste in WIPP
40. Decrease Amount of Waste per Room
41. Emplace Waste and Backfill Simultaneously
42. Selected Vegetive Uptake

TABLE A-1 (CONTINUED)
INITIAL ENGINEERED ALTERNATIVES SCREENING CANDIDATES

43 Brine Isolating Dikes
44 Raise Waste Above the Floor
45 Brine Sump and Drains
46 Gas Expansion Volume
47 Seal Repository Room Walls
48 Vent Facility
49 Ventilate Facility
50 Add floor of Brine Sorbents
51 Change Mine Extraction Ratio
52 Change Room Configurations
53 Seal Individual Rooms
54 Two Level Repository
55 Monument Forest Over Repository
56 Monument Covering the Entire Repository
57 Buried Steel Plate Over the Repository
58 Artificial Surface layer Over the Repository
59 Add Marker Dye to Strata
60 Drain Castile Reservoir
61 Grout Culebra Foundation
62 Increase Land Withdrawal Area
63 Change Waste Container Shape
64 Change Waste Container Material

The EATF Combination EAs, #65 through #79

65 EATF Baseline—As received with salt backfill.
66 EATF Alternative 1—Shred and cement organics and inorganics only, salt backfill.
67 EATF Alternative 2—Cement sludges, shred and cement organics and inorganics, salt backfill.
68 EATF Alternative 3—Cement sludges, shred and cement organics and inorganics, grout backfill.
69 EATF Alternative 4—Cement sludges, incinerate and cement organics, shred and cement inorganics, salt backfill.
70 EATF Alternative 5—Cement sludges, incinerate and cement organics, shred and cement inorganics, grout backfill.
71 EATF Alternative 6—Vitrify sludges, incinerate and vitrify organics, melt metals into TRU waste ingots, salt backfill.
72 EATF Alternative 7—Vitrify sludges, incinerate and vitrify organics, melt metals into TRU waste ingots, grout backfill.
73 EATF Alternative 8—Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, salt backfill, non-ferrous container.

TABLE A-1 (CONTINUED)
INITIAL ENGINEERED ALTERNATIVES SCREENING CANDIDATES

74 EATF Alternative 9—Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, grout backfill, non-ferrous container.

75 EATF Alternative 10—Remove metals and decontaminate by vibratory finishing and eliminate from the WIPP inventory, no backfill, nickel alloy rectangular container, 10x31x188 rooms.

76 EATF Alternative 11—Supercompact organics and inorganics, grout backfill, monolayer of 2000 drums in a 6x33x300 room.

77 EATF Alternative 12—Supercompact organics and inorganics, grout backfill, monolayer of 2000 drums, in a 6x33x300 room.

78 EATF Alternative 13—Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag, and metals are eliminated from the WIPP, no backfill, non-ferrous rectangular containers, minimize space around waste stack in a 10x31x188 room.

79 EATF Alternative 14—Supercompact organics, and inorganics, salt aggregate backfill, compartmentalize waste, 2000 drums per room, salt dikes and waste separation.

The Systems Prioritization Methodology-II (SPM-2) original EAs (SNL/NM, 1995), #80 through #99, are as follows:

80 SPM-Baseline

81 SPM-A Salt backfill 50% filling efficiency

82 SPM-B Salt/Bentonite backfill 50-50 mix, 50% filling efficiency

83 SPM-C Salt/pH buffer backfill some amount of CaO

84 SPM-D Cement grout backfill 100% filling efficiency

85 SPM-E Salt/Grout backfill 100% efficiency

86 SPM IT-1 Shred and cement organics and inorganics, salt backfill 50% filling efficiency

87 SPM IT-2 Cement sludges, shred and cement organics and inorganics, salt backfill 50% filling efficiency, nickel alloy container.

88 SPM IT-3 Cement sludges, shred and cement organics and inorganics, cement grout 100% filling efficiency.

89 SPM IT-4 Cement sludges, shred and cement organics and inorganics, salt/pH buffer backfill with some amount of CaO.

90 SPM IT-5 Cement sludges, shred and compact organics and inorganics, salt backfill with 50% filling efficiency, 200 drum monolayer, 6x33x300 room.

91 SPM IT-6 Cement sludges, shred and compact organics and inorganics, cement grout backfill 100% filling efficiency, 2000 drum monolayer, 6x33x300 room.

92 SPM IT-7 Cement sludges, compact organics and inorganics, salt/pH buffer backfill with some amount of CaO, 2000 drums monolayer, 6x33x300 room.

93 SPM IT-8 Cement sludges, shred and add bentonite to organics and inorganics, salt backfill 50% filling efficiency.

94 SPM IT-9 Cement sludges, shred and add bentonite to organics and inorganics, cement grout backfill 100% efficiency.

95 SPM IT-10 Decontaminate metals, nickel alloy container, cement grout backfill 100% filling efficiency.

TABLE A-1 (CONTINUED)
INITIAL ENGINEERED ALTERNATIVES SCREENING CANDIDATES

96 SPM EATF-8 Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, salt backfill, non-ferrous container.

97 SPM EATF-9 Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, grout backfill, non-ferrous container.

98 SPM DOE-1 Passive markers—no specific scenario given reduce human intrusion probability parameters.

99 SPM DOE-2 Compartmentalization of waste—various unspecified scenarios.

The individual EAs found in Title 40, Code of Federal Regulations (CFR), Part 194 (40 CFR 194) (EPA, 1995), #100 through #109, are as follows:

100 194—Cementation
101 194—Shredding
102 194—Supercompaction
103 194—Incineration
104 194—Vitrification
105 194—Improved waste containers
106 194—Grout and bentonite backfill
107 194—Metal Melting
108 194—Alternative configuration of waste emplacement
109 194—Alternative disposal system dimensions

The individual EAs added by the EA Screening Working Group during the screening process are as follows:

110 Enhanced solidification of sludges
111 Clay based backfill

TABLE A-2

INITIAL ENGINEERED ALTERNATIVE CANDIDATE LIST

EAs considered in the 1991 EATF
EA #1 – #79

Alternative Number	Title
1	Compact Waste
2	Incinerate and Cement
3	Incinerate and Vitrify
4	Wet Oxidation
5	Shred and Bituminize
6	Shred and Compact
7	Shred and Cement
8	Shred and Polymer Encapsulation
9	Shred add Salt and Compact
10	Plasma Processing
11	Melt Metals
12	Add Salt Backfill
13	Add other Sorbents
14	Add Gas Suppressant
15	Shred and Add Bentonite
16	Acid Digestion
17	Sterilization
18	Add Copper Sulfate
19	Add Gas Getters
20	Add Fillers
21	Segregate Waste Forms
22	Decontaminate Metals
23	Change Waste Generation Process
24	Add Anti-Bacterial Material
25	Accelerate Waste Digestion Process
26	Alter Corrosion Environment
27	Alter Bacterial Environment in WIPP
28	Transmutation of Radionuclides
29	Vitrify Sludges
30	Salt Backfill Only
31	Salt Backfill Plus Gas Getters
32	Compact Backfill
33	Salt Plus Brine Sorbents
34	Preformed Compacted Backfill
35	Grout Backfill
36	Bitumen Backfill
37	Add Gas Suppressant
38	Minimize Space Around Waste Stack
39	Segregate Waste in WIPP
40	Decrease Amount of Waste per Room
41	Emplace Waste and Backfill Simultaneously
42	Selected Vegetive Uptake
43	Brine Isolating Dikes

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TABLE A-2 (CONTINUED)

INITIAL ENGINEERED ALTERNATIVE CANDIDATE LIST

EAs considered in the 1991 EATF
EA #1 – #79 (Continued)

Alternative Number	Title
44	Raise Waste Above the Floor
45	Brine Sump and Drains
46	Gas Expansion Volumes
47	Seal Repository Room Walls
48	Vent Facility
49	Ventilate Facility
50	Add floor of Brine Sorbents
51	Change Mine Extraction Ratio
52	Change Room Configurations
53	Seal Individual Rooms
54	Two Level Repository
55	Monument Forest Over Repository
56	Monument Covering the Entire Repository
57	Buried Steel Plate Over the Repository
58	Artificial Surface layer Over the Repository
59	Add Marker Dye to Strata
60	Drain Castile Reservoir
61	Grout Culebra Foundation
62	Increase Land Withdrawal Area
63	Change Waste Container Shape
64	Change Waste Container Material
65	EATF Baseline—As Received with Salt Backfill
66	EATF Alternative 1—Shred and cement organics and inorganics only, salt Backfill.
67	EATF Alternative 2—Cement Sludges, shred and cement organics and inorganics, salt Backfill.
68	EATF Alternative 3—Cement sludges, shred and cement organics and inorganics, grout backfill.
69	EATF Alternative 4—Cement sludges, incinerate and cement organics, shred and cement inorganics, salt backfill.
70	EATF Alternative 5—Cement sludges, incinerate and cement organics, shred and cement inorganics, grout backfill.
71	EATF Alternative 6—Vitrify sludges, incinerate and vitrify organics, melt metals into TRU waste ingots, salt backfill.
72	EATF Alternative 7—Vitrify sludges, incinerate and vitrify organics, melt metals into TRU waste ingots, grout backfill.
73	EATF Alternative 8—Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, salt backfill, non-ferrous container.
74	EATF Alternative 9—Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, grout backfill, non-ferrous container.

TABLE A-2 (CONTINUED)

INITIAL ENGINEERED ALTERNATIVE CANDIDATE LIST

EAs considered in the 1991 EATF
EA #1 – #79 (Continued)

Alternative Number	Title
75	EATF Alternative 10—Remove metals and decontaminate by vibratory finishing and eliminate from the WIPP inventory, no backfill, nickel alloy rectangular container, 10X31X188 rooms.
76	EATF Alternative 11—Supercompact organics and inorganics, grout backfill, monolayer of 2000 drums in a 6X33X300 room.
77	EATF Alternative 12—Supercompact organics and inorganics, grout backfill, monolayer of 2000 drums, in a 6X33X300 room.
78	EATF Alternative 13—Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag, and metals are eliminated from the WIPP, no backfill, non-ferrous rectangular containers, minimize space around waste stack in a 10X31X188 room.
79	EATF Alternative 14—Supercompact organics, and inorganics, salt aggregate backfill, compartmentalize waste, 2000 drums per room, salt dikes and waste separation.

EAs initially considered in the SPM
EA #80 - #99

Alternative Number	Title
80	SPM-Baseline
81	SPM-A Salt backfill 50% filling efficiency
82	SPM-B Salt/Bentonite backfill 50-50 mix, 50% filling efficiency
83	SPM-C Salt/pH buffer backfill some amount of CaO
84	SPM-D Cement grout backfill 100% filling efficiency
85	SPM-E Salt/Grout backfill 100% efficiency
86	SPM IT-1 Shred and cement organics and inorganics, salt backfill 50% filling efficiency
87	SPM IT-2 Cement sludges, shred and cement organics and inorganics, salt backfill 50% filling efficiency, nickel alloy container.
88	SPM IT-3 Cement sludges, shred and cement organics and inorganics, cement grout 100% filling efficiency.
89	SPM IT-4 Cement sludges, shred and cement organics and inorganics, salt/pH buffer backfill with some amount of CaO.
90	SPM IT-5 Cement sludges, shred and compact organics and inorganics, salt backfill with 50% filling efficiency, 200 drum monolayer, 6X33X300 room.
91	SPM IT-6 Cement sludges, shred and compact organics and inorganics, cement grout backfill 100% filling efficiency, 2000 drum monolayer, 6X33X300 room.
92	SPM IT-7 Cement sludges, compact organics and inorganics, salt/pH buffer backfill with some amount of CaO, 2000 drums monolayer, 6X33X300 room.

TABLE A-2 (CONTINUED)

INITIAL ENGINEERED ALTERNATIVE CANDIDATE LIST

EAs initially considered in the SPM
EA #80 – #99 (Continued)

Alternative Number	Title
93	SPM IT-8 Cement sludges, shred and add bentonite to organics and inorganics, salt backfill 50% filling efficiency.
94	SPM IT-9 Cement sludges, shred and add bentonite to organics and inorganics, cement grout backfill 100% efficiency.
95	SPM IT-10 Decontaminate metals, nickel alloy container, cement grout backfill 100% filling efficiency.
96	SPM EATF-8 Vitrify sludges, incinerate and vitrify organics, melt metals. with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, salt backfill, non-ferrous container.
97	SPM EATF-9 Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, grout backfill, non-ferrous container.
98	SPM DOE-1 Passive markers- no specific scenario given reduce human intrusion probability parameters.
99	SPM DOE-2 Compartmentalization of waste - various unspecified scenarios.

EAs Listed in 40 CFR 194
EA #100 – #109

Alternative Number	Title
100	194—Cementation
101	194—Shredding
102	194—Supercompaction
103	194—Incineration
104	194—Vitrification
105	194—Improved Waste Containers
106	194—Grout and Bentonite Backfill
107	194—Metal Melting
108	194—Alternative Configuration of Waste Emplacement
109	194—Alternative Disposal System Dimensions

TABLE A-3

FIRST PRIORITIZED EA LIST

ID Number	Description
# 10	Plasma Processing of All Waste
# 12	Salt Backfill Around Drums and Waste Stack
# 33	Salt Plus Clay Backfill
# 35	Salt Aggregate Grout Backfill Around Drums
# 53	Seal Individual Rooms
# 60	Depressurize Castile Reservoir
# 63	Change Waste Container Shape
# 74	Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, salt aggregate grout backfill, change container material.
# 75	Decontaminate surface of metallic wastes for LLW disposal, no backfill, change container material and shape, 10x31x188 rooms.
# 83	Salt backfill with CaO
# 89	Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO.
# 94	Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.
# 95	Decontaminate surface of metallic waste for LLW disposal, change container material, salt aggregate grout backfill.
# 111	Clay Based Backfill

TABLE A-4

INITIAL PRIORITIZED LIST CHANGE JUSTIFICATIONS

EA#	Added, Removed, or Not Changed from Initial List	Description and Modifications	Basis for Modification, Addition, or Removal
1	Added	Supercompact Organics and Inorganics	High Feasibility, Lower Permeability, Increases shear strength
6	Added	Shred and Compact Organics and Inorganics	High Feasibility, Lower Permeability, Increases shear strength
10	No Change	Plasma Processing of all Waste	
12	Removed	Salt Backfill	No Benefit to Disposal System
33	No Change	Salt plus Clay backfill. *Examine using sand as the filler material instead*	Information to-date suggests that sand interacts more effectively with clay that does salt.
35	No Change	Salt Aggregate Grout Backfill Around Drums. *Perform an additional assessment with a cementitious grout.*	Allows the CAO to assess any additional benefits from using a cementitious grout.
53	Removed	Seal individual Rooms	Contrary to No Migration Determination
60	Removed	Depressurize the Castile Formation	Extra Holes and Assurance system is depressurized to 10K years not Justified (may enhance lateral flow from the repository)
63	Removed	Change Waste Container Shape	With Respect to Solubility and Shear Strength, adds No Benefit
74	Removed	Vitrify Sludges, shred and vitrify organics, melt metals and remove actinides, Salt/Agg Grout BF, Change Container Mat'l	Gas Generation Reduction EA

TABLE A-4 (CONTINUED)

INITIAL PRIORITIZED LIST CHANGE JUSTIFICATIONS

EA#	Added, Removed, or Not Changed from Initial List	Description and Modifications	Basis for Modification, Addition, or Removal
75	Removed	Decon Metals for LLW, no BF, change Container Mat'l and shape, 10x31x188 room	Gas Generation Reduction EA
77	Added	Supercompact Organics and inorganics, Salt Aggregate Grout Backfill, Monolayer of 2000 Drums in a 6x33x300 foot room. *Add assessments with clay-based backfill, sand/clay backfill, and high percentage CaO Backfill.*	Allows the CAO to assess increases in benefit for several types of backfill.
83	No Change	Salt Backfill with CaO.	CaO acts as a pH Buffer to decrease actinide solubility. The salt acts as a filler. the more CaO is emplaced the more effective the EA is at affecting solubility.
89	Removed	Enhance cement sludges, S&C orgs and inorgs, CaO BF	Very Similar to 94 which is a Final EA
94	No Change	Enhanced Cementation of Sludges, Shred and add Clay-Based Material to Organics and Inorganics. *Examine this alternative alone and with all combinations of backfills.*	Enables CAO to assess any additional benefit from adding backfill to the rooms when used in conjunction with the waste treatment activities.

TABLE A-4 (CONTINUED)

INITIAL PRIORITIZED LIST CHANGE JUSTIFICATIONS

EA#	Added, Removed or Not Changed from Initial List	Description and Modifications	Basis for Modification, Addition, or Removal
95	Removed	Decon Metals for LLW, Salt/Agg Grout BF, change Container shape	Gas Generation Reduction EA
111	No Change	Clay-Based Backfill	

APPENDIX B
ENGINEERED ALTERNATIVE PASS LIST

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ENGINEERED ALTERNATIVE PASS LIST

The following is a listing of Engineered Alternatives (EA) that passed the screening process. The listing includes the definition of the individual EA and the Engineered Alternatives Screening Working Group (EASWG) comments justifying assignment of the EA to the Pass List.

1 Supercompact Everything Except Sludges

All wastes except sludges are processed by first pre-compacting the waste into 35-gallon drums; the "pucks" are then supercompacted at forces in excess of 2,200 tons and packed for disposal in 55-gallon drums. The volume reduction is approximately 3:1.

The EASWG concluded that this EA met the definition and would be considered further. Off-the-shelf technology is available. Widely used for low-level waste (LLW). Transuranic (TRU) waste supercompacted at Rocky Flats Plant (RFP). Resource Conservation and Recovery Act (RCRA) Part B permitting in interim status at RFP.

2 Incinerate and Cement Solid Organic Waste

Solid organics are incinerated, and the resulting ash is cemented into an ash/cement matrix.

The EASWG concluded that this EA met the definition and would be considered further. Technology mature for hazardous constituents some engineering is still required for TRU waste. Commonly used for LLW—Japan, France, United States. No TRU waste incinerator operating. Permitted incinerators at Los Alamos National Laboratories for hazardous materials; moratorium on new hazardous materials incinerators; major effort required to permit future incinerators.

3 Shred and Vitrify Solid Organic Waste

Solid organics are incinerated and fused into a glass matrix by vitrifying. Vitrification melts/fuses the waste; silica may be added prior to melting.

The EASWG changed the title from "Incinerate and Vitrify" to "Shred and Vitrify" because the current vitrification technology does not require incineration, only shredding. The EASWG also concluded that this EA met the EA definition and would be considered further. Various vitrification technologies have been demonstrated related to plasma melting. France's (Marcoule Facility) is currently making radioactive glass logs. Not yet permitted for TRU waste.

4a Wet Oxidation and Cement Solid Organic Waste

Solid organics are oxidized into an ash residue. Wet oxidation involves the accelerated oxidation of waste in the presence of heated water, vapor, or steam, with the intent to chemically degraded the waste. The ash residue is cemented into an ash/cement matrix.

The EASWG concluded that wet oxidation alone did not meet the definition, because the resulting waste must be solidified to meet the Waste Acceptance Criteria (WAC). Two common solidification techniques were added to this EA to meet the definition. Wet oxidation technology demonstrated at bench scale, questions exist regarding ability to

handle all organic wastes. Currently used to treat non-radioactive organics in water. Technology never permitted but believed possible.

4b Wet Oxidation and Vitrify Solid Organic Waste

Solid organics are oxidized into an ash residue. Wet oxidation involves the accelerated oxidation of waste in the presence of heated water, vapor, or steam, with the intent to chemically degrade the waste. The ash residue is vitrified into a fused glass. Silica may be added to the residue prior to melting/fusing.

The EASWG concluded that wet oxidation alone did not meet the definition, because the resulting waste must be solidified to meet the WAC. Two common solidification techniques were added to this EA to meet the definition. Same technical and regulatory feasibility comments as EA #4a.

5 Shred and Bituminize Everything Except Sludges

All waste except sludges are mechanically shredded. A volume reduction ratio of 1.2:1 is assumed for shredding only. Bitumen is mixed into the waste, filling the void space in the waste drum.

The EASWG concluded that this EA met the definition and would be considered further. Technology is mature but not applied to TRU waste; development work required. Used in Japan for radioactive resins and sludges. This technology has not been permitted; however, the EASWG believes obtaining a permit is possible.

6 Shred and Compact Everything Except Sludges

All waste except sludges are mechanically shredded. A volume reduction ratio of 1.2:1 is assumed for shredding only. The shredded waste is compacted in the drum. Supercompaction is not used.

The EASWG concluded that this EA met the definition and would be considered further. (Not supercompaction—low pressure compaction.) Commercial nuclear plants routinely use compaction technology for LLW. Not currently being done for TRU nor demonstrated. Off-the-shelf equipment available. Permitted for LLW but not TRU, highly probable permit obtainable.

7 Shred and Cement Everything Except Sludges

All waste except sludges are mechanically shredded. A volume reduction ratio of 1.2:1 is assumed for shredding only. "Wet" cement is added to the waste creating a solid homogeneous waste/cement matrix.

The EASWG concluded that this EA met the definition and would be considered further. Grouting technology demonstrated at Hanford, believed used in German application for TRU type waste. Permitting of cementation of TRU sludges under interim status at U.S. Department of Energy (DOE) facilities. Permitting problems not expected by EASWG.

8 Shred and Cold Polymer Encapsulate Everything Except Sludges

All waste except sludges are mechanically shredded. A volume reduction ratio of 1.2:1 is assumed for shredding only. The shredded waste is encapsulated with a polymer.

The EASWG concluded that this EA met the definition and would be considered further. Commercial technology in use that polymerizes LLW. Not demonstrated for TRU waste. Technology is available off the shelf. Permitting problems are not expected by the EASWG.

9 Shred, add Salt and Compact Everything Except Sludges

All waste except sludges are mechanically shredded. A volume reduction ratio of 1.2:1 is assumed for shredding only. Shredded waste is mixed with crushed salt and compacted in the drum. Supercompaction is not used.

The EASWG concluded that this EA met the definition and would be considered further. Technology is available off the shelf; however, process not in use for TRU waste. Compaction of LLW currently permitted and performed. Permitting problems not expected by the EASWG.

10 Plasma Processing of All Waste

All waste is subjected to a high temperature plasma arc eliminating organics and melting metals and sludges into a solid form. The products of this process are vitrified glasses and solid metals.

The EASWG concluded that this EA met the definition and would be considered further. Centrifugal and fixed hearth technologies demonstrated with non-TRU materials, Centrifugal technology used to extract exotic metals in industrial applications. Pilot test completed for the Idaho National Engineering Laboratory (INEL) Pit 9 application with simulated waste. Design of a full-scale unit is approximately 90% complete at INEL (Lockheed) Research and development permitted. Not permitted for TRU waste. EASWG expects permit obtainable.

11a Melt Metals into TRU waste ingots

All metals are melted (sludges and combustibles are excluded) into an ingot and disposed of at the Waste Isolation Pilot Plant (WIPP). The size and weight of the final product are within transportation limits.

The EASWG decided to separate this EA into two categories: a) melt metals and emplace all at WIPP, and b) melt metals, partition radionuclides in slag and remove, cast metal, and dispose of as LLW. The EASWG determined that this separation allows for greater flexibilities in the analysis. The EASWG concluded that both EAs met the definition and would be considered further. Technology is mature but not applied to TRU wastes, development work required. EASWG believes technology is transferable to TRU waste uses. Technology not permitted for TRU waste, EASWG expects permits are obtainable.

11b Melt Metals with Frit to Partition Actinides

All metals are melted (sludges and combustibles are excluded). Glass Frit is added to the molten metal partitioning the radionuclides within the slag. The slag is removed, solidified, and disposed of at the WIPP. The metal is cast into ingots and disposed of as LLW at a LLW facility. The size and weight of the ingot are within transportation limits.

The EASWG decided to separate this EA into two categories: a) melt metals and emplace all at WIPP, and b) melt metals, partition radionuclides in slag and remove, cast metal, and dispose of as LLW. The EASWG determined that this separation allows for greater flexibilities in the analysis. The EASWG concluded that both EAs met the definition and would be considered further. Technology is mature but not applied to TRU wastes, development work required. EASWG believes technology is transferable to TRU waste uses. Potential to recycle waste containers/container materials. Technology not permitted for TRU waste; impacts LLW disposal facilities.

12 Salt Backfill Around Drums and Waste Stack

A crushed salt backfill is placed around and between the waste containers, filling the void space within the rooms. A 50% filling efficiency is assumed.

The EASWG concluded that this EA met the definition and would be considered further. The technology of pneumatic backfilling was demonstrated at WIPP. Can also be as simple as a pile of salt and a shovel. No regulatory concerns were noted. EASWG believes no permit is required for this technology.

15 Shred, Add Clay Based Material to Everything Except Sludges

All waste except sludges are mechanically shred. A volume reduction ratio of 1.2:1 is assumed for shredding only. Engineered clay grout is added to the shredded waste removing the void space within the waste drum. Two forms of clays are considered, swelling (smectites) and non-swelling (illite/kaolinite).

The EASWG decided to change the title of this EA to allow for various types of clays to be considered in the analysis. The EASWG concluded that this EA met the definition and would be considered further. Process is not being done for TRU waste. Equipment is available off-the-shelf. EASWG believes permits are obtainable.

16a Acid Digestion and Cementation of Solid Organics

Solid organics are dissolved in a strong acidic solution that is subsequently neutralized and precipitated, resulting in a reduced volume sludge waste form, which is solidified into a cement/precipitate matrix.

The EASWG concluded that acid digestion alone was not an EA; acid digestion must be followed by a stabilization process. Acid digestion was deleted and acid digestion with solidification was added. The EASWG determined that this EA meet the definition and should be considered further. This technology was used to process approximately 5,000 kg TRU waste between 1972 and 1980 at Hanford using sulfuric acid. Current bench-scale technology at Savanna River Site uses an acid process at 180°C and 15 psig. Belgium recovers Pu with sulfuric acid. Development of processes waste and residue stabilization systems, spent acid treatment, off-gas systems, is required. Cementation of resulting sludge has not been demonstrated. Technology not permitted. Permit issues associated with disposition of hazardous constituents. EASWG believed the technology may be permitted; however, not enough information is available to justify rejection.

16b Acid Digestion and Vitrification of Solid Organics

Solid organics are dissolved in a strongly acidic solution that is subsequently neutralized and precipitated, resulting in a reduced volume sludge waste form, which is vitrified into a fused glass. Silica may be added prior to vitrification.

The EASWG concluded that Acid Digestion alone was not an EA; acid digestion must be followed by a stabilization process. Acid digestion was deleted and acid digestion with solidification was added. The EASWG determined that this EA met the definition and should be considered further. The Technology and regulatory feasibility is identical to #16a with vitrification consideration #3.

19 Add Lime to Solid Organic Waste

Lime (CaO) is added to solid organics within a drum.

The EASWG changed the title of this EA from "Add Gas Getters" to "Add Lime to Solid Organic Waste". The new title was changed to better describe the EA. The EASWG concluded that this EA met the definition and would be considered further. This EA is a material handling process, no treatment technology is involved. Aluminum would have to be removed from the waste prior to the addition of lime. The EASWG concluded that a permit may not be required for this EA but potential WAC and U.S. Nuclear Regulatory Commission (NRC) Transuranic Package Transporter-II (TRUPACT-II) certification issues may be involved in implementing this EA.

22 Decontaminate Surface of Metallic Wastes for LLW Disposal.

Metals are sorted and decontaminated using freon or carbon dioxide. Filters are used to collect the radionuclides and are disposed of as TRU waste. Decontaminated metals are recycled or disposed of as LLW.

The EASWG concluded that this EA met the definition and would be considered further. The EASWG concluded that this technology was mature, and off-the-shelf technology is available. This technology was commonly used for alpha contaminated materials. The EASWG expects that a permit is obtainable if required.

29 Microwave Melt Sludges

Sludge waste is melted/fused into a fused glass. Silica may be added prior to vitrification.

The EASWG changed the title from "Vitrify Sludges" to "Microwave Melt Sludges" to better define the EA. The EASWG concluded that this EA met the definition and would be considered further. The microwave technology has been demonstrated for radioactive waste; however, the entire waste handling process has not been demonstrated. Completed systems with feed and off-gas processes must still be designed. Problems are expected with obtaining a permit because this is a thermal process however the EASWG believes a permit is obtainable.

33 Salt Plus Clay Backfill

Crushed salt is mixed with approximately 30% clay. The salt/clay backfill is placed around the drums filling the void space within the rooms. A 50% filling efficiency is assumed.

The EASWG determined that this EA met the definition of an EA and that it would be kept for further consideration. The EASWG changed the title to "Salt plus Clay Backfill" and described the alternative as a crushed salt backfill containing 30% clay. The technical and regulatory feasibility is identical to #12.

35 Salt Aggregate Grout Backfill Around Drums

Crushed salt is sifted and used as an aggregate in a brine based grout backfill (properties of Type 10 grout are assumed). The grout is pumped into the rooms, filling the void spaces within the rooms. A high filling efficiency is assumed.

The EASWG changed the title to specify a salt aggregate grout. The EASWG concluded that this EA met the definition and would be considered further. The technology is mature. Brine saturated grouts are commonly used in the petroleum and mining industries. Questions on gas generation potential may limit the effectiveness of this alternatives. The EASWG believed a permit would not be required—only DOE requirements need to be satisfied.

36 Bitumen Backfill

Bitumen is placed around the waste drums filling the void space within the disposal rooms.

The EASWG concluded that this EA met the definition and would be considered further. Material handling technology is mature. Bitumen backfill used in Germany. Off-the-shelf technology is available. May impact the no-migration permit; possible large increase in hazardous materials. Uncertainty in safety requirements due to combustible nature. The EASWG concluded that there is a large uncertainty in regulatory feasibility; however, not enough information is available to justify rejection.

38 Reduce Room Dimensions to Minimize Space Around Waste Stack

This alternative reduces the room dimensions to minimize space around the waste containers. Only minimal space around the waste containers is assumed after emplacement.

The EASWG concluded that this EA met the definition and would be considered further. The technology used to initially mine the rooms and panels can be used; the technology is mature. Equipment is available at the site, and the operation required to implement the EA is understood. Regulatory issues include site design validation process considerations with the State of New Mexico, the Consultation and Cooperation Agreement, and other coordination concerns with the state.

51 Change Mined Extraction Ratio

The mined extraction ratio is increased to increase the closure rate or the disposal rooms (i.e., leaving less supportive salt around the mined waste disposal rooms).

The EASWG concluded that this EA met the definition and would be considered further. The EASWG concluded that this technology is mature and understood. Equipment is available. Major analysis would be required to determine the design and the overall impact on the disposal system. Regulatory concerns include major considerations with respect to the site design validation process, State of New Mexico agreements, and Mine

Safety and Health Administration requirements. The EASWG concluded that no permit is required to implement this EA.

53 Seal Individual Rooms

Individual rooms are sealed instead of only sealing the panels. Communication between the rooms during an intrusion scenario is significantly reduced (gas, brine, and radionuclides).

The EASWG concluded that this EA met the definition and would be considered further. Technology is available off the shelf. Major analysis is required to determine seal design and performance parameters. No permitting problems were envisioned.

60 Depressurize Castile Reservoir

This alternative removes brine from the Castile Formation in sufficient quantities to remove the motive force that transports waste from the repository to the accessible environment in an intrusion event involving the Castile Formation.

The EASWG determined this EA met the definition of an EA and should be considered further. The EASWG changed the title from "Drain" to "Depressurize" stating that drain was not technically correct and was misleading. Technology is a standard oil industry practice (per Nelson Munsey of Yates Petroleum). Must dispose of brine—many options for disposal available. Technology has been permitted, minimal permitting problems anticipated. State permit required.

63 Change Waste Container Shape

Square waste or hexagonal packages are used to decrease the void space within the disposal room.

The EASWG concluded that this EA met the definition and would be considered further. Technology is mature and available. Off-the-shelf containers of different various shapes are available and may meet existing TRU waste container requirements. NRC TRUPACT-II certification modification required, and U.S. Department of Transportation certification required. These certifications have been obtained for TRU waste containers previously. Permits can be obtained.

64 Change Waste Container Material

Non-ferrous materials are used to construct the waste container. Nickel, stainless steel, copper and glass/ceramic are examples of materials that could be used.

The EASWG concluded that this EA met the definition and would be considered further. The technology is mature and available. Depending on the specific material, waste containers made of non-ferrous materials are available off-the-shelf that may meet the current TRU waste container requirements. Same regulatory feasibility comments as #63.

83 Salt backfill with CaO

Crushed salt and CaO (lime) are used to backfill around the drums and fill void space in the waste panel.

The EASWG concluded that this EA met the definition and would be considered further.

110 Enhanced Solidification of Sludges

Cementation of sludges is performed to provide a waste form with improved properties over sludges cemented with existing systems.

The EASWG determined that this EA met the definition and would be considered further. Technology of cementing sludges has been demonstrated. RFP has matured this technology. Some development work may be required. The regulatory issues include satisfying DOE requirements and RCRA permit or modification to permit.

111 Clay Based Backfill

Clay based backfill is placed around the drum, filling the void spaces within the room to hasten room closure and isolate the waste with a low permeability barrier. Two forms of clays are considered, swelling (smectites) and non-swelling (illite/kaolinite). Clay may be placed dry or water may be added and the material pumped into the rooms.

The EASWG determined that this EA met the definition and would be considered further. The Technology is mature for moist and dry clay emplacement. The EASWG believes that no permits are required and only DOE requirements must be met.

Note:

The combination EAs were derived from those used in the Engineered Alternatives Task Force (EATF) report and System Prioritization Methodology (SPM) program. The titles/descriptions have been changed to match the title of the discrete technologies. For example, the title "Nickel Alloy Container" was changed to "Change Waste Containers Material, #64" and "Rectangular Containers" was changed to "Change Waste Container Shape, #63". This was done to provide consistency throughout the analysis.

66 EATF Alternative 1—

Shred and cement organics and inorganics only, salt backfill.

The EASWG concluded that this EA met the definition and would be considered further.

67 EATF Alternative 2—

Enhanced cement sludges, shred and cement organics and inorganics, salt backfill.

The EASWG concluded that this EA met the definition and would be considered further.

68 EATF Alternative 3—

Enhanced cement sludges, shred and cement organics and inorganics, salt aggregate grout backfill.

The EASWG concluded that this EA met the definition and would be considered further.

69 EATF Alternative 4—

Enhanced cement sludges, incinerate and cement organics, shred and cement inorganics, salt backfill.

The EASWG concluded that this EA met the definition and would be considered further.

70 EATF Alternative 5—

Enhanced cement sludges, incinerate and cement organics, shred and cement inorganics, salt aggregate grout backfill.

The EASWG concluded that this EA met the definition and would be considered further.

71 EATF Alternative 6—
Vitrify sludges, shred and vitrify organics, melt metals into TRU waste ingots, salt backfill.
The EASWG concluded that this EA met the definition and would be considered further.

72 EATF Alternative 7—
Vitrify sludges, shred and vitrify organics, melt metals into TRU waste ingots, salt aggregate grout backfill.
The EASWG concluded that this EA met the definition and would be considered further.

73 EATF Alternative 8—
Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP inventory), salt backfill, change waste container material.
The EASWG concluded that this EA met the definition and would be considered further.

74 EATF Alternative 9—
Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP inventory), salt aggregate grout backfill, change waste container material.

The EASWG concluded that this EA met the definition and would be considered further.

75 EATF Alternative 10—
Decontaminate surface of metallic waste for LLW disposal, no backfill, change container material and shape, 10x31x188 rooms.
The EASWG concluded that this EA met the definition and would be considered further.

76 EATF Alternative 11—
Supercompact organics and inorganics, salt backfill, monolayer of 2,000 drums in a 6x33x300 room.
The EASWG concluded that this EA met the definition and would be considered further.

77 EATF Alternative 12—
Supercompact organics and inorganics, salt aggregate grout backfill, monolayer of 2,000 drums, in a 6x33x300 room.
The EASWG concluded that this EA met the definition and would be considered further.

78 EATF Alternative 13—
Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP), no backfill, change waste container material and shape, minimize space around waste stack in a 10x31x188 room.
The EAWG concluded that this EA met the definition and would be considered further.

79 EATF Alternative 14—
Supercompact organics, and inorganics, salt backfill, seal individual rooms, 2,000 drums per room.
The EASWG concluded that this EA met the definition and would be considered further.

87 SPM IT-2

Enhanced cement sludges, shred and cement organics and inorganics, salt backfill, change waste container material.

The EASWG concluded that this EA met the definition and would be considered further.

88 SPM IT-3

Enhanced cement sludges, shred and cement organics and inorganics, salt aggregate grout backfill.

The EASWG concluded that this EA is a duplicate of #68, "EATF Alternative 3".

89 SPM IT-4

Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO.

The EASWG concluded that this EA met the definition and would be considered further.

90 SPM IT-5

Enhanced cement sludges, shred and compact organics and inorganics, salt backfill, 2,000 drum monolayer, 6x33x300 room.

The EASWG concluded that this EA met the definition and would be considered further.

92 SPM IT-7

Enhanced cement sludges, compact organics and inorganics, salt backfill with CaO, 2,000 drums monolayer, 6x33x300 room.

The EASWG concluded that this EA met the definition and would be considered further.

93 SPM IT-8

Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt backfill.

The EASWG concluded that this EA met the definition and would be considered further.

94 SPM IT-9

Enhanced cement sludges, shred and add clay based materials to organics and inorganics, salt aggregate grout backfill.

The EASWG concluded that this EA met the definition and would be considered further.

95 SPM IT-10

Decontaminate surface of metallic waste for LLW disposal, change waste container material, salt aggregate grout backfill.

The EASWG concluded that this EA met the definition and would be considered further.

APPENDIX C
ENGINEERED ALTERNATIVES REJECTION LIST WITH JUSTIFICATIONS

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ENGINEERED ALTERNATIVES REJECTION LIST WITH JUSTIFICATIONS

The following is a listing of Engineered Alternatives (EA) that failed the screening process. A brief description of the Engineered Alternatives Screening Working Groups (EASWG) rejection justification is provided.

4 Wet Oxidation

Wet oxidation alone was not considered an EA and was deleted. The EASWG determined that wet oxidation must be followed by a stabilization process to be an EA so #4 (Wet Oxidation) was changed to wet oxidation plus two separate solidifiers, #4a and #4b.

11 Melt Metals

The EASWG decided to delete this EA and separate it into two categories: #11a (melt metals and emplace all at the Waste Isolation Pilot Plant [WIPP]) and #11b (melt metals, partition radionuclides in slag and remove, cast metal and dispose of as low-level waste). The EASWG determined that this separation allows for greater flexibility in the analysis.

13 Add Other Sorbents

The EASWG determined that this EA is a duplicate of #15.

14 Add Gas Suppressant

The EASWG concluded that this EA is a duplicate of #19.

16 Acid Digestion

The EASWG concluded that acid digestion alone was not considered an EA. Acid digestion must be followed by a stabilization process to be an EA so #16, Acid Digestion, was changed to include two separate solidifiers, #16a and #16b.

17 Sterilization

The EASWG determined that the original Engineered Alternatives Task Force (EATF) rejection justification was still valid and that this EA would be rejected. The EATF rejection justification states, "Not feasible to maintain long-term effectiveness."

18 Add Copper Sulfate

The EASWG determined that the original EATF rejection justification was still valid and that this EA would be rejected. The EATF rejection justification states, "Potential for hydrogen generation by galvanic coupling of deposited copper."

20 Add Fillers

The EASWG concluded that this EA was not specific enough to evaluate and is considered by other more specific alternatives (#7, 9, 13, 14, 15, 18, and 19).

21 Segregate Waste Forms

The EASWG concluded that this EA did not meet the definition of an EA and was inherent with most waste processing EAs. This EA was not considered for further evaluation.

23 Change Waste Generation Process

The EASWG could not define this alternative and rejected it from further consideration. The EASWG determined the original EATF rejection justification was still valid. The EATF rejection justification states, "Scope too broad to be evaluated."

24 Add Anti-Bacterial Material

The EASWG determined that the original EATF rejection justification was still valid and that this EA would be rejected. Adding mercury was discussed and rejected due to the health hazards. The EASWG stated that adding hazardous materials to increase the safety of the repository was self-defeating. The EATF rejection justification states, "Unable to identify a long-term, anti-bacterial material."

25 Accelerate Waste Digestion Process

The EASWG determined that the original EATF rejection justification was still valid and that this EA would be rejected. The EASWG discussed the experimental results for culturing digestive materials. The working group was not convinced that the WIPP environment could be controlled to the extent required by the digestion process. The EATF rejection justification states, "Technology for fast waste digestion not demonstrated."

26 Alter Corrosion Environment

The EASWG concluded that this EA was not specific enough to evaluate. The technology was less than bench scale and has not been demonstrated. This concept is considered under other alternatives.

27 Alter Bacterial Environment in WIPP

The EASWG concluded that this EA is a duplicate of #24, which was deleted.

28 Transmutation of Radionuclides

The EASWG concluded that transmutation technologies are not feasible for transuranic (TRU) wastes and that the process requires the segregation of the pure isotopes from the waste. If waste was placed directly in the reactor, activated (radioactive) materials would be generated. The EATF rejection justification states, "Technology not demonstrated for large amounts."

30 Salt Backfill Only

The EASWG concluded that this EA is a duplicate of #12.

31 Salt Backfill Plus Gas Getters

The EASWG concluded that this EA is a duplicate of #83.

32 Compact Backfill

The EASWG determined that this EA was considered under EA #12 and would not be evaluated further.

34 Preformed Compacted Backfill

The EASWG concluded that this alternative is considered under the salt backfill alternative and would not be evaluated further.

37 Add Gas Suppressant

The EASWG concluded that the original EATF rejection justification was still valid. The EATF rejection justification states, "This alternative was considered together with the 'Salt Plus Gas Getters' alternative, and therefore was not subject to separate evaluation."

39 Segregate Waste in WIPP

The EASWG concluded that this EA was part of the baseline repository design. Load management is considered in the compliance documentation. The EASWG concluded that this EA does not meet the definition of an EA.

40 Decrease Amount of Waste per Room

The EASWG concluded that the original EATF rejection justification was still valid. The EATF rejection justification states, "This alternative was considered together with some of the backfill alternatives, and hence not evaluated separately."

41 Emplace Waste and Backfill Simultaneously

The EASWG concluded that this alternative is a subset of other backfill alternatives and was not evaluated separately.

42 Selected Vegetative Uptake

The EASWG determined that the process for vegetative uptake would not allow for proper containment of the alpha emitters. This process would require the waste to be placed in soil with plants. The EASWG determined the original EATF rejection was still valid. The EATF rejection justification states, "Not been laboratory demonstrated for TRU waste."

43 Brine Isolating Dikes

The EASWG determined that the isolation dikes configuration must be maintained to be effective. Room consolidation would alter the configuration, and the EA would not be effective. The EA was not considered further.

44 Raise Waste Above the Floor

The EASWG determined that this is a short-term fix for a long-term problem. The EA would provide no benefit and therefore would not be considered further. The EASWG also concluded that the original EATF rejection justification was still valid.

45 Brine Sump and Drains

The EASWG concluded that this EA is not effective since the required configuration cannot be maintained due to creep closure and rock mechanics of the repository. The EASWG also concluded that the original EATF rejection was still valid. The EATF rejection justification states, "This alternative was deleted because the EAMP (Engineered Alternatives Multidisciplinary Panel) believed that the flow paths leading to the sumps would not remain open long enough to allow substantial amounts of brine to be isolated from the waste."

46 Gas Expansion Volume

The EASWG concluded that this EA was detrimental to repository performance because the extra void volume allows for more stored energy and greater consequences during human intrusion scenarios. The EA was not considered further.

47 Seal Repository Room Walls

The EASWG determined that the rock mechanics of the repository precluded sealing. The technology has not been proven. Creep closure and interaction with the waste would be detrimental to the seal. The EASWG determined the original EATF rejection was still valid. The EATF rejection justification states, "The technology has not been demonstrated."

48 Vent Facility

The EASWG reviewed past data from the EATF data and the Design Analysis Model and determined that higher peak pressures would result for a vented facility. The EASWG also determined the original EATF rejection justification was still valid. The EATF rejection justification states, "Not regulatory feasible after institutional control" (period).

49 Ventilate Facility

The EASWG reviewed data from the EATF and concluded that this alternative was not feasible due to both regulatory and technical concerns. Quoting the original EATF, "...regulatory concerns about maintaining active facility controls for such a long period (100 years), the difficulty of assuring continuous ventilation in all spaces, and the potential for rupturing the waste containers during the ventilation period. The difficulty of safely sealing the rooms and panels of the facility, after so many years of creep closure has taken place, was also considered. Also, ventilation might violate the RCRA 'no migration' variance proposed for the WIPP." The EASWG concluded that this EA would not be evaluated further.

50 Add Floor of Brine Sorbents

The EASWG determined that this EA is a duplicate of #44, which was deleted.

52 Change Room Configurations

The EASWG determined that this EA did not meet the definition of an EA and may be detrimental to the performance of the repository during a human intrusion scenario.

54 Two-Level Repository

The EASWG determined that this EA did not meet the definition of an EA and may be detrimental to the performance of the repository during a human intrusion scenario.

55 Monument Forest Over Repository

The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

56 Monument Covering the Entire Repository

The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

57 Buried Steel Plate Over the Repository

The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

58 Artificial Surface Layer Over the Repository

The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

59 Add Marker Dye to Strata

The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

61 Grout Culebra Foundation

The EASWG concluded that grouting the Culebra could be detrimental to the performance of the repository. The technology was not considered feasible in part, because it has not been demonstrated for this application. Verification of the effectiveness is problematic; may create alternative pathways within the Culebra formation, and the long-term effectiveness is unknown.

62 Increase Land Withdrawal Area

The EASWG concluded that increasing the area does not reduce the consequences of releases or increase the performance of the repository. Regulatory restriction on resource recovery within the new area would be problematic (resource lease acquisition).

65 EATF Baseline—As Received with Salt Backfill

The EASWG determined that this EA is a duplicate of #12, "Add Salt Backfill".

80 SPM-Baseline

The EASWG determined that the SPM baseline is the current repository baseline. The baseline is not an alternative and is inherent in the analysis.

81 SPM-A Salt Backfill

The EASWG concluded that this EA is a duplicate of #12, "Add Salt Backfill".

82 SPM-B Salt/Bentonite Backfill 50-50 Mix, 50% Filling Efficiency

The EASWG concluded that this EA is a duplicate of #22, "Salt Plus Clay Backfill".

84 SPM-D Cement Grout Backfill

The EASWG concluded that this EA is a duplicate of #35, "Salt Aggregate Grout Backfill".

85 SPM-E Salt/Grout Backfill

The EASWG concluded that this EA is a duplicate of #35, "Salt Aggregate Grout Backfill".

86 SPM IT-1 Shred and Cement Organics and Inorganics, Salt Backfill

The EASWG concluded that this EA is a duplicate of #66, "EATF Alternative 1".

88 SPM IT-3 Enhanced Cement Sludges, Shred and Cement Organics and Inorganics, Salt Aggregate Grout Backfill.

The EASWG concluded that this EA is a duplicate of #68, "EATF Alternative 3".

91 SPM IT-6 Enhanced Cement Sludges, Shred and Compact Organics and Inorganics, Salt Aggregate Grout Backfill, 2,000 drum monolayer, 6x33x300 room.

The EASWG concluded that this EA is a duplicate of #77, "EATF Alternative 12".

96 SPM EATF-8 Vitrify Sludges, Shred and Vitrify Organics, Melt Metals with Frit to Partition Actinides (metals are eliminated from the WIPP inventory), Salt Backfill, Change Waste Container Material.

The EASWG concluded that this EA is a duplicate of #73, "EATF Alternative 8".

97 SPM EATF-9 Vitrify Sludges, Shred and Vitrify Organics, Melt Metals with Frit to Partition Actinides (metals are eliminated from the WIPP inventory), Salt Aggregate Grout Backfill, Change Waste Container Material.

The EASWG concluded that this EA is a duplicate of #74, "EATF Alternative 9".

98 SPM DOE-1 Passive Markers—No Specific Scenario Given to Reduce Human Intrusion Probability Parameters.

The EASWG concluded that this EA dos not meet the definition of an alternative. The proposed alternative is a marker and not a barrier. This alternative does not increase the performance nor reduce the uncertainty in performance assessment.

99 SPM DOE-2 Compartmentalization of Waste—Various Unspecified Scenarios.

The EASWG determined that this EA is inherent in several EAs and does not require further consideration in the analysis.

100 194—Cementation

The EASWG determined that this EA is inherent in several EAs and does not require further consideration in the analysis.

101 194—Shredding

The EASWG determined that this EA is inherent in several EAs and does not require further consideration in the analysis.

102 194—Supercompaction

The EASWG concluded that this EA is a duplicate of #1, "Compact Waste."

103 194—Incineration

The EASWG concluded that this EA is inherent in #2, "Incinerate and Cement," because incineration is not an EA alone. Incineration must be followed by a form of solidification to meet the particulate restriction in the waste acceptance criteria.

104 194—Vitrification

The EASWG concluded that this EA is a duplicate of #3, "Shred and Vitrify Waste."

105 194—Improved Waste Containers

The EASWG concluded that this EA is a duplicate of #63, "Change Waste Container Shape," and #64, "Change Waste Container Material."

106 194—Grout and Bentonite Backfill

The EASWG determined that this EA is inherent in other EAs (#33 and #35) and does not require further consideration in the analysis.

107 194—Metal Melting

The EASWG concluded that this EA is a duplicate of #11a and 11b, "Melt Metals."

108 194—Alternative Configuration of Waste Emplacement

The EASWG concluded that this EA is inherent in several other EAs and does not require further consideration in the analysis.

109 194—Alternative Disposal System Dimensions

The EASWG concluded that this EA is inherent to several other EAs and does not require further consideration in the analysis.

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APPENDIX D
ENGINEERED ALTERNATIVES COST/BENEFIT STUDY REPORT ON PRIORITIZED ENGINEERED ALTERNATIVES FOR FURTHER ANALYSIS

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ENGINEERED ALTERNATIVES COST/BENEFIT STUDY REPORT ON PRIORITIZED ENGINEERED ALTERNATIVES FOR FURTHER ANALYSIS

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1.0 INTRODUCTION

This report documents the approach used to recommend a prioritized list of previously screened engineered alternatives (EA) for further analysis in the Engineered Alternatives Cost/Benefit Study (EACBS); this recommendation does not preclude further analysis of other screened engineered alternatives. The purpose and scope of the EACBS is outlined in the Engineered Alternatives Cost/Benefit Study Scoping Report (WID, 1995b). The specific approach used in screening engineered alternatives from an initial engineered alternatives candidate list is presented in the draft Engineered Alternatives Cost/Benefit Study Screening Report (WID, 1995a).

The EACBS Scoping Report outlines a general approach to screen alternatives. The approach consisted of a multi-disciplinary panel, a specified list of initial EA candidates, and a screening method to perform the screen. A multi-disciplinary panel of technical professionals facilitated the EA candidates for screening. This panel was designated as the Engineered Alternatives Screening Working Group (EASWG).

2.0 BACKGROUND

Fifty three EAs successfully passed the screening process. Analysis of EAs is a lengthy and costly process. Given limited resources, a management tool was needed to prioritize EAs for further analysis. A tool was developed and is presented in this report.

3.0 PRIORITIZATION PROCESS

Engineered Alternatives were prioritized to allow for the generation of detailed information of selected EAs through a focused analysis. This prioritization was done without eliminating any of the aspects of the engineered barrier study prescribed in proposed rule Title 40, Code of Federal Regulations (CFR), Part 194 (40 CFR 194) (EPA, 1995).

This was achieved by assessing each of the screened EAs for technological and regulatory feasibility, as well as effectiveness along four general categories of performance; gas generation, actinide solubility, permeability, and shear strength. Once the qualitative assessments were complete, a prioritization objective statement was developed. From this statement, the screening criteria were developed. Based on the criteria, a suite of EAs were retained for further analysis.

3.1 Qualitative Assessment of the Feasibility of Screened Alternatives

During the initial screening process (WID, 1995), the EASWG determined which EAs passed the definition and screening criteria for an EA. The results comprise 53 individual and combination EAs. In order to provide management guidance regarding the prioritization of EAs for analysis, further discrimination among the successfully screened EAs was required.

The discriminating criteria chosen for the prioritization process were regulatory feasibility and technological feasibility. An approach similar to that used in the 1991 Engineered Alternatives

Task Force (EATF) Final Report (DOE, 1991) was developed for the scoring process. The goal was to provide a relative feasibility score, independent of effectiveness, for each EA. The relative scores provided the input for a management to determine the prioritization of EAs for further analysis. The process assigned a score for technological feasibility, and a score for regulatory feasibility for each of the EAs under consideration by the same multi-disciplinary working group that performed the EA screening. Additionally, an independent facilitator ensured the scoring process had objectivity, help develop consensus within the working group, and maintained the process in accordance with the approach and scoring criteria.

Methodology

The methodology that was developed to score the EAs is described in Attachment D2. Attachment D2 provides the process description, basis for scoring, and example evidence that supports a given score. To assure that all EASWG members understood the meaning of "Regulatory and Technological Feasibility," definitions were provided, considered by the group, and agreed upon. The group evaluated the EAs on the basis of the current status of technology. The group concluded that, for the purpose of scoring, the relative importance or weighting of the regulatory and technology feasibility criteria was equal, and therefore gave each a relative weight of one-half of the total score.

A range of zero to five was used for both feasibility scores. A zero score is defined as not feasible, and the EA is then excluded from further analysis in the EACBS. The score of five is defined as an EA that requires no permitting to be implemented, or that the supporting technology is mature. A score of one is defined as one with a low expectation that the EA could be permitted, or that the technology is at bench or laboratory scale and not in use.

The calculation that provide the total feasibility score is:

$$F = (S_r)\cdot(W_r) + (S_t)\cdot(W_t)$$

Where F = Total weighted feasibility score or Feasibility Index

S_r = Regulatory feasibility score

W_r = Regulatory feasibility weighting (equal to .5)

S_t = Technology feasibility score

W_t = Technology feasibility weighting (equal to .5)

Each EA's score was deliberated until a consensus was formed. In some cases consensus could only be reached by allowing scores that were not whole numbers. This happened in a limited number of cases.

After all the relative scores had been developed, the EASWG went through a final review of the EA scores to determine whether the scores were realistic relative to each other. This resulted in a final list of individual EAs and their relative scores. Combinations of EAs were scored using the individual scores as a basis. Since a combination's feasibility is limited by the lowest scoring

EAs in the grouping, the lowest individual score for each feasibility criterion determined the score for the combination.

Results of the Scoring Process

Feasibility scores, rationale, and specific evidence for each EA score are shown in Attachment D3.

Results of the individual EA scoring process are shown in Attachment D4, and are sorted in a descending order of index feasibility score. The results show that EAs requiring the least amount of development, such as backfilling a waste room, have the highest feasibility, while EAs that require considerable development, such as acid digestion or wet oxidation, have the lowest feasibility.

3.2 Preliminary Assessment of the Effectiveness of Screened Alternatives

A preliminary qualitative assessment of effectiveness was determined for each of the 53 screened EAs shown in Attachment D1; this assessment provides a separate and independent process of the feasibility scoring process. This qualitative approach was efficient in that it provided an adequate level of information for consideration of each EA along several areas of effectiveness for the purpose of prioritizing analyses.

A qualified individual, with direct knowledge and involvement in the 1991 EATF, as well as knowledge of disposal system sensitive parameters, provided the assessments.

The assessment of effectiveness was combined with feasibility scores in an Effectiveness and Feasibility Matrix shown in Attachment D5. This matrix shows the results of a preliminary assessment of the effectiveness of screened engineered alternatives in terms of the following parameters:

- Gas generation
- Actinide solubility
- Waste stack permeability
- Human intrusion.

The significance of these parameters are discussed below.

Gas Generation

Gas may be generated by anoxic corrosion of metals (metallic waste and steel containers) and by microbial degradation of organic waste (paper, plastic, wood, etc.). The generation of low to moderate amounts of gas by the waste can improve performance by repressurizing the repository faster, thus minimizing the total amount of brine inflow. However, if gases are generated at rates that are greater that the rates at which gas can flow away from the repository, then the pressures that are significantly greater than lithostatic are predicted to occur. The physical response of a disposal room to excess pressure is highly uncertain. The room may respond by inflation, fracturing, or some combination of the two. Fracturing may manifest itself as generation of new fractures, or expansion of pre-existing fractures within clay and anhydrite layers. The main concern regarding high gas generation rates is that it introduces an uncertainty with respect to

the long-term performance of the disposal system. Alternatives that reduce the rate of gas generation, or eliminate any potential of the particular gas generation mechanism entirely are noted in the matrix.

Actinide Solubility

One pathway considered for the release of radionuclides to the accessible environment is the dissolution of the radionuclides in brine that may come in contact with the waste, followed by transport of the contaminated brine to the accessible environment. Brine can be transported via fractures caused by excessive pressurization of the repository by gas generation, or by pathways created by human intrusions. A key factor controlling release of radionuclides by these mechanisms is the solubility of the radionuclides in brine. Solubility is defined in this case as the maximum mass of a given actinide element that can dissolve in a unit volume of brine of a specified composition. The solubilities of the actinide elements of concern are complex functions of several parameters, however, they all show similar behavior with respect to pH, showing a solubility minimum over a pH range of 8.5 to 10.

The ability of brine to transport radionuclides could be greatly reduced if the pH of any brine that accumulates in the repository is raised from the ambient value of around 6.1 to a value corresponding to the solubility minimum range. Alternatives that buffer the pH to a more favorable range by the addition of lime (calcium oxide, or CaO) or portland-type cement (which contains a major percentage of lime) to either the drum contents of backfill are noted as decrease in actinide solubilities.

Waste Stack Permeability

The permeability of the waste stack is a major factor in controlling the flow of contaminated brine in a waste disposal room toward a human intrusion drill hole that penetrates the room. Alternatives that reduce the permeability of the waste or backfill are noted in the matrix. Supercompaction provides only a slight decrease in permeability, whereas cementation or vitrification provides a large decrease in permeability.

Human Intrusion

One significant pathway for the release of radionuclides in response to human intrusion events is the direct removal of drill cuttings to the surface. The total volume of waste that is brought to the surface in response to a drilling event is equal to the volume of waste that is physically intercepted by the drill bit. This includes the value removed by the bit ($V=\pi r^2 h$), plus any waste surrounding the hole that spalls or erodes into the hole in response to the action of the bit or circulation of drilling mud. The first volume term is directly controlled by the radius of the bit, which is an assumed value. The second volume term is controlled in part by the shear strength of the waste. Alternatives that increase the shear strength of the waste or backfill are noted in the matrix.

3.3 Prioritization Goal and Objective Statements

To prioritize EAs while satisfying the intent of the engineered barrier study prescribed in proposed rule 40 CFR 194, and allowing for the generation of valuable information through a focused

analysis of select EAs, the Waste Isolation Division (WID) of Westinghouse Electric Corporation developed a goal and objective statement as follows:

Goal

To ensure a broad spectrum of EAs have been identified for analysis in order to focus resources and efforts on pragmatic solutions to meeting the expected requirements of proposed rule 40 CFR 194.

Objective

To identify a list of engineered alternatives, either as discreet technologies or combinations of technologies, in which further analysis may be performed within the resources available.

3.4 Prioritization Criteria

Based on the goal and objective statements developed for the prioritization process, the WID developed the following steps for selecting specific EAs as recommended candidates for further analysis in the EACBS. The Effectiveness and Feasibility Matrix was the tool used for this selection.

1. At least one of the most effective EAs for each of the four impact areas (gas generation, solubility, permeability, and human intrusion) should be selected.

2. At least one of the most effective EAs from a broad spectrum effectiveness should be selected.

3. At least one high feasibility index EA for each of the four impact areas (gas generation, solubility, permeability, and human intrusion).

A given EA may be identified as potentially optimal for one or more of the criteria steps above. After accounting for the EAs identified in more than one of the criteria above, the final steps are as follows:

4. Identify and consider EAs that have technical merit but currently have no assessment along each of the four impact areas of gas generation, solubility, permeability, and human intrusion.

5. The balance of EAs shall be prioritized based on the feasibility index and broad spectrum effectiveness.

3.5 Developing the Recommended List of EAs

The criteria were applied to the list of screened and scored EAs shown in Attachment D5. The process was designed to maximize objectivity while minimizing subjectivity in the prioritization process. The selection of EAs for each of the criteria are shown in the following Tables D-1 through D-5.

TABLE D-1

SPECIFIC—MOST EFFECTIVE FOR EACH OF THE FOUR IMPACT AREAS (STEP 1)

Gas	Solubility	Permeability	Human Intrusion
#74 EATF Alternative 9—Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, salt aggregate grout backfill, change container material.	#94 SPM IT-9—Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.	#10 Plasma Processing of All Waste	#10 Plasma Processing of All Waste

1

TABLE D-2

BROAD SPECTRUM—MOST EFFECTIVE (STEP 2)

10 Plasma Processing of All Waste
89 SPM IT-4 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO.

1

TABLE D-3

SPECIFIC—HIGH FEASIBILITY (STEP 3)

Gas	Solubility	Permeability	Human Intrusion
# 95 SPM IT-10 Decontaminate surface of metallic waste for LLW disposal, change container material, salt aggregate grout backfill.	# 111 Clay Based Backfill	# 63 Change Waste Container Shape	# 12 Salt Backfill Around Drums and Waste Stack
# 111 Clay Based Backfill	# 83 Salt backfill with CaO	# 111 Clay Based Backfill # 33 Salt Plus Clay Backfill	

1

TABLE D-4

TECHNOLOGICAL MERIT (STEP 4)

# 53	Seal Individual Rooms
# 60	Depressurize Castile Reservoir

1

TABLE D-5

BROAD SPECTRUM—HIGH FEASIBILITY (STEP 5)

12 Salt Backfill Around Drums and Waste Stack

63 Change Waste Container Shape

83 Salt backfill with CaO

95 SPM IT-10 Decontaminate surface of metallic waste for LLW disposal, change container material, salt aggregate grout backfill.

35 Salt Aggregate Grout Backfill Around Drums

75 EATF Alternative 10 - Decontaminate surface of metallic wastes for LLW disposal, no backfill, change container material and shape, 10x31x188 rooms.

After accounting for duplicates in the above tables, Table D-6 shows the recommended EAs for further analysis in the EACBS. A list of these recommended prioritized EAs with feasibility and effectiveness ratings is shown in Attachment D6.

4.0 SUMMARY

As part of the EACBS, 54 EAs successfully passed the screening process. Analysis of EAs is a lengthy and costly process. Given limited resources, a management tool was developed to prioritize EAs for further analysis. The objective of the management tool was to prioritize EAs while satisfying the intent of the engineered barrier study prescribed in proposed rule 40 CFR 194, and allowing for the generation of valuable information through a focused analysis of select EAs. Qualitative assessments of feasibility and effectiveness were made for each screened EA. A criteria, consistent with the goals and objectives of this prioritization, were developed and applied to the list of screened and scored EAs shown in Attachment D5. The results of this systematic process is a recommended list of EAs (Attachment D6) for further analysis in the EACBS.

TABLE D-6

RECOMMENDED PRIORITIZED EAs

ID Number	Description
# 10	Plasma Processing of All Waste
# 12	Salt Backfill Around Drums and Waste Stack
# 33	Salt Plus Clay Backfill
# 35	Salt Aggregate Grout Backfill Around Drums
# 53	Seal Individual Rooms
# 60	Depressurize Castile Reservoir
# 63	Change Waste Container Shape
# 74	**EATF Alternative 9** - Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, salt aggregate grout backfill, change container material.
# 75	**EATF Alternative 10** - Decontaminate surface of metallic wastes for LLW disposal, no backfill, change container material and shape, 10x31x188 rooms.
# 83	Salt backfill with CaO
# 89	**SPM IT-4** Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO.
# 94	**SPM IT-9** Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.
# 95	**SPM IT-10** Decontaminate surface of metallic waste for LLW disposal, change container material, salt aggregate grout backfill.
# 111	Clay Based Backfill

APPENDIX D
ATTACHMENT D1

SCREENED ENGINEERED ALTERNATIVES—DESCRIPTION

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SCREENED ENGINEERED ALTERNATIVES—DESCRIPTION

The following is a listing of Engineered Alternatives that passed the screening process.

1	Supercompact Everything Except Sludges
2	Incinerate and Cement Solid Organic Waste
3	Shred and Vitrify Solid Organic Waste
4a	Wet Oxidation and Cement Solid Organic Waste
4b	Wet Oxidation and Vitrify Solid Organic Waste
5	Shred and Bituminize Everything Except Sludges
6	Shred and Compact Everything Except Sludges
7	Shred and Cement Everything Except Sludges
8	Shred and Cold Polymer Encapsulate Everything Except Sludges
9	Shred, add Salt and Compact Everything Except Sludges
10	Plasma Processing of All Waste
11a	Melt Metals into transuranic (TRU) waste ingots
11b	Melt Metals with Frit to Partition Actinides
12	Salt Backfill Around Drums and Waste Stack
15	Shred, Add Clay Based Material to Everything Except Sludges
16a	Acid Digestion and Cementation of Solid Organics
16b	Acid Digestion and Vitrification of Solid Organics
19	Add Lime to Solid Organic Waste
22	Decontaminate Surface of Metallic Wastes for low level waste (LLW) Disposal.
29	Microwave Melt Sludges
33	Salt Plus Clay Backfill
35	Salt Aggregate Grout Backfill Around Drums
36	Bitumen Backfill
38	Reduce Room Dimensions to Minimize Space Around Waste Stack
51	Change Mined Extraction Ratio
53	Seal Individual Rooms
60	Depressurize Castile Reservoir
63	Change Waste Container Shape
64	Change Waste Container Material
66	The 1991 Engineered Alternatives Task Forces Final Report (EATF Alternative 1 - Shred and cement organics and inorganics only, salt backfill.
67	EATF Alternative 2—Enhanced cement sludges, shred and cement organics and inorganics, salt backfill.
68	EATF Alternative 3—Enhanced cement sludges, shred and cement organics and inorganics, salt aggregate grout backfill.
69	EATF Alternative 4—Enhanced cement sludges, incinerate and cement organics, shred and cement inorganics, salt backfill.
70	EATF Alternative 5—Enhanced cement sludges, incinerate and cement organics, shred and cement inorganics, salt aggregate grout backfill.
71	EATF Alternative 6—Vitrify sludges, shred and vitrify organics, melt metals into TRU waste ingots, salt backfill.
72	EATF Alternative 7—Vitrify sludges, shred and vitrify organics, melt metals into TRU waste ingots, salt aggregate grout backfill.

73 EATF Alternative 8—Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, salt backfill, change container material.

74 EATF Alternative 9—Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, salt aggregate grout backfill, change container material.

75 EATF Alternative 10—Decontaminate surface of metallic wastes for LLW disposal, no backfill, change container material and shape, 10x31x188 rooms.

76 EATF Alternative 11—Supercompact organics and inorganics, salt backfill, monolayer of 2,000 drums in a 6x33x300 room.

77 EATF Alternative 12—Supercompact organics and inorganics, salt aggregate grout backfill, monolayer of 2,000 drums, in a 6x33x300 room.

78 EATF Alternative 13—Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, no backfill, alternate container, 10x31x188.

79 EATF Alternative 14—Supercompact organics, and inorganics, salt backfill, seal individual rooms, 2,000 supercompacted drums per room.

83 Salt backfill with CaO

87 Systems Prioritization Methodology (SPM) IT-2 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill, change container material.

89 SPM IT-4 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO.

90 SPM IT-5 Enhanced cement sludges, shred and compact organics and inorganics, salt backfill, 2,000 drum monolayer, 6x33x300 room.

92 SPM IT-7 Enhanced cement sludges, shred and compact organics and inorganics, salt backfill with CaO, 2,000 drums monolayer, 6x33x300 room.

93 SPM IT-8 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt backfill.

94 SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.

95 SPM IT-10 Decontaminate surface of metallic waste for LLW disposal, change container material, salt aggregate grout backfill.

110 Enhanced Solidification of Sludges

111 Clay Based Backfill

APPENDIX D
ATTACHMENT D2

SCORING APPROACH

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ENGINEERED ALTERNATIVES SCREENING WORKING GROUP
SCORING APPROACH

Scoring Process Description

The working group is to assign feasibility scores for each EA. Feasibility is defined in terms of two attributes:

1) Regulatory Feasibility

Ease or difficulty of achieving federal and state regulatory compliance for implementation of an EA

The working group is to identify the activities required to obtain all necessary approvals and permits to implement and consider whether the EA technology has ever been permitted, the difficulties involved with obtaining permits, the time required to achieve regulatory compliance, and if significant, the cost of permitting.

2) Technological Feasibility

Technological feasibility of the EA

The working group is to consider the maturity of the technology that forms the basis for the EA, the level of difficulty required to reach technical maturity that would allow implementation of the EA.

Basis for Scoring

Scores resulting from this process provides a measure of relative feasibility for the EA with respect to each other, rather than assessing an absolute score. The guidelines below are intended to provide consistency during the scoring process

General Considerations

As you address each EA, the following considerations are provided to assist in structuring the thought process;

1) On a broad scale, what activities, processes, and facilities will be required to implement this EA, and/or to operate the waste disposal process with the EA incorporated.

2) Consider the evidence that exists that would give us confidence that we can successfully implement and/or operate the waste disposal process with this EA. Consider;

   a. Similar processes that have operated successfully

   b. Perceived complexities

   c. Magnitude of effort

d. Research and development status of technology

e Safety considerations.

APPENDIX D
ATTACHMENT D3

FEASIBILITY SCORES WITH RATIONALE

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FEASIBILITY SCORES WITH RATIONALE

EA #01 Description:
Supercompact everything except sludges

Regulatory Feasibility 4	Technical Feasibility 4.5
- Rocky Flats Plant (RFP) in interim status of Resource Conservation and Recovery Act (RCRA) Part B Permit - Not yet permitted	- Technology mature at RFP for transuranic (TRU) waste - RFP experience not necessarily transferrable - Not widely applied at other sites for TRU waste due to need - Widely used for low-level waste (LLW)

EA #02 Description:
Incinerate and cement solid organic waste

Regulatory Feasibility 2	Technical Feasibility 4
- Los Alamos National Laboratories (LANL) incinerator permitted (controlled air incinerator for hazardous) - Moratorium on new hazardous waste incinerators - Major effort required to permit future incinerator	- Technology mature for hazardous constituents—some engineering still required for TRU waste - SEG, Japan, and France commonly use for LLW - No TRU waste incinerator currently operating - Many examples of commercial incinerators used to destroy multiple waste streams

EA #03 Description:

Shred and vitrify solid organic waste

Regulatory Feasibility 2.5	Technical Feasibility 2
- Not yet permitted for TRU waste - Questions exist regarding ability to permit - U.S. Environmental Protection Agency (EPA) has favored vitrification as a waste form	- Vitrification of combustible solids a new technology - Bench Scale - Not applied to organics currently - France's (Marcoule Facility) currently making glass radioactive logs

EA #4a Description:

Wet oxidation and cement organic solid waste

Regulatory Feasibility 2	Technical Feasibility 1
- Technology never permitted - Safety considerations (high press. and high temp.) - Not enough information to score otherwise	- At bench-scale—questions exist regarding ability to handle all organic wastes - Safety issues - Currently used to treat organics in water

EA #4b Description:
Wet oxidation and vitrify organic solid waste

Regulatory Feasibility 2	Technical Feasibility 1
- Technology never permitted - Safety considerations (high press. and high temp.) - Not enough information to score otherwise	- At bench-scale—questions exist regarding ability to handle all organic wastes - Safety issues - Currently used to treat organics in water

EA #5 Description:
Shred and bituminize everything except sludges

Regulatory Feasibility 1	Technical Feasibility 3
- Low expectation that permit can be obtained—Safety has been questioned for commercial nuclear power plant applications - Never permitted	- Technology is mature but not applied to TRU waste - Development work required - Expect technology can be applied to TRU waste - Except for sludges, never been used for solid waste - Used in Japan for radioactive resins and sludges

EA #6 Description:
Shred and compact everything except sludges

Regulatory Feasibility 4	Technical Feasibility 4
- Never been permitted for TRU - It has been allowed for commercial LLW - Process will not require thermal/chemical treatment and attendant products - Permitting problems are not expected	- Commercial nuclear plants routinely use compaction of LLW - Shred and compact not being done for TRU waste—has not been demonstrated for TRU - Equipment readily available (off the shelf) from manufactures for commercial application

EA #7 Description:
Shred and cement everything except sludges

Regulatory Feasibility 4	Technical Feasibility 4
- Cementation of TRU sludges under interim status at U.S. Department of Energy (DOE) facilities - Not been done for solid TRU wastes - Process will not require thermal/chemical treatment and attendant products - Permitting problems are not expected	- Shred and cement not being done for TRU - LLW grouting being done at Hanford (J. Ward) - Possible German applications (J. Waters & N. Rempe) - Technology is off the shelf

EA #8 Description:

Shred and cold polymer encapsulation everything except sludges

May not be an effective treatment for RH

Regulatory Feasibility 4	Technical Feasibility 4
- Allowed for LLW under commercial power plant license - Not been done for solid TRU wastes - Process will not require thermal/chemical treatment of the waste and attendant products - Permitting problems are not expected	- LLW is being polymerized commercially - Not being done for TRU - Technology is off the shelf

EA #9 Description:

Shred, add salt and compact everything except sludges

Regulatory Feasibility 4	Technical Feasibility 4
- Compaction allowed for LLW - Not permitted for TRU - Permitting problems not expected	- Process is not being done for TRU - Equipment off the shelf - LLW compaction being done at power plants

EA #10 Description:
Plasma processing of all waste

Regulatory Feasibility 2.5	Technical Feasibility 2
- Not yet permitted for TRU waste - Questions exist regarding permitability - Current Western Governors Association (WGA) considers this a promising technology - Cleaner technology than incinerate—lower level of off gas	- Beyond bench scale but not yet approaching mature technology - Commonly used for exotic metals refining - Pilot test completed for Pit 9, Idaho National Engineering Laboratory (INEL) application (simulated waste) - Design of a full scale unit is approx. 90% complete at INEL (Lockheed)

EA #11a Description:
Melt Metals

Regulatory Feasibility 3	Technical Feasibility 3
- Not yet permitted for TRU waste - Expect that permits could be obtained	- Technology is mature but not applied to TRU waste - Development work required - Expectation that technology can be applied to TRU waste

EA #11b Description:

Melt Metals with frit to partition actinides

Regulatory Feasibility 3	Technical Feasibility 3
- Not yet permitted for TRU waste - Expect that permits could be obtained - Potential for recycle as low level waste containers; perceived as a good thing to do	- Technology is mature but not applied to TRU waste - Development work required - Expectation that technology can be applied to TRU waste

EA #12 Description:

Salt backfill around drums and waste stack

Regulatory Feasibility 5	Technical Feasibility 5
- No permitting required - Original Final Safety Analysis Report (FSAR) already considers this process	- Mature - Equipment available - Operation understood

EA #15 Description:

Shred, add clay based material to everything except sludges

Regulatory Feasibility 4	Technical Feasibility 4
- Not permitted for radioactive waste - Permitting problems not expected - Process will not require thermal/chemical treatment and attendant products	- Shred and add clay process is not being done for TRU waste - Equipment off the shelf

EA #16a Description:

Acid digestion and cementation of solid organics

Regulatory Feasibility 2	Technical Feasibility 2
- Technology not been permitted - Disposition of (RCRA) hazardous constituents may be an issue - Not enough information to score otherwise	- 1972–1980 5,000 kg TRU processed with sulfuric acid at Hanford (pilot scale) - Current technology 180°C and 15 psig at bench (Savannah River Site [SRS]) - Belgium (recovery of Pu with sulfuric acid) and SRS experience with phosphoric acid (bench scale) - Feed requires shredding - Acid handling a commercial process - Development required for stabilization of residue, off gas systems, and spent acid treatment and disposal - Disposition of (RCRA) hazardous constituents during and after process unknown - Cementation of the resultant sludges has not been demonstrated

EA #16b Description:

Acid digestion and vitrification of solid organics

Regulatory Feasibility 2	Technical Feasibility 2
- Technology not been permitted - Disposition of (RCRA) hazardous constituents may be an issue - Vitrification not yet permitted for TRU waste - Questions exist regarding ability to permit vitrification - EPA has favored vitrification as a waste form - Not enough information to score otherwise	- 1972–1980 5,000 kg TRU processed with sulfuric acid at Hanford (pilot scale) - Current technology 180°C and 15 psig at bench (SRS) - Belgium (recovery of Pu with sulfuric acid) and SRS experience with phosphoric acid (bench scale) - Feed requires shredding - Acid handling a commercial process - Development required for stabilization of residue, off gas systems, and spent acid treatment and disposal - Disposition of (RCRA) hazardous constituents during and after process unknown - Cementation of the resultant sludges has not been demonstrated - Vitrification of combustible solids a new technology - Vitrification of solid organics at bench scale - Vitrification not applied to organics currently - France's (Marcoule Facility) currently making glass radioactive logs

EA #19 Description:
Add lime to solid organic waste

Regulatory Feasibility 4	Technical Feasibility 5
- May require a permit - Potential waste acceptance criteria and TRUPACT-II certification impact Chemical reaction Particulate	- Assumed that no shredding is required - This is a material handling process—no treatment technology involved - Aluminum would have to be removed for existing waste

EA #22 Description:
Decontaminate surface of metallic wastes for LLW disposal

Regulatory Feasibility 4	Technical Feasibility 5
- May require a permit - Expect permit to be obtained, if required	- Mature technology - Commonly used for alpha decontamination - Off-the-shelf technology

EA #29 Description:

Microwave melting of sludges

Regulatory Feasibility 3	Technical Feasibility 2
- Problems expected but permit can be obtained - Microwave technology generally accepted by public - WGA considers microwave melting a promising technology	- Unit operations only have been developed—complete systems (feed systems, and off gas systems) have not been developed - Has been demonstrated for radioactive waste

EA #33 Description:
Salt plus clay backfill

Regulatory Feasibility 5	Technical Feasibility 5
- No permitting required - Original FSAR does not explicitly consider this process	- Mature - Equipment available - Operation understood

EA #35 Description:
Salt aggregate grout backfill around drums

Regulatory Feasibility 5	Technical Feasibility 5
- No permits required - Only DOE requirements need to be satisfied	- Technology is mature - Brine saturated grouts used in mining and petroleum industry

EA #36 Description:
Bitumen backfill

Regulatory Feasibility 2	Technical Feasibility 5
- Will impact RCRA no-migration; large increase in a hazardous constituent - Uncertainty in safety requirements due to combustible nature - Major regulatory uncertainty	- Material handling technology is mature - Bitumen backfill used in Germany (J. Myers) Asse or Gorleben - Off-the-shelf equipment

APPENDIX D
ATTACHMENT D4

FEASIBILITY SCORES TABLE

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TABLE D4-1

FEASIBILITY SCORES TABLE

Primary Key: Index Feasibility				
Secondary Keys	Human Intrusion	Permeability	Actinide Solubility	Gas Generation
Alternative Numbers	12	35	35	35
"	35	111	111	33
"	33	33	33	111
"	111	12	83	83
"	83	83	12	12
"	38	38	38	38
"	95	63	95	95
"	110	95	110	63
"	19	110	19	75
"	63	75	63	22
"	75	22	75	51
"	64	64	51	64
"	51	51	64	19
"	22	19	22	110
"	60	53	60	60
"	53	60	53	53
"	77	77	77	77
"	79	76	76	76
"	76	79	79	79
"	1	1	1	1
"	89	89	89	89
"	94	94	94	15
"	93	92	93	67
"	68	93	67	68
"	67	90	68	87
"	87	68	87	66
"	92	67	92	7
"	90	87	66	8
"	66	66	7	94
"	7	8	15	92
"	9	7	90	93
"	15	9	9	90
"	8	15	8	9
"	6	6	6	6
"	36	36	36	36
"	69	69	70	70
"	70	70	69	69
"	2	2	2	2
"	11.2	11.2	11.2	11.2
"	11.1	11.1	11.1	11.1
"	29	29	29	29
"	10	10	74	74
"	74	74	72	73
"	72	73	10	10
"	73	72	73	72
"	71	71	71	71
"	78	78	78	78
"	3	3	3	3
"	16.2	5	16.1	16.2
"	16.1	16.2	16.2	5
"	5	16.1	5	16.1
"	4.2	4.2	4.2	4.2
"	4.1	4.1	4.1	4.1

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ATTACHMENT D5

PRELIMINARY QUALITATIVE ASSESSMENT OF EFFECTIVENESS AND FEASIBILITY

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	Engineering Alternative Title	Feasibility Index			Gas Generation			Actinide Solubility				Permeability				Human Induced Events				External Events
		Eng	Tech	Index	Microbial	Anaerobic Corrosion		In Waste Stack			In Backfill	In Waste Stack			In Backfill	Waste Stack			Backfill	
	Relative Weight ->	0.5	0.5	1	Solid Organics	Metallic Waste	Metallic Drums	Solid Organics	Solid Inorganics	Sludges	All Materials	Solid Organics	Solid Inorganics	Sludges	All Materials	Solid Organics	Solid Inorganics	Sludges		Anything
12	12 Salt Backfill Around Drums and Waste Stack	5	5	5	Small Decrease in Rate	Small Decrease in Rate	Small Decrease in Rate								Small Decrease	Small Increase	Small Increase		Increase	
33	33 Salt Plus Clay Backfill	5	5	5	Decrease Rate	Decrease Rate	Decrease Rate				Additional Actinide Sorption				Decrease				Increase	
83	83 Salt backfill with CaO	5	5	5	Decrease Rate	Decrease Rate	Decrease Rate				Decrease				Small Decrease				Increase	
36	36 Salt Aggregate Grout Backfill Around Drums	5	5	5	Decrease Rate	Decrease Rate	Decrease Rate				Decrease				Decrease				Increase	
38	38 Reduce Room Dimensions to Minimize Spaces Around Waste Stack	5	5	5	May Reduce Rate	May Reduce Rate	May Reduce Rate													
111	111 Clay Based Backfill	5	5	5	Decrease Rate	Decrease Rate	Decrease Rate				Additional Actinide Sorption				Decrease				Increase	
51	51 Change Mixed Extraction Rate	4	5	4.5	May Reduce Rate	May Reduce Rate	May Reduce Rate													
63	63 Change Waste Container Shape	4	5	4.5	Decrease Rate	Decrease Rate	Decrease Rate					Decrease	Decrease	Decrease						Enhances Closure
19	19 Add Lime to Solid Organic Waste	4	5	4.5	Decrease Rate			Decrease												
53	53 Seal Individual Rooms	4	5	4.5																
64	64 Change Waste Container Material	4	5	4.5			Eliminates Potential													
75	75 EATF Alternative 10 - Decontaminate surface of metallic waste for LLW disposal, no backfill change container material and shape, 100X11X100 rooms	4	5	4.5		Eliminate Potential	Eliminate Potential													
95	95 SPM IT 10 Decontaminate surface of metallic waste for LLW disposal, change container material, salt aggregate grout backfill	4	5	4.5		Eliminate Potential	Eliminate Potential				Decrease				Decrease				Increase	
110	110 Enhanced Solidification of Sludges	4	5	4.5						Decrease				Small Decrease				Increase		
72	72 Decontaminate Surface of Metallic Wastes for LLW Disposal	4	5	4.5		Eliminate Potential														
80	80 Depressurize Cavity Reservoir	4	5	4.5																Reduce Bldg volume in B1 and EN2 Scenarios
1	1 Supercompact Everything Except Sludges	4	4.5	4.25	May increase rate and potential	May increase rate and potential						Small Mechanical Decrease	Small Mechanical Decrease			Increase	Increase			
77	77 EATF Alternative 12 - Supercompact organics and inorganics, salt aggregate grout backfill, nonsalvaged 2000 drums, in a 8X28X300 room	4	4.5	4.25	Decrease Rate	Decrease Rate	Decrease Rate				Decrease	Decrease	Decrease		Decrease	Increase	Increase		Increase	
76	76 EATF Alternative 11 - Supercompact organics and inorganics, salt backfill, nonsalvaged of 2000 drums in a 8X28X300 room	4	4.5	4.25	Decrease Rate	Decrease Rate						Decrease	Decrease		Decrease	Increase	Increase		Increase	
79	79 EATF Alternative 14 - Supercompact organics, and inorganics, salt backfill, seal individual rooms, 2000 supercompacted drums per room	4	4.5	4.25	Decrease Rate	Decrease Rate						Decrease	Decrease		Decrease	Increase	Increase		Increase	
94	94 SPM IT 9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	4	4	4			Decrease Rate	Additional Actinide Sorption	Additional Actinide Sorption	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
67	67 EATF Alternative 2 - Enhanced cement sludges, shred and cement organics and inorganics, salt Backfill	4	4	4	Decrease Rate	Decrease Rate		Decrease	Decrease	Decrease		Decrease	Decrease	Small Decrease	Decrease	Increase	Increase	Increase	Increase	
68	68 EATF Alternative 3 - Enhanced cement sludges, shred and cement organics and inorganics, salt aggregate grout backfill	4	4	4	Decrease Rate	Decrease Rate		Decrease	Decrease		Decrease	Decrease	Decrease	Small Decrease	Decrease	Increase	Increase	Increase	Increase	
93	93 SPM IT-6 Enhanced cement sludges, shred and compact organics and inorganics, salt backfill, 2000 drum monolayer, 8X28X300 room	4	4	4						Decrease		Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
93	93 SPM IT-8 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt backfill	4	4	4				Additional Actinide Sorption	Additional Actinide Sorption	Decrease		Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
92	92 SPM IT-7 Enhanced cement sludges, shred and compact organics and inorganics, salt backfill with CaO, 2000 drums monolayer, 8X28X300 room	4	4	4			Decrease Rate			Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
69	69 SPM IT-4 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO	4	4	4	Decrease Rate	Decrease Rate	Decrease Rate	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
66	66 EATF Alternative 1 - Shred and cement organics and inorganics only, salt backfill	4	4	4	Decrease Rate	Decrease Rate		Decrease	Decrease			Decrease	Decrease		Decrease	Increase	Increase		Increase	
6	6 Shred and Compact Everything Except Sludges	4	4	4	May increase rate and potential	May increase Rate and potential						Small Decrease	Small Decrease			Small Increase	Small Increase			
9	9 Shred, add Salt and Compact Everything Except Sludges	4	4	4	May Increase Rate and Potential	May Increase Rate and Potential						Decrease	Decrease			Increase	Increase			
87	87 SPM IT-3 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill, change container material	4	4	4	Decrease Rate	Decrease Rate		Decrease	Decrease	Decrease		Decrease	Decrease	Decrease		Increase	Increase	Increase	Increase	
15	15 Shred, Add Clay Based Material to Everything Except Sludges	4	4	4	Decrease in Rate	Decrease in Rate	Decrease in Rate	Additional Actinide Sorption	Additional Actinide Sorption			Decrease	Decrease			Small Increase	Small Increase			
7	7 Shred and Cement Everything Except Sludges	4	4	4	Decrease Rate	Decrease Rate		Decrease	Decrease			Decrease	Decrease			Increase	Increase			
8	8 Shred and Cold Polymer Encapsulate Everything Except Sludges	4	4	4	Decrease Rate, Increase Potential	Decrease Rate						Large Decrease	Large Decrease			Small Increase	Small Increase			
35	35 Bitumen Backfill	2	5	3.5	Increase Potential	Decrease Rate	Decrease Rate								Large Decrease				Increase	
70	70 EATF Alternative 6 - Enhanced cement sludges, inclusions and cement organics, shred and cement inorganics, salt aggregate grout backfill	2	4	3	Eliminate Potential	Decrease Rate		Decrease	Decrease		Decrease	Decrease	Decrease	Small Decrease	Decrease	Increase	Increase	Increase	Increase	
69	69 EATF Alternative 4 - Enhanced cement sludges, inclusions and cement organics, shred and cement inorganics, salt backfill	2	4	3	Eliminate Potential	Decrease Rate		Decrease	Decrease			Decrease	Decrease	Small Decrease	Decrease	Increase	Increase	Increase	Increase	
2	2 Inclusions and Cement Solid Organic Waste	2	4	3	Eliminate			Decrease				Decrease				Increase				
11.1	11a Mill Sludge into TRU Waste Inputs	3	3	3		Decrease Rate														
11.2	11b Mill Sludge with Fat to Produce Actinides	3	3	3		Eliminate Potential														
39	39 Microwave Mill Sludges	3	2	2.5	Decrease Available Water	Decrease Available Water	Decrease Available Water			May Increase Solubility Decrease Leachability				Large Decrease				Large Increase		
3	3 Shred and Vitrify Solid Organic Waste	2.5	2	2.25	Eliminate							Large Decrease				Large Increase				
71	71 EATF Alternative 8 - Vitrify sludges, shred and vitrify organics, mask metals into TRU waste inputs, salt backfill	2.5	2	2.25	Eliminate Potential	Decrease Rate				Increase Solubility but Decrease Leach Rate		Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
73	73 EATF Alternative 7 - Vitrify sludges shred and vitrify organics, mask metals into TRU waste inputs, salt aggregate grout backfill	2.5	2	2.25	Eliminate Potential	Decrease Rate				Increase Solubility but Decrease Leach Rate	Decrease	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
73	73 EATF Alternative 5 - Vitrify sludges shred and vitrify organics, mask metals with fit to partition actinides, salt backfill, change container material	2.5	2	2.25	Eliminate Potential	Eliminate Potential	Eliminate Potential			Increase Solubility but Decrease Leach Rate		Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
10	10 Plasma Processing of All Waste	2.5	2	2.25	Eliminate Potential	Decrease Rate		Decrease Leachability	Decrease Leachability	May Increase Solubility Decrease Leachability		Large Decrease	Large Decrease	Large Decrease		Large Increase	Large Increase	Large Increase		
74	74 EATF Alternative 9 - Vitrify sludges shred and vitrify organics, mask metals with fit to partition actinides, salt aggregate grout backfill change container material	2.5	2	2.25	Eliminate Potential	Eliminate Potential	Eliminate Potential			Increase Solubility but Decrease Leach Rate	Decrease	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	
70	70 EATF Alternative 13 - Vitrify sludges shred and vitrify organics, mask metals with fit to partition actinides, no backfill, bitumen container 100X11X100	2.5	2	2.25	Eliminate Potential	Decrease Rate				Increase Solubility but Decrease Leach Rate		Decrease	Decrease	Decrease		Increase	Increase	Increase		
16.2	16a Acid Digestion and Vitrify Non of Solid Organics	2	2	2	Eliminate Potential							Large Decrease				Large Increase				
16.1	16a Acid Digestion and Cementation of Solid Organics	2	2	2	Eliminate Potential			Decrease				Decrease				Increase				
5	5 Shred and Bitumenize Everything Except Sludges	1	3	2	Decrease Rate, Increase Potential	Decrease Rate						Large Decrease	Large Decrease			Small Increase	Small Increase			
4.1	4a Wet Oxidation and Cement Solid Organic Waste	2	1	1.5	Eliminate			Decrease				Decrease				Increase				
4.2	4b Wet Oxidation and Vitrify Solid Organic Waste	2	1	1.5	Eliminate			Decrease				Large Decrease				Large Increase				

APPENDIX D
ATTACHMENT D6

PRIORITIZED EAs FOR FURTHER ANALYSIS

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Engineering Alternative Title	Feasibility Index			Gas Generation			Actinide Solubility				Permeability				Human Induced Events Direct Strength				External Drivers Anything
				Microbial	Anoxic Corrosion		In Waste Stack			In Backfill	In Waste Stack			In Backfill					
Relative Weight >	Rec 0.5	Tech 0.5	Index 1	Solid Organics	Metallic Waste	Metallic Drums	Solid Organics	Solid Inorganics	Sludges	All Materials	Solid Organics	Solid Inorganics	Sludges	All Materials	Solid Organics	Solid Inorganics	Sludges	Backfill	
33 Salt Plus Clay Backfill	5	5	5	Decrease Rate	Decrease Rate	Decrease Rate	-	-	-	Provide Additional Actinide Sorption	-	-	-	Decrease	-	-	-	Increase	-
12 Salt Backfill Around Drums and Waste Stack	5	5	5	Small Decrease in Rate	Small Decrease in Rate	Small Decrease in Rate	-	-	-	-		-		Small Decrease	Small Increase	Small Increase	Small Increase	Increase	
35 Salt Aggregate Grout Backfill Around Drums	5	5	5	Decrease Rate	Decrease Rate	Decrease Rate	-	-	-	Decrease		-		Decrease	-	-	-	Increase	-
111 Clay Based Backfill	5	5	5	Decrease Rate	Decrease Rate	Decrease Rate	-	-	-	Provide Additional Actinide Sorption	-	-	-	Decrease	-	-	-	Increase	-
83 Salt backfill with CaO	5	5	5	Decrease Rate	Decrease Rate	Decrease Rate	-	-	-	Decrease		-		Small Decrease		-		Increase	-
95 SPM IT-10 Decontaminate surface of metallic waste for LLW disposal, change container material, salt aggregate grout backfill	4	5	4.5	-	Eliminate Potential	Eliminate Potential	-	-	-	Decrease	-			Decrease	-	-	-	Increase	-
75 EATF Alternative 10 - Decontaminate surface of metallic wastes for LLW disposal, no backfill, change container material and shape, 10X31X100 rooms	4	5	4.5	-	Eliminate Potential	Eliminate Potential	-	-	-	-		-		-	-	-	-	-	-
63 Change Waste Container Shape	4	5	4.5	Decreases Rate	Decreases Rate	Decreases Rate	-	-	-	-	Decrease	Decrease	Decrease	-	-	-	-	-	-
60 Depressurize Castile Reservoir	4	5	4.5	-			-	-	-	-					-	-	-	-	Reduce Brine Volume in E1 and E1E2 Scenarios
53 Seal Individual Rooms	4	5	4.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
94 SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill	4	4	4	-	-	Decrease Rate	Additional Actinide Sorption	Additional Actinide Sorption	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	-
89 SPM IT-4 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO	4	4	4	Decrease Rate	Decrease Rate	Decrease Rate	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	-
74 EATF Alternative 6 - Vitrify sludges, shred and vitrify organics, melt metals with lid to partition actinides, salt aggregate grout backfill, change container material	2.5	2	2.25	Eliminate Potential	Eliminate Potential	Eliminate Potential	-	-	Increase Solubility but Decrease Leach Rate	Decrease	Decrease	Decrease	Decrease	Decrease	Increase	Increase	Increase	Increase	-
10 Plasma Processing of All Waste	2.5	2	2.25	Eliminate Potential	Decrease Rate		Decrease Leachability	Decrease Leachability	May Increase Solubility, Decrease Leachability	-	Large Decrease	Large Decrease	Large Decrease	-	Large Increase	Large Increase	Large Increase	-	-

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APPENDIX D
ATTACHMENT D7

ENGINEERED ALTERNATIVE COST/BENEFIT STUDY SCREENING REPORT

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PREFACE

This report documents the approach that was used to screen a list of engineered alternative (EA) candidates for the purpose of exclusion or retention in the Engineered Alternatives Cost/Benefit Study (EACBS). The EACBS is outlined in the Engineered Alternatives Cost/Benefit Study Scoping Report, WIPP/WID 95-2093.

The EACBS Scoping Report outlined a general approach to screen EAs. The approach includes use of a multi-disciplinary panel (working group), a list of initial EA candidates, and a screening method to ensure that the most viable alternatives are focused upon in .he cost/benefit study. This report documents the screening process used by the Engineered Alternatives Screening Working Group (EASWG) and presents the results of the screening process.

WIPP/WID-95-2104
Revision 0

Engineered Alternatives Cost/Benefit Study Screening Report

May 1995

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

1.0 INTRODUCTION

The Engineered Alternatives Cost/Benefit Study (EACBS) Scoping Report (WIPP/WID 95-2093) was prepared to document the approach for gathering of technical data necessary for decision making regarding engineered alternatives (EA) to be used for meeting the Title 40 Code of Federal Regulations 191 (40 CFR 191)assurance requirements. The study will provide the technical basis for determining whether or not engineered alternatives should be included in the repository as assurance measures to either increase the performance of the disposal system beyond containment requirements or to reduce uncertainty associated with the performance prediction. The screening of initial EAs to be analyzed in the study is a key part of the study. Engineered Alternatives that pass the screen will be considered for further analysis in the EACBS.

The screening process is a non-ranking pass or fail type of screen which uses a panel of technical professionals. The process is such that any prospective alternative can be investigated to determine if it should be considered for further analysis in the EACBS.

The screening process is outlined in Sections 3.1 to 3.2.3 of the scoping report. This process compiles a list of EA candidates, compares these candidates to the definitions of an EA, and screens those that meet the definition against screening criteria. Those that meet the criteria will be used in the EACBS analysis and those that do not meet the definition and/or screening criteria are documented with a justification for rejection. This process is performed by a screening panel known as the Engineered Alternatives Screening Working Group (EASWG). The EASWG was allowed to refine and improve the process outlined in the scoping report.

The following sections detail the screening process used, the results, and describe any modifications made to the process outlined in the scoping report. Justification for these changes are also provided.

1.1 WIPP Mission Description

The Waste Isolation Pilot Plant (WIPP) is a research and development facility of the U.S. Department of Energy (DOE), designed to demonstrate the safe transportation, handling, and disposal of defense generated transuranic (TRU) radioactive waste. The facility is located 26 miles east of Carlsbad, New Mexico. The repository is located in a mined geologic salt deposit, 2,150 feet below ground. The waste will be shipped to the facility and placed in the

underground repository for disposal. After the WIPP repository is filled with waste, the access ways will be closed, shafts sealed, and the surface facilities removed.

1.2 EACBS Program Purpose

The DOE has initiated a cost benefit study to provide a technical basis for the selection and rejection of EAs for the WIPP beyond the engineered barriers required for compliance with containment requirements. The results of this study will be presented in the EACBS Final Report.

Engineered Alternatives included engineered barriers, waste modifications, facility modifications, process changes, or any other approach that after qualitative analysis with respect to performance assessment sensitivity and uncertainty analysis results, would reduce uncertainty in predictions of long-term performance.

1.3 EACBS Program Background

In accordance with Subparts B and C of 40 CFR 191, the WIPP Performance Assessment (PA) is used to predict the expected cumulative release of radionuclides to the accessible environment over the long-term repository performance period. The PA uses numerical modeling to predict whether the performance of the disposal system can reasonably be expected to meet the requirements of 40 CFR 191. The numerical modeling is supported by experimental programs and expert judgement. Results of the PA are quantitative in nature and indicate the WIPP design either does or does not meet the performance criteria and release limits imposed by the regulation. The WIPP disposal system performance assessment and the 40 CFR 191 standard are designed to ensure that a margin of safety is built into the evaluation process. The calculated results of PA can therefore only be used to conclude that the disposal system will or will not comply. Relative "degrees" of compliance cannot be deduced from a mean complementary cumulative distribution function (CCDF) resulting from the WIPP PA.

The regulation specifies that assurance requirements be used to provide additional confidence for long-term compliance. These assurance requirements introduce a "defense-in-depth" concept to the disposal system design by using engineered barriers, active and passive institutional controls, long-term monitoring, and permanent markers in addition to the natural and engineered systems to contain and isolate the waste. The assurance requirements in

40 CFR 191 are used to complement the disposal system containment requirements. As part of the assurance requirements, EAs may be used to provide additional confidence in the containment requirements which also has an added benefit of possibly enhancing disposal system performance and/or reduce uncertainty in the calculated performance results.

A distinction between containment and assurance must be maintained. Containment relates to the regulatory performance limits, whereas assurance relates to reducing the uncertainty associated with a compliance determination. The disposal system design meets the multiple barrier assurance requirements specified in 40 CFR § 191.14(d). This study will provide information about additional EAs which can be evaluated within the context of a compliant disposal system.

2.0 Engineered Alternatives Screening Process

The EACBS requires an input of EA to be used in the cost/benefit analysis. Since the analysis of EAs is a lengthy and costly process, the input EAs are examined prior to the analysis to determine if they are valid and viable alternatives with some expectation that they can improve the disposal system performance and/or reduce the uncertainty in the prediction of this performance. The screening process was designed to examine the prospective inputs to determine the validity of the alternatives.

The screening was performed by the EASWG. The EASWG is composed of a professional facilitator and technical professionals from the following fields:

Waste Management
Waste Processing
Probablistic Risk Assessment
Transportation Engineering
Environmental Engineering
Mine Engineering
Radiation Risk Assessment
Chemical Engineering
Cost/Schedule Assessment
Public Relations

Personnel that had technical experience from the listed fields and had direct knowledge of the WIPP project and/or other DOE waste programs were chosen. Members were chosen by the EACBS project managers. The members of the EASWG and their resumes are listed in Appendix B.

The EASWG met on April 24, 25, and 26, 1995, and again on May 1, 2, and 3, 1995. The working group initially broke the process down into the steps listed below which were derived from the scoping report.

1. Review the definition of an EA.
2. Review the screening criteria.
3. Review the EA candidates and their definitions.
4. Outline the screening process.
5. Compare the EA candidates to the EA definition. Document the results.
6. Determine if the EAs that met the definition also meet the screening criteria.
7. Document the results.

Each step is detailed in the following sections.

2.1 Review the Definition of an Engineered Alternative

The definition stated in Section 3.2.2 of the scoping report is:

> An EA is a process, technology, method, disposal system design, or waste form modification which makes a significant positive impact on the disposal system in terms of reducing uncertainty or improving long-term performance.
>
> In order for an EA concept to be considered as an engineered alternative, it must be technically feasible and must meet at least one of the following criteria.
>
> - Reduce permeability of the waste stack
> - Increase the shear strength of the waste form
> - Reduce the total gas produced from the waste form by:
>
> - Reducing corrosion rate - oxic, anoxic, or both
> - Reducing microbial activity

- Isolating or lowering available water/brine contact with the waste (Radiolysis gas generation is not a critical issue and is not a significant factor in gas generation)

- Reduce the transport rate of radionuclides
- Reduce the consequences of human initiated processes or events
- Reduce the solubility of the radionuclides

The working group concluded that the definition should also state that the final waste form must meet the Waste Acceptance Criteria (WAC). The working group decided that this change was required because all waste shipped to the WIPP for disposal must met the WAC and that any alternative that modifies the waste such that it could not meet the WAC would not be considered. No other changes were made.

2.2 Review the Screening Criteria

The EASWG reviewed the three screening criteria, Regulatory Compliance and Permitting, Availability of Technology, and Schedule of Implementation. These criteria are described in Section 3.2.3 of the scoping report. The EASWG concluded that these criteria are based on feasibility and abbreviated two of the titles to Regulatory Feasibility and Technical Feasibility. The definitions for these two criteria were considered adequate by the EASWG. The working group noted that schedule is inherent in these two criteria. There was therefore no reason to consider schedule as a separate measure for viability determinations made during screening.

2.3 Review Engineered Alternatives and their Definitions

The EA scoping report contains the initial listing of EA candidates that were used in the screening process. This list was compiled from the 64 individual and 14 EA combinations found in the 1991 Engineered Alternatives Task Force Final Report (EATF), the 20 EAs that were considered by Sandia National Laboratories (SNL) for the Systems Prioritization Methodology-II (SPM-2), and the 10 EAs listed in the proposed rule 40 CFR 194. This list is found in Appendix C of this report.

The EASWG reviewed the list of EAs and the definitions of the 64 individual technologies listed in the EATF. Definitions for the remaining EAs were not required because the remaining EAs are either combinations or duplicates of the 64. The working group

modified the 64 EATF definitions to clarify and expand the definitions or update advancements in the technologies since 1991. Some of the original titles were modified to expand on which waste types are used with the technologies. The definitions are listed in Appendix D of this report.

2.4 Outline the Screening Process

The EASWG developed a basic outline to screen the EAs. The outline is:

1. Compare EA to definition
2. Determine if the EA is detrimental to the disposal system
3. Identify duplicate EAs and delete
4. Compare remaining EAs to screening criteria
    a. Regulatory Feasibility
    b. Technology Feasibility

2.5 Compare the Engineered Alternative Candidates to Definition

The EASWG, after reviewing the modified definition of an EA in Section 3.2.2 of the scoping report, compared the initial list of EA candidates (Appendix C) to the definition. Those that met the definition were noted as such and those that did not were documented with a brief description why the working group concluded that it did not meet the definition. Duplicates were also deleted at this time. The initial EA list was divided into a Pass and Reject list. This list can be found in Appendix E.

In reviewing the EAs, the EASWG also considered any detrimental effects due to the implementation of an EA. Any EA that would have a detrimental impact on the performance of the disposal system was deleted.

2.6 Compare the Engineered Alternatives to the Screening Criteria

The remaining EAs that meet the definition were screened by assessing Regulatory and Technical Feasibility. The scoping report definitions for these criteria were used. After a thorough review, no EAs that met the definition were screened out due to regulatory or technical feasibility. Comments from the EASWG on regulatory and technical feasibility are listed in Appendix E.

2.7 Screening Results

After completing the screening process, a Pass and Reject list with justifications was compiled and finalized. The pass list by number and title only are shown in Table 2 - 1 and the rejection list by number and title only are shown in Table 2 - 2.

Table 2 - 1
Engineered Alternative Pass List

The following is a listing of Engineered Alternatives that passed the screening process.

1 Supercompact Everything Except Sludges
2 Incinerate and Cement Solid Organic Waste
3 Shred and Vitrify Solid Organic Waste
4a Wet Oxidation and Cement Solid Organic Waste
4b Wet Oxidation and Vitrify Solid Organic Waste
5 Shred and Bituminize Everything Except Sludges
6 Shred and Compact Everything Except Sludges
7 Shred and Cement Everything Except Sludges
8 Shred and Cold Polymer Encapsulate Everything Except Sludges
9 Shred, add Salt and Compact Everything Except Sludges
10 Plasma Processing of All Waste
11a Melt Metals into TRU waste ingots
11b Melt Metals with Frit to Partition Actinides
12 Salt Backfill Around Drums and Waste Stack
15 Shred, Add Clay Based Material to Everything Except Sludges
16a Acid Digestion and Cementation of Solid Organics
16b Acid Digestion and Vitrification of Solid Organics
19 Add Lime to Solid Organic Waste
22 Decontaminate Surface of Metallic Wastes for low level waste (LLW) Disposal.
29 Microwave Melt Sludges
33 Salt Plus Clay Backfill
35 Salt Aggregate Grout Backfill Around Drums
36 Bitumen Backfill
38 Reduce Room Dimensions to Minimize Space Around Waste Stack
51 Change Mined Extraction Ratio
53 Seal Individual Rooms
60 Depressurize Castile Reservoir
63 Change Waste Container Shape
64 Change Waste Container Material
66 The 1991 Engineered Alternatives Task Forces Final Report (EATF Alternative 1 - Shred and cement organics and inorganics only, salt backfill.
67 EATF Alternative 2 - Enhanced cement sludges, shred and cement organics and inorganics, salt backfill.

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Table 2 - 1
Engineered Alternative Pass List

68 EATF Alternative 3 - Enhanced cement sludges, shred and cement organics and inorganics, salt aggregate grout backfill.
69 EATF Alternative 4 - Enhanced cement sludges, incinerate and cement organics, shred and cement inorganics, salt backfill.
70 EATF Alternative 5 - Enhanced cement sludges, incinerate and cement organics, shred and cement inorganics, salt aggregate grout backfill.
71 EATF Alternative 6 - Vitrify sludges, shred and vitrify organics, melt metals into TRU waste ingots, salt backfill.
72 EATF Alternative 7 - Vitrify sludges, shred and vitrify organics, melt metals into TRU waste ingots, salt aggregate grout backfill.
73 EATF Alternative 8 - Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, salt backfill, change container material.
74 EATF Alternative 9 - Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, salt aggregate grout backfill, change container material.
75 EATF Alternative 10 - Decontaminate surface of metallic wastes for LLW disposal, no backfill, change container material and shape, 10x31x188 rooms.
76 EATF Alternative 11 - Supercompact organics and inorganics, salt backfill, monolayer of 2,000 drums in a 6x33x300 room.
77 EATF Alternative 12 - Supercompact organics and inorganics, salt aggregate grout backfill, monolayer of 2,000 drums, in a 6x33x300 room.
78 EATF Alternative 13 - Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides, no backfill, alternate container, 10x31x188.
79 EATF Alternative 14 - Supercompact organics, and inorganics, salt backfill, seal individual rooms, 2,000 supercompacted drums per room.
83 Salt backfill with CaO
87 Systems Prioritization Methodology (SPM) IT-2 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill, change container material.
89 SPM IT-4 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO.
90 SPM IT-5 Enhanced cement sludges, shred and compact organics and inorganics, salt backfill, 2,000 drum monolayer, 6x33x300 room.
92 SPM IT-7 Enhanced cement sludges, shred and compact organics and inorganics, salt backfill with CaO, 2,000 drums monolayer, 6x33x300 room.
93 SPM IT-8 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt backfill.

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Table 2 - 1
Engineered Alternative Pass List

94 SPM IT-9 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt aggregate grout backfill.
95 SPM IT-10 Decontaminate surface of metallic waste for LLW disposal, change container material, salt aggregate grout backfill.
110 Enhanced Solidification of Sludges
111 Clay Based Backfill

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Table 2 - 2
Engineered Alternatives Rejection List

The following is a listing of Engineered Alternatives that failed the screening process.

4 Wet Oxidation
11 Melt Metals
13 Add other Sorbents
14 Add Gas Suppressant
16 Acid Digestion
17 Sterilization
18 Add Copper Sulfate
20 Add Fillers
21 Segregate Waste Forms
23 Change Waste Generation Process
24 Add Anti-Bacterial Material
25 Accelerate Waste Digestion Process
26 Alter Corrosion Environment
27 Alter Bacterial Environment in WIPP
28 Transmutation of Radionuclides
30 Salt Backfill Only
31 Salt Backfill Plus Gas Getters
32 Compact Backfill
34 Preformed Compacted Backfill
37 Add Gas Suppressant
39 Segregate Waste in WIPP
40 Decrease Amount of Waste per Room
41 Emplace Waste and Backfill Simultaneously
42 Selected Vegetative Uptake
43 Brine Isolating Dykes
44 Raise Waste Above the Floor
45 Brine Sump and Drains
46 Gas Expansion Volume
47 Seal Repository Room Walls
48 Vent Facility
49 Ventilate Facility
50 Add floor of Brine Sorbents

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Table 2 - 2
Engineered Alternatives Rejection List

52 Change Room Configurations
54 Two Level Repository
55 Monument Forest Over Repository
56 Monument Covering the Entire Repository
57 Buried Steel Plate Over the Repository
58 Artificial Surface Layer Over the Repository
59 Add Marker Dye to Strata
61 Grout Culebra Foundation
62 Increase Land Withdrawal Area
65 EATF Baseline - As Received with Salt Backfill
80 SPM-Baseline
81 SPM-A Salt backfill
82 SPM-B Salt/Bentonite backfill 50-50 mix, 50% filling efficiency
84 SPM-D Cement grout backfill
85 SPM-E Salt/Grout backfill
86 SPM IT-1 Shred and cement organics and inorganics, salt backfill - Deleted
88 SPM IT-3 Enhanced cement sludges, shred and cement orginics and inorganics, salt aggregate grout backfill.
91 SPM IT-6 Enhanced cement sludges, shred and compact organics and inorganics, salt aggregate grout backfill, 2,000 drum monolayer, 6x33x300 room.
96 SPM EATF-8 Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP inventory), salt backfill, change waste container material.
97 SPM EATF-9 Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP inventory), salt aggregate grout backfill, change waste container material.
98 SPM DOE-1 Passive markers- no specific scenario given reduce human intrusion probability parameters.
99 SPM DOE-2 Compartmentalization of waste - various unspecified scenarios.
100 194- Cementation
101 194- Shredding
102 194- Supercompaction
103 194- Incineration
104 194- Vitrification
105 194- Improved Waste Containers

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Table 2 - 2
Engineered Alternatives Rejection List

106 194- Grout and Bentonite Backfill
107 194- Metal Melting
108 194- Alternative Configuration of Waste Emplacement
109 194- Alternative Disposal System Dimensions

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Engineered Alternative Working Group

Members (resumes attached)

Peter Carson
John Case
Sayan Chakraborti
Terry DeBiase
Andrew Dykes
Michael Emerson
Denise Gelston
Dave Lechel
John McFee
Jonathan Myers
Rod Palanca
David Palmer
James Ward
James Waters
Maggie Wood

Facilitator
Hans Kresney

Program Oversight
Jayne Davis
John Magyar
Steve Wagner

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APPENDIX A

Engineered Alternatives Screening Working Group
Resumes

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Peter H. Carson

Waste Management Engineer

8 Years of Relevant Experience

SUMMARY: Mr. Carson has more than eight years of experience in providing support to the U.S. Department of Energy (DOE) and its contractors in the area of radioactive and hazardous waste management. Mr. Carson's experience also includes performing work in waste stream characterization, waste certification, project management, RCRA permit applications, waste treatment technology development, waste management and environmental restoration planning and strategy development, and waste minimization cost/benefit analysis.

EDUCATION: B.S., Chemical and Petroleum Refining Engineering, Colorado School of Mines, 1984

RELEVANT EXPERIENCE:

Authoring chapters of the interim Preliminary Safety Analysis Report (PSAR) for the Lockheed Environmental Systems and Technologies (LESAT) Pit 9 waste retrieval and processing system as part of the INEL Pit 9 Interim Action. This effort includes contributing to the hazards analysis, preparing the facility description, and authoring chapters relating to radioactive waste management and quality assurance.

Provided regulatory compliance support to LESAT for INEL Pit 9 Interim Action Proof-of-Process (POP) Tests. These POP tests will demonstrate LESAT's ability to retrieve and process buried low-level, transuranic (TRU), hazardous, and mixed waste from a shallow land burial disposal pit at the Idaho National Engineering Laboratory (INEL). This project also addresses the handling and treatment of contaminated soils from the pit. Specific assignments include preparing the Quality Assurance Program Plan, assisting in the development of the Treatment/Storage/Disposal Plan, and identifying and resolving potential compliance issues.

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Participated as a member of the Waste Isolation Pilot Plant (WIPP) Waste Acceptance Group Audit Team. This team conducted an audit of EG&G Idaho, Inc. and Argonne National Laboratory-West (ANL-W) activities directed toward selecting, characterizing, and packaging TRU waste for experimental activities at WIPP. The audit was required to demonstrate compliance with the WIPP RCRA Part B Permit Application.

Supported the INEL Transuranic Waste Program by preparing and reviewing programmatic planning documents. This work was directed toward ensuring consistency between the Waste Management Division Strategic Plan, the TRU Waste Implementation Plan, and the INEL Roadmap. Specific tasks included

preparing sections of the test, resolving review comments, and suggesting improvements in the planning process.

Supported the Experimental-Waste Characterization Program (E-WCP) at the Rocky Flats Plant (RFP). This support included preparing a Project Management Plan, reviewing and revising operating procedures from various organizations at RFP that are participating in the E-WCP, assisting in the preparation of the Quality Assurance Project Plan, and participating in the development of a self-evaluation program. The E-WCP selected, characterized, repackaged, and shipped to WIPP various transuranic waste forms for experimental activities required to demonstrate that WIPP meets regulatory requirements.

Contributed to preparation of the WIPP Strategic Plan. This plan detailed at several levels the steps required to make WIPP an operating disposal facility. This work included conducting a requirements analysis and a stakeholder analysis, defining the goals and objectives of the WIPP program, creating activity logic diagrams, and analyzing alternate strategies for attaining programmatic goals.

Supported the WIPP Management Control Task Force. This support included preparing a Test Phase Management Plan, which establishes organizational roles and responsibilities for the DOE WIPP Project Office, Westinghouse Waste Isolation Division (WID), and Sandia National Laboratories, the three primary participants in the WIPP program.

Consulted for Rockwell International as part of the Joint Integration Office. Contributed to planning and systems integration efforts related to the Defense TRU Waste Program. Possesses in-depth knowledge of the TRU waste management systems at many DOE locations, including the Idaho National Engineering Laboratory, Oak Ridge National Laboratory, Savannah River Site, and Hanford Reservation. Responsible for preparing long-range plans, cost/schedule optimization studies, and system integration implementation plans.

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Supported the Westinghouse Waste Isolation Division by assisting in revising the WIPP Waste Acceptance Criteria (WAC). Also preparing a Transportation System Management and Operating Plan utilizing detailed knowledge of TRU waste certification and transportation requirements.

PUBLICATIONS:

Carson, P.H., et al., 1990. *Sources of Waste*, Radioactive Waste Management and the Nuclear Fuel Cycle, Vol. 14 (1-2), pp. 27-44.

Kallas, J.A., Tipton, J.B., Carson, P.H., October 3, 1991. *Planning for Environmental Management Activities at the Rocky Flats Plant*, Proceedings from the 5th Annual Colorado Hazardous Waste Management Society Conference.

Ebra, M.A., Carson, P.H., Pierce, G.D., 1988. *Management of Remote-Handled Defense Transuranic Wastes*, Waste Management Eighty Eight, Volume 2 - High-Level Waste and General Interest, pg. 303.

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John B. Case, PE

Professional Qualifications

Mr. Case is a Registered Professional Engineer with more than 16 years of experience in ground and surface water hydrology and geotechnical engineering. He is a specialist in sealing technology for nuclear waste and hazardous waste management. He has been involved in many hydrological, thermomechanical, and structural analyses conducted on nuclear waste repository projects including the Waste Isolation Pilot Plant (WIPP), the Basalt Waste Isolation Project (BWIP), the Office of Nuclear Waste Isolation (ONWI), the Yucca Mountain Project (YMP), and the Office of Waste Technology Development. His work for the BWIP, the YMP, the ONWI, and the OWTD has been primarily as a Principal Investigator, and has included analyzing hydrological, stress, and thermal effects using the boundary element, finite element, and finite difference methods; modeling heat conduction; analyzing the thermomechanical behavior of seals; analyzing room closure for salt creep; analyzing consolidation of crushed salt and other backfill materials; analyzing stress buildup on waste packages in salt; analyzing groundwater flow through seals and fractured rock; and evaluating the extent of the damage zone around boreholes, shafts, and tunnels. In addition, Mr. Case assisted in performing geotechnical, hydrologic, and structural analyses for certifying existing and new underground hazardous waste tank systems and developing spill prevention plans for surface and underground tank systems.

In support of IT-Albuquerque's Geotechnical Design specialty, Mr. Case is responsible for developing and implementing project plans using critical path methods, resource leveling, and cost-tracking methods. He is a member of IT's Senior Technical Associate program.

Education

M.S., Civil Engineering, University of Colorado, Boulder, Colorado; 1974
B.S., Civil Engineering, University of Colorado, Boulder, Colorado; 1972

Registrations/Certifications

Registered Professional Engineer, New Mexico, Colorado, Arizona

Experience and Background

1976 - 1980
1981 - Present

Project Manager, Geotechnical Design, International Technology Corporation (IT), Albuquerque, New Mexico. As a project manager, Mr. Case is responsible for projects involving nuclear waste and hazardous waste disposal, including evaluations of seal and rock behavior for repositories in basalt, tuff, and salt, and for deep-well injection.

- Evaluated the disturbed zone that resulted from drilling, blasting, or machine excavation around shafts and tunnels in salt, tuff, and basalt. Utilized the elasto-plastic theory to assess the mechanical properties of rock, stress distribution, and displacements around openings.

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- Prepared field test plans for repository sealing in tuff.
- Developed a Borehole Sealing Strategy for exploratory boreholes at the YMP.
- Conducted performance assessment of repository seals for air and water flow above the groundwater table for the YMP.
- Developed field test plans for seals in terms of air flow and episodic water flow for the YMP.
- Graded quality assurance activities at the YMP for Sandia National Laboratories, Albuquerque (SNL).
- Performed selected analyses to evaluate the impact of the exploratory shaft test facility on the performance of the YMP repository.
- Designed the rock support systems at the BWIP using boundary element and rock-support interaction methods and developed the field test plans.
- Conducted performance assessment of a repository seal system in basalt at the BWIP using finite element and stochastic methods.
- Developed a numerical model to predict how cement hydration would affect the interface stress on a concrete plug at the Waste Isolation Pilot Plant (WIPP).
- Analyzed the flow of pressurized brine to and from the WIPP repository through boreholes. This represented the worst-case breach scenario for the WIPP.
- Developed a completed numerical model for evaluating brine inflow data for the WIPP.
- Provided peer review of field tests and made recommendations on test performance for the Stripa Project.
- Developed a spill prevention plan for surface and underground tanks at SNL.

1980 ***Senior Engineer, Rockwell Hanford Operations, Richland, Washington.*** Conducted thermal mechanical analyses in basalts and general rock mechanics analyses including:

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- Numerical modeling and analysis of the full-scale heater tests simulating radioactive waste emplacement for the BWIP. Team Leader of the Numerical Modeling Group responsible for planning and reviewing laboratory and field tests in rock mechanics, and for selecting thermal and thermomechanical properties used in numerical analysis. Provided a preliminary analysis of temperature data recovered after 70 days of heater test operations.

- Planned, directed, and analyzed the results of rock mechanics characterization tests in basalt associated with the BWIP to provide thermal and thermomechanical data necessary for predicting the response of the host rock to waste-induced heating.

Professional Affiliations

American Institute of Mining Engineers
American Society of Civil Engineers
Kiwanis International
National Society of Professional Engineers
Tau Beta Pi, National Engineering Association

Publications

Fernandez, J. A., J. B. Case, and J. Tyburski, 1992, "Proposed Sealing Field Tests for a Potential High-Level Waste Repository in Unsaturated Tuff," Proceedings of the Third International Conference on High-Level Radioactive Waste Management, Las Vegas, Nevada, Vol. 2, pp. 2290-2297.

Case, J. B., J. A. Fernandez, and J. R. Tyburski, 1992, "Supporting Hydration Calculation for Small- to Large-Scale Seal Tests in Unsaturated Tuff," Proceedings of the Third International Conference on High-Level Radioactive Waste Management, Las Vegas, Nevada, Vol. 2, pp. 2298-2305.

Cook, R., and J. Case, 1991, "Design and Construction Issues Associated with Sealing of a Repository in Salt," *Waste Management '91, Proceedings of the Symposium in Waste Management*, Tucson, Arizona, Vol. 2, pp. 735-742.

M

Dietz, J. M., M. G. Wallace, B. A. Lauctes, J. B. Case, and D. E. Deal, 1985, "Coupled Fluid-Flow Modeling of Brines Flowing Through Salt Around the Excavations for the Waste Isolation Pilot Plant (WIPP) in the Permian Salado Formation," *Geological Society of America, Abstracts with Programs*, p. A347.

Wallace, M. G., J. M. Dietz, B. A. Lauctes, J. B. Case, and D. E. Deal, 1990, "Coupled Fluid-Flow Through Salt Around Excavations for the Waste Isolation Pilot Plant (WIPP) in the Permian Salado Formation" *Waste Management '90,*

Proceedings of the Symposium in Waste Management, Tucson, Arizona, Vol. 2, pp. 873-880.

Fernandez, J. A., T. E. Hinkebein, and J. B. Case, 1988, "Selected Analyses to Evaluate the Effects of the Exploratory Shafts on Regulatory Performance at Yucca Mountain," *SAND0598*, Sandia National Laboratories, Albuquerque, New Mexico.

Case, J. B., and D. Deal, 1987, "Preliminary Hydrologic and Geomechanical Evaluations of Brine Inflow from Bedded Salt to a Nuclear Waste Repository," *Geological Society of America, Abstracts with Programs*, Vol. 19, No. 7, pp. 614-615.

Case, J. B., and P. C. Kelsall, 1987, "Modification of Rock Mass Permeability in the Zone Surrounding a Shaft in Fractured, Welded Tuff," *SAND86-7001*, Sandia National Laboratories, Albuquerque, New Mexico.

Case, J. B., P. C. Kelsall, and J. L. Withiam, 1987, "Laboratory Investigation of Crushed Salt Consolidation," *Proceedings of the 28th U.S. Symposium on Rock Mechanics*, A. A. Balkema, Rotterdam, pp. 189-196.

Case, J. B., S. Niou, J. Pietz, M. Wallace, and J. Zurkoff, 1987, "Coupled Fluid Flow and Salt Creep Analysis: Summary of Technical Work," *Waste Management '87, Proceedings of the Symposium on Waste Management*, University of Arizona, Tuscon, Arizona.

Deal, D. E., and J. B. Case, 1987, "Brine Sampling and Evaluation Program - Phase I Report," *DOE-WIPP-87-008*, U.S. Department of Energy, Carlsbad, New Mexico.

Fernandez, J. A., P. C. Kelsall, J. B. Case, and D. Meyer, 1987, "Technical Basis for Performance Goals, Design Requirements, and Material Recommendations for the NNWSI Repository Sealing Program," *SAND84-1895*, Sandia National Laboratories, Albuquerque, New Mexico.

Kelsall, P. C., J. B. Case, D. Meyer, J. G. Franzone, and W. E. Coons, 1986, "Schematic Designs for Penetration Seals for a Repository in the Richton Dome," *ONWI-565*, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

Kelsall, P. C., J. B. Case, W. E. Coons, J. G. Franzone, and D. Meyer, 1986, "Schematic Designs for Penetration Seals for a Repository in the Permian Basin", *ONWI-564*, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

Case, J. B., and P. C. Kelsall, 1985, "Coupled Processes in Repository Sealing," *Proceedings of the International Symposium on Coupled Processes Affecting the Performance of a Nuclear Repository*, Academic Press, Orlando, Florida, pp. 531-604.

Lundstrom, R. A., J. B. Case, and P. C. Kelsall, 1985, "The Influence of the Damaged Zone, Interface, and Various Sealing Components on Seal Performance for a Repository in Basalt," *Proceedings of the Topical Meeting on High-Level Nuclear Waste Disposal*, Battelle Press, Columbus, Ohio, pp. 727-738.

Case, J. B., P. C. Kelsall, and J. W. Holland, 1984, "The Development of Interface Stress in a Concrete Plug During Cement Hydration," presented at the Symposium on Concrete and Cementitious Materials for Radioactive Waste Management, American Concrete Institute, New York, New York.

Kelsall, P. C., J. B. Case, and C. R. Chabannes, 1984, "Evaluation of Excavation-Induced Changes in Permeability," *International Journal of Rock Mechanics and Mining Sciences*, Vol. 21, No. 3, pp. 123-125.

Kelsall, P. C., J. B. Case, J. W. Nelson, and J. G. Franzone, 1984, "Assessment of Crushed Salt Consolidation and Fracture Healing in a Nuclear Waste Respository in Salt," *Waste Management '84, Proceedings of the Symposium on Waste Management*, University of Arizona, Tuscon, Arizona.

Kelsall, P. C., J. B. Case, C. R. Chabannes, W. E. Coons, R. D. Ellison, D. Meyer, D. K. Shukla, and D. E. Stephenson, 1982, "Schematic Designs for Penetration Seals for a Reference Repository in Bedded Salt," *ONWI-405*, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

Kuhn, A. K., J. B. Case, S. M. Dass, J. G. Franzone, and J. K. Register, 1982, "Analysis of Potential Impacts of Brine Flow Through Boreholes Penetrating the WIPP Storage Facility," prepared by D'Appolonia (predecessor to International Technology Corporation), Albuquerque, New Mexico.

Chabannes, C. R., J. B. Case, D. K. Shukla, and R. D. Ellison, 1981, "Thermomechanical Considerations in Designing Tests at the Asse Mine," *Proceedings of the 1st Conference on the Mechanical Behavior of Salt*, Pennsylvania State University, University Park, Pennsylvania.

Baca, R. G., J. B. Case, and J. G. Patricio, 1980, "Coupled Geomechanical/ Hydrological Modeling; An Overview of Basalt Waste Isolation Studies," *Proceedings of the Workshop on Thermomechanical-Hydrochemical Modeling for a Hard Rock Waste Repository*, LBL-11204, Lawrence Berkeley Laboratories, Berkeley, California.

Case, J. B., 1980, "A Technical Approach to Resolving Issues on Rock Mechanics as Applied to Development of a Nuclear Waste Repository in a Crystalline Rock Formation," *RHO-BWI-SA51*, Rockwell Hanford Operations, Richland, Washington.

Case, J. B., A. D. Krug, and J. Williams, 1980, "Full Scale Heater Results," *RHO-BWI-LD34*, Rockwell Hanford Operations, Richland, Washington.

Case, J. B., J. W. Nelson, and D. E. Shaw, 1980, "Thermal Expansion Effects in Oil Storage Caverns," presented at the American Society of Mechanical Engineers, Energy Technology Conference and Exhibition, New Orleans, Louisiana.

Case, J. B., J. G. Gusek, and D. E. Shaw, 1979, "Explosive Casting Technology in Surface Mining," *Proceedings of the 20th U.S. Symposium on Rock Mechanics*, University of Texas, Austin, Texas.

Case, J. B., 1974, "The Constitutive Relations of Pittsburgh Coal Subjected to a Multiaxial State of Stress," Master's Thesis, University of Colorado, Boulder, Colorado.

M

Sayan Chakraborti

Professional Qualifications

Mr. Chakraborti is a Chemical Engineer with more than five years of experience in radioactive waste management. This includes a wide variety of projects completed in support of both the U.S. Department of Energy-Headquarters (DOE-HQ) and the DOE sites in the areas of mixed transuranic (TRU) waste, mixed low-level waste (MLLW), low-level waste (LLW), and spent fuel management. As a staff member of the Transuranic and Mixed Waste Assessment Group at IT-Albuquerque, Mr. Chakraborti was the project coordinator and one of the primary contributors to the report of the Engineered Alternatives Task Force (EATF) that was prepared for DOE in support of the Waste Isolation Pilot Plant (WIPP) project. Subsequently he was also involved in the Engineered Alternatives Program (EAP) that was the follow-on effort to the EATF. He also provided support to the WIPP project in preparation of the Waste Characterization Program Plan and the RCRA Part B permit application. More recently he supported the Hanford Site in the evaluation of impacts of WIPP uncertainties on its Solid Waste Operations Complex and the technical review of the Waste Receiving and Processing (WRAP) 1 Title I design with respect to the WIPP Waste Acceptance Criteria (WAC). His recent accomplishments include the preparation of a report on the cost and schedule of selected engineered alternatives in support of the WIPP System Prioritization Initiative. His other accomplishments during the past two years include support to DOE-HQ in the development of the MLLW Systems Analysis Methodology, preparation of the Interim Mixed Waste Inventory Report in response to the Federal Facility Compliance Act (FFCA), and support to the Idaho National Engineering Laboratory in the preparation of background reports for LLW and spent fuel in the DOE system.

Education

M.B.A., Marketing Management, University of New Mexico, Albuquerque, New Mexico; 1989

M.S., Chemical Engineering, University of New Mexico, Albuquerque, New Mexico; 1985

Bachelor of Technology, Chemical Engineering, Indian Institute of Technology, Kharagpur, India; 1983

Experience and Background

1990–Present ***Chemical Engineer and Technical Associate, IT Corporation, Albuquerque, New Mexico.*** Mr. Chakraborti has developed diverse and comprehensive expertise in both the technical and programmatic aspects of DOE radioactive waste management through his active involvement in a variety of projects for DOE-HQ and the DOE sites that addressed many different types of radioactive waste. He is currently involved in the development of an automated cost and schedule estimation model that will be used for evaluation of DOE's site treatment plans for mixed waste. During the past two years he has co-authored several publications with DOE-HQ staff on various topics of radioactive waste management.

M

TRU Waste

- Task Manager for preparation of a report that estimated the life cycle cost and schedule of implementing engineered alternatives (EAs) for the WIPP in response to the draft version of 40 CFR 194. Report compared the cost of processing the waste to the WIPP-WAC versus alternative immobilization technologies.

- Primary contributor to a variety of tasks completed for the EATF project, including cost/benefit analyses of various engineered alternatives to the current TRU waste forms and the repository design; preparation of DOE reports on behalf of two expert panels that were organized for the project; preparation of all weekly, biweekly, and monthly project status reports; and coordination of all technical groups working on the project within IT.

- Primary contributor to many tasks for the EAP, which was the follow-on effort to the EATF project. Developed a program plan for the use of alternate containers for TRU waste and also prepared the technical requirements document for an alternate container for TRU waste.

- Investigated the impact of potential changes in the WIPP-WAC on the design of different facilities in the Hanford Site Solid Waste Operations Complex (SWOC) and determined if any major design modifications would be required as a result of these changes. Also estimated the impact of these potential design changes on the capital cost and implementation schedule for the Hanford SWOC.

- Analyzed the effects of supercompacting TRU waste on both the potential performance of the WIPP repository and the transportation costs. The analysis, which was conducted for Westinghouse-WIPP, evaluated the incremental effects on WIPP performance from supercompacting only Rocky Flats' waste as well the effect of supercompacting different percentages of the entire WIPP inventory.

- Involved in the development and preparation of Revision 2.0 of the WIPP TRU Waste Characterization Program Plan, which described TRU waste characterization requirements for the originally planned WIPP Test Phase, and also served as a DOE planning document for developing and implementing site-specific TRU waste characterization programs.

- Revised the TRUPACT-II Content Codes (TRUCON) document with the objective of simplifying it in order to reduce the time and effort required for review of future payload amendments by the U.S. Nuclear Regulatory Commission (NRC). The revised document is ready for presentation to the NRC for final approval.

- Contributed to the development and finalization of the waste analysis plan in support of the WIPP RCRA Part B permit application to ensure RCRA compliance for TRU waste to be accepted at the WIPP facility.

- Evaluated the Title I design of Module 1 of the proposed WRAP facility at the Hanford Site with respect to Revision 4 the WIPP-WAC and provided recommendations to ensure that the final TRU waste forms generated by the facility will satisfy the WIPP-WAC.

- Primary author of a memorandum to the EPA that helped DOE to successfully negotiate the exclusion of certain compounds from EPA-imposed flammability testing requirements for TRU waste in the Conditional No-Migration Determination granted by the EPA in 1990.

- Prepared a report for DOE that evaluated potential flammability concerns associated with TRU waste destined for disposal at the WIPP and concluded that adequate safety regulations currently exist for minimization of flammability concerns. The report helped DOE to address flammability concerns expressed by external agencies.

- Developed complete engineering design specifications for volatile organic compound monitoring systems for five locations at the WIPP facility. Specifications included sampling method and frequency, selection of sampler and accessories, instrumentation and control requirements, fabrication and assembly drawings of the entire monitoring system, equipment layout, and field execution and quality control procedures.

Mixed Low-Level Waste

- Deputy Project Manager for IT for the development of a Systems Analysis Methodology for evaluation of "cradle-to-grave" options for management of DOE MLLW that include all major components of MLLW management, such as waste characterization, treatment, storage, transportation, and disposal. The methodology, which was developed for EG&G Idaho in support to DOE-HQ, is an analytical tool for evaluation of MLLW options in terms of the performance of final waste forms in a disposal facility, life-cycle cost and schedule for implementing options, health and safety risks associated with the options, and also the regulatory impact of each option. Apart from routine responsibilities as Deputy Project Manager for the 18-month duration of this $2.4 million project was also the leader for the development of the life-cycle cost and schedule estimation methodology.

- Provided direct support to DOE-HQ in the preparation of the Interim Mixed Waste Inventory Report that was submitted to the EPA in May 1993 in response to the FFCA. Interfaced with DOE site representatives and completed technical review of waste profile sheets for a number of waste streams from these sites to verify the correctness and consistency of the data provided by the sites.

M

Low-Level Waste

- Primary author of many sections of the draft "Low-Level Waste Background Report," which was prepared for EG&G Idaho in support of the waste type-specific strategic planning process for DOE-HQ. The report presented an overview of LLW management in the DOE complex, with an emphasis on current challenges requiring attention and potential future courses of action.

- Contributed to the development of a macroengineering design for remediation of the 100 Area at the Hanford Site. Responsible for the development of a conceptual design of an efficient on-site system for transportation of excavated waste between different areas and facilities at the Hanford Site. Also prepared cost estimates and equipment specifications for this system.

Spent Fuel

- Primary author of many sections of the draft "Spent Fuel Background Report," which was prepared for EG&G Idaho in support of the waste type-specific strategic planning process for DOE-HQ. The report summarized the DOE spent fuel inventory and applicable regulations for management of spent fuel in the DOE complex and also discussed historical spent fuel management practices at each DOE site

M

- Primary author of many sections of a report titled, "Issues Related to DOE Management of Spent Nuclear Fuel," which was prepared for EG&G Idaho in support of DOE-HQ. This report summarized current spent fuel management issues (both site-specific and DOE complexwide) and discussed their potential implications on the DOE system.

1987–1989 ***Graduate Assistant, Anderson School of Management, University of New Mexico, Albuquerque, New Mexico.*** Responsible for assisting professors in research and course work. Tutored undergraduates in financial management courses and graded graduate-level financial management course work. Collected and summarized data from the Wall Street Journal in different areas of investment analysis.

1988 ***Marketing Intern, Southwest Airlines, Albuquerque, New Mexico.*** Assisted Area Marketing Manager in marketing activities, analyzed market share data, initiated sales calls, and prepared monthly airline market analysis reports.

1984–1986 ***Research Assistant, Department of Chemical Engineering, University of New Mexico, Albuquerque, New Mexico.*** Assisted professors with research in the areas of heterogeneous catalysis and solar engineering.

- Developed a comprehensive computer model for the design, performance analysis, and optimization of a gel solar pond for domestic heating purposes. Included

detailed modeling and simulation of heat collection, temperature profiles as a function of depth, and process heat exchange from any given size pond. The model was subsequently used to design and construct a pond 5 meters deep and 400 square meters in area for a local business center in Albuquerque.

- Designed and fabricated an automatic fine particle generator to prepare nonporous spherical TiO_2 particles to be used as supports for Rh catalysts. Investigated the metal-support interactions of Rh catalysts using nonporous oxide supports of model shapes (silica and titania spheres, magnesia cubes).

1983–1984 ***Teaching Assistant, Department of Chemical Engineering, University of New Mexico, Albuquerque, New Mexico.*** Assisted professors with undergraduate courses and grading and supervised undergraduates in Unit Operations Lab. Guided undergraduates through start-up and shut-down procedures of various units. Tutored undergraduate courses in chemical engineering.

Professional Affiliations

American Institute of Chemical Engineers

Publications

Chakraborti, S., M. Abashian, J. Rhoderick, and L. Harmon, 1993, "Transportation of DOE Mixed Waste in the U.S.," *Proceedings of the Second International Mixed Waste Symposium*, August 17–20, Baltimore, Maryland, p. 12.4.1.

Chakraborti, S., and T. DeBiase, 1993, "Transportation of Liquid Mixed Waste in the U.S.: Is It Really a Problem?" *Proceedings of the Second International Mixed Waste Symposium*, August 17–20, Baltimore, Maryland, p. 12.3.1.

M

Chakraborti, S., T. DeBiase, M. Devarakonda, M. Abashian, and J. Bassi, 1993, "Estimation of Initial Costs of DOE Mixed Low-Level Waste Management Options," *Proceedings of the 1993 Incineration Conference*, May 3–7, Knoxville, Tennessee, p. 125.

Caregeorges, M., S. Chakraborti, M. Abashian, and J. Bassi, 1993, "Evaluation of the Regulatory Compliance Impact on DOE Mixed Low-Level Waste Management Options," *Waste Management '93, Proceedings of the Symposium on Waste Management*, Tucson, Arizona, February 28–March 4, p. 1809.

Melvin, J., S. Chakraborti, M. Abashian, and D. Abbott, 1993, "Spent Fuel Storage in the DOE Complex: A Discussion of the Current Status and Unresolved Issues," *Waste Management '93, Proceedings of the Symposium on Waste Management at Tucson, Arizona*, February 28–March 4, p. 877.

Chakraborti, S., T. DeBiase, M. Devarakonda, M. Abashian, and J. Bassi, 1993, "Estimation of Initial Costs of DOE Mixed Low-Level Waste Management Options," *Waste Management '93, Proceedings of the Symposium on Waste Management at Tucson, Arizona*, February 28–March 4, p. 1803.

Chakraborti, S., T. DeBiase, M. Devarakonda, M. Abashian, and J. Bassi, 1992, "Development of a Methodology for Estimation of Initial Costs of DOE Mixed Low-Level Waste Management Options," *Proceedings of the Fourteenth Annual U.S. Department of Energy Low-Level Radioactive Waste Management Conference*, November 18–20, Phoenix, Arizona.

Abashian, M., Chakraborti, S., M. Devarakonda, S. Djordjevic, and J. Bassi, 1992, "A Decision Methodology for the Evaluation of Mixed Low-Level Radioactive Waste Management Options for DOE Sites," *Proceedings of the Fourteenth Annual U.S. Department of Energy Low-Level Radioactive Waste Management Conference*, November 18–20, Phoenix, Arizona, p. 428.

Chakraborti, S., M. Abashian, J. C. Lopez, and R. Batra, 1992, "Review of Alternate Container Materials for TRU Waste: An Expert Panel Evaluation," *Proceedings of the 1992 Incineration Conference*, May 11–15, Albuquerque, New Mexico, p. 657.

Datye, A. K., S. Chakraborti, and E. J. Braunschweig, 1988, "Structure and Reactivity of Small Metal Particles," *Proceedings of the 9th International Congress on Catalysis*, p. 1122.

Chakraborti, S., N. J. Long, and A. K. Datye, 1987, "Oxidation-Reduction Treatment of Rhodium Supported on Nonporous Silica Spheres," *Journal of Catalysis*, Vol. 108, pp. 444–451.

Holt, T., S. Chakraborti, A. D. Logan, and A. K. Datye, 1987, "The Effect of Catalyst Preparation Conditions on the Morphology of MgO Catalyst Supports," *Applied Catalysis*, Vol. 34, p. 199.

Wilkins, E., T. K. Lee, and S. Chakraborti, 1986, "Optimization of the Gel Solar Pond Parameters: Comparison of Analytical Models," *Energy Conversion and Management*, Vol. 26, No. 1, pp. 123–134.

M

Terry A. DeBiase

Professional Qualifications

Mr. DeBiase is a chemical engineer with more than five years of experience in the environmental field. His technical specialties include design, costing, and construction management for remediation systems, development and application of predictive models for engineering design, as well as issues regarding transportation of radioactive mixed waste. Since joining IT, he has provided engineering support to the Los Alamos National Laboratory (LANL) Radioactive Liquid Waste Treatment Facility, U.S. Department of Energy (DOE) mixed low-level waste System Analysis Methodology, New Mexico Environment Department remediation projects, the Hanford site transuranic (TRU) waste management efforts, the Waste Isolation Pilot Plant (WIPP) project dealing with the cost and feasibility of transporting supercompacted TRU waste from the Rocky Flats Plant, and the EG&G Idaho project addressing disposal facility performance assessment for various final wasteforms. He has a strong background in field operations management, technical report preparation, permitting issues, and project and engineering support.

Education

B.S., Chemical Engineering, University of California at Berkeley, California; 1987
Groundwater Pollution and Hydrology, Princeton Short Course, Omni Environmental Corporation; 1990
OSHA Hazardous Waste Operations Training (29 CFR 1910.120, 40 hours); 1989
Management and Supervisor Training (29 CFR 1910.120, 40 hours); 1991
Hazards and Protection (annual refresher) IT Corporation; 1994

Registrations/Certifications

OSHA Engineer in Training, California

Honors and Awards

California State Finalist, Rhodes Scholarship; 1987
Male Scholar-Athlete Award; 1987
Robert Gordon and Ida Sproul Award, Outstanding Junior at University of California at Berkeley
Edmund Kraft Scholarship, Top 100 Freshmen
NCAA Swimming All-American (four-time), NCAA Academic All-American (three-time)

Experience and Background

1992-Present **Chemical Engineer, IT Corporation, Albuquerque, New Mexico.** Provides project and task management and engineering and regulatory support for DOE projects.

- Served as project manager for the technical support to the Radioactive Liquid Waste Section (CST-13) at Los Alamos National Laboratory. Project Work included the 75,000 gallon retrofit study, a tank decontamination plan, and an industrial ventilation standards study.

M

- Served as project engineer and task manager for the Lawrence Livermore National Laboratory (LLNL) project addressing proper use of the TRUPACT-II shipping package and associated equipment. Work performed included compilation of site-specific information, field survey for selection of a staging area for TRUPACT-II operations, and preparation of reports and procedures to enable LLNL personnel to use the TRUPACT-II.

- Supervised construction and installation of the remediation system at a site in Albuquerque, New Mexico. Permitted the thermal oxidation unit in Albuquerque. New Mexico, in compliance with Albuquerque-Bernalillo County Air Quality Control Board Regulations.

- Evaluated the effect of engineered soils and other site modifications as on the performance of waste disposal facilities for the National Low-Level Waste Management Program at the Idaho National Engineering Laboratory.

- Provided technical support for the environmental assessment document prepared to satisfy NEPA requirements for the environmental restoration activities planned for Sandia National Laboratories/New Mexico.

- Evaluated the effectiveness of various final waste forms and disposal sites with respect to compliance with the performance objectives in applicable DOE orders for EG&G Idaho.

- Performed an analysis of potential impacts on the Hanford Site TRU waste management efforts from uncertainties associated with the current WIPP Waste Acceptance Criteria. Work performed included compilation and analysis of site-specific information, client interface for the interpretation of relevant information and identification of additional data needs, and report preparation documenting the findings of the study.

- Analyzed U.S. Department of Transportation (DOT) and DOE requirements for transportation of radioactive mixed waste for the development of the DOE mixed low-level waste Systems Analysis Methodology, Published papers in support of this DOE effort, including the development of a cost estimation methodology for mixed low-level waste management options.

- Performed analysis of regulatory and transportation cost issues regarding the disposal of supercompacted Rocky Flats Plant TRU waste forms at the WIPP.

- Provided technical review and database support for the Mixed Waste Inventory Report prepared by DOE in response to the Federal Facility Compliance Act of 1992.

M

1989-1991 **Assistant Engineer, McLaren/Hart, Alameda, California.** Responsible for field operation management, technical report preparation, engineering support.

- Designed and supervised construction of groundwater extraction trench and hydrocarbon reclamation system at a site in Richmond, California, which was subject to the regulations established by the Resource Conservation and Recovery Act (RCRA).

- Provided database programming and maintenance as well as final quality assurance inspection in support of the final feasibility study for a site in Palo Alto, California, which was subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

- Wrote Bay Area Air Quality Management District air emission reports and National Pollutant Discharge Elimination System sewer discharge reports for groundwater extraction and treatment systems at RCRA and CERCLA sites.

- Performed operation and maintenance of groundwater extraction and treatment systems at RCRA and CERCLA sites in the San Francisco Bay area.

- Supervised soil sampling to provide final closure for a chemical dilution pit at a CERCLA site in Palo Alto, California.

- Coordinated wastewater discharge permit modifications and sampling plan preparation for a semiconductor manufacturer in Fremont, California.

- Analyzed emission control technologies for various petroleum refinery operations and processes to establish best available control technologies and maximum achievable control technologies for the American Petroleum Institute.

- Wrote a site closure plan in accordance with 40 CFR 265 for a hazardous waste generation facility.

- Coordinated and performed utility clearances for soil borings and well drilling operations.

- Provided engineering support for various projects, such as cost estimation, engineering calculations, and treatment system conceptualization, design, and permitting.

M

1989 **Staff Chemical Engineer, Aqua Resources, Inc., Berkeley, California.** Responsible for field investigations and report preparation.

- Performed model development to assess groundwater flow at a CERCLA site in Mountain View, California. Coordinated and conducted water and soil sampling at the site.
- *Conducted field surveys and wrote subsequent spill prevention, control, and* countermeasure (SPCC) plans to comply with 40 CFR 112 for various United States Naval Bases in San Diego, California.
- Assisted in supervision of the removal of 11 underground storage tanks and subsequent soil and groundwater sampling at an Emeryville, California, site.

Publications/Presentation

Smith, T. H., J. Myers, S. M. Djordjevic, T. A. DeBiase, M. T. Goodrich, D. DeWitt, 1994, "Preliminary Parametric Performance Assessment of Potential Final Waste Forms for Alpha Low-Level Waste at the Idaho National Engineering Laboratory," EEG-WM-11415, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho.

Myers, J., S. M. Djordjevic, T. A. DeBiase, M. R. Goodrich, 1994 "Use of Engineered Soils and Other Site Modifications for Low-Level Radioactive Waste Disposal," DOE/LLW-207, National Low-Level Waste Management Program, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

Chakraborti, S., and T. DeBiase, 1993, "Transportation of Liquid Mixed Waste in the U.S.: Is it Really a Problem?" Proceedings of the 2nd International Mixed Waste Symposium, at Baltimore, Maryland.

Chakraborti, S., and T. DeBiase, M. Devarakonda, and M. Abashian, 1993, "Estimation of Initial Costs of Mixed Low-Level Waste Management Option," Proceedings of the Symposium on Waste Management, Tucson, Arizona.

Bassi, J., Chakraborti, S., and T. DeBiase, M. Devarakonda, and M. Abashian, 1992, "Development of a Methodology for Estimation of Initial Costs of DOE Mixed Low-Level Waste Management Options," Proceedings of the 14th Annual U.S. DOE Low-Level Radioactive Waste Management Conference, Phoenix, Arizona.

M

Andrew A. Dykes

Professional Qualifications

Mr. Dykes is a senior consultant, for PLG, Inc., and has 29 years of relevant experience. He has experience in the application of probabilistic risk assessment (PRA) to nuclear facilities, including waste, spent fuel, and reactor facilities. Skilled at the integration of a variety of analyses into coherent products that address the client's needs. Well versed in a wide variety of analytical techniques, such as Bayesian treatment of evidence, accident analysis, decision analysis, reliability and availability assessment, and human reliability assessment. An expert in the integration of human actions into PRAs and the establishment of risk-based technical specifications.

Ph.D., Nuclear Engineering, Massachusetts Institute of Technology; 1982
M.S., Nuclear Engineering, Massachusetts Institute of Technology; 1971
B.S., United States Military Academy; 1964
Nuclear Plant Engineer Certificate, U.S. Army Power Group; 1971

Registrations/Certifications

Registered Professional Engineer, California and Virginia

Honors and Awards

Treasurer, International Association for Probabilistic Safety Assessment and Management
Chair, Conference Organizing Committee, PSAM-II
Active member of Subcommittee SC-7, Human Factors and Control Facilities, Nuclear Power Engineering Committee, of the IEEE Power Engineering Society
Alpha Nu Sigma
Phi Kappa Phi
Sigma Xi
Member, American Nuclear Society
Member, Institute of Electrical and Electronics Engineers Reliability and Power Engineering Societies
Member, Society for Risk Analysis

Recent Experience and Background

M

Project Manager, PLG, Inc. Handled a variety of projects for the utility industry, and conducted programmatic risk assessments of the options for the removal and interim storage of spent nuclear fuel at Hanford. Project manager and key technical contributor to safety analysis at the Rocky Flats Plant involving criticality safety analysis of plutonium waste drum storage and plutonium holdup material in exhaust ducts of processing lines to support the Safety Analysis Report for Building 707. Conducted the criticality hazards assessment for the preliminary hazards analysis of TA-55, the plutonium processing facility at Los Alamos National Laboratory, to

support its FSAR upgrade. The evaluation of administrative controls to minimize human error played an important role in this assessment. Member of the independent safety assessment group for the SP-100 space nuclear reactor.

Completed human factors evaluation for the Final Safety Analysis Report (FSAR) upgrade to DOE Order 5480.23 criteria at the DOE's WIPP. Task leader for human reliability analysis on four full-scope PRAs. Developed a practical approach for eliciting judgment from operations personnel regarding human performance using the success likelihood index methodology. Guided operating crews through an elicitation process to both quantify the likelihood of error and identify potential improvements to operating procedures. This process produced a number of suggestions that were implemented to improve both operations and training. Participating in revisions of IEEE standards in human factors.

Experienced in the analysis of diverse operational and test data to support programmatic planning. As consultant to a U.S. Air Force System Program Office, established a Bayesian-based system for the assessing the flight reliability of the Advanced Cruise Missile. The system consisted of a structured reliability database to organize testing, failure, root cause evaluations, and corrective action effectiveness that provided an efficient communication tool that assisted the organizational decision process. Performed a variety of analyses ranging from the cost of modifications of a nuclear plant to reduce impact on marine life to the risk of cancellation of future projects. Task leader for performance assessment of coal-fired fueled power plants, resulting in a heat rate standard that was accepted by both the utility and the Public Utilities Commission as a fair measure for a rate incentive program.

Principal investigator on an Electric Power Research Institute project to apply risk-based technologies to reduce O&M costs and nuclear power plants. Accomplished studies supporting Technical Specification submissions for a number of utilities. Benefits included consolidation of surveillance procedures, reductions in test-caused failures, and extension of test intervals. Currently, formulating a framework for Technical Specification submissions to build on lessons learned and to speed up the review and approval cycle.

Extensive experience in a wide variety of engineering positions in the U.S. Army Corps of Engineers, including military nuclear power and nuclear weapons effects research and development. As an associate professor at the United States Military Academy, taught courses in nuclear physics, nuclear reactor physics, nuclear systems design, and computer-aided design.

M

Professional Affiliations

Active DOE "Q" Security Clearance
Active DoD "Secret" Security Clearance

Publications

Dykes, A. A., 1994, "Waste Isolation Pilot Plant Human Factors Evaluation," PLG, Inc., prepared for Merrick & Company and The S. M. Stoller Corporation, PLG-1004.

Dykes, R. A., A. A. Dykes, and J. Blodgett, 1994, "Risk Management and Corrective Actions," presented at the PSAM-II Conference, San Diego, California.

Dykes, R. A., A. A. Dykes, and J. Blodgett, 1994, "An Application of Bayes' Theorem to Management Decision Making," presented at the 1994 Annual Reliability and Maintainability Symposium, Anaheim, California.

Ho, V. S., W. T. Loh, A. A. Dykes, G. A. Tinsley, and H. F. Perla, 1994, "Fire and Flooding PSAs Requantification Project," PLG, Inc., prepared for IEA of Japan Co., Ltd., and Institute of Nuclear Safety, Nuclear Power Engineering Corporation, PLG-0967.

Kindinger, J. P., A. A. Dykes, W. G. He, and J. W. Read, 1993, "Decision Analysis to Support TVA Nuclear Generation Planning — Phase 2 Report," PLG, Inc., prepared for Tennessee Valley Authority, PLG-0922.

Dykes, A. A., C. R. Grantom, K. N. Fleming, J. M. Oddo, F. J. Rahn, and D. H. Johnson, "U.S. Nuclear Industry Efforts in Utilizing PSA for Technical Specifications Changes," 1993, presented at IAEA Technical Committee Meeting on Procedures for Use of PSA for Optimizing NPP Operational Limits and Conditions, Barcelona, Spain, September 20-23.

Dykes, A. A., 1993, "Derivation of Routine Human Error Rates Used as Screening Values for the TVA IPE," PLG, Inc., prepared for Tennessee Valley Authority, PLG-0931.

PLG, Inc., 1993, "Short Course — Safety and Risk Assessment of Nuclear and Nonnuclear Facilities," PLG-0927, Newport Beach, California.

PLG, Inc., 1993, "Short Course — Risk Assessment and Risk Management of Nuclear Facilities," PLG-0926, Newport Beach, California.

Dykes, A. A., and T. J. McIntyre, 1993, "Probabilistic Safety Assessment Applications in the U.S. and Canada," PLG, Inc., prepared for Mitsubishi Atomic Power Industries, Inc.

Dykes, A. A., and J. P. Kindinger, 1993, "Rocky Flats Drum Criticality Probabilistic Risk Assessment," PLG, Inc., prepared for EG&G Rocky Flats, Inc., PLG-0838, Rev. 1.

M

PLG, Inc., 1992, "Browns Ferry Nuclear Plant Unit 2 Probabilistic Risk Assessment Individual Plant Examination," prepared for Tennessee Valley Authority.

PLG, Inc., 1992, "Sequoyah Nuclear Plant Unit 1 Probabilistic Risk Assessment Individual Plant Examination," prepared for Tennessee Valley Authority.

PLG, Inc., 1992, "Watts Bar Nuclear Plant Unit 1 Probabilistic Risk Assessment Individual Plant Examination," prepared for Tennessee Valley Authority.

Dykes, A. A., and E. L. Quinn, 1992, "Methodology for Developing Risk-Based Surveillance Programs for Safety-Related Equipment at San Onofre Nuclear Generating Station Units 2 and 3," PLG, Inc., prepared for Southern California Edison Company, PLG-0575.

PLG, Inc., 1991, "Criticality Risk Assessment of Ductwork Material Holdup in Building 707," prepared for EG&G Rocky Flats, Inc., PLG-0818.

Dykes, A. A., J. A. Mundis, and D. A. Bidwell, 1991, "Application of a Bayesian Aging Model to Predict Steam Generator Plugging Rates," *Proceedings of the International Conference on Probabilistic Safety Assessment and Management*, Beverly Hills, California.

Dykes, A. A., J. W. Read, K. Woodard, and D. R. Buttemer, 1990, "Assessment of Marine Review Committee Recommendations for SONGS Units 2 and 3," PLG, Inc., prepared for Southern California Edison Company, PLG-0805.

M

MICHAEL A. EMERSON

Consultant, PLG, Inc.

8 Years of Relevant Experience

SUMMARY: Consultant and Manager of PLG's Albuquerque office specializing in the application of risk assessments in the nuclear, chemical, and aerospace industries.

EDUCATION:

M.S., Nuclear Engineering, University of Washington, 1988
B.S., Mechanical Engineering with Distinction, University of New Mexico, 1986

RECENT EXPERIENCE: Extensive experience in assisting utilities to perform nuclear plant probabilistic risk assessments (PRA), including development of risk models using PLG's RISKMAN® software. Currently participating in the B-52H Nuclear Weapon System Safety Assessment and associated B-52H Electrical Systems Analysis to provide hazard scenario screening and quantification.

Served as manager of computer operations and software development and as project manager for RISKMAN, PLG's most important computer package that provides quantitative risk management capability. Recent RISKMAN development included the addition of new data, spatial, seismic analysis modules, and risk management facilities.

Project manager on the development of programmatic risk assessment software tools.

OTHER EXPERIENCE: Provided full-time support to Pacific Gas and Electric Company's probabilistic risk assessment (PRA) group in the development of its individual plant examination report for the Diablo Canyon Nuclear Power Plant. Was principal editor of Level 1 and Level 2 portions of the report and produced the executive summary. As part of this support, updated systems analyses, performed an update of the internal flooding analysis, and used the PRA to examine potential changes in plant and procedures. The latter use of the PRA included prioritizing masonry walls for reinforcement on the basis of their potential failure impact on adjacent equipment or mounted conduits carrying important power or control wiring, for justifying continued plant operation under certain degraded systems conditions, and for evaluating the risk of taking specific equipment out of service for maintenance.

M

Co-authored BARP, a program that provides Bayesian updating of reliability data. Served as a contributor to the development of COPILOT, an expert system that used Bayes' theorem to diagnose nuclear plant transient and accident events. Performed system analyses for boiling water reactor and space station systems.

HONORS AND AWARDS:

Institute of Nuclear Power Operations Fellowship
Tau Beta Pi, Engineering Honor Society
Member, American Society of Mechanical Engineers
Member, American Nuclear Society
Member, Society for Risk Analysis

SECURITY CLEARANCES:

Active DoD "Secret" Security Clearance

RECENT PUBLICATIONS (LAST 5 YEARS):

Kaplan, S., K. M. Naassan, M. A. Emerson, W. R. Fuller, "SBIR Phase 1 Report - Probabilistic Schedule and Cost Risk Analysis for KSC Shuttle Operations," PLG, Inc., prepared for the National Aeronautics and Space Administration, Kennedy Space Center, PLG-0934, July 1993.

Emerson, M. A., K. N. Fleming, D. J. Wakefield, S. A. Epstein, "RISKMAN® - A System for PSA," presented at Probabilistic Safety Assessment, PSA '93, Clearwater Beach, Florida, January 26-29, 1993.

Emerson, M. A., V. S. Ho, D. H. Johnson, C. M. Lankheim, and K. M. Naassan, "Risk Analysis of Environmental Hazards at the High Flux Beam Reactor," Phase 1 Interim Report, PLG, Inc., prepared for Brookhaven National Laboratory, PLG-0884, September 1992.

Contributing Author to:
"Browns Ferry Nuclear Plant Unit 2 Probabilistic Risk Assessment Individual Plant Examination," PLG, Inc., prepared for Tennessee Valley Authority, 1992.

Contributing Author to:
"Sequoyah Nuclear Plant Unit 1 Probabilistic Risk Assessment Individual Plant Examination," PLG, Inc., prepared for Tennessee Valley Authority, 1992.

Contributing Author to:
"Watts Bar Nuclear Plant Unit 1 Probabilistic Risk Assessment Individual Plant Examination, PLG, Inc., prepared for Tennessee Valley Authority, 1992.

Kaplan, S., S. A. Epstein, A. A. Dykes, and M. A. Emerson, "BARP - A PC-Based Bayesian Reliability Program Allowing Engineers to Think in the Language of Probability Curves," *Journal of Reliability Engineering and System Safety*, Vol. 30, pp. 399-408, PLG-0706, 1990.

Kaplan, S., A. Keter, S. A. Epstein, D. C. Bley, and M. A. Emerson, "COPILOT - A PC-Based Expert System for Reactor Operational Assistance Using a Bayesian Diagnostic Module,"

Journal of Reliability Engineering and System Safety, Vol. 30, No. 1-3, pp. 219-237, PLG-0705, 1990.

Fleming, K. N., G. A. Tinsley, M. A. Emerson, D. J. Wakefield, "Risk-Based Equipment Prioritization for Beaver Valley," prepared for Duquesne Light Company, PLG-0770, May 1990.

Kaplan, S., A. Keter, D. G. Lindsay, D. C. Bley, S. A. Epstein, and M. A. Emerson, "Expert Systems for Diagnosis and Decision under Substantial Uncertainty - A Classical (Bayesian) Approach," presented at Forum on Artificial Intelligence in Management, PLG-0761, Monterey, California, May 14-17, 1990.

M

Denise C. Gelston

Manager, Air Programs

AREAS OF EXPERTISE

RCRA Compliance and Permitting
Hazardous and Mixed Waste Management
Air Emission Inventories
SARA 312 Reporting
Environmental Auditing

SUMMARY OF QUALIFICATIONS

Ms. Gelston has eight years of experience in environmental compliance and permitting and hazardous and mixed waste management. She ensures regulatory compliance, prepares Air Pollutant Emission Notices (APENs), prepares and reviews RCRA permit applications and closure plans, assists in the preparation of SARA 312 chemical inventory reports, and conducts compliance audits. Ms. Gelston has also assisted in developing a course curriculum for a Clean Air Act Operating Permit course, and has participated in presenting the course.

EXPERIENCE

Manager of Air Programs — **The S.M. Stoller Corporation**
March 1990 - Present — **Boulder, Colorado**

Project manager for the preparation of a RCRA permit application for a hazardous waste landfill. Responsibilities include planning and scheduling for a completed application and overall coordination of various activities that must be completed prior to permit application submittal, including site characterization and facility design. Other responsibilities include interaction with regulators, regulatory interpretation, and preparation of several sections of the permit application.

Project manager of the development of an environmental, health, and safety management system. Ensured that activities were conducted within budget constraints, provided regulatory interpretation, ensured that system components complied with applicable regulations, and assisted in preparation of SARA 312 chemical inventory reporting.

Assisted in preparation of course curriculum for a Clean Air Act Operating Permit course. Designed a process, identified emission points, quantified emissions, determined the applicability of operating permit regulations, and identified pollution prevention and legal options that could be used to assist a facility in avoiding operating permit requirements. Prepared a course segment on enhanced monitoring provisions. Currently assisting in the presentation of the course to various clients.

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Assisted in the preparation of a RCRA closure procedure for a hazardous waste container storage area for a private client. The procedure described activities in sequence for decontaminating secondary containment, equipment, piping, and vaults; disposing of waste generated as a result of closure activities; and sampling to ensure clean closure. Identified methods to minimize waste generated during closure. The procedure was reviewed against the approved RCRA closure plan to ensure that all closure activities are consistent with the closure plan.

Assisted in revising the Rocky Flats Volume Basis Waste Management Cost Analysis, which is an effort to quantify direct labor and material costs associated with managing the principal waste streams at the Rocky Flats Environmental Technology Site. Identified waste management operations and quantified costs associated with those operations.

Served as a member of a multidisciplinary team preparing RCRA permit modification requests for hazardous, low-level mixed, and transuranic-mixed waste storage and treatment units at Rocky Flats. Prepared process flow diagrams, piping and instrumentation diagrams, unit descriptions, and secondary containment calculations for various units in Building 374 at Rocky Flats.

Assisted in preparation of the Rocky Flats Mixed Residues Part B permit modification request. The modification request included hundreds of storage tanks and container storage areas. Interpreted regulations, prepared reports on applicability of RCRA to various units, collected an extensive amount of field information regarding residue characterization and process operations, and prepared process flow diagrams, container storage area layouts, piping and instrumentation diagrams, unit descriptions, and secondary containment calculations for containers and tanks.

Prepared APEN reports for support facilities, storage tanks, and miscellaneous emission sources at Rocky Flats. Estimated airborne emissions of hazardous criteria and toxic pollutants from facilities and storage tanks. The analysis entailed the evaluation of processes and application of engineering judgment to determine source pathways and potential release rates of pollutants.

Assisted in the identification of processes and equipment at Rocky Flats that are subject to RCRA organic air emission regulations and conducted monitoring of equipment subject to the regulations. Demonstrated use of monitoring equipment to facility employees.

Participated in field surveys for the Waste Stream and Residue Identification and Characterization Program for Rocky Flats. Analyzed production and process systems and operations. Characterized both inputs and outputs to processes. Identified RCRA hazardous constituents possibly present in waste streams. Determined chemical reactions occurring during processing. Identified transfer of waste streams to waste management units.

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Assisted in the preparation of a RCRA Part B Permit modification for the Waste System Evaporator in Building 374 at the Rocky Flats Environmental Technology Site. Reviewed engineering drawings, developed process flow diagrams, and wrote sections of the permit modification.

Prepared a Waste Beer Reduction Report for a brewery. Interviewed personnel, reviewed existing data, identified projects and strategies for reducing waste beer generation, calculated VOC emissions, generated a spread sheet, and wrote the final report.

Served as a member of a team assessing the 1993 Operational Readiness Review (ORR) at the Waste Isolation Pilot Plant. Evaluated the performance criteria for the ORR and assessed the adequacy of the facility response to the performance criteria for environmental programs and the RCRA permit application.

Environmental Engineer
August 1986 - March 1990

U.S. Department of Energy
Albuquerque Operations Office
Albuquerque, New Mexico

Provided professional assistance and technical advice to DOE-AL organizations and contractors. Active in nonradioactive hazardous waste and mixed-waste management programs established in support of manufacturing and production technology and national laboratory research activities.

Evaluated DOE treatment, storage, and disposal facilities for compliance with statutes, regulations, and guidelines. Interpreted statutes, regulations, and guidelines to determine applicability to specific situations.

Reviewed and advised on potential impacts from proposed standards, guides, procedures, and regulations in waste management and environmental protection. In particular, provided assistance in determining the impacts of the RCRA Land Disposal Restrictions to mixed wastes at DOE facilities.

Coordinated permit processing in accordance with RCRA. In addition, assisted in the development of RCRA 3008(h) Orders and the response to other compliance orders issued pursuant to RCRA.

EDUCATION

B.S., Chemical Engineering, Rensselaer Polytechnic Institute, 1986

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TRAINING

OSHA 40-Hour Hazardous Waste Health and Safety Training and 8-Hour Refreshers (March 1990, April 1991, and May 1993 Urie Environmental) (May 1992 - Condor Environmental)
Fundamentals of Groundwater and Well Technology, National Water Well Association, 1990
Occupational Environmental Radiation Protection, Harvard School of Public Health, 1988
DOE Environmental Regulations course, Executive Enterprises, November 1989
Nuclear Weapons Orientation, Advanced, U.S. Air Force, June 1987

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DAVID J. LECHEL

Fields of Competence

Project management; peer review; environmental impact analysis; NEPA, CERCLA/SARA, RCRA regulatory expertise; design and implementation of environmental sampling programs; regulatory analysis and permit acquisition; strategic planning; environmental audits.

Experience Summary

Twenty one years of experience in project management and preparation of multidisciplinary environmental studies, regulatory analysis, and monitoring in support of remedial actions and construction activities. Responsibilities have included:

- Design, conduct, management, and report preparation of extensive environmental impact documents of U.S. Department of Energy defense facilities, national laboratories, and radioactive/hazardous waste disposal sites; commercial hazardous/toxic waste sites; and proposed coal mines, power plants, and wastewater treatment facilities.

- Regulatory analysis and strategic planning for compliant disposal of transuranic and mixed transuranic waste and byproduct material at U.S. Department of Energy disposal sites.

- Regulatory analysis, and licensing planning and implementation for closure of U.S. Department of Energy byproduct material disposal sites.

Credentials

M.S., Fisheries Biology -- Michigan State University (1974)
B.S., Fisheries Biology -- Michigan State University (1972)

Employment History

1992-Present	LECHEL, Inc.
1982-1992	Roy F. Weston, Inc.
1978-1982	Wapora, Inc.
1975-1978	Ichthyological Associates
1973-1975	Michigan State University

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Key Projects

Engineered Alternatives Benefit/Detriment Analysis, Waste Isolation Pilot Plant, Carlsbad, New Mexico, Westinghouse Waste Isolation Division, Technical Consultant (1994-Ongoing). Provides assessment and probabilities of occurrence of potential environmental impacts consequent to each engineered alternative. The benefit/detriment analysis focuses on identifying and quantifying relevant aspects of environmental risk that may be posed by the engineered alternatives considered. The overall analysis requires the evaluation of several waste form modifications and alternative configurations for the repository. The benefits and detriments for which each alternative will be assessed include: short- and long-term environmental consequences, ability of the barrier(s) to retard movement of water and radionuclides, risk to workers from the implementation of the barriers, affect on waste retrieval, risk from transportation, uncertainties in resultant compliance analyses, changes in public confidence in the performance of the disposal system, costs, impacts on other waste disposal systems in the DOE complex, and the effects of mitigating the consequences of human initiated processes and events. The results from the above analysis will be coupled with those of the previous engineered alternatives task force and the current Systems Prioritization Methodology for inclusion in compliance demonstrations.

Peer Review, Tank Waste Remediation System Environmental Impact Statement, Richland, Washington, U.S. Department of Energy, Technical Consultant (1994-Ongoing). Provides independent review of project documents in support of preparation of the tank waste remediation system environmental impact statement (TWRS EIS). The proposed action is subject to the National Environmental Policy Act and the Washington State Environmental Policy Act. The DOE and State of Washington propose to manage, retrieve, treat, immobilize, and dispose or store radioactive, chemical, and mixed waste from 177 underground storage tanks and 1,933 cesium and strontium capsules at the Hanford Site. Remediation of single-shell and double-shell tank wastes will be evaluated by four overall alternatives: Tri-Party Agreement Preferred Alternative, Minimal Pretreatment Alternative, Extensive Pretreatment Alternative, and In-place Stabilization and Disposal Alternative. Alternatives for the long-term disposition of the cesium and strontium capsules include Tri-Party Agreement Storage and Disposal, Tri-Party Agreement Vitrification, and Onsite Stabilization and Disposal. The No Action Alternative is also under consideration. To date, peer reviews of the preliminary Implementation Plan and Chapter 4, Affected Environment have been conducted.

National Environmental Policy Act (NEPA) Support, Office of Civilian Radioactive Waste Management, Washington, D.C., U.S. Department of Energy, Technical Consultant (1994-Ongoing). Provided independent review of DOE and contractor prepared position papers to ascertain whether a Programmatic Environmental Impact Statement (PEIS) should be prepared to address the development of the nuclear waste management system. The DOE had announced in early 1994 that it would prepare multiple environmental impact statements (EISs) for its Proposed Program Approach to dispose of high-level waste and commercial spent nuclear fuel at the Yucca Mountain, Nevada site. EISs are to be prepared for the multi-purpose canister, the

Key Projects (continued)

suitability of Yucca Mountain as a repository site, the proposed rail spur, and possibly the monitored retrievable storage facility. The State of Nevada requested that DOE prepare a Programmatic Environmental Impact Statement (PEIS) because: (1) the multiple EISs will evaluate connected actions, which depend upon a larger action; and (2) the Proposed Program Approach represents but one of many alternatives to the development of the nuclear waste management system. Assessed various topical position papers, and reviewed DOE and the Council of Environmental Quality regulations that implement NEPA and other relevant and related NEPA compliance approaches within DOE. Recommended that DOE prepare multiple and generally expansive EISs that: (1) clearly articulate the types and timing of DOE decisions; (2) ensure that the many actions assessed in the early EISs do not limit future alternatives of subsequent EISs; and (3) build upon the previously established NEPA record as new information becomes available.

Technical Support, Idaho National Engineering Laboratory, Idaho Falls, Idaho, U.S. Department of Energy, Technical Consultant (1993-Ongoing). Prepared Summary and Record of Decision for, and provided independent technical review of, DOE's Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Management Programs Environmental Impact Statement (EIS). This two volume EIS evaluates programmatic approaches to management of spent nuclear fuel across the DOE complex, and considers site-specific approaches to the future direction of environmental restoration and waste management programs at INEL. The programmatic EIS evaluated five alternatives to manage existing and projected quantities of spent nuclear fuel, until the year 2035. The analyses focused on impacts to worker safety, public health and the environment, and socioeconomic factors related to transportation, receipt, stabilization and storage of DOE and Naval reactor spent nuclear fuel, as well as special-case commercial fuel. Siting locations for fuel stabilization, and research and development were also assessed. The site-specific EIS addressed five alternatives for management of environmental restoration, waste management, and spent nuclear fuel activities, until the year 2005, at INEL. Potential impacts from facility operations and environmental restoration, including decontamination and decommissioning activities, that would contribute to waste streams and their storage, treatment and disposal were included in the evaluations.

Technical and Management Support, Waste Isolation Pilot Plant, Albuquerque, New Mexico, U.S. Department of Energy, Technical Consultant (1992-Ongoing). Provided broad support including planning for the disposal phase supplement EIS, preparation of the Remote Handled Transuranic Waste Disposal Strategy, management and preparation of the WIPP-specific Regulatory Compliance Strategy and Management Plan, peer review of plans to comply with provisions of the WIPP Land Withdrawal Act, and technical peer review of elements of the WIPP regulatory compliance and experimental programs. Authored internal planning recommendations for the scope of the next supplemental EIS, including technical and regulatory content, schedule, and cost reduction. Provided peer review of DOE's Compliance Status

Key Projects (continued)

Report and Project Technical Baseline, and EPA's working draft implementing criteria at 40 CFR 194. Managed the preparation of the Regulatory Compliance Strategy and Management Plan which provided the strategy by which WIPP Program elements are integrated to comply with selected regulations including 40 CFR 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Fuel, High-Level and Transuranic Radioactive Wastes, and RCRA including 40 CFR 264 Subparts G and X and 268 Subparts C and D. Peer-reviewed plans and documents resulting from provisions of the Land Withdrawal Act including the transportation assessment, and the test phase and waste retrieval plans. Provided independent technical review of performance assessment reports for compliance with 40 CFR 191, technical and regulatory reports prepared by Sandia National Laboratories, and other test plans and management plans for radioactive waste tests.

Technical Peer Review Support, Waste Isolation Pilot Plant, Albuquerque, New Mexico, U.S. Department of Energy, Project Manager (1992). Provided technical and regulatory peer review of a variety of test plans, policy and issues papers, decision plans, and technical and regulatory reports. Managed the preparation of a Regulatory Criteria Document that will form the basis of DOE's demonstrations of compliance with 40 CFR 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Fuel, High-Level and Transuranic Radioactive Wastes and RCRA including 40 CFR 264 Subparts G and X and 268 Subparts C and D.

EIS/EIR for Continued Operations of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore, Livermore, California, Lawrence Livermore National Laboratory, Project Manager (1991-1992). Managed the preparation of a combined environmental impact statement (EIS) and an environmental impact report (EIR) for the continued operations of the two national laboratories for the U.S. Department of Energy (DOE). The EIS complies with NEPA and the EIR complies with the comparable California law, CEQA. The EIS/EIR examined the current and future (5 to 10 years) operations of the laboratories. Emphasis was placed on waste generation and types, radionuclide/chemical/high explosive inventories, work force growth, occupational and public exposures to routine emissions of radionuclides and chemicals as well as potential exposures during various hypothetical accidents including seismic events. Other elements evaluated included environmental restoration activities, regulatory compliance, socioeconomics, land use, traffic and transportation. As part of this project, multiple libraries and reading rooms were established and maintained and an extensive community relations plan was implemented.

Supplemental EIS, Waste Isolation Pilot Plant, Albuquerque, New Mexico, U.S. DOE, Project Manager (1989-1990). Managed the preparation of the technical and regulatory aspects of a supplement to the EIS for the Waste Isolation Pilot Plant (WIPP). The WIPP is planned as the nation's first repository for disposal of defense-related transuranic waste. The supplement was prepared to report new geologic and hydrologic data (e.g., brine inflow, flow paths, and

Key Projects (continued)

velocity), changes in the waste inventory from ten DOE facilities nationwide, the consideration of hazardous chemical constituents, and changes in the routes and modes of transportation of waste. Responsibilities included the technical management and oversight of eight contractor organizations, preparation of the draft supplement, and response to nearly 20,000 comments in the final supplement.

Technical Support, Waste Isolation Pilot Plant, Albuquerque, New Mexico, U.S. Department of Energy, Project Manager (1990-1991). Provided broad-based technical, policy and regulatory compliance support to the WIPP. Required the development of various position papers regarding the proposed test phase, transuranic waste characterization, and bin-scale tests. Also involved analysis of cost schedule controls and performance monitoring tools, contractor integration, and recommendations for the continued compliance with various DOE orders and regulations.

Uranium Mill Tailings Remedial Action (UMTRA) Project, Albuquerque, New Mexico, Department of Energy (DOE), Manager, Environmental Services (1982-1987). Project Manager (1988-1989). Managed the UMTRA Project to ensure compliance with NEPA, other Federal, state, and local environmental regulations and Nuclear Regulatory Commission (NRC) licensing requirements. Managed a staff to produce EISs and Environmental Assessments (EAs). Prepared Findings of No Significant Impact (FONSI) and Records of Decision, as well as all necessary *Federal Register* notices such as notices of wetlands involvement, public hearings, and related documents. Lead the efforts and was responsible for identification of Federal, state, and local permits and approvals necessary for cleanup of radioactive mill wastes, as well as other ancillary NEPA compliance issues. Managed the preparation of DOE's guidance document for post-remedial action surveillance and maintenance. Also prepared site-specific surveillance and maintenance plans for several UMTRA Project sites, and implemented these activities at four sites. From 1988 through 1989, was Project Manager in support of DOE's UMTRA Project. Provided administrative oversight for technical issues, cost and schedule of remedial design, regulatory compliance, NEPA documentation, quality assurance and other aspects in support of remediation of 24 uranium mill tailings sites in 10 states and 2 tribal reservations.

Environmental Review, Los Angeles, California, Pacific Enterprises, Project Manager (1989). Prepared oral and written testimony for environmental aspects of proposed gas transmission lines. Three pipeline companies proposed the construction of gas pipelines from Wyoming to southern California, and Texas to southern California. Reviewed the environmental aspects of the proposal and prepared oral and written testimony. Testimony focused on cultural resources, flora and fauna, and cumulative impacts.

Environmental Audit, Pantex Plant, Amarillo, Texas, U.S. DOE, Environmental Scientist (1987). Served as member of an audit team at the DOE Pantex Plant. Audit was conducted under the guidance of the Los Alamos National Laboratory (LANL) Environmental Audit Plan

Key Projects (continued)

and the DOE headquarters survey team. Plant was surveyed using 15 different checklists in the major waste areas of radiological mixed wastes, organics, inorganics, asbestos, and polychlorinated biphenyl (PCB). Prepared the report for submittal to DOE and LANL.

Regulatory Analysis, Bear Creek Remedial Project, Oak Ridge, Tennessee, U.S. DOE, Environmental Scientist (1987). Project Scientist associated with a comparative review of the technical requirements of Resource Conservation and Recovery Act (RCRA), NEPA, and CERCLA for the Bear Creek Remedial Action Project. This effort involved a detailed listing of all discipline requirements integral to the remedial investigation/feasibility study (RI/FS) process. A document was prepared for DOE Oak Ridge Operations to serve as the basis for the implementation plan of the Bear Creek remedial program.

Public Health Evaluation, Grand Junction Facility, U.S. DOE, Grand Junction, CO., Project Manager (1986). Managed the preparation of a public health evaluation at DOE's Grand Junction Area office. Required identification of contaminants, pathways of concern, and assessment of effects with major emphasis on arsenic, barium, selenium, and PCBs.

Environmental Assessment and Design Services, SFMP Monticello Site, U.S. DOE, Project Manager (1985-1986). Lead the preparation of an EA and engineering consulting services for DOE's SFMP Monticello site. In addition to preparing the EA for remedial actions, the radon barrier and erosion protection were designed for the stabilized site. A public health evaluation was conducted. Required contaminant identification and migration pathways analysis with focus on arsenic, thorium, and uranium.

Environmental Assessment of Remedial Action at Bruin Lagoon, Philadelphia, Pennsylvania, EPA, Environmental Scientist (1982). Principal Investigator of an EA of cleanup actions at the Bruin Lagoon abandoned hazardous waste site in western Pennsylvania. Compilation and analysis of environmental and other factors led to a finding of no significant impact.

Environmental Review, Fourth Nuclear Power Plant, Taiwan, Washington, D.C., U.S. State Department, Project Manager (1980). Managed and prepared a concise environmental review of the proposed Fourth Nuclear Power Plant, Taiwan. Analyses indicated that initial plant design required additional modifications to prevent site flooding during the monsoon season. Except for an unavoidably high population density, all design features were within NRC standards and IAEA requirements.

Entrainment and Impingement Studies at Various Power Plants, Consumers Power Co., Jackson, Michigan, Detroit Edison, Detroit, Michigan, Project Manager (1979). Project Manager of 316(b) demonstrations for power plants on Western Lake Erie, the Detroit River, and the St. Clair River. The 316(b) demonstrations for the Lake Erie and St. Clair River plants

Key Projects (continued)

were the second required at the plants by the Michigan DNR because of incorrect initial assessments. All of the second demonstrations were promptly accepted by the DNR and EPA Region V.

Site Assessment, PCB Contamination, Philadelphia, Pennsylvania, SEPTA, Project Manager (1980). Project Director of a site assessment of railroad car shops contaminated with PCBs. Historical "housekeeping" practices and vertical/horizontal migrations of PCBs on and offsite were examined.

Areawide EA for New Source Coal Mines, Philadelphia, Pennsylvania, EPA, Peer Reviewer (1981). Technical administrator of area-wide assessments of new source coal mining in West Virginia and Kentucky. Extensive compilation and assessment of West Virginia and Kentucky human resources (socioeconomics, land use), natural resources (aquatic and terrestrial biota), and earth resources (coal, soils) information in support of NPDES permitting requirements.

EIS, New Source Coal Mine, Philadelphia, Pennsylvania, EPA, Project Manager (1981-1982). EIS of a new source coal mine in West Virginia. Factors of significance included the potential for the production of acid mine drainage and subsequent adverse impacts on sensitive receiving streams and the positive benefits derived from enhanced employment and induced socioeconomic effects.

Effluent Control Practices, Philadelphia, Pennsylvania, EPA, Peer Reviewer (1981). Project Director of an assessment of effluent control practices in the hard rock mining industry. Heavy metal effluent, acid mine drainage, and sediment control techniques were examined at 10 mines in the west and south. Developed a conceptual approach for further effluent abatement at one mine site in the arid southwest.

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John N. McFee

Professional Qualifications

Mr. McFee is a Registered Professional Engineer with 28 years of experience in chemical syntheses, energy recovery, waste management process design research and development, regulatory permitting, and characterization of hazardous and radioactive wastes. His technical expertise includes DOE waste treatment activities and technologies; design of incineration systems for hazardous and radioactive wastes; and developing systems for mixed waste processing. As Director of Engineering and Assessment of the IT-Albuquerque office, he supervises a staff of more than 40 environmental scientists and engineers with technical specialties in fate and transport modeling, mixed waste treatment technologies, and risk assessment. Mr. McFee is a member of IT's Technical Associate program.

Education

Nuclear Power Engineering School, Idaho National Engineering Laboratory; Idaho Falls, Idaho; 1974

B.S., Chemical Engineering, Clarkson College of Technology, Potsdam, New York; 1965

Registrations/Certifications

DOE Q Clearance, Active
Registered Professional Engineer, Idaho

Experience and Background

1988–Present ***Manager, Engineering and Assessment, IT, Albuquerque, New Mexico.*** Provides overall technical direction to IT's Albuquerque sections in remedial engineering, waste management engineering, risk assessment, and pathways modeling.

- Senior technical leader, titled Technical Area Leader for waste destruction and stabilization, supporting the DOE Office of Technology Development Mixed Waste Integrated Program. Responsibilities include review of DOE waste destruction research initiatives, technical oversight of waste destruction development programs, and consultation on DOE innovative waste treatment activities.

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- Project Manager for the identification and characterization of technology improvements to the Waste Isolation Pilot Plant (WIPP). Participated in the WIPP Engineered Alternatives Task Force (EATF) project which was formed to identify and evaluate alternatives to the WIPP repository design and/or waste forms to enhance compliance with long-term performance standards (EPA 40 CFR 191). Assisted in developing an alternatives analysis technique to reduce the large number of possible alternatives to a manageable number of feasible alternatives. The preliminary screening was accomplished using an ordered decision logic system

which quantified the decision criteria. Recommendations were developed for the number of treatment facilities and preferred locations.

- Participated in the DOE Mixed Waste Working Group as a WIPP representative. The Working Group assembled waste generation data and reviewed regulatory alternatives for compliance with the EPA's Land Disposal Restrictions. These efforts resulted in a two-year variance for radioactive mixed waste compliance.

- Member of the Technical Resource Team, supporting the DOE Mixed Waste Focus Area. Responsible for providing DOE with information and expert opinion on innovative and conventional technology application to treatment of mixed waste streams. Specific areas of expertise are thermal and nonthermal waste destruction technologies.

- Project Manager for a study of remediation technologies for removing soil contaminated with radioactive and mixed waste at the 100 Area of the DOE Hanford site. The study involved "macroengineering" technologies to determine available large-scale equipment remediation alternatives Developed a screening technique to reduce the large number of alternatives to a single feasible recommendation.

- Provided senior technical guidance and review of DOE site treatment plans for Nevada Test Site, Los Alamos National Laboratory, Sandia National Laboratories, Pantex Plant, and the Weldon Spring site.

- Senior technical contributor and project manager for a conceptual design study of alternatives addressing retrieval and processing of buried radioactive waste at the DOE's Idaho National Engineering Laboratory (INEL). Conceptual designs, cost estimates, and technology status information were developed on three incineration alternatives for waste processing.

- Project Manager for IT's contribution to the EG&G Idaho System Design Study. Numerous process flow schemes were developed to address the problem of retrieving and processing buried waste at the Idaho National Engineering Laboratory (INEL). Conceptual designs and cost estimates were prepared for the most promising schemes. Information prepared by IT staff included functional and operational requirements documents, mass balance diagrams, layout drawings, an assessment of the research necessary for successful application of the concept, and a system cost estimate.

- Participant in the DOE-Headquarters T/S/D Workshop considering treatment/storage/disposal capabilities in the overall DOE system. This expert panel was created to develop a waste generation/waste treatment data base for all DOE facilities. Mr. McFee is a contributor in the specialties of transuranic waste and waste treatment.

- Project Manager for the RCRA waste stream characterization project of all Los Alamos National Laboratory facilities and On-Site Surveyor for a TA-55, the CMR Building, and the Sigma Complex where special nuclear materials are processed. The information is being used to document the Laboratory's waste generation activities pursuant to the requirements of the Laboratory's hazardous waste operating permit, to design wastewater treatment systems, and in NPDES permit applications. In several instances, recommendations were made for solvent substitution or waste segregation to minimize mixed waste generation.

- Project Manager of the EG&G Idaho master subcontract for hazardous waste management support at INEL.

- Supervised development of an information base of the existing waste treatment technologies currently in use in DOE facilities in support of DOE's application for regulatory relief from EPA's waste treatment requirements for mixed wastes subject to the Land Disposal Restrictions.

1985–1988 ***Senior Program Specialist, EG&G Idaho, Inc., Idaho Falls, Idaho.*** Mr. McFee's three years of experience with EG&G Idaho provided a broad background and understanding of INEL's waste management system. Specific activities included:

- Managed the RCRA Trial Burn for the INEL's low level waste incinerator. This included responsibilities for development of the waste characterization, evaluation of the trial burn plan strategies, preparation of the trial burn plan documentation, negotiation with EPA Region X for trial burn plan acceptance, subcontracting the sampling and analysis firm, and management of the trial burn. The trial burn was successful in two of the three selected test burns. U.S. DOE management presented a citation for excellent performance in the trial burn.

- Developed the design and cost estimate for a mixed waste liquid feed system for the WERF controlled air incinerator. Supervised development and execution of the RCRA trial burn plan and participated in meetings with EPA Region X on the permit application. Provided the bases and calculational methodology for the environmental assessment and safety analysis of the incinerator in the modified configuration.

- At the PREPP rotary kiln incinerator for retrieved TRU waste, responsibilities included preparing start-up test plans to evaluate the incinerator and off-gas system performance, and then serving as the test engineer to supervise the tests. After data were reduced, recommendations were made for system modifications which would enhance performance and operations.

- Principal technical representative in the development of the RCRA trial burn and state compliance test for PREPP. Served as the lead technical representative in discussions of the permit application with EPA Region X.

- Supervised the process design and cost study of alternatives for disposal of spent scrub solution from the PREPP incinerator off-gas clean-up system.

- Reviewed the Title I and Title II design package for an enriched uranium incinerator scheduled for installation at a DOE facility.

1984–1985 ***Director, Engineering and Technology, Waste-Tech Services, Inc., Idaho Falls, Idaho.*** As a Director of this Energy Incorporated spin-off company, responsibilities included the design and development of mobile fluidized bed hazardous waste incineration systems to be provided by this new company. The major tasks included supervising the design effort and preparing test plans and EPA permit applications.

- Directed the initial design efforts for a packaged hazardous waste incinerator system for destruction of chlorinated materials using a fluidized bed incinerator.

- Developed numerous designs for fluidized bed destruction systems addressing client waste problems including waste films, chemical process wastes, animal wastes, and contaminated soils. Most designs were based on pilot plant tests carried out to develop the design data.

- Directed a test program to demonstrate chlorinated organic compound destruction in a fluidized bed pilot plant. The destruction efficiencies were in compliance with RCRA standards, but at temperatures less than normally used for incineration of these compounds.

- Designed, developed, and demonstrated a prototype radioactive waste volume reduction system for nuclear power plant applications. The system was based on use of a single fluidized bed for calcining aqueous wastes and the incineration of combustible materials.

1975–1984 ***Group Manager, Fluidized Bed Applications, Energy Incorporated, Idaho Falls, Idaho.*** Directed the Energy Incorporated fluidized bed development laboratory. Specific activities included:

- Directed the company's development program on hazardous waste incineration. The program was concluded successfully having demonstrated fluidized bed capabilities in meeting EPA requirements for destruction efficiency and provided design parameters for commercial systems. Following successful development, an extensive marketing program was carried out in conjunction with the corporate marketing division.

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- Developed test plans and directed numerous fluidized bed pilot plant tests to demonstrate energy recovery from various materials including: rubber tires, anthracite culm, waste hydrocarbon films, and production plant wastes.

- As Project Engineer and, subsequently, as Program Manager on the development program for the RWR-1, a commercial radioactive waste fluidized bed volume reduction system, a concept was designed, tested, and ultimately licensed by the NRC. Engineering responsibilities included: developing the concept, designing the prototype to meet regulatory and market needs, supervising the test program to develop design data, preparing the Licensing Topical Report with the appropriate safety assessment, and designing the deliverable system.

- As Senior Chemical Engineer, performed numerous process design tasks and incineration tests on fluidized bed programs.

1974–1975 ***Engineer, Westinghouse Electric Corporation, Idaho National Engineering Laboratory, Idaho Falls, Idaho.*** Graduated from a six-month, full-time Nuclear Power Engineering School for Naval Nuclear Power.

1973–1974 ***Engineer, Westinghouse Electric Corporation, Bettis Atomic Power Laboratory, West Mifflin, Pennsylvania.*** Participated in the hydraulic analysis and design of a Naval Nuclear Core.

1966–1972 ***Engineer, Hooker Chemical Corporation, Niagara Falls, New York.*** Process engineer in development, design, and startup at chemical production facilities.

Patents Granted

"Method of Recovering Hazardous Waste from the Phenolic Resin Filters," D. H. M. Krantz, G. L. Bourne, J. N. McFee, B. G. Burdge, J. W. McConnell, U.S. Patent No. 4,995,916.

Professional Acknowledgments

Invited Instructor for the 1988 and 1989 Incineration Conference Basics Short Course
Director 1990 through 1994. Incineration Conference Basics Short Course
Invited Instructor for the 1989 and 1990 ASME Radioactive Waste Management Course

Professional Affiliations

American Institute of Chemical Engineers M

Publications

McFee, J. N., W. E. Schwinkendorf, and P. W. Hart, 1995, "Evaluation of Alternatives to Incineration for DOE Mixed Waste," Waste Management '95, *Proceedings of the Symposium on Waste Management*, Tucson, Arizona.

McFee, J. N., and J. Berry, 1995, "Mixed Waste Integrated Program: Waste Destruction/Stabilization Technical Area Program Highlights," Waste Management '95, *Proceedings of the Symposium on Waste Management*, Tucson, Arizona.

McFee, J. N., P. W. Hart, D. J. Kuchynka, and W. E. Schwinkendorf, 1994, "Innovative Low-Temperature Waste Destruction Processes for U.S. Department of Energy Mixed Waste Treatment," *Emerging Technologies in Hazardous Waste Management VI*, Vol. I, D. William Tedder, American Chemical Society, Atlanta, Georgia.

McFee, J. N., and L. G. Gale, 1988, "Testing of the PREPP Rotary Kiln for Waste Incineration," *Proceedings of International Conference on Incineration of Hazardous, Radioactive, and Mixed Wastes: 1987*, San Francisco, California.

McFee, J. N., H. Bohrer, and D. Dalton, 1987, "Status Report on the INEL RCRA Permit for Incineration of Hazardous Waste," *Proceedings of Incineration of Low-Level and Mixed Waste*, St. Charles, Illinois.

Steverson, E. M., and J. N. McFee, 1987, "The Incineration of Absorbed Liquid Wastes in the INEL's WERF Incinerator," *Waste Management '95, Proceedings of the Symposium on Waste Management*, Tucson, Arizona.

McFee, J. N., and R. L. Gillins, 1986, "Low-Level Radioactive Waste Incineration at the Idaho National Engineering Laboratory During 1986," *Waste Management '86, Proceedings of the Symposium on Waste Management*, Tucson, Arizona.

Steverson, E. M., D. P. Clark, and J. N. McFee, 1986, "Addition of Liquid Waste Incineration Capability to the INEL's Low-Level Waste Incinerator," *Waste Management '86, Proceedings of the Symposium on Waste Management*, Tucson, Arizona.

McFee, J. N., G. P. Rasmussen, and C. M. Young, 1985, "The Design and Demonstration of a Fluidized Bed for the Destruction of Hazardous Organic Materials in Soils," *Journal of Hazardous Waste*.

Rasmussen, G. P., and J. N. McFee, 1983, "Fluidized Bed Incineration Systems for the Ultimate Disposal of Toxic and Hazardous Materials," *Proceedings of the First Hazardous Materials Management Conference*, Philadelphia, Pennsylvania.

Rasmussen, G. P., and J. N. McFee, 1982, "Fluidized Bed Systems for Steam Generation from Scrap Tires," *Proceedings of the Seventh International Fluidized Bed Conference*, Philadelphia, Pennsylvania.

Vance, R. F., J. N. McFee, and J. W. McConnell, 1980, "Volume Reduction of Radioactive Waste Resulting from Decontamination of Surplus Facilities,"

Decontamination and Decommissioning of Nuclear Facilities, Marilyn M. Osterhout, ed., Plenum Press, New York.

M

Jonathan Myers

Professional Qualifications

Dr. Myers holds a Ph.D. in Geochemistry and has twelve years of professional experience. His specialty involves the application of computer modeling techniques for designing waste isolation systems; predicting interactions between contaminants, soil, rock, and groundwater; and predicting the fate of hazardous, transuranic (TRU), low-level (LLW), mixed, and high-level radioactive substances released into the environment. He has been actively involved in waste characterization, site characterization, and long-term performance modeling for several nuclear waste disposal projects including the Waste Isolation Pilot Plant (WIPP), the Yucca Mountain Project (YMP), the Basalt Waste Isolation Project (BWIP), the Salt Repository Project, and the Swedish and Canadian high-level nuclear waste disposal programs. He has provided extensive support to the WIPP project for over eight years. He has also been active in LLW performance assessment projects including an assessment of treatment and disposal option for mixed LLW at the INEL, and an assessment of the effectiveness of engineered barriers for isolating commercial LLW.

He has also been active in applying computer modeling techniques for developing contaminant source terms and sorption coefficients for several mixed LLW operable units as part of the Fernald, INEL, Nevada Test Site, and Los Alamos Environmental Restoration Programs. For these projects he has developed novel computer simulation techniques to predict the limits on contaminant concentrations in leachate that may migrate from the operable units.

Other related activities include the development and use of a cement degradation model to predict the long-term performance of various cement formulations proposed for use as engineered barriers in the Yucca Mountain and Swedish high-level nuclear waste disposal programs.

Dr. Myers has also pioneered the use of computer simulation techniques to design and evaluate waste treatment processes. He has used these techniques to predict the performance of proposed air stripper systems at Mather Air Force Base, optimized the design of a lime treatment system for heavy metal waste streams, and predicted the mass and composition of sludge resulting from heavy metal and radionuclide precipitation processes.

Dr. Myers is a member of IT's Senior Technical Associate program and has published over thirty technical papers in his field of expertise. He has made many presentations to the National Academy of Sciences, the most recent being "Recommendations of the Engineered Alternatives Task Force on Improving the Long-Term Performance of WIPP." He is currently manager of the IT-Albuquerque Hydrologic and Geochemical Assessment Group with technical oversight, cost and schedule, and technical staff supervision responsibilities.

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Education

Ph.D., Geochemistry, University of Wyoming, Laramie, Wyoming; 1982
M.S., Geology, University of Wyoming, Laramie, Wyoming; 1978
B.S., Geology, City University of New York, New York, New York; 1974

Experience and Background

1991-Present

Manager, Hydrologic and Geochemical Assessment Group, International Technology Corporation (IT), Albuquerque, New Mexico. Dr. Myers manages a group of eight scientists and engineers who specialize in geochemistry, hydrology, and contaminant flow and transport. The group serves as a technical resource for clients and the company by performing computer simulations in support of site characterization, remedial investigations, feasibility and treatability studies, disposal system designs, risk assessments, and long-term performance predictions. The group has considerable experience in performing groundwater flow and contaminant transport modeling, calculation of radionuclide and heavy metal source terms, and estimation of adsorption coefficients for contaminants. His specific responsibilities have included:

- Contributing author of the WIPP Test Phase Plan. This work included the development of a methodology to address RCRA concerns for the mixed TRU waste inventory, and a definition of the testing required to provide the data necessary to evaluate compliance with the No-Migration provisions of RCRA.

- Project manager for a 1.1 million dollar contract to provide geotechnical support for the WIPP project. Tasks have included conducting computer simulations of creep closure to evaluate alternative repository configurations for extending the useful life of storage rooms and increasing the safety of underground operations.

- Project manager and technical director for a LLW performance assessment investigation for EG&G-Idaho in which the long-term performance of six waste forms proposed for the treatment of retrievably-stored mixed LLW at the INEL, and three sites proposed for disposal were evaluated. A total of thirty simulations were performed, each of which calculated a maximum annual effective dose equivalent for both undisturbed long-term performance and inadvertent human intruder scenarios. Work included the development of conceptual models, selection of numerical codes, defining site and wasteform properties, performing simulations, and interpreting results.

- Project manager and technical director for a commercial LLW performance assessment investigation for the DOE National Low-Level Waste Management Program. The work involved assessing the benefits of engineered barriers in improving the long-term performance of commercial LLW disposal facilities. Various facility designs incorporating combinations of barriers such as concrete overpacks, concrete vaults, sloped soil covers, sorptive backfill, and sorptive underlying layers were defined. Designs were evaluated by calculating a long-term dose reduction factor for each facility

design relative to a reference facility design that did not incorporate engineered barriers.

- Technical director for a project to develop and use numerical models to assess the long-term performance of various mixed low-level radioactive waste (LLW) waste forms and disposal sites with respect to the performance requirements of DOE Order 5820.2A and 10 CFR 61 in support of the DOE-Headquarters Mixed LLW Management Program. Work involved the development of conceptual models, selection and modification of source-term, flow, transport, and dose assessment modules, linkage of modules, verification, benchmarking, and performing simulations.

- Proposed and evaluated options for the pump-and-treat remediation of groundwater contaminated with hexavalent chromium at sites in West Texas and Northern California. The evaluations utilized computer modeling techniques to quantify the effects of redox and pH adjustment on chromium precipitation and effluent composition. Recommendations resulting from the simulations were successfully implemented.

- Performed simulations of the deep injection well disposal of hazardous waste to predict the mobility of hazardous constituents at a site in West Texas. Analyses included the mixing of waste fluid and formation fluid at elevated temperatures in the presence of host rock mineralogy.

- Developed americium and plutonium source-terms for use in a risk assessment at a disposal pit at INEL. Source-terms were developed by performing waste/groundwater interaction simulations.

- Contributing author of several work plans developed for the Nevada Test Site ER program. This work included defining analytical parameters and detection limits for deep groundwater samples to support groundwater flow, contaminant transport, and risk assessment studies.

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- Performed computer simulations of waste/groundwater interactions to calculate radionuclide and heavy metal leachate compositions at the central Los Alamos radioactive waste disposal facility for use in risk assessments.

- Performed simulations of the interactions that will occur at elevated temperatures between groundwater and several cement formulations proposed for seal materials at Yucca Mountain. The simulations provided estimates of the long-term seal performance.

- Used computer simulation techniques to optimize the design of a lime treatment system for the removal of radionuclides and heavy metals from

aqueous waste streams. The simulations provided very cost-effective analyses of proposed designs.

- Evaluated the potential for mineral precipitation to reduce the effectiveness of air stripper systems proposed for use at Mather Air Force Base to remove VOCs from groundwater.

- Performed computer simulations to determine the factors affecting the pH of power plant fly-ash at a commercial generation facility in Northern California. Results of analyses are being used to control process parameters to avoid the generation of hazardous by-products.

1985 - 1991 ***Section Manager, Geochemical Analysis, International Technology Corporation, Albuquerque, New Mexico.*** Dr. Myers managed technical staff involved in projects for the Geochemical Analysis specialty in Albuquerque. His specific responsibilities have included:

- In support of the WIPP Engineered Alternatives Task Force (EATF), which was created by the DOE to identify and evaluate alternatives that could enhance the WIPP facility's compliance with long-term performance standards (EPA 40 CFR 191), Dr. Myers directed the development and use of a Design Analysis Model to predict the relative improvements that could be realized from both alternative repository designs and waste forms. The model predicts the 10,000-year cumulative releases of each radionuclide while considering the coupled interactions between brine inflow, creep closure, and gas generation.

- Chaired an expert panel for the WIPP EATF to evaluate potential applications of cementitious materials as waste forms, backfill, and container materials to immobilize TRU waste.

- Evaluated the long-term performance of the WIPP in terms of EPA 40 CFR 191 and the RCRA no-migration requirements contained in 40 CFR 268.6. Analyses included the effects of processing waste forms on migration rates of radioactive and RCRA-listed contaminants.

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- Served as contributing author to the "Draft Final Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment," a five-year plan which defines all of the waste characterization, site characterization, and computer modeling activities necessary to evaluate compliance with EPA regulations (RCRA and 40 CFR 191).

- Served as principal author of the "Panel One Test Plan for the Waste Isolation Pilot Plant" which outlined the procedures for conducting

underground tests for measuring gas generation rates using actual waste in the WIPP repository.

- Provided input to the WIPP No-Migration Variance Petition under 40 CFR 268.6 by developing contaminant source terms for modeling releases of RCRA-listed hazardous components from the WIPP disposal system.

- For the WIPP Brine Sampling and Evaluation Program, performed geochemical characterization of the repository environment, including brine chemistry and brine/rock interactions, and a geochemical characterization of potential sources of intruding water, including Castile and Salado brines. This information was subsequently used to develop source terms for performance assessment activities in support of 40 CFR 191.

- Developed the Water Quality Sampling Plan for the WIPP site which involved the repeated sampling and analysis of groundwater from approximately 20 wells in the vicinity of the repository to determine groundwater characteristics. Data from the program were subsequently used to predict radionuclide migration rates through the overlying aquifers.

- Served as Project Manager during 1985 and 1986 for integrating hydrological and geochemical modeling tasks with the overall WIPP performance assessment program to determine regulatory compliance for the WIPP site. Activities included developing conceptual models and computer codes so that coupled processes could be realistically simulated. Conducted code verification and validation to ensure integrity of the results.

- Developed and used innovative geochemical modeling techniques to optimize the removal of uranium from contaminated groundwater by pH adjustment and anion exchange processes in support of the Fernald CERCLA feasibility study.

- Developed modeling techniques to estimate uranium, thorium, and heavy metal solubilities and sorption coefficients to provide input into the fate and transport modeling for CERCLA RI/FS at the Fernald site.

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- For the Yucca Mountain Project and the Swedish repository high-level nuclear waste programs, modeled the long-term performance of cementitious seals using the EQ3/EQ6 computer code.

- For the YMP, analyzed geochemical interactions between cementitious seal materials and groundwater to evaluate the longevity of shaft sealing components. The results of these studies were subsequently published and

presented at Waste Management '89 and the Sixth International Water/Rock Interactions Conference.

- Served as contributing author to the "Field Sampling and Laboratory Procedure Plan for the Fernald Geochemical Program" which defined the number, location, and types of analyses to be performed on soil, rock, and groundwater samples at the Fernald site.

1982 - 1985 ***Senior Geochemist, Basalt Waste Isolation Project, Rockwell International, Richland, Washington.*** While at Rockwell International, Dr. Myers was involved in the following activities in the field of high-level nuclear waste management and disposal:

- Served as Principal Technical Director for a large experimental test program designed to determine the interactions which occur between actual high-level nuclear waste, barrier materials, host rock, and groundwater at elevated temperatures and pressures. Duties included providing technical guidance for long-term experiments performed in a radiation environment.

- Evaluated the performance of the Basalt Waste Isolation Project repository design in terms of the regulatory requirements as defined in NRC 10 CFR 60 and EPA 40 CFR 191 governing the long-term performance of a high-level nuclear waste repository. Specific analyses included interactions between radionuclides, groundwater, and rock to predict contaminant migration rates.

- Directed a project to develop Eh and pH sensor systems which will operate at temperatures up to 300°C and pressures up to 300 Atmospheres.

- Planned and conducted an experimental test program to determine the effects of alpha and gamma radiation on water/rock interactions.

- Responsible for negotiating technical statements of work and contract terms on several subcontracts placed with organizations including Westinghouse, Battelle, University of Colorado, Arizona State University, and Temple University.

Professional Affiliations

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American Geophysical Union
Geochemical Society
International Association of Geochemistry and Cosmochemistry
Mineralogical Society of America
American Institute of Physics

Publications

Smith, T. H., J. Myers, S. M. Djordjevic, T. A. DeBiase, M. T. Goodrich, D. DeWitt, 1994, "Preliminary Parametric Performance Assessment of Potential Final Waste Forms for Alpha Low-Level Waste at the Idaho National Engineering Laboratory," EGG-WM-11415, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho.

Myers, J., S. M. Djordjevic, T. A. DeBiase, M. T. Goodrich, 1994, "Use of Engineered Soils and Other Site Modifications for Low-Level Radioactive Waste Disposal," DOE/LLW-207, National Low-Level Waste Management Program, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

Deal, D. E., R. J. Abitz, J. Myers, D. S. Belski, M. L. Martin, D. J. Milligan, R. W. Sobocinski, and P. P. James Lipponer, 1993, "Brine Sampling and Evaluation Program, 1991 Report," report prepared for the U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico, by IT Corporation, Albuquerque, New Mexico.

Gardiner, M. A. and J. Myers, 1992, "Geochemical Modeling of the Deep Injection Well Disposal of Acid Wastes into a Permian Aquifer/Aquitard System in Texas, USA, 1992," *Proceedings of the 7th International Symposium on Water-Rock Interactions*, Y. K. Kharaka and A. S. Maest, eds., Balkema, Rotterdam.

Myers, J., and R. W. Sobocinski, 1992, "Computer Simulation of the Chemical Treatment of a Heavy-Metal Contaminated Groundwater Using Geochemical Modeling Techniques," *Waste Management '92, Proceedings of the Symposium on Waste Management.*

Gardiner, M. A., T. E. Hinkebein, and J. Myers, 1991, "Modeling Geochemical Stability of Cement Formulations for use as Shaft Liner and Sealing Components at Yucca Mountain," Materials Research Society Symposium Proceeding, Vol. 212.

Krumhansl, J. L., T. E. Hinkebein, and J. Myers, 1992, "The Hydrothermal Stability of Cement Sealing materials in the Potential Yucca Mountain High Level Nuclear Waste Repository," *Advanced Cementitious Systems: Mechanisms and Properties*, Materials Research Society Symposium Proceedings, Vol. 245, Boston, Massachusetts, November 1991.

Sobocinski, R. W., and J. Myers, 1991 in press, "Evaluation of a Contaminant Pathway and Mobility at a U.S. DOE Site Using Groundwater Chemical Data," *Environmental Remediation '91, Proceedings of the Conference on Environmental Restoration.*

Myers, J., P. Drez, and P. James, 1991, "The Redox State of the Culebra Member of the Rustler Formation," in "Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico," *SAND88-0196*, M. D. Siegel, S. J. Lambert, and K. L. Robinson, eds., Sandia National Laboratories, Albuquerque, New Mexico.

Siegel, M. D., K. L. Robinson, J. Myers, 1991, "Solute Relationships in Groundwaters from the Culebra Dolomite and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico," in "Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico," *SAND88-0196*, M. D. Siegel, S. J. Lambert, and K. L. Robinson, eds., Sandia National Laboratories, Albuquerque, New Mexico.

Myers, J., S. Djordjevic, M. Adams, R. Spangler, J. Valdez, D. Vetter, and P. Drez, 1991, "Design Analysis of Engineered Alternatives for the Waste Isolation Pilot Plant", *Waste Management '91, Proceedings of the Symposium on Waste Management.*

Abitz, R., J. Myers, P. Drez, and D. Deal, 1990, "Geochemistry of Salado Formation Brines Recovered From the Waste Isolation Pilot Plant Repository," in *Waste Management '90, Proceedings of the Symposium on Waste Management.*

Ulmer, G. C., D. E. Grandstaff, and J. Myers, 1990, "A New Hydrothermal Technique for Redox Sensing Using Buffer Capsules," *Fluid-Mineral Interactions: A Tribute to H. P. Eugster*, R. J. Spencer and I-Ming Chou, eds., The Geochemical Society, Special Publication No. 2.

Alcorn, S. R., J. Myers, M. A. Gardiner, and C. A. Givens, 1989, "Chemical Modeling of Cementitious Grout Materials Alteration in HLW Repositories," in *Waste Management '89, Proceedings of the Symposium on Waste Management*, Tucson, Arizona, February 26–March 3.

M

Gardiner, M. A., S. R. Alcorn, J. Myers, and C. A. Givens, 1989, "Modeling Simple Cement-Water Systems Using the Speciation/Solubility/Reaction Path Computer Codes EQ3NR/EQ6, With Specific Application to Nuclear Waste Repositories," *Proceedings of the Sixth International Water-Rock Interaction Conference*, Grand Malvern, England, August, pp. 235–238.

Deal, D. E., J. B. Case, R. M. Deshler, P. E. Drez, J. Myers, and J. R. Tyburski, 1987, "Brine Sampling and Evaluation Program Phase II Report," *DOE-WIPP-87-010*, prepared for U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

Gunter, W. D., J. Myers, and S. Girsperger, 1987, "Hydrogen: Metal Membranes" in *Hydrothermal Experimental Techniques*, G. C. Ulmer and H. L. Barnes, eds., John Wiley & Sons, New York.

Myers, J., and I. D. Colton, 1986, "The Geochemical Environment of the Culebra Dolomite," *Transactions of the American Geophysical Union*, Vol. 67, No. 16, p. 408 (abstract).

Myers, J., and R. A. Korn, 1986, "Uranium and Plutonium Solubilities in the Culebra Dolomite Environment," *Transactions of the American Geophysical Union*, Vol. 67, No. 44, p. 1256.

Myers, J., W. E. Coons, R. Eastmond, J. Morse, S. Chakraborti, J. Zurkoff, and I. D. Colton, 1986, "The Waste Isolation Pilot Plant Performance Assessment Program," *Proceedings of the Symposium on Waste Management*, Vol. 2, pp. 203–209.

Danielson, M. J., O. H. Koski, and J. Myers, 1985, "A Performance Improvement for High Temperature Stabilized Zirconia pH Sensors," *Journal of the Electrochemical Society*, Vol. 132, No. 3, pp. 2037-2038.

Danielson, M. J., O. H. Koski, and J. Myers, 1985, "Recent Developments With High-Temperature Stabilized Zirconia pH Sensors," *Journal of the Electrochemical Society*, Vol. 132, No. 2, pp. 296-301.

Early, T. O., J. Myers, and E. A. Jenne, 1985, "Applications of Geochemical Modeling to High-Level Nuclear Waste Disposal at the Hanford Site, Washington," *Proceedings of the Conference on the Application of Geochemical Models to High-Level Nuclear Waste Repository Assessment*, G. K. Jacobs and S. K. Watley, eds., NUREG-CP-0062, pp. 104-108.

Grandstaff, D. E., G. C. Ulmer, J. Myers, and G. L. McKeon, 1985, "Palladium Redox Sensor Technique for Hydrothermal Experiments," *Transactions of the American Geophysical Union*, Vol. 66, No. 18, p. 407.

Danielson, M. J., O. H. Koski, and J. Myers, 1984, "Development of High Temperature and Pressure Eh and pH Sensing Instruments," *Scientific Basis for Nuclear Waste Management, VII, Materials Research Society Symposium Proceedings*, Vol. 26.

Lane, D. L., J. Myers, M. J. Apted, and C. C. Allen, 1984, "The Basalt/Water System: Considerations for a Nuclear Waste Repository," *Scientific Basis for Nuclear Waste Management, VII, Materials Research Society Symposium Proceedings*, Vol. 26.

Myers, J., G. C. Ulmer, D. E. Grandstaff, R. Brozdowski, M. J. Danielson, and O. H. Koski, 1984, "Developments in the Monitoring and Control of Eh and pH Conditions in Hydrothermal Experiments," *Geochemical Behavior of Disposed Radioactive Waste, American Chemical Society Symposium Series*, Vol. 246, pp. 197-216.

Myers, J., M. J. Apted, and J. J. Mazer, 1984, "Hydrothermal Reaction of Simulated Waste Forms with Basalt Under Conditions Expected in a Nuclear Waste Repository in Basalt," *RH-BW-ST-59P*, Rockwell Hanford Operations, Richland, Washington.

Myers, J., and H. P. Eugster, 1983, "The System Fe-Si-O: Oxygen Buffer Calibration to 1500° K," *Contributions to Mineralogy and Petrology*, Vol. 82, pp. 75-90.

Wood, M. I., J. F. Relyea, J. Myers, and M. J. Apted, 1983, "The Near-Field Waste Package Environment in Basalt and Its Effect on Waste Form Releases," *RHO-BW-SA-331P*, Rockwell Hanford Operations, Richland, Washington.

Apted, M. J., and J. Myers, 1982, "Comparison of the Hydrothermal Stability of Simulated Spent Fuel and Borosilicate Glass in a Basaltic Environment," *RHO-BW-ST-38*, Rockwell Hanford Operations, Richland, Washington.

Gunter, W. D., J. Myers, and J. R. Wood, 1979, "Shaw Bomb, An Ideal Hydrogen Sensor," *Contributions to Mineralogy and Petrology*, Vol. 70, No. 1, pp. 23-28.

Myers, J., and W. D. Gunter, 1979, "Measurement of the Oxygen Fugacity of the Cobalt-Cobalt Oxide Buffer Assemblage," *American Mineralogist*, Vol. 64, pp. 224-228.

Rodney A. Palanca

Mr. Palanca holds a B.S. in Chemical Engineering from the University of Washington. He served 20 years in the U.S. Nuclear Navy, retiring with the rank of Lieutenant Commander. Mr. Palanca began his Westinghouse career at the DOE's Fast Flux Test Facility, Hanford, Washington and trained as a Chief Operator. He transferred to the Waste Isolation Pilot Plant in 1986 to work on the WIPP waste acceptance criteria. Since then, he has worked in several areas of TRU waste management and waste handling operations including startup testing and writing operating procedures for the waste handling equipment, developing Operational Safety Requirements, and conducting operational readiness reviews. He has served as the WID representative on the TRU Waste Integrated Working Group (formerly the National TRU Waste Task Force) and contributed to the development of a national TRU waste strategy for the DOE. He was the WIPP waste handling representative on the Engineered Alternatives Task Force. He is currently assigned as the cognizant engineer for all waste handling systems and is preparing plans for restoring the RH TRU waste handling systems to a ready condition.

M

David C. Palmer

Manager, Health Physics

22 Years of Relevant Experience

SUMMARY: Mr. Palmer has more than 22 years of professional management experience in health physics and environmental monitoring and analysis. He has been involved in management of radioactive protection and environmental monitoring programs for both mixed radioactive waste sites and the nuclear power industry, National Environmental Policy Act (NEPA) documentation, and exposure pathway analysis, including personnel exposure and risk analysis, for both radioactive material and hazardous chemicals. He was in charge of the health physics programs at one nuclear power reactor plant where he directed the environmental monitoring program and was responsible for the plant health physics program during preparations for decommissioning the reactor. Included in this task was removal and shipment of all reactor fuel assemblies to Europe for reprocessing, removal, and disposal of all irradiated reactor control rods, and other general activities to prepare for the complete dismantling of the nuclear supply system.

EDUCATION:

M.S., Environmental Health Sciences (Radiological Health), University of Michigan, 1969

B.S., Engineering Physics, University of Michigan, 1967

RELEVANT EXPERIENCE:

Principal contributor for a study evaluating all onsite and offsite transportation risks associated with full production operations at the Rocky Flats Plant. The resulting document was designed to serve as a technical resource to evaluate transportation impacts in the proposed Site-Wide Environmental Impact Statement (SWEIS). The risk assessment involved pathway and exposure analysis and dispersion modeling of radiological and hazardous materials.

Provided the operational health physics portion of the pre-operational quality assurance audit of the health physics program at the Waste Isolation Pilot Plant (WIPP). This included audits of the operational plans and practices, as well as a general assessment of the health physics program to identify those elements of the program requiring supplementation or improvement when compared to program requirements, applicable standards, good health physics practices, and actions that might be taken to limit the potential for future legal challenges.

Project manager and principal contributor for preparation of the Action Description Memorandum (ADM) and EA to comply with NEPA requirements and risk assessment documentation to comply with CERCLA requirements for the Rocky Flats Plant remedial actions at the 903 Pad, Mound, and East Trenches areas. Environmental and public health analyses were provided for each selected alternative action to aid in the selection of the proposed remedial action.

Project manager for the analysis of injury and fatality frequency rates to be applied to the transportation of wastes from the U.S. EPA Denver Radium Superfund Site to the appropriate disposal site. Calculated estimates of the number of injuries and fatalities for various transportation modes and routes, including truck and rail transportation combinations.

Project manager and principal contributor for preparation of a comparison between the U.S. EPA "Interim Recommendations on Doses to Persons Exposed to Transuranium Elements in the General Environment" with the Colorado Department of Health plutonium in soil standard. The study included a multiple pathway analysis of the risk to persons living in a hypothetical residential development on soil contaminated to the levels proposed in the two standards.

Supported the assessment of radiological risks associated with transportation accidents included in the Supplemental Environmental Impact Statement (SEIS) for WIPP.

Principal contributor to the preparation of an EA of the Supercompactor and Repackaging Facility (SARF) and the TRU Waste Shredder (TWS) at the Rocky Flats Plant, with specific responsibilities including evaluation of radiological exposures to workers and the public from routine operations and potential accidents.

Wrote the procedure for operation and calibration of a field instrument to detect low energy radiation (FIDLER) for WIPP. The instrument is designed to detect low-level surface contamination by alpha emitters and uses a microcomputer-based, portable radiation survey instrument with digital readout and data logging capabilities. The procedure included set-up, operation, and both full geometry and single point calibrations aided by a special computer program incorporated into the procedure.

Project manager for the peer review of Section 8 (Alternatives to the Proposed Action) of the Engineering and Emissions Data Base (EEDB) for the Recovery Modification Project (RMP) for the recovery of plutonium from residues at Rocky Flats. The EEDB was to be written as a reference document to be used by the Oak Ridge National Laboratory (ORNL) to prepare an Environmental Impact Statement (EIS) for the RMP. The task involved reviewing the document to assure that all feasible alternatives had been addressed, suggesting possible alternatives, and reviewing the description and evaluation of eight alternatives included in the draft EEDB.

Principal contributor to the Safety Evaluation for the Supercompactor and Repackaging Facility (SARF) at the Rocky Flats Plant. Responsibilities included identification of potential radiological and toxicological hazards, development of methodologies for analysis of the hazards, including failure mode and effects analysis, and evaluation of the probability of occurrence and potential consequences of the hazards identified.

OTHER EXPERIENCE:

Served as the Radiation Protection Manager of the Indiana & Michigan Electric Company facility, beginning at the plant's very early stages of construction. Responsible for the design and implementation of the entire Health Physics program at the plant, including writing the original Radiation Protection Manual.

Designed and administered of the radiological assessment portion and control portions of the emergency response plan for the Indiana and Michigan Electric Company facility. Included were the writing and implementation of all radiation protection related emergency procedures, development of both manual and computerized decisional aids for use by plant operations personnel and health physics technical personnel, formation and direction of all onsite and offsite radiological assessment teams, and formulation and distribution of recommendations for offsite protective actions to the appropriate federal and state agencies during the course of an emergency. Served as the primary contact with all state and federal agency personnel for all matters of radiological or environmental matters during formation of the emergency plan and during numerous drills and exercises.

At Elk River, directed the environmental monitoring program and was responsible for the plant health physics program during preparations for decommissioning the reactor. Included in this task were removal and disposal of all irradiated reactor control rods and other general activities to prepare for the complete dismantling of the nuclear supply system.

M

JAMES E. WARD

SUMMARY OF QUALIFICATIONS

Mr. Ward has over four years of professional experience in engineering with an emphasis on nuclear facility operations, design, and project engineering. His experience associated with the nuclear operations has included a sealed source fabrication program, a remote facility restoration, various regulatory compliance, and hazardous chemical and waste transportation. This experience has included positions of research and development engineer and project engineer. Currently, Mr. Ward supports project engineering for an engineering and architecture company.

PROFESSIONAL EXPERIENCE

Merrick and Company, Carlsbad Area Office, Carlsbad, New Mexico

- **Project Engineer.** Project Technical Baseline document. Project engineer on the preparation and submittal of a document that provides the bases of the WIPP project, technical parameters, description, design, safety and operation to the project. Responsible for the timely preparation of the document that is technically correct within a limited time schedule.

- **Project Engineer.** HVAC load calculation for Waste Isolation Pilot Plant (WIPP) Support and Waste Handling Building. Project lead on the heating and cooling load calculations for two buildings at WIPP. The project included the load calculations, a cooling load assessment of the existing system, and a technical report. Responsible for the budget, manpower allocation, and schedule of the project.

- **Project Engineer.** Final Safety Analysis Report (WIPP) upgrade to meet DOE Order 5480.23. This project included development of revisions to be incorporated in the existing WIPP FSAR to meet the issuance of a new departmental order on nuclear safety analysis reports. Responsible for client interface, project controls, project reporting, and technical revisions concerning the principal health and safety criteria. The upgrade included five subtasks that specifically targeted: Hazard analysis and classification, Principal health and safety criteria, Human Factors analysis and evaluation, Analysis of abnormal, normal, and accident conditions, and Demonstrated compliance with DOE Order 4330.4A, "Maintenance Management Program".

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Battelle, Pacific Northwest Laboratories, Richland, Washington

- **Development Engineer.** Waste Management Section. Responsible for characterization, packaging, and DOT, EPA, and DOE compliance for all hazardous material and waste transportation shipments Responsibilities included staff training, packaging certification and development, procedure development, and program development.

- **Research and Development Engineer.** Nuclear Engineering and Testing Section. Selected accomplishments include the following: Feasibility study for waste management of Greater-Than-Class-C (GTCC) radioactive sealed sources, remote system and component designs for conducting research operations, perform shielding calculations and data collection for remote system designs and for reducing occupational exposure during operations, supervise operations for a medical radio-isotope program and a remote radioactive research facility restoration program, develop and implement training, and capital equipment procurement. Responsibilities

included leading research, supervising staff, procedure development, and training.

Transportation Manufacturing Corporation, Roswell, New Mexico

- **Liaison Engineer.** Liaison for design engineering that facilitated the primary interface to procurement, manufacturing, quality, and test programs. Principle accomplishments included: heads-up design changes, engineering change orders, change control management, and company wide interface.

EDUCATION AND TRAINING

B.S. Mechanical Engineering, University of New Mexico 1989

Previously Radiation worker II trained, MSA and SCBA respirator, OSHA 40-hour Hazardous Waste Worker, previous DOE "Q" and "L" clearance, DOT HM-181 shippers training. Functional knowledge of radioisotopes (radiochemistry, radiophysics, material degradation, shielding, and containment).

Computer skills include: AUTOCAD release 12 with AME, MICROSHIELD (a radioactive shielding program), COSMOS/M (finite element modeling/analysis), WordPerfect 6.0, Microsoft (WINDOWS, EXCEL), LOTUS, MATHCAD, ELITE HVAC analysis.

PROFESSIONAL EXPERIENCE

12/93 to present — **Project Engineer.** Merrick & Company, Carlsbad area office, Carlsbad, New Mexico. Engineering and Architecture firm that provides a full range of services.

1/91 - 12/93 — **Research and Development Engineer.** Battelle Pacific Northwest Laboratory, Richland, Washington. Not for profit research and development institute.

5/90 - 12/90 — **Liaison Engineer.** Design Engineering Group, Transportation Manufacturing Corporation, Roswell, New Mexico. Manufacturing facility for intercity mass transit buses.

1/89 - 8/89 — **Manufacturing Engineering CO-OP.** Advanced Composites Group, GE Aircraft Engines, Albuquerque, New Mexico. Methods engineer for development of advanced graphite composites for aircraft components.

1/88 - 8/88 — **Environmental Engineering CO-OP.** Human Resources Group, GE Aircraft Engines, Albuquerque, New Mexico. Environmental staff engineer to maintain local, state, and federal environmental compliance. Direct oversight in hazardous waste shipments, and effluent emission compliance.

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James D. Waters

Project Manager

20 Years of Relevant Experience

SUMMARY: Mr. Waters has a broad range of experience in the management and operation of complex mineral facilities including 17 years experience in the potash mining district. He has completed several different projects involving ore reserve studies, minerals recovery, and budget planning to meet market conditions. He has held high level engineering and management positions at 3 of the 5 area mines. Mr. Waters is familiar with BLM and New Mexico State Land Use rules and their resource recovery regulations.

Mr. Waters has been involved in a number of efforts to support WIPP operations. He was involved in the development of the Project Technical Baseline, the Final Safety Analysis Report Upgrade, and various other regulatory compliance projects.

Mr. Waters is an accomplished process engineer with over 25 years of experience in the design construction and start up of complex chemical and mineral flowsheets. Mr. Waters has been involved in worker safety in a variety of positions and has successfully installed employee oriented safety programs at two different mining operations.

EDUCATION: M.B.A., Western New Mexico University, 1974
B.S., Metallurgical Engineering, University of Texas at El Paso, 1968

RELEVANT EXPERIENCE:

Performed a detailed investigation on the borehole penetrations into known mining areas in the Carlsbad area and identified those boreholes available for observation in the mines. This project was performed to develop background information for future WIPP compliance permitting applications.

Assisted with development of the WIPP Project Technical Baseline. Prepared facility description, site description, and post closure sections. Performed an updated geological survey of data on the Los Medanos area and the Gnome Project and developed a resource book on geology of Project Gnome. Team member on the FSAR Upgrade project. Performed several plant walk downs to inventory hazardous chemicals and also helped develop the Hazardous Assessment criteria for the FSAR Upgrade. Reviewed the WIPP Maintenance program and wrote a new maintenance section for the WIPP FSAR. Assisted the DOE technical assistance contractor in developing a National TRU Program Manager.

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Assisted Mining Services group with the development of a comprehensive reclamation plan on the remediation of the Horizon Potash mine facility.

Performed a detailed analysis of Eddy and Horizon potash mine ore reserves. Evaluated best current process technology and developed production costs based upon current mine operating costs. This information was used to develop a plan to combine the two operations into one profitable unit. A detailed proposal was developed to accomplish this plan.

Performed a preliminary environmental site assessment of Eddy Potash Mine and submitted a report and draft reclamation plan to top management.

Managed all surface operations including production, maintenance, utilities, and engineering for the largest potash facility in the United States. Performed continuous evaluations of mine reserves and mineral recovery to meet production goals.

Served as the last Project Manager for two major expansion studies involving adjacent ore reserves. Study to acquire National Potash involved fairly detailed analysis of most potash reserves located in the northern section of the potash basin.

Administered the operation and maintenance programs of the large chemical potash refinery, loading dock (600,000 tons per year shipped, and a granulation plant located about 5 miles from the main surface facility. Planned and developed short-term and long-term operational cost budgets and capital expenditure programs. Directly supervised the process engineering group, maintenance engineering group, and environmental group.

Obtained an air quality permit for National Potash plant site.

OTHER EXPERIENCE:

As Refinery Superintendent, supervised operation of a 9,000-tons-per-day refinery including crushing, grinding, flotation, and chemical refinery. Scheduled major maintenance projects and directed refinery mechanics. Supervised 10 to 12 salaried and 66 hourly employees.

Evaluated new process technologies and their application to Kennecott Copper Corporation. Acted as a consultant to five major mining divisions in fields of mineral processing and copper smelting. Assisted exploration group with conceptual plant design and cost estimates of proposed projects. Worked in the field at several divisions on a wide variety of engineering projects, usually as project engineer.

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Margaret S. Wood

Manager, Institutional Programs

18 Years of Relevant Experience

SUMMARY: Ms. Wood currently serves as Stoller's Manager for Institutional Programs. She has 18 years of experience working in intergovernmental and public affairs, safeguards and security, personnel, industrial relations, and emergency preparedness at DOE facilities throughout the United States. She has worked at the DOE's Albuquerque Field Office, Kansas City Plant, Pinellas Plant, and Los Alamos National Laboratory, and is specifically informed about the technical and public perception issues associated with the environmental restoration and waste management programs at the Weapons Complex facilities.

EDUCATION: B.A., Public Justice, St. Mary's University, 1974

RELEVANT EXPERIENCE:

Developed a Community Relations Plan for the General Electric Corporation in St. Petersburg, Florida in accordance with Resource Conservation and Recovery Act, State of Florida, and federal requirements. Work products included development and production of a work plan, a Public Involvement Meeting and Hearing Guide, a Community Interview Plan, and a Community Relations Plan. Significant work accomplishments include identifying and developing site-specific methods for improving internal and external communication programs and public involvement in the facility's waste management and environmental restoration programs.

Developed public outreach strategies, prepared public outreach materials, and developed hearing plans and procedures for an Environmental Impact Statement prepared by the U.S. Department of Energy's (DOE) Plutonium Recovery Modification Project, Project Office. Identified the potentially affected public, applicable public involvement regulatory issues and requirements, and technical project issues that could generate public concern. Developed and produced public outreach materials, press releases, display advertisements, briefing materials, and scoping meeting and information meeting plans (including opening statements and rules of conduct), and assisted in speaker preparation. Outreach materials included design and development of fact sheets on various technical and management aspects of the project.

Project manager for the development of briefing materials and speaker preparation for the proposed Special Nuclear Materials Laboratory at the Los Alamos National Laboratory.

Project manager for the review and assessment of public outreach fact sheets being developed for the Weapons Complex Reconfiguration Programmatic Environmental Impact Statement.

Developed and produced management charters, management plans, strategic plans, work plans, and management presentations for Westinghouse, Waste Isolation Division, at the Waste Isolation Pilot Plant. The management plan serves as the superior DOE Waste Isolation Pilot Plant (WIPP) Project Site Office document in the hierarchy of management documents.

Developed and produced a Management Information Handbook for the DOE WIPP Project Site Office. The handbook presented information on DOE organizations, procedures, and directives as well as information to assist DOE personnel with interagency, intergovernmental, and contractor interactions.

Identified methods used to treat, handle, and dispose specific waste streams and the associated cost of performing this work as a part of a Volume-Based Cost Analysis that was performed for all waste streams at the Rocky Flats Plant.

Principal contributor to a Safety Analysis Report that is being developed on Pondcrete Storage for the Rocky Flats Plant.

Developed strategies to improve communication with federal, state, and local agencies, Tribal Governments, special interest groups, media, and the general public and expand public participation in major projects such as the Waste Isolation Pilot Plant (WIPP) and Uranium Mill Tailing Remedial Action projects at locations such as Riverton, Grand Junction, Ambrosia Lake, Rifle, Gunnison, and Falls City.

Participated in the preparation of public outreach materials, congressional briefings, public meetings, and public hearings for the Draft Supplement to the Environmental Impact Statement for WIPP.

Developed and presented briefings to local, state, and federal officials on issues such as WIPP and federal employment issues.

OTHER EXPERIENCE:

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As Chief of Safeguards and Security for the DOE Rocky Flats Office, directly supervised a staff of seven employees, including chemists, engineers, and security specialists. Monitored and inspected all aspects of the contractor's safeguards, security, and emergency preparedness programs to ensure adequacy and compliance with all applicable federal requirements. Developed and approved building and site security plans, approved security procedures and plans for anti-nuclear demonstrations, and conducted facility threat analyses.

PUBLICATIONS:

DOE/AL, *Security Planning Guide*, Co-author
DOE/AL, *Personnel Security Handbook*, Principal Author
DOE/AL, *Engineering Analysis - Material Surveillance Task Force*, Co-author

Initial Engineered Alternatives Screening Candidates

The individual Engineered Alternatives (EA) found in the 1991 Engineered Alternatives Task Force Final Report (EATF), #1 through #64

1 Compact Waste
2 Incinerate and Cement
3 Incinerate and Vitrify
4 Wet Oxidation
5 Shred and Bituminize
6 Shred and Compact
7 Shred and Cement
8 Shred and Polymer Encapsulation
9 Shred add Salt and Compact
10 Plasma Processing
11 Melt Metals
12 Add Salt Backfill
13 Add other Sorbents
14 Add Gas Suppressant
15 Shred and Add Bentonite
16 Acid Digestion
17 Sterilization
18 Add Copper Sulfate
19 Add Gas Getters
20 Add Fillers
21 Segregate Waste Forms
22 Decontaminate Metals
23 Change Waste Generation Process
24 Add Anti-Bacterial Material
25 Accelerate Waste Digestion Process
26 Alter Corrosion Environment
27 Alter Bacterial Environment in WIPP
28 Transmutation of Radionuclides
29 Vitrify Sludges
30 Salt Backfill Only
31 Salt Backfill Plus Gas Getters
32 Compact Backfill
33 Salt Plus Brine Sorbents

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Initial Engineered Alternatives Screening Candidates

34 Preformed Compacted Backfill
35 Grout Backfill
36 Bitumen Backfill
37 Add Gas Suppressant
38 Minimize Space Around Waste Stack
39 Segregate Waste in WIPP
40 Decrease Amount of Waste per Room
41 Emplace Waste and Backfill Simultaneously
42 Selected Vegetive Uptake
43 Brine Isolating Dykes
44 Raise Waste Above the Floor
45 Brine Sump and Drains
46 Gas Expansion Volume
47 Seal Repository Room Walls
48 Vent Facility
49 Ventilate Facility
50 Add floor of Brine Sorbents
51 Change Mine Extraction Ratio
52 Change Room Configurations
53 Seal Individual Rooms
54 Two Level Repository
55 Monument Forest Over Repository
56 Monument Covering the Entire Repository
57 Buried Steel Plate Over the Repository
58 Artificial Surface layer Over the Repository
59 Add Marker Dye to Strata
60 Drain Castile Reservoir
61 Grout Culebra Foundation
62 Increase Land Withdrawal Area
63 Change Waste Container Shape
64 Change Waste Container Material

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The EATF Combination EAs, #65 through #79

65 EATF Baseline - As received with salt backfill.
66 EATF Alternative 1 - Shred and cement organics and inorganics only, salt backfill.

Initial Engineered Alternatives Screening Candidates

The Systems Prioritization Methodology - 2 (SPM-2) original EAs, #80 through #99 (from 1/19/95 list)

80 SPM-Baseline
81 SPM-A Salt backfill 50% filling efficiency
82 SPM-B Salt/Bentonite backfill 50-50 mix, 50% filling efficiency
83 SPM-C Salt/pH buffer backfill some amount of CaO
84 SPM-D Cement grout backfill 100% filling efficiency
85 SPM-E Salt/Grout backfill 100% efficiency
86 SPM IT-1 Shred and cement organics and inorganics, salt backfill 50% filling efficiency
87 SPM IT-2 Cement sludges, shred and cement orgainics and inorganics, salt backfill 50% filling efficiency, nickel alloy container.
88 SPM IT-3 Cement sludges, shred and cement orginics and inorganics, cement grout 100% filling efficiency.
89 SPM IT-4 Cement sludges, shred and cement organics and inorganics, salt/pH buffer backfill with some amount of CaO.
90 SPM IT-5 Cement sludges, shred and compact orgainics and inorganics, salt backfill with 50% filling efficiency, 200 drum monolayer, 6x33x300 room.
91 SPM IT-6 Cement sludges, shred and compact organics and inorganics, cement grout backfill 100% filling efficiency, 2000 drum monolayer, 6x33x300 room.
92 SPM IT-7 Cement sludges, compact organics and inorganics, salt/pH buffer backfill with some amount of CaO, 2000 drums monolayer, 6x33x300 room.
93 SPM IT-8 Cement sludges, shred and add bentonite to orgainics and inorganics, salt backfill 50% filling efficiency.
94 SPM IT-9 Cement sludges, shred and add bentonite to organics and inorganics, cement grout backfill 100% efficiency.
95 SPM IT-10 Decontaminate metals, nickel alloy container, cement grout backfill 100% filling efficiency.
96 SPM EATF-8 Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, salt backfill, non-ferrous container.
97 SPM EATF-9 Vitrify sludges, incinerate and vitrify organics, melt metals with glass/glass frit, radionuclides partitioned into slag and metals are eliminated from the WIPP inventory, grout backfill, non-ferrous container.

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Initial Engineered Alternatives Screening Candidates

98 SPM DOE-1 Passive markers- no specific scenario given reduce human intrusion probability parameters.
99 SPM DOE-2 Compartmentalization of waste - various unspecified scenarios.

The individual EAs found in 40 CFR Part 194, #100 through #109

100 194- Cementation
101 194- Shredding
102 194- Supercompaction
103 194- Incineration
104 194- Vitrification
105 194- Improved waste containers
106 194- Grout and bentonite backfill
107 194- Metal Melting
108 194- Alternative configuration of waste emplacement
109 194- Alternative disposal system dimensions

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Engineered Alternatives
Definitions

The following is a list of definitions for the discrete technology EAs, # 1 through # 64. The Engineered Alternatives Screening Working Group (EASWG) reviewed the original 1991 Engineered alternatives Task Force (EATF) definitions and modified them where necessary. Those taken directly from the EATF are noted as such.

Title Description

1 Compact Waste
All wastes except sludges are processed by first pre-compacting the waste into 35 gallon drums, the "pucks" are then supercompacted at forces in excess of 2200 tons and packed for disposal in 55 gallon drums. The volume reduction is approximately 3:1.

2 Incinerate and Cement
Solid organics are incinerated and the resulting ash is cemented into an ash/cement matrix.

3 Incinerate and Vitrify
Solid organics are incinerated and fused into a glass matrix by vitrifying. Vitrification melts/fuses the waste; silica may be added prior to melting.

4a Wet Oxidation and Cement
Solid organics are oxidized into an ash residue. Wet oxidation involves the accelerated oxidation of waste in the presence of heated water vapor or steam, with the intent to chemically degraded the waste. The ash residue is cemented into an ash/cement matrix.

4b Wet Oxidation and Vitrify
Solid organics are oxidized into an ash residue. Wet oxidation involves the accelerated oxidation of waste in the presence of heated water vapor or steam, with the intent to chemically degrade the waste. The ash residue is vitrified into a fused glass. Silica may be added to the residue prior to melting/fusing.

5 Shred and Bituminize
All waste except sludges are mechanically shred. A volume reduction ratio of 1.2:1 is assumed for shredding only. Bitumen is mixed into the waste, filling the void space in the waste drum.

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Engineered Alternatives
Definitions

6 Shred and Compact
All waste except sludges are mechanically shred. A volume reduction ratio of 1.2:1 is assumed for shredding only. The shredded waste is compacted in the drum. Supercompaction is not used.

7 Shred and Cement
All waste except sludges are mechanically shred. A volume reduction ratio of 1.2:1 is assumed for shredding only. "Wet" Cement is added to the waste creating a solid homogeneous waste/cement matrix.

8 Shred and Polymer Encapsulation
All waste except sludges are mechanically shred. A volume reduction ratio of 1.2:1 is assumed for shredding only. The shredded waste is encapsulated with a polymer.

9 Shred, add Salt, and Compact
All waste except sludges are mechanically shred. A volume reduction ratio of 1.2:1 is assumed for shredding only. Shredded waste is mixed with crushed salt and compacted in the drum. Supercompaction is not used.

10 Plasma Processing
All waste is subjected to a high temperature plasma eliminating organics and melting metals and sludges into a solid form. The products of this process are vitrified glasses and solid metals.

11a Melt Metals
All metals are melted (sludges and combustibles are excluded) into an ingot and disposed at WIPP. The size and weight of the final product are within transportation limits.

11b Melt Metals - Partition Actinides with Frit
All metals are melted (Sludges and combustibles are excluded). Glass Frit is added to the molten metal partitioning the radionuclides within the slag. The slag is removed, solidified, and disposed at the Waste Isolation Pilot Plant (WIPP). The metal is cast into ingots and disposed as Low Level Waste (LLW) at a LLW facility. The size and weight of the ingot are within transportation limits.

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Engineered Alternatives
Definitions

12 Add Salt Backfill
A crushed salt backfill is placed around and between the waste containers, filling the void space within the rooms. A 50% filling efficiency is assumed.

13 Add Other Sorbents (EATF definition)
Evaluation of sorbents in addition to or other than bentonite may lead to improved waste characteristics of permeability and porosity. These sorbents are intended to sorb brine and radionuclides.

14 Add Gas Suppressant (EATF definition)
Adding materials to the waste that could reduce gas generation rates, such as materials that raise the pH of the brine that comes in contact with the waste, could prove beneficial in reducing gas pressure buildup in the waste disposal rooms.

15 Shred and Add Clay
All waste except sludges are mechanically shred. A volume reduction ratio of 1.2:1 is assumed for shredding only. Engineered clay grout is added to the shredded waste removing the void space within the waste drum. Two forms of clays are considered, swelling (smectites) and non-swelling (illite/kaolinite).

16a Acid Digestion and Cement
Solid organics are dissolved in a strong acidic solution that is subsequently neutralized and precipitated, resulting in a reduced volume sludge waste form, which is solidified into a cement/precipitate matrix.

16b Acid Digestion and Vitrify
Solid organics are dissolved in a strongly acidic solution that is subsequently neutralized and precipitated, resulting in a reduced volume sludge waste form, which is vitrified into a fused glass. Silica may be added prior to vitrification.

17 Sterilization (EATF definition)
Prior to emplacement of the waste in WIPP, sterilize the contents of each waste package to eliminate or reduce microbial gas generation. To be sufficiently effective, this alternative would probably have to be used in conjunction with sterilization of the entire underground waste disposal area, which is not considered a credible alternative.

Engineered Alternatives
Definitions

18 Add Copper Sulfate (EATF definition)
The addition of copper sulfate to the waste is expected to reduce the generation of gasses resulting from anoxic corrosion of iron based metals. The copper sulfate reacts with iron, forming ferrous sulfate and preventing the production of free hydrogen gas.

19 Add Lime
Lime (CaO) is added to solid organics within a drum.

20 Add Fillers (EATF definition)
Adding filler materials to the waste in order to reduce the initial void volume will reduce the waste's permeability and can reduce brine inflow during room reconsolidation.

21 Segregate Waste Forms (EATF definition)
This alternative refers to isolating each major waste form (i.e., sludges, combustibles, etc.) from one another. By segregating the various waste forms that are now intermingled within the waste packages, several engineered alternatives could be applied to smaller waste quantities, thereby possibly reducing costs and overall schedule.

22 Decontaminate Metals
Metals are sorted and decontaminated using freon or carbon dioxide. Filters are used to collect the radionuclides and are disposed as TRU waste. Decontaminated metals are recycled or disposed of as LLW.

23 Change Waste Generation Process (EATF definition)
Since two-thirds of the waste that will ultimately be emplaced in WIPP has not been generated, an opportunity exists to change the processes that generate the remaining waste to minimize waste porosity, permeability, and gas generation. Some progress has already been made in reducing waste generation Volume, and compaction of waste at generator sites is an example of a process that reduces porosity and permeability.

Engineered Alternatives
Definitions

24 Add Anti-Bacterial Material (EATF definition)
The addition of an anti-bacterial material to the waste could alleviate some gas production if such a material does not pose a greater challenge than the gas itself. The material must has an estimated effective lifetime sufficient to prevent those microbes already present in the repository from eventually overtaking its effectiveness.

25 Accelerate the Waste Digestion Process (EATF definition)
This alternative suggests that the gas generation process might be accelerated so that gas generation is minimized after decommissioning of the repository. This requires the addition of appropriate bacterial agents to hasten waste digestion, which would have to be essentially complete before decommissioning.

26 Alter Corrosion Environment in WIPP (EATF definition)
The use of copper sulfate has already been identified as an engineered alternative that might modify the corrosion process to generate less gas. Other alternatives may alter the chemical environment of the waste storage rooms, such as assuring dryness or maintaining a pH buffer, so that corrosion is minimized.

27 Alter Bacterial Environment in WIPP (EATF definition)
This alternative is analogous to "Alter Corrosion Environment in WIPP." By changing the chemistry of the waste, microbial gas generation rates may be reduced to acceptable levels.

28 Transmutation (EATF definition)
This alternative considers transmutation of long-lived radionuclides to short-lived nuclides, eliminating the need for long-term disposal.

29 Vitrify Sludges
Sludge waste is melted/fused into a fused glass. Silica may be added prior to vitrification.

Engineered Alternatives
Definitions

30 Salt Backfill Only (EATF definition)
This is the basic backfill material being considered to reduce void volume around the waste and to hasten room closure. The material results from mining the disposal rooms and drifts, and can be processed by crushing or pulverizing to enhance backfilling operations. Unless the salt is preformed into compact shape(s), it has significant initial porosity and permeability, but will rapidly reconsolidate as a result of creep closure.

31 Salt Backfill Plus Gas Getters (EATF definition)
The addition of gas getters with the salt backfill may be advantageous for preventing buildup of unacceptable gas Volume. A potential disadvantage of applying gas getters in this matter is that salt reconsolidation takes place fairly quickly. If reconsolidation prevents interaction of gases with the gas getters in the salt matrix, it could prove ineffective. An added advantage of certain gas getters (e.g. CaO) is they will act as pH buffers thereby minimizing corrosion and radionuclide solubility in brine.

32 Compact Backfill (EATF definition)
Compacting backfill in place could reduce its permeability sufficiently to prevent significant brine mobility. Such a procedure would probably require more storage space than currently planned to permit equipment access between and around the waste packages.

33 Salt Plus Clay Backfill
Crushed salt is mixed with approximately 30% clay. The salt/clay backfill is placed around the drums filling the void space within the rooms. A 50% filling efficiency is assumed.

34 Preformed Compacted Backfill (EATF definition)
Preforming backfill into dense compacted modules, such as bricks or blocks, or shapes that can be inserted between waste packages, may reduce the overall permeability of the waste disposal rooms, thereby reducing the potential for brine contact with the waste. Compacted backfill reduces the time required for room closure and the amount of brine that can migrate into the room from the surrounding salt.

Engineered Alternatives
Definitions

35 Salt Aggregate Grout Backfill
Crushed salt is sifted and used as an aggregate in a brine based grout backfill (properties of Type 10 grout are assumed). The grout is pumped into the rooms, filling the void spaces within the rooms. A high filling efficiency is assumed.

36 Bitumen Backfill
Bitumen is placed around the waste drums filling the void space within the disposal rooms.

37 Add gas Suppressants (EATF definition) [backfill alternative]
This alternative is analogous to that described for the waste form (same name) but the suppressing material would be mixed with the backfill.

38 Minimize Space Around Waste Stack
This alternative reduces the room dimensions to minimized space around the waste containers. Only minimal space around the waste containers is assumed after emplacement.

39 Segregate Waste in WIPP (EATF definition)
The segregation of different waste forms in or among waste disposal rooms could prove beneficial. For instance, the segregation of permeable metal waste in small amounts within more easily compacted or previously compacted waste could "encapsulate" the metals with other waste that is less permeable. The segregation of high gas-generation waste from more benign waste would focus the solution on a smaller area of WIPP. There may also be an advantage in segregating sludges that contain nitrates, from combustible wastes to prevent nitrate reducing bacteria from generating nitrogen gas.

40 Decrease the Amount of Waste per Room (EATF definition)
By leaving the room size the same as currently designed, but emplacing less waste volume per room, sufficient space may be gained around the waste stack to isolate the stack from the surrounding host salt. This would be accomplished by creating a waste stack that is as compacted as practicable, surrounded by relatively "plastic" backfill containing sorbents and gas getters that would act as a secondary encapsulation medium. The host salt would, of course, remain the primary barrier.

Engineered Alternatives
Definitions

41 Emplace Waste and Backfill Simultaneously (EATF definition)
The intent of this alternative is to emplace backfill more efficiently so that its effect is maximized. This alternative would be used in conjunction with compacting in place or using precompacted (and preformed if necessary) backfill.

42 Selective Vegetative Uptake (EATF definition)
Using the vegetative uptake of certain plants to concentrate radionuclides has been proposed. Some work has been done demonstrating the vegetative concentration of heavy metals.

43 Brine Isolating Dikes (EATF definition)
Brine dikes can consist of partial or full-height walls of material that segregate waste quantities to reduce the amount of waste accessed by inflowing brine or a driller's circulating mud.

44 Raise Waste Above Floor (EATF definition)
If it can be postulated that Salado brine will collect on the waste disposal room floor, then isolating the waste from the floor may be beneficial. If it can be further postulated that humidity generated by brine can be isolated from the waste, than this alternative may reduce the amount of corrosion-induced gas generation.

45 Brine Sumps and Drains (EATF definition)
By properly sloping the floor of waste disposal rooms toward collection sumps, it may be possible to isolate inflowing brine from the waste. Isolating the brine during room closure and designing the sumps so that they become "encapsulated" after closure, may result in reduced corrosion-induced gas generation.

46 Gas Expansion Volume (EATF definition)
This alternative refers to the mining of recesses within the repository to allow free expansion of the gases generated and thus reduce gas pressure.

47 Seal Repository Room Walls (EATF definition)
This alternative refers to a flexible, impermeable seal applied to the walls of each room such that closure does not break the seal. The intent is to prevent contact between the waste stack and interstitial brine.

Engineered Alternatives
Definitions

48 Vent Facility (EATF definition)
If gas generation results in the potential for overpressurizing waste disposal rooms, providing small engineered vents could alleviate this condition.

49 Ventilate the Facility (EATF definition)
Continuous ventilation of the waste disposal rooms until complete closure has taken place would eliminate concerns about brine from the surrounding Salado Formation collecting in the repository.

50 Add Floor of Brine Sorbent (EATF definition)
The intent of this alternative is to prevent free brine from contacting the waste stack, thereby reducing the potential for corrosion induced gas generation.

51 Change Mined Extraction Ratio
The mined extraction ratio is increased to increase the closure rate or the disposal rooms (i.e., leaving less supportive salt around the mined waste disposal rooms).

52 Change Room Configuration (EATF definition)
This alternative involves several possibilities. Stacking the waste tightly against the walls would eliminate initial void volume and enhance closure time. Another option involves increasing room size, which would also increase the extraction ratio, making room for a buffer of sorbents and gas getters completely surrounding the waste stack. A third option involves increasing room height and stacking the waste higher to reduce the overall footprint of the repository.

53 Seal Individual Rooms
Individual rooms are sealed instead of only sealing the panels. Communication between the rooms during an intrusion scenario is significantly reduced (gas, brine, and radionuclides).

Engineered Alternatives
Definitions

54 Two Level Repository (EATF definition)
A two level repository refers to decreasing the facility's surface footprint by placing half the waste disposal area above the other, creating a two level facility. Although reduction of the facility footprint will reduce the probability of human intrusion into the underground disposal area, the consequences could double of the intrusion event penetrates both levels of the repository.

55 Monument Forest over Repository (EATF definition)
The use of closely spaced surface markers, consisting of long-lasting materials, can be used to alert potential intruders about the existence of the repository. These monuments could be mass produced and include other designations describing the location and content of the disposal area. Each marker would be deeply anchored in bedrock.

56 Monument Covering the Entire Repository (EATF definition)
The waste disposal area of the WIPP consists of approximately 100 acres. A monument 2,100 feet on a side, consisting of natural and/or man-made materials, could provide adequate warning to potential intruders as well as adding to the difficulty of drilling into the repository. The alternative could consist of a single "pyramid" or multiple contiguous monuments.

57 Buried Steel Plate Over the Repository (EATF definition)
The action of a drill bit makes it difficult to penetrate non-friable materials. Burying a relatively thick steel or other metal plate at some distance below the surface over the repository could alert an intruder that this is an unusual site. The plate would probably have to be sandwiched between corrosion inhibitors to assure longevity. Additionally, site exploration and evaluation prior to drilling would alert geologists that further exploration is needed.

58 Artificial Surface Layer Over Repository (EATF definition)
Replacing the natural surface material over the repository with a layer of artificial or sterile material to a reasonable depth is another way of alerting potential intruders to explore further before taking any action.

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Engineered Alternatives
Definitions

59 Add Marker Dye to Strata (EATF definition)
The use of marker dye that is sufficiently strong to discolor the driller's mud pond may alert the intruder that some further evaluation is necessary.

60 Depressurize Castile Reservoir
This alternative removes brine from the Castile Formation in sufficient quantities to remove the motive force that transports waste from the repository to the accessible environment in an intrusion event involving the Castile Formation.

61 Grout Culebra Formation (EATF definition)
The Culebra is a potential conduit for releasing radionuclides to the accessible environment. Grouting the Culebra above the repository may reduce the pathway.

62 Increase Land Withdrawal (EATF definition)
Currently planned land withdrawal boundaries do not extend to the boundaries of 40 CFR Part 191. Extending the land withdrawal boundaries to coincide with the permitted regulatory boundaries would provide longer radionuclide transit times before reaching the boundaries used to calculate repository performance.
EASWG note: This definition was not modified even though the LWA has been enacted since this definition was generated in the EATF. The EASWG used the intent of the definition to extend the boundaries in determining the validity of this alternative.

63 Change Waste Container Shape (EATF definition)
Square waste or hexagonal packages are used to decrease the void space within the disposal room.

64 Change Waste Container Material
Materials other than ferrous materials are used to construct the waste package.. Materials shall be selected after reviewing previous material studies (further refinement at a later date).

Engineered Alternatives
Definitions

110 Enhanced Solidification of Sludges
Cementation of Sludges is performed to provided a waste from with improved properties over non-cemented sludges.

111 Clay Based Backfill
Clay based backfill is placed around the drum, filling the void spaces within the room to hasten room closure and isolate the waste with a low permeability barrier. Two forms of clays are considered, swelling (smectites) and non-swelling (illite/kaolinite). Clay may be placed dry or water may be added and the material pumped into the rooms.

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Engineered Alternatives Pass List with Comments

The following is a listing of Engineered Alternatives (EA) that passed the screening process, a brief description of the Engineered Alternatives Screening Working Groups (EASWG) conclusion is provided.

1 Supercompact Everything Except Sludges (formerly "Compact Waste")
The EASWG concluded that this EA met the definition and would be considered further. Off-The Shelf technology is available. Widely used for low level waste (LLW). Transuranic (TRU) waste supercompacted at Rocky Flats Project (RFP). Permitting in interim status at RFP - Resource Conservation and Recovery Act (RCRA) Part B.

2 Incinerate and Cement Solid Organics (formerly "Incinerate and Cement")
The EASWG concluded that this EA met the definition and would be considered further. Technology mature for hazardous constituents some engineering instill required for TRU. Commonly used for LLW - Japan, France, USA. No TRU waste incinerator operating. Permitted incinerators at Los Alamos National Laboratories (LANL) for hazardous materials, moratorium on new hazardous materials incinerators, major effort required to permit future incinerators.

3 Shred and Vitrify Solid Organic Waste (formerly "Incinerate and Vitrify")
The EASWG changed the title from "Incinerate and Vitrify" to "Shred and Vitrify" because the current vitrification technology does not require incineration, only shredding. The EASWG also concluded that this EA met the EA definition and would be considered further. Various vitrification technologies have been demonstrated; related to plasma melting. Frances (Marcoule Facility) currently making radioactive glass logs. Not yet permitted for TRU waste.

4a Wet Oxidation and Cement Solid Organics Waste (formerly "Wet Oxidation")
The EASWG concluded that wet oxidation alone did not meet the definition because the resulting waste must be solidified to meet the Waste Acceptance Criteria (WAC). The two common solidification techniques were added to this EA to meet the definition. Wet Oxidation technology demonstrated at bench scale, questions exist regarding ability to handle all organic wastes. Currently used to treat non-rad organics in water. Technology never permitted but believed possible.

Engineered Alternatives Pass List with Comments

4b Wet Oxidation and Vitrify Solid Organic Waste (formerly "Wet Oxidation")
The EASWG concluded that wet oxidation alone did not meet the definition because the resulting waste must be solidified to meet the WAC. The two common solidification techniques were added to this EA to meet the definition. Same Technical and Regulatory feasibility comments as 4a.

5 Shred and Bituminize Everything Except Sludges (formerly "Shred and Bituminize")
The EASWG concluded that this EA met the definition and would be considered further. Technology is mature but not applied to TRU waste, development work required. Used in Japan for radioactive resins and sludges. This technology has not been permitted however, the EASWG believes obtaining a permit is possible.

6 Shred and Compact Everything Except Sludges (formerly "Shred and Compact")
The EASWG concluded that this EA met the definition and would be considered further. (Not Supercompaction - low pressure compaction) Commercial nuclear plants routinely use compaction technology for LLW. Not currently being done for TRU nor demonstrated. Off-the-shelf equipment available. Permitted for LLW but not TRU, highly probable permit obtainable.

7 Shred and Cement Everything Except Sludges (formerly "Shred and Cement")
The EASWG concluded that this EA met the definition and would be considered further. Grouting technology demonstrated at Hanford, believed used in German application for TRU type waste. Permitting of cementation of TRU sludges under interim status at DOE facilities. Permitting problems not expected by EASWG.

8 Shred and Cold Polymer Encapsulate Everything Except Sludges (formerly "Shred and Polymer Encapsulation")
The EASWG concluded that this EA met the definition and would be considered further. Commercial technology in use that polymerizes LLW. Not demonstrated for TRU waste. Technology is available off-the-shelf. Permitting problems are not expected by the EASWG.

Engineered Alternatives Pass List with Comments

9 Shred, Add Salt, and Compact Everything Except Sludges (formerly "Shred add Salt and Compact")

The EASWG concluded that this EA met the definition and would be considered further. Technology is available off-the -shelf however process not in use for TRU waste. Compaction of LLW currently permitted and performed. Permitting problems not expected by the EASWG.

10 Plasma Processing of All Waste (formerly "Plasma Processing")

The EASWG concluded that this EA met the definition and would be considered further. Centrifical (molten maytag) and Fixed Hearth technologies demonstrated with non-TRU materials, Centrifical technology used to extract exotic metals in industrial applications. Pilot test completed for pit nine, INEL application with simulated waste. Design of a full-scale unit is approximately 90% complete at INEL (Lockheed) Research and Development (R&D) permitted. Not permitted for TRU waste. EASWG expects permit obtainable.

11a Melt Metals into TRU Waste Ingots (formerly "Melt Metals")

The EASWG decided to separate this EA into two categories: a) melt metals and emplace all at WIPP and b) melt metals, partition radionuclides in slag and remove, cast metal, and dispose as LLW. The EASWG determined that this separatuon allows for greater flexibilities in the analysis. The EASWG concluded that both EAs met the definition and would be considered further. Technology is mature but not applied to TRU wastes, development work required. EASWG believes technology is transferable to TRU waste uses. Technology not permitted for TRU waste, EASWG expects permits are obtainable.

11b Melt Metals with Frit to Partition Actinides (formerly "Melt Metals")

The EASWG decided to separate this EA into two categories: a) melt metals and emplace all at WIPP and b) melt metals, partition radionuclides in slag and remove, cast metal, and dispose as LLW. The EASWG determined that this separation allows for greater flexibilities in the analysis. The EASWG concluded that both EAs met the definition and would be considered further. Technology is mature but not applied to TRU wastes, development work required. EASWG believes technology is transferable to TRU waste uses. Potential to recycle waste containers/container materials. Technology not permitted for TRU waste, impacts LLW disposal. facilities.

Engineered Alternatives Pass List with Comments

12 Salt Backfill Around Drums and Waste Stack (formerly "Add Salt Backfill")
The EASWG concluded that this EA met the definition and would be considered further. The technology of pneumatic backfilling was demonstrated at WIPP. Can also be as simple as a pile of salt and a shovel. No regulatory concerns were noted. EASWG believes no permit is required for this technology.

15 Shred, Add Clay Based Material to Everything (formerly "Shred and Add Bentonite")
The EASWG decided to change the title of this EA to allow for various types of clays to be considered in the analysis. The EASWG concluded that this EA met the definition and would be considered further. Process is not being done for TRU waste. Equipment is available off-the-shelf. EASWG believes permits are obtainable.

16a Acid Digestion and Cementation of Solid Organics (formerly "Acid Digestion ")
The EASWG concluded that Acid Digestion alone was not an EA; acid digestion must be followed by a stabilization process. Acid digestion was deleted and acid digestion with solidification was added. The EASWG determined that this EA meet the definition and should be considered further. This Technology was used to process approximately 5,000 Kg TRU
waste between 1972 and 1980 at Handford using sulfuric acid. Current bench-scale technology at Savanna River Site uses an acid process at 180°C and 15 psig. Belgium recovers Pu with sulfuric acid. Development of processes waste and residue stabilization systems, spent acid treatment, off-gas systems, is required. Cementation of resulting sludge has not been demonstrated. Technology not permitted. Permit issues associated with disposition of hazardous constituents. EASWG believed the technology may be permitted however not enough information is available to justify rejection.

16b Acid Digestion and Vitrify of Solid Organics (formerly "Acid Digestion")
The EASWG concluded that Acid Digestion alone was not an EA; acid digestion must be followed by a stabilization process. Acid digestion was deleted and acid digestion with solidification was added. The EASWG determined that this EA met the definition and should be considered further. The Technology and regulatory feasibility is identical to #16a with vitrification consideration #3.

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Engineered Alternatives Pass List with Comments

19 Add Lime to Solid Organic Waste (formerly "Add Gas Getters")
The EASWG changed the title of this EA from "Add Gas Getters" to "Add Lime to Solid Organic Waste". The new title was changed to better describe the EA. The EASWG concluded that this EA met the definition and would be considered further. This EA is a material handling process, no treatment technology is involved. Aluminum would have to be removed from the waste prior to the addition of lime. The EASWG concluded that a permit may not be required for this EA but potential WAC and TRUPACT II certification issues may be involved in implementing this EA.

22 Decontaminate Surface of Metallic Wastes for LLW Disposal (formerly "Decontaminate Metals")
The EASWG concluded that this EA met the definition and would be considered further. The EASWG concluded that this technology was mature and off-the-shelf technology is available. This technology was commonly used for alpha contaminated materials. The EASWG expects that a permit is obtainable if required.

29 Microwave Melt Sludges (formerly "Vitrify Sludges")
The EASWG changed the title from "Vitrify Sludges" to "Microwave Melt Sludges" to better define the EA. The EASWG concluded that this EA met the definition and would be considered further. The microwave technology has been demonstrated for radioactive waste, however the entire waste handling process has not been demonstrated. Completed systems with feed and off-gas processes must still be designed. Problems are expected with obtaining a permit because this is a thermal process however the EASWG believes a permit is obtainable.

33 Salt Plus Clay Backfill (formerly "Salt Plus Brine Sorbents")
The EASWG determined that this EA met the definition of an EA and that it would be kept for further consideration. The EASWG changed the title to "Salt plus Clay Backfill" and described the alternative as a crushed salt backfill containing 30% clay. The technical and regulatory feasibility is identical to #12.

Engineered Alternatives Pass List with Comments

35 Salt Aggregate Grout Backfill Around Drums (formerly "Grout Backfill"
The EASWG changed the title to specify a salt aggregate grout. The EASWG concluded that this EA met the definition and would be considered further. The technology is mature. Brine saturated grouts are commonly used in the petroleum and mining industries. Questions on gas generation potential may limit the effectiveness of this alternatives. The EASWG believed a permit would not be required, only DOE requirements need to be satisfied.

36 Bitumen Backfill
The EASWG concluded that this EA met the definition and would be considered further. Material handling technology is mature. Bitumen backfill used in Germany. Off-the-shelf technology is available. May impact the no-migration permit; possible large increase in hazardous materials. Uncertainty in safety requirements due to combustible nature. The EASWG concluded that there is a large uncertainty in regulatory feasibility, however not enough information is available to justify rejection.

38 Reduce Room Dimensions to Minimize Space Around the Waste Stack (formerly "Minimize Space Around Waste Stack")
The EASWG concluded that this EA met the definition and would be considered further. The technology used to initially mine the rooms and panels can be used, the technology is mature. Equipments is available at the site and the operations required to implement the EA is understood. Regulatory issues include, site design validation process considerations with the State of New Mexico, the Consultation and Cooperation Agreement and other coordination concerns with the state.

51 Change Mine Extraction Ratio
The EASWG concluded that this EA met the definition and would be considered further. The EASWG concluded that this technology is mature and understood. Equipment is available. Mayor analysis would be required to determine the design and the overall impact on the disposal system. Regulatory concerns include: mayor considerations with respect to the site design validation process, State of New Mexico agreements and MSHA requirements. The EASWG concluded that no permit is required to implement this EA.

Engineered Alternatives Pass List with Comments

53 Seal Individual Rooms
The EASWG concluded that this EA met the definition and would be considered further. Technology is available off-the-shelf. Major analysis is required to determine seal design and performance parameters. No permitting problems were envisioned by the working group.

60 Depressurize the Castile Reservoir (formerly "Drain the Castile Formation")
The EASWG determined this EA met the definition of an EA and should be considered further. The EASWG changed the title from "drain" to "Depressurize" stating that drain was not technically correct and was misleading. Technology is a standard oil industry practices (per Nelson Munsey of Yates Petroleum). Must dispose of brine - many options for disposal available. Technology has been permitted, minimal permitting problems anticipated. State permit required.

63 Change Waste Container Shape
The EASWG concluded that this EA met the definition and would be considered further. Technology is mature and available. Off-the-shelf containers of different various shapes are available and may meet existing TRU waste container requirements. NRC TRUPACT II certification modification required, DOT certification required. These certifications have been obtained for TRU waste containers previously. Permits can be obtained.

64 Change Waste Container Material
The EASWG concluded that this EA met the definition and would be considered further. The technology is mature and available. Depending on the specific material, waste containers made of non-ferrous materials are available off-the-shelf that may meet the current TRU waste container requirements. Same regulatory feasibility comments as #63.

83 SPM-C Salt backfill with CaO
The EASWG concluded that this EA met the definition and would be considered further.

Engineered Alternatives Pass List with Comments

110 Enhanced Solidification of Sludges
The EASWG determined that this EA met the definition and would be considered further. Technology of cementing sludges has been demonstrated. RFP has matured this technology. Some development work may be required. The regulatory issues include, satisfying DOE requirements and RCRA permit or modification to permit.

111 Clay Based Backfill
The EASWG determined that this EA met the definition and would be considered further. The Technology is mature for moist and dry clay emplacement. The EASWG believes that no permits are required and only DOE requirements must be met.

Note:
The Combination EAs were derived from those used in the EATF report and SPM program. The titles/descriptions have been changed to match the title of the discrete technologies. For example, the title "Nickel Alloy Container" was changed to "Change Waste Containers Material, #64" and "Rectangular Containers" was changed to "Change Waste Container Shape, #63". This was done to provide consistency throughout the analysis.

66 EATF Alternative 1 - Shred and cement organics and inorganics only, salt backfill.
The EASWG concluded that this EA met the definition and would be considered further.

67 EATF Alternative 2 - Enhanced cement sludges, shred and cement organics and inorganics, salt backfill.
The EASWG concluded that this EA met the definition and would be considered further.

68 EATF Alternative 3 - Enhanced cement sludges, shred and cement organics and inorganics, salt aggregate grout backfill.
The EASWG concluded that this EA met the definition and would be considered further.

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Engineered Alternatives Pass List with Comments

69 EATF Alternative 4 - Enhanced cement sludges, incinerate and cement organics, shred and cement inorganics, salt backfill.
The EASWG concluded that this EA met the definition and would be considered further.

70 EATF Alternative 5 - Enhanced cement sludges, incinerate and cement organics, shred and cement inorganics, salt aggregate grout backfill.
The EASWG concluded that this EA met the definition and would be considered further.

71 EATF Alternative 6 - Vitrify sludges, shred and vitrify organics, melt metals into TRU waste ingots, salt backfill.
The EASWG concluded that this EA met the definition and would be considered further.

72 EATF Alternative 7 - Vitrify sludges, shred and vitrify organics, melt metals into TRU waste ingots, salt aggregate grout backfill.
The EASWG concluded that this EA met the definition and would be considered further.

73 EATF Alternative 8 - Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP inventory), salt backfill, change waste container material.
The EASWG concluded that this EA met the definition and would be considered further.

74 EATF Alternative 9 - Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP inventory), salt aggregate grout backfill, change waste container material.
The EASWG concluded that this EA met the definition and would be considered further.

75 EATF Alternative 10 - Decontaminate surface of metallic waste for LLW disposal, no backfill, change container material and shape, 10x31x188 rooms.
The EASWG concluded that this EA met the definition and would be considered further.

Engineered Alternatives Pass List with Comments

76 EATF Alternative 11 - Supercompact organics and inorganics, salt backfill, monolayer of 2,000 drums in a 6x33x300 room.
The EASWG concluded that this EA met the definition and would be considered further.

77 EATF Alternative 12 - Supercompact orgainics and inorganics, salt aggregate grout backfill, monolayer of 2,000 drums, in a 6x33x300 room.
The EASWG concluded that this EA met the definition and would be considered further.

78 EATF Alternative 13 - Vitrify slugdes, shred and vitrify orgainics, melt metals with frit to partition actinides (metals are eliminated from the WIPP), no backfill, change waste container material and shape, minimize space around waste stack in a 10x31x188 room.
The EAWG concluded that this EA met the definition and would be considered further.

79 EATF Alternative 14 - Supercompact organics, and inorganics, salt backfill, seal individual rooms, 2,000 drums per room.
The EASWG concluded that this EA met the definition and would be considered further.

87 SPM IT-2 Enhanced cement sludges, shred and cement orgainics and inorganics, salt backfill, change waste container material.
The EASWG concluded that this EA met the definition and would be considered further.

88 SPM IT-3 Enhanced cement sludges, shred and cement organics and inorganics, salt aggregate grout backfill.
The EASWG concluded that this EA is a duplicate of #68, "EATF Alternative 3".

89 SPM IT-4 Enhanced cement sludges, shred and cement organics and inorganics, salt backfill with CaO.
The EASWG concluded that this EA met the definition and would be considered further.

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Engineered Alternatives Pass List with Comments

90 SPM IT-5 Enhanced cement sludges, shred and compact orgainics and inorganics, salt backfill, 2,000 drum monolayer, 6x33x300 room.
The EASWG concluded that this EA met the definition and would be considered further.

92 SPM IT-7 Enhanced cement sludges, compact organics and inorganics, salt backfill with CaO, 2,000 drums monolayer, 6x33x300 room.
The EASWG concluded that this EA met the definition and would be considered further.

93 SPM IT-8 Enhanced cement sludges, shred and add clay based material to organics and inorganics, salt backfill.
The EASWG concluded that this EA met the definition and would be considered further.

94 SPM IT-9 Enhanced cement sludges, shred and add clay based materials to organics and inorganics, salt aggregate grout backfill.
The EASWG concluded that this EA met the definition and would be considered further.

95 SPM IT-10 Decontaminate surface of metallic waste for LLW disposal, change waste container material, salt aggregate grout backfill.
The EASWG concluded that this EA met the definition and would be considered further.

110 Enhanced Cementation of Sludges - Accepted
The EASWG concluded that this EA met the definition and would be considered further.

111 Clay Based Backfill
The EASWG concluded that this EA met the definition and would be considered further.

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Engineered Alternatives Rejection List with Justifications

The following is a listing of Engineered Alternatives (EA) that failed the screening process, a brief description of the Engineered Alternatives Screening Working Groups (EASWG) rejection justifications are provided.

4 Wet Oxidation

Wet Oxidation alone was not considered an EA and was deleted. The EASWG determined that wet oxidation must be followed by a stabilization process to be an EA so #4 Wet Oxidation was changed to wet oxidation plus two separate solidifiers, #4a and #4b.

11 Melt Metals

The EASWG decided to delete this EA and separate it into two categories: #11a - melt metals and emplace all at WIPP and #11b - melt metals, partition radionuclides in slag and remove, cast metal and dispose as LLW. The EASWG determined that this separations allows for greater flexibilities in the analysis.

13 Add other Sorbents

The EASWG determined that this EA is a duplicate of #15.

14 Add Gas Suppressant

The EASWG concluded that this EA is a duplicate of #19.

16 Acid Digestion

The EASWG concluded that Acid Digestion alone was not considered an EA. Acid digestion must be followed by a stabilization process to be an EA so #16, Acid Digestion, was changed to include two separate solidifiers, #16a and #16b.

17 Sterilization

The EASWG determined that the original EATF rejection justification was still valid and that this EA would be rejected. The EATF rejection justification states, "Not feasible to maintain long-term effectiveness."

Engineered Alternatives Rejection List with Justifications

18 Add Copper Sulfate
The EASWG determined that the original EATF rejection justification was still valid and that this EA would be rejected. The EATF rejection justification states, "Potential for hydrogen generation by galvanic coupling of deposited copper."

20 Add Fillers
The EASWG concluded that this EA was not specific enough to evaluate and is considered by other more specific alternatives (#7,9,13,14,15,18 & 19).

21 Segregate Waste Forms
The EASWG concluded that this EA did not meet the definition of an EA and was inherent with most waste processing EAs. This EA was not considered for further evaluation.

23 Change Waste Generation Process
The EASWG could not define this alternative and rejected it from further consideration. The EASWG determined the original EATF rejection justification was still valid. The EATF rejection justification states, "Scope too broad to be evaluated."

24 Add Anti-Bacterial Material
The EASWG determined that the original EATF rejection justification was still valid and that this EA would be rejected. Adding mercury was discussed and rejected due to the health hazards. The EASWG stated that adding hazardous materials to increase the safety of the repository was self defeating. The EATF rejection justification states, "Unable to identify a long-term, anti-bacterial material."

25 Accelerate Waste Digestion Process
The EASWG determined that the original EATF rejection justification was still valid and that this EA would be rejected. The EASWG discussed the experimental results for culturing digestive materials. The working group was not convinced that the WIPP environment could be controlled to the extent required by the digestion process. The EATF rejection justification states, "Technology for fast waste digestion not demonstrated."

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Engineered Alternatives Rejection List with Justifications

26 Alter Corrosion Environment
The EASWG concluded that this EA was not specific enough to evaluate. The technology was less than bench scale and has not been demonstrated. This concept is considered under other alternatives.

27 Alter Bacterial Environment in WIPP
The EASWG concluded that this EA is a duplicate of #24 which was deleted.

28 Transmutation of Radionuclides
The EASWG concluded that transmutation technologies are not feasible for TRU wastes, the process requires the segregation of the pure isotopes from the waste. If waste was placed directly in the reactor, activated (radioactive) materials would be generated. The EATF rejection justification states, "Technology not demonstrated for large amounts."

30 Salt Backfill Only
The EASWG concluded that this EA is a duplicate of #12.

31 Salt Backfill Plus Gas Getters
The EASWG concluded that this EA is a duplicate of #83.

32 Compact Backfill
The EASWG determined that this EA was considered under EA #12 and would not be evaluated further.

34 Preformed Compacted Backfill
The EASWG concluded that this alternative is considered under the salt backfill alternative and would not be evaluated further.

37 Add Gas Suppressant
The EASWG concluded that the original EATF rejection justification was still valid. The EATF rejection justification states, "This alternative was considered together with the 'Salt Plus Gas Getters' alternative, and therefore was not subject to separate evaluation."

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Engineered Alternatives Rejection List with Justifications

39 Segregate Waste in WIPP
The EASWG concluded that this EA was part of the baseline repository design. Load management is considered in the compliance documentation. The EASWG concluded that this EA does not meet the definition of an EA.

40 Decrease Amount of Waste per Room
The EASWG concluded that the original EATF rejection justification was still valid. The EATF rejection justification states, "This alternative was considered together with some of the backfill alternatives, and hence not evaluated separately."

41 Emplace Waste and Backfill Simultaneously
The EASWG concluded that this alternative is a subset of other backfill alternatives and was not evaluated separately.

42 Selected Vegetative Uptake
The EASWG determined that the process for vegetative uptake would not allow for proper containment of the alpha emitters. This process would require the waste to be placed in soil with plants. The EASWG determined the original EATF rejection was still valid. The EATF rejection justification states, "Not been laboratory demonstrated for TRU waste."

43 Brine Isolating Dykes
The EASWG determined that the isolation dykes configuration must be maintained to be effective. Room consolidation would alter the configuration and the EA would not be effective. The EA was not considered further.

44 Raise Waste Above the Floor
The EASWG determined that this is a short-term fix for along-term problem. The EA would provide no benefit and therefore would not be considered further. The EASWG also concluded that the original EATF rejection justification was still valid.

Engineered Alternatives Rejection List with Justifications

45 Brine Sump and Drains

The EASWG concluded that this EA is not effective since the required configuration cannot be maintained due to creep closure and rock mechanics of the repository. The EASWG also concluded that the original EATF rejection was still valid. The EATF rejection justification states, "This alternative was deleted because the EAMP (Engineered Alternatives Multidisciplinary Panel) believed that the flow paths leading to the sumps would not remain open long enough to allow substantial amounts of brine to be isolated from the waste."

46 Gas Expansion Volume

The EASWG concluded that this EA was detrimental to repository performance because the extra void volume allows for more stored energy and greater consequences during human intrusion scenarios. The EA was not considered further.

47 Seal Repository Room Walls

The EASWG determined that the rock mechanics of the repository precluded sealing. The technology has not been proven. Creep closure and interaction with the waste would be detrimental to the seal. The EASWG determined the original EATF rejection was still valid. The EATF rejection justification states, "The technology has not been demonstrated."

48 Vent Facility

The EASWG reviewed past data from the EATF data and the Design Analysis Model and determined that higher peak pressures would result for a vented facility. The EAMP also determined the original EATF rejection justification was still valid. The EATF rejection justification states, "Not regulatory feasible after institutional control" (period).

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Engineered Alternatives Rejection List with Justifications

49 Ventilate Facility

The EASWG reviewed data from the EATF and concluded that this alternative was not feasible due to both regulatory and technical concerns. Quoting the original EATF, "...regulatory concerns about maintaining active facility controls for such a long period (100 years), the difficulty of assuring continuous ventilation in all spaces, and the potential for rupturing the waste containers during the ventilation period. The difficulty of safely sealing the rooms and panels of the facility, after so many years of creep closure has taken place, was also considered. Also, ventilation might violate the RCRA "no migration" variance proposed for the WIPP." The EASWG concluded that this EA would not be evaluated further.

50 Add floor of Brine Sorbents

The EASWG determined that this EA is a duplicate of #44 which was deleted.

52 Change Room Configurations

The EASWG determined that this EA did not meet the definition of an EA and may be detrimental to the performance of the repository during a human intrusion scenario.

54 Two Level Repository

The EASWG determined that this EA did not meet the definition of an EA and may be detrimental to the performance of the repository during a human intrusion scenario.

55 Monument Forest Over Repository

The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

56 Monument Covering the Entire Repository

The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

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Engineered Alternatives Rejection List with Justifications

57 Buried Steel Plate Over the Repository
The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

58 Artificial Surface Layer Over the Repository
The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

59 Add Marker Dye to Strata
The EASWG concluded that this EA is a marker and not a barrier and does not meet the definition of an EA because it does not increase the performance or reduce the uncertainty in the performance calculations.

61 Grout Culebra Foundation
The EASWG concluded that grouting the Culebra could be detrimental to the performance of the repository. Technology was not considered feasible in part because the technology has not been demonstrated for this application, verification of the effectiveness is problematic, may create alternative pathways within the Culebre formation, and the long-term effectivity is unknown.

62 Increase Land Withdrawal Area
The EASWG concluded that increasing the area does not reduce the consequences of releases or increase the performance of the repository. Regulatory restriction on resource recovery within the new area would be problematic (resource lease acquisition).

65 EATF Baseline - As Received with Salt Backfill
The EASWG determined that this EA is a duplicate of #12, "Add Salt Backfill".

80 SPM-Baseline
The EASWG determined that the SPM baseline is the current repository baseline. The baseline case is not an alternative and is inherent in the analysis.

Engineered Alternatives Rejection List with Justifications

81 SPM-A Salt backfill
The EASWG concluded that this EA is a duplicate of #12, "Add Salt Backfill".

82 SPM-B Salt/Bentonite backfill 50-50 mix, 50% filling efficiency
The EASWG concluded that this EA is a duplicate of #22, "Salt Plus Clay Backfill".

84 SPM-D Cement grout backfill
The EASWG concluded that this EA is a duplicate of #35, "Salt Aggregate Grout Backfill".

85 SPM-E Salt/Grout backfill
The EASWG concluded that this EA is a duplicate of #35, "Salt Aggregate Grout Backfill".

86 SPM IT-1 Shred and cement organics and inorganics, salt backfill
The EASWG concluded that this EA is a duplicate of #66, "EATF Alternative 1".

88 SPM IT-3 Enhanced cement sludges, shred and cement organics and inorganics, salt aggregate grout backfill.
The EASWG concluded that this EA is a duplicate of #68, "EATF Alternative 3".

91 SPM IT-6 Enhanced cement sludges, shred and compact organics and inorganics, salt aggregate grout backfill, 2,000 drum monolayer, 6x33x300 room.
The EASWG concluded that this EA is a duplicate of #77, "EATF Alternative 12".

96 SPM EATF-8 Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP inventory), salt backfill, change waste container material.
The EASWG concluded that this EA is a duplicate of #73, "EATF Alternative 8".

97 SPM EATF-9 Vitrify sludges, shred and vitrify organics, melt metals with frit to partition actinides (metals are eliminated from the WIPP inventory), salt aggregate grout backfill, change waste container material.
The EASWG concluded that this EA is a duplicate of # 74, "EATF Alternative 9".

Engineered Alternatives Rejection List with Justifications

98 SPM DOE-1 Passive markers - no specific scenario given to reduce human intrusion probability parameters.
The EASWG concluded that this EA dos not meet the definition of an alternative. The proposed alternative is a marker and not a barrier. This alternative does not increase the performance nor reduce the uncertainty in performance assessment.

99 SPM DOE-2 Compartmentalization of waste - various unspecified scenarios.
The EASWG determined that this EA is inherent in several EAs and does not require further consideration in the analysis.

100 194- Cementation
The EASWG determined that this EA is inherent in several EAs and does not require further consideration in the analysis.

101 194- Shredding
The EASWG determined that this EA is inherent in several EAs and does not require further consideration in the analysis.

102 194- Supercompaction
The EASWG concluded that this EA is a duplicate of #1, "Compact Waste."

103 194- Incineration
The EASWG concluded that this EA is inherent in #2, "Incinerate and Cement" because incineration is not an EA alone. Incineration must be followed by a form of solidification to meet the particulate restriction in the a WAC.

104 194- Vitrification
The EASWG concluded that this EA is a duplicate of #3, "Shred and Vitrify Waste."

105 194- Improved Waste Containers
The EASWG concluded that this EA is a duplicate of #63, "Change Waste Container Shape" and #64, "Change Waste Container Material."

106 194- Grout and Bentonite Backfill
The EASWG determined that this EA is inherent in several EAs (#33 and #35) and does not require further consideration in the analysis.

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Engineered Alternatives Rejection List with Justifications

107 194- Metal Melting
The EASWG concluded that this EA is a duplicate of #11a and 11b, "Melt Metals."

108 194- Alternative Configuration of Waste Emplacement
The EASWG concluded that this EA is inherent in several other EAs and does not require further consideration in the analysis.

109 194- Alternative Disposal System Dimensions
The EASWG concluded that this EA is inherent to several other EAs and does not require further consideration in the analysis.

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APPENDIX E
DESCRIPTION OF THE DESIGN ANALYSIS MODEL

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DESCRIPTION OF THE DESIGN ANALYSIS MODEL

1.0 DESIGN ANALYSIS (COUPLED PROCESSES) MODEL

The components of the Design Analysis Model (DAM) are defined according to the physical barriers that will exist following waste emplacement at the Waste Isolation Pilot Plant (WIPP). These barriers and modeling regions are:

- Host rock and panel seals surrounding the rooms and drifts—The seven rooms and the equivalent volume of five and one-half rooms existing in the access drifts within a panel (12.5 room equivalents), are modeled on a collective basis to most accurately approximate the conditions within a disposal panel at each time step. The modeling is done using the ROOM-SCALE component of the DAM.

- Shaft and panel seals—The permeabilities of the seals are obtained as a function of time using the SHAFT-SEAL component of the DAM.

The DAM considers the processes that are essential to predicting changes in performance resulting from the application of alternative repository designs, waste forms, and backfills. The simulation by the DAM of the processes described in Section 3.1 is summarized below.

- Creep Closure of the Surrounding Host Rock—The Chabannes (1982) equation has been combined with a nonlinear regression equation based on several years of measured closure rates at 30 locations in the WIPP to predict creep closure rates of the host rock as a function of time. This equation expresses creep closure rates at each time step as a function of the room height, the room width, and the difference between lithostatic stress (14.8 MPa) and the internal stress in the panel. The internal stress is the sum of the effective stress of the waste/backfill composite and the fluid pressure inside the panel.

- Hydrogen Generation by Anoxic Corrosion—The dominant corrosion reaction is assumed to be the reaction of iron, usually in the form of mild steel, with water via one of the following two reactions (SNL/NM, 1991):

  1) $Fe + 2H_2O \rightleftharpoons Fe(OH)_2 + H_2$ E.1

  2) $3Fe + 4H_2O \rightleftharpoons Fe_3O_4 + 4H_2$ E.2

  These two reactions have differing stoichiometry; therefore, an average stoichiometry is derived as:

$$Fe + \frac{4+2x}{3}H_2O \rightleftharpoons \frac{4-x}{3}H_2 + xFe(OH)_2 + \frac{1-x}{3}Fe_3O_4 \qquad \text{E.3}$$

  where x mole fraction of iron is consumed by equation 1. The parameter x is assumed to have a uniform distribution between 0 and 1. The median value of

parameter x is reported as 0.5 (SNL/NM, 1993), resulting in an average reaction which generates seven moles of hydrogen for every ten moles of water consumed.

At each time step, brine in a disposal room (if available) is assumed to react with iron (or steel) to generate hydrogen at a rate of 0 to 0.6 moles of hydrogen per drum per year, depending on the percent saturation within the disposal panel (Brush, 1995). Any brine remaining at the end of a given time step is available for corrosion during the following time step. This corrosion process continues as long as brine (water) and corrodible metal are present in the panel. The corrosion process is self-limiting since the hydrogen that is generated contributes to the pressurization of the room, which in turn inhibits brine inflow.

- Microbial and Radiolytic Gas Generation—Microbial activity by a potentially broad range of microbes, which may be aerobic, anaerobic, halophilic, or halotolerant, is assumed to consume cellulosic materials and perhaps other organic materials in the waste as well. Since microbial activity and radiolysis utilize the same organic substrates, gas generation rates are assumed to represent both microbial and radiolytic gas generation. The total potential for microbial gas generation, along with the rate of generation, have been modeled based on the data provided in Brush (1995). The is based on the following assumptions:

  - Brine inflow is also necessary to sustain significant gas generation from microbial degradation of organic waste. Water is required to foster microbe growth, but it is not known whether microbe activity consumes or creates water. Therefore, it is assumed that microbial degradation results in gas generation without any effect on brine accumulation (Brush, 1995).

  - The gases generated during biodegredation are assumed to be methane, carbon dioxide, and nitrogen in the ratio of 15:20:12 (Lappin et al., 1989).

  - Microbial gas generation rates are assumed to vary from 0.1 to 1.0 moles of gas per drum per year, depending on the percent saturation within the disposal panels (Brush, 1995).

  - Based on the median stoichiometry for microbial gas generation presented in Sandia National Laboratories/New Mexico (SNL/NM) (1993), it is assumed that 0.835 moles of gas are generated for every one mole of cellulosics that are consumed.

- Dissolution of Gases in Brine—The moles of hydrogen, oxygen, and carbon dioxide dissolved in the brine present in a panel are evaluated at each time step. The moles of gas dissolved are calculated from phase equilibria relations using Henry's Law constants in brine (Reid et al., 1987). The Henry's Law constants and gas solubilities are evaluated from experimental correlations. The dissolution of nitrogen and methane is not considered since the brine already contains significant amounts of these gases (DOE, 1983).

- Brine Inflow—The following assumptions are made regarding brine flow into the disposal facility:

- An initial brine inflow rate of 0.597 cubic meters (m^3) per panel per year (Deal et al., 1994) is assumed. This is based on a constant room pressure of 1 atmosphere.

- The rate of brine inflow is assumed to linearly decrease as fluid (brine and gas) pressure in the room increases, and approaches zero when the pressure in the room reaches lithostatic pressure (14.8 MPa). Lithostatic rather than hydrostatic pressure is used since measurements of far-field pore pressures exceed hydrostatic (Lappin et al, 1989). This approach couples brine inflow to creep closure and gas generation, because all of these processes affect fluid pressure in the room, which in turn affects brine inflow.

- <u>CO_2/Brine/Cement Interactions</u>—Carbon dioxide (CO_2) generated by microbial or radiolytic processes will partition into any brine present in the room. This dissolved CO_2 will then react with portlandite to produce calcite plus water according to the reaction shown below. Portlandite is a major phase in Portland cement and is present in cementitious waste materials as well as sludges.

  - Carbon dioxide will react with portlandite (if present) to yield calcite and water according to the reaction:

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O \qquad \text{E.4}$$

  - The reaction rate is assumed to be proportional to the volume of free brine in the room, and the reaction stops when either all of the portlandite or the brine/water in the room is consumed.

  - At each time step, water that is generated by the above reaction is added to the total number of moles of water in the room, and portlandite that is destroyed by the above reaction is subtracted from the number of moles of portlandite in the room.

- <u>Diffusion of Gases into the Host Formation</u>—Since undisturbed Salado brines at lithostatic pressure have significant amounts of dissolved N_2 and CH_4 (DOE, 1983), it is assumed that diffusion of these gases is negligible due to the lack of concentration gradients necessary to drive diffusive transport. Diffusion H_2 and CO_2 into the host rock are considered.

- <u>Advection of Gases into the Host Formation, Across Seals, and into the Overlying and Underlying Anhydrite Beds</u>—The host formation, panel and shaft seals, and the intact anhydrite beds are modeled as parallel routes for the advection of gases out of the panel. The following assumptions and information are being used for modeling purposes:

  - The permeability of the intact halite ranges from 1×10^{-23} m^2 to 1×10^{-18} m^2 with an expected permeability of 3.4×10^{-21} m^2 (Rechard et al., 1990).

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- The permeability of the intact anhydrite beds is estimated to be 2 to 3 orders of magnitude greater than the halite (10^{-18} m^2), and as such is assumed to be the most probable pathway for gas advection (Lappin et al., 1989).

Other assumptions include:

- The halite between each room and the anhydrites is fractured such that there is hydrological communication between the rooms and the disturbed anhydrite units.

- The anhydrite beds above and below the repository are extensively fractured due to excavation of the drifts and panels, and therefore all rooms and drifts within each panel are in equilibrium with respect to gas pressure.

- The disturbed anhydrites above and below the repository are assumed to be saturated with brine at the time of WIPP decommissioning.

- The intact anhydrites, and the halite layers above and below the repository (outside the disturbed rock zone), are assumed to be saturated with brine at pore pressures of 10.36 MPa (70% of lithostatic) and 14.8 MPa (lithostatic), respectively. The pressures in the intact Salado are chosen to provide the largest driving force for brine migration as a modeling assumption. Since there are measured values of the pore pressure approaching lithostatic, it has been chosen as the value for the far-field pressure of the brine.

- When the panel fluid pressure exceeds the assumed intact anhydrite pore pressure, the brine in the disturbed anhydrite is assumed to be driven into the undisturbed anhydrite.

- The flow of brine from the disturbed anhydrites to the intact anhydrites and Salado layers, is assumed to be governed by Darcy's equation of flow through porous media.

- The volume from which the brine is expelled is assumed to provide an additional void volume for panel gases to occupy.

A program simulating two-phase flow is used to derive a parametric equation for the advection rate into the intact anhydrites when the panel fluid pressure exceeds 11.3 MPa [brine pore pressure of 10.36 MPa plus a threshold pressure of 0.94 MPa (Davies, 1989)]. Concurrently with gas advection into the anhydrites, the advection of panel gases into the four shaft seals (conductance varying with time) is also simulated. A viscosity correlation which is valid at both low and high pressures is used to estimate the viscosity of the gas mixture for use in the advection calculations.

- Gas Compressibility—The Lee-Kessler Equation of State (Reid et al., 1987) is used to estimate the compressibility of the gas mixture in a panel at each time step based in the mole fractions of each gas present. The fluid pressure is updated at each time step based on the resulting value of compressibility. The fluid pressure is then

used to estimate molar advection rates of gases, volume of brine inflow, creep closure rates, and gas solubilities in brine during the next time step.

- Waste/Backfill Composite Compaction and Resulting Mechanical Resistance to Closure—Stress/density relationships have been obtained for each waste form and backfill material from literature and experimental data. For each engineered alternative, an average density (based upon the mass fraction and density of each component) is calculated at various stress levels of compaction. The density of the waste/backfill composite is evaluated at each time step. The effective stress corresponding to this density is evaluated using the stress/density relationships of the composite. This effective stress is then used as input to the Chabannes equation (see discussion on creep closure above) as the mechanical component of resistance to creep closure.

- Development of a Zone of Enhanced Porosity Surrounding the Panel—The creep of the host rock creates an additional void volume within a zone of enhanced porosity which the panel gases will occupy. The rate and extent of creep closure will govern the magnitude of this void volume. This void volume is calculated at each time step as the product of the porosity of the Intact Salado (0.001) (Marietta et al., 1989, Table 3-9) and the difference between the initial panel volume and the panel volume at the current time step.

  - It is assumed that the zone of enhanced porosity does not contain brine.

  - It is assumed that all the pores in this zone are interconnected.

- Future Human Intrusion Into the Repository—Three human intrusion events (reference figure if there is one included in the report) were evaluated to determine the relative effectiveness of each engineered alternative in reducing radionuclide releases. The three scenarios, the modeling procedure for each scenario, and the assumptions behind them are described as follows:

  - The E1 scenario (Marietta et al., 1989) (see Figure 4-2) (SNL/NM, 1993) assumes a borehole penetration through a waste-filled panel and continuing into or through a pressurized brine pocket existing in the underlying Castile Formation. This event was modeled using a parametric equation relating flow rate through the waste/backfill composite to the hydraulic conductivity of the composite. This equation was developed by statistically regressing data resulting from a series of computer runs using the flow and transport code SWIFT III (Reeves et al., 1986).

    The modeling associated with the E1 scenario is performed on a room basis, since only the area surrounding the actual borehole allows the brine to come in contact with the waste. In order to verify this, the SWIFT III was used to determine the velocities of the fluid flow through the waste/backfill composite. A bounding brine velocity was chosen such that in 5,000 years a fluid particle would not be able to move a distance equal to the height of the room. This velocity defined a radius of influence used to calculate an effective wash-through volume. This volume was simulated as an ellipsoid, with the major axis along

the borehole and the other axes into the room. If the conductivity of the waste/backfill composite was such that the effective radius was greater than the width of the room, the width of the room was chosen for one of the axes since the halite was considered to be impermeable. The other axis was allowed to continue to the edge of the room, but in no case did the effective radius exceed half of the length of one room. The assumption of an infinite reservoir of brine in the Castile allows a constant pressure of 16 MPa to be prescribed for the brine pocket.

- The E2 scenario (Marietta et al., 1989) (see Figure 4-3) (SNL/NM, 1993) is one in the report for intrusion scenarios) assumes a borehole just penetrating into the repository, not passing through. This scenario is modeled using an analytical solution to the radial flow equation through a porous media, simulating the borehole and the panel as concentric circles. The halite is considered to be an impermeable boundary that is located at a sufficient distance to allow the volume of the cylinder to be the volume of a panel. Simplifying assumptions regarding the flow of gas and brine are made. In actuality, the gas phase would be located towards the top of the panel and the brine phase would be located towards the bottom of the panel. In fact, the amount of brine predicted by the model to be present in the panel at 5,000 years would not be enough to fill the borehole to reach the Culebra. The gas being less viscous and towards the top of the panel, would tend to escape preferentially to the brine, thereby reducing the room pressure.

  For the purposes of comparing EAs, a hypothetical "fluid" with the properties of brine is used. This fluid is comprised of the appropriate volumetric proportions of gas and brine, which are predicted by the model for each alternative. This fluid is assumed to saturate the room and be transported to the Culebra through the borehole. The amount of radionuclides within the brine portion of the fluid that is released are then compared for each alternative.

- The E1E2 scenario (Marietta et al., 1989) (see Figure 4-3) (SNL/NM, 1993) assumes a combination of the first two scenarios; two boreholes penetrate the repository in the same panel. One borehole provides a pathway for brine flow from the Castile brine pocket directly into the panel. This borehole is capped above the repository such that no brine can move vertically to the Culebra. The other borehole (occurring later in time) provides a pathway from the repository to the Culebra Dolomite. This pathway consists of a flow path through the panel from the E1 borehole to the E2 borehole. No credit is taken for any processes which may occur or change during the interim between the first and second boreholes. This scheme results in a pressurized flow path directly through a segment of the waste/backfill composite.

  The flow rate through the waste is obtained from an analytical solution to the one-dimensional flow equation through porous media, assuming the two boreholes are separated by the length of one room (300 feet [ft]; 91.44 m). Any effects of the pressure in the room being greater than the pressure of the Castile brine pocket, are neglected due to the assumption of an infinite brine pocket. It should be noted that the E2 scenario is a part of the E1E2 scenario. This

happens when the second borehole breaches the repository, potentially releasing any gases and brine initially located there. This is neglected because the amount of brine originally located in the panel would be extremely small in comparison to the volume produced from the Castile brine pocket.

The following assumptions have been applied to all human intrusion scenarios:

- The intrusion occurs 5,000 years after decommissioning.
- The diameter of the borehole is 0.355 m based upon a survey of current standard drilling practices in the Delaware Basin (SNL/NM, 1993).
- The hydraulic conductivity of the waste/backfill composite is the weighted geometric mean of the properties of the three types of waste and backfill.
- The borehole conductivity is 1×10^{-3} m/second (clean sand/gravel) obtained from Freeze and Cherry (1979, Table 2-2).
- Waste element solubilities are assigned from Attachment 1 of Appendix G (the table is in the Appendix on Radionuclide Solubilities) based on the pH of any brine present in the disposal facility.

The activity of each radionuclide at the time of intrusion is computed using the solutions to differential equations that represent mass balances for each radionuclide. Based upon the radionuclide solubilities in brine and the volume of brine released, the cumulative activity of each radionuclide released to the Culebra was determined. The objective of these human intrusion simulations is to calculate a number which is similar in functional form to the U.S. Environmental Protection Agency (EPA) Summed Normalized Release (EPA, 1993 [40 CFR 191]); the difference being that the DAM calculates the cumulative release of radionuclides into the Culebra. Alternately, the EPA Summed Normalized Release specifies calculation of the cumulative activity of each radionuclide across the regulatory boundary, and in addition, employs scenario probability weighting to each release (EPA, 1993).

The DAM does not consider probabilities of occurrence of scenarios; the scenario is assumed to occur and the effectiveness measure is evaluated. The value generated by the DAM is the singular raw score for the effectiveness of each alternative design. Calculation of the measure of relative effectiveness is performed by dividing the effectiveness measure for the alternative by the effectiveness measure for the baseline case (see Section 3.1.2). The baseline case uses "as received" waste with no backfill. "As received" waste is defined as follows:

- Sludges with some cement added as solidifying agents [i.e., current processes at the Rocky Flats Environmental Technology Site (RFETS) for Content Code 111], but not a concreted monolith (DOE, 1994b).
- Solid organics and inorganics are in unshredded form, wrapped in multiple layers of plastic, inside a 90-mil rigid liner in a steel drum [i.e., current packaging at RFETS and most other sites (DOE, 1994b)].

The improvement resulting from a waste form modification or a repository design alteration is determined by comparison with the baseline case. For the baseline case, the assumptions are as follows:

- Each room is assumed to be filled to capacity (considered to be 6,421 drums) with "as received" waste no backfill.

- The initial room dimensions used in the calculations are 13 feet (3.96 m) high by 300 feet (91.44 m) long by 33 feet (10.06 m) wide (Lappin et al., 1989).

- A two-foot high clearance is assumed to be left above the waste/backfill composite in all rooms and drifts in the panel.

- The panel capacity (including the seven disposal rooms and the surrounding access drifts) is assumed to be approximately 12.5 times the capacity of one individual room.

- The panel and shaft seals are assumed to be in place.

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APPENDIX F
PHYSICAL AND CHEMICAL PROPERTIES OF THE WASTE/BACKFILL COMPOSITE

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PHYSICAL AND CHEMICAL PROPERTIES OF THE WASTE/BACKFILL COMPOSITE

1.0 INTRODUCTION

Quantitative estimates of physical and chemical properties for the combination of waste forms and backfill, when present, are required for the Design Analysis Model (DAM) to determine the relative effectiveness of each engineered alternative. In this section, the term "properties" refers to the physical and chemical properties of a homogeneous "composite" material consisting of the various waste forms (solid organics, solid inorganics, and sludges) and backfill material when present. The properties of a particular Engineered Alternative (EA) are in most cases unique to that alternative; in some cases, similarities occur from one alternative to another. Properties of the composite such as density, porosity, hydraulic conductivity, and effective waste volume, are quantified as a function of compaction stress level and are used in the DAM to predict the long-term performance of the disposal system under undisturbed conditions as well as human intrusion events.

The following sections briefly list the properties developed (Section 1.2), discuss the assumptions made in developing properties for the baseline case and for each of the EAs (Section 1.3), sources of data (Section 1.4), and finally, the quantification of the properties (Section 1.5 and 1.6).

Some of the important properties are coupled; an example is hydraulic conductivity and permeability. Assuming a fixed value for permeability, a mathematical relationship exists to determine hydraulic conductivity. Density and porosity are similarly related.

2.0 COMPOSITE PHYSICAL AND CHEMICAL PROPERTIES

The development of physical and chemical properties for each alternative assumes the waste composite to be a homogeneous mixture. Five physical and chemical properties of the composite as a function of time or stress, are required as input to the DAM.

- Density
- Porosity
- Hydraulic conductivity
- Gas generation potential
- Effective waste volume.

These properties are discussed in more detail in Section 1.6.

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3.0 WASTE FORM DISTRIBUTION

The effectiveness of each of the various EAs is evaluated relative to the baseline case. The baseline case is defined as waste treated to the Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria (WAC) that is emplaced in the current panel design with no backfill. "As received" waste composition is assumed to comply with the Butcher (1989) classification of the waste destined for the WIPP, which can be generalized into the three major waste form categories.

The three major waste forms comprise the majority of the stored and projected contact handled transuranic (CH-TRU) waste inventories. On a volumetric basis, the proportions of the three major waste forms for the baseline case are assumed [based on the WIPP Transuranic Waste Baseline Inventory Report (WTWBIR) (DOE, 1995d)] to be:

- 44.5 Percent Solid Organics
  Comprised of:
  - Combustible waste
  - Filter waste
  - Heterogeneous waste
  - Solidified organic waste

- 23.0 Percent Solid Inorganics
  Comprised of:
  - Inorganic non-metal waste
  - Lead/Cadmium metal waste
  - Uncategorized metal waste
  - Graphite waste
  - Salt waste
  - Soil waste

- 32.5 Percent Sludges
  Comprised of:
  - Solidified Inorganic waste

These proportions were developed from the inventory descriptions in the WTWBIR (DOE, 1995d) by grouping waste types with similar physical properties. This proportional distribution for the baseline case is maintained for comparison of each alternative studied, ensuring no calculational bias. Specifying this ratio reduces the number of sensitivity runs necessary to establish the relative effectiveness of the EAs. In addition to the proportional distribution of waste forms, the initial volume of waste contained in a disposal room is assumed constant. Based on the overall capacity of the WIPP repository and the planned room and panel layout, the WIPP underground is assumed to have eight panels for TRU waste and sufficient capacity within the main access drifts to equal two additional panel volumes. Each panel consists of seven waste rooms and two panel access drifts which have a capacity equal to 5.54 additional waste room volumes. Therefore, each panel has 12.54 equivalent waste room volumes. Each "room equivalent" is assumed to contain 6,421 55-gallon drums (or equivalent) of CH-TRU waste.

The initial conditions for the baseline case waste distribution parameters are listed in Table F-1. These values, along with the density of each component as a function of stress (from creep closure), are used in computing the composite physical and chemical properties.

4.0 DATA DEVELOPMENT FOR ENGINEERED ALTERNATIVES

The EAs investigated here are made up of components which include waste treatment methodologies, various backfill material options, and waste emplacement configurations. The following subsections present the data for each of the components used for the computation of the properties for the waste composite. The raw data necessary for computation of waste composite properties were obtained from the previous Engineered Alternative Task Force Report (DOE, 1991), the WTWBIR (DOE, 1995d), and Butcher, et al. (1991).

4.1 Waste Treatments

Waste treatment components of the EAs involve the modification of the physical properties of the waste. Treatment of the CH-TRU waste may also lead to a change in total waste volume to be handled and emplaced in the WIPP underground. Details of the five waste treatment processes, that are components of the EAs investigated in this report, are presented below. The waste treatment processes are supercompaction, shredding, low-force compaction, plasma melting, enhanced cementation of sludges, and adding clay. The effects of each waste treatment process on the physical properties of the composite is also presented.

4.1.1 Supercompaction

The supercompaction process is modeled after the Supercompaction and Repackaging Facility (SARF) which is in operation at the Rocky Flats Environmental Technology Site (RFETS) (DOE 1995c). Only solid organic and solid inorganic wastes are suitable for supercompaction (sludges are excluded).

In preparation for supercompaction, waste is first emptied into a glovebox where it is sorted to remove items which cannot be supercompacted. Items suitable for supercompaction are then compacted into a 132-liter (35-gallon) drum using a low-force (30 metric ton) compactor. The compacted 132-liter (35-gallon) drums are then transferred to the supercompactor. The supercompactor applies a high force (1,500 to 2,000 metric tons) to the 132-liter (35-gallon) drum, called a "puck", to compact the waste material into a smaller volume. The compacted pucks are then transferred to a 208-liter (55-gallon) drum for final packaging to WIPP WAC requirements. On average, 4 pucks can be packaged into each 208-liter (55-gallon) drum. The volume reduction ratio for supercompaction is assumed to be 2.9 : 1. A slight increase in waste mass occurs due to the additional packaging (the 132-liter drums), resulting in a mass increase factor of 1.1. The final waste density is assumed to be 1679 kg/m^3 (104.8 lb/ft^3), compared to an initial density of approximately 534 kg/m^3 (33.3 lb/ft^3). Supercompacted waste materials exhibit the following:

- Lower effective hydraulic conductivity
- Lower total volume of CH-TRU waste.

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TABLE F-1

WASTE QUANTITIES FOR THE BASELINE CASE

Waste Form	Total Mass[1] (kg)	Total Volume[1] (m^3)	Initial Density[1] (kg/m^3)	Drums per Room Equivalent[2]
Solid Organics	47,234,933	74,339	635	2,857
Solid Inorganics	13,007,073	38,396	339	1,477
Sludges	30,921,720	54,389	569	2,087
Total	91,163,726	167,124		6,421

[1]Total mass, total volume, and initial density are from Appendix O.
[2]The number of drums is computed from the distribution of the waste forms and the total number of drums per room.

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4.1.2 Shredding

The shredding process is modeled after commercially available equipment that has been successfully used for low-level waste and TRU waste (Moghissi et al., 1986; Owens, 1995). Only solid organic and solid inorganic wastes are suitable for shredding.

The shredding procedure assumed for alternative evaluations consists of making multiple passes through multiple shredders such that no individual waste item has a dimension greater than 4 inches. Waste material is the primary target of the shredding operation, although a fraction of the waste containers (boxes and drums) may also require this processing technique. Shredding some of the waste containers and repackaging them results in a small mass increase factor of 1.1. Shredded waste materials and containers exhibit the following:

- Improved compaction capability
- Lower effective hydraulic conductivity (especially after compaction)
- Improved strength.

4.1.3 Low-Force Compaction

Low-force compaction consists of compacting waste (typically shredded waste) into a 208-liter (55-gallon) drum using a low-force (30 metric ton) compactor. This process is repeated, adding more waste to the drum and compacting it, until the drum is full. The volume reduction ratio for compaction, in conjunction with shredding the waste first, is assumed to be 1.3 : 1. Low-force compacted waste materials exhibit the following:

- Lower effective hydraulic conductivity
- Lower total volume of CH-TRU waste.

4.1.4 Plasma Processing

The plasma melting treatment system is modeled after the Plasma Arc Centrifugal Treatment (PACT) system. The PACT was developed by Retech, Inc., and is currently being implemented by Lockheed Martin Environmental Systems and Technologies, Co. as part of the Pit 9 Comprehensive Demonstration (LESAT, 1995) at the Idaho National Engineering Laboratory. Plasma processing may be performed to all waste types (solid organics, solid inorganics, and sludges). To achieve optimum operations, it is desirable to process sludges, solid organic, and solid inorganic wastes simultaneously (Nielsen, 1995).

The plasma processing is accomplished with the use of a transferred arc plasma torch operating in an oxygen-rich environment. The operation of the torch in this environment will bring the waste to a molten state, destroy any organic materials, and oxidize or immobilize any heavy metals. The molten slag will then be poured into 208-liter (55-gallon) drums and allowed to cool. The slag is assumed to have varying amounts of entrained air in the form of bubbles. Due to weight limitations for transportation of 55-gallon drums, the drums may not be filled completely, leaving a void space above the slag. Upon cooling, the final molten slag becomes a non-leachable "glass". Plasma melting results in a volume reduction ratio of approximately 3 : 1 (Nielsen, 1995). Final waste form is assumed to have a bulk density of 1,610 kg/m^3 (100.5 lb/ft^3) (including the

entrained air and void space in the drum) compared to an initial average bulk density of 534 kg/m^3 (33.3 lb/ft^3). Plasma melted waste materials and containers exhibit the following:

- Significantly lower effective hydraulic conductivity
- Destruction of organic materials which reduces the gas generation potential
- Oxidation or immobilization of heavy metals.
- Increased strength of composite.

4.1.5 Add Clay

Non-swelling clay (granular or pelletized illite or kaolinite) will be added to the waste to reduce the void spaces in the final waste form. The clay is mixed with the waste and placed into 208-liter (55-gallon) drums. It is assumed that the clay will fill 80% of the initial void volume in the waste package. It is also assumed that there will be no net change to the waste volume (i.e., treatment of one drum of waste results in one drum of treated waste). The final density of the waste is assumed to be 78.5 lb/ft^3 compared to an initial average density of 33.3 lb/ft^3. The mass increase factor due to the addition of the clay is 2.35. The density of the clay pellets added to the waste is assumed to be approximately 1,040 kg/m^3 (65 lb/ft^3) based on information from clay suppliers. Waste materials with clay added exhibit the following:

- Lower effective hydraulic conductivity
- Lower initial void volume.

4.2 Backfills

Backfills as components of the EAs involve the emplacement of earthen or cementitious materials between and around the CH-TRU waste containers. Backfills do not affect the physical properties of the waste but do have an effect on the properties of the waste composite. By both, volume and mass, backfill will typically account for a large proportion of the waste/backfill composite material. The five backfill components presented as part of these EAs are a sand and clay mixture, a salt aggregate based grout, a cementitious grout, a crushed salt and calcium oxide mixture, and a 100% clay based backfill. Details of the five backfills and their physical properties are presented below.

4.2.1 Sand and Clay Mixture Backfill

A backfill consisting of a mixture of medium grained sand and granulated clay is placed around the waste stack and between the drums filling the void space within the rooms. The backfill is 70% sand and 30% clay by volume. The clay is commercially available granulated or pelletized kaolinite or illite having a bulk density of approximately 1,040 kg/m^3 (65 lb/ft^3). Because of the inefficiencies associated with pneumatically placing a dry fine to medium grained material, a filling efficiency of 50% is assumed.

The sand plus clay backfill is placed to a height of approximately 0.6 m (2 ft) above the top of the waste stack (SNL/NM, 1991) and will fill the space between the waste drums and the room walls (approximately 0.5 m). The total volume of backfill material for the entire underground is approximately 103,500 m^3 (3,655,000 ft^3) filling an available backfill void volume of 207,000 m^3 (7,310,000 ft^3) at a 50% filling efficiency. This translates to 827 m^3 (29,200 ft^3) of backfill material per room equivalent into an available backfill void volume of 1,654 m^3 (58,400 ft^3). The initial

density of the sand plus clay backfill is 1,590 kg/m^3 (99.2 lb/ft^3) at a porosity of 40%. The density and porosity change as the load on the backfill increases due to creep closure to a final density of 1,855 kg/m^3 (115.8 lb/ft^3) and a porosity of 30% at 2,200 psi stress. The hydraulic conductivity of the sand plus clay backfill is expected to range from 6 x 10^{-7} m/second (s) at 0 psi stress to 9 x 10^{-9} m/s at 2,200 psi stress.

The sand plus clay backfill will perform as follows:

- Reduces the hydraulic conductivity of the backfill/waste composite initial void
- Reduces the initial void volume of the room.

4.2.2 Salt Aggregate Grout Backfill

A cementitious based grout backfill using crushed salt as the aggregate and simulated WIPP brine as the added water (Gulick and Wakeley, 1989), is pumped around the waste stack and between the drums filling the void space within the rooms. Some inefficiencies will occur in placing the grout backfill so a filling efficiency of 80% is assumed.

The grout backfill is placed to a height of 0.6 m (1.89 ft) above the top of the waste stack (SNL/NM, 1991) and will fill the space between the waste drums and the room walls (approximately 0.5 m). The total volume of backfill material for the entire underground is approximately 166,000 m^3 (5,862,000 ft^3) filling an available backfill void volume of 207,000 m^3 (7,310,000 ft^3) at an 80% filling efficiency. This translates to 1,323 m^3 (46,720 ft^3) of grout material per room-equivalent into an available backfill void volume of 1,654 m^3 (58,400 ft^3). The initial density of the salt aggregate grout backfill is 1,884 kg/m^3 (117.6 lb/ft^3) at a porosity of 31.3%. Because of the grout's inherent strength, the density and porosity will not change as the load on the backfill increases due to creep closure. The hydraulic conductivity of the salt aggregate grout backfill is assumed to be constant over all expected stresses at 1.3 x 10^{-12} m/s.

The high salt content will allow the grout to maintain plastic properties under the constant lithostatic load. This will ensure that the grout will not chemically degrade or fracture during the 10,000-year period of performance.

The salt aggregate grout backfill:

- reduces the hydraulic conductivity of the backfill/waste composite
- is chemically compatible with the WIPP brine and surrounding salt.

4.2.3 Cementitious Grout Backfill

A cementitious grout backfill using ordinary Portland cement, sand aggregate, and fresh water, is pumped around the waste stack and between the drums filling the void space within the rooms. As with the salt aggregate grout backfill, some inefficiencies will occur in placing the grout backfill so a filling efficiency of 80% is assumed.

The cementitious grout backfill, as with the other backfills, is placed to a height of approximately 0.6 m (2 ft) above the top of the waste stack (SNL/NM, 1991), between the waste drums, and along the room walls. The material properties, including density, porosity, and hydraulic

conductivity, of the cementitious grout backfill are assumed to be the same as that of the salt aggregate grout backfill.

The cementitious grout backfill will perform as follows:

- Reduces the hydraulic conductivity of the backfill/waste composite.
- Increases the strength of the backfill/waste composite
- Reduces the initial void volume
- Increases the pH of the brines in the repository environment which lowers the radionuclide solubility.

4.2.4 Crushed Salt and Calcium Oxide Mixture Backfill

A backfill consisting of commercially available granulated CaO (quick lime) and crushed salt aggregate is pneumatically placed around the waste stack and between the drums filling the void space within the rooms. The mixture consists of less than 10% CaO and 90% crushed salt aggregate. Because of the inefficiencies associated with pneumatically placing a dry material, a filling efficiency of 50% is assumed.

The crushed salt and CaO backfill, as with the other backfills, is placed to a height approximately 0.6 m (2 ft) above the top of the waste stack (SNL, 1991), between the waste drums, and along the room walls. The total volume and the volume per room of the crushed salt plus CaO backfill are assumed to be the same as for the sand plus clay backfill presented above. Since the mixture is predominantly crushed salt, the properties of a crushed salt aggregate backfill are assumed. The initial density of the crushed salt backfill is 1,193 kg/m^3 (74.4 lb/ft^3) at a porosity of 44.8%. The final density and porosity at 2,200 psi stress is assumed to be 1,960 kg/m^3 (122.3 lb/ft^3) and 9.3%, respectively. The hydraulic conductivity of the CaO and crushed salt backfill is assumed to range from approximately 7×10^{-2} m/s at 0 psi stress to approximately 1×10^{-11} m/s at 2,200 psi stress.

The crushed salt plus CaO backfill will perform as follows:

- Reduces the hydraulic conductivity of the backfill/waste composite
- Increases the pH of the brines in the repository environment which lowers the radionuclide solubility
- Is chemically compatible with the WIPP underground environment.

4.2.5 Clay Based Backfill

A backfill consisting of commercially available granular or pelletized kaolinite or illite clay (DOE, 1995a) is place pneumatically around the waste stack and between the drums at a filling efficiency of 50%. The initial density of the emplaced clay backfill is approximately 1,000 kg/m^3 (62.4 lb/ft^3) at a porosity of 62.5%. After consolidation at a stress of 2,200 psi due to creep closure, the clay backfill will reach a final density of 1,610 kg/m^3 (100.5 lb/ft^3) at a porosity of

39.7%. The hydraulic conductivity of the clay based backfill is assumed to range from 1×10^{-10} m/s at 0 psi stress to 2×10^{-13} m/s at 2,200 psi stress.

The clay based backfill will perform as follows:

- Reduces the hydraulic conductivity of the backfill/waste composite
- Reduces the initial void volume.

4.3 Emplacement Configurations

Two emplacement configurations are considered as components to the EAs. The differences between the two configurations are the room height and the number of drums of waste per layer within a waste emplacement room. The configurations are presented below.

4.3.1 Baseline in 13 x 33 x 300 ft Rooms

The baseline configuration assumes a waste emplacement room (or room equivalent) to be 13 ft high by 33 ft wide by 300 ft long, with waste containers stacked up to three layers high for a maximum of 6,421 drums per room equivalent. Because it is assumed that the overall radionuclide inventory within a panel cannot be greater than the inventory in the baseline engineered alternative, some of the EAs will have less than 6,421 drums of treated waste per room, resulting in waste containers being stacked less than 3 high. This configuration is still considered the baseline emplacement configuration since the room dimensions and available volume do not change.

4.3.2 Monolayer in 6 x 33 x 300 ft Rooms

The monolayer emplacement configuration assumes waste containers are emplaced in a single layer in a room that is 33 ft wide by 300 ft long but only 6 ft high. Only 2,000 drums are placed in the single layer for this configuration. This emplacement configuration is only used in the 77-series of EAs.

5.0 PHYSICAL/CHEMICAL PROPERTY CALCULATION METHODOLOGY

Initial calculations supply input values for a spreadsheet designed to compute physical/chemical properties of the waste/backfill composite on a per-room or panel basis. Therefore, generating the effective properties resulting from a given combination of engineered alternative components is reduced to specifying the basic input values for that EAs in the spreadsheet. Data files are then generated in the spreadsheet. The default values in the spreadsheet are those corresponding to the baseline case.

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Spreadsheet input parameters are listed below:

- The distribution of waste components in an average room. This distribution is dependent on the number of drums of each waste form component (solid organics, solid inorganics, and sludges) present.

- The average weight per drum of each waste form.

- Volume reduction factors, which are unique to the particular engineered alternative, and to the unprocessed waste form. They allow computation of the equivalent drum count, which is the number of unprocessed drums required to produce a processed drum of waste for the particular engineered alternative. The number of processed drums per room equivalent for each of the EAs is presented in Table F-2.

- The average height of the waste stack. Because it is assumed that the overall radionuclide inventory within a panel cannot be greater than the inventory in the baseline case, some of the EAs will have less than 6,421 drums of treated waste per room, resulting in waste containers being stacked less than 3 high. The average height of the waste stack is determined by multiplying the height of the waste stack for the baseline case (2.676 m) by the fraction of the number of drums per room equivalent for the engineered alternative relative to the baseline case (6,421 drums per room equivalent).

- The total volume of backfill (if present), volume of backfill within the waste stack, and void volume within the waste stack. The void volume within the waste stack is an estimation of the void space within the waste stack resulting from inefficiency in the backfilling process. The void volume is used to estimate an initial waste stack density. The total volume of backfill is utilized in the computation of waste/backfill composite density. The volume of backfill within the waste stack is used in the computation of hydraulic conductivity of the waste/backfill composite.

- The density variations of each waste or backfill component as a function of closure stress, from 0 psi (0 MPa) to lithostatic pressure (approximately 2,200 psi [15 MPa]) in 200 psi (1.35 MPa) increments. The waste or backfill component density values are used in the computation of waste/backfill composite density, porosity, and hydraulic conductivity of the room contents.

The effects of an EA on the waste/backfill composite properties are calculated with a computer spreadsheet. To compute physical and chemical properties of an EA, only those input values which deviate from the baseline case need to be modified in the spreadsheet. The remaining input variables are therefore unaltered from the baseline case. Some EAs require no computation of various properties (eg., cement based grout backfill is considered incompressible and therefore has a constant density and hydraulic conductivity). The hydraulic conductivity of a cement grout backfill would be considered a fixed input value for all closure stress levels. This spreadsheet computational methodology is used to evaluate the properties of each EA.

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TABLE F-2

DRUMS PER ROOM EQUIVALENT FOR EACH ENGINEERED ALTERNATIVE

Engineered Alternative	Number of Drums per Room Equivalent
Baseline Case	6,421
Alternative 1, Supercompact Solid Organics and Solid Inorganics	3,604
Alternative 6, Shred and Compact Solid Organics and Solid Inorganics	5,381
Alternative 10, Plasma Processing	2,120
Alternative 33, Sand Plus Clay Backfill	6,421
Alternative 35a, Salt Aggregate Grout Backfill	6,421
Alternative 35b, Cementitious Grout Backfill	6,421
Alternative 77a, Supercompact, Monolayer of 2000 Drums, Salt Aggregate Grout Backfill	2,000[1]
Alternative 77b, Supercompact, Monolayer of 2000 Drums, Clay Based Backfill	2,000[1]
Alternative 77c, Supercompact, Monolayer of 2000 Drums, Sand Plus Clay Backfill	2,000[1]
Alternative 77d, Supercompact, Monolayer of 2000 Drums, Crushed Salt Plus CaO Backfill	2,000[1]
Alternative 83, Crushed Salt Plus CaO Backfill	6,421
Alternative 94a, Enhanced Cementation, Shred and Add Clay, No Backfill	6,421[2]
Alternative 94b, Enhanced Cementation, Shred and Add Clay, Sand Plus Clay Backfill	6,421[2]
Alternative 94c, Enhanced Cementation, Shred and Add Clay, Cementitious Grout Backfill	6,421[2]
Alternative 94d, Enhanced Cementation, Shred and Add Clay, Salt Aggregate Grout Backfill	6,421[2]
Alternative 94e, Enhanced Cementation, Shred and Add Clay, Clay Based Backfill	6,421[2]
Alternative 94f, Enhanced Cementation, Shred and Add Clay, Crushed Salt Plus CaO Backfill	6,421[2]
Alternative 111, Clay Based Backfill	6,421

[1]2,000 drums per room defined by alternative. This alternative does not provide adequate space for all of the CH-TRU waste and leaves approximately 200,170 drums of waste outside of the WIPP.
[2]The enhanced cementation process increases the total waste volume above the WIPP capacity volume. Approximately 130,600 drums of CH-TRU waste are left outside of the WIPP.

6.0 QUANTIFICATION OF PHYSICAL AND CHEMICAL PROPERTIES

The physical and chemical properties used in the DAM are evaluated over the range of closure stress expected in the repository. The properties of primary importance are as follows

- Density
- Porosity
- Hydraulic conductivity
- Gas generation potential
- Effective waste volume.

The waste composite in the WIPP repository is assumed to contain up to four components. These components consist of the backfill material and the three major categories of waste (solid organics, solid inorganics, and sludges) which may be treated in some manner. The physical and chemical properties of each component will be dependent on the particular engineered alternative being considered. The methodologies and assumptions used to characterize these properties are detailed in the following sections.

Although material compressibility is not a DAM input property, it is a useful parameter upon which to base simplifying assumptions. Material compressibility is used to estimate the effects of creep closure on the physical properties of the waste composite. Waste and backfill materials in the WIPP repository will be subjected to triaxial compressive forces. Compressibility of these materials will affect all physical properties. The extent to which different materials consolidate is largely dependent on the strength of the bulk material. Treated wastes such as enhanced cemented sludges or vitrified glass have compressive strengths in excess of lithostatic pressure of 2,200 psi (14.8 MPa), and are assumed to be incompressible under the stresses expected in the repository.

It is important to note that effects of time on the physical properties of the waste composite are not considered in this analysis. Long-term (10,000 years) effects such as fatigue and degradation are not well quantified and are therefore considered inappropriate for these generalized calculations. Therefore, the density, porosity, and hydraulic conductivity of portland cement based materials used as backfill or sludge solidification are assumed to remain constant during the 10,000 year operating life of the WIPP.

6.1 Density

Density of the waste/backfill composite at any given stress level can be computed from the density of the individual components at that same stress level. The mass of each waste component is obtained from the mass distribution of the three major waste forms defined by Butcher, et al. (1991). The quantity of backfill is estimated from repository room design specifications from SNL/NM's performance assessment modeling (SNL/NM, 1991). Total mass for each alternative is assumed constant over the 10,000-year period for the computation of waste/backfill composite densities. This assumption simplifies the density calculations. It is understood that waste/backfill composite mass fluxes resulting from gas production/dissipation, and brine transport will vary the waste/backfill composite mass (e.g., by chemical degradation, physical erosion, and subsequent mass transfer into and out of the waste stack), though the extent to which these processes will occur is not well defined. Initial component volumes are

known from the baseline design criteria, thus initial waste/backfill composite density is readily quantified.

The waste/backfill composite density resulting from EA evaluations may or may not increase during the consolidation process. For the baseline case, waste component densities as a function of stress level were obtained from Butcher et al. (1991). The methodology of computing density of a multicomponent system is outlined in Butcher et al. (1991). This method utilizes component densities (or mass and volume) to compute waste/backfill composite density. Implicit in the calculation is the assumption that the components act independently.

The formulation can be summarized as follows; the volume occupied by component i at some stress level x is:

$$V_i(x) = \frac{M_i}{D_i(x)} \tag{3.6-1}$$

where,

$V_i(x)$ = *volume of component "i" at stress level x*
M_i = *mass of component "i"*
$D_i(x)$ = *density of component "i" at stress level x.*

The total waste/backfill composite volume at stress level x is the sum of the component volumes:

$$TV(x) = \sum_{i=1}^{n} V_i(x) \tag{3.6-2}$$

where,

TV(x) = total waste/backfill composite volume at stress level x.

The total waste/backfill composite mass is the sum of the "n" component masses, or:

$$TM = \sum_{i=1}^{n} M_i \tag{3.6-3}$$

where,

TM = the total waste/backfill composite mass.

Therefore, the waste/backfill composite density at stress level x can be computed as follows:

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$$RD(x) = \frac{TM}{TV(x)} = \sum_{i=1}^{n} \frac{TM}{(M_i/D_i(x))} \qquad (3.6\text{-}4)$$

where,

RD(x) = density of waste/backfill composite at stress level x.

Equation 1.6-4 can be simplified by introducing a component weight fraction, W_i:

$$W_i = \frac{M_i}{TM} \qquad (3.6\text{-}5)$$

After dividing the numerator and denominator of equation 3.6.4 by TM, the expression for the waste/backfill composite density becomes:

$$RD(x) = \sum_{i=1}^{n} \frac{1.0}{(W_i/D_i(x))} \qquad (3.6\text{-}6)$$

In summary, waste/backfill composite density was computed at a given stress level by:

- Using densities as a function of stress level and weights for each component
- Utilizing the experimental densities of individual components such as metal, glass, sorbents and combustibles (all under pressure) as reported by Butcher et al. (1991)
- Using component mass proportions.

Table F-3 contains waste/backfill composite densities as a function of stress for each of the EAs analyzed using the DAM.

6.2 Porosity

Porosity is a measure of void space existing in a material and is defined as the ratio of void volume to total volume of the material. Within the repository, the waste/backfill composite porosity is dependent on waste characteristics, backfill materials (if present), efficiency of waste packaging, efficiency of backfill emplacement, and the extent to which these materials compact during the consolidation process. Computation of waste/backfill composite porosity (assuming constant mass) can be made on either a volume or density basis (Butcher, 1989), for example:

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TABLE F-3

COMPOSITE DENSITIES FOR ENGINEERED ALTERNATIVES
(pounds/cubic inch)

Stress (psi)	Baseline	Alt. 1	Alt. 6	Alt. 10	Alt. 33	Alt. 35a	Alt. 35b	Alt. 77a	Alt. 77b	Alt. 77c	Alt. 77d	Alt. 83
0	0.0107	0.0203	0.0136	0.0315	0.0325	0.0427	0.0427	0.0555	0.0324	0.0447	0.0364	0.0266
0	0.0197	0.0375	0.0251	0.0581	0.0378	0.0452	0.0452	0.0582	0.0366	0.0505	0.0411	0.0309
200	0.0437	0.0699	0.0605	0.0953	0.0534	0.0610	0.0610	0.0685	0.0474	0.0609	0.0605	0.0517
400	0.0549	0.0822	0.0822	0.1042	0.0580	0.0649	0.0649	0.0706	0.0525	0.0638	0.0657	0.0583
600	0.0618	0.0839	0.0839	0.1095	0.0606	0.0667	0.0667	0.0709	0.0553	0.0649	0.0678	0.0621
800	0.0672	0.0854	0.0854	0.1142	0.0625	0.0679	0.0679	0.0711	0.0576	0.0658	0.0697	0.0652
1000	0.0716	0.0864	0.0863	0.1175	0.0642	0.0688	0.0688	0.0712	0.0597	0.0667	0.0709	0.0674
1200	0.0754	0.0872	0.0872	0.1204	0.0657	0.0695	0.0695	0.0713	0.0614	0.0676	0.0721	0.0694
1400	0.0787	0.0879	0.0879	0.1229	0.0670	0.0701	0.0701	0.0714	0.0628	0.0684	0.0731	0.0711
1600	0.0818	0.0885	0.0885	0.1250	0.0683	0.0705	0.0705	0.0715	0.0638	0.0693	0.0739	0.0725
1800	0.0845	0.0890	0.0890	0.1270	0.0696	0.0709	0.0709	0.0716	0.0651	0.0701	0.0745	0.0737
2000	0.0870	0.0895	0.0895	0.1289	0.0707	0.0713	0.0713	0.0717	0.0658	0.0709	0.0754	0.0750
2200	0.0895	0.0900	0.0900	0.1308	0.0719	0.0716	0.0716	0.0717	0.0666	0.0717	0.0759	0.0761
Solid	0.1158	0.1171	0.1171	0.1469	0.1004	0.1021	0.1021	0.1023	0.1030	0.1004	0.0873	0.0875

TABLE F-3 (Continued)

COMPOSITE DENSITIES FOR ENGINEERED ALTERNATIVES
(pounds/cubic inch)

Stress (psi)	Baseline	Alt. 94a	Alt. 94b	Alt. 94c	Alt. 94d	Alt. 94e	Alt. 94f	Alt. 111
0	0.0107	0.0146	0.0357	0.0458	0.0458	0.0269	0.0298	0.0237
0	0.0197	0.0269	0.0415	0.0486	0.0486	0.0313	0.0347	0.0276
200	0.0437	0.0352	0.0477	0.0547	0.0547	0.0378	0.0456	0.0414
400	0.0549	0.0384	0.0500	0.0566	0.0566	0.0412	0.0489	0.0473
600	0.0618	0.0402	0.0515	0.0576	0.0576	0.0435	0.0510	0.0512
800	0.0672	0.0415	0.0526	0.0583	0.0583	0.0452	0.0526	0.0543
1000	0.0716	0.0425	0.0536	0.0588	0.0588	0.0468	0.0537	0.0571
1200	0.0754	0.0433	0.0544	0.0592	0.0592	0.0481	0.0547	0.0594
1400	0.0787	0.0439	0.0552	0.0595	0.0595	0.0491	0.0556	0.0613
1600	0.0818	0.0445	0.0559	0.0598	0.0598	0.0499	0.0563	0.0629
1800	0.0845	0.0450	0.0567	0.0600	0.0600	0.0508	0.0569	0.0646
2000	0.0870	0.0454	0.0573	0.0602	0.0602	0.0513	0.0575	0.0657
2200	0.0895	0.0457	0.0579	0.0604	0.0604	0.0519	0.0580	0.0669
Solid	0.1158	0.1181	0.1022	0.1034	0.1034	0.1051	0.0905	0.1029

On volume basis:

$$Porosity = \frac{(V_{total} - V_{solid})}{V_{total}} \tag{3.6-7}$$

On density basis:

$$Porosity = 1 - \frac{(composite\ density)}{(composite\ solid\ density)} \tag{3.6-8}$$

where,

V_{total} is the total volume ($V_{solid} + V_{void}$) of the room components at some stress level, and V_{solid} is the total solid volume of all room components. Therefore, the quantity (V_{total} - V_{solid}) represents V_{void}, the room void volume including the waste/backfill composite void volume minus the volume of the overlying air gap. Due to greater availability of density data for components, waste/backfill composite porosity is computed on a density basis. Table F-4 presents the waste/backfill composite porosities as a function of stress for each of the EAs analyzed using the DAM.

6.3 Hydraulic Conductivity

Hydraulic conductivity is a measure of the permeability of a porous media. It is dependent on the properties of the media as well as the fluid. The hydraulic conductivity of the waste/backfill composite in an average WIPP repository room is dependent on the waste components, backfill material (if present), and the brine present. In multicomponent systems, an effective hydraulic conductivity can be estimated by averaging the individual component hydraulic conductivities comprising the system. The following three different averaging techniques exist:

- Arithmetic mean - applies to flow through a parallel configuration of components
- Harmonic mean - applies to flow through a series configuration of components
- Geometric mean - applies to flow through a randomly distributed configuration of components.

In practice, the effective hydraulic conductivity of randomly distributed components is estimated by using the geometric mean of components. The geometric mean is preferred over arithmetic and harmonic means (parallel and series flow configurations, respectively), because it results in a better representation of randomly distributed components (Scheidegger, 1974).

In the baseline case, hydraulic conductivity of solid inorganic and solid organic waste is assumed to vary with porosity and is estimated from a modified version of the Kozeny-Carmen equation (Bear, 1972). Components such as grout or glass are assumed incompressible under repository conditions (compressive strengths greater than lithostatic pressure) and thus have constant hydraulic conductivities.

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TABLE F-4

COMPOSITE POROSITIES FOR ENGINEERED ALTERNATIVES

Stress (psi)	Baseline	Alt. 1	Alt. 6	Alt. 10	Alt. 33	Alt. 35a	Alt. 35b	Alt. 77a	Alt. 77b	Alt. 77c	Alt. 77d	Alt. 83
0	0.908	0.826	0.884	0.785	0.677	0.582	0.582	0.457	0.686	0.686	0.583	0.696
0	0.830	0.680	0.786	0.604	0.623	0.557	0.557	0.431	0.645	0.645	0.529	0.646
200	0.623	0.403	0.484	0.351	0.468	0.402	0.402	0.331	0.540	0.540	0.308	0.409
400	0.526	0.298	0.298	0.291	0.423	0.364	0.364	0.310	0.490	0.490	0.248	0.335
600	0.466	0.284	0.284	0.255	0.397	0.347	0.347	0.307	0.463	0.463	0.223	0.290
800	0.419	0.271	0.271	0.223	0.378	0.335	0.335	0.305	0.441	0.441	0.202	0.256
1000	0.382	0.263	0.263	0.200	0.361	0.326	0.326	0.304	0.420	0.420	0.188	0.230
1200	0.349	0.255	0.255	0.180	0.346	0.319	0.319	0.302	0.403	0.403	0.175	0.208
1400	0.320	0.250	0.250	0.163	0.333	0.314	0.314	0.302	0.390	0.390	0.163	0.188
1600	0.294	0.244	0.244	0.149	0.320	0.309	0.309	0.301	0.380	0.380	0.154	0.172
1800	0.270	0.240	0.240	0.135	0.307	0.305	0.305	0.300	0.367	0.367	0.146	0.158
2000	0.248	0.235	0.235	0.123	0.296	0.301	0.301	0.299	0.361	0.361	0.137	0.143
2200	0.227	0.231	0.231	0.110	0.284	0.298	0.298	0.299	0.353	0.353	0.130	0.131

TABLE F-4 (Continued)

COMPOSITE POROSITIES FOR ENGINEERED ALTERNATIVES

Stress (psi)	Baseline	Alt. 94a	Alt. 94b	Alt. 94c	Alt. 94d	Alt. 94e	Alt. 94f	Alt. 111
0	0.908	0.876	0.651	0.557	0.557	0.744	0.671	0.770
0	0.830	0.772	0.594	0.530	0.530	0.702	0.617	0.732
200	0.623	0.702	0.533	0.471	0.471	0.640	0.496	0.597
400	0.526	0.675	0.510	0.452	0.452	0.608	0.459	0.540
600	0.466	0.659	0.496	0.443	0.443	0.586	0.436	0.502
800	0.419	0.649	0.486	0.436	0.436	0.570	0.419	0.472
1000	0.382	0.640	0.476	0.431	0.431	0.555	0.406	0.445
1200	0.349	0.634	0.467	0.428	0.428	0.543	0.395	0.422
1400	0.320	0.628	0.460	0.424	0.424	0.533	0.386	0.404
1600	0.294	0.623	0.453	0.422	0.422	0.525	0.378	0.389
1800	0.270	0.619	0.446	0.420	0.420	0.517	0.371	0.372
2000	0.248	0.616	0.440	0.418	0.418	0.512	0.365	0.361
2200	0.227	0.613	0.433	0.416	0.416	0.506	0.359	0.350

The components considered in the averaging process are the three primary waste forms and the backfill material within the waste stack. Backfill contained in the volume above the waste stack is not considered because this region is a physical extension of the host rock.

The values of hydraulic conductivity for each component are estimated on the basis of available data in literature. Components with large void space which compact under compressive stresses will typically have hydraulic conductivities that vary with the degree of compaction. This variability can be estimated or computed from the porosity. For example, the hydraulic conductivity of a crushed salt and CaO mixture is assumed to be a function of porosity and is estimated as a function of compaction with a bi-linear system of equations developed by Case and Kelsall (1987). Once the hydraulic conductivity of each component has been estimated, the effective hydraulic conductivity for the composite can be computed. The governing equation employing the geometric mean for averaging hydraulic conductivities is (Scheidegger, 1974):

$$\ln(K_{eff}) = \sum_{i=1}^{n} (F_i \ln(K_i)) . \qquad (3.6\text{-}9)$$

where,

K_{eff} = effective waste/backfill composite hydraulic conductivity at stress level x
F_i = volume fraction of component i at stress level x
K_i = hydraulic conductivity of component i at stress level x.

The component volume fraction and the hydraulic conductivity may be functions of stress level or the state of compaction. The component volume fraction is computed as the component volume divided by the waste/backfill composite volume at a particular stress level:

$$F_i(x) = \frac{V_i(x)}{TV(x)} \qquad (3.6\text{-}10)$$

where,

$F_i(x)$ = volume fraction of component i at stress level x
$V_i(x)$ = volume of component i at stress level x (including the void space within the waste/backfill composite)
$TV(x)$ = volume of waste/backfill composite at stress level x.

The component and waste/backfill composite volumes are obtained from estimated values of component masses and densities:

$$V_i(x) = \frac{M_i}{D_i(x)} \qquad (3.6\text{-}11)$$

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$$TV(x) = \sum_{i=1}^{n} V_i(x) \qquad (3.6\text{-}12)$$

where,

M_i = *mass of commponent "i"*
$D_i(x)$ = *density of component "i" at stress level x.*

The procedure allows computation of an effective hydraulic conductivity for the average contents of a WIPP repository room at various stress levels. Table F-5 contains the hydraulic conductivities for each of the EAs analyzed using the DAM.

6.4 Gas Generation Potential

Gas generation potential is defined as the maximum amount of gas that can be generated under ideal conditions. Two potentials are defined: hydrogen generation form anoxic corrosion, and "biogas" generation from microbial degradation of organics.

The potential for hydrogen is based on the total mass of corrodible metal (metallic waste and container material) present in a panel. In most cases there is insufficient brine available to corrode all of the metal so that the total potential is never reached. It is still important however to define a potential so that the model does not predict the generation of more hydrogen than is physically possible.

The potential for "biogas" gas generation by microbial degradation of organic material is based on the total mass of degradable organics in a panel. The process of microbial gas generation stops when this potential is reached. The plasma treatment alternative is assumed to destroy all degradable organics so that the potential for this option is zero.

6.5 Effective Waste Volume

The effective waste volume is used to determine the radionuclide content in drill cuttings removed from the repository during human intrusion events. The effective waste volume is the volume of the waste/backfill composite minus the volume of the backfill along the sides of the waste stack. The term "drill cuttings" refers to the waste/backfill composite which would be brought to the surface with circulating drilling fluid during an inadvertent human intrusion event. The effective waste volume evaluation requires determination of the waste/backfill composite density as a function of stress, as per Equation (3.6.6). These calculations differ from each other only in that the waste/backfill composite density calculation neglects backfill on the sides of the waste stack. If penetration through the backfill on the sides of the waste stack occurs, the waste stack is assumed to remain intact and the cuttings are assumed not to contain any radionuclides. The backfill above the waste stack is considered because it would be mixed with extracted waste in the event the waste stack is breached by drilling activities.

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TABLE F-5

COMPOSITE HYDRAULIC CONDUCTIVITY FOR ENGINEERED ALTERNATIVES

(meters/second)

Stress (psi)	Baseline	Alt. 1	Alt. 6	Alt. 10	Alt. 33	Alt. 35a	Alt. 35b	Alt. 77a	Alt. 77b	Alt. 77c	Alt. 77d	Alt. 83
0	7.39×10^{-04}	1.14×10^{-04}	3.74×10^{-04}	7.35×10^{-16}	6.48×10^{-05}	8.49×10^{-07}	8.49×10^{-07}	1.22×10^{-07}	2.57×10^{-06}	1.20×10^{-05}	6.44×10^{-04}	2.18×10^{-03}
200	6.10×10^{-05}	6.38×10^{-06}	1.44×10^{-05}	7.35×10^{-18}	2.59×10^{-06}	5.43×10^{-09}	5.43×10^{-09}	1.90×10^{-09}	4.57×10^{-08}	6.83×10^{-07}	9.34×10^{-06}	4.09×10^{-05}
400	2.11×10^{-05}	1.89×10^{-06}	1.89×10^{-08}	7.35×10^{-16}	9.30×10^{-07}	1.29×10^{-09}	1.29×10^{-09}	6.06×10^{-10}	1.02×10^{-08}	2.73×10^{-07}	2.22×10^{-06}	9.84×10^{-06}
600	1.11×10^{-05}	1.55×10^{-06}	1.55×10^{-08}	7.35×10^{-16}	5.33×10^{-07}	6.26×10^{-10}	6.26×10^{-10}	5.18×10^{-10}	7.32×10^{-09}	2.32×10^{-07}	1.22×10^{-06}	3.82×10^{-06}
800	6.51×10^{-06}	1.27×10^{-06}	1.27×10^{-06}	7.35×10^{-16}	3.48×10^{-07}	3.76×10^{-10}	3.76×10^{-10}	4.49×10^{-10}	5.59×10^{-09}	1.98×10^{-07}	7.21×10^{-07}	1.70×10^{-06}
1000	4.21×10^{-06}	1.11×10^{-06}	1.11×10^{-08}	7.35×10^{-16}	2.49×10^{-07}	2.58×10^{-10}	2.58×10^{-10}	4.07×10^{-10}	4.64×10^{-09}	1.75×10^{-07}	4.98×10^{-07}	9.19×10^{-07}
1200	2.82×10^{-06}	9.67×10^{-07}	9.66×10^{-07}	7.35×10^{-16}	1.85×10^{-07}	1.88×10^{-10}	1.88×10^{-10}	3.72×10^{-10}	4.04×10^{-09}	1.56×10^{-07}	3.58×10^{-07}	5.26×10^{-07}
1400	1.96×10^{-06}	8.59×10^{-07}	8.59×10^{-07}	7.35×10^{-16}	1.42×10^{-07}	1.45×10^{-10}	1.45×10^{-10}	3.45×10^{-10}	3.64×10^{-09}	1.40×10^{-07}	2.35×10^{-07}	2.71×10^{-07}
1600	1.38×10^{-06}	7.64×10^{-07}	7.64×10^{-07}	7.35×10^{-16}	1.10×10^{-07}	1.15×10^{-10}	1.15×10^{-10}	3.22×10^{-10}	3.27×10^{-09}	1.26×10^{-07}	1.11×10^{-07}	9.14×10^{-08}
1800	9.79×10^{-07}	6.80×10^{-07}	6.80×10^{-07}	7.35×10^{-16}	8.67×10^{-08}	9.34×10^{-11}	9.34×10^{-11}	3.00×10^{-10}	2.98×10^{-09}	1.13×10^{-07}	5.58×10^{-08}	3.33×10^{-08}
2000	7.02×10^{-07}	6.06×10^{-07}	6.06×10^{-07}	7.35×10^{-16}	6.88×10^{-08}	7.74×10^{-11}	7.74×10^{-11}	2.81×10^{-10}	2.76×10^{-09}	1.01×10^{-07}	2.32×10^{-08}	9.36×10^{-09}
2200	4.93×10^{-07}	5.35×10^{-07}	5.34×10^{-07}	7.35×10^{-16}	5.43×10^{-08}	6.42×10^{-11}	6.42×10^{-11}	2.63×10^{-10}	2.54×10^{-09}	9.05×10^{-08}	1.25×10^{-08}	3.62×10^{-09}

TABLE F-5 (Continued)

COMPOSITE HYDRAULIC CONDUCTIVITY FOR ENGINEERED ALTERNATIVES
(meters/second)

Stress (psi)	Baseline	Alt. 94a	Alt. 94b	Alt. 94c	Alt. 94d	Alt. 94e	Alt. 94f	Alt. 111
0	7.39×10^{-04}	3.59×10^{-06}	1.13×10^{-06}	2.48×10^{-08}	2.48×10^{-08}	2.90×10^{-07}	3.79×10^{-05}	1.66×10^{-05}
200	6.10×10^{-05}	3.85×10^{-07}	1.77×10^{-07}	2.57×10^{-09}	2.57×10^{-09}	2.56×10^{-08}	9.77×10^{-07}	1.81×10^{-07}
400	2.11×10^{-05}	1.72×10^{-07}	9.42×10^{-08}	1.23×10^{-09}	1.23×10^{-09}	9.85×10^{-09}	3.43×10^{-07}	3.30×10^{-08}
600	1.11×10^{-05}	1.09×10^{-07}	6.58×10^{-08}	8.33×10^{-10}	8.33×10^{-10}	5.79×10^{-09}	1.78×10^{-07}	1.27×10^{-08}
800	6.51×10^{-06}	7.94×10^{-08}	5.10×10^{-08}	6.40×10^{-10}	6.40×10^{-10}	4.02×10^{-09}	1.07×10^{-07}	6.21×10^{-09}
1000	4.21×10^{-06}	6.18×10^{-08}	4.15×10^{-08}	5.22×10^{-10}	5.22×10^{-10}	3.03×10^{-09}	7.31×10^{-08}	3.56×10^{-09}
1200	2.82×10^{-06}	5.06×10^{-08}	3.49×10^{-08}	4.45×10^{-10}	4.45×10^{-10}	2.46×10^{-09}	5.30×10^{-08}	2.26×10^{-09}
1400	1.96×10^{-06}	4.27×10^{-08}	3.00×10^{-08}	3.90×10^{-10}	3.90×10^{-10}	2.08×10^{-09}	3.67×10^{-08}	1.54×10^{-09}
1600	1.38×10^{-06}	3.71×10^{-08}	2.64×10^{-08}	3.50×10^{-10}	3.50×10^{-10}	1.81×10^{-09}	2.06×10^{-08}	1.08×10^{-09}
1800	9.79×10^{-07}	3.25×10^{-08}	2.33×10^{-08}	3.16×10^{-10}	3.16×10^{-10}	1.59×10^{-09}	1.21×10^{-09}	7.84×10^{-10}
2000	7.02×10^{-07}	2.92×10^{-08}	2.09×10^{-08}	2.92×10^{-10}	2.92×10^{-10}	1.45×10^{-09}	6.37×10^{-09}	5.93×10^{-10}
2200	4.93×10^{-07}	2.63×10^{-08}	1.88×10^{-08}	2.71×10^{-10}	2.71×10^{-10}	1.33×10^{-09}	4.05×10^{-09}	4.47×10^{-10}

7.0 SUMMARY

Input variables required by the DAM include the physical and chemical properties of the repository contents following waste and backfill emplacement in the WIPP. The contents are assumed to be a homogeneous waste/backfill composite. This composite consists the four following components:

- Solid organics
- Solid inorganics
- Sludges
- Backfill material (if present).

The properties required by the DAM for evaluation of the effectiveness of EAs include the following:

- Density
- Porosity
- Hydraulic conductivity
- Gas generation potential
- Effective waste volume.

Density of the waste-backfill composite is computed by assigning weights to the individual component densities as illustrated with Equation (3.6.6). The porosity of the composite is a function of the composite density. An estimate of the hydraulic conductivity of the waste/backfill composite is the geometric mean of the component hydraulic conductivities. Gas generation (microbial and corrosion) potentials are computed from the equivalent number of unprocessed drums emplaced in a room, taking into account the effect of waste treatment on components. With the exception of total gas generation potential, the physical properties vary with pressure resulting from creep closure. Properties for the three major waste forms and the backfill materials are obtained from available literature, applicable relationships or equations, and information from Appendix O. Using the above evaluation process, physical properties of the waste/backfill composite in an average WIPP repository room are computed for use as input to the DAM.

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APPENDIX G
SUMMARY OF LITERATURE SOLUBILITY STUDIES

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SUMMARY OF LITERATURE SOLUBILITY STUDIES

1.0 INTRODUCTION

To obtain relevant solubility data on the actinides of interest, a literature search was conducted and solubility studies on actinide-bearing solids (e.g., $Pu(OH)_3$, UO_2) were compiled into a data base. The data base Attachment 1 contains records that provide information on the solid phase, solution composition, solution description (e.g., dilute, saline or brine), actinide concentration in solution, pH, Eh or atmospheric conditions, temperature, equilibration time of the experimental run, method employed to determine the solubility (e.g., equilibrium approached from an oversaturated solution, calculated with a geochemical code, etc), and reference for the study. Most of the results tabulated in Attachment 1 are presented graphically for the actinides Thorium (Th), Uranium (U), Neptunium (Np), Plutonium (Pu), and Americium (Am) in coordinates of log molar concentration (molar (M) = moles/liter) versus pH.

2.0 THORIUM

Thorium is only stable in the IV valence state in the natural environment. Solubility is usually controlled by thorianite (ThO_2). $Th(OH)_4$ may initially precipitate from an oversaturated solution, but it will age to the more stable ThO_2 (Brookins, 1988).

Figure G-1 summarizes data on Th solubility in saline and brine chloride solutions as reported by Felmy et al. (1991). The solubility of the Th precipitate decreases approximately 6 orders of magnitude over the pH interval of 3 to 6, followed by a flattening of the trend above a pH of 6. Precipitates obtained from these experiments were analyzed by x-ray diffraction (XRD) techniques and found to be amorphous to x-rays until they had been aged for about a year. Some of the 372-day precipitate obtained from the 3M NaCl experiment displayed an XRD pattern similar to crystalline ThO_2. However, these samples do not show significantly different solubilities, and Felmy et al. (1991) concluded that an amorphous phase still controls the solubility despite the presence of some crystalline precipitate.

Based on thermodynamic solubility calculations at 25°C and 1 atm in dilute solutions (e.g., Langmuir and Herman, 1980), the thorianite (crystalline ThO_2) solubility trend lies 4 to 5 orders of magnitude below the trend of the amorphous hydrous Th oxide indicated on Figure G-1. As Th occurs in transuranic waste primarily as oxides (Weiner, 1995), and the hydrous Th oxide is more soluble than the crystalline oxide form, solubility data on Figure G-1 represent a conservative (upper bound) estimate of Th solubility.

3.0 URANIUM

The dominant valence states for U in the natural environment are IV and VI. Uranium (VI) is much more soluble that U (IV), and has a strong affinity for carbonate complexation. Important solubility-controlling minerals include uraninite (UO_2) for U (IV), and schoepite ($UO_3 \cdot 2H_2O$) for

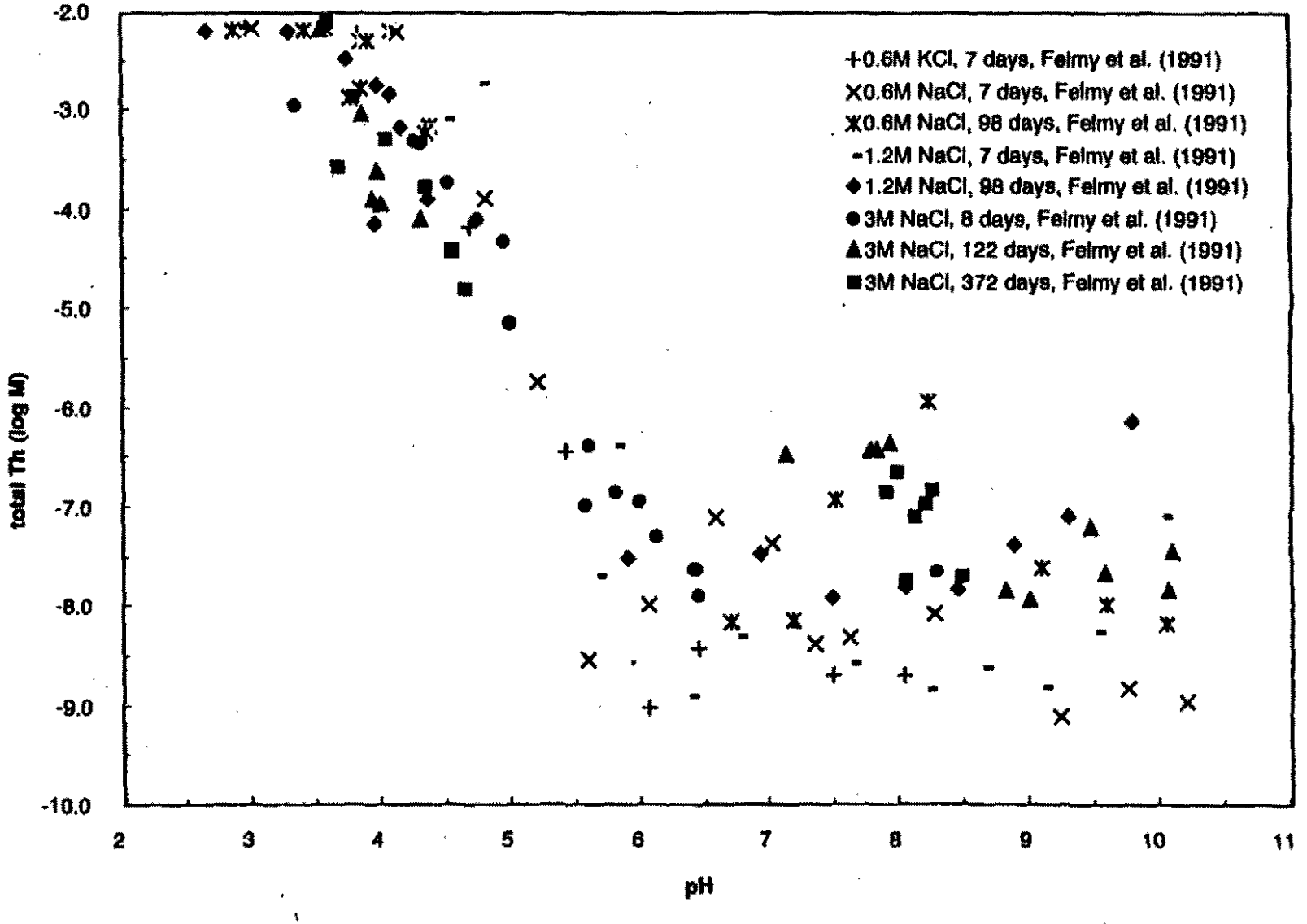

Figure G-1
Hydrous Th(IV) Oxide Solubility as a Function of pH for dilute and Brine Solutions

U (VI). The presence of organic materials and corrodable metals in the repository environment will probably restrict U to the IV state.

Figure G-2 summarizes U solubility data for uraninite (UO_2). Solubility data reported by Parks and Pohl (1988) for UO_2 at 100 and 150°C in dilute NaCl solution (0.1 M) indicate a decrease in the concentration of U from -7 to -9.5 log M as pH increases from 1 to 7. Gray (1986) investigated the solubility of unirradiated UO_2 fuel-rod pellets in a saturated NaCl brine of pH 6.2 to 6.4 and reported U concentrations of -7 to -8 log M, about 1.5 to 2.5 orders of magnitude lower than UO_2 solubility values in dilute NaCl solutions. The solubility data of Gray (1986) serve as a conservative estimate of U concentrations in Salado brine, because the solubility of UO_2 increases with temperature and the solubility data were obtained at elevated temperatures, relative to the ambient temperature of about 30°C in the WIPP repository horizon.

Figure G-3 summarizes U solubility data for schoepite ($UO_3 \bullet 2H_2O$) in $HClO_4$ solutions at 25°C. Krupka et al. (1985) obtained solubility data that indicate a decrease in the U concentration from -2 to -5 log M as pH increased from 3 to 9. This trend was followed by an increase of similar magnitude in the U concentration over the pH interval of 9 to 12. Bruno and Sandino (1989) conducted solubility experiments with amorphous and crystalline $UO_3 \bullet 2H_2O$, which show the amorphous schoepite to be one to two orders of magnitude more soluble than the crystalline form. Solubility studies for schoepite in saturated NaCl brine were not found. However, based on the studies presented on Figure G-2 for UO_2, it is expected that schoepite solubility in Salado brine will be 1 to 2 orders of magnitude greater than the dilute solution data on Figure G-3.

4.0 NEPTUNIUM

The dominant valence states for Np in the natural environment are IV, V, and VI. As is the case with U and Pu, Np solubilities are highly dependent on valence state. Np (IV) is expected to dominate in the reducing repository environment, with solubility being controlled by crystalline NpO_2. Other forms of Np (IV) such as amprphous NpO_2, $NpO_2 \bullet xH_2O$, and $Np(OH)_4$ will age to crystalline NpO_2. An important Np(V) solubility-controlling phase is NpO_2OH.

Figure G-4 summarizes Np (IV) solubility data for NpO_2 and $NpO_2 \bullet xH_2O$ in dilute solutions and NaCl brines. The studies of Rai and Strickert (1980) and Rai et al. (1982) at 25°C show a decrease in Np concentration from -5.5 to -6.5 log M as pH increases from about 2 to 6. The data of Kim et al. (1985b) were obtained in 1M and 5M NaCl solutions at 20 to 25° C. The runs at pH of 5 to 6 resulted in Np concentrations of about -4.5 log M, and those at a pH of 7.5 to 8 show a Np concentration of about -6 log M. Ionic strength does not appear to affect the solubility of Np in these 1M and 5M runs, but a comparison of these data over the pH range of 5 to 6 with the data of Rai and Strickert (1980) suggests the solubility of NpO_2 is increased by about 1.5 orders of magnitude in NaCl solutions of moderate to high ionic strength.

Pryke and Rees (1987) investigated the solubility of $NpO_2 \bullet xH_2O$ in solutions equilibrated with concrete at ambient temperature. Results on Figure G-4 show an apparent decrease in the Np concentration of about one-half log unit as the pH increase from 10 to 13. Comparing the studies of Pryke and Rees (1987) and Rai and Strickert (1980), it appears that the data of Pryke and Rees (1987) anchor the projected trend of the data of Rai and Strickert (1980).

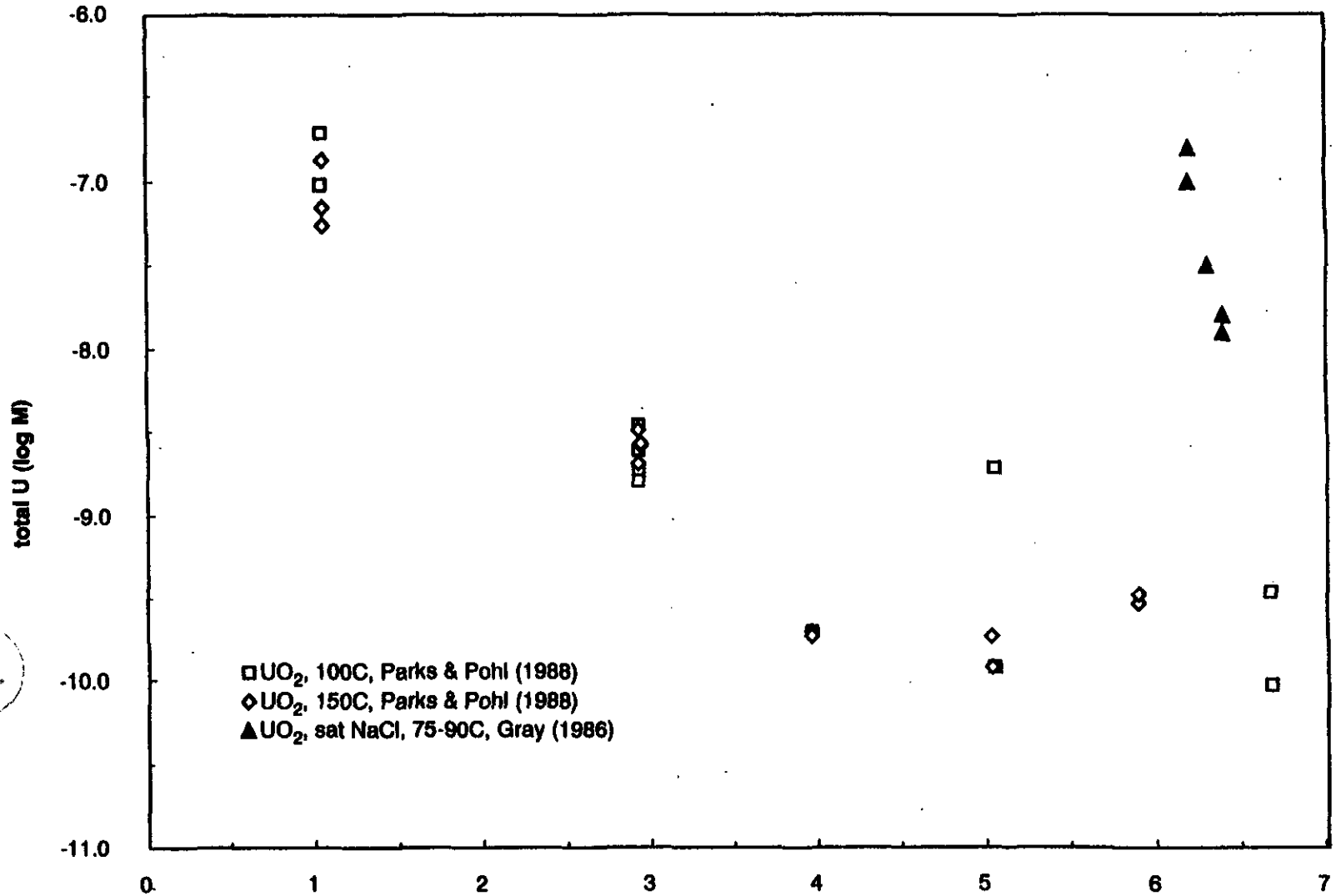

Note: UO_2, 100° C, Parks & Pohl (1988) graphed data does not include 3 outlying points: (E922, F922), (E923, F923) and (E924, F924).

Note: UO_2, 150° C, Parks & Pohl (1988) graphed data does not include 4 outlying points: (E939, F939), (E940, F940), (E941, F941) and (E942, F942).

Figure G-2
UO_2 Solubility as a Function of pH for Dilute and Brine Solutions

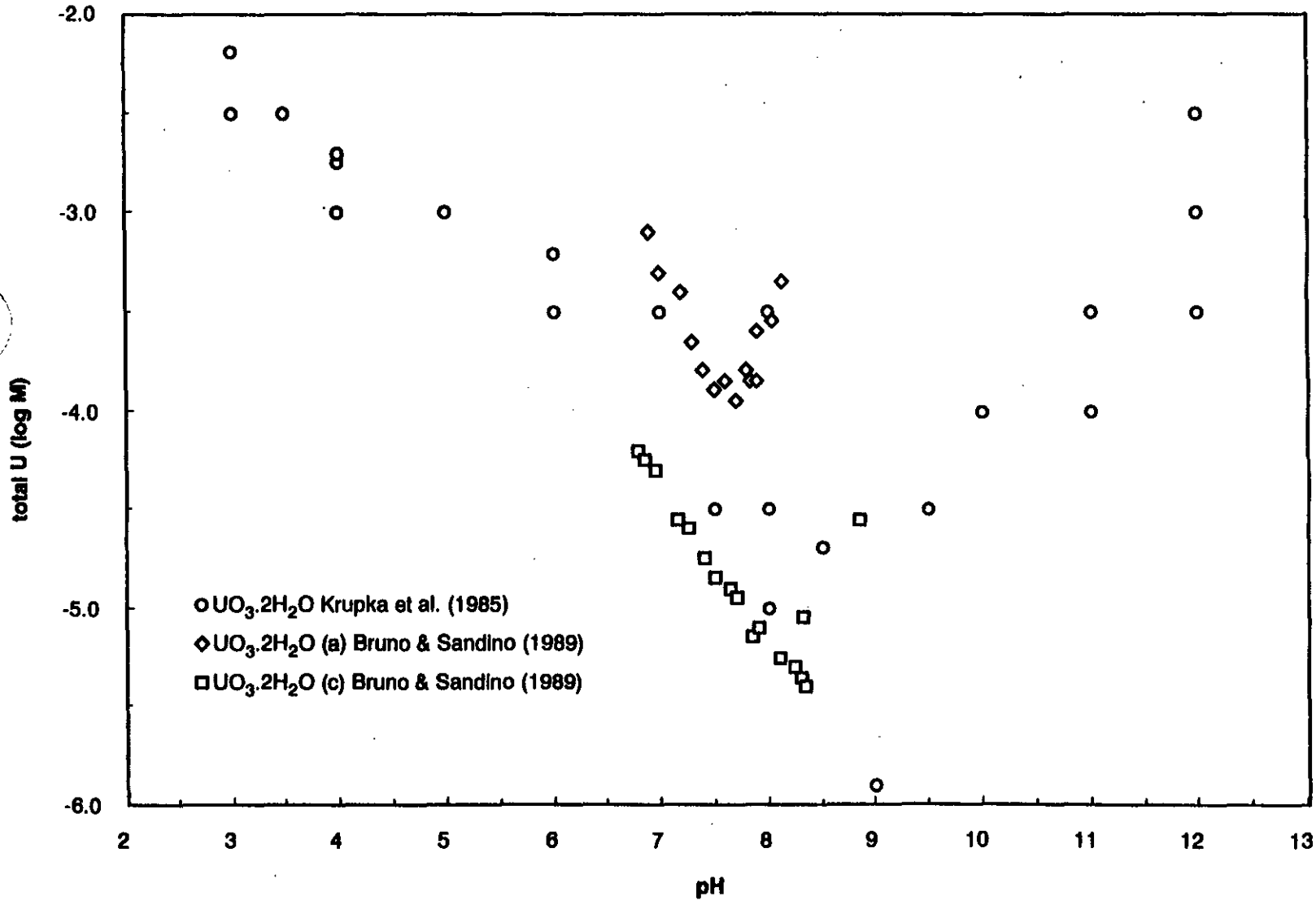

Figure G-3
UO_3:$2H_2O$ Solubility as a Function of pH for Dilute Solutions

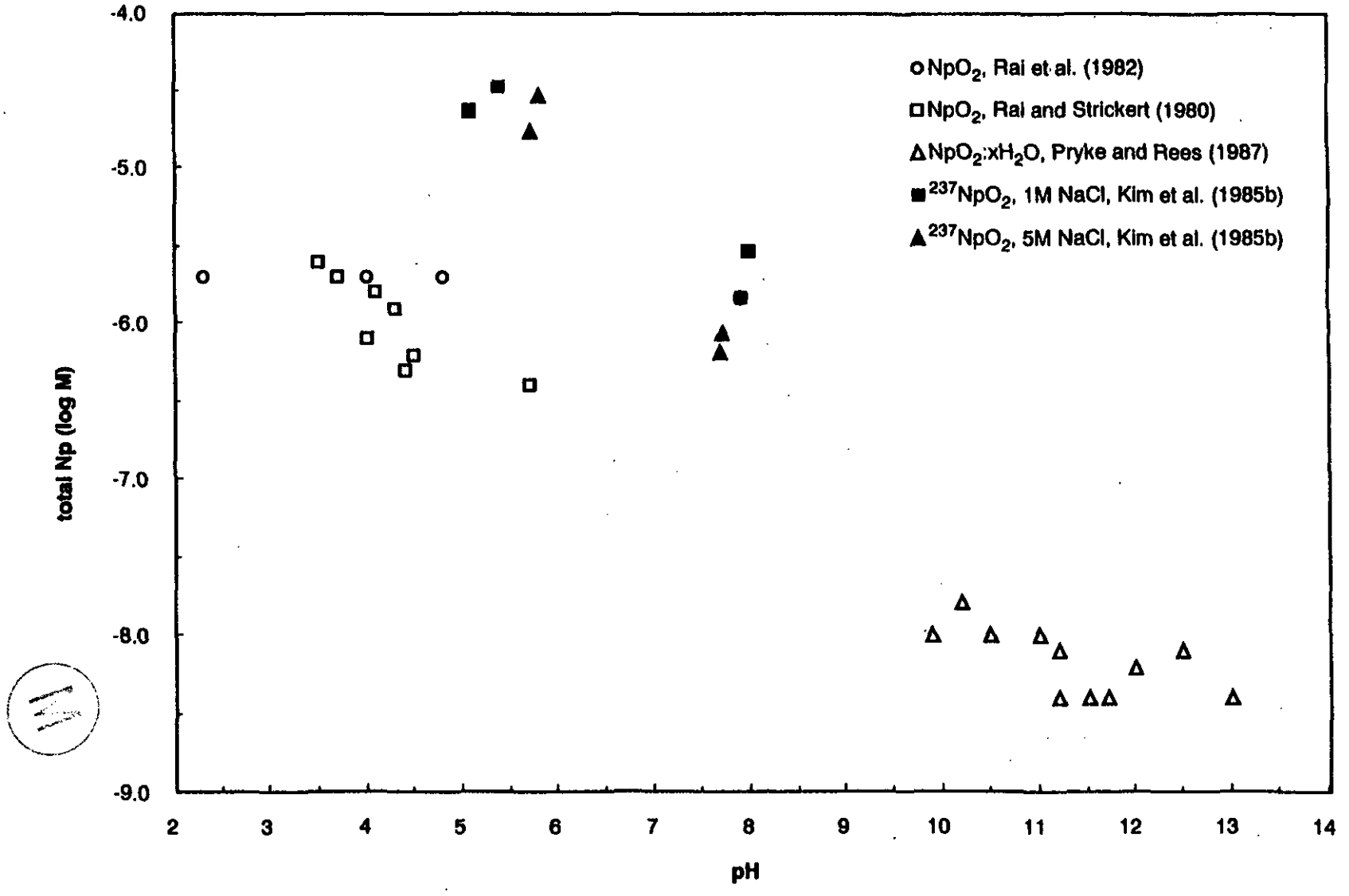

Figure G-4
NpO_2 Solubility as a Function of pH for Dilute, Saline, and Brine Solutions

Results for Np (V) solubility studies are plotted on Figure G-5. Ewart et al. (1985) investigated the solubility of NpO_2OH in cement-equilibrated water. Results for this study illustrate a rapid decrease in the Np concentration from about -5 to -9.5 log M between a pH of 9 to 13. Solubility studies on NpO_2OH in $NaClO_4$ and NaCl solutions were conducted by Kim et al. (1985b) at 20 to 25°C. Results for NpO_2OH in 1M $NaClO_4$ indicate a decrease in the Np concentration from -2 to -6 log M over the pH interval 6 to 11, followed by increasing Np concentration over the pH interval of 11 to 13. The solubility of NpO_2OH in 1M and 5M NaCl solutions is about 2.5 orders of magnitude lower at a pH of about 6.5, relative to the 1M $NaClO_4$ study. This suggests that Np (V) may be reduced to Np (IV) in the NaCl solutions, resulting in solubility control by NpO_2 rather than NpO_2OH. Additional solubility studies by Neck et al. (1992) with NpO_2OH in dilute solution and 1M and 3M $NaClO_4$ solutions indicate decreasing Np concentrations as pH increases from about 7 to 11.5 followed by a rise in the Np concentration as pH increase to 14. In comparing the dilute and 3M brine results of Neck et al. (1992), it is of interest that the 3M results indicate NpO_2OH solubility is about an order of magnitude lower in the brine relative to the dilute solution, which is in contrast to results presented on Figure G-4 for NpO_2.

5.0 PLUTONIUM

Plutonium displays the most complex behavior of the five actinides of interest because of the four (III, IV, V, and VI) possible valence states. In a reducing environment, the solubility-controlling phases are probably $Pu(OH)_3$, $PuO_2 \cdot xH_2O$, PuO_2, or $Pu(OH)_4$. Pu may be controlled in an oxidizing environment by $PuO_2(OH)_2$.

Figure G-6 summarizes Pu (III) solubility data. Rai et al. (1987) measured the Pu concentrations in deionized water and Permian Basin brines at 23°C in contact with amorphous $^{239}Pu(OH)_3$. Results for runs with deionized water show a decrease in Pu concentration from about -3.5 to -10 log M as pH increases from 6 to 9, followed by a flat data trend between pH 9 and 13 that indicates a Pu concentration of about -9.5 log M. A similar trend is observed for Pu concentration in Permian Basin brine, although the Pu concentration appears slightly greater above a pH of 7 relative to the deionized water runs. Based on the measured pH value for the Permian Basin brines, the solubility of $^{239}Pu(OH)_3$ does not appear to be affected greatly by changes in ionic strength of the solutions. However, Felmy et al. (1989) presented the preliminary data of Rai et al. (1987) with pH values of the Permian Basin brines recalculated to account for the difference in liquid junction potential between the solutions and standards. The recalculated pH values were one to two pH units greater than the measured values, which shifts the $^{239}Pu(OH)_3$ sample points in Figure G-6 to the right and suggests the amorphous hydroxide is two to three orders of magnitude more soluble in the brines at the recalculated pH, relative to deionized water.

$Pu(OH)_4$ solubility data for dilute solutions and a NaCl saturated brine are given on Figure G-7. Ewart et al. (1985) investigated the solubility of $Pu(OH)_4$ in cement-equilibrated water over the pH interval of 7 to 13. Their results show a decrease in Pu concentration from about -5.5 to -10.5 as pH increases to 12. Rai et al. (1980) presented results on the solubility of amorphous $^{239}Pu(OH)_4$ at 25°C that show Pu concentration decreases from about -4.5 to -7.5 log M as pH increases from 3 to 8. Flambard et al. (1986) conducted experiments on the solubility of $Pu(OH)_4$ in H_2O saturated with NaCl at 23°C over a pH interval of 1 to 10. Their limited data set show no significant difference in solubility relative to data sets obtained with dilute solutions at a pH of about 5. However, the comparison of the data sets at pH 10 indicates that the Pu concentration

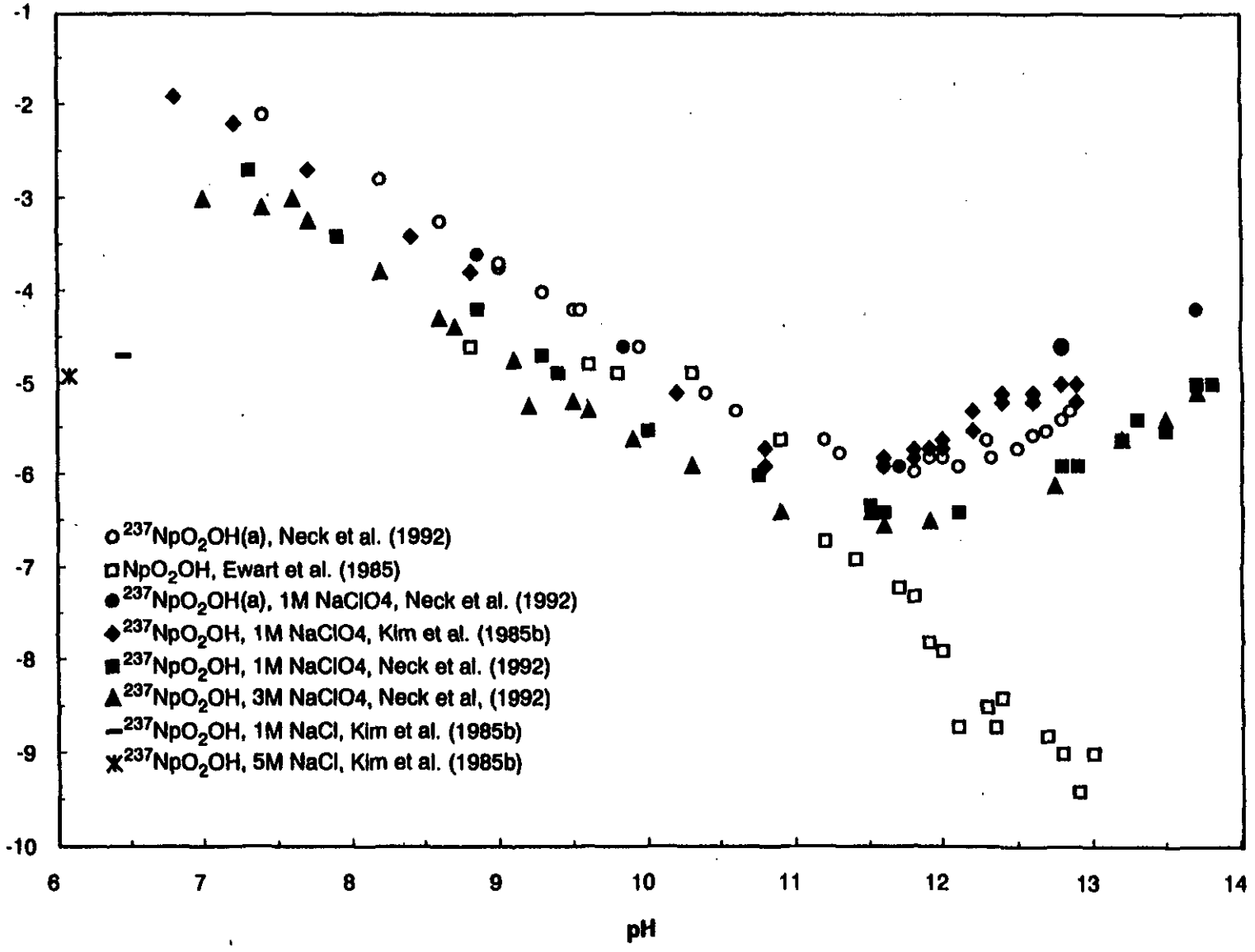

Figure G-5
NpO_2OH Solubility as a Function of pH for Dilute, Saline, and Brine Solutions

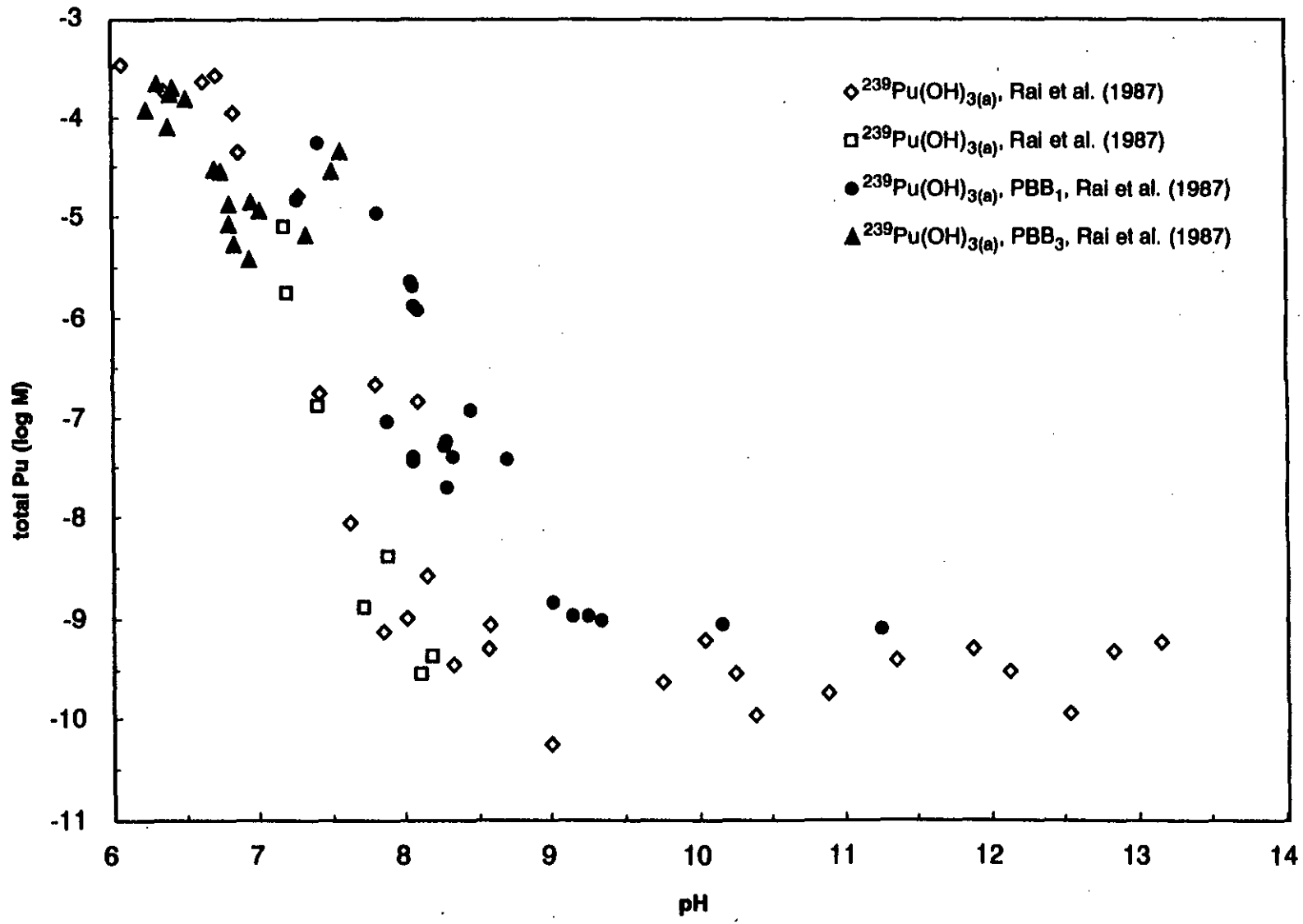

Figure G-6
Amorphous $^{239}Pu(OH)_3$ Solubility as a Function of pH for Dilute Brine and Solutions

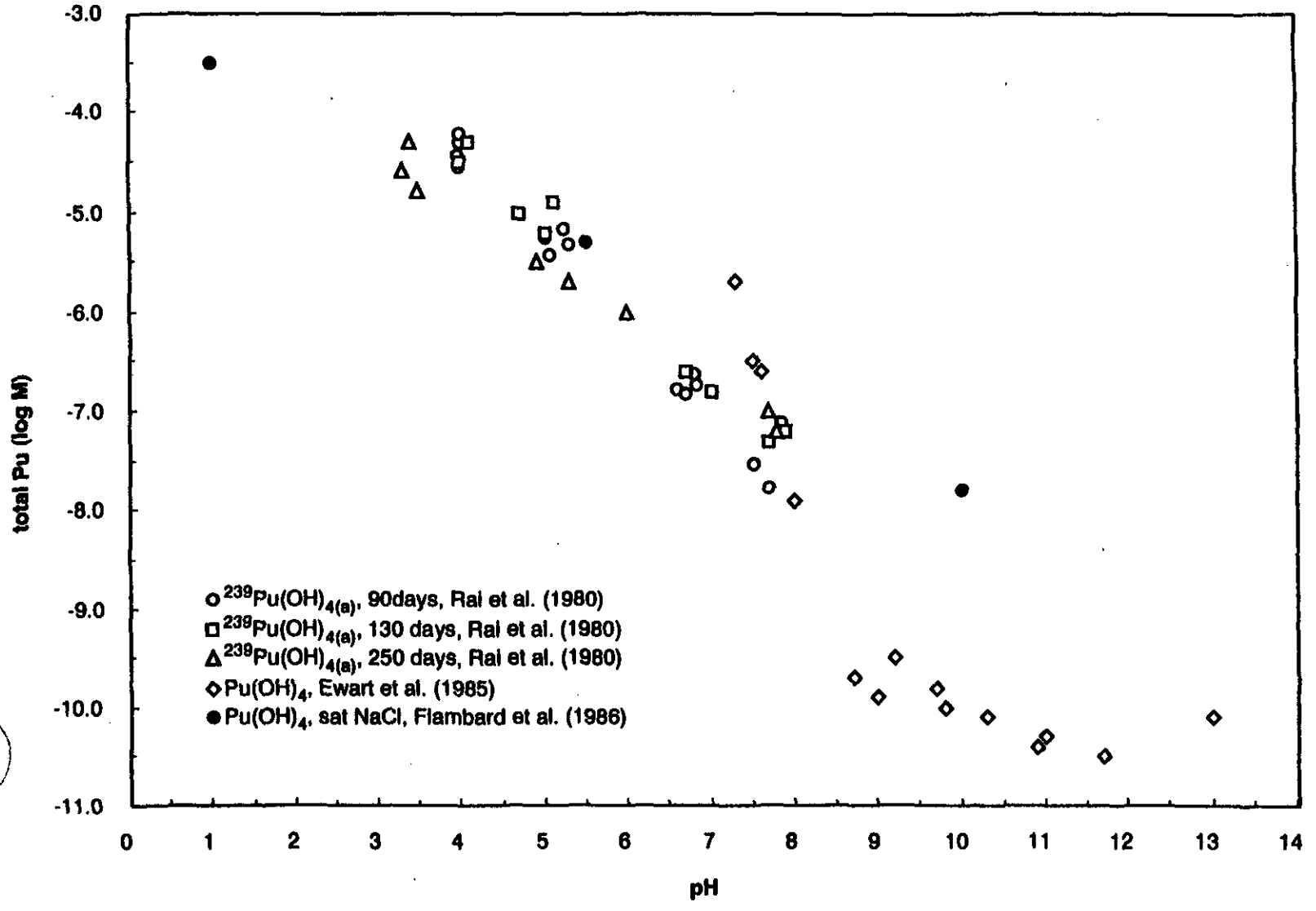

Figure G-7
Amorphous $Pu(OH)_4$ Solubility as a Function of pH for Dilute and Brine Solutions

is about two orders of magnitude greater in the brine relative to the dilute solution used by Ewart et al. (1985).

Figure G-8 summarizes solubility studies carried out by Kim et al. (1985a) and Kim et al. (1985b) with $^{238}PuO_2$ in dilute solutions and NaCl brines. The solubility of $^{238}PuO_2$ in a 0.1M NaCl solution decreases sharply from -5.5 to -7 log M over the pH interval of about 3 to 3.5, followed by an apparent increase in Pu concentration to about -6 log M as the pH rises to 5.5. Data points for the 3M and 5M NaCl brines indicate an increase in Pu concentration as pH increases. These observed trends are the opposite of most actinide solubility trends, which show decreasing actinide concentrations with increasing pH. Kim et al. (1985a) attributed the enhanced solubility to radiolysis effects and colloid formation.

Solubility data for $^{239}PuO_2$ are summarized on Figure G-9. The data reported by Rai et al. (1980) on $^{239}PuO_2$ solubility in dilute solutions shows a decrease in Pu concentration from approximately -5 to -9 log M as pH increases from about 3 to 8. Solubility data reported by Kim et al. (1985b) for $^{239}PuO_2$ follow a decreasing trend that is parallel to the data of Rai et al. (1980) but at Pu concentrations that are one to two orders of magnitude lower over the pH interval of 4 to 6.5. The large difference in the solubility of $^{239}PuO_2$ obtained by these two independent studies may be due to variation in the degree of crystallinity of the $^{239}PuO_2$ solid used in the experiments. Additional solubility studies with $^{239}PuO_2$ were carried out by Kim et al. (1985b) using 5M NaCl solutions, and these data plot below the dilute solution data obtained by Kim et al. (1985b) between pH 3.5 and 5 but then converge around a pH of 7.

Data on the solubility of $PuO_2 \cdot xH_2O$ and $^{238}PuO_2(OH)_2$ in dilute solutions are summarized on Figure G-10. Pryke and Rees (1987) examined the solubility of $PuO_2 \cdot xH_2O$ in cement-equilibrated solutions adjusted to selected pH values with HCl. Their data show a sharp decrease in Pu concentration from about -6 to -10 log M as pH increases from 7 to 9, followed by a shallow decrease as pH rises to 12. Solubility data for Pu (VI) was investigated by Kim et al. (1985b) using $^{238}PuO_2(OH)_2$. The data of Kim et al. (1985b) indicate a decrease in the Pu concentration from about -4 to -8.5 as the pH increases from about 5.5 to 10. Above a pH of 10, the solubility trend for $^{238}PuO_2(OH)_2$ shows a slight increase in Pu concentration.

6.0 AMERICIUM

Americium can be present in the natural environment in the III, IV, and V valence states. The valence state with the largest stability field is the III state.

Figure G-11 summarizes data on the solubility of $Am(OH)_3$. Rai et al. (1983) investigated the solubility of amorphous $^{241}Am(OH)_3$ in dilute solutions adjusted with HCl or NaOH to set pH, and the solubility of amorphous $^{243}Am(OH)_3$ in a pure H_2O solution that had pH adjusted with HCl or tetrapropyl NH_4OH. These data sets indicate a decrease in Am concentration from approximately -4 to -10 log M as the pH increases from about 7 to 10. Above a pH of 10, the trend of the plotted solubility points is essentially flat, and the Am concentration is maintained at around -10 log M.

Kim et al (1985b) examined the solubility of $Am(OH)_3$ in a 0.1M $NaClO_4$ solution and their data follow a trend similar to the data of Rai et al. (1983), but for a given pH the solubility data of

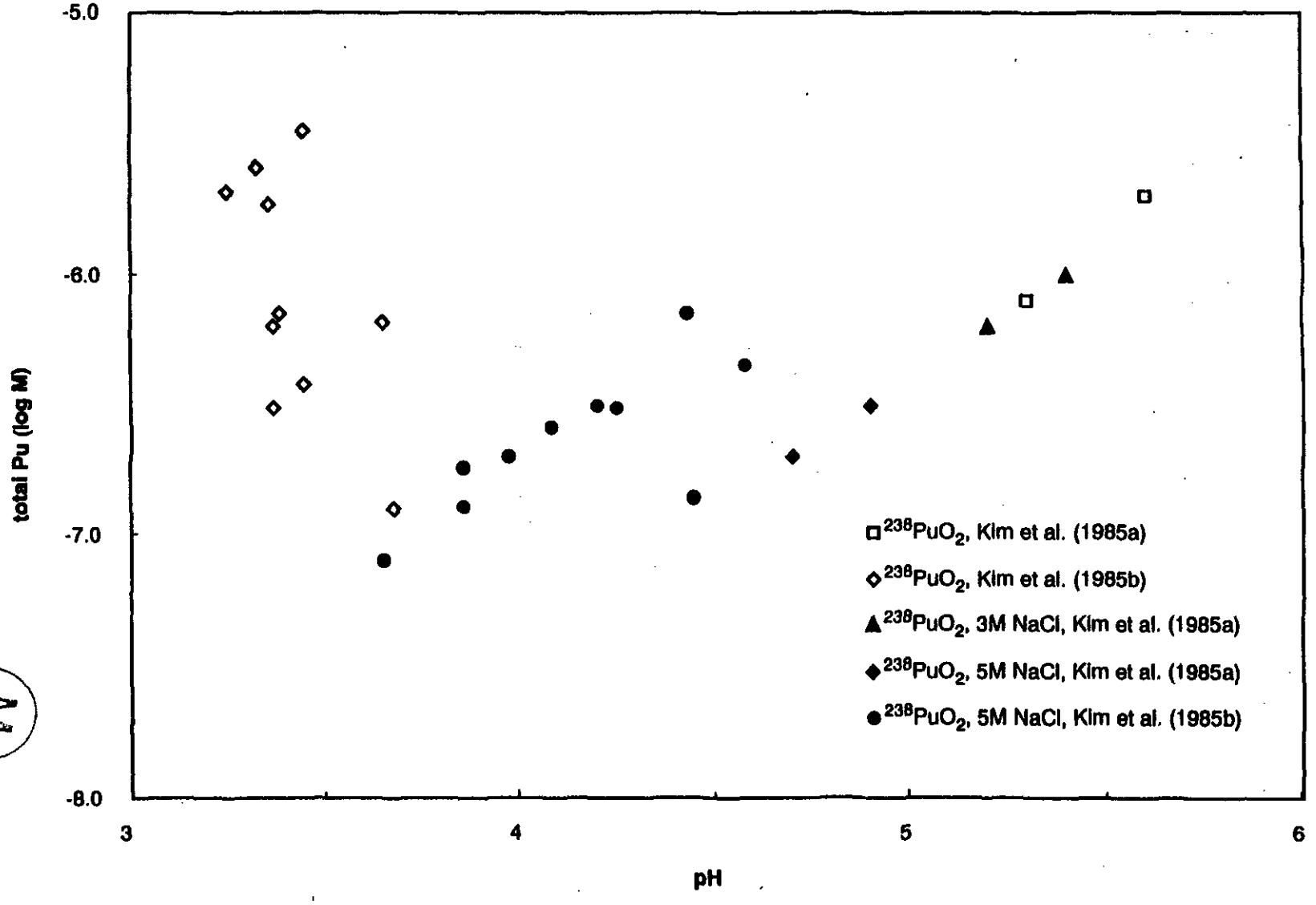

Figure G-8
$^{238}PuO_2$ Solubility as a Function of pH for Dilute and Brine Solutions

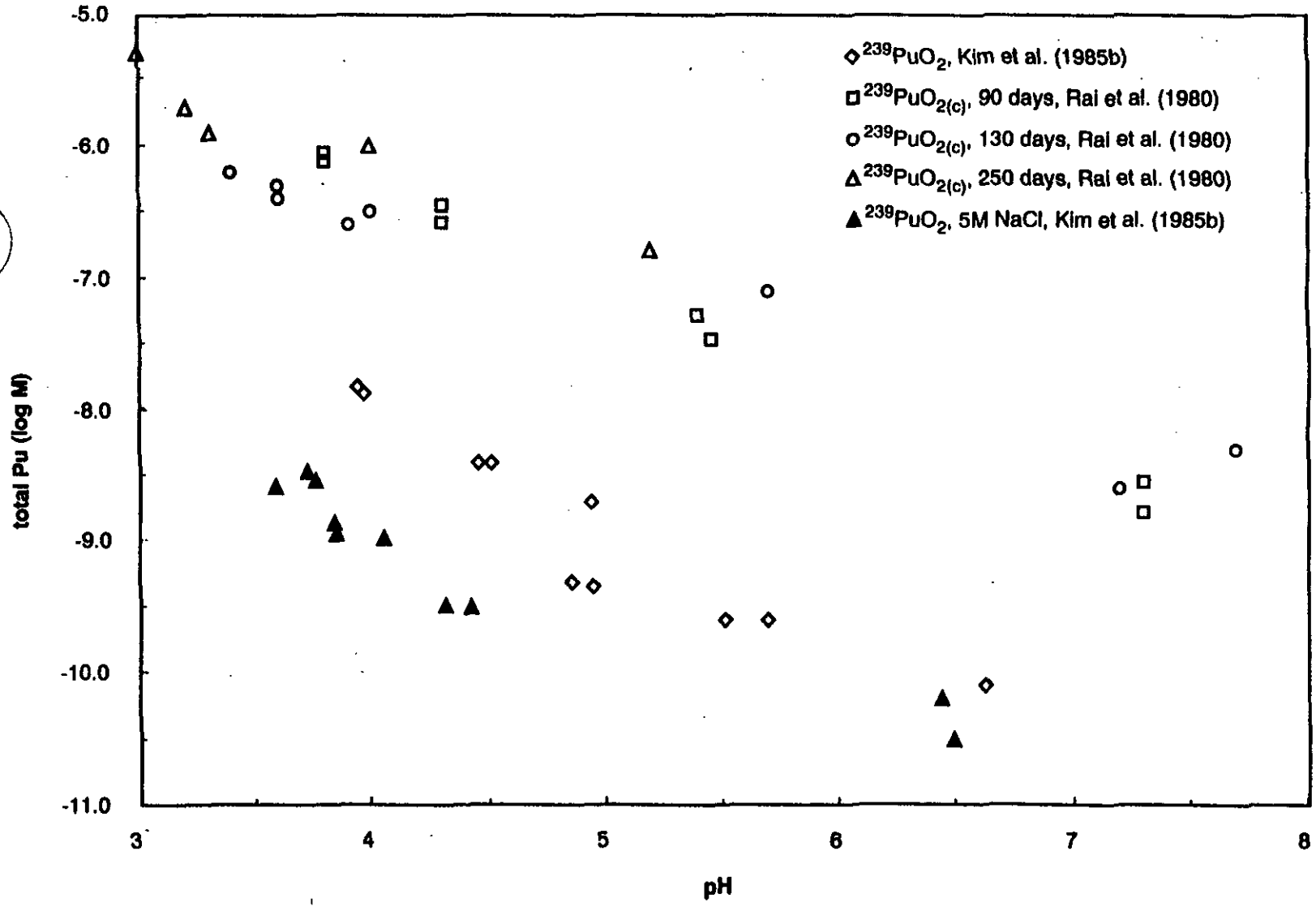

Figure G-9
$^{239}PuO_2$ Solubility as a Function of pH for Dilute and Brine Solutions

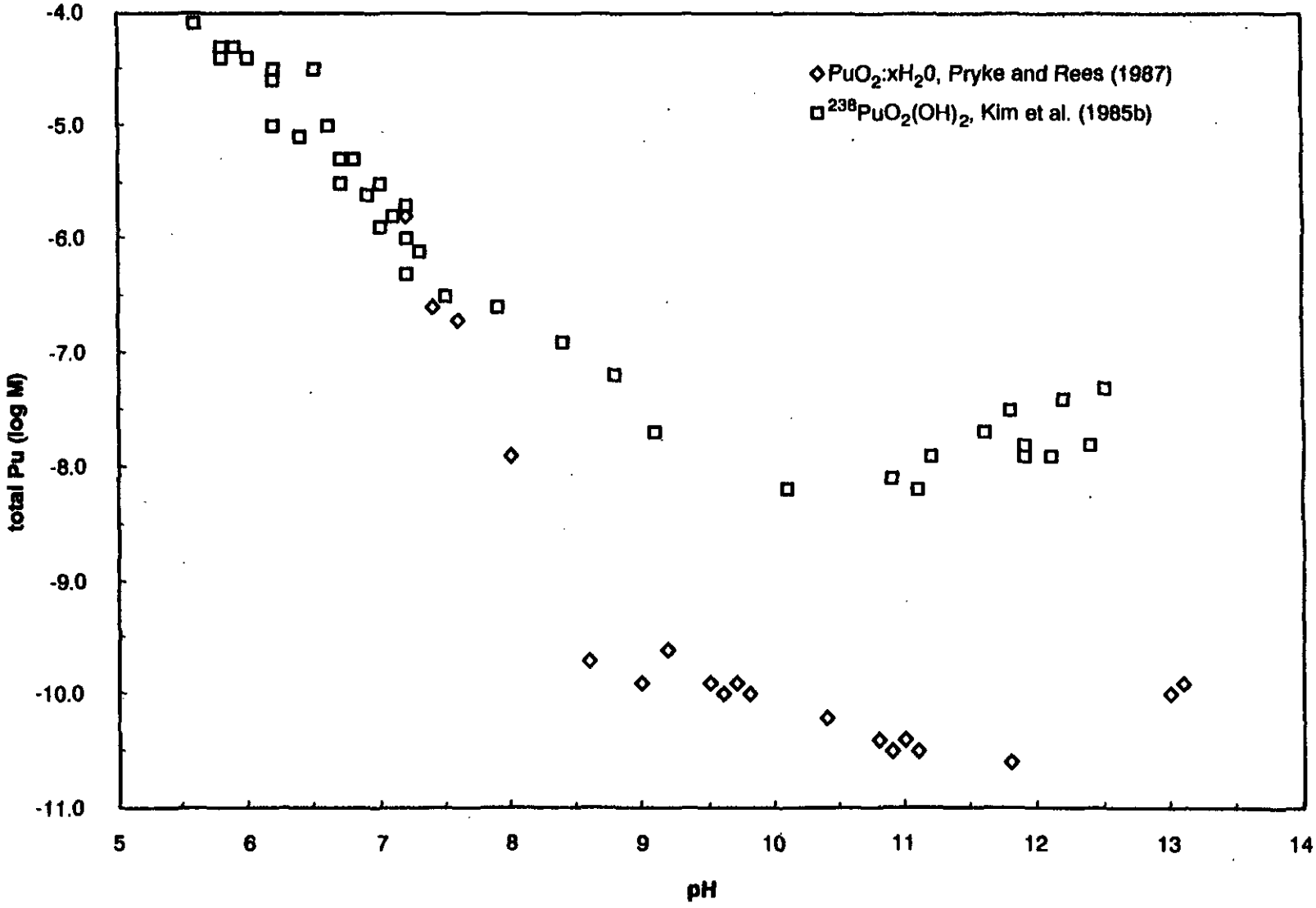

Figure G-10
$PuO_2 \cdot x\,H_2O$ and $PuO_2\,(OH)_2$ Solubilities as a Function of pH for Dilute Solutions

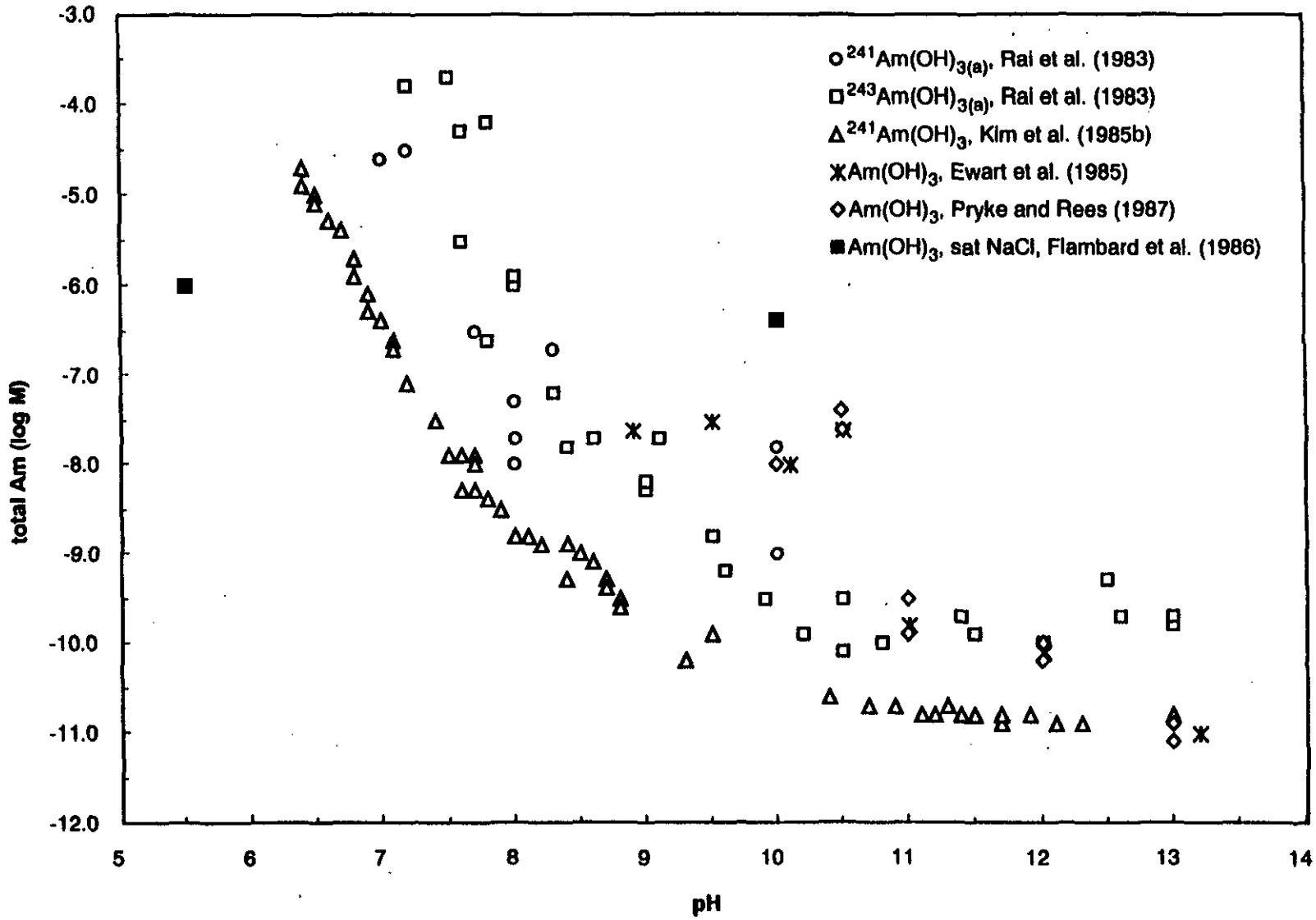

Figure G-11
$Am(OH)_3$ Solubility as a Function of pH for Dilute and Brine Solutions

Kim et al. (1985b) are about 0.5 to 1 order of magnitude lower (Figure G-11). This may indicate that the hydroxide used by Kim et al. (1985b) was aged to a microcrystalline form, relative to the amorphous form used by Rai et al. (1983).

Ewart et al. (1985) investigated the solubility of $Am(OH)_3$ in cement-equilibrated solutions and their results show an abrupt decrease in the Am concentration from about -8 to -10 log M between a pH of 10.5 to 11 (Figure G-11). The data of Pryke and Rees (1987) were also obtained with cement-equilibrated solutions and their results closely follow the trend of data reported by Ewart et al. (1985).

Flambard et al. (1986) reported limited data on the solubility of $Am(OH)_3$ in a saturated NaCl solution (Figure G-11). Their two data points on Figure G-11 suggest a slight decrease in solubility as pH increases from 5.5 to 10. Based on their data point at a pH of 10, the solubility of $Am(OH)_3$ may be 1.5 to 3 orders of magnitude greater in saturated NaCl brines relative to dilute solutions.

Figure G-12 summarizes solubility data for the Am (IV) and Am (V) solids AmO_2, AmO_2OH, and $AmOHCO_3$. Kim et al. (1985b) reported limited data on AmO_2 in 0.5 and 5M NaCl solutions over the pH range of 3.5 to 5. The overlap of data point at a pH near 4 suggests that ionic strength does not have a strong effect on the solubility of AmO_2 in this pH interval. Kim et al. (1985b) also looked at the solubility of AmO_2OH in 5M NaCl solution, and their results indicate a decrease in Am concentration from about -4 to -8 over the pH interval of 8 to 13.

Solubility studies on amorphous $AmOHCO_3$ carried out by Pryke and Rees (1987) show a decrease in Am concentration from about -4.5 to -7.5 as pH increases from 7 to 9.5 (Figure G-12). Similar studies carried out by Felmy et al. (1990) indicate significantly lower Am concentration of -8 to -8.5 log M over the pH range of 7 to 9, due to the aging of their precipitates to crystalline $AmOHCO_3$. The convergence of these independent data sets at a pH near 9.5 is due to the instability of $AmOHCO_3$ above a pH of 9.5 as $Am(OH)_3$ becomes the stable phase.

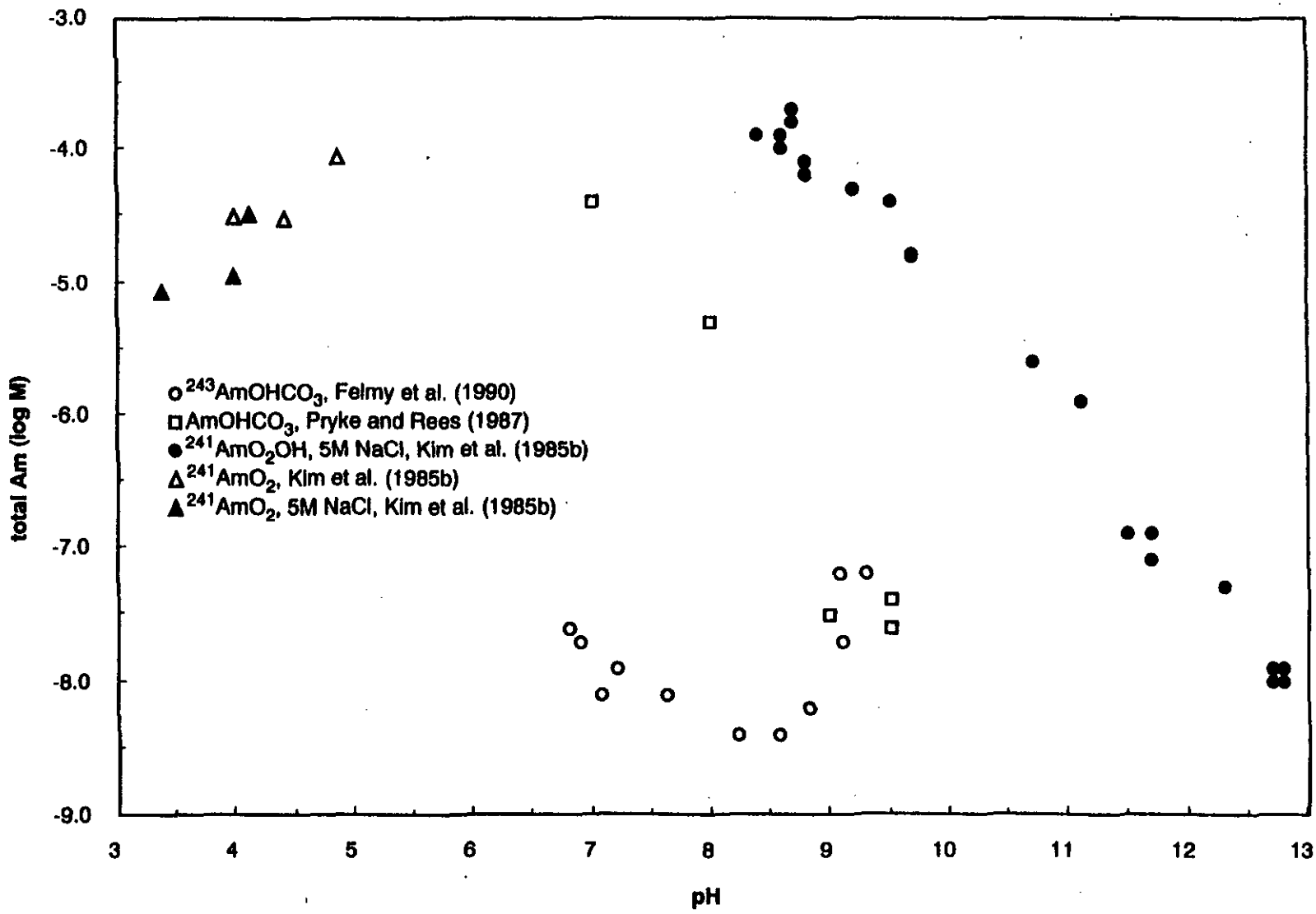

Figure G-12
$AmOHCO_3$, AmO_2OH, and AmO_2 Solubilities as a Function of pH for Dilute and Brine Solutions

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APPENDIX G
ACTINIDE SOLUBILITY DATA BASE
ATTACHMENT 1

M

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M

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Am	amorphous 241am(oh)3	h2o+1.5E-3Mcacl2 + hcl or naoh to adjust pH	dilute	7	-4.6	oversaturation	7	air atm	22	Rai et al., 1983	1,2,6
				8	-6						
				10	-7.8						
Am	amorphous 241am(oh)3	h2o+1.5E-3Mcacl2 + hcl or naoh to adjust pH	dilute	7.7	-6.5	undersaturation	4	air atm	22	Rai et al., 1983	1,2,6,8
				7.2	-4.5		7				
				8.3	-6.7		7				
				10	-9		7				
				8	-7.3		11				
				8	-7.7		14				
				8	-8		26-28				
Am	amorphous 243am(oh)3	h2o + hcl or tetrapropyl nh4oh to adjust pH	dilute	7.6	-4.2	oversaturation	7	ar+n2 atm	22	Rai et al., 1983	1,2
				7.8	-6.6						
				8.3	-7.2						
				9.1	-7.7						
Am	amorphous 243am(oh)3	h2o + hcl or tetrapropyl nh4oh to adjust pH	dilute	7.5	-3.7	undersaturation	3	ar+n2 atm	22	Rai et al., 1983	1,2
				8	-6		3				
				9	-8.3		3				
				9.6	-9.2		3				
				10.2	-9.9		3				
				10.8	-10		3				
				11.5	-9.9		3				
				12	-10		3				
				13	-9.8		3				
				7.6	-4.3		7				
				8	-5.9		7				
				8.6	-7.7		7				
				9	-8.2		7				
				9.5	-8.8		7				
				9.9	-9.5		7				
				10.5	-10.1		7				
				11.5	-9.9		7				
				12.6	-9.7		7				
				13	-9.7		7				
				7.2	-3.8		23				
				7.6	-5.5		23				
				8.4	-7.8		23				
				10.5	-9.5		23				
				11.4	-9.7		23				
				12	-10		23				
				12.5	-9.3		23				
Am	241am(oh)3	h2o + 0.1M naclo4	dilute	6.4	-4.7	undersaturation	NA	ar atm	25	Kim et al., 1985b	1,17
				6.4	-4.9						
				6.5	-5						
				6.5	-5.1						
				6.6	-5.3						
				6.7	-5.4						
				6.8	-5.7						
				6.8	-5.9						
				6.9	-6.1						
				6.9	-6.3						
				7	-6.4						
				7.1	-6.6						

APPENDIX G
ATTACHMENT #1

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Am	241am(oh)3	h2o + 0.1M naclo4	dilute	7.1	-6.7	undersaturation	NA	ar atm	25	Kim et al., 1985b	1,17
				7.2	-7.1						
				7.4	-7.5						
				7.5	-7.9						
				7.6	-7.9						
				7.7	-7.9						
				7.7	-8						
				7.8	-8.3						
				7.7	-8.3						
				7.8	-8.4						
				7.9	-8.5						
				8	-8.8						
				8.1	-8.8						
				8.2	-8.9						
				8.4	-8.9						
				8.4	-9.3						
				8.5	-9						
				8.6	-9.1						
				8.7	-9.3						
				8.7	-9.4						
				8.8	-9.5						
				8.8	-9.6						
				9.3	-10.2						
				9.5	-9.9						
				10.4	-10.6						
				10.7	-10.7						
				10.9	-10.7						
				11.1	-10.8						
				11.1	-10.8						
				11.2	-10.8						
				11.3	-10.7						
				11.4	-10.8						
				11.5	-10.8						
				11.7	-10.9						
				11.7	-10.8						
				11.9	-10.8						
				12.1	-10.9						
				12.3	-10.9						
				13	-10.8						
Am	crystalline am(oh)3	h2o + 0.1M naclo4	dilute	7	-4.3	calculated	NA	ar atm	25	Silva, 1984	1
				8	-7						
				9	-8.2						
				10	-8.2						
Am	am(oh)3	h2o saturated with nacl	brine	1	>-2.8	undersaturation	NA	NA	25	Flambard et al., 1986	4,10
				5.5	-6						
				10	-6.4						
Am	am(oh)3	cement-equilibrated water + hcl or naoh	dilute	8.9	-7.6	oversaturation	0.02	200	NA	Ewart et al., 1985	1,16
				9.5	-7.5						
				10.1	-8						
				10.5	-7.6						
				11	-9.8						
				12	-10.1						
				13.2	-11						

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Am	am(oh)3	deionized water equilibrated with crushed cement,	dilute	10	-8	oversaturation	0.02	200 mV in	ambient	Pryke and Rees, 1987	1, 21
		composition(M): ca+2=1E-2; na+=5E-5; mg+2=5E-6;		10.5	-7.4			n2 atm at			
		cl-=2E-3; so4-2=3E-3; co3-2=3E-5; pH=12; pH adjusted with		10.5	-7.6			pH = 12			
		hcl or naoh. I = 0.04 M		11	-9.5						
				11	-9.9						
				12	-10						
				12	-10.2						
				13	-10.9						
				13	-11.1						
Am	243amco3 (SB)	h2o + 0.01 M nahco3	dilute	6.8	-7.6	oversaturation	66	10-3 atm	ambient	Felmy et al., 1990.	1,2
				6.89	-7.7			CO2 in Ar			
				7.08	-8.1						
				7.21	-7.9						
				7.63	-8.1						
				8.22	-8.4						
				8.57	-8.4						
				8.83	-8.2						
				9.09	-7.2						
				9.11	-7.7						
				9.3	-7.2						
Am	crystalline amohco3	h2o + 0.1M naclo4 + E-3.5atm co2	dilute	6	-4.5	calculated	NA	ar+co2 atm	25	Silva, 1984	1
				7	-7.3						
				8	-9.1						
				8.5	-9.3						
				9	-9.1						
				10	-8.2						
Am	crystalline amohco3	h2o + 0.1M naclo4 + 2E-3M co3	dilute	6	-6.3	calculated	NA	ar+co2 atm	25	Silva, 1984	1
				7	-8						
				8	-9.1						
				9	-9.7						
				10	-9.3						
Am	amohco3	deionized water equilibrated with crushed cement,	dilute	7	-4.4	oversaturation	0.02	200 mV in	ambient	Pryke and Rees, 1987	1, 21
		composition(M): ca+2=1E-2; na+=5E-5; mg+2=5E-6;		8	-5.3			n2 atm at			
		cl-=2E-3; so4-2=3E-3; co3-2=3E-5; pH=12; pH adjusted with		9	-7.5			pH = 12			
		hcl or naoh. I = 0.04 M		9.5	-7.4						
				9.5	-7.6						
Am	241amo2oh	h2o + 5M nacl	brine	8.4	-3.9	undersaturated	NA	ar atm	25	Kim et al., 1985b	1,17
				8.6	-3.9						
				8.6	-4						
				8.7	-3.7						
				8.7	-3.8						
				8.8	-4.1						
				8.8	-4.2						
				9.2	-4.3						
				9.5	-4.4						
				9.7	-4.8						
				10.7	-5.6						
				11.1	-5.9						
				11.5	-6.9						

APPENDIX G
ATTACHMENT #1

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Am	241amo2	h2o + 0.1M nacl	dilute	11.7	-6.9	undersaturated	160	ar atm	22	Kim et al., 1985b	4,20
				11.7	-7.1						
				12.3	-7.3						
				12.7	-7.9						
				12.7	-8						
				12.8	-7.9						
				12.8	-8						
				4	-4.51						
				4.42	-4.53						
				4.66	-4.06						
Am	241amo2	h2o + 5M nacl	brine	3.39	-5.08	undersaturated	160	ar atm	22	Kim et al., 1985b	4,20
				4.12	-4.49						
				3.99	-4.95						
Am	243am-doped PNL 76-68 glass	nacl brine, WIPP brine B	brine	NA	-8.72	undersaturation	2	13.8MPa ar	150	Westsik et al., 1983	1,12,13,14
					-9.19		4				
					-8.65		8				
					-8.94		16				
					-8.99		32				
Am	ILW solidified with bitumen	h2o sat w/ca(oh)2,fe(oh)2,nacl,tbp,dbp,edta,cit&ox	brine	NA	-9.64	undersaturation	41	NA	NA	Marx and Keiling, 1989	4,18
Cm	244cm-doped PNL 76-68 glass	nacl brine, WIPP brine B	brine	NA	-10.03	undersaturation	2	13.8MPa ar	150	Westsik et al., 1983	1,12,13,14
					-9.99		8				
					-10		16				
					-10.47		32				
Np	npo2:xh2o	deionized water equilibrated with crushed cement, composition(M): ca+2=1E-2; na+=5E-5; mg+2=5E-6; cl-=2E-3; so4-2=3E-3; co3-2=3E-5; pH=12; pH adjusted with hcl or naoh. I = 0.04 M	dilute	9.9	-8	oversaturation	1	-400 mV in in n2 atm at pH = 12	ambient	Pryke and Rees, 1987	1, 21
				10.2	-7.8						
				10.5	-8						
				11	-8						
				11.2	-8.1						
				11.2	-8.4						
				11.5	-8.4						
				11.7	-8.4						
				12	-8.2						
				12.5	-8.1						
				13	-8.4						
Np	237np-doped PNL 76-68 glass	nacl brine, WIPP brine B	brine	NA	-6.17	undersaturation	2	13.8MPa ar	150	Westsik et al., 1983	1,12,13,14
					-6		4				
					-5.96		8				
					-6.11		16				
					-6.11		32				
Np	237np-doped PNL 76-68 glass	h2o+1.5E-3Mcacl2+E-3Mquinhydrone + hcl or naoh	dilute	6.8	-6.7	undersaturation	5	296	25	Rai et al., 1982	1,2
				6	-6.7		5	343			
				5.2	-6.3		5	391			
				3.9	-6.3		5	467			
				2.8	-5.8		5	533			
				6.5	-6.3		41	314			
				4.8	-6.1		41	414			
				3.8	-5.6		41	473			
				6.4	-6		67-83	320			
				5.3	-6		67-83	385			
				4.3	-5.7		67-83	444			
				5.8	-5.7		288-302	355			

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Np	237np-doped PNL 76-68 glass	h2o+1.5E-3Mcacl2+E-3Mquinhydrone + hcl or naoh	dilute	4.4	-5.4	undersaturation	288-302	438	25	Rai et al., 1982	1,2
Np	237np-doped PNL 76-68 glass	h2o+1.5E-3Mcacl2+E-3Mquinhydrone + hcl or naoh	dilute	3	-5.4	undersaturation	NA	NA	NA	Rai and Strickert, 1980	1,5
				3.2	-5.5						
				4.1	-6.1						
				4.8	-6.1						
				6.3	-6.7						
				6.7	-6.8						
				6.8	-6.8						
				6.9	-6.7						
Np	237npo2	h2o+1.5E-3Mcacl2+E-3Mquinhydrone + hcl or naoh	dilute	4.8	-5.7	undersaturation	54	414	25	Rai et al., 1982	1,5
				4	-5.7			462			
				2.3	-5.7			562			
Np	237npo2	h2o+1.5E-3Mcacl2+E-3Mquinhydrone + hcl or naoh	dilute	3.5	-5.6	undersaturation	NA	NA	NA	Rai and Strickert, 1980	1,5
				3.7	-5.7						
				4	-6.1						
				4.1	-5.8						
				4.3	-5.9						
				4.4	-6.3						
				4.5	-6.2						
				5.7	-6.4						
Np	237npo2	h2o + 1M nacl	saline	5.4	-4.48	undersaturation	118	ar atm	25	Kim et al., 1985b	4,20
				5.08	-4.63		118				
				7.91	-5.83		72				
				7.99	-5.54		72				
Np	237npo2	h2o + 5M nacl	brine	5.82	-4.53	undersaturation	118	ar atm	25	Kim et al., 1985b	4,20
				5.72	-4.77		118				
				7.69	-6.19		72				
				7.72	-6.07		72				
Np	npo2oh	cement-equilibrated water + hcl or naoh	dilute	8.8	-4.6	oversaturation	1	200	NA	Ewart et al., 1985	1,16
				9.6	-4.8						
				9.8	-4.9						
				10.3	-4.9						
				10.9	-5.6						
				11.2	-6.7						
				11.4	-6.9						
				11.7	-7.2						
				11.8	-7.3						
				11.9	-7.8						
				12	-7.9						
				12.1	-8.7						
				12.3	-8.5						
				12.4	-8.7						
				12.4	-8.4						
				12.7	-8.8						
				12.8	-9						
				12.9	-9.4						
				13	-9						
Np	npo2oh	h2o sat w/ ca(oh)2, fe(oh)2 and nacl	brine	NA	-3.62	undersaturation	NA	NA	NA	Marx and Kelling, 1989	4,18
Np	npo2oh	h2o sat w/ ca(oh)2, fe(oh)2, nacl and TBP	brine	NA	-5.26	undersaturation	NA	NA	NA	Marx and Kelling, 1989	4,18
Np	npo2oh	h2o sat w/ ca(oh)2, fe(oh)2, nacl and DBP	brine	NA	-5.26	undersaturation	NA	NA	NA	Marx and Kelling, 1989	4,18
Np	npo2oh	h2o sat w/ ca(oh)2, fe(oh)2, nacl and EDTA	brine	NA	-3.76	undersaturation	NA	NA	NA	Marx and Kelling, 1989	4,18
Np	npo2oh	h2o sat w/ ca(oh)2, fe(oh)2, nacl and citrate	brine	NA	-3.14	undersaturation	NA	NA	NA	Marx and Kelling, 1989	4,18
Np	npo2oh	h2o sat w/ ca(oh)2, fe(oh)2, nacl and oxalate	brine	NA	-3	undersaturation	NA	NA	NA	Marx and Kelling, 1989	4,18

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Np	237npo2oh	h2o + 1M naclo4	saline	6.8	-1.9	undersaturation	NA	ar atm	25	Kim et al., 1985b	1,17
				7.2	-2.2						
				7.7	-2.7						
				8.4	-3.4						
				8.8	-3.8						
				10.2	-5.1						
				10.8	-5.7						
				10.8	-5.9						
				11.6	-5.8						
				11.6	-5.9						
				11.8	-5.8						
				11.8	-5.7						
				11.9	-5.7						
				12	-5.6						
				12	-5.7						
				12.2	-5.3						
				12.2	-5.5						
				12.4	-5.1						
				12.4	-5.2						
				12.6	-5.1						
				12.6	-5.2						
				12.8	-5						
				12.9	-5						
				12.9	-5.2						
				12.8	-4.6						
Np	237npo2oh	h2o + 1M nacl	saline	6.44	-4.7	undersaturation	14	ar atm	22	Kim et al., 1985b	4,19
Np	237npo2oh	h2o + 5M nacl	brine	6.07	-4.91	undersaturation	14	ar atm	22	Kim et al., 1985b	4,19
Np	237npo2oh (amorphous)	np237,10-30mg dissolved as npo2clo4 in 0.1M naclo4	dilute	7.4	-2.1	oversaturation	1-2	ar atm	25	Neck et al., 1992	1,20
				8.2	-2.8						
				8.6	-3.25						
				9	-3.75						
				9	-3.7						
				9.3	-4						
				9.5	-4.2						
				9.55	-4.2						
				9.95	-4.6						
				10.4	-5.1						
				10.6	-5.3						
				11.2	-5.6						
				11.3	-5.75						
				11.6	-5.9						
				11.8	-5.95						
				11.9	-5.8						
				12	-5.8						
				12.1	-5.9						
				12.3	-5.6						
				12.3	-5.8						
				12.5	-5.7						
				12.6	-5.55						
				12.7	-5.5						
				12.8	-5.4						
				12.9	-5.3						

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Np	237npo2oh (amorphous)	np237,10-30mg dissolved as npo2clo4 in 1.0M naclo4	saline	8.85	-3.6	oversaturation	1-2	ar atm	25	Neck et al., 1992	1,20
				9.85	-4.6						
				11.7	-5.9						
				13.7	-4.2						
Np	237npo2oh (aged, grey-white ppt)	np237,10-30mg dissolved as npo2clo4 in 1.0M naclo4	saline	7.3	-2.7	oversaturation	14-28	ar atm	25	Neck et al., 1992	1,20
				7.9	-3.4						
				8.85	-4.2						
				9.3	-4.7						
				9.4	-4.9						
				10	-5.5						
				10.8	-6						
				11.5	-6.33						
				11.6	-6.4						
				12.1	-6.4						
				12.8	-5.9						
				12.9	-5.9						
				13.2	-5.6						
				13.3	-5.4						
				13.5	-5.5						
				13.7	-5						
				13.8	-5						
Np	237npo2oh (aged, grey-white ppt)	np237,10-30mg dissolved as npo2clo4 in 3.0M naclo4	brine	7	-3	oversaturation	14-28	ar atm	25	Neck et al., 1992	1,20
				7.4	-3.1						
				7.6	-3						
				7.7	-3.25						
				8.2	-3.8						
				8.6	-4.3						
				8.7	-4.4						
				9.1	-4.75						
				9.2	-5.25						
				9.5	-5.2						
				9.6	-5.3						
				9.9	-5.6						
				10.3	-5.9						
				10.9	-6.4						
				11.5	-6.4						
				11.6	-6.55						
				11.9	-6.5						
				12.8	-6.1						
				13.2	-5.6						
				13.5	-5.4						
				13.7	-5.1						
Pu	puo2:xh2o	deionized water equilibrated with crushed cement, composition(M): ca+2=1E-2; na+=5E-5; mg+2=5E-6; cl-=2E-3; so4-2=3E-3; co3-2=3E-5; pH=12; pH adjusted with hcl or naoh. I = 0.04 M	dilute	7.2	-5.8	oversaturation	0.02	-300 mV in ar/5%h2 atm at pH = 12	ambient	Pryke and Rees, 1987	1, 21
				7.4	-6.6						
				7.6	-6.7						
				8	-7.9						
				8.6	-9.7						
				9	-9.9						
				9.2	-9.6						
				9.5	-9.9						
				9.6	-10						

APPENDIX G
ATTACHMENT #1

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Pu	puo2:xh2o	deionized water equilibrated with crushed cement, composition(M): ca+2=1E-2; na+=5E-5; mg+2=5E-6; cl-=2E-3; so4-2=3E-3; co3-2=3E-5; pH=12; pH adjusted with hcl or naoh. I = 0.04 M	dilute	9.7	-9.9	oversaturation	0.02	-300 mV in ar/5%h2 atm at pH = 12	ambient	Pryke and Rees, 1987	1, 21
				9.8	-10						
				10.4	-10.2						
				10.8	-10.4						
				10.9	-10.5						
				11	-10.4						
				11.1	-10.5						
				11.8	-10.6						
				13	-10						
				13.1	-9.9						
Pu	239pu-doped PNL 76-68 glass	nacl brine, WIPP brine B	brine	NA	-8.74	undersaturation	2	13.8MPa ar	150	Westsik et al., 1983	1,12,13,14
				NA	-8.67		4				
				NA	-8.49		8				
				NA	-8.65		16				
				NA	-8.67		32				
Pu	amorphous 239pu(oh)3	h2o + hcl or naoh to adjust pH	dilute	7.85	-9.11	oversaturation	8	-402	23	Rai et al., 1987	2,4
				8.14	-8.57		12	-359			
				10	-9.21		12	-417			
				8.57	-9.05		12	-339			
				8.32	-9.45		13	-283			
				8.99	-10.23		13	-331			
				10.2	-9.54		13	-219			
				10.4	-9.95		13	-233			
				10.9	-9.73		13	-207			
				11.4	-9.39		13	-262			
				11.9	-9.29		13	-293			
				12.1	-9.52		13	-266			
				12.5	-9.93		13	-190			
				12.8	-9.31		13	-237			
				13.2	-9.23		13	-281			
				7.63	-8.04		22	-340			
				6.08	-3.46		2	-185			
				6.36	-3.73		2	-256			
				7.41	-6.74		2	-335			
				6.71	-3.56		2	-310			
				6.86	-4.33		7	-294			
				6.83	-3.95		7	-355			
				6.62	-3.64		8	-278			
				7.8	-6.66		8	-352			
				8.08	-6.83		8	-311			
				7.28	-4.77		8	-282			
				9.76	-9.81		10	-194			
				8.01	-8.99		24	-238			
				8.56	-9.28		24	-295			
Pu	amorphous 239pu(oh)3	h2o + hcl or naoh to adjust pH	dilute	7.19	-5.75	undersaturation	21	-273	23	Rai et al., 1987	2,4
				7.18	-5.09		21	-314			
				7.4	-6.88		21	-310			
				7.71	-8.86		21	-305			
				7.87	-8.37		21	-322			
				8.18	-9.36		21	-330			
				8.1	-9.54		21	-327			
Pu	amorphous 239pu(oh)3	PBB1 + hcl or naoh to adjust pH	brine	7.26	-4.83	oversaturation	3	-267	23	Rai et al., 1987	2,4
				8.06	-5.87		3	-288			

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Pu	amorphous 239pu(oh)3	PBB1 + hcl or naoh to adjust pH	brine	7.41	-4.24	oversaturation	7	-293	23	Rai et al., 1987	2,4
				7.82	-4.94		7	-310			
				8.04	-5.64		7	-310			
				8.05	-5.68		7	-289			
				8.45	-6.93		7	-297			
				8.7	-7.4		7	-301			
				9.01	-8.84		7	-311			
				9.34	-9		7	-334			
				10.2	-9.06		7	-324			
				11.3	-9.09		7	-387			
				8.08	-5.91		14	-269			
Pu	amorphous 239pu(oh)3	PBB1 + hcl or naoh to adjust pH	brine	7.88	-7.03	undersaturation	13	-284	23	Rai et al., 1987	2,4
				8.28	-7.23		19	-268			
				8.28	-7.68		19	-252			
				8.06	-7.39		19	-230			
				8.05	-7.42		19	-218			
				8.32	-7.36		19	-276			
				8.26	-7.28		19	-251			
				9.15	-8.97		19	-338			
				9.25	-8.97		19	-362			
Pu	amorphous 239pu(oh)3	PBB3 + hcl or naoh to adjust pH	brine	6.32	-3.66	oversaturation	3	-244	23	Rai et al., 1987	2,4,11
				6.5	-3.82		3	-262			
				6.41	-3.7		8	-287			
				6.4	-3.77		8	-287			
				6.24	-3.93		8	-285			
				6.95	-4.85		8	-333			
				7.01	-4.92		8	-330			
				7.5	-4.53		8	-355			
				7.57	-4.34		8	-357			
				6.39	-4.09		10	-256			
				6.8	-4.87		10	-286			
Pu	amorphous 239pu(oh)3	PBB3 + hcl or naoh to adjust pH	brine	6.7	-4.52	undersaturation	14	-301	23	Rai et al., 1987	2,4,11
				6.75	-4.53			-302			
				6.81	-5.05			-367			
				6.83	-5.25			-303			
				6.94	-5.42			-303			
				7.32	-5.18			-307			
Pu	238puo2	h2o+0.1Mnacl pH adjusted with hno3?	dilute	5.3	-6.1	undersaturation	120	air atm	25	Kim et al., 1985a	1,7
				5.6	-5.7		210				
Pu	238puo2	h2o+0.5Mnacl pH adjusted with hno3?	saline	5.7	-5.7	undersaturation	120	air atm	25	Kim et al., 1985a	1,7
				5.9	-5.5		210				
Pu	238puo2	h2o+1Mnacl pH adjusted with hno3?	saline	5.4	-5.9	undersaturation	120	air atm	25	Kim et al., 1985a	1,7
				5.7	-5.7		210				
Pu	238puo2	h2o+3Mnacl pH adjusted with hno3?	brine	5.2	-6.2	undersaturation	120	air atm	25	Kim et al., 1985a	1,7
				5.4	-6		210				
Pu	238puo2	h2o+5Mnacl pH adjusted with hno3?	brine	4.7	-6.7	undersaturation	120	air atm	25	Kim et al., 1985a	1,7
				4.9	-6.5		210				
Pu	238puo2	h2o+ 0.1Mnacl	dilute	3.25	-5.68	undersaturation	120	ar atm	21	Kim et al., 1985b	4,20
				3.37	-6.51						
				3.45	-5.46						
				3.45	-6.42						
				3.37	-6.2						
				3.33	-5.59						

APPENDIX G
ATTACHMENT #1

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Pu	238puo2	h2o+ 0.1Mnacl	dilute	3.68	-6.9	undersaturation	120	ar atm	21	Kim et al., 1985b	4,20
				3.36	-5.73						
				3.65	-6.18						
				3.39	-6.15						
Pu	238puo2	h2o+5Mnacl	brine	3.65	-7.1	undersaturation	120	ar atm	22	Kim et al., 1985b	4,20
				3.86	-6.74						
				3.97	-6.7						
				4.2	-6.5						
				3.86	-6.69						
				4.25	-6.51						
				4.43	-6.15						
				4.08	-6.59						
				4.58	-6.35						
				4.45	-6.86						
Pu	239puo2	h2o+0.1Mnacl pH adjusted with hno3?	dilute	2.48	-8.8	undersaturation	250	air atm	25	Kim et al., 1985a	1,7
Pu	239puo2	h2o+0.5Mnacl pH adjusted with hno3?	saline	2.8	-8.5	undersaturation	250	air atm	25	Kim et al., 1985a	1,7
Pu	239puo2	h2o+1Mnacl pH adjusted with hno3?	saline	2.7	-8.7	undersaturation	250	air atm	25	Kim et al., 1985a	1,7
Pu	239puo2	h2o+3Mnacl pH adjusted with hno3?	brine	2.2	-9.2	undersaturation	250	air atm	25	Kim et al., 1985a	1,7
Pu	239puo2	h2o+5Mnacl pH adjusted with hno3?	brine	2.2	-9.2	undersaturation	250	air atm	25	Kim et al., 1985a	1,7
Pu	239puo2	h2o+ 0.1M nacl	dilute	3.97	-7.88	undersaturation	250	ar atm	21	Kim et al., 1985b	4,20
				3.94	-7.83						
				4.51	-8.4						
				4.46	-8.4						
				4.94	-8.7						
				5.69	-9.6						
				4.85	-9.3						
				4.95	-9.34						
				6.63	-10.1						
				5.51	-9.6						
Pu	239puo2	h2o+5Mnacl	brine	3.76	-8.53	undersaturation	250	ar atm	24	Kim et al., 1985b	4,20
				3.72	-8.47						
				3.85	-8.95						
				3.58	-8.58						
				4.31	-9.48						
				4.42	-9.51						
				4.05	-8.98						
				3.84	-8.88						
				6.49	-10.5						
				6.44	-10.2						
Pu	239puo2(c)	h2o+0.0015Mcacl2	dilute	3.8	-6.12	undersaturation	90	air atm	25	Rai et al., 1980	4,5
				3.8	-6.05						
				4.3	-6.57						
				4.3	-6.44						
				5.4	-7.29						
				5.45	-7.47						
				7.3	-8.55						
				7.3	-8.78						
Pu	239puo2(c)	h2o+0.0015Mcacl2	dilute	3.4	-6.2	undersaturation	130	air atm	25	Rai et al., 1980	1,15
				3.6	-6.3						
				3.6	-6.4						
				4	-6.5						
				3.9	-6.6						
				5.7	-7.1						

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Pu	239puo2(c)	h2o+0.0015Mcacl2	dilute	7.2	-8.6	undersaturation	130	air atm	25	Rai et al., 1980	1,15
				7.7	-8.3						
Pu	239puo2(c)	h2o+0.0015Mcacl2	dilute	3	-5.3	undersaturation	250	air atm	25	Rai et al., 1980	1,15
				3.2	-5.7						
				3.3	-5.9						
				4	-6						
				5.2	-6.8						
Pu	freshly declad spent fuel	PBB1	brine	NA	-8.5	undersaturation	5	air atm	25-30	Gray, 1986	1,2,9
				NA	-8.6		5				
				NA	-8.7		14				
				NA	-8.8		14				
				NA	-8.8		28				
				NA	-8.9		28				
				NA	-8.8		60				
				NA	-8.9		60				
Pu	previously declad spent fuel	PBB1	brine	NA	-7.4	undersaturation	5	air atm	25-30	Gray, 1986	1,2,9
				NA	-8		5				
				NA	-7.8		14				
				NA	-7.7		28				
				NA	-8.3		28				
				NA	-7.5		60				
				NA	-8.3		60				
				NA	-7.5		90				
				NA	-8.4		120				
				NA	-7.2		180				
				NA	-7.6		180				
Pu	ILW solidified with bitumen	h2o sat w/ca(oh)2,fe(oh)2,nacl,tbp,dbp,edta,cit&ox	brine	NA	-9.13	undersaturation	41	NA	NA	Marx and Keiling, 1989	4,18
Pu	pu(oh)4	h2o saturated w/ ca(oh)2, fe(oh)2 and nacl	brine	NA	-7.6	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
Pu	pu(oh)4	h2o saturated w/ ca(oh)2, fe(oh)2, nacl and TBP	brine	NA	-7.8	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
Pu	pu(oh)4	h2o saturated w/ ca(oh)2, fe(oh)2, nacl and DBP	brine	NA	-6.8	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
Pu	pu(oh)4	h2o saturated w/ ca(oh)2, fe(oh)2, nacl and EDTA	brine	NA	-5	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
Pu	pu(oh)4	h2o saturated w/ ca(oh)2, fe(oh)2, nacl and citrate	brine	NA	-4.9	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
Pu	pu(oh)4	h2o saturated w/ ca(oh)2, fe(oh)2, nacl and oxalate	brine	NA	-6.4	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
Pu	pu(oh)4	h2o saturated with nacl	brine	1	-3.5	undersaturation	NA	NA	25	Flambard et al., 1986	4,10
				5.5	-5.3						
				10	-7.8						
Pu	239pu(oh)4(a)	h2o+0.0015Mcacl2	dilute	3.95	-4.44	undersaturation	90	air atm	25	Rai et al., 1980	4,15
				4	-4.54						
				4	-4.31						
				4	-4.22						
				5	-5.25						
				5.05	-5.44						
				5.25	-5.17						
				5.3	-5.31						
				6.6	-6.77						
				6.7	-6.83						
				6.8	-6.63						
				6.83	-6.73						
				7.5	-7.54						
				7.7	-7.77						
				7.85	-7.11						

APPENDIX G
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ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Pu	239pu(oh)4(a)	h2o+0.0015Mcacl2	dilute	4	-4.5	undersaturation	130	air atm	25	Rai et al., 1980	1,15
				4.1	-4.3						
				4.7	-5						
				5	-5.2						
				5.1	-4.9						
				6.7	-6.6						
				7	-6.8						
				7.7	-7.3						
				7.9	-7.2						
Pu	239pu(oh)4(a)	h2o+0.0015Mcacl2	dilute	3.3	-4.6	undersaturation	250	air atm	25	Rai et al., 1980	1,15
				3.4	-4.3						
				3.5	-4.8						
				4.9	-5.5						
				5.3	-5.7						
				6	-6						
				7.7	-7						
				7.8	-7.2						
Pu	pu(oh)4	cement-equilibrated water + hcl or naoh	dilute	7.3	-5.7	oversaturation	0.02	-300	NA	Ewart et al., 1985	1,16
				7.5	-6.5						
				7.6	-6.6						
				8	-7.9						
				8.7	-9.7						
				9	-9.9						
				9.2	-9.5						
				9.7	-9.8						
				9.8	-10						
				10.3	-10.1						
				10.9	-10.4						
				11	-10.3						
				11.7	-10.5						
				13	-10.1						
Pu	pu(oh)4??	cement-equilibrated water + E-5M D-saccharic	dilute	12	-5.14	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-4M D-saccharic	dilute	12	-5.14	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-3M D-saccharic	dilute	12	-5.09	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-2M D-saccharic	dilute	12	-5.04	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-5M D-gluconic	dilute	12	-7.15	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-4M D-gluconic	dilute	12	-6.25	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-3M D-gluconic	dilute	12	-5.24	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-2M D-gluconic	dilute	12	-5.19	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-5M glutaric	dilute	12	-7.28	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-4M glutaric	dilute	12	-6.62	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-3M glutaric	dilute	12	-6.22	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-2M glutaric	dilute	12	-5.59	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-5M glyceric	dilute	12	-7.4	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-4M glyceric	dilute	12	-6.74	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-3M glyceric	dilute	12	-6.2	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-2M glyceric	dilute	12	-5.98	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-5M glycolic	dilute	12	-8.19	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-4M glycolic	dilute	12	-7.33	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-3M glycolic	dilute	12	-6.82	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-2M glycolic	dilute	12	-6.27	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-5M glyoxylic	dilute	12	-8.48	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-4M glyoxylic	dilute	12	-7.39	oversaturation	0.02	200	80	Cross et al., 1989	4,16

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Pu	pu(oh)4??	cement-equilibrated water + E-3M glyoxylic	dilute	12	-6.92	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	pu(oh)4??	cement-equilibrated water + E-2M glyoxylic	dilute	12	-6.59	oversaturation	0.02	200	80	Cross et al., 1989	4,16
Pu	238puo2(oh)2	h2O + 0.1M naclo4	dilute	5.6	-4.1	undersaturation	NA	ar atm	25	Kim et al., 1985b	1,17
				5.8	-4.3						
				5.8	-4.4						
				5.9	-4.3						
				6	-4.4						
				6.2	-4.5						
				6.2	-4.6						
				6.5	-4.5						
				6.2	-5						
				6.4	-5.1						
				6.6	-5						
				6.7	-5.3						
				6.7	-5.5						
				6.8	-5.3						
				6.9	-5.6						
				7	-5.5						
				7	-5.9						
				7.1	-5.8						
				7.2	-5.7						
				7.2	-6						
				7.2	-6.3						
				7.3	-6.1						
				7.5	-6.5						
				7.9	-6.6						
				8.4	-6.9						
				8.8	-7.2						
				9.1	-7.7						
				10.1	-8.2						
				10.9	-8.1						
				11.1	-8.2						
				11.2	-7.9						
				11.6	-7.7						
				11.8	-7.5						
				11.9	-7.8						
				11.9	-7.9						
				12.1	-7.9						
				12.2	-7.4						
				12.4	-7.8						
				12.5	-7.3						
Th	thorianite-tho2	h2o	dilute	2	-6	calculated	NA	NA	25	Langmuir and Herman, 1980	1
				5-9	-14						
Th	thorianite-tho2	h2o+1ppm(c2o4(oxalate)	dilute	2	-5	calculated	NA	NA	25	Langmuir and Herman, 1980	1
				4.5	-6						
				7-9	-14						
Th	thorianite-tho2	h2o+0.1ppm(EDTA	dilute	2-5	-6	calculated	NA	NA	25	Langmuir and Herman, 1980	1
				8.5	-14						
Th	thorianite-tho2	h2o+0.2ppm(f	dilute	2	-5.5	calculated	NA	NA	25	Langmuir and Herman, 1980	1
				5-7	-14						
Th	thorianite-tho2	h2o+0.1ppm(po4	dilute	2	-6	calculated	NA	NA	25	Langmuir and Herman, 1980	1
				4	-9.5						
				7.5	-14						

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ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Th	thorianite-tho2	h2o+100ppm(so4	dilute	2	-3.5	calculated	NA	NA	25	Langmuir and Herman, 1980	1
				5-7.5	-14						
Th	thorianite-tho2	h2o+10ppm(cl+2.5ppm(no3+100ppm(so4+0.3ppm(f+0.1ppm (po4	dilute	2	-4	calculated	NA	NA	25	Langmuir and Herman, 1980	1
				4	-9.5						
				7-8.5	-14						
Th	hydrous thorium (IV) oxide	h2o + 0.6M KCl	saline	3.83	-2.19	undersaturation	7	ar atm	ambient	Felmy et al., 1991	2
				4.68	-4.17						
				5.42	-6.43						
				6.05	-9						
				6.44	-8.41						
				7.46	-8.68						
				8.03	-8.67						
Th	hydrous thorium (IV) oxide	h2o + 0.6M NaCl	saline	3.02	-2.15	undersaturation	7	ar atm	ambient	Felmy et al., 1991	2
				3.59	-2.16		7				
				4.09	-2.17		7				
				4.14	-2.19		7				
				4.81	-3.87		7				
				5.21	-5.73		7				
				5.59	-8.53		7				
				6.06	-7.97		7				
				6.58	-7.08		7				
				7.01	-7.36		7				
				7.34	-8.38		7				
				7.61	-8.3		7				
				8.26	-8.07		7				
				9.23	-9.09		7				
				9.74	-8.82		7				
				10.2	-8.95		7				
				2.87	-2.17		98				
				3.42	-2.18		98				
				3.86	-2.29		98				
				3.91	-2.28		98				
				4.38	-3.14		98				
				3.86	-2.77		98				
				3.77	-2.86		98				
				4.35	-3.21		98				
				6.69	-8.15		98				
				7.18	-8.12		98				
				7.5	-6.92		98				
				8.21	-5.92		98				
				9.08	-7.6		98				
				9.58	-7.97		98				
				10.04	-8.16		98				
Th	hydrous thorium (IV) oxide	h2o + 1.2M NaCl	saline	2.94	-2.16	undersaturation	7	ar atm	ambient	Felmy et al., 1991	2
				3.58	-2.16		7				
				4.1	-2.2		7				
				4.52	-3.09		7				
				4.79	-2.73		7				
				5.68	-7.69		7				
				5.83	-6.39		7				
				6.38	-8.9		7				
				6.76	-8.3		7				

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Th	hydrous thorium (IV) oxide	h2o + 1.2M NaCl	saline	7.16	-8.2	undersaturation	7	ar atm	ambient	Felmy et al., 1991	2
				7.63	-8.57		7				
				8.21	-8.83		7				
				8.64	-8.82		7				
				9.09	-8.8		7				
				9.52	-8.25		7				
				10.03	-7.1		7				
				2.87	-2.2		98				
				3.3	-2.19		98				
				3.76	-2.48		98				
				4.17	-3.16		98				
				4.37	-3.9		98				
				4.08	-2.83		98				
				3.99	-2.75		98				
				3.97	-4.13		98				
				5.91	-7.51		98				
				6.92	-7.46		98				
				7.47	-7.9		98				
				8.05	-7.8		98				
				8.44	-7.82		98				
				8.86	-7.38		98				
				9.3	-7.08		98				
				9.8	-6.14		98				
Th	hydrous thorium (IV) oxide	h2o + 3M NaCl	brine	3.36	-2.95	undersaturation	8	ar atm	ambient	Felmy et al., 1991	2
				4.27	-3.3		8				
				4.32	-3.33		8				
				4.52	-3.71		8				
				4.76	-4.09		8				
				4.96	-4.32		8				
				5	-5.13		8				
				5.58	-6.98		8				
				5.61	-6.39		8				
				5.81	-6.84		8				
				5.99	-6.94		8				
				6.12	-7.28		8				
				6.41	-7.61		8				
				6.42	-7.62		8				
				6.44	-7.89		8				
				8.27	-7.64		8				
				3.56	-2.17		122				
				3.87	-3.03		122				
				3.98	-3.61		122				
				3.95	-3.9		122				
				4.02	-3.94		122				
				4.32	-4.1		122				
				7.12	-6.47		122				
				7.77	-6.44		122				
				7.82	-6.43		122				
				7.93	-6.37		122				
				8.82	-7.84		122				
				9	-7.92		122				
				9.47	-7.2		122				
				9.58	-7.66		122				

APPENDIX G
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ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
Th	hydrous thorium (IV) oxide	h2o + 3M NaCl	brine	10.06	-7.83	undersaturation	122	ar atm	ambient	Felmy et al., 1991	2
				10.1	-7.45		122				
				3.61	-2.09		372				
				3.69	-3.56		372				
				3.81	-2.87		372				
				4.05	-3.28		372				
				4.38	-3.77		372				
				4.58	-4.4		372				
				4.65	-4.79		372				
				7.89	-6.85		372				
				7.98	-6.66		372				
				8.2	-6.96		372				
				8.11	-7.09		372				
				8.04	-7.73		372				
				8.05	-7.73		372				
				8.24	-6.83		372				
				8.48	-7.68		372				
U	233u-doped PNL 76-68 glass	nacl brine, WIPP brine B	brine	NA	-6	undersaturation	2	13.8MPa ar	150	Westsik et al., 1983	1,12,13,14
				NA	-6.13		4				
				NA	-6.1		8				
				NA	-6.03		16				
				NA	-6.15		32				
U	uraninite-uo2	h2o	dilute	2	-10.2	calculated	NA	<200	25	Langmuir, 1978	1
				4	-13			<200			
				9	-8.8			<-100			
U	uraninite-uo2	h2o+E-2atmPco2	dilute	8	-10	calculated	NA	<-200	25	Langmuir, 1978	1
				8	-4			0			
U	uraninite-uo2	h2o+E-3.5atmPco2	dilute	8	-10	calculated	NA	<-100	25	Langmuir, 1978	1
				8	-4			100			
U	uraninite-uo2	h2o+E-2atmPco2+E-8Mpo4	dilute	6	-12	calculated	NA	<-100	25	Langmuir, 1978	1
				6	-4			150			
U	uraninite-uo2	h2o+0.11125Mhcl	dilute	1.04	-6.717	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
				1.04	-7.022						
U	uraninite-uo2	h2o+1.51E-3Mhcl+0.098Mnacl	dilute	2.92	-8.452	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
				2.92	-8.733						
U	uraninite-uo2	h2o+1.22E-3Mhcl	dilute	2.93	-8.598	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
				2.93	-8.766						
U	uraninite-uo2	h2o+9.366E-6Mhcl	dilute	5.03	-8.704	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
				5.03	-9.914						
U	uraninite-uo2	h2o+1.136E-3Mhcl	dilute	3.95	-9.695	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o	dilute	6.67	-9.463	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
				6.67	-10.015						
U	uraninite-uo2	h2o+0.01097Mhcl	dilute	2.01	-9.381	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o+1.26E-3Mhcl	dilute	1.85	-9.377	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o+0.01569Mnaoh+0.0866Mnacl	dilute	1.04	-9.583	undersaturation	NA	h2=50MPa	100	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o+0.11125Mhcl	dilute	1.05	-6.875	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4
				1.05	-7.147						
				1.05	-7.259						
U	uraninite-uo2	h2o+1.51E-3Mhcl+0.098Mnacl	dilute	2.93	-8.479	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4
				2.93	-8.676						
U	uraninite-uo2	h2o+1.22E-3Mhcl	dilute	2.94	-8.57	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4
				2.94	-8.557						
U	uraninite-uo2	h2o+9.366E-6Mhcl	dilute	5.02	-9.733	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
U	uraninite-uo2	h2o+9.366E-6Mhcl	dilute	5.02	-9.914	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o+1.136E-3Mhcl	dilute	3.95	-9.704	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4
				3.95	-9.733						
U	uraninite-uo2	h2o	dilute	5.89	-9.532	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4
				5.89	-9.474						
U	uraninite-uo2	h2o+0.01097Mhcl	dilute	2.01	-9.347	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4
				2.01	-9.263						
U	uraninite-uo2	h2o+1.26E-3Mhcl	dilute	1.86	-9.335	undersaturation	NA	h2=50MPa	150	Parks and Pohl, 1988	3,4
				1.86	-9.422						
U	uraninite-uo2	h2o+0.11125Mhcl	dilute	1.08	-7.075	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				1.08	-7.2						
				1.08	-7.45						
U	uraninite-uo2	h2o+1.51E-3Mhcl+0.098Mnacl	dilute	2.95	-8.507	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				2.95	-8.514						
U	uraninite-uo2	h2o+1.22E-3Mhcl	dilute	2.94	-8.256	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				2.94	-8.652						
U	uraninite-uo2	h2o+9.366E-6Mhcl	dilute	5.01	-8.283	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				5.01	-9.714						
U	uraninite-uo2	h2o+1.136E-3Mhcl	dilute	3.95	-9.403	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				3.95	-9.551						
U	uraninite-uo2	h2o	dilute	5.64	-9.474	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				5.64	-9.598						
U	uraninite-uo2	h2o+0.01097Mhcl	dilute	2.02	-9.237	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				2.02	-9.598						
U	uraninite-uo2	h2o+1.26E-3Mhcl	dilute	1.87	-9.098	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				1.87	-9.335						
U	uraninite-uo2	h2o+1.00E-3Mhcl+0.0988Mnacl	dilute	3.43	-8.652	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				3.43	-8.468						
U	uraninite-uo2	h2o+0.0342Mhcl+0.0662Mnacl	dilute	1.6	-8.013	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				1.6	-8.021						
U	uraninite-uo2	h2o+3.07E-3Mhcl+0.0969Mnacl	dilute	2.64	-8.839	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o+3.17E-4Mhcl+0.0992Mnacl	dilute	3.59	-9.034	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o+0.0601Mhcl+0.0399Mnacl	dilute	2.35	-8.885	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				2.35	-9.175						
U	uraninite-uo2	h2o+0.0601Mhcl+0.0399Mnacl+1.23E-5uo2(no3)2	dilute	1.35	-8.067	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				1.35	-8.228						
U	uraninite-uo2	h2o+0.01569Mnaoh+0.0866Mnacl	dilute	9.3	-9.024	undersaturation	NA	h2=50MPa	200	Parks and Pohl, 1988	3,4
				9.3	-9.189						
U	uraninite-uo2	h2o+0.11125Mhcl	dilute	1.14	-7.132	undersaturation	NA	h2=50MPa	250	Parks and Pohl, 1988	3,4
				1.14	-6.466						
				1.14	-7.117						
U	uraninite-uo2	h2o+1.51E-3Mhcl+0.098Mnacl	dilute	3.02	-8.437	undersaturation	NA	h2=50MPa	250	Parks and Pohl, 1988	3,4
				3.02	-8.413						
U	uraninite-uo2	h2o+1.22E-3Mhcl	dilute	2.94	-8.305	undersaturation	NA	h2=50MPa	250	Parks and Pohl, 1988	3,4
				2.94	-8.621						
U	uraninite-uo2	h2o+9.366E-6Mhcl	dilute	5	-9.82	undersaturation	NA	h2=50MPa	250	Parks and Pohl, 1988	3,4
				5	-9.644						
U	uraninite-uo2	h2o+1.136E-3Mhcl	dilute	3.95	-9.473	undersaturation	NA	h2=50MPa	250	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o	dilute	5.55	-9.519	undersaturation	NA	h2=50MPa	250	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o+0.01097Mhcl	dilute	2.04	-8.917	undersaturation	NA	h2=50MPa	250	Parks and Pohl, 1988	3,4
				2.04	-9.531						

APPENDIX G
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ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
U	uraninite-uo2	h2o+1.26E-3Mhcl	dilute	1.89	-8.774	undersaturation	NA	h2=50MPa	250	Parks and Pohl, 1988	3,4
				1.89	-8.889						
U	uraninite-uo2	h2o+0.11125Mhcl	dilute	1.23	-6.096	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				1.23	-6.128						
				1.23	-6.056						
				1.23	-6.121						
U	uraninite-uo2	h2o+1.51E-3Mhcl+0.098Mnacl	dilute	3.12	-7.945	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				3.12	-8.089						
U	uraninite-uo2	h2o+1.22E-3Mhcl	dilute	2.95	-8.146	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
U	uraninite-uo2	h2o+9.366E-6Mhcl	dilute	4.99	-9.502	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				4.99	-9.502						
U	uraninite-uo2	h2o+1.136E-3Mhcl	dilute	3.96	-9.036	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				3.96	-9.82						
U	uraninite-uo2	h2o	dilute	5.57	-9.39	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				5.57	-9.403						
U	uraninite-uo2	h2o+0.01097Mhcl	dilute	2.07	-8.339	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				2.07	-9.297						
U	uraninite-uo2	h2o+1.26E-3Mhcl	dilute	1.93	-8.774	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				1.93	-8.652						
U	uraninite-uo2	h2o+1.00E-3Mhcl+0.0988Mnacl	dilute	3.59	-8.544	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				3.59	-8.479						
U	uraninite-uo2	h2o+0.0342Mhcl+0.0662Mnacl	dilute	1.75	-7.761	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				1.75	-7.88						
U	uraninite-uo2	h2o+3.07E-3Mhcl+0.0969Mnacl	dilute	2.8	-8.287	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				2.8	-8.532						
U	uraninite-uo2	h2o+3.17E-4Mhcl+0.0992Mnacl	dilute	3.76	-8.275	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				3.76	-8.977						
U	uraninite-uo2	h2o+0.0601Mhcl+0.0399Mnacl	dilute	2.51	-8.623	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				2.51	-8.531						
U	uraninite-uo2	h2o+0.0601Mhcl+0.0399Mnacl+1.23E-5uo2(no3)2	dilute	1.5	-7.191	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
				1.5	-7.464						
U	uraninite-uo2	h2o+0.01569Mnaoh+0.0866Mnacl	dilute	9.07	-9.387	undersaturation	NA	h2=50MPa	300	Parks and Pohl, 1988	3,4
U	uraninite-uo2	saturated NaCl solution	brine	6.2	-6.8	undersaturation	NA	air	75-90	Gray, 1986	1,2,9
				6.2	-7						
				6.3	-7.5						
				6.4	-7.9						
				6.4	-7.8						
				6.4	-7.8						
U	carnotite-k2(uo2)2(vo4)2	h2o+E-2atmPco2+E-3Mk+E-6M(v	dilute	3	-2.5	calculated	NA	NA	25	Langmuir, 1978	1
				6	-7.5			>100			
				8.5	-1			>50			
U	carnotite-k2(uo2)2(vo4)2	h2o+E-3.5atmPco2+E-3Mk+E-6M(v	dilute	3	-2.5	calculated	NA	NA	25	Langmuir, 1978	1
				7	-9			>100			
				9	-4			>50			
U	tyuyamunite-ca(uo2)2(vo4)2	h2o+E-2atmPco2+E-2.7Mca+E-6M(v	dilute	3	-2	calculated	NA	NA	25	Langmuir, 1978	1
				6	-7						
				8.5	-1						
U	tyuyamunite-ca(uo2)2(vo4)2	h2o+E-3.5atmPco2+E-2.7Mca+E-6M(v	dilute	3	-2	calculated	NA	NA	25	Langmuir, 1978	1
				7	-8						
				9	-3.5						
U	autunite-ca(uo2)2(po4)2	h2o+E-2atmPco2+E-2.7Mca+E-6M(po4	dilute	7	-4	calculated	NA	NA	25	Langmuir, 1978	1
				9.5	0						
U	autunite-ca(uo2)2(po4)2	h2o+E-3.5atmPco2+E-2.7Mca+E-6M(po4	dilute	7	-6	calculated	NA	NA	25	Langmuir, 1978	1

ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
U	autunite-ca(uo2)2(po4)2	h2o+E-3.5atmPco2+E-2.7Mca+E-6M(po4	dilute	10	-0.5	calculated	NA	NA	25	Langmuir, 1978	1
U	k-autunite-k2(uo2)2(po4)2	h2o+E-2atmPco2+E-3Mk+E-6M(po4	dilute	6	-6	calculated	NA	NA	25	Langmuir, 1978	1
				9.5	0						
U	k-autunite-k2(uo2)2(po4)2	h2o+E-3.5atmPco2+E-3Mk+E-6M(po4	dilute	6	-7	calculated	NA	NA	25	Langmuir, 1978	1
				10	-1.5						
U	schoepite-uo3.2h2o(syn)	h2o + hclo4 or tetramethyl nh4oh to adjust pH	dilute	3.5	-2.5	oversaturation	9	ox	25	Krupka et al., 1985	1,2
				4	-3		9				
				6	-3.5		9				
				8	-4.5		9				
				11	-4		9				
				12	-3		9				
				3	-2.2		14-53				
				4	-2.7		14-53				
				5	-3		14-53				
				6	-3.2		14-53				
				7	-3.5		14-53				
				8	-3.5		14-53				
				10	-4		14-53				
				11	-3.5		14-53				
				12	-2.5		14-53				
U	schoepite-uo3.2h2o(syn)	h2o + hclo4 or tetramethyl nh4oh to adjust pH	dilute	4	-2.75	undersaturation	14	ox	25	Krupka et al., 1985	1,2
				8	-5		14				
				9	-5.9		14				
				11	-4		14				
				12	-3.5		14				
				3	-2.5		14-53				
				4	-2.7		14-53				
				5	-3		14-53				
				7.5	-4.5		14-53				
				8.5	-4.7		14-53				
				9.5	-4.5		14-53				
				11	-3.5		14-53				
				12	-3.5		14-53				
U	schoepite-uo3.2h2o(a)	h2o + 0.5M naclo4	dilute	6.9	-3.1	undersaturation	NA	n2 atm	25	Bruno and Sandino, 1989	1,17
				7	-3.3						
				7.2	-3.4						
				7.3	-3.65						
				7.4	-3.8						
				7.5	-3.9						
				7.6	-3.85						
				7.7	-3.95						
				7.8	-3.8						
				7.85	-3.85						
				7.9	-3.85						
				7.9	-3.6						
				8.05	-3.55						
				8.15	-3.35						
U	schoepite-uo3.2h2o(c)	h2o + 0.5M naclo4	dilute	6.8	-4.2	undersaturation	NA	n2 atm	25	Bruno and Sandino, 1989	1,17
				6.85	-4.25						
				6.95	-4.3						
				7.15	-4.55						
				7.25	-4.6						
				7.4	-4.75						

APPENDIX G
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ACTINIDE	SOLID	SOLUTION COMPOSITION	SOLUTION DESCRIPTION	pH	SOLUBILITY (log M)	METHOD	EQtime (days)	Eh (mV) or atm	T (oC)	REFERENCE	NOTES
U	schoepite-uo3.2h2o(c)	h2o + 0.5M naclo4	dilute	7.5	-4.85	undersaturation	NA	n2 atm	25	Bruno and Sandino, 1989	1,17
				7.65	-4.9						
				7.7	-4.95						
				7.85	-5.15						
				7.9	-5.1						
				8.1	-5.25						
				8.25	-5.3						
				8.3	-5.35						
				8.35	-5.4						
				8.33	-5.05						
				8.85	-4.55						
U	na2u2o7	h2o sat w/ ca(oh)2, fe(oh)2, and nacl	brine	NA	-4.69	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
U	na2u2o7	h2o sat w/ ca(oh)2, fe(oh)2, nacl and TBP	brine	NA	-4.98	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
U	na2u2o7	h2o sat w/ ca(oh)2, fe(oh)2, nacl and DBP	brine	NA	-4.34	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
U	na2u2o7	h2o sat w/ ca(oh)2, fe(oh)2, nacl and EDTA	brine	NA	-3.26	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
U	na2u2o7	h2o sat w/ ca(oh)2, fe(oh)2, nacl and citrate	brine	NA	-3.51	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
U	na2u2o7	h2o sat w/ ca(oh)2, fe(oh)2, nacl and oxalate	brine	NA	-3.69	undersaturation	NA	NA	NA	Marx and Keiling, 1989	4,18
U	freshly declad spent fuel	PBB1	brine	NA	-6.7	undersaturation	5	air atm	25-30	Gray, 1986	1,2,9
				NA	-5.7		5				
				NA	-5.4		14				
				NA	-5.6		14				
				NA	-5.3		28				
				NA	-4.9		28				
				NA	-4.9		60				
				NA	-4.8		60				
U	previously declad spent fuel	PBB1	brine	NA	-4.2	undersaturation	5	air atm	25-30	Gray, 1986	1,2,9
				NA	-4.3		5				
				NA	-4.1		14				
				NA	-3.9		28				
				NA	-4		28				
				NA	-3.9		60				
				NA	-4.5		60				
				NA	-4		90				
				NA	-4.2		120				
				NA	-4		180				
				NA	-4.8		180				
U	uo2	PBB1	brine	NA	-6.4	undersaturation	5	air atm	25-30	Gray, 1986	1,2,9
				NA	-6.3		14				
				NA	-6.2		28				
				NA	-6		60				

REFERENCES

Cross, J.E., F.T. Ewart, and B.F. Greenfield, 1989. Modelling the behaviour of organic degradation products, Material Research Society Symposia, v. 127, p. 715.
Bruno, J., and Sandino, A., 1989. The solubility of amorphous and crystalline schoepite in neutral to alkaline aqueous solutions, Material Research Society Symposia Proceedings, v. 127, p. 871.
Ewart, F.T., R.M. Howse, H.P. Thomason, and J.E. Cross, 1985. The solubility of actinides in the near field, Material Research Society Symposia Proceedings, v. 50, p. 701.
Felmy, A.R., D. Rai, and M.J. Mason, 1991. The solubility of hydrous thorium(IV) oxide in chloride media: development of an aqueous ion-interaction model, Radiochimica Acta, v. 55, p. 177.
Felmy, A.R., D. Rai, and R.W. Fulton, 1990. The Solubility of $AmOHCO_3(c)$ and the Aqueous Thermodynamics of the System Na^+ Am^{3+} HCO_3^- $(CO_3)^{2-}$ OH^- H_2O, Radiochimica Acta, p. 193.
Flambard, A.R., G. Marx, H.U. Esser, and C. Keiling, 1986. Americium and plutonium in concentrated salt solutions and their interactions with geological material specific to a waste repository, Journal of the Less-Common Metals, v. 122, p. 525.
Gray, W.J., 1986. Comparison of uranium release from spent fuel and unirradiated UO_2 in salt brine, Pacific Northwest Laboratory, PNL-SA-14054.
Kim, J.I., W. Treiber, C. Lierse, and P. Offerman, 1985a. Solubility and colloid generation of plutonium from leaching of a HLW gl[illegible] in salt solutions, Material Research Society Symposia Proceedings, v. 44, p. 359.
Kim, J.I., Ch. Apostolidis, G. Buckau, K. Buppelman, B. Kanellakopulos, Ch. Lierse, S. Magirius, R. Stumpe, I. Hedler, Ch. Rah[illegible] and W. Stower, 1985b. Chemisches Verhalten von Np, Pu und Am in vershiedenen konzentrierten Salzosugen, Institut fur Radiochemie, Technische Universitat Munchen, RCM 01085.
Krupka, K.M., D. Rai, R.W. Fulton, R.G. Strickert, 1985. Solubility data for U(VI) hydroxide and Np(IV) hydrous oxide: Application of MCC-3 methodology, Material Research Society Symposia Proceedings, v. 44, p. 753.
Langmuir, D., 1978. Uranium solution-mineral equilibria at low temperatures with applications to sedimentary ore deposits, Geochimica et Cosmochimica Acta, v. 42, p. 547.
Langmuir, D., and J.S. Herman, 1980. The mobility of thorium in natural waters at low temperatures, Geochimica et Cosmochimica Acta, v. 44, p. 1753.
Marx, G., and Ch. Keiling, 1989. Investigation into the solubilities, sorption and migration behaviour of AgI, $CsNO_3$, $Na_2U_2O_7$ and $Pu(OH)_4$ in near-field systems, Material Research Society Symposia Proceedings, v. 27, p. 855.
Neck, V., J.I. Kim, and B. Kanellakopulos, 1992. Solubility and hydrolysis behavior of neptunium(V), Radiochimica Acta, v. 56, pg. 25.
Parks, G.A., and D.C. Pohl, 1988. Hydrothermal solubility of uraninite, Geochimica et Cosmochimica Acta, v. 52, p. 863.
Pryke, D.C., and J.H. Rees, 1987. Understanding the behaviour of the actinides under disposal conditions: a comparison between calculated and experimental solubilities, Radiochimica Acta, p. 27.
Rai, D., J.A. Schramke, and J.L. Ryan, 1987. Salt Repository Project: Data report on solubility of $Pu(OH)_3$(am), Pacific Northwest Laboratory, PNL/SRP-6215.
Rai, D., R.G. Strickert, D.A. Moore, and J.L. Ryan, 1983. Am(III) hydrolysis constants and solubility of Am(III) hydroxide, Radiochimica Acta, v. 33, p. 201.
Rai, D., R.G. Strickert, and G.L. McVay, 1982. Neptunium concentrations in solutions contacting actinide-doped glass, Nuclear Technology, v. 58, p. 69.
Rai, D., R.J. Serne, and D.A. Moore, 1980. Solubility of plutonium compounds and their behavior in soils, Soil Science Society of America Journal, v. 44, p. 490.
Rai, D., and R.G. Strickert, 1980. Chemical aspects of medium and long-term radioactive waste disposal, Transactions of the American Nuclear Society and the European Nuclear Society, v. 35, p. 185.
Silva, R.J., 1984. The behavior of americium in aqueous carbonate systems, Material Research Society Symposia Proceedings, v. 26, p. 875.
Westsik, J.H., Jr, C.O. Harvey, and W.L. Kuhn, 1983. High-temperature leaching of an actinide-bearing simulated high-level waste glass, Pacific Northwest Laboratory, PNL-3172.

NOTES

1 = data obtained from graphical results
2 = concentration in 18A filtrate
3 = concentration in 2000A filtrate
4 = data obtained from tabulated results
5 = concentration in 150A filtrate
6 = some solutions contained 10mg caco3
7 = concentration in 10A filtrate
8 = in pH solutions <7, essentially all am(oh)3 dissolved
i.e., maximum am+3 = E-3
9 = pH of sample not reported, initial pH = 6.2 to 6.4
10 = concentration in 20A filtrate
11 = PBB3 is similar to BSEP brines
12 = nonfiltered solutions acidified with HNO3
13 = log M calculated from normalized release value
14 = glass wt loss increased linearly with time
15 = concentration in 1000A filtrate
16 = actinide conc in solution determined by difference
between added conc and activity of 18A filtered ppt
17 = filter size unknown
18 = no details on the experimental conditions
19 = concentration in 13A filtrate
20 = concentration in 2200A filtrate
21 = ultrafiltration noted; size unknown
NA = not available

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APPENDIX H
STATISTICAL ANALYSIS AND RESULTS OF SOLUBILITY DATA

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STATISTICAL ANALYSIS AND RESULTS OF SOLUBILITY DATA

1.0 INTRODUCTION

Engineered Alternatives (EA) that increase the pH of the brine in the repository by two to three pH units results in improved performance of the repository because of lower actinide solubilities. Statistical analysis of existing relevant solubility data was performed to quantify the effects of such a pH increase on radionuclide solubilities.

Linear segments of the data sets displayed in Appendix E (Figures E-1 through E-12) were evaluated with a simple linear regression model to establish estimates of actinide solubilities at pH values of 6.1 and 8.3. Generally, the solubility of the radionuclides followed a linear trend between these pH values. The pH value of 6.1 corresponds to an indigenous Salado Formation brine (Deal et al., 1995) evaluated in the baseline case. The pH value of 8.3 corresponds to the approximate pH established in Salado brine by the brucite buffer when a limited amount of lime (CaO) is added to the backfill (Appendix G). A simple linear regression analysis was carried out on the linear or near linear data segments using Statgraphics Plus Version 7.0 software. The results of the regression analyses are shown in Figures H-1 through H-5. The estimated actinide solubilities and ranges are summarized in Table H-1 and additional statistical parameters are given in Table H-2.

2.0 REGRESSION ANALYSIS METHODOLOGY

Figures H-1 through H-5 show the data points used for regression analysis as well as the bold regression line. The solubility data were regressed using a least squares linear regression. Curved lines directly above and below the regression line (Figures H-1 through H-5) indicate the 95 percent confidence on the regression line. The true population regression line has a 95 percent chance of occurring between these two curves. The two curved lines farthest from the regression line in Figures H-1 through H-5 are the upper and lower 95 percent prediction intervals. These curves indicate the confidence interval for predicting a single value of the concentration at any pH. Upper and lower values reported for the 95 percent prediction interval represent the estimated range of solubility for the given actinide at the pH values of 6.1 and 8.3. The range takes into account the experimental uncertainties in the data and the uncertainties introduced by predicting a solubility at a pH value of interest. The estimated actinide solubilities and ranges determined from these curves are summarized in Table H-1.

In addition to the regression line and the confidence and prediction intervals around the regression line, several other regression analysis statistics were also calculated. These additional statistics are, the intercept and slope of the regression line, the correlation coefficient, the coefficient of determination, the standard error of the estimate, a T-test for significance of slope and intercept, and an analysis of variance (F-test) for significance of slope. These statistics are summarized in Table H-2.

The correlation coefficient (r), the coefficient of determination (r^2), and the standard error of the estimate are statistical parameters which describe how well the data points fit the linear regression line. The T-test and the analysis of variance test determine whether the concentration

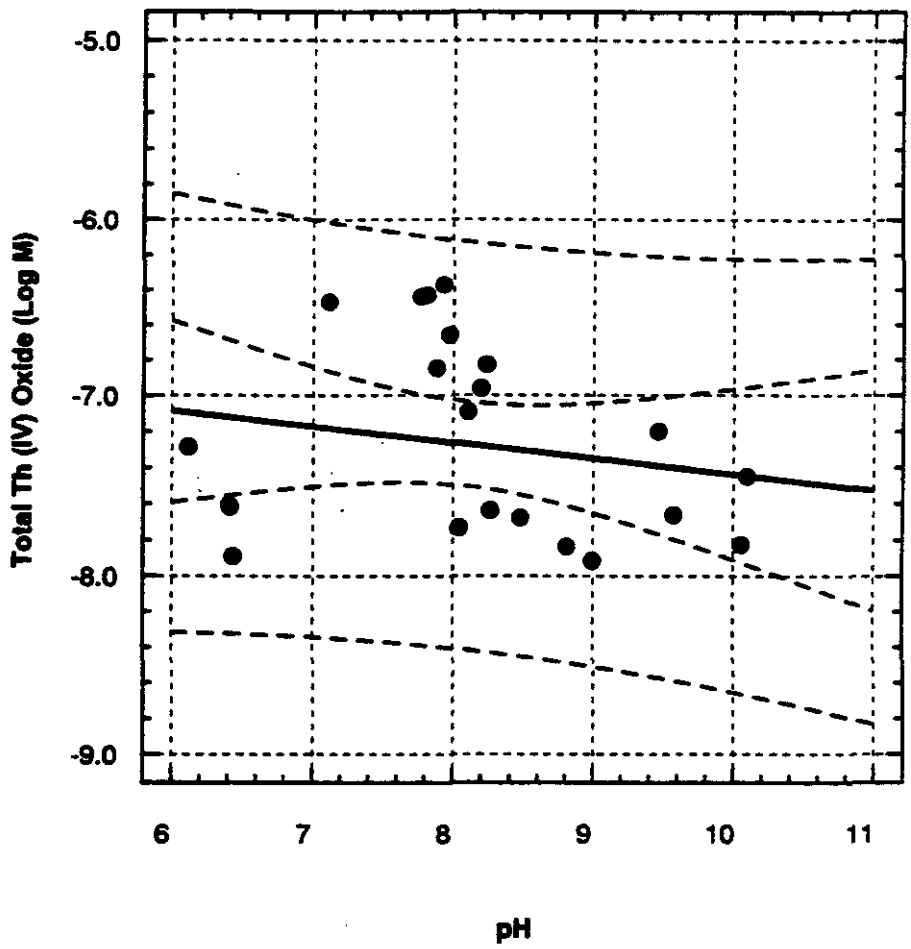

Figure H-1
Linear Regression for Hydrous Th (IV) oxide Solubility as a Function of pH for 3 M Solutions of NaCl; Data from Felmy et al. (1991)

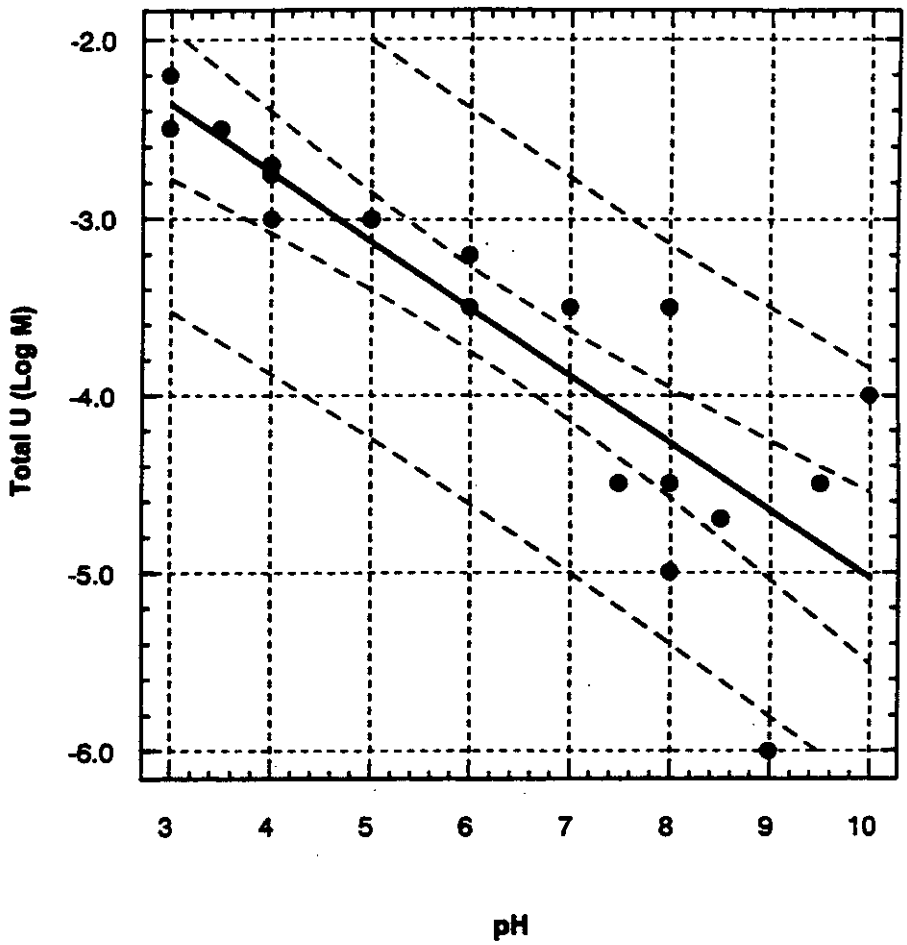

Figure H-2
Linear Regression for UO_3:$2H_2O$ Solubility as a Function of pH for Dilute Solutions; Data from Krupka et al. (1985)

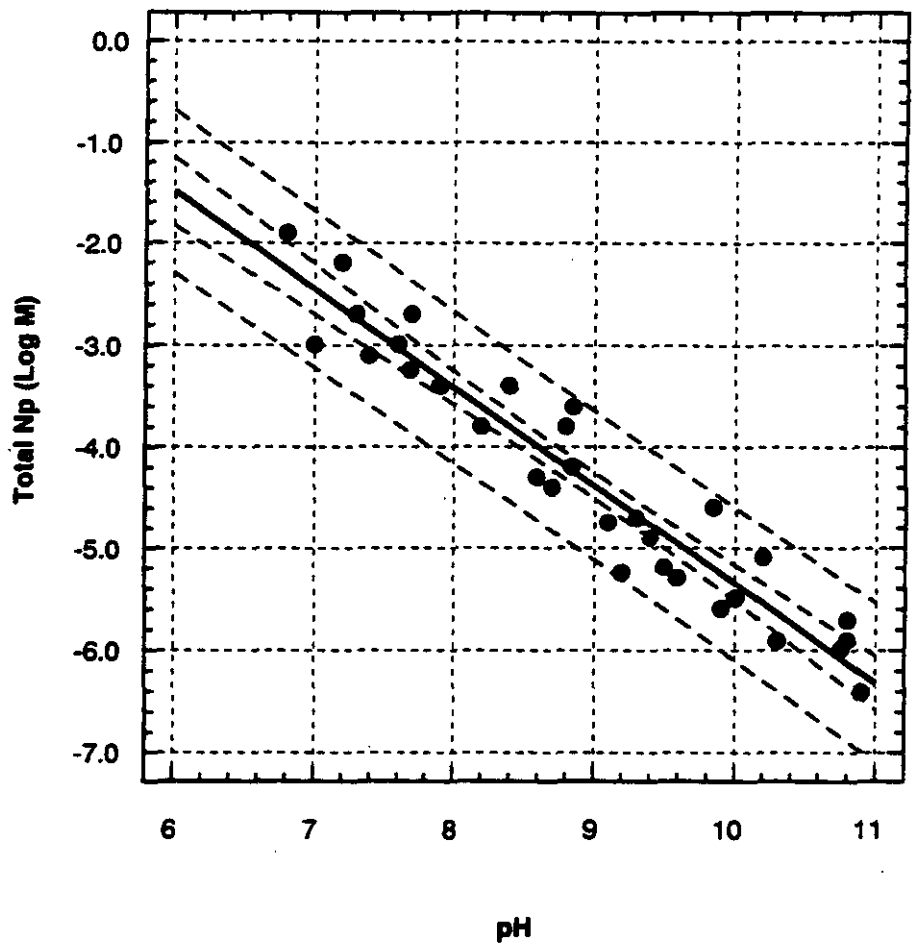

Figure H-3
Linear Regression for $NpO_2(OH)$ Solubility as a Function of pH for 1 M and 3 M Solutions of $NaClO_4$; Data from Kim et al. (1985b) and Neck et al. (1992).

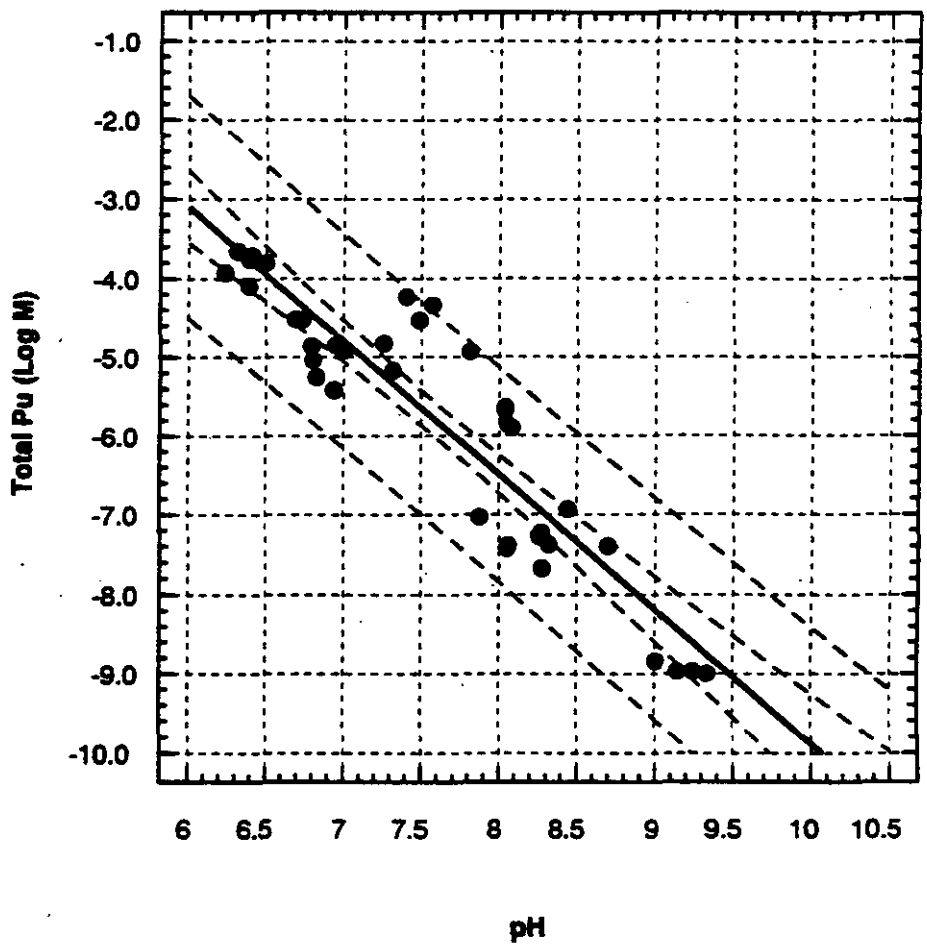

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Figure H-4
Linear Regression for Amorphous $^{239}Pu(OH)_3$ Solubility as a Function of pH for PBB1 and PBB3 Brine Solutions; Data from Rai et al. (1987)

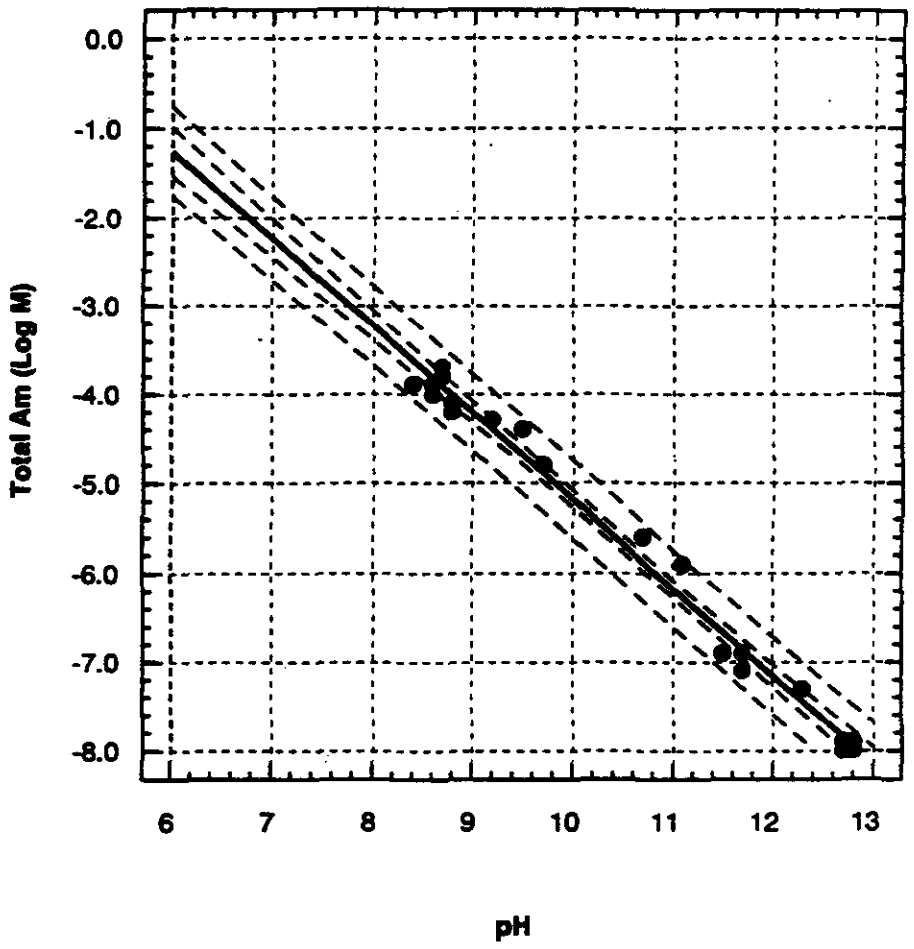

Figure H-5
Linear Regression for AmO2(OH) Solubility as a Function of pH for 5 M Solutions of NaCl; Data from Kim et al. (1985b)

and pH values are linearly correlated by examining the slope and intercept of the regression line. Each of these statistical parameters and procedures are described below.

The coefficient of determination (r^2) is the square of the correlation coefficient (r). The coefficient of determination is defined as the ratio of the sum of squares of the error in the regression line (explained variation) to the sum of squares of the total error (Kennedy and Neville, 1986). This ratio must lie between zero and unity. When $r^2 = 1$, all the variation is explained and the data points have a perfect fit with the regression line. The closer r^2 is to unity the less unexplained variation exists and the better the data points fit the regression line.

The standard error of the estimate is a measure of the variability of the dependent variable estimated by the regression line. The standard error of the estimate is defined as the square root of the sum of the squares of the residuals divided by the number of degrees of freedom (Kennedy and Neville, 1986). The residuals or deviations are the amount of difference between the modeled regression line and the measured value of concentration. Thus, if the sum of the squares of the residuals are small, the data points all fall close to or on the regression line, and the value of The Standard Error of the Estimate is low. The lower the Standard Error of the Estimate, *the greater the confidence that the linear regression fits the data.*

The T-test for significance of slope and intercept is used to determine if the slope or intercept of the regression line are significantly different than zero (Kennedy and Neville, 1986). Likewise, the analysis of variance (F-test), tests for the significance of slope (Kennedy and Neville, 1986). A slope and/or intercept of zero may indicate no correlation or dependence of concentration on pH. These tests are performed under the hypothesis that the slope or the intercept are equal to zero (null hypothesis), and then testing this hypothesis against the alternative hypothesis that the slope or the intercept are not equal to zero. The test results are indicated by the probability level. The probability level is the probability of a Type I error or the probability of rejecting the null hypothesis when it is true (Kennedy and Neville, 1986). Thus, if the probability level is greater than 0.05, there is no reasonable doubt to reject the null hypothesis at the 95th percent confidence level and it is concluded that the slope or intercept is equal to zero. If the probability level is less than 0.05, the null hypothesis is rejected at the 95th percent confidence level and it is concluded that the slope or the intercept are not equal to zero.

These statistical parameters and tests were used to determine how well the linear model fits the solubility data over the pH range of interest. If the solubility data follow a linear trend the coefficient of determination (r^2) will be close to unity, and the standard error of the estimate will be low. If there is a strong correlation between concentration of the radionuclides and pH, the regression line will also have a non-zero slope. If the linear model fits the solubility data and the regression line is significant, then there is a high degree of confidence in the predicted values of solubility at pH values of 6.1 and 8.3.

3.0 RESULTS OF REGRESSION ANALYSES

A discussion of the solubility of Th, U, Np, Pu and Am with respect to Ph is presented below. Results from the regression analysis and predicted solubilities at Ph values of 6.1 and 8.3 are discussed.

3.1 Thorium

The Th solubility data of Felmy et al. (1991) for amorphous $ThO_2 \bullet xH_2O$ in 3M NaCl solutions (Figure H-1) are the closest approximation to saturated NaCl conditions imposed by Salado brine. Data points falling in the pH interval of 6 to 10 were used in the linear regression model and results are displayed on Figure H-1, with Table H-1 and Table H-2 summarizing results of the regression analysis. The coefficient of determination value (r^2 = 3 percent) given on Figure H-1 indicate the data are a very poor fit to the linear model. Additionally, results from the T-test for significance of slope and results from the analysis of variance (Table H-2) indicate that the slope is equal to zero at the 95th percent confidence limit (probability level = 0.4).

Felmy et al. (1991) noted that most of the measured Th concentrations above a pH of 6 are near the analytical detection limit of about -8.5 log M, and greater error in analytical precision probably accounts for the large scatter in the data set. However, the solubility of ThO_2 is known to be independent of pH above near neutral pH values (Felmy et al., 1991), and theoretical calculations of the solubility of crystalline ThO_2 indicate a linear trend for Th concentration above a pH of 6, corresponding to an intercept of -14 log M and a slope of zero (Langmuir and Herman, 1980). Therefore, the solubility estimates determined from linear regression (Table H-1) were used to estimate $ThO_2 \bullet xH_2O$ solubility because analytical measurement of Th concentration is difficult above a pH of 7, due to the insoluble nature of ThO_2, and a linear relationship is known to exist once ThO_2 solubility becomes independent of pH.

3.2 Uranium

Uranium solubility data (Figures H-2 and H-3) indicate that schoepite ($UO_3 \bullet 2H_2O$) is more soluble than uraninite (UO_2) and, as a conservative measure, the most soluble U phase is selected for this analysis. The solubility data reported by Krupka et al. (1985) for amorphous schoepite were selected over that of Bruno and Sandino (1989) because of the greater pH range studied. Similar U concentrations are reported for amorphous schoepite when the two studies overlap in pH space (Figure H-3). Figure H-2 displays results for the linear model over the pH range of 3 to 10, Table H-1 and Table H-2 summarize the results from the regression analysis. The coefficient of determination on Figure H-2 indicate that the data of Krupka et al. (1985) are a fair fit to the model (r^2 = 75 percent). Additionally, results from the T-test for significance and the analysis of variance indicate that the slope and intercept are not equal to zero at the 95th percent confidence level (probability level = 0.0).

Solubility data for schoepite in saturated NaCl brine was not found during this study. Examining Figure H-2, it appears that the solubility of uraninite is increased by about 2 orders of magnitude in the presence of a saturated NaCl brine. Therefore, results summarized in Table H-1 for shoepite solubility in dilute solutions are recommended to be increased by two orders of magnitude to account for the expected enhancement of schoepite solubility in Salado brine.

3.3 Neptunium

Solubility data on Np solids (Figures H-4 and H-5) indicate that NpO_2OH is more soluble than NpO_2 and, as a conservative measure, the most soluble Np phase is selected for this analysis. The 1M and 3M $NaClO_4$ data sets of Neck et al. (1992) and Kim et al. (1985b) are in good agreement and the closest approximation to saturated NaCl conditions imposed by Salado brine. Therefore, these data sets were selected for regression analysis over the pH interval of 6 to 11.

Figure H-3 summarizes the regression analysis for the data sets. The r^2 value of 92 percent, indicates that the data sets are a good fit to the linear model and the T-test and analysis of variance indicate a non zero slope at the 95th percent confidence limit (probability level = 0.0). Table H-1 summarizes the model results for the pH values of interest and Table H-2 summarizes additional regression statistics.

3.4 Plutonium

Figures H-6 through H-10 summarize data on the solubility of Pu solids. The most soluble phase over the pH interval of interest (6 to 9) is amorphous $Pu(OH)_3$ (Figure H-6) and, as a conservative measure, the most soluble Pu phase is selected for this analysis. Rai et al. (1987) studied the solubility of amorphous $Pu(OH)_3$ in Permian Basin brines (PBB), and these data sets are chosen for regression analysis because the saturated NaCl PBB are good analog for Salado brine. Regression results presented on Figure H-4 indicate the linear model is a fair to good fit to the data sets [r^2 = 85 percent, slope and intercept are not equal to zero (probability level = 0.0)]. Table H-1 summarizes the model results for the pH values of interest and Table H-2 summarizes additional regression statistics.

3.5 Americium

Americium solubility data are presented on Figures H-11 and A-12, and the most soluble phase indicted on these plots is AmO_2OH (Figure H-12). The solubility data of Kim et al. (1985b) for $^{241}AmO_2OH$ in 5M NaCl solution is selected for this analysis, because these data represent the closest approximation to saturated NaCl conditions imposed by Salado brine. Figure H-5 summarizes the regression analysis and indicates that the linear model is an excellent fit to the data over the pH interval of 8 to 13 [r^2 = 99 percent, slope and intercept are not equal to zero (probability level = 0.0)]. Note that the regression analysis has been extrapolated to a pH of 6 to allow a calculation of the solubility estimate at a pH of 6.1 (baseline case for Salado brine). Table H-1 summarizes the model results for the pH values of interest and Table H-2 summarizes additional regression statistics.

TABLE H-1

RESULTS OF REGRESSION ANALYSIS ON ACTINIDE SOLUBILITY

Actinide	Most Soluble Oxide/Hydroxide Phase	Solution Composition	pH	Estimated Solubility	Estimated Range of Solubility
				log (mole/liter)	
Thorium	$ThO_2 \cdot xH_2O$	3M NaCl	6.1	-7.1	-5.9 to -8.3
			8.3	-7.3	-6.1 to -8.4
Uranium	$UO_3 \cdot 2H_2O(a)$	dilute	6.1	-3.5[a]	-2.4 to -4.7[a]
			8.3	-4.4[a]	-3.2 to -5.5[a]
Neptunium	$NpO_2OH(a)$	1M and 3M $NaClO_4$	6.1	-1.6	-0.8 to -2.4
			8.3	-3.7	-3.0 to -4.4
Plutonium	$Pu(OH)_3(a)$	Permian Basin Brines	6.1	-3.3	-1.9 to -4.7
			8.3	-7.0	-5.6 to -8.4
Americium	$AmO_2OH(a)$	5M NaCl	6.1	-1.4[b]	-0.9 to -1.8[b]
			8.3	-3.5	-3.1 to -4.0

[a]It is recommended that values be increased by 2 log units to account for enhanced solubility in saturated NaCl solutions. See text for discussion.
[b]Value is obtained from extrapolation of regression analysis to pH 6.1.

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TABLE H-2

REGRESSION STATISTICS ON ACTINIDE SOLUBILITY

1) Regression Analysis - Thorium

Dependent variable: Th(IV) Oxide — Independent variable: pH

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	-6.5484	0.847345	-7.72814	0.00000
Slope	-0.0889158	0.103675	-0.857641	0.40077

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	0.2137470	1	0.2137470	0.735547	0.40077
Residual	6.102514	21	0.290596		
Total (Corr.)	6.316261	22			

Correlation Coefficient = -0.183959 R-squared = 3.38 percent
Stnd. Error of Est. = 0.539069

2) Regression Analysis - Uranium

Dependent variable: UO3+2H2O — Independent variable: pH

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	-1.21305	0.337455	-3.59472	0.00207
Slope	-0.382024	0.0515513	-7.41055	0.00000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	14.674492	1	14.674492	54.91627	0.00000
Residual	4.809883	18	0.267216		
Total (Corr.)	19.484375	19			

Correlation Coefficient = -0.867837 R-squared = 75.31 percent
Stnd. Error of Est. = 0.516929

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TABLE H-2 (CONTINUED)

REGRESSION STATISTICS ON ACTINIDE SOLUBILITY

3) Regression Analysis - Neptunium

Dependent variable: NpO2OH Independent variable: pH

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	4.30194	0.476779	9.02292	0.00000
Slope	-0.964968	0.052955	-18.2224	0.00000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	41.85969	1	41.85969	332.0563	0.00000
Residual	3.655798	29	0.126062		
Total (Corr.)	45.515484	30			

Correlation Coefficient = -0.959 R-squared = 91.97 percent

Stnd. Error of Est. = 0.355052

4) Regression Analysis - Plutonium

Dependent variable: Pu(OH)3 Independent variable: pH

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	7.07026	0.928106	7.61794	0.00000
Slope	-1.69515	0.121298	-13.9751	0.00000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	83.86683	1	83.86683	195.3031	0.00000
Residual	15.029656	35	0.429419		
Total (Corr.)	98.896481	36			

Correlation Coefficient = -0.920883 R-squared = 84.80 percent

Stnd. Error of Est. = 0.6553

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TABLE H-2 (CONTINUED)

REGRESSION STATISTICS ON ACTINIDE SOLUBILITY

5) Regression Analysis - Americium

Dependent variable: AmO2OH Independent variable: pH

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	4.64694	0.284859	16.3131	0.00000
Slope	-0.983439	0.0269227	-36.5283	0.00000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	53.1451	1	53.1451	1334.316	0.00000
Residual	0.716930	18	0.039829		
Total (Corr.)	53.862000	19			

Correlation Coefficient = -0.993322 R-squared = 98.67 percent

Stnd. Error of Est. = 0.199573

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APPENDIX I
GEOCHEMICAL SIMULATIONS OF ENGINEERED ALTERNATIVES WITH SALADO BRINE

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GEOCHEMICAL SIMULATIONS OF ENGINEERED ALTERNATIVES WITH SALADO BRINE

1.0 INTRODUCTION

One pathway considered for the release of radionuclides to the accessible environment is the dissolution of radionuclides in brine that may come in contact with the waste, followed by transport of the contaminated brine to the accessible environment. Brine can be transported via fractures caused by excessive pressurization of the repository by gas generation, or by pathways created by human intrusions. A key factor controlling the release of radionuclides by these mechanisms is the solubility of the radionuclides in brine. Solubility is defined, in this case, as the maximum mass of a given actinide element that can dissolve in a unit volume of brine of a specified composition. The solubilities of the actinide elements of concern are complex functions of several parameters, however, they all show similar behavior with respect to pH. Solubility decreases as the pH rises above neutrality, often reaching a solubility minimum in the range of 8.5 to 10.

The ability of brine to transport radionuclides could be greatly reduced if the pH of any brine that accumulates in the repository is raised from the ambient value of around 6.1 to a value that is closer to the solubility minimum range. Engineered alternatives (EA) that buffer the pH to a more favorable range (by the addition of lime [calcium oxide, or CaO] or portland-type cement, which contains a large percentage of hydrated lime [portlandite, or $Ca(OH)_2$], to either the drum contents or backfill) will show improved performance because of lower actinide solubilities.

An increase in pH by the addition of lime can be thought of as a two-step reaction in which calcium oxide forms portlandite by the reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad \text{I.1}$$

followed by portlandite dissociation by the reaction:

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^- \qquad \text{I.2}$$

to yield calcium ions (Ca^{2+}) and hydroxide ions (OH-). The additional hydroxide ions increases the pH of the Salado brine which has a desirable effect of lowering actinide solubilities.

The addition of lime to pure water at and above the saturation point will raise the pH to an equilibrium value of ~11.8. A significant difference between pure water and Salado brine however, is the very high magnesium concentration which buffers the pH at values significantly below 11.8.

Computer simulations were performed to predict the effects of the addition of lime to Salado brine to determine the equilibrium pH value and buffer capacity. These simulations were performed using the EQ3NR and EQ6 geochemical speciation-solubility-reaction path models (Wolery, 1992a and Wolery, 1992b). The following sections describe some background information on the EQ3NR/EQ6 geochemical model, the modeling approach used for the simulations, and the results and conclusions of the geochemical simulations.

2.0 BACKGROUND

The computer code EQ3NR/EQ6 is an industry-standard chemical reaction model that performs solubility, speciation, and reaction-path calculations. The initial version of the EQ3NR/EQ6 code was developed in 1979 at Lawrence Livermore National Laboratory for predicting the behavior of metals, radionuclides, and other contaminants in the natural environment. The code has been actively maintained and improved over the last fourteen years with funding from a wide variety of sources. The current version of the code accesses a database containing the thermodynamic properties of 78 elements, 862 aqueous species, 886 minerals, and 76 gases; and is valid over a temperature range of 0° to $300^{o}C$.

The database also contains references for all of the values to provide traceability, and can be modified or expanded by the user. EQ3NR/EQ6 has been validated using standard geochemistry problems such as the speciation of sea water, basalt/sea water interactions, and numerous comparisons with experimentally determined mineral solubilities. Successful benchmark comparisons with the results of similar codes have also been performed. The code allows the use of the Pitzer approach as an option for the calculation of activity coefficients. This approach allows accurate modeling of high ionic strength solutions such as Salado brines using a specifically designed thermodynamic data base (Harvie, Moller, and Weare data base).

The main advantage of EQ3NR/EQ6 over other chemical reaction codes is the ability to perform reaction path simulations. When operated in this mode, an assemblage of reactants (liquids, solids, or gases) are introduced to an aqueous solution in a series of small steps. An unlimited number of reactants can be added in parallel, each at its own rate. At each step, the composition of the fluid is recalculated and the data base of solid minerals is scanned to determine if any minerals are oversaturated. If oversaturation of a particular mineral occurs, then it is allowed to precipitate so that it is maintained in equilibrium with the fluid. The code then loops back to add another small mass of reactants, recalculate fluid composition, and solve for saturation. This process is repeated (typically hundreds to thousands of times) until the either the system reaches equilibrium with the reactants or the originally specified mass of reactants are exhausted. The output of the code includes tables that chart the composition, pH, and redox state of the fluid; the mass of each reactant consumed, and the mass of each mineral that has precipitated, all as functions of reaction progress.

3.0 MODELING APPROACH

For this application, the composition of an average Salado brine is first defined. This composition is based on data presented in the *1992-1993 Brine Sampling and Analysis Program report* (Deal et al., 1995). Lime is then added in a series of small increments to the brine to determine the effects on pH as a function of the amount of lime added. These simulations are appropriate for EAs that include lime as a backfill additive, or include a portland-based grout backfill. These grouts contain lime as a principal component. The simulations were performed using the Pitzer approach as an option for the calculation of activity coefficients, and accessed the Harvie-Moller-Weare data base which yields accurate results for high ionic strength solutions such as brines.

Results of these simulations directly provide the changes in solution composition and pH as a function of the mass of lime added to a unit mass of brine. Results also provide the mass of lime consumed and the mass of new minerals precipitated during the process.

4.0 RESULTS

Figure I-1 summarizes the results of the simulation of lime addition to Salado brine. The addition of a very small amount of lime to the brine raises the pH from the ambient value of 6.1 to a value of ~8 corresponding to the solubility of magnesium-oxychloride [$Mg_2Cl(OH)_3 \bullet 4H_2O$]. At this point, the further addition of lime results in precipitation of Mg-oxychloride and brucite [$Mg(OH)_2$] with little change in pH. After the addition of 1.1 moles of lime to the original kilogram of brine, almost all of the original Mg present in the brine will have precipitated. At this point, further addition of lime will raise the pH to values above 11, corresponding to the portlandite [$Ca(OH)_2$] pH buffer. The presence of the original Mg concentration of 22,700 mg/l (0.93 moles/liter) thus serves as an effective pH buffer, maintaining the pH between 8.0 and 9.0 in response to the addition of anywhere between 0.05 to 1.1 moles of lime per kg of brine.

The results suggest that the addition of 0.5 moles of lime per kilogram of Salado brine anticipated to flow into the room will poise the system in the middle of the pH-buffer zone at a pH of about 8.2.

Effects of Boron on pH buffer

Boron is present in the brine at an average concentration of 0.13 moles/l (Deal et al., 1995). Boron can act under some conditions as a pH buffer. The results shown in Figure I-1 do not consider the effects of boron in the simulation because boron is not present in the Harvie-Moller-Weare database.

To investigate the role of boron on the effects of lime addition, the simulation was rerun with the extended Debye-Hückel activity coefficient option. This option produces less accurate results than the Pitzer option when simulating brine interactions, but it accesses a different thermodynamic database that does contain boron species.

Results from this simulation indicate brucite will buffer the brine pH between 8.5 and 9 until magnesium ion is depleted. Boron speciation is initially dominated by $B(OH)_3^o$ at near neutral pH, but the speciation changes to $CaB(OH)_4^+$, $NaB(OH)_4^o$, and to $MgB(OH)_4^+$ (aqueous species of Boron) as pH and calcium (Ca) ion concentration increases. Assuming an average boron concentration in Salado brine of 0.13 mole/L, the addition of 0.13 mole/L of hydroxide ion is necessary to convert all $B(OH)_3^o$ to metal-$B(OH)_4$ species. The addition of 0.13 mole/L of hydroxide ion is equivalent to the addition of 0.07 moles of lime, since two moles of hydroxide ions are liberated for each mole of lime that goes into solution by the reaction:

$$CaO + H_2O \rightarrow Ca^{+2} + 2OH^- \qquad \text{I.3}$$

Thus, conversion of all $B(OH)_3^o$ to metal-$B(OH)_4$ species requires the addition of 0.07 moles of lime This is a small amount of lime compared to the 0.5 moles/L necessary to reach the midpoint of the Mg-oxychloride/brucite pH buffer. Additionally, at the pH-buffer value of about 8.5, only 65

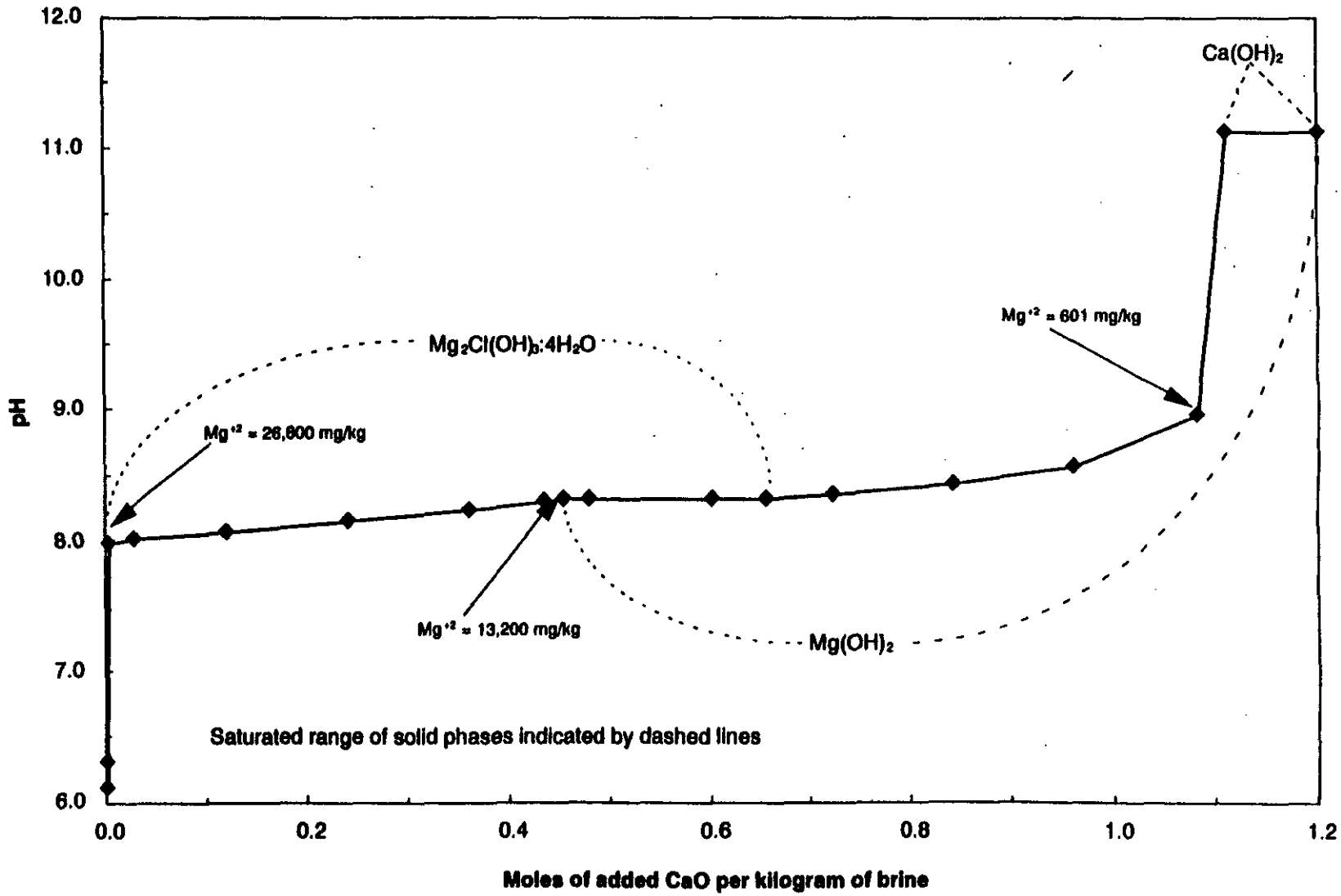

Figure I-1
EQ6 Modeling Results Showing pH as a function of Moles of CaO Added per Kilogram of WIPP Brine

percent of the $B(OH)_3^o$ would be converted to metal-$B(OH)_4$ species. Therefore, it appears that the presence of boron in the brine does not require any significant increase in the amount of lime that must be added to the brine to reach the midpoint of the Mg-oxychloride/brucite pH buffer.

5.0 CONCLUSIONS

The pH of the brine can be controlled by adding 0.5 moles of lime per kilogram of Salado brine expected to flow into the disposal rooms. The addition of this amount of lime would raise the pH to ~8.2 and fix the system in the middle of the Mg-oxychloride/brucite pH buffer zone. The anticipated volume of brine inflow does not need to be accurately known because the addition of anywhere between 0.05 to 1.1 moles of lime per kg of brine will maintain the pH between 8 and 9.

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APPENDIX J
DESCRIPTION OF UNCERTAINTY CALCULATIONS

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DESCRIPTION OF UNCERTAINTY CALCULATIONS

1.0 MONTE CARLO SAMPLING WITH THE STADIC CODE

1.1 General Description

The Monte Carlo technique maps uniform, random numbers through a cumulative distribution function (CDF) of a physical or decision parameter of the FORTRAN code to generate a value of that parameter for use in the analysis. Given a uniform density of random deviates on the ordinate, n, the total number of random deviates on any interval, dy, is n(dy). The corresponding interval on the abscissa then has density n(dy/dx). Since the probability density function (PDF) of a random variable is proportional to the derivative of the corresponding CDF, this method of mapping uniform deviates through the CDF, in effect, simulates the PDF of the random variable.

The STADIC code was developed by PLG to accomplish Monte Carlo sampling for engineering oriented applications. The STADIC code has been certified under QA and is used by PLG as a production code on the PC. It is designed to generate values of input parameters from user specified distributions and pass them to a subroutine for calculation. The results of each iteration is then stored for statistical and trend analysis. Thus, STADIC automates the Monte Carlo technique by providing a convenient platform to run standard FORTRAN engineering code. Further information on the code can be found in Wakefield and Fleming (1990).

1.2 Description of STADIC Subroutine for EA Evaluations

The STADIC subroutine specifies the probability distributions to be sampled for use in the Design Analysis Model (DAM) calculation cases. The code has the capability to accept the parameters for some of the standard distributions used in this study. These include those parameters that specify normal, lognormal, uniform, and discrete distributions. Other distributions (such as piece wise continuous and triangular distributions) are converted into CDFs for input to the Monte Carlo algorithms in the STADIC code.

Dependencies are established by standard FORTRAN programming. For example, full dependence corresponds to use of the same random number to sample the two separate CDFs for the dependent variables. The subroutine first queries the Monte Carlo random number generator with an intermediate variable corresponding to a uniform distribution between 0 and 1. It then uses the resulting value to select a sample value from the CDFs of each of the dependent variables.

For the Engineered Alternatives (EA) Cost Effectiveness Study, the STADIC code was used to generate a file consisting of 1,000 sets of input for the uncertain variables, indexed from 1 to 1,000. The modeling of the probability distributions for these variables is discussed in Section 2.0 of this appendix. The input file was then used to run 1,000 iterations of the DAM code. One set of input initiated a 10,000 year calculation in the DAM. The results of each calculation were then saved with the index number corresponding to the input set. In this manner the output of each DAM calculation can be easily correlated with its input set for calculation of Measures of Relative Effectiveness (MRE) and examination of sensitivities to obtain physical insight into the influence of the EA on performance.

The same random number seed was used to generate the input set for the baseline and all the EAs. This insured that the "unknown future conditions" that sampling process simulates is consistent across all the EA options so that the relative response of the to the conditions can be compared. Thus, the uncertainty associated with the resultant MRE may be considered to be due to the uncertainty in our state-of-knowledge regarding physical processes under those future conditions and not the nature of the random sampling process.

2.0 INPUT PARAMETER DISTRIBUTIONS

2.1 Summary of Uncertain Parameters Modeled

This section summarizes the modeling of the DAM parameters whose uncertainties were considered important to determining the significance of the various for improving confidence of compliance. Table J-1 provides summary information regarding these parameters and references to the sources of evidence used to establish their probability distributions.

Figure J-1(a–p) presents a graphical representation of the cumulative distribution functions generated by the STADIC code for the baseline design. The graphs are presented in the same order as they are listed in Table J-1. As a matter of clarification, the graphs of hydrogen generation rate under humid conditions (HHUMRATE) and negative log permeability of the anhydrite units (KPANH) appear to be step functions. This reflects the fact that these two variables are discrete distributions. For example, all random numbers between 0 and 0.2 would return a value of 17 for KPANH.

2.2 Dependencies Among Variables

The following dependencies and correlations among input parameters are modeled in the STADIC sampling subroutine:

- Inundated and Humid anoxic corrosion gas generation rates: The same random number is used to sample the distributions for the variables HINURATE and HHUMRATE that represent these two processes. These two processes could proceed in parallel within the repository, depending on the amounts of brine available for the conversion reaction. The dependency reflects the similarity of the chemical conversion involved, with the differences in brine saturation producing a different model for the rate of the process. The use of the same random number for the two processes reflects the judgement that the humid gas generation rate should never exceed the inundated anoxic gas generation rate, since the cumulative distribution of the humid process has lower values at all percentiles of the distribution.

- Inundated and Humid biodegradation gas generation rates: The same random number is used to sample the distributions for the variables BINURATE and BHUMRATE that represent these two processes. These two processes could proceed in parallel within the repository, depending on the amounts of brine available for the conversion reaction. The dependency reflects the similarity of the chemical conversion involved, with the differences in brine saturation producing a

TABLE J-1

INPUT VARIABLES TO THE DAM THAT ARE MODELED WITH UNCERTAINTY

DAM Variable Name	Variable Description (units)	Point Estimate[a]	Range of Values[b]	Type of Distribution	Dependencies	Comments	Reference
BHUMRATE	Microbial gas generation rate under humid facility conditions (moles/kg cellulosics-yr)	0.01	0 - 0.1	Piece-wise Uniform	BINURATE >= BHUMRATE	Range of values above and below point estimate weighted to make overall mean value of distribution equal to the point estimate.	Brush, 1994, and SNL/NM, 1993, Vol. 3, p. 3-52
BINURATE	Microbial gas generation rate from anoxic corrosion under inundated facility conditions (moles/kg cellulosics-yr)	0.1	0 - 0.5	Piece-wise Uniform	BINURATE >= BHUMRATE	Range of values above and below point estimate weighted to make overall mean value of distribution equal to the point estimate.	Brush, 1994, and SNL/NM, 1993, Vol. 3, pp. 3-50, 3-51
BIOSTOIC	Ratio of moles of biogas generated to moles of cellulosics consumed (dimensionless)	0.835	0 - 1.67	Uniform	None		See Note h.
CB	Brine inflow rate at a pressure difference of lithostatic minus atmospheric (m^3/yr-panel)	0.60	0 - 1.19	Uniform	None		See Note h.
H2MAX	Maximum hydrogen gas generation potential from anoxic corrosion (mol/panel)	7.9E+07	5.5E7 - 1.1E8	Derived distribution	Derived directly from RHTORW.	H2MAX=H2MAX0*RHTORW/0.7 See comments for variable RHTORW.	See Note g.
HHUMRATE	Hydrogen gas generation rate from anoxic corrosion under humid facility conditions (moles/drum-yr)	9.0E-04	0 - 0.06	Discrete	HINURATE >= HHUMRATE	Three values assigned the following weights: 97.5% .@ 0.0, 2% @ 0.03, 0.5% @ 0.06 See Note i	Brush, 1994, and SNL/NM, 1993, Vol. 3, pp. 3-46, 3-47
HINURATE	Hydrogen gas generation rate from anoxic corrosion under inundated facility conditions (moles/drum-yr)	0.6	0 - 10	Piece-wise Uniform	HINURATE >= HHUMRATE	Range of values above and below point estimate weighted to make overall mean value of distribution equal to the point estimate.	Brush, 1994, and SNL/NM, 1993, Vol. 3, pp. 3-44, 3-45
KPANH	Negative log of the permeability of the anhydrite beds (dimensionless)	18	17,18,19,20	Discrete	None	Due to DAM code, probability assigned to 17,18,19, or 20 only. Assigned equal probability weight.	See Note f.

Refer to footnotes at end of table.

TABLE J-1 (Continued)

INPUT VARIABLES TO THE DAM THAT ARE MODELED WITH UNCERTAINTY

DAM Variable Name	Variable Description (units)	Point Estimate[a]	Range of Values[b]	Type of Distribution	Dependencies	Comments	Reference
RADFAC	Factor used to estimate the effective borehole radius during intrusion (dimensionless)	3.0	2.1 - 3.9	Triangular	None	Range to minimum and maximum values estimated as plus or minus 30% of the point estimate.	See Note g.
RADSOL (1)	Pu-240 solubility in brine (mol/l)	5.01E-04	2E-05 - 0.013	Lognormal[c,d]	None		See Note e.
RADSOL (2)	U-236 solubility in brine (mol/l)	3.16E-02	2E-03 - 0.39	Lognormal[c,d]	None		See Note e.
RADSOL (3)	Am-241 solubility in brine (mol/l)	3.98E-02	0.0158 - 0.126	Lognormal[c,d]	None		See Note e.
RADSOL (5)	Np-237 solubility in brine (mol/l)	2.51E-02	0.005 - 0.158	Lognormal[c,d]	None		See Note e.
RADSOL (5)	U-233 solubility in brine (mol/l)	3.16E-02	2E-03 - 0.39	Lognormal[c,d]	See comments	Assigned same value as RADSOL (2) and RADSOL (8)	See Note e.
RADSOL (6)	Th-229 solubility in brine (mol/l)	7.94E-08	5E-09 - 1.26E-06	Lognormal[c,d]	None		See Note e.
RADSOL (7)	Pu-238 solubility in brine (mol/l)	5.01E-04	2E-05 - 0.013	Lognormal[c,d]	See comments	Assigned same value as RADSOL (1) and RADSOL (12)	See Note e.
RADSOL (8)	U-234 solubility in brine (mol/l)	3.16E-02	2E-03 - 0.39	Lognormal[c,d]	See comments	Assigned same value as RADSOL (2) and RADSOL (5)	See Note e.
RADSOL (9)	Th-230 solubility in brine (mol/l)	7.94E-08	5E-09 - 1.26E-06	Lognormal[c,d]	See comments	Assigned same value as RADSOL (6)	See Note e.
RADSOL (12)	Pu-239 solubility in brine (mol/l)	5.01E-04	2E-05 - 0.013	Lognormal[c,d]	See comments	Assigned same value as RADSOL (1) and RADSOL (7)	See Note e.

Refer to footnotes at end of table.

TABLE J-1 (Continued)

INPUT VARIABLES TO THE DAM THAT ARE MODELED WITH UNCERTAINTY

DAM Variable Name	Variable Description (units)	Point Estimate[a]	Range of Values[b]	Type of Distribution	Dependencies	Comments	Reference
RBOR	Radius of borehole for intrusion scenarios (m)	0.18	0.134-0.222	Uniform	None	Distributions taken directly from 92PA due to the lack new data.	Distribution Type and range from SNL/NM, 1993
RHTORW	Ratio of hydrogen gas generation rate to water consumption rate during anoxic corrosion (dimensionless)	0.72	0.5 - 1	Derived Distribution	None	RHTORW=(4-x)/(4+2x) where x is uniform between 0 and 1.	See Note g.

Notes:

[a]Point estimate value is the mean of the distribution for all distribution types except for the lognormal distribution.

[b]Range of values represent all possible values of the distribution (0th to 100th percentile) for all distributions except for the lognormal distribution.

[c]For lognormal distribution, the point estimate value is the median.

[d]For lognormal distribution, the range of values is between 5th percentile and 95th percentile.

[e]Point estimate (median) and range values for these variables are taken from Table H-1 Results of Regression Analysis on Actinide Solubility

[f]KPANH distribution from EATF Report (DOE, 1991).

[g]Guidance regarding these variables are taken from equations provided in SNL/NM, 1993.

[h]The complete distributions for these variables are from SNL/NM, 1993, considerations.

[i]This discrete distribution is formulated to recognize that the humid anoxic gas generation rate is very likely zero, but there is some chance that it could be as high as 0.06. Use of discrete distribution would permit examination of a distinct set of cases if an impact is found.

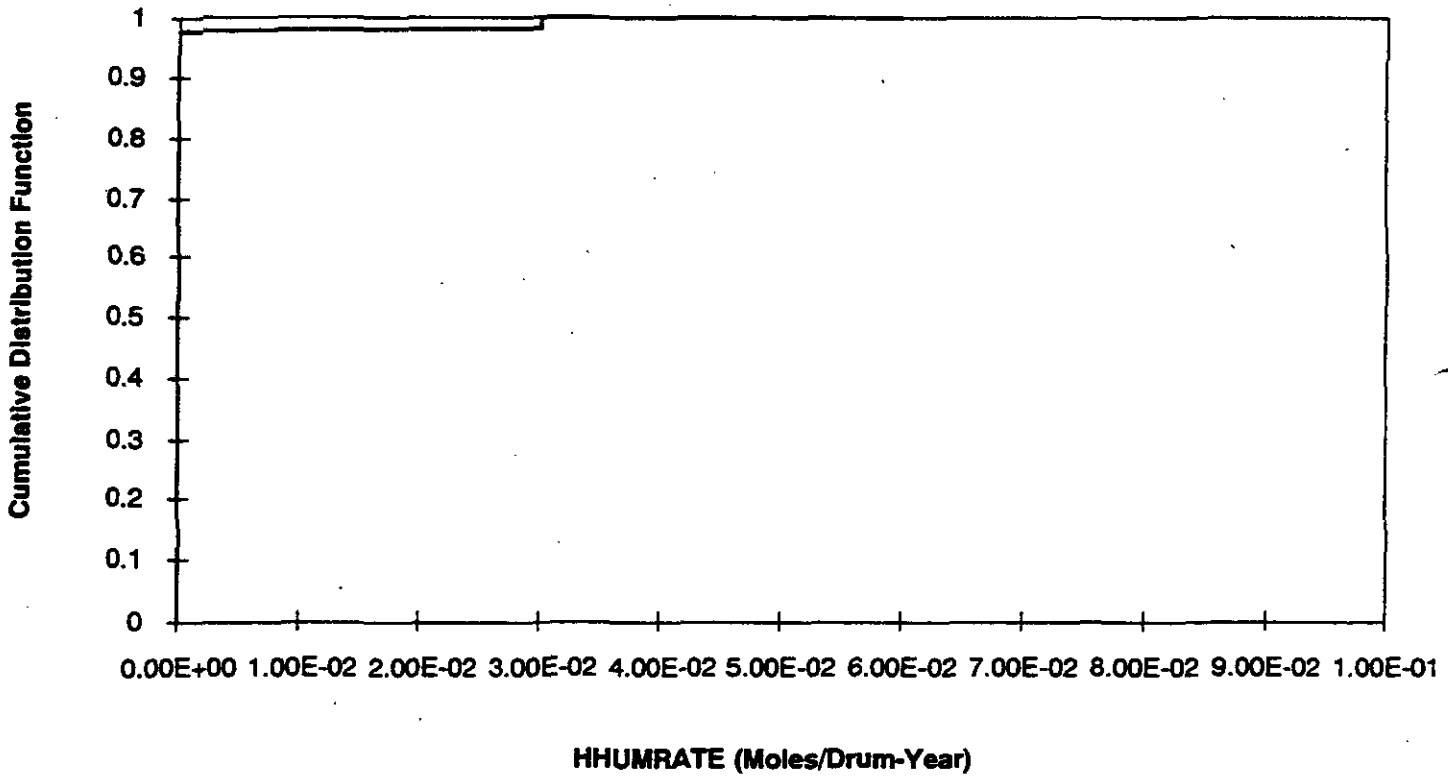

M

Figure J-1a
Cumulative Distribution Function

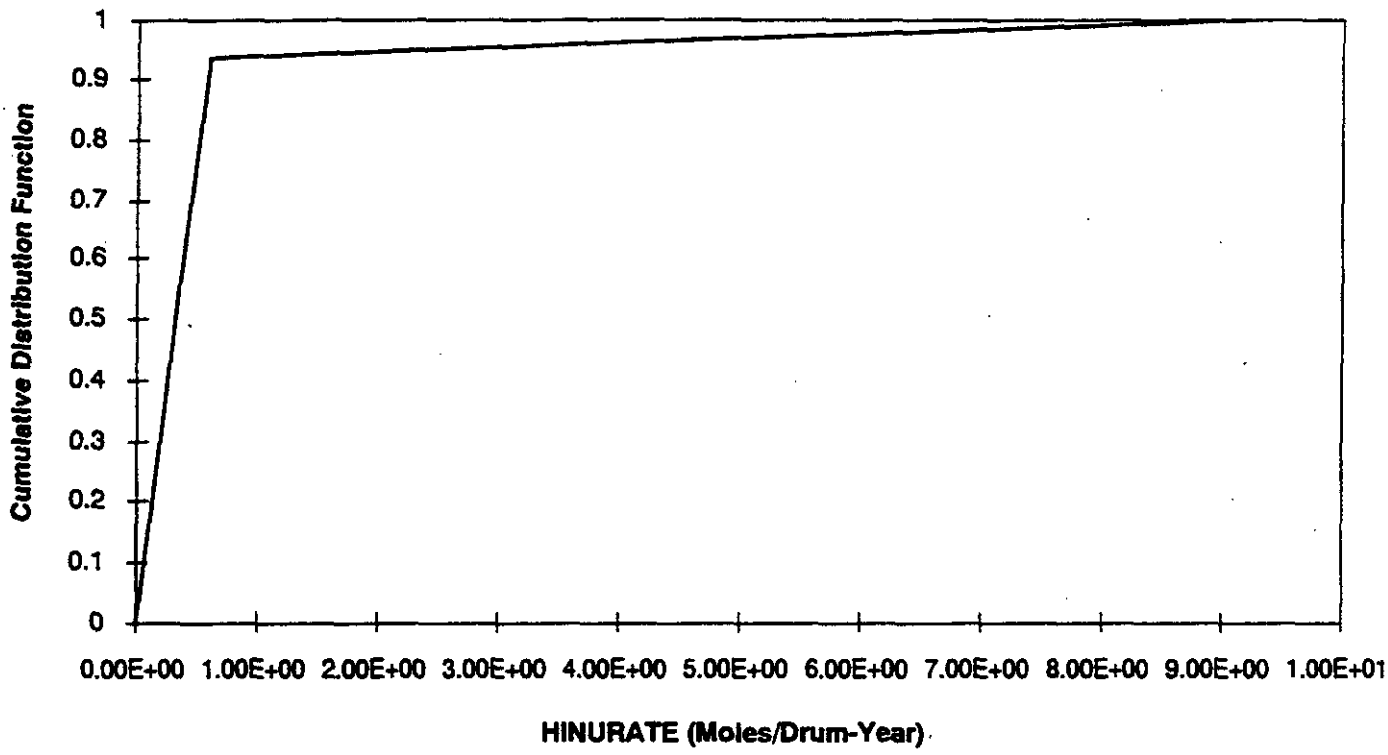

M

Figure J-1b
Cumulative Distribution Function

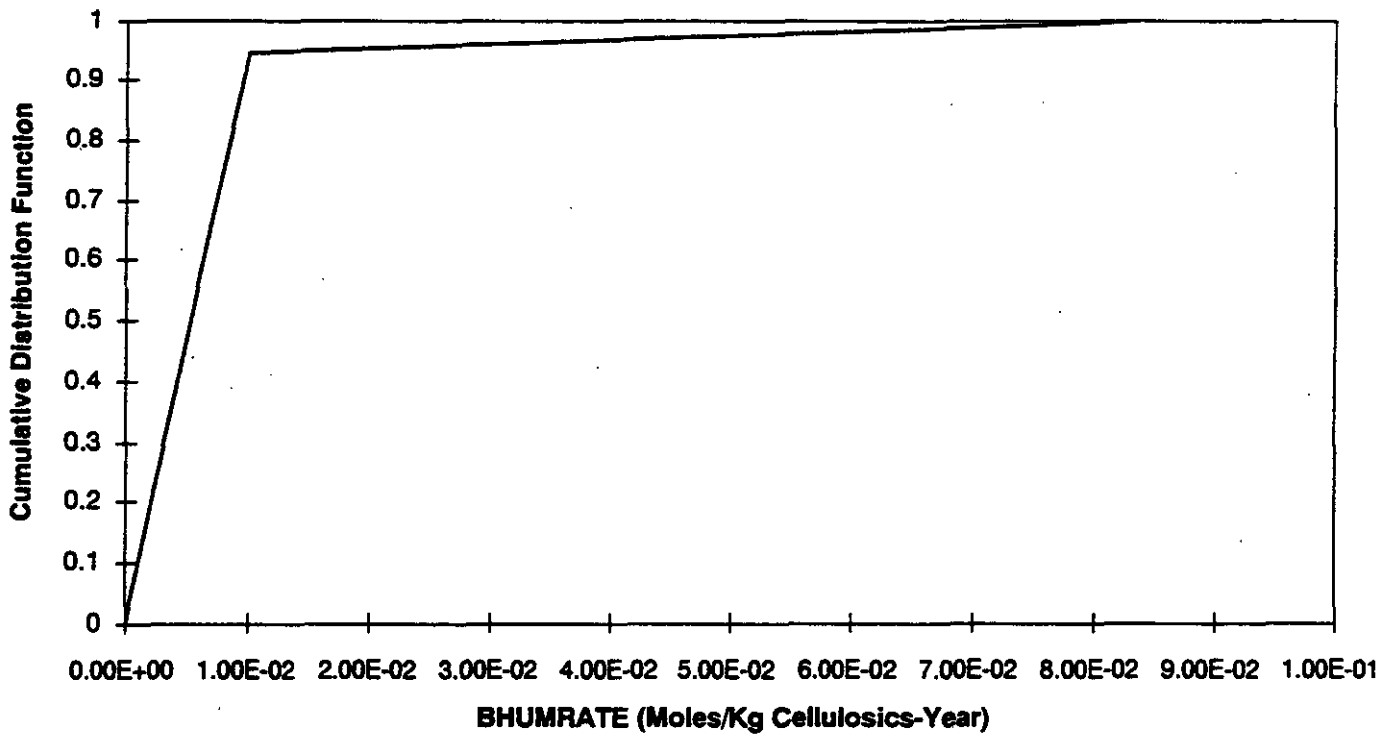

Figure J-1c
Cumulative Distribution Function

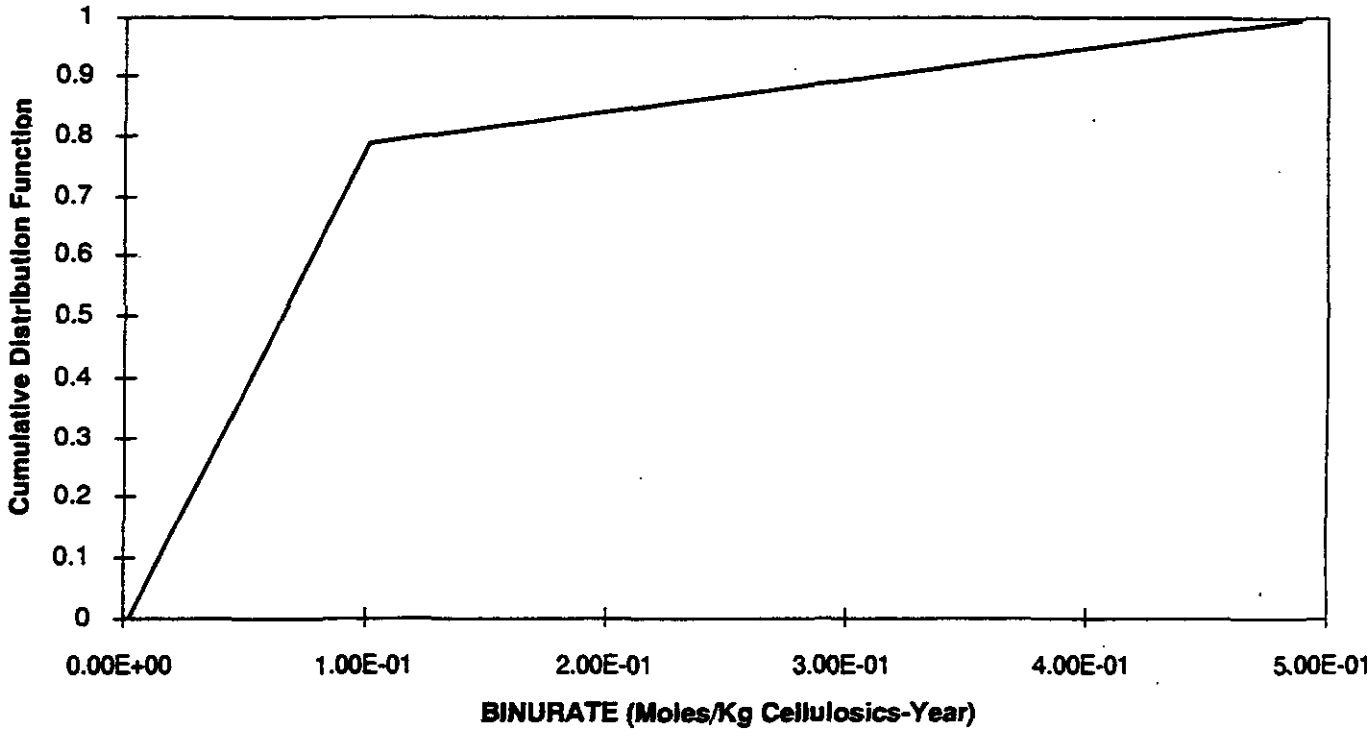

M

Figure J-1d
Cumulative Distribution Function

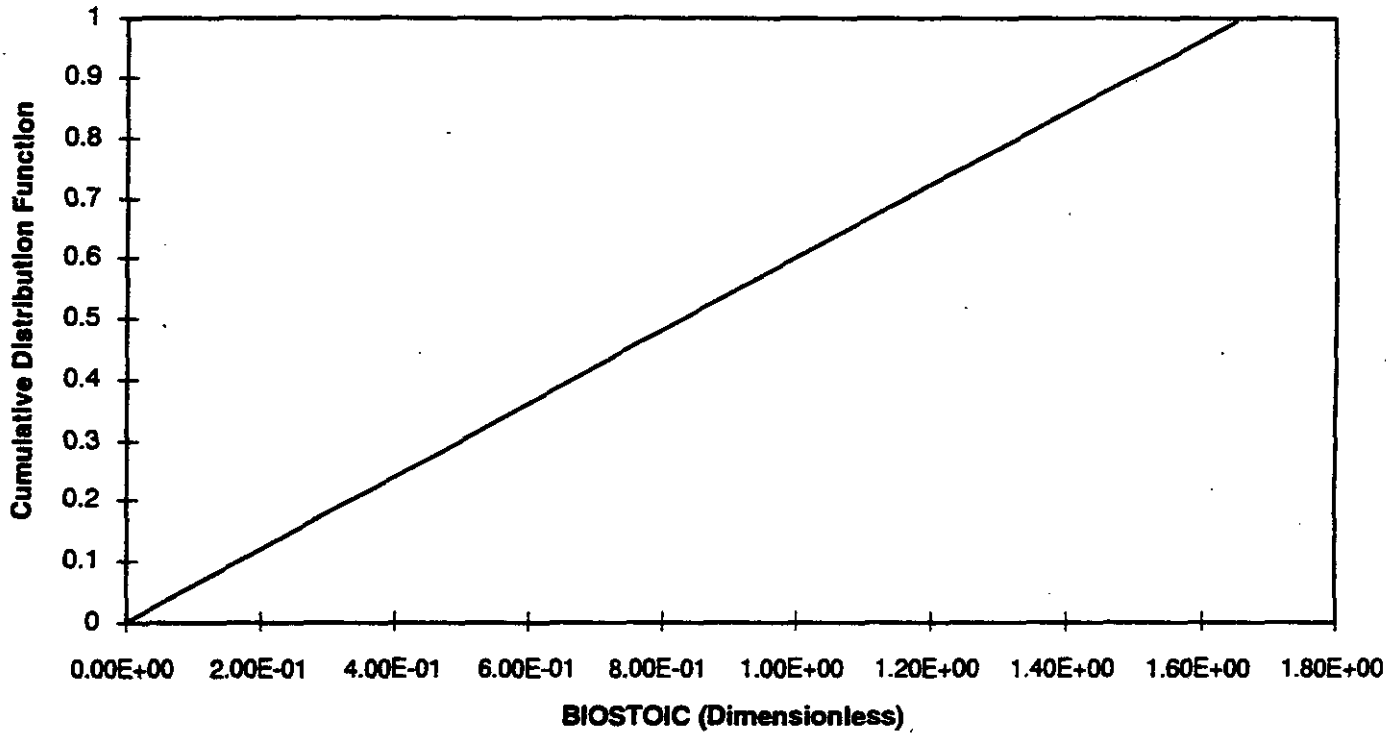

Figure J-1e
Cumulative Distribution Function

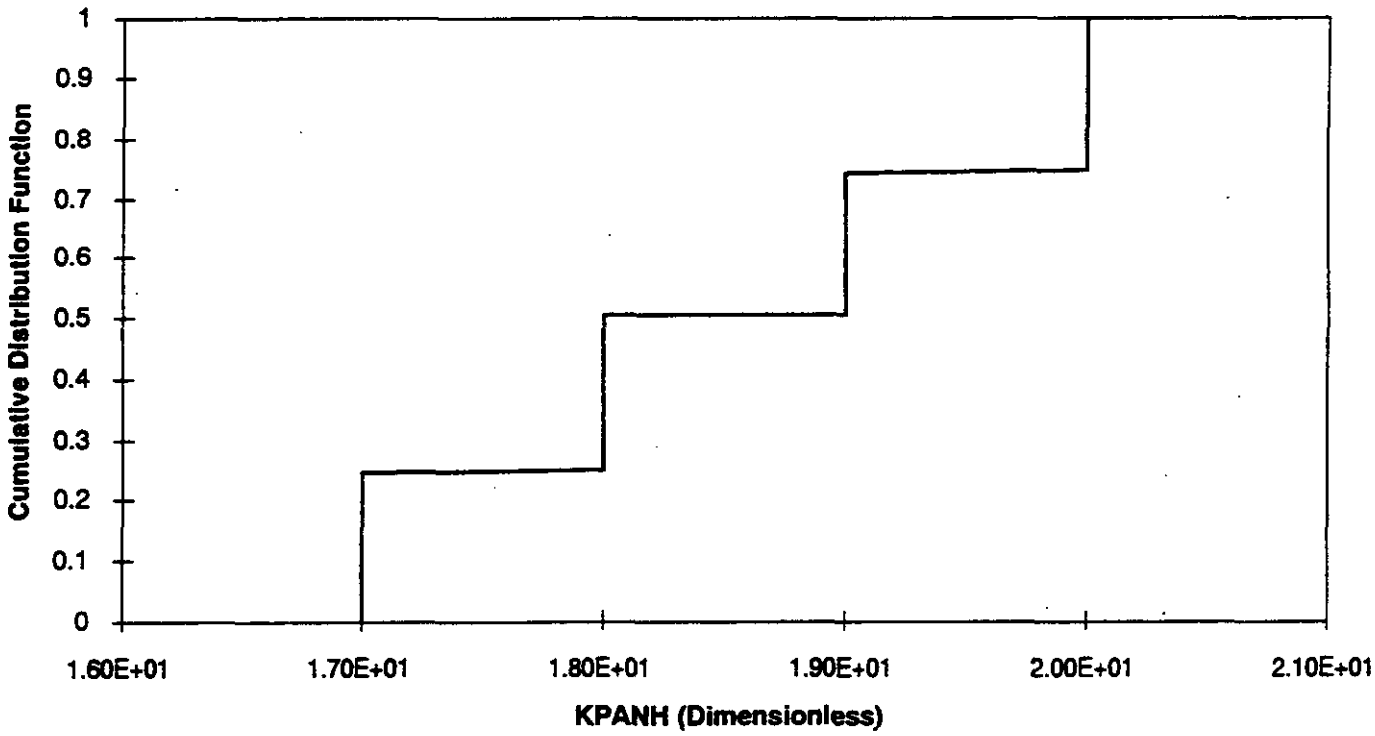

Figure J-1f
Cumulative Distribution Function

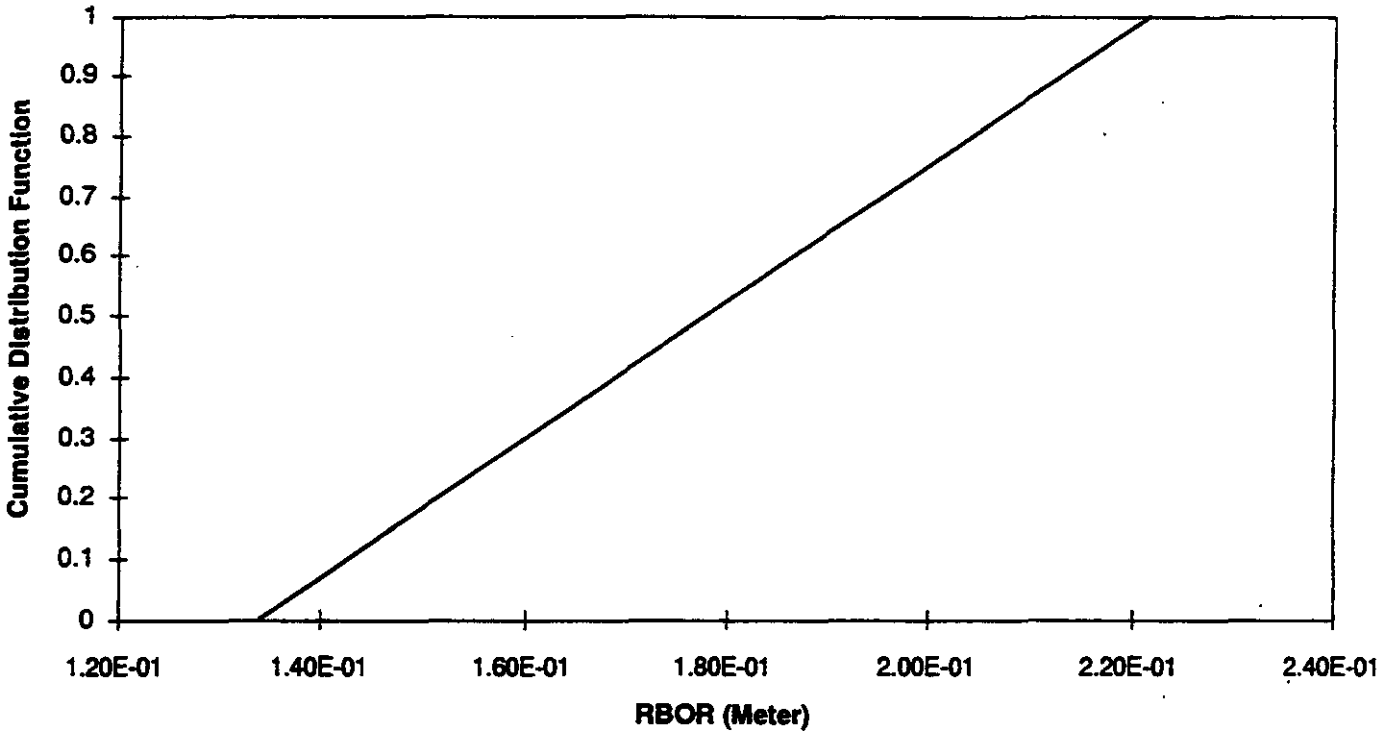

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Figure J-1g
Cumulative Distribution Function

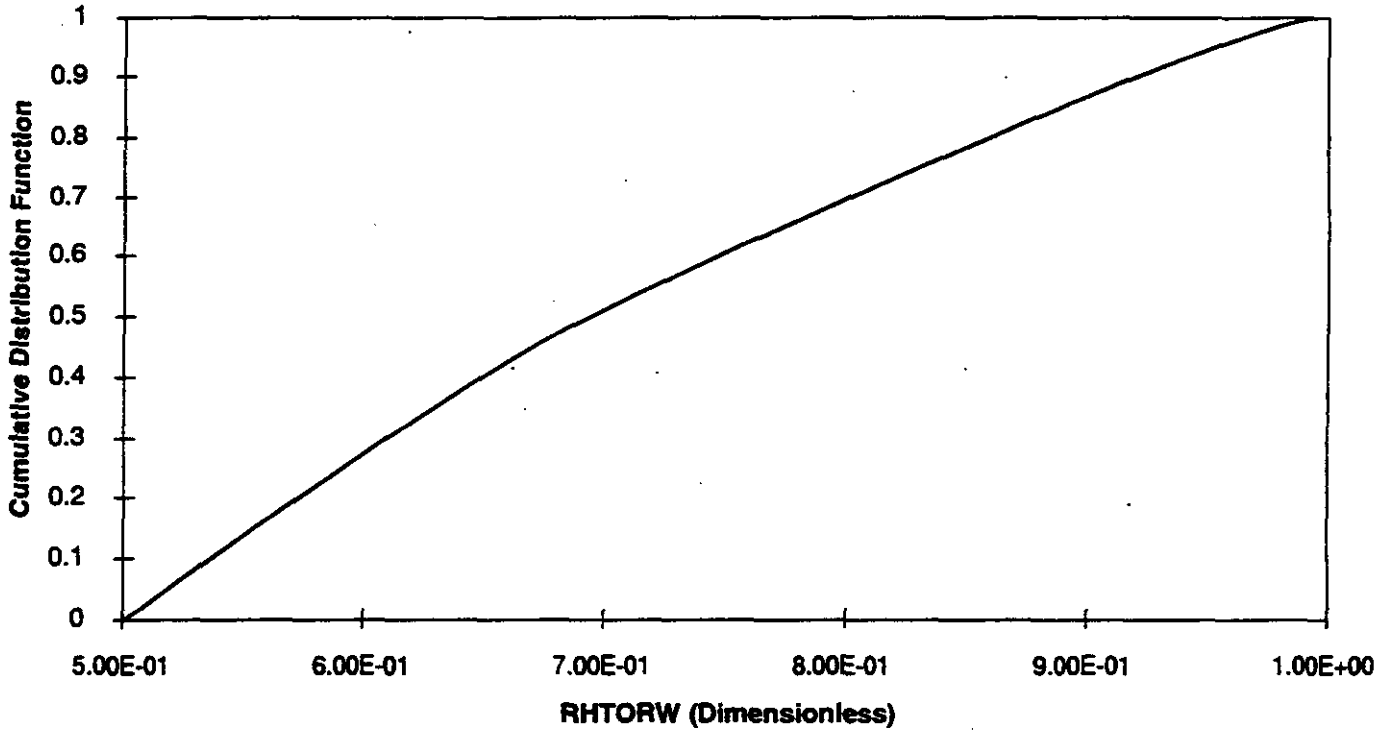

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Figure J-1h
Cumulative Distribution Function

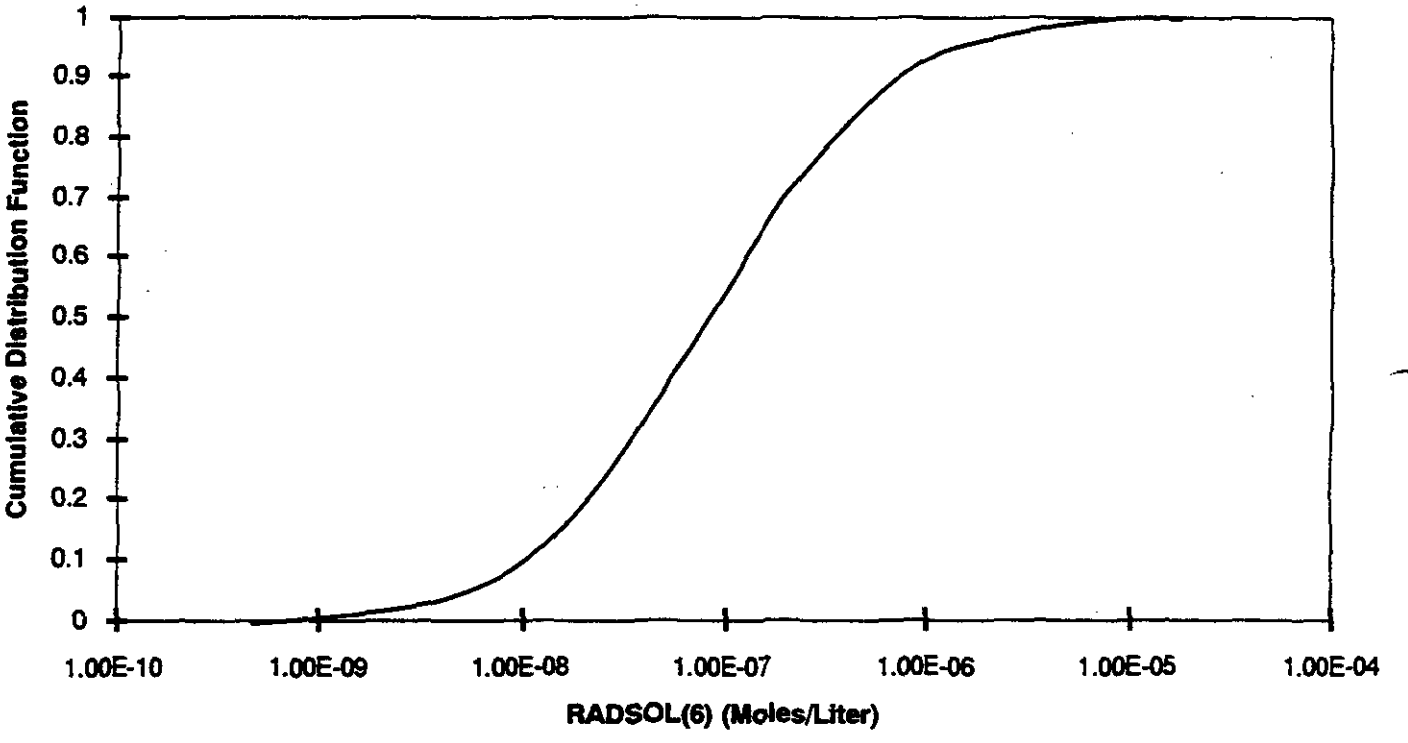

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Figure J-1i
Cumulative Distribution Function

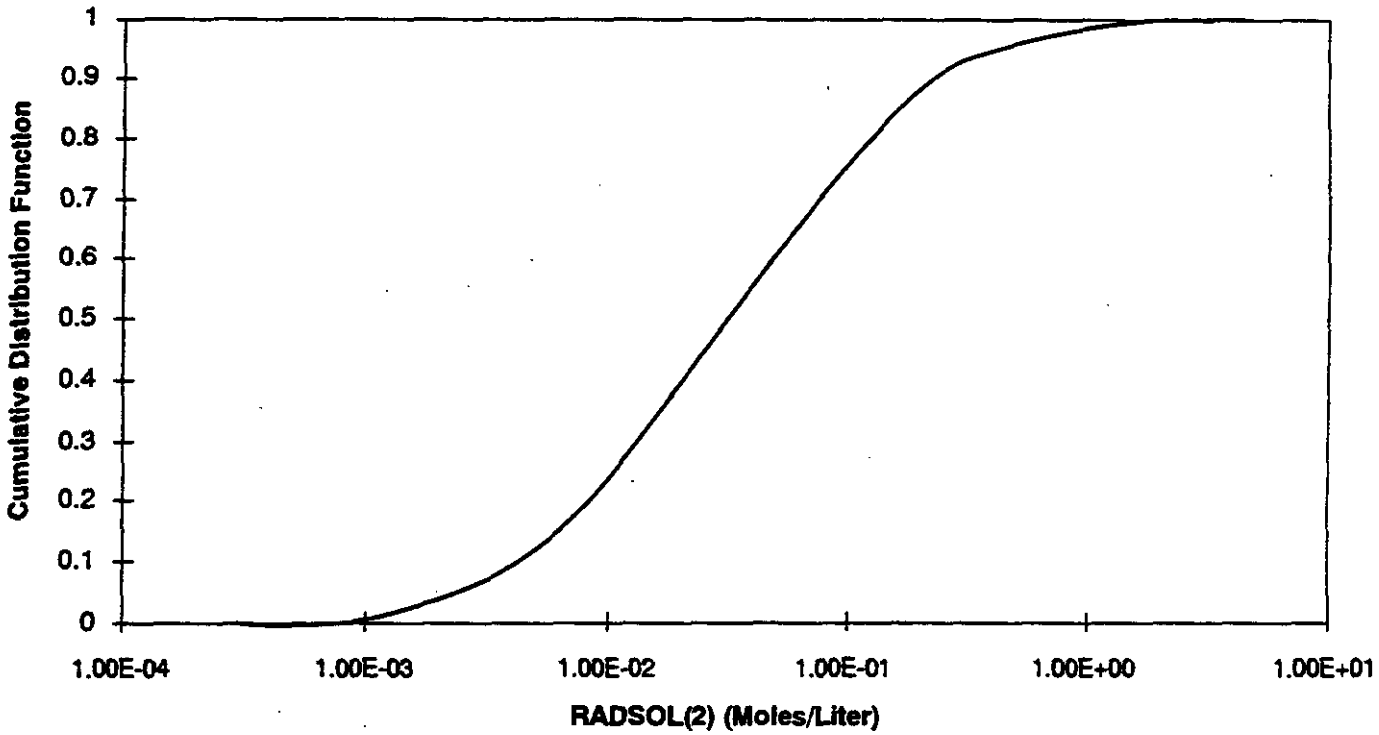

M

Figure J-1j
Cumulative Distribution Function

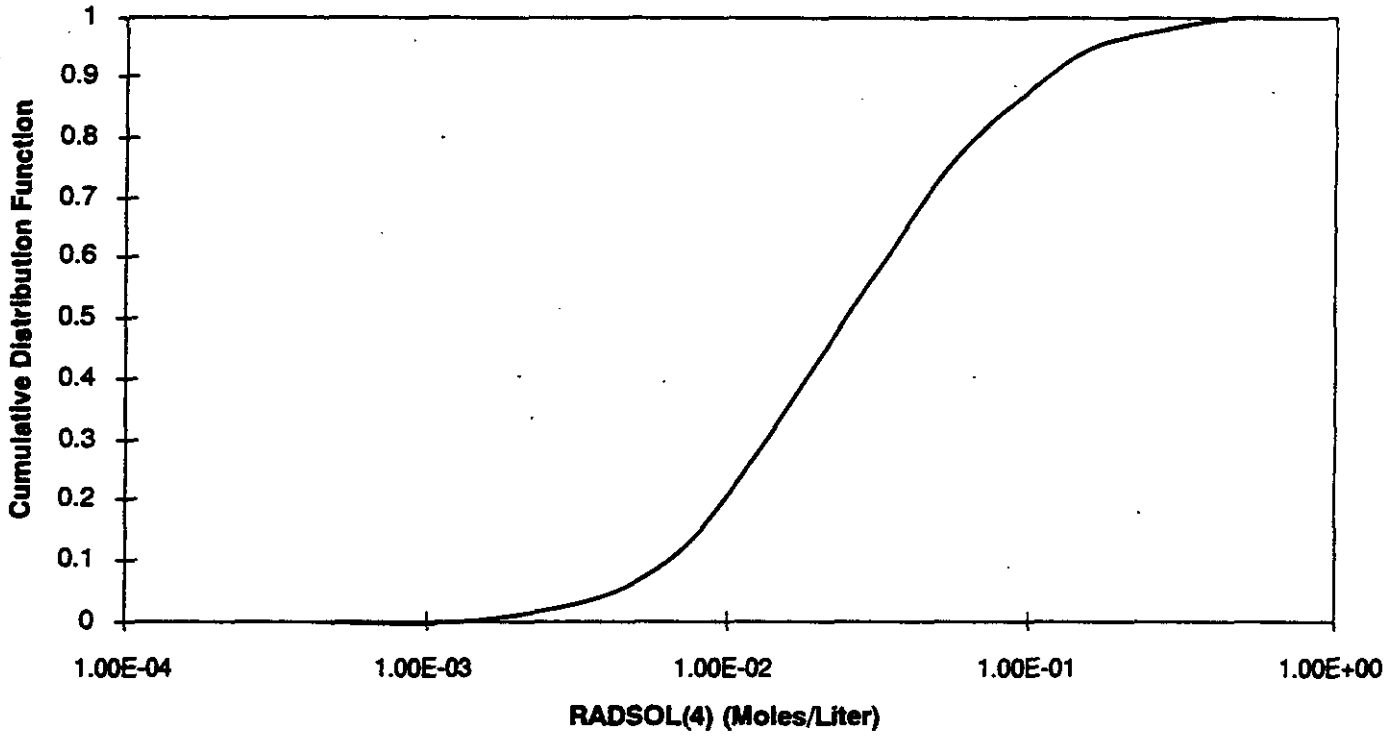

M

Figure J-1k
Cumulative Distribution Function

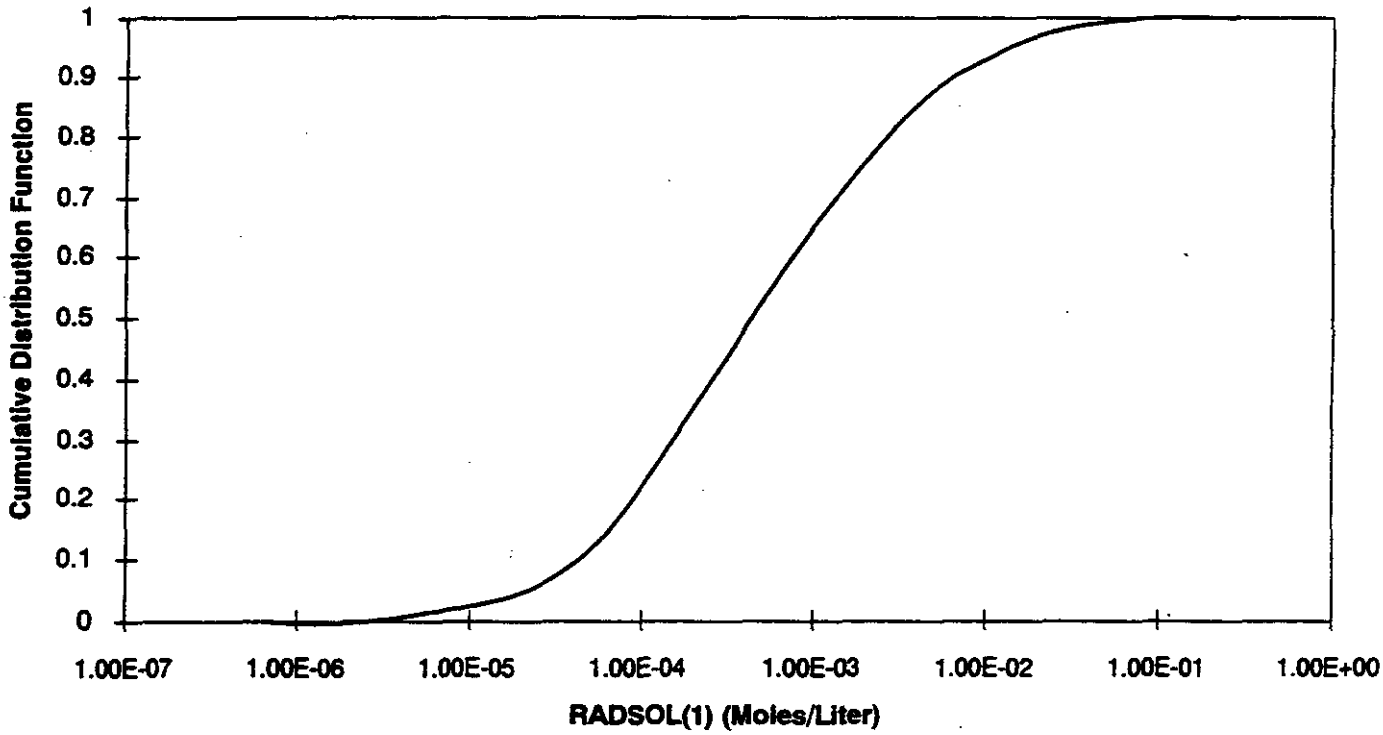

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Figure J-1l
Cumulative Distribution Function

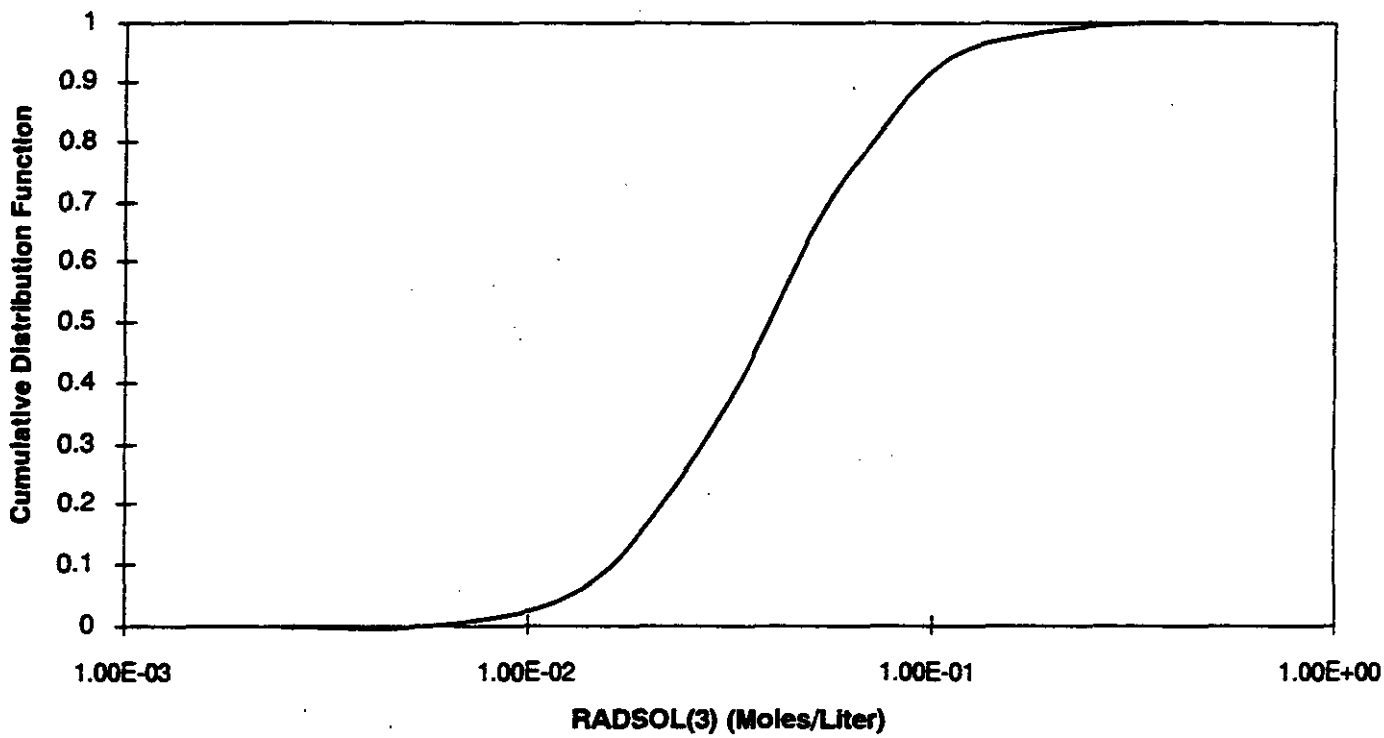

Figure J-1m
Cumulative Distribution Function

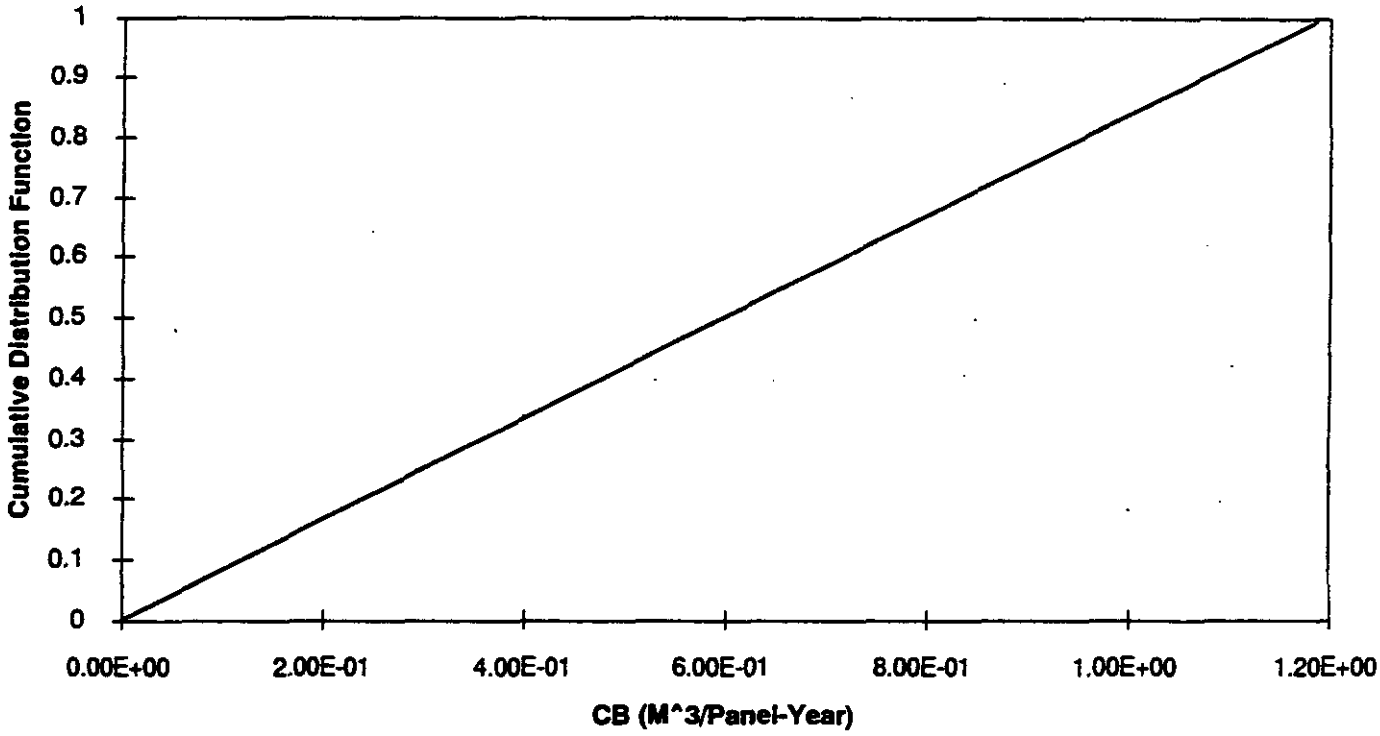

Figure J-1n
Cumulative Distribution Function

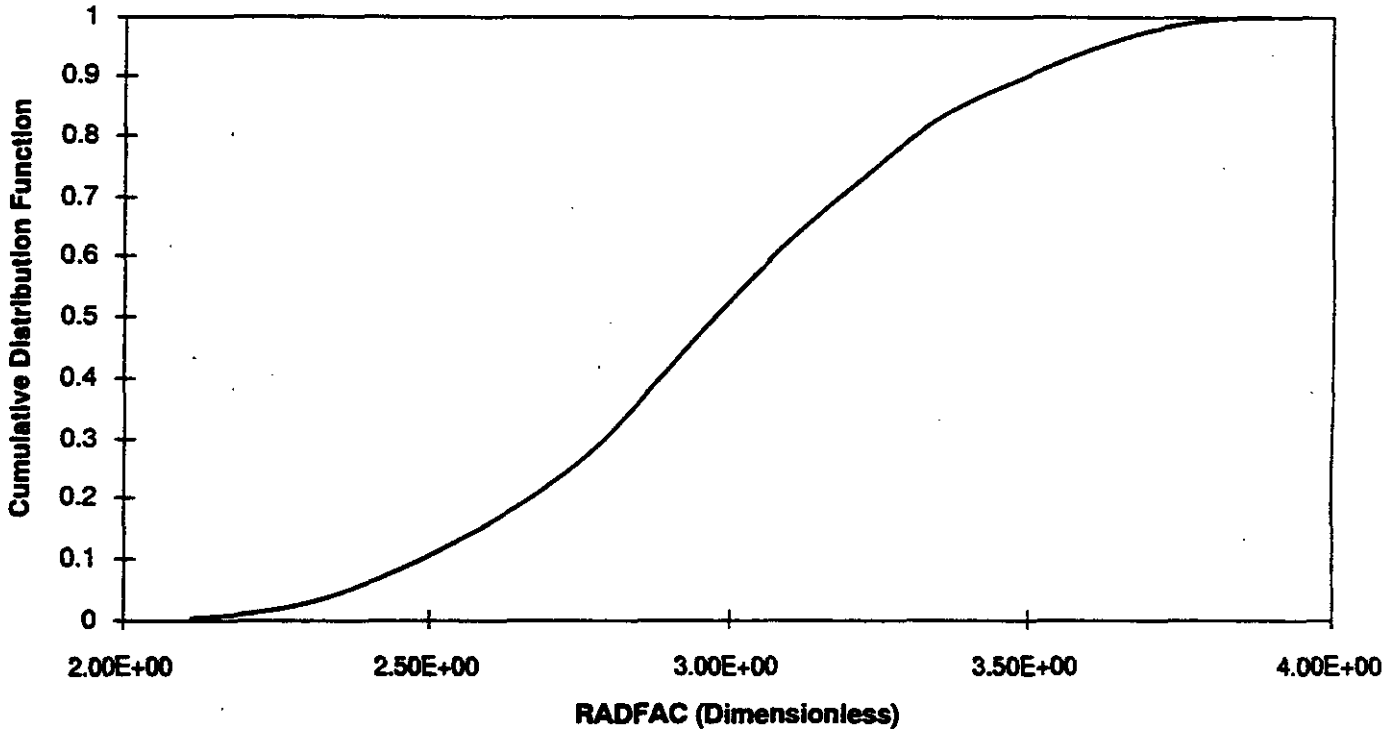

M

Figure J-1o
Cumulative Distribution Function

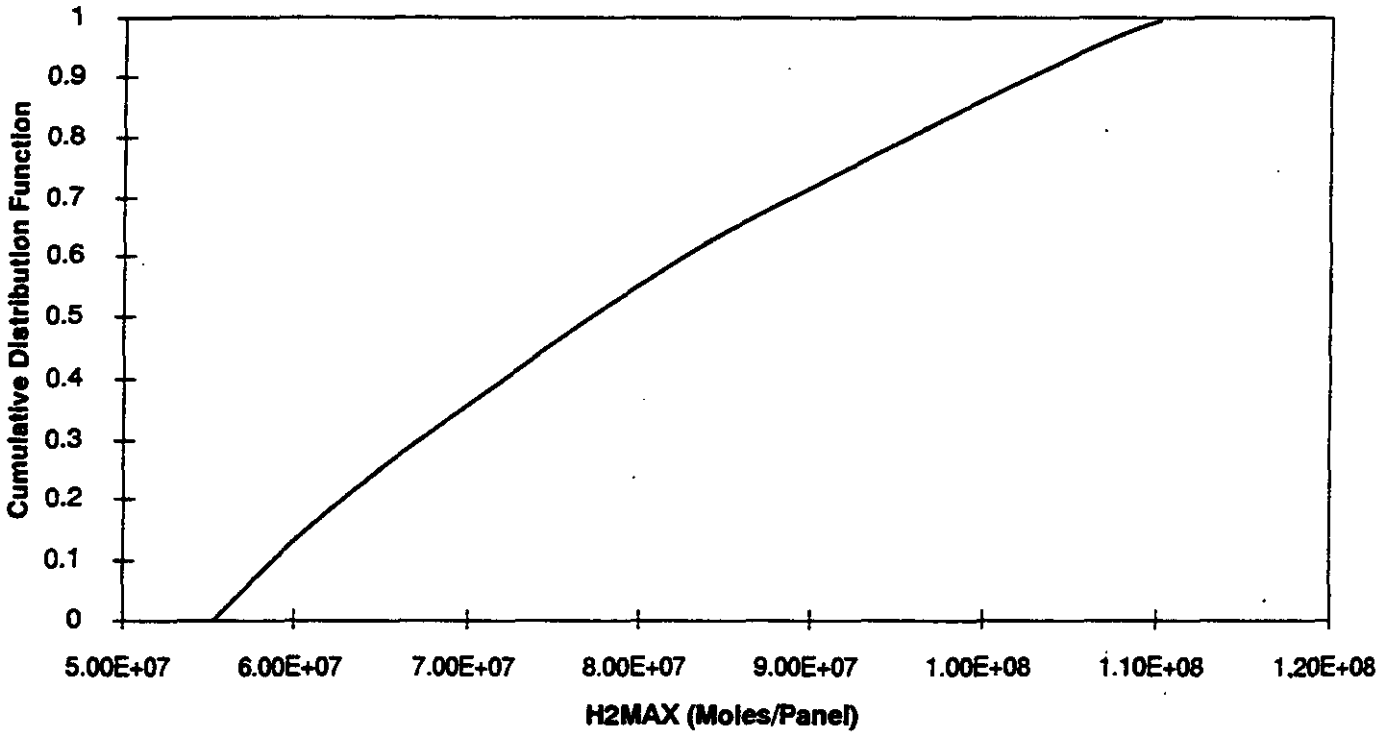

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Figure J-1p
Cumulative Distribution Function

- Different Model for the Rate of the Process. The use of the same random number for the two processes reflects the judgement that the humid gas generation rate should never exceed the inundated biodegradation gas generation rate, since the cumulative distribution of the humid process has lower values at all percentiles of the distribution.

- Solubility of Actinides: The solubility of all the isotopes of a given actinide element are considered to be the same, and the elemental distribution is sampled only once for any given random sample calculation. Individual radioelements are sampled independently.

- Maximum Hydrogen Gas Generation Potential for Anoxic Corrosion (H2MAX): This parameter is calculated by multiplying H2MAX0, the parameter that relates the maximum potential based on metal inventory, and RHTORW, the ratio of the hydrogen gas generation rate to water consumption rate. The parameter H2MAX0 is based on an assumed metallic inventory, and is expressed as a constant. Consequently, the value of H2MAX is totally dependent on the random number used to produce RHTORW.

3.0 IMPACT OF ENGINEERED ALTERNATIVES ON INPUT PARAMETER DISTRIBUTIONS

This section documents the changes to the probability distributions of parameters given in Section 2.0 that result from each engineered alternative. The engineered alternative may also impact best point estimates of input parameters to the DAM whose uncertainties were not modeled. Documentation of the those changes can be found in Appendix E.

Table J-2 identifies the changes made to the uncertain input parameters to reflect the influence of the various EAs. The impacts of these changes are discussed below.

3.1 Changes to H2MAX

Waste processing options that reduce the total number of steel waste containers that would be impacted in a given panel of the Waste Isolation Pilot Plant repository have the potential to reduce the maximum hydrogen gas generation potential from anoxic corrosion. This reduction in potential is reflected by changing the value of H2MAX0, the constant coefficient of the equation that generates the distribution for H2MAX.

Three of the waste processing options have the potential to reduce the number of steel waste containers. Table J-3 below relates the quantities by which the containers would be reduced per room to the reduction in H2MAX0. It should be noted that the values of H2MAX0 do not scale directly with the reduction in equivalent drums, since the mass of contaminated metallic waste and interior metallic containers must also be accounted for.

Figure J-2(a-d) compares the CDF for each of these processing options with that of the baseline value of H2MAX. The net effect of the engineered alternative is to shift the maximum potential anoxic gas generation rate in proportion to the reduction in steel available for the reaction. This

IMPACT OF ENGINEERED ALTERNATIVES ON UNCERTAIN INPUT PARAMETERS IN THE DESIGN ANALYSIS MODEL

Parameters Having Uncertainty	Variable Description (units)	Impact of EA on Probability Distribution															
		1	6	10	33	35a,b	77a	77b	77c	77d	83	94a	94b	94c,d	94e	94f	111
BHUMRATE	Microbial gas generation rate under humid facility conditions (moles/kg cellulosics-yr)	No Change From Baseline															
BINURATE	Microbial gas generation rate under inundated facility conditions (moles/kg cellulosics-yr)	No Change From Baseline															
BIOSTOIC	Ratio of moles of biogas generated to moles of cellulosics consumed (dimensionless)	No Change From Baseline															
CB	Brine inflow rate at a pressure difference of lithostatic minus atmospheric (m^3/yr-panel)	No Change From Baseline															
H2MAX	Maximum hydrogen gas generation potential from anoxic corrosion (mol/panel)	A	A	A	Baseline		A	A	A	A	No Change from Baseline						
HHUMRATE	Hydrogen gas generation rate from anoxic corrosion under humid facility conditions (moles/drum-yr)	No Change From Baseline															
HINURATE	Hydrogen gas generation rate from anoxic corrosion under inundated facility conditions (moles/drum-yr)	No Change From Baseline															
KPANH	Negative log of the permeability of the anhydrite beds (dimensionless)	No Change from Baseline															
RADFAC	Factor that the drill bit radius (RBOR) is multiplied by to yield an effective radius for use in the cuttings model.	B	B	B	BL	B	B	B	B	B	BL	B	B	B	B	B	BL
RADSOL (1)	Pu-240 solubility in brine (mol/l)	No Change from Baseline								C	C	No Change from BL				C	BL
RADSOL (2)	U-236 solubility in brine (mol/l)	No Change from Baseline								C	C	No Change from BL				C	BL
RADSOL (3)	Am-241 solubility in brine (mol/l)	No Change from Baseline								C	C	No Change from BL				C	BL

TABLE J-2 (Continued)

IMPACT OF ENGINEERED ALTERNATIVES ON UNCERTAIN INPUT PARAMETERS IN THE DESIGN ANALYSIS MODEL

Parameters Having Uncertainty	Variable Description (units)	Impact of EA on Probability Distribution														
		1	6	10	33	35a,b	77a	77b	77c	77d	83	94a	94b	94c,d	94e	94f	111
RADSOL (4)	Np-237 solubility in brine (mol/l)	No Change from Baseline								C	C	No Change from BL				C	BL
RADSOL (5)	U-233 solubility in brine (mol/l)	Completely Correlated With RADSOL(2)															
RADSOL (6)	Th-229 solubility in brine (mol/l)	No Change from Baseline								C	C	No Change from BL				C	BL
RADSOL (7)	Pu-238 solubility in brine (mol/l)	Completely Correlated With RADSOL(1)															
RADSOL (8)	U-234 solubility in brine (mol/l)	Completely Correlated With RADSOL(2)															
RADSOL (9)	Th-230 solubility in brine (mol/l)	Completely Correlated With RADSOL(4)															
RADSOL (12)	Pu-239 solubility in brine (mol/l)	Completely Correlated With RADSOL(1)															
RBOR	Radius of borehole for intrusion scenarios (m)	No Change From Baseline															
RHTORW	Ratio of hydrogen gas generation rate to water consumption rate during anoxic corrosion (dimensionless)	No Change From Baseline															

Notes:

BL No Change from Baseline

A Reflects reduction in the metallic content of waste composite expected to be present with these engineered alternatives.

B Factor reduced to various degrees to reflect improved strength and toughness of waste composite to resist borehole erosion.

C Modified to reflect reduced solubility of actinides at as pH moves from 6.1 to 8.3 due to presence of CaO.

1

TABLE J-3

VALUES OF H2MAX0 BASED ON INVENTORIES OF METAL ASSOCIATED WITH VARIOUS ENGINEERED ALTERNATIVES

Waste Processing Option	Impacted EAs	Equivalent Number Drums per Room	H2MAX0 (moles/panel)
None	Baseline	6421	7.0E+07
Shred and Compact	6	5381	6.7E+07
Super Compact	1	3604	6.1E+07
Super Compact	77a-d	2000	3.4E+07
Plasma Processing	10	2120	3.7E+07

M

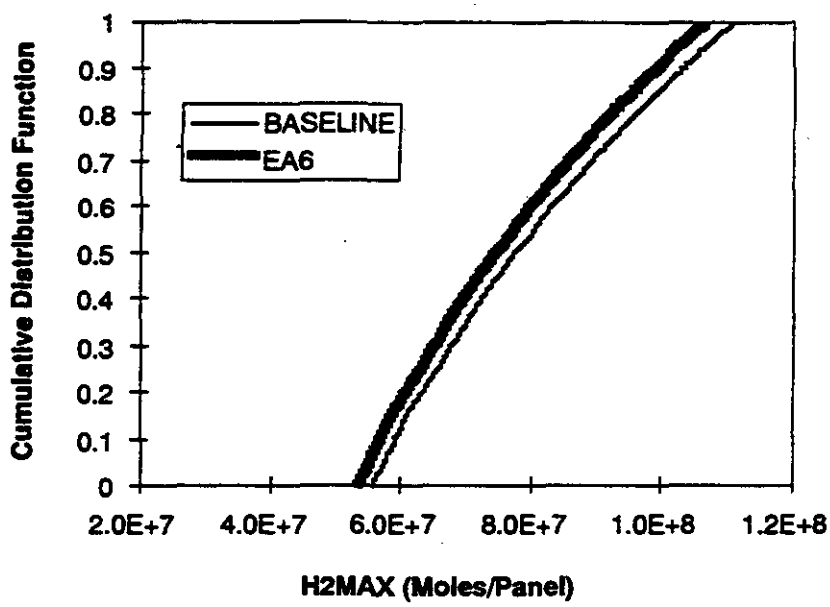

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Figure J-2a
Uncertainty Distribution of Input Variable H2MAX for EA6

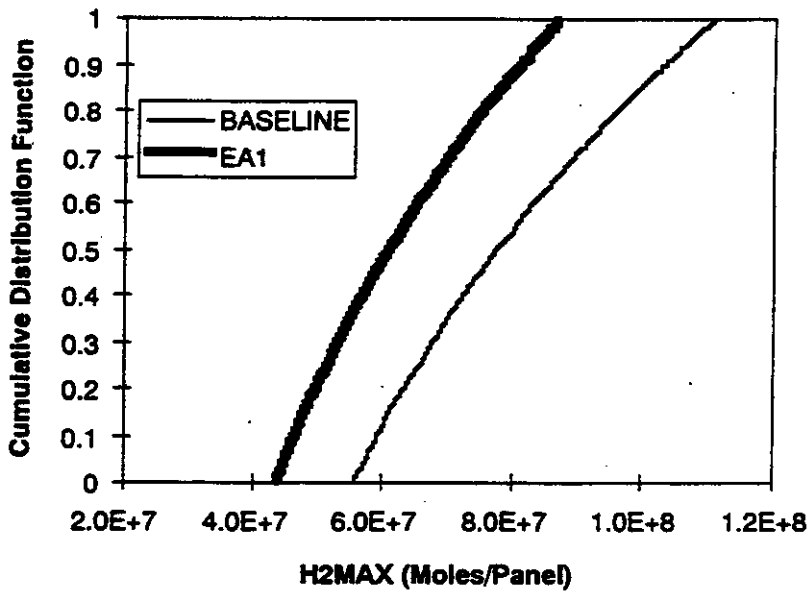

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Figure J-2b
Uncertainty Distribution of Input Variable H2MAX for EA1

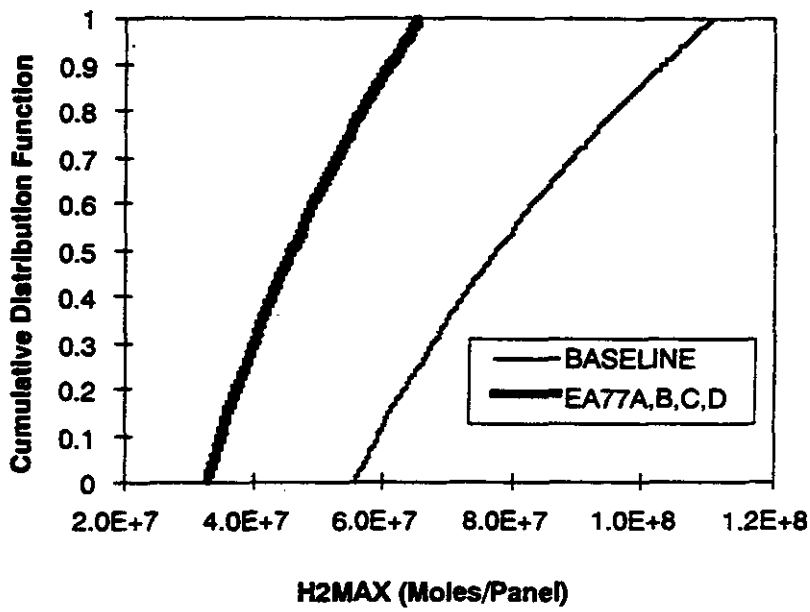

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Figure J-2c
Uncertainty Distribution of Input Variable H2MAX for EA77A,B,C,D

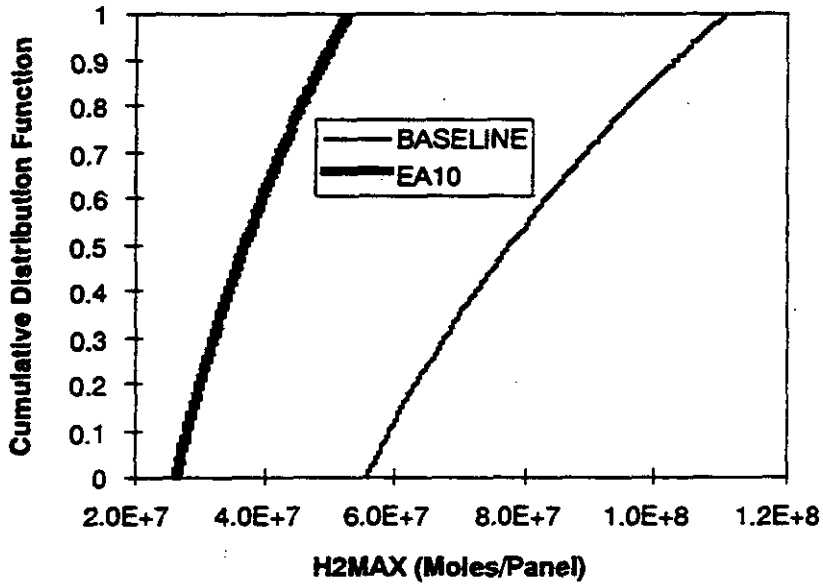

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Figure J-2d

Uncertainty Distribution of Input Variable H2MAX for EA10

impact is believed to become important only when there is sufficient water available to totally react with that quantity of steel.

3.2 Changes to RADFAC

Some EAs improve the shear strength and toughness of the waste/backfill composite that forms at the waste horizon after consolidation. As a result, these EAs are expected to exhibit enhanced resistance to enlargement of borehole due to erosion and slurry action during the drilling process. The first principles model of borehole erosion is still under development in Sandia Performance Assessment Model. In the absence of available insights from that model, the strength and toughness of the waste/backfill composite anticipated to be achieved by the various were grouped and judgmentally ranked from highest to lowest resistance to erosion based on their anticipated strength and toughness. The variable RADFAC is a factor that the drill bit radius is multiplied by to determine the effective radius for use in the cuttings release model. The results of the RADFAC ranking is given in the Table J-4.

TABLE J-4

SUMMARY OF STRENGTH AND TOUGHNESS RANKS FOR ASSESSMENT OF RADFAC

Waste/Backfill Composition	EA Case Number	RADFAC Range	Comments
Solid resulting from Plasma Processing, no backfill	10	50% at 1 50% 1->1.3	If the solid does not degrade it should cut cleanly. Minor erosion if it does degrade.
Supercompacted waste both with and without backfill	1, 77a-d	1.5 ± 30%	Super compaction creates a very dense composite structure
Solids shredded and packed with clay, enhanced sludge cement with cementitious or salt aggregate grout backfill	94c,d	1.75 ± 30%	Combination of enhanced cementation of sludges and grout backfill creates strong composite
No waste processing, but cementitious or salt aggregate grout backfill	35a,b	2.0 ± 30%	Grout backfills increase strength of composite
Solids shredded and packed with clay, enhanced sludge cement, with backfills providing no additional toughness	94a,b,e,f	2.3 ± 30%	Enhanced cementation of sludges provides minor strength increase
Shred and Compact Solid Waste, no backfill	6	2.6 ± 30%	Low-force compaction provides only slight increase in strength of composite
Alternatives providing no additional toughness	33,83	3.0 ± 30%	Resistance to erosion taken to be the same as that used for the baseline design.

Figure J-3(a-f) compares the CDF for each of the modified RADFAC values for with that of the baseline value of RADFAC.

3.3 Changes to RADSOL (All Actinide Elements)

When lime is used in the backfill of the repository it raises the pH of the brine flowing into waste horizon. The solubility of actinides that the repository is designed to contain are strongly dependent on the pH of the brine. Within the DAM, this impact is modeled by changing the CDFs for the solubility for five elemental actinide solubility from those corresponding to a pH of 6.1 in the baseline to solubilities for a pH of 8.3. The CDFs associated with these solubility changes are shown in Figure J-4(a-e). These changes are based a regression analysis on actinide solubility presented in Appendix H.

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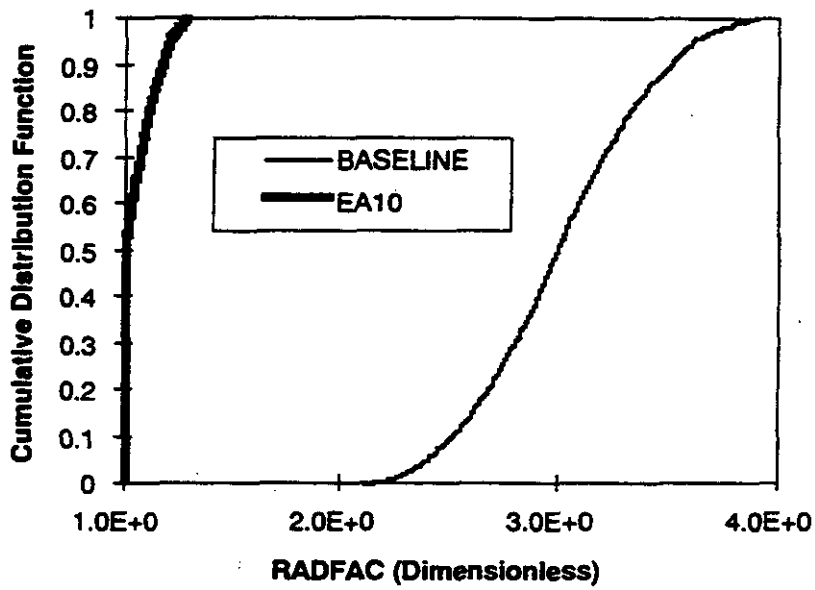

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Figure J-3a
Uncertainty Distribution of Input Variable RADFAC for EA10

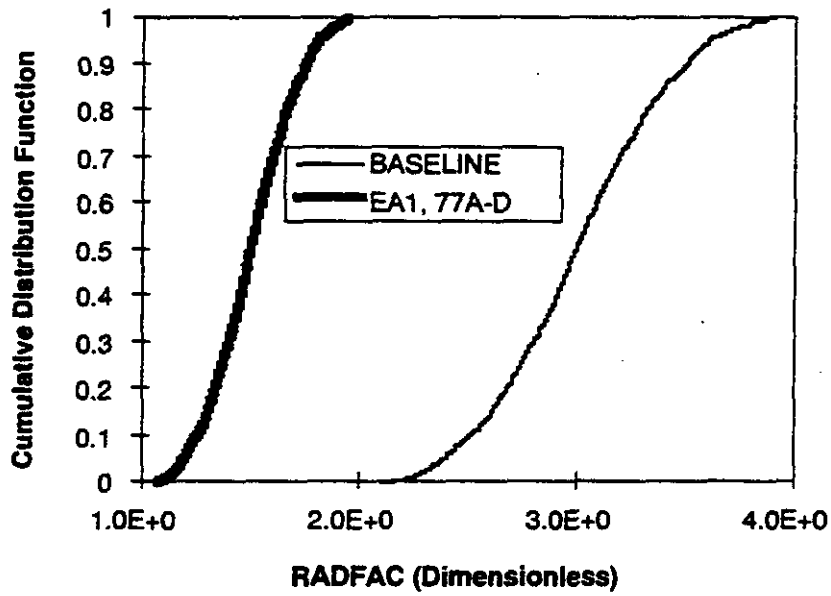

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Figure J-3b
Uncertainty Distribution of Input Variable RADFAC for EA1,77A-D

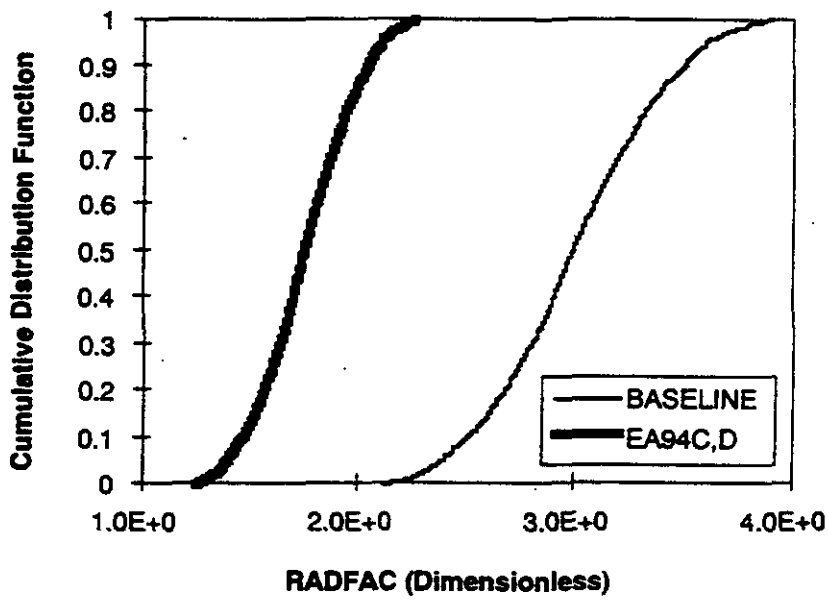

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Figure J-3c
Uncertainty Distribution of Input Variable RADFAC for EA94C,D

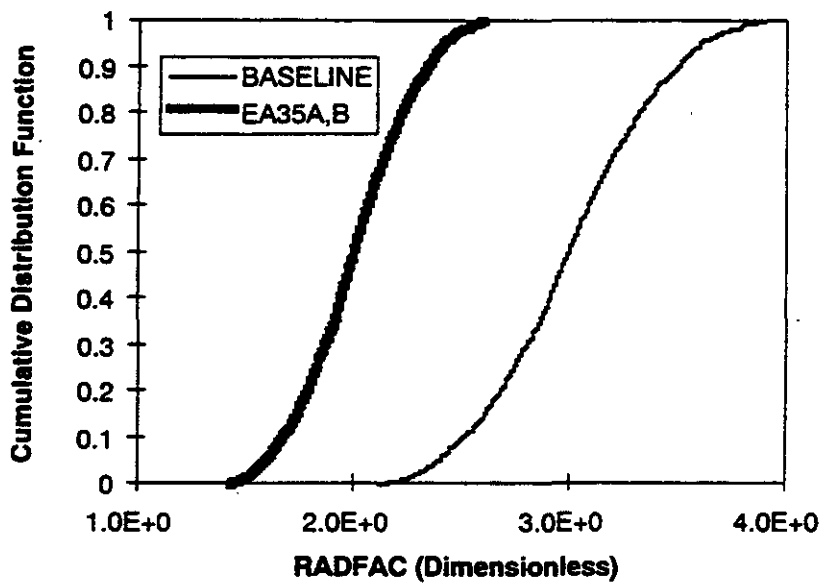

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Figure J-3d
Uncertainty Distribution of Input Variable RADFAC for EA35A,B

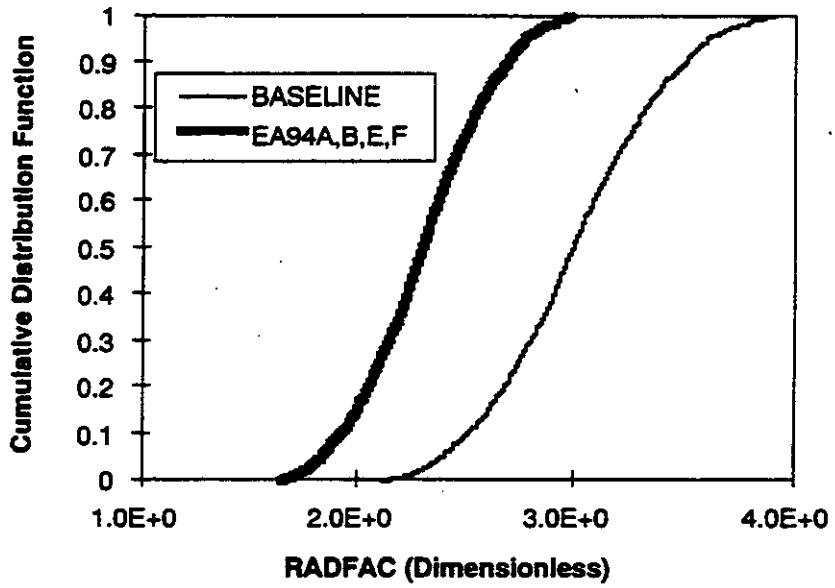

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Figure J-3e
Uncertainty Distribution of Input Variable RADFAC for EA94A,B,E,F

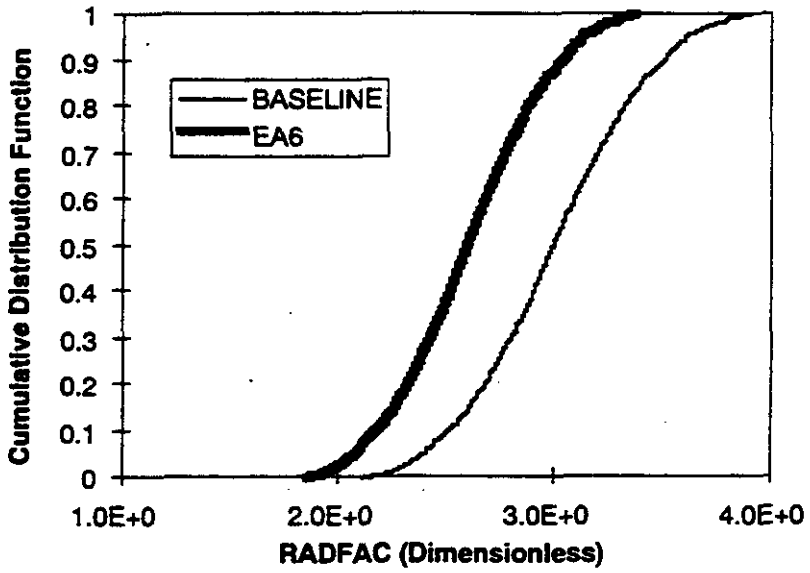

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Figure J-3f
Uncertainty Distribution of Input Variable RADFAC for EA6

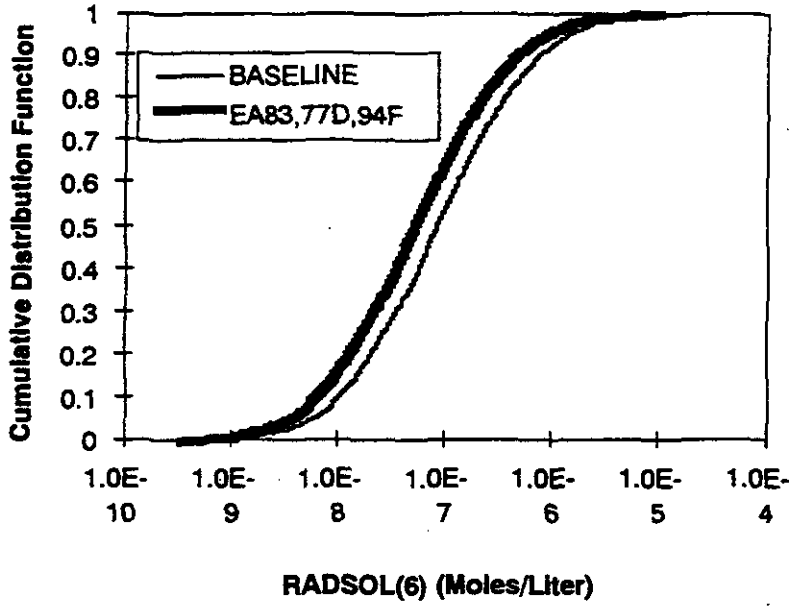

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Figure J-4a
Uncertainty Distribution of Input Variable RADSOL(6) for EA83,77D,94F

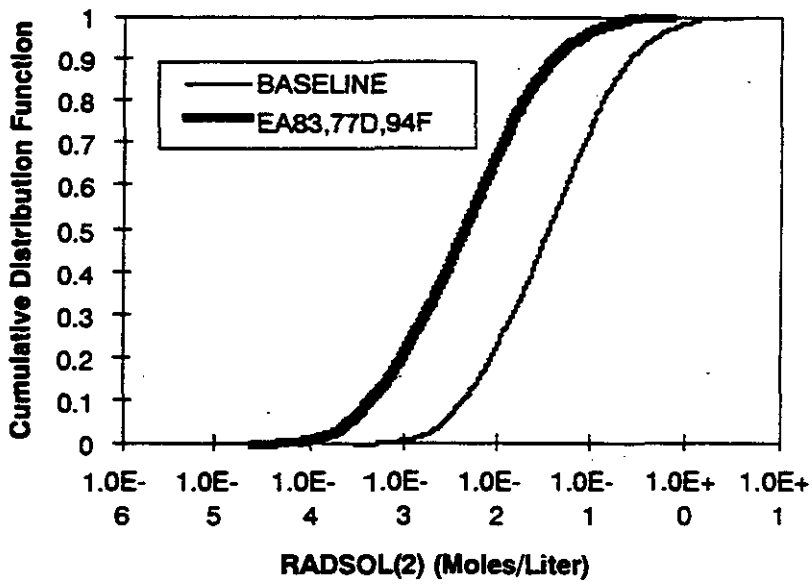

Figure J-4b
Uncertainty Distribution of Input Variable RADSOL(2) for EA83,77D,94F

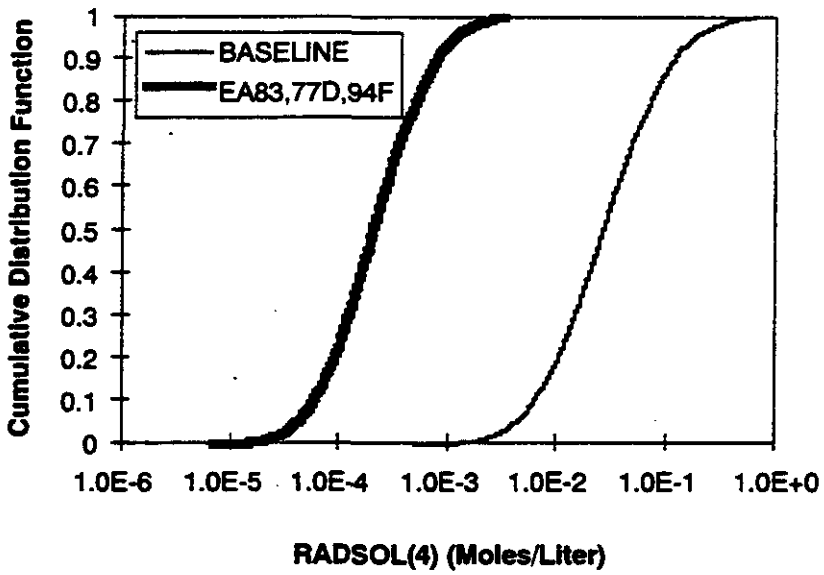

Figure J-4c
Uncertainty Distribution of Input Variable RADSOL(4) for EA83,77D,94F

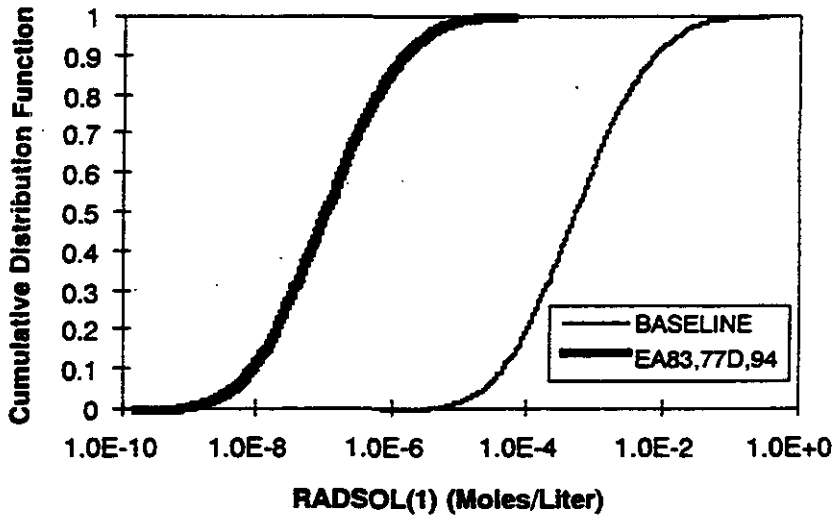

Figure J-4d

Uncertainty Distribution of Input Variable RADSOL(1) for EA83,77D,94F

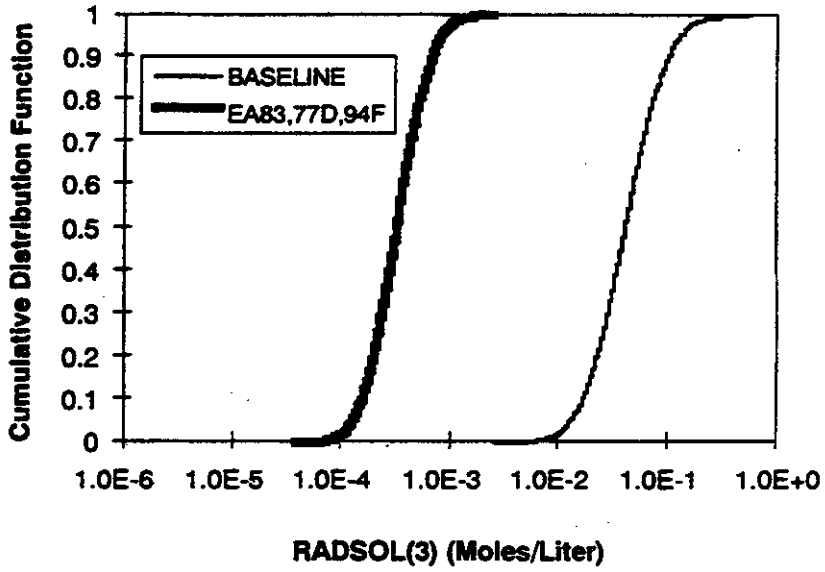

Figure J-4e
Uncertainty Distribution of Input Variable RADSOL(3) for EA83,77D,94F

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APPENDIX K

MODELING OF HUMAN HEALTH IMPACTS

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MODELING OF HUMAN HEALTH IMPACTS

1.0 INTRODUCTION

This appendix describes in greater detail the modeling performed to support the data presented in Section 3.3, IMPACT ON WORKER AND PUBLIC RISK. The sections in this appendix are described below. Section 1.0 describes the way scaling factors were used, a general discussion of how they were developed, and the relationships between the available data and the scaling factors developed. Section 2.0 presents the data used from the Waste Management Programmatic Environmental Impact Statement (PEIS). Section 3.0 presents a brief description of the waste volume data, the source, and use of the data. Section 4.0 is a discussion of the Full-Time Equivalent (FTE) curves, the development of scaling factors from the data in those curves, and the application of the derived scaling factors. Section 5.0 describes the site specific risk models and scaling factors developed from those models. Sections 2.0 through 5.0 deal primarily with modeling for waste handling and processing facilities throughout the U.S. Department of Energy (DOE) system. Section 6.0 details the models used to estimate the human health impacts from specific Waste Isolation Pilot Plant (WIPP) waste handling and disposal activities including aboveground waste handling, emplacement below ground, and installation of backfill materials after emplacement of the waste.

2.0 GENERAL SCALING PRINCIPLES USED IN SECTION 3.3

As described in Section 3.3.2.1 of the report, estimation of the impacts to the various groups for differing activities performed at multiple sites and combinations of sites requires very complex models and involves large data sets, both of which are beyond the needs and scope of this report. The method used to analyze the numerous combinations of waste processes and processing configurations was to develop scaling factors specific to the available analytical results. The PEIS data include DOE system-wide summations for an adequate range of risk endpoints but only for a limited number of processes and processing configurations (see Section 2.0 for a complete discussion of results available from the PEIS). Overall scaling factors are needed to apply to the site-wide risk data to model additional treatment facility configurations and additional types of processing. Risk factors are available for sites with a significant amount of transuranic (TRU) waste but only for certain combinations of risk factors. Modeling was performed to adjust the available data to account for more recent estimates of TRU waste currently available and estimated to be generated in the future. This allowed the development of system-wide scaling factors to be applied to the PEIS system-wide data for those processes and configurations applicable to the selected engineered alternatives (EA).

Additional modeling was required to adjust the individual site estimates of risk found in the PEIS for differences between processes and configurations in the PEIS and those analyzed in the EA report. This involved not only the modeling of waste processing of varying amounts of waste at processing facilities, but also risks involved with retrieving and preparing the waste for shipment to the waste processing facilities. In the case of alternates involving supercompaction of waste, data were combined from both the PEIS and another source to develop the scaling factors to be applied to the appropriate PEIS data. The new estimates of site risks were combined and used

to calculate system-wide scaling factors to be applied to the most appropriate PEIS system-wide risk data.

3.0 PEIS DATA

The cases for which program-wide and individual facility risk data are available in the PEIS are described in Section 3.3.3 of the report. The March 1995 draft of the PEIS (DOE, 1995b) included program-wide risk data for the four cases that are used as the basis of the EA risk estimations by applying appropriate scaling factors. Tables K-1[1] through K-4 show the applicable system-wide data from the March draft of the PEIS.

The PEIS also listed site-specific risk data but did not use the same breakdown of risk parameters. Table K-5 shows the acronyms used to identify the sites in the remainder of the appendix. Tables K-6 through K-9 show the PEIS site-specific data for the four applicable cases. The fatalities shown for the individual sites include fatalities associated with both radiation exposures and physical hazards. The cancer incidence shown on these tables includes those associated with both radiation and chemical carcinogen exposures.

The waste volumes on which the PEIS risk estimates were based are shown in Table K-10. The source for these data was the November 4, 1994, draft of the PEIS (DOE, 1994a). For each site, the PEIS data included the total assumed to be in storage and an estimated annual generation rate. The total waste shown in the last column was calculated by multiplying the annual rate shown by the 20-year waste processing period and adding that to the waste in storage at that facility.

4.0 SCALING FACTORS FOR CO-LOCATED WORKERS AND OFF-SITE INDIVIDUALS

The major contributor to the risks for off-site personnel is the material released to the air during waste handling. That is also true for co-located worker personnel. The model assumes that air releases are a function of the process and throughput. The relationship between process and release rate is too complex to be addressed in this model so each process is treated uniquely. That is, there is no effort to use releases from shred and compact waste to estimate the releases from plasma processing. The model treats airborne releases as proportional to throughput. That is, if throughput is increased by 20 percent, the normal airborne releases also increase by 20 percent.

The airborne releases from a given process or module may be proportional to the waste throughput, but the impact of those releases is not. For a given amount of material released to the air, the impact on off-site personnel and co-located workers is a very complex function of meteorology, population density, and distribution around the facility, and the location of the individuals who may be candidates for the most exposed individual. However, for long-term

[1]Please note that throughout this appendix, the following notation is frequently used in tables: 1.23e-4 is equivalent to 1.23×10^{-4}.

TABLE K-1

SYSTEM-WIDE HUMAN HEALTH IMPACTS
MEET WIPP WAC AT 10 LOCATIONS
PEIS CASE 4

Receptor	Endpoint	Radionuclides	Hazardous Chemicals		Physical Hazards
			Carcinogens	Noncarcinogens	
Co-located Workers	Dose (person-rem)	2.30e-02			
	Excess Fatalities	1.10e-05			
	Excess Cancers		3.40e-08		
Most Exposed Co-located Individual	Dose (rem)	9.50e-06			
	Excess Risk	4.80e-09			
	Excess Cancers		8.90e-12		
	Hazard Index			1.40e-09	
Offsite Population	Dose (person-rem)	2.40e-01			
	Excess Fatalities	1.20e-04			
	Excess Cancers		1.30e-07		
Most Exposed Offsite Individual	Dose (rem)	1.10e-05			
	Excess Risk	5.70e-09			
	Excess Cancers		2.80e-12		
	Hazard Index			1.50e-10	
Workers	Dose (FTE-rem)	1.50e+03			
	Excess Fatalities	6.00e-01			
	Excess Cancers		1.00e-05		
	Exposure Index			3.10e-05	
	Construction Fatalities				7.80e-01
	Construction Injuries				6.70e+02
	Operations Fatalities				1.40e+00
	Operations Injuries				5.90e+02

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TABLE K-2

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND GROUT AT 5 LOCATIONS
PEIS CASE 5

Receptor	Endpoint	Radionuclides	Hazardous Chemicals		Physical Hazards
			Carcinogens	Noncarcinogens	
Co-located Workers	Dose (person-rem)	3.20e-01			
	Excess Fatalities	1.60e-05			
	Excess Cancers		5.80e-08		
Most Exposed Co-located Individual	Dose (rem)	1.50e-05			
	Excess Risk	7.70e-09			
	Excess Cancers		1.50e-11		
	Hazard Index			2.50e-09	
Offsite Population	Dose (person-rem)	3.40e-01			
	Excess Fatalities	1.70e-04			
	Excess Cancers		2.30e-07		
Most Exposed Offsite Individual	Dose (rem)	1.40e-05			
	Excess Risk	6.90e-09			
	Excess Cancers		4.80e-12		
	Hazard Index			2.20e-10	
Workers	Dose (FTE-rem)	1.60e+03			
	Excess Fatalities	6.30e-01			
	Excess Cancers		2.00e-05		
	Exposure Index			3.10e-05	
	Construction Fatalities				1.00e+00
	Construction Injuries				8.70e+02
	Operations Fatalities				1.70e+00
	Operations Injuries				7.50e+02

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TABLE K-3

SYSTEM-WIDE HUMAN HEALTH IMPACTS
INCINERATE AT 5 LOCATIONS
PEIS CASE 6

Receptor	Endpoint	Radionuclides	Hazardous Chemicals		Physical Hazards
			Carcinogens	Noncarcinogens	
Co-located Workers	Dose (person-rem)	6.90e+02			
	Excess Fatalities	3.40e-01			
	Excess Cancers		5.60e-08		
Most Exposed Co-located Individual	Dose (rem)	4.90e-01			
	Excess Risk	2.40e-04			
	Excess Cancers		1.50e-11		
	Hazard Index			1.30e-07	
Offsite Population	Dose (person-rem)	6.70e+03			
	Excess Fatalities	3.30e+00			
	Excess Cancers		2.20e-07		
Most Exposed Offsite Individual	Dose (rem)	1.30e-01			
	Excess Risk	6.70e-05			
	Excess Cancers		4.80e-12		
	Hazard Index			1.10e-08	
Workers	Dose (FTE-rem)	1.50e+03			
	Excess Fatalities	6.10e-01			
	Excess Cancers		2.50e-05		
	Exposure Index			8.60e-04	
	Construction Fatalities				1.80e+00
	Construction Injuries				1.50e+03
	Operations Fatalities				2.60e+00
	Operations Injuries				1.10e+03

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TABLE K-4

SYSTEM-WIDE HUMAN HEALTH IMPACTS
INCINERATE AT 1 LOCATION
PEIS CASE 9

Receptor	Endpoint	Radionuclides	Hazardous Chemicals		Physical Hazards
			Carcinogens	Noncarcinogens	
Co-located Workers	Dose (person-rem)	9.90e+01			
	Excess Fatalities	5.00e-02			
	Excess Cancers		6.60e-08		
Most Exposed Co-located Individual	Dose (rem)	3.80e-01			
	Excess Risk	1.90e-04			
	Excess Cancers		1.50e-11		
	Hazard Index			4.60e-07	
Offsite Population	Dose (person-rem)	1.20e+03			
	Excess Fatalities	6.10e-01			
	Excess Cancers		2.30e-07		
Most Exposed Offsite Individual	Dose (rem)	3.20e-01			
	Excess Risk	1.60e-04			
	Excess Cancers		4.80e-12		
	Hazard Index			7.60e-08	
Workers	Dose (FTE-rem)	1.70e+03			
	Excess Fatalities	6.80e-01			
	Excess Cancers		8.60e-05		
	Exposure Index			1.10e-03	
	Construction Fatalities				1.20e+00
	Construction Injuries				1.10e+03
	Operations Fatalities				1.80e+00
	Operations Injuries				7.90e+02

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TABLE K-5

FACILITY ACRONYMS

Department of Energy Facility	Acronym
Ames Laboratory	Ames
Argonne National Laboratory-East	ANL-E
Bettes	BT
Energy Technology Engineering Center	ETEC
Hanford	Hanford
Idaho National Engineering Laboratory	INEL
Knolls Atomic Propulsion Laboratory	KAPL
Los Alamos National Laboratory	LANL
Lawrence Berkeley Laboratory	LBL
Lawrence Livermore National Laboratory	LLNL
Mound Plant	Mound
University of Missouri at Columbia	UMC
Nevada Test Site	NTS
Oak Ridge National Laboratory	ORNL
Paducah Gaseous Diffusion Plant	PGDP
Pantex Plant	Pantex
Rocky Flats Environmental Technology Site	RFETS
Sandia National Laboratories	SNL
Savannah River Site	SRS

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TABLE K-6

PEIS RISK DATA
TREAT TO MEET WIPP WAC (CASE 4)

	Fatalities			Cancer Incidence		
Site	Public	Offsite MEI	Worker	Public	Offsite MEI	Public
ANL-E	1.80e-06	9.90e-12	1.00e-01	6.10e-06	3.40e-11	3.00e-02
Hanford	1.40e-06	2.90e-11	3.30e-01	4.80e-06	9.90e-11	3.60e-01
INEL	1.10e-06	1.40e-10	1.00e+00	3.80e-06	4.80e-10	8.70e-01
LANL	5.40e-05	5.70e-09	4.90e-01	1.80e-04	1.90e-08	5.00e-01
LBL	6.30e-09	9.40e-14	8.40e-03	2.10e-08	3.20e-13	7.60e-09
LLNL	3.50e-06	5.70e-11	1.10e-01	1.20e-05	2.00e-10	2.00e-03
Mound	8.40e-07	4.80e-11	3.20e-02	2.90e-06	1.60e-10	4.80e-04
NTS	1.10e-10	3.00e-14	6.80e-02	3.90e-10	1.00e-13	7.30e-04
ORNL	0.00e+00	0.00e+00	4.70e-04	0.00e+00	0.00e+00	7.90e-14
PGDP	3.50e-09	3.50e-09	1.30e-02	1.20e-08	1.30e-12	1.60e-06
RFETS	9.30e-06	1.30e-10	2.20e-01	3.20e-05	4.30e-10	2.70e-02
SNL	2.70e-09	1.10e-13	8.70e-03	9.10e-09	3.60e-13	2.10e-08
SRS	5.10e-05	4.80e-10	3.50e-01	1.70e-04	1.60e-09	3.10e-01

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TABLE K-7

PEIS RISK DATA
SHRED AND GROUT (CASE 5)

	Fatalities			Cancer Incidence		
Site	Public	Offsite MEI	Worker	Public	Offsite MEI	Public
ANL-E	1.50e-06	8.50e-12	4.50e-02	5.20e-06	2.90e-11	3.00e-02
Hanford	2.30e-06	4.70e-11	5.30e-01	7.70e-06	1.60e-10	4.50e-01
INEL	1.40e-06	1.80e-10	1.20e+00	4.90e-06	6.00e-10	8.70e-01
LANL	6.50e-05	6.90e-09	6.40e-01	2.20e-04	2.30e-08	5.00e-01
LBL	9.80e-09	1.50e-13	1.80e-04	3.40e-08	5.00e-13	7.50e-09
LLNL	3.60e-06	5.90e-11	5.70e-02	1.30e-05	2.10e-10	2.00e-03
Mound	1.50e-06	8.60e-11	1.40e-02	5.10e-06	2.90e-10	4.70e-04
NTS	1.50e-10	3.90e-14	4.20e-02	5.10e-10	1.30e-13	7.00e-04
ORNL						
PGDP	5.30e-09	5.90e-13	2.50e-03	1.80e-08	2.00e-12	1.70e-06
RFETS	1.50e-05	2.00e-10	3.40e-01	5.10e-05	6.90e-10	2.70e-02
SNL	3.50e-09	1.40e-13	4.50e-04	1.20e-08	4.80e-13	2.10e-08
SRS	8.10e-05	7.70e-10	4.60e-01	2.80e-04	2.60e-09	3.10e-01

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TABLE K-8

PEIS RISK DATA
INCINERATE AT 5 SITES (CASE 6)

	Fatalities			Cancer Incidence		
Site	Public	Offsite MEI	Worker	Public	Offsite MEI	Public
ANL-E	1.50e-06	8.50e-12	4.50e-02	5.20e-06	2.90e-11	3.00e-02
Hanford	4.50e-03	9.40e-08	8.10e-01	1.60e-02	3.20e-07	4.90e-01
INEL	7.30e-03	9.10e-07	1.80e+00	2.50e-02	3.10e-06	8.30e-01
LANL	6.40e-01	6.70e-05	9.60e-01	2.20e+00	2.30e-04	4.80e-01
LBL	9.80e-09	1.50e-13	1.80e-04	3.40e-08	5.00e-13	7.50e-09
LLNL	3.60e-06	5.90e-11	5.70e-02	1.30e-05	2.10e-10	2.00e-03
Mound	1.50e-06	8.60e-11	1.40e-02	5.10e-06	2.90e-10	4.70e-04
NTS	1.50e-10	3.90e-14	4.20e-02	5.10e-10	1.30e-13	7.00e-04
ORNL						
PGDP	5.30e-09	5.90e-13	2.50e-03	1.80e-08	2.00e-12	1.70e-06
RFETS	1.10e-01	1.50e-06	5.70e-01	3.70e-01	5.00e-06	2.50e-02
SNL	3.50e-09	1.40e-13	4.50e-04	1.20e-08	4.80e-13	2.10e-08
SRS	2.60e+00	2.40e-05	6.80e-01	8.80e+00	8.20e-05	3.00e-01

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TABLE K-9

PEIS RISK DATA
INCINERATE AT 1 SITE (CASE 9)

	Fatalities			Cancer Incidence		
Site	Public	Offsite MEI	Worker	Public	Offsite MEI	Public
ANL-E	1.50e-06	8.50e-12	4.50e-02	5.20e-06	2.90e-11	3.00e-02
Hanford	1.30e-06	2.70e-11	2.40e-01	4.40e-06	9.10e-11	3.30e-01
INEL	1.60e-06	2.00e-10	7.60e-01	5.30e-06	6.60e-10	8.50e-01
LANL	7.10e-05	7.40e-09	3.80e-01	2.40e-04	2.50e-08	5.00e-01
LBL	9.80e-09	1.50e-13	1.80e-04	3.40e-08	5.00e-13	7.50e-09
LLNL	3.60e-06	5.90e-11	5.70e-02	1.30e-05	2.10e-10	2.00e-03
Mound	1.50e-06	8.60e-11	1.40e-02	5.10e-06	2.90e-10	4.70e-04
NTS	1.50e-10	3.90e-14	4.20e-02	5.10e-10	1.30e-13	7.00e-04
ORNL						
PGDP	5.30e-09	5.90e-13	2.50e-03	1.80e-08	2.00e-12	1.70e-06
RFETS	1.20e-05	1.60e-10	1.60e-01	4.10e-05	5.60e-10	1.00e-01
SNL	3.50e-09	1.40e-13	4.50e-04	1.20e-08	4.80e-13	2.10e-08
SRS	6.40e-05	6.00e-10	2.20e-01	2.20e-04	2.00e-09	3.30e-01

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TABLE K-10

PEIS TRANSURANIC WASTE VOLUMES
TOTAL WASTE IN STORAGE AND GENERATED OVER 20 YEARS

Site	Stored Waste (cubic meters)	Annual Generation (cubic meters / year)	Total (cubic meters)
ANL-E	15.00	47.00	955.00
Hanford	9987.00	465.00	19287.00
INEL	38095.00	14.00	38375.00
LANL	8199.00	125.00	10699.00
LBL	0.80	0.01	1.00
LLNL	200.00	74.00	1680.00
Mound	255.00	60.00	1455.00
NTS	612.00	0.00	612.00
ORNL	670.00	18.00	1030.00
PGDP	14.00	0.00	14.00
RFETS	1480.00	238.00	6240.00
SNL	1.00	0.00	1.00
SRS	5371.00	605.00	17471.00
UMC	0.10	2.00	40.10
Total	64899.90	1648.01	97860.10

releases, the impacts at individual sites may be modeled as a function of waste throughput.

Therefore, the modeling is performed for each process at each site and the impacts combined to establish a combined impact for all facilities.

Waste throughput at each site may vary for three reasons. One reason is that the total amount of waste processed in the PEIS would not be the amount needed to fill WIPP to capacity. The second reason is that more recent estimates of waste currently stored at sites or likely to be generated at sites have a different distribution throughout the DOE system than were used in the PEIS calculations. Thirdly, as the consolidation configuration changes, the throughput at individual sites varies from that used in the PEIS. For example, the PEIS Case 5 involves transporting waste from throughout the system to five selected sites where it is processed by shredding and grouting the waste. More recent data on waste volumes and estimated generation make the amounts to be treated at each of the five selected sites different in this model from the PEIS model. The EA model must also assume a greater total waste, distributed among the five sites, to meet WIPP's design limit. Finally, this model must also estimate the impact of the shredding and grouting of waste at 10 selected sites and a single site.

The first two volume effects are treated simultaneously by comparing the waste to be handled at each site in the PEIS, without regard to what process is to be performed, to that estimated to be handled in the EA model. The latter data were determined as part of the estimation of cost and schedule and are explained in Section 3.7.2.1 of the report. The EA scaled waste totals are shown in Table K-11. A linear scaling factor was determined for each site by dividing the EA scaled throughput for each site by the PEIS throughput for that site.

The volume effect from consolidating waste at various sites was performed in an analogous way for each consolidation configuration. For each site where waste is to be consolidated, the sum of waste from all sites contributing to that site was determined. Table K-12 shows the consolidation configurations used. This was done based on both the PEIS waste total for each site and the EA waste total. Scaling factors for each consolidation configuration were developed by dividing the total EA throughput by the PEIS throughput for the same combination of sites. For example, in the distributed configuration, where waste processing is performed at 10 sites, Hanford processes only it's own waste. Therefore, the volume scaling factor for Hanford in the distributed configuration (10 sites) is

$$\begin{aligned} \textit{Scaling Factor}_{\textit{Hanford, 10 site}} &= \frac{\textit{EA Throughput}_{\textit{Hanford}}}{\textit{PEIS Throughput}_{\textit{Hanford}}} \\ &= \frac{48044.55}{19287.00} \\ &= 2.49 \end{aligned}$$

In the regional (five site) configuration, the wastes from Lawrence Berkeley Laboratory (LBL) and Lawrence Livermore National Laboratory (LLNL) are shipped to Hanford for treatment. The scaling factor for Hanford in the regional configuration (five sites) is

These scaling factors are then used to estimate corrections to the PEIS risk data by multiplying the appropriate PEIS risk factor for the Hanford site by the desired scaling factor. See

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TABLE K-11

ENGINEERED ALTERNATIVES SCALED TOTAL WASTE VOLUMES TOTAL WASTE IN STORAGE AND GENERATED OVER 20 YEARS

Site	Total Waste (cubic meters)
Ames	0.13
ANL-E	31.31
BT	159.90
ETEC	8.61
Hanford	48044.55
INEL	39203.61
KAPL	2.40
LANL	20805.18
LBL	6.57
LLNL	1158.04
Mound	263.29
UMC	2.14
NTS	612.60
ORNL	1124.94
PGDP	2.10
Pantex	0.62
RFETS	6249.25
SNL	17.11
SRS	26653.39
Total	144345.73

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TABLE K-12

WIPP ENGINEERED ALTERNATIVES HUMAN HEALTH IMPACTS TRU WASTE CONSOLIDATION CONFIGURATIONS

Consolidation Configuration	Processing Site	Sites Supplying Waste
Distributed (10 sites)	ANL-E	Ames, ANL-E, UMC
	Hanford	Hanford
	INEL	INEL
	LANL	LANL, Pantex, SNL
	LLNL	LBL, LLNL
	Mound	BT, KAPL, Mound, WVDP
	NTS	ETEC, NTS
	ORNL	ORNL, Paducah
	RFETS	RFETS
	SRS	SRS
Regional (5 Sites)	Hanford	Hanford, LBL, LLNL
	INEL	ETEC, INEL, NTS
	LANL	LANL, Pantex, SNL
	RFETS	RFETS
	SRS	Ames, ANL-E, BT, KAPL, Mound, MU, ORNL, Paducah, SRS, WVDP
Centralized (1 Site)	WIPP	All sites

$$Scaling\ Factor_{Hanford,\ 5\ site} = \frac{EA\ Throughput_{Hanford+LBL+LLNL}}{PEIS\ Throughput_{Hanford+LBL+LLNL}} = \frac{48044.55+6.57+1158.04}{19287.00+1.00+1680.00} = 2.35$$

Section 5.0 of this appendix for a more extended explanation of the use of the scaling factors.

5.0 SCALING FACTORS FOR WASTE HANDLING WORKERS

The primary influences on the impacts to workers are materials released to the working environment, especially the air, and external exposures from radioactive material, especially from waste and processing equipment. Exposures from these sources are more a function of the time spent in the work area than the amount of material processed. The amount of work time is expressed in FTEs. The number of injuries and fatalities from physical hazards are also a function of the FTEs. FTEs are a function of waste throughput, but because of volume efficiencies and other factors, the function is not linear with respect to waste throughput. Therefore, scaling factors for adjusting the PEIS risk data for workers are based on variations in the total number of FTEs projected for the 20-year processing facility lifetime.

The PEIS analysis used selections of individual process modules (waste receiving and inspection, waste compaction, incineration, etc.) to model different types of waste process streams. Curves of FTEs as a function of waste throughput were developed to model each module (Feizollahi and Shropshire, 1994). For each type of module, curves have been plotted for construction, preoperational activities, 10- and 20-year operations and maintenance (O&M), decontamination and decommissioning (D&D), and 10- and 20-year total FTEs. Polynomial equations were developed to fit each of the curves. Table K-13 shows an example of the curves and curve equations.

Two of the components of the greatest importance in estimating worker impacts are the 20-year O&M total FTEs and the construction FTEs. The O&M activities are not only the major contributor to the total FTEs, but it is during O&M activities that most worker exposures are expected to occur. Construction activities are of particular importance because they involve a large number of FTEs and often represent a time of increased risks from physical hazards. Equations were used to calculated O&M and construction FTEs for the following modules: waste retrieval, receipt and inspection, waste characterization, waste compaction, shred and grout, incineration, vitrification, and certification and shipping. Table K-14 lists the equations developed for each of the modules. The equations were used to calculate the total FTEs required for each type of module at each site for each consolidation configuration based on the throughputs used in the PEIS. Because the PEIS throughputs were given in cubic meters, the conversion to kilograms per hour (kg/hr) was made based on 20 years of operation, 4,032 hours per year, and an average waste density of 594 kg/cubic meter. Similar calculations were also performed based on the mass-flows representing the EA volumes shown in Table K-11.

TABLE K-13

FULL TIME EQUIVALENTS (FTES) AS A FUNCTION OF WASTE THROUGHPUT
WASTE RECEIPT AND INSPECTION

TABLE K-14

MODELING
FULL TIME EQUIVALENTS AS A FUNCTION OF WASTE THROUGHPUT (KG/HR)

Waste Handling Module	Construction Curve Fit Equation	O&M Curve Fit Equation
Retrieval	1.79e-0x + 10.1	3.64x + 181.37
Receipt and Inspection	$-3.3e\text{-}6x^2 + 4.68e\text{-}2x + 9.37$	$4.50e\text{-}9x^3 - 6.00e\text{-}5x^2 + 3.45e\text{-}1x + 16.27$
Waste Characterization	4.78x + 156.89	9.56x + 313.77
Compaction	1.13e-1x +170.18	$1.70e\text{-}7x^3 - 6.70e\text{-}4x^2 + 1.20x + 491.7$
Shred and Grout	$-3.9e\text{-}5x^2 + 1.85e\text{-}1x + 214.4$	$9.1e\text{-}8x^3 - 3.80e\text{-}4x^2 + 6.13e\text{-}1x + 264.4$
Incineration	3.14e-1x + 275	1.09x + 767.2
Vitrification	$-3.5e\text{-}8x^4 + 4.1e\text{-}5x^3 - 0.0173x^2 + 3.582x + 480.1$	$1.61e\text{-}3x^2 + 2.95x + 937$
Certification and Shipping	1.22e-2x + 45.752	1.02e-1x + 298.61

System-wide FTE scaling factors were calculated for each alternative case and configuration. The methods used to calculate the scaling factor were the same for each case and configuration but the details of what combination of modules and waste throughputs were used were different for each case and configuration. The following paragraphs describe the common method used. Details are presented in tabular form. All calculations were performed for both construction and O&M scaling factors. Only one set of calculations will be described. The only difference between the calculations for construction and O&M scaling factors is the values for the individual FTE totals, the initial database.

For each PEIS case, modules were selected that would be used in the particular waste process. Table K-15 lists the modules used for each PEIS case. It was assumed that the process of shipping waste to another site for treatment, including the necessary inspections, is numerically equivalent in FTEs and exposures to the receipt and inspection of incoming waste at a processing facility. For each PEIS case, the total FTEs were calculated for each site by summing the FTEs from the individual modules. FTE site totals were calculated for each waste processing used in the alternatives in the same way as the PEIS totals. Table K-15 shows which modules were used in each EA waste processing.

Site FTE scaling factors were calculated for each EA waste process and each consolidation configuration. Whenever possible, the site FTE total for the EA waste process was divided by the site FTE total from the equivalent PEIS case. However, there are more combinations of EA waste processes and consolidation configurations than there are PEIS cases that are equivalent. In these cases, the ratio was formed between EA and PEIS cases that involved different consolidation configurations or between two EA alternatives, one of which was established by comparing it to an equivalent PEIS case. Table K-16 lists the combinations of cases used to assess each alternative and consolidation configuration.

It should be noted that not all modules apply to each site in a particular PEIS case or EA alternative; nor are the EA and PEIS sets of modules necessarily the same. Each site must be considered individually in each waste processing and configuration combination. As an example of how modules were combined, Table K-17 displays the module combinations used to establish the FTE scaling factor for plasma processing at 10 sites by comparing FTEs for EA modules at 10 sites with the PEIS modules at 5 sites.

As described in Section 5.0, the site-specific scaling factors were used to adjust the PEIS-based worker risk estimates.

6.0 SYSTEM-WIDE SCALING FACTORS

6.1 Volume-based Scaling Factors

In order to extend the PEIS system-wide risk estimates, as shown in Tables K-1 through K-4, to additional consolidation configurations and processes, the analysis model must provide system-wide scaling factors. These were developed by comparing the total of the PEIS site risk results with the totals of the scaled site-specific data. The effect is to produce a weighted average of the individual site scaling factor for co-located worker/off-site personnel risks and for worker risks for each waste process and consolidation configuration. As an example, Table K-18 shows the

TABLE K-15

TRU WASTE HANDLING MODULES USED TO MODEL WASTE PROCESSING PEIS CASES AND ENGINEERED ALTERNATIVES

	RETRV[1]	INSHP[2]	RCINS[3]	GROUT[4]	CSHIP[5]	CMPCT[6]	INCIN[7]	WCHA[8]	VITRFY[9]
PEIS									
Treat to Meet WIPP WAC	●				●			●	
Shred and Grout	●	●	●	●	●				
Incinerate	●	●	●		●		●		
Engineered Alternatives									
Baseline	●				●			●	
Shred and Grout	●	●	●	●	●				
Incinerate	●	●	●		●				●
Supercompaction	●	●	●		●	●			

[1]Waste Retrieval
[2]Waste Inspection and Shipping (Numerically identical to Waste Receipt and Inspection)
[3]Waste Receipt and Inspection
[4]Shred and Grout
[5]Certification and Shipping
[6]Compaction
[7]Incineration
[8]Waste Characterization
[9]Vitrification

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TABLE K-16

TRU WASTE FULL-TIME EQUIVALENT SCALING FACTORS CASES USED FOR EACH WASTE PROCESS AND CONSOLIDATION CONFIGURATION

Treatment Process	Configuration	FTE Modules for Base Numbers	FTE Modules for Scaled Numbers
Baseline	10 sites	PEIS Case 4	EA Scaled for all sites
Supercompaction	10 sites	Scaled Shred & Grout at 10 sites	Scaled Supercompaction at 10 sites
Supercompaction	5 sites	Scaled Shred & Grout at 5 sites	Scaled Supercompaction at 5 sites
Supercompaction	1 site	Scaled Shred & Grout at 1 site	Scaled Supercompaction at 1 site
Shred and Compact	10 sites	Scaled Shred & Grout at 5 sites	Scaled Shred & Grout at 10 sites
Shred and Compact	5 sites	PEIS Shred & Grout at 5 sites	Scaled Shred & Grout at 5 sites
Shred and Compact	1 site	Scaled Shred & Grout at 5 sites	Scaled Shred & Grout at 1 site
Plasma Processing	10 sites	PEIS Vitrify at 5 sites	Scaled Vitrify at 10 sites
Plasma Processing	5 sites	PEIS Incinerate at 5 sites	Scaled up Vitrify at 5 sites
Plasma Processing	1 site	PEIS Incinerate at 1 site	Scaled up Vitrify at 1 site
Shred and Add Clay	10 sites	Scaled Shred & Grout at 5 sites	Scaled Shred & Grout at 10 sites
Shred and Add Clay	5 sites	PEIS Shred & Grout at 5 sites	Scaled Shred & Grout at 5 sites
Shred and Add Clay	1 site	Scaled Shred & Grout at 5 sites	Scaled Shred & Grout at 1 site

TABLE K-17

TRU WASTE HANDLING MODULES USED TO MODEL WASTE PROCESSING INCINERATION AT 10 SITES COMPARED TO PEIS INCINERATION AT 5 SITES

	PEIS Incineration at 5 Sites					Engineered Alternatives Incineration at 10 Sites				
Location[1]	RETRV[2]	INSHP[3]	RCINS[4]	VITRFY[5]	CSHIP[6]	RETRV	INSHP	RCINS	VITRFY	CSHIP
ANL-E	•	•				•		•	•	•
Hanford	•		•	•	•	•		•	•	•
INEL	•		•	•	•	•		•	•	•
LANL	•		•	•	•	•		•	•	•
LBL	•	•				•	•			
LLNL	•	•				•		•	•	•
Mound	•	•				•		•	•	•
NTS	•	•				•		•	•	•
ORNL	•	•				•		•	•	•
PGDP	•	•				•	•			
RFETS	•		•	•	•	•		•	•	•
SNL	•	•				•	•			
SRS	•		•	•	•	•		•	•	•

[1]See Table XX-5
[2]Waste Retrieval
[3]Waste Inspection and Shipping
[4]Waste Receipt and Inspection
[5]Vitrification
[6]Certification and Shipping

TABLE K-18

ENGINEERED ALTERNATIVES HUMAN HEALTH IMPACTS
CALCULATION OF SYSTEM-WIDE SCALING FACTORS FOR BASELINE

	PEIS Risk Value						Volume Scaling Factor	FTE Scaling Factor	Scaled Risk Value					
	Fatalities			Cancer Incidence					Fatalities			Cancer Incidence		
Location	Public	Offsite MEI	Worker	Public	Offsite MEI	Worker			Public	Offsite MEI	Worker	Public	Offsite MEI	Worker
ANL-E	1.80e-06	9.90e-12	1.00e-01	6.10e-06	3.40e-11	3.00e-02	0.03	0.89	5.90e-08	3.25e-13	8.89e-02	2.00e-07	1.11e-12	2.67e-02
Hanford	1.40e-06	2.90e-11	3.30e-01	4.80e-06	9.90e-11	3.60e-01	2.49	1.97	3.49e-06	7.22e-11	6.49e-01	1.20e-05	2.47e-10	7.08e-01
INEL	1.10e-06	1.40e-10	1.00e+00	3.80e-06	4.80e-10	8.70e-01	1.02	1.02	1.12e-06	1.43e-10	1.02e+00	3.88e-06	4.90e-10	8.85e-01
LANL	5.40e-05	5.70e-09	4.90e-01	1.80e-04	1.90e-08	5.00e-01	1.94	1.48	1.05e-04	1.11e-08	7.25e-01	3.50e-04	3.69e-08	7.40e-01
LBL	6.30e-09	9.40e-14	8.40e-03	2.10e-08	3.20e-13	7.60e-09	6.57	1.00	4.14e-08	6.17e-13	8.41e-03	1.38e-07	2.10e-12	7.61e-09
LLNL	3.50e-06	5.70e-11	1.10e-01	1.20e-05	2.00e-10	2.00e-03	0.69	0.96	2.41e-06	3.93e-11	1.06e-01	8.27e-06	1.38e-10	1.93e-03
Mound	8.40e-07	4.80e-11	3.20e-02	2.90e-06	1.60e-10	4.80e-04	0.18	0.88	1.52e-07	8.69e-12	2.83e-02	5.25e-07	2.90e-11	4.24e-04
NTS	1.10e-10	3.00e-14	6.80e-02	3.90e-10	1.00e-13	7.30e-04	1.00	1.00	1.10e-10	3.00e-14	6.80e-02	3.90e-10	1.00e-13	7.30e-04
ORNL	0.00e0	0.00e0	4.70e-04	0.00e0	0.00e0	7.90e-14	1.09	1.01	0.00e0	0.00e0	4.76e-04	0.00e0	0.00e0	7.99e-14
PGDP	3.50e-09	3.50e-09	1.30e-02	1.20e-08	1.30e-12	1.60e-06	0.15	1.00	5.25e-10	5.25e-10	1.30e-02	1.80e-09	1.95e-13	1.60e-06
RFETS	9.30e-06	1.30e-10	2.20e-01	3.20e-05	4.30e-10	2.70e-02	1.00	1.00	9.31e-06	1.30e-10	2.20e-01	3.20e-05	4.31e-10	2.70e-02
SNL	2.70e-09	1.10e-13	8.70e-03	9.10e-09	3.60e-13	2.10e-08	17.11	1.00	4.62e-08	1.88e-12	8.72e-03	1.56e-07	6.16e-12	2.10e-08
SRS	5.10e-05	4.80e-10	3.50e-01	1.70e-04	1.60e-09	3.10e-01	1.53	1.38	7.78e-05	7.32e-10	4.83e-01	2.59e-04	2.44e-09	4.27e-01
Total	1.23e-04		2.73e+00	4.12e-04		2.10e+00			1.99e-04		3.42e+00	6.67e-04		2.82e+00
Maximum										1.11e-08			3.69e-08	
System-Wide Scaling Factor									1.62		1.25	1.62		1.34

calculation of the effective scaling factors for the Baseline. The PEIS values are those from PEIS Case 4 (also shown on Table K-6). The Volume Scaling Factor column is made up of the site-specific scaling factors for the Baseline calculated as described in Section 3.0. The FTE Scaling Factors are those calculated for the Baseline as described in Section 4.0. The Scaled Risk Values for the public and off-site maximum exposed individual (MEI) are calculated by multiplying the equivalent PEIS risk value by the appropriate Volume Scaling Factor. The Scaled Risk Values for the workers are calculated by multiplying the equivalent PEIS worker risk values by the appropriate FTE Scaling Factor. The System-Wide Scaling Factor is calculated for the public and worker risk values by dividing the total Scaled Risk Value for all sites by the total PEIS Risk Value summed over all sites. A weighted average risk value is not meaningful for the off-site MEI. Instead, the site with the maximum value for the scaled risk is reported as the off-site MEI risk.

In addition to the Baseline, three other waste processing alternatives have PEIS equivalents and use the same calculation method: Shred and Grout at five sites, Incineration at five sites, and Incineration at one site.

6.2 Supercompaction Scaling Factors

The system-wide scaling factors for the three consolidation configurations for supercompaction are calculated using a single technique. Because supercompaction does not add to the airborne releases, the public and off-site MEI risk numbers are the same as for the respective configurations of Shred and Grout. The worker risk estimates are calculated using the following formulas:

$$\textit{Worker cancers} = \textit{shred \& grout worker cancers} + (\textit{Cancer Risk Factor} \times \textit{supercompactor FTEs})$$
$$\textit{Worker fatalities} = \textit{shred \& grout worker fatalities} + (\textit{Fatality Risk Factor} \times \textit{supercompactor FTEs})$$

where

$$\textit{Cancer Risk Factor} = \textit{SARF doses} \times \frac{\textit{ICRP Cancer Risk Coefficent}}{\textit{SARF FTEs}}$$
$$\textit{Fatality Risk Factor} = \textit{SARF doses} \times \frac{\textit{ICRP Fatality Risk Coefficent}}{\textit{SARF FTEs}}$$

and

$$\textit{ICRP Cancer Risk Coefficient} = 8.00 \times 10^{-5}$$
$$\textit{ICRP Fatality Risk Coefficient} = 4.00 \times 10^{-4} \quad \text{(ICRP,1990)}$$

The supercompactor FTEs are calculated as described in Section 4.0. Supercompaction and Repackaing Facility doses and FTEs are taken from the environmental assessment of the supercompactor at the Rocky Flats Environmental Technology Site (DOE, 1990a).

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6.3 Scaling Factors for Significant Configuration Cases

Three of the consolidation configurations did not parallel PEIS configurations: Shred and Grout at 10 sites, Shred and Grout at 1 site, and Incineration at 10 sites. In these circumstances, the calculation of each site was analyzed separately and the sum of the risk factors for all sites was used to calculate the system-wide scaling factors. The calculation methods for each site could be classed as one of four types of formulas.

6.3.1 Site Actions Unchanged from Other Cases

Five sites (LANL, LBL, PGDP, RFETS, and SNL) do not change activities between regional consolidation (5 sites) and distributed (10 sites). In these circumstances, all the risk values remain the same so data used in the regional configuration was used in the distributed configuration.

6.3.2 Site Actions Involve Only Retrieval and Shipping

With the exception of the WIPP, all sites in the Shred and Grout at one site perform exactly the same activities as they do for incinerate at one site, PEIS Case 9. Because the activities and volumes involved are the same, all non-WIPP risk values are the same in Shred and Grout at one site and Incinerate at one site.

6.3.3 Waste Volume Adjustments

Five of the processing sites in the distributed (10 site) configuration are also processing sites in the regional (5 site) configuration. These five sites perform the same activities and have the same facilities. Only the volume processed is changed. The risk values for these five sites were calculated by applying the correct scaling factors in the same manner as described in Section 5.1 except that the scaled regional risk values (which are based on PEIS values) are used in place of the PEIS values.

6.3.4 Process Ratio Adjustments

The remaining sites in these three configurations are designated as waste processing sites for a particular process in the EA but not in the PEIS. Because FTE curves were available for the necessary processes and worker impacts are not dependant on site characteristics like the public or co-located worker impacts, the FTE Scale Factor was calculated and applied as described in Section 5.3.3. To permit estimation of the public and co-located worker risk values, the concept of process ratio was introduced.

For any given site, the impact on the public and co-located workers was modeled at a function of the total releases from the facility. The risks values are modeled as a function of the process and the throughput. That is,

$$Risk_{process,\,throughput}$$

If the Risk Rate is defined as the risk value divided by the throughput:

$$\frac{Risk_{process,\ throughput}}{throughput} = Risk\ Rate_{process}$$

For two selected processes (p1 and p2), the ratio of the Risk Rates, called the process ratio, is a constant:

$$\frac{Risk\ Rate_{p1}}{Risk\ Rate_{p2}} = K_{p1,p2}$$

Process p1 was chosen to have PEIS data for all sites, such as preparation for shipment to WIPP from PEIS Case 9. Process p2, for which PEIS data did not exist for the sites of interest, was known for other sites. $K_{p1,p2}$ was calculated for one or more sites for which the risks for both p1 and p2 were represented in the PEIS. Then the unknown risk value was calculated as:

$$Risk_{p1} = k_{p1,p2} \times Risk\ Rate_{p2} \times throughput$$

Using the scaled throughputs, risk values for the remaining sites may be calculated, allowing the summing of risk values for all sites and calculation of the system-wide scaling factor as described previously.

7.0 WASTE HANDLING, EMPLACEMENT, AND BACKFILL

Modeling for waste handling and emplacement was performed separately from the modeling for backfill activities. The total impacts were calculated as the sum of the two models.

7.1 Waste Handling and Emplacement

As described in Section 3.3.2.2 of the report, radiation doses for emplacement are modeled as being the same for all emplacement alternatives and waste forms because the amount of radioactivity is unchanged. While some waste forms may decrease the dose rate from the package, the increased handling time for those heavier waste forms offsets the decrease in dose rate. Chemical and radioactive material releases are modeled as being linear with waste volume handled. All risk values for released material are compared to those given in the Final Supplement Environmental Impact Statement Waste Isolation Pilot Plant (DOE, 1990b) using the following formula:

$$Case\ risk\ value = FEIS\ risk\ value \times \frac{case\ waste\ volume}{FEIS\ waste\ volume}$$

Case waste volumes were taken from the summary of waste inventories.

Doses are converted to risk estimates using the dose conversion factors from the 1990 Recommendations of the International Commission of Radiological Protection (ICRP,1990):

Doses to the public: 5.00×10^{-4} cancer fatalities per rem
Doses to worker: 4.00×10^{-4} cancer fatalities per rem

Injuries and fatalities from industrial accidents were calculated based on the number of FTEs expected to be working multiplied by the appropriate incident rate (IR). The total FTEs were calculated from the following formula:

$$\textit{Total FTEs} = \textit{Daily FTEs} \times \textit{activity hours/shift} \times \textit{days per year} \times \textit{WIPP operational lifetime}$$

Table K-19 shows the daily FTEs estimated for aboveground waste handling, emplacement, and backfill activities for each of the EAs. The number of FTEs per shift was provided by WIPP personnel.

As explained in Section 3.3.3.7 of the report, the IR for underground work was taken from industry data for salt mine operation (USDL, 1978–1993) adjusted for types of accidents that were judged not likely to be applicable to WIPP. Because of a lack of applicable data for aboveground IR data, it was assumed that waste handling above ground would have half the mining IR. The following formula was used to calculate the injury and accident risks for the 35-year lifetime of the WIPP:

$$\textit{Accident Impact} = \frac{\textit{Total FTEs}}{200000} \times \textit{IR} \times \textit{Effective Fraction}$$

where:

IR (injuries, waste handling) = 2.3603
IR (injuries, underground) = 4.7206
Effective Fraction (injuries) = 0.805
IR (fatalities, waste handling) = 0.02059
IR (fatalities, underground) = 0.04118
Effective Fraction (fatalities) = 0.275

Effective Fraction is the fraction of salt mining industry average incident rates that are likely to occur at the WIPP. It excludes incidents involving falls of the roof, face, or sides of panels; explosives handling; fires; and explosions (D'Appolonia, 1976). The formula includes the divisor of 200,000 because the data from which the IR values were taken are based on incidents per 200,000 person-hours worked.

7.2 Backfill Operations

Backfill operations only impact workers. The calculation of injuries and fatalities from physical hazards was calculated the same way as for emplacement activities. No chemical risks are calculated because it is assumed that all leakage from waste containers was addressed during waste handling and emplacement activities and no further leakage routinely occurs. Radiation doses from working around the emplaced waste during backfill operations was modeled using the

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TABLE K-19

WASTE HANDLING, EMPLACEMENT, AND BACKFILL ACTIVITIES NUMBER OF FULL-TIME EQUIVALENTS PER DAY REQUIRED

		Full-Time Equivalents per Shift to accomplish the task		
Identifier	Case Description	Waste Handling	Emplacement	Backfill
0	Baseline	44	20	0
1	Compact Waste	33	18	0
6	Shred and Compact	33	18	0
10	Plasma Processing	32	10	0
33	Salt + Clay backfill	44	20	15
35(a)	Salt Aggregate Grout	44	20	23
35(b)	Cementitious Grout	44	20	23
111	Clay-based backfill	44	20	13
77(a)	Supercompact, salt aggregate	33	18	10
77(b)	Supercompact, clay based	33	18	9
77(c)	Supercompact, clay/sand	33	18	11
77(d)	Supercompact, CaO backfill	33	18	8
83	CaO Backfill	44	20	11
94(a)	Shred & add clay	44	20	0
94(b)	Shred & add clay, clay/sand	44	20	16
94(c)	Shred & add clay, cementitious	44	20	29
94(d)	Shred & add clay, salt aggregate	44	20	14
94(e)	Shred & add clay, clay based	44	20	13
94(f)	Shred & add clay, CaO backfill	44	20	11

same dose rate as emplacement. The radiation doses were calculated using the following formula:

$$\textit{Backfill Impact} = \textit{Emplacement Impact} \times \frac{\textit{backfill total FTEs}}{\textit{emplacement total FTEs}}$$

The impacts from backfill operations were added to those from waste handling and emplacement for the totals shown in the report.

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APPENDIX L
TRANSPORTATION RISK ANALYSIS

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TRANSPORTATION RISK

Tables L-1 through L-29 provide the detailed analysis results for Factor 5. Factor 5 evaluates human health impacts associated with the transportation of contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste to the Waste Isolation Pilot Plant (WIPP). Impacts are presented for the baseline and engineered alternative/configuration combinations on a per-shipment and cumulative WIPP lifetime basis. The analysis methodology, results overview, and conclusions are presented in Section 3.5.

TABLE L-1

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE BASELINE

Waste Origin Site	To Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	1.06×10^{-01}	6.36×10^{-01}	5.45×10^{-07}	1.78×10^{-03}
INEL	WIPP	8.81×10^{-03}	5.27×10^{-02}	5.86×10^{-08}	5.97×10^{-04}
LANL	WIPP	1.01×10^{-03}	6.14×10^{-03}	2.81×10^{-08}	6.54×10^{-04}
RFETS	WIPP	6.03×10^{-05}	3.53×10^{-04}	7.61×10^{-10}	4.09×10^{-03}
SRS	WIPP	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	2.13×10^{-02}
Small CH-TRU Waste Sites					
AMES	ANL-E	2.35×10^{-03}	1.37×10^{-02}	5.86×10^{-08}	1.66×10^{-04}
	WIPP	9.75×10^{-03}	5.64×10^{-02}	5.86×10^{-08}	8.44×10^{-04}
ANL-E	WIPP	9.75×10^{-05}	5.64×10^{-04}	5.86×10^{-10}	4.75×10^{-04}
BETTIS	MOUND	2.69×10^{-03}	1.33×10^{-02}	5.86×10^{-08}	6.14×10^{-04}
	WIPP	1.06×10^{-02}	6.10×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
ETEC	NTS	1.78×10^{-02}	9.27×10^{-02}	3.28×10^{-07}	4.02×10^{-04}
	WIPP	4.17×10^{-02}	2.55×10^{-01}	3.28×10^{-07}	2.08×10^{-04}
KAPL	MOUND	6.17×10^{-03}	3.08×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
	WIPP	1.06×10^{-02}	6.10×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
LBL	LLNL	9.84×10^{-06}	4.30×10^{-05}	5.86×10^{-10}	2.57×10^{-05}
	WIPP	9.54×10^{-05}	5.61×10^{-04}	5.86×10^{-10}	6.05×10^{-05}
LLNL	WIPP	9.54×10^{-05}	5.61×10^{-04}	5.86×10^{-10}	5.22×10^{-04}
MOUND	WIPP	1.06×10^{-04}	6.10×10^{-04}	5.86×10^{-10}	2.44×10^{-02}
MU	ANL-E	2.94×10^{-05}	1.61×10^{-04}	5.86×10^{-10}	9.30×10^{-05}
	WIPP	9.75×10^{-05}	5.64×10^{-04}	5.86×10^{-10}	1.90×10^{-04}
NTS	WIPP	7.45×10^{-03}	4.54×10^{-02}	5.86×10^{-08}	7.24×10^{-04}
ORNL	WIPP	1.32×10^{-01}	7.38×10^{-01}	1.26×10^{-05}	1.60×10^{-03}
PADUCAH	ORNL	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	1.01×10^{-04}	5.88×10^{-04}	5.86×10^{-10}	6.99×10^{-03}

TABLE L-1 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE BASELINE

Waste Origin Site	To Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PANTEX	LANL	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	2.10×10^{-05}	1.28×10^{-04}	5.86×10^{-10}	3.45×10^{-06}
SNL	LANL	7.74×10^{-06}	4.27×10^{-05}	5.86×10^{-10}	4.36×10^{-07}
	WIPP	2.10×10^{-05}	1.28×10^{-04}	5.86×10^{-10}	4.27×10^{-07}

TABLE L-2

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY BASELINE

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$6.05x10^{+02}$	$3.63x10^{+03}$	$3.11x10^{-03}$	$1.02x10^{+01}$
INEL	WIPP	4974	$4.38x10^{+01}$	$2.62x10^{+02}$	$2.91x10^{-04}$	$2.97x10^{+00}$
LANL	WIPP	2835	$2.86x10^{+00}$	$1.74x10^{+01}$	$7.97x10^{-05}$	$1.85x10^{+00}$
RFETS	WIPP	931	$5.61x10^{-02}$	$3.29x10^{-01}$	$7.08x10^{-07}$	$3.81x10^{+00}$
SRS	WIPP	2827	$3.05x10^{-01}$	$1.71x10^{+00}$	$1.66x10^{-06}$	$6.02x10^{+01}$
		Subtotal	**$6.52x10^{+02}$**	**$3.91x10^{+03}$**	**$3.48x10^{-03}$**	**$7.90x10^{+01}$**
Small CH-TRU Waste Sites						
AMES	ANL-E	1	$2.35x10^{-03}$	$1.37x10^{-02}$	$5.86x10^{-08}$	$1.66x10^{-04}$
	WIPP	1	$9.75x10^{-03}$	$5.64x10^{-02}$	$5.86x10^{-08}$	$8.44x10^{-04}$
ANL-E	WIPP	5	$4.88x10^{-04}$	$2.82x10^{-03}$	$2.93x10^{-09}$	$2.38x10^{-03}$
BETTIS	MOUND	17	$4.57x10^{-02}$	$2.26x10^{-01}$	$9.96x10^{-07}$	$1.04x10^{-02}$
	WIPP	17	$1.80x10^{-01}$	$1.04x10^{+00}$	$9.96x10^{-07}$	$1.80x10^{-02}$
ETEC	NTS	2	$3.56x10^{-02}$	$1.85x10^{-01}$	$6.56x10^{-07}$	$8.04x10^{-04}$
	WIPP	2	$8.34x10^{-02}$	$5.10x10^{-01}$	$6.56x10^{-07}$	$4.16x10^{-04}$
KAPL	MOUND	1	$6.17x10^{-03}$	$3.08x10^{-02}$	$5.86x10^{-08}$	$1.06x10^{-03}$
	WIPP	1	$1.06x10^{-02}$	$6.10x10^{-02}$	$5.86x10^{-08}$	$1.06x10^{-03}$
LBL	LLNL	1	$9.84x10^{-06}$	$4.30x10^{-05}$	$5.86x10^{-10}$	$2.57x10^{-05}$
	WIPP	1	$9.54x10^{-05}$	$5.61x10^{-04}$	$5.86x10^{-10}$	$6.05x10^{-05}$
LLNL	WIPP	136	$1.30x10^{-02}$	$7.63x10^{-02}$	$7.97x10^{-08}$	$7.10x10^{-02}$
MOUND	WIPP	29	$3.07x10^{-03}$	$1.77x10^{-02}$	$1.70x10^{-08}$	$7.08x10^{-01}$
MU	ANL-E	1	$2.94x10^{-05}$	$1.61x10^{-04}$	$5.86x10^{-10}$	$9.30x10^{-05}$
	WIPP	1	$9.75x10^{-05}$	$5.64x10^{-04}$	$5.86x10^{-10}$	$1.90x10^{-04}$
NTS	WIPP	66	$4.92x10^{-01}$	$3.00x10^{+00}$	$3.87x10^{-06}$	$4.78x10^{-02}$
ORNL	WIPP	119	$1.57x10^{+01}$	$8.78x10^{+01}$	$1.50x10^{-03}$	$1.90x10^{-01}$
PADUCAH	ORNL	1	$2.26x10^{-05}$	$1.26x10^{-04}$	$5.86x10^{-10}$	$1.86x10^{-03}$
	WIPP	1	$1.01x10^{-04}$	$5.88x10^{-04}$	$5.86x10^{-10}$	$6.99x10^{-03}$
PANTEX	LANL	1	$2.05x10^{-05}$	$1.26x10^{-04}$	$5.86x10^{-10}$	$3.83x10^{-06}$
	WIPP	1	$2.10x10^{-05}$	$1.28x10^{-04}$	$5.86x10^{-10}$	$3.45x10^{-06}$

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TABLE L-2 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY BASELINE

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	6.30×10^{-05}	3.84×10^{-04}	1.76×10^{-09}	1.28×10^{-06}
		Subtotal	**$1.66 \times 10^{+01}$**	**$9.30 \times 10^{+01}$**	**1.51×10^{-03}**	**$1.06 \times 10^{+00}$**
		TOTAL	**$6.69 \times 10^{+02}$**	**$4.00 \times 10^{+03}$**	**4.99×10^{-03}**	**$8.01 \times 10^{+01}$**

TABLE L-3

RADIOLOGICAL DOSES PER SHIPMENT FOR RH-TRU WASTE BASELINE

Waste Origin Site	To Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major RH-TRU Waste Sites					
HANFORD	WIPP	1.12×10^{-01}	4.75×10^{-01}	2.08×10^{-06}	8.27×10^{-05}
ORNL	WIPP	2.80×10^{-02}	4.08×10^{-01}	5.87×10^{-07}	9.86×10^{-05}
Small RH-TRU Waste Sites					
BATTELLE	ORNL	1.90×10^{-04}	3.50×10^{-03}	1.14×10^{-08}	4.73×10^{-05}
	WIPP	5.43×10^{-04}	1.14×10^{-02}	1.14×10^{-08}	5.91×10^{-05}
BETTIS	ORNL	2.18×10^{-04}	4.17×10^{-03}	9.59×10^{-09}	7.11×10^{-06}
	WIPP	4.57×10^{-04}	9.63×10^{-03}	9.59×10^{-09}	8.89×10^{-06}
INEL	WIPP	3.00×10^{-03}	6.48×10^{-02}	7.19×10^{-08}	2.19×10^{-05}
KNOLL	ORNL	7.07×10^{-04}	1.35×10^{-02}	2.13×10^{-08}	9.55×10^{-06}
	WIPP	1.01×10^{-03}	2.13×10^{-02}	2.13×10^{-08}	8.89×10^{-06}
LANL	WIPP	3.86×10^{-04}	8.49×10^{-03}	3.90×10^{-08}	8.02×10^{-06}
SRS	WIPP	2.38×10^{-02}	4.19×10^{-01}	4.64×10^{-07}	1.47×10^{-04}

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TABLE L-4

CUMULATIVE RADIOLOGICAL DOSES FOR RH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY BASELINE

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Incident-Free Doses			Accident Risk Dose
			Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major RH-TRU Waste Sites						
HANFORD	WIPP	5176	$5.80 \times 10^{+02}$	$2.46 \times 10^{+03}$	1.08×10^{-02}	4.28×10^{-01}
ORNL	WIPP	2002	$5.61 \times 10^{+01}$	$8.17 \times 10^{+02}$	1.18×10^{-03}	1.97×10^{-01}
		Subtotal	**$6.36 \times 10^{+02}$**	**$3.28 \times 10^{+03}$**	**1.20×10^{-02}**	**6.25×10^{-01}**
Small RH-TRU Waste Sites						
BATTELLE	ORNL	123	2.34×10^{-02}	4.31×10^{-01}	1.40×10^{-06}	5.82×10^{-03}
	WIPP	123	6.68×10^{-02}	$1.40 \times 10^{+00}$	1.40×10^{-06}	7.27×10^{-03}
BETTIS	ORNL	3	6.54×10^{-04}	1.25×10^{-02}	2.88×10^{-08}	2.13×10^{-05}
	WIPP	3	1.37×10^{-03}	2.89×10^{-02}	2.88×10^{-08}	2.67×10^{-05}
INEL	WIPP	109	3.27×10^{-01}	$7.06 \times 10^{+00}$	7.84×10^{-06}	2.39×10^{-03}
KNOLL	ORNL	57	4.03×10^{-02}	7.70×10^{-01}	1.21×10^{-06}	5.44×10^{-04}
	WIPP	57	5.76×10^{-02}	$1.21 \times 10^{+00}$	1.21×10^{-06}	5.07×10^{-04}
LANL	WIPP	249	9.61×10^{-02}	$2.11 \times 10^{+00}$	9.71×10^{-06}	2.00×10^{-03}
SRS	WIPP	56	$1.33 \times 10^{+00}$	$2.35 \times 10^{+01}$	2.60×10^{-05}	8.23×10^{-03}
		Subtotal	**$1.94 \times 10^{+00}$**	**$3.65 \times 10^{+01}$**	**4.88×10^{-05}**	**2.68×10^{-02}**
		TOTAL	**$6.38 \times 10^{+02}$**	**$3.32 \times 10^{+03}$**	**1.20×10^{-02}**	**6.52×10^{-01}**

TABLE L-5

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVES No. 1 & 77 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	9.11×10^{-02}	5.46×10^{-01}	4.68×10^{-07}	1.06×10^{-04}
INEL	WIPP	7.93×10^{-03}	4.75×10^{-02}	5.27×10^{-08}	2.38×10^{-05}
LANL	WIPP	1.42×10^{-03}	8.69×10^{-03}	3.98×10^{-08}	2.71×10^{-05}
RFETS	WIPP	4.18×10^{-05}	2.45×10^{-04}	5.27×10^{-10}	1.68×10^{-04}
SRS	WIPP	1.19×10^{-04}	6.65×10^{-04}	6.44×10^{-10}	1.71×10^{-03}
Small CH-TRU Waste Sites					
AMES	ANL-E	2.35×10^{-03}	1.37×10^{-02}	5.86×10^{-08}	1.66×10^{-04}
	WIPP	8.78×10^{-03}	5.08×10^{-02}	5.27×10^{-08}	5.13×10^{-05}
ANL-E	WIPP	1.07×10^{-04}	6.22×10^{-04}	6.44×10^{-10}	9.55×10^{-06}
BETTIS	MOUND	2.69×10^{-03}	1.33×10^{-02}	5.86×10^{-08}	6.14×10^{-04}
	WIPP	9.55×10^{-03}	5.49×10^{-02}	5.27×10^{-08}	6.42×10^{-05}
ETEC	NTS	1.78×10^{-02}	9.27×10^{-02}	3.28×10^{-07}	4.02×10^{-04}
	WIPP	9.68×10^{-02}	5.70×10^{-01}	7.61×10^{-07}	2.57×10^{-05}
KAPL	MOUND	6.17×10^{-03}	3.08×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
	WIPP	9.55×10^{-03}	5.49×10^{-02}	5.27×10^{-08}	6.42×10^{-05}
LBL	LLNL	9.84×10^{-06}	4.30×10^{-05}	5.86×10^{-10}	2.57×10^{-05}
	WIPP	1.05×10^{-04}	6.18×10^{-04}	6.44×10^{-10}	9.27×10^{-06}
LLNL	WIPP	1.05×10^{-04}	6.18×10^{-04}	6.44×10^{-10}	4.89×10^{-05}
MOUND	WIPP	1.17×10^{-04}	6.71×10^{-04}	6.44×10^{-10}	2.82×10^{-03}
MU	ANL-E	2.94×10^{-05}	1.61×10^{-04}	5.86×10^{-10}	9.30×10^{-05}
	WIPP	1.07×10^{-04}	6.22×10^{-04}	6.44×10^{-10}	1.63×10^{-05}
NTS	WIPP	6.70×10^{-03}	4.08×10^{-02}	5.27×10^{-08}	8.92×10^{-05}
ORNL	WIPP	1.32×10^{-01}	7.38×10^{-01}	6.21×10^{-06}	1.68×10^{-04}

TABLE L-5 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVES No. 1 & 77 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PADUCAH	ORNL	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	1.11×10^{-04}	6.47×10^{-04}	6.44×10^{-10}	3.00×10^{-04}
PANTEX	LANL	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	2.30×10^{-05}	1.41×10^{-04}	6.44×10^{-10}	4.16×10^{-07}
SNL	LANL	7.74×10^{-06}	4.27×10^{-05}	5.86×10^{-10}	4.36×10^{-07}
	WIPP	2.30×10^{-05}	1.41×10^{-04}	6.44×10^{-10}	5.19×10^{-08}

TABLE L-6

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVES No. 1 & 77 - DECENTRALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$5.20\times10^{+02}$	$3.12\times10^{+03}$	2.67×10^{-03}	6.05×10^{-01}
INEL	WIPP	4974	$3.94\times10^{+01}$	$2.36\times10^{+02}$	2.62×10^{-04}	1.18×10^{-01}
LANL	WIPP	2835	$4.03\times10^{+00}$	$2.46\times10^{+01}$	1.13×10^{-04}	7.68×10^{-02}
RFETS	WIPP	931	3.89×10^{-02}	2.28×10^{-01}	4.91×10^{-07}	1.56×10^{-01}
SRS	WIPP	2827	3.36×10^{-01}	$1.88\times10^{+00}$	1.82×10^{-05}	$4.83\times10^{+00}$
		Subtotal	**$5.64\times10^{+02}$**	**$3.38\times10^{+03}$**	**3.05×10^{-03}**	**$5.79\times10^{+00}$**
Small CH-TRU Waste Sites						
AMES	ANL-E	1	2.35×10^{-03}	1.37×10^{-02}	5.86×10^{-08}	1.66×10^{-04}
	WIPP	1	8.78×10^{-03}	5.08×10^{-02}	5.27×10^{-08}	5.13×10^{-05}
ANL-E	WIPP	5	5.35×10^{-04}	3.11×10^{-03}	3.22×10^{-09}	4.78×10^{-05}
BETTIS	MOUND	17	4.57×10^{-02}	2.26×10^{-01}	9.96×10^{-07}	1.04×10^{-02}
	WIPP	17	1.62×10^{-01}	9.33×10^{-01}	8.96×10^{-07}	1.09×10^{-03}
ETEC	NTS	2	3.56×10^{-02}	1.85×10^{-01}	6.56×10^{-07}	8.04×10^{-04}
	WIPP	2	1.94×10^{-01}	$1.14\times10^{+00}$	1.52×10^{-06}	5.14×10^{-05}
KAPL	MOUND	1	6.17×10^{-03}	3.08×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
	WIPP	1	9.55×10^{-03}	5.49×10^{-02}	5.27×10^{-08}	6.42×10^{-05}
LBL	LLNL	1	9.84×10^{-06}	4.30×10^{-05}	5.86×10^{-10}	2.57×10^{-05}
	WIPP	1	1.05×10^{-04}	6.18×10^{-04}	6.44×10^{-10}	9.27×10^{-06}
LLNL	WIPP	136	1.43×10^{-02}	8.40×10^{-02}	8.76×10^{-08}	6.65×10^{-03}
MOUND	WIPP	29	3.39×10^{-03}	1.95×10^{-02}	1.87×10^{-08}	8.18×10^{-02}
MU	ANL-E	1	2.94×10^{-05}	1.61×10^{-04}	5.86×10^{-10}	9.30×10^{-05}
	WIPP	1	1.07×10^{-04}	6.22×10^{-04}	6.44×10^{-10}	1.63×10^{-05}
NTS	WIPP	66	4.42×10^{-01}	$2.69\times10^{+00}$	3.48×10^{-06}	5.89×10^{-03}
ORNL	WIPP	119	$1.57\times10^{+01}$	$8.78\times10^{+01}$	7.39×10^{-04}	2.00×10^{-02}
PA	ORNL	1	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	1	1.11×10^{-04}	6.47×10^{-04}	6.44×10^{-10}	3.00×10^{-04}
PANTEX	LANL	1	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1	2.30×10^{-05}	1.41×10^{-04}	6.44×10^{-10}	4.16×10^{-07}

TABLE L-6 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVES No. 1 & 77 - DECENTRALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	6.90×10^{-05}	4.23×10^{-04}	1.93×10^{-09}	1.56×10^{-07}
		Subtotal	$1.66 \times 10^{+01}$	$9.32 \times 10^{+01}$	$\mathbf{7.47 \times 10^{-04}}$	$\mathbf{1.30 \times 10^{-01}}$
		TOTAL	$5.81 \times 10^{+02}$	$3.47 \times 10^{+03}$	$\mathbf{3.80 \times 10^{-03}}$	$\mathbf{5.92 \times 10^{+00}}$

TABLE L-7

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVES No. 1 & 77 - REGIONALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	9.11×10^{-02}	5.46×10^{-01}	4.68×10^{-07}	1.06×10^{-04}
INEL	WIPP	7.93×10^{-03}	4.75×10^{-02}	5.27×10^{-08}	2.38×10^{-05}
LANL	WIPP	1.42×10^{-03}	8.69×10^{-03}	3.98×10^{-08}	2.71×10^{-05}
RFETS	WIPP	4.18×10^{-05}	2.45×10^{-04}	5.27×10^{-10}	1.68×10^{-04}
SRS	WIPP	1.19×10^{-04}	6.65×10^{-04}	6.44×10^{-10}	1.71×10^{-03}
Small CH-TRU Waste Sites					
AMES	SRS	8.88×10^{-03}	4.85×10^{-02}	5.86×10^{-08}	1.07×10^{-03}
	WIPP	9.73×10^{-03}	5.43×10^{-02}	5.27×10^{-08}	7.78×10^{-05}
ANL-E	SRS	7.06×10^{-05}	3.71×10^{-04}	5.86×10^{-10}	6.35×10^{-04}
	WIPP	1.19×10^{-04}	6.65×10^{-04}	6.44×10^{-10}	1.45×10^{-05}
BETTIS	SRS	5.30×10^{-03}	2.85×10^{-02}	5.86×10^{-08}	7.15×10^{-04}
	WIPP	9.73×10^{-03}	5.43×10^{-02}	5.27×10^{-08}	7.78×10^{-05}
ETEC	INEL	4.06×10^{-02}	2.23×10^{-01}	3.28×10^{-07}	6.88×10^{-04}
	WIPP	1.15×10^{-01}	6.62×10^{-01}	7.61×10^{-07}	3.78×10^{-05}
KAPL	SRS	7.49×10^{-03}	3.97×10^{-02}	5.86×10^{-08}	9.92×10^{-04}
	WIPP	9.73×10^{-03}	5.43×10^{-02}	5.27×10^{-08}	7.78×10^{-05}
LBL	HANFORD	6.53×10^{-05}	3.57×10^{-04}	5.86×10^{-10}	6.10×10^{-05}
	WIPP	1.25×10^{-04}	7.52×10^{-04}	6.44×10^{-10}	7.28×10^{-06}
LLNL	HANFORD	6.70×10^{-05}	3.66×10^{-04}	5.86×10^{-10}	5.42×10^{-04}
	WIPP	1.25×10^{-04}	7.52×10^{-04}	6.44×10^{-10}	3.84×10^{-05}
MOUND	SRS	5.14×10^{-05}	2.70×10^{-04}	5.86×10^{-10}	1.77×10^{-02}
	WIPP	1.19×10^{-04}	6.65×10^{-04}	6.44×10^{-10}	3.43×10^{-03}
MU	SRS	6.81×10^{-05}	3.63×10^{-04}	5.86×10^{-10}	2.49×10^{-04}
	WIPP	1.19×10^{-04}	6.65×10^{-04}	6.44×10^{-10}	2.48×10^{-05}
NTS	INEL	4.92×10^{-03}	2.82×10^{-02}	5.86×10^{-08}	1.17×10^{-03}
	WIPP	7.93×10^{-03}	4.75×10^{-02}	5.27×10^{-08}	1.31×10^{-04}
ORNL	SRS	3.65×10^{-02}	1.87×10^{-01}	1.26×10^{-05}	7.15×10^{-04}
	WIPP	1.41×10^{-01}	7.59×10^{-01}	6.21×10^{-06}	2.50×10^{-04}

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TABLE L-7 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVES No. 1 & 77 - REGIONALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PADUCAH	SRS	4.61×10^{-05}	2.42×10^{-04}	5.86×10^{-10}	6.34×10^{-03}
-	WIPP	1.19×10^{-04}	6.65×10^{-04}	6.44×10^{-10}	4.48×10^{-04}
PANTEX	LANL	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	2.30×10^{-05}	1.41×10^{-04}	6.44×10^{-10}	4.16×10^{-07}
SNL	LANL	7.74×10^{-06}	4.27×10^{-05}	5.86×10^{-10}	4.36×10^{-07}
	WIPP	2.30×10^{-05}	1.41×10^{-04}	6.44×10^{-10}	5.19×10^{-08}

TABLE L-8

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVES No. 1 & 77 - REGIONALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	To Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$5.20\times10^{+02}$	$3.12\times10^{+03}$	2.67×10^{-03}	6.05×10^{-01}
INEL	WIPP	4974	$3.94\times10^{+01}$	$2.36\times10^{+02}$	2.62×10^{-04}	1.18×10^{-01}
LANL	WIPP	2835	$4.03\times10^{+00}$	$2.46\times10^{+01}$	1.13×10^{-04}	7.68×10^{-02}
RFETS	WIPP	931	3.89×10^{-02}	2.28×10^{-01}	4.91×10^{-07}	1.56×10^{-01}
SRS	WIPP	2827	3.36×10^{-01}	$1.88\times10^{+00}$	1.82×10^{-06}	$4.83\times10^{+00}$
		Subtotal	**$5.64\times10^{+02}$**	**$3.38\times10^{+03}$**	**3.05×10^{-03}**	**$5.79\times10^{+00}$**
Small CH-TRU Waste Sites						
AMES	SRS	1	8.88×10^{-03}	4.85×10^{-02}	5.86×10^{-08}	1.07×10^{-03}
	WIPP	1	9.73×10^{-03}	5.43×10^{-02}	5.27×10^{-08}	7.78×10^{-05}
ANL-E	SRS	5	3.53×10^{-04}	1.86×10^{-03}	2.93×10^{-09}	3.18×10^{-03}
	WIPP	5	5.95×10^{-04}	3.33×10^{-03}	3.22×10^{-09}	7.25×10^{-05}
BETTIS	SRS	17	9.01×10^{-02}	4.85×10^{-01}	9.96×10^{-07}	1.22×10^{-02}
	WIPP	17	1.65×10^{-01}	9.23×10^{-01}	8.96×10^{-07}	1.32×10^{-03}
ETEC	INEL	2	8.12×10^{-02}	4.46×10^{-01}	6.56×10^{-07}	1.38×10^{-03}
	WIPP	2	2.30×10^{-01}	$1.32\times10^{+00}$	1.52×10^{-06}	7.56×10^{-05}
KAPL	SRS	1	7.49×10^{-03}	3.97×10^{-02}	5.86×10^{-08}	9.92×10^{-04}
	WIPP	1	9.73×10^{-03}	5.43×10^{-02}	5.27×10^{-08}	7.78×10^{-05}
LBL	HANFORD	1	6.53×10^{-05}	3.57×10^{-04}	5.86×10^{-10}	6.10×10^{-05}
	WIPP	1	1.25×10^{-04}	7.52×10^{-04}	6.44×10^{-10}	7.28×10^{-06}
LLNL	HANFORD	136	9.11×10^{-03}	4.98×10^{-02}	7.97×10^{-08}	7.37×10^{-02}
	WIPP	136	1.70×10^{-02}	1.02×10^{-01}	8.76×10^{-08}	5.22×10^{-03}
MOUND	SRS	29	1.49×10^{-03}	7.83×10^{-03}	1.70×10^{-08}	5.13×10^{-01}
	WIPP	29	3.45×10^{-03}	1.93×10^{-02}	1.87×10^{-08}	9.95×10^{-02}
MU	SRS	1	6.81×10^{-05}	3.63×10^{-04}	5.86×10^{-10}	2.49×10^{-04}
	WIPP	1	1.19×10^{-04}	6.65×10^{-04}	6.44×10^{-10}	2.48×10^{-05}

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TABLE L-8 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVES No. 1 & 77 - REGIONALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	To Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
NTS	INEL	66	3.25×10^{-01}	$1.86 \times 10^{+00}$	3.87×10^{-06}	7.72×10^{-02}
	WIPP	66	5.23×10^{-01}	$3.14 \times 10^{+00}$	3.48×10^{-06}	8.65×10^{-03}
ORNL	SRS	119	$4.34 \times 10^{+00}$	$2.23 \times 10^{+01}$	1.50×10^{-03}	8.51×10^{-02}
	WIPP	119	$1.68 \times 10^{+01}$	$9.03 \times 10^{+01}$	7.39×10^{-04}	2.98×10^{-02}
PADUCAH	SRS	1	4.61×10^{-05}	2.42×10^{-04}	5.86×10^{-10}	6.34×10^{-03}
	WIPP	1	1.19×10^{-04}	6.65×10^{-04}	6.44×10^{-10}	4.48×10^{-04}
PANTEX	LANL	1	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1	2.30×10^{-05}	1.41×10^{-04}	6.44×10^{-10}	4.16×10^{-07}
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	6.90×10^{-05}	4.23×10^{-04}	1.93×10^{-09}	1.56×10^{-07}
		Subtotal	$2.26 \times 10^{+01}$	$1.21 \times 10^{+02}$	2.25×10^{-03}	9.20×10^{-01}
		TOTAL	**$5.87 \times 10^{+02}$**	**$3.50 \times 10^{+03}$**	**5.30×10^{-03}**	**$6.71 \times 10^{+00}$**

TABLE L-9

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE CENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	1.06×10^{-01}	6.36×10^{-01}	5.45×10^{-07}	1.78×10^{-03}
INEL	WIPP	8.81×10^{-03}	5.27×10^{-02}	5.86×10^{-08}	5.97×10^{-04}
LANL	WIPP	1.01×10^{-03}	6.14×10^{-03}	2.81×10^{-08}	6.54×10^{-04}
RFETS	WIPP	6.03×10^{-05}	3.53×10^{-04}	7.61×10^{-10}	4.09×10^{-03}
SRS	WIPP	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	2.13×10^{-02}
Small CH-TRU Waste Sites					
AMES	WIPP	8.06×10^{-03}	4.79×10^{-02}	5.86×10^{-08}	6.23×10^{-04}
ANL-E	WIPP	9.75×10^{-05}	5.64×10^{-04}	5.86×10^{-10}	4.75×10^{-04}
BETTIS	WIPP	1.27×10^{-02}	7.17×10^{-02}	5.86×10^{-08}	1.42×10^{-03}
ETEC	WIPP	4.44×10^{-02}	2.55×10^{-01}	3.28×10^{-07}	5.26×10^{-04}
KAPL	WIPP	1.62×10^{-02}	8.93×10^{-02}	5.86×10^{-08}	1.86×10^{-03}
LBL	WIPP	1.05×10^{-04}	6.02×10^{-04}	5.86×10^{-10}	8.60×10^{-05}
LLNL	WIPP	9.54×10^{-05}	5.61×10^{-04}	5.86×10^{-10}	5.22×10^{-04}
MOUND	WIPP	1.06×10^{-04}	6.10×10^{-04}	5.86×10^{-10}	2.44×10^{-02}
MU	WIPP	7.44×10^{-05}	4.39×10^{-04}	5.86×10^{-10}	1.48×10^{-04}
NTS	WIPP	7.45×10^{-03}	4.54×10^{-02}	5.86×10^{-08}	7.24×10^{-04}
ORNL	WIPP	1.32×10^{-01}	7.38×10^{-01}	1.26×10^{-05}	1.60×10^{-03}
PADUCAH	WIPP	8.99×10^{-05}	5.25×10^{-04}	5.86×10^{-10}	6.01×10^{-03}
PANTEX	WIPP	2.72×10^{-05}	1.65×10^{-04}	5.86×10^{-10}	5.01×10^{-06}
SNL	WIPP	1.93×10^{-05}	1.16×10^{-04}	5.86×10^{-10}	4.36×10^{-07}

TABLE L-10

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY CENTRALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$6.05\times10^{+02}$	$3.63\times10^{+03}$	3.11×10^{-03}	$1.02\times10^{+01}$
INEL	WIPP	4974	$4.38\times10^{+01}$	$2.62\times10^{+02}$	2.91×10^{-04}	$2.97\times10^{+00}$
LANL	WIPP	2835	$2.86\times10^{+00}$	$1.74\times10^{+01}$	7.97×10^{-05}	$1.85\times10^{+00}$
RFETS	WIPP	931	5.61×10^{-02}	3.29×10^{-01}	7.08×10^{-07}	$3.81\times10^{+00}$
SRS	WIPP	2827	3.05×10^{-01}	$1.71\times10^{+00}$	1.66×10^{-05}	$6.02\times10^{+01}$
		Subtotal	$6.52\times10^{+02}$	$3.91\times10^{+03}$	3.48×10^{-03}	$7.90\times10^{+01}$
Small CH-TRU Waste Sites						
AMES	WIPP	1	8.06×10^{-03}	4.79×10^{-02}	5.86×10^{-08}	6.23×10^{-04}
ANL-E	WIPP	5	4.88×10^{-04}	2.82×10^{-03}	2.93×10^{-09}	2.38×10^{-03}
BETTIS	WIPP	17	2.16×10^{-01}	$1.22\times10^{+00}$	9.96×10^{-07}	2.41×10^{-02}
ETEC	WIPP	2	8.88×10^{-02}	5.10×10^{-01}	6.56×10^{-07}	1.05×10^{-03}
KAPL	WIPP	1	1.62×10^{-02}	8.93×10^{-02}	5.86×10^{-08}	1.86×10^{-03}
LBL	WIPP	1	1.05×10^{-04}	6.02×10^{-04}	5.86×10^{-10}	8.60×10^{-05}
LLNL	WIPP	136	1.30×10^{-02}	7.63×10^{-02}	7.97×10^{-08}	7.10×10^{-02}
MOUND	WIPP	29	3.07×10^{-03}	1.77×10^{-02}	1.70×10^{-08}	7.08×10^{-01}
MU	WIPP	1	7.44×10^{-05}	4.39×10^{-04}	5.86×10^{-10}	1.48×10^{-04}
NTS	WIPP	66	4.92×10^{-01}	$3.00\times10^{+00}$	3.87×10^{-06}	4.78×10^{-02}
ORNL	WIPP	119	$1.57\times10^{+01}$	$8.78\times10^{+01}$	1.50×10^{-03}	1.90×10^{-01}
PADUCAH	WIPP	1	8.99×10^{-05}	5.25×10^{-04}	5.86×10^{-10}	6.01×10^{-03}
PANTEX	WIPP	1	2.72×10^{-05}	1.65×10^{-04}	5.86×10^{-10}	5.01×10^{-06}
SNL	WIPP	3	5.79×10^{-05}	3.48×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
		Subtotal	$1.65\times10^{+01}$	$9.28\times10^{+01}$	1.51×10^{-03}	$1.05\times10^{+00}$
		TOTAL	**$6.69\times10^{+02}$**	**$4.00\times10^{+03}$**	**4.99×10^{-03}**	**$8.01\times10^{+01}$**

TABLE L-11

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 6 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	8.54×10^{-02}	5.13×10^{-01}	4.39×10^{-07}	1.61×10^{-03}
INEL	WIPP	7.66×10^{-03}	4.59×10^{-02}	5.09×10^{-08}	4.89×10^{-04}
LANL	WIPP	1.38×10^{-03}	8.43×10^{-03}	3.87×10^{-08}	5.46×10^{-04}
RFETS	WIPP	4.18×10^{-05}	2.45×10^{-04}	5.27×10^{-10}	3.39×10^{-03}
SRS	WIPP	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	2.06×10^{-02}
Small CH-TRU Waste Sites					
AMES	ANLE-E	2.35×10^{-03}	1.37×10^{-02}	5.86×10^{-08}	1.66×10^{-04}
	WIPP	8.49×10^{-03}	4.91×10^{-02}	5.09×10^{-08}	6.92×10^{-04}
ANL-E	WIPP	9.75×10^{-05}	5.64×10^{-04}	5.86×10^{-10}	1.48×10^{-04}
BETTIS	MOUND	2.69×10^{-03}	1.33×10^{-02}	5.86×10^{-08}	6.14×10^{-04}
	WIPP	9.23×10^{-03}	5.30×10^{-02}	5.09×10^{-08}	8.65×10^{-04}
ETEC	NTS	1.78×10^{-02}	9.27×10^{-02}	3.28×10^{-07}	4.02×10^{-04}
	WIPP	5.51×10^{-02}	3.36×10^{-01}	4.33×10^{-07}	2.02×10^{-04}
KAPL	MOUND	6.17×10^{-03}	3.08×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
	WIPP	9.23×10^{-03}	5.30×10^{-02}	5.09×10^{-08}	8.65×10^{-04}
LBL	LLNL	9.84×10^{-06}	4.30×10^{-05}	5.86×10^{-10}	2.57×10^{-05}
	WIPP	9.54×10^{-05}	5.61×10^{-04}	5.86×10^{-10}	6.19×10^{-05}
LLNL	WIPP	9.54×10^{-05}	5.61×10^{-04}	5.86×10^{-10}	4.76×10^{-04}
MOUND	WIPP	1.06×10^{-04}	6.10×10^{-04}	5.86×10^{-10}	2.32×10^{-02}
MU	ANL-E	2.94×10^{-05}	1.61×10^{-04}	5.86×10^{-10}	9.30×10^{-05}
	WIPP	9.75×10^{-05}	5.64×10^{-04}	5.86×10^{-10}	1.39×10^{-04}
NTS	WIPP	6.48×10^{-03}	3.95×10^{-02}	5.09×10^{-08}	6.94×10^{-04}
ORNL	WIPP	1.32×10^{-01}	7.38×10^{-01}	7.79×10^{-06}	1.51×10^{-03}
PADUCAH	ORNL	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	1.01×10^{-04}	5.88×10^{-04}	5.86×10^{-10}	5.12×10^{-03}

TABLE L-11 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 6 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PANTEX	LANL	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	2.10×10^{-05}	1.28×10^{-04}	5.86×10^{-10}	3.33×10^{-06}
SNL	LANL	7.74×10^{-06}	4.27×10^{-05}	5.86×10^{-10}	4.36×10^{-07}
	WIPP	2.10×10^{-05}	1.28×10^{-04}	5.86×10^{-10}	4.11×10^{-07}

TABLE L-12

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 6 - DECENTRALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$4.88x10^{+02}$	$2.93x10^{+03}$	$2.51x10^{-03}$	$9.20x10^{+00}$
INEL	WIPP	4974	$3.81x10^{+01}$	$2.28x10^{+02}$	$2.53x10^{-04}$	$2.43x10^{+00}$
LANL	WIPP	2835	$3.91x10^{+00}$	$2.39x10^{+01}$	$1.10x10^{-04}$	$1.55x10^{+00}$
RFETS	WIPP	931	$3.89x10^{-02}$	$2.28x10^{-01}$	$4.91x10^{-07}$	$3.16x10^{+00}$
SRS	WIPP	2827	$3.05x10^{-01}$	$1.71x10^{+00}$	$1.66x10^{-06}$	$5.82x10^{+01}$
		Subtotal	**$5.30x10^{+02}$**	**$3.18x10^{+03}$**	**$2.88x10^{-03}$**	**$7.45x10^{+01}$**
Small CH-TRU Waste Sites						
AMES	ANL-E	1	$2.35x10^{-03}$	$1.37x10^{-02}$	$5.86x10^{-08}$	$1.66x10^{-04}$
	WIPP	1	$8.49x10^{-03}$	$4.91x10^{-02}$	$5.09x10^{-08}$	$6.92x10^{-04}$
ANL-E	WIPP	5	$4.88x10^{-04}$	$2.82x10^{-03}$	$2.93x10^{-09}$	$7.40x10^{-04}$
BETTIS	MOUND	17	$4.57x10^{-02}$	$2.26x10^{-01}$	$9.96x10^{-07}$	$1.04x10^{-02}$
	WIPP	17	$1.57x10^{-01}$	$9.01x10^{-01}$	$8.65x10^{-07}$	$1.47x10^{-02}$
ETEC	NTS	2	$3.56x10^{-02}$	$1.85x10^{-01}$	$6.56x10^{-07}$	$8.04x10^{-04}$
	WIPP	2	$1.10x10^{-01}$	$6.72x10^{-01}$	$8.66x10^{-07}$	$4.04x10^{-04}$
KAPL	MOUND	1	$6.17x10^{-03}$	$3.08x10^{-02}$	$5.86x10^{-08}$	$1.06x10^{-03}$
	WIPP	1	$9.23x10^{-03}$	$5.30x10^{-02}$	$5.09x10^{-08}$	$8.65x10^{-04}$
LBL	LLNL	1	$9.84x10^{-06}$	$4.30x10^{-05}$	$5.86x10^{-10}$	$2.57x10^{-05}$
	WIPP	1	$9.54x10^{-05}$	$5.61x10^{-04}$	$5.86x10^{-10}$	$6.19x10^{-05}$
LLNL	WIPP	136	$1.30x10^{-02}$	$7.63x10^{-02}$	$7.97x10^{-08}$	$6.47x10^{-02}$
MOUND	WIPP	47	$4.98x10^{-03}$	$2.87x10^{-02}$	$2.75x10^{-08}$	$1.09x10^{+00}$
MU	ANL-E	1	$2.94x10^{-05}$	$1.61x10^{-04}$	$5.86x10^{-10}$	$9.30x10^{-05}$
	WIPP	1	$9.75x10^{-05}$	$5.64x10^{-04}$	$5.86x10^{-10}$	$1.39x10^{-04}$
NTS	WIPP	66	$4.28x10^{-01}$	$2.61x10^{+00}$	$3.36x10^{-06}$	$4.58x10^{-02}$
ORNL	WIPP	119	$1.57x10^{+01}$	$8.78x10^{+01}$	$9.27x10^{-04}$	$1.80x10^{-01}$

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TABLE L-12 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 6 - DECENTRALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PADUCAH	ORNL	1	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	1	1.01×10^{-04}	5.88×10^{-04}	5.86×10^{-10}	5.12×10^{-03}
PANTEX	LANL	1	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1	2.10×10^{-05}	1.28×10^{-04}	5.86×10^{-10}	3.33×10^{-06}
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	6.30×10^{-05}	3.84×10^{-04}	1.76×10^{-09}	1.23×10^{-06}
		Subtotal	**$1.65 \times 10^{+01}$**	**$9.27 \times 10^{+01}$**	**9.34×10^{-04}**	**$1.42 \times 10^{+00}$**
		TOTAL	**$5.47 \times 10^{+02}$**	**$3.27 \times 10^{+03}$**	**3.81×10^{-03}**	**$7.59 \times 10^{+01}$**

TABLE L-13

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 6 - REGIONALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	8.54×10^{-02}	5.13×10^{-01}	4.39×10^{-07}	1.61×10^{-03}
INEL	WIPP	7.66×10^{-03}	4.59×10^{-02}	5.09×10^{-08}	4.89×10^{-04}
LANL	WIPP	1.38×10^{-03}	8.43×10^{-03}	3.87×10^{-08}	5.46×10^{-04}
RFETS	WIPP	4.18×10^{-05}	2.45×10^{-04}	5.27×10^{-10}	3.39×10^{-03}
SRS	WIPP	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	2.06×10^{-02}
Small CH-TRU Waste Sites					
AMES	SRS	8.88×10^{-03}	4.85×10^{-02}	5.86×10^{-08}	1.07×10^{-03}
	WIPP	9.41×10^{-03}	5.26×10^{-02}	5.09×10^{-08}	1.05×10^{-03}
ANL-E	SRS	7.06×10^{-05}	3.71×10^{-04}	5.86×10^{-10}	6.35×10^{-04}
	WIPP	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	2.25×10^{-04}
BETTIS	SRS	5.30×10^{-03}	2.85×10^{-02}	5.86×10^{-08}	7.15×10^{-04}
	WIPP	9.41×10^{-03}	5.26×10^{-02}	5.09×10^{-08}	1.05×10^{-03}
ETEC	INEL	4.06×10^{-02}	2.23×10^{-01}	3.28×10^{-07}	6.88×10^{-04}
	WIPP	6.52×10^{-02}	3.90×10^{-01}	4.33×10^{-07}	2.98×10^{-04}
KAPL	SRS	7.49×10^{-03}	3.97×10^{-02}	5.86×10^{-08}	9.92×10^{-04}
	WIPP	9.41×10^{-03}	5.26×10^{-02}	5.09×10^{-08}	1.05×10^{-03}
LBL	HANFORD	6.53×10^{-05}	3.57×10^{-04}	5.86×10^{-10}	6.10×10^{-05}
	WIPP	1.14×10^{-04}	6.84×10^{-04}	5.86×10^{-10}	4.96×10^{-05}
LLNL	HANFORD	6.70×10^{-05}	3.66×10^{-04}	5.86×10^{-10}	5.42×10^{-04}
	WIPP	1.14×10^{-04}	6.84×10^{-04}	5.86×10^{-10}	3.81×10^{-04}
MOUND	SRS	5.14×10^{-05}	2.70×10^{-04}	5.86×10^{-10}	1.77×10^{-02}
	WIPP	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	2.82×10^{-02}
MU	SRS	6.81×10^{-05}	3.63×10^{-04}	5.86×10^{-10}	2.49×10^{-04}
	WIPP	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	2.11×10^{-04}

TABLE L-13 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 6 - REGIONALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
NTS	INEL	$4.92X10^{-03}$	$2.82X10^{-02}$	$5.86x10^{-08}$	$1.17X10^{-03}$
	WIPP	$7.66X10^{-03}$	$4.59X10^{-02}$	$5.09X10^{-08}$	$1.03X10^{-03}$
ORNL	SRS	$3.65X10^{-02}$	$1.87X10^{-01}$	$1.26X10^{-05}$	$7.15X10^{-04}$
	WIPP	$1.41X10^{-01}$	$7.58X10^{-01}$	$7.79X10^{-06}$	$2.14X10^{-03}$
PADUCAH	SRS	$4.61X10^{-05}$	$2.42X10^{-04}$	$5.86X10^{-10}$	$6.34X10^{-03}$
	WIPP	$1.08X10^{-04}$	$6.05X10^{-04}$	$5.86X10^{-10}$	$7.68X10^{-03}$
PANTEX	LANL	$2.05X10^{-05}$	$1.26X10^{-04}$	$5.86X10^{-10}$	$3.83X10^{-06}$
	WIPP	$2.10X10^{-05}$	$1.28X10^{-04}$	$5.86X10^{-10}$	$3.33X10^{-06}$
SNL	LANL	$7.74X10^{-06}$	$4.27X10^{-05}$	$5.86X10^{-10}$	$4.36X10^{-07}$
	WIPP	$2.10X10^{-05}$	$1.28X10^{-04}$	$5.86X10^{-10}$	$4.11X10^{-07}$

TABLE L-14

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 6 - REGIONALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Incident-Free Doses			Accident Risk Dose
			Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$4.88 \times 10^{+02}$	$2.93 \times 10^{+03}$	2.51×10^{-03}	$9.20 \times 10^{+00}$
INEL	WIPP	4974	$3.81 \times 10^{+01}$	$2.28 \times 10^{+02}$	2.53×10^{-04}	$2.43 \times 10^{+00}$
LANL	WIPP	2835	$3.91 \times 10^{+00}$	$2.39 \times 10^{+01}$	1.10×10^{-04}	$1.55 \times 10^{+00}$
RFETS	WIPP	931	3.89×10^{-02}	2.28×10^{-01}	4.91×10^{-07}	$3.16 \times 10^{+00}$
SRS	WIPP	2827	3.05×10^{-01}	$1.71 \times 10^{+00}$	1.66×10^{-06}	$5.82 \times 10^{+01}$
		Subtotal	**$5.30 \times 10^{+02}$**	**$3.18 \times 10^{+03}$**	**2.88×10^{-03}**	**$7.45 \times 10^{+01}$**
Small CH-TRU Waste Sites						
AMES	SRS	1	8.88×10^{-03}	4.85×10^{-02}	5.86×10^{-08}	1.07×10^{-03}
	WIPP	1	9.41×10^{-03}	5.26×10^{-02}	5.09×10^{-08}	1.05×10^{-03}
ANL-E	SRS	5	3.53×10^{-04}	1.86×10^{-03}	2.93×10^{-09}	3.18×10^{-03}
	WIPP	5	5.40×10^{-04}	3.03×0^{-03}	2.93×10^{-09}	1.13×10^{-03}
BETTIS	SRS	17	9.01×10^{-02}	4.85×10^{-01}	9.96×10^{-07}	1.22×10^{-02}
	WIPP	17	1.60×10^{-01}	8.94×10^{-01}	8.65×10^{-07}	1.79×10^{-02}
ETEC	INEL	2	8.12×10^{-02}	4.46×10^{-01}	6.56×10^{-07}	1.38×10^{-03}
	WIPP	2	1.30×10^{-01}	7.80×10^{-01}	8.66×10^{-07}	5.96×10^{-04}
KAPL	SRS	1	7.49×10^{-03}	3.97×10^{-02}	5.86×10^{-08}	9.92×10^{-04}
	WIPP	1	9.41×10^{-03}	5.26×10^{-02}	5.09×10^{-08}	1.05×10^{-03}
LBL	HANFORD	1	6.53×10^{-05}	3.57×10^{-04}	5.86×10^{-10}	6.10×10^{-05}
	WIPP	1	1.14×10^{-04}	6.84×10^{-04}	5.86×10^{-10}	4.96×10^{-05}
LLNL	HANFORD	136	9.11×10^{-03}	4.98×10^{-02}	7.97×10^{-08}	7.37×10^{-02}
	WIPP	136	1.55×10^{-02}	9.30×10^{-02}	7.97×10^{-08}	5.18×10^{-02}
MOUND	SRS	29	1.49×10^{-03}	7.83×10^{-03}	1.70×10^{-08}	5.13×10^{-01}
	WIPP	29	3.13×10^{-03}	1.75×10^{-02}	1.70×10^{-08}	8.18×10^{-01}
MU	SRS	1	6.81×10^{-05}	3.63×10^{-04}	5.86×10^{-10}	2.49×10^{-04}
	WIPP	1	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	2.11×10^{-04}

TABLE L-14 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 6 - REGIONALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Incident-Free Doses			Accident Risk Dose
			Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
NTS	INEL	66	3.25×10^{-01}	$1.86 \times 10^{+00}$	3.87×10^{-06}	7.72×10^{-02}
	WIPP	66	5.06×10^{-01}	$3.03 \times 10^{+00}$	3.36×10^{-06}	6.80×10^{-02}
ORNL	SRS	119	$4.34 \times 10^{+00}$	$2.23 \times 10^{+01}$	1.50×10^{-03}	8.51×10^{-02}
	WIPP	119	$1.68 \times 10^{+01}$	$9.02 \times 10^{+01}$	9.27×10^{-04}	2.55×10^{-01}
PADUCAH	SRS	1	4.61×10^{-05}	2.42×10^{-04}	5.86×10^{-10}	6.34×10^{-03}
	WIPP	1	1.08×10^{-04}	6.05×10^{-04}	5.86×10^{-10}	7.68×10^{-03}
PANTEX	LANL	1	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1	2.10×10^{-05}	1.28×10^{-04}	5.86×10^{-10}	3.33×10^{-06}
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	6.30×10^{-05}	3.84×10^{-04}	1.76×10^{-09}	1.23×10^{-06}
		Subtotal	**$2.25 \times 10^{+01}$**	**$1.20 \times 10^{+02}$**	**2.44×10^{-03}**	**$2.00 \times 10^{+00}$**
		TOTAL	**$5.53 \times 10^{+02}$**	**$3.28 \times 10^{+03}$**	**5.32×10^{-03}**	**$7.65 \times 10^{+01}$**

TABLE L-15

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 10 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	$1.12x10^{-01}$	$6.70x10^{-01}$	$5.74x10^{-07}$	$2.86x10^{-05}$
INEL	WIPP	$1.06x10^{-02}$	$6.32x10^{-02}$	$7.03x10^{-08}$	$1.00x10^{-05}$
LANL	WIPP	$2.10x10^{-03}$	$1.28x10^{-02}$	$5.86x10^{-09}$	$1.19x10^{-05}$
RFETS	WIPP	$8.35x10^{-05}$	$4.90x10^{-04}$	$1.05x10^{-09}$	$8.49x10^{-05}$
SRS	WIPP	$1.30x10^{-04}$	$7.25x10^{-04}$	$7.03x10^{-10}$	$3.00x10^{-04}$
Small CH-TRU Waste Sites					
AMES	ANLE-E	$2.35x10^{-03}$	$1.37x10^{-02}$	$5.86x10^{-08}$	$1.66x10^{-04}$
	WIPP	$1.17x10^{-02}$	$6.78x10^{-02}$	$7.03x10^{-08}$	$1.40x10^{-05}$
ANL-E	WIPP	$1.17x10^{-04}$	$6.78x10^{-04}$	$7.03x10^{-10}$	$3.01x10^{-06}$
BETTIS	MOUND	$2.69x10^{-03}$	$1.33x10^{-02}$	$5.86x10^{-08}$	$6.14x10^{-04}$
	WIPP	$1.27x10^{-02}$	$7.32x10^{-02}$	$7.03x10^{-08}$	$1.75x10^{-05}$
ETEC	NTS	$1.78x10^{-02}$	$9.27x10^{-02}$	$3.28x10^{-07}$	$4.02x10^{-04}$
	WIPP	$9.72x10^{-02}$	$5.70x10^{-01}$	$8.20x10^{-07}$	$3.03x10^{-06}$
KAPL	MOUND	$6.17x10^{-03}$	$3.08x10^{-02}$	$5.86x10^{-08}$	$1.06x10^{-03}$
	WIPP	$1.27x10^{-02}$	$7.32x10^{-02}$	$7.03x10^{-08}$	$1.75x10^{-05}$
LBL	LLNL	$9.84x10^{-06}$	$4.30x10^{-05}$	$5.86x10^{-10}$	$2.57x10^{-05}$
	WIPP	$1.14x10^{-04}$	$6.74x10^{-04}$	$7.03x10^{-10}$	$1.06x10^{-06}$
LLNL	WIPP	$1.14x10^{-04}$	$6.74x10^{-04}$	$7.03x10^{-10}$	$8.79x10^{-06}$
MOUND	WIPP	$1.27x10^{-04}$	$7.32x10^{-04}$	$7.03x10^{-10}$	$3.46x10^{-04}$
MU	ANL-E	$2.94x10^{-05}$	$1.61x10^{-04}$	$5.86x10^{-10}$	$9.30x10^{-05}$
	WIPP	$1.17x10^{-04}$	$6.78x10^{-04}$	$7.03x10^{-10}$	$1.77x10^{-06}$
NTS	WIPP	$8.94x10^{-03}$	$5.45x10^{-02}$	$7.03x10^{-08}$	$1.05x10^{-05}$
ORNL	WIPP	$1.32x10^{-01}$	$7.38x10^{-01}$	$6.73x10^{-06}$	$2.29x10^{-05}$

TABLE L-15 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 10 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PADUCAH	ORNL	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	1.21×10^{-04}	7.06×10^{-04}	7.03×10^{-10}	6.59×10^{-05}
PANTEX	LANL	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	2.51×10^{-05}	1.53×10^{-04}	7.03×10^{-10}	4.74×10^{-08}
SNL	LANL	7.74×10^{-06}	4.27×10^{-05}	5.86×10^{-10}	4.36×10^{-07}
	WIPP	2.51×10^{-05}	1.53×10^{-04}	7.03×10^{-10}	5.65×10^{-09}

TABLE L-16

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 10 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	No. Of Shipments	Incident-Free Doses			Accident Risk Dose
			Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$6.40\times10^{+02}$	$3.83\times10^{+03}$	3.28×10^{-03}	1.63×10^{-01}
INEL	WIPP	4974	$5.27\times10^{+01}$	$3.14\times10^{+02}$	3.50×10^{-04}	4.97×10^{-02}
LANL	WIPP	2835	$5.95\times10^{+00}$	$3.63\times10^{+01}$	1.66×10^{-04}	3.37×10^{-02}
RFETS	WIPP	931	7.77×10^{-02}	4.56×10^{-01}	9.78×10^{-07}	7.90×10^{-02}
SRS	WIPP	2827	3.68×10^{-01}	$2.05\times10^{+00}$	1.99×10^{-06}	8.48×10^{-01}
		Subtotal	**$6.99\times10^{+02}$**	**$4.18\times10^{+03}$**	**3.80×10^{-03}**	**$1.17\times10^{+00}$**
Small CH-TRU Waste Sites						
AMES	ANL-E	1	2.35×10^{-03}	1.37×10^{-02}	5.86×10^{-08}	1.66×10^{-04}
	WIPP	1	1.17×10^{-02}	6.78×10^{-02}	7.03×10^{-08}	1.40×10^{-05}
ANL-E	WIPP	5	5.85×10^{-04}	3.39×10^{-03}	3.52×10^{-09}	1.51×10^{-05}
BETTIS	MOUND	17	4.57×10^{-02}	2.26×10^{-01}	9.96×10^{-07}	1.04×10^{-02}
	WIPP	17	2.16×10^{-01}	$1.24\times10^{+00}$	1.20×10^{-06}	2.98×10^{-04}
ETEC	NTS	2	3.56×10^{-02}	1.85×10^{-01}	6.56×10^{-07}	8.04×10^{-04}
	WIPP	2	1.94×10^{-01}	$1.14\times10^{+00}$	1.64×10^{-06}	6.06×10^{-06}
KAPL	MOUND	1	6.17×10^{-03}	3.08×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
	WIPP	1	1.27×10^{-02}	7.32×10^{-02}	7.03×10^{-08}	1.75×10^{-05}
LBL	LLNL	1	9.84×10^{-06}	4.30×10^{-05}	5.86×10^{-10}	2.57×10^{-05}
	WIPP	1	1.14×10^{-04}	6.74×10^{-04}	7.03×10^{-10}	1.06×10^{-06}
LLNL	WIPP	136	1.55×10^{-02}	9.17×10^{-02}	9.56×10^{-08}	1.20×10^{-03}
MOUND	WIPP	47	5.97×10^{-03}	3.44×10^{-02}	3.30×10^{-08}	1.63×10^{-02}
MU	ANL-E	1	2.94×10^{-05}	1.61×10^{-04}	5.86×10^{-10}	9.30×10^{-05}
	WIPP	1	1.17×10^{-04}	6.78×10^{-04}	7.03×10^{-10}	1.77×10^{-06}
NTS	WIPP	66	5.90×10^{-01}	$3.60\times10^{+00}$	4.64×10^{-06}	6.93×10^{-04}
ORNL	WIPP	119	$1.57\times10^{+01}$	$8.78\times10^{+01}$	8.01×10^{-04}	2.73×10^{-03}

TABLE L-16 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 10 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	No. Of Shipments	Incident-Free Doses			Accident Risk Dose
			Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PADUCAH	ORNL	1	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	1	1.21×10^{-04}	7.06×10^{-04}	7.03×10^{-10}	6.59×10^{-05}
PANTEX	LANL	1	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1	2.51×10^{-05}	1.53×10^{-04}	7.03×10^{-10}	4.74×10^{-08}
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	7.53×10^{-05}	4.59×10^{-04}	2.11×10^{-09}	1.70×10^{-08}
		Subtotal	**$1.68 \times 10^{+01}$**	**$9.45 \times 10^{+01}$**	**8.11×10^{-04}**	**3.58×10^{-02}**
		TOTAL	**$7.16 \times 10^{+02}$**	**$4.27 \times 10^{+03}$**	**4.61×10^{-03}**	**$1.21 \times 10^{+00}$**

TABLE L-17

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 10 - REGIONALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	1.12×10^{-01}	6.70×10^{-01}	5.74×10^{-07}	2.86×10^{-05}
INEL	WIPP	1.06×10^{-02}	6.32×10^{-02}	7.03×10^{-08}	1.00×10^{-05}
LANL	WIPP	2.10×10^{-03}	1.28×10^{-02}	5.86×10^{-08}	1.19×10^{-05}
RFETS	WIPP	8.35×10^{-05}	4.90×10^{-04}	1.05×10^{-09}	8.49×10^{-05}
SRS	WIPP	1.30×10^{-04}	7.25×10^{-04}	7.03×10^{-10}	3.00×10^{-04}
Small CH-TRU Waste Sites					
AMES	SRS	8.88×10^{-03}	4.85×10^{-02}	5.86×10^{-08}	1.07×10^{-03}
	WIPP	1.30×10^{-02}	7.25×10^{-02}	7.03×10^{-08}	2.12×10^{-05}
ANL-E	SRS	7.06×10^{-05}	3.71×10^{-04}	5.86×10^{-10}	6.35×10^{-04}
	WIPP	1.30×10^{-04}	7.25×10^{-04}	7.03×10^{-10}	4.56×10^{-06}
BETTIS	SRS	5.30×10^{-03}	2.85×10^{-02}	5.86×10^{-08}	7.15×10^{-04}
	WIPP	1.30×10^{-02}	7.25×10^{-02}	7.03×10^{-08}	2.12×10^{-05}
ETEC	INEL	4.06×10^{-02}	2.23×10^{-01}	3.28×10^{-07}	6.88×10^{-04}
	WIPP	1.15×10^{-01}	6.62×10^{-01}	8.20×10^{-07}	4.41×10^{-06}
KAPL	SRS	7.49×10^{-03}	3.97×10^{-02}	5.86×10^{-08}	9.92×10^{-04}
	WIPP	1.30×10^{-02}	7.25×10^{-02}	7.03×10^{-08}	2.12×10^{-05}
LBL	HANFORD	6.53×10^{-05}	3.57×10^{-04}	5.86×10^{-10}	6.10×10^{-05}
	WIPP	1.37×10^{-04}	8.21×10^{-04}	7.03×10^{-10}	7.99×10^{-07}
LLNL	HANFORD	6.70×10^{-05}	3.66×10^{-04}	5.86×10^{-10}	5.42×10^{-04}
	WIPP	1.37×10^{-04}	8.21×10^{-04}	7.03×10^{-10}	6.61×10^{-06}
MOUND	SRS	5.14×10^{-05}	2.70×10^{-04}	5.86×10^{-10}	1.77×10^{-02}
	WIPP	1.30×10^{-04}	7.25×10^{-04}	7.03×10^{-10}	4.18×10^{-04}
MU	SRS	6.81×10^{-05}	3.63×10^{-04}	5.86×10^{-10}	2.49×10^{-04}
	WIPP	1.30×10^{-04}	7.25×10^{-04}	7.03×10^{-10}	2.69×10^{-06}

TABLE L-17 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 10 - REGIONALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
NTS	INEL	4.92×10^{-03}	2.82×10^{-02}	5.86×10^{-08}	1.17×10^{-03}
	WIPP	1.06×10^{-02}	6.32×10^{-02}	7.03×10^{-08}	1.53×10^{-05}
ORNL	SRS	3.65×10^{-02}	1.87×10^{-01}	1.26×10^{-05}	7.15×10^{-04}
	WIPP	1.41×10^{-01}	7.59×10^{-01}	6.73×10^{-06}	3.38×10^{-05}
PADUCAH	SRS	4.61×10^{-05}	2.42×10^{-04}	5.86×10^{-10}	6.34×10^{-03}
	WIPP	1.30×10^{-04}	7.25×10^{-04}	7.03×10^{-10}	9.73×10^{-05}
PANTEX	LANL	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	2.51×10^{-05}	1.53×10^{-04}	7.03×10^{-10}	4.74×10^{-08}
SNL	LANL	7.74×10^{-06}	4.27×10^{-05}	5.86×10^{-10}	4.36×10^{-07}
	WIPP	2.51×10^{-05}	1.53×10^{-04}	7.03×10^{-10}	5.65×10^{-09}

TABLE L-18

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 10 - REGIONALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	To Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$6.40 \times 10^{+02}$	$3.83 \times 10^{+03}$	3.28×10^{-03}	1.63×10^{-01}
INEL	WIPP	4974	$5.27 \times 10^{+01}$	$3.14 \times 10^{+02}$	3.50×10^{-04}	4.97×10^{-02}
LANL	WIPP	2835	$5.95 \times 10^{+00}$	$3.63 \times 10^{+01}$	1.66×10^{-04}	3.37×10^{-02}
RFETS	WIPP	931	7.77×10^{-02}	4.56×10^{-01}	9.78×10^{-07}	7.90×10^{-02}
SRS	WIPP	2827	3.68×10^{-01}	$2.05 \times 10^{+00}$	1.99×10^{-06}	8.48×10^{-01}
		Subtotal	**$6.99 \times 10^{+02}$**	**$4.18 \times 10^{+03}$**	**3.80×10^{-03}**	**$1.17 \times 10^{+00}$**
Small CH-TRU Waste Sites						
AMES	SRS	1	8.88×10^{-03}	4.85×10^{-02}	5.86×10^{-08}	1.07×10^{-03}
	WIPP	1	1.30×10^{-02}	7.25×10^{-02}	7.03×10^{-08}	2.12×10^{-05}
ANL-E	SRS	5	3.53×10^{-04}	1.86×10^{-03}	2.93×10^{-09}	3.18×10^{-03}
	WIPP	5	6.50×10^{-04}	3.63×10^{-03}	3.52×10^{-09}	2.28×10^{-05}
BETTIS	SRS	17	9.01×10^{-02}	4.85×10^{-01}	9.96×10^{-07}	1.22×10^{-02}
	WIPP	17	2.21×10^{-01}	$1.23 \times 10^{+00}$	1.20×10^{-06}	3.60×10^{-04}
ETEC	INEL	2	8.12×10^{-02}	4.46×10^{-01}	6.56×10^{-07}	1.38×10^{-03}
	WIPP	2	2.30×10^{-01}	$1.32 \times 10^{+00}$	1.64×10^{-05}	8.82×10^{-06}
KAPL	SRS	1	7.49×10^{-03}	3.97×10^{-02}	5.86×10^{-08}	9.92×10^{-04}
	WIPP	1	1.30×10^{-02}	7.25×10^{-02}	7.03×10^{-08}	2.12×10^{-05}
LBL	HANFORD	1	6.53×10^{-05}	3.57×10^{-04}	5.86×10^{-10}	6.10×10^{-05}
	WIPP	1	1.37×10^{-04}	8.21×10^{-04}	7.03×10^{-10}	7.99×10^{-07}
LLNL	HANFORD	136	9.11×10^{-03}	4.98×10^{-02}	7.97×10^{-08}	7.37×10^{-02}
	WIPP	136	1.86×10^{-02}	1.12×10^{-01}	9.56×10^{-08}	8.99×10^{-04}
MOUND	SRS	29	1.49×10^{-03}	7.83×10^{-03}	1.70×10^{-08}	5.13×10^{-01}
	WIPP	29	3.77×10^{-03}	2.10×10^{-02}	2.04×10^{-08}	1.21×10^{-02}
MU	SRS	1	6.81×10^{-05}	3.63×10^{-04}	5.86×10^{-10}	2.49×10^{-04}
	WIPP	1	1.30×10^{-04}	7.25×10^{-04}	7.03×10^{-10}	2.69×10^{-06}

TABLE L-18 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 10 - REGIONALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	To Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
NTS	INEL	66	3.25×10^{-01}	$1.86 \times 10^{+00}$	3.87×10^{-06}	7.72×10^{-02}
	WIPP	66	7.00×10^{-01}	$4.17 \times 10^{+00}$	4.64×10^{-06}	1.01×10^{-03}
ORNL	SRS	119	$4.34 \times 10^{+00}$	$2.23 \times 10^{+01}$	1.50×10^{-03}	8.51×10^{-02}
	WIPP	119	$1.68 \times 10^{+01}$	$9.03 \times 10^{+01}$	8.01×10^{-04}	4.02×10^{-03}
PADUCAH	SRS	1	4.61×10^{-05}	2.42×10^{-04}	5.86×10^{-10}	6.34×10^{-03}
	WIPP	1	1.30×10^{-04}	7.25×10^{-04}	7.03×10^{-10}	9.73×10^{-05}
PANTEX	LANL	1	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1	2.51×10^{-05}	1.53×10^{-04}	7.03×10^{-10}	4.74×10^{-08}
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	7.53×10^{-05}	4.59×10^{-04}	2.11×10^{-09}	1.70×10^{-08}
		Subtotal	**$2.29 \times 10^{+01}$**	**$1.23 \times 10^{+02}$**	**2.31×10^{-03}**	**7.93×10^{-01}**
		TOTAL	**$7.22 \times 10^{+02}$**	**$4.30 \times 10^{+03}$**	**6.11×10^{-03}**	**$1.96 \times 10^{+00}$**

TABLE L-19

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 94 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	6.72×10^{-02}	4.04×10^{-01}	3.46×10^{-07}	1.30×10^{-03}
INEL	WIPP	4.49×10^{-03}	2.69×10^{-02}	2.99×10^{-08}	3.03×10^{-04}
LANL	WIPP	9.01×10^{-04}	5.50×10^{-03}	2.52×10^{-08}	4.01×10^{-04}
RFETS	WIPP	3.71×10^{-05}	2.18×10^{-04}	4.68×10^{-10}	2.91×10^{-03}
SRS	WIPP	8.65×10^{-05}	4.83×10^{-04}	4.68×10^{-10}	1.56×10^{-02}
Small CH-TRU Waste Sites					
AMES	ANLE-E	2.35×10^{-03}	1.37×10^{-02}	5.86×10^{-08}	1.66×10^{-04}
	WIPP	4.97×10^{-03}	2.88×10^{-02}	2.99×10^{-08}	4.29×10^{-04}
ANL-E	WIPP	7.80×10^{-05}	4.52×10^{-04}	4.68×10^{-10}	9.08×10^{-05}
BETTIS	MOUND	2.69×10^{-03}	1.33×10^{-02}	5.86×10^{-08}	6.14×10^{-04}
	WIPP	5.41×10^{-03}	3.11×10^{-02}	2.99×10^{-08}	5.37×10^{-04}
ETEC	NTS	1.78×10^{-02}	9.27×10^{-02}	3.28×10^{-07}	4.02×10^{-04}
	WIPP	7.45×10^{-02}	4.54×10^{-01}	5.86×10^{-07}	1.53×10^{-04}
KAPL	MOUND	6.17×10^{-03}	3.08×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
	WIPP	5.41×10^{-03}	3.11×10^{-02}	2.99×10^{-08}	5.37×10^{-04}
LBL	LLNL	9.84×10^{-06}	4.30×10^{-05}	5.86×10^{-10}	2.57×10^{-05}
	WIPP	7.63×10^{-05}	4.49×10^{-04}	4.68×10^{-10}	4.42×10^{-05}
LLNL	WIPP	7.63×10^{-05}	4.49×10^{-04}	4.68×10^{-10}	3.75×10^{-04}
MOUND	WIPP	8.49×10^{-05}	4.87×10^{-04}	4.68×10^{-10}	1.72×10^{-02}
MU	ANL-E	2.94×10^{-05}	1.61×10^{-04}	5.86×10^{-10}	9.30×10^{-05}
	WIPP	7.80×10^{-05}	4.52×10^{-04}	4.68×10^{-10}	1.39×10^{-04}
NTS	WIPP	3.80×10^{-03}	2.31×10^{-02}	2.99×10^{-08}	5.29×10^{-04}
ORNL	WIPP	1.32×10^{-01}	7.38×10^{-01}	4.02×10^{-06}	1.03×10^{-03}

TABLE L-19 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 94 - DECENTRALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PADUCAH	ORNL	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	8.07×10^{-05}	4.71×10^{-04}	4.68×10^{-10}	2.05×10^{-03}
PANTEX	LANL	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1.68×10^{-05}	1.02×10^{-04}	4.68×10^{-10}	2.54×10^{-06}
SNL	LANL	7.74×10^{-06}	4.27×10^{-05}	5.86×10^{-10}	4.36×10^{-07}
	WIPP	1.68×10^{-05}	1.02×10^{-04}	4.68×10^{-10}	3.13×10^{-07}

TABLE L-20

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 94 - DECENTRALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$3.84 \times 10^{+02}$	$2.31 \times 10^{+03}$	1.98×10^{-03}	$7.43 \times 10^{+00}$
INEL	WIPP	4974	$2.23 \times 10^{+01}$	$1.34 \times 10^{+02}$	1.49×10^{-04}	$1.51 \times 10^{+00}$
LANL	WIPP	2835	$2.55 \times 10^{+00}$	$1.56 \times 10^{+01}$	7.14×10^{-05}	$1.14 \times 10^{+00}$
RFETS	WIPP	931	3.45×10^{-02}	2.03×10^{-01}	4.36×10^{-07}	$2.71 \times 10^{+00}$
SRS	WIPP	2827	2.45×10^{-01}	$1.37 \times 10^{+00}$	1.32×10^{-06}	$4.41 \times 10^{+01}$
		Subtotal	**$4.09 \times 10^{+02}$**	**$2.46 \times 10^{+03}$**	**2.20×10^{-03}**	**$5.69 \times 10^{+01}$**
Small CH-TRU Waste Sites						
AMES	ANL-E	1	2.35×10^{-03}	1.37×10^{-02}	5.86×10^{-08}	1.66×10^{-04}
	WIPP	1	4.97×10^{-03}	2.88×10^{-02}	2.99×10^{-08}	4.29×10^{-04}
ANL-E	WIPP	5	3.90×10^{-04}	2.26×10^{-03}	2.34×10^{-09}	4.54×10^{-04}
BETTIS	MOUND	17	4.57×10^{-02}	2.26×10^{-01}	9.96×10^{-07}	1.04×10^{-02}
	WIPP	17	9.20×10^{-02}	5.29×10^{-01}	5.08×10^{-07}	9.13×10^{-03}
ETEC	NTS	2	3.56×10^{-02}	1.85×10^{-01}	6.56×10^{-07}	8.04×10^{-04}
	WIPP	2	1.49×10^{-01}	9.08×10^{-01}	1.17×10^{-06}	3.06×10^{-04}
KAPL	MOUND	1	6.17×10^{-03}	3.08×10^{-02}	5.86×10^{-08}	1.06×10^{-03}
	WIPP	1	5.41×10^{-03}	3.11×10^{-02}	2.99×10^{-08}	5.37×10^{-04}
LBL	LLNL	1	9.84×10^{-06}	4.30×10^{-05}	5.86×10^{-10}	2.57×10^{-05}
	WIPP	1	7.63×10^{-05}	4.49×10^{-04}	4.68×10^{-10}	4.42×10^{-05}
LLNL	WIPP	136	1.04×10^{-02}	6.11×10^{-02}	6.36×10^{-08}	5.10×10^{-02}
MOUND	WIPP	29	2.46×10^{-03}	1.41×10^{-02}	1.36×10^{-08}	4.99×10^{-01}
MU	ANL-E	1	2.94×10^{-05}	1.61×10^{-04}	5.86×10^{-10}	9.30×10^{-05}
	WIPP	1	7.80×10^{-05}	4.52×10^{-04}	4.68×10^{-10}	1.39×10^{-04}
NTS	WIPP	66	2.51×10^{-01}	$1.52 \times 10^{+00}$	1.97×10^{-06}	3.49×10^{-02}
ORNL	WIPP	119	$1.57 \times 10^{+01}$	$8.78 \times 10^{+01}$	4.78×10^{-04}	1.23×10^{-01}

TABLE L-20 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 94 - DECENTRALIZED CONFIGURATION

			Incident-Free Doses			Accident Risk Dose
Waste Origin Site	Route Segment Destination	No. Of Shipments	Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
PADUCAH	ORNL	1	2.26×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	1.86×10^{-03}
	WIPP	1	8.07×10^{-05}	4.71×10^{-04}	4.68×10^{-10}	2.05×10^{-03}
PANTEX	LANL	1	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1	1.68×10^{-05}	1.02×10^{-04}	4.68×10^{-10}	2.54×10^{-06}
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	5.04×10^{-05}	3.06×10^{-04}	1.40×10^{-09}	9.39×10^{-07}
		Subtotal	**$1.63 \times 10^{+01}$**	**$9.14 \times 10^{+01}$**	**4.84×10^{-04}**	**7.35×10^{-01}**
		TOTAL	**$4.25 \times 10^{+02}$**	**$2.55 \times 10^{+03}$**	**2.68×10^{-03}**	**$5.76 \times 10^{+01}$**

TABLE L-21

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 94 - REGIONALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites					
HANFORD	WIPP	6.72×10^{-02}	4.04×10^{-01}	3.46×10^{-07}	1.30×10^{-03}
INEL	WIPP	4.49×10^{-03}	2.69×10^{-02}	2.99×10^{-08}	3.03×10^{-04}
LANL	WIPP	9.01×10^{-04}	5.50×10^{-03}	2.52×10^{-08}	4.01×10^{-04}
RFETS	WIPP	3.71×10^{-05}	2.18×10^{-04}	4.68×10^{-10}	2.91×10^{-03}
SRS	WIPP	8.65×10^{-05}	4.83×10^{-04}	4.68×10^{-10}	1.56×10^{-02}
Small CH-TRU Waste Sites					
AMES	SRS	8.88×10^{-03}	4.85×10^{-02}	5.86×10^{-08}	1.07×10^{-03}
	WIPP	5.51×10^{-03}	3.08×10^{-02}	2.99×10^{-08}	6.52×10^{-04}
ANL-E	SRS	7.06×10^{-05}	3.71×10^{-04}	5.86×10^{-10}	6.35×10^{-04}
	WIPP	8.65×10^{-05}	4.83×10^{-04}	4.68×10^{-10}	1.38×10^{-04}
BETTIS	SRS	5.30×10^{-03}	2.85×10^{-02}	5.86×10^{-08}	7.15×10^{-04}
	WIPP	5.51×10^{-03}	3.08×10^{-02}	2.99×10^{-08}	6.52×10^{-04}
ETEC	INEL	4.06×10^{-02}	2.23×10^{-01}	3.28×10^{-07}	6.88×10^{-04}
	WIPP	8.81×10^{-02}	5.27×10^{-01}	5.86×10^{-07}	2.25×10^{-04}
KAPL	SRS	7.49×10^{-03}	3.97×10^{-02}	5.86×10^{-08}	9.92×10^{-04}
	WIPP	5.51×10^{-03}	3.08×10^{-02}	2.99×10^{-08}	6.52×10^{-04}
LBL	HANFORD	6.53×10^{-05}	3.57×10^{-04}	5.86×10^{-10}	6.10×10^{-05}
	WIPP	9.11×10^{-05}	5.46×10^{-04}	4.68×10^{-10}	3.54×10^{-05}
LLNL	HANFORD	6.70×10^{-05}	3.66×10^{-04}	5.86×10^{-10}	5.42×10^{-04}
	WIPP	9.11×10^{-05}	5.46×10^{-04}	4.68×10^{-10}	3.00×10^{-04}
MOUND	SRS	5.14×10^{-05}	2.70×10^{-04}	5.86×10^{-10}	1.77×10^{-02}
	WIPP	8.65×10^{-05}	4.83×10^{-04}	4.68×10^{-10}	2.09×10^{-02}
MU	SRS	6.81×10^{-05}	3.63×10^{-04}	5.86×10^{-10}	2.49×10^{-04}
	WIPP	8.65×10^{-05}	4.83×10^{-04}	4.68×10^{-10}	2.11×10^{-04}

TABLE L-21 (Continued)

RADIOLOGICAL DOSES PER SHIPMENT FOR CH-TRU WASTE ENGINEERED ALTERNATIVE No. 94 - REGIONALIZED CONFIGURATION

Waste Origin Site	Route Segment Destination	Incident-Free Doses			Accident Risk Dose
		Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
NTS	INEL	4.92×10^{-03}	2.82×10^{-02}	5.86×10^{-08}	1.17×10^{-03}
	WIPP	4.49×10^{-03}	2.69×10^{-02}	2.99×10^{-08}	7.82×10^{-04}
ORNL	SRS	3.65×10^{-02}	1.87×10^{-01}	1.26×10^{-05}	7.15×10^{-04}
	WIPP	1.41×10^{-01}	7.59×10^{-01}	4.02×10^{-06}	1.54×10^{-03}
PADUCAH	SRS	4.61×10^{-05}	2.42×10^{-04}	5.86×10^{-10}	6.34×10^{-03}
	WIPP	8.65×10^{-05}	4.83×10^{-04}	4.68×10^{-10}	3.07×10^{-03}
PANTEX	LANL	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1.68×10^{-05}	1.02×10^{-04}	4.68×10^{-10}	2.54×10^{-06}
SNL	LANL	7.74×10^{-06}	4.27×10^{-05}	5.86×10^{-10}	4.36×10^{-07}
	WIPP	1.68×10^{-05}	1.02×10^{-04}	4.68×10^{-10}	3.13×10^{-07}

TABLE L-22

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 94 - REGIONALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Incident-Free Doses			Accident Risk Dose
			Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
Major CH-TRU Waste Sites						
HANFORD	WIPP	5712	$3.84 \times 10^{+02}$	$2.31 \times 10^{+03}$	1.98×10^{-03}	$7.43 \times 10^{+00}$
INEL	WIPP	4974	$2.23 \times 10^{+01}$	$1.34 \times 10^{+02}$	1.49×10^{-04}	$1.51 \times 10^{+00}$
LANL	WIPP	2835	$2.55 \times 10^{+00}$	$1.56 \times 10^{+01}$	7.14×10^{-05}	$1.14 \times 10^{+00}$
RFETS	WIPP	931	3.45×10^{-02}	2.03×10^{-01}	4.36×10^{-07}	$2.71 \times 10^{+00}$
SRS	WIPP	2827	2.45×10^{-01}	$1.37 \times 10^{+00}$	1.32×10^{-06}	$4.41 \times 10^{+01}$
		Subtotal	**$4.09 \times 10^{+02}$**	**$2.46 \times 10^{+03}$**	**2.20×10^{-03}**	**$5.69 \times 10^{+01}$**
Small CH-TRU Waste Sites						
AMES	SRS	1	8.88×10^{-03}	4.85×10^{-02}	5.86×10^{-08}	1.07×10^{-03}
	WIPP	1	5.51×10^{-03}	3.08×10^{-02}	2.99×10^{-08}	6.52×10^{-04}
ANL-E	SRS	5	3.53×10^{-04}	1.86×10^{-03}	2.93×10^{-09}	3.18×10^{-03}
	WIPP	5	4.33×10^{-04}	2.42×10^{-03}	2.34×10^{-09}	6.90×10^{-04}
BETTIS	SRS	17	9.01×10^{-02}	4.85×10^{-01}	9.96×10^{-07}	1.22×10^{-02}
	WIPP	17	9.37×10^{-02}	5.24×10^{-01}	5.08×10^{-07}	1.11×10^{-02}
ETEC	INEL	2	8.12×10^{-02}	4.46×10^{-01}	6.56×10^{-07}	1.38×10^{-03}
	WIPP	2	1.76×10^{-01}	$1.05 \times 10^{+00}$	1.17×10^{-06}	4.50×10^{-04}
KAPL	SRS	1	7.49×10^{-03}	3.97×10^{-02}	5.86×10^{-08}	9.92×10^{-04}
	WIPP	1	5.51×10^{-03}	3.08×10^{-02}	2.99×10^{-08}	6.52×10^{-04}
LBL	HANFORD	1	6.53×10^{-05}	3.57×10^{-04}	5.86×10^{-10}	6.10×10^{-05}
	WIPP	1	9.11×10^{-05}	5.46×10^{-04}	4.68×10^{-10}	3.54×10^{-05}
LLNL	HANFORD	136	9.11×10^{-03}	4.98×10^{-02}	7.97×10^{-08}	7.37×10^{-02}
	WIPP	136	1.24×10^{-02}	7.43×10^{-02}	6.36×10^{-08}	4.08×10^{-02}
MOUND	SRS	29	1.49×10^{-03}	7.83×10^{-03}	1.70×10^{-08}	5.13×10^{-01}
	WIPP	29	2.51×10^{-03}	1.40×10^{-02}	1.36×10^{-08}	6.06×10^{-01}
MU	SRS	1	6.81×10^{-05}	3.63×10^{-04}	5.86×10^{-10}	2.49×10^{-04}
	WIPP	1	8.65×10^{-05}	4.83×10^{-04}	4.68×10^{-10}	2.11×10^{-04}

TABLE L-22 (Continued)

CUMULATIVE RADIOLOGICAL DOSES FOR CH-TRU WASTE SHIPMENTS OVER THE LIFETIME OF THE WIPP FACILITY ENGINEERED ALTERNATIVE No. 94 - REGIONALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Incident-Free Doses			Accident Risk Dose
			Crew (person-rem)	Public (person-rem)	Max Individual (rem)	Public (person-rem)
NTS	INEL	66	3.25×10^{-01}	$1.86 \times 10^{+00}$	3.87×10^{-06}	7.72×10^{-02}
	WIPP	66	2.96×10^{-01}	$1.78 \times 10^{+00}$	1.97×10^{-06}	5.16×10^{-02}
ORNL	SRS	119	$4.34 \times 10^{+00}$	$2.23 \times 10^{+01}$	1.50×10^{-03}	8.51×10^{-02}
	WIPP	119	$1.68 \times 10^{+01}$	$9.03 \times 10^{+01}$	4.78×10^{-04}	1.83×10^{-01}
PADUCAH	SRS	1	4.61×10^{-05}	2.42×10^{-04}	5.86×10^{-10}	6.34×10^{-03}
	WIPP	1	8.65×10^{-05}	4.83×10^{-04}	4.68×10^{-10}	3.07×10^{-03}
PANTEX	LANL	1	2.05×10^{-05}	1.26×10^{-04}	5.86×10^{-10}	3.83×10^{-06}
	WIPP	1	1.68×10^{-05}	1.02×10^{-04}	4.68×10^{-10}	2.54×10^{-06}
SNL	LANL	3	2.32×10^{-05}	1.28×10^{-04}	1.76×10^{-09}	1.31×10^{-06}
	WIPP	3	5.04×10^{-05}	3.06×10^{-04}	1.40×10^{-09}	9.39×10^{-07}
		Subtotal	**$2.23 \times 10^{+01}$**	**$1.19 \times 10^{+02}$**	**1.99×10^{-03}**	**$1.67 \times 10^{+00}$**
		TOTAL	**$4.31 \times 10^{+02}$**	**$2.58 \times 10^{+03}$**	**4.19×10^{-03}**	**$5.86 \times 10^{+01}$**

TABLE L-23

CHEMICAL AIRBORNE RELEASES FOR A POSTULATED VERY SEVERE ACCIDENT (CH-TRU TRUCK SHIPMENT) - BASELINE[1,3,4,5,6]

Chemical	Release Form	Release Fraction	Fraction of Waste Chemical is Present	Chemical Fraction in Waste Matrix	Quantity Released (mg)	Receptor Concentration (mg/m3)	Adjusted ERPG-2 Value (mg/m3)	Receptor Concentration/ Adj.'d ERPG-2 Value
Beryllium	particulate	$2.0x10^{-04}$	$2.1x10^{-01}$	$1.0x10^{-02}$	$2.6x10^{+03}$	$4.1x10^{-05}$	$2.5x10^{-03}$	$1.6x10^{-02}$
Bromine	vapor	$5.0x10^{-01}$	$6.6x10^{-02}$	$1.0x10^{-02}$	$2.0x10^{+06}$	$3.2x10^{-02}$	$3.3x10^{+00}$	$9.7x10^{-03}$
Cadmium	particulate	$2.0x10^{-04}$	$1.9x10^{-01}$	$3.0x10^{-01}$	$7.0x10^{+04}$	$1.1x10^{-03}$	$1.5x10^{-01}$	$7.3x10^{-03}$
Cadmium	vapor	$1.6x10^{-02}$	$1.9x10^{-01}$	$3.0x10^{-01}$	$5.6x10^{+06}$	$8.8x10^{-02}$	$1.5x10^{-01}$	$5.9x10^{-01}$
Carbon Tetrachloride	vapor	$5.0x10^{-01}$	$1.3x10^{-01}$	$3.0x10^{-01}$	$1.2x10^{+08}$	$1.9x10^{+00}$	$7.9x10^{+01}$	$2.4x10^{-02}$
Cellulose	particulate	$2.0x10^{-02}$	$9.1x10^{-02}$	$3.0x10^{-01}$	$3.4x10^{+06}$	$5.3x10^{-02}$	$2.5x10^{+01}$	$2.1x10^{-03}$
Chloroform	vapor	$5.0x10^{-01}$	$6.0x10^{-03}$	$3.0x10^{-01}$	$5.5x10^{+06}$	$8.7x10^{-02}$	$2.4x10^{+02}$	$3.6x10^{-04}$
Chlorosulporic acid	vapor	$5.0x10^{-01}$	$1.8x10^{-01}$	$1.0x10^{-02}$	$5.5x10^{+06}$	$8.7x10^{-02}$	$5.0x10^{+00}$	$1.7x10^{-02}$
Chromium VI compounds	particulate	$2.0x10^{-04}$	$1.9x10^{-01}$	$1.0x10^{-02}$	$2.3x10^{+03}$	$3.7x10^{-05}$	$1.3x10^{-01}$	$2.8x10^{-04}$
Copper	particulate	$2.0x10^{-04}$	$1.9x10^{-01}$	$1.0x10^{-01}$	$2.3x10^{+04}$	$3.7x10^{-04}$	$5.0x10^{-01}$	$7.3x10^{-04}$
Hydrazine	vapor	$5.0x10^{-01}$	$1.3x10^{-01}$	$1.0x10^{-02}$	$4.0x10^{+06}$	$6.3x10^{-02}$	$5.5x10^{-01}$	$1.1x10^{-01}$
Lead	particulate	$2.0x10^{-04}$	$1.9x10^{-01}$	$3.0x10^{-01}$	$7.0x10^{+04}$	$1.1x10^{-03}$	$3.8x10^{-01}$	$2.9x10^{-03}$
Mercury	vapor	$5.0x10^{-01}$	$3.6x10^{-02}$	$1.0x10^{-02}$	$1.1x10^{+06}$	$1.7x10^{-02}$	$5.0x10^{-02}$	$3.5x10^{-01}$
Oxalic acid	vapor	$5.0x10^{-01}$	$1.8x10^{-01}$	$1.0x10^{-02}$	$5.5x10^{+06}$	$8.7x10^{-02}$	$2.5x10^{+00}$	$3.5x10^{-02}$
Platinum	particulate	$2.0x10^{-04}$	$2.8x10^{-01}$	$1.0x10^{-01}$	$3.4x10^{+04}$	$5.4x10^{-04}$	$2.5x10^{+00}$	$2.2x10^{-04}$

Refer to footnotes at end of table.

TABLE L-23 (Continued)

CHEMICAL AIRBORNE RELEASES FOR A POSTULATED VERY SEVERE ACCIDENT (CH-TRU TRUCK SHIPMENT) - BASELINE[1,3,4,5,6]

Chemical	Release Form	Release Fraction	Fraction of Waste Chemical is Present	Chemical Fraction in Waste Matrix	Quantity Released (mg)	Receptor Concentration (mg/m3)	Adjusted ERPG-2 Value (mg/m3)	Receptor Concentration/ Adj.'d ERPG-2 Value
Phosphoric acid	particulate	$2.0x10^{-04}$	$6.0x10^{-03}$	$1.0x10^{-02}$	$7.4x10^{+01}$	$1.2x10^{-06}$	$2.5x10^{+00}$	$4.6x10^{-07}$
Silver	particulate	$2.0x10^{-04}$	$1.5x10^{-01}$	$1.0x10^{-02}$	$1.8x10^{+03}$	$2.9x10^{-05}$	$2.5x10^{-01}$	$1.2x10^{-04}$
Sodium hydroxide	particulate	$2.0x10^{-04}$	$1.6x10^{-01}$	$1.0x10^{-02}$	$2.0x10^{+03}$	$3.1x10^{-05}$	$1.0x10^{+00}$	$3.1x10^{-05}$
Tributyl phosphate	vapor	$5.0x10^{-01}$	$2.4x10^{-02}$	$3.0x10^{-01}$	$2.2x10^{+07}$	$3.5x10^{-01}$	$5.5x10^{+00}$	$6.3x10^{-02}$
Tungsten	particulate	$2.0x10^{-04}$	$1.9x10^{-01}$	$1.0x10^{-01}$	$2.3x10^{+04}$	$3.7x10^{-04}$	$2.5x10^{+00}$	$1.5x10^{-04}$
Uranium	particulate	$2.0x10^{-04}$	$1.5x10^{-01}$	$1.0x10^{-02}$	$1.8x10^{+03}$	$2.9x10^{-05}$	$5.0x10^{-01}$	$5.8x10^{-05}$
TOTAL								$1.2X10^{+03}$

[1]Assumes a severity category VIII accident.
[2]See Section 3.5.2.1.3 text for basis of chemicals evaluated and release quantities.
[3]The receptor is the maximum exposed member of the public, with downwind dispersion characteristics based on a wind speed of 1 meter/sec and Pasquill Stability Class F ($X/Q = 1.13x10^{-04}$).
[4]Quantity Released = Release Fraction x Fraction of Waste Chemical is Present x Chemical Fraction in Waste x Weight of Waste/Shipment.
[5]Weight of Waste/Shipment (mg) = 3.67 (m3/TRUPACT) x 3 (TRUPACT/Shipment) x 559 (kg/m3) x $1x10^{+06}$; TRUPACT cargo volume based on 2 SWBs.
[6]Receptor Concentration = X/Q (max individual) x Release rate (mg/sec); = 1.13x10-04 ($sec/^{m3}$) x Release Quantity (mg)/7200 (sec); assumes a two hour release.

TABLE L-24

CHEMICAL AIRBORNE RELEASES FOR A POSTULATED VERY SEVERE ACCIDENT (CH-TRU TRUCK SHIPMENT) - ENGINEERED ALTERNATIVES[1,2,3,4,5,6]

		Engineered Alternatives No. 1 & 77		Engineered Alternative No. 6		Engineered Alternative No. 10		Engineered Alternative No. 94	
Chemical	Release Form	Release Fraction	Receptor Concentration/ Adj'd ERPG-2 Value	Release Fraction	Receptor Concentration/ Adj'd ERPG-2 Value	Release Fraction	Receptor Concentration/ Adj'd ERPG-2 Value	Release Fraction	Receptor Concentration/ Adj'd ERPG-2 Value
Beryllium	particulate	2.0×10^{-05}	2.4×10^{-03}	2.0×10^{-04}	1.6×10^{-02}	7.0×10^{-08}	1.6×10^{-05}	2.0×10^{-04}	1.1×10^{-02}
Bromine	vapor	5.0×10^{-01}	1.4×10^{-02}	5.0×10^{-01}	9.4×10^{-03}	$0.0\times10^{+00}$	$0.0\times10^{+00}$	5.0×10^{-01}	6.4×10^{-03}
Cadmium	particulate	2.0×10^{-05}	1.1×10^{-03}	2.0×10^{-04}	7.2×10^{-03}	$0.0\times10^{+00}$	$0.0\times10^{+00}$	2.0×10^{-04}	4.9×10^{-03}
Cadmium	vapor	1.6×10^{-02}	8.6×10^{-01}	1.6×10^{-02}	5.7×10^{-01}	$0.0\times10^{+00}$	$0.0\times10^{+00}$	1.6×10^{-02}	3.9×10^{-01}
Carbon Tetrachloride	vapor	5.0×10^{-01}	3.5×10^{-02}	5.0×10^{-01}	2.3×10^{-02}	$0.0\times10^{+00}$	$0.0\times10^{+00}$	5.0×10^{-01}	1.6×10^{-02}
Cellulose	particulate	2.0×10^{-02}	3.1×10^{-03}	2.0×10^{-02}	2.1×10^{-03}	$0.0\times10^{+00}$	$0.0\times10^{+00}$	2.0×10^{-02}	1.4×10^{-03}
Chloroform	vapor	5.0×10^{-01}	5.3×10^{-04}	5.0×10^{-01}	3.5×10^{-04}	$0.0\times10^{+00}$	$0.0\times10^{+00}$	5.0×10^{-01}	2.4×10^{-04}
Chlorosulporic acid	vapor	5.0×10^{-01}	2.5×10^{-02}	5.0×10^{-01}	1.7×10^{-02}	$0.0\times10^{+00}$	$0.0\times10^{+00}$	5.0×10^{-01}	1.2×10^{-02}
Chromium VI compounds	particulate	2.0×10^{-05}	4.1×10^{-05}	2.0×10^{-04}	2.8×10^{-04}	7.0×10^{-08}	2.8×10^{-07}	2.0×10^{-04}	1.9×10^{-04}
Copper	particulate	2.0×10^{-05}	1.1×10^{-04}	2.0×10^{-04}	7.2×10^{-04}	7.0×10^{-08}	7.3×10^{-07}	2.0×10^{-04}	4.9×10^{-04}
Hydrazine	vapor	5.0×10^{-01}	1.7×10^{-01}	5.0×10^{-01}	1.1×10^{-01}	$0.0\times10^{+00}$	$0.0\times10^{+00}$	5.0×10^{-01}	7.6×10^{-02}
Lead	particulate	2.0×10^{-05}	4.2×10^{-04}	2.0×10^{-04}	2.8×10^{-03}	7.0×10^{-08}	2.9×10^{-06}	2.0×10^{-04}	1.9×10^{-03}

Refer to footnotes at end of table.

TABLE L-24 (Continued)

CHEMICAL AIRBORNE RELEASES FOR A POSTULATED VERY SEVERE ACCIDENT (CH-TRU TRUCK SHIPMENT) - ENGINEERED ALTERNATIVES[1,2,3,4,5,6]

		Engineered Alternatives No. 1 & 77		Engineered Alternative No. 6		Engineered Alternative No. 10		Engineered Alternative No. 94	
Chemical	Release Form	Release Fraction	Receptor Concentration/ Adj'd ERPG-2 Value	Release Fraction	Receptor Concentration/ Adj'd ERPG-2 Value	Release Fraction	Receptor Concentration/ Adj'd ERPG-2 Value	Release Fraction	Receptor Concentration/ Adj'd ERPG-2 Value
Mercury	vapor	$5.0x10^{-01}$	$5.x10^{-01}$	$5.0x10^{-01}$	$3.4x10^{-01}$	$0.0x10^{+00}$	$0.0x10^{+00}$	$5.0x10^{-01}$	$2.3x10^{-01}$
Oxalic acid	vapor	$5.0x10^{-01}$	$5.1x10^{-02}$	$5.0x10^{-01}$	$3.4x10^{-02}$	$0.0x10^{+00}$	$0.0x10^{+00}$	$5.0x10^{-01}$	$2.3x10^{-02}$
Platinum	particulate	$2.0x10^{-05}$	$3.2x10^{-05}$	$2.0x10^{-04}$	$2.1x10^{-04}$	$7.0x10^{-08}$	$2.2x10^{-07}$	$2.0x10^{-04}$	$1.4x10^{-04}$
Phosphoric acid	particulate	$2.0x10^{-05}$	$6.8x10^{-06}$	$2.0x10^{-04}$	$4.5x10^{-07}$	$0.0x10^{+00}$	$0.0x10^{+00}$	$2.0x10^{-04}$	$3.1x10^{-07}$
Silver	particulate	$2.0x10^{-05}$	$1.7x10^{-05}$	$2.0x10^{-04}$	$1.1x10^{-04}$	$7.0x10^{-08}$	$1.2x10^{-07}$	$2.0x10^{-04}$	$7.7x10^{-05}$
Sodium hydroxide	particulate	$2.0x10^{-05}$	$4.5x10^{-06}$	$2.0x10^{-04}$	$3.0x10^{-05}$	$7.0x10^{-08}$	$3.1x10^{-08}$	$2.0x10^{-04}$	$2.0x10^{-05}$
Tributyl phosphate	vapor	$5.0x10^{-01}$	$9.2x10^{-02}$	$5.0x10^{-01}$	$6.2x10^{-02}$	$0.0x10^{+00}$	$0.0x10^{+00}$	$5.0x10^{-01}$	$4.2x10^{-02}$
Tungsten	particulate	$2.0x10^{-05}$	$2.1x10^{-05}$	$2.0x10^{-04}$	$1.4x10^{-04}$	$7.0x10^{-08}$	$1.5x10^{-07}$	$2.0x10^{-04}$	$9.7x10^{-04}$
Uranium	particulate	$2.0x10^{-05}$	$8.5x10^{-06}$	$2.0x10^{-04}$	$5.7x10^{-05}$	$7.0x10^{-08}$	$5.8x10^{-08}$	$2.0x10^{-04}$	$3.8x10^{-05}$
TOTAL			**$1.8x10^{+00}$**		**$1.2x10^{+00}$**		**$2.1x10^{-05}$**		**$8.1x10^{-01}$**

[1]The receptor is the maximum exposed member of the public and the analysis assumes a severity category VIII accident.
[2]See Section 3.5.2.1.3 text for basis of chemicals evaluated and analysis methodology.
[3]Engineered Alternatives No. 1 & 77 calculation basis: system-wide average waste density of 1031 kg/m^3, waste shipped in drums, particulate releases assumed to be the same as radiological particulate releases for the same alternative, vapor releases assumed to be the same as the baseline.
[4]Engineered Alternative No. 6 basis: system-wide average waste density of 689 kg/m^3, waste shipped in drums, particulate releases assumed to be the same as radiological particulate releases for the same alternative, vapor releases assumed to be the same as the base case.
[5]Engineered Alternative No. 10 basis: system-wide average waste density of 1595 kg/m^3, waste may be shipped in SWBs, all organics and cadmium (low vaporization temperature) removed by processing and would have no accident releases, particulate releases assumed to be the same as radiological particulate releases for the same alternative.
[6]Engineered Alternative No. 94 basis: system-wide average waste density of 997 kg/m^3, waste shipped in drums, same release fractions as Alternative No. 6, addition of clay reduces average chemical constituent fraction in the waste matrix to a value equal to 0.468 of the baseline value.

TABLE L-25

NONRADIOLOGICAL/NONCHEMICAL PER-SHIPMENT RISK FOR CH-TRU AND RH-TRU WASTE

Waste Origin Site	To Route Segment Destination	Zone	Injuries	Fatalities
AMES	ANL-E	Rural	8.00×10^{-04}	6.56×10^{-05}
		Suburban	6.35×10^{-05}	2.70×10^{-06}
		Urban	2.59×10^{-06}	6.47×10^{-08}
AMES	SRS	Rural	2.35×10^{-03}	1.92×10^{-04}
		Suburban	3.69×10^{-04}	1.57×10^{-05}
		Urban	1.93×10^{-05}	4.84×10^{-07}
AMES	WIPP	Rural	2.98×10^{-03}	2.44×10^{-04}
		Suburban	1.49×10^{-04}	6.34×10^{-06}
		Urban	1.93×10^{-05}	4.84×10^{-07}
ANL-E	SRS	Rural	1.56×10^{-03}	1.28×10^{-04}
		Suburban	3.36×10^{-04}	1.43×10^{-05}
		Urban	2.92×10^{-05}	7.30×10^{-07}
ANL-E	WIPP	Rural	3.29×10^{-03}	2.70×10^{-04}
		Suburban	2.57×10^{-04}	1.09×10^{-05}
		Urban	1.70×10^{-05}	4.25×10^{-07}
BATTELLE	ORNL	Rural	6.45×10^{-04}	5.29×10^{-05}
		Suburban	1.91×10^{-04}	8.15×10^{-06}
		Urban	1.84×10^{-05}	4.59×10^{-07}
BETTIS	MOUND	Rural	4.12×10^{-04}	3.38×10^{-05}
		Suburban	1.44×10^{-04}	6.12×10^{-06}
		Urban	2.46×10^{-05}	6.16×10^{-07}
BETTIS	SRS	Rural	1.29×10^{-03}	1.06×10^{-04}
		Suburban	2.38×10^{-04}	1.01×10^{-05}
		Urban	1.53×10^{-05}	3.82×10^{-07}
BETTIS	WIPP	Rural	3.86×10^{-03}	3.17×10^{-04}
		Suburban	4.02×10^{-04}	1.71×10^{-05}
		Urban	3.87×10^{-05}	9.67×10^{-07}

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TABLE L-25 (Continued)

NONRADIOLOGICAL/NONCHEMICAL PER-SHIPMENT RISK FOR CH-TRU AND RH-TRU WASTE

Waste Origin Site	To Route Segment Destination	Zone	Injuries	Fatalities
ETEC	INEL	Rural	2.01×10^{-03}	1.65×10^{-04}
		Suburban	1.79×10^{-04}	7.61×10^{-06}
		Urban	7.60×10^{-05}	1.90×10^{-06}
ETEC	NTS	Rural	7.16×10^{-04}	5.87×10^{-05}
		Suburban	7.75×10^{-05}	3.30×10^{-06}
		Urban	5.49×10^{-05}	1.37×10^{-06}
ETEC	WIPP	Rural	2.65×10^{-03}	2.17×10^{-04}
		Suburban	1.28×10^{-04}	5.43×10^{-06}
		Urban	6.50×10^{-05}	1.63×10^{-06}
HANFORD	WIPP	Rural	4.38×10^{-03}	3.59×10^{-04}
		Suburban	1.83×10^{-04}	7.77×10^{-06}
		Urban	2.23×10^{-05}	5.57×10^{-07}
INEL	WIPP	Rural	3.36×10^{-03}	2.75×10^{-04}
		Suburban	1.44×10^{-04}	6.14×10^{-06}
		Urban	1.90×10^{-05}	4.74×10^{-07}
KAPL	MOUND	Rural	1.02×10^{-03}	8.32×10^{-05}
		Suburban	3.68×10^{-04}	1.57×10^{-05}
		Urban	2.54×10^{-05}	6.34×10^{-07}
KAPL	ORNL	Rural	7.83×10^{-04}	6.42×10^{-05}
		Suburban	1.80×10^{-04}	7.68×10^{-06}
		Urban	6.04×10^{-06}	1.51×10^{-07}
KAPL	SRS	Rural	1.71×10^{-03}	1.40×10^{-04}
		Suburban	3.73×10^{-04}	1.59×10^{-05}
		Urban	1.44×10^{-05}	3.60×10^{-07}
KAPL	WIPP	Rural	4.47×10^{-03}	3.66×10^{-04}
		Suburban	6.27×10^{-04}	2.67×10^{-05}
		Urban	3.93×10^{-05}	9.83×10^{-07}

TABLE L-25 (Continued)

NONRADIOLOGICAL/NONCHEMICAL PER-SHIPMENT RISK FOR CH-TRU AND RH-TRU WASTE

Waste Origin Site	To Route Segment Destination	Zone	Injuries	Fatalities
LANL	WIPP	Rural	8.47×10^{-04}	6.94×10^{-05}
		Suburban	2.70×10^{-05}	1.15×10^{-06}
		Urban	2.59×10^{-06}	6.47×10^{-08}
LBL	HANFORD	Rural	1.78×10^{-03}	1.46×10^{-04}
		Suburban	2.11×10^{-04}	8.99×10^{-06}
		Urban	4.34×10^{-05}	1.08×10^{-06}
LBL	LLNL	Rural	5.29×10^{-05}	4.34×10^{-06}
		Suburban	4.02×10^{-05}	1.71×10^{-06}
		Urban	2.86×10^{-05}	7.15×10^{-07}
LBL	WIPP	Rural	3.51×10^{-03}	2.88×10^{-04}
		Suburban	1.65×10^{-04}	7.02×10^{-06}
		Urban	8.75×10^{-05}	2.19×10^{-06}
LLNL	HANFORD	Rural	1.80×10^{-03}	1.47×10^{-04}
		Suburban	2.32×10^{-04}	9.89×10^{-06}
		Urban	3.79×10^{-05}	9.49×10^{-07}
LLNL	WIPP	Rural	3.47×10^{-03}	2.84×10^{-04}
		Suburban	1.27×10^{-04}	5.40×10^{-06}
		Urban	5.90×10^{-05}	1.48×10^{-06}
MOUND	SRS	Rural	1.13×10^{-03}	9.25×10^{-05}
		Suburban	2.61×10^{-04}	1.11×10^{-05}
		Urban	1.28×10^{-05}	3.20×10^{-07}
MOUND	WIPP	Rural	3.46×10^{-03}	2.84×10^{-04}
		Suburban	2.96×10^{-04}	1.26×10^{-05}
		Urban	2.56×10^{-05}	6.41×10^{-07}
MU	ANL-E	Rural	7.84×10^{-04}	6.43×10^{-05}
		Suburban	1.12×10^{-04}	4.79×10^{-06}
		Urban	1.13×10^{-05}	2.83×10^{-07}

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TABLE L-25 (Continued)

NONRADIOLOGICAL/NONCHEMICAL PER-SHIPMENT RISK FOR CH-TRU AND RH-TRU WASTE

Waste Origin Site	To Route Segment Destination	Zone	Injuries	Fatalities
MU	SRS	Rural	1.61×10^{-03}	1.32×10^{-04}
		Suburban	2.92×10^{-04}	1.24×10^{-05}
		Urban	3.35×10^{-05}	8.38×10^{-07}
MU	WIPP	Rural	2.71×10^{-03}	2.22×10^{-04}
		Suburban	1.38×10^{-04}	5.89×10^{-06}
		Urban	2.21×10^{-05}	5.51×10^{-07}
NTS	INEL	Rural	1.60×10^{-03}	1.31×10^{-04}
		Suburban	1.17×10^{-04}	4.97×10^{-06}
		Urban	2.50×10^{-05}	6.25×10^{-07}
NTS	WIPP	Rural	3.02×10^{-03}	2.48×10^{-04}
		Suburban	8.06×10^{-05}	3.43×10^{-06}
		Urban	1.65×10^{-05}	4.13×10^{-07}
ORNL	SRS	Rural	6.51×10^{-04}	5.33×10^{-05}
		Suburban	1.40×10^{-04}	5.94×10^{-06}
		Urban	3.70×10^{-06}	9.24×10^{-08}
ORNL	WIPP	Rural	3.50×10^{-03}	2.87×10^{-04}
		Suburban	2.30×10^{-04}	9.80×10^{-06}
		Urban	2.60×10^{-05}	6.50×10^{-07}
PADUCAH	ORNL	Rural	6.68×10^{-04}	5.47×10^{-05}
		Suburban	7.80×10^{-05}	3.32×10^{-06}
		Urban	5.42×10^{-06}	1.36×10^{-07}
PADUCAH	SRS	Rural	1.01×10^{-03}	8.29×10^{-05}
		Suburban	2.16×10^{-04}	9.21×10^{-06}
		Urban	2.17×10^{-05}	5.42×10^{-07}
PADUCAH	WIPP	Rural	3.12×10^{-03}	2.56×10^{-04}
		Suburban	2.17×10^{-04}	9.22×10^{-06}
		Urban	1.71×10^{-05}	4.28×10^{-07}

TABLE L-25 (Continued)

NONRADIOLOGICAL/NONCHEMICAL PER-SHIPMENT RISK FOR CH-TRU AND RH-TRU WASTE

Waste Origin Site	To Route Segment Destination	Zone	Injuries	Fatalities
PANTEX	LANL	Rural	8.36×10^{-04}	6.85×10^{-05}
		Suburban	2.14×10^{-05}	9.09×10^{-07}
		Urban	4.68×10^{-06}	1.17×10^{-07}
PANTEX	WIPP	Rural	1.10×10^{-03}	8.99×10^{-05}
		Suburban	3.37×10^{-05}	1.44×10^{-06}
		Urban	4.44×10^{-06}	1.11×10^{-07}
RFETS	WIPP	Rural	1.65×10^{-03}	1.35×10^{-04}
		Suburban	8.99×10^{-05}	3.83×10^{-06}
		Urban	1.74×10^{-05}	4.34×10^{-07}
SNL	LANL	Rural	2.18×10^{-04}	1.79×10^{-05}
		Suburban	2.11×10^{-05}	8.98×10^{-07}
		Urban	6.41×10^{-06}	1.60×10^{-07}
SNL	WIPP	Rural	7.67×10^{-04}	6.28×10^{-05}
		Suburban	2.36×10^{-05}	1.01×10^{-06}
		Urban	4.80×10^{-06}	1.20×10^{-07}
SRS	WIPP	Rural	3.15×10^{-03}	2.58×10^{-04}
		Suburban	3.85×10^{-04}	1.64×10^{-05}
		Urban	2.44×10^{-05}	6.10×10^{-07}

TABLE L-26

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE
DECENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
Major CH-TRU Waste Sites					
HANFORD	WIPP	5712	Rural	$2.50 \times 10^{+01}$	$2.05 \times 10^{+00}$
			Suburban	$1.05 \times 10^{+00}$	4.44×10^{-02}
			Urban	1.27×10^{-01}	3.18×10^{-03}
INEL	WIPP	4974	Rural	$1.67 \times 10^{+01}$	$1.37 \times 10^{+00}$
			Suburban	7.16×10^{-01}	3.05×10^{-02}
			Urban	9.45×10^{-02}	2.36×10^{-03}
LANL	WIPP	2835	Rural	$2.40 \times 10^{+00}$	1.97×10^{-01}
			Suburban	7.65×10^{-02}	3.26×10^{-03}
			Urban	7.34×10^{-03}	1.83×10^{-04}
RFETS	WIPP	931	Rural	$1.54 \times 10^{+00}$	1.26×10^{-01}
			Suburban	8.37×10^{-02}	3.57×10^{-02}
			Urban	1.62×10^{-03}	4.04×10^{-04}
SRS	WIPP	2827	Rural	$8.91 \times 10^{+00}$	7.29×10^{-01}
			Suburban	$1.09 \times 10^{+00}$	4.64×10^{-02}
			Urban	$6.90 \times 10^{+00}$	1.72×10^{-03}
			Subtotal	**$6.47 \times 10^{+01}$**	**$4.64 \times 10^{+00}$**
Small CH-TRU Waste Sites					
AMES	ANL-E	1	Rural	8.00×10^{-04}	6.56×10^{-05}
			Suburban	6.35×10^{-05}	2.70×10^{-06}
			Urban	2.59×10^{-06}	6.47×10^{-08}
	WIPP	1	Rural	3.29×10^{-03}	2.70×10^{-04}
			Suburban	2.57×10^{-04}	1.09×10^{-05}
			Urban	1.70×10^{-05}	4.25×10^{-07}
ANL-E	WIPP	5	Rural	1.65×10^{-02}	1.35×10^{-03}
			Suburban	1.29×10^{-03}	5.45×10^{-05}
			Urban	8.50×10^{-05}	2.13×10^{-06}

TABLE L-26(Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE
DECENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
BETTIS	MOUND	17	Rural	$7.00x10^{-03}$	$5.75x10^{-04}$
			Suburban	$2.45x10^{-03}$	$1.04x10^{-04}$
			Urban	$4.18x10^{-05}$	$1.05x10^{-05}$
	WIPP	17	Rural	$5.88x10^{-02}$	$4.83x10^{-03}$
			Suburban	$5.03x10^{-03}$	$2.14x10^{-04}$
			Urban	$4.35x10^{-04}$	$1.09x10^{-05}$
ETEC	NTS	2	Rural	$1.43x10^{-03}$	$1.17x10^{-04}$
			Suburban	$1.55x10^{-04}$	$6.60x10^{-06}$
			Urban	$1.10x10^{-04}$	$2.74x10^{-05}$
	WIPP	2	Rural	$6.04x10^{-03}$	$4.96x10^{-04}$
			Suburban	$1.61x10^{-04}$	$6.86x10^{-06}$
			Urban	$3.30x10^{-05}$	$8.36x10^{-07}$
KAPL	MOUND	1	Rural	$1.02x10^{-03}$	$8.32x10^{-05}$
			Suburban	$3.68x10^{-04}$	$1.57x10^{-05}$
			Urban	$2.54x10^{-05}$	$6.34x10^{-07}$
	WIPP	1	Rural	$3.46x10^{-03}$	$2.84x10^{-04}$
			Suburban	$2.96x10^{-04}$	$1.28x10^{-05}$
			Urban	$2.56x10^{-05}$	$6.41x10^{-07}$
LBL	LLNL	1	Rural	$5.29x10^{-05}$	$4.34x10^{-06}$
			Suburban	$4.02x10^{-05}$	$1.71x10^{-06}$
			Urban	$2.86x10^{-05}$	$7.15x10^{-07}$
	WIPP	1	Rural	$3.47x10^{-03}$	$2.84x10^{-04}$
			Suburban	$1.27x10^{-04}$	$5.40x10^{-06}$
			Urban	$5.90x10^{-05}$	$1.48x10^{-06}$
LLNL	WIPP	136	Rural	$4.72x10^{-01}$	$3.86x10^{-02}$
			Suburban	$1.73x10^{-02}$	$7.34x10^{-03}$
			Urban	$8.02x10^{-03}$	$2.01x10^{-04}$

TABLE L-26 (Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE
DECENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
MOUND	WIPP	29	Rural	1.00×10^{-01}	8.24×10^{-03}
			Suburban	8.58×10^{-03}	3.65×10^{-05}
			Urban	7.42×10^{-04}	1.86×10^{-05}
MU	ANL-E	1	Rural	7.84×10^{-04}	6.43×10^{-05}
			Suburban	1.12×10^{-04}	4.79×10^{-06}
			Urban	1.13×10^{-05}	2.83×10^{-07}
	WIPP	1	Rural	3.29×10^{-03}	2.70×10^{-04}
			Suburban	2.57×10^{-04}	1.09×10^{-05}
			Urban	1.70×10^{-05}	4.25×10^{-07}
NTS	WIPP	66	Rural	1.99×10^{-01}	1.64×10^{-02}
			Suburban	5.32×10^{-03}	2.26×10^{-04}
			Urban	1.09×10^{-03}	2.73×10^{-05}
ORNL	WIPP	119	Rural	4.17×10^{-01}	3.42×10^{-02}
			Suburban	2.74×10^{-02}	1.17×10^{-01}
			Urban	3.09×10^{-03}	7.74×10^{-05}
PADUCAH	ORNL	1	Rural	6.68×10^{-04}	5.47×10^{-05}
			Suburban	7.80×10^{-05}	3.32×10^{-06}
			Urban	5.42×10^{-06}	1.36×10^{-07}
	WIPP	1	Rural	3.50×10^{-03}	2.87×10^{-04}
			Suburban	2.30×10^{-04}	9.80×10^{-06}
			Urban	2.60×10^{-05}	6.50×10^{-07}
PANTEX	LANL	1	Rural	8.36×10^{-04}	6.85×10^{-05}
			Suburban	2.14×10^{-05}	9.09×10^{-07}
			Urban	4.68×10^{-06}	1.17×10^{-07}
	WIPP	1	Rural	8.47×10^{-04}	6.94×10^{-05}
			Suburban	2.70×10^{-05}	1.15×10^{-06}
			Urban	2.59×10^{-06}	6.47×10^{-08}

TABLE L-26 (Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE
DECENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
SNL	LANL	3	Rural	6.54×10^{-04}	5.37×10^{-05}
			Suburban	6.33×10^{-05}	2.99×10^{-06}
			Urban	1.92×10^{-05}	4.80×10^{-07}
	WIPP	3	Rural	2.54×10^{-03}	2.08×10^{-04}
			Suburban	8.10×10^{-05}	3.45×10^{-06}
			Urban	7.77×10^{-06}	1.94×10^{-07}
			Subtotal	**$1.39 \times 10^{+00}$**	**2.32×10^{-01}**
			TOTAL	**$6.61 \times 10^{+01}$**	**$4.87 \times 10^{+00}$**

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TABLE L-27

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE
REGIONALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
Major CH-TRU Waste Sites					
HANFORD	WIPP	5712	Rural	$2.50x10^{+01}$	$2.05x10^{+00}$
			Suburban	$1.05x10^{+00}$	$4.44x10^{-02}$
			Urban	$1.27x10^{-01}$	$3.18x10^{-03}$
INEL	WIPP	4974	Rural	$1.67x10^{+01}$	$1.37x10^{+00}$
			Suburban	$7.16x10^{-01}$	$3.05x10^{-02}$
			Urban	$9.45x10^{-02}$	$2.36x10^{-03}$
LANL	WIPP	2835	Rural	$2.40x10^{+00}$	$1.97x10^{-01}$
			Suburban	$7.65x10^{-02}$	$3.26x10^{-03}$
			Urban	$7.34x10^{-03}$	$1.83x10^{-04}$
RFETS	WIPP	931	Rural	$1.54x10^{+00}$	$1.26x10^{-01}$
			Suburban	$8.37x10^{-02}$	$3.57x10^{-03}$
			Urban	$1.62x10^{-02}$	$4.04x10^{-04}$
SRS	WIPP	2836	Rural	$8.93x10^{+00}$	$7.32x10^{-01}$
			Suburban	$1.09x10^{+00}$	$4.65x10^{-02}$
			Urban	$6.92x10^{-02}$	$1.73x10^{-03}$
			Subtotal	**$5.79x10^{+01}$**	**$4.61x10^{+00}$**
Small CH-TRU Waste Sites					
AMES	SRS	1	Rural	$1.56x10^{-03}$	$1.28x10^{-04}$
			Suburban	$3.36x10^{-04}$	$1.43x10^{-05}$
			Urban	$2.92x10^{-05}$	$7.30x10^{-07}$
	WIPP	1	Rural	$3.15x10^{-03}$	$2.58x10^{-04}$
			Suburban	$3.85x10^{-04}$	$1.64x10^{-05}$
			Urban	$2.44x10^{-05}$	$6.10x10^{-07}$
ANL-E	SRS	5	Rural	$7.80x10^{-03}$	$6.40x10^{-04}$
			Suburban	$1.68x10^{-03}$	$7.15x10^{-05}$
			Urban	$1.46x10^{-04}$	$3.65x10^{-06}$

TABLE L-27 (Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE
REGIONALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
BETTIS	SRS	17	Rural	2.19×10^{-02}	1.80×10^{-03}
			Suburban	4.05×10^{-03}	1.72×10^{-04}
			Urban	2.60×10^{-04}	6.49×10^{-06}
	WIPP	17	Rural	5.36×10^{-02}	4.39×10^{-03}
			Suburban	6.55×10^{-03}	2.79×10^{-04}
			Urban	4.15×10^{-04}	1.04×10^{-05}
ETEC	INEL	2	Rural	4.02×10^{-03}	3.30×10^{-04}
			Suburban	3.58×10^{-04}	1.52×10^{-05}
			Urban	1.52×10^{-04}	3.80×10^{-06}
	WIPP	2	Rural	5.30×10^{-03}	4.34×10^{-04}
			Suburban	2.56×10^{-04}	1.09×10^{-05}
			Urban	1.30×10^{-04}	3.26×10^{-06}
KAPL	SRS	1	Rural	1.71×10^{-03}	1.40×10^{-04}
			Suburban	3.73×10^{-04}	1.59×10^{-05}
			Urban	1.44×10^{-05}	3.60×10^{-07}
	WIPP	1	Rural	3.15×10^{-03}	2.58×10^{-04}
			Suburban	3.85×10^{-04}	1.64×10^{-05}
			Urban	2.44×10^{-05}	6.10×10^{-07}
LBL	HANFORD	1	Rural	1.78×10^{-03}	1.46×10^{-04}
			Suburban	2.11×10^{-04}	8.99×10^{-06}
			Urban	4.34×10^{-05}	1.08×10^{-06}
	WIPP	1	Rural	4.38×10^{-03}	3.59×10^{-04}
			Suburban	1.83×10^{-04}	7.77×10^{-06}
			Urban	2.23×10^{-05}	5.57×10^{-07}

TABLE L-27 (Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE
REGIONALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
LLNL	HANFORD	136	Rural	$2.45x10^{-01}$	$2.00x10^{-02}$
			Suburban	$3.16x10^{-02}$	$1.35x10^{-03}$
			Urban	$5.15x10^{-03}$	$1.29x10^{-04}$
	WIPP	136	Rural	$4.72x10^{-01}$	$3.86x10^{-02}$
			Suburban	$1.73x10^{-02}$	$7.34x10^{-04}$
			Urban	$8.02x10^{-03}$	$2.01x10^{-04}$
MOUND	SRS	29	Rural	$3.28x10^{-02}$	$2.68x10^{-03}$
			Suburban	$7.57x10^{-03}$	$3.22x10^{-04}$
			Urban	$3.71x10^{-04}$	$9.28x10^{-06}$
	WIPP	29	Rural	$1.00x10^{-01}$	$8.24x10^{-03}$
			Suburban	$8.58x10^{-03}$	$3.65x10^{-04}$
			Urban	$7.42x10^{-04}$	$1.86x10^{-05}$
MU	SRS	1	Rural	$1.61x10^{-03}$	$1.32x10^{-04}$
			Suburban	$2.92x10^{-04}$	$1.24x10^{-05}$
			Urban	$3.35x10^{-05}$	$8.38x10^{-07}$
	WIPP	1	Rural	$3.15x10^{-03}$	$2.58x10^{-04}$
			Suburban	$3.85x10^{-04}$	$1.64x10^{-05}$
			Urban	$2.44x10^{-05}$	$6.10x10^{-07}$
NTS	INEL	66	Rural	$1.06x10^{-01}$	$8.65x10^{-03}$
			Suburban	$7.72x10^{-03}$	$3.28x10^{-04}$
			Urban	$1.65x10^{-03}$	$4.13x10^{-06}$
	WIPP	66	Rural	$1.99x10^{-01}$	$1.64x10^{-02}$
			Suburban	$5.32x10^{-03}$	$2.26x10^{-04}$
			Urban	$1.09x10^{-03}$	$2.73x10^{-06}$
ORNL	SRS	119	Rural	$7.75x10^{-02}$	$6.34x10^{-03}$
			Suburban	$1.67x10^{-02}$	$7.07x10^{-04}$
			Urban	$4.40x10^{-04}$	$1.10x10^{-05}$
	WIPP	119	Rural	$3.75x10^{-01}$	$3.07x10^{-02}$
			Suburban	$4.58x10^{-02}$	$1.95x10^{-03}$
			Urban	$2.90x10^{-03}$	$7.26x10^{-06}$

TABLE L-27 (Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE
REGIONALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
PADUCAH	ORNL	1	Rural	$6.68x10^{-04}$	$5.47x10^{-05}$
			Suburban	$7.80x10^{-05}$	$3.32x10^{-06}$
			Urban	$5.42x10^{-06}$	$1.36x10^{-07}$
	WIPP	1	Rural	$3.50x10^{-03}$	$2.87x10^{-04}$
			Suburban	$2.30x10^{-04}$	$9.80x10^{-06}$
			Urban	$2.60x10^{-05}$	$6.50x10^{-07}$
PANTEX	LANL	1	Rural	$8.36x10^{-04}$	$6.85x10^{-05}$
			Suburban	$2.14x10^{-05}$	$9.09x10^{-07}$
			Urban	$4.68x10^{-06}$	$1.17x10^{-07}$
	WIPP	1	Rural	$8.47x10^{-04}$	$6.94x10^{-05}$
			Suburban	$2.70x10^{-05}$	$1.15x10^{-06}$
			Urban	$2.59x10^{-06}$	$6.47x10^{-08}$
SNL	LANL	3	Rural	$6.54x10^{-04}$	$5.37x10^{-05}$
			Suburban	$6.33x10^{-05}$	$2.69x10^{-06}$
			Urban	$1.92x10^{-05}$	$4.80x10^{-07}$
	WIPP	3	Rural	$2.30x10^{-03}$	$1.88x10^{-04}$
			Suburban	$7.08x10^{-05}$	$3.03x10^{-06}$
			Urban	$1.44x10^{-05}$	$3.60x10^{-07}$
			Subtotal	**$1.91x10^{+00}$**	**$1.49x10^{-01}$**
			TOTAL	**$5.98x10^{+01}$**	**$4.76x10^{+00}$**

TABLE L-28

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE CENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
Major CH-TRU Waste Sites					
HANFORD	WIPP	5712	Rural	$2.50x10^{+01}$	$2.05x10^{+00}$
			Suburban	$1.05x10^{+01}$	$4.44x10^{-02}$
			Urban	$1.27x10^{-01}$	$3.18x10^{-03}$
INEL	WIPP	4974	Rural	$1.67x10^{+01}$	$1.37x10^{+00}$
			Suburban	$7.16x10^{-01}$	$3.05x10^{-02}$
			Urban	$9.45x10^{-02}$	$2.36x10^{-03}$
LANL	WIPP	2835	Rural	$2.40x10^{+00}$	$1.97x10^{-01}$
			Suburban	$7.65x10^{-02}$	$3.26x10^{-03}$
			Urban	$7.34x10^{-03}$	$1.83x10^{-04}$
RFETS	WIPP	931	Rural	$1.54x10^{+00}$	$1.26x10^{-01}$
			Suburban	$8.37x10^{-02}$	$3.57x10^{-03}$
			Urban	$1.62x10^{-02}$	$4.04x10^{-04}$
SRS	WIPP	2827	Rural	$8.91x10^{+00}$	$7.29x10^{-01}$
			Suburban	$1.09x10^{+00}$	$4.64x10^{-02}$
			Urban	$6.90x10^{-02}$	$1.72x10^{-03}$
			Subtotal	**$6.73x10^{+01}$**	**$4.61x10^{+00}$**
Small CH-TRU Waste Sites					
AMES	WIPP	1	Rural	$2.98x10^{-03}$	$2.44x10^{-04}$
			Suburban	$1.49x10^{-04}$	$6.34x10^{-06}$
			Urban	$1.93x10^{-05}$	$4.84x10^{-07}$
ANL-E	WIPP	5	Rural	$1.65x10^{-02}$	$1.35x10^{-03}$
			Suburban	$1.29x10^{-03}$	$5.45x10^{-05}$
			Urban	$8.50x10^{-05}$	$2.13x10^{-06}$
BETTIS	WIPP	17	Rural	$6.56x10^{-02}$	$5.39x10^{-03}$
			Suburban	$6.83x10^{-03}$	$2.91x10^{-04}$
			Urban	$6.58x10^{-04}$	$1.64x10^{-05}$

TABLE L-28 (Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE CENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
ETEC	WIPP	2	Rural	$5.30x10^{-03}$	$4.34x10^{-04}$
			Suburban	$2.56x10^{-04}$	$1.09x10^{-05}$
			Urban	$2.00x10^{+00}$	$3.26x10^{-06}$
KAPL	WIPP	1	Rural	$4.47x10^{-03}$	$3.66x10^{-04}$
			Suburban	$6.27x10^{-04}$	$2.67x10^{-05}$
			Urban	$3.93x10^{-05}$	$9.83x10^{-07}$
LBL	WIPP	1	Rural	$3.51x10^{-03}$	$2.88x10^{-04}$
			Suburban	$1.65x10^{-04}$	$7.02x10^{-06}$
			Urban	$8.75x10^{-05}$	$2.19x10^{-06}$
LLNL	WIPP	136	Rural	$4.72x10^{-01}$	$3.86x10^{-02}$
			Suburban	$1.73x10^{-02}$	$7.34x10^{-04}$
			Urban	$8.02x10^{-03}$	$2.01x10^{-04}$
MOUND	WIPP	29	Rural	$3.28x10^{-02}$	$2.68x10^{-03}$
			Suburban	$7.57x10^{-03}$	$3.22x10^{-04}$
			Urban	$3.71x10^{-04}$	$9.28x10^{-06}$
MU	WIPP	1	Rural	$2.71x10^{-03}$	$2.22x10^{-04}$
			Suburban	$1.38x10^{-04}$	$5.89x10^{-06}$
			Urban	$2.21x10^{-05}$	$5.51x10^{-07}$
NTS	WIPP	66	Rural	$1.99x10^{-01}$	$1.64x10^{-02}$
			Suburban	$5.32x10^{-03}$	$2.26x10^{-04}$
			Urban	$1.09x10^{-03}$	$2.73x10^{-05}$
ORNL	WIPP	119	Rural	$4.17x10^{-01}$	$3.42x10^{-02}$
			Suburban	$2.74x10^{-02}$	$1.17x10^{-03}$
			Urban	$3.09x10^{-03}$	$7.74x10^{-05}$
PADUCAH	WIPP	1	Rural	$3.12x10^{-03}$	$2.56x10^{-04}$
			Suburban	$2.17x10^{-04}$	$9.22x10^{-06}$
			Urban	$1.71x10^{-05}$	$4.28x10^{-07}$

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TABLE L-28 (Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
CH-TRU WASTE CENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
PADUCAH	WIPP	1	Rural	$3.12x10^{-03}$	$2.56x10^{-04}$
			Suburban	$2.17x10^{-04}$	$9.22x10^{-08}$
			Urban	$1.71x10^{-05}$	$4.28x10^{-07}$
PANTEX	WIPP	1	Rural	$1.10x10^{-03}$	$8.99x10^{-05}$
			Suburban	$3.37x10^{-05}$	$1.44x10^{-06}$
			Urban	$4.44x10^{-06}$	$1.11x10^{-07}$
SNL	WIPP	3	Rural	$2.30x10^{-03}$	$1.88x10^{-04}$
			Suburban	$7.08x10^{-05}$	$3.03x10^{-06}$
			Urban	$1.44x10^{-05}$	$3.60x10^{-07}$
			Subtotal	**$3.31x10^{+00}$**	**$1.04x10^{-01}$**
			TOTAL	**$7.06x10^{+01}$**	**$4.71x10^{+00}$**

TABLE L-29

NONCHEMICAL/NONRADIOLOGICAL RISK
RH-TRU WASTE DECENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
Major RH-TRU Waste Sites					
HANFORD	WIPP	5176	Rural	$2.27 \times 10^{+01}$	$1.86 \times 10^{+00}$
			Suburban	9.47×10^{-01}	4.02×10^{-02}
			Urban	1.15×10^{-01}	2.88×10^{-03}
ORNL	WIPP	2002	Rural	$7.01 \times 10^{+00}$	5.75×10^{-01}
			Suburban	4.60×10^{-01}	1.96×10^{-02}
			Urban	5.21×10^{-02}	1.30×10^{-03}
			Subtotal	**$3.13 \times 10^{+01}$**	**$2.50 \times 10^{+00}$**
Small RH-TRU Waste Sites					
BATTELLE	ORNL	123	Rural	7.93×10^{-02}	6.51×10^{-03}
			Suburban	2.35×10^{-02}	1.00×10^{-03}
			Urban	2.26×10^{-03}	5.65×10^{-05}
	WIPP		Rural	4.31×10^{-01}	3.53×10^{-02}
			Suburban	2.83×10^{-02}	1.21×10^{-03}
			Urban	3.20×10^{-03}	8.00×10^{-05}
BETTIS	ORNL	3	Rural	1.94×10^{-03}	1.59×10^{-04}
			Suburban	5.73×10^{-04}	2.45×10^{-05}
			Urban	5.52×10^{-05}	1.38×10^{-06}
	WIPP		Rural	1.05×10^{-02}	8.61×10^{-04}
			Suburban	6.90×10^{-04}	2.94×10^{-05}
			Urban	7.80×10^{-05}	1.95×10^{-06}
INEL	WIPP	109	Rural	9.66×10^{-01}	3.00×10^{-02}
			Suburban	1.57×10^{-02}	6.69×10^{-04}
			Urban	2.07×10^{-03}	5.17×10^{-05}

TABLE L-29 (Continued)

NONCHEMICAL/NONRADIOLOGICAL RISK
RH-TRU WASTE DECENTRALIZED CONFIGURATION

Waste Origin Site	To Route Segment Destination	No. Of Shipments	Zone	Injuries	Fatalities
KAPL	ORNL		Rural	4.46×10^{-02}	3.66×10^{-03}
			Suburban	1.03×10^{-02}	4.38×10^{-04}
			Urban	3.44×10^{-04}	8.61×10^{-05}
	WIPP		Rural	2.00×10^{-01}	1.64×10^{-02}
			Suburban	1.31×10^{-02}	5.59×10^{-04}
			Urban	1.48×10^{-04}	3.71×10^{-05}
LANL	WIPP	249	Rural	2.11×10^{-01}	1.73×10^{-02}
			Suburban	6.73×10^{-03}	2.86×10^{-04}
			Urban	6.45×10^{-04}	1.61×10^{-05}
SRS	WIPP	56	Rural	1.76×10^{-01}	1.44×10^{-02}
			Suburban	2.16×10^{-02}	9.18×10^{-04}
			Urban	1.37×10^{-03}	3.42×10^{-05}
			Subtotal	**$2.55 \times 10^{+00}$**	**1.30×10^{-01}**
			TOTAL	**$3.35 \times 10^{+01}$**	**$2.63 \times 10^{+00}$**

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APPENDIX M

WASTE ISOLATION PILOT PLANT FOCUS GROUP DISCUSSIONS CONCERNS STATED

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WASTE ISOLATION PILOT PLANT FOCUS GROUP DISCUSSIONS
CONCERNS STATED

1.0 INTRODUCTION

The U.S. Department of Energy Carlsbad Area Office (DOE-CAO) is conducting an Engineered Alternatives (EA) Cost/Benefit Study. In support of that study, focus group discussions were held in Carlsbad, Albuquerque, and Santa Fe, New Mexico. The focus group setting and format were consistent at each location. The purpose of these discussions was to identify public concerns about the ability of the Waste Isolation Pilot Plant (WIPP) to protect the public health and the environment once waste is emplaced and WIPP is closed and sealed.

2.0 CARLSBAD, NEW MEXICO

SESSION I, June 26, 1995

At the focus group discussion held in Carlsbad, New Mexico on June 26, 1995, seven participants were present for the discussion. Mr. Steve Wilkes was the moderator. Other attendees were Maggie Wood and Rebecca Grohler from the S.M. Stoller Corporation; Ann Marshall, Advanced Sciences, Inc.(who served as note takers); and Patty Barratti-Sallani, a DOE-CAO public affairs representative.

Mr. Wilkes opened the meeting with a brief discussion of the purpose of focus groups in general and how this particular session would be conducted. He addressed the ground rules for the discussions, the desired outcome, the assumptions to be used as a basis for the discussions, and then introduced Maggie Wood.

Ms. Wood's presentation addressed the purpose and objectives of the focus group discussion, how participants were selected, and how comments would be used.

Ms. Wood advised the focus group that the Environmental Evaluation Group (EEG) had requested that she give the participants copies of a paper prepared by EEG stating their position on Engineered Barriers at the WIPP site. Copies of the paper were distributed to the participants at the end of the discussion.

Mr. Wilkes then led the remainder of the session, beginning with a discussion of concerns about the long-term performance of the WIPP disposal system. After all the concerns had been stated, Mr. Wilkes asked each participant to summarize their concerns in the form of a one minute statement to the DOE. The focus group session was then concluded.

Verbatim notes were not taken. The comments are shown in the order in which they were presented.

CONCERNS STATED[1]

Moderator: What are your concerns about the ability of WIPP to protect human health and the environment once WIPP is closed, waste is emplaced, and the site is sealed?

WIPP should be marked so that any future society knows the site is there to prevent intrusion inadvertently. Adequate records must be maintained. **[2.4, 3.1 - Y]**

Concerned about oil exploration or recovery of oil far below the WIPP, but by the time WIPP is closed, it will not be a concern. Oil recovery is only a 25-year concern. **[3.1 - Y]**

Concerned about BLM management of drilling programs, but don't want to add huge costs to drilling. **[3.1 - Y]**

Concerned about gas generation in the waste after it is buried. **[1.2 - Y]**

The formation is adequate, stable, solid, for holding waste. Adding unnecessary engineered alternatives will just add cost and complexity that aren't needed. **[2.1 - Y]**

Potash mining has been conducted in same formation [as WIPP] for over 60 years. We have a good understanding of what that formation does, and it is relatively stable, even in blasting. Historical proof is that the underground is dry and stable. **[2.1 - Y]**

Strong belief that future generations will be as knowledgeable as we are. The 10,000- year period is a ridiculous requirement. Fairherst said it's like asking the Wright Brothers to develop a plane that can fly 400 people to Europe. Within 100 years we will come up with other solutions. It is impossible to predict what technology will exist at that time. **[3.3 - Y]**

Oil and potash reserves can be removed from around the site without penetrating or affecting the site in any way. **[2.1 - Y]**

Concerned that EAs will be used that simply have no merit. **[7.1 - Y]**

Concerned that DOE is not educating the public enough about WIPP. People wouldn't be concerned if they knew more about the project. **[7.2 - N]**

Some people have said that they don't believe DOE is telling the truth. DOE needs to be open and honest about everything that is going on. **[7.2 - N]**

As long as EPA requirements are met there shouldn't be any additional EAs. Additional EAs add no value. **[7.1 - Y]**

Numbers in brackets at the end of each comment indicate the taxonomic category to which each comment was assigned. In some cases a comment was assigned to more than one category. In other cases separate statements within one comment were assigned different categories and were counted as separate comments. The Y or N letter that follows the category number(s) indicates whether the comment was related to postclosure [Y] or not related to postclosure [N].

Our [society's] body of knowledge is constantly changing and improving. In even as few as 25 years many of the things that may have been of concern are no longer relevant. **[3.3 - Y]**

Some resentment has been expressed that this [WIPP project] didn't go to a local vote. How was the site chosen? **[7.2 - N]**

People don't like the perception that it's secretive--they think the government is not telling the truth. **[7.2 - N]**

Moderator: Is there anything about the waste itself which concerns you?

Human intrusion isn't a serious concern because the waste being put in there isn't very hazardous now, and hundreds of years from now it will be continually less hazardous. If a breach were to occur from drilling, it may allow some gas to come to the surface, but not the actual waste materials. **[1.4 - Y]**

Any gas generated will be under high pressure and, if drilled into, it may be released along with *some brine. Once saturation occurs, though, the brine doesn't move.* **[1.2 - Y]**

Moderator: If you had one minute to talk to DOE about WIPP and its ability to protect human health and the environment once it is closed, what would you say?

Keep good records and be open and honest with people. **[2.4, 7.2 - Y]**

Keep accurate records and continue to look for solutions like isolation or neutralizing the waste. **[1.3, 2.4 - Y]**

Continue to support the [Carlsbad] Environmental Monitoring [and Research] Center. **[not counted]**

DOE has done a good job, the public's concerns have been addressed. The markings and records will last forever. WIPP is ready to go and it's safe--open it. **[2.4 - Y]**

Don't abandon the project. **[97.4 - N]**

Continue keeping good records and monitoring. Keep researching new technologies--not just for this site, but for other sites, too. **[2.4 - Y]**

If there is this much trouble getting low-level waste repository open, how will DOE ever handle high-level waste? This level of indecision would not be tolerated in industry. When will you say, "*enough is enough.*" *Either do it [open WIPP] or pull out. You will never convince every single* person. You have the authority to open WIPP, so use it. **[7.4 - N]**

WIPP has undergone all the scrutiny it needs to. It's ready to open tomorrow. **[7.4 - N]**

WIPP is technologically and scientifically sound. DOE should proceed and get it open. Move forward. **[7.4 - N]**

SESSION II, July 6, 1995

An independent interview was held on July 6, 1995, with two participants, in lieu of their attendance at the focus group discussion held June 26, 1995. Both of the participants were knowledgeable about the WIPP site and had been actively involved since about 1980. Ms. Wood, served as the moderator and also prepared summarized notes. Ms. Grohler was also present at this session to take more detailed notes.

Ms. Wood opened the interview by introducing the purpose and objectives of the focus group session, how participants were selected, and how comments would be used.

Verbatim notes were not taken. The comments are shown in the order in which they were presented.

CONCERNS STATED

Moderator: What are your concerns about the ability of WIPP to protect human health and the environment once WIPP is closed, waste is emplaced, and the site is sealed?

Don't want the waste to be migrating from room to room. Water may get into a room and could dissolve the salt around the waste, allowing the water to flow from room to room. If inflow isn't kept out of the rooms, it can migrate throughout the site. **[3.1 - Y]**

Due to the presence of oil and gas in the area of the site, human intrusion will occur. We know that WIPP will be drilled into someday, and the drill would probably use a water circulation drill which could introduce water into the repository. This is of concern because when the site is breached it could result in massive contamination to the surrounding ecosystem. **[3.1 - Y]**

The water flow into and around the site hasn't been studied enough. They don't realize that water flow could eventually become a problem and it could contaminate the water table. If contamination reaches the surface it could be carried into the Pecos River if there were a flood through that area. **[2.1, 4.0, - Y]**

Concern that Pecos River could be contaminated. If WIPP were breached, the contamination could migrate to the Rustler Formation and be carried through the Formation to the river. Seals or other engineered barriers sound like a needed safety measure to these concerns. **[4.0, - Y]**

Concerned about the adequacy of seals in the underground and shafts. If the site isn't sealed properly, fresh water could get into the site and erode the salt, creating a bigger hole and dissolving the natural barrier. **[2.2, 4.0 - Y]**

Primarily concerned about the integrity of the site. When the DOE discovered water at the original proposed site, they just moved the site a half-mile away. WIPP shouldn't have been located where it is. **[2.1, 4.0 - Y]**

Moderator: Is there anything about the waste itself which concerns you?

The mixed waste concerns me. They [DOE] don't really know what all is going in it, and mixing it together concerns me. I would feel better if waste were characterized better. But perhaps good

engineered barriers would take care of that. If the waste were encased in glass or cement or whatever, that may negate the need for better characterization. **[1.1, 1.3 - Y]**

Moderator: Do you have any other concerns that we haven't addressed?

Transportation. The WIPP bypass road is planned for the north side of town [Carlsbad], but the south side won't have a bypass. Even though they could use highway 31, which is a natural bypass for the south, they are going to bring the waste all the way through the south part of town. **[7.3 - N]**

The "rich side" of town has a bypass, but the "poor side" not only won't have a bypass, but they won't even use Route 31 even though it is available. All the money is being spent on the north end, and the south end of town is unprotected. **[7.3 - N]**

The cost/benefit analysis should also look at the way money is being spent. There is an incredible amount of money wasted right now. Why do they need to fully staff the site when there won't be any waste there for two years? Also, why do DOE managers come all the way into town for lunch when there's a cafeteria right there at the site? They're using government cars and it's the taxpayers who are paying for that. **[7.2 - N]**

A cost/benefit study of safety issues is mandatory, but the government will eventually have to do a cost/benefit study of comfort, too, because someday someone is really going to sink their teeth into the way money is being spent. **[6.0, 7.2 - N]**

Moderator: If you had one minute to talk to DOE about WIPP and its ability to protect human health and the environment once it is closed, what would you say?

I would say that I hear what you are saying, but what you are doing doesn't match what you are saying. It is supposed to be a new, open DOE, but I would like to see the DOE stop covering up problems and tell people the truth about WIPP. Admit to the people that there is risk, and talk about the risk openly. DOE said that water was no problem. Then the site was moved a half-mile years ago when water was discovered. The whole concept of WIPP was to have dry salt, and now it isn't dry salt--there is water in the area. DOE has promised that there will be no breach of the site. They need to tell the truth. People who live here should be aware of the truth. People can deal with it if they know the facts. **[4.0, 7.2 - Y]**

SESSION III, July 10, 1995

An independent interview was held on July 10, 1995 with one participant in lieu of her attendance at the focus group discussion held June 26, 1995 (see Section B.1). The interview was conducted via conference call and included the participant; Maggie Wood, who acted as the moderator; and Rebecca Grohler, who took detailed notes.

Ms. Wood opened the interview by introducing the purpose and objectives of the focus group session, how participants were selected, and how comments would be used.

Verbatim notes were not taken. The comments are shown in the order in which they were presented.

CONCERNS STATED

Moderator: What are your concerns about the ability of WIPP to protect human health and the environment once WIPP is closed, waste is emplaced, and the site is sealed?

It may be naive on my part, but I have no major concerns. We have the best technologies available to any of us in this country, and I feel that the topography of the area and the geological aspect of the site where DOE is looking at storing these wastes provides tremendous safety compared to where the waste is now--at sites, because there is no place to take it. **[2.2 - N]**

Moderator: Is there anything about the waste itself which concerns you?

Anyone would have some concerns about radiation. I certainly don't want to see any releases of radiation which could contaminate the region, or cause illnesses or deaths. However, with the technology we have to handle this material, I believe we're more at risk right now, prior to storage, rather than after it is stored. **[5.0 - Y]**

Moderator: Can you tell me the nature of your concerns about the current risks?

The current risk is at the site locations where they are creating nuclear waste. It is a fact that human risk factors are involved, and mistakes can be made. It [the waste] is in a temporary holding position at the sites, compared to a long-term position at WIPP. Currently I'm concerned that there could be an event that could result in contamination of the region, soil, water, and air around these site locations. **[4.0. 5.0 - N]**

Moderator: If you were living thousands of years in the future in southeast New Mexico and you learned that there was a repository for radioactive materials in the area, what would be your concerns?

I imagine the biggest concern would be to make sure that it's [WIPP is] sealed properly and is being handled properly. I would want to be sure that there is no movement of the waste to the surrounding soil or movement into water sources in the area. I would want to be sure that there is no migration to places not intended for the waste to migrate to and that the site continues to be handled as it is supposed to be handled. I would want a check system [monitoring system] to ensure it is maintained as it should be. **[2.2, 2.4, 4.0 - Y]**

Moderator: If you had one minute to talk to DOE about WIPP and its ability to protect human health and the environment once it is closed, what would you say?

I think we have now invested tremendous time, energy, and money in creating a technical environment to properly handle nuclear and radioactive waste, and it is critical that we take advantage of these technological developments and start cleaning the vast areas of this country that we recognize are tremendously contaminated, such as the Rocky Flats area, soils around Pantex and other sites. We need to place these radioactive materials into a safeguarded environment, which WIPP provides. **[7.2 - N]**

Moderator: Is there anything else you'd like to say?

If I have any concern about WIPP at all it's that we seem to have continually delayed, through continuing regulations and requirements, the opening of this facility, which in the long run is jeopardizing other areas of this country, like the sites where this waste is now being kept. **[7.2 - N]**

I would like to see WIPP in operation and to start collecting the material it is designed to collect. **[7.4 - N]**

I believe WIPP is a great benefit to the State of New Mexico, and our region is fortunate that we have the geologic formations to be the pilot center and to go into operations. It will be a benefit to the entire country. **[7.4 - N]**

I have been aware of WIPP since about 1981. The nature of my involvement has primarily been because of the proximity of WIPP's location with regard to economic development of this region (i.e., relocation of companies to the area, and the economic impact of WIPP in this region). I was very active in getting funding for a bypass to take the waste around Roswell rather than going down the main street in Roswell, not because we were concerned about the physical danger, but mainly because of the psychological impact to residents. People are afraid of anything called "radioactive" and the bypass solves an emotional need and will make them [the residents] feel safer. **[7.3 - N]**

3.0 ALBUQUERQUE, NEW MEXICO

June 27, 1995

A focus group discussion was held in Albuquerque, New Mexico on June 27, 1995. There were eight participants present for the discussion. Mr. Steve Wilkes was the moderator. Other attendees were Maggie Wood and Rebecca Grohler from the S.M. Stoller Corporation; Ann Marshall, Advanced Sciences, Inc.(who served as note takers); and Patty Barratti-Sallani, a DOE-CAO public affairs representative.

Mr. Wilkes opened the meeting with a brief discussion of the purpose of focus groups in general and how this particular session would be conducted. He addressed the ground rules for the discussions, the desired outcome, the assumptions to be used as a basis for the discussions, and then introduced Maggie Wood.

Ms. Wood's presentation addressed the purpose and objectives of the focus group discussion, how participants were selected, and how comments would be used. Ms. Wood advised the focus group that the EEG had requested that she give the participants copies of a paper prepared by EEG stating their position on Engineered Barriers at the WIPP site. Copies of the paper were then distributed to the participants at the end of the discussion.

Mr. Wilkes then led the remainder of the session, beginning with a discussion of concerns about the long-term performance of the WIPP disposal system. After all the concerns had been stated,

Mr. Wilkes asked each participant to summarize their concerns in the form of a one minute statement to the DOE. The focus group session was then concluded.

Verbatim notes were not taken. The major comments or points that were made during the focus group discussion are shown in the order in which they were presented in the following section.

CONCERNS STATED[2]

Moderator: What are your concerns about the ability of WIPP to protect human health and the environment once WIPP is closed, waste is emplaced, and the site is sealed?

My confidence levels of the long-term stability of the waste facility shot way up after hearing about vitrification. I have zero confidence in mixed waste stored in salt caverns that will crush and collapse on the waste mixture. Some other concerns are drilling, boreholes, and flooding. I have zero confidence in a system designed like this. Characterizing waste is the first step in improving my confidence [in the facility]. **[1.1, 1.3, 2.2, 3.1 - Y]**

My confidence level would be greatly improved if the waste were vitrified. There is no way to evaluate whether waste would drain into gas, brine, or water. If waste is encapsulated, it will be fully characterized in order to be vitrified. **[1.1, 1.3, 4.0 - Y]**

Flooding into WIPP from oil operations can't be avoided. **[3.1 - Y]**

There are two premises with which I disagree. First, the WIPP is a facility planned to put waste away forever. This is a long time concern. In a recent DOE news release, WIPP is being hailed as a "pilot" plant. Been told for years that this is a "pilot" plant. In reality, all along, WIPP has been geared as a permanent repository. Recently high level delegates from France toured the plant and were quoted as saying that it is a wonderful "pilot research and development" facility. But WIPP is still being planned [by DOE] for permanent disposal. This is the same as using Agent Orange during Operation Harvest. This is another example of the government's propensity to lie. Stop calling WIPP a "pilot" facility and a research and development facility. Just call it what it is--a permanent facility. Don't apologize for the past, but start calling it what it is in the future. Secondly, engineered barriers are not simply frosting on the cake. 40 CFR 191 section 141 clearly requires the use of engineered barriers. Again, these are not "extra" or "frosting on the cake," as described by Ms. Wood. **[7.1, 7.2 - N]**

Calling WIPP a low-level waste facility is incorrect. Even news releases as recently as a couple of weeks ago still refer to it [WIPP] as a low-level facility, and that is not true. It is a transuranic waste repository. **[1.4 - N]**

Engineered barriers are a requirement. DOE will not change the name of WIPP, but will say that using room seals is okay. The facility will be built with inferior engineered barriers incapable of

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Numbers in brackets at the end of each comment indicate the taxonomic category to which each comment was assigned. In some cases a comment was assigned to more than one category. In other cases separate statements within one comment were assigned different categories and were counted as separate comments. The Y or N letter that follows the category number(s) indicates whether the comment was related to postclosure [Y] or not related to postclosure [N].

withstanding natural and man-made intrusion events. WIPP will still be dangerous because future generations cannot deal with it. DOE doesn't understand its job. **[3.3, 7.1 - Y]**

Engineered barriers will not prevent human intrusion. Engineered barriers need to withstand future slant drilling. Slant drilling can be done right now. WIPP must protect against intrusion for thousands of years. **[3.1, 3.3 - Y]**

Public confidence should be a serious concern. We're looking at future concerns, but we should look at present concerns. Troubled by assuming WIPP "already filled and sealed." Present concerns for safety and health must be met in order to talk about long-term concerns. DOE is so committed to opening WIPP, and will do whatever it takes to open it. It is prepared to cut corners to get it open quickly. Environmental safety and health issues are being deferred. These should be addressed in the present. DOE needs to be candid and frank with these issues, but is being pressured by waste management issues to get WIPP open. Not very many who would be talking about disposal [of radioactive waste] in a salt medium like WIPP. I am concerned with intrusion and barriers and safety and health. There are too many unknowns and uncertainties. No one knows how to deal with high-level or mixed-waste forms. **[1.4, 2.1, 3.1, 7.2, 7.4 - Y]**

DOE talks like this is a closed issue. DOE has this dimension of arrogance. **[7.2 - N]**

It is not possible to prevent intrusion. Public health and environment cannot be assured. There are too many unknowns and uncertainties. **[3.1, 3.3, 4.0, 5.0 - Y]**

What I'm hearing is a distrust of the government and that the WIPP site is unequivocally going to leak radiation--that there are no controls. We are looking at something that is 2,150 feet below ground. We have been dicking around with this since 1972. Where is the stuff being currently produced being stored? In generator warehouses and docks sitting in barrels. 2,150 feet below is more secure than where it is now. A concern is if someone [people] forgets that waste is stored in the WIPP. The buildings will go away, the area will be replanted. Hundreds of years from now, this might possibly still be remembered. Thousands of years from now, drilling may not be necessary, but some exploration might occur. But we need to be sure it is historically remembered. I'm not concerned about radiation leakage. **[3.3 - Y]**

I do not support nor discourage the use of nuclear energy. My concern is with high-level waste and mixed-waste storage. My concerns mirror the same concerns expressed here. High-level waste is a valid concern. The salt bins would collapse. **[1.4 - Y]**

I have been shocked by DOE presentations about transportation. **[7.3 - N]**

A 55-gallon steel barrel is a ridiculous container that won't last. Who decided on the 55-gallon *drum as the container of choice ... the janitor at Los Alamos 50 years ago? There is the mindset* that everything would be buried. Why not store it in better containers. I am shocked that the TRUPACT was designed around the 55-gallon drum. **[2.3 - Y]**

My confidence is shattered after reading the EEG report about active oil wells being around the site and not being addressed by the EIS [*Environmental Impact Statement*]. Why haven't alternate sites been considered. **[2.1 - N]**

Once WIPP is open all sort of things will go into it. WIPP seems to be it [the site of choice]. DOE doesn't seem willing to consider any other sites, containers, methods, etc. Vitrification would greatly improve public confidence. But even with the vitrification there are other concerns with the long-term destructive effects of plutonium on the glass. **[1.2, 1.3, 1.4, 2.1, 2.3, 7.2 - Y]**

[A participant gave the following explanation of the characteristics of TRU and high-level waste.] High-level waste, like fuel rods, in 1,000 years becomes like TRU. TRU is not lower level waste. Eighty percent of TRU waste not planned for WIPP will remain above ground and [DOE] is not planning to do anything with it. Waste is not even in drums--its just buried a few feet underground. DOE has to say what they're going to do with it. **[not counted]**

Some other concerns include performance assessments and projections. I am humbled by trying to project 10,000 years from now. In 100,000 years the waste will still be radioactive; 10,000 years was used randomly by EPA. By using all these modeling tools, we give the impression that we know with certainty what will occur thousands of years from now. For example, if 300 years ago, we had been asked to look at 1995, no one would have predicted that we would be drilling thousands of feet underground for oil or minerals. We don't know and there is no way of knowing what will occur, even hundreds of years into the future. That's where engineered barriers come in--to give an extra assurance that inadvertent human intrusion will not result in a release of radioactivity. Considering drilling scenarios in the future, let's do something to the waste, the drum, and use engineered barriers to make sure the waste stays buried. **[3.3, 7.1 - Y]**

Shaft or panel seals are clumsy attempts to undo what we are doing to the environment. Creating panel and shaft seals may be worse than using the rock already there. The rock is more solid; the seals would be a patch and may actually weaken the rock. It would be easier to penetrate a patch than the rock. A rock is much better than a seal. **[2.2, 7.1 - Y]**

Also, a canister, like a 55-gallon drum was going to be certified in the Waste Acceptance Criteria Revision 4, for 20 years longevity. However, the 20-year criteria was removed because the drums were already 20 years old and falling apart. **[2.3 - Y]**

DOE will not do vitrification and is leaning toward not using backfill. **[1.3, 7.1 - Y]**

Regarding future uncertainties, use engineered and natural barriers to keep waste forms from entering the environment. **[3.3, 7.1 - Y]**

DOE has said that they will **not** do vitrification--they **will not** do it. **[1.3 - Y]**

The [WIPP] repository could be reopened by future generations. There could be intentional intrusion to study reopening the repository to store more waste in there. I would feel more comfortable if DOE pre-treats the solid waste stuff, and not just future waste but existing waste. For example, at Rocky Flats Plant, there is a process for looking into barrels with something like x-rays to catch previously undetected liquids in WIPP-bound barrels. Improvements need to be made to the up-front procedures. That is, pre-analyze, assess and characterization. This is a problem--the uncertainty with the barrel contents. There needs to be better engineered barrier systems. There will be a problem with salt migration. I am uncertain if the WIPP site would be permanently closed. **[1.1, 1.3, 3.1, 2.2, 7.1 - Y]**

[DOE] has to admit that we can't predict the future, so we must just do the best we can right now, using the best technologies available. Use engineered barriers as well as natural barriers to get as much confidence as possible. **[3.3 - Y]**

Once WIPP is closed it could be opened by future generations because of interest in what was done. **[3.1 - Y]**

The government may make a decision to expand from just disposal of military waste to include civilian high-level waste as well. Intrusion may not be unintentional--they may say "let's open it and put more stuff in it." **[3.3, 7.2 - Y]**

Would feel more confident if DOE would make decision to go back and pre-treat some of this waste before they ship it. Not just future waste, but some of the waste now existing. **[1.3 - Y]**

Characterization is inadequate--it is very impressive, but still needs improvement. Barrels could contain **anything**. May not really know what is inside, so whatever engineered barrier is used, it may not work for that type of waste. **[1.1 - Y]**

I am concerned with current waste improprieties. That is, illegal openings [of waste disposal sites] that are politically driven. Recently an old, unsafe landfill was reopened, illegally. What's to stop the government from doing this at WIPP? Can't predict political situation. **[3.3, 7.2 - Y]**

WIPP should not be near locations with significant natural resources, such as potash.
How do we let future people know that waste is buried? Do we want to let future people know that waste is buried? **[2.1, 2.4 - Y]**

In the future, people may actually be looking for radioactive waste or other materials. They may dig up WIPP deliberately--like King Tut's tomb. **[3.1 - Y]**

Mixed waste--for example, plutonium--is long-lived, and hazardous chemicals are long-lived. The mixed waste, plutonium, and hazardous chemicals are going to be dangerous for a very long time, and we don't really know how they will interact. **[1.2 - Y]**

I have some high-level waste concerns, like putting more high-level waste in. The heat generated by the high-level waste will affect other natural processes such as geologic and hydrologic processes. **[1.2, 7.4 - Y]**

WIPP is more than a mixed-waste facility. If another place is used to store waste, WIPP can be use to store other types of waste. **[7.4 - N]**

This creates a situation where waste is all around and there are possibilities of additional intrusions by people landfilling around these areas. **[3.1 - Y]**

Concerned that WIPP will open and will continue to be used even if it is not safe because nothing else is even close to opening. **[7.2 - N]**

People may want to get into WIPP [in the future] for reasons that can't even be imagined at this time. **[3.1, 3.3 - Y]**

Per the Land Withdrawal Act, no high-level waste can be emplaced [into WIPP]. But the DOE is trying to change the Land Withdrawal Act. WIPP as the forerunner, as the showpiece, is actually the bastard child of the nuclear industry. It is a result of the nuclear community, but it doesn't even require an NRC [Nuclear Regulatory Commission] certification license. WIPP will not be certified by the NRC. It was called an R&D facility so that it wouldn't have to be licensed by the NRC--DOE wanted it that way, so they got it. The regional control was given to the EPA because DOE didn't want to reverse its decision [about NRC] but now they say they want NRC regulation instead of EPA. **[7.2 - N]**

High-level and low-level waste is certified by the NRC. Why not TRU waste? **[1.1 - N]**

WIPP is put in a natural resource rich area. The standard that DOE has to comply with talks about resources being avoided. WIPP was placed in an area of rich resources, so it already violates these requirements. **[2.1 - N]**

Other countries are looking at vitrification, containers other than 55-gallon drums, and other methods [of storing waste]. If we [U.S.] really want to do this, we must spend the money to do it right. **[1.3, 2.3 - Y]**

The Land Withdrawal Act does allow "remote-handled" [RH] waste that is actually **more** radioactive than that considered "high-level waste." **[1.4 - N]**

Part of the Waste Handling Building [at WIPP] has equipment to handle RH waste. There hasn't been any characterization at all of RH waste. Characterization of RH-TRU waste needs to be done soon, before emplacement. There is no idea of how it will react and affect the long-term performance of the facility. **[1.1, 1.2 - Y]**

If we were going to do WIPP right, we'd be talking about doing the very best we can and not looking at engineered alternatives as icing on the cake. DOE is trying to get away with not doing any backfill. **[7.1, 7.2 - Y]**

We need to construct the best containers possible and use the best waste form modifications possible. We can do a lot better than 55-gallon drums today, so why isn't DOE going to use more robust containers? If people [in the future] were to encounter these more robust containers, it would give them a reason to stop and consider what they might be getting into. **[2.3, 3.1 - Y]**

Let's leave the future the best that we can. DOE is not wanting to improve, for example, containers and salt backfill. DOE has been avoiding doing this. **[2.3, 7.2 - Y]**

We [the public] have been saying these same things since the 70s, so this is **not** an attempt by DOE to get "early public participation." **[7.2 - N]**

No transportation cask [for RH TRU] has been built. The first will be ready in 2015. **[2.3, 7.3 - N]**

Remote-handled waste leaves a wide open door. It may be much more hazardous, or "hotter" in radioactivity than high-level waste. **[1.4 - Y]**

Moderator: Suppose you had one minute to talk to DOE about WIPP and its ability to protect human health and the environment, what would you say?

[DOE] should characterize the waste first, and not just be mixing it and storing it away. I can't believe that this hasn't been done already. DOE should be putting efforts into this now, not waiting until WIPP opens and putting it [the waste] all together. **[1.1 - Y]**

Salt is not as thought [ideal storage medium] because it cracks. Clay is proven to limit movement of waste, but it is not even being considered. Existing reports say that use of specific proportions of a soil and clay mixture will work. DOE is backtracking on C&C agreement to use backfill. In official meetings with the EPA and regulators, they [DOE] have said they are not going to use backfill unless it is required by regulations. Just put salt around it. **[2.2, 7.2 - Y]**

DOE's got a big problem--they must solve the problem of getting rid of waste, but if they try to appease the general public and all the special interest groups, WIPP will never be opened. **[7.2 - N]**

The Land Withdrawal Act requires the DOE to comply with the EPA's 40 CFR 191. They haven't done so yet. Two things are required. The containment requirements include doing computer projections of the future about how the waste might get out [of the repository], and doing engineered barriers. The assurance requirements address engineered and natural barriers, because of the uncertainties of computer projections. **[3.3 - Y]**

The DOE is in the process of trashing the standard. DOE should show compliance. Instead of trying to get out of it, just do it. **[7.2 - N]**

Give assurances that engineered barriers will be used. Don't use panel seals. A panel seal is not a barrier. **[7.1 - Y]**

Get down to using public solutions. I believe that the DOE has generated some solutions. Just use them. Don't gather intelligence and then ignore it. Stop wasting our time. **[7.2 - N]**

[DOE needs to] do it right. Do more than just the minimum. DOE is trying to avoid doing the best that it could and doing it right. DOE is spending too much time fighting the Land Withdrawal Act. Become more definitive with getting waste in the ground after showing that the best has been done using robust engineered barriers. DOE needs to move from saying "Our job is to get waste in the ground and we don't care how much contamination there is" to "Our job is to get waste in the ground once we prove that it will remain there." **[7.1, 7.2 - Y]**

DOE should obey existing laws and standards rather than trying to water them down. **[7.2 - N]**

Characterize waste beforehand. Use the best containers. Engineered and natural barriers must be used. **[1.1, 2.3, 7.1 - Y]**

Do the disposition question soundly and well, and show that the environment and human health is protected. The history of WIPP has been pushing through solutions quickly. DOE has made major steps in the right direction to reach out for public support. Continue to gage public confidence, and get public involvement and participation. Use a rigorous scientific approach. Attain the highest standards of safety and environmental protection. **[7.2 - Y]**

The nuclear industry is ignoring disposition issues and is in a mess. They felt it was a technical problem, easily solved. Now it is learning that disposition has given rise to major problems. It needs to approach the question of waste management as a whole and get public involvement and participation. In some ways it [nuclear industry] is still assuming that the solution is somewhere in the future and isn't handling it now. **[7.2 - Y]**

Regarding the disposition question, DOE has ignored the concerns expressed over many years. Approach the question of waste management and disposition with the best science possible and winning the support of the public. The public should feel it is not being coerced into accepting currently proposed solutions. **[7.2 - Y]**

Since 1993, the DOE has made great strides in trying to involve the public much more than ever before; for example, it abandoned the idea of burying waste for the sake of experimenting with something like gas generation. It went from 200,000 drums to 12 to zero. The new administration feels the public pressure for money spent. The public is questioning the [WIPP] progress. Perhaps DOE has spent too much money in the past, but it now must do the right thing and not bend to pressure to rush this through. Doing the right thing requires time and money. DOE has hard-working, well-intentioned people. Nuclear waste is a universal problem. There are some good public servants at DOE who are feeling the new pressure. **[7.2 - Y]**

How about a contingency plan? What will happen if the DOE is abolished? **[3.3 - Y]**

4.0 SANTA FE, NEW MEXICO

AFTERNOON SESSION, June 28, 1995

A focus group discussion was held in Santa Fe, New Mexico the afternoon of June 28, 1995. Six participants attended this discussion. Mr. Steve Wilkes was the moderator. Other attendees were Maggie Wood, Rebecca Grohler, and Richard Quintana from the S.M. Stoller Corporation; Ann Marshall, from Advanced Sciences, Inc.(who served as note takers); and Patty Barratti-Sallani, a DOE-CAO public affairs representative

Mr. Wilkes opened the meeting with a brief discussion of the purpose of focus groups in general and how this particular session would be conducted. He addressed the ground rules for the discussions, the desired outcome, the assumptions to be used as a basis for the discussions, and then introduced Maggie Wood.

Ms. Wood's presentation addressed the purpose and objectives of the focus group discussion, how participants were selected, and how comments would be used. Ms. Wood advised the focus group that the EEG had requested that she give the participants copies of a paper prepared by EEG stating their position on Engineered Barriers at the WIPP site. Copies of the paper were then distributed to the participants at the end of the discussion.

Mr. Wilkes then led the remainder of the session, beginning with a discussion of concerns about the long-term performance of the WIPP disposal system. After all the concerns had been stated, Mr. Wilkes asked each participant to summarize their concerns in the form of a one minute statement to the DOE. The focus group session was then concluded.

Verbatim notes were not taken. The comments presented during the focus group discussion are shown in the order in which they were expressed.

CONCERNS STATED[3]

Moderator: What are your concerns about the ability of WIPP to protect human health and the environment once WIPP is closed, waste is emplaced, and the site is sealed?

WIPP can't meet all criteria unless engineered and natural barriers are used. Both natural and engineered barriers are required by EPA. If these rules are followed, I would have fewer concerns. **[7.1 - Y]**

Even if all the requirements for the integrity of WIPP are met, future climate conditions on the planet could change; weather patterns could be altered globally. Models predict 15 inches of rain, but what if pattern changes to 150 inches per year? What will that do? Will integrity of repository be breached and contamination leaked to aquifers? **[3.3 - Y]**

Models used for WIPP show geology unchanged by any climatic or geologic changes, but earthquakes do occur here. Are assumptions upon which WIPP is based (seismic, climate, etc.) valid? I'm concerned about Westinghouse's attitude that the EPA 194 requirements are burdensome, duplicative, and unnecessary, and about their unwillingness to meet the criteria because they interfere with their expectations. **[3.2, 3.3, 7.2 - Y]**

I am concerned about the whole premise on which WIPP is based. Assumptions and values are what dictates integrity of facility--DOE/Westinghouse have no values. They lie, look down on [patronize] the public, and cover up; there's no basis for trust. On **whose** values are "criteria" predicated on? On what are they based? The workers, scientists, and engineers believe environmentalists are simply using delay tactics. These are the people who will have to enforce requirements, so how can we trust them to do that if they don't believe requirements are necessary? **[7.2 - Y]**

I have a major problem with the assumption that human beings, through questionable science, are trying to make these predictions. Nature cannot be fooled--we're trying to make predictions, but the earth doesn't care. Nature can't be controlled and there is no way to predict the future. The views of the worth of natural resources will change in the future. What will be valuable later? Perhaps the waste itself will be valuable and intrusion will occur to get material; or terrorists may intrude. This [WIPP] is political rather than "natural" need. There is a prevailing problem of politics ruling over science. **[3.3, 7.2 - Y]**

The repository's placement in an area rich with natural resources is a mistake. Drill holes [boreholes] and the effect of pressurization underground due to gas generation is a problem. The waste will come out; the loose waste of the waste will facilitate surface releases. The waste

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Numbers in brackets at the end of each comment indicate the taxonomic category to which each comment was assigned. In some cases a comment was assigned to more than one category. In other cases separate statements within one comment were assigned different categories and were counted as separate comments. The Y or N letter that follows the category number(s) indicates whether the comment was related to postclosure [Y] or not related to postclosure [N].

should be treated to minimize the release of pressurized gas. Engineered alternatives should be pursued to prevent waste migration and increase the sheer strength. **[2.1, 1.2, 5.2, 1.3, 7.1 - Y]**

In a closed system there is no real disposal; the wastes may be hidden, but they are still down there and will eventually be exposed. Above-ground, accessible waste that could be continually monitored is better solution. **[3.3 - Y]**

I am concerned that signs and site markers may be interpreted differently in the future. Monuments themselves may be destroyed, or the materials from which the monuments are made could become valuable and the monuments could be stolen or "harvested." **[2.4, 3.3 - Y]**

There is a lot of momentum for the WIPP site being built simply because we have to continue since so much money has been spent on it [WIPP] already. **[7.2 - N]**

I'm really concerned that continuous monitoring is not being planned; there are no provisions for monitoring for more than a short time after WIPP is closed. There are also no plans for remediation. What if better technology comes about? Once collapsed, how do you remediate? There is a whole national debate on nuclear issue of waste that hasn't been done. **[2.4 - Y]**

There is a need for independent oversight of WIPP. There is no long-range planning and there is a lot of rule breaking. DOE "paperworks" their way around concerns instead of dealing with them. **[7.2 - N]**

EPA rules have been weakened by DOE. The standards and requirements are lessened by government pressure. We have no power to change/shape overall policy. There needs to be independent agency to track DOE. Past agreements have been broken. Government violates its own laws. It doesn't matter that public says they don't want it [WIPP], it just continues. DOE can't be trusted. Whistleblowers have said that waste has already been secretly shipped to WIPP, but DOE hasn't done anything about it. If WIPP is so safe, why has such an effort been made to locate it in unpopulated areas? TRUST is the issue. **[7.2 - N]**

I am concerned about institutional controls; record keeping control. How do you mark something in perpetuity? We may lose all knowledge that waste is down there, or WIPP may become a "treasure" site. **[2.4, 3.3 - Y]**

Moderator: What about the waste itself concerns you?

My concerns include insufficient waste characterization and inadequate sampling. Some of this waste is very old and accurate records haven't been kept of what's in the drums. DOE has said that they'll only sample 10 drums in 1000. That leaves 990 drums that could be a nuclear soup, with no way to control interactions among the waste. Each drum should be sampled. Carbon detectors can't detect most explosive wastes. Waste may mutate over time. **[1.1, 1.2 - Y]**

If characterization is not adequately done, then DOE can't meet the criteria because they won't really know what is in the drums. If characterization is properly done, DOE will be able to predict gas generation and other reactions; otherwise they won't. "Legal" methods to ensure accurate characterization is fallible. **[1.1 - Y]**

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DOE has exempted themselves from having to meet safety considerations such as flammability, gas, moisture, etc. based on assumptions that nothing in the waste will be explosive. If they're wrong about what [waste] is going down there, then how can they control what will happen if there is a spark or fumes or something else from the equipment being used. **[1.1, 1.2 - Y]**

Some low-level waste is actually very "hot" thermally and radioactively and could contaminate workers or the water supply. Even without an explosion, the waste could present huge problems if it got to the surface. The fracture structure of the surrounding geology is a problem. Thermal heat from the waste could attract moisture from salt. **[1.2, 4.0 - Y]**

DOE has assumed that the waste won't generate heat, but now they're saying that it may very well increase the temperature of the area. How will that affect brine movement or water supplies? **[1.2, 4.1 - Y]**

WIPP is not being designed to be monitored, so basically it is an uncontrolled experiment. There's not even any remote monitoring planned. Test wells are the only plan for monitoring. **[2.4 - Y]**

What if water is injected into wells near WIPP at instead of below the repository level? If water injection penetrates the site and waste moves into the McNutt Potash Zone, it won't have to migrate all the way to the Culebra, it will get out in the potash. **[4.1 - Y]**

Potash resources should be included in Performance Assessments. **[2.1 - N]**

Look at changes in the physical form of the waste. Efforts should be made to cement or vitrify the waste to prevent mobility of the waste. **[1.3 - Y]**

This is a political issue - you're either for or against the nuclear industry. Even God standing at WIPP's gates saying it was safe couldn't convince some people. This is about educating the public about what is going on. Tests like those conducted at Idaho Falls contributed to my confidence about WIPP. I think WIPP has gone overboard with the protection issue; there are so many safeguards. Gasoline trucks are much more dangerous than the TRUPACT, which poses no danger at all, but people aren't concerned at all about it [the gasoline truck]. **[7.2 - Y]**

Technology will change, and there is no way of knowing exactly what will happen, but I have no concerns about WIPP. **[3.3 - Y]**

Moderator: Are there other concerns that we haven't yet addressed?

Concerned about systematic, bureaucratic breakdown; war; institutional collapse; changes in society's values, etc. **[3.3 - Y]**

If the gold mines of the past were trying to be built today, they'd never make it.
Difference between things like gold mines and WIPP is that those [harmful byproducts] don't last as long. It is the longevity of the waste at WIPP that is the problem. We're dealing with the most dangerous product in the world and it will last for hundreds of thousands of years. **[1.4, 3.3 - Y]**

DOE has looked at alternatives such as cementation, clay, better containment methods, etc., but DOE won't use these. **[1.3, 2.0, 7.1, 7.2 - Y]**

DOE is a much stronger agency than EPA, so it can run right over them. Also, the EPA has invited the OMB [Office of Management and Budget] into the process, but they are much stronger than EPA as well. The entire process is "non-public." **[7.2 - N]**

The future of the EPA will be one of cutbacks, breakdown, and collapse. **[3.3 - N]**

DOE may try to change WIPP to store something it is not designed for, such as Yucca Mountain waste if it isn't approved. **[3.3, 7.2 - Y]**

There may be no EPA or DOE in the near future, much less 10,000 years from now. What will happen then? **[3.3 - Y]**

Showing causality is so difficult, how will it ever be found? For example, 50 years ago a village was using cobalt as jewelry, and even after they all started getting sick they didn't relate it to the cobalt. **[3.3 - Y]**

On the other hand, there is no way to know, so why go on at all, with anything? We just have to use the best technology now and go on. **[3.3 - Y]**

There are political and economic drivers. Why are there 600 employees at WIPP if there's no waste there? Who's benefitting at the expense of other people's values. **[7.2 - N]**

I'm concerned about how actual costs are determined. There is no continuity over these little parts, like this focus group meeting and public confidence study. There are gaps in the way things are done because they're being done in a vacuum. Nobody's "minding the store." People state their feelings and concerns but they seem to drop into a bottomless hole. **[7.2 - N]**

WIPP is a symbol of something that people have no control over. Most people realize that they can get much more exposure from other things, but WIPP symbolizes DOE's total unconcern for the <u>individual</u>. That the government really cares about people is a faulty premise. **[7.2 - N]**

Concerned that all criteria will not be met because the government can refuse funding in future. If they stop funding, then markers may not get put up even if they are planned now. **[3.3, 7.2 - Y]**

Oldest written history we have is less than 5,000 years. Governments come and go, as does currency, language, and everything else, so how can we be sure written records will mean anything? **[3.3 - Y]**

If we continue with these assumptions [that we can't predict future] then we can't do <u>anything</u>--not just WIPP. **[3.3 - Y]**

The 10,000-year expert projections don't fool anyone, so stop faking it. We can't predict that far into the future, so don't try to have experts assume that they can. We need to take the best technologies available now and use them instead of fighting it. **[3.3, 7.2 - Y]**

Money and time should be spent on the whole scenario, like shortening the half-lives, reducing volume, characterizing waste, and neutralizing the waste. Things like this should have been done first instead of using all that money to bury the waste. **[1.0, 2.0 - N]**

There isn't an iterative process in the federal government planning process. They never stop to consider what went wrong in the past in order to improve the future. The existing process doesn't allow for goal evaluation and changes. **[7.2 - N]**

Moderator: If you had one minute to talk to DOE about WIPP and its ability to protect human health and the environment once it is closed, what would you say?

WIPP is a bad idea. A national debate is needed on how to deal with the country's nuclear waste. This needs a more holistic focus. **[7.2 - N]**

What is needed is more open public debate and stakeholder involvement in the policy making. Empower stakeholders to solve the problems. **[7.2 - N]**

Educate the public, educate the public, educate the public. WIPP won't work forever; it will eventually fail. The issue cannot be swept under the rug; the problems will just be passed on to future generations. **[3.3, 7.2 - Y]**

Stop letting the schedule drive the process. It leaves no room for questions or change. The process needs to be more open. The EPA will be making important scientific determinations with a small group of dedicated people evaluating the work of much more experienced scientists. The EPA staff won't have as much experience and qualifications as the DOE. **[7.2 - N]**

Stakeholders have very little scientific knowledge. Don't fake the performance assessments with fancy numbers and expert panel projections. These are just devices to fake confidence, and the public won't be fooled. Don't avoid consideration of natural resources like potash. **[7.2 - N]**

If the determination that WIPP has met all compliance requirements is totally open to the public, the public may accept it; but they won't if the determination is government-controlled. **[7.2 - N]**

EVENING SESSION I, June 28, 1995

A focus group discussion was held in Santa Fe, New Mexico the evening of June 28, 1995. Three participants attended this discussion. Mr. Steve Wilkes was the moderator. Other attendees were Maggie Wood, Rebecca Grohler, and Richard Quintana from the S.M. Stoller Corporation; Ann Marshall, from Advanced Sciences, Inc. (who served as note takers), and Patty Barratti-Sallani, a DOE-CAO public affairs representative.

Mr. Wilkes opened the meeting with a brief discussion of the purpose of focus groups in general and how this particular session would be conducted. He addressed the ground rules for the discussions, the desired outcome, the assumptions to be used as a basis for the discussions, and then introduced Maggie Wood.

Ms. Wood's presentation addressed the purpose and objectives of the focus group discussion, how participants were selected, and how comments would be used. Ms. Wood advised the focus group that the EEG had requested that she give the participants copies of a paper prepared by EEG stating their position on Engineered Barriers at the WIPP site. Copies of the paper were then distributed to the participants at the end of the discussion.

Mr. Wilkes led the remainder of the session, beginning with a discussion about participants' concerns about the long-term performance of the WIPP disposal system. After all the concerns had been stated, Mr. Wilkes asked each participant to summarize their concerns in the form of a one minute statement to the DOE. The focus group session was then concluded.

Verbatim notes were not taken. The major comments or points made during the focus group discussion are presented in the following section. The comments are shown in the order in which they were presented.

CONCERNS STATED

Moderator: What are your concerns about the ability of WIPP to protect human health and the environment once WIPP is closed, waste is emplaced, and the site is sealed?

How can we predict what will happen in the future? We thought we knew in the past and we were wrong. We can surmise, but there is no way of knowing. How do we know the site will work the way it is designed? **[3.3 - Y]**

I sat in on a National Academy of Science (NAS) meeting where they told DOE that man-made cavern in salt will not work; it would be better to use a natural cavern in the salt. With movement expected from both the top and the bottom, the capsules can't resist the moisture for thousands of years. They recently found out that water flow from the Rio Grande is not what they thought. Nature will fill the void. **[2.1 - Y]**

DOE says that no water goes through or near the site, but the Ogallala Aquifer, one of the main aquifers that feeds the southwest, is in that area. Concerned that the waste containment capsules will not be water resistant and if water were to get into the facility the capsules could break down and allow contamination to enter the aquifer or contaminate the air. **[2.3, 4.1, 5.2 - Y]**

What happened to create all the layers above WIPP and how do we know the earth won't revert to those conditions? **[3.3 - Y]**

One citizen asked what kind of waste will be put into the WIPP. DOE representative Patty Barratti-Sallani provided a brief description of transuranic waste. **[not counted]**

Citizen: Plutonium is plutonium whether it's a lab coat or a fuel rod; DOE can't simply cut a fuel rod in small pieces and call it low-level waste. Should consider it the same material regardless of what kind of item it is. Need to have one standard for all waste. Even if the [contaminated] lab coat disintegrates, the part containing the radionuclides will have an impact for 240,000 years. How can we look at 240,000 years and predict what affect it [plutonium] will have on the genetic makeup of society? We don't know how Mother Earth might react--she might through it out if we stuff her. That's longer than the history of man. The entire gene pool of my tribe could be wiped out if there were an incident. **[3.3, 5.2, 7.2 - Y]**

We don't know what kind of effect there will be from burying this waste in the earth. We don't know what the Arabs might do or the Bosnians in 100 years. They might bombard the site. **[3.3 - Y]**

I sit squarely on the fence, but in 240,000 years we should be able to fix that [the waste problem]. **[3.3 - Y]**

A citizen asked "Once waste is emplaced, can it ever be taken out?" The DOE Representative explained that the area could be remined, but it could result in exposure and mining risks to the workers. **[not counted]**

A concern was expressed if the salt would act as predicted and collapsed on the waste. **[1.2 - Y]**

Concerned that we won't be able to continue to monitor the site in the future to ensure that it is performing as expected. **[2.4, 3.3 - Y]**

We've done this to ourselves. All of this [waste] is out there now and poses a danger and great risk to this generation and those in the next few hundred years, so surely we would be better off if the waste were isolated in the WIPP. **[7.4 - N]**

I agree. Maybe we get the technology to clean the water if it gets into the water, but we don't know. **[7.4 - N]**

The unknown itself is the concern. With not being able to monitor, we need to do the best we can now. Then, in the future, if better technology is developed, it could be used...**[2.4, 3.3 - Y]**

Society's tendency is to bury what we don't understand-- "out of sight, out of mind." I hope in 500 years we will find ways to mine and neutralize it--with all safety networks. Maybe we'll have submarines to go in and neutralize it. **[3.3, 7.2 - Y]**

I'm concerned about whether or not we'll be able to get back to the waste and retrieve it if we find a better way. Or, perhaps we will have the technology to clean any contaminated water or air that might result from burying the waste. **[2.0, 3.3 - Y]**

No other society has lived over 500 years--who will be in charge? Will the United States even exist then? **[3.3 - Y]**

Concerned that enough money isn't being put into finding ways to neutralize the substances produced instead of putting all the money into developing disposal facilities. A proportion of the money spent for these facilities should be used on finding ways to prevent these problems. Similar to forest service--spends 90% on suppression and only 10% on prevention. **[7.2 - N]**

Moderator: Is there anything about the waste itself which concerns you?

Concerned about both hazardous and radioactive wastes being placed together in the facility. Perhaps the waste should be more homogeneous. **[1.1, 1.2 - Y]**

I'm concerned about the byproducts of hazardous waste degradation. Biodegradation of natural substances may create oils or other liquids as a result of decomposition. These decomposed products may get into the water. **[1.2, 4.1 - Y]**

We get oil and gas from the earth - that doesn't really bother me. Life is precious and we need to protect our water system; maybe we can, maybe we can't, but [the waste] is still safer underground than on top. **[7.2 - N]**

Moderator: Are there additional concerns which have not yet been addressed?

DOE has a real public relations problem. Past errors, blunders, blatant deceit have created considerable distrust of DOE. DOE is an amorphous body; there's not an "individual" that the public can look to and learn to trust. Some of its blunders are just from ignorance, but DOE lies and tries to cover up and tell the public that everything's fine; later we discover it wasn't fine--look at Agent Orange. How can they [DOE] assure us that everything's fine when there is no way to predict what will happen? God help us if we say in 50 years that this salt experiment didn't work. **[3.3, 7.2 - Y]**

What if WIPP doesn't work? What prevents area from becoming prone to earthquakes or floods? **[3.2 - Y]**

Participant question: When they detonate underground explosions, is this worse than that? **[not counted]**

WIPP may not be as bad as other sites that do underground detonation, but it's like comparing two bad apples. My concern is that we don't just bury it and forget it. We need to know that the government is doing its very best to protect the southeast corner of our state. We need to continue to monitor for as long as the waste is hazardous, no matter what agency or government is in charge. **[2.4, 7.2 - Y]**

We were told that Los Alamos [National Laboratory] wouldn't contaminate our aquifer because it was 2,500 feet underneath Los Alamos; then two years later they [DOE] admitted that there is contamination, but tried to say it came from the Chernobyl incident. **[7.2 - N]**

What good is open, honest communication by DOE? When PR people start talking, it's a scam. DOE is a con artist. We need to be able to look up information ourselves. Everything should be public record. There is public involvement and willingness to listen. An ongoing dialog is important to maintain. **[7.2 - N]**

Moderator: If you had one minute to talk to DOE about WIPP and its ability to protect *human health and the environment once it is closed, what would you say?*

I need more information based on what we discussed. I don't know enough about the site. From a humanitarian point of view we have, because of a hunger for exploration of new and different elements and a thirst for knowledge and going forward, created a problem for ourselves and future generations; now how do we best serve future generations. How can we neutralize the waste and resolve this problem? **[7.2 - N]**

With information we have, I would have to do the "ostrich thing" and bury my head in the ground until we can divert our attention from burying/generating waste to actually finding an antidote. **[7.2 - N]**

I would like to know what's wrong with the existing storage situation. Just because we've spent two billion dollars on [WIPP], we must be able to pull back from it--not just do it because we've gone too far. We need to be cautious. If some other technology can be developed in next ten years or so, then they [DOE] should walk away from it [WIPP]. Don't succumb to pressure--if we need WIPP that badly, explain what is the situation in other areas. **[7.2 - N]**

OTHER DISCUSSIONS

Can we cause the salt to collapse instead of letting it happen naturally? Can we encapsulate the waste by deliberately collapsing the salt around it, and then let the natural occurrence we expect to happen naturally. My understanding is that it will generate so much heat it will melt the salt and encapsulate everything. NAS is very creative. Now they're trying to encase it in glass at Hanford. **[1.2, 1.3, 2.2 - Y]**

Concerned about transportation risks with regard to tourism in Santa Fe and New Mexico. An accident, no matter how minor, would affect tourism for the whole state because it would be exaggerated by the media and the public. **[6.1, 7.3 - N]**

We've spent billions on everything else so don't scrimp on the transportation--not just on equipment, but with escorts or whatever it takes to ensure safety. Block the roadways so no one can overtake the TRUPACTs, have police escorts surrounding it, or whatever is necessary. What kind of qualifications do drivers need--airline pilots have to go through years of training, will these drivers have special training? Will they be under time constraints or can they take two days instead of one day to get to WIPP? **[7.3 - N]**

A citizen asked if shipments would be escorted or if drivers were on their own. The DOE representative said drivers would be on their own. The citizen then asked how DOE could keep track of the shipments. The DOE representative said that there would be a satellite tracking system that would verify the vehicle's location every 15 minutes and that communication via computer would be made, if no answer, emergency vehicles will be sent to investigate **[7.3 - N]**

One citizen said that measures should not be reactive, but proactive, to prevent any mishaps, such as terrorists. **[7.4 - Y]**

The tribes are not being kept informed. Recently there was an incident in the State of New Mexico. They couldn't handle it and had to bring responders in from Oklahoma. In every exercise we have participated in, our people died because of a lack of communication. We need one common frequency with police, fire department, WIPP, and all other emergency participants. Also expressed concern that if pueblo emergency personnel are first on the scene, that they have the same equipment (such as protective suits) that police and fire department have. **[5.0, 7.3 - N]**

Also expressed some concern about the emergency response system. Who responds? Who coordinates? How do we know that it will work? **[7.3 - N]**

EVENING SESSION II, June 28, 1995

An independent interview was conducted on the evening of June 28, 1995, with one individual who was invited to participate in the focus group discussions but was unable to participate in the Albuquerque focus group due to a misunderstanding about the location where the focus group discussion was held. The participant was invited to attend other focus group discussions in Santa Fe but was unable to attend these sessions. This interview was therefore conducted subsequent to the evening session of the Santa Fe focus group discussion. Maggie Wood of the S.M. Stoller Corporation lead the interview using the same questions that were used in other focus group discussions. She started the interview with a presentation on the objectives and purpose of the interview and focus group discussions. This presentation was also given at all the other focus group discussions and is attached to this report as Exhibit A. Ms. Ann Marshall, Advanced Sciences, Inc. took notes and Patty Barratti-Sallani, a DOE-CAO public affairs representative was also present.

Verbatim notes were not taken. The major comments or points made during the interview are presented in the following section. The comments are shown in the order in which they were expressed.

CONCERNS PRESENTED

Moderator: What are your concerns about WIPP's ability to protect human health and the environment once waste has been emplaced, it is closed, and sealed?

I am concerned that WIPP relies too much on passive measures rather using than active measures to protect the waste. DOE expects the waste to stay where it is emplaced. I am concerned because this is not a 10,000 year problem, which is an arbitrarily number, but rather a 100,000 to 200,000 year problem. **[2.0, 3.3 - Y]**

I believe that the containers which are used to store the waste [55-gallon drums] are inadequate. We heard that the geologic containment was deemed sufficient because they couldn't come up with a container that would last. There was a failure of common sense at the beginning with the use of this premise which may lead to a failure of common sense latter. It would be common sense to design a waste container that would last the entire period of time that the waste is radioactive or 200,000 years. **[2.3, Y]**

Monitoring. I think that the current plans for monitoring are totally inadequate. It is ethically repugnant to emplace the waste and then just walk away from it. **[2.4 - Y]**

Moderator: If you were going to monitor what would you monitor for?

I would keep people on the site for the 200,000 year period of risk to identify any problems that might come up and materials that might sneak out. The biggest thing is water intrusion into the site. You need to monitor for water intrusion into the site. If water intrusion occurred you would need to detect it so that you could remediate the site. You need to figure out what should be done if water intrusion occurs. Salt will move, and there will be a mobility of the elements [e.g., hazardous and radioactive constituents].. There are no real barriers to contain the radioactive and hazardous elements and with the inadequate containers what will indicate movement of the

elements? Monitoring of heat was ruled out decades ago because they know that there will be heat. Will there be an expanding bubble of elements and will they be monitored? **[2.0, 2.3, 2.4, 3.2, 4.1 - Y]**

How will we know if WIPP has failed? There really isn't any way to make a plug (seal), and there is no way to prevent a borehole from releasing pressurized brine. DOE initially predicted a 2 percent to 70 percent chance of an inadvertent intrusion into the site. Then finally the prediction moved to 2 percent to 48 percent over a 100,000 to 200,000 year period. I believe that human intrusion is highly probable with a probability of 1.0. Even if you were monitoring the site for human intrusion, how would you detect intrusion from the side, like in slant drilling? Or what would you do? **[2.4, 3.1 - Y]**

Brine pockets which reside in the site itself could create a shaft. How do you monitor for pressurized gas? **[1.2, 2.1, 2.4 - Y]**

My preference is retrievable waste which will be monitored outside each container, which is imbedded in a steel matrix - so you could pull it out. That should be specified. **[2.2, 2.3 - Y]**

There are a variety of ways that could be used to get the containers out of the salt beds once they are emplaced such as a cable system with computer codes. **[2.2, 2.3 - Y]**

Once the stuff [waste] is out of the bottle [container], it just doesn't make any sense at all. The waste should be put in a stable container so that it can't get out. Then you could mine out the containers in the future. **[2.3 - Y]**

I am also concerned about the current methods that are used to perform risk assessments which are woefully inadequate. Do we know how to predict thousands of years in the future? If we used comparable techniques in medicine, they would be considered primitive. Current risk analysis only uses single element analysis. In medical science we know that there is a synergy of multiple factors like birth defects or lead poisoning. Those factors that are in the ground and all other potential factors should be used in performing risk assessments. **[3.3, 5.1 - Y]**

WIPP is symbolic of society's attitude toward waste and how we produce, handle, and store toxic materials. **[7.2 - N]**

I am concerned about the opportunity costs associated with WIPP. If we allow waste to be emplaced too quickly, society will not take the effort to solve the problems that occur from exposure to radioactive materials like plutonium and other exposures. **[7.2 - N]**

WIPP fits in with other vectors of illness and disease. WIPP has a function to serve as it gives us the opportunity to perform research and development on toxins and improve global health. If waste is emplaced in WIPP and it is closed and you walk away from it, you will lose the impetus for research and development. **[7.2 - N]**

Geo-satellite monitoring could be used to monitor the facility. You could monitor activity in the vicinity by implanting sensor devices and monitoring geological data for the introduction of water into the site. **[2.4 - Y]**

I am also concerned about treatment, pretreatment, and stabilization of the waste. Is the waste in the best form for storage? **[1.3 - Y]**

I also believe that waste characterization should be performed on a barrel-by-barrel basis and that an analysis of the waste should be performed so that we will know what we are putting in there. Without knowing the exact composition of the waste we lose the ability to know what you're protecting the public from and a particular isotope could become a key factor. **[1.1 - Y]**

We should be building a system that will allow improvements over time, not degrade over time. **[7.2 - N]**

Another concern is future generations mining the site out of curiosity and the potential health impacts from such activities. The use of markers will be as likely to attract as repel efforts of this nature. What should we do if someone decides what is in WIPP is valuable and wants it? **[2.4, 3.1 - Y]**

Moderator: If you were living thousands of years in the future in southeastern New Mexico, and you knew that radioactive waste was buried in WIPP, what do you wish people had thought of?

I would want people to tell the whole story of nuclear weapons. Why we made them, and why we made so many of them. If future generations knew about the production of nuclear waste and the waste by-products it would reduce the potential of people messing around with the waste in the future. **[7.2 - Y]**

I am concerned that in the future people might want to mine the waste for the materials which could be used for the production of weapons. I am concerned that uranium and plutonium could be mined. If this mining were to occur these materials could get into the food chain. **[3.1, 5.0 - Y]**

Looking at 1 ppm - biological organisms could concentrate these elements [plutonium and uranium] and move them into the food chain. We are now finding micro-organisms way underground. The radioactive elements in the waste might become a medium for these micro-organisms and a microbial bridge could be formed and mutate the organisms. **[4.3, 5.0 - Y]**

I am truly concerned about adequate monitoring of the site in the future and container retrievability. DOE currently has no real plan for retrievability. We want to see more modern materials considered for the waste containers. We would like studies of what materials can be used to achieve a longer container life. **[2.3, 2.4 - Y]**

We need specific sensors that can track specific elements. Invitro stabilization techniques, ways to pretreat and separate the waste should be explored and then decide what's the best way to store these wastes. A variety of stabilization techniques should be explored. I am concerned about mobility of the waste in the salt, gas pressure build up, and the lack of boundaries and barriers to prevent the waste from getting out and affecting human health and the total ecological environment. There could be indirect health effects on other species, like coyotes, deer mice, it could be like the hanta virus. **[1.1, 1.3, 2.4, 4.0, 4.3, 5.0 - Y]**

Moderator: If you had one minute to talk to DOE what would you want to say?

The plan of putting the waste into containers and walking away from it does not use the best available technology. Its not even using the best technology that we have gained over the last 30 years. We should prepare waste containment strategies so we can improve containment in the future. Something that will give assurance of an ability to improve rather than degrade - Go for 10,000 year or 100,000 year improvements. We currently don't know the right balance between concentration and dispersal - or somewhere in-between. That is the problem for the stuff in WIPP and other stuff too. **[2.3, 7.2 - Y]**

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APPENDIX N

WASTE ISOLATION PILOT PLANT RELATIVE FREQUENCY OF COMMENTS BY CATEGORY

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Phase 2
Fosuc Group Comments Pertinent or Not Pertinent
Postclosure WIPP

	Carlsbad		Albuquerque		Santa Fe		Total				
	Yes	No	Yes	No	Yes	No	Yes + No	Yes		No	
1.0 Waste Conditions	6	0	22	3	25	4	60	53	88%	7	12%
2.0 Technology Applied	13	1	15	3	39	1	72	67	93%	5	7%
3.0 Disposal Period Events	7	0	23	0	40	0	70	70	100%	0	0%
4.0 Ecological Impacts	6	1	2	0	11	0	20	19	95%	1	5%
5.0 Human Health	1	1	1	0	8	1	12	10	83%	2	17%
6.0 Economic Impacts	0	1	0	0	0	1	2	0	0%	2	100%
7.0 Other	4	17	23	13	20	28	105	47	45%	58	55%
Total	37 64%	21 36%	86 82%	19 18%	143 80%	35 20%	341 100%	266	78%	75	22%

Relative Frequency of Comments by Category
(Focus Group Meetings—June, 1995)

	CBAD #	CBAD %	SF #	SF %	ABQ #	ABQ %	Composite #	Composite %
1.0 Waste Conditions	1	2%	1	1%	0	0%	2	1%
1.1 Characterization/Identification	1	2%	6	4%	10	10%	17	5%
1.2 In-Storage Reaction	2	3%	10	6%	5	5%	17	5%
1.3 Treatment	1	2%	6	4%	8	8%	15	5%
1.4 Characteristics	1	2%	1	1%	2	2%	4	1%
2.0 Technology Applied	1	2%	5	3%	0	0%	6	2%
2.1 Siting	5	9%	4	2%	4	4%	13	4%
2.2 Site Design	2	3%	3	2%	4	4%	9	3%
2.3 Containers	0	0%	8	5%	9	9%	17	5%
2.4 Monitoring & Marking	2	3%	15	9%	1	1%	18	6%
3.0 Disposal Period Events	1	2%	0	0%	0	0%	1	0%
3.1 Human-Caused Intrusion	5	9%	3	2%	11	11%	19	6%
3.2 Intrusion Due to Natural Causes	0	0%	3	2%	0	0%	3	1%
3.3 Disposal Period Uncertainties	5	9%	32	19%	12	12%	49	15%
4.0 Ecological Impacts	2	3%	2	1%	0	0%	4	1%
4.1 Water (ground water and surface water)	5	9%	5	3%	1	1%	11	3%
4.2 Air	0	0%	0	0%	0	0%	0	0%
4.3 Flora and Fauna	0	0%	2	1%	0	0%	2	1%
5.0 Human Health	1	2%	4	2%	0	0%	5	2%
5.1 Risk Assessment	0	0%	1	1%	0	0%	1	0%
5.2 Toxic Effects	1	2%	3	2%	0	0%	4	1%
6.0 Economic Impacts	1	2%	0	0%	0	0%	1	0%
6.1 Tourism	0	0%	1	1%	0	0%	1	0%
7.0 Other	0	0%	0	0%	0	0%	0	0%
7.1 Engineered Alternatives Study	2	3%	3	2%	9	9%	14	4%
7.2 Value/Ethics	10	17%	39	24%	19	19%	68	21%
7.3 Transportation	3	5%	5	3%	2	2%	10	3%
7.4 Miscellaneous	6	10%	3	2%	3	3%	12	4%
	58	100%	165	100%	100	100%	323	100%

APPENDIX O

WASTE INVENTORY

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WASTE INVENTORY

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) has initiated a cost benefit study to provide a technical basis for the selection and rejection of engineered alternatives (EAs) for the Waste Isolation Pilot Plant (WIPP) should it be determined that additional barriers are desirable. The EAs are analyzed with respect to the following eight factors:

- Effects of EAs impact on long-term performance of the disposal system
- Worker and public exposures
- Impact on removing waste from the repository
- Risk of transportation
- Impact on uncertainty in compliance assessment
- Impact on public confidence in performance of the repository
- Impact on total system cost and schedule
- Impact on other waste disposal programs.

Processed waste masses and volumes are used to support the analyses associated with many of these factors.

The purpose of this appendix is to describe the methodology used in determining final waste form masses and volumes for the baseline and each of the EAs in greater detail than provided in the report.

2.0 METHODOLOGY

The methodology for determining final processed masses and volumes for the WIPP inventory is depicted in Figure O-1. Each step is described in the following subsections.

2.1 STEP 1: WASTE STREAM-SPECIFIC MASS AND VOLUME

Initial waste stream-specific volumes (i.e., pre-processed volumes) were obtained from the Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report (WTWBIR), CAO-94-1005, Revision 1, February 1995. The WTWBIR contained two types of waste volumes: (1) the "initial" volume, which represents the volume of the waste in its current form and (2) the final form volume, which represents the volume of the final form of the waste for shipment to WIPP. The initial volumes were used in this methodology. The following data were obtained from the waste stream profile:

- Site name
- WIPP ID
- Handling (i.e., contact-handled [CH] or remote-handled [RH])
- Waste type (i.e., transuranic [TRU] or TRU mixed [TRUM])
- Waste matrix code group

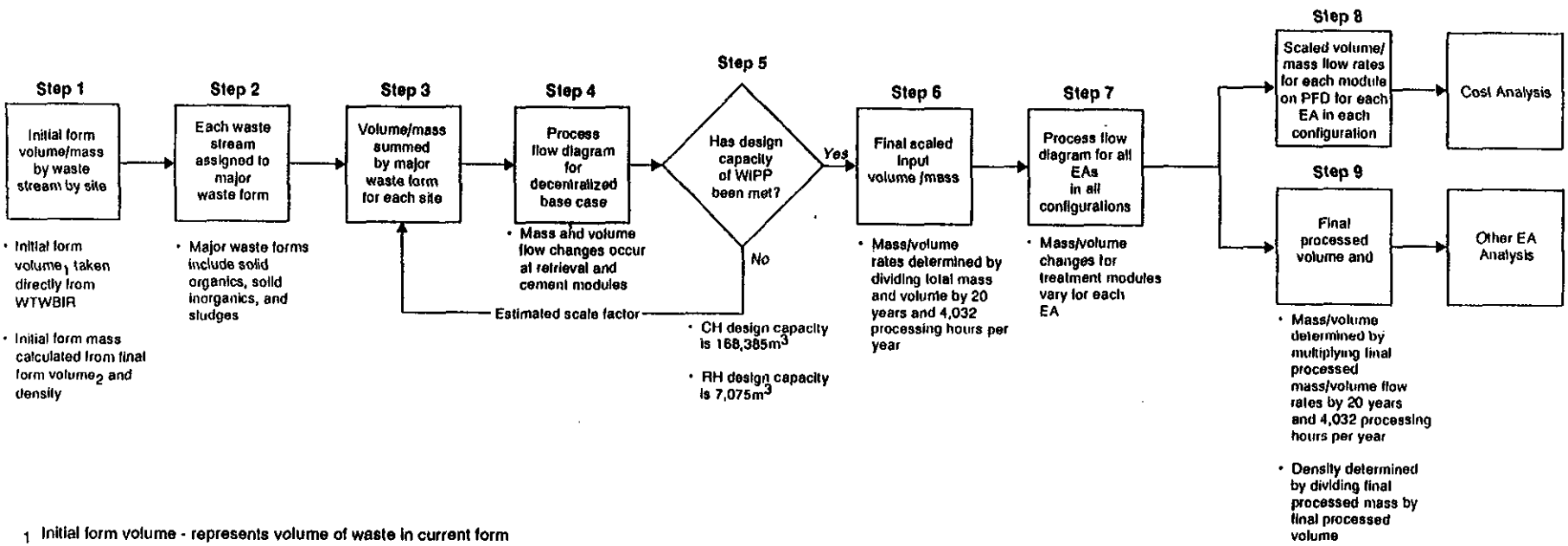

1 Initial form volume - represents volume of waste in current form
2 Final form volume - represents volume of waste in final form for shipment to WIPP

Figure O-1
Methodology for Determining Final Processed Mass and Volume of WIPP Inventory

- Volume of retrievable waste (stored inventory)
- Volume of projected waste (projected inventory).

Mass data were not provided in the WTWBIR; masses were obtained by multiplying the volume of each waste stream by an average density for the waste matrix code group associated with that waste stream. The average densities are shown in Table O-1 for CH waste and Table O-2 for RH waste. The WTWBIR includes waste material parameters, in terms of kilograms per cubic meter, for iron-based, aluminum-based, other metals, other inorganics, cellulose, rubber, plastics, solidified inorganic material, and solidified-organic material constituents for both CH and RH waste. These parameters were summed to obtain the density for the waste matrix code group. However, these densities represent the final form waste densities. Therefore, the final form waste volume was multiplied by the sum of the material parameters to calculate final form mass. As a simplifying assumption, it was assumed that the initial form and final form masses for the stored sludges, solid organics, and solid inorganics were equal. However, for projected sludges, it was assumed that the final form mass represented the initial form mass plus the cement added to the sludges in grouting; as a result, the contribution of cement was subtracted from the final form masses of the projected sludges to obtain the initial form mass. The average weight percent of cement in grouted sludge was calculated at approximately 62 percent, based upon a memo from E.R. Naimon to A.E. Whiteman (Naimon, 1988), thus the final form projected sludge mass was multiplied by (1-0.62) to obtain the initial form of the sludge mass.

2.2 STEP 2: ASSIGNMENT OF MAJOR WASTE FORM TO WASTE STREAMS

As shown in step 2 of Figure 1, the waste streams were assigned to three major waste form categories: sludges, solid organics, and solidified inorganics, based on waste matrix code group. The correlation between waste matrix code group and the major waste forms was obtained from the Final Report on Cost and Schedule of Selected Engineered Alternatives, IT Corporation, September 27, 1994, and is presented in Table O-3.

2.3 STEP 3: SUMMATION BY MAJOR WASTE FORM

As shown in step 3 of Figure 1, waste streams were summed by site by major waste form category. Initial masses for CH and RH waste are shown in Tables O-4 and O-5, respectively. Initial volumes for CH and RH waste are shown in Tables O-6 and O-7.

Mass and volume flow rates were calculated assuming a 20-year inventory processing period and 4,032 hours of operation per year (three 8-hour shifts, 240 days per year at 70 percent availability). Initial mass rates for CH and RH waste are shown in Tables O-8 and O-9, respectively. Initial volume rates for CH and RH waste are shown in Tables O-10 and O-11.

2.4 STEP 4: APPLICATION OF MASSES AND VOLUMES TO THE PROCESS FLOW DIAGRAM FOR THE DECENTRALIZED BASELINE

The mass and volume flow rates were applied to the process flow diagrams for the decentralized baseline for CH waste (Figure O-2) and RH waste (Figure O-3), respectively. The modules included in Figure O-2 and Figure O-3 are discussed in more detail in Section 2.7. The process flow diagrams are based on the DOE Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task

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TABLE O-1

SUM OF WASTE MATRIX CODE GROUP PARAMETERS FOR CH WASTE

Final Waste Form	Sum of Waste Matrix Code Group Parameters (kg/m^3)
Combustible	463.24
Filter	171.75
Graphite	245.90
Heterogeneous	691.59
Inorganic Nonmetal	274.57
Lead/Cadmium Metal Waste	336.76
Salt Waste	270.81
Soils	688.04
Solidified Inorganics	769.98
Solidified Organics	776.93
Uncategorized Metal	328.56
Unknown	000.00

1

TABLE O-2

SUM OF WASTE MATRIX CODE GROUP PARAMETERS FOR RH WASTE

Final Waste Form	Sum of Waste Matrix Code Group Parameters (kg/m^3)
Combustible	354.10
Filter	241.30
Heterogeneous	239.74
Lead/Cadmium Metal Waste	344.04
Salt Waste	270.81
Solidified Inorganics	793.27
Uncategorized Metal	519.14
Unknown	000.00

1

TABLE O-3

CORRELATION BETWEEN WASTE MATRIX CODE GROUP AND MAJOR TRU WASTE FORMS

Waste Matrix Code Group	Major Waste Form
Combustible Waste	Solid Organics
Filter Waste	Solid Organics
Graphite Waste	Solid Inorganics
Heterogeneous Waste	Solid Organics
Inorganic Nonmetal Waste	Solid Inorganics
Lead/Cadmium Metal Waste	Solid Inorganics
Salt Waste	Solid Inorganics
Soil	Solid Inorganics
Solidified Inorganic Waste	Sludges
Solidified Organic Waste	Solid Organics
Unspecified Metal Waste	Solid Inorganics

M

TABLE O-4

CH SITE-SPECIFIC MASS (IN KILOGRAMS)

	Sludges		Solid Organics		Solid Inorganics		Unknown	
Site	Retrievable	Projected	Retrievable	Projected	Retrievable	Retrievable	Projected	Projected
AMES	0	29	0	0	0	0	0	0
ANL-E	17,744	328	19	0	2,000	184	0	0
ANL-W	0	0	0	2,324	7	835	0	0
BT	0	0	0	85,630	0	0	0	0
ETEC	0	0	1,148	3,596	71	0	0	0
HANFORD	2,256	922,709	6,174,947	6,478,969	133,813	4,759,249	0	0
INEL	9,366,245	0	7,748,875	692	2,943,209	0	0	0
KAPL	0	0	1,660	0	0	0	0	0
LANL	3,733,153	602,456	819,162	1,141,703	1,433,799	1,087,211	0	0
LBL	0	0	581	3,057	0	0	0	0
LLNL	10,243	19,354	25,501	178,078	47,589	81,944	0	0
MOUND	5,605	0	3,318	0	134,721	0	0	0
MU	0	0	41	1,109	0	0	0	0
NTS	0	0	428,439	0	0	0	0	0
ORNL	26,888	0	465,426	182,510	0	0	0	0
PA	2,656	0	0	0	0	0	0	0
PANTEX	0	0	432	0	0	0	0	0
RFETS	176,040	874,298	337,402	781,162	109,011	296,437	0	0
SNL/NM	0	0	5,560	4,841	0	0	0	0
SRS	31	0	9,205,766	7,501,480	0	0	0	0

TABLE O-5

RH SITE-SPECIFIC MASS (IN KILOGRAMS)

	Sludges		Solid Organics		Solid Inorganics		Unknown	
Site	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected
ANL-W	0	0	356	523	3,723	830	0	0
BCLDP	0	0	0	17,021	0	0	0	0
BT	0	0	0	373	0	0	0	0
HANFORD	0	0	7,950	712,915	0	0	0	0
INEL	1,666	0	3,269	671	2,134	5,592	0	0
KAPL	0	0	2,692	6,049	0	0	0	0
LANL	0	0	5,255	1,119	39,694	41,272	0	0
ORNL	153,869	52,451	91,775	43,800	0	0	0	0
SRS	0	0	0	15,324	0	0	0	0

TABLE O-6

CH SITE-SPECIFIC VOLUME (IN CUBIC METERS)

	Sludges		Solid Organics		Solid Inorganics		Unknown	
Site	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected
AMES LAB	0	0	0	0	0	0	0	0
ANL-E	23	1	0	0	6	1	0	0
ANL-W	0	0	0	3	0	2	0	0
BT	0	0	0	123	0	0	0	0
ETEC	0	0	2	5	0	0	0	0
HANFORD	3	3,154	7,798	13,557	259	14,147	0	0
INEL	18,150	0	11,043	0	8,752	0	1,252	0
KAPL	0	0	2	0	0	0	0	0
LANL	4,848	2,059	1,768	2,465	4,244	3,151	0	0
LBL	0	0	1	4	0	0	0	0
LLNL	13	66	66	405	145	250	0	0
MOUND	7	0	7	0	249	0	0	0
MU	0	0	0	2	0	0	0	0
NTS	0	0	613	0	0	0	0	0
ORNL	110	0	673	264	0	0	0	0
PA	2	0	0	0	0	0	0	0
PANTEX	0	0	1	0	0	0	0	0
RFETS	188	1,346	533	1,684	341	972	0	0
SNL/NM	0	0	8	7	0	0	0	0
SRS	0	0	9,336	13,365	0	0	0	0

TABLE O-7

RH SITE-SPECIFIC VOLUME (IN CUBIC METERS)

	Sludges		Solid Organics		Solid Inorganics		Unknown	
Site	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected
ANL-W	0	0	1	2	7	2	0	24
BCLDP	0	0	0	71	0	0	0	0
BT	0	0	0	2	0	0	0	0
HANFORD	0	0	32	2,974	0	0	0	0
INEL	2	0	14	3	4	6	11	0
KAPL	0	0	11	25	0	0	0	0
LANL	0	0	15	3	76	80	0	0
ORNL	611	174	383	183	0	0	0	0
SRS	0	0	0	32	0	0	0	0

1

TABLE O-8

INITIAL MASS RATES FOR CH WASTE
(kg/hr)

	Sludges		Solid Organics		Solid Inorganics		Unknown	
Site	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected
AMES LAB	0	0	0	0	0	0	0	0
ANL-E	< 1	< 1	< 1	0	< 1	< 1	0	0
BT	0	0	0	1	0	0	0	0
ETEC	0	0	< 1	< 1	< 1	0	0	0
HANFORD	< 1	11	77	80	2	59	0	0
INEL/ANL-W	116	0	96	< 1	36	< 1	0	0
KAPL	0	0	< 1	0	0	0	0	0
LANL	46	7	10	14	18	13	0	0
LBL	0	0	< 1	< 1	0	0	0	0
LLNL	< 1	< 1	< 1	2	< 1	1	0	0
MOUND	< 1	0	< 1	0	2	0	0	0
MU	0	0	< 1	< 1	0	0	0	0
NTS	0	0	5	0	0	0	0	0
ORNL	1	0	6	2	0	0	0	0
PANTEX	0	0	< 1	0	0	0	0	0
PA	< 1	0	0	0	0	0	0	0
RFETS	2	11	4	10	1	4	0	0
SNL/NM	0	0	< 1	< 1	0	0	0	0
SRS	< 1	0	114	93	0	0	0	0

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TABLE O-9

INITIAL MASS RATES FOR RH WASTE
(kg/hr x 10^{-5})

	Sludges		Solid Organics		Solid Inorganics		Unknown	
Site	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected
BCLDP	0	0	0	0	0	0	0	0
BT	0	0	0	463	0	0	0	0
HANFORD	0	0	9,859	884,071	0	0	0	0
INEL/ANL-W	2,066	0	4,495	1,482	7,263	7,964	0	0
KAPL	0	0	3,339	7,501	0	0	0	0
LANL	0	0	6,516	1,388	49,223	51,181	0	0
ORNL	601,051	65,043	113,808	54,316	0	0	0	0
SRS	0	0	0	19,003	0	0	0	0

TABLE O-10

INITIAL VOLUME RATES FOR CH WASTE
(cu. m/hr x 10^{-5})

	Sludges		Solid Organics		Solid Inorganics		Unknown	
Site	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected
AMES LAB	0	< 1	0	0	0	0	0	0
ANL-E	29	1	< 1	0	8	< 1	0	0
BT	0	0	0	153	0	0	0	0
ETEC	0	0	2	6	< 1	0	0	0
HANFORD	4	3,911	9,670	16,812	322	17,543	0	0
INEL/ANL-W	22,508	0	13,694	4	10,853	2	1,553	0
KAPL	0	0	3	0	0	0	0	0
LANL	6,012	2,553	2,193	3,056	5,263	3,907	0	0
LBL	0	0	1	5	0	0	0	0
LLNL	16	82	81	502	180	310	0	0
MOUND	9	0	8	0	309	0	0	0
MU	0	0	< 1	2	0	0	0	0
NTS	0	0	760	0	0	0	0	0
ORNL	136	0	835	327	0	0	0	0
PANTEX	0	0	< 1	0	0	0	0	0
PA	3	0	0	0	0	0	0	0
RFETS	234	1,670	661	2,088	423	1,206	0	0
SNL/NM	0	0	10	9	0	0	0	0
SRS	< 1	0	11,577	16,573	0	0	0	0

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TABLE O-11

INITIAL VOLUME RATES FOR RH WASTE
(cu. m/hr x 10^{-5})

	Sludges		Solid Organics		Solid Inorganics		Unknown	
Site	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected	Retrievable	Projected
BCLDP	0	0	0	0	0	0	0	0
BT	0	0	0	2	0	0	0	0
HANFORD	0	0	40	3,688	0	0	0	0
INEL/ANL-W	3	0	19	6	14	9	14	29
KAPL	0	0	14	31	0	0	0	0
LANL	0	0	18	4	95	99	0	0
ORNL	758	216	475	227	0	0	0	0
SRS	0	0	0	40	0	0	0	0

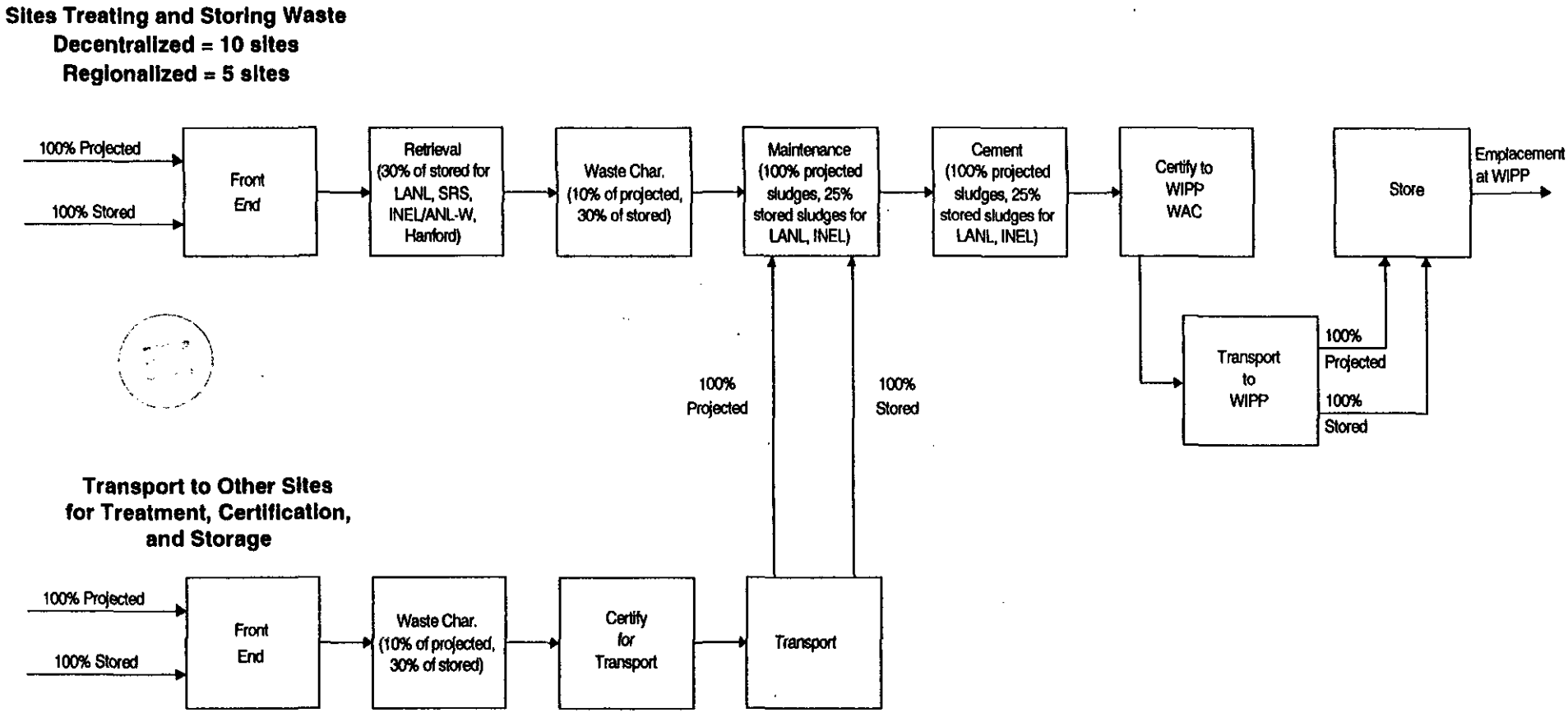

Figure O-2

Decentralized and Regionalized Base Cases and Alternative ID #s 33, 35(a&b), 83, and 111 Contact Handled

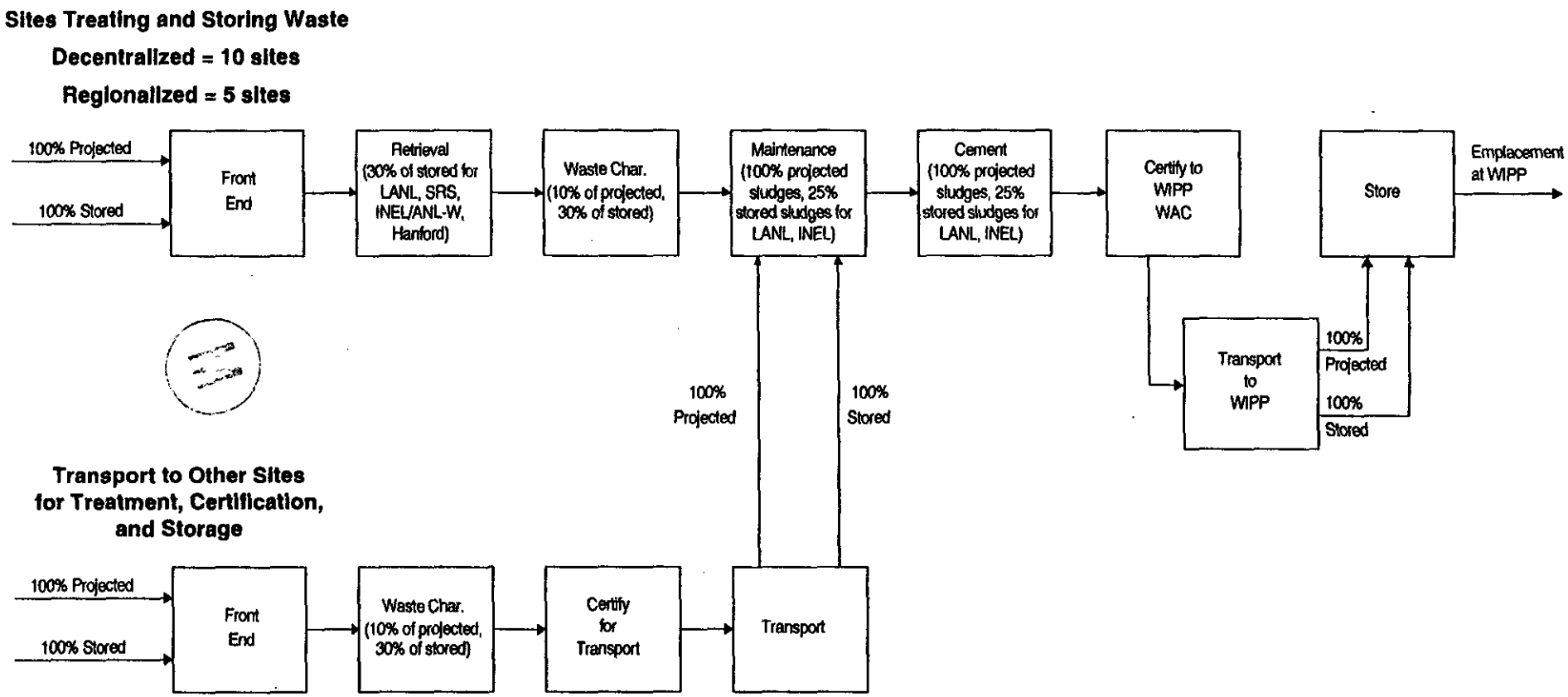

Figure O-3
Decentralized and Regionalized Base Cases Remote Handled

Force (DOE, 1991), the draft Environmental Management Programmatic Environmental Impact Statement (EM-PEIS) report (DOE, 1995b), and the Waste Management Facility Cost Information for Transuranic Waste (WMFCITRUW) report (Feizollahi and Shropshire, 1994). Information from these sources was used to correct each of the modules and to construct a visual description of mass and volume flow through each treatment process. The process flow diagrams were designed mostly in accordance with the EM-PEIS and the WMFCITRUW report; however, not every module recommended in the WMFCITRUW report was included in this study. The reasons for deviating from the recommended WMFCITRUW guidance include (1) minimizing the costs of duplicate equipment contained in more than one module and (2) more accurately representing the functions in existing and planned TRU waste facilities.

For the decentralized baseline, mass and volume changes result from both the retrieval and grouting modules. The results of applying the process flow diagram to the initial mass and volume flow rates are new flow rates that represent the final processed waste. Changes to mass and volume are discussed further in Section 2.7.

2.5 STEP 5: DETERMINATION OF WHETHER WIPP DESIGN CAPACITY HAS BEEN REACHED

The final processed flow rates were multiplied by 20 years and 4,032 working hours per year to determine the final processed masses and volumes. The final processed volume was compared against the design capacity of WIPP. For the purposes of this study, the design capacity of WIPP was considered to be 168,385 cubic meters for CH waste and 7,075 cubic meters for RH waste.

If the final processed volume was less than the design capacity of WIPP, a scale factor was estimated and applied to the mass and volume flow rates in Step 3 for projected waste. Steps 4 and 5 were then repeated until the final processed volume was slightly less than or equal to the design capacity of WIPP. The final scale factor for CH waste was determined to be 1.296775896, and the final scale factor for RH waste was calculated to be 1.537947416.

2.6 STEP 6: DETERMINATION OF FINAL SCALED INPUT MASS AND VOLUMES

As shown in Figure O-1, after the initial masses and volumes have been scaled to the design capacity of WIPP for the decentralized baseline, these scaled initial masses and volumes were used as inputs for each of the EAs in each of the configurations. In other words, the same scale factor developed for CH waste in the baseline was applied to each of the EAs for CH waste. The scaled initial mass and volume flow rates were calculated assuming a 20-year inventory processing period and 4,032 hours of operation per year (three 8-hour shifts, 240 days per year at 70 percent availability).

2.7 STEP 7: APPLICATION OF PROCESS FLOW DIAGRAM TO EACH ALTERNATIVE IN EACH CONFIGURATION

Ten EAs were considered in addition to the baseline. Table O-12 shows treatment options for sludges, solid organics, and solid inorganics for each EA. Processing schemes for EAs 33, 35(a-b), 83, and 111 are identical to the processing schemes for the baseline for each of the configurations; therefore, mass and volume changes are assumed to be identical to the mass and volume changes for the baseline. The processing scheme for EA 77(a-d) is the same as the

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TABLE O-12

WIPP ENGINEERED ALTERNATIVES

	Waste Type		
ID Number	Sludges	Solid Organic	Solid Inorganic
#1	Baseline	Supercompact	Supercompact
#6	Baseline	Shred and compact	Shred and compact
#10	Plasma	Plasma	Plasma
#33	Baseline	Baseline	Baseline
#35 (a and b)	Baseline	Baseline	Baseline
#77 (a–d)	Baseline	Supercompact	Supercompact
#83	Baseline	Baseline	Baseline
#94 (a–f)	Enhanced cement	Shred and add clay	Shred and add clay
#111	Baseline	Baseline	Baseline

processing scheme for EA 1 for each of the configurations; therefore, its mass and volume changes are assumed to be equal to those of EA 1. EA 33, 35(a-b), 77(a-d), 83, and 111 are omitted from further discussion in this section because they are not unique with respect to mass and volume.

Additionally, each EA is defined in Section 2.2.1, Engineered Alternative Definition. Each EA was also considered with respect to three configurations: decentralized, regionalized, and centralized. Table O-13 indicates which sites send waste to other sites to be processed and/or stored for each configuration.

Waste flow diagrams for each EA are shown in Figures O-4 through O-12. Figures O-4 through O-7 represent both the decentralized and regionalized configurations for EAs 1, 6, 10, and 94 for CH waste, including sites that treat and store waste and sites that ship pre-processed waste to other sites for treatment and storage. Figures O-8 through O-12 represent the centralized configuration for CH waste, which includes shipment of pre-processed waste to WIPP for treatment, storage, and disposal.

2.7.1 Front End Module

Front-end support facilities consist of all administrative and laboratory buildings required for the waste management support functions. Front-end support functions include security, personnel decontamination (radioactive and hazardous), maintenance of noncontaminated areas and equipment, health physics, radiation badges, facility access control, sanitary facilities, work control and personnel support, internal and external communications, spill or emergency response provisions (radioactive and hazardous), analytical laboratory, environmental field sampling, environmental regulatory reporting, and records management. Front-end support facilities include all administrative and laboratory buildings required for the waste management support functions.

2.7.2 Waste Retrieval Module

This module consists of all-weather excavation, inspection, and repackaging of bermed waste. The module includes three principal unit operations: earthen cover extraction and decontamination, waste container retrieval and inspection, and packaging and staging for shipment.

2.7.3 Waste Characterization Module

This module is a self-contained facility in which waste characterization is performed. Activities include extracting physical samples of waste; conducting chemical, physical, and radiological sampling of waste; and repackaging drums and boxes to remove and stabilize noncompliant waste.

2.7.4 Maintenance Module

A maintenance facility is used in conjunction with treatment facilities. It consists of a failed equipment receiving and repair building housing machinery and tools.

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TABLE O-13

TRANSFER OF WASTE FOR THE DECENTRALIZED, REGIONALIZED, AND CENTRALIZED CONFIGURATIONS

Decentralized			Regionalized			Centralized		
Site	CH	RH	Site	CH	RH	Site	CH	RH
ANL-E*	WIPP	ORNL+	ANL-E	SRS	ORNL	ANL-E	WIPP	WIPP
AMES	ANL-E#		AMES	SRS		AMES	WIPP	
BCLDP		ORNL+	BCLDP		ORNL	BCLDP		WIPP
BT	MOUND	ORNL+	BT	SRS	ORNL	BT	WIPP	WIPP
ETEC	NTS		ETEC	INEL/ANL-W		ETEC	WIPP	
INEL/ANL-W*	WIPP	WIPP	INEL/ANL-W*	WIPP	HANFORD	INEL/ANL-W	WIPP	WIPP
KAPL	MOUND	ORNL+	KAPL	SRS	ORNL	KAPL	WIPP	WIPP
LANL*	WIPP	WIPP	LANL*	WIPP	HANFORD	LANL	WIPP	WIPP
LBL	(LLNL)		LBL	HANFORD		LBL	WIPP	
LLNL*	WIPP		LLNL	HANFORD		LLNL	WIPP	
MOUND*	WIPP		MOUND	SRS		MOUND	WIPP	
MU	ANL-E#		MU	SRS		MU	WIPP	
NTS*	WIPP	WIPP	NTS	INEL/ANL-W	HANFORD	NTS	WIPP	WIPP
ORNL*	WIPP	WIPP	ORNL* (rh)	SRS	WIPP	ORNL	WIPP	WIPP
PA	ORNL		PA	SRS		PA	WIPP	
PANTEX	LANL		PANTEX	LANL		PANTEX	WIPP	
RFETS*	WIPP		RFETS*	WIPP		RFETS	WIPP	
HANFORD*	WIPP	WIPP	HANFORD*	WIPP	WIPP	HANFORD	WIPP	WIPP
SNL/NM	LANL		SNL/NM	LANL		SNL/NM	WIPP	
SRS*	WIPP	WIPP	SRS*	WIPP	ORNL	SRS	WIPP	WIPP

Notes:

* Denotes a processing site.

ORNL+ Remote handled wastes from BCLDP, BT, KAPL, (these are not discussed in the EM-PEIS) and ANL-E should be processed at ORNL instead of Mound because Mound currently does not process or store RH waste.

ANL-E# The EM-PEIS discusses that ANL-E will process and ship its own CH waste but does not cover Ames and MU which are closer to ANL-E than ORNL.

(LLNL) EM-PEIS indicates LBL waste will be shipped to Hanford. LBL waste should be shipped to LLNL because it is much closer.

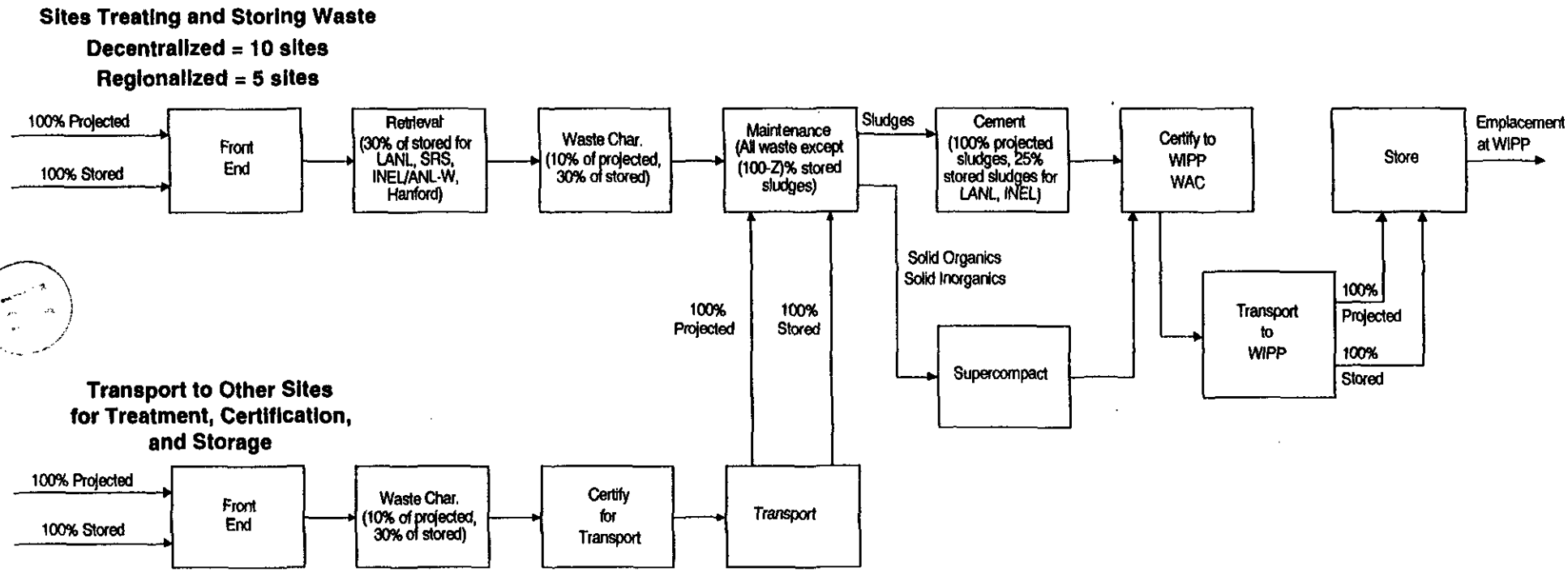

DEFINITIONS
Z = 25% for LANL and INEL
Z = 0% for all other sites

Alternative ID# 1

Sludges:	Baseline (grout)
Solid Inorganics:	Supercompact
Solid Organics:	Supercompact

Figure O-4

Decentralized and Regionalized Alternative ID #s 1 and 77(a-d) Contact Handled

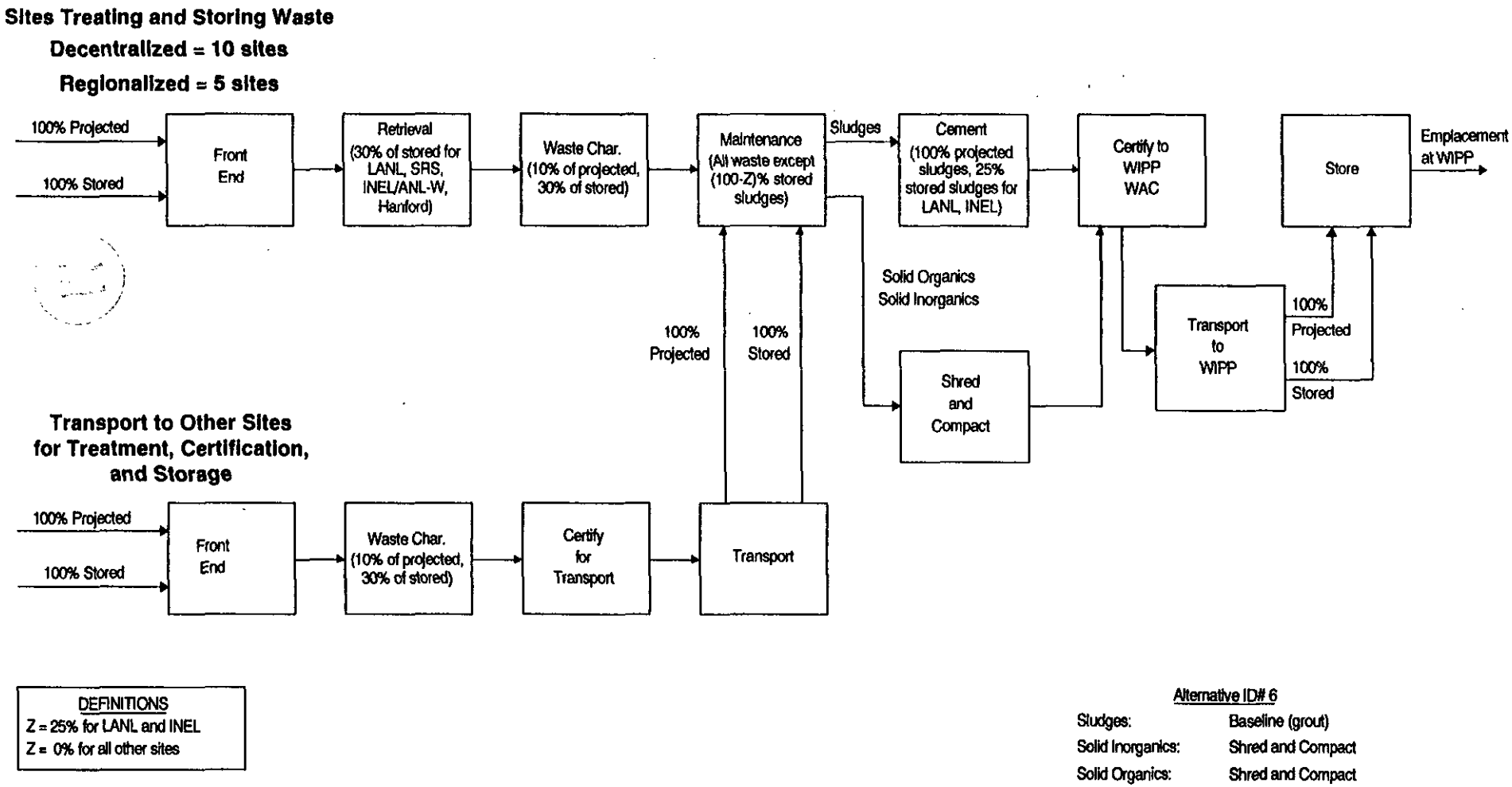

DEFINITIONS
Z = 25% for LANL and INEL
Z = 0% for all other sites

Alternative ID# 6

Sludges:	Baseline (grout)
Solid Inorganics:	Shred and Compact
Solid Organics:	Shred and Compact

Figure O-5
Decentralized and Regionalized Alternative ID# 6 Contact Handled

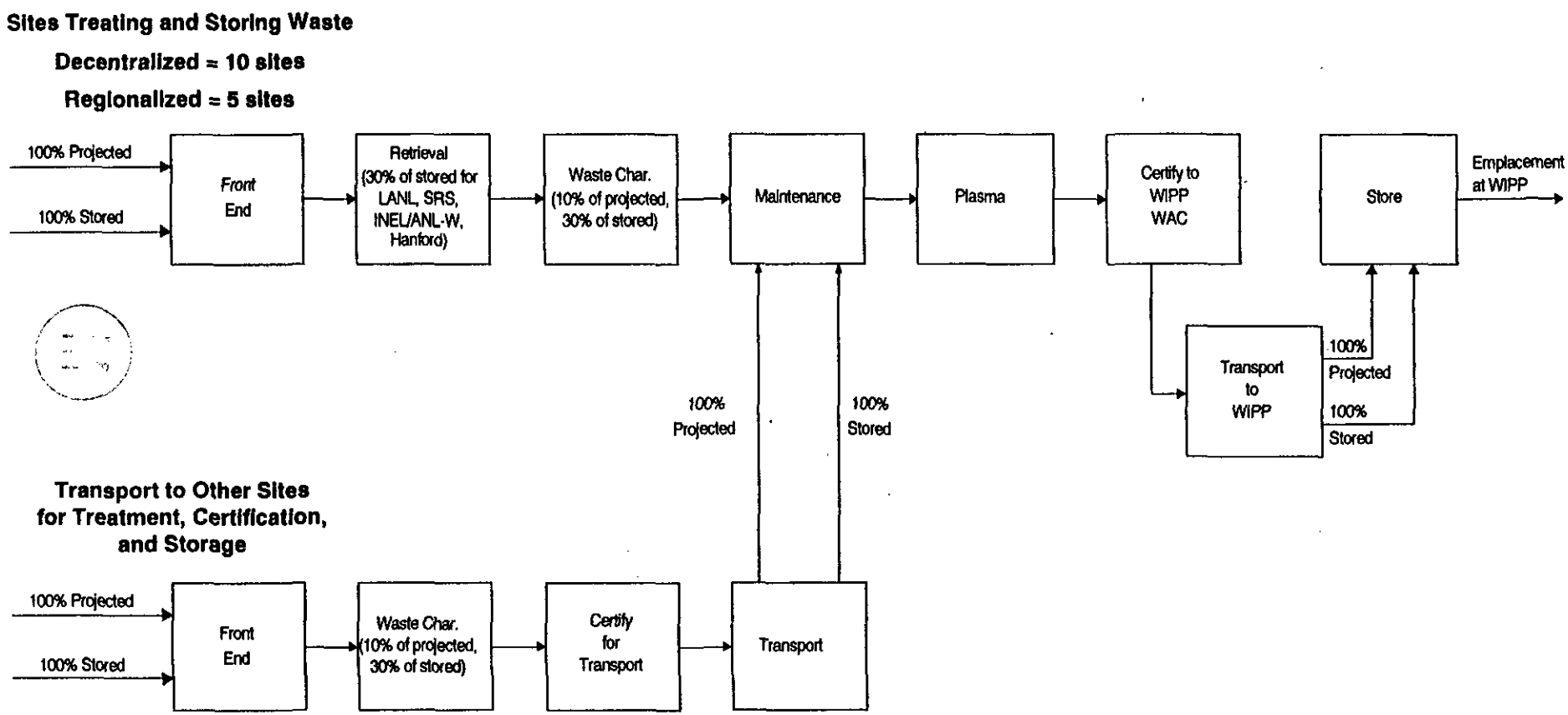

Alternative ID# 10

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure O-6

Decentralized and Regionalized Alternative ID# 10 Contact Handled

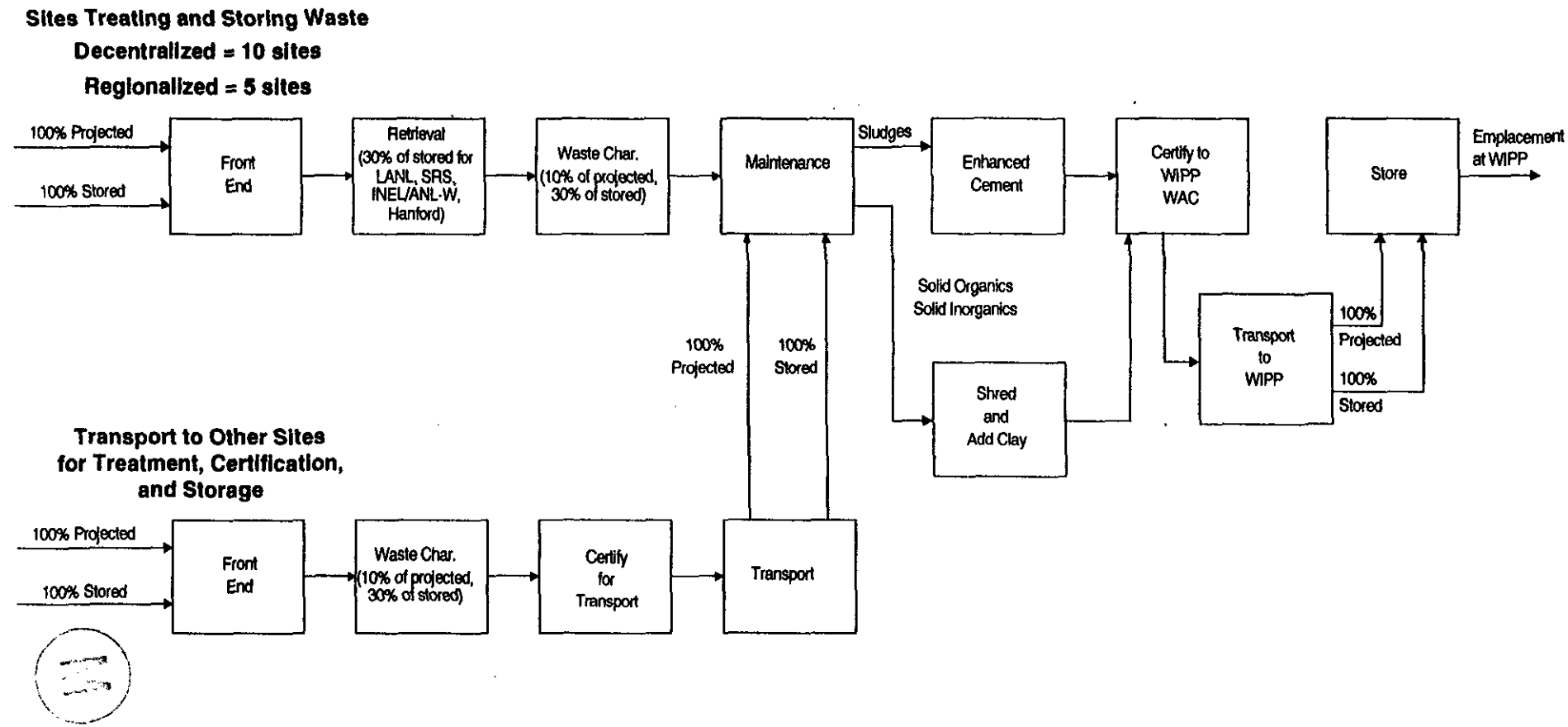

Alternative ID# 94(a-f)

Sludges:	Enhanced Cement
Solid Inorganics:	Shred and Add Clay
Solid Organics:	Shred and Add Clay

Figure O-7

Decentralized and Regionalized Alternative ID# 94(a-f) Contact Handled

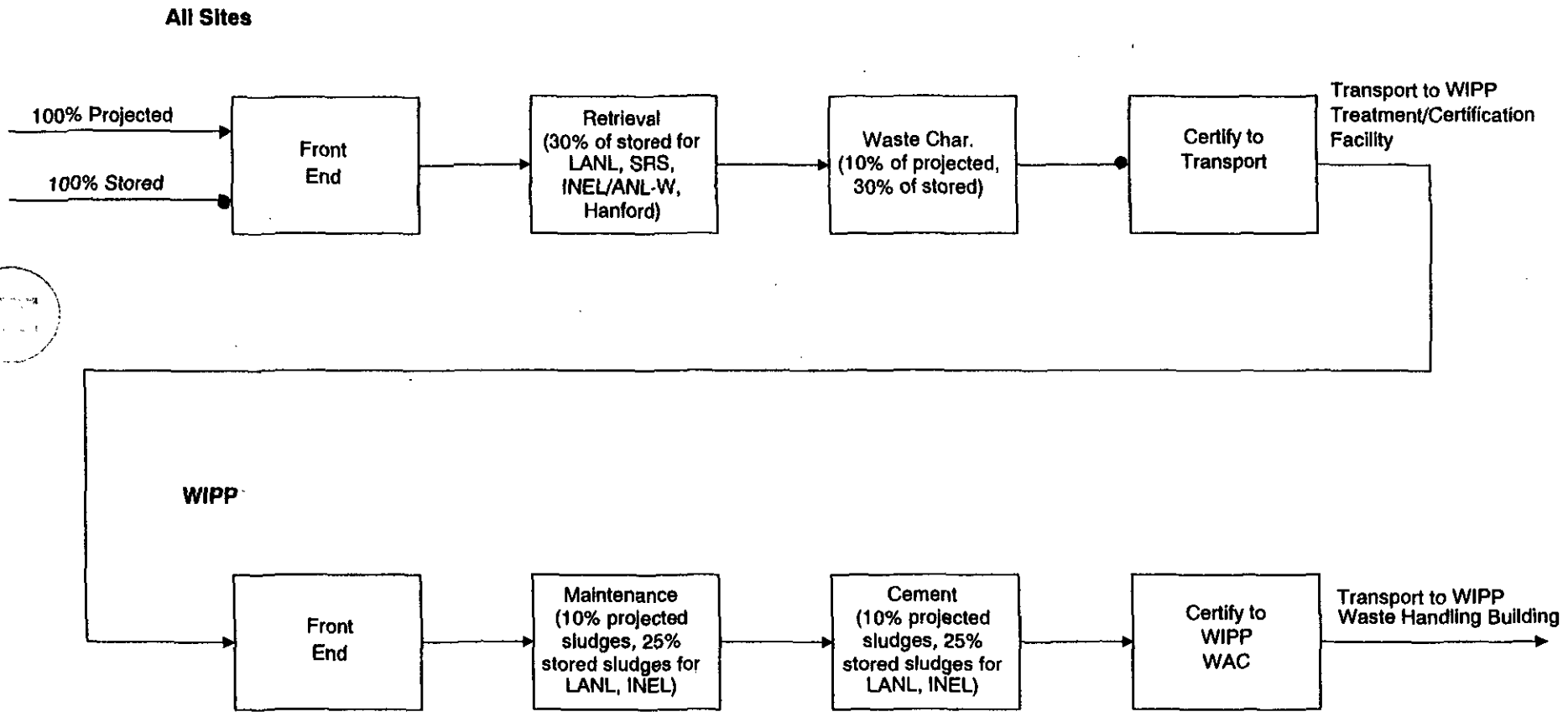

Figure O-8

Centralized Base Case and Alternative ID #s 33, 35(a&b), 83, and 111 Contact Handled

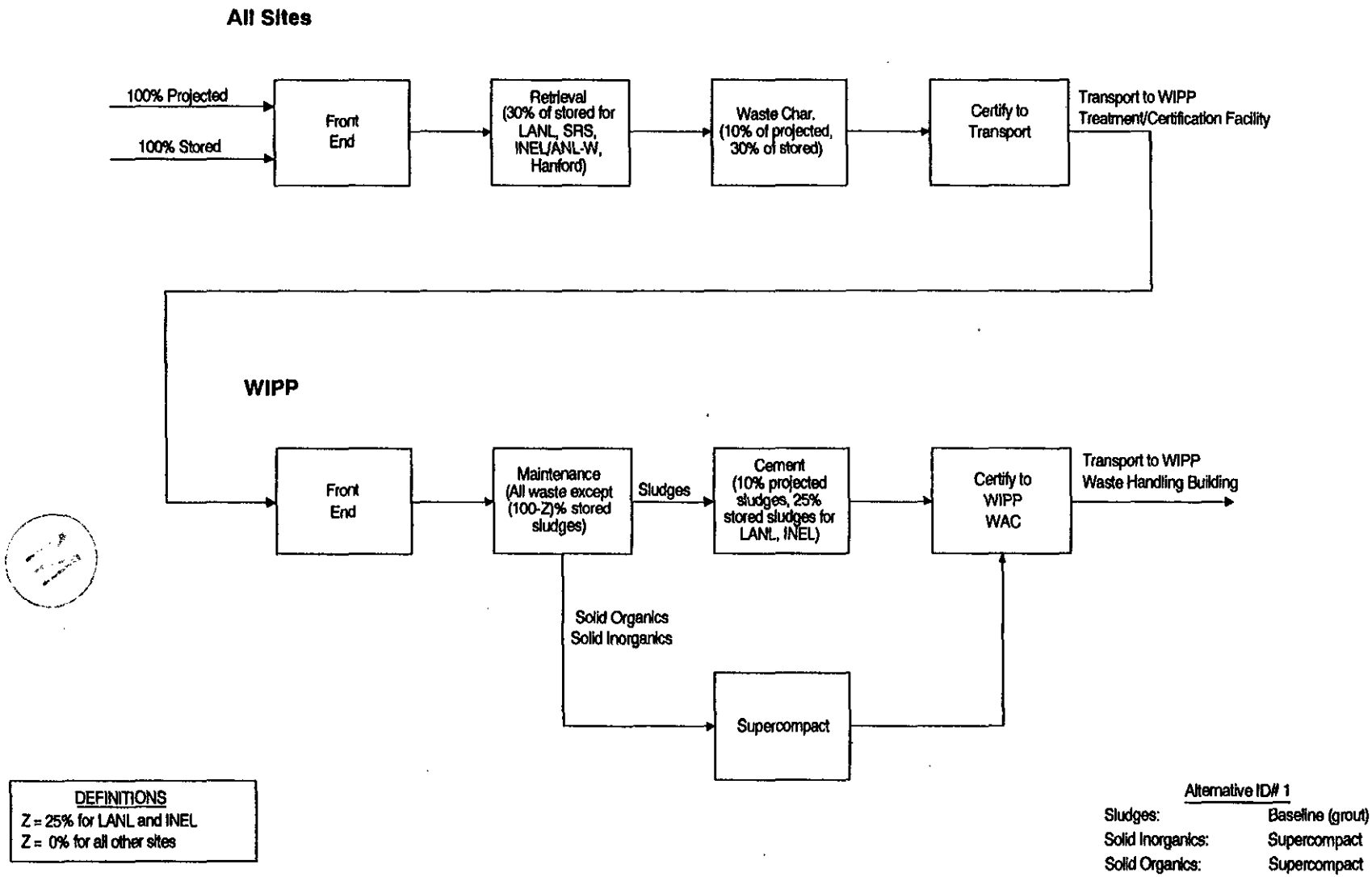

Figure O-9

Centralized Alternative ID#s 1 and 77(a-d) Contact Handled

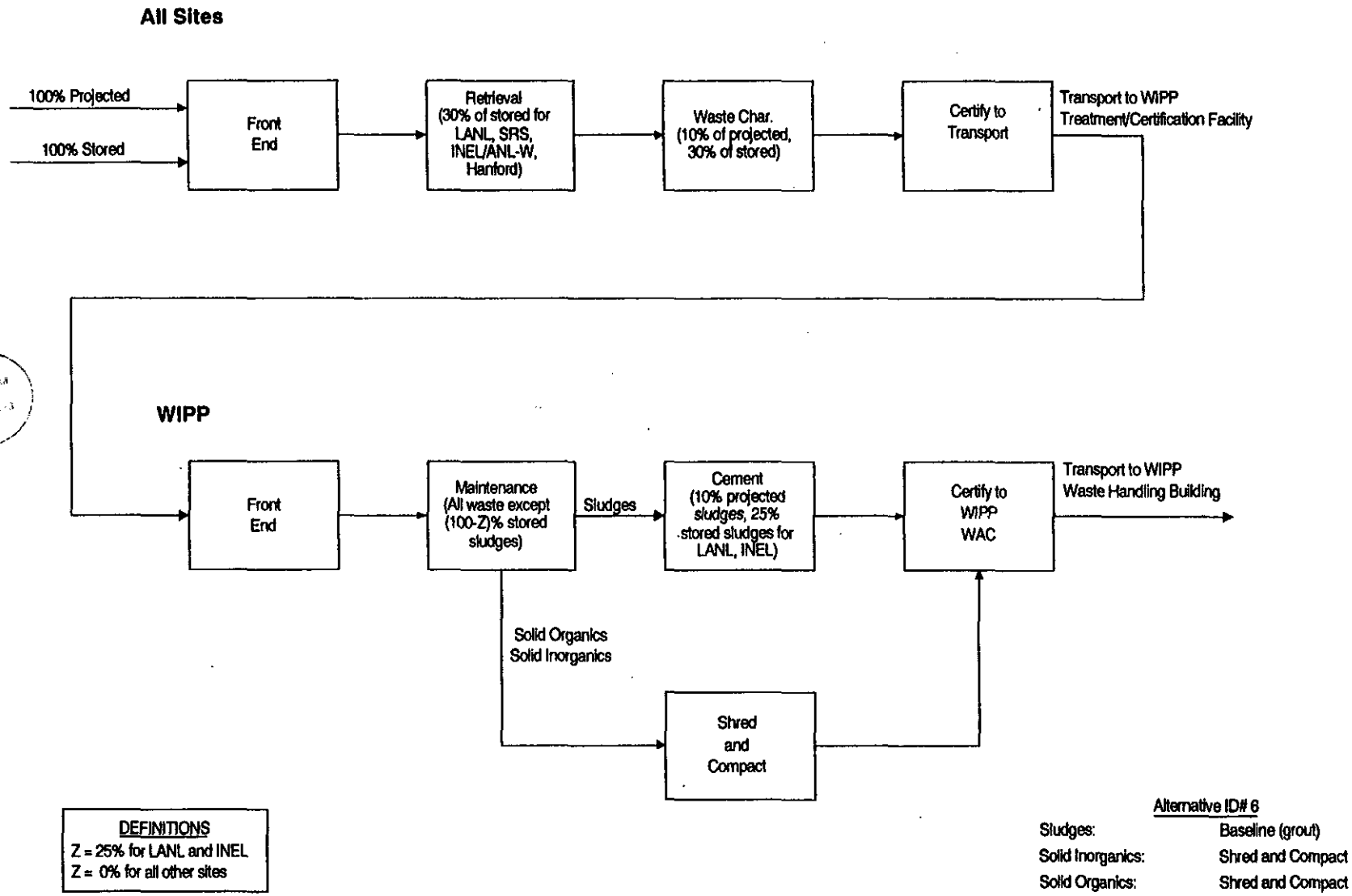

Figure O-10
Centralized Alternative ID# 6 Contact Handled

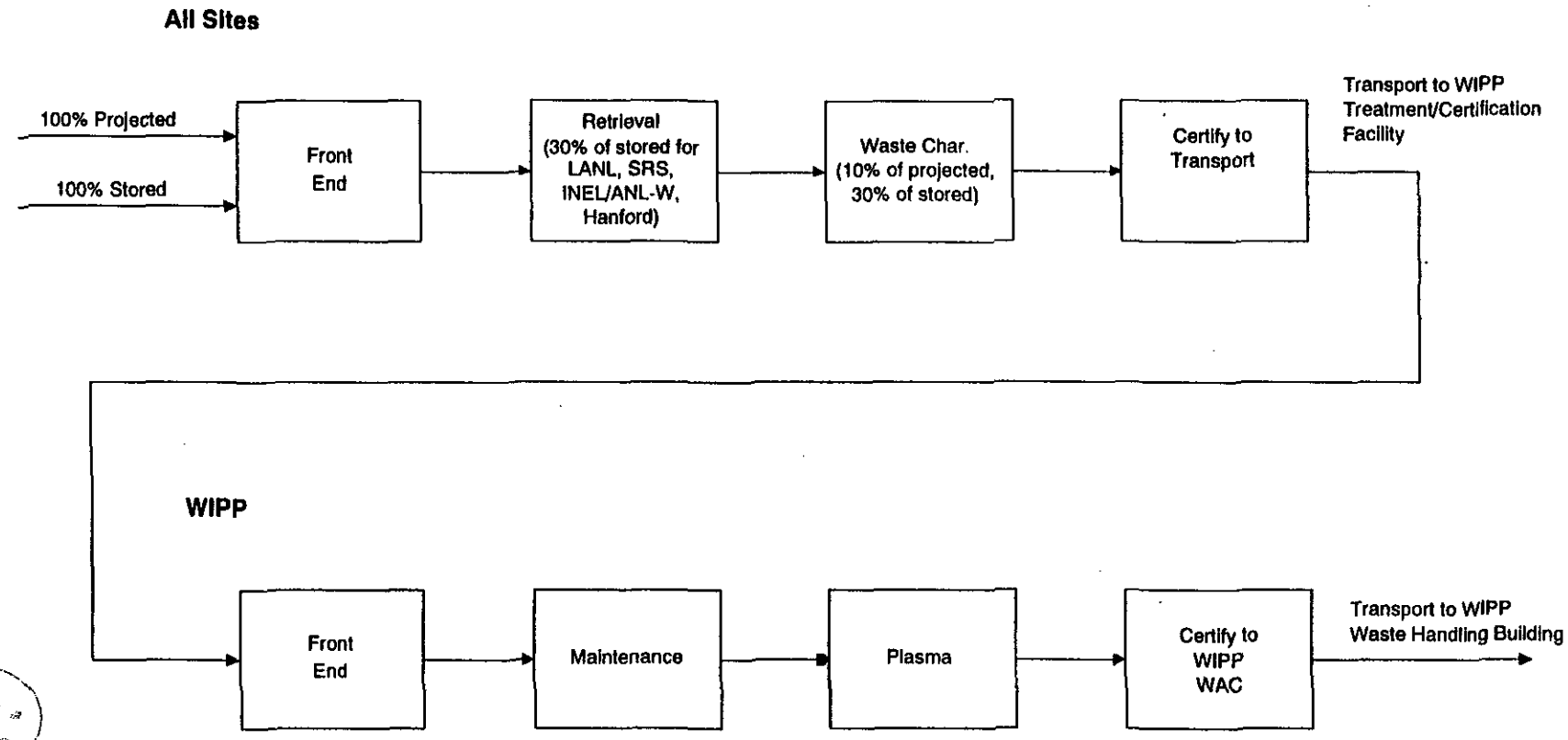

Alternative ID# 10

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure O-11
Centralized Alternative ID# 10 Contact Handled

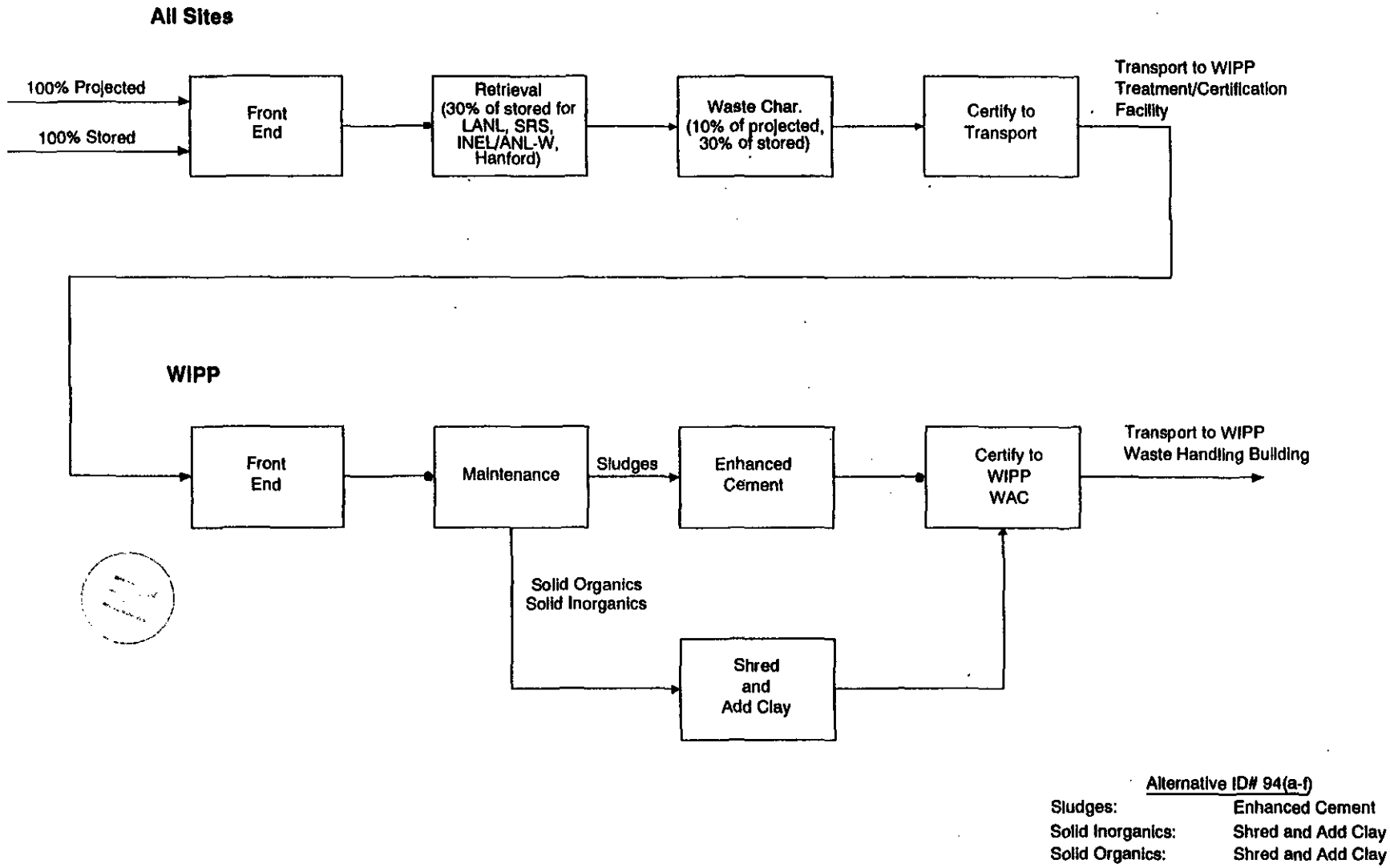

Figure O-12
Centralized Alternative ID# 94(a-f)

2.7.5 Treatment Module

The treatment module varies based on the EA being considered. Treatment options include grouting, supercompacting, shredding and compacting, plasma melting, enhanced- cement processing, and shredding and adding clay.

2.7.6 Storage Module

This module consists of a Resource Conservation and Recovery Act compliant storage building sized to accommodate an accumulation of waste from treatment modules for a maximum of 20 years. Storage area features include spill collection, sloping floors, sumps, and concrete berms. Monitoring is included for both gamma and alpha radiation control.

2.7.7 Certification and Shipping Module

Certification and shipping consists of storage of incoming material, assay and certification, and truck loading. The facility is equipped with a bridge crane and a forklift. It is assumed that certification and shipping operations will take place indoors.

2.7.8 Transportation Module

Transportation consists of truck shipments, including a tractor and trailer transporting three Transuranic Package Transporter-IIs (TRUPACT-IIs) for CH waste or one RH-72B cask (a cylinder consisting of a separate inner vessel within an outer cask protected by impact limiters at each end) for RH waste.

Mass and volume changes occur in the retrieval module and the treatment modules. Table O-14 summarizes these changes. Several other assumptions were made in addition to the mass and volume changes:

- All waste within a major waste form category (i.e., sludges, solid organics, solid inorganics) can be treated using a selected technology.

- The volume of waste categorized as "unknown" in the WTWBIR is processed the same as solid organics and inorganics. However, the mass of unknown waste is assumed to be zero because no information was available regarding the density of the unknown waste and the volume of this waste is small compared to the total volume of waste destined for WIPP.

- All projected sludges were grouted in the baseline. In general, stored sludges were not treated in the baseline because they were assumed to have been grouted previously; however, 25 percent of the stored sludges from Los Alamos National Laboratory (LANL) and the Idaho National Engineering Laboratory (INEL) were regrouted and all of the stored sludges at Oak Ridge National Laboratory (ORNL) were grouted.

- All sludges, including stored, are treated in the enhanced-cement treatment option.

- All sludges, solid organics, and solid inorganics are treated in the plasma melter.

1

TABLE O-14

MASS AND VOLUME CHANGES FOR WASTE TREATMENT/PROCESSING MODULES

Module	Mass Ratio (Output/Input)	Volume Ratio (Output/Input)
Front End	1.00[1]	1.00[2]
Retrieval	1.10[1]	1.10[2]
Waste Characterization	1.00[2]	1.00[2]
Maintenance	1.00[2]	1.00[2]
Grout	3.15[1]	2.50[2]
Supercompact	1.10[1]	0.35[2]
Shred and Compact	1.10[1]	0.76[2]
Shred and Add Clay	2.35[2]	1.00[2]
Plasma	1.00[1]	0.33[2]
Certification and Shipping	1.00[2]	1.00[2]
Storage	1.00[2]	1.00[2]

[1]Source (Feizollahi and Shropshire, 1994)
[2]Values derived from engineering calculations

- Ten percent of projected waste and 30 percent of stored waste requires characterization.

- Thirty percent of stored waste from LANL, Savannah River Site (SRS), INEL/Argonne National Laboratory-West (ANL-W), and Hanford requires retrieval.

3.0 RESULTS

Tables O-15 through O-30 show the mass and volume processing rates (i.e., inputs) to each of the modules for each of the EAs in each of the configurations that were calculated based on the methodology and assumptions provided previously in this appendix. These flow rates were then used to calculate the costs associated with each module. The cost analysis is described in Section 3.7 and Appendix P of this report.

Tables O-31 and O-32 show final treated mass and volume by EA and primary waste form for each EA, for CH waste and RH waste, respectively. The final mass and volume do not differ by configuration, because the same amount of waste is treated regardless of the site at which the waste is treated. The treated volume of waste for EA 94 exceeds the design capacity of WIPP; it is assumed that this waste would have to be managed in some other way when the WIPP reaches full capacity.

The final processed mass and volume were used as inputs to other EA analyses.

TABLE O-15

INPUTS TO MODULES FOR THE CONTACT-HANDLED WASTE DECENTRALIZED BASELINE

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.01	0.01	0.28	1.80
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	14.83	14.83	307.90	2720.79
INEL/ANL-W	248.80	74.62	76.87	29.91	29.91	320.57	2369.50
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	21.60	21.60	168.55	1351.17
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.31	0.31	6.25	64.66
MOUND	1.78	0.00	0.53	0.00	0.00	4.37	35.92
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.39	31.06
ORNL	9.04	0.00	2.12	0.33	0.33	9.79	56.35
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	14.05	14.05	69.29	443.31
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	238.12	1346.67
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.93	0.00

TABLE O-16

INPUTS TO MODULES FOR DECENTRALIZED ALTERNATIVE 1

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Supercompact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.03	0.01	0.03	0.29	1.51
BT	1.38	0.00	0.14	1.38	0.00	1.38	1.51	0.00
ETEC	0.07	0.00	0.01	0.07	0.00	0.07	0.08	0.00
HANFORD	273.67	23.48	43.72	275.99	14.83	261.16	334.01	1284.39
INEL/ANL-W	248.80	74.62	76.87	166.54	29.91	136.63	334.23	1664.74
KAPL	0.02	0.00	0.01	0.02	0.00	0.02	0.02	0.00
LANL	119.73	22.27	27.49	86.19	21.60	64.59	175.03	912.85
LBL	0.06	0.00	0.01	0.06	0.00	0.06	0.06	0.00
LLNL	5.52	0.00	0.76	5.40	0.31	5.08	6.76	30.03
MOUND	1.78	0.00	0.53	1.71	0.00	1.71	4.80	12.96
MU	0.02	0.00	0.00	0.02	0.00	0.02	0.02	0.00
NTS	5.31	0.00	1.59	5.31	0.00	5.31	5.92	10.87
ORNL	9.04	0.00	2.12	9.04	0.33	8.70	10.66	23.37
PANTEX	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	36.90	14.05	22.85	71.57	303.03
SNL/NM	0.15	0.00	0.03	0.15	0.00	0.15	0.16	0.00
SRS	234.70	34.25	47.33	238.12	0.00	238.12	261.93	471.34
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	3.21	0.00

TABLE O-17

INPUTS TO MODULES FOR DECENTRALIZED ALTERNATIVE 6

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Shred & Compact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.03	0.01	0.03	0.29	1.69
BT	1.38	0.00	0.14	1.38	0.00	1.38	1.51	0.00
ETEC	0.07	0.00	0.01	0.07	0.00	0.07	0.08	0.00
HANFORD	273.67	23.48	43.72	275.99	14.83	261.16	334.01	2190.43
INEL/ANL-W	248.80	74.62	76.87	166.54	29.91	136.63	334.23	2109.28
KAPL	0.02	0.00	0.01	0.02	0.00	0.02	0.02	0.00
LANL	119.73	22.27	27.49	86.19	21.60	64.59	175.03	1189.33
LBL	0.06	0.00	0.01	0.06	0.00	0.06	0.06	0.00
LLNL	5.52	0.00	0.76	5.40	0.31	5.08	6.76	51.87
MOUND	1.78	0.00	0.53	1.71	0.00	1.71	4.80	27.44
MU	0.02	0.00	0.00	0.02	0.00	0.02	0.02	0.00
NTS	5.31	0.00	1.59	5.31	0.00	5.31	5.92	23.61
ORNL	9.04	0.00	2.12	9.04	0.33	8.70	10.66	44.17
PANTEX	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	36.90	14.05	22.85	71.57	391.52
SNL/NM	0.15	0.00	0.03	0.15	0.00	0.15	0.16	0.00
SRS	234.70	34.25	47.33	238.12	0.00	238.12	261.93	1023.47
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	3.21	0.00

TABLE O-18

INPUTS TO MODULES FOR DECENTRALIZED ALTERNATIVE 10

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Plasma Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.25	0.25	0.27	0.55
BT	1.38	0.00	0.14	1.38	1.38	1.38	0.00
ETEC	0.07	0.00	0.01	0.07	0.07	0.07	0.00
HANFORD	273.67	23.48	43.72	276.02	276.02	276.02	796.72
INEL/ANL-W	248.80	74.62	76.87	256.26	256.26	256.26	666.26
KAPL	0.02	0.00	0.01	0.02	0.02	0.02	0.00
LANL	119.73	22.27	27.49	121.96	121.96	122.11	348.95
LBL	0.06	0.00	0.01	0.06	0.06	0.06	0.00
LLNL	5.52	0.00	0.76	5.52	5.52	5.58	19.22
MOUND	1.78	0.00	0.53	1.78	1.78	4.37	11.85
MU	0.02	0.00	0.00	0.02	0.02	0.02	0.00
NTS	5.31	0.00	1.59	5.31	5.31	5.39	10.25
ORNL	9.75	0.00	2.34	9.75	9.75	9.79	18.60
PANTEX	0.01	0.00	0.00	0.01	0.01	0.01	0.00
PA	0.03	0.00	0.01	0.03	0.03	0.03	0.00
RFETS	39.08	0.00	5.45	39.08	39.08	39.08	103.11
SNL/NM	0.15	0.00	0.03	0.15	0.15	0.15	0.00
SRS	234.70	34.25	47.33	238.12	238.12	238.12	444.40
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-19

INPUTS TO MODULES FOR DECENTRALIZED ALTERNATIVE 94

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Enhanced Cement Mass (kg/hr)	Shred & Add Clay Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.25	0.23	0.03	0.82	3.53
BT	1.38	0.00	0.14	1.38	0.00	1.38	3.24	0.00
ETEC	0.07	0.00	0.01	0.07	0.00	0.07	0.17	0.00
HANFORD	273.67	23.48	43.72	276.02	14.86	261.16	661.29	2721.02
INEL/ANL-W	248.80	74.62	76.87	256.26	119.63	136.63	698.32	3421.07
KAPL	0.02	0.00	0.01	0.02	0.00	0.02	0.05	0.00
LANL	119.73	22.27	27.49	121.96	57.36	64.59	333.03	1632.08
LBL	0.06	0.00	0.01	0.06	0.00	0.06	0.13	0.00
LLNL	5.52	0.00	0.76	5.52	0.44	5.08	13.48	65.66
MOUND	1.78	0.00	0.53	1.78	0.07	1.71	10.38	36.81
MU	0.02	0.00	0.00	0.02	0.00	0.02	0.04	0.00
NTS	5.31	0.00	1.59	5.31	0.00	5.31	12.67	31.06
ORNL	9.75	0.00	2.34	9.75	1.05	8.70	23.89	64.76
PANTEX	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00
PA	0.03	0.00	0.01	0.03	0.03	0.00	0.10	0.00
RFETS	39.08	0.00	5.45	39.08	16.23	22.85	104.90	457.44
SNL/NM	0.15	0.00	0.03	0.15	0.00	0.15	0.35	0.00
SRS	234.70	34.25	47.33	238.12	0.00	238.12	560.28	1346.67
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE O-20

INPUTS TO MODULES FOR REGIONALIZED BASELINE

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grout Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	15.14	15.14	314.14	2785.45
INEL/ANL-W	248.80	74.62	76.87	29.91	29.91	325.95	2400.56
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	21.60	21.60	168.55	1351.17
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	14.05	14.05	69.29	443.31
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.34	0.34	252.57	1440.74
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-21

INPUTS TO MODULES FOR REGIONALIZED ALTERNATIVE 1

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Supercompact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	281.44	15.14	266.30	340.77	1314.42
INEL/ANL-W	248.80	74.62	76.87	171.92	29.91	142.02	340.15	1675.61
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	86.35	21.60	64.74	175.03	912.85
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	36.90	14.05	22.85	71.57	303.03
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	251.47	0.34	251.13	277.68	509.17
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-22

INPUTS TO MODULES FOR REGIONALIZED ALTERNATIVE 6

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Shred & Compact Mass (kg/hr)	CERT & SHIP MASS (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	281.44	15.14	266.30	340.77	2242.30
INEL/ANL-W	248.80	74.62	76.87	171.92	29.91	142.02	340.15	2132.89
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	86.35	21.60	64.74	175.03	1189.33
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	36.90	14.05	22.85	71.57	391.52
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	251.47	0.34	251.13	277.68	1096.77
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-23

INPUTS TO MODULES FOR REGIONALIZED ALTERNATIVE 10

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	PLASMA MASS (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	281.60	281.60	281.60	815.94
INEL/ANL-W	248.80	74.62	76.87	261.65	261.65	261.65	676.51
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	122.11	122.11	122.11	348.95
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.31	0.00
ORNL	9.75	0.00	2.34	0.00	0.00	9.75	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	39.08	39.08	39.08	103.11
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	252.56	252.56	252.56	475.40
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-24

INPUTS TO MODULES FOR REGIONALIZED ALTERNATIVE 94

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Enhanced Cement Mass (kg/hr)	Shred & Add Clay Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	281.60	15.29	266.3045	674.77	2786.67
INEL/ANL-W	248.80	74.62	76.87	261.65	119.63	142.0159	711.00	3452.13
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	122.11	57.36	64.74	333.03	1632.08
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.75	0.00	2.34	0.00	0.00	0.00	9.75	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	39.08	16.23	22.85	104.90	457.44
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	252.56	1.42	251.13	595.37	1451.77
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-25

INPUTS TO MODULES FOR CENTRALIZED BASELINE

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grout Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	238.12	0.00
WIPP	940.81	0.00	0.00	81.04	81.04	1130.50	323.89
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-26
INPUTS TO MODULES FOR CENTRALIZED ALTERNATIVE 1

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Supercompact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	0.00	238.12	0.00
WIPP	940.81	0.00	0.00	828.08	81.04	747.05	1205.21	181.35
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-27

INPUTS TO MODULES FOR CENTRALIZED ALTERNATIVE 6

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Shred & Compact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	0.00	238.12	0.00
WIPP	940.81	0.00	0.00	828.08	81.04	747.05	1205.21	271.26
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-28

INPUTS TO MODULES FOR CENTRALIZED ALTERNATIVE 10

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Plasma Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.31	0.00
ORNL	9.75	0.00	2.34	0.00	0.00	9.75	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	238.12	0.00
WIPP	941.53	0.00	0.00	956.99	956.99	956.99	93.07
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-29

INPUTS TO MODULES FOR CENTRALIZED ALTERNATIVE 94

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Enhanced Cement Mass (kg/hr)	Shred & Add Clay Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.75	0.00	2.34	0.00	0.00	0.00	9.75	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	0.00	238.12	0.00
WIPP	941.53	0.00	0.00	956.99	209.94	747.05	2419.07	376.16
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-30

INPUTS TO MODULES FOR REMOTE-HANDLED WASTE BASELINE

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
BCLDP	0.32	0.00	0.03	0.00	0.00	0.32	0.00
BT	0.01	0.00	0.00	0.00	0.00	0.01	0.00
HANFORD	13.70	0.03	1.39	0.00	0.00	13.70	230.32
INEL/ANL-W	0.28	0.04	0.06	0.01	0.01	0.30	4.85
KAPL	0.15	0.00	0.02	0.00	0.00	0.15	0.00
LANL	1.37	0.17	0.25	0.00	0.00	1.38	11.07
ORNL	4.88	0.00	1.10	2.91	2.91	11.62	105.27
SRS	0.29	0.00	0.03	0.00	0.00	0.29	2.46

TABLE O-31

CH SUMMARY
MASS AND VOLUME OUTPUT
WIPP ENGINEERED ALTERNATIVES
JULY 1995

	Sludges			Solid Organics			Solid Inorganics		
Case #	Total Mass (kg)	Total Volume (cu. m)	Density (kg/cu. m)	Total Mass (kg)	Total Volume (cu. m)	Density (kg/cu. m)	Total Mass (kg)	Total Volume (cu. m)	Density (kg/cu. m)
Baseline	30,921,720	54,389	569	47,234,933	74,339	635	13,007,073	38,396	339
Alternative 1	30,921,720	54,389	569	51,958,427	26,019	1,997	14,307,781	13,438	1,065
Alternative 6	30,921,720	54,389	569	51,958,427	56,498	920	14,307,781	29,181	490
Alternative 10	16,929,945	10,767	1,572	47,234,933	24,532	1,925	13,007,073	12,671	1,027
Alternative 94	53,329,327	81,566	654	69,576,926	74,339	936	19,159,383	38,396	499

TABLE O-32

RH SUMMARY, RH MASS, AND VOLUME OUTPUT
WIPP ENGINEERED ALTERNATIVES
JULY 1995

Baseline	Sludges	Solid Organics	Solid Inorganics
Total Mass (kg)	741,427	1,338,770	120,268
Total Volume (cu. m)	1,283	5,524	224
Density (kg/cu. m)	578	242	537

processing scheme for EA 1 for each of the configurations; therefore, its mass and volume changes are assumed to be equal to those of EA 1. EA 33, 35(a-b), 77(a-d), 83, and 111 are omitted from further discussion in this section because they are not unique with respect to mass and volume.

Additionally, each EA is defined in Section 2.2.1, Engineered Alternative Definition. Each EA was also considered with respect to three configurations: decentralized, regionalized, and centralized. Table O-13 indicates which sites send waste to other sites to be processed and/or stored for each configuration.

Waste flow diagrams for each EA are shown in Figures O-4 through O-12. Figures O-4 through O-7 represent both the decentralized and regionalized configurations for EAs 1, 6, 10, and 94 for CH waste, including sites that treat and store waste and sites that ship pre-processed waste to other sites for treatment and storage. Figures O-8 through O-12 represent the centralized configuration for CH waste, which includes shipment of pre-processed waste to WIPP for treatment, storage, and disposal.

2.7.1 Front End Module

Front-end support facilities consist of all administrative and laboratory buildings required for the waste management support functions. Front-end support functions include security, personnel decontamination (radioactive and hazardous), maintenance of noncontaminated areas and equipment, health physics, radiation badges, facility access control, sanitary facilities, work control and personnel support, internal and external communications, spill or emergency response provisions (radioactive and hazardous), analytical laboratory, environmental field sampling, environmental regulatory reporting, and records management. Front-end support facilities include all administrative and laboratory buildings required for the waste management support functions.

2.7.2 Waste Retrieval Module

This module consists of all-weather excavation, inspection, and repackaging of bermed waste. The module includes three principal unit operations: earthen cover extraction and decontamination, waste container retrieval and inspection, and packaging and staging for shipment.

2.7.3 Waste Characterization Module

This module is a self-contained facility in which waste characterization is performed. Activities include extracting physical samples of waste; conducting chemical, physical, and radiological sampling of waste; and repackaging drums and boxes to remove and stabilize noncompliant waste.

2.7.4 Maintenance Module

A maintenance facility is used in conjunction with treatment facilities. It consists of a failed equipment receiving and repair building housing machinery and tools.

1

TABLE O-13

TRANSFER OF WASTE FOR THE DECENTRALIZED, REGIONALIZED, AND CENTRALIZED CONFIGURATIONS

Decentralized			Regionalized			Centralized		
Site	CH	RH	Site	CH	RH	Site	CH	RH
ANL-E*	WIPP	ORNL+	ANL-E	SRS	ORNL	ANL-E	WIPP	WIPP
AMES	ANL-E#		AMES	SRS		AMES	WIPP	
BCLDP		ORNL+	BCLDP		ORNL	BCLDP		WIPP
BT	MOUND	ORNL+	BT	SRS	ORNL	BT	WIPP	WIPP
ETEC	NTS		ETEC	INEL/ANL-W		ETEC	WIPP	
INEL/ANL-W*	WIPP	WIPP	INEL/ANL-W*	WIPP	HANFORD	INEL/ANL-W	WIPP	WIPP
KAPL	MOUND	ORNL+	KAPL	SRS	ORNL	KAPL	WIPP	WIPP
LANL*	WIPP	WIPP	LANL*	WIPP	HANFORD	LANL	WIPP	WIPP
LBL	(LLNL)		LBL	HANFORD		LBL	WIPP	
LLNL*	WIPP		LLNL	HANFORD		LLNL	WIPP	
MOUND*	WIPP		MOUND	SRS		MOUND	WIPP	
MU	ANL-E#		MU	SRS		MU	WIPP	
NTS*	WIPP	WIPP	NTS	INEL/ANL-W	HANFORD	NTS	WIPP	WIPP
ORNL*	WIPP	WIPP	ORNL* (rh)	SRS	WIPP	ORNL	WIPP	WIPP
PA	ORNL		PA	SRS		PA	WIPP	
PANTEX	LANL		PANTEX	LANL		PANTEX	WIPP	
RFETS*	WIPP		RFETS*	WIPP		RFETS	WIPP	
HANFORD*	WIPP	WIPP	HANFORD*	WIPP	WIPP	HANFORD	WIPP	WIPP
SNL/NM	LANL		SNL/NM	LANL		SNL/NM	WIPP	
SRS*	WIPP	WIPP	SRS*	WIPP	ORNL	SRS	WIPP	WIPP

Notes:

* Denotes a processing site.

ORNL+ Remote handled wastes from BCLDP, BT, KAPL, (these are not discussed in the EM-PEIS) and ANL-E should be processed at ORNL instead of Mound because Mound currently does not process or store RH waste.

ANL-E# The EM-PEIS discusses that ANL-E will process and ship its own CH waste but does not cover Ames and MU which are closer to ANL-E than ORNL.

(LLNL) EM-PEIS indicates LBL waste will be shipped to Hanford. LBL waste should be shipped to LLNL because it is much closer.

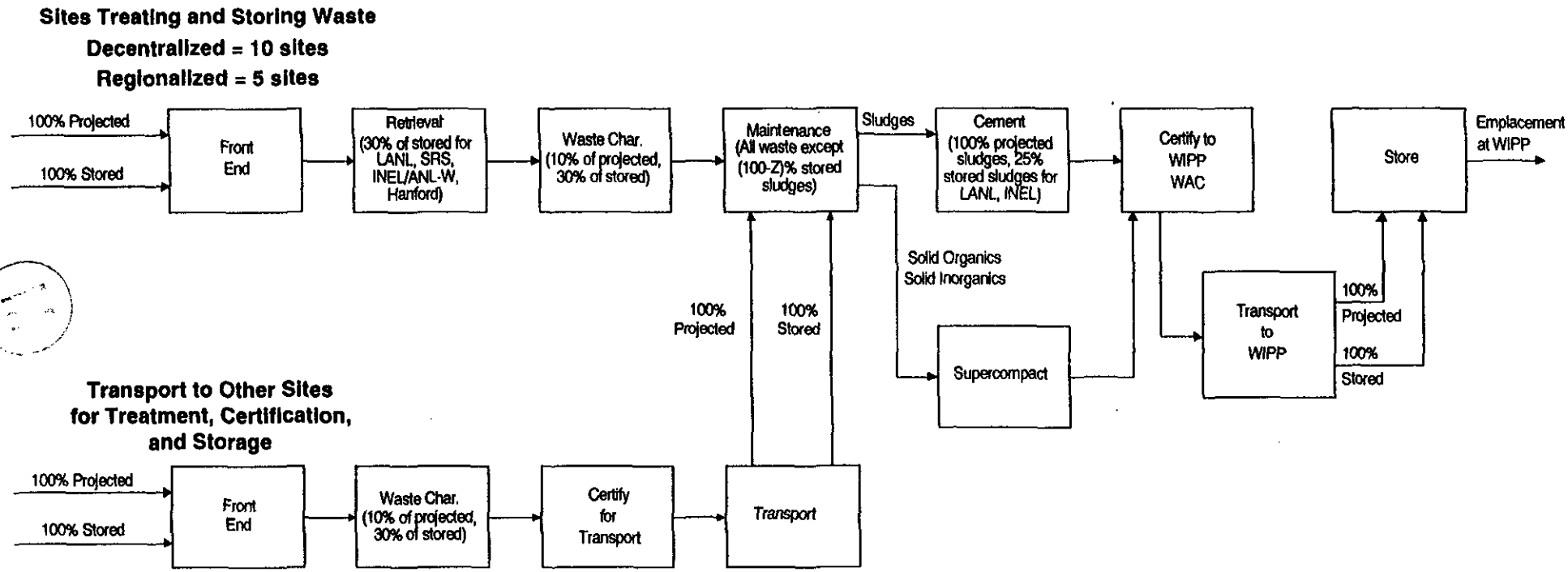

DEFINITIONS
Z = 25% for LANL and INEL
Z = 0% for all other sites

Alternative ID# 1

Sludges:	Baseline (grout)
Solid Inorganics:	Supercompact
Solid Organics:	Supercompact

Figure O-4

Decentralized and Regionalized Alternative ID #s 1 and 77(a-d) Contact Handled

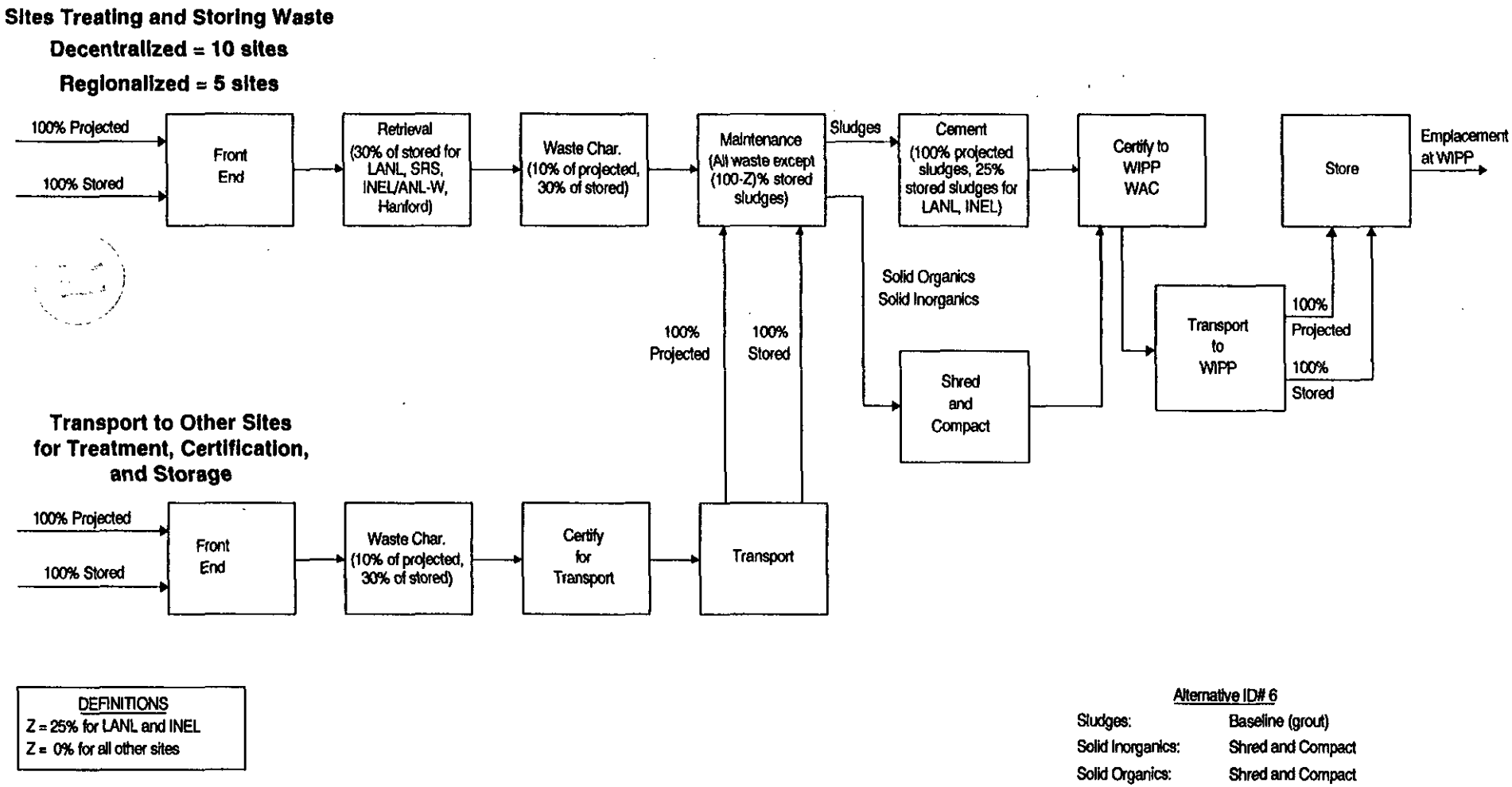

DEFINITIONS
Z = 25% for LANL and INEL
Z = 0% for all other sites

Alternative ID# 6

Sludges:	Baseline (grout)
Solid Inorganics:	Shred and Compact
Solid Organics:	Shred and Compact

Figure O-5
Decentralized and Regionalized Alternative ID# 6 Contact Handled

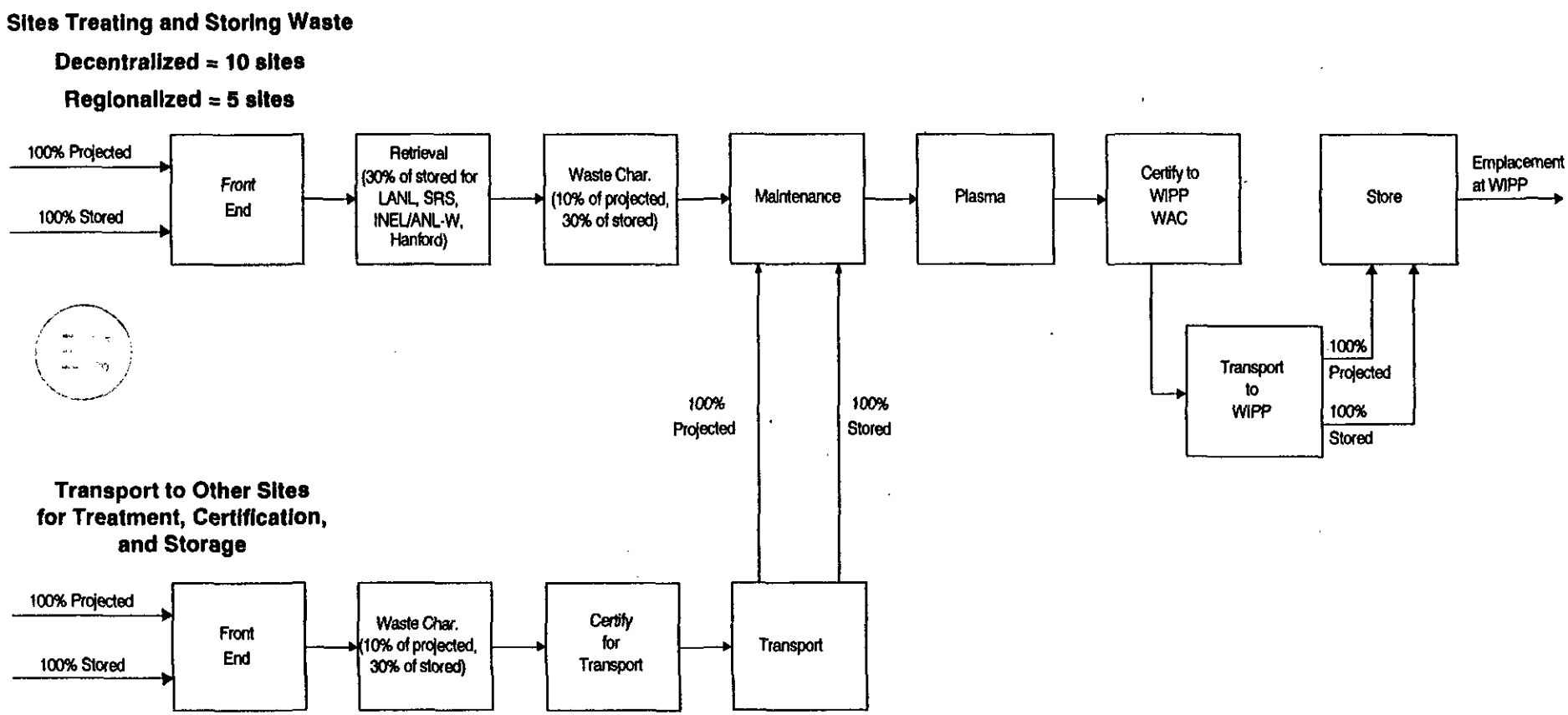

Alternative ID# 10

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure O-6

Decentralized and Regionalized Alternative ID# 10 Contact Handled

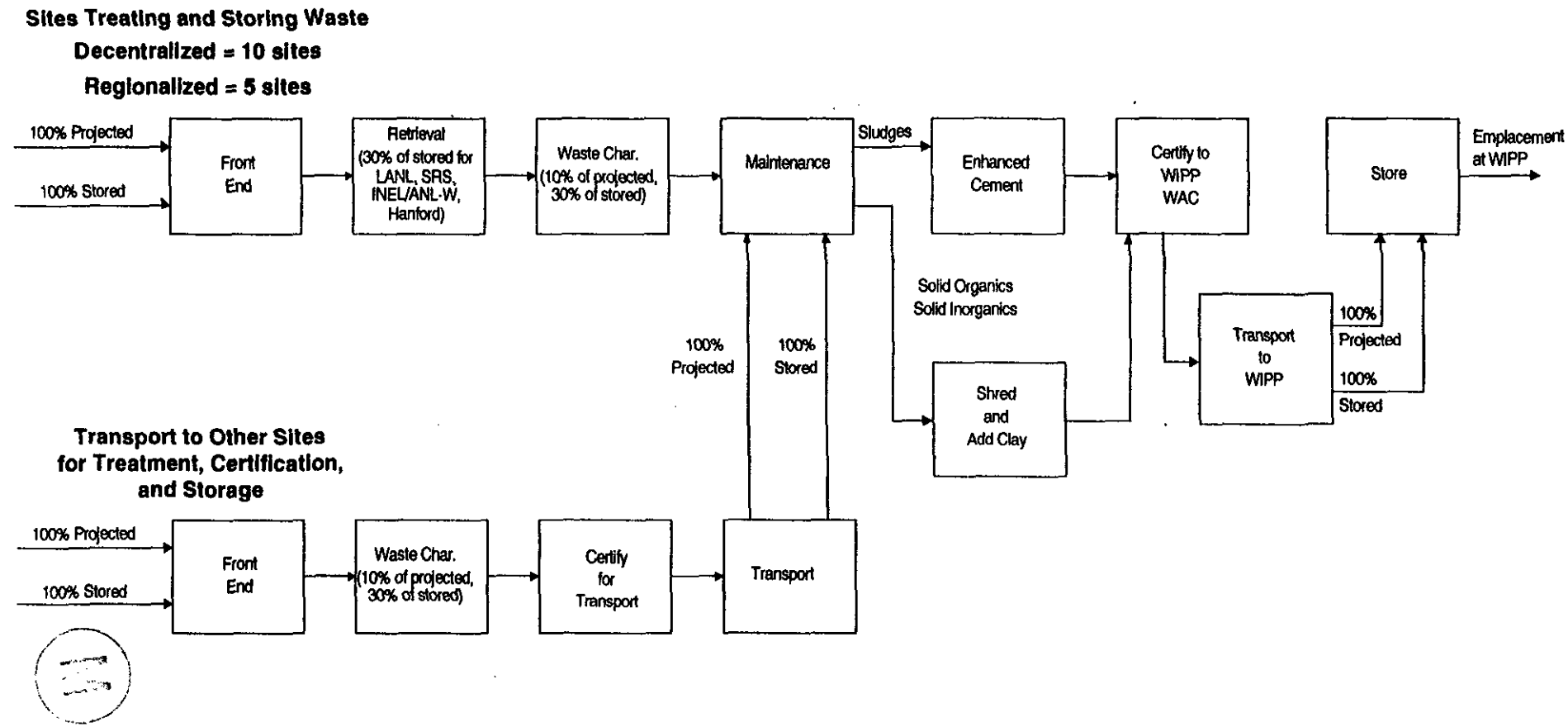

Alternative ID# 94(a-f)

Sludges:	Enhanced Cement
Solid Inorganics:	Shred and Add Clay
Solid Organics:	Shred and Add Clay

Figure O-7

Decentralized and Regionalized Alternative ID# 94(a-f) Contact Handled

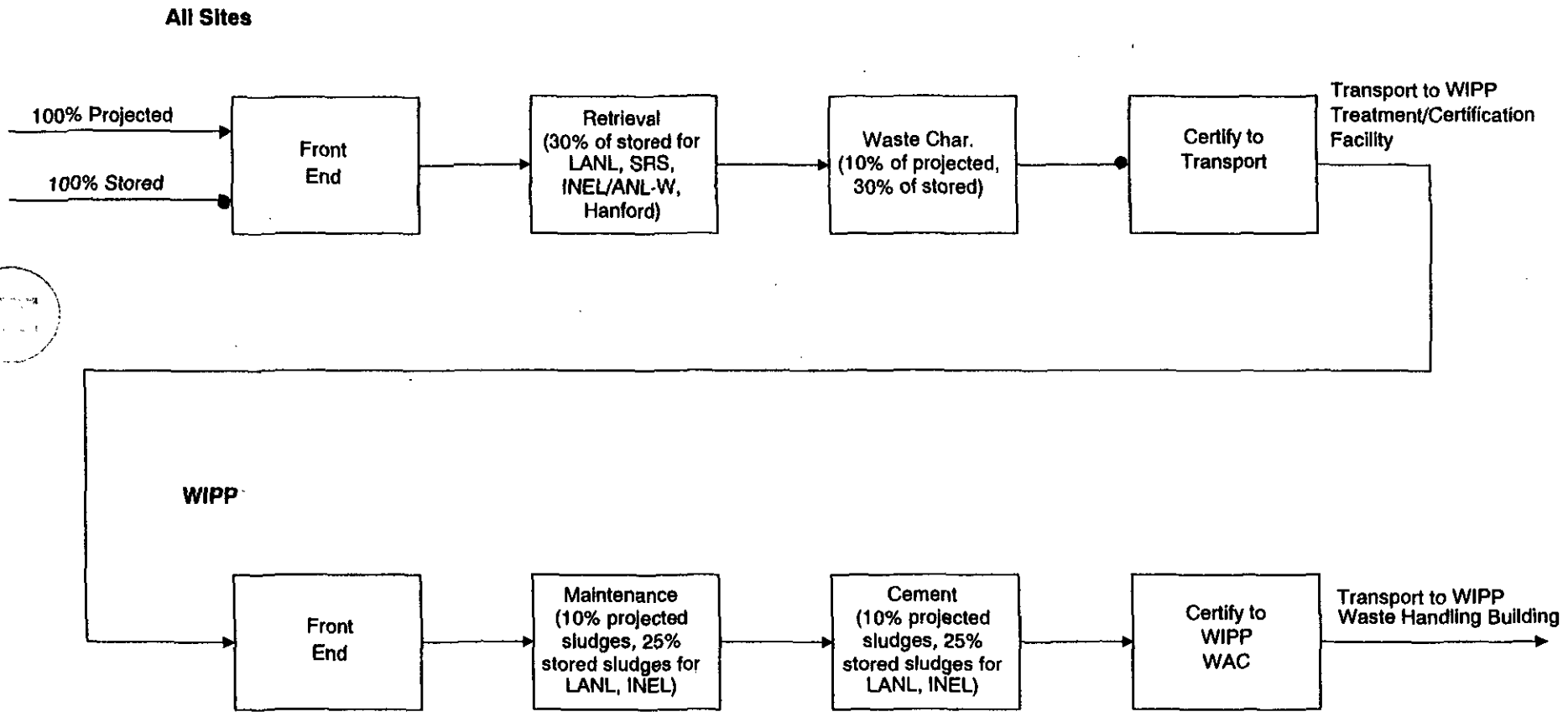

Figure O-8

Centralized Base Case and Alternative ID #s 33, 35(a&b), 83, and 111 Contact Handled

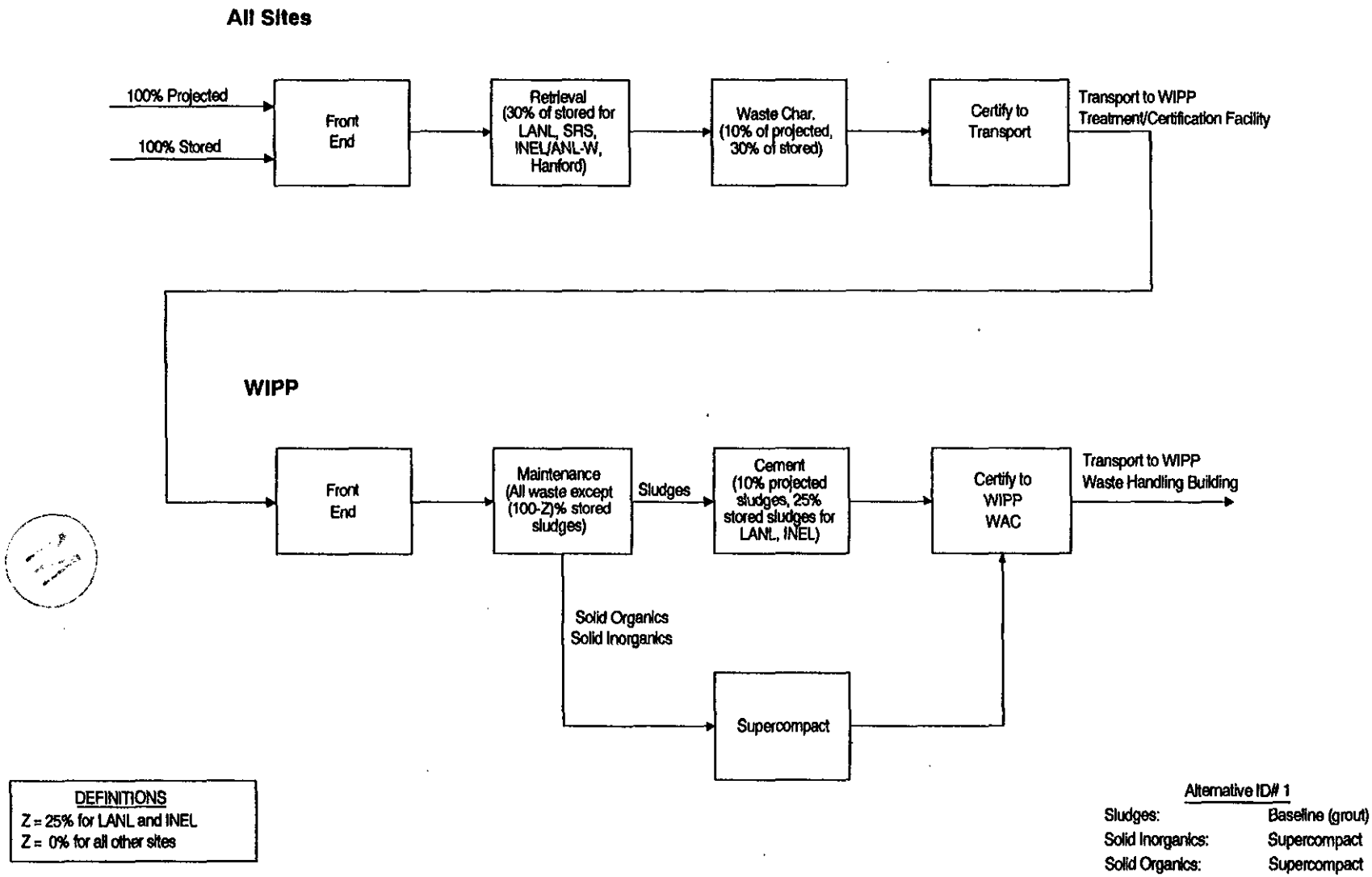

Figure O-9

Centralized Alternative ID#s 1 and 77(a-d) Contact Handled

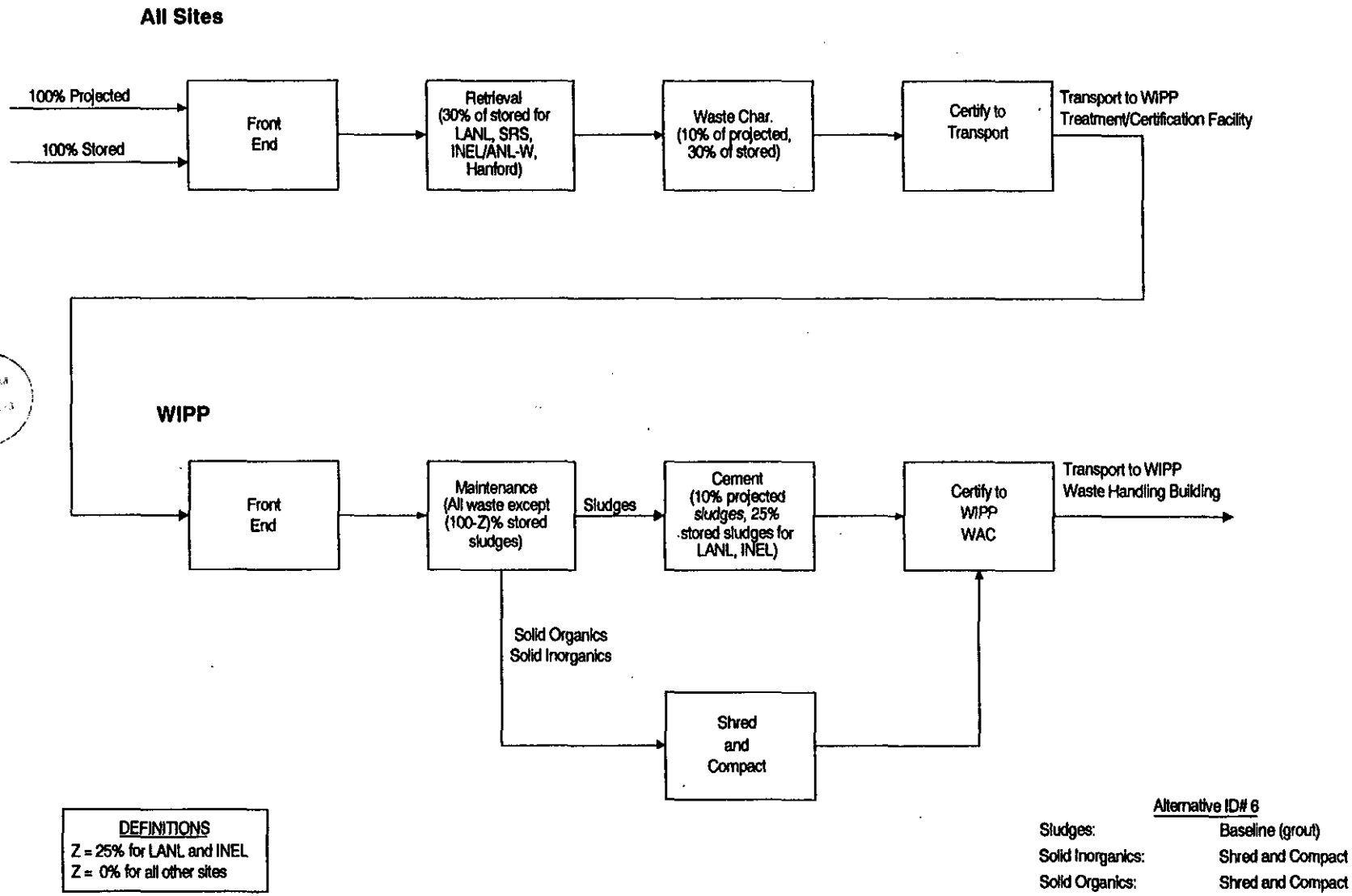

Figure O-10
Centralized Alternative ID# 6 Contact Handled

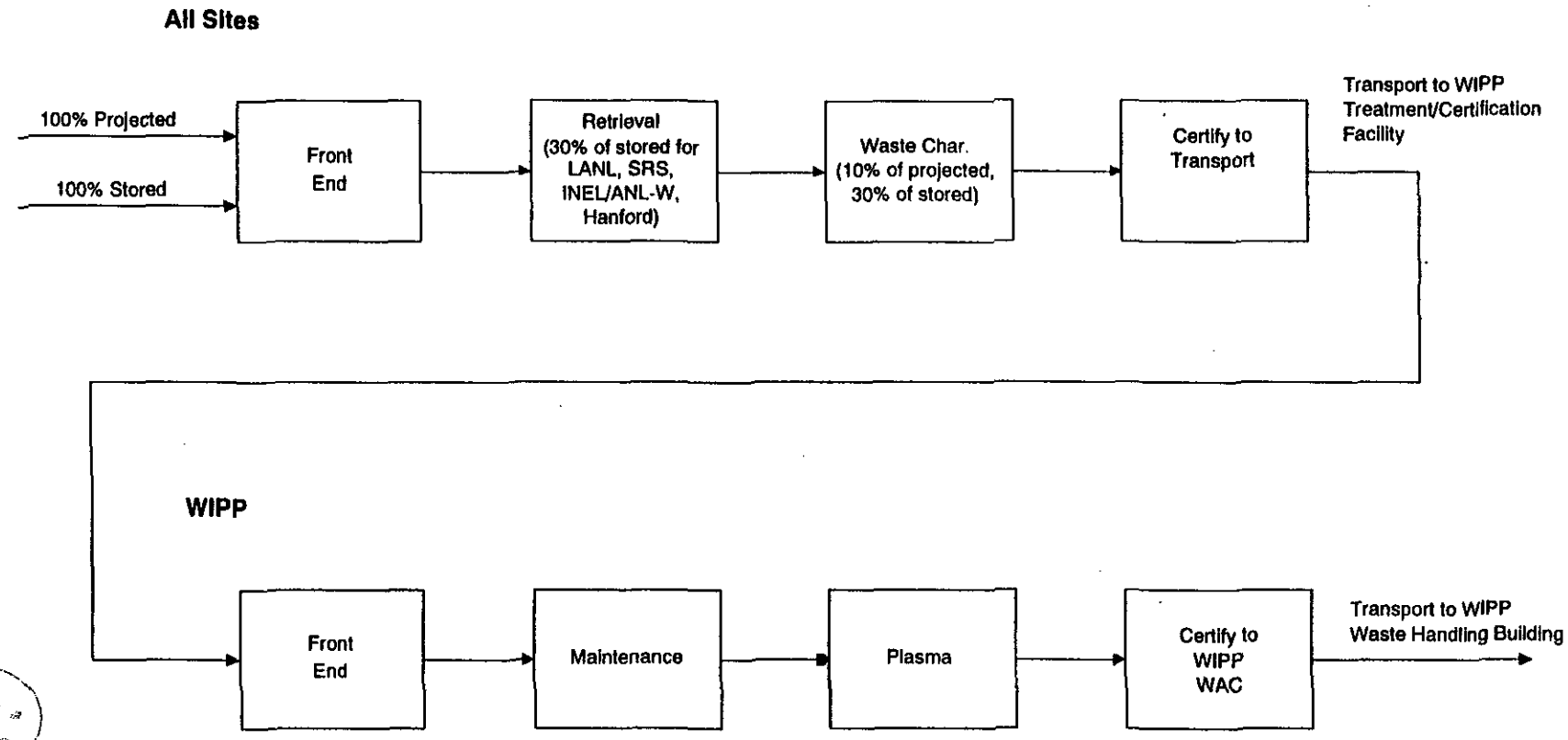

Alternative ID# 10

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure O-11
Centralized Alternative ID# 10 Contact Handled

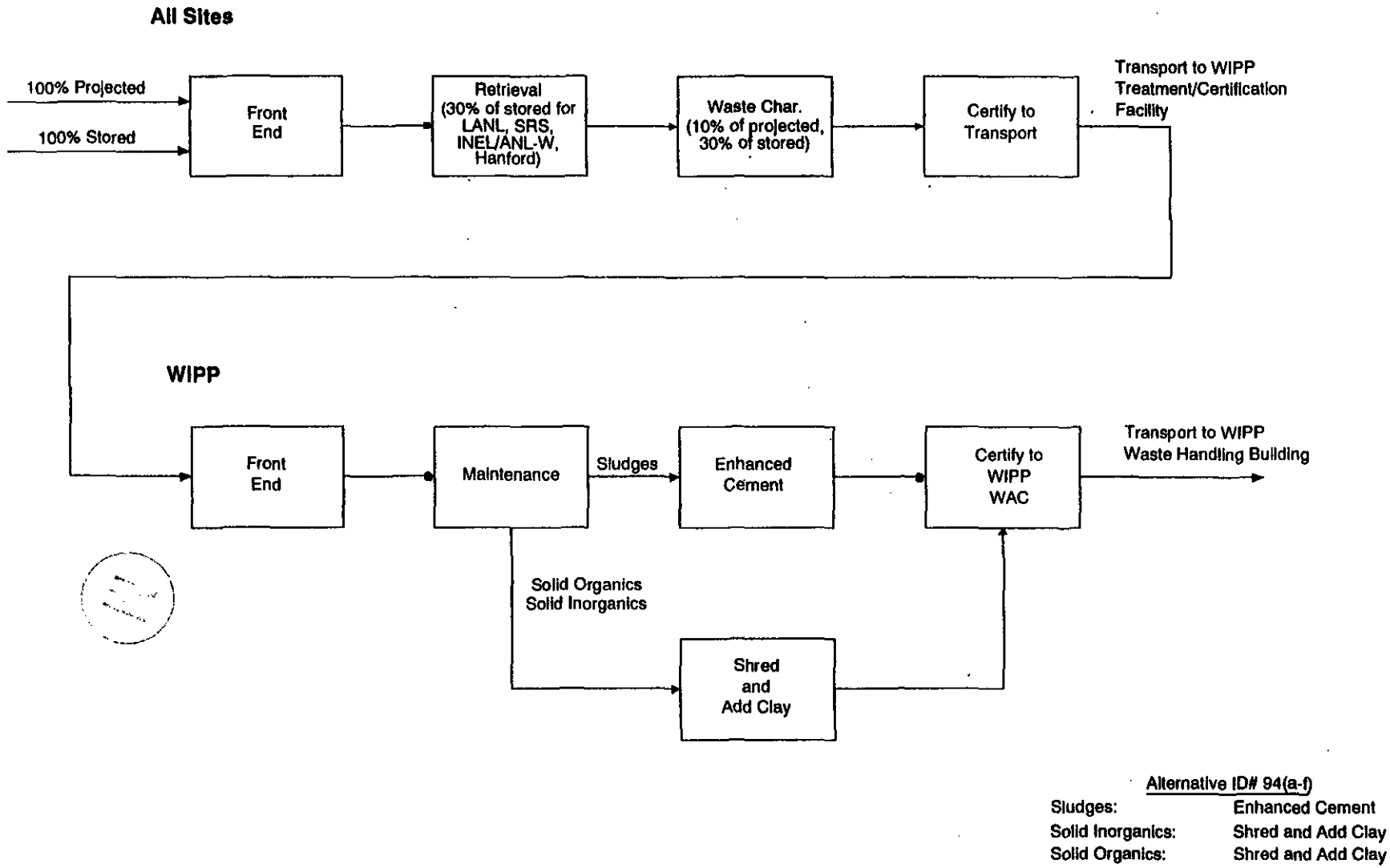

Figure O-12
Centralized Alternative ID# 94(a-f)

2.7.5 Treatment Module

The treatment module varies based on the EA being considered. Treatment options include grouting, supercompacting, shredding and compacting, plasma melting, enhanced- cement processing, and shredding and adding clay.

2.7.6 Storage Module

This module consists of a Resource Conservation and Recovery Act compliant storage building sized to accommodate an accumulation of waste from treatment modules for a maximum of 20 years. Storage area features include spill collection, sloping floors, sumps, and concrete berms. Monitoring is included for both gamma and alpha radiation control.

2.7.7 Certification and Shipping Module

Certification and shipping consists of storage of incoming material, assay and certification, and truck loading. The facility is equipped with a bridge crane and a forklift. It is assumed that certification and shipping operations will take place indoors.

2.7.8 Transportation Module

Transportation consists of truck shipments, including a tractor and trailer transporting three Transuranic Package Transporter-IIs (TRUPACT-IIs) for CH waste or one RH-72B cask (a cylinder consisting of a separate inner vessel within an outer cask protected by impact limiters at each end) for RH waste.

Mass and volume changes occur in the retrieval module and the treatment modules. Table O-14 summarizes these changes. Several other assumptions were made in addition to the mass and volume changes:

- All waste within a major waste form category (i.e., sludges, solid organics, solid inorganics) can be treated using a selected technology.

- The volume of waste categorized as "unknown" in the WTWBIR is processed the same as solid organics and inorganics. However, the mass of unknown waste is assumed to be zero because no information was available regarding the density of the unknown waste and the volume of this waste is small compared to the total volume of waste destined for WIPP.

- All projected sludges were grouted in the baseline. In general, stored sludges were not treated in the baseline because they were assumed to have been grouted previously; however, 25 percent of the stored sludges from Los Alamos National Laboratory (LANL) and the Idaho National Engineering Laboratory (INEL) were regrouted and all of the stored sludges at Oak Ridge National Laboratory (ORNL) were grouted.

- All sludges, including stored, are treated in the enhanced-cement treatment option.

- All sludges, solid organics, and solid inorganics are treated in the plasma melter.

1

TABLE O-14

MASS AND VOLUME CHANGES FOR WASTE TREATMENT/PROCESSING MODULES

Module	Mass Ratio (Output/Input)	Volume Ratio (Output/Input)
Front End	1.00[1]	1.00[2]
Retrieval	1.10[1]	1.10[2]
Waste Characterization	1.00[2]	1.00[2]
Maintenance	1.00[2]	1.00[2]
Grout	3.15[1]	2.50[2]
Supercompact	1.10[1]	0.35[2]
Shred and Compact	1.10[1]	0.76[2]
Shred and Add Clay	2.35[2]	1.00[2]
Plasma	1.00[1]	0.33[2]
Certification and Shipping	1.00[2]	1.00[2]
Storage	1.00[2]	1.00[2]

[1]Source (Feizollahi and Shropshire, 1994)
[2]Values derived from engineering calculations

- Ten percent of projected waste and 30 percent of stored waste requires characterization.

- Thirty percent of stored waste from LANL, Savannah River Site (SRS), INEL/Argonne National Laboratory-West (ANL-W), and Hanford requires retrieval.

3.0 RESULTS

Tables O-15 through O-30 show the mass and volume processing rates (i.e., inputs) to each of the modules for each of the EAs in each of the configurations that were calculated based on the methodology and assumptions provided previously in this appendix. These flow rates were then used to calculate the costs associated with each module. The cost analysis is described in Section 3.7 and Appendix P of this report.

Tables O-31 and O-32 show final treated mass and volume by EA and primary waste form for each EA, for CH waste and RH waste, respectively. The final mass and volume do not differ by configuration, because the same amount of waste is treated regardless of the site at which the waste is treated. The treated volume of waste for EA 94 exceeds the design capacity of WIPP; it is assumed that this waste would have to be managed in some other way when the WIPP reaches full capacity.

The final processed mass and volume were used as inputs to other EA analyses.

TABLE O-15

INPUTS TO MODULES FOR THE CONTACT-HANDLED WASTE DECENTRALIZED BASELINE

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.01	0.01	0.28	1.80
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	14.83	14.83	307.90	2720.79
INEL/ANL-W	248.80	74.62	76.87	29.91	29.91	320.57	2369.50
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	21.60	21.60	168.55	1351.17
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.31	0.31	6.25	64.66
MOUND	1.78	0.00	0.53	0.00	0.00	4.37	35.92
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.39	31.06
ORNL	9.04	0.00	2.12	0.33	0.33	9.79	56.35
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	14.05	14.05	69.29	443.31
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	238.12	1346.67
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.93	0.00

TABLE O-16

INPUTS TO MODULES FOR DECENTRALIZED ALTERNATIVE 1

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Supercompact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.03	0.01	0.03	0.29	1.51
BT	1.38	0.00	0.14	1.38	0.00	1.38	1.51	0.00
ETEC	0.07	0.00	0.01	0.07	0.00	0.07	0.08	0.00
HANFORD	273.67	23.48	43.72	275.99	14.83	261.16	334.01	1284.39
INEL/ANL-W	248.80	74.62	76.87	166.54	29.91	136.63	334.23	1664.74
KAPL	0.02	0.00	0.01	0.02	0.00	0.02	0.02	0.00
LANL	119.73	22.27	27.49	86.19	21.60	64.59	175.03	912.85
LBL	0.06	0.00	0.01	0.06	0.00	0.06	0.06	0.00
LLNL	5.52	0.00	0.76	5.40	0.31	5.08	6.76	30.03
MOUND	1.78	0.00	0.53	1.71	0.00	1.71	4.80	12.96
MU	0.02	0.00	0.00	0.02	0.00	0.02	0.02	0.00
NTS	5.31	0.00	1.59	5.31	0.00	5.31	5.92	10.87
ORNL	9.04	0.00	2.12	9.04	0.33	8.70	10.66	23.37
PANTEX	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	36.90	14.05	22.85	71.57	303.03
SNL/NM	0.15	0.00	0.03	0.15	0.00	0.15	0.16	0.00
SRS	234.70	34.25	47.33	238.12	0.00	238.12	261.93	471.34
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	3.21	0.00

TABLE O-17

INPUTS TO MODULES FOR DECENTRALIZED ALTERNATIVE 6

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Shred & Compact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.03	0.01	0.03	0.29	1.69
BT	1.38	0.00	0.14	1.38	0.00	1.38	1.51	0.00
ETEC	0.07	0.00	0.01	0.07	0.00	0.07	0.08	0.00
HANFORD	273.67	23.48	43.72	275.99	14.83	261.16	334.01	2190.43
INEL/ANL-W	248.80	74.62	76.87	166.54	29.91	136.63	334.23	2109.28
KAPL	0.02	0.00	0.01	0.02	0.00	0.02	0.02	0.00
LANL	119.73	22.27	27.49	86.19	21.60	64.59	175.03	1189.33
LBL	0.06	0.00	0.01	0.06	0.00	0.06	0.06	0.00
LLNL	5.52	0.00	0.76	5.40	0.31	5.08	6.76	51.87
MOUND	1.78	0.00	0.53	1.71	0.00	1.71	4.80	27.44
MU	0.02	0.00	0.00	0.02	0.00	0.02	0.02	0.00
NTS	5.31	0.00	1.59	5.31	0.00	5.31	5.92	23.61
ORNL	9.04	0.00	2.12	9.04	0.33	8.70	10.66	44.17
PANTEX	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	36.90	14.05	22.85	71.57	391.52
SNL/NM	0.15	0.00	0.03	0.15	0.00	0.15	0.16	0.00
SRS	234.70	34.25	47.33	238.12	0.00	238.12	261.93	1023.47
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	3.21	0.00

TABLE O-18

INPUTS TO MODULES FOR DECENTRALIZED ALTERNATIVE 10

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Plasma Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.25	0.25	0.27	0.55
BT	1.38	0.00	0.14	1.38	1.38	1.38	0.00
ETEC	0.07	0.00	0.01	0.07	0.07	0.07	0.00
HANFORD	273.67	23.48	43.72	276.02	276.02	276.02	796.72
INEL/ANL-W	248.80	74.62	76.87	256.26	256.26	256.26	666.26
KAPL	0.02	0.00	0.01	0.02	0.02	0.02	0.00
LANL	119.73	22.27	27.49	121.96	121.96	122.11	348.95
LBL	0.06	0.00	0.01	0.06	0.06	0.06	0.00
LLNL	5.52	0.00	0.76	5.52	5.52	5.58	19.22
MOUND	1.78	0.00	0.53	1.78	1.78	4.37	11.85
MU	0.02	0.00	0.00	0.02	0.02	0.02	0.00
NTS	5.31	0.00	1.59	5.31	5.31	5.39	10.25
ORNL	9.75	0.00	2.34	9.75	9.75	9.79	18.60
PANTEX	0.01	0.00	0.00	0.01	0.01	0.01	0.00
PA	0.03	0.00	0.01	0.03	0.03	0.03	0.00
RFETS	39.08	0.00	5.45	39.08	39.08	39.08	103.11
SNL/NM	0.15	0.00	0.03	0.15	0.15	0.15	0.00
SRS	234.70	34.25	47.33	238.12	238.12	238.12	444.40
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-19

INPUTS TO MODULES FOR DECENTRALIZED ALTERNATIVE 94

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Enhanced Cement Mass (kg/hr)	Shred & Add Clay Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.25	0.23	0.03	0.82	3.53
BT	1.38	0.00	0.14	1.38	0.00	1.38	3.24	0.00
ETEC	0.07	0.00	0.01	0.07	0.00	0.07	0.17	0.00
HANFORD	273.67	23.48	43.72	276.02	14.86	261.16	661.29	2721.02
INEL/ANL-W	248.80	74.62	76.87	256.26	119.63	136.63	698.32	3421.07
KAPL	0.02	0.00	0.01	0.02	0.00	0.02	0.05	0.00
LANL	119.73	22.27	27.49	121.96	57.36	64.59	333.03	1632.08
LBL	0.06	0.00	0.01	0.06	0.00	0.06	0.13	0.00
LLNL	5.52	0.00	0.76	5.52	0.44	5.08	13.48	65.66
MOUND	1.78	0.00	0.53	1.78	0.07	1.71	10.38	36.81
MU	0.02	0.00	0.00	0.02	0.00	0.02	0.04	0.00
NTS	5.31	0.00	1.59	5.31	0.00	5.31	12.67	31.06
ORNL	9.75	0.00	2.34	9.75	1.05	8.70	23.89	64.76
PANTEX	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00
PA	0.03	0.00	0.01	0.03	0.03	0.00	0.10	0.00
RFETS	39.08	0.00	5.45	39.08	16.23	22.85	104.90	457.44
SNL/NM	0.15	0.00	0.03	0.15	0.00	0.15	0.35	0.00
SRS	234.70	34.25	47.33	238.12	0.00	238.12	560.28	1346.67
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE O-20

INPUTS TO MODULES FOR REGIONALIZED BASELINE

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grout Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	15.14	15.14	314.14	2785.45
INEL/ANL-W	248.80	74.62	76.87	29.91	29.91	325.95	2400.56
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	21.60	21.60	168.55	1351.17
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	14.05	14.05	69.29	443.31
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.34	0.34	252.57	1440.74
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-21

INPUTS TO MODULES FOR REGIONALIZED ALTERNATIVE 1

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Supercompact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	281.44	15.14	266.30	340.77	1314.42
INEL/ANL-W	248.80	74.62	76.87	171.92	29.91	142.02	340.15	1675.61
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	86.35	21.60	64.74	175.03	912.85
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	36.90	14.05	22.85	71.57	303.03
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	251.47	0.34	251.13	277.68	509.17
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-22

INPUTS TO MODULES FOR REGIONALIZED ALTERNATIVE 6

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Shred & Compact Mass (kg/hr)	CERT & SHIP MASS (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	281.44	15.14	266.30	340.77	2242.30
INEL/ANL-W	248.80	74.62	76.87	171.92	29.91	142.02	340.15	2132.89
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	86.35	21.60	64.74	175.03	1189.33
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	36.90	14.05	22.85	71.57	391.52
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	251.47	0.34	251.13	277.68	1096.77
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-23

INPUTS TO MODULES FOR REGIONALIZED ALTERNATIVE 10

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	PLASMA MASS (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	281.60	281.60	281.60	815.94
INEL/ANL-W	248.80	74.62	76.87	261.65	261.65	261.65	676.51
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	122.11	122.11	122.11	348.95
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.31	0.00
ORNL	9.75	0.00	2.34	0.00	0.00	9.75	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	39.08	39.08	39.08	103.11
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	252.56	252.56	252.56	475.40
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-24

INPUTS TO MODULES FOR REGIONALIZED ALTERNATIVE 94

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Enhanced Cement Mass (kg/hr)	Shred & Add Clay Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	281.60	15.29	266.3045	674.77	2786.67
INEL/ANL-W	248.80	74.62	76.87	261.65	119.63	142.0159	711.00	3452.13
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	122.11	57.36	64.74	333.03	1632.08
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.75	0.00	2.34	0.00	0.00	0.00	9.75	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	39.08	16.23	22.85	104.90	457.44
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	252.56	1.42	251.13	595.37	1451.77
WIPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-25

INPUTS TO MODULES FOR CENTRALIZED BASELINE

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grout Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	238.12	0.00
WIPP	940.81	0.00	0.00	81.04	81.04	1130.50	323.89
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-26
INPUTS TO MODULES FOR CENTRALIZED ALTERNATIVE 1

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Supercompact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	0.00	238.12	0.00
WIPP	940.81	0.00	0.00	828.08	81.04	747.05	1205.21	181.35
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-27

INPUTS TO MODULES FOR CENTRALIZED ALTERNATIVE 6

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Shred & Compact Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.04	0.00	2.12	0.00	0.00	0.00	9.04	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	0.00	238.12	0.00
WIPP	940.81	0.00	0.00	828.08	81.04	747.05	1205.21	271.26
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-28

INPUTS TO MODULES FOR CENTRALIZED ALTERNATIVE 10

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Plasma Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	5.31	0.00
ORNL	9.75	0.00	2.34	0.00	0.00	9.75	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	238.12	0.00
WIPP	941.53	0.00	0.00	956.99	956.99	956.99	93.07
PORTABLE	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-29

INPUTS TO MODULES FOR CENTRALIZED ALTERNATIVE 94

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Enhanced Cement Mass (kg/hr)	Shred & Add Clay Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/2-week period)
AMES LAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ANL-E	0.25	0.00	0.07	0.00	0.00	0.00	0.25	0.00
BT	1.38	0.00	0.14	0.00	0.00	0.00	1.38	0.00
ETEC	0.07	0.00	0.01	0.00	0.00	0.00	0.07	0.00
HANFORD	273.67	23.48	43.72	0.00	0.00	0.00	276.02	0.00
INEL/ANL-W	248.80	74.62	76.87	0.00	0.00	0.00	256.26	0.00
KAPL	0.02	0.00	0.01	0.00	0.00	0.00	0.02	0.00
LANL	119.73	22.27	27.49	0.00	0.00	0.00	121.96	0.00
LBL	0.06	0.00	0.01	0.00	0.00	0.00	0.06	0.00
LLNL	5.52	0.00	0.76	0.00	0.00	0.00	5.52	0.00
MOUND	1.78	0.00	0.53	0.00	0.00	0.00	1.78	0.00
MU	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NTS	5.31	0.00	1.59	0.00	0.00	0.00	5.31	0.00
ORNL	9.75	0.00	2.34	0.00	0.00	0.00	9.75	0.00
PANTEX	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
PA	0.03	0.00	0.01	0.00	0.00	0.00	0.03	0.00
RFETS	39.08	0.00	5.45	0.00	0.00	0.00	39.08	0.00
SNL/NM	0.15	0.00	0.03	0.00	0.00	0.00	0.15	0.00
SRS	234.70	34.25	47.33	0.00	0.00	0.00	238.12	0.00
WIPP	941.53	0.00	0.00	956.99	209.94	747.05	2419.07	376.16
PORTABLE	0.00	0.00	0.00	0.00	0.00	0.00	2.92	0.00

TABLE O-30

INPUTS TO MODULES FOR REMOTE-HANDLED WASTE BASELINE

Site	Front End Mass (kg/hr)	Retrieval Mass (kg/hr)	Waste Char Mass (kg/hr)	Maintenance Mass (kg/hr)	Grouting Mass (kg/hr)	Cert & Ship Mass (kg/hr)	Storage Volume (cu m/yr.)
BCLDP	0.32	0.00	0.03	0.00	0.00	0.32	0.00
BT	0.01	0.00	0.00	0.00	0.00	0.01	0.00
HANFORD	13.70	0.03	1.39	0.00	0.00	13.70	230.32
INEL/ANL-W	0.28	0.04	0.06	0.01	0.01	0.30	4.85
KAPL	0.15	0.00	0.02	0.00	0.00	0.15	0.00
LANL	1.37	0.17	0.25	0.00	0.00	1.38	11.07
ORNL	4.88	0.00	1.10	2.91	2.91	11.62	105.27
SRS	0.29	0.00	0.03	0.00	0.00	0.29	2.46

TABLE O-31

CH SUMMARY
MASS AND VOLUME OUTPUT
WIPP ENGINEERED ALTERNATIVES
JULY 1995

	Sludges			Solid Organics			Solid Inorganics		
Case #	Total Mass (kg)	Total Volume (cu. m)	Density (kg/cu. m)	Total Mass (kg)	Total Volume (cu. m)	Density (kg/cu. m)	Total Mass (kg)	Total Volume (cu. m)	Density (kg/cu. m)
Baseline	30,921,720	54,389	569	47,234,933	74,339	635	13,007,073	38,396	339
Alternative 1	30,921,720	54,389	569	51,958,427	26,019	1,997	14,307,781	13,438	1,065
Alternative 6	30,921,720	54,389	569	51,958,427	56,498	920	14,307,781	29,181	490
Alternative 10	16,929,945	10,767	1,572	47,234,933	24,532	1,925	13,007,073	12,671	1,027
Alternative 94	53,329,327	81,566	654	69,576,926	74,339	936	19,159,383	38,396	499

TABLE O-32

RH SUMMARY, RH MASS, AND VOLUME OUTPUT
WIPP ENGINEERED ALTERNATIVES
JULY 1995

Baseline	Sludges	Solid Organics	Solid Inorganics
Total Mass (kg)	741,427	1,338,770	120,268
Total Volume (cu. m)	1,283	5,524	224
Density (kg/cu. m)	578	242	537

APPENDIX P
COST ASSOCIATED WITH SCREENED ENGINEERING ALTERNATIVES

COST ASSOCIATED WITH SCREENED ENGINEERING ALTERNATIVES

1.0 INTRODUCTION

This appendix describes the methodology for determining estimated costs associated with the screened engineering alternatives (EA). Costs will be calculated for each of the screened EAs in the Decentralized, Regionalized, and Centralized configuration. The cost consists of summarizing waste processing, transportation, repository backfill, and emplacement handling for the selected EAs. The collection of the analyzed costs includes comparative analysis of the incremental change of the screened EAs relative to the repository baseline cost. The impact of cost for each EA will be an important tool for planning the implementation of an EA since it will typically determine the level of funding that must be appropriated. Costs are analyzed by developing process flow diagrams that segment the EA into conceptual elements. The costs for the EAs are developed on the basis of waste quantities and rate to meet schedule constraints.

Cost are based on an approach that utilized an approach consistent with current U.S. Department of Energy (DOE) methodologies and assumptions. The results of the analysis are presented according to backup calculations and summarized according to each EA.

2.0 METHODOLOGY USED TO EVALUATE COSTS

2.1 Process Costing Methodology

The waste processing costs were estimated using information contained in "Interim Report: Waste Management Facilities Cost Information for Transuranic Waste" (WMFCITRUW) (Feizollahi and Shropshire, 1994). The cost estimating method used by Feizollahi and Shropshire involves segmenting waste management facilities into discrete modules which are used to estimate the costs for building and operating facilities to perform various waste management functions. Cost estimates for different types of integrated transuranic (TRU) waste facilities are created by linking modules for different functions together in such a way that they closely approximate an actual waste management facility. This methodology provides the flexibility to estimate the costs many different sized facilities with many different functions without having to perform a rigorous conceptual design and cost estimate for each facility configuration.

Figure P-1 shows the information flow diagram used to develop waste processing cost estimates. Information from process flow diagrams and mass flow rates are required as input to the cost modules. A combination of data sources were used to develop this information, including existing waste inventories and waste generation projections (Appendix O), processing schedules (Appendix Q), a listing of EAs that require waste processing (Section 2), and the system configuration for the waste processing facilities (i.e., centralized, regionalized, or decentralized) (Section 2).

Process flow diagrams were developed for each alternative in each configuration (see Figures P-2 to P-12). These flow schemes were based on the DOE "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives:

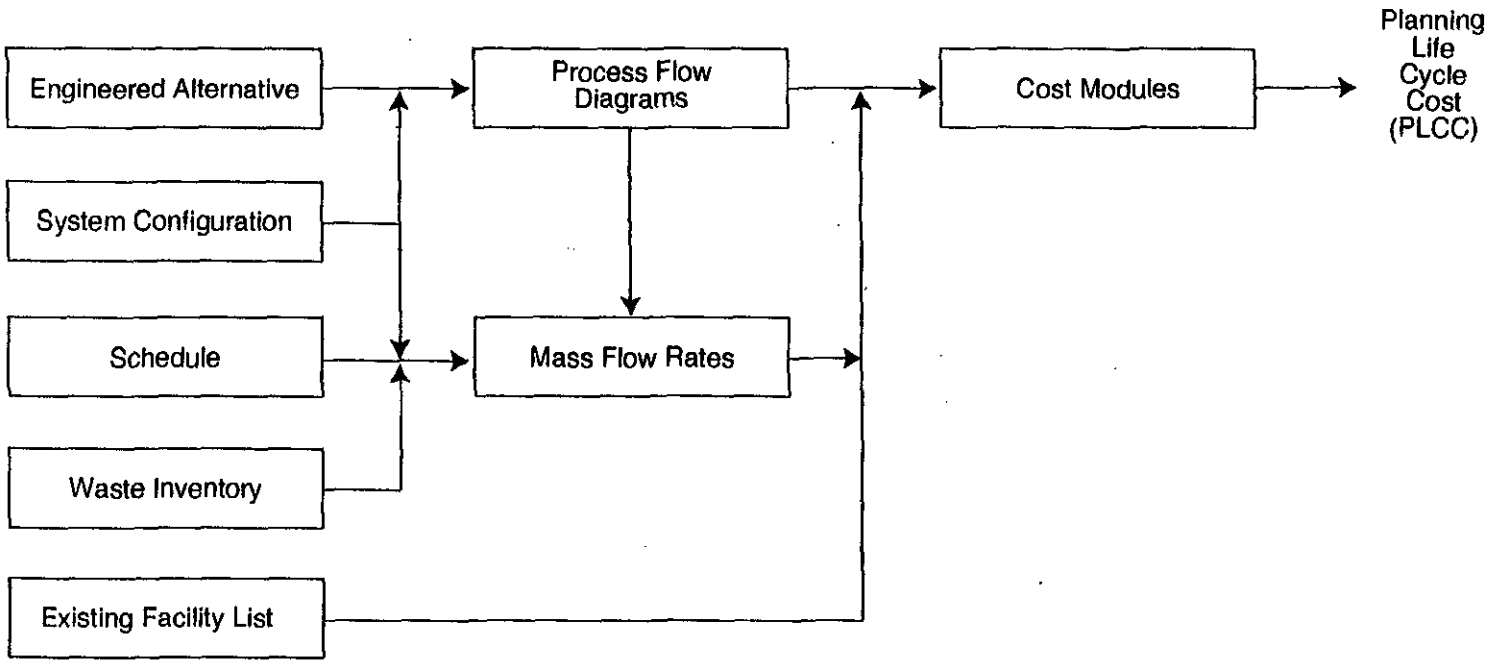

Figure P-1
Process Costing Methodology Flow Diagram

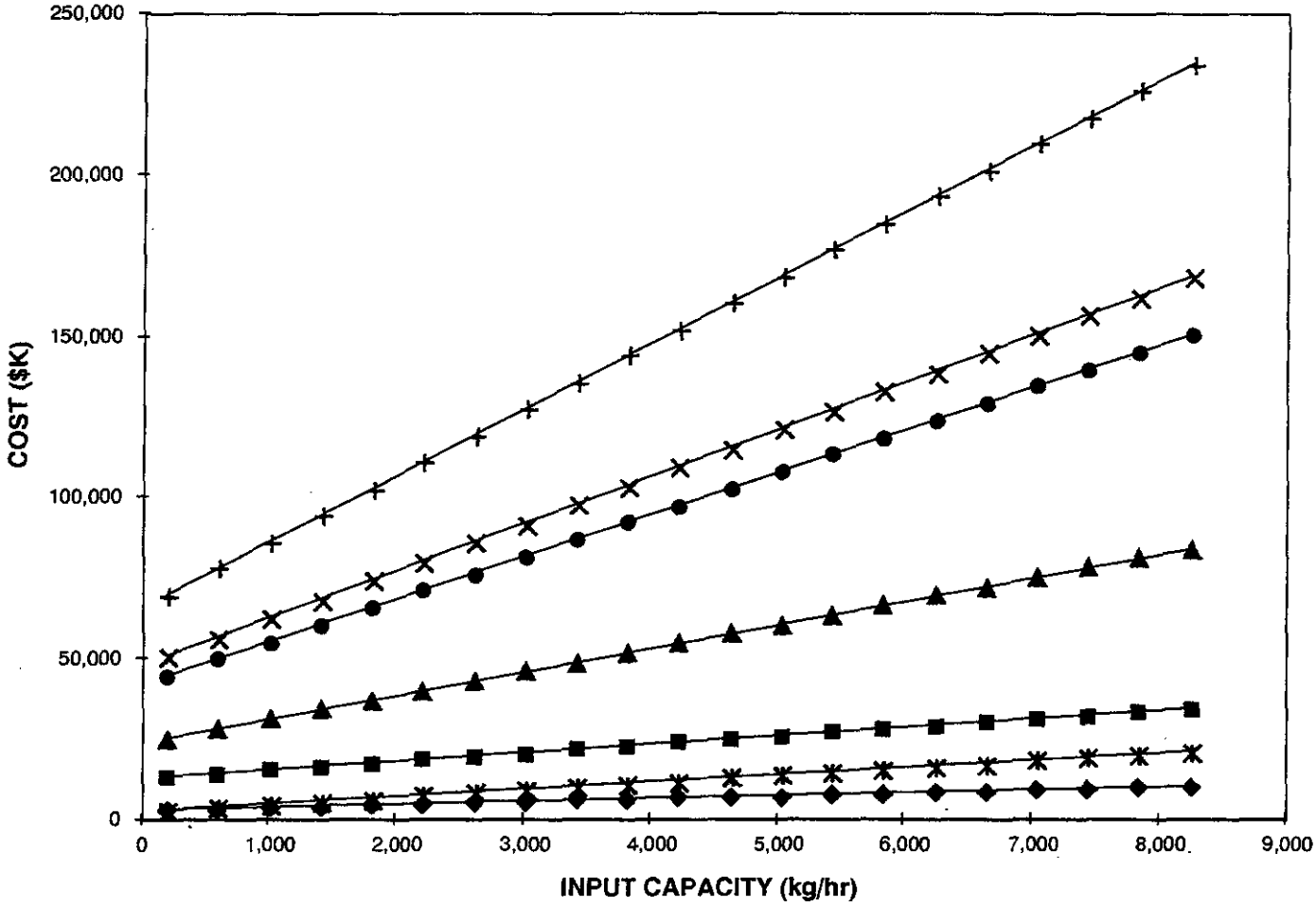

LEGEND

- ◆ 1.0 PRE-OPERATION
  y = 0.878x + 2969.1
  $R^2 = 1$
- ■ 2.0 CONSTRUCTION
  y = 2.6672x + 12644
  $R^2 = 1$
- ▲ 3.0 O& M (10 yr)
  y = 7.3151x + 23831
  $R^2 = 1$
- × 3.0 O& M (20 yr)
  y = 14.63x + 47661
  $R^2 = 1$
- ✱ 4.0 D & D
  y = 2.2816x + 2395.4
  $R^2 = 1$
- ● TOTAL PLCC (10 yr) $K
  y = 13.142x + 41839
  $R^2 = 1$
- + TOTAL PLCC (20 yr) $K
  y = 20.457x + 65670
  $R^2 = 1$

- Linear (TOTAL PLCC (20 yr) $K)
- Linear (3.0 O& M (20 yr))
- Linear (TOTAL PLCC (10 yr) $K)
- Linear (3.0 O& M (10 yr))
- Linear (2.0 CONSTRUCTION)
- Linear (4.0 D & D)
- Linear (1.0 PRE-OPERATION)

Figure P-2

CH-RH Certification and Shipping Cost Curves

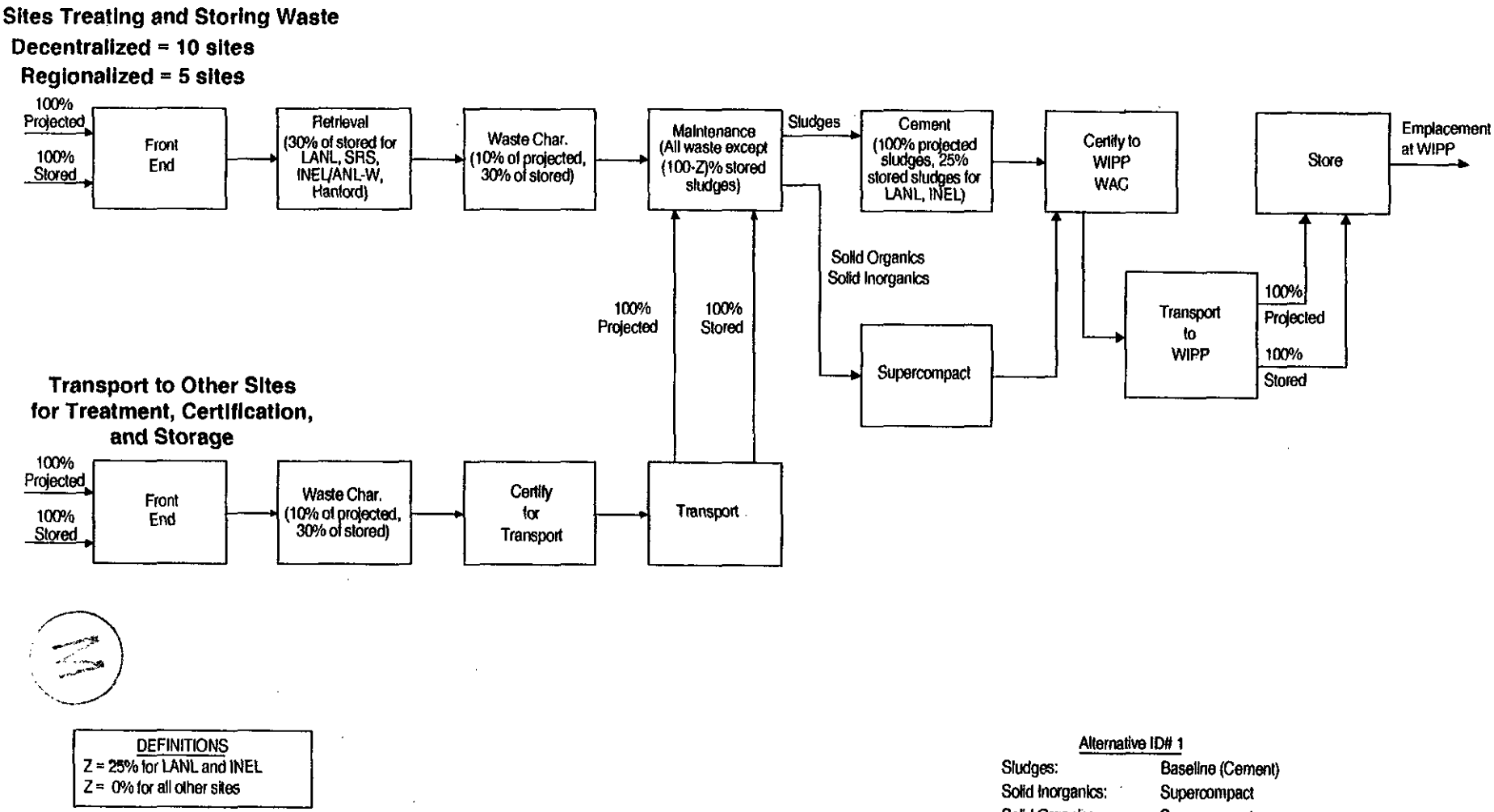

Figure P-3

Decentralized and Regionalized Alternative ID #s 1 and 77(a-d) Contact Handled Process Flow Diagram B

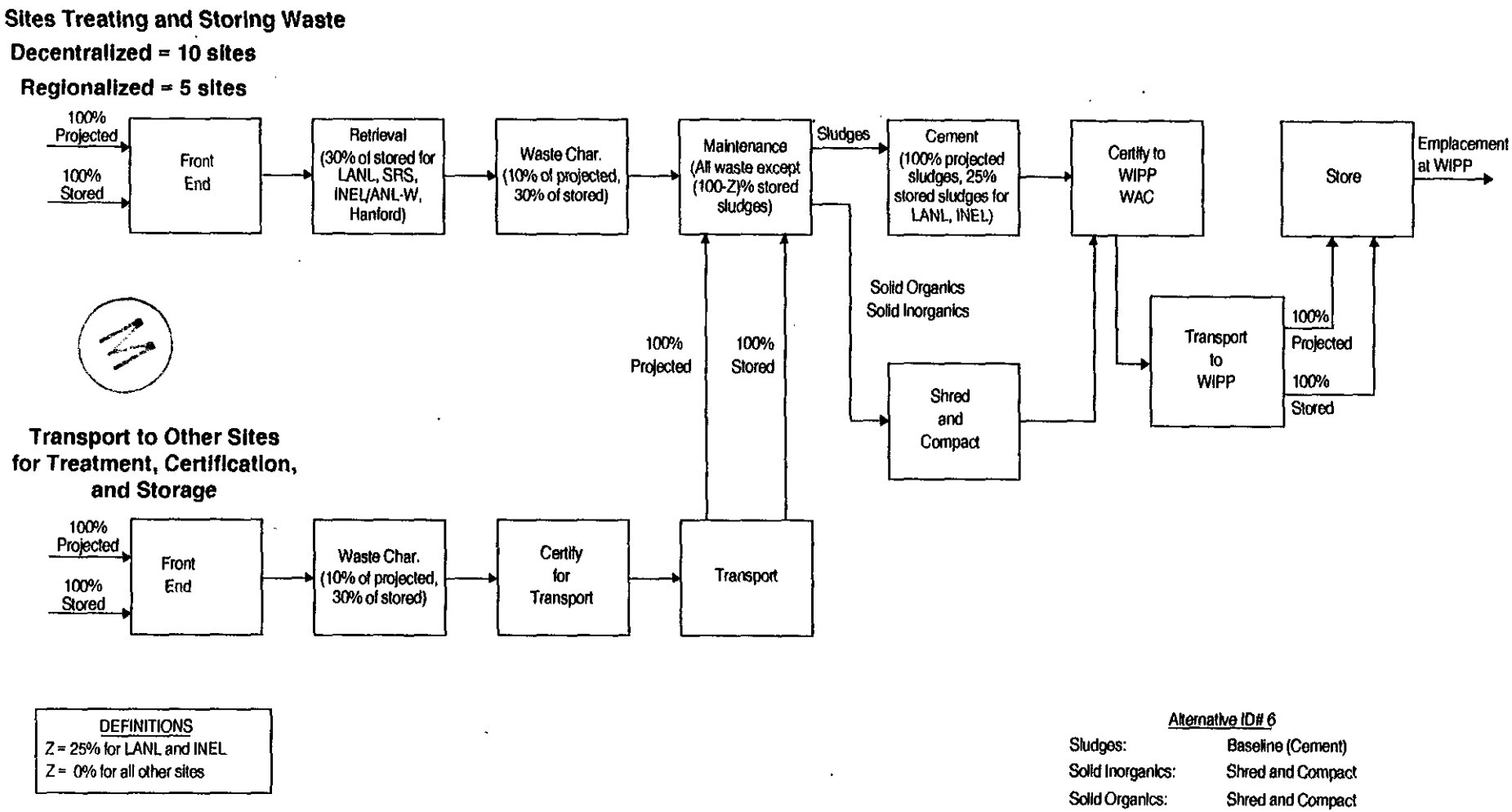

DEFINITIONS
Z = 25% for LANL and INEL
Z = 0% for all other sites

Alternative ID# 6

Sludges:	Baseline (Cement)
Solid Inorganics:	Shred and Compact
Solid Organics:	Shred and Compact

Figure P-4

Decentralized and Regionalized Alternative ID# 6 Contact Handled Process Flow Diagram C

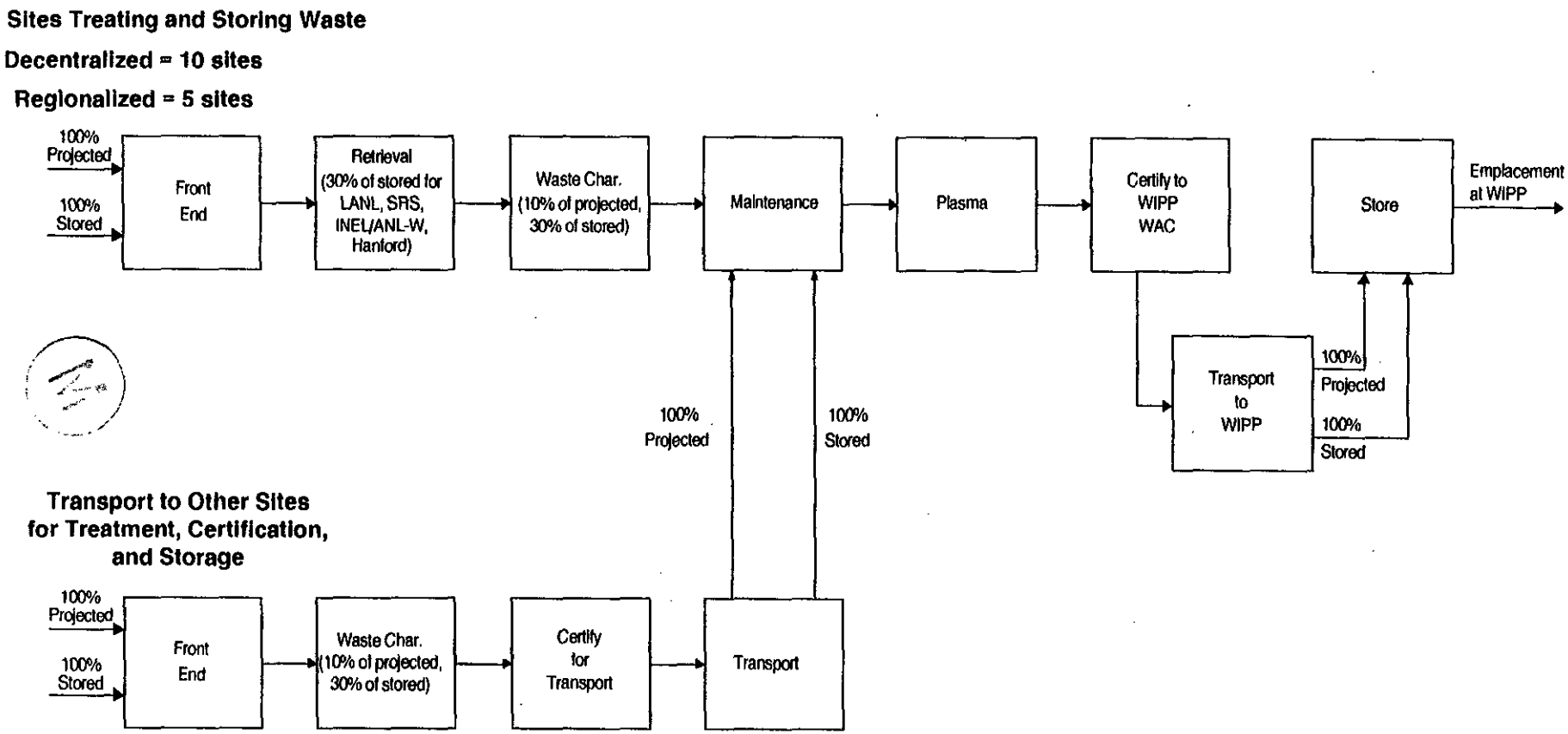

Alternative ID# 10

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure P-5

Decentralized and Regionalized Alternative ID# 10 Contact Handled Process Flow Diagram D

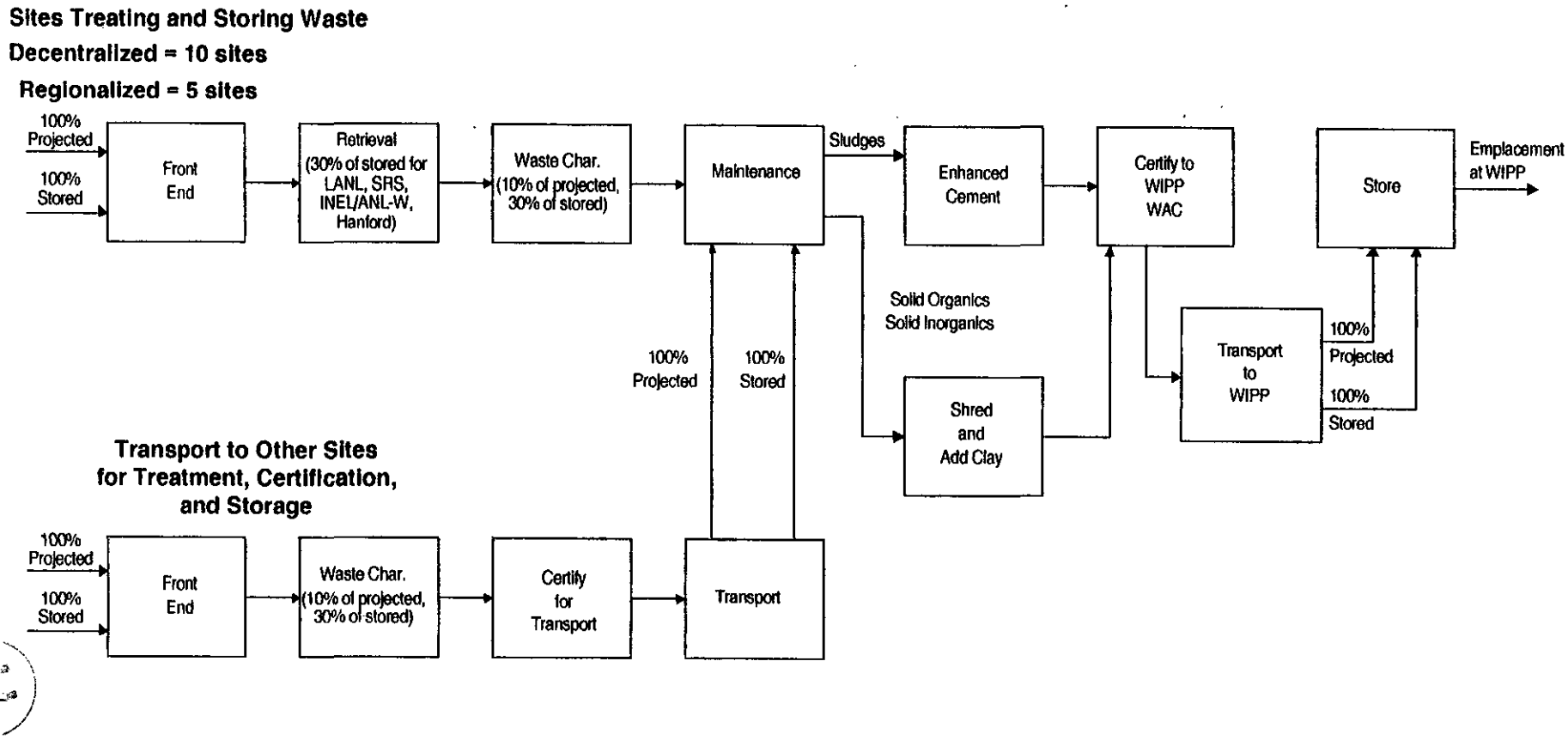

Alternative ID# 94(a-f)

Sludges:	Enhanced Cement
Solid Inorganics:	Shred and Add Clay
Solid Organics:	Shred and Add Clay

Figure P-6

Decentralized and Regionalized Alternative ID# 94(a-f) Contact Handled Process Flr Diagram E

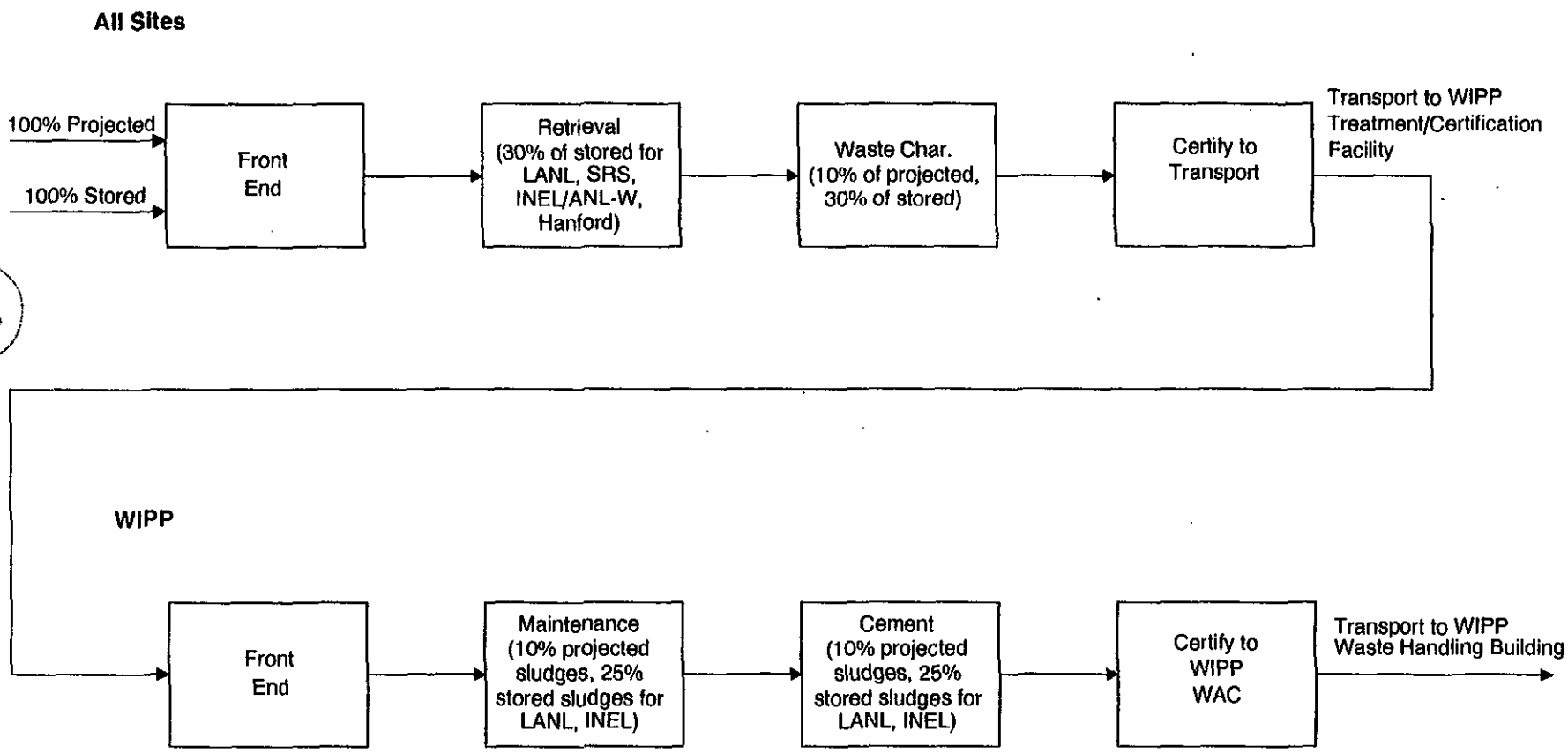

Figure P-7

Centralized Base Case and Alternative ID #s 33, 35(a&b), 83, and 111 Contact Handled Process Flow Diagram F

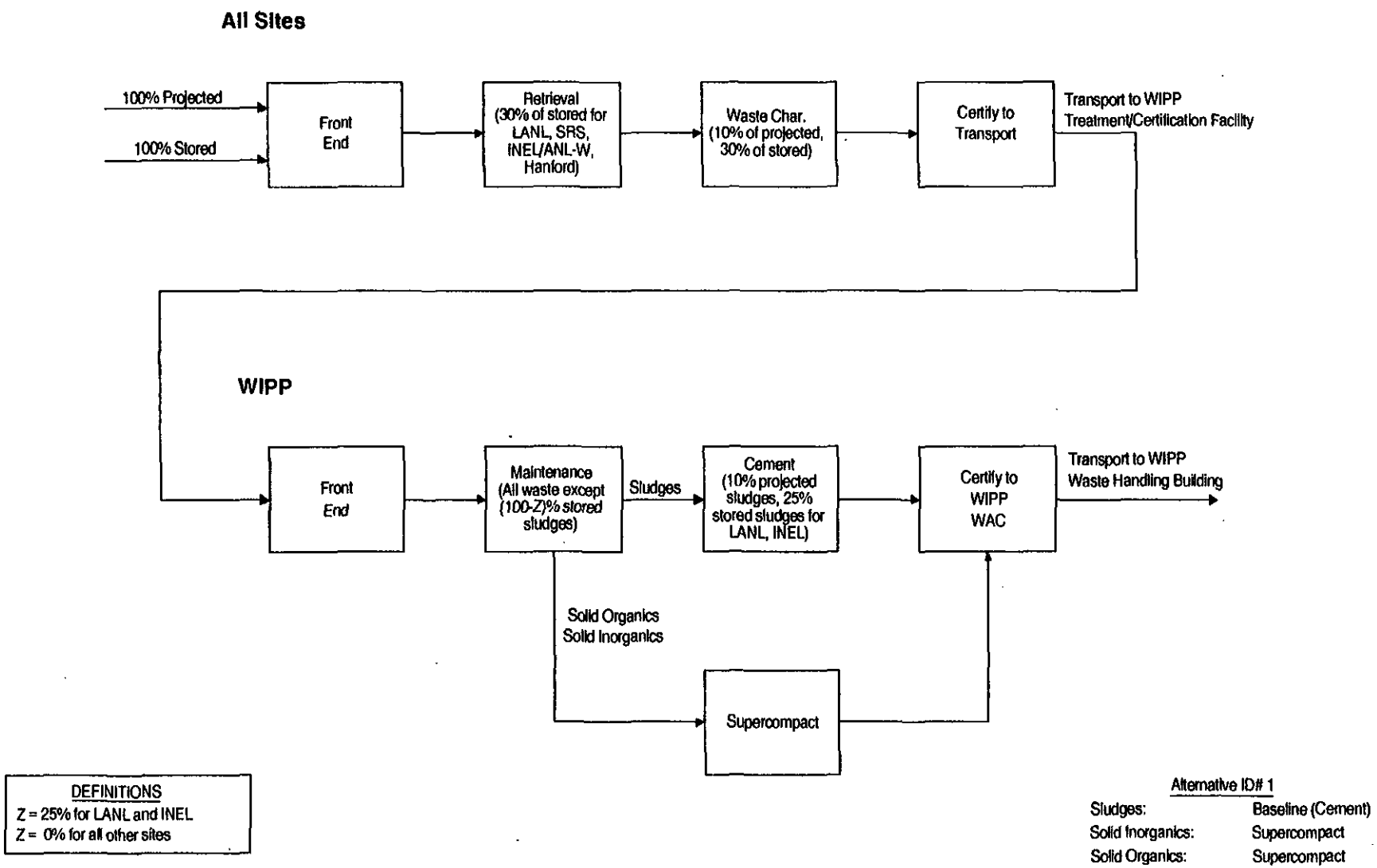

Figure P-8

Centralized Alternative ID#s 1 and 77(a-d) Contact Handled Process Flow Diagram G

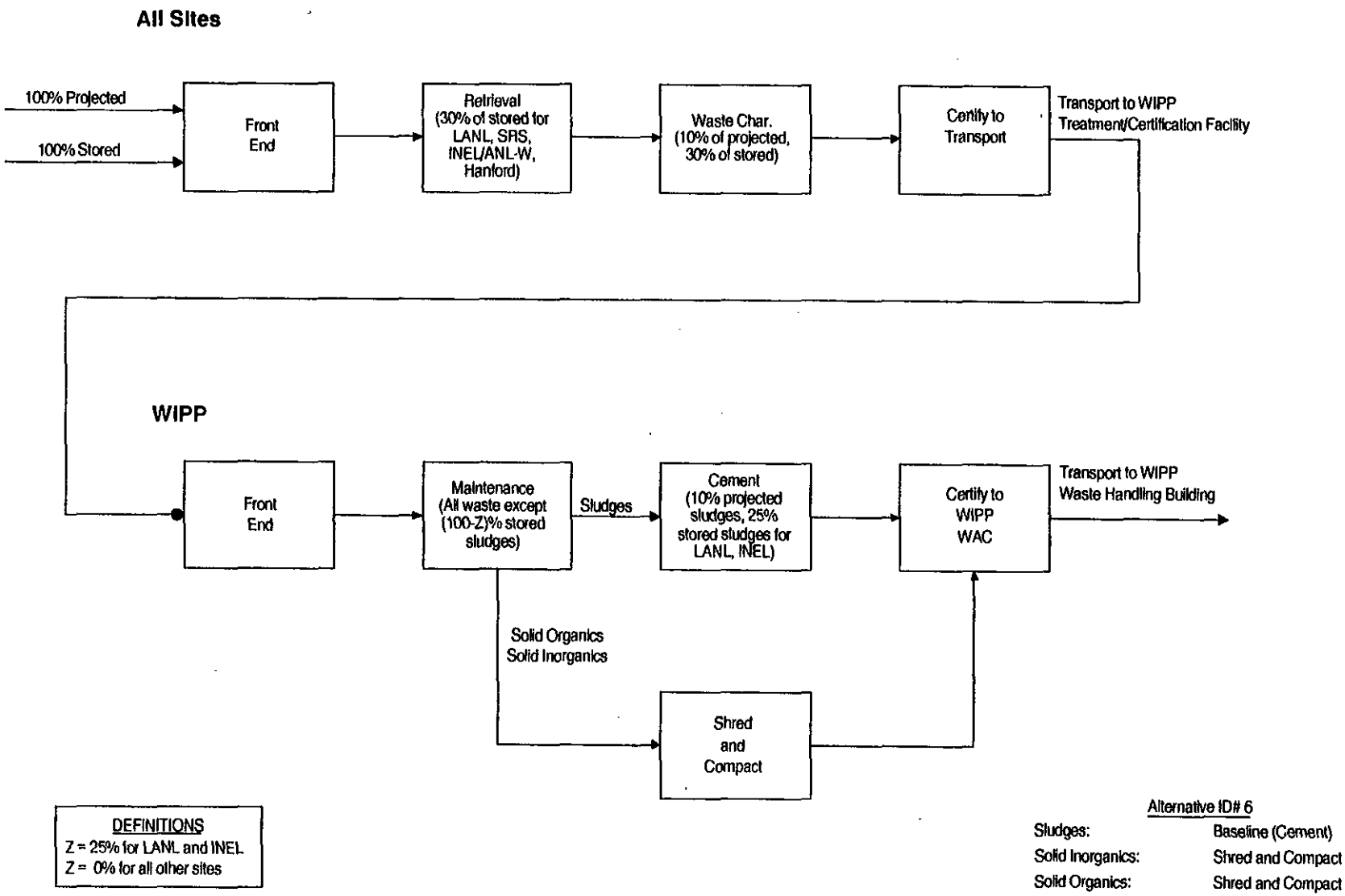

Figure P-9
Centralized Alternative ID# 6 Contact Handled Process Flow Diagram H

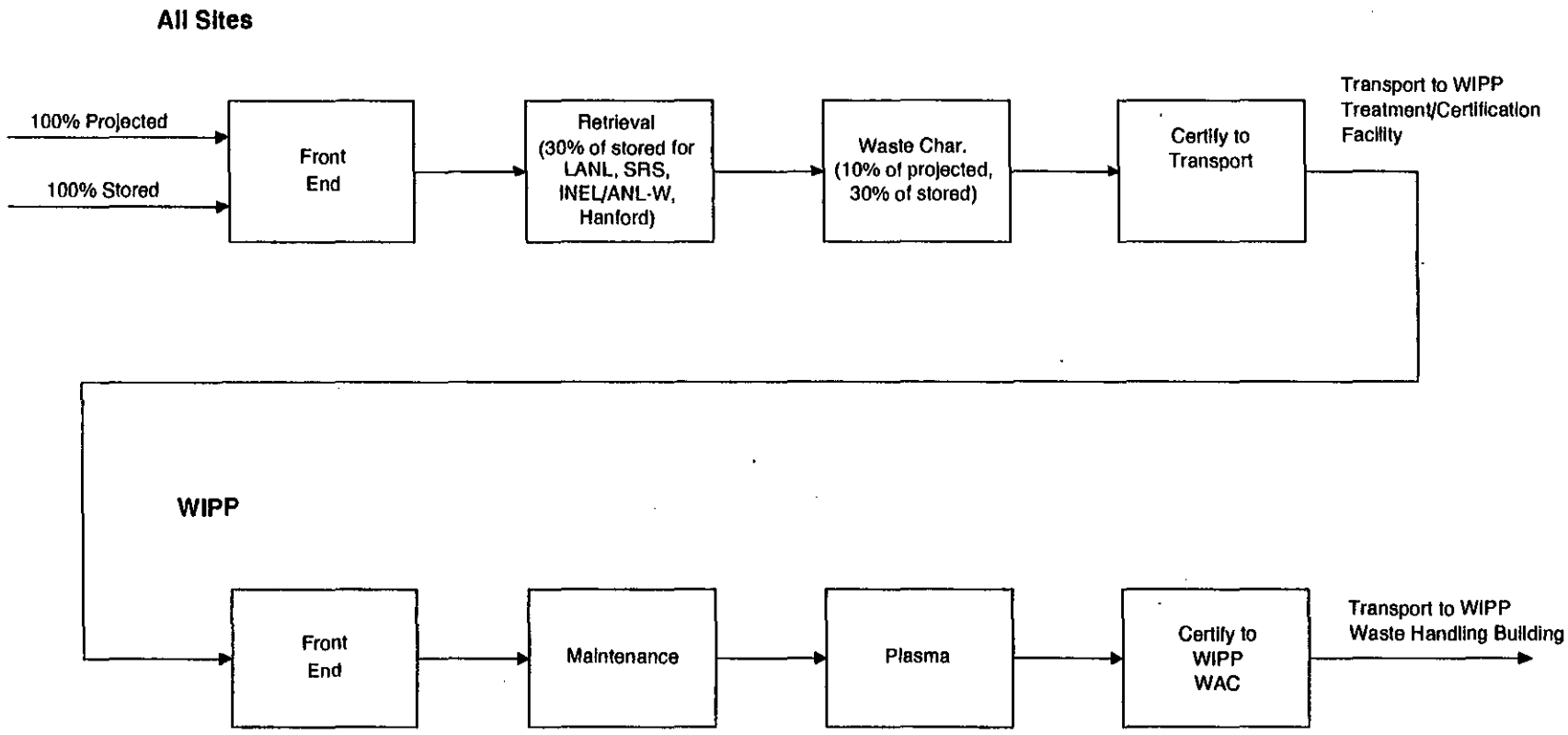

Alternative ID# 10

Sludges:	Plasma
Solid Inorganics:	Plasma
Solid Organics:	Plasma

Figure P-10

Centralized Alternative ID# 10 Contact Handled Process Fl· ·Diagram I

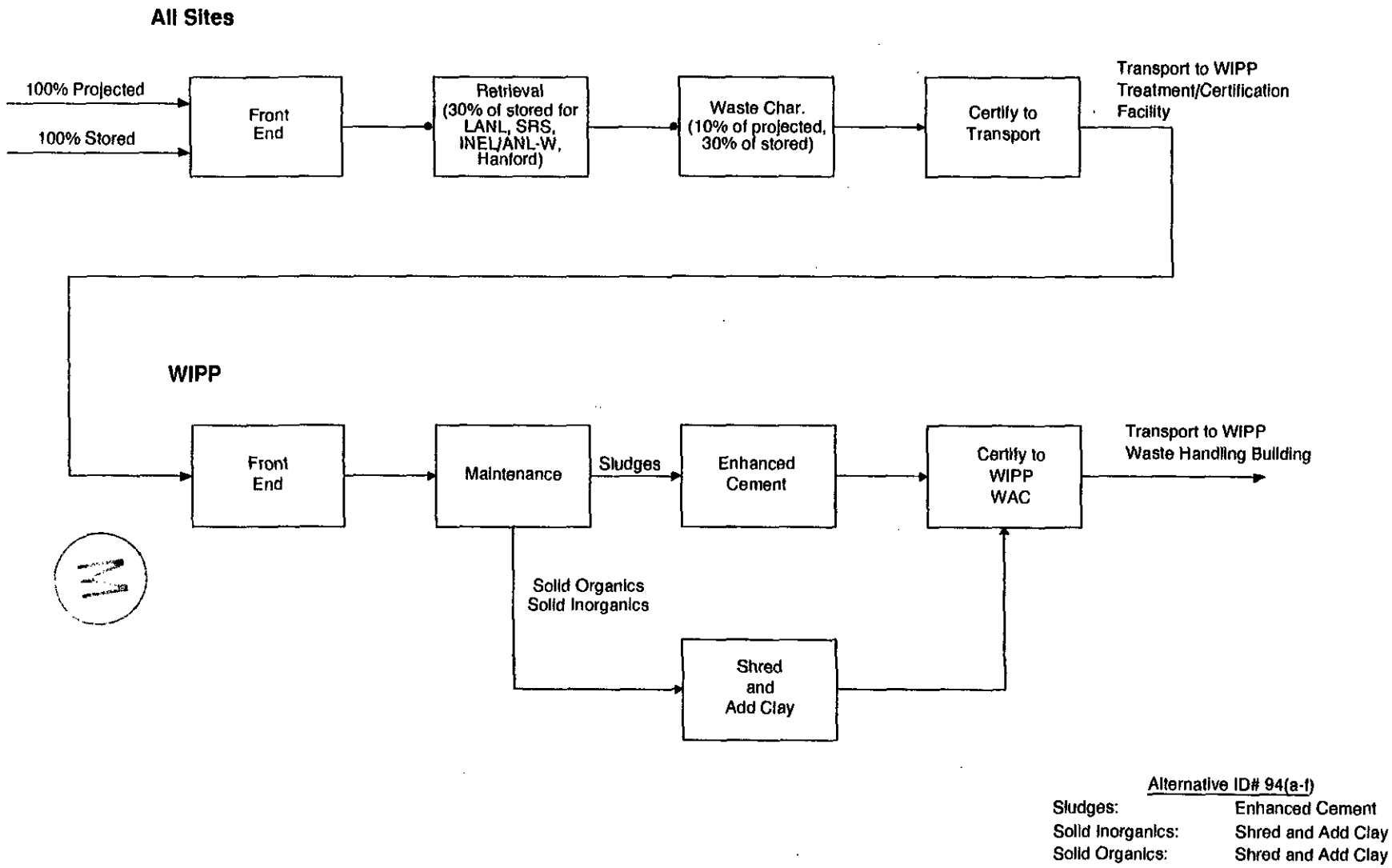

Figure P-11
Centralized Alternative ID# 94(a-f)
Process Flow Diagram J

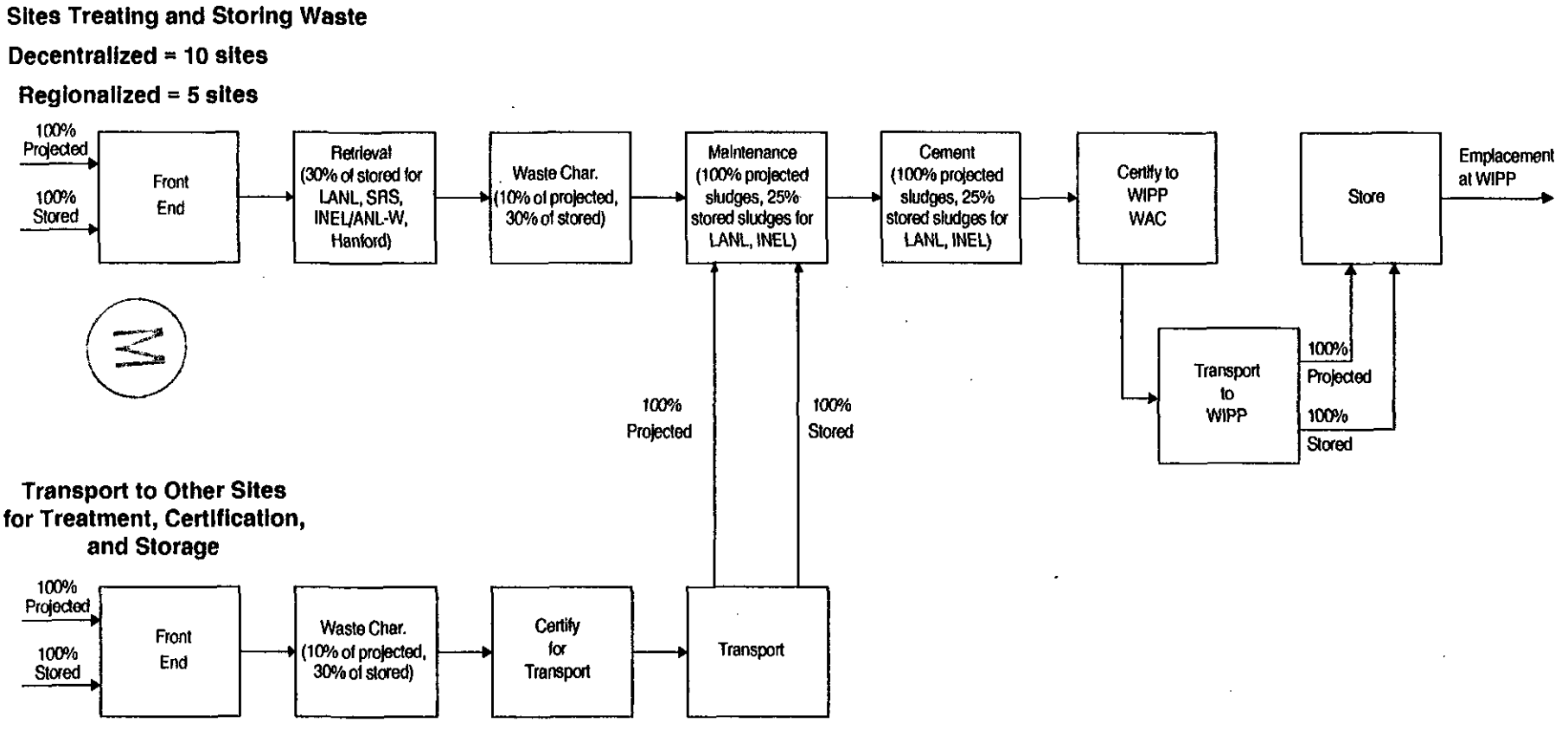

Figure P-12
Decentralized Base Case Remote Handled Process Flow Diagram K

Final Report of the Engineered Alternatives Task Force" (DOE, 1991), the Draft Environmental Management Programmatic Environmental Impact Statement (EM-PEIS) report (DOE, 1995b), and the WMFCITRUW report (Feizollahi and Shropshire, 1994). Information from these sources were used to connect each of the modules and to construct a visual description of mass and volume flow through each treatment process.

The modules are described below:

- Front End: Front-end support facilities consist of all administrative and laboratory buildings required for the waste management support functions. Front-end support functions include security, personnel decontamination (radioactive and hazardous), maintenance of noncontaminated areas and equipment, health physics, radiation badges, facility access control, sanitary facilities, work control and personnel support, internal and external communications, spill or emergency response provisions (hazardous and radioactive), analytical laboratory, environmental field sampling, environmental regulatory reporting, and records management.

- Retrieval: This module consists of all-weather excavation, inspection, and repackaging of bermed waste. The module includes three principal unit operations: earthen-cover extraction and decontamination, waste-container retrieval and inspection, and packaging and staging for shipment.

- Waste Characterization: This module is a self-contained facility in which waste characterization is performed. Activities include extracting physical samples of waste; conducting chemical, physical, and radiological analysis of waste samples; and repackaging drums and boxes to remove and stabilize noncompliant waste.

- Maintenance: A maintenance facility is used in conjunction with treatment facilities. It consists of a failed-equipment receiving and repair building housing machinery and tools.

- Treatment: The treatment module varies based on the alternative being considered. Treatment options include grouting, supercompacting, shredding and compacting, plasma melting, enhanced-cement processing, and shredding and adding clay.

- Storage: This module consists of a Resource Conservation and Recovery Act (RCRA)-compliant storage building sized to accommodate an accumulation of up to 20 years' volume of waste input from treatment modules. Storage area features include spill collection, sloping floors, sumps, and concrete berms. Monitoring is included for both gamma and alpha radiation control.

- Certification: Certification consists of storage of incoming material, assay and certification, and truck loading. The facility is equipped with a bridge crane and a forklift. It is assumed that certification operations will take place indoors.

- Transportation: Transportation consists of truck shipments. Equipment includes a tractor and trailer transporting three Transuranic Package Transporter-II (TRUPACT-IIs) for contact-handled (CH) waste or one remote-handled (RH) cask (RH-72B) (a cylinder consisting of a separate inner canister within an outer cask protected by impact limiters at each end) for RH waste.

The process flow diagrams are developed from multiple data sources, and TRU waste processing knowledge from various sources; therefore, the uncertainty of the process flow diagrams cannot be quantified, but should be in the same order of magnitude as the documents used as guidelines for this study. The process flow diagrams developed for this study were designed mostly in accordance with the EM-PEIS and the WMFCITRUW report; however, not every module recommended in the WMFCITRUW report was included in this study. The reasons for deviating from the recommended WMFCITRUW guidance include (1) minimizing the costs of duplicate equipment contained in more than one module, and (2) more accurately representing the functions in existing and planned TRU waste facilities.

Mass and volume throughput are calculated using data from the Waste Isolation Pilot Plant (WIPP) Transuranic Waste Baseline Inventory Report (BIR) (DOE, 1995d). These rates are calculated using a 20-year processing period and a 4,032-hour working year. The mass or volume input to each of the individual modules is shown in Appendix O and is used as the basis for the module throughput which is the primary data used to estimate the cost of the module.

"The TRU waste disposal inventory in the BIR is derived from existing information on waste, which has been provided by DOE TRU waste generator/storage sites and is predominately based on process knowledge" (DOE, 1995d). Any uncertainty within the BIR is carried into this EA study. Calculated processing rates using a 20-year period and 4,032-hour working year may also introduce a level of uncertainty in estimating the costs. Many of the calculated processing rates were below or beyond the range of processing rates listed in the WMFCITRUW report and may cause the calculated costs to be skewed.

Numerical data values for cost versus flow rate information were obtained from the authors of the WMFCITRUW and used to construct approximate relations or curve fits for cost versus mass or volume throughput for a specific processing module, as shown in Figures P-13 through P-23. Cost data are available in the WMFCITRUW report according to specific project activities including pre-operations (pre-ops), planning life-cycle cost (PLCC), construction, operations and maintenance (O&M), and decontamination and decommissioning (D&D). Appendix P provides additional information on the method for establishing the modules. The PLCC is the summation of pre-ops, construction, O&M and D&D cost.

The WMFCITRUW was developed specifically to calculate facility costs in the EM-PEIS. Neither the WMFCITRUW nor the EM-PEIS provide a quantitative uncertainty of the costing data. From the costing categories listed in Plant Design and Economics for Chemical Engineers (Peters et al., 1991), the WMFCITRUW study cost estimates fall into the Study Estimate cost category where the probable accuracy of the estimate is plus or minus 30 percent.
To ensure that the waste processing cost estimates presented in this study account for those facilities that currently exist, a list of existing facilities was assembled from information gathered from several sources, including personal communications (Bjotvedt, 1995; George, 1995) and preliminary information being developed by the DOE National TRU Program Office. Data from these sources were consolidated into a single list used to describe existing TRU waste processing

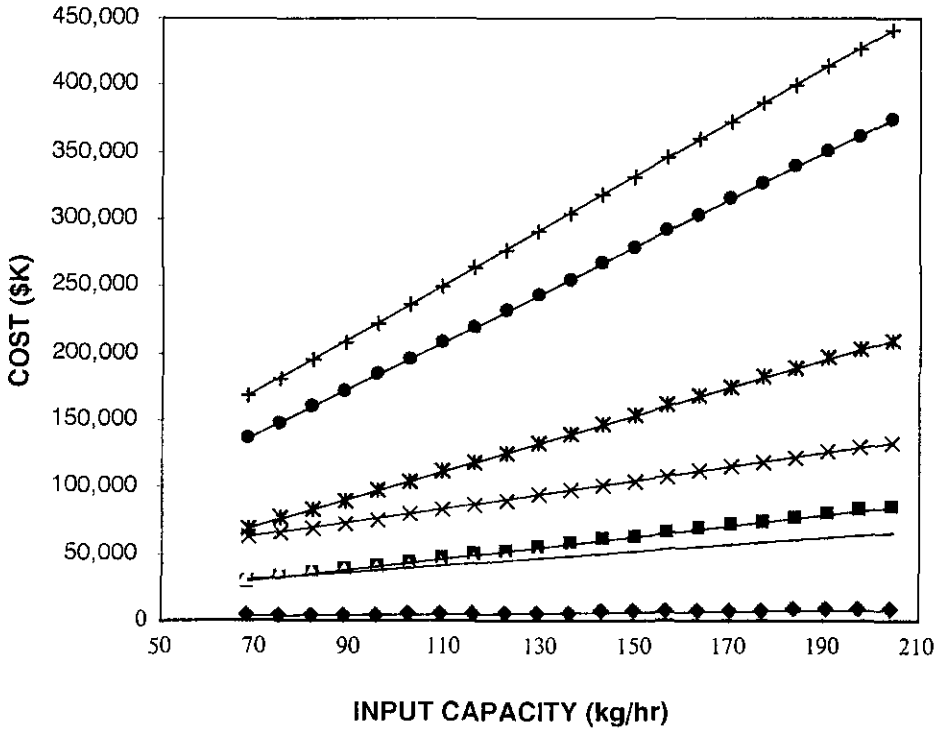

LEGEND

- ● 1.0 PRE-OPERATIONS
  y = 39.957x + 1603.4
  R^2= 1
- ■ 2.0 CONSTRUCTION
  y = 410.93x + 2820.7
  R^2= 1
- 3.0 O & M 10 years
  y = 260.51x + 13871
  R^2= 1
- × 3.0 O & M 20 years
  y = 521.02x + 27742
  R^2= 1
- ✱ 4.0 D & D
  y = 1035.7x - 3E-10
  R^2= 1
- ● TOTAL PLCC (10 yr)
  y = 1747.1x + 18295
  R^2= 1
- + TOTAL PLCC (20 yr)
  y = 2007.6x + 32166
  R^2= 1

——Linear (TOTAL PLCC (20 yr) $K)

——Linear (TOTAL PLCC (10 yr) $K)

------Linear (4.0 D&D)

——Linear (3.0 O& M 20 years)

——Linear (2.0 Const)

——Linear (3.0 O& M 10 years)

——Linear (1.0 Pre-Ops)

Figure P-13
CH-RH Retrieval

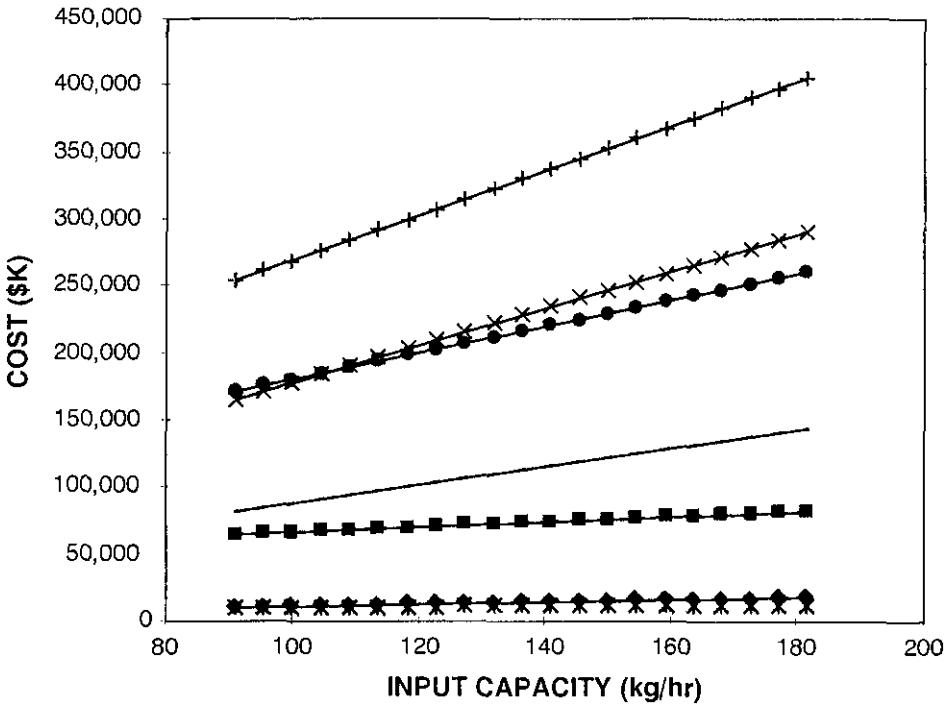

LEGEND

◆ 1.0 PRE-OPERATIONS
y = 81.515x + 4188.3

■ 2.0 CONSTRUCTION
y = 200.17x + 47294
$R^2 = 1$

3.0 O& M
10 years
y = 691x + 20625
$R^2 = 1$

× 3.0 O& M
20 years
y = 1382x + 41250
$R^2 = 1$

✱ 4.0 D&D
y = 12.555x + 10374
$R^2 = 1$

● TOTAL PLCC (10 yr)
$K
y = 1676.3x + 103106
$R^2 = 1$

+ TOTAL PLCC (20 yr)
$K
y = 985.25x + 82481
$R^2 = 1$

—— Linear (TOTAL PLCC (20 yr) $K)

—— Linear (TOTAL PLCC (10 yr) $K)

—— Linear (3.0 O& M 10 years)

—— Linear (2.0 Const)

—— Linear (1.0 Pre-Ops)

—— Linear (4.0 D&D)

—— Linear (3.0 O& M 20 years)

Figure P-14
Waste Characterization

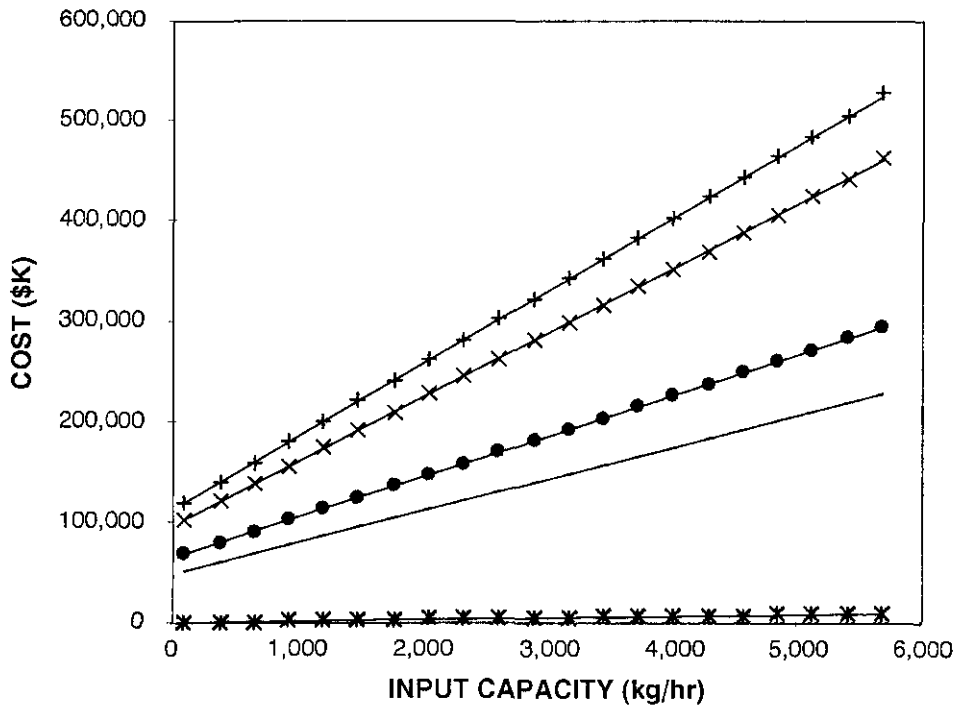

LEGEND

3.0 O& M
10 years
y = 31.836x + 49523
R^2 = 1

× 3.0 O& M
20 years
y = 63.673x + 99046
R^2 = 1

✱ 4.0 D&D
y = 1.5643x + 2136.6
R^2 = 1

● TOTAL PLCC (10 yr)
$K
y = 40.578x + 65777
R^2 = 1

+ TOTAL PLCC (20 yr)
$K
y = 72.415x + 115300
R^2 = 1

—— Linear (TOTAL PLCC (20 yr)
$K)

—— Linear (3.0 O& M
20 years)

—— Linear (TOTAL PLCC (10 yr)
$K)

—— Linear (3.0 O& M
10 years)

—— Linear (4.0 D&D)

Figure P-15
CH-RH Front End Support (TADMIN)

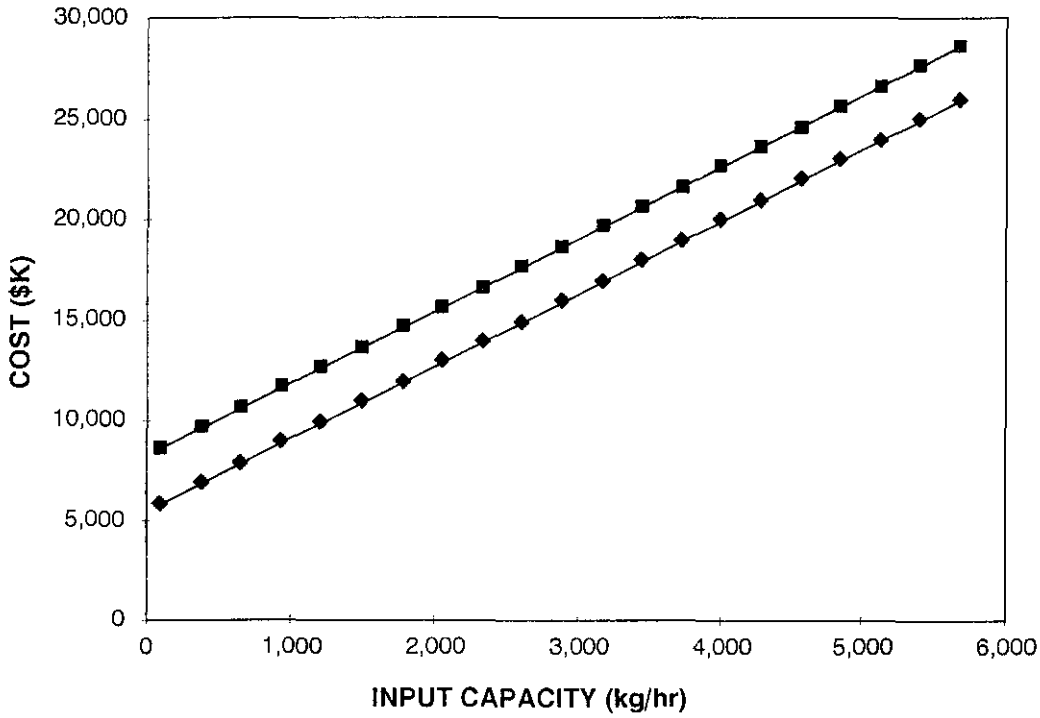

LEGEND

◆ 1.0 PRE-OPERATIONS
y = 3.6004x + 5679.6
R^2 = 1

■ 2.0 CONSTRUCTION
y = 3.5771x + 8437.9
R^2 = 1

——Linear (2.0 Const)
——Linear (1.0 Pre-Ops)

M

Figure P-16
CH-RH (TADMIN)

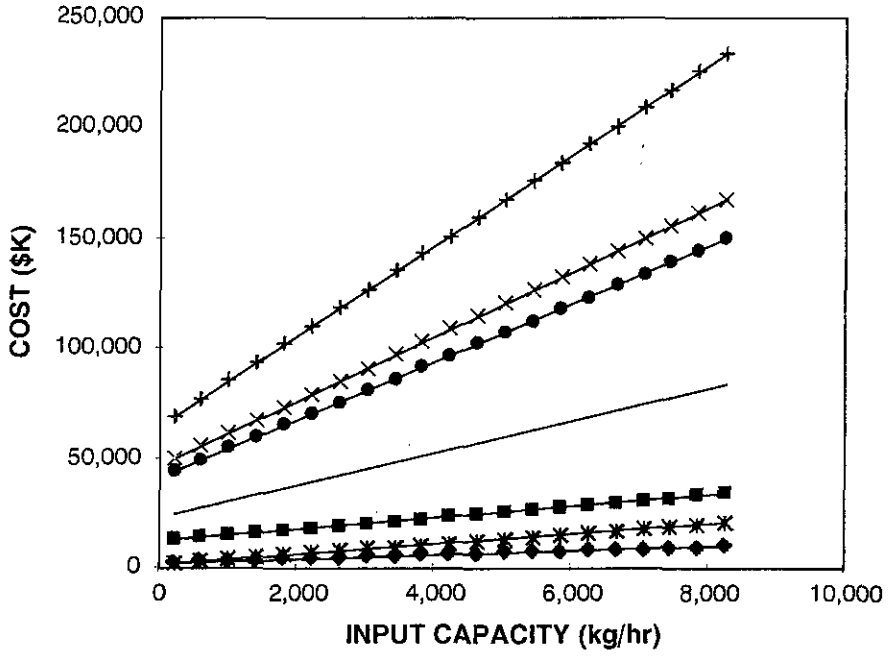

LEGEND

◆ 1.0 PRE-OPERATIONS
y = 0.878x + 2969.1
$R^2 = 1$

■ 2.0 Const
y = 2.6672x + 12644
$R^2 = 1$

3.0 O& M
10 years
y = 7.3151x + 23831
$R^2 = 1$

× 3.0 O& M
20 years
y = 14.63x + 47661
$R^2 = 1$

✱ 4.0 D&D
y = 2.2816x + 2395.4
$R^2 = 1$

● TOTAL PLCC (10 yr)
$K
y = 13.142x + 41839
$R^2 = 1$

+ TOTAL PLCC (20 yr)
$K
y = 20.457x + 65670
$R^2 = 1$

—— Linear (TOTAL PLCC (20 yr) $K)

—— Linear (3.0 O& M 20 years)

—— Linear (TOTAL PLCC (10 yr) $K)

—— Linear (3.0 O& M 10 years)

—— Linear (2.0 Const)

—— Linear (4.0 D&D)

—— Linear (1.0 Pre-Ops)

Figure P-17
CH-RH Certify and Ship

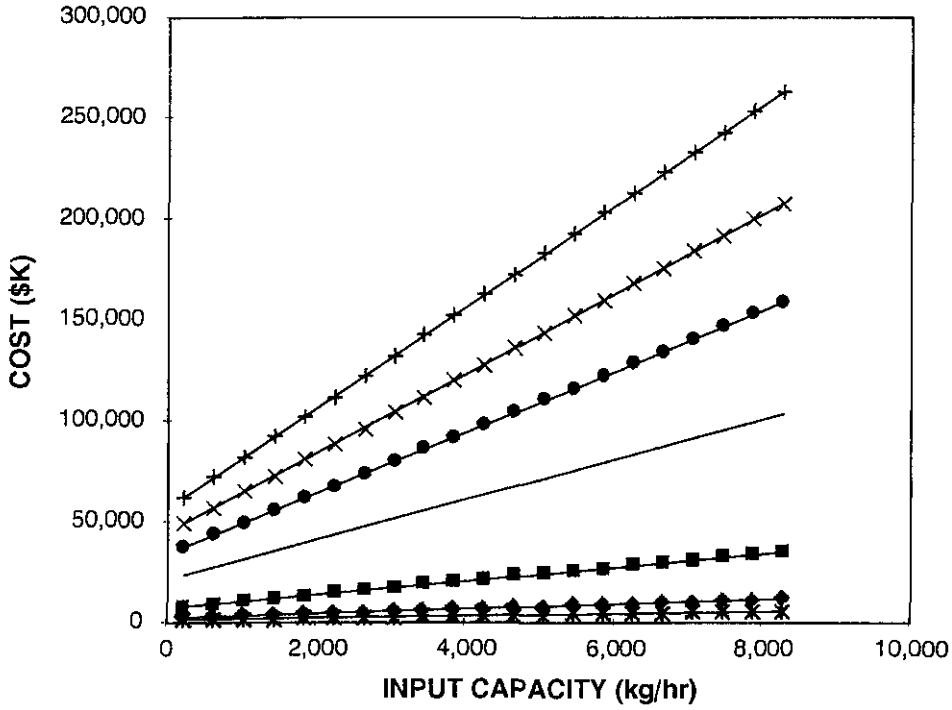

LEGEND

- ◆ 1.0 PRE-OPERATIONS
  y = 1.181x + 2724.3
  R^2= 1
- ■ 2.0 CONSTRUCTION
  y = 3.458x + 7922
- 3.0 O& M
  10 years
  y = 9.8717x + 22786
  R^2= 1
- × 3.0 O& M
  20 years
  y = 19.743x + 45572
  R^2= 1
- ✱ 4.0 D&D
  y = 0.6254x + 1592
  R^2= 1
- ● TOTAL PLCC (10 yr)
  $K
  y = 15.136x + 35024
  R^2= 1
- + TOTAL PLCC (20 yr)
  $K
  y = 25.008x + 57811
  R^2= 1

——Linear (TOTAL PLCC (20 yr) $K)

——Linear (3.0 O& M 20 years)

——Linear (TOTAL PLCC (10 yr) $K)

——Linear (3.0 O& M 10 years)

——Linear (2.0 Const)

——Linear (1.0 Pre-Ops)

——Linear (4.0 D&D)

Figure P-18
CH-RH Maintenance

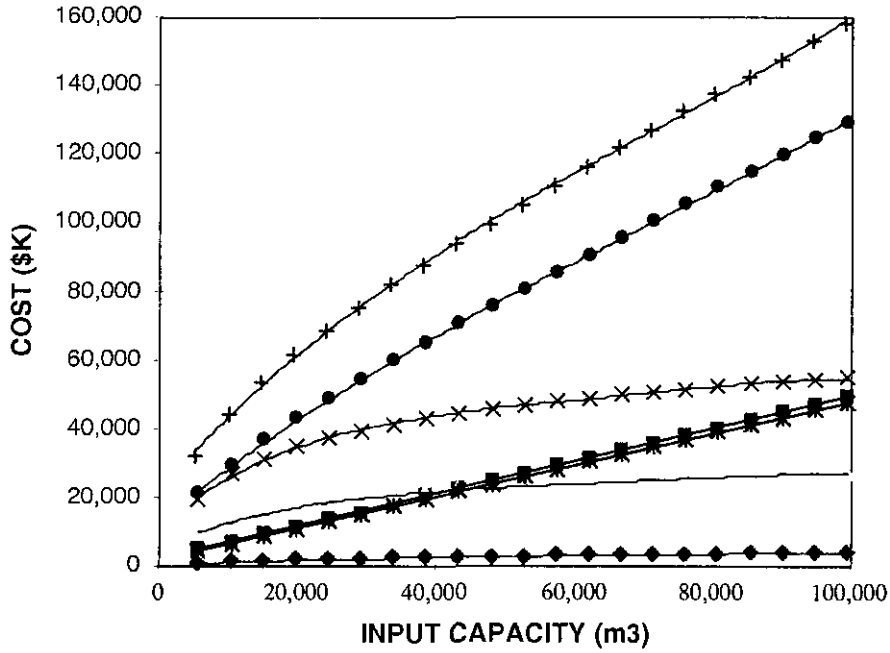

LEGEND

◆ 1.0 PRE-OPERATIONS
$y = -7.905E\text{-}17^4x + 2.058E\text{-}11^4x - 1.997E\text{-}06^2x + 1.095E\text{-}01x + 7.279E+02$
$R^2 = 9.995E\text{-}01$

■ 2.0 CONSTRUCTION
$y = 0.4628x + 2222.5$
$R^2 = 1$

3.0 O& M
10 years
$y = 0.4715x + 2753$
$R^2 = 1$

× 3.0 O& M
20 years
$y = -1.437E\text{-}15^4x - 3.631E\text{-}05^3x + 3.743E\text{-}10^2x + 1.756E+00x + 1.186E+04$
$R^2 = 9.985E\text{-}01$

✱ 4.0 D&D
$y = -7.186E\text{-}16^4x + 1.871E\text{-}10^3x - 1.816E\text{-}05^2x + 8.778E\text{-}01x + 5.929E+03$
$R^2 = 9.985E\text{-}01$

● TOTAL PLCC (10 yr)
$K
$y = 4.012E\text{-}11^3x - 8.584E\text{-}06^2x + 1.631E+00x + 1.358E+04$
$R^2 = 9.998E\text{-}01$

+ TOTAL PLCC (20 yr)
$K
$y = 7.626E\text{-}11^3x - 1.632E\text{-}05x^2 + 2.247E+00x + 2.126E+04$
$R^2 = 9.996E\text{-}01$

——Poly. (TOTAL PLCC (20 yr) $K)

——Linear (4.0 D&D)

——Poly. (TOTAL PLCC (10 yr) $K)

——Poly. (3.0 O& M 10 years)

——Poly. (3.0 O& M 20 years)

——Poly. (1.0 Pre-Ops)

——Linear (2.0 Const)

Figure P-19
CH-RH Storage

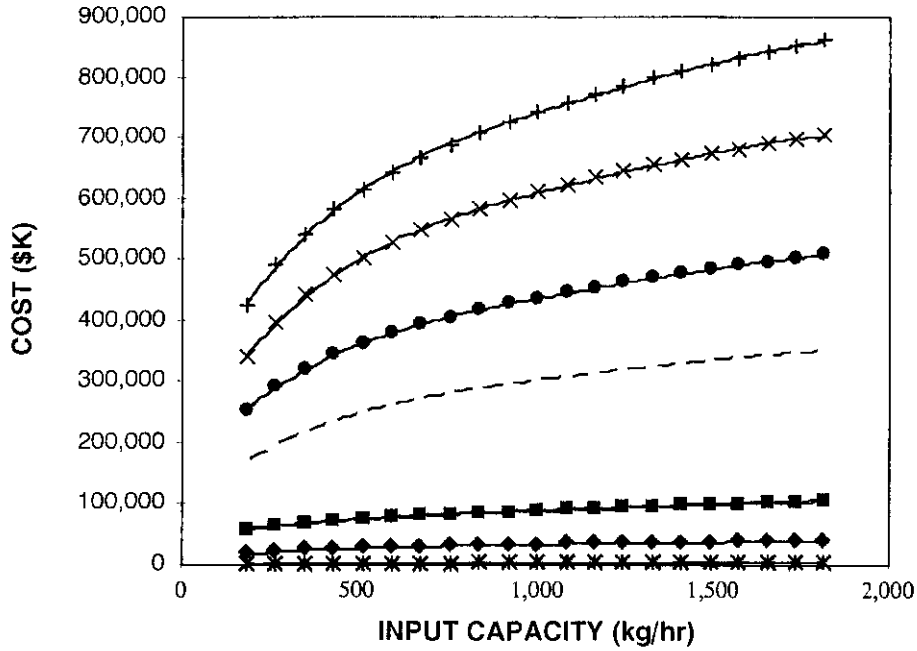

LEGEND

◆ 1.0 PRE-OPERATIONS
$y = -5.890E-09^4x + 2.963E-05^3x - 5.700E-02^2x + 5.747E+01x + 1.195E+04$
$R^2 = 9.997E-01$

■ 2.0 CONSTRUCTION
$y = -8.831E-09^4x + 4.443E-05^3x - 8.547E-02^2x + 9.580E+01x + 4.519E+04$
$R^2 = 9.998E-01$

3.0 O& M
10 years
$y = -5.133E-08^4x + 2.583E-04^3x - 4.968E-01^2x + 4.985E+02x + 9.730E+04$
$R^2 = 9.996E-01$

× 3.0 O& M
20 years
$y = -1.027E-07^4x + 5.166E-04^3x9.937E-01^2x + 9.970E+02x + 1.946E+05$
$R^2 = 9.996E-01$

✱ 4.0 D&D
$y = 1.6149x + 3941.1$
$R^2 = 1$

● TOTAL PLCC (10 yr)
$K
$y = -6.605E-08^4x + 3.323E-04^3x - 6.393E-01^2x + 6.534E+02x + 1.584E+05$
$R^2 = 9.997E-01$

+ TOTAL PLCC (20 yr)
$K
$y = -1.174E-07^4x + 5.906E-04^3x - 1.136E+00^2x + 1.152E+03x + 2.557E+05$
$R^2 = 9.997E-01$

——Poly. (TOTAL PLCC (20 yr) $K)
——Poly. (3.0 O& M 20 years)
——Poly. (TOTAL PLCC (10 yr) $K)
——Poly. (3.0 O& M 10 years)
——Poly. (2.0 Const)
——Poly. (2.0 Const)
——Poly. (1.0 Pre-Ops)
——Linear (4.0 D&D)

Figure P-20
CH Cement

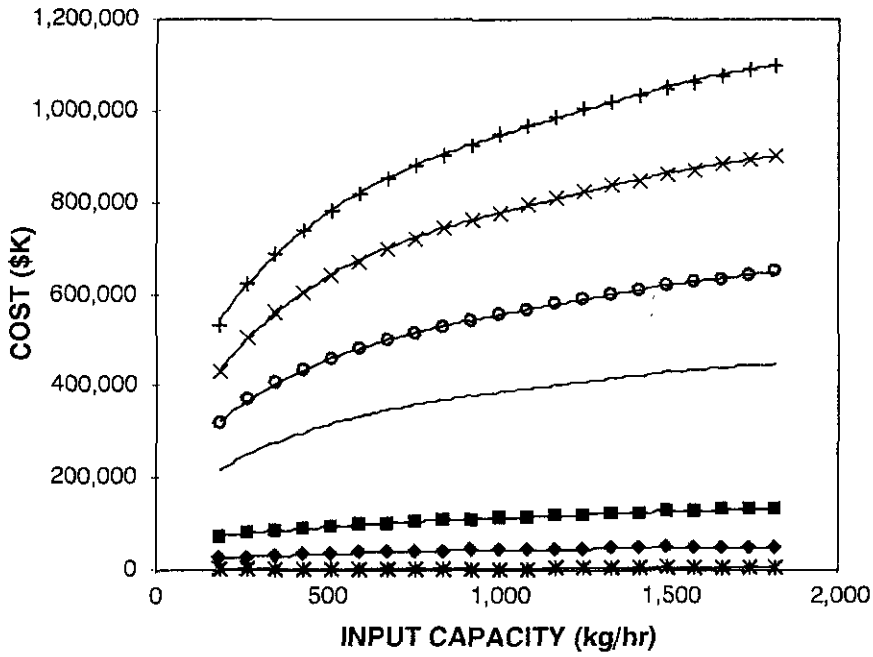

LEGEND

◆ 1.0 PRE-OPERATIONS
$y = -7.612E-09^4x + 3.830E-05^3x - 7.367E-02^2x + 7.427E+01x + 1.489E+04$
$R^2 = 9.996E-01$

■ 2.0 CONSTRUCTION
$y = 1.226E-05^3x - 5.104E-02^2x + 9.489E+01x + 6.073E+04$
$R^2 = 9.991E-01$

3.0 O& M
10 years
$y = -6.625E-08^4x + 3.333E-04^3x - 6.412E-01^2x + 6.434E+02x + 1.214E+05$
$R^2 = 9.996E-01$

× 3.0 O& M
20 years
$y = -1.325E-07^4x + 6.667E-04^3x - 1.282E+00^2x + 1.287E+03x + 2.428E+05$
$R^2 = 9.996E-01$

✱ 4.0 D&D
$y = 1.9412x + 4832.6$
$R^2 = 1$

o TOTAL PLCC (10 yr.)
$K
$y = -8.57E-08^4x + 4.31E-04^3x - 8.29E-01^2x + 8.47E+02x + 1.97E+05$
$R^2 = 1.00E+00$

+ TOTAL PLCC (20 yr.)
$K
$y = -1.519E-07^4x + 7.643E-04^3x - 1.470E+00^2x + 1.490E+03x + 3.184E+05$
$R^2 = 9.997E-01$

——Poly. (TOTAL PLCC (20 yr.) $K)
——Poly. (3.0 O& M 20 years)
——Poly. (TOTAL PLCC (10 yr.) $K)
——Poly. (3.0 O& M 10 years)
——Poly. (2.0 Const)
——Poly. (1.0 Pre-Ops)
——Linear (4.0 D&D)

Figure P-21
RH Cement Grout

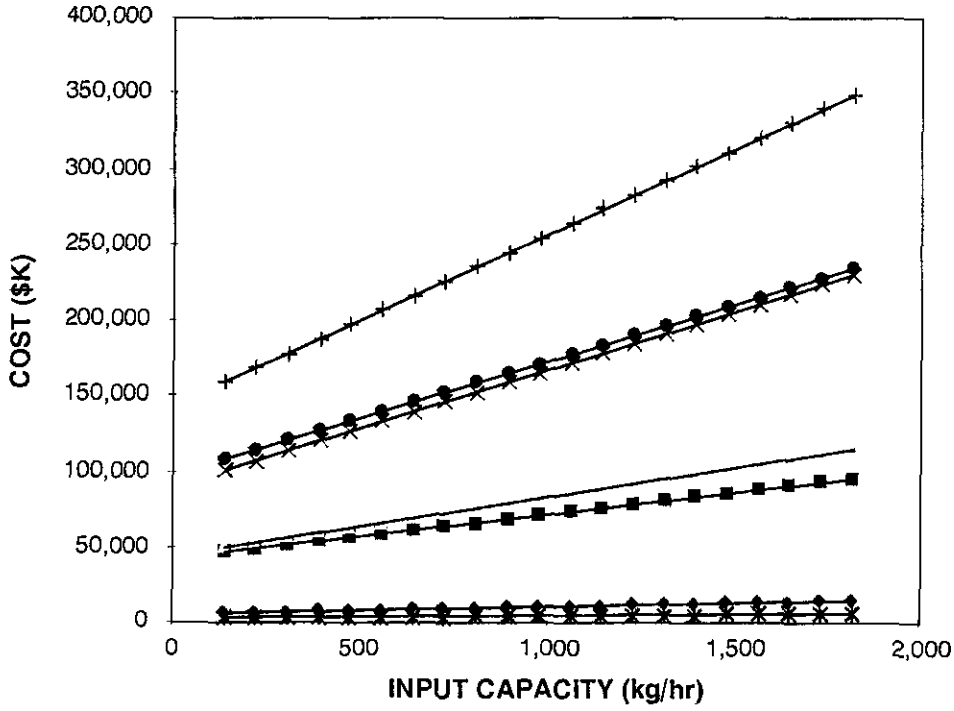

LEGEND

- ◆ 1.0 PRE-OPERATIONS
  y = 5.0482x + 6231.2
  R^2 = 1
- ■ 2.0 CONSTRUCTION
  y = 29.447x + 43598
  R^2 = 1
- 3.0 O& M
  10 years
  y = 38.531x + 45748
  R^2 = 1
- × 3.0 O& M
  20 years
  y = 77.062x + 91496
  R^2 = 1
- ✱ 4.0 D&D
  y = 2.0512x + 3408.2
  R^2 = 1
- ● TOTAL PLCC (10 yr)
  $K
  y = 75.077x + 98986
  R^2 = 1
- + TOTAL PLCC (20 yr)
  $K
  y = 113.61x + 144734
  R^2 = 1

- —— Linear (TOTAL PLCC (20 yr) $K)
- —— Linear (TOTAL PLCC (10 yr) $K)
- —— Linear (3.0 O& M 20 years)
- —— Linear (3.0 O& M 10 years)
- —— Linear (2.0 Const)
- —— Linear (1.0 Pre-Ops)
- —— Linear (4.0 D&D)

Figure P-22
CH Compact

CH VITRIFICATION (PLASMA)

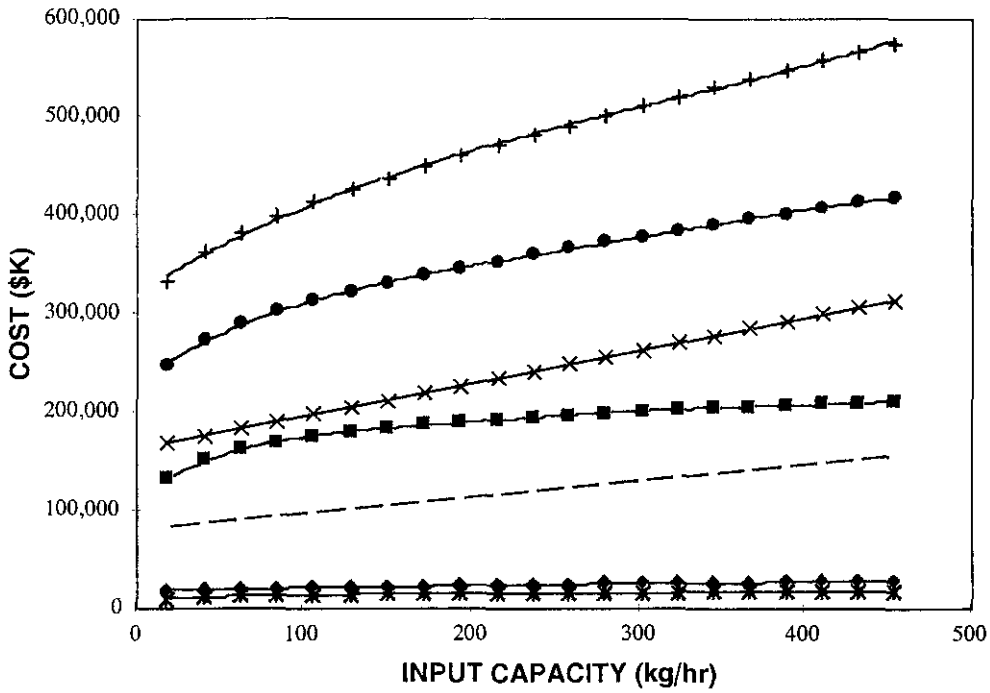

LEGEND

◆ 1.0 PRE-OPERATIONS
$y = -0.0122^2x + 28.113x + 19882$
$R^2 = 0.9987$

■ 2.0 CONSTRUCTION
$y = 4.233E\text{-}08^3x - 5.855E\text{-}05^4x + 3.112E\text{-}02^3x - 8.093E+00^3x + 1.155E+03x + 1.157E+05$
$R^2 = 9.991E\text{-}01$

3.0 O& M 10 years
10 years
$y = 167.24x + 82022$
$R^2 = 1$

× 3.0 O& M 20 years
20 years
$y = 334.48x + 164045$
$R^2 = 1$

✱ 4.0 D&D
$y = 3.943E\text{-}09^5x - 5.454E\text{-}06^4x + 2.899E\text{-}03^3x - 7.538E\text{-}01^2x + 1.075E+02x + 9.789E+03$
$R^2 = 9.991E\text{-}01$

● TOTAL PLCC (10 yr)
$K
$y = -9.666E\text{-}06^4x + 1.119E\text{-}02^3x - 4.763E+00^2x + 1.168E+03x + 2.329E+05$
$R^2 = 9.993E\text{-}01$

+ TOTAL PLCC (20 yr)
$K
$y = 2.073E\text{-}03^3x - 1.965E+00^2x + 1.030E+03x + 3.232E+05$
$R^2 = 9.988E\text{-}01$

—— Poly. (TOTAL PLCC (20 yr) $K)
—— Poly. (TOTAL PLCC (10 yr) $K)
—— Linear (3.0 O& M 20 years)
—— Poly. (2.0 Const)
—— Linear (3.0 O& M 10 years)
—— Poly. (4.0 D&D)
—— Poly. (1.0 Pre-Ops)

Figure P-23
CH Vitrification (Plasma)

facilities for this study, as shown in Table P-1. All of the information sources have not been subject to extensive review, thus uncertainty of the data arises from the uncertainties associated with the sources themselves, and any changes that have occurred between the current time and the time these sources were compiled.

The existing facility list was used to adjust process cost estimates. O&M and D&D costs were added and applied to facilities that had current existing TRU waste processing facilities for a specific module, while the PLCC was applied to facilities that did not have existing processing capabilities for a specific module.

Combining all of the information gathered, computer cost-model programs have been developed using Visual Basic computer programming language and cost equations were applied based on a calculated mass or volume throughput for a specific module. These programs were implemented using a computer spreadsheet with mass and volume throughput data. The computer cost model programs calculate the cost for each processing module for each alternative in each configuration. Summary results for process costs are presented in Section 4.1 of this appendix.

2.2 TRU Waste Transportation Cost Estimation Methodology

This section will supply information on the sources and assumptions used to complete transportation cost estimations for the various EAs.

The guidance chosen for development of transportation cost estimates is based on a report titled "Waste Management Facilities Cost Information for Transportation of Radioactive and Hazardous Materials," co-authored by Fred Feizollahi and David Shropshire of the Idaho National Engineering Laboratory (INEL) (Feizollahi and Shropshire, 1994). This report is also used as guidance for development of transportation cost estimation in the Draft EM-PEIS. The report also covers the procedure for estimating the costs of various types of wastes, including an entire section on RH and CH-TRU waste transportation.

It is important to note that the report does not make an attempt to limit the volume or radionuclides of the waste being transported; all shipments are mass-limited. The report includes only guidance for estimating the cost of transportation of waste; loading and unloading operations are included in the facility operating and maintenance costs.

It is assumed that all CH-TRU waste will be shipped by truck in TRUPACT-II containers, which have weight, volume, and radionuclide restrictions that limit the amount of waste transported in one shipment. Given waste volume and mass data for each of the sites, both mass-limited and volume-limited cases were developed. It was found that the treatment of the weight results in the majority of the shipments will carry waste of sufficiently high density to be mass-limited. The mass limitation of the TRUPACT-II shipments requires that the transportation of the waste be load

managed. The load management of the waste requires that payload scenarios be taken into account for the shipment of TRUPACT-IIs. RH-TRU waste, however, did have limitations on the radionuclide content and the volumes had to be further reduced to meet container and shipping specifications. The number of shipments was ultimately derived by making assumptions not included in the report. It was assumed that a 60/40 split between 55-gallon drums and standard waste boxes would be made (for volume limited shipments). The mass limited shipments required that the waste be packaged into 55-gallon drums to maintain loading efficiency (see Tables P-53 through P-74). Fourteen 55-gallon drums or two standard waste boxes can fit into a TRUPACT-II container. A truck shipment has the capacity for three TRUPACT-II containers. The mass limited shipments varied the number of drums that were shipped from 42 drums to 7 drums per TRUPACT-II. Additionally, the number of TRUPACT-II per shipment varied from 3 to 1.

The planned route and total mileage traveled for each of the shipments is determined by the HIGHWAY 3.3 Routing Model that was prepared by the Oak Ridge National Laboratory for use by DOE. The model is an extensive computerized atlas that determines the optimum route for a given origin and destination. The DOE sites that produce and treat TRU waste are all included, as is the WIPP repository. The program allows the user to place constraints on route choices, and several were invoked in order to choose the most preferred route for TRU waste transportation. Route constraints include the barred use of roads that prohibit truck use, the preferred use of routes already designated for hazardous waste transportation, and the use of roads in New Mexico designated as preferred shipment routes to the WIPP. The model is described in Section 3.5.2 of this report, Methodology Used to Evaluate Factor 5 (Risk of Transportation).

There are three types of costs associated with transportation. Carrier costs and hardware costs are functions of a moving vehicle and are combined to make up the "costs per loaded mile" (CPLM). Carrier costs include tractor, fuel, labor, insurance, security escort, taxes, tools, permit fees, and related costs incurred during waste transportation. Hardware costs are associated with maintenance of the specialized trailers and railroad cars used to transport waste. Fixed costs are independent of the distance traveled and are considered separately. Fixed costs include demurrage costs of the carrier and the hardware used in the shipment. The total cost for a single shipment can be determined by adding the fixed costs to the product of the CPLM and the number of miles traveled. It should be noted that the CPLM unit rate is based on one-way mileage from origin to destination, but that the total cost for one shipment includes the return trip (see Section 3.5.2.5).

Finally, the process of estimating the costs is a straightforward analysis. The costs are derived from the number of shipments based on a volumetric and mass calculation, taking into consideration the volume and mass of drums or standard waste boxes. The number of shipments are applied to the CPLM and the round-trip mileage, and the fixed costs are added to determine the total transportation costs for each individual site. Transportation cost estimations were performed for the decentralized and regionalized cases and each EA therein. An estimation was also made for the centralized baseline. Since the centralized transportation configuration requires that all waste be treated at the WIPP, all the centralized EAs are similar from a transportation point of view. Results are discussed in Section 4.2.

There are relatively few sources of uncertainty in the development of the transportation cost estimations. Included in these are the uncertainty of the waste volumes and masses requiring

transportation and the uncertainty in the numbers provided in the report used as guidance for estimate development. The level of uncertainty is discussed in Section 4.2.

2.3 Backfill Emplacement Cost Estimation Methodology

Backfill emplacement costs were developed by analyzing a logical approach to emplacing material into a panel. The approach had to be generic in nature to accommodate the fact that an exact method of emplacement has not been developed. The approach for estimating the costs of emplacement are generated by applying mine development data sources to an activity that is not characteristic the mining industry. The backfilling of waste emplaced in a mine has not been an activity that is common practice for the DOE or mining industry.

The cost estimation of a backfill operation was developed based on the rate at which backfill would be emplaced. The assumptions for this estimation are listed in Section 3.0. Once the capacity of the equipment requirement was determined a cost model was developed to determine the cost requirements for backfill.

The primary source of costing information is the SME Mining Engineering Handbook (Hartman, 1992), which provided a logical approach to the activities that would be performed. Assumptions had to be made in order to provide some logical data points for performing a backfill activity. An estimation of this type would be categorized as a Study Estimate where the uncertainty of the estimate is plus or minus 30 percent.

Data for the estimate was dependent on the mass and volume of backfill material. The backfill was to be emplaced daily as a batch and would not interrupt the waste emplacement activities. The rate for backfill was assumed to be 960 hours per year for 35 years.

Calculation of the cost estimation was developed utilizing a spreadsheet format that applied the cost equations to the rate at which the backfill would be emplaced. The spreadsheet calculated the cost for each EA that had a backfill associated with it.

Costs included in the estimate are based on capital equipment design and development and on operation and maintenance. The capital is based on actual equipment costs and the tons per day of emplacement capacity (Hartman, 1992). The operating costs are calculated as the total number of FTEs for backfill operations multiplied by the number of hours to perform the backfill times a labor rate. Maintenance costs are assumed to be 30 percent of total capital equipment costs. Design and development of the backfill emplacement activities is calculated as 30 percent of the total capital equipment expenditures. A contingency factor of 25 percent was applied to the overall cost. The manpower for the backfill emplacement was analyzed similarly to an unmechanized shrinkage mine. This facilitated the complexity of departmental requirements for safety of operations.

2.4 WIPP Waste Operations Emplacement Cost Estimation Methodology

The cost estimation for the impacts associated with the WIPP operations only analyzed the incremental costs to the actual activities associated with waste handling and emplacement. These impacts provide a measure of the planning necessary to implementing an EA.

For each of the EAs and configuration (i.e., decentralized, regionalized, or centralized) the throughput of the waste was determined in order to handle and emplace the waste at WIPP. The throughput rate was based on the number of transported waste shipments that were to be handled at WIPP. The waste work-off and repository configuration is analyzed and accounted for to determine additional equipment requirements or modifications. The next parameter is to determine the manpower necessary to handle the waste. Guidance was provided (Palanca, 1995) in order to determine the size of a crew and the waste handling capacity.

The number of waste shipments to the WIPP was determined based on the methodology for transportation (see Section 2.2) The throughput rate was calculated by applying the number of shipments to the operational period of the WIPP. The waste transported to the WIPP site had to meet the time constraint of a 35 year operational life for the treatment and emplacement. The alternatives that required waste treatment would not have waste available for approximately 10 years, which only allows 25 years for transportation and emplacement. Additionally, the manpower requirements for the waste handling operation were given as three possible crews based on the throughput rate. The capital equipment requirement was estimated and totaled for the applicable EA.

Calculation of the WIPP handling cost estimation was developed utilizing a spreadsheet format that applied the capital requirements and the throughput rate of the waste to the manpower requirement. The cost was calculated for each EA and configuration. A comparative analysis was performed to the baseline decentralized EA.

3.0 ASSUMPTIONS AND DATA FOR FACTOR 7

Two major sources of data were used for the analysis of cost and schedule:

- The initial retrievable and projected waste volumes were obtained from the WIPP BIR (DOE, 1995d)
- Guidance for process flow diagrams and costing and cost curves were obtained from the draft EM-PEIS (DOE, 1995b).

The major assumptions follow:

- Cited references are the most current information source of the reference subject and the information gathered from these references are correct.
- Mass and volume changes occur during certain processing activities. A summary of the mass and volume changes is presented in Table P-1.

- The volume of waste categorized as "unknown" was processed the same as solid organics and inorganics. However, the mass of unknown waste was assumed to be zero because no information was available regarding the density of the unknown waste and the volume of this waste was small compared to the total volume of waste destined for WIPP.

- Thirty percent of the stored waste at Los Alamos National Laboratory (LANL), Savannah River Site (SRS), INEL/Argonne National Laboratory-West (ANL-W), and Hanford requires retrieval.

- Twenty-five percent of stored sludges at LANL and INEL require re-grouting.

- Waste is treated and or stored according to the site configurations denoted in Table P-2.

- Waste is processed 4,032 hours per year over a 20-year waste treatment facility operating life.

- All waste within a major waste form category (i.e., sludges, solid organic, solid inorganic) can be treated using a specified technology.

- The supercompaction module does not include shredding.

- Costs for supercompaction processing were analyzed as a modified cost module for the WMFCITRUW supercompaction module.

- Costs for a vitrification unit were considered adequate for the costs for a plasma melter.

- Costs for enhanced cement processing are identical to costs for grouting except for material costs.

- Costs for shredding and adding clay are identical to costs for grouting except for material costs.

- Costs for shredding and compacting were analyzed as a modified cost module for supercompaction.

- Transportation of waste to WIPP is either mass or volume limited. The limiting factor determines the number of shipments.

- Costs for a throughput of 0.05 kg/hr or less to any processing module are considered zero.

- Costs are in 1994 dollars and do not take into account escalation or the time value of dollars.

- The operations at WIPP are 35 years. Waste treatment alternatives require 10 years for start-up to turnkey operations.

- The waste emplacement operations at WIPP consists of two eight hour shift operation five days a week.

- EAs 94(a-f) decentralized and regionalized requires 28.6 years of waste emplacement which exceeds the time constraint of 35 years by 3.6 years.

- Both waste handling and backfill is completed in the 35 year operational period.

- Waste emplacement is dependent upon the number of TRUPACT-IIs per day.

- Backfill costs are based on a batch per day (tons) of material that would be emplaced each day.

- Backfill of the rooms does not impact operations.

4.0 RESULTS OF ANALYSIS FOR FACTOR 7

4.1 Process Costing Results

As described in Section 2.1, process costs are calculated using computer program cost models developed for this study. Costs are calculated for each EA in each configuration for CH waste and for decentralized baseline for RH waste. Cost values are based on 1994 cost data and do not take into consideration time value of money or escalation for expenditures occurring during the planning life cycle cost (Feizollahi and Shropshire, 1994). Summaries of these costs are presented in Tables P-3 and P-4. These tables present the summary of process costs for the baseline and each of the different EAs in each of the configurations for CH waste and for the decentralized baseline for RH waste.

Processing schemes for EAs 33, 35(a&b), 83, and 111 are identical to the processing schemes for the baseline for each of the configurations, therefore their processing costs are assumed to be identical to the processing costs for the baseline. The processing scheme for EA 77 (a-d) is the same as the processing scheme for Alternative 1 for each of the configurations; therefore, its processing costs are identical to the process costs for EA 1. EA 33, 35 (a and b), 77 (a through d), 83, and 111 will be omitted from further discussion in this section because they are not unique with respect to processing cost.

The range of processing costs for CH waste varies between $3.2 billion for the centralized baseline and $6.3 billion for decentralized EAs 94(a-f). The process costs for the decentralized EAs are the highest for a specific EA; the process costs for the centralized configuration are the lowest. This was expected because process costs for treatment (maintenance and specific alternative treatments) are applied to a larger number of sites in the decentralized (10 sites) and regionalized (5 sites) configuration as compared to the centralized (1 site) configuration.

The processing costs for the baseline case were least expensive when compared to the EAs; processing costs for EA 94 (a-f) were most expensive. This results from a combination of effects. One explanation for this is that the treatment module throughput values for the baselines are lowest; treatment module throughput values for EA 94 (a-f) are highest. The baseline consists

of treating to the WIPP-Waste Acceptance Criteria (WAC) standards. Treatment to WIPP-WAC entailed shredding and grouting a portion of the existing sludges and all of the projected sludges, along with repackaging waste as necessary to meet transportation and WIPP requirements. In EA 94(a-f) all of the waste was treated in some way by either repackaging, enhanced-cement processing, or shredding and adding clay. Thus, the "treatment" processing throughput for EA 94 (a-f) is higher than the baseline.

The second explanation is that for the shred-and-add-clay and, enhanced-cement cost modules, it was assumed that there were currently no facilities that had these processing capabilities. The result was that the PLCC was applied to all appropriate sites (decentralized, regionalized and centralized configurations) making EA 94 (a-f) more costly than other EAs (e.g EA 1, etc.) where some facilities currently do have a specific processing capability.

Another observation from the information presented in Table P-3 is that after taking the level of uncertainty of the cost estimations plus or minus 30 percent (Section 2.1), that the centralized EA processing costs are approximately the same as compared to the decentralized baseline. The decentralized baseline represents the current strategy for managing CH waste. Thus, a greater benefit may be obtained by implementing a centralized case for the same cost as the current strategy.

The RH process costs for the baseline decentralized configuration is $1.01 billion.

Costs are calculated for each EA in each configuration, for CH waste, on the basis of sites and processing modules. The results of these calculations are presented in Tables P-5 to P-34. Information contained in these tables represent the highest level of cost detail per EA. The purpose of these tables is to present detailed cost for an individual EA not provided in the summary table.

Costs are calculated for each Decentralized, Regionalized and Centralized configurations on the basis of EA ID number and site. The results of these calculations are presented in Tables P-35 to P-37. The purpose of these tables is to provide a comparative view of site costs per EA.

Costs percentages are calculated on the basis of cost percentage of each EA cost attributed to a specific site for each EA. These results are presented in Tables P-38 to P-40. The purpose of these tables is to provide normalized view of the data presented in Tables P-35 to P-37 and in assist in comparing the site costs to each other for all configurations.

Cost percentages are calculated on the basis of cost percentage of the each EA total cost attributed to a specific cost module (front end, retrieval, waste characterization, etc.). The results of these calculations are presented in Tables P-41 to P-43. The purpose off these tables is to present a normalized view of the data presented in Tables P-5 to P-34 and in assist in comparing the module costs to each other for all configurations.

Cost percentages are calculated on the bases of cost percentage of the total cost attributed to a specific area of processing. The results are presented in Tables P-44 to P-46 For the basis of this comparison, the total processing scheme is divided into three sections. The first section is named "Front-End Processing" and is a roll-up of the Front End, Retrieval and Waste Characterization processing modules. The second section is named "Treatment Process" and is a roll-up of the Maintenance and any EA specific treatment modules (e.g. Plasma,

Supercompaction, etc.). The third processing area is named "Back-End Processing" and is a roll-up of the Certification and Shipping, and the Storage modules. The purpose of these tables to determine how costs are distributed throughout the total processing scheme.

Similar results are available for RH waste process cost data. Table P-47 presents the Decentralized Base Case cost per module for each site processing or shipping RH waste. Table P-48 presents the cost percentage of the total cost on a per site basis. Table P-50 presents the costs attributed to each processing module. Table P-49 presents the cost percentages of the total cost attributed to each processing module and lastly, Table P-51 presents the cost percentages attributed to each area of processing (Front End, Treatment and Back End).

4.2 TRU Waste Transportation Cost Estimation Results

This section provides information on the results of the transportation cost estimations for the various EAs. For information regarding the sources and assumptions used to complete transportation cost estimations, refer to Section CS.2.2.

Transportation cost estimations are performed for each configuration and EA. Within the centralized, regionalized, and decentralized configurations, some of the EAs are identical from a transportation standpoint, making the transportation costs for these EAs the same. For example, the centralized configuration provides only one set of transportation requirements because all treatment occurs at the WIPP, making the transportation costs for all centralized EAs the same. Similarly, the regionalized and decentralized EAs that vary backfill options do not provide unique situations to transportation, so these cases have transportation costs equal to those of other EAs. EAs that present transportation with a unique scheme include base case EAs and EAs 1, 6, 10, and 94(a-f).

The transportation scheme chosen has little effect on cost for any given EA. This is clearly demonstrated by the decentralized, regionalized, and centralized base cases. The total costs for transportation of CH-TRU waste are $690 million, $701 million, and $611 million, respectively. The centralized scheme requires that all waste be transported directly from its current site to the WIPP. Even though not treated, the waste must be handled only one time. The regionalized transportation configuration resulted in the highest percentage of waste to be handled twice; once from its storage site to the treatment site, and then on to the WIPP. The decentralized case avoids some of this "double handling" by treating at more sites, allowing more waste to take a more direct route to the WIPP. The overwhelming factor in determining transportation costs, as described below, is the volume of waste being transported.

As explained in Section 2.2, each case is found to be mass-limited. Logically, therefore, the effect each EA has on mass will have a proportional effect on transportation costs. The baseline EA and EA 94(a-f) treat sludges by grouting and enhanced cement, respectively. These are processes that increase the volume of waste. Solid organics and solid inorganics are treated by processes that have little effect on volume in these EAs. These are clearly the two most expensive EAs from a transportation point of view. Transportation of wastes treated with EAs 1, 6, and 10 are less expensive because they reduce volume. EA 6 grouts sludges, which initially increases their volume, but further shredding and compaction of solid wastes reduces volumes by a ratio of approximately 1.3:1. EA 1, which grouts sludges but supercompacts solid wastes,

is less expensive still. Supercompaction reduces solid wastes by a ratio of 2.9:1. EA 10 is the least expensive. It treats waste by plasma melting, reducing volume by a ratio of approximately 3:1.

The transportation costs range from a minimum of $611 million for centralized EA's, which are transported directly to the WIPP, to a maximum of $1,146 million for regionalized EA 94(a-f), which not only increases the original volume of waste by the largest percentage, but also has the highest percentage of "double handled" waste. An estimate to handle RH waste for the decentralized baseline is also prepared. In addition to the $611 million estimated to transport CH waste for this EA, $318.3 million is estimated to transport RH waste. Even though the volume of RH waste is significantly smaller than CH waste, to avoid radionuclide limitations during transportation, a much smaller volume is carried by each shipment. The Transportation Cost Estimation Summary, Table P-52 presents the estimated transportation costs for each EA.

Detailed costs are presented in Tables P-53 to P-77. These tables include site specific information used to calculate total site costs for shipping. This information includes waste destination, CPLM, number of shipments, total miles traveled, fixed cost, variable cost, and total cost. These tables present the costs in the highest level of detail and provide information not otherwise found in Table P-52.

The level of uncertainty in the cost estimates comes from two sources. One, the level of uncertainty in the stored and projected waste volumes in the Baseline Inventory Report (DOE, 1995d) and two, the level of uncertainty in the studies used as guidance to develop the transportation cost estimates. For guidance in estimating transportation costs, a report titled "Waste Management Facilities Cost Information for Transportation of Radioactive and Hazardous Materials" (Feizollahi and Shropshire, 1994), was contracted by the DOE, and Revision 1 was completed in September, 1994. A report of this nature would be classified as a "study estimate" (Peters and Timmerhaus, 1991), and would have a probable accuracy only within plus or minus 30 percent.

4.3 Backfill Emplacement Cost Results

Backfill emplacement costs were performed for each of the EAs that specified backfill. The cost for emplacement activities was independent to the case of the EA (decentralized, regionalized, centralized) and was only affected by the mass and volume of the backfill. This costs for the EAs were dependent upon the amount and type of backfill that was to be utilized.

Table P-75 (Backfill Emplacement Cost Total Summary) provides a summary of the estimated cost total for each EA. The lowest cost for backfill are EAs 77 (a-d) which consists of the least amount of backfill material due to the reduced room height for waste. The highest cost for backfill are EAs 35 (a-b) and 94c, respectively. This is due to the increased complexity of emplacing a wet (grout) backfill.

Cost of backfill is categorized as a planning cost estimate and has an uncertainty of plus or minus 30 percent. In addition the estimation does not include the cost of the material to be utilized for backfill. It is assumed that backfill materials consisting of salt would utilize the existing mined materials.

4.4 WIPP Waste Operations Emplacement Cost Results

Incremental cost information for the emplacement activities associated with the waste handling at the WIPP are discussed in this section. The discussion includes the assumptions and limitations of the results.

The comparative analysis of the WIPP waste handling and emplacement activities is discussed is shown in Table P-76. The cost of WIPP handling and emplacing the waste is primarily independent of the cases (decentralized, regionalized, centralized) for this cost estimate study. For this estimate there were three waste handling/emplacement crew configuration that were utilized as input for the EAs. The crew sized was dependent upon the number of TRUPACT-IIs that were processed per day as shown in Table P-77. The number of TRUPACT-IIs that were processed was based on the number of waste shipment and the limiting factor of a 35 year operational life for WIPP.

Baseline cost is established based on the required labor to handle and emplace the waste. The EAs 33, 35 (a-b) and 111 have the same comparable cost as the baseline. The EA with the highest handling savings are number 10 and 94 (a-f) in emplacement activities for 25 years instead of 35 years based on 100% processing of waste. This is due to the decrease in the total waste generated by approximately 3:1. EAs 1 and 6 have the same handling savings. EA 77(a-d) has a reduced savings as compared to EA 1. This is due to the reduced room height which does not accommodate the current remote handled underground handling equipment or emplacement configuration.

The limitation of this estimate is that the total WIPP budget is not included in this estimate. The only costs included are labor and anticipated capital equipment or modifications. Additional cost not included in this comparative analysis is the required budget that would be needed to manage and operate the WIPP, departmental management, and any additional research and development. This estimate is only intended to provide a measure of the relative cost savings or burden for an EA.

TABLE P-1

EXISTING TRU FACILITIES

	Waste Processing Functions								
								Treatment[2]	
Site	Retrieve	Waste Char	Front End	Certify/ Ship	Maint	Storage	Grout	Super Cmpct	Plasma
Major Generator/Storage Sites									
ANL-E	–		X		X	X			
Hanf		X	X	X	X	X			
INEL/ ANL-W		X	X	X	X	X			X[3]
LANL		X	X		X	X	X		
LLNL	–	X	X	X	X	X			
Mound	–		X		X				
NTS	–		X		X	X			
ORNL	–	X	X	X	X	X			
RFETS	–	X	X	X	X	X	X	X	
SRS			X		X	X			
Small Quantity Sites									
Ames	–	P	[1]	P	–	–	–	–	–
BCLDP	–	P	[1]	P	–	–	–	–	–
BT	–	P	[1]	P	–	–	–	–	–
ETEC	–	P	[1]	P	–	–	–	–	–
KAPL	–	P	[1]	P	–	–	–	–	–
LBL	–	P	[1]	P	–	–	–	–	–
Pad	–	P	[1]	P	–	–	–	–	–
Pantex	–	P	[1]	P	–	–	–	–	–
SNL	–	P	[1]	P	–	–	–	–	–
U Mo	–	P	[1]	P	–	–	–	–	–
WVDP	–	P	[1]	P	–	–	–	–	–

Notes:
X = Site has existing facilities to perform this function. No credit was given for planned facilities. Costs only include 20 years of O&M and D&D.
– = Site will not require this function.
P = This function will be accomplished utilizing portable equipment.
[1]For sites which will use portable equipment for waste characterization and certification and shipment, it is assumed that existing facilities will be sufficient for administrative purposes.
[2]No facilities exist to treat TRU waste using shred/compact, shred/add clay, or enhanced cement.
[3]It is assumed that the INEL Pit 9 treatment facility will be available to treat stored waste.

TABLE P-2

SITE TRANSFERS FOR THE DECENTRALIZED, REGIONALIZED, AND CENTRALIZED CONFIGURATIONS

Decentralized			Regionalized			Centralized		
Site	CH	RH	Site	CH	RH	Site	CH	RH
ANL-E*	WIPP	ORNL+	ANL-E	SRS	ORNL	ANL-E	WIPP	WIPP
Ames	ANL-E#		Ames	SRS		Ames	WIPP	
BCLDP		ORNL+	BCLDP		ORNL	BCLDP		WIPP
BT	Mound	ORNL+	BT	SRS	ORNL	BT	WIPP	WIPP
ETEC	NTS		ETEC	INEL/ ANL-W		ETEC	WIPP	
INEL/ ANL-W*	WIPP	WIPP	INEL/ ANL-W*	WIPP	Hanford	INEL/ ANL-W	WIPP	WIPP
KAPL	Mound	ORNL+	KAPL	SRS	ORNL	KAPL	WIPP	WIPP
LANL*	WIPP	WIPP	LANL*	WIPP	Hanford	LANL	WIPP	WIPP
LBL	(LLNL)		LBL	Hanford		LBL	WIPP	
LLNL*	WIPP		LLNL	Hanford		LLNL	WIPP	
Mound*	WIPP		Mound	SRS		Mound	WIPP	
MU	ANL-E#		MU	SRS		MU	WIPP	
NTS*	WIPP	WIPP	NTS	INEL/ ANL-W	Hanford	NTS	WIPP	WIPP
ORNL*	WIPP	WIPP	ORNL* (rh)	SRS	WIPP	ORNL	WIPP	WIPP
PA	ORNL		PA	SRS		PA	WIPP	
Pantex	LANL		Pantex	LANL		Pantex	WIPP	
RFETS*	WIPP		RFETS*	WIPP		RFETS	WIPP	
Hanford*	WIPP	WIPP	Hanford*	WIPP	WIPP	Hanford	WIPP	WIPP
SNL/NM	LANL		SNL/NM	LANL		SNL/NM	WIPP	
SRS*	WIPP	WIPP	SRS*	WIPP	ORNL	SRS	WIPP	WIPP

Notes:

* Denotes a processing site.

ORNL+ Remote handled wastes from BCLDP, BT, KAPL, (these are not discussed in the EM-PEIS) and ANL-E should be processed at ORNL instead of Mound because Mound currently does not process or store RH waste.

ANL-E# The EM-PEIS discusses that ANL-E will process and ship their own CH waste, but does not cover Ames and MU, which are closer to ANL-E than ORNL.

(LLNL) EM-PEIS indicates LBL waste will be shipped to Hanford. LBL waste should be shipped to LLNL because it is much closer.

TABLE P-3

CH PROCESS GRAND TOTALS
($K)

Alternative ID #	Decentralized	Regionalized	Centralized
Base Case	3,576,954	3,418,650	3,202,376
1	4,379,357	3,974,696	3,411,991
6	4,117,678	3,757,294	3,329,333
10	5,966,427	4,992,885	3,960,139
33	3,576,954	3,418,650	3,202,376
35 (a&b)	3,576,954	3,418,650	3,202,376
77	4,379,357	3,974,696	3,411,991
83	3,576,954	3,418,650	3,202,376
94 (a-f)	6,301,672	5,502,932	4,217,091
111	3,576,954	3,418,650	3,202,376

TABLE P-4

RH DECENTRALIZED BASELINE COST PER SITE ($K)

Site	Cost
BCLDP	0
BT	0
HANFORD	173,279
INEL/ANL-W	170,849
KAPL	0
LANL	206,932
ORNL	339,190
SRS	121,730
GRAND TOTAL	**1,011,980**

TABLE P-5

CH DECENTRALIZED BASELINE COST SUMMARY ($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	4,850	170,847
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,466	119,034	88,819	55,263	15,878	513,712
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,477	14,413	693,385
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	47,170	101,543	88,819	10,831	4,850	288,556
MOUND	0	50,674	0	101,299	0	14,123	6,405	172,502
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	4,850	171,177
ORNL	0	35,343	47,171	101,772	88,819	10,831	4,850	288,786
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	9,705	461,273
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**284,635**	**1,073,005**	**532,831**	**398,857**	**80,380**	
GRAND TOTAL								**3,576,954**

TABLE P-6

CH DECENTRALIZED ALTERNATIVE ID #1
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Supercompaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	4,850	170,847
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	52,786	119,034	88,819	146,500	55,705	9,388	659,484
INEL/ANL-W	181,977	158,617	50,556	117,412	117,717	134,615	55,708	11,257	827,859
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	48,920	108,993	76,332	96,559	55,150	7,392	548,034
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	47,274	101,543	88,819	26,162	10,831	4,850	314,822
MOUND	0	50,674	47,199	101,299	0	26,162	14,123	6,405	245,862
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	47,272	101,529	0	26,162	14,123	4,850	244,611
ORNL	0	35,343	47,348	101,772	88,819	26,162	10,831	4,850	315,125
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	47,916	103,732	72,326	30,731	22,617	4,850	317,515
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	52,015	116,492	0	144,301	71,028	4,850	655,350
WIPP	0	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**441,285**	**1,073,005**	**532,831**	**657,355**	**404,089**	**63,546**	
GRAND TOTAL									**4,379,357**

TABLE P-7

CH DECENTRALIZED ALTERNATIVE ID #6
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Shred and Compaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	4,850	170,847
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	52,786	119,034	88,819	83,714	55,705	13,642	600,952
INEL/ANL-W	181,977	158,617	50,556	117,412	117,717	76,923	55,708	13,286	772,196
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	48,920	108,993	76,332	55,177	55,150	8,896	508,155
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	47,274	101,543	88,819	14,950	10,831	4,850	303,610
MOUND	0	50,674	47,199	101,299	0	14,950	14,123	6,405	234,650
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	47,272	101,529	0	14,950	14,123	4,850	233,399
ORNL	0	35,343	47,348	101,772	88,819	14,950	10,831	4,850	303,913
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	47,916	103,732	72,326	26,661	22,617	4,850	313,444
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	52,015	116,492	0	82,458	71,028	8,009	596,665
WIPP	0	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**441,285**	**1,073,005**	**532,831**	**384,731**	**404,089**	**74,490**	
GRAND TOTAL									**4,117,678**

TABLE P-8

CH DECENTRALIZED ALTERNATIVE ID #10
COST SUMMARY ($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Plasma	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	47,169	101,199	67,478	14,123	4,850	285,494
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	52,787	119,034	501,386	54,724	6,721	921,904
INEL/ANL-W	181,977	158,617	52,384	117,412	267,218	54,390	5,930	837,927
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	49,648	108,993	423,349	42,865	4,850	784,392
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	47,276	101,543	168,035	10,831	4,850	367,879
MOUND	0	50,674	47,200	101,299	76,105	14,123	6,405	295,807
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	47,272	101,529	163,545	14,123	4,850	381,994
ORNL	0	35,343	47,363	101,819	250,235	10,831	4,850	450,441
PANTEX	0	Portable	0	0	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,960	103,732	360,578	14,808	4,850	567,272
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	52,015	116,492	485,036	68,413	4,850	993,469
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**491,074**	**1,073,051**	**2,762,966**	**379,080**	**53,009**	
GRAND TOTAL								**5,966,427**

TABLE P-9

CH DECENTRALIZED ALTERNATIVE ID #33
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	4,850	170,847
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,466	119,034	88,819	55,263	15,878	513,712
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,477	14,413	693,385
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	47,170	101,543	88,819	10,831	4,850	288,556
MOUND	0	50,674	0	101,299	0	14,123	6,405	172,502
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	4,850	171,177
ORNL	0	35,343	47,171	101,772	88,819	10,831	4,850	288,786
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	9,705	461,273
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**284,635**	**1,073,005**	**532,831**	**398,857**	**80,380**	
GRAND TOTAL								**3,576,954**

TABLE P-10

CH DECENTRALIZED ALTERNATIVE ID #35 (A&B)
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	4,850	170,847
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,466	119,034	88,819	55,263	15,878	513,712
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,477	14,413	693,385
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	47,170	101,543	88,819	10,831	4,850	288,556
MOUND	0	50,674	0	101,299	0	14,123	6,405	172,502
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	4,850	171,177
ORNL	0	35,343	47,171	101,772	88,819	10,831	4,850	288,786
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	9,705	461,273
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**284,635**	**1,073,005**	**532,831**	**398,857**	**80,380**	
GRAND TOTAL								**3,576,954**

TABLE P-11

CH DECENTRALIZED ALTERNATIVE ID #77 (A-D)
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Supercompaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	4,850	170,847
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	52,786	119,034	88,819	146,500	55,705	9,388	659,484
INEL/ANL-W	181,977	158,617	50,556	117,412	117,717	134,615	55,708	11,257	827,859
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	48,920	108,993	76,332	96,559	55,150	7,392	548,034
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	47,274	101,543	88,819	26,162	10,831	4,850	314,822
MOUND	0	50,674	47,199	101,299	0	26,162	14,123	6,405	245,862
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	47,272	101,529	0	26,162	14,123	4,850	244,611
ORNL	0	35,343	47,348	101,772	88,819	26,162	10,831	4,850	315,125
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	47,916	103,732	72,326	30,731	22,617	4,850	317,515
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	52,015	116,492	0	144,301	71,028	4,850	655,350
WIPP	0	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**441,285**	**1,073,005**	**532,831**	**657,355**	**404,089**	**63,546**	
GRAND TOTAL									**4,379,357**

TABLE P-12

CH DECENTRALIZED ALTERNATIVE ID #83
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	4,850	170,847
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,466	119,034	88,819	55,263	15,878	513,712
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,477	14,413	693,385
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	47,170	101,543	88,819	10,831	4,850	288,556
MOUND	0	50,674	0	101,299	0	14,123	6,405	172,502
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	4,850	171,177
ORNL	0	35,343	47,171	101,772	88,819	10,831	4,850	288,786
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	9,705	461,273
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**284,635**	**1,073,005**	**532,831**	**398,857**	**80,380**	
GRAND TOTAL								**3,576,954**

TABLE P-13

CH DECENTRALIZED ALTERNATIVE #94
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Enhanced Cement	Shred and Add Clay	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	47,169	101,199	92,751	0	14,123	4,850	310,767
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	52,787	119,034	92,751	500,396	61,239	15,879	1,029,337
INEL/ANL-W	181,977	158,617	52,384	117,412	324,409	348,839	61,865	18,639	1,264,140
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	49,648	108,993	193,928	206,476	72,483	11,102	797,317
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	47,276	101,543	92,751	90,879	10,831	4,850	383,473
MOUND	0	50,674	47,200	101,299	92,751	90,879	14,123	6,405	403,332
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	47,272	101,529	0	90,879	14,123	4,850	309,328
ORNL	0	35,343	47,363	101,819	92,751	90,879	10,831	4,850	383,836
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	47,960	103,732	92,751	99,766	29,556	4,850	413,958
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	52,015	116,492	0	484,177	77,132	9,705	1,006,183
WIPP	0	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	0	0	0	0
Module Total	**444,535**	**762,712**	**491,074**	**1,073,051**	**1,074,840**	**2,003,170**	**366,307**	**85,981**	
GRAND TOTAL									**6,301,672**

TABLE P-14

CH DECENTRALIZED ALTERNATIVE #111
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	4,850	170,847
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,466	119,034	88,819	55,263	15,878	513,712
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,477	14,413	693,385
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	47,170	101,543	88,819	10,831	4,850	288,556
MOUND	0	50,674	0	101,299	0	14,123	6,405	172,502
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	4,850	171,177
ORNL	0	35,343	47,171	101,772	88,819	10,831	4,850	288,786
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	9,705	461,273
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**284,635**	**1,073,005**	**532,831**	**398,857**	**80,380**	
GRAND TOTAL								**3,576,954**

TABLE P-15

CH REGIONALIZED BASELINE COST SUMMARY ($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,472	119,034	88,819	55,369	16,141	514,087
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,568	14,545	693,609
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	47,171	116,492	88,819	70,837	10,174	600,156
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**237,471**	**1,073,005**	**444,012**	**401,478**	**55,438**	
GRAND TOTAL								**3,418,650**

TABLE P-16

CH REGIONALIZED ALTERNATIVE ID #1
COST SUMMARY
($K)

Site	Retrieval	Waste Characterizatio n	Maintenance	Front End	Grouting	Supercompaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	0	165,997
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	52,897	119,034	88,819	146,991	55,819	9,541	660,353
INEL/ANL-W	181,977	158,617	50,666	117,412	117,717	135,129	55,808	11,309	828,635
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	48,923	108,993	76,332	96,719	55,150	7,392	548,196
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	0	14,123	0	166,096
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	0	101,529	0	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	47,916	103,732	72,326	30,731	22,617	4,850	317,515
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	52,286	116,492	88,819	145,543	71,351	4,912	746,066
WIPP	0	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**252,688**	**1,073,005**	**444,012**	**555,112**	**404,626**	**38,005**	
GRAND TOTAL									**3,974,696**

TABLE P-17

CH REGIONALIZED ALTERNATIVE ID #6
COST SUMMARY
($K)

Site	Retrieval	Waste Characterizatio n	Maintenance	Front End	Grouting	Shred and Compaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	0	165,997
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	52,897	119,034	88,819	83,995	55,819	13,867	601,683
INEL/ANL-W	181,977	158,617	50,666	117,412	117,717	77,217	55,808	13,390	772,803
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	48,923	108,993	76,332	55,268	55,150	8,896	508,249
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	0	14,123	0	166,096
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	0	101,529	0	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	47,916	103,732	72,326	26,661	22,617	4,850	313,444
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	52,286	116,492	88,819	83,167	71,351	8,406	687,184
WIPP	0	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**252,688**	**1,073,005**	**444,012**	**326,307**	**404,626**	**49,409**	
GRAND TOTAL									**3,757,294**

TABLE P-18

CH REGIONALIZED ALTERNATIVE ID #10
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Plasma	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	52,900	119,034	503,717	54,818	6,834	924,555
INEL/ANL-W	181,977	158,617	52,494	117,412	269,074	54,481	5,994	840,048
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	49,651	108,993	423,447	42,865	4,850	784,492
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,819	0	10,831	0	147,993
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,960	103,732	360,578	14,808	4,850	567,272
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	52,309	116,492	491,390	70,837	4,850	1,002,541
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**255,314**	**1,073,051**	**2,048,205**	**381,689**	**27,379**	
GRAND TOTAL								**4,992,885**

TABLE P-19

CH REGIONALIZED ALTERNATIVE ID #33
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,472	119,034	88,819	55,369	16,141	514,087
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,568	14,545	693,609
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	47,171	116,492	88,819	70,837	10,174	600,156
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	**444,535**	**762,712**	**237,471**	**1,073,005**	**444,012**	**401,478**	**55,438**	
GRAND TOTAL								**3,418,650**

TABLE P-20

CH REGIONALIZED ALTERNATIVE ID #35
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,472	119,034	88,819	55,369	16,141	514,087
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,568	14,545	693,609
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	47,171	116,492	88,819	70,837	10,174	600,156
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	237,471	1,073,005	444,012	401,478	55,438	
GRAND TOTAL								3,418,650

TABLE P-21

CH REGIONALIZED ALTERNATIVE ID #77 (A-D)
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Supercompaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	0	165,997
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	52,897	119,034	88,819	146,991	55,819	9,541	660,353
INEL/ANL-W	181,977	158,617	50,666	117,412	117,717	135,129	55,808	11,309	828,635
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	48,923	108,993	76,332	96,719	55,150	7,392	548,196
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	0	14,123	0	166,096
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	0	101,529	0	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	47,916	103,732	72,326	30,731	22,617	4,850	317,515
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	52,286	116,492	88,819	145,543	71,351	4,912	746,066
WIPP	0	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	252,688	1,073,005	444,012	555,112	404,626	38,005	
GRAND TOTAL									3,974,696

TABLE P-22

CH REGIONALIZED ALTERNATIVE ID #83
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,472	119,034	88,819	55,369	16,141	514,087
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,568	14,545	693,609
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	47,171	116,492	88,819	70,837	10,174	600,156
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	237,471	1,073,005	444,012	401,478	55,438	
GRAND TOTAL								**3,418,650**

TABLE P-23

CH REGIONALIZED ALTERNATIVE ID #94
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Enhanced Cement	Shred and Add Clay	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	0	165,997
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	52,900	119,034	92,751	503,907	61,467	16,146	1,033,457
INEL/ANL-W	181,977	158,617	52,494	117,412	324,409	358,409	62,079	18,757	1,274,152
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	49,651	108,993	193,928	206,816	72,483	11,102	797,660
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	0	14,123	0	166,096
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	0	101,529	0	0	14,123	0	166,327
ORNL	0	35,343	0	101,819	0	0	10,831	0	147,993
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	47,960	103,732	92,751	99,766	29,556	4,850	413,958
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	52,309	116,492	92,751	493,433	77,850	10,229	1,109,726
WIPP	0	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	255,314	1,073,051	796,588	1,662,331	447,315	61,084	
GRAND TOTAL									**5,502,932**

TABLE P-24

CH REGIONALIZED ALTERNATIVE ID #111
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	47,472	119,034	88,819	55,369	16,141	514,087
INEL/ANL-W	181,977	158,617	47,773	117,412	117,717	55,568	14,545	693,609
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	47,604	108,993	76,332	53,714	9,727	451,057
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	47,450	103,732	72,326	22,109	4,850	285,810
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	47,171	116,492	88,819	70,837	10,174	600,156
WIPP	0	0	0	0	0	0	0	0
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	237,471	1,073,005	444,012	401,478	55,438	
GRAND TOTAL								**3,418,650**

TABLE P-25

CH CENTRALIZED BASELINE COST SUMMARY ($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	42,827	0	306,507
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	0	451,568
WIPP	0	0	48,815	162,552	236,513	86,797	6,405	543,082
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	48,815	1,235,557	236,513	467,839	6,405	
GRAND TOTAL								3,202,376

TABLE P-26

CH CENTRALIZED ALTERNATIVE ID #1
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Supercompaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	0	165,997
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	0	42,827	0	306,507
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	0	14,123	0	166,096
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	0	101,529	0	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	0	68,413	0	451,568
WIPP	0	0	64,032	162,552	236,513	192,869	90,325	6,405	752,697
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	64,032	1,235,557	236,513	192,869	469,368	6,405	
GRAND TOTAL									3,411,991

TABLE P-27

CH CENTRALIZED ALTERNATIVE ID #6
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Shred and Compaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	0	165,997
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	0	42,827	0	306,507
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	0	14,123	0	166,096
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	0	101,529	0	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	0	68,413	0	451,568
WIPP	0	0	64,032	162,552	236,513	110,211	90,325	6,405	670,039
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	64,032	1,235,557	236,513	110,211	469,368	6,405	
GRAND TOTAL									**3,329,333**

TABLE P-28

CH CENTRALIZED ALTERNATIVE ID #10
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Plasma	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	42,827	0	306,507
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,819	0	10,831	0	147,993
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	0	451,568
WIPP	0	0	66,658	162,599	979,888	85,247	6,405	1,300,797
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	66,658	1,235,650	979,888	464,290	6,405	
GRAND TOTAL								3,960,139

TABLE P-29

CH CENTRALIZED ALTERNATIVE ID #33
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	42,827	0	306,507
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	0	451,568
WIPP	0	0	48,815	162,552	236,513	88,797	6,405	543,082
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	*444,535*	*762,712*	*48,815*	*1,235,557*	*236,513*	*467,839*	*6,405*	
GRAND TOTAL								3,202,376

TABLE P-30

CH CENTRALIZED ALTERNATIVE ID #35 (A & B)
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	42,827	0	306,507
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	0	451,568
WIPP	0	0	48,815	162,552	236,513	88,797	6,405	543,082
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	48,815	1,235,557	236,513	467,839	6,405	
GRAND TOTAL								3,202,376

TABLE P-31

CH CENTRALIZED ALTERNATIVE ID #77 (A-D)
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Supercompaction	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	0	165,997
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	0	42,827	0	306,507
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	0	14,123	0	166,096
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	0	101,529	0	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	0	68,413	0	451,568
WIPP	0	0	64,032	162,552	236,513	192,869	90,325	6,405	752,697
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	64,032	1,235,557	236,513	192,869	469,368	6,405	
GRAND TOTAL									**3,411,991**

TABLE P-32

CH CENTRALIZED ALTERNATIVE ID #83
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	42,827	0	306,507
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	0	451,568
WIPP	0	0	48,815	162,552	236,513	88,797	6,405	543,082
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	48,815	1,235,557	236,513	467,839	6,405	
GRAND TOTAL								3,202,376

TABLE P-33

CH CENTRALIZED ALTERNATIVE ID #94
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Enhanced Cement	Shred and Add Clay	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	0	14,123	0	165,997
BT	0	Portable	0	A	0	0	Portable	0	0
ETEC	0	Portable	0	A	0	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	0	42,827	0	306,507
LBL	0	Portable	0	A	0	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	0	14,123	0	166,096
MU	0	Portable	0	A	0	0	Portable	0	0
NTS	0	50,674	0	101,529	0	0	14,123	0	166,327
ORNL	0	35,343	0	101,819	0	0	10,831	0	147,993
PANTEX	0	Portable	0	A	0	0	Portable	0	0
PA	0	Portable	0	A	0	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	0	68,413	0	451,568
WIPP	0	0	66,658	162,599	498,895	708,036	115,157	6,405	1,557,749
PORTABLE	0	B	0	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	66,658	1,235,650	498,895	708,036	494,200	6,405	
GRAND TOTAL									4,217,091

TABLE P-34

CH CENTRALIZED ALTERNATIVE ID #111
COST SUMMARY
($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
AMES LAB	0	Portable	0	A	0	Portable	0	0
ANL-E	0	50,674	0	101,199	0	14,123	0	165,997
BT	0	Portable	0	A	0	Portable	0	0
ETEC	0	Portable	0	A	0	Portable	0	0
HANFORD	80,387	106,865	0	119,034	0	54,724	0	361,010
INEL/ANL-W	181,977	158,617	0	117,412	0	54,390	0	512,395
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	77,468	77,219	0	108,993	0	42,827	0	306,507
LBL	0	Portable	0	A	0	Portable	0	0
LLNL	0	35,343	0	101,543	0	10,831	0	147,717
MOUND	0	50,674	0	101,299	0	14,123	0	166,096
MU	0	Portable	0	A	0	Portable	0	0
NTS	0	50,674	0	101,529	0	14,123	0	166,327
ORNL	0	35,343	0	101,772	0	10,831	0	147,946
PANTEX	0	Portable	0	A	0	Portable	0	0
PA	0	Portable	0	A	0	Portable	0	0
RFETS	0	35,343	0	103,732	0	14,808	0	153,883
SNL/NM	0	Portable	0	A	0	Portable	0	0
SRS	104,703	161,960	0	116,492	0	68,413	0	451,568
WIPP	0	0	48,815	162,552	236,513	88,797	6,405	543,082
PORTABLE	0	B	0	0	0	79,848	0	79,848
Module Total	444,535	762,712	48,815	1,235,557	236,513	467,839	6,405	
GRAND TOTAL								3,202,376

TABLE P-35

DECENTRALIZED CONFIGURATION
CH ALTERNATIVE COST PER SITE
COST SUMMARY
($K)

Site	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
AMES LAB	0	0	0	0	0	0	0	0	0	0	0
ANL-E	170,847	170,847	170,847	285,494	170,847	170,847	170,847	170,847	170,847	310,767	170,847
BT	0	0	0	0	0	0	0	0	0	0	0
ETEC	0	0	0	0	0	0	0	0	0	0	0
HANFORD	513,712	659,484	600,952	921,904	513,712	513,712	513,712	659,484	513,712	1,029,337	513,712
INEL/ANL-W	693,385	827,859	772,196	837,927	693,385	693,385	693,385	827,859	693,385	1,264,140	693,385
KAPL	0	0	0	0	0	0	0	0	0	0	0
LANL	451,057	548,034	508,155	784,392	451,057	451,057	451,057	548,034	451,057	797,317	451,057
LBL	0	0	0	0	0	0	0	0	0	0	0
LLNL	288,556	314,822	303,610	367,879	288,556	288,556	288,556	314,822	288,556	383,473	288,556
MOUND	172,502	245,862	234,650	295,807	172,502	172,502	172,502	245,862	172,502	403,332	172,502
MU	0	0	0	0	0	0	0	0	0	0	0
NTS	171,177	244,611	233,399	381,994	171,177	171,177	171,177	244,611	171,177	309,328	171,177
ORNL	288,786	315,125	303,913	450,441	288,786	288,786	288,786	315,125	288,786	383,836	288,786
PANTEX	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0	0	0
RFETS	285,810	317,515	313,444	567,272	285,810	285,810	285,810	317,515	285,810	413,958	285,810
SNL/NM	0	0	0	0	0	0	0	0	0	0	0
SRS	461,273	655,350	596,665	993,469	461,273	461,273	461,273	655,350	461,273	1,006,183	461,273
WIPP	0	0	0	0	0	0	0	0	0	0	0
PORTABLE	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848	0	79,848
GRAND TOTAL	3,576,954	4,379,357	4,117,678	5,966,427	3,576,954	3,576,954	3,576,954	4,379,357	3,576,954	6,301,672	3,576,954

TABLE P-36

REGIONALIZED CONFIGURATION
CH ALTERNATIVE COST PER SITE
COST SUMMARY
($K)

Site	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
AMES LAB	0	0	0	0	0	0	0	0	0	0	0
ANL-E	165,997	165,997	165,997	165,997	165,997	165,997	165,997	165,997	165,997	165,997	165,997
BT	0	0	0	0	0	0	0	0	0	0	0
ETEC	0	0	0	0	0	0	0	0	0	0	0
HANFORD	514,087	660,353	601,683	924,555	514,087	514,087	514,087	660,353	514,087	1,033,457	514,087
INEL/ANL-W	693,609	828,635	772,803	840,048	693,609	693,609	693,609	828,635	693,609	1,274,152	693,609
KAPL	0	0	0	0	0	0	0	0	0	0	0
LANL	451,057	548,196	508,249	784,492	451,057	451,057	451,057	548,196	451,057	797,660	451,057
LBL	0	0	0	0	0	0	0	0	0	0	0
LLNL	147,717	147,717	147,717	147,717	147,717	147,717	147,717	147,717	147,717	147,717	147,717
MOUND	166,096	166,096	166,096	166,096	166,096	166,096	166,096	166,096	166,096	166,096	166,096
MU	0	0	0	0	0	0	0	0	0	0	0
NTS	166,327	166,327	166,327	166,327	166,327	166,327	166,327	166,327	166,327	166,327	166,327
ORNL	147,946	147,946	147,946	147,993	147,946	147,946	147,946	147,946	147,946	147,993	147,946
PANTEX	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0	0	0
RFETS	285,810	317,515	313,444	567,272	285,810	285,810	285,810	317,515	285,810	413,958	285,810
SNL/NM	0	0	0	0	0	0	0	0	0	0	0
SRS	600,156	746,066	687,184	1,002,541	600,156	600,156	600,156	746,066	600,156	1,109,726	600,156
WIPP	0	0	0	0	0	0	0	0	0	0	0
PORTABLE	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848
GRAND TOTAL	3,418,650	3,974,696	3,757,294	4,992,885	3,418,650	3,418,650	3,418,650	3,974,696	3,418,650	5,502,932	3,418,650

TABLE P-37

CENTRALIZED CONFIGURATION
CH ALTERNATIVE COST PER SITE
COST SUMMARY
($K)

Site	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
AMES LAB	0	0	0	0	0	0	0	0	0	0	0
ANL-E	165,997	165,997	165,997	165,997	165,997	165,997	165,997	165,997	165,997	165,997	165,997
BT	0	0	0	0	0	0	0	0	0	0	0
ETEC	0	0	0	0	0	0	0	0	0	0	0
HANFORD	361,010	361,010	361,010	361,010	361,010	361,010	361,010	361,010	361,010	361,010	361,010
INEL/ANL-W	512,395	512,395	512,395	512,395	512,395	512,395	512,395	512,395	512,395	512,395	512,395
KAPL	0	0	0	0	0	0	0	0	0	0	0
LANL	306,507	306,507	306,507	306,507	306,507	306,507	306,507	306,507	306,507	306,507	306,507
LBL	0	0	0	0	0	0	0	0	0	0	0
LLNL	147,717	147,717	147,717	147,717	147,717	147,717	147,717	147,717	147,717	147,717	147,717
MOUND	166,096	166,096	166,096	166,096	166,096	166,096	166,096	166,096	166,096	166,096	166,096
MU	0	0	0	0	0	0	0	0	0	0	0
NTS	166,327	166,327	166,327	166,327	166,327	166,327	166,327	166,327	166,327	166,327	166,327
ORNL	147,946	147,946	147,946	147,993	147,946	147,946	147,946	147,946	147,946	147,993	147,946
PANTEX	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0	0	0
RFETS	153,883	153,883	153,883	153,883	153,883	153,883	153,883	153,883	153,883	153,883	153,883
SNL/NM	0	0	0	0	0	0	0	0	0	0	0
SRS	451,568	451,568	451,568	451,568	451,568	451,568	451,568	451,568	451,568	451,568	451,568
WIPP	543,082	752,697	670,039	1,300,797	543,082	543,082	543,082	752,697	543,082	1,557,749	543,082
PORTABLE	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848	79,848
GRAND TOTAL	3,202,376	3,411,991	3,329,333	3,960,139	3,202,376	3,202,376	3,202,376	3,411,991	3,202,376	4,217,091	3,202,376

TABLE P-38

DECENTRALIZED CONFIGURATION
CH COST PERCENT PER SITE

Site	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
AMES LAB	0	0	0	0	0	0	0	0	0	0	0
ANL-E	5	4	4	5	5	5	5	4	5	5	5
BT	0	0	0	0	0	0	0	0	0	0	0
ETEC	0	0	0	0	0	0	0	0	0	0	0
HANFORD	14	15	15	15	14	14	14	15	14	16	14
INEL/ANL-W	19	19	19	14	19	19	19	19	19	20	19
KAPL	0	0	0	0	0	0	0	0	0	0	0
LANL	13	13	12	13	13	13	13	13	13	13	13
LBL	0	0	0	0	0	0	0	0	0	0	0
LLNL	8	7	7	6	8	8	8	7	8	6	8
MOUND	5	6	6	5	5	5	5	6	5	6	5
MU	0	0	0	0	0	0	0	0	0	0	0
NTS	5	6	6	6	5	5	5	6	5	5	5
ORNL	8	7	7	8	8	8	8	7	8	6	8
PANTEX	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0	0	0
RFETS	8	7	8	10	8	8	8	7	8	7	8
SNL/NM	0	0	0	0	0	0	0	0	0	0	0
SRS	13	15	14	17	13	13	13	15	13	16	13
WIPP	0	0	0	0	0	0	0	0	0	0	0
PORTABLE	2	2	2	1	2	2	2	2	2	0	2
Sum	100	100	100	100	100	100	100	100	100	100	100

TABLE P-39

REGIONALIZED CONFIGURATION
CH COST PERCENT PER SITE

Site	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
AMES LAB	0	0	0	0	0	0	0	0	0	0	0
ANL-E	5	4	4	3	5	5	5	4	5	3	5
BT	0	0	0	0	0	0	0	0	0	0	0
ETEC	0	0	0	0	0	0	0	0	0	0	0
HANFORD	15	17	16	19	15	15	15	17	15	19	15
INEL/ANL-W	20	21	21	17	20	20	20	21	20	23	20
KAPL	0	0	0	0	0	0	0	0	0	0	0
LANL	13	14	14	16	13	13	13	14	13	14	13
LBL	0	0	0	0	0	0	0	0	0	0	0
LLNL	4	4	4	3	4	4	4	4	4	3	4
MOUND	5	4	4	3	5	5	5	4	5	3	5
MU	0	0	0	0	0	0	0	0	0	0	0
NTS	5	4	4	3	5	5	5	4	5	3	5
ORNL	4	4	4	3	4	4	4	4	4	3	4
PANTEX	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0	0	0
RFETS	8	8	8	11	8	8	8	8	8	8	8
SNL/NM	0	0	0	0	0	0	0	0	0	0	0
SRS	18	19	18	20	18	18	18	19	18	20	18
WIPP	0	0	0	0	0	0	0	0	0	0	0
PORTABLE	2	2	2	2	2	2	2	2	2	1	2
Sum	100	100	100	100	100	100	100	100	100	100	100

TABLE P-40

CENTRALIZED CONFIGURATION
CH COST PERCENT PER SITE

Site	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
AMES LAB	0	0	0	0	0	0	0	0	0	0	0
ANL-E	5	5	5	4	5	5	5	5	5	4	5
BT	0	0	0	0	0	0	0	0	0	0	0
ETEC	0	0	0	0	0	0	0	0	0	0	0
HANFORD	11	11	11	9	11	11	11	11	11	9	11
INEL/ANL-W	16	15	15	13	16	16	16	15	16	12	16
KAPL	0	0	0	0	0	0	0	0	0	0	0
LANL	10	9	9	8	10	10	10	9	10	7	10
LBL	0	0	0	0	0	0	0	0	0	0	0
LLNL	5	4	4	4	5	5	5	4	5	4	5
MOUND	5	5	5	4	5	5	5	5	5	4	5
MU	0	0	0	0	0	0	0	0	0	0	0
NTS	5	5	5	4	5	5	5	5	5	4	5
ORNL	5	4	4	4	5	5	5	4	5	4	5
PANTEX	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0	0	0
RFETS	5	5	5	4	5	5	5	5	5	4	5
SNL/NM	0	0	0	0	0	0	0	0	0	0	0
SRS	14	13	14	11	14	14	14	13	14	11	14
WIPP	17	22	20	33	17	17	17	22	17	37	17
PORTABLE	2	2	2	2	2	2	2	2	2	2	2
Sum	100	100	100	100	100	100	100	100	100	100	100

TABLE P-41

DECENTRALIZED CONFIGURATION
CH COST PERCENT PER MODULE

Module	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
Front End	30	25	26	18	30	30	30	25	30	17	30
Retrieval	12	10	11	7	12	12	12	10	12	7	12
Waste Characterization	21	17	19	13	21	21	21	17	21	12	21
Maintenance	8	10	11	8	8	8	8	10	8	8	8
Grout	15	12	13	0	15	15	15	12	15	0	15
Supercompact	0	15	0	0	0	0	0	15	0	0	0
Shred & Compact	0	0	9	0	0	0	0	0	0	0	0
Plasma	0	0	0	46	0	0	0	0	0	0	0
Enhanced Cement	0	0	0	0	0	0	0	0	0	17	0
Shred & Add Clay	0	0	0	0	0	0	0	0	0	32	0
Certification & Shipping	11	9	10	6	11	11	11	9	11	6	11
Storage	2	1	2	1	2	2	2	1	2	1	2
Sum	100	100	100	100	100	100	100	100	100	100	100

TABLE P-42

REGIONALIZED CONFIGURATION
CH COST PERCENT PER MODULE

Module	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
Front End	31	27	29	21	31	31	31	27	31	19	31
Retrieval	13	11	12	9	13	13	13	11	13	8	13
Waste Characterization	22	19	20	15	22	22	22	19	22	14	22
Maintenance	7	6	7	5	7	7	7	6	7	5	7
Grout	13	11	12	0	13	13	13	11	13	0	13
Supercompact	0	14	0	0	0	0	0	14	0	0	0
Shred & Compact	0	0	9	0	0	0	0	0	0	0	0
Plasma	0	0	0	41	0	0	0	0	0	0	0
Enhanced Cement	0	0	0	0	0	0	0	0	0	14	0
Shred & Add Clay	0	0	0	0	0	0	0	0	0	30	0
Certification & Shipping	12	10	11	8	12	12	12	10	12	8	12
Storage	2	1	1	1	2	2	2	1	2	1	2
Sum	100	100	100	100	100	100	100	100	100	100	100

TABLE P-43

CENTRALIZED CONFIGURATION
CH COST PERCENT PER MODULE

Module	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
Front End	39	36	37	31	39	39	39	36	39	29	39
Retrieval	14	13	13	11	14	14	14	13	14	11	14
Waste Characterization	24	22	23	19	24	24	24	22	24	18	24
Maintenance	2	2	2	2	2	2	2	2	2	2	2
Grout	7	7	7	0	7	7	7	7	7	0	7
Supercompact	0	6	0	0	0	0	0	6	0	0	0
Shred & Compact	0	0	3	0	0	0	0	0	0	0	0
Plasma	0	0	0	25	0	0	0	0	0	0	0
Enhanced Cement	0	0	0	0	0	0	0	0	0	12	0
Shred & Add Clay	0	0	0	0	0	0	0	0	0	17	0
Certification & Shipping	15	14	14	12	15	15	15	14	15	12	15
Storage	0	0	0	0	0	0	0	0	0	0	0
Sum	100	100	100	100	100	100	100	100	100	100	100

TABLE P-44

DECENTRALIZED CONFIGURATION
CH COST PERCENT PER AREA OF PROCESSING

Area of Processing	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
Front End Processing[1]	64	52	55	38	64	64	64	52	64	36	64
Treatment[2]	23	37	33	55	23	23	23	37	23	57	23
Back End Processing[3]	13	11	12	7	13	13	13	11	13	7	13
Sum	100	100	100	100	100	100	100	100	100	100	100

[1]Front End processing includes Front End, Retrieval, and Waste Characterization Modules.
[2]Treatment includes Maintenance and specific alternative treatment modules (e.g., Plasma, Grout, etc.).
[3]Back End processing includes Certification and Shipping and Storage Modules.

TABLE P-45

REGIONALIZED CONFIGURATION
CH COST PERCENT PER AREA OF PROCESSING

Area of Processing	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
Front End Processing[1]	67	57	61	46	67	67	67	57	67	41	67
Treatment[2]	20	31	27	46	20	20	20	31	20	49	20
Back End Processing[3]	13	11	12	8	13	13	13	11	13	9	13
Sum	100	100	100	100	100	100	100	100	100	100	100

[1]Front End processing includes Front End, Retrieval, and Waste Characterization Modules.
[2]Treatment includes Maintenance and specific alternative treatment modules (e.g., Plasma, Grout, etc.).
[3]Back End processing includes Certification and Shipping and Storage Modules.

TABLE P-46

CENTRALIZED CONFIGURATION
CH COST PERCENT PER AREA OF PROCESSING

Area of Processing	Base Case	1	6	10	33	35 (a&b)	60	77 (a-d)	83	94 (a-f)	111
Front End Processing[1]	76	72	73	62	76	76	76	72	76	58	76
Treatment[2]	9	14	12	26	9	9	9	14	9	30	9
Back End Processing[3]	15	14	14	12	15	15	15	14	15	12	15
Sum	100	100	100	100	100	100	100	100	100	100	100

[1]Front End processing includes Front End, Retrieval, and Waste Characterization Modules.
[2]Treatment includes Maintenance and specific alternative treatment modules (e.g., Plasma, Grout, etc.).
[3]Back End processing includes Certification and Shipping and Storage Modules.

TABLE P-47

RH DECENTRALIZED BASELINE COST SUMMARY ($K)

Site	Retrieval	Waste Characterization	Maintenance	Front End	Grouting	Certification and Shipping	Storage	Site Total
BCLDP	0	Portable	0	A	0	Portable	0	0
BT	0	Portable	0	A	0	Portable	0	0
HANFORD	0	50,674	0	102,076	0	14,123	6,405	173,279
INEL/ANL-W	0	50,674	0	101,201	0	14,123	4,850	170,849
KAPL	0	Portable	0	A	0	Portable	0	0
LANL	34,458	50,674	0	101,272	0	14,123	6,405	206,932
ORNL	0	50,674	57,884	101,501	108,602	14,123	6,405	339,190
SRS	0	0	0	101,202	0	14,123	6,405	121,730
Portable	0	B	0	0	0	C	0	0
Module Total	34,458	202,697	57,884	507,251	108,602	70,617	30,471	
GRAND TOTAL								1,011,980

TABLE P-48

RH DECENTRALIZED BASELINE COST PERCENTAGE BY SITE

Site	Cost Percentage
BCLDP	0
BT	0
HANFORD	17
INEL/ANL-W	17
KAPL	0
LANL	20
ORNL	34
SRS	12
Sum	100

M

TABLE P-49

RH DECENTRALIZED BASELINE COST PER MODULE ($K)

Module	Cost
Front End	507,251
Retrieval	34,458
Waste Characterization	202,697
Maintenance	57,884
Grout	108,602
Certification & Shipping	70,617
Storage	30,471
GRAND TOTAL	1,011,980

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TABLE P-50

RH DECENTRALIZED BASELINE COST PERCENTAGE PER MODULE

Module	Cost Percentage
Front End	50
Retrieval	3
Waste Characterization	20
Maintenance	6
Grout	11
Certification and Shipping	7
Storage	3
Sum	100

M

TABLE P-51

RH DECENTRALIZED BASELINE COST PERCENTAGE PER PROCESSING AREA

Processing Area	Cost Percentage
Front End Processing[1]	74
Treatment[2]	16
Back End Processing[3]	10
Sum	100

[1]Front End processing includes Front End, Retrieval, and Waste Characterization Modules.
[2]Treatment includes Maintenance and specific alternative treatment modules (e.g., Plasma, Grout, etc.).
[3]Back End processing includes Certification and Shipping and Storage Modules.

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TABLE P-52

TRANSPORTATION COST GRAND TOTAL SUMMARY

	Number of Shipments	Total Miles Traveled	Fixed Costs($K)	Variable Costs($K)	Total Costs($K)
CH Centralized Baseline	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 1	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 6	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 10	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 33	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 35	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 60	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 77	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 83	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 94	17,662	47,388,994	163,550	446,272	609,822
CH Centralized Alternative 111	17,662	47,388,994	163,550	446,272	609,822
CH Regionalized Baseline	18,045	48,001,334	167,097	452,756	619,852
CH Regionalized Alternative 1	10,539	26,366,812	97,591	249,770	347,361
CH Regionalized Alternative 6	15,576	40,837,024	144,234	385,541	529,775
CH Regionalized Alternative 10	5,593	14,831,054	51,791	140,129	191,920
CH Regionalized Alternative 33	18,045	48,001,334	167,097	452,756	619,852
CH Regionalized Alternative 35	18,045	48,001,334	167,097	452,756	619,852
CH Regionalized Alternative 60	18,045	48,001,334	167,097	452,756	619,852
CH Regionalized Alternative 77	10,539	26,366,812	97,591	249,770	347,361
CH Regionalized Alternative 83	18,045	48,001,334	167,097	452,756	619,852
CH Regionalized Alternative 94	18,526	48,425,946	171,551	456,701	628,252
CH Regionalized Alternative 111	18,045	48,001,334	167,097	452,756	619,852
CH Decentralized Baseline	17,690	47,397,822	163,809	446,380	610,190
RH Decentralized Baseline	7,958	26,210,998	73,691	244,610	318,301
CH Decentralized Alternative 1	10,182	25,845,272	94,285	244,174	338,459
CH Decentralized Alternative 6	15,227	40,280,216	141,002	379,625	520,627
CH Decentralized Alternative 10	5,237	14,331,254	48,495	134,734	183,229
CH Decentralized Alternative 33	17,690	47,397,822	163,809	446,380	610,190
CH Decentralized Alternative 35	17,690	47,397,822	163,809	446,380	610,190
CH Decentralized Alternative 60	17,690	47,397,822	163,809	446,380	610,190
CH Decentralized Alternative 77	10,182	25,845,272	94,285	244,174	338,459
CH Decentralized Alternative 83	17,690	47,397,822	163,809	446,380	610,190
CH Decentralized Alternative 94	18,181	47,862,978	168,356	450,731	619,087
CH Decentralized Alternative 111	17,690	47,397,822	163,809	446,380	610,190

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TABLE P-53

CH DECENTRALIZED BASELINE TRANSPORTATION COSTS

Origin	Destination	One-Way Mileage[1]	CPLM2 ($/mile)	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL-E	353	10.87	1	706	9	8	17
ANL-E	WIPP	1,455	9.31	7	20,370	65	190	254
BT	MOUND	289	10.87	17	9,826	157	107	264
ETEC	NTS	375	10.87	2	1,500	19	16	35
HANFORD	WIPP	1,808	9.31	5,712	20,654,592	52,893	192,294	245,187
INEL/ANL-W	WIPP	1,392	9.31	4,974	13,847,616	46,059	128,921	174,981
KAPL	MOUND	694	10.87	1	1,388	9	15	24
LANL	WIPP	342	10.87	2,839	1,941,876	26,289	21,108	47,397
LBL	LLNL	75	19.65	1	150	9	3	12
LLNL	WIPP	1,452	9.31	137	397,848	1,269	3,704	4,973
MOUND	WIPP	1,557	9.31	47	146,358	435	1,363	1,798
MU	ANL-E	393	10.87	1	786	9	9	18
NTS	WIPP	1,214	9.31	68	165,104	630	1,537	2,167
ORNL	WIPP	1,521	9.31	120	365,040	1,111	3,399	4,510
PANTEX	LANL	335	10.87	1	670	9	7	17
PA	ORNL	317	10.87	1	634	9	7	16
RFETS	WIPP	704	10.87	931	1,310,848	8,621	14,249	22,870
SNL-NM	WIPP	104	19.65	3	624	28	12	40
SRS	WIPP	1,509	9.31	2,827	8,531,886	26,178	79,432	105,610
TOTAL				**17,690**	**47,397,822**	**163,809**	**446,380**	**610,190**

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Assume that shipments will be volume limited.
Volumes represent total stored and projected volumes.
Volume at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.

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TABLE P-54

CH DECENTRALIZED ALTERNATIVE ID #1
TRANSPORTATION COSTS

Origin	Destination	One-Way Mileage[1]	CPLM2 ($/mile)	Volume (m3)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL-E	353	10.87	0	1	0	1	1	706	9	8	17
ANL-E	WIPP	1,455	9.31	30	90	7	10	4	11,640	37	108	145
BT	MOUND	289	10.87	56	167	13	19	7	4,046	65	44	109
ETEC	NTS	375	10.87	3	9	1	2	1	750	9	8	17
HANFORD	WIPP	1,808	9.31	25,688	76,301	5,709	8,305	2,769	10,012,704	25,641	93,218	118,859
INEL/ANL-W	WIPP	1,392	9.31	33,295	98,896	7,399	10,764	3,588	9,988,992	33,225	92,998	126,222
KAPL	MOUND	694	10.87	1	3	1	1	1	1,388	9	15	24
LANL	WIPP	342	10.87	18,257	54,229	4,058	5,903	1,968	1,346,112	18,224	14,632	32,856
LBL	LLNL	75	19.65	2	7	1	1	1	150	9	3	12
LLNL	WIPP	1,452	9.31	601	1,784	134	195	65	188,760	602	1,757	2,359
MOUND	WIPP	1,557	9.31	259	770	58	84	28	87,192	259	812	1,071
MU	ANL-E	393	10.87	1	3	1	1	1	786	9	9	18
NTS	WIPP	1,214	9.31	217	646	49	71	24	58,272	222	543	765
ORNL	WIPP	1,521	9.31	467	1,389	104	152	51	155,142	472	1,444	1,917
PANTEX	LANL	335	10.87	0	1	0	1	1	670	9	7	17
PA	ORNL	317	10.87	2	7	1	1	1	634	9	7	16
RFETS	WIPP	704	10.87	6,061	18,003	1,347	1,960	654	920,832	6,056	10,009	16,065
SNL-NM	WIPP	104	19.65	6	18	2	3	1	208	9	4	13
SRS	WIPP	1,509	9.31	9,427	28,001	2,095	3,048	1,016	3,066,288	9,408	28,547	37,955
TOTAL								**10,182**	**25,845,272**	**94,285**	**244,174**	**338,459**

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
Notes:
This table presents the costs for transporting CH TRU waste by truck.
Assume that shipments will be volume limited.
Volumes represent total stored and projected volumes.
Volume at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.

TABLE P-55

CH DECENTRALIZED ALTERNATIVE ID #6
TRANSPORTATION COSTS

Origin	Destination	One-Way Mileage[1]	CPLM2 ($/mile)	Volume (m3)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total
AMES	ANL-E	353	10.87	0	1	0	1	1	706	9	8	17
ANL-E	WIPP	1,455	9.31	34	101	8	12	4	11,640	37	108	145
BT	MOUND	289	10.87	122	361	28	40	14	8,092	130	88	218
ETEC	NTS	375	10.87	7	20	2	3	1	750	9	8	17
HANFORD	WIPP	1,808	9.31	43,809	130,125	9,736	14,163	4,721	17,071,136	43,716	158,932	202,649
INEL/ANL-W	WIPP	1,392	9.31	42,186	125,304	9,375	13,638	4,546	12,656,064	42,096	117,828	159,924
KAPL	MOUND	694	10.87	2	6	1	1	1	1,388	9	15	24
LANL	WIPP	342	10.87	23,787	70,654	5,286	7,690	2,564	1,753,776	23,743	19,064	42,806
LBL	LLNL	75	19.65	5	15	2	3	1	150	9	3	12
LLNL	WIPP	1,452	9.31	1,037	3,082	231	336	112	325,248	1,037	3,028	4,065
MOUND	WIPP	1,557	9.31	549	1,631	122	178	60	186,840	556	1,739	2,295
MU	ANL-E	393	10.87	2	5	1	1	1	786	9	9	18
NTS	WIPP	1,214	9.31	472	1,403	105	153	51	123,828	472	1,153	1,625
ORNL	WIPP	1,521	9.31	883	2,625	197	286	96	292,032	889	2,719	3,608
PANTEX	LANL	335	10.87	0	2	0	1	1	670	9	7	17
PA	ORNL	317	10.87	2	7	1	1	1	634	9	7	16
RFETS	WIPP	704	10.87	7,830	23,259	1,741	2,532	844	1,188,352	7,815	12,917	20,733
SNL-NM	WIPP	104	19.65	13	39	3	5	2	416	19	8	27
SRS	WIPP	1,509	9.31	20,469	60,801	4,549	6,618	2,206	6,657,708	20,428	61,983	82,411
TOTAL								**15,227**	**40,280,216**	**141,002**	**379,625**	**520,627**

[1]Source: ORNL, 1993
2Source: INEL, 1994b
Notes:
This table presents the costs for transporting CH TRU waste by truck.
Assume that shipments will be volume limited.
Volumes represent total stored and projected volumes.
Volume at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.

TABLE P-56

CH DECENTRALIZED ALTERNATIVE ID #10
TRANSPORTATION COSTS

Origin	Destination	One-Way Mileage[1]	CPLM2 ($/mile)	Volume (m3)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL-E	353	10.87	0	1	0	1	1	706	9	8	17
ANL-E	WIPP	1,455	9.31	11	33	3	4	2	5,820	19	54	73
BT	MOUND	289	10.87	53	157	12	18	6	3,468	56	38	93
ETEC	NTS	375	10.87	3	9	1	2	1	750	9	8	17
HANFORD	WIPP	1,808	9.31	15,934	47,331	3,541	5,152	1,718	6,212,288	15,909	57,836	73,745
INEL/ANL-W	WIPP	1,392	9.31	13,325	39,580	2,962	4,309	1,437	4,000,608	13,307	37,246	50,552
KAPL	MOUND	694	10.87	1	3	1	1	1	1,388	9	15	24
LANL	WIPP	342	10.87	6,979	20,730	1,551	2,257	753	515,052	6,973	5,599	12,571
LBL	LLNL	75	19.65	2	7	1	1	1	150	9	3	12
LLNL	WIPP	1,452	9.31	384	1,142	86	125	42	121,968	389	1,136	1,524
MOUND	WIPP	1,557	9.31	237	705	53	77	26	80,964	241	754	995
MU	ANL-E	393	10.87	1	3	1	1	1	786	9	9	18
NTS	WIPP	1,214	9.31	205	609	46	67	23	55,844	213	520	733
ORNL	WIPP	1,521	9.31	372	1,105	83	121	41	124,722	380	1,161	1,541
PANTEX	LANL	335	10.87	0	1	0	1	1	670	9	7	17
PA	ORNL	317	10.87	1	3	1	1	1	634	9	7	16
RFETS	WIPP	704	10.87	2,062	6,126	459	668	223	313,984	2,065	3,413	5,478
SNL-NM	WIPP	104	19.65	6	17	2	3	1	208	9	4	13
SRS	WIPP	1,509	9.31	8,888	26,401	1,976	2,874	958	2,891,244	8,871	26,917	35,789
TOTAL								**5,237**	**14,331,254**	**48,495**	**134,734**	**183,229**

[1]Source: ORNL, 1993
[2]*Source: INEL, 1994b*

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Assume that shipments will be volume limited.
Volumes represent total stored and projected volumes.
Volume at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.

TABLE P-57

CH DECENTRALIZED ALTERNATIVE ID #33
TRANSPORTATION COSTS

Origin	Destination	One-Way Mileage[1]	CPLM2 ($/mile)	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL-E	353	10.87	1	706	9	8	17
ANL-E	WIPP	1,455	9.31	7	20,370	65	190	254
BT	MOUND	289	10.87	17	9,826	157	107	264
ETEC	NTS	375	10.87	2	1,500	19	16	35
HANFORD	WIPP	1,808	9.31	5,712	20,654,592	52,893	192,294	245,187
INEL/ANL-W	WIPP	1,392	9.31	4,974	13,847,616	46,059	128,921	174,981
KAPL	MOUND	694	10.87	1	1,388	9	15	24
LANL	WIPP	342	10.87	2,839	1,941,876	26,289	21,108	47,397
LBL	LLNL	75	19.65	1	150	9	3	12
LLNL	WIPP	1,452	9.31	137	397,848	1,269	3,704	4,973
MOUND	WIPP	1,557	9.31	47	146,358	435	1,363	1,798
MU	ANL-E	393	10.87	1	786	9	9	18
NTS	WIPP	1,214	9.31	68	165,104	630	1,537	2,167
ORNL	WIPP	1,521	9.31	120	365,040	1,111	3,399	4,510
PANTEX	LANL	335	10.87	1	670	9	7	17
PA	ORNL	317	10.87	1	634	9	7	16
RFETS	WIPP	704	10.87	931	1,310,848	8,621	14,249	22,870
SNL-NM	WIPP	104	19.65	3	624	28	12	40
SRS	WIPP	1,509	9.31	2,827	8,531,886	26,178	79,432	105,610
TOTAL				**17,690**	**47,397,822**	**163,809**	**446,380**	**610,190**

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Assume that shipments will be volume limited.
Volumes represent total stored and projected volumes.
Volume at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.

TABLE P-58

CH DECENTRALIZED ALTERNATIVE ID #35 (a & b)
TRANSPORTATION COSTS

Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL-E	353	10.87	1	706	9	8	17
ANL-E	WIPP	1,455	9.31	7	20,370	65	190	254
BT	MOUND	289	10.87	17	9,826	157	107	264
ETEC	NTS	375	10.87	2	1,500	19	16	35
HANFORD	WIPP	1,808	9.31	5,712	20,654,592	52,893	192,294	245,187
INEL/ANL-W	WIPP	1,392	9.31	4,974	13,847,616	46,059	128,921	174,981
KAPL	MOUND	694	10.87	1	1,388	9	15	24
LANL	WIPP	342	10.87	2,839	1,941,876	26,289	21,108	47,397
LBL	LLNL	75	19.65	1	150	9	3	12
LLNL	WIPP	1,452	9.31	137	397,848	1,269	3,704	4,973
MOUND	WIPP	1,557	9.31	47	146,358	435	1,363	1,798
MU	ANL-E	393	10.87	1	786	9	9	18
NTS	WIPP	1,214	9.31	68	165,104	630	1,537	2,167
ORNL	WIPP	1,521	9.31	120	365,040	1,111	3,399	4,510
PANTEX	LANL	335	10.87	1	670	9	7	17
PA	ORNL	317	10.87	1	634	9	7	16
RFETS	WIPP	704	10.87	931	1,310,848	8,621	14,249	22,870
SNL-NM	WIPP	104	19.65	3	624	28	12	40
SRS	WIPP	1,509	9.31	2,827	8,531,886	26,178	79,432	105,610
TOTAL				**17,690**	**47,397,822**	**163,809**	**446,380**	**610,190**

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Assume that shipments will be volume limited.
Volumes represent total stored and projected volumes.
Volume at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.

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Table P-59
CH Decentralized Alternative ID #77 (a-d)
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Minimum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL-E	353	10.87	0.32	119.43	1	0	1	1	2	76.68	A	42	3	1	VOLUME	1	1	706	9	8	17
ANL-E	WIPP	1455	9.31	30.13	23311.75	90	7	10	4	145	160.93	B	35	15	5	MASS	5	15	14550	46	135	182
BT	MOUND	289	10.87	55.96	122052.74	167	13	19	7	322	453.62	XX	14	46	23	MASS	23	46	13294	213	145	357
ETEC	NTS	375	10.87	3.01	6466.56	9	1	2	1	18	448.44	XX	14	4	2	MASS	2	4	1500	19	16	35
HANFORD	WIPP	1808	9.31	25687.77	26934798.08	76301	5708	8305	2769	123499	218.10	D	21	11762	5881	MASS	5881	11762	21265698	54,458	197,984	252,442
INEL/ANL-W	WIPP	1392	9.31	33294.81	26952245.98	98896	7399	10764	3588	160072	158.38	C	28	11434	5717	MASS	5717	11434	15918128	52,939	148,179	201,118
KAPL	MOUND	694	10.87	0.84	1825.80	3	1	1	1	5	452.10	XX	14	2	1	VOLUME	1	1	1388	9	15	24
LANL	WIPP	342	10.87	18257.03	14114042.46	54229	4058	5903	1968	87775	160.80	B	35	7524	2508	MASS	2508	7524	1715472	23,224	18,647	41,871
LBL	LLNL	75	19.65	2.30	4896.08	7	1	1	1	14	452.10	XX	14	2	1	VOLUME	1	1	150	9	3	12
LLNL	WIPP	1452	9.31	600.54	545260.94	1784	134	195	65	2888	148.85	C	28	208	104	MASS	104	208	302016	963	2,812	3,775
MOUND	WIPP	1557	9.31	259.12	386958.46	770	58	84	28	1246	310.62	E	14	178	89	MASS	89	178	277146	824	2,580	3,404
MU	ANL-E	393	10.87	0.75	1626.80	3	1	1	1	5	452.10	XX	14	2	1	VOLUME	1	1	786	9	9	18
NTS	WIPP	1214	9.31	217.42	477750.02	646	49	71	24	1258	407.05	XX	14	180	90	MASS	90	180	218520	833	2,034	2,868
ORNL	WIPP	1521	9.31	467.33	859464.22	1389	104	152	51	2262	312.53	XX	14	324	162	MASS	162	324	492804	1,500	4,588	6,088
PANTEX	LANL	335	10.87	0.22	474.71	1	0	1	1	2	452.10	XX	14	2	1	VOLUME	1	1	670	9	7	17
PA	ORNL	317	10.87	2.10	2658.43	7	1	1	1	11	243.11	E	14	2	1	VOLUME	1	1	634	9	7	16
RFP	WIPP	704	10.87	8060.69	3771670.13	18003	1347	1960	654	29138	119.08	C	28	2082	1041	MASS	1041	2082	1465728	9,640	15,932	25,572
SNL-NM	WIPP	304	19.65	5.99	13018.73	18	2	3	1	35	452.10	XX	14	6	3	MASS	3	6	624	28	12	40
SRS	WIPP	1509	9.31	8426.72	21122425.35	28001	2095	3048	1016	55586	465.06	XX	14	7942	3971	MASS	3971	7942	11984478	36,771	111,575	148,347
TOTAL																	19,602	41,711	53,672,290	181,516	504,689	686,204

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory
Notes:
This table presents the costs for transporting CH TRU waste by truck.
Volumes and masses represent total stored and project volumes and masses.
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.
Shipment Configuration is dependent on the average drum mass.
A -- Maximum of 42 drums in three TRUPACT-II'S
B -- Maximum of 35 drums in three TRUPACT-II's
C -- Maximum of 28 drums in two TRUPACT-II's
D -- Maximum of 21 drums in two TRUPACT-II's
E -- Maximum of 14 drums in two TRUPACT-II's
XX -- Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg/drum for calculations. Use Shipment Configuration E.

Table P-60
CH Decentralized Alternative ID #83
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[1]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL E	353	10.87	0.32	119.43	1	0	1	1	2	76.68	A	42	3	1	VOLUME	1	1	706	9	8	17
ANL E	WIPP	1455	9.31	35.95	22938.06	107	8	12	4	173	132.73	A	42	15	5	MASS	5	15	14550	46	135	182
BT	MOUND	289	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	12716	204	138	342
ETEC	NTS	375	10.87	8.61	5878.71	26	2	3	1	42	143.05	B	35	6	2	MASS	2	6	1500	19	16	35
HANFORD	WIPP	1808	9.31	54415.83	24828774.58	161632	12093	17592	5864	261615	94.91	A	42	18687	6229	MASS	6229	18687	22524064	57,681	209,699	267,380
INEL/ANL-W	WIPP	1392	9.31	47390.00	25850461.76	140763	10532	15321	5107	227837	113.46	A	42	16275	5425	MASS	5425	16275	15103200	50,236	140,611	190,848
KAPL	MOUND	694	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1388	9	15	24
LANL	WIPP	342	10.87	27023.49	13591943.62	80268	6006	8737	2913	129921	104.62	A	42	9282	3094	MASS	3094	9282	2116296	28,650	23,004	51,655
LBL	LLNL	75	19.65	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	150	9	3	12
LLNL	WIPP	1452	9.31	1293.18	503804.65	3842	288	419	140	6218	81.03	A	42	447	149	MASS	149	447	432696	1,380	4,028	5,408
MOUND	WIPP	1557	9.31	718.35	352609.62	2134	160	233	78	3454	102.10	A	42	249	83	MASS	83	249	258462	769	2,406	3,175
MU	ANL-E	393	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	786	9	9	18
NTS	WIPP	1214	9.31	621.21	434318.20	1846	139	202	68	2987	145.42	B	35	258	86	MASS	86	258	208808	796	1,944	2,740
ORNL	WIPP	1521	9.31	1127.04	789272.40	3348	251	365	122	5419	145.66	B	35	465	155	MASS	155	465	471510	1,435	4,390	5,825
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	ORNL	317	10.87	2.10	2656.43	7	1	1	1	11	262.11	E	14	2	1	VOLUME	1	1	634	9	7	16
RFP	WIPP	704	10.87	8866.22	5587396.08	26336	1971	2867	956	42627	131.08	A	42	3045	1015	MASS	1015	3045	1429120	9,399	15,535	24,933
SNL NM	WIPP	104	19.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	26933.46	19202207.74	80001	5986	8708	2903	129488	148.29	B	35	11100	3700	MASS	3700	11100	11166600	34,262	103,961	138,223
TOTAL																	19,974	59,913	53,744,480	184,959	505,929	690,888

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory
Notes:
This table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass
A - Maximum of 42 drums in three TRUPACT-II'S
B - Maximum of 35 drums in three TRUPACT-II's
C - Maximum of 28 drums in two TRUPACT-II's
D - Maximum of 21 drums in two TRUPACT-II's
E - Maximum of 14 drums in two TRUPACT-II's
XX - Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg/drum for calculations. Use Shipment Configuration E

Table P-61
CH Decentralized Alternative ID #94
Transportation Costs

								VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS													
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Revised Volume (m^3)	Mass (kg)	Revised Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Case 1	Number of TRUPACTs for Case	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL-E	353	10.87	0.32	0.28	119.43	102.83	1	0	1	1	2	76.68	A	42	3	1	VOLUME	1	0	706	9	8	17
ANL-E	WIPP	1455	9.31	70.51	60.72	66143.70	56953.63	181	14	20	7	292	195.11	C	28	22	11	MASS	11	22	32010	102	298	400
BT	MOUND	289	10.87	159.90	137.68	261072.26	224798.62	409	31	45	15	662	339.61	E	14	96	48	MASS	48	96	27744	444	302	746
ETEC	NTS	375	10.87	8.61	7.41	13832.09	11910.25	23	2	3	1	36	334.23	E	14	6	3	MASS	3	6	2250	26	24	52
HANFORD	WIPP	1808	9.31	54420.36	46859.14	53326437.16	45917208.65	139186	10414	15149	5050	225285	203.82	C	28	16092	8046	MASS	8046	16092	29094336	74,508	270,868	345,374
INEL/ANL-W	WIPP	1392	9.31	68421.44	58914.90	56312806.14	48488648.54	174995	13093	19047	6349	283245	171.19	C	28	20232	10116	MASS	10116	20232	28162944	93,674	262,197	355,871
KAPL	MOUND	694	10.87	2.40	2.07	3905.40	3362.78	7	1	1	1	10	338.47	E	14	2	1	VOLUME	1	1	1388	9	15	24
LANL	WIPP	342	10.87	32641.55	28106.30	26855786.89	23124417.00	83485	6246	9087	3029	135127	171.13	C	28	9652	4826	MASS	4826	9652	3300984	44,689	35,882	80,570
LBL	LLNL	75	19.65	6.57	5.65	10686.68	9201.86	17	2	3	1	28	338.47	E	14	4	2	MASS	2	4	300	19	6	24
LLNL	WIPP	1452	9.31	1313.13	1130.68	1086694.76	935708.31	3359	252	366	122	5436	172.13	C	28	390	195	MASS	195	390	566280	1,806	5,272	7,078
MOUND	WIPP	1557	9.31	736.12	633.84	836930.14	720646.23	1883	141	205	69	3048	236.49	D	21	292	146	MASS	146	292	454644	1,352	4,233	5,585
MU	ANL-E	393	10.87	2.14	1.84	3479.75	2996.27	6	1	1	1	9	338.47	E	14	2	1	VOLUME	1	1	786	9	9	18
NTS	WIPP	1214	9.31	621.21	534.90	1021912.97	879927.36	1589	119	173	58	2572	342.17	E	14	368	184	MASS	184	368	446752	1,704	4,159	5,863
ORNL	WIPP	1521	9.31	1295.19	1115.23	1926718.19	1659018.03	3313	248	361	121	5362	309.42	E	14	766	383	MASS	383	766	1165086	3,547	10,847	14,394
PANTEX	LANL	335	10.87	0.62	0.54	1015.40	874.32	2	0	1	1	3	338.47	E	14	2	1	VOLUME	1	0	670	9	7	17
PA	ORNL	317	10.87	5.25	4.52	8367.75	7205.13	14	2	2	1	22	331.52	E	14	4	2	MASS	2	4	1268	19	14	32
RFP	WIPP	704	10.87	9148.83	7877.68	8458950.48	7283635.45	23400	1751	2547	849	37874	192.32	C	28	2706	1353	MASS	1353	2706	1905024	12,529	20,708	33,236
SNL-NM	WIPP	104	19.65	17.11	14.73	27842.94	23974.41	44	4	6	2	71	338.47	E	14	12	6	MASS	6	12	1248	56	25	80
SRS	WIPP	1509	9.31	26933.49	23191.32	45181150.31	38903636.11	68886	5154	7498	2500	111497	348.92	E	14	15930	7965	MASS	7965	15930	24038370	73,756	223,797	297,553
TOTAL																			31,290	66,574	89,202,790	308,266	838,670	1,146,935

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Volumes and masses represent total stored and project volumes and masses.
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.
Shipment Configuration is dependent on the average drum mass.
A - Maximum of 42 drums in three TRUPACT-II's
B - Maximum of 35 drums in three TRUPACT-II's
C - Maximum of 28 drums in two TRUPACT-II's
D - Maximum of 21 drums in two TRUPACT-II's
E - Maximum of 14 drums in two TRUPACT-II's
XX - Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg/drum for calculations. Use Shipment Configuration E

Revised Mass and Volume Scaling Factor 0.861059

Table P-62
CH Decentralized Alternative ID #111
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	ANL-E	353	10.87	0.32	119.43	1	0	1	1	2	76.68	A	42	3	1	VOLUME	1	1	706	9	8	17
ANL-E	WIPP	1455	9.31	35.95	22938.06	107	8	12	4	173	132.73	A	42	15	5	MASS	5	15	14550	48	135	182
BT	MOUND	289	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	12716	204	138	342
ETEC	NTS	375	10.87	8.81	5878.71	26	2	3	1	42	142.05	B	35	6	2	MASS	2	6	1500	19	16	35
HANFORD	WIPP	1808	9.31	54415.83	24828774.58	161632	12093	17592	5864	261615	94.91	A	42	18687	6229	MASS	6229	18687	22524064	57,681	209,699	267,380
INEL/ANL-W	WIPP	1392	9.31	47390.00	25850481.76	140763	10532	15321	5107	227837	113.46	A	42	16275	5425	MASS	5425	16275	15103200	50,236	140,611	190,848
KAPL	MOUND	694	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1388	9	15	24
LANL	WIPP	342	10.87	27023.49	13591943.62	80268	6006	8737	2913	129921	104.62	A	42	9282	3094	MASS	3094	9282	2116296	28,650	23,004	51,655
LBL	LLNL	75	19.65	6.57	4541.69	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	150	9	3	12
LLNL	WIPP	1452	9.31	1293.18	503804.65	3842	288	419	140	6218	81.03	A	42	447	149	MASS	149	447	432696	1,380	4,028	5,408
MOUND	WIPP	1557	9.31	718.35	352609.62	2134	160	233	78	3454	102.10	A	42	249	83	MASS	83	249	258462	769	2,406	3,175
MU	ANL-E	393	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	786	9	9	18
NTS	WIPP	1214	9.31	621.21	434318.20	1846	139	202	68	2987	45.42	B	35	258	86	MASS	86	258	208608	798	1,944	2,740
ORNL	WIPP	1521	9.31	1127.04	789272.40	3348	251	365	122	5419	145.66	B	35	465	155	MASS	155	465	471510	1,435	4,390	5,825
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	43.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	ORNL	317	10.87	2.10	2656.43	7	1	1	1	11	263.11	E	14	2	1	VOLUME	1	1	634	9	7	16
RFP	WIPP	704	10.87	8866.22	5587396.08	26336	1971	2867	956	42627	131.08	A	42	3045	1015	MASS	1015	3045	1429120	9,399	15,535	24,933
SNL-NM	WIPP	104	19.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	26933.46	19202207.74	80001	5986	8708	2903	129488	148.29	B	35	11100	3700	MASS	3700	11100	11166800	34,262	103,961	138,223
TOTAL																	19,974	59,913	53,744,480	184,959	505,929	690,888

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Volumes and masses represent total stored and project volumes and masses.
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.
Shipment Configuration is dependent on the average drum mass.
A - Maximum of 42 drums in three TRUPACT-II's
B - Maximum of 35 drums in three TRUPACT-II's
C - Maximum of 28 drums in two TRUPACT-II's
D - Maximum of 21 drums in two TRUPACT-II's
E - Maximum of 14 drums in two TRUPACT-II's
XX - Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg/drum for calculations. Use Shipment Configuration E.

Table P-63
CH Regionalized Baseline
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Minimum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	9.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2380	9	22	31
ANL-E	SRS	877	10.87	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	7016	37	76	113
BT	SRS	686	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	30184	204	328	532
ETEC	INEL/ANL-W	958	10.87	8.61	5878.71	26	2	3	1	42	142.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	9.31	55709.01	25332579.23	165473	12380	18010	6004	267832	94.58	A	42	19131	6377	MASS	6377	19131	23059232	59,051	214,681	273,732
INEL/ANL-W	WIPP	1392	9.31	48011.21	26284779.96	142608	10670	15522	5174	230824	113.87	A	42	16488	5496	MASS	5496	16488	15300864	50,893	142,451	193,344
KAPL	SRS	949	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1898	9	21	30
LANL	WIPP	342	10.87	27023.49	13591943.62	80268	6006	8737	2913	129921	104.62	A	42	9282	3094	MASS	3094	9282	2116296	26,650	23,004	51,655
LBL	HANFORD	870	10.87	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	1740	9	19	28
LLNL	HANFORD	890	10.87	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	236740	1,232	2,573	3,805
MOUND	SRS	641	10.87	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	39742	287	432	719
MU	SRS	863	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	121210	787	1,318	2,105
ORNL	SRS	358	10.87	1124.94	728806.41	3342	250	364	122	5409	134.76	A	42	387	129	MASS	129	387	92364	1,195	1,004	2,199
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	SRS	569	10.87	2.10	2656.43	7	1	1	1	11	263.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
RFP	WIPP	704	10.87	8866.22	5587396.08	26336	1971	2867	956	42627	131.08	A	42	3045	1015	MASS	1015	3045	1429120	9,399	15,535	24,933
SNL-NM	LANL	104	10.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	28814.79	20367027.82	85589	6404	9316	3106	138533	147.02	B	35	11877	3959	MASS	3959	11877	11948262	36,660	111,238	147,899
TOTAL																	20,356	61,058	54,395,038	188,497	512,795	701,291

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory
Notes
This table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass
A - Maximum of 42 drums in three TRUPACT-II'S
B - Maximum of 35 drums in three TRUPACT-II's
C - Maximum of 28 drums in two TRUPACT II's
D - Maximum of 21 drums in two TRUPACT-II's
E - Maximum of 14 drums in two TRUPACT-II's
XX -- Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg /drum for calculations. *Use Shipment Configuration E*

Table P-64
CH Regionalized Alternative ID #1
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	9.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2380	9	22	31
ANL E	SRS	877	10.87	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	7016	37	76	113
BT	SRS	686	10.87	159.90	110957.04	475	36	52	18	769	44.34	B	35	66	22	MASS	22	66	30184	204	328	532
ETEC	INEL/ANL-W	958	10.87	8.61	5878.71	26	2	3	1	42	42.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	9.31	26288.31	27460059.02	78065	5842	8499	2833	126387	217.43	D	21	12038	6019	MASS	6019	12038	21764704	55,736	202,629	258,365
INEL/ANL-W	WIPP	1392	9.31	33512.23	27429996.01	99542	7448	10835	3612	161117	70.25	C	28	11510	5755	MASS	5755	11510	16021920	53,291	149,164	202,455
KAPL	SRS	949	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1898	9	21	30
LANL	WIPP	342	10.87	18257.03	14114042.46	54229	4058	5903	1968	87775	160.80	B	35	7524	2508	MASS	2508	7524	1715472	23,224	18,647	41,871
LBL	HANFORD	870	10.87	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	1740	9	19	28
LLNL	HANFORD	890	10.87	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	236740	1,232	2,573	3,805
MOUND	SRS	641	10.87	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	39742	287	432	719
MU	SRS	863	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	121210	787	1,318	2,105
ORNL	SRS	358	10.87	1124.94	728806.41	3342	250	364	122	5409	134.76	A	42	387	129	MASS	129	387	92364	1,195	1,004	2,199
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	SRS	569	10.87	2.10	2656.43	7	1	1	1	11	253.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
RFP	WIPP	704	10.87	6060.69	5771670.13	18003	1347	1960	654	29138	198.08	C	28	2082	1041	MASS	1041	2082	1465728	9,640	15,932	25,572
SNL NM	LANL	104	19.65	17.11	11833.39	51	4	6	2	83	113.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	10183.30	22392159.78	30248	2263	3293	1098	58927	457.37	XX	14	8420	4210	MASS	4210	8420	12705780	38,985	118,291	157,275
TOTAL																	19,948	42,809	54,214,868	184,718	510,549	695,268

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory

Notes:
The table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass
A - Maximum of 42 drums in three TRUPACT-II'S
B - Maximum of 35 drums in three TRUPACT-II's
C - Maximum of 28 drums in two TRUPACT-II's
D - Maximum of 21 drums in two TRUPACT-II's
E - Maximum of 14 drums in two TRUPACT-II's
XX - Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg /drum for calculations. Use Shipment Configuration E

Table P-65
CH Regionalized Alternative ID #6
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS													
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	9.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2380	9	22	31
ANL-E	SRS	877	10.87	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	7016	37	76	113
BT	SRS	686	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	30184	204	328	532
ETEC	INEL/ANL-W	958	10.87	8.61	5878.71	26	2	3	1	42	142.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	9.31	44845.98	27480059.02	133206	9966	14498	4833	215606	127.46	A	42	15402	5134	MASS	5134	15402	18564544	47,541	172,836	220,377
INEL/ANL-W	WIPP	1392	9.31	42657.74	27429996.01	126707	9480	13791	4597	205086	133.75	A	42	14649	4883	MASS	4883	14649	13594272	45,217	126,563	171,779
KAPL	SRS	949	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1898	9	21	30
LANL	WIPP	342	10.87	23786.64	14114042.46	70654	5286	7690	2564	114359	123.42	A	42	8169	2723	MASS	2723	8169	1862532	25,215	20,246	45,461
LBL	HANFORD	870	10.87	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	1740	9	19	28
LLNL	HANFORD	890	10.87	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	236740	1,232	2,573	3,805
MOUND	SRS	641	10.87	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	39742	287	432	719
MU	SRS	863	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	121210	787	1,318	2,105
ORNL	SRS	358	10.87	1124.94	726806.41	3342	250	364	122	5409	134.76	A	42	387	129	MASS	129	387	92364	1,195	1,004	2,199
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	SRS	569	10.87	2.10	2656.43	7	1	1	1	11	263.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
RFP	WIPP	704	10.87	7830.33	5771670.13	23259	1741	2532	844	37646	153.32	B	35	3228	1076	MASS	1076	3228	1515008	9,964	16,468	26,432
SNL NM	LANL	104	19.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	21935.47	22392159.78	65155	4875	7092	2364	105460	212.33	D	21	10044	5022	MASS	5022	10044	15156396	46,504	141,106	187,610
TOTAL																	19,253	52,727	51,234,016	178,283	483,104	661,387

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory

Notes
This table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass
A - Maximum of 42 drums in three TRUPACT II'S
B - Maximum of 35 drums in three TRUPACT II's
C - Maximum of 28 drums in two TRUPACT II's
D - Maximum of 21 drums in two TRUPACT-II's
E - Maximum of 14 drums in two TRUPACT-II's
XX - Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg/drum for calculations. Use Shipment Configuration E

Table P-66
CH Regionalized Alternative ID #10
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	9.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2380	9	22	31
ANL-E	SRS	877	10.87	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	7016	37	76	113
BT	SRS	686	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	30184	204	328	532
ETEC	INEL/ANL-W	958	10.87	8.61	5878.71	26	2	3	1	42	142.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	9.31	16318.82	22708067.71	48472	3627	5276	1759	78456	289.44	E	14	11208	5604	MASS	5604	11208	20264064	51,893	188,658	240,551
INEL/ANL-W	WIPP	1392	9.31	13530.24	21099392.64	40189	3007	4375	1459	65050	324.36	E	14	9294	4647	MASS	4647	9294	12937248	43,031	120,446	163,477
KAPL	SRS	949	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1898	9	21	30
LANL	WIPP	342	10.87	6979.09	9846783.71	20730	1551	2257	753	33554	293.47	E	14	4794	2397	MASS	2397	4794	1639548	22,196	17,822	40,018
LBL	HANFORD	870	10.87	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	1740	9	19	28
LLNL	HANFORD	890	10.87	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	236740	1,232	2,573	3,805
MOUND	SRS	641	10.87	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	39742	287	432	719
MU	SRS	863	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	121210	787	1,318	2,105
ORNL	SRS	358	10.87	1124.94	786615.97	3342	250	364	122	5409	145.44	B	35	465	155	MASS	155	465	110980	1,435	1,206	2,642
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	SRS	569	10.87	2.10	2656.43	7	1	1	1	11	243.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
RFP	WIPP	704	10.87	2062.25	3151674.56	6126	459	668	223	9915	317.88	E	14	1418	709	MASS	709	1418	998272	6,565	10,851	17,417
SNL-NM	LANL	104	19.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	9508.10	20366033.36	28242	2113	3074	1025	53595	415.53	XX	14	7658	3829	MASS	3829	7658	11555922	35,457	107,586	143,042
TOTAL																	17,627	35,685	47,954,934	163,226	451,451	614,677

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Volumes and masses represent total stored and project volumes and masses.
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.
Shipment Configuration is dependent on the average drum mass.
A - Maximum of 42 drums in three TRUPACT-II'S
B - Maximum of 35 drums in three TRUPACT-II's
C - Maximum of 28 drums in two TRUPACT-II's
D - Maximum of 21 drums in two TRUPACT-II's
E - Maximum of 14 drums in two TRUPACT-II's
XX - Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg /drum for calculations. Use Shipment Configuration E

Table P-67
CH Regionalized Alternative ID #33
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[2]	CPLM[3] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[1]	Maximum Drums per Shipment[1]	Maximum Number of TRUPACTs[1]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	9.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2380	9	22	31
ANL-E	SRS	677	10.87	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	7016	37	76	113
BT	SRS	686	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	30184	204	328	532
ETEC	INEL/ANL-W	958	10.87	8.61	5878.71	26	2	3	1	42	142.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	9.31	55709.01	25332579.23	165473	12380	18010	6004	267832	94.58	A	42	19131	6377	MASS	6377	19131	23059232	59,051	214,681	273,732
INEL/ANL-W	WIPP	1392	9.31	48011.21	26284779.96	142608	10670	15522	5174	230824	113.87	A	42	16488	5496	MASS	5496	16488	15300664	50,993	142,451	193,344
KAPL	SRS	949	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1898	9	21	30
LANL	WIPP	342	10.87	27023.49	13591943.62	80268	6006	8737	2913	129921	104.62	A	42	9282	3094	MASS	3094	9282	2116296	26,650	23,004	51,655
LBL	HANFORD	870	10.87	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	1740	9	16	26
LLNL	HANFORD	890	10.87	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	236740	1,232	2,573	3,805
MOUND	SRS	641	10.87	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	39742	267	432	719
MU	SRS	863	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	121210	787	1,318	2,105
ORNL	SRS	358	10.87	1124.94	728806.41	3342	250	364	122	5409	134.76	A	42	387	129	MASS	129	387	92364	1,195	1,004	2,199
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	SRS	569	10.87	2.10	2656.43	7	1	1	1	11	261.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
RFP	WIPP	704	10.87	8866.22	5587396.06	26336	1971	2867	956	42627	131.08	A	42	3045	1015	MASS	1015	3045	1429120	9,399	15,535	24,933
SNL-NM	LANL	104	19.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	29	12	40
SRS	WIPP	1509	9.31	28814.79	20367027.82	85589	6404	9316	3106	138533	147.02	B	35	11877	3959	MASS	3959	11877	11948262	36,660	111,238	147,899
TOTAL																	20,356	61,068	54,395,038	188,497	512,795	701,291

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Volumes and masses represent total stored and project volumes and masses.
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.
Shipment Configuration is dependent on the average drum mass.
A -- Maximum of 42 drums in three TRUPACT II's
B -- Maximum of 35 drums in three TRUPACT II's
C -- Maximum of 28 drums in two TRUPACT II's
D -- Maximum of 21 drums in two TRUPACT II's
E -- Maximum of 14 drums in two TRUPACT II's
XX -- Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg/drum for calculations. Use Shipment Configuration E

Table P-68
CH Regionalized Alternative ID #35 (a&b)
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS													
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	9.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2380	9	22	31
ANL-E	SRS	877	10.87	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	7016	37	76	113
BT	SRS	686	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	30184	204	328	532
ETEC	INEL/ANL-W	958	10.87	8.61	5878.71	26	2	3	1	42	142.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	9.31	55709.01	25332578.23	165,473.00	12380	18010	6004	267832	94.58	A	42	19131	6377	MASS	6377	19131	23059232	59,051	214,681	273,732
INEL/ANL-W	WIPP	1392	9.31	48011.21	26284779.96	142608	10670	15522	5174	230824	113.87	A	42	16488	5496	MASS	5496	16488	15300864	50,893	142,451	193,344
KAPL	SRS	949	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1898	9	21	30
LANL	WIPP	342	10.87	27023.49	13591943.62	80268	6006	8737	2913	129921	104.62	A	42	9282	3094	MASS	3094	9282	2116296	26,650	23,004	51,655
LBL	HANFORD	870	10.87	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	1740	9	19	28
LLNL	HANFORD	890	10.87	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	236740	1,232	2,573	3,805
MOUND	SRS	641	10.87	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	39742	267	432	719
MU	SRS	863	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	121210	787	1,318	2,105
ORNL	SRS	358	10.87	1124.94	728806.41	3342	250	364	122	5409	134.76	A	42	387	129	MASS	129	387	92364	1,195	1,004	2,199
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	SRS	569	10.87	2.10	2656.43	7	1	1	1	11	263.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
RFP	WIPP	704	10.87	8866.22	5587396.08	26336	1971	2867	956	42627	131.08	A	42	3045	1015	MASS	1015	3045	1429120	9,399	15,535	24,933
SNL-NM	LANL	104	19.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	28814.79	20367027.82	85589	6404	9316	3106	138533	147.02	B	35	11877	3959	MASS	3959	11877	11948262	36,660	111,238	147,899
TOTAL																	20,356	61,058	54,385,038	188,497	512,785	701,281

[1]Source ORNL, 1993
[2]Source INEL, 1994b
[3]Source Personal Communication with Phil Gregory
Notes
The table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass.
A - Maximum of 42 drums in three TRUPACT-II'S
B - Maximum of 35 drums in three TRUPACT-II's
C - Maximum of 28 drums in two TRUPACT-II's
D - Maximum of 21 drums in two TRUPACT-II's
E - Maximum of 14 drums in two TRUPACT-II's
XX - Average drum mass exceeds expected upper limit Average drum weight set at 380 kg/drum for calculations Use Shipment Configuration E

Table P-69
CH Regionalized Alternative ID #77 (a-d)
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1,190 00	9 31	0 13	37 91	1 00	0 00	1 00	1 00	1 00	60 86	A	42 00	3 00	1 00	VOLUME	1 00	1 00	2,380 00	9 26	22 16	31 42
ANL-E	SRS	877 00	10 87	31 31	20,426 77	93 00	7 00	11 00	4 00	151 00	135 71	A	42 00	12 00	4 00	VOLUME	4 00	11 00	7,016 00	37 04	76 26	113 30
BT	SRS	686 00	10 87	159 90	110,957 04	475 00	36 00	52 00	18 00	769 00	144 34	B	35 00	66 00	22 00	MASS	22 00	66 00	30,184 00	203 72	328 10	531 82
ETEC	INEL/ANL-W	958 00	10 87	8 61	5,878 71	26 00	2 00	3 00	1 00	42 00	142 05	B	35 00	6 00	2 00	MASS	2 00	6 00	3,832 00	18 52	41 65	60 17
HANFORD	WIPP	1,808 00	9 31	26,288 31	27,480,059 02	78,085 00	5,842 00	8,499 00	2,833 00	126,387 00	217 43	D	21 00	12,038 00	6,019 00	MASS	6,019 00	12,038 00	21,764,704 00	55,735 94	202,629 39	258,365 33
INEL/ANL-W	WIPP	1,392 00	9 31	33,512 23	27,429,996 01	99,542 00	7,448 00	10,835 00	3,612 00	161,117 00	170 25	C	28 00	11,510 00	5,755 00	MASS	5,755 00	11,510 00	16,021,920 00	53,291 30	149,164 08	202,455 38
KAPL	SRS	949 00	10 87	2 40	1,659 81	8 00	1 00	2 00	1 00	12 00	143 85	B	35 00	3 00	1 00	VOLUME	1 00	2 00	1,898 00	9 26	20 63	29 89
LANL	WIPP	342 00	10 87	18,257 03	14,114,042 46	54,229 00	4,058 00	5,903 00	1,968 00	87,775 00	160 80	B	35 00	7,524 00	2,508 00	MASS	2,508 00	7,524 00	1,715,472 00	23,224 08	18,647 18	41,871 26
LBL	HANFORD	870 00	10 87	8 57	4,541 89	20 00	2 00	3 00	1 00	32 00	143 85	B	35 00	3 00	1 00	VOLUME	1 00	3 00	1,740 00	9 26	18 91	28 17
LLNL	HANFORD	890 00	10 87	1,158 04	445,343 02	3,440 00	258 00	375 00	125 00	5,568 00	79 99	A	42 00	399 00	133 00	MASS	133 00	399 00	236,740 00	1,231 58	2,573 36	3,804 94
MOUND	SRS	641 00	10 87	263 29	143,644 06	783 00	59 00	86 00	29 00	1,266 00	113 48	A	42 00	93 00	31 00	MASS	31 00	93 00	39,742 00	287 06	432 00	719 06
MU	SRS	863 00	10 87	2 14	1,476 91	7 00	1 00	1 00	1 00	11 00	143 85	B	35 00	3 00	1 00	VOLUME	1 00	1 00	1,726 00	9 26	18 76	28 02
NTS	INEL/ANL-W	713 00	10 87	612 60	428,439 49	1,820 00	137 00	199 00	67 00	2,946 00	145 47	B	35 00	255 00	85 00	MASS	85 00	255 00	121,210 00	787 10	1,317 55	2,104 65
ORNL	SRS	358 00	10 87	1,124 94	726,806 41	3,342 00	250 00	364 00	122 00	5,409 00	134 76	A	42 00	387 00	129 00	MASS	129 00	387 00	92,364 00	1,194 54	1,004 00	2,198 54
PANTEX	LANL	335 00	10 87	0 62	431 55	2 00	0 00	1 00	1 00	3 00	143 85	B	35 00	3 00	1 00	VOLUME	1 00	1 00	670 00	9 26	7 28	16 54
PA	SRS	569 00	10 87	2 10	2,656 43	7 00	1 00	1 00	1 00	11 00	163 11	E	14 00	2 00	1 00	VOLUME	1 00	1 00	1,138 00	9 26	12 37	21 63
RFP	WIPP	704 00	10 87	6,060 69	5,771,670 13	18,003 00	1,347 00	1,960 00	654 00	29,138 00	198 08	C	28 00	2,082 00	1,041 00	MASS	1,041 00	2,082 00	1,465,728 00	9,639 66	15,932 46	25,572 12
SNL-NM	LANL	104 00	19 65	17 11	11,833 39	51 00	4 00	6 00	2 00	83 00	143 85	B	35 00	9 00	3 00	MASS	3 00	9 00	624 00	27 78	12 26	40 04
SRS	WIPP	1,509 00	9 31	10,183 30	22,392,159 78	30,248 00	2,263 00	3,293 00	1,098 00	58,927 00	457 37	XX	14 00	8,420 00	4,210 00	MASS	4,210 00	8,420 00	12,705,780 00	38,984 60	118,290 81	157,275 41
													1,000 00									
TOTAL																	19,948 00	42,809 00	54,214,868 00	184,718 48	510,549 23	695,267 71

[1]Source ORNL, 1993
[2]Source INEL, 1994b
[3]Source Personal Communication with Phil Gregory

Notes
This table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass
A – Maximum of 42 drums in three TRUPACT-IIS
B – Maximum of 35 drums in three TRUPACT-IIs
C – Maximum of 28 drums in two TRUPACT-IIs
D – Maximum of 21 drums in two TRUPACT-IIs
E – Maximum of 14 drums in two TRUPACT-IIs
XX – Average drum mass exceeds expected upper limit Average drum weight set at 380 kg /drum for calculations Use Shipment Configuration E

Table P-70
CH Regionalized Alternative ID #83
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS													
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	0.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2380	9	22	31
ANL-E	SRS	877	10.87	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	7016	37	76	113
BT	SRS	686	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	30184	204	328	532
ETEC	INEL/ANL-W	958	10.87	8.61	5878.71	26	2	3	1	42	142.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	0.31	55709.01	25332579.23	165473	12380	18010	6004	267832	94.58	A	42	19131	6377	MASS	6377	19131	23059232	59,051	214,681	273,732
INEL/ANL-W	WIPP	1392	0.31	48011.21	26284779.96	142608	10670	15522	5174	230824	113.87	A	42	16488	5496	MASS	5496	16488	15300864	50,893	142,451	193,344
KAPL	SRS	949	10.87	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	1898	9	21	30
LANL	WIPP	342	10.87	27023.49	13591943.62	80268	6006	8737	2913	129921	104.62	A	42	9282	3094	MASS	3094	9282	2116296	28,650	23,004	51,655
LBL	HANFORD	870	10.87	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	1740	9	19	28
LLNL	HANFORD	890	10.87	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	236740	1,232	2,573	3,805
MOUND	SRS	641	10.87	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	39742	287	432	719
MU	SRS	663	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	121210	787	1,318	2,105
ORNL	SRS	358	10.87	1124.94	728806.41	3342	250	364	122	5409	134.76	A	42	387	129	MASS	129	387	92364	1,195	1,004	2,199
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	SRS	569	10.87	2.10	2656.43	7	1	1	1	11	263.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
RFP	WIPP	704	10.87	6666.22	5587396.08	26336	1971	2867	956	42627	131.08	A	42	3045	1015	MASS	1015	3045	1429120	9,399	15,535	24,933
SNL-NM	LANL	104	10.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	0.31	28814.79	20367027.82	85589	6404	9316	3106	138533	147.02	B	35	11877	3959	MASS	3959	11877	11948262	36,660	111,238	147,899
TOTAL																	20,356	61,058	54,395,038	188,497	512,795	701,291

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory
Notes:
This table presents the costs for transporting CH TRU waste by truck.
Volumes and masses represent total stored and project volumes and masses.
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.
Shipment Configuration is dependent on the average drum mass.
A -- Maximum of 42 drums in three TRUPACT-II's
B -- Maximum of 35 drums in three TRUPACT-II's
C -- Maximum of 28 drums in two TRUPACT-II's
D -- Maximum of 21 drums in two TRUPACT-II's
E -- Maximum of 14 drums in two TRUPACT-II's
XX -- Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg/drum for calculations. Use Shipment Configuration E

Table P-71
CH Regionalized Alternative ID #94
Transportation Costs

								VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS												
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Revised Volume (m^3)	Mass (kg)	Revised Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	9.31	0.13	0.11	37.91	32.65	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	0	2380	9	22	31
ANL-E	SRS	877	10.87	31.31	26.96	20426.77	17588.65	81	6	9	3	130	135.71	A	42	12	4	MASS	4	12	7016	37	76	113
BT	SRS	686	10.87	159.90	137.68	110957.04	95540.56	409	31	45	15	662	144.34	B	35	57	19	MASS	19	57	26080	176	283	459
ETEC	INEL/ANL-W	958	10.87	8.61	7.41	5878.71	5061.92	23	2	3	1	36	142.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1809	9.31	55733.49	47989.82	54413131.92	46852916.96	142545	10685	15515	5172	230721	203.07	C	28	16482	8241	MASS	8241	16482	29799456	78,312	277,433	353,745
INEL/ANL-W	WIPP	1392	9.31	69042.65	59449.80	57334719.11	49358575.90	176594	13212	19220	6407	285817	172.73	C	28	20416	10208	MASS	10208	20416	28419072	94,526	264,582	359,108
KAPL	SRS	949	10.87	2.40	2.07	1659.81	1429.20	7	1	1	1	10	143.85	B	35	3	1	VOLUME	1	1	1898	9	21	30
LANL	WIPP	342	10.87	32641.55	28106.30	26855786.89	23122417.00	83485	6246	9087	3029	135127	171.13	C	28	9652	4826	MASS	4826	9652	3300984	44,889	33,882	80,370
LBL	HANFORD	870	10.87	6.57	5.65	4541.89	3910.84	17	2	3	1	28	143.85	B	35	3	1	VOLUME	3	2	9220	28	57	85
LLNL	HANFORD	890	10.87	1158.04	997.14	445343.02	383466.61	2962	222	323	108	4794	79.99	A	42	345	115	MASS	115	345	204700	1,065	2,225	3,290
MOUND	SRS	641	10.87	263.29	226.71	143644.06	123686.01	674	51	74	25	1090	113.48	A	42	78	26	MASS	26	78	33332	241	362	603
MU	SRS	963	10.87	2.14	1.84	1478.91	1273.43	6	1	1	1	9	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	812.60	527.46	428439.49	368911.68	1567	118	171	57	2536	145.47	B	35	219	73	MASS	73	219	104098	676	1,132	1,808
ORNL	SRS	358	10.87	1124.94	968.84	786615.97	677322.76	2878	216	314	105	4657	145.24	B	35	402	134	MASS	134	402	95944	1,241	1,043	2,284
PANTEX	LANL	335	10.87	0.62	0.54	431.55	371.59	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	0	670	9	7	17
PA	SRS	569	10.87	2.10	1.81	2656.43	2287.34	9	1	1	1	9	263.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
REP	WIPP	704	10.87	9148.83	7877.68	8458950.48	7283655.45	23400	1751	2547	849	37874	192.32	C	28	2706	1353	MASS	1353	2706	1905024	12,529	20,708	33,236
SNL-NM	LANL	104	19.65	17.11	14.73	11633.39	10189.25	44	4	6	2	71	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	29035.31	25001.11	48010942.34	41340254.00	74261	5556	8083	2695	120198	343.94	E	14	17172	8586	MASS	8586	17172	25912548	10,506	241,246	320,752
TOTAL																			73,598	67,561	89,825,720	311,117	845,183	1,156,280

[1]Source ORNL, 1993
[2]Source INEL, 1994b
[3]Source Personal Communication with Phil Gregory

Notes
This table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass.
A -- Maximum of 42 drums in three TRUPACT-IIS
B -- Maximum of 35 drums in three TRUPACT-IIs
C -- Maximum of 28 drums in two TRUPACT-IIs
D -- Maximum of 21 drums in two TRUPACT-IIs
E -- Maximum of 14 drums in two TRUPACT-IIs
XX Average drum mass exceeds expected upper limit Average drum weight set at 380 kg /drum for calculations Use Shipment Configuration E
Revised Mass and Volume Scaling Factor 0.861059

Table P-72
CH Regionalized Alternative ID #111
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS													
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	SRS	1190	9.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2380	9	22	31
ANL-E	SRS	877	10.87	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	7016	37	76	113
BT	SRS	686	10.87	159.90	110957.04	475	36	52	18	769	144.34	B	35	66	22	MASS	22	66	30184	204	328	532
ETEC	INEL/ANL-W	958	10.87	8.61	5878.71	26	2	3	1	42	142.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	9.31	55709.01	25332579.23	165473	12380	18010	6004	267832	94.58	A	42	19131	6377	MASS	6377	19131	23059232	59,051	214,681	273,732
INEL/ANL-W	WIPP	1392	9.31	48011.21	26284779.96	142608	10670	15522	5174	230824	13.87	A	42	16488	5496	MASS	5496	16488	15300864	50,893	142,451	193,344
KAPL	SRS	949	10.87	2.40	1659.81	8	1	2	1	12	43.85	B	35	3	1	VOLUME	1	2	1898	9	21	30
LANL	WIPP	342	10.87	27023.49	13591943.62	80268	6006	8737	2913	129921	104.62	A	42	9282	3094	MASS	3094	9282	2116296	28,650	23,004	51,655
LBL	HANFORD	870	10.87	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	1740	9	19	28
LLNL	HANFORD	890	10.87	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	236740	1,232	2,573	3,805
MOUND	SRS	641	10.87	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	39742	287	432	719
MU	SRS	863	10.87	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	1726	9	19	28
NTS	INEL/ANL-W	713	10.87	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	121210	787	1,318	2,105
ORNL	SRS	358	10.87	1124.94	728806.41	3342	250	364	122	5409	134.76	A	42	387	129	MASS	129	387	92364	1,195	1,004	2,199
PANTEX	LANL	335	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	670	9	7	17
PA	SRS	569	10.87	2.10	2656.43	7	1	1	1	11	263.11	E	14	2	1	VOLUME	1	1	1138	9	12	22
RFP	WIPP	704	10.87	8866.22	5587396.08	26336	1971	2867	956	42627	131.08	A	42	3045	1015	MASS	1015	3045	1429120	9,399	15,535	24,933
SNL-NM	LANL	104	19.65	17.11	11833.39	51	4	6	2	83	143.85	B	35	9	3	MASS	3	9	624	28	12	40
SRS	WIPP	1509	9.31	28814.79	20367027.82	85589	6404	9316	3106	138533	147.02	B	35	11877	3959	MASS	3959	11877	11948262	36,660	111,238	147,899
TOTAL																	20,356	61,058	54,395,038	188,497	512,785	701,281

[1]Source ORNL, 1993
[2]Source INEL, 1994b
[3]Source Personal Communication with Phil Gregory

Notes
The table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass
A -- Maximum of 42 drums in three TRUPACT-II's
B -- Maximum of 35 drums in three TRUPACT-II's
C -- Maximum of 28 drums in two TRUPACT-II's
D -- Maximum of 21 drums in two TRUPACT-II's
E -- Maximum of 14 drums in two TRUPACT-II's
XX -- Average drum mass exceeds expected upper limit Average drum weight set at 380 kg/drum for calculations Use Shipment Configuration E

Table P-73
CH Centralized Baseline
Transportation Costs

						VOLUME LIMITING CALCULATIONS				MASS LIMITING CALCULATIONS													
Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Volume (m^3)	Mass (kg)	Number of Drums	Number of SWBs	Number of TRUPACTs	Number of Shipments	Number of Drums	Average Drum Mass (kg)	Shipment Configuration[3]	Maximum Drums per Shipment[3]	Maximum Number of TRUPACTs[3]	Number of Shipments	Mass or Volume Limited?	Number of Shipments for Calcs	Number of TRUPACTs for Calcs	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
AMES	WIPP	1255	9.31	0.13	37.91	1	0	1	1	1	60.86	A	42	3	1	VOLUME	1	1	2510	9	23	33
ANL-E	WIPP	1455	9.31	31.31	20426.77	93	7	11	4	151	135.71	A	42	12	4	VOLUME	4	11	11640	37	108	145
BT	WIPP	1803	9.31	159.90	110957.04	475	36	52	18	769	44.34	B	35	66	22	MASS	22	66	79332	204	739	942
ETEC	WIPP	958	10.87	8.61	5878.71	26	2	3	1	42	42.05	B	35	6	2	MASS	2	6	3832	19	42	60
HANFORD	WIPP	1808	9.31	48286.36	22258182.80	143425	10731	15611	5204	232146	95.88	A	42	16584	5528	MASS	5528	16584	19989248	51,189	186,100	237,289
INEL/ANL-W	WIPP	1392	9.31	40379.52	20665074.44	119940	8974	13055	4352	194133	106.45	A	42	13869	4623	MASS	4623	13869	12870432	42,809	119,824	162,633
KAPL	WIPP	2208	9.31	2.40	1659.81	8	1	2	1	12	143.85	B	35	3	1	VOLUME	1	2	4416	9	41	50
LANL	WIPP	342	10.87	21131.01	9834518.77	62766	4696	6832	2278	101592	96.80	A	42	7257	2419	MASS	2419	7257	1654596	22,400	17,985	40,385
LBL	WIPP	1522	9.31	6.57	4541.89	20	2	3	1	32	143.85	B	35	3	1	VOLUME	1	3	3044	9	29	38
LLNL	WIPP	1452	9.31	1158.04	445343.02	3440	258	375	125	5568	79.99	A	42	399	133	MASS	133	399	386232	1,232	3,596	4,827
MOUND	WIPP	1557	9.31	263.29	143644.06	783	59	86	29	1266	113.48	A	42	93	31	MASS	31	93	96534	287	899	1,186
MU	WIPP	1145	9.31	2.14	1478.91	7	1	1	1	11	143.85	B	35	3	1	VOLUME	1	1	2290	9	21	31
NTS	WIPP	1214	9.31	612.60	428439.49	1820	137	199	67	2946	145.47	B	35	255	85	MASS	85	255	206380	787	1,921	2,708
ORNL	WIPP	1521	9.31	1124.94	728806.41	3342	250	364	122	5409	134.76	A	42	387	129	MASS	129	387	392418	1,195	3,653	4,848
PANTEX	WIPP	443	10.87	0.62	431.55	2	0	1	1	3	143.85	B	35	3	1	VOLUME	1	1	886	9	10	19
PA	WIPP	1360	9.31	2.10	2656.43	7	1	1	1	11	233.11	E	14	2	1	VOLUME	1	1	2720	9	25	35
RFETS	WIPP	704	10.87	6249.25	3151674.56	18563	1389	2021	674	30045	134.90	A	42	2148	716	MASS	716	2148	1008128	6,630	10,958	17,589
SNL NM	WIPP	311	10.87	17.11	11833.39	51	4	6	2	83	113.85	B	35	9	3	MASS	3	9	1866	28	20	48
SRS	WIPP	1509	9.31	26933.46	19202207.74	80001	5986	8708	2903	129488	148.29	B	35	11100	3700	MASS	3700	11100	11166600	34,262	103,961	138,223
TOTAL																	17,401	52,193	47,883,104	161,133	449,956	611,089

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b
[3]Source: Personal Communication with Phil Gregory
Notes
This table presents the costs for transporting CH TRU waste by truck
Volumes and masses represent total stored and project volumes and masses
Volume and mass at sites that receive waste includes the waste received for treatment and/or interim storage from other sites
Shipment Configuration is dependent on the average drum mass
A -- Maximum of 42 drums in three TRUPACT-II'S
B -- Maximum of 35 drums in three TRUPACT-II's
C -- Maximum of 28 drums in two TRUPACT-II's
D -- Maximum of 21 drums in two TRUPACT-II's
E -- Maximum of 14 drums in two TRUPACT-II's
XX -- Average drum mass exceeds expected upper limit. Average drum weight set at 380 kg/drum for calculations. Use Shipment Configuration E

TABLE P-74

RH DECENTRALIZED BASELINE TRANSPORTATION COSTS

Origin	Destination	One-Way Mileage[1]	CPLM[2] ($/mile)	Number of Shipments	Total Miles Traveled	Fixed Costs ($K)	Variable Costs ($K)	Total Costs ($K)
BATELLE	ORNL	409	10.87	123	100,614	1,139	1,094	2,233
BT	ORNL	607	10.87	3	3,642	28	40	67
HANFORD	WIPP	1,808	9.31	5,176	18,716,416	47,930	174,250	222,180
INEL/ANL-W	WIPP	1,392	9.31	109	303,456	1,009	2,825	3,835
KAPL	ORNL	884	10.87	57	100,776	528	1,095	1,623
LANL	WIPP	342	10.87	249	170,316	2,306	1,851	4,157
ORNL	WIPP	1,521	9.31	2,185	6,646,770	20,233	61,881	82,115
SRS	WIPP	1,509	9.31	56	169,008	519	1,573	2,092
TOTAL				**7,958**	**26,210,998**	**73,691**	**244,610**	**318,301**

[1]Source: ORNL, 1993
[2]Source: INEL, 1994b

Notes:
This table presents the costs for transporting CH TRU waste by truck.
Assume that shipments will be volume limited.
Volumes represent total stored and projected volumes.
Volume at sites that receive waste includes the waste received for treatment and/or interim storage from other sites.

TABLE P-75

BACKFILL EMPLACEMENT COST TOTALS SUMMARY

Alternative ID#	Capital Equipment	Design and Development	Operations and Maintenance	Total Cost[1] ($K)
33	1,007	302	43,114	55,527
35a	1,199	360	67,352	86,139
35b	1,200	360	67,352	86,141
77a	1,110	333	46,871	60,394
77b	760	228	24,052	31,299
77c	820	246	28,923	34,487
77d	805	241	27,669	35,894
83	981	294	41,241	53,146
94b	1,165	350	39,051	50,707
94c	1,418	425	61,025	78,536
94d	1,679	504	61,104	79,057
94e	1,037	311	32,462	42,262
94f	1,131	340	37,355	48,533
111	910	273	35,839	46,272

[1]Includes a 25% contingency factor.

TABLE P-76

WIPP WASTE HANDLING COMPARATIVE COST IMPACTS

Alternative ID#	Cost Impacts ($K)[1]
1[2]	(61,440)
6[2]	(61,440)
10 (Decentralized, Regionalized)[2]	(80,640)
10 (Centralized)[2]	(61,440)
33	0
35(a-b)	0
77(a-d)[2]	(621,440)
83	0
94(a-f) (Decentralized, Regionalized)[2,3]	(39,322)
94(a-f) (Centralized)	(61,440)
111	0

Notes.
[1] Values in parentheses represent a reduction from the baseline costs.
[2] The emplacement of waste occurs during 25 years due to processing facility construction estimation of approximately 10 years.
[3] The waste handling for the WIPP occurs for approximately 28.6 years which exceeds the 35 year time constraint (10 year process facility start + 25 year emplacement).

TABLE P-77

WIPP WASTE EMPLACEMENT WORKOFF AND LABOR COST ESTIMATE

Engineered Alternative	Case	Number of CH shipments[1]	Number TRUPACT-IIs per day	Number of FTEs for operations[2]	Change in emplacement labor cost ($K)
Baseline, 33, 35(a,b), 83, 111	Decentralized	19,944	7.12	64	215,040
	Regionalized	19,944	7.12	64	215,040
	Centralized	17,401	6.21	64	215,040
1[3]	Decentralized	19,571	6.94	64	153,600
	Regionalized	19,548	6.93	64	153,600
	Centralized	17,401	8.70	64	153,600
6[3]	Decentralized	18,794	8.52	64	153,600
	Regionalized	18,838	8.58	64	153,600
	Centralized	17,401	8.70	64	188,160
10[3]	Decentralized	17,174	5.72	56	134,400
	Regionalized	17,186	5.80	56	134,400
	Centralized	17,401	8.70	64	153,600
77(a-d)[3]	Decentralized	19,571	6.94	64	153,600
	Regionalized	19,548	6.93	64	153,600
	Centralized	17,401	8.70	64	153,600
94(a-f)	Decentralized[3,4]	33,225	9.70	64	175,718
	Regionalized[3,4]	33,214	9.70	64	175,718
	Centralized	17,401	9.70	64	153,600

Notes.
[1] The number of shipments is for waste transported to the WIPP site.
[2] The number of FTEs is based on the crew directly involved in emplacement activities only.
[3] The number of TRUPACT-IIs and dollars for emplacement is based on a 25 year emplacement activity due to the lag in processing capability.
[4] The waste emplacement for this alternative exceeds the 25 year constraint by 3.6 years.

APPENDIX Q
WASTE PROCESSING SCHEDULE ANALYSIS

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WASTE PROCESSING SCHEDULE ANALYSIS

1.0 INTRODUCTION

1.1 SCHEDULE DEVELOPMENT

The schedules for implementing the waste processing engineered alternatives (EA) were evaluated using PRIMAVERA, a commonly used computer application. Since the waste processing EAs include the construction of major capital facilities, it was assumed that these would be line item projects, as defined by DOE Order 4700.1, *Project Management System* (DOE 1992a). The schedules for these projects include activities required to take a project from initial conception through design, permitting, construction, operations, and final decontamination and decommissioning. *These activities are grouped into the following summary-level activities:*

- **Project Conception and Funding Request**—This includes preparing a preconceptual design, conducting laboratory scale and pilot scale testing (if required), and requesting and receiving approval for line item funding.

- **National Environmental Policy Act Process**—The National Environmental Policy Act (NEPA) requires that any major federal action be analyzed to provide decision makers information on the environmental impact of the proposed action. The level of analysis required for each action may vary depending on the potential impacts, but it was assumed that an Environmental Impact Statement (EIS) would be required for each of the waste processing EAs. Preparing an EIS includes preparing an Action Description Memorandum (ADM), scoping the analysis, preparing a draft and a final EIS, soliciting and responding to comments, and ultimately issuing a Record of Decision (ROD).

- **Other Permitting**—To demonstrate compliance with the Clean Air Act (CAA) and other federal and state regulations, several plans and regulatory documents must be prepared, including a Health and Safety Plan, Quality Assurance Program Plan (QAPP), Air Pollution Emission Notices (APENs), a determination that the project complies with National Emission Standards for Hazardous Air Pollutants (NESHAPS), and a Prevention of Significant Deterioration (PSD) permit.

- **Resource Conservation and Recovery Act Permitting**—The Resource Conservation and Recovery Act (RCRA) requires that any treatment/storage/disposal (TSD) facility for hazardous waste must operate under a RCRA permit. Most DOE facilities are already operating under a RCRA permit, so this section illustrates the required activities to modify an existing RCRA permit.

- **Safety Analysis Review**—DOE Order 5480.23, *Nuclear Safety Analysis Reports* (DOE 1994c) requires that safety analyses be developed that establish and evaluate the adequacy of the safety bases for nuclear facilities. The results of the safety analysis are documented in a Safety Analysis Report (SAR). A SAR is prepared in stages which include a Preliminary Safety Analysis Report (PSAR) and a Final Safety Analysis Report (FSAR).

- **Design & Construction**—This includes the activities required for development of a detailed design and for facility construction. Construction could not begin until the RCRA permit modification is approved.

- **Procedures Development and Personnel Training**—DOE Order 5480.19, *Conduct of Operations* (DOE 1992b) requires that operations at DOE facilities be conducted in accordance with written and approved directives, plans, and/or procedures, and that personnel be adequately trained to perform their assigned tasks. The activities included in the schedule include the development of plans and procedures for equipment testing, data management, operations, and maintenance, and the training of personnel.

- **Equipment and Facility Testing**—All equipment and systems must be tested, both individually and in combination, to assure that they perform as planned and to assure that the facility will operate safely. Testing includes the performance of system operations (SO) tests and conduct of an Operational Readiness Review (ORR), as required by DOE Order 5480.31, *Startup and Restart of Nuclear Facilities* (DOE 1993).

- **Operations**—Operations includes the activities required for the retrieval, characterization, repackaging, treatment, certification, storage, and shipment of transuranic (TRU) waste. It was assumed that facilities would have an operating life of 20 years.

- **Decontamination and Decommissioning**—Decontamination and Decommissioning (D&D) includes deactivating the facilities after their operational lives have expired and decontaminating the facility equipment, structures, and surrounding areas so that the area can be safety used for another purpose.

1.2 SCHEDULING ASSUMPTIONS

In the process of developing the schedules for the various waste processing EAs, it was necessary to make many assumptions regarding the relationships between activities (e.g., which activities must be complete before another could begin). Tables Q-1 through Q-5 (see Attachment 1) present the assumptions used for each major element of each waste processing EA.

1.3 ACTIVITY DURATIONS

A key element to establishing schedules for waste processing EAs is to estimate the time required to accomplish each activity. For activities which are the same or similar to activities that have been accomplished as part of previous projects, estimating the duration of the activity based on historical performance information is appropriate. The critical path method (CPM) is best suited for this type of situation (see Section 1.3.1). Each of the waste processing EAs, with the exception of Alternative 10 (plasma melting), involves activities and processes that are well understood and for which historical data is available. Therefore, CPM was used to estimate the duration of these activities.

Little or no scheduling information is available for processes similar to utilizing plasma melting to treat mixed TRU waste. The program evaluation review technique (PERT) was used to develop time estimates for critical plasma melting activities (see Section 1.3.2). The PERT techniques use multiple time estimates in order to take into account time variability. PERT time estimates were also developed for major activities that were assigned CPM durations to assure that the CPM estimates are reasonable.

Activity schedules and durations for possible scenarios are presented in Figures Q-1 through Q-5.

1.3.1 Critical Path Method

The critical path method (CPM) of scheduling involves developing a network model of the project by organizing the work to be accomplished into logical activities and linking activities to other activities in ways to illustrate their relationships (e.g., by defining the activities that must be accomplished before another can begin). The CPM technique involves using a single estimate for the time duration of an activity. This estimate is best based on historical information from similar projects. Time estimates were based on schedule information from a number of projects including: 1) the environmental restoration, waste management, and technology development programs at the Rocky Flats Environmental Technology Site (RFETS), 2) the RFETS Site Treatment Plan, 3) the Hanford High-Level Waste Tanks, and 4) the Pit 9 Comprehensive Demonstration at the Idaho National Engineering Laboratory.

In this analysis, Alternative 6 (shred and compact) was used as the basis for establishing baseline time estimates. The durations for major components (i.e., Design, Construction, and D&D) of other EAs were adjusted to account for the complexity and anticipated difficulty of implementing the different EAs, as shown below:

Alternative	Adjustment to Title I and Title II Design, Construction, and Internal D&D.
#6 Shred and compact	NA
Baseline	0%
#1 Supercompact	+12%
#94 Enhanced cement and shred/add clay	+10%

1.3.2Program Evaluation Review TechniqueTo determine appropriate times to accomplish major activities, three time estimates were developed, an optimistic estimate (T_o), a most probable estimate (T_m), and a pessimistic estimate (T_p). The time estimate used for the schedule analysis (T_e) was calculated by the following formula:

$$T_e = [T_o + T_m(4) + T_p]/6$$

Table Q-6 shows the preliminary PERT time estimates for Alternative #6 (Shred and Compact).

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Act ID	Activity Description	Orig Dur	Early Start
WIPP TRU FACILITY			
05	WIPP TRU FACILITY	10,451*	14JUL88A
PROJECT CONCEPT/FUNDING REQUEST PROCESS			
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A
10	PRECONCEPTUAL DESIGN	250	14JUL88A
15	DECISION TO PROCEED	0	14JUL88A
20	DEVELOP & SUBMIT FUNDING REQUEST	248	14JUL88A
25	BENCH SCALE TESTING	640	17JUL89A
30	DETERMINE PROJECT FEASIBILITY	20	28JAN92A
35	PILOT SCALE	840	25FEB92A
40	DETERMINE PROJECT FEASIBILITY	90	01JUN95A
45	FUNDING REQUEST	60	09OCT95
50	DETERMINE LINE ITEM FUNDING	248	04JAN96
51	DESIGN CRITERIA COMPLETE	0	
55	PRIORITIZATION & SELECTION OF PROJECTS	60	23DEC96
60	GAIN FUNDING APPROVAL	248	19MAR97
65	OPERATIONAL REQUIREMENTS DOCUMENT	60	10MAR98
70	DESIGN INPUT & REVIEW/APPROVAL	20	27AUG98
NEPA PROCESS			
74	NEPA PROCESS	530*	04JAN96
75	PREPARE ENVIRONMENTAL CHECKLIST	60	04JAN96
80	NEPA COMPLIANCE COMMITTEE REVIEW	10	28MAR96
100	PREPARE ADM	60	11APR96
105	NEPA DETERMINATION DOE REVIEW ADM	30	08JUL96
165	PREPARE NOTICE OF INTENT	10	19AUG96
170	PUBLIC SCOPING	30	03SEP96
175	PREPARE IMPLEMENTATION PLAN	60	15OCT96
180	PREPARE DRAFT ENVIRONMENTAL IMPACT	120	10JAN97
185	DOE REVIEW DRAFT ENVIR. IMPACT	30	30JUN97
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97
195	STATE REVIEW & PUBLIC COMMENT PERIOD	60	12AUG97
200	REVIEW & FINALIZE ENV. IMPACT	60	05NOV97
205	ISSUE ROD	0	
OTHER PERMITTING			
434	MISCELLANEOUS PERMITTING	881*	10MAR98
440	HEALTH AND SAFETY PLAN	60	10MAR98
435	PREPARE QAPP FOR IMPLEMENTATION	60	10MAR98
460	PREPARE OPERATING QAPP	60	03JUN98
465	REVIEW/APPROVE IMPLEMENTATION PHASE	30	03JUN98
485	REVIEW AND APPROVE OPERATING QAPP	30	27AUG98
486	QAPP COMPLETE	0	
445	UPDATE/REVISE PROGRAM PLAN	60	10MAR98
470	DOE REVIEW PROGRAM PLAN	30	03JUN98
490	FINALIZE PROGRAM PLAN	30	16JUL98
450	APENs DETERMINATION	120	10MAR98
475	AGENCY REVIEWS APENs	60	27AUG98
495	FINALIZE APENs	40	20NOV98
451	APENs DETERMINATION COMPLETE	0	

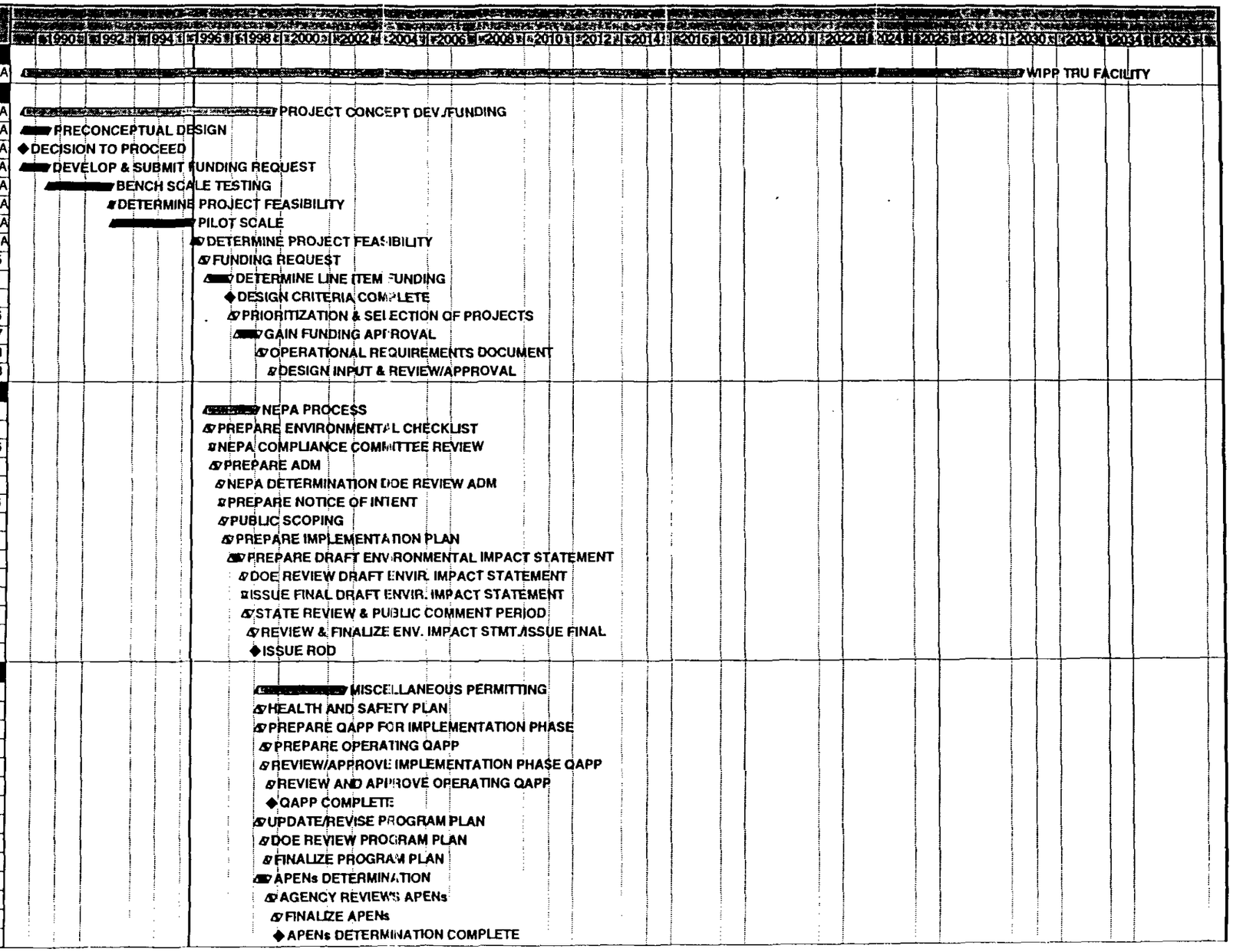

Figure Q-1a
Basecase Scenario

ACT ID	Activity Description	Orig Dur	Early Start
455	NESHAPS DETERMINATION	150	07SEP99
480	AGENCY REVIEWS NESHAPS	60	07APR00
500	FINALIZE NESHAPS	40	03JUL00
501	NESHAPS DETERMINATION COMPLETE	0	
502	PREPARE PSD PERMIT APPLICATION	250	07SEP99
503	PSD PERMIT REVIEW and APPROVAL	250	29AUG00
504	PSD PERMIT COMPLETE	0	
RCRA PERMITTING			
338	RCRA PERMITTING PROCESS	530*	29AUG00
339	BEGIN RCRA PERMIT MOD	0	29AUG00
380	PREPARE RCRA PERMIT MODIFICATION	140	29AUG00
385	DOE REVIEWS PERMIT MOD	30	19MAR01
390	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	90	30APR01
395	PUBLIC COMMENT PERIOD	60	06SEP01
400	PUBLIC HEARING	2	06SEP01
405	RESPOND TO COMMENTS & FINALIZE PERMIT	90	30NOV01
410	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	120	09APR02
430	PERMIT APPROVAL	0	
SAFETY ANALYSIS REVIEW			
209	SAFETY ANALYSIS REVIEW	550*	03JUN98
210	PREPARE HAZARD CLASSIFICATION	60	03JUN98
215	PSAR DEVELOPMENT	120	27AUG98
220	TSAR DEVELOPMENT	120	27AUG98
225	CRITICALITY SAFETY ASSESSMENT	120	27AUG98
230	ORC REVIEW	40	17FEB99
235	DOE REVIEW & APPROVE PSAR	40	14APR99
240	FSAR DEVELOPMENT	250	10JUN99
245	DOE REVIEW	40	02JUN00
DESIGN & CONSTRUCTION			
249	DESIGN & CONSTRUCTION	1,571*	25SEP98
250	BID/NEGOTIATE & AWARD DESIGN	90	25SEP98
260	PREPARE TITLE I DESIGN	151	03FEB99
265	PREPARE TITLE II DESIGN	375	07SEP99
270	LONG LEAD PROCUREMENT	210	07SEP99
266	TITLE II DESIGN COMPLETE	0	
275	PREPARE CONSTRUCTION PACKAGE	21	26FEB01
280	BID/NEGOTIATE & AWARD CONSTRUCTION	90	27MAR01
285	RCRA HOLD	0	
289	BEGIN CONSTRUCTION	0	27SEP02
290	CONSTRUCTION	450	27SEP02
291	CONSTRUCTON COMPLETE	0	
295	FINAL INSPECTIONS	10	02JUL04
300	TITLE III AS-BUILTS	90	19JUL04
PROCEDURES/TRAINING			
304	OPERATION PROCEDURES DEVELOPMENT &	180*	02JUL04
305	PREPARE S.O. TEST PLAN & PROCEDURES	60	02JUL04
310	DEVELOP DATA MANAGEMENT PROCEDURES	60	02JUL04
315	DEVELOP TECHNICAL PROCEDURES	60	02JUL04

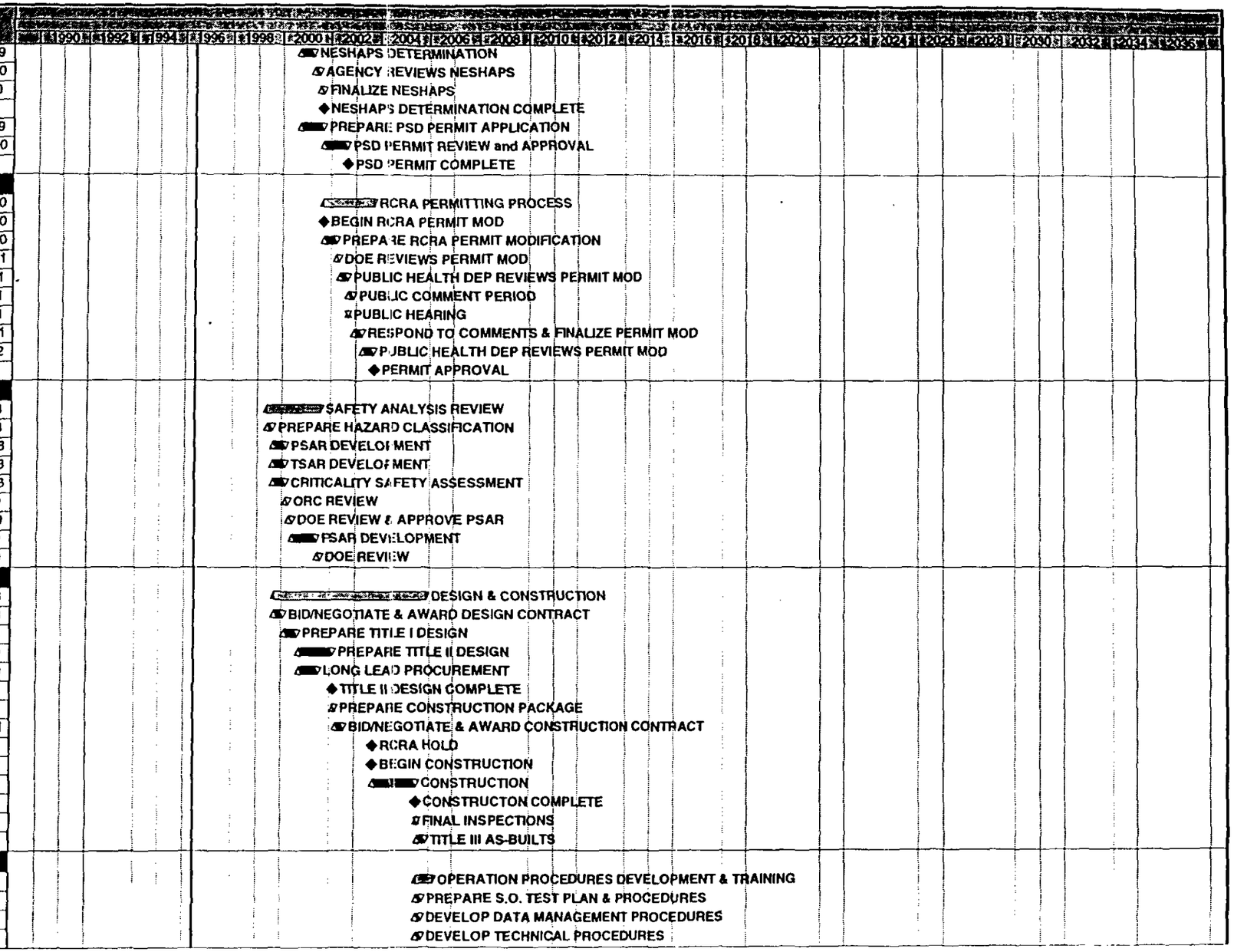

Figure Q-1b
Basecase Scenario

Act ID	Activity Description	Orig Dur	Early Start
320	DEVELOP MAINTANENCE PROCEDURES	60	28SEP04
330	DEVELOP OPERATOR TRAINING PROGRAM	60	28SEP04
325	MAINTENANCE TRAINING	40	22DEC04
335	TRAIN OPERATORS	60	22DEC04
TESTING			
507	TESTING	460*	28SEP04
509	PERFORM S.O. TEST	120	28SEP04
510	ORR	160	18MAR05
520	PROCESS CONTROL PLAN	40	02NOV05
525	REVIEW AND APPROVAL OF ORR	140	02NOV05
530	ORR COMPLETE	0	
535	START-UP	40	22MAY06
OPERATIONS			
539	OPERATIONS	5,100*	19JUL06
545	BENEFICIAL OCCUPANCY	20	19JUL06
550	SYSTEM/OPERATOR CERTIFICATION	60	19JUL06
555	FINAL WASTE ANALYSIS/CERTIFICATION	20	19JUL06
560	IMPLEMENT SYSTEM USAGE	0	19JUL06
565	FACILITY ACCEPTANCE	0	12OCT06
570	FACILITY OPERATION	5,040	12OCT06
567	OPERATIONS COMPLETE	0	
D&D			
574	D&D	760*	22JUL26
575	FACILITY DEACTIVATION	120	22JUL26
580	ENGINEERING DESIGN	120	12JAN27
585	INTERNAL D&D OPERATIONS	220	30JUN27
590	STRUCTURAL D&D OPERATIONS	120	10MAY28
595	SUB-GRADE D&D OPERATIONS	120	30OCT28
600	VERIFICATION OF CLOSEOUT	60	19APR29

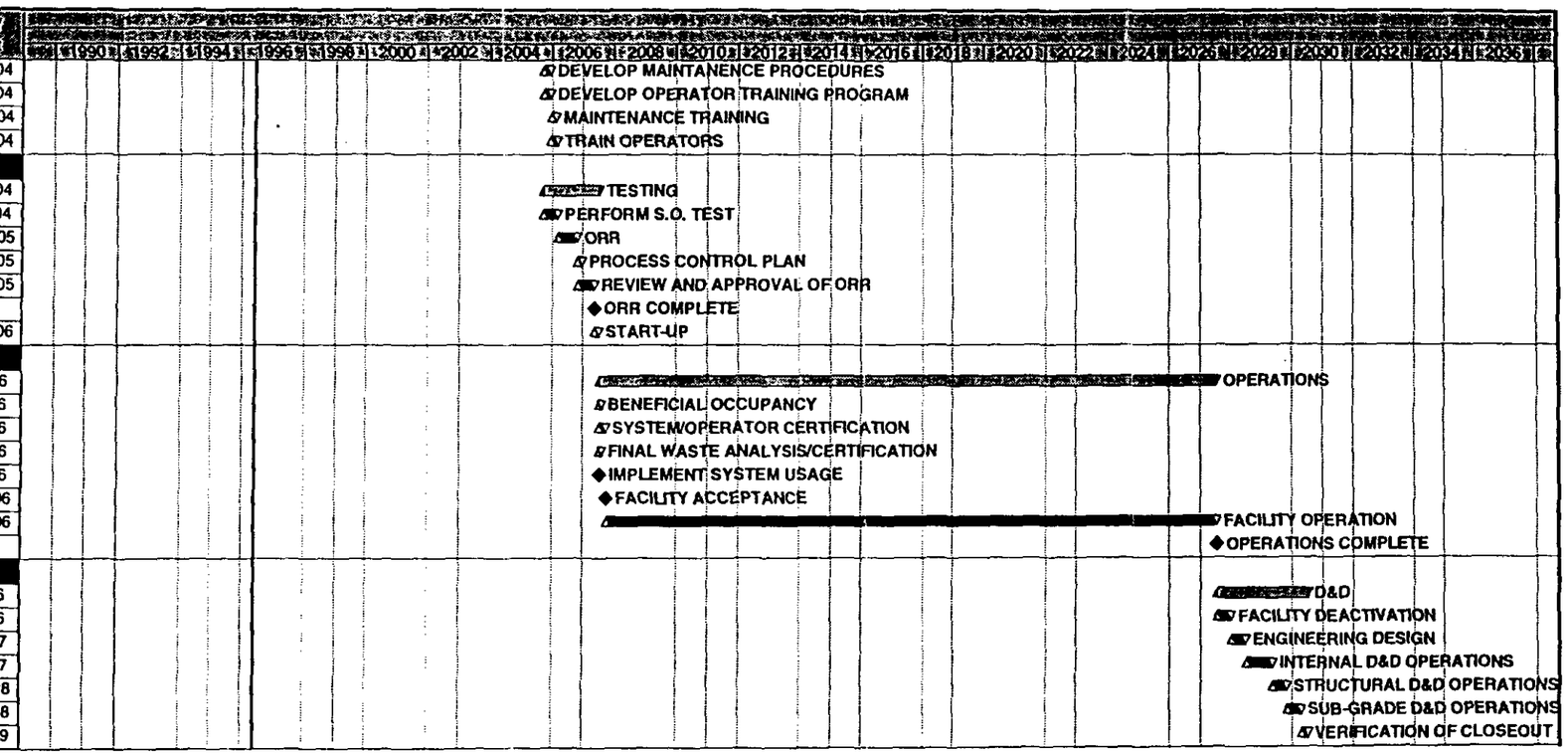

Figure Q-1c
Basecase Scenario

ACT ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,681*	14JUL88A	07JUN30
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
10	PRECONCEPTUAL DESIGN	250	14JUL88A	17JUL89A
15	DECISION TO PROCEED	0	14JUL88A	
20	DEVELOP & SUBMIT FUNDING REQUEST	248	14JUL88A	14JUL89A
25	BENCH SCALE TESTING	640	17JUL89A	27JAN92A
30	DETERMINE PROJECT FEASIBILITY	20	28JAN92A	24FEB92A
35	PILOT SCALE	840	25FEB92A	31MAY95A
40	DETERMINE PROJECT FEASIBILITY	90	01JUN95A	06OCT95
45	FUNDING REQUEST	60	09OCT95	03JAN96
50	DETERMINE LINE ITEM FUNDING	248	04JAN96	20DEC96
51	DESIGN CRITERIA COMPLETE	0		20DEC96
55	PRIORITIZATION & SELECTION OF PROJECTS	60	23DEC96	18MAR97
60	GAIN FUNDING APPROVAL	248	19MAR97	09MAR98
65	OPERATIONAL REQUIREMENTS DOCUMENT	60	10MAR98	02JUN98
70	DESIGN INPUT & REVIEW/APPROVAL	20	27AUG98	24SEP98
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
75	PREPARE ENVIRONMENTAL CHECKLIST	60	04JAN96	27MAR96
80	NEPA COMPLIANCE COMMITTEE REVIEW	10	28MAR96	10APR96
100	PREPARE ADM	60	11APR96	05JUL96
105	NEPA DETERMINATION DOE REVIEW ADM	30	08JUL96	16AUG96
165	PREPARE NOTICE OF INTENT	10	19AUG96	30AUG96
170	PUBLIC SCOPING	30	03SEP96	14OCT96
175	PREPARE IMPLEMENTATION PLAN	60	15OCT96	09JAN97
180	PREPARE DRAFT ENVIRONMENTAL IMPACT	120	10JAN97	27JUN97
185	DOE REVIEW DRAFT ENVIR. IMPACT	30	30JUN97	11AUG97
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
195	STATE REVIEW & PUBLIC COMMENT PERIOD	60	12AUG97	04NOV97
200	REVIEW & FINALIZE ENV. IMPACT	60	05NOV97	30JAN98
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	899*	10MAR98	17SEP01
440	HEALTH AND SAFETY PLAN	60	10MAR98	02JUN98
435	PREPARE QAPP FOR IMPLEMENTATION	60	10MAR98	02JUN98
460	PREPARE OPERATING QAPP	60	03JUN98	26AUG98
465	REVIEW/APPROVE IMPLEMENTATION PHASE	30	03JUN98	15JUL98
485	REVIEW AND APPROVE OPERATING QAPP	30	27AUG98	08OCT98
486	QAPP COMPLETE	0		08OCT98
445	UPDATE/REVISE PROGRAM PLAN	60	10MAR98	02JUN98
470	DOE REVIEW PROGRAM PLAN	30	03JUN98	15JUL98
490	FINALIZE PROGRAM PLAN	30	16JUL98	26AUG98
450	APENs DETERMINATION	120	10MAR98	26AUG98
475	AGENCY REVIEWS APENs	60	27AUG98	19NOV98
495	FINALIZE APENs	40	20NOV98	19JAN99
451	APENs DETERMINATION COMPLETE	0		19JAN99

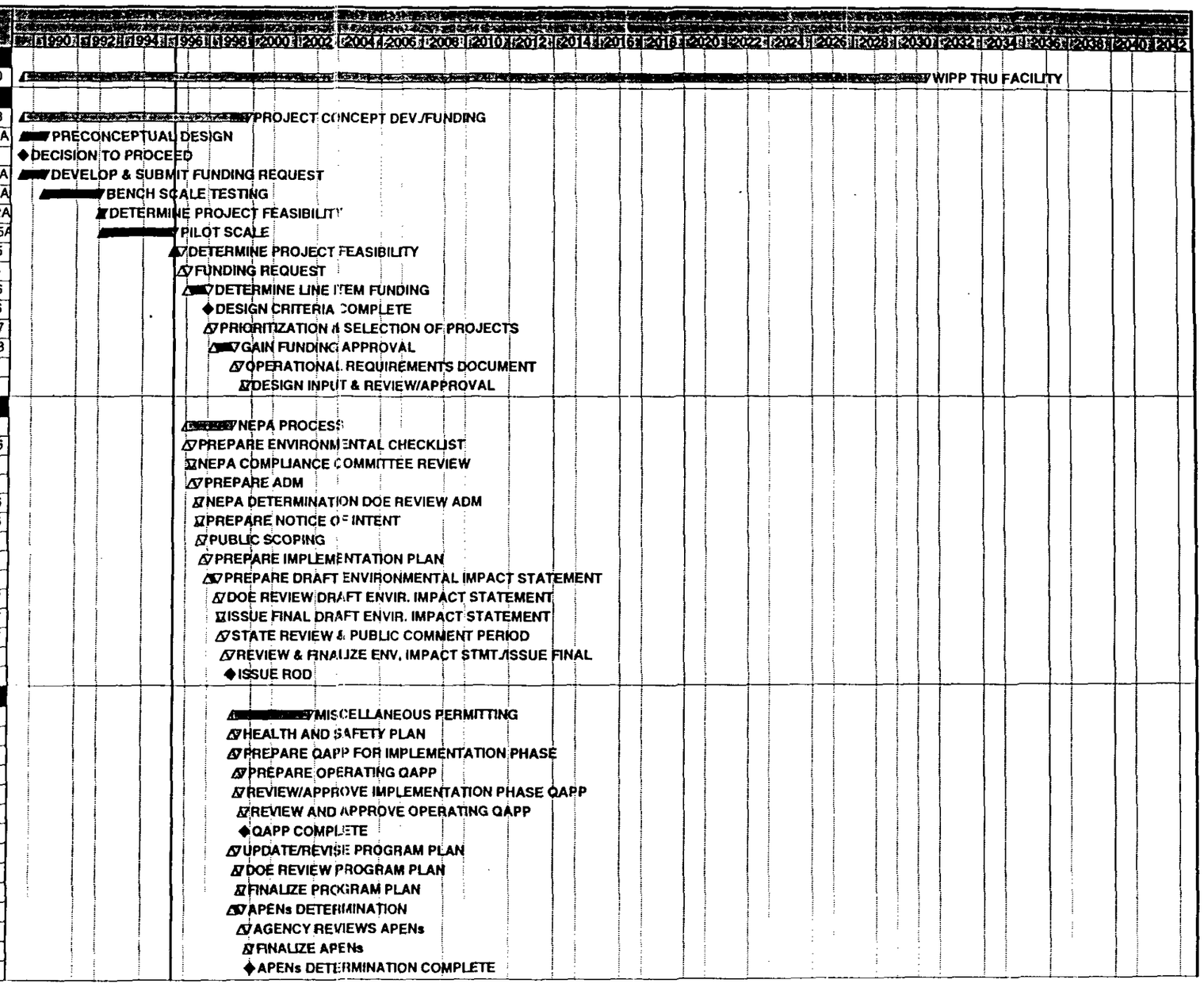

Figure Q-2a
Supercompaction Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
455	NESHAPS DETERMINATION	150	01OCT99	02MAY00
480	AGENCY REVIEWS NESHAPS	60	03MAY00	27JUL00
500	FINALIZE NESHAPS	40	28JUL00	22SEP00
501	NESHAPS DETERMINATION COMPLETE	0		22SEP00
502	PREPARE PSD PERMIT APPLICATION	250	01OCT99	22SEP00
503	PSD PERMIT REVIEW and APPROVAL	250	25SEP00	17SEP01
504	PSD PERMIT COMPLETE	0		17SEP01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	28NOV00	26DEC02
339	BEGIN RCRA PERMIT MOD	0	28NOV00	
380	PREPARE RCRA PERMIT MODIFICATION	140	28NOV00	14JUN01
385	DOE REVIEWS PERMIT MOD	30	15JUN01	27JUL01
390	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	90	30JUL01	04DEC01
395	PUBLIC COMMENT PERIOD	60	05DEC01	28FEB02
400	PUBLIC HEARING	2	05DEC01	06DEC01
405	RESPOND TO COMMENTS & FINALIZE PERMIT	90	01MAR02	08JUL02
410	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	120	09JUL02	26DEC02
430	PERMIT APPROVAL	0		26DEC02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
210	PREPARE HAZARD CLASSIFICATION	60	03JUN98	26AUG98
215	PSAR DEVELOPMENT	120	27AUG98	16FEB99
220	TSAR DEVELOPMENT	120	27AUG98	16FEB99
225	CRITICALITY SAFETY ASSESSMENT	120	27AUG98	16FEB99
230	ORC REVIEW	40	17FEB99	13APR99
235	DOE REVIEW & APPROVE PSAR	40	14APR99	09JUN99
240	FSAR DEVELOPMENT	250	10JUN99	01JUN00
245	DOE REVIEW	40	02JUN00	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,744*	25SEP98	28JUL05
250	BID/NEGOTIATE & AWARD DESIGN	90	25SEP98	02FEB99
260	PREPARE TITLE I DESIGN	169	03FEB99	30SEP99
265	PREPARE TITLE II DESIGN	420	01OCT99	23MAY01
270	LONG LEAD PROCUREMENT	210	01OCT99	27JUL00
266	TITLE II DESIGN COMPLETE	0		23MAY01
275	PREPARE CONSTRUCTION PACKAGE	21	24MAY01	22JUN01
280	BID/NEGOTIATE & AWARD CONSTRUCTION	90	25JUN01	30OCT01
285	RCRA HOLD	0		26DEC02
289	BEGIN CONSTRUCTION	0	27DEC02	
290	CONSTRUCTION	560	27DEC02	08MAR05
291	CONSTRUCTION COMPLETE	0		08MAR05
295	FINAL INSPECTIONS	10	09MAR05	22MAR05
300	TITLE III AS-BUILTS	90	23MAR05	28JUL05
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	09MAR05	18NOV05
305	PREPARE S.O. TEST PLAN & PROCEDURES	60	09MAR05	01JUN05
310	DEVELOP DATA MANAGEMENT PROCEDURES	60	09MAR05	01JUN05
315	DEVELOP TECHNICAL PROCEDURES	60	09MAR05	01JUN05

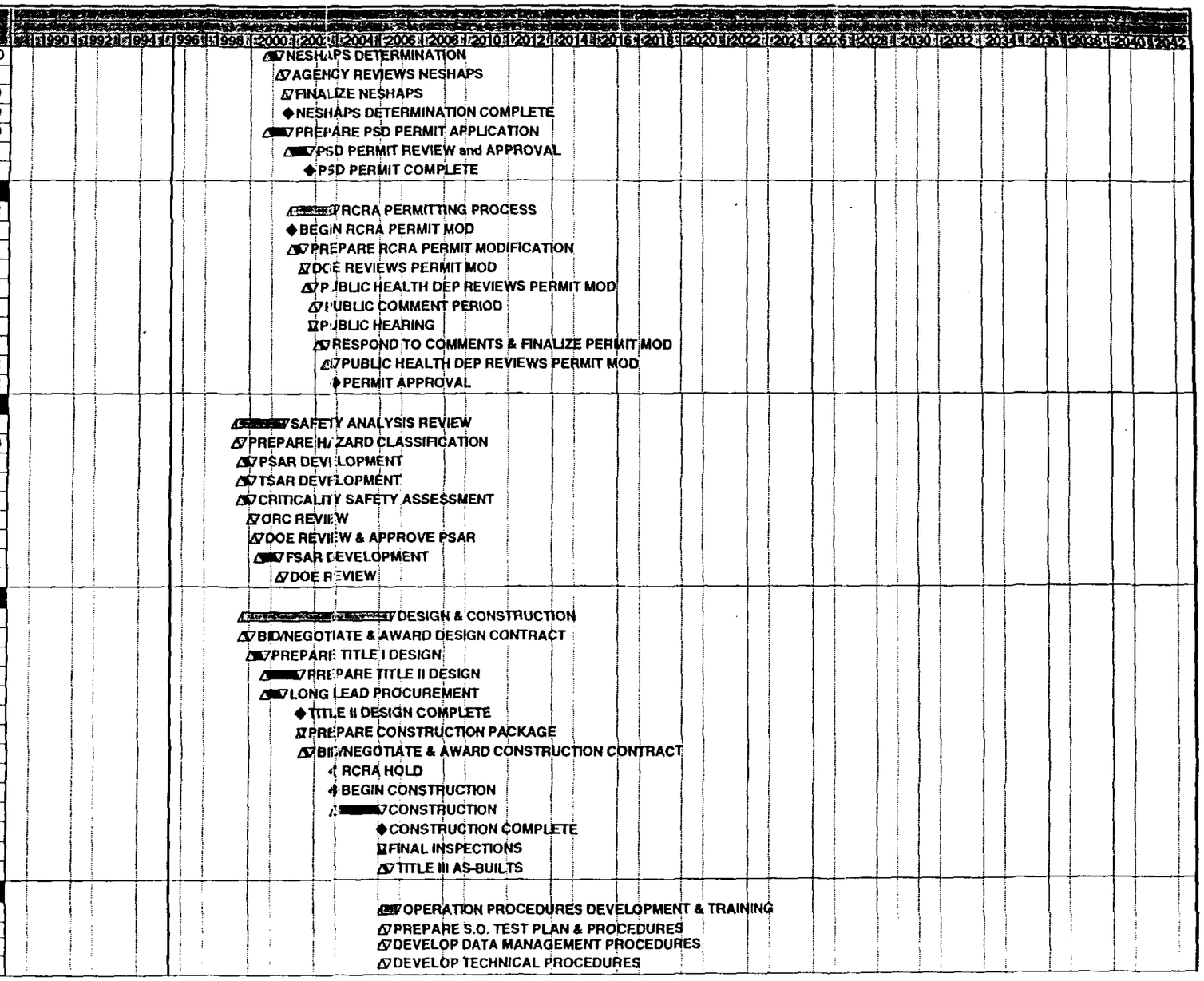

Figure Q-2b
Supercompaction Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
320	DEVELOP MAINTENANCE PROCEDURES	60	02JUN05	25AUG05
330	DEVELOP OPERATOR TRAINING PROGRAM	60	02JUN05	25AUG05
325	MAINTENANCE TRAINING	40	26AUG05	21OCT05
335	TRAIN OPERATORS	60	26AUG05	18NOV05
TESTING				
507	TESTING	460*	02JUN05	22MAR07
509	PERFORM S.O. TEST	120	02JUN05	18NOV05
510	ORR	160	21NOV05	07JUL06
520	PROCESS CONTROL PLAN	40	10JUL06	01SEP06
525	REVIEW AND APPROVAL OF ORR	140	10JUL06	25JAN07
530	ORR COMPLETE	0		25JAN07
535	START-UP	40	26JAN07	22MAR07
OPERATIONS				
539	OPERATIONS	5,100*	23MAR07	25MAR27
545	BENEFICIAL OCCUPANCY	20	23MAR07	19APR07
550	SYSTEM/OPERATOR CERTIFICATION	60	23MAR07	15JUN07
555	FINAL WASTE ANALYSIS/CERTIFICATION	20	23MAR07	19APR07
560	IMPLEMENT SYSTEM USAGE	0	23MAR07	
565	FACILITY ACCEPTANCE	0	18JUN07	
570	FACILITY OPERATION	5,040	18JUN07	25MAR27
567	OPERATIONS COMPLETE	0		25MAR27
D&D				
574	D&D	817*	26MAR27	07JUN30
575	FACILITY DEACTIVATION	120	26MAR27	14SEP27
580	ENGINEERING DESIGN	120	15SEP27	03MAR28
585	INTERNAL D&D OPERATIONS	277	06MAR28	04APR29
590	STRUCTURAL D&D OPERATIONS	120	05APR29	24SEP29
595	SUB-GRADE D&D OPERATIONS	120	25SEP29	14MAR30
600	VERIFICATION OF CLOSEOUT	60	15MAR30	07JUN30

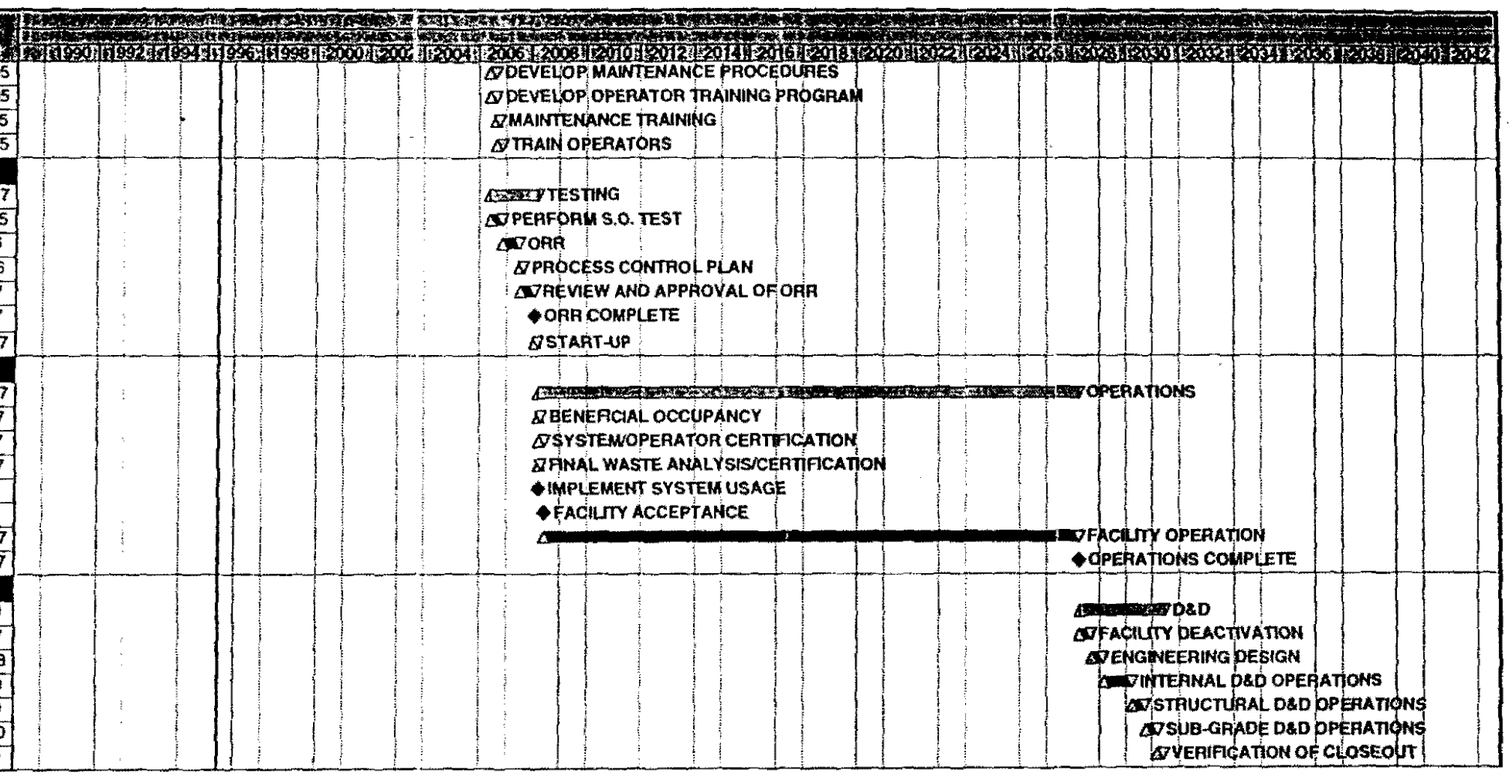

Figure Q-2c
Supercompaction Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,529*	14JUL88A	01NOV29
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
10	PRECONCEPTUAL DESIGN	250	14JUL88A	17JUL89A
15	DECISION TO PROCEED	0	14JUL88A	
20	DEVELOP & SUBMIT FUNDING REQUEST	248	14JUL88A	14JUL89A
25	BENCH SCALE TESTING	640	17JUL89A	27JAN92A
30	DETERMINE PROJECT FEASIBILITY	20	28JAN92A	24FEB92A
35	PILOT SCALE	840	25FEB92A	31MAY95A
40	DETERMINE PROJECT FEASIBILITY	90	01JUN95A	06OCT95
45	FUNDING REQUEST	60	09OCT95	03JAN96
50	DETERMINE LINE ITEM FUNDING	248	04JAN96	20DEC96
51	DESIGN CRITERIA COMPLETE	0		20DEC96
55	PRIORITIZATION & SELECTION OF PROJECTS	60	23DEC96	18MAR97
60	GAIN FUNDING APPROVAL	248	19MAR97	09MAR98
65	OPERATIONAL REQUIREMENTS DOCUMENT	60	10MAR98	02JUN98
70	DESIGN INPUT & REVIEW/APPROVAL	20	27AUG98	24SEP98
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
75	PREPARE ENVIRONMENTAL CHECKLIST	60	04JAN96	27MAR96
80	NEPA COMPLIANCE COMMITTEE REVIEW	10	28MAR96	10APR96
100	PREPARE ADM	60	11APR96	05JUL96
105	NEPA DETERMINATION DOE REVIEW ADM	30	08JUL96	16AUG96
165	PREPARE NOTICE OF INTENT	10	19AUG96	30AUG96
170	PUBLIC SCOPING	30	03SEP96	14OCT96
175	PREPARE IMPLEMENTATION PLAN	60	15OCT96	09JAN97
180	PREPARE DRAFT ENVIRONMENTAL IMPACT	120	10JAN97	27JUN97
185	DOE REVIEW DRAFT ENVIR. IMPACT	30	30JUN97	11AUG97
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
195	STATE REVIEW & PUBLIC COMMENT PERIOD	60	12AUG97	04NOV97
200	REVIEW & FINALIZE ENV. IMPACT	60	05NOV97	30JAN98
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	881*	10MAR98	21AUG01
440	HEALTH AND SAFETY PLAN	60	10MAR98	02JUN98
435	PREPARE QAPP FOR IMPLEMENTATION	60	10MAR98	02JUN98
460	PREPARE OPERATING QAPP	60	03JUN98	26AUG98
465	REVIEW/APPROVE IMPLEMENTATION PHASE	30	03JUN98	15JUL98
485	REVIEW AND APPROVE OPERATING QAPP	30	27AUG98	08OCT98
486	QAPP COMPLETE	0		08OCT98
445	UPDATE/REVISE PROGRAM PLAN	60	10MAR98	02JUN98
470	DOE REVIEW PROGRAM PLAN	30	03JUN98	15JUL98
490	FINALIZE PROGRAM PLAN	30	16JUL98	26AUG98
450	APENs DETERMINATION	120	10MAR98	26AUG98
475	AGENCY REVIEWS APENs	60	27AUG98	19NOV98
495	FINALIZE APENs	40	20NOV98	19JAN99
451	APENs DETERMINATION COMPLETE	0		19JAN99

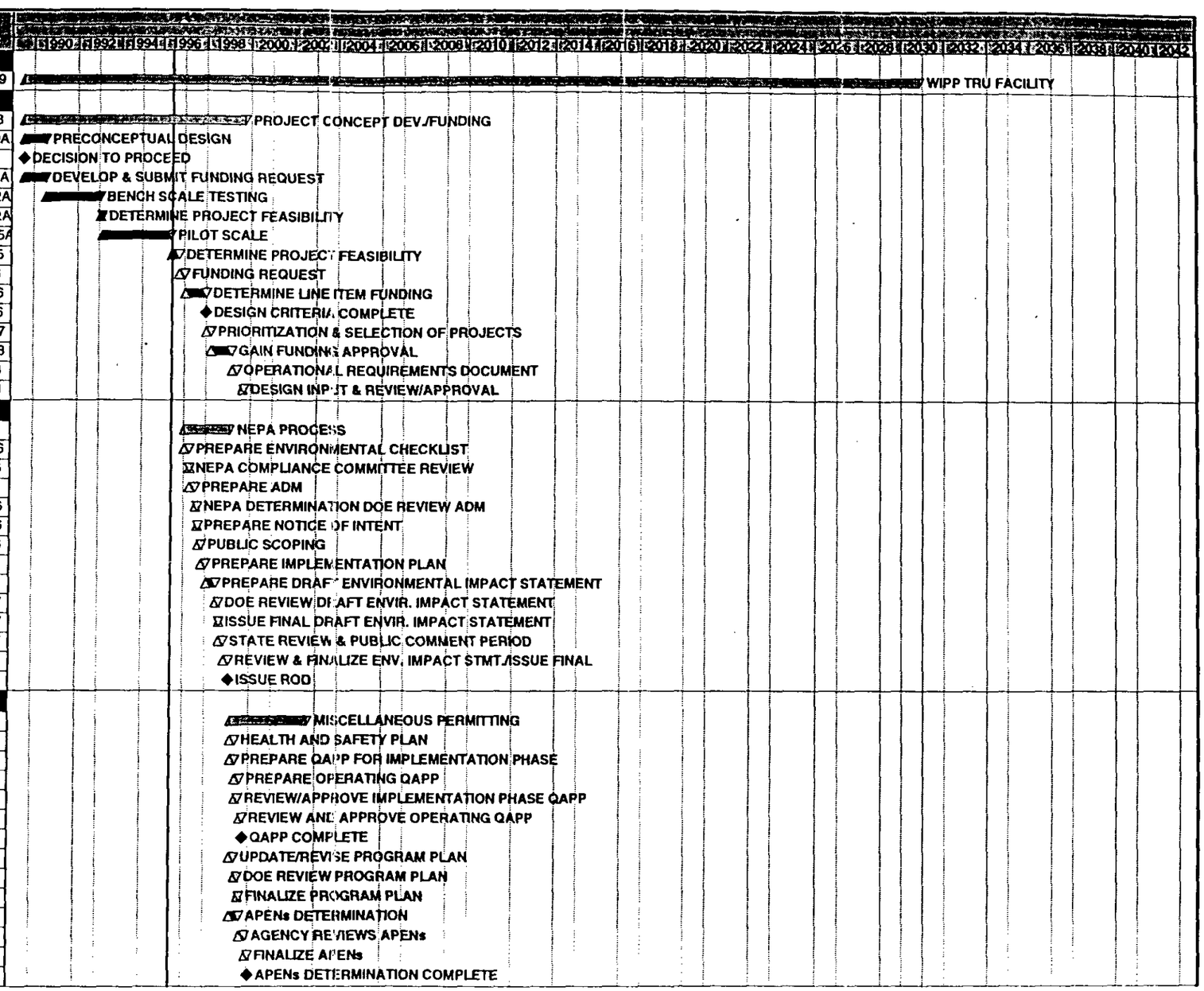

Figure Q-3a
Shred & Compact Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
455	NESHAPS DETERMINATION	150	07SEP99	06APR00
480	AGENCY REVIEWS NESHAPS	60	07APR00	30JUN00
500	FINALIZE NESHAPS	40	03JUL00	28AUG00
501	NESHAPS DETERMINATION COMPLETE	0		28AUG00
502	PREPARE PSD PERMIT APPLICATION	250	07SEP99	28AUG00
503	PSD PERMIT REVIEW and APPROVAL	250	29AUG00	21AUG01
504	PSD PERMIT COMPLETE	0		21AUG01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	29AUG00	26SEP02
339	BEGIN RCRA PERMIT MOD	0	29AUG00	
380	PREPARE RCRA PERMIT MODIFICATION	140	29AUG00	16MAR01
385	DOE REVIEWS PERMIT MOD	30	19MAR01	27APR01
390	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	90	30APR01	05SEP01
395	PUBLIC COMMENT PERIOD	60	06SEP01	29NOV01
400	PUBLIC HEARING	2	06SEP01	07SEP01
405	RESPOND TO COMMENTS & FINALIZE PERMIT	90	30NOV01	08APR02
410	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	120	09APR02	26SEP02
430	PERMIT APPROVAL	0		26SEP02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
210	PREPARE HAZARD CLASSIFICATION	60	03JUN98	26AUG98
215	PSAR DEVELOPMENT	120	27AUG98	16FEB99
220	TSAR DEVELOPMENT	120	27AUG98	16FEB99
225	CRITICALITY SAFETY ASSESSMENT	120	27AUG98	16FEB99
230	ORC REVIEW	40	17FEB99	13APR99
235	DOE REVIEW & APPROVE PSAR	40	14APR99	09JUN99
240	FSAR DEVELOPMENT	250	10JUN99	01JUN00
245	DOE REVIEW	40	02JUN00	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,621*	25SEP98	03FEB05
250	BID/NEGOTIATE & AWARD DESIGN	90	25SEP98	02FEB99
260	PREPARE TITLE I DESIGN	151	03FEB99	03SEP99
265	PREPARE TITLE II DESIGN	375	07SEP99	23FEB01
270	LONG LEAD PROCUREMENT	210	07SEP99	30JUN00
266	TITLE II DESIGN COMPLETE	0		23FEB01
275	PREPARE CONSTRUCTION PACKAGE	21	26FEB01	26MAR01
280	BID/NEGOTIATE & AWARD CONSTRUCTION	90	27MAR01	01AUG01
285	RCRA HOLD	0		26SEP02
289	BEGIN CONSTRUCTION	0	27SEP02	
290	CONSTRUCTION	500	27SEP02	13SEP04
291	CONSTRUCTION COMPLETE	0		13SEP04
295	FINAL INSPECTIONS	10	14SEP04	27SEP04
300	TITLE III AS-BUILTS	90	28SEP04	03FEB05
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	14SEP04	26MAY05
305	PREPARE S.O. TEST PLAN & PROCEDURES	60	14SEP04	07DEC04
310	DEVELOP DATA MANAGEMENT PROCEDURES	60	14SEP04	07DEC04
315	DEVELOP TECHNICAL PROCEDURES	60	14SEP04	07DEC04
320	DEVELOP MAINTENANCE PROCEDURES	60	08DEC04	03MAR05

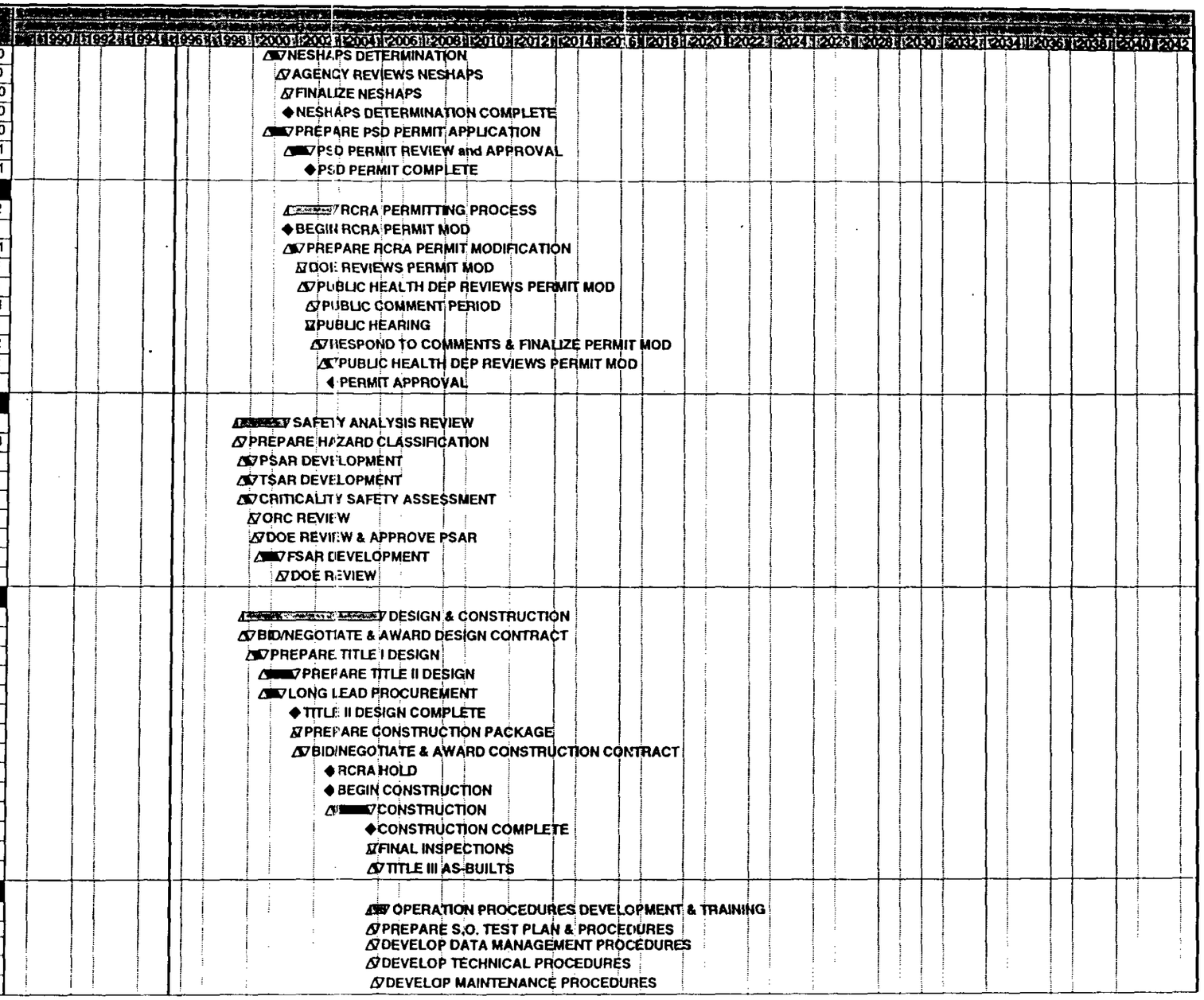

Figure Q-3b
Shred & Compact Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
330	DEVELOP OPERATOR TRAINING PROGRAM	60	08DEC04	03MAR05
325	MAINTENANCE TRAINING	40	04MAR05	28APR05
335	TRAIN OPERATORS	60	04MAR05	26MAY05
TESTING				
507	TESTING	460*	08DEC04	27SEP06
509	PERFORM S.O. TEST	120	08DEC04	26MAY05
510	ORR	160	27MAY05	13JAN06
520	PROCESS CONTROL PLAN	40	16JAN06	10MAR06
525	REVIEW AND APPROVAL OF ORR	140	16JAN06	01AUG06
530	ORR COMPLETE	0		01AUG06
535	START-UP	40	02AUG06	27SEP06
OPERATIONS				
539	OPERATIONS	5,100*	28SEP06	30SEP26
545	BENEFICIAL OCCUPANCY	20	28SEP06	25OCT06
550	SYSTEM/OPERATOR CERTIFICATION	60	28SEP06	21DEC06
555	FINAL WASTE ANALYSIS/CERTIFICATION	20	28SEP06	25OCT06
560	IMPLEMENT SYSTEM USAGE	0	28SEP06	
565	FACILITY ACCEPTANCE	0	22DEC06	
570	FACILITY OPERATION	5,040	22DEC06	30SEP26
567	OPERATIONS COMPLETE	0		30SEP26
D&D				
574	D&D	788*	01OCT26	01NOV29
575	FACILITY DEACTIVATION	120	01OCT26	22MAR27
580	ENGINEERING DESIGN	120	23MAR27	09SEP27
585	INTERNAL D&D OPERATIONS	248	10SEP27	29AUG28
590	STRUCTURAL D&D OPERATIONS	120	30AUG28	19FEB29
595	SUB-GRADE D&D OPERATIONS	120	20FEB29	08AUG29
600	VERIFICATION OF CLOSEOUT	60	09AUG29	01NOV29

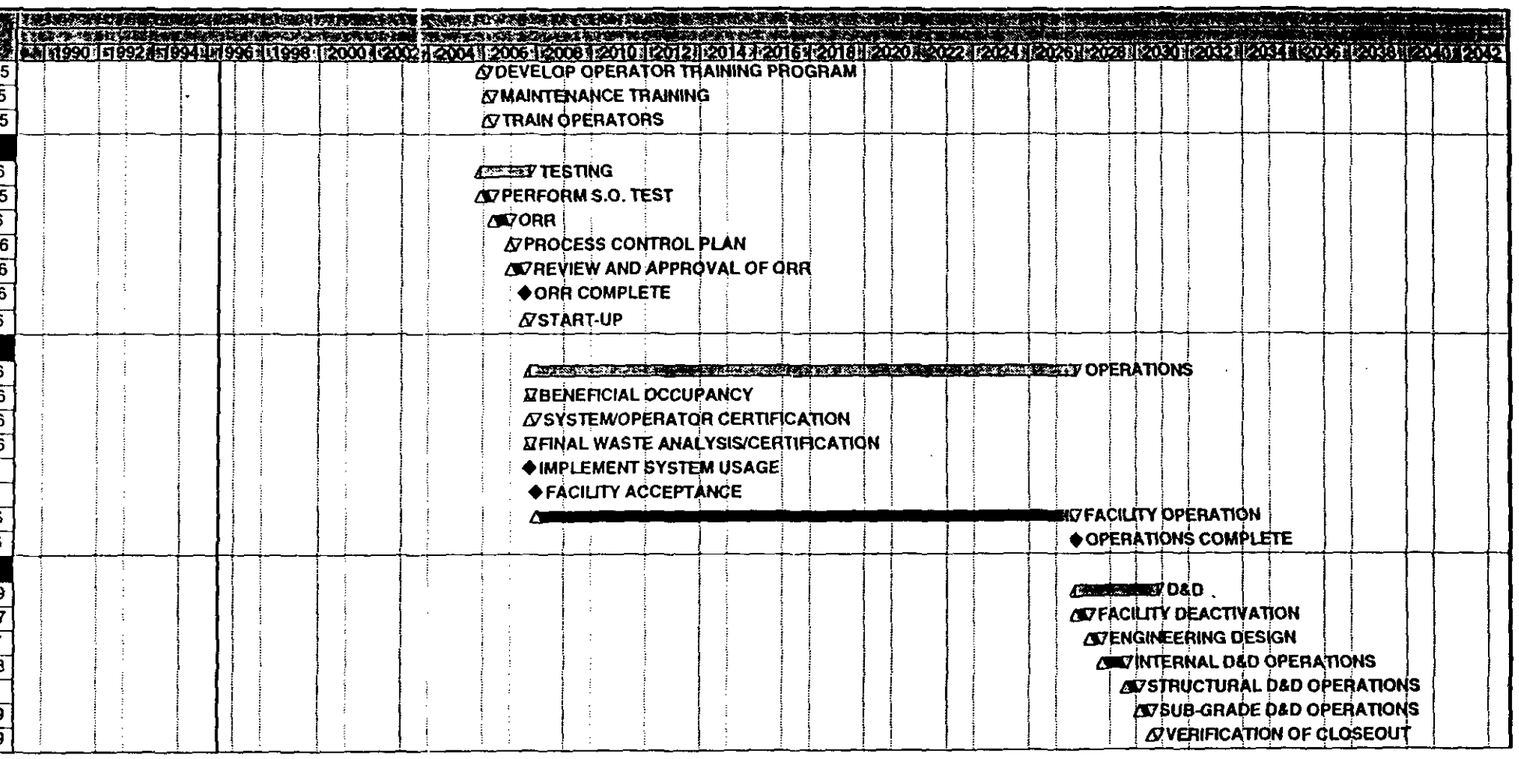

Figure Q-3c
Shred & Compact Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,903*	14JUL88A	22APR31
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
10	PRECONCEPTUAL DESIGN	250	14JUL88A	17JUL89A
15	DECISION TO PROCEED	0	14JUL88A	
20	DEVELOP & SUBMIT FUNDING REQUEST	248	14JUL88A	14JUL89A
25	BENCH SCALE TESTING	640	17JUL89A	27JAN92A
30	DETERMINE PROJECT FEASIBILITY	20	28JAN92A	24FEB92A
35	PILOT SCALE	840	25FEB92A	31MAY95A
40	DETERMINE PROJECT FEASIBILITY	90	01JUN95A	06OCT95
45	FUNDING REQUEST	60	09OCT95	03JAN96
50	DETERMINE LINE ITEM FUNDING	248	04JAN96	20DEC96
51	DESIGN CRITERIA COMPLETE	0		20DEC96
55	PRIORITIZATION & SELECTION OF PROJECTS	60	23DEC96	18MAR97
60	GAIN FUNDING APPROVAL	248	19MAR97	09MAR98
65	OPERATIONAL REQUIREMENTS DOCUMENT	60	10MAR98	02JUN98
70	DESIGN INPUT & REVIEW/APPROVAL	20	27AUG98	24SEP98
NEPA PROCESS				
74	NEPA PROCESS	680*	04JAN96	01SEP98
75	PREPARE ENVIRONMENTAL CHECKLIST	60	04JAN96	27MAR96
80	NEPA COMPLIANCE COMMITTEE REVIEW	10	28MAR96	10APR96
100	PREPARE ADM	60	11APR96	05JUL96
105	NEPA DETERMINATION DOE REVIEW ADM	30	08JUL96	16AUG96
165	PREPARE NOTICE OF INTENT	10	19AUG96	30AUG96
170	PUBLIC SCOPING	30	03SEP96	14OCT96
175	PREPARE IMPLEMENTATION PLAN	60	15OCT96	09JAN97
180	PREPARE DRAFT ENVIRONMENTAL IMPACT	240	10JAN97	17DEC97
185	DOE REVIEW DRAFT ENVIR. IMPACT	60	18DEC97	13MAR98
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	16MAR98	13MAR98
195	STATE REVIEW & PUBLIC COMMENT PERIOD	60	16MAR98	08JUN98
200	REVIEW & FINALIZE ENV. IMPACT	60	09JUN98	01SEP98
205	ISSUE ROD	0		01SEP98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	1,138*	10MAR98	23AUG02
440	HEALTH AND SAFETY PLAN	60	10MAR98	02JUN98
435	PREPARE QAPP FOR IMPLEMENTATION	60	10MAR98	02JUN98
460	PREPARE OPERATING QAPP	60	03JUN98	26AUG98
465	REVIEW/APPROVE IMPLEMENTATION PHASE	30	03JUN98	15JUL98
485	REVIEW AND APPROVE OPERATING QAPP	30	27AUG98	08OCT98
486	QAPP COMPLETE	0		08OCT98
445	UPDATE/REVISE PROGRAM PLAN	60	10MAR98	02JUN98
470	DOE REVIEW PROGRAM PLAN	30	03JUN98	15JUL98
490	FINALIZE PROGRAM PLAN	30	16JUL98	26AUG98
450	APENs DETERMINATION	240	10MAR98	16FEB99
475	AGENCY REVIEWS APENs	90	17FEB99	23JUN99
495	FINALIZE APENs	80	24JUN99	15OCT99
451	APENs DETERMINATION COMPLETE	0		15OCT99

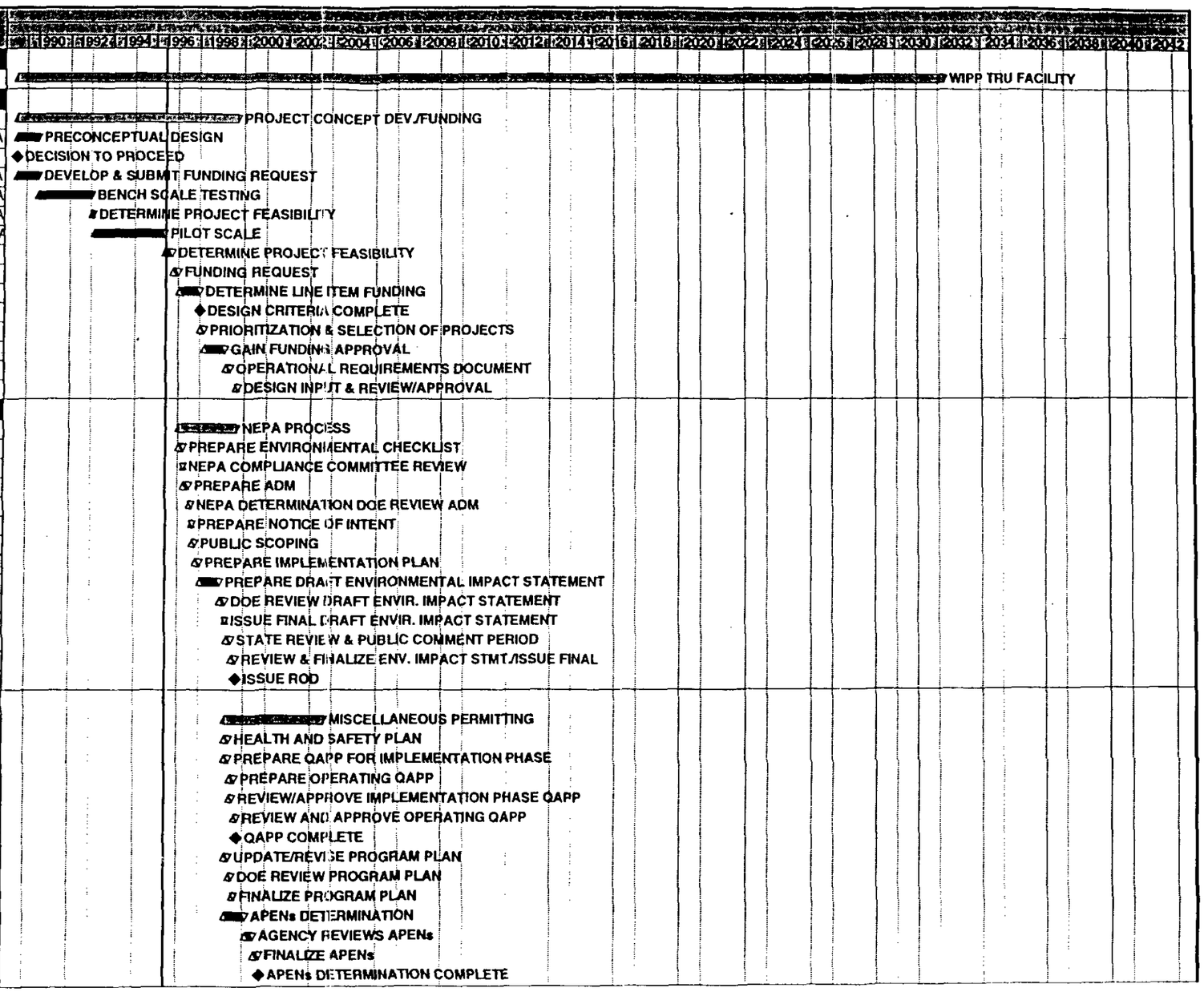

Figure Q-4a
Plasma Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
455	NESHAPS DETERMINATION	300	28OCT99	02JAN01
480	AGENCY REVIEWS NESHAPS	90	03JAN01	08MAY01
500	FINALIZE NESHAPS	80	09MAY01	30AUG01
501	NESHAPS DETERMINATION COMPLETE	0		30AUG01
502	PREPARE PSD PERMIT APPLICATION	250	28OCT99	19OCT00
503	PSD PERMIT REVIEW and APPROVAL	250	31AUG01	23AUG02
504	PSD PERMIT COMPLETE	0		23AUG02
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	700*	22SEP00	20JUN03
339	BEGIN RCRA PERMIT MOD	0	22SEP00	
380	PREPARE RCRA PERMIT MODIFICATION	250	22SEP00	14SEP01
385	DOE REVIEWS PERMIT MOD	60	17SEP01	10DEC01
390	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	120	11DEC01	30MAY02
395	PUBLIC COMMENT PERIOD	60	31MAY02	23AUG02
400	PUBLIC HEARING	2	31MAY02	03JUN02
405	RESPOND TO COMMENTS & FINALIZE PERMIT	90	26AUG02	02JAN03
410	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	120	03JAN03	20JUN03
430	PERMIT APPROVAL	0		20JUN03
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
210	PREPARE HAZARD CLASSIFICATION	60	03JUN98	26AUG98
215	PSAR DEVELOPMENT	120	27AUG98	16FEB99
220	TSAR DEVELOPMENT	120	27AUG98	16FEB99
225	CRITICALITY SAFETY ASSESSMENT	120	27AUG98	16FEB99
230	ORC REVIEW	40	17FEB99	13APR99
235	DOE REVIEW & APPROVE PSAR	40	14APR99	09JUN99
240	FSAR DEVELOPMENT	250	10JUN99	01JUN00
245	DOE REVIEW	40	02JUN00	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,933*	25SEP98	25APR06
250	BID/NEGOTIATE & AWARD DESIGN	90	25SEP98	02FEB99
260	PREPARE TITLE I DESIGN	188	03FEB99	27OCT99
265	PREPARE TITLE II DESIGN	468	28OCT99	28AUG01
270	LONG LEAD PROCUREMENT	350	28OCT99	13MAR01
266	TITLE II DESIGN COMPLETE	0		28AUG01
275	PREPARE CONSTRUCTION PACKAGE	60	31AUG01	26NOV01
280	BID/NEGOTIATE & AWARD CONSTRUCTION	120	27NOV01	15MAY02
285	RCRA HOLD	0		20JUN03
289	BEGIN CONSTRUCTION	0	23JUN03	
290	CONSTRUCTION	625	23JUN03	02DEC05
291	CONSTRUCTION COMPLETE	0		02DEC05
295	FINAL INSPECTIONS	10	05DEC05	16DEC05
300	TITLE III AS-BUILTS	90	19DEC05	25APR06
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	05DEC05	17AUG06
305	PREPARE S.O. TEST PLAN & PROCEDURES	60	05DEC05	28FEB06
310	DEVELOP DATA MANAGEMENT PROCEDURES	60	05DEC05	28FEB06
315	DEVELOP TECHNICAL PROCEDURES	60	05DEC05	28FEB06
320	DEVELOP MAINTENANCE PROCEDURES	60	01MAR06	23MAY06

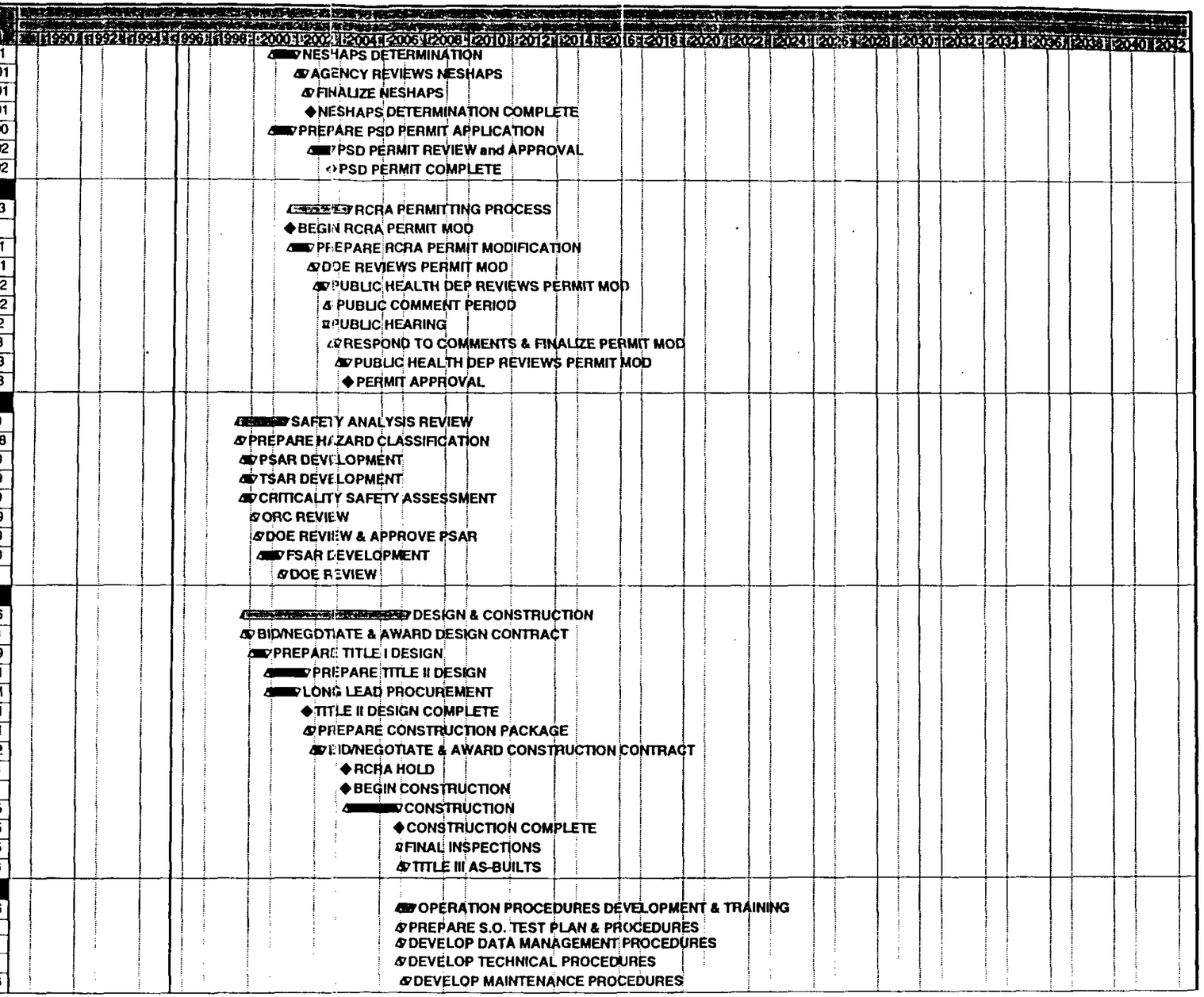

Figure Q-4b
Plasma Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
330	DEVELOP OPERATOR TRAINING PROGRAM	60	01MAR06	23MAY06
325	MAINTENANCE TRAINING	40	24MAY06	20JUL06
335	TRAIN OPERATORS	60	24MAY06	17AUG06
TESTING				
507	TESTING	460*	01MAR06	18DEC07
509	PERFORM S.O. TEST	120	01MAR06	17AUG06
510	ORR	160	18AUG06	04APR07
520	PROCESS CONTROL PLAN	40	05APR07	31MAY07
525	REVIEW AND APPROVAL OF ORR	140	05APR07	22OCT07
530	ORR COMPLETE	0		22OCT07
535	START-UP	40	23OCT07	18DEC07
OPERATIONS				
539	OPERATIONS	5,100*	19DEC07	21DEC27
545	BENEFICIAL OCCUPANCY	20	19DEC07	17JAN08
550	SYSTEM/OPERATOR CERTIFICATION	60	19DEC07	13MAR08
555	FINAL WASTE ANALYSIS/CERTIFICATION	20	19DEC07	17JAN08
560	IMPLEMENT SYSTEM USAGE	0	19DEC07	
565	FACILITY ACCEPTANCE	0	14MAR08	
570	FACILITY OPERATION	5,040	14MAR08	21DEC27
567	OPERATIONS COMPLETE	0		21DEC27
D&D				
574	D&D	850*	22DEC27	22APR31
575	FACILITY DEACTIVATION	120	22DEC27	09JUN28
580	ENGINEERING DESIGN	120	12JUN28	29NOV28
585	INTERNAL D&D OPERATIONS	310	30NOV28	18FEB30
590	STRUCTURAL D&D OPERATIONS	120	19FEB30	07AUG30
595	SUB-GRADE D&D OPERATIONS	120	08AUG30	28JAN31
600	VERIFICATION OF CLOSEOUT	60	29JAN31	22APR31

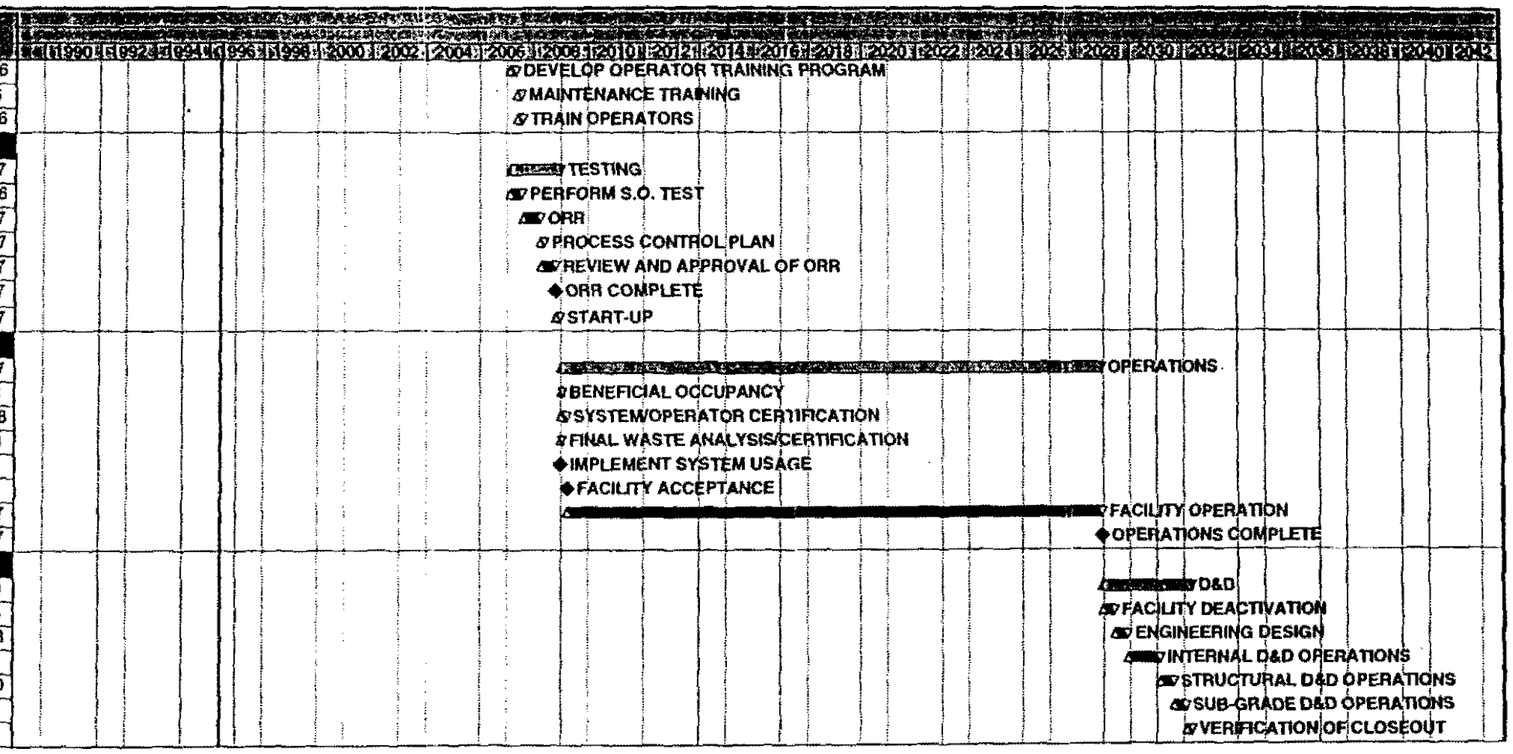

Figure Q-4c
Plasma Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
WIPP TRU FACILITY				
05	WIPP TRU FACILITY	10,618*	14JUL88A	11MAR30
PROJECT CONCEPT/FUNDING REQUEST PROCESS				
09	PROJECT CONCEPT DEV./FUNDING	2,600*	14JUL88A	24SEP98
10	PRECONCEPTUAL DESIGN	250	14JUL88A	17JUL89A
15	DECISION TO PROCEED	0	14JUL88A	
20	DEVELOP & SUBMIT FUNDING REQUEST	248	14JUL88A	14JUL89A
25	BENCH SCALE TESTING	640	17JUL89A	27JAN92A
30	DETERMINE PROJECT FEASIBILITY	20	28JAN92A	24FEB92A
35	PILOT SCALE	840	25FEB92A	31MAY95A
40	DETERMINE PROJECT FEASIBILITY	90	01JUN95A	06OCT95
45	FUNDING REQUEST	60	09OCT95	03JAN96
50	DETERMINE LINE ITEM FUNDING	248	04JAN96	20DEC96
51	DESIGN CRITERIA COMPLETE	0		20DEC96
55	PRIORITIZATION & SELECTION OF PROJECTS	60	23DEC96	18MAR97
60	GAIN FUNDING APPROVAL	248	19MAR97	09MAR98
65	OPERATIONAL REQUIREMENTS DOCUMENT	60	10MAR98	02JUN98
70	DESIGN INPUT & REVIEW/APPROVAL	20	27AUG98	24SEP98
NEPA PROCESS				
74	NEPA PROCESS	530*	04JAN96	30JAN98
75	PREPARE ENVIRONMENTAL CHECKLIST	60	04JAN96	27MAR96
80	NEPA COMPLIANCE COMMITTEE REVIEW	10	28MAR96	10APR96
100	PREPARE ADM	60	11APR96	05JUL96
105	NEPA DETERMINATION DOE REVIEW ADM	30	08JUL96	16AUG96
165	PREPARE NOTICE OF INTENT	10	19AUG96	30AUG96
170	PUBLIC SCOPING	30	03SEP96	14OCT96
175	PREPARE IMPLEMENTATION PLAN	60	15OCT96	09JAN97
180	PREPARE DRAFT ENVIRONMENTAL IMPACT	120	10JAN97	27JUN97
185	DOE REVIEW DRAFT ENVIR. IMPACT	30	30JUN97	11AUG97
190	ISSUE FINAL DRAFT ENVIR. IMPACT	0	12AUG97	11AUG97
195	STATE REVIEW & PUBLIC COMMENT PERIOD	60	12AUG97	04NOV97
200	REVIEW & FINALIZE ENV. IMPACT	60	05NOV97	30JAN98
205	ISSUE ROD	0		30JAN98
OTHER PERMITTING				
434	MISCELLANEOUS PERMITTING	896*	10MAR98	12SEP01
440	HEALTH AND SAFETY PLAN	60	10MAR98	02JUN98
435	PREPARE QAPP FOR IMPLEMENTATION	60	10MAR98	02JUN98
460	PREPARE OPERATING QAPP	60	03JUN98	26AUG98
465	REVIEW/APPROVE IMPLEMENTATION PHASE	30	03JUN98	15JUL98
485	REVIEW AND APPROVE OPERATING QAPP	30	27AUG98	08OCT98
486	QAPP COMPLETE	0		08OCT98
445	UPDATE/REVISE PROGRAM PLAN	60	10MAR98	02JUN98
470	DOE REVIEW PROGRAM PLAN	30	03JUN98	15JUL98
490	FINALIZE PROGRAM PLAN	30	16JUL98	26AUG98
450	APENs DETERMINATION	120	10MAR98	26AUG98
475	AGENCY REVIEWS APENs	60	27AUG98	19NOV98
495	FINALIZE APENs	40	20NOV98	19JAN99
451	APENs DETERMINATION COMPLETE	0		19JAN99

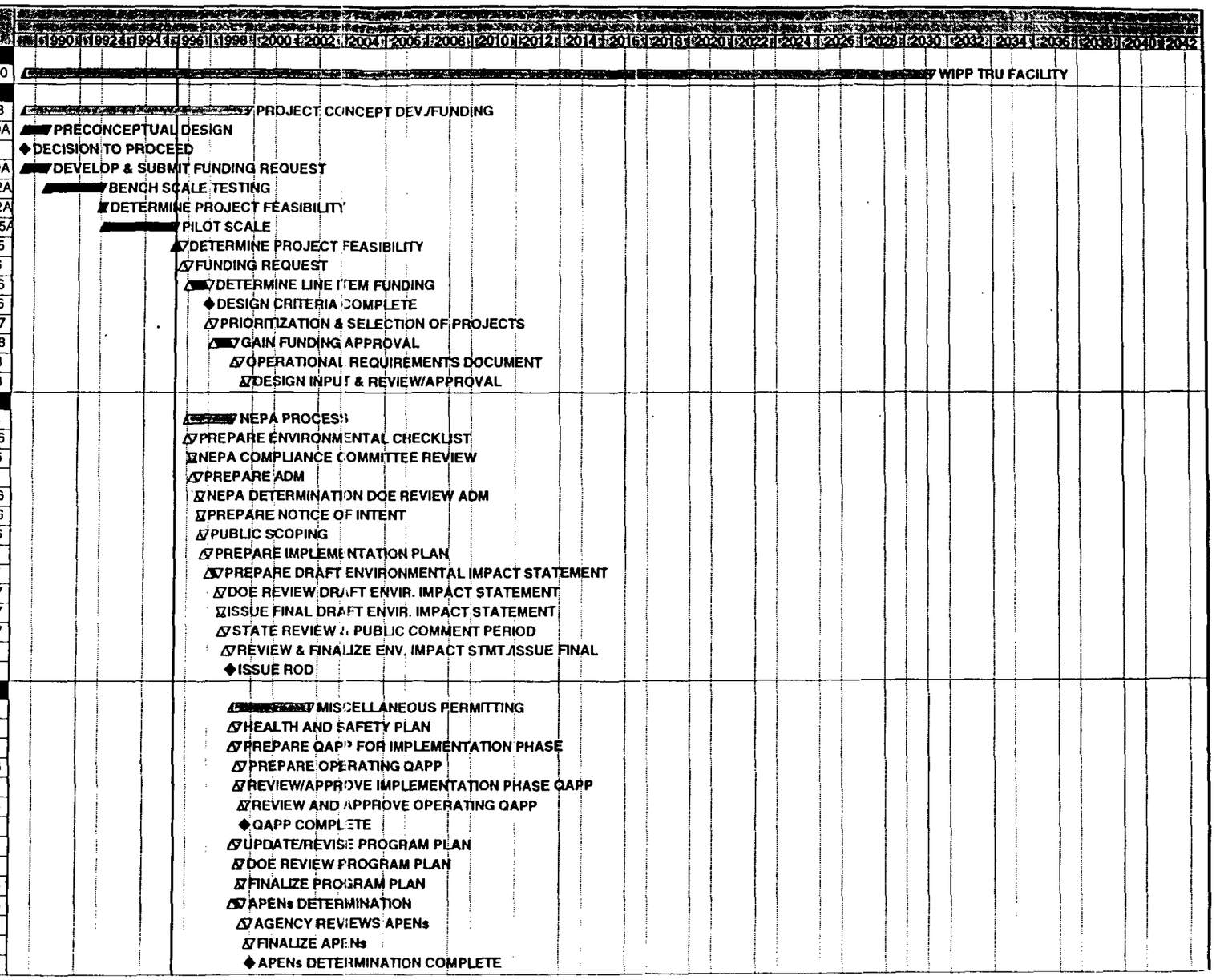

Figure Q-5a
Cementation/Shred/ Add Clay Scenario

ACT ID	Activity Description	Orig Dur	Early Start	Early Finish
455	NESHAPS DETERMINATION	150	28SEP99	27APR00
480	AGENCY REVIEWS NESHAPS	60	28APR00	24JUL00
500	FINALIZE NESHAPS	40	25JUL00	19SEP00
501	NESHAPS DETERMINATION COMPLETE	0		19SEP00
502	PREPARE PSD PERMIT APPLICATION	250	28SEP99	19SEP00
503	PSD PERMIT REVIEW and APPROVAL	250	20SEP00	12SEP01
504	PSD PERMIT COMPLETE	0		12SEP01
RCRA PERMITTING				
338	RCRA PERMITTING PROCESS	530*	20SEP00	17OCT02
339	BEGIN RCRA PERMIT MOD	0	20SEP00	
380	PREPARE RCRA PERMIT MODIFICATION	140	20SEP00	06APR01
385	DOE REVIEWS PERMIT MOD	30	09APR01	18MAY01
390	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	90	21MAY01	26SEP01
395	PUBLIC COMMENT PERIOD	60	27SEP01	20DEC01
400	PUBLIC HEARING	2	27SEP01	28SEP01
405	RESPOND TO COMMENTS & FINALIZE PERMIT	90	21DEC01	29APR02
410	PUBLIC HEALTH DEP REVIEWS PERMIT MOD	120	30APR02	17OCT02
430	PERMIT APPROVAL	0		17OCT02
SAFETY ANALYSIS REVIEW				
209	SAFETY ANALYSIS REVIEW	550*	03JUN98	28JUL00
210	PREPARE HAZARD CLASSIFICATION	60	03JUN98	26AUG98
215	PSAR DEVELOPMENT	120	27AUG98	16FEB99
220	TSAR DEVELOPMENT	120	27AUG98	16FEB99
225	CRITICALITY SAFETY ASSESSMENT	120	27AUG98	16FEB99
230	ORC REVIEW	40	17FEB99	13APR99
235	DOE REVIEW & APPROVE PSAR	40	14APR99	09JUN99
240	FSAR DEVELOPMENT	250	10JUN99	01JUN00
245	DOE REVIEW	40	02JUN00	28JUL00
DESIGN & CONSTRUCTION				
249	DESIGN & CONSTRUCTION	1,686*	25SEP98	05MAY05
250	BID/NEGOTIATE & AWARD DESIGN	90	25SEP98	02FEB99
260	PREPARE TITLE I DESIGN	166	03FEB99	27SEP99
265	PREPARE TITLE II DESIGN	412	28SEP99	08MAY01
270	LONG LEAD PROCUREMENT	210	28SEP99	24JUL00
266	TITLE II DESIGN COMPLETE	0		08MAY01
275	PREPARE CONSTRUCTION PACKAGE	21	09MAY01	07JUN01
280	BID/NEGOTIATE & AWARD CONSTRUCTION	90	08JUN01	15OCT01
285	RCRA HOLD	0		17OCT02
289	BEGIN CONSTRUCTION	0	18OCT02	
290	CONSTRUCTION	550	18OCT02	14DEC04
291	CONSTRUCTION COMPLETE	0		14DEC04
295	FINAL INSPECTIONS	10	15DEC04	29DEC04
300	TITLE III AS-BUILTS	90	30DEC04	05MAY05
PROCEDURES/TRAINING				
304	OPERATION PROCEDURES DEVELOPMENT &	180*	15DEC04	29AUG05
305	PREPARE S.O. TEST PLAN & PROCEDURES	60	15DEC04	10MAR05
310	DEVELOP DATA MANAGEMENT PROCEDURES	60	15DEC04	10MAR05
315	DEVELOP TECHNICAL PROCEDURES	60	15DEC04	10MAR05
320	DEVELOP MAINTENANCE PROCEDURES	60	11MAR05	03JUN05

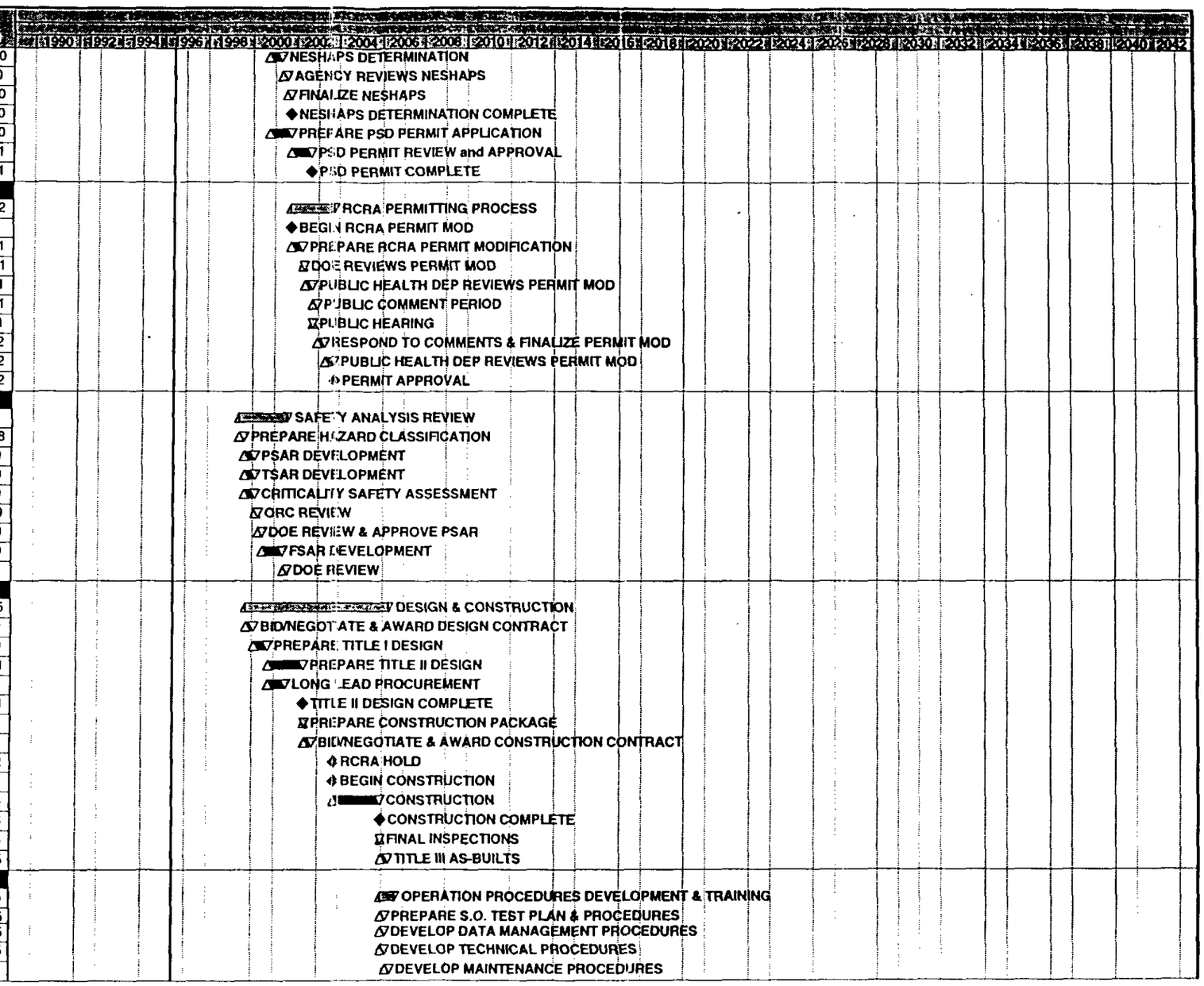

Figure Q-5b
Cementation/Shred/ Add Clay Scenario

Act ID	Activity Description	Orig Dur	Early Start	Early Finish
330	DEVELOP OPERATOR TRAINING PROGRAM	60	11MAR05	03JUN05
325	MAINTENANCE TRAINING	40	06JUN05	01AUG05
335	TRAIN OPERATORS	60	06JUN05	29AUG05
TESTING				
507	TESTING	460*	11MAR05	29DEC06
509	PERFORM S.O. TEST	120	11MAR05	29AUG05
510	ORR	160	30AUG05	14APR06
520	PROCESS CONTROL PLAN	40	17APR06	12JUN06
525	REVIEW AND APPROVAL OF ORR	140	17APR06	01NOV06
530	ORR COMPLETE	0		01NOV06
535	START-UP	40	02NOV06	29DEC06
OPERATIONS				
539	OPERATIONS	5,100*	02JAN07	04JAN27
545	BENEFICIAL OCCUPANCY	20	02JAN07	29JAN07
550	SYSTEM/OPERATOR CERTIFICATION	60	02JAN07	26MAR07
555	FINAL WASTE ANALYSIS/CERTIFICATION	20	02JAN07	29JAN07
560	IMPLEMENT SYSTEM USAGE	0	02JAN07	
565	FACILITY ACCEPTANCE	0	27MAR07	
570	FACILITY OPERATION	5,040	27MAR07	04JAN27
567	OPERATIONS COMPLETE	0		04JAN27
D&D				
574	D&D	812*	05JAN27	11MAR30
575	FACILITY DEACTIVATION	120	05JAN27	22JUN27
580	ENGINEERING DESIGN	120	23JUN27	10DEC27
585	INTERNAL D&D OPERATIONS	272	13DEC27	05JAN29
590	STRUCTURAL D&D OPERATIONS	120	08JAN29	25JUN29
595	SUB-GRADE D&D OPERATIONS	120	26JUN29	13DEC29
600	VERIFICATION OF CLOSEOUT	60	14DEC29	11MAR30

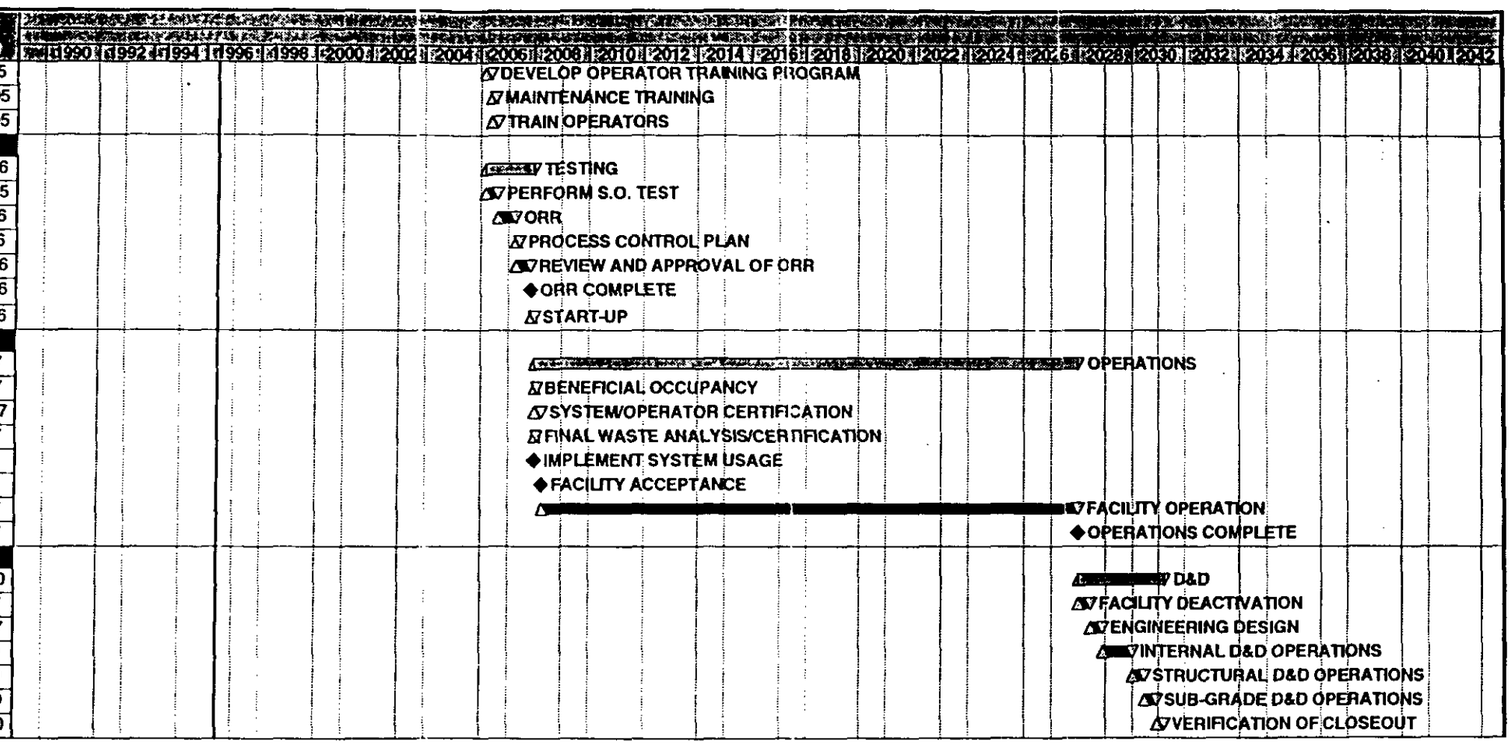

Figure Q-5c
Cementation/Shred/ Add Clay Scenario

TABLE Q-6

PRELIMINARY PERT TIME ESTIMATES FOR ALTERNATIVE #6
(Time in Years)

Major Activity	T_o	T_m	T_p	T_e	T_e (days)
Preliminary Safety Analysis Report	.890	1.00	2.25	1.19	298
Final Safety Analysis Report	1.420	2.000	4.440	2.310	578
Title I Design	.375	.500	1.250	.604	151
Title II Design	.738	.860	1.810	.998	250
Construction	.910	1.000	2.160	1.178	295
NEPA Documentation	1.781	2.120	7.632	2.982	746
PSD Permit Preparation	.840	1.000	2.250	1.182	295
PSD Permit Approval	.335	.830	2.330	.996	249
NESHAPs	.750	1.000	2.500	1.208	302
RCRA Permit Preparation	.269	.320	.720	.378	95
ORR	1.840	1.840	4.287	2.248	562

The time estimates for Alternative #10 (Plasma Melting) were adjusted from the values given in Table Q-6 by the following:

Activity	Adjustment
Title I and Title II Design	+25%
Construction	+25%
D&D	+25%
RCRA Permit & NEPA	+100%

1.4DETAILED SCHEDULESAttachment 2 shows the detailed schedules for the waste processing EAs.

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APPENDIX Q

ATTACHMENT 1

SCHEDULING ASSUMPTIONS FOR WASTE PROCESSING ENGINEERED ALTERNATIVES

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APPENDIX Q

ATTACHMENT 1
SCHEDULING ASSUMPTIONS FOR WASTE PROCESSING ENGINEERED ALTERNATIVES

This attachment presents the assumptions used in developing the detailed schedules for each of the waste processing EAs. The assumptions are organized into tables, where each table presents the assumptions used for a specific alternative, as shown:

TABLE	ALTERNATIVE
Q-1	Baseline
Q-2	#1 Supercompact
Q-3	#6 Shred & Compact
Q-4	#10 Plasma Melting
Q-5	#94 Enhanced Cement/Shred & Clay

TABLE Q-1

Schedule Assumptions
Baseline Case

09 PROJECT CONCEPT DEVELOPMENT/FUNDING

Assumptions:

1. Funding request submitted after demo-scale will drive NEPA activities

2. Funding approval after project prioritization will drive other permitting and RCRA activities

3. Project requests line item funding

74 NEPA PROCESS

Assumptions:

1. EIS will be required resulting in a ROD

2. NEPA must be complete prior to Title I Design

209 SAFETY ANALYSIS REVIEW

Assumptions:

1. Preparation of the operational requirement document initiates the SAR process

2. PSAR must be completed prior to construction

3. FSAR must be completed prior to ORR

249 DESIGN AND CONSTRUCTION

Assumptions:

1. Facility is a concrete/steel structure

2. Facility retrieves, characterizes, treats to WIPP WAL, stores, and ships waste

338 RCRA PERMITTING PROCESS

Assumptions:

1. Facility requires a RCRA permit modification

2. Permit required prior to construction

434 MISCELLANEOUS PERMITTING

Assumptions:

1. A H&S Plan is required prior to construction

2. Current program plan will require updating

3. APENS will be determined

4. NESHAPS will be determined prior to design

5. A QAPP is required prior to construction

6. PSD permit required

539 OPERATIONS

Assumptions:

1. Facility will operate for 20 years

574 D&D

Assumptions:

1. Facility will undergo decontamination and decommissioning after its 20 year operation period

TABLE Q-2

Schedule Assumptions
Alternative #1—Supercompaction

09 PROJECT CONCEPT DEVELOPMENT/FUNDING

Assumptions:

1. Funding request submitted after demo-scale will drive NEPA activities
2. Funding approval after project prioritization will drive other permitting and RCRA activities
3. Project requests line item funding

74 NEPA PROCESS

Assumptions:

1. EIS will be required resulting in a ROD
2. NEPA must be complete prior to Title I Design

209 SAFETY ANALYSIS REVIEW

Assumptions:

1. Preparation of the operational requirement document initiates the SAR process
2. PSAR must be completed prior to construction
3. FSAR must be completed prior to construction of ORR

249 DESIGN AND CONSTRUCTION

Assumptions:

1. Facility is a concrete/steel structure
2. In addition to baseline functions, facility receives drums and supercompacts solid organic and solid inorganic waste
3. Title II design complete prior to RCRA permit application submittal

338 RCRA PERMITTING PROCESS

Assumptions:

1. Facility requires a RCRA permit modification

2. Permit required prior to construction

434 MISCELLANEOUS PERMITTING

Assumptions:

1. A H&S Plan is required prior to construction

2. Current program plan will require updating

3. APENS will be determined

4. NESHAPS will be determined

5. A QAPP is required prior to design

6. PSD permit required prior to construction

539 OPERATIONS

Assumptions:

1. Facility will operate for 20 years

574 D&D

Assumptions:

1. Facility will undergo decontamination and decommissioning after its 20 year operation period

TABLE Q-3

Schedule Assumptions
Alternative #6—Shred and Compact

09 PROJECT CONCEPT DEVELOPMENT/FUNDING

Assumptions:

1. Funding request submitted after demo-scale will drive NEPA activities
2. Funding approval after project prioritization will drive other permitting and RCRA activities
3. Project requests line item funding

74 NEPA PROCESS

Assumptions:

1. EIS will be required resulting in a ROD
2. NEPA must be complete prior to Title I Design

209 SAFETY ANALYSIS REVIEW

Assumptions:

1. Preparation of the operational requirement document initiates the SAR process
2. PSAR must be completed prior to construction
3. FSAR must be completed prior to ORR

249 DESIGN AND CONSTRUCTION

Assumptions:

1. Facility is a concrete/steel structure
2. In addition to baseline functions, facility receives drums, shreds and compacts contents, and repacks for disposal
3. Title II design complete prior to RCRA permit application submittal

338 RCRA PERMITTING PROCESS

Assumptions:

1. Facility requires a RCRA permit modification

2. Permit required prior to construction

434 MISCELLANEOUS PERMITTING

Assumptions:

1. A H&S Plan is required prior to construction

2. Current program plan will require updating

3. APENS will be determined

4. NESHAPS will be determined

5. A QAPP is required prior to design

6. PSD permit required prior to construction

539 OPERATIONS

Assumptions:

1. Facility will operate for 20 years

574 D&D

Assumptions:

1. Facility will undergo decontamination and decommissioning after its 20 year operation period

TABLE Q-4

Schedule Assumptions
Alternative #10—Plasma Melting

09 PROJECT CONCEPT DEVELOPMENT/FUNDING

Assumptions:

1. Funding request submitted after demo-scale will drive NEPA activities
2. Funding approval after project prioritization will drive other permitting and RCRA activities
3. Project requests line item funding

74 NEPA PROCESS

Assumptions:

1. EIS will be required resulting in a ROD
2. NEPA must be complete prior to Title I Design

209 SAFETY ANALYSIS REVIEW

Assumptions:

1. Preparation of the operational requirement document initiates the SAR process
2. PSAR must be completed prior to construction
3. FSAR must be completed prior to ORR

249 DESIGN AND CONSTRUCTION

Assumptions:

1. Facility is a concrete/steel structure
2. In addition to baseline functioning, facility houses a plasma arc furnace
3. Title II design complete prior to RCRA permit application submittal

338 RCRA PERMITTING PROCESS

Assumptions:

1. Facility requires a RCRA permit modification

2. Permit required prior to construction

434 MISCELLANEOUS PERMITTING

Assumptions:

1. A H&S Plan is required prior to construction

2. Current program plan will require updating

3. APENS will be determined

4. NESHAPS will be determined

5. A QAPP is required prior to design

6. PSD permit required prior to construction

539 OPERATIONS

Assumptions:

1. Facility will operate for 20 years

574 D&D

Assumptions:

1. Facility will undergo decontamination and decommissioning after its 20 year operation period

TABLE Q-5

Schedule Assumptions
Alternative #94—Enhanced Cementation/Shred and Add Clay

09 PROJECT CONCEPT DEVELOPMENT/FUNDING

Assumptions:

1. Funding request submitted after demo-scale will drive NEPA activities
2. Funding approval after project prioritization will drive other permitting and RCRA activities
3. Project requests line item funding

74 NEPA PROCESS

Assumptions:

1. EIS will be required resulting in a ROD
2. NEPA must be complete prior to Title I Design

209 SAFETY ANALYSIS REVIEW

Assumptions:

1. Preparation of the operational requirement document initiates the SAR process
2. PSAR must be completed prior to construction
3. FSAR must be completed prior to ORR

249 DESIGN AND CONSTRUCTION

Assumptions:

1. Facility is a concrete/steel structure
2. In addition to baseline functions, facility receives drums, shreds contents, and adds clay. Enhanced cementation will be used for sludges.
3. Title II design complete prior to RCRA permit application submittal

338 RCRA PERMITTING PROCESS

Assumptions:

1. Facility requires a RCRA permit modification

2. Permit required prior to construction

434 MISCELLANEOUS PERMITTING

Assumptions:

1. A H&S Plan is required prior to construction

2. Current program plan will require updating

3. APENS will be determined

4. NESHAPS will be determined

5. A QAPP is required prior to design

6. PSD permit required prior to construction

539 OPERATIONS

Assumptions:

1. Facility will operate for 20 years

574 D&D

Assumptions:

1. Facility will undergo decontamination and decommissioning after its 20 year operation period

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APPENDIX Q

ATTACHMENT 2
DETAILED SCHEDULES FOR WASTE PROCESSING ENGINEERED ALTERNATIVES

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APPENDIX Q

ATTACHMENT 2
DETAILED SCHEDULES FOR WASTE PROCESSING ENGINEERED ALTERNATIVES

this attachment presents detailed schedules for the waste processing EAs. The schedule for each alternative is presented in a separate figure, as shown below:

FIGURE	ALTERNATIVE
Q-1	Baseline
Q-2	#1 Supercompact
Q-3	#6 Shred & Compact
Q-4	#10 Plasma Melting
Q-5	#94 Enhanced Cement/Shred & Clay

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APPENDIX R
IMPACT ON OTHER WASTE DISPOSAL PROGRAMS

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IMPACT ON OTHER WASTE DISPOSAL PROGRAMS

This appendix presents the detailed methodology used to evaluate Factor 8. Backup data that were used to calculate the results of this factor analysis are also included.

Data from four TRU waste cementation treatment processes at Rocky Flats were analyzed, and the low-level secondary waste stream volumes were summed for each treatment process. The data analyzed for this factor came from the Rocky Flats Waste Stream and Residue Identification and Characterization report (WSRIC), version 5.0. The following treatment processes were reviewed:

Building 774: Organic and Sludge Immobilization System (OASIS)
Building 774: Miscellaneous Waste Handling
Building 774: Precipitation/Filtration
Building 374: Sludge Solidification

Tables R-1 through R-4 present summaries of secondary waste generation for these processes, all of which involve cementation of TRU waste and occur in gloveboxes. It was assumed that the Rocky Flats data would generally be representative of TRU waste cementation processes at any DOE facility. Several other assumptions were made in assembling and compiling the data:

- All secondary waste characterized as "transuranic (TRU) or low level (LL)" was assumed to be LL, to estimate conservatively the potential impacts on the LL waste program. Likewise, waste characterized as "(TRU mixed (TRUM) or low level mixed (LLM)" was assumed to be LLM, and waste characterized as "LLM or hazardous (HAZ)" was assumed to be LLM.

- Several waste streams listed generation rates as "variable" or "insufficient data." Generation rates for these waste streams were estimated based on other similar processes and wastes. The assumptions used are documented in the tables.

- Most generation rates were provided on a volume basis. Those that were presented on a mass basis were converted to volume basis using assumed densities based on other Rocky Flats data and the Baseline Inventory Report. Assumed densities are included in the tables.

Other TRU waste treatment processes at Rocky Flats that parallel treatment options being evaluated in this study, such as the supercompactor, did not have secondary waste estimates provided in the WSRIC report. Because other data were not readily available, it was assumed that the other waste treatments being evaluated (with the exception of plasma melting) generate similar volumes of secondary low-level waste as the cementation process, on a waste input basis.

The four waste generation rates, calculated as volume of low-level secondary waste generated per volume of cemented (output) waste, were then averaged. This average was 0.3 drums of secondary waste generated per drum of output cemented waste. The percents of the total secondary waste generated as low level waste (LLW) and low level mixed waste (LLMW) were also averaged for the four treatment processes. Table R-5 presents a summary of the secondary

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TABLE R-1

BUILDING 774 OASIS PROCESS
SUMMARY OF SECONDARY WASTE GENERATION

Waste Description	Generation Rate[1]	Assumptions	Waste Category
Solidified oil	600 drums/yr		TRUM or LLM
Leaded glovebox gloves	1 drum/yr		TRUM or LLM
Glovebox filters	4 drums/yr		TRUM or LLM
Line metal	4 drums/yr		TRUM or LLM
Nonline wet combustibles	240 drums/yr		LLM or HAZ
Line wet combustibles	50 drums/yr		TRUM or LLM
Nonline metal	Insufficient data *4 drums/yr*	same as line metal	LLW or nonradioactive
Plastic (PPE)	25 lb/yr *0.1 drum/yr*	combustible drum wt = 212 lb	TRUM or LLM
Dry combustibles	Variable *30 drums/yr*	5% of solidified oil output	LLW

[1]Italic indicates assumed or calculated generation rate.

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TABLE R-2

BUILDING 774 MISCELLANEOUS WASTE-HANDLING PROCESS SUMMARY OF SECONDARY WASTE GENERATION

Waste Description	Generation Rate[1]	Assumptions	Waste Category
Solidified lab waste, nonhazardous	14,000 lb/yr *22 drums/yr*	640 lb/drum (Rocky Flats data)	TRU or LLW
Solidified lab waste, hazardous	Variable *22 drums/yr*	Same as nonhazardous	TRUM or LLM
Leaded glovebox gloves	50 lb/yr *0.2 drum/yr*	300 lb/drum	TRUM or LLM
Glovebox HEPA filters	500 lb/yr *6.3 drums/yr*	79 lb/drum (WTWBIR)	TRU or LLW
Light metal, hazardous	Variable *0.3 drums/yr*	0.6% of total solidified lab waste, same as OASIS	TRUM or LLM
Light metal, nonhazardous	Variable *0.3 drums/yr*	0.6% of total solidified lab waste, same as OASIS	LLW
Dry combustibles	Variable *2.2 drums/yr*	5% of total solidified lab waste	TRU or LLW
Cement	Variable *0 drums/yr*	Minimal generation	TRU or LLW
Line plastic (empty bottles)	Insufficient data *2.2 drums/yr*	5% of total solidified lab waste	TRU or LLW

[1]Italic indicates assumed or calculated generation rate.

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TABLE R-3

BUILDING 774 PRECIPITATION/FILTRATION PROCESS SUMMARY OF SECONDARY WASTE GENERATION

Waste Description	Generation Rate[1]	Assumptions	Waste Category
Cemented sludge	456,000 lb/yr *912 drums/yr*	500 lb/drum (Rocky Flats data)	TRUM or LLM
Line wet combustibles	Insufficient data *46 drums/yr*	5% of cemented sludge	TRUM or LLM
Leaded glovebox gloves	2 drums/yr		TRUM or LLM
Light metal, nonhazardous	3 drums/yr		TRU or LLW
Plenum prefilters	24 to 72 filters/yr *24 drums/yr*	Avg 48 filters/yr 2 filters/drum	LLW
Oil (lube)	4 gal/yr *0.07 drums/yr*		TRUM or LLM
Nonline dry combustibles	50 drums/yr		LLW
Filtrate	Insufficient data *0 drums/yr*	Recycled in process	TRUM or LLM
Glovebox filters	1-2 drums/yr *1.5 drums/yr*	Average	TRU or LLW
Nonline wet combustibles	Variable *46 drums/yr*	5% of cemented sludge	LLW
Light metal, hazardous	3 drums/yr		TRUM or LLM
Plastic (PPE)	25 lb/yr *0.1 drum/yr*	Combustible drum wt = 212 lb	TRUM or LLM

[1]Italic indicates assumed or calculated generation rate.

TABLE R-4

BUILDING 374 SLUDGE SOLIDIFICATION PROCESS SUMMARY OF SECONDARY WASTE GENERATION

Waste Description	Generation Rate[1]	Assumptions	Waste Category
Solidified bypass sludge	5-10 drums/month *90 drums/yr*	Average	TRUM or LLM
Process liquid waste (filtrate)	Variable *0 drums/yr*	Recycled in process	TRUM or LLM
Process liquid waste (supernatant)	Variable *0 drums/yr*	Recycled in process	TRUM or LLM
Wet combustibles	11 gal/month *2.4 drums/yr*		TRUM or LLM
Dry combustibles	11 gal/month *2.4 drums/yr*		TRUM or LLM
Plastic, hazardous	11 gal/month *2.4 drums/yr*		TRUM or LLM
Light metal, hazardous	11 gal/month *2.4 drums/yr*		TRUM or LLM
Absolute drybox filters	Variable *1.5 drums/yr*	Same as 774 precip/filtration (glovebox filters)	TRU or LLW
Light metal, nonhazardous	11 gal/month *2.4 drums/yr*		LLW
Dry combustibles, nonhazardous	11 gal/month *2.4 drums/yr*		LLW
Plastic, nonhazardous	11 gal/month *2.4 drums/yr*		LLW
Insulation, nonhazardous	11 gal/yr *0.2 drums/yr*		LLW
Insulation, hazardous	11 gal/yr *0.2 drums/yr*		TRUM or LLM
Glass, nonhazardous	11 gal/yr *0.2 drums/yr*		LLW
Hypalon glovebox gloves	Variable *0 drum/yr*	Minimal generation	TRU or LLW

[1]Italic indicates assumed or calculated generation rate.

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TABLE R-5

WASTE GENERATION RATE SUMMARY

Process	Secondary Waste Generation (drums waste per drum solidified output)	Percentage of LL secondary waste	Percentage of LLM secondary waste
OASIS	0.56	10	90
Misc. Waste Handling	0.26	96	4
Precip/filtration	0.19	71	29
Sludge solidification	0.21	48	52
Averages	0.30	56	44

waste generation and percentages of LLW and LLMW for the four processes. The percentages of LLW and LLMW varied greatly, so an average of approximately 50 percent LLW and 50 percent LLMW was used in the analysis, instead of the calculated averages of 56 percent LLW and 44 percent LLMW.

Because data were not available for other treatment processes, it was assumed that the other waste treatments being evaluated (with the exception of plasma melting) generate similar volumes of secondary low-level waste as the cementation process, on a waste input basis. To convert the cementation data from an output basis to an input basis, the volume increase factor for cementation of 1:2.5 was used (refer to Table 3-73). This waste input basis factor, calculated to be 0.75 drums of secondary waste per drum of input waste, was then applied to each treatment process to calculate the volume of secondary low-level waste generated.

For the plasma melting process, the secondary low-level waste generation was assumed to be zero because the treatment process is designed such that secondary waste is fed back through the plasma melter. The volume reduction achieved in the plasma process for typical secondary wastes such as personal protective equipment, filters, and combustibles, is very high, so the volume of secondary wastes generated from the treatment process will be negligible. However, secondary waste will still be generated in the waste characterization step.

The waste characterization step is shown in the process flow diagrams in Section 3.7.2.1.1. The waste characterization module, as defined in the EMPEIS, includes opening and sorting drum contents, collecting waste samples, and repackaging, if necessary, to remove and stabilize noncompliant waste. This operation, which occurs in a glovebox, is assumed to generate secondary low-level waste at the same rate (input basis) as the treatment processes. The secondary waste generated was calculated only for the portion of the waste inventory that passes through the waste characterization step (assumed to be 30 percent of stored waste and 10 percent of projected waste, as discussed in Section 3.7.2.1.1). Secondary waste generated from waste characterization is the same for the baseline and all engineered alternatives (EA).

Table R-6 shows secondary waste volumes broken down by characterization and treatment steps. The calculated secondary waste generation rates shown in this table were then used to determine impacts on the DOE low-level programs. The calculated generation rates of LLW and LLMW for each EA were compared to current and projected total DOE inventories of LLW and LLMW to determine impact in terms of percentage increase over current levels for each EA. Data for total DOE waste inventories and projections for LLW and LLMW were obtained from the IDB and the MWIR, respectively.

Tables R-7 through R-9 show the secondary waste volumes by site for each configuration and EA. When combined with site-specific waste inventory and generation data, this data could be used to determine impacts on the low-level waste program at each site. A site-specific analysis was outside the scope of this report. Data in these tables were derived from the scaled volumes of sludges, solid organics, and solid inorganics that were used as inputs in the EA cost analysis.

Backup documentation attached to this appendix includes the WSRIC process descriptions for the four processes analyzed and pertinent sections of the IDB.

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TABLE R-6

SECONDARY WASTE VOLUMES
(cubic meters)

	Secondary Waste Generated (m^3)		
Alternative	Waste Char.	Treatment	Total
Baseline	21,848	10,881	32,729
1	21,848	96,192	118,040
6	21,848	96,192	118,040
10	21,848	0	21,848
94	21,848	109,777	131,625

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TABLE R-7

TOTAL SECONDARY WASTE GENERATED
DECENTRALIZED ALTERNATIVES
CUBIC METERS

Site	Baseline	1	6	10	94
AMES LAB	0	0	0	0	0
ANL-E	8	15	15	7	32
BT	12	12	12	12	12
ETEC	1	1	1	1	1
HANFORD	7,932	41,079	41,079	4,867	41,082
INEL/ANL-W	12,590	28,853	28,853	9,084	39,369
KAPL	1	1	1	1	1
LANL	6,200	16,315	16,315	3,263	19,124
LBL	1	1	1	1	1
LLNL	185	984	984	120	994
MOUND	59	373	373	59	378
MU	0	0	0	0	0
NTS	138	604	604	138	604
ORNL	202	963	963	202	1,047
PANTEX	0	0	0	0	0
PA	0	0	0	0	0
RFP	1,937	5,174	5,174	628	5,315
SNL/NM	2	2	2	2	2
SRS	3,462	23,662	23,662	3,462	23,662
WIPP	0	0	0	0	0
TOTAL	32,729	118,040	118,040	21,848	131,625

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TABLE R-8

TOTAL SECONDARY WASTE GENERATED
REGIONALIZED ALTERNATIVES
CUBIC METERS

Site	Baseline	1	6	10	94
AMES LAB	0	0	0	0	0
ANL-E	7	7	7	7	7
BT	12	12	12	12	12
ETEC	1	1	1	1	1
HANFORD	7,996	41,943	41,943	4,867	41,955
INEL/ANL-W	12,590	29,319	29,319	9,084	39,835
KAPL	1	1	1	1	1
LANL	6,200	16,315	16,315	3,263	19,124
LBL	1	1	1	1	1
LLNL	120	120	120	120	120
MOUND	59	59	59	59	59
MU	0	0	0	0	0
NTS	138	138	138	138	138
ORNL	202	202	202	202	202
PANTEX	0	0	0	0	0
PA	0	0	0	0	0
RFP	1,937	5,174	5,174	628	5,315
SNL/NM	2	2	2	2	2
SRS	3,464	24,745	24,745	3,462	24,856
WIPP	0	0	0	0	0
TOTAL	32,729	118,040	118,040	21,848	131,629

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TABLE R-9

TOTAL SECONDARY WASTE GENERATED
CENTRALIZED ALTERNATIVES
CUBIC METERS

Site	Baseline	1	6	10	94
AMES LAB	0	0	0	0	0
ANL-E	7	7	7	7	7
BT	12	12	12	12	12
ETEC	1	1	1	1	1
HANFORD	4,867	4,867	4,867	4,867	4,867
INEL/ANL-W	9,084	9,084	9,084	9,084	9,084
KAPL	1	1	1	1	1
LANL	3,263	3,263	3,263	3,263	3,263
LBL	1	1	1	1	1
LLNL	120	120	120	120	120
MOUND	59	59	59	59	59
MU	0	0	0	0	0
NTS	138	138	138	138	138
ORNL	202	202	202	202	202
PANTEX	0	0	0	0	0
PA	0	0	0	0	0
RFP	628	628	628	628	628
SNL/NM	2	2	2	2	2
SRS	3,462	3,462	3,462	3,462	3,462
WIPP	10,881	96,192	96,192	0	109,781
TOTAL	32,729	118,040	118,040	21,848	131,629

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ATTACHMENT 1

INTEGRATED DATA BASE REPORT—1993: U.S. SPENT NUCLEAR FUEL AND RADIOACTIVE WASTE INVENTORIES, PROJECTIONS, AND CHARACTERISTICS

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DOE/RW-0006, Rev. 10

December 1994

Integrated Data Base Report—1993: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics

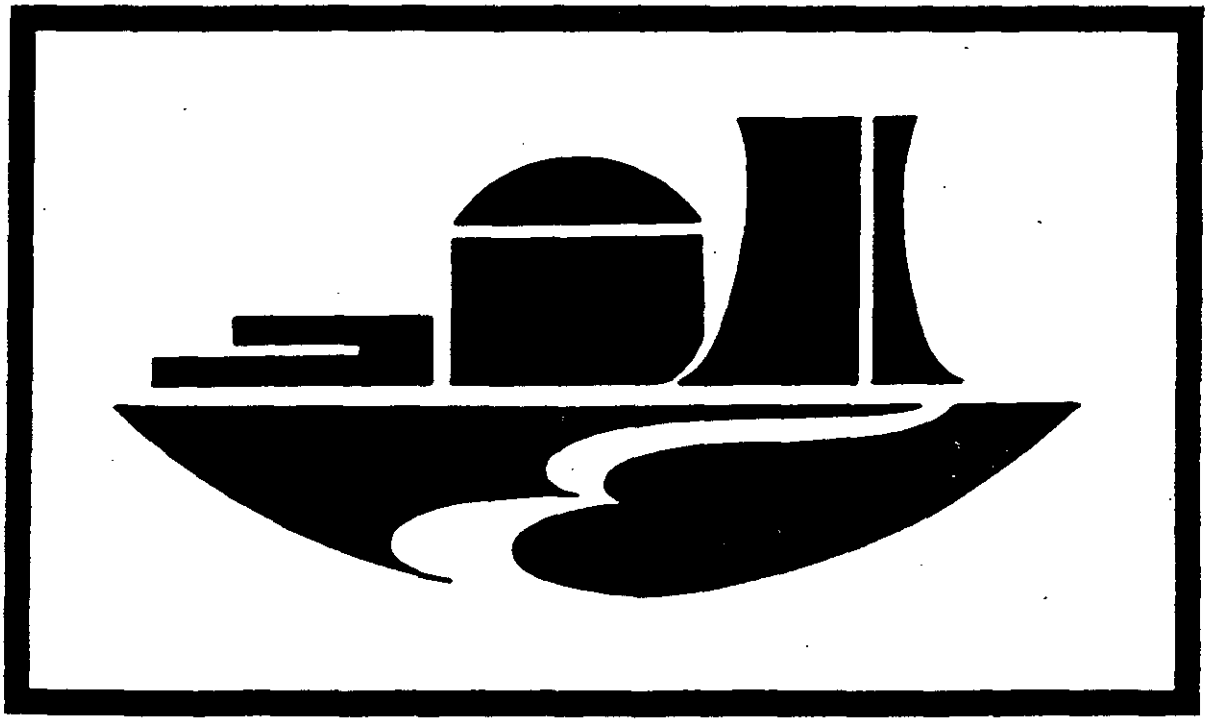

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Prepared by

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Table 4.2. Historical and projected volume, radioactivity, and thermal power of buried DOE LLW[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual	Cumulative	Annual	Cumulative[b]	Annual	Cumulative
1990	60.0	2,759	545	13,516	2,013	17,844
1991	53.6	2,812	717	13,277	2,788	18,220
1992	48.3	2,860	1,078	13,401	4,947	20,741
1993	50.5	2,911	894	13,147	3,263	20,398
1994	44.2	2,955	756	12,993	3,073	21,143
1995	44.2	2,999	756	12,906	3,073	22,066
1996	69.3	3,068	757	12,847	3,076	23,009
1997	117.2	3,186	759	12,807	3,080	23,928
1998	131.3	3,317	777	12,796	3,122	24,849
1999	146.2	3,463	769	12,785	3,103	25,708
2000	116.7	3,579	763	12,775	3,089	26,510
2001	131.3	3,710	756	12,765	3,073	27,260
2002	131.3	3,841	759	12,764	3,081	27,983
2003	132.6	3,975	764	12,775	3,091	28,687
2004	44.2	4,019	756	12,780	3,073	29,342
2005	131.3	4,150	756	12,792	3,073	29,974
2006	131.2	4,281	761	12,815	3,084	30,596
2007	88.0	4,368	757	12,838	3,076	31,188
2008	88.0	4,457	756	12,864	3,073	31,757
2009	87.7	4,545	756	12,894	3,073	32,309
2010	57.5	4,602	756	12,927	3,073	32,842
2011	64.3	4,666	756	12,963	3,073	33,359
2012	85.3	4,750	757	13,004	3,074	33,866
2013	131.3	4,885	763	13,055	3,088	34,374
2014	95.9	4,979	758	13,102	3,078	34,858
2015	87.7	5,063	756	13,150	3,073	35,322
2016	131.3	5,197	756	13,199	3,073	35,774
2017	131.3	5,331	756	13,251	3,073	36,216
2018	131.3	5,455	756	13,305	3,073	36,648
2019	87.7	5,550	756	13,358	3,073	37,067
2020	87.7	5,634	756	13,416	3,074	37,480
2021	44.2	5,678	756	13,472	3,073	37,879
2022	44.2	5,722	756	13,531	3,073	38,270
2023	44.2	5,766	756	13,590	3,073	38,652
2024	44.2	5,811	756	13,649	3,073	39,025
2025	44.2	5,855	756	13,709	3,073	39,390
2026	44.2	5,899	756	13,770	3,073	39,748
2027	44.2	5,943	756	13,832	3,073	40,098
2028	44.2	5,987	756	13,893	3,073	40,440
2029	44.2	6,031	756	13,955	3,073	40,775
2030	44.2	6,076	756	14,017	3,073	41,104

[a]Summation of values in Tables 4.16 (buried DOE LLW, except SRS saltstone) and 4.17 (LLW saltstone at SRS).

[b]The radioactivity added each year for each waste type is decayed as described in the footnotes of Tables 4.16 and 4.17.

Table 4.6. Summary of physical characteristics for LLW at DOE sites[a]

Waste type	Physical characteristic[b]	Volume, m^3			Activity, Ci		
		1993	Cumulative[c]	1994 (projected)	1993	Total gross[d]	1994 (projected)
Generated on-site	Biological	285	e	317	2,608	e	6,343
	Contaminated equipment	3,531	e	3,347	665,714	e	846,445
	Decontamination debris	4,814	e	5,870	704	e	986
	Dry solids	18,611	e	16,256	76,312	e	87,642
	Solidified sludge	745	e	843	1,657	e	3,673
	Other	13,429	e	7,742	4,168	e	5,235
	Total	41,415	e	34,375	751,163	e	950,324
Stored	Biological	167	939	200	1,361	13,441	3,806
	Contaminated equipment	852	42,248	1,986	109,538	877,888	267,317
	Decontamination debris	2,021	9,164	2,909	607	1,180	852
	Dry solids	4,338	46,332	4,429	20,046	680,334	36,518
	Solidified sludge	639	26,081	738	1,657	1,665	3,583
	Other	6,964	30,902	3,342	213,564	294,664	92,215
	Total	14,981	155,666	13,604	346,773	1,869,172	404,291
Buried	Biological	117	f	122	1,247	f	2,537
	Contaminated equipment	8,783	f	6,324	104,780	f	170,480
	Decontamination debris	7,313	f	10,292	193	f	213
	Dry solids	27,663	f	24,200	785,388	f	579,902
	Solidified sludge	106	f	197	2	f	90
	Other	6,481	f	3,049	2,670	f	2,884
	Total	50,463	2,911,177	44,184	894,280	45,286,174	756,106

[a]Based on DOE site information provided in ref. 1. Totals reported in this table may not equal the sum of component entries because of round-off and truncation of numbers.

[b]Physical characteristics: (1) biological (sewage sludge, animal carcasses, excreta, etc.); (2) contaminated equipment (components, maintenance wastes, etc.); (3) decontamination debris (wastes resulting from decontamination and decommissioning efforts, construction debris, etc.); (4) dry solids (normal plant wastes, blotting paper, combustible materials, etc.); (5) solidified sludge (any wastes solidified from a process sludge such as evaporator bottoms solidification, solidification of precipitated salts, etc.); and (6) other (materials which are outside of the above categories).

[c]From beginning of operations through 1993.

[d]Sum of annual additions without decay.

[e]Not applicable [i.e., generation is taken to be an intensive quantity (amount/year) and is not additive; whereas stored and buried are extensive quantities (amounts) and are additive].

[f]Information not available.

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ATTACHMENT 2

TREATMENT PROCESSES

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3.0 PROCESS 374-3: SLUDGE SOLIDIFICATION

The Sludge Solidification Process, located in Rooms 2804, 3803, and 4805, immobilizes radioactive and hazardous materials from decontamination-precipitation, and neutralization for shipment off site. The slurry waste to be solidified in this process is fed to Tanks D-824 A and B from the clarifier bottoms (Tanks D-815, D-819, and D-823) of the Radioactive Decontamination Process, from Tank D-808 of the Acid Neutralization Process, and acid descaling waste from Tank D-845. Equipment used in this process includes various tanks, conveyors, and drum vacuum filters. Figure 3.1 shows the inputs, process flow, and outputs associated with the Sludge Solidification process.

The Sludge Solidification Process contains an associated subprocess comprised of a vent scrubber system. This system collects and neutralizes fumes from chemical preparation area tanks; waste receiving tanks; reactor, flocculator, and clarifier tanks; the sludge dryer; and GB 118 and GB 120 for the Sludge Solidification Process. The fumes from these areas pass through a variable throat venturi where they contact a basic solution injected through sets of nozzles. A short elbow connects the venturi to the gas absorber, which has eight nozzles below a demister pad. Gases are pulled through the system by one of the two blowers. The scrubbing solution contains parallel pumps which switch automatically when a low liquid flow is detected by a sensor. The solution is cooled in the heat exchanges. A portion of the scrubbing solution is drawn off periodically to maintain proper Ph and solids concentration and is transferred to Tanks D-811 A or B. A level controller in the scrubber sump operates a valve used to replenish the liquid with process water. A manual valve in the caustic supply line allows personnel to replenish the caustic materials when necessary. The scrubber pulls a slight vacuum on the tanks and gloveboxes, which is controlled by the pressure drop across the scrubber, set at 600 millimeters absolute pressure. The scrubber vents to the Building 374 filter plenums, which contain two sets of HEPA filters.

Supernatant from Tanks D-824 A and B (at A, Figure 3.1) is decanted to Tank D-812 in the Radioactive Decontamination Process. The slurry from these tanks is pumped to the rotary drum vacuum filter, FL-802 A (at B, Figure 3.1), which is inside a large glovebox (GB 120). The filter drum is coated with a mixture of diatomite and either water or filtrate; this mixture is prepared in Tank D-848 (at C, Figure 3.1). The slurry is fed into the filter pan, and the filtrate is drawn through the precoat by a vacuum, leaving a sludge of precipitated solids on the surface of the filter media. An advancing blade continuously removes the sludge and a thin layer of precoat. Tanks D-825 A or B (at D, Figure 3.1) collect the filtrate from the rotary drum filter for transfer to the Radioactive Decontamination Process. Two mist tanks are associated with the vacuum pumps on the rotary drum filter. The tanks may receive some filtrate, which is discharged to Sump Tank D-852 (Figure 2.1A).

The sludge is solidified using either the sludge dryer system or the bypass system. In the sludge dryer system, the sludge is dried in a dryer (at E, Figure 3.1). The sludge from the vacuum filters is fed to the dryer feed hopper by a drop chute. The sludge is then conveyed through the dryer in heated flights. The dried sludge overflows directly into the conveying system of the direct cementation sludge hopper. In the direct cementation procedure (at F, Figure 3.1), dried sludge, cement, and water are metered by a computer and mixed using a paddle mixer to produce a cemented waste product. The cement is transferred pneumatically to a cement hopper from outside storage. The sludge, cement, and water are deposited in a 55-gallon drum and allowed to solidify. Filter FL-802B supports the direct cementation, which is not currently in operation.

The bypass system (FL-802A) transfers wet sludge directly from the vacuum filter to a 55-gallon drum via a conveyor system (at G, Figure 3.1). Cement and diatomaceous earth are metered into the drum with the sludge to absorb liquids. Various combustibles, glass (from lights and glassware), metals (from tools and pipes, etc.), plastics, and gloves are used in general cleanup and maintenance of the system.

Cemented drummed solids are put in a 90-day drum storage area WMU 379 or WMU 2005 before being sent to Real Time Radiography (RTR), and storage for eventual off-site storage. Filtrate is stored in Tanks D-804 A, B, C and D (Figure 2.1A) and Tank D-811 for eventual treatment in the Radioactive Decontamination Process. Exhaust fumes are passed to the vent scrubber system and are vented to the building filter plenum. Most hazardous wastes are collected in a 90-day area, WMU 379 or WMU 2005. Sealed containers are sent to the drum assay counter, RTR, then stored for eventual off-site storage. Nonhazardous wastes are collected in 55-gallon drums in Room 3801 or 3810. Sealed containers are sent to the drum assay counters, to RTR, and then to storage for eventual off-site storage.

Filters are assayed at a drum counter and taken to Size Reduction in Building 776. Process Table 374-3 presents the outputs associated with the Sludge Solidification Process and provides their dispositions and hazardous character.

AutoCAD 12, File Name: 374-3 05/04/95

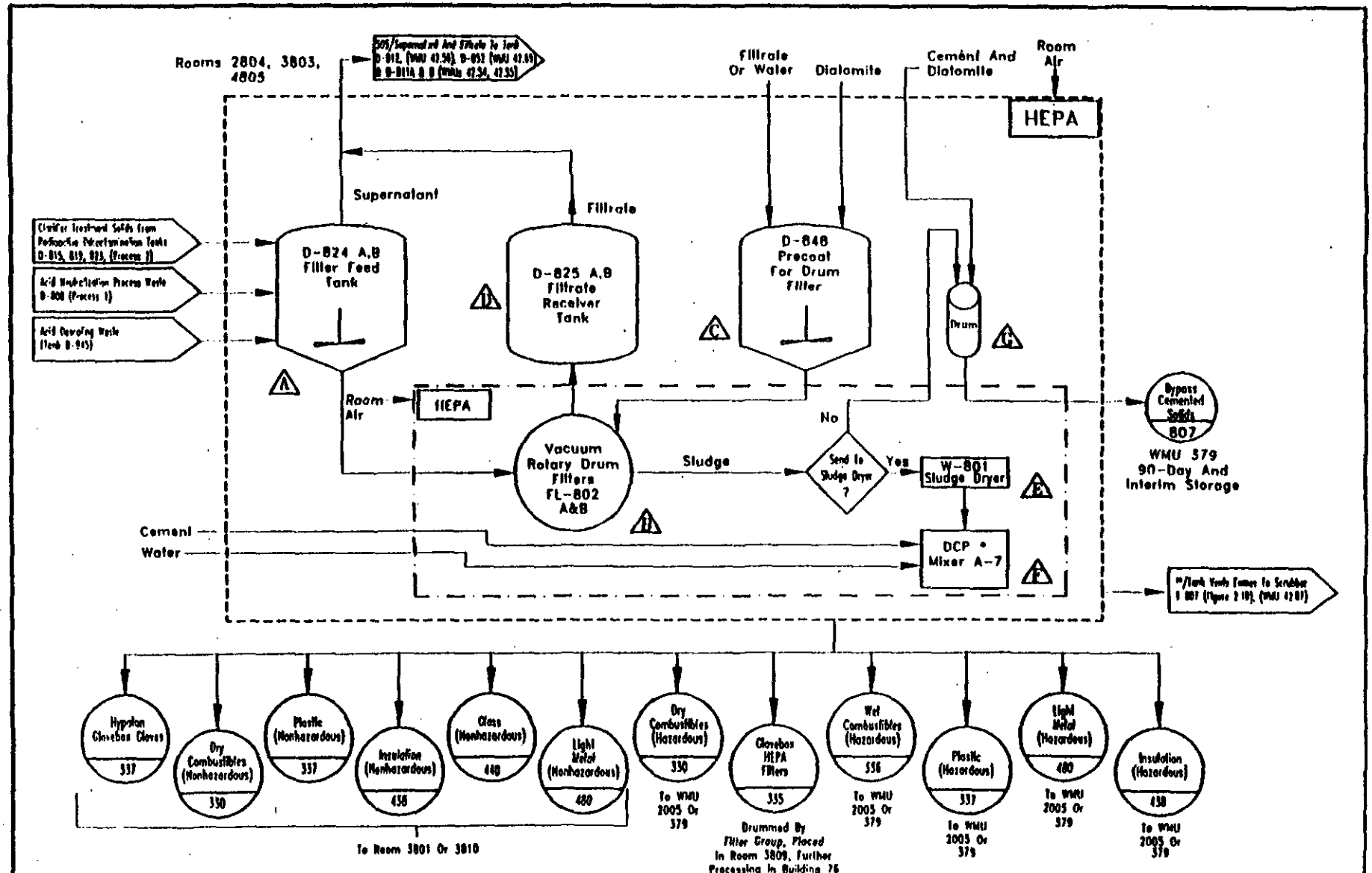

FIGURE 3.1

Rocky Flats Environmental Technology Site Waste Stream & Residue Identification & Characterization	BUILDING 374/PROCESS 3 SLUDGE SOLIDIFICATION	Task	By	Date
		Designed	J. Johnson	11/25/92
		Drawn	B. Crawford	05/04/95
		Checked	J. Joyce	05/04/95

PROCESS 374-3 SLUDGE SOLIDIFICATION

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
374-3-2	807	BS	00	NA	Solidified Bypass Sludge, Building 374 RCRA Reg. Chemical Constituents: DCP Bypass Sludge Non-RCRA Reg. Chemical Constituents: None	WMU 379 WMU 2005	Yes	Yes	Yes	Waste	F001, F002, F003, F005, F006, F007, F009, F039

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Code
374-3-3	505	HC96	00	3A	Process Liquid Waste (Filtrate) RCRA Reg. Chemical Constituents: Arsenic, Carbon Tetrachloride, Chlorinated Fluorocarbons, Methylene Chloride, Tetrachloroethylene, Trichloroethylene, 1,1,1-Trichloroethane, 1,1,2-Trichloro, 1,2,2-Trifluoroethane, Toluene, Cadmium, Chromium, Lead, Selenium, Silver; Can Also Contain Acids, Bases, Beryllium, Barium, Denatured Alcohol, Diamond Paste, Ethylene Glycol, Isopropanol, Mercury, Methanol, Mariko, Nickel, Oakite, Penetrate Oil, Spent Emulsifier, Spent Developer, Spent X-ray Developer/Starter And Trim Sol Leachate Non-RCRA Reg. Chemical Constituents: None	WMU 42.54 WMU 42.55 WMU 42.56 WMU 42.69 WMU 42.81 WMU 42.82	Yes	Yes	Yes	Waste	F001 F002 F00[illegible] F00[illegible] F00[illegible] F00[illegible] F00[illegible] F03[illegible]

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
374-3-4	505	HC96	00	3A	Process Liquid Waste (Supernatant) RCRA Reg. Chemical Constituents: Arsenic, Carbon Tetrachloride, Chlorinated Fluorocarbons, Methylene Chloride, Tetrachloroethylene, Trichloroethylene, 1,1,1-Trichloroethane, 1,1,2-Trichloro, 1,2,2-Trifluoroethane, Toluene, Cadmium, Chromium, Lead, Selenium, Silver; Can Also Contain Acids, Bases, Beryllium, Barium, Denatured Alcohol, Diamond Paste, Ethylene Glycol, Isopropanol, Mercury, Methanol, Mariko, Nickel, Oakite, Penetrate Oil, Spent Emulsifier, Spent Developer, Spent X-ray Developer/Starter And Trim Sol Leachate Non-RCRA Reg. Chemical Constituents: None	WMU 42.54 WMU 42.55 WMU 42.56 WMU 42.69	Yes	Yes	Yes	Waste	F001, F002, F003, F005, F006, F007, F009, F039

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EP/ Cod
374-3-6	336	HC	00	NA	Combustibles, Wet RCRA Reg. Chemical Constituents: Arsenic, Carbon Tetrachloride, Chlorinated Fluorocarbons, Methylene Chloride, Tetrachloroethylene, Trichloroethylene, 1,1,1-Trichloroethane, 1,1,2-Trichloro, 1,2,2-Trifluoroethane, Toluene, Cadmium, Chromium, Lead, Selenium, Silver; Can Also Contain Acids, Bases, Beryllium, Barium, Denatured Alcohol, Diamond Paste, Ethylene Glycol, Isopropanol, Mercury, Methanol, Mariko, Nickel, Oakite, Penetrate Oil, Spent Emulsifier, Spent Developer, Spent X-ray Developer/Starter And Trim Sol Non-RCRA Reg. Chemical Constituents: None	WMU 379 WMU 2005	Yes	Yes	Yes	Waste	F00 F00 F00 F00 F00 F00 F00 F0

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
374-3-7	330	HC	00	NA	Combustibles, Dry (Hazardous) RCRA Reg. Chemical Constituents: Arsenic, Carbon Tetrachloride, Chlorinated Fluorocarbons, Methylene Chloride, Tetrachloroethylene, Trichloroethylene, 1,1,1-Trichloroethane, 1,1,2-Trichloro, 1,2,2-Trifluoroethane, Toluene, Cadmium, Chromium, Lead, Selenium, Silver; Can Also Contain Acids, Bases, Beryllium, Barium, Denatured Alcohol, Diamond Paste, Ethylene Glycol, Isopropanol, Mercury, Methanol, Mariko, Nickel, Oakite, Penetrate Oil, Spent Emulsifier, Spent Developer, Spent X-ray Developer/Starter And Trim Sol Non-RCRA Reg. Chemical Constituents: None	WMU 379 WMU 2005	Yes	Yes	Yes	Waste	F001, F002, F003, F005, F006, F007, F009, F039

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Cod
374-3-8	337	HC	00	NA	Plastic (Hazardous)(Teflon, PVC, Poly, Etc) RCRA Reg. Chemical Constituents: Arsenic, Carbon Tetrachloride, Chlorinated Fluorocarbons, Methylene Chloride, Tetrachloroethylene, Trichloroethylene, 1,1,1-Trichloroethane, 1,1,2-Trichloro, 1,2,2-Trifluoroethane, Toluene, Cadmium, Chromium, Lead, Selenium, Silver; Can Also Contain Acids, Bases, Beryllium, Barium, Denatured Alcohol, Diamond Paste, Ethylene Glycol, Isopropanol, Mercury, Methanol, Mariko, Nickel, Oakite, Penetrate Oil, Spent Emulsifier, Spent Developer, Spent X-ray Developer/Starter And Trim Sol Non-RCRA Reg. Chemical Constituents: None	WMU 379 WMU 2005	Yes	Yes	Yes	Waste	F00 F00 F00 F00 F00 F00 F00 F03

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
374-3-10	480	HC96	00	NA	Light Metal (Hazardous) RCRA Reg. Chemical Constituents: Arsenic, Carbon Tetrachloride, Chlorinated Fluorocarbons, Methylene Chloride, Tetrachloroethylene, Trichloroethylene, 1,1,1-Trichloroethane, 1,1,2-Trichloro, 1,2,2-Trifluoroethane, Toluene, Cadmium, Chromium, Lead, Selenium, Silver; Can Also Contain Acids, Bases, Beryllium, Barium, Denatured Alcohol, Diamond Paste, Ethylene Glycol, Isopropanol, Mercury, Methanol, Mariko, Nickel, Oakite, Penetrate Oil, Spent Emulsifier, Spent Developer, Spent X-ray Developer/Starter And Trim Sol Leachate Non-RCRA Reg. Chemical Constituents: None	WMU 379 WMU 2005	Yes	Yes	Yes	Waste	F001, F002, F003, F005, F006, F007, F009, F039

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Code
374-3-11	303	00	00	NA	Absolute Drybox Filters(Not Acid Contaminated) RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 3809	Yes	No	No	Waste	
374-3-13	480	00	00	NA	Light Metal (Nonhazardous) RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 3801 Or 3810	Yes	No	No	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
374-3-15	330	00	00	NA	Combustibles, Dry (Nonhazardous) RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 3801 Or 3810	Yes	No	No	Waste	
374-3-16	337	00	00	NA	Plastic (Nonhazardous) RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 3801 Or 3810	Yes	No	No	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Code
374-3-17	438	00	00	NA	Insulation (Nonhazardous) RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 3801 Or 3810	Yes	No	No	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
374-3-18	438	HC	00	NA	Insulation (Hazardous) RCRA Reg. Chemical Constituents: Arsenic, Carbon Tetrachloride, Chlorinated Fluorocarbons, Methylene Chloride, Tetrachloroethylene, Trichloroethylene, 1,1,1-Trichloroethane, 1,1,2-Trichloro, 1,2,2-Trifluoroethane, Toluene, Cadmium, Chromium, Lead, Selenium, Silver; Can Also Contain Acids, Bases, Beryllium, Barium, Denatured Alcohol, Diamond Paste, Ethylene Glycol, Isopropanol, Mercury, Methanol, Mariko, Nickel, Oakite, Penetrate Oil, Spent Emulsifier, Spent Developer, Spent X-ray Developer/Starter And Trim Sol Non-RCRA Reg. Chemical Constituents: None	WMU 379 WMU 2005	Yes	Yes	Yes	Waste	F001, F002, F003, F005, F006, F007, F009, F039

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Code
374-3-19	440	00	00	NA	Glass (Nonhazardous) RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 3801 Or 3810	Yes	No	No	Waste	
374-3-21	337	00	00	NA	Hypalon Glovebox Gloves RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 3801 Or 3810	Yes	No	No	Waste	

Process Number: 374-3-2 **Title:** SLUDGE SOLIDIFICATION
IDC: 807 **Description:** Solidified Bypass Sludge, Building 374

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- ■ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- ■ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes:
F001, F002, F003, F005, F006, F007, F009, F039

Description (Material, Type, Size, Color, etc.):
Cemented solids from the bypass system are a mixture of wet sludge, cement, and diatomaceous earth that have been placed into 55-gallon drums. The wet sludge consists of solids that have been precipitated from process waste water and separated from filtrate water by a vacuum drum filter. The cement and diatomaceous earth are metered into the drum with the wet sludge to absorb free liquids.

How the Output is Generated:
Solids Filtered From Slurry

Generation Rate:
5-10, 55-Gallon Drums Monthly

How the Output is Managed:
Cemented solids from the bypass system are brought to a 90-day area WMU 379 or WMU 2005 for storage until sample results are received. Based upon sample results, the containers are taken to WMU 19 if TRU mixed or WMU 24 if LLM.

Chemicals/Contaminants in or on the Output:
Building 374 Process Waste Stream

Characterization Rationale:
This output is characterized using information, based on the same IDC, contained in the Backlog Baseline Book. This output is an F-listed waste because it is derived from the treatment of F-listed wastes. Therefore, this output may be a mixed, transuranic or low-level waste.

Process Number: 374-3-3 **Title:** SLUDGE SOLIDIFICATION
IDC: 505 **Description:** Process Liquid Waste (Filtrate)

- ● RCRA Hazardous
- ▫ RCRA Nonhazardous
- ▫ By Analytical Data
- ● By Process Knowledge
- ■ LDR Regulated
- ▫ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:
F001, F002, F003, F005, F006, F007, F009, F039

Description (Material, Type, Size, Color, etc.):
Filtrate from the vacuum filter is the liquid that is separated from precipitated solids by the FL-802 A and B vacuum drum filters. This filtrate is recycled through the filtrate receiver tank, and eventually mixed with Output 374-3-4, supernatant.

How the Output is Generated:
Generated During The Process

Generation Rate:
Combined With Item 4

How the Output is Managed:
Filtrate may be collected in Tank D-812 (WMU 42.56), Tanks D825 A and B (WMUs 42.81, 42.82), Tank D-852 (WMU 42.69), and Tanks D-811 A and B (WMUs 42.54 and 42.55) for treatment in the Radioactive Decontamination Process.

Chemicals/Contaminants in or on the Output:
Building 374 Process Waste

Characterization Rationale:
This output consists of liquids which are nonline generated in a Radioactive Materials Management Area. According to process knowledge, this output may contain F-listed spent solvents, electroplating wastes, and multi-source leachate. This output may be a mixed, transuranic or low-level waste.

Process Number: 374-3-4 **Title:** SLUDGE SOLIDIFICATION
IDC: 505 **Description:** Process Liquid Waste (Supernatant)

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes:
F001, F002, F003, F005, F006, F007, F009, F039

Description (Material, Type, Size, Color, etc.):
Supernatant from Tanks D-824 A and B (filter feed tanks) is the decanted liquid from tanks that receive clarifier solids from the Radioactive Decontamination Process.

How the Output is Generated:
Decant Solution

Generation Rate:
Variable

How the Output is Managed:
Supernatant from Tanks D-824 A and B (Filter Feed Tanks) is collected in the feed tank D-812, for the Radioactive Decontamination Process (WMU 42.56), Tank D-852 (WMU 42.69) and Tanks D-811 A and B (WMUs 42.54, 42.55).

Chemicals/Contaminants in or on the Output:
Building 374 Process Waste

Characterization Rationale:
This output consists of liquids which are nonline generated in a Radioactive Materials Management Area. According to process knowledge, this output may contain F-listed spent solvents, electroplating wastes, and multi-source leachate. This output may be a mixed, transuranic or low-level waste.

Process Number: 374-3-6 **Title:** SLUDGE SOLIDIFICATION
IDC: 336 **Description:** Combustibles, Wet

- ● RCRA Hazardous
- ▫ RCRA Nonhazardous
- ▫ By Analytical Data
- ● By Process Knowledge
- ● LDR Regulated
- ▫ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:
F001, F002, F003, F005, F006, F007, F009, F039

Description (Material, Type, Size, Color, etc.):
Wet Combustibles Such As Kimwipes, Surgeon's Gloves And Tyveks Which Have Come In Contact With Waste From The Sludge Solidification Process

How the Output is Generated:
Cleanup Activities In The Sludge Solidification Process And Routine Maintenance

Generation Rate:
11 Gallons Monthly

How the Output is Managed:
Combustibles are collected in a 90-day area, WMU 379 or WMU 2005. Sealed containers are sent to the drum assay counters, RTR, and then storage for eventual offsite storage.

Chemicals/Contaminants in or on the Output:
Waste From The Sludge Solidification Process

Characterization Rationale:
This output is characterized using information, based on the same IDC, contained in the Backlog Baseline Book. This output is contaminated with F-listed spent solvents, electroplating wastes, and multi-source leachate. This output is nonline generated in a Radioactive Materials Management Area and may be a mixed, transuranic or low-level waste.

Process Number: 374-3-7 **Title:** SLUDGE SOLIDIFICATION
IDC: 330 **Description:** Combustibles, Dry (Hazardous)

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes:
F001, F002, F003, F005, F006, F007, F009, F039

Description (Material, Type, Size, Color, etc.):
Dry Combustibles Such As Surgeon's Gloves. Kimwipes, Tyveks, And Wood That Have Been Contaminated With Waste From The Sludge Solidification Process

How the Output is Generated:
Cleanup Activities In The Sludge Solidification Area And Routine Maintenance

Generation Rate:
11 Gallons Monthly

How the Output is Managed:
Dry combustibles are collected in a 90-day area, WMU 379 or WMU 2005. Sealed containers are sent to the drum assay counters, RTR, and then storage for eventual offsite storage.

Chemicals/Contaminants in or on the Output:
Waste From The Radioactive Decontamination Process

Characterization Rationale:
This output is characterized using information, based on the same IDC, contained in the Backlog Baseline Book. This output is contaminated with F-listed spent solvents, electroplating wastes, and multi-source leachate. This output is nonline generated in a Radioactive Materials Management Area and may be a mixed, transuranic or low-level waste.

Process Number: 374-3-8 **Title:** SLUDGE SOLIDIFICATION
IDC: 337 **Description:** Plastic (Hazardous)(Teflon, PVC, Poly, Etc)

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- ■ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes:
F001, F002, F003, F005, F006, F007, F009, F039

Description (Material, Type, Size, Color, etc.):
Plastic (PVC, Teflon, Polyethylene) Wastes Such As Sample Vials, Bottles, Sheets Of Plastic, Bags, Santa Claus Booties, Oak Ridge Booties, And Pump Box Plexiglass

How the Output is Generated:
Cleanup Activities In The Sludge Solidification Area, Replacement Of Pump Box Plexiglas And Routine Repair Of Equipment

Generation Rate:
11 Gallons Monthly

How the Output is Managed:
Plastic waste is collected in a 90-day area, WMU 379 or WMU 2005. Sealed containers are sent to the drum assay counters, RTR, and then storage for eventual offsite storage.

Chemicals/Contaminants in or on the Output:
Waste From The Sludge Solidification Process

Characterization Rationale:
This output is characterized using information, based on the same IDC, contained in the Backlog Baseline Book. This output is contaminated with F-listed spent solvents, electroplating wastes, and multi-source leachate. This output is nonline generated in a Radioactive Materials Management Area and may be a mixed, transuranic or low-level waste.

M

Process Number: 374-3-10 **Title:** SLUDGE SOLIDIFICATION
IDC: 480 **Description:** Light Metal (Hazardous)

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- ■ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes:
F001, F002, F003, F005, F006, F007, F009, F039

Description (Material, Type, Size, Color, etc.):
Light metal wastes include carbon steel, stainless steel, aluminum, copper, and steel alloys that are part of the equipment for the sludge solidification process.

How the Output is Generated:
Replacement And Repair Of Equipment Contaminated With Sludge Solidification Waste

Generation Rate:
11 Gallons Monthly

How the Output is Managed:
Light metal wastes are collected in a 90-day area, WMU 379 or WMU 2005. Sealed containers are sent to the drum assay counter, RTR, and storage for eventual offsite storage.

Chemicals/Contaminants in or on the Output:
Sludge Solidification Wastes

Characterization Rationale:
This output is characterized using information, based on the same IDC, contained in the Backlog Baseline Book. This output is contaminated with F-listed spent solvents, electroplating wastes, and multi-source leachate. This output is generated in a Radioactive Materials Management Area and may be a mixed, transuranic or low-level waste.

Process Number: 374-3-11 **Title:** SLUDGE SOLIDIFICATION
IDC: 303 **Description:** Absolute Drybox Filters(Not Acid Contaminated)

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Glovebox HEPA filters are used as room air intake filters only. The filters are used to remove particulates from incoming air. Glovebox HEPA filters are not changed unless air pressure is below .25 inches of water.

How the Output is Generated:
During Routine Scheduled Filter Replacement

Generation Rate:
Variable

How the Output is Managed:
The filters are packed in 55-gallon drums by the Filter Group, then placed in Room 3809 for staging before being sent to the drum assay counter, RTR, and then Size Reduction in Building 776.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
According to process knowledge, this output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. This output is nonline generated in a Radioactive Materials Management Area and is therefore characterized as a TRU or low-level, nonhazardous waste.

M

Process Number: 374-3-13 **Title:** SLUDGE SOLIDIFICATION
IDC: 480 **Description:** Light Metal (Nonhazardous)

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▫ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Light metal wastes include carbon steel, stainless steel, aluminum, copper, and steel alloys that are part of the equipment not contaminated with waste from the sludge solidification process.

How the Output is Generated:
Cleanup Of The Sludge Solidification Process And Some Routine Maintenance

Generation Rate:
11 Gallons Monthly

How the Output is Managed:
Nonhazardous light metal is collected in Room 3801 or 3810. Sealed containers are sent to the drum assay counters, RTR, and then storage for evennual offsite storage.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
According to process knowledge, this output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. This output is nonline generated in a Radioactive Materials Management Area and is therefore characterized as a low-level, nonhazardous waste.

Process Number: 374-3-15 **Title:** SLUDGE SOLIDIFICATION
IDC: 330 **Description:** Combustibles, Dry (Nonhazardous)

- ▫ RCRA Hazardous
- ● RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated

- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▫ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials

- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Dry Combustibles Such As Kimwipes, Surgeon's Gloves, Tyveks, And Paper Products That Are Not Contaminated In The Sludge Solidification Process

How the Output is Generated:
Cleanup Activities In The Sludge Solidification Area And Some Routine Maintenance

Generation Rate:
11 Gallons Monthly

How the Output is Managed:
Nonhazardous dry combustibles are collected in Room 3801 or 3810. Sealed containers are sent to the drum assay counter, RTR, and then storage for eventual offsite storage.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
According to process knowledge, this output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. This output is nonline generated in a Radioactive Materials Management Area and is therefore characterized as a low-level, nonhazardous waste.

Process Number: 374-3-16 **Title:** SLUDGE SOLIDIFICATION
IDC: 337 **Description:** Plastic (Nonhazardous)

- ☐ RCRA Hazardous
- ■ RCRA Nonhazardous
- ☐ By Analytical Data
- ■ By Process Knowledge
- ☐ LDR Regulated
- ■ Not LDR Regulated
- ☐ Product
- ☐ High Content Residue
- ☐ Low Content Residue
- ☐ Transuranic
- ■ Low-Level
- ☐ Nonradioactive
- ☐ Source/Special Nuclear Materials
- ☐ Fuel Blending
- ☐ Uncontained Gas
- ☐ RCRA Sample
- ☐ Recyclable Material
- ☐ Recycled/Reused
- ☐ TSCA Reg. Waste
- ☐ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Plastic (PVC, Teflon, Polyethylene) Wastes Such As Sample Vials, Bottles, Plastic Sheets, Santa Claus Booties, Oak Ridge Booties, Rain Suits, Bags, And Pump Box Plexiglas That Have Not Come In Contact With The Sludge Solidification Process Waste

How the Output is Generated:
Cleanup Activities In The Process Area And Routine Maintenance

Generation Rate:
11 Gallons Monthly

How the Output is Managed:
Nonhazardous plastic is collected in Room 3801 or 3810. Sealed containers are sent to drum assay counter, RTR, and storage pending offsite storage.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
According to process knowledge, this output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. This output is nonline generated in a Radioactive Materials Management Area and is therefore characterized as a low-level, nonhazardous waste.

Process Number: 374-3-17 **Title:** SLUDGE SOLIDIFICATION
IDC: 438 **Description:** Insulation (Nonhazardous)

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ● By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated

- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▫ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials

- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Insulation Scrap Waste That Is New Or Has Not Been In Contact With Waste From The Sludge Solidification Process

How the Output is Generated:
Cleanup Activities In The Sludge Solidification Area And Routine Maintenance Of Equipment

Generation Rate:
11 Gallons Yearly

How the Output is Managed:
Nonhazardous insulation is collected in Room 3801 or 3810. Sealed containers are sent to the drum assay counter, RTR, and storage pending offsite storage.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
According to process knowledge, this output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. This output is nonline generated in a Radioactive Materials Management Area and is there characterized as a low-level, nonhazardous waste.

Process Number: 374-3-18 **Title:** SLUDGE SOLIDIFICATION
IDC: 438 **Description:** Insulation (Hazardous)

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes:
F001, F002, F003, F005, F006, F007, F009, F039

Description (Material, Type, Size, Color, etc.):
Insulation That Has Come In Contact With The Liquids From The Sludge Solidification Process

How the Output is Generated:
Cleanup Activities In The Sludge Solidification Area And Routine Maintenance Of Equipment

Generation Rate:
11 Gallons Yearly

How the Output is Managed:
Insulation is collected in a 90-day area, WMU 379 or WMU 2005. Sealed containers are sent to drum assay counter, RTR, then storage pending offsite storage.

Chemicals/Contaminants in or on the Output:
Process Liquid From The Sludge Solidification Process

Characterization Rationale:
This output is characterized using information, based on the same IDC, contained in the Backlog Baseline Book. This output contains listed spent solvents, electroplating wastes, and multi-source leachate. This output is generated in a Radioactive Materials Management Area and may be a mixed, transuranic or low-level waste.

Process Number: 374-3-19 **Title:** SLUDGE SOLIDIFICATION
IDC: 440 **Description:** Glass (Nonhazardous)

- ☐ RCRA Hazardous
- ■ RCRA Nonhazardous
- ☐ By Analytical Data
- ■ By Process Knowledge
- ☐ LDR Regulated
- ■ Not LDR Regulated
- ☐ Product
- ☐ High Content Residue
- ☐ Low Content Residue
- ☐ Transuranic
- ■ Low-Level
- ☐ Nonradioactive
- ☐ Source/Special Nuclear Materials
- ☐ Fuel Blending
- ☐ Uncontained Gas
- ☐ RCRA Sample
- ☐ Recyclable Material
- ☐ Recycled/Reused
- ☐ TSCA Reg. Waste
- ☐ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Glass Waste Such As Jars, Sample Vials, Beakers, And Assorted Laboratory Glassware That Has Not Come In Contact With Waste From The Sludge Solidification Process Waste

How the Output is Generated:
Through Breakage And During Routine Process Operations

Generation Rate:
11 Gallons Yearly

How the Output is Managed:
Nonhazardous glass is collected in Room 3801 or 3810. Sealed containers are sent to drum assay counter, RTR, and storage pending offsite storage.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
According to process knowledge, this output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. This output is nonline generated in a Radioactive Materials Management Area and is therefore characterized as a low-level, nonhazardous waste.

Process Number: 374-3-21 **Title:** SLUDGE SOLIDIFICATION
IDC: 337 **Description:** Hypalon Glovebox Gloves

- ▫ RCRA Hazardous
- ● RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Hypalon glovebox gloves are used for handling process contaminated equipment or materials within a glovebox that encloses the conveyer vacuum drum filter, and cementation process.

How the Output is Generated:
Hypalon glovebox gloves are generated when gloves deteriorate or are scheduled for change.

Generation Rate:
Variable

How the Output is Managed:
Hypalon glovebox gloves are collected in a 55-gallon drum in either Room 3801 Or 3810.

Chemicals/Contaminants in or on the Output:
Incidental Contact With Sludge Solidification Waste

Characterization Rationale:
This output is line generated in a Radioactive Materials Management Area. According to process knowledge, this output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. Therefore, this output may be a nonhazardous, transuranic or low-level waste.

4.0 PROCESS 774-04: PRECIPITATION/FILTRATION

The Precipitation/Filtration Process treats aqueous waste in two stages; removing radioactive contaminants from the waste and solidifying the material as transuranic mixed waste. Building 774 receives transuranic aqueous wastes from production facilities in Building 771. The precipitation process uses various holding tanks, pumps, controllers, valves, heat exchangers, and numerous filters. Figure 4.1 shows the inputs, process flow, and outputs associated with the Precipitation/Filtration Process.

Transfer tanks accumulate the aqueous waste in Building 771. These tanks are sampled for plutonium, americium, and uranium. If the measured levels are below the economic discard limit (EDL) and the nuclear material safety limit (NMSL), the tank contents are transferred into the Building 774 treatment processes.

Sludge from Tank C-1 gravity flows to Tank T-9 (at A, Figure 4.1). Silver recovery effluent and sludge from various tanks in the Basic Liquid Waste Process—Second Stage are pumped to Tank 40 (at B, Figure 4.1). The waste from Tank 40 and Tanks 4L, 4R, and 12 in the Neutralization Process are pumped to Tank 210A (at C, Figure 4.1). Sludge from Tanks T-9 and 210A are then sent to a precoated rotary drum vacuum filter (at D, Figure 4.1) which separates out the solids. The resultant wet sludge is solidified with a mixture of cement and diatomaceous earth at the rotary drum vacuum filter glovebox.

The slurry waste stream is pulled through the filter pad by a vacuum inside the rotating filter drum. A thin layer of filter pad plus solid contaminants from the slurry is continuously scraped from the outside of the filter. The sludge is collected in a 55-gallon drum which contains a rigid polyethylene liner and an inner PVC liner. A Portland cement/diatomite mixture is added to the drum along with the sludge as it collects in the drum. The cement/diatomite is added to the glovebox via a hopper and screw feeder mounted on the outside of the glovebox. The filtrate is recycled back into the first stage precipitation process described in the Basic Liquid Waste Process—First Stage. Gloves, Oil Dri, Kimwipes, towels, and paper coveralls are used for general room cleanup and materials handling. Oil, HEPA filters, valves, pumps, and lines are used for system maintenance.

The resultant solidified sludge is placed in 55-gallon drums and handled as a low-level or transuranic mixed waste; these drums are taken to Room 241. Excess filtrate separated from the solids in the vacuum filter is piped to Tanks 1RF or 1A, to be handled as part of Process 2, Basic Liquid Waste—First Stage. Exhaust air is passed to the building filter plenum system and then to the atmosphere. Nonline dry combustibles, nonline wet combustibles, glovebox gloves, nonhazardous light metal, plenum prefilters, and glovebox filters are put in the appropriate 55-gallon drums. Waste oil is placed in one-gallon plastic jugs and line wet combustibles are placed in 55-gallon drums and sent to the storage unit in Room 241. Hazardous light metal is placed in the appropriate 55-gallon drum. Waste plastic is collected in Room 241, Unit 73. Process Table 774-4 presents the outputs associated with the Precipitation/Filtration process and provides their dispositions and hazardous character.

AutoCAD 12, File Name: 774-4 12/12/94

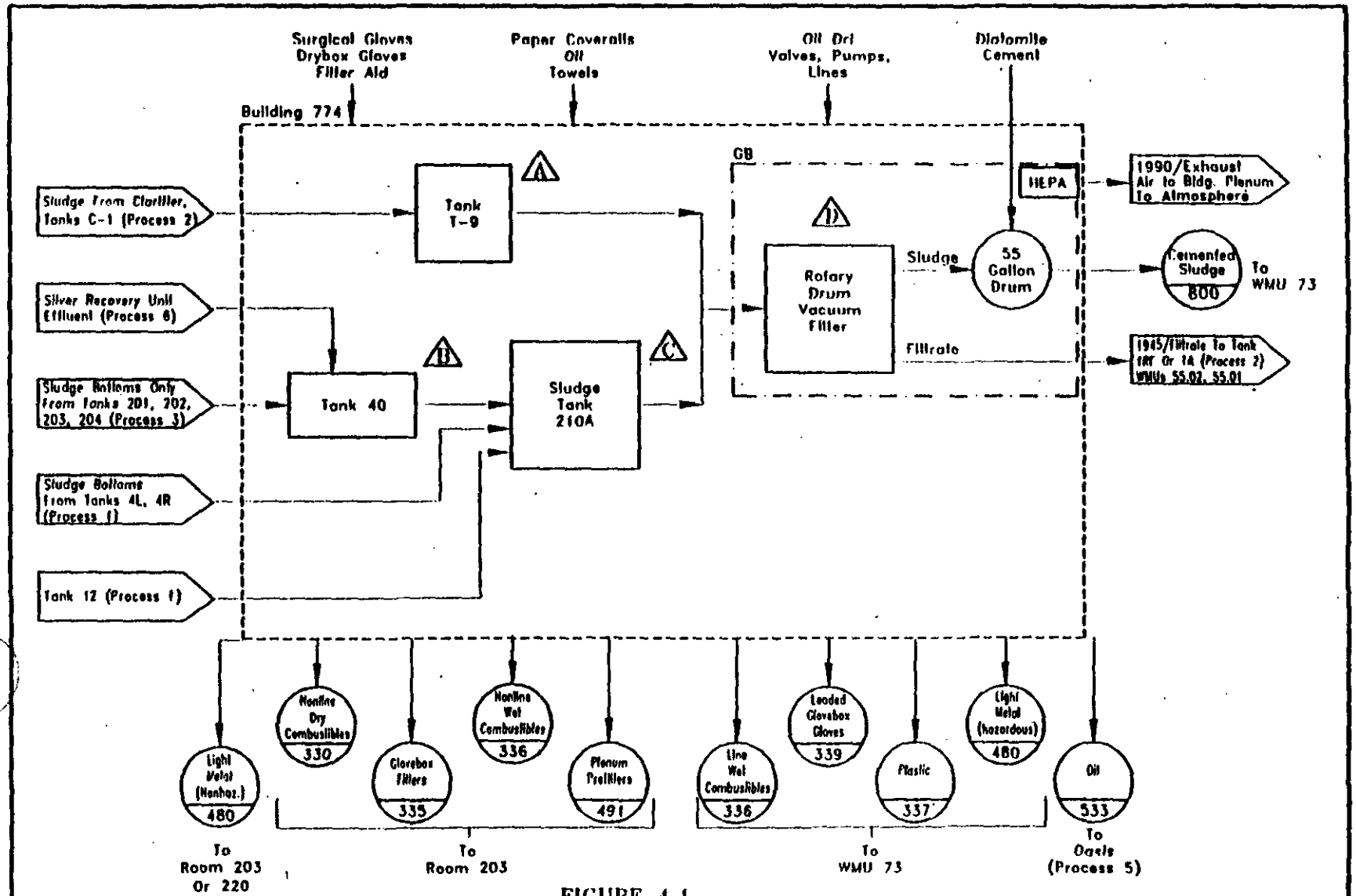

FIGURE 4.1

Rocky Flats Environmental Technology Site Waste Stream & Residue Identification & Characterization	BUILDING 774/PROCESS 4 PRECIPITATION/FILTRATION	Task	By	Date
		Designed	C. Wood	04/23/90
		Drawn	C.B. Grilli	07/14/90
		Checked	T. Horton	12/12/94

PROCESS 774-4 PRECIPITATION/FILTRATION

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-4-1	800	1236	00	NA	Cemented Sludge RCRA Reg. Chemical Constituents: Chromium Silver Non-RCRA Reg. Chemical Constituents: None	WMU 73	YES	YES	YES	Waste	D007, D011
774-4-3	336	1236	00	NA	Line Wet Combustibles RCRA Reg. Chemical Constituents: Chromium Silver Non-RCRA Reg. Chemical Constituents: None	WMU 73	YES	YES	YES	Waste	D007, D011

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-4.4	330	24	00	NA	Leaded Glovebox Gloves RCRA Reg. Chemical Constituents: Lead Non-RCRA Reg. Chemical Constituents: None	WMU 73	YES	YES	YES	Waste	D008
774-4.5	480	00	00	NA	Light Metal (Nonhazardous) RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	Room 203 Or In A Crate In Room 220	YES	NO	NO	DBC	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-4-6	491	00	00	NA	Plenum Prefilters RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	Room 203	YES	NO	NO	Waste	
774-4-7	533	G436	32	4A	Oil RCRA Reg. Chemical Constituents: Corrosive Liquids And Chromium Metal Silver Non-RCRA Reg. Chemical Constituents: Oil (Used)	1-Gallon Plastic Jug WMU 73	YES	YES	YES	Waste	D002, D007, D011

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid. Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-4-8	330	00	00	NA	Nonline Dry Combustibles RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	Room 203	YES	NO	NO	Waste	
774-4-9	1945	G436	00	1A	Filtrate RCRA Reg. Chemical Constituents: Corrosive Liquids And Chromium Metal Silver Non-RCRA Reg. Chemical Constituents: None	WMU 55.01 WMU 55.02	YES	YES	YES	Waste	D002, D007, D011

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-4-10	335	00	05	NA	Glovebox Filters RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: Base	Drum, Room 203	YES	NO	NO	DBC	
774-4-11	336	00	0205	NA	Nonline Wet Combustibles RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: Acid - General Base	55-Gallon Drum, Room 203	YES	NO	NO	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-4-13	480	1236	00	NA	Light Metal (Hazardous) RCRA Reg. Chemical Constituents: Chromium Silver Non-RCRA Reg. Chemical Constituents: None	WMU 73	YES	YES	YES	Waste	D007 D011
774-4-14	337	1236	00	NA	Plastic RCRA Reg. Chemical Constituents: Chromium Silver Non-RCRA Reg. Chemical Constituents: None	WMU 73	YES	YES	YES	Waste	D007 D011

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-1 **Title:** PRECIPITATION/FILTRATION
IDC: 800 **Description:** Cemented Sludge

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: D007, D011

Description (Material, Type, Size, Color, etc.):
Tank Sludge Mixed With Cement And Placed In Plastic Lined 55-Gallon Drums

How the Output is Generated:
Results Of Building 771 Waste Treatment

Generation Rate:
456,000 Pounds Yearly

How the Output is Managed:
The sludge is collected in WMU 73. The drums are sampled then sent to Real Time Radiography (RTR) in Building 664 and evennually will be shipped offsite for disposal.

Chemicals/Contaminants in or on the Output:
Basic Waste

Characterization Rationale:
This cemented sludge is line generated in a Radioactive Materials Management Area and is always generated as TRU or low-level waste. According to process knowledge, it also exhibits the characteristic of toxicity for chromium and silver. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-3 **Title:** PRECIPITATION/FILTRATION
IDC: 336 **Description:** Line Wet Combustibles

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ● LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: D007, D011

Description (Material, Type, Size, Color, etc.):
Wet Combustibles Include Kimwipes, Rags, And Paper Cloth, And Plastic, These Materials Are Pu Contaminated

How the Output is Generated:
During General Room Cleanup And Materials Handling

Generation Rate:
Insufficient Data

How the Output is Managed:
Line wet combustibles are collected in 55-gallon drums, Room 241, WMU 73, and transferred to the drum counter and RTR.

Chemicals/Contaminants in or on the Output:
Waste, Acids, Or Other Liquids

Characterization Rationale:
These line wet combustibles are line generated in a Radioactive Materials Management Area and are always generated as TRU or low-level waste. According to process knowledge, this output also exhibits the characteristic of toxicity for chromium and silver. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

Process Number: 774-4-4 **Title:** PRECIPITATION/FILTRATION
IDC: 339 **Description:** Leaded Glovebox Gloves

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- ■ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: D008

Description (Material, Type, Size, Color, etc.):
Leaded glovebox gloves are used for handling plutonium contaminated equipment. The gloves typically contain up to 50% weight lead.

How the Output is Generated:
These gloves are replaced on a periodic or as-needed basis.

Generation Rate:
2 Drums Yearly

How the Output is Managed:
Glovebox gloves are collected in 55-gallon drums, WMU 73, Room 241, and transferred to the drum counter and RTR.

Chemicals/Contaminants in or on the Output:
Lead

Characterization Rationale:
These leaded glovebox gloves are line generated in a Radioactive Materials Management Area and are always generated as TRU or low-level waste. According to process knowledge, and supported by analytical data (G910049, 93G0191), the gloves also exhibit the characteristics of toxicity for lead. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-5 **Title:** PRECIPITATION/FILTRATION
IDC: 480 **Description:** Light Metal (Nonhazardous)

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated

- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials

- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Pumps, Valves, Pipes And Other Materials Require Periodic Replacement

How the Output is Generated:
Replacement Of Pumps, Valves, Pipes And Other Materials

Generation Rate:
3 Drums Yearly

How the Output is Managed:
These materials are collected in 55-gallon drums, in Room 203 or in a crate in room 220, and transferred to the drum counter and RTR.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
This light metal is line generated in a Radioactive Materials Management Area and is always a transuranic or low-level waste. According to process knowledge, the output has no contact with the RCRA hazardous materials used in this process. Therefore, this output can be a nonhazardous, transuranic or low-level waste. The level of radioactivity will be determined by assay of each collection container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-6 **Title:** PRECIPITATION/FILTRATION
IDC: 491 **Description:** Plenum Prefilters

▫ RCRA Hazardous	▫ Product	▫ Fuel Blending
▪ RCRA Nonhazardous	▫ High Content Residue	▫ Uncontained Gas
▫ By Analytical Data	▫ Low Content Residue	▫ RCRA Sample
▪ By Process Knowledge	▫ Transuranic	▫ Recyclable Material
▫ LDR Regulated	▪ Low-Level	▫ Recycled/Reused
▪ Not LDR Regulated	▫ Nonradioactive	▫ TSCA Reg. Waste
	▫ Source/Special Nuclear Materials	▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Air plenum HEPA prefilters are used in areas with high dust particulate loading in order not to overload building air plenum filters.

How the Output is Generated:
During Plenum Prefilters Replacement

Generation Rate:
24 To 72 Filters Yearly

How the Output is Managed:
Used plenum prefilters are collected and placed in filter 55 gallon drums in Room 203.

Chemicals/Contaminants in or on the Output:
Process Particulates (Building Dust)

Characterization Rationale:
These plenum prefilters are nonline generated in a Radioactive Materials Management Area and can be a low-level waste. According to process knowledge, the output has no contact with the RCRA hazardous materials used in the process. Therefore, it can be a nonhazardous, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-7 **Title:** PRECIPITATION/FILTRATION
IDC: 533 **Description:** Oil

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ● By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ● Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- ■ Evaluated in Another Process

EPA Codes: D002, D007, D011

Description (Material, Type, Size, Color, etc.):
Small amounts of oil are used by equipment in the Precipitation Process area.

How the Output is Generated:
During Equipment Lubrication

Generation Rate:
4 Gallons Yearly

How the Output is Managed:
Oil is collected in one-gallon plastic jugs and transferred to the OASIS.

Chemicals/Contaminants in or on the Output:
Used Oil

Characterization Rationale:
This oil is line generated in a Radioactive Materials Management Area and is always generated as TRU or low-level waste. According to process knowledge, this output also exhibits the characteristics of corrosivity and toxicity for chromium and silver. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-8 **Title:** PRECIPITATION/FILTRATION
IDC: 330 **Description:** Nonline Dry Combustibles

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▫ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Nonline dry combustibles result from the Precipitation/Filtration Process.

How the Output is Generated:
During General Room Cleanup And Materials Handling

Generation Rate:
50 Drums Yearly

How the Output is Managed:
These materials are collected in 55-gallon drums in Room 203, and sent to Room 241.

Chemicals/Contaminants in or on the Output:
Cement And Diatomite

Characterization Rationale:
This output is nonline generated in a Radioactive Materials Management Area, and is known by the generator to always be low-level waste. According to process knowledge, no RCRA hazardous constituents are used in this process, and the output contains no RCRA hazardous constituents, and exhibits no RCRA hazardous characteristics. It is designated as low-level, nonhazardous waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-9 **Title:** PRECIPITATION/FILTRATION
IDC: 1945 **Description:** Filtrate

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: D002, D007, D011

Description (Material, Type, Size, Color, etc.):
The filtrate liquid is the liquid remaining after filtering to remove waste sludge contamination. The filtrate liquid material is recycled back into the first stage Precipitation Process.

How the Output is Generated:
During Waste Sludge Contamination Removal

Generation Rate:
Insufficient Data

How the Output is Managed:
Filtrate is collected in WMU 55.01 and 55.02 and transferred to WMU 55.07.

Chemicals/Contaminants in or on the Output:
Basic Liquid

Characterization Rationale:
This filtrate is line generated in a Radioactive Materials Management Area and is always generated as TRU or low-level waste. According to process knowledge, this output also exhibits the characteristics of corrosivity and toxicity for chromium and silver. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

Process Number: 774-4-10 **Title:** PRECIPITATION/FILTRATION
IDC: 335 **Description:** Glovebox Filters

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Air within gloveboxes is vented through high efficiency particulate air filters to remove potential particulate contamination.

How the Output is Generated:
During Glovebox Filters Replacement

Generation Rate:
1-2 Drums Yearly

How the Output is Managed:
Filters are collected in 55-gallon drums, Room 203 and transferred to the drum counter and RTR.

Chemicals/Contaminants in or on the Output:
Process Particulates

Characterization Rationale:
These glovebox filters are a solid form waste contaminated with basic liquid. Although this basic liquid is known to be corrosive under RCRA, it cannot exhibit the characteristic in this case because the waste form is not liquid. Therefore, the output can be a nonhazardous, transuranic or low-level waste, and the level of radioactivity will be determined by assay of each collection container. This output is generated in a Radioactive Materials Management Area.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-11 **Title:** PRECIPITATION/FILTRATION
IDC: 336 **Description:** Nonline Wet Combustibles

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▫ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Nonline Wet Combustibles Include Gloves, Kimwipes, Towels, And Paper Coveralls

How the Output is Generated:
During General Room Cleanup And Materials Handling

Generation Rate:
Variable

How the Output is Managed:
Placed In A 55-Gallon Drum In Room 203, And Sent To Room 241

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
These nonline wet combustibles are a solid form waste contaminated with acids and bases. Although these acids and bases are known to be corrosive liquid under RCRA, they cannot exhibit the characteristic in this case because the waste form is not liquid. This output is generated in a Radioactive Materials Management Area and can be a nonhazardous, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-13 **Title:** PRECIPITATION/FILTRATION
IDC: 480 **Description:** Light Metal (Hazardous)

- ▪ RCRA Hazardous
- ▫ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▪ LDR Regulated
- ▫ Not LDR Regulated

- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials

- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes: D007, D011

Description (Material, Type, Size, Color, etc.):
Pumps, valves, pipes and other materials require periodic replacement. Contaminated spent parts constitute line light metal.

How the Output is Generated:
Replacement Of Pumps, Valves, Pipes And Other Materials

Generation Rate:
3 Drums Yearly

How the Output is Managed:
These materials are collected in 55-gallon drums, WMU 73, Room 241 and transferred to the drum counter and RTR.

Chemicals/Contaminants in or on the Output:
Corrosive Sludge From Process

Characterization Rationale:
This light metal is line generated in a Radioactive Materials Management Area and is always generated as TRU or low-level waste. According to process knowledge, this output also exhibits the characteristic of toxicity for chromium and silver. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-4-14 **Title:** PRECIPITATION/FILTRATION
IDC: 337 **Description:** Plastic

- ▪ RCRA Hazardous
- ▫ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▪ LDR Regulated
- ▫ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes: D007, D011

Description (Material, Type, Size, Color, etc.):
Supplied Air Suits, Gloves, Booties

How the Output is Generated:
During Routine Process Operations

Generation Rate:
25 Pounds Yearly

How the Output is Managed:
Placed In A 55-Gallon Drum, Room 241, WMU 73

Chemicals/Contaminants in or on the Output:
Solvents

Characterization Rationale:
This plastic is line generated in a Radioactive Materials Management Area and is always generated as TRU or low-level waste. According to process knowledge, the output also exhibits the characteristic of toxicity for chromium and silver. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

5.0 PROCESS 774-05: OASIS

The Organic and Sludge Immobilization System (OASIS) Process accepts waste oils from any building at the Rocky Flats Environmental Technology Site which contain transuranic material, combines the waste with emulsifier, Envirostone and accelerator, and solidifies the mixture for transport in drums. The waste oil primarily comes from Buildings 707, 776, and 777. The OASIS process uses various holding tanks, pumps, controllers, valves, and mixers. Figure 5.1 shows the inputs, process flow, and outputs associated with the OASIS Process.

Waste oil being transferred from Buildings 707, 776, and 777 is stored in Tanks T-13 and T-14 (at A, Figure 5.1). A third tank, T-374A, has been used in the past to store feed to this system; however, this tank has been tagged out, and there are no plans for future use. From Tanks T-13 and T-14, the waste oil is pumped to the OASIS mixer (at B, Figure 5.1). The pump is enclosed in a small glovebox. Waste oil, water, emulsifier, Envirostone, and accelerator (to speed up the setting process) are mixed in a 55-gallon drum attached to the bottom of the glovebox. The waste is then sampled for plutonium, americium, and uranium. After the mixture has set, the drum is moved to Room 241 for storage. Surgical gloves, Kimwipes, tape, plastic, paper, and coveralls are used for general room cleanup and materials handling.

After a sufficient number of drums have accumulated in Room 241, (including waste drums not associated with the OASIS process), the waste is sent to RTR. Glovebox exhaust is discharged to the main HEPA filter plenum in Room 341. In addition to the solidified waste oil, outputs from the OASIS process include glovebox filters and metal. These wastes are put in the appropriate 55-gallon drums or crates in Rooms 203 or 220, then sent to Building 371 or 776 for counting. Leaded glovebox gloves are collected in a drum in Unit 73. Line and nonline-generated combustibles such as tape, plastic, Kimwipes, paper, and contaminated coveralls are generated throughout the building, collected in a 55-gallon drum, and placed in Rooms 210 or 203. Plastic is accumulated in Unit 73. Sanitary trash (packaging waste) is placed in a dumpster adjacent to the powder shed. Process Table 774-5 presents the outputs associated with OASIS and provides their dispositions and hazardous character.

AutoCAD 12, File Name: 774-5 12/12/94

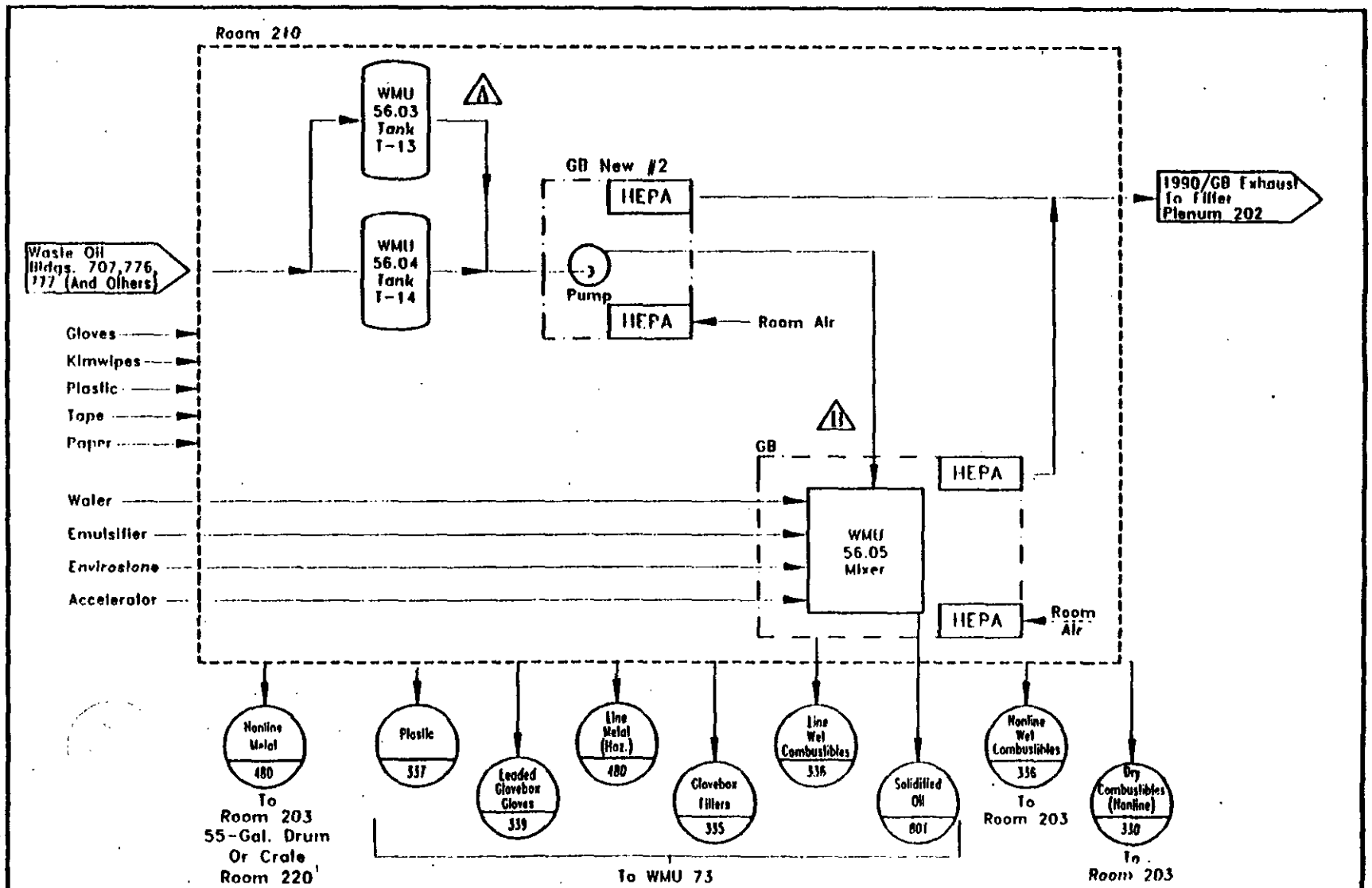

FIGURE 5.1

Rocky Flats Environmental Technology Site Waste Stream & Residue Identification & Characterization	BUILDING 774/PROCESS 5 OASIS	Task		Date
		Designed	D. Gelston	04/19/90
		Drawn	J.D. Sikora	07/19/90
		Checked	T. Horton	12/12/94

PROCESS 774-5 OASIS

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-5-1	801	B1	32	NA	Solidified Oil RCRA Reg. Chemical Constituents: Freon TF, Carbon Tetrachloride, 1,1,1-Trichloroethane, Lead, Chromium, Cadmium Non-RCRA Reg. Chemical Constituents: Oil (Used)	WMU 73	YES	YES	YES	Waste	F001, F002

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-5-2	339	J7	32	NA	Leaded Glovebox Gloves RCRA Reg. Chemical Constituents: OASIS Liquid/Solidified Liquid Containing Oil, Freon TF, Carbon Tetrachloride And 1,1,1-Trichloroethane Non-RCRA Reg. Chemical Constituents: Oil (Used)	WMU 73	YES	YES	YES	Waste	D008, F001, F002
774-5-3	335	B1	32	NA	Glovebox Filters RCRA Reg. Chemical Constituents: Freon TF, Carbon Tetrachloride, 1,1,1-Trichloroethane, Lead, Chromium, Cadmium Non-RCRA Reg. Chemical Constituents: Oil (Used)	WMU 73	YES	YES	YES	Waste	F001, F002

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Code
774-5-4	480	B1	32	NA	Line Metal (Hazardous) RCRA Reg. Chemical Constituents: Freon TF, Carbon Tetrachloride, 1,1,1-Trichloroethane, Lead, Chromium, Cadmium Non-RCRA Reg. Chemical Constituents: Oil (Used)	WMU 73	YES	YES	YES	Waste	F001 F002
774-5-6	336	B1	32	NA	Nonline Wet Combustibles RCRA Reg. Chemical Constituents: Freon TF, Carbon Tetrachloride, 1,1,1-Trichloroethane, Lead, Chromium, Cadmium Non-RCRA Reg. Chemical Constituents: Oil (Used)	WMU 73	YES	YES	YES	Waste	F001 F002

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-5-7	336	B1	32	NA	Line Wet Combustibles RCRA Reg. Chemical Constituents: Freon TF, Carbon Tetrachloride, 1,1,1-Trichloroethane, Lead, Chromium, Cadmium Non-RCRA Reg. Chemical Constituents: Oil (Used)	WMU 73	YES	YES	YES	Waste	F001, F002
774-5-11	480	00	00	NA	Nonline Metal RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum	YES	NO	NO	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Code
774-5-12	337	B1	32	NA	Plastic RCRA Reg. Chemical Constituents: Freon TF, Carbon Tetrachloride, 1,1,1-Trichloroethane, Lead, Chromium, Cadmium Non-RCRA Reg. Chemical Constituents: Oil (Used)	WMU 73	YES	YES	YES	Waste	F001 F002
774-5-13	330	00	00	NA	Dry Combustibles RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum	YES	NO	NO	Waste	

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-5-1 **Title:** OASIS
IDC: 801 **Description:** Solidified Oil

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: F001, F002

Description (Material, Type, Size, Color, etc.):
Oils from Buildings 707, 776, and 777 (as well as other buildings) are transferred by pipeline to Tanks T-13 and T-14 and are solidified during the process.

How the Output is Generated:
During OASIS Process

Generation Rate:
600 Drums Yearly

How the Output is Managed:
Solidified oil is collected in 55-gallon drums and stored in Room 241, WMU 73.

Chemicals/Contaminants in or on the Output:
Oil, Emulsifier, Envirostone, And Accelerator

Characterization Rationale:
This solidified oil is nonline generated in a Radioactive Materials Management Area and is always generated as TRU or low-level waste. According to process knowledge, this output contains spent halogenated solvents and therefore the output meets the definition of an F-listed waste. It also exhibits the characteristic of toxicity for carbon tetrachloride. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-5-2 **Title:** OASIS
IDC: 339 **Description:** Leaded Glovebox Gloves

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- ● By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ● Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- ■ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: D008, F001, F002

Description (Material, Type, Size, Color, etc.):
Leaded gloves are used in gloveboxes to handle plutonium contaminated material.

How the Output is Generated:
During Materials Handling For OASIS Process

Generation Rate:
1 Drum Yearly

How the Output is Managed:
Gloves are collected in drums in Room 241, WMU 73.

Chemicals/Contaminants in or on the Output:
Lead

Characterization Rationale:
These leaded glovebox gloves are line generated in a Radioactive Materials Management Area and are never generated as a residue. According to process knowledge, and supported by analytical data (G910049, 93G0191), this output contains lead and exhibits the characteristic of toxicity. The gloves contain Freon TF, carbon tetrachloride, and 1,1,1-trichloroethane, which means the output also meets the definition of an F-listed waste. Therefore, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-5-3 **Title:** OASIS
IDC: 335 **Description:** Glovebox Filters

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ● Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- ■ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: F001, F002

Description (Material, Type, Size, Color, etc.):
High efficiency particulate air filters remove particulates from air exhausted from the glovebox.

How the Output is Generated:
During Filter Replacement

Generation Rate:
4 Drums Yearly

How the Output is Managed:
The used filters are collected in 55-gallon drums (WMU 73) in Room 241.

Chemicals/Contaminants in or on the Output:
Process Particulates

Characterization Rationale:
These glovebox filters are line generated in a Radioactive Materials Management Area and are always generated as TRU or low-level waste. Using information, based on the same IDC, contained in the Backlog Baseline Book (10/21/94), the output contains spent halogenated solvents wastes and therefore the output meets the definition of an F-listed waste. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-5-4 **Title:** OASIS
IDC: 480 **Description:** Line Metal (Hazardous)

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- ■ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: F001, F002

Description (Material, Type, Size, Color, etc.):
Metal includes light metal scraps from glovebox operations and maintenance activities.

How the Output is Generated:
During General Room/Process Maintenance Activities

Generation Rate:
4 Drums Yearly

How the Output is Managed:
Light metal scraps are collected in 55-gallon drums (WMU 73) in Room 241, if generated in the line.

Chemicals/Contaminants in or on the Output:
Oil, Emulsifier, Envirostone, And Accelerator

Characterization Rationale:
This line metal is line generated in a Radioactive Materials Management Area and is always generated as TRU or low-level waste. According to process knowledge, the output contains spent halogenated solvents and therefore the output meets the definition of an F-listed waste. It also exhibits the characteristic of toxicity for carbon tetrachloride. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-5-6 **Title:** OASIS
IDC: 336 **Description:** Nonline Wet Combustibles

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated

- □ Product
- □ High Content Residue
- □ Low Content Residue
- □ Transuranic
- ■ Low-Level
- ● Nonradioactive
- □ Source/Special Nuclear Materials

- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: F001, F002

Description (Material, Type, Size, Color, etc.):
Nonline generated soft waste includes Kimwipes, tape and other materials generated throughout the building.

How the Output is Generated:
During General Cleanup And Working In Glovebox

Generation Rate:
240 Drums Yearly

How the Output is Managed:
Nonline generated soft waste is collected in 55-gallon drums in Room 203.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
These nonline wet combustibles are nonline generated in a Radioactive Materials Management Area, and are always generated as nonradioactive or low-level waste. According to process knowledge, this output contains spent halogenated solvents and therefore the output meets the definition of an F-listed waste. Consequently, this output is a mixed, low-level or nonradioactive, hazardous waste.

Process Number: 774-5-7 **Title:** OASIS
IDC: 336 **Description:** Line Wet Combustibles

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- □ Nonradioactive
- ■ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- ■ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: F001, F002

Description (Material, Type, Size, Color, etc.):
Line generated soft waste includes Kimwipes, tape, and other materials generated within the glovebox.

How the Output is Generated:
During OASIS Process And Cleanup

Generation Rate:
50 Drums Yearly

How the Output is Managed:
Line generated soft waste is collected in 55-gallon drums (WMU 73) in Room 241.

Chemicals/Contaminants in or on the Output:
Oil, Emulsifier, Envirostone, And Accelerator

Characterization Rationale:
These line wet combustibles are line generated in a Radioactive Materials Management Area, and are always generated as TRU or low-level waste. According to process knowledge, the output contains spent halogenated solvents and therefore the output meets the definition of an F-listed waste. Consequently, this output is a mixed, transuranic or mixed, low-level waste. The level of radioactivity will be determined by assay of each collection container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-5-11 **Title:** OASIS
IDC: 480 **Description:** Nonline Metal

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▫ Transuranic
- ▪ Low-Level
- ▪ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Nonline Generated Metal

How the Output is Generated:
During Routine Room/Process Maintenance Operations

Generation Rate:
Insufficient Data

How the Output is Managed:
Collected In 55-Gallon Drum In Room 203

Chemicals/Contaminants in or on the Output:
Unknown

Characterization Rationale:
This nonline metal is nonline generated in a Radioactive Materials Management Area and can be a low-level or nonradioactive waste. According to process knowledge, the output has no contact with the RCRA hazardous materials used in the process. Therefore, it can be a nonhazardous, low-level or a nonradioactive waste.

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WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-5-12 **Title:** OASIS
IDC: 337 **Description:** Plastic

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- ■ Not LDR Regulated
- ■ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- ■ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: F001, F002

Description (Material, Type, Size, Color, etc.):
Supplied Air Suits, Gloves, Booties

How the Output is Generated:
During Routine Process Operations

Generation Rate:
25 Pounds Yearly

How the Output is Managed:
Placed In A 55-Gallon Drum, WMU 73

Chemicals/Contaminants in or on the Output:
Oasis, Solvents

Characterization Rationale:
This plastic is line generated in a Radioactive Materials Management Area, and is always generated as TRU or low-level waste. According to process knowledge, the output contains spent halogenated solvents and therefore the output meets the definition of an F-listed waste. Consequently, this output is a mixed, transuranic or mixed, low-level waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-5-13 **Title:** OASIS
IDC: 330 **Description:** Dry Combustibles

- ▫ RCRA Hazardous
- ● RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ● Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▫ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Kimwipes, Rags, Dry Combustibles

How the Output is Generated:
During Routine Operations

Generation Rate:
Variable

How the Output is Managed:
Placed In A 55-Gallon Drum In Room 203

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
This output is nonline generated in a Radioactive Materials Management Area, and is known by the generator to always be low-level waste. According to process knowledge, no RCRA hazardous constituents are used in this process, and the output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. It is designated as low-level, nonhazardous waste.

9.0 PROCESS 774-09: MISCELLANEOUS WASTE HANDLING

The cementation of aqueous waste is carried out during the Miscellaneous Waste Handling process. Waste is primarily generated through processes in Buildings 559, 771, and 371. Aqueous waste containing complexing agents detrimental to the radioactive decontamination process and containing certain radioactive isotopes or hazardous chemicals undesirable in the regular waste system are entered into the solidification process. The bulk of these wastes are received as package shipments. Figure 9.1 shows the inputs, process flow, and outputs to be associated with the Miscellaneous Waste Handling Process.

Specially prepared waste shipping drums, containing a mixture of Portland cement and an absorbent material, are attached by O-ring drum liner to the solidification glovebox, No. 4. All waste are basic before placement in the drums.

Packaged waste received in plastic bottles are entered via bag-in operations into the glovebox. The bottles containing acid waste are emptied by vacuum into receiver and neutralizer Tank T-7, adjacent to the glovebox. Sodium hydroxide reagent is added until the color indicator shows the contents of the tank to be basic. The neutralized waste is then drained by gravity back into the glovebox. There, a connecting hose directs the waste into the prepared drum. A maximum of 80 liters of basic waste solution can be added to the prepared drum. Solutions are verified basic by checking with pH paper. The cement chemically reacts with the waste solution to form a solid.

Basic bottled waste enters the glovebox to be poured directly into the prepared drum. The empty bottles are discarded into a shipping drum attached to the glovebox. Highly concentrated chloride wastes received from Building 771 Recovery Operations by pipeline into Tank 7 are neutralized (as described earlier) and drained into the prepared drum(s).

The filled shipping drums are separated from the glovebox by the standard bag cut procedure. This generates line plastic, cemented solids, glovebox gloves, dry combustibles and glovebox HEPA filters. The 55-gallon sludge drums containing cemented solids from the Unit 57 glovebox are taken to Room 241, then to the RTR unit to determine if there are any free liquids present. These drums are then stored as transuranic-mixed waste or straight TRU drums. Glovebox HEPA filters are placed in the appropriate 55-gallon drum in Rooms 203 or 241. Plastic bottles are also placed in a 55-gallon drum in Room 203. Light metal (hazardous) is placed in WMU 73, light metal (non hazardous) is placed in a 55-gallon drum, or crate and sent to room 203 or 220. Glovebox gloves are placed in a storage area. Dry combustibles are also sent to Room 203. Glovebox exhaust is vented through the building filter plenum. Process Table 774-9 presents the outputs associated with the Miscellaneous Waste Handling Process and provides their dispositions and hazardous character.

AutoCAD 12, File Name: 774-9 03/14/95

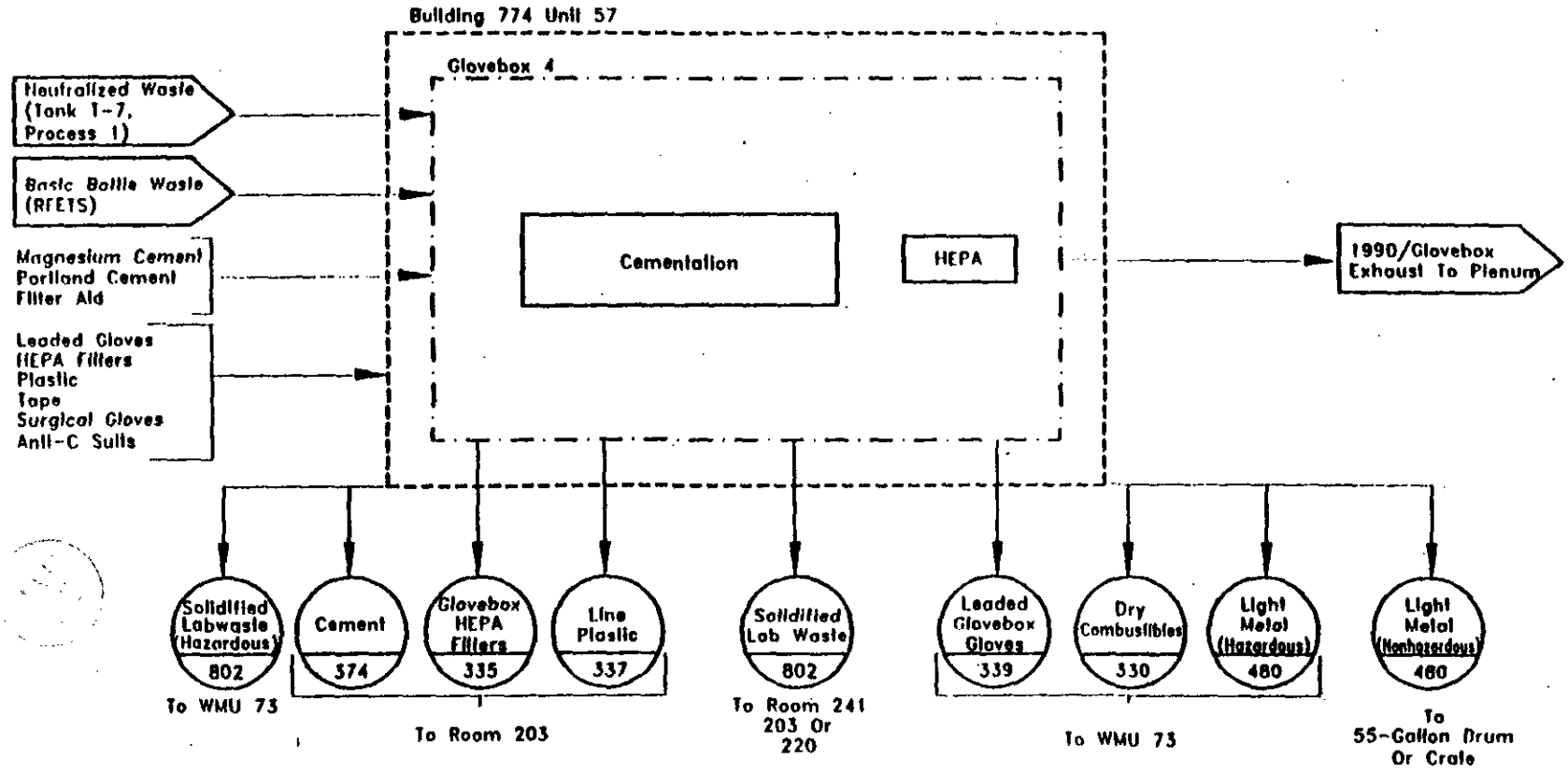

FIGURE 9.1

Rocky Flats Environmental Technology Site Waste Stream & Residue Identification & Characterization	BUILDING 774/PROCESS 9 MISCELLANEOUS WASTE HANDLING	Task	By	Date
		Designed	J. Johnson	08/07/92
		Drawn	B. Crawford	03/14/95
		Checked	J. Joyce	03/14/95

PROCESS 774-9 MISCELLANEOUS WASTE HANDLING

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-9-1	335	00	00	NA	Glovebox HEPA Filters RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 203	YES	NO	NO	Waste	
774-9-2	337	00	0205	NA	Line Plastic RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: Acid - General Base	55-Gallon Drum, Room 203	YES	NO	NO	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-9-3	339	24	00	NA	Leaded Glovebox Gloves RCRA Reg. Chemical Constituents: Lead Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum WMU 73	YES	YES	YES	Waste	D008
774-9-4	802	00	00	NA	Solidified Lab Waste (Unit 57) Nonhazardous RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum	YES	NO	NO	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-9-6	330	00	00	NA	Dry Combustibles RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum, Room 203	YES	NO	NO	Waste	
774-9-8	374	00	00	NA	Cement RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum	YES	NO	NO	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-9-9	480	1236	00	NA	Light Metal (Hazardous) RCRA Reg. Chemical Constituents: Chromium Silver Non-RCRA Reg. Chemical Constituents: None	WMU 73	YES	YES	YES	Waste	D007, D011
774-9-10	480	00	00	NA	Light Metal (Nonhazardous) RCRA Reg. Chemical Constituents: None Non-RCRA Reg. Chemical Constituents: None	55-Gallon Drum Or Crate In Room 203 Or 220	YES	NO	NO	Waste	

Process Number	IDC/ WFC Number	CCCs RCRA Reg. Const.	CCCs Non-RCRA Reg. Const.	Comp. Codes	Description RCRA Reg. Chemical Constituents: Non-RCRA Reg. Chemical Constituents:	Collection	Solid Waste	RCRA Hazardous Waste	RCRA-Land Disposal Restricted (Part 268)	Output Category	EPA Codes
774-9-11	802	??	00	NA	Solidified Lab Waste (Unit 57)(Hazardous) RCRA Reg. Chemical Constituents: Constituents vary and will be determined on a case-by-case basis. Non-RCRA Reg. Chemical Constituents: None	WMU 73	YES	YES	YES	Waste	See Rational

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-1 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 335 **Description:** Glovebox HEPA Filters

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Glovebox HEPA filters are inlet and outlet filters associated with Glovebox Unit 57.

How the Output is Generated:
During Waste Solidification Routine Operations

Generation Rate:
500 Pounds Yearly

How the Output is Managed:
Glovebox filters are placed in 55-gallon drums in Rooms 203 or 241.

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
These HEPA filters are line generated but are always a transuranic or low-level waste. According to process knowledge, the output has no contact with the RCRA hazardous materials used in this process. Therefore, this output can be a nonhazardous, transuranic or low-level waste. The level of radioactivity will be determined by assay of each collection container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-2 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 337 **Description:** Line Plastic

- ▫ RCRA Hazardous
- ● RCRA Nonhazardous
- ▫ By Analytical Data
- ■ By Process Knowledge
- ▫ LDR Regulated
- ● Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ● Transuranic
- ■ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Bottles Which Formerly Contained Basic Or Acid Waste Or Spent Halogenated Solvents

How the Output is Generated:
When Bottles Are Emptied Into Tank T-7 Or Into Glovebox

Generation Rate:
Insufficient Data

How the Output is Managed:
Empty Bottles Are Placed In A 55-Gallon Drum In Room 203

Chemicals/Contaminants in or on the Output:
Traces Of Basic, Acid Waste Solution, Or Spent Halogenated Solvents

Characterization Rationale:
This line plastic is a solid form waste contaminated with bases and acids. Although these liquids are known to be corrosive under RCRA, they cannot exhibit the characteristic in this case because the waste form is not liquid. The output is line generated in a Radioactive Materials Management Area and can, therefore, be a nonhazardous, TRU or low-level waste. The level of radioactivity will be determined by assay of each collection container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-3 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 339 **Description:** Leaded Glovebox Gloves

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- ■ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- ■ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: D008

Description (Material, Type, Size, Color, etc.):
Leaded glovebox gloves are used to protect operating personnel.

How the Output is Generated:
During Cementation Of Neutralized Waste Solutions

Generation Rate:
50 Pounds Yearly

How the Output is Managed:
Placed In A 55-Gallon Drum WMU 73, Room 241

Chemicals/Contaminants in or on the Output:
Lead

Characterization Rationale:
These leaded glovebox gloves are line generated in a Radioactive Materials Management Area and are never generated as a residue. According to process knowledge, and supported by analytical data (G910049, 93G0191), this output contains lead and exhibits the characteristic of toxicity. They are therefore, a mixed, transuranic or mixed, low-level waste. The level of radioactivity will be determined by assay of each collection container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-4 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 802 **Description:** Solidified Lab Waste (Unit 57) Nonhazardous

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▪ By Analytical Data
- ▫ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Magnesium And Portland Cement, Solidified Sludge

How the Output is Generated:
Produced During Treatment Of Aqueous Waste

Generation Rate:
14000 Pounds Yearly

How the Output is Managed:
Placed In 55-Gallon Drums, Sent To Room 241, Then To RTR To Determine Presence Of Free Liquids

Chemicals/Contaminants in or on the Output:
Aqueous Waste, Magnesium Cement, And Filter Aid

Characterization Rationale:
This solidified lab waste is characterized as nonhazardous per analytical data, sample numbers 94S0227, 94S0228, and 94S0229. This output is line generated in a Radioactive Materials Management Area and can be a low-level or transuranic waste. The level of radioactivity will be determined by assay of each collection container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-6 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 330 **Description:** Dry Combustibles

- ☐ RCRA Hazardous
- ■ RCRA Nonhazardous
- ☐ By Analytical Data
- ■ By Process Knowledge
- ☐ LDR Regulated
- ■ Not LDR Regulated
- ☐ Product
- ☐ High Content Residue
- ☐ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- ☐ Nonradioactive
- ☐ Source/Special Nuclear Materials
- ☐ Fuel Blending
- ☐ Uncontained Gas
- ☐ RCRA Sample
- ☐ Recyclable Material
- ☐ Recycled/Reused
- ☐ TSCA Reg. Waste
- ☐ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Dry Combustibles

How the Output is Generated:
During Routine Process Cleanup Operations

Generation Rate:
Variable

How the Output is Managed:
Collected In A 55-Gallon Drum In Room 203

Chemicals/Contaminants in or on the Output:
Neutralized Acid/Base Waste, Reagents

Characterization Rationale:
These dry combustibles are nonline generated in a Radioactive Materials Management Area and are always generated as low-level or nonradioactive waste. According to process knowledge, the output has no contact with the RCRA hazardous materials used in this process. Therefore, this output can be a nonhazardous, transuranic or low-level waste. The level of radioactivity will be determined by assay of each collection container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-8 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 374 **Description:** Cement

- ▫ RCRA Hazardous
- ● RCRA Nonhazardous
- ▫ By Analytical Data
- ● By Process Knowledge
- ▫ LDR Regulated
- ● Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▪ Transuranic
- ● Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Cement

How the Output is Generated:
During Solidification Process

Generation Rate:
Variable

How the Output is Managed:
Placed In A 55-Gallon Drum, Then Sent To Room 203

Chemicals/Contaminants in or on the Output:
Cement

Characterization Rationale:
This output is line generated in a Radioactive Materials Management Area, but is never generated as a residue. According to process knowledge, no RCRA hazardous constituents are used in this process, and the output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. Therefore, the output can be a nonhazardous, transuranic or low-level waste. The level of radioactivity will be determined by assay of each collection container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-9 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 480 **Description:** Light Metal (Hazardous)

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- □ By Analytical Data
- ■ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated
- □ Product
- □ High Content Residue
- □ Low Content Residue
- ● Transuranic
- ■ Low-Level
- □ Nonradioactive
- □ Source/Special Nuclear Materials
- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: D007, D011

Description (Material, Type, Size, Color, etc.):
Light Metal

How the Output is Generated:
During Routine Operations

Generation Rate:
Variable

How the Output is Managed:
Placed In WMU 73

Chemicals/Contaminants in or on the Output:
Chromium And Silver

Characterization Rationale:
This light metal is line generated in a Radioactive Materials Management Area and is generated as TRU or low level waste. According to process knowledge, the output also exhibits the characteristic of toxicity for chromium and silver. The output is characterized as a mixed, TRU or mixed, low-level waste. The level of radioactivity will be determined by assay of each container.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-10 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 480 **Description:** Light Metal (Nonhazardous)

- ▫ RCRA Hazardous
- ▪ RCRA Nonhazardous
- ▫ By Analytical Data
- ▪ By Process Knowledge
- ▫ LDR Regulated
- ▪ Not LDR Regulated
- ▫ Product
- ▫ High Content Residue
- ▫ Low Content Residue
- ▫ Transuranic
- ▪ Low-Level
- ▫ Nonradioactive
- ▫ Source/Special Nuclear Materials
- ▫ Fuel Blending
- ▫ Uncontained Gas
- ▫ RCRA Sample
- ▫ Recyclable Material
- ▫ Recycled/Reused
- ▫ TSCA Reg. Waste
- ▫ Evaluated in Another Process

EPA Codes:

Description (Material, Type, Size, Color, etc.):
Light Metal

How the Output is Generated:
During Routine Operations

Generation Rate:
Variable

How the Output is Managed:
Placed In A 55-Gallon Drum Or Crate And Stored In Room 203 Or In 220

Chemicals/Contaminants in or on the Output:
None

Characterization Rationale:
This output is nonline generated in a Radioactive Materials Management Area, and is known by the generator to always be low-level waste. According to process knowledge, no RCRA hazardous constituents are used in this process, and the output contains no RCRA hazardous constituents and exhibits no RCRA hazardous characteristics. It is designated as low-level, nonhazardous waste.

WASTE STREAM AND RESIDUE DESCRIPTION AND CHARACTERIZATION

Process Number: 774-9-11 **Title:** MISCELLANEOUS WASTE HANDLING
IDC: 802 **Description:** Solidified Lab Waste (Unit 57) (Hazardous)

- ■ RCRA Hazardous
- □ RCRA Nonhazardous
- ■ By Analytical Data
- □ By Process Knowledge
- ■ LDR Regulated
- □ Not LDR Regulated

- □ Product
- □ High Content Residue
- □ Low Content Residue
- ■ Transuranic
- ■ Low-Level
- ■ Nonradioactive
- □ Source/Special Nuclear Materials

- □ Fuel Blending
- □ Uncontained Gas
- □ RCRA Sample
- □ Recyclable Material
- □ Recycled/Reused
- □ TSCA Reg. Waste
- □ Evaluated in Another Process

EPA Codes: See Rationale

Description (Material, Type, Size, Color, etc.):
Magnesium And Portland Cement - Solidified Sludge

How the Output is Generated:
Produced During Treatment Of Aqueous Waste

Generation Rate:
Variable

How the Output is Managed:
Placed In 55-Gallon Drums, In Room 241, 203, 220

Chemicals/Contaminants in or on the Output:
Aqueous Waste

Characterization Rationale:
This solidified lab waste is characterized as hazardous. The EPA codes have not been identified because the chemicals involved in this process vary considerably in composition and characteristics; therefore, the appropriate codes will be assigned on a case-by-case basis, depending on analytical data. The chemical constituent code (??) is to be replaced by the actual numeric or alphanumeric constituent code on the drum traveler. This output is line generated in a Radioactive Materials Management Area and can be a low level or TRU, mixed waste.

APPENDIX S
FACTOR SPECIFIC QUALITY ASSURANCE

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FACTOR SPECIFIC QUALITY ASSURANCE

1.0 INTRODUCTION

Within the eight factors there were specific quality assurance measure taken. Some factors used computer codes while many used manual calculation and estimates to analyze the Engineered Alternatives (EAs). The following section describes Quality Assurance (QA) measure used within most of the factors.

1.1 TRANSPORTATION FACTOR

1.1.1 Computer Codes

All codes used for the transportation risk were developed under applicable QA standards. Previous verification has been performed on all models used in this analysis.

- RADTRAN—RADTRAN was developed by Sandia National Laboratories (SNL). The code has been continuously updated and subjected to SNL's QA procedures and standards. The code is accepted by the U.S. Department of Energy (DOE) for transportation use in estimating radiological risks.

- HIGHWAY—HIGHWAY was developed by Oak Ridge National Laboratory (ORNL). The code is continuously updated and subjected to ORNL's QA procedures and standards. The code is accepted by DOE for use in estimating routes, mileage, and fraction of travel in population zones.

- MICROSHIELD—MICROSHIELD was developed by Grove Engineering. The code meets American National Standards Institute standards and QA requirements.

1.1.2 Reporting

All transportation analysis results presented in the transportation risk section were double checked by independent review. The text was technically edited and subjected to a peer review.

1.2 IMPACT ON UNCERTAINTY IN COMPLIANCE ASSESSMENT

During the performance of the technical analysis, control of quality was maintained by verification and review of the work in progress. These reviews were performed at various stages of the work to assure that all aspects of the work affecting project quality requirements have been properly considered. Calculations, input data, report sections, and drawings were checked and verified during these reviews.

The computer codes developed for this factor were documented and validated in accordance with a defined QA procedure and includes the specification requirements, design and development information flowcharts, source code and sample data, and verification records documenting the test plan and results.

1.3 COST AND SCHEDULE FACTOR

1.3.1 Mass and Volumes

This section describes the quality assurance procedures used for the calculation of transuranic (TRU) waste preprocessed masses and volumes and final postprocessed masses and volumes.

1.3.2 Calculation of Initial Masses and Volumes

An electronic copy of the Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report (WTWBIR), which is a reference DOE document, was used as the basis for determining the preprocessing masses and volumes. The WTWBIR data were imported into spreadsheets and manipulated to calculate the masses and volumes. These spreadsheets are subject to the following peer review:

- Transcription checkpoints were performed for data entered manually.
- Data sorts were spot-checked to ensure no loss of data during the sorting operation.
- Manual calculations were performed on random samples of data to verify spreadsheet calculations.

Records were generated that show the spreadsheet was verified, the date of the review, the reviewer, results, and corrective action (if required). The text of the Waste Inventory Appendix (Appendix O) was subject to peer reviews and technical editing.

1.3.3 Calculation of Final masses and Volumes

Computer programs were developed to determine final masses and volumes for the baseline and each alternative in each configuration, based on scaled initial masses and volumes. The computer code was reviewed against process flow diagrams to ensure proper logic. Manual calculations were performed to demonstrate the capability of the computer program to produce valid results. Manual calculations were used to test the overall computer program results additionally, tests were performed at several intermediate stages to verify proper working of individual modules. Tests were not performed to verify 100% of the results, but rather for each program. At least one result was tested for each logic branch in the program.

The computer programs were not installed on any other computer nor were significant hardware or operational systems configuration changes made. Therefore, no in-use tests were performed.

Records were generated that show the program tested, the date of the test, the tester, testing results, and corrective actions (if required).

1.3.4 Cost Calculations

This section describes the quality assurance procedures for calculation of process, transportation and backfill costs.

Information regarding the current DOE-TRU waste process capability was gathered from the Environmental Management Programmatic Environmental Impact Statement, Preliminary Draft Site Treatment Plan Database and the Preliminary Draft National TRU Program TRU Waste Management Program and consolidated in a single matrix. The resulting matrix was compared to the initial sources and checked for transcription errors, incorrect information, or missing information.

Costing data were gathered from an electronic copy of the Waste Management Facility Cost Information for Transuranic Waste. Cost data were charted and curve fitted into a spreadsheet. The trendlines were specified as either linear or polynomial, dependent on the resulting R^2 value. The trendline was qualified when R^2 rounded to 0.999 for the curve. These trendlines and their resulting equations were spot checked for their precision using visual observation and manual calculations.

These equations were used to develop programs that determine cost on the basis of mass or volume throughput. The computer code was reviewed against the equations obtained from the curve fitting and the processing schemes of the decentralized, regionalized, and centralized configurations to ensure proper logic was used. Manual calculations were performed to demonstrate the capability of the computer program to produce valid results.

The resulting costs for this study were spot checked to assure the appropriate cost programs were run for the appropriate masses or volume throughput. Spreadsheet links were checked to assure the correct costs were displayed in tables placed in this report.

The computer programs were not installed on any other computer nor were significant hardware or operating system configuration changes made; therefore no in-use tests were performed.

Records were generated that show the program tested, the date of the test, the tester, testing results, and corrective action (if required). All of the resulting tables, figures, and text for processing costing were subjected to peer review and technical editing.

1.3.5 Calculation of Transportation Costs

Costing information for transportation was obtained from the Waste Management Facility Cost Information for Transportation of Radioactive and Hazardous Materials. The primary information gathered, specific to the calculations, was the cost per loaded mile and the fixed cost equation. Mileage between the sites was obtained using HIGHWAY 3.3. This mileage was peer reviewed and checked for accuracy and is consistent with the mileage used in the transportation risk section of this report. The number of shipments was calculated based on the calculated waste output masses and volumes. Both the fixed costs and the variable costs were based on round trips in shipping. Manual calculations were performed to assure the performance of the spreadsheet calculations at each intermediate calculation step, up to and including, the final costs.

These manual calculations were archived as quality records.

1.3.6 Schedule Calculations

This section describes the quality assurance procedures for ensuring accurate schedule.

A preliminary baseline schedule scenario logic diagram was generated and subjected to a peer review to ensure that the flow of activities was accurate. Following this review, a Project Evaluation and Review Technique analysis was performed to verify the durations used were within acceptable limits. The start and finish dates were calculated using computer scheduling software then verified with manual calculations. All changes to the schedule were tracked using schedule-generated revision control and maintaining a computer backup of all schedule information. Upon completion, the schedules were peer reviewed again.

1.4 IMPACT ON OTHER DISPOSAL SYSTEMS FACTOR

Calculations based in Rocky Flats secondary waste data were peer reviewed, all the data summaries were checked against the original Rocky Flats Waste Stream and Residue Identification and Characterization reports, and 100% of the calculations were manually checked. The calculations for secondary waste generated for each EA were based on spreadsheets used for the cost analysis that had previously been through QA (see QA discussion for cost analysis). The new spreadsheets generated for this factor were checked for accuracy and logic. The final calculations to determine impacts on DOE low-level waste programs were based on referenceable information in the Integrated Data Base and Mixed Waste Inventory Report and 100% of these calculations were manually checked.

APPENDIX T
REFERENCES TO APPENDICES

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REFERENCES TO APPENDICES

Bear, J., 1972, *Dynamics of Fluids in Porous Media*, Dover Publications, New York, New York, 764 pp.

Brookins, 1988, "Eh-pH Diagrams for Geochemistry," Springer-Verlag, New York, New York.

Bruno, J., and Sandino, A., 1989, "The Solubility of Amorphous and Crystalline Schoepite in Neutral to Alkaline Aqueous Solutions," Material Research Society Symposia Proceedings, v. 127, p. 871.

Brush, L. H., 1995, "Position Paper on Gas Generation in the Waste Isolation Pilot Plant," Sandia National Laboratories, Albuquerque, New Mexico.

Bjotvedt, L., MACTEC, 1995, Personal Communication.

Butcher, B. M., 1989, "Waste Isolation Pilot Plant Simulated Waste Compositions and Mechanical Properties," *SAND89-0372*, Sandia National Laboratories, Albuquerque, New Mexico.

Butcher, B. M., T. W. Thompson, R. G. VanBuskirk, and N. C. Patti, 1991, "Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste," *SAND90-1206*, Sandia National Laboratories, Albuquerque, New Mexico.

Case, J. B., and P. C. Kelsall, 1987, "Laboratory Investigation of Crushed Salt Consolidation," *Rock Mechanics: Proceedings of the 28th U.S. Symposium*, University of Arizona, Tucson, Arizona.

Chabannes, C. R., 1982, "An Evaluation of the Time-Dependent Behavior of Solution Mined Caverns in Salt for the Storage of Natural Gas," Master's Thesis, Pennsylvania State University, University Park, Pennsylvania.

D'Appolonia Consulting Engineers, Inc., 1976, "Preliminary State-of-the-Art Survey: Mining Techniques for Salt and Other Rock Types," Report to Office of Waste Isolation, Nuclear Division, D'Appolonia Consulting Engineers, Denver, Colorado.

Davies, P. P., 1989, "Preliminary Threshold Pressure Estimates and Status of Two-Phase Simulation of Waste-Generated Gas," presented at the National Academy of Sciences WIPP Review Panel, December 13, 1989, Half Moon Bay, California.

Deal, D.E., R.J. Abitz, D.S. Belski, J.B. Case, M.E. Crawley, C.A. Givens, P.P. James Lipponer, D.J. Milligan, J. Myers, D.W. Powers, M.A. Valdivia, 1995, "Brine Sampling and Evaluation Program 1992-1993 Report and Summary of BSEP Data Since 1982, DOE-WIPP 94-011," report prepared for U.S Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

DOE, see U.S. Department of Energy.

EPA, see U.S. Environmental Protection Agency.

Ewart, F.T., R.M. Howse, H.P. Thomason, and J.E. Cross, 1985, "The Solubility of Actinides in the Near Field," Material Research Society Symposia Proceedings, v. 50, p. 701.

Feizollahi, F., and Shropshire, D., 1994, "Interim Report: Waste Management Facilities Cost Information for Transuranic Waste," *EGG-WM-11274*, Idaho Falls, Idaho.

Felmy, A.R., D. Rai, and M.J. Mason, 1991, "The Solubility of Hydrous Thorium(IV) Oxide in Chloride Media: Development of An Aqueous Ion-Interaction Model," Radiochimica Acta, v. 55, p. 177.

Felmy, A.R., D. Rai, and R.W. Fulton, 1990, "The Solubility of $AmOHCO_3$(c) and the Aqueous Thermodynamics of the System Na^+-Am^{3+} -HCO_3^- -CO_3^{2-} -OH^- -H_2O," Radiochimica Acta, p193.

Felmy, A.R., D. Rai, J.A. Schramke, and J.L. Ryan, 1989, "The Solubility of Plutonium Hydroxide in Dilute Solution and in High-Ionic-Strength Chloride Brines," Radiochimica Acta, v. 48, p. 29.

Flambard, A.R., G. Marx, H.U. Esser, and C. Keiling, 1986, "Americium and Plutonium in Concentrated Salt Solutions and their Interactions With Geological Material Specific to a Waste Repository, Journal of the Less-Common Metals, v. 122, p. 525.

Freeze, R. A., and J. A. Cherry, 1979, *Groundwater*, Prentice Hall, Englewood Cliffs, New Jersey.

George, D., The S. M. Stoller Corporation, 1995, Personal Communication.

Gray, W.J., 1986, "Comparison of Uranium Release from Spent Fuel and Unirradiated UO2 in Salt Brine, Pacific Northwest Laboratory, PNL-SA-14054.

Gulick, C. W., and L. D. Wakeley, 1989, "Reference Properties of Cement-Based Plugging and Sealing Materials for the Waste Isolation Pilot Plant (WIPP)," *Technical Report SL-89-17*, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

Hartman, Howard L., 1992, Society of Mining Engineers, *Mining Engineering Handbook*, 2nd ed., Society of Mining Engineers.

ICRP, see International Commission on Radiological Protection.

International Commission on Radiological Protection, 1990, *1990 Recommendations of the International Commission on Radiological Protection*, Pergamon Press, New York, New York.

Kim, J.I., W. Treiber, C. Lierse, and P. Offerman, 1985a, "Solubility and Colloid Generation of Plutonium from Leaching of a HLW Glass in Salt Solutions," Material Research Society Symposia Proceedings, v. 44, p. 359.

Kim, J.I., Ch. Apostolidis, G. Buckau, K. Buppelman, B. Kanellakopulos, Ch. Lierse, S. Magirius, R. Stumpe, I. Hedler, Ch. Rahner, and W. Stower, 1985b, "Chemisches Verhalten Von Np, Pu und Am in Vershiedenen Konzentrierten Salzosungen," Institut fur Radiochemie, Technische Universitat Munchen, RCM 01085.

Kennedy, J. B., and A. M. Neville, 1986, "Basic Statistical Methods for Engineers and Scientists, Harper and Row," Publishers, New York, New York.

Krupka, K.M., D. Rai, R.W. Fulton, and R.G. Strickert, 1985, "Solubility Data for U(IV) Hydroxide and Np(IV) Hydrous Oxide: Application of MCC-3 Methodology," Material Research Society Symposia Proceedings, v. 44, p. 753.

Langmuir, D., and J.S. Herman, 1980, "The Mobility of Thorium in Natural Waters at Low Temperatures, Geochimica et Cosmochimica Acta," v. 44, p. 1753

Lappin, A. R., R. L. Hunter, eds., D. P. Garber, P. B. Davies, assoc. eds., March 1989, "Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989," *SAND89-0462*, Sandia National Laboratories, Albuquerque, New Mexico.

LESAT, see Lockheed Environmental Systems & Technologies Co.

Lockheed Environmental Systems & Technologies Co. (LESAT), 1995, "Pit 9 Comprehensive Demonstration Phase II Preliminary Safety Analysis Report draft", *LAE-0001* Draft, under Subcontract No. C91-133136 to the U.S. Department of Energy.

Marietta, M. C., S. G. Bertram-Howery, D. R. Anderson, K. F. Brinster, R. V. Guzowski, H. Iussolino, and R. P. Rechard, 1989, "Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant," *SAND89-2027*, Sandia National Laboratories, Albuquerque, New Mexico.

Moghissi, A. A., Godbee, H. W., and Hobart, S. A., 1986, *Radioactive Waste Technology*, American Society of Mechanical Engineer, New York, New York.

Neck, V., J.I. Kim, and B. Kanellakopulos, 1992, "Solubility and Hydrolysis Behaviou of Neptunium(V)," Radiochimica Acta, v. 56, p. 25.

Nielsen, T. J., Lockheed Martin Environmental Systems and Technologies Co., 1995, Personal Communications.

Owens, C. B., Scientific Ecology Group, Inc., 1995, Personal Communication.

Parks, G.A., and D.C. Pohl, 1988, "Hydrothermal Solubility of Uraninite, Geochimica et Cosmochimica Acta," v. 52, p. 863.

Peters, M. S., and K. D. Timmerhaus, 1991, *Plant Design and Economics for Chemical Engineers*, 4th ed., McGraw Hill, Inc., New York, New York.

Peters, R. D., D. N. Berger, and W. A. Ross, 1991, "Design and Development of a Plasma Furnace to Treat Radioactive Wastes," Presented at the Spectrum '90 Nuclear and Hazardous Waste Management International Topical Meeting, Knoxville, Tennessee, September 30 to October 4, 1990.

Pryke, D.C., and J.H. Rees, 1987, "Understanding the Behaviour of the Actinides Under Disposal Conditions: A Comparison Between Calculated and Experimental Solubilities," Radiochimica Acta, p.27.

Rai, D., J.A. Schramke, and J.L. Ryan, 1987. "Salt Repository Project: Data Report on Solubility of Pu(OH)3(am)," Pacific Northwest Laboratory, PNL/SRP-6215.

Rai, D., R.G. Strickert, R.G. Moore, and J.L. Ryan, 1983, "Am(III) Hydrolysis Constants and Solubility of Am(III) Hydroxide," Radiochimica Acta, v. 33, p. 201.

Rai, D., R.G. Strickert, and G.L. McVay, 1982, "Neptunium Concentrations in Solutions Contacting Actinide-Doped glass," Nuclear Technology, v. 58, p. 69.

Rai, D., R.J. Serne, and D.A. Moore, 1980, "Solubility of Plutonium Compounds and Their Behavior in Soils," Soil Science Society of America Journal, v. 44, p. 490.

Rai, D., and R.G. Strickert, 1980, "Chemical Aspects of Medium and Long-Term Radioactive Waste Disposal," Tranactions of the American Nuclear Society and the European Nuclear Society, v. 35, p.185.

Rechard, R. P., W. Beyeler, R. D. McCurloy, D. K. Rudeen, J. E. Bean, and J. D. Schreiber, 1990, "Parameter Sensitivity Studies of Selected Components of the Waste Isolation Pilot Plant Repository/Shaft System," *SAND89-2030*, Sandia National Laboratories, Albuquerque, New Mexico.

Reeves, M., D. S. Ward, N. J. Johns, and R. M. Cranwell, 1986, "The Sandia Waste-Isolation Flow and Transport Model for Fractured Media; Release 4.84: Theory and Implementation," *NUREG/CR-3328*, U.S. Nuclear Regulatory Commission, Washington, D.C.

Reid, R. C., J. M. Prausnitz, and B. E. Poling, 1987, *The Properties of Gases and Liquids*, 4th ed., McGraw-Hill Book Co., New York, New York, 741 pp.

Sandia National Laboratories/New Mexico, 1995, "Systems Prioritization Method—Iteration 2 Baseline Position Paper: Actinide Source Term," C. F. Novak, N. J. Dhooge, H. W. Papenguth, and R. F. Weiner, Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories/New Mexico, 1993, "Preliminary Performance Assessment for the Waste Isolation Pilot Plant," December 1992, *SAND92-0700*, Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories/New Mexico, December 1991, "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991," Vol. 3: Reference Data, WIPP Performance Assessment Division, *SAND91-0893/3*, Sandia National Laboratories, New Mexico.

Scheidegger, A. E., 1974, *Physics of Flow Through Porous Media*, 3rd ed., University of Toronto Press, Toronto, Ontario.

SNL/NM, see Sandia National Laboratories/New Mexico.

U.S. Department of Energy, 1995a, "Clay Information for Engineered Alternatives Cost/Benefit Study," Memorandum from James Maes, Regulatory Engineer, DOE/CAO, to Jonathan Myers, IT Corporation.

U.S. Department of Energy, 1995b, "Environmental Restoration and Waste Management Programmatic Environmental Impact Statement," Appendix D, March 7, 1995, draft.

U.S. Department of Energy, 1995c, "State RCRA Permit Modification Request #33 for the Supercompactor," *State RCRA Permit No. 91-02-30-01 CO 7890010526*, Rocky Flats Environmental Technology Site, Golden, Colorado.

U.S. Department of Energy, 1995d, "Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report," *CAO-94-1005*, Rev. 1, Carlsbad, New Mexico.

U.S. Department of Energy, 1994a, "Office of Environmental Management Programmatic Environmental Impact Statement," *DOE/EIS-0200*, Vol 2, draft.

U.S. Department of Energy, 1994b, "TRUPACT-II Content Codes (TRUCON)," *DOE/WIPP 89-004*, Rev. 8, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

U.S Department of Energy, 1994c, "Nuclear Safety Analysis Reports," *DOE Order 5480.23*, Change 1, U.S. Department of Energy, Washington, D.C.

U.S Department of Energy, 1993, "Startup and Restart of Nuclear Facilities," Order 5480.31, Washington, D.C., September 1993.

U.S Department of Energy, 1992a, "Project Management System," *DOE Order 4700.1A*, U.S. Department of Energy, Washington, D.C.

U.S Department of Energy, 1992b, "Conduct of Operations Requirements for DOE Facilities," *DOE Order 5480.19*, Change 1, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1991, "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force," *DOE/WIPP 91-007*, Vol. 1, Rev. 0, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy, 1990a, "Environmental Assessment of Supercompactor and Repackaging Facility and TRU Waste Shredder," *DOE/EA-0432*, Golden, Colorado.

U.S. Department of Energy, 1990b, "Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant," *DOE/EIS-0026-FS*, Office of Environmental Restoration and Waste Management, Washington, D.C.

U.S. Department of Energy, 1983, "Quarterly Geotechnical Field Data Report Part III: Gas Testing Data Update," *WIPP-DOE-177*, U.S. Department of Energy, Waste Isolation Pilot Plant Project Office, Albuquerque, New Mexico.

U.S. Department of Labor, 1978–1993, "Injury Experience in Nonmetallic Mineral Mining (Except Stone and Coal), 19[78–93]," Mine Safety and Health Administration, Division of Mining

Information Systems, Denver Safety and Health Technology Center Technical Support, Denver, Colorado.

U.S. Environmental Protection Agency, 1995, Proposed Rule, "Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes," Title 40, Code of Federal Regulations, Part 194, (40 CFR 194), U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, 1993, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes," Title 40, Code of Federal Regulations, Part 191, (40 CFR 191), U.S. Environmental Protection Agency, Washington, D.C.

Wakefield, D. J., and K. N. Fleming, 1990, *STADIC Computer Code User Manual*, PLG-0689, PLG, Inc.

Weiner, R., June 9, 1995, "Planned Activities for the Actinide Source Term and Chemical Retardation Pprograms," Enclosure to Letter for Proffessor Charles Fairhurst, University of Minnesota, Chairman, National Research Council Committee on the Waste Isolation Pilot Plant, letter from E. J. Nowak, Manager, Chemical and Disposal Room Processes Project Management Department, Sandia National Laboratories.

Westinghouse Electric Corporation, Waste Isolation Division, 1995a, "Engineered Alternatives Cost/Benefit Study Screening Report," *WID/WIPP 95-2093*, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

Westinghouse Electric Corporation, Waste Isolation Division, 1995b, "Engineered Alternatives Cost/Benefit Study Scoping Report," *WID/WIPP 95-2093*, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

WID, see Westinghouse Electric Corporation, Waste Isolation Division.

Wolery, T.J., 1992a, EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0), UCRL-MA-110662 PT III, Lawrence Livermore National Laboratory, Livermore, CA.

Wolery, T.J., 1992b, EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0), UCRL-MA-110662 PT IV, Lawrence Livermore National Laboratory, Livermore, CA.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix EMP

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Waste Isolation Pilot Plant
Environmental Monitoring Plan

Waste Isolation Pilot Plant

Environmental Monitoring Plan

DOE/WIPP 96-2194

This document is issued by Westinghouse Electric Corporation, Waste Isolation Division, as the Management and Operating Contractor for the Department of Energy, Waste Isolation Pilot Plant, Carlsbad, New Mexico, 88221.

DOE CONTRACT NUMBER: DE-AC04-86AL31950

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LIST OF ACRONYMS

AEC	Atomic Energy Commission
AIBS	American Institute of Biological Scientists
ANSI	American National Standards Institute
SER	Site Environmental Report
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management
CAM	Continuous Air Monitor
CAO	Carlsbad Area Office
CAP88-PC	Clean Air Act Associated Package, 1988
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CH	Contact-Handled
CMS	Central Monitoring System
DOE	Department of Energy
DOE/AL	DOE Albuquerque Operations Office
DOT	Department of Transportation
EC	Electrical Conductivity
EDE	Effective Dose Equivalent
EEG	Environmental Evaluation Group
EMP	Environmental Monitoring Plan
EPA	Environmental Protection Agency
FAS	Fixed Air Sampler

LIST OF ACRONYMS
(CONTINUED)

FEIS	Final Environmental Impact Statement
HEPA	High Efficiency Particulate Air (filter)
ICRP	International Commission on Radiological Protection
LD	Limit of Detection
LoVol	Low Volume Air Sampler
LWA	Land Withdrawal Act
NCR	Nonconformance Report
NCRP	National Commission on Radiation Protection and Measurements
NES	Nonradiological Environmental Surveillance
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NIST	National Institute of Standards and Technology
NMD	No-Migration Determination
NMED	New Mexico Environment Department
NMVP	No-Migration Variance Petition
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
OEMP	Operational Environmental Monitoring Plan
PDR	Program Deficiency Report
QA/QC	Quality Assurance/Quality Control
RBP	Radiological Baseline Program
RCA	Request for Corrective Action
RCRA	Resource Conservation and Recovery Act

LIST OF ACRONYMS
(CONTINUED)

RES	Radiological Environmental Surveillance
RH	Remote-Handled
SAR	Safety Analysis Report
SEIS	Final Supplement Environmental Impact Statement
SES	Storage Exhaust Shaft
SNL	Sandia National Laboratories
SOP	Standard Operating Procedure
STAR	Stability and Array File
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TLD	Thermoluminescent Dosimeter
TRU	Transuranic
TRUPACT	Transuranic Package Transporters
TSP	Total Suspended Particulates
TSS	Total Suspended Solids
USBM	United States Bureau of Mines
USGS	United States Geological Survey
VOC	Volatile Organic Compound
WHB	Waste Handling Building

LIST OF ACRONYMS
(CONTINUED)

WID	Westinghouse, Waste Isolation Division
WIPP	Waste Isolation Pilot Plant
WQSP	Water Quality Sampling Program

PREFACE

DOE Order 5400.1 (1990) requires each DOE site to prepare an Environmental Monitoring Plan (EMP). This document is to be reviewed annually and updated every three years. This is the second update of the EMP.

This EMP will be reviewed annually and will document any proposed changes in the environmental monitoring program. Changes to the environmental monitoring program may be necessary to allow the use of advanced technology and new data collection techniques.

The fundamental purpose of this document is to describe the programs established to ensure that there are no detrimental effects on the environment as a result of routine WIPP activities.

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1.0 INTRODUCTION

U.S. Department of Energy (DOE) Order 5400.1, General Environmental Protection Program Requirements (DOE, 1990a), requires each DOE facility to prepare an Environmental Monitoring Plan (EMP). This document is prepared for the Waste Isolation Pilot Plant (WIPP) in accordance with the guidance contained in DOE Order 5400.1 (DOE, 1990a); DOE Order 5400.5, Radiation Protection of the Public and Environment; and the Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance (DOE/EH-0173T, 1991). (Note: Draft 10 CFR 834, Radiation Protection of the Public and Environment is expected to be finalized in 1996 and will replace DOE Order 5400.5). The WIPP project is operated by Westinghouse Electric Corporation, Waste Isolation Division (WID), for the DOE.

This plan defines the extent and scope of the WIPP effluent and environmental monitoring programs during the facility's preoperational and operational life. This document also discusses the WIPP's quality assurance/quality control programs as they relate to environmental monitoring.

This plan provides a comprehensive description of environmental activities at WIPP including:

- A summary of environmental programs including the status of environmental permits and monitoring activities (Section 1.0);
- A description of the WIPP project and its mission (Section 2.0);
- A description of the local environment including demographics (Section 3.0);
- An overview of the methodology used to assess radiological consequences to the public including brief discussions of potential exposure pathways, routine and accidental releases, and their consequences (Section 4.0);
- A summary of preoperational environmental monitoring and assessment activities (Section 5.0); and
- Responses to the requirements described in the Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance (DOE/EH-0173T).

This document extensively references DOE Orders and other federal and state regulations affecting environmental monitoring programs at the site. WIPP procedure manuals, which implement the requirements of this program plan, are also referenced.

The DOE regulates its own activities for radiation protection of the public under the authority of the Atomic Energy Act of 1954, as amended. The effluent and environmental monitoring activities prescribed by DOE Order 5400.5 and the DOE/EH-0173T guidance manual are designed to ensure that DOE facilities collect the information required to estimate potential and actual radiation doses to the surrounding population. Effluent and environmental monitoring also provide the data necessary to demonstrate compliance with applicable environmental protection regulations.

Other federal agencies, such as the U.S. Environmental Protection Agency (EPA), are empowered through specific legislation to regulate certain aspects of DOE activities potentially affecting public health and safety or the environment. Presidential Executive Order 12088, *Federal Compliance with Pollution Control Standards*, requires the heads of executive agencies to ensure that all federal facilities and activities comply with applicable pollution control standards and to take all necessary actions for the prevention, control, and abatement of environmental pollution.

Beyond statutory requirements, the DOE has established a general environmental protection policy. The "Environmental Policy Statement (issued by then Secretary Herrington on January 8, 1986, and extended on January 7, 1987) describes the DOE's commitment to national environmental protection goals by conducting operations "in an environmentally safe and sound manner . . . in compliance with the letter and spirit of applicable environmental statutes, regulations, and standards" (DOE, 1986a). This Environmental Policy Statement also states the DOE's commitment to "good environmental management in all of its programs and at all of its facilities in order to correct existing environmental problems, to minimize risks to the environment or public health, and to anticipate and address potential environmental problems before they pose a threat to the quality of the environment or public welfare." Additionally, "it is DOE's policy that efforts to meet environmental obligations be carried out consistently across all operations and among all field organizations and programs" (DOE, 1986a).

The WIPP complies with the terms of the Agreement for Consultation and Cooperation established in 1981 with the State of New Mexico. This agreement, required by the federal legislation which authorized the WIPP project (Public Law 96-164, 1980), specifies that DOE notify the State of New Mexico prior to commencement of key events. The Supplemental Stipulated Agreement requires DOE to provide the State with sufficient information to conduct an independent review of WIPP activities.

The 1992 WIPP Land Withdrawal Act (LWA), Public Law 102-579, requires the DOE to prepare and implement a Land Management Plan and Memorandum of Understanding with the Bureau of Land Management (BLM). The primary objectives of the Land Management Plan are to identify resource values, promote multiple-use management, and identify long term goals for the management of WIPP lands through the decommissioning phase.

Environmental activities at the WIPP project generally fall into three categories: (1) the performance of analyses and preparation of documents to address DOE requirements, as well as applicable regulations of the EPA and other federal and state agencies; (2) the conduct of environmental studies to monitor site impacts; and (3) the implementation of measures to mitigate adverse impacts.

A number of provisions taken to mitigate potential environmental impacts appear in Statements of Work issued to all contractors involved in the construction of the WIPP facility. These provisions are listed below:

- Protection of environmental resources including the avoidance of unnecessary damage to vegetation, wildlife, and soil by controlling traffic, minimizing disturbance zones, and cleaning up spills.

- Protection of air resources including the control of hydrocarbon emissions by using proper fuels, the suppression of dust by spraying with water, and the monitoring and control of noise.

- Protection of water resources including the use of retention ponds for controlling suspended materials, solutes, and other pollutants.

- Preservation and recovery of historical, archaeological, and cultural resources including the interruption of construction activities as necessary to investigate and mitigate impacts to historical or archaeological resources.

- Post-construction cleanup including the removal of temporary construction facilities, haul roads, stockpiles, and work areas, as well as the restoration of all damaged landscape features outside the limits of approved work areas.

WIPP must also comply with specified permitting and approval requirements of several federal and state regulating agencies. A database is maintained of all required permits, notices, and approvals which apply to the WIPP project. This database enables environmental personnel to anticipate commitments such as renewal dates, fee payments, and reclamation requirements. This database is updated and published annually in the WIPP Site Environmental Report (SER).

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2.0 PROJECT DESCRIPTION

The purpose of WIPP is to provide for disposal of transuranic waste by establishing an effective system for management of transuranic waste from generation to disposal. This program only applies to transuranic (TRU) waste generated by the defense activities of the U.S. Government.

The preoperational radiological and ecological environmental monitoring programs were detailed in earlier documents entitled: *Radiological Baseline Program for the Waste Isolation Pilot Plant* (Reith and Daer, 1985) and *Ecological Monitoring Program for the Waste Isolation Pilot Plant, Semi-annual Report* (Reith et al., 1985). A summary of those programs is presented in Section 5.0 of this document. The environmental monitoring program continues the established preoperational environmental monitoring efforts as appropriate and adds monitoring of the airborne and liquid effluent discharges. Details regarding the design and operation of the WIPP facility are in the Safety Analysis Report (SAR) (DOE/WIPP-95-2065 REV.0, 1995).

Both contact handled (CH) and remote handled (RH) waste will be received and disposed of at the WIPP facility. CH waste consists of TRU waste that has a relatively low surface dose rate and therefore lends itself to direct handling. RH waste is TRU waste that, due to higher levels of penetrating radiation, must be shielded and handled remotely. Waste will be classed as CH or RH based on whether surface dose rates are less than or greater than 200 mrem/hr, respectively. TRU waste is radioactive waste that, without regard to source or form, is contaminated with alpha-emitting TRU radionuclides having atomic numbers larger than 92 and half-lives longer than 20 years in concentrations greater than 100 nanocuries per gram of waste. The CH and RH waste contain both alpha and beta-gamma emitting nuclides. Isotopes of plutonium, americium, and curium will be the predominant radionuclides contaminating the TRU waste. The waste will be in a variety of forms such as concrete stabilized sludges, decommissioned machine tools, glove boxes, etc. All wastes received by the WIPP will be restricted to those that meet specific Waste Acceptance Criteria (WAC Rev. 5) which prohibit pressurized gases and explosives, and limits free liquids to less than one percent of the volume of each container. General criteria defining the various categories of radioactive waste, including TRU waste, appear in DOE Order 5820.2A and DOE/AL Order 5820.2. A portion of the waste that will be emplaced will also be contaminated with hazardous materials. The hazardous waste component is subject to regulation by the NMED under the Resource Conservation and Recovery Act (RCRA), and consists largely of toxicity characteristic metals, halogenated organic compounds, and nonhalogenated organic compounds.

Waste will be delivered to the WIPP Waste Handling Building (WHB) via semi-trailer trucks. CH wastes will arrive in shipping packages known as TRUPACT IIs (TRansUranic PACkage Transporters). TRUPACT IIs are durable, Type B, Nuclear Regulatory Commission (NRC) certified transport containers, designed to accommodate both waste boxes and drums. The DOE has received a certificate of compliance from the NRC for use of the TRUPACT II. Remote-handled transuranic (RH TRU) wastes will be packaged in waste canisters and shipped to WIPP in special transportation casks. The remote-handled casks are awaiting NRC approval.

The disposal rooms prepared for the waste have been excavated from the Salado Formation, a thick sequence of salt beds deposited 250 million years ago (Permian age). The disposal horizon is located at a depth of 655 meters (2,150 feet). Once waste containers are removed from the TRUPACT II, they are secured to a transport pallet and then within the WHB placed on the waste-handling hoist, and lowered to the disposal horizon. Waste containers will then be removed from the hoist and emplaced within the disposal rooms. Eventually, specially designed seals and closure systems will be placed in the excavated shafts and in the drifts. Geologic pressures and the plasticity of the salt will result in the excavation's gradual closure due to creep. This closure will encapsulate and isolate any waste within the Salado formation.

The underground area is ventilated by air entering via the Salt Handling, Air Intake, and Waste Handling Shafts and exiting through the Exhaust Shaft. In the event of an accident involving waste in the underground, air from the Exhaust Shaft will be directed, at a reduced flow rate, through the Exhaust Filter Building containing banks of high efficiency particulate air (HEPA) filters in order to remove potentially contaminated particulates. Exhaust ventilation from the WHB is continuously HEPA filtered and is not expected to represent a significant release point. Effluent monitoring is discussed in Chapter 5.0.

3.0 SITE CHARACTERISTICS

3.1 GEOGRAPHY

The WIPP site is located in Eddy County in southeastern New Mexico (Figure 3-1) within the Pecos Valley section of the southern Great Plains physiographic province (Powers et al., 1978). The site is 42 km (26 miles) east of Carlsbad in an area known as Los Medaños (the dunes). Los Medaños is a relatively flat, sparsely inhabited plateau with little surface water.

The WIPP site (Figure 3-2) consists of 16 sections of federal land in Township 22 South, Range 31 East. The 16 sections of federal land were withdrawn from the application of public land laws by the WIPP Land Withdrawal Act (LWA), Public Law 102-579, that was signed on October 30, 1992. The LWA transferred the responsibility for the administration of the 16 sections from the Department of Interior, Bureau of Land Management, to the Department of Energy. This law specified that mining and drilling for purposes other than support of the WIPP project are restricted within this 16 section area with the exception of Section 31. Oil and gas activities are restricted in Section 31 from the surface down to 6,000 feet.

3.2 GEOLOGY

Los Medaños soils are sandy and well drained with a well developed caliche layer occurring below one meter. There are no integrated natural surface drainage features at the site. Scattered throughout the local area are numerous livestock watering ponds (tanks) and seasonally wet, shallow lakes (playas) which are located approximately seven miles southwest of the site. Geologically, the site is located in the northern portion of the Delaware Basin, one of the western--most sedimentary basins known collectively as the Permian Basin. Approximately 3,960 meters (13,000 feet) of strata are present in the Delaware Basin (Bachman, 1984) including hundreds of meters of evaporite sequences composed in part of halite, anhydrite, and gypsum. Figure 3-3 illustrates the local stratigraphy.

3.3 CLIMATOLOGY

Regional climate is semi-arid with generally warm temperatures. Approximately 31 centimeters (12 inches), is the average annual precipitation amount. About half of the precipitation is received from June through September in the form of high intensity-short duration thunderstorms. Daytime summer temperatures consistently exceed 32°C (90°F) and often rise above 38°C (100°F). Winter temperatures often rise as high as 21°C (70°F) during the afternoon. Night time lows during winter average near -5°C (23°F), occasionally dipping below -10°C (14°F). Prevailing winds are from the southeast; however, strong winds are common and can blow from any direction creating potentially violent windstorms which carry large volumes of dust and sand. The wind test data have remained essentially the same from year to year. Detailed compilations of climatic data have appeared in the Ecological Monitoring Reports (Fischer et al., 1985; 1987) and in the Annual Site Environmental Reports for calendar years 1988, 1989, 1990, 1991, 1992, 1993, 1994, and 1995 (DOE/WIPP 89-005, DOE/WIPP 90-003, DOE/WIPP 91-008, DOE/WIPP 92-007, DOE/WIPP 93-017, DOE/WIPP 94/2033, DOE/WIPP 95-2094 and DOE/WIPP 96-2182, respectively). Additional climatic information appears in the Final Environmental Impact Statement (FEIS) (DOE, 1980), Final Supplement Environmental Impact Statement (SEIS) (DOE, 1990d), and the SAR (DOE, 1995).

3.4 HYDROLOGY

Surface water is absent at the WIPP site. The nearest large surface water body, Laguna Grande de la Sal, is located approximately 13 kilometers (8 miles) west-southwest of the WIPP site in Nash Draw where shallow brine ponds occur. The Pecos River is located 22.4 kilometers (14 miles) southwest of the WIPP site.

Several water-bearing zones have been studied near the WIPP. The most significant are the Culebra and Magenta Members of the Rustler Formation, which consist primarily of fractured dolomite. These dolomite units produce brackish to saline water. Another saline water-bearing zone identified is the Rustler-Salado contact, which contains very little water at the WIPP site. It was exposed during shaft construction and produced only a small amount of brine seepage. Other water bearing zones that have been evaluated as part of site characterization include the Dewey Lake Redbeds and the overlying Triassic Dockum Group, the Bell Canyon and Castile Formations.

The Dewey Lake Formation, which contains limited amounts of potable water, is comprised of alternating thin, even beds of siltstone and mudstone with lenticular interbeds of fine-grained sandstone. Exploratory drilling during site hydrogeologic evaluation did not identify a continuous zone of saturation within the Dewey Lake. The few Dewey Lake wells yielding water for domestic and stock purposes are believed to be completed in the thin, discontinuous lenticular sands where favorable groundwater recharge occurs (Mercer, 1983). A more complete discussion of both the regional and site-specific groundwater hydrology is contained in the WIPP SAR.

3.5 ECOLOGY

The biota of Los Medaños represent a transition between the northern Chihuahuan Desert and the southern Great Plains. The soils at the site include sandy surface soils with wind-blown particles, a thin soil crust, and a layer of moist subsoil. These sandy soils form stabilized coppice dunes interspersed with swales.

Shrubs and grasses are the most prominent components of the local flora. The development of specific plant communities is dependent on such factors as the infiltration rate of the surface soil, depth to a restrictive layer (e.g., caliche), and the extent to which the surface soil has been reworked by wind or water erosion. The area is dominated by the shinnery oak, mesquite, sand sage, and perennial grasses. Typical grassland and shrubland species dominate the fauna of the area. The primary mammals found at the site include the lagomorphs (rabbits and hares), desert mule deer, desert dwelling rodent species, and carnivore species such as the coyote, gray fox, badger, and striped skunk.

A large variety of bird species are also found in the region. The following avian species are present in greatest densities: scaled quail, mourning dove, mocking bird, loggerhead shrike, pyrrhuloxia, black-throated sparrow, western meadowlark, the lark bunting, vesper sparrow, Cassin's sparrow, and the white-crowned sparrow. The Harris hawk, the Chihuahuan raven, Swainson's hawk, the Northern Harrier, and the American kestrel are also found at the site.

There have been 29 species of amphibians and reptiles observed in the site vicinity. Characteristic reptiles in the region include the western box turtle, side-blotched lizard, western whiptail, bullsnake, and prairie rattlesnake. The representative amphibians are the tiger salamander, green toad, and plain's spadefoot.

A brief summary of the ecological baseline surveys appears in Appendix H of the FEIS (DOE, 1980). If there are any changes observed in the area ecology they will be noted in the WIPP SERs.

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3.6 DEMOGRAPHY

There are 26 permanent residents at various locations within 10 miles of the WIPP site. Most of the population within 50 miles of the WIPP site is concentrated in and around the communities of Carlsbad, Hobbs, Eunice, Loving, Jal and Artesia, New Mexico. The nearest community is the village of Loving, New Mexico, 18 miles west-southwest of the center of the WIPP site. The population of Loving decreased from an estimated 1,600 in 1980 to 1,243 in 1990, the year of the latest census. The nearest major population center is the city of Carlsbad, New Mexico, 26 miles west of the WIPP site. The population of Carlsbad has increased from an estimated 28,600 in 1980 to an estimated 29,500 in 1990. The population within 10 miles of the WIPP site is associated with ranching, oil/gas well activities, and potash mining. These levels fluctuate depending on the manpower needs of these businesses.

The nearest residents to the site include eight individuals living at the Mills Ranch, 5.8 km (3.5 miles) south-southwest of the center of the site, and two individuals living at the Smith Ranch, 10 km (6 miles) west-northwest of the center of the site (DOE/WIPP 93-017). Both neighboring ranches have been and will continue to be monitored as part of WIPP's environmental surveillance program. Detailed demographic summaries and projections are in the WIPP SEIS (DOE, 1990d) and WIPP SAR (DOE, 1995).

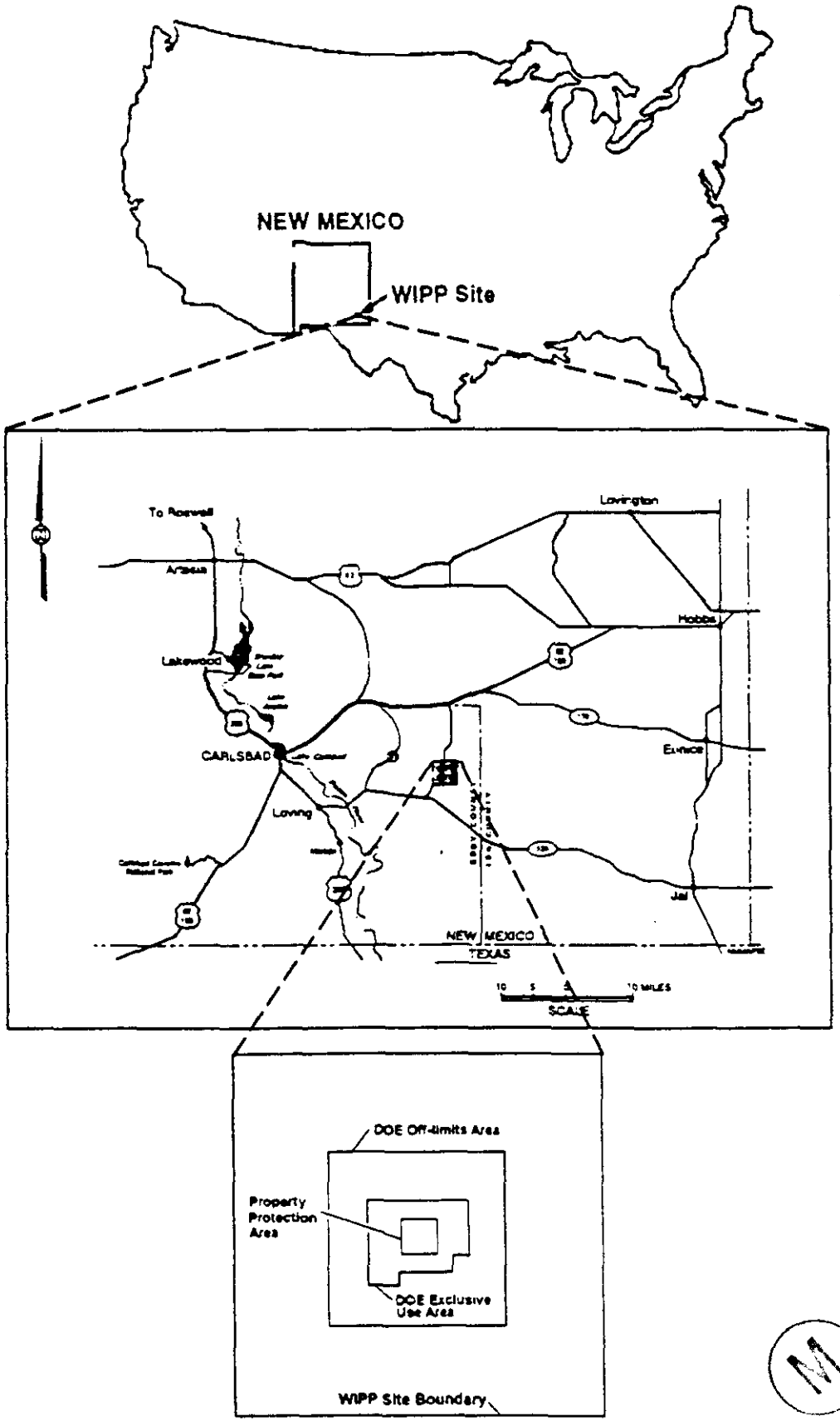

Figure 3-1 Location of the WIPP Site

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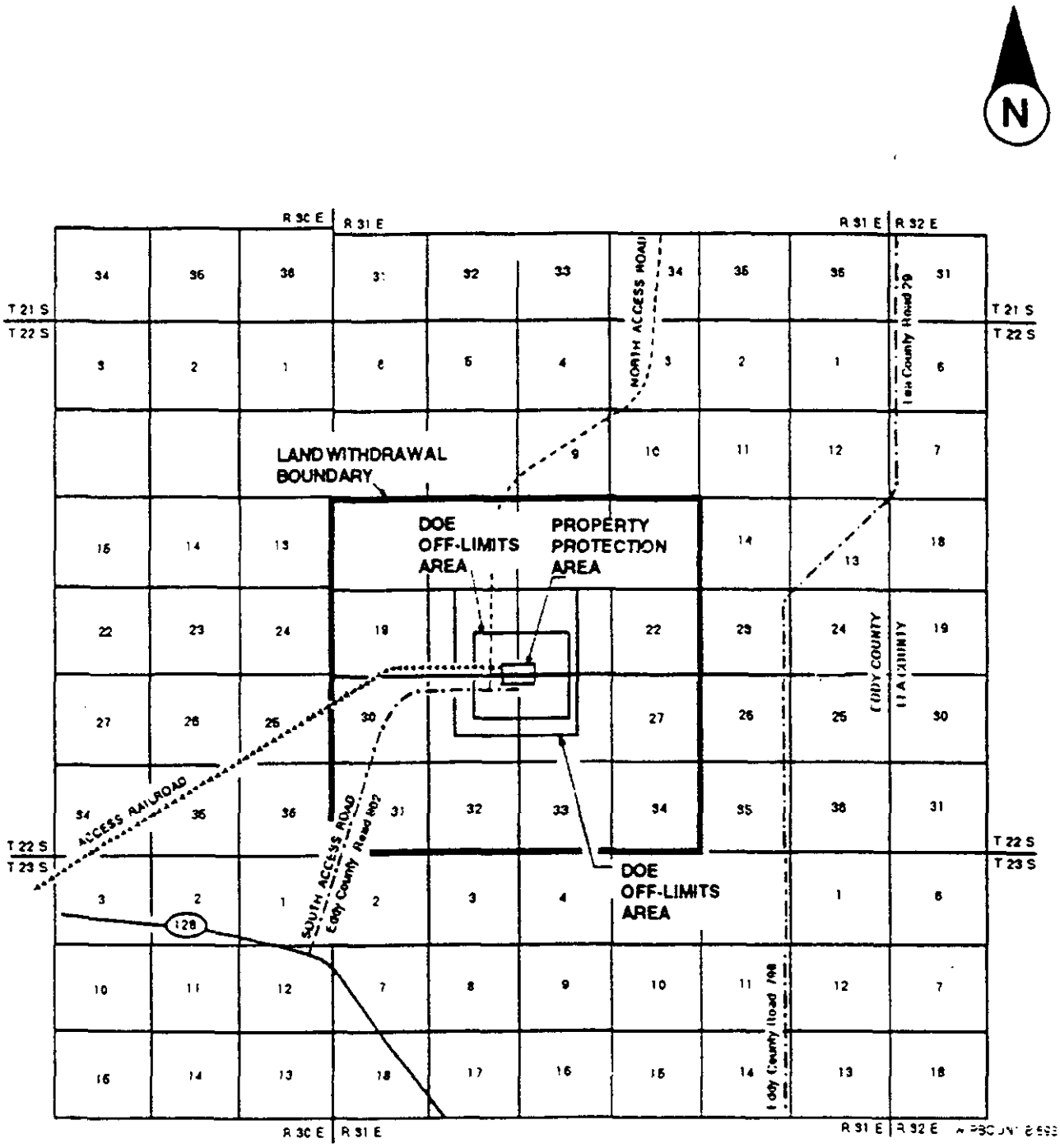

Figure 3-2 Plat of WIPP Site

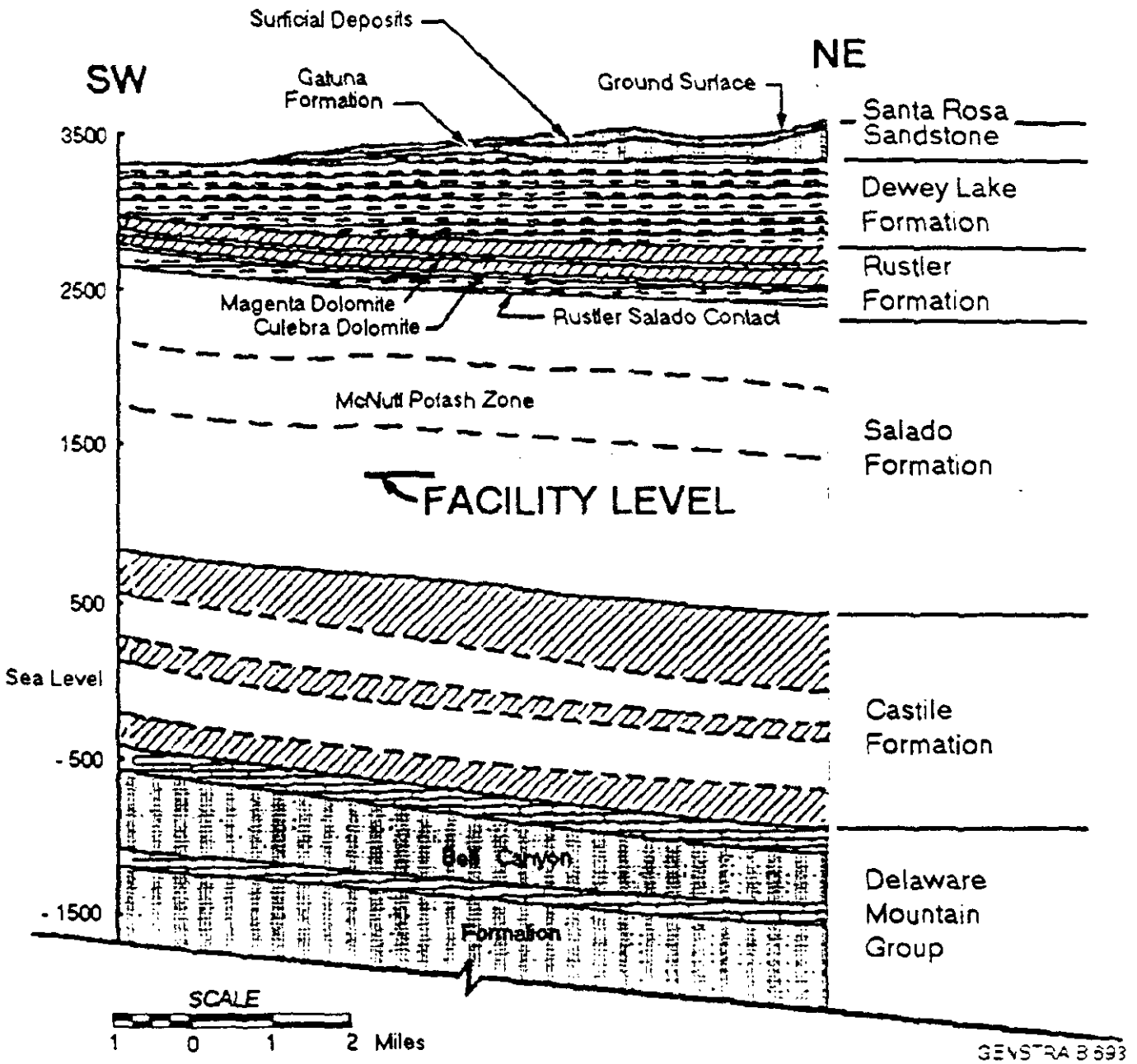

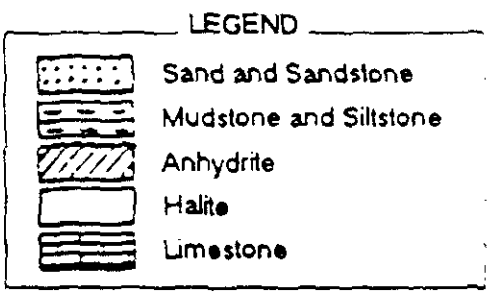

Figure 3-3 Generalized Stratigraphy of the WIPP Site

4.0 DOSE CALCULATIONS

This section is typically written to discuss dose calculations involving on and off site dose assessment. As stated in sections *7.1.4.1 On-Site Dose Assessment* and *7.1.4.2 Off-site Dose Assessment* of the WIPP Safety Analysis Report (DOE/WIPP-95-2065 Rev. 0); "Therefore, WIPP normal operations do not involve or entail any planned or expected releases of airborne radioactive materials."

Due to the current interpretation of requirements affecting dose calculations with respect to WIPP activities, this updated Environmental Monitoring Plan has all calculations and associated discussions relating to radiological dose assessment removed to comply with the current version of the WIPP SAR.

Nonradiological consequences to members of the public associated with potential airborne chemical releases from the WIPP facility during normal operations are expected to be *de minimus*. This expectation is based on (1) extensive site exposure measurements and calculations which indicate that employee exposures are being maintained well below Occupational Safety and Health Administration Permissible Exposure Limits (as stipulated in 29 CFR 1910.1000), (2) all chemicals used on site must receive approval prior to purchase, with approval based on the minimization of personnel exposure and environmental impact, and (3) the site Nonradiological Environmental Program which has been monitoring for nonradiological emissions from the time of the site's inception with no indication of environmental impact.

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5.0 ENVIRONMENTAL MONITORING PROGRAM

As required by DOE Order 5400.1, each facility is required to perform a "preoperational study to begin not less than one year, and preferably two years before start-up to evaluate seasonal changes." The DOE WIPP is complying with this requirement by compiling preoperational radiological and non-radiological environmental data. The environmental data is published annually in the Site Environmental Report.

An analysis of the historical preoperational data is contained in the following documents: 1) *Statistical Summary of the Radiological Baseline for the WIPP*, (DOE/WIPP 92-037), 2) *Summary of the Salt Impact Studies at the WIPP, 1984 to 1990*, (DOE/WIPP 92-038), 3) *A Study of Disturbed Land Reclamation Techniques for the WIPP*, (DOE/WIPP 92-039), and 4) *Background Water Quality Characterization Report for the WIPP*, (DOE/WIPP 92-013).

The environmental sampling programs used to establish the preoperational study were originally defined in Chapter 5 of the OEMP (DOE/WIPP 88-025). The OEMP was updated in 1994 into the WIPP Environmental Monitoring Plan (EMP) (DOE/WIPP 94-024). This is an update of the 1994 EMP. This plan describes the current environmental monitoring efforts at the WIPP as the project moves from the predisposal phase into the disposal phase. An additional change in this updated EMP is the inclusion of *7.1.4.1 On-Site Dose Assessment* and *7.1.4.2 Off-site Dose Assessment* of the *WIPP Safety Analysis Report (DOE/WIPP-95-2065 Rev. 0)*, that states, "Therefore, WIPP normal operations do not involve or entail any planned or expected releases of airborne radioactive materials." With the inclusion of this referenced document, the environmental monitoring data being collected is being compiled to broaden the radiological baseline in the WIPP vicinity and could be used as a confirmatory tool used to quantify unplanned radiological occurrences.

The Westinghouse, Waste Isolation Division (WID) Environmental Monitoring Section at the WIPP is administered by the Environment, Safety, & Health Department to ensure compliance with pertinent environmental regulations as required by DOE Order 5400.1. DOE Order 5400.1 states that environmental surveillance shall be conducted to monitor the effects, if any, of DOE activities on-site and off-site. An environmental surveillance program shall be undertaken at DOE sites to determine the need for a permanent surveillance program. In addition, environmental surveillance programs and components should be determined on a site-specific basis by the field organization. These programs should not be considered static but flexible to allow for samples of opportunity and conversely, not to collect samples if circumstances warrant cancellation of a sampling activity. Programs should reflect facility characteristics; applicable regulations; hazard potential; quantities and concentrations of materials released; the extent and use of affected air, land, biotics, and water; and specific local public interest or concern (DOE, 1990a).

5.1 GUIDELINES

Under the Atomic Energy Act of 1954, as amended, the DOE is obligated to regulate its own activities so as to provide radiation protection for both workers and the public. Presidential Executive Order 12088, *Federal Compliance with Pollution Control Standards*, further requires the heads of executive agencies to ensure that all Federal facilities and activities comply with applicable pollution control standards and to take all actions necessary for the prevention, control, and abatement of environmental pollution.

It is the policy of the DOE to conduct effluent monitoring and environmental surveillance programs that are appropriate for determining adequate protection of the public and the environment during DOE operations and to assure that operations are in compliance with DOE and other applicable Federal, State, and local radiation standards and requirements. It is also DOE policy that departmental monitoring and surveillance programs be capable of detecting and quantifying unplanned releases, while meeting high standards of quality and credibility. It is DOE's objective

that all DOE operations properly and accurately measure radionuclides in effluent streams and in the ambient environmental media.

A Guide for Environmental Radiological Surveillance at DOE Installations, (DOE/EP-0023) (Corley et al., 1981) states that the factors which should be considered in determining the relative level of environmental surveillance required at a facility include:

(1) the potential hazard of the materials released, considering both expected quantities and relative radiotoxicities;

(2) the extent to which facility operations are routine and unchanging;

(3) the need for supplementing and complementing effluent monitoring;

(4) the size and distribution of the exposed population;

(5) the cost-effectiveness of increments to the environmental surveillance program; and

(6) the availability of measurement techniques which will provide sufficiently sensitive comparisons with applicable standard and background measurements.

The above guidance, the risk analysis in the WIPP SAR, and the dose criteria in DOE Order 5400.5 indicate that operational dose estimates for the WIPP are significantly below dose criteria. However, the purpose of the WIPP is to demonstrate that the long-term disposal of TRU waste in bedded salt can be accomplished safely, and that the natural environment will not be significantly impacted as a result of the construction and operation of the disposal facility. The WIPP EMP encompasses a comprehensive set of parameters that detect environmental impacts. As required in DOE Order 5400.1, the EMP is reviewed annually and updated every three years. The EMP scope and intensity is adjusted in response to changing facility processes, environmental parameters, and program results.

Parameters measured include environmental radiation analysis of air, surface and groundwater, sediments, soils, and biotics, the status of the local biological community, and groundwater quality measurements. Nonradiological portions of the program focus on the immediate area surrounding the site, whereas radiological surveillance generally covers a broader geographical area including nearby ranches, villages, and cities. Environmental monitoring will continue at the site during project operations and through decommissioning and beyond for 2-5 years in accordance with the *Agreement for Consultation and Cooperation between the Department of Energy and the State of New Mexico*.

The goal of the environmental monitoring program is to determine if the local ecosystem has been impacted during the predisposal and disposal phases of the WIPP, and if so, to evaluate their severity, geographic extent, and environmental significance. Tables 5-1 and 5-2 summarize the EMP sampling schedule and analytical array. These tables list the sample types, number of sampling stations, approximate sampling schedule and the environmental/ecological parameters monitored or analyzed. It is important to emphasize the need for flexibility in the design and implementation of the EMP. Additional or different types of samples will be collected and analyzed as necessary to investigate and explain trends or anomalies that may have a bearing on the WIPP's environmental impacts. Baseline conditions were initially characterized by the Radiological Baseline Program (RBP) and summarized in the Statistical Summary of the Radiological Baseline for the WIPP (DOE/WIPP 92-037). The RBP will continue until first waste receipt at which point it will become an operational monitoring program. Environmental and ecological sampling during operations will be adjusted to fit the needs of the project.

As recommended in DOE/EH-0173T, the EMP provides the guidance for monitoring levels of naturally occurring radionuclides, those associated with world-wide fallout, and those expected in

the WIPP wastes. The geographic scope of radiological sampling is based on projections of potential release pathways for the types of radionuclides in the WIPP wastes. Also, the surrounding population centers are monitored even though release scenarios involving radiation doses to residents of those population centers are improbable. Ecological sampling activities may be performed at the permanent ecological monitoring plots. These sampling locations are unchanged from those reported in the OEMP.

Sampling and related activities (sample logging, packaging, and shipping) are conducted in accordance with the procedures and instructions described in the WIPP Procedures. Standard sampling practices and techniques are used (see Section 6.0). Samples sent off site are analyzed by a commercial laboratory.

Sample splits are made available to the Environmental Evaluation Group (EEG) and the NMED. The EEG has developed and implemented an environmental monitoring program at WIPP which provides independent verification of the WIPP's environmental monitoring results. The EEG environmental surveillance program has provided independent data verification for the WIPP Project during the preoperational phase to date. Historically, NMED oversight at the WIPP has included independent verification of environmental sampling, effluent and spill sampling, oversight of cleanup and environmental restoration activities, data validation/verification, and comprehensive program evaluations.

The Carlsbad Environmental Monitoring and Research Center, operated by New Mexico State University, is a research organization which also conducts independent environmental monitoring in the WIPP vicinity. The Center currently operates one underground and two surface aerosol monitoring sites at the WIPP. Studies are now being conducted to determine the size distribution for atmospheric aerosols as well as their chemical and radionuclide composition. The results of these studies will provide the basis for identifying the various sources of atmospheric aerosols (e.g., oil and gas, potash mining, soil, and WIPP).

Quality assurance/quality control has been established within the framework of the overall WID Quality Assurance Manual (WP 13-1) and is described in Section 8 of this EMP. When the WIPP data are received, they are evaluated and presented in the WIPP Site Environmental Report.

5.2 SITE CHARACTERIZATION

Characterization studies were initiated to begin evaluating the adequacy of the site as a long-term repository and to obtain information necessary for modeling. These earlier studies have influenced the current WIPP environmental monitoring efforts described below.

5.2.1 WIPP Biology Program

The WIPP Biology Program (Best and Neuhauser, 1980) began in August 1975 with baseline studies of climate, soils, vegetation, arthropods, and vertebrates. The program was expanded in late 1977 to include studies of floristics, primary productivity, plant succession, microbial biogeochemistry, and the aquatic ecosystem of the lower Pecos River. The major objectives were: 1) to acquire baseline data on the WIPP environment, including information for environmental documentation; 2) to provide data useful in the determination of possible radionuclide pathways between the WIPP facility and humans; and 3) to aid in the establishment of a long-term ecological monitoring program.

In 1980, the program was re-oriented to emphasize studies that would help predict specific environmental impacts associated with construction and operations. Soils were experimentally treated with salt, and plants were trampled and grazed in order to make quantitative predictions of the effects of these potential impacts. The effects of salt on population of arthropods and

decomposition of leaf litter were also studied because of the relatively high sensitivity of these ecosystem components and processes as possible indicators of chemical impacts.

5.2.2 United States Geological Survey (USGS) Studies

Oak Ridge National Laboratory (ORNL) and the USGS jointly selected the northern portion of the Delaware Basin as a general location for waste disposal in early 1972. Following the initial site selection the USGS began regional geologic investigations. Their research documented naturally occurring radionuclide levels in subsurface water of the three major members of the Rustler Formation. Data on gross alpha/beta, radium, and uranium levels in each member from a total of 20 well locations were obtained (USGS, 1983). Also, the USGS maintains a routine surface sampling program on the Pecos River (USGS, 1978-1984). Summaries of the USGS mineral, petroleum, and geohydrology studies are presented in the WIPP FEIS (DOE, 1980).

Additionally, Columbia University personnel under Nuclear Regulatory Commission (NRC) contract performed a study of radionuclide mobility in the highly saline groundwater of the Delaware Basin, which is the area underlying the WIPP (Simpson et al., 1985). This study documented radium, uranium, thorium, and plutonium levels in groundwater and surface waters of the Delaware Basin. A summary of the data from the Columbia University study is presented in Bradshaw and Louderbough (1987).

5.3 RADIOLOGICAL ENVIRONMENTAL MONITORING

The operational environmental surveillance program will be continued, with some modifications of the preoperational program and parameters monitored during the RBP and Ecological Monitoring Program. Each sampling subprogram of the EMP is described below.

5.3.1 Effluent Monitoring - Liquid Releases

DOE Order 5400.5 is the DOE driver that sets dose limits and requires monitoring of liquid effluent streams. The *Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (DOE/EH-0173T) is the guidance document that sets the standard for meeting the requirements of DOE order 5400.5. Liquid effluent monitoring is necessary to quantify radionuclides released to the environment and to alert operators of process inconsistences and malfunctions of emission controls.

The only credible source of waste-generated liquid contamination at the WIPP is the Waste Handling Building (WHB). There is no direct connection between the WHB and the sewage treatment system; therefore, there is no direct pathway for radioactive or hazardous contaminants associated with the TRU wastes to enter the WIPP sewage treatment system. There is a sump in the WHB that collects liquids from throughout the WHB. Should there ever be any liquid accumulation in the sump as a result of a waste package release or subsequent fire-suppression water collection, the water in the sump will be sampled and analyzed for contamination as shown in Table 5-2. The following would then be performed in order to assure proper management of the waste:

- If the fire water is radioactive, it will be assumed to be TRU mixed waste and will be managed as derived waste. Solidification will occur as the water is transferred to the derived waste drum. Characterization will be in accordance with the WIPP Resource, Conservation, and Recovery Act Part B Permit Application.

- If the fire water is nonradioactive, a determination will be made if the water is hazardous waste. The determination will include sampling and analysis. Any waste determined to be nonradioactive hazardous waste will be managed in accordance with WIPP facility procedures for such waste.

- If the fire water is nonhazardous, as described in the New Mexico Environment Department (NMED) Discharge Plan for the WIPP (DP-831), it will be discharged to the WIPP facility sewage lagoon.

If the sump contents are radioactive or hazardous, or both, the WIPP will remove and solidify the contents of the sump.

The WIPP sewage treatment system is a zero discharge facility made up of parallel synthetically lined settling and polishing cells that gravity flows treated effluent into a chlorination system, and then flows through lined evaporation ponds. The berm that surrounds the sewage lagoon is designed to eliminate storm water inflows and potential discharges. The facility is designed to contain a 100 year/24 hour storm event. The facility is designed to accommodate normal sewage effluent and to provide for disposal of nonhazardous waters. Brine waters discharged into the sewage evaporation basin result from observation well pumping around the WIPP site.

Although the sewage treatment facility is a zero discharge facility, when it was expanded in 1993 the NMED required that a Discharge Plan be prepared which would stipulate monitoring requirements for water quality, and effluent volume.

WIPP procedure WP 02-EM1001, *Sewage Discharge Monitoring* incorporates the requirements of the Discharge Plan. Sewage system effluent water samples are collected quarterly from the primary settling ponds and evaporation ponds. Samples are analyzed for Nitrates (NO_3), Total Kjeldahl Nitrogen (TKN), Total Dissolved Solids (TDS), and Radium 226 and 228.

The WIPP also conducts oversight sampling twice annually for ammonia, total metals, dissolved metals, chemical oxygen demand, cyanide, total organic compounds, oil/grease, phenols, pesticides, semi-volatiles, volatiles, pH, hexavalent chromium, total suspended solids, and total dissolved solids.

The level of sludges accumulating in the sewage system are monitored by WID operations as part of routine maintenance. If sludges accumulate in the sewage lagoon to a level that could impact facility storage capacity, representative samples of the solids will be collected and analyzed for the parameters defined in 40 CFR 503, *Standards for the use or Disposal of Sewage Sludge*. Based on the analytical results, the sludge will be managed and disposed in accordance with 40 CFR Part 503.

The drinking water supplied to the WIPP is also sampled annually to monitor differences between the influent and effluent.

5.3.2 Effluent Monitoring - Airborne Emissions

Airborne effluent monitoring is especially important to the WIPP EMP. There are two potential sources of contaminated airborne emissions from the WIPP operations: releases generated above ground in WHB operations, and those generated underground that are released through the Exhaust Shaft (Figure 5-1). As recommended by DOE/EH-0173T both potential sources are sampled as appropriate.

Two effluent monitoring stations, A and B, sample exhaust from the underground operations. Sample extraction probes sample the unfiltered exhaust stream in the Exhaust Shaft (Station A), the filtered exhaust down stream of the Exhaust Filter Building (Station B), and the filtered exhaust of the Waste Handling Building (Station C). The filtered exhaust passes through HEPA filter banks prior to reaching the sample extraction probes at Stations B and C.

Because significant concentrations of salt dust are potentially present in the airstream at Station A, standard isokinetic sampling probes have been demonstrated to be ineffective. Therefore, an

anisokinetic, shrouded probe system has been designed, developed and tested specifically for use at the WIPP. The Station A sampling array is composed of the anisokinetic shrouded probe, a flow controlling device, and a sample-collection filter. Station B, in the Exhaust Filter Building, is configured similarly. The exhaust air from the WHB (Station C) is continuously routed through two stages of HEPA filters. After the air is filtered, it is sampled with an isokinetic sampling array connected to a flow-control and sampling system.

After Transuranic waste is received at the WIPP, filters (samples) from the fixed air samplers (FAS) systems at Stations A, B, and C will be collected (at two cubic feet per minute) each working day, and counted for gross alpha and gross beta activity. Selected effluent air samples will be analyzed for specific radionuclides (Table 5-2) on site or at an off-site lab if significant gross alpha or beta activity is indicated.

Gross alpha and beta counting are performed with gas-flow proportional counters. If a sample is counted and activity is recorded equal to, or less than 2.0 E^{-13} μCi/ml alpha, or 2.0 E^{-10} μCi/ml beta, (one-tenth of the Derived Air Concentration) then no action is required.

5.3.3 External Radiation

Continuous Exposure Rate Measurements

An assessment of the capabilities of the Reuter-Stokes with regard to the gamma source term of the WIPP bound transuranic waste indicates that such a dose-rate instrument would be ineffective for detecting a radiological release. The likelihood of detecting a release with the transuranic alpha emitters from air samples far exceeds the real-time dose rate capability of the Reuter-Stokes. Therefore, the decision was made to discontinue the Reuter-Stokes monitoring program.

5.3.4 Airborne Particulates

The WIPP SEIS identifies the atmospheric pathway as the most credible exposure pathway to the public from the WIPP. Therefore, airborne particulate sampling for alpha-emitting radionuclides is emphasized in the EMP. Air sampling results are used to trend environmental radiological levels and determine if there has been a deviation from established background radiological levels. The inhalation of airborne radionuclides, either directly from the source (facility) or from resuspension following deposition, may result in their uptake from the lung or the gastro-intestinal tract. Intake and subsequent distribution in the human body depends on the particle size and the chemical state of the radionuclide. DOE/EH-0173T and DOE/EP-0023 provide guidance on deployment, operations, and program management of an airborne particulate monitoring program.

DOE/EH-0173T recommends that:

> "Air sampling locations should be selected to represent radionuclide concentrations breathed by the population surrounding the nuclear facility. Selection of background sampling and measurement locations for air must be made with special care. For measurements to be compared with the effects of airborne releases, a minimum distance of 15 to 20 km from the larger sites and 10 to 15 km from the smaller sites in the least prevalent wind direction is suggested for background sampling.
>
> Off-site air samplers should be employed at each DOE site having potential airborne releases that could result in an annual effective dose equivalent greater than 1 mrem to the maximally exposed individual. Sample locations should include the following: a background or control location; locations of maximum predicted ground-level concentration from stack (or vent) releases, averaged over a period of

1 year where members of the public reside or abide; and locations in the nearest community within a 15-km radius of the site.

The exact number of samplers will be determined by meteorology, demography, and the magnitude of projected doses to the surrounding population. Unless documented site-specific evidence exists to justify otherwise, the sample(s) at each air sampling station should be collected at a height of 2 m above ground level (approximately the height of inhalation for adults), in a location free from unusual localized effects or other conditions (e.g., in proximity to a large building, vehicular traffic, or trees) that could result in artificially high or low concentrations. Locations should be selected to avoid areas where large-particle (nonrespirable) fugitive dusts can dominate the sample (Ludwig 1976)."

A method similar to that developed (Waite 1973b) and evaluated by Waite (1973a) was used to determine the number of air sampling stations and their placement. Waite's method entails examining demographic and meteorologic data for the site to determine the distance to local population centers, their population, and the wind frequency distribution and weighing factors that are scaled to equal the desired number of sampling locations.

Low volume fixed air samplers (Lo-Vols) operating at two cubic feet per minute (0.056 cubic meters) are used to collect airborne particulates. As recommended in DOE/EH-0173T, the sample inlet probes are located approximately 2 meters (6.5 feet) above ground level in sites free from unusual micrometeorological or other conditions (e.g., proximity of large buildings, vehicular traffic) that could result in air concentration measurements that are artificially high or low. the inlets are configured to provide a minimum of 270 degree sample radius.

The current Lo-Vol sampling array (Figure 5-1) consists of seven sampling stations, the locations of which are based primarily on meteorological and demographic considerations and the need to provide as much continuity as possible between baseline and operational data. Lo-Vol samplers are at Carlsbad, Smith Ranch, Mills Ranch, WIPP South, WIPP East, and the WIPP Far Field sites. The original WIPP northwest location was discontinued due to its location being in a high vehicular traffic area. This location received heavy filter loading from dusts being resuspended by the traffic. One quality control sampler is rotated every quarter to a different sampling location to provide added assurance that the air samplers are operating consistently. As recommended in DOE/EH-0173T, a sampling station was added to incorporate a control site in the predominant upwind direction of the WIPP (the southeast control sampling location is approximately 12 miles southeast of the WIPP).

Lo-Vol filters are exchanged weekly, and after a 12-hour desiccation period, the loaded filters are weighed to calculate total suspended particulates. The filters are then transmitted to the WIPP radiochemistry counting laboratory and individually counted for gross alpha and beta activity. The filters are counted on a gas flow proportional counter with detection limits capable of ensuring compliance with regulatory standards. Quarterly composites of filters from each location undergo specific radionuclide analysis in accordance with Table 5-2.

Modifications have been proposed to the airborne emissions monitoring program. These changes would incorporate the use of continuous high volume (approximately 40 cubic feet per minute) air samplers around the WIPP site, and an increase in the number of sampling locations. Any changes implemented into the WIPP environmental air sampling program will be approved by the Carlsbad Area Office and discussed in the next updated EMP.

5.3.5 BIOTICS

Vegetation

Collection and analysis of vegetation samples serves three useful purposes: evaluating the potential radiation doses received by people consuming such vegetation; predicting the possible concentrations in meat, eggs, and milk from animals consuming contaminated forage (and resultant radiation doses to consumers of the animal products); and monitoring trends in environmental contamination and possible long term accumulation of radionuclides.

EMP vegetation samples are collected from the permanent locations where air samples and soil samples are collected (Figure 5-2). With multiple media samples collected at the same location, it provides for a broad environmental evaluation of a location with multi environmental media. In addition, if vegetable gardens are grown at the Smith and/or Mills Ranches, a leafy vegetable sample may be collected annually, and analyzed as specified in Table 5-2. Each sample will be collected as specified in the Environmental Procedures Manual (WP 02-3). Sufficient material will be collected to meet the needs of the analytical laboratory.

Beef/Deer

The WIPP SEIS indicates beef is not a significant pathway at the WIPP facility. Samples of tissues are not ideal indicator materials because of the time delay for transfer of radionuclides from the point of release through vegetation to muscle tissue. Therefore, frequent sampling of meat is normally required only when it is necessary to evaluate the radiation doses received via this foodstuff. With a few exceptions, radiation doses from ingestion of radionuclides are a measure of secondary importance.

Due to this secondary importance, the WIPP now only collects beef and deer samples on an as available basis. This is primarily through livestock and vehicle collisions on the roads in the WIPP vicinity. Therefore, the tissue and organ samples are collected only if they are easily attainable.

Quail, Rabbits, and Fish

As previously stated, muscle tissue is not a significant exposure pathway. However, DOE/EH-0173T indicates that game birds and mammals hunted locally should be sampled during the hunting season in the vicinity (within 25 km) of the site.

Rabbits and quail are collected annually on an "as available" basis. Quail are trapped at the facility, while rabbits are collected when found on roads in the WIPP site vicinity. A composite sample of muscle tissue from each type of animal is analyzed as shown in Table 5-2.

Fish are analyzed to quantify the dietary radionuclide intake by humans, and secondarily, as indicators of radioactivity in the ecosystem. Although aquatic foodstuffs are not considered a significant pathway from the WIPP operations, catfish are collected annually from the Pecos River near Carlsbad, Brantley Lake which is located on the Pecos River between Artesia and Carlsbad, New Mexico, and from a location noted as Pierce Canyon that is slightly down stream from Malaga, a small village south of Carlsbad.

The fish samples (tissue fillets) are removed from the carcass to approximate the activities of a sportsman (if fish are small they may be halved after the head and tail is removed). The fish samples are composited by location and analyzed for gross alpha and beta activity and the specific radionuclides indicated in Table 5-2. Catfish are appropriate for analysis in this program because they dwell and feed in bottom sediments where transuranic radionuclides may accumulate.

5.3.6 SOIL SAMPLING

EMP surface soil samples are collected annually from the six locations shown in Figure 5-3. Sampling sites are co-located at air particulate sampling locations and the vegetation sampling sites recommended in HASL-300 and DOE/EH-0173T. The frequency of sampling also follows the guidance contained in DOE/EH-0173T for obtaining long-term accumulation trends. Samples are currently being collected at depths of 0-2, 2-5, and 5-10 cm. However, this method is under review and may be modified. The soil samples are analyzed as indicated in Table 5-2.

5.3.7 SURFACE WATER/DRINKING WATER

Surface water is absent within the WIPP site. The EMP surface water samples are collected annually from the 14 locations in the WIPP vicinity specified in Figure 5-4. These locations comprise the major bodies of surface water in the WIPP vicinity and provide adequate data concerning the surface water pathway. Analyses are performed as specified in Table 5-2.

In addition to the regularly sampled surface water locations there will be additional "samples of opportunity" collected from the site run-off water catchment basins. Due to the varied precipitation events at the WIPP these samples will only be collected when there is adequate run-off available to be properly sampled. As standard for most of the surface water sampling sites, a sediment sample is also collected at the same location. Due to the construction of the basins it is not advisable to perforate the clay bottom to collect the sediment samples. Therefore, sediment samples will not be collected from these sites located directly south and west of the WIPP facility.

Drinking water is collected at the pumphouse from the WIPP supply system. This is the facility which receives/stores the fresh water that is supplied to the site. This water is sampled annually and analyzed for constituents in Table 5-2.

5.3.8 GROUNDWATER

DOE 5400.1 requires that groundwater that may potentially be affected by DOE operations be monitored to detect and document the effects of such operations on groundwater quality and quantity and to show compliance with applicable Federal and State laws and regulations. The groundwater monitoring programs should be conducted on-site and in the vicinity of DOE facilities to:

- Obtain data to determine baseline conditions of groundwater quality and quantity;
- Demonstrate compliance with and implementation of all applicable regulations and DOE Orders;
- Provide data for the early detection of groundwater pollution or contamination;
- Identify existing and potential groundwater contamination sources and to maintain surveillance of these sources; and
- Provide data upon which decisions can be made concerning land disposal practices and the management of groundwater resources.

The WIPP Groundwater Surveillance Program supports Performance Assessment and the EMP. The Groundwater Surveillance Program consists of two subprograms, the Groundwater Level Monitoring Program and the Water Quality Sampling Program (WQSP).

The Groundwater Level Monitoring Program consists of monthly collecting water level measurements from approximately 63 wells (Figure 5-5) in the vicinity of the WIPP. These measurements are tracked to determine if there is a change in the water levels over time and if so to determine the cause of the change.

For the WQSP, samples are collected from the wells noted on Figure 5-6. These samples taken are analyzed for chemical and physical parameters, as well as specific radionuclides as noted in Table 5-2. The protocols specified in the Groundwater Surveillance Program Plan and Procedures manual (WP 02-1) are followed in collecting groundwater samples.

In September and October 1994, six new wells (WQSP 1-6) were installed in the Culebra member of the Rustler formation and one new well (WQSP 6a) in the Dewey Lake for the purpose of water quality sampling. The new wells are constructed to EPA standards and have the potential to meet detection monitoring standards. Recommended EPA drilling methods were used to minimize the introduction of foreign materials into the well bore and prevent contamination of the aquifer. The addition of the new wells to the program is expected to improve the quality of the data collected and reduce the time and cost of sampling. The results of the first samples taken for the new well are reported in the 1995 WIPP Site Environmental Report.

5.3.9 SEDIMENT SAMPLING

Sediment samples are collected from 12 locations (Figure 5-7) annually in the vicinity of the WIPP site and analyzed for specific radionuclides noted in Table 5-2. On the Pecos River there are four locations located; at the upper Pecos near Artesia, New Mexico, Brantley Lake State Park, Lake Carlsbad recreational park, and Pierce Canyon. Eight dirt tanks (earthen catchment basins) are used by area ranchers to collect runoff water for livestock, these tanks are; Tut, Noya, Red, Indian, Lost, Bottom-of-the-Hill, Poker Trap, and Hill. Samples will be taken from the sewage lagoon outflow as soon as sediment build up is adequate for sampling purposes. There are no sediment samples collected from the WIPP water supply line. The analytical results for the sediment sample analysis are reported annually in the WIPP Site Environmental Report.

5.4 NONRADIOLOGICAL ENVIRONMENTAL MONITORING

Nonradiological environmental monitoring activities at the WIPP consist of a comprehensive set of sampling programs designed to detect and quantify impacts of construction and operational activities, and surface storage of salt on the local ecosystem. The requirements and objectives of both preoperational and operational nonradiological environmental monitoring are described in the WIPP FEIS (DOE, 1980). The ecological monitoring program functions as an "operational program" prior to and after commencement of waste emplacement, because it focuses on nonradiological effects which are ongoing.

Section 2.5 of Appendix J of the FEIS states:

> "The operational ecological monitoring program, building on the foundation established through preoperational ecological monitoring, will document the ecological effects of construction and operation . . . and will focus primarily on indicator organisms and selected abiotic parameters."

Primary guidance for ecological monitoring was derived from the WIPP FEIS and the American Institute of Biological Scientists (AIBS) evaluation of the WIPP Biology Program.

Projected construction impacts on the ecosystem include the deposition of fugitive dust generated by the handling of materials such as salt, caliche, and topsoil at the site, as well as noise and other unnatural conditions associated with human activities at the site. A detailed description of the rationale for the ecological studies appears in the first semiannual Ecological Monitoring Program

Report (Reith et al., 1985). Table 5-2 lists parameters which will be monitored by the EMP for evidence of possible site impacts. Results of these studies are published in the SER.

5.4.1 Meteorological Monitoring

The DOE/EH-0173T guidance manual lists guidance for each DOE site to establish a meteorological monitoring program appropriate for the activities at the site and the local topography and demography. Weather data must be monitored and recorded to supplement characterization of the local environment and facilitate the interpretation of data from other environmental monitoring activities at the WIPP.

Meteorological conditions were monitored by SNL at the WIPP from 1975 through 1980. Between 1984 and 1988, temperature, wind speed, and wind direction were continuously monitored from a 10-meter (33 feet) tower at the northwest corner of DOE Exclusive Use Area. Equipment to monitor precipitation and barometric pressure were added to this station during that period.

Use of the 10-meter (33 feet) tower as the primary meteorological monitoring station was discontinued in 1988, and the 10-meter station was relocated to the WIPP Far Field sampling location. The WIPP Far Field site is in the predominantly downwind direction from the WIPP exhaust releases and is the principal air quality sampling location for the EMP.

The primary meteorological monitoring station, is a 50-meter tower located northeast of the WIPP as shown in Figure 5-8. Temperature, wind speed, and wind direction are monitored at 2, 10, and 50 meters (16, 33, and 165 feet, respectively) barometric pressure, humidity, solar radiation, and precipitation are also monitored at this location. Dew point values are also calculated by the Central Monitoring System (CMS) from the temperature and humidity values and recorded for future reference. Measurements are recorded at the CMS, which tracks numerous real-time parameters on a centralized computer system.

A Quality Assurance Project Plan (QAPjP) is being developed for the collection of meteorological data use for regulatory purposes. The QAPjP will incorporate requirements of RCRA, Title 40 CFR 268.6, *EPA Guidance Manual for Petitioners*, EPA 530-R-92-023, and *On-Site Meteorological Program Guidance for Regulatory Modeling Applications*, EPA-450/4-87-13. This section of the EMP fulfills the requirement to have a meteorological monitoring plan as noted in DOE Order 5400.1.

5.4.2 Volatile Organic Compound Monitoring Program

The Volatile Organic Compound (VOC) Monitoring Program was established at the WIPP as required by the EPA. The requirements for the program published in the No-Migration Determination (NMD) issued by the EPA on November 14, 1990 (55 FR 47700). The DOE's 1993 decision to cancel the Bin-Scale and Alcove Test Phase activities resulted in amending the VOC Monitoring Programs objectives.

The DOE has collected airborne VOC data since 1990; these data will serve to characterize the background concentration levels for the WIPP. The VOC Monitoring Program will be in a state of transition until the requirements for a Disposal-Phase monitoring program have been established. Under the Baseline VOC Monitoring Program, the DOE will continue to collect background VOC data until the EPA issues an NMD for the Disposal Phase. The DOE anticipates that this NMD will be issued by June 1997 and will reflect the requirements for VOC Monitoring during disposal operations.

5.4.2.1. VOC Monitoring Plan

The Baseline VOC Monitoring Program measures VOC concentrations in the ambient air to determine the WIPP facility's background levels. This program will serve to differentiate between background VOCs from aboveground and underground sources and VOCs that will be released from TRU mixed waste during disposal operations. Monthly sampling is conducted at the following three stations:

- Near the top of the Exhaust Shaft (Station VOC-1)
- Near the air intake shaft (Station VOC-2)
- Ventilation air intake passageways to the waste-containing rooms (Station VOC-8)

Based on field and analytical VOC data collected under the Baseline VOC Monitoring Program, a Disposal-Phase monitoring plan was developed and submitted in the Final No-Migration Variance Petition (NMVP). In the NMVP, which is currently under review by the EPA, the DOE proposes a Confirmatory Monitoring Plan (CMP) for the Disposal Phase. The CMP describes a limited sampling and analysis program by which the DOE will confirm the accuracy of the compliance calculations presented in the NMVP. This program will involve the collection of air samples upstream and down stream of Panel 1 beginning just prior to waste emplacement and proceeding until at least six months following completion of panel closure. The DOE will continue monitoring until the criterion for terminating monitoring, as set forth in the CMP, are met.

5.4.3 Groundwater Surveillance

The objective of the Groundwater Surveillance Program is to provide qualitative characterization of the groundwater within and the area surrounding the WIPP site. This surveillance program will document the groundwater quality through time to determine if the water quality is changing. Collection of these samples will be from the wells noted in Figure 5-5.

General chemistry of the water is monitored utilizing standard wet chemistry analytical methods. These methods will analyze for standard primary constituents such as chlorides, magnesium, calcium and sulfates. In addition to the general chemistry analysis, background data on the 255 constituents listed in Appendix IX of 40 CFR 264 are also being monitored as a requirement of the WIPP RCRA Part B Permit Application.

Constituents listed in Appendix IX include, purgable volatile compounds, non-purgable volatile compounds, semi-volatile compounds, pesticides, polychlorinated biphenyls, herbicides, dioxins, and furans. A future determination will be made whether to continue to monitor all 255 constituents or target specific constituents during the operational phase of groundwater surveillance activities.

5.4.4 Ecological Monitoring Plot Selection

Sampling for the nonradiological environmental portions of the EMP focus on components of the ecosystem immediately surrounding the site and on the ecological parameters most likely to reflect the impact of construction and operational activities (see Section 3.5 for a discussion of the ecosystem at the WIPP). Sampling activities are performed at seven permanently marked ecological monitoring plots whose locations are unchanged from the original preoperational EMP. An identification sign located at the center of each plot serves as a permanent reference for the selection of sampling locations. Each plot is approximately 150 meters (492 feet) by 150 meters (492 feet), although the size of some plots are slightly restricted by roads and other barriers.

Ecological monitoring plots have been located with several criteria in mind:

- Some plots are in areas not directly disturbed by construction, but where the probability and extent of ecological impacts is greatest;
- Controls have been cited where potential impacts from the site are small or negligible; and
- Comparability among the plots has been maximized by situating them where soil, vegetation, and general appearance are judged to be as similar as possible.

Figure 5-9 illustrates the location of the permanent ecological monitoring plots. The plots likely to be impacted by site activities are Southeast 1 (SE1), Northwest 1 (NW1), and East 1 (E1). These three plots are adjacent to the two stockpiles where excavated salt is stored. NW1 is downwind from the facility and the active salt pile according to the prevailing winds, that blow from the southeast. Westerly winds tend to blow during the spring, and can be strong and persistent. During the spring westerlies, E1 is downwind of the site and the active storage pile. SE1 is adjacent to the smaller salt pile, but is outside the path of either primary or secondary wind directions.

Both SE1 and NW1 have counterparts (SE2 and NW2 respectively) located approximately 150 meters (492 feet) farther from the site and the salt piles to help determine the range of any ecological impacts. Finally, Control 1 (CT1) and Control 2 (CT2) are located more than two kilometers (1.2 miles) from the center of the WIPP activities. These are believed to be sufficiently distanced from the facility to minimize exposure, and be an effective "control" site to evaluate and compare ecological impacts.

5.4.5 Aerial Photography

Aerial photographs are utilized to document impacts of the WIPP activities on the local ecology. Removal of native habitat is due to construction of roads, parking lots, buildings, and salt storage piles. The extent of this habitat replacement is documented in aerial photographs. These photographs are typically taken annually.

Aerial photographs produce color stereo-pair photographs for stereoscopic examination as well as enlarged "spot photos" of the WIPP installation. The large-negative spot photographs are available for enlargements in both color and black and white, and can used for planimetric and/or other evaluations of the displacement of native habitat by WIPP activities. Project personnel and local emergency response agencies are also provided with spot photos for their own use. Selected key locations are temporarily flagged with conspicuous aerial markers to facilitate their recognition on the aerial photographs. Aerial photographic mission parameters may be altered as necessary to investigate areas of special interest.

5.4.6 Wildlife Ecology

Birds and mammals comprise the upper levels of the food chain in the natural ecosystem around the WIPP. These organisms may be impacted by noise and human presence as well as by changes in habitat structure due to salt impacts. Population densities are monitored annually to define normal cycles of abundance and to detect major changes in populations or communities which may be due to activities at the WIPP facility.

Wildlife within the WIPP Land Withdrawal Area are given consideration during planning stages of projects involving the disturbance or encroachment of wildlife habitat inside DOE lands by way of the WIPP Land Use Request process. Monitoring and research of specific wildlife populations occurs in accordance with applicable laws, agreements, and regulations subject to funding.

The WIPP conducts a number of general wildlife management activities. Each activity is mandated and/or supported by state and federal guidelines or by way of commitments created through interagency agreements (e.g., *Raptor Research and Monitoring Interagency Agreement*, and/or Memorandums of Understanding with other federal or state agencies).

Examination of wildlife species in the area reveals significant diversity and complexity. Management of indigenous wildlife incorporates the development of a logical sequence when programming activities. Solutions for problems (e.g., home-range, territoriality of desert mule deer) will serve the implementation of conservation and resource management objectives as they pertain to the management and operation of the WIPP site.

TABLE 5-1

EMP SAMPLING SCHEDULE

SAMPLE TYPE	NUMBER OF SAMPLING LOCATIONS	SAMPLING FREQUENCY
Liquid Influent	1	Annual
Liquid Effluent		
DP-831	1	Quarterly
WIPP Oversight	1	Biannual
Airborne Effluent	3	Continuous
Meteorology	2	Continuous
Air Particulate	7	Weekly
Game Birds	WIPP Vicinity	As Available
Rabbits	WIPP Vicinity	As Available
Beef/Deer	WIPP Vicinity	As Available
Fish	3	Annual
Vegetation	6	Annual
Soil	6	Annual
Surface Water*	14	Annual
Sediment	12	Annual
Groundwater	7 (others added as needed)	Annual
Aerial Photography	Site Wide	Annual
Volatile Organic Compound's	3	Monthly
• Site Run-off Catchment Basins	3	As Available

TABLE 5-2

EMP ANALYTICAL ARRAY

TYPE OF SAMPLE	ANALYSIS
Drinking Water	Residual chlorine, choloforms, nitrates, elemental lead
Liquid Influent	(1) Specific Radionuclides
Liquid Effluent	(1) Specific Radionuclides
DP-831	(3) DP-831 Constituents
WIPP Oversight	(4) Oversight Constituents
Airborne Effluent (Stations A, B, and C)	Gross α, Gross β, ^{238}Pu, ^{239}Pu, ^{241}Am
Meteorology	Temperature, Wind Speed, Wind Direction, Precipitation, Dew Point, Barometric Pressure, Solar Radiation
Atmospheric Particulate	Gross α, Gross β, Total Suspended Particulates (TSP), (2) Specific Radionuclides
Beef	(1) Specific Radionuclides
Game Animals	(1) Specific Radionuclides
Vegetation	(1) Specific Radionuclides
Rabbits	(1) Specific Radionuclides
Beef/Deer	(1) Specific Radionuclides
Game Birds	(1) Specific Radionuclides
Fish	(1) Specific Radionuclides
Soil	(1) Specific Radionuclides
Surface Water	(1) Specific Radionuclides
Sediment	(1) Specific Radionuclides
Groundwater	(1) Specific Radionuclides, (5) Chemical Analysis, (6) Physical Properties
Drinking Water	(1) Residual chlorine, choloforms, nitrates, elemental lead
Aerial Photography	Changes occurring to land surface

TABLE 5-2

EMP ANALYTICAL ARRAY
(continued)

TYPE OF SAMPLE	ANALYSIS

BOD5 = Biochemical Oxygen Demand (5 days)
COD = Chemical Oxygen Demand
TDS = Total Dissolved Solids
TOC = Total Organic Compounds
TKN = Total Kjeldahl Nitrogen
TSP = Total Suspended Particulates
TSS = Total Suspended Solids

(1) Specific Radionuclides:	^{241}Am, ^{60}Co, ^{137}Cs, ^{40}K, ^{210}Pb, ^{210}Po, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{226}Ra, ^{228}Ra, ^{90}Sr, ^{228}Th, ^{230}Th, ^{232}Th, ^{233}U, ^{234}U, ^{235}U, and ^{238}U.
(2) Specific Radionuclides:	^{241}Am, ^{7}Be, ^{60}Co, ^{137}Cs, ^{40}K, ^{210}Pb, ^{210}Po, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{230}Th, ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{238}U, and ^{90}Sr.
(3) DP-831 Constituents:	NO_3, TKN, ^{226}Ra, ^{228}Ra, and TDS.
(4) WIPP Oversight Constituents:	pH, NH_3, BOD5, COD, TOC, oil/grease, metals, dissolved metals, cyanide, phenols, volatiles, semi-volatiles, pesticides, TSS, TDS, TKN

(5) Chemical Analysis: alkalinity, bromide, chloride, fluoride, iodide, nitrate, phenolics, phosphate, sulfate, total organic halogens, TOC, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, iron, lead, lithium magnesium, mercury, potassium, selenium, silica, silver, sodium, carbon tetrachloride, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, and 1,1,2-trichloro-1,2,2-trifluoroethane.

(6) Physical Properties: pH, specific gravity, specific conductance, TDS, and TSS.

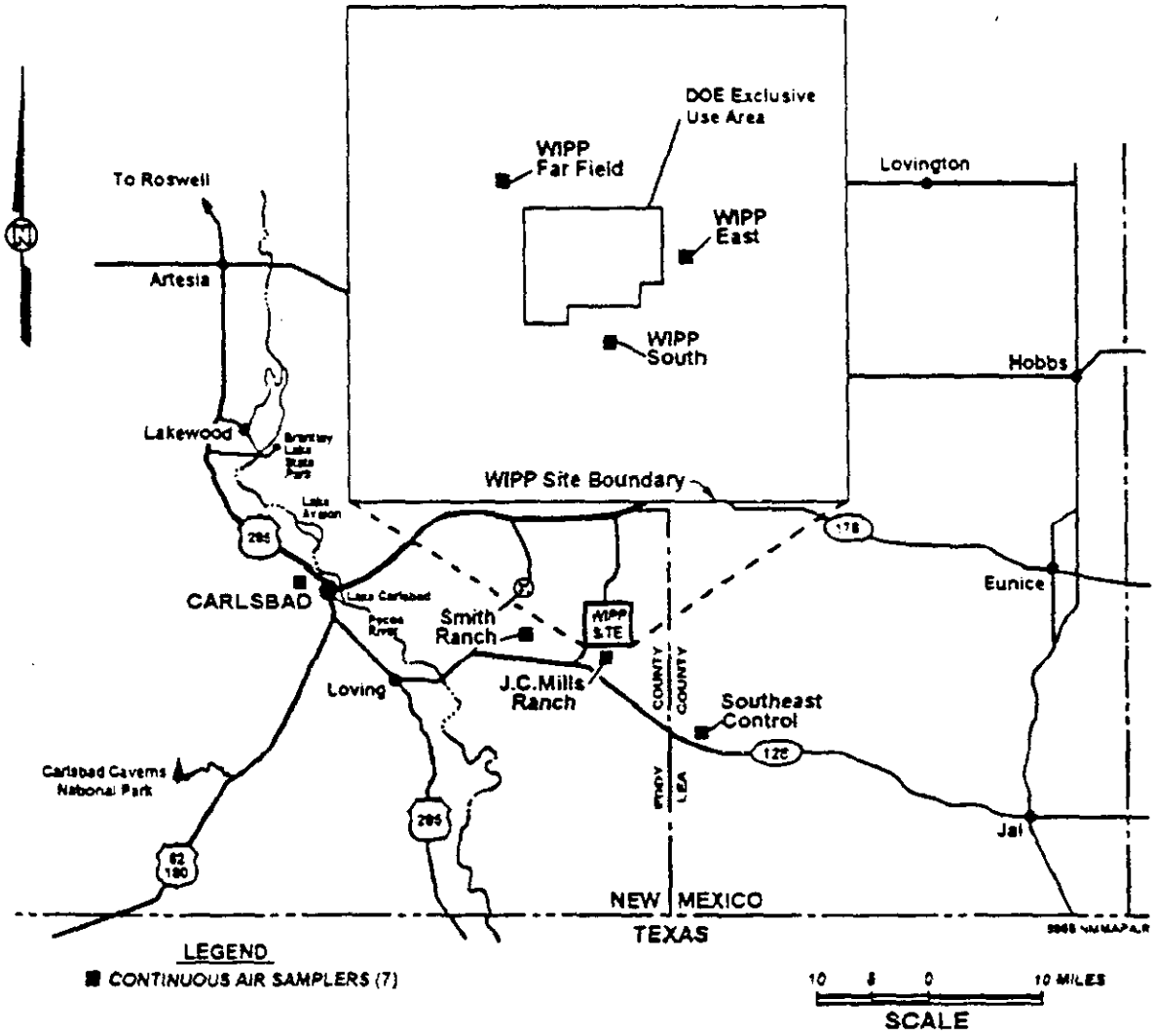

Figure 5-1 Air Sampling Sites

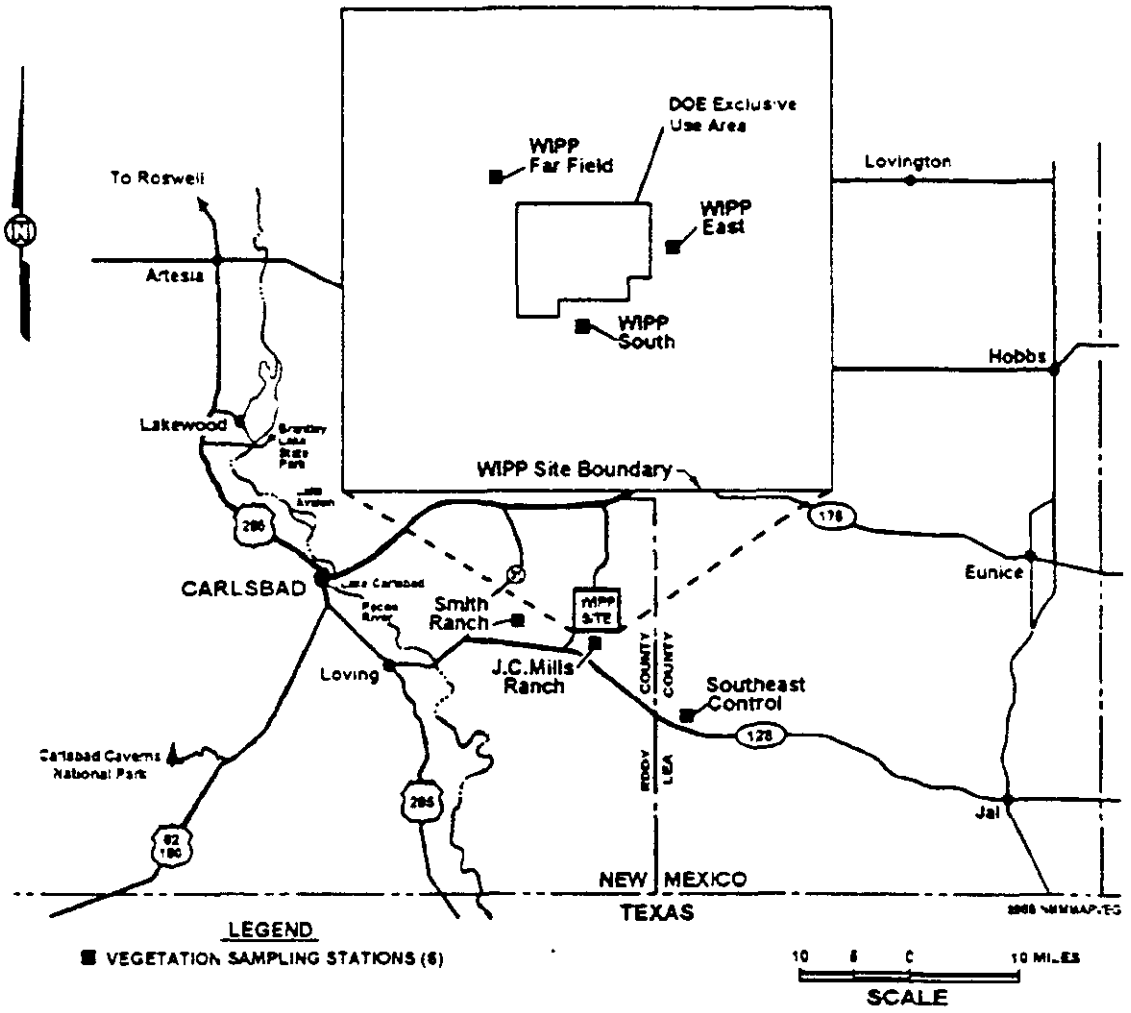

Figure 5-2 Vegetation Sampling Sites

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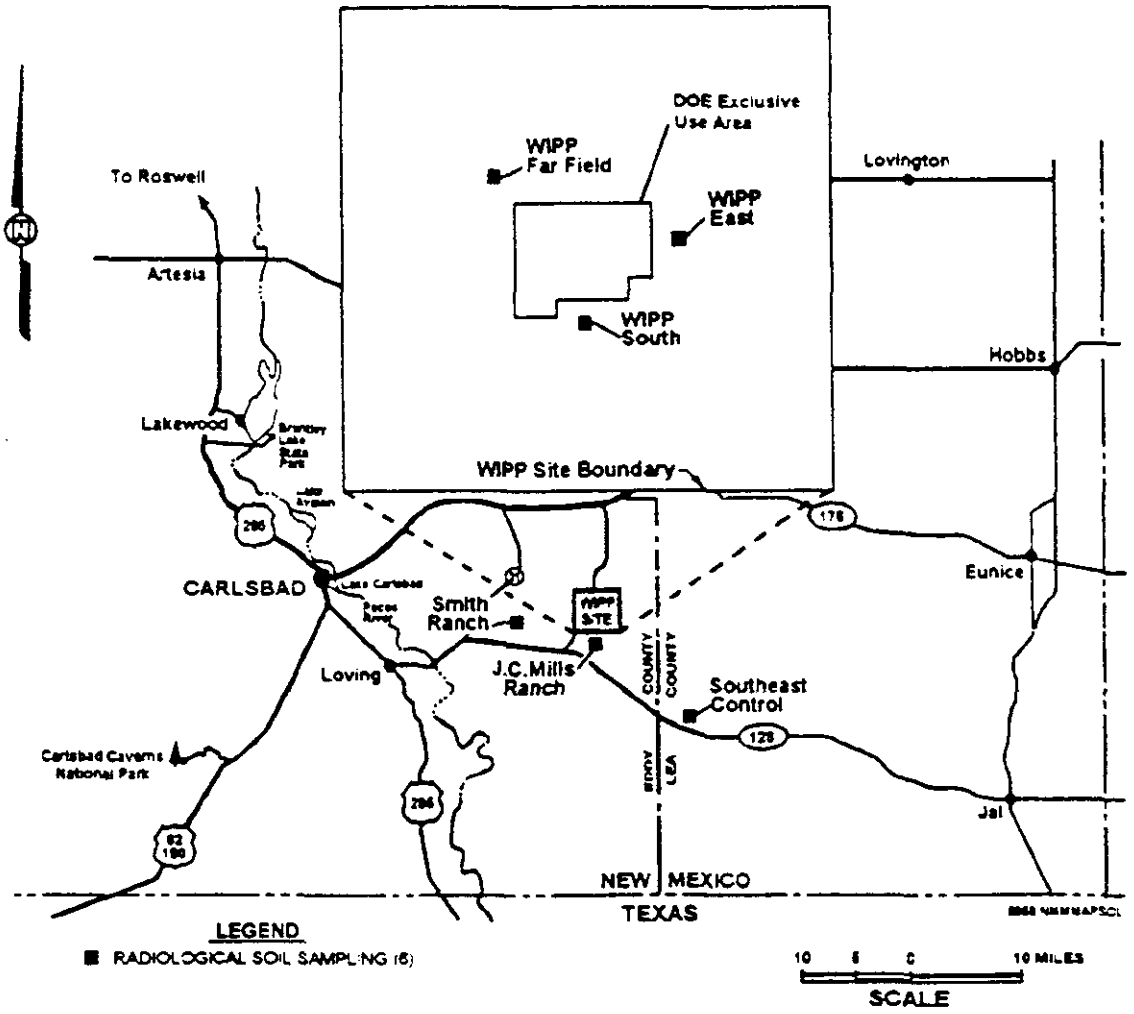

Figure 5-3 Soil Sampling Sites

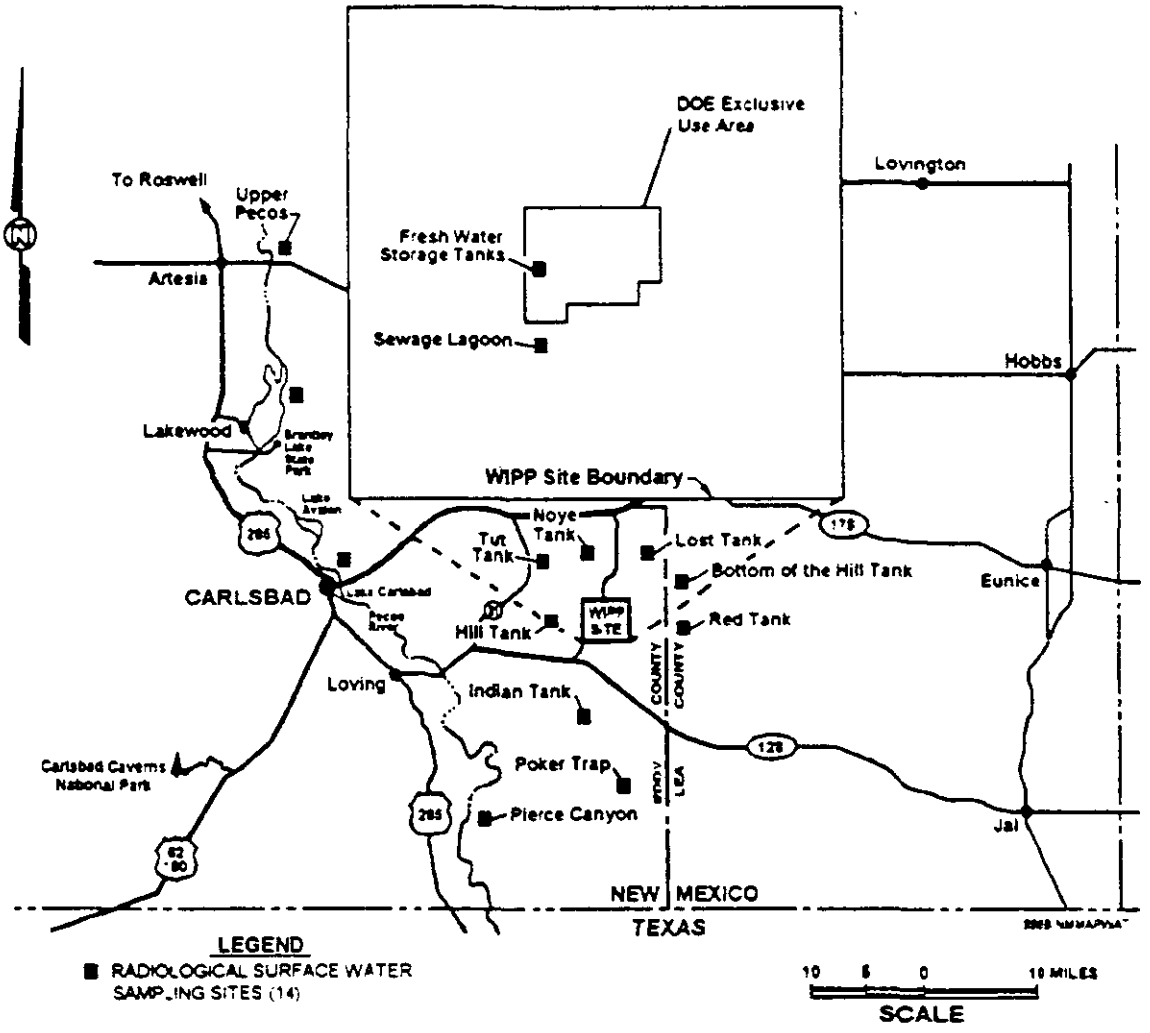

Figure 5-4 Surface Water/Drinking Water Sampling Sites

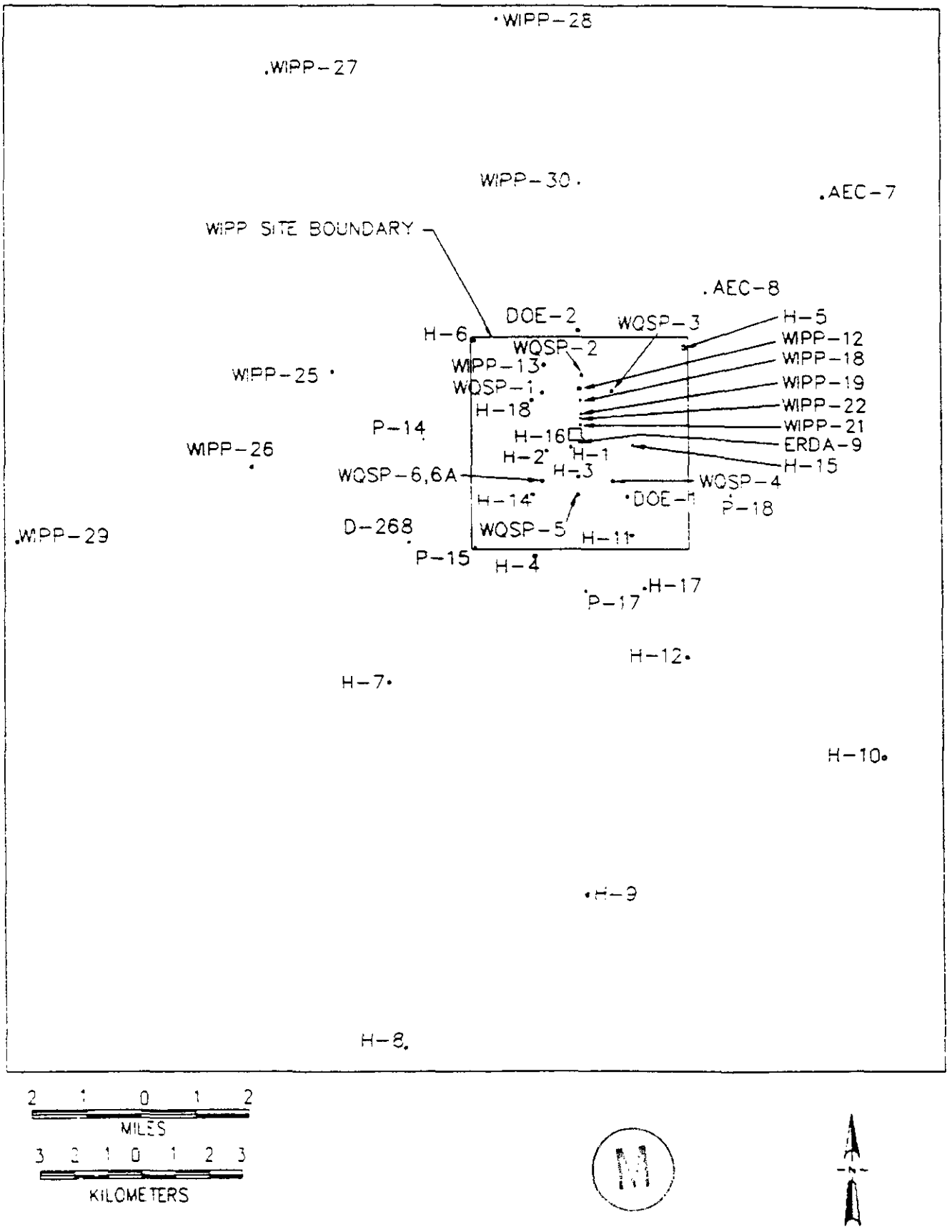

Figure 5-5 Groundwater Level Surveillance Wells

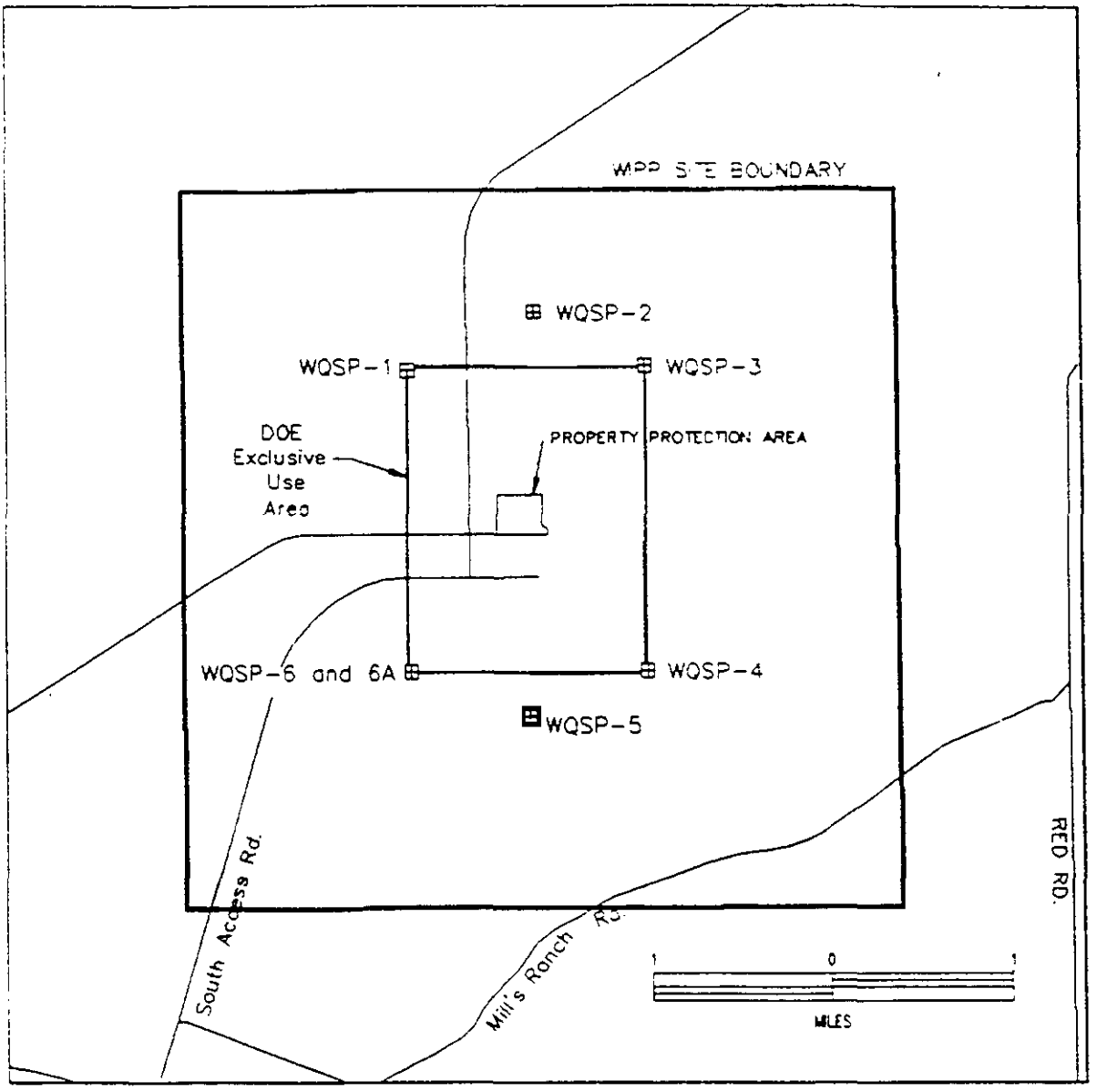

Figure 5-6 Location of the New Water Quality Sampling Wells

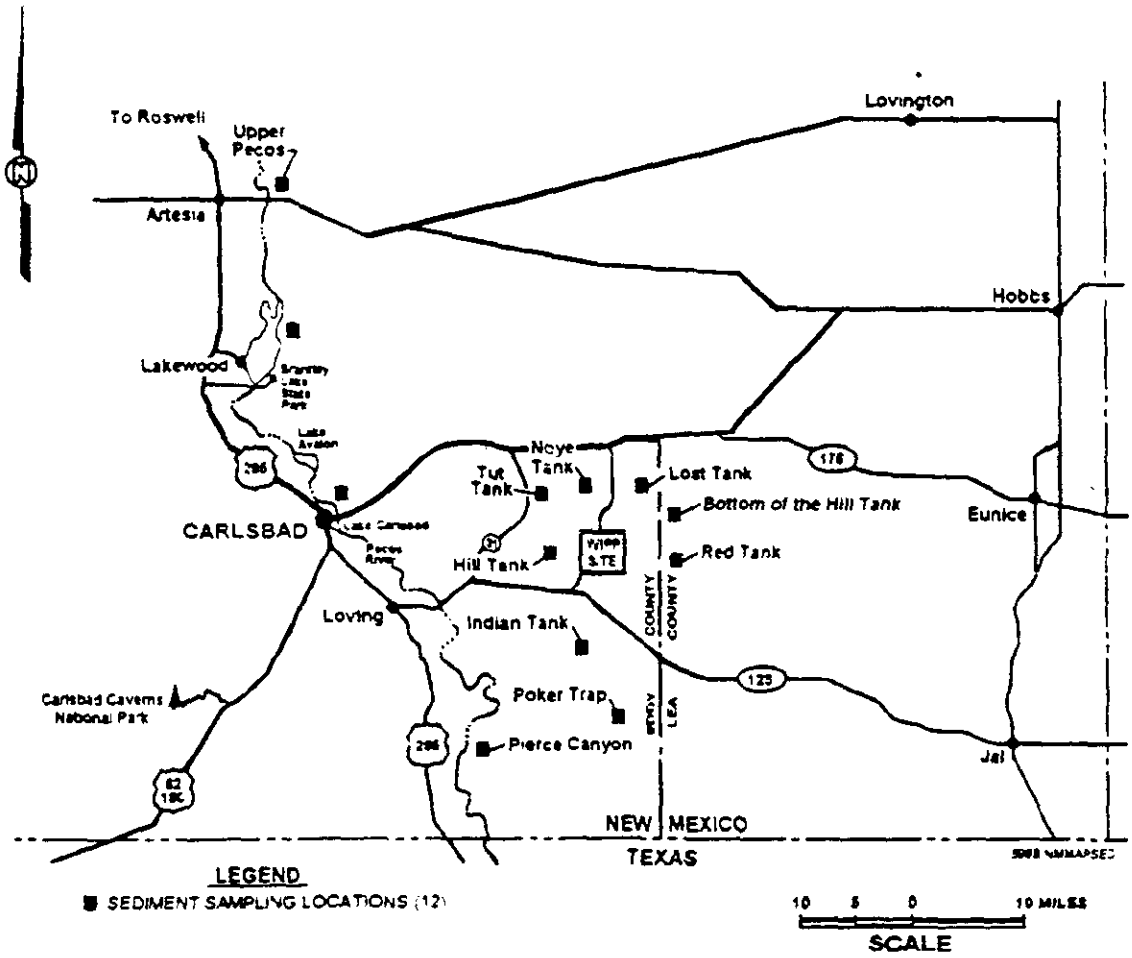

Figure 5-7 Sediment Sampling Sites

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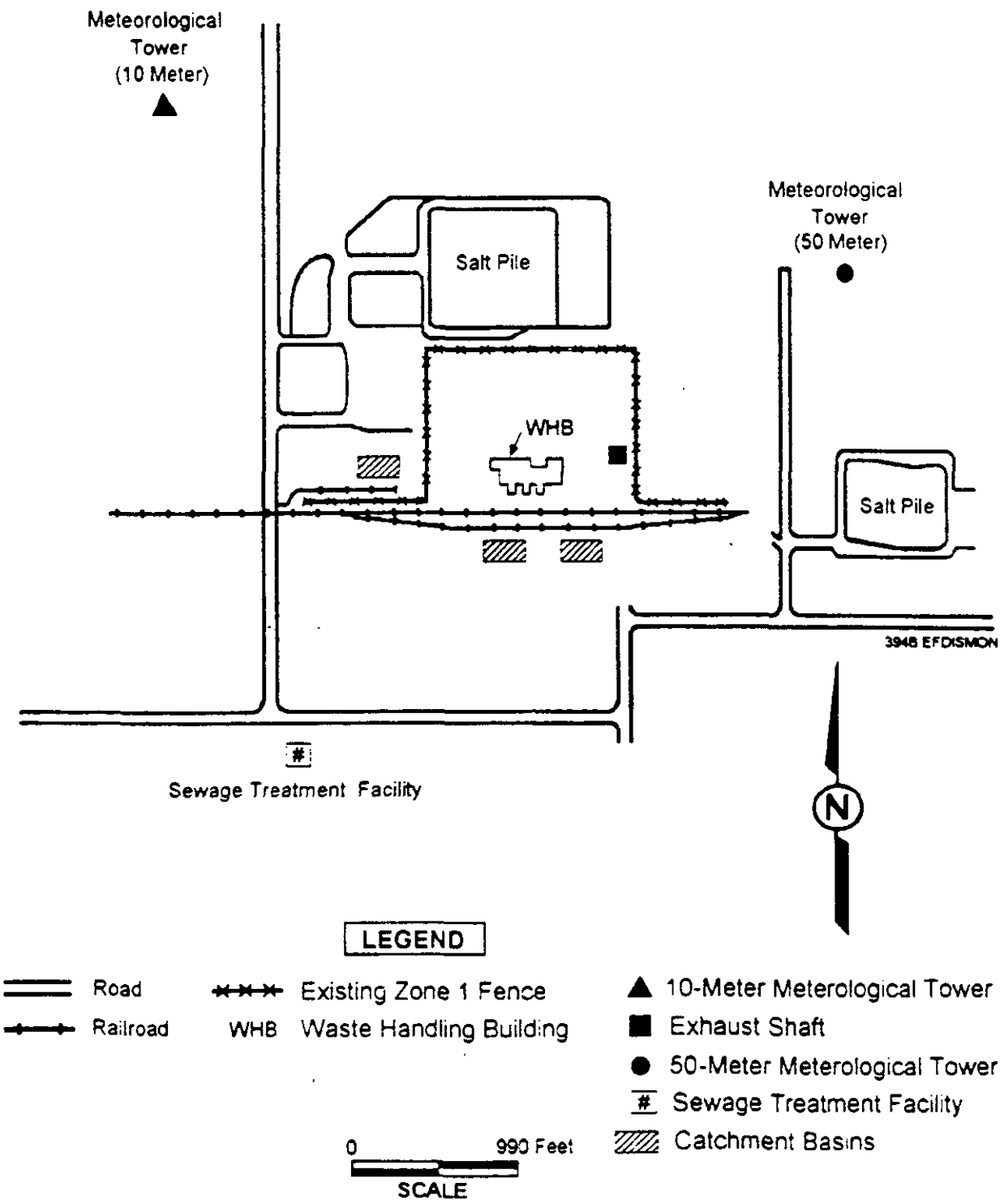

Figure 5-8 Catchment Basins and Meteorological Monitoring Sites

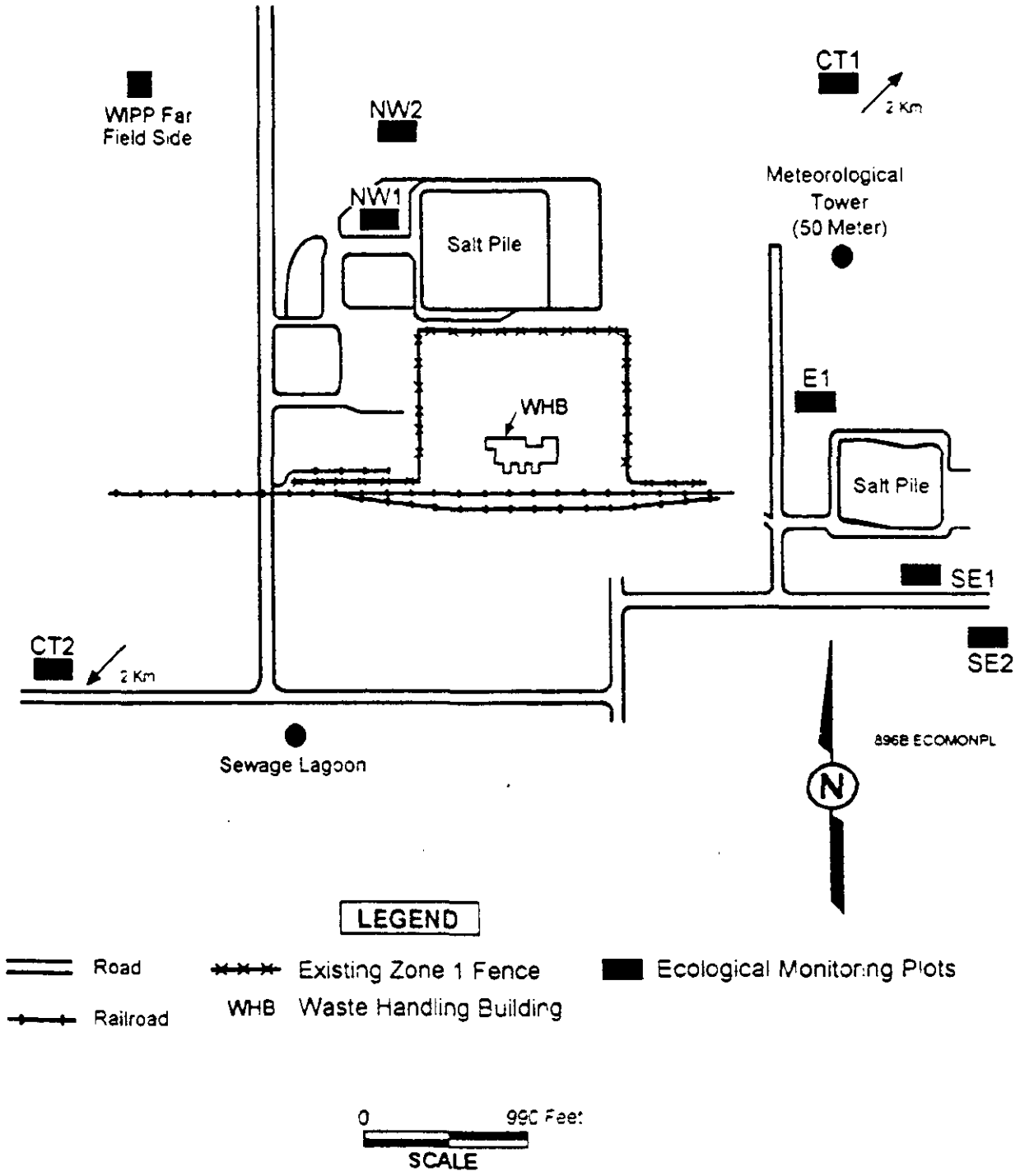

Figure 5-9 Locations of Ecological Monitoring Sites

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6.0 SAMPLE HANDLING AND LABORATORY PROCEDURES

Environmental sampling and analytical laboratory procedures used to obtain quality results for the WIPP are contained and/or described in the following documents:

- Environmental Procedures Manual (WP 02-3)
- Groundwater Monitoring Program Plan and Procedures Manual (WP 02-1)
- Radiological Control Manual (WP 12-5)
- *WID Quality Assurance Program Description* (WP 13-1)

The WIPP has analytical capabilities as well as subcontracted analytical support. Each laboratory is responsible for maintaining an approved quality assurance program for each program discussed in Chapter 5.

6.1 SAMPLE HANDLING

Sample Identification

There is a sample identity code used to uniquely identify environmental samples collected. The code contains sample-specific information used to accurately identify sample type, sample location, date, and sequence of sampling event. A detailed description of the sample identification for radiological and nonradiological samples, including sample identification, calculations, computer inputs, and other applicable reviews are described in environmental sampling procedures.

Environmental Activity Levels

During operations, all TRU wastes will remain in sealed containers. Therefore, radionuclide levels in environmental samples are expected to remain minute during operations. All environmental samples are collected in accordance with accepted practices and widely recognized methodologies and criteria for environmental monitoring (WP 02-3).

Packaging and Shipping of Samples Off-Site

Environmental samples sent off-site for analysis are packaged according to the specific sampling procedures (i.e., soil, water, vegetation, etc.) listed in the Environmental Procedures Manual (WP 02-3). The Environmental Monitoring procedures outline the chain-of-custody requirements that ensure the integrity of samples. The WIPP does not handle high-activity samples in the environmental monitoring programs. Contract laboratories are required to follow Quality Assurance/Quality Control (QA/QC) procedures to ensure cross-contamination between high and low activity samples will not occur. The quality of the data from analytical contract laboratories is verified by 1) participation in interlaboratory cross-checks, 2) duplicate, and blank sample analysis, and 3) occasional comparison of results from sample splits that are provided to stakeholders.

Quality Assurance

A comprehensive QA program has been implemented to ensure that the data collected are representative of actual concentrations in the environment. Each contract laboratory is responsible for maintaining an approved quality assurance program detailing the following:

1) routine calibration of instruments;

2) frequent source and background checks (as appropriate);

3) routine yield determinations of radiochemical procedures;

4) replicate/ duplicate analyses to check precision;

5) standard and spike analyses to check accuracy; and

6) expiration of reagents to ensure chemical purity that could affect the results of the analytical process is not compromised

The accuracy of radionuclide determination is ensured through the use of standards traceable to the National Institute of Standards and Technology, participation in the Environmental Protection Agency Cross-check Interlaboratory Comparison Program, the DOE/Environmental Measurements Laboratory cross-check program, and other interlaboratory analytical assessment programs, when available.

6.2 RADIOLOGICAL ENVIRONMENTAL SURVEILLANCE

A detailed explanation and justification of all radiological and non-radiological Environmental Surveillance is contained in Chapter 5 of this document.

Airborne Particulates

Continuous Low Volume air samplers are used at WIPP for particulate collection. These samplers have a regulated flow rate of 0.056 cubic meters per minute (two cubic feet per minute) of air through a 47-mm (1.9 inch) glass fiber filter. Filters are collected weekly and sent to the analytical laboratory in accordance with the Low-Volume Airborne Particulate Sampling Procedure. A gross alpha and gross beta count of each weekly filter is completed prior to compositing filters from each location for each sampling quarter. This analyses is conducted by the WIPP radiochemistry counting lab in accordance with approved operation and calibration procedures. Quarterly composite samples are also sent off site to a contract laboratory and analyzed using gamma spectrometry for representative gamma-emitting radionuclides typically present in the environment and those expected to occur in the waste received at WIPP. The contract laboratory also performs destructive chemical analysis for the specific alpha and beta activity.

Biotic Samples

Samples of native mammals, quail, fish, locally-produced beef, and vegetation are collected and prepared for radionuclide analyses as described in the Biotic Sampling Procedure. Analyses of all samples are performed by a laboratory in accordance with appropriate EPA and DOE approved methods.

Soil Sampling

Soil sampling procedures used at the WIPP are given in the Soil Sampling Procedure. Analyses of all samples are performed by a laboratory in accordance with appropriate EPA or DOE approved methods.

Surface Water and Sediments

Surface water and sediment samples for radionuclides are collected and handled according to Surface Water and Sediment Sampling Procedure. This procedure describes methods for collecting, preserving, and packaging representative water and sediment samples. Analyses of all samples are performed by a laboratory in accordance with appropriate EPA or DOE approved methods.

Groundwater

Groundwater sampling for radiological analyses is conducted according to the Groundwater Monitoring Program Plan and Procedures Manual. This sampling plan includes detailed procedures on collecting a representative sample by measurement of field parameters to determine a chemical steady-state with respect to those constituents. Included in this plan are the procedures associated with the pumping of groundwater, the serial sampling and analysis program, and the final sample collection and preparation for shipment to contract laboratories. Samples are analyzed by a laboratory in accordance with appropriate EPA or DOE approved methods.

6.3 NONRADIOLOGICAL ENVIRONMENTAL MONITORING

Groundwater

Groundwater sampling and handling procedures for nonradionuclide analyses are conducted in accordance with the Groundwater Monitoring Program Plan and Procedures manual (WP 02-1). Field parameters for nonradiological analyses include pH, EC, specific gravity, specific conductance, temperature, flow volumes and rates, chloride, calcium, magnesium, total sulfide as H_2S, alkalinity, and dissolved iron. Samples are also collected and sent to a contract laboratory for more extensive analyses performed in accordance with appropriate EPA methods.

VOC Monitoring

VOC sampling and analysis are performed at the WIPP facility using guidance in the EPA Compendium Method TO-14, *Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using SUMMA Passivated Canister Sampling and Gas Chromatographic Analysis*, as a basis. The VOC samplers are operated by the WIPP facility personnel, and sample analyses are performed by a contract laboratory.

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7.0 DATA ANALYSES

This section describes the criteria and methods used for statistically analyzing data collected in the environmental monitoring program. The goal of statistical data analyses is to provide an objective and reliable means for interpreting data in relation to the objectives of the data collection program. For the program the principal goal is twofold: 1) to compile baseline data for historical comparison purposes, 2) to analyze for comparison to a data point or data set of equivalent data.

The data results of the sample media are graphed by analyte to evaluate analytical consistency. This initial data evaluation process provides a method of evaluating data consistency and trends. *During this review should a discrepancy be noted, an in-depth evaluation can be performed* to identify the source of the deviation, (i.e. statistical outlier or analytical technique).

Analyses are required for each parameter before statistically valid interpretation can be achieved. The type of analysis used varies among parameters due to the particular characteristics of parameters and the specific objectives of monitoring. Five general levels of data analyses are described here. Analyses at each of these levels is considered for each parameter. The levels are:

(1) Determination of accuracy for each point measurement by quantification and control of precision and bias;

(2) Evaluation of the effects of correlation on the expected value of the point measurement due to location and time of sampling;

(3) Identification of the appropriate model of variability (i.e., a probability density distribution) for each point measurement and the calculation of descriptive statistics based on the chosen model;

(4) Treatment of data anomalies; and

(5) Interpretation of data through statistically valid comparisons (tests) and trend analysis.

Each of these levels of data analyses are described below and with the requirements for application to the EMP.

7.1 ACCURACY

Accuracy is the closeness of a measurement to its actual, or true, value. Since the true value cannot be determined independently, accuracy cannot be absolutely determined. However, accuracy is controlled by two basic elements: bias (consistent over or underestimation of the true value) and precision, [concentration of repeated measurements around a central (expected) value]. Accuracy is maximized when bias is minimized and precision is maximized.

To some extent precision and bias are controlled by strict adherence to sample collection, handling, and measurement protocols. Environmental Monitoring procedures specify the protocols for those functions performed at the WIPP and quality control procedures establish control on precision and bias for contractors (see Section 8.0).

The remaining element of precision and bias is quantitatively estimated through periodic performance of the following measurements:

- measurement of duplicate samples;
- repeated measurement of the same sample;
- measurement of blank samples; and
- measurement of standard pseudo-samples (samples of an equivalent medium containing a known amount of the target species, i.e. spiked samples)

The measurement of duplicate samples is used for estimation of the amount of imprecision incurred through the entire process of sample collection, handling, and measurement. Repeated measurements are used to determine the amount of imprecision attributable to measurement. Blanks and pseudo-samples are used to evaluate bias incurred through measurement processes. Measurements of duplicate samples and repeated measurements have been performed. Results of the EPA cross-check Interlaboratory Comparison Program indicate that laboratories supporting the WIPP environmental monitoring program are within specified control limits. As required by DOE Order 5400.1, contract laboratories performing radiological analysis on WIPP samples, and the WIPP radiochemistry counting lab will participate in the DOE interlaboratory QA program coordinated by the DOE Environmental Measurements Laboratory of New York, New York.

The methods for satisfying these requirements will be dependent upon the sampling and measurement characteristics of each parameter. Generally, the following specifications will be followed:

- one duplicate sample is collected for each ten samples collected;
- one repeated measurement is made for each discrete set of samples analyzed, or for each tenth sample analyzed, whichever is more frequent;
- one blank sample is analyzed for each discrete set of samples analyzed (for radioactivity counts, the background count is not considered a blank); and
- measurements of pseudo-samples, (Note: until the WIPP has the capability to prepare or obtain "spiked samples", WIPP will rely on the contract laboratory's in-house spike sample and recovery process)

Variations from these specifications may be required due to peculiarities of the individual parameters, and is stated in the procedure for that parameter.

7.2 TEMPORAL AND SPATIAL ANALYSIS

Environmental parameters vary with space and time. The effect of one or both of these two factors on the expected value of a point measurement is statistically evaluated through spatial analysis and time series analysis; however, these methods often require extensive sampling efforts which are in excess of the practical requirements of the WIPP program. The application of these methods to a particular parameter must, therefore, be limited by consideration of its significance in the final interpretation of the data.

In particular, spatial analysis has limited use in this program, although the effect of spatial correlation on the interpretation of the data is considered for each parameter. Spatial variability is accounted for by the use of predetermined key sampling locations. Data analysis is performed on a

location-specific basis, or data from different locations is combined only when the data are considered to be statistically homogeneous.

Time series analysis plays a more important role in data analysis for the EMP. Parameters are reported as time series, either in tabular form or plots. For key time series parameters, these plots are in the form of control charts on which control levels will be identified based on the preoperational data base, fixed standards, control location data bases, or other standards for comparison.

7.3 DISTRIBUTIONS AND DESCRIPTIVE STATISTICS

Descriptive statistics are calculated for each homogeneous data set. At a minimum, these include a central value and a standard deviation. The central value is the mean of the data. The standard deviation is calculated and used as a basis for the reported range in variation. Typically, plus or minus two standard deviations from the mean are plotted on the graphs. It is expected that 95 percent of the data will fall within the two standard deviation values. This provides for a 95 percent confidence level for the data.

7.4 DATA ANOMALIES

For many facilities data anomalies include data points reported as being below the minimum detectable concentration (MDC) or otherwise censored over a specific range of values, missing data points occurring randomly in the data set, and outliers which cannot be attributed to a known source of variation. This is somewhat misleading for radiological data from WIPP samples. Due to the low background concentrations within the geographical area of the WIPP, and to the fact that WIPP is not operational and considered a no-release facility, it is expected that a significant percentage of data will be below the analytical MDC. These values are not necessarily anomalies due to the rarity of measurable amounts of radioactivity in the WIPP vicinity.

Missing data points comprising less than 10 percent of the data set do not affect data analyses. Results based on data in which more than 10 percent is missing are identified as such at the time of reporting. Consideration of the potential effect of missing data must be made when the majority of the data are missing from a discrete time span.

An outlier is defined as any data point occurring in either extreme upper or lower range of the data distribution for which there is very low probability of occurrence, for normally distributed data. When no probability model is identified, outliers may only be found through visual inspection of the data. These occasionally occurring data values are withdrawn from data calculations and graphs. When a value of this type is removed it allows a better graphical presentation of quality data to maintain a reasonable scale on the graphs.

Data values below the MDC are not typically graphed or used in the standard deviation calculation. The mean is determined by dividing the sum of the data points above the MDC by the total number of data points (excluding blanks). There may not be a graph produced for every analyte corresponding to each matrix. Matrices with less than four data values at or above the MDC are typically not graphed. However, all data values are available for review relative to the matrix type and location.

If outside sources of variation are not identified to account for outliers in a data set, it is included in the data set and all subsequent analyses. If the inclusion of such outliers is found to affect the final results of the analyses significantly, both results (with and without outliers) are reported.

7.5 COMPARISONS AND REPORTING

Comparisons between data sets may be performed using standard statistical tests. The selection of the specific test is dependent upon the relative power of the test and the degree to which the underlying requirements of the test are met. In addition to tests comparing data from distinct locations and times, trend analyses may be performed on time series where sufficient data exist. A 95 percent confidence level will be used for the final interpretation of results.

Note: *There has been no attempt in this section to define standard statistical terminology nor to* reference common statistical formulae and derivations. Many satisfactory statistical texts and handbooks, in addition to those given in the reference, are available for this purpose.

8.0 QUALITY ASSURANCE

8.1 INTRODUCTION

This section defines the policies and procedures that have been implemented at the WIPP to provide confidence in the quality of the environmental data that are generated. Quality Assurance (QA) practices that cover monitoring activities at the WIPP are consistent with applicable elements of the 10-element format in ANSI/ASME NQA-I.

The WID Quality Assurance Program Description (QAPD), WP 13-1, defines QA requirements and responsibilities that apply to WID work. The format of Revision 16 of WP 13-1 is based on the QA criteria of 10 CFR 830.120. Because QA requirements of data collection for compliance with environmental regulations are less detailed than those usually applied to nuclear facilities, the WID QAPD also addresses EPA QA requirements extracted from the EPA's QAMS-005/80, *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*. For the WIPP project, these EPA QA requirements apply to Environmental Data Operations (EDOs); that is, compliance activities associated with collection and analysis of environmental samples, including data reduction, handling, reporting, and records management. Examples of EDOs at the WIPP include the monitoring programs for compliance with the No-Migration Variance, NESHAPS, and RCRA hazardous waste characterization. Table 8-1 demonstrates the relationship between QA requirements from 10 CFR 830.120, ASME NQA-1, and EPA QAMS-005/80.

8.2 GOAL

The Westinghouse Waste Isolation Division (WID) quality assurance policy sets a goal to perform all work in such manner that the required quality is attained or exceeded. To attain this goal the WID has developed and implemented a formal QA program that is tailored for activities associated with receipt of TRU waste, including operational safety, environmental compliance, and performance assessment.

TABLE 8-1

10 CFR 830.120 CROSS REFERENCE TO ASME NQA-1 AND EPA QAMS-005/80

	10 CFR 830.120	ASME NQA-1 BASIC REQUIREMENT	EPA QAMS-005/80 ELEMENT
MANAGEMENT	1. Program	1. Organization 2. Quality Assurance Program	3. Project Description 4. Project Organization & Responsibility 16. Quality Assurance Reports to Management
	2. Personnel Training and Qualification	2. Quality Assurance Program	3. Project Description 16. Quality Assurance Reports to Management
	3. Quality Improvement	15. Control of Nonconforming Items 16. Corrective Action	15. Corrective Action
	4. Documents and Records	6. Document Control 17. Quality Assurance Records	1. Title Page 2. Table of Contents
PERFORMANCE	5. Work Processes	5. Instructions, Procedures and Drawings 8. Identification and Control of Items 9. Control of Processes 12. Control of Measuring and Test Equipment 13. *Handling, Storage and Shipping*	6. Sampling Procedures 7. Sample Custody 8. Calibration 9. Analytical Procedures 13. *Preventive Maintenance*
	6. Design	3. Design Control	5. Data Quality Objectives 6. Sampling Procedures 10. Data Reduction 11. Internal Quality Control 14. Routine Procedures to Assess Data Quality
	7. Procurement	4. Procurement Document Control 7. Control of Purchased Items and Services	N/A
	8. Inspection and Acceptance Testing	10. Inspection 11. Test Control 12. Control of Measuring and Test Equipment 14. Inspection, Test and Operating Status	8. Calibration 13. Preventive Maintenance
ASSESS	9. Management Assessment	2. Quality Assurance Program	3. Project Description 12. Audits 14. Routine Procedures to Assess Data Quality 16. Quality Assurance Reports to Management
	10 Independent Assessment	18. Audits	14. Routine Procedures to Assess Data Quality

8.3 PROGRAM ELEMENTS/CRITERIA

The specific WIPP QA program elements/criteria that are applicable to the performance of the EMP are listed below by 10 CFR 830.120 criterion. These elements establish the applicable QA requirements that are required for compliance activities associated with the collection and analysis of environmental samples, including data reduction, handling, reporting, and records management.

8.3.1 Program

This element includes programmatic practices and procedures that include QA project plans for EDOs that consider and address the 16 essential elements described in Section 5 of the EPA QAMS-005/80. Project descriptions for specific EDOs are provided in project-specific QA project plans (QAPjPs). These project-specific QA project plans include explanations for exclusion of any of the 16 elements that would not be relevant to a specific project. The project descriptions include an experiment design description in sufficient detail for stand-alone review and approval of the plan. EDO project descriptions incorporate the following elements, as appropriate:

- Flow diagrams, tables, and charts;
- Dates anticipated for start and completion; and
- Intended end use of acquired data.

Each WIPP organization involved with activities and operations affecting environmental data quality will specify QA/QC responsibilities in departmental or project-specific QA project plans. The QA project plans include tables or charts showing the project organization and line authority. Key individuals, including the designated QA officer, who are responsible for ensuring the collection of valid data and the routine assessment of measurement systems for precision and accuracy, are listed.

Precision and accuracy of all environmental monitoring data are routinely assessed and reported. Project-specific QA project plans associated with EDOs provide the mechanism for periodic reports to the DOE WIPP project management on the performance of measurement systems and data quality. These reports include:

- Periodic assessment of measurement data accuracy, precision, and completeness;
- Results of performance audits;
- Results of system audits;
- Significant QA problems which if uncorrected could have a serious effect on the health and safety of WIPP workers and the public, seriously impact the operation of the WIPP, or have a noticeable adverse impact on the environment;
- Recommended corrective actions;
- Identification of individuals responsible for report preparation; and
- Provisions in the final report for a separate QA section that summarizes data quality information contained in the periodic reports.

8.3.2 Personnel Training and Qualification

The WIPP training program has been designed to ensure that personnel performing work are capable of performing their assigned task in a proficient manner. Personnel who perform work that requires special skills or abilities are required to meet the qualification requirements for that specific task unless directly supervised by a qualified person.

8.3.3 Quality Improvement

The quality improvement process has been established and implemented to improve quality and provide corrective action procedures. Corrective action procedures for activities associated with environmental data collection are identified in project-specific QA project plans. At a minimum, the following elements are addressed:

- Predetermined limits for data acceptability beyond which corrective action is required;
- Procedures for corrective action; and
- Identification of individuals responsible for initiating corrective action and individuals responsible for verifying and approving implementation of the corrective action.

Corrective action may be initiated through routine operations, performance audits, system audits, inter/intralaboratory comparison studies, or performance demonstrations conducted by DOE-CAO.

8.3.4 Documents and Records

Procedures are established that control the preparation, review, approval, issuance, use, and revision of documents that establish policies, prescribe work, specify requirements, establish design, or that are being used for the performance of quality-related activities. Each project-specific QA implementation plan for EDOs includes documentation of approval, in the form of a title page.

Procedures are also in place to ensure that records are specified, prepared, reviewed, approved, and maintained to accurately reflect completed work. This process is described in PR-15, Records management Plan. The WIPP record management program provides a project-wide records management system that coordinates the collection, maintenance, identification, and preservation of WIPP project records, in accordance with standards mandated by DOE Order 1324.5, *Records Management Program*.

8.3.5 Work Processes

Work is performed to established technical standards and administrative controls. For each major measurement parameter, the design of sampling methodology, equipment, and procedures are documented and approved. The following requirements for sample design are addressed in project-specific technical and/or QA plans, as applicable:

- Description of techniques or guidelines used to select sampling sites;
- Inclusion of specific sampling procedures to be used, either by reference in the case of approved standard operating procedures (SOPs), or in entirety if the procedures are nonstandard;

- Charts, flow diagrams, or tables delineating sampling program operations;
- A description of containers, procedures, reagents, etc., used for sample collection, preservation, transportation, and storage;
- Special conditions for the preparation of sampling equipment and containers to avoid sample contamination;
- Sample preservation methods and holding times;
- Time considerations for shipment of samples to the laboratory;
- Sample custody or chain-of-custody procedures; and
- Forms, notebooks, databases, and procedures to be used to document sample history, sampling conditions, and required analyses.

Samples collected for environmental compliance activities or for site validation are controlled by approved chain-of-custody procedures. The actual practices used are documented in project-specific QA implementation plans. The following sample custody procedures are specified in the QA project plan:

- For field sampling operations:
  - Documentation of procedures for preparation of reagents or supplies which become an integral part of the sample;
  - Procedures and forms for recording the exact location and specific considerations associated with sample acquisition;
  - Documentation of specific sample preservation methods; and
  - Sample labels containing all information necessary for effective sample tracking.
- For laboratory operations:
  - Identification of responsible party to act as sample custodian at the laboratory facility authorized to sign for incoming field samples, obtain documents of shipment, and verify the data entered onto the same custody records;
  - A laboratory sample custody log consisting of serially numbered standard lab-tracking report sheets; and
  - Specification of laboratory sample custody procedures for sample handling, storage, and dispersement for analysis.

Custody records are treated as permanent QA records by the recipient upon final transmission of the analytical data.

Calibration procedures and frequency for EDO activities are specified in project specific QA implementation plans. The plans include:

- A reference to the applicable SOP, or written description of the calibration procedures used for each major measurement parameter;

- Frequency of calibration; and
- Calibration standards to be used, as well as their sources and traceability.

Preventive maintenance of equipment used for collection and measurement of environmental data are identified in project specific QA implementation plans. The following types of preventive maintenance items are addressed:

- A schedule for preventive maintenance tasks; and
- A list of critical spare parts that should be available.

Procedures used for controlling the analysis of samples collected for EDO activities are specified in project-specific QA implementation or technical plans. For each measurement parameter the applicable procedure is either described in writing, or referenced as an SOP.

8.3.6 Design

Each major measurement parameter, the design of sampling methodology, equipment and procedures are documented and approved. The following requirements for sample design are addressed in project-specific plans and/or QA plans:

- Description of techniques or guidelines used to select sampling sites;
- Inclusion of specific sampling procedures to be used, either by reference in the case of approved SOPs, or in entirety if the procedures are nonstandard;
- Charts, flow diagrams, or tables delineating sampling program operations;
- Description of containers, procedures, reagents, etc., used for sample collection, *preservation, transport, and storage;*
- Special conditions for the preparation of sampling equipment and containers to avoid sample contamination;
- Sample preservation methods and holding times;
- Time considerations for shipment of samples to the laboratory;
- Sample custody or chain-of-custody procedures; and
- Forms, notebooks, databases, and procedures to be used to document sample history, sampling conditions, and required analyses.

8.3.7 Procurement

The control of procurement documents ensures that procured items and services meet established requirements and specifications. Basic procurement requirements include:

- Applicable design specifications and other order requirements are \or referenced in documents for procurement of items and services;
- That the supplier have a QA program consistent with applicable requirements; and

- That all procurement actions be performed in accordance with written procedures that describe the actions involved in the preparation, review, approval, control and changes of procurement documents.

8.3.8 Inspection and Acceptance Testing

Inspection and acceptance testing of specified items and processes are conducted using established acceptance and performance criteria.

Equipment used for inspections and tests are calibrated and maintained. Calibration procedures and frequency for EDO activities are specified in project specified QA implementation plans. These plans will include:

- A reference to the applicable SOP, or written descriptions of the calibration procedures used for each major measurement parameter;
- Frequency of calibration; and
- Calibration standards to be used, as well as their sources and traceability.

8.3.9 Management Assessment

Senior management assembles input from the following sources to form the basis of management assessment:

- Line management's self-assessment reports;
- Independent assessment reports; and
- Corrective action reports including conditions adverse to quality, non-conformance reports (NCRs), program deficiency reports (PDRs), audit reports, and requests for corrective action (RCAs).

Following the assessment, the effectiveness of the QA program is documented. Further, areas for quality improvement root cause analysis (for severe non-conformances or high-risk items/activities), preventive or corrective actions, milestones for completion, responsibility assignments, trend analysis, and lessons learned are documented and transmitted to the DOE.

8.3.10 Independent Assessment

Independent Assessment is performed to verify procedure compliance. Independent assessment is also used to prove independent oversight of the self-assessment process performed by line management. Independent assessment focuses on improving items and processes by emphasizing line organization's achievement of quality. Results from independent assessments are transmitted to senior management as input for determination of the effectiveness of the integrated QA program. In this regard, personnel performing independent assessments act in a management advisory function.

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9.0 REQUIRED RECORDS AND REPORTS

9.1 GENERAL INFORMATION AND PURPOSE

The purpose of this chapter of the WIPP EMP is to define the environmental records and reports criteria regulations, and guidelines requirements with which the WID will comply.

The following regulations contain the reporting requirements applicable to the WID's environmental monitoring program:

- DOE/EH-0173T
- DOE Order 5400.1
- DOE Order 5400.5
- DOE Order 1324.2A
- Clean Air Act
- Clean Water Act
- Superfund Amendments and Reauthorization Act (SARA) Title 3
- Resource Conservation and Recovery Act (RCRA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Office of Management and Budget (OMB) Circular A-196

Thorough reporting and recordkeeping will be performed at WID as essential elements of complying with state and federal regulations.

The environmental reports and notifications specified in DOE Orders 5400.1 and 5400.5 will be submitted to DOE within the required time periods.

Complete, accurate, and auditable environmental monitoring program records will be maintained. The WID record inventory and disposal system (RIDS) will govern environmental monitoring records management.

9.2 RECORD KEEPING

Records generated through environmental monitoring activities are controlled and maintained in accordance with the WIPP *Records Management Plan*, WP 15-PR. This plan interprets and implements the records management requirements contained in the *Carlsbad Area Office Information Management Plan*, CAO 94-1001. The requirements stated in this plan apply to all WID organizations. The plan provides the interpretations and the guidance necessary to meet the records management requirements for the creation, maintenance, use and disposition of records that document and support the WIPP mission.

9.3 REPORTING

The WIPP EMP is reviewed annually and updated at least every three years in accordance with DOE Order 5400.1 (DOE, 1988d). Changes are made as new regulations are promulgated which specify record-keeping, reporting, and other programmatic requirements applicable to the environmental monitoring program at the WIPP.

The Environmental Protection Implementation Plan (EPIP) is revised annually in accordance with DOE Order 5400.1 (DOE, 1988d). This document delineates how the WIPP implements the provisions of DOE Order 5400.1. The EPIP identifies compliance strategies and manpower allocations, and describes the WIPP organizational structure.

The WIPP Annual Site Environmental Report is prepared according to DOE Order 5400.1 (DOE, 1988d). This report summarizes the facility's compliance with applicable environmental regulations

and informs the public as to the impact of the operations at WIPP on the surrounding environment.

The Annual Mitigation Report (AMR), required by DOE Order 5440.1E, is issued each July. This document describes the progress made in implementing the commitments made in the FEIS and SEIS Records of Decision. Several of the commitments that are being tracked pertain to environmental monitoring and environmental compliance.

The No-Migration Determination Annual Report is submitted annually to the EPA in November. This document meets the requirements of the *Conditional No-Migration Determination for the Department of Energy Waste Isolation Plant* (55 FR 47700). This report contains summaries of air monitoring and waste characterization data, as well as VOC monitoring results.

When WIPP begins to receive TRU waste, Radioactive Effluent and On-site Discharge Data Reports will be prepared and submitted to the Waste Information System Branch of EG&G Idaho, Inc., by April 1 of each year. DOE Order 5480.14 specifies instructions for implementing a DOE Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program (DOE, 1985c). No inactive hazardous-waste disposal sites requiring remedial action under CERCLA exist at WIPP. WIPP notifies the National Response Center in the case of a release of "reportable quantities" of radionuclides or other hazardous substances at the WIPP as required by CERCLA §102(a) (DOE, 1985c).

The EPA has promulgated environmental standards for the management and disposal of transuranic radioactive wastes under the authority of the EPA and the Nuclear Waste Policy Act (NWPA). The EPA has not specified reporting requirements applicable to the WIPP under this regulation.

The Office of Management and Budget Circular A-106, *Reporting Requirements in Connection with the Prevention, Control, and Abatement of Environmental Pollution at Existing Federal Facilities* (OMB, 1975), has established a semiannual reporting requirement for implementing Sections 1 through 4 of Presidential Executive Order 12088 and Presidential Executive Order 11752 pertaining to the control of environmental pollution from existing federal facilities. The plans, to be submitted on December 31 and June 30, identify projects necessary to bring federal facilities into compliance with applicable environmental standards.

10.0 REFERENCES

Agreement for Consultation and Cooperation between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant, 1981.

AIM (Agricultural and Industrial Minerals, Inc.), 1979, *Resource Study for the Waste Isolation Pilot Plant, Eddy County, New Mexico*, San Carlos, California.

AMO-8809, 1989, *An Aerial Radiological Survey of the Waste Isolation Pilot Plant and Surrounding Area, Carlsbad, New Mexico*.

ANSI (American National Standards Institute), 1986, *Quality Assurance Program Requirements for Nuclear Facilities*, ANSI/ASME NQA-1, 1986 Edition.

Atomic Energy Act of 1954 (AEA) (42 U.S.C. sec. 2011 et seq.)

Bachman, G. O., 1984, *Regional Geology of Ochoan Evaporites, Northern Part of Delaware Basin, New Mexico Bureau of Mines and Mineral Resources*, Circular 184, p.22.

Best, T. L., and S. Neuhauser, 1980, *A Report of Biological Investigations at the Los Medanos Waste Isolation Pilot Plant (WIPP) Area of New Mexico During FY 1978*, Sandia National Laboratories Report SAND79-0368, Albuquerque, New Mexico.

Bradshaw, P. L., and E. T. Louderbough, 1987, *Compilation of Historical Radiological Data Collected in the Vicinity of the WIPP Site*, DOE/WIPP 87-004, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

Brewer, L. W., and J. H. Metcalf, 1977, *Environmental Monitoring at the WIPP Site, CY-1976*, Sandia National Laboratories Report SAND77-1021, Albuquerque, New Mexico.

Conditional No-Migration Determination for the WIPP (55 FR 47700), November 14, 1990.

Corley, J. P., D. H. Denham, R. E. Jaguish, D. E. Michels, A. R. Olsen, and D. A. Waite, 1981, *A Guide for Environmental Radiological Surveillance at U.S. Department of Energy Installations*, DOE/EP-0023, U.S. Department of Energy, Washington, D.C.

Public Law 96-164, Department of Energy National Security and Military Application of Nuclear Energy Authorization Act of 1980.

DOE, 1980, *Final Environmental Impact Statement, Waste Isolation Pilot Plant*, DOE/EIS-0026, Vols. 1 and 2, Washington, D.C.

DOE, 1984, Procedures for Sampling Radium-Contaminated Soils, DOE GJ/TMC-13.

DOE, 1985a, Radioactive Waste Management, DOE/AL Order AL 5820.2, U.S. Department of Energy, Albuquerque, New Mexico.

DOE, 1986a, Environmental Policy Statement, Secretary of Energy Herrington, Washington, D.C.

DOE, 1985b, *Radiation Standards for the Protection of the Public in the Vicinity of DOE Facilities*, Memorandum from William A. Vaughan, Assistant Secretary for Environment, Safety, and Health, U.S. Department of Energy (August 5, 1985), Washington, D.C.

DOE, 1985c, *Comprehensive Environmental Response, Compensation and Liability Act Program*, DOE Order 5480.14, Washington, D.C.

DOE, 1988a, *External Dose-Rate Conversion Factors for Calculation of Dose to the Public*, DOE/EH-0070, U.S. Department of Energy, Washington D.C., 1988.

DOE, 1988b, *Internal Dose Conversion Factors for Calculation of Dose to the Public*, DOE/EH-0071, U.S. Department of Energy, Washington D.C., 1988.

DOE, 1988c, General Design Criteria Manual, DOE Order 6430.1A,(draft), Washington, D.C.

DOE, 1989, *Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant*, DOE/WIPP 88-025, U.S. Department of Energy, Carlsbad, N.M., March, 1989.

DOE, 1990c, *Final Safety Analysis Report*, Waste Isolation Pilot Plant, WP 02-9 Rev. 0, Carlsbad, New Mexico.

DOE, 1990d, *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant*, DOE/EIS-0026 FS, Washington, D.C.

DOE, 1981a, *Environmental Protection, Safety, and Health Protection Information Reporting Requirements*, DOE Order 5484.1, Washington, D.C.

DOE, 1981c, *Waste Isolation Pilot Plant (WIPP); Record of Decision*, 46 Federal Register 9162.

DOE, 1982, *Hazardous and Radioactive Mixed Waste Management*, DOE Order 5480.2, Washington, D.C.

DOE, 1987, *Radioactive Waste; Byproduct Material*, Code of Federal Regulations, Title 10, Part 962.

DOE, 1988, *Records Disposition*, DOE Order 1324.2A, Washington, D.C.

DOE, 1988g, *Radioactive Waste Management*, DOE Order 5820.2A, U.S. Department of Energy, Washington, D.C.

DOE, 1988h, *Radiation Protection for Occupational Workers*, DOE Order 5480.11, Washington, D.C.

DOE, 1989, *Hazardous and Radioactive Mixed Waste Program*, DOE Order 5400.3, Washington, D.C.

DOE, 1990a, *General Environmental Protection Program*, DOE Order 5400.1, Washington, D.C.

DOE, 1990b, *Radiation Protection of the Public and the Environment*, DOE Order 5400.5, Washington, D.C.

DOE, 1991a, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, DOE/EH-0173T, Washington, D.C.

DOE, 1991b, letter from Arlen Hunt, WIPP Project Manager, to Mr. Robert Neil, Environmental Evaluation Group, March 27, 1991.

DOE, 1991c, *Quality Assurance*, DOE Order 5700.6C, Washington, D. C.

DOE/WIPP 89-013, WIPP Project Records Management Handbook

DOE/WIPP 89-005, *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1988.*

DOE/WIPP 90-003, *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1989.*

DOE/WIPP 91-008, *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1990.*

DOE/WIPP 91-059, *No-Migration Determination Annual Report for the period November 1990 through September 1991.*

DOE/WIPP 92-007, *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1991.*

DOE/WIPP 93-017, *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1992.*

DOE/WIPP 92-037, *Statistical Summary of the Radiological Baseline for the WIPP.*

DOE/WIPP 92-038, *Summary of the Salt Impact Studies at he WIPP, 1984 to 1990.*

DOE/WIPP 92-039, *A Study of Disturbed Land Reclamation Techniques for the WIPP.*

DOE/WIPP 92-013, *Background Water Quality Characterization Report for the WIPP.*

DOE/WIPP 92-057, *No-Migration Determination Annual Report for the period October 1991 through August 1992*

DOE/WIPP 93-004, *Waste Isolation Pilot Plant Land Management Plan*

DOE/WIPP 95-2094, *Waste Isolation Pilot Plant Site Environmental Report for Calendar year 1994*

DOE/WIPP 95-2182, *Waste Isolation Pilot Plant Site Environmental Report for Calendar year 1995*

Emlen, J. T., 1971, *Population Densities of Birds Derived From Transect Counts*, Auk, Vol. 88, pp. 323-342.

EPA, 1976, *National Interim Primary Drinking Water Regulations*, U.S. EPA Report EPA-570-9-70-003 and 40 CFR 141.

EPA, 1983b, *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*, QAMS-005/80.

EPA, 1984, *Off-Site Environmental Monitoring Reports, Radiation Monitoring Around United States Nuclear Test Areas, CY-1983*, EPA-600/9-84-040.

EPA, 1985b, *National Emission Standard for Radionuclide Emissions from Department of Energy Facilities*, Code of Federal Regulations, Title 40, Part 61, Subpart H.

EPA, 1985d, *Standards for the Management of Specific Hazardous Wastes and Specific Types of Hazardous Waste Management Facilities*, Code of Federal Regulations, Title 40, Part 266.

EPA, 1986b, *RCRA Ground Water Monitoring Technical Enforcement Guidance Document*, OSWER-9950.1.

EPA, 1980a, *Hazardous Waste Management System: General*, Code of Federal Regulations, Title 40, Part 260.

EPA, 1980b, *Identification and Listing of Hazardous Waste*, Code of Federal Regulations, Title 40, Part 261.

EPA, 1980c, *Standards Applicable to Generators of Hazardous Waste*, Code of Federal Regulations, Title 40, Part 262.

EPA, 1980d, *Standards Applicable to Transporters of Hazardous Waste*, Code of Federal Regulations, Title 40, Part 263.

EPA, 1980e, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*, Code of Federal Regulations, Title 40, Part 264.

EPA, 1980f, *Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*, Code of Federal Regulations, Title 40, Part 265.

EPA, 1981, *Interim Standards for Owners and Operators of New Hazardous Waste Land Disposal Facilities*, Code of Federal Regulations, Title 40, Part 267.

EPA, 1986a, *Land Disposal Restrictions*, Code of Federal Regulations, Title 40, Part 268.

EPA, 1983a, *EPA Administered Permit Programs: The Hazardous Waste Permit Program*, Code of Federal Regulations, Title 40, Part 270.

EPA, 1985a, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes*, Code of Federal Regulations, Title 40, Part 191.

EPA Compendium Method TO-14, *Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Summa® Passivated Canister Sampling and Gas Chromatographic Analysis*

EPA, 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, EPA-520/1-88-20, U.S. Environmental Protection Agency, Washington, D.C., 1988.

Fischer, N. T. (editor), 1987, *Ecological Monitoring Program, Annual Report, FY 1986, Waste Isolation Pilot Plant, Carlsbad, New Mexico*, DOE/WIPP 87-003.

Fischer, N. T., E. T. Louderbough, C. C. Reith, A. L. Rodriguez, and D. Uhland, 1985, *Ecological Monitoring Program, Second Semi-Annual Report*, U.S. DOE Waste Isolation Pilot Plant, DOE/WIPP 85-002, Carlsbad, New Mexico.

Gilbert, R. O., 1987, *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand, Reinhold, New York, New York.

HASL-300, *Environmental Measurement Laboratory Procedures Manual* (revised annually).

Hayne, D.W., 1949, *Two Methods for Estimating Populations From Trapping Records*, J. Mammal, Vol. 30, pp. 399-411.

ICRP, 1977, *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 26, International Commission on Radiological Protection, Pergamon Press, Oxford, New York, 1978.

ICRP (International Commission on Radiological Protection), 1979, *Limits for Intakes of Radionuclides by Workers*, ICRP Publication 30 (ICRP 79a), Pergamon Press, Elmsford, New York.

ICRP, 1986, *The Metabolism of Plutonium and Related Elements*, ICRP Publication 48, International Commission on Radiological Protection, Pergamon Press, Oxford, New York, 1986.

Keesey, J. J., 1979, *Evaluation of Directional Drilling for Oil and Gas Reserves Underlying the WIPP Site Area, Eddy County, New Mexico, Sipes*, Williamson & Associates, Midland, Texas.

Lantz, M. W., and Berry, H. A., 1978, *Gnome Site Decontamination and Decommissioning - Phase I*, Reynolds Electrical and Engineering Company, Inc., Las Vegas, Nevada, Report NVO/0410-48.

Ludwig, F. L., 1976, *Siting Air Monitoring Stations*, Environmental Science and Technology, 12(7):774-778.

Mercer, J. W., 1983, *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico*, U.S. Geological Survey, Water-Resources Investigations Report 83-4016.

NCRP (National Council on Radiation Protection and Measurements), 1975, *Natural Background Radiation in the United States*, NCRP Report 45.

New Mexico Environment Department Discharge Plan, DP-831

OMB (Office of Management Budget), 1975, *Reporting Requirements in Connection with the Prevention, Control, and Abatement of Environmental Pollution at Existing Federal Facilities*, OMB Circular A-106.

Pocalujka, L. P., E. Babij, H. W. Church, 1979, *Meteorological and Air Quality Data Quarterly Report WIPP Site: Eddy County, New Mexico, Winter Quarter, December 1976 - February 1977*, Sandia National Laboratories Report SAND 79-1042, Albuquerque, New Mexico.

Pocalujka, L. P., E. Babij, P. A. Catizone, H. W. Church, 1980a, *Meteorological and Air Quality Data Quarterly Report WIPP Site: Eddy County, New Mexico, Spring Quarter, March 1977 - May 1977*, Sandia National Laboratories Report SAND 79-7109, Albuquerque, New Mexico.

Pocalujka, L. P., E. Babij, P. A. Catizone, H. W. Church, 1980b, *Meteorological and Air Quality Data Quarterly Report WIPP Site: Eddy County, New Mexico, Summer Quarter, June 1977 - August 1977*, Sandia National Laboratories Report SAND 80-7107, Albuquerque, New Mexico.

Pocalujka, L. P., E. Babij, P. A. Catizone, H. W. Church, 1980c, *Meteorological and Air Quality Data Quarterly Report WIPP Site: Eddy County, New Mexico, Autumn Quarter, September 1977 - November 1977*, Sandia National Laboratories Report SAND 80-7121, Albuquerque, New Mexico.

Pocalujka, L. P., E. Babij, P. A. Catizone, H. W. Church, 1981a, *Meteorological and Air Quality Data Quarterly Report WIPP Site: Eddy County, New Mexico, Winter Quarter, December 1977 - February 1978*, Sandia National Laboratories Report SAND 80-7160, Albuquerque, New Mexico.

Pocalujka, L. P., E. Babij, P. A. Catizone, H. W. Church, 1981b, *Meteorological and Air Quality Data Quarterly Report WIPP Site: Eddy County, New Mexico, March 1978 - February 1980*, Sandia National Laboratories Report, SAND 81-7052, Albuquerque, New Mexico.
Public Land Order 6403, June 29, 1983.

Powers, D. W., S. J. Lambert, S. E. Shaffer, L. R. Hill, W. D. Weart (editors), 1978, *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico*, Sandia National Laboratories Report SAND78-1596, Albuquerque, New Mexico, Vol. 1 and Vol. 2.

Presidential Executive Order 12088, *Federal Compliance with Pollution Control Standards*, Code of Federal Regulations, Title 3, Part 1978, October 13, 1978.

Reith, C. C., and G. Daer, 1985, *Radiological Baseline Program for the Waste Isolation Pilot Plant: Program Plan*, WTSD-TME-057, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

Reith, C. C., J. K. Prince, N. T. Fischer, A. Rodriguez, D. W. Uhland, and D. J. Winstanley, 1986, *Annual Site Environmental Monitoring Report for the Waste Isolation Pilot Plant, Carlsbad, New Mexico*, DOE/WIPP 86-002, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

Simpson, H. J., A. L. Herczeg, R. F. Anderson, R. M. Trier, G. G. Mathieu, and B. L. Deck, 1985, *Mobility of Radionuclides in High Chloride Environments: A Case Study of Waters Within and Near The Delaware Basin, Southeastern New Mexico*, Lamont-Doherty Geological Laboratory, Columbia University for Division of Radiation Programs in Earth Sciences, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, NUREG/CR-4237.

USAEC (U.S. Atomic Energy Commission), 1962a, Project Gnome: Project Manager's Report, Washington, D.C.

USAEC (U.S. Atomic Energy Commission), 1962b, *Project Gnome Final Report: Weather and Surface Radiation Prediction Activities*, PNE-126F, Washington, D.C.

USAEC (U.S. Atomic Energy Commission), 1962c, *Project Gnome Final Report: Off-Site Radiological Safety Report*, PNE-132F, Washington, D.C.

USAEC (U.S. Atomic Energy Commission), 1962d, *Project Gnome Final Report: On-Site Radiological Safety Report*, PNE-133F, Washington, D.C.

USAEC (U.S. Atomic Energy Commission), 1973, *Carlsbad Reconnaissance 1972 (Gnome Site)*, Washington, D.C.

USBM (U.S. Bureau of Mines), 1977, *Valuation of Potash Occurrences Within the Waste Isolation Pilot Plant in Southeastern New Mexico*.

U.S. Department of Energy, Final Safety Analysis Report, Waste Isolation Pilot Plant, (WP 02-9, Rev. 0), May 1990.

USGS (U.S. Geological Survey), 1978-1984, *Water Resources Data New Mexico, Water Years 1978 - 1984, in separate volumes, NM78-1, NM79-1, NM80-1, NM81-1, NM82-1, NM83-1, NM84-1*.

USGS (U.S. Geological Survey), 1983, *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico*, USGS 83-4016.

VOC Monitoring Plan for the WIPP (January 1990).

Waite, D. A., 1973a, *Analysis of an Analytical Technique for Distributing Air Sampling Locations Around Nuclear Facilities*, BNWL-SA-4676, Pacific Northwest Laboratory, Richland, Washington.

Waite, D. A., 1973b, *An Analytical Technique for Distributing Air Sampling Locations Around Nuclear Facilities*, BNWL-SA-4534, Pacific Northwest Laboratory, Richland, Washington.

Waste Acceptance Criteria for the Waste Isolation Pilot Plant (WAC), WIPP-DOE-069, Rev.4, December 1991.

The WIPP Land Withdrawal Act, Public Law 102-579, October 30, 1992.

WP 02-1, *Groundwater Monitoring Program Plan and Procedures Manual*

WP 02-3, *Environmental Procedures Manual*

WP 04-1, *WIPP Facility Operations Manual*

WP 13-1, *WID Quality Assurance Manual*

WP-QPM-WP 13-1, *Management and Operating Contractor WIPP Quality Program Manual*

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix EPIC

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments

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WIPP/CAO-96-3168
June 4, 1996

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

WIPP/CAO-96-3168
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Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments

Kathleen M. Trauth,[1] Robert V. Guzowski,[2] Chris G. Pflum,[3] and Ronald J. Rodriguez[4]

ABSTRACT

The U.S. Environmental Protection Agency requires the use of passive institutional controls (PICs) to discourage future generations from inadvertently intruding into the Waste Isolation Pilot Plant (WIPP) waste repository and the contiguous 16 sections. The controls are to include markers, records, archives, and government ownership and land-use restrictions. Credit may be allowed in performance assessments for these controls to reduce the frequency of inadvertent intrusion for several hundred years after disposal.

A task force was formed to estimate the credit for the passive controls for the WIPP repository. The estimate was constrained by the use of existing conceptual designs of these controls, the use of historical analogues for the endurance of materials and structures, the consideration of possible failure modes for each control, and the regulatory assumption of societal "common denominators."

Because of the redundancy of messages to be built into the passive controls, human error was identified by the task force as the only mechanism that could result in inadvertent intrusion for the 10,000 years of regulatory concern. An examination of 80 years of drilling records for the New Mexico portion of the Delaware Basin identified no instances of the mislocation of drilling sites due to human error. The task force concluded that the failure of passive controls to correctly communicate the location and hazards of the waste, thereby deterring inadvertent intrusions for the first several hundred years of performance assessments will be no greater than 0.01. This failure rate is a bounding value intended to account for possible failure mechanisms that the task force failed to identify.

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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is an experimental facility located in bedded-salt deposits in southeastern New Mexico that is owned by the U.S. Government and operated by the U.S. Department of Energy (DOE). This facility is being evaluated as a permanent disposal location for transuranic waste produced by defense-related activities and programs. To demonstrate suitability, the DOE must comply with the performance criteria established by the U.S. Environmental Protection Agency (EPA) in *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule* (40 CFR Part 191). Four main provisions apply to the postdisposal performance criteria: (1) probabilistic radionuclide release limits to the accessible environment (§ 191.13), (2) additional assurance requirements to supplement the natural radionuclide-containment capabilities of the disposal system (§ 191.14), (3) dose limits to individuals for undisturbed conditions (§ 191.15), and (4) protection of underground sources of drinking water from radionuclide contamination for undisturbed conditions (§ 191.24). With the exception of the qualitative assurance requirements, each of the other performance criteria is based on 10,000 years of regulatory concern after disposal.

One of the Assurance Requirements (§ 191.14[c]) states that "disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location" (50 FR 38086c). Another role for the passive institutional controls (PICs) was identified by the EPA with the promulgation of *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule* (40 CFR Part 194). This role (§ 194.43) allows credits for PICs to reduce the frequency of inadvertent human intrusion into the WIPP disposal system for the performance assessments (PAs) required to address the Containment Requirements of § 191.13.

The PICs Task Force (PTF) was created by the DOE to assess the level of correct communication of the location and hazards of the waste that a system of PICs, conforming to the design considerations of the Assurance Requirements, would have in the context of reducing (i.e., deterring) inadvertent intrusion frequencies for PAs. Guidance about societal "common denominators" was identified in EPA's *Compliance Application Guidance for 40 CFR Part 194* (EPA 402-R-95-014). These "common denominators" were a partial list that are a foundation for a "prudent extrapolation for the future state assumptions established in § 194.25." The PTF defined additional assumptions ("common denominators") for use in assessing the effectiveness of PICs.

In order to assess the effectiveness of the PICs in deterring inadvertent intrusion, the PTF examined the DOE's conceptual designs of the PICs components that will form an integrated system of PICs. This system will be composed of monuments and other markers that will be located both at the repository footprint and at the boundary of the Withdrawal (i.e., 16 sections of the WIPP), records in both archives and records centers, and a variety of other PICs intended to distribute knowledge about the WIPP to future generations. These components are consistent with the EPA's requirements and will include redundancy and reinforcement of the warnings. Estimates were made about the durability of the material that will be used to construct/develop

the PICs and the messages themselves (i.e., engraved and printed) based on comparisons with historical analogues. In addition, possible failure modes for each component were identified and examined in the context of how the conceptual designs of the various PICs components would counter the failure modes.

Of the PICs components, the marker system to be located at the repository footprint will be the most durable and effective deterrent. Based on the durability of materials at Stonehenge, the Egyptian pyramids, the stele containing the Code of Hammurabi, and the Rock of Behistun as analogues, the granite monuments, information center, and the engraved messages that will be exposed to the weathering at the WIPP are not expected to undergo significant deterioration within the regulatory time frame. Additional deterrence will be provided by the buried markers and storage rooms. The berm itself will be an awareness trigger and not a deterrent by itself.

The monuments at the boundary of the Withdrawal are expected to last as long as the monuments at the repository footprint. The danger associated with intrusion in the Withdrawal is more obscure than the warning on the inner monuments about intruding into the repository. These monuments will lose some deterrent value in the future, starting perhaps about 1,000 years after closure when the more subtile messages in the nearby records centers becomes more difficult to decipher.

Historical analogues used to estimate the life expectancy of the WIPP records are paper fragments that have lasted almost since the beginning of paper, nearly 2,000-years ago, and pieces of papyrus that are about 5,000-years old. Modern technology should be able to at least duplicate these durabilities. Working assumptions of the PTF were that the records will not be duplicated if the original records deteriorate because of wear and age, and that catastrophic loss of records due to fire or natural disaster will result in reconstruction of the entire records center and contents from other surviving records centers and archives.

Records about the WIPP submitted to records centers will be printed on archival paper with special ink to ensure a long life expectancy for the documents. Special bindings and covers will be used to emphasize the importance of these documents. These records are expected to be completely effective in deterring inadvertent intrusion early in the regulatory time frame. Records submitted to records centers associated with property and resource rights are expected to be a completely effective deterrent much longer than in the general records centers because of the importance of these rights to society. Some loss of effectiveness of records in the resource centers may begin at the time when paper deterioration may start to be a problem in the 4,000- to 5,000-year time period, when the paper deteriorates. English will continue to be decipherable by the resource community for thousands of years.

Records submitted to archives also will be printed on special archival paper with special ink to ensure a long life expectancy for the documents, especially under the controlled environmental conditions within the archives. In addition, a special filing code will be developed and special bindings and covers will be used in order to emphasize the importance of the documents within the vast quantities of documents that will accumulate in the archives during the regulatory time frame. The PTF concluded that the archives would have little deterrence value early in the regulatory time frame because of the distant locations of the archives from the WIPP. As

documents in the records centers closer to the WIPP deteriorate or are "lost," the effectiveness of the archives as deterrents will increase.

Government control of land use is based on written instructions being submitted to the appropriate agencies and covenants being included in surface and resource leases and stored in records center. As with records center previously discussed, land use controls will be a completely effective deterrent for thousands of years.

The remaining PICs (e.g., encyclopedias and road maps) components will act as awareness triggers rather than deterrents. These components will increase the public's and the potential intruders' awareness of the WIPP so that other components will be consulted prior to any type of human intrusion into the WIPP disposal system. The PTF did not assume any contribution of the awareness triggers to the deterrence provided by the PICs system.

Based on the assessments of the PICs components and the fact that the PICs system will be as effective as the most effective component, the PTF concluded that the PICs system will offer virtually complete effectiveness in deterring inadvertent human intrusion into the repository footprint for the entire regulatory time frame. The PICs system will deter inadvertent intrusion into the Withdrawal outside the repository footprint for thousands of years after disposal with this deterrence decreasing slightly over time to account for the more esoteric warning on the outer monuments and the possible deterioration of confirmatory records.

After examining the historical analogues and failure modes, the PTF ascertained that the PICs will be highly effective for long periods of time within the 10,000-year regulatory period. An examination of drilling records and personal interviews with individuals having extensive experience with drilling in the Delaware Basin revelated no instances of wells being drilled in the wrong location in the Delaware Basin (i.e., failure of 0.00). When the survey was extended to a much larger area, five instances of wells drilled in the wrong location out of over 400,000 wells drilled in total were identified (i.e., failure of 0.00001) For the sake of addressing the needs of the PA and to account for unidentified possible failure mechanisms and sources of human error that could result in reduced effectiveness of the PICs system, the PTF recommends that the failure of the PICs system in deterring inadvertent human intrusion within the entire Withdrawal be increased to a bounding value of 0.01 for the time interval from 100 to 700 years after disposal.

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1.0 INTRODUCTION

1.1 WIPP and Its Regulatory Requirements

The Waste Isolation Pilot Plant (WIPP) is a research and development facility authorized in 1979 (Public Law 96-164, 1979) to "demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." After the successful demonstration, the WIPP will become a facility for the permanent disposal of this transuranic waste. The proposed disposal facility is located in southeastern New Mexico (Figures 1-1 and 1-2) at a depth of 655 meters (2,150 feet) and within a bedded-salt unit (the Salado Formation) (Figures 1-3 and 1-4).

Before permanently disposing of the defense-generated transuranic waste at the WIPP, the Department of Energy (DOE) must demonstrate compliance with applicable long-term disposal standards of the U.S. Environmental Protection Agency (EPA). These disposal standards have been promulgated at Title 40 Code of Federal Regulations (CFR) Part 191, Subparts B and C.

Title 40 CFR Part 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule" was promulgated on September 19, 1985 (EPA, 1985). Parts of 40 CFR Part 191 were vacated and remanded to the EPA for reconsideration in 1987 in response to a lawsuit. The aspects of 40 CFR Part 191 relating to passive institutional controls (PICs) were not impacted as a result of the lawsuit. The aspects of 40 CFR Part 191 that were impacted by the lawsuit were repromulgated on December 20, 1993 under the title "40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule" (EPA, 1993).

Subparts B and C of the 1993 40 CFR Part 191 contain four main provisions related to disposal of radioactive waste in a repository. Firstly, in Subpart B, performance-assessment (PA) analyses calculate the performance of a disposal system for 10,000 years and compare calculated radionuclide releases to probabilistic radionuclide release limits found in §191.13. Secondly, the Assurance Requirements, found in §191.14, indicate complementary actions (e.g., PICs and monitoring) to be taken to provide additional confidence for long-term compliance with §191.13. Thirdly, the radionuclide doses that individuals may receive from an undisturbed disposal system are limited for the 10,000 years of regulatory concern in §191.15. Fourthly, Subpart C incorporates the requirements of the National Primary Drinking Water Regulations (40 CFR 141.15 and 141.16) to protect underground sources of drinking water (USDWs) from radionuclide contamination from an undisturbed disposal system for 10,000 years (§191.24).

On October 30, 1992, Congress passed the WIPP Land Withdrawal Act (LWA) (Public Law 102-579, 1992). The major purpose of the LWA was to transfer jurisdiction over the 16-square-mile area including and surrounding the WIPP facility, from the Department of the Interior to the DOE. Congress has defined this area as the "Withdrawal" in the LWA. The term Withdrawal is used throughout this report for this area. In addition, Congress required that the EPA promulgate proposed "criteria for the Administrator's certification of compliance with the final disposal

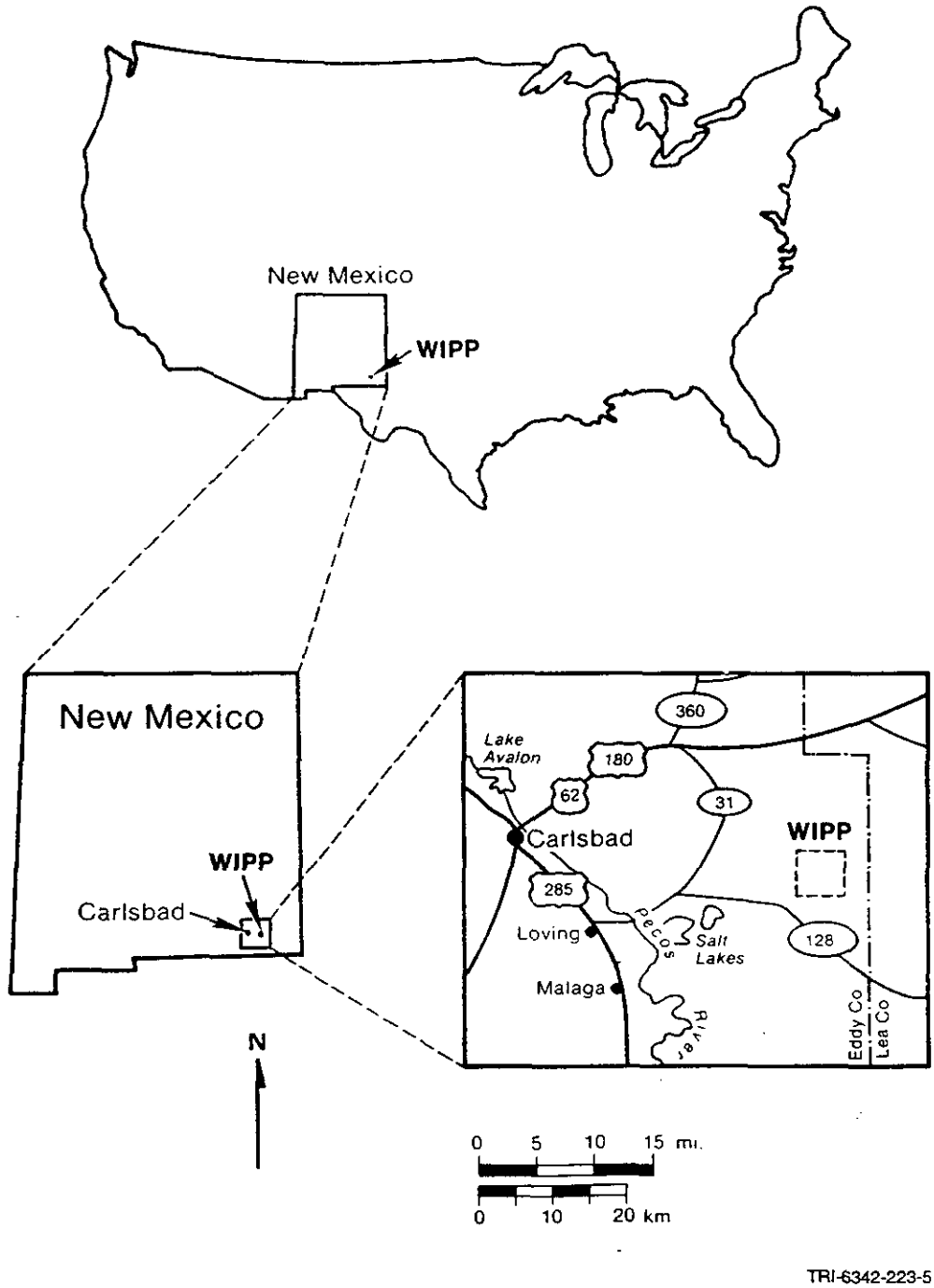

Figure 1-1. Location of the WIPP (after Bertram-Howery and Hunter, 1989).

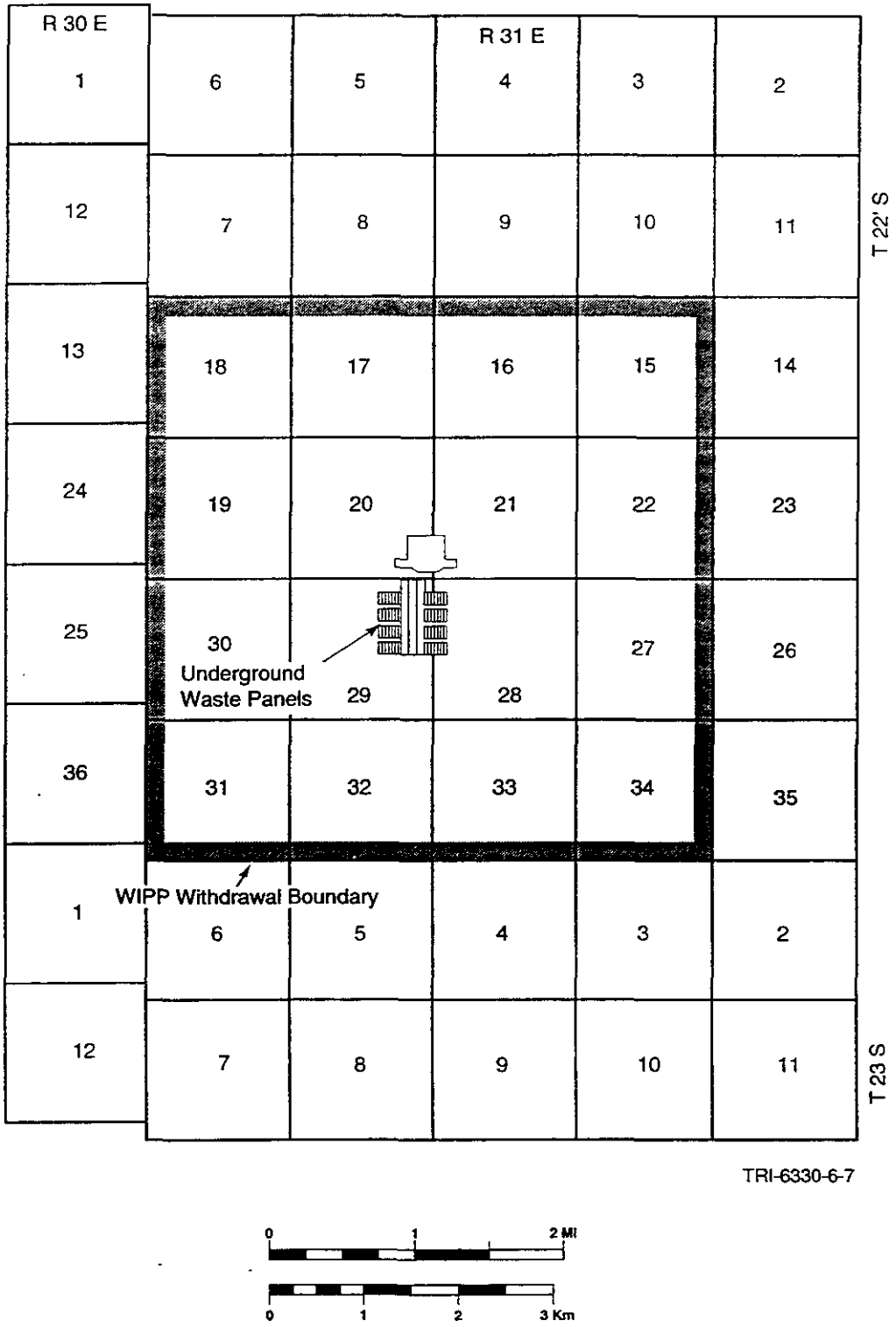

Figure 1-2. Position of the WIPP waste panels within the Withdrawal (DOE, 1990a).

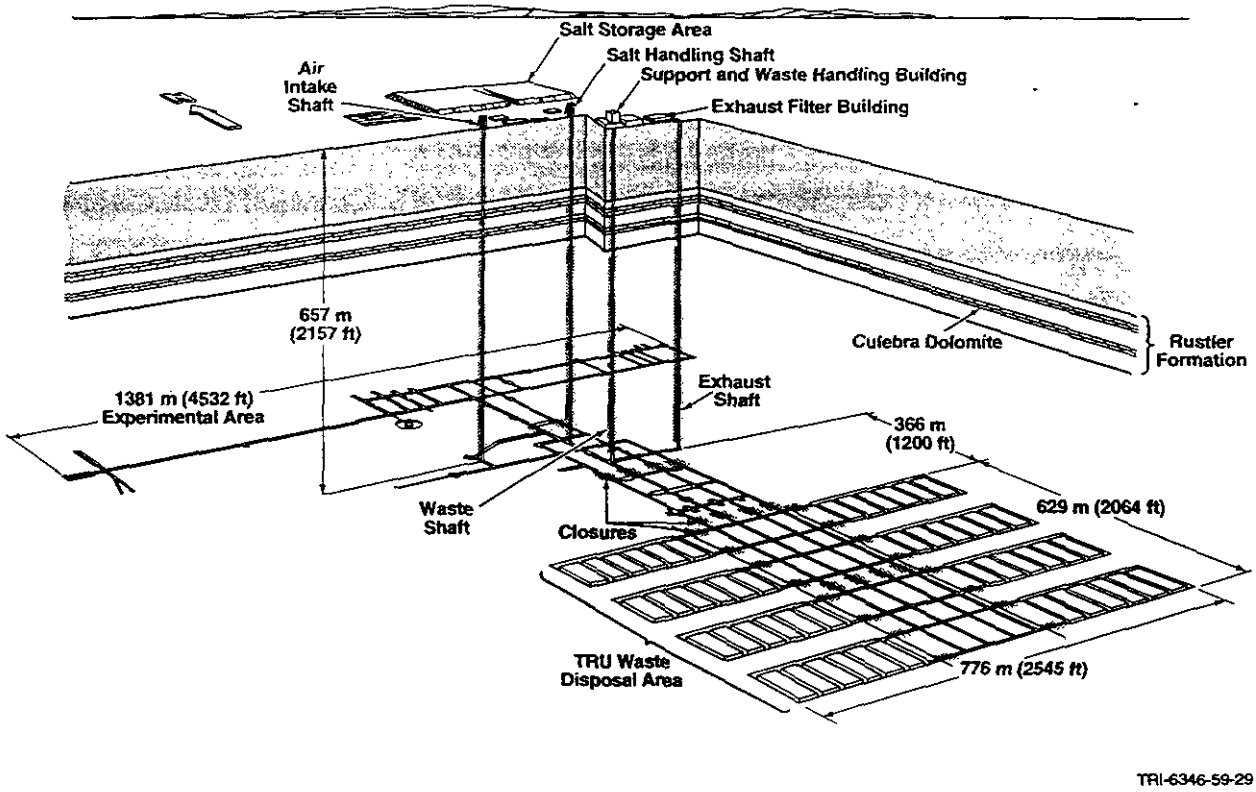

Figure 1-3. Relationship between the WIPP surface and subsurface facilities (after Waste Management Technology Department, 1987).

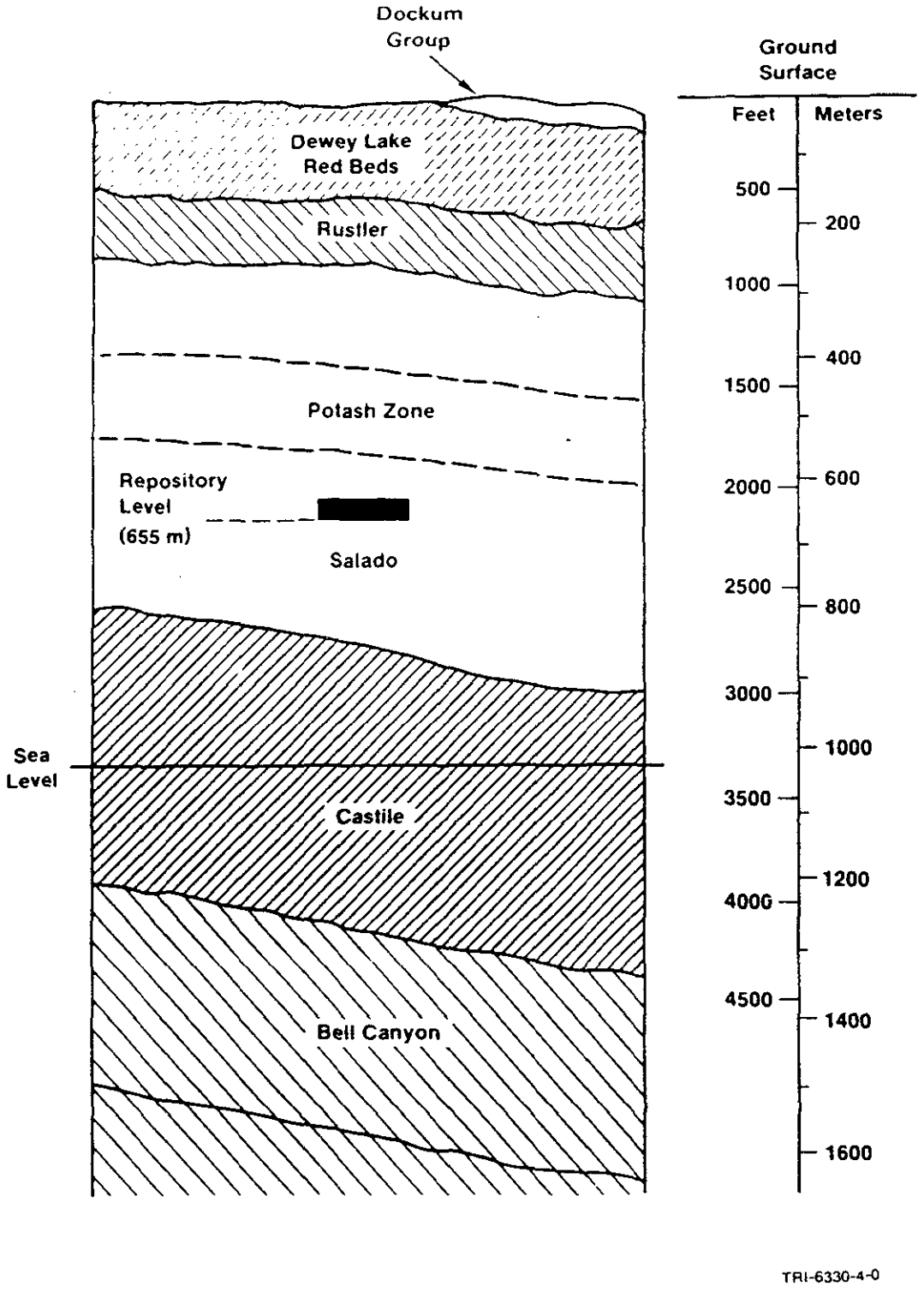

Figure 1-4. Generalized stratigraphy at the WIPP (after Waste Management Technology Department, 1987).

regulations" (Public Law 102-579, 1992, Sec. 8[c][1]). The EPA's proposed rule, "Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance With Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Proposed Rule" (40 CFR Part 194) (EPA, 1995a) was published in the *Federal Register* (FR) January 30, 1995. As stated in the LWA, the criteria were intended to be used to determine "whether the WIPP facility will comply with the final disposal regulations" (Public Law 102-579, 1992, Sect. 8 [c] [1]). The EPA promulgated the final version of 40 CFR Part 194 under the title "Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations; Final Rule" on February 9, 1996 (EPA, 1996c).

1.2 Passive Institutional Controls

PICs are intended to communicate to potential intruders information about the existence and location of the repository, the wastes buried there, the nature of the hazard the wastes represent, and the goal of not disturbing the disposal system. A fundamental assumption about nuclear-waste disposal is that if future generations have and understand the appropriate information, they will not intrude into the repository or disturb the remainder of the disposal system. With the requirement to mark the withdrawal, the message for the larger area outside the repository footprint is not the danger of intruding into the repository, but the danger of impacting ground-water flow and possibly affecting radionuclide transport from the disposal facility toward the biosphere.

The recently promulgated WIPP-specific 40 CFR Part 194 (EPA, 1996c) states both the requirement for PICs and the permission for the PA to take advantage of PICs to reduce drilling and mining frequencies. The language states that the DOE may take credit for the PICs in deterring inadvertent human intrusion into the WIPP facility and disposal system in the PA calculations for the Compliance Certification Application (CCA) that will be submitted. Concurrently, § 194.26 establishes requirements on the use of expert judgment and indicates that expert judgment would probably be used to assess the effectiveness of PICs in deterring inadvertent human intrusion into the disposal system.

In other language, the EPA indicates a concern about the justification for such credit and a desire for clear justification for this credit within the EPA's regulatory assumption (61 FR 5231/EPA, 1996c). The regulatory language also indicates an expectation that the effectiveness of PICs will be assessed by individuals independent of the DOE (61 FR 5228 and 61 FR 5232/EPA, 1996c).

1.3 PICs Task Force Objectives

The PICs Task Force (PTF) has been charged with developing a numerical representation of the effectiveness of PICs in deterring inadvertent human intrusion into the WIPP disposal system. This numerical representation must be developed in a usable format for the PA calculations. The documentation of the deliberations of the PTF provide well-reasoned arguments to support the results.

As described in Section 1.4, the deliberation of the PTF will be followed by external peer review of the results and the process by which the results were developed. As such, the PTF will provide the input materials for the peer review—writing the issue statement that the peer reviewers will address, supplying the effectiveness estimates and supporting arguments, and providing the peer-review panel with answers to questions or concerns.

This report does not address the conduct of the external peer review, which will be conducted within the DOE's peer-review process.

1.4 Work Approach

A work approach has been developed by the DOE that addresses the dual requirements of (1) providing justified input to the PA calculations as to the efficacy of the PICs in deterring inadvertent human intrusion, and (2) developing such information based on existing evidence and with the assistance of individuals with perspectives beyond the DOE.

The DOE has developed a four-step approach to achieve these goals. The first step was to convene the Markers Panel in 1991 (Trauth et al., 1993) in a process following steps refined in NUREG-1150 (Hora and Iman, 1989). A comparison of the process for convening the Markers Panel in 1991 with the 1996 requirements of §194.26 Expert Judgment leads the DOE to conclude that they are substantially equivalent. The two Markers Panel teams developed marker designs that were distilled into a set of fundamental design principles about long-term marking and communicating with future generations. The second step took these design principles and specific marker elements, supplemented by other documentation of structures, records systems, and information that have endured for long periods of time, to develop the PICs Conceptual Design Report (DOE, 1996). The third step (which is documented here) was to utilize a PTF comprised of individuals with relevant knowledge supplemented by external expertise, to examine existing documentation (information and perspectives developed external to the DOE), to finalize the conceptual models of the system of PICs that the DOE will commit to implementing, and to assess the effectiveness of the PICs in reducing the inadvertent intrusion frequency for the PA calculations. The fourth step in the approach will be to submit the report of the PTF to external peer review. The results of the PTF analysis will be used as input to the PA forming the basis of the CCA.

The PTF consists of representatives from the DOE Carlsbad Area Office (CAO), the Carlsbad Technical Assistance Contractor (CTAC), Sandia National Laboratories (SNL), Westinghouse Waste Isolation Division (WID), and technical consultants. The following is a list of the PTF members:

Task Coordinator
- Michael M. Oliver - CAO

Report Authors
- Kathleen M. Trauth - SNL
- Robert V. Guzowski - SNL/SAIC
- Chris G. Pflum - CTAC

Ronald J. Rodriguez - WID

Technical Consultants
David Givens - American Anthropological Association
Suzanne Pasztor - Randolph-Macon College

1.5 Constraints

Two major constraints directed this effort. The first of these constraints is that the PTF must work within the regulatory confines established by the EPA in 40 CFR Part 191 and 40 CFR Part 194 (including the Supplementary Information (SI) and the Background Information Document [BID] [EPA, 1996a]), as to what is required and what assumptions to make. These limitations for the PA calculations are that (1) PICs cannot be assumed to completely eliminate inadvertent human intrusion for any portion of their life; (2) credit for the effectiveness of PICs in deterring inadvertent human intrusion cannot be taken for more than approximately 700 years after disposal; and (3) the future-state assumptions in §194.25, that characteristics of the future unrelated to hydrogeologic, geologic, and climatic conditions are to be assumed to be as they are today. The second constraint is that estimates of the efficacy of PICs must be clearly linked with existing evidence on the longevity of structures and materials and the long-term maintenance and interpretability of messages.

A number of operational constraints were imposed on the deliberations of the PTF. One constraint was to begin deliberations using the system of PICs discussed in the Passive Institutional Controls Conceptual Design Report (DOE, 1996), with expansion and modification of the system as necessary. Another operational constraint was to work within what is practicable to implement in the construction and development of the PICs, and what the DOE will commit to implementing.

1.6 Preview of Chapters

Chapter 2 outlines the pertinent regulatory language from 40 CFR Part 191 and 40 CFR Part 194 (including the Supplementary Information and the BID). Chapter 3 discusses the role of PICs in nuclear waste management and includes national perspectives other than the EPA. Chapter 4 builds upon the strict regulatory requirements and indicates assumptions used by the PTF in the assessment, both from the EPA and by the PTF when an assumption had to be made to implement the language of the regulations. Chapter 5 begins with a discussion of the systems approach to long-term communication and addresses the relationships between PICs components. Chapter 6 is a linked discussion of the PICs components, the historical analogues that support the design, potential failure mechanisms, and design characteristics that counter the potential failure mechanisms. Chapter 7 outlines the numerical representation of the effectiveness of PICs and provides the corresponding justification by examining historical analogues, while showing graphically the interrelationships of the PICs components in supporting deterrence. Chapter 8 contains the references cited throughout this report.

2.0 APPLICABLE REGULATIONS

2.1 Basis for Regulatory Aspect

The PTF's estimation of the effectiveness of the PICs must take place within a regulatory context that establishes the requirements for the PICs and the assumptions that govern considerations of their effectiveness. This chapter deals with these regulatory requirements.

2.2 Requirements for Active Institutional Controls in 40 CFR Part 191

This discussion of active institutional controls (AICs) is relevant because the AICs establish when consideration of PICs is assumed to be a factor in the PA and are another example of the EPA's treatment of human intrusions.

The EPA defines AICs as:

> "(1) Controlling access to a disposal site by any means other than passive institutional controls; (2) performing maintenance operations or remedial actions at a site; (3) controlling or cleaning up releases from a site; or (4) monitoring parameters related to disposal system performance." (50 FR 38085c/EPA, 1985)

For the PA, which assesses the performance of the disposal system for isolation of wastes from the accessible environment, the EPA prohibits consideration of any contribution from AICs for more than 100 years after disposal.

The PTF traced the origin of this 100-year limit to the EPA's 1978 draft "Criteria for Radioactive Wastes" (EPA, 1978). These criteria were intended to provide general guidance for the disposal of all forms of radioactive waste. Criteria No. 2 states:

> "The fundamental goal for controlling any type of radioactive waste should be complete isolation over its hazardous lifetime. Controls which are based on institutional functions should not be relied upon for longer than 100 years to provide such isolation; radioactive wastes with a hazardous lifetime longer than 100 years should be controlled by as many engineered and natural barriers as are necessary." (43 FR 53265/EPA, 1978)

Although the EPA's standards and criteria for the WIPP impose limits on AICs, the EPA's standards for uranium and thorium mill tailings (40 CFR Part 192/EPA, 1995b) do not.

The 100-year limit on AICs portends an early end to the United States government. The PTF does not believe that the U.S. government—with its institutions, laws, and sanctions—will collapse in 100 years or change to an extent that a location as important as the WIPP will be forgotten. Indeed, other countries have expressed more faith in their governments. Their waste disposal systems will rely on active controls for 100 to 500 years (NEA, 1995).

The EPA's limitations on the credit for AICs (100 years) in the PA calculations represent conservative assumptions meant to place the emphasis for regulatory compliance on the isolation afforded by the site, and limit reliance on societal actions (either active or passive). This limitation should not be construed as meaning that active control over the site by the federal government

will end after 100 years. In fact, the existence of PICs means that AICs would have further reinforcement by virtue of activities involved with testing and constructing the PICs.

2.3 Requirement for Passive Institutional Controls in 40 CFR Part 191

As part of the assurance requirements of the general standard, 40 CFR Part 191, the EPA requires the implementation of PICs. Section 191.14 states that:

> "(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location." (50 FR 38086c/EPA, 1985)

In §191.12, the EPA defined PICs as:

> "(1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system." (50 FR 38085c/EPA, 1985)

The definition of "passive" can be understood, in part, by contrasting the definitions of PICs and AICs, in §191.12. Active institutional control means:

> "(1) Controlling access to a disposal site by any means other than passive institutional controls, (2) performing maintenance operations or remedial actions at a site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance." (50 FR 38085c/EPA, 1985)

The distinction between active and passive is the nature of the deterrence. For AICs, an institution (i.e., the DOE) deters intrusions, whereas for PICs, the warning is the deterrent.

The DOE reads the text within the Supplementary Information that was published with the original promulgation of 40 CFR Part 191 to further explain the rationale in developing the rule as indicating that the EPA intended for the implementing agency to take credit for the effectiveness of PICs in deterring inadvertent human intrusion:

> "The Agency [EPA] believes that the most productive consideration of inadvertent intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive institutional controls (although passive institutional controls should not be assumed to completely rule out the possibility of intrusion)." (50 FR 38089a/EPA, 1985)

and

> "Not allowing passive institutional controls to be taken into account to some degree when estimating the consequences of inadvertent human intrusion could lead to less protective geologic media being selected for repository sites." (50 FR 38080b,c/EPA, 1985)

DOE's reading of the above regulatory language, and the need to address PICs, resulted in the Markers Panel being convened in 1991 to address this issue in a multidisciplinary fashion. The language in 40 CFR Part 191 provided the context for the deliberations of the Markers Panel.

2.4 Criteria for Passive Institutional Controls in 40 CFR Part 194

The requirements in 40 CFR Part 191 are explicitly applied to the WIPP through 40 CFR Part 191. Section 194.43(a) builds upon the language of 40 CFR Part 191 and requires a description of the proposed PICs:

> "Any compliance application shall include detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system. Such measures shall include: (1) Identification of the controlled area by markers that have been designed and will be fabricated and emplaced to be as permanent as practicable." (61 FR 5243c/EPA, 1996c)

In addition, §194.43(b) requires that an assessment of how long PICs might be effective must be undertaken:

> "Any compliance application shall include the period of time passive institutional controls are expected to endure and be understood." (61 FR 5243c/EPA, 1996c)

2.5 EPA's Allowance of Credit for Passive Institutional Controls

In §194.43, the EPA has clearly stated that the DOE may take credit for the PICs deterring inadvertent human intrusion in the PAs:

> "(c) The Administrator may allow the Department to assume passive institutional control credit, in the form of reduced likelihood of human intrusion, if the Department demonstrates in the compliance application that such credit is justified because the passive institutional controls are expected to endure and be understood by potential intruders for the time period approved by the Administrator. Such credit, or a smaller credit as determined by the Administrator, cannot be used for more than several hundred years and may decrease over time. In no case, however, shall passive institutional controls be assumed to eliminate the likelihood of human intrusion entirely." (61 FR 5243c/EPA, 1996c)

The Supplementary Information for 40 CFR Part 194 provides further detail and indicates the importance of the justification of the credit proposed:

> "Additionally, the final rule allows the Department to reduce the likelihood of future human intrusion that is used in performance assessments by a proposed amount corresponding to the predicted effect of PICs . . . . Thus, DOE may propose in its compliance application to reduce the rate of human intrusion by a fractional amount, extending over a technically supportable period of time, and must justify this using the plans for the implementation for PICs and associated evidence of their effectiveness." (61 FR 5231a,b/EPA, 1996c)

as well as the means of mathematically describing such credit:

> "This credit may take the form of a constant reduction in the rate of human intrusion lasting several hundred years or may be a reduction in the rate which tapers off in size over several hundred years." (61 FR 5231b/EPA, 1996c)

Further qualifications on the implementation of credit are:

> "Such credit cannot be assumed to eliminate completely the possibility of human intrusion, even for a short period of time after the active institutional controls at the WIPP are assumed to be ineffective." (61 FR 5231b/EPA, 1996c)

and

> "Having considered the public comments regarding PICs, the Agency believes that such credit could be no more than approximately 700 years past the time of disposal. Thus, the final rule limits to several hundred years the amount of credit that EPA may grant for PICs. Any determination that a specific numerical credit would be appropriate for a much longer period of time would be unduly speculative and therefore inappropriate." (61 FR 5231b/EPA, 1996c)

The EPA quotes from the Supplementary Information published with the 1985 promulgation of 40 CFR Part 191 to provide the context for the treatment of PICs in 40 CFR Part 194:

> "With respect to performance assessments, the Agency examined whether PICs should be taken into account to some degree when estimating the likelihood of inadvertent human intrusion and concluded that 'a limited role for passive institutional controls would be appropriate when projecting the long-term performance of mined geologic repositories to judge compliance with (the containment requirements of 40 CFR part 191).' At the same time, the Agency explicitly determined that PICs should not be assumed to completely prevent the possibility of inadvertent human intrusion." (61 FR 5231c/EPA, 1996c)

The EPA goes on to note that some comments received on the draft 40 CFR Part 194 stated that the Agency was acting beyond their authority in proposing to allow credit for PICs in the analyses for the containment requirements:

> "Still other comments asserted that, in allowing for the possibility of credit, the Agency had revised the intent of the assurance requirements, one of which being the requirement for the implementation of PICs. Specifically, comments stated that the assurance requirements were not intended to be considered when determining compliance with the numerical containment requirements found at 40 CFR 191.13." (61 FR 5231c-5232a/EPA, 1996c)

The EPA's statement immediately following that comment is:

> "The provisions of the final rule entertaining possible credit for PICs are within EPA's authority." (61 FR 5232a/EPA, 1996c)

The BID for 40 CFR Part 194 is another source of information as to not just the appropriateness of taking credit for PICs, but the necessity:

> "In this chapter the *necessity* [emphasis added] of incorporating passive institutional controls in the WIPP compliance criteria is discussed in terms of their ability to reduce the likelihood of human intrusion." (EPA, 1996a, p. 12-1)

DOE's reading of the above regulatory and associated language caused the DOE to conclude that in addition to being necessary under the Assurance Requirements, the PICs were intended to be a part of determining compliance with the Containment Requirements of §191.13. The PTF was convened to provide the input to PA.

While the EPA stated the necessity for including PICs in the compliance criteria, the EPA also stated concerns in Chapter 12 of the BID (EPA, 1996a) that were used to justify limiting the amount of credit that PICs can provide in deterring inadvertent human intrusion. Appendix A contains a discussion of a selected number of the EPA's concerns and the PTF's responses as to why these limitations are not appropriate.

2.6 Reasonable-Expectation Requirement in 40 CFR Part 191

The measure by which the compliance of the WIPP with the disposal standards will be determined to be one of a "reasonable expectation" as stated in the Supplementary Information published with the original promulgation of 40 CFR Part 191:

> "The containment requirements call for a 'reasonable expectation' that their various quantitative tests be met. This phrase reflects the fact that unequivocal numerical proof of compliance is neither necessary nor likely to be obtained. A similar qualitative test, that of 'reasonable assurance,' has been used with NRC regulations for many years. Although the Agency's intent is similar, the NRC phrase has not been used in 40 CFR Part 191 because 'reasonable assurance' has come to be associated with a level of confidence that may not be appropriate for the very long-term analytical projections that are called for by 191.13. The use of a different test of judgment is meant to acknowledge the unique considerations likely to be encountered upon implementation of these disposal standards." (50 FR 38071c/EPA, 1985)

The concept of reasonable expectation in the Containment Requirements was not an issue in the legal challenge 40 CFR Part 191. With the repromulgation of 40 CFR Part 191 in 1993, the EPA did not reverse its position on reasonable expectation in the containment requirements, and in fact the EPA extended the concept of reasonable expectation to the Individual Protection Requirements in §191.15:

> "Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved." (58 FR 66414c/EPA, 1993)

2.7 Reasonable-Expectation Requirement for PICs

The estimation of the effectiveness of PICs in deterring inadvertent human intrusion into the disposal system is to be used to modify an input to the PA calculations that are used to produce families of complementary cumulative distribution functions (CCDFs). These CCDFs are then compared with the release limits in the Containment Requirements of §191.13 to determine compliance with the disposal standards. As quoted above, the Containment Requirements of 40 CFR Part 191 are guided by the reasonable-expectation requirement. Because the effectiveness of the PICs are an integral part of the PA calculation used to address the Containment Requirements, the reasonable-expectation requirement also applies to the estimation of the effectiveness of PICs. DOE reads the reasonable-expectation language in 40 CFR Part 191 as meaning that absolute proof of the longevity of a marker, a records system, or a message is

neither achievable nor required to take credit for PICs in the PA calculations. The fact that the EPA required the implementation of the reasonable-expectation concept at two different times (the 1985 and 1993 promulgations of 40 CFR Part 191) and for different contexts (PAs and Compliance Assessments) supports the DOE's interpretation of the language for the concept.

2.8 Deterring Inadvertent Human Intrusion

References to human intrusion in 40 CFR Part 191 and in the Supplementary Information are to *inadvertent human intrusion*. Statements such as the following suggest that the requirement for PICs is to protect against the inadvertent human intrusion:

> "The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion." (50 FR 38088c/EPA, 1985)

The EPA has included provisions in 40 CFR 194.33(b)(1) that limit consideration of intrusion into the disposal system to inadvertent drilling:

> "Inadvertent and intermittent intrusion by drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario." (61 FR 5242b/EPA, 1996c)

This provision allows for the assumption that the message of the PICs is to be directed at discouraging those efforts to locate and exploit natural resources. Under this assumption, individuals locating and conducting drilling operations will avoid intruding into the repository and disturbing the disposal system if warning messages against intruding and disturbing are correctly conveyed to future generations. If, however, a potential intruder realizes that a drilling or mining activity may intersect the repository or the Withdrawal and understands the associated risks, but decides to intrude anyway, the intrusion is not inadvertent. Intentional intrusions are not to be considered in the PA calculations. "Deter" consists of the messages enduring and being correctly understood. Correct communication means that inadvertent human intrusion has been deterred. Understanding but ignoring the messages results in intentional human intrusion, which is beyond the scope of PA.

2.9 EPA Definition of Human Intrusion and the Area of Concern for Drilling

The definition of "human intrusion" has changed between the promulgation of 40 CFR Part 191 and the promulgation of 40 CFR Part 194. In 40 CFR Part 191, the term human intrusion was limited to boreholes drilled within the surface projection of the repository "footprint" and that actually penetrated to at least the depth of the repository. Appendix C of 40 CFR Part 191 restricted the consideration of drilling for natural resources to the repository area:

> " . . . the Agency assumes that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer *of repository area* [emphasis added] . . . . " (50 FR 38089b/EPA, 1985)

As a result of this guidance, the area of interest in considering the effectiveness of PICs by the Markers Panel was limited to the area of the repository. The revised guidance in 40 CFR Part 194 does not limit the area in which drilling can occur. Title 40 CFR 194.33(a) states that:

> "Performance assessments shall examine deep drilling and shallow drilling that may potentially affect the disposal system during the regulatory time frame." (61 FR 5242b/EPA, 1996c)

The EPA has thus indicated that "human intrusion" is not limited to events that actually penetrate the repository, but includes a broader list including shallow drilling and excavation mining. By this definition, human intrusion (drilling) must be considered to occur anywhere in the Withdrawal—within the footprint or within the Withdrawal outside the repository footprint. Thus, when the EPA states that PICs may reduce the likelihood of inadvertent human intrusion, it has indicated that PICs may be useful in deterring these other activities, including mining for natural resources.

With 40 CFR Part 194, the EPA has stated that drilling and mining will be treated the same in terms of the efficacy of PICs to deter inadvertent intrusion:

> "Performance assessments may assume that the likelihood of mining may be decreased by PICs and active institutional controls, to the extent that can be justified in the compliance application and to a degree identical to that assumed for drilling." (61 FR 5230a/EPA, 1996c)

Because the risks that are associated with drilling directly into the repository are potentially greater than those associated with drilling into the Withdrawal outside of the repository footprint, a greater effort will be made to deter intrusion into the repository footprint than outside of this footprint. The result is that the PICs are assumed to have different levels of deterrence for these areas.

When the Markers Panel was convened in 1991, the existing regulatory guidance stated that:

> "Therefore inadvertent and intermittent intrusion by *exploratory drilling* [emphasis added] for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies." (50 FR 38089a/EPA, 1985)

Based on 40 CFR Part 194, the definition of inadvertent human intrusion as used in this report includes any human activity that disrupts the disposal system (i.e., deep or shallow within the Withdrawal). These inadvertent human intrusions are limited to drilling and mining for natural resources, but include both exploration and development.

2.10 Dual Nature of Passive Institutional Controls for Assurance Requirements and for PA

To comply with the Assurance Requirements, a system of PICs has been identified for implementation at the WIPP (DOE, 1996). When the DOE addressed the issue of markers for the WIPP, by convening the Markers Panel, the charge was to design a system of markers that would be effective in communicating with individuals in unknown future societies. Thus, one could not assume anything about the nature of the individuals or their actions (e.g., level of technology, language, culture, and natural-resource usage). The designs of the Markers Panel have formed the basis of the DOE's conceptual design. The PICs that the DOE is committing to implementing are comprehensive. (See Appendix A, "Compliance with the Passive Institutional Controls Assurance Requirement," for a brief discussion on the compliance of the PICs with the Assurance Requirements, as opposed to the effort described in this report that supports the PA calculations.)

The Assurance Requirements do not require a specific level of efficacy for the PICs in order to show compliance, only that within the four specified categories (markers, records and archives, government ownership and regulations, and other) that the most permanent practicable means be used. These requirements are thus qualitative requirements.

There is no indication in §194.43(c) that if credit were not applied for or granted, that the PICs would not be sufficient to comply with the assurance requirements. The requirement for having PICs, and applying for credit for their use in the PA are separate issues. Applying credit for PICs only makes sense for those cases where inadvertent human intrusion is a factor—the Containment Requirements of §191.13.

The BID, published with the promulgation of 40 CFR Part 194, indicates the dual nature of PICs:

> "In developing the 40 CFR part 191 rule, EPA recognized that the quantification of risk over long periods of time was subject to considerable uncertainty and consequently introduced assurance requirements into the rule to *qualitatively address this uncertainty* [emphasis added]. One of the assurance requirements deals with passive institutional controls. Passive institutional controls are designed to reduce the probability of inadvertent human intrusion into a repository by conveying information about location, design, and hazards of the WIPP."
> (EPA, 1996a, p. 12-1)

Thus, PICs play a dual role in the compliance with the disposal standards. The design and implementation of the most permanent PICs practicable are required for compliance with §191.14. Assessing PICs for efficacy in deterring inadvertent human intrusion, and providing appropriate justification is wholly within the tasks associated with compliance with §191.13.

3.0 ASSUMPTIONS USED IN ESTIMATING THE EFFECTIVENESS OF PICS IN DETERRING FUTURE INADVERTENT HUMAN INTRUSIONS

The PICs are intended to convey a convincing message to future generations that discourages them from disturbing the disposal system. Because of the changing nature of most aspects of society and technology, the long-term effectiveness of the PICs in conveying the warning messages to future generations depends on what the message says, how it is conveyed, and the nature of its audience. The EPA has recognized that long-term predictions about society and technology include a level of uncertainty that can have a significant impact on the PAs.

> "The Agency recognizes the inherently conjectural nature of specifications on future states and wishes to minimize such speculation in compliance applications. The Agency has found no acceptable methodology that could make reliable prediction of the future state of society, science, languages or other characteristics of future mankind." (61 FR 5227c/EPA, 1996c)

The EPA helped reduce the uncertainty associated with predicting the risk of inadvertent human intrusion by mandating certain assumptions about the future in areas where scientific predictions cannot be validated. These future-state assumptions, which are really "present-day" assumptions, are based on the language in §194.25(a), which states:

> "Unless otherwise specified in this part or in the disposal regulations, performance assessments conducted pursuant the provisions of this part to demonstrate compliance with §191.13, §191.15, and part 191 subpart C shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions." (61 FR 5241a/EPA, 1996c)

The rule's supplementary information elaborates that for the purposes for assessing inadvertent human intrusion, PAs can assume that current social conditions persist for 10,000 years:

> "...the final rule requires that performance assessments and compliance assessment shall include dynamic analyses of geologic, hydrologic and climatic processes and events that will evolve over the 10,000-year regulatory time frame. DOE shall assume that *all other present day conditions will exist in their present state for the entire 10,000-year regulatory time frame*" (emphasis added) (61 FR 5228a/EPA,1996c)

Although future uncertainty represents itself in assessments of both human intrusion and the PICs that would deter human intrusion, only the uncertainty associated with human intrusion may be reduced by using future states assumptions. In regard to PICs, the EPA's Compliance Application Guidance (CAG) states,

> "Explicit application of future state assumptions to passive controls — i.e., the assumption that all present-day societal and demographic factors will remain constant — will not be considered by EPA to justify adequately the design of PICs or the estimation of credit." (EPA, 1996d)

To accommodate the EPA's guidance, assumptions regarding PICs and human intrusion cannot be contemporaneous. The PICs must deter an unknown intruder from the faraway future, while the DOE must assume that the repository would attract a contemporary intruder with contemporary skills and values. To some extent, the CAG relieves this inequity:

> "EPA expects that DOE will establish a framework of assumptions for PICs that is a prudent extrapolation of the future state [i.e., present day] assumptions established in §194.25" (EPA, 1996d)

In determining the amount of credit that the PA may take for PICs, this "prudent extrapolation" would consider certain societal "common denominators," such as the existence of some form of government and some level of regulatory control over the exploration for and development of resources. According to the CAG,

> "These common denominators are patterns of human behavior that may be detected throughout history and around the world. The degree to which the PICs implemented at the WIPP rely on common denominators will determine the degree to which the PICs are effective at being understood by potential intruders in the future." (EPA, 1996d)

Besides these "common denominators," the PTF made assumptions that are consistent with EPA's requirements for consideration of drilling events in the PA:

> "Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared" (40 CFR 194.33(c)(1)).

According to the Supplementary Information, these requirements provide "further clarification on which activities fall within the scope of human intrusion." Because the requirements of §194.33 and their basis are not part of the EPA's future state assumptions, there is no apparent prohibition from applying them to PICs. The PTF therefore considers that current drilling practices in the Delaware Basin are activities that fall within the scope of PICs. The following sections list and develop both the basic working assumptions from the CAG and assumptions developed by the PTF.

3.1 Basic Human Attributes

Assumption (1): Curiosity of humans [will continue]. (CAG)

People will continue to be curious about writing, pictures, symbols, and structures, and they will attempt to decipher them.

Assumption (2): The use of the written word to transmit information and concepts [will continue]. (CAG)

Assumption (3): Story-telling or the generational "passing down" of history [will continue]. (CAG)

People will continue to be interested in their past history and will continue to pass it down to future generations through writings and story telling.

Assumption (4): The ability of pictures to convey meaning [will continue]. (CAG)

Basic symbols will be understood (e.g., moon, people, animals), and basic emotions can be expressed through facial expressions (e.g., horror, disgust, happiness). Pictographs will reinforce

the linguistic messages as long as languages can be understood, and replace the linguistic warnings if the language is no longer functional.

Assumption (5): Some people will avoid, ignore or be ignorant of governmental controls. (CAG)

Some people will always try to avoid controls that they do not agree with and from which no perceived benefits are derived or from which there is a perceived harm.

Assumption (6): Individuals will continue to look out for their own self interest. (PTF)

Individuals will continue to monitor the activities of their competitors to gain a personal benefit or to prevent the competition from gaining a perceived unfair advantage. "Individual" can be a single person, a corporation, or the State.

3.2 Government

Assumption (7): The existence of some form of government [is assumed]. (CAG)

Government will exist in some form for the entire regulatory period. When people form an association, someone either assumes control or is elected to be in charge. The "individual" or "group" in control makes decisions either for its own benefit or the benefit of the association.

Assumption (8): [Government will exert] some level of regulatory control. (CAG)

Governments are established to provide a certain level of control upon society. The level of control depends on the type of government. One means of exerting control is to issue regulations or edicts to inform the society about what is and is not permitted, and to provide a mechanism to enforce the regulations or edicts (e.g., legal procedures, armed force, penalties).

Assumption (9): Governments will require and maintain records as part of the procedure to maintain controls. (PTF)

Records address the issues of who did what, where, and when. Knowledge of these issues is vital for the government to exert control. By requiring records, government establishes the information needed to exert control.

Assumption (10): Governments will continue to protect property rights. (PTF)

Under a government that respects individual property rights, the government will establish procedures and laws to protect those rights, including surface and mineral rights associated with property ownership. In the case where the government is the steward for the society (e.g., publicly owned material resources), agents of the government will monitor societal property in order to assure that society's rights are protected and compensation is received in exchange for the sale of societal property. If the government does not recognize individual property rights, agents of the government have a vested interest in protecting society property (e.g., natural resources) from exploration or development by nongovernmental entities.

Whereas some individuals have a tendency to avoid or ignore government control (see Assumption 5) that is perceived to be of no direct benefit, individuals and agents of the state have a vested interest in eliminating this avoidance (e.g., in the area of illicit exploration or development of natural resources).

3.3 Language

Assumption (11): Current English will continue to increase in the size of its vocabulary and the areas of use, but the basic vocabulary and structure will resist change. (PTF)

Current English is now the international language of science, technology, commerce, and diplomacy, which are major societal drivers. Estimates of the number of people who speak English world-wide range from 800,000,000 to 1,500,000,000, and English has official status in over 60 countries (Crystal, 1994). The widespread use of current English by the international community presents considerable resistance to rapid and drastic changes in the basic vocabulary and structure of English. People have invested so much time and effort in learning English that they will not accept wholesale changes except over extremely long time frames.

Assumption (12): Current English will remain decipherable by future generations of English readers for at least 1,000 years after disposal. (PTF)

Current high school students can read the works of Shakespeare (i.e., modern English), which are approximately 350 years old, and understand the basic concepts. College students can read the works of Chaucer (i.e., Middle English), which is approximately 600 years old, with some effort and understand the concepts. Linguistic scholars can read the epic poem *Beowulf* (i.e., Old English), which is approximately 1,000 years old (Crystal, 1994). Current English will remain decipherable to some members of society for at least as long as Old English has remained decipherable to current society.

In a case where the structure of English does change significantly, the fact that information is economically important will result in a concerted effort being made to understand the information. For example, when treasure hunters were trying to locate the wreck of the Spanish treasure ship *Atocha*, the available documents were handwritten in Spanish in a form in which the characters bear no resemblance to current written Spanish and the text contains no punctuation (e.g., no commas and no periods). Because of the potential value of the treasure, considerable effort was expended to translate the documents (Sullivan, 1987).

Assumption (13): English will continue to be read by the natural-resources exploration and exploitation industries. (PTF)

Because of the specialization of the vocabulary in the natural-resources industries, the extent of changes that may occur in current English for the general populace will not extend into the technical aspects of these industries. As a result, current English will become an industry-specific "second" language. This situation is analogous to Latin, which was used as the written language by the scientific community many centuries after the fall of Rome.

3.4 Natural Resources

Assumption (14): Resource exploration and extraction will be conducted using drilling technology that is basically the same as today's. (40 CFR 194.33 and Supplementary Information)

This is not a future-state assumption because it is presented in the section on Human Intrusion, which is guidance for the PA. These assumptions are being developed to provide input to the PA and are not used in any other context.

> 40 CFR 194.33(c)(1): "Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared." (61 FR 4242c)
>
> 40 CFR 194, Supplementary Information: "...drilling practices will remain as those of today and may vary depending on the resource." (61 FR 5230b)
>
> Assuming the use of higher technology is nonconservative, because higher technology is likely to include the means to detect the repository and radioactivity.
>
> Assuming the existence of a lower technology is nonconservative, because drilling to the depths being considered requires a relatively sophisticated technology that will not exist under this assumption (Guzowski, 1990, see Appendix C)

This assumption is consistent with the position of the International Atomic Energy Agency (IAEA) (1994) that stated:

> "For the purposes of assessing the consequences of future human actions . . . the future level of technology should be assumed to be at least equivalent to that existing at present. A lower level of technology would make it less likely that intrusion could be technically achieved. On the other hand, an improved technology supposes an increased knowledge, retention of records and an awareness of the risks of such repositories." (IAEA, 1994, p. 18)

Assumption (15): Because of the uncertainties associated with predicting future natural resources, the historical drilling rates for oil and gas in the Delaware Basin are to be used in the PA as surrogates for future drilling rates for these unknown other resources. (40 CFR 194.33 and Supplementary Information)

As the EPA has explained, this is not a future-state assumption. This assumption was established by the EPA to address the uncertainties of what resources will be important to societies in the near to distant future for the PA calculations. For example, uranium was a novelty element prior to the development of the theoretical basis for nuclear reactions. During and after WW II when a use for uranium was discovered, this element became a major source of resource exploration and production efforts.

> 40 CFR 194, Supplementary Information: "In effect, when used for the purpose of determining the future drilling rate, today's drilling activities act as surrogates for the unknown resources that will be drilled for in the future." (61 FR 5233c)

Assumption (16): There will always be natural resources of value within the Delaware Basin that will attract future exploration and support exploitation efforts. (40 CFR 194.33 and Supplementary Information)

As the EPA explained, this is not a future-state assumption. This assumption was established by the EPA to address the uncertainties of when and where resources will be found by societies in the near to distant future for the PA calculations.

> 40 CFR 194.33(b)(2): "In performance assessments, drilling events shall be assumed to occur in the Delaware Basin at random intervals in time and space *during the regulatory time frame* [emphasis added]." (61 FR 5242b)
>
> 40 CFR 194, Supplementary Information: "With respect to drilling rates, the Agency reasoned that while the resources drilled for today may be the same as those drilled for in the future, the present rates at which these boreholes are drilled can nonetheless provide an estimate of the future rate at which boreholes will be drilled. The Agency does expect that drilling will never completely cease; while some resources may become depleted over time and, while the rate of extraction of those resources may decrease, the increased rate of drilling for newly discovered resources will compensate for this decline." (61 FR 5233c)

Assumption (17): There will be virtually continuous natural-resource exploration and exploitation activities in the Delaware Basin during the entire regulatory time period. (40 CFR 194.33 and Supplementary Information)

40 CFR 194.33 requires the PA calculations to consider future drilling for exploration and exploitation to be random in time and space (see Assumption 6). Thus over time, the drilling rate will approximate an even distribution of boreholes (i.e., boreholes will be drilled at approximately equal intervals of time). Historical drilling rates for oil and gas in the Delaware Basin have been calculated to be approximately 48 boreholes/km^2 for 10,000 years. With a withdrawal area of 41 km^2, this drilling density results in one borehole being drilled within the Withdrawal every five years.

The drilling rate is assumed to extend beyond the boundaries of the Withdrawal to include the entire Delaware Basin (194.33(b)(2)). With the Delaware Basin area of approximately 23,100 km^2, this drilling density results in 111 boreholes being drilled per year. This level of drilling activity will attract attention from the competition and also keep the records centers busy processing the paperwork associated with this activity.

Assumption (18): Resource exploration and exploitation is not a casual activity. (PTF)

Resource exploration and exploitation requires a significant expenditure of time and money. As a result, certain procedures have been developed to optimize the benefits received from these expenditures. These procedures include investigating records centers to address ownership issues, checking pertinent literature to obtain resource information, and site investigations. All these steps occur prior to drilling.

3.5 Estimating PICs Effectiveness

Assumption (19): The determination of intrusion as inadvertent or intentional is not based solely on the actions of an individual but is also based on the actions of government in carrying out its responsibilities. (PTF)

For example, Congress has established the LWA that prohibits intrusion into the Withdrawal in perpetuity. Given that WIPP records will continue to exist, be understood, and be stored with resource records, if Congress decides to rescind the LWA, it will be done with full knowledge of the WIPP and any subsequent intrusions are not inadvertent. Government has failed its obligations by removing this prohibition, and this failure is not the responsibility of the generation responsible for the construction and disposal of the waste within. These same obligations apply to any subsequent governments that assume power.

Assumption (20): Communicating with future societies using words, pictographs, symbols, and diagrams through a variety of media is possible. (PTF)

Assumption (21): Historical analogues of structures, media, and messages that have withstood the test of time allow the DOE to design for success. (PTF)

Assumption (22): Today's scientific and engineering communities have the capability to create PICs that will perform at least as effectively as historical analogues. (PTF)

3.6 Summary

The EPA (1996d) suggests that the DOE not explicitly use "future state" assumptions to assess the effectiveness of PICs. Rather the DOE should establish a framework of assumptions for PICs that is a "prudent extrapolation" of the future state (i.e., present-day) assumptions established in §194.25. In determining the amount of credit that the PA may take for PICs, this "prudent extrapolation" would consider certain societal "common denominators." The PTF has identified the common denominators that could be prudently extrapolated into assumptions regarding the future environment in which PICs would deter inadvertent human intrusion. Other EPA assumptions that are not "future state" but are relevant to the assessment of human intrusion and PICs are incorporated. The PTF's assumptions are numbered and italicized throughout this chapter. These assumptions provide a basis for the communication concepts discussed in Chapter 5, the PICs discussed in Chapter 6, and the conclusions presented in Chapter 7.

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4.0 BASIC COMMUNICATIONS CONCEPTS

The regulatory bases for PICs are discussed in Chapter 2. In developing the conceptual designs for the PICs, care has been taken to ensure that all of the areas of PICs development and message transmittal established by the EPA (§191.12) have been addressed. The PICs are an integrated system of components that contains both on-site and off-site components, general and detailed warnings, written messages targeted at the technical and academic communities, and symbolic messages targeted at a more general audience. In addition, the system of PICs includes both redundant components (defense-in-"depth"), in that more than one component will convey the same information and warnings, and complementary components, in that some components will contain information and messages to direct individuals to other components with more detail. Some individual components also contain redundancy that can include how the message is transmitted and the locations in which the messages are stored. The integration of the PICs components into a system along with redundancy of messages within certain components suggests that the effectiveness of the PICs system in deterring future drilling and mining activities will remain high even if the effectiveness of individual components is compromised by some failure mechanism.

4.1 Systems Approach for PICs

The PICs being proposed for the WIPP disposal system (see Chapter 5) are an integrated system of components that include redundancy of the information being transmitted and reinforcement of the information; some components direct potential intruders to other components. This systems approach is derived directly from the design characteristics proposed by both teams (Team A and Team B) of the Markers Panel. As stated by Team A:

> "This team's thinking is founded on two major themes. The first theme states that the use of communication technology cannot bypass the problem of the certain transformation and succession of cultures, but use of fundamental and enduring psychology can. The second theme states that the entire site must be experienced as an integrated system of mutually reinforcing messages, and designed accordingly." (Trauth et al., 1993, p. F-27)
>
> "As well, we use the more culture-bound modes of communications such as languages and diagrams, but these are used as part of a larger system of communications. This system is to be one with great redundancy of messages and modes, so that even with some loss the goals of the system are met.
>
> "As well as being conceived as (1) a whole communication experience, (2) having a systemic character in which pieces are related in meaningful ways that add meaning, and (3) being sufficiently redundant to endure loss of elements, we apply the principle of Gestalt, in which the experience of the total communicated message is greater than the sum of the parts (even with some of the parts missing or degraded)." (Trauth et al., 1993, p. F-29)

Archives and records were not within the purview of the Markers Panel. Thus, their systems approach addressed only physical markers. Consistent with the requirement in 40 CFR Part 191, the DOE has extended the systems concept to incorporate archives, records, government land ownership and control, and other means of communication into the total PICs design.

Because of this redundancy and reinforcement, the effectiveness of the PICs system is not adequately represented as the sum of the effectiveness of the individual components. To estimate the effectiveness of the PICs system in reducing the frequency of inadvertent human intrusion, the interrelationships of the components must be recognized. This is clearly stated by Team B of the Markers Panel:

> "The probabilities and performance characteristics proposed above [Markers Report, Trauth et al., 1993] for the individual markers would be greatly enhanced by their inclusion within a larger, well-integrated marking system.
>
> "Message redundancy would be increased, of course. But the additional cross-referencing and multiple linkages of markers, signs, symbols, text and diagrams also would help reduce the likelihood of inadvertent intrusion. Furthermore, use of teaching principles throughout the message system (i.e., defining the meaning of a given symbol or iconic sign by placement within appropriate linguistic and diagrammatic messages) would augment performance of the entire marker." (Trauth et al., 1993, p. G-64)

The design of the PICs in order to comply with the Assurance Requirements is based on the two premises that (1) the PICs must be the most permanent practicable, and (2) one can make no assumptions about the future state(s) of society, technology, and language (i.e., one must design for the range of possibilities). With no assumptions about the future, the systems approach means (1) that the multiple (a) messages, (b) levels of complexity, and (c) communication media all reinforce each other to fill in gaps in communication, and (2) that the PICs are actually available to reestablish societal knowledge about the WIPP should there be societal discontinuities.

The use of the PICs, as designed to meet the Assurance Requirements, to take credit in PA is undertaken within EPA's framework of societal assumptions. Credit for PICs in PA is also limited to the much shorter time frame of 700 years. For PA, EPA's expectation is for assumptions based on a prudent extrapolation of today's conditions and using common denominators of human behavior. Under these circumstances, the PICs design exceeds what the assumptions would call for, and the systems approach means that each PICs component (other than the berm) is redundant and any one could correctly communicate the information and deter the potential intrusion.

4.2 Complexity of Messages

Five levels of messages will be used for the PICs at the WIPP based on Givens (1982):

- Message Level I conveys the message that the site is manmade. The message itself is in the physical form of the marker system and the effort expended in constructing it.
- Message Level II conveys the message that something dangerous is buried here and that no digging or drilling should be conducted.
- Message Level III conveys basic information that tells what, why, when, where, who, and how.

- Message Level IV conveys complex information in seven languages along with symbols and pictures.
- Message Level V is archival and stores a more complete rulemaking record than the messages provided at the WIPP site.

4.3 Encountering the PICs

Some of the PICs components are designed to instill a knowledge of the WIPP into the general public. Information about the PICs in textbooks, dictionaries, and encyclopedias should expose a large segment of the population to basic information about the WIPP. Although individuals in general are unlikely to remember much about the WIPP, those individuals who become involved in natural resources and environmental endeavors are more likely to be exposed to more detailed information about the WIPP and may be more likely to recognize the term "WIPP" because of an interest in the topic. These PICs may heighten the awareness of the potential intruder to the WIPP's presence so that other sources of information will be checked.

Natural-resource exploration/exploitation consists of three basic steps: (1) identification of areas that have resource potential, (2) evaluation of the resources in the areas, and (3) exploitation of the resources if the area-evaluation results confirm the presence of economically viable resources. Because of high levels of expenses in evaluating resources through field work, the first step in locating areas with resource potential is to research available sources of geologic and related information. Selected PICs components are designed to provide warnings and/or information on geologic and resource-related maps that someone interested in the resource potential of the northern part of the Delaware Basin is likely to check. These PICs are likely to heighten the awareness of the potential intruder to the presence of the WIPP so that other sources of information will be checked. Government ownership of the land at the WIPP could be determined at this stage of the investigation. The PICs component of government ownership would not be a deterrent, because government ownership of land is a common occurrence in resource exploration in the West.

If the WIPP region has resource potential, the next step would be a check of the ownership of the surface and mineral rights prior to any exploration activities. Expending time and effort to locate resources would be pointless if no opportunity exists to recover these investments. An investigation of ownership would lead to various government offices (federal, state, county, and local) where deeds and leases could be checked. This search could extend to birth/death records and probate-court records if surface or mineral rights could have been inherited. This phase of the investigation would encounter a number of PICs. Someone driving to a records center could encounter an area designated as "the WIPP" on road maps and atlases. As with other maps, these PICs would heighten the awareness of the investigator to the presence of the WIPP so that other sources of information will be checked. At the records centers, the investigator would encounter the fact in property records that the land within the land-withdrawal boundary is owned by the federal government and that leases contain land-use restrictions as covenants prohibiting drilling. The location and design of the WIPP facility and the hazards associated with the buried waste will be determined from the special, WIPP-specific records on file in the records center. Government ownership by itself would not deter a potential intruder but would force the investigator to obtain

the proper permits to avoid charges of mineral/resource trespass. Such permits could not be obtained because of the covenants. Land-use restrictions by themselves would not prohibit a potential intruder unless the government at some level is willing and able to enforce the restrictions. The WIPP-specific records within the records center would provide a major deterrent to intruding at or near the WIPP.

As part of the regional site evaluation, the investigator might conduct a field check of the WIPP out of curiosity or as part of the investigation of land adjacent to the Withdrawal. A site visit would encounter the markers. The warnings provided by the messages on the markers would reinforce the warnings already encountered at the records center(s). If the site visit occurs prior to visiting a records center, the warnings on the markers would still be deterrents and also provide additional incentives to find out more about the WIPP at records centers or archives, where the investigator would encounter the PICs of government ownership, land-use restrictions, and the formal WIPP-specific records.

4.4 Relationships between PICs Components

The PICs components form an integrated synergistic system that contains redundancy and reinforcement of information. Some components are designed to act primarily as deterrents on their own, while other components are primarily designed to direct an investigator or potential intruder to other components that contain more information and/or more explicit warnings.

Based on the discussion in Section 6.1, the following PICs components are intended to inform the general public about the existence of the WIPP; they are called "awareness triggers" (see Chapter 7):

- textbooks
- dictionaries
- encyclopedias
- road maps
- road atlases

The following components are more likely to reinforce this same function in the technical and resource-related community:

- geologic maps
- resource-related maps

For each of these components, the basic message is that something named "WIPP" is present in the northern part of the Delaware Basin, and the investigator should seek additional information before proceeding with any resource exploration or exploitation activities. More detailed information about the WIPP will be provided in textbooks, dictionaries, and encyclopedias, but investigators for the resource industry are likely to consult more "technical" sources.

Government ownership of the surface and mineral/resource rights conveys no information about the WIPP, but does convey the message that certain procedures must be followed in order to

obtain permission to evaluate resources. In following procedures to obtain permission, the investigator will encounter other PICs that will provide information about the location and hazards of the WIPP. An absence of government ownership would have little effect on deterring human intrusions, because the investigator would still go to records centers to identify ownership of the surface and mineral/resource rights.

The following PICs components are the primary deterrents to human intrusions at the WIPP:

- markers
  - monuments at boundary of repository footprint
  - buried markers throughout repository footprint
  - monuments at boundary of the Withdrawal
- records centers
- archives
- government control of land-use (covenants)

Although the level of detailed information provided by each component differs on why intrusion into the Withdrawal or the repository footprint should be avoided, the basic warning not to intrude is present in each component. Each component is an independent deterrent to future human intrusions. The warnings communicated by each component are reinforced if the investigator or potential intruder encounters more than one of these components, but the message of each component does not depend on the investigator or potential intruder encountering more than one component. Because of this relationship between components, potential future intruders should be effectively deterred from drilling into the Withdrawal as long as one of these components remains sufficiently intact to provide a warning.

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5.0 PASSIVE INSTITUTIONAL CONTROLS CONCEPTUAL DESIGN

5.1 Introduction

This chapter presents a linked discussion of the conceptual design for the PICs, the historical analogues that illustrate long-term survival of structures, institutions, and messages, potential mechanisms for the failure of PICs, and how the design of the PICs can serve to counteract the potential failure modes. The descriptions of the permanent markers, messages, and records embodied in this report are general. For a detailed description of the conceptual design of individual components of the permanent markers system and their associated messages, as well as the type of records and the locations of records archives that the DOE intends to establish as PICs, the reader is referred to the *Passive Institutional Controls Conceptual Design Report* (DOE, 1996).

Historical analogues define characteristics that have allowed structures and human institutions to endure for extended periods of time. As a result they influenced the thinking on the conceptual design of the PICs components. With a recognition of these characteristics, the PTF assumes that with current technology, these characteristics can be matched or exceeded to ensure the durability of the PICs components.

In addition, for each component, potential failure mechanisms are listed, along with a brief description of how the PICs design addresses the failure mechanisms. The climate to which an historical analogue is subjected versus the climate at the WIPP will vary. In general, the climate at the WIPP is as dry or drier than the climate at the historical analogue. Thus, weathering impacts related to water at the WIPP will be less than or equal to the impacts on historical analogues. Wind blown sand may be a concern at the WIPP as well as at various of the historical analogues. In response to this concern with erosion, pristine granite has been selected for its durability, and most of the elements of the site marker system will be placed within a protective berm that will reduce wind velocity. An experimental program for PICs will assess potential impacts of the natural environment on PICs and identify any design modifications necessary to address these impacts.

The specific PICs components are based on the requirements established by the EPA in 40 CFR Part 191: (1) markers, (2) public records and archives, (3) government ownership and land-use regulations, and (4) other (see Section 2.3). "Markers" were not defined in the regulation and are not defined in common usage, so the DOE convened the Markers Panel (Trauth et al., 1993) to address this issue. Of the PICs components, the issue of markers is unique in that the development of the design considerations that will assure "success" requires the input from and interaction of a broad spectrum of disciplines. The Markers Panel developed concepts for the designs for physical markers and for the mechanisms of long-term communication with future generations. The charge to the Markers Panel was not constrained by cost or level-of-effort requirements. Thus, the development of a conceptual design for the PICs components that are intended to be implemented by the DOE requires the consideration of what is "practicable." As a result, the DOE has maintained the design considerations of the Markers Panel recommendations while modifying the specific recommended designs in order to be "practicable."

"Public records and archives," on the other hand, have specific definitions and specific disciplines that direct their creation and maintenance. Functioning archives and records centers exist, and so DOE has based its design considerations on these institutions. In addition, the EPA, in 40 CFR Part 194, has indicated the materials that must be stored in the records centers and archives. This report combined with a consideration of how communication can fail have resulted in specific recommendations on details of document storage.

5.2 Permanent Markers

The marker system conceptual design was derived from the conceptual designs developed by the Marker Panel (Trauth et al., 1993), and is described in detail in "Passive Institutional Controls Conceptual Design Report" (DOE, 1996, Sections III through VIII, and XI). Figure 6-1 depicts the general layout and relative positions of the major components of the permanent marker system at the repository footprint. The most massive component is a large berm that surrounds the repository footprint. Buried within the berm are radar reflectors and large permanent magnets to permit future generations to find the berm should environmental effects cover the structure over the years. Sixteen large granite monuments outline the footprint perimeter. These monuments will include engraved warning messages in seven different languages. Two large rooms also are buried. One room will be buried within the southern segment of the berm (Figure 6-1), and the other room will be buried outside the berm at a location aligned with the room in the berm, the Information Center, and the decommissioned and decontaminated WIPP Hot Cell (located within the Support and Waste Handling Building in Figure 1-3). Each buried room has a more detailed message describing the WIPP site, the waste contents, and their danger. This detailed message will be engraved in granite and will be repeated within each room in seven languages. At the center of the footprint a readily accessible "Information Center" will be erected on the surface. The Information Center contains the same messages as the two buried rooms. Throughout the repository footprint, small markers engraved with a warning not to drill or dig will be buried randomly between 0.6 and 1.8 meters (2 and 6 feet) below the surface.

The conceptual model includes marking the 16-section Withdrawal with 32 granite monuments evenly spaced around the area perimeter (Figure 6-2). The design of these monuments will be similar to the monuments marking the repository footprint, although the message on these markers will primarily attempt to deter potentially disruptive inadvertent human intrusions within the Withdrawal but outside of the repository footprint.

5.2.1 Berm

5.2.1.1 Conceptual Design

The largest component of the PICs is a 10-meter-high (33-feet-high) berm with a 30-meter-wide (98-feet-wide) base tapering to a 4-meter-wide (13-feet-wide) top constructed just outside of the repository footprint (DOE, 1996, Section VIII). The berm is to be made up of a salt core from repository tailings, a layer of crushed caliche, a layer of riprap, and a final layer of mixed riprap and soil planted with vegetation native to the area. The total volume of the berm will be approximately 750,000 cubic meters (975,000 cubic yards). Within the berm will be buried

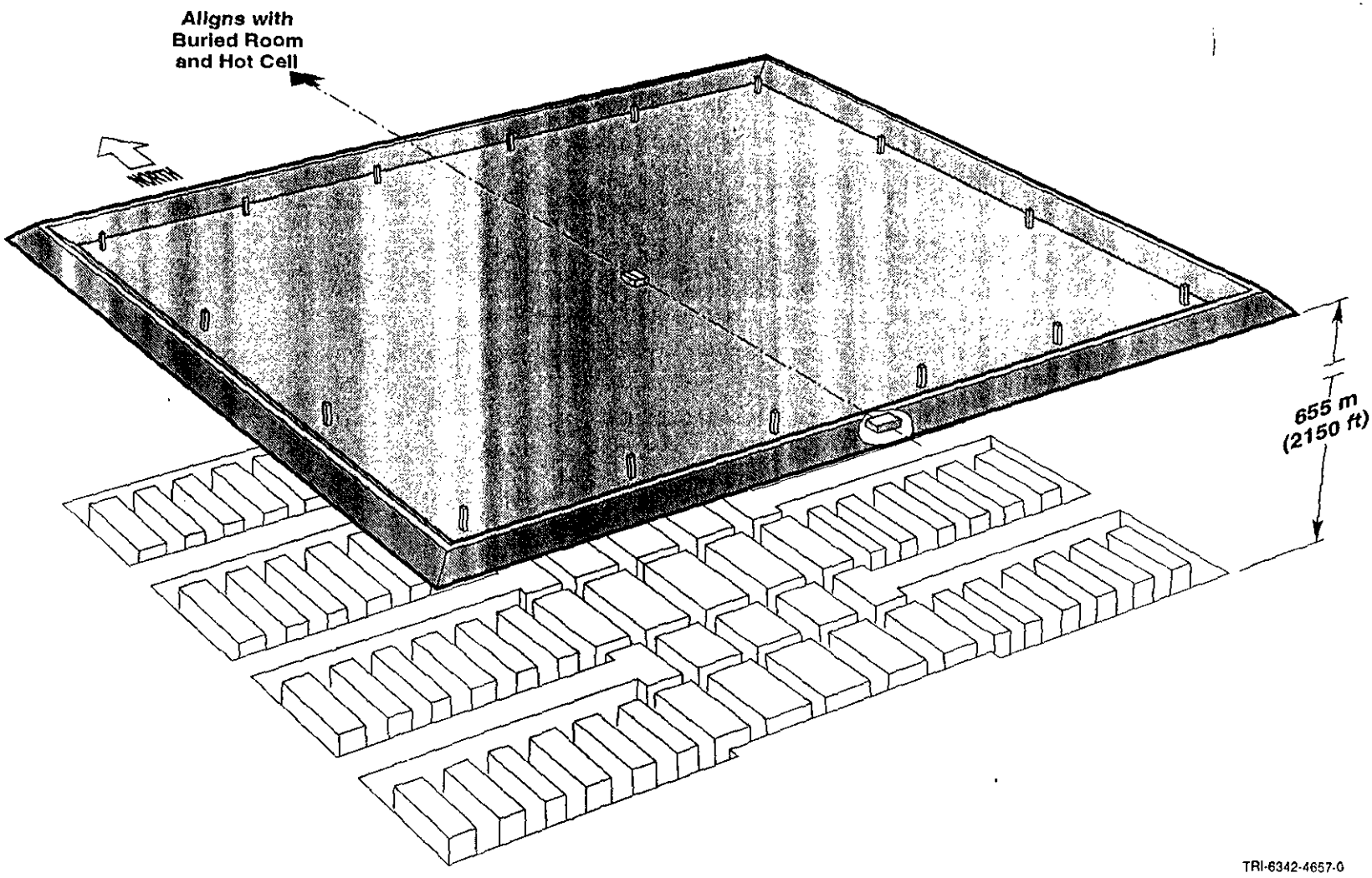

Figure 5-1. General layout of major components of the permanent-marker system at the repository footprint.

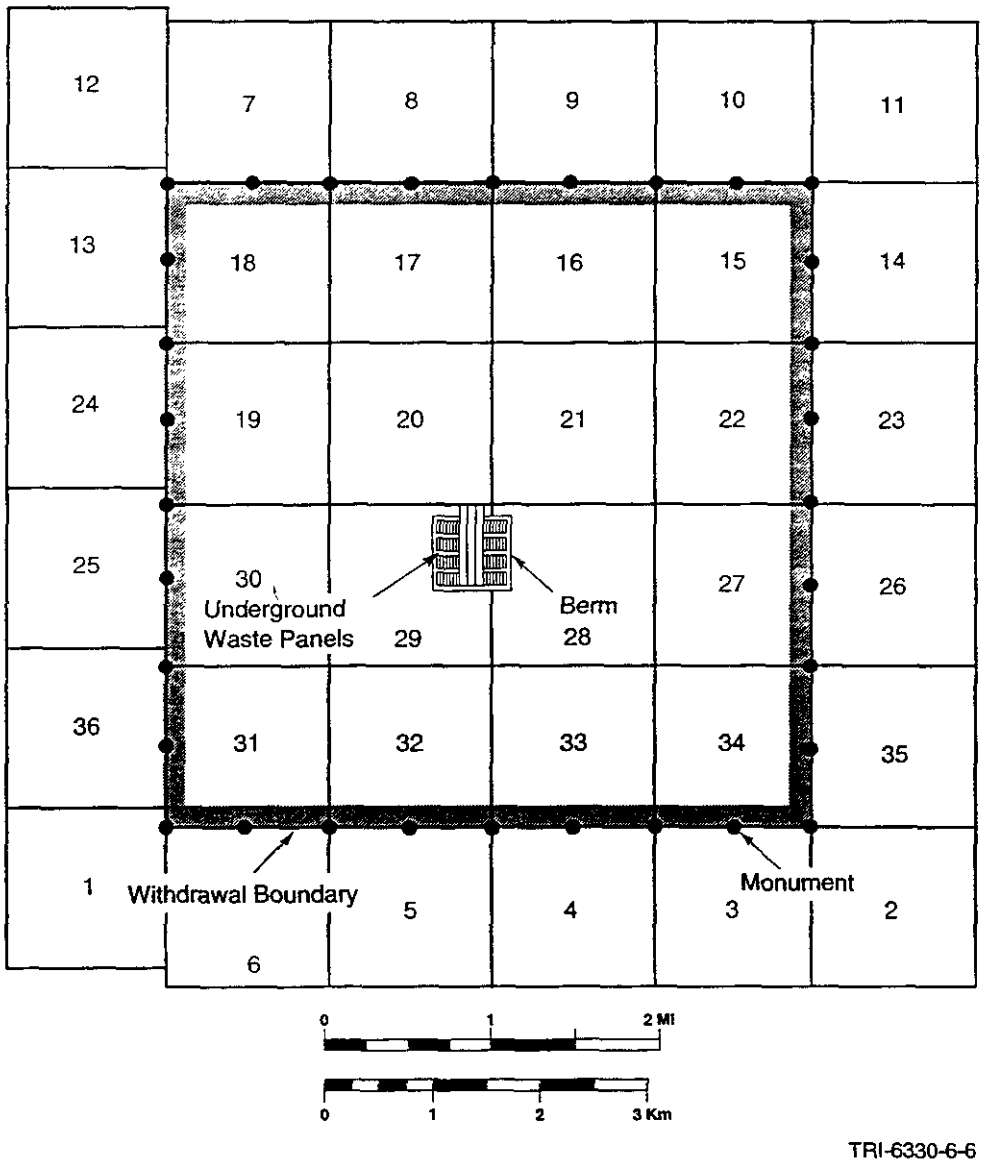

Figure 5-2. Proposed distribution of the permanent markers at the withdrawal boundary (modification of DOE, 1989).

concrete-encased steel radar reflectors and large permanent magnets. These devices will provide the capability for future generations to locate the berm with remote-sensing techniques.

5.2.1.2 Historical Analogue: Stonehenge

One of the most famous structures that has endured for thousands of years is Stonehenge. Located on the English plain about 32 kilometers (20 miles) south of Marlborough Downs, construction of Stonehenge began about 2700 to 2500 B.C. and concluded about 2100 to 1900 B.C. (Kaplan, 1982).

That earthworks can survive for thousands of years is demonstrated by the two concentric banks (i.e., earthen mounds surrounding the circular configuration of the stone structures) present at Stonehenge. The first building phase at Stonehenge began circa 2700 to 2500 B.C. and included the construction of the banks (Kaplan, 1982). The banks are made of chalk (a soft limestone) and the outer bank is 2.4 meters (8 feet) wide and 0.6 to 0.9 meters (2 to 3 feet) high with a diameter of approximately 115 meters (380 feet). The inner bank was originally 6 meters (20 feet) wide and 1.8 meters (6 feet) high with a diameter of approximately 98 meters (320 feet). Due to erosion, the bank is now approximately 0.3 meters (1 foot) high (Hawkins, 1973). A ditch 3 to 6 meters (10 to 20 feet) wide and 1.2 to 2.1 meters (4 to 7 feet) deep lies between the banks (Kaplan, 1982). The ditch probably served as the source of material for the banks. The banks are an example of an earthworks aged 4,500 to 4,700 years old.

5.2.1.3 Historical Analogue: Serpent Mound

The Serpent Mound in Ohio is not as old as Stonehenge. However, it is generally accepted that it was built by the Adena Indians who lived in the area from 1000 B.C. to 700 A.D. (Kaplan, 1982). The Serpent was formed by blocking out the pattern with stones and clay. A 0.3-meter (1-foot) layer of clay was then laid over the stones and another 0.7-meter (2-foot) layer of dark soil on top of the clay. The Serpent length is 383 meters (1,254 feet) long, an average width of 6 meters (20 feet) wide and 1.2 meters (4 feet) high. The mound was restored to its present contours by Putnam in 1886 (Kaplan, 1982).

5.2.1.4 WIPP Relevance: Stonehenge and Serpent Mound

Both the Stonehenge and Serpent Mound earthworks are ancient structures built of on-site or near-site materials in climates more severe with respect to erosion of earthen structures than the climate found in southeastern New Mexico. The current remains of the banks and the mound do not contain any design features explicitly intended for the long-term preservation of the structures. Both structures originally had cross sections substantially smaller than that of the planned berm. The maintenance of a significant portion of the original cross-sectional area is what allows the berms to be identified as human construction (Level I message).

With the larger cross-sectional area of the berm compared to the historical analogues and the incorporation of a layered design to minimize erosion, and considering the age of ancient mounds, the DOE asserts that the berm will endure as a Level I message for at least 5,000 years, and has a high probability of lasting beyond the period of regulatory concern.

5.2.1.5 Potential Failure Mechanisms and Design Solutions

Erosion. *(1) Materials selection—soil to support plants to stabilize surface against water or wind erosion; riprap to drain away water and as safety factor against wind erosion; caliche as safety factor to keep water away from salt core. (2) Size—so large so as to take a long time to obliterate; such a large volume of material so that even if the berm were to lose its shape, material would remain in the area as a Level I message.*

Buried by migrating dunes. *(1) Height of the berm—higher than the height of surrounding existing dunes. (2) Design—even if portions were covered, the berm has such a large lineal design that it all could not be covered.*

Deliberate dismantling and /or removal. *Size—large effort required to completely dismantle and completely remove. Even a decision to mine the salt or recover the magnets or reflectors would still result in a large amount of material at the site, at least a portion of which is not native to the immediate area.*

5.2.2 Monuments

5.2.2.1 Conceptual Design

Sixteen monuments will be evenly spaced around the perimeter of the repository footprint (inside the boundary of the berm). Each of these monuments will extend 7.6 meters (25 feet) above the surface (DOE, 1996, Section V). Each monument will comprise two granite stones. The upper stone will weigh 36.4 metric tons (40 tons) and will be placed over the base tendon weighing 59.1 metric tons (65 tons). Pristine granite blocks will be used in the construction and surface preparation will include polishing to shed water rather than containing small pits places for water retention. Each stone will be engraved with Level II and Level III messages. Thirty-two monuments similar to the footprint monuments will outline the Withdrawal and convey the message that the entire area enclosed by the monument should not be disturbed. The monuments will be shipped by rail to the WIPP.

5.2.2.2 Historical Analogue: Stonehenge

Durability. Initial construction of Stonehenge included the placement of the 32 metric-ton (35 ton) "Heel Stone" (sarsen rock) and concluded 400 to 800 years later with placement of 4 ton "Horseshoe" rocks (bluestone). The structure also includes a horseshoe of "Trilithons" 6.1 to 7.3 meters (20 to 24 feet) high made of sarsen stone and weighing 41 to 45.5 metric tons (45 to 50 tons) each. Three of the original five trilithons are intact. The other two lack a lintel and one is upright. Eighteen monoliths and five lintels of a ring originally consisting of 30 monoliths with lintels of 23 metric tons (25 tons) each still exist today (Kaplan, 1982). Compared to the environment at the WIPP, the structure has endured the ravages of the much wetter environment of the British Isles for 4,000 years without losing the characteristics that define its configuration. The sarsen rock is silicified sandstone, which is a common rock type on the surface of the English chalk downs. Bluestone is a local term used in Great Britain for bluish rocks, most of which are dolomite, but with some rhyolite, sandstone, and consolidated volcanic ash. The bluestones occur

together only in a small area (1.6 kilometers square [about one mile square]) in the Prescelly Mountains of Wales, some 322 kilometers (200 miles) from Stonehenge (Kaplan, 1982).

Since the construction of Stonehenge, the British Isles have been subject to numerous foreign invasions (e.g., Romans, the Jutes, the Angles, the Saxons, the Normans, the Danes, and the Norwegians) (Kinder and Hilgemann). There were also numerous episodes of internal strife (e.g., lines of successions, the War of the Roses) (Kinder and Hilgemann) that introduced political turmoil to the land.

After nearly 4000 years of weathering impacts and being subject to potential vandalism, engravings of two axes and a sword can be seen on one of the uprights at Stonehenge, as photographed by Mohen (1989). Thus, engravings can remain visible for thousands of years.

Communication. Stonehenge was no doubt useful to the society(ies) that used this structure in antiquity. Construction by humans is obvious (Level I message). Indirect evidence from excavations within and beyond the site's footprint conveys a fragmentary Level III message (i.e., who built the monument, when, what for and why [in part, for astronomical observation]) (Mohen, 1990). No evidence exists of an attempt by the creators of Stonehenge to communicate the structure's usage across the centuries to future generations living in societies different than the creators' society.

5.2.2.3 WIPP Relevance: Stonehenge

The people who built Stonehenge selected specific rock types based on hardness (e.g., they selected bluestone rather than the much softer chalk). The blocks selected were at or near the surface, which suggests that the blocks had experienced some weathering prior to quarrying. For the WIPP monuments, pristine granite will be used. The weathering and erosion characteristics of this granite are superior to the rock types (silicified sandstone and dolomite) employed in the construction of Stonehenge. The WIPP monuments will be located in a drier environment than are the Stonehenge monuments, providing an environment more conducive to long-term durability. Weathering is the physical disintegration and chemical decomposition of rock by such processes as hydration of minerals, dissolution of minerals, chemical alteration of minerals, abrasion of minerals (e.g., by blowing sand), and physical breakup of minerals (e.g., freeze/thaw). Physical removal of the altered material generally is considered to be part of erosion and not part of weathering. In the case of the monuments to be emplaced at the WIPP, the exposure to rain and snow will lead to the hydration of some minerals in the granite (i.e., the feldspar will eventually weather to clay) and the weathering products will be removed by rainwater and/or wind. Some mechanical abrasion by wind-blown sand is likely to occur, although the abrasion typically occurs close to the land surface and will be limited by the protection offered by the berm and/or local vegetation. Any cracks that develop in the rock or between mineral crystals will tend to be enlarged by freezing and thawing when the rock is wet. Dissolution is not a process to consider for the silicate minerals of granite.

The durability of the Stonehenge monument system both in terms of natural deterioration and survival through numerous episodes of social turmoil provides evidence that a system of monuments can endure for thousands of years. Based on the WIPP design of a set of multiple

monuments, the DOE asserts that some of the WIPP monuments will remain to define an area for at least 4,000 years, with a high probability of lasting beyond the regulatory period. Even fallen monuments, as has occurred to some monoliths at Stonehenge, can contribute to defining the perimeter of the repository footprint. Based on the usage of rocks of greater durability than those used at Stonehenge and the survival of Stonehenge engravings on an exposed surface, individual WIPP monuments and their engraved warnings on all four sides will survive for at least 4,000 years, with a high probability of lasting beyond the regulatory period.

The historical analogues listed in a later section for the Information Center provide further support for a reasonable expectation that the WIPP monuments will last for thousands of years.

5.2.2.4 Historical Analogue: Rock of Behistun

At the foot of the Zagros Mountains in the Kermanshah region of Iran, over 2,500 years ago the Persian King, Darius I, inscribed a memorial commemorating events that took place from about the autumn of 522 to the spring of 520 B.C. in his victory over a group of rebels and his ascension to power. An enormous bas-relief was carved more than 61 meters (200 feet) above an ancient road from Hamadan to Babylon into the sheer face of a 610-meter (2000-foot) high mountain proclaiming the might of Darius to all who pass by (Frimmer, 1969; Encyclopedia Britannica, 1994). Darius chose this location for its prominence. The message was inscribed for the purpose of reaching generations to come and includes a sculptured scene with 14 columns of writing at its sides and beneath it. The writing, using cuneiform script, is in three languages that today are known to be Old Persian, Elamite, and Babylonian. The memorial is 45.7 meters (150 feet) wide and 30.5 meters (100 feet) long (Frimmer, 1969). This memorial has withstood the rigors of time and weather in an exposed location so that its inscriptions can still be read today.

As is the case with the Egyptian pyramids, the sculpture has endured longer than the common use of the languages its contains, but the essence of its message remains interpretable by modern day scholars. It is an example of an authority creating a message for future generations to learn of the deeds of an earlier generation.

5.2.2.5 WIPP Relevance: Rock of Behistun

The Rock of Behistun is another example of exposed engravings that have endured for thousands of years. The purpose of the WIPP Permanent Markers is to inform future generations of the existence of the WIPP and the risk of intruding into the Withdrawal. As does the Rock of Behistun, the monuments will provide this information in several languages. The information medium for the WIPP monuments is granite into which the text is engraved. Based on the durability of the rock used and the depth of the inscriptions, there is a reasonable expectation that the WIPP monuments will perform as well as the ancient inscriptions. This reasonable expectation provides further support for the DOE's previous assertion that monuments and their inscriptions will survive for at least 4,000 years, with a high probability of lasting beyond the regulatory period.

The multiple languages repeating the message on the Rock of Behistun are an analogue for the design concept of multiple languages on the WIPP monuments to communicate with a broad spectrum of cultures.

5.2.2.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for building construction. Granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles).*

Erosion (physical removal of material). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Message location—messages will not be directly at ground level because that is where erosion from blowing sand would be the most destructive. (4) Protection offered by the berm—the presence of the berm will reduce wind speeds within the berm, especially as the berm is higher than the monuments, and thus reduce possible wind erosion.*

Buried by migrating dunes. *(1) Height—monument height will be higher than existing dunes. (2) Multiple monuments—some individual monuments can be removed and the component can still communicate effectively. (3) Distribution of monuments over a wide area—dunes migrating in one area will leave other monuments untouched. (4) Protection offered by the berm (only for those monuments located within the berm)—because the berm is so high, with an original height of 10 meters (33 feet), it will reduce the amount of sand that could be carried up over the berm and into the area of the repository footprint. The presence of the berm will reduce wind speeds within the berm, and reduce the possibility that the material within the berm will form huge dunes.*

Removal intact (museum). *(1) Multiple monuments—some individual monuments can be removed and the component can still communicate effectively. (2) Size and weight—difficult to transport. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Multiple monuments—some individual monuments can be removed and the component can still communicate effectively. (2) Size and weight—difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission*

Defacement (including gouges from target practice, being knocked over, and destruction of the messages). *(1) Materials selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Multiple monuments—some individual monuments can be removed and the component can still*

communicate effectively. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Engraved messages—messages will still be readable under paint.

5.2.3 Information Center

5.2.3.1 Conceptual Design

An Information Center will be erected at the center of the repository footprint (DOE, 1996, Section VII). This Information Center will have internal walls but no roof. The overall dimensions of the Information Center are 12.2 meters by 9.8 meters by 3.0 meters (40 feet by 32 feet by 10 feet). These dimensions exclude 1.5 meters (5 feet) of each wall buried in the caliche. Complex information (Level IV) will be contained within the Information Center, and includes a highly detailed written record of location, design, and hazards of the WIPP and in addition to text, includes tables, figures, diagrams, and maps. The Level IV text information contained on the engraved granite walls will be provided in seven languages.

5.2.3.2 Historical Analogue: Australian Rock Art

The EPA (1996a, p. 12-14) discusses ancient Australian rock art that includes paintings, engravings, and peckings located on protected (but not in enclosed tombs, etc.) surfaces. This rock art is estimated to be approximately 25,000 years old and possibly 35,000 years old. The location of the rock art in a desert environment means it has endured the onslaught of wind-borne sand, and wide temperature fluctuations, although weathering was not a problem.

5.2.3.3 WIPP Relevance: Australian Rock Art

While the relatively fragile media of Australian painted and pecked rock art has endured for thousands of years, the messages in the WIPP information center will be engraved for maximum durability. The location of messages on the inside of the granite walls and on the exterior granite walls within the protection of the berm will protect the engravings from some of the wind-borne erosion. The DOE asserts that performance of the Information Center will be at least as good as the endurance of Australian rock art and will be recognizable for the entire regulatory period.

5.2.3.4 Historical Analogue: The Acropolis

The Acropolis, a world-famous site of antiquity, is an elevated region overlooking Athens, Greece. This location and position have attracted human habitation since approximately 5000 B.C. During the Mycenian period (c. 1400-1200 B.C.), a massive fortification wall was built, part of which can still be seen today near the Propylia. This wall and an altar seem to have survived intact until the Persian sack of Athens in 480 B.C. Pericles was the prime mover in the decision to rebuild the Acropolis on a monumental scale after peace was made with Persia. The following monuments exist today within the Acropolis:

- Beule Gate. The first ceremonial entrance to the Acropolis is the Beule Gate. This monument was built from limestone blocks taken from an earlier monument that dates from

approximately 310 B.C. An inscription on the monument states that the structure was built in about A.D. 280 and was paid for by F. Septimus Marcellinus (Kaplan, 1982).

- Agrippa Monument. The monument stands on a natural terrace between the Beule Gate and the Propylia. The slab for the statue stands 8.8-meters (29-feet) high and is made of marble. The slab originally bore a four-horse chariot dedicated to celebrate a chariot victory by the city of Pergamon in the Panathenaic Games in about 178 B.C. Inscriptions on the slab tell us that the latest statue was raised to Marcus Agrippa in 27 B.C. From writings of Plutarch and Dio Cassius, we know that the slab once bore statues of Anthony and Cleopatra, but that these statues blew down in 31 B.C. (Kaplan, 1982).

- Propylaia. This is the classical gateway to the Acropolis. It is a part of the overall monumental rebuilding of the Acropolis undertaken by Pericles after the Persian Wars. Construction was begun in 437 B.C. with work halted in 432 B.C. because of the start of the Peloponnesian War. Work on this structure was never resumed. The gate is constructed of Pentelic Marble (Kaplan, 1982).

- Temple of Athena Nike. This structure was constructed during the period of 427 to 424 B.C. to celebrate peace with Persia. The major construction material was marble. A frieze, sculpted in high relief, ran around the exterior of the building. Four of the 14 slabs originally in the frieze are now in the British Museum (Kaplan, 1982).

- Erechtheion. This structure is a multiple-level building meant to house several cults, including those of Athena, Poseidon, and the founding rulers of Athens. Construction began in 421 B.C. and was completed in 409 B.C. The building was part of Pericles' plan for the Acropolis. This building is also constructed of Pentelic marble. In one part of the building known as the Porch of Maidens, six statues of young maidens support the roof. One of these statues has been removed to the British Museum (Kaplan, 1982).

- The Parthenon. This temple occupies the highest part of the Acropolis. It was built in the period from 447 to 438 B.C. as the cardinal feature of Pericles' plan. The best and most celebrated sculptors in Athens were engaged in its construction. Forty-six columns, each 10.5-meter (34.5-feet) high, ring the building. A frieze made up of alternating sculptures and grooved panels also originally surrounded this structure. Of the original 92 sculptures/panels, 15 are in the British Museum, one is in the Louvre, and 41 remain in place. In A.D. 1687 while the Turks were using the building as a powder magazine, a direct hit by a mortar caused a major explosion blowing the temple into two parts. The explosion destroyed 35 of the frieze panels (Kaplan, 1982).

Durability. Part of the massive fortification wall built approximately 1400 to 1200 B.C. can still be seen today. The major construction materials for all of the Acropolis' structures are marble and limestone. The metal features of the structures have been removed over the ages. However, the stone structures have endured the weather and the ravages of war, and although damaged, much of their original materials of construction and their overall configuration remain. As noted above, most of the structures in existence today date from the fifth century B.C., more than 2400 years ago.

Communication. Much is known about the Acropolis from ancient texts that have also passed through the ages. The degree of detail known about the Acropolis demonstrates that written communication can convey an extensive amount of knowledge across many centuries. For example, it is known that Pericles was the prime mover in the decision to rebuild the Acropolis on a monumental scale after peace was made with Persia (Kaplan, 1982). In several cases the architects and sculptors who worked on the project are known. Records indicate that money was raised from the sale of old building material, from grants by the Treasuries of Athena and Hephaistos, and from the Delian League in order to beautify the Acropolis. Annual building accounts for the Parthenon and Propylaia that were publicly displayed on the Acropolis still exist (Kaplan, 1982). Information documenting much of the history of the Acropolis has survived more than 2,400 years in a region of the world that has experienced much conflict and occupation by armed foreigners. An important point to note is that in more recent history portions of the Acropolis have been removed to museums elsewhere in the world. Because the site contains a substantial amount of material, sufficient information remains at the site to convey the configuration of the structures and enough records have survived to convey their meaning. In addition, placing portions of the Acropolis' structures in foreign museums has increased the exposure to many people outside of Greece to the existence and meaning of the Acropolis.

5.2.3.5 WIPP Relevance: Acropolis

The major materials found in the Acropolis are limestone and marble (Kaplan, 1982). Calcite ($CaCO_3$) is the predominant mineral of these rock types. As a result, both limestone and marble have relatively low resistance to abrasion, and both rock types have a relatively high solubility when exposed to acidic conditions. Based on historical records, the main threats to the buildings of the Acropolis have been their accidental (e.g., war) and deliberate (e.g., recycling of building stone) destruction. In the past 50 years, a significant amount of damage has been done to the Acropolis' structures because of the atmospheric pollution and acid rain that have accompanied the industrialization of Greece (Kaplan, 1982). The use of pristine granite for the major WIPP structures will provide an increased resistance to weathering and the adverse affects of acid rain over the marble and limestone used at the Acropolis. In addition, the location of the WIPP site will provide a lower acid-rain risk than many areas of the world because of insufficient water in this region to support significant industrialization and urbanization. Minimizing heavy industrialization and urbanization of the area also reduces the risk of significant levels of atmospheric pollution developing from vehicle exhaust and industry.

The PICs marker system includes redundancy of monuments and markers and could accommodate removal of some of the markers without destroying the definition of the extent of the site, the purpose, and the dangers associated with intrusion into the repository. Upon comparison of the Acropolis' lower durability structural materials to WIPP markers and the history of conflicts in the Mediterranean area that did not destroy either the physical artifacts or their purpose and meaning for more than 2,400 years, the conceptual design of the WIPP marker system using granite provides a credible argument for confidence in the marker system's ability to survive many centuries and convey the intended warnings. With the monuments of the Acropolis having survived for more than 2,400 years, survival of the granitic WIPP monuments and rooms well in excess of the 2,400 years is a reasonable extrapolation.

Using the more durable granite, rather than limestone or marble, combined with the less damaging environment, the WIPP Information Center will have higher durability than the building of the Acropolis. The DOE asserts that the building of the WIPP Information Center will survive with its engravings legible for at least 2,400 years, with a high probability of enduring for the entire regulatory period.

5.2.3.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles).*

Erosion (physical removal of material). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Message location—messages will be located on the walls inside the information center to reduce the impact of blowing sand. (4) Protection offered by the berm—the presence of the berm will reduce wind speeds within the berm. Lower wind speeds within the berm, especially for the Information Center that is well protected by the berm by its height of 3 meters (10 feet), will reduce possible wind erosion.*

Buried by migrating dunes or the impact of vegetation. *Protection offered by the berm—because the berm is so high, with an original height of 10 meters (33 feet), it will reduce the amount of sand that could be carried up over the berm and into the area of the repository footprint, and be available to form dunes. The presence of the berm will reduce wind speeds within the berm, and reduce the possibility of the material within the berm from forming huge dunes.*

Removal intact (museum). *(1) Interior walls of the Information Center contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and difficult to transport. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Interior walls of the information center contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and the granite is difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission.*

Defacement (gouges from target practice, walls knocked down, and destruction of the messages). *(1) Material selection—granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the Information Center—perpetrator*

would be harmed from ricocheting gunfire within the information center. (3) Interior walls of the information center contain two layers of messages—one entire layer can be defaced and removed and the component can still communicate effectively. (4) Engraved messages—messages will still be readable under paint.

5.2.4 Buried Storage Rooms

5.2.4.1 Conceptual Design

One granite storage room with an overall dimension of approximately 11.9 meters long by 6.7 meters wide by 4.9 meters high (39 feet long by 22 feet wide by 16 feet high) will be buried within the berm that surrounds the repository footprint (DOE, 1996, Section VI). A second room with the same dimensions will be buried in the Withdrawal outside the footprint approximately half way between the berm and the Hot Cell. Within each room, message texts and diagrams will be engraved on both sides of the interior walls and on the interior of the external walls. To provide redundancy, additional granite slabs engraved with the message text and the diagrams will be held in place against the interior walls. The granite slabs making up an individual room and the internal walls will have a combined weight of approximately 545 metric tons (600 tons). The existence of the storage rooms will be documented in the records located in the archives. The information contained in the buried storage rooms is the same as in the information center.

5.2.4.2 Historical Analogue: Newgrange

Newgrange, located in County Meath, Ireland, is an ancient passage grave, even older than the Egyptian pyramids. This passage grave was constructed by Stone Age farmers in approximately 3150 B.C. When constructed, the grave was an unmortared stone structure approximately 85 meters (280 feet) in diameter, with a facing of white quartz. The internal structure consists of a single passage into the center of the grave, opening up into a central chamber 5 meters (17 feet) long. Located off of this central chamber are three recesses. Far from being simply a mound of stones, the grave was carefully designed, as described by Fagan (1994):

> "The ceiling of the passage is six feet high and made of large slabs of overlapping boulders that form a corbel vault. The roof in the central chamber is twenty feet high and is made of boulders tightly packed with clay and sand. O'Kelly [the individual who excavated Newgrange between 1962 and 1975] found cleverly placed grooves pecked into the boulders designed to carry rainwater away from the apex of the chamber, effectively keeping it dry for 5,000 years." (Fagan, 1994, pp. 16-17)

Engraving on the internal walls include spirals and zigzag patterns. These engravings are distinct and show no signs of weathering, making them clearly discernible today.

5.2.4.3 WIPP Relevance: Newgrange

The existence of Newgrange indicates that stone structures can last for thousands of years, providing protection for openings within the structures and the engraved messages. Use of corbel construction, while stable in the case of newgrange, can foil resulting in collapse of the roof, as in the case of one passge in the passage grave at Knowth, which is near Newgrange (Fagan, 1994). To avoid potential structural instabilities, the buried storage rooms designed for the WIPP will

consist of slabs of pristine granite specifically designed to maximize the structural integrity of the rooms. Consistent with the Newgrange analogue, the rooms are expected to survive for at least 5,000 years, with a high probability of lasting beyond the regulatory period. The engravings will be protected from weathering for this same time period. When and if the buried storage rooms are exposed by excavation, their durability will be that of the Information Center planned for the center of the repository footprint.

5.2.4.4 Historical Analogue: The Egyptian Pyramids

The Pyramids of Egypt represent examples of the ability of stone structures erected by human beings to successfully function as monuments for thousands of years. The three great pyramids at Giza were built during the Fourth Dynasty of Egypt approximately 2600 to 2500 B.C. (Kaplan, 1982). These pyramids were burial tombs for the pharaohs who had them built. The messages conveyed by these structures and their associated inscriptions are Levels I, II, III, and IV.

Durability. The core of the Khufu (Cheops in the Greek historical text) pyramid, which is the first and largest of the Giza pyramids, consists of limestone blocks from a local quarry. The basic construction materials of the other two pyramids at Giza were quarried from the same location. The blocks vary in weight from about 2.3 to 13.6 metric tons (2.5 tons to 15 tons). Within Khufu's pyramid, the final chamber is lined with granite slabs. The roof slabs for this chamber are estimated to weigh 45.5 metric tons (50 tons) each. The name Khufu appears in the quarry marks on some of these stones (Kaplan, 1982). The stone used for the pyramids is the best and hardest stone from the quarry.

If the funerary nature of these structures was ever in doubt, any alternate hypotheses would be disproved by the Pyramid texts. These texts are inscribed on the walls of the burial chamber in the pyramid of Onis, who, having died about 2350 B.C., was the last pharaoh of the Fifth Dynasty (Kaplan, 1982) and in all other remaining pyramids of the Old Kingdom. The texts contain chants and incantations to insure the future happiness of the deceased pharaoh. Although the pyramids were looted during times of central-government chaos, the inscriptions remained.

Information about the Egyptian Pyramids was recorded by several historians. These include Herodotus (5th century B.C. Greek historian), Diodorus Siculus (1st century B.C. Roman historian), and Abd el Latif (12th century A.D. Arab historian). Siculus was in Egypt from 60 to 57 B.C. Much of what he reported echoes Herodotus' reports about who built the Pyramids. In addition, Siculus noted that ramps were used to construct the pyramids. The remains of such a ramp occur at the Unfinished Pyramid of Sekhment (approximately 2650 B.C.) (Kaplan, 1982). Abd el Latif (born A.D. 1179) mentions numerous inscriptions that covered the casing of the Great Pyramid. These inscriptions were lost when the casing stones were quarried away during and after the 13th century. The inscriptions had endured for almost 4,000 years before being removed (2500 B.C. to A.D. 1200). What is significant is that these inscriptions had not been obliterated by the blowing sands and erosion that had damaged the Sphinx (Kaplan, 1982). The fact that historical information recorded about a certain site by several individuals at several points in time is known today bears witness to the ability for information to remain accessible for many centuries.

The records of the history of the pyramids conveyed through Greek, Roman, and Arabic historians is demonstrative of the ability of written records to endure across cultures and centuries. A significant consideration is the fact that during the history of the pyramids, chaos reigned repeatedly in the region of the pyramids and centralized government control was lost and regained several times. Yet, throughout this period, both the structures and their purpose were preserved.

5.2.4.5 WIPP Relevance: Egyptian Pyramids

Engraving messages on the granite walls in the buried rooms can be reasonably assumed to preserve the information for many thousands of years. The granite in the rooms within the pyramid is harder than the limestone used to construct the rest of the pyramid. The Khufu markings on 45.5 metric-ton (50-ton) granite slabs buried within the pyramid have remained intact and communicated their message over a period of more than 4,500 years. As long as the WIPP buried rooms remain buried, they will be available for at least 4,500 years, with a high probability of lasting beyond the regulatory period. When and if such rooms are exposed or excavated, the durability of the newly exposed rooms and their engravings will be similar to that of the Information Center (i.e., a durability of at least 2,400 years starting at the time of excavation).

5.2.4.6 Potential Failure Mechanisms and Design Solutions

The following discussion is for the room buried in the berm (at grade, but covered).

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location—rooms will be buried within the berm and should thus be protected from infiltration of rainfall.*

Erosion (physical removal of material). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Message location—messages will be located on the interior walls of the buried room to reduce the impact of blowing sand. (4) Protection offered by the berm—the presence of the berm will reduce wind speeds in the vicinity of the berm. Lower wind speeds around the berm, especially if only part of the buried room is uncovered, will reduce possible wind erosion.*

Buried by migrating dunes or the impact of vegetation. *If the buried room has been uncovered, then dunes or vegetation are not an immediate problem. Even if the room becomes covered over, it is then potentially available to another generation.*

Removal intact (museum). *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and difficult to transport. (3)*

Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.

Removal for recycling. *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and the granite is difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission.*

Defacement (target practice, walls knocked over, and destruction of the messages). *(1) Material selection—granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the buried rooms—perpetrator would be harmed from ricochetting gunfire within the buried rooms. (3) Interior walls of the buried rooms contain two layers of messages—one entire layer can be defaced and removed and the component can still communicate effectively. (4) Engraved messages—messages will still be readable under paint.*

The following discussion is for the room buried outside of the berm (below grade). The following are potential failure mechanisms if the room is excavated but left in place below grade.

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location—messages will be located on the interior walls of the buried room to protect the message panels from rain*

Infill. *Material selection—Pristine granite is so durable that if the buried room becomes covered over, then it is available to another generation.*

Removal intact (museum). *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and difficult to transport. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Interior walls of the information center contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and the granite is difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission.*

Defacement (target practice, walls knocked over, and destruction of the messages. *(1) Material selection—granite is the most durable of rocks routinely used for construction and thus gouging*

with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the buried rooms—perpetrator would be harmed from ricochetting gunfire within the buried rooms. (3) Interior walls of the buried rooms contain two layers of messages—one entire layer can be defaced and removed and the component can still communicate effectively. (4) Engraved messages—messages will still be readable under paint.

If the room buried below grade is excavated, dismantled, and reconstructed on the surface, certain potential failure mechanisms become issues.

Weathering (chemical alteration of rock structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location—messages will be located on the interior walls of the buried rooms to protect the message panels from rain.*

Erosion (physical removal of material). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Message location—messages located on the walls inside the buried rooms to reduce the impact of blowing sand. (4) Protection offered by the berm—the presence of the berm will reduce wind speeds within the berm. Lower wind speeds within the berm, especially for the buried rooms that are well protected by the berm by their height of 4.9 meters (16 feet), will reduce possible wind erosion.*

Buried by migrating dunes or the impact of vegetation. *Durability of materials—if the reconstructed buried room becomes covered over, then it is available to another generation.*

Removal intact (museum). *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and difficult to transport. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight—message panels are large and the granite is difficult to break up. (3) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission.*

Defacement (target practice, walls knocked over, and destruction of the messages. *(1) Material selection—granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the buried rooms—perpetrator would be harmed from ricochetting gunfire within the buried room. (3) Interior walls of the information center contain*

two layers of messages—one entire layer can be defaced and removed and the component can still communicate effectively. (4) Engraved messages—messages still readable under paint.

5.2.5 Small Buried Markers

5.2.5.1 Conceptual Design

Several thousand small warning markers will be buried 0.6 to 1.8 meters (2 to 6 feet) below the surface (DOE, 1996, Section V). A Level II message will be engraved on each marker. Each marker will have the message in one of seven languages. Warning markers will be placed throughout the repository footprint, within the berm, and in the shaft-sealing system. Individual warning markers will be made of one of three materials: granite, aluminum oxide, or fired clay. Spacing between warning markers will be random within a range of 4.6 to 12.2 meters (15 to 40 feet).

5.2.5.2 Historical Analogue: Code of Hammurabi

In 1901, a diorite stele was discovered in a tell in Iraq that contained 282 legal decisions of Hammurabi, who was the 6th ruler of the 1st (Amorite) dynasty of Babylon (c. 1792-1750 B.C.). The stele is now located at the Louvre in Paris. The legal decisions known as the Code of Hammurabi were case law including economic provisions, family law, criminal law, and civil law. The text was in cuneiform and in the Akkadian (Semitic) language. This is another example of communications enduring for over 3,700 years. Much of the Code of Hammurabi was used by following generations and civilizations (Encyclopedia Britannica, 1994).

5.2.5.3 WIPP Relevance: Code of Hammurabi

The WIPP buried markers are essentially modern stela. Similar to Hammurabi's diorite stele, the markers will be made of granite and other materials specifically selected for their durability when buried. The WIPP buried markers will be engraved with information warning against intrusion into the repository. The small buried markers are expected to survive burial and the inscriptions remain legible for 4,000 years, with a high probability of enduring for the entire regulatory period.

5.2.5.4 Historical Analogue: Mesopotamian Artifacts

As described in EPA, 1996a:

"Fired clay tablets containing written material in cuneiform script are commonly found in Mesopotamian tells, as are elaborately carved statuary and bas-relief panels portraying rulers, wars, rituals, and aspects of daily life." (EPA, 1996a, p. 12-10)

For example, rich burial gifts were excavated at Ur (Tell Magajir) dating from approximately 2500 B.C. Inscribed clay tablets have been recovered in the same region dating from as early as 3200 B.C. (Kinder and Hilgemann, 1974).

5.2.5.5 WIPP Relevance: Mesopotamian Artifacts

In addition to the granite markers, other buried markers are also to be fashioned using other durable materials for redundancy purposes, as suggested by Team A of the Markers Panel (Trauth et al., 1993). One of the other materials being considered for the buried markers is fired clay. Based on evidence found in the Mesopotamian tells, the DOE asserts that buried clay markers will last for 5,000 years, with a high probability of enduring for the entire regulatory period.

5.2.5.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of structure). *(1) Material selection—granite is the most durable of rocks routinely used for construction. Fresh granite will be used that has not experienced weathering. (2) Surface preparation—surfaces will be polished to remove all loose material and indentations where water could remain. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location—buried markers to be located 0.6 to 1.8 meters (2 to 6 feet) below the surface will reduce the amount of rainfall that infiltrates down to the markers.*

Excavated during a previous exploration and not there for future communication. *Aerial coverage afforded by the buried markers—surface preparation would have to be done in the exact same location for no markers to be found. Any larger area or slightly different location would mean that buried markers would be found.*

Removal intact (museum). *(1) Multiple markers—if a museum were to remove a few of the markers for a collection, there will still be many markers in place to correctly communicate. (2) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (3) Exhibition in museums provides wider distribution of information; encourages interpretation and study.*

Removal for recycling. *(1) Multiple markers—if a museum were to remove a few of the markers for a collection, there will still be many markers in place to correctly communicate. (2) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (3) random distribution and depths of markers precludes a cost-effective process for recovering the markers.*

5.3 Archives

5.3.1 Conceptual Design

Webster's Collegiate Dictionary (Merriam-Webster, 1991) defines archive as "a place in which public records or historical documents are preserved." This definition implies control of the environment, control of access to the records and documents, and control/selection of the storage medium. A significant part of the overall plan to provide PICs is the distribution of important information remote from the repository for preservation. The archived material will include information that is important to defining the location, design, content, and hazards associated with the WIPP (DOE, 1996, Section XIV). This information will be broader in scope and more extensive in volume than that available within the PICs at the repository-footprint location and

will be widely distributed in a number of locations including some locations worldwide. The initial form of the information will be on archival-quality paper.

Specific documents that will be included in the archived information portfolio include:

1. The *Final Safety Analysis Report* (FSAR) (DOE, 1990a) and the addenda that describe the disposal phase of the WIPP.

2. The Final Environmental Impact Statement (DOE, 1980) for the WIPP and the Supplement(s) to the Environmental Impact Statement (DOE, 1989; DOE, 1990b.)

3. The No-Migration Variance Petition (DOE, 1995b) and the No-Migration Determination for Disposal.

4. The Resource Conservation and Recovery Act (RCRA) Permit (DOE, 1995a).

5. The Certification of Demonstration of Compliance with Title 40 CFR 191.

6. Environmental and ecological background data collected during the pre-operational phase of the WIPP and summaries of data collected during the disposal and decommissioning phases of the WIPP.

7. Records of the waste container contents and disposal locations within the WIPP repository.

8. Drawings defining the construction and configuration of the repository and shafts.

9. Drawings, procedures, and design report(s) describing how the waste was emplaced; how the rooms, drifts, and panels were closed; and how the shafts were backfilled and sealed.

10. Detailed maps describing the exact location of the repository.

11. Design information for the PICs.

In addition, a summary document will be developed that will provide, in a quickly accessible format, the information necessary to communicate the nature and hazards of the waste in the WIPP, in order to deter inadvertent human intrusion.

Locations for this information will include publicly funded organizations that may be more likely to expend the resources necessary to preserve the documents in well-controlled environments. However, the most likely strategy for long-term protection of the information is through widespread distribution. The information will be submitted to the following facilities/ organizations for archiving pending their agreement to receive these documents:

- National Archives and Records Services
- The State Archives of New Mexico and Texas

- The national archives of the world nations that possess nuclear weapons and/or operate nuclear power generating plants
- The archives of the United Nations
- The national archives of the world nations that possess natural gas and/or petroleum resources

5.3.2 Historical Analogue: Vatican Archives

The Vatican Archives (Pasztor and Hora, 1991) were established by Pope Paul V in 1612, almost 400 years ago. The oldest series of documents contained in the Secret Vatican Archives are handwritten copies of the official letters of the popes that form a continuous collection beginning with the papacy of Innocent III from 1198 to 1216, more than 750 years ago. These archives also contain documents dating back to the ninth century (Pasztor and Hora, 1991). The current holdings of the archives consist of some 48 kilometers (30 miles) of full shelves and 15,240 linear meters (50,000 linear feet) of administrative records. For more than 800 years the Vatican Archives and predecessor archives that were incorporated into the Vatican Archives have been receiving documents.

Papal documents are written on organic materials. In 1881, Pope Leo XIII began a restoration laboratory that is today the Vatican's School of Paleography. This laboratory has been supplemented with modern facilities for photographic reproduction. Despite restoration efforts, thousands of documents have turned purple because of a violet-colored fungus scientists have so far been unable to control (Pasztor and Hora, 1991). Several projects are reproducing portions of the Vatican Archives. Some archival documents have been microfilmed and are deposited in the Pius XII Library of St. Louis University. The Vatican Library now stores its most valuable documents in a steel and aluminum vault with a controlled environment and shelving covered with neutral polished aluminum. The covering resists parasites and water seepage.

5.3.3 WIPP Relevance: Vatican Archives

The relevance of the Vatican Archives is both in the durability of the materials and the long-term existence of an institution dedicated to maintaining information despite repeated periods of turmoil.

Various documents within the Vatican Archives have survived for 1,100 years, without the archives' manager being able to control temperature or humidity for most of this period. The materials used were those available at the time, not specially selected papers or inks. Paper with a high cloth content was the norm.

The Vatican Archives represents an institution created to maintain information that was important within a particular religious context. The survival of the archives is evidence that institutions can survive for long periods of time if the information is deemed to be important. The underlying human tendency for story telling, with increased worldwide literacy, is being transformed into a desire to maintain written records of our history. Thus, archives maintaining information of a historical importance can be expected to have a greater impetus for survival than in the past. The health issues associated with nuclear waste disposal will make the information important as long as cancer is still a disease that causes suffering and death and will contribute to the information

being maintained within archives. In addition, the archives will contain data and information of economic importance toindustries and government agencies involved in natural resource exploration and exploitation. Economic importance also will contribute to maintenance of the archives.

The experience of the Vatican Archives provides lessons about what to do and what not to do for long-term maintenance of records. The Vatican, for much of its history, was in the midst of the surrounding political maneuverings, and control of the Vatican and possession of the archives was a strategic prize. For example, Napoleon annexed the Papal States in 1809 and ordered the archives moved to France. The transfer of the archives to France (1810-1811) and the eventual return to Rome (completed by 1817) resulted in the loss of almost one-third of the documents then in the archives; the loss occurred mainly during the period the archives were in France. To guard against such a situation for the WIPP information and to establish the importance of maintaining the WIPP information in the context of personnel safety, the information about the WIPP should be placed in a non-political context. Also for the Vatican records, single copies of documents meant that political turmoil with its attendant destruction could eliminate information. Thus, for the WIPP, multiple storage arenas must exist to guard against losing information.

The DOE will provide WIPP documentation to archives worldwide. The documents will be prepared on archival quality paper. Unlike the one-of-a-kind Vatican documents, many copies of the WIPP documents will exist, adding significantly to a reasonable expectation that catastrophes will not destroy all copies of the documents and that the information will survive for an extended period of time. This philosophy mitigates the risks involved from individual authorities causing the archival material to be moved over a period of hundreds or thousands of years. Multiple copies also provide society with the ability to reconstruct portions or all of a given archive of WIPP documentation should that particular information be lost or destroyed.

The Vatican Archives analogue, combined with improvement associated with lessons learned, would mean that an archive could be expected to endure and maintain records for at least 1,100 years, and have a high probability of enduring for thousands of years. WIPP information could be expected to endure as long as the original paper can survive (i.e., thousands of years).

5.3.4 Historical Analogue: Ancient Documents

Many thousands of ancient documents composed of organically based materials currently are stored in museums, monasteries, and archives around the world. The existence of these documents proves that writing materials other than engravings in stone or clay tablets can preserve information for thousands of years. The British Museum's Department of Antiquities has the world's largest collection of original papyrus documents from Egypt. Thousand of these papyrus documents are from the period of 2400 to 30 B.C. (Rodriguez, 1996a). The University of Michigan has the world's fifth or sixth largest collection of ancient documents. Most of these documents are on papyrus and parchment and are from about 400 B.C. to A.D. 800 (Rodriguez, 1996b). The Greek manuscripts of the Philotheou Monastery on Mt. Athos in Greece number in the hundreds. A catalogue of 125 of the manuscripts cover the period from the 9th century to the 19th century A.D. The oldest of these original documents are on parchment. For the documents

printed on paper, the oldest document on Arabic paper dates from about A.D. 1292, and the oldest document on European paper dates from about A.D. 1315 (Allison, 1996).

Examples of paper enduring for thousands of years are confirmed by Hunter (1978). According to Hunter (1978), a number of original papers have been unearthed covering every century from its "original invention by Ts'ai Lun in China, A.D. 105, onward through the introduction of papermaking in the Occident and its eight hundred years of history in Europe." Illustrations of the oldest printed text in Japan dated from A.D. 770, fragments of paper from the Eastern Han period (A.D. 25 to 220), and a manuscript on paper found in ruins of the Great Wall of China dated from about A.D. 150 are included in Hunter (1978).

5.3.5 WIPP Relevance: Ancient Documents

The examples described above provide evidence of the preservation of documents for thousands of years. The fact that paper exists today that dates to near the time paper was invented supports the premise that society can preserve paper documents for thousands of years. As described above, archiving WIPP information on archival-quality paper in multiple archives worldwide is an unprecedented effort to save information for future generations.

The fact that manuscripts have survived for 1500 to 2000 years, from the time when paper was invented, and can still be read and interpreted by scholars lends credence to society's ability to preserve information and the media upon which that information is recorded. Based on the historical analogue of ancient documents, the DOE asserts that paper will last for 2,000 years and has a high probability of lasting 4,400 years (the duration of papyrus, another crganic material for records).

5.3.6 Potential Failure Mechanisms and Design Solutions

Decay of paper. (1) *Archival paper. (2) Carbon black ink. (3) Controlled environment—even small records centers control temperature. Not withstanding the desirability of controlling the environment to increase durability, temperature and humidity will be controlled for the comfort of the individuals working in an archive.*

Theft. (1) *No original signatures, seals or other items to make the physical record salable on the black market. (2) Multiple copies—records can be recreated; reduces sale value.*

Misfiling. (1) *Indexing system created and agreed upon before records are ever sent to a records center or an archive. (2) Distinctive (inexpensive) binding for the records.*

Catastrophes (including fire, flood, tornadoes, earthquakes). *Multiple copies—records can be recreated.*

Recycling. (1) *Concise summary—reduces the shelf space required for the information and discourages the entire collection from being discarded. (2) Cover contains language about long-term importance of the information contained in the record (safety).*

Archivist deciding that records are no longer important. (1) *Concise summary—reduces the shelf space required for the information and discourages the entire collection from being discarded. (2) Cover contains language about long-term importance of the information contained in the record (safety).*

Lost (including while consolidating collections, moving). *Multiple copies—records can be re-created.*

Deliberate destruction (other than governmental actions). *Multiple copies—records can be re-created.*

Warning understood but believed to be for prior generations or other intruders. *Cover contains language about long-term importance of the information contained in the records (safety issues).*

Warning not understood. *(1) Endurance of English (Assumptions 11-13). (2) Communication through means other than language (e.g., pictures, graphs, figures, and maps) (see assumptions).*

5.4 Records Centers

5.4.1 Conceptual Design

Records centers, for the purpose of making a distinction from archives, are locations that would generally permit freer access by members of the public and do not normally exercise the degree of environmental control and information-medium selection to be found in modern archives. These records centers will not receive the same quantity of information allocated to archives (DOE, 1996, Section XV). Information provided to these records centers will be focused on location, design, and hazards information. The DOE will provide a summary document with a distinctive and easily recognizable binding for each records center. The records centers will include various federal and state agencies and commercial mapping agencies to ensure that the WIPP location and drilling or mining restrictions are identified on widely distributed maps used by almost all public and private organizations. These federal and state agencies (or their successors) include:

- The U.S. Nuclear Regulatory Commission
- Bureau of Land Management
- U.S. Geological Survey
- Library of Congress
- Defense Mapping Agency
- International Boundary Commission
- Federal Highway Administration
- New Mexico State Highway Department Planning and Research Division, Cartography Section
- One-Call System of notification of underground utilities
- The local office of the Bureau of Land Management
- The local office of the Bureau of Reclamation
- The Albuquerque office of the Bureau of Indian Affairs

- The Federal Records Center serving New Mexico
- The local offices of the New Mexico Oil Conservation Division

To further the widespread distribution of WIPP information, materials will also be offered to a number of libraries including:

- The New Mexico and Texas State Libraries
- The state libraries of the remaining 48 states
- The City Libraries of population centers exceeding 15,000 within 150 miles of the WIPP site
- The 53 Federal Regional Depository Libraries
- The major universities of New Mexico and Texas

To ensure widespread distribution of location information of the WIPP site and the hazards associated with the emplaced waste, detailed maps and descriptions of the hazardous material will be sent to national and international professional societies of cartographers and geographers. Weitzburg (1982) suggests the following organizations and societies receive this location and hazards information:

- The American Congress on Surveying and Mapping
- The American Society of Cartographers
- The Commission for the Geological Map of the World
- The International Cartographic Association
- The American Geographical Society
- The Association of American Geographers
- The International Geographical Union
- The Society of Women Geographers
- The American Geological Institute
- The American Geophysical Union
- The American Society of Professional Geographers
- The National Geographic Society
- The Federal Aviation Administration
- Mining, Oil, and Gas Professional Organizations

These organizations and societies can be supplemented by contacting the American Historical Association, the National Institutes of Health, and the Centers for Disease Control for guidance in the distribution of documents. The actual distribution of the information will depend on agreements worked out between the DOE and these organizations and societies.

Many members of these various organizations are employed in secondary and college education providing an opportunity for this information to become more widely disseminated among students during their formal education. In addition, companies providing energy and resource-related data to commercial ventures active in the Delaware Basin will receive location and hazardous record information. Examples of such companies include

- Midland Map Company of Midland, Texas
- Petroleum Information Corporation of Midland, Texas
- Tobin Data Graphics of Austin, Texas
- Dwight's Energy Data of Denver, Colorado

5.4.2 Historical Analogue: German Archives

The German archives discussed here (Brachmann et al., 1991) consisted of state, city, and church archives of the pre-WW II era. These archives contained one-of-a kind records pertinent to the location of the archives. During the course of the war most of the archives were moved in part or in whole in order to protect them from Allied bombing. The failure modes were from direct war damage (e.g., bombing, fire, or water from putting fires out), or from transit (vehicles were direct targets, vehicles broke down and were pillaged by the local inhabitants), and from alternate storage options (wine cellars were relatively inaccessible but damp, thus promoting the deterioration of the paper, and salt mines provided a dry, bomb-proof environment, but this environment resulted in the corrosion of any metals associated with binding the books or storage containers).

Extraordinary measures may be taken by at least some segments of society to protect documents perceived to be of value to society (including such things as church records of births, deaths, baptisms, etc.). For example, numerous archivists were killed trying to save records. and common individuals recognized the importance of the archives:

> "Putting individual material in private locations was considered 'billeting'. The question of moral or materialistic motivation of the individuals providing their property for storage purposes could be of significance. However, a large part of the population esteemed not only German archival material but also foreign and even enemy 'cultural assets.' Appeals for the protection of cultural assets found support, despite the tremendous existential problems of the period." (Brachmann et al., 1991, pt. II, p. 41)

Pillaging of the archives by the local population was generally driven by desperation caused by the shortages of basic goods necessary for survival. Even the 'enemy' valued the intrinsic value of archives and records. For example, after the war, the allied forces sent special commandos into occupied territory to protect the general cultural and archival materials.

Despite the ravages of war, a surprising number of archives remained relatively intact. According to Brachmann et al. (1991):

> "A number of archives suffered varying degrees of damage during WW II. Some archives did not suffer losses or damages, others were totally destroyed. However, the large part of archival materials in Germany survived the war without appreciable damages." (Brachmann et al., 1991, pt. I, p. 10)

5.4.3 WIPP Relevance: German Archives

This experience indicates that even in a "total" war, areas away from strategic targets and areas of troop engagements can remain virtually untouched. During periods of crisis and upheaval, some

buildings and documents will be lost, and no way exists to predict what will constitute a target at any particular time.

The lessons learned from the German archives are that numerous copies of the WIPP records should be produced, these records should be widely distributed (i.e., to assure that at least some of the records are not in strategic locations), and an effort should be made to impart a sense of value to the records so that future generations will make the necessary effort to preserve them.

The experience of the German archives and the great effort that went into preserving the records and the lessons learned indicate that even with significant political and social upheaval, records can and are likely to be maintained.

5.4.4 Potential Failure Mechanisms and Design Solutions

Decay of paper. (1) *Archival paper. (2) Carbon black ink. (3) Controlled environment—even small records centers control temperature. Not withstanding the desirability of controlling the environment to increase durability, temperature and humidity will be controlled for the comfort of the individuals working in an archive.*

Theft. (1) *No original signatures, seals or other items to make the physical record salable on the black market. (2) Multiple copies—records can be recreated; reduces sale value.*

Misfiling. (1) *Indexing system created and agreed upon before records are ever sent to a records center or an archive. (2) Distinctive (inexpensive) binding for the records.*

Catastrophes (including fire, flood, tornadoes, earthquakes). *Multiple copies—records can be re-created.*

Recycling. (1) *Concise summary—reduces the shelf space required for the information and discourages the entire collection from being discarded. (2) Cover contains language about long-term importance of the information contained in the record (safety).*

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Deliberate destruction (other than governmental actions). *Multiple copies—records can be re-created.*

Warning understood but believed to be for prior generations or other intruders. *Cover contains language about long-term importance of the information contained in the records (safety issues).*

Warning not understood. *(1) Endurance of English (see assumptions). (2) Communication through means other than language (e.g., pictures, graphs, figures, and maps) (see assumptions).*

5.5 Government Land Ownership and Control

5.5.1 Conceptual Design

The U.S. Government controls the 16 sections that are included in the WIPP Withdrawal (Figure 1-2). Within this Withdrawal, all land-use leases are also retained by the federal government with the exception of two, 129.5-hectare (320-acre), oil and gas leases in Section 31. Section 31 is the southwestern most section of the 16 sections withdrawn under the LWA. The two leases permit oil and gas development below 1,829 meters (6,000 feet) from the surface. Section 31 does not include the area planned for repository use. Government control is a passive control providing for the transfer of information on the status of land ownership. It is not an active control, in so far as the information does not overtly prevent intrusion. It is expected that government control of this area will be retained for as long as a U.S. Government exists. With government ownership of the resource leases for the withdrawn sections, commercial resource exploration and development entities cannot drill or mine in and immediately around the repository without receiving permission. Any organization contemplating resource exploration and development within the Withdrawal would learn of the government control immediately upon initiating search of lease availability within the appropriate records center(s) pertaining to Eddy County New Mexico.

In accordance with the LWA, the 16 sections at the WIPP were " . . . withdrawn from all forms of entry, appropriation, and disposal under the public land laws, the material sale laws . . . and mining laws" [Public Law 102-579, 1992, Sect. 3(a)(1)]. The objective of the DOE with respect to mining and oil and gas production is to ensure that the development of resource leases does not affect the integrity of the disposal system. Accordingly, no surface or subsurface mining unrelated to the WIPP construction, or oil or gas production, including slant drilling from outside the boundaries of the Withdrawal are permitted at any time, including post-decommissioning, with the exception of the two existing oil and gas leases. These leases prohibit drilling within the first 1,829 meters (6,000 feet) of the surface within the Withdrawal (DOE, 1993). The LWA does permit the Secretary of Energy to permit grazing, hunting, and trapping within the Withdrawal.

This prohibition is in direct contradiction to the PA assumptions that drilling will take place at historic rates for the 10,000 years of regulatory concern.

5.5.2 Historical Analogue

The search for historical analogues for land restrictions at the WIPP suggests examples such as the Boston Commons and the plaza in Santa Fe. These locations are both examples of areas that have been owned by a government and under government control for long periods of time. Both locations are areas of controlled public usage (some activities are allowed and some activities are prohibited), despite changes in the particular government. Boston Commons was created when the land was a part of the thirteen colonies of Great Britain (Boston was founded in 1630), and

the public land use continued once it was a part of the United States. The plaza of Santa Fe was created under Spanish rule (Santa Fe was founded in 1610), remained as such under Mexican rule (1821-1846), U.S. rule, a brief occupation by Confederate forces (1862), and once again U.S. rule (Jenkins and Schroeder, 1974). The only period of unknown status was the period during and after the Pueblo revolt (1680-1692) until the location was reestablished as being a part of Spanish lands. More contemporary examples of areas of land being set aside for the public use/good are New York City's Central Park, the Mall in Washington D.C., and Balboa Park in San Diego.

A different type of government land for public use is Yellowstone National Park, established in 1890 as the United States' first national park. Park management allows access by the public, but with restrictions on the activities that can take place within the Park (e.g., no new leases for resource development). At the time of its establishment, Yellowstone was a remote area, with limited access to communication or transportation. Yellowstone was established to benefit the nation as a whole by preservation of our natural assets.

5.5.3 WIPP Relevance

Within our national history, governments have established and controlled areas for the greater good of the society by restricting the activities taking place there.

Even though the Boston Commons and the Santa Fe plaza could be of major financial benefit were they to be sold for private development, governments have chosen to retain ownership and control rather than short-term financial gain. As long as significant public pressure is applied that the value of safety is greater than the financial value of land or mineral resources, the Withdrawal, and especially the repository footprint will be maintained.

Throughout its history, Yellowstone has been located in an area more remote than the area surrounding the WIPP. The WIPP is not situated in as remote a location as it appears—people travel to the City of Carlsbad by plane and by private vehicle, and the WIPP is only 42 kilometers (26 miles) from the City of Carlsbad. Significant traffic is generated by trucks collecting oil from tanks and by gas lines being monitored periodically. Increased population and the ease of travel and communication cast doubt on the WIPP/Carlsbad area becoming more remote in the future.

5.5.4 Potential Failure Mechanisms and Design Solutions

Government considering opening up the Withdrawal to resource exploration and exploitation. *Wide dissemination of information about the safety issues associated with maintaining the integrity of the disposal system—wide distribution of the information will make it available to more of the general populace so that there continues to be pressure not to open up the Withdrawal.*

5.6 Other PICs

Other PICs may be incorporated to trigger society's awareness of the WIPP location and cautions regarding the maintenance of its integrity. These "awareness triggers," which will be discussed in Chapter 7, include

- Incorporation of the WIPP's location on various maps and road atlases
- Description of the WIPP's location and content within the subject matter of encyclopedias and common reference material
- Identification of the WIPP as a geographical name in dictionaries
- Descriptions of the WIPP incorporated within the text of high-school and college-level history and science books
- Development of a home page for the WIPP on the Internet (the current home page address for WIPP information is **http://www.wipp.carlsbad.nm.us**)

Examples of specific areas being identified on maps can be found in various road atlases. Gousha (1993) designates specific sites such as the "Nevada Test Site" and "Nellis Air Force Range" in Nevada, the "Chocolate Mountain Gunnery Range" in southern California, and the "White Sands Missile Range" in New Mexico. Certain areas in western Nevada are designated by the generic warning "Danger Area."

5.7 Materials Issues

Granite is an igneous rock that crystallized at depth within the Earth's crust. As a result, the minerals that compose granite are not thermodynamically and chemically stable in geologic timeframes at the lower pressures and temperatures at the Earth's surface. However, for the time frames of interest, the thermodynamic instabilities of the minerals in granite are much less important than physical properties (e.g., mineral solubilities and rock porosities) of other rock types used in buildings and monuments (e.g., marble, limestone, and sandstone). Because the minerals in granite are less soluble than those in marble and limestone, and have a lower porosity than sandstone to resist water intrusion with freeze and thaw cycles, granite is more resistant to weathering than these other rock types.

Selection of stainless steel for use as the radar reflectors is based on a combination of cost and corrosion resistance. The reflectors would be constructed of sections about 1.3 cm thick and approximately 0.9 m on a side and welded to form a trihedral. Berry (1983) reviews earlier studies of various stainless steel alloys in soils. Type 316 stainless is the most resistant of the steels covered in Berry (1983). In one study the weight loss extrapolated to penetrations of 0.0027 to 0.55 millimeters in 10,000 years. Encasing the reflectors in concrete should further enhance their survivability. Berry (1983) also provides data supporting much better corrosion resistance for titanium and hastealloy. However, both of these materials are more costly than stainless steel. A fourth material that may also prove acceptable for this application is monel. Testing during the operational and active-controls period after disposal will be utilized to determine whether or not protecting the stainless steel will improve its survivability sufficiently to justify its use instead of the more corrosion resistant materials available. Use of titanium or hastealloy may also increase the likelihood of future generations mining the reflectors for their commercial value.

The planned use of strontium ferrite magnets is based upon their retentive ability, strength, and cost. In discussions with a supplier, Magnet Sales & Manufacturing Co. of Culver City, California, it was stated that although strontium ferrite magnets are not quite as strong as samarium cobalt, there is significant cost differential (a factor of 7). Alinco magnets are the least

expensive of the three materials but lose their strength at an almost linear rate of 0.1 percent per 10,000 hours. However, samarium cobalt and strontium ferrite magnets achieve a nearly asymptotic value in 10,000 hours. More extensive testing during the latter part of the operational phase and the active-controls phase will be conducted to determine the best alternative for the final design.

5.8 Conclusion

The historical analogues described above support the premise that our current society has the capability to develop systems composed of components that will endure and pass information on to succeeding generations. The use of large, massive structures provides the greatest chance for the survival and promulgation of information for thousands of years. By their presence, large structures will convey a Level I message that something made by humans is present. Information preservation is enhanced by engraving messages in stone and burying the information. However, this approach to preservation does pose the problem of discovery of the message by future generations. Alternatively, engraving on massive stone outcroppings, such as the Rock of Behistun, or on stone markers, such as the Code of Hammurabi stele, supports the premise that engraving can withstand the ravages of the environment for thousands of years. Although not as durable as stone, organic-based materials such as vellum and papyrus have also been successful in preserving original records for more than 2,000 years. Not only have these ancient records survived, but also their languages can be understood today even though the languages may not be in use. The Vatican Archives demonstrate that records can be stored for centuries. An additional aspect supporting the preservation of information over thousands of years is that historians and archivists have had and continue to have an ongoing interest in the preservation of information and documents. An example of this is Herodotus' history (written in the 5th century B.C.) of the Pyramids, which were built about 2,000 years before his time. His descriptions have survived to our time through additional historical documentation efforts even though the original materials upon which he described the individual events may not have survived. Thus, even if original documents do not survive, the information contained in them can survive through the efforts of historians and archivists.

The use of these historical analogues as models for the PICs system support the concept that the WIPP warnings will be successfully conveyed to the future. Historically, some monuments have ceased to exist. However, the permanent marker design concept has focused on successful monuments that have withstood time and provide support for the "reasonable expectation" that the WIPP's PICs will endure for thousands of years and may even surpass the 10,000-year regulatory time frame.

The single most significant feature of the PICs for the WIPP is the widespread distribution of information describing the history, design, location, and hazards associated with WIPP's storage of transuranic and hazardous wastes. No historical analogue replicates the degree of effort represented in the WIPP PICs in communicating with future generations. The widespread distribution of WIPP information in archives, records centers, and other published media gives ample justification for a reasonable expectation that future generations will have information in an understandable format regarding the hazards associated with intruding into the WIPP repository and its location.

6.0 EFFECTIVENESS OF PICS IN REDUCING THE FREQUENCY OF INADVERTENT HUMAN INTRUSIONS AT THE WIPP

The previous chapters to this report have discussed the regulatory constraints on assessing the effectiveness of PICs in deterring inadvertent human intrusions, the assumptions used by the PTF in estimating this effectiveness, the conceptual design of the PIC components, the historical analogues that provide insight into how long structures and materials can last and information can be understood, possible failure mechanisms for each component and how the conceptual design for each component counteracts these mechanisms, and the redundancy and reinforcement between PIC components. This chapter integrates the information in these earlier chapters and provides the PTF's estimates of the effectiveness of PICs in discouraging inadvertent human intrusion into the repository footprint and the Withdrawal as a function of time. These inadvertent human intrusions, as guided by 40 CFR Part 194, are drilling for and the mining of natural resources. This chapter also includes arguments supporting these estimates.

6.1 PTF Estimates of PIC Effectiveness in Deterring Future Inadvertent Human Intrusions

The PIC system consists of integrated components some of which act as "awareness triggers" designed to encourage an investigator or potential intruder to obtain additional information before engaging in potentially disruptive actions at the repository footprint or within the Withdrawal. These awareness triggers by themselves have no deterrent value. Other components, both alone and in combination, are designed to act as deterrents to potentially disruptive actions. The following discussion examines each of the components from the point of view of effectiveness as a function of time.

6.1.1 Deterrence of the Marker System at the Repository Footprint

Each of the markers at the repository footprint has been specifically designed for durability. Durability will be achieved by the choice of construction material used along with the size of the marker and/or placement (i.e., exposed versus buried). In estimating deterrence for this component, the marker system is considered as a whole to account for its Gestaltic nature rather than as individual markers

6.1.1.1 Berm

The berm surrounding the repository footprint is intended to convey a Level I message that something built by humans is present. A Level I message is an awareness trigger rather than a deterrent. As a result, this particular marker has no deterrent value, although the presence of the berm may enhance the deterrence of the other markers by making the potential intruder aware that the repository site is different than the surrounding area and more information is needed prior to the initiation of intrusion activities. The historical analogues used to estimate the durability of the berm are the earthen banks surrounding the monoliths at Stonehenge (see Chapter 6). These banks were constructed as piles of earth with no reinforcement or other features designed to extend their lifetime. Based on the assumption that current science and technology has the capability to construct an earthen structure at least as durable as the banks at Stonehenge (Assumption 22) and the belief that this capability is represented in the conceptual design of the

berm (Assumption 21), the PTF concluded that the berm will survive for at least 4,700 years after disposal, which is the minimum lifetime of the banks at Stonehenge. The size, the layered structure, and the selected materials of the berm will ensure that this structure has a high probability of surviving far longer than the Stonehenge banks have survived to date. Because of the volume of the various materials in the berm, recycling of any of these materials in the future will result in large volumes of the other materials (e.g., mining the salt) being left behind (e.g., the ripramand caliche), which will continue to convey the Level I message.

6.1.1.2 Monuments Outlining the Repository Footprint

The monuments that contain Levels II, III, and IV messages will be composed of granite. Based on the historical analogues of the monoliths at Stonehenge and the Rock of Behistun, (see Chapter 6), these monuments at the WIPP will be able to remain intact for at least 4,000 years, which is the minimum lifetime of the Stonehenge monoliths, and the engraved messages on the monument will be legible for at least 4,000 years, which is the minimum lifetime of the engraved messages on the Rock of Behistun. Because these ages are minimums, a life expectancy for the inscriptions on the monuments substantially longer than 4,000 years after disposal is realistic and highly probable.

Estimates of the ability of future generation to read and understand the warnings on the monuments are based on the assumptions that current English will continue to be readable by individuals working in the natural-resource industries (possibly as a specialized second language) due to the nearly continuous resource exploration and exploitation in the WIPP area and the Delaware Basin (Assumption 13) and that pictures will be able to convey meaning independent of or as a supplement to written warnings (Assumption 4) (e.g., facial expressions representing emotions and pictographs representing potentially harmful activities). Based on these assumptions, the warnings inscribed on the monuments will be understood by individuals within the natural-resource industries for thousands of years after disposal

The number of monuments within the relatively small repository area provide a level of redundancy that suggests that the monuments will remain an effective deterrent to inadvertent human intrusion into the repository in the event that one or several of the monuments are deliberately destroyed or removed.

6.1.1.3 Information Center

An Information Center will be constructed in the center of the footprint. This center will have granite walls set into caliche, and these walls will be inscribed with Level IV information. The lack of a roof for this room provides natural lighting but also allows for the walls to be exposed to a limited amount of weathering and for wind-blown sand to settle into the room. The historical analogues used by the PTF for the Information Center are the Acropolis for the durability of the structure and Australian rock art for the partially exposed engravings. Based on the assumption that today's scientists and engineers, through engineering design and selection of materials, can built a rock structure that endure for at least as long as the structures at the Acropolis (Assumption 22), the PTF concluded that the Information Center will survive for at least 2,400 years after disposal, which is the minimum age for most of the structures at the Acropolis. The

much-older Egyptian pyramids were not used as an analogue for the Information Center, because the pyramids are massive structures, which are not structurally analogous to the Information Center, whereas buildings at the Acropolis were designed for human use and structurally more analogous to the Information Center.

Inscriptions on the walls within the Information Center will be partially protected from wind-driven rain, snow, and sand by the outer walls. This configuration is similar to the Australian rock art consisting of paintings, engravings, and peckings located on partially protected surface. The fact that this rock art has been able to survive for tens of thousands of years indicates that the inscriptions in the granitic rock of the Information Center will endure for as long as the inscribed surfaces are protected (Assumption 22) (including walls knocked over in a face-down position or buried by drifting sand). Even if the structue of the Informaiton Center fails, the protected insriptions could survive for tens of thousands of years.

The Level IV messages within the Information Center will consist of both written messages and pictures. Estimates by the PTF of the interpretability of the warnings within the Information Center were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about the meaning behind unfamiliar structures and writings (Assumption 1), (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries or governmental agencies (Assumption 13) (possibly as a specialized second language), and (4) pictures will be able to convey meaning independent of or as a supplement to written warnings (e.g., facial expressions representing emotions and pictograph representing potentially harmful activities). Based on these assumptions, the PTF concluded that the inscribed warnings on the walls of the Information Center will be understood by individuals within the natural-resource industries or governmental agencies for thousands of years after disposal.

6.1.1.4 Buried Storage Rooms

The two buried storage rooms also will be constructed of granite. One room will be buried in the berm as protection during the early times of the regulatory time frame. As the berm ages and erosion occurs, portions of the buried room (e.g., a corner, edge, or wall) may become exposed at the surface thereby informing future generations of the existence of another source of information, and adding another source of warning messages to potential intruders. Exposure of the buried room would occur later in the regulatory time frame after the monuments and the information center have been exposed to surficial erosion processes and may undergo some surficial degradation. Although both the monuments and the Information Center are expected to remain intact for at least several thousand years, the exposure of the buried room will reveal another source of detailed information as to why human intrusion should not be attempted. The other room will be buried below grade outside the berm. This room is not expected to be exposed by natural processes, but its location will be described in the archives and in the Information Center. Future generations may choose to excavate this room to obtain Level IV information.

The historical analogues for the buried rooms are Newgrange and the rooms within the Egyptian pyramids. Based on the assumption that current science and technology have the capability to

construct buried rooms at least as durable as these analogues, and the belief that this capability is represented in the conceptual design of the buried rooms, the PTF concluded that the buried rooms will survive for at least 5,000 years after construction, which is the minimum age of Newgrange.

Inscriptions in the walls of the buried rooms will be completely protected from weathering and erosion for as long as the rooms remain buried. The inscriptions in the walls of the rooms contained within the Khufu pyramid exhibit no signs of deterioration 4,500 years after being carved into the rock, and the broader patterns engraved in the interior walls of Newgrange exhibit no signs of significant deterioration after 5,000 years. Based on these analogues, the PTF concluded that the inscriptions in the walls of the buried rooms at the WIPP will endure for at least 5,000 years.

The Level IV messages within the buried rooms will consist of both written messages and pictures. Estimates of the interpretability of the warnings within the buried rooms were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about the meaning of unfamiliar structures and writings (Assumption 1), (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries or governmental agencies (possibly as a specialized second language) (Assumption 13), and (4) pictures will be able to convey meanings (Assumption 4) independent of or as a supplement to written warnings or by themselves, if the buried rooms are exposed or exhumed far enough into the future when an understanding of current English is lost by the general populace. Based on these assumptions, the PTF concluded that the inscribed warnings on the walls of the buried rooms will be understood by individuals within the natural-resource industries or governmental agencies for thousands of years after disposal.

6.1.1.5 Small Buried Markers

The conceptual design for the marker system includes a relatively large number of small markers that will be buried at random intervals and depths across the area of the repository footprint. By design, these markers will be encountered during the preparation of any location within the footprint for drilling operations (e.g., digging a mud pit). The material used to construct these markers will be selected through an experimental program to assure that the markers will not undergo significant chemical alterations from contact with the enclosing sediments and soils within the regulatory time frame, thereby ensuring that these markers will endure.

The historical analogues for the buried markers are the diorite stele that contains the inscriptions of the Code of Hammurabi and the artifacts found in Mesopotamian tells and tombs. Based on the assumption that the materials selected through the experimental program for these markers will survive with no significant deterioration of the inscriptions for at least as long as the stele and the artifacts (Assumption 22), the PTF concluded that the buried markers will survive for at least 3,700 years, which is the approximately the time frame during which the stele was buried, with a high probability of surviving longer than 4,500 years, which is the minimum age of some of the older Mesopotamian artifacts.

Buried markers will contain a Level II message. Estimates of the interpretability of the warnings on these markers were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about the meaning of unfamiliar objects and writings (Assumption 1), (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries or government agencies (possibly as a specialized second language) (Assumption 13), and (4) pictures will be able to convey meanings (Assumption 4). Because the buried markers will contain symbols instead of pictographs, the effectiveness of this portion of the message may be less than the higher-level messages conveyed by the figures and pictographs on the markers and in the buried rooms and Information Center. The PTF concluded that the basic message of danger conveyed by the text inscriptions will be understood by individuals associated with natural resources for the sands of years after disposal. If the symbols cannot be understood, the inherent curiosity of future generations will make the symbols awareness triggers.

6.1.1.6 Effectiveness and Endurance of the Repository Marker System

Each marker component, except for the berm which is an awareness trigger, will have the capability to independently deter future inadvertent human intrusion. Failure of the marker system requires the failure of all of the components of the system. No failure mechanism for all of the components has been identified. Based on the materials to be used to construct the various types of markers, the redundancy of the warning messages at the various message levels, the numbers of markers, and the marker distribution, the marker system at the repository footprint (approximately 0.5 square kilometers [0.2 square miles]) will completely deter inadvertent human intrusions within the repository footprint for thousands of years based on the assumptions previously discussed about the nature of people and society and the use of historical analogues.

6.1.2 Monuments at the Land Withdrawal Area Boundary

An additional set of monuments is to be placed along the boundary of the Withdrawal (approximately 41 square kilometers [16 square miles]). These monuments have the same design specifications as the monuments at the boundary of the repository footprint, although the warning message on these outer monuments will place more emphasis on deterring intrusion into the Withdrawal outside of the repository footprint. Because these outer monuments will be compositionally and dimensionally the same as the inner monuments, the estimates of durability for these two sets of monuments is the same. The warning message on these outer markers will be a little less emphatic than the one on the inner markers. A warning to not disturb the ground-water flow system is abstract and is unlikely to have the same sense of importance as a warning against activities that could result in the release of radionuclides from a buried storage facility. In addition, the area of danger clearly will be the one marked by the berm, the inner monuments, and the information center based on the greater level of effort in constructing markers. This lack of compelling reason not to intrude along with an absence of redundancy of the message on other markers will likely result in less deterrence than the message to be conveyed by the repository markers, especially if the other confirmatory components (e.g., records and government control) of the importance of the entire Withdrawal begin to fail. For these reasons, the marker system at the Withdrawal boundary is assumed to be less effective than the markers at the repository

footprint, although this decrease in effectiveness will not occur until at least a 1,000 years after disposal, which is equivalent to the time between current and Old English.

6.1.3 Records Centers

For the purpose of estimating the effectiveness of records in deterring intrusion, the records are considered in two types of records centers. One type of records center consists of depositories at both the regional and national levels (e.g., regional depository libraries and the Federal Records Center in Denver, Colorado). The depositories hold a wide variety of information and documents among which the WIPP records would be just one more set of records. The other type of records center consists of agencies that deal with land use, especially in the areas of natural-resource exploration and exploitation (e.g., Bureau of Land Management and New Mexico Oil Conservation Division). In this second type of records center, the WIPP records would be more distinctive, because these records will deal with how the land can and cannot be used, in addition to containing potentially significant economic information.

Based on historical records, fragments of wood-based paper have survived for most of the nearly 2,000 years since its invention, and an uninscribed papyrus roll has been found in an Egyptian grave approximately 5,000 years old (Gaur, 1992). The volume of ancient documents that have survived to the present with no or limited attention to preservation indicates that the survivability of documents that are cared for will be high. These historical analogues suggest that the WIPP records printed on paper developed for an extended life expectancy and stored in records centers should be able to survive relatively intact for several thousand years. As a historical analogue for writing on an organic material, papyrus with written hieroglyphics dates to approximately 4,500 years ago (Gaur, 1992). This historical analogue indicates that printed WIPP documents can survive for as long as the paper. An additional factor that improves the survival of the records is the human habit of reproducing records. The PTF estimates have not included credit for future generations reproducing documents except in the case of restoration of a records center following catastrophic loss of records (e.g., fire or natural disaster).

The German archives during WWII serve as the historical analogue for the distribution of the WIPP documents in numerous records centers. The fact that the large part of these archives survived the war indicates that the distribution of WIPP records to a large number of records centers essentially guarantees that at least some copies of these records will survive for an extended period of time into the future.

The general records centers are and will be depositories for a wide variety of information and a large volume of documents. These records centers also will contain Level V WIPP messages. Over time, the importance of the normal records may be lost to individuals operating the records centers, and the records may be replaced with what are perceived to be more important records, in which case the records could be destroyed or relegated to a less prominent area within the records center. The conceptual design for the WIPP records contain provision for making them distinctive, concise, and of readily recognized value. Estimates of the effectiveness of the general records centers in deterring inadvertent intrusion were based on the following assumptions:
(1) future generations will continue to use writing as a means of communication (Assumption 2),
(2) future generations will continue to be curious about unfamiliar writings and structures

(Assumption 1), and (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries and government agencies (Assumption 13) along with those individuals in other fields of endeavor in which historical documents are important (Assumption 12). Because of the prominence of the WIPP records, the PTF concluded that the warnings contained in the WIPP records of the general records centers will be completely effective deterrents for anyone checking these records centers for possibly 1,000 years or more after disposal. Beyond this time, the records begin to decrease in deterrence value because of the likelihood of these records will be lost within the records centers. In the vicinity of 4,000 years (i.e., twice the lifetime of the oldest existing paper fragments and approximately the lifetime of some of the older papyrus), the possible deterioration of the original records may begin to be a factor. This deterioration combined with the possible loss of records in the records centers may result in a rapid decrease in the deterrence value of the general records centers. Because of the wide-spread distribution of general records centers and the diverse nature of the types of records centers, no pattern of document survival or effectiveness is applicable to all records centers.

The resource records centers are and will be the depositories for more specialized documents and information related to resource and land ownership and use. Based on the same assumptions used for the general records centers and the addition assumptions that resource exploration and exploitation will continue for the entire regulatory period (Assumptions 16 and 17) and government in any form will require record keeping and consultation of records (Assumptions 8, 9, and 10), the PTF concluded that resource records centers will remain active throughout the regulatory period. Because of this activity and the importance of the WIPP records, these records will be consulted by individuals associated with natural resource exploration and exploitation (Assumption 18) and will be highly effective deterrents to inadvertent intrusion (Assumptions 6, 8, and 10) for at least a couple of thousands of years after closure. Failure of the WIPP records to deter will be the result of catastrophic record destruction and the physical deterioration of the records. The wide distribution of the WIPP records in numerous records centers virtually assure that at least some copies of these records will survive for an extended time and that lost records can be reproduced.

6.1.4 Archives

Archives are designed to preserve historically significant documents. In this capacity, the role of archives is preservation rather than the dissemination of information. As a result, the WIPP records will be stored under conditions that will extend their life expectancy relative to documents in records centers. The PTF considered the Vatican Archives as a historical analogue for the durability of an archive as an institution and the ancient paper, papyrus, and other documents as historical analogues for the WIPP documents to be stored in the archives. The assumptions used by the PTF to estimate the effectiveness of the archives in deterring inadvertent intrusion were basically the same as for the records centers (see Section 7.2.3).

Using the Vatican Archives as a historical analogue, the PTF concluded that the archives in which the WIPP records will be stored have the capability to survive as institutions for at least 1,100 years, which is the minimum age of the Vatican Archives. Because of the seemingly universal recognition of the documents in archives as historically important, the PTF concluded that future societies will go to great lengths to preserve the documents within an archive, even though the

structure housing the documents is expendable and replaceable. The limiting factor is the life of the paper, because the institution or a successor was assumed to last indefinitely. With optimum storage conditions and limited use, the documents within the archives, and especially the WIPP records, will last substantially longer than the records in the records centers. Documents in the archives should last as long as the ancient documents considered as historical analogues described above even if the physical structure housing the documents do not. The PTF concluded that the WIPP records in archives will survive in at least some of the archives for at least 5,000 years. Archives suffer some of the same problems as records centers in that documents can be "lost" through such actions as misfiling, reshelving, and in some cases, destruction or theft.

The WIPP records in the archives will contain Level V messages. Estimates of the effectiveness of the archives in deterring inadvertent intrusion were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Assumption 2), (2) future generations will continue to be curious about unfamiliar structures and writings (Assumption 1), and (3) current English will continue to be understood by individuals within the natural-resources exploration and exploitation industries and government agencies (Assumption 13) along with those individuals in others fields of endeavor in which historical documents are important (Assumption 12). For the potential intruder or the site investigator who visits an archive, the warnings within the WIPP records will be readily understood for more than 1,000 years after disposal because of the specialized vocabulary based on current English associated with natural resource and land use. Because of the large volume of records and document in current English within an archive, a high probability exists that someone working at the archive will be able to translate current English into the future dialect of the time for anyone unfamiliar with current English. Readily available translation will be available for a much longer period beyond 1,000 years after disposal, which is equivalent to the time between current and Old English.

In a regional sense, the deterrence value of the archives compared to records centers will be relatively low in the early part of the regulatory time frame, because the archives will be farther away from the WIPP than the records centers, which are the traditional sources of land-use and natural-resource information to the natural-resource industry. As the documents in the records centers start to deteriorate and/or become lost in the volume of records that will be submitted, the reliance on the archives will increase because of the better preservation of the documents. The level of deterrence of the archives will not reach the peak levels achieved by the deterrence of the records centers because of the remoteness of the archive sites from the WIPP, and the possibility of archives losing the records.

6.1.5 Government Control of Land Use

Government control of land use consists of written instructions in any government-agency offices where land-use determinations are and will be made specifying the prohibited uses, and covenants on land use written into surface- and resource/mineral-rights leases. A basic assumption used by the PTF is that any prudent extrapolation of the current form of government (Assumption 7) will continue some form of land-use control (Assumption 8), especially in those areas having natural-resource potential (Assumption 10). These offices are one of the types of records centers discussed in Section 7.1.3.

The PTF concluded that land-use restriction will be completely effective deterrents against inadvertent human intrusion for as long as the paper recording these restrictions lasts. Because of the specialized and limited vocabulary associated with land-use restrictions, these restrictions will be interpretable by individuals in the natural-resource industries and/or government agencies (Assumption 13) for thousands of years. The PTF assumed no credit for the land-use restrictions being transcribed to other copies of documents.

6.2 Awareness Triggers

Several of the components described in Chapter 6 have no deterrent value on their own, but may contribute to the effectiveness of the PICs system. These components have been labeled as "awareness triggers," because each of these components has the potential to make a potential intruder or site investigator aware of the existence of the WIPP, and therefore aware that additional information about the WIPP should be obtained. These awareness triggers are:

- berm
- government ownership of the Withdrawal
- incorporation of the WIPP's location on maps and road atlases
- description of the WIPP in encyclopedias
- identification of the WIPP in dictionaries
- description of the WIPP in science and history textbooks
- a WIPP homepage on the Internet

Although these components will contribute to the effectiveness of the PICs system, the PTF has taken no credit for these components in the effectiveness estimates presented in Section 7.4 below.

6.3 Effectiveness of PICs System in Deterring Inadvertent Human Intrusions

The PICs components are an integrated system that includes redundancy in the ability to deter future inadvertent human intrusions within the Withdrawal. System deterrence is as effective as the most effective component. As long as the most effective component does not fail, total or partial failure of one or more of the other components will not compromise the effectiveness of the overall PICs system. Based on the above analyses, the PICs system will offer virtually complete effectiveness in deterring inadvertent human intrusions within the repository footprint for as long as the marker-system components at this location are in place. The effectiveness of the PICs system in deterring inadvertent human intrusions within the Withdrawal outside the repository footprint will offer virtually complete effectiveness for the period from 100 years (when the PA can no longer take credit for AICs) after disposal to at least a couple of thousand years after disposal. Over time, the PTF believes that the effectiveness of the PICs in protecting the Withdrawal outside of the repository footprint will not be as high as the effectiveness for the smaller, more highly marked footprint. The primary function of the PICs for the Withdrawal outside of the footprint is to protect the integrity of the disposal system rather than protecting a driller, which is the primary function of the PICs at the footprint. The difference in the level of effectiveness will not manifest itself until some thousands of years after disposal.

6.4 Conclusions for Use in PA

As noted in Section 1.5 of this report, the EPA states that for the PAs, PICs cannot totally deter inadvertent human intrusion for even a short period of time after active controls are assumed to end and cannot deter for more than several hundred years. Looking at the historical analogues and potential failure modes for the PICs components, the PTF ascertained that the PICs will be highly effective for periods of time much longer than several hundred years. The attempt to quantify "highly effective" in order to provide input to the PA calculations focused on possible failure mechanisms. Designing physical monuments and markers and establishing institutions for control based on historical analogues leads the DOE to assert that for the time period of interest to PA, these PICs will perform virtually perfectly in enduring and preserving messages for interpretation. The assumptions developed in Chapter 3 lead the DOE to assert that current English will be decipherable by the resource community for the entire period of interest to PA. Thus, the only allure mechanisms of the PICs for communicating with a potential driller/intruder centered around human error in the permitting process (retaining knowledge of the prohibition of drilling and mining, and correctly preparing/rejecting permits) or in locating a permitted operation.

During the deliberation of the PTF, members of WID's Long-Term Regulatory Compliance Section have reviewed drilling records for the New Mexico portion of the Delaware Basin dating back to 1914 and located at the Hobbs and Artesia offices of the state of New Mexico's Oil Conservation Division. One aspect of this review was to determine if any of the well records identified a case or cases wherein the driller set up and drilled in a location other than that authorized. Similarly, the PTF could not locate any record or individual that could confirm that any of the 11,500 wells of the Delaware Basin were drilled at the wrong location. As a follow-up, members of each office were contacted by phone on April 4, 1996, (Johns, 1996) and asked if they recall any incidents of drilling in an unauthorized location. No incidents were recalled.

In a follow-up investigation, the PTF contacted four experts with a total of 106 years of field experience in the oil and gas industry (Rodriguez, 1996e; Rodriguez, 1996f; Rodriguez, 1996g and Rodriguez, 1996h). The experts could recall only five instances, all outside of the Delaware Basin, where someone had drilled a well at the wrong location; three occurred in Texas about 15 years ago and two near Eunice, New Mexico about 30 years ago (Rodriguez, 1996h). These five instances are out of the some 429,000 wells that have been drilled in the Permian Basin (29,000 in southern New Mexico and 400,000 in eastern Texas). Three of the five instances occurred thirty years ago during a period of high activity that the Permian Basin had not witnessed before or afterwards.

The error rate for drilling wells is 0.00 in the Delaware Basin and 0.00001 for a much larger area extending beyond the boundaries of the Delaware Basin. Other than the PICs of government control of land rise through records centers, no other PICs exist in the Permian Basin to deter drilling at any particular site. Yet only five out of hundreds of thousands of wells were drilled at the wrong location, and these wrong locations were still within established claims. The addition of PICs, such as restrictive government control of land use, extensive records, and elaborate monuments and markers would eliminate drilling error as a possible failure mode at the WIPP.

For the sake of addressing the needs of PA and to account for unidentified possible failure mechanisms and sources of human error that could result in reduced effectiveness of the PICs system, the PTF recommends that the failure rate for PA calculations (years 100 to 700 after disposal) be increased to a bounding value of 0.01. Thus, the PICs are to be 0.99 effective in successfully communicating about the WIPP. A 1-percent failure rate would mean that out of every 100 permit requests, one involved an unlawful permit, a location error on the permit itself, or the drillers setting up in the wrong location. This is not believed to be possible in the future because such a high error rate would be widely known within the drilling community, and thus would cause the implementation of stronger controls over drilling.

The numerical percentage by which the intrusion rate will be reduced in the PA calculations is taken to be the probability of successful communication of the information. This assumption is made based on the thought that, for example, if the PICs are effective in correctly transmitting the information 99 percent of the time, then 99 percent of the potential intrusions are either deterred or are made with full information and thus are not inadvertent (i.e., do not have to be considered in the PAs).

The PTF emphasizes that these accommodations to the regulation for both the repository footprint and the remainder of the Withdrawal are bounding values that underestimate the effectiveness of the PICs system in deterring inadvertent human intrusions under the assumptions established in Chapter 3.

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7.0 REFERENCES

Allison, R.W. 1996. "Summary Catalog of the Greek Manuscripts of Philotheou Monastery." Web Page http://abacus.bates.edu:80. Lewiston, ME: Bates College, Department of Philosophy and Religion. (Paper copy of web page on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Berry, W.E. 1983. *Durability of Marker Materials for Nuclear Waste Isolation Sites*. ONWI-474. Washington, DC: Office of Nuclear Waste Isolation, Batelle Memorial Institute.

Bertram-Howery, S.G., and R.L. Hunter. 1989. *Plans for Evaluation of the Waste Isolation Pilot Plant's Compliance with EPA Standards for Radioactive Waste Management and Disposal*. SAND88-2871. Albuquerque, NM: Sandia National Laboratories.

BLM (Bureau of Land Management). 1992. "Legal Description of the Waste Isolation Pilot Plant (WIPP) Withdrawal; NM," *Federal Register*. Vol. 57, no. 227, 55277.

Brachmann, B., M. Herrman, and S. Pollert. 1991. *Archive Safety Analysis. Case Study: German Archives During the 20th Century*. NKS/KAN 1.3(91)5. [Stockholm, Sweden]: Nordic Nuclear Safety Research Programme. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Brausch, L.M., A.K. Kuhn, and J.K. Register. 1982. *Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico*. WTSD-TME-3156. Albuquerque, NM: U.S. Department of Energy, Waste Isolation Pilot Plant.

Crystal, D., 1994. *An Encyclopedic Dictionary of Language and Languages*. New York, NY: Penguin Books.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026. Washington, DC: U.S. Department of Energy. Vols. I-II.

DOE (U.S. Department of Energy). 1989. *Draft Supplement Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026-DS. Washington, DC: U.S. Department of Energy.

DOE (U.S. Department of Energy). 1990a. *Final Safety Analysis Report, Waste Isolation Pilot Plant, Carlsbad, New Mexico*. WP 02-9, Rev. 0. Carlsbad, NM: Westinghouse Electric Corporation

DOE (U.S. Department of Energy). 1990b. *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026-FS. Washington, DC: U.S. Department of Energy, Office of Environmental Restoration and Waste Management. Vols. 1-13.

DOE (U.S. Department of Energy). 1993. *Waste Isolation Pilot Plant Land Management Plan*. DOE/WIPP 93-004. [Carlsbad, NM]: U.S. Department of Energy, Waste Isolation Pilot Plant.

DOE (U.S. Department of Energy). 1995a. *Resource Conservation and Recovery Act Part B Permit Application.* DOE/WIPP 91-005 Revision 5. Carlsbad, NM: Waste Isolation Pilot Plant. Vols. I-X.

DOE (U.S. Department of Energy). 1995b. *Draft No-Migration Variance Petition.* DOE/CAO-95-2043. Carlsbad, NM: U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad Area Office. Vols. I-VII.

DOE (U.S. Department of Energy). 1996. *Passive Institutional Controls Conceptual Design Report.* Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Encyclopedia Britannica. 1994. *New Encyclopedia Britannica.* 15th ed. Chicago, IL: Encyclopedia Britannica. (Sections on "Behistun" and "Hammurabi, Code of" on file in Sandia WIPP Central Files.)

EPA (U.S. Environmental Protection Agency). 1978. "Criteria for Radioactive Wastes," *Federal Register.* Vol. 43, no. 221, 53262-53268.

EPA (U.S. Environmental Protection Agency). 1985. "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register.* Vol. 50, no. 182, 38066-38089.

EPA (U.S. Environmental Protection Agency). 1993. "40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register.* Vol. 58, no. 242, 66398-66416.

EPA (U.S. Environmental Protection Agency). 1995a. "40 CFR Part 194: Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Proposed Rule," *Federal Register.* Vol. 60, no. 19, 5766-5791.

EPA (U.S. Environmental Protection Agency). 1995b. "Part 192—Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings," *Code of Federal Regulations 40 Part 192.* Washington, DC: U.S. Government Printing Office, Superintendent of Documents.

EPA (U.S. Environmental Protection Agency). 1996a. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document.* EPA 402-R-96-002. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

EPA (U.S. Environmental Protection Agency). 1996b. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191*

Disposal Regulations. Response to Comments Document for 40 CFR Part 194. EPA 402-R-96-001. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

EPA (U.S. Environmental Protection Agency). 1996c. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations; Final Rule," *Federal Register*. Vol. 61, no. 28, 5224-5245.

EPA (U.S. Environmental Protection Agency). 1996d. *Compliance Application Guidance for 40 CFR Part 194.* EPA 402-R-95-014. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

Fagan, B. 1994. "Neolithic Newgrange," *Archaeology*, Vol. 47, no. 5, 16-17.

Frimmer, S. 1969. *The Stone That Spoke, and Other Clues to the Decipherment of Lost Languages.* New York, NY: Putnam Publishing Co. 100-117.

Gaur, A. 1992. "The Process of Writing," *A History of Writing*. Rev. ed. New York, NY: Cross River Press, A Division of Abbeville Press. 35-48.

Gillis, D. 1985. "Preventing Human Intrusion into High-Level Nuclear Waste Repositories," *Underground Space*. Vol. 9, no. 1, 51-59.

Givens, D.B. 1982. "From Here to Eternity: Communicating with the Distant Future," *Etc. Et cetera.* Vol. 39, no. 2, 159-179.

Gousha. 1993. *New Deluxe 1993 Road Atlas. United States, Canada, Mexico.* H.M. Gousha, Simon & Schuster, Inc.

Guzowski, R.V. 1990. *Preliminary Identification of Scenarios That May Affect the Escape and Transport of Radionuclides From the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND89-7149. Albuquerque, NM: Sandia National Laboratories.

Hawkins, G.S. 1973. *Beyond Stonehenge.* New York, NY: Harper and Row.

Hora, S.C., and R.L. Iman. 1989. "Expert Opinion in Risk Analysis: The NUREG-1150 Methodology," *Nuclear Science and Engineering.* Vol. 102, no. 4, 323-331.

Hunter, D. 1978. *Papermaking: The History and Technique of an Ancient Craft.* New York, NY: Dover Publications.

IAEA (International Atomic Energy Agency). 1994. *Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories.* IAEA-TECDOC-767. Vienna, Austria: International Atomic Energy Agency.

Jenkins, M.E., and A.H. Schroeder. 1974. *A Brief History of New Mexico*. Albuquerque, NM: University of New Mexico Press.

Johns, James. 1996. Telephone conversation with Paul Katz, Hobbs OCD, and Ray Smith, Artesia OCD. April 4, 1996. (Log copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Kaplan, M.F. 1982. *Archaeological Data as a Basis for Repository Marker Design*. ONWI-354. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute, Project Management Division.

Keesey, J.J. 1976. *Hydrocarbon Evaluation, Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico*. SAND77-7033. Midland, TX: Sipes, Williamson, and Aycock; Albuquerque, NM: Sandia National Laboratories.

Kerr, R.A. 1989. "Oil and Gas Estimates Plummet," *Science*. Vol. 245, no. 4924, 1330-1331.

Kinder, H., and W. Hilgemann. 1974. *The Anchor Atlas of World History. Volume I. From the Stone Age to the Eve of the French Revolution*. New York, NY: Anchor Press.

Merriam-Webster, Inc. 1991. *Merriam-Webster's Ninth New Collegiate Dictionary*. Springfield, MA: Merriam-Webster, Inc. p. 101.

Mohen, J.-P. 1990. *The World of Megaliths*. New York, NY: Facts on File.

NEA (Nuclear Energy Agency). 1995. *Future Human Actions at Disposal Sites, A Report of the NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites*. Paris, France: Nuclear Energy Agency, Organisation for Economic Co-Operation and Development.

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. *Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant* (WIPP) Site. [Carlsbad, NM]: Westinghouse Electric Corporation; Socorro, NM: New Mexico Bureau of Mines and Mineral Resources.

Pasztor, S.B., and S.C. Hora. 1991. *The Vatican Archives: A Study of its History and Administration*. NKS/KAN 1.3(91)6. [Stockholm, Sweden]: Nordic Nuclear Safety Research Programme. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Powers, D.W., S.J. Lambert, S.-E. Shaffer, L.R. Hill, and W.D. Weart, eds. 1978. *Geologic Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, Volume II*. SAND78-1596. Albuquerque, NM: Sandia National Laboratories.

Public Law 96-164. 1979. *Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980*.

Public Law 102-579. 1992. *Waste Isolation Pilot Plant Land Withdrawal Act.*

Rodriguez, R. 1996a. Telephone conversation with Miss Andrews of the British Museum. March 6, 1996. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Rodriguez, R. 1996b. Telephone conversation with Traianos Gagos of the University of Michigan. March 6, 1996. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Rodriguez, R. 1996c. Telephone conversation with Richard R. Navarro of the DOE Las Vegas, NV office. March 11, 1996 (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996d. Telephone conversation with Roxanne Danz of Restoration Physics group at the DOE's Las Vegas, NV office. March 12, 1996 (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996e. Telephone conversation with Larry Scott, Petroleum Engineer for Lynx Petroleum. May 8, 1996 (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996f. Telephone conversation with Jack Ahlen, Consulting Geologist. May 8, 1996. (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996g. Telephone conversation with Floyd Ferguson, Consulting Geologist. May 8, 1996 (Notes on file with Sandia WIPP Central Files.)

Rodriguez, R. 1996h. Telephone conversation with Ron Eidson, Supervisor of Surveyors, John West Engineering. May 8, 1996 (Notes on file with Sandia WIPP Central Files.)

Sullivan, G. 1987. "Vital Clue," *Treasure Hunt.* New York, NY: Henry Holt and Company. 56-63.

Tannenbaum, P.H. 1984. *Communication Across 300 Generations: Deterring Human Interference with Waste Deposit Sites.* BMI/ONWI-535. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute.

Thue, H. 1991. "The Right to a Future," *Transmittal of Information Over Extremely Long Periods of Time, Proceedings from a Conference Arranged by Scandpower AS, Oslo, Norway, September 26-27, 1991.* NKS/KAN 1.3(91)9. Scandpower AS. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Waste Management Technology Department. 1987. *The Scientific Program at the Waste Isolation Pilot Plant.* SAND85-1699. Albuquerque, NM: Sandia National Laboratories.

Weitzberg, A. 1982. *Building on Existing Institutions to Perpetuate Knowledge of Waste Repositories*. ONWI-379. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute.

WIPP (Waste Isolation Pilot Plant) Inadvertent Intrusion Advisory Panel and New Mexico Junior College. 1995. *Analytical Study of an Inadvertent Intrusion of the WIPP Site*. Westinghouse Electric Corporation Procurement Services, Waste Isolation Pilot Plant.

Woodard, L.L. 1996. "Appendix 12B: Letter to U.S. Archivist Transmitting WIPP Land Withdrawal Information," *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document.* EPA 402-R-96-002. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

APPENDIX A

COMPLIANCE WITH THE PASSIVE INSTITUTIONAL CONTROLS ASSURANCE REQUIREMENT

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APPENDIX A

COMPLIANCE WITH THE PASSIVE INSTITUTIONAL CONTROLS ASSURANCE REQUIREMENT

In 40 CFR 194.43, the U.S. Environmental Protection Agency (EPA) requires that:

> "Any compliance application shall include the period of time passive institutional controls are expected to endure and be understood." (61 FR 5243c/EPA, 1996b).

At the same time, the EPA has indicated in the Supplementary Information published with 40 CFR Part 194 their desire to reduce undue speculation as it relates to human actions in their specification of what they call the "future states assumption":

> "The Agency recognizes the inherently conjectural nature of specifications on future states and wishes to minimize such speculation in compliance applications. The Agency has found no acceptable methodology that could make reliable predictions of the future state of society, science, languages or other characteristics of future mankind . . . . Hence, the final rule requires that performance assessments and compliance assessments shall include dynamic analyses of geologic, hydrogeologic and climatic processes and events that will evolve of the 10,000-year regulatory time frame. DOE shall assume that all other present day conditions will exist in their present state for the entire 10,000-year regulatory time frame." (61 FR 5227c-5228a/EPA, 1996c)

In addition, the EPA has stated in their Response to Comments Document For 40 CFR Part 194 that

> "The design of passive institutional controls, both markers and records, must be designed so that they are as permanent as possible, taking into account, to the extent possible, potential collapses in institutional, societal, or linguistic structures. The final rule requires that DOE document the period of time passive controls are expected to endure and be understood [§194.44]. Compliance with the assurance requirement for passive controls will be evaluated based in part on the depth of the analysis and the scope of potential societal changes which are accounted for in the design of passive controls." (EPA, 1996b, p. 7-7)

Thus, the DOE must address the two objectives of longevity of marker structures and communications means, and the addressing potential variability in society. The combination of the requirement for analysis and the prohibition on undue speculation about the future state of society leads one to conclude that the analysis must be qualitative in nature and not require specific numbers that would involve assumptions about the future state of society and the undue speculation EPA attempted to eliminate.

Analysis of Most Permanent Practicable Passive Institutional Controls

A method for evaluating the requirement in §191.14 for "the most permanent markers, records, and other passive institutional controls practicable" is to examine analogues of human constructed buildings or sites as a key to what is most permanent and what was practicable to create. If markers incorporate lessons learned in long-term durability and communication effectiveness, and are consistent in design with the longest lasting structures, then markers and records are the most permanent designs practicable.

Reference to Chapters 5 and 8, and to the Markers Panel reports (Trauth et al., 1993) will indicate that the design elements reflect lessons learned. The DOE's commitment to the design elements as represented in the conceptual design show the PICs to be implemented are consistent with the longest lasting human structures.

Scope of Potential Societal Changes Represented in the Passive Institutional Controls Design

A method for evaluating the design of the PICs in response to consideration by the EPA of the "depth of the analysis and the scope of potential societal changes which are accounted for in the design of passive controls" is to examine the societal basis for the communications recommendations from the Markers Panel.

The Markers Panel deliberations did not assume that one could validate predictions about the future state of languages, level of technological sophistication, or governmental control. Their response to the uncertainty of future societies was to assume that communication means had to be available for individuals from any culture, speaking any language, or with any level of technological sophistication.

The overall recommendations for markers (which is applicable to archives and records) was to utilize a systems approach whereby different components are available to communicate with different individuals and to provide different pieces of information, with enough interconnections to reinforce the information and help fill in any gaps. Within the system, messages are to be provided in different levels of complexity (five different levels from the most basic information of a manmade structure to detailed scientific information on the waste inventory) to address possible variation in the future level of technological sophistication. The different media used for the communications (e.g., berms, stone monuments, buried ceramic disks, and paper) address durability and access issues. Information was to be communicated by linguistic (seven current languages of wide distribution and usage) and non-linguistic (e.g., pictographs, star charts, and the periodic table of the elements) means to address uncertainty about languages to be spoken in the future. While languages change over time, certain basic words are more stable, so the linguistic messages need to be created with simple sentences (no idioms or complex sentences) and with the most basic vocabulary available. Even the uncertainties of human actions with respect to vandalism or the desire to place things of value in museums, the marker design fundamentals suggest large constructions that are difficult to move or destroy. Even the uncertainty about future continuity of property rights is addressed by the requirement for truthful messages about the health implications of possible intrusions.

Technical consultations on archives and records suggest that for long-term maintenance of information in an archives or records system, the physical format should be rather small in size (communicate the salient information quickly and as a guard against curators destroying bulky information), have distinctive binding (reduce the probability of being misfiled and not rediscovered), be produced on durable archival paper, with the documents having little resale value (no original signatures in the records and multiple copies in different locations), and with distinct cover language convincing a curator of the importance of the information and the need to preserve it for long periods of time.

APPENDIX B

SELECTED EPA CONCERNS ABOUT PICS

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APPENDIX B

SELECTED EPA CONCERNS ABOUT PICS

The following discussion is derived from: EPA, 1996a, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Background Information Document for 40 CFR 191*, EPA 402-R-96-002.

1. Section 12.2.5.2, last paragraph of the section on page 12-33 "EPA did not review the Markers Panel Team's results in order to apply numerical values to credit for PICs or even develop a credit methodology. Instead, EPA noted the great variability and uncertainty in the efforts of the two teams."

Response: The designs proposed by the two marker teams contained many of the same elements. These similarities do not support the EPA's claim of great variability. The estimates by each team of the duration and effectiveness of the marker components were relatively close with the markers being most effective in early times and the effectiveness decreasing in later times as the uncertainty about future societies and technologies increases. In the future-state assumptions of 40 CFR Part 194, the EPA has eliminated the speculation about the uncertainties in how societies and technologies may evolve. If the EPA had established these future-state assumptions in 40 CFR Part 191, the marker teams would not have had to deal with "great uncertainty."

2. Section 12.2.5.3, last sentence of the section on page 12-37 "Status of site markings at the other NTS off-site locations is not well documented and is currently being investigated (DOE94b)." DOE94b is "Communication with R. Navarro, Nevada Operations Office, Las Vegas, NV, January 14, 1994."

Response: Mr. Navarro was contacted regarding this topic on March 11, 1996, by the PTF (Rodriguez, 1996c). He did not recall any conversation concerning the topic of investigating the marking of Plowshare Projects. Further conversation with Ms. Roxanne Danz, a supervisor in the Restoration Health Physics group at the DOE's Las Vegas office (Rodriguez, 1996d), confirmed that all Plowshare Projects are marked. However, there is no record of any criteria or design basis being established with respect to what these markings are intended to convey or accomplish. Ms. Danz stated that all of the project sites she has visited have different configurations of markers.

Considering the variation of current marking configurations at the various Plowshare sites and the lack of any criteria for their marking design, it is not reasonable to make a comparison between Plowshare markers (for example the marker indicating Project Gnome) and the criteria established for the WIPP markers in 40 CFR Part 191 and 40 CFR Part 194. Furthermore, the conceptual design for the WIPP permanent markers system and worldwide information distribution is virtually in a class of markers and knowledge distribution unprecedented in history. Although some of the historical analogues are substantial in volume and mass, none of history's enduring markers were associated with an intent to distribute information worldwide to ensure their lasting knowledge in the mind of the public. Neither the analogues nor the Plowshare Projects took the additional step to ensure identification on maps and charts as a means of conveying information.

3. Section 12.3.1.1, page 12-45 "On November 24, 1992, BLM published a description of the WIPP in the *Federal Register* as required by the LWA (57 FR 55277) [BLM, 1992]. BLM also submitted the required documentation to various governmental organizations on November 16, 1992. . . . [Woodard, 1996] (While this information was supplied to the Archivist of the United States and presumably has been filed, the existence and location within the Archives have not been uncovered in spite of numerous inquiries.)."

Response: The archival specialist working with the PTF recommended that the DOE should establish a filing code that the national archives will use when archiving documents and records received from the DOE related to the WIPP Project and that all documents submitted to the archive will contain this filing code. The DOE has an official archivist, and this archivist will be consulted in the development of this filing code.

4. Section 12.3.2, page 12-46, last paragraph "Even so, Tannenbaum has observed that storage materials may not last for the required 10,000 years; therefore, records must be periodically reproduced and perhaps translated into contemporary language (TAN84)."

Response: The records are not required to last for the entire 10,000 years of regulatory concern. The assurance requirements mandate that the PICs are the most permanent practicable. The DOE has developed a PICs system that contains redundant components so that the failure of a single component does not compromise the effectiveness of the PICs system. The PTF believes that future generations will reproduce these documents provided that they are perceived to be important. No credit was taken for the reproduction of information in estimating the effectiveness of the PICs system for PA calculations.

5. Section 12.3.2, page 12-47, second paragraph "Gillis mentions a downside to record-keeping redundancy (GIL85). Dispersal of the information to ensure its survivability may reduce detectability by persons at the site for whom it is most relevant."

Response: This is not a logical conclusion. Dispersal of information does not impact the detectability by persons at or near the site when that same information is provided at a number of locales near the site. The response to this concern is to make a sufficient number of copies that copies can be stored both locally and regionally.

6. Section 12.3.4.1, page 12-57 cites failure of the DOE to document the presence of an oil and gas well under the southwestern corner of the land-withdrawal area.

Response: As mentioned in Chapter 7, the DOE refutes this unfounded claim.

7. Section 12.4.1, page 12-64, last paragraph provides a discussion ending with "Institutions frequently outlive the governments which inaugurate them."

Response: This statement further supports the EPA's future-state assumptions in § 194.25.

8. Section 12.5.1.1, page 12-66, the EPA makes the statement "It is highly unlikely that a drilling crew would detect the presence of the markers."

Response: Surface preparation for drilling crew setup using today's technology make extremely likely the discovery of buried markers positioned at intervals selected randomly between 4.6 and 12.2 meters (15 to 40 feet), and 0.6 to 1.8 meters (2 to 6 feet) below ground, while the drilling crew is preparing a mud pit, which typically is of the dimensions of 30.5 meters by 61 meters (100 feet by 200 feet). This assertion of detection was confirmed by discussions with members of the WIPP Inadvertent Intrusion Advisory Panel and New Mexico Junior College (1995) on May 26, 1995. Their report of September 5, 1995, stated that intervals of 12 meters (40 feet) and 0.3 to 1.8 meters (1 to 6 feet) deep would ensure some markers are seen during excavation.

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APPENDIX C

EFFECTS OF THE COLLAPSE OF CIVILIZATION ON THE PROBABILITY OF EXPLORATORY DRILLING AT THE WIPP

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Sandia National Laboratories

Albuquerque, New Mexico 87185

date: April 2, 1990

to: D. R. Anderson, 6342

Robert V. Guzowski

from: R. V. Guzowski, 6342

subject: Effects Of The Collapse Of Civilization On The Probability Of Exploratory Drilling At The WIPP

A preliminary scenario analysis for the WIPP (Guzowski, 1990) indicated that the integrity of the disposal system depends on whether or not future drilling occurs into the waste-filled rooms and drifts. In dealing with future human intrusion, the question arises as to how long into the future exploratory drilling for resources is likely to occur. At the WIPP, the only natural resource at depths greater than the disposal rooms and drifts with the potential to be present in economic quantities is natural gas (Powers and others, 1978). Based on estimates of the quantities of reserves and undiscovered resources for oil and natural gas (Mast and others, 1989; Kerr, 1989) and the current rate at which the reserves are being consumed (Kerr, 1989), the trend suggests that all of the oil and natural gas resources in the continental U.S. for practical purposes will be consumed within a relatively short period of time. The question arises as to how long exploratory drilling will continue. Depletion of a resource in an area generally will result in an end to exploratory drilling for that resource at that location. For some undefined time after depletion, the possibility exists that industry will go back to an area for "one more look." This rechecking of areas also will eventually stop if no new resources are discovered. Another question arises as to what conditions are required for exploratory drilling to begin again. In various discussions on the subject, a number of people have stated the opinion that exploratory drilling would begin again as society redeveloped after the collapse of civilization even if exploratory drilling had previously been abandoned. The purpose of this memo is to consider the factors that have allowed drilling technology to develop to its present level, and to consider whether these same factors would be available after the collapse of civilization.

DEGREE OF COLLAPSE

In this discussion on the reestablishment of drilling technology, collapse of civilization is considered to occur at a time after the period of active institutional controls of the WIPP and to include complete loss of knowledge of drilling technology, the geologic controls for hydrocarbon accumulation, and the exploitation of natural resources by a previous civilization.

FACTORS THAT CONTROLLED THE DEVELOPMENT OF DRILLING TECHNOLOGY

Several factors were required for the development and advancement of the petroleum industry. In the past, natural gas usually was burned at the well as a waste product. At some locations, this practice continues today. The following discussion is based on the factors in oil discovery that led to advancement in drilling technology. Advancements in drilling for oil also apply to drilling for natural gas. These factors are:

(1) In the early stages of oil discovery, shallow reservoirs supplied enough petroleum so that once uses were found for the material, supply was sufficient or could readily be located to maintain the demand for the product.

(2) Oil reservoirs were associated with certain geologic settings. The distribution of reservoirs was not random. A theory was developed as to the origin and accumulation of oil and gas. Through time, the number of geologic settings where hydrocarbons could be found increased, although the basic theory as to why hydrocarbons accumulated remained basically the same. A relatively consistent association was noted between production and geologic setting when moving from one region into new but geologically similar region. This association confirmed the theory of the origin and accumulation of oil and gas.

(3) Once the targets of hydrocarbon accumulation were identified, progressively deeper targets were investigated as demand increased and techniques were developed to locate deeper targets. Improved drilling techniques had to be developed before boreholes could reach greater depths.

REDEVELOPMENT OF DRILLING TECHNOLOGY AFTER CIVILIZATION COLLAPSE

In order to develop the capability to drill to depths greater than the waste-filled rooms and drifts, the same basic steps would have to be followed as listed above. For the following reasons, the steps cannot be followed. These reasons are:

(1) Except for possibly small occurrences, all of the shallow oil and gas reservoirs have been located and exploited. Any remaining reservoirs are not likely to supply sufficient material to create enough demand to encourage drilling for additional supplies.

(2) Because of the previous exploitation of reservoirs and the use of secondary and tertiary recovery techniques, little if any production is likely to occur from previously worked reservoirs. As a result, no association between the accumulation of productive amounts of oil and gas with particular geologic settings is likely to be recognized. If the location of hydrocarbon reservoirs is not observed or is not predictable, a theory of hydrocarbon accumulation cannot be developed or confirmed.

(3) With no consistent association between shallow geologic settings and productive hydrocarbon reservoirs, no reason would exist to suspect that deeper geologic settings would be more productive than the shallower

settings. With no incentive for deep drilling, drilling technology would not progress beyond the early stages, if any development occurs at all.

CONCLUSIONS

The technology that enables drilling to considerable depths evolved from a technology that was initially limited to drilling to shallower depths. As shallower resources were consumed and demand continued to increase, the economic incentive developed to encourage deeper drilling. Progressively deeper drilling required the development of progressively more sophisticated drilling techniques. A total collapse of civilization would result in the loss of drilling technology. Because of previous exploitation of hydrocarbon resources, all of the factors that led to the evolutionary development of drilling technology are not currently present and will not be present again in the future. As a result, a collapse of the current civilization or the projection of what the current civilization will develop into would mean that the next civilization, if one develops at all, will not redevelop to the level of a hydrocarbon-based industrialized economy.

M

REFERENCES

Guzowski, R.V., 1990, Preliminary identification of scenarios that may affect the escape and transport of radionuclides from the Waste Isolation Pilot Plant, southeastern New Mexico: Sandia National Laboratories, Report SAND89-7149.

Kerr, R.A., 1989, Oil and gas estimates plummet: Science, v. 245, p. 1330-1331.

Powers, D.W., Lambert, S.J., Shaffer, S.-E., Hill, L.R., and Weart, W.D., eds., 1978, Geologic characterization report, Waste Isolation Pilot Plant (WIPP) site, southeastern New Mexico, Volume II: Sandia National Laboratories, Report SAND78-1596.

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WIPP/CAO-96-3168, Revision 1
November 14, 1996

Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments

Kathleen M. Trauth,[1] Robert V. Guzowski,[2] Chris G. Pflum,[3] and Ronald J. Rodriguez[4]

ABSTRACT

The U.S. Environmental Protection Agency (EPA) requires the use of passive institutional controls (PICs) to discourage future generations from inadvertently intruding into the Waste Isolation Pilot Plant (WIPP) nuclear-waste repository and the contiguous 16 sections. The PICs are to include markers, records, archives, and government ownership and land-use restrictions, and other forms of communication. Credit may be allowed in performance assessment (PA) calculations for these PICs to reduce the frequency of inadvertent intrusion for up to 700 years after disposal.

A task force was formed by the U.S. Department of Energy (DOE) to estimate the credit for the PICs in PA calculations for the WIPP repository over the 700 years for which credit is possible. The estimate was constrained by the use of existing conceptual designs of these PICs, the use of design characteristics of historical analogues for the endurance of materials and structures, the consideration of possible failure modes for each PICs component, and the regulatory mandates established by the EPA for purposes of PA calculations.

Because of the durability of the PICs and the redundancy of messages and the PICs components, human error was identified by the task force as the only credible mechanism that could result in inadvertent intrusion for the 700 years under consideration. An examination of 80 years of drilling records for the New Mexico portion of the Delaware Basin identified no instances of drilling occurring in the wrong leases. Further investigation of errors for boreholes in other areas of the U.S. and Canada at least partially underlain by bedded salt resulted in an overall failure rate of 3.5×10^{-5}. The task force concluded that the most appropriate approach to the assessment of the effectiveness of PICs over 700 years was to develop a bounding value intended to account for possible error rates and failure mechanisms that the task force failed to identify. The overall

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observed failure rate was increased orders of magnitude to a level that would be unacceptably high (and which would induce corrective action) within the natural-resources and legal communities. For purposes of PA calculations, and consistent with EPA regulatory assumptions, the task force recommended that the failure of passive controls to correctly communicate the location and hazards of the waste, thereby deterring inadvertent intrusions for the first 700 years after closure of the WIPP, should be 0.01.

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PREFACE

The PICs Task Force (PTF) developed a process for estimating credit for PICs in PA calculations and documented the effort in Revision 0 of this report. Subsequently, Revision 0 of this report was reviewed by the PICs Peer Review Panel (PRP), which convened under the auspices of the Department of Energy (DOE). Revision 1 of this report addresses the issues raised by the PRP, in terms of the presentation of the process and the rationale for the process, although the process itself is the one originally developed by the PTF.

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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is an experimental facility located in bedded-salt deposits in southeastern New Mexico that is owned by the U.S. Government and operated by the U.S. Department of Energy (DOE). This facility is being evaluated as a permanent disposal location for transuranic waste produced by defense-related activities and programs. To demonstrate suitability, the DOE must comply with the performance criteria established by the U.S. Environmental Protection Agency (EPA) in *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule 40 CFR Part 191* (EPA, 1985, 1993). Four main provisions apply to the postdisposal performance criteria: (1) probabilistic radionuclide release limits to the accessible environment (§191.13), (2) additional assurance requirements to supplement the natural radionuclide-containment capabilities of the disposal system (§191.14), (3) dose limits to individuals for undisturbed conditions (§191.15), and (4) protection of underground sources of drinking water from radionuclide contamination for undisturbed conditions (§191.24). With the exception of the qualitative Assurance Requirements, each of the other performance criteria is based on 10,000 years of regulatory concern after disposal.

One of the Assurance Requirements (§191.14[c]) states that "disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location" (EPA, 1985). Another role for the passive institutional controls (PICs) was identified by the EPA with the promulgation of *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule 40 CFR Part 194* (EPA, 1996b). This role (§194.43) allows credits for PICs to reduce the frequency of inadvertent human intrusion into the WIPP disposal system for the performance assessments (PAs) required to address the Containment Requirements of §191.13. Analyses supporting the dose limits to individuals (§191.15) and the protection of underground sources of drinking water (§191.24) do not include the assessment of human intrusion, and as a result, the credit for PICs in reducing the frequency of human intrusion is not a relevant issue.

The PICs have a dual role. The design of the PICs must accommodate the Assurance Requirements (§191.14) by being the most permanent practicable with no regulatory constraints on what the future of society and technology will be like. To comply with this requirement, the DOE has developed a conceptual design (DOE, 1996) that incorporates many of the communications concepts identified by the Markers Panel (Trauth et al., 1993), which was convened by the DOE to examine long-term communications concepts.

This conceptual design consists of several components. Markers at the WIPP are to include 32 granite monuments defining the boundary of the 16 sections defining the Withdrawal. Each monument will be 1.2 meters (4 feet) on a side, 7.6-meters (25-feet) high, and extend 5.2 meters (17 feet) into the subsurface. Messages and pictographs will be engraved on each above-surface and subsurface face of the monuments. A rectangular berm made of earthen materials will surround the footprint repository. This berm will have a trapezoidal cross section and will be 10-meters (33-feet) high and will have a 30-meter (98-feet) base and a 4-meter (13-feet) top width. Inside the boundary of the berm, 16 monuments will outline the footprint of the repository.

These monuments will be composed of the same material and will have the same dimensions as those monuments at the Withdrawal boundary. Each face of each monument also will be engraved with messages and pictographs. An Information Center will be located at the center of the repository footprint and will consist of four walls surrounding seven interior information walls. All of the walls will be embedded in the ground, and the room will not have a roof. Messages will be engraved on the interior side of the outer walls and on both sides of the interior information walls. The overall dimensions of the Information Center will be 12.2-meters (40-feet) wide by 9.8-meters (32-feet) deep by 3.0-meters (10-feet) high, and all of the walls will be composed of granite. Two closed rooms will be constructed that will be similar to the Information Center. One of these rooms will be buried in the southern segment of the berm, and the other room will be buried equidistant between the northern berm segment and the hot cell. Each of the buried rooms will contain seven interior information walls with each wall having messages repeated in a veneer wall. The dimensions of the buried rooms will be 11.9-meters (39-feet) long by 6.7-meters (22-feet) wide by 4.9-meters (16-feet) high, and all structural features and interior walls will be composed of granite. Relatively small markers composed of a variety of durable materials will be buried at random spacing and depths throughout the repository footprint.

Documentation about the WIPP will be sent to regional, national, and international records centers and archives. The specific documentation will depend on the specific type of records center and archive. General records centers both regionally and nationally—consisting of community and university libraries, federal and state agencies, professional societies, and natural-resources companies—will receive detailed documentation about the WIPP along with a summary document. Resource records centers are those centers specifically intended for use by the site investigator in the natural-resources industry. In addition to documentation about the WIPP, the surface and natural-resource leases in these records centers will be modified with covenants that will prohibit future intrusive activities. National and international archives will received a more extensive set of documents along with the summary document. Documents will be printed on archival paper with carbon-black ink with covers and bindings compatible with long-term preservation.

An "other" PICs component is designed for the general dissemination of information about the existence of the WIPP. This information will be incorporated into maps and road atlases, textbooks, dictionaries, encyclopedias, and other common reference sources. The purpose of these information sources is to perpetuate knowledge about something called WIPP and to stimulate interest about the WIPP so that other more detailed sources of information will be investigated.

Five levels of messages will be incorporated into and on the various components. Level I messages indicate that something made by humans is present. Each of the markers convey this level of message. Level II messages convey that something dangerous is present and the site should not be disturbed. Each of the monuments and the buried markers will include this level of message. Level III messages convey basic information about the WIPP, such as location, design, contents, and hazard. Each of the monuments will include this level of message. Level IV messages convey complex information about and related to the WIPP in multiple languages and through symbols and pictures. The Information Center and the buried rooms will contain

Level IV messages. Level V messages are the detailed documentation to be stored in records centers and archives.

Depending on the message conveyed, a PICs component can be classified as either a Deterrent Component or an Awareness Trigger. A Deterrent Component is one that contains a message and/or warning that will be sufficient to discourage a potential intruder from disturbing or intruding into the WIPP. Each of the elements of the markers system (except for the berm), the records centers, the archives, and the land-use controls are Deterrent Components. An Awareness Trigger is a component that contains a message about the WIPP without necessarily providing enough information to discourage inadvertent intrusion. The berm (a Level I message) and the "other" category of PICs are Awareness Triggers.

PICs also can be incorporated into performance assessments in the form of "credit" towards reducing the frequency of inadvertent human intrusion into the WIPP (§194.43). To address the issue of credit for PICs in performance assessments, the DOE created the PICs Task Force (PTF) with the charter of estimating the effectiveness of PICs in deterring inadvertent human intrusion under the constraints developed by the EPA to limit undue speculation in performance-assessment analyses about the future of society and technology. The EPA's constraints include limiting the period during which PICs can deter inadvertent intrusion to 700 years after repository closure and prohibiting the PICs from being completely effective for any time period after the assumed loss of active institutional controls.

A generic communications model consists of nine steps: (1) development of the intention, (2) identification of the audience, (3) encoding of the message in language, (4) capture of the message in media, (5) transmission of the message, (6) receipt of the message, (7) decoding of the message, (8) understanding the message, and (9) responding to the message. Steps 1 through 5 of this model have been or are being addressed by the EPA (through regulatory guidance) or the DOE (through the development of procedures that will ensure that the PICs will be correctly constructed and emplaced). The effectiveness of a message or warning in deterring a future action is dependent on the endurance of the message medium and the message being understood. The task of the PTF was to estimate how long the PICs would endure (Step 6—the PICs must survive in order for the message to be received) and how effective the messages will be in conveying their intended message (Steps 7 and 8). The response of future generations to a message that is understood (Step 9) was not a concern to the PTF. A warning that is understood and heeded results in no human intrusion in PA analyses, and a warning that is understood but ignored results in intentional intrusions, which are discounted from PA analyses.

The actions used by the PTF in estimating the effectiveness of the PICs are

1. Working premises were developed based on regulatory requirements and guidance along with logical deductions based on the regulations and guidance.

2. Historical analogues were examined to determine what design characteristics of the PICs components will contribute to their longevity and to determine how long the design characteristics can last.

3. Potential failure mechanisms for each PICs component were considered along with the identification of how the PICs design characteristics would counter these mechanisms.

4. Data was collected on the historical rates at which boreholes have been drilled on the wrong property.

5. An estimate was made of a bounding value for the failure rate of the PICs in deterring inadvertent intrusion for use in performance-assessment calculations.

In Action 1, the PTF relied on upon guidance that the EPA provided on how drilling for natural resources should be addressed in performance-assessment calculations (§194.33). This guidance states that drilling shall be assumed to occur during the regulatory time period (throughout the 10,000 years of concern to performance assessment) (§194.33(b)(2)), that the frequency of drilling for the Delaware Basin within the 10,000 years of concern to performance assessment should be based on historical drilling rates from the past 100 years (§194.33(b)(3)), and that future drilling practices and technology, including the sealing of boreholes, will remain consistent with the practices and technology at the time the compliance application is prepared (§194.33(c)(1)). Based on this guidance, the PTF concluded that for the 700 years after closure, government will continue to exist along with regulatory agencies and the associated permitting and record keeping for natural-resources exploration and exploitation. Exploratory and developmental drilling will continue throughout the Delaware Basin at such a high yearly rate that the records centers will remain active, and no time intervals will occur during which the procedures will be forgotten. A major premise that the PTF derived from this guidance is that the continuous natural-resources activity means that the information in current English will have considerable economic value far into the future, which means that current English will continue to be understood by personnel in the natural-resources industry for the entire 700 years of concern to PICs effectiveness.

An examination of the durability of design characteristics in historical analogues to the PICs components (Action 2) allowed the PTF to conclude that each of the PICs components is virtually certain to survive for the entire 700 years of concern to PICs effectiveness. Both the materials to be used and the component designs, especially the redundancy, virtually eliminate any credible mechanism within the regulatory guidance for performance assessments for a single PICs component to fail, let alone all of the PICs components that would have to fail in order for inadvertent intrusion to occur.

Each of the potential failure mechanisms identified in Action 3 for each PICs component is countered by the materials selected and the design for each component.

In Action 4, an examination of drilling records and personal interviews with individuals having extensive experience with drilling in the Delaware Basin revealed no instances of wells being drilled in the wrong location in the Delaware Basin (i.e., failure of 0.0). When the survey was extended to the much larger area of the Permian Basin in New Mexico and Texas, five instances of wells drilled in the "wrong" location out of some 429,000 wells drilled in total were identified (i.e., failure of 0.00001). Further investigation of errors for boreholes in areas of the U.S. and Canada at least partially underiain by bedded salt resulted in an overall failure rate of 3.5×10^{-5}

(20 errors out of at least 564,700 wells drilled). The fact that this failure rate is higher than the rate for the Permian Basin is largely due to an anomalously high failure rate for one Canadian province.

In Action 5, the PTF examined the ways in which the components of a PICs system can interact, depending on how the messages are conveyed: (i) if each component has a complete message, each component can independently convey the complete message, (ii) if each component contains a part of the message and understanding the message requires all the parts, loss of any component means failure for the entire system, (iii) if each component contains a part of the message that contributes to the complete message, loss of a component will reduce the effectiveness of the message, and (iv) if each component contains a message and also reinforces the other components (i.e., a Gestalt—the total effectiveness is greater than the combined component effectivenesses), the effect of the loss of a component on the system's performance is dependent the contribution of the component to the Gestalt. Although the PTF concluded that the PICs system for the WIPP will be a Gestalt (i.e., a (iv)), the decision was made to consider the PICs components to be independent (i.e., a (i)) for ease of analysis and to underestimate the PICs effectiveness.

The PTF also took into account the fact that the failure rates in Action 4 were for the single PICs component of government control of land use. The working premises in Action 1, which were derived from the EPA's regulatory guidance, indicate that the other PICs components would be at least as effective as the government control of land use. For the sake of addressing the needs of the PA and to account for unidentified possible failure mechanisms and sources of human error that could result in reduced effectiveness of the PICs system, the PTF decided to bound the problem and increased the observed failure rate by orders of magnitude to a level that would not be consistent with the regulatory assumptions established by the EPA (i.e., the bounding value is so high that it is not consistent with EPA's statements that drilling procedures will be similar to today's procedures). The PTF thus recommends that the failure of the PICs system in deterring inadvertent human intrusion within the entire Withdrawal be increased to a bounding value of 0.01 for the time interval from 100 to 700 years after disposal. Because the premises under which the PTF worked apply equally well to mining as to drilling, the PTF recommends that the failure estimate developed for inadvertent drilling also be used for potential mining intrusions.

ACRONYMS/INITIALISMS

AIC	active institutional controls
BID	Background Information Document
BLM	Bureau of Land Management
CAG	Compliance Application Guidance
CAO	Carlsbad Area Office, DOE
CCA	Compliance Certification Application
CCDF	complementary cumulative distribution function
CDR	Conceptual Design Report
CFR	Code of Federal Regulations
CTAC	Carlsbad Technical Assistance Contractor
DOE	Department of Energy
EPA	Environmental Protection Agency
FR	Federal Register
FSAR	Facility Safety Analysis Report
IAEA	International Atomic Energy Agency
LWA	Land Withdrawal Act
PA	performance assessment
PICs	passive institutional controls
PRP	PICs Peer Review Panel
PTF	PICs Task Force
QA	quality assurance
RCRA	Resource Conservation Recovery Act
SAIC	Science Applications International Corporation
SI	Supplementary Information
SNL	Sandia National Laboratories
TRU	transuranic
USDWs	underground sources of drinking water
WID	Westinghouse Waste Isolation Division
WIPP	Waste Isolation Pilot Plant

1.0 INTRODUCTION

1.1 WIPP and Its Regulatory Requirements

The Waste Isolation Pilot Plant (WIPP) is a research and development facility authorized in 1979 (Public Law 96-164, 1979) to "demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." After the successful demonstration, the WIPP will become a facility for the permanent disposal of this transuranic (TRU) waste. The proposed disposal facility is located in southeastern New Mexico (Figures 1-1 and 1-2) at a depth of 655 meters (2,150 feet) and within a bedded-salt unit (the Salado Formation) (Figures 1-3 and 1-4).

Before permanently disposing of the defense-generated transuranic waste at the WIPP, the Department of Energy (DOE) must demonstrate compliance with the applicable long-term disposal standards of the U.S. Environmental Protection Agency (EPA). These disposal standards have been promulgated at Title 40 Code of Federal Regulations (CFR) Part 191, Subparts B and C.

Title 40 CFR Part 191, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule" was promulgated on September 19, 1985 (EPA, 1985). Parts of 40 CFR Part 191 were vacated and remanded to the EPA for reconsideration in 1987 in response to a lawsuit. The aspects of 40 CFR Part 191 relating to passive institutional controls (PICs) were not impacted as a result of the lawsuit. The aspects of 40 CFR Part 191 that were impacted by the lawsuit were repromulgated on December 20, 1993, under the title "40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule" (EPA, 1993).

Subparts B and C of 40 CFR Part 191 contain four main provisions related to disposal of radioactive waste in a repository. Firstly, Subpart B requires the use of performance-assessment (PA) analyses to calculate the performance of a disposal system for 10,000 years and to compare calculated radionuclide releases to probabilistic radionuclide release limits found in §191.13. Secondly, the Assurance Requirements, found in §191.14, indicate complementary actions (e.g., PICs and monitoring) to be taken to provide additional confidence for long-term compliance with §191.13. Thirdly, the radionuclide doses that individuals may receive from an undisturbed disposal system are limited for the 10,000 years of regulatory concern in §191.15. Fourthly, Subpart C incorporates the requirements of the National Primary Drinking Water Regulations (40 CFR 141.15 and 141.16) to protect underground sources of drinking water (USDWs) from radionuclide contamination from an undisturbed disposal system for 10,000 years (§191.24).

On October 30, 1992, Congress passed the WIPP Land Withdrawal Act (LWA) (Public Law 102-579, 1992). The major purpose of the LWA was to transfer jurisdiction over the 16-square-mile area including and surrounding the WIPP facility, from the Department of the Interior to the DOE. Congress has defined this area as the "Withdrawal" in the LWA. The term Withdrawal is used throughout this report for this area. In addition, Congress required that the EPA promulgate proposed "criteria for the Administrator's certification of compliance with the final disposal

regulations" (Public Law 102-579, 1992, Sec. 8[c][1]). The EPA's proposed rule, "Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance With Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Proposed Rule" (40 CFR Part 194) (EPA, 1995a) was published in the *Federal Register* (FR) January 30, 1995. As stated in the LWA, the criteria were intended to be used to determine "whether the WIPP facility will comply with the final disposal regulations" (in 40 CFR Part 191) (Public Law 102-579, 1992, Sect. 8 [c] [1]). The EPA promulgated the final version of 40 CFR Part 194 under the title "Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations; Final Rule" on February 9, 1996 (EPA, 1996c).

1.2 Passive Institutional Controls

PICs are intended to deter to potential intruders by providing information about the existence and location of the repository, the wastes buried there, the nature of the hazard the wastes represent, and the necessity of not disturbing the disposal system. The use of PICs is based on a fundamental assumption about nuclear-waste disposal that if future generations have and understand the appropriate information, they will not intrude into the repository or disturb the remainder of the disposal system. With the requirement to mark the Withdrawal, the message for the larger area outside the repository footprint is not the danger of intruding into the repository, but the danger of impacting ground-water flow and possibly affecting radionuclide transport from the disposal facility toward the biosphere.

The recently promulgated WIPP-specific 40 CFR Part 194 (EPA, 1996c) includes both the requirement for PICs and the permission for the PA calculations to take advantage of PICs to reduce drilling and mining frequencies. The language states that the DOE may take credit for the PICs in deterring inadvertent human intrusion into the WIPP facility and disposal system in the PA calculations for the Compliance Certification Application (CCA) that will be submitted to the EPA. Concurrently, §194.26 establishes requirements on the use of expert judgment and indicates that expert judgment would probably be used to assess the effectiveness of PICs in deterring inadvertent human intrusion into the disposal system.

In other language, the EPA indicates a concern about the justification for such credit and a desire for clear justification for this credit within the EPA's regulatory framework (61 FR 5231/EPA, 1996c).

The EPA's regulations, both 40 CFR Parts 191 and 194, establish the framework for the consideration of PICs in PA (i.e., defining what is to be considered and how) with the intent of limiting undue speculation about the future. For PA purposes, PICs are intended to deter inadvertent human intrusion by the natural-resources industry anywhere within the Withdrawal. The consideration is only for 700 years after closure, and the current procedures and technologies of the natural-resources industry are assumed to be used for the entire 700 year period.

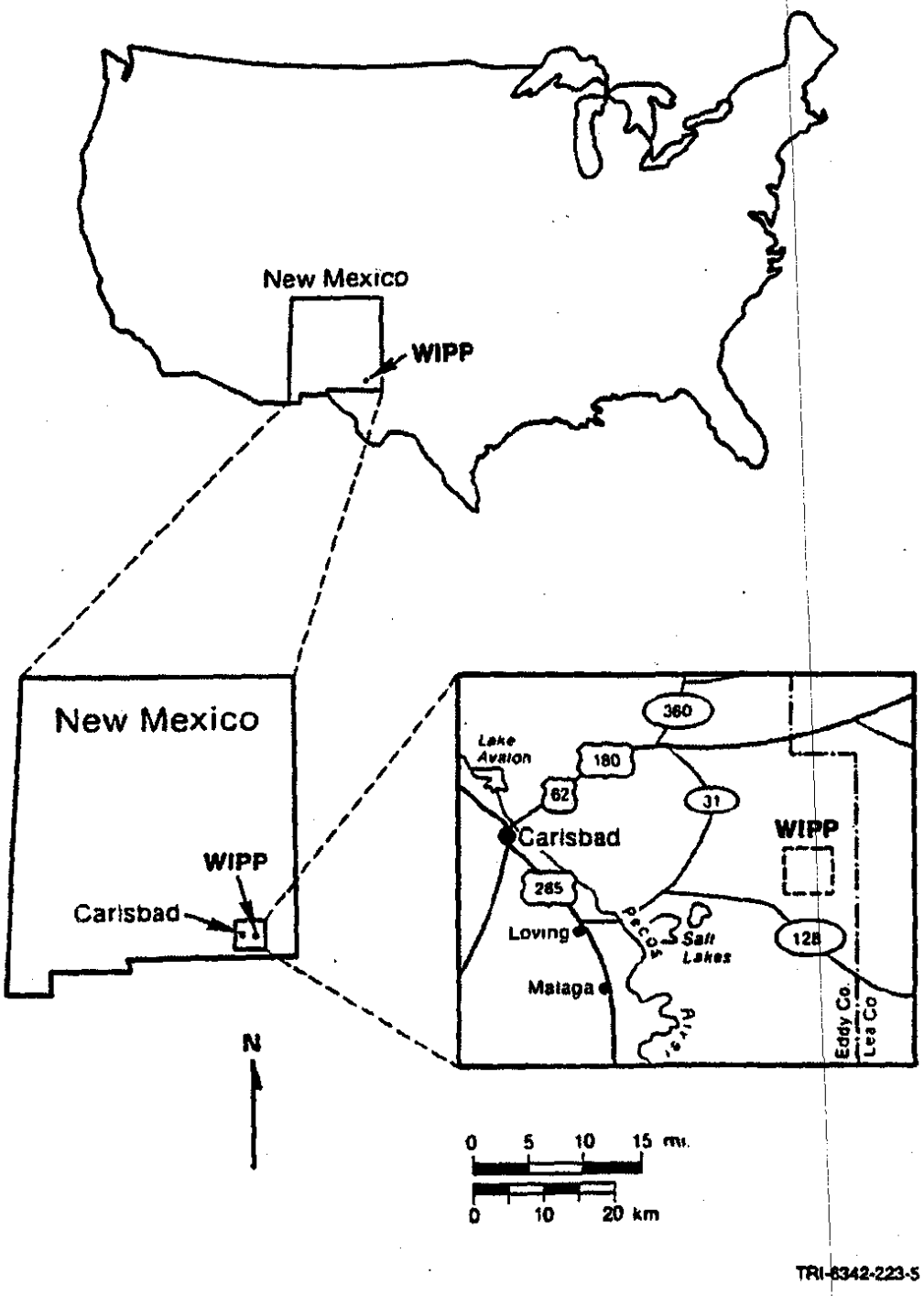

Figure 1-1. Location of the WIPP (after Bertram-Howery and Hunter, 1989).

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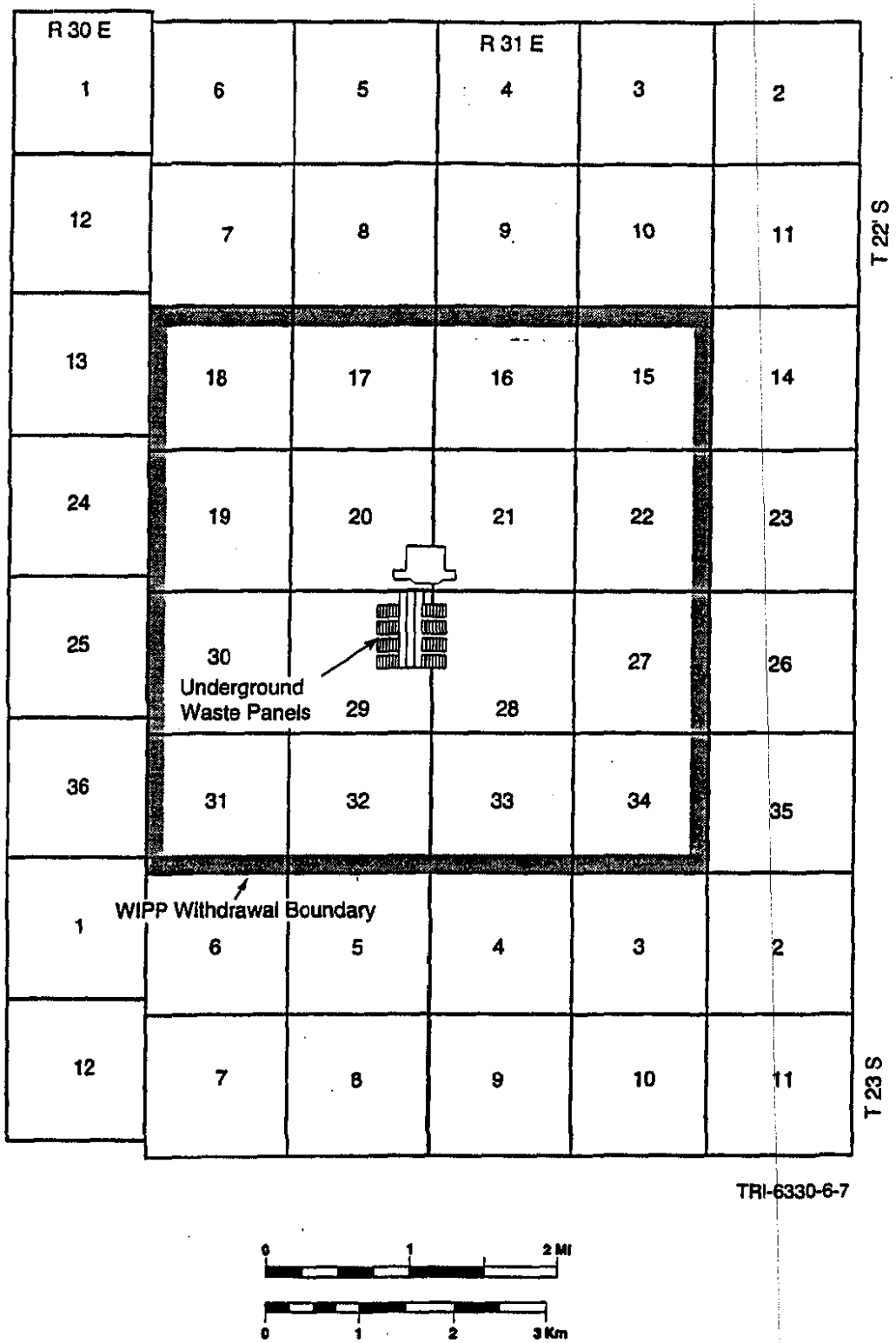

Figure 1-2. Position of the WIPP waste panels within the Withdrawal (DOE, 1990a).

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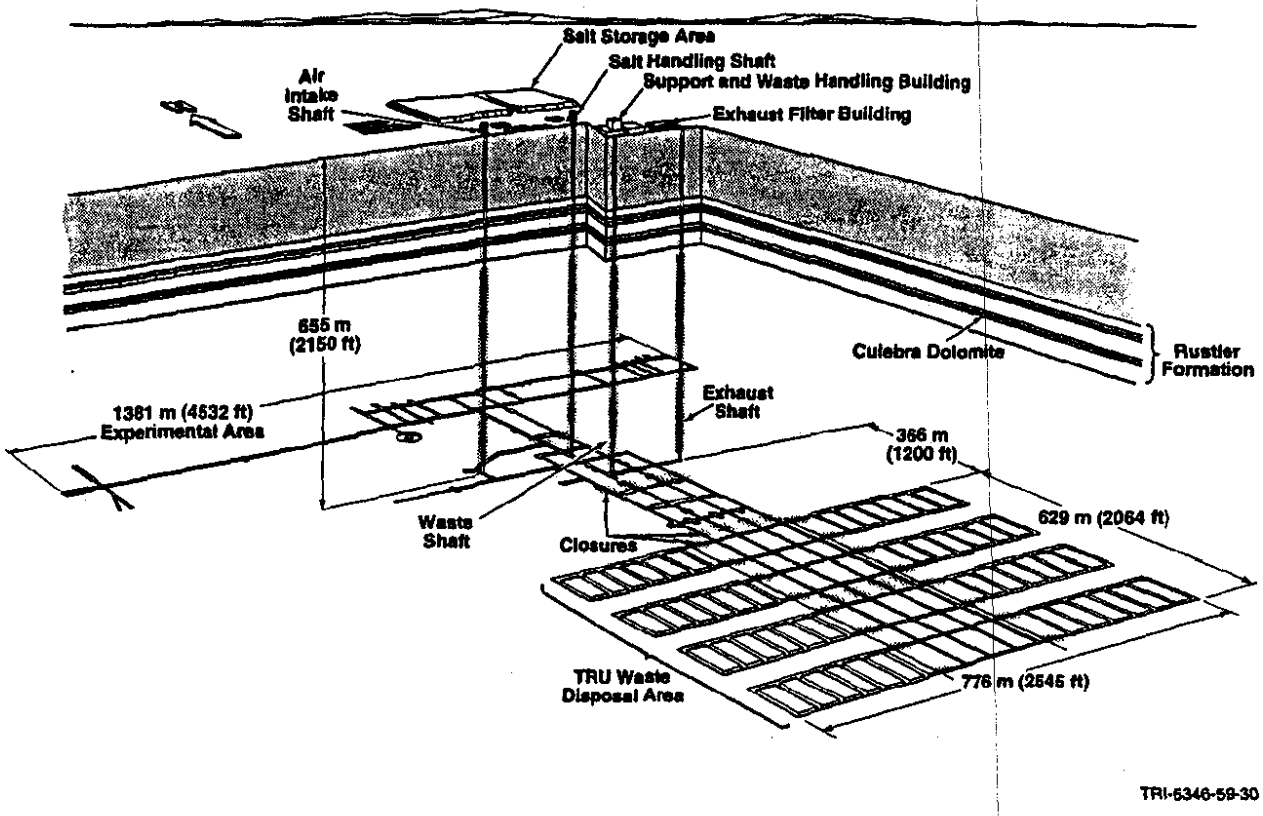

Figure 1-3. Relationship between the WIPP surface and subsurface facilities (after Waste Management Technology Department, 1987).

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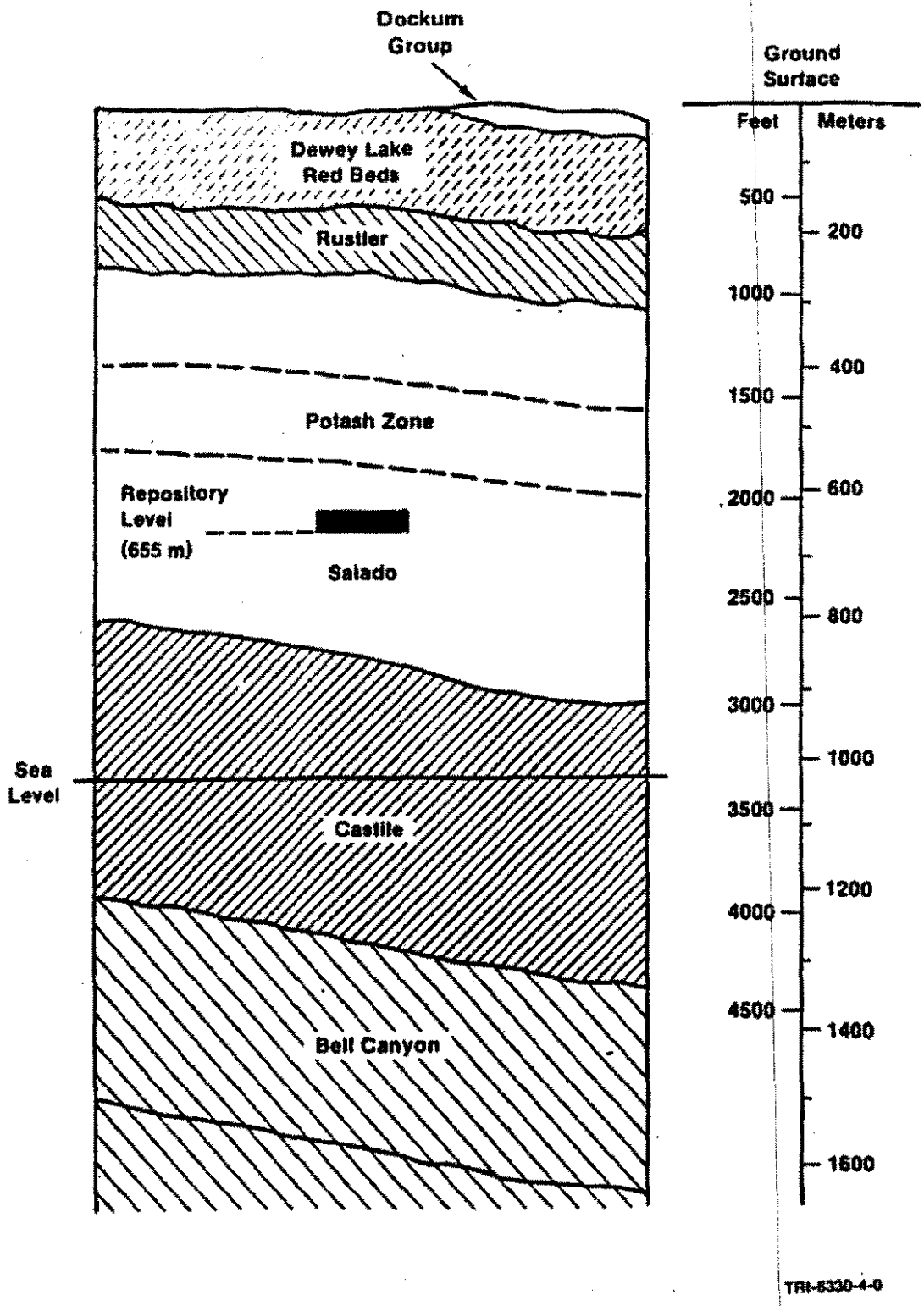

Figure 1-4. Generalized stratigraphy at the WIPP (after Waste Management Technology Department, 1987).

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1.3 PICs Task Force Objectives

The PICs Task Force (PTF) was charged with developing a numerical representation of the effectiveness of PICs in deterring inadvertent human intrusion into the WIPP disposal system. This numerical representation was to be developed in a usable format for the PA calculations. The PTF was to provide well-reasoned arguments to support the results.

As described in Section 1.4, the deliberations of the PTF were followed by external peer review of the results and the process by which the results were developed. As such, the PTF provided input materials for the peer review—supplying the effectiveness estimates and supporting arguments, and providing the PICs Peer Review Panel (PRP) with answers to questions or concerns. This report does not address the conduct of the external peer review, which was conducted within the DOE's peer-review process. This version of the report does, however, address issues raised by the peer review.

1.4 Work Approach

A work approach has been developed by the DOE that addresses the dual requirements of (1) providing justified input to the PA calculations as to the efficacy of the PICs in deterring inadvertent human intrusion, and (2) developing such information based on existing evidence and with the assistance of individuals with perspectives beyond the DOE.

The DOE developed a four-step approach to achieve these goals. The first step was to convene the Markers Panel in 1991 (Trauth et al., 1993) using a process that followed the steps refined in NUREG-1150 (Hora and Iman, 1989). A comparison between the process for convening the Markers Panel in 1991 and the 1996 requirements of §194.26 Expert Judgment leads the DOE to conclude that the processes are substantially equivalent. The two Markers Panel teams developed marker designs that were distilled into a set of fundamental design principles about long-term marking and communicating with future generations. The second step took these design principles and specific marker elements, supplemented by other documentation of structures, records systems, and information that have endured for long periods of time, to develop the PICs Conceptual Design Report (DOE, 1996). The third step (which is documented here) was to utilize a PTF comprised of individuals with relevant knowledge supplemented by external expertise, to examine existing documentation (information and perspectives developed external to the DOE), to finalize the conceptual models of the system of PICs that the DOE will commit to implementing, and to assess the effectiveness of the PICs in reducing the inadvertent intrusion frequency for the PA calculations. The fourth step in the approach was to submit the report of the PTF to external peer review (the PRP). The results of the PTF analysis were used as input to the PA forming the basis of the CCA.

The PTF consists of representatives from the DOE Carlsbad Area Office (CAO), the Carlsbad Technical Assistance Contractor (CTAC), Sandia National Laboratories (SNL), Westinghouse Waste Isolation Division (WID), and technical consultants with SNL having the lead responsibility. The following is a list of the PTF members:

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Robert V. Guzowski - SNL/SAIC
Chris G. Pflum - CTAC
Ronald J. Rodriguez - WID

Technical Consultants
David Givens - American Anthropological Association
Suzanne Pasztor - Randolph-Macon College (currently at University of the Pacific)

1.5 Constraints

Two major constraints directed this effort. The first of these constraints is that the PTF must work within the regulatory confines established by the EPA in 40 CFR Part 191 and 40 CFR Part 194 (including the Supplementary Information), the Background Information Document [BID] [EPA, 1996a], and the Compliance Application Guidance (CAG) (EPA, 1996d) as to what is required and what assumptions to make. These limitations for the PA calculations are that (1) PICs cannot be assumed to completely eliminate inadvertent human intrusion for any portion of their life; (2) credit for the effectiveness of PICs in deterring inadvertent human intrusion cannot be taken for more than approximately 700 years after disposal; and (3) the framework of premises for the PICs must be consistent with current drilling procedures and technology in §194.33. The second constraint is that estimates of the efficacy of PICs must be clearly linked with existing evidence on the longevity of structures and materials and the long-term maintenance and interpretability of messages, consistent with the 700 year limitation.

A number of operational constraints were imposed on the deliberations of the PTF. One constraint was to begin deliberations using the system of PICs discussed in the Passive Institutional Controls Conceptual Design Report (CDR) (DOE, 1996), with expansion and modification of the system as necessary. Another operational constraint was to work within what is practicable to implement in the construction and development of the PICs, and what the DOE will commit to implementing.

1.6 Preview of Approach to PICs Effectiveness

The PTF examined 40 CFR 194.33 as providing the regulatory context for addressing the resource exploration and exploitation procedures and technology, and the means of deterring intrusion for PA. The individual boxes in Figure 1-5 represent conditions or activities that contribute to the three key elements of deterrence: (1) to endure for the required 700 years, (2) to be encountered by potential intruders (i.e., the natural-resources industry), and (3) to be understood by that same industry. The diagram starts out with General Societal Behavior [Box 1], realizing that society and the needs of society dictate the existence and operation of the

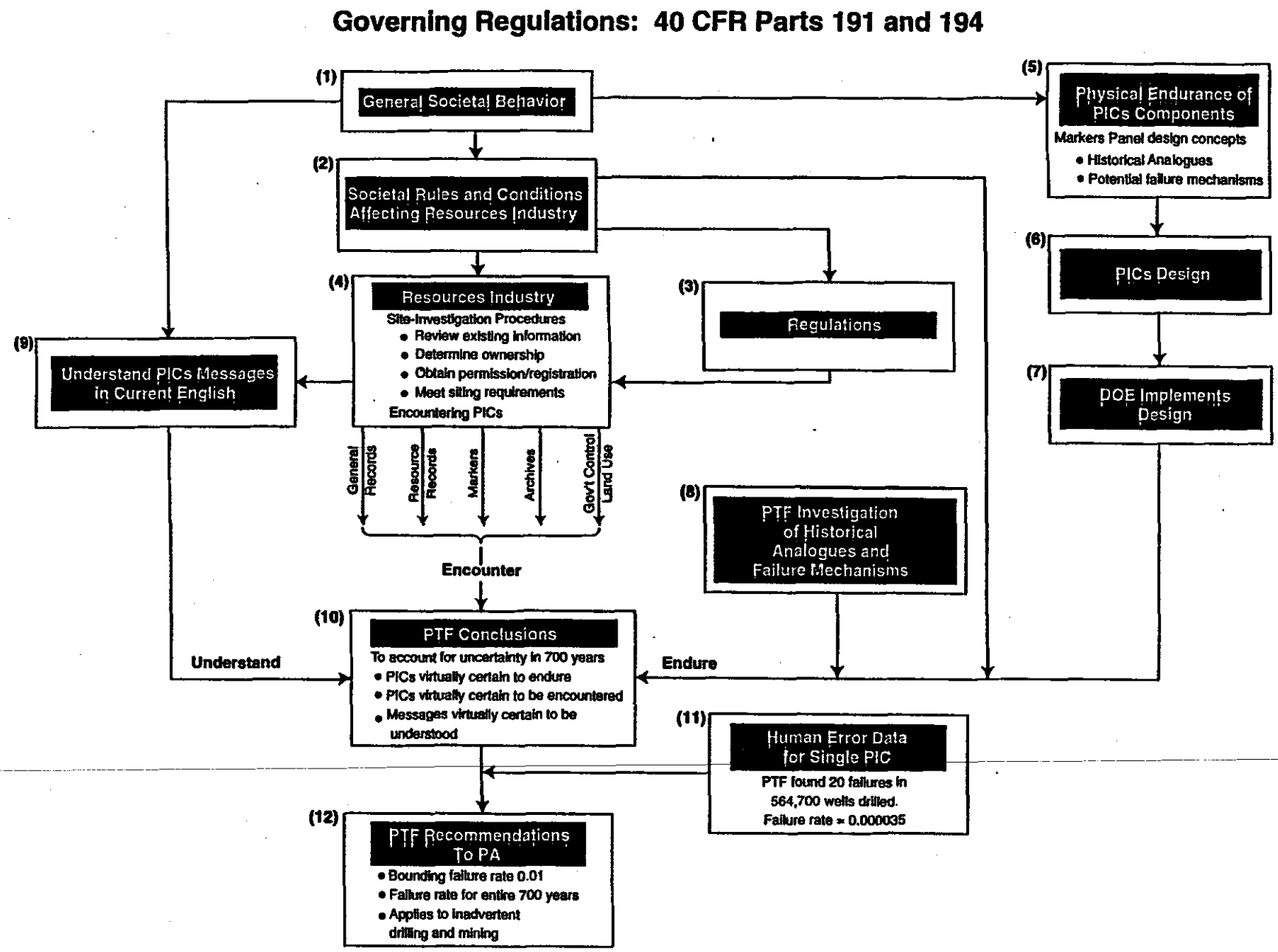

Figure 1-5. Flow diagram of PICs effectiveness (deterring inadvertent intrusion by the natural-resources industry for 70 years).

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natural resources industry [Box 2]. Regulatory guidance provided by the EPA limits the scope of the societal changes to consider for PA calculations in order to limit speculation about an unknowable future. Additional guidance provided by the EPA also limits the speculation about the future of the natural-resources industry [Box 3]. Guidance from EPA through the societal rules and conditions [Box 2] and regulations [Box 3] establishes that in the future the natural-resources industry will operate in a fashion similar to that of today (as of the date the application was submitted) [Box 4]. This industry will use site investigation procedures that are basically the same as today before drilling a borehole; industry will (a) review existing information on geology and resource potential of an area, (b) determine ownership of the property of interest, (c) go through proper channels to obtain ownership or lease, and (d) meet siting requirements for the operation of the drilling procedure.

The objective of the DOE is to provide a mechanism for preventing the natural-resources industry described in the above paragraph from intruding into the Withdrawal. Typical site investigation involves activities that will encounter the following: (a) general records centers, (b) archives, (c) resource records centers, and (d) government agencies controlling land use. In addition, this investigation is likely to include a visit to the site of interest (roads). To communicate the hazards associated with the WIPP, the EPA has identified passive institutional controls that must be implemented by the DOE, and these PICs are the same sources of information that would be utilized by the site investigator. These PICs will be encountered by the natural-resources industry in the normal conduct of their operations.

To ensure that the markers will endure in order for site investigators to encounter WIPP information, the DOE (1) convened the Markers Panel that identified design concepts for long-term communication taking into account historical analogues and potential failure mechanisms [Box 5]; (2) developed a conceptual design based on the recommendations from the Markers Panel and expanded it to include archives and records centers (incorporating features more durable than those in the historical analogues—size, number, materials, etc.—to improve durability) [Box 6]; and (3) is developing plans for implementing the designs [Box 7]. The PTF, in its deliberation, has investigated the durability of design concepts from historical analogues along with potential failure mechanisms within the 700-year regulatory time frame [Box 8]. In addition, the PTF considered those societal rules and conditions the contribute to the endurance of structures and institutions. Because the durability of the WIPP PICs is expected to exceed the durability of historical analogues and the redundancy designed into the PICs system will counter potential failure mechanisms, the PTF has concluded that the PICs will survive long enough to be encountered by the natural-resources industry for hundreds and possibly thousands of years.

To ensure that the PICs will be understood, the PTF has identified those characteristics of society that will enable current English incorporated into the PICs to be understood by future generations [from Box 1 to Box 9]. Society has developed such that current English is the international language of science, technology, commerce, and diplomacy. Wholesale, rapid changes in current English would be counter-productive for these enterprises. In addition, the PTF examined the history of English and determined that older versions of English can be read today by various individuals. Thus, this suggests that various individuals far into the future will be able to read current English. The potential economic benefit to be derived by the natural-resources industry from the information located in documents (i.e., locations of previous exploration and

2.0 APPLICABLE REGULATIONS

2.1 Basis for Regulatory Aspect

The PTF's estimation of the effectiveness of the PICs must take place within a regulatory context that establishes the requirements for the PICs and the assumptions that govern considerations of their effectiveness. This chapter deals with these regulatory requirements.

2.2 Requirements for Active Institutional Controls in 40 CFR Part 191

This discussion of active institutional controls (AICs) is relevant because the AICs establish when consideration of PICs is assumed to be a factor in the PA and are another example of the EPA's treatment of human intrusions.

The EPA defines AICs as:

> "(1) Controlling access to a disposal site by any means other than passive institutional controls; (2) performing maintenance operations or remedial actions at a site; (3) controlling or cleaning up releases from a site; or (4) monitoring parameters related to disposal system performance." (50 FR 38085c/EPA, 1985)

For the PA, which assesses the performance of the disposal system for isolation of wastes from the accessible environment, the EPA prohibits consideration of any contribution from AICs in preventing human intrusion for more than 100 years after disposal.

The PTF traced the origin of this 100-year limit to the EPA's 1978 draft "Criteria for Radioactive Wastes" (EPA, 1978). These criteria were intended to provide general guidance for the disposal of all forms of radioactive waste. Criteria No. 2 states:

> "The fundamental goal for controlling any type of radioactive waste should be complete isolation over its hazardous lifetime. Controls which are based on institutional functions should not be relied upon for longer than 100 years to provide such isolation; radioactive wastes with a hazardous lifetime longer than 100 years should be controlled by as many engineered and natural barriers as are necessary." (43 FR 53265/EPA, 1978)

While credit for AICs in preventing intrusion at the WIPP cannot be taken for more than 100 years, the PTF does not believe that the U.S. government—with its institutions, laws, and sanctions—will collapse in 100 years or change to an extent that a location as important as the WIPP will be forgotten. Indeed, other countries have expressed more faith in their governments. Their waste disposal systems will rely on active controls for 100 to 500 years (NEA, 1995).

The EPA's limitations on the credit for AICs (100 years) in the PA calculations represent conservative assumptions meant to place the emphasis for regulatory compliance on the isolation afforded by the site, and limit reliance on societal actions. This limitation should not be construed as meaning that active control over the site by the federal government will end after 100 years. In fact, the existence of PICs means that AICs would have further reinforcement by virtue of activities involved with testing and constructing the PICs.

2.3 Requirement for Passive Institutional Controls in 40 CFR Part 191

As part of the Assurance Requirements of the general standard, 40 CFR Part 191, the EPA requires the implementation of PICs. Section 191.14 states that:

> "(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location." (50 FR 38086c/EPA, 1985)

In §191.12, the EPA defined PICs as:

> "(1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system." (50 FR 38085c/EPA, 1985)

The definition of "passive" can be understood, in part, by contrasting the definitions of PICs and AICs, in §191.12. Active institutional control means:

> "(1) Controlling access to a disposal site by any means other than passive institutional controls, (2) performing maintenance operations or remedial actions at a site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance." (50 FR 38085c/EPA, 1985)

The distinction between active and passive institutional controls centers primarily around issues of maintenance and whether activities are directed specifically at the WIPP. Active institutional controls include physical components that will need maintenance (e.g., fences and signs) by someone who is visiting the site because it is the WIPP, who either initiates or makes arrangements for corrective actions. The medic of the passive institutional controls, including the granite of the site markers, and the paper records, and the written text, in the records centers and archives, will need no maintenance efforts. Other than the markers, the PICs "plug in" to existing societal institutions/activities (e.g., libraries, resource-development activities and government control of land use). While these institutions/activities may require the maintenance of their individual records centers or archives, this maintenance is not directed at the WIPP-specific records, and would be conducted whether or not the WIPP exists. In contrast, AICs, such as a guard driving around the perimeter of the Withdrawal, are undertaken specifically because the WIPP exists.

The DOE reads the text within the Supplementary Information that was published with the original promulgation of 40 CFR Part 191 to further explain the rationale in developing the rule as indicating that the EPA intended for the implementing agency to take credit for the effectiveness of PICs in deterring inadvertent human intrusion:

> "The Agency [EPA] believes that the most productive consideration of inadvertent intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive institutional controls (although passive institutional controls should not be assumed to completely rule out the possibility of intrusion)." (50 FR 38089a/EPA, 1985)

and

> "Not allowing passive institutional controls to be taken into account to some degree when estimating the consequences of inadvertent human intrusion could lead to less protective geologic media being selected for repository sites." (50 FR 38080b,c/EPA, 1985)

DOE's reading of the above regulatory language, and the need to address PICs, resulted in the Markers Panel being convened in 1991 to address this issue in a multidisciplinary fashion. The language in 40 CFR Part 191 provided the context for the deliberations of the Markers Panel (Trauth et al., 1993).

2.4 Criteria for Passive Institutional Controls in 40 CFR Part 194

The requirements in 40 CFR Part 191 are explicitly applied to the WIPP through 40 CFR Part 191. Section 194.43(a) builds upon the language of 40 CFR Part 191 and requires a description of the proposed PICs:

> "Any compliance application shall include detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system. Such measures shall include: (1) Identification of the controlled area by markers that have been designed and will be fabricated and emplaced to be as permanent as practicable; (2) placement of records in the archives and land record systems of local, State, and Federal governments, and international archives, that would likely be consulted by individuals in search of unexploited resources . . . (3) other passive institutional controls practicable to indicate the dangers of the waste and its location."(61 FR 5243c/EPA, 1996c)

In addition, §194.43(b) requires that an assessment of how long PICs might be effective must be undertaken:

> "Any compliance application shall include the period of time passive institutional controls are expected to endure and be understood." (61 FR 5243c/EPA, 1996c)

2.5 EPA's Allowance of Credit for Passive Institutional Controls

In §194.43, the EPA has clearly stated that the DOE may receive credit for the PICs deterring inadvertent human intrusion in the PAs:

> "(c) The Administrator may allow the Department to assume passive institutional control credit, in the form of reduced likelihood of human intrusion, if the Department demonstrates in the compliance application that such credit is justified because the passive institutional controls are expected to endure and be understood by potential intruders for the time period approved by the Administrator. Such credit, or a smaller credit as determined by the Administrator, cannot be used for more than several hundred years and may decrease over time. In no case, however, shall passive institutional controls be assumed to eliminate the likelihood of human intrusion entirely." (61 FR 5243c/EPA, 1996c)

The Supplementary Information for 40 CFR Part 194 provides further detail and indicates the importance of the justification of the credit proposed:

> "Additionally, the final rule allows the Department to reduce the likelihood of future human intrusion that is used in performance assessments by a proposed amount corresponding to the predicted effect of PICs. . . . Thus, DOE may propose in its compliance application to reduce the rate of human intrusion by a fractional amount, extending over a technically supportable period of

> time, and must justify this using the plans for the implementation for PICs and associated evidence of their effectiveness." (61 FR 5231a,b/EPA, 1996c)

as well as the means of mathematically describing such credit:

> "This credit may take the form of a constant reduction in the rate of human intrusion lasting several hundred years or may be a reduction in the rate which tapers off in size over several hundred years." (61 FR 5231b/EPA, 1996c)

Further qualifications on the implementation of credit are:

> "Such credit cannot be assumed to eliminate completely the possibility of human intrusion, even for a short period of time after the active institutional controls at the WIPP are assumed to be ineffective." (61 FR 5231b/EPA, 1996c)

and

> "Having considered the public comments regarding PICs, the Agency believes that such credit could be no more than approximately 700 years past the time of disposal. Thus, the final rule limits to several hundred years the amount of credit that EPA may grant for PICs. Any determination that a specific numerical credit would be appropriate for a much longer period of time would be unduly speculative and therefore inappropriate." (61 FR 5231b/EPA, 1996c)

The EPA quotes from the Supplementary Information published with the 1985 promulgation of 40 CFR Part 191 to provide the context for the treatment of PICs in 40 CFR Part 194:

> "With respect to performance assessments, the Agency examined whether PICs should be taken into account to some degree when estimating the likelihood of inadvertent human intrusion and concluded that 'a limited role for passive institutional controls would be appropriate when projecting the long-term performance of mined geologic repositories to judge compliance with (the containment requirements of 40 CFR part 191).' At the same time, the Agency explicitly determined that PICs should not be assumed to completely prevent the possibility of inadvertent human intrusion." (61 FR 5231c/EPA, 1996c)

The EPA goes on to note that some comments received on the draft 40 CFR Part 194 stated that the Agency was acting beyond their authority in proposing to allow credit for PICs in the analyses for the containment requirements:

> "Still other comments asserted that, in allowing for the possibility of credit, the Agency had revised the intent of the assurance requirements, one of which being the requirement for the implementation of PICs. Specifically, comments stated that the assurance requirements were not intended to be considered when determining compliance with the numerical containment requirements found at 40 CFR 191.13." (61 FR 5231c-5232a/EPA, 1996c)

The EPA's statement immediately following that comment is:

> "The provisions of the final rule entertaining possible credit for PICs are within EPA's authority." (61 FR 5232a/EPA, 1996c)

The BID for 40 CFR Part 194 is another source of information as to not just the appropriateness of taking credit for PICs, but the necessity:

> "In this chapter the *necessity* [emphasis added] of incorporating passive institutional controls in the WIPP compliance criteria is discussed in terms of their ability to reduce the likelihood of human intrusion." (EPA, 1996a, p. 12-1)

DOE's reading of the above regulatory and associated language caused the DOE to conclude that in addition to being necessary under the Assurance Requirements of §191.14, the PICs were intended to be a part of determining compliance with the Containment Requirements of §191.13. The PTF was convened to estimate the credit for PICs in PA. This report does not address the issue of the compliance of the WIPP PICs with the Assurance Requirements.

While the EPA stated the necessity of including PICs in the compliance application, the EPA also stated concerns in Chapter 12 of the BID (EPA, 1996a) that were used to justify limiting the amount of credit that PICs can provide in deterring inadvertent human intrusion. Appendix A contains a discussion of a selected number of the EPA's concerns and the PTF's responses as to why these concerns are outside the context of credit for PICs in PA.

2.6 Reasonable-Expectation Requirement in 40 CFR Part 191

The measure by which the compliance of the WIPP with the disposal standards will be determined to be one of a "reasonable expectation" as stated in the Supplementary Information published with the original promulgation of 40 CFR Part 191:

> "The containment requirements call for a 'reasonable expectation' that their various quantitative tests be met. This phrase reflects the fact that unequivocal numerical proof of compliance is neither necessary nor likely to be obtained. A similar qualitative test, that of 'reasonable assurance,' has been used with NRC regulations for many years. Although the Agency's intent is similar, the NRC phrase has not been used in 40 CFR Part 191 because 'reasonable assurance' has come to be associated with a level of confidence that may not be appropriate for the very long-term analytical projections that are called for by 191.13. The use of a different test of judgment is meant to acknowledge the unique considerations likely to be encountered upon implementation of these disposal standards." (50 FR 38071c/EPA, 1985)

The concept of reasonable expectation in the Containment Requirements was not an issue in the legal challenge 40 CFR Part 191. With the repromulgation of 40 CFR Part 191 in 1993, the EPA did not reverse its position on reasonable expectation in the containment requirements, and in fact the EPA extended the concept of reasonable expectation to the Individual Protection Requirements in §191.15:

> "Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved." (58 FR 66414c/EPA, 1993)

2.7 Reasonable-Expectation Requirement for PICs

The estimation of the effectiveness of PICs in deterring inadvertent human intrusion into the disposal system is to be used to modify an input to the PA calculations that are used to produce families of complementary cumulative distribution functions (CCDFs). These CCDFs are then compared with the release limits in the Containment Requirements of §191.13 to determine compliance with the disposal standards. As quoted above, the Containment Requirements of 40 CFR Part 191 are guided by the reasonable-expectation requirement. Because the effectiveness of the PICs are an integral part of the PA calculations used to address the Containment Requirements, the reasonable-expectation requirement also applies to the estimation of the effectiveness of PICs. DOE reads the reasonable-expectation language in 40 CFR Part 191 as meaning that absolute proof of the longevity of a marker, a records system, or a message is neither achievable nor required to take credit for PICs in the PA calculations. The fact that the EPA required the implementation of the reasonable-expectation concept at two different times (the 1985 and 1993 promulgations of 40 CFR Part 191) and for different contexts (PAs and Compliance Assessments) supports the DOE's interpretation of the language for the concept.

2.8 Deterring Inadvertent Human Intrusion

References to human intrusion in 40 CFR Part 191 and in the Supplementary Information are to inadvertent human intrusion. Statements such as the following suggest that the requirement for PICs is to protect against the inadvertent human intrusion:

> "The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion." (50 FR 38088c/EPA, 1985)

The EPA has included provisions in 40 CFR 194.33(b)(1) that limit consideration of intrusion into the disposal system to inadvertent drilling:

> "Inadvertent and intermittent intrusion by drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario." (61 FR 5242b/EPA, 1996c)

This provision allows for the assumption that the message of the PICs is to be directed at discouraging those efforts to locate and exploit natural resources. Under this assumption, individuals locating and conducting drilling operations will avoid intruding into the repository and disturbing the disposal system if warning messages against intruding and disturbing are correctly conveyed to future generations. If, however, a potential intruder realizes that a drilling or mining activity may intersect the repository or the Withdrawal and understands the associated risks, but decides to intrude anyway, the intrusion is not inadvertent. Intentional intrusions are not to be considered in the PA calculations. "Deter" consists of the messages enduring and being correctly understood. Correct communication means that inadvertent human intrusion has been deterred. Understanding but ignoring the messages results in intentional human intrusion, which is beyond the scope of PA.

2.9 EPA Definition of Human Intrusion and the Area of Concern for Drilling

The definition of "human intrusion" has changed between the promulgation of 40 CFR Part 191 and the promulgation of 40 CFR Part 194. In 40 CFR Part 191, the term human intrusion was limited to boreholes drilled within the surface projection of the repository "footprint" and that actually penetrated to at least the depth of the repository. Appendix C of 40 CFR Part 191 restricted the consideration of drilling for natural resources to the repository area:

> " . . . the Agency assumes that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer *of repository area* [emphasis added] . . . . " (50 FR 38089b/EPA, 1985)

As a result of this guidance, the area of interest in considering the effectiveness of PICs by the Markers Panel was limited to the area of the repository. The revised guidance in 40 CFR Part 194 does not limit the area in which drilling can occur. Title 40 CFR 194.33(a) states that:

> "Performance assessments shall examine deep drilling and shallow drilling that may potentially affect the disposal system during the regulatory time frame." (61 FR 5242b/EPA, 1996c)

The EPA has thus indicated that "human intrusion" is not limited to events that actually penetrate the repository, but includes a broader list including shallow drilling and excavation mining. By this definition, human intrusion (drilling) must be considered to occur anywhere in the Withdrawal—within the footprint or within the Withdrawal outside the repository footprint. Thus, when the EPA states that PICs may reduce the likelihood of inadvertent human intrusion, it has indicated that PICs may be useful in deterring these other activities, including mining for natural resources.

With 40 CFR Part 194, the EPA has stated that drilling and mining will be treated the same in terms of the efficacy of PICs to deter inadvertent intrusion:

> "Performance assessments may assume that the likelihood of mining may be decreased by PICs and active institutional controls, to the extent that can be justified in the compliance application and to a degree identical to that assumed for drilling." (61 FR 5230a/EPA, 1996c)

Because the risks that are associated with drilling directly into the repository are potentially greater than those associated with drilling into the Withdrawal outside of the repository footprint, a greater effort will be made to deter intrusion into the repository footprint than outside of this footprint. The result is that the PICs may have different levels of deterrence for these areas.

When the Markers Panel was convened in 1991, the existing regulatory guidance stated that:

> "Therefore inadvertent and intermittent intrusion by *exploratory drilling* [emphasis added] for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies." (50 FR 38089a/EPA, 1985)

Based on 40 CFR Part 194, the definition of inadvertent human intrusion as used in this report includes any human activity that disrupts the disposal system. These inadvertent human intrusions are limited to drilling and mining for natural resources, but include both exploration and development.

2.10 Dual Nature of Passive Institutional Controls for Assurance Requirements and for PA

To comply with the Assurance Requirements, a system of PICs has been identified for implementation at the WIPP (DOE, 1996). When the DOE addressed the issue of markers for the WIPP, by convening the Markers Panel, the charge was to design a system of markers that would be effective in communicating with individuals in unknown future societies. Thus, one could not assume anything about the nature of the societies or the actions of individuals (e.g., level of technology, language, culture, and natural-resource usage), only that they would be human beings with mental capabilities and bodies much like today's humans. The designs of the Markers Panel have formed the basis of the DOE's conceptual design. The PICs that the DOE is committing to implementing are comprehensive. (See Appendix B, "Compliance with the Passive Institutional Controls Assurance Requirement," for a brief discussion on the compliance of the PICs with the Assurance Requirements, as opposed to the effort described in this report that supports the PA calculations.)

The Assurance Requirements do not require a specific level of efficacy for the PICs in order to show compliance, only that within the four specified categories (markers, records and archives, government ownership and regulations, and other) that the most permanent practicable means be used. These requirements are thus qualitative requirements.

There is no indication in §194.43(c) that if credit were not applied for or granted, that the PICs would not be sufficient to comply with the Assurance Requirements. The requirement for having PICs, and applying for credit for their use in the PA are thus separate issues. Applying credit for PICs only makes sense for those cases where inadvertent human intrusion is a factor—the Containment Requirements of §191.13.

The BID, published with the promulgation of 40 CFR Part 194, indicates the dual nature of PICs:

> "In developing the 40 CFR part 191 rule, EPA recognized that the quantification of risk over long periods of time was subject to considerable uncertainty and consequently introduced assurance requirements into the rule to *qualitatively address this uncertainty* [emphasis added]. One of the assurance requirements deals with passive institutional controls. Passive institutional controls are designed to reduce the probability of inadvertent human intrusion into a repository by conveying information about location, design, and hazards of the WIPP." (EPA, 1996a, p. 12-1)

Thus, PICs play a dual role in the compliance with the disposal standards. The design and implementation of the most permanent PICs practicable are required for compliance with the Assurance Requirements of §191.14. Assessing PICs for efficacy in deterring inadvertent human intrusion over the 700 years for which credit is possible, and providing appropriate justification is wholly within the tasks associated with compliance with the Containment Requirements of §191.13.

2.11 Summary of Application Regulations

For the benefit of the reader, the major regulatory points identified in this chapter are listed below.

- AICs can be effective in deterring inadvertent human intrusion for no more than 100 years after closure.
- Implementation of PICs is required to address the Assurance Requirements.
- EPA may allow credit in PA for PICs deterring inadvertent human intrusion within the Withdrawal.
- The proposed period of time must be technically supportable, not to exceed 700 years after closure.
- Credit may be a constant or tapering reduction in the rate of human intrusion for the proposed time period.
- Credit for the PICs is to be based on a reasonable expectation that the information will endure and be understood for the proposed time period.
- The intent of PICs is to deter inadvertent human intrusion rather than intentional intrusion.
- Intrusion into the entire Withdrawal, not just the repository footprint, is a concern.
- For PA purposes, human intrusion is limited to drilling and mining.

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3.0 PREMISES USED IN ESTIMATING THE EFFECTIVENESS OF PICS IN DETERRING FUTURE INADVERTENT HUMAN INTRUSIONS

3.1 Introduction

The Markers Panel identified design characteristics for the PICs to communicate with future societies of unknown social structures and technologies. This panel recommended messages and communication techniques ranging from simple warnings about the dangers associated with intruding into the WIPP to technical information that would help reestablish the technical basis of radiation and the health hazards associated with radiation exposure. Most of the Markers Panel's recommendations were incorporated into the PICs conceptual design that has been developed for the WIPP Project.

Consequence analyses of human intrusion with no constraints on the mechanisms by which this intrusion may occur presents major problems to the analysts who are trying to do complete analyses and to the regulator who must evaluate the adequacy of the analyses. To address these problems, the EPA has provided guidance designed to limit the speculation that must be incorporated into these analyses. This guidance was originally manifested as Appendix C of 40 CFR Part 191, which was replaced by the requirements in 40 CFR Part 194. Information in the CAG provides an additional view of the intent of the EPA in limiting speculation about the future.

This chapter discusses what the PTF established as the future framework of society and technology based on the regulatory guidance provided by the EPA and logical deductions following from this guidance. *The EPA's regulations, both 40 CFR Parts 191 and 194, establish the framework for the consideration of PICs in PA (i.e., defining what is to be considered and how) with the intent of limiting undue speculation about the future. For PA purposes, PICs are intended to deter inadvertent human intrusion by the natural-resources industry anywhere within the Withdrawal. The consideration is only for 700 years after closure, and the current procedures and technologies of the natural-resources industry are assumed to be used for the entire 700-year period.*

3.1.1 Regulations

The PICs are intended to convey a convincing message to future generations that deters them from disturbing the disposal system. Because of the changing nature of most aspects of society and technology, the long-term effectiveness of the PICs in conveying the warning messages to future generations depends on what the message says, how it is conveyed, and the nature of its audience. The EPA has recognized that long-term predictions about society and technology include a level of uncertainty that can have a significant impact on the PAs.

> "The Agency recognizes the inherently conjectural nature of specifications on future states and wishes to minimize such speculation in compliance applications. The Agency has found no acceptable methodology that could make reliable prediction of the future state of society, science, languages or other characteristics of future mankind." (61 FR 5227c/EPA, 1996c)

The EPA helped reduce the uncertainty associated with predicting the risk of inadvertent human intrusion by mandating certain assumptions about the future in areas where scientific predictions cannot be validated. These future-state assumptions, which are really "present-day" assumptions, are based on the language in §194.25(a), which states:

> "Unless otherwise specified in this part or in the disposal regulations, performance assessments conducted pursuant the provisions of this part to demonstrate compliance with §191.13, §191.15, and part 191 subpart C shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions." (61 FR 5241a/EPA, 1996c)

The rule's Supplementary Information elaborates that for the purposes of assessing inadvertent human intrusion, PAs can assume that current social conditions persist for 10,000 years:

> ". . . the final rule requires that performance assessments and compliance assessment shall include dynamic analyses of geologic, hydrologic and climatic processes and events that will evolve over the 10,000-year regulatory time frame. DOE shall assume that *all other present day conditions will exist in their present state for the entire 10,000-year regulatory time frame.*" [emphasis added] (61 FR 5228a/EPA, 1996c)

3.1.2 Compliance Application Guidance

With regard to PICs, the EPA's CAG states,

> "Explicit application of future state assumptions to passive controls — i.e., the assumption that all present-day societal and demographic factors will remain constant — will not be considered by EPA to justify adequately the design of PICs or the estimation of credit." (EPA, 1996d)

The EPA does provide an approach to dealing with the issues of how PICs can be addressed in the context of PA by establishing guidance in the CAG with regard to assumptions and societal "common denominators." Guidance for the assumptions that can be used states that:

> "EPA expects that DOE will establish a framework of assumptions for PICs that is a prudent extrapolation of the future state [i.e., present day] assumptions established in §194.25." (EPA, 1996d)

In an example provided on what will and will not be accepted in the context of the future state of society, the EPA states that government regulations will remain in force, but the exact form and content of the regulations cannot be identified with certainty. In continuing the guidance, the EPA does not require justification for the existence of government but does require justification why any assumptions about the regulations are sound. The treatment of government in this example is consistent with the paragraph in the CAG following this example that discusses societal "common denominators."

Societal "common denominators" are described as:

> ". . . patterns of human behavior that may be detected throughout history and around the world." (EPA, 1996d)

Nowhere in this paragraph are these common denominators described as "assumptions," nor is there any suggestion that the discussion of assumptions in the previous paragraph applies to common denominators. This approach is consistent with the view that basic human characteristics (i.e., societal common denominators) are facts and not assumptions. In addition, nowhere in this paragraph does the EPA state or imply that these societal common denominators need to be justified by the DOE.

The guidance provided in the CAG about the prudent extrapolation of the future states of society and technology are more speculative than the current conditions of society and technology described in the future-state assumptions of §194.25. As a result, estimates of PICs effectiveness based on the guidance in the CAG would be more conservative than estimates based on the future-state guidance in §194.25.

3.2 PTF Approach

The PTF did not use or rely on the future-state assumptions of §194.25 in the development of estimates of effectiveness of PICs in deterring inadvertent human intrusion for PA calculations.

While §194.25 mandates the use of future-state assumptions, EPA's Response to Comments states that the future-state assumptions do not apply to work on PICs;

> "Future states assumptions do not apply to passive institutional controls. The final rule states that conditions will be assumed to be the same as the present unless otherwise specified in the rule. The final rule also clarifies that such assumptions apply in performance assessments and in compliance assessments; they are not to be applied to assurance requirements." (EPA 1996b, p. 7-7)

The PTF relied upon the language in §194.33 as the primary guidance for assessing the effectiveness of PICs in deterring inadvertent human intrusion for PA calculations.

In addition to guidance on future-state assumptions and common denominators, the EPA provides additional specific guidance in §194.33 and the related Supplementary Information for the treatment of future drilling practices and technology. Because the requirements of §194.33 and their basis are not part of the EPA's future-state assumptions in §194.25, there is no apparent prohibition from applying this guidance to PICs. The PTF therefore considers that current drilling practices in the Delaware Basin are activities that fall within the scope of PICs.

The EPA states that

> "Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared. Such future drilling practices shall include, but shall not be limited to: The types and amounts of drilling fluids; borehole depths, diameters, and seals; and the fraction of such boreholes that are sealed by humans;" (61 FR 5242c/EPA, 1996c)

This statement has widespread implications for the consideration of PICs as deterrents to future inadvertent human intrusion into the WIPP in PA. The guidance that future drilling practices and technology will remain consistent with current practices (as of October 30, 1996) implies that

basic human attributes regarding natural resources will not change over the period of regulatory concern (i.e., 700 years in the case of PICs). In addition, the PTF interprets the term "practices" to include those typical procedures employed by the natural resources industry prior to drilling (e.g., site investigations and lease acquisitions). Guidance with regard to borehole sealing, which is an activity that is regulatory driven to protect public safety and site preservation rather than something a company would normally do as part of resource development, requires the existence of a regulatory body (i.e., government) and the accompanying tools to ensure compliance with the regulations.

With respect to the appropriate treatment of the non-binding guidance in the CAG, the PTF notes that the CAG (on PICs issues) and §194.33 are consistent. The PTF interprets this consistency as resulting from the fact that the CAG (with regard to societal common denominators derived from historical and world-wide observations) is an expansion of the intent represented in §194.33. Language in the CAG describing the situation established by §194.33 as a "prudent extrapolation" was retained by the PTF because it very succinctly describes the relationship between §194.33 and the PICs. The PTF has likewise retained the CAG terminology of "common denominator" because this term describes the historical and societal conditions implicit in §194.33.

Examples of the consistency between §194.33 and the CAG include the existence of some form of government and regulations dealing with natural resources. The EPA has classified the existence of government as a societal common denominator, but the specific contents of regulations may vary and require justification. In a broader context, the existence of regulations and procedures associated with drilling also ensures that site characterization will continue to be required before drilling can begin.

The following sections list and the explain premises that the PTF used in estimating the effectiveness of PICs in deterring inadvertent human intrusion. To avoid possible confusion in terminology and/or origin of these working assumptions, each one is labeled as either a Common Denominator, a Regulatory Assumption, a PTF Assumption, or a PTF Conclusion (derived from the PTF Assumptions). Human attributes listed in Section 3.2.1 were derived from the regulatory guidance provided by the EPA on drilling procedures and technology in §194.33. Because these human attributes are basically the same as those identified by the EPA in the CAG, the PTF has labeled these attributes as Common Denominators. Section 3.2.2 deals with government. The continued existence of government and government regulatory controls also are Common Denominators and are implied in §194.33, although the PTF Assumptions related to government and controls were logical deductions based on the operations of governments. PTF Assumptions about the future of language (Section 3.2.3) were logical deductions based on the worldwide use of current English, the reduced rate of structural change in recent centuries, and the economic value of information written in current English to the natural resources industries. The PTF also has listed Regulatory Assumptions in the area of natural resources (Section 3.2.4) that were derived from §194.33 and the relevant material in the Supplementary Information to 40 CFR Part 191. PTF Assumptions and a PTF Conclusion that had a major impact on the PTF's estimate of PICs effectiveness are described in Section 3.2.5.

3.2.1 Basic Human Attributes

Common Denominator (1): Humans will continue to be curious.

People will continue to be curious about writing, pictures, symbols, and structures, and they will attempt to decipher them or have them deciphered. This common denominator is especially prevalent in the natural resources industry (and over the 700 years under consideration) where site investigators are paid to be curious in order to obtain as much relevant information about the possible presence of natural resources as possible prior to drilling operations and to secure the legal rights to the natural resources being sought. The PTF believes that curiosity will continue to be a trait of individuals in this industry, and this belief is consistent with §194.33.

Common Denominator (2): The use of the written word to transmit information and concepts will continue.

As Gaur (1992, p. 14) has stated, "All writing is information storage." The primary advantages of written information over other forms of information storage are that, at least theoretically, no limit exists on the amount of information that can be stored and written information can be manipulated (Gaur, 1992). Written information about potential natural resources in an area (as recorded in written records and documents) has widespread economic value. This ability of the natural resources industry to record and manipulate written information will not be replaced unless an entirely new technology is developed to replace writing. In addition, writing has been and is used to establish and communicate property ownership, contracts, and governmental control through regulations.

Common Denominator (3): Storytelling or the generational "passing down" of history will continue.

People will continue to be interested in their history and will continue to pass it down to future generations through writings and storytelling. In the natural resources industry, this passing down of history has included and will continue to include stories about the "big strikes" and the major financial and legal disasters of the past because of the potential economic benefit from undertaking certain activities and not undertaking other activities.

Common Denominator (4): The ability of pictures to convey meaning will continue.

In the natural resources industry, pictures include maps (e.g., geologic and geophysical maps), cross sections, fence diagrams, and well logs, all of which have economic value in the areas of natural-resource exploration and site evaluation. Pictures are currently used to store and communicate information and will continue to do so in the future because of the potential economic benefit to be gained through the use of the information.

Common Denominator (5): Some people will avoid, ignore or be ignorant of governmental controls.

Some people will always try to avoid controls that they do not agree with and from which no perceived benefits are derived or from which there is a perceived harm. The tendency of people

to avoid governmental controls has led to an extensive regulatory structure established by governments to control the impulses of individuals or companies in the natural-resource industry (and other industries) to "take advantage of the situation." In addition to the regulatory structure, established legal remedies and penalties for non-compliance have been implemented throughout history. The existence of prisons is a basic example of the fact that some people do avoid or ignore controls.

PTF Assumption (1): Individuals will continue to look out for their own interests in the economic arena.

Individuals will continue to monitor the activities of their competitors in order to gain a personal benefit from competitors' actions or to prevent the competition from gaining a perceived unfair advantage. In the natural resources industry, individuals have a vested interest in obtaining information as economically as possible and estimating the risk (cost versus benefit) of an endeavor before investing large sums of capital. If the risk is too large (e.g., the cost of development is too high or ownership cannot be obtained), the investment will not be made. "Individual" can mean a single person, a corporation, or the State.

This assumption is focused on behavior related to locating and acquiring natural resources and does not address either individual, corporate, or government altruism with regard to the treatment of individuals in need or danger or charitable causes.

3.2.2 Government

Common Denominator (6): The existence of some form of government will continue.

Governments have existed throughout recorded history and worldwide. The functional nature of government indicates that government will exist in some form for the entire regulatory period. Government by definition means "the control and administration of public policy" (Houghton Mifflin Company, 1991). When people form an association, someone either assumes control or is elected to be in charge. The "individual" or "group" in control makes decisions either for its own benefit or the benefit of the association. In the area of natural resources, some form of regulation is required for dispute resolution and maintenance of public safety (e.g., borehole sealing) for as long as natural resources have value and attract exploration and exploitation activities. The guidance in §194.33 that drilling procedures will continue requires the existence of government, because some of these procedures involve economic matters and conflict resolutions.

Common Denominator (7): Government will exert some level of regulatory control over the exploration for and development of resources.

Governments are established to provide a certain level of control upon society. The level of control depends on the type of government. One means of exerting control is to issue regulations or edicts to inform the society about what is and is not permitted, and to provide a mechanism (e.g., legal procedures, armed force, penalties) to enforce the regulations (e.g., borehole sealing) or edicts. Because borehole sealing requires financial expenditures that have no immediate

returns, regulatory authority will be used to ensure the "public good," along with governmental ability to enforce the regulations.

PTF Assumption (2): Governments will require and maintain records as part of the procedure to maintain controls.

Records address the issues of who did what, where, and when. Knowledge of these issues is vital for the government to exert control. By requiring records, government establishes the information needed to exert control. Governments currently require record keeping and will continue to do so in the future. In dealing with natural resource, governments require and maintain records to ensure proper ownership of the resources at specific locations, to ensure the payment of rents, royalties, and taxes and to ensure that procedures have been followed (e.g., boreholes are located, cased, and sealed correctly).

PTF Assumption (3): Governments will continue to protect property rights.

Under a government that respects individual property rights, the government will establish procedures and laws to protect those rights, including surface and mineral rights associated with property ownership. In the case where the government is the steward for the society (e.g., publicly owned material resources), agents of the government will monitor societal property in order to ensure that society's rights are protected and compensation is received in exchange for the sale of societal property. If the government does not recognize individual property rights, agents of the government have a vested interest in protecting society property (e.g., natural resources) from exploration or development by nongovernmental entities.

Whereas some individuals have a tendency to avoid or ignore government control (see Common Denominator 5) that is perceived to be of no direct benefit, individuals and agents of the State have a vested interest in eliminating this avoidance (e.g., in the area of illicit exploration or development of natural resources).

3.2.3 Language

PTF Assumption (4): Current English will continue to increase in the size of its vocabulary and areas of use, but the basic vocabulary and structure will resist change.

Current English is now the international language of science, technology, commerce, and diplomacy, which are major societal drivers. Estimates of the number of people who speak English worldwide range from 800,000,000 to 1,500,000,000, and English has official status in more than 60 countries (Crystal, 1994). Because of this widespread use and official status, at least a portion of both government records and those private records having a connection to the government in non-English-speaking countries are and will be in English. In order for government regulations to take place and for contracts in the private sector to be fulfilled, participants must be able to understand the language of the regulations and contracts even over long periods of time. Translating large volumes of documents in current English to another language would require considerable effort and would require negotiating precise meanings to words and concepts in the translations. As a result, retaining a knowledge of current English is an economic benefit.

The widespread use of current English by the international community presents considerable resistance to rapid and drastic changes in the basic vocabulary and structure of English. People have invested so much time and effort in learning English that they will not accept wholesale changes except over extremely long time frames.

PTF Assumption (5): Current English will remain decipherable by future generations of English readers for at least 1,000 years after disposal.

Current high school students can read the works of Shakespeare (i.e., modern English), which are approximately 350 years old, and understand the basic concepts. College students can read the works of Chaucer (i.e., Middle English), which is approximately 600 years old, with some effort and understand the concepts. Linguistic scholars can read the epic poem Beowulf (i.e., Old English), which is approximately 1,000 years old (Crystal, 1994). Current English will remain decipherable to some members of society for at least as long as Old English has remained decipherable to current society.

In a case where the structure of English does change significantly, the fact that information is economically important will result in a concerted effort being made to understand the information. For example, when treasure hunters were trying to locate the wreck of the Spanish treasure ship Atocha, the available documents were handwritten in Spanish in a form in which the characters bear no resemblance to current written Spanish and the text contains no punctuation (e.g., no commas and no periods). Because of the potential value of the treasure, considerable effort was expended to translate the documents (Sullivan, 1987).

This PTF assumption is consistent with the conclusion of Team B of the Markers Panel (Trauth et al., 1993).

PTF Assumption (6): Current English will continue to be read by the natural resources exploration and exploitation industries.

Because of the specialization of the vocabulary in the natural resources industries, the extent of changes that may occur in current English for the general populace will not extend into the technical aspects of these industries. As a result, current English will become an industry-specific "second" language. This situation is analogous to Latin, which was used as the written language by the scientific community many centuries after the fall of Rome. For an example of an "industry"-specific language being resurrected and maintained, refer to the discussion on the *Atocha* (Sullivan, 1987) in PTF Assumption 5.

3.2.4 Natural Resources

Regulatory Assumption (1): Resource exploration and extraction will be conducted using drilling technology that is basically the same as today's. (40 CFR 194.33 and Supplementary Information)

This is not a future-state assumption, because it is presented in the section on Human Intrusion, which is guidance for the PA. These assumptions are being developed to provide input to the PA and are not used in any other context.

> 40 CFR 194.33(c)(1): "Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared." (61 FR 5242c)
>
> 40 CFR 194, Supplementary Information: ". . . drilling practices will remain as those of today and may vary depending on the resource." (61 FR 5230b)

Assuming the use of higher technology is nonconservative, because higher technology is likely to include the means to detect the repository and radioactivity.

Assuming the existence of a lower technology is nonconservative, because drilling to the depths being considered requires a relatively sophisticated technology that will not exist under this assumption (Guzowski, 1990, see Appendix C)

This assumption is also consistent with the position of the International Atomic Energy Agency (IAEA) (1994) that stated:

> "For the purposes of assessing the consequences of future human actions . . . the future level of technology should be assumed to be at least equivalent to that existing at present. A lower level of technology would make it less likely that intrusion could be technically achieved. On the other hand, an improved technology supposes an increased knowledge, retention of records and an awareness of the risks of such repositories." (IAEA, 1994, p. 18)

Regulatory Assumption (2): Because of the uncertainties associated with predicting future natural resources, the historical drilling rates for oil and gas in the Delaware Basin are to be used in the PA as surrogates for future drilling rates for these unknown other resources. (Supplementary Information corresponding to §194.33)

As the EPA has explained, this is not a future-state assumption. This assumption was established by the EPA to address the uncertainties of what resources will be important to societies in the near to distant future for the PA calculations. For example, uranium was a novelty element before the theoretical basis for nuclear reactions was developed. During and after WW II when a use for uranium was discovered, this element became a major source of resource exploration and production efforts.

> 40 CFR 194, Supplementary Information: "In effect, when used for the purpose of determining the future drilling rate, today's drilling activities act as surrogates for the unknown resources that will be drilled for in the future." (61 FR 5233c)

Regulatory Assumption (3): There will always be natural resources of value within the Delaware Basin that will attract future exploration and support exploitation efforts. (40 CFR 194.33 and Supplementary Information)

As the EPA explained, this is not a future-state assumption. This assumption was established by the EPA to address the uncertainties of when and where resources will be found by societies in the near to distant future for the PA calculations.

> 40 CFR 194.33(b)(2): "In performance assessments, drilling events shall be assumed to occur in the Delaware Basin at random intervals in time and space *during the regulatory time frame* [emphasis added]." (61 FR 5242b)

> 40 CFR 194, Supplementary Information: "With respect to drilling rates, the Agency reasoned that while the resources drilled for today may not be the same as those drilled for in the future, the present rates at which these boreholes are drilled can nonetheless provide an estimate of the future rate at which boreholes will be drilled. The Agency does expect that drilling will never completely cease; while some resources may become depleted over time and, while the rate of extraction of those resources may decrease, the increased rate of drilling for newly discovered resources will compensate for this decline." (61 FR 5233c)

Regulatory Assumption (4): There will be virtually continuous natural-resource exploration and exploitation activities in the Delaware Basin during the entire regulatory time period. (40 CFR 194.33 and Supplementary Information)

40 CFR 194.33(b)(2) states that the drilling of exploration and exploitation boreholes is to be considered as random in time and space during the regulatory time frame for PA purposes (see Regulatory Assumption 3). Regulatory guidance also states that the rate of drilling of both deep and shallow boreholes is to be based on the rate of drilling for the previous 100 years (see §194.33(b)(3) and §194.33(b)(4)).

For the purposes of developing this regulatory assumption, only deep drilling is considered. This historical drilling record for deep boreholes in the Delaware Basin converts to a drilling rate of approximately 47 boreholes/km^2 for the 10,000-year regulatory time frame. This relatively high drilling rate virtually ensures that random sampling of the time of occurrence of drilling will result in boreholes being drilled throughout the regulatory period. If this sampling resulted in a uniform distribution of boreholes in time within the 23,100 km^2 of the Delaware Basin, this drilling rate would result in approximately 108 boreholes being drilled per year.

For a Poisson model, the probability (Pr) of drilling not occurring within a time interval (Δt) for a particular drilling rate per year (λ) can be determined with the equation

$$Pr = e^{-\lambda \Delta t}.$$

Using this equation with the regulatory-derived drilling rate (λ=108.57/yr), the probability of no drilling within the Delaware Basin in any year (Δt=1) is approximately 1×10^{-47}.

The point of this discussion is that the drilling rate that must be used in PA ensures that the drilling in the Delaware Basin will continue over the regulatory time period with no time breaks during which knowledge associated with natural resources can be lost. The records centers dealing with natural-resource exploration and exploitation will be busy processing and maintaining permits and records on a continuous basis, and these records centers will continue to be sources of information for the natural resources industry.

PTF Assumption (7): Resource exploration and exploitation are not casual activities.

Resource exploration and exploitation require a significant expenditure of time and money. As a result, certain procedures have been developed to optimize the benefits received from these expenditures. These procedures include investigating records centers to address ownership issues, checking pertinent literature to obtain resource information, and performing site investigations. All these steps occur prior to drilling.

3.2.5 Estimating PICs Effectiveness

PTF Assumption (8): The determination of intrusion as inadvertent or intentional is not based solely on the actions of an individual but is also based on the actions of government in carrying out its responsibilities.

For example, Congress has established the LWA, which prohibits intrusion into the Withdrawal in perpetuity. Given that WIPP records will continue to exist, be understood, and be stored with resource records, if Congress decides to rescind the LWA, it will be done with full knowledge of the WIPP and any subsequent intrusions are not inadvertent. Government has failed its obligations by removing this prohibition, and this failure is not the responsibility of the generation responsible for the construction and disposal of the waste within. These same obligations apply to any subsequent governments that assume power. This assumption is an extrapolation of EPA's requirement that only inadvertent intrusion must be considered. This extrapolation is from the requirement of individuals to be responsible for their actions to governments that also must be responsible.

PTF Conclusion (1): Communicating with future societies using words, pictographs, symbols, and diagrams through a variety of media is possible.

This conclusion is derived from Common Denominators 2, 3, and 4.

PTF Assumption (9): Historical analogues of structures, media, and messages that have withstood the test of time represent design characteristics that allow the DOE to design for success.

Historians and archaeologists have observed that certain structures, media and messages have survived for long periods of time, whereas others have not. Such observations suggest that certain design considerations of structures, certain materials, and certain communication methods are more durable than others. The DOE can incorporate successful design characteristics to improve the prospects that PICs will endure and will be understood.

PTF Assumption (10): Today's scientific and engineering communities have the capability to create PICs that will perform at least as effectively as historical analogues.

The technology used to construct the historical analogues was primitive by today's standards in that it was based on muscle power and the use of readily available materials. With the development of the PICs, the DOE is attempting to exceed the results of the historical analogues with a much higher knowledge base (why things survive) using much more advanced technology (e.g., mechanization, chemical composition of archival paper, environmental controls for records maintenance).

3.3 The Relationship Between PTF Working Premises and the Activities/Conditions Contributing to Deterrence

Figure 1-5, which is the flow diagram of PICs effectiveness, is reproduced as Figure 3-1 with the incorporation of the PTF's working premises to indicate how all the premises were used in the

development of an estimate of effectiveness. Figure 3-1 indicates those premises upon which each of the activities/conditions were based. When a premise is repeated within the figure, the intent is to emphasize its importance for a particular activity/condition.

3.4 Summary

The EPA (1996b) states that the "future-state" assumptions in §194.25 do not apply to the PICs. As a result, the PTF relied on the EPA guidance in §194.33, which deals with the premises that the DOE can use in the areas of drilling procedures and technology to eliminate undue speculation about future states in PA, to establish societal framework for assessing the effectiveness of PICs. In addition to establishing the pertinence of various regulatory assumptions to PICs in PA, the PTF used §194.33 guidance and related Supplementary Information to establish common denominators and PTF assumptions that are consistent with the additional guidance that the EPA provided in the CAG. Each of these categories is numbered and italicized throughout this chapter. These premises provide a basis for the communication concepts discussed in Chapter 4, the PICs discussed in Chapter 5, and the estimate of PICs effectiveness presented in Chapter 6.

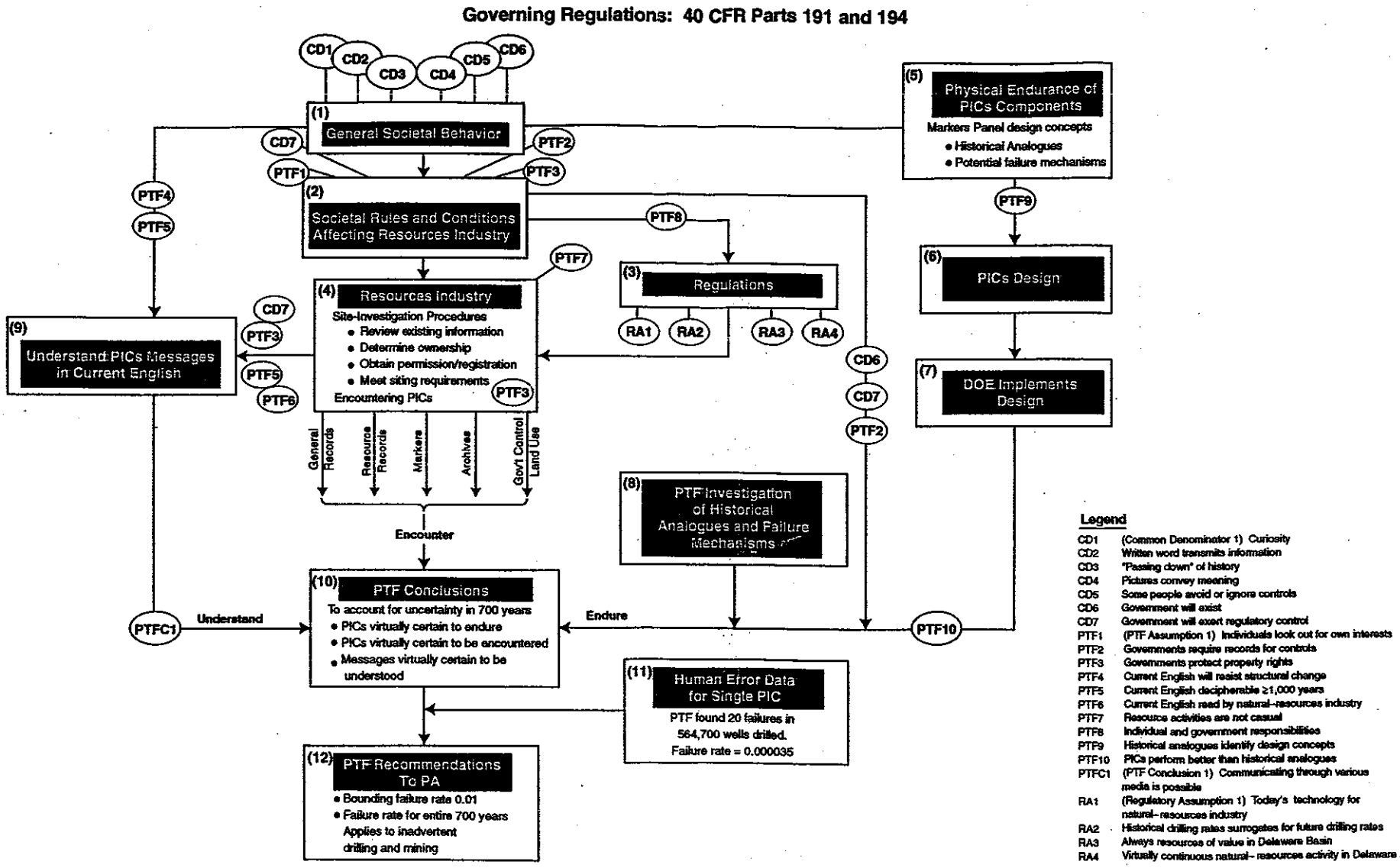

Figure 3-1. **Flow diagram of PICs effectiveness incorporating PTF premises (deterring inadvertent intrusion by the natural-resources industry for 700 years).**

4.0 BASIC COMMUNICATIONS CONCEPTS

The regulatory bases for PICs in PA are discussed in Chapter 2. In developing the conceptual designs for the PICs to address the Assurance Requirements (§191.14(c)), care has been taken to ensure that all of the areas of PICs development and message transmittal established by the EPA (§191.12) have been addressed. The PICs are an integrated system of components that contains both on-site and off-site components, general and detailed warnings, written messages targeted at the technical and academic communities, and symbolic messages targeted at a more general audience.

In addition, the PICs system for the WIPP consists of two types of components. Awareness Triggers are one type of component and are intended to alert the potential intruder or site investigator that something anomalous is present at the WIPP site, and that more information should be obtained before proceeding with the intrusion activity. In the search for additional information, the potential intruder or site investigator will encounter one or more Deterrent Components, which are the other type of components. Deterrent Components are designed to convey a warning to the potential intruder or site investigator that the WIPP site contains hazardous materials and drilling is not allowed.

4.1 Communications Model

4.1.1 Generic Communications Model

The PRP, in a review of an earlier version of this report, discussed the inclusion of a generic communications model. A model consisting of these steps is appropriate for anyone trying to communicate with anyone else. For example, these steps are as appropriate for writing a letter for someone who will receive it tomorrow as they are for PICs communicating with someone who will not be born for generations. The steps in the generic model discussed by the PRP are: (1) Develop Intention, (2) Identify Audience, (3) Encode In Language, (4) Capture In Media, (5) Transmit, (6) Receive, (7) Decode, (8) Understand, and (9) Respond (Glicken, 1996).

4.1.2 Generic Communications Model with Reference to WIPP PICs

Although no communications model was identified in the CDR for the PICs design, the PTF has identified the WIPP activities corresponding to each of the steps in the above generic communications model:

(1) Develop Intention

For PA calculations, communicate concepts of location, design, and content of the repository, and the hazard of the wastes in the repository.

For the Assurance Requirements, (a) communicate concepts of location, design, and content of the repository, and the hazard of the waste in the repository; (b) provide enough information to enable future societies to reestablish scientific basis for radiation and associated hazards (archives, general records centers, Information Center, buried rooms); and (c) provide enough

information to reestablish knowledge of WIPP site, repository, ground-water flow, etc. (archives, general records centers).

(2) Identify Audience

For PA calculations, the audience is established in 40 CFR Part 194 as the potential intruder for resources (i.e., the natural-resources industry and not the individual drill-rig operator).

For the Assurance Requirement for PICs, EPA provides no guidance on what limitations DOE can assume about the future, so DOE cannot make any assumptions about the state of society or technology. As a result, the target audience cannot be identified.

(3) Encode In Language

For PA calculations, PTF Assumptions 4 through 6 in Chapter 3 established that current English is sufficient for correct communication.

For the Assurance Requirements, to accommodate the possible range of future societies, DOE will use five levels of messages ranging from a simple message that humans did something here to highly complex messages that can help to reestablish knowledge about radioactivity and possible health effects from exposure to radiation and detailed information about the WIPP facility, the contents, and the disposal system. Messages will be in the form of objects, text, pictographs, tables, and charts. DOE will test these messages by seeing if transcultural groups can understand the various messages in the different formats. These principles of communication were established by the Markers Panel (Trauth et al., 1993).

(4) Capture In Media—Selection of materials that are the most permanent practicable and placing the correct messages on the selected materials (e.g., granite and archival paper).

(5) Transmit—Physical markers are sent to the WIPP site and emplaced as per the design; paper records are sent to the designated records centers and archives and are incorporated into the collections per agreed upon indexing system; land use covenants sent to government agencies controlling land use and incorporated into the regulatory system; correct information sent to previously agreeable publishers of textbooks, reference books, and maps for publication and distribution through normal channels. Transmission occurs when the information gets into specific system above.

(6) Receive—PICs components endure for future generations to encounter.

(7) Decode—Warnings/messages are understood by future generations.

For PA calculations, this step requires that the potential intruder be able to understand the words of current English.

For the Assurance Requirements, this step requires that the potential intruder be able to understand either the written messages (in one of the languages used) or the pictographs.

(8) Understand—Future generations comprehend that the warnings/messages are directed at them.

DOE will have a testing program to ensure that the intended messages and warnings are captured in the text and pictographs.

(9) Respond

For PA, the response of future generations to the warnings/messages is not relevant—if warnings are ignored and intrusion occurs with knowledge of the possible consequences, the intrusion is intentional and is not part of PA.

For the Assurance Requirement, how future generations respond to the warnings/messages is not relevant to complying with this requirement.

4.1.3 PTF Focus for PICs Communication

EPA regulations identified the intentions of the PICs (Step 1); the Futures Panel (Hora et al., 1991) identified the audience in the Assurance Requirement arena whereas the rule identified the audience in the PA arena (a potential intruder in the natural resources industry) (Step 2); the Markers Panel identified the communications principles; and the DOE incorporated these principles into a conceptual design of the most permanent PICs practicable (Step 3).

The PTF dealt with the issues of how long the PICs would endure with their messages intact and whether the messages could be decoded (recognized) and understood in the 700 years of PA concern. The inappropriate response of future societies that have understood the messages was not a PTF concern.

The approach of the PTF was to focus on the EPA's two concerns of messages enduring and being understood (Steps (6) through (9) of the general communications model—see Section 4.1.1). Steps (3), (4), and (5) of the general communications model were assumed to be completed because the DOE has committed to implementing the PICs as described in the CDR.

QA procedures are being developed by the DOE that will ensure that Steps (3), (4), and (5) of the PRP's general communications model take place: (3) ensure that the linguistic and non-linguistic messages are developed to communicate the intended information, (4) the correct media are selected (e.g., correct paper, correct quality of granite), and the correct messages are captured in the appropriate media (e.g., the printer copies the correct messages on the correct paper, the engraver carves the correct messages at the correct locations in the granite monuments and walls), and (5) the completed PICs components will be transported to the correct locations (e.g., the records get to the correct records centers and archives, the granite monuments are delivered and emplaced in the correct locations).

Step (6) Receive—If the messages are to be received, they must endure (Step 6a) and be understood (Step 6b).

Step (6a) The PICs must endure for the regulatory time frame of interest.

An examination of historical analogues pertinent to certain design characteristics of the PICs identified physical characteristics that increase the likelihood that materials and structures will endure for extended periods of time. Among the characteristics identified were the use of durable materials and the development of multiple copies. The PICs planned for the WIPP were designed to take advantage of these characteristics using current design knowledge and technology to develop PICs that have a high probability of exceeding the performance of the historical analogues.

Step (6b) The PICs must be encountered.

When the DOE refers to a potential intrusion being deterred, the deterrence is not aimed primarily at the drill rig operator, but at other personnel involved in site investigations who are paid to be curious and find out all the pertinent facts about a site. Because resource exploration and extraction are not casual activities, decisions authorizing the expenditure of funds for drilling will be made by a senior official with the authority to commit the needed financial resources based on the site's geology, obtaining resource rights, and the probability of adequate financial return, and not made by the drill rig operators. As a result, the individual doing the site investigation must search records to establish ownership of surface and natural resource rights and may visit the site itself to determine the feasibility of drilling at the site. The locations of the PICs were selected to ensure that someone doing a site evaluation would encounter at least one of the Deterrent Components.

Step (7) Decode—The contents of the messages must be comprehended.

The PTF developed an assumption that current English will be understood by potential intruders (i.e., people involved in natural resource exploration and exploitation) for at least 700 years after disposal. This assumption was based on the ability of current societies to read and understand past versions of English, the volume of resource-related records and information that will be of economic importance to future societies, and the virtually continuous high level of resource-related activities in the Delaware Basin required by regulatory guidance. This assumption ensures that future societies will be able to read and understand the messages on deterrent PICs that survive intact (or relatively intact for some deterrent PICs).

Step (8) Understood—The messages are understood as a warning for the current reader.

When a message is comprehended as a warning, then a potential intruder recognizes the danger of intruding as a fact (not a myth) and knows that the warning is not just the remnant of a previous danger, but is intended to warn the current generation and future generations. The DOE will undertake a testing program prior to the implementation of the PICs to ensure that the messages can be understood as an ongoing warning.

Step (9) Respond—The warnings must deter future societies from inadvertently intruding into the WIPP.

For the purpose of this analysis and to be consistent with regulatory usage of the term "deterrence," the DOE assumed that deterrence would occur if the PICs endured long enough for future societies to encounter them and the messages could be understood. The DOE concluded that in the regulatory framework established by the EPA and the assumptions that could be developed from this framework, each of the Deterrent Components of the PICs contains sufficient warning in current English for a potential intruder to understand the potential dangers of the radioactive material.

4.2 Systems Approach for PICs Design

The PICs being proposed for the WIPP disposal system (see Chapter 5) are an integrated system of components that include redundancy of the information being transmitted and reinforcement of the information. The PICs system is designed to include a wide variety of PICs components encompassing a variety of message levels (see Section 4.3) and using a variety of media for conveying the messages. This systems approach is derived directly from the design characteristics proposed by both teams (Team A and Team B) of the Markers Panel. As stated by Team A:

> "This team's thinking is founded on two major themes. The first theme states that the use of communication technology cannot bypass the problem of the certain transformation and succession of cultures, but use of fundamental and enduring psychology can. The second theme states that the entire site must be experienced as an integrated system of mutually reinforcing messages, and designed accordingly." (Trauth et al., 1993, p. F-27)
>
> "As well, we use the more culture-bound modes of communications such as languages and diagrams, but these are used as part of a larger system of communications. This system is to be one with great redundancy of messages and modes, so that even with some loss the goals of the system are met.
>
> "As well as being conceived as (1) a whole communication experience, (2) having a systemic character in which pieces are related in meaningful ways that add meaning, and (3) being sufficiently redundant to endure loss of elements, we apply the principle of Gestalt, in which the experience of the total communicated message is greater than the sum of the parts (even with some of the parts missing or degraded)." (Trauth et al., 1993, p. F-29)

Archives and records were not within the purview of the Markers Panel. Thus, their systems approach addressed only physical markers. Consistent with the requirement in §191.14, the DOE has extended the systems concept to incorporate archives, records centers, government land ownership and control, and other means of communication into the total PICs design.

The design of the PICs in order to comply with the Assurance Requirements is based on the two premises that (1) the PICs must be the most permanent practicable, and (2) one can make no assumptions about the extent of changes in the future state(s) of society, technology, and language (i.e., one must design for the range of possibilities, but one can make the assumption that basic biological traits of humans will remain the same). With limited assumptions about the future, the systems approach means that (1) the multiple messages, levels of complexity, and

communication media all reinforce each other to fill in gaps in communication and (2) the PICs are actually available and contain the necessary information to reestablish societal knowledge about the WIPP, should there be societal discontinuities.

The use of the PICs, as designed to meet the Assurance Requirements, to take credit in PA is undertaken within EPA's framework of regulatory assumptions. Credit for PICs in PA is also limited to the much shorter time frame of 700 years. Under these circumstances, the PICs design exceeds what the assumptions would call for, and the systems approach means that each PICs component (other than the berm) is redundant and that any one could correctly communicate the information and deter the potential intrusion.

4.3 Complexity of Messages

Five levels of messages will be used for the PICs at the WIPP based on Givens (1982):

- Message Level I conveys the message that the site is manmade. The message itself is in the physical form of the marker system and the effort expended in constructing it.
- Message Level II conveys the message that something dangerous is buried here and that no digging or drilling should be conducted.
- Message Level III conveys basic information that tells what, why, when, where, who, and how.
- Message Level IV conveys complex information in seven languages along with symbols and pictures.
- Message Level V is archival and stores a more complete rulemaking record than the messages provided at the WIPP site.

These different message levels are generally targeted at different audiences to address the Assurance Requirements rather than to address the credit for PICs in PA. Level II, and perhaps Level III, messages are targeted at people in societies that are not drastically different from our own who are involved in the natural resource industries that might be interested in locating or exploiting natural resources at the WIPP site. Levels III, IV, and V messages are designed to reestablish basic scientific concepts within societies in which these concepts have been lost or the social/technological/language changes have been so great that the connection between the text messages and the concepts have to be reestablished. In addition, these higher-level messages provide basic information about the characteristics of the WIPP site, the repository, and TRU waste.

4.4 PTF Approach to the PICs System for PA

The PICs components as a deterrent can be viewed in several ways:

(i) Each component is an independent deterrent whose effectiveness is uninfluenced by other components. The effectiveness of the PICs set or system is as effective as the most

effective component that will be encountered by the potential intruder. Failure of one or more components could either reduce or leave unchanged the total effectiveness, depending on the differences in effectiveness of the components and the particular component(s) that fail. The message on each Deterrent Component conveys sufficient information so that comprehension precludes inadvertent human intrusion. As will be discussed in more detail below, this model is used by the PTF because of simplicity and conservatism.

(ii) The effectiveness of each of the components is dependent on the effectiveness of all of the other components. The effectiveness of the PICs system is the product of the effectiveness of each component in the system. Failure of any component to deter would mean that the entire PICs system fails.

(iii) The effectiveness of each component contributes to the effectiveness of the PICs system. The effectiveness of the PICs system is the sum of the component effectivenesses. Failure of one or more components would reduce the effectiveness of the PICs system.

(iv) The effectiveness of each component contributes to the effectiveness of the PICs system, but because of the Gestaltic nature of the system design, the effectiveness of the total PICs system is greater than the combined effectivenesses of the components. The effect of the failure of any component on the system effectiveness depends on the contribution of the component to the Gestalt.

A Gestalt is a system in which the whole cannot be determined by simply summing the parts within the whole. The Gestaltic nature of the PICs system refers to the PTF's belief that the effectiveness of the system cannot be determined by summing the estimated effectivenesses of the PICs components. The physical presence of the PICs components, the repetition of the warning over and over on different media and in different ways, the size of the markers, and the level of effort required to construct the markers and distribute the records will reinforce to the potential intruder the importance of the location, and thereby reinforce the importance of the messages and warnings to an extent that simply reading a single message is unlikely to convey.

The concept of Gestalt for PICs addresses the requirements of the Assurance Requirements; because of the potential for discontinuities in society and information, a future society might need to recreate all the information about the WIPP.

Team B of the Markers Panel discussed the relationship of the individual PICs components:

> "The probabilities and performance characteristics proposed above [Markers Report, Trauth et al., 1993] for the individual markers would be greatly enhanced by their inclusion within a larger, well-integrated marking system.
>
> "Message redundancy would be increased, of course. But the additional cross-referencing and multiple linkages of markers, signs, symbols, text and diagrams also would help reduce the likelihood of inadvertent intrusion. Furthermore, use of teaching principles throughout the message system (i.e., defining the meaning of a given symbol or iconic sign by placement within

> appropriate linguistic and diagrammatic messages) would augment performance of the entire marker." (Trauth et al., 1993, p. G-64)

The PTF agrees with Team B that incorporating the impact of the Gestalt is appropriate and would result in greater probabilities of success, although representing such interactions would add additional controversy. An alternative that would introduce conservatism into the assessment of effectiveness would be to not take credit for the Gestalt, and view the components as acting as (i). The PICs for the WIPP for PA purposes are envisioned to operate as alternative (i) rather than alternative (iv) for the sake of simplicity and as a conservative action.

WIPP PICs components do not act either as alternative (ii) or (iii). Alternatives (ii) and (iii) would have portions of the messages or warnings on each of the components (i.e., no component contains the complete message or warning). For alternative (ii), the loss of any part of the warning or message means that the surviving parts are insufficient to construct the warning or message. In other words, loss of any component means that the entire system fails. For alternative (iii), each component contains a partially complete message or warning with the complete message or warning requiring all of the components. Loss of any component would reduce but not eliminate the effectiveness of the system.

Further, in an integrated system, where all of the components must be effective for the system to be effective, system effectiveness is controlled by the weakest link. An example of this would be a secret society where all members must maintain silence for the society to remain secret.

In a system where controls may reinforce each other, but essentially act independently, the most effective control determines effectiveness of the set of controls. An example of this case is the imposition of speed limits. A roadway sign indicating the legal speed limit is a control that contains sufficient information to keep a motorist from acting illegally by speeding. It may have varying effectiveness depending on the motorist and traffic conditions, for example. Police officers patrolling the highways is another means of controlling the illegal activity of speeding. If a police officer travels down the highway, then the probability of compliance with the speed limit will increase in most cases.

The PICs for the WIPP are akin to the second case, because each PICs component contains sufficient information to deter inadvertent human intrusion, and because while different components may have varying effectiveness, it doesn't matter as long as the activity is deterred.

Any one of the various PICs Deterrent Components that is encountered can deter the potential intrusion: (1) information encountered in any one of the records centers is sufficient to indicate to a site investigator that the Withdrawal is federally owned and has covenants to prohibit resources exploration or exploitation, and in addition, sufficient information is present to indicate the hazardous nature of the site and the personal hazards associated with intrusion; (2) information encountered in any one of the archives is sufficient to indicate to a site investigator that the Withdrawal is federally owned and has covenants to prohibit resources exploration or exploitation, and in addition, sufficient information is present to indicate the hazardous nature of the site and the personal hazards associated with intrusion; (3) prohibitions against drilling or mining attached to land records are sufficient to indicate to a potential intruder (even without being denied a lease) not to drill because they could not take advantage of anything they find; and

(4) information encountered at the site from the markers is sufficient to communicate that drilling is prohibited and they could not benefit from any drilling, and in addition, sufficient information is present to indicate the hazardous nature of the site and the personal hazards associated with intrusion.

Through the previous discussion of PICs, the reader should note that a "failure" for the purposes of PA is the inadvertent drilling of a borehole at a location where the driller does not own the property or lease (i.e., a "failure to deter" an inadvertent intrusion). In Chapter 5, the concept of a "failure mechanism" is introduced as a means by which the ability of a PICs component to endure and/or be understood is impaired or eliminated. The action of a failure mechanism to impair or eliminate a PICs component does not in and of itself constitute failure to deter for the entire system of PICs for the WIPP. Incorrect designation of the location of a borehole after it has been drilled in the correct location does not constitute either a "failure to deter" or a failure mechanism for the PICs for the purposes of estimating PICs effectiveness (signs after the fact are not a part of the PICs system and do not impact other boreholes).

4.5 Encountering the PICs

Some of the PICs components are designed to instill a knowledge of the WIPP into the general public. Information about the PICs in textbooks, dictionaries, and encyclopedias should expose a large segment of the population to basic information about the WIPP. Although individuals in general are unlikely to remember much about the WIPP, those individuals who become involved in natural resources and environmental endeavors are more likely to be exposed to more detailed information about the WIPP and may be more likely to recognize the term "WIPP" because of an interest in the topic. These PICs may heighten the awareness of the potential intruder to the WIPP's presence so that other sources of information will be checked.

Natural resource exploration/exploitation consists of three basic steps: (1) identification of areas that have natural resource potential, (2) evaluation of the natural resources in the areas, and (3) exploitation of the natural resources if the area-evaluation results confirm the presence of economically viable natural resources. Because of the high levels of expenses in evaluating resources through field work, the first step in locating areas with resource potential typically is to research available sources of geologic and related information. Selected PICs components are designed to provide warnings and/or information on geologic and resource-related maps that someone interested in the resource potential of the northern part of the Delaware Basin is likely to check. These PICs are likely to heighten the awareness of the potential intruder to the presence of the WIPP so that other sources of information will be checked. Government ownership of the land at the WIPP could be determined at this stage of the investigation. The PICs component of government ownership would not be a deterrent, because government ownership of land is a common occurrence in resource exploration in the West.

If the WIPP region has resource potential, the next step would be to check the ownership of the surface and mineral rights prior to any exploration activities. Expending time and effort to locate resources would be pointless if no opportunity exists to recover these investments. An investigation of ownership would lead to various government offices (federal, state, county, and local) where deeds and leases could be checked. This search could extend to birth/death records

and probate court records if surface or mineral rights could have been inherited. This phase of the investigation would encounter a number of PICs. Someone driving to a records center could encounter an area designated as "the WIPP" on road maps and atlases. As with other maps, these PICs would heighten the awareness of the investigator to the presence of the WIPP so that other sources of information will be checked. At the records centers, the investigator would learn from the fact in property records that the land within the land-withdrawal boundary is owned by the government and that leases contain land-use restrictions as covenants prohibiting drilling. The location and design of the WIPP facility and the hazards associated with the buried waste will be determined from the special, WIPP-specific records on file in the records center. Government ownership by itself would not deter a potential intruder but would force the investigator to obtain the proper permits to avoid charges of mineral/resource trespass. Such permits could not be obtained because of the covenants. Land-use restrictions by themselves would not prohibit a potential intruder unless the government at some level is willing and able to enforce the restrictions. The WIPP-specific records within the records center would provide a major deterrent to intruding at or near the WIPP.

As part of the regional site evaluation, the investigator might conduct a field check of the WIPP out of curiosity or as part of the investigation of land adjacent to the Withdrawal. A site visit would encounter the markers. The warnings provided by the messages on the markers would reinforce the warnings already encountered at the records center(s). If the site visit occurs prior to visiting a records center, the warnings on the markers would still be deterrents. These warnings would also provide additional incentives to find out more about the WIPP at records centers or archives, where the investigator would encounter the PICs of government ownership, land-use restrictions, and the formal WIPP-specific records.

Land-use restrictions and ownership do not depend on the existence of a particular records center but are established and maintained by government as a whole. As a result, even if a records center were to be destroyed, this destruction would not cancel existing property rights or existing regulations. Just as government would be obligated to maintain the previous property rights and regulations, anyone wanting to exploit natural resources would remain obligated to establish ownership of the natural resources and to obtain the necessary permits prior to starting the exploration or exploitation activities by checking with other records centers.

5.1 Potential Failure Mechanisms Eliminated From Consideration

The PICs PRP identified a number of potential failure mechanisms that needed specific treatment. Each of the potential failure mechanisms is discussed below to indicate how the topic was addressed in the Conceptual Design Report, why a potential failure mechanism is beyond the scope of credit for PICs in PA, or how the potential failure mechanism is subsumed into another failure mechanism already addressed.

5.1.1 Casual and Systematic Vandalism

Vandalism was taken into account in the designs. The PICs components are not replicates of the historical analogues examined, but take the basic design concept from the historical analogue that enabled these structures to endure and enhances them to compensate for natural and human factors that will tend to destroy the components. Specific examples of design solutions incorporated to counteract the effects of vandalism include: (1) selection of granite for the monuments and other markers as a durable rock that will resist chipping and limit damage from bullets; (2) use of multiple copies of the individual monuments and markers so the system will continue to communicate even if one or more individual monuments or markers are damaged or removed; (3) use of right angles and relatively large, flat surfaces in the shape of the monuments to reduce the amount of material that can be chipped away by someone hammering on a monument; (4) use of the large size of the monuments and the berm to make these components difficult to destroy or remove; (5) inclusion of two copies of the Level IV messages on the granite walls in each of the buried rooms; and (6) use of an irregular pattern of the spacing and depth of the small buried markers to make systematic collection of these markers difficult.

The PTF expects that the markers at the WIPP, with their multiplicity of copies, will be able to withstand casual vandalism and souvenir hunting (e.g., spray paint, bullet holes, chipping of edges) from 100 to 700 years after closure so that a sufficient number of components or pieces of components will remain to communicate their intended messages.

The PTF believes that systematic vandalism (e.g., the monuments and markers at the WIPP being caught in the middle of a tank fight, the target of a scorched earth policy of a retreating army, the target of rampaging renegade troops, the target of deliberate destruction by cults, or the development of new highly destructive technologies that can be owned by the general public) will be a low probability event at the WIPP from 100 to 700 years after closure. In addition, vandalism of this type is beyond the realm of a prudent extrapolation of today's societal conditions.

5.1.2 Collateral Effects of War

The collateral effects of war were not addressed and need not be addressed, because they would be such a low probability event. Collateral effects might destroy some parts of a component or some parts of several components, but would be unlikely to take out all of the markers at the site. It would take a very large bomb to destroy all of the markers to the point that pieces of text on monuments did not remain in pieces large enough to read. The trinitite produced from a nuclear device would itself be a marker. In discussing the impact of war damage, i.e., bomb damage on a

repository, the EPA has stated that "Similar to the question of sabotage is the question of damage to the repository through some act of war. The only credible act that could even fracture the rock down to about 500 meters would be the detonation of at least a ten-megaton or larger nuclear device. During a war, it is hardly likely that bombs would be aimed at a repository. Cities and strategic installations are far more attractive targets. In addition, the effects on the biosphere from a damaged repository would be insignificant compared with the other damage inflicted in such a conflict" (EPA 1980). The WIPP is not a strategic target and is many miles away from any strategic targets. The probability of a stray missile in the expanse of southeastern New Mexico away from strategic targets, of a capacity large enough to destroy all the markers was below the regulatory cut-off for scenarios that had to be considered. In addition, to paraphrase the EPA, if a bomb that large did explode, it would disturb the repository, and that bomb would represent far greater impacts than the disruption of the repository itself. In addition, collateral effects of war at the WIPP would not destroy all of the records centers and archives containing WIPP information.

5.1.3 Horizontal Drilling for Resources

Horizontal drilling would be subject to the same regulations as vertical drilling, and as a result would be subject to the same procedures. Consistent with these procedures (including examining maps and other Awareness Triggers), horizontal drilling would require obtaining ownership or resource rights, both at the drill site and along the length of the drill string. There would be the same prohibitions on drilling into the disposal system from outside the Withdrawal as drilling vertically into the disposal system. As a result of being subject to the same procedures, the failure rate for horizontal drilling can be assumed to be the same as the failure rate for vertical drilling.

Horizontal drilling is required to go through the same site-evaluation procedures and permitting processes as vertical drilling. As a result, the PICs will be as effective in deterring inadvertent horizontal drilling into the Withdrawal as they will be in deterring inadvertent vertical drilling.

5.2 Permanent Markers

The marker system conceptual design was derived from the conceptual designs developed by the Marker Panel (Trauth et al., 1993), and is described in detail in "Passive Institutional Controls Conceptual Design Report" (DOE, 1996, Sections III through VIII, and XI). Figure 5-1 depicts the general layout and relative positions of the major components of the permanent marker system at the repository footprint. The most massive component is a large berm that surrounds the repository footprint. Buried within the berm are radar reflectors and large permanent magnets to permit future generations to find the berm, should sand dunes cover the structure over the years. Sixteen large granite monuments outline the footprint perimeter. These monuments will include engraved warning messages in seven languages. Two large rooms are also buried. One room will be buried within the southern segment of the berm (Figure 5-1), and the other room will be buried outside the berm at a location aligned with the room in the berm, the Information Center, and the decommissioned and decontaminated WIPP Hot Cell (located within the Support and Waste Handling Building in Figure 1-3). Each buried room has a detailed message describing the WIPP site, the waste contents, and their danger. This detailed message will be engraved in granite and will be repeated within each room in seven languages. At the center of

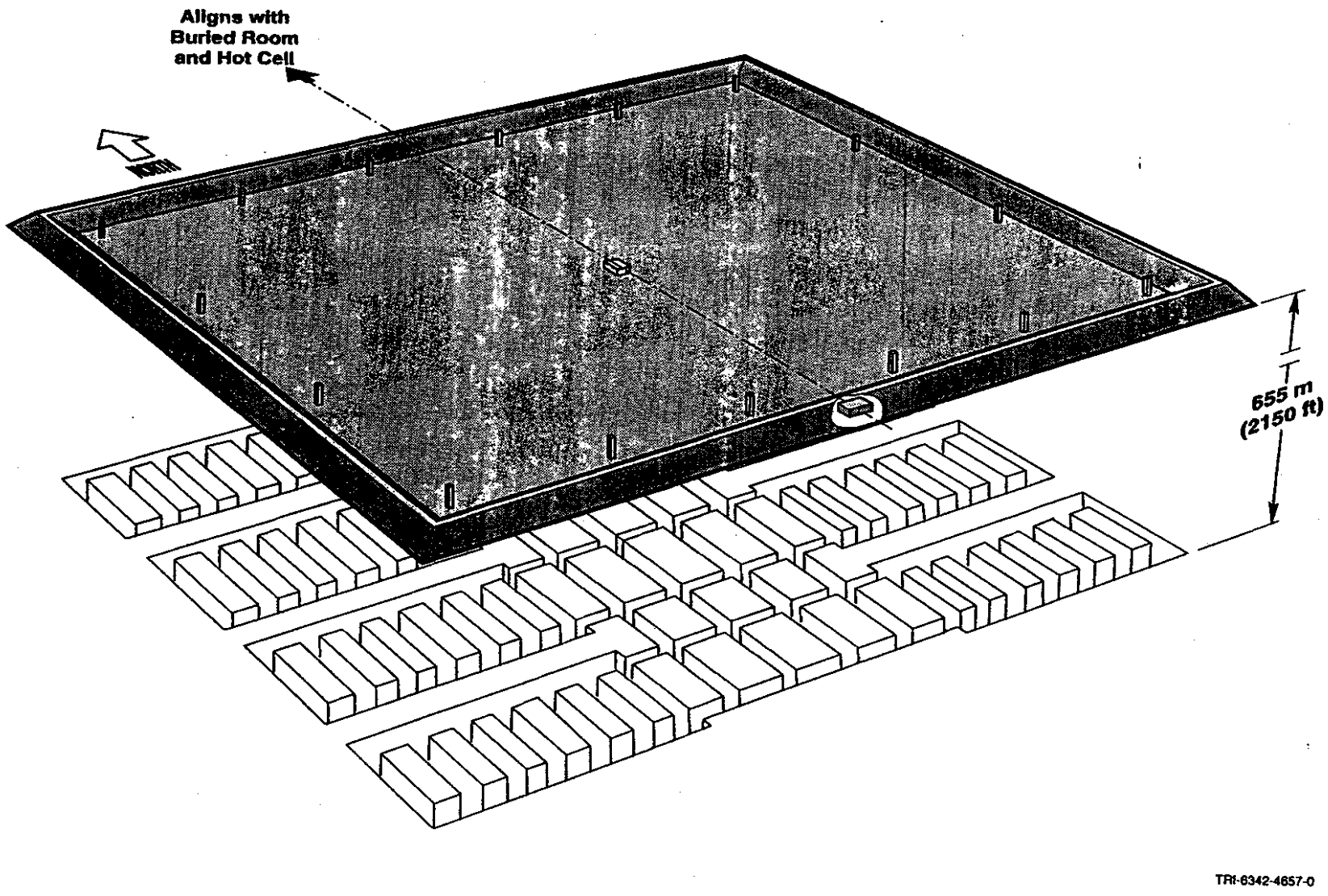

Figure 5-1. General layout of major components of the permanent marker system at the repository footprint.

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the footprint, a readily accessible "Information Center" will be erected on the surface. The Information Center contains the same messages as the two buried rooms. Throughout the repository footprint, relatively small markers engraved with a warning not to drill or dig will be buried at randomly selected locations and depths (between 0.6 and 1.8 meters [2 and 6 feet] below the surface).

The conceptual design includes marking the 16-section Withdrawal with 32 granite monuments evenly spaced around the area perimeter (Figure 5-2). The design of these monuments will be similar to the monuments marking the repository footprint, although the message on these markers will primarily attempt to deter potentially disruptive inadvertent human intrusions within the Withdrawal but outside of the repository footprint.

With regard to failure mechanisms and design solutions, climate is an issue that will potentially affect all of the markers at the site. The climate to which a historical analogue has been subjected versus the climate that the markers will experience at the WIPP will vary. In general, the climate at the WIPP is as dry or drier than the climate at the historical analogues. Thus, weathering impacts related to water at the WIPP will be less than or equal to the impacts on historical analogues. Wind-blown sand may be a concern at the WIPP as well as at the various historical analogues. In response to this concern with erosion, pristine granite has been selected for its durability, and most of the elements of the site marker system will be placed within a protective berm that will reduce wind velocity. An experimental program for PICs will assess potential impacts of the natural environment on PICs and identify any design modifications necessary to address these impacts.

5.2.1 Berm

5.2.1.1 Conceptual Design

The largest component of the PICs is a 10-meter-high (33-feet-high) berm with a 30-meter-wide (98-feet-wide) base tapering to a 4-meter-wide (13-feet-wide) top constructed just outside of the repository footprint (DOE, 1996, Section VIII). The berm is to be made up of a salt core from repository tailings, a layer of crushed caliche, a layer of riprap, and a final layer of mixed riprap and soil planted with vegetation native to the area. The total volume of the berm will be approximately 750,000 cubic meters (975,000 cubic yards). Within the berm will be buried concrete-encased steel radar reflectors and large permanent magnets. These devices will provide the capability for future generations to locate the berm with remote-sensing techniques.

5.2.1.2 Historical Analogue: Stonehenge

One of the most famous structures that has endured for thousands of years is Stonehenge. Located on the English plain about 32 kilometers (20 miles) south of Marlborough Downs, construction of Stonehenge began about 2700 to 2500 B.C. and concluded about 2100 to 1900 B.C. (Kaplan, 1982).

The survivability of earthworks for thousands of years is demonstrated by the two concentric banks (i.e., earthen mounds surrounding the circular configuration of the stone structures) present at Stonehenge. The first building phase at Stonehenge began circa 2700 to 2500 B.C. and

included the construction of the banks (Kaplan, 1982). The banks are made of chalk (a soft limestone) and the outer bank is 2.4 meters (8 feet) wide and 0.6 to 0.9 meters (2 to 3 feet) high with a diameter of approximately 115 meters (380 feet). The inner bank was originally 6 meters (20 feet) wide and 1.8 meters (6 feet) high with a diameter of approximately 98 meters (320 feet). Due to erosion, the bank is now approximately 0.3 meters (1 foot) high (Hawkins, 1973). A ditch 3 to 6 meters (10 to 20 feet) wide and 1.2 to 2.1 meters (4 to 7 feet) deep lies between the banks (Kaplan, 1982). The ditch probably served as the source of material for the banks. The banks are an example of an earthworks aged 4,500 to 4,700 years old.

5.2.1.3 Historical Analogue: Serpent Mound

The Serpent Mound in Ohio is not as old as Stonehenge. However, it is generally accepted that it was built by the Adena Indians who lived in the area from 1000 B.C. to 700 A.D. (Kaplan, 1982). The Serpent was formed by blocking out the pattern with stones and clay. A 0.3-meter (1-foot) layer of clay was then laid over the stones and another 0.7-meter (2-foot) layer of dark soil on top of the clay. The Serpent length is 383 meters (1,254 feet) long, an average width of 6 meters (20 feet) wide and 1.2 meters (4 feet) high. The mound was restored to its present contours by Putnam in 1886 (Kaplan, 1982).

5.2.1.4 WIPP Relevance: Stonehenge and Serpent Mound

Both the Stonehenge and Serpent Mound earthworks are ancient structures built of on-site or near-site materials in climates more severe with respect to erosion of earthen structures than the climate found in southeastern New Mexico. The current remains of the banks and the mound do not contain any design features explicitly intended for the long-term preservation of the structures. Both structures originally had cross sections substantially smaller than that of the planned berm at the WIPP. The maintenance of a significant portion of the original cross-sectional area is what allows the berms to be identified as human construction (Level I message).

With the larger cross-sectional area of the berm compared to the historical analogues and the incorporation of a layered design to minimize erosion, and considering the age of ancient mounds, the DOE asserts that the berm is virtually certain to endure as a Level I message for at least 5,000 years, and has a high probability of lasting beyond the period of regulatory concern.

5.2.1.5 Potential Failure Mechanisms and Design Solutions

Erosion. (1) Materials selection — soil to support plants to stabilize surface against water or wind erosion; riprap to drain away water and as safety factor against wind erosion; caliche as safety factor to keep infiltrating water away from salt core. (2) Size — so large so as to take a long time to obliterate; such a large volume of material so that even if the berm were to lose its original shape, substantial quantities of material would remain in the area as a Level I message.

Buried by migrating dunes. (1) Height of the berm — higher than the height of surrounding existing dunes. (2) Design — even if portions were covered, the berm has such a large aerial extent that it all could not be entirely covered.

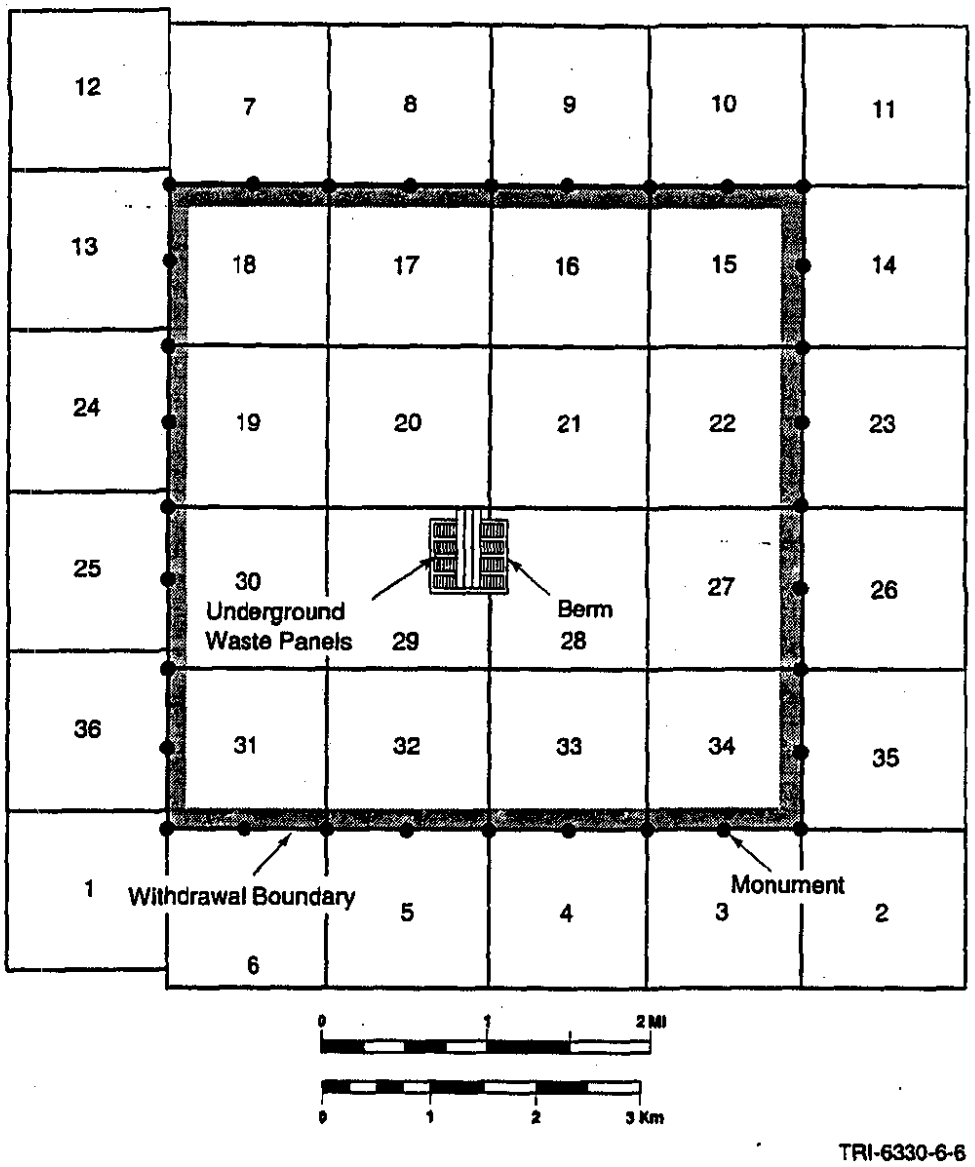

Figure 5-2. Proposed distribution of the permanent markers at the withdrawal boundary (modification of DOE, 1989).

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Deliberate dismantling and /or removal. Size — large effort required to completely dismantle and completely remove. Even a decision to mine the salt or recover the magnets or reflectors would still result in a large amount of material at the site, at least a portion of which is not native to the immediate area.

5.2.2 Monuments

5.2.2.1 Conceptual Design

Sixteen monuments will be evenly spaced around the perimeter of the repository footprint (inside the boundary of the berm [see Figure 5-1]). Each of these monuments will extend 7.6 meters (25 feet) above the surface and 5.2 meters (17 feet) below the surface (DOE, 1996, Section V). Each monument will be comprised of two granite stones. The upper stone will weigh 36.4 metric tons (40 tons) and will be placed over the base tendon weighing 59.1 metric tons (65 tons). Pristine granite blocks will be used in the construction and surface preparation of the granite will include polishing so the surfaces will shed water rather than leaving the surface rough where small pits can serve as locations for water retention. Each stone will be engraved with Level II and Level III text messages and Level IV pictographs. Thirty-two monuments similar to the footprint monuments will outline the Withdrawal (see Figure 5-2) and convey the message that the entire area enclosed by the monuments should not be disturbed.

5.2.2.2 Historical Analogue: Stonehenge

Durability. Initial construction of Stonehenge included the placement of the 32 metric-ton (35 ton) "Heel Stone" (i.e., an upright monolith made of sarsen rock located outside the complex perimeter) and concluded 400 to 800 years later with placement of 4-ton "Horseshoe" rocks (bluestone). The structure also includes a horseshoe of "Trilithons" 6.1 to 7.3 meters (20 to 24 feet) high made of sarsen stone and weighing 41 to 45.5 metric tons (45 to 50 tons) each. Three of the original five trilithons are intact. The other two lack a lintel and one is upright. Eighteen monoliths and five lintels of a ring originally consisting of 30 monoliths with lintels of 23 metric tons (25 tons) each still exist today (Kaplan, 1982). Compared to the environment at the WIPP, the structure has endured the ravages of the much wetter environment of the British Isles for 4,000 years without losing the characteristics that define its configuration. The sarsen rock is silicified sandstone, which is a common rock type on the surface of the English chalk downs. Bluestone is a local term used in Great Britain for bluish rocks, most of which are dolomite, but with some rhyolite, sandstone, and consolidated volcanic ash. The bluestones occur together only in a small area (1.6 kilometers square [about one mile square]) in the Prescelly Mountains of Wales, some 322 kilometers (200 miles) from Stonehenge (Kaplan, 1982).

Since the construction of Stonehenge, the British Isles have been subject to numerous foreign invasions (e.g., the Romans, the Jutes, the Angles, the Saxons, the Normans, the Danes, and the Norwegians) (Kinder and Hilgemann, 1974). There were also numerous episodes of internal strife (e.g., lines of successions, the War of the Roses) (Kinder and Hilgemann, 1974) that introduced political turmoil to the land.

After nearly 4,000 years of weathering impacts and being subject to potential vandalism, engravings of two axes and a sword can be seen on one of the uprights at Stonehenge, as photographed by Mohen (1990). Thus, engravings can remain visible for thousands of years on exposed surfaces.

Communication. Stonehenge was no doubt useful to the society(ies) that used this structure in antiquity. Construction by humans is obvious (Level I message). Evidence from excavations within and beyond the site's footprint conveys a fragmentary Level III message (i.e., who built the monument, when, what for, and why [in part, for astronomical observation]) (Mohen, 1990). No evidence exists of an attempt by the creators of Stonehenge to communicate the structure's usage across the centuries to future generations living in societies different than the creators' society. The PTF examined the physical endurance of Stonehenge as a historical analogue for a series of monuments. Stonehenge as a communications analogue (other than Level I) was not examined.

5.2.2.3 WIPP Relevance: Stonehenge

The people who built Stonehenge selected specific rock types based on hardness (e.g., they selected bluestone rather than the much softer chalk). The blocks selected were at or near the surface, which suggests that the blocks had experienced some weathering prior to quarrying. For the WIPP monuments, pristine granite will be used. The weathering and erosion characteristics of this granite are superior to the rock types (silicified sandstone and dolomite) employed in the construction of Stonehenge. The WIPP monuments will be located in a drier environment than are the Stonehenge monuments, providing an environment more conducive to long-term durability. Weathering is the physical disintegration and chemical decomposition of rock by such processes as hydration of minerals, dissolution of minerals, chemical alteration of minerals, abrasion of minerals (e.g., by blowing sand), and physical breakup of minerals (e.g., freeze/thaw). Physical removal of the altered material generally is considered to be part of erosion and not part of weathering. In the case of the monuments to be emplaced at the WIPP, the exposure to rain and snow will lead to the hydration of some minerals in the granite (i.e., the feldspar will eventually weather to clay) and the weathering products will be removed by rainwater and/or wind. Some mechanical abrasion by wind-blown sand is likely to occur, although the abrasion typically occurs close to the land surface and will be limited by the protection offered by the berm and/or local vegetation. Any cracks that develop in the rock or between mineral crystals will tend to be enlarged by freezing and thawing when the rock is wet. Dissolution is not a process to consider for the silicate minerals of granite.

The durability of the Stonehenge monument system both in terms of natural deterioration and survival through numerous episodes of social turmoil provides evidence that a system of monuments can endure for thousands of years. Based on the WIPP design of a set of multiple monuments, the DOE asserts that at least some of the WIPP monuments are virtually certain to remain to define an area for at least 4,000 years, with a high probability of lasting beyond the regulatory period. Even fallen monuments, as has occurred to some monoliths at Stonehenge, can contribute to defining the perimeter of the repository footprint and transmit the engraved messages. Based on the usage of rocks of greater durability than those used at Stonehenge and the survival of Stonehenge engravings on an exposed surface, individual WIPP monuments and

their engraved warnings on all four sides are virtually certain to survive for at least 4,000 years, with a high probability of lasting beyond the regulatory period.

The historical analogues listed in a later section for the Information Center provide further support for a reasonable expectation that the WIPP monuments will last for thousands of years.

5.2.2.4 Historical Analogue: Rock of Behistun

Durability. At the foot of the Zagros Mountains in the Kermanshah region of Iran, more than 2,500 years ago the Persian King, Darius I, inscribed a memorial 45.7 meters (150 feet) wide and 30.5 meters (100 feet) long (Frimmer, 1969) commemorating events that took place from about the autumn of 522 to the spring of 520 B.C. in his victory over a group of rebels and his ascension to power. Enormous bas-relief figures were carved more than 61 meters (200 feet) above an ancient road from Hamadan to Babylon into the sheer face of a 610-meter (2000-foot) high mountain proclaiming the might of Darius to all who pass by (Frimmer, 1969; Encyclopedia Britannica, 1994). Darius chose this location for its prominence. This memorial has withstood the rigors of time and weather in an exposed location so that its inscriptions can still be read today.

Communication. The accompanying text was inscribed for the purpose of reaching generations to come and includes a sculptured scene with 14 columns of writing at its sides and beneath it. The writing, using cuneiform script, is in three languages that today are known to be Old Persian, Elamite, and Babylonian.

The sculpture has endured longer than the common use of the languages its contains, but the essence of its message remains interpretable by modern day scholars. It is an example of an authority creating a message for future generations to learn of the deeds of an earlier generation.

5.2.2.5 WIPP Relevance: Rock of Behistun

The Rock of Behistun is another example of exposed engravings that have endured for thousands of years. The purpose of the WIPP Permanent Markers is to inform future generations of the existence of the WIPP and the risk of intruding into the Withdrawal. As in the case of the Rock of Behistun, the monuments will provide this information in several languages. The information medium for the WIPP monuments is granite into which the text is engraved. Based on the durability of the rock used and the depth of the inscriptions, there is a reasonable expectation that the WIPP monuments will endure as long as the ancient inscriptions. This reasonable expectation provides further support for the DOE's previous assertion that monuments and their inscriptions are virtually certain to survive for at least 4,000 years, with a high probability of lasting beyond the regulatory period.

The multiple languages repeating the message on the Rock of Behistun are an analogue for the design concept of multiple languages on the WIPP monuments to communicate with a broad spectrum of cultures to address the Assurance Requirement for PICs.

5.2.2.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of rock). (1) Material selection — granite is the most durable of rocks routinely used for building construction. Granite will be used that has not experienced weathering. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles).

Erosion (physical removal of material). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Message location — messages will not be directly at ground level, because that is where erosion from blowing sand would be the most destructive. (4) Protection offered by the berm — the presence of the berm will reduce wind speeds within the area outlined by the berm, especially as the berm is higher than the monuments, and thus reduce possible wind erosion.

Buried by migrating dunes. (1) Height — monument height will be higher than existing dunes. (2) Multiple monuments — some individual monuments can be buried and the component can still communicate effectively. (3) Distribution of monuments over a wide area — dunes migrating in one area will leave other monuments untouched. (4) Protection offered by the berm (only for those monuments located within the area outlined by the berm) — because the berm is so high, with an original height of 10 meters (33 feet), it will reduce the amount of sand that could be carried up over the berm and into the area of the repository footprint, for all but the highest of the dunes.

Removal intact (museum). (1) Multiple monuments — some individual monuments can be removed and this PICs component can still communicate effectively. (2) Size and weight — difficult to transport. (3) Government ownership and regulation — museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.

Removal for recycling. (1) Multiple monuments — some individual monuments can be removed and this PICs component can still communicate effectively. (2) Size and weight — difficult to break up. (3) Government ownership and regulation — recycling efforts cannot remove material from private or government land without permission

Defacement (including gouges from target practice, being knocked over, and destruction of the messages). (1) Materials selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Multiple monuments — some individual monuments can be removed or damaged and the component can still communicate effectively. (3) Government ownership and regulation—it is illegal to damage or destroy private or government property without permission. (4) Engraved messages — messages will still be readable under paint. (5) Design — monuments are designed to have

large flat surfaces that will be difficult to deface and sides that meet at right angles to limit the extent of chipping.

5.2.3 Information Center

5.2.3.1 Conceptual Design

An Information Center will be erected at the center of the repository footprint (DOE, 1996, Section VII). This Information Center will have exterior walls and seven parallel interior information walls but no roof. The sediments at the location of the Information Center will be excavated down to the level of the underlying caliche, and this excavation will be filled with caliche to the original land surface level. The overall dimensions of the Information Center are 12.2 meters wide by 9.8 meters deep by 3.0 meters high (40 feet wide by 32 feet deep by 10 feet high). The dimensions of the interior information walls are 5.2 meters wide by 2.1 meters high (17 feet wide by 7 feet high). These dimensions exclude 1.5 meters (5 feet) of each wall buried in the caliche. Level IV messages indicating the location, design, and hazards of the WIPP will be contained within the Information Center. The Level IV text information will be engraved on both sides of the seven granite information walls with one wall for each of the seven languages (the six official languages of the United Nations plus Navajo), while tables, figures, diagrams, and maps will be engraved on the interior side of the exterior walls.

5.2.3.2 Historical Analogue: Australian Rock Art

Durability. The EPA (1996a, p. 12-14) discussed ancient Australian rock art that includes paintings, engravings, and peckings located on protected surfaces (but not in enclosed rooms, etc.). This rock art is estimated to be approximately 25,000 years old and possibly 35,000 years old. The location of the rock art in a desert environment means that it has endured the onslaught of wind-borne sand, and wide temperature fluctuations, without these processes destroying it.

Communication. This historical analogue was not examined for communication.

5.2.3.3 WIPP Relevance: Australian Rock Art

The relatively fragile media of Australian painted and pecked rock art has endured for thousands of years with only minimal effort towards long-term preservation, while the messages in the WIPP Information Center will be engraved to improve durability. Durability is increased by the selection of granite as the medium for the messages and the placement of the engraved messages within an Information Center designed to afford protection from weathering and erosion. The location of the Information Center within the berm offers additional protection against erosion. The DOE asserts that the performance of the Information Center is virtually certain to be as good as the endurance of Australian rock art and is virtually certain to be recognizable for the entire regulatory period.

5.2.3.4 Historical Analogue: The Acropolis

The Acropolis, which is a world-famous site of antiquity, is an elevated region overlooking Athens, Greece. This location and position have attracted human habitation since approximately

5000 B.C. During the Mycenian period (c. 1400-1200 B.C.), a massive fortification wall was built, part of which can still be seen today near the Propylia. This wall and an altar seem to have survived intact until the Persian sack of Athens in 480 B.C. Pericles was the prime mover in the decision to rebuild the Acropolis on a monumental scale after peace was made with Persia. The following monuments exist today within the Acropolis:

- Beule Gate. The first ceremonial entrance to the Acropolis is the Beule Gate. This monument was built from limestone blocks taken from an earlier monument that dates from approximately 310 B.C. An inscription on the monument states that the structure was built in about A.D. 280 and was paid for by F. Septimus Marcellinus (Kaplan, 1982).

- Agrippa Monument. The monument stands on a natural terrace between the Beule Gate and the Propylia. The slab for the statue stands 8.8-meters (29-feet) high and is made of marble. The slab originally bore a four-horse chariot dedicated to celebrate a chariot victory by the city of Pergamon in the Panathenaic Games in about 178 B.C. Inscriptions on the slab tell us that the latest statue was raised to Marcus Agrippa in 27 B.C. From the writings of Plutarch and Dio Cassius, we know that the slab once bore statues of Anthony and Cleopatra, but that these statues blew down in 31 B.C. (Kaplan, 1982).

- Propylaia. This is the classical gateway to the Acropolis. It is a part of the overall monumental rebuilding of the Acropolis undertaken by Pericles after the Persian Wars. Construction was begun in 437 B.C. with work halted in 432 B.C. because of the start of the Peloponnesian War. Work on this structure was never resumed. The gate is constructed of Pentelic Marble (Kaplan, 1982).

- Temple of Athena Nike. This structure was constructed during the period of 427 to 424 B.C. to celebrate peace with Persia. The major construction material was marble. A frieze, sculpted in high relief, ran around the exterior of the building. Four of the 14 slabs originally in the frieze are now in the British Museum (Kaplan, 1982).

- Erechtheion. This structure is a multiple-level building meant to house several cults, including those of Athena, Poseidon, and the founding rulers of Athens. Construction began in 421 B.C. and was completed in 409 B.C. The building was part of Pericles' plan for the Acropolis. This building is also constructed of Pentelic marble. In one part of the building known as the Porch of Maidens, six statues of young maidens support the roof. One of these statues has been removed to the British Museum (Kaplan, 1982).

- The Parthenon. This temple occupies the highest part of the Acropolis. It was built in the period from 447 to 438 B.C. as the cardinal feature of Pericles' plan. The best and most celebrated sculptors in Athens were engaged in its construction. Forty-six columns, each 10.5-meters (34.5-feet) high, ring the building. At one time, metal "shields" were placed above the series of columns. A frieze made up of alternating sculptures and grooved panels also originally surrounded this structure. Of the original 92 sculptures/panels, 15 are in the British Museum, one is in the Louvre, and 41 remain in place. In A.D. 1687 while the Turks were using the building as a powder magazine, a direct hit by a mortar

caused a major explosion, blowing the temple into two parts. The explosion destroyed 35 of the frieze panels (Kaplan, 1982).

Durability. As noted above, most of the structures in existence today at the Acropolis date from the fifth century B.C., more than 2,400 years ago. The Acropolis has endured as a transcultural religious site (of importance to the Greeks, the Romans, Christians, and Muslims at various times), with many buildings that are analogues for the Information Center. While individuals/ museums wanted to remove pieces to their own countries, there was no desire then to destroy the original site. This removal to indoor museums has actually prolonged the durability of some friezes, statues, and columns, and also provided greater dissemination of information about the Acropolis, which has contributed to the Acropolis being seen as a cultural artifact worth preserving. The fact that no mortar was used would suggest that the structures would be relatively unstable, except for the fact that the building stones were extremely well dressed and afforded the structures greater stability. The building stone, while relatively soft and soluble, was not significantly degraded by natural weathering until the past 50 years when industrialization and automobile exhaust significantly increased the acidity of the rainfall. Even with some components being damaged or removed, the basic building structures remain distinguishable and these structures contain portions that include intricate carvings, some of which are in remarkably good condition even after weathering and periods of social chaos.

Communication. The PTF examined the physical endurance of the Acropolis as a historical analogue for a buried storage room. The Acropolis as a communications analogue (other than Level I) was not examined. The great detail that is known about the history of the Acropolis indicates that the long-term preservation of knowledge is possible, and this active transmission of information (historical records and translations) is discussed in the section on "Other PICs" (Section 5.6).

5.2.3.5 WIPP Relevance: Acropolis

The major materials found in the Acropolis are limestone and marble (Kaplan, 1982). Calcite ($CaCO_3$) is the predominant mineral of these rock types. As a result, both limestone and marble have relatively low resistance to abrasion, and both rock types have a relatively high solubility when exposed to acidic conditions. Based on historical records, the main threats to the buildings of the Acropolis have been their accidental (e.g., war) and deliberate (e.g., recycling of building stone) destruction. In the past 50 years, a significant amount of damage has been done to the Acropolis' structures because of the atmospheric pollution and acid rain that have accompanied the industrialization of Greece (Kaplan, 1982). The use of pristine granite for the major WIPP structures will provide an increased resistance to weathering and the adverse affects of acid rain over the marble and limestone used at the Acropolis. In addition, the location of the WIPP site will provide a lower acid-rain risk than many areas of the world because of insufficient water in this region to support significant industrialization and urbanization. Minimizing heavy industrialization and urbanization of the area also reduces the risk of significant levels of atmospheric pollution developing from vehicle exhaust and industry. History provides information about what did not survive at the Acropolis, namely metal monuments, most of which seem to have been recycled. This knowledge of what does not endure, because of natural

processes and/or human actions, is applicable to the WIPP PICs in suggesting that messages presented on metal not be used as they may be recycled.

The PICs marker system includes redundancy of monuments and markers and could accommodate removal of some of the markers without destroying the definition of the extent of the site, the purpose, and the dangers associated with intrusion into the repository. Upon comparison of the Acropolis' lower durability structural materials to WIPP markers and the history of conflicts in the Mediterranean area that did not destroy either the physical artifacts or their purpose and meaning for more than 2,400 years, the conceptual design of the WIPP marker system using granite provides a credible argument for confidence in the marker system's ability to survive many centuries and convey the intended warnings. With the monuments and structures of the Acropolis having survived for more than 2,400 years, survival of the granitic WIPP monuments and Information Center well in excess of the 2,400 years is a reasonable extrapolation.

Using the more durable granite, rather than limestone or marble, combined with the less damaging environment, the WIPP Information Center will have higher durability than the buildings of the Acropolis. The DOE asserts that the WIPP Information Center is virtually certain to survive with its engravings legible for at least 2,400 years, with a high probability of enduring for the entire regulatory period.

5.2.3.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of rock structure). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles).

Erosion (physical removal of material). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Message location — messages will be located on the walls inside the Information Center to reduce the impact of blowing sand. (4) Protection offered by the berm — the presence of the berm will reduce wind speeds within the area enclosed by the berm. Lower wind speeds, especially for the Information Center (height of 3 meters [10 feet]) that is well protected by the berm (height of 10 meters [33 feet]), will reduce possible wind erosion.

Buried by migrating dunes or the impact of vegetation. Protection offered by the berm — because the berm is so high, with an original height of 10 meters (33 feet), it will reduce the amount of sand that could be carried up over the berm and into the area of the repository footprint, and be available to form dunes. The presence of the berm will reduce wind speeds within the berm, and reduce the possibility of the material within the berm from forming huge dunes.

Removal intact (museum). (1) Size and weight — message panels are large and difficult to transport. (2) Government ownership and regulation—museums or private collectors cannot remove material from private or government land without permission. (3) Exhibition in museums provides wider distribution of information; encourages interpretation and study.

Removal for recycling. (1) Size and weight — message panels are large and the granite is difficult to break up. (2) Government ownership and regulation — recycling efforts cannot remove material from private or government land without permission.

Defacement (gouges from target practice, walls knocked down, and destruction of the messages). (1) Material selection — granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite that has not experienced weathering will be used. (2) Messages located on interior walls of the Information Center — perpetrator would be harmed from ricocheting gunfire within the Information Center. (3) Engraved messages — messages will still be readable under paint. (4) Design — the walls are designed to be large flat surfaces that will be difficult to deface.

5.2.4 Buried Storage Rooms

5.2.4.1 Conceptual Design

One granite storage room with an overall dimension of approximately 11.9 meters long by 6.7 meters wide by 4.9 meters high (39 feet long by 22 feet wide by 16 feet high) will be buried within the berm that surrounds the repository footprint (DOE, 1996, Section VI). A second room with the same dimensions will be buried in the Withdrawal outside the footprint approximately halfway between the berm and the Hot Cell. Within the buried storage room, tables, figures, diagrams, and maps will be engraved in the interior sides of the exterior structural walls. Seven granite slabs 3.7 meters wide by 3.0 meters high (12 feet wide by 10 feet high) will be emplaced within the buried storage room to create interior message walls for text information. Each interior message wall has engraved text on both sides, with one wall for each of the seven languages (the six official languages of the United Nations plus Navajo). Both sides of the interior message walls and the interior sides of the structural walls will have a granite veneer with duplicate engraved information of the material underneath. The existence of the storage rooms will be documented in the records located in the archives, the records centers, and the Information Center. The information contained in the buried storage rooms is the same as in the Information Center.

5.2.4.2 Historical Analogue: Newgrange

Durability. Newgrange, located in County Meath, Ireland, is an ancient passage grave, even older than the Egyptian pyramids. This passage grave was constructed by Stone Age farmers in approximately 3150 B.C. When constructed, the grave was an unmortared stone structure approximately 85 meters (280 feet) in diameter, with a facing of white quartz. The internal structure consists of a single passage into the center of the grave, opening up into a central chamber 5 meters (17 feet) long. Located off of this central chamber are three recesses. Far from being simply a mound of stones, the grave was carefully designed, as described by Fagan (1994):

> "The ceiling of the passage is six feet high and made of large slabs of overlapping boulders that form a corbel vault. The roof in the central chamber is twenty feet high and is made of boulders tightly packed with clay and sand. O'Kelly [the individual who excavated Newgrange between 1962 and 1975] found cleverly placed grooves pecked into the boulders designed to carry rainwater away from the apex of the chamber, effectively keeping it dry for 5,000 years." (Fagan, 1994, pp. 16-17)

Engravings on the internal walls include spirals and zigzag patterns. These engravings are distinct and show no signs of weathering, making them clearly discernible today.

Communication. Newgrange was no doubt useful to the society(ies) that built and used this structure in antiquity. Construction by humans is obvious (Level I message). Evidence from excavations within and beyond the passage grave conveys a Level III message (i.e., who built the passage grave, when, what for, and why) [in part, for astronomical observations]) (O'Kelly, 1982). No evidence exists of an attempt by the creators of Newgrange to communicate the structure's usage across the centuries to future generations living in societies different than the creators' society. The PTF examined the physical endurance of Newgrange as a historical analogue for a buried storage room. Newgrange as a communications analogue (other than Level I) was not examined.

5.2.4.3 WIPP Relevance: Newgrange

The existence of Newgrange indicates that buried stone structures can last for thousands of years, providing protection for openings within the structures and the engraved messages on interior walls. Use of corbel construction, while stable in the case of Newgrange, can fail, causing the roof to collapse, as in the case of one passage in the passage grave at Knowth, which is near Newgrange (Fagan, 1994). To avoid potential structural instabilities, the buried storage rooms designed for the WIPP will consist of slabs of pristine granite specifically designed to maximize the structural integrity of the rooms. Consistent with the Newgrange analogue, the rooms are expected to survive for at least 5,000 years, with a high probability of lasting beyond the regulatory period. The engravings will be protected from weathering for this same time period. When and if the buried storage rooms are exposed by excavation, their durability will be that of the Information Center planned for the center of the repository footprint.

5.2.4.4 Historical Analogue: The Egyptian Pyramids

The Pyramids of Egypt represent examples of the ability of stone structures erected by human beings to successfully function as monuments for thousands of years. The three great pyramids at Giza were built during the Fourth Dynasty of Egypt approximately 2600 to 2500 B.C. (Kaplan, 1982). These pyramids were burial tombs for the pharaohs who had them built. The messages conveyed by these structures and their associated inscriptions are Levels I, II, III, and IV.

Durability. The core of the Khufu (Cheops in the Greek historical text) pyramid, which is the first and largest of the Giza pyramids, consists of limestone blocks from a local quarry. The basic construction materials of the other two pyramids at Giza were quarried from the same location. The blocks vary in weight from about 2.3 to 13.6 metric tons (2.5 tons to 15 tons). Within

Khufu's pyramid, the final chamber is lined with granite slabs. The roof slabs for this chamber are estimated to weigh 45.5 metric tons (50 tons) each. The name Khufu appears in the quarry marks on some of these stones (Kaplan, 1982). The stone used for the pyramids is the best and hardest stone from the quarry.

If the funerary nature of these structures was ever in doubt, any alternate hypotheses would be disproved by the Pyramid texts. These texts are inscribed on the walls of the burial chamber in the pyramid of Onis, who, having died about 2350 B.C., was the last pharaoh of the Fifth Dynasty (Kaplan, 1982) and in all other remaining pyramids of the Old Kingdom. The texts contain chants and incantations to insure the future happiness of the deceased pharaoh. Although the pyramids were looted during times of central-government chaos, the inscriptions remained.

A significant consideration is the fact that during the history of the pyramids, chaos reigned repeatedly in the region of the pyramids and centralized government control was lost and regained several times. Yet, throughout this period, both the structures and their purpose were preserved.

Communication. This historical analogue was not examined for communication.

5.2.4.5 WIPP Relevance: Egyptian Pyramids

Engraving messages on the granite walls in the buried rooms can be reasonably assumed to preserve the information for many thousands of years. The granite in the rooms within the pyramid is harder than the limestone used to construct the rest of the pyramid. The Khufu markings on 45.5-metric-ton (50-ton) granite slabs buried within the pyramid have remained intact and communicated their message over a period of more than 4,500 years. As long as the WIPP buried rooms remain buried, they will be available for at least 4,500 years, with a high probability of lasting beyond the regulatory period. When and if such rooms are exposed or excavated, the durability of the newly exposed rooms and their engravings will be similar to that of the Information Center (i.e., expected durability of at least 2,400 years starting at the time of excavation).

5.2.4.6 Potential Failure Mechanisms and Design Solutions

The following are potential failure mechanisms for an unexcavated buried room (including consideration of a shaft dug to the room entrance).

Weathering (chemical alteration of rock structure). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location — rooms will be buried and have a roof and should thus be protected from infiltration of rainfall.

Removal intact (museum). (1) Interior walls of the buried rooms contain two layers of messages — one entire layer can be removed and the remaining message can still communicate effectively. (2) Size and weight — message panels are large and difficult to transport. (3) Government

ownership and regulation — museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.

Removal for recycling. (1) Interior walls of the buried rooms contain two layers of messages — one entire layer can be removed and the remaining message can still communicate effectively. (2) Size and weight — message panels are large and the granite is difficult to break up. (3) Government ownership and regulation — recycling efforts cannot remove material from private or government land without permission.

Defacement (target practice, walls knocked over, and destruction of the messages). (1) Material selection — granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite that has not experienced weathering will be used. (2) Messages located on interior walls of the buried rooms — perpetrator would be harmed from ricocheting gunfire within the buried rooms. (3) Interior walls of the buried rooms contain two layers of messages — one entire layer can be defaced and removed and the remaining message can still communicate effectively. (4) Engraved messages — messages will still be readable under paint. (5) Design — walls are designed to have large, flat surfaces that will be difficult to deface.

The following are potential failure mechanisms if a buried room is excavated but left in place.

Weathering (chemical alteration of rock structure). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location — messages will be located on the interior walls of the buried room with a roof to protect the message panels from rain

Infill. Material selection — Pristine granite is so durable that if the buried room becomes covered over by dunes, then it is available to later generations.

Removal intact (museum). (1) Interior walls of the buried rooms contain two layers of messages — one entire layer can be removed and the remaining message can still communicate effectively. (2) Size and weight — message panels are large and difficult to transport. (3) Government ownership and regulation — museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.

Removal for recycling. (1) Interior walls of the information center contain two layers of messages — one entire layer can be removed and the remaining message can still communicate effectively. (2) Size and weight — message panels are large and the granite is difficult to break up. (3) Government ownership and regulation — recycling efforts cannot remove material from private or government land without permission.

Defacement (target practice, walls knocked over, and destruction of the messages). (1) Material selection — granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite that has not experienced weathering will be used. (2) Messages located on interior walls of the buried rooms — perpetrator would be harmed from ricocheting gunfire within the buried rooms. (3) Interior walls of the buried rooms contain two layers of messages — one entire layer can be defaced and removed and the remaining message can still communicate effectively. (4) Engraved messages — messages will still be readable under paint. (5) Design — walls are design to have large flat surfaces that will be difficult to deface.

If the room buried below grade is excavated, dismantled, and reconstructed elsewhere certain potential failure mechanisms become issues.

Weathering (chemical alteration of rock structure). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Dry climate at the WIPP (limited water available for ice wedging in freeze and thaw cycles). (4) Message location — messages will be located on the interior walls of the buried rooms to protect the message panels from rain.

Erosion (physical removal of material). (1) Material selection — granite is the most durable of rocks routinely used for construction. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Message location — messages located on the walls inside the buried rooms to reduce the impact of blowing sand.

Buried by migrating dunes or the impact of vegetation. Durability of materials — if the reconstructed buried room becomes covered over, then it is available to later generations.

Removal intact (museum). (1) Interior walls of the buried rooms contain two layers of messages—one entire layer can be removed and the component can still communicate effectively. (2) Size and weight — message panels are large and difficult to transport. (3) Government ownership and regulation — museums or private collectors cannot remove material from private or government land without permission. (4) Exhibition in museums provides wider distribution of information; encourages interpretation and study.

Removal for recycling. (1) Interior walls of the buried rooms contain two layers of messages — one entire layer can be removed and the remaining message can still communicate effectively. (2) Size and weight — message panels are large and the granite is difficult to break up. (3) Government ownership and regulation — recycling efforts cannot remove material from private or government land without permission.

Defacement (target practice, walls knocked over, and destruction of the messages). (1) Material selection — granite is the most durable of rocks routinely used for construction and thus gouging with hand tools is difficult. Fresh granite will be used that has not experienced weathering. (2) Messages located on interior walls of the buried rooms — perpetrator would be

harmed from ricocheting gunfire within the buried room. (3) Interior walls of the buried rooms contain two layers of messages — one entire layer can be defaced and removed and the remaining message can still communicate effectively. (4) Engraved messages — messages still readable under paint. (5) Design — walls are designed to have large flat surfaces that will be difficult to deface.

5.2.5 Small Buried Markers

5.2.5.1 Conceptual Design

Several thousand small warning markers will be buried at randomly selected depths ranging from 0.6 to 1.8 meters (2 to 6 feet) below the surface (DOE, 1996, Section V). A Level II message will be engraved on each marker. Each marker will have the message in one of seven languages. Warning markers will be placed throughout the repository footprint. Some individual warning markers will be made of granite, while others will be made of aluminum oxide or fired clay. Spacing between warning markers will be random within a range of 4.6 to 12.2 meters (15 to 40 feet).

5.2.5.2 Historical Analogue: Code of Hammurabi

Durability. In 1901, a diorite stele was discovered in a tell in Iraq that contained 282 legal decisions of Hammurabi, who was the 6th ruler of the 1st (Amorite) dynasty of Babylon (c. 1792-1750 B.C.). The stele is now located at the Louvre in Paris. The legal decisions known as the Code of Hammurabi were case law including economic provisions, family law, criminal law, and civil law. This state of the engraved text has survived both exposure on the surface and burial for over 3,600 years.

Communication. The text was written in cuneiform and in the Akkadian (Semitic) language. This is another example of communications enduring for more than 3,700 years. Much of the Code of Hammurabi was used by following generations and civilizations (Encyclopedia Britannica, 1994).

5.2.5.3 WIPP Relevance: Code of Hammurabi

Similar to Hammurabi's diorite stele, the markers will be made of granite and other materials specifically selected for their durability. The WIPP buried markers will be engraved with information warning against intrusion into the repository. The small buried markers are expected to survive burial and the inscriptions are expected to remain legible for 4,000 years, with a high probability of enduring for the entire regulatory period.

5.2.5.4 Historical Analogue: Mesopotamian Artifacts

Durability. As described in EPA, 1996a:

> "Fired clay tablets containing written material in cuneiform script are commonly found in Mesopotamian tells, as are elaborately carved statuary and bas-relief panels portraying rulers, wars, rituals, and aspects of daily life." (EPA, 1996a, p. 12-10)

For example, rich burial gifts were excavated at Ur (Tell Magajir) dating from approximately 2500 B.C.

Communication. Inscribed clay tablets have been recovered in the same region dating from as early as 3200 B.C. (Kinder and Hilgemann,1974). These inscriptions can be translated.

5.2.5.5 WIPP Relevance: Mesopotamian Artifacts

In addition to the granite markers, other buried markers are also to be fashioned using other durable materials for redundancy purposes, as suggested by Team A of the Markers Panel (Trauth et al., 1993). One of the other materials being considered for the buried markers is fired clay. Based on evidence found in the Mesopotamian tells, the DOE asserts that buried clay markers are virtually certain to last for 5,000 years, with a high probability of enduring for the entire regulatory period.

5.2.5.6 Potential Failure Mechanisms and Design Solutions

Weathering (chemical alteration of structure). (1) Material selection — granite, fired clay, and aluminum oxide will be used because of their durability. Fresh granite that has not experienced weathering will be used. (2) Surface preparation — surfaces will be polished to remove all loose material and indentations where water could collect. (3) Dry climate at the WIPP (limited water available for chemical weathering). (4) Message location — buried markers to be located 0.6 to 1.8 meters (2 to 6 feet) below the surface will reduce the amount of rainfall that infiltrates down to the markers.

Excavated during a previous exploration and not there for future communication. Aerial coverage afforded by the buried markers — surface preparation would have to be done in the exact same location for no markers to be found. Any larger area or slightly different location would mean that buried markers would be found.

Removal intact (museum). (1) Multiple markers — if a museum were to remove a few of the markers for a collection, there will still be many markers in place to correctly communicate. (2) Government ownership and regulation — museums or private collectors cannot remove material from private or government land without permission. (3) Exhibition in museums provides wider distribution of information; encourages interpretation and study. (4) Random distribution and depths of markers preclude a cost-effective process for recovering the markers.

Removal for recycling. (1) Multiple markers — if a museum were to remove a few of the markers for a collection, there will still be many markers in place to correctly communicate. (2) Government ownership and regulation — museums or private collectors cannot remove material from private or government land without permission. (3) Random distribution and depths of markers precludes a cost-effective process for recovering and recycling the markers.

5.3 Archives

5.3.1 Conceptual Design

Webster's Collegiate Dictionary (Merriam-Webster, 1991) defines archive as "a place in which public records or historical documents are preserved." This definition implies control of the environment, control of access to the records and documents, and control/selection of the storage medium. A significant part of the overall plan to provide PICs is the distribution of important information remote from the repository for preservation. The archived material will include information that is important to defining the location, design, content, and hazards associated with the WIPP (DOE, 1996, Section XIV). This information will be broader in scope and more extensive in volume than that available within the PICs at the repository-footprint location and will be widely distributed in a number of locations including some locations worldwide. The initial form of the information will be on archival-quality paper printed with carbon-black ink.

Specific documents that will be included in the archived information portfolio include:

1. The *Final Safety Analysis Report* (FSAR) (DOE, 1990a) and the addenda that describe the disposal phase of the WIPP.

2. The Final Environmental Impact Statement (DOE, 1980) for the WIPP and the Supplement(s) to the Environmental Impact Statement (DOE, 1989; DOE, 1990b.)

3. The No-Migration Variance Petition (DOE, 1995b) and the No-Migration Determination for Disposal.

4. Waste Isolation Pilot Plant Land Withdrawal Act

5. The Resource Conservation and Recovery Act (RCRA) Permit (DOE, 1995a).

6. The Certification of Demonstration of Compliance with 40 CFR Part 191.

7. Environmental and ecological background data collected during the pre-operational phase of the WIPP and summaries of data collected during the disposal and decommissioning phases of the WIPP.

8. Records of the waste container contents and disposal locations within the WIPP repository.

9. Drawings defining the construction and configuration of the repository and shafts.

10. Drawings, procedures, and design report(s) describing how the waste was emplaced; how the rooms, drifts, and panels were closed; and how the shafts were backfilled and sealed.

11. Detailed maps describing the exact location of the repository.

12. Design information for the PICs.

In addition, a summary document will be developed that will provide, in a quickly accessible format, the information necessary to communicate the nature and hazards of the waste in the WIPP, in order to deter inadvertent human intrusion.

Locations for this information will include publicly funded organizations that may be more likely to expend the resources necessary to preserve the documents in well-controlled environments. However, the most likely strategy for long-term protection of the information is through widespread distribution. The information will be submitted to the following facilities/ organizations for archiving pending their agreement to receive these documents:

- National Archives and Records Services
- The State Archives of New Mexico and Texas
- The national archives of the world nations that possess nuclear weapons and/or operate nuclear power generating plants
- The archives of the United Nations
- The national archives of the world nations that possess natural gas and/or petroleum resources

5.3.2 Historical Analogue: Vatican Archives

Durability. The Vatican Archives (Pasztor and Hora, 1991) were established by Pope Paul V in 1612, almost 400 years ago. The oldest documents contained in the Secret Vatican Archives are from the ninth century, while the oldest series of documents are the handwritten copies of the official letters of the popes that form a continuous collection beginning with the papacy of Innocent III from 1198 to 1216, more than 750 years ago. These archives also contain documents dating back to the ninth century (Pasztor and Hora, 1991). The current holdings of the archives consist of some 48 kilometers (30 miles) of full shelves and 15,240 linear meters (50,000 linear feet) of administrative records. For more than 800 years, the Vatican Archives and predecessor archives that were incorporated into the Vatican Archives have been receiving documents.

Papal documents are written on organic materials. In 1881, Pope Leo XIII began a restoration laboratory that is today the Vatican's School of Paleography. This laboratory has been supplemented with modern facilities for photographic reproduction. Despite restoration efforts, thousands of documents have turned purple because of a violet-colored fungus scientists have so far been unable to control (Pasztor and Hora, 1991). Several projects are reproducing portions of the Vatican Archives. Some archival documents have been microfilmed and are deposited in the Pius XII Library of St. Louis University. The Vatican Library now stores its most valuable documents in a steel and aluminum vault with a controlled environment and shelving covered with neutral polished aluminum. The covering resists parasites and water seepage.

Communication. With the focus on current English for communication over the 700 years over which credit for PICs may be applied to PA calculations (see PTF Assumptions (4) through (6)), the PTF did not emphasize languages other than current English. In fact, no credit is claimed for

the communication in the other languages that will be a part of the WIPP PICs. However, it is clear that the Vatican Archives are an example of a body of documents whose intent can be understood centuries after their creation. This is all the more important because the Latin used in the documents in the Vatican Archives is now only a scholarly language, and is no longer even a widespread liturgical language.

5.3.3 WIPP Relevance: Vatican Archives

The relevance of the Vatican Archives is both in the durability of the materials and the long-term existence of an institution dedicated to maintaining information despite repeated periods of turmoil.

Various documents within the Vatican Archives have survived for 1,100 years, without the Archives' manager being able to control temperature or humidity for most of this period. The materials used were those available at the time, not specially selected papers or inks. Paper with a high cloth content was the norm.

The Vatican Archives represents an institution created to maintain information that was important within a particular religious context. The survival of the Vatican Archives is evidence that institutions can survive for long periods of time if the information is deemed to be important. The underlying human tendency for story telling, with increased worldwide literacy, is being transformed into a desire to maintain written records of our history. Thus, archives maintaining information of historical importance can be expected to have greater prospects for survival than in the past. The health issues associated with nuclear waste disposal will make the information important as long as cancer is still a disease that causes suffering and death and will contribute to the information being maintained within archives. In addition, the WIPP archives will contain data and information of economic importance to industries and government agencies involved in natural resource exploration and exploitation. Economic importance also will contribute to maintenance of the archives.

The experience of the Vatican Archives provides lessons about what to do and what not to do for long-term maintenance of records. The Vatican, for much of its history, was in the midst of the surrounding political maneuverings, and control of the Vatican and possession of the Archives was a strategic prize. For example, Napoleon annexed the Papal States in 1809 and ordered the Archives moved to France. The transfer of the Archives to France (1810-1811) and the eventual return to Rome (completed by 1817) resulted in the loss of almost one-third of the documents then in the Archives; the loss occurred mainly during the period the Archives were in France. To guard against such a situation for the WIPP information and to establish the importance of maintaining the WIPP information in the context of personnel safety, the information about the WIPP should be placed in a non-political context. Also for the Vatican records, single copies of documents meant that political turmoil with its attendant destruction could eliminate information. Thus, for the WIPP, multiple storage arenas must exist to guard against losing information.

The DOE will provide WIPP documentation to archives worldwide. The documents will be prepared on archival quality paper. Unlike the one-of-a-kind Vatican documents, many copies of the WIPP documents will exist, adding significantly to a reasonable expectation that catastrophes

will not destroy all copies of the documents and that the information will survive for an extended period of time. This philosophy mitigates the risks involved from individual authorities causing the archival material to be moved over a period of hundreds or thousands of years. Multiple copies also provide society with the ability to reconstruct portions or all of a given archive of WIPP documentation should that particular information be lost or destroyed.

The Vatican Archives analogue, combined with improvement associated with lessons learned, would mean that an archive is expected to endure and maintain records for at least 1,100 years, and has a high probability of enduring for thousands of years. WIPP information is expected to endure at least as long as the original paper can survive (i.e., thousands of years).

5.3.4 Historical Analogue: Ancient Documents

Durability. Many thousands of ancient documents composed of organically based materials currently are stored in museums, monasteries, and archives around the world. The existence of these documents proves that writing materials other than engravings in stone or clay tablets can preserve information for thousands of years. The British Museum's Department of Antiquities has the world's largest collection of original papyrus documents from Egypt. Thousands of these papyrus documents are from the period of 2400 to 30 B.C. (Rodriguez, 1996a). The University of Michigan has the world's fifth or sixth largest collection of ancient documents. Most of these documents are on papyrus and parchment and are from about 400 B.C. to A.D. 800 (Rodriguez, 1996b). The Greek manuscripts of the Philotheou Monastery on Mt. Athos in Greece number in the hundreds. A catalogue of 125 of the manuscripts cover the period from the 9th century to the 19th century A.D. The oldest of these original documents are on parchment. For the documents printed on paper, the oldest document on Arabic paper dates from about A.D. 1292, and the oldest document on European paper dates from about A.D. 1315 (Allison, 1996).

Examples of paper enduring for thousands of years are confirmed by Hunter (1978). According to Hunter (1978), a number of original papers have been unearthed covering every century from its "original invention by Ts'ai Lun in China, A.D. 105, onward through the introduction of papermaking in the Occident and its eight hundred years of history in Europe." Illustrations of the oldest printed text in Japan dated from A.D. 770, fragments of paper from the Eastern Han period (A.D. 25 to 220), and a manuscript on paper found in the ruins of the Great Wall of China dated from about A.D. 150 are discussed in Hunter (1978).

Communication. As was stated for the Vatican Archives, the focus of the PTF is on current English for communication over the 700 years over which credit for PICs may be applied to PA calculations (see PTF Assumptions (4) through (6)), and no credit is claimed for the communication in the other languages that will be a part of the WIPP PICs. However, it is clear that many ancient documents exist and their messages can be understood. This comprehension of ancient documents is, in many cases, possible even though the language may no longer be in common usage.

5.3.5 WIPP Relevance: Ancient Documents

The examples described above provide evidence of the preservation of documents for thousands of years. The fact that paper exists today that dates to near the time paper was invented supports the premise that society can preserve paper documents for thousands of years. As described above, archiving WIPP information on archival-quality paper in multiple archives worldwide is an unprecedented effort to save information for future generations.

The fact that manuscripts have survived for 1,500 to 2,000 years, from the time when paper was invented, and can still be read and interpreted by scholars lends credence to our society's ability to preserve information and the media upon which that information is recorded. Based on the historical analogues of ancient documents, the DOE asserts that paper is expected to last for at least 2,000 years and has a high probability of lasting 4,400 years (the duration of papyrus, another organic material used for ancient records).

5.3.6 Potential Failure Mechanisms and Design Solutions

Decay of paper. (1) Archival paper. (2) Carbon black ink. (3) Controlled environment — even small records centers control temperature. Not withstanding the desirability of controlling the environment to increase durability, temperature and humidity will be controlled for the comfort of the individuals working in an archive.

Theft. (1) No original signatures, seals or other items to make the physical record salable on the black market. (2) Multiple copies — records can be recreated; reduces sale value.

Misfiling. (1) Indexing system created and agreed upon before records are ever sent to a records center or an archive. (2) Distinctive (inexpensive) binding for the records.

Catastrophes (including fire, flood, tornadoes, earthquakes). Multiple copies — records can be recreated.

Recycling. (1) Cover of the Concise Summary contains language about long-term importance of the information contained in the record (safety). (2) Concise Summary — discourages the entire collection from being discarded because the summary points out the importance of the other documents.

Archivist deciding that records are no longer important. (1) Cover of the Concise Summary contains language about long-term importance of the information contained in the record (safety). (2) Concise Summary — discourages the entire collection from being discarded because the summary points out the importance of the other documents.

Lost (including while consolidating collections, moving). Multiple copies — records can be re-created.

Deliberate destruction (other than governmental actions). Multiple copies — records can be re-created.

Warning understood but believed to be for prior generations or other intruders. Cover contains language about long-term importance of the information contained in the records (safety issues).

Warning not understood. (1) Endurance of English (PTF Assumptions 4-6). (2) Communication through means other than language (e.g., pictures, graphs, figures, and maps) (Common Denominator 4 and PTF Conclusion 1).

5.4 Records Centers

5.4.1 Conceptual Design

Records centers, for the purpose of making a distinction from archives, are facilities created to facilitate certain activities (public and private) and that generally permit freer access by members of the public. These facilities do not normally exercise the degree of environmental control and information-medium selection as in modern archives. These records centers will not receive the same quantity of information allocated to archives (DOE, 1996, Section XV). Information provided to these records centers will be focused on location, design, and hazards information. The DOE will provide a summary document with a distinctive and easily recognizable binding for each records center. The records centers will include various federal and state agencies and commercial mapping agencies to ensure that the WIPP location and drilling and mining restrictions are identified on widely distributed maps used by almost all public and private organizations. These federal and state agencies (or their successors) include

- The U.S. Nuclear Regulatory Commission
- Bureau of Land Management
- U.S. Geological Survey
- Library of Congress
- Defense Mapping Agency
- International Boundary Commission
- Federal Highway Administration
- New Mexico State Highway Department Planning and Research Division, Cartography Section
- One-Call System of notification of underground utilities
- The local offices of the Bureau of Land Management
- The local offices of the Bureau of Reclamation
- The Albuquerque office of the Bureau of Indian Affairs
- The Federal Records Center in Denver, Colorado
- The local offices of the New Mexico Oil Conservation Division

To further the widespread distribution of WIPP information, materials will also be offered to a number of libraries including

- The state libraries of the 50 states
- The City Libraries of population centers exceeding 15,000 within 150 miles of the WIPP site
- The 53 Federal Regional Depository Libraries

- The major universities of New Mexico and Texas

To ensure widespread distribution of location information of the WIPP site and the hazards associated with the emplaced waste, detailed maps and descriptions of the hazardous material will be sent to national and international professional societies of cartographers and geographers. Weitzburg (1982) suggests the following organizations and societies receive this location and hazards information:

- The American Congress on Surveying and Mapping
- The American Society of Cartographers
- The Commission for the Geological Map of the World
- The International Cartographic Association
- The American Geographical Society
- The Association of American Geographers
- The International Geographical Union
- The Society of Women Geographers
- The American Geological Institute
- The American Geophysical Union
- The American Society of Professional Geographers
- The National Geographic Society
- The Federal Aviation Administration
- Mining, Oil, and Gas Professional Organizations

These organizations and societies can be supplemented by contacting the American Historical Association, the National Institutes of Health, and the Centers for Disease Control for guidance in the distribution of documents to health-related records centers. The actual distribution of the information will depend on agreements worked out between the DOE and these organizations and societies.

Many members of these various organizations are employed in secondary and college education providing an opportunity for this information to become more widely disseminated among students during their formal education. In addition, companies providing energy and resource-related data to commercial ventures active in the Delaware Basin will receive location and hazardous record information. Examples of such companies include

- Midland Map Company of Midland, Texas
- Petroleum Information Corporation of Midland, Texas
- Tobin Data Graphics of Austin, Texas
- Dwight's Energy Data of Denver, Colorado

5.4.2 Historical Analogue: German Archives

Durability. The German archives discussed here (Brachmann et al., 1991) consisted of separate state, city, and church archives of the pre-WW II era. These archives contained one-of-a kind records pertinent to the location of the archives. During the course of the war, most of the archives were moved in part or in whole in order to protect them from Allied bombing. The

failure modes were from direct war damage (e.g., bombing, fire, or water from putting fires out), or from transit (vehicles were direct targets, vehicles broke down and were pillaged by the local inhabitants), and from alternate storage options (wine cellars were relatively inaccessible but damp, thus promoting the deterioration of the paper, and salt mines provided a dry, bomb-proof environment, but this environment resulted in the corrosion of any metals associated with binding the books or storage containers).

Extraordinary measures may be taken by at least some segments of society to protect documents perceived to be of value to society (including such things as church records of births, deaths, baptisms, etc.). For example, numerous archivists were killed trying to save records, and common individuals recognized the importance of the archives:

> "Putting individual material in private locations was considered 'billeting.' The question of moral or materialistic motivation of the individuals providing their property for storage purposes could be of significance. However, a large part of the population esteemed not only German archival material but also foreign and even enemy 'cultural assets.' Appeals for the protection of cultural assets found support, despite the tremendous existential problems of the period." (Brachmann et al., 1991, pt. B, p. 17-18)

Pillaging of the archives by the local population was generally driven by desperation caused by the shortages of basic goods necessary for survival. Even the 'enemy' valued the intrinsic value of archives and records. For example, after the war, the allied forces sent special commandos into occupied territory to protect the general cultural and archival materials.

Despite the ravages of war, a surprising number of archives remained relatively intact. According to Brachmann et al. (1991):

> "Numerous archives suffered varying degrees of damages during World War II[.] Some archives did not suffer losses or damages, others were totally destroyed. However, the large part of archival materials in Germany survived the war without appreciable damages." (Brachmann et al., 1991, pt. A, p. v)

Communication. Communication was not an issue for this historical analogue.

5.4.3 WIPP Relevance: German Archives

This experience indicates that even in a "total" war, areas away from strategic targets and areas of troop engagements can remain virtually untouched. During periods of crisis and upheaval, some buildings and documents will be lost, and no way exists to predict what will constitute a strategic target at any particular time.

The lessons learned from the German archives are that numerous copies of the WIPP records should be produced, these records should be widely distributed (i.e., to assure that at least some of the records are not in strategic locations), and an effort should be made to impart a sense of value to the records so that future generations will make the necessary effort to preserve them.

The experience with the German archives and the great effort that went into preserving the records and the lessons learned indicate that even with significant political and social upheaval, records can and are likely to be maintained.

5.4.4 Potential Failure Mechanisms and Design Solutions

Decay of paper. (1) Archival paper. (2) Carbon black ink. (3) Controlled environment — even small records centers control temperature. Not withstanding the desirability of controlling the environment to increase durability, temperature and humidity will be controlled for the comfort of the individuals working in a records center.

Theft. (1) No original signatures, seals or other items to make the physical record salable on the black market. (2) Multiple copies — records can be recreated; reduces sale value.

Misfiling. (1) Indexing system created and agreed upon before records are ever sent to a records center or an archive. (2) Distinctive (inexpensive) binding for the records.

Catastrophes (including fire, flood, tornadoes, earthquakes). Multiple copies — records can be re-created.

Recycling. (1) Cover of the Concise Summary contains language about long-term importance of the information contained in the record (safety) (2) Concise Summary — discourages the entire collection from being discarded, because the summary points out the importance of the other documents.

Archivist deciding that records are no longer important. (1) Cover of the Concise Summary contains language about long-term importance of the information contained in the record (safety). (2) Concise Summary — discourages the entire collection from being discarded because the summary points out the importance of the other documents.

Lost (including while consolidating collections, moving). Multiple copies — records can be re-created.

Deliberate destruction (other than governmental actions). Multiple copies — records can be re-created.

Warning understood but believed to be for prior generations or other intruders. Cover contains language about long-term importance of the information contained in the records (safety issues).

Warning not understood. (1) Endurance of English (see PTF Assumptions 4-6).
(2) Communication through means other than language (e.g., pictures, graphs, figures, and maps) (Common Denominator 4 and PTF Conclusion 1).

5.5 Government Land Ownership and Control

5.5.1 Conceptual Design

The U.S. Government controls the 16 sections that are included in the WIPP Withdrawal (Figure 1-2). Within this Withdrawal, all land-use leases are also retained by the federal government with the exception of two, 129.5-hectare (320-acre), oil and gas leases in Section 31. Section 31 is the southwestern most section of the 16 sections withdrawn under the LWA. The

two leases permit oil and gas development below 1,829 meters (6,000 feet) from the surface. Section 31 does not include the area planned for repository use. Government control is a passive control providing for the transfer of information on the status of land ownership. It is not an active control, in so far as the information does not overtly prevent intrusion. It is expected that government control of this area will be retained for as long as a potential for natural-resource exploitation exists. With government ownership of the resource leases for the withdrawn sections, commercial resource exploration and development entities cannot drill or mine in and immediately around the repository without receiving permission. Any organization contemplating resource exploration and development within the Withdrawal would learn of the government control immediately upon initiating search of lease availability within the appropriate records center(s).

In accordance with the LWA, the 16 sections at the WIPP were " . . . withdrawn from all forms of entry, appropriation, and disposal under the public land laws, the material sale laws . . . and mining laws" [Public Law 102-579, 1992, Sect. 3(a)(1)]. The objective of the DOE with respect to mining and oil and gas production is to ensure that the development of resource leases does not affect the integrity of the disposal system. Accordingly, no surface or subsurface mining unrelated to the WIPP construction, or oil or gas production, including slant drilling from outside the boundaries of the Withdrawal are permitted at any time, including post-decommissioning, with the exception of the two existing oil and gas leases. These leases prohibit drilling within the first 1,829 meters (6,000 feet) of the surface within the Withdrawal (DOE, 1993). The LWA does permit the Secretary of Energy to permit grazing, hunting, and trapping within the Withdrawal.

This prohibition is a direct contradiction to the EPA's requirement that the PA assume that drilling will take place at historic rates for the 10,000 years of regulatory concern throughout the Delaware Basin including the Withdrawal.

5.5.2 Historical Analogue

Durability. The search for historical analogues for land restrictions at the WIPP suggests examples such as the Boston Commons in Boston, Massachusetts, and the plaza in Santa Fe, New Mexico. These locations are both examples of areas that have been owned by a government and under government control for long periods of time. Both locations are areas of controlled public usage (some activities are allowed and some activities are prohibited), despite changes in the particular government. Boston Commons was created when the land was a part of the thirteen colonies of Great Britain (Boston was founded in 1630), and the public land use continued once it was a part of the United States. The plaza of Santa Fe was created under Spanish rule (Santa Fe was founded in 1610), remained as such under Mexican rule (1821-1846), U.S. rule, a brief occupation by Confederate forces (1862), and once again U.S. rule (Jenkins and Schroeder, 1974). The only period of unknown status was the period during and after the Pueblo revolt (1680-1692) until the location was reestablished as being a part of Spanish lands. More contemporary examples of areas of land being set aside for the public use/good are New York City's Central Park in New York state, the Mall in Washington D.C., and Balboa Park in San Diego, California.

A different type of government land for public use is Yellowstone National Park, established in 1890 as the United States' first national park. Park management allows access by the public, but with restrictions on the activities that can take place within the Park (e.g., no new leases for resource development). At the time of its establishment, Yellowstone was a remote area, with limited access to communications or transportation. Yellowstone was established to benefit the nation as a whole by preservation of our natural assets.

Communication. Communications is not relevant to the PTF's examination of this historical analogue.

5.5.3 WIPP Relevance

Within our national history, governments have established and controlled areas for the greater good of the society by restricting the activities taking place there.

Even though the Boston Commons and the Santa Fe plaza could be of major financial benefit were they to be sold for private development, governments have chosen to retain ownership and control rather than to receive short-term financial gain. As long as significant public pressure is applied that the value of safety is greater than the financial value of land or mineral resources, the Withdrawal, and especially the repository footprint, will be maintained.

Throughout its history, Yellowstone has been located in an area more remote than the area surrounding the WIPP. The WIPP is not situated in as remote a location as it appears—people travel to the City of Carlsbad by plane and by private vehicle, and the WIPP is only 42 kilometers (26 miles) from the City of Carlsbad. Significant traffic is generated by trucks collecting oil from tanks and by gas lines being monitored periodically. Increased population and the ease of travel and communication cast doubt on the WIPP/Carlsbad area becoming more remote in the future. The importance of a remote location is that it is easier to conduct prohibited activities without being detected.

5.5.4 Potential Failure Mechanisms and Design Solutions

Government considering opening up the Withdrawal to resource exploration and exploitation. Wide dissemination of information about the safety issues associated with maintaining the integrity of the disposal system — wide distribution of the information will make it available to more of the general populace so that there continues to be pressure not to open up the Withdrawal.

5.6 Other PICs

Other PICs may be incorporated to trigger society's awareness of the WIPP location and cautions regarding the maintenance of its integrity. These "Awareness Triggers," which will be discussed in Section 6.2 and that were introduced in Section 4.4, include

- Incorporation of the WIPP's location on various maps and road atlases

- Description of the WIPP's location and content within the subject matter of encyclopedias and common reference material
- Identification of the WIPP as a geographical name in dictionaries
- Descriptions of the WIPP incorporated within the text of high-school and college-level history and science books
- Development of a home page for the WIPP on the Internet (the current home page address for WIPP information is **http://www.wipp.carlsbad.nm.us**)

Examples of specific areas being identified on maps can be found in various road atlases. Gousha (1993) designates specific sites such as the "Nevada Test Site" and "Nellis Air Force Range" in Nevada, the "Chocolate Mountain Gunnery Range" in southern California, and the "White Sands Missile Range" in New Mexico. Certain areas in western Nevada are designated by the generic warning "Danger Area."

While the DOE cannot require future societies to reproduce documents or information as part of the PICs, evidence exists of information being reproduced/translated and passed down through history. Information about the Egyptian pyramids and the Acropolis are two examples.

Information about the Egyptian Pyramids was recorded by several historians. These include Herodotus (5th century B.C. Greek historian), Diodorus Siculus (1st century B.C. Roman historian), and Abd el Latif (12th century A.D. Arab historian). Siculus was in Egypt from 60 to 57 B.C. Much of what he reported echoes Herodotus' reports about who built the Pyramids. In addition, Siculus noted that ramps were used to construct the pyramids. The remains of such a ramp occur at the Unfinished Pyramid of Sekhment (approximately 2650 B.C.) (Kaplan, 1982). Abd el Latif (born A.D. 1179) mentions numerous inscriptions that covered the casing of the Great Pyramid. These inscriptions were lost when the casing stones were quarried away during and after the 13th century. The inscriptions had endured for almost 4,000 years before being removed (2500 B.C. to A.D. 1200). What is significant is that these inscriptions had not been obliterated by the blowing sands and erosion that had damaged the Sphinx (Kaplan, 1982). The fact that historical information recorded about a certain site by several individuals at several points in time is known today bears witness to the ability for information to remain accessible for many centuries.

The records of the history of the pyramids conveyed through Greek, Roman, and Arabic historians demonstrate the ability of written records to endure across cultures and centuries.

Much is known about the Acropolis from ancient texts that have also passed through the ages. The degree of detail known about the Acropolis demonstrates that written communication can convey an extensive amount of knowledge across many centuries. For example, it is known that Pericles was the prime mover in the decision to rebuild the Acropolis on a monumental scale after peace was made with Persia (Kaplan, 1982). In several cases the architects and sculptors who worked on the project are known. Records indicate that money was raised from the sale of old building material, from grants by the Treasuries of Athena and Hephaistos, and from the

Delian League in order to beautify the Acropolis. Annual building accounts for the Parthenon and Propylaia that were publicly displayed on the Acropolis still exist (Kaplan, 1982). Information documenting much of the history of the Acropolis has survived more than 2,400 years in a region of the world that has experienced much conflict and occupation by armed foreigners.

5.7 Materials Issues

Granite is an igneous rock that crystallized at depth within the Earth's crust. As a result, the minerals that compose granite are not thermodynamically and chemically stable in geologic time frames at the lower pressures and temperatures at the Earth's surface. However, for the time frames of interest, the thermodynamic instabilities of the minerals in granite are much less important than physical properties (e.g., mineral solubilities and rock porosities) of other rock types used in buildings and monuments (e.g., marble, limestone, and sandstone). Because the minerals in granite are less soluble than those in marble and limestone, and have a lower porosity than sandstone to resist water intrusion with freeze and thaw cycles, granite is more resistant to weathering than these other rock types.

Selection of stainless steel for use as the radar reflectors is based on a combination of cost and corrosion resistance. The reflectors would be constructed of sections about 1.3 cm thick and approximately 0.9 m on a side and welded to form a trihedral. Berry (1983) reviews earlier studies of various stainless steel alloys in soils. Type 316 stainless is the most resistant of the steels covered in Berry (1983). In one study, the weight loss extrapolated to penetrations of 0.0027 to 0.55 millimeters in 10,000 years. Berry (1983) also provides data supporting much better corrosion resistance for titanium and hastelloy. However, both of these materials are more costly than stainless steel. A fourth material that may also prove acceptable for this application is monel. Testing during the operational and active-controls period after disposal will be utilized to determine whether or not protecting the stainless steel will improve its survivability sufficiently to justify its use instead of the more corrosion resistant materials available. Use of titanium or hastelloy may also increase the likelihood of future generations mining the reflectors for their commercial value.

The planned use of strontium ferrite magnets is based upon their retentive ability, strength, and cost. In discussions with a supplier, Magnet Sales & Manufacturing Co. of Culver City, California, it was stated that although strontium ferrite magnets are not quite as strong as samarium cobalt, there is significant cost differential (a factor of 7). Alinco magnets are the least expensive of the three materials but lose their strength at an almost linear rate of 0.1 percent per 10,000 hours. However, samarium cobalt and strontium ferrite magnets achieve a nearly asymptotic value in 10,000 hours. More extensive testing during the latter part of the operational phase and the active-controls phase will be conducted to determine the best alternative for the final design.

5.8 Conclusion

The historical analogues described above support the premise that our current society has the capability to develop a PICs system composed of components that will endure and pass

information on to succeeding generations. The use of large, massive structures provides the greatest chance for the survival and promulgation of information for thousands of years. By their presence, large structures will convey a Level I message that something made by humans is present. Information preservation is enhanced by engraving messages in stone and burying the information. However, this approach to preservation does pose the problem of discovery of the message by future generations. Alternatively, engraving on massive stone outcroppings, such as the Rock of Behistun, or on stone markers, such as the Code of Hammurabi stele, supports the premise that engraving can withstand the ravages of the environment for thousands of years. Although not as durable as stone, organic-based materials such as vellum and papyrus have also been successful in preserving original records for more than 2,000 years. Not only have these ancient records survived, but also their languages can be understood today even though the languages may not be in use. The Vatican Archives demonstrate that records can be stored for centuries. An additional aspect supporting the preservation of information over thousands of years is that historians and archivists have had and continue to have an ongoing interest in the preservation of information and documents. An example of this is Herodotus' history (written in the 5th century B.C.) of the Pyramids, which were built about 2,000 years before his time. His descriptions have survived to our time through additional historical documentation efforts even though the original materials upon which he described the individual events may not have survived. Thus, even if original documents do not survive, the information contained in them can survive through the efforts of historians and archivists.

The use of these historical analogues as models for the PICs system support the concept that the WIPP warnings will be successfully conveyed to the future. Historically, some monuments have ceased to exist. However, the permanent marker design concept has focused on successful monuments that have withstood time and provide support for the "reasonable expectation" that the WIPP's PICs will endure for thousands of years and may even surpass the 10,000-year regulatory time frame.

The single most significant feature of the PICs for the WIPP is the widespread distribution of information describing the history, design, location, and hazards associated with WIPP's storage of transuranic and hazardous wastes. No historical analogue replicates the degree of effort represented in the WIPP PICs in communicating with future generations. The widespread distribution of WIPP information in archives, records centers, and other published media gives ample justification for a reasonable expectation that future generations will have information in an understandable format regarding the hazards associated with intruding into the WIPP repository and its location.

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6.0 EFFECTIVENESS OF PICS IN REDUCING THE FREQUENCY OF INADVERTENT HUMAN INTRUSIONS AT THE WIPP

The previous chapters to this report have discussed the regulatory framework on assessing the effectiveness of PICs in deterring inadvertent human intrusions, the premises used by the PTF in estimating this effectiveness, the conceptual design of the PICs components, the historical analogues that provide insight into how long certain design characteristics and materials can last and information can be understood, and possible failure mechanisms for each component and how the conceptual design for each component counteracts these mechanisms. This chapter integrates the information in these earlier chapters and provides the PTF's estimate of the effectiveness of PICs in deterring inadvertent human intrusion into the repository footprint and into the Withdrawal for the 700 years after closure. These inadvertent human intrusions, as guided by 40 CFR Part 194 (EPA, 1996c), are drilling for and the mining of natural resources. This chapter also includes arguments supporting this estimate.

6.1 Deterrent Components

Deterrent Components are those components that provide sufficient information to deter a potential intruder. These Deterrent Components were designed based on lessons learned from historical analogues as discussed in Chapter 5. The PTF believes that while some historical (ancient) structures have failed, those failures are not controlling in the discussion of the effectiveness of PICs for the WIPP, because all ancient structures are not analogues for the WIPP PICs. The WIPP PICs have been designed to exceed the performance of the historical analogues of which there is evidence and because of the regulatory constraints established for the WIPP.

Information located in records centers and archives may fail to correctly communicate because of natural or human initiated disasters/events. Fire, floods and rain damage, earthquakes, and tornadoes are examples of natural disasters. Additional natural events are the decay of paper and the deterioration of ink. Archival paper and carbon black ink will improve the performance of the information against natural forces. Even if a records center or an archive were subjected to fire, flood, etc., the WIPP information is located with other important information and people will attempt to save all of the records. In addition, multiple copies of the information will exist if the contents of an entire records center or archive are lost. The loss of one set of the information does not indicate failure for the entire component because within the regulatory framework established by the EPA, resource companies will still need to establish ownership and will go to another records location to find the necessary information (loss of records does not mean loss of ownership of resource rights).

Other aspects of the information located in the records centers and archives counteract the human initiated failure events of theft, misfiling, recycling. Control of who accesses documents, an established filing system, and attempts to establish the long-term importance of the information will increase their endurance. Once again, the existence of multiple copies means that the information will still be available for site investigators.

Natural or human-initiated disasters/events, such as fire, floods and rain, earthquakes, and tornadoes initially seem to pose threats to the survival of the markers components. To counter

these threats, the markers have been designed to counteract these processes through the use of durable materials and designs. The use of granite for the markers will result in fire, rain, and tornadoes having superficial effects on the surfaces of the markers, and the structural considerations incorporated in the construction of the markers will eliminate any effects from the magnitude earthquakes to which southeastern New Mexico are subjected. The lack of drainage features at the WIPP indicates that this area is not subject to extensive flooding.

Human-initiated events, such as war, vandalism, and recycling pose threats to the markers' components. To counter the threat of vandalism, the markers will be made of large blocks of granite whose durability, size, and shape (e.g., large flat surfaces) limit the effects of casual vandalism. Recycling efforts for the granite markers are countered by the size and hardness of the markers, and the inability of these activities to occur in secret (i.e., the level of effort required to perform these activities would also attract attention from resource workers and the ranchers whose stock are being frightened and forage that is being destroyed by these activities). As stated previously, collateral war damage and systematic vandalism (e.g., the monuments and markers at the WIPP being caught in the middle of a tank fight, the target of a scorched earth policy of a retreating army, the target of rampaging renegade troops, the target of deliberate destruction by cults, or the development of new highly destructive technologies that can be owned by the general public) will be low probability events at the WIPP for 700 years after closure. In addition, vandalism of this type is beyond the realm of a prudent extrapolation of today's societal conditions.

Historical analogues are used for design purposes and to indicate how long records can last. The PTF believes that the design solutions implemented for the records centers and archives for retaining WIPP material apply lessons learned from known failures and make retention of sufficient material to correctly communicate the necessary information a highly likely event. The design solutions implemented range from having both records centers (easier access to potential intruders) and archives (greater preservation potential) retain the information to having multiple locations for storing the information under multiple jurisdictions to having a truthful representation of the risks of intruding upon the disposal system transmitted to future generations. Past failure rates are not applicable here because the archives and records systems envisioned to be a part of the PICs are more elaborate and scientifically based than past systems and incorporate design solutions to address past failure modes.

The following discussion examines each of the Deterrent Components from the view point of effectiveness over 700 years. Rather than present quantitative effectiveness estimates that suggest a level of precision that cannot be supported by available information (Budescu and Wallsten, 1987), the PTF provides qualitative estimates. The expression "virtually certain" is used to indicate a high level of confidence while recognizing a possibility, no matter how remote, that an alternative conclusion may occur.

6.1.1 Deterrence of the Marker System at the Repository Footprint

Each of the markers at the repository footprint has been specifically designed for durability. Durability will be achieved by the choice of construction material used along with the size of the marker and/or placement (i.e., exposed versus buried).

6.1.1.1 Monuments Outlining the Repository Footprint

The monuments that contain Levels II, III, and IV messages will be composed of granite. Based on the historical analogues of the monoliths at Stonehenge and the Rock of Behistun, (see Section 5.2.2.4) and barring unforeseen failure mechanisms, these monuments at the WIPP will be able to remain intact for at least 4,000 years, which is the minimum lifetime of the Stonehenge monoliths, and the engraved text on the monuments are virtually certain to be legible for at least 2,500 years, which is the minimum lifetime of the engraved text on the Rock of Behistun. Because these ages are minimums, a life expectancy for the inscriptions on the monuments substantially longer than 2,500 years after disposal is realistic and highly probable, because the Stonehenge engravings of figures, which are at least 4,000 years old, are still distinguishable.

Estimates of the ability of future generations to read and understand the warnings on the monuments are based on the assumptions that current English will continue to be readable by individuals working in the natural resource industries (possibly as a specialized second language) due to the nearly continuous resource exploration and exploitation in the WIPP area and the Delaware Basin (PTF Assumption 6 and Regulatory Assumption 4) and that pictures will be able to convey meaning independent of or as a supplement to written warnings (Common Denominator 4) (e.g., facial expressions representing emotions and pictographs representing potentially harmful activities). Based on these assumptions and common denominator, the warnings inscribed on the monuments are virtually certain to be understood by individuals within the natural resource industries for thousands of years after disposal.

The number of monuments within the relatively small repository area provide a level of redundancy that suggests that the monuments will remain an effective deterrent to inadvertent human intrusion into the repository if one or several of the monuments are deliberately destroyed or removed.

6.1.1.2 Information Center

An Information Center will be constructed in the center of the footprint. This center will have granite walls set into caliche, and these walls will be inscribed with Level IV information. The lack of a roof for this room provides natural lighting but also allows for the walls to be exposed to a limited amount of weathering and for wind-blown sand to settle into the room. The historical analogues used by the PTF for the Information Center are the Acropolis for the durability of the structure and Australian rock art for the partially exposed engravings. Based on the assumption that today's scientists and engineers, through engineering design and selection of materials, can build a rock structure that will endure for at least as long as the structures at the Acropolis (PTF Assumption 10), the PTF concluded that the Information Center is virtually certain to survive for at least 2,400 years after disposal, which is the minimum age for most of the structures at the Acropolis. The much older Egyptian pyramids were not used as an analogue for the Information Center, because the pyramids are massive structures and are not structurally analogous to the Information Center, whereas buildings at the Acropolis were designed for human use and are structurally more analogous to the Information Center.

Inscriptions on the walls within the Information Center will be partially protected from wind-driven rain, snow, and sand by the outer walls. This configuration is similar to the Australian rock art consisting of paintings, engravings, and peckings located on partially protected surface. The fact that this rock art has survived for tens of thousands of years indicates that the inscriptions in the granitic rock of the Information Center will endure for as long as the inscribed surfaces are protected (PTF Assumption 10) (including walls knocked over in a face-down position or buried by drifting sand). Even if the structure of the Information Center fails, the protected inscriptions could survive for tens of thousands of years.

The Level IV messages within the Information Center will consist of both written messages and pictures. Estimates by the PTF of the interpretability of the warnings within the Information Center were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Common Denominator 2); (2) future generations will continue to be curious about the meaning behind unfamiliar structures and writings (Common Denominator 1); (3) current English will continue to be understood by individuals within the natural resource exploration and exploitation industries or governmental agencies (PTF Assumptions 4-6) (possibly as a specialized second language); and (4) pictures will be able to convey meaning independent of or as a supplement to written warnings (e.g., facial expressions representing emotions and pictograph representing potentially harmful activities) (Common Denominator 4 and PTF Conclusion 1). Based on these premises, the PTF concluded that the inscribed warnings on the walls of the Information Center will be understood by individuals within the natural resource industries or governmental agencies for thousands of years after disposal.

6.1.1.3 Buried Storage Rooms

The two buried storage rooms also will be constructed of granite. One room will be buried in the berm as protection during the early times of the regulatory time frame. As the berm ages and erosion occurs, portions of the buried room (e.g., a corner, edge, or wall) may become exposed at the surface, thereby informing future generations of the existence of another source of information, and adding another source of warning messages to potential intruders. Exposure of the buried room would occur later in the regulatory time frame after the monuments and the information center have been exposed to surficial erosion processes and may undergo some surficial degradation. Although both the monuments and the Information Center are expected to remain intact for at least several thousand years, the exposure of a buried room will reveal another source of detailed information explaining why human intrusion should not be attempted. The other room will be buried below grade outside the berm. This room is not expected to be exposed by natural processes, but its location will be described in the archives and in the Information Center. Future generations may choose to excavate this room to obtain Level IV information.

The historical analogues for the buried rooms are Newgrange and the rooms within the Egyptian pyramids. Based on the assumption that current science and technology have the capability to construct buried rooms at least as durable as these analogues (PTF Assumption 10), and the belief that this capability is represented in the conceptual design of the buried rooms, the PTF

concluded that the buried rooms will survive for at least 5,000 years after construction, which is the minimum age of Newgrange.

Inscriptions in the walls of the buried rooms will be completely protected from weathering and erosion for as long as the rooms remain buried. The inscriptions in the walls of the rooms contained within the Khufu pyramid exhibit no signs of deterioration 4,500 years after being carved into the rock, and the broader patterns engraved in the interior walls of Newgrange exhibit no signs of significant deterioration after 5,000 years. Based on these analogues, the PTF concluded that the inscriptions in the walls of the buried rooms at the WIPP have the design characteristics to endure for at least 5,000 years. If a buried room is excavated and left exposed, its durability will be similar to that of the Information Center.

The Level IV messages within the buried rooms will consist of both written messages and pictures. Estimates of the interpretability of the warnings within the buried rooms were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Common Denominator 2); (2) future generations will continue to be curious about the meaning of unfamiliar structures and writings (Common Denominator 1); (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries or governmental agencies (possibly as a specialized second language) (PTF Assumptions 4-6); and (4) pictures will be able to convey meanings (Common Denominator 4 and PTF Conclusion 1) independent of or as a supplement to written warnings, if the buried rooms are exposed or exhumed far enough into the future when an understanding of current English is lost by the general populace. Based on these common denominators and the PTF assumption, the PTF concluded that the inscribed warnings on the walls of the buried rooms are virtually certain to be understood by individuals within the natural-resource industries or governmental agencies for thousands of years after disposal.

6.1.1.4 Small Buried Markers

The conceptual design for the marker system includes a relatively large number of small markers that will be buried at random intervals and depths across the area of the repository footprint. By design, these markers will be encountered during the preparation of any location within the footprint for drilling operations (e.g., digging a mud pit). The material used to construct these markers will be selected through an experimental program to ensure that the markers will not undergo significant chemical alterations from contact with the enclosing sediments and soils within the regulatory time frame, thereby ensuring that these markers will endure. Granite, fired clay, and aluminum oxide currently are the candidate materials being considered for these markers.

The historical analogues for the buried markers are the diorite stele that contains the inscriptions of the Code of Hammurabi and the artifacts found in Mesopotamian tells and tombs. Based on the assumption that the materials selected through the experimental program for these markers will survive with no significant deterioration of the inscriptions for at least as long as the stele and the artifacts (PTF Assumption 10), the PTF concluded that the buried markers are virtually certain to survive for at least 3,700 years, which is the approximately the time since the stele was created, with a high probability of surviving longer than 4,500 years, which is the minimum age

of some of the older Mesopotamian artifacts. The precise duration that the stele and the artifacts were buried is not known, but any time that these objects were at the surface was time exposed to harsher conditions than when the objects were buried.

Buried markers will contain a Level II message. Estimates of the interpretability of the warnings on these markers were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Common Denominator 2); (2) future generations will continue to be curious about the meaning of unfamiliar objects and writings (Common Denominator 1); (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries or government agencies (possibly as a specialized second language) (PTF Assumptions 4-6); and (4) pictures will be able to convey meanings (Common Denominator 4). Because the buried markers will contain symbols instead of pictographs, the effectiveness of this portion of the message may be less than the higher level messages conveyed by the figures and pictographs on the markers and in the buried rooms and Information Center. The PTF concluded that the basic message of danger conveyed by the text inscriptions is virtually certain to be understood by individuals associated with natural resources for thousands of years after disposal. If the symbols cannot be understood, the inherent curiosity of future generations will make the symbols Awareness Triggers, although the text will remain a deterrent.

6.1.1.5 Effectiveness and Endurance of the Repository Marker System

Each marker component, except for the berm, which is an Awareness Trigger, will have the capability to independently deter future inadvertent human intrusion. Failure of the marker system requires the failure of all of the components of the system. No failure mechanism for all the copies of all the components has been identified. Based on the materials to be used to construct the various types of copies of all markers, the redundancy of the warning messages at the various message levels, the numbers of markers, and the marker distribution, the marker system at the repository footprint (approximately 0.5 square kilometers [0.2 square miles]) is virtually certain to completely deter inadvertent human intrusions within the repository footprint for thousands of years based on the assumptions previously discussed about the nature of people and society and the use of historical analogues.

6.1.2 Monuments at the Land Withdrawal Area Boundary

An additional set of monuments is to be placed along the boundary of the Withdrawal (approximately 41 square kilometers [16 square miles]). These monuments have the same design specifications as the monuments at the boundary of the repository footprint, although the warning message on these outer monuments will place more emphasis on deterring intrusion into the Withdrawal outside of the repository footprint. Because these outer monuments will be compositionally and dimensionally the same as the inner monuments, the estimates of durability for these two sets of monuments is the same. The warning message on these outer markers will be less emphatic than the one on the inner markers. A warning not to disturb the ground-water flow system is abstract and is unlikely to have the same sense of importance as a warning against activities that could cause the release of radionuclides from a buried storage facility. In addition, the area of danger clearly will be the one marked by the berm, the inner monuments, and the

Information Center based on the greater level of effort in constructing markers. This lack of compelling reason not to intrude along with an absence of redundancy of the message on other markers will likely result in less deterrence than the message to be conveyed by the repository markers, especially if the other confirmatory components (e.g., records and government control) of the importance of the entire Withdrawal begin to fail. For these reasons, the marker system at the Withdrawal boundary is assumed to be less effective than the markers at the repository footprint, although this decrease in effectiveness will not occur until at least a 1,000 years after disposal, which is equivalent to the time between current and Old English.

6.1.3 Records Centers

For the purpose of estimating the effectiveness of records in deterring intrusion, the records are considered in two types of records centers. General records centers consist of depositories at both the regional and national levels (e.g., regional depository libraries and the Federal Records Center in Denver, Colorado). The depositories hold a wide variety of information and documents among which the WIPP records would be just one more set of records. Resource records centers are maintained by agencies that deal with land use, especially in the areas of natural-resource exploration and exploitation (e.g., the Bureau of Land Management and the New Mexico Oil Conservation Division). In this second type of records center, the WIPP records would be more distinctive, because these records will deal with how the land can and cannot be used, in addition to containing potentially significant economic information.

Based on historical records, fragments of wood-based paper have survived for most of the nearly 2,000 years since its invention, and an uninscribed papyrus roll has been found in an Egyptian grave that is approximately 5,000 years old (Gaur, 1992). The volume of ancient documents that have survived to the present with no or limited attention to preservation indicates that the survivability of documents that are cared for will be high. These historical analogues suggest that the WIPP records printed on paper developed for an extended life expectancy and stored in records centers should be able to survive relatively intact for several thousand years. As a historical analogue for writing on an organic material, papyrus with written hieroglyphics dates to approximately 4,500 years ago (Gaur, 1992). This historical analogue indicates that printed WIPP documents can be expected to survive for as long as the paper. An additional factor that improves the survival of the records is the human habit of reproducing records. The PTF estimates have not included credit for future generations reproducing documents. If a natural resources records center were destroyed through fire or natural disaster, a site investigator would be required to seek the information in another records center. The loss of a particular records center or piece of paper does not remove the requirements to identify current lease owners and to obtain permission to develop the resources.

The German archives during WWII serve as the historical analogue for the distribution of the WIPP documents in numerous records centers. The fact that a large part of these archives survived the war indicates that the distribution of WIPP records to a large number of records centers essentially guarantees that at least some copies of these records will survive for an extended period of time into the future.

The general records centers are and will be depositories for a wide variety of information and a large volume of documents. These records centers also will contain Level V WIPP messages. Over time, the importance of the normal records may be lost to individuals operating the records centers, and the records may be replaced with what are perceived to be more important records, in which case the records could be destroyed or relegated to a less prominent area within the records center. The conceptual design for the WIPP records contains provision for making them distinctive, concise, and of readily recognized value. Estimates of the effectiveness of the general records centers in deterring inadvertent intrusion were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Common Denominator 2); (2) future generations will continue to be curious about unfamiliar writings and structures (Common Denominator 1); and (3) current English will continue to be understood by individuals within the natural-resource exploration and exploitation industries and government agencies (PTF Assumption 6) along with those individuals in other fields of endeavors in which historical documents are important (PTF Assumptions 4 and 5). Because of the prominence of the WIPP records, the PTF concluded that the warnings contained in the WIPP records of the general records centers are expected to be completely effective deterrents for anyone checking these records centers for possibly 1,000 years or more after disposal. Beyond this time, the records begin to decrease in deterrence value because of the likelihood that these records will be lost within the records centers. In the vicinity of 4,000 years (i.e., twice the lifetime of the oldest existing paper fragments and approximately the lifetime of some of the older papyrus), the possible deterioration of the original records may begin to be a factor. This deterioration combined with the possible loss of records in the records centers may result in a rapid decrease in the deterrence value of the general records centers. Because of the widespread distribution of general records centers and the diverse nature of the types of records centers, no pattern of document survival or effectiveness is applicable to all records centers.

The resource records centers are and will be the depositories for more specialized documents and information related to resource and land ownership and use. Based on the same assumptions used for the general records centers and the additional assumptions that resource exploration and exploitation will continue for the entire regulatory period (Regulatory Assumptions 3 and 4) and government in any form will require record keeping and consultation of records (Common Denominator 7 and PTF Assumptions 2 and 3), the PTF concluded that resource records centers will remain active throughout the regulatory period (PTF Assumption 2 and Regulatory Assumption 4). Because of this activity and the importance of the WIPP records, these records will be consulted by individuals associated with natural resource exploration and exploitation (PTF Assumption 7) and will be highly effective deterrents to inadvertent intrusion (Common Denominator 7 and PTF Assumptions 1 and 3) for at least a couple of thousands of years after closure. Failure of the WIPP records to deter will be the result of catastrophic record destruction and the physical deterioration of the records. The wide distribution of the WIPP records in numerous records centers virtually ensures that at least some copies of these records will survive for an extended time and that lost records in some records centers can be reproduced from records in other records centers.

6.1.4 Archives

Archives are designed to preserve historically significant documents. In this capacity, the role of archives is preservation rather than dissemination of information. As a result, the WIPP records will be stored under conditions that will extend their life expectancy relative to documents in records centers. The PTF considered the Vatican Archives as a historical analogue for the durability of an archive as an institution and the ancient paper, papyrus, and other documents as historical analogues for the WIPP documents to be stored in the archives. The assumptions used by the PTF to estimate the effectiveness of the archives in deterring inadvertent intrusion were basically the same as for the records centers (see Section 6.1.3).

Using the Vatican Archives as a historical analogue, the PTF concluded that the archives in which the WIPP records will be stored have the capability to survive as institutions for at least 1,100 years, which is the minimum age of the Vatican Archives. Because of the seemingly universal recognition of the documents in archives as historically important, the PTF concluded that future societies will go to great lengths to preserve the documents within an archive, even though the structure housing the documents is expendable and replaceable. The limiting factor is the life of the paper, because the institution or a successor was assumed to last indefinitely. With optimum storage conditions and limited use, the documents within the archives, and especially the WIPP records, will last substantially longer than the records in the records centers. Documents in the archives should last as long as the ancient documents considered as historical analogues described above, even if the physical structure housing the documents do not. The PTF concluded that the WIPP records in archives are capable of surviving in at least some of the archives for more than 4,000 years based on the fact that papyrus with hieroglyphics approximately 4,500 years old and uninscribed papyrus approximately 5,000 years old have been found. Archives suffer some of the same problems as records centers in that documents can be "lost" through such actions as misfiling, reshelving, and in some cases, destruction or theft.

The WIPP records in the archives will contain Level V messages. Estimates of the effectiveness of the archives in deterring inadvertent intrusion were based on the following assumptions: (1) future generations will continue to use writing as a means of communication (Common Denominator 2); (2) future generations will continue to be curious about unfamiliar structures and writings (Common Denominator 1); and (3) current English will continue to be understood by individuals within the natural resources exploration and exploitation industries and government agencies (PTF Assumption 6) along with those individuals in others fields where historical documents are important (PTF Assumptions 4 and 5). For the potential intruder or the site investigator who visits an archive, the warnings within the WIPP records are almost certain to be readily understood for more than 1,000 years after disposal because of the specialized vocabulary based on current English associated with natural-resource and land use. Readily available translation will most likely be available for a much longer period beyond 1,000 years after disposal, which is equivalent to the time between current and Old English.

In a regional sense, the deterrence value of the archives compared to records centers will be relatively low in the early part of the regulatory time frame, because the archives will be farther away from the WIPP than the records centers, which are the traditional sources of land-use and natural-resource information to the natural-resource industry. As the documents in the records

centers start to deteriorate and/or become lost in the volume of records that will be submitted, the reliance on the archives will increase because of the better preservation of the documents. The level of deterrence of the archives will not reach the peak levels achieved by the deterrence of the records centers because of the remoteness of the archive sites from the WIPP.

6.1.5 Government Control of Land Use

Government control of land use consists of written instructions in any government agency offices where land-use determinations are and will be made specifying the prohibited uses and covenants on land use written into surface- and resource/mineral-rights leases. A basic assumption used by the PTF is that any prudent extrapolation of the current form of government (Common Denominator 6) will continue some form of land-use control (Common Denominator 7), especially in those areas having natural-resource potential (PTF Assumption 3). These offices are the resource records centers discussed in Section 6.1.3.

Drilling on the incorrect lease will subject the company to lawsuits for resource/mineral trespass. Exploiting resources on someone else's leases without being caught is highly unlikely because of state/agency inspections and the likelihood of being reported by economic competitors.

The PTF concluded that land-use restrictions are virtually certain to be completely effective deterrents against inadvertent human intrusion for as long as the paper recording these restrictions lasts. Even if an error is made in issuing a permit, a resource company has a vested interest in drilling on the correct lease instead of the incorrect lease. Because of the specialized and limited vocabulary associated with land-use restrictions, these restrictions are virtually certain to be interpretable by individuals in the natural-resource industries and/or government agencies (PTF Assumptions 4-6) for thousands of years. The PTF assumed no credit for the land-use restrictions being transcribed to other copies of documents.

6.2 Awareness Triggers

Several of the components described in Chapter 5 have no deterrent value on their own, but may contribute to the effectiveness of the PICs system. These components have been labeled as "Awareness Triggers," because each of these components has the potential to make a potential intruder or site investigator aware of the existence of the WIPP, and therefore aware that additional information about the WIPP should be obtained. These Awareness Triggers are

- incorporation of the WIPP's location on maps and road atlases
- description of the WIPP in encyclopedias
- identification of the WIPP in dictionaries
- description of the WIPP in science and history textbooks
- WIPP homepage on the Internet

For each of these components, the basic message is that something named "WIPP" is present in the northern part of the Delaware Basin, and the investigator should seek additional information before proceeding with any resource exploration or exploitation activities. More detailed information about the WIPP will be provided in textbooks, dictionaries, and encyclopedias, but investigators for the resource industry are likely to consult more "technical" sources.

- berm

The berm surrounding the repository footprint is intended to convey a Level I message indicating that something built by humans is present. A Level I message is an Awareness Trigger rather than a deterrent. As a result, this particular marker has no deterrent value, although the presence of the berm may enhance the deterrence of the other markers by making the potential intruder aware that the repository site is different from the surrounding area and more information is needed prior to the initiation of intrusion activities and by protecting the exposed markers enclosed within the aerial extent of the berm.

The historical analogues used to estimate the durability of the berm are the earthen banks surrounding the monoliths at Stonehenge (see Section 5.2.2.2). These banks were constructed as piles of earth with no reinforcement or other features designed to extend their lifetime. No credible occurrence in the prudent extrapolation of today's conditions was identified by the PTF that could disassemble the berm and completely remove the volume of material from the site. Based on the assumption that current science and technology have the capability to construct an earthen structure at least as durable as the banks at Stonehenge (PTF Assumption 10) and the belief that this capability is represented in the conceptual design of the berm (PTF Assumption 9), the PTF concluded that the berm is virtually certain to survive for at least 4,700 years after disposal, which is the minimum lifetime of the banks at Stonehenge. The size, the layered structure, and the selected materials of the berm and the physical setting will ensure that this structure has a high probability of surviving far longer than the Stonehenge banks have survived to date. Because of the volume of the various materials in the berm, recycling of any of these materials in the future (e.g., mining the salt) will result in large volumes of the other materials being left behind (e.g., the riprap and caliche), which will continue to convey the Level I message.

- government ownership of the Withdrawal

Government ownership of the surface and mineral/resource rights conveys no information about the WIPP, but does convey the message that certain procedures must be followed in order to obtain permission to evaluate resources. In following procedures to obtain permission, the investigator will encounter other PICs that will provide information about the location and hazards of the WIPP. An absence of government ownership would have little effect on deterring human intrusions, because the investigator would still go to records centers to identify ownership of the surface and mineral/resource rights.

Although these components will contribute to the effectiveness of the PICs system, the PTF has taken no credit for these components in the effectiveness estimates presented in Section 6.4.

6.3 Effectiveness of PICs System in Deterring Inadvertent Human Intrusions

The PTF did not attempt to estimate the contribution of the Gestaltic nature of the PICs system (see Section 4.4) when estimating the effectiveness of the PICs for PA. Given the short time frame for which credit may be given for the PICs in PA and the high levels of effectiveness of each component when considered independently in this time frame, the PTF decided not to

include the concept of Gestalt and the likely accompanying controversies into the PTF estimates. For longer time frames in which substantially greater changes to society, technology, and language are likely to occur, the contribution of the Gestaltic nature of the PICs system is likely to be a larger contributor to estimates of PICs effectiveness in deterring inadvertent intrusions.

Based on the PICs systems approach (Chapter 4) and the PICs designs (Chapter 5), each of the individual Deterrent Components in the PICs system will offer virtually complete effectiveness in deterring inadvertent human intrusions within the repository footprint for thousands of years. Over time, the PTF believes that the effectiveness of the PICs in protecting the Withdrawal outside of the repository footprint will not be as high as the effectiveness for the smaller, more highly marked footprint. The primary function of the PICs for the Withdrawal outside of the footprint is to protect the integrity of the disposal system rather than protecting the repository, which is the primary function of the PICs at the footprint. The difference in the level of effectiveness will not manifest itself until some thousands of years after disposal.

The PTF believes that the design solutions implemented for the records centers and archives for retaining WIPP material apply lessons learned from known failures and make retention of sufficient material to correctly communicate the necessary information a highly likely event. The design solutions implemented range from having both records centers (easier access to potential intruders) and archives (greater preservation potential) retain the information to having multiple locations for storage of the information under multiple jurisdictions to having a truthful representation of the risks of intruding upon the disposal system transmitted to future generations.

To ensure that these design solutions are implemented as specified, the DOE is developing QA procedures addressing the three implementation steps (encode in language, capture in media, and transmit) from the general communications model (see Section 4.1) The PTF believes that these QA procedures will ensure that the correct information will get into the records centers and archives. This documentation will support the PTF conclusions as to the effectiveness of records centers and archives.

6.4 Conclusions for Use in PA

As noted in Section 2.5 of this report, the EPA states that for the PAs, PICs cannot totally deter inadvertent human intrusion for even a short period of time after the 100 years for which AICs are assumed to be effective in PA and cannot deter for more than several hundred years after closure. Looking at the historical analogues and potential failure modes for the PICs components, the PTF ascertained that the PICs will be highly effective for periods of time much longer than several hundred years. The attempt to quantify "highly effective" in order to provide input to the PA calculations focused on possible failure mechanisms. Designing physical monuments and markers and establishing institutions for control based on historical analogues leads the DOE to assert that for the time period of interest to PA, these PICs will perform virtually perfectly in enduring and preserving messages for interpretation. The PTF assumptions developed in Chapter 3 lead the PTF to assert that current English will be decipherable by the resource community for the entire period of interest to PA. Thus, the only failure mechanisms of the PICs for communicating with a potential intruder (i.e., a decision maker in the natural-resources

industry) centered around human error in the permitting process (retaining knowledge of the prohibition of drilling and mining, and correctly preparing/rejecting permits) or in locating a permitted operation.

No failure mechanisms compatible with a prudent extrapolation of today's societal conditions have been identified by the PTF or any reviewer that could destroy all of the Deterrent Components associated with the WIPP. Because these PICs components are expected to perform so well for the 700 years of regulatory interest, the PTF decided to examine an existing PICs component (control of land use) for which failures are known to exist.

6.4.1 Types of Failure Data Appropriate for Consideration

Because the intent of the PICs will be to deter inadvertent human intrusion by the natural-resources industry, the PTF believes that it was appropriate to use information on recent failure rates within this industry as a surrogate for future activities (e.g., drilling activity). This approach is consistent with the EPA's approach on drilling rates. The evidence that is appropriate to look at in estimating failure rates is the evidence that is consistent with the type of activity that the PICs are designed to deter.

Drilling operations are not casual activities that can be done in secret. These operations include:

- site modification to accommodate access to the site and setting up the drilling rig and support facilities
- using large and noisy equipment
- a period of time that may extend to weeks or months for the drilling of a borehole.

In addition, drilling activities are in an industry where companies keep track of competitors' activities that could provide economically beneficial information. For example, one company setting up a drill rig on one lease is likely to attract other companies that will try to obtain adjacent leases in case the drilling locates economically important resources that may extend into the adjacent leases. Estimates of the effectiveness of controls for activities that can be conducted quickly, quietly, privately, and with no outward signs of activity are not relevant. Also illegal activities conducted deliberately are outside of the regulatory guidance for "inadvertent" activities.

6.4.2 Failure Data for Land-Use Controls

During the deliberations of the PTF, members of WID's Long-Term Regulatory Compliance Section reviewed drilling records for the New Mexico portion of the Delaware Basin dating back to 1914. These records are located at the Hobbs and Artesia offices of the State of New Mexico's Oil Conservation Division. One aspect of this review was to determine if any of the well records identified a case or cases wherein the driller set up and drilled in a location other than that authorized. The WID personnel could not locate any record or individual that could confirm that any of the 11,500 wells of the Delaware Basin were drilled at the wrong location. As a follow-up, members of each office were contacted by phone on April 4, 1996, (Johns, 1996) and asked if they recalled any incidents of drilling in an unauthorized location. No incidents were recalled.

In a follow-up investigation, the PTF contacted four experts with a total of 106 years of field experience in the oil and gas industry in the region (Rodriguez, 1996e; Rodriguez, 1996f; Rodriguez, 1996g; and Rodriguez, 1996h). The experts could recall only five instances, all outside of the Delaware Basin, where someone had drilled a well at the wrong location; three occurred in Texas about 15 years ago and two near Eunice, New Mexico about 30 years ago (Rodriguez, 1996h). These five instances are out of the some 429,000 wells that have been drilled in the Permian Basin (29,000 in southern New Mexico and 400,000 in eastern Texas). Occurrences of resource trespass are so rare that none of the agencies contacted have kept records. As a result, the PTF relied on anecdotal information from knowledgeable individuals. For the 11,500 oil and gas wells drilled in the Delaware Basin, no instances of drilling on the wrong leases were recalled. As a result, the failure rate (i.e., the rate of drilling in the "wrong" leases) was 0.0. For the Permian Basin in New Mexico and Texas, but outside the Delaware Basin, no instances of drilling on the wrong leases were recalled, but perhaps five instances of drilling in the correct leases but outside the designated drilling area of those leases have occurred out of 429,000 wells drilled. In the initial analysis, the PTF considered these five instances to be "failures" in order to introduce an element of conservatism. Even with this conservatism, the failure rate was 0.00001.

Subsequent investigations were conducted to determine the reliability of these failure rates for other geologic settings and other governmental administrations. Agencies in three states and three Canadian provinces were contacted, although one of the provincial agencies did not provide any data. To address the issue of what effect a prudent extrapolation of today's regulatory environment in the Delaware Basin would have on the rate of drilling in the "wrong" location (i.e., trespassing), the PTF considered contacting government agencies in countries with distinctly different regulatory environments from those in the U.S.A. and Canada. One of the problems in expanding the data base to other countries is that in most other countries, the central governments exclusively own the natural resources and either exclusively exploit the resources or strictly control which companies do. "Failures" in these countries by drilling on the wrong *claim* or *lease* do not occur and have not occurred, because claims and leases similar to those claims and leases in the U.S.A. and Canada do not exist and have not existed. Mexico can serve as an example of natural-resource development in a developing country in which the central government owns the natural resources. Exploration and exploitation of oil and natural gas in Mexico prior to 1938 was conducted by foreign petroleum companies that were invited in to develop large areas (i.e., hundreds of thousands of acres) when compared to the sizes of claims or leases that are available in the USA and Canada. Under the conditions at the time, any borehole drilled within the area being developed by a company was in the "correct" location (i.e., inside the property). After the Mexican government nationalized the petroleum industry in 1938, the federal government continued to own the resource rights and reserved exploration and exploitation for a government-owned company (National Petroleum Company). Exploration and exploitation continued to deal with large areas rather than small claims and leases. As a result, failures (drilling in the wrong claim or lease) do not occur.

For the reasons discussed above, the PTF limited the investigations to states in the U.S.A. and provinces of Canada that were at least partially underlain by bedded salt. The results of the investigations (Guzowski, 1996) for the states and provinces are: (1) in Montana, more than 1,200 wells have been drilled during the past six years with no instances of drilling on or into the

wrong leases; (2) in Michigan, more than 40,000 wells have been drilled since the current drilling regulations went into effect in 1927 with no instances of drilling on or into the wrong leases; (3) in Wyoming, more than 60,000 wells have been drilled with perhaps two or three instances of drilling on or into the wrong leases; (4) in Manitoba, a total of 4,500 wells have been drilled for oil and gas with no instances of drilling on or into the wrong leases; and (5) in Alberta, the number of wells drilled ranges from 30,000 to 50,000 with perhaps 10 or 12 instances of drilling on or into the wrong leases.

The results of these investigations support the results from the Permian Basin investigation in that the occurrence of drilling on the wrong lease is a rare event. The typical failure rate for the states and provinces is 0.0 with an anomalously high rate for one Canadian province of approximately one in 3,000 or 5,000. A conservative estimate for all of the areas investigated (i.e., taking the low end of any ranges in the possible number of boreholes and the high end in the range of the number of failures) has 20 failures for 564,700 wells, or a failure rate of 3.5×10^{-5}. This failure rate is based on the single PICs component of government control of land use through records centers. No other PICs components planned for the WIPP exist for any of the areas investigated. If the WIPP area becomes one where all natural resources belong to the central government and claims and leases do not exist, the government or company involved in natural-resource exploitation will have a vested interest in conserving financial resources. The same basic procedure to site evaluation will be followed as today by conducting both literature and field research on the geology and natural-resource potential of an area prior to drilling. This literature research initially would encounter, at the very least, the Awareness Triggers in the natural-resource maps and records centers, and possibly the archives, thereby stimulating additional research that would encounter the deterrent messages and warnings. Field research would encounter the markers component.

6.4.3 PTF Recommendation of the Bounding Value

The PTF recognized two approaches to estimating the effectiveness of the PICs in PA. One approach estimates a specific value intended to represent the "real" effectiveness of the PICs, and a second approach estimates a bounding value that deliberately underestimates the PICs effectiveness. The PTF recognized that estimating a "real" value of PICs effectiveness would create additional areas of controversy, such as whether the estimated value is the "correct" value and whether effectiveness should be represented as a probability distribution function. To limit the areas of controversy, the PTF chose to estimate a bounding value for PICs effectiveness that encompasses any uncertainties associated with PICs effectiveness in PA.

For the sake of addressing the needs of PA, to account for unidentified possible failure mechanisms and sources of human error that could result in reduced effectiveness of the PICs system, and to account for any uncertainty in the performance of the individual components, the PTF recommends that the failure rate for PA calculations (years 100 to 700 after disposal) be increased to a bounding value of 0.01. For PA purposes, the AICs are assumed to be completely effective in deterring inadvertent intrusions for the first 100 years after disposal (see Section 2.2). This estimated value is approximately two orders of magnitude higher than the anomalously high failure rate for Alberta and approximately three orders of magnitude greater than the mean failure rate for the areas, states, and provinces for which the PTF was able to obtain failure rates for the

single PICs component of government control of land use. The PTF believes that the existence of additional Deterrent Components would have reduced the obtained failure rates. Thus, the PICs are to be 0.99 effective in successfully communicating with future generations about the WIPP. A 1-percent failure rate would mean that out of every 100 permit requests that result in the drilling of a borehole, one is a location error on the permit itself or one results in the drillers setting up on a wrong location that was not detected by any of the several personnel involved in resource acquisition and site development, whose jobs include ensuring that the company is legally secure in exploiting a resource. As stated in PTF Assumption 8, any government action that deliberately ignores or changes the land-use restrictions will result in intentional intrusion (e.g., a government agency that deliberately allows drilling at the WIPP to occur), and intentional intrusions are not relevant to PA.

A failure rate this high is not possible within an industry constrained by current procedures and technology, because such a high error rate would be widely known within the natural resources community, and the natural resources community would demand the implementation of stronger controls over drilling to protect financial investments and natural-resource assets.

The numerical percentage by which the intrusion rate will be reduced in the PA calculations is taken to be the probability of successful communication of the information. This assumption is made based on the thought that, for example, if the PICs are effective in correctly transmitting the information 99 percent of the time, then 99 percent of the potential intrusions are either deterred or are made with full information and thus are not inadvertent (i.e., do not have to be considered in the PAs).

The PTF emphasizes that these accommodations to the regulation for both the repository footprint and the remainder of the Withdrawal are bounding values that underestimate the effectiveness of the PICs system in deterring inadvertent human intrusions under the premises established in Chapter 3.

The EPA's guidance states that

> "Performance assessments may assume that the likelihood of mining may be decreased by PICs and active institutional controls, to the extent that can be justified in the compliance application and to a degree identical to that assumed for drilling." (61 FR 5230a/EPA, 1996c)

The PTF believes that the common denominators, regulatory assumptions, and PTF assumptions developed for drilling are equally applicable for mining. As a result, the PICs effectiveness in deterring future drilling also applies to future mining.

7.0 REFERENCES

Allison, R.W. 1996. "Summary Catalog of the Greek Manuscripts of Philotheou Monastery." Web Page http://abacus.bates.edu:80. Lewiston, ME: Bates College, Department of Philosophy and Religion. (Paper copy of web page on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WPO 39128.)

Berry, W.E. 1983. *Durability of Marker Materials for Nuclear Waste Isolation Sites*. ONWI-474. Washington, DC: Office of Nuclear Waste Isolation, Batelle Memorial Institute.

Bertram-Howery, S.G., and R.L. Hunter. 1989. *Plans for Evaluation of the Waste Isolation Pilot Plant's Compliance with EPA Standards for Radioactive Waste Management and Disposal.* SAND88-2871. Albuquerque, NM: Sandia National Laboratories.

BLM (Bureau of Land Management). 1992. "Legal Description of the Waste Isolation Pilot Plant (WIPP) Withdrawal; NM," *Federal Register*. Vol. 57, no. 227, 55277.

Brachmann, B., M. Herrman, and S. Pollert. 1991. *Archive Safety Analysis. Case Study: German Archives During the 20th Century.* NKS/KAN 1.3(91)5. [Stockholm, Sweden]: Nordic Nuclear Safety Research Programme. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WPO 39109.)

Budescu, D.V., and T.S. Wallsten. 1987. "Chapter 4: Subjective Estimation of Precise and Vague Uncertainties," *Judgmental Forecasting*. Eds. G. Wright and P. Ayton. New York, NY: John Wiley & Sons. P. 63. (Submitted copy to SWCF 7/31/96)

Crystal, D. 1994. *An Encyclopedic Dictionary of Language and Languages*. New York, NY: Penguin Books.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026. Washington, DC: U.S. Department of Energy. Vols. I-II.

DOE (U.S. Department of Energy). 1989. *Draft Supplement Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-DS. Washington, DC: U.S. Department of Energy.

DOE (U.S. Department of Energy). 1990a. *Final Safety Analysis Report, Waste Isolation Pilot Plant, Carlsbad, New Mexico.* WP 02-9, Rev. 0. Carlsbad, NM: Westinghouse Electric Corporation.

DOE (U.S. Department of Energy). 1990b. *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-FS. Washington, DC: U.S. Department of Energy, Office of Environmental Restoration and Waste Management. Vols. 1-13.

DOE (U.S. Department of Energy). 1993. *Waste Isolation Pilot Plant Land Management Plan.* DOE/WIPP 93-004. [Carlsbad, NM]: U.S. Department of Energy, Waste Isolation Pilot Plant.

DOE (U.S. Department of Energy). 1995a. *Resource Conservation and Recovery Act Part B Permit Application.* DOE/WIPP 91-005 Revision 5. Carlsbad, NM: Waste Isolation Pilot Plant. Vols. I-X.

DOE (U.S. Department of Energy). 1995b. *Draft No-Migration Variance Petition.* DOE/CAO-95-2043. Carlsbad, NM: U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad Area Office. Vols. I-VII.

DOE (U.S. Department of Energy). 1996. *Passive Institutional Controls Conceptual Design Report.* Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Encyclopedia Britannica. 1994. *New Encyclopedia Britannica.* 15th ed. Chicago, IL: Encyclopedia Britannica. (Sections on "Behistun" and "Hammurabi, Code of" on file in Sandia WIPP Central Files as WPO 39116-39117.)

EPA (U.S. Environmental Protection Agency). 1978. "Criteria for Radioactive Wastes," *Federal Register.* Vol. 43, no. 221, 53262-53268.

EPA (U.S. Environmental Protection Agency). 1980. *Technical Support for High-Level Radioactive Waste Management. Volume D. Release Mechanisms.* EPA 520/4-79-007D. Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation Programs.

EPA (U.S. Environmental Protection Agency). 1985. "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register.* Vol. 50, no. 182, 38066-38089.

EPA (U.S. Environmental Protection Agency). 1993. "40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," *Federal Register.* Vol. 58, no. 242, 66398-66416.

EPA (U.S. Environmental Protection Agency). 1995a. "40 CFR Part 194: Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Proposed Rule," *Federal Register.* Vol. 60, no. 19, 5766-5791.

EPA (U.S. Environmental Protection Agency). 1995b. "Part 192—Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings," *Code of Federal Regulations 40 Part 192.* Washington, DC: U.S. Government Printing Office, Superintendent of Documents.

EPA (U.S. Environmental Protection Agency). 1996a. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document for 40 CFR Part 194.* EPA 402-R-96-002. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

EPA (U.S. Environmental Protection Agency). 1996b. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Response to Comments Document for 40 CFR Part 194.* EPA 402-R-96-001. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

EPA (U.S. Environmental Protection Agency). 1996c. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations; Final Rule," *Federal Register*. Vol. 61, no. 28, 5224-5245.

EPA (U.S. Environmental Protection Agency). 1996d. *Compliance Application Guidance for 40 CFR Part 194.* EPA 402-R-95-014. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

Fagan, B. 1994. "Neolithic Newgrange," *Archaeology*, Vol. 47, no. 5, 16-17.

Frimmer, S. 1969. *The Stone That Spoke, and Other Clues to the Decipherment of Lost Languages*. New York, NY: Putnam Publishing Co. 100-117.

Gaur, A. 1992. "The Process of Writing," *A History of Writing*. Rev. ed. New York, NY: Cross River Press, A Division of Abbeville Press. 35-48.

Gillis, D. 1985. "Preventing Human Intrusion into High-Level Nuclear Waste Repositories," *Underground Space*. Vol. 9, no. 1, 51-59.

Givens, D.B. 1982. "From Here to Eternity: Communicating with the Distant Future," *Etc. Et cetera*. Vol. 39, no. 2, 159-179.

Glicken, J., E. Hocking, and R. LaPointe. 1996. *Final Report. Waste Isolation Pilot Plant Passive Institutional Controls Peer Review Report*. Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office (copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM.)

Gousha. 1993. *New Deluxe 1993 Road Atlas. United States, Canada, Mexico*. H.M. Gousha, Simon & Schuster, Inc.

Guzowski, R.V. 1990. *Preliminary Identification of Scenarios That May Affect the Escape and Transport of Radionuclides From the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND89-7149. Albuquerque, NM: Sandia National Laboratories.

Guzowski, R.V., 1996. Additional Information on Rate That Oil and Gas Wells have been Drilled on the Wrong Leases, August 26, 1996, memorandum to K. Trauth. Albuquerque, NM: Sandia National Laboratories. (Copy on file with Sandia WIPP Central Files.)

Hawkins, G.S. 1973. *Beyond Stonehenge.* New York, NY: Harper and Row.

Hora, S.C., and R.L. Iman. 1989. "Expert Opinion in Risk Analysis: The NUREG-1150 Methodology," *Nuclear Science and Engineering.* Vol. 102, no. 4, 323-331.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Houghton Mifflin Company. 1991. *The American Heritage Dictionary, Second College Edition.* 1991. Boston, MA: Houghton Mifflin Company. (Page 569 with definition for "government" on file in the Sandia WIPP Centra Files, Sandia National Laboratories, Albuquerque, NM.)

Hunter, D. 1978. *Papermaking: The History and Technique of an Ancient Craft.* New York, NY: Dover Publications.

IAEA (International Atomic Energy Agency). 1994. *Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories.* IAEA-TECDOC-767. Vienna, Austria: International Atomic Energy Agency.

Jenkins, M.E., and A.H. Schroeder. 1974. *A Brief History of New Mexico.* Albuquerque, NM: University of New Mexico Press.

Johns, James. 1996. Telephone conversation with Paul Katz, Hobbs Oil Conservation Division (OCD), and Ray Smith, Artesia OCD. April 4, 1996. (Log copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WPO 39120.)

Kaplan, M.F. 1982. *Archaeological Data as a Basis for Repository Marker Design.* ONWI-354. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute, Project Management Division.

Kinder, H., and W. Hilgemann. 1974. *The Anchor Atlas of World History. Volume I. From the Stone Age to the Eve of the French Revolution.* New York, NY: Anchor Press.

Merriam-Webster, Inc. 1991. *Merriam-Webster's Ninth New Collegiate Dictionary.* Springfield, MA: Merriam-Webster, Inc. p. 101.

Mohen, J.-P. 1990. *The World of Megaliths.* New York, NY: Facts on File.

NEA (Nuclear Energy Agency). 1995. *Future Human Actions at Disposal Sites, A Report of the NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites.* Paris, France: Nuclear Energy Agency, Organisation for Economic Co-Operation and Development.

O'Kelly, M.J. 1982. *Newgrange*. New York, NY: Rames and Hudson, Inc.

Pasztor, S.B., and S.C. Hora. 1991. *The Vatican Archives: A Study of its History and Administration*. NKS/KAN 1.3(91)6. [Stockholm, Sweden]: Nordic Nuclear Safety Research Programme. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WPO 39114.)

Powers, D.W., S.J. Lambert, S.-E. Shaffer, L.R. Hill, and W.D. Weart, eds. 1978. *Geologic Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, Volume II*. SAND78-1596. Albuquerque, NM: Sandia National Laboratories.

Public Law 96-164. 1979. *Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980.*

Public Law 102-579. 1992. *Waste Isolation Pilot Plant Land Withdrawal Act.*

Rodriguez, R. 1996a. Telephone conversation with Miss Andrews of the British Museum. March 6, 1996. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WPO 39161.)

Rodriguez, R. 1996b. Telephone conversation with Traianos Gagos of the University of Michigan. March 6, 1996. (Copy on file in Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM as WPO 39161.)

Rodriguez, R. 1996c. Telephone conversation with Richard R. Navarro of the DOE Las Vegas, NV office. March 11, 1996 (Notes on file with Sandia WIPP Central Files as WPO 39125.)

Rodriguez, R. 1996d. Telephone conversation with Roxanne Danz of Restoration Physics group at the DOE's Las Vegas, NV office. March 12, 1996 (Notes on file with Sandia WIPP Central Files as WPO 39125.)

Rodriguez, R. 1996e. Telephone conversation with Larry Scott, Petroleum Engineer for Lynx Petroleum. May 8, 1996 (Notes on file with Sandia WIPP Central Files as WPO 39160.)

Rodriguez, R. 1996f. Telephone conversation with Jack Ahlen, Consulting Geologist. May 8 and May 21, 1996. (Notes on file with Sandia WIPP Central Files as WPO 39160.)

Rodriguez, R. 1996g. Telephone conversation with Floyd Ferguson, Consulting Geologist. May 8, 1996 (Notes on file with Sandia WIPP Central Files as WPO 39160.)

Rodriguez, R. 1996h. Telephone conversation with Ron Eidson, Supervisor of Surveyors, John West Engineering. May 8 and May 21, 1996. (Notes on file with Sandia WIPP Central Files as WPO 39160.)

Sullivan, G. 1987. "Vital Clue," *Treasure Hunt*. New York, NY: Henry Holt and Company. 56-63.

Tannenbaum, P.H. 1984. *Communication Across 300 Generations: Deterring Human Interference with Waste Deposit Sites.* BMI/ONWI-535. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Waste Management Technology Department. 1987. *The Scientific Program at the Waste Isolation Pilot Plant.* SAND85-1699. Albuquerque, NM: Sandia National Laboratories.

Weitzberg, A. 1982. *Building on Existing Institutions to Perpetuate Knowledge of Waste Repositories.* ONWI-379. Columbus, OH: Office of Nuclear Waste Isolation, Battelle Memorial Institute.

WIPP (Waste Isolation Pilot Plant) Inadvertent Intrusion Advisory Panel and New Mexico Junior College. 1995. *Analytical Study of an Inadvertent Intrusion of the WIPP Site.* Westinghouse Electric Corporation Procurement Services, Waste Isolation Pilot Plant.

Woodard, L.L. 1996. "Appendix 12B: Letter to U.S. Archivist Transmitting WIPP Land Withdrawal Information," *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document.* EPA 402-R-96-002. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

APPENDIX A

SELECTED EPA CONCERNS ABOUT PICS

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APPENDIX A

SELECTED EPA CONCERNS ABOUT PICS

The following discussion is derived from: EPA, 1996a, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Background Information Document for 40 CFR 191*, EPA 402-R-96-002.

1. Section 12.2.5.2, last paragraph of the section on page 12-33 "EPA did not review the Markers Panel Team's results in order to apply numerical values to credit for PICs or even develop a credit methodology. Instead, EPA noted the great variability and uncertainty in the efforts of the two teams."

Response: The designs proposed by the two marker teams contained many of the same elements. These similarities do not support the EPA's claim of great variability. The estimates by each team of the duration and effectiveness of the marker components were relatively close with the markers being most effective in early times and the effectiveness decreasing in later times as the uncertainty about future societies and technologies increases. In the future-state assumptions of 40 CFR Part 194, the EPA has eliminated the speculation about the uncertainties in how societies and technologies may evolve. If the EPA had established these future-state assumptions in 40 CFR Part 191, the marker teams would not have had to deal with "great uncertainty."

2. Section 12.2.5.3, last sentence of the section on page 12-37 "Status of site markings at the other NTS off-site locations is not well documented and is currently being investigated (DOE94b)." DOE94b is "Communication with R. Navarro, Nevada Operations Office, Las Vegas, NV, January 14, 1994."

Response: Mr. Navarro was contacted regarding this topic on March 11, 1996, by the PTF (Rodriguez, 1996c). He did not recall any conversation concerning the topic of investigating the marking of Plowshare Projects. Further conversation with Ms. Roxanne Danz, a supervisor in the Restoration Health Physics group at the DOE's Las Vegas office (Rodriguez, 1996d), confirmed that all Plowshare Projects are marked. However, there is no record of any criteria or design basis being established with respect to what these markings are intended to convey or accomplish. Ms. Danz stated that all of the project sites she has visited have different configurations of markers.

Considering the variation of current marking configurations at the various Plowshare sites and the lack of any criteria for their marking design, it is not reasonable to make a comparison between Plowshare markers (for example the marker indicating Project Gnome) and the criteria established for the WIPP markers in 40 CFR Part 191 and 40 CFR Part 194. Furthermore, the conceptual design for the WIPP permanent markers system and worldwide information distribution is virtually in a class of markers and knowledge distribution unprecedented in history. Although some of the historical analogues are substantial in volume and mass, none of history's enduring markers were associated with an intent to distribute information worldwide to ensure their lasting knowledge in the mind of the public. Neither the analogues nor the

Plowshare Projects took the additional step to ensure identification on maps and charts as a means of conveying information.

3. Section 12.3.1.1, page 12-45 "On November 24, 1992, BLM published a description of the WIPP in the *Federal Register* as required by the LWA (57 FR 55277) [BLM, 1992]. BLM also submitted the required documentation to various governmental organizations on November 16, 1992. . . . [Woodard, 1996] (While this information was supplied to the Archivist of the United States and presumably has been filed, the existence and location within the Archives have not been uncovered in spite of numerous inquiries.)."

Response: The archival specialist working with the PTF recommended that the DOE should establish a filing code that the national archives will use when archiving documents and records received from the DOE related to the WIPP Project and that all documents submitted to the archive will contain this filing code. The DOE has an official archivist, and this archivist will be consulted in the development of this filing code.

4. Section 12.3.2, page 12-46, last paragraph "Even so, Tannenbaum has observed that storage materials may not last for the required 10,000 years; therefore, records must be periodically reproduced and perhaps translated into contemporary language (TAN84)."

Response: The records are not required to last for the entire 10,000 years of regulatory concern. The assurance requirements mandate that the PICs are the most permanent practicable. The DOE has developed a PICs system that contains redundant components so that the failure of a single component does not compromise the effectiveness of the PICs system. The PTF believes that future generations will reproduce these documents provided that they are perceived to be important. No credit was taken for the reproduction of information in estimating the effectiveness of the PICs system for PA calculations.

5. Section 12.3.2, page 12-47, second paragraph "Gillis mentions a downside to record-keeping redundancy (GIL85). Dispersal of the information to ensure its survivability may reduce detectability by persons at the site for whom it is most relevant."

Response: This is not a logical conclusion. Dispersal of information does not impact the detectability by persons at or near the site when that same information is provided at a number of locales near the site. The response to this concern is to make a sufficient number of copies that copies can be stored both locally and regionally.

6. Section 12.3.4.1, page 12-57 cites failure of the DOE to document the presence of an oil and gas well under the southwestern corner of the land-withdrawal area.

Response: As mentioned in Chapter 7, the DOE refutes this unfounded claim.

7. Section 12.4.1, page 12-64, last paragraph provides a discussion ending with "Institutions frequently outlive the governments which inaugurate them."

Response: This statement further supports the EPA's future-state assumptions in § 194.25.

8. Section 12.5.1.1, page 12-66, the EPA makes the statement "It is highly unlikely that a drilling crew would detect the presence of the markers."

Response: Surface preparation for drilling crew setup using today's technology make extremely likely the discovery of buried markers positioned at intervals selected randomly between 4.6 and 12.2 meters (15 to 40 feet), and 0.6 to 1.8 meters (2 to 6 feet) below ground, while the drilling crew is preparing a mud pit, which typically is of the dimensions of 30.5 meters by 61 meters (100 feet by 200 feet). This assertion of detection was confirmed by discussions with members of the WIPP Inadvertent Intrusion Advisory Panel and New Mexico Junior College (1995) on May 26, 1995. Their report of September 5, 1995, stated that intervals of 12 meters (40 feet) and 0.3 to 1.8 meters (1 to 6 feet) deep would ensure some markers are seen during excavation.

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APPENDIX B

COMPLIANCE WITH THE PASSIVE INSTITUTIONAL CONTROLS ASSURANCE REQUIREMENT

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APPENDIX B

COMPLIANCE WITH THE PASSIVE INSTITUTIONAL CONTROLS ASSURANCE REQUIREMENT

In 40 CFR 194.43, the U.S. Environmental Protection Agency (EPA) requires that:

> "Any compliance application shall include the period of time passive institutional controls are expected to endure and be understood." (61 FR 5243c/EPA, 1996b).

At the same time, the EPA has indicated in the Supplementary Information published with 40 CFR Part 194 their desire to reduce undue speculation as it relates to human actions in their specification of what they call the "future states assumption":

> "The Agency recognizes the inherently conjectural nature of specifications on future states and wishes to minimize such speculation in compliance applications. The Agency has found no acceptable methodology that could make reliable predictions of the future state of society, science, languages or other characteristics of future mankind .... Hence, the final rule requires that performance assessments and compliance assessments shall include dynamic analyses of geologic, hydrogeologic and climatic processes and events that will evolve of the 10,000-year regulatory time frame. DOE shall assume that all other present day conditions will exist in their present state for the entire 10,000-year regulatory time frame." (61 FR 5227c-5228a/EPA, 1996c)

In addition, the EPA has stated in their Response to Comments Document For 40 CFR Part 194 that

> "The design of passive institutional controls, both markers and records, must be designed so that they are as permanent as possible, taking into account, to the extent possible, potential collapses in institutional, societal, or linguistic structures. The final rule requires that DOE document the period of time passive controls are expected to endure and be understood [§194.44]. Compliance with the assurance requirement for passive controls will be evaluated based in part on the depth of the analysis and the scope of potential societal changes which are accounted for in the design of passive controls." (EPA, 1996b, p. 7-7)

Thus, the DOE must address the two objectives of longevity of marker structures and communications means, and the addressing potential variability in society. The combination of the requirement for analysis and the prohibition on undue speculation about the future state of society leads one to conclude that the analysis must be qualitative in nature and not require specific numbers that would involve assumptions about the future state of society and the undue speculation EPA attempted to eliminate.

Analysis of Most Permanent Practicable Passive Institutional Controls

A method for evaluating the requirement in §191.14 for "the most permanent markers, records, and other passive institutional controls practicable" is to examine analogues of human constructed buildings or sites as a key to what is most permanent and what was practicable to create. If markers incorporate lessons learned in long-term durability and communication effectiveness, and are consistent in design with the longest lasting structures, then markers and records are the most permanent designs practicable.

Reference to Chapters 5 and 8, and to the Markers Panel reports (Trauth et al., 1993) will indicate that the design elements reflect lessons learned. The DOE's commitment to the design elements as represented in the conceptual design show the PICs to be implemented are consistent with the longest lasting human structures.

Scope of Potential Societal Changes Represented in the Passive Institutional Controls Design

A method for evaluating the design of the PICs in response to consideration by the EPA of the "depth of the analysis and the scope of potential societal changes which are accounted for in the design of passive controls" is to examine the societal basis for the communications recommendations from the Markers Panel.

The Markers Panel deliberations did not assume that one could validate predictions about the future state of languages, level of technological sophistication, or governmental control. Their response to the uncertainty of future societies was to assume that communication means had to be available for individuals from any culture, speaking any language, or with any level of technological sophistication.

The overall recommendations for markers (which is applicable to archives and records) was to utilize a systems approach whereby different components are available to communicate with different individuals and to provide different pieces of information, with enough interconnections to reinforce the information and help fill in any gaps. Within the system, messages are to be provided in different levels of complexity (five different levels from the most basic information of a manmade structure to detailed scientific information on the waste inventory) to address possible variation in the future level of technological sophistication. The different media used for the communications (e.g., berms, stone monuments, buried ceramic disks, and paper) address durability and access issues. Information was to be communicated by linguistic (seven current languages of wide distribution and usage) and non-linguistic (e.g., pictographs, star charts, and the periodic table of the elements) means to address uncertainty about languages to be spoken in the future. While languages change over time, certain basic words are more stable, so the linguistic messages need to be created with simple sentences (no idioms or complex sentences) and with the most basic vocabulary available. Even the uncertainties of human actions with respect to vandalism or the desire to place things of value in museums, the marker design fundamentals suggest large constructions that are difficult to move or destroy. Even the uncertainty about future continuity of property rights is addressed by the requirement for truthful messages about the health implications of possible intrusions.

Technical consultations on archives and records suggest that for long-term maintenance of information in an archives or records system, the physical format should be rather small in size (communicate the salient information quickly and as a guard against curators destroying bulky information), have distinctive binding (reduce the probability of being misfiled and not rediscovered), be produced on durable archival paper, with the documents having little resale value (no original signatures in the records and multiple copies in different locations), and with distinct cover language convincing a curator of the importance of the information and the need to preserve it for long periods of time.

APPENDIX C

EFFECTS OF THE COLLAPSE OF CIVILIZATION ON THE PROBABILITY OF EXPLORATORY DRILLING AT THE WIPP

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Sandia National Laboratories

Albuquerque, New Mexico 87185

date: April 2, 1990

to: D. R. Anderson, 6342

Robert V. Guzowski

from: R. V. Guzowski, 6342

subject: Effects Of The Collapse Of Civilization On The Probability Of Exploratory Drilling At The WIPP

A preliminary scenario analysis for the WIPP (Guzowski, 1990) indicated that the integrity of the disposal system depends on whether or not future drilling occurs into the waste-filled rooms and drifts. In dealing with future human intrusion, the question arises as to how long into the future exploratory drilling for resources is likely to occur. At the WIPP, the only natural resource at depths greater than the disposal rooms and drifts with the potential to be present in economic quantities is natural gas (Powers and others, 1978). Based on estimates of the quantities of reserves and undiscovered resources for oil and natural gas (Mast and others, 1989; Kerr, 1989) and the current rate at which the reserves are being consumed (Kerr, 1989), the trend suggests that all of the oil and natural gas resources in the continental U.S. for practical purposes will be consumed within a relatively short period of time. The question arises as to how long exploratory drilling will continue. Depletion of a resource in an area generally will result in an end to exploratory drilling for that resource at that location. For some undefined time after depletion, the possibility exists that industry will go back to an area for "one more look." This rechecking of areas also will eventually stop if no new resources are discovered. Another question arises as to what conditions are required for exploratory drilling to begin again. In various discussions on the subject, a number of people have stated the opinion that exploratory drilling would begin again as society redeveloped after the collapse of civilization even if exploratory drilling had previously been abandoned. The purpose of this memo is to consider the factors that have allowed drilling technology to develop to its present level, and to consider whether these same factors would be available after the collapse of civilization.

DEGREE OF COLLAPSE

In this discussion on the reestablishment of drilling technology, collapse of civilization is considered to occur at a time after the period of active institutional controls of the WIPP and to include complete loss of knowledge of drilling technology, the geologic controls for hydrocarbon accumulation, and the exploitation of natural resources by a previous civilization.

FACTORS THAT CONTROLLED THE DEVELOPMENT OF DRILLING TECHNOLOGY

Several factors were required for the development and advancement of the petroleum industry. In the past, natural gas usually was burned at the well as a waste product. At some locations, this practice continues today. The following discussion is based on the factors in oil discovery that led to advancement in drilling technology. Advancements in drilling for oil also apply to drilling for natural gas. These factors are:

(1) In the early stages of oil discovery, shallow reservoirs supplied enough petroleum so that once uses were found for the material, supply was sufficient or could readily be located to maintain the demand for the product.

(2) Oil reservoirs were associated with certain geologic settings. The distribution of reservoirs was not random. A theory was developed as to the origin and accumulation of oil and gas. Through time, the number of geologic settings where hydrocarbons could be found increased, although the basic theory as to why hydrocarbons accumulated remained basically the same. A relatively consistent association was noted between production and geologic setting when moving from one region into new but geologically similar region. This association confirmed the theory of the origin and accumulation of oil and gas.

(3) Once the targets of hydrocarbon accumulation were identified, progressively deeper targets were investigated as demand increased and techniques were developed to locate deeper targets. Improved drilling techniques had to be developed before boreholes could reach greater depths.

REDEVELOPMENT OF DRILLING TECHNOLOGY AFTER CIVILIZATION COLLAPSE

In order to develop the capability to drill to depths greater than the waste-filled rooms and drifts, the same basic steps would have to be followed as listed above. For the following reasons, the steps cannot be followed. These reasons are:

(1) Except for possibly small occurrences, all of the shallow oil and gas reservoirs have been located and exploited. Any remaining reservoirs are not likely to supply sufficient material to create enough demand to encourage drilling for additional supplies.

(2) Because of the previous exploitation of reservoirs and the use of secondary and tertiary recovery techniques, little if any production is likely to occur from previously worked reservoirs. As a result, no association between the accumulation of productive amounts of oil and gas with particular geologic settings is likely to be recognized. If the location of hydrocarbon reservoirs is not observed or is not predictable, a theory of hydrocarbon accumulation cannot be developed or confirmed.

(3) With no consistent association between shallow geologic settings and productive hydrocarbon reservoirs, no reason would exist to suspect that deeper geologic settings would be more productive than the shallower

settings. With no incentive for deep drilling, drilling technology would not progress beyond the early stages, if any development occurs at all.

CONCLUSIONS

The technology that enables drilling to considerable depths evolved from a technology that was initially limited to drilling to shallower depths. As shallower resources were consumed and demand continued to increase, the economic incentive developed to encourage deeper drilling. Progressively deeper drilling required the development of progressively more sophisticated drilling techniques. A total collapse of civilization would result in the loss of drilling technology. Because of previous exploitation of hydrocarbon resources, all of the factors that led to the evolutionary development of drilling technology are not currently present and will not be present again in the future. As a result, a collapse of the current civilization or the projection of what the current civilization will develop into would mean that the next civilization, if one develops at all, will not redevelop to the level of a hydrocarbon-based industrialized economy.

ADDENDUM
to
Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments,

WIPP/CAO-96-3168,

November 14, 1996, Revision 1

December 6, 1996

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

ADDENDUM

to

Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments WIPP/CAO-96-3168, Revision 1, November 14, 1996

December 6, 1996

Robert V. Guzowski[1] and Kathleen M. Trauth[2]

INTRODUCTION

The following is a brief discussion that indicates the typical process that takes place prior to resource exploration and extraction by drilling or mining, and how the WIPP PICs fit into the process to deter inadvertent human intrusion. A few clarifications must be made. The first of these clarifications is that this process does not invoke §194.25 Future state assumptions. Instead, this process relies on the PA guidance found in §194.33 Consideration of drilling events in performance assessments. In this case, procedures do not have to be exactly as they are today, but must operate in a similar fashion to achieve the same goals.

The second clarification is to reiterate that failure to deter considers only inadvertent human intrusion. Any drilling or mining that takes place with the knowledge that the WIPP Withdrawal is an area where drilling or mining is prohibited is intentional and is not to be considered by the PTF or in the PA calculations.

The third clarification is that the failure of any one PICs component (or a portion of a PICs component) to correctly communicate does not constitute a failure to deter, as defined in Rev. 1. Because of the regulatory framework established by the EPA, the normal conduct of resource exploration and extraction would require a failure of each of the PICs deterrent components encountered in order to have an inadvertent drilling or mining activity. It is possible that information transfer in one of the portions of a PICs component could fail, e.g., incorrect information transfer at one of the steps shown below. The discussion below shows that the resource development system has so many internal and external checks that the likelihood of all

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of the steps failing in order to allow a failure to deter is extremely small. Because each of the deterrent components contains the message "DO NOT DRILL," any one of the PICs deterrent components could, by itself, deter an inadvertent human intrusion.

The source of error that potentially has the greatest impact is human error, and this error would be most associated with the information transfer associated with records and archives, and with the implementation of government control of land use.

Types of failures incorporated into the data obtained from discussions with regulatory resource personnel include: (a) having a correct lease, having a correct permit for the same location, but setting up in the wrong location (i.e., not setting up in the area for which the leases and the permit were obtained); (b) having a correct lease, having been provided with a permit for a location other than the area for which the lease was obtained, and drilling at the location on the permit even though the leases had not been obtained; and (c) having a correct lease, having been provided with a permit for that location when the permit should have been denied, and drilling at the location on the permit.

The specific New Mexico information is provided as an example of current procedures, and the general activities that, based on §194.33, will be a part of resource-development procedures.

ACTIVITIES MODEL

The following figure indicates the pathways through resource exploration and extraction activities where PICs could be encountered and where PICs could succeed or fail. The drawing accounts for both vertical (A) and horizontal (B) drilling, and accounts for potential intrusions that are new activities and those that would be extensions of existing activities (C). The 1, 2, or 3 designations attached to A and B indicate the locations that the potential intruder could enter into the PICs system. The text discusses the pathways for success or failure, realizing that a potential intruder could enter the system at different locations or be deterred at different locations.

Site investigation to identify candidate sites for drilling encounters awareness triggers

The "other" PICs category includes designation of the WIPP location on both general-use and professional-use maps. Anyone who has worked or owns leases in the northern Delaware Basin is virtually certain to have seen maps of one or more types with the WIPP designation. Anyone new to the northern Delaware Basin will be interested in obtaining information about where drilling and/or resource production has occurred in the past, whether the terrain is suitable for resource development, and where roads and power lines are located. In the process of searching for this information, maps and possibly other sources of information in which the WIPP is designated will be encountered. An exclusion zone consisting of 16 sections is virtually certain to be noticed by anyone engaged in resource exploration and/or production. The information conveyed by the awareness triggers (i.e., something called WIPP exists as a resource-exclusion or danger zone) may be sufficient to discourage a potential intruder from proceeding with the

ACTIVITIES MODEL INDICATING PICS A POTENTIAL INTRUDER COULD ENCOUNTER AND POSSIBLE PATHWAYS FOR PICS SUCCESS OR FAILURE (I.E., INADVERTENT HUMAN INTRUSION).

A. Vertical Drilling

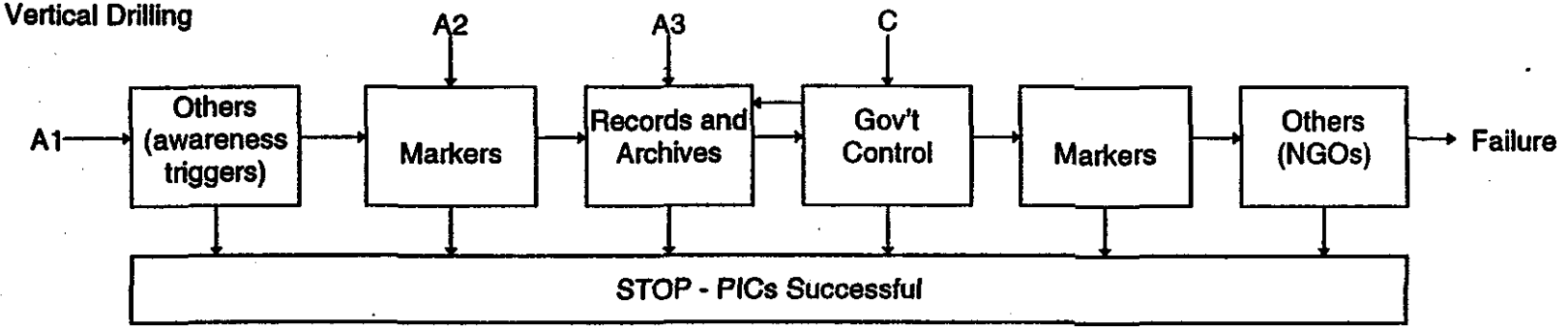

B. Horizontal Drilling

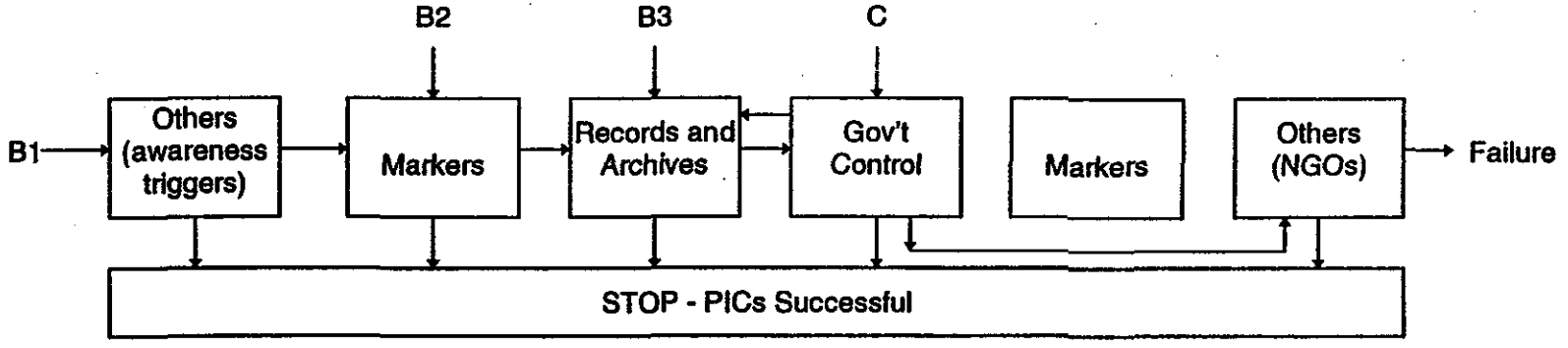

A and B lease and drilling permit must be acquired.
C lease held and work done adjacent to Withdrawal, effort made to obtain lease and permit in the Withdrawal.

(NGO = non-governmental organization)

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process of obtaining resource rights. The PTF did not take credit for any deterrence offered by the awareness triggers that are likely to be encountered during the initial phase of site investigation.

A decision is made to obtain resource rights within the Withdrawal

At some point during the site investigation, a decision is made by the potential intruder to obtain resource rights within the Withdrawal. To qualify as a potential step leading to an inadvertent intrusion, the person trying to obtain resource rights would have to remain uninformed about the existence of the WIPP and the associated prohibitions. A potential intruder lacking this information is highly unlikely, and would be akin to individuals involved in the current resource industry in the northern Delaware Basin not knowing about the Potash Exclusion Area. If this decision is made with full knowledge about the existence of the WIPP and the prohibitions against human intrusion, any subsequent intrusion would be deliberate and therefore outside the scope of PA.

A records search is conducted to determine ownership of the resource rights of interest within the Withdrawal

Information about lease ownership can be obtained from some awareness triggers (e.g., land-status maps produced by the federal government, maps produced by companies supporting the resource industry) or through records centers dedicated to the resource industry, which would be the most current source of information. A search of a records center is virtually certain to encounter information that the resources within the Withdrawal are not available for exploitation. Information-transfer procedures for the Withdrawal will be similar to the procedures currently in place to notify resource personnel about the presence of the Potash Exclusion Area. Completion of this step in the procedure requires that the resource person remains uninformed about the WIPP, which is highly unlikely, because a 16-section no-intrusion zone in the area that the resource person is investigating would be difficult to miss.

Resource rights are applied for and obtained

The resource rights for the federal land within the Withdrawal, except for state leases in the southwestern corner of the Withdrawal, have been obtained by the Department of Energy, and these leases have been terminated. If someone is interested in acquiring the resource rights within the Withdrawal, the party would submit an application to the Santa Fe office of the Bureau of Land Management (BLM) for those rights. The Santa Fe office would then send the application to the district office of the BLM, where the district office checks the Resource Management Plan (RMP) to see if a lease for those particular resources is available. The RMP contains stipulations recorded by township and range on the availability of the land for leasing. In the case of the Withdrawal, no leases are available, because these leases have been terminated. For the drilling procedure to continue, new leases would have to be developed without knowledge of the prohibitions within the Withdrawal. Following normal procedures for issuing leases, the newly created lease would then go on a list of leases that will be available for competitive bidding. The availability of the list is published in a newspaper to inform the general

public, and the list itself is sent to interested parties. At this point, non-governmental organizations (NGOs), some of whom are likely to have an interest in activities at the WIPP would be informed of a new lease in a previously designated exclusion area, and other companies/individuals in the resources industry would be aware that part of the Withdrawal has been opened for resource exploration and development and are highly likely to make inquiries to confirm the availability of the lease and to check whether the rest of the Withdrawal will also be opened. The likelihood that the status of the Withdrawal and the error in issuing the lease in the Withdrawal would not be noted by someone in the number of people and groups involved in this lease acquisition process is extremely low.

For drilling procedures to continue to the next step, the following individuals would have to remain unaware of the Withdrawal: the person/company interested in the resource rights within the Withdrawal, the personnel at the BLM who accepted the application and created a new lease, the personnel in NGOs with an interest in the WIPP, and the personnel in the resources industry on the notification list. The issuance of improper lease rights must remain a rare event. Because of the potential economic consequences associated with resource leases, the resources industry requires stability in the obtaining and holding of resource rights. If the issuing of improper resource rights were common, the resources industry would demand revisions to the procedures that would ensure that everyone played by the same rules.

The state leases in the southwestern corner of the Withdrawal are currently held by a company. Pending a final decision by the Environmental Protection Agency as to whether or not the Department of Energy has to acquire the leases, these leases can be transferred but not worked (i.e., no drilling). Application for transfer must be made to the Oil and Gas Division of the State Land Office, which must approve the transfer. Written procedures are available and must be followed, and a data base must be checked. Errors in the data base or in the application would be detected if the name and location on the application did not match the lease holder and lease location in the data base.

A drilling permit is applied for and improperly issued

If a person can progress to the point of obtaining the resource rights without knowledge of the WIPP, the next step of applying for a permit, which also would require this lack of knowledge, could occur. The fact that the issuance of a permit incurs financial commitments in the form of surety bonds ensures that certain regulatory obligations such as borehole sealing and site restoration are met. These financial commitments are likely to involve additional personnel within a company whose jobs include cost-benefit assessments in the commitment of financial resources. These additional personnel would also have to be unaware of the drilling exclusions for the Withdrawal.

Applications for drilling permits must include the location of the lease and the planned location of the borehole both at the surface and at depth. Additional information that must be supplied includes a description of the target unit(s) and plans for conducting the drilling (along with safety measures), closing the borehole, and remediating the site. The application is accompanied by surveying records locating the claim and the drilling site within the claim. The survey must be

done by a registered surveyor. An engineer from the resource company may accompany the survey party. The probability that none of the additional company, surveying, and government personnel involved in this step would be aware of the prohibitions against drilling into the Withdrawal is extremely small. Being unaware of the Withdrawal is especially unlikely for the surveyor who is likely to have experience surveying in the region and who has traveled to the site while doing the survey, thereby encountering the marker system.

The legal and financial ramifications associated with drilling for natural resources ensures that operators keep track of each other in the areas of obtaining and developing leases. This is an internal check within the industry promoting accuracy in both the records centers and in the field activities (i.e., the correct drilling locations are developed).

Site preparation begins

Before drilling can begin, the site has to be prepared so that the drilling rig and supporting facilities can be set up. Site preparation consists of constructing access roads, leveling the drilling pad, constructing any structures, and the digging of necessary pits. The crew doing the work (or at least the foreman) will check maps and surveying flags to make certain than the required roads, facilities, and pits are in the correct locations. In the preliminary states of site preparation, someone in the crew is likely to notice the Withdrawal on the maps or to recall from previous experience that the Withdrawal is a no-drill area. The crew itself has no authority to stop work, although someone in the crew may check with someone with higher authority whether the location described in the work order is correct. If the crew goes to the drill site within the Withdrawal, at least some of the elements of the marker component are likely to be encountered. Because of the persistence of current English in the resources industry, someone on the crew may be able to understand the messages engraved on the monuments and Information Center. If the planned drilling is to occur within the area enclosed by the berm, the berm would provide a major obstacle to reaching the drill site, and inquiries are likely to ensure that the specified site is the correct site.

If none of these points of inquiry result in a stop-work order, site preparation can begin. For drilling sites within the berm enclosure, leveling the site and digging the pits is virtually certain to encounter one or more buried markers, whose depth and distribution were specified to ensure that they would be encountered during site preparation. These markers may or may not be noticed by the site-preparation crew. If none of these activities during site preparation alert a decision-maker in the company about the existence of the Withdrawal and the associated prohibitions, the next step in the drilling procedure can begin.

Site preparation for horizontal drilling could, at least theoretically, occur outside the Withdrawal without any of the markers being encountered.

Drilling operations begin at a site within the Withdrawal or a site that would penetrate the Withdrawal (horizontal drilling)

Upon the arrival of the drill rig, drill crew, mud engineer, and geologist, the markers would again be encountered. For inadvertent intrusion to occur, the personnel involved with setting up the drill rig, conducting the drilling operation, and the monitoring of the drilling fluid and geologic/resource data in the borehole would have to remain unaware that the drilling is occurring within the Withdrawal.

Non-governmental Organizations

Non-governmental organizations (NGOs) include conservation, environmental, and historical groups that have an interest in particular private or governmental activities, and who follow the progress of these activities. In the case of the WIPP, the NGOs would probably follow the activities of the natural-resources industry, as being the source of potential human intrusion. NGOs may act at any point in this process to question activities to ensure that laws and procedures are followed correctly.

CONCLUSION

From the figure and the accompanying discussion, one can see that the PICs of records centers and governmental control of land use would be encountered by all potential intrusions by the natural-resources industry. Some potential intrusions could encounter three or all four of the PICs (although it is possible to be deterred by the "others" category, explicit credit is not taken for them because they do not all provide sufficient information to indicate not to drill). Thus, examining only records centers and archives and governmental control of land use is the most conservative approach. If these two PICs can be successful, then the PICs system is successful.

The operation of the existing natural-resources industry is an analogue that can be useful in assessing the effectiveness of the PICs. The natural-resources industry operates with records centers and archives and with governmental control of land use, which are the PICs that would be encountered by all credible potential intrusion scenarios. These two PICs as encountered by the natural-resources industry have a historical rate of failure. Because the WIPP PICs are intended to deter inadvertent activity associated with the exploration for and exploitation of natural resources, the PTF believes that the historical rate of failure in the natural resources industry is an analogue for the future failure rate of the PICs. The historical rate of failure for selected U.S. states and Canadian provinces (as described in Rev. 1) is approximately 3.5×10^{-5}. The DOE intends to add additional deterrence (i.e., through markers) to a system that is highly effective. Because of the potential for error in the memory of failures and because of the potential for confusion as to the sources of errors (setting up on the wrong lease versus the issuance of incorrect permits), the PTF has recommended that the PA calculations use a failure rate that is approximately three orders of magnitude higher (i.e., 0.01) than the overall historical failure rate. Although the PTF has not distinguished between the various sources of historical errors, the PTF believes that errors of any source would have been recalled by the personnel contacted about the historical failure rates. The PTF also believes that any undetected/unremembered failures would

be less than the bounding value recommended for PA calculations. A failure rate on the order of that recommended by the PTF would have resulted in enough litigation that regulatory personnel would have remembered many more incidents of failure than were reported.

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix FAC

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Facies Variability and Post-Depositional Alterations Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant

M

DOE/WIPP-88-004

FACIES VARIABILITY AND POST-DEPOSITIONAL ALTERATION WITHIN THE RUSTLER FORMATION IN THE VICINITY OF THE WASTE ISOLATION PILOT PLANT, SOUTHEASTERN NEW MEXICO

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January, 1988

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FOREWORD

Over the history of the WIPP project, extraordinary properties have been attributed to "the halite that was" ... and wasn't in the Rustler. Halite is quite thick in some members of the Rustler east of the site; these same members are much thinner and are mostly mudstone at the WIPP site. A simple assumption was made that these halites continued laterally - after all, some of the beds above and below are continuous over very large areas. The mudstones then must be "dissolution residues," following this simple assumption. Still, we know that environments always change laterally, and halite (or mudstone or carbonate) must give way laterally to another rock or an area that isn't accumulating halite. Where were these transitions for the Rustler?

After our experience mapping the waste shaft, we felt strongly that we were seeing transitional area. The bedding, fossils, bioturbation, and sedimentary structures were convincing evidence to us that the shaft area had not undergone significant dissolution since the Rustler was deposited and that sufficient features were observable in shafts and cores to recontruct depositional environments. From this reconstruction, we expected that more realistic limits could be placed on the extent of salt dissolved from the Rustler since the Permian. Here we report our reconstructed depositional environments.

The initial response to our mapping experience varied, though much of it was skeptical. Some workers have felt strongly that expectations of lateral continuity outweigh specific evidence we presented such as continuity of bedding and primary sedimentary features. Very slow dissolution was postulated, so that sedimentary features and relationships can be preserved while 75 to 90% of the rock is removed. While we are reluctant to say that such a process cannot occur, we believe a more appropriate explanation is available.

Halite does appear and disappear in parts of the Rustler. But observable features and relationships in the Rustler indicate that it can disappear soon after it was deposited, as might be expected for one of the more soluble of evaporite minerals. It creates interpretable structures as it is dissolved, some of which are newly described in this report. We hope that other geologists who are interested in evaporites will benefit from our experience, too.

Many individuals have helped us during this investigation. Not all can reasonably be acknowledged, but some have been extensively involved: Mel Balderrama, David Frederick, Merrie Martin, Kathy Schiel, Mary Jane Graham, Linda Foster, and Judi Williamson. We thank them for persevering. The manuscript was reviewed by Steve Lambert, Sue Hovorka, Rick Deshler, Barb Deshler, Roy McKinney, Dwight Deal, and Ken Broberg, Mike Schulz, and Bennet Young. We especially thank Steve Lambert, Sue Hovorka, and Barb Deshler for their extra time and effort. We absolve all of the above for any mistakes we may have made.

The main thrust of this report is to describe and interpret sedimentological features in terms of depositional environments. It was written mainly for sedimentologists. A few obscure but useful words are explained in the text. We anticipate that geologists less familiar with evaporites and sedimentology will require occasional reference to the American Geological Institute Glossary of Geology, 3rd ed., ed. by R.L. Bates and J.A. Jackson.

Robert M. Holt

Dennis W. Powers

ABSTRACT

The late Permian Rustler Formation is the youngest of three evaporite-bearing formations in the Delaware Basin. The depositional environments which formed the Rustler and the post-depositional events which subsequently modified the Rustler have never before been investigated in a detailed, systematic way. The purpose of this study is to describe the detailed sedimentology and interpret the depositional environments of the Rustler. Another objective of this study is to reassess the extent of Rustler dissolution. The reconstructed depositional environments help to bound the extent and relative timing of dissolution. Existing literature was surveyed to distill criteria by which dissolution can be recognized. Microscopic examination of diagenetic alteration of the Rustler rounds out the evidence.

The Rustler was examined in detail in two shafts and many cores from the vicinity of the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. Nearly 600 geophysical logs from boreholes in southeastern New Mexico were interpreted, and the stratigraphy and lithology over a larger study area were related to units observed in cores and shafts from the WIPP site.

The Rustler consists of sulfates, carbonates, halite, and clastic rocks. Rustler sulfates and carbonates are areally extensive and vary little. Those zones containing halite and mudstone laterally change greatly in thickness and lithology. The Rustler thickens considerably toward a depocenter east and southeast of the WIPP site. Most of the variation in Rustler thickness is attributed to those stratigraphic intervals containing halite.

The depositional environments of the various units within the Rustler were reconstructed using a sedimentological approach. Carbonate and sulfate units were deposited subaqueously following a transgression or freshening event. Among the diagnostic features for subaqueous deposition are algal beds and laminations, bioturbation, fossils, gypsum growth textures, and cross-bedding sequences. Halite and mudstone units accumulated slowly due to repeated solution and reprecipitation of halite in salt pan and marginal mudflat environments. Subsidence in the depocenter allowed halite to accumulate and be preserved. Halite commonly was dissolved syndepositionally from parts of the halite and mudstone units. Small scale dissolution, often

reported in halite from both modern and ancient evaporite environments, was common, and, on a larger scale, syndepositional dissolution drastically modified the sedimentary sequence. Diagnostic features include pedogenic clay skins, incorporative gypsum, incorporative and displacive halite in various stages of growth and solution, and bedding. Smeared intraclast textures are a newly-described feature formed by repeated solution of halite in mudflat environments.

Several times during Rustler deposition, relatively fresh water transgressed rapidly over very low topography. Carbonate or sulfate formed subaqueously as evaporation proceeded. Salinity increased and the brine margins retracted as desiccation continued. Marginal clastics and a halite lens in the depocenter accumulated relatively slowly and were controlled by subsidence and cannibalism of soluble minerals at the margins. Deposition of these saline facies was abruptly ended by another freshening event. This style of deposition began with an initial marine transgression over the Salado and was repeated several times.

The Rustler in, and adjacent to, Nash Draw has been brecciated because of solution of the Salado. Breccias were superimposed on Rustler rocks, including clastic rocks exhibiting smeared intraclasts which are due to syndepositional dissolution. These breccias have a stratiform base, and the degree of brecciation diminished upwards. These features are consistent with post-depositional dissolution of a bed at depth as described in the literature. Some of these areas are now also being affected by karst processes (as at WIPP 33).

Most of the immediate site area is unaffected by large-scale post-depositional dissolution. Halite was removed from parts of the lower unnamed member, Tamarisk Member, and Forty-niner Member before overlying units were deposited. Minor brecciation at boreholes H-3 and H-11 indicates some dissolution and collapse after the Rustler was deposited. These boreholes are in marginal areas of the depositional environments where some halite precipitated in mudstone units. Part of the Tamarisk Member is brecciated in WIPP 13. Partial core from WIPP 13 limits interpretation of this anomaly. Halite is not predicted for the Tamarisk Member at this location, but the brecciation may have begun below the Tamarisk.

The Rustler has been altered extensively at the microscopic scale. Petrographic evidence demonstrates mainly volume-for-volume replacement of minerals, especially sulfates. Overgrowths on some clastic gypsum grains preserve shapes, suggesting the gypsum may never have inverted to anhydrite. These phenomena help limit hypotheses of the effects of the volume changes associated with sulfate mineral inversion.

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1.0 INTRODUCTION

The Late Permian Rustler Formation is the youngest of three Ochoan evaporite-bearing formations in the Delaware Basin, and it overlies the Salado Formation which contains the facility horizon of the Waste Isolation Pilot Plant (WIPP). The Rustler is being characterized in detail to understand the geological history of the strata overlying, and in the area surrounding, the WIPP. The long-term isolation of waste at the WIPP will be evaluated partly on our understanding of this geological history.

The Rustler must be characterized in two ways. First, the condition of the Rustler at the present time must be clearly understood. Hydrologic and water-quality data have been collected and synthesized to explain groundwater sources and movement in the Rustler. Second, data must be collected in order to interpret more precisely those events which formed the Rustler and subsequently modified it through geologic time. In this report, Rustler sedimentary features are reported and the depositional history of the Rustler is interpreted. Post-depositional history of the formation is partially assessed.

The WIPP project is a Department of Energy (DOE) research-and-development facility constructed to demonstrate the safe disposal of radioactive wastes derived from the defense activities of the United States. The WIPP site is located about 26 miles east of Carlsbad, New Mexico, in an area known as Los Medanos (Fig. 1.1).

1.1 GENERAL

The Late Permian Rustler Formation of the Delaware Basin in southeastern New Mexico and west Texas records, perhaps uniquely, the evaporitic end stages of a cratonic basin. The Rustler is unusual as it represents the transition from the thick bedded evaporites of the Salado Formation to the clastic dominated continental deposits of the Dewey Lake Redbeds (also called Dewey Lake Formation). Transitional deposits of this nature have not been widely investigated.

The depositional pattern of the Salado (thicker, laterally continuous beds of halite bounded by thinner, areally extensive beds of sulfate) did not continue in the Rustler. The Rustler lithology is more variable, consisting of interbedded sulfates, clastics, carbonates, and halite. The lower Rustler

contains principally clastic rocks with interbedded sulfates and halite. The upper Rustler consists of carbonates and thick sulfates which sandwich thinner units of clastics and laterally equivalent halite.

The depositional environments which produced the Rustler are poorly understood, as no attempt had been made until recently to collect and synthesize detailed sedimentological data into a depositional model (Holt and Powers, 1984, 1986a & b, 1987; Powers and Holt, 1984). Before this work, data on the Rustler came from studies of limited and highly disrupted outcrops (e.g. Vine, 1963), field examination of core, and general interpretations of geophysical logs. Most studies of ancient evaporites are based on observations of cores and interpretations made from geophysical logs. This is partially due to the fact that evaporites crop out poorly. Hydration and dissolution seldom leave original textures and features intact. Most core studies concentrate on recognizing features with modern analogs. In this study, an in situ sequence was directly observed and combined with detailed core description and geophysical log interpretation to yield a much better set of sedimentary features and more complete understanding of lateral lithologic relationships.

The Rustler at the WIPP site near Carlsbad, New Mexico, has been investigated recently in detail, providing unique lithologic data for this formation. The Rustler was directly observed, described, and geologically mapped in two shafts. The mapping revealed lateral relationships and sedimentary features that rarely are observed in core or surface outcrop. As the shafts displayed the entire Rustler section in situ, data from the shafts (Holt and Powers, 1984, 1986a) are superior to those collected by other means. Observations made in the WIPP shafts provided the impetus for further study; cores were also re-examined and redescribed, and lithologies were interpreted in some detail from geophysical logs. The purpose of this investigation is to synthesize the data collected from the northern Delaware Basin (WIPP site area) and surrounding areas into a detailed depositional model of the Rustler Formation. Once a detailed depositional model has been established, it becomes possible to separate depositional from diagenetic features and to more accurately access diagenetic models.

Jones and others (1973), Bachman (1974, 1976, 1980, 1984a), and Lambert (1983) have discussed dissolution or proposed models of dissolution for the Rustler in the vicinity of the WIPP. An improved understanding of the

depositional environments of the Rustler should enhance our understanding of any diagenetic events, including dissolution, that have affected the Rustler.

1.2 STUDY AREA

The Delaware Basin of southeastern New Mexico and west Texas is a major subdivision of the Permian Basin (Fig. 1.2). It is bounded on the west by the Diablo Platform, on the east by the Central Basin Platform, and on the north by the Northwestern Shelf. The areal extent of the basin is greater than 13,000 mi^2 (33,500 km^2), and it is filled with as much as 24,600 ft (7,500 m) of Phanerozoic sedimentary rocks (Hills, 1984). The Capitan reef almost completely surrounds the Delaware Basin. It is considered among the latest deposits immediately preceding deposition of the Ochoan evaporites. This study concentrates on the northern portion of the Delaware Basin and adjacent parts of the Northwestern Shelf and Central Basin Platform. The WIPP site lies among the vegetated dunes of the Los Medanos area, some 26 mi (42 km) east of Carlsbad, and is located in the northern part of the Delaware Basin between Nash Draw and San Simon Swale.

1.3 REVIEW OF PREVIOUS WORK

The depositional and diagenetic events which produced the Rustler Formation have not been investigated in any detailed, systematic way. Early workers (e.g. Lang, 1935; Adams, 1944) described the Rustler from outcrop and well data, but they provided little assessment of depositional environments or post-depositional events. Donegan and DeFord (1950) asserted that the Rustler was Permian in age on the basis of invertebrate fossils collected from the Culebra Dolomite Member of the Rustler in Culberson County, Texas. Walter (1953) further identified and examined these fossils, and he indicated that the environment was quite saline based on the restricted fauna. Vine (1963) described the Rustler outcrops in Nash Draw and the Rustler from a core south of the WIPP site as part of the geological work preparatory to Project Gnome, a nuclear device exploded in 1961 in the Salado Formation south of the WIPP site. Cooper and Glanzman (1971) and Gard (1968) provided final reports on hydrology and geology of the Project Gnome site that include considerable discussion of the Rustler stratigraphy and lithology as well as the effects of dissolution. Geologists from the U.S. Geological Survey prepared several reports in the early 1970s as part of broad site selection

activities for radioactive waste disposal that resulted in investigation of the Los Medanos area. Jones and others (1973) interpreted the regional thinning of the Rustler as the result of an eastward migrating wedge of dissolution.

Eager (1983) broadly described a core through the Rustler in Culberson County, Texas, and related lithology to geophysical logs. Six stratigraphic units were identified by Eager (1983): the four formal members and two informal members below the Culebra Dolomite Member. The basal 96 ft (29 m) was called the "siltstone member" and includes about 22 ft (6.7 m) of dolomite. The "lower gypsum and mudstone member" of Eager (1983) is between the "siltstone member" and the Culebra and is about 50 ft (15.2 m) thick. Eager (1983) attributes the Rustler to eolian, supratidal carbonate flats, brine pan and mud flat environments based on the general lithologic similarities to evaporites of the Palo Duro Basin as reported by Handford (1981), Handford and Fredericks (1980), McGillis and Presley (1981), and Presley and McGillis (1982).

Field investigations began in 1974 in the Los Medanos area to locate a site for the WIPP, and the present site was located in 1975. The site was investigated in detail to validate it based upon established criteria. The Rustler was deemed of importance to the WIPP as it overlies the Salado and contains two water-bearing units (the Magenta and Culebra Dolomite Members). The hydrology of the Rustler has been characterized extensively to help determine the likelihood of the Rustler acting as a conduit for radioactive materials to the biosphere. As part of the site investigations, a number of Rustler cores were taken. The initial field descriptions of those cores appear in basic data reports for each hole (e.g. Jones and Gonzalez, 1980). Data and interpretations of the hydrology of the Rustler have been presented in several WIPP documents (e.g. Mercer and Orr, 1979; Gonzales, 1982; Mercer, 1983). Ferrall and Gibbons (1980), Lambert (1983), and Powers and others (1978) discussed dissolution within the Rustler. The WIPP site location and design met all established criteria and the site validation report was published in 1983.

In 1984 and 1985, two shafts were enlarged or newly constructed through the Rustler to the WIPP facility level. These shafts were mapped in their entirety (Holt and Powers, 1984, 1986a), giving special attention to the Rustler. The Rustler exhibited none of the features that would be expected

if recent dissolution had occurred. Holt and Powers (1984) state that:

> "Post-depositional dissolution features were not observed in any stratigraphic horizons in the waste shaft. In fact, several zones previously identified as dissolution residues in nearby boreholes (e.g., ERDA-9) contain pronounced primary sedimentary features. This is of great significance since dissolution has, historically, been considered as an important process that has greatly modified the Rustler Formation in this area."

The authors were subsequently given the task to study in detail the sedimentology, depositional environments, and subsequent modifications of the Rustler, building on their unique experience in mapping and describing the Rustler in the waste handling and exhaust shafts. This report is the consequence of that task.

Several of the intervals within the Rustler were modified by diagenetic processes. Based upon examination of four cores and one geophysical log, Lowenstein (1987c) discussed post-depositional alteration within the Rustler. Bachman (1987b) reported on evaporite karst, culminating years of study of the processes and features in Ochoan rocks, including the Rustler. Diagenetic alterations are assessed in this study as they pertain to both the depositional environments and dissolution.

1.4 METHODS OF ANALYSIS OR APPROACH TO EVAPORITE STUDIES

As previously discussed, the surface outcrops of most ancient evaporites provide little or no significant data concerning the depositional environment which formed the evaporites or subsurface geologic processes that modified them. In turn, the majority of evaporite-related studies rely on two types of data from the subsurface: geophysical logs and core. Among the most common tools available for evaporite studies are geophysical logs. The geophysical log itself is data about the physical properties of the rocks that must be interpreted. The interpretations are sometimes not unique and are frequently based upon a factor which cannot be quantified - experience. Geophysical logs become more useful when the logs from holes containing core are compared with descriptions of that core. This procedure allows for better extrapolation of rock types away from a data area.

Geophysical log interpretations are limited. No information can be collected or inferred beyond that which is inherent in each specific logging tool. In the best of cases, geophysical logs individually may yield general or semi-quantitative information concerning density, water content, natural radioactivity, acoustic velocity, conductivity, resistivity, spontanteous potential and dip. As one type of geophysical log data does not usually yield a unique interpretation of lithology, geophysical log types are combined in a manner in which the data collected allows unique, or nearly so, interpretations of parameters of interest. At best, these interpretations can reveal general information concerning rock type, mineralogy and pore fluid type. Geophysical logs normally cannot provide any information concerning sedimentary features (although the dip log may indicate crossbedding). Therefore, it is improper to rely on geophysical logs for the interpretation of anything they are not designed to provide. The value of geophysical logs lies in their availability across the region of interest. Thus, vertical and lateral lithologic and stratigraphic relationships can be inferred from logs of boreholes without core, providing much greater range to interpret geological history for the Rustler.

In most cases, geophysical logs cannot provide the types of data most needed for accurate and detailed reconstruction of depositional and diagenetic models. Just as it is impossible, using geophysical logs, to differentiate directly between sulfate deposited in a sabkha and that deposited in a saline lagoon or lake, it is also generally impossible to distinguish between a clastically deposited mudstone and a mudstone residue left after the removal of salt. The features and fabrics we rely on for the interpretation of depositional environment and diagenetic history (including dissolution) come from direct observation of rock.

This can be done in one of two ways. First, rock samples collected by coring can easily be described and allow for the direct observation of sedimentary features. The surface of evaporite core is frequently less than ideal for detailed observations, so it is often desirable to cut a slab from the core. Another advantage of cores is that they can be taken from holes over a wide area relatively cheaply, providing a larger view of the unit. One disadvantage of the study of core is that the data are limited by core size and the chance of coring and preserving specific features of importance. Second, <u>in situ</u> observations of rock can be done in manmade underground openings such as shafts and drifts. Observation of the rocks <u>in</u>

situ has distinct advantages over observation of core, although it may be orders of magnitude more expensive than core. The entire sequence may be observed without interruption. Larger scale features may be readily observed and relationships not clear in core may be obvious. Thus the features observed in core can be understood with greater confidence.

Nevertheless, the surface of underground excavations is usually rough, and some of the details which are readily distinguishable in core may not bevisible. This is especially true for sulfate rocks. It is clear that the best approach toward collecting direct observational data is to use both core and observations from underground excavations, as one's weakness is the other's strength.

Other types of direct observations on evaporite cores or samples can be made. These include thin sections, X-ray diffraction, and other chemical and microscopic techniques.

As geophysical log data are more common and of greater areal extent than data collected from direct observations, it is important to integrate the data types. One can compare the direct observations from core with the geophysical logs and determine what geophysical log signatures correspond with the observed rocks. One can reasonably expect to extrapolate lithologies between direct data points via geophysical logs. Those interpretations become less valid when they are not bounded by directly observed data and lose validity further from a direct observation. It is best to use caution when using geophysical logs alone.

Once the data have been collected and compiled, features with easily recognizable modern depositional analogs should be identified. The sequence of occurrence of those features in both the lateral and vertical sense should be analyzed and lithofacies should be determined. As few ancient examples exactly mimic modern analogs, it is not necessary to find an exact environmental match. The processes which formed the sedimentary features are commonly recognizable. It is the assimilation of those processes and their inherent limitations that yields a range of possibilities of original depositional environment. Further narrowing of the field is then done by determining which of the possible models is inconsistent with the lateral and vertical lithofacies relationships. Once this process is completed on a small scale, it should then be reapplied to the larger scale. The most reasonable interpretation should be selected and tested.

Data have been compiled on several types of maps and diagrams for interpretation. Lithofacies are identified, and their lateral variations assessed. By comparing the features and facies relationships of the Rustler to modern analogs, depositional models have been generated for various parts of the Rustler and integrated to create a composite depositional model of the Rustler Formation.

2.0 GEOLOGIC HISTORY OF THE DELAWARE BASIN

2.1 PRE-PENNSYLVANIAN

Prior to the Late Mississippian, Paleozoic depositional patterns in the Delaware Basin reflect migrations of epeiric seas over the region and the structural development of the Tobosa Basin, the predecessor to the Permian Basin. From the Late Cambrian/Early Ordovician until the Late Mississippian, a nearly continuous record of sedimentation is preserved as the region was, for the most part, tectonically stable during that time. Carbonates deposited under shallow shelf conditions dominate the rock record. However, carbonate deposition was interrupted by shale sedimentation during the Middle Ordovician, Late Devonian, and Early Mississippian.

During and immediately following the Late Mississippian, the Delaware Basin began to develop structurally by vertical movement along pre-existing structural trends (Hills, 1984). A thick sequence of basinal shales was deposited in the Delaware Basin during the Late Mississippian.

2.2 PENNSYLVANIAN PERIOD

The tectonic processes that were initiated during the Mississippian continued into the Early Pennsylvanian, and clastic materials derived from the Pedernal uplift in central New Mexico, the exposed Central Basin Platform, mountains in the Ouachita-Marathon area, and the Matador Arch filled the growing Delaware Basin (Hills, 1984; Powers and others, 1978).

During the Middle to Late Pennsylvanian, tectonic activity increased in the region (Ross, 1986). Broad carbonate shelves grew concurrently along the margins of the Delaware Basin (Hills, 1984). Carbonate bank development began in Atoka time and persisted through the Late Pennsylvanian and much of Permian time (Mazzulo, 1981). For the most part, clastic input from the north was trapped behind the carbonate banks, thus starving the Delaware Basin of sediment (Adams and others, 1951).

By early Permian (mid-Wolfcampian) time, tectonic activity had ceased (Ross, 1986), and the entire region subsided, deepening the Delaware Basin and establishing the major features of the Permian Basin.

2.3 PERMIAN PERIOD

2.3.1 Wolfcampian Epoch

In the Early Permian, the last stages of the Marathon orogeny thrust

geosynclinal rocks northward providing a source of fine clastic material which filled much of the southern and central portion of the Delaware Basin (Hills, 1984; Ross, 1986). Limestones, including the Abo reef, were deposited on the shelfal areas and during periods of quiescence, as thin units within the basin (Hills, 1972; Hills, 1984). The development of carbonate reefs severely restricted basinal circulation (Hills, 1984). Regional tectonic stability marked the remainder of the Permian, although local structural events continued to modify the basin (Powers and others, 1978).

2.3.2 Leonardian Epoch

The restriction of marine circulation continued into the Middle Permian, and the sea regressed to the southwest (Hills, 1972). This led to the development of large reefs and carbonate banks. Evaporites were deposited in highly saline shallow lagoons in the back reef (Hills, 1972). Sandstones continued to be deposited in the central part of the basin and were interbedded with carbonate wedges thinning toward the center of the basin.

2.3.3 Guadalupian Epoch

A general eastward tilting of the Delaware Basin began near the end of Leonardian time and subsidence continued through Guadalupian time (Hills, 1984). About 3,000 to 4,000 ft (900 to 1,200 m) of Guadalupian sands and silts were poured into the Delaware Basin; large carbonate reefs developed through later Guadalupian time (Hills, 1984).

As circulation became widely restricted due to the upward growth of the reefs and continued subsidence, the basin became sediment-starved (Oriel and others, 1967; Hayes, 1964; Hills, 1984). Reef and bank growth continued around the basin margins, and by late Guadalupian time had closed the Hovey Channel (Fig. 1.2) (Ross, 1986). The salinity of the fluids within the basin increased, dramatically halting reef growth.

2.3.4 Ochoan Epoch

The Delaware Basin was very restricted by the beginning of Ochoan time and evaporative conditions prevailed. Topographically, the Delaware Basin was fairly deep. Up to 1600 ft (500 m) of Castile evaporites consisting of carbonate and anhydrite with interbeds of halite were deposited on the

Guadalupian sediments. The Castile is restricted to the Delaware Basin, because Lang (1939, 1942) redefined the base of the Salado as the base of the Fletcher anhydrite that rests on the Capitan reef in the subsurface.

Following the deposition of the Castile, the basin desiccated to an areally extensive salt-pan/saline mudflat. Surface topography was essentially nonexistent and the laterally continuous desiccating-upward cycles of carbonate - sulfate - halite were deposited (Jones, 1972; Lowenstein, 1982, 1987a). Locally, over 2300 ft (700 m) of the Salado evaporites, mostly halite, were deposited in the basin. Salado deposition extended over the margins of the then buried Capitan reef.

Rustler time was marked by a major freshening of the basin. Clastic sediments were introduced into a deeper, somewhat less saline lagoonal type environment which later desiccated to a saline mudflat/salt pan. Rapid transgressions followed by desiccation deposited carbonates, sulfates, and halite rocks during the remainder of Rustler time.

Near the end of the Permian, nearly 650 ft (200 m) of siltstones and sandstones were deposited over Rustler evaporites. Earlier studies of the Dewey Lake Redbeds have been limited in scope (e.g., Miller, 1955, 1957). Miller (1966) interpreted the Dewey Lake as having been deposited in a shallow marine environment. Oriel and others (1967) followed Miller (1966), while Eager (1983) suggested that the Dewey Lake originated as prodeltaic sediments. Schiel (1987), as part of a continuing study, suggests the Dewey Lake is a continental deposit, in contrast with previous marine interpretations.

2.4 POST-PERMIAN

Following the deposition of the Dewey Lake Redbeds, most of southeastern New Mexico and west Texas were subject to erosion. The uplift and/or tilting that caused erosion was minor as the unconformity between the Late Triassic Dockum Group and the Late Permian Dewey Lake Redbeds is minimal. By the Late Triassic, southeastern New Mexico was reduced to a broad peneplain (Kelley, 1971). A northwesterly draining flood-plain basin formed in the Late Triassic and was not contained by the Delaware Basin (Hills, 1963; Brokaw and others, 1972; McGowen and others, 1983). Source areas to the south provided detrital material for the Santa Rosa and Chinle Formations (McGowan and others, 1983).

The Jurassic was a period of uplift and erosion of Triassic and possibly Permian rocks in the western part of the Delaware Basin. Southeastern New Mexico was a source area for Jurassic rocks in central and northern New Mexico (Powers and others, 1978).

By Cretaceous time, earlier erosion had exposed Precambrian to Permian rocks in the region. From late in the Early Cretaceous until early in the Late Cretaceous, southeastern New Mexico was covered by shallow shelfal seas (Hills, 1984). Thin deposits of limestone and coarse sandstone and conglomerate were deposited. In the Delaware Basin, the Cretaceous rocks were removed by later erosion, save isolated slump blocks of limestone and shale associated with karst features (Bachman, 1974). Late in the Cretaceous or early in the Tertiary, the Guadalupe Mountains were uplifted and tilted to the northeast. Mild tectonism affected the Northwestern Shelf (Kelley, 1971).

Regional uplift and tilting of southeastern New Mexico and west Texas to the east and southeast occurred in the late Tertiary. Tectonic activity to the west increased, resulting in the uplift of the Delaware, Guadalupe, and Sacramento Mountains. Eastward flowing streams drained the recently elevated highlands forming coalescing alluvial systems. These systems eventually produced an extensive blanket of sands and gravels called the Ogallala Formation. The Ogallala represents the first preserved sedimentary record since the Cretaceous (Bachman, 1974). Ogallala deposition ended in the Pliocene with the advent of additional regional uplift and warping (Powers and others, 1978). The surface became stabilized, and soil forming processes began that resulted in the formation of an extensive caliche caprock (Bachman, 1980).

A major uplift of the Guadalupe Mountains occurred in the late Pliocene and early Pleistocene. Subsequent erosion and coalescence of subsided areas removed Ogallala sediments (Nicholson and Clebsch, 1961; Mercer and Orr, 1979). During the early to middle Pleistocene, Nash Draw, the Clayton Basin, and San Simon Swale underwent subsidence (Bachman, 1974).

The middle Pleistocene was relatively humid, and the conditions were right for the fluvial reworking and deposition of earlier sediments as the Gatuna Formation. Gatuna time was followed by a much more arid environment. The arid conditions coupled with a tectonic and an erosionally stable surface permitted the formation of the Mescalero caliche. During the late

Pleistocene to Holocene, eolian reworking of detrital materials formed the extensive dune fields which now blanket large portions of southeastern New Mexico.

3.0 STRATIGRAPHY

3.1 OCHOAN STRATIGRAPHY

The Ochoan Series in the Delaware Basin was named by Adams and others (1939) for the Ochoa Post Office (T.24S., R.34E., Lea County). It includes four formations, three of which consist primarily of evaporites. They are, in ascending order, the Castile, Salado, and Rustler Formations, and the Dewey Lake Redbeds (or Formation)(Fig. 3.1).

3.1.1 Castile Formation

Richardson (1904) named the Castile Formation for outcrops near Castile Spring in Culberson County, Texas. The Castile was divided into a "lower" and an "upper" salt series until Lang (1935) named the upper salt series the Salado Formation.

The Castile Formation consists of thick units of laminated anhydrite/carbonate and halite. The sulfatic beds dominate. Halite is thin or absent in the western part of the Delaware Basin. The change is usually attributed to dissolution of halite (Anderson and others, 1972, 1978; Anderson, 1978, 1981, 1982; Bachman, 1984b; Lambert, 1983).

Anderson and others (1972) divided the Castile into additional informal members from the base upwards: basal limestone, anhydrite I, halite I, anhydrite II, halite II, anhydrite III, halite III, and anhydrite IV. Bachman (1984b) reported additional halite within anhydrite IV and called it halite V (sic). The informal framework provided by Anderson and his co-workers is in regular usage by investigators of the Castile Formation.

The basal contact of the Castile with the underlying Bell Canyon Formation of the Delaware Mountain Group is poorly exposed at best. Geophysical logs display a sharp transition based on natural gamma, acoustic, density, and other parameters. The contact has been considered unconformable based on these signatures. Cys (1978) reviews the evidence from a core of the transition in Winkler County, Texas, and concludes that the contact is clearly transitional. Cys (1978) placed the contact at the first lamina of anhydrite. He indicates that the sharp log signature is due to the thinness of the transitional contact relative to the resolution of the log. Anderson and others (1972) report a thin limestone unit at the base of the Castile. More recently, Robinson and Powers (1987) examined cores of the contact from numerous boreholes along the western edge of the Delaware Basin, and

geophysical logs from a larger area. Cores show the transition over a few tens of centimeters, and the logs display sharp transitions. In addition, there appears to be an intertonguing of limestone and sulfate near the base of the Castile forming what has been called "false Lamar" (Powers and Robinson, in prep.). The intertonguing occurs east of Whites City over several miles. While the Bell Canyon/Castile contact is transitional over an interval of < 3 ft (1 m) and the log signature is distinctive, some marginal variation in the contact is demonstrable.

The upper contact with the Salado is less clear. Lang (1939, 1942) placed the base of the Salado at the base of the Fletcher Anhydrite Member which rests immediately on the Capitan Limestone. Jones (1954) and Jones and others (1973) included the Fletcher Anhydrite Member in an anhydrite unit considered part of the Castile in the Delaware Basin. This anhydrite was informally designated anhydrite III or IV, or a combination of III/IV, by Anderson and others (1972).

Bachman (1984b) reviewed the nature of the Castile/Salado contact in some detail. He generally confirms (p. 8) the conclusion of Jones (1954) that "the contact between the Castile and Salado is gradational and interfingering."

Bachman (1984b) interprets the contact as generally sharp, but modified in part by dissolution resulting in a residue resting on the Castile.

The Castile has been the subject of many well-known studies. Anderson and others (1972) relate studies of the anhydrite/carbonate laminations begun by Udden (1924), carried on by Adams (1944), and extended by Anderson and co-workers. The Castile Formation is usually considered an example of a deep-water evaporite basin; the characteristics attendant with such deposits are discussed more fully by Schmalz (1969), Dean and others (1975), and Kendall (1984).

The Castile Formation is dominated lithologically by thick units of sulfate (mainly anhydrite) or thinly laminated anhydrite and carbonate. Near the center of the basin, thick units of relatively pure halite are interbedded to intertonguing with the sulfate units. The thickness of beds within the Castile can be consistent over considerable distances, interrupted only by intraformational deformation or by dissolution. Anderson and Powers (1978) report on deformation of parts of the Castile from several areas within the Delaware Basin buried no more than about 4000 ft (1200 m) deep at

present. Borns and others (1983) and Borns and Shaffer (1985) examined deformation in the Castile near the WIPP site and in larger areas of the basin. Borns and Shaffer (1985) concluded that the structures outlined by Anderson and Powers (1978) were smaller than originally conceived and were similar to salt flowage/deformation structures near the WIPP site.

Some investigators report basin margin effects, including submarine fan deposits of gypsum or anhydrite (Billo, 1986), along the eastern and northern basin margin. Robinson and Powers (1987) report a fan-like deposit of sulfate clasts approximately equivalent to halite I (Anderson and others, 1972) along the western margin of the basin. Details of the sedimentological processes for the Castile are still being profitably studied.

3.1.2 Salado Formation

The term Salado was originated by Lang (1935) for the upper, salt-rich part of the Castile gypsum of Richardson (1904). An informal threefold division of the Salado Formation is utilized here: an unnamed upper member, a middle member locally designated the McNutt potash zone, and an unnamed lower member. As each of the members contains similar amounts of halite, anhydrite, and polyhalite (Jones, 1972), the members are distinguished by their content of other potassium and magnesium-bearing minerals. The upper and lower members generally lack these minerals, while the middle member (McNutt potash zone) contains a relative abundance of potassium and magnesium-bearing minerals. Due to the abundance of laterally persistent beds, the middle and upper Salado are also subdivided on a much finer scale. A system of numbering individual beds of anhydrite and polyhalite (marker beds) was introduced by geologists of the U. S. Geological Survey (Jones and others, 1960). The marker bed system is used extensively by mining companies in the Carlsbad potash mining district.

The Salado consists of halite, anhydrite, and polyhalite with varying amounts of other potassium-bearing minerals. About 85-90% of the Salado is halite (Jones and others, 1973). Beds of anhydrite and polyhalite alternate with thicker beds of halite throughout the Salado section.

Halite in the Salado is rarely pure and often contains minor amounts of clay, polyhalite, and anhydrite. The halite is generally white to clear, but it may be tinted orange, reddish-brown, and gray by varying amounts of interstitial polyhalite or clay (here used mainly as a textural term as the

finest grain sizes include clay and other minerals). Halite may also occur in some argillaceous beds and anhydrites as displacive crystals. Halite replacements of sulfate are common; the most recognizable are halite pseudomorphs after gypsum swallowtail crystals.

In the Salado, argillaceous halite is reddish-brown to gray. In an argillaceous halite, clay minerals may occur as matrix material, interstitial material, and intercrystalline material. The clay mineral content of the Salado (Bodine, 1978) and most individual argillaceous halites increases upward (Lowenstein, 1982, 1987a).

Most sulfate units in the Salado consist of finely crystalline polyhalite and anhydrite. During geologic mapping in the exhaust shaft, various classic sulfate sedimentary structures were observed in the anhydrites and polyhalites of the Salado, including nodular structures, enterolithic structures, and swallowtail structures. Some of the anhydrite and polyhalite beds are visually structureless. The majority of the polyhalite and anhydrite beds are underlain by thin beds of gray carbonate-rich claystone. Polyhalite and anhydrite may also occur in halite beds as disseminated, irregularly shaped blebs or as stringers.

Unlike the Castile, the Salado is not confined to the Delaware Basin. North and east of the WIPP site Salado deposition passed well beyond the Capitan reef and occurred on the Northwestern Shelf and the Central Basin Platform. The Salado has been erosionally removed from the west and south sides of the Delaware Basin leaving a horseshoe-shaped rim of brecciated insoluble material.

The upper contact of the Salado with the Rustler within the central part of the basin is marked consistently on geophysical logs by a relatively large increase in natural gamma over an interval as thick as 100 ft (30 m). This log signature immediately overlies successively deeper Salado marker beds to the west (Jones and others, 1960; Bachman, 1974), usually attributed to solution or leaching of salt from the upper Salado (Vine, 1963). Jones and others (1973) argue that this zone is partly attributable to the Rustler and partly to the Salado Formation. Holt and Powers (1984) described erosion and channeling very near the base of the Rustler that indicates processes other than late dissolution may contribute part of the apparently unconformable relationship between Salado and Rustler.

3.1.3 Rustler Formation

The Rustler Formation is the youngest of three Ochoan evaporite-bearing formations in the Delaware Basin (Fig. 3.1). Richardson (1904) named the Rustler for outcrops in the Rustler Hills, Culberson County, Texas. Lang (1939) clarified the term "Rustler" to stratigraphically define the interval between the Pierce Canyon Redbeds (abandoned term; now recognized in part as the Dewey Lake Redbeds) and the Salado Formation. Lang (1939; in Adams, 1944) recognized and named two laterally extensive dolomite units. The lower is named the Culebra Dolomite Member, and the upper is named the Magenta Dolomite Member.

Vine (1963) introduced the presently used fivefold stratigraphic subdivision of the Rustler (Fig. 3.2). Vine named the interval above the Magenta the Forty-niner Member, and the interval between the Culebra and the Magenta the Tamarisk Member. The interval between the Rustler/Salado contact and the Culebra was not named and is referred to as the unnamed lower member.

The Rustler Formation in this area is characterized by a variable lithology consisting of interbedded sulfates, carbonates, clastics, and halite. Jones (1972) reported the Rustler as consisting of 10% carbonate rocks, 30% sulphate rocks, 43% chloride rocks, and 17% clastic rocks.

The Rustler varies in thickness from tens of feet, where exposed and subjected to solution and erosion, to nearly 560 ft (170 m) in the northeastern part of the Delaware Basin. The western margin of the Rustler has been removed by erosion. The Rustler crops out along the Pecos River Valley, within Nash Draw, and in an arcuate pattern near the southwestern edge of the Delaware Basin. It has been extensively altered by near-surface ground water in Nash Draw.

Outcrops of the Rustler are poor at best. Solution and/or hydration of the soluble rocks within the Rustler, and frequently the solution of halite from the underlying Salado Formation, extensively modify and disrupt any primary sedimentary features. Rustler units may be displaced from their expected position. Where dissolution of the underlying Salado is complete, Rustler outcrops may consist only of broken blocks of less soluble rocks.

The upper contact of the Rustler with the Dewey Lake Redbeds has been reported as conformable (e.g., Bachman, 1984b). Within the shafts of the WIPP site, Holt and Powers (1984, 1986a) report local minor erosional relief on the contact.

3.1.4 Dewey Lake Redbeds

The Dewey Lake Redbeds are the uppermost of the four Ochoan formations and represent the close of the Paleozoic in the Delaware Basin. The assignment of the Dewey Lake to the Permian is somewhat arbitrary as it is not supported by radiometric dating or fossil evidence in the Delaware Basin. Fracasso and Kolker (1985) provide Permian radiometric ages from the Quartermaster Formation, the Dewey Lake equivalent in the Texas panhandle. The Dewey Lake was named by Page and Adams (1940) based on samples from the Penn Oil, Habenstreit #1 well, Glasscock County, Texas. The term "Dewey Lake" superseded the term "Pierce Canyon" originally proposed by Lang (1935) for redbeds in the Delaware Basin. The term "Pierce Canyon" was used as late as 1963 by Vine in his descriptions of the Permian redbeds in Nash Draw. However, the U.S.Geological Society later abandoned the term "Pierce Canyon" and adopted the term "Dewey Lake," as it was more widely accepted by geologists, and "Pierce Canyon," as defined, included rocks of the Pleistocene Gatuna Formation.

The Dewey Lake conformably overlies the Rustler Formation on a large scale (with local minor erosional relief) and underlies Late Triassic and younger rocks. The Dewey Lake thins to the northwest as the result of pre-Late Triassic erosion. The Dewey Lake is often assumed to be laterally equivalent to the Quartermaster Formation or Group of the Texas panhandle and Oklahoma (Hills and Kottlowski, 1983). However, the age of the Quartermaster is not consistently stated, and the relationship with the Dewey Lake is not clear (Hills and Kottlowski, 1983).

The Dewey Lake is characterized by its reddish-orange to reddish-brown color and varying sedimentary structures. The Dewey Lake consists almost entirely of mudstone, claystone, siltstone, and interbedded sandstone. Abundant sedimentary structures are characteristic of the Dewey Lake (Holt and Powers, 1984, 1986a) and include horizontal laminations, fine cross-laminations of varying size, rip-up clasts, silt-filled mud cracks, interbasinally derived pebble conglomerates, fining upward sequences, and soft sediment deformation features. Locally, greenish-gray reduction spots are abundant, and a few beds may have a gray color. Schiel (1987), in a continuing study of the Dewey Lake, has also provided initial interpretations of geophysical logs indicating generalized lithologic trends within the Dewey Lake.

With the exception of the upper portion, the Dewey Lake is characterized by locally abundant gypsum-filled fractures. The majority of the fractures are filled with fibrous gypsum, although granular gypsum fracture fillings do occur in the upper portion of the Dewey Lake. The significance of the first occurrence (from the surface) of gypsum-filled fractures at various localities is not clear. It informally has been considered a possible indicator of the depth and extent of infiltration of recent meteoric water, though this is certainly not a unique interpretation. Preliminary comparisons of data gathered from the waste handling and exhaust shafts with data gathered from boreholes around the WIPP site indicate that the first occurrence of gypsum fracture fillings does not occur in the same stratigraphic interval laterally (Holt and Powers, 1986a).

The majority of all fractures in the Dewey Lake are horizontal to subhorizontal and follow bedding planes. High angle fractures are the least common fracture type in the Dewey Lake. At least three separate episodes of fracturing and subsequent filling with gypsum have been reported from the Dewey Lake at the exhaust shaft (Holt and Powers, 1986a).

3.2 RUSTLER STRATIGRAPHY

The stratigraphy of the Rustler Formation at the WIPP site is discussed in the following sections. Vine's (1963) fivefold subdivision of the Rustler is used as the stratigraphic framework for the Rustler data in later chapters (e.g., sedimentological data in Ch. 5). Some units of the Rustler vary considerably beyond the area of the WIPP site. These variations, including hydration and alteration of sulfates near the surface, are not considered here.

3.2.1 Unnamed Lower Member

The unnamed lower member consists of clastic sediments with subordinate amounts of bedded halite, anhydrite, and polyhalite (Fig. 3.2). The lower member is roughly 130 ft (40 m) thick. The basal contact with the Salado, as observed in the shafts, indicates neither significant erosion nor dissolution (Holt and Powers, 1984, 1986a).

The lowermost 65 ft (20 m) of the lower member consists of siltstone with minor amounts of sandstone. Two halite-rich sequences overlie the siltstone. These sequences are in turn overlain by a 10 ft (3 m) thick,

bedded anhydrite sequence. The top of the unnamed lower member is marked by roughly 10 ft (3 m) of claystone.

3.2.2 Culebra Dolomite Member

The Culebra consists of brown, finely crystalline, locally argillaceous and arenaceous dolomite with rare to abundant vugs with variable gypsum and anhydrite filling (Fig. 3.2). The Culebra is about 27 ft (7 m) thick. Frequently, the upper 4 inches to 1 ft (0.1 to 0.3 m) consists of organic-rich, thinly to micro-laminated claystone and carbonate.

3.2.3 Tamarisk Member

The Tamarisk Member varies from about 100 to 170 ft (30 to 50 m) thick in normal sections. It consists of a lower and an upper anhydrite separated by either a thin 6.5 to 10 ft (2 to 3 m) thick claystone or a thicker interval of halite (Fig. 3.2).

3.2.4 Magenta Dolomite Member

The Magenta is a light gray to dark brown gypsiferous and arenaceous dolomite roughly 25 ft (8 m) thick (Fig. 3.2). It displays abundant primary sedimentary structures including wavy and lenticular bedding, cross-stratification, climbing ripple structures, and nodules of gypsum. The Magenta assumes a purplish cast after surficial weathering or in the shallow subsurface.

3.2.5 Forty-niner Member

The Forty-niner is similar to the Tamarisk as it consists of a lower and an upper anhydrite which sandwiches claystone or a laterally equivalent halite (Fig. 3.2). The contact with the Dewey Lake Redbeds is sharp and undulatory within the WIPP shafts; it is regionally conformable.

4.0 LATERAL RELATIONSHIPS WITHIN THE RUSTLER FORMATION

Lateral relationships will be described at two different scales: local (WIPP site area) and regional. The local geology reported here is strongly influenced by previous shaft descriptions (Holt and Powers, 1984, 1986a) and redescribed cores from WIPP boreholes, emphasizing sedimentary features and relationships important in interpreting the depositional history and subsequent events. Geophysical logs of these boreholes have been correlated to details from shaft and core descriptions. The local sedimentary features and relationships are presented elsewhere in detail (Ch. 6); here, we summarize briefly the site relationships as a prelude to a regional synthesis. The regional lateral relationships are based principally on our interpretation of geophysical logs, tied to the stratigraphy and lithology of the site area. A variety of isopach maps and structure contour maps will be used in conjunction with cross sections to provide the basis for lateral relationships in the Rustler at both scales.

The regional information serves mainly to illustrate important stratigraphic and sedimentologic relationships. These relationships are best preserved from the vicinity of the site to the east, north, and south, limited by the state boundary. Outcrops of the Rustler west of the site have not been examined in detail for stratigraphic and sedimentologic data for reasons outlined by Vine (1963). West of the site, logs are increasingly difficult to interpret as they are near the surface and have been disrupted by erosion and solution of both Rustler and Salado. For this report, which concentrates on depositional and dissolution features in the vicinity of the WIPP site, the region includes the site (see Fig. 4.20) and areas west, but usable information is from the site area to the east, north, and south.

Several distinctive, widespread lithostratigraphic units may be correlated. This kind of correlation does not require synchronous deposition or bounding isochronous surfaces (Hedberg, 1976), although widespread beds of similar mineralogy and geochemistry in an evaporite basin are often, at least implicitly, assumed to be isochronous or nearly so. Within parts of the Rustler, the vertical sequence of beds is similar to lithofacies developed laterally in evaporite deposits, and thus they may generally be interpreted as prograding or retrograding deposits. Mildly disjunct facies, somewhat similar in arrangement to punctuated aggradational cycles (PACs) of Goodwin and Anderson (1980) and Anderson and others (1984), indicate rapid relative

changes in sea level or regional base level (Ch. 6).

The framework for lateral relationships is the five member lithostratigraphic designation of the Rustler (Vine, 1963). Individual beds within these members are described in some detail in shafts and cores (Ch. 5). These beds, as far as geophysical characteristics permit (Fig. 4.1), are traced laterally across the region. Some lithologies (e.g., Tamarisk halites) occur regionally, as interpreted from geophysical logs, and do not occur in cores from the site area. These lithologies vary within well-defined members, however, and are easily assigned to lateral lithofacies variations in most areas. The region well north and east of the site demonstrates some changes within the lower Rustler requiring considerable care in interpretation. Some of these lateral changes are briefly mentioned, as they are beyond the areal scope of this report and are not resolved.

The isopach and structure contour maps may be used to infer considerable information about the depositional history and structural evolution of the late stages of the Delaware Basin and immediate surroundings. Section 4.3 summarizes that information, part of which is also used to interpret the depositional history section.

4.1 WIPP SITE

Within the site area, all members are clearly defined and change little in thickness and general lithology. The Tamarisk and Forty-niner Members vary most in thickness and lithology due to the presence or absence of halite.

4.1.1 Unnamed Lower Member

The lower contact of the unnamed lower member is at the base of a section of reddish-brown to greenish-gray siltstones, above a halitic and sulfatic section of the Salado. Within the shafts, this boundary is sharply defined. Cores also show sharp differentiation of the boundary, and these boundaries are closely related to natural gamma increase (from the underlying Salado Formation), and changes in the sonic, density, or neutron character (Fig. 4.2).

To the west, this basal contact has been considered less definable. Jones and others (1973) have stated that the argillaceous clastics above

halitic Salado include the residue from dissolution of the upper Salado, meaning that the Rustler/Salado contact may not always be located at the base of the natural gamma bulge characteristic of the lower Rustler. Some of the evidence for this conclusion is observable near the site. In the Nash Draw area, Salado halite can be demonstrated to have been removed sometime after Rustler deposition on the basis of brecciation of much of the Rustler (Ch. 7; see also Mercer, 1983). Within the site, however, there is very clear evidence of erosive channeling and fill near the base of the Rustler (Holt and Powers, 1984), and the Salado/Rustler contact is variable within the region in areas that have not undergone post-Rustler dissolution. Channeling, fossils, and bioturbation in the basal Rustler are clear indicators of much less saline water compared to the Salado brines (Holt and Powers, 1984, 1986b; Ch. 5, 6). It is reasonable to suppose that this water caused dissolution and/or erosion of the upper Salado, though the amount is yet undetermined. The extent of this early process may be obscured in the western part of the study area by later solution and collapse of the Rustler and upper Salado.

The upper boundary of the unnamed lower member is placed at the base of the Culebra Dolomite Member, specifically at the contact with a gray claystone unit. This contact is among the clearest and most easily interpreted both in the site area and the region (Fig. 4.2). The correspondence between shafts, cores and logs is excellent. This boundary is used as a baseline in profiles for correlation purposes in this report (Fig. 4.3 - 4.6).

Within the lower unnamed member are two main anhydrite beds. These beds are traceable regionally as well as through the eastern part of the site area, providing a tie within the lower section. The lower, thinner sulfate thins or disappears in the western part of the site.

4.1.2 Culebra Dolomite Member

The upper contact of the Culebra within the site area was poorly preserved and described prior to shaft excavation. Within both shafts, a waxy organic-rich, well-laminated carbonate and clay bed occurs. It is cored with difficulty, probably washes out during drilling, and can be associated with a gamma spike and low density, low acoustic velocity signature on logs (Fig. 4.2). This signature carries through much of the region and is the

basis for interpreting its regional extent. In this chapter of the report, the contact of the Culebra has been placed at the base of this organic unit because of the variable thickness in the organic-rich unit. In many previous reports, the Culebra boundary was placed above the organic-rich beds on the basis of gamma logs. For the discussion of sedimentary features (Ch. 5) and depositional environments (Ch. 6), the organic-rich unit is included in the Culebra. Some of the systematic variation in Culebra thickness in the site area between this and other reports can be attributed to this interpretive difference.

Within the site, the Culebra is slightly variable in thickness. It is present throughout the site and is an important regional marker.

4.1.3 Tamarisk Member

The upper contact of the Tamarisk with the Magenta Dolomite Member is distinctive in shafts, cores, and logs throughout the site and region (Fig. 4.2). It is a transitional boundary spanning a few feet (1-2 m) between the upper sulfate of the Tamarisk and the carbonate, including algal structures, of the basal Magenta.

The most laterally continuous unit of the Tamarisk Member is the upper sulfate. A sulfate above the basal organic claystone and carbonate (see 4.1.2) is regionally continuous, though it is absent in WIPP 19, a borehole about 0.5 mi (0.8 km) north of the site center.

The beds between these sulfates are among the most variable units in the Rustler. Even within the site area, the interval between these sulfates varies in thickness from about 15 to about 115 ft (4.6 to 35 m). A polyhalite bed occurs within this interval in the eastern part of the site area; the polyhalite can be traced through a part of the region as well especially in the Rustler depocenter southeast of the site (e.g. log of H01, Fig. 4.2, 4.3, 4.5, 4.6).

4.1.4 Magenta Dolomite Member

The upper contact of the Magenta is transitional over a small thickness, resulting in easy identification in the site area and easy correlation within the region (Fig. 4.2). As with the Culebra, the Magenta varies slightly in thickness within the site area, though it is continuous throughout the site area and the region.

4.1.5 Forty-niner Member

The upper contact of the Forty-niner is sharp in shafts, core, and logs (Fig. 4.2). The transition from the sulfate of the Forty-niner to the clastics of the overlying Dewey Lake Redbeds has local relief of a few inches (a few cm) in shafts and cores.

The sulfate beds at the base and top of the Forty-niner are persistent throughout the site area as well as the region. The thickness of these sulfates varies only slightly within the site area. However, the thickness of the clastic/halitic beds between the sulfates varies greatly both locally and regionally. The thickness varies mainly with the volume of halite present.

4.2 REGIONAL LATERAL RELATIONSHIPS

Important regional relationships have been defined by correlating geophysical logs with cores and shaft descriptions. In addition, certain units of the Rustler vary considerably within the region studied, providing evidence of facies changes.

4.2.1 Lower Unnamed Member

The basal contact of the Rustler a few tens of miles east and southeast of the site appears very much like the contact at the site (Fig. 4.2). At the fringes of the study area, the basal contact may exhibit a variable position with respect to Salado marker beds (e.g., MB 103 and 109) and the Culebra. At the eastern and northern edges of the region, the log character indicates that the part of the section equivalent to the lower silts and clays of the Rustler is very similar to, and perhaps continuous in deposition from, the Salado; it could possibly be considered part of the Salado. The natural gamma bulge is much diminished, indicating less clay in a thinner unit, and acoustic velocities are similar to halite (Fig. 4.2). Because the basal gamma signature appears continuous though diminished, we consider this interval part of the Rustler. A further study of the regional character of this boundary is obviously warranted, though not a part of this report.

Two anhydrite beds within the lower unnamed member are prominent in the site area and to the east (Fig. 4.3 - 4.6). These distinctive units occur in the upper part of the member at the site but are lower in the member to the

east and south. Further to the south, these two anhydrites are again high in the member, and a sulfate/carbonate which is not present at the site appears near the base of the member. The position of these anhydrites is variable with respect to the base of the Rustler and with respect to the base of the Culebra. Their position generally relates to the thickness of halite in the member. As halite decreases above the anhydrites, their position is closer to the Culebra. As halite decreases below the anhydrites, their position is closer to the base of Rustler. These changes do not occur at the same locations along the constructed profiles (Fig. 4.3 - 4.6), indicating the cause of position change is not common to both sections of the member. In addition, clastics between the upper anhydrite and Culebra vary in thickness, but the variation does not appear to directly relate to thinning or absence of halite. The position changes and relationships appear to be due to variations in depocenter for a saline pan and attendant clastic deposits.

Halite below the two anhydrite markers is thickest to the east of the site area. The relationships within the lower unnamed member (as well as the rest of the Rustler) are somewhat unclear due to a lack of data in the immediate vicinity of the buried Capitan reef margin east and north of the site. The thickness of this lower part of the member does not appear to vary greatly across the reef at the north, though it may be significantly thinner along some areas southeast of the site. The proportion of halite in the member is greater over the Central Basin Platform, and the lithologic sequence is similar to the Salado. The Central Basin Platform area may have formed a semi-independent depocenter dominated by a saline pan during this time.

The lower unnamed member is thickest (550 ft; 168 m) east and south of the site, both within the Delaware Basin and across the margin of the Capitan reef to the east (Fig. 4.7). Though data are few over the reef, the areas east of the reef are clearly equivalent in maximum thickness.

Borns and Shaffer (1985) also found the thickest part of the upper Salado to the south and east of the site area. Within that area, the Salado/Rustler contact usually varies slightly in position above distinctive beds above MB 103. The contact is not perfectly concordant even in these areas, indicating erosion and/or solution of the uppermost Salado with the influx of water with much lower salinity to begin Rustler deposition.

4.2.2 Culebra Dolomite Member

The Culebra varies moderately in thickness, from about 10 to 35 ft (3 to 11 m), through the region (Fig. 4.8). The Rustler dolomites are reported to be oolitic (Lang, 1935; Adams, 1944) but we have not confirmed this. Limited field observations and core descriptions from sulfur exploration in Culberson County, Texas, indicate that the Culebra is richer in clastics to the south and southwest of the site.

The distinctive Culebra log signature within the Delaware Basin begins to fade at about T15S. The Culebra thins to the north, appears to become increasingly sulfatic, and then disappears as a distinctive unit. It is not clear whether the Culebra disappears entirely by pinching out or merges with the upper anhydrite of the Tamarisk Member. Along the western edges of the Rustler (outcrops in T17S, R28E), a very thin unit of mottled to color-laminated clastics with no distinctive anhydrite occurs between the Culebra and Magenta. The lower Magenta shows probable algal laminations and thin breccia zones bounded by zones of continuous bedding. Geophysical logs east of this outcrop show the upper anhydrite of the Tamarisk Member. This important question of the lateral relationship of the Culebra to Tamarisk is still unresolved.

At the southeastern corner of the regional study area, the Culebra underlies a single anhydrite. The lower Tamarisk anhydrite has pinched out or perhaps combined with the upper Tamarisk anhydrites. This relationship on the Central Basin Platform is similar to that north of T15S.

The eastward extent of the Culebra has not yet been determined in this study, but the Culebra appears to be thinner (about 10 to 15 ft; 3 to 4 m) over the Central Basin Platform. A few of the available logs suggest the Culebra becomes sulfatic and combines with the upper Tamarisk anhydrite in the northeastern part of the study area.

4.2.3 Tamarisk Member

The Tamarisk has a maximum thickness of about 270 ft (82 m) in the region (Fig. 4.9), while in the site area it is commonly about 90 ft (72 m) thick. The difference is mainly attributable to a thick section of halite within the Tamarisk depocenter (Fig. 4.9).

The organic-rich carbonate and clay bed immediately overlying the Culebra has good continuity within most of the region. It varies locally in

thickness and may also be absent in a few wells (Fig. 4.3 - 4.6). At this time, no apparent trend in either thickness variations or rare absences of the bed has been observed.

The lower anhydrite of the Tamarisk is generally about 20 to 25 ft (6 - 6.7 m) thick in R32-34E. It thins away from this zone and disappears entirely north of the study area. Within the thicker zone, the unit is divided by a clastic, and probably carbonate-rich, zone into two beds approximately equal in thickness (Fig. 4.10). The separating bed is considered to be the lateral equivalent of a persistent thin claystone observed in shafts, some cores, and most logs. The clastic/carbonate bed is 5 to 10 ft (1.5 - 3 m) thick in parts of the area where the anhydrite is thickest. Eastward, onto the Central Basin Platform, only about 10 ft (3 m) of anhydrite, undivided by other beds, is usually present. It appears that the upper part of the unit pinches out depositionally toward the east and northeast. Local variations, such as the lack of this anhydrite bed immediately north of the site center (WIPP 19), have not been demonstrated on the regional scale.

The beds between the anhydrites of the Tamarisk are laterally traceable, but are among the most variable lithologically in the Rustler. Within the region, the beds vary from 0 to about 200 ft (0 - 61 m) thick. Its thickest area is east of the site, along the Delaware Basin margin and on the Central Basin Platform. The beds consist largely of halite where they are thickest. The interbeds thin to the north, west, and south (Fig. 4.3 - 4.6, 4.11), and are dominantly clastics when less than 20 to 30 ft (6 - 9 m) thick. North of R18S, this unit may be entirely missing, as the Culebra appears to underlie the upper Tamarisk anhydrite or even the Magenta (4.2.2). Clastic zones in the Tamarisk are also generally traceable laterally within parts of the halite unit; in some areas southeast of the site, halite clearly surrounds a clastic or mudstone unit (e.g., C04, Fig. 4.10; Fig. 4.5).

A polyhalite or polyhalite/anhydrite bed is associated with the halite between the two sulfates of the Tamarisk. This bed, which occurs along the eastern part of the WIPP site, is very distinct because of the high natural gamma and associated high acoustic velocity and/or density (Figs. 4.2, 4.10). The polyhalite exists within the Delaware Basin as well as on both the Central Basin Platform and Northwest Shelf areas. Within the Tamarisk depocenter, it maintains a rather constant position above the lower anhydrite

of the Tamarisk, but its position is more variable with respect to the upper anhydrite. Where halite is thickest in this member, the polyhalite is about 100 ft (30 m) below the upper anhydrite. As this halite thins, the polyhalite approaches the upper anhydrite base, and, in T25S, R33E for example, the polyhalite immediately underlies the upper anhydrite of the Tamarisk without any evidence of intervening halite or clastics (Figs. 4.3, 4.5, 4.6). Where this occurs, the polyhalite may be underlain either by halite or by clastics overlying halite. Snyder (1985, p. 4) reports "...that no polyhalite is present where all halite has been removed from the Tamarisk Member".

This marker is important evidence of the lateral depositional variations within the Delaware Basin during this depositional episode. Polyhalite overlies halite or halitic units east of the WIPP site. Polyhalite also overlies clastic zones (mudrocks) in several boreholes around the margins of the halitic areas. The clastics are lateral equivalents to the halitic zones. This relationship of polyhalite over clastics indicates that solution did not remove halite from the clastics after formation of the polyhalite, or the polyhalite would have been dissolved. Polyhalite is very soluble, and it is usually considered a secondary or diagenetic mineral.

Through much of the basin area east of the WIPP site, polyhalite underlies a thick, relatively pure halite that laterally thins and disappears. In several boreholes around the margins of this halite lens, polyhalite directly underlies anhydrite. There is no log evidence of either clastics or erosional plane between polyhalite and anhydrite in these holes. If there is any "dissolution residue" present in these holes, it would have to be anhydrite in good contact with the overlying anhydrite. The presence of the polyhalite indicates that any removal of halite (laterally equivalent to the halite lens) must have taken place before formation of the polyhalite.

When did the polyhalite form? There is no direct evidence. Reasoning suggests it formed early, perhaps nearly coeval with the original sulfate (assuming this polyhalite is not primary). As the polyhalite thickness is about the same whether it underlies anhydrite or halite, it is unlikely that the polyhalite originated as a replacement or alteration of anhydrite or gypsum by downward percolating fluids. Within the basin, under the halite lens, polyhalite is unlikely to have formed from solutions percolating downward through much halite as permeability is plugged quite early

(Lowenstein, 1987) and the halites indicate no diagenetic alternation by potassium-rich solutions (no increase of natural gamma). If polyhalitization was driven by brines from the underlying zones, these fluids passed equally effectively through halitic and clastic zones. There is no gamma log evidence of alteration by potassium-rich solution in halitic zones, and they are usually plugged very early.

The polyhalite within the Tamarisk is present in locations where it limits the timing of any removal of halite from adjacent units. Halite is not believed to have been dissolved from any zone adjacent to extant polyhalite since polyhalite formed. Though the absolute age of the polyhalite is not known, the polyhalite occurs in areas where adjacent halites should show very little permeability to brines that would alter original sulfate minerals to polyhalite. The polyhalite is thought to have formed very early, showing in its lateral extent and relationships effects of the basin margins and limiting the timing, at least, of any dissolution of halite in clastic units laterally equivalent to halitic zones.

Two thin anhydrites (possibly mixed anhydrite and halite or carbonate) occur within the halite, above and parallel to the polyhalite (Fig. 4.10). These two anhydrites are easily traceable outside the Delaware Basin, providing evidence of continuity of both depositional process and lithology for this unit (Fig. 4.3, 4.5, 4.6). As the halite above these thin beds thins and disappears laterally, the halite between these two beds does not thin. The thin anhydrites in turn disappear or merge with the upper anhydrite of the Tamarisk. It is possible these two beds are successively truncated by the upper anhydrite of the Tamarisk, but borehole well log locations are not appropriately located to resolve this question.

The upper thick anhydrite of the Tamarisk is persistent throughout the study area. It is persistent beyond the extent of the Culebra and lower part of the Tamarisk. This anhydrite usually varies moderately in thickness, as where the polyhalite merges with the base of the anhydrite. Laterally, the high gamma spike of the ^{40}K in the polyhalite disappears, and the thickness of anhydrite is similar to the combined thickness of anhydrite and polyhalite. Local thickening in the site area has also been noted, as in WIPP 13. West of the site area and in parts of the site area, Snyder (1985) attributes thickening to gypsification and the attendant volume increase.

Within the upper Tamarisk Member anhydrite (A3 of Ch. 5), laterally

continuous features occur in logs throughout the basin (Fig. 4.12). From core descriptions (Ch. 5), lithologies and sedimentary features from this anhydrite in the site area can be grouped into broad units. A three part division of the anhydrite core features appears to correspond well to the geophysical log features (Fig. 4.12).

Within the upper Tamarisk anhydrite, the basal log unit displays breaks in the acoustic velocity attributed mostly to carbonate; there is a probable higher organic content and a few thin argillaceous intervals. This unit may be as much as 40% of the bed thickness, though it is more commonly 25-30%. On many logs, natural gamma is noticeably higher in this lower part of A3 than in the upper parts. This corresponds to the carbonate plus organic/argillaceous content apparent in some cores. Within the site area, decreased neutron activity from this part of the sulfate bed has been attributed to gypsification (Snyder, 1985). Gypsification of these units can be demonstrated petrographically, but it is an inadequate explanation for the observations as similar log features occur throughout the basin. Both organic and clay content also affect neutron log signatures in a way similar to hydrated minerals. And this lower unit is clearly discernible in the basin overlying halite. That is inconsistent with the hypothesis of gypsification by circulating water removing halite.

The middle log unit of the upper Tamarisk anhydrite generally has a very low background natural gamma and a consistently high acoustic velocity, indicating high purity anhydrite. This log unit is about 35-40% of the thickness of A3. Within cores, this segment corresponds to a zone of anhydrite pseudomorphs and crushed pseudomorphs after gypsum growth textures as well as crushed nodular textures. Only the great continuity of this subunit can be observed in the logs, not the presence of specific textures.

The upper subunit of A3 is thinner than the lower subunits, usually representing about 20-25% of A3. Natural gamma activity is usually slightly above, and acoustic velocity is more variable than, the middle subunit. A persistent, thin zone of lower acoustic velocity is taken as the base of this subunit. The cores corresponding to this zone are dolomitic and also partly nodular. The transition to Magenta is gradual within both cores and log signatures over a few ft (1 - 2 m).

4.2.4 Magenta Dolomite Member

The Magenta is a carbonate sandwiched between two anhydrite layers (Fig. 4.1, 4.2) and it is marked by a characteristic high gamma associated with relatively low densities and acoustic velocities. It can be traced throughout the study area (Fig. 4.3 - 4.6). The Magenta thins across the Central Basin Platform and may be absent or dominantly sulfatic along the eastern margin of the study area.

An outcrop of the Magenta from T17S, R28E, shows that the Magenta appears well-laminated from algal growth. The Magenta thins to the north and northeast of the site; there is little variation to the south and east in the study area. Within the site area, algal features appear near the base of the Magenta. Along the western edge of Nash Draw, algal structures are more common near the middle of the Magenta. Specific algal features are discussed in Chapter 5.

An isopach map of the Magenta is not presented. The thickness is not great, but the variability is significant. Normal contouring is not possible, nor is it seemingly fruitful.

4.2.5 Forty-niner Member

The sulfate beds of the Forty-niner are the most widespread units of the Rustler Formation. The upper sulfate is easily traced and is frequently called "first anhydrite" by oil companies working in the area. Though details have not been worked out, it appears that this unit may onlap older rocks (Salado?) to the north of the study area. The maximum apparent thickness of the Forty-niner is 104 ft (32 m) (Fig. 4.13).

The lower anhydrite of the Forty-niner maintains its thickness immediately north of the study area. The upper anhydrite thins by 50% or more by T8S and T9S. These units are consistently detectable near the Texas-New Mexico border this far north (T8-9S). To the west, the units are either eroded or thin to the point of not being consistently detected.

Between the two anhydrite beds is a bed of clastics and halite. In the shafts at the WIPP site, the clastic unit displays clear bedding and cut and fill, showing detrital origin. The halite is apparently restricted to the Delaware Basin proper from the eastern part of the WIPP site to the east and south. When halite is present in the halite/mudstone, it is present at the base. In some boreholes, this basal halite is overlain by a clastic bed or

alternating clastic-halite beds. The exception is in the southeastern part of the study area where borehole D04 (Fig. 4.5) shows halite sandwiched between possible clastic layers. The thickness of the bed without salt varies little over the study area, and it is traceable as far as the sulfate units. Its fullest extent has not been determined.

The upper anhydrite of the Forty-niner Member southeast of the site is interpreted to enclose a halite lens (Fig. 4.14, 4.6). The best evidence is in a borehole (B06) in Sec. 6, T24S, R34E, where the acoustic travel time indicates halite less than 10 ft (3 m) thick. The natural gamma is at background levels, consistent with halite. Several logs in the vicinity also show a distinct lowering of acoustic velocity, usually much less than halite acoustic velocities. As the gamma is not elevated in most of these logs halite is interpreted to be present. Acoustic logs are normally corrected for borehole diameter. It is believed that the low acoustic velocity in this zone is probably due to inadequate correction for highly enlarged borehole diameters caused by drilling with undersaturated fluids. A few logs indicate a modest increase in gamma, probably due to clay content.

About 10 ft (3 m) below the top of the upper anhydrite, many borehole logs exhibit a thin zone of increased natural gamma, accompanied sometimes by a slight decrease in acoustic velocity (Fig. 4.14). This zone is detectable mainly along the western and northern parts of the general Rustler depocenter, and it is probably indicative of increased carbonate/organic content. This zone in cores is generally laminar.

The upper contact of the Rustler is placed at the top of the upper anhydrite of the Forty-niner Member throughout the study area. As the bed is consistently present and only thins significantly well north of the main study area, there is no evidence of real unconformity at the contact within this area. There may be disconformity. The Dewey Lake Redbeds have been studied petrographically (Miller, 1966), and some sedimentary features are reported (Holt and Powers, 1984, 1986a). Its internal stratigraphic relationships and depositional environments remain to be determined (Schiel, 1987).

4.3 REGIONAL STRUCTURAL RELATIONSHIPS

The isopach map of the Rustler Formation (Fig. 4.15, 4.27), and those of members or parts of members (Fig. 4.7 - 4.9, 4.11, 4.13, 4.22 - 4.26),

consistently indicate a general depocenter east and south of the site. Perhaps the most significant observation is that the depocenter includes areas behind the Capitan reef, on the Central Basin Platform or adjacent Northwest Shelf. The data are few close to the reef, but it appears that the Rustler does not diminish in thickness over the reef, indicating a common depocenter and that the reef and former basin margin affected deposition of the Rustler little, if at all. Preliminary data, beyond the area of study, indicate that the Rustler is considerably thinner outside the map area. There does not appear to be a secondary or equal depocenter in the region. In the Midland Basin, the Rustler is thinner and clastic-dominated.

All of the structure contour maps, from base to top (Fig. 4.16-4.19, 4.28 - 4.31), of the Rustler show similar features. The depocenter area from isopach maps also is a structurally low area. A basin form trends from south to north, apparently turning to the northeast to cross the Capitan reef margin. This structure is considered to have developed at an equal rate or pace with the Rustler, as it coincides with the depocenter for all of the members.

Superimposed on the basin structure are two important post-Rustler structures. A fault, downthrown on the west side, is interpreted to account for the large structural differences on various Rustler beds along the approximate western margin of the Central Basin Platform. This fault trends slightly east of south, from the northern edge of the map toward the southeastern map area. Its southern extent in the Rustler is indeterminate based on the information available to us at this time. In addition, a significant structural low exists west from this fault to the approximate area of the Capitan reef. The western margin of this wedge-shaped structural low could be a fault or a monoclinal fold. It is left as a fold in the absence of closer-spaced data demanding a fault interpretation.

In addition to the fault and the fold, smaller structural lows and highs exist. In addition to the low coinciding with the depocenter, a conspicuous high exists along the eastern margin of the fault in the area of T19-20S, R36-37E. North of this bulge, the structure on both sides of the fault is reversing. No simple interpretation of the fault mechanism exists, though adjacent strike-slip faults have been known to produce adjacent highs and lows across faults (R. Dyer, pers. comm.). Hills (1984) infers two parallel right-lateral strike-slip faults underlying the faulted Rustler section on

Precambrian basement. It is not clear if there is a relationship between faults in the Rustler and this much earlier trend.

Aside from the form of the deformation of the Rustler in this area, it is important to note that the deformation clearly indicates post-Rustler tectonics along the Central Basin Platform margin, later than previously suspected (Hills, 1984). Continuing study of the Dewey Lake Redbeds (Schiel, 1987) should clarify the extent of deformation during or after the Dewey Lake.

5.0 RUSTLER SEDIMENTOLOGY

The Rustler sedimentology is described in considerable detail from shafts and cores (Fig. 5.1) because some features have not been described previously in the literature and because prior core descriptions include few sedimentary features. The sedimentary structures and lithologic features and their associations are the principal framework for interpreting depositional environments. The depositional environments for the Rustler, in turn, will provide a framework for interpreting the degree to which the absence of certain evaporite minerals is due to non-deposition or syngenetic dissolution versus epigenetic dissolution.

5.1 UNNAMED LOWER MEMBER

The unnamed lower member of the Rustler Formation is by far the most lithologically variable stratigraphic unit within the Rustler (Figs. 5.2a and b). Rock types vary laterally within the unnamed lower member, and are obvious even within the limited core study area. In the WIPP site area, the unnamed lower member consists dominantly of siliciclastic rocks interbedded with lesser amounts of halite and sulfate.

5.1.1 Rustler/Salado Contact

In the WIPP site area, the Rustler/Salado contact is arbitrarily assigned to the base of a thin, stratigraphically distinct sulfate unit immediately underlying siliciclastics of the lower Rustler. Although this unit is more genetically related to Salado deposition than to Rustler, it is used in cores and shafts for its stratigraphic continuity. This sulfate unit consists of anhydrite and occasionally, polyhalite. It commonly is laminated and can show textures similar to swallowtail gypsum. The lower part of the sulfate is generally argillaceous, while the upper portion is commonly free of clay. Both the upper and lower contacts of the sulfate are sharp and readily distinguishable.

Within Nash Draw, the Rustler/Salado contact is often disturbed and the lower portion of the unnamed lower member is brecciated (Pl. 1). Where this is the case, the Rustler still retains a general sense of stratigraphic organization and the general location of the lower contact can be inferred. The lower contact area is distinguished by an upward matrix color change from reddish-brown to gray. The contact between the Rustler and Salado in cores

from Nash Draw is arbitrarily placed at the highest occurrence of gypsum clasts in a reddish-brown matrix. These clasts are assumed to be the brecciated remnant of the lowermost sulfate assigned in cores and shafts to the Rustler (see above).

Two or more reddish-brown clastic units commonly overlie the sulfate unit. The thickness of the combined reddish-brown zone rarely exceeds a few feet (about 1 m). The units are usually mudstone or siltstone and are frequently separated by an erosional surface exhibiting several feet (1 - 2 m) of relief (Holt and Powers, 1984, 1986a). Soft sediment deformation enhances erosional relief on the contact and modifies bedding adjacent to the erosional surface. In both the waste handling and exhaust shafts at the WIPP site and in several nearby cores, the erosional surface is capped by a siltstone and/or sandstone pebble/cobble conglomerate containing fossil bivalve fragments (Holt and Powers, 1984, 1986a). The lowermost units are commonly sulfatic and can exhibit tabular mudstone clasts flattened parallel to bedding. The lowermost unit of WIPP 19 exhibits cracks that may be due to desiccation. In some cases, the bedding in these lower units becomes more distinct upward. The upper unit(s) (those above the sharp, undulatory contact marked by a conglomerate) commonly contains coarser-grained clastic material. Near the top of the reddish zone, gypsum or anhydrite nodules are abundant. Thin laminations are common throughout the reddish-brown zone and often show cross-cutting relationships. Cross-laminations are rare. The size of sedimentary structures generally decreases upward.

The bedding is partly modified by soft sediment deformation, though this is less intense and less common upward; it is most common above and below the erosional surface. The upper contact of this basal zone is marked by a color change from reddish-brown to gray and is erosional in many cores.

5.1.2 Clastic-Bioturbated Interval

The gray zone in the lower part of the unnamed lower member contains interbedded mudstone, siltstone, and locally very fine sandstone. The coarser grain sizes occur at the base and near the top of the gray zone, and these coarser grained beds are well lithified. The middle part of the gray zone within the WIPP area is soft and slightly argillaceous. This middle interval becomes more calcareous and less clastic to the south (borehole H-12). Anhydrite or gypsum nodules are abundant near the base of the gray

zone; nodules occur near the top of the unit in a few cores (e.g., DOE 2). Horizontal to subhorizontal stratification and cross-stratification are locally common and some show the effects of soft sediment loading. Light to dark gray mottling results from bioturbation. Stratification is poorly preserved in mottled zones, and is very irregular, wavy, and discontinuous. Subhorizontal to subvertical burrows, about 1/4 to 1/2 inch (6 to 12 mm) diameter, are very common throughout the entire interval and they are observed cutting across poorly preserved strata. Casts and molds of fossils, mostly bivalves, were preserved in the bioturbated interval of WIPP 19. Halite-replaced fossils and fossil fragments occur through the equivalent section in H-12. Possible coated grains and oolites were found in the lower calcareous portion of H-12 . Near the top of the bioturbated zone, the grain size increases as does the degree of preservation of stratification. The upper contact is gradational and is usually assigned to the first occurrence of a reddish or reddish-brown interbeds.

The equivalent to the lower bioturbated zone, in Culberson County, Texas, consists of siltstone, calcareous siltstone, and carbonate. The lower zone commonly exhibits thin, parallel laminae which can be disrupted locally and display some wavy to lenticular bedding. Bioturbation and burrowing are common within the upper dolomitic equivalent to this upper bioturbated zone observed in cores from Texas.

5.1.3 Clastic-Transition Interval

A color transition zone of alternating gray to reddish-brown and brownish-gray siltstone and very fine sandstone overlies the gray zone (clastic bioturbated interval). Gray is dominant near the base, while reddish-brown predominates near the top. Well preserved laminations, local cross-laminations, and rare erosional scour and fill structures characterize this interval. Within the exhaust shaft, interpretable paleocurrent directions mostly trend toward the south. Burrows are common near the base, but do not occur higher in the section. Subhorizontal laminations and cross-laminations become more distinctive upward as the grain size increases. In some cores, the upper portion exhibits gray, possibly anhydrite-rich, interbeds and very small clasts or nodules of gypsum or anhydrite. In general, the upper 3 to 4 ft (0.9 - 1.1 m) of this unit exhibits wavy to contorted and convoluted to lenticular laminations. Soft

sediment deformation is common in this interval. In the upper one to two ft (30 - 60 cm), the sulfate content increases upward, and displacive halite crystals occur in some cores. The upper contact is gradational, showing a marked increase in the content of sulfate.

A gypsiferous or anhydritic sandstone, between one and two ft (< 1 m) thick, tops the transition zone. It contains gray to dark gray interbeds and a few reddish-brown interbeds. The unit is microlaminated to thinly laminated, convoluted to contorted, and was deformed as a soft sediment. Structures interpreted to be either fluid escape structures or polygonal cracks are found consistently in this interval. A nodular to somewhat enterolithic texture marks some interbeds. The upper contact of the sulfatic bed is sharp to gradational.

5.1.4 Halite/Mudstone Interval 1 (H-1/M-1)

In the WIPP site area, a zone containing halite (H-1) and laterally equivalent mudstone (M-1) overlies the sulfatic zone at the top of the clastic-transition interval. The halite can be subdivided into three distinct intervals. The lower (H-1a) and the upper (H-1c) intervals consist primarily of a mix of clastics and halite. Relatively clean halite and traces of sulfate characterize the middle interval (H-1b). As a whole, the first halite zone (H-1) in the unnamed lower member varies in thickness from 34 ft (10 m) to a maximum of 50 ft (15 m) in H-12 and 48 ft (14.6 m) in AEC 8. Where mudstone is laterally equivalent to halite, the mudstone interval can be subdivided into an upper and a lower part separated by one sulfatic interbed. The overall thickness of this interval is about 19 ft (5.8 m) in those cores where the lower contact was cored. The thickness of the upper half varies between 3 and 6 ft (0.9 - 1.8 m).

5.1.4.1 Lower Halite Bearing Zone (H-1a)

In most WIPP cores examined, the sulfatic unit is normally overlain by the first halite bearing zone (H-1a) within the Rustler. This interval thickens to the south and east, reaching the thickest point observed in core at H-12. The basal part of H-1a consists primarily of slightly halitic siltstone which may be sandy in some places. The siltstone is commonly microlaminated to laminated and can be wavy to slightly contorted. White, anhydritic laminae and zones are commonly wavy to distorted. At H-12,

sulfate is more prevalent near the base of this zone than in other boreholes. A few small incorporative halite crystals occur near the base of the zone, and, in general, the halite content increases upward. Halite crystal size varies; some incorporative crystals are up to one inch (2.5 cm) on a side. A halite-filled prismatic crack (possibly due to desiccation) occurs near the top of H-1a in core from the borehole WIPP 19. The upper portion of the first halitic zone (H-1a) is dominated by clastics and anhydrite-rich laminae and zones.

5.1.4.2 Middle Halite Bearing Zone (H-1b)

The lower halite-bearing zone (H-1a) is overlain by a much purer halite interval (H-1b) that varies in thickness from 5 ft to 8 ft (1.5 to 2.4 m) in WIPP cores. Sulfate (anhydrite to gypsum) occurs as stringers and laminae to thick beds with thinly laminated internal structure. Irregular zones of halite occur within some of the sulfates. Anhydrite is more common near the base and top of H-1b. Thin laminae to laminae of clastic material separate beds of halite. The halite is medium to coarsely crystalline, clear to orange tinted with traces of intercrystalline and interstitial sulfate and clastic material and thinly to medium bedded. Vertically oriented, elongate crystals due to competetive growth (Shearman, 1978) occur locally, some exhibiting zones of fluid inclusions. Cloudy halite, due to fluid inclusions and indicating primary origins, is not abundant, but it does occur.

5.1.4.3 Upper Halite-Bearing Zone (H-1c)

The middle halite zone (H-1b) is overlain by an upper, more clastic-dominated halite-bearing interval (H-1c) that varies from 11 to 18 ft (3.4 to 5.5 m) thick. It is thinnest in the area of DOE 2 and WIPP 34 and thickens to the east and south with the thickest section at AEC 8 and the next thickest interval at H-12. The transition from H-1b to H-1c is marked by a sharp increase in the clastic content. The clastic content in H-1c fluctuates, with maxima near the middle and top of the unit. The clastic material consists mostly of siltstone and in H-1c is typically reddish-brown with some greenish-gray reduction spots and zones and white to gray sulfatic zones. The uppermost bed of H-1c is an anhydritic mudstone which exhibits thin laminae, sulfate nodules, and locally, clasts of mudstone.

5.1.4.4 Textures and Fabrics in Clastic-Rich Halite

The fabric of these halite-bearing rocks is quite variable; the most notable variations of fabric are type and amount of halite. Incorporative halite crystal fabric varies from isolated individual crystals (Pl. 2), to tightly packed locally touching crystals (Pl. 3). Interstitial matrix boundaries vary from planar to irregular. Displacive/incorporative overgrowths on halite crystals occur along the contact between aggregate halite and matrix material. Skeletal crystals occur in more clastic zones. Zones of partly incorporative halite crystals occur in distinct zones at the top of, and parallel to, well-defined clastic interbeds. Many of these crystals exhibit euhedral crystal faces oriented upward. Some zones of halite crystals display irregular to poorly defined bases with well defined upper boundaries. In these cases, planed-off crystals mark the upper boundaries. Some of these surfaces exhibit euhedral overgrowths oriented upward. Halite also occurs in zones and pods containing interlocking mosaics of crystals with some interstitial clastic material or sulfate (Pl. 4). These pods may be surrounded by clastic material or argillaceous halite. Where halite is abundant, crude stratification is common. Channel forms were reported in both intervals in the waste handling shaft and the exhaust shaft (Holt and Powers, 1984; 1986). These channel forms may be filled with dominantly clastic material or with halite.

The fabric of the rock is also controlled by the distribution of the clastic material. Clastic material occurs as matrix, intercrystalline material, interstitial material, and isolated pods or blebs within a dominantly halite rock. In most cases, the clastic material is relatively structureless, exhibits wavy to contorted to smeared thin laminae to thin beds, or contains smeared/deformed intraclasts showing no evidence of transport (Pl. 5). Some laminae surrounding incorporative halite crystals are contorted or displaced by those crystals.

5.1.4.5 Mudstone Interval (M-1)

Mudstone, claystone, and minor amounts of siltstone (M-1) are laterally equivalent to the halitic zone H-1. Where the lower contact was cored, this zone rests conformably upon the transition zone. This zone (M-1) is preserved in WIPP cores from Nash Draw and in the core from WIPP 30. M-1 is subdivided into an upper and a lower part by a medium to thick bed of

sulfate. The thickness of the lower part can not always be determined as the lower contact with the transition zone is not always preserved, or may be difficult to recognize, in the core. The upper part of M-1 varies in thickness from 3 to 6 ft (.9 to 1.8 m).

The mudstone commonly exhibits a smeared intraclast/laminae texture similar to that seen in halite clastic rocks. This texture consists of deformed or smeared intraclasts showing no evidence of transport and in some cases, irregular, poorly preserved, discontinuous laminae. The intraclasts and laminae appear to be squashed together while soft (Pl. 6, 7). Smeared laminae and intraclasts may be well preserved and distinct. In other cases, indistinct mottling is present. The mudstone may be structureless where the grain size is more uniform. M-1 has irregularly distributed and oriented slickensides. A few small nodules or clasts of gypsum and anhydrite occur within M-1. Some cores of this interval have a characteristic lumpy or corrugated surface indicative of the preferential removal of matrix or pseudomatrix by drilling fluids during coring. A few nodules and clasts of gypsum and anhydrite occur within M-1.

The lower contact of M-1 with the transition zone is generally well preserved. The mudstone (in some cores siltstone or very fine sandstone) is ordinarily thinly laminated to laminated within the first few ft (1 - 2 m) of the lower contact. The zone may also be slightly gypsiferous. The laminated zone is overlain by a zone exhibiting the smeared intraclast/laminae texture with varying amounts of clasts versus laminae. Zones containing well preserved (i.e., not disrupted) depositional fabrics occur in the lower part of M-1 and can bound zones exhibiting the smeared intraclast/laminae texture. Smeared intraclast/laminae textures are more abundant upward within the section and dominate the textures in the upper few feet of the lower part of M-1. Near the base of the lower part of M-1, gypsiferous interbeds may occur. Near the top of the lower part of M-1, small nodules of gypsum/anhydrite may occur. A medium to thick bed of mostly gypsum separates the upper part of M-1 from the lower part. The gypsum is thinly laminated to laminated and may locally exhibit swallowtail structures or nodules. The strata within the gypsum may be disrupted near the base of the bed. The gypsum contains laminae or very thin interbeds of claystone in some cores. The upper part of M-1 principally consists of claystone exhibiting the smeared intraclast/laminae texture. It is mostly reddish-brown with gray

smeared intraclasts of siltstone. The upper contact of M-1 is sharp to gradational with the overlying gypsum.

Within Nash Draw, portions of M-1 as well as most of the entire Rustler are disturbed and brecciated. In some cores (e.g., WIPP 25, WIPP 28, and WIPP 32), subangular to subrounded clasts of sulfate may be found near the top of both the upper and lower parts of M-1. In some cases, these gypsum clasts are derived from gypsum fracture filling (Pl. 8). Often these clasts are associated with breccia clasts and clay filled fracture-bounded blocks of mudstone exhibiting the smeared intraclast/laminae texture (Pl. 9). Some blocks are bounded by possible clay skins. Some zones exhibit well preserved stratification, now dipping. M-1 is not the only stratigraphic unit disturbed. In all cases, when M-1 is disturbed both the overlying and underlying rocks exhibit similar disturbance.

5.1.5 Anhydrite (A-1)

The first major sulfate unit of the Rustler overlies the halite zone and consists of anhydrite and gypsum. It varies in thickness from about 7 to 10 ft (2.1 to 3 m) to a maximum of 13 ft (4 m) in cores from WIPP 25 and WIPP 29. The increase in thickness in the Nash Draw boreholes is probably attributable to local dip (up to 25°) and lengthening of the section due to downdropping, rotation of blocks, and brecciation within the section. The core of WIPP 32 exhibits only broken rotated blocks in this interval. The section there is considerably thinner than in other Nash Draw holes, as a block probably representing the lower portion of A-1 occurs 5 ft (1.5 m) below the base of the anhydrite surrounded by clastic matrix material.

The lowermost few inches (cm) of this bed appear nodular to enterolithic. Much of the section is thinly laminated to laminated. Laminae are commonly slightly wavy and some may be slightly contorted. A few stylolites occur within the laminated portion of A-1. Halite and anhydrite pseudomorphs after gypsum swallowtail crystals 1/4 inch to 6 inches (6 mm - 1.5 cm) high, are locally common in A-1 (Pl. 10). Swallowtails are most abundant and largest in the lower 2 to 3 ft (0.6 to 0.9 m). A second zone of swallowtails occurs near the middle of A-1 in several cores. It, too, may show an upward decrease of crystal size. A-1 in some of the WIPP cores exhibits the collapsed pseudomorph texture described elsewhere in this report. The upper 1 to 2 ft (30 to 60 cm) of A-1 is a stratigraphically

persistent pink-colored that shows in some cores a nodular texture, irregular/discontinuous laminae, and/or disturbed stratification/nodules. Clay content increases in the uppermost few inches (cm) of A-1. The upper contact is slightly gradational and irregular with the transition from sulfate to clastic material occurring over 1 to 2 inches (2.5 - 5 cm).

5.1.6 Mudstone/Halite Interval 2 (M-2/H-2)

A clastic zone (M-2), above A-1 in the WIPP site area, is partially equivalent to a halite-bearing interval (H-2) as much as 50 ft (15 m) south and east of the WIPP site center (Figs. 4.5, 4.6). The halite-bearing equivalent of this zone is not contained within any WIPP cores. However, its presence to the east is confirmed by both the cuttings and geophysical logs from the borehole P-18; the halitic zone is about 30 ft (9 m) thick there. The upper portion of interval M-2/H-2 has a widespread and characteristic gamma log signature regardless of the underlying material. The geophysical log signature suggests that this upper unit is generally argillaceous; it is up to 20 ft (6 m) thick east of the site (Figs. 4.5, 4.6). In the vicinity of the WIPP site, the thickness of M-2 varies slightly but averages about 10 ft (3 m).

In cores M-2 can be subdivided into two lithologically distinct zones: an upper gray zone and a lower reddish-brown zone. The gray upper zone is usually only about 2 ft (60 cm) thick in cores while the lower reddish-brown zone is about 7 to 8 ft (2.1 to 2.4 m) thick.

The reddish-brown lower zone commonly consists of mudstone and siltstone. It may be either calcareous or gypsiferous or both. Interbeds of gypsum, argillaceous gypsum, and carbonate are common. These interbeds and other distinct color changes within the clastic material have been reported as continuous, albeit undulatory, around the circumference of two shafts at the WIPP site (Holt and Powers, 1984, 1986a). Small clasts/nodules of gypsum up to 2 inches (5 cm) in diameter exist near the base of the lower zone. Sediment-incorporative gypsum crystals are found locally throughout the lower zone (Pl. 11). They are often euhedral to subhedral with a stubby-equant to bladed, or rarely stellate, habit. The clastic sediment in some cores contains gray zones or greenish-gray reduction spots. It can be structureless, or it can exhibit irregular and discontinuous laminae and thin laminae. Angular to sub-rounded clasts of siltstone and mudstone are

abundant and are often associated with zones exhibiting a smeared-interclast-laminae texture. Slickensides are common in the lower interval. Thin sections from this interval reveal oriented clay skins and possibly cutans (Pl. 12). In the core of WIPP 25, dolomite clasts believed to have originated from the overlying Culebra occur in this interval and are intermixed within the mudstone.

The upper gray zone is ordinarily about 2 ft (60 cm) thick and it consists of calcareous claystone and mudstone. The contact between the upper gray and lower reddish-brown zones is distinct. It can be structureless or micro to thinly laminated with flat to wavy strata. Light gray to tan carbonate clasts are abundant in this interval and vary in size from coarse sand-size to pebble-size (Pl. 13). These clasts can be well rounded to angular, and many were deformed while soft. In most cases, clasts are overlain by well preserved stratification. This interval locally exhibits slickensides. The upper contact with the Culebra Dolomite shows no clear break in deposition. The upper contact is undulatory in the exhaust shaft at the WIPP site (Holt and Powers, 1986a) and shows the effects of differential loading and subsequent settling of the Culebra. Similar features exist along this contact in outcrops east of Artesia, New Mexico (T17S, R28E). The upper interval is poorly preserved and/or deformed in some of the Nash Draw cores.

Holt and Powers (1986a) report a disrupted zone (discussed below) at the upper contact of this interval in the exhaust shaft at the WIPP site.

5.2 CULEBRA DOLOMITE MEMBER

The Culebra Dolomite Member of the Rustler Formation is the lowermost of two areally extensive dolomite units within the Rustler. The thickness of the Culebra varies from 20 to 30 ft (6.1 to 9.1 m) within the cores described (Figs. 5.4 and 5.5). The Culebra consists mainly of micritic dolomite.

The Culebra often cores poorly because of fractures. Holt and Powers (1986a) report that the Culebra is extensively fractured in the exhaust shaft at the WIPP and that mapping units were selected partly, if not wholly, on the basis of fracture patterns. Holt and Powers (1986a) also note an apparent relationship between the degree of induration, competency, and fracture patterns of mapping units and the amount of clay-rich interbeds and the apparent clay content of the dolomite. They generally correlate the abundance of broken, fractured beds and the overall content of clay.

The lowermost foot (30 cm) of the Culebra locally is thinly laminated to laminated with alternating light and dark brown laminae. This zone is rarely preserved in core. Within the exhaust shaft at the WIPP site, Holt and Powers (1986a) report that this zone is extremely undulatory and locally dips up to 45°. Deformational space problems manifest themselves as locally contorted and displaced laminae. Holt and Powers (1986a) report that this zone is brecciated in the vicinity of one of the major downwarps of this lowermost Culebra unit. The breccia consists of roughly 80% angular to subangular clasts of dolomite within a dolomite matrix. The units described and mapped within M-2 in the exhaust shaft parallel the lower contact of the Culebra. Directly below the downwarp and associated breccia, the upper units of M-2 are also downwarped and cut by the breccia. The middle and upper part of the Culebra is unaffected by the brecciation.

The bulk of the Culebra is microlaminated to thinly laminated. The strata may be flat to wavy to locally contorted and discontinuous. Portions of the Culebra appear macroscopically devoid of depositional fabric. The dolomite is mottled in some zones. With the exception of the upper and lower contact zones, there is very little variation of depositional sedimentary features throughout most of the Culebra.

The uppermost few inches to 1 ft (30 cm) of the Culebra often differs radically from the underlying dolomite. The gamma ray signature of this zone is unique and is present throughout the Delaware Basin (Ch. 4). Within the WIPP site area, this interval consists of waxy golden-brown carbonate, dark brown to black highly organic claystone, and locally coarser grained clastic material including siltstone. The interval exhibits microlaminated to thinly laminated strata that are usually subhorizontal, irregular, contorted on a fine scale, and discontinuous. Small gypsum nodules often occur flattened parallel to stratification. Holt and Powers (1984) report details of this interval in the waste handling shaft at the WIPP site. They describe moundlike or domal structures in this interval and assign a probable algal origin. Cornell (pers. comm., 1984) reported that material from this zone is rich in organic carbon.

Both open and filled porosity occur in the Culebra (Holt and Powers, 1984; 1986a). Gypsum is the major pore-filling mineral. Three porosity types were observed: vuggy porosity, intercrystalline porosity, and fracture porosity. Vuggy porosity varies in size from fractions of an inch to two

inches (up to 5 cm). Many large vugs are interconnected by fractures, and when unfilled, vugs and fractures commonly contain clay rims. When vugs and fractures are filled with gypsum, a portion of some vug-filling material may be optically continuous with adjacent fracture filling. Vug-filling gypsum is often polycrystalline, exhibiting two or more crystals with different optical positions. Twinning is common, and extensively twinned crystals may exhibit a somewhat undulatory extinction. Many filled vugs have one optically continuous, yet extremely undulose, crystal as a partial and imperfect rim with two other crystals constituting the bulk of the vug filling. Laminae often are terminated abruptly at the vug/dolomite contact. However, laminae in the dolomite also appear displaced around some vugs. Smaller vugs appear to have some depositional control, as they occur in distinct sub-horizontal zones.

Biogenic features have been observed in and reported from the Culebra at several localities, including the WIPP. Fossils in the Culebra were first reported by Donegan and DeFord (1950) and were studied further by Walter (1953). The authors have also observed gypsum-replaced bivalves in Culebra core from Texas. Some thin sections of the Culebra from WIPP 19 and H-12 contain fecal pellets and possible shell fragments. Burrows and mottling occur near the top of the Culebra in H-12. Holt and Powers (1984) suggest the organic-rich carbonate and clay at the top of the Culebra is algal in origin.

5.3 TAMARISK MEMBER

The Tamarisk Member of the Rustler Formation is divided into three parts: a lower sulfate (A-2), a middle halite/mudstone zone (H-3/M-3), and an upper sulfate (A-3) (Figs. 5.4 and 5.5). The Tamarisk thickens toward the south and east of the WIPP site. The Tamarisk within the WIPP cores described varies in thickness from 82 ft (25 m) at WIPP 19 to 121 ft (36.9 m) in H-12 and 120 and 119 ft (36.6 and 36.3 m) respectively in WIPP 13 and WIPP 25.

5.3.1 Anhydrite (A-2)

The lower anhydrite of the Tamarisk Member is an areally extensive unit. Several geophysical logs within the Delaware Basin of New Mexico indicate that A-2 is locally absent. This is also the case within the WIPP site area as A-2 is not present at WIPP 19. The maximum thickness of A-2 in cores is

21 ft (6.4 m) in WIPP 25. A-2 can be subdivided consistently into an upper and a lower part by a bed of mudstone. This mudstone bed occupies a stratigraphically distinct position and is areally extensive (Ch. 4). The lower part of A-2 varies in thickness within WIPP cores from a minimum of 6 ft (1.8 m) in the core of WIPP 12 to a maximum of 16 ft (4.9 m) in the core of WIPP 25. The average thickness of the lower part is about 9 to 10 ft (2.7 to 3 m). The upper part varies in thickness from 3 ft (0.9 m) at boreholes B-25 and H3-b3 to a maximum of 8 ft (2.4 m) at borehole H-11b3.

The sulfate consists of anhydrite in many cores but can be part gypsum. The most common sedimentary structure is stratification ranging from microlaminate to laminate. The strata are commonly wavy, may be locally contorted, or discontinuous, and in some extreme cases, can exhibit dipping strata (up to 80° in WIPP 13). The laminae consist of sulfate interbedded with carbonate and/or claystone. The strata locally become convolute to crenulate with a small wavelength and amplitude. Stylolites are locally common within the laminated parts of A-2.

Both anhydrite and halite pseudomorphs after gypsum swallowtail crystals occur within the laminated sulfate of A-2. They are most abundant in the upper part of A-2. Zones where the size of swallowtails decreases upward are common in the upper part of A-2. In H-12, a similar zone of halite pseudomorphs after gypsum swallowtail crystals overlies a core that clearly does not retain a swallowtail morphology. The basal part of this zone exhibits a "pile of sticks" morphology; the "sticks" are similar to the intercrystalline laminae-like inclusions preserved in large swallowtail crystals, but are not arranged in any pattern reflecting swallowtail morphology. The base of this unit is in turn overlain by clearly more regular and vertically oriented halite pseudomorphs after gypsum that are up to 3 inches (7.6 cm) high. These larger pseudomorphs are followed vertically by smaller pseudomorphs and thinner laminae. The laminae within this zone become more horizontal, and the halite pseudomorphs become better aligned upward. Because of the clearly gradational sequence of textures from "pile of sticks" to pseudomorphs, this "pile of sticks" texture is interpreted as crushed pseudomorphs.

The sulfate of A-2 can also be nodular, especially near the upper and lower contacts and near the claystone which subdivides the unit. These poorly formed nodules are distributed unevenly within argillaceous anhydrite.

Within an argillaceous zone that is laterally equivalent to the subdividing claystone of A-2, an irregular vertically-oriented prism crack occurs which is filled with less argillaceous gypsum. (This prism crack appears similar to desiccation cracks in other sediments.)

The basal contact of A-2 is gradational. In the core of WIPP 13 a deformed calcareous mudstone at the base contains clasts and interbeds of gypsum. The core of WIPP 25 exhibits zones of breccia clasts of gypsum contained within a clear gypsum cement. The upper contact of A-2 may be slightly brecciated and irregular, and fractures displacing strata locally occur in this stratigraphic position. A small prism-crack is developed in the core of H-12 at the upper contact of A-2 with H-3. The upper contact of this zone is extremely undulatory and erosional in WIPP shafts (Holt and Powers, 1984, 1986a).

5.3.2 Halite (H-3) and Mudstone (M-3)

An interval containing halite (H-3) and laterally equivalent mudstone (M-3) occurs above the lower anhydrite (A-2) of the Tamarisk Member. Only the core of borehole H-12 contains halite (H-3) in this interval. H-3 in the core of H-12 is 40 ft (12.1 m) thick. M-3 varies from 9 ft (2.7 m) in DOE 2 to 17 ft (5.2 m) in WIPP 19. The halite is subdivided into lower (H-3a) and upper (H-3b) units by an areally extensive sulfate bed composed of polyhalite in much of the region (see Ch 4). Where the interval H-3 is thinned, the sulfate commonly directly underlies the upper anhydrite of the Tamarisk Member. Where this occurs, the upper part of H-3 (H-3b) has pinched out leaving no evidence of a clastic-rich stratigraphic equivalent (e.g., H-12) or disrupted or interrupted section. The halite represented in the core of H-12 is the lower part of the halite interval (H-3a). West of H-12, the stratigraphic equivalent of H-3a thins considerably and consists of mudstone (M-3) in the remaining WIPP cores described. This interval (M-3) is usually overlain by a sulfate sequence similar to the sequence preserved in the interval overlying the halite interval (H-3a) at H-12.

5.3.2.1 Tamarisk Member Halite (H-3)

H-3 forms a lens-shaped body with its thickest area (207 ft; 63 m) located in T22-24S, R33-35E (Fig. 4.4). It is subdivided into a lower (H-3a) and an upper (H-3b) part by a 1 to 3 ft (0.3 to 0.9 m) thick bed of

polyhalite. The thicknesses over much of the study area of H-3a and H-3b vary independently of one another, and one may occur where the other does not. However, H-3a is the more laterally extensive bed; H-3b is laterally more confined and pinches out near the eastern margin of the WIPP area (Ch. 4). The only core containing any halite in this stratigraphic interval is from borehole H-12, and only part of the interval H-3a exists there.

The lower part of H-3 (H-3a) can be subdivided on the basis of geophysical logs into lower and upper clean zones (low natural gamma, not argillaceous) separated by a clastic-rich/argillaceous zone (Ch. 4). The upper clean zone is restricted to the Rustler depocenter of the Delaware Basin. The middle clastic-rich/argillaceous zone occurs at the top of H-3a around the margins of the depocenter and is generally thinner toward the center of the basin. The core from H-12 is complete through the stratigraphic interval between the lower (A-2) and the upper (A-3) anhydrites of the Tamarisk; within this interval at H-12, the upper clean zone of H-3a does not occur while both the lower clean zone and the middle argillaceous zones are present. The upper clean zone pinches out east of H-12. The sulfate unit which separates H-3a from H-3b is present at H-12 at the top of the halite interval (H-3a) and converges with the upper anhydrite of the Tamarisk (A-3) to the west.

The lower clean halite zone from H-3a in the core of H-12 is nearly pure halite. Halite crystals from this zone may be equidimensional and, rarely vertically elongate. Zones of cloudy halite occur but are rare. Clay and sulfate occur as minor intercrystalline material and irregular blebs. The halite is mostly thin to medium bedded with strata separated by irregular laminae of anhydrite or (rarely) claystone and thin color bands, usually brown from disseminated clay. The surfaces under both sulfate and claystone beds are marked by dissolution; small trough-shaped dissolution pits filled with claystone or sulfate also occur. Some erosional surfaces are marked by thin crusts of sulfate. Laminae of claystone are more abundant near the top of this zone.

The middle argillaceous halite zone of H-3a is the uppermost zone of H-3a in the core of H-12 as the upper clear zone pinches out east of H-12. The lower contact is gradationally overlain by increasingly argillaceous halite which is in turn overlain by halitic siltstone. The clastic content decreases dramatically above the halitic siltstone and then increases

upward. The upper contact is marked by a halitic, anhydritic claystone with deformed, discontinuous, irregular laminae and halite containing blebs of claystone. Planar halite crystal boundaries are not common through this interval as most crystals do not exhibit a cubic form. Some incorporative crystals of halite do occur. Smeared intraclast/laminae textures occur in clastic sediments. As the clay content decreases, the fabric becomes more irregular.

The polyhalite which is so continuous in the center of the basin (Ch. 4) directly underlies the anhydrite (A-3) with no clastic unit separating them, as is the case at H-12 (Snyder, 1987). The upper part of H-3 (H-3b) does not occur within the core of H-12.

5.3.2.2 Tamarisk Member Mudstone (M-3)

Mudstones occur within a rough ring around a regionally extensive lens of halite (H-3). Most of the cores fall into this ring. Lateral variations within this mudstone ring are evident in cores of this interval in the vicinity of WIPP. The Tamarisk Member mudstone (M-3) thickens and thins on a local scale, and some variations reflect a controlled areal distribution or pattern of occurrence.

The term mudstone, as used here, allows for a range of lithologies including claystone and siltstone. M-3 is sulfatic and somewhat calcareous. The interval is predominantly reddish-brown with an uppermost gray zone. The color relationship was described by Holt and Powers (1984, 1986a) in both the waste handling and exhaust shafts as a reduction/oxidation contact. The gray zone may have associated pyrite and/or marcasite (Holt and Powers, 1986a).

The contact of M-3 with the lower anhydrite of the Tamarisk (A-2) is sharp and very undulatory. This contact undulates over four feet in the waste handling shaft and three feet in the exhaust shaft, and it is erosional (Holt and Powers, 1984; 1986a) (Pl. 14). At WIPP 19, the lower anhydrite (A-2) does not occur; M-3 is thicker, and directly overlies the Culebra with a sharp lower contact.

Unmodified sedimentary structures indicating clastic transport are rare within M-3, although subhorizontal laminae do occur. The most common texture is the smeared intraclast/laminae texture. Soft sediment deformation is a common feature where stratification is preserved. As deformation becomes more extreme, soft sediment deformation grades into the smeared

intraclast/laminae texture. Some subangular to subrounded clasts of mudstone and siltstone are included. Where the grain size and the color is uniform, as in most claystone intervals, the rock may appear structureless. Many surfaces of unslabbed core of M-3 exhibit a corrugated or lumpy appearance. This is associated with the smeared intraclast/laminae texture and is caused by removal of less well indurated matrix and pseudomatrix material during coring. M-3 has many slickensides, and slickensides may show differing orientations within several inches (cm).

Some sulfate occurs in M-3 as cements, incorporative crystals, gypsum pseudomorphs after anhydrite nodules, nodular anhydrite pseudomorphs after gypsum crystals, angular to subrounded clasts, local fibrous gypsum fracture fillings and overgrowths on detrital gypsum grains (Pl. 15). Incorporative gypsum crystals may be lenticular, subhedral, or euhedral, and both isolated crystals and stellate aggregates are common. Incorporative gypsum occurs in the following boreholes: WIPP 30, WIPP 34, WIPP 13, WIPP 33, DOE 2, AEC 8, and WIPP 12. Nodules and clasts of gypsum may be disseminated through M-3 but most commonly occur near the base (Holt and Powers, 1984; 1986a). Fibrous gypsum fracture fillings are locally common within M-3 and in the shafts (Holt and Powers 1984; 1986a); several generations of fracturing and subsequent filling are evident. The fractures may exhibit arcuate patterns possibly parallel with zones exhibiting slickenside partings. The fibrous fillings within fractures are variably oriented with some exhibiting a perpendicular relationship to the wall rock while others have a tilted to sigmoidal morphology.

The core of WIPP 19 is unique through this interval as the lower anhydrite of the Tamarisk Member (A-2) does not occur and the clastic rocks of M-3 directly overlie the Culebra Dolomite. The organic-rich stromatolitic zone at the top of the Culebra is overlain by smeared irregular strata and rip-up clasts. A thinly laminated claystone above the clasts is in turn overlain by deformed and contorted gray laminae. A claystone and siltstone clast conglomerate follows vertically the contorted laminae (Pl. 16). This clast-supported conglomerate consists of subangular to rounded granule- to pebble-sized clasts of gray and reddish-brown siltstone and rare clasts of gypsum. The average clast size appears to decrease upward. Some of the reddish-brown clasts have been deformed and form a pseudomatrix The conglomerate is overlain by a very thin bed of gypsum with an undulatory

base. Above the gypsum is a sequence of mudrocks that is similar to M-3 in other cores. The smeared intraclast/laminae texture is common, and local nodules/clasts of gypsum occur. A few carbonate clasts have been observed in this interval.

The upper contact of M-3 is sharp (Pl. 17). A distinctive 1 to 3 ft (0.3 to 0.9 m) zone of sulfate overlain by thinly laminated claystone overlies M-3 and is commonly preserved intact. However, the upper contact of M-3 is not everywhere distinct and undisturbed. The contact is disrupted in cores from Nash Draw and in several cores outside Nash Draw (WIPP 13, H-3b3, and H-11b3). Within these disrupted zones, the overlying stratigraphy is preserved to varying degrees. Extreme brecciation occurs at the upper contact of M-3 at WIPP 13. Allochthonous blocks of the overlying laminated anhydrite float within a claystone matrix. Block sizes increase upward until they occur as rotated blocks separated by thin stringers of claystone. Finally, the claystone does not occur and the blocks are in direct contact. Throughout the brecciated lower zone, recognizable clasts of well-laminated claystone occur. At borehole H-3b3, the sulfate and thinly laminated claystone which usually overlie M-3 do not occur, and a large rotated gypsum block floats within claystone near the top of the claystone. A 1.6 ft (0.5 m) thick breccia with clast size increasing upward and consisting of sulfate and laminated claystone occurs at the upper contact of M-3 in core from borehole H-11b3.

5.3.2.3 Polyhalite-Equivalent Sulfate

A 1 to 2 ft (30 to 60 cm) thick anhydrite or gypsum bed overlies M-3 in cores that have been disrupted along the upper contact of M-3 and H-3a. It is apparently stratigraphically equivalent to the polyhalite that separates H-3a from H-3b east and south of the WIPP site. This sulfate in most cores has a horizontal to subhorizontal fabric with hints of laminations, nodules, convulate stratification, and anhydrite pseudomorphs after vertically-oriented gypsum crystals. The sulfate may be argillaceous and consist of nodules surrounded by claystone within the lower part. Neomorphic gypsum commonly surrounds angular zones of anhydrite and some fractures are filled by fibrous gypsum. The upper contact with the thinly laminated claystone is sharp but does not appear erosional.

5.3.2.4 Claystone

Claystone, described as limestone in some core, overlies the polyhalite-equivalent sulfate. This bed is less than 1 ft (30 cm) thick, calcareous, locally organic-rich, and interbedded with some gypsum. The claystone is distinguished by parallel and predominantly flat microlaminations and thin laminations with alternating light and dark gray. Soft sediment deformation (slumping, contortion, and/or microfaulting) in this claystone is similar in appearance to the synsedimentary non-tectonically brecciated sediments of Brodzikowski and Van Loon (1985). Micronodules of gypsum are overlain by thin laminae of claystone. Fibrous gypsum-filled fractures are abundant within this zone. An en echelon pattern of gypsum-filled fractures reported in this zone in the waste handling shaft (Holt and Powers, 1984) indicates a shear along a subhorizontal or horizontal plane with displacement of the upper zone to the south. One fracture in this interval in the DOE 2 core demonstrates thrusting. The upper contact of this zone is gradational. The stratigraphic significance of this interval toward the center of the basin is not known as it is not distinguishable on geophysical logs, but it is a stratigraphically continuous and significant zone within the core-study area.

5.3.3 Tamarisk Member Upper Anhydrite (A-3)

The Tamarisk Member upper anhydrite (A-3) can be subdivided into three stratigraphically distinct zones which grade upward from one to another. These zones are, in ascending order, as follows: a lower laminated zone (A-3a), a middle zone (A-3b) exhibiting a crushed prismatic texture, and an upper bedded nodular zone (A3-c). Within the A-3, other distinct beds are present. For example, a very thin bed of claystone occurs 20 ft (6.1 m) up from the base of A-3 in the shafts . This claystone is usually washed out of core during drilling. Geophysical logs reveal it in those boreholes. Other stratigraphically distinct zones are evident in geophysical logs of this interval throughout the Delaware Basin (Ch. 4). In WIPP cores, the thickness of A-3 varies from 57 ft (17.4 m) at H-3b3 to 93 ft (28.4 m) at WIPP 13. Some general relationships can be inferred by comparing the combined thickness of the middle (A-3b) and the upper (A-3c) zones to the thickness of the lower zone (A-3a). A-3b and A-3c are combined as they are vertically quite gradational. It varies from 33 to 40 ft (10 to 12.2 m) and averages

about 35 ft (10.7 m). A-3a varies in thickness from 19 ft (5.8 m) at H-3b3 to 47 ft (14.3 m) at WIPP 25. For the most part, the thickness of A-3 varies with the thickness of A-3a.

5.3.3.1 Lower Laminated Zone (A-3a)

The lower laminated portion (A-3a) of the upper Tamarisk Member anhydrite (A-3) consists of anhydrite with minor gypsum. Near the lower contact, the anhydrite is interbedded with carbonate. Poorly preserved ripple cross-laminae occur within both carbonate-rich and anhydrite interbeds, and cross-cutting relationships are evident. Microlaminae to laminae predominate and may be flat and parallel but are wavy or contorted to cremulate. Anhydrite halite pseudomorphs after gypsum are common in borehole H-12. Pseudomorphs after vertically oriented prismatic gypsum crystals are abundant locally and occur in genetically related zones exhibiting an upward decrease in crystal size. The height of the prisms varies from less than 1/4 to 4 inch (6 mm to 10 cm). These pseudomorphs are not all oriented perpendicular to the substrate and may be tipped over to one side, crushed, slumped, smeared, and disrupted (Pl. 18). Carbonate and gypsum laminae locally drape pseudomorphs. In many cases, pseudomorphs after prismatic gypsum contain microlaminae to thin laminae of carbonate or fine grained anhydrite oriented parallel to crystal growth planes. Pseudomorphs after epitaxial gypsum prisms are rare but do occur. Probable stylolites through this interval are distinguished by a cremulate zone parallel to stratification and marked by a dark concentration of clay and carbonate. The upper contact of A-3a is gradational with A-3b.

5.3.3.2 Middle "Crushed Prism" Zone (A-3b)

The middle zone (A-3b) within the Tamarisk upper anhydrite is characterized by the "crushed prism" texture (Pl. 19, 20 and 21). This texture is created by modifying the volume of an originally laminated sediment containing large or small prismatic gypsum crystals. Some to all of the volume originally occupied by the crystals was lost to create the characteristic texture. The genesis of the texture will be described later.

The most prominent feature of the crushed prism texture is irregularly shaped masses of sulfate that are vertically elongate. These may be lighter in color than the sulfate between these masses. The masses have parallel

internal stratification, though it is not continuous between masses. The stratification indicates displacement or rotation of the mass relative to adjacent masses. The stratification can also be disk-shaped. Anhydrite pseudomorphs after tiny prismatic gypsum crystals may be preserved. Boundaries between these vertically elongate masses are commonly v-shaped and may have angles of 45° or more. As further evidence of the origin of this texture, a portion or ghost of an original prismatic gypsum crystal is visible in some of the v-shaped darker sulfate between masses.

This texture might initially be confused with nodular textures. It can be separately diagnosed in the absence of ghost or remnant prismatic gypsum by the irregular vertically elongate shape, v-shaped boundaries, and the lack of an exclusionary margin. A strong sub-horizontal pattern, to be confused with bedded-nodular texture, is not seen though it is possible that the original size and space of prismatic gypsum could vary such that the crushed prism texture would appear similar.

The textures preserved in A-3b indicate that the rock was originally dominated by prismatic gypsum crystals. One or more sequences are present where crystal size decreases upward. Some of the crystals grew to be at least 1 ft (30 cm) high. Strata size is proportional to crystal size. The crushed prism texture is increasingly developed, and apparently becomes more mature, upward from the base of the zone. Prismatic crystals are present, although visibly reduced in volume at the base. Crystal preservation decreases upward until no relic or ghost prisms remain.

5.3.3.3 Bedded Nodular Zone (A-3c)

The upper zone of A-3 is stratified with a superimposed nodular texture (bedded nodular zone - A-3c). The lower contact of A-3c is gradational, and locally A-3c exhibits the crushed prism texture. The sulfate is interbedded with carbonate, and the carbonate content increases upward. Anhydrite is increasingly altered to gypsum upward.

The bedded-nodular fabric results from an exclusive nodular fabric superimposed on stratified sulfate rock (Pl. 22). Internal layering is traceable from nodule to nodule. In general, nodules occur in distinct horizontal zones with similar nodule sizes, reflecting bedding control on size and distribution. Some nodules exhibit anhydrite pseudomorphs after prismatic gypsum crystals. Unlike the crushed prism texture, the

bedded-nodular fabric shows extremely good lateral continuity of small-scale stratification between nodules. Strata dip uniformly and are neither displaced nor rotated. The nodules are usually bounded by an irregular, dark, very thin rind of excluded material. The nodules are better developed in those zones containing less carbonate and more gypsum. Carbonate-rich zones display more original depositional features.

The base of A-3c exhibits laminated gypsum, with pseudomorphs after prismatic gypsum crystals, modified by the bedded nodular fabric. Further up the section, carbonate interbeds become more abundant, and the nodules become more lenticular in shape. Near the top of A-3c, lenticular and wavy interbeds of ripple cross-laminated gypsum and carbonate have been modified by the bedded nodular fabric. The upper 1 to 2 ft (30 to 60 cm) of A-3c contains abundant gypsum-rich carbonate interbeds and dark brown, very wavy, and irregular thin laminations of organic material. These wavy laminae occur in distinct zones which become more common upward. The upper contact of A-3c with the Magenta Dolomite is gradational.

5.4 Magenta Dolomite Member

The Magenta Dolomite Member of the Rustler is the uppermost of two regionally persistent dolomites within the Rustler. Within the cores examined at and around the WIPP site, the thickness of the Magenta varies from 23 ft (7 m) at H-3b3 to 28 ft (8.5 m) at H-11b3 (Fig.5.4 and 5.5). In comparison with the Culebra, the Magenta exhibits more primary sedimentary structures, fewer fractures, larger average grain size, and is overall a much more competent unit as it cores very well. Within the WIPP site area, the vertical sequence of sedimentary structures does not vary significantly. The Magenta consists of arenaceous dolomite and gypsum with lesser amounts of quartz silt and sand-size grains, clay, and organic material. The Magenta can be subdivided into two major zones: a lower algal-dominated unit and an upper ripple cross-laminated unit. In outcrop east of Artesia, New Mexico, the algal-dominated unit displays thin zones of breccia underlain and overlain by continuous bedding.

5.4.1 Algal-Dominated Unit

Algal features dominate a zone at the base of the Magenta varying 3 ft to 5 ft (0.9 to 1.5 m) thick. Wavy to locally crenulate, subhorizontal, and

commonly, irregular organic-rich laminations occur in groups or zones and are very common at and near the base of the Magenta. This lower zone exhibits very low-amplitude laterally-linked hemispheroids. Within the core of WIPP 19, probable small vertically oriented prismatic gypsum crystals occur within an algal laminated zone of low-amplitude laterally-linked hemispheroids.

The subhorizontal laminae are overlain by a zone containing closely spaced, microlaminated to thinly laminated algal hemispheroids. These hemispheroids may be laterally linked by laminations. In some cases, the laminae within hemispheroids retain the same radius and thus appear vertically stacked. The basal radius varies from 4 to 8inches (10 to 20 cm). These hemispheroids are similar to algal biscuits observed by Gebelein (1969).

A zone dominated by wavy laminations and lenticular-shaped, very thin beds overlies the hemispheroids. Draping laminae are common through this zone. Lens shaped or lenticular interbeds often thicken in the trough and thin over the tops of the underlying wavy strata. The amplitude of the wavy strata decreases upward while the wavelength appears to increase upward. Dark organic-rich interlaminae are common through this zone.

Gypsum nodules near the base of the algal-dominated unit decrease in size and abundance upward. Subhorizontal gypsum-filled fractures are common throughout the algal-dominated unit but are most common in the wavy to lenticular bedded zone where there are abundant clay interbeds and partings.

5.4.2 Cross-Laminated Unit

The upper of the Magenta is dominated by horizontal to subhorizontal, wavy to lenticular beds exhibiting cross-laminations and cross-laminated bedforms. The cross-laminated unit was subdivided into six mapping units during the mapping of the Magenta in the exhaust shaft (Holt and Powers, 1986a). Those mapping units can be identified in cores of the Magenta. The vertical sequence of sedimentary structures will be discussed later.

The clastic sedimentary structures observed within the upper unit include: ripple cross-laminations; ripple drift cross-laminations, starved ripples; both erosional stoss and depositional stoss climbing ripples; wavy and lenticular bedding; flaser bedding; erosional scour marks; clay drape; soft sediment loading; probable rip-up pebbles; pebbles at base of cross-laminations; local cross-bedding; and structureless beds. These

sedimentary features are most common within subhorizontal, very thin and thin beds that are laterally continuous.

At the base of the cross-laminated unit, grain sizes are more homogeneous and clay-rich interbeds are less common than in the underlying unit. Wavy bedding with low-angle cross-stratification is very common. The amount of cross-laminations and ripple forms and the average set size increases upward as does the grain size. Nearly structureless very thin interbeds are common near the top of the cross-laminated unit. Gypsum nodules become more common and an areally persistent, very thin bed containing abundant gypsum nodules occurs within the upper 2 ft (60 cm). The uppermost contact with the overlying Forty-niner Member is gradational as the carbonate fraction decreases and is interbedded with gypsum. Small nodules of gypsum are common both within the gypsum-rich interbeds and the carbonate interbeds.

5.5 FORTY-NINER MEMBER

The Forty-niner Member of the Rustler Formation is similar to the Tamarisk Member as it consists of a lower (A-4) and an upper (A-5) sulfate unit separated by a mudstone unit (M-4) and laterally equivalent halite (H-4) unit (Figs. 5.4 and 5.5). Within the upper anhydrite (A-5), a second halite unit present at the depocenter of the basin (Ch. 4) does not occur near the WIPP site.

5.5.1 Anhydrite (A-4)

The lower sulfate unit (A-4) within the Forty-niner is an areally extensive unit that varies from 15 to 21 ft (4.6 to 6.4 m) thick in cores. The sulfate mainly consists of anhydrite with some gypsum and carbonate. The carbonate interbeds are most abundant at the base of A-4 and decrease upward. The uppermost foot (30 cm) of A-4 is partly argillaceous. Small nodules of sulfate are abundant in the lower interbeds. Bedded nodular textures locally occur, and nodules may be superimposed upon nodules. Chicken-wire nodular and enterolithic textures are present. The nodular texture becomes better developed and larger upward as the more mature nodular features dominate. The upper few feet (m) of A-4 may be in part laminated to thinly laminated, and the laminae may be wavy to slightly contorted. The upper contact of A-4 is sharp.

5.5.2 Mudstone (M-4) and Halite (H-4)

The mudstone interval of the Forty-niner Member is laterally equivalent to an argillaceous halite and halite toward the depositional center of the Delaware Basin. Of the WIPP cores examined, only H-12 contained halite in this unit. Geophysical log interpretations suggest that halite occurs within this zone in boreholes from the eastern site area (e.g., P-18, P-19, P-20). The M-4/H-4 interval consistently thickens toward the depositional center of the basin as the halite content appears to increase.

5.5.2.1 Forty-niner Member Mudstone (M-4)

M-4 varies from a minimum of 6 ft (2 m) at AEC 8 to a maximum of 17 ft (5.2 m) at WIPP 25. In addition to mudstone, M-4 may consist of siltstone, claystone, and locally some sandstone. It is commonly gypsiferous and/or calcareous. Thin sections from this interval at WIPP 19 show a halite cement and incipient displacive halite crystals (Pl. 23). Both large and small scale primary sedimentary structures are common through this interval. In the waste handling shaft, large scale cross-cutting relationships were observed in M-4 as a wedge-shaped unit bounded by erosional surfaces (Holt and Powers, 1984).

M-4 was subdivided into five mapping units in the exhaust shaft, and they are recognizable in the cores as three reddish-brown units between upper and lower gray beds. The lowermost unit within M-4 is gray siltstone 2 to 3 ft (0.6 to 0.9 m) thick. It is locally gypsiferous and contains irregular gypsum-rich laminae and some gypsum nodules. The lower gray unit has well defined and preserved horizontal to subhorizontal thin laminae to very thin beds. It may locally be structureless. The lower reddish-brown unit is the thickest and usually varies from 5 to 6 ft (1.5 to 1.8 m) in thickness. The stratification within this unit is less distinct than that of the underlying and overlying units. Stratification is more abundant near the top of the unit and occurs as discontinuous, wavy to irregular, locally slightly contorted thin laminae to very thin beds. Interbeds are white to gray. The lower part of this unit displays small granule to small pebble sized clasts of mudstone and exhibits smeared intraclast textures. Greenish-gray reduction spots are common. The middle and upper reddish-brown units are not always distinguishable from one another in core. The middle reddish-brown unit is about 1 ft (30 cm) thick. It is separated from the underlying unit

by a relatively large scale erosional surface that is continuous around the circumference of the exhaust shaft. As in the underlying unit, the stratification is distinguished by color and consists of irregular to discontinuous wavy laminations to thin beds. The unit is locally gypsiferous. The upper reddish-brown unit is also about 1 ft (30 cm) thick. It has subhorizontal to horizontal, slightly wavy thin laminations to laminations. In general, stratification is more continuous and better preserved than in the underlying units. The uppermost gray bed has sedimentary structures similar to the upper reddish-brown unit. The upper contact of M-4 with the overlying anhydrite (A-5) is sharp and distinct (Pl. 24). Gypsum nodules and gypsum crystals appear to be areally restricted, as they are most common in WIPP 12, WIPP 19, B-25, exhaust shaft, waste handling shaft, H-3, H-11, and H-12.

5.5.2.2 Forty-niner Member Halite (H-4)

Within the cores examined, only H-12 contained halite in the stratigraphic unit equivalent to M-4. The halite interval (H-4) there is argillaceous and not very thick. Geophysical log interpretations suggest that the amount of clay in this unit decreases and the overall thickness of H-4 increases eastward toward the depositional center of the basin. At borehole H-13, the stratigraphic sequence described for the interval M-4 is present. Five ft (1.5 m) of halite-bearing sediment occurs within the 12 ft (3.7 m) section of H-4. The halite is in a stratigraphic position equivalent to the lower part of the lower reddish-brown unit of M-4.

The lower contact of the halite-bearing zone with the lateral equivalent of the lower gray unit of M-4 is sharp. Siltstone and claystone matrix is abundant near the upper and lower contacts where incorporative halite crystals are common. Aggregates of halite crystals are associated with irregular blebs of siltstone within the remainder of the halite section. The upper contact of the halite-bearing interval is gradational and is overlain by the lateral equivalent of the upper part of the lower reddish-brown unit. The remainder of the sequence at H-12 is similar to the sequence observed in M-4 in other cores and the shafts and preserves the middle and upper reddish-brown units and the upper gray unit.

5.5.3 Anhydrite (A-5)

The uppermost sulfate within the Rustler Formation is areally extensive and is locally subdivided into two parts by a thin halite unit (see Ch.4: Lateral Relationships). The thickness of the sulfate varies from 28 to 37 ft (8.5 to 11.3 m) in the core study area.

The sulfate bed consists of anhydrite, gypsum, and carbonate. The anhydrite is usually thinly laminated to laminated, wavy to slightly contorted, with locally abundant anhydrite pseudomorphs after vertically oriented prismatic gypsum crystals up to two inches high. Pseudomorphs after prismatic gypsum can be tipped over, smeared, or vertically oriented. Some reflect epitaxial gypsum growth. Pseudomorphs in some zones become smaller upward. Very carbonate-rich interbeds occur. Horizontal to subhorizontal stylolites within laminated intervals are common. The anhydrite may locally exhibit nodules and/or the bedded nodular fabric. Possible prism cracks occur locally. The upper contact is sharp and erosional.

6.0 DEPOSITIONAL ENVIRONMENTS

The depositional environments of the Rustler Formation are interpreted using a comparative, sedimentological approach to determine the extent of halite surviving depositional processes. Those features with modern or experimental analogs are emphasized. Depositional analogs for individual features and sets of features are derived from the available literature and continuing studies of modern analogs. The features observed within the Rustler have been compiled, and their modern or experimental analogs are compared to the features. Depositional models are synthesized for rock units that are apparently genetically related. These models are then integrated to create a depositional history for the Rustler.

The principal depositional environments of the Rustler are synopsized first. A depositional model for Rustler salt pans and adjacent environments, three syndepositional dissolution models, a summary of syndepositional dissolution fabrics, and a discussion of sedimentation and tectonics are discussed after synopses of all depositional models.

6.1 RUSTLER DEPOSITIONAL ENVIRONMENTS

6.1.1 Saline to Fresh Transitional Facies

In the WIPP site area, the first descriptive unit assigned to the Rustler in core and shaft studies is a thin bed of sulfate. This unit, although probably related to Salado style deposition, is a consistent stratigraphic marker throughout the WIPP area, and the Rustler/Salado contact is usually placed at the base of this unit for convenience. The sulfate overlies 1 to 3 ft (0.3 - 1 m) of halitic mudstone which is included within the Salado and contains very small incorporative halite crystals. The halitic mudstone was deposited within a halite-saturated saline mudflat. The water table throughout the deposition of displacive/incorporative halite crystals was located at or very near the surface of the mudstone. The sulfate unit is generally argillaceous at the base and becomes less clastic upward. The argillaceous portion of the sulfate records the settling and deposition of the clastic material associated with a minor freshening event. The remaining sulfate was most likely deposited subaqueously.

The base level was again lowered and clastic input and grain size increased. A gypsum-rich saline mudflat developed. Either the kinetic

energy of the depositional system was high or the sulfate content was low enough to prevent incorporative gypsum development. Instead, gypsum was precipitated during the desiccation phase following flooding. After flooding, the base level or water table was at the surface of the mudflat. Evaporative pumping concentrated the sulfate at the surface where gypsum was precipitated within void spaces, forming a gypsum cement or incipient gypcrete within one to several laminae. Further evaporation drove the water table deeper. This resulted in desiccation of the muds and upon the next flooding event, reworking and deposition of fragile rip up clasts from desiccation. This clastic interval records an initial increase of the potential and kinetic energy of the basin.

6.1.2 Lagoonal Environment

An unconformity with a documented local relief of over 3 ft (1 m) marks the beginning of perhaps the greatest variation of depositional style and environment within the Delaware Basin since the Guadalupian/Ochoan transition. Once again, the waters within the basin were, for at least a short period of time, directly connected with marine waters. The unconformity was described in shafts within a few ft (1 to 2 m) of the base of the Rustler. The presence of fossil bivalve fragments within a thin conglomerate locally overlying the unconformity suggests that a basin-wide freshening to at least near-marine conditions had already occurred and may have been quite rapid. Presumably, the source of the water and fauna was to the south through the Hovey Channel. The transgression was rapid, leaving only isolated occurrences of conglomerate as record of its passing. Consistent with the rapid nature of the transition, grain size and sedimentary structure size within the rocks overlying the unconformity indicate a decrease of system energy upward. Within a few feet of the unconformity, the system's energy reached a relative steady state as burrowing and bioturbation become prevalent within a near-marine to marine lagoon-like environment.

Clastic deposition continued under shallow lagoonal conditions, and clastic depositional fabrics were subsequently modified by burrowing organisms. Most bedding fabrics are not the result of migrating bedforms. However, cross-laminations do occur and are more abundant higher in the section. During quiescent times of little or no deposition of clastic

materials, bioturbation and burrowing were prevalent and in some cases so complete as to completely eradicate any sedimentary structure and leave only mottled siltstone. This mottled appearance formed during periods when the substrate was relatively stable (i.e., limited addition of clastics), and in general, the degree of completeness of the bioturbation reflects of the length of time that the substrate was stable. In other instances, when the energy of the system was higher, clastics were deposited more rapidly, essentially eliminating bioturbation or, at the least, diluting its effect. This is represented by those zones containing well preserved stratification with no or few burrows.

The presence of a lagoon with water of near-marine salinity has important implications. A direct connection to marine waters can be implied by the presence of marine to near-marine fossils. This is important as it represents the first and only documented near-marine episode within the Delaware Basin during the Ochoan Epoch. (There is growing evidence that the Dewey Lake is not marine (Schiel, 1987, in progress) contary to earlier suggestions.) Several possible events could result in such a marine incursion. First, a rapid change of absolute sea level could result in such a rapid transgression. However, there is no direct evidence to support it, and such an event would be likely to have longer lasting and broader effects. More than likely, whatever had barred the Delaware Basin during the preceding portion of the Ochoan was breached, and marine water rapidly transgressed over a large area with very low relief. Such a breach could have easily resulted from a local tectonic event resulting also in subsidence. It is clear that the marine invasion and the subsequent shallow lagoonal system yielded a higher overall base level, and the effect of a raising of base level is to decrease the hydrologic gradient in the depositional basin. However, for coarse clastic material to continue to be supplied to the lagoonal setting, the gradient within the basin must rise to counter the decrease caused by a rising base level. In the face of a rising base level, the gradient could only increase as the result of tectonic activity. As the distribution of clastic material seems to decrease somewhat to the south (Ch. 4), the source areas for clastic materials within the northern part of the Delaware Basin were probably to the north and northwest. Whatever tectonic activity increased the potential for clastic deposition must have affected those areas to the north and northwest.

Although separate tectonic events could have resulted in local subsidence and uplift of potential clastic source areas, one tectonic event could be envisioned that could account for both the breach of a southern barrier and yet could keep the energy of the basin at or near the same level in the north. A southerly tilting of the Delaware Basin and possibly a portion of the Northwestern Shelf could account simultaneously for both situations. Figures 4.3 and 4.6 display thicker basal clastics to the south consistent with this proposal.

6.1.3 Fresh to Saline Transitional Facies

The transition between marine or near-marine lagoonal deposition and playa-like deposition of evaporites is recorded by several ft (2 - 3 m) of dominantly clastic rock about 35 - 40 ft (10.7 - 12.2 m) below the Culebra at the WIPP site. This zone contains no obvious erosional surfaces of any magnitude and is not very thick, so it is likely that deposition was nearly continuous with no major hiatus. Thus, the transition itself must have been rapid. As the size of both sedimentary structures and clastic grains increases upward within the section, both the potential and kinetic energy of the system increased with time. This is consistent with shallowing upward in near-shore or shallow marine systems.

Near the top of the sequence, groups of carbonate-rich interlaminae occur and are followed vertically by groups of gypsiferous interlaminae. Their presence indicates that solutes were being concentrated within the ground/depositional waters. Less indurated laminae commonly bound the calcareous or gypsiferous laminae that stand out as resistant zones in cores of this interval. The tops of laminae commonly contain the most cement. These laminae have been preferentially cemented by the precipitation of either carbonate or sulfate without affecting the overlying laminae and with minimal effect on the underlying strata. It is very unlikely that this cement is the result of a much later pervasive diagenetic process as porosity and permeability do not vary significantly from lamina to lamina. Therefore, the cements must be related to an early process. Did these cements form by the concentration of solutes at the sediment/air interface on a subaerially exposed mudflat, or did they form subaqueously?

In subaerially exposed gypsum saline mudflats in Death Valley, Saline Valley and Bristol Dry Lake, California, most clastic laminae are very

irregular in both thickness and shape. These irregularities are in part due to very early diagenetic growth of gypsum within the sediment. Efflorescent crusts are commonly found at the surface of an active saline mudflat and also contribute to the formation of irregular stratification. Eolian sediment is trapped within the efflorescence crust and on the lee side of irregularities (e.g. polygonal cracks) on the surface of the crust. The efflorescent crust is ephemeral and dissolves with the next rainfall or flooding event. The trapped sediment is then deposited on the underlying clastic material creating very irregular, discontinuous pockets of sediment and laminae. If a flooding event causes the dissolution of the efflorescent crust, the sediment carried with the flood is deposited over a rapidly dissolving irregular surface. Should the crust be dissolved before sediment is deposited, an irregular surface forms from freshly freed eolian sediment. Once the water evaporates or infiltrates, another efflorescent crust forms and displacive growth within the crust further disrupts the sediment. Preservation of efflorescence crust is highly unlikely, and none was observed within the sediment sections in any of the California examples. The laminae in this section of the Rustler are, however, regular in nature and do not resemble those observed in subaerially exposed mudflats. It is unlikely, then, that the cements observed within the laminae originated at the sediment/air interface.

The cements are clearly early, but did not originate due to subaerial exposure; they must have occurred early in a subaqueous environment. The laminae have a regular morphology. They are somewhat wavy and locally contorted, but this deformation is due to soft-sediment loading. As the tops of the laminae contain the most cement, it is likely that deposition of the clastic laminae was followed by a period of nucleation of carbonate and/or gypsum on and within the substrate. During this time, little or no reworking of clastic sediment could have occurred. The cement effectively stabilized the substrate preserving the laminae. Early cementation of laminae at the bottom of a saline body has been reported for both modern and ancient examples by other workers (e.g. Garrison and others, 1978, for Messinian gypsum; Warren, 1982a, for Holocene gypsum in salinas). Clastic deposition resumed and either a freshening or the mechanical energy of the system prevented further precipitation of cement. As long as the system remained energetic, cement did not precipitate. This type of laminae can be used to

indicate subaqueous depositional environments

Sulfate within the sediment is more concentrated up section until sulfate laminae are common forming a 1 to 2 ft (30 to 60 cm) thick zone about 30 to 35 ft (9.1 to 10.7 m) below the Culebra in the WIPP site area. In most cores, clastics are still present. Most of the laminations are regular and suggest a subaqueous origin. However, the stratification may be very convoluted to contorted. Soft sediment shear and loading are in part responsible for this deformation. Enterolithic and nodular structures locally are present. These formed by expansive growth within the soft sediment and partially deformed some laminae. Irregular to prismatic vertical features are abundant in the zone containing enterolithic and nodular textures and are interpreted as possible desiccation cracks.

The sulfate-rich interval represents the final stage of the transition from the near-marine lagoonal deposits to playa-like deposits. This interval may be a silica-rich version of Warren's (1982a) gypsarenite, which he uses without genetic connotation. Warren (1982a) defines gypsarenite as "gypsum which contains at least 50% sand-sized gypsum grains." From the preserved sediment record, it has not been possible to determine the original grain size of the gypsum due to diogenesis. However, it is likely that depositional processes similar to these suggested by Warren produced the sulfate interval. Laminated gypsarenite (after Warren, 1982a) consists of laminae of mechanically deposited gypsum and/or gypsum formed <u>in situ</u>. In this interval, most of the gypsum was probably reworked mechanically and deposited with some clastic material. The gypsum converted to anhydrite during burial and/or early diagenetic growth of gypsum within the sediment probably destroyed all of the original gypsum textures but the laminations. Arakel (1980) observed similar sediments in the Hutt and Leaman Lagoons of western Australia and found that early diagenesis of gypsum (less than 6,000 years old) had obliterated most primary crystal fabrics.

The desiccation cracks and enterolithic to nodular structures within the sulfate are consistent with subaerial exposure. The prismatic cracks found within this stratigraphic zone may be parts of large scale polygonal cracks. Several authors (e.g. Neal and others, 1968; Tucker, 1981; and Lowenstein and Hardie, 1985) have discussed the possible origins of these features. These prismatic cracks are clear evidence of subaerial exposure. Nodular and enterolithic structures, however, are not unique indicators of subaerial

exposure; syndepositional diagenetic growth of sulfate is common in both the subaqueous and subaerially deposited sediments. Enterolithic and nodular structures, when observed within some stratigraphic sequences, are often interpreted to have formed in a subaerially exposed environment (e.g., a sabkha: Shearman, 1978). Other examples of enterolithic and/or nodular sulfate are interpreted to have formed diagenetically in sediments in subaqueous environments (e.g., the Castile Formation: Dean and others, 1975). Dean and others (1975) suggest that nodular and enterolithic structures are not diagnostic of either subaerial exposure or subaqueous deposition.

During subaerial exposure of the sulfate interval, sulfate was precipitated and disseminated throughout the soft sediment, including those rocks associated with the marine transgression. When the potentiometric surface of the water table is at or below the surface of the sediment, the salinity of the groundwater became much higher than the maximum salinity of the previously standing body of water due to capillary evaporation. This would be the optimal time to develop early diagenetic gypsum. Cody and Hull (1980) demonstrated that primary anhydrite could nucleate in the presence of certain types of macromolecular organic compounds at temperatures and salinities expected in hot, arid regions. It is possible that some of the sulfate originated as primary anhydrite.

The sulfate interval meets Warren's (1982a) hydrologic criteria for a continental playa: 1) the hydrologic system depositing the sulfate interval was clearly separated from large volumes of saline water (e.g., marine water), and 2) the sulfate was deposited on a clastic (clayey) substrate. Further, Warren reports that the gypsum within the central part of the paleopond area of continental playas in Australia is usually less than 3 ft (1 m) thick, nearly the same thickness as the sulfate interval in the Rustler. Clastic material was brought into the basin during episodic flooding. Both cementing processes (previously discussed) and precipitation and reworking of gypsum on the substrate account for the presence of sulfate in this interval. Analogous sediments with a similar origin are reported in Hutt Lagoon, western Australia (Arakel, 1980). The variable depositional style and lack of larger, more stable forms of gypsum reflect the dynamic chemical and mechanical nature of the small, precipitating brine body.

Any connection with marine waters must have been blocked prior to the deposition of this zone as the transition appears to have taken little time and an overall salinity change occurred rapidly. Potential evaporation rates were apparently high as saturation with respect to gypsum was reached easily and quickly. As Warren (1982) points out in his discussion concerning salinas in Australia, rapid changes of salinity cannot occur within fluid well connected with a large (for all practical purposes, infinite) body of fluid with a constant salinity. Rapid changes of salinity can, therefore, most reasonably occur within small volumes of fluid. The preservation of the transitional sequence indicates continued relative subsidence through the period of deposition while the sedimentary features indicate a rapid shallowing upward. If the basin were not effectively sealed from marine waters, subsidence would not be reflected within the sediment as shallowing upward. Instead, lagoonal-type sediment deposition would have begun again or continued. The rapid increase of the kinetic energy of the system and the concentration of solutes within the water resulted in the death of burrowing organisms. The ease of gypsum saturation, the increase of grain size (potential energy), the increasing-upward occurrence of sedimentary structures showing the migration of bedforms, and the presence of probable polygonal/desiccation structures are all consistent with a transition from a near-marine lagoon, via a rapid shallowing upward due to evaporation, to a subaerially exposed sulfatic saline mudflat.

Such a transition is rarely preserv geologically. Usually, the evident transitions between widely differing depositional environments are erased by one or more erosional events. The time between preserved depositional events is unknown, and those events whose records were erased by, and the amount of time unrecorded by, the hiatus cannot be determined. The complete transition between near-marine conditions and the deposition of halite in a saline mudflat is preserved here. These sediments recording the transition were preserved because of continued subsidence through the transition. Subsidence prevented reworking of sediment within the basin during a time of decreasing base level and allowed nearly continuous deposition to occur.

6.1.4 Halite (H-1) and Mudstone (M-1) Deposition

The fresh to saline transitional facies are overlain by a sequence of rock dominated by halite and laterally equivalent mudstone. The lateral

relationships between the halite-bearing zone and the mudstone zone are in part depositionally controlled. The halite sequence (H-1) appears to be the product of the interaction between halite saline mudflat, mud-rich salt pan, and mud-poor salt pan environments (see section 6.2). Marginal subenvironments consisting of gypsum saline mudflats and mudflats existed around the periphery of the halite depositing environments (see section 6.2). Halite was further concentrated in the depositional center of the basin by the syndepositional dissolution of halite from marginal environments and relocation of solutes toward the center during episodic subsidence of the depocenter center. The WIPP site and Nash Draw area are located along the margin of the depocenter center of the basin, and the rocks present in the H-1/M-1 stratigraphic interval in the study area formed as the result of the interaction of halite depositional environments with marginal nonevaporitic environments.

Above the transitional facies, clastics continued to be deposited. Groundwater salinity increased by evaporation, and halite reached saturation. Displacive crystals nucleated and precipitated within the clastic sediment in a halite saline mudflat. An increasing upward content of displacive crystals suggests that the salinity was also increasing with time. A standing brine body developed in the depocenter and a mud-rich to mud-poor halite pan developed. The halite pan occupied the lowest topographic areas. The mud-rich part of the salt pan was affected more by syndepositional dissolution as it was closer to the margin. Within the WIPP area, unit H-1a was deposited by the interaction of both saline mudflat and mud-rich salt pan environments. A minor transgression or flooding event halted the deposition of H-1a. The input of clastic material was stopped by the sudden rise of base level. Sulfate was locally deposited as the standing body of water was concentrated through evaporation. As evaporation and attendant concentration continued, halite saturation was again reached. A large mud-poor salt pan developed and H-1b was deposited. Minor freshening events did not bring much clastic material into the system but did precipitate thin layers of gypsum. Subsidence increased, and the base level was lowered. Flooding associated with subsidence again introduced clastic material into the system. The size of the mud-poor salt pan decreased considerably, and mud-rich salt pan deposition dominated the system throughout the deposition of H-1c.

Cores of M-1 suggest that it was deposited by the interaction of mudflat, saline mudflat, and possibly mud-rich salt pan environments and with intermittent syndepositional dissolution resulting from flooding events and vadose exposure. Halitic facies of H-1 extended beyond their present boundaries before being partially removed by syndepositional dissolution. Some flooding or transgressive events inundated the margins. Subaqueous gypsum deposition followed resulting in widespread sulfate units that extend beyond the bounds of the salt pan and associated environments.

6.1.5 Anhydrite (A-1)

A rapid, nearly instantaneous transgression of fresher water, of possible marine origin abruptly terminated halite deposition and further planed a very broad, topographically low area. Syndepositional dissolution similar to that reported by Hovorka (1983b, in press), Hovorka and Granger (in press), and Fraccasso and Hovorka (1986) for halites underlying anhydrite and carbonate rocks of the San Andres Formation in the Palo Duro Basin affected the upper part of the H-1 sequence. The top of the syndepositional dissolution residue represents a time-line or the base of a punctuated aggradational cycle (e.g., Goodwin and Anderson, 1980). A thin gypsum unit, now anhydrite (A-1), was deposited over the H-1 sequence. The nearly uniform thickness of A-1 suggests that rapid deposition of the sulfate occurred as there is no thickening of the section attributable to subsidence of the depositional center of the basin. The sedimentary structures preserved in the anhydrite confirm that the deposition was rapid and the result of one major transgressive pulse with minor fluctuations of base level. One thicker, and in some areas a second thinner, zone of anhydrite and halite pseudomorphs after vertically oriented gypsum crystals occurs within a wavy-laminated to ripple-laminated anhydrite. Vertically oriented selenite crystals and their pseudomorphs are commonly reported features in both modern sediment and ancient rocks, respectively (e.g., Schreiber, 1978; Warren, 1982; Vai and Ricci Luchi, 1977). They are usually interpreted to have formed in a subaqueous setting. The size of pseudomorphs after selenite decreases upward. Both Warren (1982b) and Vai and Ricci Luchi (1977) interpret similar sequences as shallowing upward. Wavy-laminated to ripple laminated anhydrite overlies the pseudomorph zones, and in some cores the top of the anhydrite is nodular. A-1 is interpreted to have been rapidly deposited in a shallowing upward subaqueous environment. Slight base-level fluctuations are recorded

by the presence of more than one zone of decreasing upward pseudomorph size. The base level dropped considerably at the end of A-1 deposition, and subaerial exposure of some of the sulfate in the western part of the study area may have occurred, but the evidence is equivocal.

6.1.6 Halite (H-2) and Mudstone (M-2) Deposition

Once A-1 was deposited and the base level lowered, clastic material could again be transported into the study area. Either an increase of the subsidence of the depositional center, or a decrease in the rate of evaporite deposition, increased the potential for clastic transport. Minor tectonic activity outside of the study area may have added to the potential energy of the basin. Evaporitic conditions remained, and siltstone, mudstone, and claystone were deposited in mudflat, saline mudflat, and mud-rich halite pan environments in marginal environments (including the study area) while mud-free halite pan environments existed in the depositional center. Along the margins of the depositional center, repetitive displacive growth of evaporite minerals and subsequent dissolution, driven by a fluctuating water table, churned the clastic sediment. The original clastic texture was disrupted, mixing intraclasts of various grain sizes within a very poorly sorted matrix. Subsidence in the depositional center of the basin lowered the base level, and subsequently, lowered the protective water-table on the margins of the deposition center exposing the evaporite minerals to dissolution by meteoric waters. Halite was remobilized, transported to the depositional center, and redeposited leaving a very churned and haloturbated muddy sediment free of halite (Smith, 1971, p. 229: "... repeated re-solution and re-precipitation of ... salts ... might ... cause ... the almost total lack of sedimentary structures in the clastic parts ... for which the term haloturbation would seem appropriate..."). This muddy sediment developed incipient soil textures (clay cutans or argillaceous), as meteoric fluids percolated downward toward the phreatic zone. Gypsum nodules and crystals and possibly anhydrite nodules grew within the vadose zone. When the water table was at or below the top of the sulfate A-1, some leaching of sulfate may have occurred. Interbeds of gypsum were deposited following episodic flooding events when the salinity of the water was decreased. The areal extent of these gypsum interbeds was several times greater than that of halite as the size of the brine pond increased considerably following flooding. Gypsum saline mudflats formed locally on

the margins of the basin, and displacive gypsum and anhydrite grew within the sediment.

Subsidence was probably episodic, and during periods of no subsidence, the pattern of depositional environments was shifted outward like an expanding bullseye as the depression within the depositional center was filled, causing the available fluid to spread outward. Once again, the clastic marginal sediments were churned by the displacive action of evaporite minerals. When subsidence resumed, syndepositional dissolution again removed the halite from the marginal clastic sediments, leaving behind a syndepositional dissolution residue. Near the end of the deposition of the H-2/M-2 interval, very little halite remained within the interval in the WIPP site area.

6.1.7 Culebra Transgression and Deposition

Halite deposition and the deposition and subsequent modification of related muddy sediments was halted by a transgression of waters with near-marine salinity. Marine waters transgressed across an extremely low relief area. Both dissolution of underlying halite as waters of low salinity came into contact with the halite and erosional reworking of clastic material further flattened the topography. The upper gray zone of M-1 records the transgression and subsequent reworking of muddy sediments and some carbonates. Nontectonic deformation, similar to that described by Brodzikowski and Van Loon (1985) for sediments deformed as ice melts, occurred as the underlying halite continued to be dissolved after the initial deposition of the gray claystone. Erosion, transport, and deformation of soft clasts of carbonate occurred. Once the transgression was complete, a stable substrate developed and carbonate deposition began.

A low-energy, productive carbonate lagoon developed following the transgression. Pelletal carbonate mud was deposited along with a minor amount of clastic material, mostly clay. Water depth was great enough to allow only minimal reworking of pelletal mud and clay and fine silt sized material into bedforms. However, the energy of the system occasionally increased, and migrating bedforms developed. The substrate was often stable and shows evidence of locally extensive bioturbation. Algal mats developed episodically on the substrate. These were, however, very thin and were usually choked and covered by rapid deposition of pelletal material and clay. Reworking of the algal mats was minimal. Near the end of Culebra

deposition, the marine connection was blocked and the salinity of the water increased. Grazing invertebrates apparently decreased, and algal mats and stromatolitic forms developed on the substrate. Shallowing occurred, and some clastic material was carried into the basin.

Algal features are commonly reported in evaporite settings (e.g., Carozzi, 1962; Kendall and Skipwith, 1968; Friedman and others, 1973; Peryt and Piatkowski, 1977; Shearman, 1978; Butler and others, 1982; Warren, 1982a; Toomey, 1985). They have been interpreted to indicate: a) subaerial exposure in a subtidal environment (after Logan, 1961; Kendall and Skipwith, 1968), b) subtidal settings (e.g., Gebelein, 1969), and c) deep water (e.g., Hoffman, 1974; Playford and Cockbain, 1969). The occurrence of algal features is not unique to any environment. Desiccation cracks and chips are evidence of subaerial exposure, but none were found in the Culebra. No head or club-shaped forms indicating subaerial exposure (e.g., Logan, 1961) were observed, and fenestral fabrics do not occur. Instead, algal mat, biscuit, and dome-shaped features similar to those described in subtidal environments by Gebelein (1969) were found.

During and shortly following Culebra deposition, halite within the M-2/H-2 interval continued to be partially dissolved. Further soft sediment deformation occurred, and the lower beds of the Culebra slumped partially in those zones affected by the dissolution.

Regional isopachs of the Culebra show a thickening in the depositional center indicating that Culebra depositional conditions existed long enough to be affected by the subsidence of the depositional center.

6.1.8 Anhydrite (A-2) Deposition

The connection with marine waters that existed during the initial Culebra transgression became more restricted during the later stages of Culebra deposition. This restriction continued after the end of the Culebra time. The water continued to increase in salinity, becoming saturated with respect to gypsum. Gypsum and carbonate algal material were interlayered. The environment was sufficiently energetic to locally rework the fine-grained gypsum and carbonate into low relief bed forms. Local subaerial exposure occurred. Once gypsum saturation was reached, gypsum crystals nucleated and grew displacively within the still soft carbonate of the Culebra.

Sulfate was deposited rapidly, and was subaerially exposed. Some clastic material and possibly some halite were deposited over the nearly exposed to exposed surface of the sulfate. Halite, if present, was dissolved by another rapid transgression. The transgressive waters concentrated quickly and sulfate saturation was again reached. A more stable substrate existed and vertically oriented selenitic gypsum grew at the sediment water interface. Shallow conditions are implied by the lack of large vertically oriented selenite prisms.

The sulfate was deposited in a shallowing upward environment. Subaerial exposure of sulfate along the margins of the depocenter resulted in the dissolution and erosion of sulfate by meteoric waters.

6.1.9 Halite and Mudstone (H-3/M-3)

The deposition of clastic materials and halite followed the lowering of the water table after the deposition of A-2. The standing body of water was reduced in size by evaporation, solutes were concentrated, and the sediment along the margins of the depocenter was exposed to erosion and dissolution. Local channels developed among the margins dissolving or eroding into A-2. The absence of A-2 at WIPP 19 is interpreted to be the result of syndepositional channeling. Halite began to be deposited within the lowest areas. The saline pan was largely desiccated and then flooded to bring clastics across the basin. The following depositional environments were recognized, from the margin to the middle of the depocenter: gypsum-saline mudflat, halite-saline mudflat, mud-rich saltpan, and mud-poor saltpan. The size of depositional environments changed in response to changes in the relative position of base level and surficial hydrologic system. Subsidence controlled the basin geometry and subsequent facies distribution. During episodic subsidence, syndepositional dissolution of soluble minerals occurred during subaerial exposure of the marginal sediments. This remobilized soluble minerals and relocated them toward the depocenter. During the exposure, these marginal sediments were affected by soil-forming processes which translocated and reoriented clay-sized particles in microscopic fractures and as cutans.

Initially, nearly pure halite was deposited in the depocenter, and the depositional environments remained stable for some time with no large scale facies migration. After the initial halite deposition within the depocenter, clastic materials were brought into the study area during episodic flooding

events. Clastics were sedimented along the margins of the depocenter and rarely were deposited within the depocenter. Later, subsidence and fluctuating base levels were conducive to the continued deposition and dissolution of saline minerals in the saline mudflat areas, further churning the sediment.

Clastic deposition increased after the initial period of uniform conditions. A more clastic-rich halite was deposited in the depocenter. Depositional facies migrated inward toward the depocenter. Subsequently, the size of the mud-poor salt pan decreased while the size of the mud-rich pan increased. The mud-rich and mud-poor salt pan environments interfingered with one another, with the mud-rich facies dominating. The source of clastic material was interrupted and clastic material, once again, could not reach the depocenter. Subsidence in the depocenter accelerated, and clear halite was deposited in the depocenter in a mud-poor salt pan environment. Further base-level drops associated with the increased subsidence exposed additional margin areas and allowed more syndepositional dissolution of those soluble minerals, particularly halite, in the newly created vadose zone. The base level stabilized or rose, and clastic deposition decreased dramatically in the depocenter. Mud-poor salt pan deposition once again dominated, depositing relatively clear halite in the depocenter.

A basin-wide freshening occurred following the deposition of a second clear halite unit in the depocenter. Minor amounts of halite dissolved from the interaction of halite with the fresher fluids. Laminated to nodular gypsum was deposited in a thin blanket over the underlying halite. The base of this sulfate probably represents a nearly isochronous event. The sulfate was rapidly deposited following the freshening event as it shows little evidence of thickening in the depocenter.

The fluids concentrated, and the areal extent of the standing body of water decreased, in response to evaporation. Sulfate deposition ceased in the depocenter, and mud-free salt began to precipitate. The underlying sulfate unit locally consists of polyhalite, suggesting that extreme salinities were reached during evaporation. The polyhalitized sulfate extends in some areas beyond the overlying halite This suggests that extremely saline fluids affected a larger area than is indicated by the halite. Clastic materials were no longer contributed to the basin in any large amount, and clastic facies are nonexistent. Subsidence was relatively rapid, and deposition was confined to a smaller area. A thick, lenticular

unit of nearly mud-free halite with two thin sulfate interbeds was deposited. Nondeposition prevailed along the margins of the salt pan, including much of the study area. This marginal area is apparently quite complex, and there are no cores to examine from the northern and eastern part of the study area to resolve some critical concepts. It was argued in Ch. 5 that the polyhalite probably formed early and halite was not dissolved late because: 1) permeability is usually low in halite zones, 2) polyhalite is about equal thickness whether adjacent to halite, mudstone, or anhydrite, and 3) removing halite should affect adjacent polyhalite. If polyhalitization occurred very early, there is still no direct evidence of specific mechanism, such as percolation of overlying brines, lateral migration of polyhalitizing fluids within unlithified sulfate, or evaporative pumping of brines associated with lateral migration. Within all of the cores described, this time is represented by a hiatus. A freshening event terminated halite deposition.

6.1.10 Anhydrite (A-3)

Fresher water, of possible marine origin, transgressed rapidly across the low topography. The base of the sulfate is nearly a time-line. The transgressive waters overlaid halite in the depocenter and the thin sulfate unit on the margins. Some halite within the depocenter area undoubtedly dissolved by direct contact with the transgressive fluids. Initially, thin laminae of carbonate-rich claystone were deposited by settling out of the transgressive waters. Locally, small stromatolitic algal forms grew. The water was fairly deep but probably not below storm-wave base. The salinity of the waters increased, and sulfate began to deposit. Fine-grained gypsum was deposited in thin laminae over the claystone. Vertically oriented crystals of selenitic gypsum grew along the substrate. Carbonate-rich interbeds were deposited with the gypsum. A thin rip-up breccia was deposited locally. It consists of thin, tabular clasts of anhydrite and carbonate in a gypsum matrix. Hardie and Eugster (1971) and Garrison and others (1978) report similar rip-up breccias. Hardie and Eugster (1971) interpret them to be the result of wave reworking of subaerially hardened crusts. It is possible that the rip-up breccias formed in that manner, although no other evidence of subaerial exposure (e.g., desiccation cracks) was found. Regardless of whether the clasts were derived from sediment hardened or lithified by subaerial exposure or in a subaqueous environment,

the breccias were deposited in a shallow subaqueous setting as infrequent storm events locally ripped up parts of the laminated gypsum, redepositing them as thin beds of tabular clasts. Dissolution continued to affect the underlying halite resulting in slumping and soft sediment deformation of the overlying sediment in a manner similar to the slumping and deformation of glacial and related sediments during the melting of ice, as described by Brodzikowski and Van Loon (1985). Vertically oriented selenitic gypsum crystals were disrupted by slumping due to dissolution and isolated storm events (e.g., Schreiber and Schreiber, 1977; Schreiber, 1978). The water depth decreased and low-angle slipface migration of bedforms became common. Vertically oriented selenitic gypsum continued to be deposited when the substrate was stable. Sequences of vertically oriented selenitic gypsum crystals with size decreasing upward were deposited as the water depth decreased. In at least one case, a shallowing upward sequence reached or nearly reached subaerial exposure and was accompanied by clastic deposition. Slumping of the overlying beds suggests that halite may have originally been present and dissolved soon after the deposition of the overlying gypsum beds (e.g., Schreiber and Schreiber, 1977; Schreiber, 1978).

After the deposition of the thick section of gypsum (A-3a), the substrate became very stable, and large vertically oriented selenitic gypsum crystals grew competitively upward and eventually became interlocking. The size of these crystals decreased upward indicating a shallowing upward (e.g. Warren, 1982a). Some of the large selenite crystals were syndepositionally dissolved. All or part of the coarsely crystalline gypsum was preferentially dissolved and removed to create a characteristic "crushed prism texture." The fine grained crystalline matrix deformed in response to the partial to complete removal of the selenitic gypsum. The size and number of prismatic selenite crystals controlled the morphology of the texture. Undeformed anhydrite above zones exhibiting the crushed prism texture indicates that the texture was fully developed prior to the deposition of the overlying material. The upper contact of the zones exhibiting the crushed prism texture (A-3b) is gradational.

Following the deposition and partial syndepositional dissolution of vertically oriented selenitic gypsum crystals in A-3b, the energy of the system gradually increased and more carbonate was deposited during the deposition of A-3c. The vertical change of bedforms reflects a change in energy, a shoaling upward. A fairly low energy depositional environment

producing subhorizontal to slightly wavy bedforms gradually became more energetic and dominated by wavy to lenticular bedded gypsum and carbonate. The amplitude and size of the cross-laminations increases upward reflecting shoaling conditions. Small, vertically oriented selenitic gypsum crystals were deposited during quiescent periods and, in some cases, were reworked. A nodular fabric was superimposed over laminated sediment. Similar bedded nodular textures have been reported by Hovorka (in press) who recognized that textures indicative of subaqueous deposition were preserved within the nodules. However, Hovorka (in press) did not assess the origin of the texture, and it has not been interpreted elsewhere. The texture is probably early and developed prior to, or synchronous with, the replacement of gypsum with anhydrite. Near the end of the deposition of A-3c, algal mats and stromatolites grew on and stabilized the gypsum and carbonate substrate. Algal forms are not persistent vertically through the section as they were short-lived and effectively swamped by overlying carbonate and gypsum.

6.1.11 Magenta Dolomite

Carbonate material rapidly dominated the clastic grain type at the onset of Magenta deposition, and both gypsum and carbonate sand and mud were interbedded. Subaqueous algal forms similar to those reported by Gebelein (1969) developed on the shallow sea floor. Algal mats, biscuits, and domes have all been observed. Algal mats stabilized the substrate providing a protective cover from erosion (e.g., Neuman and others, 1970). The sedimentation rate governed the morphology, with the biscuits and domes being deposited in areas with higher sedimentation rates (Gebelein, 1969). The lack of rip-up clasts of algal material indicates that wave energy never exceeded the strength of the mat. During quiet periods, vertically oriented prismatic gypsum crystals grew on the substrate. Algal biscuits and domes (laterally linked hemispheroids, after Logan and others, 1964) were deposited over carbonate and mat sediments. Over the algal biscuits and domes, carbonate sand and silt were deposited in wavy beds. The amplitude of the wavy beds decreases while the wave length increases upward, indicating a decrease in energy.

Gypsum and carbonate silt, sand, and mud were deposited in a cross-laminated unit which overlies the algal unit. The cross-laminated unit commonly exhibits lenticular and wavy bedding (after Reineck and Singh, 1980). Erosional scour and fill and drape features are common. Wavy and

lenticular bed forms become more abundant upward, while cross-laminated carbonate and gypsum of a more uniform grain size occurs near the base of the unit. Some small, tabular rip-up pebbles occur near the base of ripples and cross-laminae. The cross-laminated unit records an increase of energy over the algal unit. As both the grain size and the sedimentary structure size increase up the section, the kinetic energy of the depositional system is interpreted to have increased through time. This is consistent with shallowing upward. Unequivocal evidence of subaerial exposure has not been found. However, the presence of tabular rip-up clasts is consistent with subaerial exposure. Most of the deposit is interpreted to have formed within the subtidal environment. Deposition and accumulation was periodically rapid, depositing local climbing ripples. Near the end of Magenta deposition, gypsum again became a more common grain type as gypsum and carbonate laminae and beds alternated.

Several authors report cross-laminated carbonate deposits within various evaporite depositional environments (e.g. Eugster and Hardie, 1975, for sedimentation related to a playa lake complex; Demicco, 1983, for sedimentation in a transgressive, shallow subtidal to intertidal zone associated with a sabkha). Wavy and lenticular bedded carbonates described and interpreted by Demicco (1983) are similar to the Magenta. Demicco (1983) presented and interpreted an ideal cycle within the Conococheague Limestone of the central Appalachians. The ideal cycle consisted of, from bottom to top, with description (interpretation): intraformational conglomerate (sheet storm deposits); thrombolitic bioherms (subtidal algal patch-reefs); cross-stratified grainstone (subtidal ooid-peloid sand shoals); ribbon rock (intertidal-subtidal mixed sand-mud flats); prism-cracked laminate (high intertidal algal mud flat); mud-cracked laminated dolostone (sabkha). The Magenta does not totally fit Demicco's (1983) ideal Conococheague cycle. However, there are clear similarities. No intraformational conglomerate occurs at the base of the Magenta, as the base of the Magenta appears to be gradational with the underlying anhydrite. The next unit Demicco reports is a thrombolitic bioherm. This is somewhat similar to the Magenta as subtidal algal mats and stromatolitic forms occur at the base of the Magenta. The next Conococheague unit is a cross-stratified grainstone which is followed by a ribbon-rock unit (Demmico, 1983). Demmico's ribbon-rock unit displays wavy to lenticular bedding similar to that of Reineck and Singh (1980). The sedimentary structures contained within those two units are similar in

occurrence and distribution to the cross-laminated unit of the Magenta. Prism-cracked and mud-cracked units do not occur at the top of the Magenta.

The Magenta is not exactly analogous to a Conococheague cycle, which Demicco (1983) interprets as a shallowing upward sequence. It is not exactly analogous to either playa lake carbonates (Eugster and Hardie, 1975) or shallow, clastic marine evaporites proposed for sandstones of the Upper Miocene Solfera Series of Sicily (Hardie and Eugster, 1971). Yet the algal forms and bedding suggest relatively high energy in a shallow tidal shelf to lagoon environment. In the case of the Magenta, there is no specific evidence in cores to suggest the site area was subaerially exposed to any extent. The WIPP site apparently remained subtidal through the Magenta, and did not accumulate intertidal or supratidal deposits. Outcrops of Crow Flats (T17S, R28E) display thin brecciated zones within the algal laminated zone, indicating syngenetic dissolution and probably subaerial exposure. The Magenta was probably shallower than the underlying (A-3) sulfates; it was certainly a higher energy environment.

6.1.12 Anhydrite (A-4)

Gypsum and carbonate deposited subaqueously with intermittent subaerial exposure followed Magenta deposition. Crystals of gypsum and/or nodules of anhydrite grew displacively in the soft sediment during subaerial exposure. Chicken wire nodular and enterolithic textures developed near the end of A-4 deposition as subaerial exposure times increased. During subaerial exposure, nodules grew within the underlying soft sediment, including the Magenta. The bedded-nodular texture in A-3c developed during this time. During episodic floods, the water level increased, allowing the deposition of laminated gypsum sediment. Near the end of A-4 deposition, the water level dropped due to evaporation and sulfate deposition ceased as halite saturation was reached.

6.1.13 Mudstone/Halite (M-4/H-4)

Following the deposition of A-4, evaporation decreased the size of the standing body of water and subsequently initiated halite deposition. Salt pan halite was deposited in the lowest parts of the basin. Within the WIPP area, the margin was subaerially exposed and clastics were eroded and deposited. The basin flooded once again, bringing clastic material across gypsum at the basin margin and across halite in the depocenter. Halite

deposition resumed and the following facies were present, from basin margin to depocenter: mudflat, gypsum saline mudflat, halite saline mudflat, mud-rich and, episodically, mud-poor halite pans. Subsidence within the depocenter again controlled the vertical and lateral distribution of facies. Subsidence followed and the syndepositional dissolution of halite from halite saline mudflat facies along the basin margins occurred. A mud-poor halite pan developed within the depocenter. A second major flooding event again distributed clastic material to the depocenter of the basin. The facies were redistributed toward the depositional center. Minor subsidence within the depocenter followed and a nearly mud-free halite pan developed at the depocenter.

Within the WIPP site area, M-4/H-4 records the interaction between mudflat, gypsum saline mudflat, halite saline mudflat, and mud-rich halite pan environments. M-4 in the waste handling shaft and several cores resembles gypsum-rich mudflats at Saline Valley, California (Pl. 25, 26, 27 and 28). Syndepositional dissolution caused by water table variations is recorded near the base of the sequence in cut and fill deposits.

6.1.14 Anhydrite (A-5)

A basin wide transgression caused the halite and mudstone associated with M-4/H-4 to cease deposition. Minor syndepositional dissolution may have occurred within those areas containing abundant halite. Gypsum saturation was reached very quickly, and subaqueous laminated gypsum with minor amounts of carbonate began forming. Minor amounts of slipface migration occurred as low relief ripples migrated across the substrate. The substrate was occasionally capable of supporting the growth of vertically oriented selenite crystals. The standing body of water decreased in size and halite was deposited in the vicinity of the depocenter at least once during the deposition of the A-5 interval. Clastic material did not accompany halite deposition. Halite was not preserved within that interval in the vicinity of the WIPP. However, evidence of subaerial exposure occurs within the WIPP cores. A second transgression occurred, and gypsum and carbonate deposition resumed as before.

6.1.15 Rustler Formation/Dewey Lake Formation Contact

The contact between Rustler and Dewey Lake Formations is erosional at the scale of cores and shafts. However, the thickness of the upper Rustler anhydrite (A-5) varies little across the basin indicating a limited hiatus. Little or no localized tectonic activity occurred during the hiatus as there is no apparent angular component to the unconformity.

6.2 HALITE/MUDSTONE (H/M) DEPOSITIONAL MODEL

All of the zones now containing or previously containing halite within the Rustler exhibit several of the facies attributed to a halite/mudstone depositional model. Five major facies are recognized, including mudflat, gypsum saline mudflat, halite saline mudflat, mud-rich halite pan, and mud-poor halite pan (Fig. 6.1). The facies distribution is controlled by chemical and physical parameters associated with pan and mudflat environments. The H/M zones throughout the study area exhibit vertical as well as lateral mineralogical zonation within some units. This is the consequence of salinity zonations within the depositional environments, with the least saline ground waters and surficial waters at the margins or near sources and the most concentrated at the depocenter. This distribution contrasts with sabkha other environments marginal and connected to the sea. The distribution of facies is also constrained by the potential for clastic deposition, a function of the capacity and competence of the hydrologic regime within a particular depositional setting. Clastic material is introduced into the depositional environment only when the hydrologic system can carry it.

Modern marine evaporite deposits and saline continental playas are known to be chemically zoned (e.g., Hardie, 1968; Hardie and others, 1978; Eugster and Hardie, 1978; Till, 1978; Kendall, 1984). In most marginal marine-derived evaporites, seawater is the main source of fluid. Concentrations increase from the seawater to a maximum, usually in the supratidal area, and finally the concentration decreases further landward as nonmarine ground water dominates. The zonal pattern of mineralogies of the marginal marine environment records these salinity variations. Inland playa lakes are very commonly chemically zoned (Eugster and Hardie, 1978; Hardie, and others, 1978). Fluids move from their source at the margins of the basin to the center of the basin. Ground water increases in solute concentration toward the center of the basin. The least soluble minerals precipitate

first, along the margins, and the most soluble minerals deposit last, at the basin center. Rustler H/M sediments are similarly zoned and are considered to have formed in a setting very similar to inland playa lakes, though there was some marine influence on Rustler deposition.

The relief within the depositional area was extremely low, and clastic material should therefore show a relatively simple distribution pattern.

Although clay-sized material could probably be transported in suspension across the basin, the distance that coarser clastic material can be transported into the system is limited by the capacity and competence of the hydrologic system feeding the basin. In a basin with an extremely broad and flat topography and distant clastic sources, the maximum limits of clastic deposition probably varied little. Following the flooding stage (which may have been a gradual rising water level/not necessarily a sudden and energetic went), the base level raise further, pushing the limit of clastic deposition away from the depocenter.

Claystone, mudstone, and siltstone were deposited in marginal mud-rich environments. The marginal mud-rich environments were areally less extensive than the mud-poor salt pan. Evaporite minerals grew displacively within both the vadose and phreatic zones in the saline mudflat environments. Gypsum grew from less saline fluids further from the depocenter while halite precipitated from more concentrated brines near the halite pan environments. The halite salt pan deposits are subdivided into two parts: a mud-rich salt pan and a mud-poor salt pan. The mud-rich saltpan received more clastic input during the flooding stage. The mud-poor salt pan is the zone that was minimally affected by clastic deposition during flooding events. The primary distinguishing characteristic of halite deposited within the mud-rich salt pan is displacive growth of cements on multicrystalline seeds or relicts of halite crust. Mud-poor salt pan sediments are recognized by the classic void-filling cements with little or no displacive growth into muddy sediment. The terms mud-rich and mud-poor only reflect the ability of the hydrologic system to transport clastic material during flood episodes. The style of halite deposition is the same from one to another. However, the early diagenetic growth styles of halite are different. Episodes of flooding following desiccation brought clastic material out onto the mud-free salt pan environments creating mudstone and/or claystone interbeds within mostly clear halite.

6.3 SYNDEPOSITIONAL DISSOLUTION

Syndepositional dissolution plays an important role in the formation of evaporite sequences. Many authors have reported or interpreted the occurrence of syndepositional dissolution in both modern and ancient evaporite depositional environments (e.g., Schreiber and Schreiber, 1977; Schreiber, 1978; Powers and Hassinger, 1985; Lowenstein and Hardie, 1985; Shearman, 1970; Arthurton, 1973; Hovorka, 1983a, 1983b, in press; Hovorka and Granger, in press; Wardlaw and Schwedtner, 1966; Adams, 1969; Fracasso and Hovorka, 1986). Primary depositional fabrics within evaporites often are extensively modified by syndepositional dissolution. Three models for syndepositional dissolution have been created. Syndepositional dissolution fabrics are unique, and several criteria for their identification have been presented.

6.3.1 Syndepositional Dissolution Mechanisms

Soluble minerals can be exposed to undersaturated fluids in a variety of ways. Three hydrologic situations can cause syndepositional dissolution of evaporites. These include raising of the water table, lowering of the water table, and varying of the positions of fresh and saline ground water zones. In many respects, it is remarkable that evaporites are well preserved within the rock record at all. Halite deposition can be extremely rapid, but it is mostly ephemeral within the depositional setting.

The most commonly recognized and reported dissolution process occurs with the raising of the base level during flooding or transgressive events. Voids caused by the dissolution of halite during minor flooding events are considered to be unique to, and diagnostic of, salt pan deposition of halite (Lowenstein and Hardie, 1985). These voids are recognized petrographically by the abrupt termination of zones of fluid inclusions with a depositional origin. In some cases, very little primary depositional fabric is preserved within the halite. In mud-free halite, clear halite cements and void fillings bound those crystals exhibiting primary inclusion zoning. In mud-rich halite, displacive overgrowths on relict salt pan halite seed crystals exhibiting growth zonation are characteristic textures indicating syndepositional dissolution due to minor flooding. Large scale flood events result in the dissolution of a greater volume of salt, sometimes the entire existing sequence (Fig. 6.2). This style of dissolution has occurred in the Great Salt Lake and has been discussed by Hardie and others (1978). Hovorka

(in press) reports ancient analogues of dissolution due to major flooding during transgressions of less -saline water in the San Andres Formation of the Texas panhandle. Dissolution related to a major freshening or transgression can occur below the immediate sediment fluid interface. This results in the slumping and soft sediment deformation of the overlying, recently deposited sediment. The textures observed in the overlying sediment could resemble those formed by the melting of ice in periglacial sediments (e.g., Brodzikowski and Van Loon, 1985). Some authors (e.g., Schreiber, 1978; Schreiber and Schreiber, 1977) attribute deformation of evaporite beds to nearly syndepositional dissolution of underlying halite. One feature that is easy to diagnose is disrupted, tilted and slumped zones containing vertically oriented selenite crystals. These deformational textures develop before the overlying sediment is lithified. If a large body of low salinity water overlies a zone containing soluble material, or the sediment overlying the soluble material, for an extended period of time, a relatively thick vertical section of soft sediment can be deformed by dissolution.

The second major dissolution style is caused by the lowering of the water table. When the water table is lowered, those soluble minerals occurring within the newly created vadose zone are susceptible to dissolution by downward percolating meteoric water and surface runoff (Fig. 6.3). Erosion can also play a role in the process. Regardless of the composition of the fluids below the water table, the soluble minerals within the vadose zone will continue to dissolve until the water table, with fluids of sufficient concentration, is again raised. If no less-soluble or insoluble material is contained within the soluble rock, then no record of the dissolution is preserved, unless the dissolution is incomplete. If this is the case, then filled void space within rock will attest to the dissolution. This dissolution style accounts for some of the void space developed in salt pans following complete desiccation. In addition, this style of dissolution has been observed within the dominant halite sediments of the Devil's Golf Course in Death Valley, California and the muddy sediments of Bristol Dry Lake, California. If the water table remains lowered for an extended period of time, soluble minerals from the vadose zone are completely dissolved. A considerable thickness of soluble material could be dissolved if the water table dropped sufficiently. The water table can be lowered by a general reduction of the volume of fluid within the basin with little or no basin configuration change; vadose dissolution would then affect a distinct stratigraphic zone.

Tectonic activity can also produce a widespread water table drop. Subsidence within the depositional center lowers the water table along the margins (Fig. 6.4). This allows for the dissolution of soluble materials and subsequent redistribution of the solutes to the depositional center. The soluble minerals are effectively cannibalized from the margin. This type of syndepositional dissolution can cut across facies tracts significantly modifying their lateral distribution. Essentially, a new facies type is created by the dissolution and superimposed over the preexisting facies pattern.

The third hydrologic regime conducive to syndepositional dissolution is the result of changes in the lateral salinity distribution. Fresher water may be driven by higher potentiometric surfaces from the margins toward the solute sink, allowing a fresher groundwater to interact with the soluble minerals.

Within a basin or playa setting, this process is controlled by the size and density of the body of saline groundwater. As the areal extent of the saline groundwater and surface body responds to outside controls (evaporation, subsidence, and rates of precipitation), the freshwater zone moves and changes the maximum distribution of soluble minerals. Similar interactions of fresher groundwater are reported by Butler (1969) in the sabkhas along the Persian Gulf. Fresh groundwater from the landward side of the sabkhas dilutes the saline groundwaters derived from the lagoon (Butler, 1969).

6.3.2 Syndepositional Dissolution Fabrics

Fabrics representing all stages of syndepositional dissolution have been recognized or interpreted by a number of authors for both gypsum and halite (e.g., Lowenstein and Hardie, 1985 for incomplete dissolution of halite; Hovorka, 1983a, 1983b, in press; Hovorka and Granger, in press, for complete syndepositional dissolution of halite). Where halite is partially preserved, syndepositional dissolution terminates or truncates original depositional textures within a soluble material. When the most soluble minerals are entirely removed, less-soluble or insoluble constituents of the sediment are characteristically disrupted.

Syndepositional textures within halite from modern environments have been recognized and described in detail by Lowenstein and Hardie (1985). These textures are primarily voids and dissolution surfaces which truncate primary

fluid inclusion zones. Lowenstein and Hardie (1985) attribute some depositional fabric control to the orientation of voids, and they consider that the presence of these dissolution fabrics are unique to salt pan environments. These dissolution textures form during Lowenstein and Hardie's (1985) desiccation stage. During this stage, the water table is at or below the surface. If the water table is below the surface, the halite within the vadose zone is subject to dissolution by meteoric water. In either case, dissolution will occur during the next flooding event when the base level is raised and fresh water is brought in to contact with the halite.

Those sediments consisting of a high percentage of mud will also record the effects of syndepositional dissolution. Smith (1971) coined the term "haloturbation" for the repetitive disruption of muddy sediment by the expansive growth and dissolution of halite. Haloturbated sediments show a smeared intraclastic texture. Clasts and strata from the zone of removal will be smeared, distorted, and disrupted proportionally to the net volume of material precipitated and removed by haloturbation. Hovorka (1983a) implies that the matrix material will be poorly sorted due to the mixing of material derived from various clast types. Surviving clasts will retain their sorting. If the soluble material dissolves above the water table in the vadose zone, then soil or ped textures indicating the downward percolating water may be present. Complete soil development is not expected. However, incipient soils should be common and can be diagnosed by translocated clays and cutans. The degree of disruption is a factor of the number of growth and solution episodes that have occurred and the length of time above the phreatic zone. Mixing of intraclast types, without evidence of post-lithification brecciation of the overlying material suggests a syndepositional origin.

6.4 SEDIMENTATION AND TECTONICS

The depositional setting of the Rustler was controlled largely by the tectonic setting. Other authors (e.g., Valyashko, 1972) have discussed the relationship between evaporite deposition and tectonic history, particularly with respect to continental or continentally-influenced evaporite environments. The Rustler provides an excellent record of the tectonic end stages of a continental basin. The depositional style of the Rustler, evaporite pan/playa deposits with episodic transgressive deposits (the bases of which are essentially time lines), creates a picture of the subtle tectonic events that occurred during Rustler time.

The depositional style of the Rustler initially reflects a change in the local tectonic setting from Salado time. The Salado Formation was deposited in a setting influenced by little or no tectonic activity. Sedimentation kept up with subsidence, and the base level of the basin remained relatively constant with respect to the surrounding topography and underwent no major fluctuations. Minor changes in the base level caused by episodic flooding and subsequent desiccation are recorded by the Salado as areally extensive vertical changes in lithology. As the clastic content of the Salado is small and clastic materials were brought into the basin mainly following desiccation, the maximum potential energy of the system or the ability of the system to supply clastic material to the basin was quite low.

The lower portion of the Rustler consists predominantly of clastic materials. The presence of these clastic rocks suggests that the maximum potential energy level of the basin increased during Rustler time. As the transition from Salado evaporites to Rustler clastics is quite abrupt, the change of potential energy must have also been abrupt. The situation is compounded further when the depositional environments that produced the clastic rocks are assessed. Bioturbation, preserved fossils fragments, and fossils casts and molds in the lower Rustler indicate that those rocks were deposited in near-marine conditions. This implies that at the start of Rustler time the local to regional base level or sea level was much higher than that which produced the Salado. When the base level of a system rises, the potential energy of the system decreases. So base-level rise or decrease of potential energy must have been more than offset by a much greater increase of potential energy yielding a relatively thick Rustler clastic section.

Local and possibly regional tectonic activity increased during Rustler time. This provided the potential energy change that initiated Rustler deposition. Tectonic events which could produce such a change include uplift of clastic source areas, basin-wide subsidence and/or tilting, and subsidence of local depocenters. Of the possible tectonic events mentioned, only subsidence of local depocenters can be supported by direct evidence. Isopach maps of the total Rustler thickness and unnamed lower member (Fig. 4.7, 4.15) show evidence of thickening in the area of those depocenters. It can be generalized, however, that if either uplift of clastic source areas or basin-wide subsidence and/or tilting had occurred, the effect and, therefore, the actual extent of those processes was minor.

Zones containing halite and the bittern salts and their stratigraphic equivalents are especially useful for paleotectonic investigations. Halite and the bittern salts will be concentrated in the lowest topographic area within the basin. If the topography is very flat, then halite can be deposited over a large area. As the topography changes in response to tectonic influences, the distribution of halite also changes. Should differential subsidence occur, older halite will be exposed along the margins of the developing basin. Soluble minerals will be cannabilized. Halite will be dissolved from the margin of the basin, transported in groundwater or surface runoff, and redeposited in a halite pan. Thus, the halite section develops a lenticular shape with the thickest section at the point of greatest subsidence. The distribution of halite will record the shape of the subsiding area. It, therefore, becomes imperative that one can distinguish between halite removed by syndepositional processes related to tectonic activity and later dissolution unrelated to the depositional environment. In this report, halite is demonstrated to have been dissolved syndepositionally from specific facies tracts laterally adjacent to halitic rocks. The features that show this process can be used to better differentiate such processes from much later dissolution that has also affected some of these Rustler rocks.

Nearly instantaneous freshening events or transgressions create an effective time line or isochronous surface. The sediments deposited over the time line represent punctuated aggradational cycles (e.g., Anderson and others, 1984; Goodwin and Anderson, 1980). Within the Rustler, transgressions and freshening events are recorded by carbonates, gypsum, and anhydrite. The thickness does not vary much, indicating that either subsidence slowed during the deposition of these units or, perhaps more reasonably, the units were deposited rapidly enough not to greatly reflect ongoing subsidence. Where these units thicken slightly in the depocenter, it is reasonable to assume that they were more slowly deposited.

Evaporite beds of differing composition can have contacts that are fairly sharp and show no evidence of a hiatus or subaerial exposure between them. Over the lateral extent of such a contact, the standing body of water must have changed chemistry nearly uniformly by mixing. These contacts can be considered nearly isochronous planes. Chemically gradational contacts between carbonate and sulfate are an example of this type of isochronous surface. One example of this type of isochronous surface within the Rustler

is the contact between the Culebra and A-2. This contact appears to be gradational within the WIPP site area, and no evidence of subaerial exposure between the two units has been found. Thus, the lithologic change is interpreted to be the result of gradually increasing salinity causing biogenic activity within the waters to cease and sulfate saturation to be reached. Sulfate saturation and deposition was not absolutely isochronous everywhere, but in terms of Rustler events, it can be considered isochronous.

Isochronous events can readily occur within continental evaporitic depositional environments. Subtle changes in the tectonic development of the area can be reflected by these boundaries.

W

7.0 REVIEW OF DISSOLUTION

7.1 INTRODUCTION

From the time bedded salt was initially recommended (NAS, 1957) as the preferred rock type for the disposal of radioactive waste, part of the concern in selecting specific sites has been the role of dissolution. Thick sections of evaporites, including halite, in basins around the world clearly attest to the fact that circulating water has played little or no role in these parts of the basins. No halite section could long remain in the presence of circulating fresh, or even moderately saline, fluid in any quantity. Nevertheless, some basins, such as the Delaware Basin, that have evaporite rocks include areas in which outcrops and/or beds at depth contain no halite or appear to have greatly reduced sections of halite compared to other parts of the basin. These areas are frequently interpreted, with or without additional criteria, as the result of the dissolution of halite or other soluble evaporites from the section.

Within this chapter, many studies of rocks are reviewed; the examples range from modern to ancient and surficial to subsurface. The objective of this chapter is to summarize at least a portion of the evidence and collective wisdom that may be used to interpret rock units that are subject to solution. Some criteria are also distilled from the literature to use in separating processes and establishing relative ages, though these will no doubt be refined or rejected with experience.

Walters (1977) describes the circumstances in which halite is dissolving in central Kansas, causing continuing subsidence and collapse. Landes (1945), for example, describes features that he attributes to dissolution of halite and collapse of overlying beds, all occurring before the end of the Devonian. However, a number of studies concern basins where evidence may be mixed between modern and ancient (perhaps unrelated) episodes of dissolution. So too, the Delaware Basin continues to be examined for evidence of dissolution and the processes, rates and ages of such dissolution. The discussion and search for evidence continues partly because opinions vary as to the effects such dissolution might have on the long-term isolation of radioactive waste in the Waste Isolation Pilot Plant (WIPP). The extent and processes of dissolution are of industrial interest as well, as the dominant theory explaining the origin of native sulfur in world-class deposits such as the Pennzoil (formerly Duval) Culberson mine includes circulating water dissolving salt within the Castile Formation (Smith, 1978).

Evaporites are generally considered to dissolve when the factors of source, solution, pathway, and sink are present (Johnson, 1981). That is, a soluble material needs to be present, a fluid capable of dissolving the soluble rocks exists, a pathway for movement is provided, and a sink is available to permit continuing drainage from the area of solution. Lambert (1983) used slightly different terminology for these factors, using five terms (trigger, path, continuity, source, and sink) to be more explicit about initiating events (trigger), lateral or vertical extent of soluble rock (continuity), and the nature of the fluid (source). Though these factors are usually invoked in discussion of dissolution interpreted to take place at some depth within the rock column, they are certainly applicable as well for surficial or near-surface dissolution such as that which occurs in karst terrains. For the Rustler study, there is concern about the factors of continuity and trigger. More fundamental questions, however, override the discussion of these factors:

What is the real extent of dissolution in the Rustler Formation?

What is the timing of dissolution in the Rustler Formation?

What are the criteria by which we separate depositional variation, modern or continuing dissolution, and ancient dissolution?

The focus to this time has been to provide reasonable or possible explanations of relatively conservative estimates (that is, assuming the maximum) of the extent and effects of dissolution. Through re-examination of the extent, timing, and nature of the dissolution products, a better hypothesis or set of hypotheses should emerge which is applicable to southeastern New Mexico as well as other basins. There has been, within the discussion of the hypothesized processes and observable features of dissolution in southeastern New Mexico, an implicit notion of the scale of effects and features of significance. The features generally attributed to dissolution in this area are features observable at the scales effective for geophysical logs, perhaps mappable at scales ranging up to 1:100,000 or even 1:250,000, and visible in hand specimen without magnification. It is clear from this study (Ch. 8) that minerals and rock fragments have also been dissolved in the microscopic range. At all of these scales, the same factors are critical, as mentioned previously. The fundamental, observable difference in scale is due to the relative volume of material dissolved and whether the solutes were transported out of the system (at whatever scale of

observation). For example, a large relative volume may be removed from a microscopic volume without necessarily affecting operations or isolation of waste on the scale of a repository. These microscopic diagenetic alterations to the sediment are important in the history of the sediment, and will be examined. But the major focus of the review and discussion of dissolution phenomena and processes in this chapter is on scales that are nearer repository size.

7.1.1 Dissolution in Southeastern New Mexico

Dissolution of rocks in southeastern New Mexico has long been described and discussed. Lee (1925) discussed solution and fill related to the Pecos River valley and gypsum terrains here. Maley and Huffington (1953) described stratigraphic relationships of evaporite beds near and under the Pecos River valley; dissolution of some of the units was considered the source of thinned beds and the observable stratigraphic relationships. Olive (1957) described surficial troughs on a surface of Castle gypsum in the Yeso Hills/Gypsum Plain area; he concluded that subsidence had occurred as a result of dissolution of gypsum. More recently, Anderson and several co-workers, in a series of papers (Anderson, 1978, 1981, 1982; Anderson and others, 1972, 1978), discussed data and interpreted dissolution of the Castile and Salado Formations. These authors generally conclude that about 50% of the halite in the Delaware Basin has been dissolved and that a major part dissolved in the late Tertiary. Bachman (1974, 1976, 1980, 1981, 1984a,b) extends the period of possible dissolution, mainly for the Rustler and Salado Formations, back to Triassic, and possibly Permian, time. Lambert (1983) extensively reviewed the data and hypotheses concerning the existence, processes, and rates of dissolution for evaporites of the northern Delaware Basin. He has modified dissolution hypotheses previously presented by Anderson (1978). Holt and Powers (1984, 1986b) demonstrated the presence of abundant depositional features in the Rustler Formation at the WIPP site, including some zones that have been interpreted as dissolution residues. They concluded that dissolution of the Rustler was less extensive than had previously been interpreted. Sares and Wells (1984) present some of the details of dissolution associated with karsting of evaporites in their study of the Gypsum Plains.

While this section does not provide an exhaustive account of the study of dissolution in the Delaware Basin, it does indicate the range of studies that bear on the general problem of dissolution of evaporite units in this area. As part of a better approximation of the extent of dissolution of the Rustler, the sedimentology of the Rustler was examined and presented in detail in previous chapters. The features of several zones previously attributed to dissolution are interpreted as depositional phenomena, albeit with synsedimentary dissolution for some areas. Within this chapter, the features that have been attributed in other studies to dissolution, both surficial and at depth, from modern examples as well as ancient, are summarized. These features, as summarized, indicate relative timing as well as the nature of the process. These are compared to the explicit features of the Rustler Formation attributable to dissolution (Ch. 8).

7.1.2 Objective of the Rustler Dissolution Study

The principal objective of the Rustler study is to reassess the limits to which the Rustler has suffered solution. A better understanding of the depositional environments, as described in other chapters, provides an important step. Beyond that, other research on the effects of dissolution and the diagnostic features has been extensively reviewed. To this review and understanding of depositional environments are added direct observations of shafts, cores, and logs in order to better determine the extent to which dissolution has altered the Rustler Formation.

7.2 REVIEW OF DISSOLUTION

Dissolution processes and features are reviewed to set the stage for further analysis. In addition to the data and hypotheses concerning southeastern New Mexico and the Rustler Formation, the wider literature has been examined for related discussions. Some of the opposing viewpoints and some of the assumptions and/or background information and implications for southeastern New Mexico will be stated out as they may not always be explicit or familiar to some readers. Certainly, some of the details are not reviewed here, as that has frequently been done before (e.g., Anderson, 1978, 1981, 1982; Anderson and others, 1972, 1978; Anderson and Kirkland, 1980; Bachman, 1974, 1976, 1980, 1981, 1984a,b; Bachman and others, 1973; Lambert, 1983; Powers and others, 1978), particularly in these references with some emphasis

on the suitability of the northern Delaware Basin or the WIPP site for the disposal of radioactive waste. Several authors (e.g., Anderson, 1982; Bachman, 1984b; Lambert, 1983) have reviewed various hypotheses to account for some of the features in southeastern New Mexico.

This review begins with the features and characteristics from a number of studies in the literature and summarizes the evidence and processes hypothesized to account for them. It will become evident that there are processes which may occur at or near the surface (karst) as well as those hypothesized to occur at some depth within the sedimentary pile ("deep" dissolution or stratabound dissolution resulting in solution breccias). In addition, there will be features attributed to "early" and "late" stages; early may mean synsedimentary (e.g., Powers and Hassinger, 1985), or it may mean that the dissolution is geologically old and has been succeeded by some length of time with no evidence of dissolution. Late usually means that dissolution has occurred within the Quaternary or may be active. Neither of these terms has necessarily been used consistently with depth of process, so that near-surface ("shallow") and deep are also used as modifiers to describe the relative position of the sediments when dissolution took place.

Within this chapter, dissolution features or processes are grouped according to implicit or explicit interpretation of the location of the solution process: a) karst, if the dissolution occured at or near the surface, or b) solution breccia beds, if dissolution occurred at sufficient depth (undefined) to result in brecciation of the units.

7.2.1 Karst

The literature on near-surface dissolution or karst is very extensive for carbonates. Excellent reviews of karst and their hydrologic systems have been provided by Herak and Stringfield (1972), Boeglie (1980), Sweeting (1972), Jennings (1971), and in Dilamarter and Csallany, eds. (1977). Examples of paleokarst in carbonates are becoming more commonly reported.

Evaporite rocks dissolving at and near the surface by karst processes are much less frequently treated in the literature, partly because sulfates and halite, especially, are more soluble and do not crop out well. Among the reports of research on karst in evaporites in the southeastern New Mexico area are those by Sares and Wells (1984) and Bachman (1973, 1974, 1976, 1980, 1981, 1984, 1985, 1987a,b). These reports largely follow carbonate karst

terminology, as carefully reviewed in Bachman (1985), though additional terms have been introduced (Bachman, 1980). The processes by which karst is formed in evaporites are differentiated from carbonate karst by Bachman (1985), following Pfeiffer and Hahn (1972, p. 211); he considers the dissolution and corrosion of evaporites as dominantly physical processes in contrast to the chemical activity where meteoric water combines with CO_2 to form acid which dissolves carbonate. Though the processes by which karst is formed might be differentiated, most of the resulting landforms and near surface features are described by the same terminology and will not be described here.

Two new terms, karst mounds and karst domes, are applied by Bachman (1980) to evaporite karst features from southeastern New Mexico. Karst mounds are slightly elevated topographic features consisting of brecciated material attributed to solution-collapse and subsequent erosion of less resistant surrounding rocks. Karst domes are also slightly elevated topographic features, apparently domal in structure, and attributed to solution of surrounding evaporites at shallow depths and subsidence of these areas to leave the domal features. Some karst domes may be resistant to shallow solution due to a collapsed core from earlier dissolution. Extreme examples of this, from rather deep-seated earlier dissolution and collapse, have been reported from southeastern New Mexico (e.g., Elliot, 1976; Anderson, 1978; Bachman, 1987a,b) and elsewhere (e.g., Landes, 1945; Bowles and Braddock, 1963; Wenrich, 1985); among the names applied to these features are breccia pipes, breccia chimneys, and transformational breccias.

Modern surfaces on which evaporite-related karst has formed, or is forming, exhibit a variety of karst features. Pfeiffer and Hahn (1972) report large depressions as well as sinks as a consequence of evaporite dissolution in Germany. In the Swabian Alps, Pfeiffer and Hahn (1972) report karst as deep as 6,400 ft (2000 m) with fresh water. Few details of features are provided, though it is clear that open fracture and cavernous porosity must be present in highly productive karst zones. Pfeiffer and Hahn (1972) relate basins or dolines in evaporite karst to "regular salt leaching" from outcrop down along dip. They expect sinks and marginal tensional gashes to reflect "irregular salt leaching," solution at greater depth where water circulates in zones of deformation and disruption. Belloni and others (1972) report karst in Miocene gypsum along the Central Apennines of Italy and in Sicily, but they provide no details of internal features. Glazek and others

(1972) indicate karst phenomena, unspecified, occur on the Zechstein evaporites of western Poland. Bleahu (1972) reports collapse sinks or "suffusion phenomena" from underground solution of evaporites; he also refers to lapies, dolines, natural bridges, or blind valleys "when salt outcrops." Bleahu (1972) comments that some of these forms "owing to rapidity of the dissolution...display only an ephemeral existence."

Sares and Wells (1987) report their work on the karst of the Gypsum Plain of southeastern New Mexico. Among the features formed are dolines, collapse sinkholes, caves and erosional surfaces, while the drainage system has been significantly affected by karst processes. From the same general area, Olive (1957) examined large linear valleys which he termed solution-subsidence troughs. Bachman (1974, 1976, 1980) also reports dolines and collapse features in the Pecos River valley, some of which are attributable to evaporite karst. Nash Draw is considered by Bachman (1974) to be due to solution, erosion and subsidence from evaporite karst processes.

Modern or active karst terrains are mainly investigated for their hydrological patterns and may exhibit few important features to interpret ancient karst systems from the breccias and related rocks, including residues, that are the preserved record. Several studies of interpreted ancient karst in carbonates are important summaries. Units from two separate areas, the Madison Limestone or Group of Wyoming and Montana and the Mississippi Valley-type (MVT) lead-zinc deposits of Missouri and surrounding areas, reveal important features that are partially attributed to surficial and near-surface processes.

Roberts (1966) describes both paleokarst features and solution breccia beds from the Madison Group of south-central Montana. The Mission Canyon Limestone is the principal formation displaying these features. Roberts (1966) states that the paleokarst and solution breccia beds have some features in common: unstratified deposits, mainly carbonate fragments with some chert in a matrix that weathers reddish or yellowish gray, and mostly angular to subangular fragments. The clay mineralogy is different, mainly kaolinite in karst deposits and illite in solution breccias. Roberts (1966) reports that karst is not stratigraphically controlled, exhibiting poorly defined upper and lower surfaces, cavities that widen upward, and more matrix. Roberts (1966) also inferred that the karst developed in the late Mississippian, prior to the sedimentation of the Amsden Formation of late

Mississippian (Chesterian) to Pennsylvanian age. He separated the karst in process and time from the solution breccia beds.

Sando (1974) examined the Madison Limestone of north-central Wyoming, generally equivalent to the Madison Group of Montana, and described several features he attributed to paleokarst. Enlarged joints, marked by a filling of red clastics, are interpreted as fractures enlarged by meteoric water percolating down from the surface. Large cavities, with angular blocks of carbonate and clastic fill, occur at the top of the Madison and extend to as much as 90 ft (30 m) below the surface of the Madison. Sando (1974) interprets these cavities as sinkholes, as he did not find evidence of collapse of caves. Caves are also common in this part of the Madison. Sando (1974) differentiates pre-Amsden caves, filled with red clastics, from open cavities which may be Tertiary or Holocene in age. The older caves lack flowstones and dripstones, and are interpreted to have occurred below the vadose zone during the time of exposure in the late Mississippian; the limit to the vadose zone is also indicated by the deepest local base levels for erosion of the surface. Breccia zones that are stratigraphically limited and have a clastic matrix were also reported by Sando (1974). He follows McCaleb and Wayhan (1969) in interpreting these forms as having originated as another phase of the same process that formed caves, sinkholes, and enlarged joints during the Mississippian. In this respect, these authors differ from the interpretation by Roberts (1966) of breccia beds caused by solution at depth (see below).

The Carrara Formation and overlying Bonanza King Limestone in southern Nevada display angular breccia blocks, varying in size, that are grossly stratiform. The lithologies are distinctive and can be attributed to specific units, revealing that rough stratigraphic order is preserved in the breccia. Gillett (1983) proposes this breccia unit as a "healed" early Tertiary age cave. The hypothesis of collapse due to evaporite dissolution was rejected by Gillett (1983); he follows Middleton (1961), Roberts (1966), and Vaughn (1978) (see below) in expecting a planar basal contact and strongly stratiform body to form from evaporite dissolution. No direct evidence of evaporites was found and Gillett (1983) cites work by Palmer and Halley (1979) suggesting open-shelf, unrestricted marine environments. Gillett (1983) did not record flowstone features or speleothems commonly attributed to vadose zone caves. It is inferred here that Gillett (1983)

considers evaporite dissolution as a process that occurs at depth, though he did not directly state conditions.

Bretz (1950) describes features called circle deposits from Missouri. He attributes these to collapsed caves. Bretz also reports filled caves which "are so obviously solution caves that there never have been other interpretations of their origin" (p. 831).

7.2.2 Solution Breccia Beds

Several features, including solution breccia beds or rough equivalents and transformational breccias or breccia pipes, have been described by a variety of authors, most of whom have attributed the phenomena to dissolution of a bed, especially evaporite rock, at some depth under saturated (phreatic) conditions. The descriptions of these features yield some comparisons with the apparently karst-related phenomena. The Madison Group and MVT deposits are important areas displaying these features.

Landes (in Landes and others, 1945) extensively describes the Mackinac Breccia, brecciated equivalents to several Silurian to Devonian age formations of northern southern Michigan. Landes divides the breccia into three types: megabreccia, intra-formational breccia, and trans-formational breccia. Megabreccia consists of very large inclined blocks with random orientations. Stages of brecciation range from "let-down" to severely shattered and disturbed. Intra-formational breccia occurs in layers surrounded by non-brecciated rock. Landes always associates intra-formational breccias with megabreccias. Stages range from extensive fissuring to complete brecciation. Trans-formational breccias cut through several stratigraphic units, occurring as vertical bodies to several hundred feet in width. Landes estimates the vertical thickness to be as much as 1500 ft (500 m). Fragments are nearly all very angular. Some trans-formational breccias are well-indurated, forming prominent stacks or other features due to higher resistance to recent erosion than the surrounding rocks. More commonly, these breccias are porous and non-indurated to partially indurated and do not stand out as an erosion-resistant rock.

Landes (in Landes and others, 1945) concludes that brecciation occurred before deposition of the overlying Devonian Dundee Limestone. "Irregularities" (not further described) in the Dundee are attributed to later settling, but not to the episode of brecciation.

Based on relationships to the Silurian Salina Group, Landes interprets the Mackinac Breccia to have formed from collapse of overlying units when salt was dissolved from the Salina Group. He envisions solution and collapse as the Salina was exposed during early Devonian around the margin of the basin. Brines created by the solution may be the source of the central basin salts of the lower Devonian Detroit River Formation. The surface was eroded and smoothed, and the Dundee Limestone was deposited unconformably over the Mackinac Breccia and related formations. Recent erosion has re-exposed these breccias.

This report by Landes and others (1945) is the earliest extensive report of evaporite dissolution and collapse features not attributed partially or wholly to Pleistocene or later activity. The variety of breccia types are clearly distinguished, though the underlying mechanism is considered the same for all. Internally, breccias are consistently angular, though the degree of brecciation varies. The relationship to overlying beds, starting with the Dundee Limestone, is a clear feature to differentiate age. Landes clearly places the brecciation process as pre-Dundee based on the lack of breccia-related features in overlying rocks. It is not clear from review whether some breccias should be attributed to karst or not; most are clearly associated by Landes with solution at depth.

The Mississippian Boone Formation of the area around the Kansas-Oklahoma border near Missouri is a dominantly carbonate unit that hosts lead and zinc deposits and displays solution/subsidence features (McKnight and Fischer, 1970). Slump pipes are brecciated, irregularly cylindrical masses 100 to 300 ft (33 - 100 m) in diameter with a vertical displacement of several tens of feet along bounding vertical faults. Slump breccias are chert nodules to fragments of rock in a clay residuum in the Boone Formation. Later Mississippian units overlying the Boone have slump breccias with large limestone blocks and angular fragments in a residual material. McKnight and Fischer (1970) infer that these slump breccias are basal parts of slump pipes.

McKnight and Fischer (1970) also report on breccias formed tectonically within the Joplin Member of the Boone Formation. There, carbonate layers may be less competent structurally than chert zones. Along with brecciation, McKnight and Fischer (1970) report, for example, a large block of chert plucked from the lower part of the overlying unit and pulled laterally under

the unbroken part of the unit. Small thrusts and normal faults with low angles in the incompetent beds also signal this horizontal slippage even though the region has suffered only slight structural warping.

Ohle (1985) reviewed breccia types and probable breccia-producing processes for a variety of districts in North America hosting MVT Pb-Zn and related deposits. The breccia bodies are considered by Ohle (1985) to comprise two broad types: strata-bound (or mantos) and breccia columns or chimneys (or breccia bodies transecting strata boundaries). With some exceptions, the breccias are attributed principally to gravity-induced collapse associated with solution. Most of the solution and collapse is attributed to passage of hot fluids related to ore deposition, though some has been attributed to true karst. The breccias may consist of very large to very small, angular clasts that tend to be equidimensional rather than slab-like blocks associated with cave fillings. Ohle (1985) believes this shape factor, combined with unusual, often very narrow, breccia body dimensions, may indicate additional forces beyond gravity-induced collapse of dissolution zones. He proposes that tectonic forces may have been responsible for rockburst-like fragmentation of solution cavities in carbonates. As either an alternative or additional force, Ohle (1985) considers chemical brecciation (Sawkins, 1969; Lemish, pers. comm. cited by Ohle, 1985) a possible means of producing smaller breccia fragments consistent with these Mississippi Valley-type deposits.

Ohle (1985) also briefly mentions breccias of minor extent probably caused by sedimentary processes or syndepositional slides. Snyder and Odell (1958), as reviewed below, consider some of the breccia bodies to be syndepositional slides.

Rogers and Davis (1977) reviewed the geology of the Buick mine, a Pb-Zn mine along the Viburnum Trend of southeast Missouri formed in carbonate breccias. The setting is considered by Rogers and Davis (1977) to have been consistent with a carbonate-evaporite margin, and they attribute the brecciation as having been initiated through solution of evaporites and subsequent collapse. No direct evidence of evaporites was presented.

Beales and Hardy (1977) have summarized the indirect evidence for evaporites in the Viburnum Trend of southeastern Missouri. The "white rock facies" is associated with algal carbonates and minor redbeds, and the lateral relationships are similar to marginal carbonate-evaporite settings.

Beales and Hardy (1977) have also found small amounts of tiny gypsum crystals, including swallowtail twins, in impervious breccias which they conclude is direct indication of the former, more general presence of evaporites. These authors propose that evaporites may have been much more widespread, leading to much of the brecciation in the region now hosting abundant Pb-Zn ore bodies. The problem of "occult" evaporites was also discussed by Schreiber and Schreiber (1977) in a study of Mediterranean Messinian evaporites and modern solar salt works. On a very small scale (mm), halite layers between layers of gypsum crystals grown vertically on the sediment surface have disrupted normal epitaxial growth. The halite layers are absent laterally, due probably to dissolution. Thick units of Messinian gypsum consisting of thin beds with breaks in crystal growth are therefore considered suggestive that very thin beds of halite formerly existed.

Middleton (1961) also describes breccias within the Mission Canyon Formation of the Madison Group in Montana. He reports that the fragments are variable in size (microscopic to 10 ft or 3 m) and very angular to slightly rounded on edges. Limestone is the common lithology, but clasts are sometimes polymictic. Breccias of former breccias indicate multiple episodes. Fragments of different strata may be mixed, though a crude stratigraphy may be preserved. Middleton (1961) states that "the lower boundary of almost every breccia is well defined" (p. 191), though the breccias do not have the same extent upward. He describes well the upward transitions (p. 191):

> "A gradual transition may take place upwards from a breccia consisting of mixed, rotated fragments into one in which there is demonstrably little movement of the fragments and the rock has been brecciated in place."

Middleton suggests brecciation may have taken place before the Amsden Formation was deposited, but he is careful to point out he did not have evidence to support or refute this hypothesis. Finally, as the overlying units are not extensively brecciated, Middleton (1961) believes that "a thick breccia usually indicates an original zone of thin interbeds or interlaminations of limestone and anhydrite" (p. 194). Roberts (1966) investigated the Mission Canyon Formation as well, finding both paleokarst (see above) and solution breccia beds. Roberts found that solution breccia beds have a sharp, well-defined, and laterally continuous lower boundary. Roberts (1966) reported, as did Middleton (1961) and Severson (1952), a vertical progression of breccia fabrics from small heterogenous unsorted

fragments upward to slightly fractured and displaced roof rocks. Some wells in the area show anhydrite that is considered stratigraphically in the same position as the solution-breccias. Roberts (1966) considers this solution at depth to have occurred during or after Laramide orogeny.

Evaporites from the Williston Basin and surrounding areas are interpreted by Parker (1967) to have been partially dissolved. Beds overlying the evaporites are thickened by additional sedimentation to compensate for the salt removal and indicate the time of removal. Parker (1967) interprets these changes of thickness and lateral loss of halite mainly on the basis of geophysical logs. An important (and arguable) inference is that "thin regionally persistent sedimentary units directly above, between, and below the salt beds prove that locally there was little depositional change of salt thickness." In the Dillinger Ranch field (Wyoming), an estimated 100 ft of salt loss resulted in 38 to 93 ft (11.6 to 28.4 m) of thickening of Morrison and Dakota Formations in adjacent wells. From the Hurd area of North Dakota, 160 ft (48.8 m) of salt in a 200 ft (61 m) section is correlated laterally with 60 ft (18.3 m) of reported rubble/breccia. The cross-section accompanying this shows about 250 ft (76.2 m) of apparent compensation. Also from North Dakota (Fryberg field), salt was removed from Permian rocks resulting in complete compensation by the end of the Jurassic (Swift Formation), though elsewhere in the area, Parker (1967) cites Anderson (1966) to indicate that collapse may affect Jurassic and Cretaceous rocks. In the Outlook field in Montana, Parker (196[illegible]) shows that solution of the Lower Devonian Prairie Formation is completely compensated by sedimentation during the late Devonian.

In a review of features and processes related to dissolution of the Upper Devonian Leduc Formation from the South Sturgeon Lake field, Alberta, Stanton (1966) concluded that the late features were indistinguishable from the Mission Canyon solution breccias and the Mackinac Breccia. Stanton (1966) reports successive stages of primary evaporite, breccia composed of evaporite matrix with floating dolomite clasts, and evaporite-free breccia. The lithologies are dolomite clasts with anhydrite or dolomite matrix; the clasts range from sand to cobble size, are unsorted and angular. Anhedral dolomite clasts have sharp, straight edges while sucrosic dolomite is crumbly. Clasts may be fractured, brecciated and displaced. Stanton lists four features he considers important:

1) angular, unsorted, unbedded clasts; broken fragments displaced within breccia,
2) clasts often float in anhydrite matrix,
3) complete sequence: breccia with clasts floating in anhydrite --> breccia with more closely packed clasts and anhydrite matrix --> breccia without anhydrite,
4) fractures are rare beneath breccia; breccia grades upward into highly fractured rock.

Stanton (1966) considered four processes in the development of the Leduc breccias:

a) solution brecciation causing settling of evaporites, plastic deformation, concentration of fine clasts up against clast surfaces,
b) change in volume as gypsum --> anhydrite; lower strength from water in the rock,
c) simultaneous clasts and evaporite "deposition"; no bedding or rounding,
d) selective replacement of carbonate by anhydrite to explain anhydrite matrix.

Of these mechanisms, Stanton (1966) considers solution brecciation to account for all features observed. He also concludes that the solution brecciation is probably common at very shallow depths and that "gradual subsidence, brecciation, small-scale solution precipitation, and evaporite flowage occur simultaneously with the evaporite solution."

The Elk Point Group evaporites of the Prairie Provinces, Canada, are considered Devonian in age. The Prairie Formation, part of the Upper Elk Point Subgroup, consists of sulfates and halite; it overlies the Winnepegosis Formation, a limestone unit. Gorrell and Alderman (1968) review evidence of salt solution from the Prairie Formation in Saskatchewan. On the basis of geologic data, solution began as early as late Devonian. Salt springs in the area are considered evidence that salt solution is continuing.

Salt solution of the Elk Point Group locally has resulted in collapse features (DeMille and others, 1964; Christensen, 1971; Gendzwill and Hajnal, 1971), similar to breccia pipes reported for southeastern New Mexico (Snyder and Gard, 1984; Bachman, 1987a; Davies, 1983) as well as broader structural lows and unit thinning. Compensating thicknesses of overlying units may be used to infer ages of solution and, in some circumstances, differentiate

solution from tectonic or depositional features. Gorrell and Alderman (1968) distinguish depositional from dissolution edges on the basis of the configuration of the underlying units versus dip on the salt units (Fig. 7.1). Sharp changes in halite with reversal of dip are associated with dissolution. The underlying units change little. Consistent dip directions and changes in dip of underlying units are associated with depositional changes. The Palo Duro Basin of the Texas panhandle is one of the potential sites for the first repository to dispose of high-level radioactive waste. As the rocks of interest are evaporites, various geological and geomorphological studies examine the extent, nature, and timing of dissolution.

Gustavson and others (1980) recognize salt dissolution based on: 1) high solute loads, especially chlorides, in streams; 2) salt sequences that abruptly disappear between relatively closely spaced wells, as well as abrupt thinning of stratigraphic sequences away from salt units; 3) zones with abrupt salt thinning that also truncate facies tracts; 4) cores that show poorly consolidated to unconsolidated red-brown mud overlying salt beds; and 5) folds, collapse chimneys, breccia blankets, and sinkholes on Permian outcrops.

Criteria 2 and 3 are not easily reconciled with the figures referred to in Gustavson and others (1980) as the "relatively close spaced wells" usually appear to be 5 miles or more apart, and it is not clear, on the basis of the natural gamma ray logs presented, how the presence/absence of halite is always interpreted. Criterion 4 could be consistent with syn-sedimentary dissolution.

A playa, Lake McConnell, overlies an area where about 165 ft (50 m) of salt appears to have been removed. Gustavson and others (1980) question if the relationships are clear in indicating cause and effect between lake and salt dissolution. The origin of other playas appears to be different, in that some do not show any evidence of salt dissolution in underlying formations. Modern collapse is occurring in Hall County as sinks and depressions have been formed and attributed to salt dissolution.

Collapse chimneys in different areas of the Texas panhandle range in probable age from late Cretaceous to as late as Quaternary. Boundaries are nearly vertical with slickensides. Bedding may be vertical, and breccias may be cemented or uncemented. The breccia chimneys are located over areas

identified as actively being dissolved or of possible paleodissolution of salt.

Dissolution is considered also to have caused fracturing of Permian mudstones and filling of fractures with gypsum. Goldstein and Collins (1984) describe in some detail the fault and fracture sets in outcrops of Permian formations overlying areas believed to have undergone or be subject to salt dissolution.

Portions of the Permian age evaporite-bearing section in the Palo Duro Basin area have been described as having undergone dissolution, and salt springs and chloride loads in drainages demonstrate salt is still being dissolved (e.g., Gustavson and others, 1980). Gustavson (1986) has re-examined evidence of salt deposition and dissolution in the vicinity of the Canadian River valley to test the hypothesis that the river developed in response to solution and collapse. As evidence of dissolution of evaporites, Gustavson (1986) cites the following:

a) "abrupt" lateral loss of subjacent salt associated with "structural collapse" of overlying units (emphasis added);

b) brecciated zones, fractures with slickensides, extension fractures filled with gypsum, insoluble residues of soft mudstone, anhydrite, or dolomite overlying salt;

c) folds, breccia-filled chimneys, and systems of gypsum-filled fractures in Permian outcrops along the Canadian River Valley;

d) sodium chloride brines in some wells above salt; and

e) high chloride in the Canadian River.

Gustavson concludes there "is strong evidence that Permian salts formerly extended farther to the north, northeast, and northwest beneath the valley of the Canadian River" (p. 463). Gustavson (1986) concludes also that a few salt units show lateral facies changes, generally without change in thickness or structural complications. Gustavson (1986) relates the Canadian River valley to salt dissolution based on several factors: the river trend is not that of the Ogallala system; the trend follows the structural trend on the Alibates, overlying the zone attributed to dissolution; and the plain north of the valley is about 250 ft (75 m) lower than to the south. This difference is also attributed to dissolution. Gustavson (1986) infers that the age of dissolution may be as early as Miocene.

Residues or breccias are reported by Smith (1972) as textural evidence of more extensive or "mature" near surface dissolution of the Upper Magnesian Limestone of England. Beds of the Upper Magnesian Limestone have variously collapsed or foundered as a consequence of dissolution of the underlying anhydrite beds. The residue from the anhydrite consists of carbonates and clay minerals with some gypsum and quartz and traces of detrital heavy minerals. It has been estimated that the original anhydrite might have been 100 to 200 ft (30 to 60 m) thick based on the insoluble content of the equivalent anhydrite elsewhere.

The degree of brecciation reported by Smith (1972) is highly variable. The clasts may vary from angular to subangular. The clast margins and the matrix from the Upper Magnesian Limestone are enriched in calcite relative to the center of clasts; this "dedolomitization" is attributed to the reaction between groundwater and the rock at the time of the dissolution of the underlying anhydrite and collapse of the limestone. Smith (1972) attributes the brecciation to "a number of rapid collapses separated by a long period of relative stability" (p. 264). In addition, broader scale foundering of strata is interpreted by Smith (1972) to be the result of gentle and slow sagging, and the process is considered to cause only slight brecciation. Along with this gentle foundering, the Upper Magnesian Limestone in the area displays "a gentle warping (not found in beds underlying the evaporites) into innumerable domes and basins of up to 10 metres (sic) amplitude and 25 to 200 metres (sic) diameter" (p. 266).

7.2.3 Other Breccia Sources

The Bonneterre Dolomite of Late Cambrian age is a Pb-Zn ore-bearing unit in southeast Missouri interpreted by Snyder and Odell (1958) to include breccias of approximately syndepositional origin. The breccias lie laterally adjacent to carbonate bars or banks and possible reef deposits. The breccias vary from very small clasts to large blocks >3 ft (>1 m); "locally within the disturbed mass, beds may be crumpled and folded without fracturing..." (p. 906). Snyder and Odell (1958) report that fragments are angular and there is little evidence of abrasion. The matrix is dolomite with other constituents, and it encloses breccia blocks. In addition to carbonate breccias, dolomitic shale breccias occur with carbonate matrix. Both types of breccia are tight, with rare cavities or open spaces.

The breccias are interbedded with undisturbed beds. The bodies of breccia may be >2 mi (3 km) wide, >100 ft (300 m) wide, and as thick as 80 ft (25 m). Later breccias can truncate earlier breccias. The basal contact may also be concordant or gradational with soft sediment to more brittle deformation marking the contact. While the units are adjacent to carbonate banks and reefs, they also tend to accumulate in areas where the carbonates are thin (and the depositional surface was presumably lower). Internal structures include small thrust faults and drag folds.

Snyder and Odell (1958) believe the breccia bodies moved and formed during early diagenetic and lithification stages. A bed on the margin of a carbonate was subjected to increased slope by greater compaction of the basin facies. A glide plane forms in more indurated units as the unconsolidated material near the surface-water interface from higher on the slope begins to move. More lithified beds are brecciated, and drag folds and thrust faults are created by the slumping mass. The glide planes and different brecciation styles within the breccia masses have been used by Snyder and Odell (1958) to separate breccia masses into distinct events.

Important diagnostic characters used by Snyder and Odell (1958) were:

a) localization and shape of breccia bodies,

b) interbedded undisturbed units,

c) position relative to carbonate banks or reefs,

d) different degrees of brecciation within masses, and

e) glide planes.

An individual mass, encountered in a core, for example, would reveal angular fragments within a matrix. It is possible the undisturbed units would also be properly interpreted. But the interpretation reached by Snyder and Odell (1958) would not have been reached without the extensive three-dimensional data available within the Pb-Zn mines.

Smith and others (1961) describe limestone breccia in a calcareous siltstone matrix and small shale and sandstone masses in the Mississippian St. Louis Limestone in Indiana. The breccia and clastic masses have dimensions of a few to tens of feet (m). The breccia body is "crudely funnel shaped". Breccia fragments range from very angular to subangular and up to about 6 ft (2 m) in length. Some fragments are reported to have stylolitic surfaces. Matrix displays contorted to sinuous bands of siltstone and sandstone that are even vertical in some places. Smith and others (1961)

suggest these breccias formed, probably during the Pennsylvanian, by folding and slumping due to movement on the Mt. Carmel fault. Other origins may not be eliminated, given the limited data, though Smith and others (1961) consider tectonic breccia, glacial loading, cave collapse, and evaporite solution and collapse as less likely alternatives. Evaporites in the St. Louis occur at or above the zone of breccias, and the thickness of evaporite is small in undisturbed areas. Undisrupted lateral beds also suggest that evaporite solution-collapse is not applicable.

The sandstone and siltstone masses are interpreted by Smith and others (1961) to have formed by filling small caverns on a paleokarst terrain now reactivated on a modern karst surface.

7.2.4 Delaware Basin Features

Anderson and others (1972), in a now classic paper on the laminated Castile Formation of the Delaware Basin, discussed the relationships between beds of anhydrite breccia and laterally equivalent halite units. During earlier work, Anderson and Kirkland (1966) and Kirkland and Anderson (1970) reported that short, selected thin intervals of laminated couplets from a few cores across the basin showed high correlation coefficients ($r = 0.99$). Anderson and his coworkers have concluded that there is a near one-to-one correspondence of laminae couplets across the basin, as well as of larger units, nodular zones, and other features. They concluded that lateral facies changes did not occur within the basin. Around the western margin of the basin, Anderson and others (1972) reported finding breccia beds in positions stratigraphically equivalent to halite units in the eastern part of the basin. Anderson and others (1972, p. 70ff) recorded some of the details of the arrangements of breccias in these beds:

> "Beds of laminated anhydrite as thin as one foot thick within halite beds more than 50 ft (15.2 m) thick are also present as unbrecciated layers within correlative breccia units, involve approximately the same number of laminae, and maintain their identity and remain undisturbed within overlying and underlying breccia beds despite the removal of salt. The presence of thin anhydrite beds within halite members can also be inferred from sonic logs, and these beds can be correlated with breccia zones in the University of New Mexico-Phillips no. 1 core...."
> "The breccia generally consists of rectangular-shaped, subangular fragments of single laminae or groups of laminae embedded in a matrix of anhydrite... The fragments, generally less than one cm in length, occur

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in various orientations, but most occur with stratification, if visible, and long dimension near the horizontal. Many of the fragments appear to have been only slightly displaced."
"In some of the blanket breccia beds it is difficult to correlate the upper contact because of solution collapse that resulted in a collapse-type breccia...consisting of larger, more angular fragments than the blanket solution breccia, and with little matrix. Good examples of collapse-type breccia have been observed at the top of the Halite II Member (sic) and in the upper part of the Anhydrite IV Member (sic) above blanket solution breccia."

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Along the eastern margin of the Delaware Basin, Anderson and others (1972) report the relationships within halite of the Union-University "37" core:

"The Winkler County core, however, revealed that thin anhydrite beds of only a few decimeters thick within more massive halite units maintained their position and character after halite solution. This fact (sic), and the observation that single anhydrite laminae, once separated by several centimeters of halite, were sometimes little disturbed upon solution, showed that the withdrawal of halite was a very gentle process."

Anderson and others (1972) consider dissolution most likely to have taken place after Salado time.

Both in Anderson and others (1972) and Anderson and others (1978), geophysical logs were used in conjunction with core to conclude that dissolution accounted for the lateral thinning of units from thick halite to thin breccia beds. It was concluded that each of the halite units is represented by a breccia bed. Interpreted geophysical logs also yielded thickness information for halite and sulfatic units indicating differing thickness patterns for these units, unlike models of deep water deposition.

Anderson and others (1978) recognize two different types of breccias within the breccia beds: dissolution breccias and collapse breccias. Within dissolution breccias, Anderson and others (1978) see textures similar to those described above, having fragments oriented generally parallel to bedding in units above and below. In addition, they also report that some fragments "are quite small (less than 0.5 cm), rounded, and suspended in random orientations within a matrix that comprises more than half the volume of material." The matrix is an impure anhydrite matrix. Anderson and others (1978) report that the dissolution breccias may be as much as a few tens of feet (several m) thick and "are approximately proportional to the thicknesses of correlative salt beds." These authors estimate that the ratios of breccia

to salt thickness is about .03 to .05 within the examples available to them. Collapse breccias are angular fragments of anhydrite often overlying the dissolution breccias. "The angular fragments are fitted together in a tight interlocking pattern with little or no fine-grained anhydrite matrix. The fragments range in size from a few millimeters to blocks of more than 30 cm, with a definite tendency for fragments of similar size to be found together." These authors describe this type of breccia as forming "at apparently random positions in overlying anhydrite beds" as a consequence of dissolution chambers collapsing resulting in "a diminishing chain reaction above."

In addition to the features of the breccia beds, Anderson and others (1972, 1978) consider that solution and subsidence/collapse caused, or is related to, the Big Sinks dissolution area, troughs with Gatuna-age sediments at the surface (Maley and Huffington, 1953), and breccia pipes, castiles (Kirkland and Evans, 1976; Anderson and Kirkland, 1980) and other collapse structures (Vine, 1960, 1963).

Anderson and others (1978), as well as Anderson (1978), attribute dissolution around the margins of the basin to probable effects of contact with the Capitan reef. Anderson and others (1978) are somewhat vague about the general process of dissolution, referring to an advancing front in the subsurface, probably preceded by caverns and tunnels at the leading edge developing an uneven front. They also attribute part of the dissolution to breccia pipes and other collapse structures. Anderson (1978) and Anderson and Kirkland (1978) described more specific roles for intrusion of water from the underlying Delaware Mountain Group through fractures, resulting in collapse structures or breccia pipes. Anderson and others (1978) suggest some blocks and fragments may have moved laterally into voids between separated horizontal laminae of anhydrite, and that fluids or slurries may have helped move brecciated rock.

More recently, Robinson and Powers (1987) report a fan-shaped "breccia" unit in the Castile near the western margin of the Delaware Basin as a gravity-driven clastic deposit. Multiple cores from a relatively small area reveal bedding in clast units, graded clasts, clasts in an anhydrite matrix or cement, and intermittent normal laminated beds similar to those described by Anderson and others (1972, quoted above). Robinson and Powers (1987) interpret this unit as a Permian-age gravity-driven clastic unit, not as a

dissolution breccia. It is not clear that Halite I of the Castile was deposited west of this area.

In many publications (e.g., Jones and others, 1973), the Rustler and upper Salado have been described as having undergone dissolution, resulting in complicated surficial features. However, specific features of the breccia beds have not generally been presented. Basic data reports for WIPP boreholes variously present general to detailed descriptions of material attributed to "dissolution residue"; the information from redescribed cores (Ch. 5) and interpretations (Ch. 6, 8) differ in many ways from those in the basic data reports. Lambert (1983) describes the relationships among several features related to dissolution or hydration in the vicinity of Nash Draw; he indicates that geophysical log signatures in the area of Nash Draw may be guides to units that have been partially dissolved.

Core from the Permian in Culberson County, Texas, is described by Eager (1983) as exhibiting breccia within parts of the Rustler and Salado Formations, but no details are given of the nature of the breccia or extent. Natural gamma ray and neutron logs accompanying the lithologic log do not indicate any signatures diagnostic of the breccia, and Eager (1983) did not report any difficulties in reconstructing the stratigraphic sequence within the cores.

7.3 DISCUSSION OF LITERATURE REVIEW

The review of the literature reveals several points and areas that may be inferred to be common. Various authors clearly differentiate between those solution events that occur from the surface downward, either at or near the surface, and those events which took place after some amount of burial and which begin at the bed. These concepts have been paralleled by the discussion of dissolution in southeastern New Mexico, where a dichotomy has been constructed between "deep dissolution" and near surface (generally related to karst processes) dissolution. It is not possible to assign specific depths to these phenomena, for the various authors appear to have different, sometimes unspecified, criteria for deep and near-surface. However, we may here differentiate these two end members of a probable general continuum as follows:

Surficial to near-surface processes show clear and relatively direct connection to meteoric water sources from the surface downward, with soluble material dissolving as meteoric water passes through. "Deep dissolution" shows an indirect connection to meteoric water with dissolution initially generally confined stratigraphically and not immediately affecting the superjacent rocks except by brittle deformation as a consequence of removal of material from the affected bed.

These two kinds of processes, in the reviewed literature, result in grossly different features as they are preserved in the geological record. Near-surface, karst-related processes will result in a sequence of brecciated material with sharp boundaries at the upper surface (Fig. 7.2a) as deposition covers karst and ends the process. The lower extent of dissolution may be controlled at a water table or at some chemical boundary, but, unless the dissolution proceeds to a very mature stage, the lower boundary is likely to be poorly defined and irregular. By dissolving a bed buried to some depth, a lower boundary will usually be much sharper, defined by an insoluble or much less soluble underlying rock. The breccia is likely to be more continuous laterally, and brecciation will propagate upward to a variable distance (Fig. 7.2b) in response to the removal of soluble rock. The upward boundary will generally, in this process, be more diffuse and undefinable, unless so much material is removed that fracturing propagates uniformly to the surface. We should still expect, however, that the brecciation, as described well by Middleton (1961) and others, will decrease upward as the fractures become hairline cracks to microcracks and may disappear.

The time of dissolution can be well-defined in some cases. It is clear that there are rocks in which dissolution has occurred, but in which the process has long ceased to operate. Landes (1945) and Parker (1967) provide two differing kinds of evidence of dissolution episodes from the geologic past. The criteria by which these authors decided the issue are that deposits overlying a surface that had been brecciated were unaffected and that compensation in the form of deposition had taken place by a particular point in geologic time. Present day geomorphic and sedimentologic adjustments may not easily be interpreted to determine if dissolution is contributing to the adjustment or not. It may be in a developmental stage or have been completed without a unique stage being assignable. Gustavson

(1986) and other authors describing the Palo Duro Basin have compiled criteria they believe indicate continuing dissolution. Among these criteria, local subsidence and water carrying a large chloride content are the clearest, most easily accepted evidence of continuing dissolution.

A particular problem, largely unaddressed at this time, is assessing the effects and extent of early or synsedimentary dissolution. Among the papers surveyed, few reveal any consideration of early or synsedimentary dissolution of evaporites. Of these, Powers and Hassinger (1985) relate synsedimentary dissolution in one horizon from the Salado as exposed in workings at the WIPP site. Hovorka (1983a, in press) provides evidence of synsedimentary dissolution of halite to produce disturbed textures within parts of the San Andres Formation of the Palo Duro Basin. Of the papers known to consider dissolution of these most soluble of rocks, only these present significant evidence of synsedimentary dissolution (other papers consider mainly microscopic evidence of very minor removal; e.g., Schreiber and Schreiber, 1977). Lowenstein (1985, 1987a) proposes that early diagenesis cements and plugs halite units before the sediment is buried deeper than a few tens of feet (several m). Early dissolution features as they are presently known are tied very closely to the sedimentation surface by observation, consistent with the proposal by Lowenstein. It seems clear that the rocks demand an examination of modern analogs for evidence of significant dissolution.

The extent of dissolution has been assessed largely by extrapolation from areas with evaporites to areas without evaporites or with a decreased section. Parker (1967) presents an early example based nearly exclusively on geophysical log interpretations. This approach, supplemented by some core information, was also used by Anderson and others (1972, 1978) and by other authors attempting to understand the extent and nature of dissolution in the Delaware Basin. As reviewed in several sources, the principal justification for this practice is that underlying and overlying units are laterally extensive from areas with salt to areas without salt; it is believed that lateral facies changes within salt beds did not occur over short distances either. Gustavson (1986), Anderson and others (1972, 1978), and Parker (1967) clearly follow this line of reasoning. Anderson and others (1972) utilized the correlation of limited sequences of anhydrite/carbonate couplets within the Castile to bolster their belief that sulfatic and chloride beds extended virtually from side to side of the Delaware Basin. This provides a

conservative, upper limit to the extent of salt dissolution within the basin. It is also clear, however, that within salt pan environments (Lowenstein and Hardie, 1985) lateral facies changes may occur over rather short distances, enhanced by the depositional changes that bring clastics to the margins and remove soluble materials. In addition, as water evaporates from basins, the brine is restricted to well-defined areas, again resulting in lateral facies changes over short distances. Within the Rustler Formation, as previously discussed, and in the San Andres (Hovorka, 1983a, in press), significant changes in environments and/or relative sea level may occur rapidly, resulting in the rapid covering of an area with a carbonate from much higher and fresher water. These units may extend laterally far beyond the extent of a previous saline pan, and they should not be considered direct evidence of the extent of the most saline facies. As in some previous types of evidence, the extent of evaporites will have to be evaluated basin by basin and case by case.

The rate at which evaporites dissolve is not easy to evaluate. The criteria and examples provided by Parker (1967) may be as clear as any. In the Williston Basin, sedimentary units which adjust to dissolution have lower and upper bounds well defined in geologic time. The adjustment within parts of the Fryberg field of North Dakota clearly took place during the latest Jurassic, bounded by the deposition of the Swift Formation. Approximately 100 ft (30 m) of compensating sediments were deposited within a few million years. Within the Delaware Basin, different authors have attributed dissolution to widely varying lengths of time as far back as Permian. Significant amounts of evaporites have been considered dissolved even as early as the time of the end of Castile deposition (Anderson and others, 1972; Bachman, 1974, 1976, 1980). In contrast, Anderson (1978, 1982) and Anderson and Kirkland (1980) attribute most dissolution to Cenozoic or later Cenozoic time.

The forms which the dissolution residues take are often considered rate-dependent. Breccia and brecciation are considered consequences of evaporite solution and subsidence/collapse. However, several authors (e.g., Anderson and others, 1972, previously quoted) have also interpreted dissolution to occur under some circumstances so gradually that thin, laminated anhydrite beds within halite beds may be undisturbed while large volumes and percentages of halite are removed; at the same time breccias are

formed around the undisturbed thin anhydrite beds. Though this process is not advocated in this report, it may be important from a risk assessment view to question whether such a slow, gradual process would, even if it occurs, be of any consequence to a waste repository.

Following this last point, it is appropriate to comment on the scale of events and processes that may be said to involve the dissolution of rock materials. Within the sedimentary sequence, several types of processes, sometimes given various names, may involve small or large amounts of dissolved rocks with transport distances of solutes ranging from microns to kilometers. Pressure solution from grain-grain contact and the creation or destruction of porosity is near one end of this scale. Hardly any sedimentary rock is free from the minute effects of diagenesis, including for some the effects of weathering immediately following deposition. These well-known, if imperfectly understood, phenomena are not reviewed here, though their effects are seen even in the Rustler (Ch. 8) and are reported. Near the other end of the scale, relatively high proportions of rocks of considerable volume may be removed completely from the system. This scale of process and consequent features are of principal concern within the previous review as these are the scale of processes and features that are hypothesized and reported, respectively, to occur in the Rustler as well as in the underlying evaporite formations.

It is important also to note a distinction in timing for the processes normally attributed to dissolution. It is quite clear, from published studies of dissolution of the Rustler and other evaporites in the Delaware Basin, that dissolution is a term used for processes occurring long after the deposition of the affected units. The term is used in the same sense in this report. These are phenomena associated with very early, approximately synsedimentary solution of evaporites from the Rustler, occurring before burial and lithification. In that sense, part of the reported sedimentary process includes the effects of early removal of evaporites from some of the same units interpreted by others as dissolution having occurred after burial and lithification. Synsedimentary processes are distinguised from late-stage dissolution in this report by calling it early or synsedimentary dissolution. Such features and processes clearly are associated with the sedimentary history of the units, differentiating them as well because they may be eliminated from the calculations of the consequences of dissolution affecting the WIPP at some future time.

The general features that are most widely accepted as evidence of later dissolution at depth are angular breccias that have propagated upward but with diminishing strain. These have lower bounds that locally are well defined. Early, synsedimentary dissolution or dissolution before subsequent burial reveals an upper boundary that is stratiform. Some of these relationships are applied to the physical features apparent in cores, shafts, and geophysical logs in the next chapter.

8.0 POST-DEPOSITIONAL ALTERATION

The late Permian Rustler Formation has a complex post-depositional history. Diagenetic reactions and mechanical responses to various stress fields have altered and in some cases have drastically changed the appearance and the nature of Rustler rocks. Although the origin and history of any one of the post-depositional alterations within the Rustler may be very complex, each feature is the result of one or more simpler mechanisms. These mechanisms or processes must be understood and kept in perspective. All post-depositional modifications or alterations are the driven by disequilibrium. Chemical disequilibrium causes either the addition of solutes or the subtraction/removal of solutes. Disequilibrium between a stress field and the rock may result in a mechanical adjustment toward equilibrating the system. In general, chemical reactions cause what are considered to be diagenetic features, while mechanical reactions to stress fields cause most of the remaining post-depositional alterations. Regardless of the complexity of the genesis of any one individual diagenetic feature, they can all be attributed to the operation of one or both of the following chemical reactions: the addition of solutes to, and/or the removal of solutes from, a particular site of reaction. Likewise, all of those post-depositional features that can be attributed to a mechanical process are the result of a mechanical, albeit ductile or brittle, response to various non uniform stress fields. Non uniform stress fields can result from the action of either tectonic processes or chemical diagenesis.

Numerous studies of evaporites report, interpret, or infer the occurrence, and recognize the importance, of early/syndepositional chemical diagenesis, including solute addition (e.g., Arakel, 1980; Butler and others, 1982; Eugster & Hardie, 1978; Gornitz and Schreiber, 1981; Hardie, 1968; Kinsman, 1976; Lowenstein and Hardie, 1985; Shearman, 1970, 1978; and Smith, 1971) and solute removal (e.g., Schreiber and Schreiber, 1977; Hardie and others, 1978; Hovorka, 1983a, in press; Lowenstein and Hardie, 1985; and Powers and Hassinger, 1985). As early diagenetic reactions are common within the depositional settings of most evaporites and, in fact, are responsible for the formation of many of the diagnostic evaporite sedimentary structures unique to a particular depositional setting, it is necessary to differentiate between those early/syndepositional diagenetic reactions and those late stage diagenetic reactions not related to the original depositional setting. So,

for the purpose of this study, early/syndepositional diagenetic reactions will not be considered in the same context as later diagenetic reactions, and the following definition of late stage diagenetic features will hold. Late stage diagenetic features originate in a system not closely tied by time or original ground-water conditions to the host material. In other words, features formed within the ground water system at or near the time of deposition of the host material are considered to be part of the depositional system and will not be discussed in context with late-stage diagenetic features.

8.1 CEMENTS

Several cements were observed at various locations throughout the Rustler section. The clastic rocks near the base of the bioturbated clastic interval and within H-1, H-3, and H-4, and locally M-4 contain halite cement. Most halite cements appear poikilitic. Halite cements are common within halite-bearing rocks, but as yet, no clear method exists for uniquely distinguishing between halite cement precipitated in the near surface environment and that precipitated during burial (Lowenstein and Hardie, 1985). This being the case, no interpretation of timing of halite cement in H-1, H-3, or H-4 can be made. However, halite cements within the lowermost part of the Rustler clearly have a diagenetic origin as halite was not associated with the depositional setting of that unit. As halite occurs within the intervals both above (H-1) and below (the Salado) this zone, it is likely that the solutes that formed the cement were derived from one of these zones. Halite cements within M-4 probably have an early or syndepositional origin. Thin sections from M-4 at WIPP 19 show halite-filled voids. Some of these voids are morphologically similar to skeletal and displacive halite crystals, while other voids are irregularly shaped. Poikilitic halite is an intergranular cement in the vicinity of the halite-filled voids. The halite-filled voids are relicts of displacive and skeletal halite crystals which have suffered syndepositional dissolution. The cements formed after the partial dissolution of the halite crystals, probably sometime during early burial (e.g., Lowenstein, 1987a).

Gypsum cements are common within some of the clastic units of the Rustler. Gypsum cements have been observed in the transition zone, the Magenta, M-2, and M-3. A syndepositional origin has been assigned to the

gypsum cemented part of the transition zone and it will not be discussed here. Gypsum cement occurs as an alteration of anhydrite within the Magenta Dolomite Member. The gypsum contains relics of large poikilitic anhydrite crystals. The fabric locally appears to be expansive. It is likely that much of the sulfate originated as transported grains; evidence of those grains has been destroyed by one or more episodes of replacement/alteration of gypsum with/to anhydrite and back to gypsum. Some poikilitic gypsum cement occurs within the coarser parts of some of the mudstone (M) units. However, no anhydrite precursor was observed.

Gypsum cements occur locally within M-2 and M-3. Some are poikilitic while others are not so coarsely crystalline. The cements are not pervasive throughout the mudstone units. They are most common near the top and the base of the mudstones and near sulfate interbeds.

8.2 OVERGROWTHS

Overgrowths on clastic transported grains are found within some zones in the Rustler. Silt and very fine sand-sized quartz grains, within the Culebra and some of the mudstone (M) units, exhibit euhedral terminations and dark, irregular, and roughly elliptical rims of foreign material within the crystal. These euhedral crystals are interpreted to be detrital grains with quartz overgrowths. Many of the quartz grains have corroded boundaries. These grains and their overgrowths were present prior to the dolomitization of the ground mass. Euhedral rhombohedrons of carbonate with M-3 and M-4 display thin, roughly elliptical zones of dark material which are interpreted to be the original clast boundaries prior to overgrowth development. The volume of the overgrowth is usually much greater than the original grain. The margins of the carbonate grains frequently display evidence of corrosion.

Large gypsum overgrowths on fine sand-sized grains of gypsum are found in thin sections from the M-3 internal of WIPP 19. These grains have not been replaced by, or altered to, anhydrite since their deposition and subsequent overgrowth. The grain margin might have survived the replacement of gypsum by anhydrite, but it could not have survived the conversion to anhydrite. The anhydrite-to-gypsum conversion would have destroyed the original grain margin.

M

8.3 STYLOLITES AND PRESSURE SOLUTION

Stylolites demonstrate pressure solution within the Rustler anhydrites. The stylolites within the anhydrites are subhorizontal to horizontal and only occur within laminated sulfate. Clay and carbonate mark the stylolite surface. They are extremely common within the upper Rustler anhydrites. Pressure solution within the Rustler occurred in response to a stress-field with the maximum principal stress in the vertical. Calcium sulfate was liberated by the pressure solution and removed from the site of reaction.

8.4 REPLACEMENT

Replacement occurs when the processes of solute addition and removal are simultaneous and balanced. Pseudomorphs are interpreted to be replacements. The most common replacement is anhydrite after gypsum as pseudomorphs. Sometime prior to maximum burial and the development of stylolites, anhydrite replaced gypsum on a volume for volume basis. Conversion or dehydration of gypsum did not occur, as a volume reduction is associated with that reaction and no evidence of volume change is found. Conversion or dehydration of gypsum to anhydrite would cause a loss of original depositional textures.

Secondary gypsum after anhydrite occurs throughout the anhydrite (A) units. Where both gypsum and anhydrite are present, the gypsum crystals usually crosscut the anhydrite crystals. The volume of gypsum observed within the anhydrite (A) units is at a minimum near the centers of the A-units and a maximum near the margins. Relationships between the gypsum and anhydrite fabrics cannot be determined when gypsum is the main constituent. However, disruption of the fabric caused by a volume increase during the conversion of anhydrite to gypsum was not observed when gypsum occurred within anhydrite. So, the gypsum is interpreted to be a volume for volume replacement of anhydrite when anhydrite is the major constituent. The relationship between what is converted to gypsum and what is replaced by gypsum becomes less distinct as the percentage of gypsum increases.

Gypsum-filled vugs within the Culebra are interpreted to be partly displacive as early syndepositional nodules and partly replacive. Stratification within the carbonate surrounding some of the gypsum-filled vugs appears to have been displaced away from the vug. This supports an early syndepositional displacive origin for the vugs. The majority of the vugs, however, do not have definite expansive textures preserved within the surrounding carbonate. In fact, stratification within the carbonate often

terminates abruptly at the vug-carbonate margin indicating that some of the carbonate was removed. No evidence of crystal growth inward into a void was found within the vug fillings. This suggests at least a partly replacive origin of the sulfate vug filling with no evidence of passive pore filling. Relict crystals of anhydrite are preserved as centers within some gypsum vug fillings at H-12. Petrographic relationships indicate that anhydrite once entirely filled the vugs and is now partially replaced by gypsum. Once again, as late stage expansive textures are not commonly associated with or attributed to the development of the vugs, gypsum did not result from the hydration of anhydrite, but is instead, the volume for volume replacement of anhydrite with gypsum.

Gypsum is a major constituent within the Magenta and is at least partly replacive of anhydrite. Relict crystals of anhydrite occur within the Magenta. Gypsum appears to crosscut optically continuous anhydrite crystals. Anhydrite is interpreted to have been the principal sulfate present within the Magenta and to have been replaced with or converted to gypsum. It is probable that much of the sulfate within the Magenta originated as detrital grains of gypsum. These gypsum grains were probably replaced by anhydrite prior to maximum burial and later replaced/converted to gypsum. Conversion to gypsum will be discussed in the following section of this report.

Halite pseudomorphs after gypsum swallowtail crystals are common within those anhydrites in contact with halite units. When halite pseudomorphs after gypsum are present, the remaining sulfate rock consists of anhydrite with no, or very little, gypsum. Unlike anhydrite, halite appears to only pseudomorph coarsely crystalline gypsum, leaving the ground mass/matrix unreplaced. Thin sections of anhydrite pseudomorphs after gypsum swallowtail crystals indicate that the anhydrite within the surrounding material is micro- to finely crystalline while the anhydrite within the swallowtail crystal form is also finely crystalline (slightly larger than the ground mass). Halite is interpreted to have replaced/pseudomorphed the gypsum crystals prior to, or synchronous with, the replacement of gypsum with anhydrite. The energy required to replace a large crystal is less than that required to replace microcrystalline material. After the gypsum was replaced by anhydrite the whole rock was finely crystalline. If halite had replaced anhydrite, there would have been little reason for the halite to have

preferentially replaced the swallowtails. Halite replacement would have more readily occurred when the rock was gypsum.

Halite replaced aragonite allochems in the carbonate-rich unit equivalent to the bioturbated clastic zone of the unnamed lower member. Shells and shell fragments are the most common allochem affected by halite replacement. In many places, the halite content in the matrix is volumetrically much greater than the carbonate. As the allochems did not collapse within these zones, the halite could not have been a void filling cement, but instead, was a replacement.

Anhydrite replaced halite along the margins of crystals within anhydrite and halite psuedomorphs after vertically grown gypsum crystals. Long, thin blades of anhydrite project into the crystals of halite. They are interpreted to be replacements as the space occupied by the halite could not have remained open while the anhydrite crystals grew into a void.

Elongate dolomite crystals occur within halite pseudomorphs after gypsum crystals in the unnamed lower member of H-12. These crystals could not have grown into void space, as the void would have collapsed. A replacement origin is proposed for the elongate dolomite crystals. Other authors (e.g., Hovorka, 1985a) have interpreted multifaceted dolomite crystals in halite as replacements.

Dolomite replaced some detrital and authigenic quartz grains within the Culebra. Some quartz crystals with irregular and embayed margins have ghost margins within the dolomite. Other quartz grains display irregular or embayed margins without any evidence of replacement. Some authigenic crystals and grains with euhedral overgrowths also exhibit corroded margins. The authigenic quartz crystals and quartz grains with overgrowths formed prior to dolomitization. The dolomicrite ground mass has partially replaced the quartz grains and crystals.

8.5 RECRYSTALLIZATION

Recrystallization occurs when crystals, under increased temperatures and pressures during burial, change their morphology to minimize energy. Recrystallization results in equigranular crystals with few inclusions as foreign material is purged to the crystal margin. Annealing textures in halite yield triple junctions at angles of roughly 120 degrees. Depositional textures are usually disturbed/destroyed by recrystalliztion of evaporite minerals.

Halite at several locations within the Rustler is interpreted to have been recrystallized. Triple junctions, purged inclusions, and equigranular grains showing no depositional fabrics all occur within that part interpreted to be recrystallized. These textures are found within zones H-1b and H-3. The recrystallization is probably the result of pressure caused by loading rather than increased temperature during burial as the geothermal gradient within the Delaware Basin has been considered low.

Recrystallized gypsum occurs at several locations within the Rustler section. The base of A-5 is recrystallized at the waste handling shaft (Holt and Powers, 1984). Some of the coarsely crystalline gypsum found in the lower part of A-2 and A-3 is interpreted to be recrystallized. The finely crystalline gypsum was reorganized in the presence of fluids at the lithologic contacts.

8.6 CALCIUM SULFATE STABILITY

The relationship between anhydrite and gypsum is complex. The stability of each depends upon temperature, pressure, and the ionic strength of fluids in contact with the minerals. When both are present, one is metastable. The actual processes of either replacement or conversion are not well understood. Anhydrite pseudomorphs after gypsum have yet to be reported from modern evaporite deposits. The volume problem associated with the conversion of one to another at lithostatic pressure has yet to be adequately addressed. However, one feature is suggested here to be indicative of, but not unique to, the simple hydration of anhydrite to gypsum or dehydration of gypsum to anhydrite. Unless the sulfate was only a minor constituent within the sediment, primary depositional features within the sediment would be destroyed during the simple conversion of one to another via the addition or subtraction of water from the crystal structure. Gypsum or anhydrite that has undergone simple conversion retains no primary depositional structures. They are all be severely deformed if not destroyed by the volume change.

The majority of the Rustler sulfate studied macroscopically and microscopically preserves primary sedimentary structures and shows no evidence of either expansive or implosive textures. This indicates that replacement, not simple conversion, was the main process of change between the two

sulfates. Anhydrite pseudomorphing gypsum indicates replacement. Several highly gypsiferous zones, however, preserve fewer original depositional textures than are preserved elsewhere where replacement of gypsum with anhydrite clearly has occurred. These zones are thin and located at the base of A-2, A-3, A-4, and A-5 and at the top of A-3. These zones may have seen the conversion of anhydrite to gypsum in the presence of fluids.

Several authors (e.g. Snyder, 1984) have proposed that increased thicknesses within the Rustler in the vicinity of Nash Draw are the result of the "jacking up" of the section due to the volume change during the hydration of gypsum. Detailed description of cores from the Rustler within Nash Draw reveals an abundance of primary features preserved within the Rustler anhydrites. So, it is unlikely that a large scale simple conversion of anhydrite to gypsum in the presence of fluids occurred. In addition, the Rustler section within Nash Draw is brecciated. The breccia originates within the Salado Formation indicating removal of volume from within the Salado. The brecciation has lengthened the Rustler section giving rise to an apparent increase of thickness within Nash Draw. This apparent thickness adjustment affects nearly all of the units within the Rustler, not just the sulfates.

Not all of the gypsum in the Rustler is secondary. Some of the Rustler gypsum is primary and was never converted to or replaced by anhydrite. Gypsum overgrowths on clastic gypsum grains are preserved within M-3 at WIPP-19. The internal texture of these grains would not be preserved had they been converted from anhydrite to gypsum. Other primary fabrics occur in gypsum from mudstone (M) units. Incorporative gypsum crystals are common. Isolated, twinned, stellate, and palmate crystal forms are present. Lenticular gypsum is rare as the proper organic compounds required to form lenticular gypsum (Cody, 1979) were not present in the depositional system. Most Rustler gypsum is diagenetic. Anhydrite precursors for gypsum are common. Primary gypsum occurs only in the mudstone (M) units. Perhaps the mudstone units protected some gypsum during diagenesis.

8.7 FRACTURES

Much of the Rustler and the overlying Dewey Lake is extensively fractured, with many of the fractures filled with fibrous gypsum. Within competent rocks, the majority of the fractures are horizontal or

subhorizontal and parallel to bedding planes. Sub-vertical and vertical fractures are less common. Gypsum fracture fillings usually indicate separation along a single fracture. Several episodes of crosscutting relationships show that the fracture style changed through time. Gypsum-filled fractures occasionally parallel slickensided surfaces in the mudstone units. This occurs at the exhaust shaft, where arcuate gypsum-filled fractures have slickensided surfaces. The slickensides probably developed as the mudstone units deformed due to loading and unloading.

These fractures are dissimilar to fracturing associated with solution collapse (e.g. Middleton, 1961). Solution collapse breccias vertically decrease clast separation to give way to a series of fractures, hairline fractures and cracks, and then undisturbed beds. Within WIPP cores and shafts, fractures are commonly, but not exlusively, horizontal. They occur in zones that are not well interconnected or continuous in the vertical. This fracture style persists through the Dewey Lake. There is no apparent relationship of WIPP fracturing to dissolution at the site area. A vertical to sub-vertical minimum principal stress in indicated by the horizontal to sub-horizontal fractures. The orientation of the least principal stress was somewhat variable, as suggested by variable fracture orientations. The data are consistent with an unloading origin for Rustler fractures. Differential unloading is considered responsible for the majority of the Rustler fractures.

8.8 FRACTURE FILLINGS

Fracture filling materials are very common through the Rustler. Two types of fracture fillings occur within the Rustler: halite and gypsum.

Halite-filled fractures appear to be contained within those zones containing halite (H-1, H-3, and H-4) and within the lower part of the unnamed lower member between H-1 and the Rustler/Salado contact. Most of the halite fracture fillings are fibrous and may be clear, white, orange or blue. A few of the fracture fillings are color zoned (e.g. WIPP 19) in the clastic units located stratigraphically below H-1. Within the halite-bearing units, the halite fracture fillings are considered to be syntaxial, while in the clastic units below H-1, they are syntaxial and antitaxial (after Durney and Ramsay, 1973).

Gypsum-filled fractures commonly occur above the H-1 unit where that unit is present. The gypsum fracture fillings are clear to white and fibrous and are both syntaxial and antitaxial. Pieces of the wall-rock material are commonly included within the fracture filling. Most of the larger fibrous fracture fillings observed within the Rustler appear to have a "suture" line which always parallels the fracture surface of the host material. The suture line is the site of a moderate to abundant amount of inclusion of wall rock material. Most of the fibrous fracture fillings are parallel to host rock. However, some are tilted away from the perpendicular, and in rare cases, some are sigmoidal.

Fibrous fracture fillings result from growth of the individual fibers as the fracture opens in small increments. When the fracture initially opens, this creates a void and a zone of low pressure. Intercrystalline or pore fluid migrates to the site of low pressure. The pressure decrease coupled with newly created void space is conducive to solute precipitation along the fracture surface. If the fluid is near saturation for a particular mineral, the pressure decrease associated with fracturing can drive the fluid to become saturated with that mineral and precipitation can occur. If the wall rock and the fracture filling contain the same mineral, overgrowth upon grains or crystals of that mineral will occur and the fracture filling is syntaxial (Durney and Ramsay, 1973). If the wall rock does not consist of the same mineral as that precipitating in the void provided by the fracture, then nucleation of the mineral occurs, and the fracture filling is antitaxial (Durney and Ramsay, 1973). The suture line is most visible in antitaxial fracture fillings as small parts of the wall rock are included within the crystals during the initial fracturing and precipitation. The suture line exhibits the same morphology as the fracture surface on the wall rock.

Once the initial fracturing and subsequent precipitation occurs, the fracture filling grows incrementally as the fracture filling mineral precipitates as overgrowths. These overgrowths are constrained by each other in the direction parallel to the fracture surface, so they must grow competitively in the direction perpendicular to the wall rock and away from the seed crystal. This causes a fibrous crystal habit to develop. This habit is visually enhanced when the filling material consists of one of the minerals that are readily twinned (e.g., gypsum).

When the fracturing continues, separation occurs between one side of the fracture filling and the wall rock. Fluids migrate to that point, and precipitation then occurs at the contact between the wall rock and the filling material. So, the youngest part of the filling is next to the wall rock, and the oldest part of the fracture filling is adjacent to the suture line. The width of the fracture on each side of the suture line is related to the availability of chemical nutrients and the frequency of reseparation by fracturing along each side.

The morphology of the fibrous fracture filling is the result of the stress field which produced it (Durney and Ramsay, 1973). Fibers perpendicular to the fracture surface indicate that there was no displacement parallel to the fracture surface at the time of fracturing and subsequent filling. Fibers that are tilted with respect to the perpendicular indicate that there was a component of displacement parallel to the fracture surface and that the component was present throughout the period of fracturing and filling. Sigmoidal morphologies develop when a component of displacement parallel to the fracture surface occurs after the initial fracturing.

The fracture fillings within the Rustler contain information about any changes through time of the chemistry of the precipitating fluid and the stress fields which formed the fracture. Chemical analysis of the minerals contained within the gypsum filled fractures and detailed analysis of the fracture filling morphologies was not part of this study. However, solutes for both halite and gypsum fracture fillings were probably locally derived, as possible sources for all the solutes exist within close proximity to the fractures.

Halite-filled fractures seem to be confined to either zones containing halite or zones adjacent to halitic intervals. Halite-filled fractures within the clastic part of the unnamed lower member appear to occur only when H-1 occupies the stratigraphic interval above the clastic zone. No evidence of the removal of halite from fractures was ever found in the clastic interval when M-1 was present. However, WIPP 30 is the only core through the unnamed lower member where M-1 overlies the clastic interval and the Rustler/Salado contact is in its normal position with a normal appearance, and it is possible that the core did not intersect a halite-filled fracture as they are most often vertical or sub-vertical. The remainder of the cores containing M-1 are located within Nash Draw where some disturbance occurs within the Salado in the vicinity of the Rustler/Salado contact.

Gypsum-filled fractures occur only above the interval H-1, when halite is present. This apparently indicates that gypsum-saturated fluids did not or could not migrate downward below the halite. Lowenstein (1987) believes that porosity in such halitic units is plugged syndepositionally, within a few meters at most. Where M-1 is present, no halite existed and gypsum precipitated in fractures within the mudstone. Gypsum-filled fractures are less common in those cores which have less gypsum within sulfate units. In other words, gypsum-filled fractures are less common when the gypsum to anhydrite ratio of the sulfate rocks is smaller. Less gypsum was observed within the anhydrites (A-units) in the thin sections of H-12. The Rustler at H-12 has seen less fluid capable of precipitating gypsum within fractures.

8.9 DISSOLUTION

Removal of solutes by dissolution occurs when a fluid is present that is undersaturated with respect to the mineral being dissolved and the energy to drive the reaction exists. Dissolution creates void space. Preserved void space or evidence indicating the former presence of void space must be present if dissolution and removal of solutes has occurred. Dissolution porosity varies in scale from intercrystalline to vuggy to cavernous. While preserved porosity is obvious, the former presence of porosity is more difficult to see; it can be recognized by filled void space or features indicating the ductile or brittle mechanical adjustment to the nonuniform stress field caused by the porosity.

Preserved porosity occurs throughout the Rustler. Most of the porosity can be directly attributed to the void space created during the dissolution of soluble minerals. Preserved dissolution porosity occurs within the carbonate, sulfate, and halite-bearing rocks of the Rustler.

8.9.1 Microporosity and Vuggy Porosity

Intercrystalline microporosity and vuggy porosity is common within the Culebra. Neither filled nor open intergranular porosity occurs within the Culebra as the Culebra consists of dense micrite and argillaceous material. Sulfate is not a major constituent within the Culebra. Sulfate occurs as a pore and fracture filling material and locally as a cement. Intercrystalline and vuggy porosity resulted from the dissolution of carbonate, where there is no gypsum precursor. Some vuggy and intercrystalline porosity is

attributable to the dissolution of gypsum. All large scale vugs within the Culebra are interpreted to have contained gypsum. Large, open vugs may have resulted from the dissolution of gypsum. Vuggy porosity is locally well developed in gypsum fracture fillings. Dissolution of gypsum is the last distinguishable event to occur within the Culebra as gypsum dissolution appears to effect gypsum-filled fractures. Dissolved sulfate within the Culebra has a solubility index close to one (Myer, pers.comm.). The sulfate within the Culebra waters is probably partially derived from the gypsum fracture fillings and the apparently related gypsum vug fillings. Further dissolution of sulfate and carbonate within the Culebra is not likely given the present chemical conditions of the waters within the Culebra as they are apparently in equilibrium with gypsum, ordered and disordered dolomite, calcite, and anhydrite in the vicinity of the WIPP site (Myer, pers.comm.). Where fresher fluids have access to the Culebra in Nash Draw, dissolution of carbonate and sulfate can continue.

Dissolution of gypsum is common within the sulfate units across the study area. Intercrystalline porosity was found in thin sections from most of the anhydrite units. Intercrystalline porosity was less common in thin sections from H-12 than WIPP 19 and in both cases appeared to be more abundant near the upper and lower contacts of the anhydrite units. Where present, porosity within the anhydrites was usually less than one percent. Several of the cores from Nash Draw showed the development of vuggy porosity within the sulfate units. Large open vugs, some containing gypsum crystals which grew inward toward the void center, are preserved within some cores. This porosity is interpreted to have originated from the dissolution of sulfate within the Rustler. The presence of large vuggy and cavernous porosity within the Rustler in the vicinity of Nash Draw is interpreted to have formed as the result of dissolution of gypsum by meteoric groundwaters (see also Bachman, 1984 a, 1987 a,b).

Evidence of gypsum dissolution within the Magenta was found in thin sections from H-12 and WIPP 19. Intercrystalline porosity occurs within the gypsum. Small relics of anhydrite remain within the gypsum and appear to be unaffected by the dissolution. Dissolution of gypsum at Magenta outcrops is common.

Intergranular porosity is commonly well developed in halite cemented clastic rocks. M-4 at WIPP 19 is cemented by halite and exhibits microscopic halite crystals. Halite cemented clastic units in the unnamed lower member also exhibit some intergranular porosity.

8.9.2 Caves and Cave Fillings

The only known cavernous porosity encountered in drilling the Rustler near the site was in WIPP 33 (Sandia National Laboratories and U.S. Geological Survey, 1980). There, drilling, logs, and downhole television scanning demonstrated fluid-filled (at the time of drilling) cavernous porosity within the Magenta of undetermined lateral dimensions. Bachman (1980) attributes this porosity to dissolution near the margin of Nash Draw. It is clear that cavernous porosity also is prominent within Nash Draw as part of karst-forming processes.

Ferrall and Gibbons (1978) attribute the laminated claystones found above the Culebra in WIPP 19 to filling of cavernous porosity. This claystone, observed closely in the WIPP shafts, is considered to be partially algal in origin and is believed to be ubiquitous (Ch. 45). The lack of a lower Tamarisk anhydrite clearly leads Ferrall and Gibbons (1970) to consider that dissolution had destroyed that bed, and that a bedded claystone must therefore have formed in cavernous porosity during this dissolution event. In this document, the claystone, which is present even below the lower Tamarisk anhydrite, is considered depositional in origin, and the anhydrite is considered to have been lost very early at WIPP 19 (Ch. 5, 6). Cave fillings found elsewhere sometimes exhibit bedded clastics, but the more common characteristic attributed to cave fillings is the piled to floating, slab-like collapse blocks piled one on another or floating in a matrix. More importantly, on a broader scale, caves and cave fillings are likely to show an upper limit that is well defined and an irregular lower boundary. No feature in cores or shafts is considered likely to be a cave filling.

8.9.3 Dissolution and Collapse Features

As discussed in the previous chapter, overlying competent rocks deform brittely when large volumes of material are removed from stratigraphically distinct zones. The behavior of Rustler materials due to the removal of underlying evaporites can be assessed after observing the cores of the Rustler from Nash Draw.

The upper portion of the Salado Formation within Nash Draw thins dramatically. The depositional environments of the upper Salado give little reason to expect depositional thinning is present in the vicinity of Nash Draw. The stratigraphic units overlying the Salado in Nash Draw are brittely deformed. Upward stoping and downward mixing of clasts derived from overlying stratigraphic units occur within the upper Salado and the Rustler. The upper Salado within Nash Draw is interpreted to have partially dissolved (Vine, 1963; Bachman, 1974). The extent of brecciation varies from borehole to borehole, but in each case is known to include more than a small or isolated zone within the borehole. These breccias are similar to those described previously from the Mission Canyon, for example, in that clasts are generally quite angular, though they may vary in size. These breccias in some cores display the upward decreasing extent of brecciation also described from the Mission Canyon (e.g., Middleton, 1961) and other evaporite solution zones. As the various boreholes in Nash Draw were differentially affected by dissolution of the upper Salado, the apparent loss of Salado salt was tabulated for each of these boreholes (Table 8.1), and the amount of the Rustler section deformed has been estimated (Table 8.1). The ratio of thickness disturbed to the thickness reduction is estimated to be between 1:1 and 1:2. Few previous studies report sufficient data to obtain an equivalent relationship, but there are suggestions of a correspondence. A study such as that by Parker (1967) contains data on the thickness of removed salt, but the logs do not reveal the extent of brecciation and the removal may have been early enough that breccias did not result.

Adjacent boreholes WIPP 29 and WIPP 32 show two important effects related to dissolution. Within the lower unnamed member, WIPP 32 in particular displays brecciated smeared intraclast textures in zones that laterally have halite (see Ch 5). Much of the lower unnamed member in this borehole is brecciated, but the superposition of brecciation over smeared intraclast texture (described in Ch. 5) reveals that the halite in the lower member was dissolved essentially syndepositionally, while the brecciated texture is post-lithification. The brecciated texture is clearly consistent with late removal of salt from the Salado. The upward extent of deformation is not clear as the upper portions of the Rustler have been removed by erosion. The textures in WIPP 29 are similar, but seem much reduced. Though this may partially be due to locally varying processes of dissolution, most of the

difference in this report is attributed to the difference in core diameter between the two boreholes. WIPP 29 is about a 2 inch (5 cm) diameter core while WIPP 32 core is about 4 inches (10 cm) in diameter. The increased diameter is important to the detection and interpretation of these textures.

Collapse, upward stoping, and mixing of clasts derived from various stratigraphic horizons occur in core from WIPP 13 where the deformation is not clearly attributable to Salado dissolution. The lowest deformed unit is A-2. The overlying mudstone (M-3) is also deformed and contains clasts clearly derived from the overlying anhydrite (A-3). A-3 is brecciated and deformed near the base. The center of A-3 was not cored, but core of A-3 below the Magenta displays dipping stratification. The source of at least part of the deformation is within or below A-2, but the originating horizon for the deformation is not clearly identified as the entire Rustler section was not cored at WIPP 13. The extreme deformation of the M-3/A-3 contact does not require that some of the void space originated within the M-3 horizon. However, this cannot be overruled. Dissolution of a large thickness of halite from either the M-2 or M-3 horizon and the collapse of the overlying beds could partially account for the features observed. However, our depositional model generally predicts that halite was not preserved within the M-2 or M-3 stratigraphic interval after the deposition of the overlying units. Our depositional model is based upon the descriptions of several cores and shafts and regional interpretations of geophysical logs, while WIPP 13 is an isolated drill hole. Without more complete Rustler data within the WIPP 13 area, the cause of the structural deformation observed at WIPP 13 cannot be adequately constrained. Therefore, it must be considered an anomaly until more data are available from that area.

Collapse, upward stoping, and mixing of stratigraphic units originating in the M-3 stratigraphic interval occur in the core from borehole H-3b3. M-3 contains readily identifiable clasts and blocks of the overlying rocks. The overlying anhydrite contains dipping and overturned stratification. Our depositional model does not exclude halite within the M-3/H-3 stratigraphic interval at H-3b3. Based upon the apparent distribution of facies, H-3b3 could have contained a small volume of halite. The ratio (1:1 or 1:2) of deformation of the Rustler section within Nash Draw to the volume of Salado removed indicates the thickness of the M-3/H-3 interval may have been reduced by 10 to 30 ft (3 to 9 m).

The M-4 interval at H-3b3 also contains a large block of anhydrite, presumably downdropped, and a clay-filled fracture at the M-4/A-5 contact. A small amount of halite may have been removed from the M-4/H-4 stratigraphic interval. This would also be consistent with the depositional model of that interval. Actual volume reduction could have been at most several feet.

The M-3/A-3 contact at H-11b3 is brecciated. The claystone and the underlying thin sulfate unit are brecciated, but the breccia clasts are confined to the top of the M-3. Minor amounts of subvertical fracturing occurs within the extreme lower part of A-3. This disruption could have resulted from the dissolution of a very thin section of halite. Our depositional model for the M-3/H-3 interval supports the occurrence of halite at H-11b3.

Dissolution of halite is not a unique explanation for the features occurring at the M-3/A-3 contact. Brittle deformation at the contacts of brittle and ductile materials can occur when the ductile material flows (e.g., McKnight and Fischer, 1970).

As described by McKnight and Fischer (1970), incompetent beds between stronger units may show brecciation due to tectonic events. They described plucking of blocks from an overlying chert by a less competent carbonate. Within the Rustler, it is quite possible that some breccia, local in extent, could be attributed to this mechanism as the contrast in competence is large for several beds. As McKnight and Fischer (1970) point out, the movement on adjacent beds may be very small to produce these features. From shaft mapping, slickensides and minor deformation may be consistent with a small amount of lateral movement taken up by incompetent beds. Though it seems likely that some breccia (or deformation) may be formed in such a manner, no feature has been uniquely attributed to the process. It may only be possible to do so where the affected units are exposed along drifts, as in the MVT PB-ZN deposits examined by McKnight and Fischer (1970).

There exists within the shaft, and possibly within some core material, rare and isolated slightly brecciated areas. These areas, as in the Culebra in the exhaust shaft (Holt and Powers, 1986a), have throughgoing stratification underlying and overlying the brecciated area. There is no justification for interpreting these as evidence of broader dissolution, although in the case of the Culebra, extremely local solution of carbonate may have caused such a feature.

Borehole	Approximate Thickness Reduction in the Upper Salado	Approximate Thickness of Rustler Section Disrupted
WIPP 25	115 ft	280 ft
WIPP 27	155 ft	Entire Section
WIPP 29	455 ft	Entire Section
WIPP 30	0 ft	-
WIPP 32	460 ft	Entire Section
WIPP 33	0 ft	-

Table 8.1. Thickness of Rustler section disrupted versus thickness reduction by dissolution in the upper Salado in the vicinity of Nash Draw.

9.0 CONCLUSIONS

The Rustler Formation is the last evaporite deposit of the Permian Ochoan Series in the Delaware Basin. The depositional environments and distribution of the Rustler vary considerably from the older Castile and Salado Formations. The Rustler exhibits abundant primary depositional features permitting detailed reconstruction of facies relationships and depositional environments. Most of the major units of the Rustler thicken in an area east and south of the WIPP site. Resting over and outside of the Capitan reef which restricted earlier deposits, this area served as a depocenter that had shifted east and north of the earlier Castile depocenter. The Rustler formed from environments ranging from shallow lagoons and subtidal environments to shallow saline pans and environments marginal to the saline pan. These environments changed laterally over distances of a few miles, resulting in observable lithofacies changes within cores and shafts at the WIPP site.

The depositional environments of various Rustler units have been reconstructed using a sedimentological approach. Observable bedding, primary features, and certain secondary features (such as pseudomorphs after primary gypsum textures) were described and placed in stratigraphic sequence. Lithologic units and their features have been compared to facies models constructed from modern and ancient analogs. For some features and their associations, such as pedogenic clay skins on clasts and intraclasts in some mudstone units, modern evaporite analogs have not been reported. Nonetheless, soil and paleosol features are well known independently and can be linked readily to the environmental setting of the Rustler. As is common in such studies, new features and associations were described and interpreted from the geological context established from better-known features. Smeared intraclasts and crushed pseudomorphs are expected to become established, independently interpretable features as modern analogs are found and described. In this manner, facies and environmental models are constructed and refined with modern and ancient examples.

Parts of the Rustler formed when fresher water, possibly marine, transgressed rapidly over very low topography, depositing clastics, carbonates, or subaqueous sulfates. A marine transgression over the Salado is the initial example. The transgressing water evaporated to increase salinity and deposit halite. Halite and clastics were reworked along margins, and halite was concentrated in the depocenter, maintaining low topography. A rapid transgression of fresher water terminated halite

precipitation in the depocenter. Several shallowing-upward or desiccating-upward sequences comprise most of the Rustler (Fig. 9.1). Because the upper boundaries are abrupt and are overlain by widespread units of sulfates or carbonates of nearly uniform thickness, these contacts are thought to be nearly isochronous surfaces.

Halite units are lenticular with the thickest part south and east of the WIPP site, in the depocenter. Sulfate units are more nearly uniform in thickness from depocenter outward, indicating either an increase in sedimentation rate or a decrease in subsidence rate. Here it is suggested that sedimentation or accumulation rates may have been relatively greater for sulfates and carbonates as halite accumulation rates were controlled by syndepositional dissolution. The Culebra is somewhat thicker in the depocenter, generally corresponding to mudstone and halite unit patterns.

The halite and mudstone units vary most in lithofacies and thickness from depocenter to margins. Five major facies were deposited, from depocenter outward, in the study area in these generalized depositional environments: mud-poor halite pan, mud-rich halite pan, halite saline mudflat, gypsum saline mudflat, and mudflat. Clastic sediments were distributed mainly around the margins as the capacity and competence of the hydrologic system decreased toward the depocenter. Flooding events introduced clastics and moved them toward the depocenter. Transgressions, or a rise in the base level, caused larger areas to be covered with water that was very likely to be undersaturated with respect to halite. Halite was dissolved around the margins as a consequence. The water became more saline and contracted as evaporation continued. Halite was concentrated in the depocenter as the edges of the brine contracted. During lower water levels (lower base level) additional halite was cannibalized and moved toward the depocenter by rainwater or the encroaching lens of shallow groundwater. Unless subsidence rates varied dramatically during deposition of halite and mudstone units, halite and mudstone accumulated slowly relative to sulfates and carbonates.

Halite was dissolved syndepositionally from halite and mudstone beds at small to large scales. In the Rustler, the sedimentary sequence was drastically modified by large scale dissolution in response to various conditions: a transgression or freshening event that raised the water table or base level, a lowering of the watertable or base level due to evaporation or subsidence, or a changing in the lateral position of saline groundwaters.

Halite was dissolved by less saline water after a transgression. Dissolution continued in some cases after the overlying sediment was deposited, deforming and slumping this sediment. Subsidence or evaporation lowered the water table at the margins, subjecting halite to dissolution by meteoric water in the vadose zone and redepositing it in the depocenter (soluble mineral cannibalism). Incipient soil features formed in the vadose zone of the marginal mud-rich sediments. This hypothesis differs greatly from previous ideas of dissolution of halite from mudstone units. Several features demonstrate that halite was removed from marginal saline pan to mudflat environments before lithification and before the overlying sulfates were deposited. This contrasts with explicit and implicit ideas that Rustler salt was dissolved long after the Rustler was deposited. In addition, the cumulative thickness of halite removed from mudstones is considered here to be much less than the thickness of halite in equivalent zones.

Rustler sediments have also been alterred since deposition. Halite and gypsum cements are common. Some transported grains have been overgrown by authigenic minerals. Overgrowths on some clastic gypsum grains indicate that gypsum-anhydrite-gypsum alteration did not occur. This implies that other gypsum may be primary.

Halite pseudomorphs after gypsum occurred early, prior to or synchronous with the replacement of gypsum with anhydrite. Halite also replaced carbonate allochems. Both dolomite and anhydrite replace halite locally. Quartz grains with overgrowths were partly replaced by dolomite in the Culebra.

Implosive or expansive textures resulting from a volume change, associated with the direct conversion of gypsum to anhydrite or anhydrite to gypsum, do not occur within the sulfate units of the Rustler. Anhydrite pseudomorphs after gypsum are volume-for-volume replacements of gypsum. Gypsum within anhydrite exhibits no evidence of expansion due to a volume increase and is interpreted to also be a volume-for-volume replacement (not pseudomorphous). Snyder (1984) proposed, on the basis of geophysical log interpretations, that the the Rustler section thickens in Nash Draw due to the hydration and subsequent jacking up of the section. However, core from Nash Draw was examined in detail, revealing that the Rustler section is elongated by brecciation originating in the Salado, not by hydration.

A detailed literature review indicates that two major styles of dissolution exist: karst processes at, and relatively near, the surface and bed-controlled dissolution at greater depths. Near-surface dissolution and karst has poor stratigraphic control, an irregular lower boundary, and an upper boundary that is well-defined by subsequent deposits. Solution breccia beds and related features resulting from the dissolution of soluble materials at depth are stratigraphically controlled by the soluble unit. Where a zone of soluble material near the surface is mostly dissolved, the zone may be bounded below by undisturbed, relatively insoluble material and overlain by a post-dissolution deposit with little or no disruption. The mudstone units in the vicinity of the WIPP have undergone complete syndepositional dissolution of halite and show these relationships. Large scale dissolution of soluble rocks at depth creates breccia beds or strata-bound deposits consisting of angular blocks with a variable matrix. The block size and packing increase upward until the separation between blocks decreases to fractures and, finally, microcracks before disappearing. As dissolution proceeds, collapse occurs when the overlying material can no longer bridge the newly created void. Clasts and blocks are displaced downward from their stratigraphic position and mixed with clasts and blocks from other stratigraphic positions.

The Rustler section in Nash Draw is brecciated at various scales due to dissolution of halite and collapse in the upper Salado. Breccias and downward disruption of a lesser scale were found in several cores. Significant features include collapse, upward stoping, and mixing of clasts derived from various stratigraphic horizons. The borehole WIPP 13 exhibits this style of deformation through A-2, M-3, and A-3, but the zone in which the disruption originates was either not cored or is not apparent in the existing core. In the general sedimentological framework proposed in this study, halite in the Rustler is not expected to have survived deposition at this location. As incomplete core data are present at WIPP 13 and other core data in the vicinity are very limited, the disruption observed in the WIPP 13 core is considered an anomaly. Further interpretation of its origin will be reserved until additional drilling in the vicinity is completed and core can be described. Disruption is present in cores from H-3b3 and to a much lesser extent H-11. These boreholes lie in a boundary zone surrounding the zone now containing halite. As it is very possible that halite survived deposition within this boundary zone, the deformation in H-3b3 is attributed to

dissolution and collapse. The deformation at H-11 is minor. Dissolution is not a unique explanation for the features observed at H-11, as brittle beds bounding a less competent unit may show brecciation due to tectonic events.

The fractures in the Rustler and the Dewey Lake are dominantly horizontal and persist in vertically isolated zones. They are not similar to fractures caused by dissolution and are attributed to unloading. Many of the fractures are filled with fibrous gypsum of both syntaxial and antitaxial types.

Minerals dissolved at varying scales throughout the Rustler. Microporosity and vuggy porosity have been created by dissolution of carbonate and sulfate in both the Culebra and Magenta Dolomite Members. Some porosity was created in the sulfate units by dissolution. Halite cements have been dissolved creating intergranular porosity in clastic rocks. Cavernous porosity was encountered in the sulfate units during the coring of WIPP 33 near Nash Draw. Bedded claystone at WIPP 19, interpreted by Ferrall and Gibbons (1980) as cave filling, is here interpreted as syndepositional.

REFERENCES

Adams, J. E., 1944, Upper Permian Ochoan Series of Delaware Basin, west Texas and southeast New Mexico: Am. Assoc. Pet. Geol. Bull., v. 28, p. 1596-1625.

Adams, J.E., Cheney, M.G., DeFord, R.K., Dickey, R.I., Dunbar, C.O., Hills, J.M., King, R.E., Lloyd, E.R., Miller, A.K., and Needham, C.E., 1939, Standard Permian section of North America: Am. Assoc. Pet. Geol. Bull., v. 23, p. 689-700.

Adams, J. E., Frenzel, H. N., Rhodes, M. L., and Johnson, D. P., 1951, Starved Pennsylvanian Midland Basin: Am. Assoc. Pet. Geol. Bull., v. 35, p. 2600-2607.

Adams, S. S., 1969, Bromine in the Salado Formation, Carlsbad Potash District, New Mexico: Bull. New Mex. Bur Mines and Min Res., v. 93, 122 p.

Anderson, E. J., Goodwin, P. W., and Sobieski, T. H., 1984, Episodic accumulation and the origin of formation boundaries in the Helderberg Group of New York State: Geology, v. 12, p. 120-123.

Anderson, R. Y., 1978, Deep dissolution of salt, northern New Mexico: report to Sandia National Laboratories, 106 p.

Anderson, R. Y., 1981, Deep seated salt dissolution in the Delaware Basin, Texas and New Mexico: New. Mex. Geol. Soc., Spec. Pub. 10, p. 133-145.

Anderson, R.Y., 1982, Deformation-dissolution potential of bedded salt, Waste Isolation Pilot Plant site, Delaware Basin, New Mexico: in Lutze, W., Ed., Scientific basis for Radioactive Waste Management - V, p. 449-458.

Anderson, R. Y., Dean, W. E., Jr., Kirkland, D. W., and Snider, H. I., 1972, Permian Castile varved evaporite sequence, west Texas and New Mexico: Geol. Soc. Am. Bull., v. 83, p. 59-86.

Anderson, R. Y., Kietzke, K.K., and Rhodes, D. J., 1978, Development of dissolution breccias, northern Delaware Basin, New Mexico and Texas: New Mex. Bur. Mines and Min. Res., Circ. 159, p. 47-52.

Anderson, R. Y., and Kirkland, D. W., 1966, Intrabasin varve correlation: Geol. Soc. Am. Bull., v. 77, p. 241-256.

Anderson, R. Y., and Kirkland, D. W., 1980, Dissolution of salt deposits by brine density flow: Geology, v. 8, p. 66-69.

Anderson, R.Y., and Powers, D.W., 1978, Salt anticlines in Castile-Salado evaporite sequence, northern Delaware Basin, New Mexico: New Mex. Bur. Mines and Min. Res., Circ. 159, p. 79-83.

Anderson, S. B., 1966, A look at the petroleum potential of southwestern North Dakota: N. Dak. Geol. Survey Rpt. Inv. 42, 3 sheets.

Arakel, A. V., 1980, Genesis and diagenesis of Holocene evaporitic sediments in Hutt and Leeman Lagoons, Western Australia: Jour. Sed. Pet., v. 50, p. 1305-1326.

Arthurton, R. S., 1973, Experimentally produced halite compared with Triassic layered halite-rock from Cheshire, England: Sed., v. 20, p. 145-160.

Bachman, G. O., 1974, Geological processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U. S. Geol. Survey OFR 74-194,81 p.

Bachman, G. O., 1976, Cenozoic deposits of southeastern New Mexico and an outline of the history of evaporite dissolution: J. of Res., v. 4, p. 135-149, U. S. Geol. Survey.

Bachman, G. O., 1980, Regional geology and Cenozoic history of Pecos region, southeastern New Mexico: U. S. Geol. Survey OFR 80-1099.

Bachman, G.O., 1981, Geology of Nash Draw, Eddy County, N.M.: U.S. Geol. Survey OFR 81-31.

Bachman, G. O., 1984a, Assessment of near-surface dissolution in the vicinity of the Waste Isolation Pilot Plant: SAND84-7178, Sandia National Laboratories, Albuquerque, NM, 87185.

Bachman, G.O., 1984b, Regional geology of Ochoan evaporites, northern part of Delaware Basin: New Mex. Bur. Mines and Min. Res., Circ. 184, 22 p.

Bachman, G.O., 1987a, Evaporite karst in the Pecos drainage, southeastern New Mexico: Guidebook 18, El Paso Geol. Soc., p. 118-123.

Bachman, G.O., 1987b, Karst in evaporites in southeastern New Mexico: SAND86-7078, Sandia National Laboratories, Albuquerque, New Mexico, 87185, 82 p.

Bachman, G.O., Johnson, R. B., and Swenson, F. A., 1973, Stability of salt in the Permian salt basin of Kansas, Oklahoma, Texas and New Mexico: U.S. Geol. Survey, OFR USGS-4339-4, 62 p.

Baker, M. R., 1987, Quantitative log interpretation using probabilistic internally consistent inversion (PICI): Proc. of Geoscience Coll., Univ. of Texas at El Paso, P. 49-60.

Beales, F.W., and Hardy, J.L., 1977, The problem of recognition of occult evaporites with special reference to southeast Missouri: Econ. Geol., v. 72, p. 487-490.

M

Belloni, S., Martinis, B., and Orombelli, G., 1972, Karst of Italy: in Herak and Stringfield (1972), p. 85 - 128.

Billo, S.M., 1986, Petroleum sedimentology of the Ochoa Group (sic), Texas and New Mexico: Abstr., 12th Int. Sed. Congress, Canberra, Australia, p. 30-31.

Bleahu, M.D., 1972, Karst of Rumania: in Herak and Stringfield (1972),p. 341 - 353.

Bodine, M.W., Jr., 1978, Clay-mineral assemblages from drill core of Ochoan evaporites, Eddy County: New Mex. Bur. Mines and Min. Res., Circ. 159, p. 21-32.

Boeglie, A., 1980, Karst Hydrology and Physical Speleology: Springer-Verlag, Berlin, 284 p.

Borns, D.J., Barrows, L.J., Powers, D.W., and Snyder, R.P., 1983, Deformation of evaporites near the Waste Isolation Pilot Plant (WIPP) site: SAND82-1069, Sandia National Laboratories, Albuquerque, New Mexico, 87185, 143 p.

Borns, D.J., and Shaffer, S-E., 1985, Regional well-log correlation in the New Mexico portion of the Delaware Basin: SAND83-1798, Sandia National Laboratories, Albuquerque, New Mexico, 87185, 73 p.

Bowles, C. G., and Braddock, W. A., 1963, Solution breccias of the Minnelusa Formation in the Black Hills, South Dakota and Wyoming: Art. 83, U. S. Geol. Survey Prof. Paper 475-c, p. C91-C95.

Bretz, J.H., 1950, Origin of the filled sink-structures and circle deposits of Missouri: Geol. Soc. Am. Bull., v. 61, p. 789-833.

Brodzikowski, K., and Van Loon, A. J., 1985, Penecontemporaneous non-tectonic brecciation of unconsolidated silts and muds: Sed. Geol., v. 41, p. 269-282.

Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hays, W.H., 1972, Geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico: U.S. Geol. Survey, OFR USGS-4339-1, 86 p.

Butler, G. P., 1969, Modern evaporite deposition and geochemistry of coexisting brines, the sabkha, Trucial Coast, Arabian Gulf: Jour. Sed. Pet., v. 39, p. 70-89.

Butler, G. P., Harris, P. M., and Kendall, C. G. St. C., 1982, Recent evaporites from the Abu Dhabi coastal Flats: in Depositional and Diagenetic Spectra of Evaporites - A Core Workshop, SEPM Core Workshop no. 3, p. 33-64.

Carozzi, A. V., 1962, Observations on algal biostromes in the Great Salt Lake, Utah: Jour. Geol., v. 70, p. 246-252.

Christiansen, E. A., 1971, Geology of the Crater Lake collapse structure in southeastern Saskatchewan: Can. J. Earth Sci., v. 8, p. 1505-1513.

Cody, R. D., and Hull, A. B., 1980, Experimental growth of primary anhydrite at low temperatures and water salinities: Geology, v. 8, p. 505-509.

Cooper, J.B., and Glanzman, V.M., 1971, Geohydrology of Project Gnome site, Eddy County, New Mexico: U.S. Geol. Survey Prof. Paper 712-A, 24 p.

Cornell, 1984, Pers. Comm. to Dennis Powers.

Cys, J.M., 1978, Transitional nature and significance of the Castile-Bell Canyon contact: New Mex. Bur. Mines and Min. Res., Circ 159, p. 53-56.

Davies, P. B., 1983, Structural characteristics of a deep-seated dissolution-subsidence chimney in bedded salt: Sixth Int. Symp. on Salt, v. I, p. 331-350.

Dean, W. E., Davies, G. R., and Anderson R. Y., 1975, Sedimentological significance of nodular and laminated anhydrite: Geology, v. 3, p. 367-372.

Demicco, R. V., 1983, Wavy and lenticular-bedded carbonate ribbon rocks of the Upper Cambrian Conochocheague Limestone, Central Appalachians: Jour. Sed. Pet., v. 53, p. 1122-1132.

DeMille, G., Shouldice, J.R., and Nelson, H.W., 1964, Collapse structures related to evaporites of the Prairie Evaporite Formation, Saskatchewan: Geol. Soc. Am. Bull, v. 75, p. 307-316.

Dilamarter, R.R., and Csallany, S.C., eds., 1977, Hydrologic Problems in Karst Regions: Western Kentucky University, Bowling Green, Kentucky, 481 p.

Donegan, B., and DeFord, R.K., 1950, Ochoa is Permian: Am. Assoc. Pet. Geol. Bull., v. 34, p. 2356-2359.

Doveton, J. H., 1986, Log Analysis of Subsurface Geology - Concepts and Computer Methods: Wiley-Interscience, New York, 273 p.

Durney, D. W., and Ramsay, J. G., 1973, Incremental strains measured by syntectonic crystal growths: in Gravity & Tectonics, eds., K. A. DeJong and R. Scholter, p. 67-96.

Eager, G. P., 1983, Core from the lower Dewey Lake, Rustler, and upper Salado Formation, Culberson County, Texas: Permian Basin Section SEPM Core Workshop #2, p. 273-283.

Elliot, C. L., 1976, An experimental detailed resistivity survey of Hills C and D, Eddy County, New Mexico: report to Sandia National Laboratories, Albuquerque, New Mexico, 13 p.

Eugster, H. P., and Hardie, L. A., 1975, Sedimentation in an ancient playa-lake complex: The Wilkins Peak Member of the Green River Formation of Wyoming: Geol. Soc. Amer. Bull., v. 86, p. 319-334.

Eugster, H. P., and Hardie, L. A., 1978, Saline Lakes: in Lerman, A., ed., Lakes - Chemistry, Geology, Physics, Springer-Verlag, New York, p. 237-293.

Ferrall, C. C., and Gibbons, J. F., 1980, Core study of the Rustler Formation over the WIPP site: SAND79-7110, Sandia National Laboratories, Albuquerque, New Mexico, 87185, 81 p.

Fracasso, M. A., and Hovorka, S. D., 1986, Cyclicity in the Middle Permian San Andres Formation, Palo Duro Basin, Texas panhandle: Texas Bur. of Econ. Geol., Report of Investigations no. 156, 48 p.

Fracasso, M.A., and Kolker, A., 1985, Later Permian volcanic ash beds in the Quartermaster-Dewey Lake Formations, Texas Panhandle: Bull. West Texas Geol. Soc., v. 24, no. 6, p. 5-10.

Friedman, G. M., Amiel, A. J., Braun, M. and Miller, D. S., 1973, Generation of carbonate particles and laminites in algal mats-example from sea-marginal hypersaline pool, Gulf of Aqaba, Red Sea: Am. Assoc. Pet. Geol. Bull., v. 57, p. 541-557.

Gard, L.M., Jr., 1968, Geologic studies, Project Gnome, Eddy County, New Mexico: U.S. Geol. Survey Prof. Paper 589, 33 p.

Garrison, R. E., Schreiber, B. C., Bernoulli, D., Fabricius, F. H., Kidd, R. B., and Melieres, F., 1978, Sedimentary petrology and structures of Messinian evaporitic sediments in the Mediterranean Sea, Leg 42A, Deep Sea Drilling Project: Initial Reports of the Deep Sea Drilling Project, Volume XLII, Part 1, Washington, p. 571-611.

Gebelein, C. D., 1969, Distribution, morphology, and accretion rate of recent subtidal algal stromatolites, Bermuda: Jour. Sed. Pet., v. 39, p. 49-69.

Gendzwill, D.J., and Hajnal, Z., 1971, Seismic investigation of the Crater Lake collapse structure in southeastern Saskatchewan: Can. J. Earth Sci., v. 8, p. 1514-1524.

Gillett, S.L., 1983, A probable cave breccia in Middle Cambrian limestone, southern Nevada: Jour. Sed. Pet., v. 53, p. 221-229.

Glazek, J., Dabrowski, T., and Gradzinski, R., 1972, Karst of Poland: in Herak and Stringfield (1972), p. 327 - 340.

Goldstein, A.G., and Collins, E.W., 1984, Deformation of Permian strata overlying a zone of salt dissolution and collapse in the Texas panhandle: Geology, v. 12, p. 314-417.

Gonzalez, D. D., 1982, Fracture flow in the Ruster Formation: Waste Isolation Pilot Plant (WIPP), southeast New Mexico: SAND82-1012, Sandia National Laboratories, Albuquerque, New Mexico, 87185.

Goodwin, P.W., and Anderson, E.J., 1980, Punctuated aggradational cycles; A general hypothesis of stratigraphic accumulation: Abstr. Geol. Soc. Am., v. 12, p. 436.

Gornitz, V. M., and Schreiber, B. C., 1981, Displacive halite hoppers from the Dead Sea: some implications for ancient evaporite deposits: Jour. Sed. Pet., v. 51, p. 787-794.

Gorrell, H.A., and Alderman, G.R., 1968, Elk Point Group saline basins of Alberta, Saskatchewan, and Manitoba, Canada: in Mattox, R.B., ed., Saline Deposits, Geol. Soc. Am. Spec. Papers, no. 88, p. 291-317.

Griswold, G. B., 1977, Site selection and evaluation studies of the Waste Isolation Pilot Plant (WIPP), Los Medanos, Eddy County, New Mexico: SAND77-0946, Sandia National Laboratories, Albuquerque, New Mexico, 87185.

Gustavson, T.C., 1986, Geomorphic development of the Canadian River Valley, Texas panhandle: an example of regional salt dissolution and subsidence: Geol. Soc. Am. Bull., v. 97, p. 459-472.

Gustavson, T.C., Finley, R.J., and McGillis, K.A., 1980, Regional dissolution of Permian salt in the Anadarko, Dalhart, and Palo Duro Basins of the Texas panhandle: Texas Bur. Econ. Geol., Report of Investigations no. 106, 40 p.

Handford, C. R., 1981, Coastal sabkha and salt pan deposition of the Lower Clear Fork Formation (Permian), Texas: Jour. Sed. Pet. v. 51, p. 761-778.

Handford, C. R., 1982, Sedimentology and evaporite genesis in a Holocene continental-sabkha playa basin-Bristol Dry Lake, California: Sed., v. 29, p. 239-253.

Handford, C. R. and Fredricks, P. E., 1980, Facies patterns and depositional history of a Permian Sabkha complex: Red Cave Formation, Texas Panhandle: Texas Bur. Econ. Geol., Geol. Circ. 80-9, 38 p.

Hardie, L. A., 1968, The origin of the Recent non-marine evaporite deposit of Saline Valley, Inyo County, California: Geochimica et Cosmochimica Acta, v. 32, p. 1279-1301.

Hardie, L. A., and Eugster, H. P., 1971, The depositional environment of marine evaporites: a case for shallow, clastic accumulation: Sed., v. 16, p. 187-220.

Hardie, L. A., Smoot, J. P., and Eugster, H. P., 1978, Saline lakes and their deposits: a sedimentological approcah: Spec. Publs. Int. Assoc. Sed., v. 2, p. 7-41.

Hayes, P. T., 1964, Geology of the Guadalupe Mountains, New Mexico: U.S. Geol. Survey. Prof. Paper No. 446

Hedberg, H.D., 1976, International Stratigraphic Guide: A guide to stratigraphic classification, terminology, and procedure: John Wiley & Sons, New York, 200 p.

Herak, M., and Stringfield, V.T., eds', 1972, Karst: Important Karst Regions of the Northern Hemisphere: Elsevier, Amsterdam, 551 p.

Hills, J.M., 1963, Late Paleozoic tectonics and mountain ranges, western Texas to southern Colorado: Am. Assoc. Pet. Geol. Bull., v.47, p. 1709-1725.

Hills, J. M., 1972, Late Paleozoic sedimentation in west Texas Permian basin: Am. Assoc. Pet. Geol. Bull., v. 56, p. 2303-2322.

Hills, J. M., 1984, Sedimentation, tectonism, and hydrocarbon generation in Delaware basin, west Texas and southeastern New Mexico: Am. Assoc. Pet. Geol. Bull., v. 68, p. 250-267.

Hills, J.M., and Kottlowski, F.E., coordinators, 1983, Southwest/southwest mid-continent region: Am. Assoc. Pet. Geol., Correlation Chart Series.

Hoffman, P., 1974, Shallow and deepwater stromatolites in Lower Proterozoic Platform-to-basin facies change, Great Slave Lake, Canada: Am. Assoc. Pet. Geol. Bull., v. 58, p. 856-867.

Holt, R. M., and Powers, D. W., 1984, Geotechnical activities in the waste handling shaft: WISD-TME-038, U.S. Dept. of Energy, Carlsbad, New Mexico.

Holt, R. M., and Powers, D. W., 1986a, Geotechnical activities in the exhaust shaft: DOE-WIPP-86-008,U.S. Dept. of Energy, Carlsbad, New Mexico.

Holt, R.M., and Powers, D.W., 1986b, Rustler Formation: evaporite end stanges of a continental basin: Abstr., 12th Int. Sed. Congress, Canberra, Australia, p. 141-142.

Holt, R.M., and Powers, D. W., 1987, The Permian Rustler Formation at the WIPP site, southeastern New Mexico: Guidebook 18, El Paso Geol. Soc., p. 140-148.

Hovorka, S. D., 1983a, Sedimentary structures and diagenetic modifications in halite and anhydrite, Palo Duro Basin: Texas Bur. Econ. Geol., Geol. Circ. 83-4, p.49-57.

Hovorka, S. D., 1983b, Dissolution and recrystallization fabrics in halite and interpretation of the timing of their development, Palo Duro Basin: Texas Bur. Econ. Geol., Geol. Circ. 83-4, p.58-65.

Hovorka, S. D., in press, Depositional environments of marine-dominated banded halite, Permian San Andres Formation: Sed.

Hovorka, S. D. and Granger, P. A., in press, Subsurface to surface correlation of Permian evaporites: San Andres-Blaine-Flowerpot relationships, Texas Panhandle: Midcontinent SEPM Symposium on the Permian of the Midcontinent.

Jennings, J. N., 1971, Karst: M.I.T. Press.

Johnson, K.S., 1981, Dissolution of Salt on the east flank of the Permian Basin in the southwestern U.S.A.: Jour. Hydrol., v. 54, p. 75 - 93.

Jones, C.L., 1954, The occurrence and distribution of potassium minerals in southeastern New Mexico: Guidebook to Southeastern New Mexico, New Mex. Geol. Soc., p. 107-112.

Jones, C. L., 1972, Permian basin potash deposits, southwestern United States: in Geology of saline deposits, UNESCO, Earth Sci. Ser., No. 7, p. 191-201.

Jones, C.L., Bowles, C.G., and Bell, K.G., 1960, Experimental drill hole logging in potash deposits of the Carlsbad District, New Mexico: U.S. Geol. Survey, OFR 60-84, 22 p.

Jones, C.L., Cooley, M.E., and Bachman, G.O., 1973, Salt deposits of Los Medanos area, Eddy and Lea Counties, New Mexico: U.S. Geol. Survey, OFR 4339-7, 67 p.

Jones, C. L., and Gonzales, J. L., 1980, Geologic data for borehole WIPP 19, Ch. 3: in Basic data report for drillhole WIPP-19 (Waste Isolation Pilot Plant - WIPP): SAND79-0276, Sandia National Laboratories, Albuquerque, New Mexico, 87185.

Kelley, V.C., 1971, Geology of the Pecos country, southeastern New Mexico: N.Mex Bur. Mines and Min. Res., Mem. 24, 75 p.

Kendall, A.C., 1984, Evaporites: in Facies Models, 2nd Ed., Geoscience Canada Reprint Series 1, p. 259-296.

Kendall, C. G. C., and Skipwith, P. A., 1968, Recent algal mats of a Persian Gulf lagoon: Jour. Sed. Pet., v. 38, p. 1040-1058.

Kinsman, D. J. J., 1976, Evaporites: relative humidity control of primary mineral facies: Jour. Sed. Pet., v. 46, p. 273-279.

Kirkland, D.W., and Anderson, R.Y., 1970, Microfolding in the Castile and Todilto evaporites, Texas and New Mexico: Geol. Soc. Am. Bull., v. 81, p. 3259-3282.

Kirkland, D. W., and Evans, R., 1976, Origin of limestone buttes, Gypsum Plain, Culberson County, Texas, and Eddy County, New Mexico: Am. Assoc. Pet. Geol. Bull., v. 60, p. 2005-2018.

Lambert, S. J., 1983, Dissolution of evaporites in and around the Delaware Basin, southeastern New Mexico and west Texas: SAND82-0461, Sandia National Laboratories, Albuquerque, New Mexico, 87185.

Landes, K. K., 1945, Ch. 3 - The Mackinac Breccia: in Landes and others, 1945, p. 123-153.

Landes, K.K., Ehlers, G.M., and Stanley, G.M., 1945, Geology of the Mackinac Straits region and subsurface geology of northern southern Peninsula: Pub. 44, Geol. Series 37, Geol. Survey Div., Michigan, 204 p.

Lang, W. B., 1935, Upper Permian formation of Delaware Basin of Texas and New Mexico: Am. Assoc. Pet. Geol. Bull., v. 19, p. 262-276.

Lang, W.B., 1939, Salado Formation of the Permian Basin: Am. Assoc. Pet. Geol. Bull., v. 23, p. 1569-1572.

Lang, W. B., 1942, Basal beds of Salado Formation in Fletcher potash core test near Carlsbad, New Mexico: Am. Assoc. Pet. Geol. Bull., v. 26, p. 63-79.

Lee, W. T., 1925, Erosion by solution and fill (Pecos Valley, New Mexico): U. S. Geol. Survey, Bull. 760-c, p. 107-121.

Logan, B. W., 1961, Cryptozoon and associate stomatolites from the recent, Shark Bay, Western Australia: Jour. Geol., v. 69, p. 517-533.

Logan, B. W., Rezak, R., and Ginsburg, R. N., 1964, Classification and environmental significance of algal stromatolites: Jour. Geol., v. 72, p. 68-83.

Lowenstein, T.K., 1982, Primary features in a potash evaporite deposit, the Permian Salado formation of west Texas and New Mexico, in Handford, C.R., Loucks, R.G., and Davies, G.R., eds., Depositional and diagenetic spectra of evaporites -- a core workshop: SEPM Core Workshop No. 3, Calgary, Canada, p. 276-304.

Lowenstein, T.K., 1987a, Depositional cycles in the Permian Salado Formation, southeastern New Mexico: Guidebook 18, El Paso Geol. Soc., p. 124-132.

Lowenstein, T. K., 1987b, Evaporite depositional fabrics in the deeply buried Jurassic Buckner Formation, Alabama: Jour. Sed. Pet. v. 57, p. 108-116.

Lowenstein, T. K., 1987c, Post-burial alteration of the Permian Rustler Formation evaporites, WIPP site, New Mexico: textural, stratigraphic and chemical evidence: EEG-36, DOE/AL 10752-36, Environmental Evaluation Group, 54 p.

Lowenstein, T. K., and Hardie, L. A., 1985, Criteria for the recognition of salt-pan evaporites: Sed., v. 32, p. 627-644.

Maley, V. C., and Huffington, R. M., 1953, Cenozoic fill and evaporite solution in the Delaware Basin, Texas and New Mexico: Geol. Soc. Am. Bull, v. 64, p. 539-546.

Mazzulo, S. J., 1981, Facies and burial diagenesis of a carbonate reservoir - Chapman deep (Atoka) field, Delaware County, Texas: Am. Assoc. Pet. Geol. Bull., v. 65, p. 850-865.

McGowen, J. H., Granata, G. E., and Seni, S. J., 1983, Depositional setting of the Triassic Dockum Group, Texas Panhandle and Eastern New Mexico: in Mesozoic Paleogeography of West Central United States, eds., M. W. Reynolds and D. Dolly, Rocky Mountain Section S.E.P.M., p. 13-38.

W

McGillis, K. A. and Presley, M. W., 1981, Tansill, Salado, and Alibates Formations: Upper Permian Evaporite/Carbonate Strata of the Texas Panhandle, Texas Bur. Econ. Geol., Circ. 81-8.

McKnight, E.T., and Fischer, R.P., 1970, Geology and ore deposits of the Picher Field, Oklahoma and Kansas: U.S. Geol. Survey Prof. Paper 588, 165 p. + plates.

Mercer, J. W., 1983, Geohydrology of the proposed Waste Isolation Pilot Plant site, Los Medanos area, southeastern New Mexico: U.S. Geol. Surv., Water Resources Inv. Report 83-4016.

Mercer, J.W., 1986, Compilation of hydrologic data from drilling the Salado and Castile Formations near the WIPP site, southeastern New Mexico: SAND86-0954, Sandia National Laboratories, Albuquerque, NM 87185.

Mercer, J.W., and Orr, B.R., 1979, Interim data report on the geohydrology of the proposed Waste Isolation Pilot Plant site, southeast New Mexico: U.S. Geol. Survey Water Resources Investigations 79-98, 178 p.

Middleton, G.V., 1961, Evaporite solution breccias from the Mississippian of southwest Montana: Jour. Sed. Pet., v. 31, p. 189-195.

Miller, D.N., 1955, Hollow sanidine grains, a stratigraphic marker for the Pierce Canyon Formation, west Texas and southeast New Mexico: Jour. Sed. Pet., v. 25, p. 235-237.

Miller, D.N., 1957, Authigenic biotite in spheroidal reduction spots, Pierce Canyon Redbeds, Texas and New Mexico: Jour. Sed. Pet., v. 27, p. 177-180.

Miller, D. N., 1966, Petrology of Pierce Canyon Redbeds, Delaware Basin, Texas and New Mexico: Am. Assoc. Petrol. Geol. Bull., v. 80, p. 283-307.

Myer, J., 1987, Pers. Com. to Robert Holt.

NAS, 1957, Disposal of radioactive wastes on land: National Academy of Sciences - National Research Council, Washington, D. C., Publ. 519.

Neal, J. T., Langer, A. M., and Kerr, P. F., 1968, Giant desiccation polygons of Great Basin playas: Geol. Soc. Amer. Bull., v. 79, p. 69-90.

Neumann, A. C., Gebelein, C. D., and Scoffin, T. P., 1970, The composition, structure and erodability of subtidal mats, Abaco, Bahamas: Jour. Sed. Pet., v. 40, p. 274-297.

Nicholson, A., Jr., and Clebsch, A., Jr., 1961, Geology and ground-water conditions in southern Lea County, New Mexico: N. Mex. Bur. Mines and Min. Res. Ground-water Report 6, 120 p.

Ohle, E.L., 1985, Breccias in Mississippi Valley-type deposits: Econ. Geol., v. 80, p. 1736-1752.

Olive, W.W., 1957, Solution-subsidence troughs, Castile Formation of Gypsum Plain, Texas and New Mexico: Geol. Soc. Am. Bull., v. 68, p. 351-358.

Oriel, S. S., Myers, D. A., and Crosby, E. J., 1967, West Texas Permian Basin region, in Paleotectonic investigations of the Permian System in the United States: U.S. Geol. Surv. Prof. Paper 515, p. 21-60.

Page, L.R., and Adams, J.E., 1940, Stratigraphy, Eastern Midland Basin, Texas: Am. Assoc. Pet. Geol. Bull., v. 24, p. 52-64.

Palmer, A.R., and Halley, R.B., 1979, Physical stratigraphy and trilobite biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in the southern Great Basin: U.S. Geol. Survey Prof. Paper 1047.

Parker, J. M., 1967, Salt solution and subsidence structures, Wyoming, North Dakota, and Montana: Am. Assoc. Pet. Geol. Bull, v. 51, p. 1929-1947.

Peryt, T. M., and Piatkowski, T. S., 1977, Stromatolites from the Zechstein Limestone (Upper Permian) of Poland: in Fossil Algae, Recent Results and Developments, ed., E. Flugel, International Symposium on Fossil Algae, p. 124-135.

Pfeiffer, D., and Hahn, J., 1972, Karst of Germany: in Herak and Stringfield (1972), p. 189 - 224.

Playford, P. E., and Cockbain, A. E., 1969, Algal stromatolites: Deepwater forms in the Devonian of Western Australia: Science, v. 165, p. 1008-1010.

Powers, D. 1986, Interpretation of geophysical logs to select stratigraphic horizons within the Rustler Formation: App. D, in Winstanley, D. J., and Carrasco, R. C., Annual Hydrogeologic data report: 1985/1986: DOE-WIPP86-004, Dept. of Energy, Carlsbad, NM.

Powers, D.W., and Holt, R.M., 1984, Depositional environments and dissolution in the Rustler Formation (Permian), southeastern New Mexico: Abstr. Geol. Soc. Am., v. 16, no. 6, p. 627.

Powers, D.W., and Hassinger, B.W., 1985, Synsedimentary dissolution pits in halite of the Permian Salado Formation, southeastern New Mexico: Jour. Sed. Pet., v. 55, p. 769-773.

Powers, D. W., Holt, R. M., and Hoffer, J. M., 1987, Preliminary studies of near-surface sediments, Salt Flat graben, west Texas: Guidebook 18, El Paso Geol. Soc., p. 194-194.

Powers, D.W., Lambert, S.J., Shaffer, S., Hill, L.R., and Weart, W.D., eds., 1978, Geological characterization report, Waste Isolation Pilot Plant (WIPP) site, southeastern New Mexico: SAND78-1596, Vols. I and II, Sandia National Laboratories, Albuquerque, N.M., 87185, about 1500 p.

Presley, M. W., and McGillis, K. A., 1982, Coastal evaporite and tidal-flat sediments of the Upper Clear Fork and Glorieta Formations, Texas panhandle: Texas Bur. of Econ. Geol., Report of Investigations 115, 50 p.

Reineck, H. E., and Singh, I. B., 1980, Depositional sedimentary environments: Springer-Verlag, New York-Heidelberg-Berlin, 549 p.

Richardson, G. B., 1904, Report of a reconnaisance in Trans-Pecos Texas north of the Texas and Pacific Railway: Univ. Texas Bull. 23.

Roberts, A.E., 1966, Stratigraphy of the Madison Group near Livingston, Montana, and discussion of karst and solution-breccia features: U.S. Geol. Survey Prof. Paper 526-B, 23 p.

Robinson, J.Q., and Powers, D.W., 1987, A clastic deposit within the lower Castile Formation, western Delaware Basin, New Mexico: Guidebook 18, El Paso Geol. Soc., p. 69-79.

Rogers, R.K., and Davis, J.H., 1977, Geology of the Buick mine, Viburnum Trend, southeast Missouri: Econ. Geol., v. 72, p. 372-280.

Ross, C.A., 1986, Paleozoic evolution of southern margin of Permian basin: Geol. Soc. Am. Bull., v.97, p. 536 - 554.

Sandia National Laboratories and U.S. Geological Survey, 1980, Basic data report for drillhole WIPP 33: SAND80-2011, Sandia National Laboratories, Albuquerque, N.M., 87185, 27 p.

Sando, W.J., 1974, Ancient solution phenomena in the Madison Limestone (mississippian) of north-central Wyoming: Jour. Res., U.S. Geol. Survey, v. 2, p. 133 - 141.

Sares, S.W., and Wells, S.G., 1987 Geomorphic and hydrogeologic development of the gypsum plain karst, Delaware Basin, New Mexico: Guidebook 18, El Paso Geol. Soc., p. 98-117.

Sawkins, F. J., 1969, Chemical brecciation, an unrecognized mechanism for breccia formation?: Econ. Geol., v. 64, p. 613-617.

Schiel, K.A., 1987, Investigations of the Dewey Lake Formation, Delaware Basin, New Mexico: Guidebook 18, El Paso Geol. Soc., p. 149-156.

Schmalz, R.F., 1969, Deep-water evaporite deposition: a genetic model: Am. Assoc. Pet. Geol. Bull., v. 53, p. 798-823.

Schreiber, B. C., 1978, Environments of subaqueous gypsum deposition: in Marine Evaporites, SEPM Short Course notes no. 4, p. 43-73.

Schreiber, B.C., and Schreiber, E., 1977, The salt that was: Geology, v. 5, p. 527-528.

Severson, J.L., 1952, A comparison of the Madison Group (Mississippian) with its subsurface equivalents in central Montana: unpub. Ph.D. diss., Univ. of Wisconsin, Madison.

Shearman, D. J., 1970, Recent halite rock, Baja California, Mexico: Inst. Mining Met., Trans., v. 79. p. 155-162.

Shearman, D. J., 1978, Evaporites of coastal sabkhas: in Marine Evaporites, SEPM Short Course no. 4, p. 6-42.

Smith, A. R., 1978, Sulfer deposits in Ochoan Rocks of southeastern New Mexico and west Texas: New Mex. Bur. Mines and Min. Res., Circ 159, p. 71-77.

Smith, D. B., 1971, Possible displacive halite in the Permian Upper Evaporite Group of northeast Yorkshire: Sed., v. 17, p. 221-232.

Smith, D. B., 1972, Foundered strata, collapse-breccias and subsidence features of the English Zechstein: in Geology of saline deposits, UNESCO, Earth Sci. Ser., no. 7, p. 255-269.

Smith, N.M., Sunderman, J.A., and Melhorn, W.N., 1961, Breccia and Pennsylvanian cave filling in Mississippian St. Louis Limestone, Putnam County, Indiana: Jour. Sed. Pet., v. 31, p. 275-287.

Snyder, R.P., 1985, Dissolution of halite and gypsum, and hydration of anhydrite to gypsum, Rustler Formation, in the vicinity of the Waste Isolation Pilot Plant, southeastern New Mexico: U. S. Geol. Survey OFR Report 85-229, 11 p.

Snyder, R. P., and Gard, L. M., Jr., 1982, Evaluation of breccia pipes in southeastern New Mexico and their relation to the Waste Isolation Pilot Plant (WIPP) site: U. S. Geol. Survey OFR 82-968, 73 p.

Snyder, F.G., and Odell, J.W., 1958, Sedimentary breccias in the southeast Missouri lead district: Geol. Soc. Am. Bull., v. 69, p. 899-926.

Southgate, P. N., 1982, Cambrian skeletal halite crystals and experimental analogues: Sed., v. 29, p. 391-407.

Stanton, R. J., Jr., 1966, The solution brecciation process: Geol. Soc. Am. Bull., v. 77, p. 843-848.

Sweeting, M. M., 1972, Karst Landforms: MacMillan, London.

Till, R., 1978, Arid shorelines and evaporites: in Sedimentary Environments and Facies, ed. by Reading, H. G., p. 178-206.

Toomey, D. F., 1985, Dasyclad Algae within Permain (Leonard) cyclic shelf carbonates ("Abo"), Northern Midland Basin, West Texas: in Paleoalgology, Contemporary Research and Applications, eds., D. F. Toomey and M. H. Nitecki, p. 315-329.

Tucker, R. M., 1981, Giant polygons in the Triassic salt of Cheshire, England: a thermal contraction model for their origin: Jour. Sed. Pet., v. 51, p. 779-786.

Udden, J.A., 1924, Laminated anhydrite in Texas: Geol. Soc. Am. Bull, v. 35, p. 347-354.

Vai, G. B., and Ricci Lucchi, F., 1977, Algal crusts, autochthonous and clastic gypsum in a cannibalistic evaporite basin: a case history from the Messinian of Northern Apennines: Sed., v. 24, p. 211-244.

Valyashko, M. G., 1972, Playa lakes-a necessary stage in the development of a salt-bearing basin: in Geology of saline deposits, UNESCO, Earth Sci. Ser., no. 7, p. 41-51.

Vaughn, F.R., 1978, The origin and diagenesis of the Arroyo Penasco collapse breccia: unpub. M.S. thesis, SUNY Stony Brook, 70 p.

Vine, J. D., 1963, Surface geology of the Nash Draw Quadrangle, Eddy County, New Mexico: U.S. Geol. Surv. Bull. 1141-B.

Walter, J. C., Jr., 1953, Paleontology of the Rustler Formation, Culberson County, Texas: Jour. Paleontology, v. 27, p. 679-702.

Walters, R.F., 1977, Land subsidence in central Kansas related to salt dissolution: Kans. State Geol. Surv. Bull. 214, 82 p.

Wardlaw, N. C. and Schwerdter, W. M., 1966, Halite-anhydrite seasonal layers in the middle Devonian Prarie Evaporite Formation, Saskatchewan, Canada: Geol. Soc. Am. Bull., V. 7, 331-342.

Warren, J. K., 1982a, The hydrological significance of Holocene tepees, stromatolites, and boxwork limestones in coastal salinas in South Australia: Jour. Sed. Pet., v. 52, p. 1171-1201.

Warren, J. K., 1982b, The hydrological setting, occurrence and significance of gypsum in late Quaternary salt lakes in South Australia: Sed., v. 29, p. 609-630.

Wenrich, K.J., 1985, Mineralization of breccia pipes in northern Arizona: Econ. Geol., v. 80, p. 1722-1735.

FIGURES

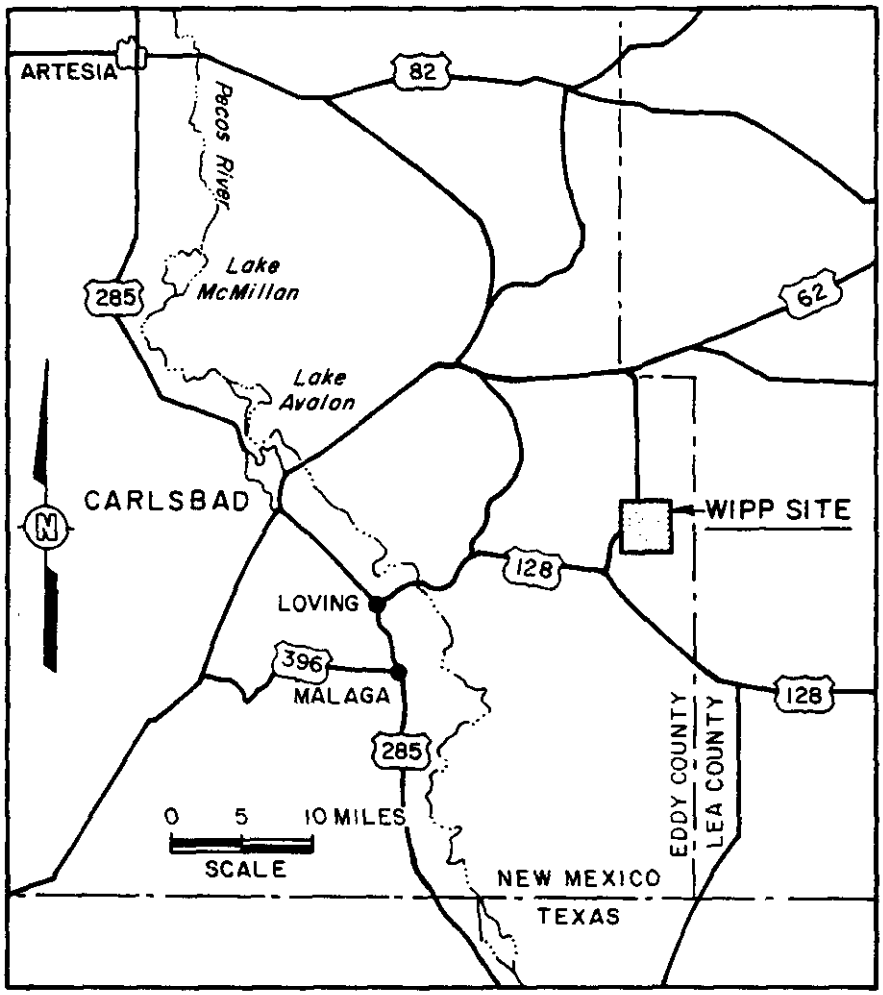

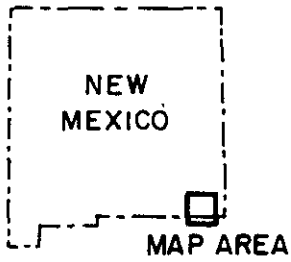

LOCATION MAP

FIGURE 1.1

GENERAL LOCATION
OF THE WIPP SITE

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

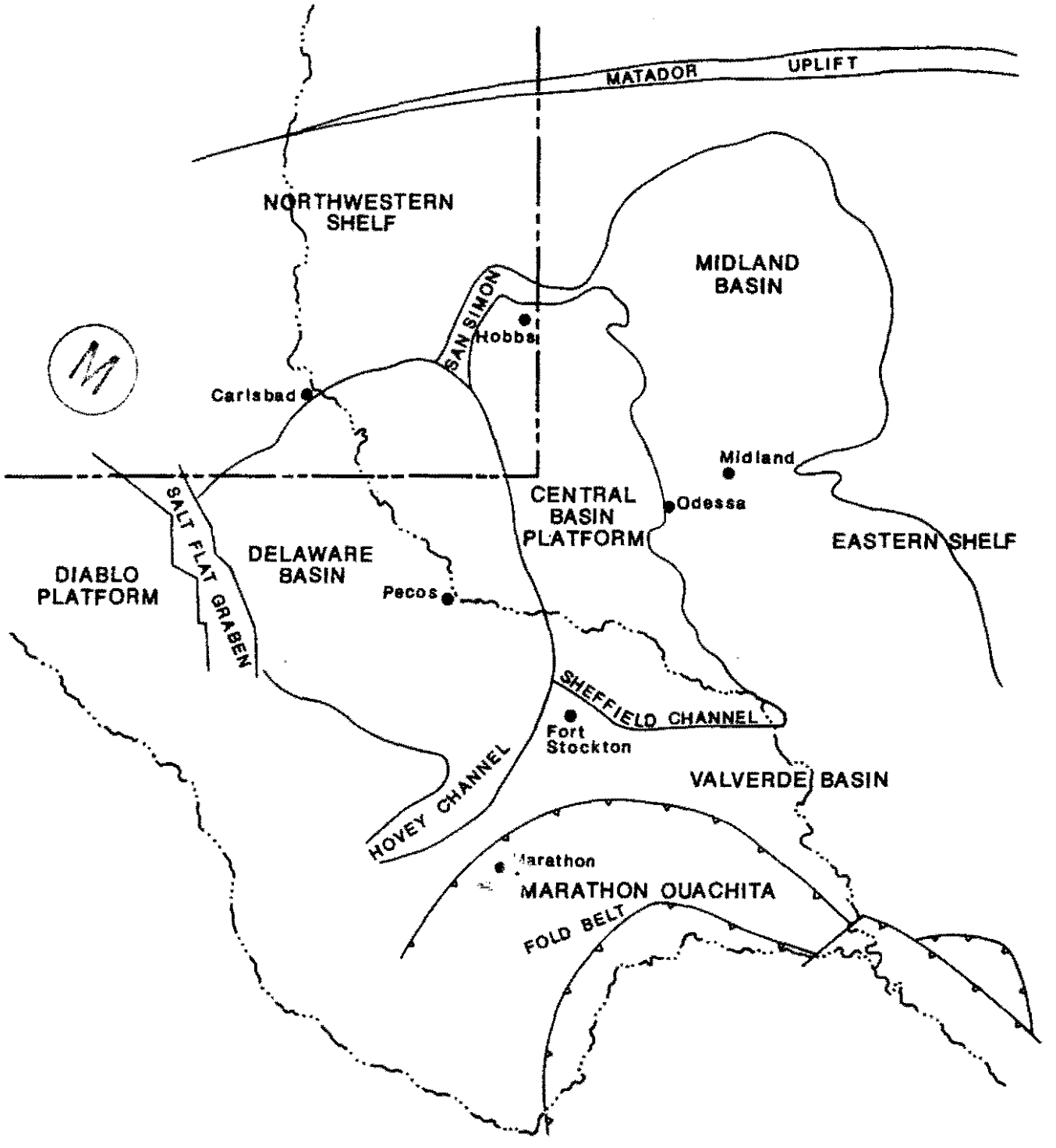

FIGURE 1.2

STRUCTURAL PROVINCES OF THE PERMIAN BASIN REGION (After Hills, 1984)

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

SYSTEM	SERIES	FORMATION
PERMIAN	OCHOAN	DEWEY LAKE REDBEDS
		RUSTLER FORMATION
		SALADO FORMATION
		CASTILE FORMATION

M

FIGURE 3.1

OCHOAN SERIES IN THE
DELAWARE BASIN

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

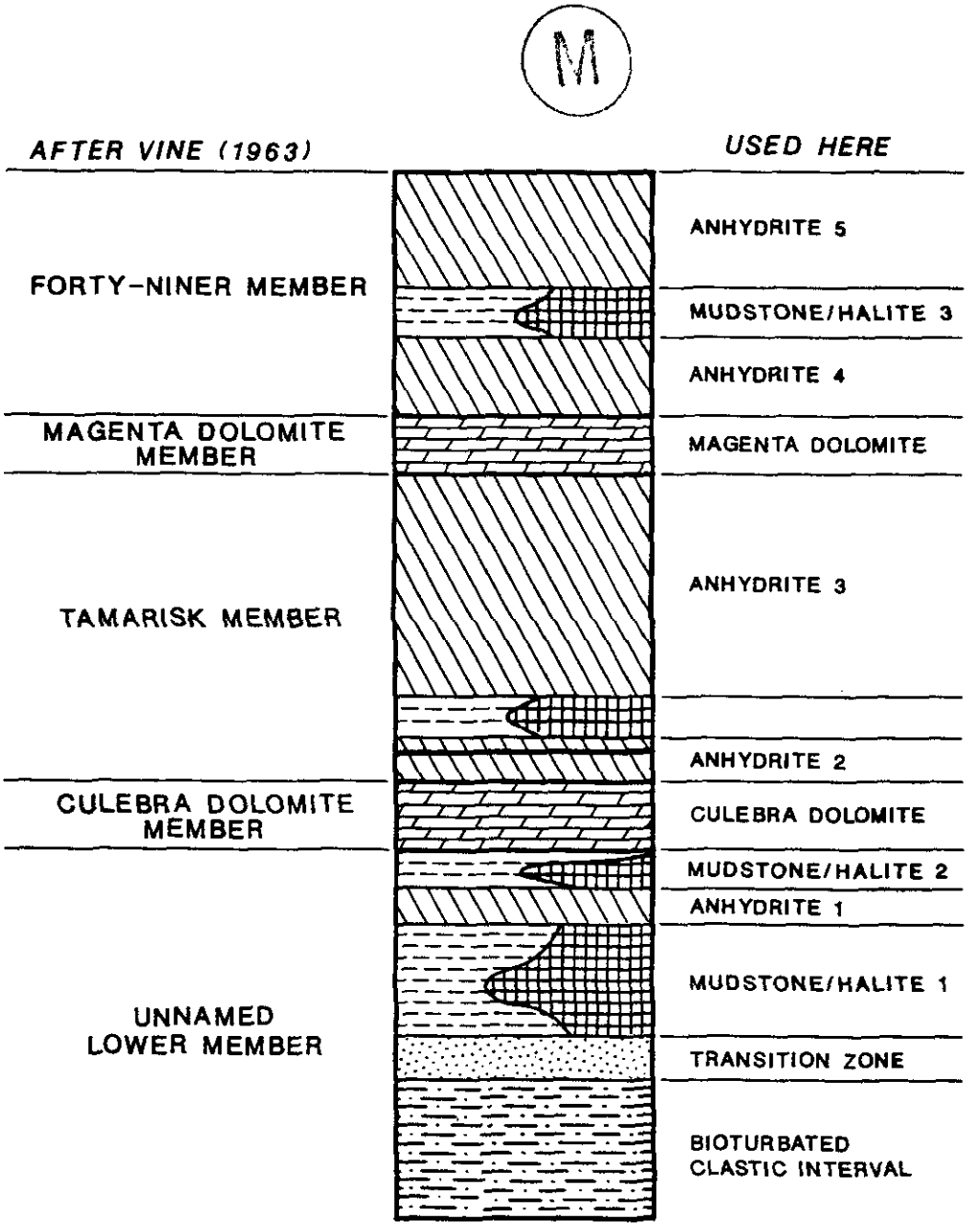

FIGURE 3.2

RUSTLER STRATIGRAPHY

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

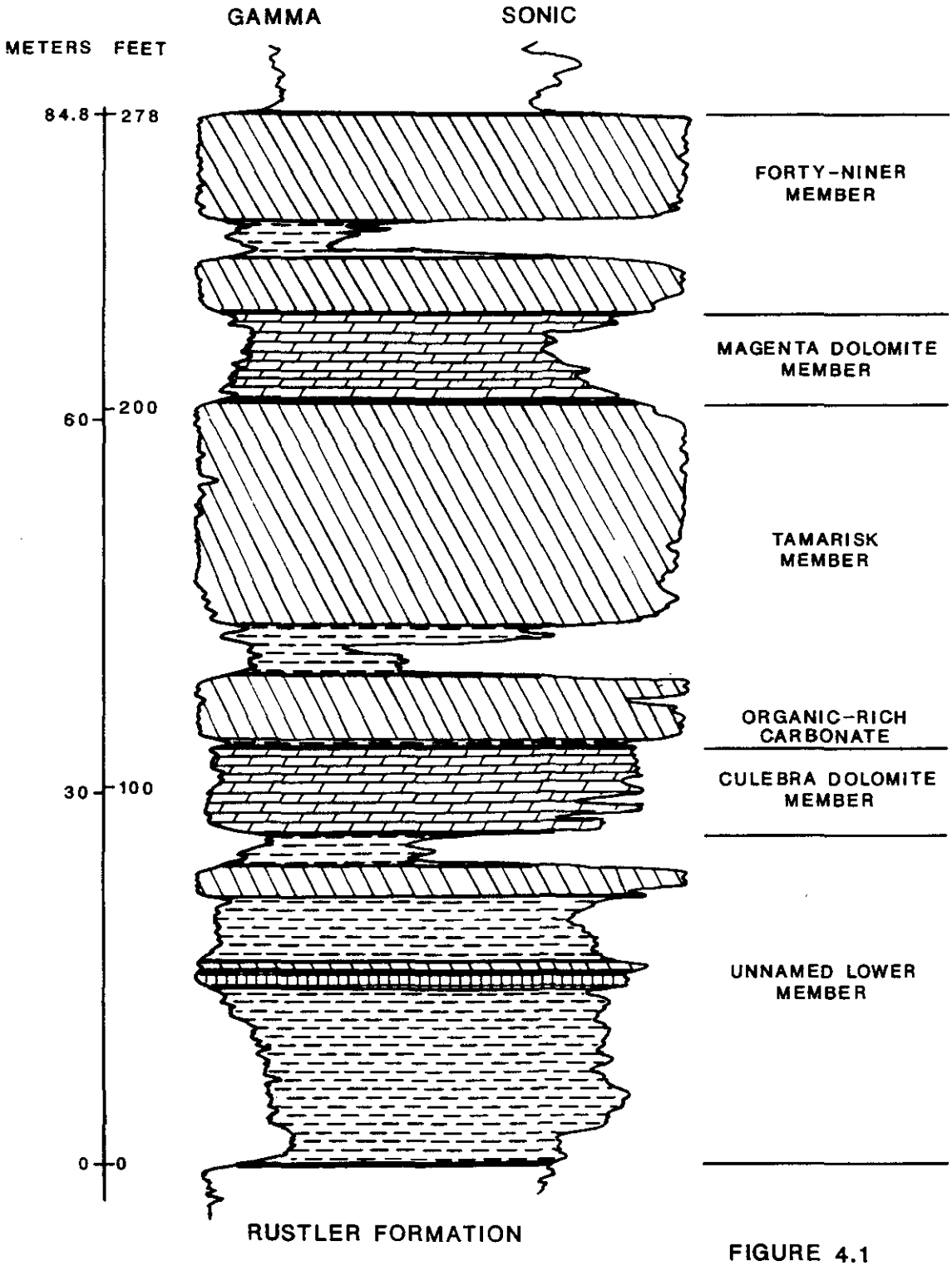

FIGURE 4.1

GENERAL GEOPHYSICAL AND
LITHOLOGIC CHARACTER OF THE RUSTLER

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

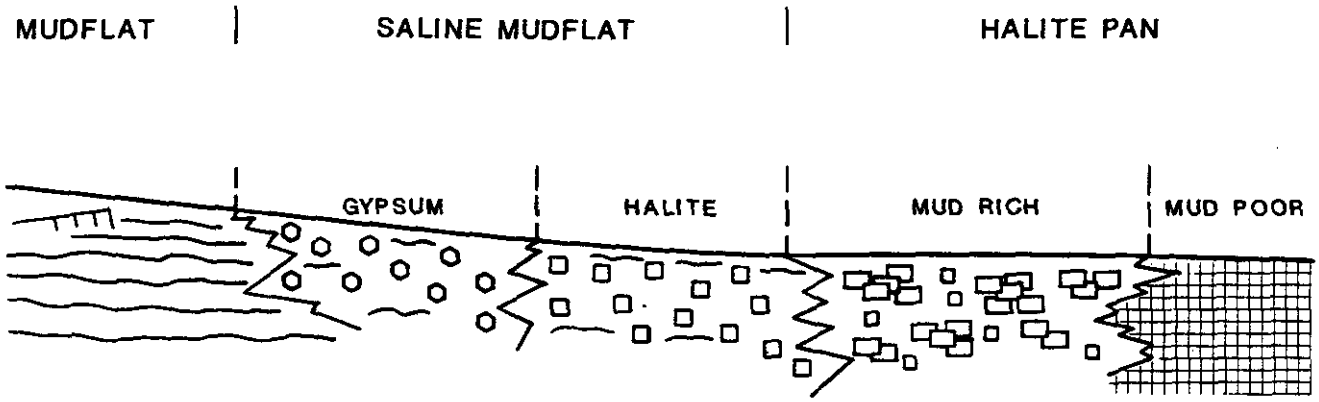

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FIGURE 6.1

HALITE PAN AND MARGINAL
DEPOSITIONAL ENVIRONMENTS

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

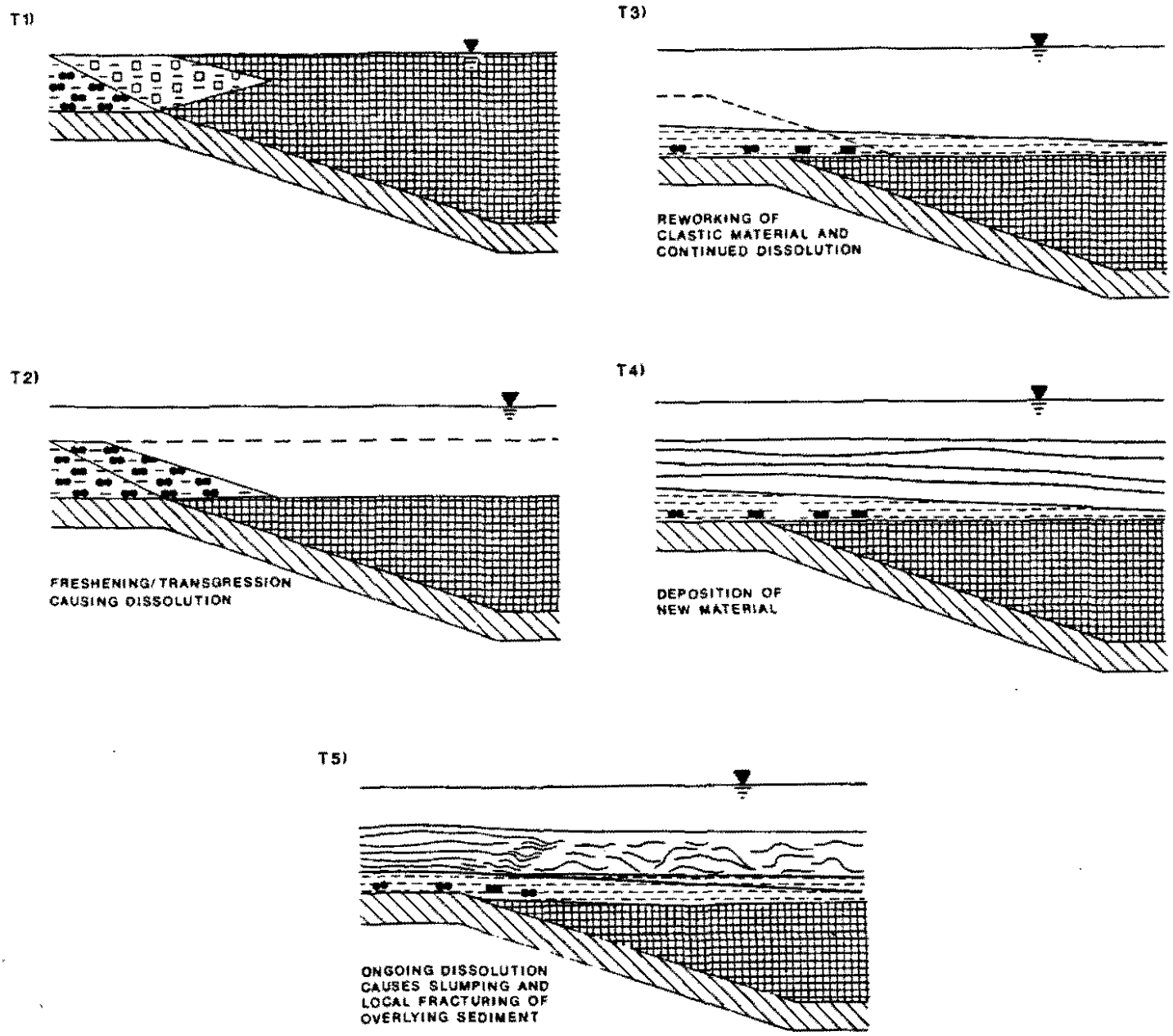

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FIGURE 6.2

SYNDEPOSITIONAL DISSOLUTION
DURING A MAJOR FLOOD
OR TRANSGRESSIVE EVENT

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

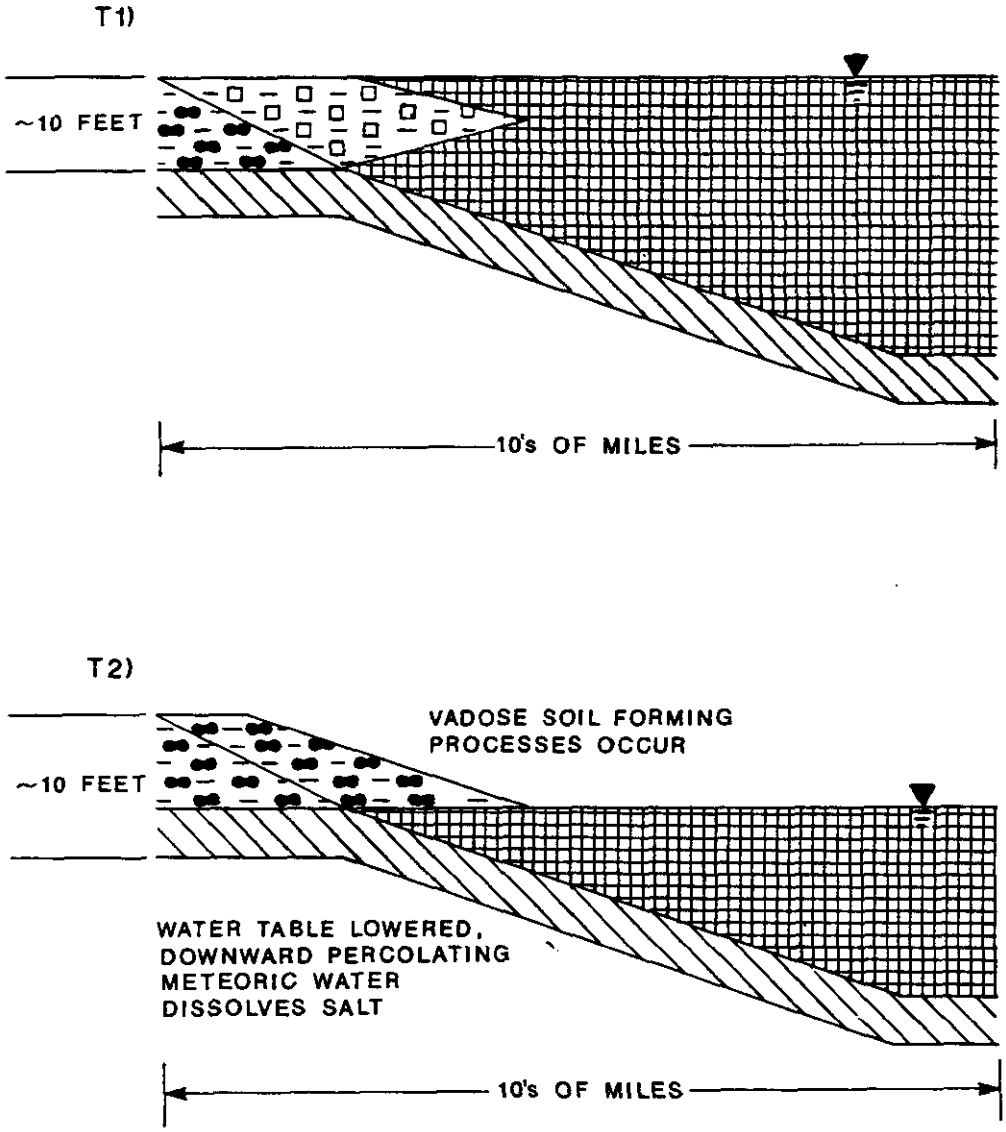

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FIGURE 6.3

SYNDEPOSITIONAL DISSOLUTION
CAUSED BY LOWERING THE WATER TABLE

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

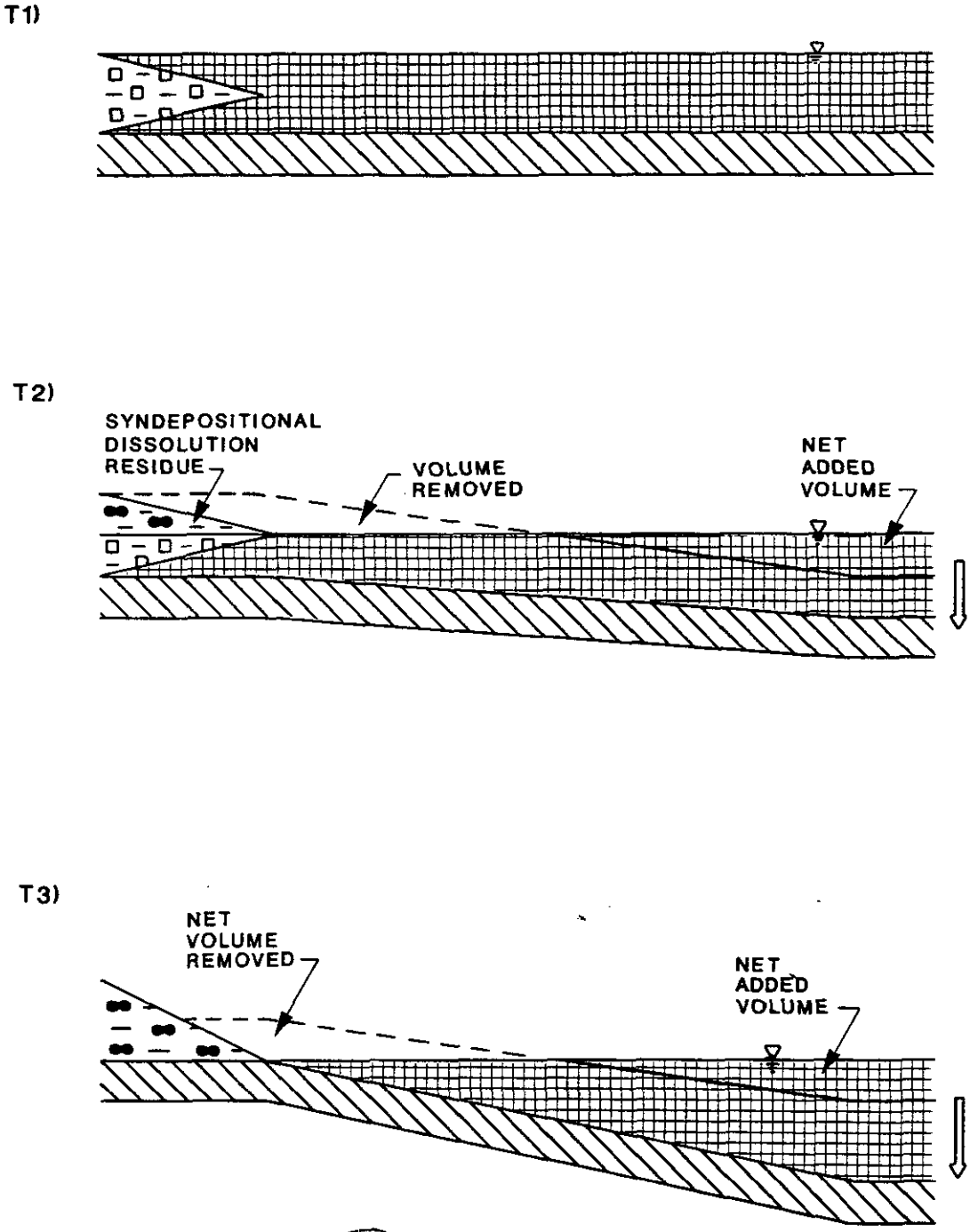

FIGURE 6.4

SUBSIDENCE-CONTROLLED
MODEL FOR SYNDEPOSITIONAL
DISSOLUTION AND REDISTRIBUTION OF HALITE FROM
THE BASIN MARGIN TO THE DEPOCENTER

PREPARED FOR

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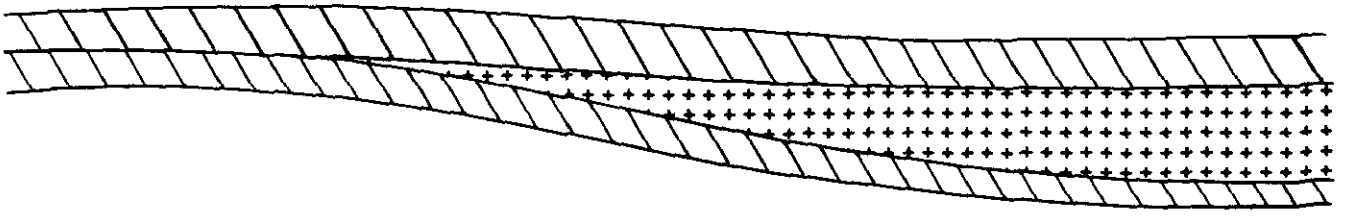

CONSISTENT DIPS, GRADUAL? THINNING: DEPOSITIONAL MARGIN

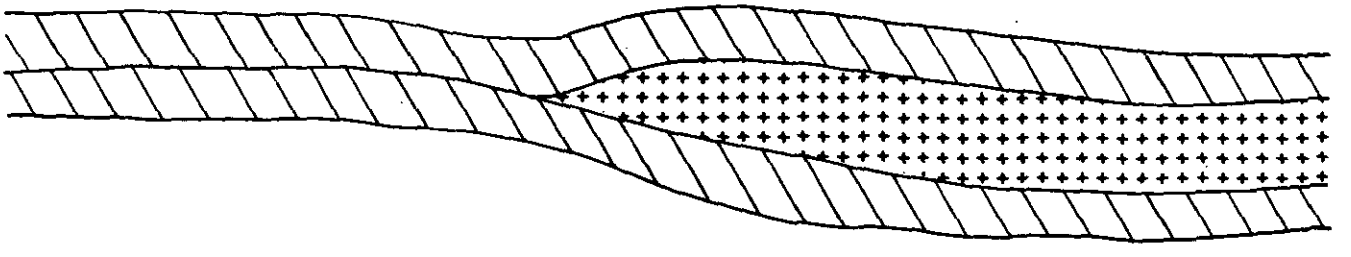

REVERSAL OF DIPS, MORE ABRUPT THINNING: DISSOLUTION MARGIN

After Gorrell and Alderman (1968)

M

FIGURE 7.1

GENERAL BASIN MARGIN RELATIONSHIPS:
DEPOSITIONAL vs DISSOLUTION

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

a. KARST

UPPER HORIZON CONTROLLED, BRECCIATION MAY INCREASE UPWARD, MIXING OF STRATA IN CLASTS, TRUNCATED UPPER SURFACE BOUNDING AGE

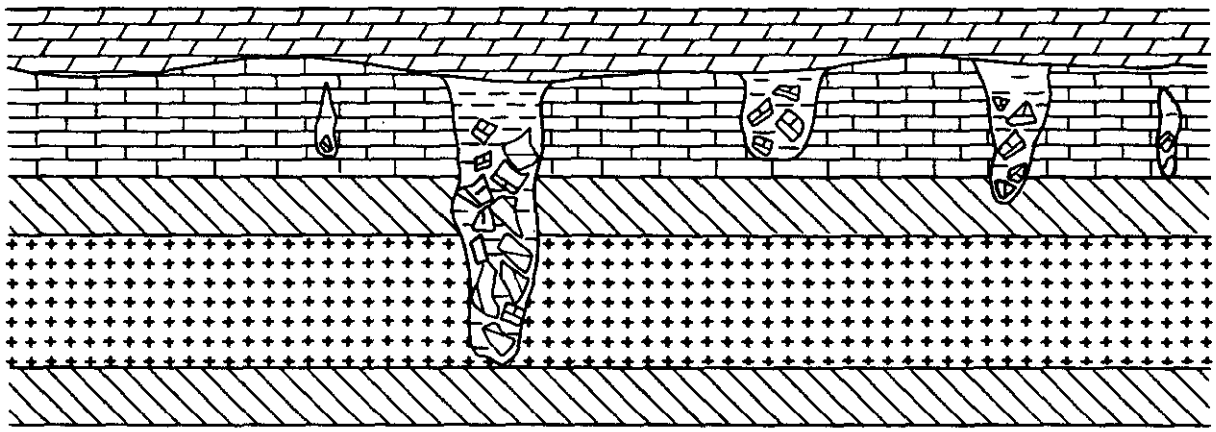

b. SOLUTION

LOWER HORIZON-CONTROLLED, BRECCIATION DECREASES UPWARD, STRATIGRAPHIC RELATIONS INTACT, POST-DEPOSITIONAL, POST-LITHIFICATION SOLUTION ("LATE")

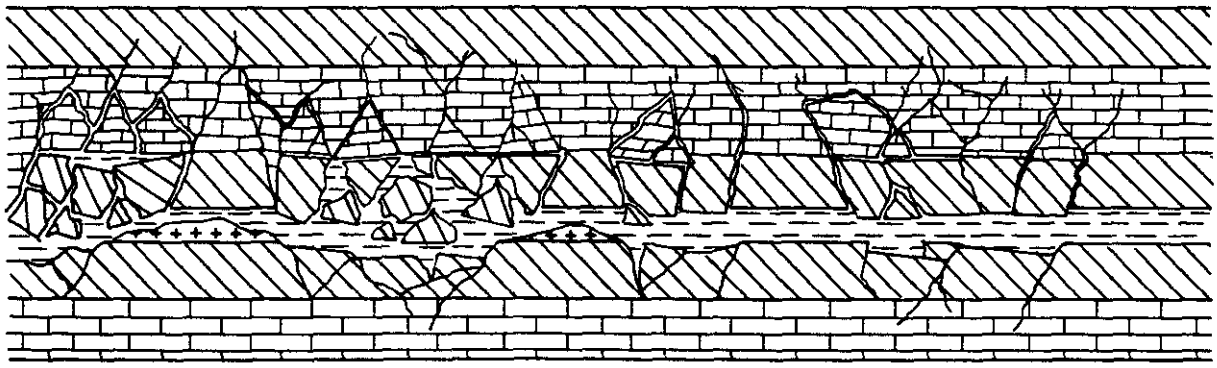

(NOT TO SCALE)

NOTE: SYMBOLS DO NOT REPRESENT SPECIFIC LITHOLOGY

FIGURE 7.2

GENERAL MID-STAGE FEATURES PRESERVED FOR KARST AND SOLUTION AT DEPTH

PREPARED FOR

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CARLSBAD, NEW MEXICO

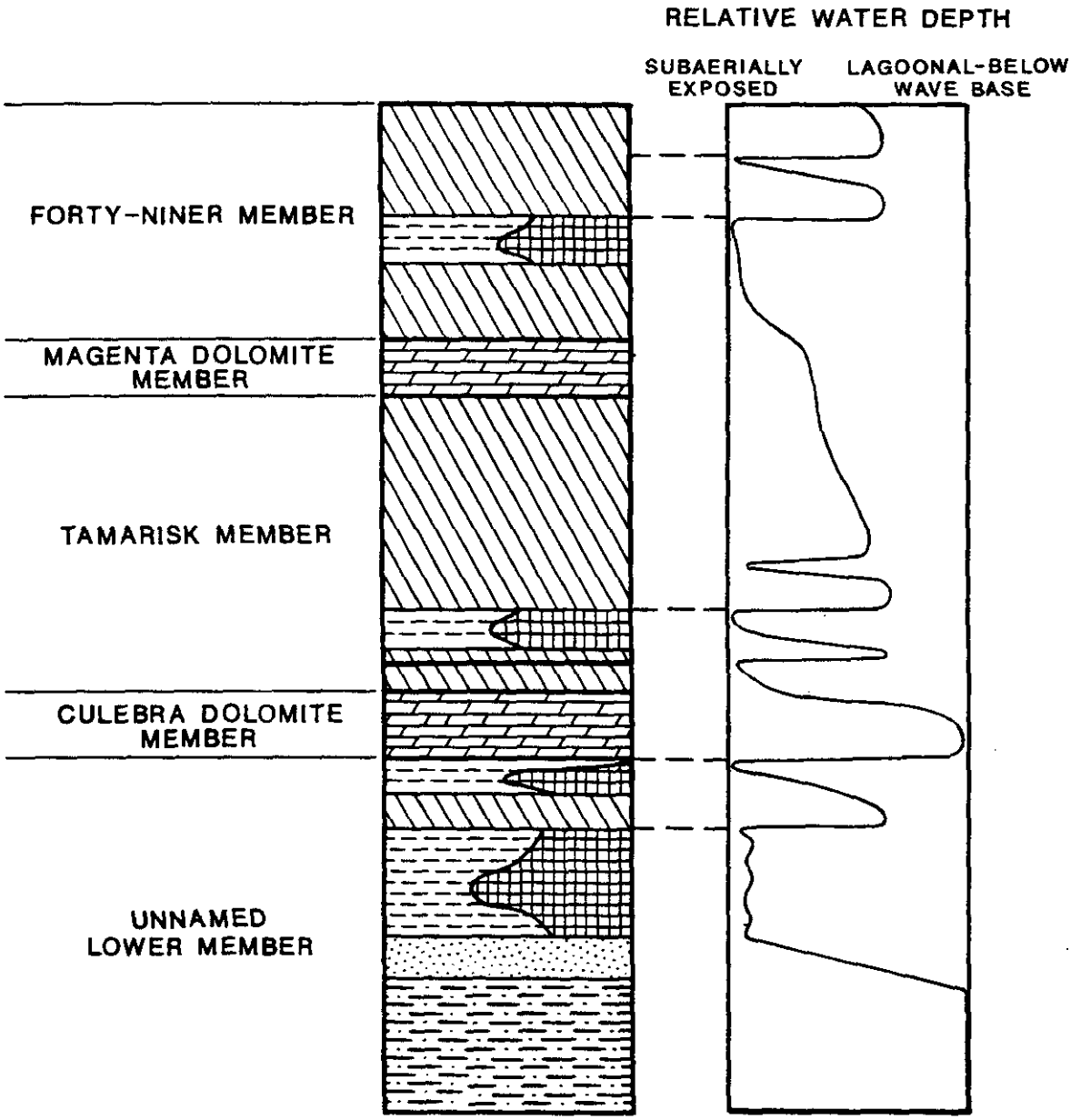

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FIGURE 9.1

VARIATION IN
RUSTLER WATER DEPTH

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

PLATES

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Plate 1. Brecciation within the unnamed lower member showing vertical translation of rocks derived from various stratigraphic intervals. Clasts from the bioturbated clastic interval, M-1, and A-1 are all in close proximity.

Plate 2. Displacive halite in siltstone from M-1.

Plate 3. Displacive halite crystals that have coalesced and are tightly packed.

Plate 4. A pod containing an aggregate of halite crystals.

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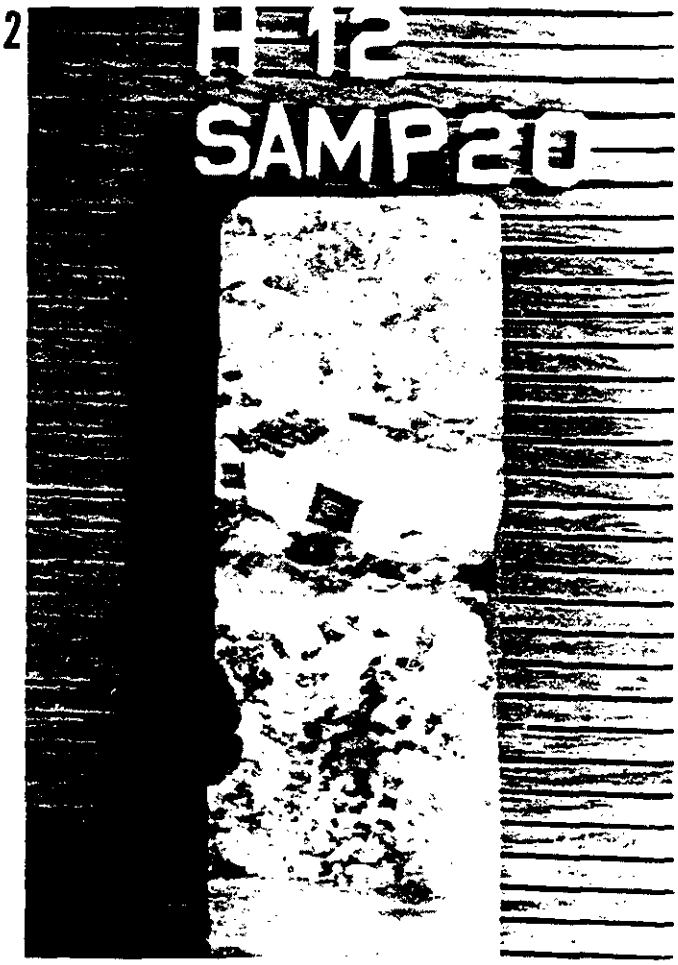

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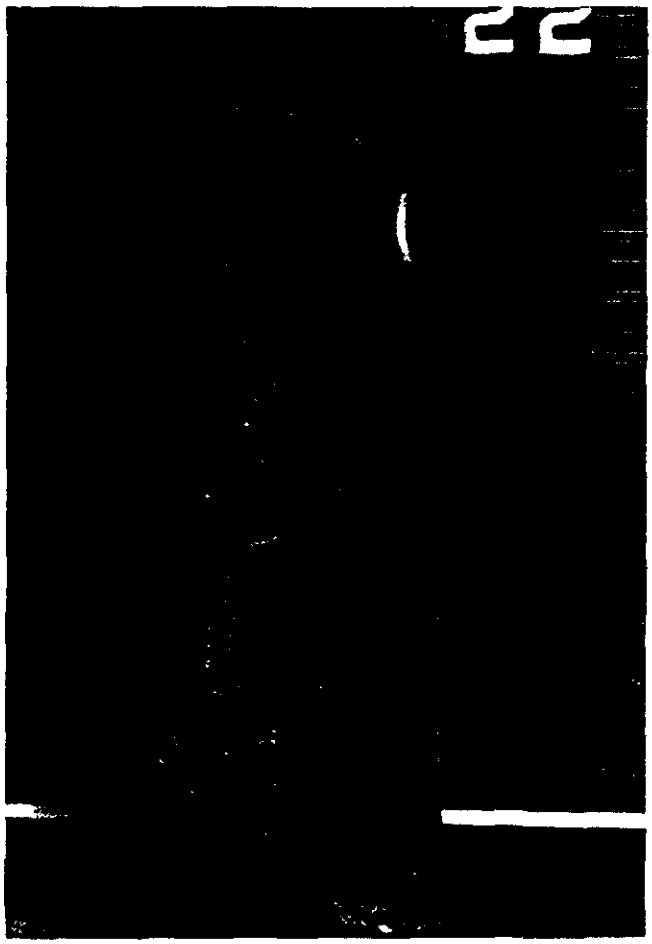

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Plate 5. Clastic material contained within halite exhibiting the smeared intraclast/laminae texture.

Plate 6. Siltstone and mudstone from M-1 exhibiting the smeared intraclast/laminae texture.

Plate 7. Smeared intraclast/laminae texture from M-1.

Plate 8. Brecciation in Nash Draw showing vertical translation of clasts derived from A-1 into the stratigraphic position of M-1. Note the clast in the lower center of the photograph is a derived from a gypsum fracture filling.

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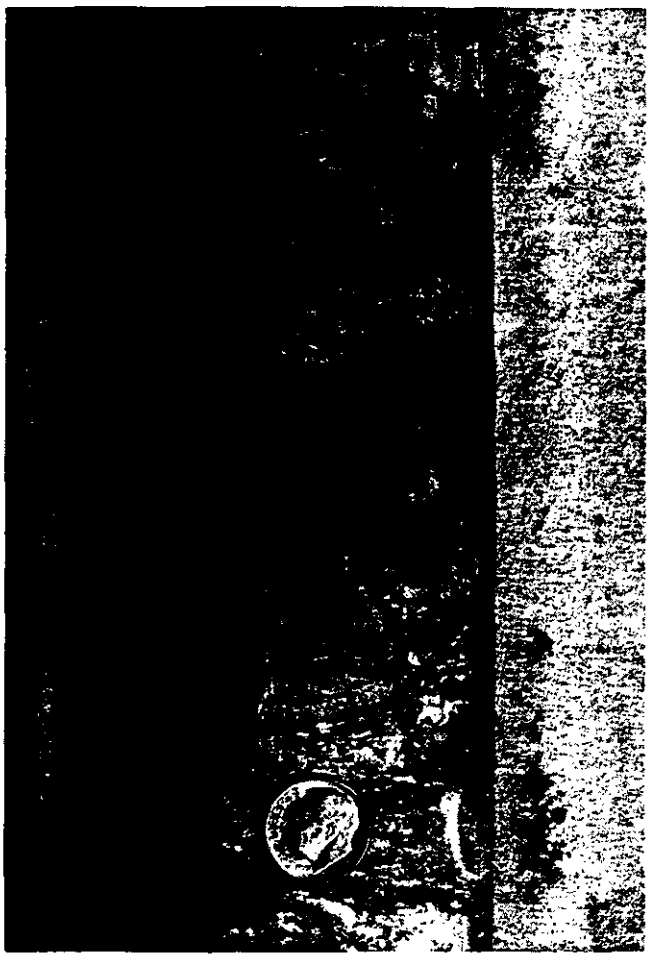

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Plate 9. Breccia clasts and blocks of M-1 from Nash Draw. Note the clasts and blocks exhibit the smeared intraclast/laminae texture.

Plate 10. Halite pseudomorphs after gypsum swallowtail crystals, A-1.

Plate 11. Sediment-incorporative gypsum crystals in M-2.

Plate 12. Photomicrograph from M-2 showing oriented clay skins and cutans on mudstone particles.

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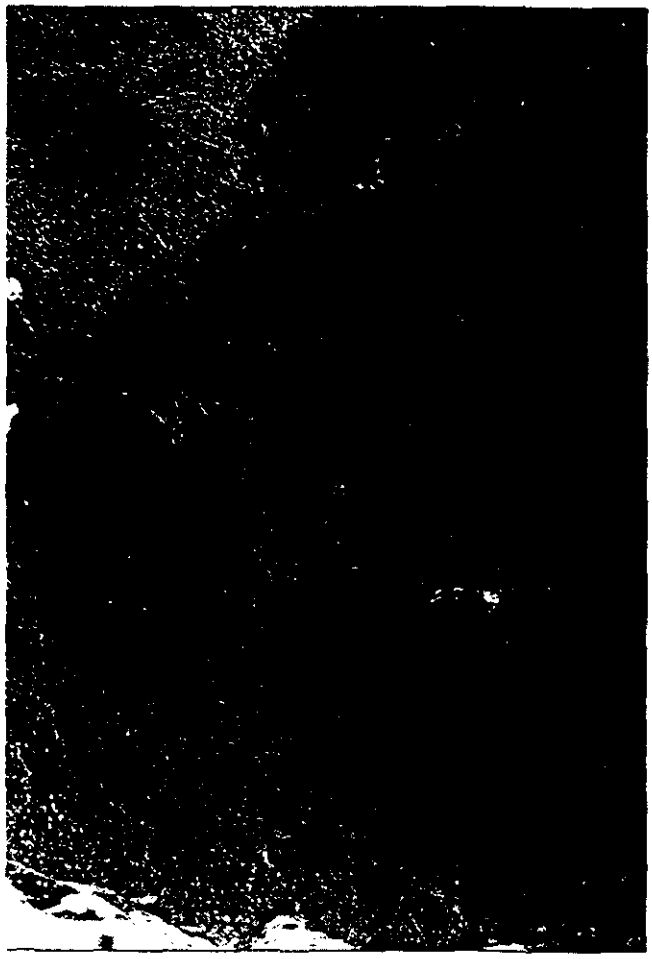

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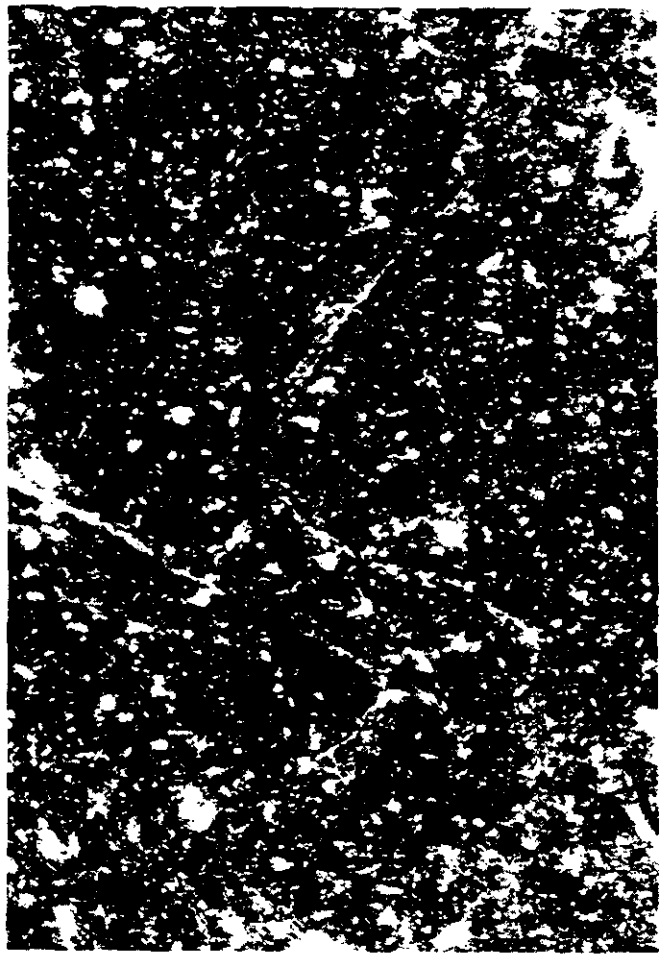

Plate 13. Pebbles of carbonate overlain by subhorizontal laminae in the upper part of M-2.

Plate 14. The upper contact of A-2 with M-3 in the waste handling shaft showing three feet of relief.

Plate 15. Photomicrograph of gypsum overgrowths on detrital gypsum grains, from M-3.

Plate 16. Siltstone and claystone pebble conglomerate in the lower part of M-3 at WIPP 19.

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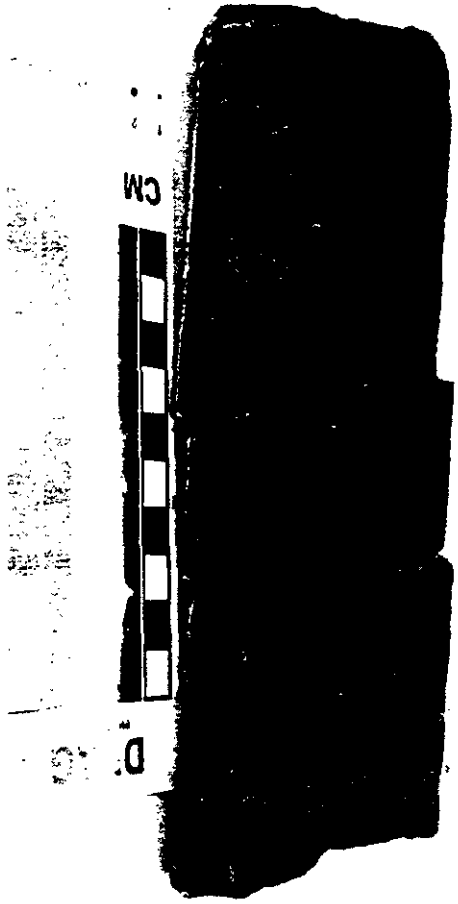

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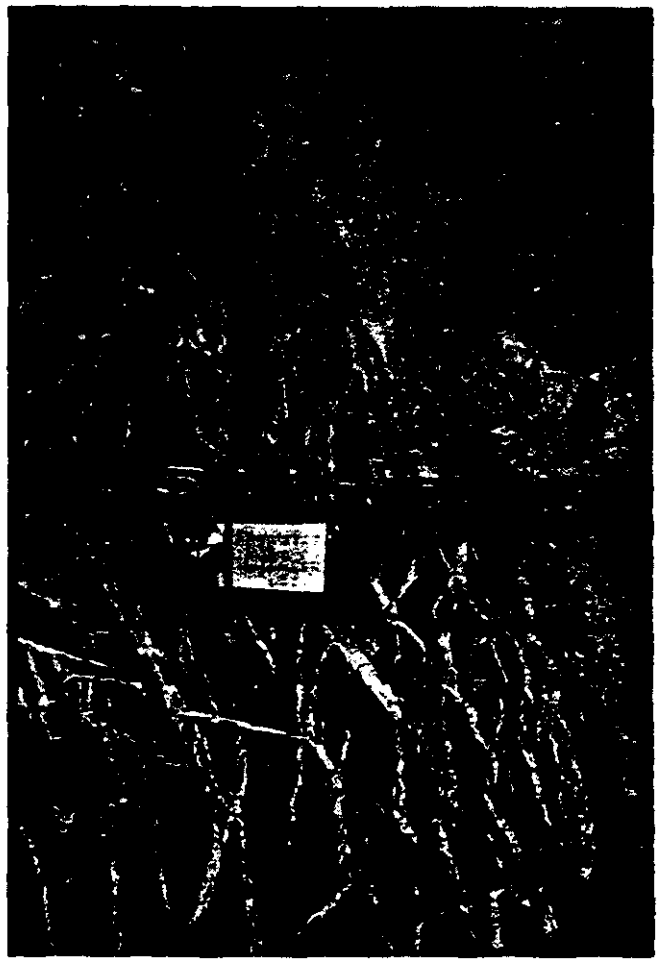

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Plate 17. The upper contact of M-3 with A-3.

Plate 18. Tipped and slumped anhydrite pseudomorphs after gypsum swallowtail crystals near the base of A-3.

Plate 19. Incipient development of the crushed prism texture. Note relict halite pseudomorphs after gypsum swallowtail crystals have reduced volume.

Plate 20. Middle stage in the development of the crushed prism texture.

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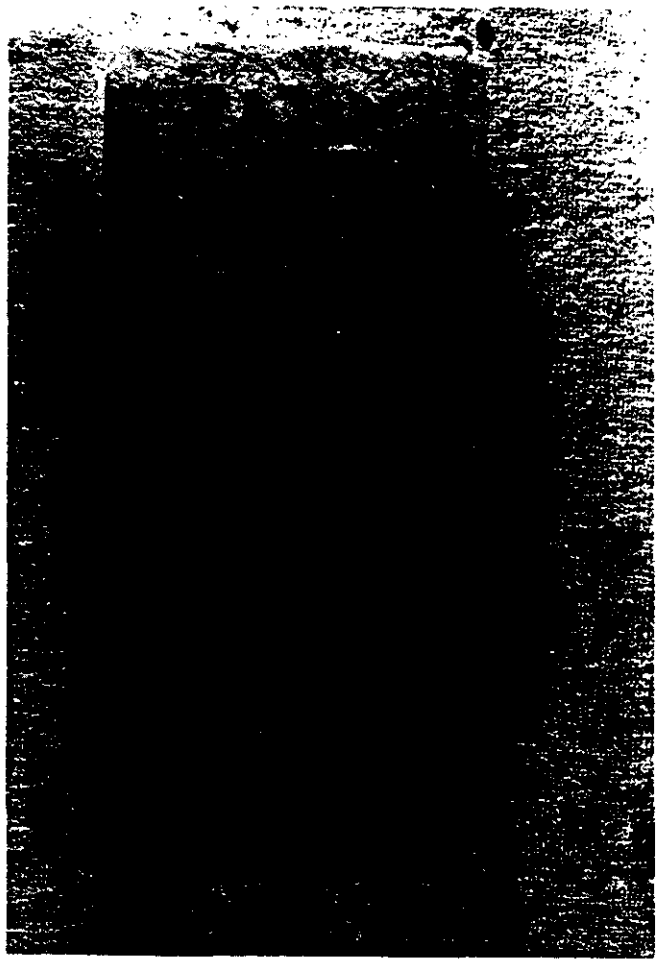

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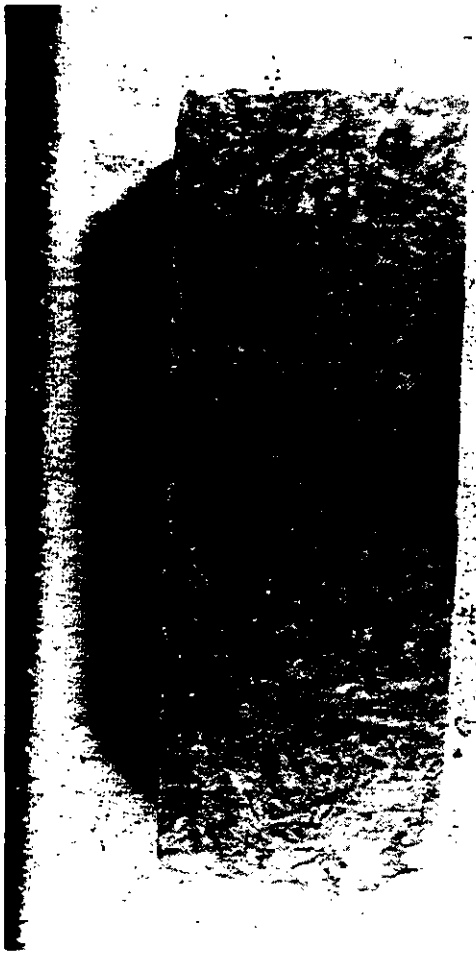

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Plate 21. End-stage in the development of the crushed prism texture.

Plate 22. Bedded nodular texture in A-3. Note nodules containing small pseudomorphs after gypsum swallowtail crystals.

Plate 23. Photomicrograph of M-4 siltstone and sandstone from WIPP 19 with crossed nicols. Halite cement and incipient displacive halite crystals black.

Plate 24. Upper contact of M-4 with A-5.

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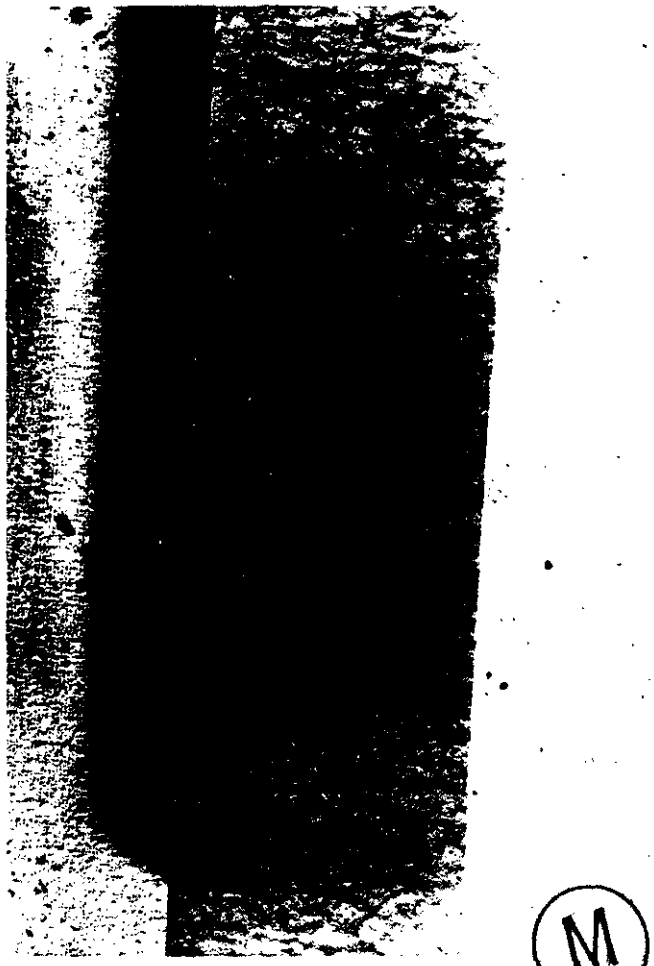

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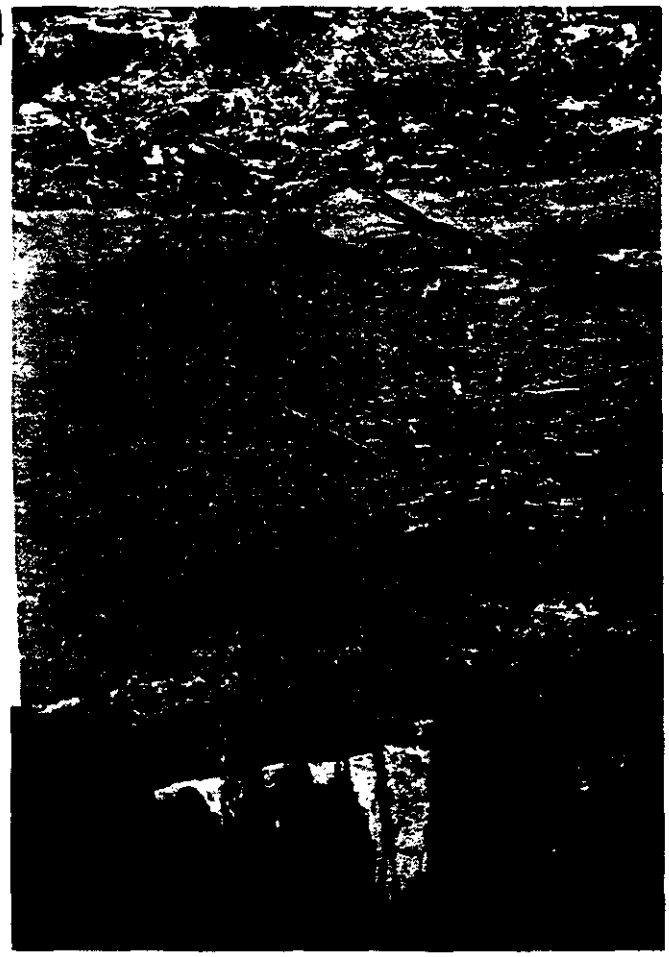

Plate 25. Irregular stratification in M-4 from WIPP 19.

Plate 26. Irregular stratification in mudflat sediments from Saline Valley, California.

Plate 27. Irregular subhorizontal stratification in M-4 at the waste handling shaft.

Plate 28. Irregular subhorizontal stratification in mudflat sediments from Saline Valley, California.

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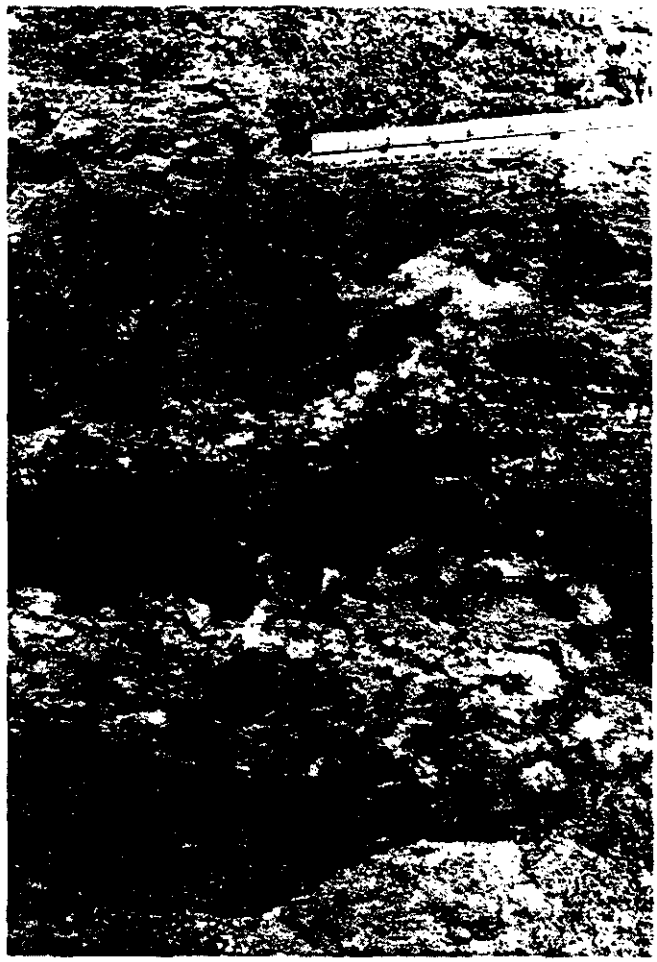

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APPENDIX I

Interpretation of Geophysical Logs to Select Stratigraphic Horizons Within the Rustler Formation

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INTERPRETATION OF GEOPHYSICAL LOGS TO SELECT STRATIGRAPHIC HORIZONS WITHIN THE RUSTLER FORMATION

Depth and Thickness Information

Geophysical logs from various boreholes for the WIPP project have been interpreted to represent the following stratigraphic markers: Rustler/Salado contact; base and top of Culebra Dolomite Member; base and top of Magenta Dolomite Member; and Rustler/Dewey Lake contact. For the Tamarisk Member, the contacts at the top of the lower anhydrite (A2) and base of upper anhydrite (A3) show regional thickness changes in a halite/mudstone unit of geological significance; we include these data as well (Ch. 4). Here we discuss the bases of our log interpretation for both stratigraphic and lithologic information and some factors that affect the accuracy and precision of the interpretations. The stratigraphy of the Rustler Formation is based on Vine (1963). Details of the Rustler vary, based on shaft mapping (Holt and Powers, 1984, 1986a) and this work.

The basic geophysical log for interpreting the Rustler stratigraphy is the natural gamma ray log (Fig. 4.1). Throughout much of the northern Delaware Basin, the contacts and members can be picked with confidence and good precision based on this log alone. In some areas, acoustic or sonic logs, for example, provide a sharp and significant response where the gamma log is not as sharp. In these interpretations, the gamma ray log was used as consistently as possible because it is the most comon usable log and to avoid small registration problems that occur between logs, especially if the final log was a composite of two logs obtained at different times.

Lithologic Information

Specific lithologies may be interpreted through cross-plots of geophysical data for an interval. This procedure is well-known within the petroleum industry, and is adapted for computer with modern borehole geophysical records. A similar, though less mechanical, approach has been used for this report because we have only analog records. For more detailed lithological interpretation, we combined the natural gamma log with acoustic or sonic logs, density logs, or neutron logs, permitting most of the common lithologies to be discriminated. For the Delaware Basin proper, gamma ray-sonic was used nearly exclusively. Over parts of the Central Basin Platform, combined gamma ray-neutron logs are much more common. Gamma

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ray-density logs are much less common in the region than at the site and were sparingly used. The common lithologies and their signatures for the Rustler are given in Table 1.

In the vicinity of the WIPP site, log signatures may be matched with descriptions from shafts (Holt and Powers, 1984, 1986a), basic data reports (e.g. Sandia National Laboratories and U. S. Geological Survey, 1980), and redescribed cores from holes with geophysical logs. Examples of the match between detailed logs and core and shaft descriptions form a "type" against which most log interpretations were made. Some of the interpretations here vary from those made previously (Borns and Shaffer, 1985; Griswold, 1977) because of differences in criteria and the details of lithology now available (Ch. 5).

Accuracy and Precision

For stratigraphic interpretation, copies of logs at a scale of 1" = 100 feet were most commonly available and were used, providing a consistent data base. Lines drawn to mark contacts cover about 1 foot, and precision associated with these lines can probably be no better than about 1 foot. The numbers presented are visual interpolations representing a variation estimated at about $\pm$ 1 ft., not allowing for other sources of "error".

The sum of geologic variations and "errors" has been assessed empirically by examining the cluster of data points in T.25S., R.32E. (Ch. 4). The isopachs of four members and part of one member provide data to calculate average thickness as well as sample standard deviation s (Table 2). A plot of thickness vs s partially reveals the effects of these errors (Fig. 1). The relative standard deviation generally decreases as thickness increases. This reflects the compensating effects of sedimentation over time for small, possibly random, local variations in depositional processes. The standard deviation is less than 10 % of the total thickness for the four thicker intervals. For the two intervals averaging less than 25 ft thickness, the standard deviation exceeds 10%. A least squares regression of s (Y) on average thickness (X) (Fig. 1) provides an intercept (b_o) of 3.5 on Y. This intercept is consistent with "errors" of about $\pm$ 1 foot on each contact as previously described. The remaining difference (that part > 3.5 ft) is more likely attributable to geological processes. Though a linear regression of standard deviation on thickness has been calculated, the data points are

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probably also consistent with the idea expressed above that greater thickness is related to exponentially smaller standard deviations as a consequence of compensating sedimentologic conditions over a longer period of time.

We may not truly generalize about thicknesses of individual members for the region from the example above, as as it is obvious that some units (e.g. between A2 and A3 of the Tamarisk) vary greatly over the region compared to T.25S., R.32E. However, the "error" associated with picking an individual contact is estimated. An "error" of the type where a mistake in elevation or zero point occurs is not analyzed in this example, as the data are the difference between two successive contacts and will be immune to those two types of errors.

Powers (1986) examined geophysical logs from hydrologic holes at and near the WIPP site, showing that interpreted stratigraphic picks of a horizon from various logs of the same borehole usually vary by 2 feet or less. There is no assurance in some of these cases which is the more accurate depth. For the most part, these small variations from log to log can be attributed to several types of factors such as differences in zero depth point. This kind of variation is usually unimportant for geological interpretations of either isopachs or structure contours. A $\pm$ 2 ft variation on both contacts could conceivably result in an 8 ft discrepancy in thickness between adjacent boreholes. This is unlikely, as common practice here and elsewhere is to compare adjacent logs frequently to minimize such discrepancies. Elevation/depth discrepancies are more important to resolve for the subtle questions of possible hydrologic transport in the Rustler.

Lithologic interpretations are not significantly affected by questions of accurate depths. A more important, and difficult to consider, problem is registration, especially if the log associated with gamma is a composite. Where there is no obvious problem with this particular log, the gamma ray with compensated acoustic (sonic) or compensated density is chosen as the standard over the combination gamma ray with neutron because the lithologic information from the first two combinations is usually more helpful than with neutron.

Geophysical logs contain inherent uncertainties. Stretch in the cable is usually predictable, about 1 foot/1000 feet. This is the same order of magnitude as the resolution for the tools (e.g. natural gamma and acoustic) which operate over a discrete interval or sample a certain volume. The

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sharpness of a log response to a sharp change in geophysical properties is a function of this interval, the rate at which the tool is drawn through the borehole, and time constants for data acquisition. Gradual lithologic transitions decrease the sharpness of the response further. In general, lithologic transitions and sampling interval have been dealt with arbitrarily by picking a contact at the midpoint of the geophysical response, and by attempting to make a consistent log response the standard for each "pick." Inconsistent application of standard log signature or criteria leads to error. All logs were interpreted by one person (DWP) to minimize operator to operator inconsistencies in establishing the intervals and contacts, though operator bias may be unchecked by this procedure.

Several "random" factors contribute to errors. Incorrect placement of the logging tool relative to a reference elevation (the zero point referred to above) appears to have occurred on some logs (e.g. compensated neutron, gamma ray for H-9c; Powers, 1986). Incorrect base elevations and locations may occur, but only gross errors will be detected in this study. Log reading errors may occur; they are most easily found through multiple logs of a single borehole and through structure contour and isopach map anomalies.

Further Remarks

No attempt has been made to rectify differences with other interpretations. Minor differences on picks are here of little consequence. Major anomalies may be resolved as necessary by re-examining logs and picks or by obtaining additional logs from the vicinity of the anomaly.

Geophysical well log data are used routinely within industry to infer rock properties. Doveton (1986) summarizes common approaches to log interpretations, but the limitations and problems associated with precision and accuracy of interpretation are not well addressed. The mechanical precision associated with the geophysical tool is commonly considered. For the hydrological studies of the WIPP, the uncertainties beyond mechnical precision can be important, and here we have presented information and analysis of log information that should provide perspective on this problem. Baker (1987) examines methods of quantitative interpretation that integrate geological and geophysical log data. Such approaches will be very helpful in assessing data, and the associated uncertainties, that will be used in complicated numerical codes for hydrologic modeling.

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TABLE 1

General Log Responses for Rustler Lithologies

lithology	natural gama (std API units)	sonic travel time (micro-sec/ft)	neutron (API units)
anhydrite	low (<10 API)	high (50)	high
salt	low (<10 API)	medium (70)	variable
dolomite	variable (10-50)	variable (50-90)	variable
siltstones	variable (10-50)	low (>70)	low
gypsum	low (<10)	medium (70-80)	low
polyhalite	very high (50-150)	med to high (50)	med to low

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TABLE 2

Statistical Summary of Isopach Data, T.25S., R.32E.

Isopach Interval Name	Number of Data Points	Average Thickness (ft)	Sample Standard Deviation(s)
Forty-niner	83	63.7	4.12
Tamerisk	82	102.8	8.55
A2-A3 of Tamerisk	78	13.0	4.58
Culebra	83	24.5	2.76
1. unnamed mbr.	82	151.9	12.3
Rustler	82	364.6	16.8

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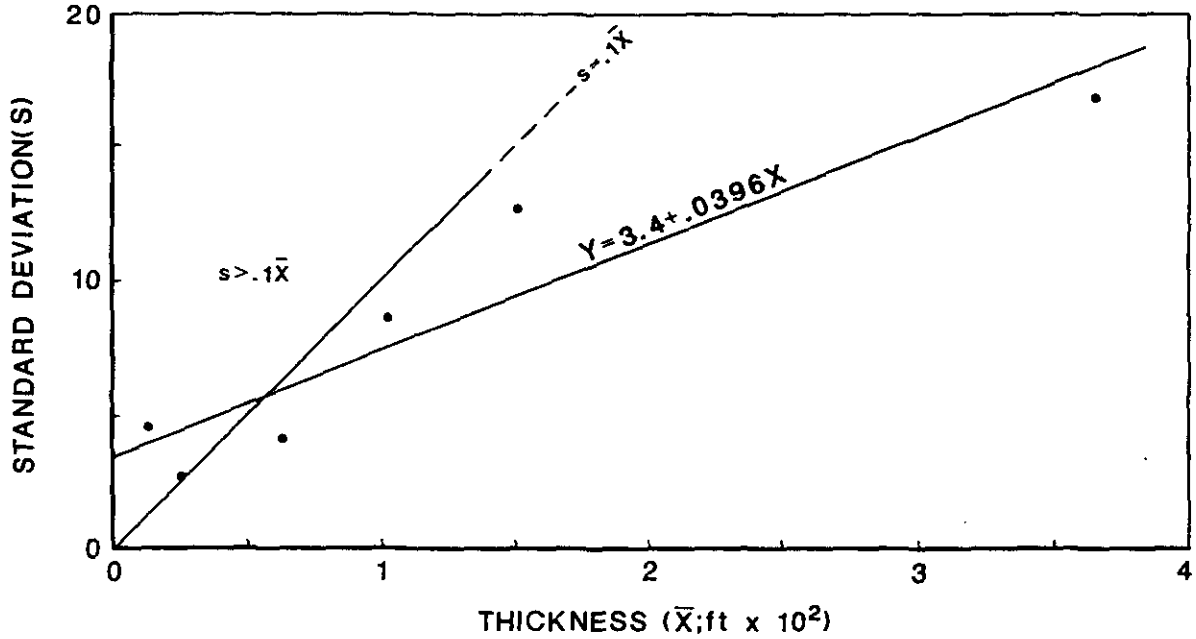
20
10
0
0
1
2
3
4
STANDARD DEVIATION(S)
THICKNESS ($\bar{X}$;ft x 10^2)
$s=.1\bar{X}$
$s>.1\bar{X}$
$Y=3.4+.0396X$

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APPENDIX II

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GEOPHYSICAL LOG DATA

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
		T18S, R29E							
W04	Roach Drlg, West. Dev. Miller No. 1	s4,1980fnl,1980fwl	?	278	?	?	?	?	118
T19	Yates, Travis Fed.2	s19,660fsl,1980fel	3568	?	?	?	?	?	?
		T18S, R30E							
L18	Newmont, Loco Hills 21-B-6	s18,1650fnl,924fwl	3510	316	?	?	?	?	164
C25	Yates, Creek"AL"#1	s25,990fnl,330fel	3618	736	675	660	582	565	504
G26	Hanson, Ginsberg Fed. No. 11	s26,990fsl,330fel	3466	624	587	576	?	?	500
M27	Texaco, L.R. Manning "B" NCT-1 Well #20	s27,990fnl,1651fwl	3554	587	525	508	434	411	358
R28	Texaco, L.R. Manning Fed. "B" #4	s28,330fsl,1491fel	3510	557	483	468	396	375	314
		T18S, R31E							
M02	W. S. Montgomery, Magnolia State #1	s2,330fsl,660fwl	3766	1017	942	927	856	841	794
S11	Hudson&Hudson, Shugart B-1	s11,660fsl,660fwl	3733	990	913	902	824	808	757
M16	M. R. Voltz, Magnolia State 2	s16,1980fel,660fsl	3651	840	754	730	628	606	561
F22	Gulf, Fed. LIttlefield #1	s22,660fsl,660fwl	3648	?	?	?	?	?	?
F28	Gulf, Fed. Keohane et al "B" No. 1	s28,660fwl,1980fnl	3624	790	720	706	634	619	563
K28	Gulf, Fed. Keohane etal "B" #3	s28,1980fnl,1980fwl	3631	775	736	721	650	632	578
C31	Campana, Pure Fed. #1	s31,1980fnl,1980fel	3551	785	708	692	618	596	545
H31	R. M. Hall, Pure Fed. #1	s31,330fnl,844fwl	3568	735	663	648	576	555	500
M32	Chambers & Kennedy, Monterey State #4	s32,1980fnl,1980fwl	3566	810	734	720	640	622	574
S32	Sumray, State "Y" #1	s32,2310fel,1650fnl	3580	830	748	732	660	638	590
P32	L. T. Pate, Monterrey State #5	s32,330fwl,330fnl	3571	840	775	760	682	665	606
W33	V. S. Welch, Shugart No. 5-B	s33,330fnl,330fwl	?	828	775	759	687	670	613
		T18S, R32E							
J04	B. M. Jackson, Fed. #2	s4,1650fnl,990fel	3885	1394	1322	1302	1222	1207	1158
G16	Gulf, Lea State "HS" #3	s16,1980fnl,1980fwl	3783	1350	1275	1260	1168	1150	1103
J20	J. M. Beard, Young Fed. #5	s20,2310fsl,990fwl	3751	1247	1168	1157	1060	1044	1017
C28	Texaco, C. D. Unit No. 53	s28,1980fnl,660fwl	3382	1300	1137	1112	1019	996	940
		T18S, R33E							
C10	Carper, Corbin R #1	s10,1980fnl,660fel	4027	1828	1755	1743	1652	1634	1587
B12	Miller, B.A.State #2	s12,660fnl,1980fel	4104	1988	1915	1904	1815	1797	1753
D13	O'Neill, Dorothy Swigart #1	s13,1650fsl,2310fwl	3952	1880	1807	1796	1699	1682	1633
S28	Sumray, Fed. "E" #1	s28,center NE of SE	3800	1663	1588	1576	1479	1460	1407
H30	Penzoil, Hudson "29" Fed. #3	s30,1980fsl,1980fwl	3779	1546	1462	1447	1351	1330	1278

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
		T18S, R34E							
N01	Texaco, State of NM "M" #5	s1,560fnl,760fwl	4011	1677	1615	1602	1540	1525	1483
L06	Phillips, Lea No. 17	s6,989fnl,330fwl	4098	1843	1783	1774	1694	1675	1631
B07	Richardson & Bass, State of NM #1	s7,660fsl,660fel	?	2026	1947	1932	1842	1824	1775
S22	Cont., State V-22 #2	s22,1980fsl,1980fwl	4023	2075	1999	1985	1892	1872	1820
T22	Cont., State V-22 #1	s22,1980fwl,330fsl	4000	2050	1972	1960	1870	1852	1793
M33	Tom Brown, Marathon State #1	s33,330fsl,1980fwl	3957	1983	1905	1885	1793	1775	1714
		T18S, R35E							
F03	Phillips, Santa Fe No. 114	s3,2310fsl,330fel	3920	1968	1900	1885	1807	1794	1745
V04	Vac. Edge Unit #2	s4,1980fnl,660fwl	3961	1810	1750	1733	1658	1645	1600
F05	Phillips Pet., Santa Fe No. 111	s5,1650fnl,990fel	3962	1765	1705	1690	1619	1604	1562
S05	Phillips Pet., Santa Fe No. 93	s5,1650fnl,2285fel	3968	1744	1683	1668	1595	1580	1535
V05	Standard Oil of Tx, Vac Edge #19	s5,990fsl,990fel	3958	1814	1748	1737	1657	1643	1598
W06	Ohio Oil, State Waren Acct 2 #9	s6,330fsl,913fwl	3991	1678	1653	1647	1582	1566	1512
A07	Tidewater Oil, State AN #1	s7,330fnl,990fel	3980	1720	1657	1640	1562	1547	1501
C29	Carper, Carper-Luthy No. 1	s29,1980fnl,660fwl	3948	2112	2036	2022	1926	1908	1853
		T18S, R36E							
C01	Cactus Drilling, Catron "B" No. 2	s1,1980fsl,1980fel	3789	2038	1948	1945	1883	1870	1825
K11	J. M. Kelly, State J.J. #1	s11,660fsl,660fel	3816	2030	1943	1940	1870	1855	1811
P11	J. M. Kelly, State PE #1	s11,1980fsl,1980fwl	3822	2137	2050	2042	1969	1958	1909
C12	Cactus Drilling, Amerada State #1	s12,660fnl,1980fwl	3783	1997	1908	1904	1840	1828	1783
		T18S, R37E							
A14	Amerada, State W. H. "B" #2	s14,1650fsl,2310fwl	3698	1810	?	?	1700	1685	1643
W31	Amerada Pet., State WM "E" #3	s31,1980fnl,660fwl	3750	?	?	?	?	?	?
		T18S, R38E							
A03	O. D. Alsabrook, Saunders #1	s3,1980fsl,1980fel	3660	2168	2090	2084	2017	2007	1965
M19	Shell, Mckinley A-19 #1	s19,2310fsl,1650fel	3664	1653	?	?	1572	1560	1520
		T19S, R29E							
N06	Shamrock Drlg., Nix & Curtis #1	s6,1980fsl,1765fwl	3399	305	?	?	?	?	?

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
S21	W. J. Spears, Stout State #1	s21,2015fnl,1880fel	?	218	114	90	?	?	?
U26	W. J. Spears, Union State #1	s26,NW/4 of NW/4	?	245	142	120	?	?	?
		T19S, R30E							
P05	Yates, Perkins "AD" 3	s5,1980fnl,330fwl	3402	388	310	290	245	223	183
		T19S, R31E							
U06	Texaco, USA Fed. #1	s6,330fnl,1650fwl	3529	740	692	673	596	576	524
S13	Phillips, Simon "A" No. 1	s13,660fsl,1980fel	3577	978	873	853	764	745	682
S14	Phillips, Simon "A" #2	s14,660fsl,660fel	3559	898	796	775	702	685	619
T21	Texas Crude, Tenn. Fed. # 1-21	s21,1980fsl,660fel	3526	746	683	666	586	565	497
		T19S, R32E							
E29	Epng, Southern Cal. Fed. #1	s29,1980fnl,660fel	3576	1172	1064	1045	927	906	802
		T19S, R34E							
C12	Carper, U.S. Smelting State #1	s12,660fnl,660fwl	3974	2150	2063	2037	1940	1920	1855
		T19S, R35E							
A14	Atlantic Ref., State AU #1	s14,660fsl,660fwl	3815	2080	2000	1979	1884	1867	1805
S27	Shell, Allen Estate A #1	s27,1980fnl,660fel	3723	2045	1963	1944	1840	1822	1761
C28	Cabot Carbon, State G #1	s28,1980fsl,660fwl	3743	2052	1966	1950	1838	1818	1753
L33	Lea State BG #8	s33,1980fnl,660fel	3703	2080	1995	1970	1863	1845	1779
		T19S, R36E							
P01	Pan Amer., State "B" #1	s1,1980fnl,330fel	?	1680	1614	1604	1538	1525	1480
H11	Humble, N.M. State AO#1	s11,660fsl,1980fwl	3759	1704	1660	1650	1533	1517	1474
S18	Tom Brown, Sunray Bryan #1	s18,1980fnl,1980fwl	3744	2038	1955	1942	1841	1828	1777
A25	Amerada Pet., State "T" No. 4	s25,NE/4 of NW/4	3702	1446	1371	1363	1293	1280	1230
		T19S, R37E							
A32	Amerada, May Love Unit #1	s32,1980fsl,1980fel	3580	1397	1325	1320	1272	1257	1220
		T20S, R32E							
F10	Shell, Perry Fed. #1	s10,330fnl,990fwl	3448	1170	1068	1052	915	892	828
P15	Phillips, Plata Deep Unit #1	s15,1980fsl,1980fwl	3510	1236	1128	1112	972	949	883
		T20S, R33E							
B18	R. F. Montgomery, Bass STate #1	s18,660fnl,2080fwl	3524	1470	1362	1343	1194	1172	1103
S18	R. F. Montgomery, Bass State #2	s18,1650fnl,1650fwl	3509	1450	1335	1314	1165	1140	1076
		T20S, R34E							
L13	Marathon, Lea Unit #3	s13,1980fsl,1980fel	3677	2110	2009	1994	1830	1814	1743
F29	E.G. Colton, Fed. #1	s29,1980fsl,330fel	3720	1949	1847	1827	1660	1639	1567

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
		T20S, R35E							
B28	W. H. Black, Phillips State No. 1	s28,660fnl,660fel	3701	2315	2220	2208	2067	2048	1973
		T20S, R36E							
S02	Superior Oil, State "A" No. 2	s2,660fnl,1980fel	3603	1218	1143	1135	1062	1050	1005
U30	Union Oil of Cal, Sims State 1-30	s30,660fnl,660fwl	3662	2330	2227	2210	2073	2058	1985
		T20S, R37E							
H01	Humble Oil, N. M. State "AG" No. 6	s1,990fnl,1650fwl	3604	1671	?	?	1516	1505	1465
		T20S, R38E							
W27	Cont. Oil, Warren Unit "BT" No. 26	s27,660fsl,660fwl	3542	1635	1559	1551	1480	1470	1427
		T21S, R29E							
P03	Pan Amer., Big Eddy Unit #18	s3,1980fnl,1980fwl	3412	495	?	?	?	?	187
N04	Union Oil, Cowden Fed. #1	s4,4620fsl,1980fwl	3471	500	?	?	?	?	200
P05	Meadco, Harris-Bell #1	s5,1980fnl,600fel	3472	550	410	?	?	?	255
M05	Meadco, Harris-Bell #2	s5,980fnl,1880fwl	3468	740	608	?	?	?	445
M06	Meadco, Harris 6 #1	s6,3147fnl,660fel	3487	1145	1032	1012	915	895	830
P18	Pan Amer, Big Eddy Unit #16	s18,1980fsl,1980fel	3309	450	291	?	?	?	146
B22	P. R. Bass, Big Eddy Unit #40	s22,1980fnl,1980fel	3458	655	490	?	?	?	345
E34	Bass, Big Eddy No. 38	s34,660fnl,1980fwl	3444	505	?	?	?	?	200
		T21S, R30E							
D21	WIPP 27	s21,90fnl,1485fwl	3177	421	318	292	193	175	152
P26	Phillips, James "D" 1	s26,660fsl,1980fwl	3250	502	?	?	?	?	160
P35	Phillips, James "C" 1	s35,1980fsl,660fwl	3218	485	356	?	?	?	130
		T21S, R31E							
D18	WIPP 28	s18,99fnl,2401fel	3347	?	?	?	?	?	?
D33	WIPP 30	s33,667fnl,177fwl	3427	748	653	631	537	513	449
Q35	ERDA 6	s35,2152fsl,910fel	3540	811	739	713	623	598	538
		T21S, R32E							
F01	Kimball, Fed. #1	s1,660fsl,1980fwl	3792	1945	1840	1820	1645	1622	1550
E01	Phillips, ETZ Fed. #1	s1,3255fnl,1972fel	3748	1890	1785	1772	1598	1575	1505
P02	Amini, Pubco Fed. #1	s2,3300fnl,660fwl	3740	1950	1860	1838	?	?	1530
H02	Phillips, Hat Mesa "A" #1	s2,660fsl,1980fel	3793	1988	1862	1840	1665	1645	1568
N04	Amini, N.M. Fed. #1	s4,1683fnl,1650fwl	3668	1765	1570	1545	?	?	1345
G10	Superior, Government "H" Com. #1	s10,1980fnl,1980fel	3800	1885	1760	1734	1550	1525	1450
F11	Gackle, Fed. 1	s11,SE/4 of SE/4	3862	2005	1858	1837	1664	1642	1565
H11	Phillips, Hat Mesa 2 #2	s11,660fsl,1980fwl	3861	1947	1858	1833	1617	1593	1515

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
M11	Phillips, Hat Mesa #1	s11,1980fnl,1980fel	3834	1972	1857	1840	1654	1630	1555
S21	Skelly, Salt Lake South Unit #1	s21,660fnl,660fwl	3679	1455	1303	1282	1130	1110	1056
G26	Gulf, San Simon #1	s26,1980fnl,660fel	3798	1781	1635	1610	1382	1360	1293
H31	Gulf, H. T. Mattern #10	s31,660fnl,1980fwl	3504	?	?	?	?	?	?
U31	Union Carbide, AEC-7	s31,2040fnl,2040fel	3662	982	896	872	758	732	670
		T21S, R33E							
S02	C. Read, Sinclair State #1	s2,2310fsl,2310fwl	3802	2180	2055	2032	1858	1838	1760
		T21S, R35E							
W01	Amerada, State WE "F" #3	s1,660fnl,660fel	3565	1758	1668	1655	1526	1504	1455
N04	British Amer, N.M. State "F" #1	s4,1902fnl,660fwl	3638	2095	1997	1983	1843	1825	1757
C16	Cosden, Cosden State D #1	s16,660fsl,660fel	3603	2200	2092	2074	1917	1900	1825
R32	Resler & Sheldon, Phillips State "C" No. 2	s32,1650fnl,660fel	?	?	2105	2094	1896	1880	1804
		T21S, R36E							
C17	Atlantic Ref., Coleman #1	s17,1650fwl,990fnl	?	?	?	?	?	?	?
A21	Gulf, Arnott Ramsey "C" No. 5	s21,SE/4 of SW/4	3593	1670	1590	1582	1475	1464	1425
H26	Humble Oil, N. M. State "G" #14	s26,1980fnl,1980fwl	3550	1660	1579	1572	?	?	1420
A27	Gulf, Arnott Ramsey "C" No. 5	s27,SE/4 of SW/4	3593	1670	1589	1583	1478	1466	1426
R27	Gulf, W.A. Ramsey #39	s27,1980fsl,510fel	3545	1720	1640	1630	1527	1517	1486
G27	Gulf, W. A. Ramsy NCT A #42	s27,650fnl,1980fel	3568	1720	1640	1634	1527	1517	1476
L31	Late Oil, Rector A #1	s31,1980fnl,1980fel	3635	1900	1807	1799	1661	1642	1580
A33	Gulf, Arnett Ramsey NCT-D #2	s33,1980fsl,1980fel	3581	1817	1740	1735	1612	1600	1560
R34	Gulf, W.A. Ramsey #38	s34,1980fnl,660fwl	3580	1817	1732	1722	1614	1597	1555
		T21S, R37E							
C28	Gulf, J. N. Carson C#9	s28,2085fsl,765fel	?	1377	1305	1295	1219	1210	1167
M31	Gulf, N. T. Mattern (NCT) No. B-12	s31,1980fnl,660fwl	?	1368	1283	1275	1200	1190	1150
		T22S, R29E							
E06	Hudson, Eddy Fed. #1	s6,660fsl,660fel	3304	495	?	?	?	?	?
D33	WIPP 32	s33,1673fsl,29fel	3023	166	90	61	36	19	surf
D34	WIPP 29	s34,404fsl,1824fel	2977	130	43	-	-	-	-
		T22S, R30E							
T01	Tropora, Cabana #1	s1,990fsl,1980fwl	3357	625	515	495	400	380	315
M02	Phillips, James "A" #1	s2,665fsl,2006fel	3193	520	?	?	?	?	170
D11	Phillips, James "E" #1	s11,1980fnl,1980fel	3221	600	?	?	?	?	275
D13	WIPP 33	s13,1762fsl,2426fwl	3323	677	578	550	468	449	401
D15	WIPP 25	s15,1852fsl,2838fel	3212	565	472	447	328	302	232
P24	P - 14	s24,312fsl,613fwl	3358	686	595	576	477	452	387
Q24	P - 12	s24,167fnl,195fel	3376	747	656	636	544	519	462
B27	Richardson & Bass, Fed. Legg #1	s27,660fnl,2003fel	3309	535	?	?	?	?	215

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
D29	WIPP 26	s29,2232fnl,12fel	3152	306	208	187	99	79	12
		T22S, R31E							
C06	B. McKnight etal, Campero No. 1	s6,1980fnl,660fwl	?	708	591	572	479	454	395
Z08	DOE 2	s8,698fsl,122fel	3418	962	849	828	724	700	641
D09	WIPP 11	s9,712fnl,294fwl	3439	964	881	857	764	740	676
I09	WIPP 14	s9,97fsl,2104fel	3249	952	836	817	729	707	639
W09	WIPP 34	s9,202fsl,1000fwl	3433	973	860	834	740	716	657
A11	AEC 8	s11,935fnl,1979fwl	3541	990	873	848	750	727	668
P14	P - 20	s14,794fsl,103fel	3553	1100	979	957	866	839	780
B15	C. W. Williams, Badger Unit - Fed. No. 1	s15,1980fsl,1980fwl	3496	?	?	?	?	?	?
H15	H - 5c	s15,1006fnl,134fel	3508	1041	922	900	809	784	732
P15	P - 21	s15,852fnl,150fel	3510	1040	924	904	812	786	734
D17	WIPP 13	s17,2564fsl,1727fwl	3405	845	725	704	583	564	517
P17	P - 5	s17,202fsl,164fel	3472	946	827	808	710	685	623
W17	WIPP 12	s17,175fsl,84fel	3484	966	848	825	727	703	641
H18	H-6c	s18,209fnl,375fwl	3349	-	632	612	515	492	427
P18	P - 13	s18,125fnl,116fwl	3345	720	628	608	513	490	426
D20	WIPP 21	s20,1451fsl,10fel	3417	867	752	732	641	617	559
I20	WIPP 19	s20,2986fsl,50fel	3433	894	777	756	672	647	590
S20	WIPP 18	s20,4306fsl,50fel	3457	928	810	791	698	674	614
W20	WIPP 22	s20,2547fsl,50fel	3426	885	763	742	654	630	574
Q20	ERDA 9	s20,267fsl,177fel	3420	860	739	716	632	608	550
P2[illegible]	P - 3	s20,3122fel,103fsl	3382	783	665	645	553	528	468
Q23	P - 19	s23,2330fwl,1652fsl	3546	1116	995	972	839	816	759
P23	P - 11	s23,175fnl,177fwl	3506	1058	938	916	823	799	746
W23	Texas Crude, Wright Fed. #1-23	s23,330fsl,330fel	3596	1190	1038	1018	856	830	755
Q26	P - 18	s26,797fel,134fsl	3479	1084	936	912	728	703	626
P26	P - 10	s26,2315fnl,339fwl	3508	1084	957	935	781	758	686
P28	P - 4	s28,1487fel,146fsl	3441	928	802	782	685	662	610
Q28	P - 2	s28,172fel,125???	3478	1008	884	864	774	748	690
DOE 1	DOE 1	s28,182fsl,610fel	3473	977	851	829	745	722	668
H29	H-14	s29,372fsl,562fwl	3345	-	-	-	446	422	357
L29	H-1	s29,623fnl,1083fel	3398	7	?	?	?	?	?
P29	P - 1	s29,551fwl,327fsl	3345	676	567	546	448	424	359
R29	H-2c	s29,770fnl,3584fel	3377	-	647	627	542	516	457
Y29	H-3	s29,3200fnl,140fel	3395	826	700	680	590	565	509
P30	P - 6	s30,199fwl,2767fsl	3354	656	560	540	442	418	358
P31	P - 15	s31,184fwl,398fsl	3310	542	436	420	322	296	232
H33	H-11	s33, ?, ?	3409	-	754	731	638	613	557
P33	P - 9	s33,143fel,1493fsl	3409	880	758	738	644	617	562
		T22S, R32E							
T13	Ray Smith, B&H Fed. 1	s13,660fsl,660fel	3644	1275	1125	1100	942	920	860
C14	Carper Drilling, #2 Red Tank Unit	s14,660fsl,1980fwl	3731	1290	1165	1140	1025	1005	950
C17	Cleary Pet, Fed. 1-17	s17,1980fsl,1980fel	3701	1200	1103	1072	960	940	885

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
T18	J.H. Trigg, Fed. Jennings 1-18	s18,660fsl,660fel	3696	1230	1110	1090	980	955	900
B19	R. Lowe, Bass Fed. #1	s19,660fsl,660fel	3620	1245	1090	1070	860	835	760
M20	R.J. Zonne, #1 Federal	s20,1980fnl,1980fel	3640	1240	1110	1080	920	895	835
T22	J. Trigg, Fed. Red Tank Unit # 1-22	s22,1980fnl,660fwl	3687	1265	1125	1100	960	935	870
A25	Gulf, Covington "A" Fed. #1	s25,660fnl,1980fwl	3789	1462	1315	1285	1140	1115	1048
T36	Richardson&Bass,State "AQ" #1	s36,660fnl,660fel	3756	1608	1460	1430	1230	1210	1145
		T22S, R34E							
H01	Humble, N.M. State BS #1	s1,1980fsl,660fel	3640	2160	2030	2000	1805	1785	1715
N08	Sunry, N.M. State "AE" No. 1	s8,660fsl,1980fel	?	2092	1942	1918	1700	1682	1600
H10	Allison Fed. No. 1	s10,1980fnl,660fel	3573	2185	2032	2005	1795	1778	1690
		T22S, R35E							
J01	British Amer, Jalmat Deep #1	s1,660fsl,660fwl	3611	2225	2112	2102	1915	1900	1822
D03	Western Drilling, Donegan State No. 1	s3,660fnl&660fwl	3613	2285	2160	2148	1952	1936	1856
A04	Ashmun & Hilliard, Skelly State No. 1 "U"	s4,660fsl,660fel	3611	2300	2175	2142	1955	1935	1860
S05	Skelly Oil, State "U" #1	s5,660fnl,660fel	3623	?	?	?	?	?	?
H09	Hudson, Humble State #1	s9,1980fsl,1980fwl	3581	2275	2142	2110	1905	1885	1810
B11	British Amer., Hall State "F" #9	s11,990fwl,660fsl	3610	?	2193	2180	1979	1960	1877
C20	Carper, Carper Aztec No. 1	s20,1980fnl,660fel	3533	2470	2322	2290	2020	2005	1920
H22	C. Hankamer, Humble State #1	s22,1980fel,1980fsl	3571	2292	2165	2130	1910	1890	1815
A23	Atlantic Ref., State "A" No. 1	s23,330fel,1980fsl	?	2210	2108	2098	1855	1840	1755
G35	J.M. Kelly, Gulf State 1-A	s35,660fsl,660fwl	?	2275	2142	2125	1877	1860	1770
		T22S, R36E							
L03	Gulf, H. Leonard No. 9	s3,660fnl,660fwl	?	1825	1735	1724	1611	1603	1560
G03	Gulf, H. Leonard No. 10	s3,1980fnl,1980fwl	3571	1822	1734	1722	1612	1603	1560
J04	Gulf, J.F. Janda NCT F#15	s4,1980fsl,660fel	3587	1825	1739	1728	1620	1610	1567
S09	Sinclair, State 157 A #3	s9,660fsl,660fel	3540	1687	1600	1590	1480	1472	1424
G09	Sinclair, State 157 A #4	s9,1980fsl,660fel	3552	1725	1641	1632	1517	1508	1465
W10	Western Natural Gas, Record #2	s10,560fsl,660fwl	3560	1735	1645	1637	1528	1517	1475
A17	Cont., Arrowhead Deep Unit #1	s17,1980fnl,1980fwl	3582	1685	1588	1572	1430	1420	1360
C19	Cities Svc., Closson "B" #14	s19,660fnl,330fwl	3589	2008	1890	1875	1700	1678	1602
C23	Shell, Christmas #A-2	s23,660fsl,660fwl	3507	1805	1715	1700	1588	1578	1535
A33	Atlantic Ref., J. L. Selby No. 2	s33,1980fnl,1830fwl	3498	1683	1575	1562	1427	1415	1360

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
M36	Ohio Oil, State McDonald A/C 1-B #11	s36,2310fnl,330fwl	3469	1684	1594	1584	1474	1466	1422
		T22S, R37E							
W15	Amerada Pet., E. W. Walden No. 4	s15,NW/4 of SW/4	3410	1385	1305	1295	1180	1170	1125
R16	E. P. Campbell, R. E. Cole #1	s16,2310fsl,1650fel	3405	1360	?	?	1182	1173	1130
A36	Aztec Oil, State BD 36 #1	s36,1980fsl,1980fel	3316	1408	?	?	?	?	1190
		T22S, R38E							
W30	Western Oil Fields, Gulf Drinkard #2	s30,990fsl,330fwl	3337	1350	1268	1259	1170	1160	1123
		T23S, R28E							
M02	N. H. Wills, Martin & Pardue #1	s2,1560fsl,330fwl	?	?	?	?	?	?	?
C11	N. H. Wills, C. P. Pardue #1	s11,2316fsl,2390fwl	?	?	?	?	?	?	?
P17	Cities Serv., Polk "A" #1	s17,660fnl,2310fel	3045	?	?	?	?	?	?
		T23S, R29E							
N12	Mesa Pet., Nash Unit #3	s12,1980fsl,1980fwl	2996	?	?	?	?	?	?
M13	Mesa Pet., Nash Unit #4	s13,990fnl,330fel	3014	195	?	?	?	?	?
P13	Mesa Pet., Nash Unit #5	s13,2310fsl,330fel	3027	212	?	?	?	?	?
U13	Mesa Pet., Nash Unit #1	s13,1980fnl,660fel	3024	212	?	?	?	?	?
		T23S, R30E							
H14	H - 7C	s14,2595fnl,2471fwl	3163	283	274	237	140	117	87
F16	Skelly Oil, Forty Niner Ridge Unit #1	s16,1980fsl,1980fel	3197	425	?	?	?	?	?
U18	Mesa Pet., Nash Unit #6	s18,1980fnl,330fwl	3028	217	?	?	?	?	?
N21	Skelly Oil, Forty Niner Ridge Unit 2	s21,1980fsl,1980fel	3215	?	?	?	?	?	?
S21?	Skelly Oil, Forty Niner Ridge Unit 2	s21,1980fnl,1980fel	3215	?	?	?	?	?	?
S24	Phillips, Sandy Unit #1	s24,1980fnl,660fwl	3290	470	325	305	235	210	150
Q34	ERDA 10	s34,200fnl,2327fel	3371	?	?	?	?	?	?
U34	Atomic Energy Coms, U.S.G.S. Test Hole #1	s34,center of sec	?	710	?	?	?	?	310
		T23S, R31E							
O04	P - 17	s4,1351fsl,395fwl	3339	713	582	562	463	438	382
P04	P - 8	s4,642fnl,96fwl	3336	715	587	565	477	450	391
H05	H - 4C	s5,447fnl,719fwl	3335	626	515	493	403	377	315
P05	P - 7	s5,513fnl,396fwl	3332	627	521	500	398	373	312
O05	P - 16	s5,951fwl,1629fwl	3323	642	523	503	402	376	316
T14	Texas Amer., Todd Fed. "14" No. 1	s14,1980fsl,1980fwl	3511	1100	990	968	876	850	794
H15	H-12	s15,NE1/4,NE1/4,NE1/4	3425	976	849	825	703	678	621
P21	Patoil, Muse-Fed. #1	s21,660fsl,660fel	3374	797	663	645	542	520	460
T23	Texas Amer, Todd "23" Fed. No. 1	s23,660fsl,1650fel	3461	1090	978	945	850	830	775
T25	Skelly, Todd 25 Fed. #1-Z	s25,1980fnl,1970fwl	3506	1190	1072	1050	940	922	865

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
A26	Texas Amer, Todd Fed 26 #2	s26,1980fnl,1650fel	3454	1063	950	927	830	810	750
T26	Texas Amer, Todd Fed "26" No. 1	s26,1980fnl,1980fel	3464	1070	955	922	835	814	758
B26	Texas Amer, Todd Fed. #4	s26,660fnl,1980fel	3458	1060	945	920	825	806	750
P27	Patoil, Wright-Fed. #1	s27,1980fsl,660fwl	3402	837	705	680	585	560	497
M29	El Paso Nat. Gas, Mobil Fed. #1	s29,1980fsl,1980fel	3374	?	?	?	?	?	?
L32	J.A. Leonard, Cont. State No. 1	s32,660fnl,660fwl	3358	695	587	570	450	430	360
H36	C. P. Miller, P. Harrison State #1	s36,sw/4 of sw/4	?	1095	975	950	860	835	780
		T23S, R32E							
K03	O.B. Kiel, Fed. #1	s3,1980fnl,660fel	3727	1584	1445	1420	1235	1213	1155
M09	McBee, Cont. Fed. #1-9	s9,1980fel,660fsl	3699	1545	1405	1383	1215	1195	1140
H11	Hill & Meeker, Matthews "11" #1	s11,1980fnl,1980fel	3723	1680	1529	1505	1294	1275	1195
T15	J.H. Trigg, Fed. Cont. 1-15	s15,1980fnl,1980fel	3722	1640	1500	1473	1263	1243	1178
F18	Skelly, Fed. Sand 18-1	s18,1980fnl,660fel	3622	?	1245	1215	1110	1085	1025
H20	H-10c	s20,381fsl,1978fel	3699	-	1402	1376	1294	1270	1217
K20	Kirklin, Fed. Estill AF-1	s20,660fsl,1980fel	3696	1512	1392	1368	1285	1262	1210
G21	C. Hankamer, Gulf-Fed. "A-A" #1	s21,660fnl,1980fwl	3701	1517	1401	1377	1240	1215	1163
H24	HL Johnson, Conoco-Fields Fed. #1	s24,1650fsl,330fel	3720	1710	1557	1526	1315	1294	1225
C24	Cont., Fields Fed. No. 1	s24,660fsl,660fel	3725	1727	1570	1532	1325	1308	1235
C25	Cont., Fields No. 2	s25,990fsl,330fwl	3700	1683	1532	1510	1300	1280	1208
J25	H.L. Johnson, Wehrli-Fed. #1	s25,990fnl,2310fwl	3720	1695	1544	1520	1302	1282	1212
W26	J. Trigg, Fed. "WL" #3-26	s26,330fsl,330fel	3698	1678	1525	1500	1315	1295	1225
P26	P.M. Drilling, Fed. Field #1	s26,660fsl,1980fwl	3658	1630	1493	1472	1312	1292	1222
F26	P.M. Drilling, Fed. James No. 4	s26,1980fsl,330fel	3705	1680	1532	1512	1306	1288	1215
L26	J.H. Trigg, No. 4-26 Fed. WL	s26,330fsl,1650fel	3713	1667	1520	1496	1312	1296	1225
W28	M. Wilson, Cont. Fed. No.1	s28,660fnl,1980fwl	3687	1535	1415	1385	1258	1236	1180
H31	C. Hankamer, Hankamer No. 1 Cont. Fed.	s31,660fsl,660fwl	3551	1206	1078	1050	945	923	862
C33	C. Hankamer, Holder Fed. #1	s33,1980fnl,660fel	3666	1520	1386	1355	1285	1260	1200
P34	Pure Oil, Fed. "K" No. 1	s34,1980fsl,330fel	3629	1508	1387	1365	1250	1230	1170
A35	J.H. Trigg, Fed. WL 1-35	s35,1650fnl,2310fel	3694	1657	1506	1483	1298	1282	1206
T35	P.M. Drilling, Fed. James No. 1	s35,660fnl,660fel	3675	1675	1527	1507	1308	1290	?

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
R35	P.M. Drilling, Fed. James No. 2	s35,660fnl,1980fel	3669	1655	1512	1490	1300	1282	1210
D35	P.M. Drilling, Fed. Payne No. 3	s35,1980fsl,330fwl	3630	1505	1387	1355	1252	1233	1183
M35	P.M. Drilling, Payne No. 2	s35,990fnl,2310fwl	3700	1635	1495	1475	1302	1281	1215
J35	J. Trigg, Fed. "WL" No. 2-35	s35,1650fnl,990fel	3691	1653	1498	1475	1293	1275	1205
F35	P.M. Drilling, Payne Fed. No. 4	s35,1980fnl,660fwl	3663	1567	1448	1425	1282	1263	1200
P35	P.M. Drilling, Fed. Payne No. 1	s35,2310fnl,2310fwl	3689	1623	1475	1453	1280	1262	1193
Q35	P.M. Drilling, Fed. James No. 3	s35,1980fsl,1980fel	3670	1623	1472	1453	1278	1260	1187
B36	Pure Oil, Brinninstool Deep Unit #1	s36,1980fsl,1980fel	3689	1680	1517	1493	1296	1280	1210
P36	Penroc, Triste State #1	s36,330fnl,330fwl	3694	1670	1526	1496	1295	1276	1207
G36	D. Fasken, Gulf State #1	s36,1980fnl,660fwl	3664	1673	1517	1495	1297	1278	1206
		T23S, R33E							
C04	Cabeen Exp., Cont. Fed #1-P	s4,660fsl,660fel	3636	1657	1507	1485	1260	1240	1160
T06	Hudon, Shell Fed. #1-6	s6,330fsl,330fel	3704	1772	1622	1600	1355	1340	1260
H07	Hudson, Fed. 7 well #1	s7,660fsl,660fwl	3722	1757	1612	1588	1367	1350	1270
T17	P.M. Oil, Texaco State No. 1	s17,660fsl,660fwl	3715	1773	1615	1590	1367	1350	1268
S18	Helbing & Podeschan, #1 "A" Shell State	s18,660fsl,660fwl	3722	1710	1568	1545	1328	1310	1230
T18	Tenneco, Skelly State #1	s18,660fnl,1980fel	3726	?	1635	1610	1387	1370	1290
B19	Cont, I.J. Marshall 19-1	s19,660fsl,660fwl	3720	1735	1573	1550	1330	1310	1233
C19	Cont., Marshall #19-2	s19,1980fsl,1910fwl	3703	1720	1568	1541	1320	1303	1225
M19	Cont., Marshall #3	s19,660fsl,1980fwl	3711	1732	1571	1550	1327	1310	1230
A19	Cont., Marshall #4	s19,1980fsl,625fwl	3713	1710	1553	1530	1313	1296	1222
A20	Amer., Quaser, Brinninstool #1	s20,1980fnl,1980fel	3713	1790	1634	1610	1385	1364	1285
C20	Cont., Levick Fed. #1	s20,660fsl,660fel	3701	1785	1620	1597	1376	1358	1280
K31	Kirklin, Lea State #1	s31,660fnl,660fel	?	1760	1600	1577	1349	1333	1252
H32	El Cinco, Humble State 1-32	s32,660fnl,1980fel	3683	1770	1606	1582	1360	1343	1268
B35	G. L. Buckles, State 1-35	s35,660fsl,660fwl	3659	1815	1672	1650	1415	1395	1310
		T23S, R34E							
B18	Cont., Bell Lake #9	s18,1980fsl,1980fwl	3533	1469	1330	1310	1084	1066	988
L19	Cont., Bell Lake Unit #10	s19,1980fnl,1980fwl	3555	1605	1455	1425	1200	1182	1095
N22	Shell, N. Antelope Ridge Unit #1	s22,1980fnl,1980fel	3425	1275	?	?	1006	984	912
S34	Shell, Antelope Ridge Unit 34-1	s34,1980fsl,1650fwl	3490	1400	?	?	?	?	944

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
		T23S, R35E							
M01	Schermerhorn, Malco Fed. No. 1	s1,2310fsl,330fwl	3494	2020	1900	1885	1740	1725	1655
E01	Kenwood, Ehrman Fed. #1	s1,660fnl,660fel	3515	2030	1903	1888	1723	1708	1625
		T23S, R36E							
G03	A. Gackle, Sinclair State #7	s3,660fnl,660fel	?	1663	1577	1570	1446	1437	1393
F17	Cont., Farney A-17 No. 3	s17,1650fnl,990fwl	3468	1950	1837	1824	1635	1625	?
S20	Sinclair Oil, Fed. 714 #4	s20,1980fsl,1980fwl	3459	?	?	?	1683	1672	1593
		T23S, R37E							
H04	Samedan Oil, Hughes A-1 #6	s4,1980fsl,660fwl	3324	1337	1252	1244	1188	1176	1143
K06	R. Lowe, King "B" #5	s6,330fnl,330fel	3383	1493	?	?	?	?	1262
H09	Skelly Oil, Harrison B-10	s9,1980fsl,1980fwl	3317	1287	1200	1192	1137	1130	1090
T16	The Texas Co., #3 State of N.M. "BZ" NCT-8	s16,1980fsl,1980fel	3317	1228	1165	1154	1097	1086	1047
O24	E.M. Craig, Ohio State #1	s24,660fel,660fsl	3282	1620	1531	1522	1418	1410	1365
B31	Texaco, E.E. Blinberry A NCT 1-2	s31,1980fsl,660fel	3320	1435	1340	1329	1219	1214	1168
		T24S, R29E							
C05	Chase Pet., Valley #1	S5,1650fsl,660fwl	2968	?	?	?	?	?	?
E06	El Capitan Oil, Fed. Reid No. 1	s6,330fsl,2510fel	2984	?	?	?	?	?	?
F07	Southern Cal. Pet., Fed. Reid #1	s7,2310fsl,2310fel	?	?	?	?	?	?	?
V07	Tenn. Prod., Valley Land Comp. #2	s7,990fsl,330fwl	?	?	?	?	?	?	?
R07	Southern Cal. Pet., Fed. Reid #2	s7,2310fnl,2310fel	?	?	?	?	?	?	?
T07	Tenn. Prod., Valley Land #3	s7,1650fsl,1650fwl	?	?	?	?	?	?	?
C09	Skelly, Cedar Canyon #1	s9,770fsl,770fel	2969	?	?	?	?	?	?
S09	Skelly, Cedar Canyon 9D#1	s9,660fsl,1980fel	2941	?	?	?	?	?	?
C10	Skelly, Cedar Canyon #10-1	s10,1980fwl,2180fnl	2997	?	?	?	?	?	?
P27	Pennzoil, Mobil-Fed. "27" #1	s27,660fsl,660fwl	2924	696	?	?	?	?	450
		T24S, R30E							
P18	P. R. Bass, Poker Lake #45	s18,460fnl,660fel	3179	?	?	?	?	?	?
H23	H-8	s23,2059fnl,1420fel	3433	-	614	589	492	467	400
B25	Hill & Meeker, Bass Fed. #1 - 25	s25,660fsl,660fwl	3429	840	675	650	572	552	473
C29	Ford Chapman, Fed. - Nettles No. 1	s29,660fsl,660fel	3266	?	?	?	?	?	?
		T24S, R31E							
T02	Skelly, Todd "2" State #1	s2,1980fnl,1980fwl	3502	1250	1095	1065	935	912	853
J03	M. Wilson, Jennings Fed. No. 1	s3,660fsl,660fel	3500	1010	880	852	762	750	676

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
F03	J.L. McClellan,Jennings Fed. No. 1	s3,660fnl,660fwl	3432	835	725	696	600	578	?
B04	Sundance, Betty Fed. #1	s4,1659fnl,2310fwl	3414	812	675	648	545	522	453
H04	H-9c	s4,2482fnl,193fwl	3406	-	687	665	565	535	465
S04	Texaco, M.M. Stewart Fed. #1	s4,660fnl,660fel	3436	832	715	688	573	553	485
E04	El Paso Nat. Gas, Sundance Fed. #1	s4,1980fnl,1980fwl	3430	805	680	658	548	528	455
D06	Amer. Quasar, Dunes Unit Fed. #1	s6,1980fwl,1980fnl	3438	826	720	700	573	550	478
Y07	Ambassador, Fed. "Y" #1	s7,660fsl,660fel	3535	960	810	790	692	670	600
G11	Gulf, Fed. Littlefield "CT" #1	s11,660fnl,1980fel	3528	1130	1010	986	850	826	768
W17	W.J. Weaver, Cont. Fed. #1	s17,660fnl,660fel	3553	1025	873	850	755	730	665
R18	C. B. Read, Ritchie Fed. #1	s18,660fsl,660fel	3514	915	795	780	667	645	576
P20	Pauley, Jennings Fed. #1	s20,660fnl,660fel	3530	965	820	800	690	670	605
F20	D. Fasken, Poker Lake #40	s20,660fsl,1980fwl	3490	895	750	729	619	597	530
H21	Hill & Meeker, Carper Fed. #1-21	s21,660fnl,660fel	3535	923	813	792	?	?	693
T24	Texas Co., T. Heflin-Fed. #1	s24,660fsl,1980fel	3551	1017	895	872	775	755	695
M28	Pan Amer., Poker Lake Unit #36	s28,660fsl,660fel	3502	?	?	?	?	?	595
M35	Texaco, C. D. Unit No. 67	s35,1980fsl,660fwl	3508	1010	855	828	722	702	628
		T24S, R32E							
U01	Union Oil of Cal, Union Fed. "1" #1	s1,660fsl,1980fel	3620	1562	1433	1410	1269	1252	1183
C01	Cabeen Exp., Cont. Fed. #1-L	s1,1980fsl,660fwl	3623	?	?	?	?	?	?
M02	Calco, Marathon St #1	s2,1990fnl,1990fwl	3632	1500	1371	1348	1255	1239	1185
O02	P.M. Drilling, Ohio State No.1	s2,1980fnl,660fel	3631	1533	1408	1388	1255	1238	1172
H06	C. Hankamer, Bondurant Fed. No. 1	s6,1980fel,660fnl	3584	1246	1116	1090	965	947	888
G10	Gulf, Fed. Hanagan D #1	s10,1980fsl,1980fel	3628	1394	1270	1248	1161	1138	1088
C11	Cont., Wimberly #2	s11,660fnl,660fel	3615	?	?	?	?	?	?
H11	Gulf, Fed. Hanagan D #3	s11,1980fsl,660fel	3637	?	?	?	?	?	?
F11	Gulf, Fed. Hanagan D #2	s11,1980fsl,1980fel	3637	?	?	?	?	?	?
W11	Cont., Wimberly #1	s11,1980fnl,1980fel	3640	1502	1378	1352	1227	1210	1157
N11	C. Hankamer, Hanagan Fed. No. 2	s11,660fsl,1980fel	?	?	?	?	?	?	?
G11	C. Hankamer, Gulf Hanagan #1	s11,660fsl,660fel	3637	1504	1372	1352	1264	1247	1192
C12	Cont., Wimberly "12" #2	s12,1980fnl,660fel	3600	1203	1253	1269	?	?	?
H12	C. Hankamer, Hanagan Fed. No. 3	s12,1980fnl,660fwl	?	1495	1370	1347	1220	1201	1130

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
W12	Cont., Wimberly 12#1	s12,1980fnl,1650fel	3606	?	?	?	?	?	?
A13	Cont., Wimberly "A" #1	s13,660fnl,1980fel	3599	?	?	?	?	?	?
W13	Westates, Woolley #1	s13,660fsl,660fel	3586	1503	1371	1352	1260	1238	1187
U14	Tenneco, U.S.A. Jennings N.M. Well #3	s14,660fnl,1980fel	3624	1453	1327	1309	1218	1199	1142
J14	Tenneco, #1 USA Jennings	s14,660fnl,1980fwl	3628	1445	1315	1295	1204	1184	1132
T14	Tenneco, U.S.A. Jennings N.M. No. 2	s14,882fsl,882fwl	3588	1437	1308	1283	1200	1182	1122
F14	Tenneco, Jennings Fed. 4	s14,1980fsl,1650fwl	3591	1456	1323	1301	1210	1190	1130
H15	Gulf, Fed. Hanagan "B" #1	s15,660fsl,1980fel	3622	1396	1258	1239	1145	1126	1065
F15	Gulf, Fed. Hanagan "B" #2	s15,660fsl,720fel	3606	1438	1306	1287	1198	1180	1122
G15	Gulf, Fed. Hanagan "B" #3	s15,1980fsl,660fel	3591	1428	1298	1275	1180	1158	1110
T15	Tenneco, Hicks-Fed. #1	s15,660fsl,1980fwl	3602	1340	1208	1191	1102	1083	1025
T22	Tennessee Gas, U.S. Smelting U.S.A. #1	s22,660fnl,1980fel	3602	1384	1246	1225	1140	1125	1066
G22	Tenneco, U.S. Smelting U.S.A. #2	s22,1980fnl,660fwl	3618	1312	1188	1165	1072	1053	998
S22	Tenneco, U.S. Smelting U.S.A. No. 3	s22,1980fsl,660fel	3607	1375	1243	1222	1132	1114	1060
U22	Tenneco, U.S. Smelting USA #4	s22,2310fnl,1650fel	3604	1383	1248	1226	1140	1120	1062
N22	Tenneco, U.S. Smelting U.S.A. No. 5	s22,990fsl,330fel	3591	1362	1223	1201	1118	1100	1047
B22	C. B. Read, Bradley #1	s22,1980fsl,1980fel	3608	1368	1235	1213	1122	1106	1052
R22	C. B. Read, Bradley #2	s22,1980fnl,990fel	3604	1400	1265	1243	1151	1132	1070
E23	C. Hankamer, Ernest Fed. #1	s23,1980fnl,660fwl	3609	1415	1284	1261	1170	1150	1093
B23	C. B. Read, Bradley #3	s23,660fnl,660fel	3605	1412	1275	1253	1168	1148	1088
D33	Texaco, C. D. Unit Well #72	s33,660fsl,660fel	3510	1145	1025	1002	910	890	830
C34	Texaco, C. D. Unit #69	s34,1980fsl,1980fwl	3519	1190	1075	1052	960	940	881
		T24S, R33E							
B01	Cont., Bell Lake Unit #7	s1,660fnl,660fel	3625	1806	1632	1600	1382	1367	1278
G06	Hondo, Gulf State "NW" #1	s6,660fsl,660fwl	3598	1612	1467	1445	1265	1246	1174
H06	Hondo, Gulf N.W. #2	s6,1980fsl,660fwl	3606	1635	1475	1452	1272	1255	1187
T07	T.L. Ingram, State "P" #1	s7,330fnl,1750fwl	3636	1647	1490	1468	1290	1270	1203
O07	T.L. Ingram, State "O" #1	s7,660fnl,660fwl	3590	1635	1475	1452	1273	1257	1184
R07	G.W. Riley, State #1-7	s7,660fsl,660fel	3547	1620	1485	1462	1310	1292	1225
I07	T.L. Ingram, State "O" 2	s7,1980fnl,660fwl	3603	1595	1465	1440	1276	1257	1204
F07	D. Fasken, Gulf State #7-2	s7,2310fnl,2310fwl	3578	1630	1486	1465	1287	1270	1194
S08	Sunray, N.M. State A.G. 1	s8,660fnl,660fwl	3637	1700	1542	1520	1308	1291	1215
B13	B. Bennett, Holland #1	s13,1980fnl,660fel	3598	1785	1613	1600	1347	1330	1245
T17	Tenneco, State Lowe #1	s17,660fsl,660fwl	3554	1540	1409	1385	1267	1250	1190
H17	R.B. Holt, Holly State #1	s17,660fnl,1980fel	3592	1676	1503	1485	1297	1282	1205
C20	Cont., State "BB" 20 No. 1	s20,660fsl,1980fwl	3540	1495	1357	1335	1228	1212	1140
J22	F.R. Jackson, State #1	s22,1980fnl,660fwl	3594	1735	1527	1502	1309	1289	1220

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
T27	Tenneco, Sunray State #1	s27,1980fsl,1980fwl	3502	1621	1481	1458	1275	1259	1186
T29	Tidewater, State "AP" #1	s29,660fsl,1980fel	3525	1492	1332	1314	1224	1206	1146
C30	Kirklin, Continental State #1	s30,330fnl,330fwl	3556	1410	1260	1240	1138	1120	1070
G31	A. Gackle, Cont. State 1	s31,1980fsl,660fel	3524	1392	1250	1228	1141	1122	1063
K36	Gulf, #1 Lea St. "GX"	s36,660fnl&660fel	?	1695	1535	1513	1243	1230	1163
		T24S, R34E							
H01	Hanagan, #1 Gerdlag	s1,1980fnl,1980fel	3447	1125	1012	995	?	?	?
D04	Shell, Fed., "BE" #1	s4,1650fel,660fnl	3567	1537	1392	1368	1139	1122	1045
C05	Cont., Bell Lake Unit #14	s5,1650fnl,1650fwl	3619	1690	1540	1517	1282	1263	1185
B06	Cont., Bell Lake Unit No. 3	s6,660fnl,3300fel	3630	1760	1598	1573	1345	1327	1245
S09	Shell, Hall Fed. #1	s9,660fnl,1980fel	3570	1660	1482	1455	1230	1215	1134
		T24S, R35E							
W05	Gulf, Wilson Fed. Com #1	s5,1980fnl,1980fwl	3488	1085	1025	1005	920	900	835
A16	Texas, Aztec State No. 1	s16,1650fnl,1980fel	3378	1186	1062	1040	905	890	820
		T24S, R37E							
F05	Texaco, E. D. Fanning No. 7	s5,1966fnl,1980fel	3295	?	1320	1311	1210	1197	1155
		T24S, R38E							
H30	R. Lowe, Hair #2	s30,535fnl,2310fwl	3156	1482	?	?	?	?	1202
		T25S, R28E							
E28	Gulf, Eddy State FD #1-S	s28,1980fnl,1980fwl	2997	?	?	?	?	?	?
		T25S, R29E							
B03	J. G. Bennett, Superior Fed. #1-3	s3,660fnl,660fel	2985	340	182	147	?	?	?
B08	J. G. Bennett, Superior #1-8	s8,980fnl,660fwl	2921	?	?	?	?	?	?
W08	N. H. Willis, Superior Fed. #1	s8,660fsl,660fel	2923	?	?	?	?	?	?
M14	Mobil, Corral Draw Unit #1	s14,1980fsl,1980fwl	3118	945	?	?	?	?	670
B15	J. G. Bennett, Superior Fed. 15 No. 1	s15,660fsl,660fwl	3041	775	?	?	?	?	?
W22	Mobil, Corral Draw Unit #2	s22,1580fsl,1980fwl	3078	905	?	?	?	?	680
B26	J. G. Bennett, No. 1-26 Superior Fed.	s26,660fsl,660fel	3043	530	?	?	?	?	175
B27	J. G. Bennett, Superior Fed. 1-27	s27,660fsl,660fwl	2990	414	?	?	?	?	115
B29	Bell Pet., Fed. #1	s29,660fnl,1880fwl	2936	?	?	?	?	?	?
B30	Bell, Cities Svc Fed. #1	s30,660fsl,760fel	2945	393	?	?	?	?	260
		T25S, R30E							
J04	Ritchie etal, #1 Hopp Fed	s4,660fsl,660fel	3283	1014	?	?	?	?	888
P04	Pat Oil, R & B Fed. #1	s4,1980fnl,1980fwl	3273	1096	1041	1029	937	915	848
K08	R. Lowe, Poker Lake Superior State #1	s8,663fsl,667fwl	3210	1255	1094	1078	?	?	970
R08	F. Pool, Superior State 1	s8,1980fnl,660fel	3210	760	597	560	?	?	970

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
T08	R. Lowe, T&P State #1	s8,660fnl,660fwl	3197	790	?	?	?	?	678
S08	R. Lowe, Superior State 1	s8,1980fsl,1980fwl	3210	1100	?	?	?	?	970
P08	R. Lowe, Poker Lake State #3	s8,1980fsl,660fwl	3190	880	848	820	?	?	699
L08	R. Lowe, Poker Lake State #1	s8,660fsl,660fwl	3199	915	?	?	?	?	745
P10	Bass, Poker Lake #44	s10,2030fnl,2180fel	3317	1050	900	878	809	799	780
A10	Alamo, Poker Lake Unit #5X-1A	s10,660fsl,645fwl	3282	1235	?	?	?	?	900
A17	Alamo, Poker Lake Unit #11A-7	s17,660fsl,660fwl	3219	898	?	?	?	?	640
X17	R. Lowe, #1-X R&B Fed. "A"	s17,610fnl,610fwl	3210	786	?	?	?	?	595
M18	R. Lowe, R&B Fed. #1	s18,660fnl,660fel	3192	1205	?	?	?	?	1050
B18	P. R. Bass, Jennings Fed. No. 1	s18,660fnl,1980fel	3186	1075	908	886	797	782	725
A18	Alamo, Poker Lake #12A-9	s18,660fsl,1980fel	3207	1542	1375	1360	?	?	1053
P19	Central States, Poker Lake Unit No. 38	s19,330fnl,900fel	3209	1100	?	?	?	?	880
F20	P. R. Bass, Cont. Fed. #1	s20,660fnl,660fwl	3204	915	?	?	?	?	675
C20	P. R. Bass, Cont. Fed. #2	s20,1980fsl,660fwl	3184	840	?	?	?	?	608
A21	Alamo, Poker Lake Unit #6-2A	s21,660fnl,660fel	3252	1373	1283	1270	1208	1194	1178
		T25S, R31E							
D02	Texaco, C. D. Unit No. 65	s2,1980fnl,1980fel	3476	1012	870	842	?	?	715
A28	Alamo, Poker Lake Unit 7-A-3	s28,660fnl,660fwl	3348	1123	1032	1010	915	890	820
C32	J. A. Leonard, Cont. State No. 1	s32,660fnl,660fwl	3358	697	588	560	450	427	360
S35	Gold Metals etal, #1 Del. Basin Fed.	s35,660fsl,660fwl	3319	1622	?	?	?	?	1325
		T25S, R32E							
C03	Texaco, C. D. Unit No. 49	s3,1650fsl,1980fel	3486	1127	1004	978	882	863	803
D09	Texaco, C. D. Unit No. 52	s9,1650fsl,330fel	3461	1104	967	940	848	820	756
R09	Texaco, E.F. Ray Nct-2 No. 1	s9,330fsl,330fel	?	1160	1006	983	875	855	790
E10	Tenneco, E. F. Ray U.S.A. 41	s10,1650fsl,660fwl	3470	1140	993	972	872	850	793
C10	Texaco, C. D. Unit No. 39	s10,1980fnl,660fwl	3472	1130	993	965	868	847	787
D10	Texaco, C. D. Unit No. 40	s10,660fnl,1980fwl	3478	1127	993	968	872	850	792
M10	Texaco, C. D. Unit No. 60	s10,2145fnl,2310fel	3464	1118	993	968	868	848	785
S10	Texaco, E.F. Ray Fed. No. 1	s10,660fsl,1980fwl	?	1120	988	963	865	845	780
Q10	Texaco, C. D. Unit #66	s10,2080fnl,760fwl	3480	1140	999	972	872	853	791
F10	Texaco, E.F. Ray-Fed. No. 2	s10,1980fsl,1980fwl	?	1147	1005	980	878	858	793

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
V10	Texaco, E.F. Ray- Fed. "B" Well No. 1	s10,660fsl,1980fel	?	1140	1007	982	880	860	794
Y10	Texaco, C. D. Unit No. 63	s10,660fnl,660fwl	3477	1125	990	964	862	840	780
T10	Tennessee, Ray U.S.A. #1	s10,660fnl,660fwl	3460	1122	996	973	866	845	782
R10	Texaco, E.F. Ray Fed. "B" No. 2	s10,1980fnl,1980fwl	?	1123	987	962	854	833	774
C11	Westates, Cont. Fed. #1	s11,sw/4 of se/4	3410	1177	1044	1021	923	899	837
P13	Patoil, Union Fed. #1	s13,660fsl,1980fwl	3468	1140	1013	991	905	876	808
F14	J. O'Neill, Fed. "O" #1	s14,660fsl,660fel	3445	1103	972	949	848	825	762
H14	Hill&Meeker, Ora Hall Fed. 14 #1	s14,2310fnl,330fwl	3455	1133	982	962	862	840	773
O14	J. O'Neill, Fed. "O" #2	s14,1980fsl,660fel	3454	1132	998	976	875	852	787
W15	Texaco, C. D. Unit No. 46	s15,2130fsl,2130fel	?	1150	995	973	867	846	780
F15	Texaco, G.E. Jordan Fed. Well No. 1	s15,1980fnl,660fwl	?	1158	1003	985	875	854	787
J15	Texaco, G.E. Jordan Fed. #2	s15,1980fsl,1980fwl	?	1145	992	968	863	843	782
G15	Texaco, G.E. Jordan-Fed. No. 2	s15,660fnl,660fwl	?	1158	1008	983	878	858	792
M15	Tennessee, G.E. Jordan USA #2	s15,1980fnl,1980fwl	3443	1165	1003	982	875	854	787
R15	Tennessee, G.E. Jordan #3	s15,660fnl,1980fwl	3451	1144	993	963	865	843	780
N15	Tennessee, G.E. Jordan USA 4	s15,1980fsl,660fwl	3441	1138	965	942	862	841	776
T15	Texaco, G. E. Jordan Fed. #6	s15,1980fnl,1980fel	3447	1137	983	962	855	834	769
E15	Texaco, G. E. Jordan Fed. No. 8	s15,660fnl,1980fel	?	1140	990	966	867	845	780
U15	Tenn. Gas, #1 USA G.E. Jordan	s15,660fsl,660fwl	3427	1137	982	953	848	828	765
P16	Tenneco, State Monsanto #6	s16,1650fsl,2310fwl	3423	1098	938	915	823	805	743
Z16	Cont., State Z 16 #1	s16,1980fnl,1980fel	3444	1128	972	952	844	822	760
X16	Shoreline, Cont. State #1	s16,2080fnl,1650fel	3442	1130	983	961	855	836	768
M16	Tennessee, State Monsanto #1	s16,1980fsl,660fel	3439	1137	980	955	856	833	769
E16	Tennesse, Monsanto #2	s16,660fsl,660fel	3433	1125	976	953	852	833	772
C16	Tenneco, State Monsanto #7	s16,330fsl,990fwl	3411	1075	918	895	786	765	697
A16	Tennessee, State Monsanto #3	s16,660fsl,1980fel	3434	1115	960	936	816	795	727
N16	Tennessee, State Monsanto #4	s16,660fsl,1980fwl	3421	1095	927	902	779	758	695
L16	Tenneco, State Monsanto #5	s16,1650fsl,1650fel	3437	1120	960	942	832	810	745
S16	Tenneco, Monsanto State #8	s16,1660fsl,990fwl	3426	1077	922	898	800	778	715

M

GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
F16	Tennessee, State Bradley #2	s16,660fnl,660fel	3458	1157	984	962	852	828	766
B16	Tennessee, State E. L. Bradley #1	s16,1980fnl,660fel	3444	1140	983	960	850	827	763
T16	Tenneco, State E.L. Bradley #3	s16,2310fnl,2310fwl	3434	1110	961	940	835	813	742
D18	Texaco, C. D. Unit #64	s18,660fnl,1650fwl	3431	940	822	803	692	668	607
S18	Texas Comp., J. B. Shaw Fed. #1	s18,660fnl,1980fel	3438	1015	857	836	727	705	643
C20	Texaco, C. D. Unit #42	s20,1650fsl,330fel	3394	1086	932	905	812	790	730
P21	Tennessee, E.H. Perry U.S.A. 2	s21,660fnl,660fwl	3408	1062	905	877	776	756	692
H21	Tenneco, E.H. Perry "USA" Well No. 36	s21,1980fnl,660fwl	3404	1073	917	894	792	770	707
T21	Tennessee, E. H. Perry USA #1	s21,660fnl,1980fel	3428	1130	970	945	828	804	730
E21	Tennessee, #3 E.H Perry U.S.A.	s21,1980fnl,1980fel	3422	1125	967	941	826	806	738
F21	Panther City Invest., Perry Fed. #1	s21,660fnl,660fel	3430	1128	973	948	865	845	768
R21	Panther City Invest., Perry Fed. #2	s21,1980fnl,660fel	3421	1109	943	918	806	782	720
G21	Panther City Invest., Perry Fed. No. 5	s21,1980fsl,1980fwl	3408	1117	957	930	832	810	746
Y21	Panther City Invest., Perry Fed. No. 6	s21,1980fnl,1980fwl	?	1106	953	927	813	792	726
K21	Panther City Invest., Perry Fed. No. 7	s21,660fnl,1980fwl	3414	1097	934	907	803	784	713
I21	Panther City Invest., Perry Fed. #27	s21,2310fsl,990fel	3406	1116	966	943	823	802	737
B21	Panther City Invest., Perry Fed. #28	s21,1980fsl,1980fel	3413	1125	975	947	835	815	752
M21	Panther City Invest., Perry Fed. #37	s21,660fsl,660fwl	3398	1117	958	931	822	800	747
N21	Panther City Invest., Perry Fed. #38	s21,660fsl,1980fwl	3404	1148	985	962	863	842	775
V21	P. R. Bass, Perry Fed. #43	s21,330fsl,330fel	3382	1112	962	943	835	812	755
C21	Texaco, C. D. Unit #44	s21,990fsl,2310fel	3400	1132	978	952	836	816	756
D21	Texaco, C. D. Unit #57	s21,990fsl,990fel	?	1115	967	938	834	811	740
J21	Panther City Invest., Perry Fed. #35	s21,1980fsl,660fwl	3396	1100	938	916	810	787	726
E22	Texaco, G. E. Jordan Fed. No. 1	s22,660fnl,660fwl	3419	1115	959	933	825	800	738
T22	Texaco, G. E. Jordan Fed. NCT-1 No. 5	s22,510fnl,1830fwl	3421	1142	977	953	860	825	770
J22	Texaco, G. E. Jordan Fed. #3	s22,1980fnl,660fwl	?	1130	966	942	835	812	748

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
C22	Texaco, C. D. Unit no. 48	s22,2310fsl,330fwl	3411	1117	960	935	832	810	747
O23	J. L. O'Neill, Fed. "P" #1	s23,660fnl,1980fel	3429	1085	955	930	834	808	748
G25	Texaco, G. E. Jordan Fed. No. 4	s25,660fsl,1980fwl	3430	1155	993	970	861	838	773
C27	Texaco, C. D. Unit no. 61	s27,330fnl,330fwl	3391	1130	988	960	845	823	755
D28	Tenneco, J. D. Sena Jr. U.S.A. No. 2	s28,2310fsl,990fwl	3370	1335	1166	1140	1042	1023	957
J28	Tenneco, J. D. Sena USA No. 1	s28,2310fsl,1650fwl	3375	?	1097	1072	977	958	900
C28	Texaco, C. D. Unit No. 45	s28,660fnl,660fwl	3382	1175	1018	993	895	875	818
U28	Texaco, C. D. Unit No. 47	s28,660fnl,1980fwl	3392	1170	1008	984	875	856	785
X28	Texaco, C. D. Unit no. 51	s28,660fnl,2310fel	3398	1140	985	960	870	850	782
W28	Texaco, C. D. Unit No. 54	s28,1980fnl,2310fel	3386	1178	1018	993	895	875	813
V28	Texaco, C. D. Unit No. 50	s28,1980fnl,1980fwl	3414	1230	1063	1040	950	930	868
N28	Texaco, C. D. Unit No. 56	s28,660fnl,990fel	3388	1118	953	930	822	802	738
Z28	Texaco, C. D. Unit No. 59	s28,1650fnl,990fel	3386	1148	987	960	855	832	768
T29	Texaco, C. D. Unit No. 58	s29,1980fnl,330fel	3356	1310	1132	1100	1012	988	923
C29	I. W. Lovelady, Conoco Fed. #1-29	s29,990fsl,330fel	3366	1485	1347	1315	1224	1202	1142
S31	R. Smith, Ray Smith #1	s31,1980fnl,660fwl	3311	1417	1270	1242	1150	1132	1072
C32	R.C. Graham, Conoco State No. 1	s32,1980fnl,1980fwl	3307	1412	1263	1238	1153	1130	1075
H33	Hill&Meeker, Hall Fed. "33" #1	s33,660fsl,660fwl	3332	1440	1277	1250	1142	1116	1055
M33	Hill&Meeker, Jennings #33-1	s33,2310fnl,2310fwl	3354	1405	1250	1225	1128	1112	1045
W33	Westates, Jennings #1	s33,1980fsl,560fel	3348	1297	1155	1128	1020	995	935
		T25S, R33E							
J01	P. R. Bass, Fed-Muse #1	s1,660fnl,660fwl	3490	1673	1530	1506	1268	1255	1200
H05	Hill&Meeker, Bass Fed. #1	s5,660fnl,660fel	3478	1433	1292	1258	1186	1168	1106
S08	Santana, A. Bass Fed. #1	s8,1980fsl,660fel	3456	1428	1285	1259	1140	1120	1065
H11	C. Hankamer, Muse Fed. #1	s11,660fnl,660fwl	3424	1550	1395	1372	1213	1195	1138
J18	S. H. Jolliffe, #1 Bass Fed.	s18,660fnl,660fwl	3497	1312	1180	1150	1057	1038	985
H20	C. Hankamer, Fed. Bass #1	s20,660fnl,1980fel	3431	1347	1210	1183	1095	1077	1012
A21	Amer. Quasar, Vaca Draw #1	s21,660fsl,660fel	3392	1335	1209	1184	1092	1075	1006
B21	G. L. Buckles, Fed. Marshall #1	s21,660fnl,660fel	?	1374	1232	1207	1117	1098	1042
T22	Texaco, C. D. Unit No. 18	s22,1650fnl,1650fwl	3414	1130	973	950	837	816	750
M23	Hill & Meeker, Muse Fed. 23 #1	s23,660fsl,660fwl	3353	1410	1250	1227	1130	1114	1060
F24	R. B. Farris, Perry Fed. 1	s24,660fsl,660fwl	3358	1463	1310	1283	1136	1117	1045
K25	King Resources, Pan Amer Fed. #1	s25,1980fsl,660fwl	3342	1435	1285	1258	1127	1105	1047
A25	Ashmun&Hilliard, Fed. No. 1-25	s25,660fsl,660fel	3332	1395	1237	1210	1125	1108	1045

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
D27	R. A. Dean, H. Dickson #1	s27,660fsl,660fel	3320	1387	1237	1213	1098	1082	1023
T28	Tidewater, A. R. Bass Fed. #1	s28,660fsl,660fel	3353	1315	1170	1143	1053	1038	975
C28	C. Hankamer, Conley Fed. #1	s28,660fnl,660fel	3344	1339	1188	1167	1074	1056	1002
T29	Tenneco, W.H. Jennings Inc. USA No. 1	s29,1980fnl,660fwl	3422	1385	1196	1171	1083	1060	995
T31	Tennessee, Richardson& Bass USA 1	s31,660fsl,660fwl	3386	1096	951	927	824	800	742
D32	Pure Oil, Red Hills Unit #1	s32,330fsl,2310fel	3332	1192	1067	1042	945	927	875
W32	N. H. Wills, Cont. State No. 1	s32,1980fsl,660fel	3391	1224	1096	1070	971	956	900
W36	M. M. Wilson, Marathon State #1	s36,660fsl,660fwl	3325	1334	1197	1170	1045	1025	965
A36	Ashmun Hilliard, State #1-36	s36,660fnl,660fwl	3346	1432	1277	1250	1117	1102	1038
		T25S, R34E							
F19	Ashmun&Hilliard, Fed. 2-19 No. 5	s19,660fnl,1980fwl	3346	1437	1287	1260	1104	1085	1023
C27	Tenneco, Conoco Fed. #1	s27,1980fnl,660fel	3339	1265	1119	1083	925	905	852
		T25S, R37E							
S02	Cont., State A-2 #2	s2,2310fsl,1650fel	3163	1095	?	?	?	?	917
L03	G. L. Buckles, Liberty Royalty No. 4	s3,330fsl,990fwl	3143	1290	?	?	?	?	1030
J14	Johnson & French, Fed. "A" #1	s14,560fnl,330fel	3123	1068	990	980	920	912	870
L14	Atlantic Ref., Langlie Fed. #2	s14,1650fsl,1650fel	3115	1065	992	979	919	913	873
W24	Western Natural Gas, Wimberly #4	s24,1980fnl,990fwl	3087	973	915	906	838	830	790
		T26S, R30E							
K04	Aztec, Fed. K.W. No. 1	s4,660fnl,660fwl	3179	?	1257	1225	1133	1115	1046
B06	J. G. Bennett, No. 1 Brunson Fed.	s6,660fsl,660fwl	3059	1162	978	948	?	?	815
		T26S, R32E							
C05	F. Pool, Conoco Bradley #1	s5,660fnl,1980fwl	3282	1685	1567	1542	1460	1445	1388
B15	Brown&Krug, Ben Fed. #1	s15,NE/4 of SE/4	3177	956	798	768	667	650	589
R19	Cont., Russell Fed. 19 No. 4	s19,660fsl,1980fwl	3180	1595	1467	1453	1350	1335	1280
F25	Cont., Wilder #12	s25,660fsl,660fel	3113	1006	847	830	702	684	623
E25	Cont., Wilder #10	s25,1980fnl,660fel	3130	1034	874	852	717	698	633
J25	Cont., Wilder #23	s25,990fnl,990fwl	3133	963	794	770	662	643	583
I25	Cont., Wilder #15	s25,660fnl,1980fwl	3131	967	813	792	672	653	587
H25	Cont., Wilder #14	s25,1980fnl,660fwl	3124	967	802	780	664	648	590
A25	Cont., Wilder #6	s25,1980fnl,1980fwl	?	975	816	798	676	656	593
G25	Cont., Wilder #13	s25,1980fsl,660fel	3122	1020	855	828	708	687	625

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GEOPHYSICAL LOG DATA
(Continued)

Well Identifier	Name of well	Location	Ref. Elev.	Top S	Top u.l.	Top C	Top T	Top M	Top F-N
B25	Cont., W.W. Wilder No. 7	s25,1980fsl,1980fel	3122	987	825	805	682	665	600
C25	Cont., W.W. Wilder #8	s25,1980fnl,1980fel	3131	994	828	807	687	670	595
D25	Cont., W.W. Wilder Fed. #9	s25,660fnl,1980fel	3130	1005	848	824	708	690	623
K25	Cont., Wilder 25 Fed. No. 1	s25,330fsl,330fwl	3113	930	765	745	620	600	540
		T26S, R33E							
L17	Gulf, Fed. Littlefield DP Optional #1	s17,660fsl,660fwl	3264	1095	956	930	826	808	740
P30	Cont., Payne #3	s30,1980fsl,660fwl	3122	1055	897	876	746	727	659
		T26S, R34E							
Y03	Gulf, Gulf Yates Fed. #1	s3,660fnl,1980fwl	3414	1235	1084	1052	926	915	856
B19	Cont., Bradley 19 #2	s19,1980fsl,1980fel	3392	1115	972	943	830	810	744
L20	M. Wilson, Leonard Fed. No. 1	s20,660fnl,660fel	3332	1005	862	833	714	699	635
		T26S, R36E							
S05	Cities Service, Sand Hills Unit #9-A	s5,660fsl,660fwl	?	1203	1168	1152	1117	1102	1054
		T26S, R37E							
J04	Jal Oil, Farnsworth #6	s4,990fsl,990fwl	?	1265	1156	1145	1045	1034	983
L11	Stanolind, U.S.A. Leonard Oil No. 1	s11,660fsl,660fel	3013	1163	?	?	981	972	932
		T26S, R38E							
F07	Forest Oil, Fed. Lowe #1	s7,1980fsl,660fwl	3032	1194	1102	1082	?	?	970

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APPENDIX III

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APPENDIX III

X-Ray Diffraction

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X-RAY DIFFRACTION DATA

The interpreted x-ray diffraction (XRD) data for samples distributed throughout the Rustler from WIPP 19 and H-12 are presented in tables attached to this section. The data are only generally semi-quantitative and are limited by procedures (SOP for XRD at end of this Appendix) to major evaporite minerals. Clays have not been included in this investigation.

Two features of this XRD study are somewhat unusual. Quartz occurs more frequently and more abundantly than expected in purer chemical sediments, and dolomite and high magnesium calcite are more ubiguitous than expected. The carbonate phases are apparent through petrography, and XRD confirms the Mg content. Further petrographic study might be necessary to evaluate the significance of carbonate where a dolomite as well as probable high magnesium calcite occur.

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X-RAY DIFFRACTION - H-12

NO*	GYPSUM	ANHYDRITE	QUARTZ	HALITE	DOLOMITE	CALCITE	POLYHALITE	OTHER
1				XX				
5	x	?tr	X	tr	x	? Mg calcite		? feldspar
8			X	x	x			? feldspar
10			X	X	x	? Mg calcite		? feldspar
12			X		x	? Mg calcite		
13			X	X	x	? Mg calcite		? feldspar
15		x	X	X	x	x Mg calcite		? feldspar
19		x	X	X				
23			? tr	X				
25		X	tr	tr				
28			x	X				
31		x		X				
33		XX						
36			X	x				
39			X	x	X	x		
41	X				X			
42	X			x	x?			
46		XX						
50		X		x				prob.elec.err
51		X		X				
52		x		X				? magnesite t
54		tr		X				
58		tr	x	X				
59		tr	x	X				
61		tr	x	X				
62		X		?tr				X magnesite
63		X			x?		?tr	
64		XX					?tr	
65		XX		?				
67		X			x		?	
68		X		x				
71	X		x	tr?	x		?	
73	X		tr	tr?	x	x?		
74	tr	X						
76			x		X			
79		x	X	x	x			
80			X	X	x			
81		X		tr?				
82		X			x			

KEY: XX - sole or overwhelming mineral
X - major
x - minor
tr - trace
? - questionable
Mg calcite - magnesium-rich calcite, generally >20% Mg
*Sample Number

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X-RAY DIFFRACTION - WIPP 19

NO*	GYPSUM	ANHYDRITE	QUARTZ	HALITE	DOLOMITE	CALCITE	POLYHALITE	OTHER
1		X	x	x				
2		tr	X	x		? Mg calcite		unidentified
4	x		X		x	? Mg calcite		unidentified
5		tr	X	x	x	?		unidentified
6	tr	tr	X	x	x			
10			X	X	x			
11		x	X	X				
12		X		x				
14		x	x	X				
20	X		x					
23				?	X			
24			x	x?	X			
25			tr		X			
38	X	tr				x		
39	X					x		
40	X	X				tr		
41		XX						
42		X				tr		
43		X	x					
44	x	X	tr		x			
46	X	tr	X		X			
47	?	X			X			
49	X	x						unidentified
50	XX							
55			X		x	?tr		? Feldspars
57	x	tr	X	X		? Mg calcite		
60		XX						
62		XX		tr?	x			
63	x	X			?tr			

KEY: XX - sole or overwhelming mineral
X - major
x - minor
tr - trace
? - questionable
Mg calcite - magnesium-rich calcite, generally >20% Mg
unidentified - unidentified minor peaks
*Sample Number

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STANDARD OPERATING PROCEDURE

X-RAY DIFFRACTION ANALYSIS

RUSTLER FORMATION

Dennis W. Powers

Robert M. Holt

October 13, 1986

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GENERAL

This procedure is developed for use on samples from the Waste Isolation Pilot Plant (WIPP) project to determine mineralogy and qualitative to semi-quantitative mineral proportions from samples from the Rustler Formation. The techniques presented here are collectively based on experience of the authors and well-known sources such as Mueller (1967) and more recent literature (e.g. Fang and Zevin, 1985).

OBJECTIVES

There are two principal objectives for the X-ray diffraction work on samples from the Rustler Formation:

a) provide a basic comparative mineralogy for the Rustler based on regular sampling procedure from available core, and

b) provide specialized mineral identification (e.g. clays or rare mineral phases) for further interpretive work.

The first objective is met through a sampling program from two boreholes (WIPP 19 and H-12) which provide a general sampling from both near the site center and in an area near the depocenter for parts of the Rustler. Samples were collected at regular spacings to provide a general representation of the mineralogy of the formation. The second objective is met through some initial specialized sampling of minerals and features of particular interest and through separation and/or concentration of mineral phases of interest from these special samples or from regularly spaced samples.

METHODS

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Sample Preparation

A sample of the core will be selected for XRD analysis; general samples will usually be about 20-100 gms in weight while specialized samples may be as small as an individual crystal. The sample will be visually selected to be representative of the core specimen or to be a sample consistent with the analytical objective.

The sample will be individually stored in a plastic canister labeled by the sample identifier. The sample will be crushed in a mortar and a smaller amount, as a subsample, will be ground in an agate mortar with an agate pestle to obtain powder of the order of 10ï in maximum diameter. A small amount of

Si metal or powdered fluorite (CaF_2) will be added to provide an internal standard peak. General mineralogy samples will be approximately unoriented samples obtained by sprinkling powder onto a glass slide with vaseline on the surface.

Specialized samples may be prepared differently. Clay samples may be obtained after concentration of the clay fraction through dissolution of water and/or acid soluble portions (Bodine and Fernalld, 1973; Bodine, 1978). Clay identification will be made on the basis of three general tests (Carroll, 1970; Millot, 1970):

a) oriented sample

b) oriented sample treated with ethylene glycol

c) oriented sample heated to 550°C.

Oriented samples will be made in triplicate by sedimentation onto glass slide from water (with Calgon) suspension or by soaking the sample with acetone on the slide. Samples to be treated for ethylene glycol will be moistened and placed for 24+ hours in a desiccator with liquid ethylene glycol in the bottom. Heated samples will be kept at 550°C for a period of at least 1 hour, and will be X-rayed within four hours of heating. Samples will be kept in a desiccator with desiccant as appropriate during the interval.

Other special techniques of importance will be documented as carried out.

X-ray Diffraction

All XRD work for this project will be done with Cu K_A radiation with a Ni filter to eliminate Cu K_B-radiation. The current and voltage will be set at 18 mA and 30 kV, respectively for all runs. Scaling and time factors will be established each day, and will be as uniform as is reasonably possible. These parameters will be recorded for each trace of any sample.

For general samples, a speed of 2°/minute for the goniometer and a chart speed of 1"/minute will be used. Each sample will be examined through 2-35° 2θ. The trace will be compared to an artificial pattern for common minerals. Peaks not in this set will be identified by satndard methods of comparing peak intensities to patterns within ASTM card files. Peaks not identified by this methods will be noted for possible further work.

Special samples will be characterized through an appropriate range of 2θ and with modified chart and goniometer speeds as appropriate to the type of sample.

Interpretation

All identified minerals will be listed and note taken of unidentified or unidentifiable peaks. The relative intensities of mineral peaks will be used to assigned general abundance descriptors: major, minor, trace. As appropriate, certain mineral combinations, such as gypsum and anhydrite, may be assigned semi-quantitative proportions based on comparison of peak heights with artificial mixes. Records of these mixes will also be kept for checking.

Safety

All operators of XRD equipment will meet Department of Geological Sciences training requirements. All operators are required to wear monitoring badges for exposure to radiation. These badges are checked periodically by the University.

Quality Assurance

All operators are experienced in the use of XRD equipment for mineral analysis. Holt and Powers will provide supervision of the sample preparation and equipment operation periodically to ensure that record-keeping is appropriate.

All samples are marked with unique identifiers. Subsamples and all subsequent slides and traces will be immediately marked with identifying sample numbers and modifiers (e.g. G or H to denote glycolated or heated, respectively) as appropriate. Patterns will be individually marked with equipment operating parameters. Traces will be maintained in a file. An individual worksheet will be prepared with a summary of important information, including mineral identification for each sample (see attached).

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REFERENCES CITED

Bodine, M.W., Jr., 1978, Clay-mineral assemblages from drill core of Ochoan evaporites, Eddy County, New Mexico: Circ. 159, New Mexico Bureau of Mines and Mineral Resources, pp. 21-31.

Bodine, M.W., Jr., and Fernalld, T.H., 1973, EDTA dissolution of gypsum, anhydrite, and Ca-Mg carbonates: Jour. of Sedimentary Petrol., v. 43, pp. 1152-1156.

Carroll, D., 1970, Clay Minerals: a guide to their X-ray identification: Spec. Paper 126, Geol. Soc. Am.

Fang, J.H., and Zevin, L., 1985, Quantitative X-ray diffractometry of carbonate rocks: Jour. of Sedimentary Petrol., v. 55, pp. 611-613.

Millot, G., 1970, Geology of Clays: Springer-Verlag, New York, Heidelberg, Berlin, 429 p.

Mueller, G., 1967, Methods in sedimentary petrology: Hafner Publishing Co., New York, London, 283 p.

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix GCR

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Geological Characterization Report

SAND 78-1596
UNLIMITED RELEASE

Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico

Volume I

August 1978

Dennis W. Powers, Steven J. Lambert, Sue-Ellen Shaffer, Leslie R. Hill, Wendell D. Weart, Editors

Sandia Laboratories

SF 2900 Q(7-73)

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GEOLOGICAL CHARACTERIZATION REPORT
WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

SAND78-1596

VOLUME I

Dennis W. Powers, Steven J. Lambert, Sue-Ellen Shaffer,
Leslie R. Hill, Wendell D. Weart, Editors

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Sandia Laboratories
Albuquerque, New Mexico 87185

AUGUST, 1978
PRINTED DECEMBER, 1978

PREFACE

The Geological Characterization Report (GCR) for the WIPP site presents, in one document, a compilation of geologic information available to August, 1978, which is judged to be relevant to studies for the WIPP. As such, commonly available documents are summarized as appropriate while other documents may be presented more fully. In some instances, the information presented may be preliminary or may reflect continuing studies not yet complete. The Geological Characterization Report certainly should not be construed as the final word on the WIPP geology. Furthermore, specific judgements of how the geologic information affects the WIPP are restricted since the document is intended as a source of information. However, recommendations may be made on the basis of the document. The Geological Characterization Report for the WIPP site is neither a Preliminary Safety Analysis Report nor an Environmental Impact Statement; these documents, when prepared, should be consulted for appropriate discussion of safety analysis and environmental impact. The Geological Characterization Report of the WIPP site is a unique document and at this time is not required by regulatory process.

The Geological Characterization Report (GCR) for the WIPP has been created through the efforts of many individuals who are to be acknowledged for their contributions; little of the material presented, however, is original material created solely for the Geological Characterization Report. At Sandia Laboratories, principal contributors to the writing of the GCR are, in alphabetical order: G.E. Barr, B.M. Butcher, R.G. Dosch, L.R. Hill, S.J. Lambert, D.W. Powers, S.E. Shaffer, W. Wawersik, and W.D. Weart. Bechtel Corporation provided basic summaries for many chapters; the principal participants were: D. Dale, C. Farrell, V. Howes, J. Litehiser, D. Roberts, R. Sayer. In particular, J. Litehiser provided the analysis of seismic risk in Chapter 5. G.B. Griswold of Tecolote Corporation summarized resources in Chapter 8. F.H. Dove of NUS summarized hydrology in Chapter 6.

Editorial and review comments were solicited on a working copy and received from independent agencies with personnel familiar with the geology of southeastern New Mexico, particularly the New Mexico Bureau of Mines and Mineral Resources. An internal review at Sandia Laboratories of a working copy of the entire document also resulted in detailed comments. Those review comments were incorporated as appropriate into this draft copy. As usual, some of the suggestions were not followed for various reasons. The draft copy received review and comment by the WIPP Panel (Committee on Radioactive Waste Management, National Research Council) of the National Academy of Science, the Office of Nuclear Waste Isolation (ONWI) and various subcontractors, and by Westinghouse as a contractor to DOE. Major parts of the draft were reviewed by members of the Special Projects Branch, USGS. These comments have resulted in some revision of the final copy, as seemed appropriate. The editors assume responsibility for the contents of this report.

The editors and writers acknowledge the enormous volume of accumulated data and interpretations which provide the background for the Geological Characterization Report; referencing of authors is intended to reflect this background and to properly attribute material.

The Report is primarily intended for use by those with a technical background in earth sciences. However, the text should also be generally readable without all of this background by referral to the American Geological Institute Glossary of Geology (1974).

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GCR CHAPTER 1

EXECUTIVE SUMMARY

This Executive Summary presents, in condensed form, geotechnical information relevant to the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico. The presentation of material follows the Geological Characterization Report (GCR) chapter organization, beginning with Chapter 2, INTRODUCTION. Figures and a reference list are not included in the Executive Summary; where desired the reader must examine the figure and reference list following each Chapter.

INTRODUCTION (Chapter 2)

The Introduction provides an overview of the purpose of the WIPP, the purpose of the Geological Characterization Report, the site selection criteria, the events leading to studies in New Mexico, status of studies, and the techniques employed during geological characterization.

The purpose of the Waste Isolation Pilot Plant (WIPP) is to demonstrate the technology for the disposal of the transuranic (TRU) waste resulting from this nation's past and current defense programs. It is anticipated that the WIPP will be converted to a repository after successful demonstration of this technology and assessment of safety of a repository for southeastern New Mexico. In addition, the WIPP is to provide a research facility to examine, on a large scale, the interactions between bedded salt and high-level radioactive waste. A Department of Energy (DOE) Task Force (DOE/ER-0004/D, 1978) has recommended that WIPP also be used to demonstrate surface and subsurface methods of handling, storing and disposing of up to 1,000 canisters of spent reactor fuel. A decision on implementing this recommendation has not been made at this time.

If this site is accepted by the DOE, the schedule calls for the initiation of facility construction in early 1981; completion is to be late 1985, and the first waste to be accepted in 1986. The TRU waste would be readily retrievable for a five to ten year period of initial

operation. All HLW for experiments would be retrieved upon completion of the experiments. The conceptual design of WIPP facilities is complete. DOE has expressed an intent to request licensing of the WIPP by the Nuclear Regulatory Commission (NRC), but this issue is not yet resolved.

Interest in disposal of radioactive waste in geologic media may be traced back to a 1957 committee report by the National Academy of Sciences - National Research Council, that recommended guidelines for permanent disposal of radioactive waste in geological media. Recommendations fell into two categories: burial in bedded salt deposits or in deep sedimentary basins (perhaps 4000 - 5000 m deep).

Salt became the leading candidate as a disposal medium, and from 1957 until the 1970's most disposal studies in the U.S. concentrated on bedded salt. In the mid-1960's, Oak Ridge National Laboratories (ORNL) conducted a successful in situ experimental program called "Project Salt Vault" in a salt mine near Lyons, Kansas. A subsequent plan to establish a federal repository near Lyons was withdrawn due to both technical and political objections.

Subsequent evaluation of salt basins in the United States by ORNL and the USGS led in 1974 to field investigations of Permian salt deposits of the Delaware Basin in southeastern New Mexico to determine if the geologic setting was adequate for a radioactive waste repository. Permian evaporite deposits consist of the Castile Formation which is interbedded halite and anhydrite, the Salado Formation which consists principally of halite and the Rustler Formation which is mostly anhydrite but contains halite, dolomite, and siltstone.

In 1975, the AEC (later Energy Research and Development Administration (ERDA) and now Department of Energy (DOE)) assigned responsibility for site evaluation and conceptual design for this project in New Mexico to Sandia Laboratories of Albuquerque, New Mexico. The project in New Mexico is now known as the Waste Isolation Pilot Plant (WIPP).

Preliminary site selection criteria were general in nature. (Most areas are not well enough known to allow application of precise criteria.) After Sandia Laboratories determined in 1975 that the first preliminary study area originally selected by ORNL was geologically unsuitable, site selection factors were refined specifically for and applied to the Delaware Basin in New Mexico to define the present study area. The major siting factors employed in southeastern New Mexico are that the repository salt beds should be: (a) relatively pure; (b) several hundred feet thick; (c) between depths of 1000 and 3000 feet; (d) located where groundwater dissolutioning is relatively limited; (e) at least one mile from boreholes that completely penetrate the evaporite section, (f) generally located to avoid private land; (g) located where strata are relatively flat; and (h) located to minimize conflicts with mineral resources. Data from hundreds of borehole geophysical logs and more than fifteen hundred miles of existing seismic reflection lines from petroleum companies were analyzed and considered along with hydrologic data and available information on natural resources to narrow the area of search. A relatively restrictive criterion was the requirement the repository be one mile or more to the nearest borehole penetrating the complete evaporite section. Existing studies of borehole dissolution indicated one mile is sufficient, though perhaps not necessary, to ensure repository integrity.

Geologic studies for the WIPP fall into three different phases: preliminary site selection activities, geological characterization, and studies of long-range geologic processes affecting a repository. Preliminary site selection activities are complete now, and geological characterization is nearing completion with this report. Studies of long-range processes are becoming the focus of geotechnical programs; some of these latter studies are already underway. These studies, which will be oriented toward geologic processes and rates, will mostly be completed before conversion of the WIPP to a permanent repository for defense waste; these studies plus operation should provide further refinement to criteria for conversion of the WIPP.

Many standard petroleum and mineral industry techniques have been used to characterize the WIPP site. Considerable reliance has been placed on the combination of geophysical techniques corroborated by borehole information. The geophysical techniques most widely used to characterize the WIPP site include seismic reflection and resistivity. By summer, 1978, about 75 line miles of new seismic reflection data were obtained and over 9000 resistivity measurements had been made and analyzed. Twenty-one boreholes were drilled to evaluate potash, 14 hydrologic test holes were drilled and four potash holes were converted for hydrologic studies of the aquifers above the Salado Formation. Ten stratigraphic test boreholes have been drilled on or around the WIPP site as of early August, 1978, and two other holes have been drilled well away from the WIPP site to study dissolution processes. Two of these holes were drilled through the salt to test deep aquifers and to acquire geologic data.

Most of the WIPP geologic studies to date advanced geological characterization. Geologic studies will continue in order to permit a better quantification of the rates of geologic processes in and near the WIPP site and to develop a more thorough understanding of the geologic phenomena of interest (see Chapter 10).

REGIONAL GEOLOGY (Chapter 3)

Regional Geology provides a broad assessment of the surface and subsurface environment of the area within a radius of about 200 miles of the proposed WIPP Site. The discussion comprises a synthesis of the available data pertaining to the physiography and geomorphology, stratigraphy and lithology, structure, tectonic development and geologic history of this region. Such information is necessary to understand the geological processes that need to be understood for assessment of long-term safety of a repository in the Delaware Basin of southeastern New Mexico. The paragraphs below present a brief summary of this information.

The WIPP site is located within the Pecos Valley section of the southern Great Plains physiographic province, a broad highland belt which slopes gently eastward from the Rocky Mountains and Basin and Range province to the Central Lowlands province. The Pecos Valley section itself is dominated by the Pecos River valley, a long north-south trough from 5 to 30 miles wide and as much as 1,000 feet deep, which exhibits an uneven rock and alluvium-covered floor marked by widespread solution subsidence features resulting from dissolution within the underlying Upper Permian Ochoan rocks. The section is bordered on the east by the Llano Estacado, the virtually uneroded fluviatile plain of the High Plains section, and on the west by the Sacramento and Guadalupe Mountains area of the Sacramento section.

The principal geomorphic features with bearing on the site area include the Pecos River drainage system, the Mescalero Plain, karst topography and wind erosion "blow-outs." The Pecos River system has evolved from the south, cutting headward through the Ogallala sediments to capture what is now the upper Pecos and becoming entrenched sometime after the Middle Pleistocene. The system at present receives almost all the surface and subsurface drainage of the region; most of its tributaries are intermittent, due to the contemporary semi-arid climate. Most of the ground surface east of the Pecos River valley comprises the Mescalero Plain, a poorly drained surface covered by gravels, eolian sand and caliche, which has developed since Early to Middle Pleistocene time. The surface of the region exhibits karst topography containing superficial sinkholes, dolines, solution-subsidence troughs, and related features, formed as a result of both surface erosion and subsurface solutioning activity.

The WIPP site lies on a caliche and sand covered drainage divide separating two major and perhaps still developing solution-erosional features, Nash Draw on the west and San Simon Swale to the east. This prevailing erosional pattern is expected to continue in the future, with most local erosion occurring in the draw and swale areas. The site is located west of the local drainage divide.

The stratigraphic section present in the site region includes Precambrian through Triassic rocks, overlain by outliers of possible Cretaceous age, and widespread Late Tertiary through Holocene sediments.

Metasediments and granitic-volcanic igneous materials constitute the majority of the regional basement, cropping out in isolated areas to the west and north. The granitic rocks range in age from about 1,400 million years in the north to about 1,000 million years in the south and are overlain in places by younger Precanibrain volcanic terrains. The surface of the Precambrian reflects the Late Paleozoic platform and basin structural configuration of the area.

The Paleozoic section comprises up to 20,000 feet of Upper Cambrian sandstones through Upper Permian evaporites and redbeds. The Ordovician, Silurian and Devonian rocks are primarily carbonates with lesser sands, shales and cherts which were deposited in shallow, rather calm shelf areas of broadly subsiding areas of the Tobosa Basin, with some minor influence from uplifted areas such as the ancestral Central Basin Platform. The Mississippian sequence consists of locally cherty limestones overlain by silty and sandy shales, truncated against adjacent emerging uplands. Post-Mississippian orogeny caused uplift, tilting and erosion, producing a massive section of Lower Pennsylvanian continental sediments, interbedded with dark limestones, particularly toward the top of the section. Late in the Pennsylvanian, a basin, basin margin, and shelf configuration, which endured through the Permian, developed, resulting in deposition of dark shales, clastics and some limestones and bioclastics forming a series of reefs along the basin margins, and shallow-water limestones and clastics on the adjacent shelves. Upon filling of the basins in the Late Permian, a sequence of evaporites totalling 4000-5000 feet in thickness was deposited during recurrent retreats of shallow seas restricted by the encircling Guadalupian reefs. The Castile Formation consists of anyhdrite interlaminated with calcite and halite overlain by the Salado Formation, which is primarily halite with lesser clastics, anhydrite and a suite of salts. The Rustler Formation overlying the Salado is composed of anhydrite, gypsum and

lesser salt with carbonates and clastics. The top of the Paleozoic is marked by the thin Dewey Lake Redbeds.

The Mesozoic sequence is represented by only the Upper Triassic Dockum Group of terrigenous redbeds, which in many places are truncated or removed by erosion, and by scattered patches of Cretaceous limestone and sandstones.

The lower Cenozoic section is missing from the region due to erosion and/or non-deposition, and the widespread Late Miocene-Pliocene Ogallala clastics represent the earliest deposition of the section. The Ogallala is capped by a dense, resistant layer of caliche, which probably started to form during the Late Pliocene. Quaternary deposits occur only locally and consist of the Middle Pleistocene to Holocene terrace, channel and playa deposits as well as windblown sands.

The major structural framework of the region is provided by the large-scale basins and platforms of late Paleozoic age and by Cenozoic features primarily associated with Basin and Range tectonics.

The principal late Paleozoic features of the area consisted of the western extent of the Tobosa and later the Permian Basin and its border lands. These elements include the Delaware Basin, Central Basin Platform, Midland Basin, the Northwestern Shelf, Pedernal Uplift, Matador Arch, Val Verde Basin and Diablo Platform.

The site is located in the northern portion of the Delaware Basin, a broad, oval-shaped asymmetrical trough with a northerly trend and southward plunge and a structural relief of more than 20,000 feet on top of the Precambrian. Deformation of the basin rocks is minor, those formations older than Late Permian are only gently downwarped. Deep-seated faults, some reflecting Precambrian faults, occur in the basin, as do folds, joint sets, and a number of smaller, probably solution-related structures originating in the Upper Permian evaporites. The basin was defined by early Pennsylvanian time, and major structural

adjustment occurred from Late Pennsylvanian to Early Permian time. By the Late Permian, this episode of tectonic activity ended in the basin; regional eastward tilting occurred later, in the Cenozoic.

The Central Basin Platform, a northward-trending feature, separated from the Delaware Basin to its west by a zone of major normal faulting, represents a broad uplift of Precambrian to Pennsylvanian rocks, within which movement took place periodically, probably from the Precambrian until the late Paleozoic when the basin became structurally stable.

North and northwest of the Delaware Basin lies the Northwestern Shelf, which was well-developed before Permian time and may have originated in the Early Paleozoic, when it formed the margin of the Tobosa Basin. A number of flexures, arches, and faults which have been identified on the shelf had probably ceased tectonic activity in Tertiary time.

The Diablo Platform, forming the southwestern border of the Delaware Basin, experienced primary deformation in the late Paleozoic in the form of uplift, folding and faulting. Deformation also occurred here during late Tertiary time through block faulting and buckling. Recent uplift along its eastern side suggests continuing tectonic development in the area. The remainder of the previously listed late Paleozoic structural elements of the area are only remotely related to the site area.

Late Tertiary Basin and Range tectonics produced the Sacramento, Guadalupe and Delaware Mountains bordering the region on the west. These uplifts are generally eastward-tilted fault blocks bordered on the west by complex normal fault systems forming short, steep westward slopes and backslopes dipping gently eastward. Tectonic activity began in this area during Mississippian to Early Permian time in the form of fault systems, followed by the major Basin and Range tectonics. Small fault scarps in recent alluvium along the western edge of these ranges, as well as some seismic activity, suggest that structural development here may still be taking place.

Post-Precambrian igneous activity in the region consists of Tertiary intrusives and Tertiary to Quaternary volcanic terrains located on the north, west and south of the site area. Only minor igneous activity, in the form of dikes and possibly sills, is known to have occurred within the Delaware Basin.

The closest such igneous feature to the site is a near-vertical trachyte or lamprophyre dike or series of en echelon dikes trending about N50°E for perhaps 75 miles into New Mexico from near the Texas-New Mexico border southwest of Carlsbad Caverns, passing about 9 miles northwest of the site. Evidence for the dike's existence consists of exposures in two mines, cuttings from several drill holes, aeromagnetic indications and surface exposures some 42 miles southwest of the site in the Yeso Hills. This dike has been dated as mid-Tertiary and intrudes only the Late Permian Salado and underlying formations.

The principal Tertiary igneous features of the area beyond the Delaware Basin include several intrusive bodies within the Delaware Mountains, widespread occurrences further south in the Trans-Pecos region and several areas well to the north of the basin, in the form of the eastward-trending El Camino del Diablo and Railroad Mountain dikes (near Roswell) and the stocks of the Capitan and Sierra Blanca Mountains. Quaternary volcanic and related extrusive terrains are present west of the site region, well within the Basin and Range province.

The geologic history of the region is recorded in igneous and metasedimentary rocks as old as about 1,400 million years which indicate a complex Precambrian history of mountain-building, igneous events, metamorphism and erosional cycles. Probably before Paleozoic time, erosion had reduced the area to a nearly level plain.

The early to middle Paleozoic Era was characterized by generally mild epeirogenic movements and carbonate deposition interrupted by only minor clastic sedimentation. The oldest sediments in the region are the Late Cambrian and perhaps Early Ordovician Bliss sandstones. Following Early

Ordovician time, a broad sag, the Tobosa Basin, formed and began deepening. Shelf depositions of clastics continued, derived partly from the ancestral Central Basin Platform, and carbonates deposited in shallow waters. By Late Ordovician time, the Marathon Ouachita geosyncline to the south of the area began subsiding, but until the Middle Mississippian, only mild tectonic activity continued, with several periods of minor folding and perhaps some faulting, the basin subsiding, the Pedernal landmass to the north emergent and some regional erosion occurring.

From late in Mississippian time through the Pennsylvanian, regional tectonic activity accelerated, folding up the Central Basin Platform, Matador Arch and the Ancestral Rockies, producing massive deposition of clastics. The Tobosa Basin was definitively split into the rapidly subsiding Delaware, Midland and Val Verde Basins. Throughout the Permian, sedimentation was continous in the basins, climaxing in the development of massive reefs, and, following stabilization in the Late Permian, in the deposition of a thick sequence of evaporites. By the end of the period, the area was slightly emergent, and a thin sheet of redbeds covered the evaporites.

Since the close of the Permian, the basin area has been relatively stable tectonically, and the Mesozoic through Cenozoic eras have been characterized by erosion, with only relatively minor deposition of terrestrial materials. During the Triassic, a broad flood plain sediment surface developed, followed late in the period by fluvial clastic deposition and formation of a rolling topography. Sometime during the Cretaceous, submergence occurred, and thin limestone and clastics collected in intermittent, shallow seas. During the Jurassic and perhaps as early as the Triassic, subsurface dissolution of the Upper Permian evaporites began. The close of the Mesozoic was marked by the Laramide orogeny and uplift of the Rocky Mountains, with mild tectonic and igneous activity to the west and north of the site area. Throughout most of the Tertiary, erosion dominated, until deposition of the Ogallala late in the era. Mid to late Tertiary Basin and Range uplift of the Sacramento and

Guadalupe-Delaware Mountains was accompanied by regional uplift and east-southeastward tilting. Upon this gently sloping surface the Miocene-Pliocene Ogallala fan deposits accumulated, and a resistant caliche caprock began to form. During Quaternary time, the present landscape has developed through processes of surface erosion and dissolution of the Upper Permian evaporites, accompanied by terrace and stream valley deposition and eolian activity.

The regional geology shows that the northern Delaware Basin has been a part of large structures reacting slowly to tectonic and climatic processes. About 300 million years of Paleozoic geologic history indicate a downwarping basin on a grand scale. The last 200 million years are characterized by slow uplift relative to surroundings resulting in some erosion and dissolution of rocks in the Delaware Basin. Dramatic geologic events such as faults and volcanic activity have not occurred in the northern Delaware Basin where the WIPP site is located. The nearest events of this type are occurring west of the Guadalupe Mountains about 70 miles southwest of the WIPP site. The regional geology does not indicate that any dramatic changes in geologic processes or rates have recently occurred at the WIPP site.

SITE GEOLOGY (Chapter 4)

Much investigative effort has been expended to define subsurface geologic conditions at the WIPP site. These studies not only provide detailed information regarding mining conditions at the repository levels, but also furnish a basis for an assessment of the level of protection or safeguard against possible modes of containment failure at the site, in the context of the long-term isolation requirements of radioactive waste. Information for geologic investigations conducted by the U.S. Geological Survey and reported in several open-file reports by that agency, as well as details of salt deformation investigated by other consultants, have done much to define the general geologic conditions in the vicinity of the WIPP site and have been freely utilized in assembling Chapter 4 of the GCR. Detailed site-specific exploration techniques include seismic

reflection, resistivity, gravity and magnetic surveys, borehole exploration including coring, geophysical logging and hydrologic testing, and reconnaissance geologic mapping. From data thus obtained a series of structure contour and isopach maps were constructed which are presented and discussed in section 4.3 and 4.4 A continuously cored stratigraphic test hole, ERDA-9, has been drilled to a depth of 2,875 feet below ground surface near the center of the WIPP site and provides much detail on geologic properties at and above the WIPP repository levels.

The surface of the WIPP site is a slightly hummocky plain sloping gently southwest at about 50 feet per mile; elevations range at the site from about 3300 to 3600 feet above sea level. There are no permanent drainage courses in the site area. Any intermittent runoff drains west into Nash Draw, a broad swale of about 150 feet of relief leading southwest toward the Pecos River. A declivity marking the east edge of Nash Draw in the site area, known as Livingston Ridge, is located about 4 miles west of the center of the site. Nash Draw, now partly filled with Pleistocene sediments, has evolved both by surface erosion and by subsurface dissolution of salt, presumably during wetter intervals in the geologic past.

Recent windblown sand and partly stabilized sand dunes blanket most of the site area. A hard, resistant duricrust or caliche (Mescalero caliche) is typically present beneath the sand blanket and has developed upon the surface of the underlying Pleistocene fluvial (Gatuna) deposits. The fluvial deposits are tentatively assigned a Kansan age and the caliche formed upon them a Yarmouth (interglacial) age; that is, the caliche formed starting approximately 500,000 years ago. At some places, the caliche is fractured and drapes into Nash Draw along Livingston Ridge, indicating that some erosion and dissolution has taken place in Nash Draw since the caliche was formed, presumably during wetter climatic intervals associated with Illinoian and Wisconsin glaciations. Increased erosion from runoff, should the climate of the region become more humid in the future, would be expected to occur in the existing drainage courses, leaving the drainage patterns relatively unaltered.

The proposed WIPP underground storage facilities are to be placed near the middle of a 3,600-foot-thick sequence of relatively pure evaporite strata containing primarily rock salt and anhydrite, lying between depths of about 500 and 4,100 feet beneath ground surface. The formation richest in rock salt, the Salado Formation, is nearly 2,000 feet thick and contains the relatively pure salt layers in which the two proposed underground storage levels are to be constructed, at a depth near 2,120 feet for the upper level and near 2,670 feet for the lower. The storage horizons are well isolated from the hydrologic environment by adjacent evaporite strata. A thickness of at least 1,300 feet of undisturbed evaporite rock, primarily rock salt, overlies the upper storage horizon and about an equivalent thickness of anhydrite and rock salt intervenes between the lower storage horizon and the next adjacent underlying non-evaporite formation. The salt deposits of the Castile and Salado Formations at the WIPP site were formed about 225 million years ago and have remained isolated from dissolution since about that time.

The total thickness of the sedimentary pile resting on top of Precambrian basement beneath the WIPP site is about 18,000 feet of Ordovician to Recent strata. Following is a brief summary of the stratigraphy, proceeding from the surface down to the basement. Beneath a thin but persistent veneer of windblown sand at the site are sediments representing Pleistocene, Upper Triassic, and uppermost Permian strata, all of which occur above the evaporite sequence. Sandstone of the Pleistocene Gatuna Formation, capped by Mescalero caliche also developed in Pleistocene time, is only a few tens of feet thick at the site and is of interest primarily for the geochronologic and paleoclimatic implications of its presence. Between the Pleistocene deposits and the evaporite sequence is a 500-foot-thick succession of nonmarine redbeds of Late Triassic Age (Santa Rosa sandstone) and marine redbeds of latest Permian age (Dewey Lake Redbeds). This redbed sequence thins westward and thickens eastward, having been beveled westward by several post-Late Triassic erosional episodes; the thickness of redbed deposits remaining above the evaporite sequence is crudely proportional to the degree to which the underlying salt horizons have been protected from surficial processes leading to erosion and dissolution.

At the center of the site all but the uppermost 50 feet of the 18,000 feet of strata are of Paleozoic age, the marine Dewey Lake Redbeds being the topmost Paleozoic rocks. The Permian section alone, about 12,800 feet thick, constitutes over two-thirds of the sedimentary pile. The Permian section is divided into four series, the three lowest of which (Wolfcampian, Leonardian and Guadalupian) contain thick clastic sequences, and the uppermost of which (Ochoan) is represented by the Castile, Salado, Rustler, and Dewey Lake (in ascending order).

The Rustler, which lies over the Salado, contains the largest percentage of clastic material of the three evaporite formations, yet where its original thickness of around 450 feet has been protected from salt dissolution, about 70 percent of the formation is composed of evaporite minerals, more than half of which is halides. Beneath the Los Medanos site the Rustler has been leached of most of its rock salt, with the result that 310 feet of the formation was encountered at ERDA-9 at the center of the site. This implies that up to 140 feet of rock salt have been removed and that the overlying strata have subsided accordingly; it does not, however, imply that dissolution and subsidence is presently active or even that it has recently occurred. The uppermost occurrence of halite in the Rustler Formation was encountered at a depth of about 760 feet (about 100 feet above the base of the formation). Between this level and the upper level storage zone of the proposed WIPP facility over 1,300 feet of undisturbed evaporite rock, primarily Salado rock salt, intervene.

The 2,000-foot thickness of the salt-rich Salado Formation is divided into three members by the recognition of a middle member referred to as the McNutt potash zone, which is the interval within the Salado that contains all of the potential reserves of potash, or potassium minerals commercially mined in the Carlsbad district west of the site. The lowest member of the Salado, beneath the McNutt potash member, is the member that contains the nearly pure halite chosen for the proposed facility. The Castile Formation beneath the Salado contains highly pure beds of halite but, unlike the Salado, also contains much massive anhydrite.

The rest of the Permian section beneath the evaporite sequence, together with the subjacent Pennsylvanian and possibly Late Mississippian sections, contain dominantly clastic rocks that represent deposition during the time in which the Delaware Basin existed as a distinct structural entity. Much of these pre-evaporite, basinal sediments, which total about 11,000 feet in thickness beneath the site, have been targeted for petroleum exploration at one point or another in the Delaware Basin and contain nearly all of the region's known potential reserve of hydrocarbons.

The remainder of the Paleozoic section (Mississippian down through the Ordovician) consists of about 3,000 feet of mainly carbonate strata deposited in shallow-water or shelf conditions over a period of long-sustained crustal stability.

The underlying crystalline basement is believed to be a granitic terrane, formed about 1,300 million years ago. The only other igneous rocks that are known in the site area are known only in the subsurface and occur as lamprophyre (basaltic) dike rock intruded into evaporite beds along a single northeast dike trend that approaches no closer than about 9 miles northwest of the center of the proposed WIPP site.

With regard to subsurface geologic structure at the site, all of the Permian and older strata exhibit a gentle, regional homoclinal dip to the east or southeast, reflecting the presence of the Delaware Basin tectonic structure. No surface faulting is known. A general summary and assessment of structure in the site area was provided by C.L. Jones in an open-file report issued by the U.S. Geological Survey in 1973. Jones stated,

> "The structure of the Los Medanos area is basically simple and the rocks are, for the most part, only slightly deformed. Nevertheless, the rocks have been tilted, warped, eroded, and subroded, (ed. note: subjected to subsurface removal by dissolution), and discrete structural features can be recognized. These include: (1) structural features of regional extent related to Permian sedimentation, (2) intraformational folds of limited extent related

> to "down-the-dip" movement of salt under the influence of gravity and weight of overburden and (3) subsidence folds related to warping and settling of rocks to conform with the general shape and topography of the surface of salt in areas of subrosion...
>
> "On the basis of available geological information, the salt deposits of Los Medanos area seem in many ways to constitute a suitable receptacle for use in a pilot-plant repository for radioactive wastes. The deposits have thick seams of rock salt at moderate depths, they have a substantial cover of well-consolidated rocks, and they have escaped almost completely undamaged long periods of erosion. The deposits are only slightly structurally deformed, and they are located in an area that has had a long history of tectonic stability."

Information developed in the succeeding five years of investigations do not significantly alter that assessment relative to the structural and tectonic conditions present at the Los Medanos site. Based on exploration accomplished to date, a series of structure contour and isopach maps are presented for rocks ranging in age from Devonian to Pleistocene. This and other information indicate that active tectonic faulting and warping of rocks in the site vicinity seems to have predated Permian evaporite deposition; certain minor faulting within the thick Permian section appears to have occurred contemporaneously with sedimentation and may be ascribed to compaction. Deformation related to salt flowage has occurred primarily in the Castile Formation beneath the Salado, and has locally modified the regional easterly gradient to 80 to 100 feet per mile at the level of the storage horizons near the base of the Salado. Areas in the vicinity of the site in which artesian brine reservoirs have been encountered are associated with thickened salt sections and salt-flow anticlines in the Castile, but no such major structural features are recognizable within the limits of the WIPP storage facility on any of the Salado horizons contoured. The site appears to be in a slight structural saddle, a condition considered to be favorable for site selection. Dissolution of bedded salt at the site has been restricted to horizons within the Rustler Formation; there is no evidence that the resulting settlement produced any significant

structural irregularities or collapse features in the overlying strata within the area of the Los Medanos site. Investigations are continuing to further define the extent to which salt deformation in the Castile may have affected the structural configuration within the lower part of the Salado where excavation of the remote handling (RH) and contact handling (CH) levels is presently planned. These investigations will permit a more detailed assessment of the optimum layout, design and construction method of the storage facility.

The geologic history of the Los Medanos site may be organized into three main phases occurring subsequent to the original establishment of a granitic basement intrusive complex between about one billion and 1.4 billion years ago, forming the cratonic crust beneath the site. The first phase, of at least 500 million years duration, was a time of uplift and erosion of all pre-existing Precambrian sedimentary and metamorphic rocks which may have once been deposited or formed in the site area, eventually exposing the deep-seated igneous rocks.

The second phase, which corresponds to the Paleozoic Era, was characterized by an almost continuous marine submergence lasting about 225 million years, wherein shelf and shallow basin sediments slowly accumulated. It culminated in a comparatively rapid accumulation of over 13,000 feet of Permian sediment within a relatively brief period lasting 50 to 55 million years, toward the end of which time thick evaporite beds, mainly rock salt, were deposited. This rapid Permian deposition was presaged in Late Mississippian time by tectonic activity that differentially upwarped elements of the craton, such as the Central Basin Platform, thereby defining the Delaware Basin as a tectonic feature for the first time. During Pennsylvanian time, repeated marginal faulting caused periodic uplift of bordering platforms and some warping within the basin. By early Permian time, this tectonic activity apparently died out as basin subsidence and sedimentation accelerated. Eventually the Permian sea became shallow and briny, at first characterized by extensive reef development, but eventually in Ochoan time by a vast brine flat in

which thick evaporite deposits formed, burying the earlier reef masses. The final event of the long, nearly continuous accumulation of marine sediment of the second phase was deposition of a blanket of marine or brackish tidal flat redbeds over the evaporite strata.

Uplift and subaerial conditions next occurred at the site in the third and final phase, and persisted some 225 million years to the present, with the exception of a brief marine inundation in about the middle of that span of time. Periods of terrestrial deposition alternated with erosional episodes, so that a series of nonmarine deposits separated by angular unconformities blanket the evaporite beds at the site. These angular unconformities represent intervals during which the salt beds at the WIPP site were tilted and subjected to potential dissolution. At least four erosional episodes separated by depositional intervals are recognized: (1) Early Triassic time in which the Dewey Lake Redbeds were tilted and eroded to a slight angular unconformity before deposition of the Upper Triassic Dockum Group; (2) Jurassic-Early Cretaceous time in which the Dockum Group was tilted and eroded to a wedge before marine inundation in Washitan time (latest Early Cretaceous); (3) a Late Cretaceous through mid-Tertiary erosional interval when the region was again tilted and the Triassic Dockum Group of sediments was bevelled for a second time; and (4) a post-Ogallala (post-Pliocene) uplift and erosion in early Pleistocene time, prior to deposition of the (Kansan?) Gatuna Formation took place. Subsequent to deposition of the Gatuna, there probably were intervals corresponding to the later Illinoisian and Wisconsin glaciations during which accelerated erosion in these wetter times occurred in the area of the WIPP site.

Each period of tilting, which accompanied renewed erosion as outlined above, afforded an opportunity for salt flow by plastic deformation along the imposed gradient and salt deformation as the salt impinged against reef abutments or responded to uneven, differential sediment loading or erosional unloading; therefore there may have been several episodes of salt deformation of this type. To the extent that some "deep dissolution" features are recognized today in salt at depths of several

thousand feet below the surface, it seems likely that subsurface dissolution of salt could have been initiated at comparable depths beneath the surface as soon as Early Triassic time. It is reasonable to assume that episodes of active dissolution occurred during the Jurassic and Late Cretaceous-mid Tertiary erosional intervals, as well as during the several pluvial periods corresponding to Pleistocene glacial stages. Any attempt at reconstructing past history of salt dissolution in the Los Medanos area as an approach to predicting the future course of salt erosion must contend with the likelihood of the existence of times of greatly accelerated dissolution of salt in the geologic past interspersed with intervals of much lesser activity. The evidence available today indicates little if any change in erosion rates at the WIPP site in the recent geologic past. Detailed mapping studies are underway which will contribute to information on dissolution rates at various times in the geologic history of the site.

The discussion of the site geology defines the present conditions of the site which must be known to establish the WIPP. These conditions relate mostly to physical characteristics such as thickness, depth, extent, purity, and structure of the evaporites (as well as some of the surrounding beds). In addition, baseline conditions regarding the processes of dissolution and erosion as they affect the immediate site have been determined. Thus the baseline geological conditions at the site are presented so that judgement of the site relative to the present criteria may be undertaken and so that continuing studies will focus on geologic processes important to assessment of repository safety.

The site geomorphology indicates tectonic stability at the site for the last 500,000 years or more. The local stratigraphy is continuous with the regional stratigraphy. Local minor structures exist within the evaporite beds, but no severe displacements or brine or gas have been encountered. Potential repository zones at depths of 2730-2620 feet and 2176-2074 feet have been chosen on the combined basis of purity, depth, thickness, mutual separation, and depth below the potash zone.

SEISMOLOGY (Chapter 5)

Regional seismicity of the Los Medanos site is discussed in two separate time intervals suggested by the type and quality of information available for each interval. These intervals are before 1962 (non-instrumental) and from 1962 to the present (instrumental).

Before 1962 almost all data on earthquakes within 300 kilometers of the site are based on collection, cataloging, and consideration of non-instrumental reports. These data indicate that twenty earthquakes with maximum reported intensities between III and VIII on the Modified Mercalli Scale have occurred within a 300 kilometer radius of the site region from 1923 to 1960. There have been no earthquakes of epicentral intensity V or greater within about 200 kilometers of the site in this period. The closest reported shocks are two intensity IV events at Carlsbad in 1923 and 1949. The strongest reported earthquake to occur within 300 kilometers is the intensity VIII Valentine, Texas event of lugust 16, 1931 at a distance of approximately 210 kilometers.

Between 1962 and 1972 inclusive, a general instrumental survey of the site region shows 38 earthquakes with magnitudes ranging from 1.2 to 4.6 (Richter scale). The seismicity pattern of these instrumentally located events is very similar to pre-instrumental data except that a number of earthquakes occur on the Central Basin Platform in the later data set. The closest reported shock between 1962 and 1972 was a magnitude 2.8 event on July 26, 1972 about 40 kilometers northwest of the site. The largest event in this period is the magnitude 4.6 earthquake almost 300 kilometers to the southwest.

Three investigations of a more local and temporally restricted nature have impact on the Los Medanos site. These involve earthquakes recorded at a seismographic station installed near the site itself, events recorded at an array of seismographic stations installed on the Central Basin Platform near Kermit, Texas, and three earthquakes recorded regionally and found to have occurred near the site.

At the beginning of April, 1974 a vertical, single-component, continuously recording seismograph station (with letter designation CLN) was installed very near the site. During the latest available reporting period, April, 1974 to October, 1977, 291 events identifiable as local and regional earthquakes have been recorded and locations for 75 of the 291 events have been obtained. The seismicity pattern suggested is very similar to that of the general 1962-1972 instrumental survey. Approximately one-half of all located events in the CLN data set occur on the Central Basin Platform while most of the rest occur to the west and southwest of the site in the Rio Grande Rift Zone. There is also a scattering of earthquakes in the High Plains physiographic province of the site. Included is a magnitude 3.6 event on November 28, 1974 at about 40 kilometers to the northwest, which was close to the July 26, 1972 earthquake mentioned above.

Instrumental studies show earthquake activity in the Central Basin Platform at a higher level than expected. Primarily for this reason, the Kermit, Texas seismographic station array was established in late 1975 to more closely monitor this activity. During the latest available reporting period for this array (November, 1975 to July, 1977), 407 local events have been detected and 135 located with array data. Of the located events 56 were in the interior of the array while the rest have been peripheral to it. Earthquakes with magnitudes calculated both using Kermit array data and regional seismographic station and CLN data show that Kermit magnitudes are almost one unit higher. This inconsistency remains unresolved at this time.

As a result of general survey and specialized seismic instrumental studies in the Los Medanos site region there is little doubt that the Central Basin Platform has been seismically active since at least mid-1964, and that during this time it has been the most active seismic area within 300 kilometers of the site in terms of number of events. The basic conclusion from all instrumental data is that seismic activity is equally likely to occur anywhere along the Central Basin Platform structure without particular regard to small scale structural details

such as pre-Permian buried faults. Attempts have been made to relate this seismicity to secondary oil recovery operations in the area. Although both spatial and temporal coincidences of Central Basin Platform seismicity with secondary recovery projects are highly suggestive of a close relationship, this has not been satisfactorily established at this time.

Questions of the tectonism and seismic activity very near or at the site are of great interest. For this reason the most important seismic events instrumentally recorded are those closest to the site: July 26, 1972, and November 28, 1974, magnitudes 2.8 and 3.6, respectively; and a later shock on January 28, 1978, with only preliminary data yet available. If these events are an indication of normal background seismicity in the immediate site area, they might cause a re-evaluation of previous estimates of seismic risk at the Los Medanos site (Sanford and Toppozada, 1974). At the time of the first two events rockfalls and surface ground cracking were reported at the National Potash Company Eddy Co. Mine. To see if mine collapse at this mine was responsible for both events, an analysis was run to see if both epicenters could be made coincident with each other. Such a coincidence would be a strong indication of a rock fall origin for both events. At this time the best available analysis indicates that these small events did not both occur at the Eddy Co. Mine and thus they cannot both have been caused by a very localized non-tectonic source there. The third shock is located, in a very preliminary fashion, north of the station an estimated 17 km.

Using all the information developed above on regional seismicity and some additional simple assumptions about regional tectonism a preliminary analysis of risk from vibratory ground motion at the surface is derived in a way useful to seismic design characterization at the site during its active phase of development and use. The results of this analysis are that the 1000 year acceleration is less than or equal to 0.06 g and the 10,000-year acceleration is less than or equal to 0.1 g for all models tried. Probabilities at which higher acceleration levels occur depend almost exclusively on the assumptions made about the seismic potential of the immediate site area.

In addition to its use to determine risk as a function of vibratory ground motion level, regional seismicity is also considered as an indicator of longer-term tectonic processes. Natural regional seismicity should be consistent with the geologic indicators of tectonic processes unless the tectonic setting is changing. Regional stress patterns, as implied by focal mechanism solutions for regional earthquakes and in site measurements, and regional tectonism, as implied by earthquake recurrence statistics, are both considered. Although other explanations cannot be precluded, it seems that the most reasonable interpretation of the seismic implications to tectonism at this time are: (1) Observed geologic and seismic data are in general agreement in the Rio Grande rift zone to the west and southwest of the site where the largest historic earthquakes within 300 kilometers of the site have occurred. Future significant earthquakes can be expected there. (2) The current level of seismic activity on the Central Basin Platform is probably related to fluid injection for secondary recovery of oil. (3) The lack of geologic indications of natural recent tectonic activity for the High Plains province of the site can probably be reconciled with the seismic data by assuming a maximum magnitude limit of the earthquakes that have occurred here.

The importance of seismicity information over the immediate future is to provide a data base for design of facilities for the operational time of the WIPP. Seismicity information also serves as an indicator of the tectonic situation in assessing the WIPP site for a repository.

HYDROLOGY (Chapter 6)

Chapter 6 contains an assessment of surface and groundwater resources in and surrounding the proposed WIPP site and a status report of current hydrogeologic investigations in the local site area. The water resource assessment incorporates the published results of regional and local hydrologic studies supported by universities and state and federal agencies since the late 1930's. Present studies of the proposed site and

adjacent area are directed toward a more quantitative evaluation of the salt dissolution process, the hydrogeologic parameters affecting groundwater movement, and the major elements of surface and groundwater quality as related to water resource use and local ecology. The collection of hydrologic data is projected to continue for several years to provide site-specific information for a detailed safety analysis of the WIPP. Because of the relationship to hydrologic processes, dissolution activity is also summarized within this chapter.

The only major stream near the site is the Pecos River which flows southeasterly through Carlsbad. At its closest point, the river is approximately 14 miles southwest of the WIPP site. Several reservoirs, located on the Pecos upstream of the site, regulate river flow. The maximum recorded flood on the Pecos River occurred on August 23, 1966, with a discharge of 120,000 cfs and a maximum water surface elevation near Malaga of approximately 2938 feet. The minimum surface elevation of the site is more than 310 feet above this historic flood level.

Climatological records show that mean annual precipitation at the site is approximately 12 inches per year. The maximum daily precipitation recorded at Carlsbad was 5.12 inches in August 1916, and the maximum daily snowfall was 10 inches in December 1923. Winter storms in the area occur as a result of fronts moving from the west while summer storms, generally the most severe, occur as thunderstorms from moist air moving northwest from the Gulf of Mexico.

Surface drainage patterns at the site are undeveloped. Infiltration rates are high because of the sandy, gravelly soils that cover the region. However, the nearest groundwater is more than 50 feet below the land surface. Aided by the low relative humidity (typically 36% during daylight hours) and high mean annual temperature (61°F), most infiltration escapes the soil through evaporation and transpiration.

Important aquifers of the region include the San Andres Formation, a major source for irrigation waters in the Roswell Basin and other areas

to the north and northwest of the site region. Potable water is present in the Capitan aquifer southwest of the community of Carlsbad and is the primary source of municipal water in the local area. Other important aquifers of the region include the Ogallala Formation to the east of the proposed site, and unconsolidated alluvium along the Pecos River.

Groundwater within the Delaware Basin is predominantly of poor quality with total dissolved solids concentrations typically in excess of 3,000 ppm. The only large quantities of potable groundwater are found in aquifers west of and along the Pecos River. To the west, the formations of the basin crop out, and the soluble salts have been leached from the Ochoan evaporites. From recharge areas west of the Pecos River, groundwater in the Delaware Basin moves eastward. From the site area, water in hydrologic units above the salt moves generally southwest to the Pecos. These shallow units, or those cut by the Pecos River, discharge to the river, either directly or to alluvium of the river channel. Although a local hydraulic connection between the river and the Capitan aquifer may occur near Carlsbad, groundwater flow in the reef formation is severely restricted near the Eddy-Lea county line. Groundwater in formations older than the Capitan is not directly affected by the river, is present under confined conditions, and flows eastward. The aquifer of most significance to the proposed site in these older formations is the Bell Canyon Formation.

Water-bearing strata in the local site area at elevations above the proposed repository include the Santa Rosa Sandstone and the Culebra and Magenta members of the Rustler Formation. Hydrologic units below the repository elevation include the Bell Canyon Formation of the Delaware Mountain Group. Hydrologic test results to date show the average head elevations of the potentiometric surfaces from these aquifers are 3200 feet for the Santa Rosa Sandstone, 3150 feet for the composite Rustler Formation, and 3350 feet for the Delaware Mountain Group (equivalent "fresh-water" elevation). The thick halite beds of the Salado Formation are isolated from circulating groundwaters by confining layers of low hydraulic conductivity, directly above and below the salt formation.

In the vicinity of the proposed site, potable groundwater is not present, except in small, isolated, near-surface perched pockets. Thus, it would appear that the proposed repository is favorably situated in relation to groundwater circulation and occurrence. Detailed investigations of groundwater hydrology at the proposed site have been conducted and are continuing. The data will provide a basis for more quantitative determinations regarding the continued isolation of the proposed repository from groundwater circulation.

A shallow salt dissolution zone occurs in Nash Draw at the contact between the Salado and Rustler Formations. The dissolution area ranges in width from 2 to 10 miles and has a length of approximately 30 miles. The brine solution flows southwesterly and discharges into the Pecos River at Malaga Bend. The average rate of vertical dissolution has been estimated to be between 0.33 and 0.5 feet per 1,000 years, and the average rate for lateral dissolution has been estimated to be between 6 and 8 miles per million years. Dissolution of salt at the top of the Salado occurs about 2 miles west of the center of the site. Eastward across the site salt is present in the Rustler at progressively higher levels, indicating that the salt has not been dissolved out of the Rustler and that the Salado has not been attacked by dissolution.

Future measurements obtained from the hydrologic test programs and analyses of the test data will be used to refine bounding calculations, such as estimates of groundwater travel times, and to provide a more detailed description of the physical system and system dynamics. The use of computer models as predictive tools is expected to be closely coordinated with timely observations from an established monitoring network. The predictive results and the real time measurements will aid in the continued assessment of repository isolation from dissolution and groundwater circulation. The retardation of radioisotopes within the hydrologic system (Chapter 9.3), when coupled with the hydrologic model,

will allow realistic calculations of radioisotope transport for postulated failure scenarios.

GEOCHEMISTRY (Chapter 7)

Chapter 7 of this WIPP Geological Characterization Report discusses geochemical properties of geologic materials from Southeastern New Mexico. Geochemistry includes accounts of mineralogy and petrology of evaporites and the associated non-evaporites, volatile constituents of the Salado Formation, fluid inclusions in evaporite minerals, ground water chemistry, and age-dating of evaporites and ground waters.

Megascopic, microscopic and x-ray diffraction examination of the Permian (Ochoan) evaporite section showed the three most common minerals of the Salado Formation to be halite, anhydrite and polyhalite. In addition, there are the potassic and magnesic minerals sylvite, kainite, kieserite, langbeinite, loeweite and bloedite in the McNutt Potash Zone of the Salado Formation. Marker beds throughout the Salado Formation (mostly anhydrite and polyhalite) occur at intervals of a few tens of meters, are on the order of 10 to 100 cm thick, and are laterally traceable in core holes adjacent to the center of this investigation. The McNutt Potash Zone varies laterally in mineralogy, and contains "clay partings" typically at the top of each individual ore zone. Silicate minerals in the Salado Formation are quartz, illite, feldspar, chlorite, talc, serpentine, and several varieties of expandable clay, including saponite, illite-saponite and chlorite-saponite. In rock salt, the contribution of silicates is 0.004 to 2.5 weight percent in the lower part of the Salado (>2400 ft. depth in ERDA No. 9), 0.009 to 5 weight percent in the middle Salado (2000 - 2400 ft. depth), and 0.003 to 21% in the McNutt Potash Zone (above 1,650 ft. depth).

Petrographic textures reveal that significant portions of the evaporites have preserved their original depositional textures, indicating no

post-depositional recrystallization or other sorts of alteration. Other portions have undergone extensive recrystallization to non-primary evaporite minerals such as sylvite and polyhalite, which do not precipitate from sea water in normal evaporation. Textures of bedded anhydrite in the Castile Formation below the Salado Formation show a finely laminated arrangement of evaporite and detrital materials in alternating laminae, implying an original depositional form. Petrographic relationships of minerals in the McNutt Potash Zone show that at no time were these minerals in equilibrium with a solution only of sodium chloride, also precluding the possibility of large incursions of surface-derived water in the geologic past.

Amounts and compositions of volatile constituents in the evaporite minerals were determined by heating rock samples to 600°C, recording mass loss, and in some cases analyzing the effluent in a gas chromatograph/mass spectrometer. Except for samples rich in hydrous minerals (polyhalites, clay partings, potash zones), the vast majority of rock salt contains less than 0.5 weight percent total volatiles.

The most abundant volatile constituent in that 0.5% or less is water. Next most abundant is nitrogen, followed by CO_2. Traces of hydrocarbons and fluorides from drilling operations were detected as contaminants in the core.

In addition to fluid inclusions in halite, (see below), the minerals thought to be sources of volatiles in the Salado Formation include clays and polyhalite, and traces of gypsum, magnesite, carnallite, celestite, glauconite, and kainite. The typical volatile content in Salado salt is 3 to 30 times less than that in the Hutchinson (Kansas) rock salt. An additional contributor to the less than 0.5 total weight percent may be traces of hydrated iron oxides, which account for the red-orange to red-violet colors in some accumulations of polyhalite, sylvite, carnallite and halite in the evaporite section.

Fluid inclusions have been studied in core samples from nineteen horizons above and below the levels of the proposed repository in Salado salt beds. The techniques used include mainly petrography, freezing stage, heating stage, crushing stage and decrepitation tests. The purpose was to determine those inclusion parameters that might be pertinent to an understanding of the origin and geological history of these salt beds.

Four general types of inclusions were found in these samples: type A - extremely abundant but minute primary liquid inclusions, with or without a tiny vacuum bubble, outlining primary growth features; type B - much larger liquid inclusions, trapped during several stages of recrystallization of the primary salt, some with a small vacuum bubble and/or unidentified daughter crystals; type C - scarce large liquid inclusions with large and variable gas bubbles under pressure, presumably from fracturing and refilling of type B inclusions; and type D - empty (i.e., gas) inclusions, found principally along grain boundaries, that have leaked and hence have lost their liquid contents.

The total weight percent of liquid as fluid inclusions in these 19 samples, as measured, ranged from 0.1 to 1.7%, mostly as type B inclusions; the amount of liquid in these same samples <u>in situ</u> was larger, since many of the largest inclusions, that are the major contributors to the total percentage, and the intergranular fluids, have been drained during the boring and sample preparation. The temperatures at which these inclusions were trapped were generally in the range of 25-45°C. The brines in them are never simple saturated NaCl solutions, or even NaCl-KCl solutions; freezing temperatures indicate that they must contain considerable amounts of other ions such as Mg and Ca.

When the host crystal is uniaxially stressed, the geometries of the inclusion walls show visible changes within several minutes, possibly due to solution and redeposition, as well as deformation. Internal fracturing of the inclusion walls, but generally without leakage, occurs on freezing.

The distribution of primary type A inclusions provides evidence that they have not moved visibly (i.e., less than a few micrometers at most) in that fraction of the 225 million years between original deposition and the present that these samples have been in the small but finite normal-geothermal gradient.

Subsurface samples of water from various rock types in the Delaware Basin of Southeastern New Mexico and West Texas have been analyzed for their solute contents and $^{18}O/^{16}O$ and D/H ratios. Saturated brines (total dissolved solids greater than 300,000 mg/l) were found in one well in the Bell Canyon Formation, two wells in the Castile and in potash mine seeps in the Salado. According to Cl/Br ratios (between 430 and 900), all the waters have derived their dominant solute (NaCl) from nearby rocks. Potash mine seeps and saline Capitan waters contain solutes corresponding to common primary evaporite mineral assemblages, (halite-anhydrite-kainite-carnallite-bischofite) indicative of simple uptake of dissolved solids. Bell Canyon and Morrow brines contain less magnesium but more calcium than primary evaporite assemblages, and have participated in ion exchange reactions. Stable isotope measurements indicate that Santa Rosa, Rustler and Capitan waters are meteoric, while Salado, Bell Canyon, Morrow and one of the Castile waters (ERDA No. 6) have undergone episodes of low-temperature isotopic exchange with oxygen- and hydrogen-bearing minerals. Isotopically the Carlsbad Caverns hydrologic system is unique to the Guadalupe Mountains, unrelated to the Delaware Basin as a whole.

The ERDA No. 6 occurrence of saturated $NaCl-Na_2SO_4$ brine and H_2S-rich gas (55% CO_2, 28% H_2S, 15% CH_4, 1.5% N_2 and 0.5% C_2H_6 by weight) in the Castile represents a biogenically-produced sulfide-sulfate disequilibrium. The brine's Na_2SO_4 content may have arisen by rock/fluid ion exchange involving a replacement of magnesium by sodium in the solution. None of the saline groundwaters were found to be original evaporite mother-liquors or products of partial evaporation.

Rb-Sr geochronologic study of the bedded salt deposits from the Salado Formation has been undertaken to age date the last episode of evaporite

crystallization or recrystallization, and to test their feasibility for alkali and alkaline earth retention.

Whole rock samples (i.e., water soluble plus insoluble material) are typically unsuited for Rb-Sr isochron work due to the low Rb/Sr ratio; however, several of these samples do indicate the R_o (i.e., $^{87}Sr/^{86}Sr$ at T=0) value to be about 0.708, thus indicating that large amounts of brine, typically enriched in ^{87}Sr, have not been generated in the sample area since evaporite formation some 235 $\pm$ 10 m.y. ago.

The water soluble fraction of evaporite samples yields an apparent isochron date of 206 m.y. with R_o = 0.7084 while clay minerals (less than two micron size) yield 325 m.y. with R_o = 0.7123. A composite of the water soluble fractions and clay minerals yields a date of 204 m.y. with R_o = 0.7137. This 204 m.y. date is interpreted as a minimum date due to the high R_o value; but it does suffice to indicate that the evaporite-clay mineral assemblages apparently have remained closed to widespread alkali-alkaline earth migration since about the time the evaporites were formed.

Regional exploration of bedded salt for a radioactive waste repository in the Delaware Basin included boreholes into the evaporites and associated rocks. One such hole, ERDA No. 6, encountered an accumulation of saturated $NaCl-Na_2SO_4$ brine accompanied by H_2S-rich gas. This fluid and fluids from other boreholes elsewhere in the area have been characterized geochemically according to solute content, $^{18}O/^{16}O$ and D/H ratios and natural actinide content. Deviations from the equilibrium $^{234}U/^{238}U$ activity ratio (α) of 1.0 were found in all water samples. These deviations are used to affirm the isolation of ERDA No. 6 and to establish bounds on the age of the ERDA No. 6 fluid.

A mathematical model for the age of ERDA No. 6 water intrusion was formulated in terms of the following variables: initial α -value (α_0) of the brine precursor waters, zero order kinetic rate constants of leaching of ^{234}Th and ^{238}U from the rocks, and degree of leaching of

^{234}Th from the rocks. The model allows calculation of α-values of brines as a function of time, leach rate and α_0. Various combinations of α_0's, leach fractions and leach rates indicate that the leach rate must be low. If no leaching is assumed and the α_0 is the highest known α from the nearby Capitan Reef (α_0 = 5.2 at present), the fluid is older than 880,000 years. ERDA No. 6 brine has undergone more profound rock/fluid interactions, reflected in its solutes and stable isotopes, compared with younger meteoric Capitan waters.

The geochemistry of the proposed WIPP site shows that the mineralogy of most of the rock salt is relatively simple. The evaporites have been recrystallized, resulting in some mineral assemblages different from those precipitated from original sea-water-like solutions at one time present in the Delaware Basin. The last episode of such recrystallization took place more than 204 million years ago. The recrystallization resulted in evaporite mineral assemblages which apparently have reached thermodynamic equilibrium. The nature, distribution, geochronology and composition of fluid inclusions, clay minerals, and isolated accumulations of aqueous solutions in the evaporites show no evidence of movement of surface-derived water through the WIPP evaporites (at depths greater than 1000 feet) since their deposition in the Permian Period.

RESOURCES (Chapter 8)

Potash salts and natural gas are the two resources of economic significance under the WIPP site. Other minerals present are halite (salt), gypsum, and caliche, but deposits of similar (if not better) quality exist in the surrounding areas. Other economic minerals and elements, including lithium, uranium, sulfur and metalliferous deposits, could exist in a geologic setting like that of the WIPP, but none appears to be present.

Potassium salts occur in a variety of mineral types, but only sylvite (KCl) and langbeinite ($K_2Mg_2(SO_4)_3$) are mined in the Carlsbad

Potash Mining District, which is the largest domestic source of potash, accounting for approximately 80% of U.S. production. The U.S. is a net importer of potassic fertilizers. The U.S. Bureau of Mines has judged that a langbeinite deposit located in the northeast quadrant of the WIPP site could be profitably mined using today's technology at the current market price for the refined product. The deposit extends beyond the bounds of the WIPP site, but about 49 million tons of langbeinite averaging on the order of 9% K_2O, lie inside the WIPP withdrawal area. Several deposits of sylvite are present, but none meet today's economic conditions; to meet them would require the market price for refined sylvite to increase from $43 to $52 or more per ton.

Natural gas accompanied with some distillate and oil with associated gas are being produced from various beds in the Delaware Basin. One particular formation, the Morrow of Pennsylvanian age, is a consistent producer in this region, and the exploration risk ("wildcatting") is justifiable in much of the western half of the site. About 37 billion cubic feet of natural gas accompanied by about 0.5 million barrels of distillate are estimated to be economically recoverable from beneath the WIPP site.

The studies also included estimation of total resources under the site, not just the resources that could be considered economic today. The U.S. Geological Survey estimates that there are 353.3 million tons of sylvite and langbeinite mineralization under the WIPP site of sufficient quality to require competitive bidding for mineral rights. The WIPP site accounts for about 7% of the potash resources that the USGS believes to be present in the Carlsbad area. Langbeinite is probably the most significant mineral resource under the WIPP site. It is a specialized agricultural fertilizer that finds its use on crops that need potassium but cannot tolerate additional chlorine. Langbeinite adds potassium but is a sulfate. Southeast New Mexico is the only economic source for this particular mineral in the free world. Langbeinite equivalent is produced from potassium and magnesium sulfates from brine lakes. A report is in preparation for DOE which will estimate the fraction of the Carlsbad district's langbeinite resources within the WIPP site.

The New Mexico Bureau of Mines and Mineral Resources studied a large area surrounding the site area, and in its judgement the total hydrocarbon resource in that area is 37.5 million barrels of crude oil, 490 billion cubic feet of natural gas, and 7.33 million barrels of distillate. While these are large quantities, they represent only about 1% of the hydrocarbon resources for southeast New Mexico.

SPECIAL STUDIES OF REPOSITORY ROCKS (Chapter 9)

Special studies are being conducted to address issues of particular interest because the site is being evaluated for the isolation of radioactive wastes. Rocks from the WIPP site were tested in four broad areas: (1) petrography (2) physical properties (density, moisture content, resistivity), (3) thermo-mechanical properties (quasi-static and creep parameters), and 4) radionuclide sorption. Because of a scarcity of core, only those tests deemed necessary for early design were conducted. Testing at specified temperature and creep rates is continuing.

Physical properties representative of rock salt found in the WIPP horizons are summarized in the following table:

Property	Average Value* (Range)
Density	2.18 grams/cm^3
Porosity	0.5 percent (0.1-0.8)
Moisture Loss to 300°C	0.4 weight per cent (0-1.0)
Resistivity	58,100 ohm-meters (4,900-230,000)
Gas Permeability	$< 0.05 \times 10^{-6}$ darcy
Compressional Wave Velocity	4.5 km/sec (4.42-4.62)
Thermal Conductivity	5.75 w/m°K

*Except for moisture loss, values are given at 25°C

Rock salt properties are both time and temperature dependent; as a result, mechanical properties must be generated at a specific loading rate and temperature. Parameters defining the mechanical behavior at different load conditions must be inferred with considerable caution and with proper regard for the time dependent nature of the material. Quasi-static experiments were carried out at particular loading rates, e.g. 30 psi/min.

Quasi-static Properties of WIPP Rock Salt at 23 ^{o}C

Unconfined Strength	2,450 to 3,700 psi
Secant Modulus	2×10^6 psi
Principal Strain Ratio	0.25-0.35
Strain at failure:	
confining pressure	strain at failure
0 psi	2.5-6.0%
500 psi	17-20%
3,000 psi	> 20%
Tensile Strength	220 psi
Initial Yield Stress	$(\sigma_1 - \sigma_3) \approx 100$ psi

Preliminary Creep Properties

Steady State Creep Rate ($\dot{\varepsilon}$)

At 23°C:	$(\sigma_1 - \sigma_3)$=1000psi	$\dot{\varepsilon} = 10^{-10}$ sec^{-1}
At 130°C:	$(\sigma_1 - \sigma_3)$=2000psi	$\dot{\varepsilon} = 10^{-7}$ sec^{-1}

Results analyzed to date indicate that WIPP salt may undergo both transient and steady-state creep. However the latter is a tentative observation as occurrence of steady-state creep is uncommon. Indeed, if steady state creep occurs under loading conditions expected in the WIPP,

design calculations should consider creep in detail. This most likely will be of concern if elevated temperatures are involved. Although present considerations of steady-state creep are incomplete, it appears that steady-state creep rates range from 10^{-10} to 10^{-7} /sec. The transient creep results indicate that pressure, principal stress difference and temperatures are strongly coupled. Furthermore, of these three, temperature appears to have the most dramatic effect on the creep rate.

Data from the petrographic and physical properties studies show the WIPP horizon rock salt has low moisture content (less than 0.5%), is essentially impermeable (less than 5×10^{-8} darcy) and has a high thermal conductivity (about 5.75 watts/m^{o}K). These properties, along with the studies of fabric and fracture, indicate that this rock salt is ideally suited from a physical standpoint for the storage of heat producing radioactive wastes.

It has been shown that rock salt can experience large creep strains (greater than 25%) prior to loss of load bearing capacity. Gradual creep is an acceptable feature in the design of underground openings in rock salt as it allows the structure to close without a reduction in bearing strength. As long as allowances for creep are incorporated into design and the shape of the opening does not create large shear stresses, the WIPP rock salt can be expected to sustain stable openings.

A survey of the potential of geological media from the vicinity of the WIPP site in southeastern New Mexico for retardation of radionuclide migration in an aqueous carrier was conducted. The survey included the measurement of sorption coefficients (Kd) for twelve radionuclides between three natural water simulants and ten samples from various geological strata.

The nuclides included ^{137}Cs, ^{85}Sr, ^{131}I, ^{99}Tc, ^{125}Sb, ^{144}Ce, ^{152}Eu, ^{153}Gd, ^{106}Ru, ^{243}Am, ^{244}Cm, and ^{238}Pu. The compositions of the simulant solutions were those expected of water in contact with halite

deposits in the area and in a typical groundwater found in the Delaware Basin. The geological samples were obtained from potential aquifers above and below the proposed repository horizons and from bedded salt deposits in the repository horizons.

In brine solutions, Tc and I were not significantly adsorbed by any of the minerals and Cs and Sr showed minimal adsorption (Kd's < 1). The lanthanide and actinide Kd's were typically > 10^3 and Ru and Sb Kd's varied in the range of 25 to > 10^3. In the groundwater simulant, Tc and I showed the same behavior, but the Kd's of the other nuclides were generally higher.

Some initial parametric studies involving pH, trace organic constituents in the simulant solutions, and radionuclide concentrations were carried out. Differences in the observed Kd's can result from varying one or more of these solution parameters.

The WIPP site rocks, including rock salt, show an affinity for radionuclide sorption ($K_d > 0$). Even small values of K_d ($0<K_d<1$) are effective in retarding the movement of radionuclides in groundwaters.

It is not anticipated that results of these special studies will be pivotal in site selection; rather, they are being performed to provide additional confidence in geologic isolation in bedded salt.

CONTINUING STUDIES (Chapter 10)

Although much detailed information has been reported here as a result of site selection and characterization, there remain a number of programs which have not come to completion, or in some cases, have not begun. These pending programs are aimed at refining and supplementing information gathered to increase the confidence to be placed in factors relating to site selection. Furthermore, some kinds of information remain to be gathered to support laboratory and in-situ experiments and long-term safety assessment.

In regional geology, paleoclimatic studies based on detailed geologic mapping, geomorphology studies, microfossils, and age-dating are planned to provide a history of past climatic changes and to help assess the possible effects of future changes. Tectonic studies, involving examination of LANDSAT photos and accompanying field evaluation, first-order levelling surveys, and seismic monitoring of structural features adjacent to the Delaware Basin will continue to provide an account of the dynamic forces which might affect the Basin.

Continuing studies in site geology are aimed at expanding the details of site characterization for the purpose of refining site-specific safety assessment modeling scenarios for the repository. Geologic mapping is being undertaken to establish the local geomorphologic stability. High resolution aeromagnetic surveys will be implemented to provide greater confidence that possible geologic anomalies such as breccia pipes and igneous dikes have been identified and may be examined and sampled in detail.

Seismological studies will continue to document and evaluate the seismicity of the region due to various sources (mining, secondary hydrocarbon recovery, tectonic activity). The data will assure the appropriate seismic risk has been assumed in facility design and will further the safety assessment in general.

Hydrological studies will continue to expand the area around the site for which the groundwater behavior is characterized. In addition to hydrologic monitoring points near site center and periphery, a system of points will be established in nearby Nash Draw to evaluate the relationships among groundwater movement, evaporite dissolution and resulting subsidence. Also, investigations of "breccia pipes" will be undertaken to improve our understanding of why, how and when these features developed. The hydrologic monitoring system will provide the basis for development of a regional groundwater model to be used in safety assessment, and will be evaluated as a monitoring tool for repository-induced changes in the groundwater system.

Continuing studies in geochemistry are designed to support other investigations (such as the examination of dissolution products), provide detailed characterization of geologic materials to be used in in-situ and laboratory experimental programs (such as waste-rock interactions) and to contribute towards our understanding of the nature of Ochoan evaporites in general. These studies include mineralogy, petrology, volatile and fluid inclusion analyses, major, minor and trace element analyses in rocks and fluids, age-dating, stable isotopes, and examination of dike-evaporite interactions as a partial analogue of waste-evaporite interactions.

There are no continuing studies of resources planned at the WIPP site.

Continuing special studies of rock properties include long-term creep analyses in various temperature regimes, micromechanics of rock deformation, migration of volatiles, and mechanistic studies of radionuclide sorption on rocks. Some of these special studies are designed to provide an understanding about differences in mineralogy, grain size, volatile content and rock fabric which are to be found at different in-situ test horizons. The physical properties of the various horizons will be examined with these variations in mind. Non-salt horizons, which may be significant in the development of refined models for calculation of repository effects, will also be tested.

Continuing studies of radionuclide sorption include measurements of dynamic sorption from fluids flowing through columns of WIPP rocks in laboratory environments. In addition, parametric studies will continue to determine changes in sorption which accompany changes in mineralogy, pH, oxidation state, radionuclide concentration, and concentrations of organic contaminants. The rates at which sorption takes place and the differences between the processes of sorption and desorption will be investigated.

GCR CHAPTER 2

INTRODUCTION

The purpose of this chapter is to provide introductory information concerning the function of the WIPP and to discuss the site selection criteria and factors affecting the criteria; the criteria and factors are specific to the WIPP and to the Delaware Basin of southeastern New Mexico. In addition, some of the site exploration techniques are briefly mentioned here as background to further discussion of geological characterization.

2.1 THE PURPOSE OF WIPP

The purpose of the WIPP should be understood clearly as it is distinct from that of several other projects for the disposal of radioactive waste. The WIPP will demonstrate disposal technology for the transuranic (TRU) waste resulting from this nation's defense programs of over 30 years. After a period (5-10 years) of limited (pilot) operation it is anticipated that the WIPP will be converted to a full-scale repository for permanent disposal of defense TRU waste. Secondly, the WIPP is to provide a research facility to examine, on a large scale, the interactions between bedded salt and high-level radioactive waste. These interactions will involve physical and chemical phenomena resulting from thermal and radiation fluxes. A DOE Task Force (DOE/ER-0004/D, 1978) has recommended that WIPP also be used to demonstrate surface and subsurface methods of handling, storing and disposing of up to 1,000 canisters of spent reactor fuel; however, a decision on this recommendation has not been made at this time.

If the site is accepted by the DOE, the schedule calls for the initiation of facility construction in 1981; completion is to be about 1985, and the first waste to be accepted in 1986. The conceptual design of facilities is complete. The Draft Environmental Impact Statement and this Geological Characterization Report for DOE are presently scheduled for completion in late 1978. DOE has expressed an intent to request

licensing of the WIPP by the Nuclear Regulatory Commission (NRC), but this policy is presently under discussion between the DOE and Congress.

2.2 PURPOSE OF GEOLOGICAL CHARACTERIZATION REPORT (GCR)

The purpose of the GCR is to provide an account of the known geotechnical information considered relevant to site selection (see Section 2.3) for the proposed WIPP site. The GCR presents background information as well as information regarding factors related to selection criteria; for the most part, specific judgements regarding the suitability of the site are not made. Those judgements and recommendations are the function of other processes and documents. The GCR is neither a Preliminary Safety Analysis Report nor an Environmental Impact Statement; these documents, when prepared, should be consulted for appropriate discussion of safety analysis and environmental impact. The GCR is intended as a source document on the geology of the WIPP site for individuals, groups, or agencies seeking basic information. Therefore, rather extensive reference lists of reports and documents are provided at the end of chapters for the reader who may desire extended detail concerning particular geotechnical subjects discussed in this report. The GCR is not intended to present primary source material, and the instances of reporting original data or information in this document have been limited.

2.3 SITE SELECTION

Within this document, "site selection" primarily refers to the activities whereby the Los Medanos (or other) area is evaluated, on geotechnical grounds, as to whether it is an acceptable location for the WIPP. "Preliminary site selection" may be used here or elsewhere as a description of the activities which result in selecting a site for characterization; the characterization of such a site establishes technical grounds for the more specific site location of the WIPP. "Site selection" has also been described as that action which results when all technical aspects of establishing a repository site have been satisfied. For the WIPP studies, this latter action is termed "site confirmation";

the criteria for "site confirmation," which means conversion to a repository, will in part be developed through operation of the WIPP as a demonstration facility. Because of unforeseen geological occurrences or enhanced understanding of geological processes, final satisfaction regarding the geological suitability of the site for a repository may not develop until significant portions of the underground workings are explored and studies of geological processes finished. Site selection here refers to the position that most, if not all, of the extant geological characteristics are favorable to the WIPP; the rates of some geological processes may require further examination to reduce that uncertainty with regard to specific detailed effects on a repository. Site selection for the WIPP is not to be interpreted as a guarantee that a repository will be established.

2.3.1 History of WIPP Site Selection Effort

The sequence of events which has culminated in the WIPP site selection activities in the Delaware Basin of southeast New Mexico began in 1955 when the Atomic Energy Commission (AEC) requested the National Academy of Science (NAS) to examine the issue of permanent disposal of radioactive wastes. The Academy's Committee on Waste Management issued a report (NAS/NRC Report) in 1957 in which they stated, "The most promising method of disposal of high-level waste at the present time seems to be in salt deposits." This recommendation initiated several years of research, directed by Oak Ridge National Laboratory (ORNL), on the phenomena associated with disposal of radioactive waste in salt. In 1961 (NAS/NRC Meeting Minutes, December, 1961), the NAS waste management committee reaffirmed its position on the use of salt beds for disposal commenting that "Experience both in the field and in the laboratory on the disposal of wastes in salt have been very productive and well conceived; plans for the future are very promising." Pierce and Rich (1962) reported on salt deposits in the United States that might be suitable for disposal of radioactive wastes. The Delaware Basin was one of these areas discussed. The ORNL research was expanded to include a large-scale field program in which simulated waste (irradiated fuel elements), supplemented

by electric heaters, was placed in salt beds for observation of the resulting phenomena. This experiment, called Project Salt Vault (Bradshaw and McClain, 1971), was conducted in an existing salt mine at Lyons, Kansas, from 1963 to 1967. Results from this program were favorable, and no unacceptable phenomena occurred which would rule out salt as a repository medium. The NAS committee again reviewed and endorsed the NAS position regarding disposal in salt (NAS/NRC Report, 1966). In June, 1970, the Lyons site was tentatively selected by the AEC as the location for a radioactive waste repository. The concept and location were conditionally endorsed by the NAS committee in November, 1970 (NAS/NRC, 1970). Conceptual design for a facility accommodating both transuranic (TRU) and high-level waste (HLW) was completed in 1971. During 1971, as plans for the repository proceeded, two technical problems arose. The first involved the presence of a large number of existing boreholes in the vicinity of the repository which penetrated through the salt beds into underlying aquifers. There was concern that not all these holes could be adequately plugged and that not all such drill holes were on record and identified. This prospect meant that borehole dissolutioning and eventual breaching of the repository could not be ruled out. The second concern related to the solution mining being carried on by the American Salt Mining Company about three miles from the proposed repository but only 1700 feet from an extension of the Carey Salt Mine which was to contain the repository. The revelation that large volumes of water were unaccountably "lost" in the hydraulic fracturing and solution mining was regarded as illustrating a mechanism threatening to the repository site. This site was opposed by the Director of the Kansas Geologic Survey and political opposition within the state increased. By early 1972, the proposal for a repository at Lyons was abandoned and a much expanded search for a suitable repository site was commenced. Other potential sites in the state were identified by the Kansas Geological Survey, and the United States Geological Survey (USGS) examined potential salt sites in other areas of the United States.

After a nationwide search for a suitable repository site (Pierce and Rich, 1962; Anderson et al., 1973; Bachman and Johnson, 1973; Hite and

Lohman, 1973; Jones et al., 1973; Mytton, 1973; Ekren et al., 1974), the USGS and ORNL selected the Permian Basin in New Mexico as best satisfying their site selection guidelines. Four locations within this area were examined in more detail (Brokaw et al, 1972; Jones et al, 1973; Jones, 1974a; Jones, 1974b), and a location in the Los Medanos area, about 30 miles east of Carlsbad, New Mexico, was chosen for exploratory work. One of the most restrictive site selection criteria, primarily because of the Lyons experience, was avoidance of drill holes penetrating through the salt within two miles of the repository border. This criterion caused the potential site to be shifted twice within the Los Medanos area as oil/gas wells were drilled in the vicinity. The eventual site selected by ORNL was located on the Eddy-Lea county line, 30 miles due east of Carlsbad, New Mexico.

Field investigations began at this site in March, 1974, with the drilling of core holes AEC 7 (3,918 feet deep) and AEC 8 (3,028 feet deep) at the northeast and southwest corners of the 1 1/2 by 2 mile rectangular site. The data from these holes was considered satisfactory by ORNL, but further work at the site was suspended in May, 1974. This suspension was due in part to a shift in AEC waste management emphasis to retrievable surface storage facilities (RSSF) and in part to a reluctance at the commission level to ask for land withdrawal to set aside the necessary area for the repository and its protective "buffer" zones.

Sandia received program funding to continue field investigations in southeastern New Mexico on March 31, 1975. Geologic investigations resumed at the ORNL site in May, 1975. Extensive review sessions with ORNL and the USGS covered past efforts in site selection. Studies conducted by the USGS and ORNL consultants on regional geology, seismicity, hydrology and solutioning of salt were re-evaluated. Sandia concurred that the northern Delaware Basin seemed appropriate for siting a waste repository.

In the opinions of both ORNL and USGS, the two core holes, AEC 7 and 8, indicated acceptable subsurface geology at the ORNL site. The first

Sandia task, therefore, was to confirm this by additional drilling and geophysical investigations. Core hole ERDA 6 was initiated in May, 1975, at the northwest corner of the ORNL site. ERDA 6 encountered unexpected subsurface geology. Formation contacts were much higher than anticipated, and salt and anhydrite beds exhibited severe distortion with dips up to 75 degrees. Sections of the upper Castile Formation were missing, and the fractured anhydrite encountered at a depth of 2710 feet contained a pocket of pressurized brine. The unpredictability of the detailed geology at this site was not compatible with Sandia requirements for the pilot plant; therefore, site selection activities were expanded. Reconsideration of site selection guidelines in light of the results of continuing studies and exploration in southeast New Mexico led to the adoption of additional guidelines and some modification of the original guidelines. Evaluation of oil company seismic and drilling data and the resultant structural contours on the Castile Formation confirmed deformation of Castile salt beds in a band about five miles wide paralleling the Capitan Reef front. Since this deformation and the distortion of the geologic units encountered in ERDA 6 was believed due to gravity-induced buckling of salt beds abutting against the Capitan Reef, an additional site selection factor was established requiring a site area to be at least six miles from the reef front.

The proximity of boreholes penetrating the salt formations, another site selection criterion, was re-evaluated during this period. Analytical studies and field research conducted for ORNL after the Lyons, Kansas, borehole problems allowed a more quantitative judgement (Snow and Chang, 1975; Walters, 1975). In the Los Medanos area, a requirement to separate the repository from boreholes penetrating through the salt by one mile seemed quite conservative and was adopted. This buffer would assure more than a quarter million years of isolation using very conservative flow assumptions. While improved borehole plugging and study of the consequences of an unplugged hole may make such holes acceptable even closer to the repository, neither has yet been demonstrated.

The New Mexico portion of the Delaware Basin was re-examined by both the USGS and Sandia in late 1975. On November 14, 1975, the USGS recommended an area about seven miles southwest of the ORNL site for further examination. Sandia had independently selected the same area as showing the most promise for a repository site. Considerable geologic data were available in this region from oil/gas wells and from shallow drill holes used to explore for potash. In a regional study, the USGS found that initial dissolution of Salado salt, the formation of interest, was sufficiently distant from the proposed site that dissolution would pose little, if any, threat to the WIPP. The three-square mile repository could be located to avoid the known potash area (KPA) and to be at least one mile from all boreholes penetrating through the salt. No private (fee) land and less than three sections of state land were present in the potential withdrawal area. A stratigraphic core hole, ERDA 9, was started in parallel with geophysical studies of the area. ERDA 9, drilled in the center of the area under study, revealed the expected geology and indicated the desired flat bedding (dips are about 75 feet/mile). Physical properties of the salt beds were found to be satisfactory; beds at depths of about 2100 and 2600 feet were selected as appropriate for TRU and heat-generating wastes respectively. Consequently, an extensive program of site evaluation and laboratory investigation was begun and is continuing as of the date of this report (August, 1978). Sufficient information has now been developed to allow the site to be adequately characterized for site selection purposes.

2.3.2 General Location and Land Requirements of WIPP Facility

Figure 2-1 shows the general location of the Los Medanos site within the regional geographic setting. The nearest town is Loving, New Mexico, (population about 1100) 18 miles west-southwest of the site. Carlsbad, New Mexico, (population about 25,000) is 26 miles west of the site, and Carlsbad Caverns National Park is about 40 miles to the southwest.

Figure 2-2 is a diagram of the WIPP site showing proposed land use controls around the limits of the underground facilities (Zone II).

Engineering studies had indicated that approximately 3 square miles were desired for ultimate development of underground facilities at the WIPP site, necessitating the restriction of land use within an equivalent area of land at ground surface. Administrative control of additional land (Table 2-1) will also be required beyond the boundary of the excavated area to protect the repository: a mile-wide restricted zone around the repository in which, for the present, no underground mining, excavation, or through-going boreholes will be considered (Zone III); and an additional mile-wide buffer zone in which limited (i.e. subject to control and regulation by DOE) underground mining and deep drilling will be allowed (Zone IV). "Hydrofracing" and other injection methods of hydrocarbon recovery, and any kind of solution mining, would be prohibited. This zonation is shown in Figure 2-2, (which also indicates the corresponding total acreage of restricted land needed for the WIPP site). On the surface, only the plant site itself (Zone I) will exclude land access.

The irregular pattern of the outer boundary of the WIPP site (Figure 2-2) originated from a desire to conform to the Bureau of Land Management's (BLM) land subdivision system and to exclude private land and producing wells. The WIPP program plan calls for the entire area within this boundary to be brought under control of the DOE. The inner boundaries that define restricted areas are polygonal, designed to minimize the area to be withdrawn while achieving optimum conformance to the siting criteria.

2.3.3 General Considerations and Requirements of Underground Storage Facilities for Radioactive Waste

Neglecting consideration of surface restrictions and land use conflicts for the purposes of this report, geotechnical siting requirements for an underground radioactive waste repository are ultimately determined by: 1) the physical (including thermal), chemical and radioactive interactions between the waste and the surrounding media, 2) the type of rock chosen in which to place the repository, and 3) the level of

assurance desired against failure of the containment. While WIPP is anticipated to be a repository for defense transuranic waste, Sandia was also requested to consider possible future options for high-level waste in its site selection studies of bedded salt in the Delaware Basin. For WIPP, the desired goal is complete isolation of waste with negligible consequence in the event of containment failure for the total duration of time in which the radioactivity of the waste could constitute a potential hazard to the biosphere or humans in general.

These unprecedented long storage requirements, which embrace a small but significant interval of geologic time, call for a careful characterization of long-term hydrologic, geologic and climatic processes, potentially affecting stability and survival of the underground facility, in order that appropriate siting criteria may be specified. These and other considerations in the long-term management of radioactive wastes have been defined and discussed in ORNL reports by Gera and Jacobs (1972) where they identify geologic processes relevant to waste disposal and discuss the suitability of various geologic media for radioactive waste storage. Claiborne and Gera (1974) describe and evaluate potential mechanisms of containment failure and of hydrologic release of contaminants from the bedded salt deposits in the southeastern New Mexico area. The conclusions and recommendation of these studies, which are not repeated here, have been utilized as guidelines in formulating siting criteria employed in the selection of candidate site locations in the Delaware Basin area of southeastern New Mexico. Regarding the overall danger of contamination from properly sited underground waste storage facilities, however, it is appropriate for proper perspective to repeat the observation of Claiborne and Gera (1974, p.4) that

> "the conditions required for a serious release of activity to the biosphere from a repository in bedded salt tend to approach the bizarre and have considerably less credibility than the 'maximum credible accident' assumed for nuclear power plant safety analyses."

2.3.4 Initial Screening Criteria and Selection of the Original (ORNL) Site in the Delaware Basin

Preliminary site screening studies for an underground waste isolation storage facility in the Delaware Basin were initiated jointly in 1972 by ORNL and the USGS for the AEC. Guidelines developed at that time were mostly contained in the ORNL report by Gera and Jacobs (1972) and in ORNL-TM-4219, which, however, did not address conditions in the southeastern New Mexico area specifically. Geologic information was assembled by the USGS for use in evaluating the suitability of various areas in the Delaware Basin for disposal of radioactive wastes; this information appeared in open-file form in the report by Brokaw, et al. (1972). Additional data by Bachman, et al. (1972) appeared as an ORNL report.

Large-scale (Stage I) site screening criteria (ORNL-TM-4219) were developed and were employed in an initial selection of a site at the Lea-Eddy County boundary, about 7 miles northeast of the present WIPP site. In addition to the usual geologic standards some technical criteria which were applied by ORNL were as follows (Griswold, 1977, p.12):

> A two-mile radius from any boring through the Ochoan evaporites down into the Delaware, or deeper formations.
> No active mining within five miles.
> Salt of high purity at depths of less than 3,000 ft.
> A minimum depth to suitable salt of 1,000 ft.
> Avoidance of obvious mineral resources to the extent possible.

The maximum depth indicated was solely a mine engineering criterion dictated by the viscous flow potential of salt at pressures exerted by the lithostatic loading and at temperatures imposed by the expected geothermal gradient coupled with the maximum thermal flux of the stored waste; the minimum depth was that considered adequate to insure against disinterment by erosion.

Figure 2-3 shows the results of this initial screening process. A two-mile radius from deep wells proved to be the most restrictive criterion; on the figure the shaded areas indicate land, more than two miles from deep wells, also satisfying the depth and mineral resource exclusion criteria. The site initially selected by this method is also indicated.

Cores from AEC Nos. 7 and 8 intercepted leasable grades of potash; ERDA No. 6 cores did not. However, at ERDA No. 6, evidence of complex evaporite structure and the encounter of an artesian flow of brine were sufficient evidence that this original site was unsuitable and that more information would be needed to define additional criteria to be used in selection of acceptable alternate sites.

2.3.5 Site Selection and Evaluation Criteria for the Los Medanos Site

When the initial Delaware Basin repository study area was shown to be unacceptable, Sandia undertook the task of locating a satisfactory site in the New Mexico portion of the Delaware Basin. By late 1975 a more complete understanding of the geology of the basin and of potential repository failure mechanisms permitted a reformulation of siting criteria and site selection factors. These criteria and factors were developed rather specifically for the Delaware Basin in southeastern New Mexico, and are neither generic criteria for bedded salt nor generic criteria for all rock types.

Some of the specific studies contributing to this effort include the following: Claiborne and Gera (1974) considered potential failure modes of bedded salt containment in the Delaware Basin; Bachman and Johnson (1973), Jones (1973), Bachman (1974) and Piper (1973) reported on geologic and hydrologic conditions in the Permian Basin region and in the Delaware Basin in particular; Jones (1975) discussed potash deposits; and Foster (1974) and Netherland, Sewell and Associates (1975) investigated hydrocarbon resources. Reports on dissolutioning associated with unplugged boreholes (Snow and Chang, 1975; Walters, 1975; Fader, 1973)

were also available. The selection of additional alternate sites made in November, 1975, utilized this information. Two factors which received careful attention because of the experience gained in locating and evaluating the original site were the existence of salt flow structures and associated brine pockets and the dissolution potential of man-made penetrations through the evaporites.

Siting factors were formulated to eliminate from further consideration areas of possible severe structural deformation or complexity of the salt beds. Geologic evidence (Jones, 1973) indicated the tendency for greater structural complexity to occur in salt beds adjacent to the Capitan reef front. Substantial salt deformation resulting in displacement and fracturing of anyhdrite beds was encountered in ERDA-6. Structural contouring of the Castile Formation, based on petroleum drilling and seismic reflection data, indicate this distortion of salt is most severe in a belt, about five miles wide, paralleling the reef front. Accordingly, a belt with a width of six miles basinward from the Capitan reef was eliminated from eligible areas. This also served to avoid any possible dissolution hazards which might be associated with the reef. Known locations of artesian brine flow appeared to be related to anticlinal features in the subsurface; therefore, the avoidance of pronounced anticlinal structures in salt was adopted as a selection factor.

The extent of deep drilling, resulting from hydrocarbon exploration in the Delaware Basin, indicated that a careful evaluation of the required separation from boreholes be performed. Desirable regions could be excluded from consideration if this factor was unduly restrictive. The two mile separation distance established after the Lyons, Kansas, experiences, was modified to one mile based on studies by Snow and Chang (1975), Walters (1975), and Fader (1973). These studies improved prospects for assuring plugging of boreholes, and the hydrologic conditions expected in the acceptable portions of the Delaware Basin all indicate that a one-mile buffer zone is amply conservative against potential borehole dissolution (Griswold, 1977, p. 12). Figure 2-4 shows

areas that are more than one mile from boreholes penetrating into the Delaware Mountain Group. Avoiding these boreholes would also result in avoiding existing oil or gas fields.

In addition to the salt anticline and borehole restrictions already mentioned as assuming a primary role in narrowing the choice of acceptable sites, several other aspects proved to be significant for the northern portion of the Delaware Basin. Proximity to the dissolution front at the top of the Salado Formation and the existence of local solution features were prime considerations.

Although open joints, fractures or faults are not expected to occur in salt, intrusions in the form of igneous dikes which pass through the salt beds are known to exist locally in the Delaware Basin. The proximity of such a feature might be cause for rejection of a site for geologic, hydrologic and engineering reasons. Shown in Figure 2-5 are areas where undesirable structure, such as salt deformation, brine-flow anticlines, or dike trends, are known or presumed to occur; the dike trend is magnetically expressed and is defined by magnetic survey methods.

Candidate sites should be located in areas affording adequate long-term protection against encroachment of salt dissolution. Surface dissolution was assumed to be related to downward percolation of meteoric water and removal through Nash Draw and the Pecos drainage system. In addition, evidence of possible dissolution in salt over the Capitan reef aquifer is known in such places as San Simon Sink. Dissolution fronts, or boundaries at which salt has been or is being dissolved from the enclosing rock material, had been recognized at various horizons in the evaporite sequence of the Delaware Basin. Rates of dissolution were estimated by Bachman (1974), and longevity of Salado salt was diagrammed by Jones (1973, Figure 7). These observations were translated into appropriate avoidance criteria. Dissolution of salt in the Rustler Formation was not considered to be a significant hazard to a repository located in the lower part of the Salado; however, areas that exhibit extensive salt dissolution at the top of the Salado would be rejected.

For conservatism, sites that would be in, or within a mile of, areas of known dissolution at the top of the Salado were considered less desirable. Figure 2-6 displays areas where dissolution at the top of Salado was indicated to occur, based on studies current at that time.

The interception of commercial grades of potash by holes AEC-7 and AEC-8 and the known occurrences of potash nearby highlighted the necessity of evaluating the potential of this resource to assess possible resource conflict. Areas of potash mineralization meeting minimum grade and thickness criteria, termed the "potash enclave" by Aguilar et al. (1976), would be avoided to the extent possible by the three square mile core of the site. Regarding possible conflict with hydrocarbon reserves, the avoidance of deep drill holes automatically insures that a potential site would not be located over an existing oil or gas field. To minimize the possibility of siting over areas having favorable potential for discovery of additional hydrocarbon reserves, oil and gas trends in the subsurface beneath a possible site location would be considered in siting the repository. The locations of such trends are shown in Figure 2-7.

Finally, with regard to land ownership, the land withdrawn should be federally owned to the extent possible to expedite site exploration and land withdrawal. Potash lease rights would be avoided by Zones I and II to the extent feasible.

2.3.6 Site Selection: Criteria and Factors

Two principal stages are involved in establishing a nuclear waste repository. The first stage, outlined mainly in the previous section (2.3.5), involves preliminary site selection of the most desirable site from among the potentially acceptable study areas. This selection is based on application of criteria and selection factors to the existing knowledge and general reconnaissance information available for the areas. Specific and detailed studies are not conducted at this stage. The second stage is to determine the characteristics and processes affecting a site or sites sufficiently well to allow confirmation of a

site for a repository. It is possible that this detailed study will reveal that some factors are less than ideal. It is unlikely (and unnecessary) that a site will be ideal with respect to all selection factors. Similarly, it is unnecessary and, indeed, impossible to prove that the "best" site has been selected. The extent of investigation in stage two is such that all prospective sites cannot be examined in this detail. Rather it is sufficient to establish that an adequate, safe, and acceptable site has been identified. This knowledge requires that potential failure modes and hazards be recognized and that siting factors take them into consideration.

For the WIPP, the facility demonstration and additional studies of processes and underground geology will lead to further development of criteria for a repository and subsequent assessment of the safety of the WIPP site as a repository. Thus, at least for WIPP, it is necessary to refine criteria, through operation and continued study, sufficient for confirmation as a repository.

For site selection of the Los Medanos site the following criteria and the factors which address those criteria are listed. In most cases, the nature of the factor desired can be indicated but not quantitatively specified a priori since the acceptable combinations of factors under the multiple barrier concept is so large. Many of the desired factors are just that - desired. They are sufficient but may not be necessary for long-term repository safety. The general relationship of factors to WIPP studies is indicated by referring to principal chapters containing information about particular factors.

Geology Criterion: The geology of the site will be such that the repository will not be breached by natural phenomena while the waste poses a significant hazard to man. The geology must also permit safe operation of the WIPP.

Factors: Topography - Must permit access for transportation. Effect on inducing salt flow during excavation must be considered. Surface water flow and future inundation must be evaluated. (See 3.2, 4.2)

Depth - Repository horizons should be deeper than 1000 feet to assure erosion and consequences of surficial phenomena are not a major concern. Depth of suitable horizons will not exceed 3000 feet to limit rate of salt deformation around the excavations. (See 3.3, 4.3, 9.2)

Thickness - Total thickness of the salt deposits should be several hundred feet to buffer thermal and mechanical effects. The desired thickness for the repository bed is 20 feet or more to mitigate the thermal and mechanical effects at non-halite units. (See 4.3.2, 9.2)

Lateral Extent - The distance to structural or dissolution boundaries must be adequate to provide for future site integrity. For the Los Medanos area a distance of five miles to the Capitan reef and one mile to regional Salado dissolution have been established. (See 3.3, 4.3, 6.3)

Lithology - Purity of the salt beds is desirable to reduce the brine content of the salt. Pending further investigations, three percent brine is established as a desirable upper limit for the heat-producing waste horizon. Additional geochemical interactions must be considered if significant chemical or mineralogical impurities are present. (See 4.3, 7.2, 7.3, 7.4, 7.5, 7.6)

Stratigraphy - Continuity of beds, character of inter-bedding and nature of beds over- and underlying the salt are important considerations in construction of the facility and in assessment of possible failure scenarios. (See 3.3, 3.4, 4.3, 4.4)

Structure - Relatively flat bedding ($< 3^{o}$) is desirable for operational purposes. Steep anticlines and major faults are to be avoided. (See 3.4, 4.4)

Erosion - While the depth factor reduces concern for erosion it is desirable to avoid features which would tend to localize and/or accelerate erosion. (See 3.2.3, 3.6, 4.2, 4.5, 6.2)

Hydrology Criterion: The hydrology of the site must provide high confidence that natural dissolution will not breach the site while the waste poses a significant hazard to man. Accidental penetrations should not result in undue hazards to mankind.

Factors: Surface Water - Present and future run-off patterns, flooding potential, etc., should not endanger the penetrations into the repository while these openings are unplugged. (See 6.2)

Aquifers - For WIPP, the over- and underlying aquifers represent a secondary barrier if the salt is breached. Consequently low permeability and transmissivity are desirable but not mandatory. Accurate knowledge of aquifer parameters is important to construction, decommissioning and realistic calculation of the consequences of failure scenarios. (See 6.3)

Dissolution - Regional and/or local dissolution must not breach the repository while the wastes represent a significant hazard to man. While there are various suggestions for the time a repository should remain isolated from the biosphere, 250,000 years (ten half-lives of ^{239}Pu) is one period which may be sufficient for evaluating the WIPP site. (See 6.3.6)

Subsidence - Subsidence due to dissolution of salt will be avoided when the subsidence adversely affects the repository beds or unduly accelerates the rate of

dissolution to the jeopardy of long-term integrity of the repository. (See 6.3.6, 10.6)

Hydrologic Transport - For the WIPP, this is a secondary factor which must be evaluated to allow quantitative calculations of the consequences of various failure scenarios. Slow transport of isotopes is acceptable if more critical factors have been satisfied. (See 6.3, 9.3. 10.6)

Climatic Fluctuations - Possible pluvial cycles must be considered when estimating the effects of the above factors. (See 3.6, 4.5, Chapter 6, 10.3)

Man-made Penetrations - The effect of drill-holes and mining operations on the site selection must be evaluated in considerations of dissolution.

Tectonic Stability Criterion: Natural tectonic processes must not result in a breach of the site while the wastes represent a significant hazard to man and should not require extreme precautions during the operational period of the repository.

Factors: Seismic Activity - The frequency and magnitude of seismic activity impacts facility design and safety of operation. Low levels of seismicity are desirable but facility design can accommodate higher levels as well. (See Chapter 5, 10.5)

Faulting/Fracturing - While open faults, fractures or joints are not expected in salt, the more brittle units within and surrounding the salt may support such features which can enhance dissolution and hydrologic transport. Major faults and pronounced linear structural trends should be avoided. (See 3.4, 4.4)

Salt Flow/Anticlines - Major deformation of salt beds by flow can fracture brittle rock and create porosity for brine accumulations. Major anticlines resulting from salt flow should be avoided or evaluated to check on brine presence and anhydrite fracturing. (See 4.4)

Diapirism - An extreme result of salt flow, this feature will be avoided for WIPP siting. (See 4.4)

Regional Stability - Areas of pronounced regional uplift or subsidence should be avoided since such behavior makes anticipation of future dissolution, erosion and salt flow more uncertain. (See 3.4, 4.4, 10.3.2)

Igneous Activity - Areas of active or recent volcanism or igneous intrusion should be avoided to minimize these hazards to the repository. (See 3.5)

Geothermal Gradient - Abnormally high geothermal gradients should be avoided to allow construction in salt at 3000 feet. High gradients may also be indicative of recent igneous or tectonic activity. (See 4.4.1)

Physico-chemical Compatibility: The repository medium must not interact with the waste in ways which create unacceptable operational or long term hazards.

Factors: Fluid Content - The repository bed containing high level waste should not contain more than three percent brine. The limit for TRU waste has not been established, but the same value used for HLW is acceptable. (See 7.5, 10.7.8)

Thermal Properties - No major natural thermal barriers should exist closer than 20 feet to avoid undesirable temperature rises. (See 4.3, 9.2.3)

Mechanical Properties - The medium must safely support excavation of openings even while thermally loaded. Clay seams and zones of unusual structural weakness should be avoided in selection of the repository horizon. (See 9.2.4)

Chemical Properties/Mineralogy - Beds of unusual composition and/or containing minerals with bound water should not occur within 20 feet of the waste horizon. This will lessen the uncertainties with regard to thermally driven geochemical interactions. (See 4.3, 7.2, 7.3, 7.4, 7.5)

Radiation Effects - While no unacceptably deleterious effects are postulated, these phenomena are best quantified in halite and thus the purer rock salt beds are desired for high- level waste. (See 9.3)

Permeability - Salt has very low permeability and only the inter-beds and surrounding media are considered for siting with respect to this factor. Low permeability is desirable, but quantitative limits need not be specified for site selection. (Salt permeability to gases may be important in establishing waste acceptance criteria.) (See 9.2.3)

Nuclide Mobility - This is a secondary factor in siting since confinement by the salt and isolation from water is the basic isolation premise. Ion sorption must be determined to allow quantification of safety analyses and to indicate whether engineered barriers (clay) would be beneficial. (See 9.3)

Economic/Social Compatibility Criterion - The site must be operable at reasonable economic cost and should not create unacceptable impact on natural resources or the biological/sociological environment.

Factors: Natural Resources - Unavoidable conflict of the repository with actual or potential resources will be minimized to the extent possible. (See Chapter 8)

Man-made Penetrations - Boreholes or shafts which penetrate through the salt into underlying aquifers shall be avoided within one mile of the repository. Existing mining activity, unrelated to the repository, should not be present within two miles of the repository. Future, controlled mining, will be allowable up to one mile from the repository. Future studies may permit still closer mining and drilling if properly controlled. (See 2.3, Chapter 4)

Transportation - Transportation should be capable of ready development. Avoidance of population centers by transportation routes is not a factor in WIPP siting. (Not addressed in GCR)

Accessibility - The site should be readily accessible for transportation and utilities. (Not specifically addressed in GCR; see Chapter 2 figures)

Land Jurisdiction - Siting will be on federally controlled land to the extent possible. (Not specifically addressed in GCR; see Chapter 2 and 8 figures)

Population Density - Proximity to population centers and rural habitats will be considered in siting. Low population density in the immediate site area is desirable. (Not addressed in GCR)

Ecological Effects - Major impacts on ecology due to construction and operation should not occur. Archaeological and historical features of significance should be preserved. (Not addressed in GCR)

Sociological Impacts - Demographic and economic effects should not result in unacceptable sociological impacts. (Not addressed in GCR)

One may summarize the WIPP siting criteria having the greatest impact as follows:

Avoidance of land within one mile of any boring through the Ochoan evaporites and into the Delaware or deeper formations.

Salt of high purity at a depth between 1000 and 3,000 ft.

Avoidance of areas where dissolution had advanced to the top of Salado or deeper levels, by establishing a distance of one mile or more from dissolution fronts at the top of Salado.

Avoidance of possible salt deformation in a belt 6 miles wide basinward from the Capitan reef.

Avoidance of pronounced known anticlinal structures.

Avoidance of known oil and gas trends.

Avoidance of the known potash enclave above the repository and minimizing conflict with the known enclave in the buffer zone.

Minimize existing potash lease rights in Zones I and II.

Minimize state and private land in Zones I through IV.

These criteria were applied to all areas within the Delaware Basin in New Mexico. Figure 2-8 illustrates result of application of the expanded set of criteria. Two alternate sites survived the constraints imposed by the site selection criteria.

2.3.7 Preferred Preliminary Site Selection

Since only two alternate sites in the New Mexico part of the Delaware Basin withstood the set of revised Stage II siting criteria, the preliminary selection of a preferred site was fairly straightforward. Alternate I, now known as the Los Medanos site, appeared to be the preferred site. Alternate II was considered less desirable because it was restricted in size, the acceptable salt zones were deeper, and the high-purity salt lying between the Cowden anhydrite (in the lower Salado Formation) and the Castile was thought to be absent. The top of the Salado was about 800 feet deep at Los Medanos versus 1500 feet at Alternate II. Other factors that favored the selection were:

Structural interpretation of what seismic data was then available to Sandia indicated the Los Medanos site would be in a synclinal area unfavorable for oil and gas acccumulation.

Similarly, if the site were in a syncline, geopressured brine reservoirs would be less likely.

The Alternate II area lay adjacent to the Double X and Triple X shallow oil fields where water flooding for secondary recovery could occur.

No seismic exploration data whatsoever was available to Sandia on the Alternate II area, and only partial coverage at Los Medanos.

Sandia Laboratories selected the Los Medanos alternate as the best candidate area in early December, 1975. Figure 2-9 illustrates how the siting criteria apply to the Los Medanos site.

Geological characterization activities were then expanded to focus on obtaining subsurface data at the Los Medanos site. A descriptive summary of these programs is given in Section 2.5.

2.4 STATUS OF STUDIES

In review, geologic studies for the WIPP fall naturally into three different phases: preliminary site selection activities, geological characterization, and studies of long-range geologic processes affecting a repository. Preliminary site selection activities are complete now; these consisted primarily of national and regional studies over the past fifteen years, and resulted in selection of the WIPP study area for geological characterization. The work of geological characterization should be considered to have begun with the drilling of ERDA 9 and the initiation of seismic reflection work on the site. That geological characterization, which is primarily oriented to provide specific data concerning the present geology of the site, will be virtually complete in 1978 when this Geological Characterization Report is submitted to DOE; much basic information has been gathered indicating no major technical problems with the site as it is now understood. Studies of long-term

processes which might affect a repository or have an effect on safety analyses will be the major geotechnical activity for the WIPP project after 1978, although some of these activities are already underway. These studies will concern the age of significant features and the rates and processes which produce those features. The information so gained will be useful in increasing the confidence in evaluation of the safety of a repository when a decision is necessary regarding conversion of the WIPP to a repository.

2.5 EXPLORATION TECHNIQUES

Much of the geological characterization of the WIPP study area is done using exploration geophysics and boreholes. About 75 line miles of new seismic reflection data and 9000 resistivity measurements were collected and 47 drillholes completed to support WIPP geological characterization to date (August, 1978). For convenience, the boreholes are listed in Table 2-2 according to primary objective. Twelve geologic exploratory holes (two by ORNL and ten by Sandia Labs) have been drilled to date in support of this program (Table 2-2A); three holes were drilled at the old study area, two are located off the WIPP site, and seven were drilled on the WIPP site. ERDA 9 is located at the center of the present study area (Figure 2-10). These boreholes were extensively logged, cored, and drill-stem tested in the evaporite section. The cores form the basis for several continuing laboratory studies that are important to an understanding of the physical and chemical phemomena associated with the WIPP and contribute to general knowledge about the formation of evaporites. Two of the exploratory boreholes have been drilled well outside the immediate site to obtain dissolution and paleoclimate data. Twenty-one holes (Table 2-2B) were drilled in conformance with industry standards to obtain core from the potash zones to supplement more than 30 existing industry holes for evaluation of potash resources within the WIPP study area by the USGS and the U.S. Bureau of Mines (Figure 2-11). When that evaluation is complete, others may use the core for studies of potash ore formation. Fourteen hydrologic holes (Table 2-2C) have been drilled and four potash holes converted to hydrologic monitoring to

provide a total of eighteen holes now dedicated to hydrologic studies. Hydrologic tests of the Bell Canyon Formation underlying the evaporites have also been conducted in two of the exploratory boreholes, one northeast and one south of the site. Except for ERDA 9, none of the boreholes within Zones I, II, or III penetrate as deep as the repository horizons. Future holes will sample repository horizons within these zones.

Seismic reflection data available from petroleum companies and 26 line miles initially obtained strictly for the study area (Figure 2-12), were collected using standard techniques for the petroleum industry. The data are excellent for interpreting deeper structure, but are not as useful for showing reflectors in the upper 3000 feet. In 1977, about 48 line miles of new data (Figure 2-13) were collected using shorter spacings for geophones, higher frequencies from vibroseis units, and higher rates of data sampling. These data show much improved reflections from, and better resolution in, the shallow section of interest. Resistivity has also been extensively used as a characterization tool. Field tests indicated that resistivity could detect certain types of solution features; more than 9,000 measurements have been taken in the study area to search for such features (Figure 2-14). Additional measurements of resistivity using expander arrays have been made to study resistivity changes with depth and to help interpret the detailed measurements (Figure 2-15). Analysis of geophysical data for the geological characterization was nearly complete by Summer, 1978. One resistivity anomaly was drilled to determine the cause of the anomaly and consequences, if any, for the WIPP. This anomaly did not result from dissolution phenomena. Further detailed geophysical investigation of the site, using techniques previously described for better resolution of shallow horizons, is now underway (Summer, 1978) for the primary purpose of providing detailed engineering information.

A variety of studies to continue geological characterization and contribute to long-range assessments are under way. Studies directed primarily toward geochemistry include water chemistry and stable isotope

studies of surface and subsurface water of the Delaware Basin; fluid inclusion studies of the evaporite beds; chemical and mineralogic effects of an igneous intrusion into the evaporite section; Rb/Sr dating of potash ores; and sorptive capacities of evaporites and associated rocks for various radionuclides. The dissolution history for the area and the local paleoclimate are being investigated through analysis of a core taken from a sink in nearby San Simon Swale. Field investigations of the climatic history and stability of the Pecos River drainage are beginning, and caliche studies will form a significant part of this effort. Studies of LANDSAT images will conclude in 1979. In addition, the first 200 km of the first-order level line from Carlsbad to El Paso, Texas, has been resurveyed to examine regional tectonic movements associated with the West Texas salt flats graben and trans-Pecos volcanic area. A first-order level line has also been established from Carlsbad east to the WIPP site through Nash Draw for future assessment of tectonic, erosion, solutioning, and subsidence phenomena. Further assessment of basin tectonics may be derived through measurements of in situ stress. These long-range studies will continue until sufficient data are available to permit reasonable and confident assessment of the risks involved in having a repository in bedded salt in southeastern New Mexico. These studies, plus the successful operation of the WIPP as a demonstration facility, are essential for the development of criteria for the conversion of the WIPP to a repository.

2.6 SUMMARY

Bedded salt has been a leading candidate as a rock type for the storage of radioactive waste; a combination of technical factors has led to the examination of the Delaware Basin in southeastern New Mexico as a location for the WIPP. Through preliminary site selection and partial site characterization of an early site near the WIPP, site selection criteria and factors which are rather specific to southeastern New Mexico were refined, and a new preliminary site was selected. Chapter 2 contains the description of the criteria and factors used in this process as an introduction to the geological characterization of the WIPP site

which is presented in the following chapters. The geological techniques used in the characterization of the WIPP site are a combination of well-tested conventional techniques supported by state of the art tools. Multiple, supporting techniques are used where appropriate. Continuing geological studies will increase the data base for assessment of the WIPP as a repository and allow refinement of criteria for conversion to a repository.

2.6 REFERENCES

Aguilar, P.C., Cheeseman, R.J., and Sandell, E.T., Jr., 1976, Preliminary map showing distribution of potash resources, Carlsbad mining district, Eddy and Lea Counties, New Mexico: U.S. Geol. Surv., Open-file Map 76-554.

Anderson, R.E., Eargle, D.H., and Davis, B.O., 1973, Geology and Hydrologic Summary of Salt Domes in Gulf Coast Region of Texas, Louisiana, Mississippi, and Alabama: U.S. Geol. Surv. Open-file report 4339-2.

Bachman, G.O., 1974, Geologic processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U.S. Geol. Surv. Open-file report 74-194.

Bachman, G.O., and Johnson, R.B., 1973, Stability of salt in the Permian salt basin of Kansas, Oklahoma, Texas and New Mexico: U.S. Geol. Surv. Open-file report 4339-4.

Bachman, G.O., Johnson, R.B., and Swenson, R.A., 1972, Stability of bedded salt in the Permian basin, Colorado, Kansas, Oklahoma, Texas and New Mexico: in Oak Ridge National Laboratory Pilot Plant Repository Staff, Alternative geologic formations for the disposal of radioactive wastes, ORNL Report 72-6-42.

Bradshaw, R.L. and McClain, W.C. (eds.), 1971, Project Salt vault: Demonstration of the disposal of high-activity solidified wastes in underground salt mines: Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-4555.

Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hayes, W.H., 1972, Geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico: U.S. Geol. Surv. Open-file report 4339-1.

Claiborne, H.C., and Gera, F., 1974, Potential containment failure mechanisms and their consequences at a radioactive waste repository in bedded salt in New Mexico: Oak Ridge National Laboratory ORNL-TM-4369.

Department of Energy, 1978, Draft Report of Task Force for Review of Nuclear Waste Management: DOE/ER-0004/D.

Ekren, E.B., et al, 1974, Geologic and hydrologic considerations for various concepts of high-level radioactive waste disposal in conterminous United States: U.S. Geol. Surv. Open-file report 74-158.

Fader, S. W., 1973, Land subsidence caused by dissolution of salt near Four Wells in central Kansas: U.S. Geol. Surv. Administrative Report for AEC.

Foster, R.W., 1974, Oil and gas potential of a proposed site for the disposal of high-level radioactive waste: Oak Ridge National Laboratories Open-file report, Contract No. AF(40-1)-4423.

Gera, F., and Jacobs, D.G., 1972, Considerations in the long-termed management of high-level radioactive wastes: Oak Ridge National Laboratory, ORNL-4762.

Griswold, G.B., 1977, Site selection and evaluation studies of the Waste Isolation Pilot Plant (WIPP), Los Medanos, Eddy County, New Mexico: Sandia Laboratories Report SAND-77-0946.

Hite, R. J., and Lohman, S. W., 1973, Geologic Appraisal of Paradox Basin Salt Deposits for Waste Emplacement: U.S. Geol. Surv. Open-file report 4339-6.

Jones, C. L., 1973, Salt deposits of Los Medanos area, Eddy and Lea Counties, New Mexico, with sections on Ground water hydrology, by M.E. Cooley and Surficial geology, by G. O. Bachman: U.S. Geol. Surv. Open-file report 4339-7.

Jones, C.L., 1974a, Salt Deposits of the Mescalero Plains Area, Chaves County, New Mexico: U.S. Geol. Surv. Open-file report 74-190.

Jones, C. L., 1974b, Salt deposits of the Clovis-Portales area, east-central New Mexico: U.S. Geol. Surv. Open-file report 74-60.

Jones, C.L., 1975, Potash resources in part of Los Medanos area of Eddy and Lea Counties, New Mexico: U.S. Geol. Surv. Open-file report 75-407.

Mytton, James W., 1973, Two salt structures in Arizona; The Supai Salt Basin and the Luke Salt Body: U.S. Geol. Surv. Open-file report 4339-3.

NAS/NRC 1957 Disposal of Radioactive Wastes on Land, 1957, National Academy of Sciences - National Research Council, Washington, D.C., Publ. 519.

NAS/NRC, 1961, "Minutes of the Meeting of December 7-8, 1961," National Academy of Sciences - National Research Council, Division of Earth Sciences, Committee on Geologic Aspects of Radioactive Waste Disposal Advisory to the U. S. Atomic Energy Commission.

NAS/NRC, 1966, "Report to the U.S. Atomic Energy Commission," NAS-NRC, Division of Earth Sciences, Committee on Geologic Aspects of Radioactive Waste Disposal.

NAS/NRC, 1970, "Report by the Committee on Radioactive Waste Management," Disposal of solid radioactive wastes in bedded salt deposits.

Netherland, Sewell and Associates, 1974, Evaluation of hydrocarbon potential, AEC study area, southeast New Mexico: Report submitted to ORNL by Netherland, Sewell and Associates.

ORNL-TM-4219, 1973, Site Selection Factors for the Bedded Salt Pilot Plant. Staff of the ORNL Salt Mine Repository Project.

Pierce, W.G., and Rich, E.I., 1962, Summary of rock salt deposits in the United States as possible storage sites for radioactive waste materials: U.S. Geol. Surv. Bull. 1148.

Piper, A.M., 1973, Subrosion in and about the four-township study area near Carlsbad, New Mexico: ORNL Subcontract 3745.

Snow, R.H., and Chang, D.S., 1975, Prediction of cavity growth by solution of salt around boreholes, with appendix: Union Carbide Corporation IITRI C6313-14.

Vine, J.D., 1963, Surface geology of the Nash Draw Quadrangle, Eddy County, New Mexico: U.S. Geol. Surv. Bull. 1141-B.

Walters, R. F., 1975, Salt Dissolution in oil and gas test holes in Central Kansas: ORNL Contract No. 78X-38283V.

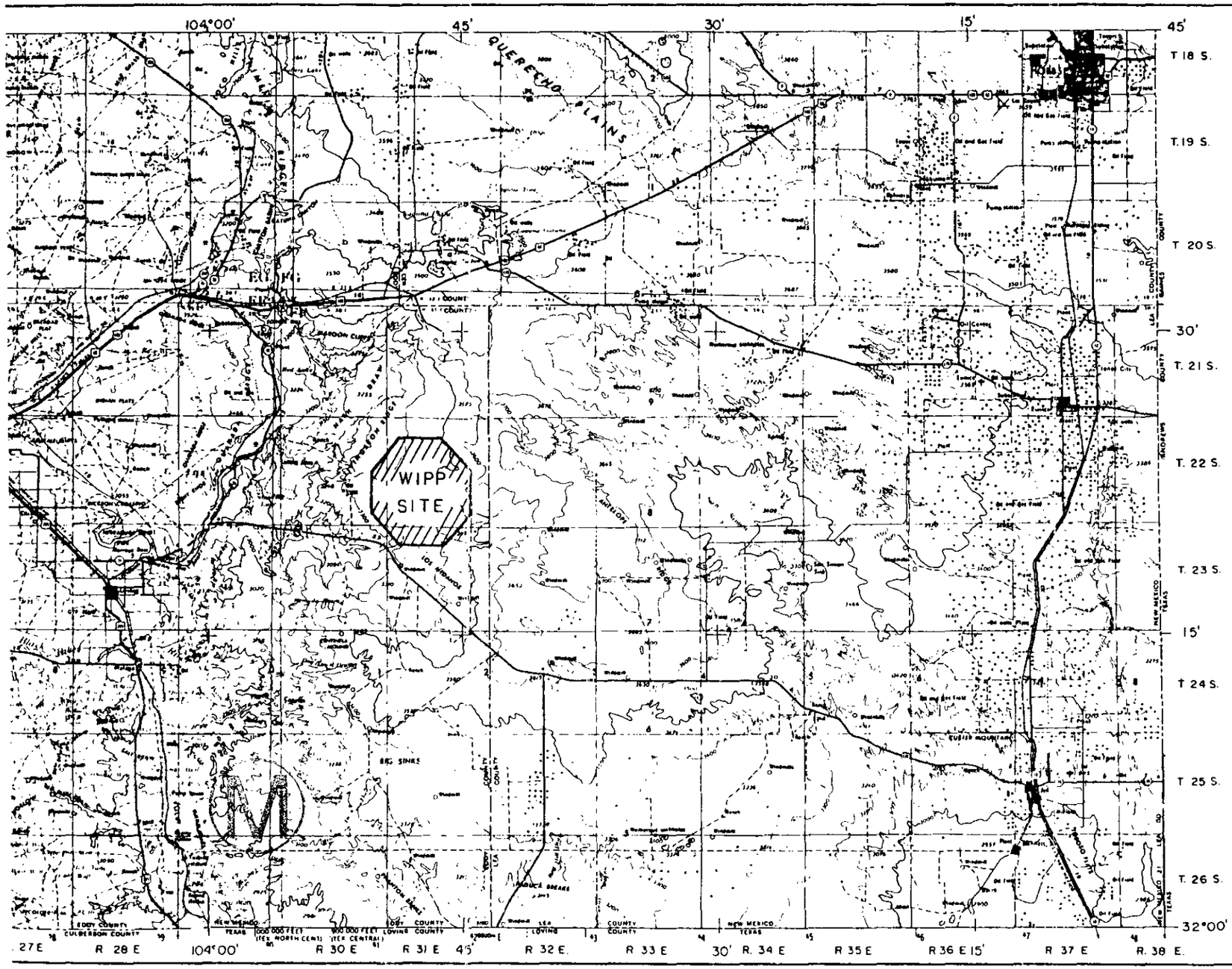

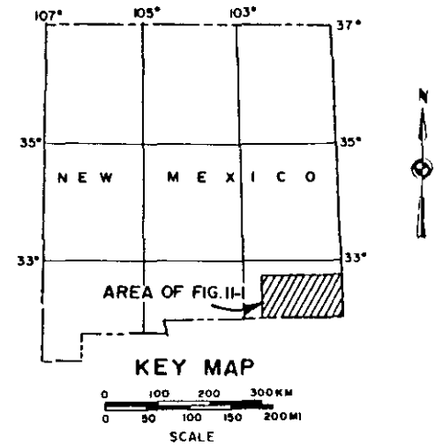

Base map from U.S.G.S. 1:250,000 series Carlsbad and Hobbs sheets.

0 5 10 15 20KM
0 5 10 15 MI
SCALE

GEOGRAPHIC LOCATION MAP

FIGURE 2-1

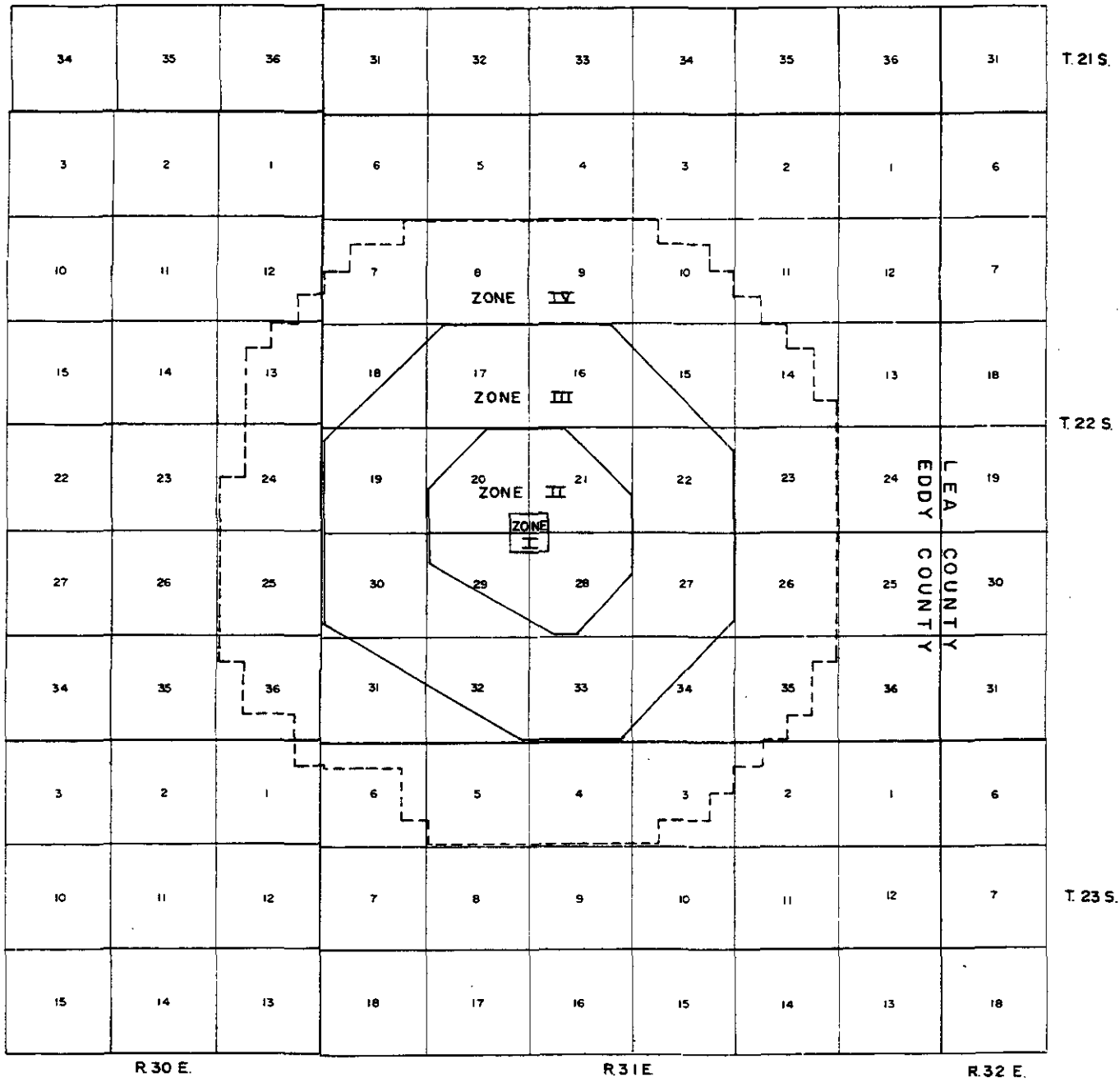

ZONE ACREAGE

ZONE I - 60-100 (surface facilities)

ZONE II - 1860 (underground repository)

ZONE III - 6230 (no mining or drilling)

ZONE IV - 10,810 (DOE-controlled mining and drilling)

1 0 1 2 3

SCALE IN MILES

WIPP SITE ZONATION

FIGURE 2-2

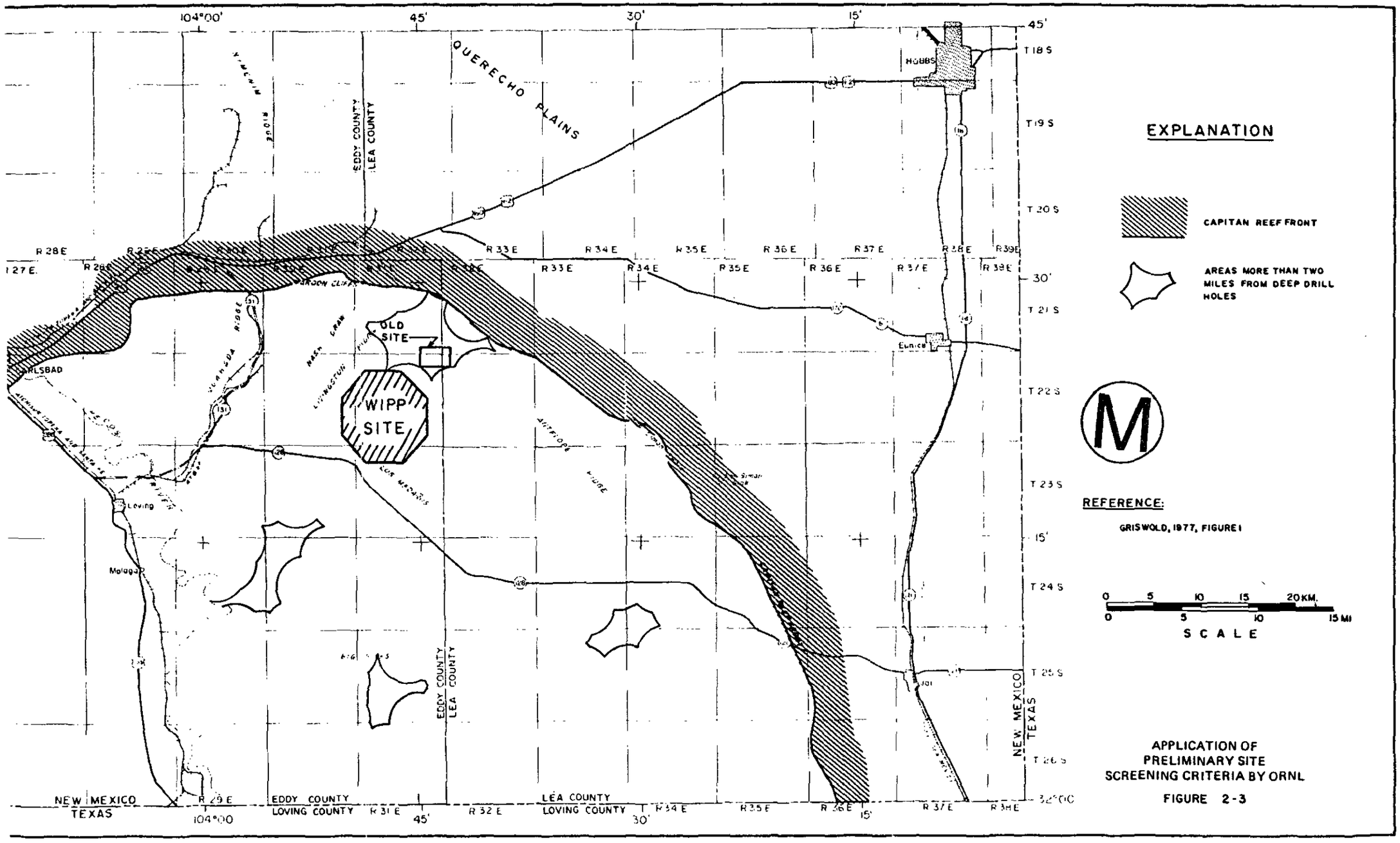

APPLICATION OF PRELIMINARY SITE SCREENING CRITERIA BY ORNL

FIGURE 2-3

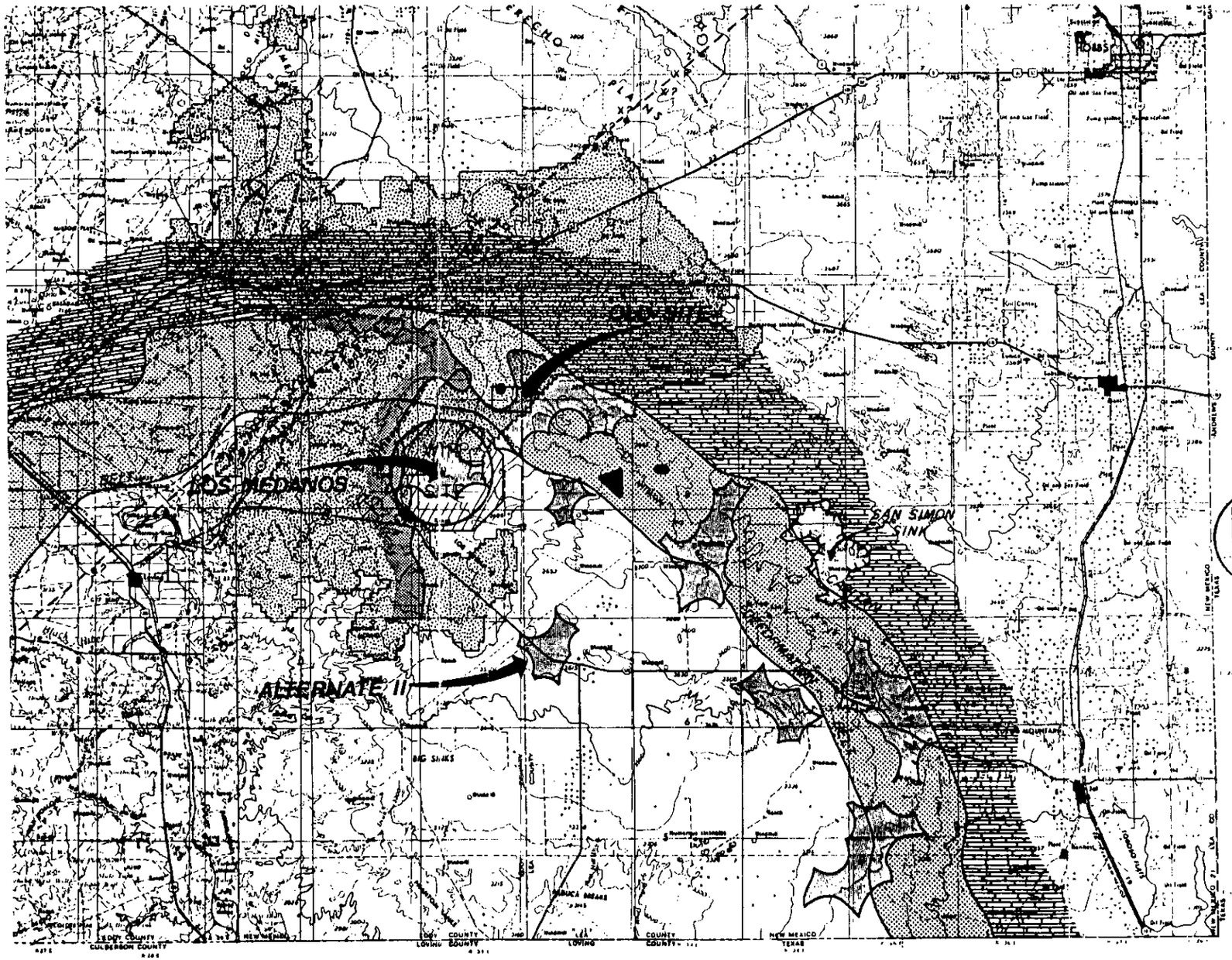

EXPLANATION

AREAS MORE THAN ONE MILE FROM DEEP DRILL HOLES

CAPITAN REEF FRONT

DEFORMATION BELT

DISSOLUTION FRONT AT TOP OF SALADO

KNOWN POTASH ENCLAVE

ARTESIAN BRINE FLOW (1, 2 OR 3 WELLS)

M

DIKE TREND SYMBOLS

- △ Outcrop of Dike
- ✧ Well Intercept of Dike
- ● Airborne Magnetic Response - 1960
- X Airborne Magnetic Response - 1963-64

0 5 10 15 20 KM.
0 5 10 15 MI
SCALE

REFERENCE:
GRISWOLD, 1977

SUMMARY OF APPLICATION OF SITE SELECTION CRITERIA BY SANDIA

FIGURE 2-4

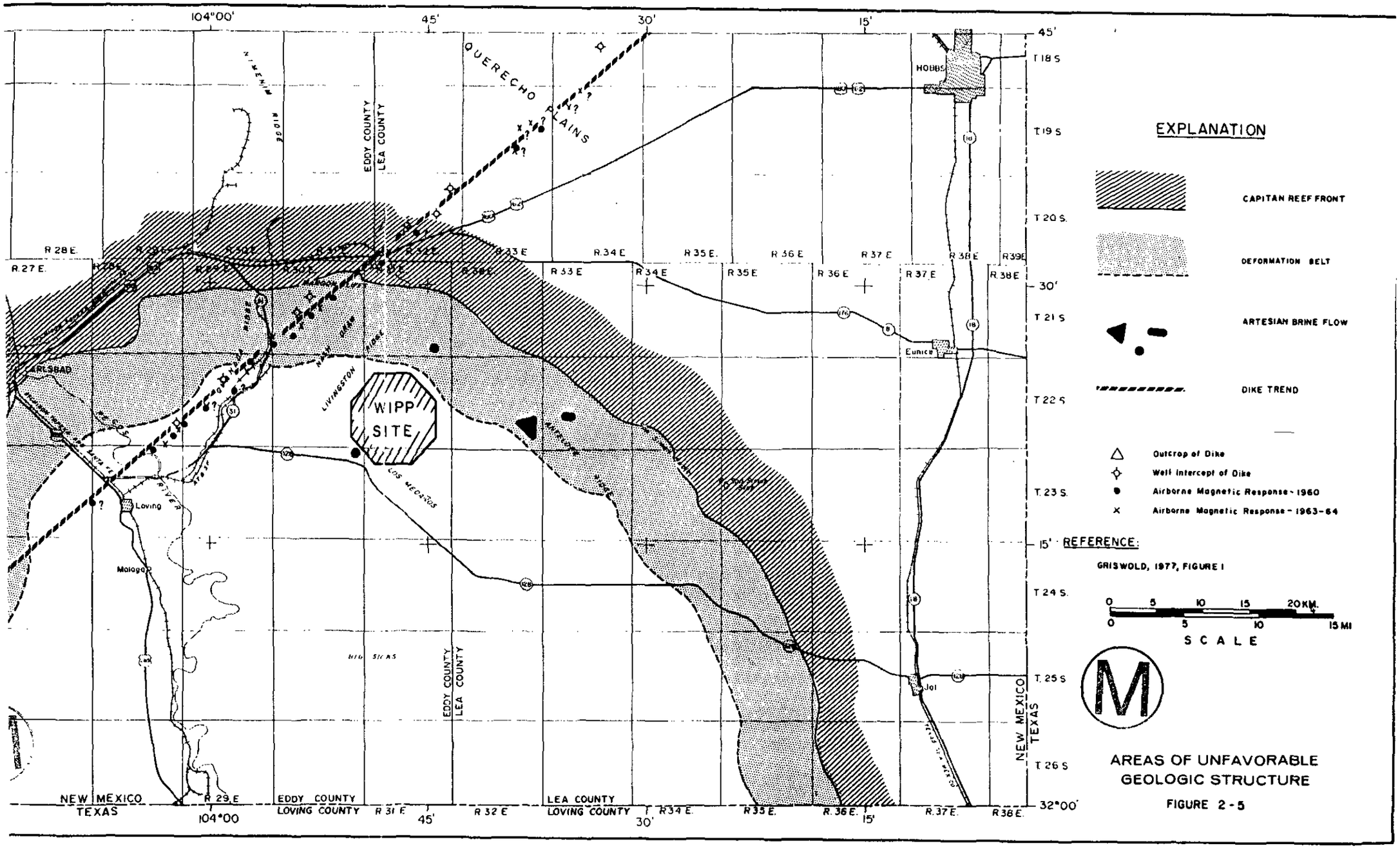

AREAS OF UNFAVORABLE GEOLOGIC STRUCTURE

FIGURE 2-5

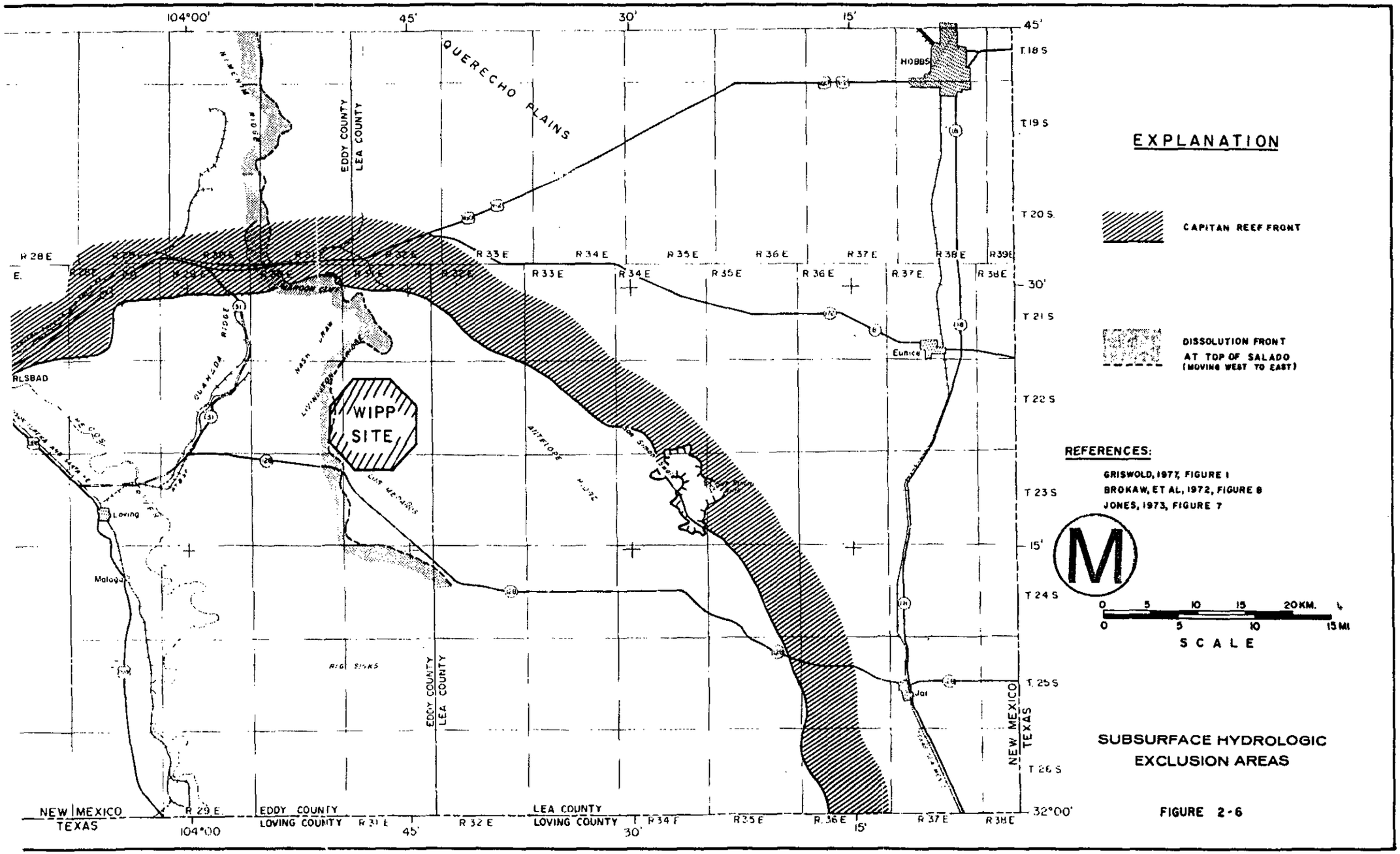

SUBSURFACE HYDROLOGIC EXCLUSION AREAS

FIGURE 2-6

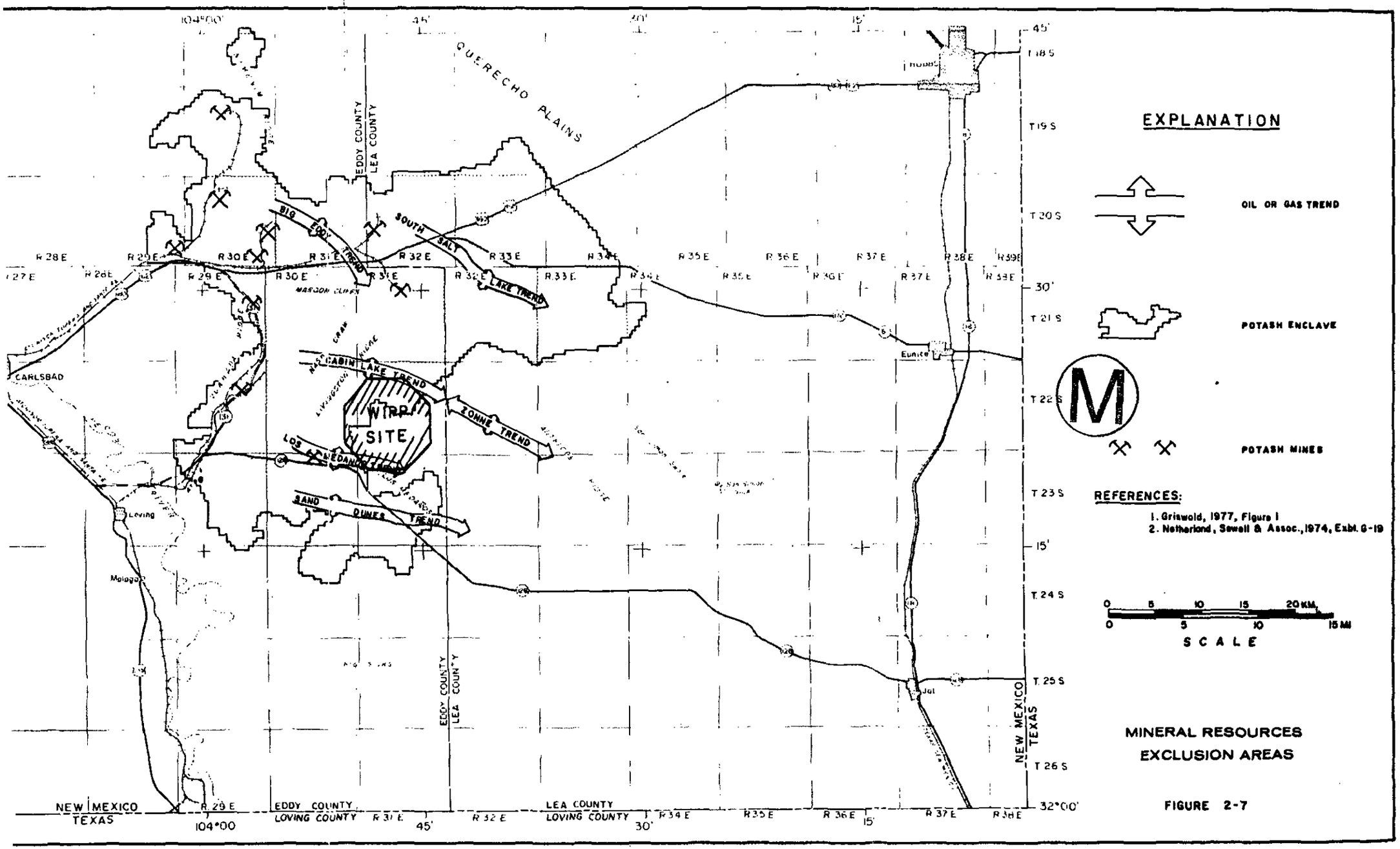
EXPLANATION
OIL OR GAS TREND
POTASH ENCLAVE
POTASH MINES
REFERENCES:
1. Griswold, 1977, Figure 1
2. Netherland, Sewell & Assoc., 1974, Exhi. G-19
SCALE
0 5 10 15 20 KM.
0 5 10 15 MI
MINERAL RESOURCES
EXCLUSION AREAS
FIGURE 2-7
QUERECHO PLAINS
EDDY COUNTY
LEA COUNTY
LOVING COUNTY
NEW MEXICO
TEXAS
CARLSBAD
Loving
Malaga
Eunice
Jal
WIPP SITE
BIG EDDY TREND
SOUTH SALT LAKE TREND
NASH CABIN LAKE TREND
ZONNE TREND
LOS MEDANOS TREND
SAND DUNES TREND
MARDON CLIFFS
LIVINGSTON RIDGE
T 18 S
T 19 S
T 20 S
T 21 S
T 22 S
T 23 S
T 24 S
T 25 S
T 26 S
R 28 E
R 29 E
R 30 E
R 31 E
R 32 E
R 33 E
R 34 E
R 35 E
R 36 E
R 37 E
R 38 E
R 39 E
104°00'
45'
30'
15'
32°00'

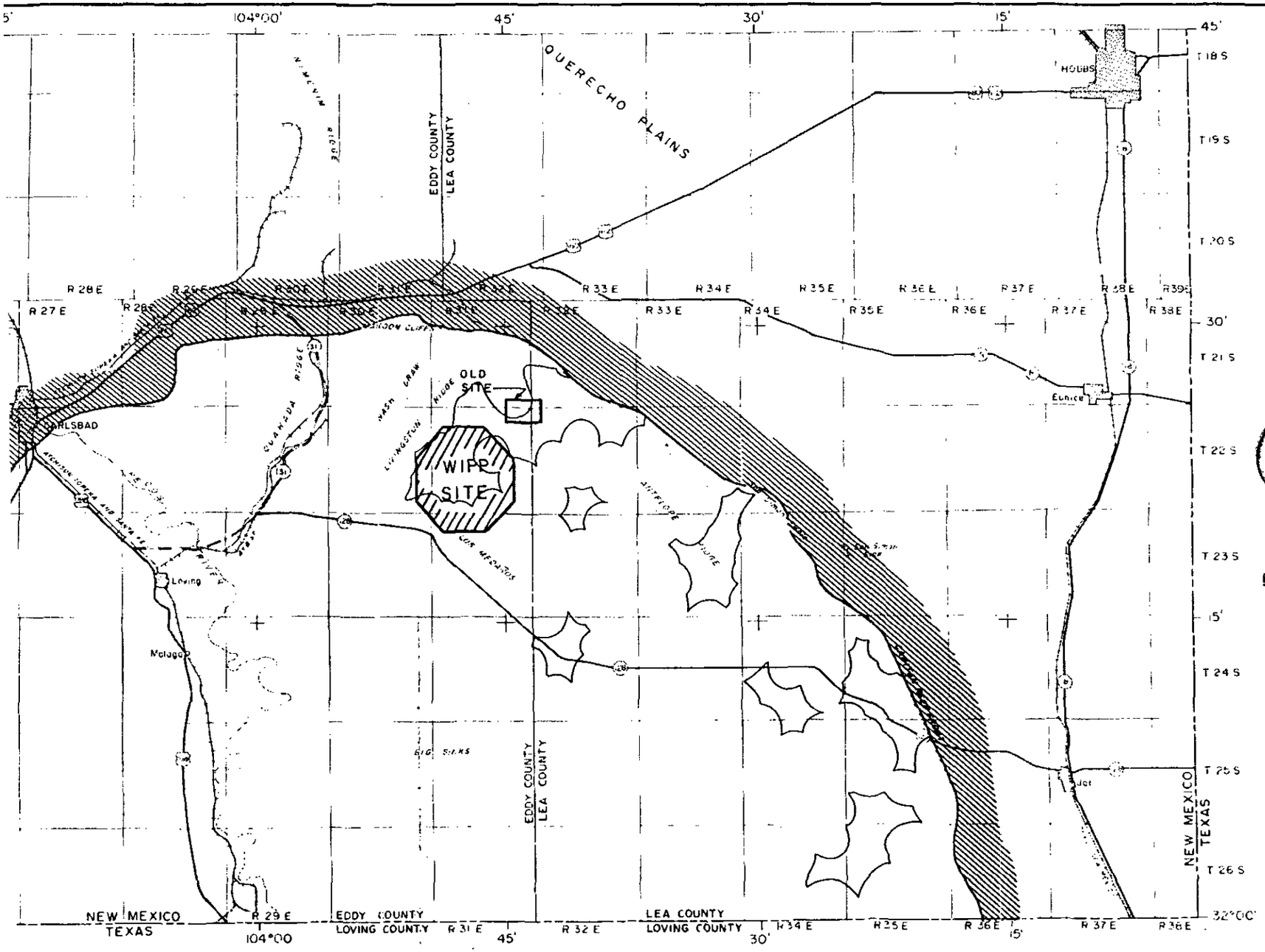

EXPLANATION

CAPITAN REEF FRONT

AREAS MORE THAN ONE MILE FROM DEEP DRILL HOLES

REFERENCE:

GRISWOLD, 1977

0 5 10 15 20 KM.
0 5 10 15 MI
SCALE

DEEP DRILL - HOLE EXCLUSION AREAS

FIGURE 2-8

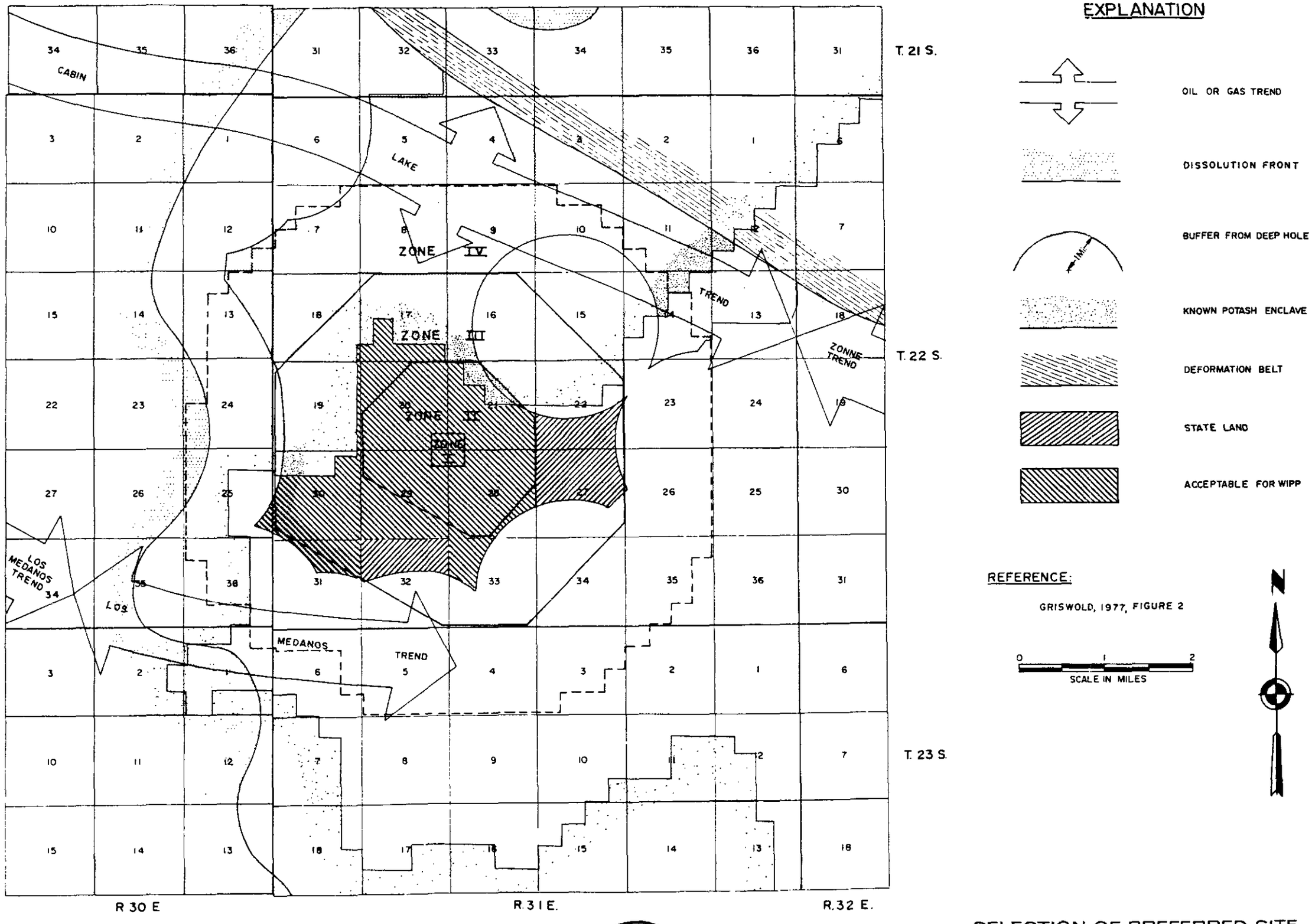

SELECTION OF PREFERRED SITE

FIGURE 2-9

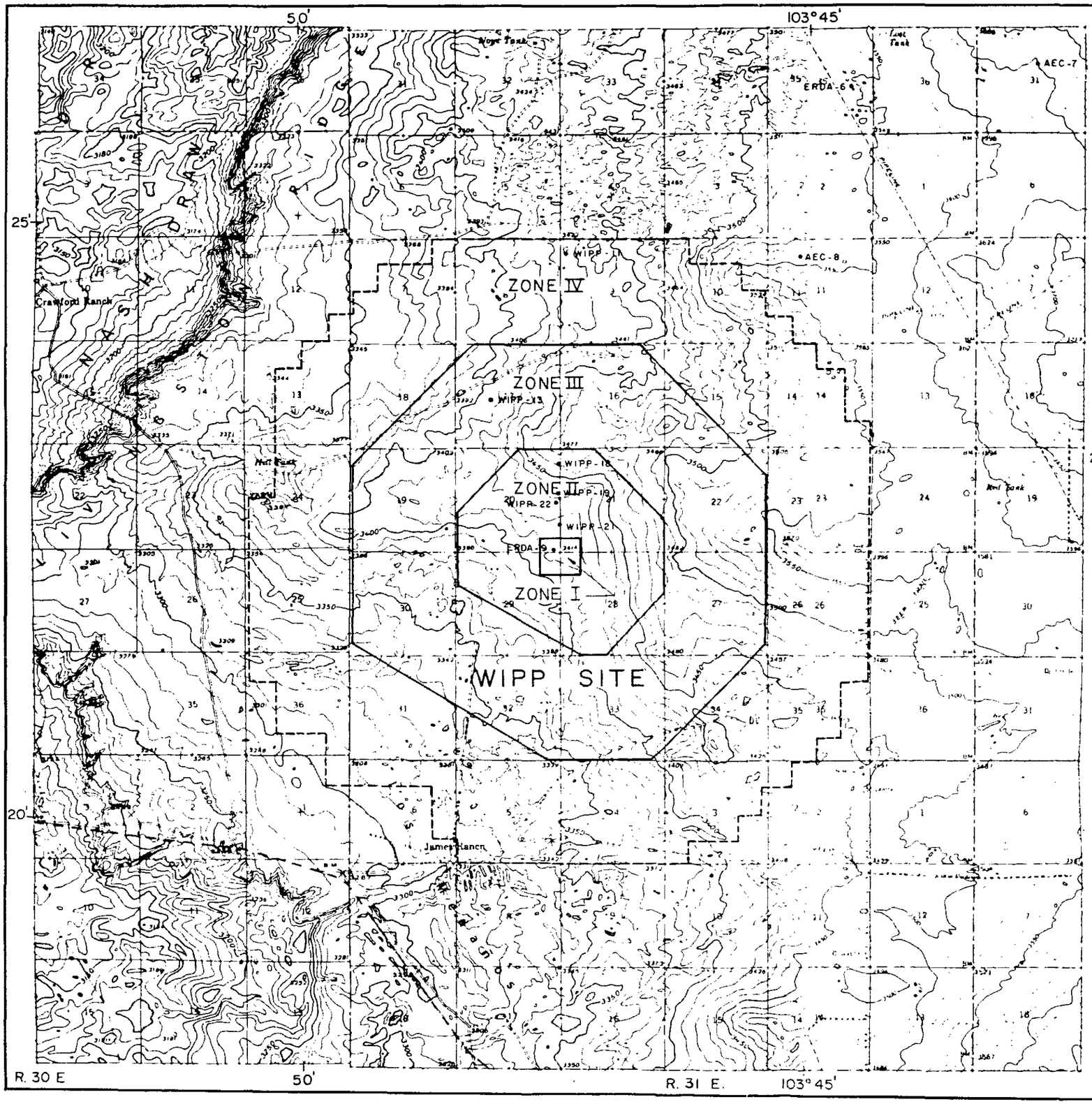

M

REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

0 1 2 3 MILES

0 1 2 3 KM.

SCALE

WIFP SITE STRATIGRAPHIC HOLES

FIGURE 2-10

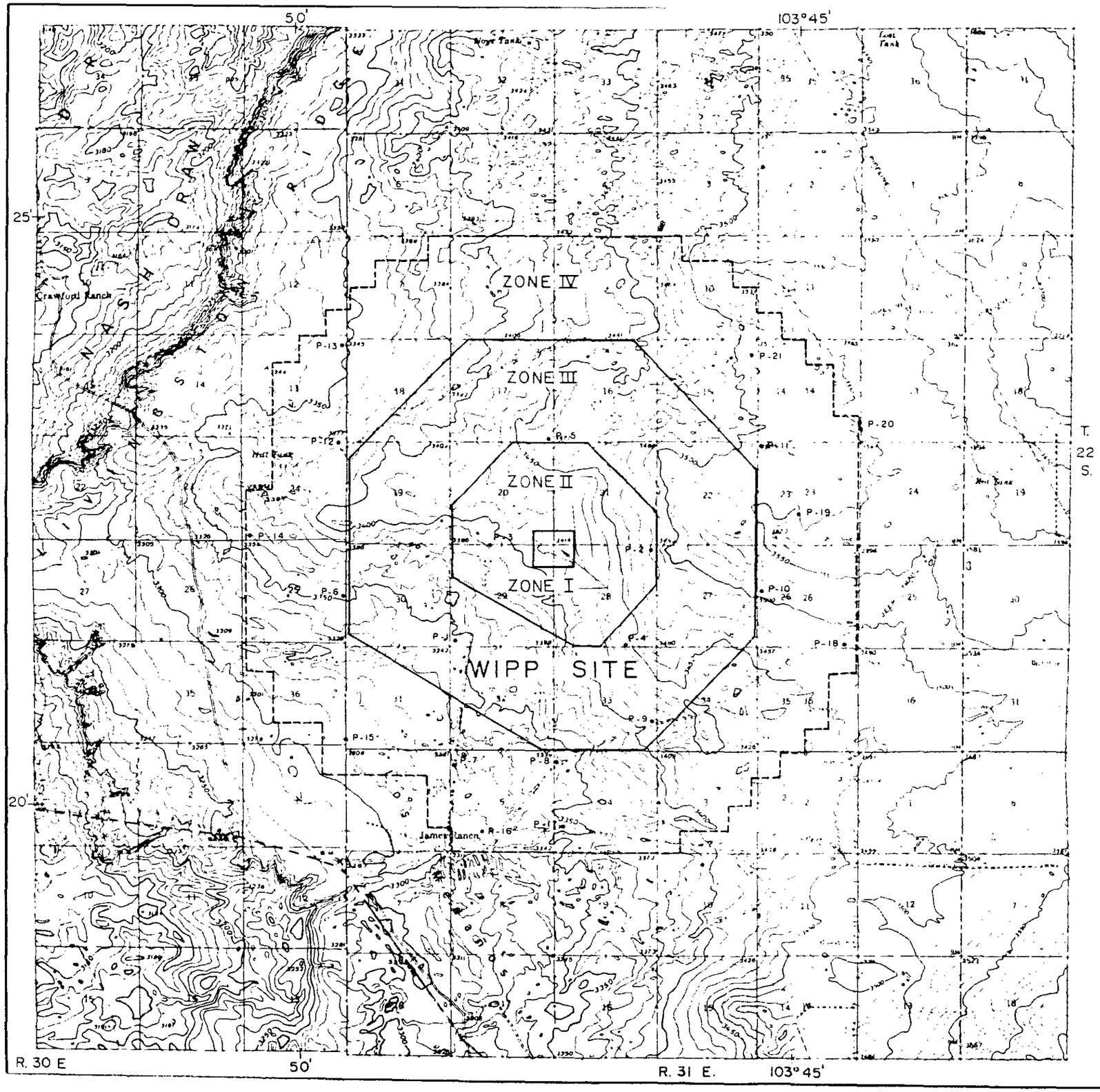

M

REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N. Mex., 1965 and Hat Mesa, N. Mex., 1972.

0 1 2 3 MILES
0 1 2 3 KM.
SCALE

WIPP SITE POTASH DRILLING BY ERDA, 1976

FIGURE 2-11

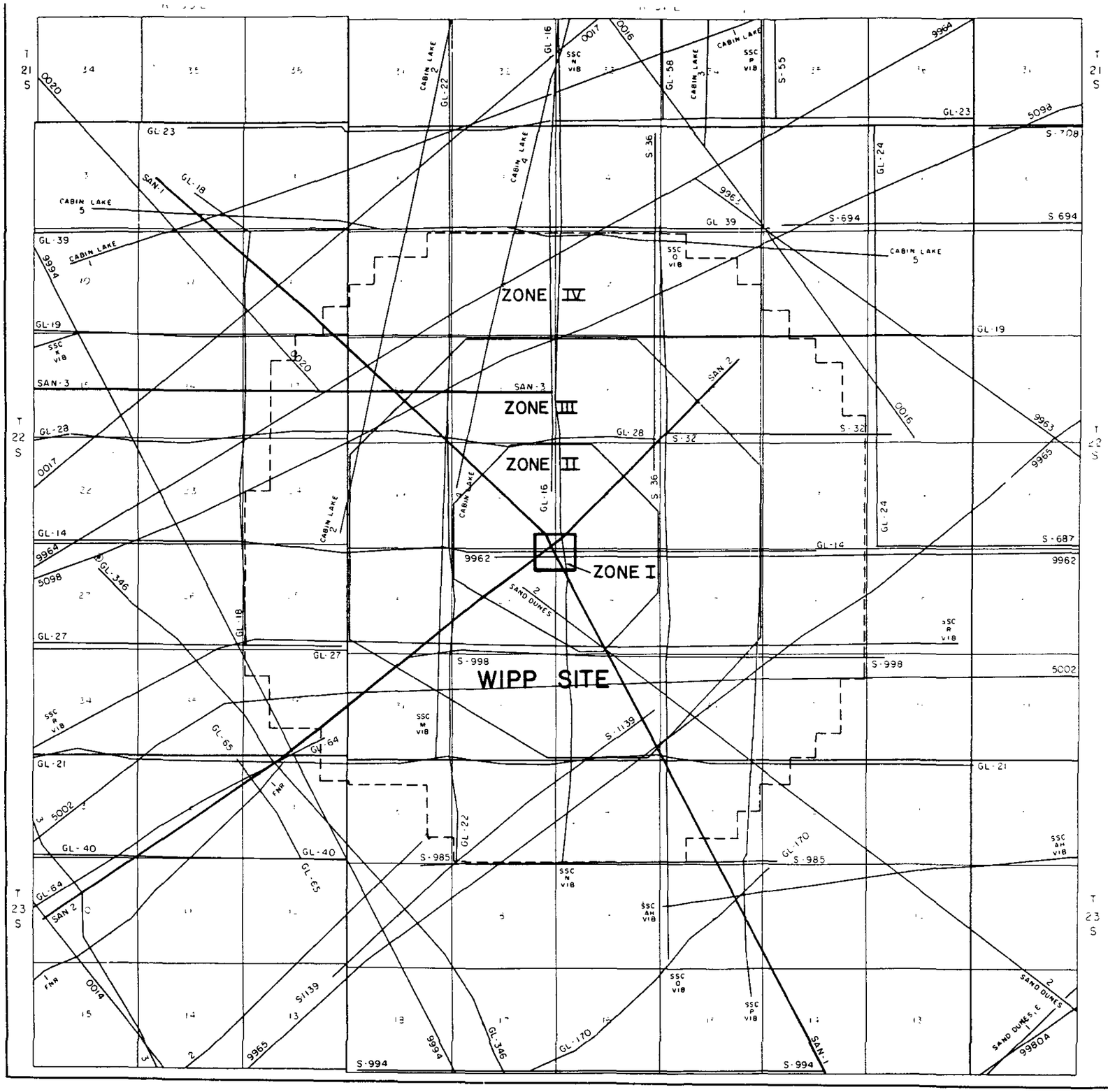

INDUSTRY SEISMIC REFLECTION LINES
PLUS SANDIA REFLECTION LINES
(SAN. – 1, 2, 3) FROM 1976

FIGURE 2-12

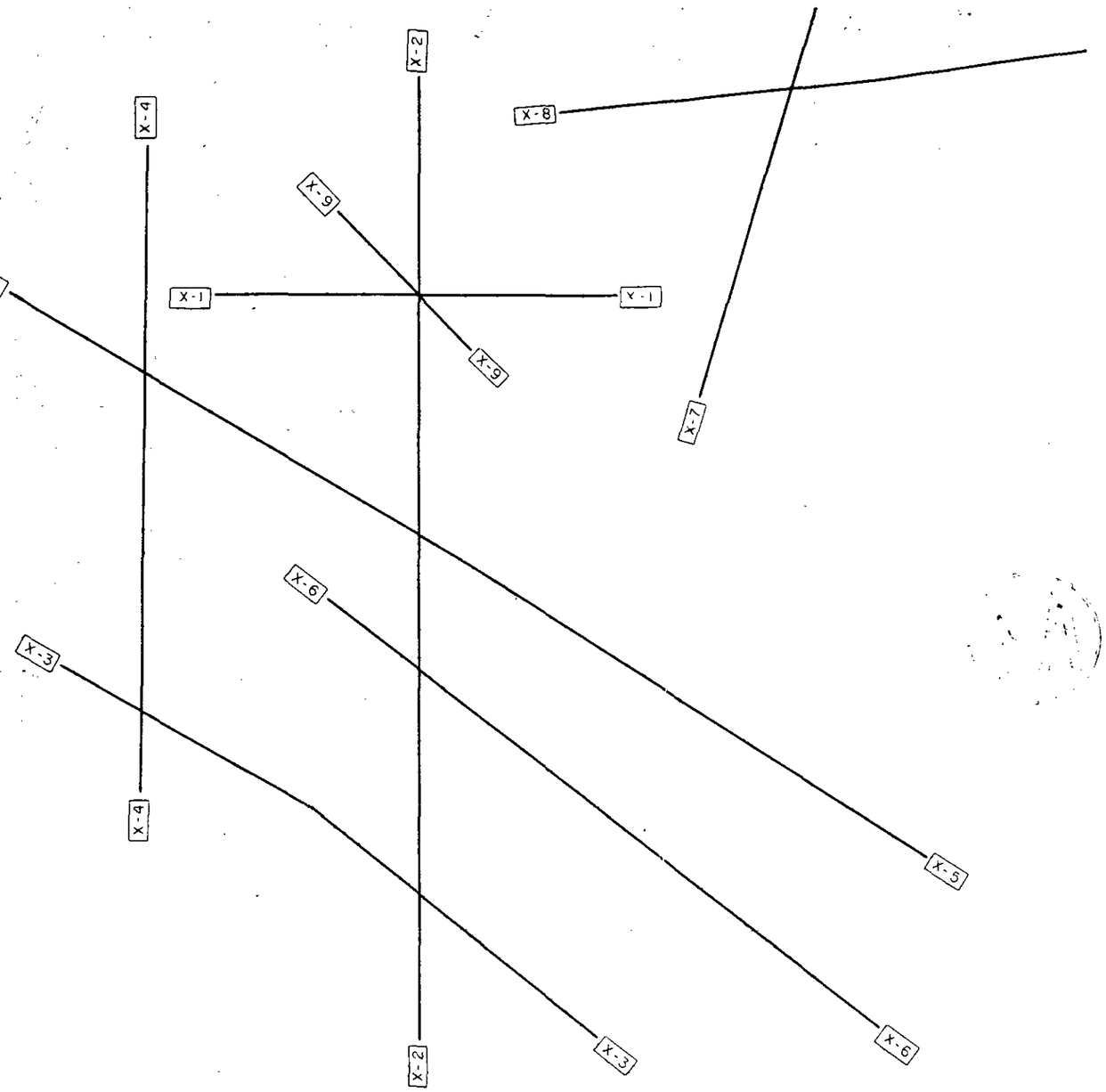

REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

0 1 2 3 MILES
0 1 2 3 KM
SCALE

SEISMIC REFECTION LINES FOR

SEISMIC PROGRAM, 1977

FIGURE 2-13

12

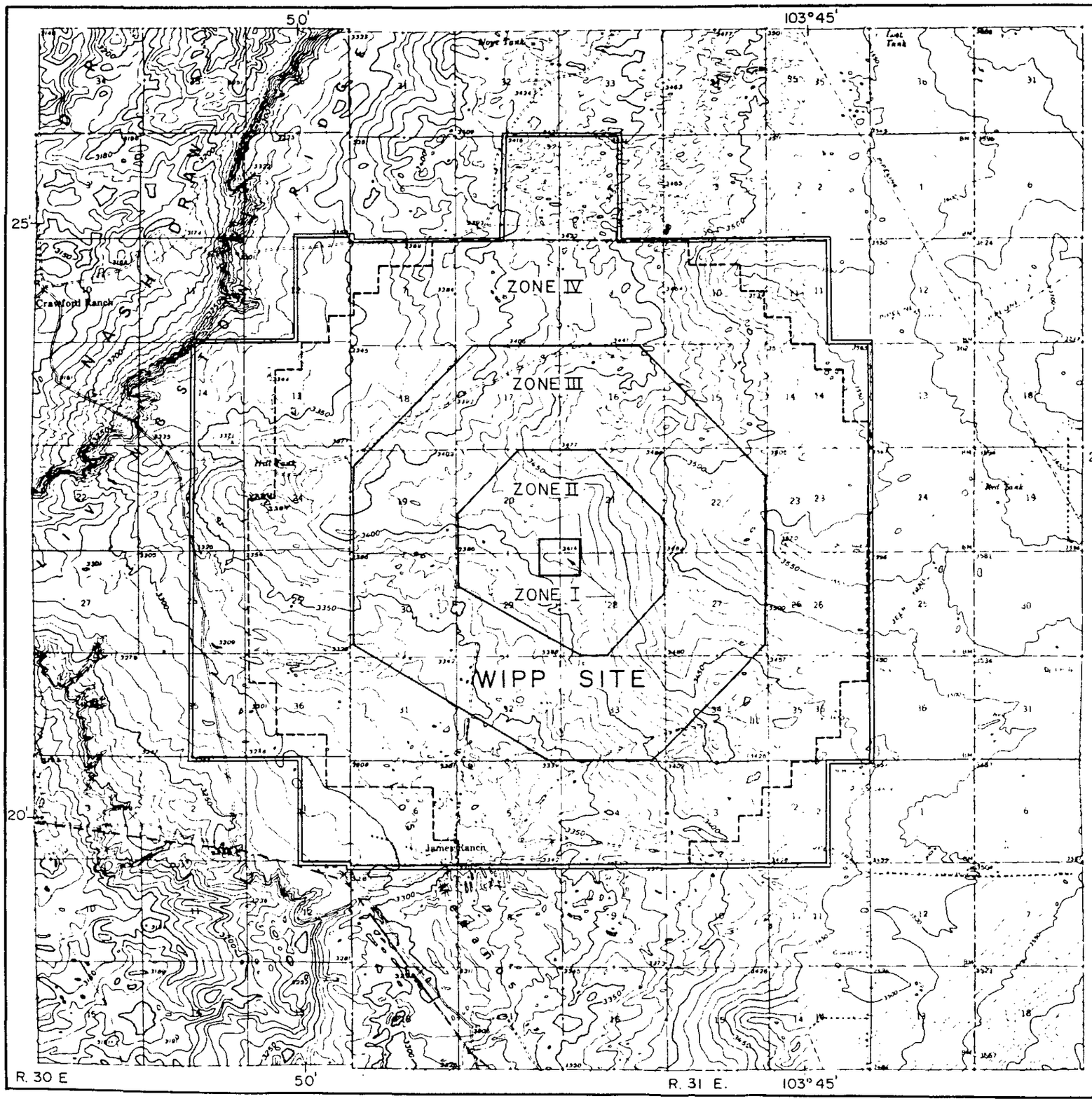

EXPLANATION:

═══ Outer Boundary of Resistivity Measurement Area

REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

0 1 2 3 MILES

0 1 2 3 KM.

SCALE

PROFILE LOCATION MAP
OF
GRADIENT ARRAY RESISTIVITY

FIGURE 2-14

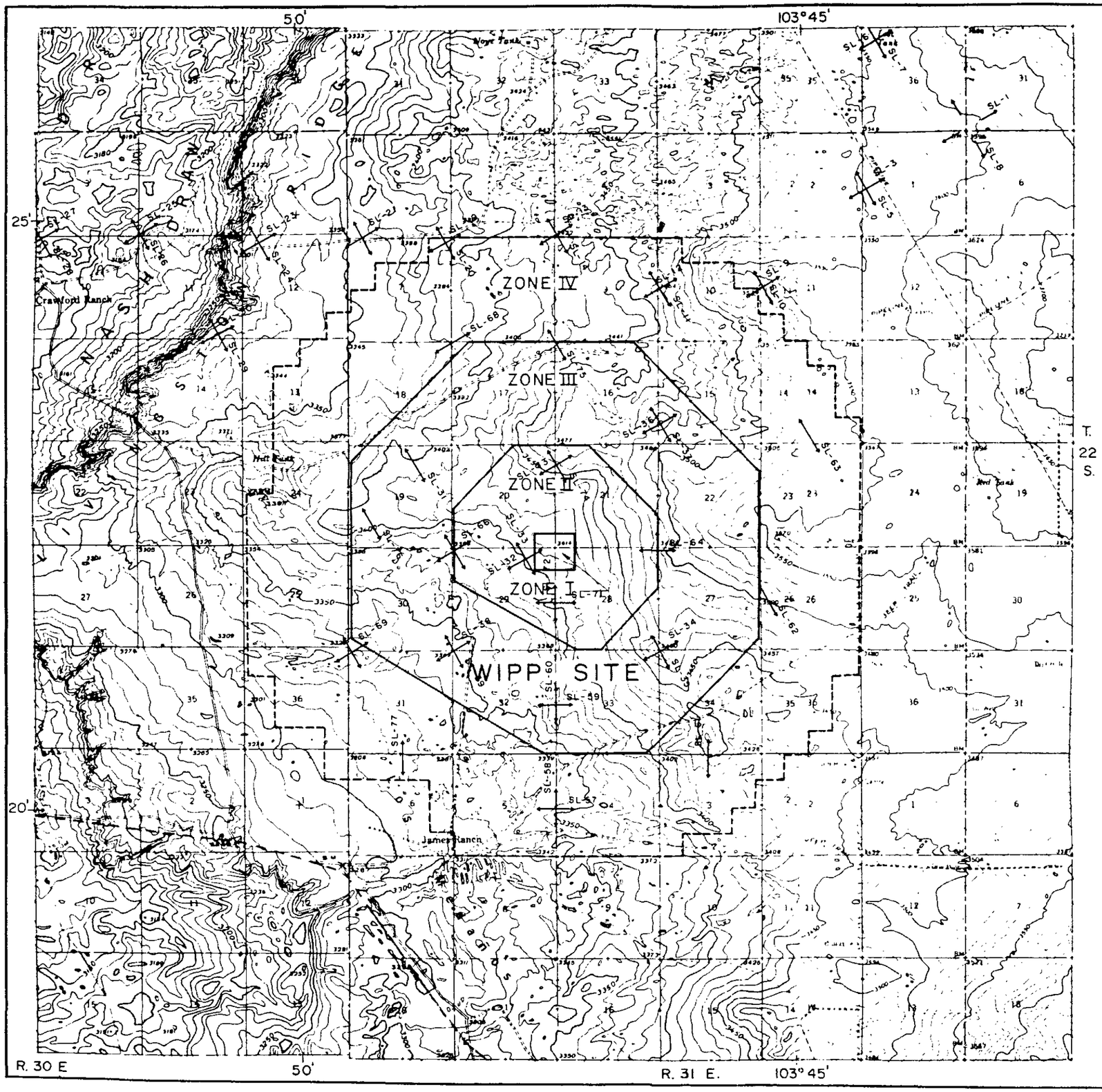

Schlumberger Array Soundings with Line No. and Direction

REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

0 1 2 3 MILES
0 1 2 3 KM.
SCALE

LOCATION MAP
FOR
RESISTIVITY SOUNDINGS

FIGURE 2-15

TABLE 2-1

WIPP SITE CONTROL ZONES

Zone	Area Description	Surface Use and Activity Control	Approximate Acreage
I	Surface Exclusion Area	All non-WIPP activities excluded (security fenced area).	60(to 100)
II	Underground Storage Limits	Restricted; land use same as Zone III. Must be free of prior lease rights.	1,860
III	Restricted Buffer Zone	Drilling & mining operations prohibited. Current livestock grazing activities permitted. Other future activities subject to approval and regulation under ERDA authority.	6,230
IV	Controlled Use Buffer Zone	Drilling and mining operations permitted but restricted in conformance with ERDA specifications. Solution mining, well injection recovery methods prohibited. Other activities as specified for Zone III.	10,810
		TOTALS	18,960

TABLE 2-2

A. GEOLOGIC EXPLORATORY HOLES
(Figure 2-10)

Designation	Location	Date	Purpose
AEC 7	21/32/31	3/74	ORNL Stratigraphic--Old Site
AEC 8	22/31/11	4/74, 6/76	ORNL Stratigraphic--Old Site Sandia--Deep Hydrology--Old Site
ERDA 6	21/31/35	6/75	Stratigraphic--Old Site
ERDA 9	22/31/20	4/76	Stratigraphic--WIPP Site
ERDA 10*	23/30/34	8/77	Deep Dissolution--Off Site
WIPP 11	22/31/9	2/78	Stratigraphic--WIPP Site
WIPP 13	22/31/17	7/78	Stratigraphic--WIPP Site
WIPP 15*	23/35/18	3/78	Paleoclimate--Off Site
WIPP 18	22/31/20	2/78	Stratigraphic--WIPP Site
WIPP 19	22/31/20	4/78	Stratigraphic--WIPP Site
WIPP 21	22/31/20	5/78	Stratigraphic--WIPP Site
WIPP 22	22/31/20	5/78	Stratigraphic--WIPP Site

* not shown on Figure 2-10

B. ERDA POTASH HOLES
(Figure 2-11)

Designation	Location	Date
P1	22/31/29	8/76
P2	22/31/21	8/76
P3	22/31/20	8/76
P4	22/31/28	8/76
P5	22/31/17	9/76
P6	22/31/30	9/76
P7	23/31/5	9/76
P8	23/31/4	9/76
P10	22/31/26	9/76
P11	22/31/23	9/76
P12	22/30/24	9/76
P13	22/31/18	9/76
P14	22/30/24	9/76
P15	22/31/21	8/76
P16	23/31/5	9/76
P17	23/31/4	10/76
P18	22/31/26	10/76
P19	22/31/23	10/76
P20	22/31/14	10/76
P21	22/31/15	10/76

TABLE 2-2 (Continued)

C. HYDROLOGIC TEST HOLES
(See Figure 6.3-5)

Designation	Location	Date	Purpose
H1	22/31/29	5/76	Rustler, Top Salado Hydro
H2a	22/31/29	2/77	Magenta
H2b	22/31/29	2/77	Culebra
H2c	22/31/29	2/77	Top Salado
H3	22/31/29	7/76	Rustler, Top Salado Hydro
H4a*	22/31/5	5/78	Magenta
H4b*	22/31/5	5/78	Culebra
H4c*	22/31/5	4/78	Top Salado
H5a*	22/31/15	6/78	Magenta
H5b*	22/31/15	6/78	Culebra
H5c*	22/31/15	5/78	Top Salado
H6a*	22/31/18	7/78	Magenta
H6b*	22/31/18	6/78	Culebra
H6c*	22/31/18	6/78	Top Salado

* Holes being drilled at time of report

GCR CHAPTER 3

REGIONAL GEOLOGY

3.1 INTRODUCTION

This chapter considers the physiography and geomorphology, stratigraphy and lithology, structure and tectonics, igneous activity, and geologic history of the southeast New Mexico-west Texas area within a radius of about 200 miles of the proposed WIPP site. The information presented in the discussion below has been derived from previously available published and unpublished sources, including well-known reference texts, U.S. Geological Survey publications and open-file reports, Roswell Geological Society and New Mexico State Bureau of Mines and Mineral Resources materials, journal articles, and reports prepared under contract to Sandia Labs. A study of LANDSAT imagery was also conducted to examine lineaments as well as physiographic and structural features.

Section 3.2 presents a general description of the physiographic divisions, illustrated in Figure 3.2-1, which lie within approximately 200 miles of the site, followed by a more detailed study of the origin and development of those geomorphic features having significance to the site and by a consideration of relative erosion rates estimated for the future in the area surrounding the site.

Section 3.3 summarizes the major rock types and stratigraphic nomenclature by which the Precambrian basement and overlying sedimentary section are characterized within an area roughly bounded by the Sacramento Mountains on the northwest, and by Texas' Midland and Val Verde basins on the south and southeast. Generalized cross sections, depicting the entire stratigraphic section present in the area (Figure 3.3-2) and a study of Permian reef relationships (Figure 3.3-4) as well as correlations of the Precambrian rocks, (Figure 3.3-1) and Permian section (Figure 3.3-3) supplement the discussion.

Section 3.4 describes the major structural elements comprising the southeast New Mexico-west Texas region and summarizes the history of their tectonic development. The features discussed include the major subsurface basins and platforms of Late Paleozoic origin, which together have produced the essential structural framework of the area, and large-scale Cenozoic features, which generally possess surficial structural expression, as well as the more important smaller structures occurring within the boundaries of these elements. The structures considered in this section are displayed in Figure 3.4-1, and a basement contour structure map (Figure 3.4-2) demonstrates the basic structural configuration of the region.

The major occurrences of igneous activity within the site region are described in Section 3.5. As demonstrated in Figure 3.5-1, this igneous activity has been generally limited to the area west and south of the proposed WIPP site, in the form of Tertiary intrusive bodies and volcanic terrains. The igneous feature nearest to the site, a northeast-trending dike located about nine miles northwest of the site, is discussed separately in this section and is illustrated in Figure 3.5-2.

Section 3.6 presents a synthesis of the major events which have affected the site region, as these have been determined from lithologic and structural data available in the area. A schematic visualization of the regional geologic history, as correlated with the geologic time scale, is provided in Figure 3.6-1.

3.2 REGIONAL PHYSIOGRAPHY AND GEOMORPHOLOGY

Figure 3.2-1 presents the major physiographic units which encompass the southeast New Mexico-west Texas region. The discussion below includes a general description of the physiographic sections, as defined by Fenneman (1931), which lie within a radius of about 200 miles of the proposed WIPP site. This is followed by a more detailed description of the development of the major nearer site landforms.

3.2.1 Physiographic Setting

The proposed WIPP site is located within the eastern part of the Pecos Valley section of the southern Great Plains physiographic province. The Great Plains physiographic province comprises a broad highland belt sloping gradually eastward from the Rocky Mountains and Basin and Range province to the Central Lowlands province. The Great Plains province in turn represents the western extent of the Interior Plains major physiographic division (Fenneman, 1931).

Pecos Valley Physiographic Section The Pecos Valley section consists of the Pecos and upper Canadian valleys, which together form a long north-south trough carved from what was once part of the High Plains section on the east, but whose axis now lies 500 to 1,000 feet below the High Plains surface -- the Llano Estacado. The Guadalupe and Sacramento mountains of the Basin and Range physiographic province flank the Pecos Valley section to the west.

The topography of the Pecos Valley section varies from flat plains and lowlands to rugged canyon lands. Except where covered by alluvium, much of the land surface has an uneven rock floor, which results from the erosion of the moderately resistant limestones, sandstones, shales and gypsum to form scarps, cuestas, terraces, side canyons and some mesas of limited extent. The valleys of the Pecos River in the vicinity of the Delaware Basin exhibit a characteristic lowland topography marked by widespread solution-subsidence features, which have resulted from dissolution within the Upper Permian Ochoan rocks (see the karst topography discussion below).

The land surface generally slopes gently eastward, reflecting the attitude of the underlying rock strata. The average elevations within the section range from over 6,000 feet above sea level in the northwest and about 5,000 feet in the north to 4,000 feet on the east and 2,000 feet to the south (Fenneman, 1931).

The Pecos Valley section is drained primarily by the Pecos River which lies slightly to the west of the center of the Pecos trough and flows in a southeast to southward direction through most of the length of the section. The extreme northeastern portion of the section is also drained by a short segment of the generally eastward-flowing Canadian River. Owing to the desert character of the area, most of the tributaries of these major streams flow only intermittently, and some creeks drain into local depressions, where the water evaporates or percolates into the underlying sediments.

The Canadian River has cut much more deeply into the surrounding land than has the Pecos River, thereby producing a much greater relief in the far nothern portion of the section than is present to the south.

The northern portion of the Pecos River, north of Roswell, has cut a valley in places as deep as 1,000 feet below the surrounding land surface and from 5 to 30 miles wide. The central portion of the river, from about 50 miles north of Roswell to near the New Mexico-Texas border, flows through an alluvial valley of comparable width but much reduced relief and is underlain by as much as 250 feet of alluvium near Carlsbad. The southern part of the Pecos, just north of the Edwards Plateau, flows across an alluvial plain, called the Toyah Basin, which is similar to that further north and comprises most of the west Texas portion of the Pecos Valley section (Fenneman, 1931). The genesis and development of the Pecos River system are discussed in Section 3.2.2, below.

The immediate valley of the Pecos River is bordered on the east by almost continuous bluffs, beyond which the eastward-dipping rock strata lie at or near the surface for a distance of several miles. A sloping alluvium-mantled plain extends eastward from this rocky belt to the westward face of the Llano Estacado (Fenneman, 1931).

<u>High Plains Physiographic Section</u> East of the Pecos Valley section lies the High Plains section of the Great Plains physiographic province,

extending from South Dakota on the north to near the Rio Grande (river) in Texas. The High Plains are remnants of a former great fluviatile plain, which stretched from the mountains on the west to the Central Lowlands on the east. The portion of the High Plains east of the Pecos valley is known as the Llano Estacado and comprises approximately 20,000 mi^2 of almost completely flat plain, which has undergone very little dissection. Northward, the land is more dissected, and the original flat surface is still preserved only along stream divides.

The High Plains originated through deposition of the Late Tertiary Ogallala Formation, resulting in more than 500 feet of silts with lesser gravels and sand. The deposits were laid down in alluvial fans by overloaded streams flowing eastward from the Rocky Mountain area over an irregular erosional surface. By the end of the time of formation of the Ogallala, the High Plains surface was probably continous across the area of the present Pecos River drainage to the back slope of the Sacramento Mountains (Bachman, 1976) (also see Section 3.6.5). In many areas, the nearly flat surface which resulted was later cemented by a hard caliche layer. The almost perfect preservation of the orginal topography in the Llano Estacado area is due to a combination of the porous nature of the sediments, the protection afforded by the caliche, and the relatively arid climate of the region (Fenneman, 1931).

The few, generally insignificant topographic features present in the High Plains section consist mainly of depressions derived from a variety of origins, such as dissolution with subsidence, blowout activity, buffalo wallowing or differential compaction of the Tertiary sediments. Ponding of water occurs in these depressions following rain storms, and a few maintain permanent pools (Thornbury, 1965). Sand dunes also occur in scattered locations throughout the section, generally fringing the leeward sides of streams (Fenneman, 1931).

<u>Edwards Plateau Physiographic Section</u> The Llano Estacado merges southward into the Edwards Plateau section of the Great Plains province by the gradual thinning and disappearance of the Ogallala Formation. It

comprises a wedge-shaped portion of west Texas, and then extends across the Rio Grande into Mexico. The Edwards Plateau is bounded on all sides by an escarpment, except for two small areas, where it merges with the Llano Estacado on the northwest and where it terminates against the mountains of the Mexican Highlands on the west. The northern edge of the plateau, bounding the Central Texas Section, is formed by an eroded and deeply notched southward-retreating escarpment, and the southern boundary is marked by a line of faulting and local folds, which produces an escarpment up to 1,000 feet high (Fenneman, 1931).

The Edwards Plateau ranges in elevation from 3,000 feet on the north at its border with the Llano Estacado and 4,000 feet at the foot of the mountains on the west to 2,200 feet along its southern margin and 1,000 feet at the southeast corner.

The surface of the Edwards Plateau is underlain by a single resistant layer of limestone dipping gently to the south and east, which has encouraged the development of rather flat-lying terrain and bold escarpments. In the eastern part of the plateau, where rainfall is greatest, the plateau is narrow and highly cut by the dissection moving inward from the margins. West of the 100th meridian, the plateau becomes a drier, broad area covered by a plain much like the Llano Estacado. The wide, shallow valleys that have formed in this part of the section generally carry runoff only during rain storms. However, the Pecos River and Rio Grande have cut canyons across the section as deep as 1,000 feet. And on all sides where escarpments exist, the dissected edges carry outflowing streams.

Other surface features on the plateau are limited and generally restricted to erosion or dissolution-type structures. Some shallow sinkholes exist in areas where dissolution of the underlying limestone has caused a collapse of the land surface (Fenneman, 1931).

<u>Sacramento Physiographic Section</u> West of the Pecos section lies the Sacramento section of the Basin and Range physiographic province,

comprising a narrow, north-south strip approximately 300 miles long and less than 70 miles wide (Fenneman, 1931). The section is bordered on the west and south by the Rio Grande depression (Thornbury, 1965) and Mexican Highlands and on the east by the Great Plains province. The northeastern boundary of the Sacramento section is formed by the eastward escarpment of the Glorieta mesa, an intricately carved divide of horizontal strata. Farther south, the Capitan escarpment marks the boundary of the two provinces along the southeast side of the Guadalupe Mountains and is exposed for a distance of some 45 miles between Carlsbad and El Capitan Peak (Thornbury, 1965).

Topographically, the section is characterized by two major basinal areas, called bolsons, located at the north and south ends of the section, and by a series of intervening mountain ranges (Thornbury, 1965).

The Estancia Valley, or Sandoval Bolson, forms the central feature of the north part of the section, and is bordered on the east by the Glorieta Mesa and Pedernal Hills, on the west by the Sandia and Manzano Mountains, and on the south by the elevated Chupadera Mesa. The Estancia Valley, primarily composed of a group of salt basins and dunes or low hills, was the site of an extensive lake during Pleistocene time (Thornbury, 1965), which is now reduced to several small salt lakes.

Southeastward from the Estancia Valley and Pedernal Hills lie a series of mountain ranges, many of which are bordered on the west by bold scarps and on the east by gently dipping slopes extending toward the Pecos Valley. Sierra Blanca, the highest of the mountain ranges, reaches an elevation of approximately 12,000 feet above sea level. The other ranges attain maximum elevations of from 8,000 to 10,000 feet (Fenneman, 1931).

At the south end of the Sacramento section is a second large bolson known as the Salt Basin, situated west of the Guadalupe and Delaware Mountains and east of the Sierra Diablo or Diablo Plateau. The Salt Basin is a large down-faulted block with an average floor elevation of about 3,600 feet above sea level. The floor lies some 800 feet below the basin rim

(Thornbury, 1965). The basin covers an area approximately 150 miles long and from 8 to 20 miles wide, rising on both north and south ends to merge into rocky plateaus (Fenneman, 1931). The floor of the basin is covered almost entirely by unconsolidated Cenozoic sediments, with rocky outcrops limited primarily to the margins of the basin (Thornbury, 1965). The LANDSAT color composite of this vicinity shows that the surface sediments are sandy, with a series of salt lakes present in the center of the Salt Basin. Evidence of two Pleistocene lake phases in the basin have been described by King (1948), but their time of formation during the Pleistocene is uncertain.

Mexican Highland Physiographic Section West and south of the Sacramento section lies the vast Mexican Highland section of the Basin and Range physiographic province. This section extends southeastward from Nevada and the Colorado Plateau far into Mexico, where it has its maximum development. The eastern boundary in New Mexio is unclear but is defined as extending east of the Rio Grande to about longitude 106°W, where alternating basins and ranges give way to the faulted and sloping plateaus of the Sacramento section (Fenneman, 1931).

The Mexican Highland section consists of almost equal areas of mountains and plains or basins. In the eastern portion of the section, the mountains generally trend north-south, while in the west they trend northwestward. Of the intermountain area, about half is bolson, and the rest drains or slopes toward the major rivers, such as the Rio Grande. The following discussion considers further only the large-scale features within the eastern part of the section.

The Mexico Highlands mountain ranges of Texas and New Mexico can be grouped into three or more north-south lines from 10 to 50 miles apart and are dominantly Great Basin type, in common with those of the western half of the section. Faulting and related deformation as well as volcanic activity have formed these ranges since Late Tertiary times.

Between the eastern mountain ranges lie generally continuous, flat-floored troughs separated by divides into bolsons or drainage basins (Fenneman, 1931). The two major basins here are the Hueco and Tularosa, on the north, which together mark the eastern border of the section in New Mexico and Texas. They form a trough about 30 to 40 miles wide and 125 miles long, interrupted at the Texas border by a low divide separating the two basins. These basins are grabens in general configuration, bordered on both east and west by fault-bounded mountain ranges. The floors of the basins are relatively flat and slope southward from an elevation of about 4,500 feet at the north end of the Tularosa Basin to 3,500 feet at the south end of the Hueco Basin. The Tularosa Basin exhibits centripetal drainage marked by arroyos and a great salt marsh flanked by the gypsum dunes of White Sands monument.

The northern end of the Tularosa Basin is bordered by Chupadera Mesa averaging 7,000 feet elevation and underlain by gently eastward-dipping Permian strata, which have been dissected almost to maturity (Fenneman, 1931).

3.2.2 Major Geomorphic Features in the Site Vicinity The geomorphic development of the major land forms which constitute the near-site setting are discussed in this section. These features include the Pecos River drainage system, the Mescalero Plain and associated deposits, karst topography and blowouts. In general, these geomorphic features as considered below are located within the Pecos Valley physiographic section.

Pecos River Drainage System The Pecos River, 20 miles west of the site, is the only major, perennial stream in the Eddy and Lea Counties area of southeastern New Mexico. It receives almost all of the surface drainage in this region and a large part of the subsurface drainage. The Pecos originates in the southern Rocky Mountains of north-central New Mexico and flows south and southeastward to join the Rio Grande in west Texas (Kottlowski, et al., 1965). The dimensions of the contemporary river valley are stated above in Section 3.2.1 under the Pecos Valley section.

According to King (1948), the Pecos River apparently had its origin to the south, in the Edwards Plateau, as a short tributary of the Rio Grande River. As the Pecos worked its way northward, eroding the Ogallala sediments in the process, it captured the westward-flowing streams of the present upper Pecos valley, thereby reversing their drainage direction. This stream piracy was facilitated by the underlying poorly resistant Permian rocks (Thornbury, 1965).

Bachman (1973, 1974) has expressed the opinion, in accordance with Lee (1925) and Morgan (1942), that the present course of the Pecos was formed, at least in part, through the coalesence of trains of solution sinks (see Karst Topography below, for discussion of solution-sink development). Bachman cites as evidence for this theory many places along the course of the river in southeast New Mexico where the river follows broad meanders, although the floodplain as a whole is unusually narrow or nonexistent, as well as locations adjacent to the Pecos where intermittant tributaries follow seimcircular collapse valleys. Bachman concludes that the river became entrenched in its present position by a combination of this solution-subsidence, headward cutting, and piracy.

The age of entrenchment of the Pecos River is somewhat uncertain. Thornbury (1965) has stated that the age of the piracy which constituted part of the entrenchment process is rather definitely dated as post-Pliocene and is assumed to have taken place in the early Pleistocene. Bachman (1974) has stated that it is not possible to precisely date the entrenchment of the ancestral Pecos River in southern New Mexico. But Bachman has observed (1976) that the Pecos entrenched itself near its present channel along the toes of pediments east of the Sacramento Mountains sometime after middle Pleistocene, which would place the establishment of the present course at a later date.

Since entrenchment, the river has carved a valley in which a variety of subsidence features have developed through dissolution processes which are probably still active in the valley today.

Mescalero Plain East of the Pecos River to about longitude 104°W lies an extensive, gently sloping pediment surface known as the Mescalero Plain (Thornbury, 1965), which extends from the vicinity of Fort Sumner in northern New Mexico to south of the Mexico-Texas border (Bachman, 1974). The surface of the plain rises eastward from about 150 feet above the Pecos River to as much as 400 feet above the river at the base of the Llano Estacado (Bachman, 1973; Kelley, 1971). The average elevations range from about 3,800 to 4,100 feet above sea level in northwestern Lea County near Mescalero Ridge to about 3,100 feet in southeastern Eddy County, south of Big Sinks (Bachman, 1973).

Although termed a "plain", the area includes many low mesas, bluffs and wide draws. Locally the surface has been dissected by intermittent streams, but in general the area is poorly drained and contains numerous playa pans and smaller sinks (Brokaw, et al., 1972; Kelley, 1971). The surface of the plain is covered widely with gravels and sands, often cemented with caliche. As much as 5 to 10 feet, and locally more, of these materials are exposed along the edges of the long irregular mesas of the area (Kelley, 1971).

The Mescalero Plain is very obvious on LANDSAT imagery. The surface materials of the plain are generally darker in color and exhibit more vegetation and higher moisture content than sandy areas.

The Mescalero Plain probably formed during a period of tectonic stability after deposition of the Gatuna Formation in the Early to Middle Pleistocene and has been modified both during and after its formation by solution-subsidence features, discussed below (Bachman, 1976). The widely distributed gravel deposits have probably been derived from erosion of the Ogallala Formation in the Llano Estacado, to the east (Kelley, 1971). The development and distribution of caliche and sand dune deposits, both of which overlie extensive portions of the pre-caliche Mescalero surface in southeast New Mexico, are discussed separately in the following paragraphs.

1) Mescalero Caliche

The deposits of the Mescalero Plain are generally covered by the calcareous, cemented remnant of an extensive soil profile known as the Mescalero caliche (see Section 3.3.4). The caliche forms a resistant caprock which averages 3 to 5 feet thick and is generally less than 10 feet thick. It consists of a basal earthy to firm, nodular calcareous deposit and an upper well-cemented laminar caprock (Bachman, 1976). In places, the caliche has weathered to a ledge that overhangs less resistant deposits. The caliche is generally thin; it is locally absent over the solution depressions of the plain, and in areas of collapse may be nearly vertical. Caliche may also be locally absent due to erosion on nondeposition. Because of the generally uniform covering by the erosion-resistant caliche, it is probable that these irregular surfaces result from subsurface solutioning and subsidence of the underlying sediments, primarily after the caliche caprock formed.

Although the genesis of the Mescalero caliche is uncertain, it is thought to be a process dependent upon climatic conditions involving certain ranges of both temperature and rainfall, in which carbonate movement is produced within the soil profile, resulting in the reworking and cementing of the soil constituents into a cohesive, calcareous mass. This caliche formed during a period of stable, semiarid climatic conditions which have been tentatively correlated with the Yarmouthian interglacial stage of the middle Pleistocene (Bachman, 1974, 1976).

2) Eolian Sand

Eolian sand covers much of the Mescalero Plain in southeastern New Mexico and is known locally as the Mescalero sand (Vine, 1963). This sand generally forms two distinct types of deposits - sheetlike stretches of surficial sand, which vary in thickness from about 5 to 15 feet (Bachman, 1973; Vine, 1963), and dunes, having a maximum thickness of about 60 feet (Hendrickson & Jones, 1952).

The eolian sand deposits of the Mescalero Plain have probably been derived from a widespread source of fine-grained sediments. Bachman (1974) suggests that most of this sand originated from the Ogallala Formation, although local sources, such as blowouts, have also been a source of some dune materials. There is litle evidence to indicate that much sand has been derived from the Pecos River (Bachman, 1973, 1974, 1976).

Except where the sand is stabilized by vegetation, it is continually blown about to form transverse dune ridges and barchan dune areas separated by broad flats. The orientation of the dune ridges is not uniform throughout the area, with the long dimension of the ridges apparently reflecting the direction of the strongest prevailing winds at the time of their formation (Vine, 1963) (also see Section 3.6.5).

At least two periods of eolian sand emplacement have occurred since the formation of the Mescalero Plain in Pleistocene time and are evidenced in some places by two distinct layers of sand. The lower deposit consists of a semiconsolidated somewhat clayey sand, as much as 1.5 feet thick, overlain by as much as 20 to 25 feet of loose surficial sand forming the contemporary sheet and dune formations (Bachman, 1976).

Karst Topography The land surface in southeastern New Mexico locally exhibits a karst topography, characterized by geomorphic features such as sinkholes, linear depressions (called solution-subsidence troughs by Olive, 1957), domes (including one known "breccia pipe"), "castiles" and collapsed outliers (Anderson, 1978). Many of these features show up on LANDSAT imagery as ponds and other water-filled depressions concentrated particularly near Roswell and also between the Pecos River and Mescalero Ridge. These features have resulted from the dissolution of salts and other soluble materials within the upper Permian Ochoan Series (see Section 3.3.2), particularly in the Rustler and the Upper Salado. The water required for the dissolution process has come into contact with the soluble materials either by surface exposure, following erosional removal of the protective mantle of younger sediments such as the Ogallala and

caliche, or at depth, by means of the downward percolation of local surface water or by contact by means of fracture systems between the Ochoan rocks and underlying regional aquifers, which have been exposed along basin margins by the Cenozoic regional uplift, tilting and erosion. These solution processes have been followed by collapse of the insoluble strata into the voids left behind by the dissolution (Bachman, 1974).

Development of karst features may have occurred in southeastern New Mexico as early as Triassic or Jurassic time, when the area was above sea level and probably undergoing extensive erosion which exposed the soluble materials. Bachman (1976) surmised that some dissolution of Permian salts and gypsum probably took place in the western part of the Delaware Basin during Jurassic time, before resubmergence in the Cretaceous. Extensive regional erosion also took place during the early Tertiary, presumably with accompanying renewed dissolution activity, although no sedimentary records of that period are preserved today. The earliest and most widespread basis for relative dating of solution-collapse features in the area is the Mescalero caliche, of Middle Pleistocene time. If, as is generally believed the caliche was derived from a soil profile, it could not have formed on the irregular and, in places, very steep slopes of today. Additionally, the fracturing and slumping of the Mescalero caliche along the widely occurring depressions of the area indicates collapse after Mescalero time. Some of the major collapse features here, such as Nash Draw, Clayton Basin and Crow Flats, exhibit evidence of several intervals of dissolution and subsidence activity. For example, Crow Flats, a large feature 15 miles east of Artesia, contains evidence for at least 3 such episodes, ranging in time from after Triassic and before Pleistocene Gatuna deposition, during or after Gatuna time and after Mescalero time (Bachman, 1976). Notwithstanding this evidence of long term dissolution history, Anderson (1978) believes that many of the deep-seated dissolution features formed during the most recent and most extensive period of salt removal following the Cenozoic erosion and exposure of the evaporites. Much of this activity is suggested to have occurred during the past few million years; dissolution has apparently progressed from west to east and from south to north across the Delaware Basin.

1) Principal Types of Solution - Subsidence Features

a) Sinkholes

Sinkholes form a category of features represented by thin or missing sections of halite in the Castile or by surficial depressions. Thin or missing halite in the Castile may be determined on the basis of borehole geophysical logs (see Anderson, 1978); the data may not assuredly represent dissolution at depth. Sinkholes designated on the basis of one borehole should also be viewed with caution. Similar data might be obtained in an area with some salt deformation. For the purposes of building a working hypothesis of deep dissolution, Anderson (1978) took these data as possible indications of deep dissolution.

Many of the sinkholes present in the northern Delaware Basin area developed as deep-seated features originating in the Castile Formation. These sinks are often expressed as thin or missing sections of the "Halite I" and "Halite II" salt of the Castile, and to a lesser extent of smaller salt beds above these units, and resulting structural depression of the overlying stratigraphic units. At least 100 deep-seated sinks are estimated to exist presently in the New Mexico portion of the basin. Around the margin of the basin, a number of these deep-seated sinks appear to be associated with anticlinal structures in the salt; in the mid-basin area, these sinks occur as both isolated features and in association with salt anticlines (Anderson, 1978). In addition to these deep-seated features, there are many sinks present in the area which are associated with active near-surface dissolution, such as those along the Pecos River and in Nash Draw (Anderson, 1978).

Compound sinkholes, resulting from coalescing collapse sinks, are common along the Pecos River valley south of Roswell. Many of these sinks have collapsed within historic time (Bachman, 1974). As discussed above, Bachman (1974) has suggested that the course of the Pecos River southward from Carlsbad to near the New Mexico-Texas border lies within a major belt of such collapse sinks. Bachman has also described similar

developments along the east side of the Pecos River southeast of Carlsbad, where a linear scarp is believed to have formed as the result of a collapse structure which is now occupied by the river.

b) Dolines

Dolines are very common features in southeastern New Mexico, forming on limestone bedrock and caliche surfaces. Dolines are defined as relatively shallow solution sinks that develop on the surface beneath the soil mantle without physically disturbing the underlying rocks or being underlain by subsurface solution cavities (Bachman, 1974).

c) Solution-Subsidence Troughs

Narrow, linear, generally northeast-trending depressions that vary in width from a few hundred feet to a mile and in length from one-half mile to 10 miles in southeastern New Mexico have been termed solution-subsidence troughs by Olive (1957), who proposes that these troughs result from the subsidence of near-surface material which fills voids dissolved by water flowing in underground channels. According to Thornbury (1965), these troughs are particularly common west of the Pecos in areas underlain by the Castile Formation and extend eastward, parallel to the regional dip as a result of dissolution along eastward-trending joint systems that parallel the regional dip.

Bachman and Johnson (1973) also describe linear features occurring in areas generally underlain by the Ogallala, to the north and northeast of the site, and suggest that at least some of these depressions may be the result of alternate leaching and wind deflation (Judson, 1950; Price, 1958). These features appear on LANDSAT imagery as alternating linear strips of vegetation and white to gray soil, trending NW-SE. They are most prominent north of Hobbs, north of San Simon Sink, and at scattered locations on the Mescalero Plain. The leaching may have been produced by the chemical action of plant growth on the caliche surface between longitudinal sand dunes where small amounts of ground water were able to

collect during periods of eolian quiescence; later periods of eolian activity removed these leached sediments from between the dunes. The swales left behind by this leaching activity mark the location of former longitudinal dune fields which have been displaced or removed by continued eolian activity. The effect of these linear features has been to provide depressions in which surface runoff collects and serves as sources of ground water recharge. Solutioning and erosion along these lineaments may have also opened conduits to the subsurface and contributed to a more rapid dissolution of the underlying soluble rocks (Bachman and Johnson, 1973).

d) Breccia Pipes and Domes

Various domal structures, having diameters of from several hundred to several thousand feet, occur in southeastern New Mexico, particularly along and east of the Pecos River, and are associated with areas of relatively recent surface salt dissolution (Anderson, 1978). Although they have been termed "breccia pipes," these features have no relationship whatsoever to volcanic activity. Many of the domes have been breached by erosion to reveal brecciated cores of stratigraphically displaced Gatuna, Rustler, and Triassic beds. These features are also characterized by doming-related deformation of rocks as young as the Mescalero caliche (Vine, 1960). The depth to which these breccia pipes extend is not known; one pipe is known to reach as deep as the McNutt member of the Salado Formation, as evidenced by underground exposures in the Mississippi Chemical Company potash mine (Griswold, 1977).

Anderson (1978) hypothesized that breccia pipes originate from the dissolution of salt at depth by waters circulating along intersecting joint sets in adjacent brittle rocks. Subsequent collapse of insolubles into the cavity forms a rubble breccia chimney, which sometimes penetrates to the ground surface. The only known breccia pipe (located in the Mississippi Chemical Corporation mine in Nash Draw) is observed to be well-cemented by fine-grained material with no perceptible open space. There is no evidence of removal of soluble material from the

evaporites adjacent to the feature in the mine. This particular feature is expressed at the surface by a dome with a collapsed center. The doming of this brecciated core takes place at a later time. Vine (1960) has suggested three possible mechanisms for this later deformation: the erosion of the rock surrounding the core of the sink; the upward flow of salt into the sink; an increase in volume of rock as anhydrite is altered to gypsum in the brecciated core. Anderson (1978) expressed the opinion that the doming has been produced by regional near-surface dissolution removing the salt from around the pipes and producing a sagging of the beds around the pipes. As a result of the doming process, the rock strata surrounding the dome at the surface generally dip away from the breccia pipe core (Vine, 1960). Underground, in the Mississippi Chemical mine, beds adjacent to the breccia pipe dip down toward the breccia pipe at about 10-20°.

The age of the breccia pipe formation in this area has not been determined. Mescalero caliche, of Middle Pleistocene age, is present on the flanks of breccia pipes and lying at steeper angles than those at which the caliche probably originally formed. This may indicate that the breccia pipes are younger than the Mid-Pleistocene. It is also possible, however, that the breccia pipes predate the caliche and that later subsurface removal of salt by dissolution produced greater amounts of downdrop away from the more resistant breccia pipes, resulting in the slopes present today. (Continuing studies of these features are addressed in Chapter 10.)

Despite the fact that the breccia pipes which have been recognized are generally expressed topographically as domes, it has been surmised that others may have no surficial expression and have therefore gone undetected to the present time. Geophysical exploration has been used to explore for pipes without surficial expression. Electrical resistivity surveys have shown that the breccia core of the known pipe has a much lower resistivity than does the surrounding undisturbed strata (Elliot, 1976). Continuity of seismic reflections are lost when similar geomorphic features are crossed by survey lines (Griswold, 1977).

e) Collapsed Outliers and "Castiles"

Outliers of the Rustler Formation, separated from the main outcrop area through erosional processes, as described by Anderson (1978), are circular to elongate or irregular collapse features consisting mostly of the Culebra dolomite. They occur where the salt has been completely dissolved from the evaporites.

Limestone buttes, called Castiles, occur west and south of the collapsed outliers, primarily in Texas, in the lower part of the Castile Formation outcrop area. These features consist of biogenic calcite which has replaced the gypsum or anhydrite of the Castile Formation, and some exhibit collapse structures with brecciated cores. These buttes are similar in size and distribution to the collapsed outliers (Anderson, 1978).

2) Major Near-Site Features

Major geomorphic features which have formed in the area of the proposed WIPP site as a result of sinkhole formation and related solution-subsidence mechanisms include Nash Draw and San Simon Swale (see Figure 2-1 for their location and topographic configurations). These features and their specific development are discussed separately, below.

a) Nash Draw

Approximately 5 miles northwest of the proposed WIPP site is a prominent geomorphic feature, known as Nash Draw, which Vine (1960) described as "a sinuous depression about 4 miles wide and 18 miles long." Its surface structural expression is similar to that of a breached anticline plunging gently northward, with the older Rustler Formation exposed in its center and the younger Dewey Lake redbeds and Santa Rosa Sandstone exposed along its flanks. However, well records in the area indicate that the bedrock underlying the draw exhibits a gentle homoclinal configuration. Accordingly, Nash Draw has been identified as an undrained physiographic

depression, which has probably developed as a result of regional and differential dissolution of the anhydrite, gypsum and halite beds of the Rustler and upper Salado Formations (Vine, 1963).

According to Vine (1963), dissolution on top of the massive salt in the Salado has produced a rather uniform lowering of the land surface in Nash Draw, but its surficial structural features have been produced and greatly modified by differential solution of the more soluble portions of the Rustler Formation. While the bedrock in the northern part of Nash Draw is generally covered by eolian sand, caliche and alluvium, the central and southern portions of the draw contain exposures of Rustler that has been highly deformed primarily as a result of large-scale collapse following solution of the Rustler and Salado. This dissolution activity has also produced numerous individual sinkholes in Nash Draw, which vary in configuration from circular features a few tens or hundreds of feet across to irregular or arcuate features up to more than a mile across. Many of the larger depressions in the area of Nash Draw, including the basin at its southwestern extent which contains Salt Lake, have probably formed through the coalescing of several smaller solution depressions or sinks. Some such places, where several depressions tend to line up may also indicate the location of subterranean cavernous water courses (Vine, 1963).

The age of the earliest solution activity that produced Nash Draw is uncertain. It is thought that some of the deep-seated solution in the Delaware Basin area had occurred by the middle part of the Mesozic, but that a substantial amount of this process has taken place since the Late Tertiary regional tilting of this area. Within Nash Draw, the formation of a large number of the individual solution features has resulted in the deformation of rock units as young as the Pleistocene Mescalero caliche, which indicates that Quaternary dissolution of the Salado and Rustler Formations is of primary importance in the geomorphic history of Nash Draw. Assuming that this disturbed caliche originally lay at an elevation corresponding to that of the adjacent Mescalero Plain, then at least 100 to 150 feet of local warping and depression has occurred in

Nash Draw within relatively recent time (Vine, 1963). Bachman (1974) estimated that at one place in Nash Draw a surface lowering of approximately 180 feet, almost wholly the result of solutioning and subsidence, has occurred in the past 600,000 years.

b) San Simon Swale

San Simon Swale is one of a series of large deep-dissolution depressions filled with Cenozoic sediments, lying above the inner margin of the Capitan reef along the eastern side of the Delaware Basin (Anderson, 1978). Situated approximately 20 miles east of the proposed WIPP site, San Simon Swale forms a southeasterly-trending depression approximately 25 miles long and from 2 to 6 miles in width. Much of the surface of the swale is at present covered by eolian sand, which masks the relief. Of particular interest within San Simon Swale is a compound collapse feature called San Simon Sink, which occupies an area about 2 miles long and 1 mile wide at the southeastern end of the swale (Bachman and Johnson, 1973).

San Simon Swale originated from a combination of surface stream erosion and solution-subsidence (Bachman & Johnson, 1973). During the Pleistocene, a major tributary of the Pecos River is thought to have flowed southeastward through what is now San Simon Swale to join the Pecos in western Texas. The initial course of this tributary was determined as it eroded its way through the caliche caprock of the Ogallala Formation (Bachman and Johnson, 1973). The dissolution and subsequent removal of these beds resulted in the formation of numerous sinkholes, some of which coalesced to form, at least in part, the depression now known as San Simon Swale (Bachman and Johnson, 1973). The swale has been lowered at least 180 to 200 feet below its original surface, in view of lake deposits in the sink encountered during preliminary WIPP studies. Current drilling operations reveal a thickness of over 600 feet of post-Ogallala sediments underlying the present floor of the swale.

Within San Simon Swale, the San Simon Sink formed as a secondary collapse structure, probably during the Pleistocene. Numerous ring fractures around the sink indicate that it has had a long history of successive collapse events since its initial formation (Bachman and Johnson, 1973). The most recent of these events is reported to have occurred in the 1930's (Nicholson and Clebsch, 1961). It is therefore assumed that salt dissolution in the underlying formation is continuing here and it is thought by some that the resulting brine is being carried in a southeasterly direction toward Texas (Bachman and Johnson, 1973).

On the basis of written communication from C.L. Jones of the U.S. Geological Survey, Bachman (1973) reported that over 500 feet of Cenozoic sediments have thus far been deposited in San Simon Sink. Nicholson and Clebsch (1961) have estimated that alluvium is presently being deposited in the sink at a rate of about 1 foot in 5 years. Recently acquired core (WIPP 15) from San Simon Sink has been analyzed in a preliminary way (Anderson, 1978) showing about 545 feet of fill on top of Triassic sediments. Dates on the fill have not yet been obtained.

Blowouts Some of the basins which are present in southeastern New Mexico have been formed by processes other than the previously described mechanisms of dissolution and collapse. The most conspicuous of these basins in the area of the proposed WIPP site are named Williams Sink, Laguna Gatuna and Laguna Plata, all of which are situated approximately 15 miles to the north of the site.

These features, termed blowouts, have formed through the removal of loose sand deposits by wind erosion. During the rainy season, many of the depressions which have resulted are partially filled with water. The floors of the blowouts are mantled with clay and saline deposits, and many blowouts are surrounded by eolian sand. Dune fields commonly develop along the northeastern and eastern leeward margins of these depressions (Bachman, 1974).

3.2.3 Erosion Rate- Significance of Geomorphic Developments to Site

This section provides a short review of the degree to which the major surface and subsurface processes discussed in the previous section have affected the land surface in the vicinity of the site and discusses to what extent these activities may be predictive of future geomorphic modifications in this area.

The resistant Mescalero caliche covers most of the land surface in the vicinity of the site and underlies the site itself. Where present, the caliche provides an indication that no significant erosion of the surface in these areas has occurred since the formation of the caliche in Mid-Pleistocene time.

The major areas of relief which have developed since this time have probably been produced to a large extent from subsurface dissolution and subsidence. The two major features of significance to the site, originating from these processes, are Nash Draw and San Simon Swale. In Nash Draw the surface has been lowered at least 100 feet by dissolution, and locally as much as 180 feet, within approximately the past half million years. Bachman (1974) also cited one location within the draw where the lowering of the ground surface appears to have exceeeded the rate of salt removal, indicating a surface erosion of about 40 feet in addition to solution activities. San Simon Swale, a product of surface erosion as well as solution-subsidence, lies at its lowest point some 180 to 200 feet below the surrounding land surface (Claiborne and Gera, 1974), and may have undergone a total subsidence of about 750 feet. No age has yet been obtained from the sediments obtained during recent drilling. (See Chapter 10, Continuing Studies.)

Wind erosion has produced other depressions in the area, with a resultant buildup of material in the same vicinity. However, these features are generally of only minor dimensions and are local in extent (Claiborne and Gera, 1974).

These observations should not be considered as constants for rates of erosion which would hold true for the future. But in providing a general indication of the surface modification in the vicinity of the WIPP site, they do indicate the pattern of continuing geomorphic development of the area. Variations in climatic conditions give rise to variations in rates of denudation and also in rates of subsurface dissolution. The nature of the ground surface is also of major importance in terms of its vulnerability to erosional processes.

The site is located west of and near a drainage divide between Nash Draw and San Simon Swale, where it appears that very little dissolution or surface erosion has occurred since Early Pleistocene time, as evidenced by the relatively undisturbed nature of the Mescalero caliche there, which has also served as a protective layer for the underlying soluble rock units. Contouring studies, too, indicate that this area has been a drainage divide between San Simon Swale and Nash Draw at least since Mid-Pleistocene time (Bachman, 1976). Although erosion here has been minimal under the present semiarid climatic conditions, if more humid conditions should develop in the future, an accelerated erosion of the caliche is reasonable to expect. However, with increased rainfall, it is also expected that Nash Draw and San Simon Swale will be exposed to more erosive stress, since most of the runoff will probably flow out of the immediate area along these depressions.

3.3 REGIONAL STRATIGRAPHY AND LITHOLOGY

3.3.1 Precambrian Rocks

Metasediments and granitic igneous materials consititute the majority of the basement rock of the southeast New Mexico - west Texas region. These Precambrian rocks crop out in only a few localities, in the western part of the region, such as the Nigger Ed Canyon area of the Sacramento Mountains (Pray, 1954), in the core of the Pajarito Mountain dome (Kelley, 1971) and in the Bent Dome, east of Tularosa (Bachman, 1960). Data on the Precambrian underlying the Delaware Basin and further east

and south across the Central Basin Platform into southwest Texas have been obtained principally through oil company records; hundreds of wells have been drilled in this area, particularly on the Central Basin Platform. Little data are available from the basin areas, where most wells penetrate only to the Upper and Middle Paleozoic sections.

The configuration of the Precambrian basement surface reflects the late Paleozoic structural framework of the region (see Figure 3.4-2). The surface is deepest along the northern axial portion of the Delaware Basin, where it reaches a depth of about 20,000 feet below sea level. The basement surface rises to the east, north and west of the Delaware Basin. On the northeast, into Otero and Chaves Counties, the basement rises fairly uniformly to more than 4,000 feet above sea level; on the east, the surface rises rapidly on the Central Basin Platform to elevations of between -5,000 and -4,000 feet (Cohee, et al., 1962; Foster and Stipp, 1961). Well data suggest that a number of post-Precambrian faults break the profile of the basement surface throughout the region. A notable example of this occurs along the west margin of the uplifted Central Basin Platform, where a vertical offset of perhaps more than 5,000 feet is present along the south portion of a large normal fault system.

The Precambrian sections which have been examined display a complex association of metasedimentary, sedimentary, metavolcanic, volcanic and plutonic rock types, suggesting a history of repeated orogenic activity interspersed with erosional episodes. Muehlberger, et al. (1967) have classified the Precambrian rocks of the region into a number of terranes of various age and lithology. A modified version of their geological map, Figure 3.3-1, presents the distribution of the major Precambrian rock types of the area.

Outcrops of probably Late Precambrian age slightly metamorphosed siltstones, shales and fine-grained quartz sandstone with associated intrusive sills are found in the vicinity of Nigger Ed Canyon in the Sacramento Mountains. The majority of the sills are diabase, and some are markedly porphyritic (Pray, 1954, 1961).

In the subsurface, similar Precambrian diabase and incipiently metamorphased clastics, including quartzite, siltstone and impure limestone, comprise a broad band which extends from southern Otero County northward for over 200 miles to southeastern Guadalupe Country. Muehlberger, et al. (1967) have termed these rocks the DeBaca terrane. In the Franklin Mountains at the extreme western tip of Texas, these metasediments attain a known thickness of almost 4,000 feet (Harbour, 1960). The rocks are underlain, at least in part, by rhyolites of the Panhandle volcanic terrane, discussed below, and are overlain in the Franklin Mountains by up to 1,000 feet of rhyolite (Harbour, 1960) dated at 900 million years.

To the east of the Sacramento Mountains on the Northwestern Shelf, an approximately 2-square-mile outcrop of Precambrian rock is exposed in the core of Pajarito Mountain dome. These rocks, radiometrically dated as 1,270 million years old, consist of hornblende, syenite, hornblende syenite gneiss, and some diabase, locally intruded by leucocratic syenite and hornblende syenite pegmatite (Kelley, 1971). Granitics apparently underlie most of the south-central parts of New Mexico and large areas in Eddy and Lea Counties (Foster & Stipp, 1961), extending at least as far west as the Guadalupe Mountains as well as south and southeastward into Texas (Flawn 1954: Muehlberger et al. 1967). These rocks, named the Chaves granitic terrane, are largely granite, granodiorite, compositionally equivalent gneiss and lesser amounts of metasedimentary and metaigneous rocks. Granite comprises about 80 percent of the samples studied. Foliation in these rocks is generally faint, but is enhanced by some shearing (Muehlberger et al., 1967). Wasserberg et al. (1962) dated the granitics in this area as between 1,250 and 1,400 million years in the north and as young as 1,090 million years to the south. These granitics appear to predate the sedimentary Precambrian rocks to the west (Foster & Stipp, 1961).

Younger volcanics, which appear to have been extruded and deposited as a relatively thin layer above the granitics, are present in at least parts of Chaves, Lea, Roosevelt, Curry and Quay counties as well as near the

south border of New Mexico west of the Brokeoff Mountains and eastward in the Texas Panhandle (Foster & Stipp, 1961; Muehlberger, 1967). These rocks, known as the Panhandle volcanics, are primarily rhyolitic flows and tuffs and pyroclastics with subordinate trachytic and andesitic types. The volcanics are mostly undeformed and unmetamorphosed. Rb-Sr dating of these rocks yields an average age of 1,140 ± 50 million years (Muehlberger et al., 1967).

Gabbro and diabase or basalt, commonly showing intergranular ophitic to subophitic textures, underlies parts of Roosevelt and southern Curry Counties and extends eastward into Texas. These rocks, termed the Swisher diabasic terrane, intrude the volcanics, and, although their age is uncertain, are considered Precambrian (Muehlberger et al., 1967; Flawn, 1954). According to Flawn (1954, 1956), these rocks appear to be a great stratiform body occupying a major basement syncline, although no large positive gravity or magnetic anomaly is present over this region.

Clastics of Late Precambrian age crop out near Van Horn, Texas. These deposits are part of an alluvial fan which is overlain by the Bliss sandstone (McGowan and Groat, 1971). Elsewhere, including the Guadalupe Mountains, these rocks have been studied through well cuttings.

3.3.2 Paleozoic Rocks

Cambrian Rocks

Very little is known about the existence or nature of any Cambrian sediments underlying the Delaware and Val Verde Basins area of southeast New Mexico-west Texas, partly because the great thickness of the overlying section in this region and partly because the belief that the Ordovician Ellenburger is the deepest potential reservoir formation has discouraged deeper drilling (Vertrees et al., 1959).

Basal Paleozoic clastics were named the Bliss Sandstone by Richardson (1904) for exposures in the Franklin Mountains. They range in thickness from 0 feet to the north to about 375 feet toward the south. The Bliss unconformably overlies the Precambrian and in most places is conformably overlain by the El Paso Group (Hayes, 1964). According to Harbour (1960), the Bliss is probably a beach or near-shore deposit of the sea in which the overlying El Paso Limestone accumulated.

In its type locality and in most areas east of longitude 107°W, the Bliss generally consists of over 90% sandstone that is thin-bedded and jointed. Subordinate, thin interbeds of siltstone or shale and rare thin beds of sandy limestone or dolomite are present. Dark siltstone grains, cemented by glauconite and hematite, combine to produce a dark color (Hayes, 1975; Harbour, 1972).

In the Sacramento Mountains of southeastern New Mexico, the Bliss Sandstone is exposed in the vicinity of Nigger Ed Canyon. A 10° angular unconformity separates it from the underlying Precambrian. The Bliss in this area contains 110 feet of quartz sandstone, minor dolomitic sandstone, sandy dolomite, brown-weathering sandstone interbeds in the upper third of the section. Abundant glauconite is present in some of the strata. In general, this section is similar to that at the type locality near El Paso (Pray 1954, 1961). Farther southeast in the subsurface at the Guadalupe Mountains area, the Bliss consists of less than 30 feet of light gray to white, poorly sorted, coarse-grained quartz sandstone at the base and top, separated by gray, fine-to-medium grained, sandy dolomite (Hayes, 1964).

Most investigators consider the Bliss Sandstone to be diachronous, ranging in age from Late Cambrian through Early Ordovician, becoming younger from west to east, as determined from faunal evidence and lithologic correlations (Hayes, 1975). The Bliss of the Sacramento Mountain area has been dated as Cambrian by the Residue Research Laboratory of Midland (Roswell Geological Society, 1953). However, Flower (1953) has indicated that the formation is time-transgressive and

contains both Late Cambrian and Early Ordovician fauna in New Mexico (Harbour, 1972). The evidence indicates that in its easternmost localities, the entire Bliss is of Early Ordovician age (Hayes, 1975). Hayes reported in 1964 that it is very likely that the Bliss in the subsurface of the Guadalupe Mountains area is entirely Ordovician. Foster (1974) also considers that the Bliss sediments of the southeastern New Mexico Delaware Basin area probably correlates only with the Ordovician part of the unit as defined in Texas.

Ordovician Rocks The Lower Ordovician section is composed mainly of carbonates deposited in a shallow sea with a relatively calm shelf environment (see Figure 3.3-2). In 1904 Richardson named exposures in the Franklin Mountains the El Paso Limestone (Hayes, 1975). Cloud and Barnes (1948) named exposures in western and central Texas the Ellenburger Group, and this name is commonly applied to subsurface rocks in the Permian Basin. Some workers have subdivided these rocks into formational groupings that are recognizable over much of the region. For discussion of nomenclature and detailed stratigraphy, refer to Hayes (1975).

Where the El Paso crops out in the Sacramento Mountains escarpment, it is composed of up to about 420 feet of light-to-olive-gray, very fine-to medium-grained dolomite. Thin to medium beds predominate, chert nodules occur sporadically, and interbeds of dolomitic quartz sandstone are common toward the base, derived from erosion of rocks to the east. In the Sacramento Mountain area, at least, the El Paso appears to be either time-transitional with the Bliss Sandstone or separated from it by a minor disconformity (Pray, 1961). To the southeast, in the subsurface of the Guadalupe Mountains, the El Paso comprises from 520 to 550 feet of gray, fine-to medium-grained, crystalline, siliceous dolomite with some sand near the base and top and some light-colored aphanitic chert. Eastward in the Delaware Basin over 700 feet of El Paso or Ellenburger has been encountered. In the New Mexico portion of the basin, the formation is almost entirely a light-gray to gray crystalline dolomite with small amounts of sandstone; much chert is present in some localities

near the top of the section (Haigler, 1962). South and southeastward in the west Texas Delaware-Val Verde Basin area, the Ellenburger reaches a maximum thickness of at least 1,600 feet and is composed almost entirely of limestone and dolomite (Vertrees et al., 1959). Its limestones are light-gray and dominantly sublithographic, becoming purer upward; the dolomites range from coarse-grained pale rocks, generally near the bottom to finer-grained, more brightly colored ones above (Cloud and Barnes, 1946).

Middle Ordovician sediments comprising the Simpson Group are recognized in the subsurface from the Guadalupe Mountains area through the Delaware Basin and east into Texas. The Simpson thins rapidly to the west at an average rate of about 10 feet per mile (Hayes, 1964), wedging out near Artesia, New Mexico. To the north, it extends to the latitude of Roswell and elsewhere is truncated by erosional unconformities. Where the Simpson, or equivalent, is encountered within the New Mexico portion of the Delaware Basin, it ranges in thickness from less than 200 feet to 1,850 feet in southern Lea County (Nicholson & Clebsch, 1961). In the basin, the Simpson consists of 3 main layers of limestone, alternating with thinner green, brown and black shale, black shale with rounded quartz grain inclusions, and sandstone (Haigler, 1962). Towards the south and southeast, the formation thickens considerably, reaching a maximum of at least 2,250 feet before wedging out in the Marathon Mountains region. Shaly facies predominate towards the south. In the Delaware-Val Verde region, the sandstones and some of the carbonate members are potential oil and gas reservoirs (Vertrees et al., 1959).

In the subsurface of the Permian Basin, the Simpson is overlain conformably by carbonates of the Montoya Group, assigned to the Middle and Late Ordovician by Hayes (1975). At the type locality in the Franklin Mountains, the Montoya ranges in thickness from about 140 to 250 feet, averaging about 200 to 225 feet, and consists of a lower olive gray to dark gray cliff-forming dolomite with a thin, very coarse-grained quartz sandstone at the base and an upper, lighter colored cherty and finer-grained, slope-forming dolomite. The top of the group is marked by

a zone of bedded chert (Bachman and Myers, 1969). Eastward in the north part of the Delaware Basin, the Montoya ranges from about 280 to 440 feet in thickness and consists of medium-to dark-gray dolomite with minor amounts of dark gray limestone and chert (Haigler, 1962). Where it occurs on the Central Basin Platform, the Montoya is a cherty limestone about 150 feet thick. To the south, the Montoya is composed of primarily chert and dolomite, reaching a maximum thickness of 600 feet (Vertrees et al., 1959).

The uppermost rocks of Ordovician age in the area consist of a generally light-gray, thin-bedded dolomite with some marl. It had been included by Darton (1917, 1928) as the lower part of the Fusselman, but having been recognized by Kelley and Silver (1952) as Ordovician, it was removed from the Fusselman and renamed the Cutter Formation. Pray (1954) called it the Valmont, where he encountered it in the Sacramento Mountains. Now, however, these beds have been established as the Cutter Member of the Montoya Dolomite (Harbour, 1972; Bachman and Myers, 1969).

Silurian Rocks The Silurian of the southeast New Mexico - west Texas areas consists of the Fusselman limestone and the carbonates and shales of an "Upper Silurian" unit, both of which were deposited in a broad subsiding area named the Tobosa Basin.

The Fusselman rests unconformably on the Late Ordovician Montoya and ranges in thickness from 0 to 1,000 feet in part of southern New Mexico and west Texas, and thins westward and northward into an erosional wedge (Hayes, 1975). It is composed of a massively-bedded, clean, light-colored dolomite and locally limestone. The limestone facies is dominant to the southeast; a thicker dolomite facies is dominant to the north and west. The Fusselman has been dated as Middle Silurian and possibly also Early Silurian in age (McGlasson, 1968; Hayes, 1975; Pray 1958).

In the Sacramento Mountain area, the sequence overlying the Montoya has been divided by Pray (1953, 1954, 1961) into two units. The lower member, which he termed the Valmont, is composed mostly of light gray, very finely textured dolomite ranging in thickness from 150 to 225 feet. The upper part of the sequence in the Sacramento area, recognized by Pray (1954) as Silurian, comprises a medium to finely crystalline, light to medium gray, cherty dolomite not exceeding 100 feet. As identified in the subsurface of the Guadalupe Mountains, the Fusselman ranges from 580 feet to about 740 feet of white to light gray, coarse to medium crystalline dolomite, which contrasts sharply with the darker, fine-grained underlying Montoya (Hayes, 1964). In the Delaware Basin, the Fusselman is a light-colored dolomite containing abundant chert and two thick limestone intervals. It reaches its maximum thickness in southern Lea Country. Eastward across the Central Basin Platform, the Fusselman is represented by a coarse-grained crystalline glauconitic limestone and dolomite 180 to 200 feet thick (Nicholson & Clebsch, 1961).

The subsurface unit informally called the "Upper Silurian" consists of a shaly facies to the southeast and much thicker carbonate facies to the north and west. The unit is more restricted areally than is the underlying Fusselman, pinching out northward and westward across north-central Eddy and Lea Counties. The carbonate facies predominates in the New Mexico portion of the Delaware Basin and includes both limestones and dolomites, reaching over 1,500 feet in thickness (McGlasson, 1969). On the Central Basin Platform, it consists of 180 feet of green, gray, and black shales interbedded with dense limestones (Nicholson & Clebsch, 1961). Southward into Texas, the shaly facies is composed of bright green to dark brown shales and white to brown calcilutites with a maximum thickness of 300 feet (McGlasson, 1968).

<u>Devonian Rocks</u> Lower to Middle Devonian rocks are known only from subsurface exploration, and only in the southeastern corner of Lea County, New Mexico. Called the "Devonian" rock unit by McGlasson (1965), these rocks are more restricted in area than the "Upper Silurian" and range in thickness from zero to 1,000 feet in the vicinity of Crane

County, Texas. The unit is composed primarily of chert in the southwest, grading northeastward into dark siliceous micrite and light-colored calcarenite. After deposition, the unit underwent considerable diagenetic alteration.

In the western part of the region, along the Sacramento Mountain escarpment, a unit dated as upper Middle Devonian, the Onate, has been recognized (Pray, 1954, 1961). It consists largely of dark gray to olive gray, very fine-grained dolomite mixed with coarse silt to very fine quartz sand, with minor shale, increasing to the south. Small, irregular chert or silicified dolomite nodules several inches long are distinctive lithologic features of the upper part of the formation in the central and northern parts of the escarpment. To the west the Onate forms beds generally less than 1 foot thick and rarely thicker than 2 feet but is as much as 60 feet thick in the central escarpment area, thinning northward and southward.

Upper Devonian rocks in the subsurface of the southeast New Mexico area constitute the Woodford shale, portions of which are also variously known as the Percha shale and Canutillo Formation. These rocks are described by McGlasson (1968) as extending from eastern Chaves and southern Roosevelt Counties in New Mexico, southward and eastward through western Texas and ranging in thickness from zero to approximately 700 feet near the southeast corner of Lea County, with an average of 200 feet elsewhere (Vertrees et al., 1959). The Woodford is a dark brown to black, fissile, bituminous, spore-bearing shale which becomes arenaceous northward and contains black chert to the south and west (McGlasson, 1968).

Across the Central Basin Platform, the rocks correlative to the Woodford in age consist of interbedded, calcareous chert and siliceous limestone, reaching a maximum thickness of 980 feet (Nicholson & Clebsch, 1961). Westward in the northern Delaware Basin, the unit decreases to less than about 200 feet thick and is an organic pyritic shale. In the Guadalupe Mountain area, the unit comprises less than 100 feet of dark gray, locally silty shale, with a few feet of dark or medium gray chert at its

base (Hayes, 1964). At the northwestern limit of the unit in the Sacramento Mountains, the lower Upper Devonian section has been called the Sly Gap Formation and consists of up to 50 feet of calcareous, yellow-gray to dark gray shale with irregular nodular limestone becoming predominant upward. This unit is absent in the south half of the escarpment, where the Upper Devonian is represented by a dark gray noncalcareous shale, considered equivalent of the Percha shale and recognized southward as the Woodford (Pray, 1954).

The Woodford and equivalent units are transgressive and lie unconformably on an erosional surface formed on the rocks of the older Devonian section through the Ordovician Montoya Group. According to McGlasson (1968), the upper portion of the Woodford deposition probably was deposited in Early Mississippian time. At its upper limit, the Woodford is conformably overlain by limestones and sandstones of the Early Mississippian.

Mississippian Rocks Mississippian rocks throughout most of the southeast New Mexico-west Texas area consist of limestones overlain by shales, which together attain a maximum thickness of some 2,400 feet, truncated by erosional unconformities (Vertrees et al., 1959). Rocks of definite Mississippian age appear to be absent across the Central Basin Platform (Nicholson & Chelbsch, 1961).

The Lower Mississippian Kinderhookian-Osagian series is represented in southeast New Mexico and west Texas by a limestone unit (Roswell Geol. Soc. 1958). It is 365 feet thick in the Guadalupe Mountains and 220 to 320 feet in the northern Delaware Basin, thickening to the southeast and thinning to the west (Haigler, 1961). The limestone is light gray to brown, finely crystalline and commonly cherty, with a basal dark gray organic-rich shale unit. The limestone partially grades to shale southeastward from the northern margin of the Delaware Basin (Brokaw et al., 1972; Haigler, 1962). The northwestern face of the Sacramento Mountains contains exposed units of equivalent age, but detailed correlation with the foregoing surface data from the rest of the area is unreliable (Haigler, 1962). The Kinderhookian here is represented by up

to 60 feet of Caballero limestone and calcareous shales. The overlying Osagian series Lake Valley Formation, which attains a thickness of about 400 feet in the northern and central Sacramento Mountains, is composed of 6 members whose dominant lithology is limestone containing various amounts of chert and argillaceous and biohermal materials (Pray, 1954).

The Upper Mississippian rocks in the subsurface of southeast New Mexico, apart from the Sacramento area, consist of black, brown and gray shale much of which is silty, variously named the Barnett, Chester or Meramec (Brokaw et al., 1972; Haigler, 1962). Near the north and west edges of the Delaware Basin, and in the Guadalupe Mountains, gray limestone beds occur at the top of the Mississippian shale, with some interspersed thin sandstone beds. To the east and south, in the central portion of the Delaware Basin, the unit consists of between 250 and 320 feet of primarily a black argillaceous shale with a dark gray to black calcareous shale of shaly limestone comprising approximately the lower 100 feet of section (Haigler, 1962). Equivalent age rocks in the western part of the region have been defined as the Rancheria and Helms Formations of Meramacian and Chesterian age, respectively. The Rancheria, whose type locality is north of El Paso, Texas, closely resembles the Lower Mississippian limestones of the southeast New Mexico area. (For detailed description, refer to Harbour, 1972). The Rancheria is up to 400 feet thick in the Franklin Mountains and 300 feet at the south end of the Sacramento Mountains, thinning northward, and is composed of gray argillaceous and silty thin-bedded limestone with minor shales and massive crinoidal limestone strata. Its basal contact is an angular unconformity with the underlying Lake Valley and Caballero. The Helms, of latest Mississippian age, which reaches a maximum of 230 feet in the Franklin Mountains and only 60 feet northward in the Sacramento Mountains, consists of thin-bedded, argillaceous limestone and yellow to gray calcareous interbedded shales with lesser limestones (Harbour, 1972; Pray, 1954).

Pennsylvanian Rocks Post-Mississippian orogeny uplifted and tilted much of the southeast New Mexico-west Texas basinal areas, eroding the exposed rocks and, upon subsequent Pennsylvanian deposition, producing a major angular unconformity called the Springer hiatus (McGlasson, 1968). Relatively rapid, almost continual deposition in most of the region resulted in a thick Pennsylvanian carbonate section, with large volumes of terrigenous clastics in some places. The Pennsylvanian in places is thicker than the entire underlying Paleozoic section (Pray, 1954). Total thickness of the Pennsylvanian section varies from about 3,000 feet in the Sacramento Mountains, near 2,500 feet in the northern Delaware Basin, and between 1,650 and 2,700 feet in southern Lea County along the Central Basin Platform.

The rocks of Pennsylvanian age were derived from a variety of different sources and deposited in increasingly active structural settings. As a result, the lithology of the section is highly variable, both horizontally and vertically, and correlations on the basis of mappable rock units are difficult to make (Pray, 1961; Oriel et al., 1967). Although a variety of schemes have thus been utilized to subdivide the Pennsylvanian section of the area, the following discussion employs the common usage of Morrowan through Virgilian stages as a framework for consideration of the dominant lithologies and several formations identified in this region.

1) Morrowan Series Of the stages present in New Mexico, the basal Pennsylvanian Morrowan rocks occupy the smallest area and contain, in the central and northern portions of the Delaware Basin, the largest proportion of clastic material. These rocks, which mark the initiation of a major transgression climaxing in the Virgilian, attain a thickness of about 1,250 feet in the Permian Basin area and wedge out northward in southeast New Mexico (Meyer, 1968). The Morrowan rocks in New Mexico consist largely of limestone and shaly limestone; fine-grained sediments predominate (Bachman, 1975).

In the Sacramento Mountains, at the northwest extent of the area, the basal Pennsylvanian strata were deposited on a surface of at least 100 feet of local relief, the lowest parts of which were filled with coarse sandstone or cobble conglomerates derived from Mississippian cherts. The percentage of shales and dark limestones increase upwards into the Atokan. These rocks have been called the basal part of the Gobbler formation by Pray (1954). Southward across the Guadalupe Mountains area of the Northwest Shelf, the Morrowan consists of from 230 to over 400 feet of fine to coarse-grained, poorly sorted, locally conglomeratic quartz sandstone, mottled medium gray oolitic limestone and medium to dark gray shale, which resemble the lower Gobbler as well as the rocks of central to northern New Mexico, called the Sandia Formation (Hayes, 1964). Fine-grained detrital sediments trend southeasterly from the Pedernal Uplift into the western Delaware Basin. Within the Delaware Basin, the Morrowan is composed primarily of brown to gray argillaceous limestones and gray quartzose sandstones with dark gray to black shale. Across the Central Basin Platform into Texas, the basal Pennsylvanian unit is a black shale (Nicholson & Clebsch, 1961; Bachman, 1975).

2) Atokan Series The Early-Middle Pennsylvanian rocks, assigned to the Atokan or Derryan Stage, consist of dark-colored sandstones, shales and limestones, which attain a maximum thickness of about 1,000 feet. These rocks were deposited over the entire area, with the exception of the Pedernal Uplift to the north (Meyer, 1968).

Interbedded shales and dark limestone constitute the top of the 200 to 500 foot section of the lower Pennsylvanian Atokan deposition to the northwest in the Sacramento Mountains (Pray, 1954). Southward into the northern Delaware Basin, the unit consists of gray to brown and black, fine-grained to dense limestone and chert and dark gray to black shale with minor sandstone. In the southern Delaware and Val Verde Basins region, the Atokan rocks consist mainly of sandstones and shales in the lower part and carbonate rocks in the upper part, reaching about 1,000 feet in thickness (Vertrees et al., 1959). The top of the Atokan section is transitional, and is placed at the change from dominantly terrigenous, detrital rocks below to predominantly carbonates above (Bachman, 1975).

3) Desmoinesian Series Upper-Middle Pennsylvanian Desmoinesian rocks are predominantly carbonates, and attain a maximum thickness of about 1,000 feet in the Delaware and Lucero Basins and in northwestern New Mexico (Bachman, 1975). Sedimentation during this time was primarily influenced by reef and adjacent shelf and basinal deposition within the areas of the Permian Basin and Orogrande Basin to the west. Also known as the Strawn, the unit is the only readily identifiable Pennsylvanian rock found widespread over the southeast New Mexico-west Texas area (Vertrees et al., 1959).

The Desmoinesian rocks of the Sacramento Mountain area constitute up to 1,000 feet of contrasting facies: a shelf limestone or reef, consisting almost entirely of cherty calcilutites, and a deltaic facies of equal thickness but smaller lateral extent, composed of quartz sandstones, subgraywackes, shales and minor limestones (Pray, 1954). Southward and eastward, in the Permian Basin area, the Desmoinesian strata were deposited in a variety of environments from back-reef lagoon, to reef, to deep marine basin - a spectrum which lasted from this time through most of the Permian (Meyer, 1968). Within the Delaware Basin, these rocks are typically dark brown, fine-grained cherty limestones, the lower part of which may contain interbeds of gray shale and gray to white, medium-grained angular quartz sandstone (Meyer, 1966). Reef facies of the Desmoinesian also extend south and eastward into the Val Verde Basin. The limestones of the Desmoinesian within both the Delaware and Val Verde Basins are known for their numerous stratigraphic traps, and have been attractive for oil and gas exploration (Vertrees et al., 1959). Desmoinesian limestones also occur across the Central Basin Platform into Texas.

4) Missourian Series The Missourian rocks of the late Lower Pennsylvanian age constitute up to 1,000 feet of mostly clastic sediments, such as interbedded arkose and arkosic sandstone, as well as mudstone and limestone, deposited in environments similar to those of Desmoinesian time (Meyer, 1968; Bachman, 1975).

On the northwest, as much as 500 feet of thin-bedded, argillaceous limestone and shale of the Missourian overlie the shelf limestone and deltaic deposits of the Desmoinesian. Most of these rocks reflect basinal deposition, but locally there was cyclic deposition in turbulent shallow waters (Pray, 1954). To the south, Missourian rocks are identified generally only in the deeper parts of the Permian Basin area. Within the New Mexico portion of the Delaware Basin, the Missourian rocks consist of dark gray shales and limestones, quartz sandstone, and some chert, ranging in thickness from zero to 1,250 feet (Meyer, 1966). Toward the Val Verde Basin near the Texas-New Mexico border and across the Central Basin Platform, the unit grades into a dark gray, non-fossiliferous shale (Vertrees et al., 1959). The absence of datable materials in this unit has made its correlation as Upper Pennsylvanian difficult to verify.

5) Virgilian Series The uppermost Pennsylvania section is similar to that of the Missourian but contains, in addition to carbonates, some continental shales, coarser clastics and evaporites.

Over most of the area to the northwest, algal reefs up to 100 feet thick formed. The Virgilian deposition grades upwards into more uniformly bedded, light-colored limestone with interbedded shale and minor sandstones. At the top of the section, red shales and limestone conglomerates repeat cyclically with nonred shales and massive nodular limestone, indicating fluctuations in depth and gradual transition to final emergence of the northwestern area. The Upper Pennsylvanian units of this area were named the Holder Formation by Pray (1959). Within the Permian Basin proper, over 1,000 feet of Virgilian limestones and shales were concurrently deposited. Southward over the Northwestern Shelf and eastern side of the Central Basin Platform and northeastward of the Horseshoe Atoll, the series is represented by limestone. Toward the Eastern shelf, the unit consists of both mudstone and limestone with some interbedded sand (Oriel et al., 1967). Reefs formed along the northern margin of the Delaware Basin (Meyer, 1968), while within the basin up to 1,000 feet of brown to tan, fine-grained limestone, black to brown shale and white, fine-to coarse-grained subangular quartz sandstone were

deposited (Meyer, 1966). Southward in the deeper part of the basin, dark nonfossiliferous shale, similar to the underlying Missourian, continued to be deposited.

Permian Rocks. In many parts of the southeast New Mexico area, the lower boundary of the Permian is difficult to determine except on the basis of fusilinids, because the Permian rocks are underlain by lithologically similar Pennsylvanian rocks. In the Delaware and Val Verde Basins, the boundary is located below several hundred feet of dark gray mudstone unit. No lithologic basis of recognizing the boundary is apparent on the Northwestern Shelf, along the east margin of the Central Basin Platform, or in the area of the Horseshoe Atoll (in the northern Midland Basin). Only in the structurally positive areas where Pennsylvanian rocks are missing, as in many locations on the Central Basin Platform, is the base of the Permian clear. In other places, such as the Sierra Diablo, an angular unconformity separates the Permian from underlying units. Ages of basin rocks to the base of the Permian are usually assigned through fusilinids interpretation but it is sometimes difficult because of the scarcity of fossils (Oriel et al., 1967). The thickness of the Permian sediments equals or exceeds the total thickness of the underlying Paleozoic systems. Details are presented in the discussions of each series below. Figure 3.3-2 provides a schematic illustration of the subsurface distribution and relative thicknesses of the Permian.

Most of the major structural elements that influenced Permian sedimentation in the area were well developed late in Pennsylvanian to very early in the Permian; thus, marked differences in lithology occur from the Northwestern shelf region, through the Delaware Basin and across the Central Basin Platform into the Midland Basin, and the stratigraphic nomenclature differs from place to place. In general, the units of the basins contain a much higher proportion of clastics than do the adjacent shelf areas, and the basin carbonates are much less dolomitized than are the shelf carbonates. The rock units along the basin margins are partially dolomitized, and contain less clastics than equivalent shelf units. In common practice, the different facies of the region have been

related to each other by time-stratigraphic units. The provincial series names used in New Mexico and Texas are, from oldest to youngest, the Wolfcampian, Leonardian, Guadalupian and Ochoan (Oriel et al., 1967). Figure 3.3-3 presents a summary and correlation of the major Permian formations of the region which are discussed below.

1) Wolfcampian Series The Wolfcampian series consists primarily of limestones and dolomites. A few reefs are present on the shelves; dark gray shales, sandstones, and conglomerates are present in the basins. The basinal sediments of the Delaware, Midland and Val Verde were probably deposited under stagnant, reducing, deep-water conditions, while the limestone on the Northwestern and Eastern shelf and Central Basin Platform were deposited in relatively shallow and well-aerated water. The series thickens southward from generally less than 1,000 feet over the shelf areas and 1,500 feet in the subsurface of the Guadalupe Mountains area of the Northwestern Shelf, to somewhat less than 5,000 feet in the Midland Basin, 7,500 feet in the central Delaware Basin, and over 15,000 feet southward in the eastern half of the Val Verde Basin (Oriel et al., 1967). The name Hueco limestone has been applied to the rocks of the basal Permian in the region; however, some workers prefer to restrict this term to the Northwestern shelf and northernmost Delaware Basin (Hayes, 1964).

On the Northwestern Shelf, the Wolfcampian is subdivided into two cherty limestone units separated by interbedded limestones and red, green and gray mudstones, which thicken northward and become sandy. Along the shelf margins, medium to dark-gray mudstone layers intertongue with the limestone (Oriel et al., 1967).

Within the northern Delaware Basin, the Wolfcamp consists of about equal parts of gray, black or brown shale and fine, crystalline, rarely cherty, brown limestone with a few thin beds of micaceous and calcareous sandstone (Hayes, 1964). Southward, in the deeper parts of the basin, it consists primarily of dark shale with brown sand and some coarser clastics. Here the absence of index fossils precludes satisfactory lower

time boundary detection. Within the Delaware Basin, both the sandstone and carbonate facies have been recognized as potential oil and gas reservoirs. Southward, in the Val Verde Basin, sandstones interbedded within the shales of the Wolfcampian are established as a commercial gas reservoir (Vertrees et al., 1959).

Eastward, over the Central Basin Platform, the Wolfcampian consists chiefly of limestone with a basal unit of as much as 440 feet of red and green shale and conglomerate (Nicholson & Clebsch, 1961). The Wolfcampian within the Midland Basin is similar to that of the Delaware Basin, except for the presence of an upper zone of dark argillaceous, locally cherty limestone and interbedded dark mudstone. The lower part of the section consists of dark mudstone with thin units of fine-grained, argillaceous sandstone and fossiliferous limestone, which increase in thickness north and west along the basin periphery (Oriel et al., 1967).

2) Leonardian Series The Leonardian series of the Lower Permian is represented by a highly variable group of facies consisting of limestone and dolomite, with mudstones, sandstones and some chert. Clastics are dominant in the lower parts of the basins, while calcareous deposits dominate the margin and shelf areas. The series was deposited under mostly marine conditions, but some strata formed in restricted or marginal environments. The Leonardian rocks are over 4,000 feet thick in two north-trending belts along the east and west margins of the Delaware Basin and in the south-central part of the Midland Basin. In the Val Verde Basin, thicknesses average 2,000 to 3,000 feet. On the shelf north and west of the Delaware Basin along the oil-producing Abo reef trend, thicknesses are over 3,500 feet. On the Eastern Shelf, the Leonardian is less than 2,000 feet. Minimum thicknesses in the area are about 800 feet (Vertrees et al., 1959; Oriel et al., 1967).

The Bone Spring Limestone represents the basin facies of the Leonardian in the Delaware Basin and northwest end of the Val Verde Basin, and consists of a dominantly dark-gray, thin-bedded, argillaceous limestone, a gray to buff, very fine-grained sandstone in three separate zones, and

a black shale with some chert nodules and beds. The base is a sandstone member which may be Wolfcampian, and the top is placed above a black shale with dark gray limestone. Deep water conditions with poor circulation probably characterized these basin settings (Oriel et al., 1967).

Eastward, in the Midland Basin, the Leonardian rocks have been assigned to formations different from those in the Delaware, but the rock types, dominantly black shales and limestones, are similar. The section--known as the upper Wichita Group, the Clear Fork Group and the lower part of the Pease River Group at the top--consists of mudstone with lesser sandstone and limestone at the base, two fine-grained sandstone members divided by dark calcareous mudstone and a muddy limestone, that may be time-correlative with two of the three sandstone layers of the Bone Spring. Above this zone, limestone and dolomite predominate, with lenses of mudstone and sandstone; the top of the unit is primarily carbonate.

At the margins of the basins, these basin units grade laterally into limestones. Around the perimeter of the Delaware Basin, the lower part of the Bone Spring Limestone grades into thick-bedded gray limestone overlapping unconformably on the Hueco Limestone (King, 1965). The middle and upper part of the Bone Spring grades into the shelf-margin dolomite of the Victorio Peak, which is correlative with the Yeso of the shelf. The Victorio Peak is a light-gray, thick-bedded fossiliferous limestone containing some chert and sandstone and made up of small, discontinuous or patch reefs and a limestone bank. Unconformably overlying the Victorio Peak of Leonardian to Guadalupian age, is the Cutoff shale consisting of as much as 150 feet of a thin-bedded, platy gray to black limestone, black siliceous or sandy mudstone, and thin-bedded, fine-grained sandstone (Hayes, 1964). In the Midland Basin, the unit grades laterally north and westward into almost pure limestone and dolomite along the peripheries of the Central Basin Platform and Northern Shelf (Oriel et al., 1967).

Away from the Delaware Basin onto the shelves and Central Basin Platform areas, the Leonardian series grades laterally from the Bone Spring and Victorio Peak a into light-colored dolomite, almost 3,000 feet thick, with a few sandstone units. The lower portion of the dolomite has been called the Wichita Group on the Central Basin Platform and the Abo Formation in central eastern New Mexico, which grades northward into red mudstone, sandstone and anhydrite. The Yeso overlies the Abo in central eastern New Mexico, and consists of medium to light gray, fine-crystalline dolomite with lesser sandstones and siltstones (Hayes, 1964). Somewhat below the middle of the Leonardian shelf dolomite on the Central Basin Platform, is a thin but extensive sandstone bed called the Tubb, Fullerton or Drinkard, which serves as a regional marker. The name "Clear Fork Group" is sometimes applied to the section of dolomite encompassing this bed on the Central Basin Platform, and is roughly age-equivalent with the Yeso. The upper limit of the Leonardian on the shelves is formed by a unit consisting of two sandstone layers separated by dolomite. On the northwest shelf, this unit is called the Glorieta; on the Central Basin Platform, it is called the San Angelo (Oriel et al., 1967; King, 1948; Hayes, 1964).

3) Guadalupian Series

The Guadalupian Series in the southeastern New Mexico region encompasses three distinct depositional settings, closely related to structural elements: clastic sedimentation in the Delaware Basin and on the Eastern shelf, carbonate reefs along the margins, and mixed carbonate and evaporite deposition on platforms and shelves other than the Eastern Shelf. The series is over 5,500 feet thick in the Delaware Basin, and gradually thins northward on the Northwestern Shelf to less than 3,000 feet. It thins southeastward from less than 2,000 feet to 1,400 feet at the south end of the Central Basin Platform. Maximum thicknesses in the Midland and Val Verde Basins are about 3,500 feet (Oriel et al., 1967).

a) Basin Facies

The basin facies of the Guadalupian, known as the Delaware Mountain Group, is composed mainly of light gray, very fine-grained sandstone and

siltstone separated by gray shale and a few thin light gray to gray limestone and dolomite members with minor evaporites, indicating frequent relative sea level changes. The Delaware Mountain sandstones produce oil and gas and are important exploration objectives (Vertrees et al., 1959). The Group has been subdivided into three formations from oldest to youngest--the Brushy Canyon, the Cherry Canyon, and Bell Canyon--each of which are up to 1,000 feet in thickness. The Brushy Canyon differs from the upper two formations in that its sandstones are coarser grained with minimal amounts of sediments other than sandstone, and its structural features are indicative of deposition in agitated water. Harms (1974) discusses the Brushy Canyon and proposes density currents as the origin of the formation rather than turbidity currents. This formation terminates northward against the Bone Spring flexure at the basin margin. The Cherry Canyon and Bell Canyon are fine-grained sandstone to siltstone and very finely laminated. The sandstone tongue of the Cherry Canyon disconformably overlies the Cutoff Shale as a shelfward extension of the lower fourth of the Cherry Canyon Formation. Along the reef facies area, the tongue averages 200 to 300 feet thick and, where described in Last Chance Canyon of the Guadalupe Mountains, consists of moderately resistant, indistinctively bedded, grayish-orange, very fine-grained, well-sorted quartz sandstone with scattered chert nodules and silicified megafossils. The upper 25 to 30 feet of the unit is transitional shelfward into an overlying dolomite tongue of the San Andres Limestone (Hayes, 1964) (Also see Figure 3.3-3). The upper Cherry Canyon and the Bell Canyon grade into reef facies at the margin of the basin.

b) Reef Facies

The Guadalupian reef facies consists of the Goat Seep Dolomite and the overlying Capitan Limestone. A generalized cross-section through the reef facies, Figure 3.3-4, demonstrates the relationships between the various Guadalupian units along the reef margins.

Gradationally overlying the sandstone tongue of the Cherry Canyon Formation is the Goat Seep Dolomite. The Goat Seep was a reef, which grew primarily upward and formed a barrier around a considerable portion of the western side of the Delaware Basin. King (1948) originally extended the name Goat Seep to include the shelfward-lying thin-bedded limestones and interbedded sandstones, but Newell et al., (1953) restricted the formation to the massive "reef and forereef talus facies" of the basin margin, a designation maintained by Hayes (1964). The lowerportion of the Goat Seep is thick-bedded, and the upper portion is a massive light gray, fine-crystalline to saccharoidal, in places very porous, dolomite.

The overlying Capitan Limestone is a light colored, fossiliferous and vuggy limestone and breccia which reaches a maximum vertical thickness of about 2,000 feet in McKittrick Canyon of the Guadalupe Mountains, and is at least 6 times as broad as thick, reaching a width of from 10 to 14 miles along the Northwestern Shelf. It apparently formed primarily by oblique or horizontal basinward growth (Newell, et al., 1972; Hayes, 1964; Hiss, 1976). The Capitan virtually encircles the Delaware Basin. It extends from the west side of the Guadalupe Mountains northward and eastward as a bold escarpment which gradually descends to the hills in the vicinity of Carlsbad, where it is overlain by younger rocks (Dunham, 1972). The buried reef front trends northeastward to eastward from there across the Eddy-Lea County line, turns southward to parallel the length of the Central Basin Platform, and then turns west and crops out in the Glass Mountains (Hiss, 1976; Kelley, 1971). The Capitan grades laterally basinward into the Bell Canyon Formation and possibly into the lowermost beds of the Castile; onto the Northwestern Shelf the Capitan grades laterally into the Seven Rivers, Yates, and Tansill Formations of the Artesia Group (Hayes, 1964) (Also see Figure 3.3-3).

The limits of the Capitan described by Crandall (1929) and Lang (1937) have been used by most of the more recent workers, including King (1948), Adams and Frenzell (1950), Newell, et al., (1957), Hayes (1964), and Kelley (1971) and are followed in this report. For a different interpretation, see Dunham (1972).

Hayes (1964) recognizes two units as comprising the Capitan Limestone, a massive member and a breccia member, which grade into each other both laterally and vertically. The massive member forms nearly vertical, smooth-weathering cliffs and ranges in thickness from about 250 to 270 feet averaging 400 feet along its Guadalupe Mountains portion. This member is composed primarily of light to yellowish gray, fine-textured, fossiliferous limestone with virtually no discernible bedding planes. Isolated aggregates of coarsely crystalline calcite are common, and some dolomite, sandstone dikes, and isolated sandstone pockets occur. Solution and recrystallization, weathering, and the very small size of the fossils have made the organic content difficult to recognize in the field. Newell, et al., (1953), however, have identified 115 species of fossils within the formation, including fusulinids, sponges, corals, crinoids, bryozoans, brachiopods, and mollusks; in total volume, stromatolites are probably most important in the construction of this rock unit (Hayes, 1964).

The breccia member, which generally forms more easily eroded uneven slopes, consists of thick beds dipping basinward at 20 to 30 degrees or more on the west side of the Delaware Basin. Most of this member is composed of microbreccia derived from the massive member and from the Artesia Group and also contains coarse, angular cobbles and boulders of limestone and dolomite from these sources. The breccia attains a maximum vertical thickness of about 1,750 feet and averages 1,250 feet and as such comprises about two-thirds of the bulk of the Capitan (Hayes, 1964).

Although it has been generally agreed that the Capitan Formation represents a "geologic reef," (a thick, laterally restricted mass of pure or largely pure carbonate, according to Dunham, 1972), investigators of the Capitan have over the years proposed different interpretations as to its genesis and environment of formation.

Crandall et al. (1929) published the barrier reef hypothesis, according to which reef-building, sediment-binding organisms grew practically at sea level on a reef which developed rapidly enough, despite erosion, to

maintain a nearly vertical front, overriding its own debris. Newell, et al., (1953) concurred with Crandall, based on their detailed petrological work on the reef constituents, and a number of recent investigators, such as Hayes (1964), Boyd (1955), Adams (1944), and Adams and Rhodes (1960) have generally followed this interpretation.

A second alternative was advocated by King (1948) and named by Dunham (1972) the "uninterrupted slope hypothesis." King used it to explain his findings in the southern Guadalupe Mountains which seemed to indicate facies change due to change in slope as the shelf descended to the Delaware Basin. Dunham (1972) pointed out, however, that King studied only portions of the structure. Had he gone farther northwestward, his findings would have corroborated Lang (1937), who proposed a third hypothesis, that of the marginal mound.

According to the marginal mound alternative, supported elaborately by Dunham (1972), organisms produced carbonate particulate sediment upon a broad topographic high which was at different times a sandy shoal or an island bordered by sand and mud flats. The sediment was cemented during the island stages of development. Achauer (1969) has advocated a somewhat similar view that the Capitan represents an ancestral organic bank, rather than a classical barrier reef.

c) Back-Reef or Shelf Facies

The thick massively-bedded limestones along the margins of the basins grade shelfward into thin-bedded dolomites. On the Northwestern and Eastern Shelves and southward along the Central Basin Platform, the Guadalupian includes the San Andres Limestone and overlying Artesia Group (also identified eastward on the Central Basin Platform as the Whitehorse Group by Nicholson and Clebsch, 1961). This group includes from base to top the Grayburg, Queen, Seven Rivers, Yates and Tansill Formations (Hayes, 1964). These shelf units are also recognized in the Midland Basin area. There is some disagreement as to whether the Lower Guadalupian there is missing or greatly resembles the upper Leonardian (Hendrickson & Jones, 1952; Oriel et al., 1967).

In the western part of the Delaware Basin, parallel to the reef front, facies encountered in a shelfward direction are: 1) dolomitized coquin and calcarenite, 2) pisolites, 3) fine-grained dolomite, 4) evaporites, and 5) terrigenous red detritus (Newell et al., 1953). This general succession of facies is also described by Dunham (1972) in the vicinity of the Capitan Escarpment. Hayes (1964) presents a comprehensive discussion of the Guadalupian shelf rocks.

The San Andres is partly time-correlative with the basinal Brushy Canyon; at its base it may be upper Leonardian, and at its top it interfingers with the base of the Cherry Canyon. The San Andres is mainly dolomite with minor limestone near its base and some chert, sandstone and reddish mudstone (Oriel et al., 1967; Kelley, 1971). It extends shelfward much farther than the Artesia Group before grading into evaporites and detrital materials. The San Andres thins eastward across the Midland Basin, and detrital and evaporite contents increase progressively to the east.

The Artesia Group ranges in thickness from about 880 feet to over 1,500 feet. In the shelf and Central Basin Platform areas, it is separated from the underlying San Andres by an unconformity, according to Nicholson and Clebsch (1961). The basal Grayburg and Queen Formations are time-correlative with the marginal Goat Seep Reef and basinal Cherry Canyon Formation. To the south, they consist of dolomites and sandstone; they grade northward into gypsum, mudstones and dolomite (Kelley, 1971). The Queen Formation is distinguished from the underlying Grayburg by its much greater abundance of clastics and red mudstones. The Seven Rivers, Yates and Tansill Formations are all correlative with the Capitan Limestone at the margin, and with the Bell Canyon in the Delaware Basin. To the south, they all resemble the lower two formations of the Group, except for the presence of gypsum and limestone in the Yates. Toward the north, gypsum and anhydrite increase in the Tansill, and siltstone and dolomite increase in both the Yates and Tansill.

Ochoan Series

The Late Permian Ochoan series consists primarily of evaporites that were deposited during recurrent retreats of a shallow sea restricted by the Guadalupian reefs. The lower three formations in the series, the Castile, Salado and Rustler, comprise what is perhaps the thickest and most extensive evaporite rock sequence in North America (Oriel et al. 1967). They are overlain by the Dewey Lake Redbeds, which may be either Permian or Triassic in age. Within the Ochoan, halite is dominant on the shelf north of the Delaware Basin, where the Salado Formation makes up the bulk of the unit; total thickness of salt is greatest, however, in the Delaware Basin, but the presence of the Castile Formation in the basin reduces the proportion of halite there. The proportion of carbonates to other rock types increases southwestward and southward, and the proportion of detrital rocks increases eastward and northeastward (Oriel et al., 1967). The total thickness of the Ochoan ranges from slightly more than 5,000 feet in the center of the Delaware Basin and 4,000 feet in a north trending belt through the basin, to about 1,500 feet in the Midland Basin and 1,000 feet on the shelves. Irregular thinning occurs near the basin margins as a result of erosion and leaching of the more soluble beds (Oriel et al., 1967; Nicholson & Clebsch, 1961).

The Castile Formation is confined to the Delaware Basin and was deposited upon the Bell Canyon, in "apparent conformity," according to Kelley (1971), but unconformably, according to Nicholson and Clebsch (1961), and is laterally bounded by the Capitan limestone reef. The Castile is generally of uniform thickness, up to about 2,000 feet, throughout the basin. The formation consists primarily of massive anhydrite, limestone interlaminated with anhydrite, and halite in beds as thick as several hundred feet (Vine, 1963). In the lower to middle portion of the sequence, banded light gray anhydrite is interlaminated with brown bituminous limestone on a scale of millimeters. Two very extensive layers of fairly pure halite averaging 200 to 350 feet thick persist throughout the northern Delaware Basin. Several smaller tongues of halite are also present through the unit. Towards the basin margins, the

Castile thins abruptly. The basal part of the banded portion grades reefward into laminated limestone and the upper part into massive anhydrite. The top of the Castile is light-gray massive anhydrite, grading into the basal part of the overlying Salado by wedging of thin anhydrite tongues northeastward into salt (Jones, 1954; Brokaw et al., 1972).

The Salado Formation extends from the Delaware Basin area beyond the limits of the Castile and across most of the Permian basin, including the Midland Basin, the Northwestern Shelf and the Central Basin Platform. The complete Salado is present only in the subsurface of this area, and is represented at the surface only by a solution residue. Its thickness varies because of leaching, but it is generally up to 2,000 feet near the northern Delaware Basin, thinning northward over the Capitan reef to 700 to 1,200 feet and thinner farther north and east. In the shelf and platform areas, it rests unconformably on the Artesia, or Whitehorse, Group (Brokaw et al., 1972; Nicholson & Clebsch, 1961).

The Salado is mainly halite, some of which is argillaceous, red mudstones, sandstone, siltstone, abundant anhydrite and a suite of salts including polyhalite, kieserite, glauberite, sylvite, carnallite, langbeinite, kainite and leonite. Beds locally rich in sylvite, KCl, and other soluble potassium minerals constitute valuable potash ores (Vine, 1963). The principle lithologic materials occur in cyclic sequences 2 to 30 feet thick consisting of a detrital layer, a relatively thin sulfate layer chiefly composed of anhydrite and polyhalite, and a thicker halite zone, overlain by a mixed halite-detrital layer, all with gradational contacts. The potash ores occur near the middle of the formation in irregularly lenticular to tabular bodies (Brokaw et al., 1972; Oriel et al., 1967). The upper part of the Salado is locally characterized by a leached zone from which the halite has been removed, and is largely unconsolidated reddish-gray to brown silt and clay with varying amounts of brecciated gray or red gypsum (Vine, 1963).

The Rustler Formation ranges in thickness from 90 to about 400 feet, and overlies the Salado in the Permian Basin area. In the central part of the Permian Basin, the Rustler conformably overlies the Salado, but in other places, as along the west and north margins of the Delaware Basin, it truncates the Salado by a marked unconformity (J. A. Adams, 1944; Nicholson and Clebsch, 1961). In outcrop, the Rustler appears as calcareous sandstone, fine grained dolomites and gypsum. The subsurface Rustler consists primarily of anhydrite or gypsum and subordinate salt, with lesser amounts of dolomite, limestone, siltstone and sandstone. Within the Delaware Basin, the limestone and dolomite increase to the south and southeast.

Vine (1963) has described the Rustler in the northern part of the Delaware Basin. Here, the lower part of the Rustler consists of over 100 feet of siltstone and very fine-grained sandstone with interbeds of gypsum or anhydrite. Next above is the Culebra dolomite, about 30 feet of uniformly microcystalline gray dolomite or dolomitic limestone with numerous small, generally unconnected, nearly spherical cavities. Overlying the Culebra is the Tamarisk member, about 115 feet of anhydrite with local gypsum and a 5 foot thick siltstone bed some 20 feet from its base. The Magenta member, above the Tamarisk, consists of about 20 feet of thin, wavy, lenticular laminae of dolomite and anhydrite (or gypsum). The uppermost member of the formation is the Forty-niner, consisting of up to 65 feet of anhydrite (or broken gypsum in outcrops) with a bed of massive siltstone near the base. According to Jones et al., (1960), the siltstone represents insoluble residue from a bed of halite present in the subsurface to the east.

The top of the Rustler has been placed at the top of the first persistent anhydrite bed penetrated by oil and gas tests and provides a clear marker for structural correlations (Oriel et al., 1967).

Overlying the Rustler in apparent conformable relationship is a sequence of redbeds, up to about 600 feet thick, which represents deposition of terrigenous materials in shallow water remaining in the basin areas over

the older evaporate sequence (Mercer & Orr, 1977; Oriel et al., 1967). On the basis of physical stratigraphy, the unit has been traditionally assigned a Permian age (Oriel et al., 1967). No fossils have been found. Although several names (e.g. the Pierce Canyon) have been proposed for this unit, the term Dewey Lake Redbeds, as defined in west Texas (Page and Adams, 1940), is generally used throughout the area (Nicholson & Clebsch, 1961).

The Dewey Lake consists of a series of micaceous, orange to red sandy siltstones, sandstones and some mudstone. Gypsum commonly forms cement, secondary crystals and veins. The lower 10 feet of the sequence contains a widely distributed zone of coarse, frosted quartz grains.

The top of the redbed unit is marked by an erosion surface, upon which younger units were deposited with a slight angular discordance. In some places, the Dewey Lake has been removed by later erosion, and rocks of Cretaceous or Cenozoic age rest on the Rustler or Salado (Oriel et al., 1967).

3.3.3 Mesozoic Rocks

Triassic Rocks Unconformably overlying the rocks of Late Permian age is the Upper Triassic Dockum Group of red beds, composed of up to 1,500 feet of moderate-reddish-brown to yellow-brown conglomeratic sandstones, siltstones and shales (Brokaw et al., 1972). The sediments of this group display characteristics of rapid deposition from a local source, in their poorly rounded sand grains and micaceous minor constituents. This group has been subdivided into two formations, the Santa Rosa Sandstone and overlying Chinle Formation; however, because of poor exposures and lithologic similarities between the sandstones of the two units, the distinction cannot be made throughout the entire southeast New Mexico area (Nicholson & Clebsch, 1961).

The Santa Rosa is a fine-to-coarse-grained sandstone, generally red but containing white, gray, and greenish to lavender sands and some minor reddish-brown mudstones and conglomerate. The unit is commonly cross-stratified and ranges in thickness from about 140 to over 300 feet (Kelley, 1971; Nicholson & Clebsch, 1961).

The upper portion of the Dockum Group, the Chinle Formation, ranges in thickness from zero to almost 1,300 feet, thickest to the east, near the Texas-New Mexico border, and entirely absent in the west, where it has been removed by post-Mesozoic erosion. The Chinle is a reddish-brown to greenish-gray shaly mudstone with interbedded lenses of conglomerate and thin, gray to reddish-brown sandstone and siltstone (Mercer & Orr, 1977; Nicholson & Clebsch, 1961).

Jurassic Rocks No record of Jurassic deposition has been shown to exist in the southeast New Mexico region.

Cretaceous Rocks Kelley (1971) described three formations, identified as Cretaceous, which crop out to the north and northwest, in the Sierra Blanca and Capitan area, named the Dakota Sandstone, Mancos Shale and Mesaverde formation. The Dakota is comprised of up to 150 feet of sandstone, conglomerate, and beach shale. The overlying Mancos is up to 700 feet of dark shales, siltstone and local thin sandstone and limestone. The Mesaverde Formation comprises from 500 to 1,500 feet of light-colored to maroon coarse clastics and mudstones, and coal. These deposits reflect subsidence of the area during the Cretaceous to a shallow marine and floodplain environment. An outlier of Cretaceous rocks is also present on the crest of the Sacramento Mountains. Here, a pebble-bearing quartz sandstone 150 feet thick is overlain by a shale containing fossils of late Early to early Late Cretaceous age (Pray & Allen, 1956).

Further south on the Northwestern Shelf, there are no definite Cretaceous age outcrops, but solution cavities on the surface of the Castile southeast of the Guadalupe Mountains contain pebbles of limestone and

sandstone with fossils of early Washita age. At several places along the top of the Reef Escarpment, low areas on the ridge and joints in the Permian Tansill formation contain conglomeratic quartz sandstone which closely resembles the Cretaceous deposits in the Sacamento Mountains (Hayes, 1964).

To the southeast, in the Lea County area, only several exposures of Cretaceous rocks are known. A gravel pit east of Eunice contains large slump blocks, up to 5 feet thick and 20 feet long, of massive, highly fossiliferous, white to buff sandstone containing some sand and shaly partings along the bedding planes (Nicholson and Clebsch, 1961; Ash and Clebsch, 1961). This rock and the Comanche limestone of Early Cretaceous age are strikingly similar, so are believed by Ash and Clebsch (1961) to be equivalent. Another outcrop of Cretaceous rocks at North Lake consists of dark gray siltstone and thin interbedded stringers of light brown crystalline to light gray, fine-grained limestone. According to fossil and lithologic similarities, the rocks at North Lake are correlated with the Early Cretaceous Tucumcari shale (Ash & Clebsch, 1961). In the subsurface of Lea County, 5 feet or more of yellow, blue, or gray clay or shale encountered by drilling and consistent with the description of the rock at North Lake constitute the major evidence for the subsurface presence of Cretaceous outliers in the area. Based on some 8,000 water-well logs and seismic shotholes, Ash and Clebsch (1961) have determined that in the subsurface Cretaceous rocks are generally continuous in the northeastern portion of Lea County, but further west and south, only scattered, discontinuous occurrences have been encountered.

Rocks of Cretaceous age were deposited over the southeast New Mexico area but have been almost entirely removed by erosion. Now only scattered patches or reworked pockets of limestone and sandstones of probable Early and Mid-Cretaceous age are present in the area; Cretaceous rocks have also been identified here in the subsurface through drilling (Bachman, 1976; Hayes, 1964; Nicholson and Clebsch, 1961).

3.3.4 Cenozoic Rocks

Tertiary Rocks. Following Cretaceous deposition, widespread uplift and erosion occurred throughout the region, and the earliest Cenozoic deposits for which there is record, the Ogallala, were depositied in Late Tertiary Miocene to Pliocene time.

The Ogallala Formation underlies the High Plains of eastern New Mexico and west Texas. Although there are no confirmed remnants of the Ogallala west of easternmost Eddy County, isolated gravels to the west in the Pecos Valley and Guadalupe Mountains have been interpreted as belonging to this formation (Mercer and Orr, 1977). The Ogallala was deposited on an irregular, broadly sloping pediment or complex alluvial fan surface by southeastward flowing streams under rapidly changing conditions (Bachman, 1976).

The Ogallala in the region is up to 400 feet thick (Bachman, 1976) and consists of a yellowish-gray semi-consolidated, fine-to medium-grained, calcarous sand containing some silt, clay, and gravel. In many places, a basal gravel deposited within stream beds is also encountered. Some beds of well consolidated silica-cemented conglomeratic sandstone from one to three feet thick also occur within the formation. As a result of intertonguing, lensing and pinching out of the beds caused by the varying depositional conditions there are no consistent marker beds within the Ogalalla (Nicholson and Clebsch, 1961; Bachman, 1973).

The Ogallala is capped by a dense layer of brecciated and pisolitic caliche ranging in thickness from a few feet to as much as 60 feet. At the surface it is a well indurated calcium carbonate, but below the surface, it becomes softer and more porous and grades into the underlying sands. This capping was formed in post-Ogallala time and before the extensive Pleistocene erosion of the area, probably during the Late Pliocene. The caliche accumulated within the zone of illuviation of a pedocal "climax soil," which developed on the depositional surface of the

Ogallala (Nicholson and Clebsch, 1961; Bachman, 1976). (Pedogenic caliche formation in southern New Mexico is described in detail by Gile, et al., (1966).)

Quaternary Rocks Following Pliocene time, erosion removed much of the Ogallala as well as some of the older materials, and stream systems became entrenched. Periodic deposition also occurred in the southeastern New Mexico area during the Pleistocene and Holocene, leaving behind the Gatuna Formation, caliche, terrace, channel and playa deposits and windblown sand.

The Gatuna, of Pleistocene age, unconformably overlies rocks as old as Permian and Triassic and consists of up to several hundred feet of reddish-brown friable sandstone, siltstone and cherty and siliceous conglomerate, but locally also includes gypsum, gray shale and claystone. Remnants of the formation are discontinuous and may have been deposited in local depressions such as stream channels and solution subsidence areas (Bachman, 1973; Vine, 1963).

Unconformably above the Gatuna and older deposits throughout southeastern New Mexico, there formed a fairly continuous mantle of caliche called the Mescalero. It is a sandy light gray to white deposit composed of a lower nodular calcareous zone and upper dense laminar caprock and ranges in thickness from 3 to 10 feet. According to Bachman (1973), the caliche is the remnant of an extensive soil profile.

Late Pleistocene to Holocene terrace and channel deposits are preserved in the western part of the area, particularly along the Pecos River and the Guadalupe Mountains area. Channel deposits consist of silt and sand to boulders. Within the Guadalupe Mountains area, deposits are generally limestone cobbles and boulders. Three terraces are commonly recognized in the area: the Blackdom, Orchard Park and Lakewood. The Blackdom and Orchard Park have been dated as Pleistocene while the Lakewood may be of Holocene age. The deposits of the Blackdom terrace are generally coarser than those of the younger terraces, but the two Pleistocene terraces are

similar in composition, consisting of limestone-porphyry conglomerates capped by caliche. The younger Lakewood terrace contains river conglomerates and pond, marsh, and lake silts (Bachman, 1973; Hendrickson and Jones, 1952).

Playa and shallow lake deposits are present in the area in many small shallow depressions, particularly east of the Pecos River. In most of these depressions, lakes formed after heavy runoff and evaporated rapidly, but some contain generally perennial lakes, the largest of which is Laguna Grande de la Sal, in Nash Draw. The playa deposits consist of alluvium, reworked eolian sands, silt and clay. Around some of the standing lakes, gypsum, carbonate minerals, and some halite have been deposited. These deposits date from the Late Pleistocene to Holocene time (Hendrickson and Jones, 1952, Vine, 1963).

Windblown sands mantle much of the surface east of the Pecos River for 20 to 30 miles eastward to the Mescalero ridge and south to the Texas border. The sand is very erratic in both thickness and distribution, and appears to be fairly uniform, fine-grained light brown to pale reddish-brown quartz. Many of the grains are rounded and frosted. Some of the sand rests in coppice dune fields where the sand is as thick as 25 feet. Most of the sand has been stablized by mesquite, bunchgrass and other vegetation.

3.4 REGIONAL STRUCTURE AND TECTONICS

The major tectonic structures of the region are displayed in Figure 3.4-1. Most of the large-scale elements that provide the structural framework of the area were developed in the Late Paleozoic, principally from Late Pennsylvanian to Early Permian time. These include the Delaware Basin, the Central Basin Platform, the Midland Basin, and the Northwestern Shelf of the western extent of the Permian Basin, the Pedernal Uplift, the Matador Arch, the Val Verde Basin, and the Diablo Platform, as well as secondary features such as the Huapache Monocline and Artesia-Vacuum Arch and the northeast-trending buckles and smaller

fold systems believed to be expressions of basement faulting. Middle to Late Tertiary Basin and Range-related doming and faulting produced the remainder of the major tectonic features in the area, including the Guadalupe, Delaware, and Sacramento Mountains, and associated west-bounding faults, as well as a gentle regional east to southeastward tilt which affected the entire region under consideration.

The WIPP site lies near the western margin of the region of the Western Interior known as the Permian Basin, which comprises a series of sedimentary basins in which halite and associated salts accumulated during Permian time and where Permian rocks have reached their maximum development. The region extends about 520 miles from the Amarillo uplift on the north to the Marathon thrust belt on the south and some 300 miles westward, from west-central Texas to the Diablo Platform and the present Sacramento and Guadalupe Mountains (Hills, 1963).

The formation of a depositional basin in the west Texas-southeast New Mexico area began following Lower Ordovician Canadian time, when a broad sag, named the Tobosa Basin by Galley (1958), developed. Several periods of minor folding and perhaps some faulting occurred in the Tobosa Basin area prior to Pennsylvanian time. There was some erosion, but a general tectonic stability prevailed until the Late Mississippian to Late Pennsylvanian-Early Permian time. Tectonic activity accelerated in the area coincident with the Marathon disturbance, and the sag was split into two rapidly subsiding basins--Midland to the east, and Delaware on the west--by the final uplift of the median ridge, the Central Basin Platform (Foster, 1974). Continuing basin and platform development occurred throughout the Permian Basin through Permian time. Stabilization of the basins followed, during which time evaporites were deposited. Since Permian time, the Permian Salt Basin has been relatively stable tectonically (Bachman & Johnson, 1973); thus, the large structural features of the Permian Basin are reflected only indirectly in the Mesozoic and Cenozoic rocks (Nicholson & Clebsch, 1961).

The structure of each of the major tectonic units of the Permian Basin in the site region is described below, followed by discussion of the larger secondary features and younger Tertiary Basin and Range-related structures.

3.4.1. Delaware Basin

The site is located within the northern portion of the Delaware Basin, which, during most of Permian time, was a deep-water embayment extending into what is now southeastern New Mexico and western Texas. The Delaware Basin is a broad, oval-shaped asymmetrical trough with a northerly trend and southward plunge, as reflected on the top of the Precambrian (Figure 3.4-2). Its axis lies in central Lea County, New Mexico, roughly paralleling the Central Basin Platform. The eastern slope of the trough rises rapidly to the platform, while the western slope is much gentler (Figure 3.3-2). The basin comprises an area of about 12,000 mi^2 and measures roughly 75 to 100 miles east to west and 135 to 160 miles north to south. The Delaware Basin is nearly surrounded by the large horseshoe-shaped Capitan limestone that extends from Carlsbad on the northwest and opens to the south in Texas, between the Davis and Glass Mountains. However, the structural boundaries of the basin encompass a larger area to the north, beyond the Capitan reef front, into which the older and deeper lying basin sediments (e.g. the Delaware Mountain Group and Bone Spring) extend. The Delaware Basin represents the area of maximum subsidence of the Permian Basin, with more than 20,000 feet of structural relief, on the Precambrian (See Figure 3.4-2), and it is also here that the Permian section is thickest, with some 13,000 feet of Permian strata present in southeast New Mexico (Oriel, et al., 1967)

Regional structural deformation of the Delaware Basin rocks is relatively minor. The sediments older than Late Permian are gently downwarped as a result of concurrent basinal development. The Late Permian Ochoan rocks and Triassic rocks do not reflect this basinwide warping; their major structural feature is the regional eastward slope (Brokaw, et al., 1972).

There are no known active faults within the northern Delaware Basin study area of the WIPP site. Deep-seated faults, which may be partly of tectonic origin, do occur within the older sediments of the Delaware Basin. Some of these faults probably originated from the rapid Pennsylvanian-Early Permian subsidence of the basin, during which widespread block faulting occurred within the basin (Adams, 1965). Others are pre-Permian and basement structures which are reflected in the overlying beds. An example of this type of intrabasin feature is the Bell Lake fault, recognized by Haigler (1962, 1972), which has a displacement of about 500 feet in the Precambrian. The structure is reflected upwards through the Pennsylvanian Section and Foster's (1974) map. It shows as a north-south high with closure on the south. Closure is also indicated on the Bone Springs map. Whether this structural representation results from continued movement of the Bell Lake fault system up to that time or is only an effect of compaction is not known (Foster, 1974). A complex series of faults with several thousand feet of offset marks the boundary between the Delaware Basin and Central Basin Platform. These faults were involved in the development of the basin and are considered to have been inactive after Permian time. They are discussed in more detail in the following section.

Two sets of joints, with strikes to the northwest and northeast, have been recognized within the basin. The northeasterly set appears to be better developed and penetrates the lower anhydrite of the Castile Formation along the western margin of the basin, where the formation is exposed. This set also controlled the emplacement of replacement limestone within the evaporites (Anderson, 1978).

Other structures within the Delaware Basin include flexures, some of which formed during Early to Mid-Permian basinal downwarping and deposition of the Bone Spring and Delaware Mountain Groups (Pray, 1954), and minor scattered folding of the younger beds (U.S. Bureau of Mines, 1977). Evidence of anticlinal structures as well as an unusual type of fracturing and microfolding within the Castile anhydrite has been cited by Anderson and Powers (1978) and Anderson, et al., (1972), as evidence

of salt movement. C. L. Jones (unpub.) has described a deformation zone encircling the inner margin of the basin and extending inward about 5 miles, as well as a number of similar structures in the interior of the basin, which, according to Anderson and Powers (1978), may be salt anticlines. These features may have formed as a result of differential stress from unloading related to salt dissolution (Anderson, 1978). Scattered small domes, various collapse structures due to salt and/or gypsum dissolution (including domal structures with collapsed centers, known colloquially as breccia pipes), limestone buttes (Castiles), collapsed outliers, and deep-seated sinks can be found in the evaporite sections (Vine, 1960; Anderson, 1978). Stipp (1954) also identified brecciation in the beds of the Wolfcampian and Leonardian rocks, which he attributed to adjustment in the basin in response to sedimentation and structural forces.

The tectonic development of the Delaware Basin, as reflected in the structures discussed in this section, may be summarized as follows. The Delaware Basin was defined by early Pennsylvanian time and major structural adjustment took place in Late Pennsylvanian to Early Permian time. Regional subsidence in conjunction with broad arching, folding, and faulting occurred until Late Permian time, when the basin's history as an active structural feature ended (Brokaw, et al., 1972). Regional uplift and deposition of continental red beds in Triassic time was followed by continued emergent conditions, resulting in erosion or nondeposition. Mid-Cenozoic to Late Cenozoic regional eastward tilting of the basin much later shifted the deepest part of the Basin to its present position close to and paralleling the Central Basin Platform (Stipp, 1954). Since then, the only structural developments in the basin have been related to hydration and solutioning of the Late Paleozoic sediments.

3.4.2 Central Basin Platform

The Central Basin Platform is a subsurface feature (see Figure 3.3-2) which represents an ancient broad uplift of Precambrian and Cambrian to

Pennsylvanian rocks separating the Delaware and Midland Basins at the southern extreme of the Permian Basin in southeastern New Mexico and southwest Texas. The platform extends in a north-northwest trend for about 200 miles to the south flank of the Matador Arch (Bachman and Johnson, 1973). The Central Basin Platform may represent a zone of structural weakness along which movements took place periodically at least into Late Paleozoic time. Displacement within and along the margins of the platform appears to have been along large, high-angle normal or reverse faults, which trend north to northwest and break Early Permian and older rocks; all faults predate the salt deposits of the adjacent basins (Bachman and Johnson, 1973). According to Hills (1970), these faults may have been involved in considerable lateral as well as vertical movement.

The platform itself is a horst. In the structurally higher parts of the platform identified by Foster (1974) as the Hobbs and Eunice blocks, the Precambrian surface is from 4,000 to 7,000 feet below sea level, while the adjacent Monument-Jal block stands at 6,500 to 11,500 feet below sea level. The fault system separating the Hobbs and Eunice blocks from the Monument-Jal block has a displacement of about 1,000 feet in the north to possibly 4,000 feet west of Eunice. The fault bounding the Monument-Jal block extends about 50 miles southward, into Texas, with an inferred displacement of 1,500 feet at the north to over 6,000 feet west of Jal. The aeromagnetic map of the Carlsbad area (U.S.G.S., 1973) provides fairly good definition of the trend of the major features of the Central Basin Platform (Foster, 1974).

The maximum structural relief east-west between the Central Basin Platform and the Delaware Basin is remarkably uniform, at about 9,000 feet (Foster, 1974). Complex fault systems form the boundary between these two structural units. Hills (1970) indicated a fault in approximately this location and termed it the West Platform fault. According to Haigler (1962), this fault system has a relief about equivalent to that of the Huapache monocline bordering the west side of the Delaware Basin.

The Central Basin Platform has been more intensely deformed than has the Delaware Basin or shelf areas (Brokaw, et al., 1972). The tectonic development of the Central Basin Platform may have begun in Precambrian time, and it appears to have been a high during Early Ordovician time. The platform was unstable during late Devonian time but was generally an area of stability thoughout early to Mid-Paleozoic time. In latest Mississippian or early Pennsylvanian time, the area was deformed to an elevated emergent fold belt, trending north-northwest. After submergence and deposition in Middle and part of Late Pennsylvanian time, renewed orogeny further elevated the area and sharpened, compressed, and faulted the folds (Hills, 1963). The complex fault system bordering the platform on the west formed either in Late Pennsylvanian or Early Permian time, according to Haigler (1962), and contributed as well to the structural development of the Delaware Basin. Claiborne and Gera (1974) also identify the subsurface faults outlying the Central Basin Platform as no younger than Permian age, since the Permian and younger beds in the area are unfaulted. Over the faulted platforms, the sedimentary formations were broadly arched, and concurrently eroded, in places to the Precambrian basement. Subsidence followed, and upper Wolfcampian- through Guadalupian-age carbonates were deposited on the roots of the earlier mountain ranges. Since filling of the Midland and Delaware Basins in Late Permian time, the platform has been structurally stable (Brokaw, et al., 1972). Recent seismic activity there is being studied to determine its relationship to secondary oil recovery operations (see Section 5.). The Central Basin Platform is probably not naturally active at the present time, in view of the lack of fault scarps to match the seismic activity (Sanford, 1978).

3.4.3 Midland Basin

The Midland Basin, situated to the east of the Central Basin Platform, is similar in most respects to the Delaware Basin but shallower, having experienced less structural development. The Midland Basin extends some 200 miles along a north to northwest trend to the Matador Arch vicinity. Its shape is much more symmetric than is the Delaware Basin, and its

relief is only 4,000 to 5,000 feet. Extensive major faulting occurred before the deposition of Late Permian salt in the southern part of the basin and on its west flank in proximity to the Central Basin Platform (Bachman & Johnson, 1973). As is the case with the Delaware Basin, general tectonic stability has prevailed in the Midland Basin since Permian time.

3.4.4 Matador Arch

The Matador Arch is a narrow east-west trending Paleozoic highland of irregular relief and outline underlain by Precambrian granitic rocks. The uplift extends for some 300 miles across the Permian Basin, from west of Wichita Falls, continuing westward, north of Lubbock and entering New Mexico in southern Roosevelt County. Its western limits are uncertain, but some have supposed a connection with the Capitan Mountains to the west, by way of the intrusive igneous Railroad Mountain and Camino del Diablo dikes that parallel the trend of the Matador arch in eastern New Mexico (Stipp, 1960). The Matador Arch provides structural division between the Delaware and Midland Basins to the south and the Hardeman, Palo Duro, and Tucumcari Basins in the northern part of the Permian Basin.

The Precambrian structural framework of the Matador Arch itself is probably not a continuous ridge, but a series of prominences which may be the roots of a chain of islands or hills existent during Precambrian and Early Paleozoic times. The only large tectonic structures on the Matador Arch consist of strong faults and folds that trend obliquely across the uplift in a northwest direction (Eardley, 1962). These faults are present only on the southern flank of the arch, near its western extremity and break only the Precambrian basement rocks (Bachman and Johnson, 1973). The history of the major tectonic development and activity of the Matador can thus be considered to have ended by early Paleozoic time.

3.4.5 Pedernal Uplift

The Pedernal Uplift represents a southward extension of the Rocky Mountains in south-central New Mexico about midway between the Rio Grande and Pecos Rivers. The boundaries of the uplift are not very well defined but in general trend north-south from the eastern side of the Sacramento Mountains in Otero County, apparently continuously to northern Torrance County (Eardley, 1962). The uplift is named for Pedernal Mountain in Torrance County, which is considered to be a remnant and the southernmost exposure of the Ancestral Rockies.

Together with the Permian Basin, the Pedernal landmass strongly influenced the depositional and structural patterns of the region. The Pedernal Uplift appears to have been a wide and not particularly emergent area connecting southward with the Diablo Uplift, and existed, according to Thompson (1942), and Pray (1961), from Early Pennsylvanian time until well after the beginning of Permian time. Within the confines of the Uplift, red shales, sandstones, variegated shales, and limestones of Permian age rest directly on igneous and metamorphic rocks of Precambrian age (Eardley, 1962). In structure, the uplift may have been a broad upwarp in some places and fault-bounded blocks in others. The uplift was probably sharpest on the west with the possible exception of the southeastern edge along the buried Huapache zone (Kelley, 1971).

There is some disagreement as to the time of initial uplift of the Pedernal. According to Stipp (1960), the uplift apparently rose in Late Mississippian or Early Pennsylvanian concurrently with the Central Basin Platform, and was subsequently eroded down to its Precambrian core. Kelley (1971) states that the Pedernal began its rise in Late Pennsylvanian time. According to Bachman (1975), the earliest indication of Ancestral Rocky Mountain building in New Mexico occurred during the Middle Pennsylvanian Desmoinesian time but the Ancestral Rocky Mountain-Pedernal Uplift activity accelerated and was extended southward into New Mexico during Late Pennsylvanian Missourian time, and the uplift reached its maximum in New Mexico during the Virgilian, with accompanying

major faulting occurring along the west side of the Pedernal Uplift. Acceleration of uplift continued through Wolfcampian time, denuding the rocks well into the Precambrian core. Some broad arching and erosion had taken place before the basal Artesia was deposited, followed by renewed rise during and following Salado deposition. Post-Triassic to pre-Dakota time saw renewed rise of the Pedernal Uplift. Structural development ended with a slight uplift and tilting of the Pedernal towards the north during Late Jurassic to Early Cretaceous time (Kelley, 1971).

3.4.6 Diablo Platform

The Diablo Platform is a northwest-trending, structurally positive area southwest of the Delaware Basin, extending southeastward from the Cornudas Mountains at the New Mexico-Texas border and terminating with the Marathon Uplift area and Ouachita tectonic belt to the southeast. The platform is a horst with an average elevation of 1,200 meters above sea level and is bounded on the east, south, and west by grabens. At its northern extent and closest approach to the site, the platform is bordered on the east by the Salt Flat graben (Barker, et al., 1977). (See Figure 3.4-1).

The Diablo Platform experienced primary deformation in Late Pennsylvanian or Early Permian time, but topographic relief and the presence of coarse detritus favor Early Permian for the major portion of the activity. Deformation consisted of uplift, folding, and faulting. The uplift was greater on the south than the north, in the Carrizo Mountain-Van Horn area, where subsequent erosion exposed Precambrian rocks. Faulting is also known to have occurred in post-Permian rocks along the northeast margin of the platform. The Late Cenozoic Basin and Range activity affected the Diablo platform through prominent block faulting and buckling. Major movement in this area was on northwest-trending faults along the northeast margin of the Diablo Platform. Late Cenozoic regional uplift concurrently affected the platform (Oriel, et al., 1967). Oliver (1977) reports several centimeters of relative uplift of the eastern Diablo Plateau and western Salt Basin between 1934 and 1958.

Releveling of this first-order line by the National Geodetic Survey in 1977 for the WIPP indicates only millimeters of relative uplift during the period 1934-1958 and about 5 centimeters of downwarping from 1958-1977 relative to the 1958 line. Further studies of this area are indicated in Chapter 10.

3.4.7 Val Verde Basin

The Val Verde Basin was a deep Early Permian depositional basin at the southwestern extent of the Permian Basin area. The Val Verde Basin trends east-southeast towards the Delaware Basin, adjacent to the north rim of the Ouachita tectonic belt.

The Val Verde Basin attained its major structural definition in Late Paleozoic time. The southeastern part of the south margin of the trough may have been established early in Pennsylvanian time. During Upper-Middle Pennsylvanian Desmoinesian time, the Val Verde area was a fairly stable foreland. But near the beginning of Permian time, the Val Verde trough was abruptly deepened and its north side irregularly steepened opposite the Marathon salient of the south rimming structural belt. Large-scale faulting believed to be of Pennsylvanian age has been recognized, through drilling, along the north flank of the trough; sagging along these zones of weakness during the Early Permian deepening of the trough is probable, according to Vinson (1959), Hester and Holland (1959) and Oriel et al., (1967). The large-scale rapid downwarping that occurred in earliest Permian time caused Permian rocks to accumulate here to a thickness exceeding 17,000 feet, the greatest accumulation of Permian rocks to be found in the Permian Basin. By the Mid-Permian there was a marked decrease in deformation, and a shelf formed across part of the area. Permian rocks here were later warped, possibly in Early Triassic time and eroded (Oriel et al., 1967).

3.4.8 Huapache Flexure

The Huapache Flexure is a long, narrow, northwest-trending monoclinal structure along the eastern slope of the Guadalupe Mountains on the west border of the Delaware Basin. The monocline extends from parallel to the Guadalupe Ridge anticline on the south, northward across the Capitan Reef escarpment, where it is offset to the west. Similar offset occurs farther north as it crosses the folds along the shelf margin. The monocline terminates at the north end of the Guadalupe uplift.

The Huapache flexure is marked by tonal and textured differences on LANDSAT imagery. On the southwest side of the mapped flexure line, the terrain is more dissected, has more vegetation, and from the visible shadows appears to be topographically much higher than the area to the northeast.

The width of the flexure ranges from 0.5 to 2.5 miles. The Precambrian structural relief ranges from 300 to 400 feet in the north to as much as 1,000 feet in the south, just north of Guadalupe Ridge. In the Delaware Basin, the structural relief on the Precambrian along the monocline is from 300 to 600 feet. The maximum dip along the flexure is about 15 degrees to the east, and above and below the structure, dips are from 3 to 5 degrees (Kelley, 1971).

Although the Huapache structure has the configuration of a monocline at the surface, there is evidence that it overlies a thrust fault or series of faults in the Precambrian basement and Paleozoic sedimentary section, and so represents the draping of sediments over a fault or fault zone (Stipp, 1960; Hayes, 1964). Haigler (1962) interpreted the results of drilling as indicating a displacement of as much as 5,400 feet along an underlying fault.

According to Claiborne and Gera (1974), the age of inception of the Huapache was Pennsylvanian; according to Haigler (1962), it was late Pennsylvanian to Permian, contributing to the final structural

development of the Delaware Basin. Hayes (1964) has indicated that the Huapache thrust faulting must have been post-Mississippian in age, since Mississippian rocks show no lithologic change across the zone but are vertically displaced as much as 4,000 to 6,000 feet, with a much higher Pennsylvanian section east of the zone (also see Meyer, 1966). According to Hayes, the zone was apparently intermittently active through all or most of Pennsylvanian time, into Early Permian. The Guadalupian San Andres Limestone, however, is not ruptured; thus, the faulting must have been pre-Guadalupian. According to Kelley (1971), too, movement ceased in Leonardian time. Since then, deposition of sediments above the fault trace has produced the low eastward-dipping flexure configuration exposed today. Although no major activity has occurred here since the Mid-Permian, Hayes (1964) believes that inasmuch as the monocline affects rocks of Late Guadalupian age, it appears that minor post-Guadalupian, probably Tertiary, movement has taken place along the old zone of weakness.

3.4.9 The Northwestern Shelf

North and northwestward of the Delaware Basin is a large platform area. Some investigators have taken the southward front of the platform to be delineated by the Capitan Reef Escarpment. Here the dips of the beds average about 20° to the southeast (Hendrickson & Jones, 1952).

The Northwestern Shelf was well developed before the onset of Permian time, as shown by the abundance of shelf limestones, including numerous reefs of Virgilian age, along its present trend. This tectonic element may have originated in early Paleozoic time, when it formed the margin of the early Tobosa Basin (Galley, 1958, Oriel, et al., 1967).

A number of flexures, arches, and buried fault systems have been identified in this area, several of the largest and best known of which are discussed below. The consensus is that tectonic activity along the individual structures had ceased in Tertiary time, and since then, only broad regional monoclinal flexing has occurred. Other than minor

surficial effects due to solution and hydration of evaporates, the entire southern part of the shelf appears to have been stable in Quaternary time (Brokaw, et al., 1972).

Folds A belt from 6 to 9 miles wide of sharply flexured folds lies just back of the Capitan Reef front, extending in long arcs convex to the west and parallel to the shelf margin for a distance of about 65 miles eastward to the Central Basin Platform. These symmetrical and parallel folds termed the Carlsbad folds by Kelley (1971), average about 1.5 miles apart from crest to crest and have an average fold amplitude of about 100 feet (Motts, 1972). Kelley (1971) describes their shape as "domical uplifts," circular to elliptical, with average dimensions of 1.5 by 3 miles. These folds are partly expressed in the present topography. Shelf domes, consisting of biohermal cores covered by shelf beds, are superimposed on the folds, which suggests to Motts (1972) that the folds may have been topographically positive features during the time of Capitan Reef. Brokaw, et al., (1972) dates these folds as of early Tertiary or perhaps older age. According to Hayes (1964), they are presumed to be Laramide in age, since they post date the Permian rocks and antedate the development of Carlsbad Cavern in early and middle Tertiary.

Another arcuate fold belt, called the Waterhole Anticlinorium, is present about 12 miles west of Carlsbad and extends for about 20 miles with a width of 1 to 2 miles. The feature consists of a narrow, closely spaced set of 3 synclines alternating with 3 anticlines. Structural relief on the folds is from 200 to 400 feet. The axes of the anticlines are sharper than those of the synclines, and locally, their axial planes appear to be faults (Kelley, 1971). Like the Carlsbad folds, this system has been dated as early Tertiary or older (Brokaw et al., 1972).

The Cenozoic folds that parallel the reef escarpment on its northwest may be indirectly related to the older Bone Spring Monocline, which formed a broad southeast-dipping fold along the basinward edge of the Victorio Peak Limestone in the Late Leonardian-Early Guadalupian time. The

monocline is exposed only in the south end of the Guadalupe Mountains in Texas but is presumed to continue northeastward into New Mexico, forming the southeast flank of the 15 to 20 mile-wide Bone Springs Arch. The arch was virtually buried in Brushy Canyon time, but near the end of San Andres time the flexure was rejuvenated and produced an accentuated northwest margin for the Delaware Basin. This had a great effect on later Permian deposition and may have controlled the position of the Capitan limestone (Hayes, 1964).

Numerous other local fold structures have been identified on the shelf area, a good number of which are described by Kelley (1971), by Motts (1972), and by Hayes (1964). Many of these folds have north to northwesterly curving axes and structural closure of up to 100 feet or more. According to Motts (1972), the size of some of these features, such as the McKittrick anticline and adjacent Dark Canyon syncline, as well as their possible influence upon the orientation of the Capitan reef, suggests that they may reflect deeper flexures or faults in the basement. Some of these features have been dated: Motts (1972) has found evidence that the McKittrick anticline and Dark Canyon syncline were a topographic high and low, respectively, during Guadalupian time.

<u>Faults</u> The most prominent area of fault-like structures on the shelf north of the Delaware Basin is the zone of straight northeast-trending shears extending from several miles north of Artesia northwestward toward the Sacramento Uplift and Capitan Mountains. The major structures of this group, such as the Y-O, Six-Mile Hill, and Border Hills Buckles, are exposed for from 35 to 80 miles along strike and spaced at distances of 8 to 20 miles. Movement along these features has involved folding, faulting along strike, and overthrusting, and along the strike of these buckles the nature of deformation may change markedly over a short distance. These features are visible on LANDSAT imagery to varying degrees. The Border Hills Buckle appears as a very obvious scarp and adjacent depression which is visible along its entire length, whereas there are no obvious scarps or depressions along the mapped trace of the Six-Mile Hill Buckle, although some stream offsets are aligned along its

trend, and the Y-O fault is marked only by portions of 3 streams which follow the fault line a short distance. Evidence exists that movement on these zones was initiated in Carboniferous or earlier times and may have been basically right lateral (Brokaw et al., 1972 and Kelley, 1971).

Kelley (1971) has described two faults, named the Barrera and Carlsbad, fronting the reef escarpment 32 kilometers and 16 kilometers southwest of Carlsbad and having "late Tertiary with possible Quarternary movement." However, many other geologists who have investigated the area are not convinced that the linear features seen on aerial photos are actually faults. (Claiborne and Gera, 1974).

Artesia-Vacuum Trend The Artesia-Vacuum trend is a long, low, east-trending arch in Permian rocks, which extends eastward from a little south of the town of Artesia, in Eddy County, New Mexico, for a distance of about 75 miles, roughly paralleling the Carlsbad folds. The trend represents slightly warped Permian strata in an eastward-plunging anticline (Stipp, 1960). The arch is almost completely covered by post-Permian beds, except for a short stretch near Chalk Bluff Draw where the plunging south limb is seen dipping southeastward at about 4 degrees. This feature has been dated as either Early Permian or pre-Permian, and, according to Brokaw et al. (1972), is largely or wholly the product of differential compaction over the Abo reef of Early Permian age.

3.4.10 Sacramento Mountains

The Sacramento Mountains constitute an uplift area to the west of the Northwestern Shelf and form the local eastern border of the Basin and Range province. The uplift extends for a distance of over 45 miles in a north to slightly northeast direction, and most of the structures within the range also exhibit a northerly trend. The overall structure of the Sacramento Mountains is a tilted fault block, with a regional dip to the east of about 1 degree. The eastern flank of the mountains is characterized by its simple, undeformed eastward dip of 100 to 140 ft/mi. Greater

uplift along the central crestal zone has produced dips of several degrees in the strata on the north and south ends of the range. The Sacramento uplift is separated from the Tularosa Basin on the west by one or more normal faults involving several thousand feet of displacement (Stipp, 1960).

The Sacramento Mountains have developed through several periods of tectonic activity, probably beginning in Late Pennsylvanian and early Wolfcampian time. Pre-Permian strata of the range are deformed by folding and faulting during this time, and many of the internal structures of the Sacramento Mountains formed then. Some further deformation occurred during Mesozoic or early Cenozoic time (Pray, 1959).Cretaceous strata, strongly folded and faulted and intruded by dikes and sills, occur extensively in the northern Sacramento Mountains, especially between the towns of Capitan and Carrizozo. Here the structure suggests a depressed synclinal block greatly affected by igneous activity (Stipp, 1960).

Late Cenozoic Basin and Range faulting, which produced uplift and tilting, gave the Sacramento Mountains their present configuration. The dominant location of this activity has been the large fault zone at the western base of the uplift in the Tularosa Basin, and the uplift appears to be still in progress (Pray, 1959).

3.4.11 Guadalupe-Delaware Mountains Uplift

The Guadalupe-Delaware Uplift is a gently northeastward-tilting fault block extending northwestward for some 110 miles, from the Diablo Platform area near Van Horn, Texas, to east of Pinon, New Mexico. In New Mexico, the western boundary of the uplift is a great fault scarp produced by a system of nearly en echelon, normal faults of Late Cenozoic age, along which the displacement ranges from 2,000 to 4,000 feet (Kelley, 1971; Hayes, 1964). The eastern margin is formed largely by erosional conformance to the Late Paleozic to Tertiary Huapache Monocline, and the southeast margin of the range coincides with the Reef

Escarpment, which, according to Hayes (1964) may have resulted partly from Cenozoic rejuvenation of the Late Paleozoic Bone Spring Monocline. Using the Huapache Monocline as the east boundary, the uplift is about 11 miles wide in its southern part, tapering northward to about 3 miles (Kelley, 1971). The Guadalupe Mountains lie within the Sacramento section of the Basin and Range province and are structurally part of the Northwestern Shelf (Brokaw, et al., 1972).

In cross section, the mountains have a cuesta-like or asymmetric profile, with the fault scarp forming a short, steep western slope and a backslope dipping gently eastward at generally less than 3° or about 200 ft/mi. The beds usually dip more steeply than the land surface, thus exposing progressively younger rocks to the east and southeast (Hendrickson & Jones, 1952).

The principal structural elements within the Guadalupe Mountains area have been described in detail by Hayes (1964), Boyd (1958), and King (1948). These include the Huapache and Bone Springs Flexures and the folds which parallel the Reef Escarpment (refer to Section 3.4.8). The only faults along the eastern periphery of the uplift, paralleling the reef, are short normal faults of very small displacement, which probably originated as tension joints (Hayes, 1964). The major faulting in the area is located to the west of the Guadalupe Mountains Uplift, where many closely spaced faults trend north to northwest. Hayes (1964) describes those in the New Mexico portion of the area in three groups: those along the Guadalupe Mountains scarp north of Stone Canyon, those parallel to the Shattuck Valley scarp south of Stone Canyon, and those in and north of the Brokeoff Mountains. Along the Guadalupe Escarpment are numerous, closely spaced, high-angle normal faults paralleling the scarp and generally downthrown on the west. From high on the scarp westward into Big Dog Canyon, the faults decrease in dip to as low as 60 degrees and increase in displacement from rarely over 100 feet on the east to about 800 feet in the canyon, low on the scarp. The faults south of Stone Canyon are separated from those to the north by an unfaulted monocline some 1 1/2 miles wide. Most of the displacement on the scarp here is

along a large fault high on the scarp having a displacement of as much as 800 feet, and an arcuarte trace convex to the east; adjacent to its trace are a number of small strike faults (Hayes, 1964; see also King, 1948; Boyd, 1958). West of the Guadalupe Mountains is a graben area occupied by a complex north-northwestward trending zone of Late Cenozoic faults in and adjacent to the Brokeoff Mountains. Most of the faults are high angle and normal and are downthrown to the east, except for several in the north that form grabens and horsts. Stratigraphic displacements here range from a few feet to about 600 feet (Hayes, 1964).

Evidence has been presented by King (1948) that tectonic deformation was occurring in the southern Guadalupe area before Middle Permian time and produced the Bone Spring Flexure, which possibly governed the location of the Delaware Basin. Hayes (1964) describes a fault zone in the Guadalupe Mountains that may have trended southeastward into the western edge of the Delaware Basin and may have been active during Mississippian to Early Permian time. Like the Sacramento Uplift, though, the Guadalupe-Delaware Mountains are primarily a Late Cenozoic structural feature, uplifted and tilted eastward by the Basin and Range tectonic activity.

King (1948) dated most of the major normal faulting of the Guadalupe Mountains area as Late Pliocene to Early Pleistocene. He did note, however, that some renewed movement along pre-existent faults probably took place in the Early Pleistocene, as evidenced by dissection of probable early Pleistocene deposits due to change in base level. But he found no evidence for younger movements in the Delaware or Guadalupe Mountains.

There is evidence, though, that development of the uplift may still be continuing at a reduced rate today. Kelley (1971) reports that during his work a small scarp in the alluvial fans along the northeastern end of the Guadalupe Fault Scarp, in T20S, R17E was found, indicating some slight Holocene uplift. More recent field investigations in the Salt Basin graben region adjacent to the Guadalupe Mountains in Texas have identified over 100 Quaternary-age normal, en echelan, and discontinuous

fault scarps and photolineaments with displacments of as much as 18 feet, which appear to be controlled by preexisting structural zones of weakness. The orientation of the scarps, the proximity of recurring seismic activity, and the youthfulness of offset surfaces suggest that these scarps have a tectonic origin and are maintained by intermittent activity which is in some places younger than 1,000 years old and probably continuing (Goetz, 1977). Such data would thus indicate some ongoing Holocene structural development of the eastern extent of the Basin and Range elements in the Southeast New Mexico west-Texas region.

3.5 REGIONAL IGNEOUS ACTIVITY

Large-scale post-Precambrian igneous activity in the southeast New Mexico-west Texas area consists of Early to mid-Tertiary intrusive bodies and Tertiary to Quaternary volcanic terrains located well to the north, west, and south of the site area. Figure 3.5-1 presents the regional distribution of known igneous features. Within the northern Delaware Basin, only minor igneous activity, in the form of one or more Tertiary dikes and possibly associated sills, is known to have occurred. This section discusses the igneous features known to exist within about 100 miles of the WIPP site and considers in particular detail the near-site intrusives within the northern Delaware Basin.

3.5.1 Near-site Activity

The outcrops of igneous dike-related material nearest to the WIPP site are located about 42 miles southwest of the site, in the Yeso Hills. Subsurface samples of intrusive igneous rock within about 9 miles of the site have also been obtained from drill holes and from two underground potash mining operations, located some 10 miles apart in the Salado Formation. Aeromagnetic investigations have also indicated the presence of magnetically responsive, perhaps igneous, materials in this area. Whether all these occurrences represent parts of one dike or en enchelon dikes, they together produce a very linear trend striking approximately N50° E for a distance in excess of 75 miles. This trend extends from a

point near the Texas-New Mexico border southeast of Carlsbad Caverns at least to the northeasterly most well intercept, some 30 miles northeast of the site (Elliot, 1976b; Claiborne and Gera, 1974). The location of the intercepts and magnetic indications and the dike trace they suggest are plotted on Figure 3.5-2.

The outcrops in the Yeso Hills consist of rectilinear patches of rust-colored, earthy material studded with occasional sharp, small fragments of a dark, fine-grained igneous rock that represent the surface expression of three parallel, en enchelon dikes within the outcropping Castile gypsum. The dikes trend east northeast and vary in width up to about 20 feet and in length up to about one-half mile (Pratt, 1954). These outcrops are separated by a distance of about 27 miles from the nearest subsurface dike intercepts or definite magnetic response along strike to the northeast.

Intercepts of intrusive igneous material have been reported from at least 9 drill holes within the northern Delaware Basin along the trend indicated above (See Table 3.5-I). These intercepts have generally been multiple in each well or drill hole. For instance, the Stanolind U.S. Duncan #1 is reported to have 8 intercepts which range in depth of location from 470 to 13,300 feet. Several petroleum exploration geologists have interpreted the occurrences to represent a series of sill-like intrusions (Elliot, 1976b), a theory which may be supported by magnetic data discussed below.

Dike exposures have also been observed in the underground workings of the International Minerals and Chemical Corporation mine, located approximately 9-1/2 miles northwest of the proposed WIPP site, and in the Hobbs Plant mine of the Kerr-McGee Chemical Corporation, some 10-1/2 miles north of the site (See Table 3.5-1). The dike exposures in these mines are intruded into the Upper Permian Salado Formation. These intrusives are nearly vertical and usually only a few inches to a foot thick, but thicken to approximately 15 feet wide at their widest observed point, in the Kerr McGee mine. No displacement exists between the salt

beds on the two sides of the dike and, in one of the mines, the end of the dike can be observed (Claiborne & Gera, 1974), indicating a discontinuous, segmented character.

Airborne magnetic surveys of the region, performed by the U.S. Geological Survey, have been utilized to help determine the position of the dike material and its genetic relationship to the surrounding rock strata. These surveys show magnetic indications of a dike-like structure extending southwestward from a point approximately 30 miles northeast of the WIPP site to near the Pecos River. The width of the magnetic anomaly so indicated varies from several miles at its base, at a depth of about 12,000 to 13,000 feet, near the Precambrian basement to a very thin trace at its upper extremity near the ground surface. Elliot (1976b) noted that an aeromagnetic response indicating such an apparent single, broad anomaly may be produced by a series of dikes which have a broad base and pinch out vertically. The feature under consideration may thus represent "a multiplicity of en echelon dikes forming a swarm, which rise generally vertically from the basement and pinch out in an upward direction (Elliot, 1976b)". According to this interpretation, one of these dikes extends upward above the other dikes, penetrating units as young as the Salado Formation, and is encountered in the outcrops and subsurface intercepts. The multiple showings from one drill hole are, according to this interpretation, thought to represent small sill-like projections which extend outward horizontally from the main vertical dike source.

The dike or series of dike-related features indicated by the above lines of evidence has a similar appearance, composition, and structure wherever it has been encountered in the subsurface. The dike rock is a medium-gray to grayish-black, fine-grained porphyritic material identified as lamprophyre by Jones (1973). The groundmass of the rock consists of orthoclase with accessory biotite, which is partially altered to vermiculite, and minor amounts of ilmenite, apatite, anatase and pyrite. The rock also contains corroded andesine phenocrysts and pseudomorphs of siderite and antigorite after pyroxene. Amygdules as large as 2 mm in diameter, filled with halite, siderite, calcite, and natrolite are dispersed through the dike rock.

Nearly vertical and subhorizontal fissures are present throughout the dike and are usually filled with halite, with local polyhalite, anhydrite and minor amounts of pyrite, dolomite, quartz and crystalline hydrocarbons. The dike has a rather poorly-developed flow structure and a chilled border. The halite of the adjacent intruded beds has been recrystallized as much as 3/4 inch along the dike contact, and, in places, contains methane and other gases under pressure. Where the termination of the intrusive mass is observed, a vein of polyhalite, also containing minor amounts of pyrite, dolomite, and crystalline hydrocarbons, extends upward into the adjacent salt, indicating that some migration of fluids along the dike must have taken place following intrusion. Later recrystallization and plastic flowage have, however, healed any permeable zones which may have formed at the time of the intrusion and flowing water is not now present where the dike is observable (Claiborne & Gera, 1974).

Specimens of the dike material from the Yeso Hills were classified by Peter H. Masson (reported in Pratt, 1954) as an alkali trachyte and as a soda trachyte of porphyritic texture with principal minerals of anorthoclase, albite, chlorite, ilmenite, and magnetite. The rocks are severely altered, and the walls of the dikes are not clearly defined. Both specimens examined were vesicular, indicating a surface environment of cooling and crystallization. Calcite and gypsum often line the vesicles as secondary deposits (Pratt, 1954).

The emplacement of the lamprophyre dikes probably occurred during mid-Tertiary time, approximately 30 million years ago. Urry (1936) dated the intrusives at 30 +1.5 m.y., from drill hole cuttings of the Texas Co. No. 1 Moore well, located about 12 miles north of the WIPP site. More recent K/Ar whole-rock dating by the U.S. Geological Survey, Denver, has determined an age for a sample (#J-1-71(M75)) of this dike of about 34.8±0.8 million years (recalculated for recent change in measured decay constant) (C. L. Jones, personal communication).

The span of time thus indicated since intrusion has been ample to provide for complete cooling of even the largest of these intrusive bodies, and at the present time there is no evidence of magnetic masses unusually close to the surface in the area.

These dike indications may represent part of an en echelon dike arrays extending northeastward for almost 80 miles from the Gypsum Hills in southern Eddy County, near the New Mexico-Texas state line, to the Vacuum oil field south of Buckeye in central Lea County, New Mexico.

The northeast trend of all these dikes generally coincides with the orientation of several tectonic lineaments in the area and also parallels the trend of crevasses and joints in the carbonate rock of the Capitan and Tansill Formation near Carlsbad Caverns. These fractures are filled with Early Cretaceous sandstones and conglomerates. Thus, the emplacement of the magmatic material may have been facilitated by earlier patterns of structural weakness, which developed in response to regional stresses operative previous to Cenozoic time. The date of the dikes, however, suggests that their development may have been related events which were precursors to the later Basin and Range tectonism of Mid-to-late Tertiary time.

3.5.2 Guadalupe-Delaware Mountains Area Activity

King (1948) described several occurrences of igneous material in the Guadalupe-Delaware Mountain area. He identified one small intrusive plug, about 15 miles southwest of the Yeso Hills dikes, located within the Delaware Mountains in a ravine one-half mile north of Lamar Canyon, 1-1/2 miles east of its junction with Cherry Canyon. This plug forms a low ridge several hundred feet long and cuts sandstones within the Guadalupian-age Bell Canyon Formation. These sandstones have been tilted, baked, and silicified, according to King, for about 10 feet from the edge of the plug. The intrusive rock itself he described as "light gray and aphanitic, probably a trachyte." Pratt (1954) later examined this reported plug and similar outcrops in the area. He found no igneous

rock or any tilted or baked sandstones, only evidence of intense silicification of the sandstones within low parallel ridges oriented north northwest. Pratt, however, interpreted these features to be evidence of underlying intrusive dikes, as did King. Pratt futher stated that the dikes formed part of the siliceous mantle of an underlying igneous intrusion.

Seven miles to the east southeast of these chalcedony-like ridges, within the Magnolia Petroleum Company's Homer Cowden No. 1 well, a body of igneous rock has been intercepted at depths from 8,730 feet to 9,140 feet (Pratt, 1954). The feature is oriented parallel to the trend of the hypothesized dikes of Lamar Canyon and is interpreted as a sill. Pratt (1954) suggests that "the source of this intrusion may also be the source of the solutions which so intensely silicified the conspicuous outcrops" in the Delaware Mountains, described above. The "sill" is composed of extremely porous, light gray and holocrystalline rock with prominent black needles of a ferromagnesian mineral, which has been analyzed by Peter T. Flawn as a "lenco syendiorite," otherwise possibly termed a monzonite (Pratt, 1954).

King (1948) has postulated the existence of a third buried intrusive, located in the Guadalupe Mountains of Texas, approximately 1-1/2 miles south of the Otero-Eddy county line, on the northeast slope of Lost Peak. His hypothesis is based on the observation that the Carlsbad limestone here, at the Calumet and Texas mine, "has been replaced by copper, lead, zinc, and iron minerals, which probably emanated from an igneous source beneath (King, 1948)."

The age of the igneous intrusive activity in the Guadalupe-Delaware Mountains region has been conjectured by King (1948) as Early Tertiary or somewhat younger, representing the northern extension of a vast number of intrusives related to the intense Trans-Pecos Davis Mountain activity. Unlike the region further south, however, little remains of these records in the Guadalupe Mountains area, and only minor igneous activity occurred here (King, 1948). Pratt (1954), in agreement with King's dating work,

has stated that the Delaware Mountain materials he investigated "may reasonably be presumed to be of Tertiary age." He based this judgement on the assumption that these rocks are similar in composition to the generally alkalic igneous rocks identified by Flawn (1952) as comprising the Tertiary intrusives of the west Texas-eastern New Mexico area.

3.5.3 Trans-Pecos Magmatic Province

The Trans-Pecos "magmatic province" comprises a vast area of both intrusive and extrusive igneous outcrop terrains of Tertiary age situated east of the Rio Grande River and west and south of the Guadalupe-Delaware Mountains, approaching within about 90 miles of the WIPP site at the northern extent of the province. The magmatic province extends a distance of about 225 miles from the Diablo Plateau-Cornudas Mountains outcrops near the New Mexico-Texas border, southeastward through the Davis Mountains volcanic area and associated intrusives to the southern tip of Texas (see Figure 3.5-I). The entire province contains in excess of 200 intrusive bodies having outcrops exceeding about 1/2 square mile each in surface area (Barker, 1977) in addition to the approximately 6,000 square-mile region of volcanic outcrop terrain of the Davis Mountains area (from Cohee, et al., 1962). According to King (1948), this magmatic province was developed during Early Tertiary time, when great sheets of lava spread over the Davis Mountains and adjacent areas, across a surface of Cretaceous and older rocks. Both the lavas and sedimentary rocks were then intruded by a host of small to large intrusive masses, some of which were far removed from the Davis Mountains region. Barker (1977) has determined that the magmatic activity in the Trans-Pecos province occurred during the interval from 43 to 16 million years before present. Those intrusives which lie closest to the site are discussed further, below.

Within the northern portion of the Diablo Plateau, some 22 intrusive igneous bodies are exposed along a north northwest trending belt. The northernmost of these igneous outcrops occurs within the Cornudas Mountains, which are centered approximately 105 miles west-southwest of the proposed WIPP site, on the Texas-New Mexico border.

These intrusions, known collectively as the Cornudas Group, generally consist of a central group of plugs, surrounded by sills and laccoliths. The materials composing these intrusions have been classified as nepheline syenites, phonolites, or quartz-bearing syenites. The older rocks are generally fine to coarse-grained, equigranular to porphyritic, with only weakly and locally developed flow structure. The younger rocks of the group are fine-grained, microporphyritic and vesicular, with strongly developed flow structure. Abundant autoliths of alkalic igneous material are contained within several of the intrusions of the Cornudas Mountains (Barker, et al., 1977).

K-Ar dating of biotite in igneous rock samples from the Cornudas Group yields an age of approximately 31 to 37 m.y. for the time of intrusion. The intrusives were emplaced in sedimentary rocks which range in age from Early Permian to Cretaceous (Barker, et al., 1977).

3.5.4 El Camino del Diablo and Railroad Mountain Dikes

The east-west trending El Camino del Diablo and Railroad Mountain dikes are the igneous features nearest to the WIPP site on the north, beyond the limits of the Delaware Basin. The outcrop areas of both dikes are covered by a thin veneer of gravel, caliche, and alluvium (Kelley, 1971), and neither have much expression on LANDSAT imagery.

The southernmost of the two dikes, El Camino del Diablo, is located approximately 67 miles north of the WIPP site. The dike can be traced on the surface for about 25 miles (Kelley, 1971) from the caliche-capped plains east of the Pecos River eastward until it disappears under the Mescalero sands. The dike varies in width from some 32 feet on the west to about 47 feet at its easternmost outcrop. Although it exhibits very little topographic expression, in places along its trace the dike is marked by a slight depression produced by a greater erosion of the dike than of the surrounding country rock. The intrusive material is an extensively altered, fine-grained, slightly porphyritic, bluish-gray rock displaying typical diabasic texture and is composed of augite and

magnetite in a matrix of lath-shaped feldspar crystals. Since the composition is intermediate between an andesite and basalt, the rock has been classified as an "augite-andesite" (Semmes, 1920). Bordering the dike are contact zones from one to 12 feet wide, which consist primarily of a mere baking of the country rock with no appreciable mineralization.

The Railroad Mountain Dike parallels the Camino del Diablo Dike 13 miles 6o the north and extends a distance of about 30 miles from the eastern side of the Pecos River eastward into the Mescalero sands. The width of the dike is remarkably constant, measuring at most about 100 feet, which suggested to Semmes (1920) that the exposed portion represents only a fraction of the entire intrusion (Kelley, 1971; Semmes, 1920). In contrast with the Camino del Diablo Dike, this dike forms a ridge, which in places reaches as high as 60 to 80 feet. On LANDSAT imagery, it has its most pronounced expression as it approaches the Matador uplift region to the east. The dike material is a massive, dense, dark-blue, medium-grained granitoid rock composed of pyroxene and olivine with considerable magnetite in a felt-like mass of interlocking lath-shaped plagioclase crystals. The rock may thus be classified as an olivine gabbro, of more basic nature than most of the other intrusives of the region. Almost no secondary alteration has occurred, which accounts for the dike's prominent ridge-like expression (Semmes, 1920). The contact zone between the dike and host rock displays a slight baking but little mineralization and is, at most, several feet wide.

Both the Railroad Mountain and El Camino del Diablo Dikes have been classified as Tertiary in age by Cohee (1962) and have intruded rocks as young as the Triassic Santa Rosa Sandstone (Kelley, 1971). Semmes (1920) considered the dikes to have been Eocene or younger in age and possibly as young as Middle to Late Tertiary, representing later stages in Tertiary igneous activity, when the basaltic intrusives and extrusives of the area originated. The generic relationship of the dikes to other features in the region is unclear, but airborne magnetic surveys indicate that both of the dikes "nose out" to both east and west (Elliot, 1976b).

This would seem to preclude the dikes being direct extensions of either the Capitan stock activity, to the west (see section 3.5.5, below), or of the Matador Arch (section 3.4.4) to the east.

3.5.5 Capitan and Sierra Blanca Mountains Region

The Capitan intrusive is located within the Capitan Mountains region approximately 117 miles northwest of the WIPP site. The feature is about 21 miles long and from 3.5 to 5 miles wide, with an above ground volume of about 20 cubic miles (Kelley, 1971; Semmes, 1920). There is some controversy regarding the nature of the intrusion, due to the fact that it has characteristics of both a laccolith and a stock. Typical of a laccolith, there is evidence of a concordant roof along most of the summit, but the structural and stratigraphic discordances, including observed uplift and structural nosing, favor its designation as a stock. In any case, the intrusion has penetrated units as young as the Rio Bonito member of the San Andres Formation and the Yeso Formation, of Middle Permian Leonardian age. Along the eastern end of the mountain, the Yeso beds stand almost vertically near the contact (Kelley, 1971). "Mesaverde beds" of Cretaceous age show thermal alteration ~~as well~~ according to Kelley (1971).

The Capitan intrusive is remarkably uniform for its size in both composition and texture. It is a medium- to fine-grained, slightly porphyritic rock, classified by Kelley (1971) as a leucoratic quartz syenite. The Capitan intrusive has been designated as Tertiary in age by Cohee (1962); Semmes (1920) suggested that it may be of Early Tertiary age, in concurrence with Lindgren, et al. (1910), who considered all of the quartz-bearing monzonitic and dioritic intrusives of this area to be Early Tertiary. Semmes (1920) considered these acidic intrusives to represent an early stage in igneous activity, preceeding the more basic, less extrusive diorities and gabbros of later Tertiary time.

Immediately west and southwest of the Capitan intrusive, underlying and cropping out in the Sierra Blanca Mountains, are the Sierra Blanca volcanics, dikes, and stocks.

The Sierra Blanca volcanics crop out in an area of some 200 square miles; Thompson (1966) believes that the field was once as large as 750 square miles prior to intrusion by the stocks and Late Tertiary erosion. The volcanics consist of massive, purplish-brown, andesitic breccias, flow, and tuffs overlain by trachtye breccia and have a recorded thickness of as much as 3,340 feet. These volcanics are thought to be of Early to Mid-Tertiary age (Kelley, 1971; Thompson, 1966).

Some 200 dikes occur in swarms oriented generally radially with respect to the Sierra Blanca stocks and in a great swarm 7 miles wide and 22 miles long, trending north northeastward from Ruidoso to east of Patos Mountain. The dikes are generally traceable for less than one mile and range in thickness from one foot to 60 or 70 feet. They vary in composition from a few occurrences of syenite porphyry to diabasic, although 60 to 70 percent of the dikes are basic (Kelley, 1971). Since the dikes intrude the Sierra Blanca volcanics, they post-date them, and may be Mid-Tertiary in age.

3.5.6 Conclusions

The data presented above indicate that, within some 100 miles of the WIPP site, no igneous activity has taken place since the early part of Basin and Range tectonism, which began in the mid-Tertiary. In the near-site vicinity, the closest igneous feature to the site is a lamprophyre dike or series of en echelon dikes, which approaches no nearer than about nine miles from the site; no associated igneous bodies have been found to approach or underlie the site itself. The dike has been dated as approximately 35 m.y. old and has long since completely solidified and cooled. Younger intrusive and extrusive features are situated far to the west of the site, beyond the area of discussion, and are associated with the regions of more recent Basin and Range tectonism. Thus, judging from the pattern of the structural development of the northern Delaware Basin area, further igneous activity is not expected in the near-site region.

3.6 REGIONAL GEOLOGIC HISTORY

Figure 3.6-1 presents a summary of the major geologic events which have affected the southeast New Mexico-west Texas area as have been determined from the rock types and structural relationships for which evidence remains and has been uncovered.

3.6.1 Precambrian

Very little is known about the Precambrian history of the southeast New Mexico-west Texas area. The Precambrian rocks penetrated in the Guadalupe Mountain and Sacramento uplift regions in southern Lea County and in west Texas, consist of plutonic granitics and metamorphics, which suggest that the region has a complex Precambrian history of mountain building, metamorphism, and erosional cycles (Nicholson & Clebsch, 1961; Hayes, 1964; Kelley, 1971). According to Flawn (1956), the Precambrian granitics encountered in the southern part of this area comprise a generally stable mass, called the Texas Craton, which extended northward from Texas into southeastern New Mexico. Muehlberger, et al. (1967), however, have demonstrated that these materials comprise part of a much more complicated basement surface representing a variety of environments involving intrusive and extrusive igneous activity as well as metamorphism of sediments.

The ages suggested for the Precambrian rocks encountered in this region are all fairly ancient. In the core of the Pajarito Mountain dome, southeast of the Sacramento uplift, the metamorphics have a radiometric date of 1,270 million years (Kelley, 1971). The granitics and metamorphics of the Guadalupe Mountain area are probably somewhat less than one billion years old (Hayes, 1964), while slightly greater ages have been indicated for the Precambrian rocks of the Texas Craton. Wasserberg, et al. (1962) determined ages of 1,250 to 1,400 million years in the northern part of the area and a younger 1,090 million years terrain to the south, suggesting progressively younger metamorphic events from north to south in this region during the Precambrian.

There is no record of the latest Precambrian or of most of the Cambrian time in this region; however, about one billion years before present the area was reduced to a nearly level plain upon which the Paleozoic rocks were later deposited (Hayes, 1964).

3.6.2 Early and Middle Paleozoic

During most of the Paleozoic Era, from at least Late Cambrian until near the close of the Mississippian Period, the eastern New Mexico-western Texas area was part of a broad, low-lying, generally stable region named the Tobosa Basin by Galley (1958). The shallow basins of the area formed northern arms of the Ouachita trough, which shoaled on the north in south-central New Mexico and merged southward with the Ouachita-Marathon geosyncline, connecting with the open sea in the vicinity of the present Gulf Coast or coast of southern California (Brokaw, et al., 1972; Hills, 1972). During the early Paleozoic there seem to have been no well-marked platforms within the basin. However, lines of weakness along strike-slip faults in the basement probably were present (Hills, 1970). Along these faults later vertical movement took place (Hills, 1972).

For a span of about 180 million years, until Late Mississippian time, almost continuous deposition occurred in this area under conditions of general tectonic stability in shallow seas periodically transgressing from the south. Shelf-type carbonate deposition predominated but was interrupted by shale sedimentation during Middle Ordovician, Late Devonian, and Early Mississippian. The total section of these sediments is about 2,500 feet, from the base of the Bliss Sandstone to the top of the Helms Shale, in the Guadalupe Uplift-southeastern New Mexico area (Hayes, 1964).

The chief events which characterized each period of the Early through Middle Paleozoic are summarized below.

Cambrian-Ordovician. No rock record older than Late Cambrian age has been uncovered in the southeastern New Mexico area (Hayes, 1964). The Bliss

Sandstone near El Paso, Texas, provides evidence of clastic sedimentation in that area during part of the Late Cambrian. After the Precambrian rocks had been uplifted and deeply eroded, a sea advanced over the region from the west or southwest and the Bliss sandstone was deposited; the abundant quartz grains in the Bliss were probably derived from reworking of sedimentary debris on the eroded Precambrian surface (Harbour, 1972; Bachman and Meyers, 1969).

During Early Ordovician time, the sea in which the Bliss was deposited continued to transgress eastward and extended at least as far north as Roswell. During this time, the carbonates and clastics known as the El Paso Formation in New Mexico and the Ellenburger in west Texas were deposited in shallow seas containing abundant marine life (Bachman, 1969). These sediments thickened southeastward from a thin layer lapping onto a positive area of Precambrian basement then present in northern New Mexico and Colorado to a massive deposit over 2,000 feet thick in Texas, at the edge of what may have been the continental shelf (Eardley, 1962). At this time, the ancestral Central Basin Platform was a granitic upland or island chain which provided clastics to the early Ordovician shelf and adjacent shallow basin deposits.

During the Ordovician, the Marathon-Ouachita geosyncline bounding the Tobosa Basin area on the south began subsiding (McGlasson, 1968). In Mid-Ordovician time, a broad and gently emergent peninsula, extending southeastward through Texas, rose, and the region was also tilted southward. To the north, the shales, sandstones, and sandy limestones of the Simpson Group were deposited above the El Paso--Ellenburger, wedging out north at the latitude of Roswell, west around Artesia and east around the Central Basin Platform. Southward, toward the deepening basin regions, the deposits thickened and became predominantly shaly. In Middle to Late Ordovician time, fewer clastics were provided to the area, and the carbonates, and fine-grained calcareous muds of the Montoya Group were deposited in shallower, calmer seas than earlier, that moved northward over the tilted surface of the El Paso Formation. At the close of Montoya time, a gentle southward tilting occurred (Bachman, 1969).

Silurian-Devonian. During Silurian and Devonian time, the Pedernal Landmass, to the northwest, and the Texas Peninsula, to the south, were land areas of low relief. The Tobosa Basin between these two areas, joined southward with the Marathon-Ouachita geosyncline. There is no evidence of major tectonic activity during this time in west Texas or southeast New Mexico. However, mild epeirogenic movements did occur, and the Tobosa Basin was gently subsiding throughout the period, becoming also more restricted areally. To the south, the Ouachita-Marathon geosyncline reached its maximum depth.

During Early Silurian time, most of the Tobosa Basin was emergent but low-lying. By the Middle Silurian, the sea returned, perhaps transgressing from the south and southeast, and broad, shallow areas developed around the northern, eastern, and western margins of the Tobosa Basin, upon which the thick Fusselman dolomites and limestones were deposited conformably in a marine environment atop the Montoya Group in clear, well-circulating water (McGlasson, 1968; Harbour, 1972; Bachman, 1969). At this time, the basin waters reached their furthest extent into New Mexico. Minor fluctuations of sea level within this shallow area of deposition produced a karst topography on the surface of the periodically exposed carbonates. During Late Silurian time, southward tilting occurred once more, and the sea regressed. Within the deeper areas to the south into Texas, a sediment-starved condition developed, resulting in deposition of micrites and green shales. Around the Tobosa Basin rim, carbonates continued to form (McGlasson, 1968).

The shallow sea continued to retreat from the New Mexico area through Early and Middle Devonian time. In Early Devonian, the shoreline had retreated, producing a carbonate plain of low relief. The depositional basin had an asymmetrical shape, with the deepest water to the west, in which cherts and silicious limestones were deposited. By the late Middle Devonian, mild uplift and southward tilting had occurred, and most of the Tobosa Basin was exposed to erosional processes; the only deep water lay to the south, where the basin plunged into the Marathon-Ouachita geosyncline. In Late Devonian time, the area was again submerged as

shallow seas spread across southern New Mexico, and the dark heavily clastic Woodford shales were deposited in a nearshore environment (Bachman 1969), overlapping all of the previous Devonian and Silurian deposits (McGlasson, 1968). Woodford deposition continued into Mississippian time.

Mississippian. Subsidence of the Tobosa Basin continued into Mississippian time. The Texas peninsula to the south and the Pedernal landmass to the northwest were mildly positive features and remained so until the Middle Mississippian (McGlasson, 1968).

In Early Mississippian time, a new paleogeographic regime began to develop in this region. The ancient Tobosa Basin began deepening on either side of a medial zone, later to become the Central Basin Platform, that was bounded by Precambrian basement faults. Shelf deposition continued along the margins of the basinal areas.

Toward Late Mississippian time, regional tectonic activity accelerated in the Tobosa Basin area, folding up the medial zone along its ancient lines of weakness. By the end of the period, erosion had probably exposed Precambrian rocks in the cores of the larger anticlines (Hills, 1963). Meanwhile, deep, broad basins, the forerunners of the Delaware and Midland Basins, formed to the east and west of the median upland area. Broad carbonate shelves developed around the margins of these basins, while black shale sedimentation occurred in their deep central portions. The black shale deposition was probably slow, much of it taking place during times of slight sea level sinking (Hills, 1972). Toward the south end of the basins, deposition of the shale and sandstone of the Tesnus Formation continued from Late Mississippian into the beginning of Pennsylvanian time, the clastics apparently being derived from highlands on the southeast which were rising in the earliest activity of the Ouachita orogeny (Flawn, 1961).

To the north of the basins, the Matador Arch was upfolded in the latest Mississippian and rapidly eroded to expose its Precambrian core. At the same time, orogenic forces raised the Ancestral Rocky Mountains to the

west, in a general north-south trend through central New Mexico (Stipp, 1960), producing a regional southward tilt which resulted in widespread erosion, exposing progressively older rocks toward the north.

By the close of the Mississippian Period, most of northeast New Mexico formed a low hilly area of Precambrian rocks, rimmed on the north and east by outcrops of Lower Ordovician dolomites and on the south by the uplifted former site of the Tobosa basin.

3.6.3 Late Paleozoic

Pennsylvanian. Following Mississippian time, the entire region was invaded by the sea from the south and east, and, particularly near the uplifted areas, tremendous thicknesses of Pennsylvanian rocks were deposited unconformably over the tilted bedrock strata, which ranged in age from Mississippian in the south to Precambrian northward in central New Mexico (Hills, 1963; Meyer, 1968). The tectonic processes initiated near the close of the Mississippian, including uplift and erosion of mountains in the Ouachita-Marathon area, of the mountain range separating the early Delaware and Midland Basin areas, and of the Matador Arch and Ancestral Rockies, continued into early Pennsylvanian, providing clastic materials to the adjacent basins. This tectonic activity also involved vertical movement along the ancient strike slip faults, with some new faulting taking place in the recently deposited early Pennsylvanian rocks (Hills, 1972; Stipp, 1960).

The basal Pennsylvanian rocks, the Morrowan, occupied the smallest area, wedging out northward, and contained the greatest proportion of coarse clastic material of the Pennsylvanian section. Along the edges of the platforms, especially in the eastern basin, strong reef and bank growth also occurred during the beginning of the Pennsylvanian. At the same time, submarine tectonism began in the Guadalupe Mountains area, continuing intermittently through the period, elevating the southeastern part of the area relative to the northeast along the northwest-trending Huapache thrust zone (Hayes, 1964).

Lower Middle Pennsylvanian Atokan strata were deposited over most of the southeastern New Mexico area except for the then-positive Pedernal uplift. During this time, anticlinal folds developed north of the Delaware Basin area on the Northwestern Shelf, and the Central Basin Platform range was uplifted as a fault block and eroded. By Desmoinesian time in upper Middle Pennsylvanian, deposition in the Permian basin region consisted primarily of limestones. The environmental setting consisted of a back-reef (lagoon), reef, and basin or open sea, a situation which persisted from this time through Late Pennsylvanian and much of Permian time (Meyer, 1968).

During most of the Late Pennsylvanian, depositional conditions in the Permian Basin were similar to those of Desmoinesian time. The sea encroached farther than before onto the rising Pedernal landmass, followed by a regression beginning in the northwest. To the northeast, the land was intermittently emergent. And southward, in Texas, the Ouachita-Marathon disturbance folding and uplift was being followed by strong northward thrusting, which continued into early Permian time (Hills, 1963). Ensuing erosion from these areas provided an abundance of clastics to the Late Pennsylvanian deposits. The Central Basin Platform, emergent throughout most of the Pennsylvanian, began to subside and received a sequence of Late Pennsylvanian sediments (Nicholson & Clebsch, 1961). Meanwhile, reef banks continued to form, especially along the northwestern edge of the Delaware Basin.

Toward the close of Pennsylvanian time, tectonic activity had virtually ceased, and mixed continental and marine sediments were deposited in the lower areas, nearly obscuring the irregular sea bottom caused by the earlier tectonism (Hayes, 1964).

At the end of Pennsylvanian time the entire region subsided, and the major features of the Permian Basin became firmly established. The rapidly eroding range of the Central Basin Platform separated the Delaware and Midland Basins which were rimmed to the north by a broad shelf area. By this time, the Delaware and Midland Basins were probably both

topographically and structurally deep; only the northern part of the Midland Basin remained a relatively shallow platform, upon which the Horseshoe Atoll grew (Oriel et al., 1967). The Central Basin Platform and shelf areas were subsiding more slowly than was the Delaware Basin and consequently received a lesser thickness of sediments, which were lithologically distinct from the deeper water deposits of the basin (Nicholson & Clebsch, 1961).

Permian. Through Early Permian Wolfcampian time, sedimentation was continuous in most of the basin areas of southeast New Mexico and west Texas, with shales deposited in the low areas and limestone on the shelves (Hills, 1972). The regression in the northwest which had commenced in the Late Pennsylvanian became pronounced, and the acceleration of the rise of the Pedernal uplift through Early Permian resulted in its denudation well into the Precambrian basement rocks. Southward, the Delaware and Midland Basins and the Val Verde Trough were rapidly sinking, at a rate exceeding that of deposition, a situation which favored shales and other stagnant-water deposits to form there (Oriel et al., 1967). The deepening of these basins, as well as uplift elsewhere, was encouraged by the development of major normal fault zones towards late Wolfcampian time (Meyer, 1968), along the north and west sides of the Diablo Platform, on the southeast side of the Pedernal Uplift, and along the periodically emergent Central Basin Platform, where strong submarine relief was produced. Around the perimeter of the Delaware Basin, the Abo reef developed, along with back-reef lagoons into which muds and carbonates accumulated. Along the south border of the Permian Basin region, the final northward thrusting of the Ouchita-Marathon structural belt occurred, causing Late Pennsylvanian and Early Permian strata to be overridden and a large volume of detritus to pour into the Val Verde trough (Hills, 1963; Oriel, et al, 1967). Following the close of this activity, the rest of Permian time was marked by regional tectonic stability in which depositional basins separated by platform areas passed through maturity.

Through Middle Permian time, restriction of marine circulation, coupled with eustatic withdrawal of the sea in a southwest direction, resulted in the development of high reefs and carbonate banks, behind which evaporites, ranging from dolomites, sulfates, and chlorides to potash minerals, were deposited in highly saline, shallow lagoons (Hills, 1972).

Early in lower Middle Permian Leonardian time, movement on a line along the Delaware Basin margin, the later Bone Spring monoclinal structure, accompanied by continued subsidence of the basin, produced a more definite northwest margin of the basin, the development of which resulted in deposition of a great submarine bank that formed a barrier to free circulation of the sea water. The gray carbonates of the Victorio Peak formation represent patch reefs which built upward and southwards across earlier deposits as the basin margin regressed. Similar carbonate reefs and banks formed along the margins of the Midland Basin as well as on the Central Basin Platform, overlying the old medial mountain range (Hills, 1972). Within the deep basin areas the black limestones and shales of the Bone Spring were deposited, and on the broad back-reef lagoonal shelf north and northeast of the basin, the Yeso gypsum and limestone or dolomite and clastics were laid down. Northwestward, the entire area including the Pedernal was gradually overlapped by sediments, and, by latest Leonardian time, all but a few of the highest Precambrian peaks were buried (Kelley, 1971).

At the end of Leonardian time and into the Guadalupian, pronounced differential movement occurred along the Delaware Basin margin, and a broad, southeastward-dipping fold, the Bone Spring Arch, was elevated, forming a barrier 15 to 20 miles wide between the basin and the Northwestern Shelf area (Hayes, 1964). In a marked regression, the seas withdrew, and were nearly restricted to the Delaware Basin (King, 1942).

As Guadalupian time opened, the arching and limited evaporitic conditions resulted in deposition of clastics in the basins and limestone on the shelf areas (Kelley, 1971; Hayes, 1964).

By the mid-Guadalupian, slight rejuvenation of the Bone Spring arch led to growth of lime-bank deposits upon the arch, which provided the foundation for a barrier reef, the Goat Seep. As the Delaware Basin continued to deepen, the reef grew primarily upwards, in consequence, restricting circulation, thus producing sediment-starved conditions within the basin and leading to the precipitation of calcium sulfate shelfward for a distance of 15 to 25 miles. (Oriel et al., 1967; Hayes, 1964). Eastward, the Midland Basin gradually filled and became favorable for evaporite deposition, in common with the adjacent shelves and Central Basin Platform.

Late Guadalupian time brought gradual subsidence of the shelf and even greater downwarping of the Delaware Basin, while renewed reef growth occurred at great pace around the periphery of the Delaware Basin. The Capitan Limestone began to grow upward and basinward in oblique fashion from the top of the Goat Seep dolomite, resulting in a wide barrier which even at its narrowest point was six times as wide as it was high (Hayes, 1964; Newell et al., 1972). Most investigators consider the Capitan to have been a true barrier reef. Achauer (1969), however, believes that it originated as a linear organic belt, instead, since he finds no coincidence between the topographic and lithologic break produced by it, and Dunham (1972) hypothesizes that the structure represents a marginal mound. In any case, as the structure grew, deposition in the basin proceeded more slowly than on the shelf and did not keep pace with the sinking of the basin, so that by the close of the period, the sea bottom in the Delaware Basin was about 1,500 feet below the adjacent reef and lagoon floor to the northwest. The reefs and banks eventually grew almost continually around the periphery of the Delaware Basin, and by the close of Guadalupian time, access of water to and from the open ocean was sharply restricted, the seas of the shelf area evaporated, and the water of the Delaware Basin itself became highly saline, thus halting the reef growth.

The Delaware Basin was essentially an evaporating pan by the beginning of Late Permian Ochoan time. Many hundreds of feet of Castile evaporites, containing anhydrite and limestone laminae at the bottom and a few beds of

halite, were deposited in the basin, with apparently little in the reef and back-reef areas. By the latest Castile time, the basin had filled such that a thin tongue of anhydrite extended northward across the reef to the shelf. Saline waters then spread from the Delaware Basin over the shelf, the Central Basin Platform and Midland Basin areas, and extensive salt deposition occurred, resulting in the predominantly halite Salado Formation. From this time on, the old Permian Basin structures, notably the Central Basin Platform, became progressively more deeply buried by Late Permian sediments and no longer constituted depositional barriers. Periodically, clastics swept into the area from the north and northwest, increasing towards the end of Salado time, as the Pedernal Landmass underwent renewed uplift. At the same time, the sea freshened somewhat, probably from the south, judging from the presence of more soluble salts northward, in New Mexico. Halite deposition decreased while anhydrite became dominant, along with an increase in carbonate muds during Rustler Formation deposition (Hayes, 1964; Brokaw et al., 1972). Broad epeirogenic uplift at the close of Permian time caused the seas to withdraw, and the continental fine sands and silts of the Dewey Lake Redbeds were deposited in a thin layer on broad mudflats over the former seabed (Brokaw et al., 1972; Kelley, 1971). As terrestrial conditions developed across the New Mexico-west Texas area, erosion became the dominant geologic process.

3.6.4 Mesozoic Rocks

Triassic. During most of Triassic time, the southeast New Mexico area was emergent and subject to erosion, and by late Triassic the entire area, including the Pedernal, must have been reduced to a great peneplain (Kelley, 1971). In Late Triassic time, a broad floodplain basin formed on the site of the Permian Basin over a large area and beyond the borders of the Delaware Basin. This was an interior basin draining toward the northwest into other interior basins (Hills, 1963, Brokaw, et al., 1972). Source areas to the north provided fluvial sands, muds, and gravels to the basin, forming the Dockum Group red beds that included the Santa Rosa Sandstone and finer-grained Chinle Formation.

The nearly conformable relationship which exists between these Upper Triassic strata and the Permian Dewey Lake Redbeds indicates continued regional tectonic stability through Triassic time (Oriel, et al., 1967). It is possible that some dissolution of soluble Permian rocks occurred during the general emergence of Triassic time. Bachman and Johnson (1973) state that during this period, sinkholes may have formed in parts of the Pecos Valley due to removal of salts (Gorman & Robeck, 1946). And Bachman (1974) describes a Late Triassic karst topography in the vicinity of Santa Rosa, New Mexico. However, direct evidence for this Triassic dissolution and collapse has not been found in southeastern New Mexico (Bachman, 1974).

Jurassic. During Jurassic time, the southeast New Mexico area was uplifted above sea level so that the Triassic and perhaps Permian rocks in the western part of the Delaware Basin and westward were eroded away. Some dissolution of Permian salt deposits probably occurred here at this time. The period of exposure, which generally affected the entire Permian Basin, may have been 50 million years; however, the surface relief was probably low, and erosion was not deep. This is the first of three erosional cycles which have incised the Triassic rocks of the area (Nicholson & Clebsch, 1961; Bachman, 1974).

During Jurassic time, continental rocks were laid down to the north, in central and northern New Mexico, derived from the sediments being stripped from the eroding basin area in southeastern New Mexico. South of the basins, in western Texas and northern Mexico, marine conditions prevailed during at least part of the time (Bachman, 1974). By Late Jurassic Entrada and Morrison time, seas again encroached on the north, covering southeast Colorado and northeastern New Mexico. And from the Late Jurassic into the Early Cretaceous, a slight tilt involving uplift took place in the northern part of the former basins region, accompanied by widespread erosional stripping across the area (Hills, 1963; Kelley, 1971).

Cretaceous. By the early part of Cretaceous time, the west Texas-southeast New Mexico area comprised a rolling topography of Triassic rocks with beds from Precambrian to Permian exposed on the uplifts and on

the Diablo Platform. The geography evolved from that of interior basins with highlands in the north and east to a general gulfward slope with highlands in the west and evidence of only slight tectonic activity (Hills, 1963; Kelley, 1971).

During Cretaceous time, a large part of the western interior of North America became submerged beneath epicontinental seas. By late in the Early Cretaceous, the southeast New Mexico area had subsided slightly, and shallow shelf seas advanced over the area from the south and remained until early in Late Cretaceous time, when the seas probably withdrew for the last time, leaving behind a thin deposit of fossiliferous limestone and coarse sandstone and conglomerate (Hayes, 1964; Nicholson & Clebsch, 1961). Isolated slump blocks of limestone and shale in Lea County east of Eunice, in the Pecos River drainage, in the Sacramento and Guadalupe Mountains and perhaps on the crest of the reef escarpment are the only remaining evidence of the sea's advance in the southeast New Mexico area (Hayes, 1964; Bachman, 1973).

There is no record of most of the Late Cretaceous in the area. The land surface was probably slightly above sea level, and the region was dry land by the close of Cretaceous time (Bachman & Johnson, 1973).

3.6.5 Cenozoic

Early Tertiary. The Mesozoic Era came to a close with the Laramide revolution and uplift of the Rocky Mountains. Late in the Cretaceous or very early in the Tertiary Period, the entire region from north of the Guadalupe Mountains through southeast New Mexico was elevated by broad epeirogenic uplift and tilted slightly to the northeast. Mild tectonism affected the Guadalupe area of the Northwestern Shelf, producing small igneous dikes, fold systems, and setting the stage for the ancestral northeast flowing drainage system (Hayes, 1964). Igneous activity also occurred to the northwest in the Sierra Blanca and Capitan Mountains (Bachman, 1974). In general, however, most of the area southwest of the Pedernal Uplift and Matador Arch was not subject to such tectonic forces.

According to Hills (1963), these ancient positive elements formed buttresses which transmitted and distributed the orogenic forces on the east, and this protected the basins on the southeast from folding.

The dominant process in southeast New Mexico from Late Cretaceous until Late Tertiary, notwithstanding the minor tectonism, was erosion. No Early or Middle Tertiary rocks are represented in the Permian Basin. The Cretaceous and Triassic rocks of the area underwent intense erosion to form a surface of low relief, sloping gently east and southeast (Bachman, 1974; Brokaw, et al., 1972). In the Lea County area of southeast New Mexico, the entire sequence of Cretaceous rocks, particularly to the west, was stripped off, except for small remnants, and the Triassic rocks were subjected to a second cycle of erosion (Nicholson & Clebsch, 1961). By Late Tertiary Miocene time, erosion had again exposed the Permian rocks to dissolution, notably in the vicinity of San Simon Swale (Bachman, 1974).

Late Tertiary (Miocene-Pliocene). In Late Tertiary time, regional uplift and east-to-southeastward tilting occurred throughout southeastern New Mexico into Texas, as Basin and Range tectonic activity commenced to the west, producing the western escarpments of the Delaware, Guadalupe, and Sacramento Mountains. The western section of the Permian evaporites was elevated, and exposed to dissolution and subsidence, particularly in the vicinity of the Pecos River divide, which created new patterns of groundwater movement (Bachman, 1973; Mercer & Orr, 1977). Erosional forces carved a pediment-like surface, down which streams flowing eastward from the Rocky Mountains deposited an extensive blanket of gravel, sand, and related deposits in coalescing fans, which comprise the Ogallala Formation. Deposition of the Ogallala began about 12 million years ago, in Miocene time. The Ogallala represents the first preserved sedimentary record in the vicinity of the Delaware Basin since Cretaceous deposition (Bachman, 1974). The Ogallala formed a thick mantle throughout the Permian Basin, producing the even surface of the High Plains, called the Llano Estacado in western Texas and eastern New Mexico. Locally, eolian activity played a part in deposition, and periodically, widespread soils formed (Frye, 1970).

Ogallala deposition ended about 4 million years ago, in Pliocene time, with regional warping and uplift. Eolian activity reworked the sediments, producing a widespread soil profile across the Great Plains. A caliche zone formed within the soil complex and constitutes the carbonate "caprock" of today (Mercer & Orr, 1977; Bachman & Johnson, 1973). The caliche caprock has since undergone a complex history of brecciation, solution, and recementation (Bachman, 1973).

Pleistocene-Holocene. During the Late Pliocene and Early Pleistocene, the major part of the faulting and uplift of the Guadalupe Mountains occurred (Hayes, 1964). Concurrently to the east, fields of great longitudinal dunes formed atop the Ogallala surface of the southern Great Plains as a result of desert conditions with westerly to northwesterly prevailing winds. Since this time, erosion has exceeded deposition in the Permian salt basin area. Etching and thinning of the caliche caprock between the dunes created series of parallel swales. Erosion and coalescence of subsided areas removed Ogallala sediments, and in places also eroded the Triassic rocks a third time and entrenched the Pecos and San Simon drainages (Nicholson Clebsch, 1961; Mercer & Orr, 1977). Also during early to Middle Pleistocene time, Nash Draw, Clayton Basin, and probably San Simon Swale underwent extensive subsidence and partial filling (Bachman, 1973). Local sink holes and other solution features began to form at this time.

The most humid climate and the greatest erosion occurred during the Middle Pleistocene. The western escarpment of the High Plains underwent severe erosion, followed by a period of aggradation in the valley areas, during which the mostly locally-derived pebbles and other coarse debris of the Gatuna Formation filled the depressions and mantled the slopes (Brokaw, et al., 1972). During this time of heavy precipitation and stream flow, major salt dissolution is assumed to have occurred within the Delaware basin (Bachman, 1974). After Gatuna time, but still during the Middle Pleistocene, the region became more stable and semi-arid, and the Mescalero caliche formed on the ground surface.

During the Late Pleistocene, there were intermittent episodes of caliche formation and renewed periods of high rainfall accompanied by erosion and salt dissolution, which produced local subsidence and deposition of fluvial and lacustrine sediments.

From Late Pleistocene through Holocene time, the climate has remained variable although becoming more arid. The detrital materials have been reworked by winds from the west and southwest, giving rise to the vast deposits of dune sand that now cover large parts of southeast New Mexico east of the Pecos River (Nicholson & Clebsch, 1961; Bachman, 1973). Some slight uplift is also probably still occurring along the western escarpments of the Basin and Range structures, such as the Guadalupe Mountains. Renewed periodic downcutting by streams and subsurface solution with resultant subsidence, have continued to the present, accompanied by intermittant local accumulations of pediment and terrace alluvium and playa deposits. Most of the recent erosion has been confined to the Pecos Valley, and solution and subsidence have occurred at a slower rate than during the earlier Pleistocene time (Bachman, 1973).

3.7 SUMMARY

The regional geology of SENM is the source of much information germane to long-term safety; knowledge of the regional geology also permits preliminary site selection and general evaluation of the consistency of site geology with regional geology.

The regional geology and geological history may first be divided into three major intervals of about .5 billion years each. This period from about 1.5 to 1.0 billion years ago is represented by metamorphosed rocks of various sedimentary to igneous origins. The time from about 1.0 to .5 billion years ago is not known to be represented by rocks through most of the region; erosion is assumed to be the dominant geological process during this time. The last interval, from about .5 billion years ago to the present, shows more complexity in the rock record. From about 500 to

100 million years ago, SENM shows a rock record of mostly marine sediments deposited in a basin that became shallower as time passed. About 225 million years ago the marine environment became quite restricted, resulting in deposition of about 4000 feet of evaporites in which it is proposed to dispose of radioactive waste. The lack of rock record in much of the region from about 100 million years to about 4 million years ago imply that erosion has been dominant. Fluvial sediments and caliche developed within the last 4 million years suggest some change in base level but considerable stability.

The list of important structural events in the region include metamonolusm and relative uplift during the Precambrian, downwarping through much of the Paleozoic, some downwarping and uplift during the Mesozoic, and some uplift during the Cenozoic. Specific structural features include basin and range type faulting more than 70 miles west of the site and about 1o eastward tilting of the Delaware Basin; both of these features are believed to be about mid-Cenozoic in age. The Central Basin Platform to the east of the site has probably not been active since the Permian (see also Chapter 5).

Thus the regional geology furnishes evidence of tectonic and geologic stability that will be used for assessing the safety of a repository at the WIPP site.

3.8 REFERENCES

Achauer, C.W., 1969, Origin of Capitan Formation, Guadalupe Mountains, New Mexico and Texas: Am. Assoc. Pet. Geol. Bull., v. 53, no. 11, p. 2314-2323.

Adams, J.E., 1944, Upper Permian Ochoan Series of Delaware Basin, west Texas and southeast New Mexico: Am. Assoc. Pet. Geol. Bull., vol. 28, no. 11, p. 1596-1625.

Adams, J.E., 1965, Stratigraphic-Tectonic Development of Delaware Basin: Am. Assoc. Pet. Geol. Bull. , v. 49, no. 11 p 2140-2148.

Adams, J.E., and Frenzel, H.N., 1950, Capitan barrier reef, Texas and New Mexico: Journal Geology, v. 58, no. 4, 289-312.

Adams, J.E., and Rhodes, M.L., 1960, Dolomitization by seepage refluxion: Am. Assoc. of Pet. Geol. Bull., v. 44, no. 12, p. 1912-1920.

Anderson, R.Y., 1978, Report to Sandia Laboratories on deep dissolution of salt, northern Delaware Basin, New Mexico.

Anderson, R.Y., Dean, W.E., Kirkland, D.N., and Snider, H.I., 1972, Permian Castile varved evaporite sequence, west Texas and New Mexico: Geol. Soc. Am. Bull., v. 83, p. 59-86.

Anderson, R.Y., and Powers, D., in press, Salt anticlines in the Castile-Salado evaporite sequence, northern Delaware Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 159.

Ash, S.R. and Clebsch, A.C., 1961, Cretaceous Rocks in Lea County, New Mexico: U.S. Geol. Surv. Prof. Paper 424-D, p. 139-142.

Bachman, G.O., 1960, Southwestern edge of late Paleozoic Landmass in New Mexico: U.S. Geol. Surv. Prof. Paper 400b, p. 239-241.

Bachman, G.O., 1973, Surficial features and late Cenozoic history in southeastern New Mexico: U.S. Geol. Surv. Open-file report.

Bachman, G.O., 1974, Geologic processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U.S. Geol. Surv. Open-file report 74-194.

Bachman, G.O., 1975, New Mexico: in McKee and Crosby, et al., Paleotectonic Investigations of the Pennsylvanian System in the United States, U.S. Geol. Surv. Prof. Paper 853L, p. 233-244.

Bachman, G.O., 1976, Cenozoic Deposits of Southeastern New Mexico and an Outline of the History of Evaporite Dissolution: U.S. Geol. Surv. Journal of Research, v. 4, no. 2, p. 135-149.

Bachman, G.O., and Johnson, R., 1973, Stability of salt in the Permian salt basin of Kansas, Oklahoma, Texas and New Mexico: U.S. Geol. Surv. Open file report 4339-4.

Bachman, G.O. and Myers, D.A., 1968, Geology of the Bear Peak area, Dona Ana County, New Mexico: U.S. Geol. Surv. Bulletin 1271C, p.1-46.

Barker, D.S., 1977, "Northern Trans-Pecos Magmatic Province: Introduction and Comparison with the Kenya Rift", Geol. Soc. Am. Bull., v. 88, no. 10, p. 1421-1427.

Barker, D.S., Lang, L.E., Hoops, G.K., Hodges, F.N., 1977, Petrology and RB-Sr isotope geochemistry of intrusives in the Diablo Plateau, northern Trans-Pecos magmatic province, Texas and New Mexico: Geol. Soc. Am. Bull., v. 88, p. 1437-1446

Boyd, D.W., 1955, San Andres Formation in the Brokeoff Mountains, Southeastern New Mexico (abs.): Geol. Soc. Am. Bull. v. 66, no. 12, pt. 2, p. 1533.

Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hays, W.H., 1972, Geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico, U.S. Geol. Surv. Open-file report 4339-1.

Claiborne, H.C. and Gera, F., 1974: Potential containment failure mechanisms and their consequences at a radioactive waste depository in bedded salt in New Mexico: ORNL-TM-4639.

Cloud, P.E., Jr., and Barnes, V.E., 1948, The Ellenburger Group of Central Texas: Texas Univ. Bur. Econ. Geol. Publ. 4621.

Cohee, G.V. (Chairman), 1962, Tectonic Map of the United States: U.S. Geol. Surv. and Am. Assoc. Pet. Geol.

Crandall, K.H., 1929, Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas: Am. Assoc. of Pet. Geol. Bull., v. 13, p. 927-944.

Darton, N.H., 1917, A comparison of Paleozoic sections in southern New Mexico: U.S. Geol. Surv. Prof. Paper 108-C, p. 31-55.

Darton, N.H., 1928, Red beds and associated formations in New Mexico, with an outline of the geology of the state, U.S. Geol. Surv. Bull. 794.

Dickey, R.I., 1940, Geologic Section from Fisher County thru Andrews County, Texas to Eddy County, New Mexico: Am. Assoc. Pet. Geol. Bull., v. 24, No. 1.

Dunham, R.J., 1972, Capitan Reef, New Mexico and Texas: Facts and questions to aid interpretation and group discussion: Permian Basin Section, Soc. Econ. Paleontologists and Mineralogists Pub. 72-14.

Eardley, A.J., 1962, Structural geology of North America: Harper & Row, New York.

Elliot, C.L., 1976a, A Laboratory Investigation of Magnetic Physical Properties of Igneous Dike Samples from Kerr-McGee Hobbs Plant, Section 32, T 20 S, R 32 E, and Surface Outcrop, Section 31, T 26 S, R 25 E, Elliot and Geophysical Company, Tucson, Arizona, p. 1-7.

Elliot, C.L., 1976b, A Preliminary Geophysical Study of a Trachyte Dike in Close Proximity to the Proposed Los Medanos Nuclear Waste Disposal Site, Eddy and Lea Counties, New Mexico, Elliot Geophysical Company, Tucson, Arizona, p. 1-19.

Elliot, C.L., 1976c., An experimental detailed resistivity survey of known or suspected breccia pipes and sinkholes, Eddy County, New Mexico. Report written under Sandia contract.

Fenneman, N.M., 1931, Physiography of Western United States, New York, McGraw-Hill Book Company, Inc., p. 11-25, 47-54, 379-395.

Flawn, P.T., 1952, Significance of alkalic igneous rocks in wells in west Texas and southeast New Mexico: Am. Assoc. Pet. Geol. Bull., v. 36, no. 7, p. 1457-1461.

Flawn, P.T., 1954, Summary of basement rocks in west-central Texas: San Angelo Geological Society, Cambrian Field Trip--Llano Area, p. 74-77.

Flawn, P.T., 1956, New study of Texas' basement rocks: Oil and Gas Journal, v. 54, no. 59.

Flawn, P.T., 1961, The Marathon area, in The Ouachita System: Texas Univ. Pub. 6120. p. 49-58.

Flower, R.H., 1953, Age of Bliss sandstone, New Mexico: Am. Assoc. Pet. Geol. Bull., v. 37, No. 8, p. 2054-2055.

Foster, R.W. and Stipp, T.F., 1961, Preliminary geologic and relief Map of the Precambrian rocks of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 67.

Foster, R.W., 1974, Oil and Gas potential of a proposed site for the disposal of high-level radioactive waste, New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology: Oak Ridge Nat'l Laboratories, Open-file report.

Frye, J.C., 1970, The Ogallala formation; a review: in Ogallala Aquifer Symposium, p. 5-14, Int. Cent. Arid Semi-arid Land Stud., Lubbock, TX.

Galley, J.E., 1958, Oil and geology in the Permian Basin of Texas and New Mexico in Weeks, L.G., ed., Habitat of oil - a symposium: p. 395-446.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulations in desert soils: Soil Science, v. 101, p. 347-360.

Goetz, L.K., 1977, Quaternary faulting in Salt Basin Graben, west Texas: M.A. thesis, University of Texas at Austin.

Gorman, J.M., and Robeck, R.C., 1946, U.S. Geol. Surv. Oil and Gas Inv. Preliminary Map 44.

Griswold, G.B., 1977, Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medanos, Eddy County, N.M., Sandia Laboratories Report 77-0946, Albuquerque, N.M., p. 11, 33, 43.

Haigler, L., 1962, Geologic notes on the Delaware Basin: New Mexico Bureau of Mines & Mineral Resources, Socorro, N.M., Circular 63.

Harbour, R.L., 1960, Precambrian rocks of North Franklin Mountains, Texas: Am. Assoc. of Pet. Geol. Bull., v. 44, no. 11, p. 1785-1792.

Harbour, R.L., 1972, Geology of northern Franklin Mountains, Texas and New Mexico: U.S. Geol. Surv. Bull. 1298.

Harms, J.C., 1974, Brushy Canyon Formation, Texas: a deep water density current deposit: Geol. Soc. Am. Bull. v. 85, p. 1763-1784.

Hayes, P.T., 1964, Geology of the Guadalupe Mountains, New Mexico: U.S. Geol. Surv. Prof. Paper No. 446.

Hayes, P.T., 1975, Cambrian and Ordovician rocks of southern Arizona and New Mexico and westernmost Texas: U.S. Geol. Surv. Prof. Paper 446.

Hendrickson, G.E. and Jones, R.S., 1952, Geology and ground water resources of Eddy County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Ground Water Report 3.

Hester, R.J., and Holland, R.R., 1959, Structure of the Puckett Field, Pecos County, Texas, in West Texas Geological Soc. Guidebook, p. 87-92.

Hills, J.M., 1963, Late Paleozoic tectonics and mountain ranges, western Texas to southern Colorado: Am. Assoc. Pet. Bull., v. 47, No. 9, p. 1709-1725.

Hills, J.M., 1968, Permian Basin Field area, west Texas and southeastern New Mexico, in Int'l Conf. on Saline Deposits, 1962: Geol. Soc. Am. Special Paper 88, p. 17-27.

Hills, J.M., 1970, Late Paleozoic structural directions in southern Permian Basin, west Texas and southeastern New Mexico: Am. Assoc. Pet. Geol. Bull. v. 54, no. 10, p. 1809-1827.

Hills, J.M., 1972, Late Paleozoic sedimentation in west Texas Permian basin: Am. Assoc. Pet. Geol. Bull., v. 56, no. 12.

Hiss, W.I., 1976, Structure of the Permian Guadalupian Capitan aquifer, southeast New Mexico and west Texas: New Mexico Bureau of Mines and Mineral Resources, Resource map 6.

Jones, C.L., 1954, The occurrence and distribution of potassium minerals in southeastern New Mexico: in, New Mexico Geol. Soc. Guidebook 5th Field Conf., Southeastern New Mexico 1954, p. 107-112.

Jones, C.L., 1960, Thickness, character and structures of Upper permian evaporites in part of Eddy County, New Mexico: U.S. Geol. Surv. TEM-1033.

Jones, C.L., 1973, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico, U.S. Geol. Surv. Open-file report 4339-7, p. 29-30.

Jones, C.L., and Madsen, B.M., 1959, Observations on Igneous Intrusions in Late Permian Evaporites, Southeastern New Mexico: (abs.), Geol. Soc. Am. Bull., v. 70, no. 12, pt. 2, p. 1625-1626.

Judson, S.S., Jr., 1950, depressions of the northern portion of the southern High Plains of eastern New Mexico: Geol. Soc. Am. Bull., v. 61, no. 3, p. 253-274.

Kelley, V.C., 1971, Geology of the Pecos County, southeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 24, 75 p.

King, P.B., 1942, Permian of west Texas and southeastern New Mexico: Am. Assoc. Pet. Geol. Bull., v. 26, p. 535-763.

King, P.B., 1948, Geology of the southern Guadalupe Mountains, Texas: U.S. Geol. Surv. Prof. Paper 215.

King, P. B., 1965, Geology of the Sierra Diablo region, west Texas: U.S.G.S., Prof. Paper 480.

Kottlowski, F.E., Cooley, M.E., and Ruhe, R.V., 1965, Quaternary Geology of the Southwest: in The Quaternary of the United States Wright, H.E., Jr., and Frey, David G., (eds.), Princeton, New Jersey, Princeton University Press, p. 290-291.

Lang, W.B., 1937, The Permian formations of the Pecos Valley of New Mexico and Texas: Am. Assoc. Pet. Geol. Bull., v. 21, p. 833-898.

Lee, W.T., 1925, Erosion by Solution and Fill, U.S. Geol. Survey Bull. 760-C, p. 107-121.

McGlasson, E.H., 1968, The Siluro-Devonian of west Texas and southeast New Mexico: West Texas Geological Society-Delaware Basin Exploration Guidebook, Pub. 68-55, p. 35-44.

McGlasson, E.H., The Siluro-Devonian of West Texas and southeastern New Mexico in border stratigraphy symposium: New Mexico State Bureau Mines Mineral Resources, Circ. 104, p. 26-37.

McGowan, J.H. and Groat, C.G., 1971, Van Horn Sandstone, West Texas: An alluvial fan model for mineral exploration: Bureau of Economic Geology, Univ. Texas at Austin, Report of Investigations, no. 72.

McKee, E.D. and Oriel, S.S., et al., 1967, Paleotectonic maps of the Permian System: U.S. Geol. Surv. Misc. Geologic Investigations Map I-450.

Mercer, J.W., and Orr, B.R., 1977, Review and analysis of hydrogeologic conditions near the site of a potential nuclear waste laboratory, Eddy and Lea Counties, New Mexico: U.S. Geol. Surv. Open-file report 77-123.

Meyer, R.F., 1966, Geology of Pennsylvanian and Wolfcampian rocks in southeast New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 17.

Meyer, R.F., 1968, Geology of Pennsylvanian and Wolcampian rocks in southeastern New Mexico (abs.): University of Kansas manuscript.

Morgan, A.M., 1942, Solution Phenomena in New Mexico, in Symposium on Relations of Geology to the Ground Water Problems of the Southwest: Am. Geophys. Union Trans., 23rd An. Mtg., Pt. 1, p. 27-35.

Motts, E.S, 1972, Geology and paleoenvironments of the northern segment, Capitan shelf, New Mexico and west Texas: Geol. Soc. Am. Bull., v. 83, p. 701-722.

Muehlberger, W.R. et al., 1967, Basement rocks in continental interior of United States: Am. Assoc. Pet. Geol. Bull., v. 51, no. 12, p. 2366-2371.

Olive, W.W., 1957, Solution-Subsidence Troughs Castile Formation of Gypsum Plain, Texas and New Mexico: Geol. Soc. Am. Bull., v. 68, p. 351-358.

Muehlberger, W.R., Denison, R.E., and Lidiak, E.G., 1967, Basement rocks in continental interior of United States: Am. Assoc. Pet. Geol. Bull., v. 51, No. 12, p. 2366-2371.

Newell, N.D., Rigby, J.K., Fischer, A.G., Whiteman, A.J., Hickox, J.E., and Bradley, J.S., 1953, The Permian Reef complex of the Guadalupe Mountains region Texas and New Mexico--A Study in Paleoecology: San Francisco, W. H. Freeman & Co., 236 p.

Newell, N.D., Rigby, J.K., Fischer, A.G., Whiteman, A.J., Hickox, J.E., and Bradley, J.S., 1972, The Permian Reef complex of the Guadalupe Mountains region Texas and New Mexico: Hafner Publishing Co., New York.

Nicholson, A., Jr., and Clebsch, A., Jr., 1961, Geology and ground-water conditions in southern Lea County, New Mexico: U.S. Geol Surv. and New Mexico Bureau of Mines and Mineral Resources, Ground-water Report 6.

Olive, W.W., 1957, Solution-Subsidence Troughs in the Castile Formation of Gypsum Plain, Texas and New Mexico: Geol. Soc. Am. Bull., v. 68, p. 351-358.

Oliver, J., 1977, Recent vertical crustal movements, The eastern United States: quarterly progress report for period Sept. 1, 1976 - Jan 1, 1977 to U.S.N.R.C., Cornell University.

Oriel, S.S., Myers, D.A., and Crosby, E.J., 1967, West Texas Permian basin region, in Paleotectonic Investigations of the Permian System in the United States: U.S. Geol. Surv. Prof. Paper 515, p. 21-60.

Page, L.R., and Adams, J.E., 1940, Stratigraphy, eastern Midland Basin, Texas: Am. Assoc. Pet. Geol. Bull., v. 24, no. 1, 52-64.

Pratt, W.E., 1954, Evidences of Igneous Activity in the Northwestern Part of the Delaware Basin: in New Mexico Geol. Soc. Guidebook of Southeastern New Mexico Fifth Field Conference, p. 143-147.

Pray, L.C., 1953, Upper Ordovician and Silurian Stratigraphy of Sacramento Mountains, Otero County, New Mexico: Am. Assoc. Pet. Geol. Bull., v. 37, no. 8, p. 1894-1918.

Pray, L.C., 1954, Outline of the stratigraphy and structure of the Sacramento Mountain Escarpment: in Fifth Field Conference, Southeastern New Mexico, New Mexico Geological Society, p. 92-106.

Pray, L.C., 1958, Stratigraphic Section, Montoya Group and Fusselman Formation, Franklin Mountains, Texas: in West Texas Geol. Soc. Guidebook, 1958 Field Trip Franklin and Hueco Mountains, Texas, p. 30-37.

Pray, L.C., 1959, Stratigraphic and structual features of the Sacramento Mountain escarpment, New Mexico: in Guidebook for Joint Field Conference in the Sacramento Mountain of Otero County, New Mexico, Alamogordo, N.M., Permian Basin section of Economic Paleontologists and Mineralgists and Roswell Geological Society.

Pray, L.C. and Allen, J.E., 1956, Outlier of Dakota (?) strata, southeastern New Mexico: Am. Assoc. Pet. Geol. Bull., v. 40, no. 11, p. 2735-2740.

Pray, L.C., 1961, Geology of the Sacramento Mountains escarpment, Otero County, New Mexico. New Mexico Bureau of Mines and Mineral Resources, Bull. 35.

Price, W.A., 1958, Sedimentology and Quaternary Geomorphology of South Texas: Gulf Coast Assoc. Geol. Soc. Trans., v. 8, p. 41-75.

Richardson, G.B., 1904, Report of a reconnaisance in Trans-Pecos Texas North of the Texas and Pacific Railway: Univ. Texas Bull. 23.

Roswell Geological Society, 1958, North-south stratigraphic cross-section; Delaware Basin-Northwest Shelf: Roswell Geological Society.

Sanford, A.R. and Toppozada, T.R., 1974, Seismicity of proposed radioactive waste disposal site in southeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 143.

Sanford, A.R., Sandford, S., Caravella, F., Merritt. L., Sheldon, J., Ward, R., 1978, Seismic Studies of the Los Medanos Area in Southeastern New Mexico: Report to Sandia Laboratories.

Semmes, D.R., 1920, Notes on the Tertiary Intrusives of the Lower Pecos Valley, New Mexico: Am. Jour. Sci., 4th Ser. v. 50, p. 415-430.

Silver, B.A. and Todd, R.G., 1969, Permian cyclic strata, northern Midland and Delaware basins, west Texas and southeast New Mexico: Am. Assoc. Pet. Geol. Bull., v. 53, no. 11 p. 2223-2251.

Stipp, T.F. (ed), 1954, Guidebook of southeastern New Mexico, Fifth Field Conference, New Mexico Geological Society.

Stipp, T.F., 1960, Major structural features and geologic history of southeastern New Mexico, the oil and gas fields of Southeastern New Mexico: Supplement: A symposium.

Stipp, T.F., and Haigler, L.B., 1956, Preliminary Structure Contour Map of a Part of Southeastern New Mexico Showing Oil and Gas Development: U.S. Geol. Surv. Oil and Gas Inv. Map OM-177 (1957).

Thompson, T.B., 1966, Geology of the Sierra Blanca, Lincoln and Otero Counties, New Mexico: Univ. N. Mex. Ph.D. dissertation, p. 47.

Thornbury, W.D., 1965, Regional Geomorphology of the United States: New York, John Wiley & Sons, Inc., p. 289-290, 300-310, 315-317, 498-501.

United States Bureau of Mines, 1977, Valuation of potash occurrences within the Waste Isolation Pilot Plant site in southeastern New Mexico: U.S. Dept. of Interior.

U.S. Geol. Surv., 1973, Aeromagnetic Map of the Carlsbad area, New Mexico and Texas: U.S. Geol. Surv. Geophysical Investigations, Map GP-861.

Urry, W.E., 1936, Post-Keweenawan Time Scale: National Research Council Rept. Comm. on Measurement of Geologic Time 1935-1936, Exh. 2, p. 35-40.

Vertrees, C.D., Atchison, C.H., and Evans, G.L., 1959, Paleozoic geology of the Delaware and Val Verde basins, in Geology of the Val Verde basin and field trip guidebook: West Texas Geological Society, p. 64-73.

Vine, J.D., 1960, Recent Domal Structures in Southeastern New Mexico Am. Assoc. Pet. Geol. Bull., v. 44, no. 12, p. 1903-1911.

Vine, J.D., 1976, Breccia Pipes and Burial Metamorphism in Permian evaporites of the Delaware Basin, New Mexico: Geol. Soc. Am. Abstracts, v. 8 No. 6.

Vine, J.D., 1963, Surface geology of the Nash Draw Quadrangle, Eddy County, New Mexico: U.S. Geol. Surv. Bull. 1141-B, U.S.G.S.

Vinson, M.G., 1959, Brown-Basset Field, Terrel County: in West Texas Geol. Soc. Guidebook, November 1959, field trip, p. 85-86.

Wasserberg, G.J., Wetherill, G.W., Silver, L.T., and Flawn, P.T., 1962, A study of the ages of the Precambrian of Texas: Journal of Geophysical Research, v. 57, No. 10, p. 4021-4046.

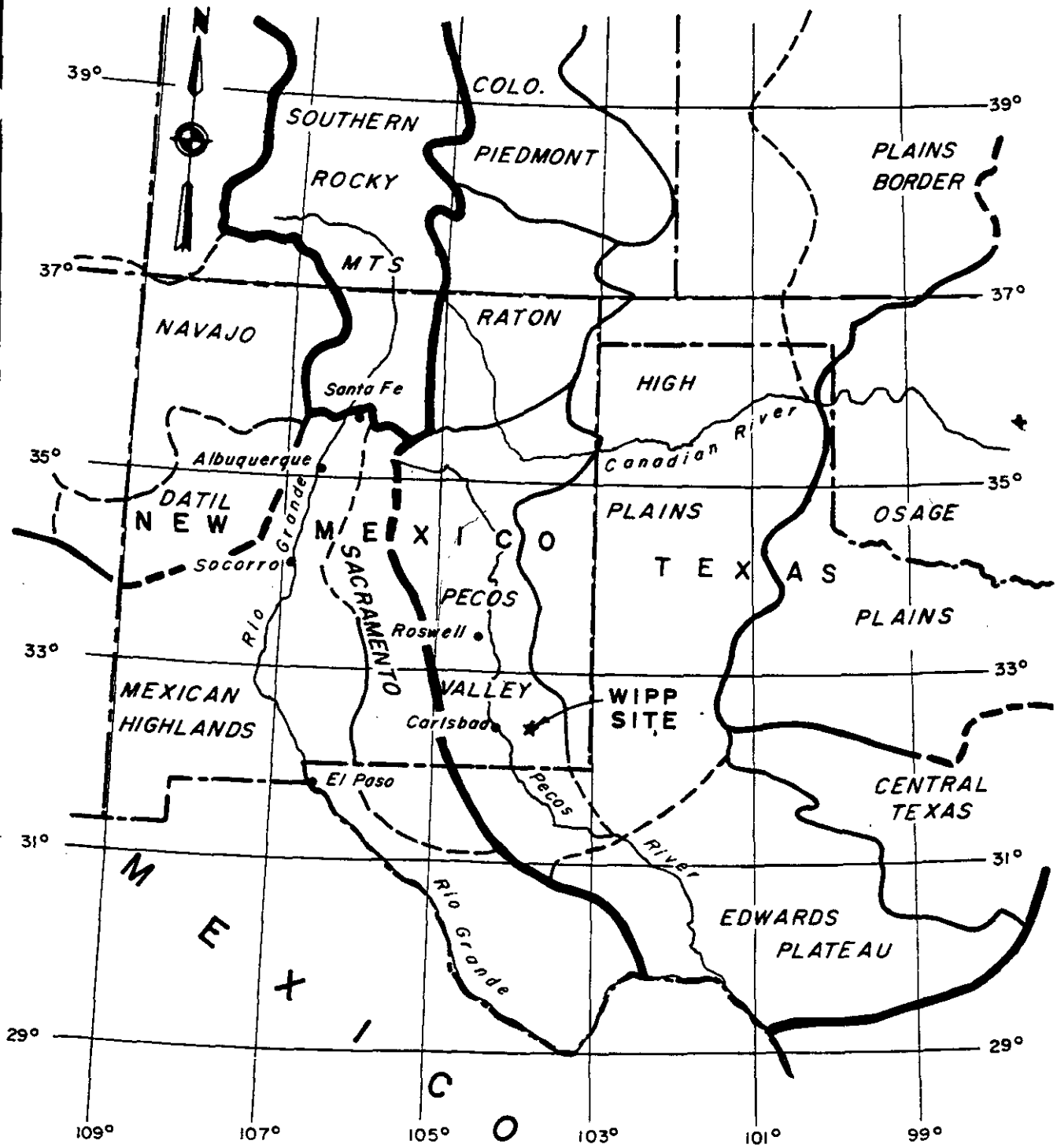

EXPLANATION

- Boundary of major physiographic division
- Boundary of physiographic province
- Boundary of physiographic section

0 100 200 300 KM
0 50 100 150 200 MI
SCALE

PHYSIOGRAPHIC SECTIONS

REFERENCE:

Fenneman, N.M., and D.W. Johnson, 1946.

FIGURE 3.2-1

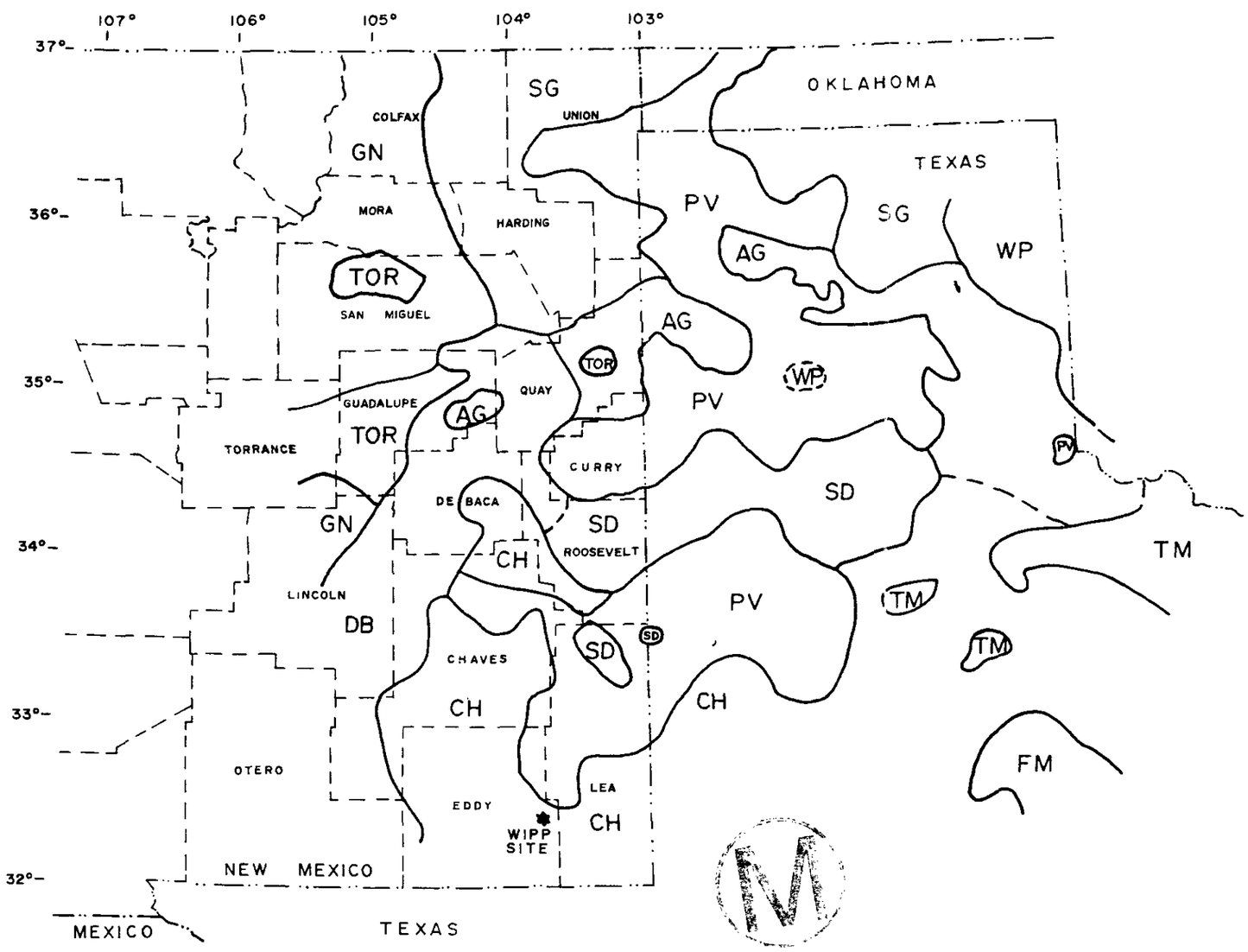

EXPLANATION

CH: Chaves granitic terrane

PV: Panhandle volcanic terrane

SD: Swisher diabasic terrane

DB: De Baca terrane

TM: Tillman metasedimentary group

GN: Older gneiss and granite

AG: Amarillo granite terrane

TOR: Older metasedimentary and meta-igneous rocks

SG: Sierra Grande granite terrane

WP: Cambrian igneous rocks: Wichita Province

FM: Fisher metasedimentary terrane

County boundary

State boundary

International boundary

REFERENCE:

Muehlberger, et al. (1967)

N

25 0 25 50 75 miles

PRECAMBRIAN ROCKS OF TEXAS PANHANDLE AND EASTERN NEW MEXICO

FIGURE 3.3-1

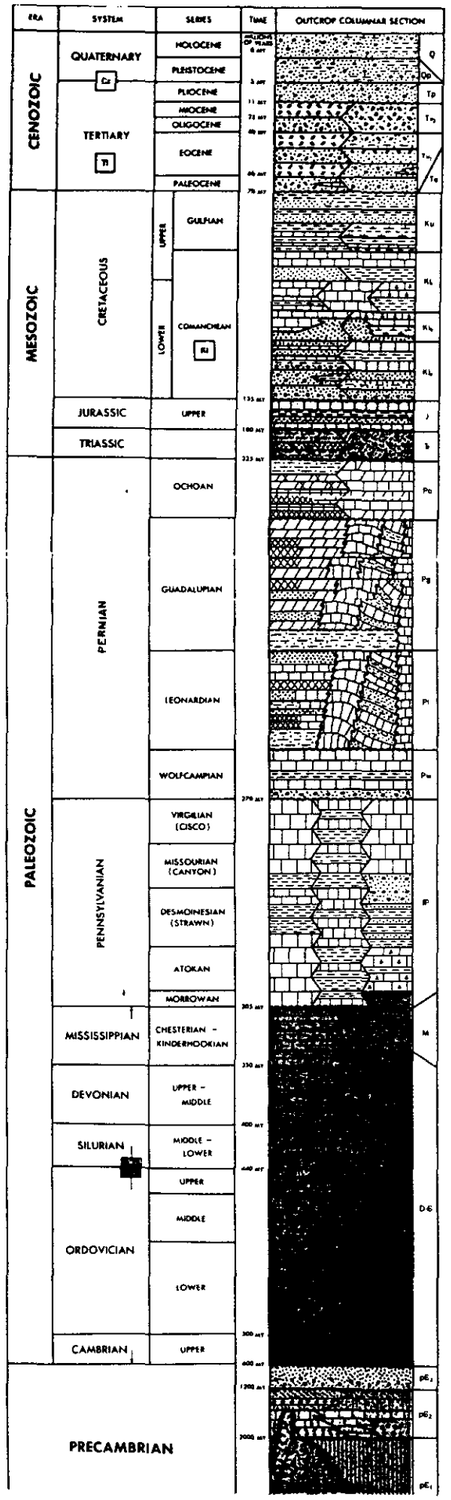

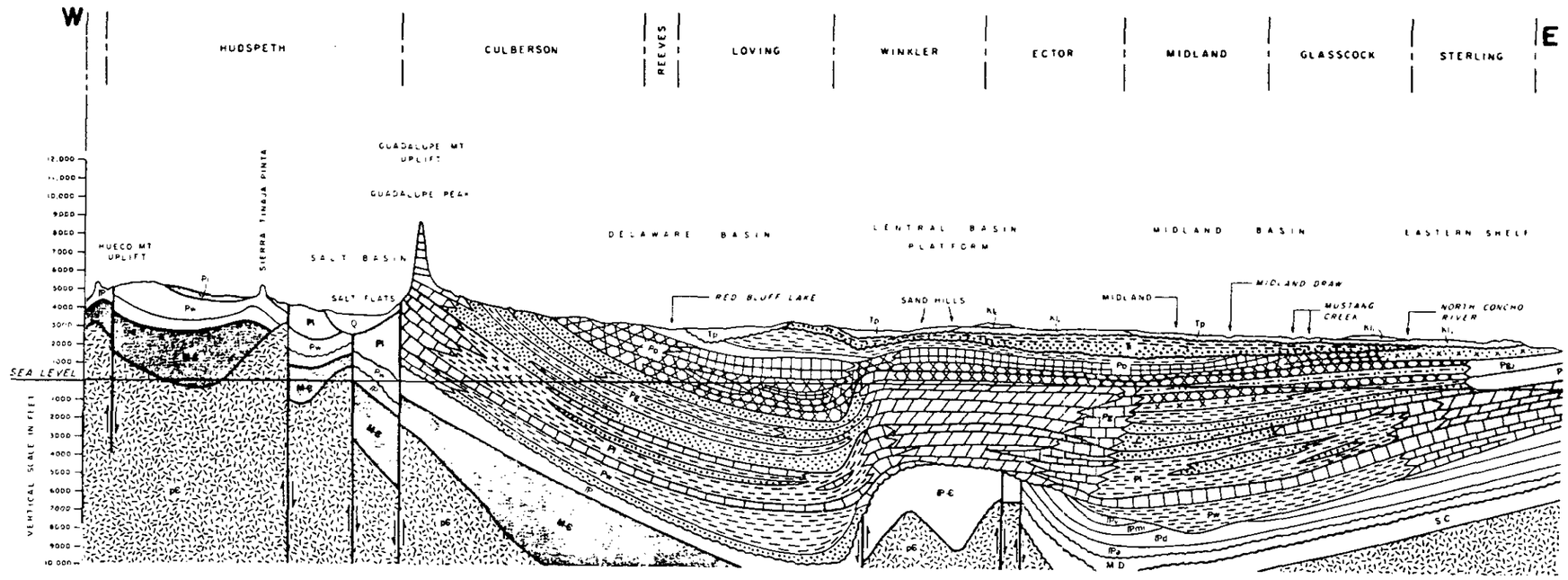

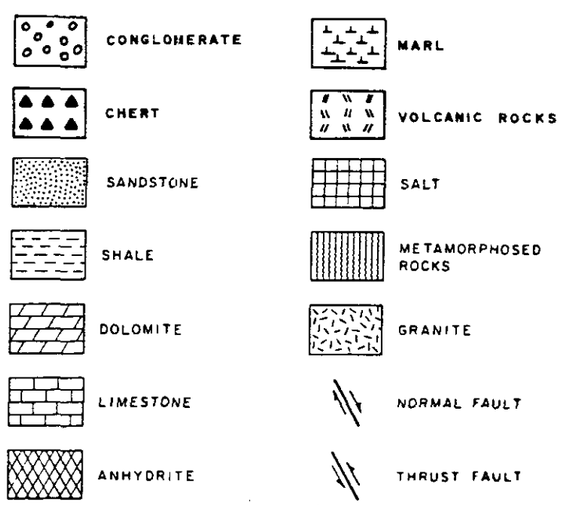

WEST–EAST CROSS SECTION
NEW MEXICO – TEXAS BORDER

REFERENCE: From Geological Highway Map of Texas, 1973

FIGURE 3.3-2

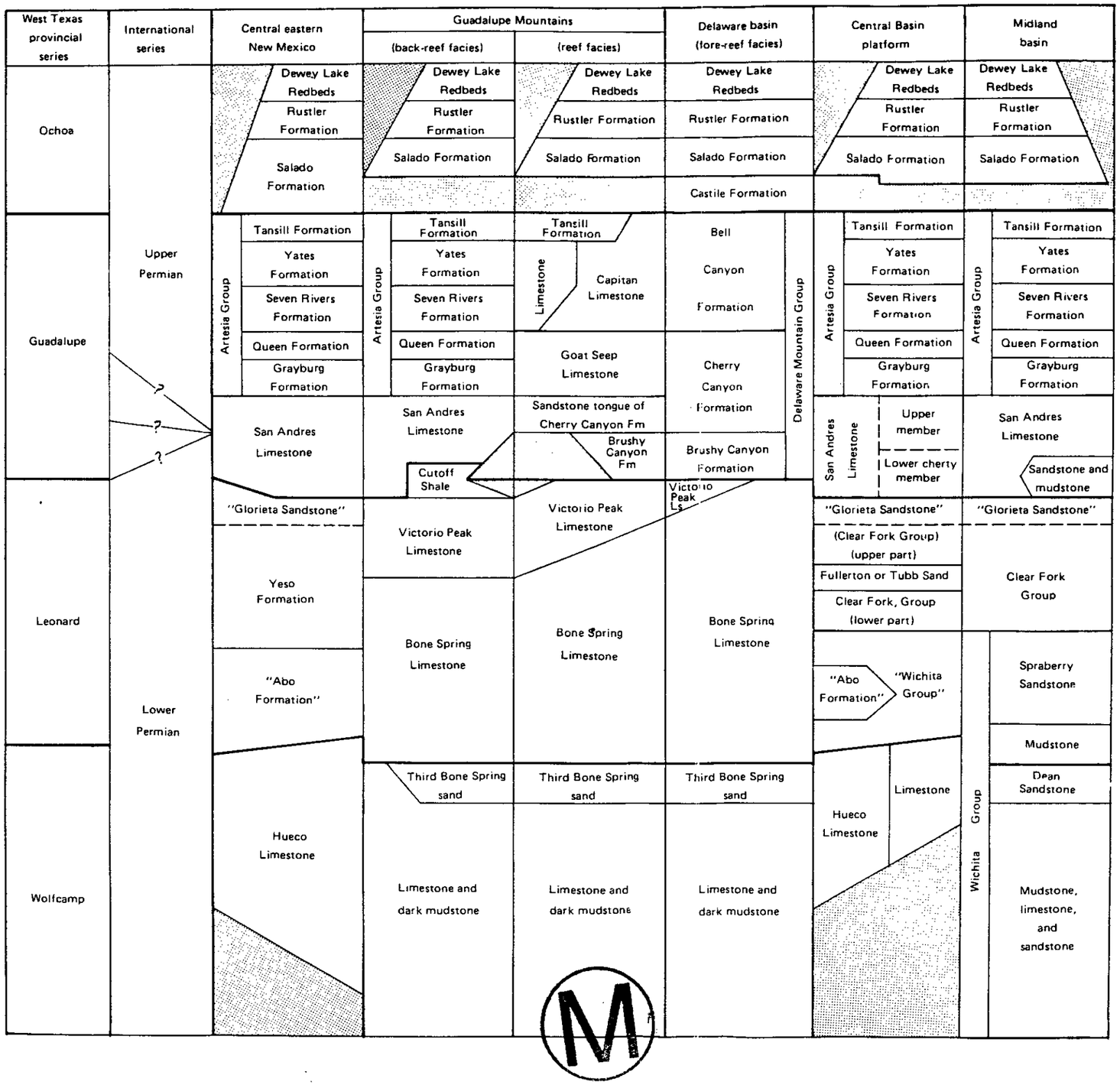

REFERENCE:

U.S.G.S. Prof. Paper 515, Table 1, 1967.

MISSING SECTION

STRATIGRAPHIC CORRELATIONS
PERMIAN SYSTEM
SOUTHEAST NEW MEXICO

FIGURE 3.3-3

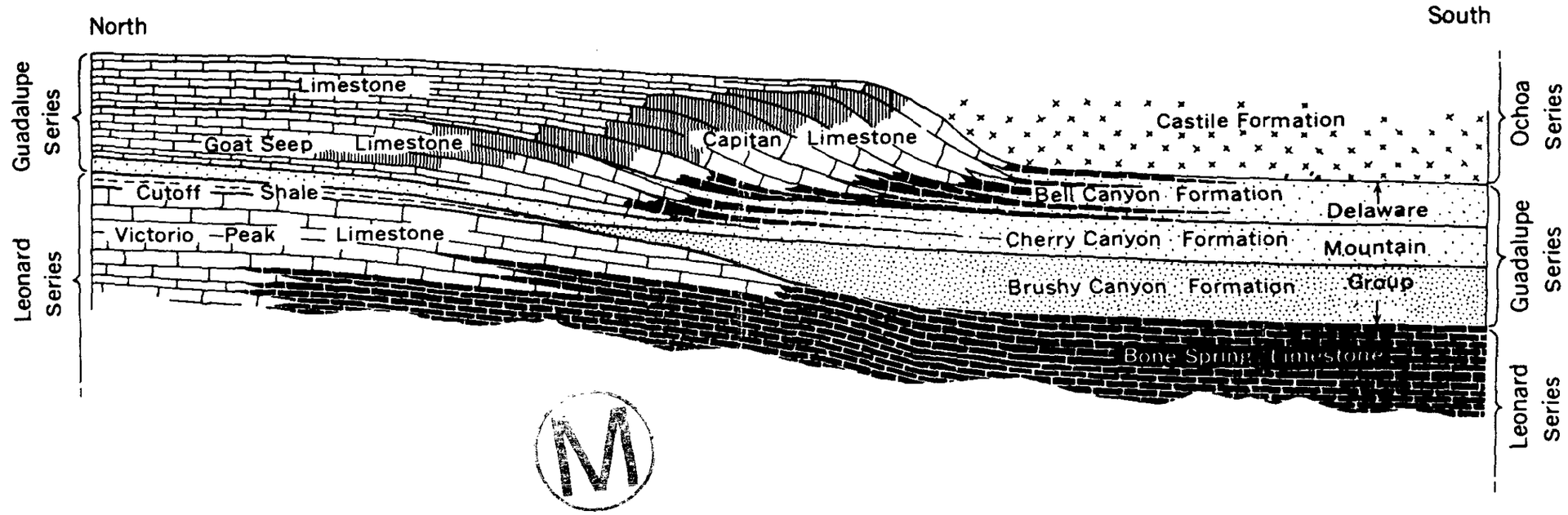

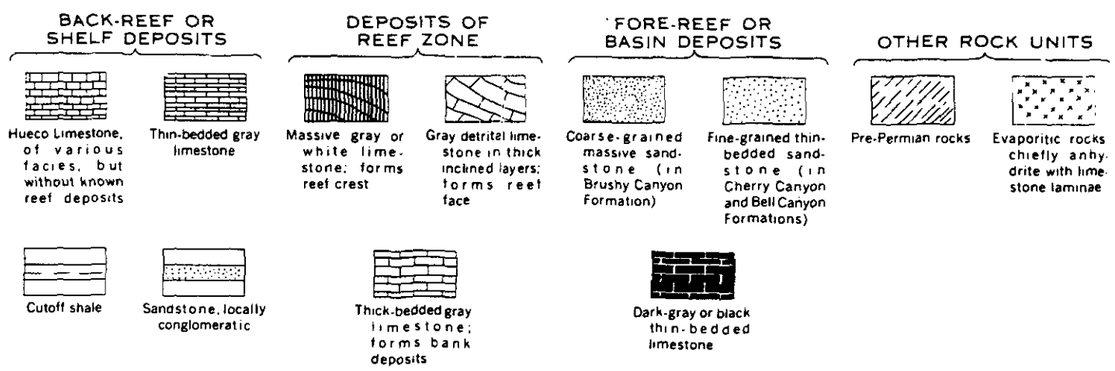

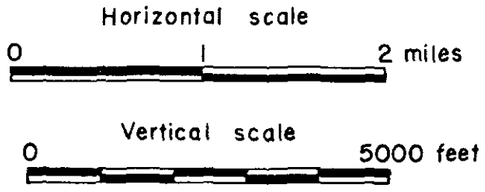

Stratigraphic summary of the Guadalupe, Leonard, and adjacent series of the Permian System in the Southern Guadalupe Mountains. The Delaware basin area is to the right and the shelf or platform area is to to the left. Rock facies are greatly generalized.

REFERENCE:

Adapted from E.D. McKee, et al. (1967).

(Originally compiled from P.B. King (1942, 1948)).

CROSS SECTION OF CAPITAN REEF AREA

FIGURE 3.3-4

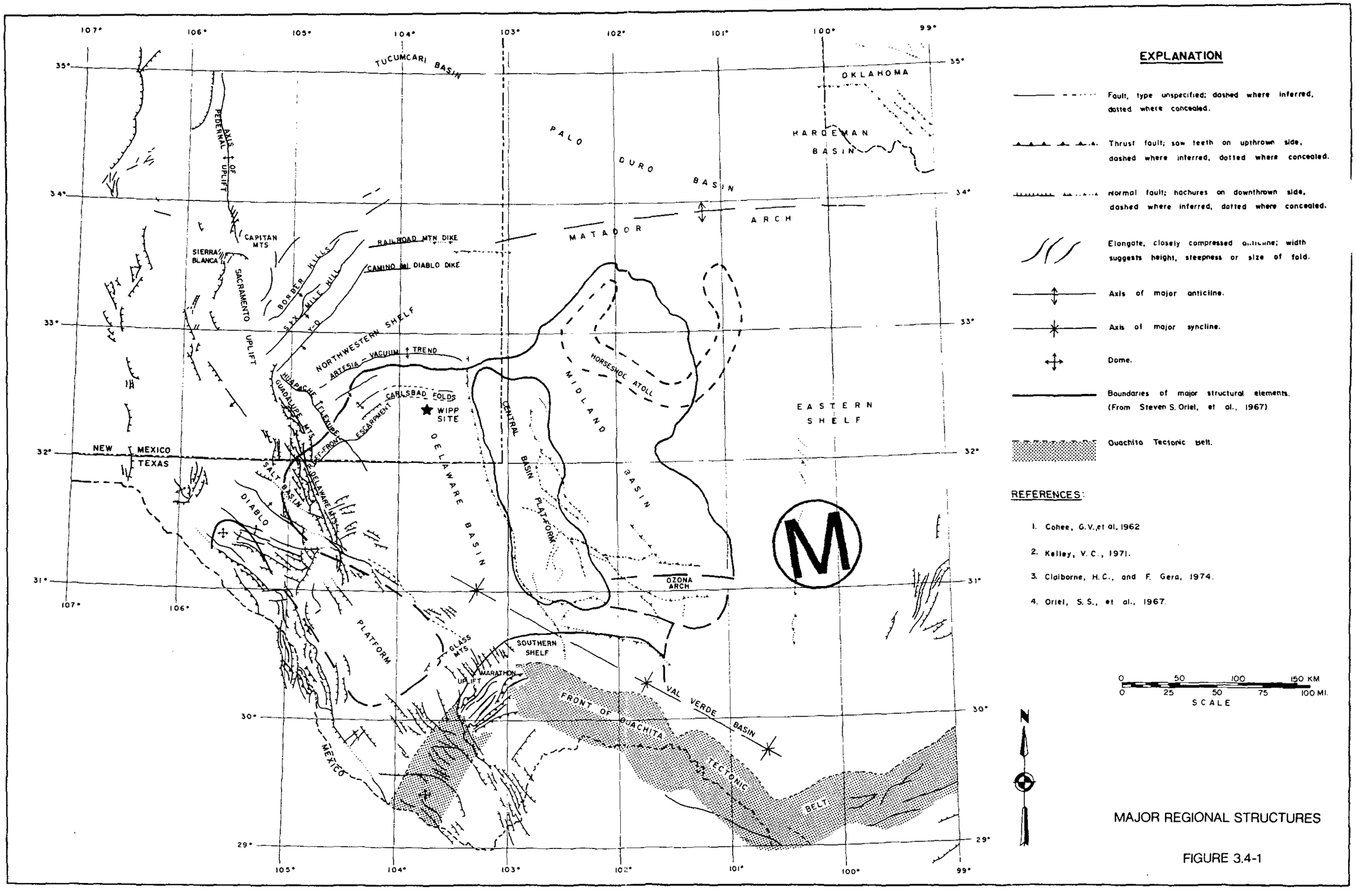

MAJOR REGIONAL STRUCTURES

FIGURE 3.4-1

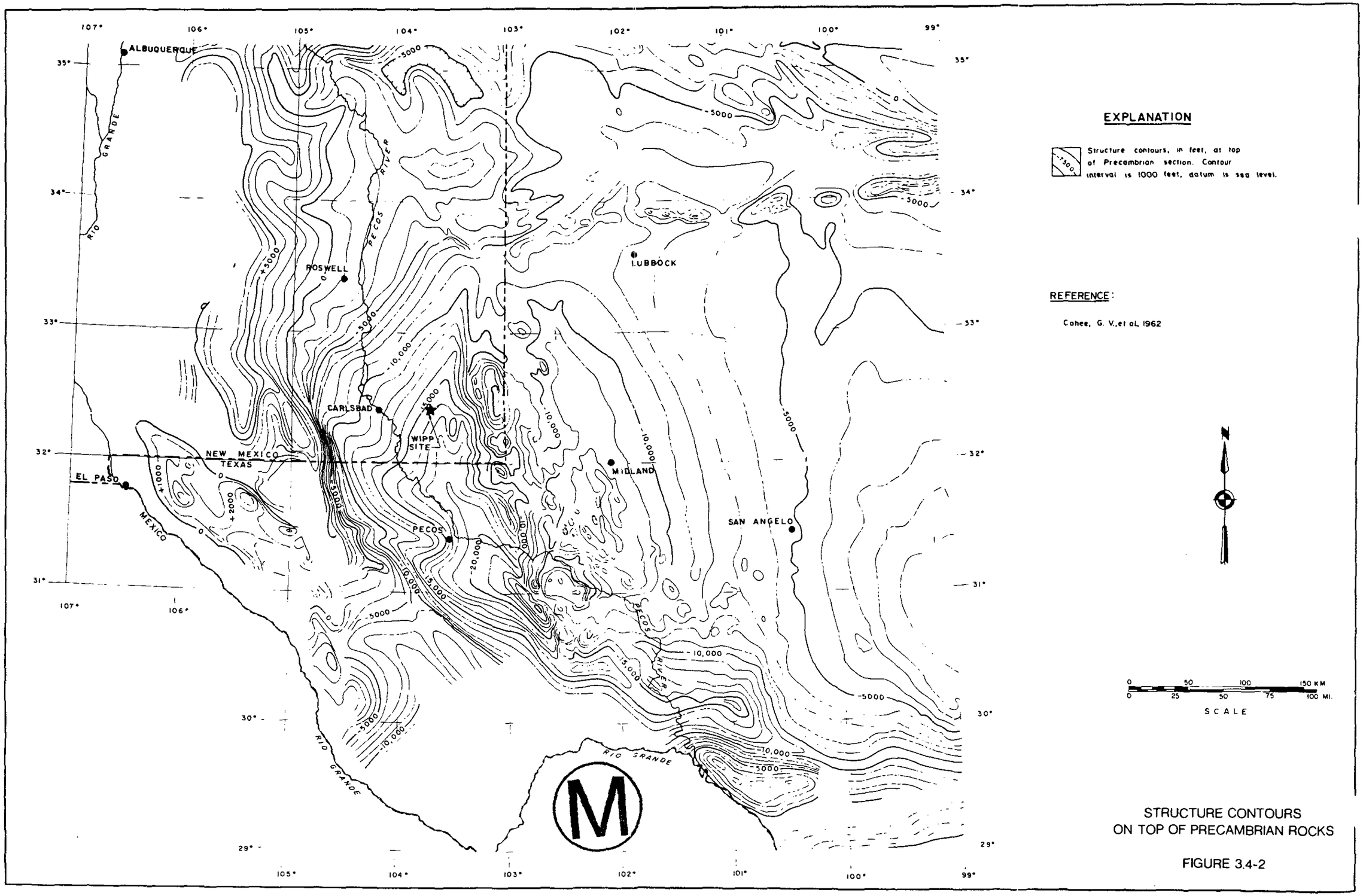

STRUCTURE CONTOURS
ON TOP OF PRECAMBRIAN ROCKS

FIGURE 3.4-2

20

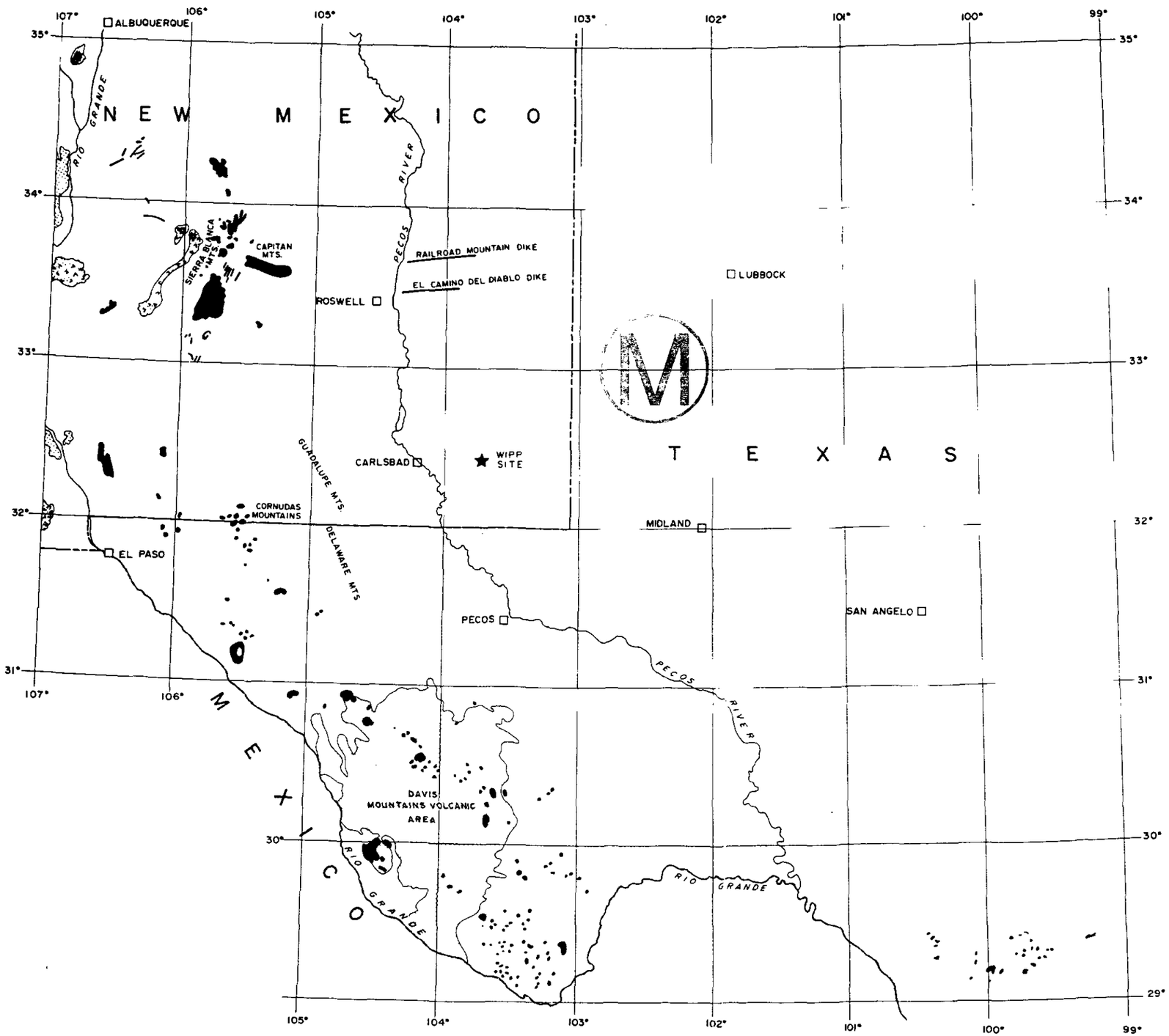

EXPLANATION

INTRUSIVE IGNEOUS ROCKS

Tertiary intrusive bodies; dikes, plugs, stocks, laccoliths

VOLCANIC ROCKS AND FEATURES

Volcanoes and volcanic cones of Quaternary and Late Tertiary age

Tertiary and Quaternary volcanic rocks Only larger areas or areas of tectonic significance are shown. Mainly of various Tertiary ages. Volcanic rocks of Quaternary distinguished in places by v pattern

REFERENCE:

Cohee, G V, et al., 1962

N

0 50 100 150 KM
0 25 50 75 100 MI

SCALE

REGIONAL DISTRIBUTION OF EXPOSED IGNEOUS FEATURES

FIGURE 3.5-1

21

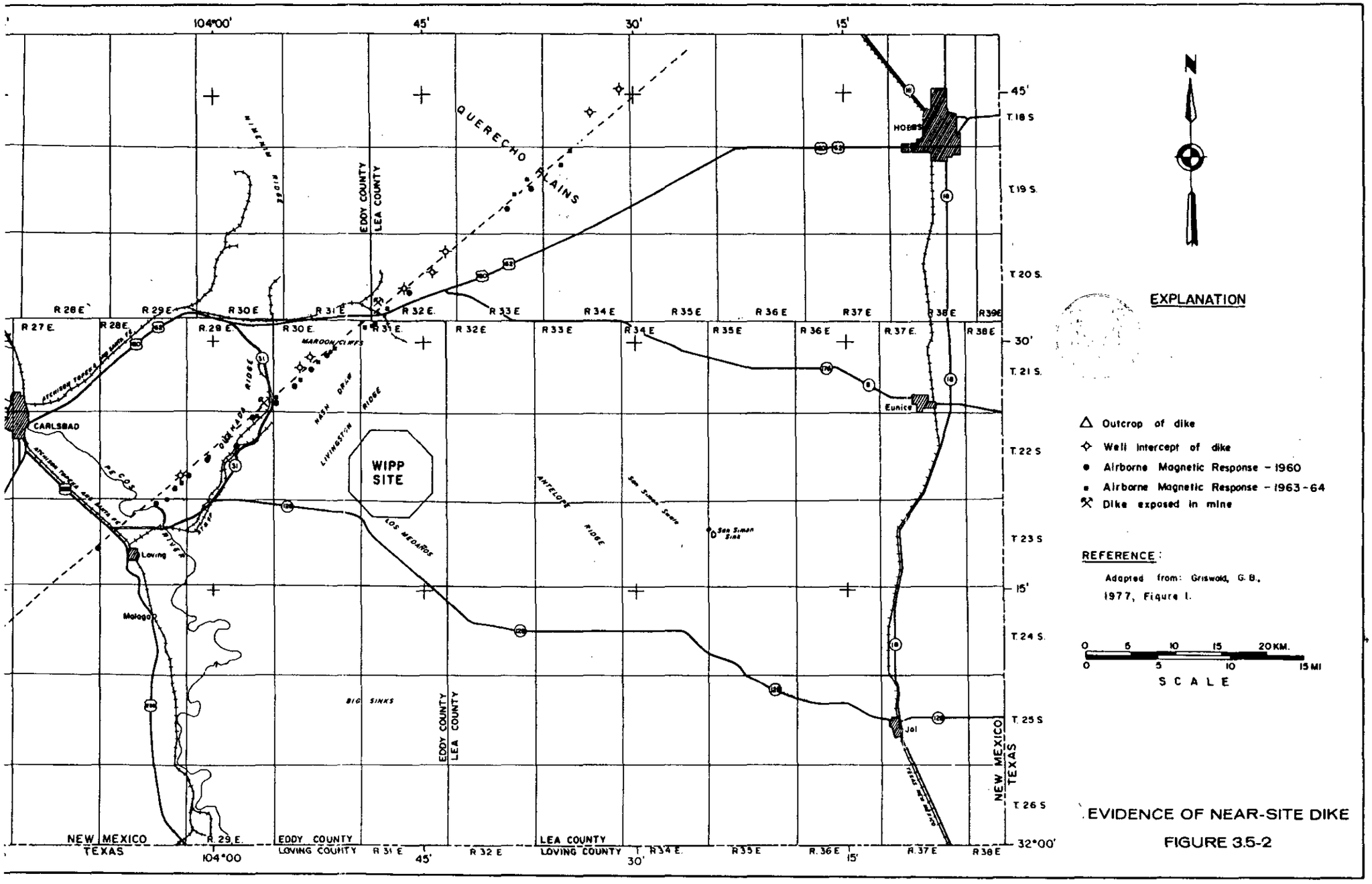

EVIDENCE OF NEAR-SITE DIKE

FIGURE 3.5-2

MAJOR GEOLOGIC EVENTS – SOUTHEAST NEW MEXICO REGION

ERAS	PERIODS	EPOCHS	MILLIONS OF YEARS DURATION	MILLIONS OF YEARS BEFORE THE PRESENT	
CENOZOIC	Quaternary	Holocene	To Present		– Eolian and erosional/solution activity. Development of present landscape.
		Pleistocene	1,000,000	1,000,000	– Deposition of Ogallala fan sediments. Formation of caliche caprock.
	Tertiary	Pliocene	12,000,000		– Regional uplift and east-southeastward tilting; Basin-Range uplift of Sacramento and Guadalupe - Delaware Mountains.
		Miocene	12,000,000		
		Oligocene	11,000,000		
		Eocene	22,000,000		– Erosion dominant. No Early to Mid-Tertiary rocks present.
		Paleocene	5,000,000	63,000,000	– Laramide "revolution." Uplift of Rocky Mountains. Mild tectonism and igneous activity to west and north.
MESOZOIC	Cretaceous		72,000,000		– Submergence. Intermittant shallow seas. Thin limestone and clastics deposited.
	Jurassic		46,000,000		– Emergent conditions. Erosion. Formation of rolling topography.
					– Deposition of fluvial clastics.
	Triassic		49,000,000		– Erosion. Broad flood plain pediment surface develops.
				230,000,000	
PALEOZOIC	Permian		50,000,000		– Deposition of evaporite sequence followed by continental redbeds.
					– Sedimentation continuous in Delaware, Midland, Val Verde basins and shelf areas.
	Pennsylvanian		30,000,000		– Massive deposition of clastics. Shelf, margin, basin pattern of deposition develops.
	Mississippian		35,000,000		– Regional tectonic activity accelerates, folding up Central Basin platform, Matador arch, Ancestral Rockies. Regional Erosion. Deep, broad basins to east and west of platform develop.
	Devonian		60,000,000		– Renewed submergence. – Shallow sea retreats from New Mexico. Erosion.
	Silurian		20,000,000		– Mild epeirogenic movements. Tobosa basin subsiding. Pedernal landmass and Texas peninsula emergent, until Middle Mississippian.
	Ordovician		75,000,000		– Marathon – Ouachita geosyncline, to south, begins subsiding. – Deepening of Tobosa basin area; shelf deposition of clastics, derived partly from ancestral Central Basin platform, and carbonates.
	Cambrian		100,000,000		– Clastic sedimentation – Bliss sandstone.
				600,000,000	– Erosion to a nearly level plain.
PRECAMBRIAN					– Mountain - building, igneous activity, metamorphism, erosional cycles.

MAJOR GEOLOGIC EVENTS – SOUTHEAST NEW MEXICO

FIGURE 3.6-1

TABLE 3.5-I

REPORTED DIKE INTERCEPTS OR SURFACE EXPOSURES

WELL OR DRILL HOLE NAME	LOCATION	INTERCEPT DEPTHS IN FEET
Humble Oil & Refining; State "BO"#3	SE 1/4 Sec. 12, T18S-R34E	8745
Continental; Forest #1	Sec. 22, T18S-R34E	7210-8640
International Minerals Corp.; ConcDale #95	NW 1/4 Sec. 12, T20S-R32E	2239
Noranda; HB-10	SW 1/4 Sec. 14, T20S-R32E	1700
Texaco; Moore #1	SW 1/4 Sec. 21, T20S-R32E	2115
Kerr-McGee; Mine	Sec. 31, T20S-R32E	1530
Perry R. Bass; Big Eddy #44	SE 1/4 Sec. 25, T22S-R28E	12120-13330
Stanolind; U.S. Duncan #1	SW 1/4 Sec. 30, T21S-R30E	470-2710(8 Intercepts)
International Minerals Corp.; Mine	Sec. 36, T21S-R29E	790
H & W Drilling; Danford #1	SE 1/4 Sec. 9, T22S-R29E	2210
Perry R. Bass; Big Eddy #43	SE 1/4 Sec. 25, T22S-R28E	940-2050
Outcrop	Sec. 31, T25S-R25E	Surface
Outcrop	Sec. 11, T26S-R24E	Surface
Amoco; Teledyne Gas #1	Sec. 13, T23S-R28E	Rumor?
Unknown	Sec. 25, T22S-R28E	1880-1900 (γ Ray Response)

Reference: C. L. Elliot (1976 b), Table I.

GCR CHAPTER 4
SITE GEOLOGY

4.1 INTRODUCTION

This chapter is a detailed review of the geologic characteristics of the Waste Isolation Pilot Plant (WIPP) repository site and its environs, including discussions of geomorphology, stratigraphy, structure, and tectonics. In keeping with the concept of underground placement of the radioactive wastes, subsurface geologic conditions are emphasized. Structure contour and isopach maps are presented and discussed. Particular effort has been made throughout the text to relate site-specific aspects to regional geologic conditions. A final section on geologic history reviews the geologic origin and development of the WIPP site.

The available literature, including maps and reports on file with federal and state agencies, has been consulted. Results of field and research investigations carried out specifically to define site geologic conditions have been integrated into the discussion and the investigative reports referenced. Detailed descriptions of the various exploration programs and investigations may be found in Chapter 2.

4.1.1 Area of Study

The area to be considered in detail in this chapter on site geology is shown in Figure 4.1-1. It represents a 10-by-10-mile square area centered on the site, including all of Township 22 South, Range 31 East and parts of the adjacent townships in eastern Eddy and western Lea Counties in the southeastern corner of New Mexico. In many instances, however, the topics under discussion were judged to require consideration of areas more distantly removed or to benefit from a somewhat broader focus, so that Figure 4.1-1 should not be construed as a limitation of the area considered or discussed.

Also shown in Figure 4.1-1 is the outline of the WIPP site itself, locating land-use restriction zones. Zone I is the area of the surface facilities. The roughly octagonal Zone II represents the underground area which would be mined if a fully developed (3 square miles) repository were developed here. No drill hole extending through the salt beds to deeper strata occurs within one mile of the Zone II boundary. Other zones represent levels of land-use restriction and are discussed elsewhere in this report (for example, see Table 2-1). The outer boundary of Zone IV defines the area of the WIPP site. The term "Los Medanos" is also frequently used to refer to the WIPP site area, as for instance in the site selection process to distinguish the WIPP site from other alternate sites in the same region (see Chapter 2). Griswold (1977) defined the 10-by-10-mile square of Figure 4.1-1 as the "Los Medanos site"; however, for the purpose of this report, it seems more appropriate to use the term "Los Medanos" to refer to the general vicinity of the WIPP site, roughly corresponding to the sand- and dune-mantled area bearing that name and within which the site occurs.

4.2.1 Sources of Data

Much of the information specific to the Los Medanos area and to the WIPP site is available from various agencies commissioned to carry out special technical studies. In assembling these descriptions, free recourse has been made to what is available in the open literature, particularly to the numerous open-file reports released by the U.S. Geological Survey. Much useful information on surficial stratigraphy of the Los Medanos area is provided by Vine (1963) and by Bachman (1974; also in Jones, 1973); both have provided surficial geologic maps of parts of the area. Valuable compilations of stratigraphy and structure of the Ochoan evaporite sequence have been assembled by Jones (1972, 1973, 1975), by Brokaw et al. (1972), by Anderson et al. (1972), and by Anderson (1978). Permian Basin geology in general is extensively discussed in King (1948) and in McKee et al. (1967a, 1967b). Pennsylvanian studies are presented for the Los Medanos area by Foster (1974) and regionally by Meyer (1966). Much of the available information regarding pre-Pennsylvanian

stratigraphy is reviewed in Foster (1974), who presents numerous reference sections and isopach and structure contour maps for these deeply buried strata.

A series of subsurface structure contour and isopach maps has been prepared specifically for the WIPP site by Griswold (1977) and most are incorporated into this chapter. The data base for these maps is furnished by available well and borehole information supplemented by specially contracted seismic reflection surveys. The location of all boreholes and seismic reflection profiles used in the subsurface studies reported herein are shown in Figure 4.1-2 and listed in Table 4.1-1.

A glance at the depths of holes listed in Table 4.1-1 shows the paucity of data available for horizons deeper than about two thousand feet. With the possible exception of oil or gas fields where deep holes are clustered, well spacing is typically such that minor faulting probably would not be delineated; only the smoothed trend of local depressions and arches is outlined. The detection of minor faulting and other local structural detail is generally possible only through the use of deep seismic reflection techniques, supplemented by deep well control where available. Horizons which most efficiently reflect seismic wave energy are the most logical targets for detailed study of deep structures. Beneath the site, horizons which are found to be good reflectors include top of the Silurian carbonate sequence, top of Morrow limestone (lower part of Pennsylvanian rocks), and top of Delaware sand (below base of Castile). Although many hundreds of miles of seismic reflection profiling have been carried out in the Delaware Basin, nearly all of it is privately owned by industry sources and the record profiles are not subject to disclosure. Accordingly, Sandia Laboratories engaged the services of G.J. Long and Associates, Inc., of Houston, Texas and Permian Exploration Company of Roswell, New Mexico, to carry out a program of seismic reflection profiling across the WIPP site, supplemented by any oil industry data which was made accessible for examination. Over 1,500 miles of private seismic data were examined and about 70 miles of new

seismic data have been obtained by Sandia. (For further information on seismic reflection profiling and well data control used in the exploration for deep structure at the site, refer to Section 2.5).

Data regarding structural detail of bedded salt in the Delaware Basin, in contrast to deeper horizons, are not generally available in the form of seismic reflection surveys of the type normally used in subsurface exploration, nor do petroleum exploration companies generally pick stratigraphic markers above the Delaware, as there is no commercial hydrocarbon interest in these relatively shallow strata. Perhaps the lack of early recognition of the character of deformation within the bedded salt sequence is accounted for by the petroleum industry's disinterest in non-petroliferous strata. The intensive exploration drilling for potash deposits by commercial mining interests, however, has provided a means of obtaining at least some general outline of deformation features within the evaporite sequence down through the McNutt potash zone of the Salado that would not otherwise have been available. In addition, mine workings have provided supplementary detail in localized areas. Within the site exclusion area, additional potash exploratory holes have been drilled under contract to Sandia Laboratories. Because commercial potash exploration is targeted to the McNutt member of the Salado Formation, shallower strata have generally not been extensively logged and sampled, with the result that details of structure in the Rustler Formation and Dewey Lake Redbeds were not well recorded. The holes drilled under contract to Sandia Laboratories to determine the extent of potash reserves in the site area were logged through these upper formations by wireline geophysical methods and are the source of much of the shallow subsurface data near the WIPP site. Figures 4.4-11 through 4.4-15 are constructed from these data.

Nothwithstanding the apparent wealth of drill hole data in the area, it should be emphasized that well data necessarily represent an incomplete sampling and extrapolation from such data will be imprecise to an extent dependent on the well spacing, the complexity of the subsurface structure, and the level of detail desired. Well picks probably will not

record absolute maxima or minima of sharper crests and troughs, and certain smaller features could remain undetected. Other techniques such as seismic reflection aid in finding smaller structures.

4.2 SITE PHYSIOGRAPHY AND SURFICIAL GEOLOGY

4.2.1 Site Physiography

The proposed WIPP site is located on the eastern edge of the Pecos Valley section of the southern Great Plains physiographic province (Figure 3.2-1). The land surface within the area of the site is a monotonous, semi-arid, eolian plain sloping gently to the west and southwest (Figure 4.2-1a), its surface made somewhat hummocky by an abundance of sand ridges and dunes. Figure 4.2-2 is a topographic map of the area in the vicinity of the site (from Nash Draw and Hat Mesa 15-minute topographic quadrangle maps). Also shown on this figure are the boundary zones of the WIPP site as discussed in Section 4.1, extending a maximum distance of about 3 miles from the geographic center of the site. Within these boundaries, elevations range from 3,570 feet in the east to 3,250 feet in the western part of the site. The average slope from east to west is 50 feet per mile (Griswold, 1977).

In the vicinity of the site, Livingston Ridge is perhaps the most prominent physiographic feature. Located about a mile beyond the northwestern border of the WIPP site, it is a northeast-southwest trending, west facing escarpment about 75 feet high marking the east edge of Nash Draw. Nash Draw, the nearest drainage course of any significance in the vicinity of the site, is a shallow, 5-mile-wide valley open to the southwest. Elevations within Nash Draw, which descend from about 3,300 feet at its northeast head to 2,945 feet at Salt Lake, near the Pecos River, are generally 200 to 300 feet lower than the surrounding terrain and may reflect substantial subsurface dissolution of salt from the Rustler and Salado Formations and accompanying subsidence of overlying materials. Livingston Ridge marks the approximate boundary, therefore, between terrain that has undergone erosion and/or solution collapse and

terrain that has not been so affected, and may be considered to indicate the approximate position east of which significant dissolution of the underlying Salado Formation has not occurred (refer to Chapter 6 and Section 3.2 for further discussion).

East of the site, the nearest major drainage course is the southeast-trending San Simon Swale, some 15 miles or more distant (a more regional topographic map is shown in Figure 2-1). It, too, most likely owes part of its decreased elevation to subsurface dissolution. Between Sam Simon Swale and the WIPP site, a broad, low mesa named "The Divide" occurs about 6 miles east of the site, rising about 100 feet above the surrounding terrain and attaining an elevation of about 3,800 feet, and, as such, marks a local boundary between general southwest drainage toward Nash Draw and general southeast drainage toward San Simon Swale. The Divide is capped by the Ogallala Formation, and overlying caprock caliche upon which have formed small, elongate depressions similar to those found developed on the Ogallala of the High Plains, proper, farther east (refer to Regional Geomorphology, Section 3.2, for additional discussion of these features).

Surface drainage in the site area is intermittent; the nearest perennial stream is the Pecos River, more than 15 miles south-west of the center of the site. Surface runoff in the site area finds its way to the Pecos River via Nash Draw; discharge of shallow groundwater is likewise believed to be controlled by the Pecos River (refer to hydrology sections 6.2.5 and 6.3). Although basins like Nash Draw may have evolved partly through active subsurface dissolution of thick, buried salt deposits, there is no evidence available at present to evaluate differences in rates of dissolution which may have prevailed under different climatic conditions. That the site is in a natural divide between drainage basins indicates that it is protected from serious flooding and erosion from heavy runoff. Should the climate of the region become more humid in the future, any perennial streams which might then arise would be expected to follow the present basins, and Nash Draw and San Simon Swale would undergo the greatest amount of erosion from this increased humidity, leaving the divide area relatively intact (Bachman, 1974).

Because of the presence in Nash Draw and elsewhere in the Delaware Basin of extensive subsidence which appears to be caused by subsurface dissolution of salt, much attention has been focused on the search for geomorphic indications of possible subsidence features in the vicinity of the site. One feature that has attracted some attention is described by Griswold (1977) as a shallow sink about 8 miles north of the site in the southeast part of Section 9, T. 21 S., R. 31 E. (pictured in Figure 4.2-1b). The feature is very subdued, about 1,000 feet in diameter and 30 feet deep. Resistivity studies conducted by Elliot (1976) indicate very shallow surficial fill within the feature and no disturbance of underlying beds, indicating a probable surface rather than subsurface origin. This type of feature is common in southeastern New Mexico and is not necessarily indicative of an origin tied to subsurface subsidence. On the other hand, recent resistivity surveys conducted over the surficial sand cover within the WIPP site area (Elliot, 1977e) have disclosed a resistivity anomaly in section 17, T. 22 S., R. 31 E., within the limits of the Zone II exclusion area. The anomaly bears some resemblance in character to the pattern observed over a known sink, a so-called salt "breccia pipe" (Elliot 1977a). Recent drilling (WIPP 13) has shown this resistivity anomaly is not caused by dissolutioning but by lower than average resistivity in the Dewey Lake Redbeds.

4.2.2 Site Surficial Geology

Most of the site area is covered by blanket eolian sand or, especially on the north, east, and southeast, by partially stabilized sand dunes. Active sand dunes are located in the southern portion of the site (Figure 4.2-3). The sand, of Holocene age ("Mescalero sand"), forms a thin, persistent veneer no more than a few meters thick (except where dunes occur) that is believed to have been swept westward from the High Plains, where the inferred source material, the sandy Ogallala Formation, is abundant. The widespread sand cover is readily apparent on the surficial geologic map of the site area, Figure 4.2-4, which is compiled from maps prepared by Vine (1963) and Bachman (1974).

Not at all apparent from the map, however, is the general occurrence of a hard, caliche layer up to 10 feet thick immediately beneath the eolian sand blanket. The relatively high resistance of the caliche to erosion has protected the more erodable underlying strata from dissection and exposure. It is recognized over a regionally broad area and has been termed the "Mescalero caliche". Caliche may form pedogenically over geologic time at or near the surface through capillary rise of carbonate-laden water in the vadose zone followed by precipitation of solute upon evaporation of pore water (Brown, 1956). The youngest formation on which the Mescalero caliche has formed is the Pleistocene Gatuna Formation, of presumed Kansan age (Bachman, 1974). Bachman (1974) indicates that the formation of the Mescalero caliche probably dates back to the Yarmouth interglacial stage, or approximately 500,000 years ago. That such a thick, areally extensive, and continuous caliche had accreted implies past stable climatic and geomorphic conditions over the considerable time period required for its formation. The relevance of this type of paleoenvironmental indicator to the stability of present climatic conditions and to possible future climatic variablility, and the implications regarding the long-term integrity of the WIPP repository, are presently being pursued by Bachman (see Chapter 10).

On the surficial geologic map (Figure 4.2-4) exposures of the Mescalero caliche are indicated. These occur where the eolian cover is very thin or removed entirely, mostly near the edge of Nash Draw, into which much of the nearby loose sand may have been swept. Along Livingston Ridge, the Mescalero caliche is draped inward into Nash Draw and is present over much of the north half of the valley, indicating that at least some subsidence or lateral backwasting along Nash Draw has occurred subsequent to the formation of the caliche, presumably during the more humid glacial stages (Illinoian or Wisconsin) of Pleistocene time.

Within Nash Draw, and the WIPP site area, the Triassic Santa Rosa Sandstone, the Ochoan Dewey Lake Redbeds, and more than half of the Rustler Formation are sporadically exposed. Field descriptions of these formations are included in Section 4.3.

The overall geology and structure of the WIPP site is quite simple. It is characterized by a persistent, gentle homoclinal dip toward the east of 50 to 200 feet per mile (2 degrees or less), depending upon depth. Successively older rocks are seen to occur toward the west, the result of erosional bevelling of the gently eastward-dipping strata. Additional information regarding erosional history of the WIPP site is presented in section 4.5; details of the site structure and stratigraphy are discussed in the following sections.

4.3 SITE STRATIGRAPHY AND LITHOLOGY

The following paragraphs briefly summarize the stratigraphic sequence at the WIPP site; systematic description of the various lithologic units commences in Section 4.3.1.

The proposed WIPP underground storage facilities are to be placed near the middle of a 3,600-foot-thick sequence of relatively pure evaporite strata containing primarily rock salt and anhydrite, lying between depths of about 500 and 4,100 feet beneath ground surface. The formation richest in rock salt, the Salado Formation, is nearly 2,000 feet thick. The Salado contains the relatively pure salt layers in which the two proposed underground storage levels are to be constructed, at a depth near 2,120 feet for the upper level and near 2,670 feet for the lower. The storage horizons are well isolated from the enviroment by adjacent evaporite strata. A thickness of at least 1,300 feet of undisturbed evaporite, primarily rock salt, overlies the upper storage horizon, and about an equivalent thickness of anhydrite and rock salt intervenes between the lower storage horizon and the next adjacent underlying non-evaporite formation. The salt deposits were formed at least 225 million years ago and have apparently remained isolated since that time.

The total thickness of the sediments resting on Precambrian basement beneath the surface of the proposed WIPP facility is about 18,000 feet of Ordovician to Recent strata. Depicted in Figure 4.3-1 is a generalized stratigraphic section of the site, showing the vertical sequence of major

units and their relative thicknesses. More detail, but still of a generalized nature, is provided in Figure 4.3-2, Site Geologic Column, which shows simplified graphic and descriptive lithologies of the major units known or inferred to occur beneath the site and gives the geologic classification of rock units used in this report. Following is a brief summary of the stratigraphy, proceeding from the surface down to basement.

Beneath a thin but persistent veneer of windblown sand at the site are sediments representing Pleistocene, Upper Triassic, and uppermost Permian strata, all of which occur above the evaporite sequence. Sandstone of the Pleistocene Gatuna Formation, capped by Mescalero caliche, also developed in Pleistocene time, is only a few tens of feet thick at the site and is of interest primarily for the geochronologic and paleoclimatic implications of its presence; it was deposited, and much of the caliche on its surface believed to have developed, half a million years ago (Kansan-Yarmouth time) (Bachman, 1974). Between the Pleistocene sandstone and the evaporite sequence is a 500-foot-thick succession of nonmarine redbeds of Late Triassic age (Santa Rosa Sandstone) and marine redbeds of latest Permian age (Dewey Lake Redbeds). This redbed sequence thins westward and thickens eastward, having been beveled to the west by one or more post-Late Triassic erosional episodes; the thickness of redbed deposits remaining above the evaporite sequence is crudely proportional to the degree to which the underlying salt horizons have been protected from surficial processes leading to erosion and dissolution.

At the center of the site, all but the uppermost 50 feet of the 18,000 feet of strata are of Paleozoic age, the marine Dewey Lake Redbeds being the topmost of the Paleozoic rocks. The Permian section alone, about 12,800 feet thick, constitutes over two-thirds of the sedimentary column. The Permian section is divided into four series, the three lowest of which (Wolfcampian, Leonardian, and Guadalupian) contain thick clastic sequences, and the uppermost of which, the Ochoan Series, contains the evaporite formations, which are in descending order the

Rustler, Salado, and Castile Formations. (The topmost Ochoan formation, the Dewey Lake Redbeds, is not part of the evaporite sequence but represents a return of clastic, normal marine deposition.)

The Rustler, which overlies the Salado, contains the largest percentage of clastic material of the three evaporite formations. However, where its original thickness of around 450 feet has been protected from salt dissolution, about 70 percent of the formation is composed of evaporite beds, including about 40 percent rock salt. Beneath the WIPP site, the Rustler has been leached of most of its rock salt in the geologic past. At ERDA-9, 310 feet of the formation was encountered, which implies that up to 150 feet of rock salt has been removed and that the overlying strata have subsided accordingly. It does not, however, imply that dissolution and subsidence is necessarily presently active or even that it has recently occurred. At ERDA 9 halite was logged in the lower 100 feet of the Rustler. Over 1,300 feet of undisturbed evaporite rock, primarily Salado rock salt, occur above the upper level storage zone of the proposed WIPP facility.

The 2,000-foot thickness of the salt-rich Salado Formation is divided into three members by the recognition of a middle member referred to as the McNutt potash zone, which is the interval within the Salado that contains the potential reserves of potash minerals mined in the Carlsbad District west of the site. The lowest member of the Salado, beneath the McNutt potash member, is the member that contains the nearly pure halite which is proposed for the WIPP facility. The Castile Formation beneath the Salado also contains nearly pure beds of halite but, unlike the Salado, also contains massive anhydrite beds.

The rest of the Permian section beneath the evaporite sequence, together with the subjacent Pennsylvanian and possibly Late Mississippian sections, contain dominantly clastic rocks that represent deposition during the time in which the Delaware Basin existed as a distinct structural entity. These pre-evaporite, basinal sediments, which total about 11,000 feet in thickness beneath the site, have been targeted for

petroleum exploration at one point or another throughout the Delaware Basin. They contain nearly all of the region's known potential reserve of hydrocarbons.

The remainder of the Paleozoic section (Mississippian down through the Ordovician) consists of about 3,000 feet of mainly carbonate strata deposited in shallow-water or shelf conditions over a period of long-sustained crustal stability.

The underlying crystalline basement is believed to be a granitic terrane, formed about 1,300 million years ago. The only other igneous rocks known in the area occur as a lamprophyre dike rock intruded into the evaporite beds along a single northeast dike trend that approaches no closer than about 8 miles northwest of the center of the proposed WIPP site.

Brief descriptions of the various stratigraphic units are provided in the following sections, in order of deposition from oldest to youngest, with emphasis on the evaporite beds, particularly the Salado Formation.

4.3.1 Precambrian Eonothem

Few holes in the near vicinity of the WIPP site have penetrated entirely through the Paleozoic section. The nearest such holes are the Richardson and Bass No. 1 Cobb-Federal, approximately 13 miles north-northwest of the center of the site, and the Texas No. 1 Richards, 12-1/2 miles to the north-northeast. Inferences about the nature of basement rock lying beneath the site have been gleaned from these wells and others more distantly removed.

Crystalline basement rocks beneath the Mesozoic and Paleozic sedimentary pile near the proposed site are believed to be either granitic igneous rock or metamorphosed granites and rhyolites. The basement surface here is at a depth of approximately 17,900 feet (Foster and Stipp, 1961); a slightly greater depth (approximately 18,200 feet) has been inferred by independent consultants (Sipes et al., 1976). The basement rocks occur

within what has been considered by Flawn (1954, 1956) to be part of a regional Precambrian granitic terrane constituting the Texas craton. A later investigation (Muehlberger et al., 1967), which reclassified the rocks within the Texas foreland or craton, among other areas, suggests that the basement rocks in the area near the site belong to the Chaves granitic terrane, composed largely of granite, granodiorite, and equivalent gneisses, with a minor amount of other metamorphic rocks included. Measured radiometric dates for basement rocks in the area range between 1,140 to 1,350 million years (Foster, 1974; Muehlberger et al., 1967); the Chaves terrane is defined to include the 1,350 m.y.-old granitic basement rocks.

4.3.2 Paleozoic Erathem

Cambrian System. No Cambrian strata are recognized in the subsurface in the vicinity of the WIPP site. Basal conglomerate and sandstone resting on the Precambrian of southeastern New Mexico are sometimes called Bliss sandstone, which is partly Late Cambrian and partly Early Ordovician in age, but such rocks in this area probably correlate only with the Ordovician part of the Bliss (Foster, 1974) and are here considered a member of the Ellenburger Group.

Ordovician System. In the Los Medanos area, the Paleozoic section begins with an estimated 1,290 feet of Ordovician rocks beneath the center of the site (Foster, 1974), assuming an even gradient between widely spaced well control points. In ascending order the sequence includes the Ellenburger, Simpson, and Montoya Groups, representing Lower, Middle, and Upper Ordovician strata, respectively.

Detail of the local stratigraphy of the Ordovician is based on samples and a radioactivity log from the Texas No. 1 Richards well, 12-1/2 miles north-northeast of the site. The Ellenburger Group there consists of at least 300 feet of dolomite with some chert; included is a basal member of sandstone and conglomerate about 75 feet thick. The top of the Ellenburger may be at a depth of as much as 17,800 feet beneath the

center of the site (Netherland, Sewell, 1974). Overlying the Ellenburger dolomite is a sequence of alternating limestone and green or gray shale members, with several sandstone units occurring in the upper half of the sequence. The Upper Ordovician Montoya Group is almost entirely carbonate rock. At the Texas 1 Richards well, the lower half of the Montoya is limestone and the upper half dolomite, chert being fairly common, particularly in the middle of the section; whereas 14 miles south of the site the Montoya has been logged as mostly limestone and sandy limestone. Some intermediate lithology is therefore to be expected beneath the WIPP site.

In the Texas 1 Richards reference section the Ordovician rocks total 975 feet in thickness; however, the section thickens in a south to southeast direction at a rate estimated to be 25 to 40 feet per mile (Foster, 1974), most of which is due to the thickening of the Ellenburger and Simpson groups in that direction. It is likely that the Ellenburger and Simpson are each between 400 and 500 feet thick in the site area.

Silurian System. Lying above the dolomite of the Ordovician Montoya Group is additional carbonate rock of Silurian, or perhaps Siluro-Devonian age. Near the site it consists entirely of light-colored dolomite with appreciable chert, except for two prominent intervals of limestone, one about 100 feet thick near the middle of the section and one about 200 feet thick near the top (Foster, 1974). The basal contact is apparently disconformable in this area.

The relatively homogenous lithology of the Silurian carbonate sequence in the subsurface of southeastern New Mexico has thus far precluded its formal separation into formational units. McGlasson (1968), however, has suggested that the lower part is correlative with the Fusselman Formation of Early and Middle Silurian age, and that the upper part, generally referred to as "Upper Silurian" strata, may be correlative with the Henryhouse Formation of partly late Middle and partly Late Silurian age. McGlasson (1968) also shows that no Devonian carbonate rocks were deposited in New Mexico, except in the extreme southwest corner of Lea

County. Nevertheless, common oil-field usage refers to these carbonates as "Siluro-Devonian" carbonates (Foster, 1974). Probably most if not all of the post-Montoya, pre-Woodford carbonate strata beneath the WIPP site is Silurian in age, according to McGlasson's studies. Isopach maps (Foster, 1974) indicate the total thickness of the Silurian or "Siluro-Devonian" carbonates at the site to be about 1,140 feet. The sequence thins westward relatively uniformly at a rate of about 25-50 feet per mile toward a landmass emergent during Silurian time.

The marked contrast in lithology between the Silurian carbonate and the overlying Devonian shale is believed to provide a good seismic reflecting horizon. Structure contour maps on top of "Siluro-Devonian lime" indicate that the top of Silurian, equivalent to base of Devonian, is at a depth of about 15,850 feet beneath the center of the WIPP site (elev. minus 12,450 feet) (Netherland, Sewell, 1974).

Devonian System. The Devonian system is represented by a distinctive unit of organic, pyritic black shale which unconformably overlies the Silurian carbonate sequence. McGlasson (1968) correlates it with the Upper Devonian Woodford Shale of Oklahoma and describes it as a "dark brown to black, fissile, bituminous, spore-bearing shale". He shows that it is a transgressive unit which overlaps successively older units to the northwest (McGlasson, 1968). Beneath the center of the site it is indicated to be about 175 feet thick, thickening gradually southeastward (Foster, 1974). Haigler and Cunningham (1972) show the top of undifferentiated Silurian and Devonian rocks at an elevation of slightly above minus 12,300 feet MSL at the center of the WIPP site. The uppermost portion of the Woodford Shale in the Delaware Basin is reported to be actually of earliest Mississippian age (McGlasson, 1968).

Mississippian System. Rocks of the Mississippian System at the site include a series of limestones referred to simply as "Mississippian limestone," and an overlying shale interval called the Barnett shale. At the Texas 1 Richards locality, the limestone is light-yellowish brown, locally cherty, with some minor gray shale, contrasting with brown,

locally silty shale of the Barnett. Like the top of Silurian carbonate, the top of Mississippian carbonate most likely affords a good reflecting horizon; structure contour maps indicate that it is about 15,150 feet below Zone I at the site (elev. minus 11,750 feet) (Netherland, Sewell, 1974). Total thickness of the carbonate appears to be about 480 feet at the site, gradually thickening northward. The overlying black shale is about 175 feet thick.

Stratigraphic relations between subsurface Mississippian strata in southeastern New Mexico and formational units defined in other areas are unclear. On the basis of the local fauna, the carbonate sequence in the Delaware Basin is assigned to the Lower Mississippian (Foster, 1974). Lithologically it is similar to the Rancheria Formation in the Franklin Mountains. At or near the site, deposition of the Barnett Shale corresponds for the most part to Late Mississippian time.

Pennsylvanian System. Approximately 2,200 feet of Pennsylvanian strata occur in the subsurface at the WIPP site (Foster, 1974). The section consists of alternating members of sandstone, shale, and limestone, and rests unconformably on the underlying Barnett Shale.

Unlike most of the earlier Paleozoic strata, the Pennsylvanian strata in the Delaware Basin, and some of the Lower Permian strata as well, are characterized by relatively numerous changes in lithology vertically in the section and by an abundance of lateral facies changes along time-equivalent horizons. Lithologic units traceable over broad areas in the subsurface generally cannot be assumed to represent time-stratigraphic units under these conditions. Attempts to construct a basin-wide geologic history for Pennsylvanian time and to develop regional correlations based on time equivalence are greatly complicated by these lithologic changes. These complexities have spawned efforts such as those of Meyer (1966) to develop a method for placing surface outcrop and subsurface strata into a formal Pennsylvanian time-stratigraphic framework. As defined by this approach, the Lower Pennsylvanian Series includes rocks assigned to the Morrowan Stage, the

Middle Pennsylvanian Series to rocks assigned to the Atokan (or Derryan) and Desmoinesian Stages, and the Upper Pennsylvanian Series to rocks assigned to the Missourian and Virgilian Stages.

In the Delaware Basin, local subsurface stratigraphic units have sometimes been informally defined, or extended on the basis of lithology and are therefore, strictly speaking, lithostratigraphic and not time-stratigraphic units. Thus, rocks considered part of, for example, the "Morrow" or the Morrow Series on the basis of subsurface lithologies may not necessarily all be encompassed within or represent all of the time of the Morrowan Stage as formally defined. Although the Pennsylvanian section is herein described by reference to lithologies recorded in nearby wells, for the reasons stated the section at the site cannot from the nature of data available be positively correlated with formal stage names or with Lower, Middle, or Upper Pennsylvanian Series. Nevertheless, the designations of Morrowan, Atokan, Desmoinesian, and Missourian-Virgilian rocks for the respective Bend, Strawn, and Canyon-Cisco rock units have frequently been used with modifications for some time (Thompson, 1942; Haigler, 1962, p. 7-8, Netherland-Sewell, 1974, exbt. G-2; see also Meyer, 1966, p. 11). The bipartite classification of Lower Pennsylvanian for Morrowan and Atoka and Upper Pennsylvanian for Strawn has also been employed (e.g., Sipes et al., 1976).

Foster (1974), in his description of Pennsylvanian subsurface lithologies in the vicinity of the site, adopted the usage of Morrow, Atoka and Strawn, which denote from deepest to shallowest the respective principal oil and gas producing zones in Pennsylvanian rocks of the Delaware Basin. He noted that the "overlying rocks of Missourian and Virgilian ages are present... but following the common oil-field usage (they) are included in the Wolfcamp sequence". Hence, "... it appears that the top of (Meyer's) Desmoinesian Stage is the same as the top of the Strawn..." (Foster, 1974). This usage is followed in this chapter in the interest of its adaptability to existing commercial exploratory data. Reference sections are provided by Foster for Pennsylvanian strata some distance

north and south of the site (his Figures 12 and 36, respectively). Sipes, et al. (1976) show "picks" on Pennsylvanian units in the Clayton W. Williams Jr., Badger Unit Federal well about 2 miles northeast of the center of the site, and they present down-hole logs on this and other exploration holes in the vicinity of the site as well.

Morrowan rocks near the site consist mostly of fine- to coarse-grained sandstone with varying amounts of dark gray shale. Some limestone, generally as a series of relatively thin beds with shale and sandstone, typically occurs in the upper part of the sequence and is often separately identified. The Morrow sand is a known hydrocarbon producer of oil and gas in this part of the Delaware Basin, particularly from fields in the area north of the site (refer to Section 8.3.2). Foster (1974) shows areal distribution of sand lithologies in this zone.

The Atoka rocks are principally limestone, becoming cherty toward the middle of the section, and alternating with varying amounts of medium- to dark-gray shale. Sandstones are subordinate. The Atoka is considered to have locally significant hydrocarbon potential in this part of the Delaware Basin, as in the Los Medanos field which is southwest of and nearest to the WIPP site.

The lower part of the Strawn (regionally the Desmoinesian) is dominated by light gray to white, medium- to coarse-grained sandstone, locally conglomeratic in the site area. In its upper part, the Strawn is dominantly limestone, apparently with a minor amount of chert but becoming more abundant northeastward in the immediate vicinity of the site (Foster, 1974). Thin beds of dark gray and brown shale are present throughout the section.

Records of the apparent thickness of the Morrow, Atoka and Strawn vary considerably from area to area simply because there is no completely agreed-upon way of selecting "picks" on down-hole logs and seismic reflection data. In some oil fields, "picks" above the Morrow include

Atoka (or Bend), Strawn, Missourian, and Virgilian. According to Foster (1974), "in well completion reports the top of the Strawn is picked fairly consistently," but selections for the top of Morrow and Atoka may differ significantly, and generally the Canyon and Cisco are not distinguished in this part of basin. Sipes et al. (1976) show the top of Strawn at elevation minus 9,400 feet msl beneath the center of the WIPP site. The "picks" they show in the C.W. Williams Jr., Badger Unit Federal well two miles northeast of ERDA 9 yield thicknesses of 1,224, 607, and 257 feet for the Morrow, Atoka, and Strawn rocks, respectively, for a total thickness of 2,088 feet for the Pennsylvanian. Presumably, one or more units thicken southwestward slightly to attain the 2,200-foot value that Foster shows at the center of the site, a value which specifically excludes at least some Missourian-Virgilian strata. Probably the value of approximately 2,500 feet shown by Meyer (1966, Figure 48) is more truly representative of the total accumulation of strata beneath the site during Pennsylvanian time.

Permian Rocks. As much as 13,000 feet of Permian strata were deposited within the area of the Delaware Basin, which constitutes the most complete succession of the Permian in North America (Brokaw et al., 1972). The entire Permian section beneath the WIPP site averages about 12,800 feet in thickness, over two-thirds that of the entire sedimentary column, or over twice as thick as all of the earlier Paleozoic formations combined (about 5,200 feet). Of this total, about 3,600 to 3,800 feet of thick, relatively pure evaporite beds (primarily salt and anhydrite) occur in the upper part of the sequence, in which the proposed waste isolation facility is to be constructed.

Because the Permian in the Delaware Basin and surrounding region has long been the subject of intensive exploration and study by both commercial and non-commercial interests, its subsurface and surface stratigraphy have become a relatively well understood aspect of a classic study area (e.g., King, 1942, 1948; Adams, 1944, Newell et al., 1953; McKee et al., 1967a, 1967b; Anderson et al., 1972; Brokaw et al., 1972; Jones, 1973).

Even so, problems in stratigraphic nomenclature still abound, particularly with regard to the more deeply buried basin sediments of the Lower Permian within the Delaware Basin.

Permian rocks are divided into four series (Adams et al., 1939), two of which (Wolfcampian and Leonardian) are equated with Lower Permian time and two (Guadalupian and Ochoan) with Upper Permian. The well-known massive reef deposits bordering the Delaware Basin were built up mainly during Guadalupian time; massive evaporite deposits were formed only during Ochoan time, between 225 and 250 million years b.p. (before present). Regional correlations of the Permian are shown in Figure 3.3-3.

1) Wolfcampian Series

"Apparently sedimentation in the Permian Basin was continuous from Pennsylvanian time throughout Wolfcampian" (Meyer, 1966, p. 1); "major tectonic elements of Early Permian time in west Texas and southeastern New Mexico were inherited from the Pennsylvanian and continued to grow" (Oriel et al., 1967, p. 37). These regional generalities suggest the difficulty that has been experienced, at least basinward from shelves, in identifying the base of the Wolfcamp strata. An arbitrary convention in exploration practice in the Delaware Basin is to use the top of the Strawn to mark the top of the Pennsylvanian. If any Pennsylvanian strata are present above the Strawn, they are very similar to the overlying Wolfcampian Series and attempts have not normally been made to distinguish the two in the subsurface.

In the site area, the Strawn is overlain by a thick sequence of interbedded, dark-colored limestone and shale, including considerable dolomite. Sandstone is insignificant. No formational status has yet been designated for this interval; informally the sequence is sometimes called "Wolfcamp formation". It is known to markedly thicken southward with increasing shale and sand content toward the Val Verde trough, where extremely thick Wolfcampian strata are known. Toward the north, it thins and gains limestone content, suggesting a shelf margin facies. Foster (1974) indicates that at the WIPP site the shale content probably nearly

equals that of the carbonate. Isopachs presented in Foster (1974) indicate slightly less than 1,400 feet of Wolfcampian strata beneath the site, whereas Meyer (1966) shows between 1,000 and 1,100 feet; the latter value excludes some rocks above the Strawn. A regional map by McKee et al., (1967a) appears to indicate nearly 2,000 feet. The nearest "pick", in the Badger Unit Federal Well, indicates 1,493 feet of Wolfcampian strata, 2 miles northeast of the center of site (Sipes et al., 1976). These differing values reflect the uncertainties in identifying lower and upper limits of subsurface Wolfcampian strata in the Delaware Basin.

2) Leonardian Series.

The Leonardian series of the Lower Permian Series is represented by basinal sandy equivalents of the Bone Springs Limestone, which was originally defined for a shelf and bank facies of the unit at the margin of the Delaware Basin. Both the name "Bone Spring" and "Bone Springs" have been used in the past, and both usages are found in the current literature. Originally defined as Bone Springs by Blanchard and Davis (1929), King (1948, p. 13) changed it to Bone Spring "to agree with the geographic term" of the type locality, which "is in the lower course of Bone Canyon below Bone Spring..." The U.S.G.S. Lexicon (Keroher et al., 1966) also gives Bone Spring Limestone, but states that it is "named for Bone Springs Canyon...," citing Blanchard and Davis (1929).

Conditions favoring significant buildup of reef and bank limestone at the edge of the Delaware Basin existed in Leonardian time (Victorio Peak Limestone), but development of by far the most extensive of these limestones occurred subsequently in Guadalupian time. Within the basin in the vicinity of the WIPP site, the Bone Springs interval thickens markedly and consists of alternating units of sandstone and dark-colored limestone, with a thick, slightly cherty limestone at the top. Three laterally persistent, very fine to fine-grained sandstone units are recognized as the first, second, and third Bone Springs sands. Shale is a minor constituent of the Bone Springs strata, but the limestone beds are commonly argillaceous.

Foster (1974) shows the WIPP site to be near a local center of maximum thickness of Bone Springs strata, about 3,500 feet. The unit becomes thinner to the east and northeast. The Badger Unit Federal well is indicated to have penetrated 3,427 feet of Bone Springs rocks.

3) Guadalupian Series.

The Delaware Mountain Group includes all basin facies rocks of Guadalupian age in the Delaware Basin, which at the site are composed mostly of sandstones interbedded with some dark shales and a few thin-bedded limestones. A dramatic facies change takes place about 10 miles north of the site, where the basin facies terminates abruptly against massive reef limestones. Because these reef limestones almost completely encircle the Delaware Basin, they seem to conveniently demark the structural limits of the basin, although earlier basin sediments of the Delaware Group extend some distance beneath, or behind, the latest and most massive of the reefs, represented by the Capitan Limestone. North of the site, these reefs are buried by later sediments but become progressively less deeply buried toward the west; west of Carlsbad they surface and form a bold escarpment that defines the eastern boundary of the Guadalupe Mountains, for which the Guadalupian Series was named.

During their earlier development, the reefs at first built upward at the margin of the basin, but during later development progressed outward into the basin as well. Thus, successively older formations of the basin facies of the Delaware Mountain Group have greater areal extent beyond the Delaware Basin as defined by the uppermost part of the Capitan reef. Like modern reefs, the lateral development of these Guadalupian reefs was accompanied by an appreciable vertical buildup of material, in some cases exceeding 1,000 feet, such that sediments being contemporaneously deposited in the basin now appear structurally to be correspondingly lower in the section, where in actuality they are time-stratigraphic equivalents. By the same token, the evaporitic materials (Ochoan evaporites) that later filled the basin now appear to some extent to be laterally equivalent to the reef masses. These stratigraphic relationships are especially well portrayed by Haigler (1962) and King (1948).

A thickness of 3,944 feet of Delaware Mountain Group strata is recorded 2 miles northeast of the center of the WIPP site. Surface mapping at the margins of the basin led to the recognition there of three formations; namely, in ascending order, the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. Generally, petroleum exploration practice in the Delaware Basin has been not to attempt to define these formations in the subsurface. However, Foster (1974) provides a reference section showing stratigraphic positions of the formations of the Delaware Mountain Group in the Shell No. 1 James Ranch well about 3 miles southwest of the site, and Sipes et al. (1976) give similar "picks" in the Clayton W. Williams, Jr., well to the northeast of the area. Foster shows 3,970 feet of Delaware Mountain strata.

The Shell No. 1 James Ranch well lithologies indicate that the Brushy Canyon Formation is 1,540 feet thick and consists of mostly fine-grained, gray to brown sandstone with minor brown shale and dolomite. The Cherry Canyon Formation consists of 1,070 feet of sandstone similar to that in the Brushy Canyon Formation, interbedded with shale, dolomite, and some limestone. The Bell Canyon Formation, 1,180 feet thick, also consists mostly of fine-grained sandstone, but has a greater percentage of limestone, the result of closer proximity to the shelf-margin carbonates. A limestone member at the top of the Bell Canyon Formation, known as the Lamar limestone, is recognizable over a considerable part of the Delaware Basin. Basinwide the sands of all three formations are targets for hydrocarbon exploration. The top of the Delaware beneath the center of the site is contoured by Sipes et al. (1976) at minus 650 feet (depth 4,065 feet). It is overlain by evaporites of the Castile Formation.

4) <u>Ochoan Series</u>.

The Ochoan Series "includes perhaps the thickest and most extensive evaporite rock sequence in North America" (Oriel et al., 1967). It also contains, within the Salado Formation east of Carlsbad, extensive potash evaporite deposits which contain 65 percent of presently exploitable potash resources available within the United States (Jones, 1975).

All of the salt deposits and other evaporites of the Los Medanos area are restricted to the Ochoan rocks, of Late Permian age. The Ochoan rocks are entirely of marine origin, but have two unlike parts--a thick lower section of evaporite and a thin upper section of red beds (Jones, 1973). The lower section includes, in ascending order, the Castile, Salado, and Rustler Formations; the upper section is made up of the Dewey Lake Redbeds. Together the four formations have a maximum thickness of 3,600 feet, slightly more than 3,000 feet of which are evaporite beds of the lower three formations, which are composed dominantly of anhydrite and rock salt with minor amounts of gypsum, potassium evaporite minerals, carbonate rock, and fine-grained clastic material.

At the WIPP site, the Ochoan rocks are about 3,900 to 4,000 feet thick, of which 3,600 to 3,800 feet, or about 90 percent, are the evaporite sequence. Of the three evaporite formations, roughly one-half the total thickness belongs to the Salado. Both the underlying Castile and overlying Rustler are richer in anhydrite and poorer in rock salt than the Salado, and they provide this salt-rich formation with considerable protection from fluids which might be present in adjacent rocks (Jones, 1973). Jones (1972) provides lithologic percentages of the complete Ochoan evaporite sequence (Castile-Rustler), obtained from exploratory potash drilling, as follows: 59 percent halite and associated potash deposits; 33 percent anhydrite and gypsum, with glauberite and polyhalite; 6 percent carbonate rock (limestone, dolomite, magnesite) and 2 percent clastic rock (clays and silts).

Considered broadly, the evaporites represent a transitional zone between underlying reef and normal marine limestones (Guadalupian beds) and the overlying Dewey Lake which was deposited under brackish or restricted marine conditions (Jones, 1968). The floor of the Delaware Basin in early Ochoan time is generally estimated to have been at least 1,200 feet below the top of the Capitan reef, which almost completely encircled it, restricting southern access to the open sea and setting the stage for deposition of evaporites within the basin (Brokaw, et al., 1972).

Castile Formation

The Castile Formation is almost completely confined within the limits of the Delaware Basin (Oriel et al., 1967), the only evaporite formation so restricted. It gradationally overlies the Bell Canyon Formation (Brokaw et al., 1972).

Lithologically, the Castile is the least complex of the evaporite formations, being composed chiefly of anhydrite with a few interbeds of rock salt. Limestone is present in secondary amounts; clastic materials (siltstone, shale, sandstone) are notably absent. A lithologic summary by Jones (1972) lists 59 percent anhydrite and other sulfates, 30 percent halite and other chlorides, 11 percent limestone, dolomite, and magnesite, and no clastic rock for the Castile Formation, based on data from exploratory drilling. The rock is sparingly bituminous and yields a fetid odor. It has a faint to conspicuous lamination or banded structure involving a color change, a difference in texture, or a rhythmic alternation of bituminous calcite and anhydrite, bitumen and anhydrite, or anhydrite and halite in layers a fraction of a millimeter to a few centimeters thick. The color of the rock ranges from white to dark gray, becoming darker with increasing depth below the top of the formation (Jones, 1975).

In the subsurface, the Castile Formation, to use Jones' description, is readily divisible into three informal members by a salt-rich zone 200-400 feet above the base: a lower member composed chiefly of anhydrite, a middle member composed chiefly of rock salt, and an upper member composed chiefly of anhydrite. The three members are discrete, readily distinguished lithologic units that are laterally persistent over wide sections of the Delaware Basin. Near the margin of the basin, however, they merge into a single wedge-like mass of anhydrite that rapidly thins to a narrow tongue and extends across the basin margin for a few miles before thinning out in the southern part of the Northwestern Shelf.

As described by Jones (1973), the lower member of the Castile Formation is a well-stratified evaporite consisting of laminae of gray anhydrite and brownish-gray limestone in regular, rhythmic alternation. Some beds of laminated dark-gray and brownish-gray limestones, a few inches to several feet thick, are present at wide intervals in the lower and middle parts of the member, and there are a few thicker beds of massive gray anhydrite at long intervals. The member is 200-240 feet thick south of the site, but it thickens northward and reaches a thickness of at least 400 feet before merging with other members of the Castile to form a single unbroken mass of anhydrite adjacent to the Capitan reef mass.

The middle member of the Castile Formation, a salt-rich, tabular zone that forms a widespread, lithologically distinct stratigraphic marker, is 500-700 feet thick in the southern part of the Carlsbad potash area, but thickens northward and attains thicknesses of 800-1000 feet along a broad 2 to 3-mile-wide belt of deformation within the evaporite sequence paralleling the margin of the Delaware Basin (refer to Section 4.3.2.7). The member is predominantly rock salt, but it contains thin to thick layers of interlaminated anhydrite-limestone rock. The thickest of these layers averages about 100 feet, and it divides the member into two almost equally thick salt beds. The upper bed includes several interlaminated anhydrite-limestone layers, some of which are 2-5 feet thick, whereas the lower bed has none. This member terminates northward by grading laterally into, and intertonguing with, anhydrite.

The upper member of the Castile Formation exhibits greater lithologic complexity and is composed chiefly of anhydrite interlaminated and interbedded with calcitic limestone and, to a lesser extent, with massive anhydrite, rock salt, and carbonate rock, including both magnesite and dolomite. It contains a northward-thinning tongue of magnesitic anhydrite that overlaps the Capitan Limestone along the margin of the Delaware Basin and extends a few miles into the northwest shelf. Though 600-700 feet thick some distance south of the site, the upper member thins rapidly northward to as little as 170 feet near the margin of the basin. The nature of this northward reduction in thickness is, as

subsurface studies in the Carlsbad potash area and elsewhere in the Delaware Basin have shown, due both to a lateral gradation and to an intertonguing, or pinching out, of individual anhydrite beds at the top of the Castile into the rock-salt beds of the overlying Salado Formation, resulting in a northward stratigraphic descent of identifiable Castile anhydrite. These relationships demonstrate that the contact between the Castile Formation and the overlying Salado Formation is conformable and gradational; nevertheless, the contact at any particular location is generally rather sharply definable as the horizon at which dominant anhydrite below gives way to rock salt above.

A somewhat different classification scheme of the Castile Formation has been established by R.Y. Anderson and his co-workers. Working in the central and southern part of the basin with thin sections of cores obtained through special drilling arrangements made with industry operators, Anderson et al. (1972) divided the Castile into three separate halite members and four anhydrite members across the width of the Delaware Basin. Furthermore, they traced individual laminae in the anhydrite members over distances as great as 113 km. Each anhydrite-calcite couplet is believed to represent an annual varve, the nature of the evaporite precipitation being controlled by changes in the partial pressure of carbon dioxide in the Castile brine sea as the growth of brine algae waxed and waned with the seasons. Some 250,000 varve couplets are inferred, by representative counts, beginning below the Lamar limestone in the Bell Canyon and ending in the lower part of the Salado (Anderson et al., 1972).

Toward the northern part of the Delaware Basin, the upper halite and anhydrite units appear to converge and cannot be traced basinwide as major units. In the site area two lower anhydrite members (AI, AII) and two halite members (HI, HII) are recognized as basinwide equivalents of units identified elsewhere; a more heterogeneous upper unit, principally anhydrite, corresponds to the position of Anhydrite IV but may not be stratigraphically equivalent to it (Anderson et al., 1972; Anderson and Powers, 1978; Anderson, 1978). These anhydrite and halite members are

identified on Figure 4.3-2. Thicknesses are taken from isopach maps which appear in Anderson et al. (1972) and Anderson, (1978). Thus, the lower anhydrite (Anhydrite-I) member is indicated to be nearly 250 feet thick in the vicinity of the WIPP site; Halite-I, about 330 feet thick; Anhydrite-II, 100 feet thick; and Halite-II, 210 feet thick. The remainder of the total thickness of the formation is occupied by the upper anhydrite described by Jones (1973), as quoted above. Jones' middle halite unit is equivalent to Anderson's Halite-I plus Anhydrite-II plus Halite-II sequence; Anderson has simply subdivided the sequence based on the presence of a middle anhydrite member (Anhydrite-II) that Jones also recognized (see above). Both Jones and Anderson recognize that here the upper anhydrite unit does not display the varved interlaminations comparable to those observed in the lower anhydrite units.

The only major disagreement between Anderson and Jones appears to center around the nature of the Castile-Salado contact. Jones asserts that the contact is conformable and laterally intertongues (see discussion above), whereas Anderson believes an unconformity exists. Anderson (1978) cites as evidence for this the presence of some dissolution breccia near the top of the Castile, suggesting a period of non-deposition or even subaerial erosion. Furthermore, Halite-III is missing over the northern part of the basin, which could be explained by a local erosional episode there. Anderson also notes that the basal infra-Cowden salt of the Salado Formation (see below) does not occur to the south and is thickest wherever the Halite-III member is absent. This controversy has not been resolved to date; whether or not significant dissolution took place during deposition of the Castile and Salado evaporite sequence could have important implications regarding models invoked to estimate past and present rates of salt dissolution in the Delaware Basin.

Because no drill hole within Zones I-III of the WIPP site has made a complete penetration of the Castile, the thickness of the Castile beneath the repository must be estimated. Beneath the site, the base of the Castile is indicated by structure contours in Figure 10 of Jones (1972)

to be at an elevation of about minus 680 feet MSL at the center of the site; Sipes, et al. (1976) show it at minus 650 feet MSL. Since ERDA-9 intersected the top of Castile at elevation 579 feet above sea level, the Castile is indicated to be about 1,230-1,260 feet thick at the site, or approximately 1,250 feet thick. Drill hole AEC-8 encountered 1,333 feet of Castile in section 11, about 4 miles northeast of ERDA-9 (Griswold, 1977, Table III).

b) Salado Formation. The Salado Formation contains the thick salt beds in which the contemplated WIPP repository would be constructed. It is one of the principal deposits of halite on the North American continent (Brokaw, et al., 1972, p. 21), and it contains the Carlsbad potash enclave, the principal producer of potash in the United States.

As of the date of this report, one core hole, ERDA No. 9, has been drilled through the Salado at the location of the proposed repository. A schematic section of that hole, including general lithology, location of marker beds, position of halite zones in which the repository will be located, and well construction data, is given in Figure 4.3-3a. The detailed lithologic log is included as Figure 4.3-3b of this report. Details of the numerous down-hole logs performed, mineralogical and geochemical determinations made, and rock mechanics tests conducted are not discussed here but are given in Chapters 7 and 9 of this report, to which the reader is referred.

At the ERDA-9 location at the center of the site, the base of the Salado is 2824 feet and the top 848 feet below ground surface (elevations 590 and 2,566 feet above sea level, respectively), for a total thickness of 1,976 feet. The proposed contact handling (CH) zone halite interval, containing halite of relatively high purity, is between elevations 1,250 and 1,352 feet, and the remote handling (RH) zone, high-purity halite interval between elevations 696 and 806 feet. (Ground surface elevation at the ERDA-9 hole location is given as 3414.70 feet MSL).

Variations in the thickness of the Salado in the vicinity of the WIPP site are on the order of 300 feet (1,700 to 2,000 feet), based on results of the AEC and ERDA test holes (Griswold, 1977, Table III). Thicker sections of the Salado (over 2,300 feet) are known where it may have been affected by deformation due to salt flow. West of the site in the Nash Draw area the thickness of the formation locally and erratically decreases owing to local solution and removal of rock salt in the upper part of the formation (Vine, 1963; Jones, 1973). These variations are illustrated by a subregional isopach map of the Salado Formation presented by Brokaw et al. (1972).

As discussed by Brokaw et al. (1972),

> "In exposures of the Salado Formation along the west side of the Carlsbad potash area (10 or more miles west of the site), all the salt has been removed by solution and the anhydrite and polyhalite have been altered to gypsum. The alternation of the evaporite rocks extends to depths ranging from 260 feet to almost 1,600 feet below the surface and is responsible for a fourfold to sixfold reduction in the thickness of that part of the Salado and for a change in composition from dominantly rock salt in the subsurface to dominantly gypsum in the outcrop. The contact between the two highly dissimilar parts of the formation, known locally as the 'base of leached zone' and also as the 'top of salt', is highly irregular, with many closed depressions and isolated pinnacles. The contact dips generally eastward but rises in stratigraphic position from the base of the Salado near the west side of the potash area to the top of the formation near the Eddy-Lea County line at the east side of the area."

Figure 8 of Brokaw, et al. (1972) shows the location of the contact at the top of the Salado, or in other words the easternmost extent of dissolution in the Salado, to be located about 1 mile from the east edge of Range 30 E.; that is, about 2 miles west of the center of the WIPP. Additional discussion of solutioning is discussed in Section 6.3.7 of this report.

Broadly considered, the Salado is characterized by a predominance of rock salt compared to a predominance of anhydrite in the Castile and by typically thinner bedding or interbedding of lithologic units. Unlike the Castile, the Salado as well as the overlying Rustler extends over and beyond the confining Capitan reef masses to the north and east, in effect

overfilling the ancient basin formed by the reefs. The Salado sea was, in general, even more saline than the sea of Castile time. Lacking a shield of carbonate reefs, it received, however, considerable fine clastic sediment. Consequently, its halite deposits are generally less pure than those of the Castile (Brokaw et al., 1972), although thick intervals of highly pure halite are known in the lower half of the Salado Formation.

A detailed description of the overall lithology and member units has been provided by Jones (1973), who studied data from the numerous potash exploratory holes drilled in the Los Medanos area. The remainder of this section incorporates Jones' description, modified where appropriate by discussion of more recent data from ERDA-9.

The Salado Formation is composed of rock salt, anhydrite, and potassium rocks with varying amounts of other evaporites and fine-grained rocks. Rock salt constitutes about 85-90 percent of the formation except in the western part of the area where percolating ground water has dissolved and removed some of it. The next most abundant rock in the formation is anhydrite. The remainder of the formation is chiefly polyhalite and other potassium and magnesium-bearing minerals with minor amounts of sandstone, and claystone.

The rock salt in the Salado is composed of halite and clayey halite in discrete layers ranging from an inch to several feet in thickness. The two rock types differ primarily in that the halite is free of detrital debris and the clayey halite characteristically contains this debris in significant but typically small amounts. The detritus is chiefly quartz and clay, including illite, chlorite, and a corrensite-type of swelling, regular mixed-layered clay mineral (Grim et al., 1960). In general, the detritus-bearing clayey halite is mostly brown and tan; it is moderately crystalline but somewhat porous with a scattering of small cavities or vugs filled with clay and other detritus, and it either lies between seams of claystone or has a layer of halite below and a seam of claystone

above. The halite is typically reddish orange but its color grades to amber, gray, and white. It is generally somewhat more coarsely crystalline than the clayey halite.

Common to both the halite and the clayey halite in the rock salt of the Salado are traces to very minor amounts of polyhalite and anhydrite. Locally, glauberite is present in small amounts, and there are several potassium and magnesium minerals, including sylvite, carnallite, kieserite, and several other exotic evaporite minerals that occur in small to large amounts in seams of rock salt in the middle and upper parts of the formation. Other constituents of the halite and clayey halite include traces to very minor amounts of brine and gas that fill microscopic to very small cubic and rectangular cavities in grains of halite and other evaporite minerals. Less common, but more notable in other respects, are much larger cavities or pockets that contain halite-saturated brine and nitrogenous gas confined under presure sufficient to produce "blow-outs" when encountered during drilling operations.

The seams of anhydrite and polyhalite, which alternate with rock salt in all sections of the Salado, are very persistent but highly variable in composition (Jones, 1954; Jones, 1972). Lateral replacement of anhydrite by polyhalite is common, and nearly all seams show one or more stages of replacement between an initial slight development of polyhalite in the lower and upper parts of the seam to complete replacement of anhydrite by polyhalite. Locally, anhydrite and polyhalite give way laterally to glauberite, and polyhalite in the middle and upper parts of the Salado is replaced by hartsalz consisting of a coarsely crystalline mixture of anhydrite, kieserite, and carnallite.

Close examination of the Salado in drill cores and geophysical logs of boreholes in the Los Medanos area and vicinity reveals that rock sequences show a regular order of succession. A typical sequence, repeated many times between the base and top of the formation, involves a change from claystone upward through anhydrite or polyhalite and halite

to clayey halite capped by claystone. In other sequences the change is from halite to clayey halite capped by claystone. Boundaries between individual members of a rock sequence are gradational, but those along the lower and upper sides of the individual sequences are corrosion surfaces that form sharp, clear-cut breaks in the evaporite section but, nevertheless, are laterally persistent and convergent northward. The rock sequences represent a fundamental sedimentation unit or evaporite cycle, and they are believed to record discrete periods of influx and subsequent precipitation of calcium sulfate and soldium chloride during evaporation of sea water or an initially dilute brine. The ubiquitous claystone is thought to be a residue concentrated during dissolution of clayey halite by inflowing sea water or dilute brine.

The Salado Formation is divided into three members (Figure 4.3-3), but more subtle divisions can be made, for the beds are very persistent. In fact, the persistence of individual beds is the prime basis for the system of numbering individual seams of anhydrite and polyhalite which was introduced by geologists of the United States Geological Survey (USGS), such as Jones (1960) and is widely used by mining companies in the Carlsbad potash field. The numbers used in the USGS system to designate some seams of anhydrite and polyhalite in selected parts of the three members of the Salado are shown on Figure 4.3-3, and on Figures 4 and 6 of Jones (1973).

The threefold division of the Salado used herein includes: an unnamed lower member, a middle member known locally as the McNutt potash zone, and an unnamed upper member. The three members are about equally rich in rock salt, anhydrite, polyhalite, and fine-grained clastic rocks, and they are generally similar in all but one major respect. The lower and upper members are generally lacking or poor in sylvite, carnallite, and other potassium- and magnesium-bearing minerals, while the McNutt potash zone is generally rich in these minerals and accounts for the large and extensive deposits in the potash field.

Lower Member. Located below Marker Bed 126, the lower member of the Salado is the rock unit in which it is proposed to place both levels of the repository. As shown in Figure 4.3-3, the CH-zone is defined as the interval between Marker Beds 137 and 139 near the middle of the lower member, 560 feet above the base of the Salado. The RH-zone is in a zone devoid of nearby polyhalite marker beds, beneath a prominent anhydrite bed known as the "Cowden anhydrite." The top of the RH-zone is 344 feet below the base of the CH-zone; its base is 106 feet above the base of the Salado. The choice of zone intervals was made on the basis of combined purity, depth, thickness, mutual separation, and depth below the potash zone (Griswold, 1977).

The Cowden anhydrite identified above forms a distinctive, areally extensive bed of anhydrite about 20 feet thick below which is a salt bed of exceptional purity. This thick salt bed lying below the Cowden and above the Castile-Salado contact is sometimes referred to as the "Infra-Cowden", a sub-member located at the base of the Salado as shown in Figure 4.3-3. It is 296 feet thick at ERDA-9.

Lithologic details of each of the three members in the site area are provided by Jones (1973). The lower member of the Salado Formation is almost entirely made up of alternating thick seams of rock salt and thinner seams of anhydrite and polyhalite. Magnesite in thin bands, laminae, and ragged knots form a carbonate-rich zone in the lower part of most anhydrite and polyhalite seams. Seams and partings of claystone underlie the anhydrite and polyhalite seams, and claystone caps layers of clayey halite in the rock salt. There are also a few beds of very-fine-grained halitic sandstone, a few inches to a foot or so thick, near the base and top of the member. Insofar as has been determined by drilling, the member is completely free of carnallite and other hydrous potassium and magnesium evaporite minerals in all parts of the Los Medanos area, but the upper part contains traces to small amounts of these minerals several miles to the north of the area.

The lower member is 1,195 feet thick as recorded in ERDA-9. The member thins to 430 feet near the northeast corner of the area; in this instance the decrease of thickness seems to be due to beds missing at the corrosion surfaces that truncate individual rock sequences, as well as to thinning of all beds northeastward. Southward, the lower 240-300 feet of the member (that is, the Infra-Cowden) grades, according to Jones (1973), by intertonguing into the upper part of the Castile Formation, and the thickness of the member decreases to between 785 and 950. Anderson (1978) disagrees with the concept of an intertonguing lithofacies relationship between the Infra-Cowden salt and Castile anhydrite. He asserts that the Infra-Cowden wedges out southward and that the top of the Castile is unconformable with the Salado because of dissolution at or near the top of Castile prior to Salado deposition (refer to discussion above). Anderson (1978) presents an isopach map showing distribution of Infra-Cowden salt across the northern part of the Delaware Basin.

McNutt Potash Zone. The McNutt potash zone, located between the Vaca Triste halitic sandstone and the 126-marker bed, is another salt-rich member of the Salado Formation. However, unlike other members of the Salado, the McNutt may contain potassic rocks rich in sylvite, langbeinite, and hydrous evaporite minerals. The potassic rocks occur at short to long intervals in seams of rock salt scattered through nearly all parts of the McNutt zone. They are the obvious lithologic feature by which the NcNutt is distinguished, yet they are absent locally and, at best, probably comprise only 3 to 5 percent of the member in the most potassium-rich sections of the Los Medanos area.

Apart from the potassic rocks, the McNutt presents virtually the same aspect as other members of the Salado. Thick seams of rock salt alternate with thinner seams of anhydrite and polyhalite. There are partings of claystone beneath most anhydrite and

polyhalite seams and above layers of clayey halite. A bed of very-fine-grained halitic sandstone, the Vaca Triste, a foot or so thick, occurs in clayey halite at the top of the member.

The McNutt potash zone is 369 feet thick at ERDA-9, decreasing in thickness to the northeast. This decrease is similar in nature to that observed for the lower member. As a rule, where the member is thinnest it seems to be more thinly bedded and to have fewer beds.

Upper member. The upper member of the Salado, located above the Vaca Triste marker, consists of rock salt, minor anhydrite and polyhalite, and two persistent beds of very-fine-grained halitic sandstone, which are, respectively, 30-40 feet and 110-115 feet below the top of the unit. Claystone underlies seams of anhydrite and polyhalite, and coats the upper surfaces of clayey halite layers in the rock salt. Most parts of the upper member are generally free of hydrous evaporite minerals, but, nevertheless, some intervals of rock salt and other rocks in the upper 130 to 180 feet of the unit commonly contain traces to very small amounts of carnallite and kieserite.

Of particular interest is the occurrence of carnallite at the top of the upper member. The carnallite forms a major deposit of potassic rock that extends over a wide section in the northern part of the Los Medanos area and much of the region immediately to the north. The deposit is the only one known to occur in the upper member of the Salado, but is not restricted to the unit. It extends irregularly upward into sandstone of the overlying Rustler Formation.

At the WIPP site, the upper member of the Salado Formation is 512 feet thick (ERDA-9), becoming thinner (between 430 to 480 feet) farther north. This thinning northward seems to be partly depositional and partly erosional, for the member is more thinly bedded in the north and contains fewer beds. Many seams of anhydrite, polyhalite, and other evaporites are only about

three-fourths as thick as at the south end of the area. Beds of halite and clayey halite are missing beneath many of the corrosion surfaces that separate rock sequences in the unit.

Several miles west of the site in the Nash Draw area, variations in thickness of the upper member are fairly complex and large. The complexity and thickness of the member are believed to reflect a combination of geologic factors involving mostly (1) gradual thinning northward in response to changes in deposition patterns during the Ochoan Epoch, and (2) rapid thinning westward in response to change in dissolution patterns during the Pleistocene and earlier parts of the Cenozoic Era. In contrast to the modest northward thinning, the westward thinning of the member toward Nash Draw involves as much as a fourfold reduction in thickness in a distance of 4 to 6 miles, and the member is as thin as 150 to 170 feet at places along the west side of the area. This small thickness is considered to include the residue or remnants of at least a 450- to 500-foot-thick section of rock from which soluble salts have been leached by percolating ground water. The section of rock from which salts have been leached decreases in thickness eastward and feathers out in the area immediately east of Nash Draw. Insofar as can be determined from drilling records, the feather-edge of the residual materials marks the easternmost extent of dissolution of the upper member of the Salado Formation at any time. Apparently the regime here is highly stabilized and of long duration, with very little or practically no dissolution since the Pleistocene, or perhaps earlier. Estimates prepared by Bachman and Johnson (1973) indicate that the rate of salt removal during dissolution may amount to as much as 0.5 foot per 1,000 years. This rate suggests that roughly 1 million years would be required to reduce 450 to 500 feet of the upper member to an insoluble residual debris, and that dissolution in the western part of Los Medanos area has a long history extending back at least as far as mid-Pleistocene time. Other considerations, however, suggest that its history is even longer and may have begun by the mid-Tertiary (Bachman, 1976).

In all parts of the Los Medanos area, where the upper member of the Salado is thinned by dissolution, the section of rock between the upper surface of salt and the upper surface of the formation is composed of clay with crudely interlayered seams of broken and shattered gypsum and fine-grained sandstone. The clay is considered to be a subsurface residue concentrated through dissolution of clayey halite and other clay-bearing evaporites by percolating ground water. The gypsum is clearly the hydrated remnant of anhydrite and polyhalite seams, for it commonly contains ragged and embayed masses of anhydrite and polyhalite, and also grades laterally into anhydrite and polyhalite. The clay, gypsum, and sandstone comprise a fairly distinct residual unit that thins out eastward by grading into, and intertonguing with, rock salt and the other precursory rocks from which it originated. The residual unit thickens westward and crops out locally along the Pecos River west of the Los Medanos area. The unit is generally assigned by geologists mapping areas along the Pecos River to the lower member of the Rustler Formation, but this practice should be discontinued, for the clayey residue is clearly part of the Salado Formation.

Isopach maps of intervals in the upper member and in the McNutt potash zone are shown in Figures 4.3-4 through 4.3-7 referenced to the marker beds indicated. The same gradual northward decrease in thickness at the rate of about 10 to 15 feet per mile is exhibited by all four intervals contoured. It is significant that pronounced westward thinning of the Salado, which would be related to dissolution of salt from the Salado toward the Nash Draw area, is evidenced only in the uppermost interval (figure 4.3-7), and then only in Range 31 E., a mile or more west of the proposed WIPP repository boundary. The onset of westward thinning of the Salado Formation as defined by these isopach countours delimits a "suberosion" front at the top of the Salado (Griswold, 1977; Brokaw, et al., 1972; Jones, 1973) or the leading edge of a wedge of dissolution in the Salado progressing from west to east. This indicates that, insofar as can be detected by isopach patterns,

leaching of salt at the top of the Salado Formation by dissolution activity centered in the Nash Draw area has not occurred closer than approximately 1 mile west of the proposed WIPP repository.

In the Los Medanos area, the Salado Formation is overlain conformably by the Rustler Formation. The contact between the two formations is rather sharply defined as the horizon at which dominant rock salt below gives way to a 35- to 55-foot-thick unit of fine-grained sandstone that is generally dolomitic in the basal few feet.

Rustler Formation. The Rustler Formation, the uppermost or last of the three Ochoan evaporite formations, contains the least quantity of rock salt and the largest proportion of clastic material in this evaporite sequence. It was deposited in the last stages of the saline Permian sea that inundated the Delaware Basin, and is very largely coextensive with the Salado in this area (Brokaw et al., 1972). Jones (1972) lists lithologic percentages in the Rustler, presumably from areas in the Delaware Basin where Rustler salt has not been leached, as follows: 43 percent rock salt and other halides, 30 percent anhydrite, polyhalite, gypsum, and other sulfates, 17 percent clastic rocks, and 10 percent dolomite, limestone, and magnesite.

Shallowest of the evaporites to be exposed in the site area, the Rustler Formation crops out locally about 5 miles west of the center of the site, beyond the Livingston Ridge escarpment which forms the east edge of Nash Draw (refer to Figure 4.2-4, Surficial Geologic Map) Generally it is covered by alluvial material, sand dunes, or collapse debris.

The following descriptions of the Rustler are given by Jones (1973). As typically exposed in outcrop, the Rustler is a broken and somewhat jumbled mass of gypsum with minor dolomite and a few crude seams of virtually unconsolidated sands and clays. The outcrops in Nash Draw are decidedly poor for any study that requires precise information on the lithology, thickness, or specific chemical or physical properties of the

formation, and, as previously noted by Vine (1963), it is impossible to piece together a meaningful stratigraphic section from study or mapping of outcrops. Exposed rocks are porous, friable, and loose-textured, and all are strongly jointed, cavernous, and locally brecciated. Stratification is obscured or completely obliterated, and the attitude of bedding can rarely be determined with any degreee of confidence. The considerable deformation attests to the removal of much soluble material by percolating ground water and to the altered nature of the debris exposed in outcrop.

Two areally persistent beds of dolomite in the Rustler serve as important marker beds. The lowermost of the two dolomite beds, normally 100-150 feet above the base of the formation, is known as the Culebra Dolomite member. The upper bed, 200-250 feet above the base, is the Magenta Dolomite member. They were named and described by Adams (1944). Clastic rocks, consisting of thin to thick beds of sandstone and claystone, make up the remainder of the less soluble part of the formation.

In the subsurface, proceeding eastward across the WIPP site and into Lea County, all the gypsum in the Rustler gives way to anhydrite and minor polyhalite, and the sands and clays grade into sandy and clayey rock salt. In western Lea County at depths of 900-1,000 feet, the Rustler is largely an alternation of thick seams of rock salt and anydrite. A persistent seam of polyhalite occurs near the middle of the formation, and, insofar as has been determined, it is the only hydrous evaporite rock of any great extent or major importance in the stratigraphy of the formation.

With the eastward, down-dip change in composition from gypsum to anhydrite and rock salt, the thickness of the Rustler also changes rather significantly. The thickness ranges between 280 and 300 feet near the Nash Draw outcrop , but increases eastward to 490 feet about 10 miles southeast of the site and to 385 feet about 10 miles to the northeast. The increase ranges in amount between 105 and 160 feet and provides a crude measure of the minimum thickness of rock salt that is missing in

the area of outcrop. The difference in formation thickness between the southeast and northeast corners of the area is probably depositional in origin, for the formation is more thickly bedded in the southeast where it is thickest (Jones, 1973). These relationships are shown on a Rustler isopach map in Brokaw, et al. (1972).

In the immediate site area, the Rustler is lithologically divisible into a sandy lower part and an anhydritic upper part (Jones, 1975). The sandy lower part, 92 to 125 feet thick, is dominantly very fine-grained, silty sandstone, with less abundant anhydrite and rock salt; the sandstone is halitic and light to dark gray in its lower section and reddish brown and salt-free in its upper section. The anhydritic upper part of the formation, 200 to 227 feet thick, is largely gray anhydrite, with a few interbeds of reddish-brown clay and gray dolomite. The anhydrite is in fairly massive beds which have gypsiferous rinds along their lower and upper sides.

At the proposed WIPP site, ERDA-9 encountered 310 feet of Rustler commencing at a depth of 550 feet (refer to Figure 4.3-3). The Culebra and Magenta members were both encountered and measured at 26 and 24 feet thick, respectively. The thickness of the formation as a whole would indicate that much of the halite originally contained in the formation has been leached away, particularly in the upper part of the formation. The detailed well record of ERDA-9 (Griswold, 1977) shows that clayey halite was encountered in the Rustler below the Culebra dolomite, about 100 feet above the base of the formation. Between this position downward to the proposed upper level CH-storage zone, over 1300 feet of undisturbed evaporite rock, primarily Salado rock salt, intervene.

An isopach map of the Rustler Formation is shown in Figure 4.3-8. The closely spaced contours at the east edge of the site are a measure of the increasing amount of salt remaining in the Rustler in the eastward direction. The formation increases in thickness eastward and southeastward by about 180 feet over a distance of about 2.7 miles, or over 65 feet per mile. As with the Salado Formation, these contours can be used to postulate a dissolution front in the Rustler.

The Rustler Formation is separated from the overlying Dewey Lake Redbeds by a sharp lithologic break, an abrupt change from gray anhydrite to reddish-brown mudstone. The anhydrite below the break is free of sand and clay, and it ranges erratically in thickness from 18 to 32 feet. There is no indication of northward thinning, such as that common to most, if not all, rock units in the Rustler and underlying Salado Formations, and it would appear that the contact between the Rustler and Dewey Lake is an unconformity. The discordance and hiatus is probably not very great.

Dewey Lake Redbeds. The Dewey Lake Redbeds are the uppermost of the Late Permian Ochoan Series of formations and represent as well the top of the Paleozoic in the Delaware Basin. The term "Dewey Lake" is synonymous with the term "Pierce Canyon" originally proposed by Lang (1935) and applied to the redbeds in the Nash Draw area by Vine (1963). Actually the assignment of the Dewey Lake to the Permian Ochoan sequence is somewhat arbitrary, being based on certain lithologic details and stratigraphic aspects, rather than any definitely demonstrable affinity. Like the underlying Ochoan evaporites, the Dewey Lake appears to lack fossils despite its marine origin. Bachman (in Jones, 1973), while acknowledging the customary age assignment of the formation, nevertheless feels "that the Dewey Lake of southeastern New Mexico may actually be Triassic in age." He does not state, however, whether he believes it might be of Early or Late Triassic age.

The Dewey Lake crops out in places along the west edge of Nash Draw where partial thicknesses are exposed (refer to Surficial Geologic Map, Figure 4.2-4), but generally the formation is mantled by dune sand and caliche. Beneath the surficial cover, however, the Dewey Lake occupies a broad band between the center of the WIPP site and Nash Draw. It is bounded on the west by gypsiferous residue of the uppermost anhydrite seam in the Rustler Formation and on the east by coarse-grained clastic rocks of the Santa Rosa Sandstone of Late Triassic age. The latter contact occurs approximately across the center of the WIPP site.

The Dewey Lake is differentiated from other formations by its lithology, distinctive reddish-orange to reddish-brown color, and sedimentary structures. The formation consists almost entirely of an alternation of siltstone and very-fine-grained sandstone beds a few inches to several feet thick, but there are a few beds of claystone in its lower and upper parts. Individual beds are persistent, and the formation is readily separable on well log records into several sequences alternately richer or poorer in sandstone. Surficially, most rock is evenly and thinly bedded, liberally sprinkled with greenish-gray spots, and irregularly intruded by horizontal and criss-crossing veins of fibrous selenite. Some beds are structureless, whereas others are either horizontally laminated or cross-laminated. Many bedding surfaces carry shallow current or oscillation ripple marks. Silt-filled mud cracks occur at the top of many mudstone layers, and there are small chips and flattened pellets of mudstone in the basal part of many siltstone and sandstone layers (Jones, 1975).

According to Vine (1963), the Dewey Lake Redbeds represent the beginning of continuous deposition of detrital sediment following the long period of predominantly evaporite deposition in the Delaware Basin and adjacent shelf areas of southeastern New Mexico. However, the abrupt change in lithology does not necessarily signify a sudden tectonic or eustatic movement, but only a gradual decrease in the salinity or depth of the water plus a new source for the detrital sediments which were deposited.

Certain general features of the Dewey Lake are especially noteworthy. The lithology and color appear to be remarkably uniform. Viewed from the distance of a few feet, the stratification nearly always appears to be parallel, even though small-scale cross-lamination may be seen on close inspection. The small grain size, together with the minute scale of primary sedimentary structures, such as cross-lamination in sets less than 1 cm thick and oscillation ripple marks less than 1 inch from crest to crest, suggests that the silt was deposited in extremely shallow water extending over a broad flat. Lenses of medium-scale, cross-laminated, fine-grained sandstone or siltstone in the upper part of the Dewey Lake

probably indicate a gradual change toward fluvial deposition near the end of Dewey Lake time. The deposit undoubtedly blanketed the Delaware Basin and part of the shelf area to the north, but the source of the sediment is unknown.

The ERDA-9 well records a thickness of 487 feet of Dewey Lake strata. The thickness varies greatly across the area, however, from about 550 feet a few miles southeast of the site to 100 feet a few miles to the southwest (refer to isopach map, Figure 4.3-9). Normally in this area, the Dewey Lake ranges betwen 500 and 560 feet in thickness, thinning to the northwest. This northwestward thinning is attributed to pre-Late Triassic erosion after the redbeds had been tilted southeastward (Jones, 1973, p. 25). Locally, however, where the Dewey Lake forms the surface of either pre-late Tertiary terrain or Quaternary terrain, erosion later than Triassic has cut through the Dewey Lake, producing the steepened isopach gradients. In Figure 4.3-9 the gradients of 20 to 40 feet per mile observable in the eastern half of the map reflect pre-Late Triassic erosional thinning, while the steeper dips of up to 150 feet per mile to the west represent later dissection, apparently related to the origin and development of Nash Draw. A geologic section given by Jones (1973, Figure 3) illustrates the effect of this later dissection on the Dewey Lake surface.

4.3.3 Mesozoic Erathem

Triassic System. Triassic rocks in the northern part of the Delaware Basin are all Late Triassic in age and are included in the Dockum Group. The Dockum is entirely of continental origin and consists of the dominantly fine sediments of broad flood plains and coarse alluvial debris deposited over a very broad area extended beyond the borders of the Delaware Basin. It surfaces the pre-Tertiary terrane at and east of the WIPP site. Local subdivisions of the Dockum Group are the Santa Rosa Sandstone (Darton, 1922) and the Chinle Formation.

1) Santa Rosa Sandstone

The Santa Rosa Sandstone rests unconformably with sharp lithologic contact on the underlying Dewey Lake Redbeds. Vine (1963), based on outcrop observation, called this contact a disconformity (that is, parallel beds on either side of the contact representing a time-rock gap), but Jones (1973) considers it "an angular unconformity of low angle." Corresponding to an interval between the end of Permian time and the start of Late Triassic time, this unconformity represents a break in deposition perhaps longer than had previously occurred in the region since Mississippian time or even earlier, assuming the assignment of the Dewey Lake Redbeds to the Permian is valid.

At the site, the Santa Rosa occurs as an erosional wedge pinching out westward just beyond the center of the site; a thickness of only 9 feet of Santa Rosa Sandstone was recorded at ERDA-9. Eastward the formation forms the pre-Gatuna surface (See Figure 2 in Jones, 1973) but is blanketed by such an extensive veneer of Upper Tertiary alluvial deposits and caliche, and Recent dune sand, that the nearest extensive outcrops occur about 7 miles to the north (Vine, 1963).

The wedge of Santa Rosa thickens relatively rapidly eastward at the rate of up to 150 feet per mile, attaining a maximum thickness of 250 feet over a distance of only two or three miles, thereafter maintaining a more uniform profile (refer to isopach map of the Santa Rosa, Figure 4.3-10). Sections compiled by Jones (1973) indicate a relatively uniform thickness of the Santa Rosa on the order of 250 feet at least as far as several miles east of the Lea County boundary. The steepened wedge effect of the Santa Rosa across the site area is undoubtedly due to the post-Late Triassic, pre-Gatuna erosion that cut downward into the Dewey Lake surface, which is discussed above (compare Figure 4.3-9).

The Santa Rosa Sandstone consists, for the most part, of cross-stratified, medium- to coarse-grained, gray to yellow-brown sandstone, but includes both conglomerate and reddish-brown mudstone. In

outcrop it has been observed by Vine (1963) to consist of large-scale, trough-type, cross-bedded, pale-red sandstone and conglomerate lenses, 3 to 15 feet thick, separated by thin partings of moderate reddish-brown siltstone and silty claystone. The conglomerate lenses contain both silty dolomite pebbles and chert or quartz pebbles. The sandstone is characteristically poorly sorted. The formation differs from the underlying Dewey Lake Redbeds by being coarser grained, less well sorted, and by having beds that are thicker and more lenticular. Fossil plant impressions, carbonaceous plant fragments, and fossil reptile bones and teeth thought to be from phytosaurs characterize some of the beds. Clay is a relatively minor constitutent in most of the Santa Rosa Sandstone. Secondary dolomite is the most abundant cement, and it probably constitutes at least 10 percent of the rock.

The Santa Rosa Sandstone represents a change in the environment of deposition as compared with the Dewey Lake Redbeds. The large-scale trough-type crossbedding probably indicates a fluvial environment. The lack of sorting, arkosic composition, and angularity of the grains suggests rapid deposition by streams descending from a predominantly crystalline terrain (Vine, 1963).

2) <u>Chinle Formation</u>

The Chinle Formation, though not present at the WIPP site itself, occurs at about the Lea County line 5 miles to the east, where it forms the subcrop surface of pre-Tertiary rock, as shown by Jones (1973). Like the Santa Rosa Sandstone at the site, in profile the Chinle is seen to wedge out from the east at the Lea County line, beveled by pre-Gatuna erosion. Farther east, the Chinle appears not to attain a thickness in excess of 100 feet as shown by Jones (1973). Northward, however, it achieves a thickness of about 800 feet near the Hat Mesa gas field, about 11 miles northeast of the site, where the Chinle is blanketed by Late Tertiary Ogallala Formation (Jones, 1973). These relationships plus the areal distribution of Ogallala remnants indicate that post-Chinle, pre-Ogallala erosion occurred subsequent to an eastward to northward tilting of at

least the northern part of the Delaware Basin, resulting in a greater amount of Chinle sediments removed progressively southward and eastward. Later, one or more erosional episodes beveled a westward-sloping surface on post-Ogallala terrain.

In lithology, the Chinle is dominantly reddish-brown shaly mudstone interspersed with some greenish-gray mudstone and minor lenses of sandstone and conglomerate, deposited in a floodplain or alluvial environment basically similar to that of the Santa Rosa. Its contact with the underlying Santa Rosa Sandstone is conformable and is at the change from sandstone of the Santa Rosa to shaly mudstone of the Chinle. It is overlain unconformably by the Ogallala Formation of Late Tertiary age.

Post-Triassic Rocks of Mesozoic Age. No Mesozoic rocks later than the Chinle strata are known to exist in the WIPP site area. According to Jones (1973), there are good reasons to infer from paleogeology and other considerations that the Jurassic Period was a time of erosion and removal of the Dockum. Some rocks of Cretaceous age, though absent from the site area, almost certainly were deposited by Early Cretaceous seas which advanced northward across southeastern New Mexico. Small outliers, crevasse deposits, and other remnants of Lower Cretaceous rocks are found lying unconformably on the Capitan, Tansill, and Castile Formations near Carlsbad Caverns (Hayes, 1964; Lang, 1937), on the Salado Formation near Black River Village, on the Rustler Formation a few miles northeast of Carlsbad, New Mexico, and on the Chinle Formation at many places to the north and east of the WIPP site area (Ash and Clebsch, 1961).

4.3.4 Cenozoic Erathem

Tertiary System. No Early or Middle Tertiary sedimentary rocks are known to be present in the region. A lamprophyre dike, the only igneous rock later than Precambrian age known in the region, is observed to intrude the Salado Formation at the Kerr-McGee potash mine, about ten miles north of the center of the WIPP site (refer to Figure 3.5-2). Part of a

northeast-southwest dike trend of regional extent, the closest approach of which is at least eight miles northwest of the center of the site, the dike is not exposed at the surface east of the Pecos River. A radiometric date of 30 million years for the lamprophyre has been in the record for some time (Urry, 1936); an Oligocene or mid-Tertiary age for emplacement is therefore indicated. Further discussion of this dike trend, including an account of more recent investigations conducted, is included in Regional Geology, Section 3.5.1.

In Late Tertiary time extensive alluvial fans carried sandy and gravelly material eastward over a broad erosional plain that had developed in the region by Late Miocene time. The sediments accumulated during this alluviation, which lasted until Late Pliocene time, constitute the Ogallala Formation. The youngest fauna present in the Ogallala Formation is of Kimball age. This fauna may be as old as 4.6 million years (Bachman, 1974).

Only one area occupied by the Ogallala is present within 10 miles of the site, namely, a relatively thin erosional remnant capping The Divide located between 6 and 9 miles east-northeast of the center of the site (refer to Figure 4.2-4, Surficial Geologic Map). A geologic map by Bachman (in Jones, 1973) indicates that the Ogallala at the Divide is restricted to elevations above 3750 feet, where it is about 25 feet thick and includes about 10 feet of conglomeratic sandstone at the base overlain by about 15 feet of caliche. Pebbles of rounded quartzite and chert as much as 1-1/2 inches in diameter are present in lenticular beds (Bachman, 1974).

Special attention has been given to the caliche developed on the Ogallala by Bachman (in Jones, 1973), who suggests that it may be distinct in origin from caliche observed elsewhere in the area. Based on field examination, he finds that

> "Caliche of the Ogallala Formation is a distinctive travertine-like calcium carbonate. It is dense, light gray to white, and composed of concentrically laminated fragments that range from less than one-half inch to more than 2 inches in diameter. Space between

these fragments is filled with structureless or, in places, laminated limestone. The weathered surface appears algal or pisolitic in places. However, these concentric laminae probably are not the result of organic activity but indicate repeated generations of inorganic solution and reprecipitation. The caliche is sandy and has been precipitated in porous spaces between sand grains; therefore, individual sand grains appear to float in the caliche. The Ogallala caliche probably formed as a part of a soil profile that developed on the High Plains surface either during or after deposition of the Ogallala Formation."

In the High Plains to the east of The Divide, longitudinal depressions in the Ogallala caliche are interpreted to be interdunal swales caused by solution etching of Ogallala caliche where it was not protected by Pleistocene sand dunes (Bachman, 1976).

Quaternary System

1) Pleistocene Series

a) Gatuna Formation

The only Pleistocene deposit at the proposed WIPP site which has been assigned a formal stratigraphic name is the Gatuna Formation. In the immediate area, the Gatuna forms a thin blanket, locally absent, ranging in thickness from zero to slightly more than 30 feet (refer to Figure 4.3-11, Gatuna Isopach Map); at ERDA-9, 27 feet of Gatuna were recognized. In spite of its shallow depth below the surface, however, the Gatuna crops out only rarely, being for the most part obscured by a thin but persistent veneer of caliche and surficial sand. The nearest mapped outcrops occur along the west-facing slope of Livingston Ridge at the edge of Nash Draw (about four miles northwest of the center of the site; see Figure 4.2-4, Surficial Geologic Map) where they were mapped by Vine (1963), and to the southeast of the site as mapped by Bachman (1974). In Nash Draw itself the Gatuna locally exceeds 100 feet in thickness and fills sinkholes previously formed by dissolution of salt and other evaporites. It has alluviated most drainage valleys of an ancient Pecos system, of which Nash Draw was a part. Though the Gatuna is predominantly a fine-grained, reddish or brownish friable sandstone,

conglomerate lenses and blankets are common regionally. It is the pebbles in the conglomerate which have proved most useful in providing evidence relating to geologic history, age, and provenance of the formation.

Bachman (1974) discusses age, lithology, and paleoclimatic implications of the Gatuna at some length. Generally, the Gatuna was stream-laid under pluvial conditions. In some areas having fine-grained materials in the lower part of thicker sections, the Gatuna first filled collapsed basins and extensive sinks; in other areas, such as in the southern part of Nash Draw, gypsum-rich clays and silts in the section suggest deposition in areas then undergoing sinking and collapse. Based on examination of pebble clasts in Gatuna gravels of the Pecos River northwest of the site in Chaves and northern Eddy Counties (refer to Regional Geology and Regional Geomorphology sections for additional discussion of these gravels), Bachman concludes that the Gatuna was deposited in a much wetter climate than present. There is no indication that modern drainage is carrying clasts of the size and quantity preserved in Gatuna stream deposits. The discovery of Ogallala pisolitic debris (i.e., pebbles of Ogallala caprock caliche) in the Gatuna demonstrates that the Gatuna is Pleistocene rather than Pliocene in age. Futhermore, on the basis of the many stream and pond deposits in the Gatuna and the evidence for widespread solution and collapse, Gatuna time represents the most humid Pleistocene stage in southeastern New Mexico. Regional considerations lead Bachman to assign a tentative Kansan age to the Gatuna, or approximately an age of 600,000 years (Bachman, 1974).

b) Mescalero Caliche

Beneath an obscuring cover of wind-blown sand, much if not all of the site area, excluding some depressions and drainages such as Nash Draw, are covered by a hard, resistant caliche crust. It is very extensive to the north in Chaves County on the Mescalero plain between the Pecos River and the Llano Estacado and is informally called the Mescalero caliche. Though generally less than 10 feet thick in the site area, its resistance to weathering in the dry climate has effectively prevented natural

exposure of older strata and has allowed it to form extensive surfaces that can themselves be mapped in definite stratigraphic sequence with other deposits.

Vine (1963) provides a detailed account of caliche as he observed its occurrence in the Nash Draw quadrangle. He states,

> "Caliche is a near-surface accumulation of calcareous and clastic material that forms a resistant mantle. It is characterized by an excess of calcareous material over that required to cement the clastic grains, with the result that the grains appear to float in the matrix. In many areas the caliche is characteristically brecciated and recemented. In addition to sand and calcareous material, pebbles are locally abundant, and silica in the form of chalcedony or opal also forms part of the cementing matrix. Other soluble minerals, including gypsum, are probably locally present. Where the top surface of caliche has long been exposed to weathering, it almost invariably has a very hard dense limestone surface that could easily be misinterpreted as an outcrop of massive limestone similar to those in some older formations. Close inspection, however, generally reveals sand grains, chalcedony, and brecciation. Commonly the dense layer at the top is only 1 or 2 feet thick, and the rock becomes more friable and shows a greater proportion of sand grains to matrix within a few feet of the surface. The less calcareous zone in turn grades downward within 5 or 10 feet into the underlying bedrock, which generally is broken into angular fragments recemented with calcareous material. (Note: five feet of caliche were encountered at ERDA-9.) In many areas caliche has concentric lamination or colloform structure resembling calcareous algal structures. The widespread mantle of caliche has much the same composition throughout the area regardless of whether the underlying bedrock is red sandstone and siltstone from the Gatuna Formation, Santa Rosa Sandstone, and Pierce Canyon (=Dewey Lake) Redbeds, or gypsum from the Rustler Formation."

Bachman (1974) shows a regional structure contour map of the Mescalero caliche. He confirms Vine's recognition of an upper dense zone over an earthy-to-firm nodular calcareous deposit, and notes that it is the upper dense caprock that is prominently laminated. The character of the laminae indicates that the Mescalero caliche arose through successive cycles of dissolution and reprecipitation of the matrix, and that this occurred during an interval of tectonic stability that followed deposition of the Gatuna Formation--that is, in the semiarid environment that followed the moist conditions of Gatuna time. Based on regional geomorphic considerations, Bachman correlates the formation of the

Mescalero caliche with the Yarmouthian interglacial stage, or mid-Pleistocene time, about 500,000 years ago. Brown (1956) reached generally similar conclusions on the origin of caliche he studied on the Llano Estacado of the Texas panhandle, where he found that "the caliche, with interruptions, apparently has been forming continuously since its inception in the Pliocene, and its multiple occurrence is a reflection of climatic variations in the Pliocene and Pleistocene". Noting that the Mescalero caliche dips abruptly into Nash Draw along Livingston Ridge, Bachman (1974; also in Jones, 1973) concludes that Nash Draw was subjected to subsidence after the formation of the caliche, presumably during the more pluvial conditions of the subsequent Illinoian or Wisconsin glaciations.

2) Recent Deposits

Deposits of Recent age in the vicinity of the WIPP site include windblown sand, alluvium, and playa lake deposits.

The most prevalent deposit by far is the windblown sand which covers nearly all of the area of the WIPP site itself. The sand, locally known as the Mescalero sand (Vine, 1963), occurs either as a sheet deposit resting on caliche or as tracts of conspicuous dune fields (Los Medanos). In the former case, the sand is probably no more than 10 to 15 feet thick on the average; in the latter, the sand may attain 100 feet in thickness locally. At many places the sand consists of two parts: a compacted, slightly clayey moderate-brown eolian sand up to 1-1/2 feet thick, overlain by loose, windblown light-brown to light yellowish-gray sand. The sand dunes appear to be relatively inactive at present, partly stabilized by sparse plant cover. The widespread deposits of windblown sand are indicative of a large source of fine sand as well as of the extreme fluctuations of climate that have occurred during Pleistocene time. There is very little evidence that much sand has been derived from the Pecos River. Bachman (1974) suggests that most sand has been derived from deposits of the Ogallala Formation. During humid intervals in Pleistocene time the sand has been eroded from the Ogallala, and during arid intervals the wind has moved this sand across the Mescalero plain.

Deposits of alluvium are mapped by Vine (1963) generally in belts 1/4 to 3/4 of a mile wide along the base of declivities into Nash Draw, as along the base of Livingston Ridge, and locally in smaller depressions (refer to Figure 4.2-4, Surficial Geologic Map). These deposits are similar to sheet wash or small alluvial fans, and Vine considers them analogous to pediment or bolson deposits.

Playa deposits occur in mudflats, and consist of eolian sand and alluvium reworked by shallow-lake waters. Vine (1963) shows these areas clustered mostly within Nash Draw, where the occasional runoff accumulates. The nearest playas are mostly small, circular areas about 5 miles west of the center of the site filling in the bottoms of sinkhole depressions adjacent to Nash Draw.

4.4 SITE STRUCTURE AND TECTONICS

4.4.1 Tectonic and Structural Setting of Los Medanos Site

Relation of Site Structure to Regional Tectonics. The single dominating tectonic feature in the region around the proposed WIPP site is the Delaware Basin, the locus of unusually thick and rapid sedimentation in Permian time. Beneath the site, for example, about 15,000 feet of Pennsylvanian and Permian clastics, limy clastics, and evaporites accumulated. The basin was marginal to an orogenic belt located farther southwest (the Diablo Platform) which was tectonically active in Late Pennsylvanian and Permian time. The basin evolved by downwarp of Precambrian basement terrane of the Texas foreland, a granitic craton. South of the New Mexico border in Texas, the Delaware Basin in Late Pennsylvanian time was trough-like and received much of its sediment from a bordering mobile orogenic belt (Marathon system), in the manner of a molasse trough or exogeosyncline; in New Mexico, however, the northern part of the Delaware Basin received sediment from intracratonic highs located both to the west (Huapache flexure) and to the east (Central Basin Platform) and assumed more the character of an intracratonic basin in which subsidence was accomplished mainly by downwarping of the craton

without major marginal faulting and without subsequent folding or compressive tectonic deformation, although buried normal faults of fairly large displacement are known at the margins of the Central Basin Platform. The Central Basin Platform, located approximately along the New Mexico-Texas border east of the site, may be viewed as a medial, arched horst, now deeply buried by later sedimentary deposits, which separated and partly isolated the Delaware Basin from its eastern counterpart, the Midland Basin, during Late Pennsylvanian and Early Permian time; later in Permian time these basins constituted part of the broad Permian Basin (refer to Sections 3.4 and 3.6; see Figure 1 of Bachman and Johnson (1973) for the extent of the Permian salt basin).

In the Delaware Basin toward the close of Permian time, as much as 4,000 feet of evaporite beds, dominantly rock salt, accumulated, during which time differential subsidence ceased and stable cratonic conditions returned to the area. Later, Triassic redbeds mantled the region. In mid to late Tertiary time, rifting and tensional faulting occurred in the Basin and Range region of New Mexico as far east as the Sacramento and Delaware Mountain anticlinal structures west of the Delaware Basin, and southeast along the Diablo Platform to the Big Bend area of Texas, but did not occur within the Delaware Basin itself. The basin was, however, tilted gently one or more times between Late Triassic and Pliocene time, producing a general net eastward tilt of about 2 degrees. The Late Permian Ochoan rocks and the Triassic rocks exposed in the basin today do not reflect basinwide warping; the major structual feature of these deposits is merely the regional eastward slope produced after Triassic time (Bachman and Johnson, 1973).

Tectonic and Nontectonic Mechanisms at the Site. At the site, stresses associated with the origin and development of the Permian Delaware Basin have deformed the pre-existing rocks or contemporaneous sediments in different ways. Specifically, these stresses included the nontectonic downward pressure imposed by the weight of rapidly deposited sediment and the tectonic stress arising from within the earth's crust and transmitted through the basement rocks to the sedimentary pile. The tectonic stress

would have been most effectively imposed upon those rocks of the sedimentary pile that had already undergone lithification and were therefore mechanically coupled with the basement rocks. Stress imposed by sedimentary loading would have been most effectively absorbed by subjacent materials that were the least lithified and therefore the most compressible and capable of adjusting to differential sediment loads. Each mechanism would have produced different kinds of structures and caused different types of faulting in the rocks beneath the basin. The temperatures measured and heat flow calculated for AEC 8 (Mansure and Reiter, 1977) show evidence of normal geothermal gradients.

The presence of thick salt beds profoundly affects the type of deformation which occurs in the salt itself and which is imposed upon rocks and sediment lying above the salt, inasmuch as thick salt is known to deform plastically and to behave as a viscous medium over extended periods of time. This behavior is promoted by high overburden pressures and increased temperatures. Under favorable conditions, even slight tilting of the beds or lateral differences in lithostatic pressure are sufficient to initiate long-term viscous flow of salt. Salt deformation is therefore quite different in mechanism and manifestation than the deformation of the enclosing rock materials. As a result, deformational features exhibited by rocks and sediments lying above thick salt would normally be expected to have little or no mechanical relationship to structures in rocks occurring beneath the salt, because the intervening salt effectively decouples the two rock masses. Rocks overlying salt would be expected to display local structures that are generated by mass flow of salt. In addition, because shallow salt is susceptible to dissolution by unsaturated ground water, sediments above shallow salt where active solutioning had occurred could be expected to exhibit karst and collapse features, or to have internal irregularity and chaotic structure brought about by uneven subsidence or upward stoping following removal of significant thicknesses of salt in the subsurface. It should be emphasized, however, that at the WIPP site, evaporite dissolution has been restricted to salt beds of the Rustler Formation. No evidence has been obtained to date to indicate that this relatively small amount of dissolution of Rustler salt has resulted in significant differential

subsidence in the site area. In contrast, the potential for subsidence structures to occur has been realized in areas such as Nash Draw, where partial dissolution of Salado evaporite beds has taken place.

It is concluded on the basis of the preceding discussion that the nature of the origin and development of possible structural features in the rocks which occur in the Los Medanos area is spatially related to the position of these rocks in the geologic column relative to the position of thick bedded salt. Accordingly, the following description of geologic structure at the WIPP site is organized into separate discussions of deep structure (i.e., structure in rocks underlying Ochoan salt), salt deformation, and shallow structure.

4.4.2 Deep Structures

Subregional Structure of Pre-Evaporite Rocks. A variety of structure contour maps covering an area within about a 25-mile radius of the WIPP site has been prepared, generally from well data. Foster (1974) provides seven such subregional maps from top of Precambrian to top of Bell Canyon (base of Castile); Sipes et al. (1976) show somewhat more structural detail on top of Devonian, Morrow, Atokan, Strawn, and Delaware strata (their exhibits 11,10, 9, and 8, respectively, the first two of which incorporate seismic reflection profile interpretations). Netherland, Sewell and Associates (1974) present generalized structure contour maps of a slightly different area on eleven horizons, from Ellenburger to top of Bell Canyon (their Figures G-6 through G-16).

Structure contour maps express a homoclinal regional dip toward the southeast to east on all pre-Ochoan Paleozoic strata, reflecting the presence of the Delaware Basin downwarp. Gradients on all pre-Permian horizons are similar in magnitude and direction, decreasing from about 150 feet per mile southeasterly in the lower Paleozoic to about 100 feet per mile at the top of the Pennsylvanian. The nearest fault large enough to be indicated by subsurface well control is a north-trending fault shown by Foster (1974) about 15-20 miles east and southeast of the WIPP

site, and referred to as the "Bell Lake fault." It has a length of about 15 miles and a displacement of about 500 feet. Located west of the central axis of the Delaware Basin, it nevertheless appears to be structurally related by orientation and displacement (upthrown to the east) to the west-bounding fault of the Central Basin Platform farther east, as is shown on the regional structure contour map of Haigler and Cunningham (1972). The fault is not indicated to offset Permian strata (Foster, 1974), but contours of Wolfcamp and Bone Springs strata in the lower part of the Permian section are deflected in the area of the fault. Permian structure contour maps indicate a difference in gradient and direction of horizons compared to earlier strata. This indicates significant tectonic activity in the basin in Late Pennsylvanian and Early Permian time, which was the major period of structural adjustment in the Delaware Basin (Foster, 1974). Permian strata beneath the Ochoan Series slope east-southeast at about 50 feet per mile (Foster, 1974), markedly less than pre-Permian strata.

Site-Specific Interpretations. In the immediate site area seismic reflection data can be utilized as an adjunct to well control in preparing more detailed structure contour interpretations. Figures 4.4-1 thru 4.4-3 contour horizons at, respectively, the top of the Silurian (Siluro-Devonian carbonate, refer to Section 4.3.2), top of Morrow, and near the top of the Delaware. Seismic profile lines are indicated and well control points are shown. Structural interpretation of seismic reflection profiles has been furnished by G.J. Long and Associates, Inc. (1977). (Additional seismic profiling has been performed (G.J. Long, 1977b) or is presently being undertaken as part of a continuing program by Sandia Laboratories to delineate subsurface structures at the WIPP site. These additional data will be presented and discussed when the analyses are completed.)

In general, Figures 4.4-1 through 4.4-3 reveal the existence of minor faulting and secondary warping (swells and saddles) in Paleozoic strata below the evaporite beds. Comparing Figure 4.4-1 with 4.4-2, a pattern of generally north-northeast-trending faults has been interpreted,

oriented roughly parallel to regional strike and typically upthrown to the east. Small, subdued dome-like features and complementary saddles spaced several miles apart and with crest-to-trough amplitude of several hundred feet are superimposed on the regional gradient and appear to persist in position through both horizons. In the Silurian, for example, several small arches of up to 300 feet of relief are aligned in an east-southeast or west-northwest anticlinal trend passing just north of the Zone II exclusion area (Figure 4.4-1). In the Morrow a similar east-west trend in about the same location is defined by more subdued structural gradients and highs of lower amplitude (Figure 4.4-2). This trend is identified as the "Cabin Lake" trend by Netherland, Sewell and Assoc. (1974); see also Figure 2-7 of this report. On both horizons a domal feature is evident beyond the southwest edge of the site. This feature, which Netherland, Sewell (1974) indicate is at the east edge of the "Los Medanos" trend, is presumably responsible for the gas production of the Los Medanos field, the nearest hydrocarbon field to the site. Between these two anticlinal trends, a northwest-trending saddle is defined, located beneath the southwestern edge of the site.

The north-northeast-trending faults inferred in Figures 4.4-1 and 4.4-2 are, as interpreted from seismic reflection records, of greater intensity in the Devonian, being traceable over distances exceeding ten miles and having displacements of up to 400 feet (Figure 4.4-1). Faulting of the Morrow (Figure 4.4-2), some 2,500 feet higher stratigraphically, is roughly correlative with the deeper displacements, but seems to dissipate into discontinuous segments of generally smaller displacement.

Small-scale structures interpreted on the Delaware Mountain Group, roughly 9,500 feet above the Morrow horizon, show little or no correlation with deeper features (refer to Figure 4.4-3). The north-northeast-trending faulting is no longer apparent; instead, seismic reflection studies (G.J. Long, 1977a) indicate short (less than 5 miles in length), discontinuous northwest-trending offsets of small displacement (less than 50 feet) passing beneath the northeast half of the site; refer to Figure 4.4-3. The fact that the faults are not

detected at greater depths suggests a shallow-seated origin. Warping in the Delaware Mountain Group appears to be much more subdued than in the Morrow; structure contours lack closure around irregularities, and trends in the Delaware Mountain Group appear to be unrelated to Morrow and deeper trends. One feature of note shown (Figure 4.4-3) is a shallow, northwest-trending saddle of not more than 100 feet of structural relief, located beneath the center of the site; the presence of such structural lows is considered to be a favorable site selection criterion (refer to Section 2).

The contrasting structural characteristics between the Delaware and pre-Permian horizons suggest different origins. All strata from the Pennsylvanian on down have been deformed in continuity, with intensity of deformation increasing with depth. Tectonic deformation apparently occurred in Late Pennsylvanian or Early Permian time and established the local structural elements of all pre-Permian rocks. The "rootless" character of at least some of the normal faulting in the Permian suggests that these are shallow-seated features. Considering the unusually rapid rate of accumulation of material in Permian time (about 13,000 feet), it seems reasonable to presume a predisposition for the occurrence of contemporaneous sedimentary deformation brought about by such factors as gravity creep, compaction during diagenesis, differential sedimentary loading and rates of dewatering, and differential subsidence. Such deformation has been documented along "growth faults" in the Gulf Coast basin (Murray, 1961, p. 137; Fisher and McGowen, 1967, Figure 3; Bishop, 1973; Bruce, 1973). Contemporaneous faults of this type may have been initiated during deposition of thick pre-Ochoan clastic sequences. Conceivably, further movement might have been promoted by mass movement of salt subsequent to evaporite deposition, which shifted overburden loads over possibly still compressible sedimentary material.

Figures 4.4-4 and 4.4-5 show southwest-northeast and northwest-southeast sections, respectively, across the proposed WIPP site area, adapted from Griswold (1977). The overwhelming thickness of Permian pre-evaporite strata relative to earlier deposition is graphically displayed. Faults

arising in the basement offset Pennsylvanian strata but do not propagate through the lowest Permian series, the Wolfcampian. The regional dip of the Delaware Basin is most evident in Figure 4.4-5.

4.4.3 Salt Deformation

For the purpose of this discussion, detailed description of deformational features within the salt beneath the site and in the northern part of the Delaware Basin is restricted to consideration of structure displayed by the Castile and Salado Formations even though the Rustler is normally considered part of the evaporite sequence. At the site and in the vicinity of the site, the Rustler has been leached of much of its salt with the result that most of its structure is surficial in origin and is included in the discussion of site surficial structure, Section 4.4.4.

Of previous studies available in the literature on the northern part of the Delaware Basin, the papers by Brokaw et al. (1972), Anderson et al. (1972), Jones (1973) and Anderson (1978) are most relevant to salt deformation in the area of the proposed WIPP site.

Subregional Structure of Evaporite Beds. Throughout the northern Delaware Basin, the general uniformity in direction and amount of the gentle southeastward homoclinal dip is practically the only structural feature that is common to all levels of the evaporite section (Jones, 1973). Superimposed on this homocline is a rather complex system of flow features variably developed relative to both areal location and stratigraphic position, features attributable to mass migration of salt.

Features that are of subregional significance, and that appear to have a fundamental role in the development of salt deformation, include the Capitan reef front. It formed a steep, submarine prominence or wall 1,000 to 1,500 feet high isolating the deep water of the early Castile brine sea from the rest of the Permian inland sea (refer to Sections 4.3.2 and 3.6). Figure 10 of Jones (1973), a structure contour map on the base of the Castile Formation, graphically depicts the structural

relationship of reef and basin in the site area. Immediately basinward of these buried reef masses, which are located 8 miles north of the WIPP site, is a northwest-southeast-trending structural trough paralleling the base of the reef and descending in elevation, or plunging, southeastward. The most intense deformation in the evaporite sequence seems to be spatially related to this trough; not only is the trough expressed within the salt layers, but the top of the clastic Delaware Mountain Group (Bell Canyon Formation) is also depressed. Subregional geologic sections constructed by Jones across Nash Draw and Livingston Ridge (Brokaw, et al., 1972, Jones, 1973,) illustrate the general configuration of reef, trough, and deformation within the evaporite sequence in the site area. Jones' (1973) assessment of these particular features is pertinent:

> "At intermediate and other levels in the (evaporite) section, the structure is generally more uneven than at the base of the Castile Formation, and minor folds are somewhat more prominent. Salt and anhydrite in the middle member of the Castile are crumpled in sharp intraformational folds that appear to die out northwestward up the dip and to become more pronounced southeastward down the dip. Spatially the intraformational folding of the salt and anhydrite appears to be confined to a single long northwestwardly-trending belt, about 3-4 miles wide, that more or less coincides in trend and extent with the prominent southeastwardly plunging trough at the base of the Castile. The folding has resulted in some buckling and downwarping of rocks in the Salado Formation, and it has uplifted the Salado and other rocks as young as the Chinle Formation in a fairly broad arch that trends northwestward across the area. The exact age of the deformation is unknown; it can be dated only very broadly as post-Late Triassic to pre-Pliocene. Specific considerations concerning minimum thickness of overburden required to initiate salt movement suggest that the deformation may have occurred during or shortly after the period of regional tilting that followed the deposition of Cretaceous rocks. The deformation almost certainly had to occur before any great thickness of Cretaceous rocks was removed by erosion."

Subsequent studies by Anderson (1978) and Anderson and Powers (1978) have supplied some detail on the character of the salt deformation recognized by Jones. Apparently the only part of the Castile that has not been

involved in significant plastic flow deformation is the lower or basal anhydrite, Anhydrite I (refer to site stratigraphy, section 4.3.2 for discussion of Castile stratigraphy). On the other hand, the lowest thick Castile salt member, Halite I, has undergone severalfold increases in thickness in some areas. Anderson (1978) presents a basinwide isopach map of the lower Castile Halite-I unit which shows an increase of thickness from a normal value of about 300-350 feet, as occurs in the area of the proposed WIPP site, to a value of 1,200 feet at the ERDA-6 location 5 miles north-northeast of the site. The isopach lines at this location define an elongate, sharply thickened bulge of the Halite-I unit, the long axis of which is about 12 miles long and is oriented parallel to, and on the basin side of, the buried Capitan reef front. Anderson's isopach map also shows numerous similar, slightly smaller elongate bulges, their long axes all about 3-1/2 times the length of their shorter ones, contained within a belt about 5 miles wide paralleling the basin side of the reef front. Since the anhydrite unit (Anhydrite I) underlying this deformed salt is not significantly deformed and does not itself rest on deformed rocks (Jones, 1973), the tops of these large salt mounds or bulges define what may be termed salt anticlines. These are not anticlines in the usual sense of the term because the top and base of the unit have totally dissimilar profiles; piercement associated with the term salt anticline is not generally present. This belt of salt anticlines, then, is the northwestward-trending belt of intraformational salt deformation recognized by Jones as occurring within the Castile and affecting strata above the Castile.

Structural detail within the large salt anticline located about 5 miles northeast of the center of the proposed WIPP site has been provided by cores recovered from the ERDA-6 hole drilled near the center of the anticline (Anderson and Powers, 1978). Stratigraphic interpretation made by Anderson and Powers from study of the core indicates that the middle anhydrite bed which overlies the salt has indeed been pushed up by the rising salt but has apparently acted as a semirigid confining blanket that was stretched upward like a flexible sheath; whether the anhydrite bed everywhere remained intact or was in places fully ruptured and

detached by extension is not known. What is displayed in the core is that most of the anhydrite, which actually consists of finely interlaminated calcite and anhydrite, was stretched by extensional microfracturing of the calcite laminae and in-filling of the fractures by mobilized calcium sulfate, which presumably was derived by diffusion or creep from adjacent anhydrite laminate. The process seems closely analogous to boudinage in metamorphic rocks, and could be viewed as a microboudinage structure brought about by the properties of finely laminated calcite and anhydrite when subjected to high shear stress under sufficient confining pressure.

Anderson and Powers (1978) find that Halite-I salt, together with streched Anhydrite II or middle anhydrite, have in their upward migration pushed aside both the overlying upper salt (Halite II) and upper anhydrite (Anhydrite III) beds in the manner of an intrusion, since the stratigraphy in the ERDA-6 hole passes directly from Infra-Cowden salt to Anhydrite II. The authors show that the overlying Salado beds, though not breached by the intrusion, are arched over it. It is therefore evident that the arching effect in beds of the Salado and even younger rocks referred to by Jones (1973) along the belt of deformation is in at least some cases due to the presence beneath these anticlines of a salt core which arose from the lower part of the Castile and partly intruded the overlying rocks.

In addition to revealing the cores of many of the salt anticlines in the northwest-southeast belt of deformation described above, the subregional Halite-I isopach map (Anderson, 1978) shows numerous, sharply defined localized depressions at locations where the Halite-I salt is entirely missing from the section. In the central part of the basin, these "deep-seated sinks", as Anderson calls them, do not have obvious surface expression, and are not clearly related to shallower dissolution features--such as collapsed and uncollapsed domes, dissolution fronts, castiles, and collapsed outliers--which have been described and

documented elsewhere in the Delaware Basin region. Many of these isopachous depressions, some of which are defined by a single data point, may possibly be attributed to "deep dissolution" processes (Anderson, 1978), presumably acting from near, or perhaps below, the base of the salt section. A few appear, however, to originate within the Castile in salt zones above the lower halite. Anderson (1978) has proposed that some of them may have propagated vertically upward in the evaporite section to form known cylinders or chimneys of dissolved and collapsed debris. Alternatively, halite flow from adjacent regions into anticlines may account for these paired features as illustrated in Anderson and Powers (1978). (For description of these features in the Delaware Basin subregion and a discussion of their origin and development, refer to regional geomorphology, regional structure, and subsurface hydrology, Sections 3.2, 3.4, and 6.3).

Unlike the belt of salt anticlines having cores of Halite-I salt, the distribution of the localized pockets of missing, or greatly reduced thickness of, Halite I and higher Castile or Infra-Cowden halite that Anderson classifies as "deep sinks" is not confined to a belt above or adjacent to the Capitan reef but includes mid-basin areas as well, as illustrated by Figure 16 of Anderson (1978). The nearest of these deep mid-basin features to the proposed WIPP site as disclosed by the various halite isopach maps of Anderson (1978) occurs about 5 miles southeast of the site at the Eddy-Lea County line. This particular feature is not indicated to originate within the Halite-I zone of the Castile; rather, it appears to be a feature in the infra-Cowden salt (Anderson, 1978, Figure 7); compare this report, Figure 4.4-7, and refer to the section immediately following for additonal detail on the near-site structure.

It is not yet clear whether all or even some of these deeply buried mid-basin "sinks" identified by Anderson have a hydrologic origin subsequent to diagenesis and salt deformation. If they do, they may well be related to other collapse features in the Delaware Basin region as simply one manifestation of the same general process being seen at different levels of exhumation by erosion (Anderson, 1978, p. 58-59).

The concept that these diverse solution structures are being exhumed by present-day erosion suggests that the conditions of their formation in the geologic past may not be present today in kind or to the same degree.

The nature of the deformation in the middle and upper part of the salt sequence above the Halite-I zone is recorded by the subregional halite isopach and structure contour maps of Anderson (1978) and Brokaw et al. (1972). The salt isopachs of Anderson (1978, Figures 4 through 10) clearly show that no other salt member of the evaporite sequence has experienced local flow deformation as severe as the Halite-I zone, nor are the "deep sinks" apparently as prevalent in the middle and upper part as they are near the base of the Castile. The Halite-II member of the Castile mirrors the same thickness trends exhibited by the Halite-I bed, but in a much muted manner. The infra-Cowden salt is the highest salt of the Castile-Salado sequence to exhibit marked thickening along the trend of the buried Capitan reef; it is also the lowest, or first, major salt bed to overtop and extend beyond the confines of the reef margin in this part of the basin. Even though no appreciable thickening of Salado salt above the infra-Cowden is apparent over the Capitan reef margin (Anderson, 1978), structure contours at the base of the Salado Formation (= top of Castile) (Jones, 1973) and on the 124-marker bed within the McNutt potash zone (Anderson, 1978) document that the Salado is indeed arched along the basinward edge of the reef and confirm that the salt deformation which occurs at depth around this margin had imposed an anticlinal structure on overlying strata, much as Jones (1973) described (also compare Brokaw et al., 1972 with Jones, 1973).

The evidence presented in this section regarding the subsurface structure of Castile and Salado halite beds and the spatial relationship of deformation structures with the bounding Capitan reef margin suggests that viscous flow of salt was initiated by post-depositional regional tilting and that the Capitan reef acted as a dam or abutment obstructing the eastward subsurface viscous flow of the lower part of the salt section which impinged against it. The salt piled up slightly, as a rug might when gently pushed against a wall, until lithostatic equilibrium

was attained with the superjacent rock mass. That larger, more dramatic salt plumes were not formed in the Delaware Basin, as they are known to occur in the Gulf Coast basin, for example, may be attributed to several factors. Two of these factors are the gentleness of the regional tilt and perhaps a relatively shallow depth of burial of salt. This would have resulted in lower lithostatic pressures and relatively higher viscosity of salt and hence greater resistance to migration. Evidence from structures nearer the site (e.g., WIPP 11, as discussed in the next section) indicates that the redbeds overlying the Salado are not always involved in the structure. This implies that some of the structures may be Permian in age.

No conclusive evidence establishing the exact time of regional tilting of the Delaware Basin has yet been found, except that it occurred after Chinle deposition (Late Triassic time) and before Ogallala time (uppermost Miocene). King (1948) has proposed that regional tilting took place in early to mid-Tertiary, concomitant with known Basin and Range faulting that occurred in the region west of the Delaware Basin, with relative upthrow of the Guadalupe and Delaware Mountains. Certain relations of Cretaceous strata, as described and discussed in section 4.5 on geologic history, and the long time span between Triassic and Late Cenozoic, suggest that there may have been earlier episodes of moderate regional tilting, of which the present eastward tilt is merely the resultant vector summation.

Geologic Structure of Salt at the Site. Within the context of the subregional relationships of deformation in the Castile-Salado evaporite sequence described and discussed in the previous sub-section, geologic structural features in the salt lying beneath the WIPP site may now be reviewed. Figures 4.4-6 through 4.4-10 show, respectively, structure contours on top of Castile, on the 124-marker bed of the Salado (within the McNutt potash zone in the middle part of the Salado), on top of the Vaca Triste member (top of NcNutt), on the 103-marker bed, and on top of the Salado. Geological sections across the site area are shown on Figures 4.4-4 and 4.4-5. Gross structure of all evaporite horizons

reflects the regional easterly homoclinal dip of 50 to 100 feet per mile. Salt deformation has modified this homocline to a variable extent, generally more so in the Castile than in the Salado, inasmuch as the lower halite beds of the Castile appear to have been the most mobile (refer to subsection 4.3.3).

Seismic reflection surveys performed at the site (G.J. Long, 1977a, 1977b) were designed in part to record the relatively shallow Castile horizons (for description of the seismic survey programs refer to Section 2.4); survey lines are shown on Figure 4.4-6 along with the well control points. A reflecting horizon tentatively identified on the seismic records as the top of Castile (located about 100 feet below the base of the RH-zone) is contoured on Figure 4.4-6, which also shows preliminary structural interpretations made from the seismic records. The contours of Figure 4.4-6 indicate that the easterly regional dip of the Castile is modified by a broad, northwesterly-trending ridge and saddle configuration, with crest-to-trough separation of 2 to 3 miles and total structural relief of up to 400 feet. According to this interpretation, the normal gradient of bedding in this part of the Delaware Basin (about 100 feet per mile or 1 to 2 degrees to the east/southeast) may be significantly greater and different in direction locally at the top of Castile, directly beneath the proposed WIPP underground Facility. Specifically, Figure 4.4-6, G.J. Long's preliminary interpretation of structure on the presumed top of Castile about 100 feet beneath the proposed RH-Zone level, indicates as drawn that local gradients may be as great as 400 feet per mile (about 4 1/2 degrees) to the south and southwest.

Northeast of the site, G.J. Long (December, 1977) shows a domal feature in section 36, T. 31 S., R. 22 E of about 500 feet of structural relief (Figure 4.4-6). ERDA-6, which was drilled in section 35 just west of the crest of this feature, encountered a geopressured (artesian) brine reservoir in the Castile. Studies of the ERDA-6 core establish that the doming in this area is due to a salt anticline with a core of mobilized Halite-I salt (Anderson and Powers, 1978); refer to Figure 4.4-4. This

dome is located within the belt of salt deformation flanking the Capitan reef (refer to Section 4.4.3.1 and Chapter 2, Figure 2-4) where such occurrences are to be expected. Artesian brine flow was also encountered by Belco No. 1 Hudson-Federal over a similar domal feature southwest of the site in the Los Medanos gas field area (Section 1, T. 23 S., R. 30 E)., although no salt-cored anticline of the type encountered at ERDA-6 is known to occur there.

The origin of the inferred northwest-trending structural ridge at the top of the Castile at the northeast edge of the Zone-II exclusion area has not yet been determined; it may be a depositional structure, or it may reflect possible past deformation by salt in underlying halite units. The steepness of the southward gradient suggests possible offset of one or more anhydrite beds as G.J. Long (1977b) has proposed. By contrast, a deep seismic reflection profile running southwest-northeast across the center of the site (Sandia Line 2, G.J. Long, 1977a; compare Figure 4.4-4) detected no anomalies at and below the lower part of the Castile across the trend of the ridge, whereas a significant anomaly is apparent in the same profile at the lower Castile-upper Delaware levels across the Los Medanos gas field southwest of the site (refer to Figure 4.4-4).

The more recent seismic investigation (G.J. Long, 1977b) also defined an area of poor data quality to the north of the site. From the ERDA-6 anomaly westward into Range 30 E. and southward into section 17 at the north edge of the the site, the quality and continuity of data as viewed on the seismic records deteriorate. This suggests the possibility of increased structural disturbance in this area, presumably caused, if real, by some form of previous salt deformation. Deterioration of the seismic record can also be brought about by anomalous or irregular transmission characteristics of the overlying medium. For example, near-surface structural disturbance, such as might be caused by dissolution in the Rustler, or the presence of an anomalously rigid near-surface layer such as caliche could change the quality of the seismic record (Dobrin, et al., 1954). A salt anticline at the northwest corner of Section 9, T22S, R31E, was suspected on the basis of seismic reflection data; drilling (WIPP 11) confirmed the structure was present

in the Castile. WIPP 11 did not show any brine or gas though drilled to the lower anhydrite of the Castile Formation. This confirms that anticlinal structures within the evaporites are not always associated with brine and gas. The apparent non-involvement of the redbeds in the structure may be interpreted, as noted in the previous section, as indicating a Permian age for this structure.

At the present time, while these seismic reflection records are undergoing further study and review, additional seismic reflection surveys are being undertaken in conjunction with exploratory drilling at critical locations. The results of these further investigations are to be reported at a later date.

Figure 4.4-7 presents 10-foot structural contours on the base of the 124-marker bed of the Salado, which is the deepest and most consistently reported horizon in the potash exploration grid. Figure 4.3-3 provides a stratigraphic orientation for the 124 bed, which is in the lower part of the McNutt, or middle Salado; at ERDA-9, the 124 marker is 470 and 1,020 feet, respectively, above the CH- and RH-level mining horizons selected for waste disposal. A uniform, gentle eastward regional gradient of 80 to 100 feet per mile across the repository is evident; there is no suggestion of a northwest-southeast ridge for the Castile (Figure 4.4-6). Two anticlines, or domal structures, are present, one centered near the ERDA-6 locality and the other at the Los Medanos gas field. At both structures, and only at these structures in the map area, exploratory drilling encountered artesian brine reservoirs in the Castile. No such structures are indicated by the 124-marker bed contours to be present within the site exclusion area.

The comparison of Figures 4.4-6 through 4.4-8 to each other indicates that structural disturbance is present within the Castile that is not reflected upward to any great extent. Structural relief on the upper beds is a fraction of that of the Castile. The inferred faulting at depth has not been confirmed by drilling, seismic data and drilling in the area indicates salt remains in the Castile rather than disappearing as any consequence of the faulting.

Two depressions in the 124-marker bed are indicated to occur near the site (Figure 4.4-7). In Lea County in section 31 at the east edge of the map there is a depression with probably less than 100 feet of closure; this is the same feature identified by Anderson (1978) as a possible "deep sink", and apparently is related to a greatly reduced or missing section of the Infra-Cowden (Anderson, 1978, Figure 7). It is nearly 4 miles from the edge of the Zone-II exclusion area. A second depression of the 124-marker bed horizon is centered about a mile north of Zone-II exclusion area, at the southwest corner of section 9. A single-hole anomaly with 50 feet structural closure, it is not reflected by any isopach anomalies in the Salado (Figures 4.3-4 through 4.3-7), nor does it correspond to any evident structural feature higher in the Salado (compare figures 4.4-8 thru 4-4-10). Salt isopach maps of Anderson (1978) indicate no anomaly at this location, nor does the recent seismic reflection work by Long (1977b) show subsurface disturbance of horizons near this point. These negative indications suggest the feature might have developed contemporaneously with depostion and is not significant to the WIPP site. Nevertheless, results obtained from exploratory drilling will be noted and applied if relevant. Higher levels within the Salado are contoured in Figures 4.4-8 and 4.4-9 (refer to Figure 4.3-3 for location in section). Within the area contoured on these Figures, which is somewhat less than the area covered by Figures 4.4-7 and 4.4-10, the two maps are virtually identical in configuration and gradient and exhibit no significant structural features other than the regional gradient.

Structure contours on top of the Salado, or at the contact between the Salado and the Rustler, are displayed in Figure 4.4-10. It should be recalled (Section 4.1) that there is less data control for the top of the Salado than for deeper horizons in the Salado, because potash industry exploration practice normally includes coring and geophysical wireline logging only for horizons below the top of the Salado. Reliable control for top of the Salado is therefore provided mainly by those potash exploratory holes commissioned by DOE. Outlined by contours on Figure 4.4-10, the same domal feature associated with the salt-cored anticline

and brine reservoir encountered by ERDA-6 is still in evidence. The change from regular contours in Range 31 E. to a more irregular configuration in Range 30 E. is due to dissolution at the top of Salado, and is also reflected in the upper Salado isopach map (Figure 4.3-7). (Refer to Section 6.3 for a discussion of dissolution processes in the site area.). A 70-foot depression is apparently recorded by an industrial potash hole (Hole F-91) a mile northeast of the Zone-II exclusion boundary; two similar but smaller features occur a couple of miles farther northwest. Since there is no geophysical or core record available for hole F-91 at the top of the Salado, it may well be that the first encounter of Salado salt is simply not recognizable in the record for this particular hole.

Assuming the record is accurate, however, it is not known at this time whether the apparent depression is a feature of sedimentary origin, although the horizon is a contact zone between two formations, or whether the feature is related to post-depositional solution processes. It should be noted that this apparent depression is about a mile east of, and structurally about 700 feet higher than, a similar depression contoured on the 124-marker bed (Figure 4.4-7, discussed above). However, no such anomalies have been detected on intervening horizons in the Salado (Figures 4.4-8 and 4.4-9). Furthermore, a line connecting the two apparent depressions would have a maximum slope of less than 8 degrees. The available evidence therefore indicates that it is unlikely that there is a physical continuation of this assumed depression at the top of the Salado to horizons lower in the evaporite sequence. On the other hand, there is an approximate spatial coincidence of this depression with a shallow (less than 30 feet of relief) topographic depression at ground surface containing mapped playa deposits (Figure 4.2-4). Resistivity profiles (Elliot, 1977) indicate only minor surficial disturbance attributable to shallow basin fill with no indication of probable subsurface collapse structure.

Preliminary interpretation of seismic reflection data (Long, 1977b) near the top of the Salado indicated the possibility of faulting, with a possible displacement of 100-250 feet, less than one mile north of ERDA 9. Consequently four holes (WIPP 18, 19, 21, 22) were drilled bracketing the possible location of the faulting (see Figure 2-10) to validate the interpretation. The resulting borehole data shows no apparent faulting in this region. The data collected by seismic reflection for that particular seismic program are not apparently useful for primary interpretation of the stratigraphy at the top of the Salado. Revision of field parameters in future surveys may permit more secure interpretation of data for such shallow reflectors.

A preliminary assessment of the proposed WIPP site relative to structural features presently indicated in the Salado and Castile salt formation enclosing the selected CH- and RH-storage levels can now be stated. *Structure contour maps of various horizons in the Salado Formation* indicate a uniform easterly regional structural gradient of about 80 to 100 feet per mile across the limits of the proposed storage facility, with little indication of the presence of any significant structural anomalies. Plastic deformation and buckling associated with salt migration or flowage has apparently not occurred in the Salado in the geologic past to the extent that it has in the lower levels of the underlying Castile Formation. Areas in the region in which artesian brine reservoirs have been encountered are associated with thickened salt sections and salt-cored anticlines in the Castile. However, a thickened salt section and salt cored anticline was drilled in WIPP 11 (Sec. 9, T. 22 S. R. 31 E.) without encountering fluids. Further, the occurrence of these reservoirs appears to be correlative with consistent structural highs, delimited by structure contours of successive horizons in the overlying Salado Formation. No such structural features are recognizable within the limits of the WIPP storage facility on any of the Salado horizons contoured; in fact, the site, if anything, appears to be in a slight structural saddle.

Among aspects needing further investigation, perhaps the most significant is a determination of the extent to which the upper levels of the Castile closest to the repository levels have been deformed by any salt deformation that may have taken place in the lower halite units of the Castile. There is no suggestion here of deformation of the type associated with artesian brine reservoirs. Seismic reflection techniques suggest, however, that a certain amount of flexure occurs in the upper levels of the Castile beneath the proposed limits of the repository, which could possibly affect local structural gradients in the lower part of the Salado. Faulting on the Castile reflector has also been inferred. Investigations are in progress to further define and delimit structural configurations near the top of the Castile and the extent to which these structures may be reflected within the lower part of the Salado where excavation of the RH- and CH-levels is presently planned. This knowledge will permit a more detailed assessment relative to the location, design and construction of the storage facility but is not believed necessary for a general qualification of the site area.

4.4.4 Shallow Structure

As discussed in Section 4.4.1, in the Los Medanos area a distinction may conveniently be made between structural features exhibited by rocks occurring above unleached salt beds and structural features of all other strata. The distinction may be made because rocks above the Salado at the site have at one time or another in the geologic past been subject to weathering processes and hence might display secondary structures related to surficial dissolution and subsidence that would not have been imposed upon deeper strata. Accordingly, shallow structures at the WIPP site have a potential for greater irregularity and complexity than those which occur at depth. "Shallow structure" is here defined to include the Rustler Formation which extends to a depth of about 850 feet beneath the center of the site (refer to Figure 4.3-3). Figures 4.4-11 through 4.4-15 are structure contour maps on Rustler and higher strata, constructed from the data obtained from wireline geophysical logging of holes drilled at the WIPP site to assess potash reserve potential.

Shallow Subsurface Structure. Structure contours on top of the Culebra Dolomite member of the Rustler Formation are shown on Figure 4.4-11 (refer to Figure 4.3-3 for location in site geologic column). The Culebra is the most productive aquifer in the Rustler Formation. The closely spaced contours in the southwestern quadrant of the map define a slope of about 80 feet per mile eastward (compare Figure 4.4-9). The wider spacing of contours in the eastern half of the map is anomalous with respect to regional structure and marks the increasing amount of halite preserved progressively eastward in the Rustler below the Culebra member. A similar configuration is evident on top of the Rustler, Figure 4.4-12: again the regional gradient appears in the southwestern quadrant, while an anomalously gentle eastward gradient, in some places even reversed, signifies thickening due to an increasing content of salt preserved from dissolution (see Figure 6.3-7). Virtually the same pattern is observed with respect to the structure contours of the Magenta Dolomite member (Griswold, 1977). Isopachs of the Rustler (Figure 4.3-8) show the gradient and amount of eastward thickening. A broad, shallow depression with 30 to 40 feet of closure near hole P-11 appears near the northeast corner of the site on both the Magenta and the top of Rustler levels, but not on the Culebra. Possibly it represents an area of greater dissolution in the upper part of the Rustler, since Rustler isopachs show the Rustler is not thickening eastward at this particular location (Figure 4.3-8)

The area in Figures 4.4-11 and 4.4.-12 wherein the regional gradient is reflected by the Rustler structure contours identifies the area where the Rustler has been leached of most of its salt, and hence presumably where maximum settlement of overlying rocks has occurred, assuming, of course, that no dissolution took place prior to deposition of overlying Dewey Lake strata. Jones (1973) supplies a subregional structure contour map of the Dewey Lake-Rustler contact and recognizes that the unevenness it shows is due to the added complexities of subsidence (Jones, 1973). A low resolution seismic reflection survey conducted at the site (C.B. Reynolds, 1976) suggests the presence in the Rustler of more localized and higher amplitude irregularities than would necessarily be defined by

data points in Figure 4.4-12. However, the known top-of-Rustler data points from potash exploration shown on Figure 4.4-12 are in nearly complete disagreement with elevations of this horizon interpreted from the shallow seismic data (Reynolds, 1976). It would appear that the reflections of horizons in the Rustler obtained by this shallow survey method are not of sufficient quality to provide a basis for making structural interpretations. The subsurface data collected to date indicate that the dissolution of salt in the Rustler has not been accompanied by the development of highly irregular subsidence structures in the overlying strata at the WIPP site.

Proceeding higher in the section, the top of Dewey Lake Redbeds (Figure 4.4-13) is the first horizon that does not reveal the eastward gradient of the Delaware Basin that all lower horizons show. The Dewey Lake surface across the site area is undulatory, possibly reflecting to some extent original undulations in the uncomformable Dewey Lake-Santa Rosa contact mentioned by Jones (1973). A broad depression near hole P-11 with about 50 feet of closure is in the same location as a similar depression on the underlying Rustler surface (Figure 4.4-12). Subregional structure contours of Jones (1973) indicate considerable irregularity of the Dewey Lake surface as is also suggested by Figure 4.4-13, but overall the surface slopes northeastward. Isopachs of the Dewey Lake Redbeds (Figure 4.3-9) disclose that the west-trending slope of the Dewey Lake surface at the west edge of Figure 4.4-13 is the result of the Late Tertiary erosion which is associated with the development of Nash Draw and which completely truncates the Dewey Lake in Nash Draw itself (Brokaw, et al., 1972). Continuation of this erosion surface to the east across higher strata is quite obvious in Figure 4.4-14, contoured on the surface of the Santa Rosa Sandstone. Structure contours of the Gatuna surface (below Mescalero caliche) (refer to Figure 4.4-15) show virtually the same configuration as does the Santa Rosa surface on the east and the Dewey Lake surface on the west, indicating that the thin Gatuna veneer was deposited over these surfaces after erosion occurred.

Surficial Structures. Extensive surficial deposits of dense sand all but preclude the observation of surface geologic structure at the WIPP site (Figure 4.2-4; refer to maps by Bachman in Jones, 1973, and by Vine, 1963). The nearest measurements of bedding orientation appearing on Bachman's map are at the edge of The Divide, some 6 miles northeast of the center of the proposed WIPP site. The Nash Draw geologic quadrangle map by Vine (1963) shows no such measurements, for Vine recognized that dissolution of salt in rocks beneath Nash Draw had caused widespread slumping of the surface rocks. Thus, they are not indicative of original structures. He documents places where not only salt but considerable gypsum has been dissolved. In Nash Draw the Magenta and Culebra dolomite members of the Rustler are observed in contact, whereas normally, when leached of salt only, they are separated by 120 feet of gypsum (Vine, 1963). In mapping the overlying Dewey Lake Redbeds, he noted that,

> "exposures of the redbeds are commonly tilted or draped into simple structures as a result of the collapse and swelling that accompanies solution and hydration of the underlying evaporite rocks. Some exposures...along the margin of Nash Draw show a downwarping into the topographic depression that is presumably the result of removal of soluble rocks. For this reason, strike and dip readings, even on the very apparent parallel stratification of the redbeds, do not necessarily reflect the structure of older rocks" (Vine, 1963).

Jones (1973) affirms that "it is impossible to piece together a meaningful stratigraphic section from study or mapping of outcrops" in Nash Draw. "The (exposed) rocks are porous, friable, and loose-textured, and all are strongly jointed, cavernous, and locally brecciated. Stratification is obscured or completely obliterated, and the attitude of bedding can rarely be determined with any degree of confidence" (Jones, 1973, refer also to discussion of Rustler stratigraphy, Section 4.3.2). It should be emphasized that this surface evidence of jumbled structure is restricted to Nash Draw and has not been described for the area between Livingston Ridge and the WIPP site.

No surface faults have been mapped within 5 miles of the center of the WIPP site; faults that are mapped at the surface are distant and are plainly related to collapse features. Bachman's (1976) mapping east of the WIPP site shows no surface faults. The nearest faults mapped by Vine (1963) involve Rustler offsets in Nash Draw about 9 miles southwest of the site in section 18, T. 23 S., R. 30 E. Although he recognized these faults as being produced by karst processes, involving areas of circular or semicircular rock deformation up to a few thousand feet in diameter, he was unsure of how to account for the fact that some were positive

topographic features or domes (Vine, 1960; Vine, 1963). Anderson (1978) believes that they may be the eroded remnants of former caverns in salt whose roofs had collapsed; the collapsed debris then remained as the upper part of the surrounding salt was partially dissolved and carried away (refer to regional geomorphology, Section 3.2).

Livingston Ridge, 4 miles northwest of the site, marks the edge of Nash Draw, a broad swale developed by a combination of erosional and dissolution processes. Bachman (1974) mapped occurrences of caliche in the region around the WIPP site, and noted the structural relationship of the caliche to depressions such as Nash Draw (refer to structure contour map of the Mescalero caliche in Bachman, 1976). He concludes that,

> "major solution and collapse preceded and followed the accumulation of the Mescalero caliche in Nash Draw..." (Bachman,1976). "The Mescalero caliche probably formed on an undulatory stable surface. ...Along Livingston, Quehada, and Nimenim Ridges...the caliche dips abruptly into the adjacent depressions. The crowding of contours, the presence of fractures, and the uniform thickness of the caliche along these ridges indicate that Nash Draw Draw and Clayton Basin were subjected to collapse after the formation of the Mescalero caliche. On the other hand... the uniform spacing of the contours in the area of the Divide between Livingston and Antelope Ridges suggest that this surface...approaches its original slope" (Bachman, 1974).

Thus, surface mapping and structural interpretations have found no evidence of any anomalous structure in the vicinity of the WIPP site east of Nash Draw that might be indicative of significant differential subsidence of underlying strata. Such surface features and structural relationships that are exposed in the area reveal no indication of any surface faulting at the WIPP site.

In summary, surface and shallow subsurface structure in the vicinity of the WIPP site has presumably been modified to some extent by loss from dissolution of 100-200 feet of salt originally present in the Rustler Formation. The resulting subsidence and settlement would not be expected to have progressed in a perfectly constant and uniform manner over an area of several square miles. On the other hand, there is no indication of the presence of the types of chaotic structure encountered in the Rustler in Nash Draw, as described by Jones (1973) and by Vine (1963).

In the Nash Draw area, the widespread collapse structures observed are due to extensive dissolution in the Salado rather than in the Rustler alone. Further, the successive erosional stripping of Santa Rosa, Dewey, and Rustler strata westward into Nash Draw, coupled with the general eastward regional dip of the evaporite strata, indicates that the amount of overburden above the level of dissolution actually was much less in Nash Draw than it presently is east of Livingston Ridge. Thus the potential for significant differential subsidence to have occurred beneath the Los Medanos site seems to have been minimized by the restriction of salt dissolution to beds within the Rustler and by the relatively high overburden pressure which would have tended to provide more uniform settlement as salt was being removed. Stratigraphic data from potash holes drilled in the site area indicate no major irregularities in horizons above the Salado (Figures 4.4-10 through 4.4-15).

4.4.5 Summary and Conclusions

Jones (1973) concludes that:

> "The structure of the Los Medanos area is basically simple and the rocks are, for the most part, only slightly deformed. Nevertheless, the rocks have been tilted, warped, eroded, and subroded (i.e., subjected to subsurface solution), and discrete structural features can be recognized. These include: (1) structural features of regional extent related to Permian sedimentation, (2) intra-formational folds of limited extent related to "down-the-dip" movement of salt under the influence of gravity and weight of overburden, and (3) subsidence folds related to warping and settling of rocks to comform with the general shape and topography of the surface of salt in areas of subrosion...
>
> "On the basis of available geological information, the salt deposits of (the) Los Medanos area seem in many ways to constitute a suitable receptacle for use in a pilot-plant repository for radioactive wastes. The deposits have thick seams of rock salt at moderate depths, they have escaped almost completely undamaged from long periods of erosion. The deposits are only slightly structurally deformed, and they are located in an area that has had a long history of tectonic stability."

Information that has been developed in the succeeding five years of investigations has little altered that assessment relative to the

structural and tectonic conditions present at the WIPP site. Based on exploration accomplished to date, a series of structure contour and isopach maps is presented for rocks ranging in age from Devonian to Pleistocene. This and other information indicates that tectonic faulting and warping of rocks in the site vicinity seems to be restricted to Pennsylvanian and older rocks and to have predated Permian evaporite deposition; certain minor faulting within the thick Permian section appears to have occurred contemporaneously with sedimentation. Deformation related to salt flowage has occurred primarily in the Castile Formation beneath the Salado, and has perhaps modified the regional easterly gradient to 80 to 100 feet per mile to some extent at the level of the storage horizons near the base of the Salado. Areas in the vicinity of the site in which artesian brine reservoirs have been encountered are associated with thickened salt sections and salt-cored anticlines in the Castile, but no such structural features are recognizable within the limits of the WIPP storage facility on any of the Salado horizons contoured. The site, if anything, appears to be in a slight structural saddle, a condition considered to be a favorable criterion for site selection. Dissolution of bedded salt beneath the site has been resticted to horizons within the Rustler Formation; there is no evidence that the resulting settlement produced any significant structural irregularities or collapse features in the overlying strata within the area of the WIPP site. Investigations are continuing to further define the extent to which salt deformation in the Castile may have affected the structural configuration within the lower part of the Salado where excavation of the RH- and CH- levels is presently planned. These investigations will permit a more detailed assessment of the optimum location, design, and construction method of the storage facility.

4.5 Site Geologic History

Three main phases characterize the geologic history of the WIPP site subsequent to the original establishment of a granitic basement intrusive complex between a billion and a half-billion years ago, forming the cratonic crust beneath the site. The first phase, of at least 500

million years' duration, was a time of uplift and erosion of all pre-existing Precambrian sedimentary and metamorphic rocks which may have once been deposited or formed in the site area, eventually exposing the deep-seated igneous rocks. The second phase was characterized by an almost continuous marine submergence lasting about 225 million years, wherein shelf and shallow basin sediments slowly accumulated. This depositional phase culminated in a comparatively rapid accumulation of over 13,000 feet of sediment within a relatively brief period lasting 50 to 75 million years, toward the end of which time thick evaporite beds, mainly rock salt, were deposited. Uplift and subaerial conditions next returned to the site in the third and final phase, and have persisted some 225 million years to the present, with the exception of a brief marine inundation in the middle of that span of time. Periods of terrestrial deposition alternated with erosional episodes, so that a series of nonmarine deposits separated by unconformities blanket the evaporite beds at the site.

Since the first phase mentioned above really reflects the absence of any evidence in the geologic record at the site for specific events which may have occurred during the latter part of Precambrian time, the following review of site geologic history considers only post-Precambrian events. Additional discussion of geologic history in a regional context is contained in Section 3.6. The reader is referred to Figure 4.3-2 for stratigraphic orientation.

The Precambrian basement terrane, exhumed during the vast erosional regime of late Precambrian time, was first submerged at the start of Ordovician time, with deposition of the basal Bliss Sandstone. From Ordovician time through Pennsylvanian time in the southeastern part of New Mexico where the site is located, marine sediments accumulated slowly but continuously. Shelf and shallow basin deposition progressed marginally to or within broad, nearly flat subsiding basin areas of the Tobosa Basin that formed northern arms of the Ouachita trough (Brokaw et al., 1972).

The dominantly carbonate section (dolomite and limestone) from Ordovician through Mississippian time (a span of roughly 180 million years) indicates stable shelf and gently subsiding shallow basin environments. A sandy clastic sequence in mid-Ordovician time (Simpson Group) may perhaps signify mild uplift of a landmass ancestral to the Central Basin Platform. Although an Ordovician-Silurian unconformity has been recognized elsewhere in the region (refer to Section 3.5), none is evident in the site area. The first significant post-Cambrian emergence or marine regression occurred during the Early and Middle Devonian, but the area apparently was a broad plain never elevated much above sea level. Marine waters reinvaded the area in Late Devonian time, accompanied by unconformable deposition of distinctive black shale (Woodford Shale), followed by a return to carbonate accumulation in Early Mississippian time. Continued subsidence of the area was accompanied by deep-water deposition of dark, silty shale (Barnett).

The end of Mississipian time heralded significant regional warping and tectonic activity. Major faulting accompanied upwarp of positive tectonic elements in the region, including the Central Basin Platform area (refer to Section 3.6). These positive land masses provided a more abundant supply of clastic detritus which was carried into adjacent marine basins and deposited on moderately warped, tilted surfaces. At about this time, the tectonic framework of the Delaware Basin began development. The site area received sandy Lower Pennsylvanian Morrowan sediment and more or less continuously accumulated sediment over the remainder of the period as repeated basin margin faulting caused periodic, strong uplift of the bordering platforms and some warping within the basin. By the end of Pennsylvanian time, differential tectonic upwarp had ceased (refer to Section 3.6).

At the WIPP site, sedimentation was continuous from Pennsylvanian into Early Permian time. In contrast to Pennsylvanian deposition, however, the Delaware Basin subsided at a greatly accelerated pace during Permian time, partly by downwarp and partly by downfaulting along pre-existing basin margin faults. Perhaps the previous Pennsylvanian tectonic

activity had predisposed the Delaware Basin to more rapid downwarping; at any rate, a thickness of about 9,000 feet of Wolfcampian, Leonardian, and Guadalupian sediment was deposited over little more time than had been required for about 2,500 feet of Pennsylvanian strata to accumulate. The sequence tended to progress from shale to basin limestone to sand, possibly related to encroachment of the basin margin reef deposits, as the central part of the basin continued to subside more rapidly than the shelf areas. Although basin margin reef buildup was active in both Leonardian (Bone Springs) and Guadalupian (Delaware Mountain) time, it was not until the latter part of Guadalupian time that continuous, massive reefs, accreting rapidly to keep pace with continued basin subsidence, virtually encircled the basin. This process culminated with the formation of the massive Capitan reef limestone, which approaches to within 9 miles of the site and delimited the Delaware Basin at that time. Although for many millions of years previous to this time, various lesser reef deposits had been encroaching inward upon the basin, the Capitan reef defined a more restricted area of the Delaware Basin than was ever the case previously. At the WIPP site, the basin facies equivalent to the Capitan reef is the Bell Canyon Formation, mostly siliceous sandstone in lithology. When the Capitan reef eventually encircled the basin at the close of Guadalupian time, the top of Bell Canyon was 1,000 to 1,500 feet lower in elevation than its facies equivalent high on top of the reef only a few miles away. At this time the reef had closed off free access of the open sea to the Delaware Basin, setting the stage for the ensuing precipitation of the Ochoan evaporites.

As the seawater in the salt basin of Castile time evaporated to brine, precipitation of anhydrite and limestone, followed by anhydrite and finally salt (halite) occurred. Several major incursions of seawater must have refilled the basin, for there are a number of thick, laminated anhydrite-calcite beds separated by thick salt members. Because this salt basin was shielded from clastic sediment deposition by high bounding reefs, the Castile evaporites tend to be the most chemically pure of the Ochoan evaporites. Eventually the Castile evaporites filled the basin

enclave to the level of the top of the sheltering reef masses. The Salado salt then extended over the top of the still subsiding reefs, burying them and extending outward into the Permian Basin. Although the region continued to subside, reef organisms could not survive in the briny environment, and burial of the reefs by the Salado resulted in the final disappearance of the Delaware Basin as a paleogeomorphic entity.

The Salado, inasmuch as it formed in a broad, regionally extensive brine basin not bounded by protective reefs, was more susceptible to clastic influx, and therefore its halite deposits are generally somewhat less pure than those of the Castile. Nearly 2,000 feet of mostly rock salt accumulated before an increase of clastic influx accompanied by a decrease in salinity caused deposition of Rustler lithologies to occur (anhydrite more dominant with significant thicknesses of clastic rocks). Finally in a shallowing sea or on marginal mudflats, the Dewey Lake Redbeds were deposited as subsidence gradually ended, covering the salt beds with a thick clastic blanket. This was the final episode, about 225 million years ago, of a remarkable accumulation of marine deposits which had been first laid down in Ordovician time.

No Lower Triassic strata occur at the WIPP site, nor are they known in the region (refer to Section 3.6.4). It was a time of general regional epeirogenic uplift and erosion; only a slight angular unconformity is present between Dewey Lake strata and overlying strata (Jones, 1973). According to Bachman (1974), "it is possible that some dissolution of Permian soluble rocks occurred in the periods of uplift during Triassic time", but direct evidence of this has not been found in southeastern New Mexico. Isopachs of the Dewey Lake where it is covered by Upper Triassic rocks indicate a thickness of about 500 feet. Furthermore, Jones (1973) indicates the pre-Upper Triassic Dewey Lake thickness decreases northwestward. Although the actual original protective thickness of the Dewey Lake westward across Nash Draw and over to the Pecos is now indeterminate due to later removal by erosion, it is interesting to speculate whether some dissolution features and processes presently observed there may not have had their beginning in Early Triassic time, over 200 million years ago.

In Late Triassic time inland basin streams laid down floodplain deposits of the Santa Rosa and Chinle Formations, the first record of non-marine deposition in the area. The total original thickness of Late Triassic deposition is not known, because of an erosional surface on the Triassic of the region. The first erosion to have acted upon the Triassic rocks lasted from the close of Triassic time to Late Early Cretaceous, a period which may have lasted as long as 90 million years. In latest Early Cretaceous time (Washita, about 100 m.y.b.p), a shallow sea transgressed across the site area and deposited an unknown thickness of marine sediments. Later erosion removed all but slumped or sunken residual fragments of a presumably once extensive Cretaceous cover.

These Late Triassic-Early Cretaceous relationships hold important implications for the history of both salt dissolution and salt deformation in the Delaware Basin. As Bachman (1974), has stated,

> "In central and southeastern New Mexico where Triassic rocks are preserved they are overstepped by rocks of Cretaceous age. In general, these Cretaceous rocks rest on progressively older rocks toward the south and southwest. After cutting across the wedge edge of Triassic rocks, the Cretaceous rocks rest on Permian or older strata at many places in southern New Mexico."

By plotting locations of these small Cretaceous outliers and noting the age of rocks on which they occur, Bachman (1976) reconstructed an approximation of the Jurassic erosion surface, showing where Permian rocks were unprotected by Triassic cover and exposed to erosion sometime during the Jurassic-Early Cretaceous erosional interval. The sketch shows that Permian rocks along the western edge of the Delaware Basin were exposed to the atmosphere and presumably eroded during Jurassic time. "Probably some dissolution of Permian salt and gypsum occurred in the western part of the Delaware Basin at this time" (Bachman, 1976). To the extent that "deep dissolution" features are recognized today in salt at depths of several thousand feet below the surface (Anderson, 1978), it seems quite likely that similar features would have been present and developing at comparable depths during the Jurassic erosion 100-190 million years ago. Further, considerable dissolution effects could have been initiated or accelerated during the Cretaceous at times preceding or

subsequent to Washitan submergence, particularly in view of the humid or even tropical conditions known to have characterized the Cretaceous in North America.

A second aspect of the above-described Triassic-Early Cretaceous relationships relates to the history of salt deformation at the WIPP site. Prior to Cretaceous submergence, Jurassic erosion had bevelled the blanket of Upper Triassic Dockum sediments to a wedge that pinched out westward across the Delaware Basin. Evidently, eastward regional tilting had occurred, at least by the end of Jurassic erosion. Since this tilt would have involved the underlying salt beds, some salt flow and deformation may have occurred at this time. Deformation may even have continued during the time in which the region was submerged by the Cretaceous marine incursion and was later covered by an unknown thickness of marine strata.

Although the duration of the Cretaceous epicontinental marine transgression is not precisely known for this area, probably early in late Cretaceous time the sea withdrew; during the remainder of Late Cretaceous time the area was probably of low relief and only slightly above sea level (Hayes, 1964). No early or middle Tertiary deposits are known in the site area, so that geologic events near the site over the 60 million years after the end of Cretaceous time and the beginning of Pliocene time are poorly known. Major uplift probably took place concurrent with the Laramide orogeny that occurred farther north and west. "Probably late in the Cretaceous Period or very early in the Tertiary Period the entire region was elevated by broad epirogenic uplift and was tilted slightly to the northeast" (Hayes, 1964). The Cretaceous rocks were eroded to expose Triassic rocks in the eastern half of the Delaware Basin and Permian rocks in the western half of the basin. This erosion again subjected Permian salt to further dissolution (Bachman, 1974), and produced a second erosional truncation of Late Triassic Dockum sediments (Jones, 1973). In Oligocene time (35 m.y.b.p.), lamprophyre

(basaltic) dikes were intruded in the subsurface along a northeast-southwest dike trend which occurs about 8 miles northwest of the site; this is the only post-Precambrian igneous rock known in the New Mexico part of the Delaware basin.

By Late Miocene time conditions became less arid and eastward-flowing alluvial distributories began to deposit sandy and gravelly sediment over an irregular erosion surface. Deposition of these sediments, referred to as the Ogallala Formation, began as early as 12 million years ago and ended before the close of Pliocene time, perhaps as early as 4 million years ago (Bachman and Johnson, 1973). The nearest Ogallala occurrence is at The Divide, 6 or more miles northeast of the site, where its maximum thickness is only 27 feet, which is considered to represent an original, or depositional, thickness (Bachman, 1974).

It is not known whether any Ogallala sediments were ever deposited at or west of the site, or to what extent dissolution subsidence features were geomorphically expressed in Nash Draw and southwestward within the Delaware Basin by the time the erosional plain associated with Ogallala deposition had developed. Bachman (1976) states that, "by the end of Ogallala time the High Plains surface was probably continuous westward across the present Pecos River drainage to the backslope of the Sacramento Mountains" in the region north of the Delaware Basin but that "the Ogallala Formation may not have been deposited in the Pecos depression southward from Carlsbad.... Although some form of major drainage may have been present in the vicinity of the modern Pecos River during pre-Ogallala time, (Bachman's) work does not support an interpretation of thick Ogallala fill southwest of The Divide" (Bachman, 1974). Nevertheless, Bachman (1976) believes "much of the lowering of the Pecos River Valley has occurred as a result of dissolution of evaporites in the underlying Permian rocks since Ogallala time."

When Ogallala deposition ceased in Late Pliocene time, the region around the site was tectonically stable and the climate was arid to semiarid: during this time a caliche caprock developed on the Ogallala surface.

Renewed erosion took place during early Pleistocene time following Basin-and-Range tectonic activity and rejuvenation of the Rocky Mountains. At the site the effect of this uplift and increased rainfall was to cause a renewal of erosional and dissolutional activity. Active stream erosion in the site area caused a third erosional surface to be incised into the Late Triassic sediments; in Nash Draw, this erosion cut deep into the Dewey Lake Redbeds at the same time that Nash Draw was actively collapsing due to subsurface dissolution. Eventually these channels and sinks were filled with the Gatuna Formation, which was derived from reworked Ogallala and older sediments, and a veneer of Gatuna material was deposited across the Los Medanos Mid-Pleistocene surface. Bachman considers that this erosion and deposition occurred "during the most humid climatic conditions that have existed in the area since Ogallala time" (Bachman, 1974), and tentatively correlates the Gatuna deposition with Kansan time, which ended approximately 600,000 years ago.

After deposition of the Gatuna Formation, a caliche (Mescalero caliche) caprock formed on the Gatuna surface in a semiarid environment during an interval of climatic and tectonic stability (Bachman, 1974). Regional climatic considerations lead Bachman to assign a mid-Pleistocene age for the Mescalero caliche, which he tentatively correlates with the Yarmouth interglacial stage, or about 600,000 years before the present (refer to Section 4.3.2).

Since the formation of the Mescalero caliche some half a million years ago, little geological activity has occurred at the WIPP site. In the Pecos Valley a number of Pleistocene surfaces can be identified which provide some clue to the evolution of the regional drainage system (refer to Regional Geomorphology, section 3.2.2.1). At the edge of Nash Draw along Livingston Ridge, the Mescalero caliche is fractured and draped into the draw, indicating that Nash Draw was subjected to some dissolution and subsidence in the half million years subsequent to formation of the caliche, presumably during the more pluvial periods of Illinoian or Wisconsinan glaciations. Similar evidence exists along

other slopes and in sinks within and adjacent to Nash Draw, but is not observed away from Nash Draw in the direction of the site. Perhaps the most obvious activity at the site has been the formation of a nearly continuous cover of windblown sand and sand dunes in Late Pleistocene and Recent time, believed to have been supplied from the east rather than from the Pecos area to the west. The sand apparently was eroded from the Ogallala in wet climatic intervals and was blown westward across the area during dry intervals.

4.6 SUMMARY

Investigations of the site geology for the WIPP define the geology as it is presently known for determination of the general suitability of the site. Many of the factors in Chapter 2 are addressed here in Chapter 4. The ultimate acceptability of the site for a repository may only come after the detailed geology of the site is known from underground workings.

The site physiography and geomorphology shows the site to have been relatively stable through the last 500,000 years or more. The development of the Mescalero caliche, and the lack of developed drainage are indicative. Localized sinks or basins are surficial.

Site stratigraphy and lithology including the evaporites shows continuity from the regional setting. The evaporites at the site are about 3500' thick, and include the Castile Formation, Salado Formation and Rustler Formation from bottom to top. The subsurface structure at the WIPP site within the evaporites is salt deformation three miles north of the site center and possibly also one mile north. The structure three miles north involves deformation of the Castile and lower Salado; drilling (WIPP 11) showed the deformation to be upward bulging of salt, but no severe displacements and no brine or gas were encountered. The structure one mile north appears to be smaller, and is of concern mainly for design of underground workings. It is being investigated further for this purpose. Within the site structure contours on evaporite horizons show areas with slight closure; the range of precision of data from industry

sources and natural variability can probably account for these features though slight deformation or dissolution could also be invoked. No surficial faults are known at the WIPP site.

The potential repository zones are located in the Salado Formation at depths from 2730' to 2620' (remote handling) and 2176' to 2074' (contact handling). These beds are chosen on the combined basis of purity, depth, thickness, mutual separation, and depth below the potash zone.

The geological history of the site is encompassed in the geological history of the region.

4.7 REFERENCES

Adams, J.E., 1944, Upper Permian Series of Delaware Basin, west Texas and southeastern New Mexico: Am. Assoc. Pet. Geol. Bull., v. 28, p. 1592-1625.

Adams, J.E., et al., 1939, Standard Permian section of North America: Am. Assoc. Pet. Geol. Bull., v. 23, p. 1673-1681.

Anderson, R.Y., 1978, Report to Sandia Laboratories on deep dissolution of salt, northern Delaware Basin, New Mexico: Sandia Laboratories, Albuquerque, New Mexico.

Anderson, R.Y., and Powers, D.W., 1978, Salt anticlines in the Castile-Salado evaporite sequence, northern Delaware Basin, New Mexico: (preprint), New Mexico Bureau Mines and Mineral Resources, Circ. 159 (in press).

Anderson, R.Y. et al., 1972, Permian Castile varved evaporite sequence, west Texas and New Mexico: Geol. Soc. Am. Bull., v. 83, p. 59-86.

Ash, S.R., and Clebsch, A.C., 1961, Cretaceous rocks in Lea County, New Mexico: U.S. Geol. Surv., Prof. Paper 424-D, p. 139-D142.

Bachman, G.O., 1974, Geologic processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U.S. Geol. Surv., Open-file report 74-194.

Bachman, G.O., 1976, Cenozoic deposits of southeastern New Mexico and an outline of the history of evaporite dissolution: U.S. Geol. Surv., Journal of Research, v. 4, no. 2, p. 135-149.

Bachman G.O., and Johnson, R.B., 1973, Stability of salt in Permian salt basin of Kansas, Oklahoma, Texas and New Mexico: U.S. Geol. Surv. Open-file Report 4339-4.

Bishop, W.F., 1973, Late Jurassic contemporaneous faults in north Louisiana and south Arkansas: Am. Assoc. Pet. Geol. Bull., v. 57, p. 858-877.

Blanchard, W.G., Jr., and Davis, M.J., 1929, Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Pet. Geol. Bull., v. 13, p. 957-995.

Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hays, W.H., 1972, Geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico: U.S. Geol. Surv. Open-file report 4339-1.

Brown, C.N., 1956, The origin of caliche on the northeastern Llano Estacado, Texas: Jour. Geology, v. 64, p. 1-15

Bruce, C.H., 1973, Pressured shale and related sediment deformation mechanism for development of regional contemporaneous faults: Am. Assoc. Pet. Geol. Bull., v. 57, p. 878-886.

Darton, N.H., 1922, Geologic structure of parts of New Mexico: U.S. Geol. Surv. Bull. 726-E, p. 173-275.

Dobrin, M.B., Lawrence, P.L., and Sengbush, R.L., 1954, Surface and near-surface waves in the Delaware Basin: Geophysics, v. 19, p. 695-715.

Elliot, C.L., 1976a, A Laboratory investigation of magnetic physical properties of igneous dike samples from Kerr-McGee Hobbs plant, section 31, T. 20., R. 32 E. and surface outcrop, section 31, T. 26 S., R. 25 E.: Report submitted to Sandia Laboratories, Albuquerque, New Mexico, dated December 1, 1976.

Elliot, C.L., 1976b, A preliminary geophysical study of a trachyte dike in close proximity to the proposed Los Medanos nuclear waste disposal site, Eddy and Lea Counties, New Mexico, dated December 10, 1976.

Elliot, C.L., 1976c, An experimental detailed resistivity survey of known or suspected breccia pipes and sinkholes: report submitted to Sandia Laboratories, Albuquerque, New Mexico.

Elliot, C.L., 1977a, Experimental resistivity soundings near a known breccia pipe, Weaver area, Eddy County, New Mexico: Report submitted to Sandia Laboratories, Albuquerque, New Mexico.

Elliot, C.L., 1977b, Evaluation of the proposed Los Medanos nuclear waste desposal site by means of electrical resistivity surveys, Eddy and Lea Counties, New Mexico: Report (in two volumes) submitted to Sandia Laboratories, Albuquerque, New Mexico.

Fisher, W.L., and McGowen, J.H., 1967, Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas: Gulf Coast Assoc. Geol. Soc. Trans., v. 17, p. 105-125; see also Univ. Texas Bur. Econ. Geology, Geol. Circ. 67-4.

Flawn, P.T., 1954, Summary of southeast New Mexico basement rocks, in New Mexico Geol, Soc. 5th Field Conf.: Guidebook of southeastern New Mexico, p. 114-116.

Flawn, P.T., 1956, Basement rocks of Texas and southeast New Mexico: Univ. Texas Bur. Econ. Geol. Pub. 5605.

Foster, R.W., 1974, Oil and gas potential of a proposed site for the disposal of high-level radioactive waste: Oak Ridge National Laboratory, Open-file report (Contract No. AF(40-1)-4423).

Foster, R.W., and Stipp, T.F., 1961, Preliminary geologic and relief map of the Precambrian rocks of New Mexico: New Mexico Bureau of Mines and Mineral Resorces, Circ. 57.

Grim, R.E., Droste, J.B., and Bradley, W.F., 1960, A mixed-layer clay mineral associated with an evaporite: in Swineford, Ada (ed.), Clays and clay minerals, v. 8, Proc. 8th Natl. Conf. Clays and Clay Minerals, p. 228-236.

Griswold, G.B., 1977, Site selection and evaluation studies of the Waste Isolation Pilot Plant (W.I.P.P.), Los Medanos, Eddy County, New Mexico: Sandia Laboratories Rept. SAND-77-0946, Albuquerque, New Mexico.

Haigler, L.B., 1962, Geologic notes on the Delaware Basin: New Mexico Bureau of Mines and Mineral Resources, Circ. 63.

Haigler, L.B., and Cunningham, R.R., 1972, Structure contour map on top of the undifferentiated Silurian and Devonian rocks in southeastern New Mexico: U.S. Geol. Surv. Map OM-218.

Hayes, P.T., 1964, Geology of the Guadalupe Mountains, New Mexico: U.S. Geol. Surv. Prof. Paper 446.

Hills, J.M., 1942, Rhythm of Permian seas, a paleogeographic study: Am. Assoc. Pet. Geol. Bull., v. 26, p. 217-225.

Jones, C.L., 1954, The occurrence and distribution of potassium minerals in southeastern New Mexico: New Mex. Geol. Soc., 5th Field Conf., Guidebook of southeastern New Mexico, p. 107-112.

Jones, C.L., 1968, Some geologic and petrographic features of Upper Permian evaporites in southeastern New Mexico: Geol. Soc. Am. Special Paper No. 88, p. 538-539.

Jones, C.L., 1972, Permian basin potash deposits, southwestern United States, in Geology of Saline deposits: UNESCO, Earth Sci. Ser, No. 7, p. 191-201 (reprinted in Brokaw, et al., 1972, Geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico: U.S. Geol. Survey Open-file report, 4339-1, Appendix A)

Jones, C.L., 1973, Salt deposits of Los Medanos area, Eddy and Lea Counties, New Mexico: U.S. Geol. Surv., Open-file report, 4339-7.

Jones, C.L., 1975, Potash resources in part of Los Medanos area of Eddy and Lea Counties, New Mexico: U.S. Geol. Survey, Open-file report, 75-407.

Jones, C.L., Bowles, C.G., and Bell, K.G., 1960, Experimental drill hole logging in potash deposits of the Carlsbad district, New Mexico: U.S. Geol. Surv. Open-file report, 60-84.

Keroher, G.C., et al., 1966, Lexicon of geologic names of the United States for 1936-1960: U.S. Geol. Surv. Bull. 1200.

King, P.B., 1942, Permian of west Texas and southeastern New Mexico: Am. Assoc. Pet. Geol. Bull., v. 26, p. 535-763.

King. P.B., 1948, Geology of the southern Guadalupe Mountains, Texas: U.S. Geol. Surv., Prof. Paper 215.

Lang, W.B., 1935, Upper Permian formation of Delaware Basin of Texas and New Mexico: Am. Assoc. Pet. Geol. Bull., v. 19, p. 262-276.

Lang, W. B., 1937, The Permian formations of the Pecos Valley of New Mexico and Texas: Am. Assoc. Pet. Geol. Bull., v. 21, no. 7, p. 833-898.

Long, G.J., and Associates, Inc., 1977a, Final report, Waste Isolation Pilot Plant (WIPP), Los Medanos area, Eddy and Lea Counties, New Mexico: Report submitted to Sandia Laboratories, Albuquerque, New Mexico.

Long, G.J., and Associates, Inc., 1977b, Letter report from J.L. Hern of G.J. Long and Associates, Houston, Tex,. to W.D. Weart of Sandia Laboratories, Albuquerque, New Mexico.

Mansure, A., and Reiter, M., 1977, An accurate equilibrium temperature log in AEC #8, a drill test in the vicinity of the Carlsbad disposal site: New Mexico Bureau Mines and Mineral Resources, Open-file report #80.

McGlasson, E.H., 1968, Siluro-Devonian of west Texas and southeastern New Mexico: New Mexico Bureau Mines and Mineral Resources, Circ. 10, p. 26-37.

McKee, E.D., and Oriel, S.S., et al., 1967a, Paleotectonic investigations of the Permian System in the United States: U.S. Geol. Surv. Prof. Paper 515.

McKee, E.D., and Oriel, S.S., et al., 1967b, Paleotectonic maps of the Permian System: U.S. Geol. Surv. Misc. Geologic Investigations Map I-450.

Meyer, R.F., 1966, Geology of Pennsylvanian and Wolfcampian rock in southeast New Mexico: New Mexico Bureau Mines and Mineral Resources, Memoir 17.

Muehlberger, W.R., Denison, R.E., and Lidiak, E.G., 1967, Basement rocks in continental interior of United States: Am. Assoc. Pet. Geol. Bull., v. 51, p. 2351-2380.

Murray, G.E., 1961, Geology of the Atlantic and Gulf coastal province of North America: Harper Bros., New York.

Netherland, Sewell and Associates, 1974, Evaluation of hydrocarbon potential, AEC study area, southeast New Mexico, based on geological and engineering studies as of May, 1974: report submitted to Oak Ridge National Laboratory, Oak Ridge, Tennesee, dated June 11, 1974.

Newell, N.D., Rigby, J.K. Fischer, A.G., Whiteman, A.J., Hickox, J.E., and Bradley, J.S., 1953, The Permian reef complex of the Guadalupe Mountains region, Texas and New Mexico -- A study in paleoecology: W.H. Freeman & Co., San Francisco, 236p.

Oriel, S.S., Myers, D.A., and Crosby, E.J., 1967, West Texas Permian Basin region, Chapter C, in McKee, E.D., et al., Paleotectonic Investigations of the Permian System of the United States: U.S. Geol. Surv. Prof. Paper 515-C, p. 21-60.

Reynolds, C.B., and Associates, 1976, Summary and final report, shallow seismic reflection survey, Phases I and II, Los Medanos area, Eddy County, New Mexico: Report submitted to Sandia Laboratories, Albuquerque, New Mexico, undated.

Sipes, Williamson and Aycock, Inc., 1976, Hydrocarbon evalution, proposed southeastern New Mexico radioactive material storage site, Eddy County, New Mexico: Report submitted to Sandia Laboratories, Albuquerque, New Mexico, dated September 1, 1976.

Vine, J.D., 1960, Recent domal structures in southeastern New Mexico: Am. Assoc. Pet. Geol. Bull., v. 44, no. 12, p. 1903-1911.

Vine, J.D., 1963, Surface geology of the Nash Draw quadrangle, Eddy County, New Mexico: U.S. Geol. Surv. Bull. 1141-B.

Thompson, M.L., 1942, Pennsylvanian system in New Mexico: New Mexico School of Mines, Bull. 17.

Urry, W.E., 1936. Post-Keweenawan time scale: Nat. Res. Council Comm. on Measurement of Geologic Time, 1935-1936: Rept. Exbt. 2, p. 35-40.

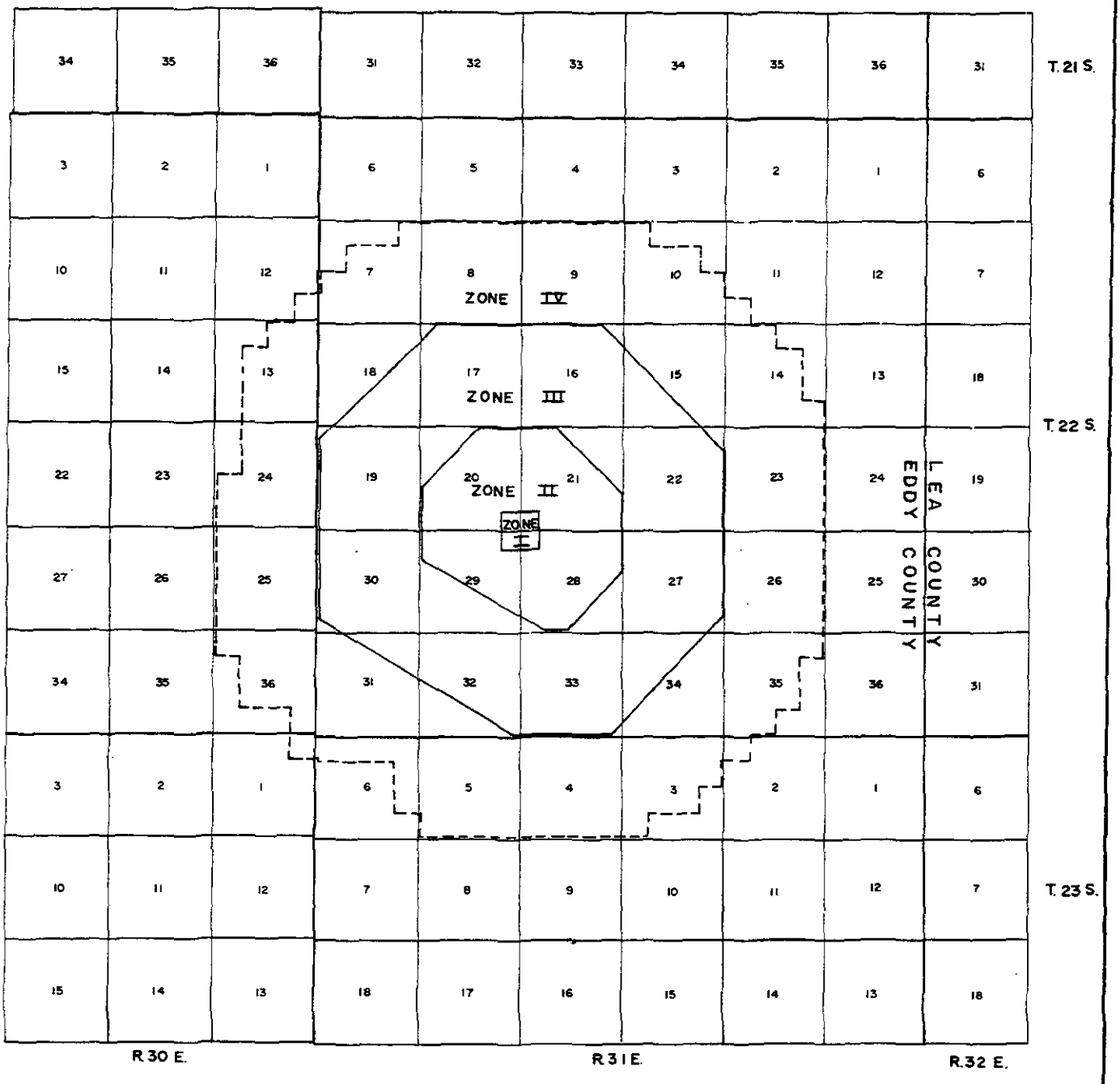

ZONE ACREAGE

ZONE I - 60-100 (surface facilities)

ZONE II - 1860 (underground repository)

ZONE III - 6230 (no mining or drilling)

ZONE IV - 10,810 (DOE-controlled mining and drilling)

1 0 1 2 3

SCALE IN MILES

WIPP SITE ZONATION

FIGURE 4.1-1

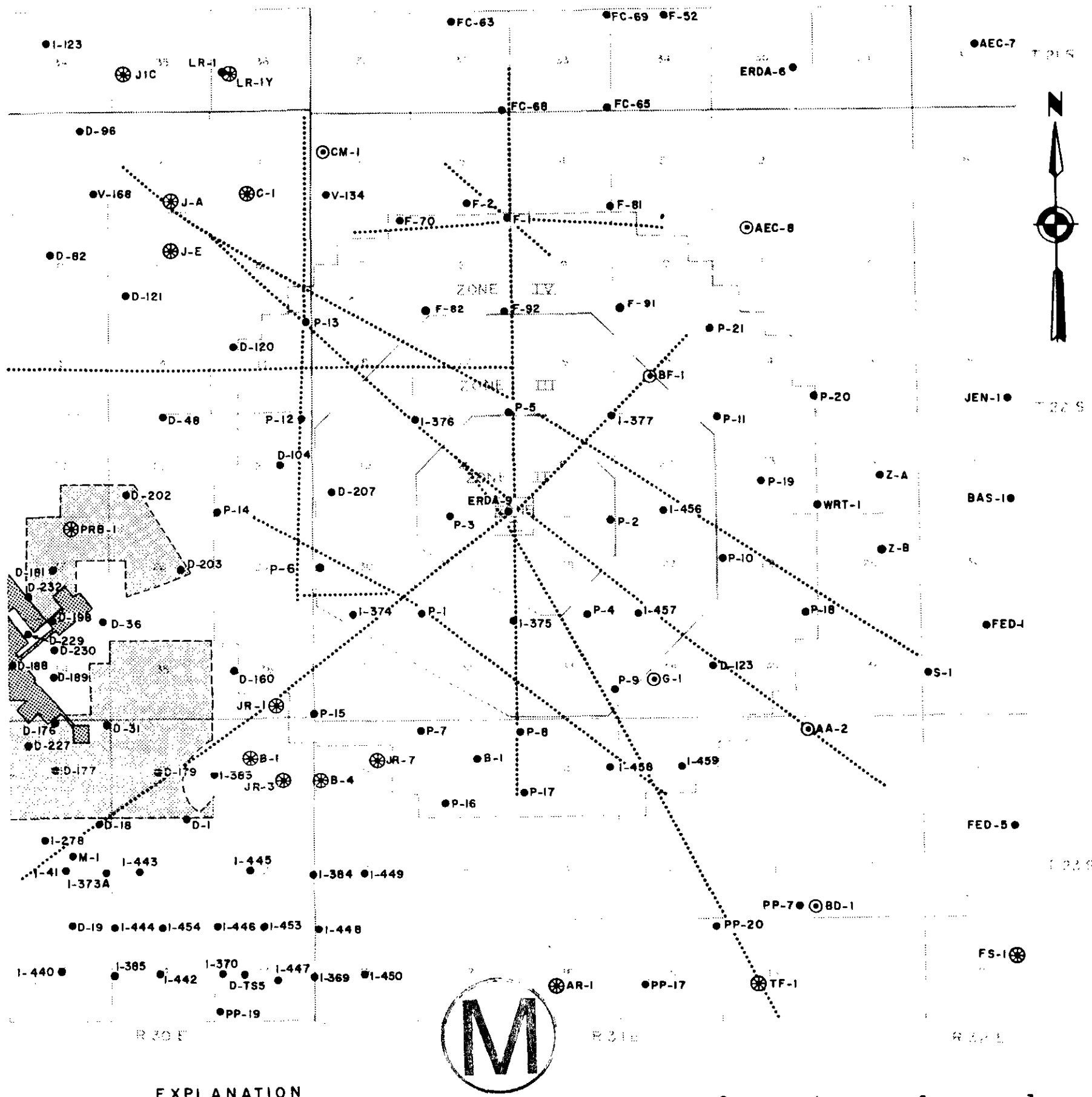

EXPLANATION

- ● Shallow drill holes (bottoming above the Delaware)
- ⊙ Drill holes penetrating Delaware and deeper horizons
- ⊛ Hydrocarbon producer (past or present)
- ····· Seismic reflection survey lines
- Location of underground potash mines
- Area of planned underground potash mining

NOTE:

1. Additional drill hole data are listed in Table 4.1-1
2. All seismic profiling shown was performed under contract to Sandia Laboratories for the WIPP Site.

REFERENCES:

Griswold, 1977, figure 4.
G. J. Long & Associates, May, 1977
G. J. Long & Associates, Dec., 1977

SITE EXPLORATION
DRILL HOLES AND SEISMIC REFLECTION LINES

FIGURE 4.1-2

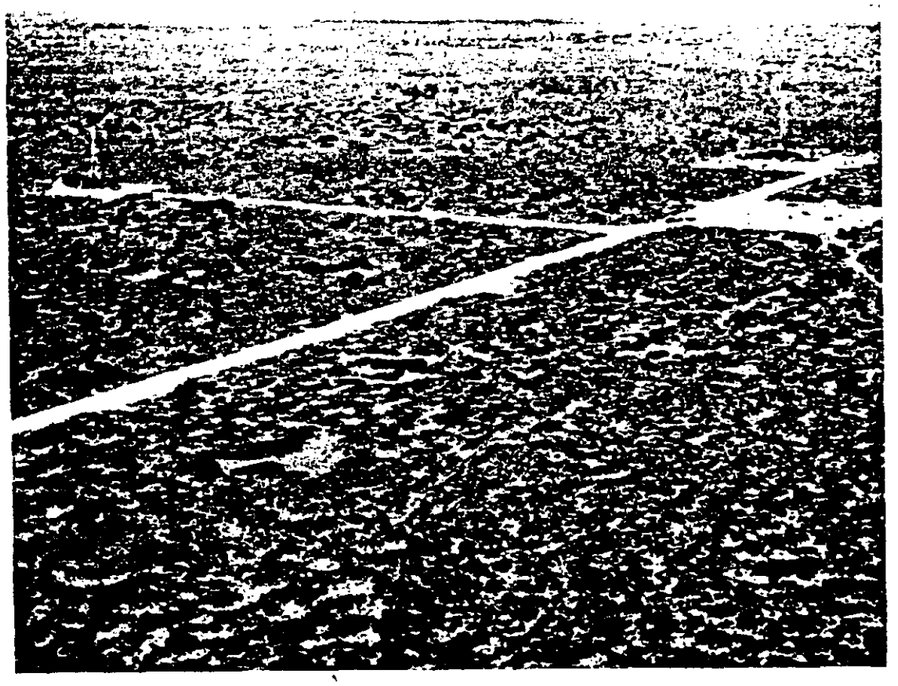

A) Air view northwest across WIPP Site, showing general terrain. Drill rig at right is near center of site, working on ERDA-9. Rig at left is set up on hole H-1.

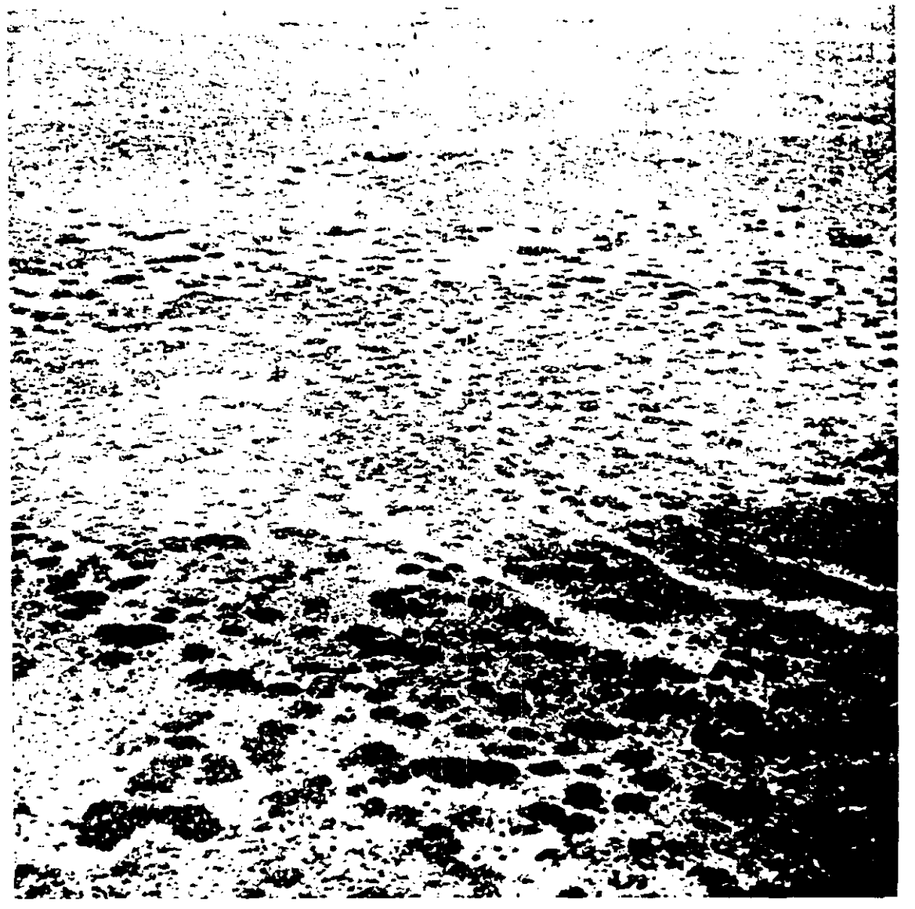

B) Shallow depression eight miles north of site. Diameter about 1000 feet and relief about 30 feet. Investigation of this feature has found no indication of subsurface subsidence or collapse.

SITE PHYSIOGRAPHIC FEATURES

FIGURE 4.2-1

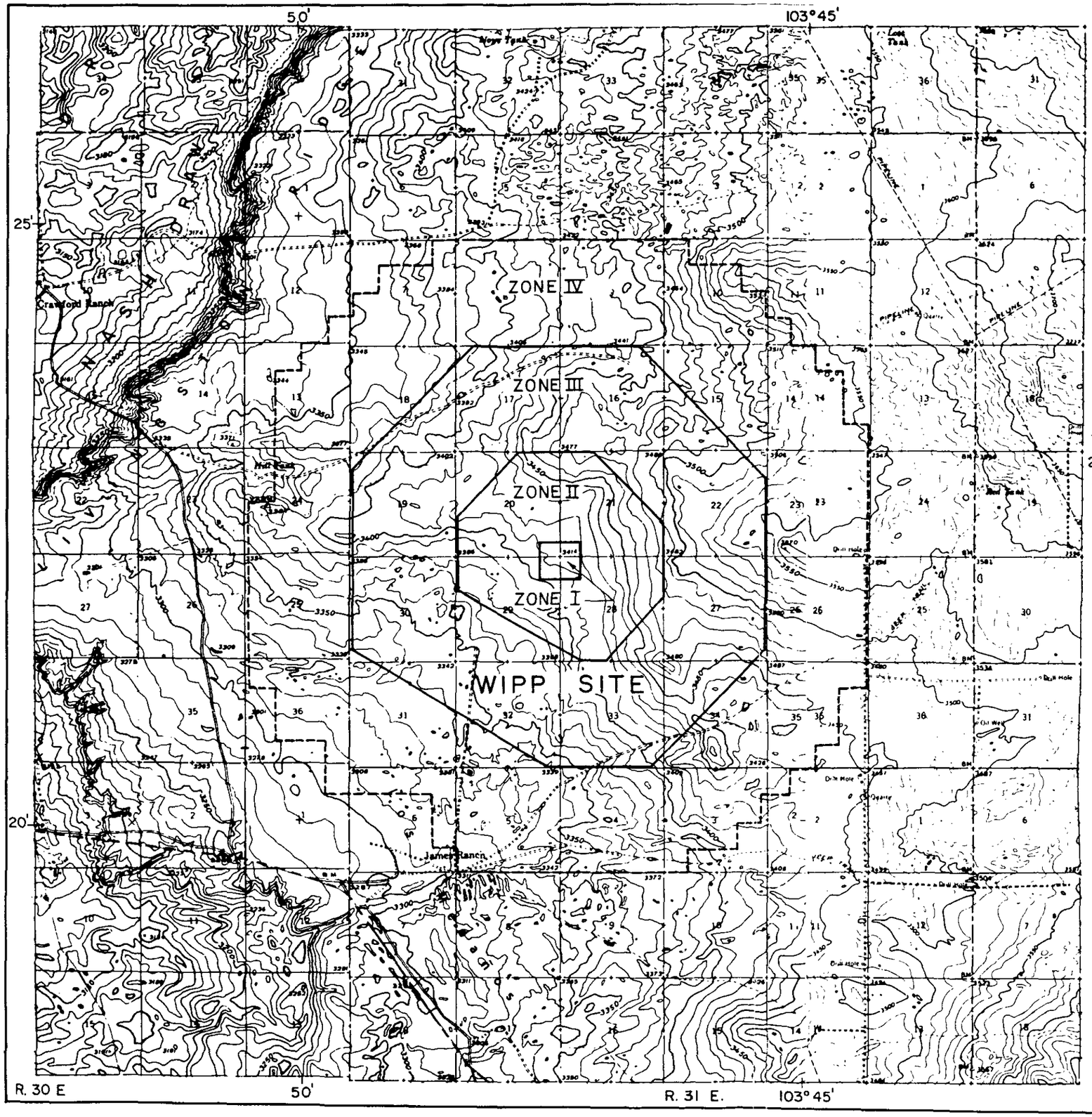

REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

0 1 2 3 MILES

0 1 2 3 KM.

SCALE

SITE TOPOGRAPHIC MAP

FIGURE 4.2-2

26

Active sand dunes at James Ranch. Location is 3 miles south of center of site. Viewed southeast.

ACTIVE DUNES NEAR SITE

FIGURE 4.2-3

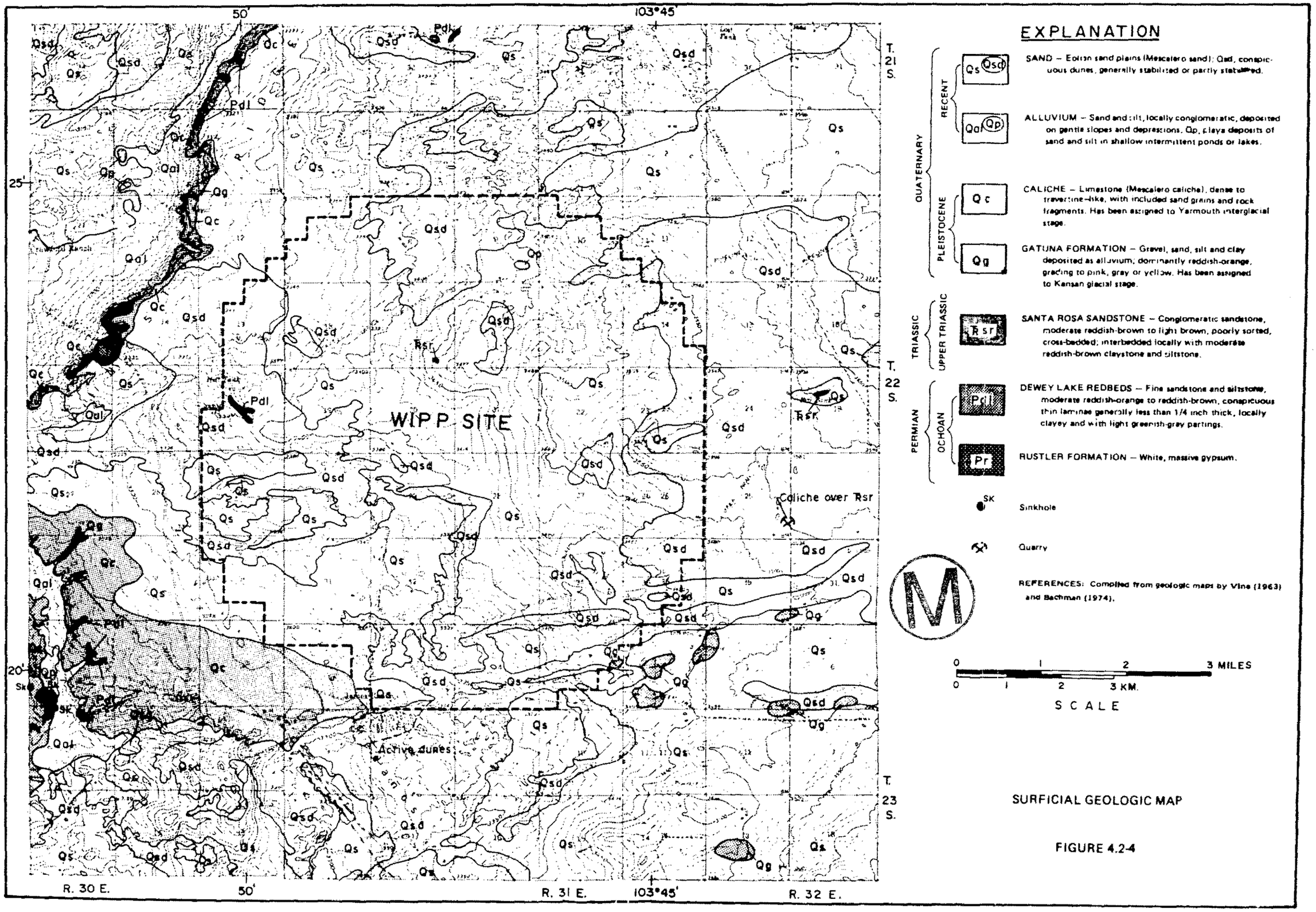

SURFICIAL GEOLOGIC MAP

FIGURE 4.2-4

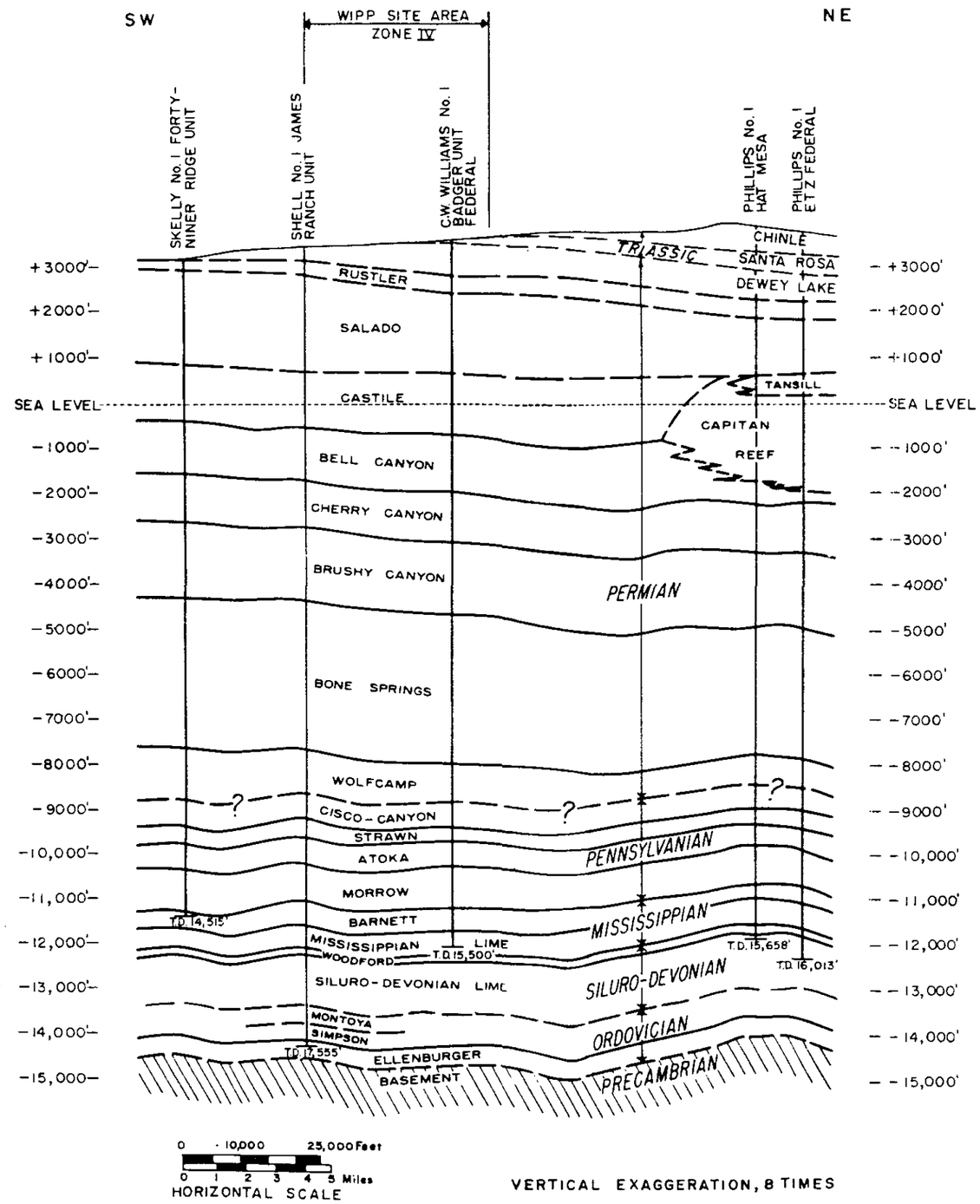

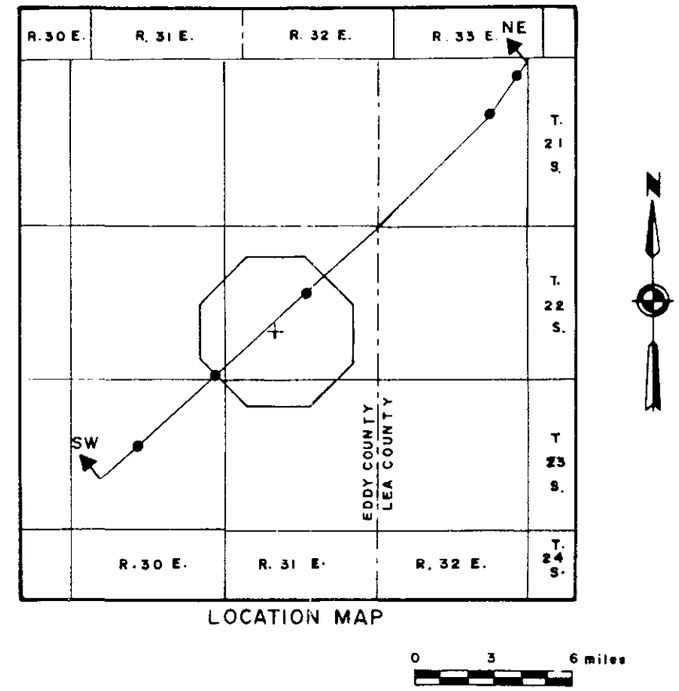

LOCATION MAP

REFERENCE:
Netherland, Sewell & Associates, 1974, Exbt. G-18

GENERALIZED SITE STRATIGRAPHIC SECTION

FIGURE 4.3-1

EXPLANATION

LITHOLOGIC SYMBOLS

- Sandstone
- Mudstone; siltstone; silty and sandy shale.
- Shale
- Limestone
- Dolomite
- Cherty limestone and dolomite
- Shaly limestone
- Anhydrite (or gypsum)
- Interlaminated anhydrite-calcite
- Halite (rock salt)
- Granitic rocks

REFERENCES:

1. Anderson, 1978
2. Anderson, et al, 1972
3. Brokaw, et al, 1972
4. Foster, 1974
5. Griswold, 1977
6. Meyer, 1966
7. Sipes, Williamson and Aycock, 1976

NOTE:

For complete citations, refer to reference list for chapter 4.

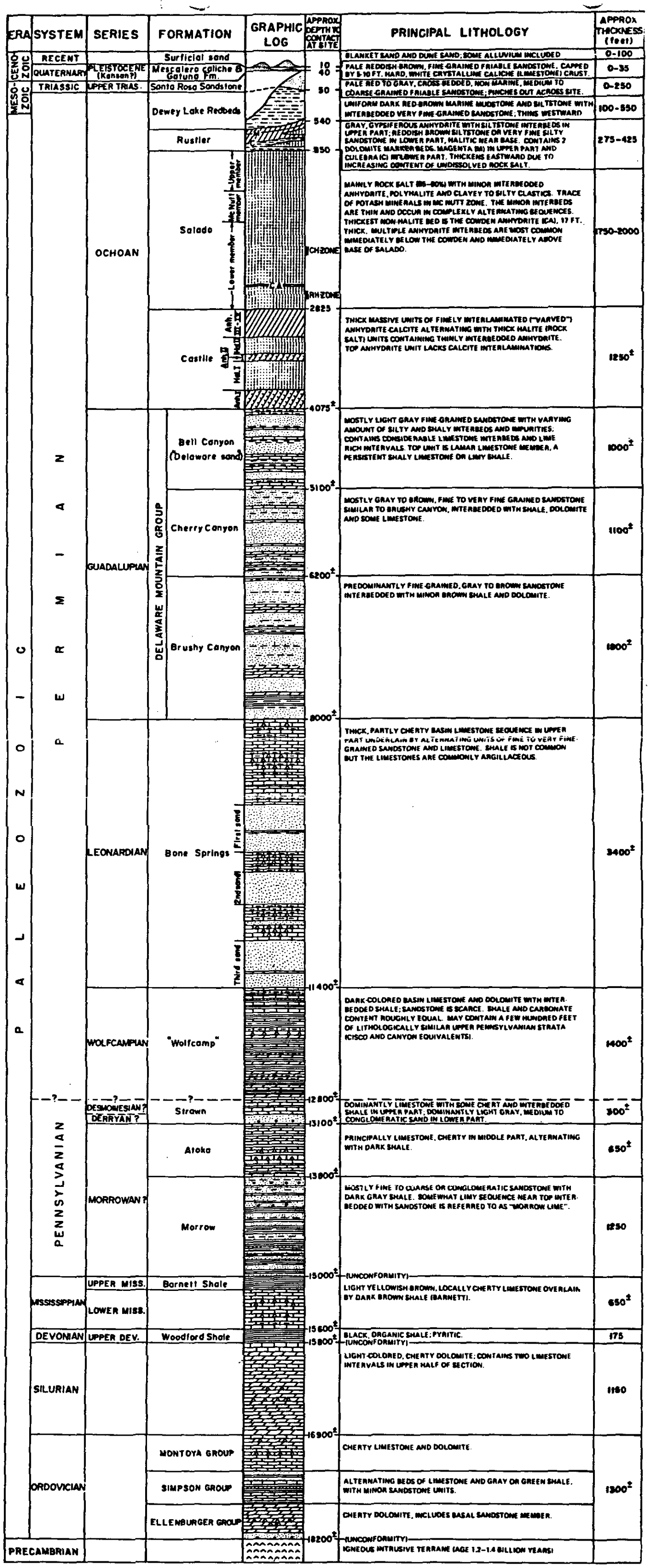

0
300
600
1200
1800
2400
3000

VERTICAL SCALE OF SECTION IN FEET

SITE GEOLOGIC COLUMN

FIGURE 4.3-2

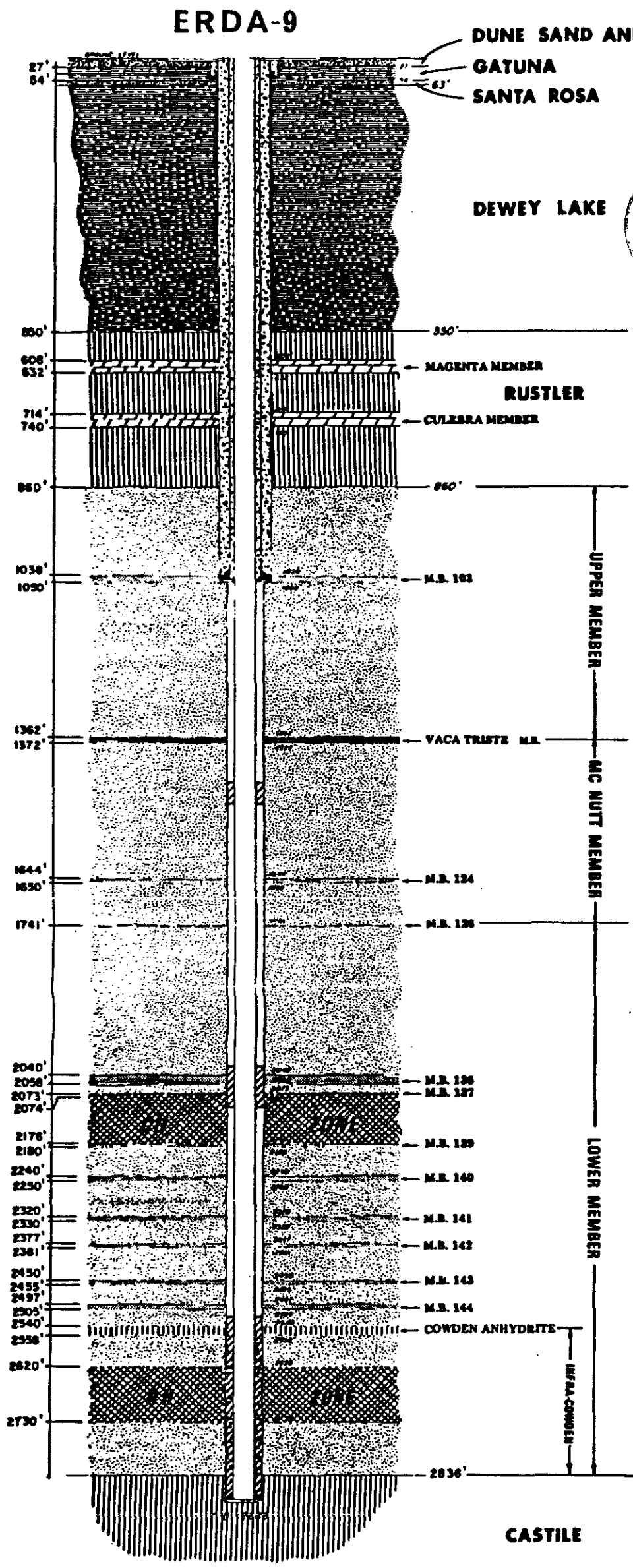

EXPLANATION

- Sand and Sandstone
- Mudstone and Siltstone
- Anhydrite
- Rock Salt
- Dolomite
- Storage zones
- Drill Stem Test Interval
- Cement grout
- Bottom of casing
- Marker bed zones

NOTES:

1. All rocks below Santa Rosa are Permian in age.
2. All depths given are measured from Kelly bushing reference point (See note 4).
3. Ground surface elevation is 3414.70 feet, MSL
4. Kelly bushing elevation is 3426.25 feet, MSL
5. MB = Marker Bed

REFERENCE:

Griswold, 1977, fig. 19

KEY PLAN

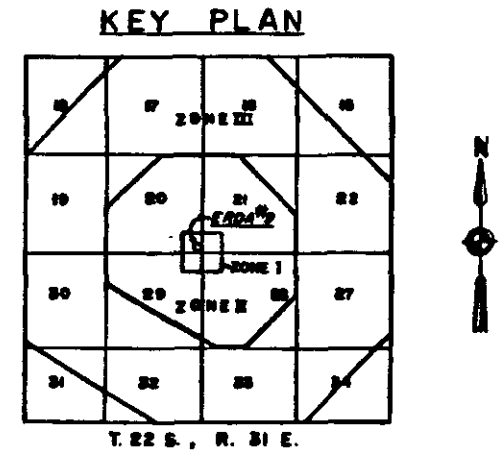

GENERALIZED ERDA-9 STRATIGRAPHY

FIGURE 4.3-3 A

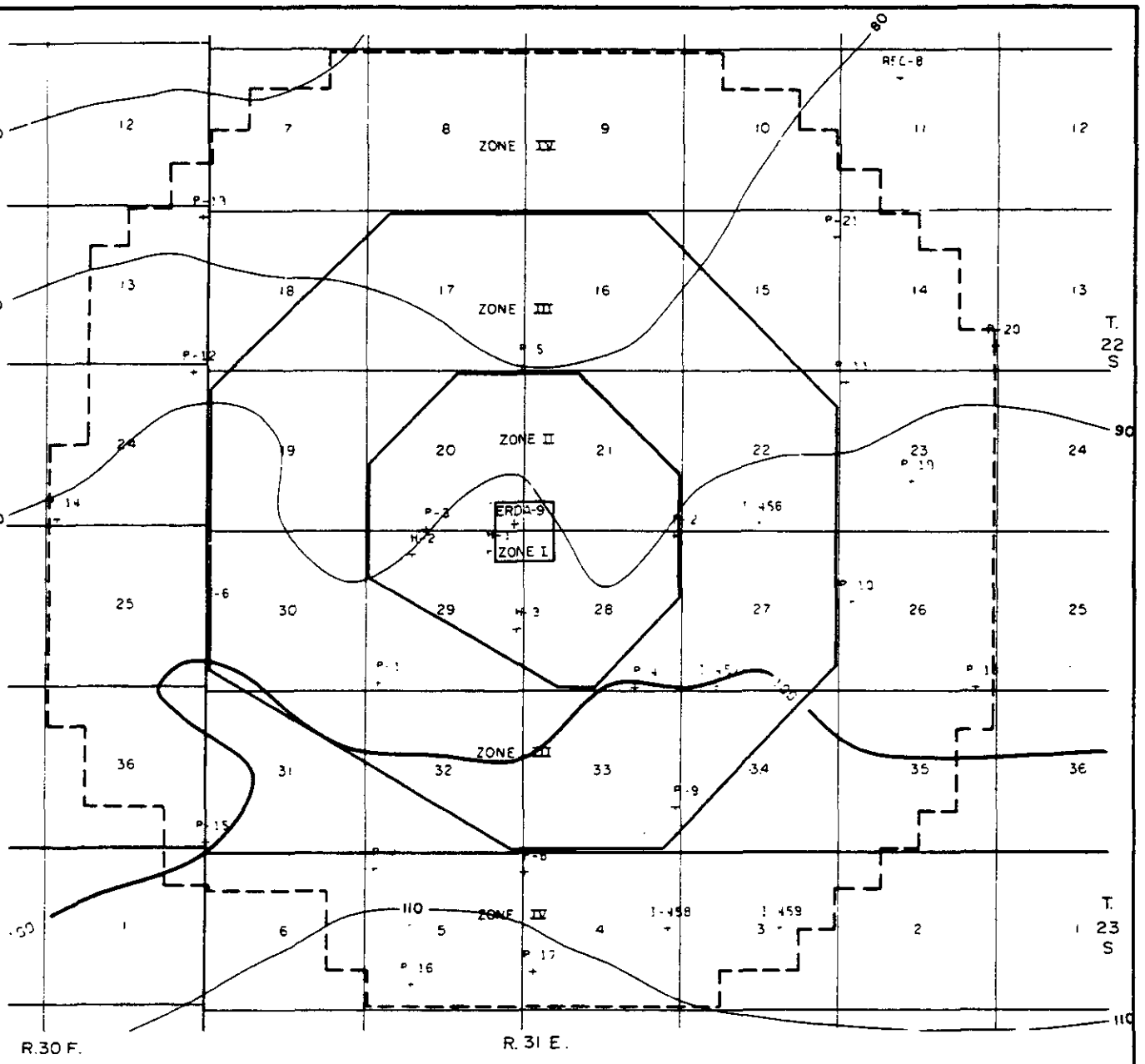

CONTOUR INTERVAL - 10 FEET

REFERENCE:

Griswold, 1977, figure 11

ISOPACH MAP

124 TO 126 MARKER BEDS

FIGURE 4.3-4

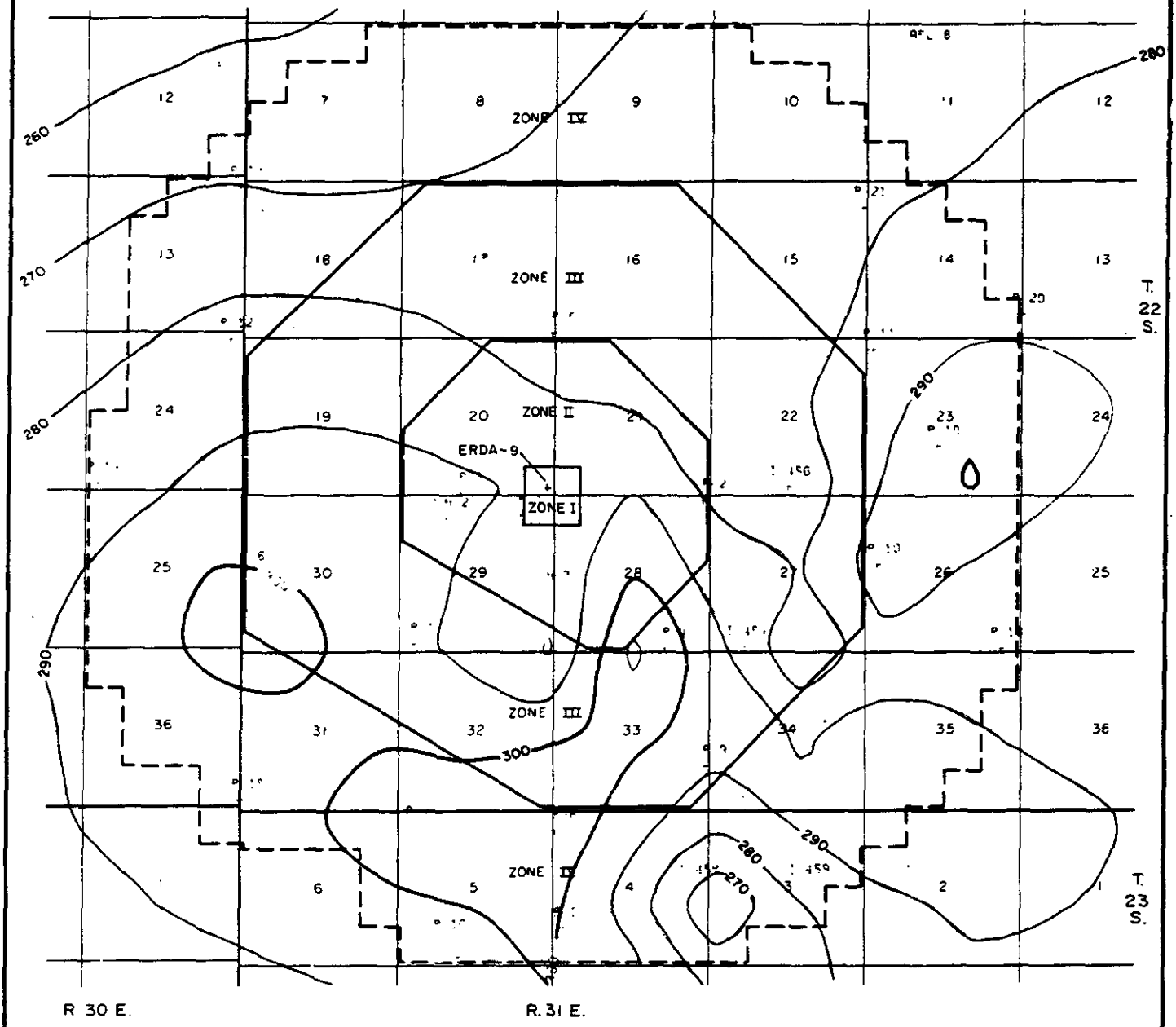

0 1 2 3

SCALE IN MILES

CONTOUR INTERVAL - 10 FEET

N

ISOPACH MAP VACA TRISTE TO 124-MARKER BEDS

REFERENCE:

Griswold, 1977, figure 11

FIGURE 4.3-5

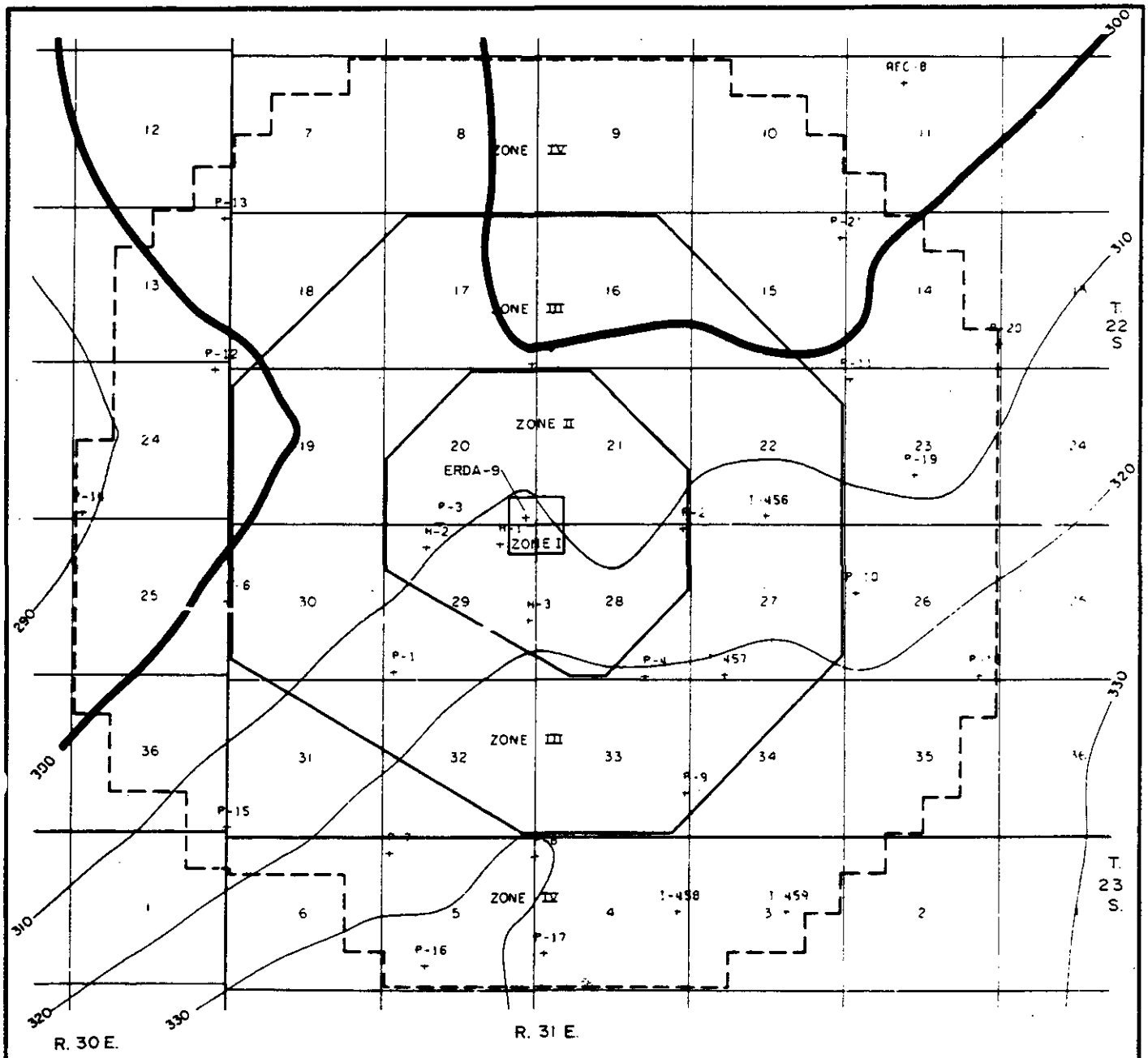

0 1 2

SCALE IN MILES

CONTOUR INTERVAL - 10 FEET

N

ISOPACH MAP 103 TO
VACA TRISTE MARKER BEDS

REFERENCE:

Griswold, 1977, figure 11

FIGURE 4.3-6

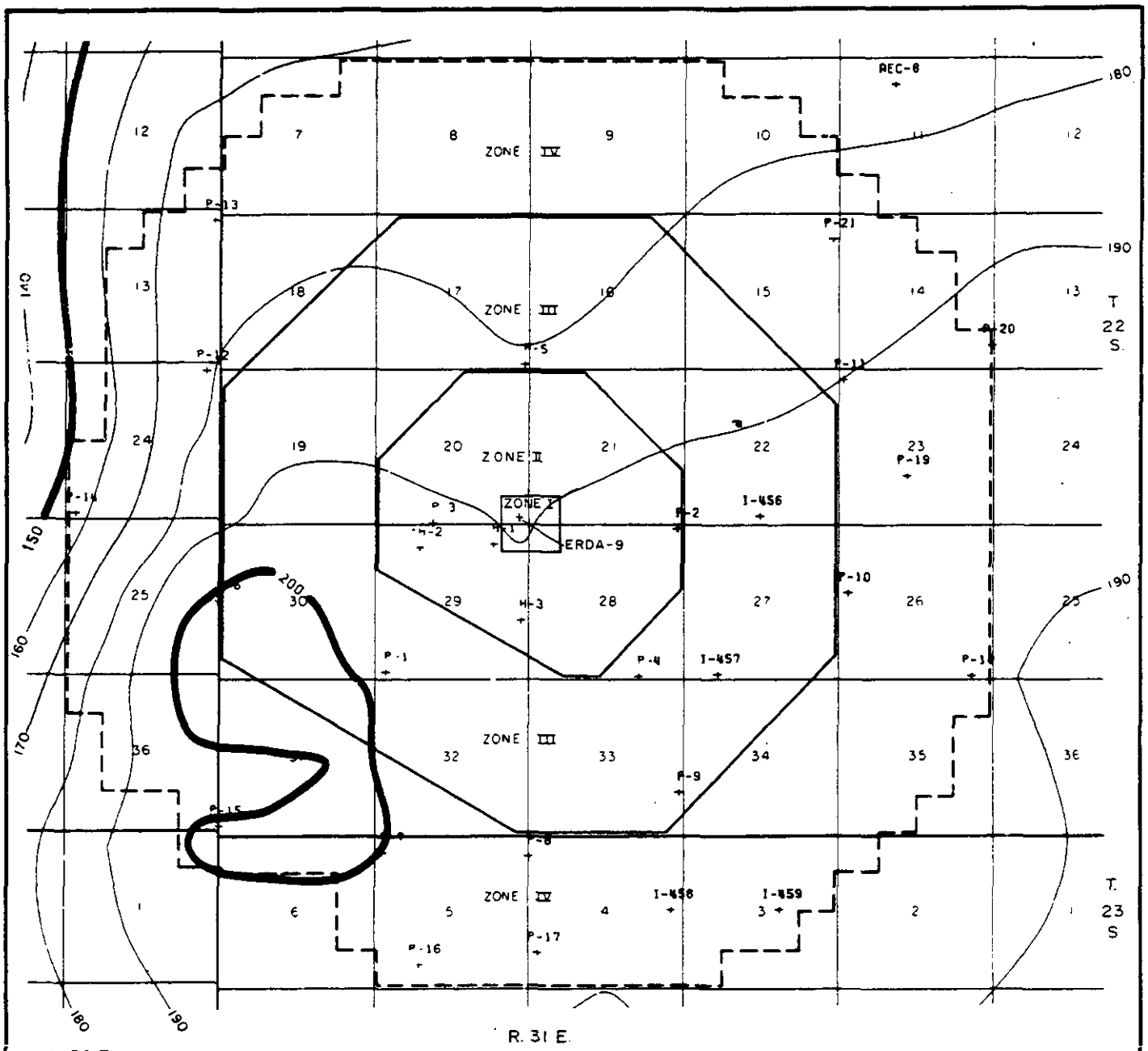

0 1 2 3

SCALE IN MILES

CONTOUR INTERVAL - 10 FEET

ISOPACH MAP TOP OF SALADO TO 103-MARKER BED

REFERENCE:

Griswold, 1977, figure 11

FIGURE 4.3-7

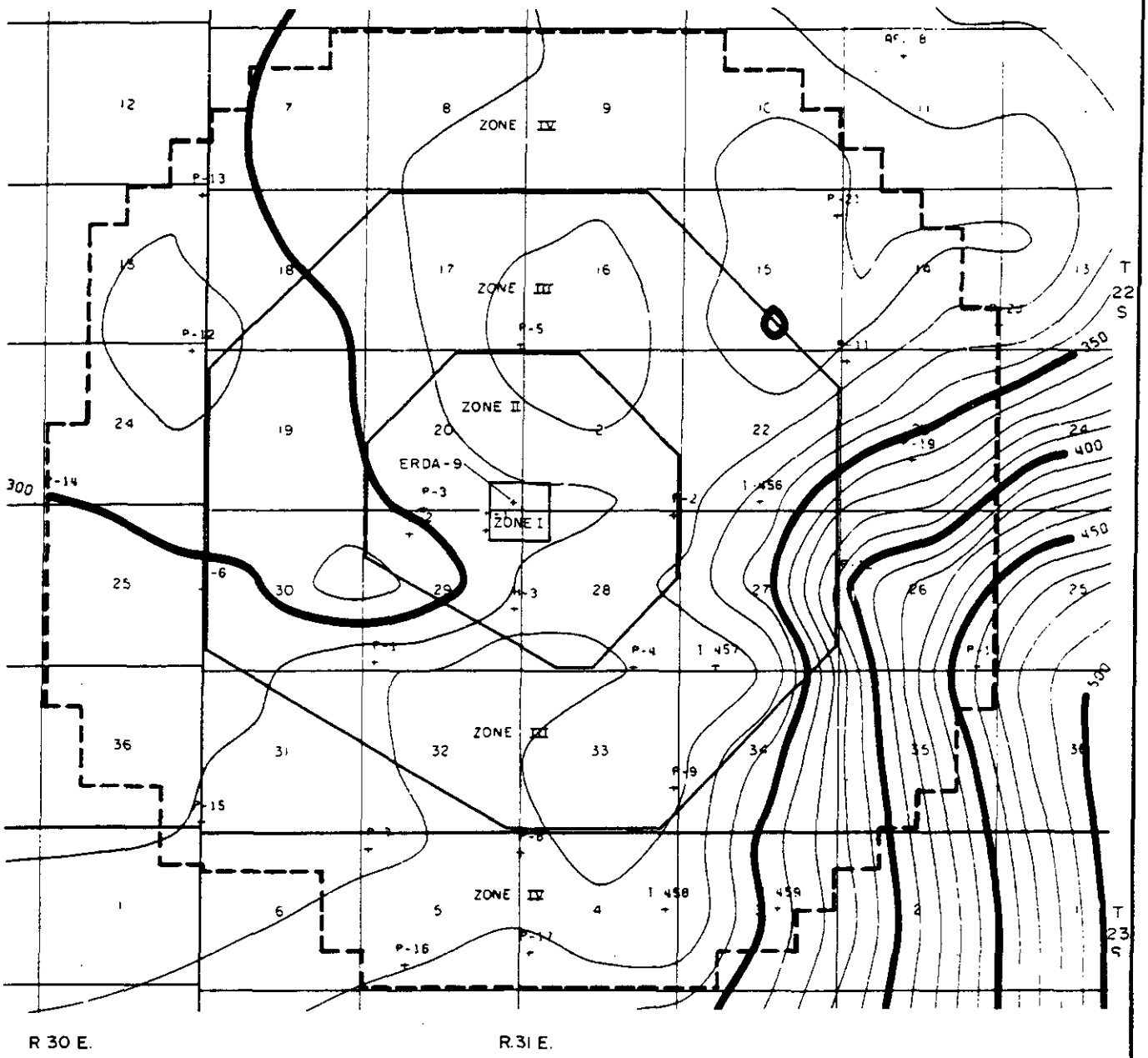

CONTOUR INTERVAL - 10 FEET

ISOPACH MAP
RUSTLER FORMATION

REFERENCE:

Griswold, 1977, figure 10

FIGURE 4.3-8

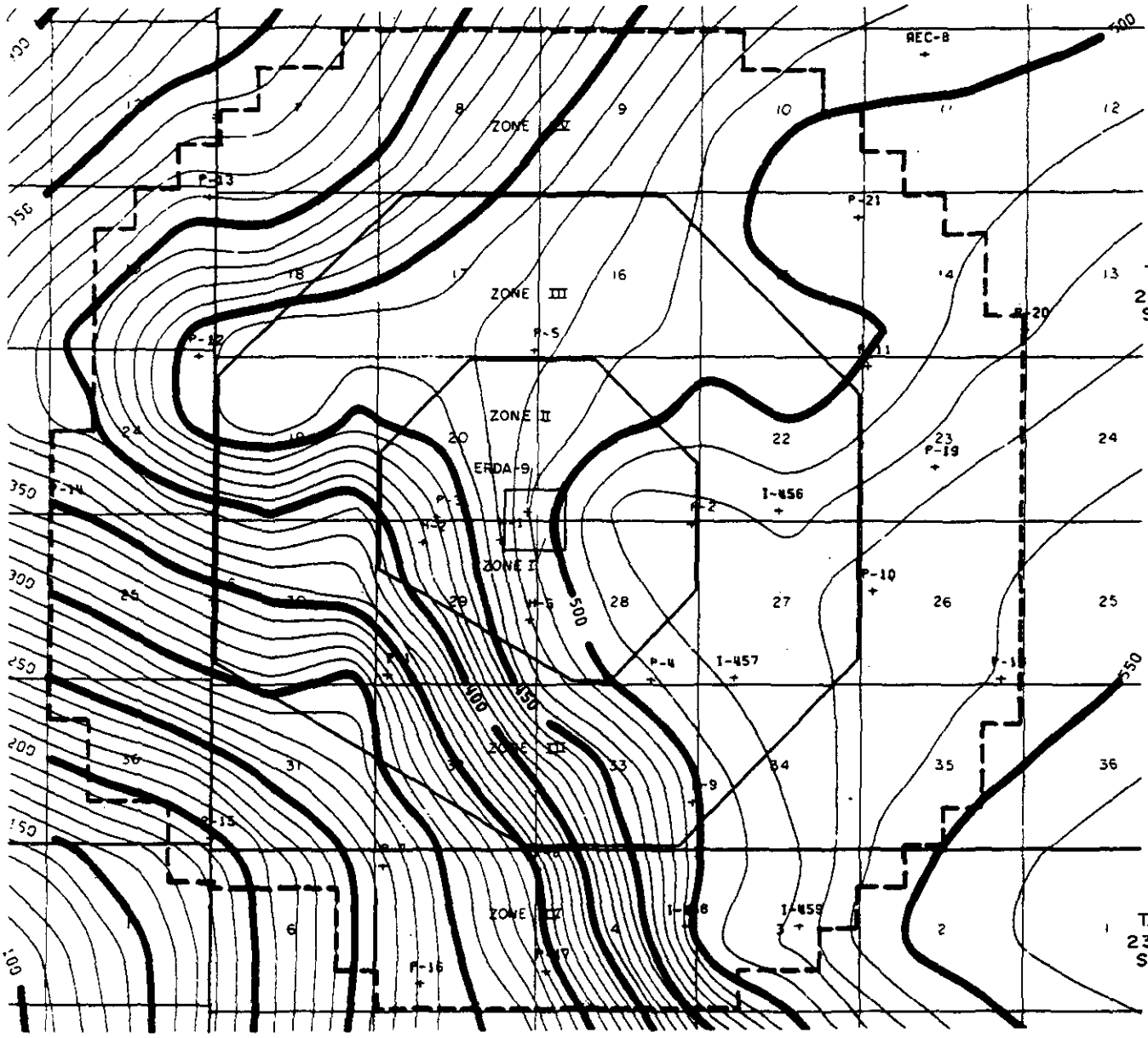

0 1 2 3

SCALE IN MILES

CONTOUR INTERVAL - 10 FEET

N

REFERENCE:

Griswold, 1977, figure 10

ISOPACH MAP

DEWEY LAKE REDBEDS

FIGURE 4.3-9

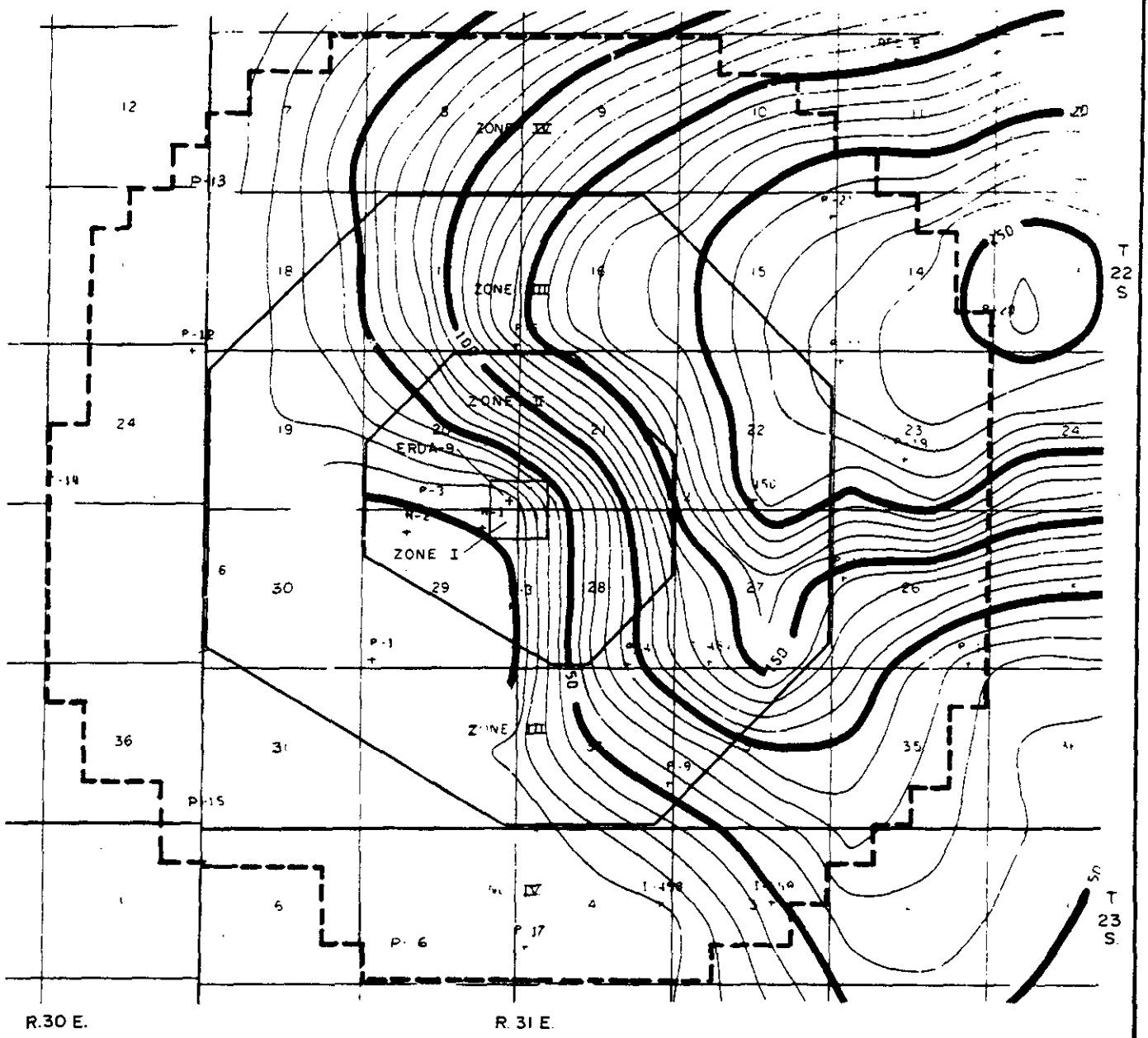

CONTOUR INTERVAL - 10 FEET

ISOPACH MAP
SANTA ROSA SANDSTONE

REFERENCE:

Griswold, 1977, figure 10

FIGURE 4.3-10

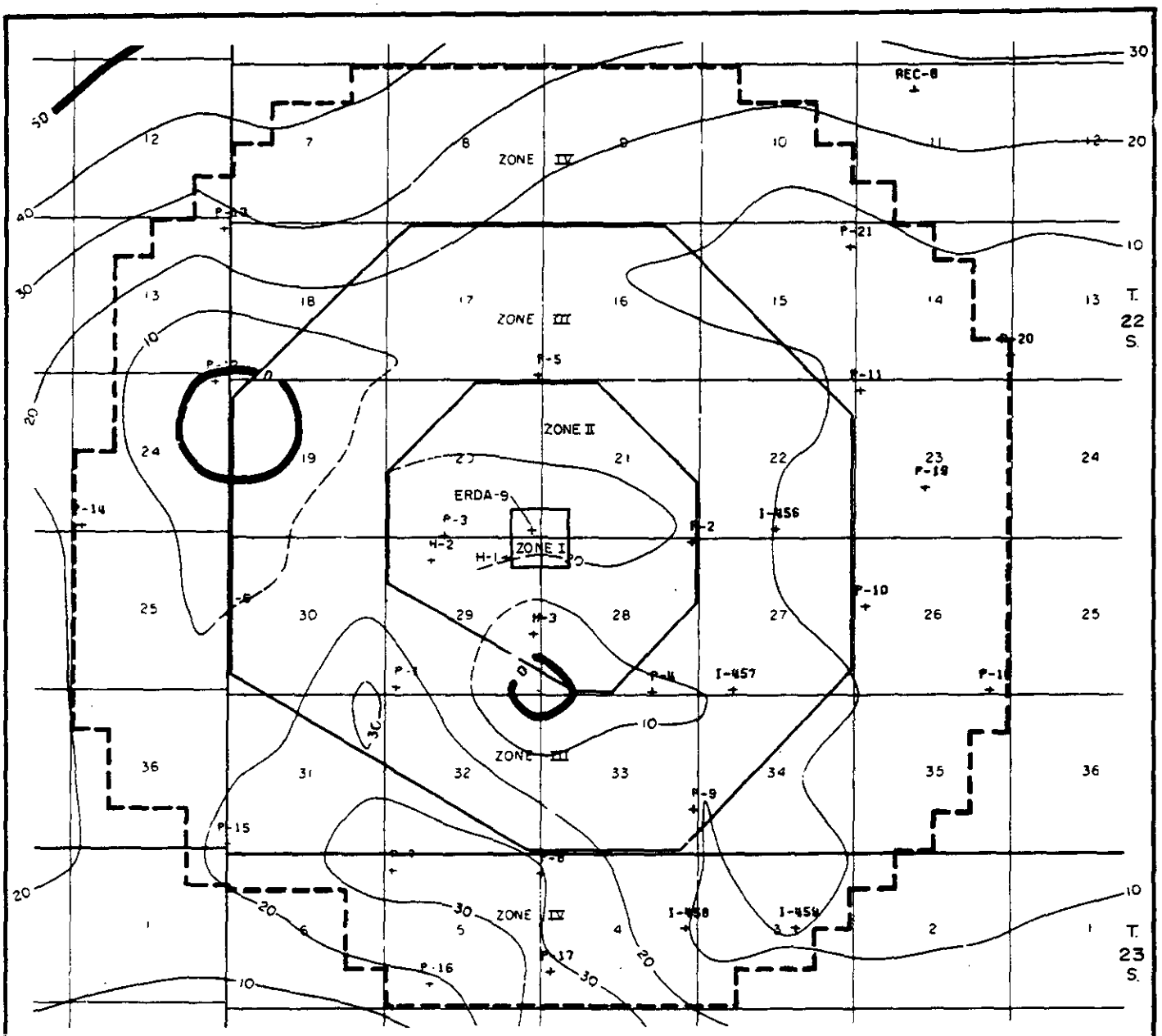

0 1 2 3

SCALE IN MILES

CONTOUR INTERVAL - 10 FEET

N

ISOPACH MAP
GATUNA FORMATION

REFERENCE:

Griswold, 1977, figure 10

FIGURE 4.3-11

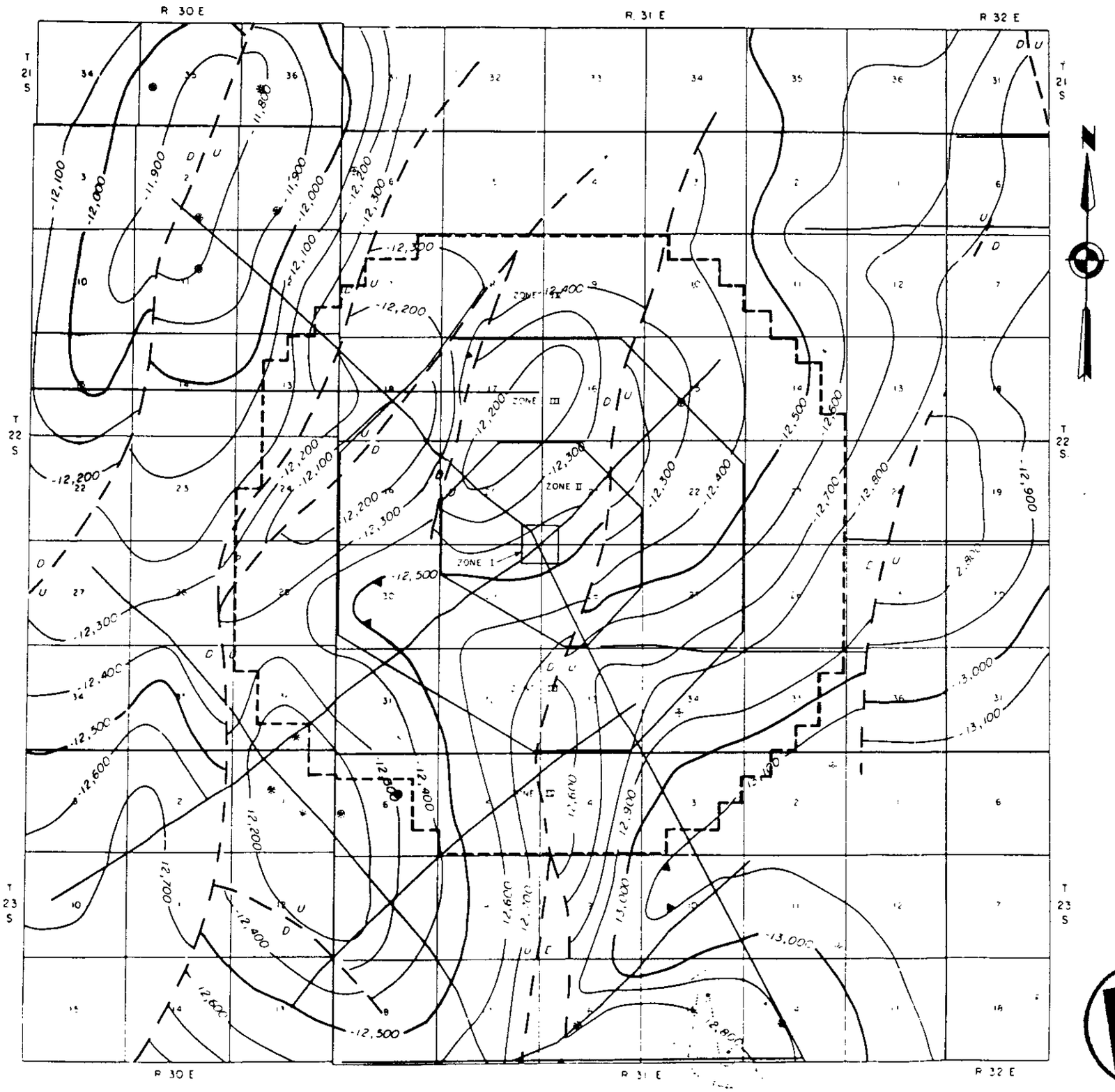

EXPLANATION

Seismic reflection profile lines

Inferred faults
U – Upthrown side
D – Downthrown side

- Well - Dry and Abandoned
- Completed Well - Producing Gas
- Completed Well - Producing Oil

Contour interval - 100 feet
Datum is mean sea level

REFERENCE
Griswold, 1977, figure 17

0 1 2 3
SCALE IN MILES

M STRUCTURE CONTOURS ON TOP OF SILURIAN

FIGURE 4.4-1

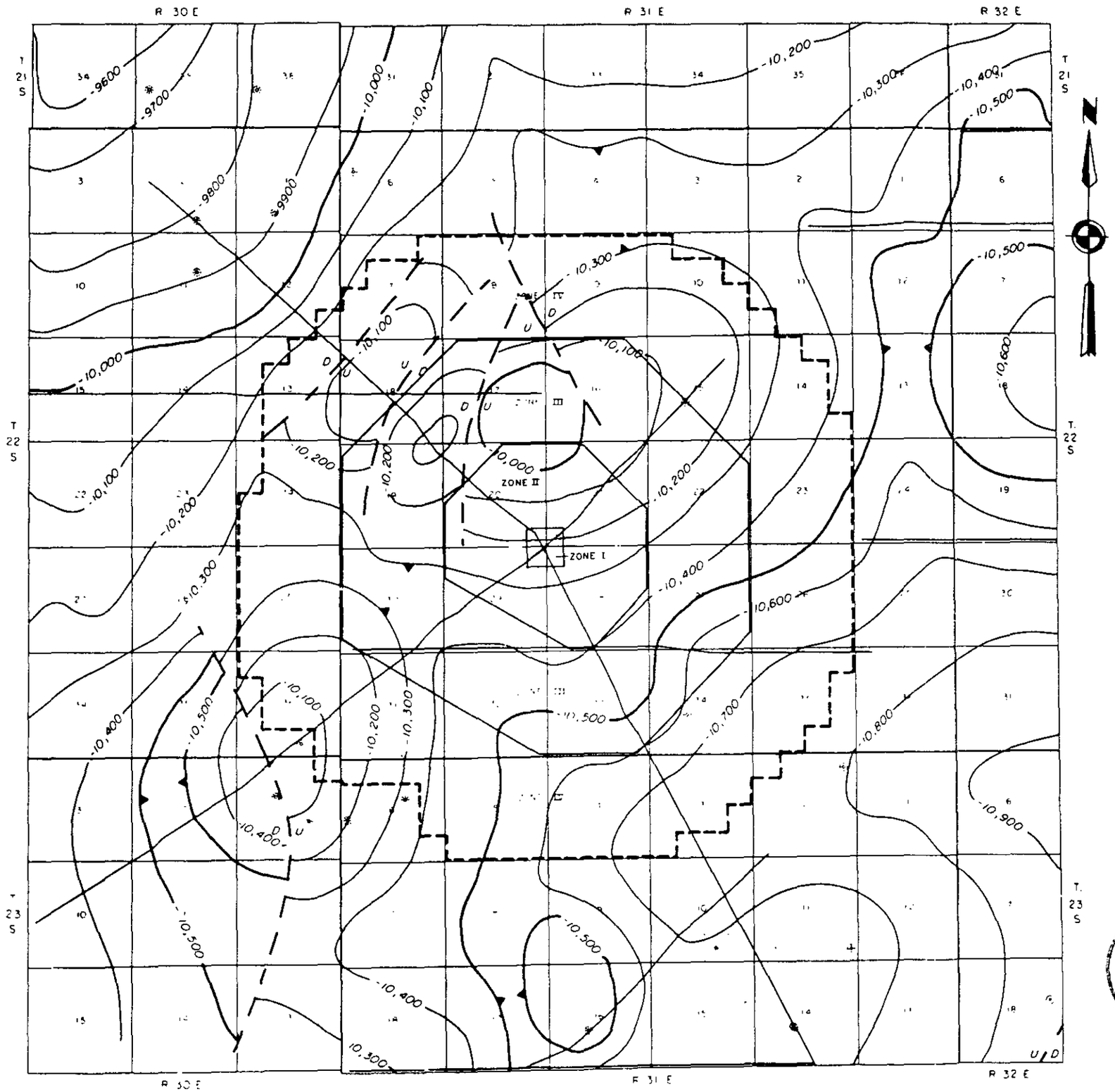

EXPLANATION

Seismic reflection profile lines.

Inferred faults.
U–Upthrown side
D–Downthrown side

- Well - Dry and Abandoned
- Completed Well - Producing Gas
- Completed Well - Producing Oil

Contour interval - 100 feet
Datum is mean sea level

REFERENCE:

Griswold, 1977, figure 16.

0 1 2 3
SCALE IN MILES

STRUCTURE CONTOURS
ON TOP OF
MORROW LIMESTONE

FIGURE 4.4-2

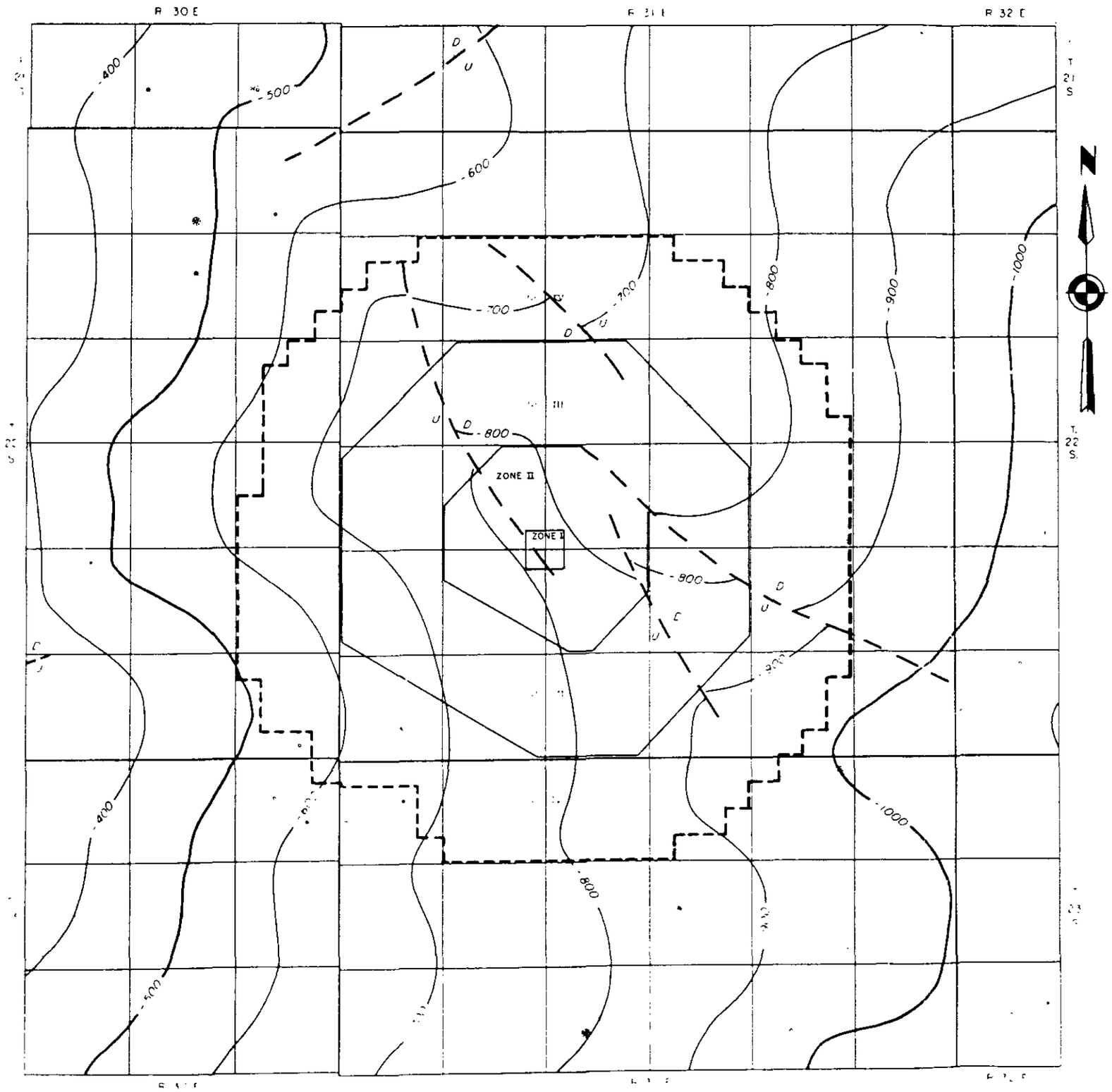

EXPLANATION

Possible faults.
U – Upthrown side
D – Downthrown side

- Well-Dry and Abandoned
- Completed Well - Producing Gas
- Completed Well - Producing Oil

Contour interval - 100 feet
Datum is mean sea level

REFERENCE:

Griswold, 1977, figure 15

0 1 2 3
SCALE IN MILES

STRUCTURE CONTOURS
ON TOP OF
DELAWARE SANDSTONE

FIGURE 4.4-3

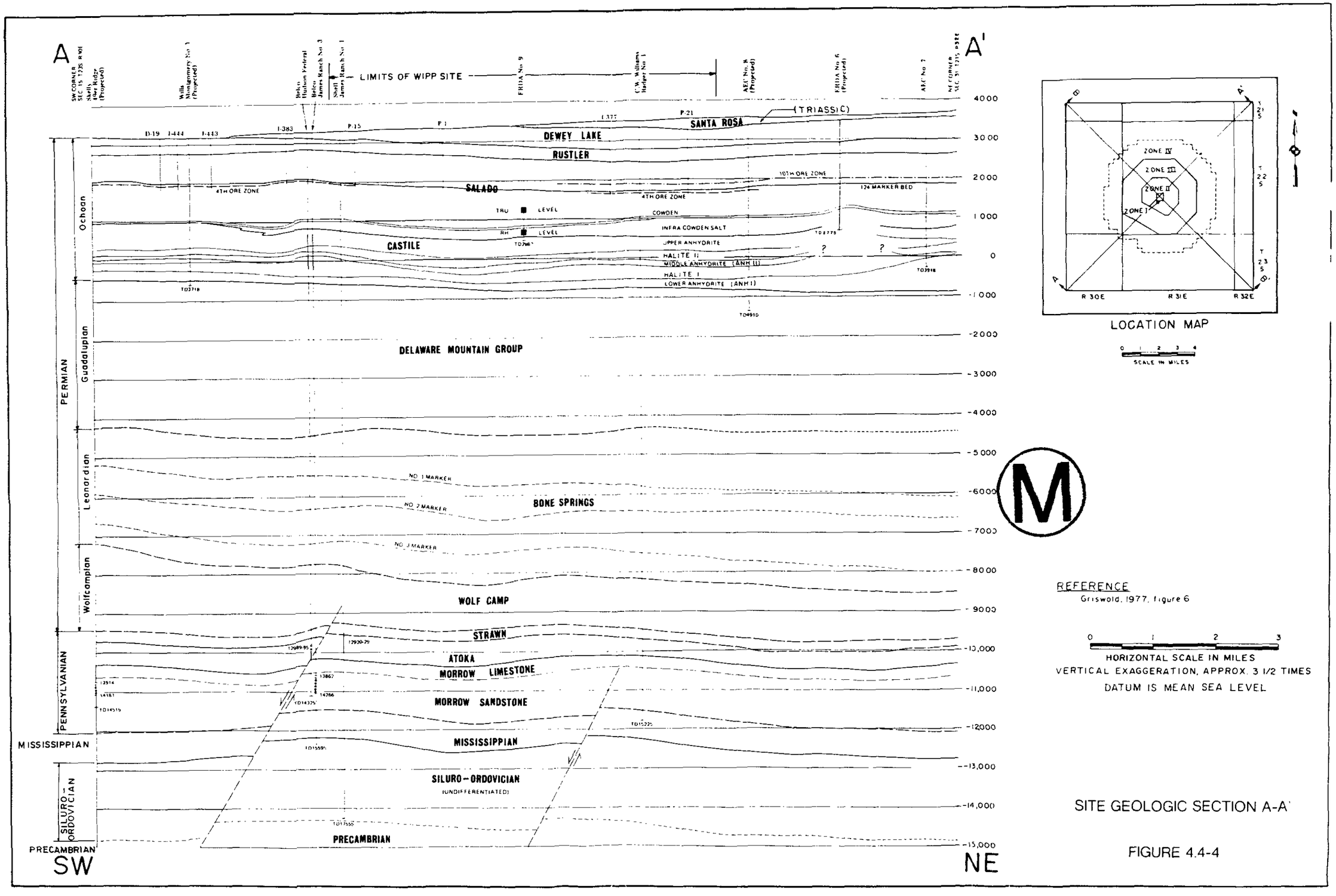

SITE GEOLOGIC SECTION A-A'

FIGURE 4.4-4

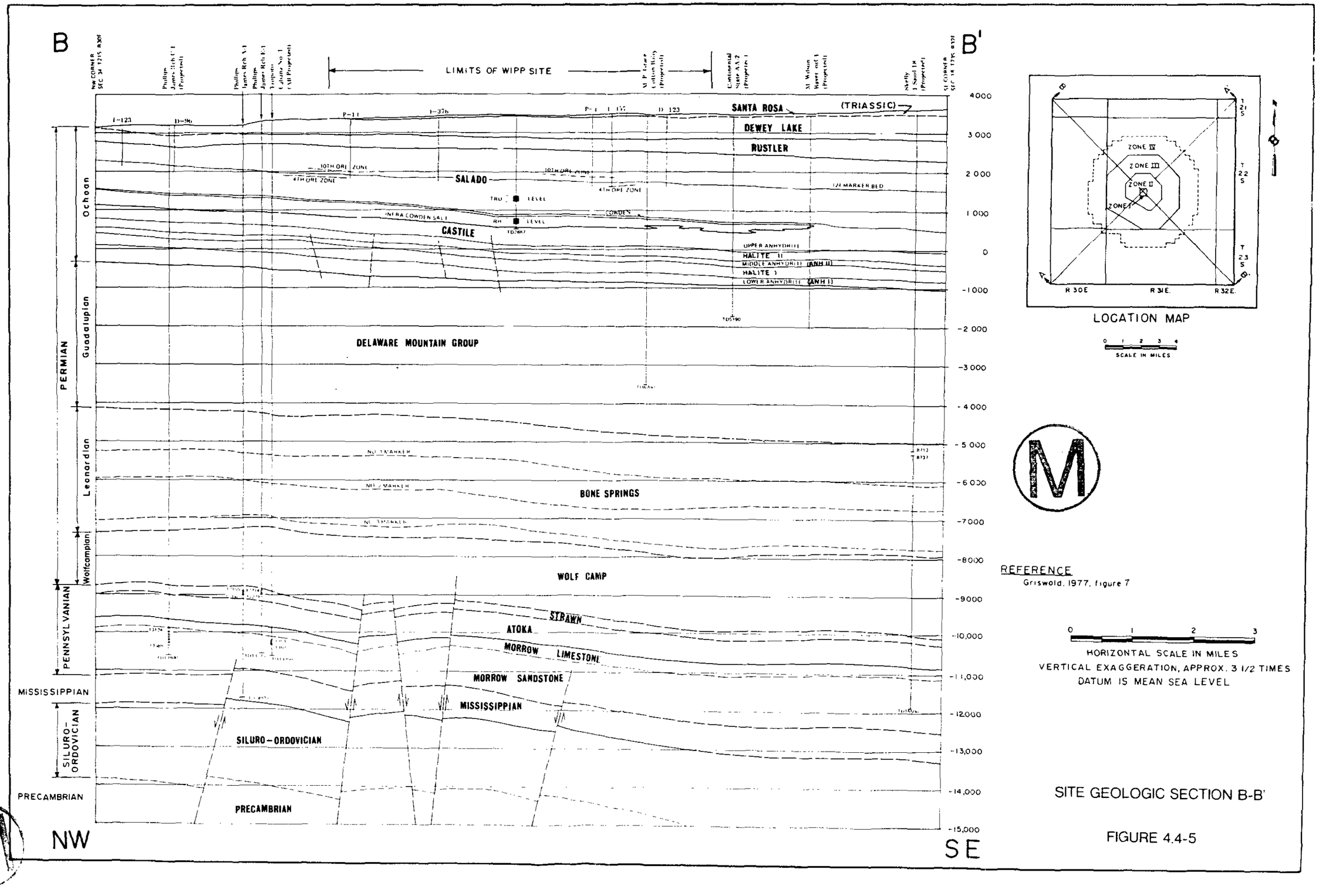

SITE GEOLOGIC SECTION B-B'

FIGURE 4.4-5

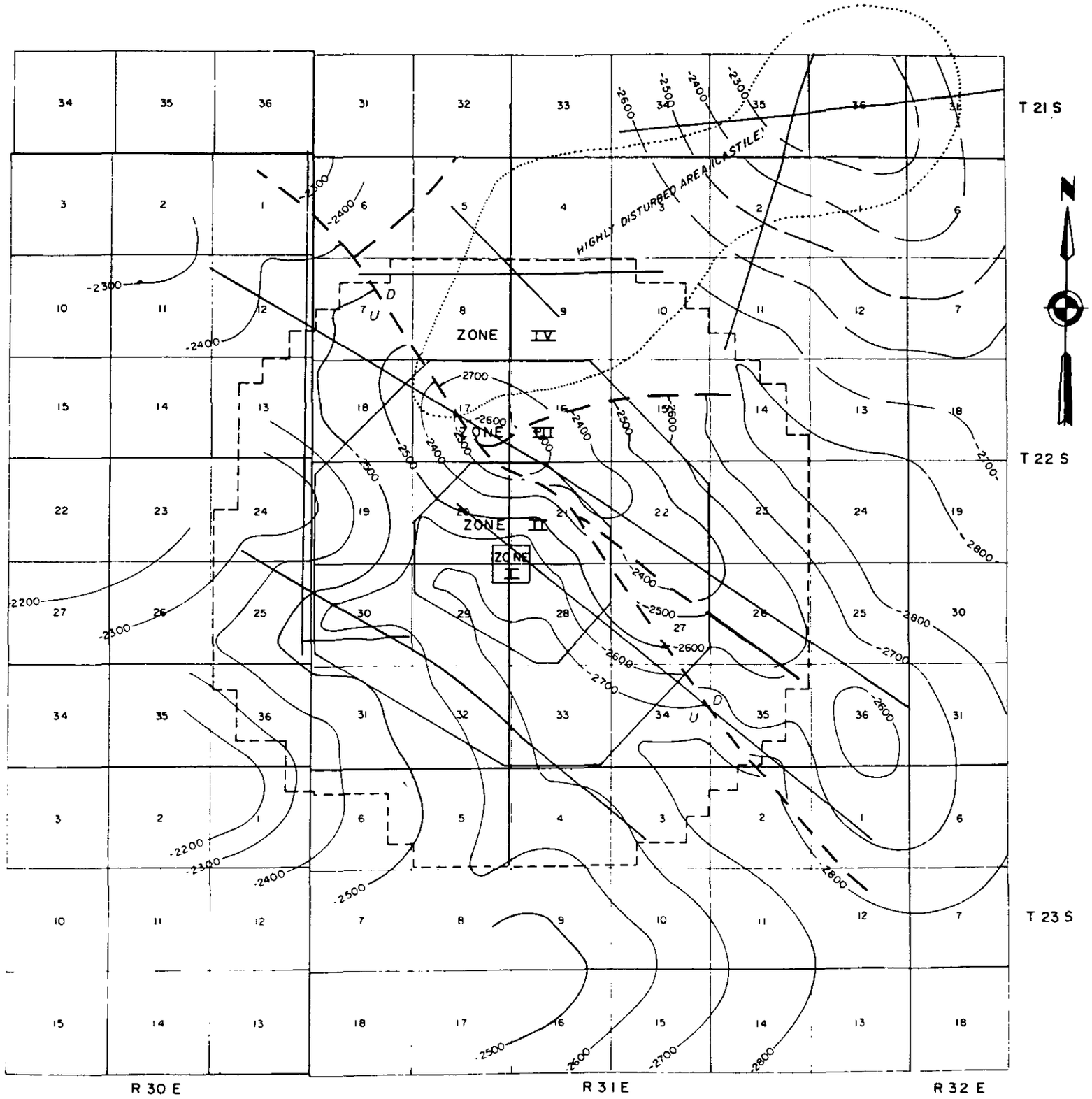

EXPLANATION

Seismic reflection profile lines

U
D
Inferred faults
U-Upthrown side
D-Downthrown side

Contour interval, 100 ft.

REFERENCE:
G.J. LONG & ASSOC., DEC. 1977

0 1 2 3
SCALE IN MILES

DATUM IS 3400' ABOVE MEAN SEA LEVEL

STRUCTURE CONTOURS ON TOP OF CASTILE

FIGURE 4.4-6

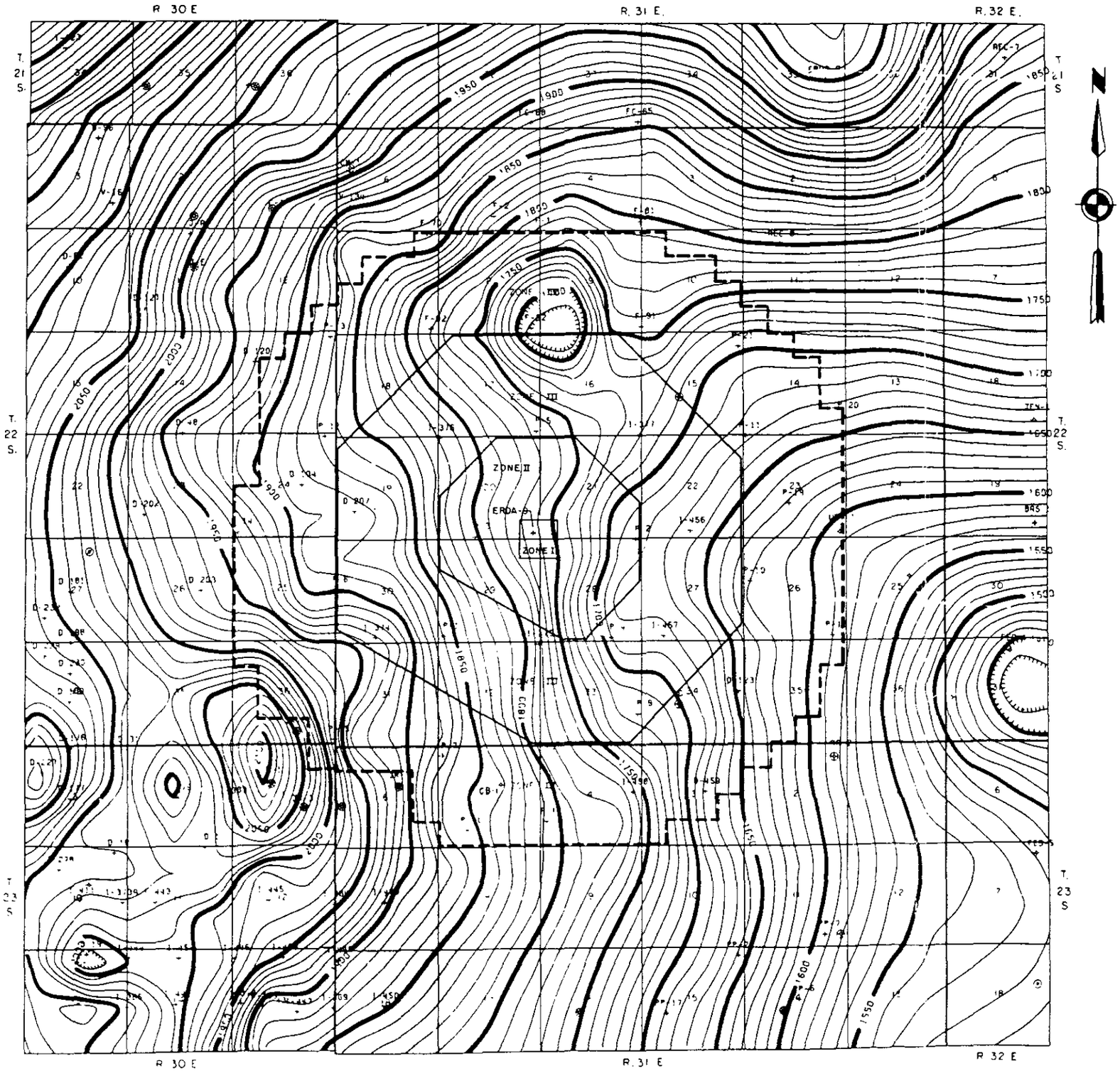

Note:
Borehole sources of data are shown.

REFERENCE
Griswold, 1977, figure 13

Contour interval, 10 feet

0 1 2 3
SCALE IN MILES

STRUCTURE CONTOURS
ON 124-MARKER BED

FIGURE 4.4-7

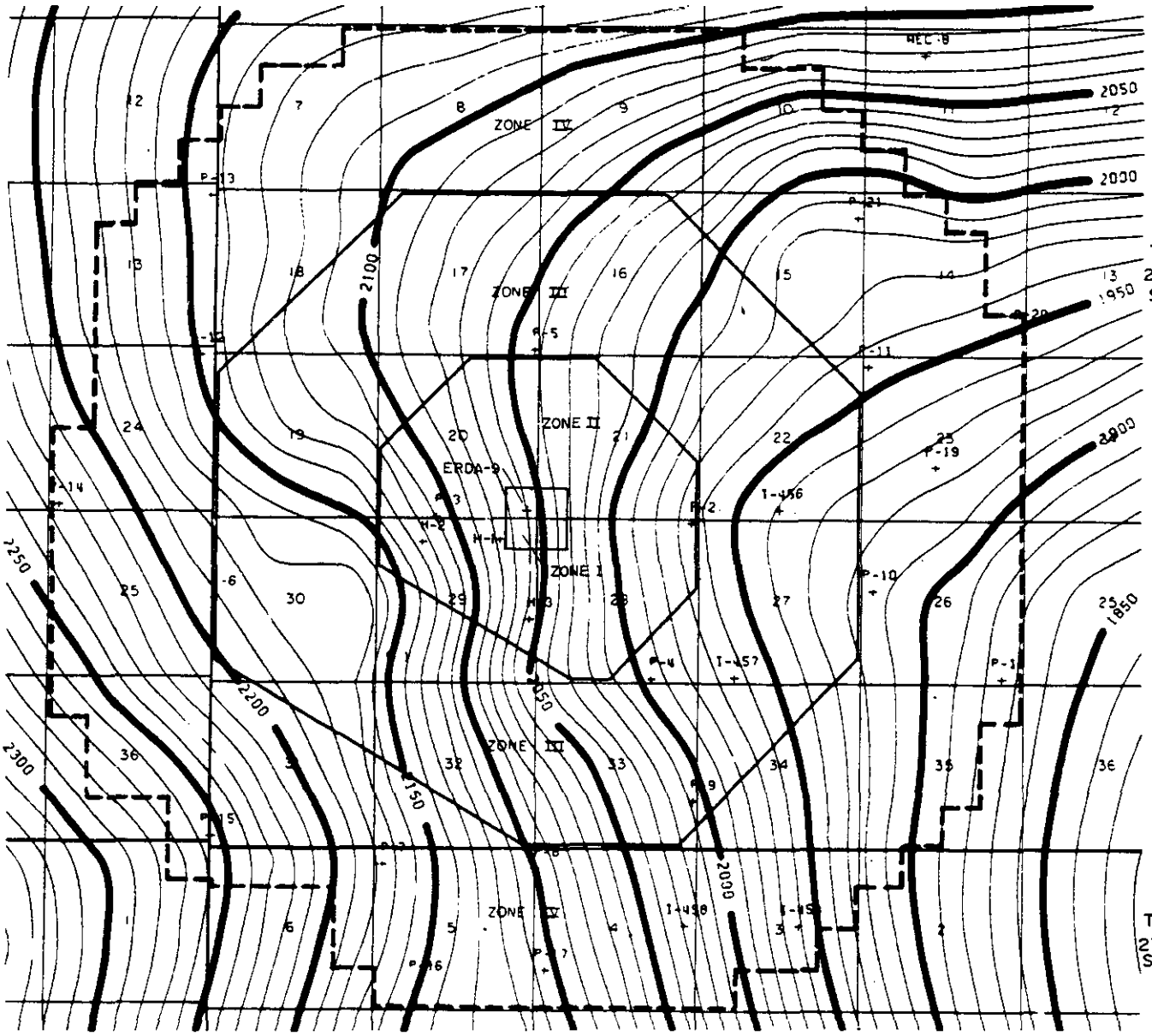

Contour interval, 10 feet

Note:
Borehole sources of data are shown.

0 1 2 3

SCALE IN MILES

REFERENCE:

Griswold, 1977, figure 9

STRUCTURE CONTOURS
ON TOP OF
VACA TRISTE MARKER BED

FIGURE 4.4-8

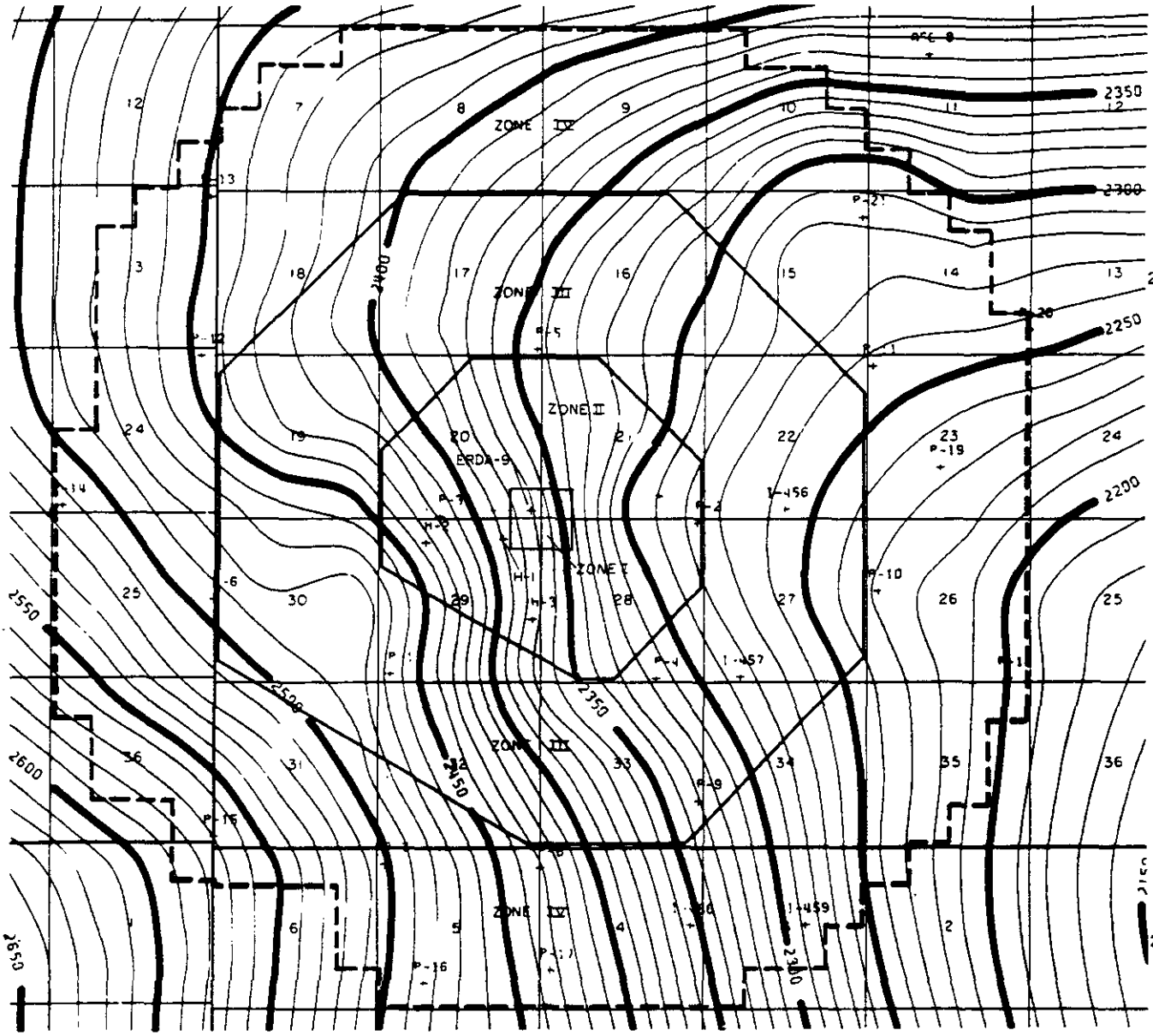

R. 30 E.

R. 31 E.

0 1 2 3

SCALE IN MILES

Contour interval, 10 feet

Note:
Borehole sources of data are shown.

N

STRUCTURE CONTOURS

ON 103 MARKER BED

REFERENCE:

Griswold, 1977, figure 9

FIGURE 4.4-9

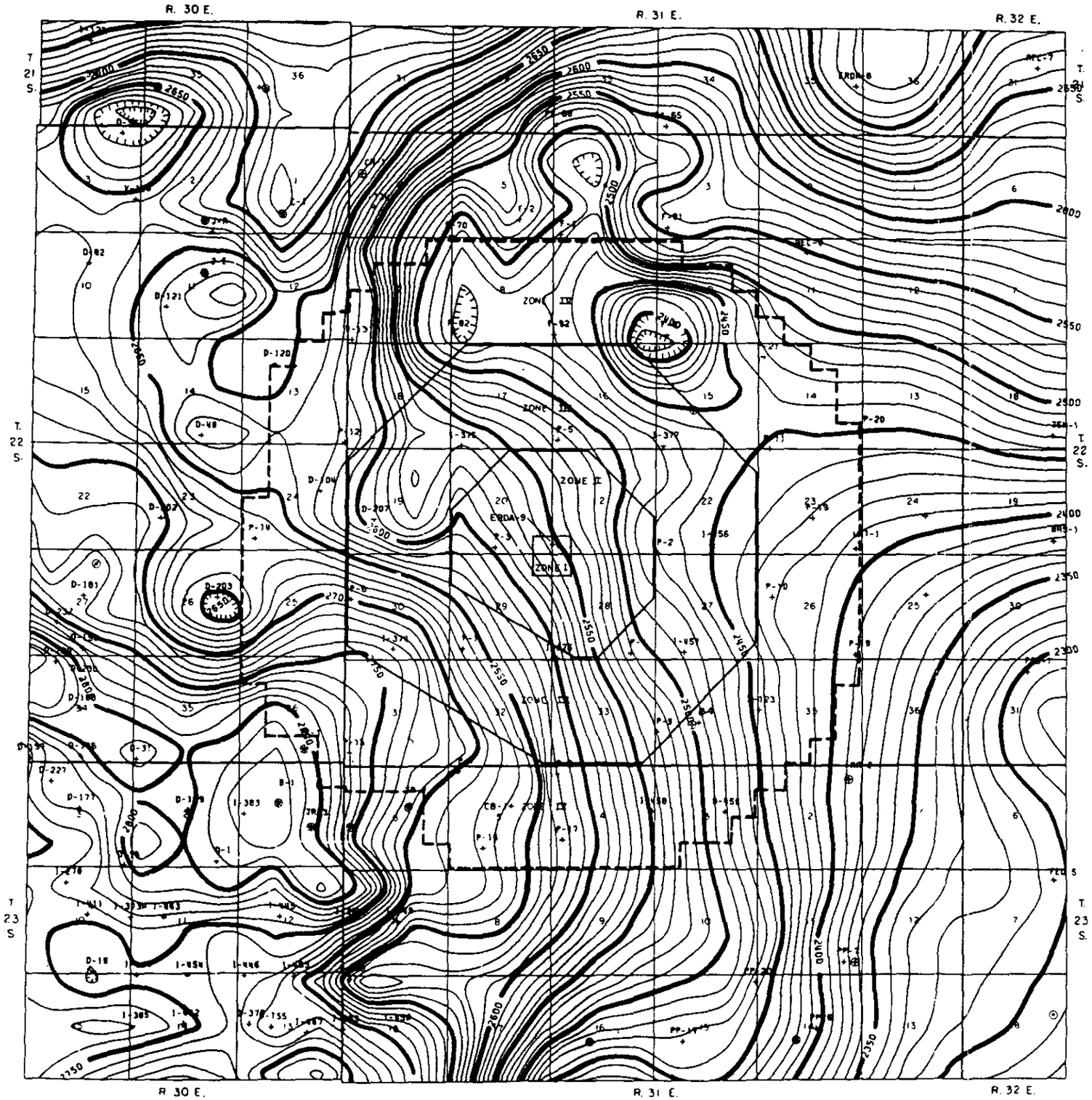

EXPLANATION

Contours based on geologic logs of ERDA and industry potash exploration logs. In the site area i.e., within Zones 1–IV, the contours are considered accurate within 10 feet in elevation. Outside Zone IV they are approximate, and the error may exceed 50 feet in some areas. The Top of Salado may be higher in the west because drill records report only "top of salt". Datum is sea level.

Note:
Borehole sources of data are shown.

REFERENCE:
Griswold, 1977, figure 12

Contour interval, 10 feet

0 1 2 3
SCALE IN MILES

STRUCTURE CONTOURS
ON TOP OF
SALADO FORMATION

FIGURE 4.4-10

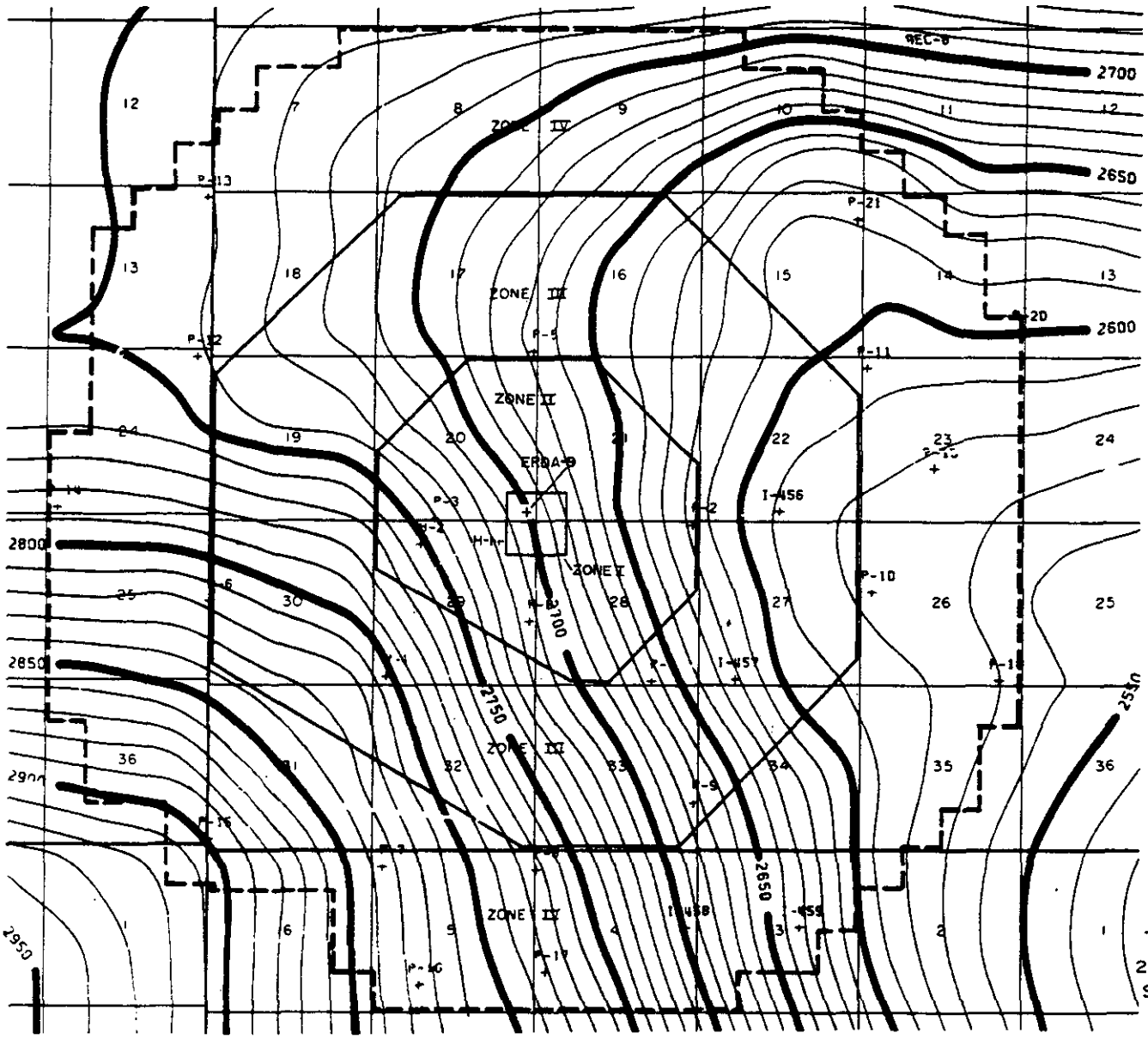

Contour interval, 10 feet

Note:
Borehole sources of data are shown.

STRUCTURE CONTOURS
ON TOP OF
CULEBRA DOLOMITE MEMBER

REFERENCE:

Griswold, 1977, figure 9

FIGURE 4.4-11

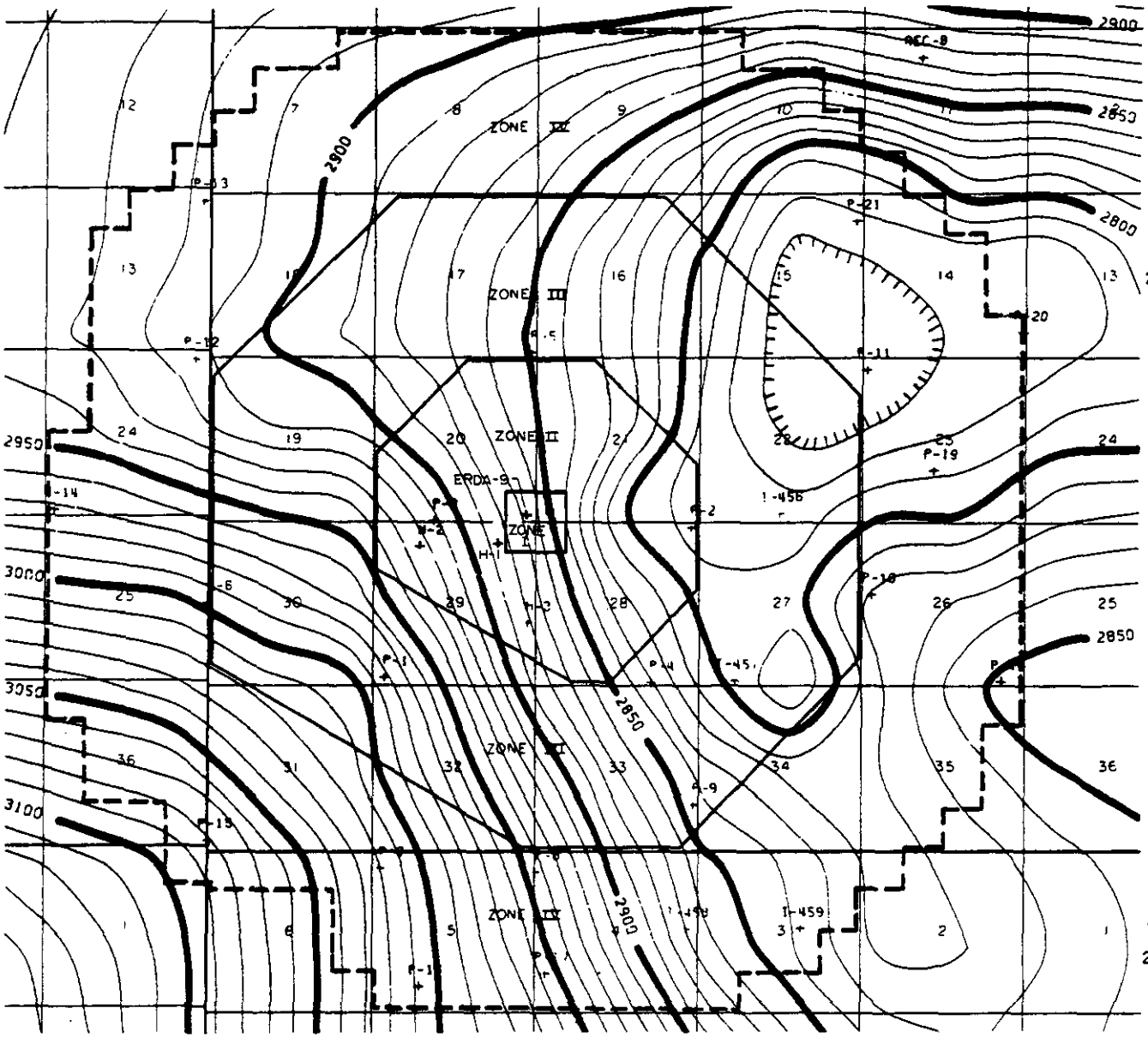

Contour interval, 10 feet

Note:
Borehole sources of data are shown.

0 1 2 3
SCALE IN MILES

STRUCTURE CONTOURS
ON TOP OF
RUSTLER FORMATION

REFERENCE:

Griswold, 1977, figure 8

FIGURE 4.4-12

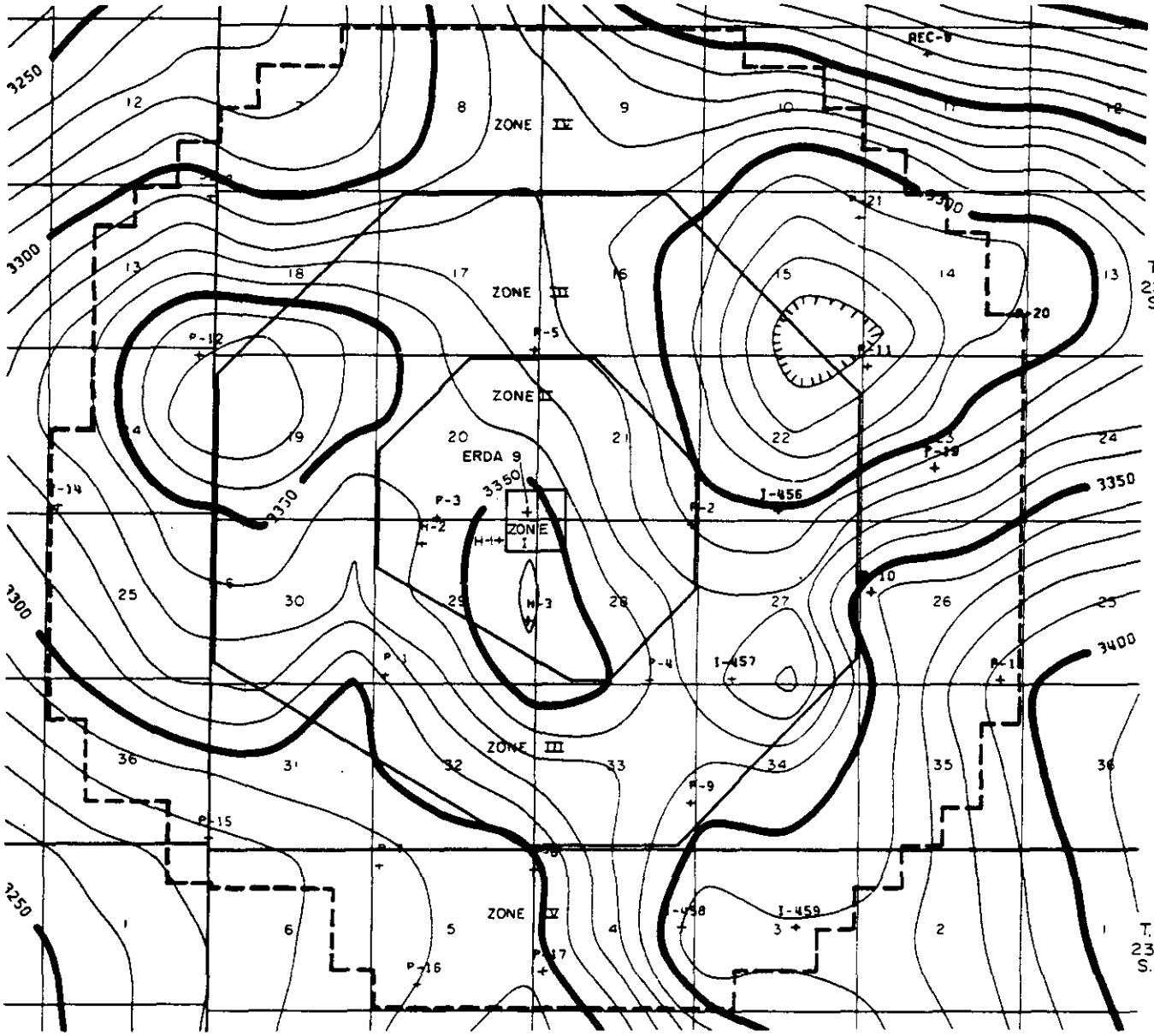

Contour interval, 10 feet

Note:
Borehole sources of data are shown.

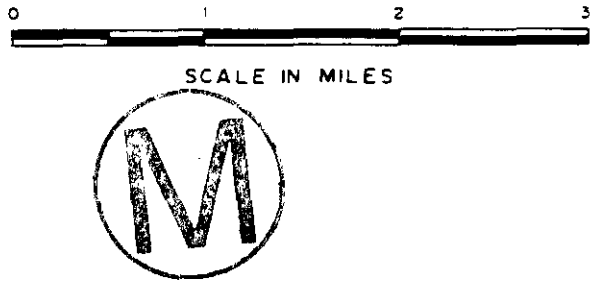

STRUCTURE CONTOURS
ON TOP OF
DEWEY LAKE REDBEDS

REFERENCE:

Griswold, 1977, figure 8

FIGURE 4.4-13

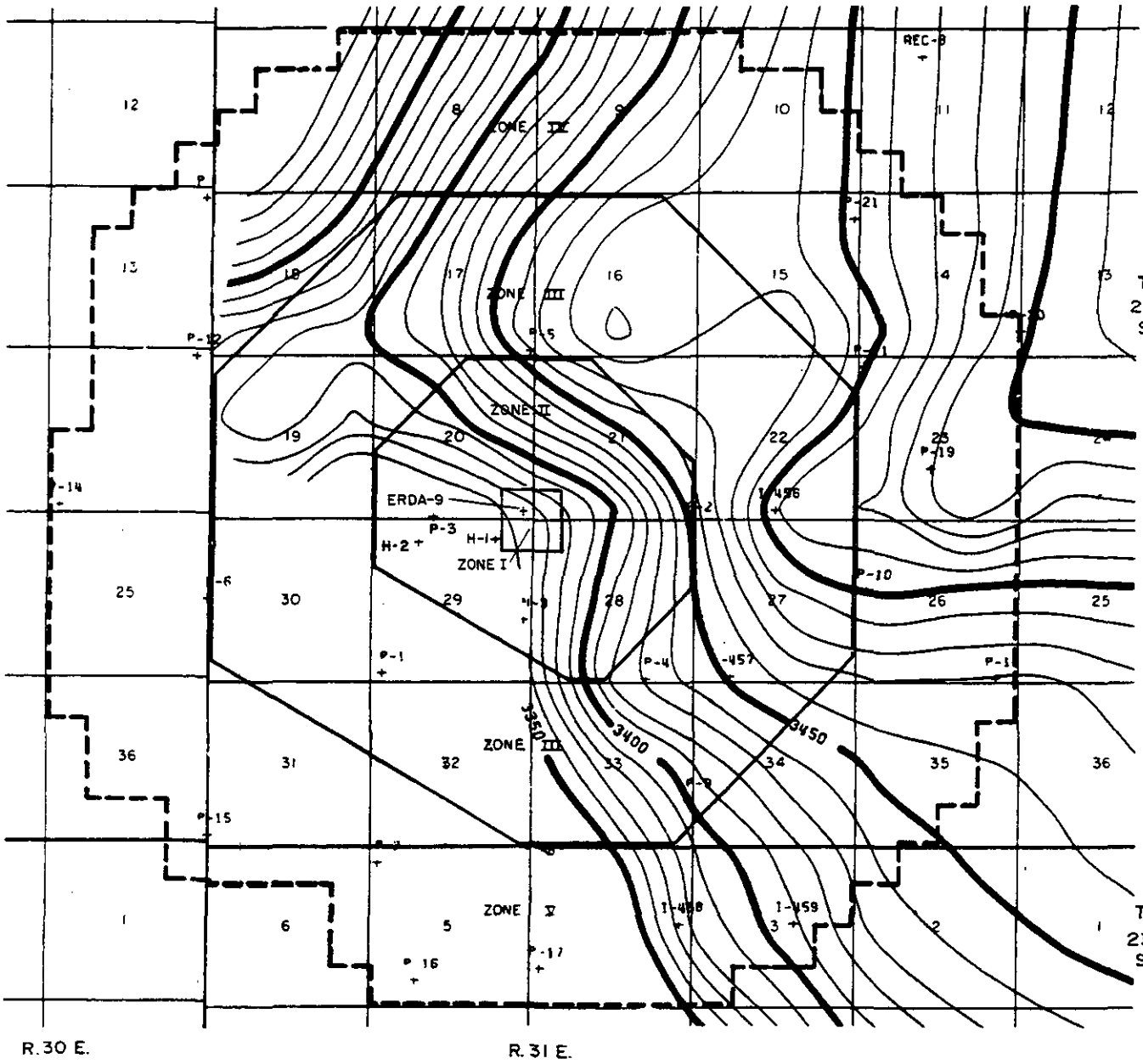

Contour interval, 10 feet

Note:
Borehole sources of data are shown.

STRUCTURE CONTOURS
ON TOP OF
SANTA ROSA SANDSTONE

REFERENCE:

Griswold, 1977, figure 8

FIGURE 4.4-14

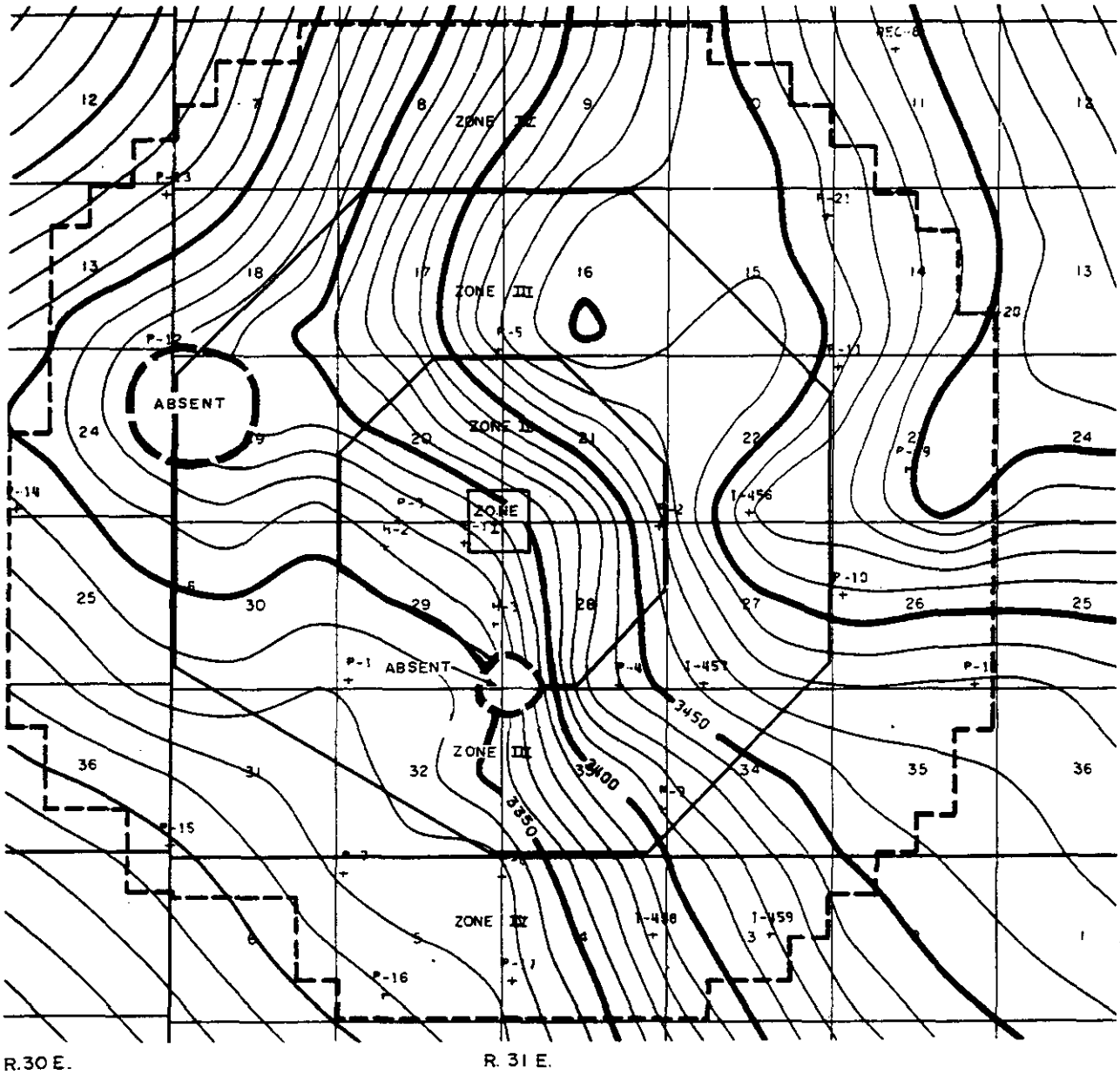

0 1 2 3

SCALE IN MILES

Contour interval, 10 feet

Note:
Borehole sources of data are shown.

N

STRUCTURE CONTOURS
ON TOP OF
GATUNA FORMATION

REFERENCE:

Griswold, 1977, figure 8

FIGURE 4.4-15

BOREHOLE INFORMATION FOR THE VICINITY OF THE WIPP SITE

TABLE 4.1-1

HOLE NO.	T/R/S	COLLAR ELEVATION	SALADO ELEVATION	BASE 124 ELEVATION	TOTAL DEPTH
I 123	21/30/34	3170	2182	1382	1880
W-7	21/31/31	3333	2743	2046	N/A
FC-63	21/31/32	3409	2719	1997	1483
FC-68	21/31/32	3430	2510	1881	1644
F-52	21/31/34	3485	2625	1970	1623
FC-65	21/31/34	3465	2645	1856	1669
FC-69	21/31/34	3461	2632	1962	1562
ERDA-6	21/31/35	3536	2721	1999	2775
AEC-7	21/32/31	3662	2664	1874	3918
C-1	22/30/1	3357	2727	1954	13950
D-96	22/30/3	3189	2609	2133	1210
V 168	22/30/3	3170	2660	2108	1173
D-82	22/30/10	3149	2669	2102	1135
D-121	22/30/11	3202	2642	2045	1266
J-A	22/30/11	3191	2673	2014	14923
J-E	22/30/11	3220	2626	1991	13950
D-120	22/30/13	3338	2654	1930	1500
D-48	22/30/14	3337	2627	1937	1524
D-202	22/30/23	3323	2703	1981	1443
D-104	22/30/24	3388	2629	1883	1596
P-12	22/30/24	3376	2627	1867	1598
P-14	22/30/24	3358	2671	1939	1545
D-203	22/30/26	3317	2647	1965	1443
D-181	22/30/27	3288	2748	2039	1345
D-198	22/30/27	3258	2748	2069	1302
D-229	22/30/27	3218	2825	2068	1266
D-232	22/30/27	3258	N/A	2063	1221
D-36	22/30/34	N/A	N/A	N/A	N/A
D-180	22/30/34	3210	2790	2083	1230
D-188	22/30/34	N/A	N/A	N/A	N/A
D-230	22/30/34	3231	2821	2067	1195
JR-1	22/30/36	3308	2802	2037	17555
D-160	22/30/36	N/A	N/A	N/A	N/A
F-81	22/31/3	3471	2651	1797	1735
F-2	22/31/5	3404	2529	1818	1690
CM-1	22/31/6	3376	2668	1961	14050
V-134	22/31/6	3363	2622	1898	1563
F-70	22/31/7	3388	2490	1867	1603
F-82	22/31/8	3382	2472	1781	1684
F-92	22/31/8	3420	2470	1688	1818
F-1	22/31/9	3422	2482	1781	1747
F-91	22/31/10	3460	2390	1755	1788
AEC-8	22/31/11	3542	2548	1801	4910
P-20	22/31/14	3553	2450	1662	1995
P-21	22/31/15	3510	2467	1705	1915
P-5	22/31/17	3472	2525	1767	1830
P-13	22/31/18	3345	2624	1874	1576
D-207	22/31/19	3406	2595	1886	1613
ERDA-9	22/31/20	3415	2555	1765	2890
I-376	22/31/20	3410	2570	1819	1702
P-3	22/31/20	3382	2596	1803	1676
I-377	22/31/22	3490	2476	1720	1876
I-456	22/31/22	3520	2451	1867	1975
P-11	22/31/23	3506	2448	1673	1940
P-19	22/31/23	3546	2429	1629	2000
WRT-1	22/31/23	3595	2406	1596	4766
P-10	22/31/26	3508	2422	1820	2009
P-18	22/31/26	3479	2391	1590	1993
I-457	22/31/27	3460	2480	1683	1885
P-2	22/31/28	3478	2470	1683	1895
P-4	22/31/28	3441	2511	1688	1857
P-1	22/31/29	3446	2668	1859	1591
P-6	22/31/30	3554	2695	1892	1573
I 374	22/31/30	3340	2735	1931	1538
P-15	22/31/31	3310	2768	1957	1465
P-9	22/31/33	3408	2528	1714	1796
I-375	22/31/33	3390	2600	1788	1746
D 123	22/31/34	3432	2444	1844	1880
G-1	22/31/34	3450	2495	1708	4476
JEN-1	22/32/18	3896	2471	1664	4896
BAS-1	22/32/19	3820	2378	1578	4802
FED-1	22/32/31	3627	2294	1447	4777
B-1	23/30/1	3290	2825	2115	14312
I 383	23/30/1	3272	2832	2061	1307
JR-3	23/30/1	3288	2806	2041	16692
D-1	23/30/2	3241	2809	2032	1310
D-31	23/30/2	3244	2812	2036	1314
D-179	23/30/2	3244	2794	1997	1350
D-176	23/30/3	3197	2782	2078	1223
D-177	23/30/3	3151	2741	2088	1188
D-197	23/30/3	3141	2731	2110	1138
D-227	23/30/3	3246	2818	N/A	1073
D-18	23/30/10	3190	2806	2040	1265
I 278	23/30/10	3120	2780	2035	1217
I-373A	23/30/10	3140	2765	2036	1242
I-411	23/30/10	3128	2753	2041	1206
I-443	23/30/11	3185	2770	2028	1270
I-445	23/30/12	3235	2765	1968	1385
D-TS5	23/30/13	3210	2685	1848	1495
PP-19	23/30/13	N/A	N/A	N/A	N/A
I-370	23/30/13	3220	2740	1988	1341
I-446	23/30/13	3210	2730	1976	1345
I-447	23/30/13	3250	2741	1891	1480
I-453	23/30/13	3240	2730	1963	1405
I-385	23/30/14	3185	2770	2045	1235
I-442	23/30/14	3170	2755	2007	1275
I-444	23/30/14	3130	2745	2003	1240
I-454	23/30/14	3170	2735	2000	1300
D-19	23/30/15	3149	2727	1957	1369
I-440	23/30/15	N/A	N/A	N/A	N/A
AA 2	23/31/2	3453	2383	1583	5190
I-459	23/31/3	3418	2482	1679	1855
I-458	23/31/4	3385	2549	1762	1750
P-8	23/31/4	3336	2621	1791	1660
P 17	23/31/4	3340	2625	1805	1660
P 7	23/31/5	3332	2702	1873	1575
P 16	23/31/5	3323	2677	1853	1585
CB-1	23/31/5	3320	2662	1845	4150
JR-7	23/31/6	3319	2713	1920	14590
I-384	23/31/7	3290	2790	1964	1438
I-449	23/31/7	3310	2680	1906	1515
PP-7	23/31/11	3485	2375	1593	2033
PP-6	23/31/14	3485	2405	1594	2079
PP 17	23/31/15	3418	2468	1689	1920
PP-20	23/31/15	3429	2469	1660	1910
I-369	23/31/18	3280	2715	1871	1538
I-448	23/31/18	3290	2625	1900	1510
I-450	23/31/18	3300	2690	1854	1570
FED-5	23/32/7	3539	N/A	N/A	4712

P—ERDA POTASH HOLE
V—U.S. POTASH CO. (MISSISSIPPI POTASH)
D DTS -DUVAL CORP.
I-INTERNATIONAL MINERALS
PP—PERMIAN POTASH
F—FC -KERR McGEE
N/A—NOT AVAILABLE

REFERENCE:
Adapted from Griswold, 1977

GCR CHAPTER 5

SEISMOLOGY

5.1 INTRODUCTION

The study of the Los Medanos site region's seismicity is of interest for two reasons. First, it forms the primary basis for the analysis and selection of reasonably expected vibratory ground motion for use in aseismic design; second, when considered along with the geology and tectonic history of the region, it provides some indication of current and long-term tectonic stability. In this chapter both aspects of the regional seismicity are discussed.

In Section 5.2 the temporal and geographic distribution of observed earthquakes in the site region are discussed. The regional seismicity is considered in two separate time intervals suggested by the type and quality of information available during each interval. These intervals are: before 1962, and from 1962 to the present. In the post-1962 period, several specialized instrumental studies are considered in addition to a more general regional instrumental survey.

Using the information developed on regional seismicity, and some additional simple assumptions about regional tectonism, a preliminary analysis of probabilistic vibratory ground motion at the ground surface is derived in Section 5.3 in a way that is useful for seismic design characterization at the site during its active phase of development and use. This analysis shows that short-term accelerations during the operational phase are likely to be very modest. Probabilities at which higher acceleration levels occur depend almost exclusively on the assumptions made about the seismic capabilities of the immediate site area.

Finally, in Section 5.4, regional seismicity is considered as an indicator of long-term tectonic processes. Regional stress patterns, as implied by focal mechanism solutions for regional earthquakes and in-situ stress measurements, and regional tectonism, as implied by earthquake

recurrence statistics, are both considered. Several tentative conclusions are reached as a result of this study and are outlined at the conclusion of this chapter.

5.2 SEISMICITY

In this section the temporal and geographic distribution characteristics of observed earthquakes in the site region are discussed. Detailed discussion is restricted to earthquakes within 300 kilometers (about 186 miles) of the Los Medanos site in view of historical analysis by Sanford and Toppozada (1974).

As always, in studying any single earthquake or group of earthquakes, it is important to note the date of occurrence in relation to the state of the art of seismology at the time. The certainty with which fundamental properties of earthquakes, such as size and location, can be determined largely depends on the availability and quality of instrumental data. Prior to 1960, nearly all information on the strengths and distribution of earthquakes in New Mexico was determined without the aid of instruments (Sanford, 1965). Therefore, inferences which may be drawn from pre-1960 seismicity studies are fundamentally different and more speculative than instrumentally derived parameters.

Instrumental studies of earthquakes in New Mexico began in June 1960 when high magnification seismographs were placed in operation by the New Mexico Institute of Mines and Technology at Socorro, and by the Atomic Energy Commission at Sandia Base near Albuquerque (Sanford et al., 1972). These two stations provided some information on locations and strengths of earthquakes in central New Mexico, but accurate information about locations throughout the state was not available until the beginning of 1962, when additional high-gain stations went into operation in New Mexico and bordering states (Las Cruces, N.M.; Payson, Arizona; Ft. Sill, Oklahoma). Also at this time the United States Coast and Geodetic Survey (U.S.C.G.S.) established a regular reporting station at Albuquerque. Instrumental seismology for the state of New Mexico as a whole dates from this time.

In this discussion the format of a previous study by Sanford and Toppozada (1974) is followed. Regional seismicity of the Los Medanos site area is considered in two distinct time frames in accordance with the types of data available. Preinstrumental data, roughly that before 1962 in the site area, is treated first; a separate study of the later period for which seismograph records exist follows in several separate subsections.

Two very recent investigations of seismicity on a much more local scale affect the Los Medanos site. One involves recordings made on a continuously operating, vertical component, high frequency system installed and operated at the site itself by personnel from the New Mexico Institute of Mining and Technology at Socorro. The principal objective of this station, which has gathered data for most of the interval April 5, 1974, to October 29, 1977, and which continues to function, has been to determine if seismic activity is occurring at or near the proposed nuclear waste repository at such a low level that it might not be adequately detected by more standard instrumental data surveys (Sanford et al., 1976a). The other recent study is one designed to investigate in detail local small magnitude seismicity in and near the Central Basin Platform of west Texas. To this end, a seismic array centered near Kermit, Texas, has been installed. Initial operation of this array began in early November 1975, and some preliminary conclusions have been reached at this time (Hays, 1977; Rogers and Malkiel, 1978). Both of these recent study efforts will be discussed in separate subsections of this report.

In a final subsection, two small earthquakes important to the question of background seismicity level in the immediate site area are discussed.

5.2.1 Preinstrumental Data - Regional

Most historic earthquakes in New Mexico cataloged before seismic instrumentation occur in the Rio Grande Valley area between Albuquerque and Socorro. About half the earthquakes of Modified Mercalli Intensity V

or greater in New Mexico between 1868 and 1973 are in this region. In conformity with previous studies (Sanford and Toppozada, 1974; Sanford et al., 1978) these events are not considered to be of immediate concern for this study and will not be discussed further. As will be seen, the area within roughly 200 kilometers of the site has experienced only low intensity earthquakes prior to the first availability of seismographic data in 1961; there have been a few modestly damaging earthquakes during the same interval between 200 and 300 kilometers from the site. The area up to 300 kilometers from the site is defined as the site region in the following discussions.

Figure 5.2-1 shows locations of earthquakes occurring before 1961 that have been assigned epicenters within 300 kilometers of the site. Table 5.2-1 lists the events shown on Figure 5.2-1. Intensities appearing in this table, and anywhere in this section, are Modified Mercalli intensities (Wood and Neumann, 1931).

The primary source used was Sanford and Toppozada (1974), although some supplemental descriptive material was obtained from Neumann and Bodle (1932), Neumann (1932, 1938, and 1940), Murphy and Ulrich (1951), Murphy and Cloud (1954 and 1957), Northrop and Sanford (1972), and Coffman and Von Hake (1973). An abridged version of the Modified Mercalli Intensity Scale of 1931 may be found in Table 5.2-2. In the descriptions below, intensities in parentheses were assigned by Sanford and Toppozada (1974) based only on their personal evaluation of the data.

<u>1923, Mar. 7</u> El Paso, Texas V Felt in Sierra Blanca (166 kilometers to SE), Columbus (130 kilometers to W), Alamogordo (135 kilometers to N). Newspaper accounts suggest epicenter in northern Chihuahua. (Sanford and Toppozada, 1974).

<u>1926, July 17</u> Hope and Lake Arthur, N.M. III Earth sounds heard in NE direction at Hope; windows rattled at Lake Arthur. (Sanford and Toppozada, 1974).

1930, Oct. 4 Duran, N.M. IV A moderate shock felt by many. Rolling motion, rumbling sound, rattled windows. No damage. (Neumann and Bodle, 1932).

1931, Aug. 16 Valentine, Texas VIII At Valentine, the point of maximum destruction, all types of buildings, especially adobe, were heavily damaged; many chimneys fell. There were some cracks in the ground, and tombstones rotated both clockwise and counterclockwise. While people were panic-stricken, there were no fatalities and only a few minor casualties. There were cracked walls and damaged chimneys in several towns in Brewster, Jeff Davis, Culberson, and Presidio Counties. Some rockslides occurred in the mountains. There were rumbling and roaring sounds. This earthquake would have been severe in a densely populated region. (Coffman and Von Hake, 1973).

1931, Aug. 16 Valentine, Texas (V) Strong aftershock of intensity VIII event.

1931 Aug. 18 West Texas V at Alpine, Pecos, Lobo, and Valentine; IV at Carlsbad, N. Mex. This was preceded by a lighter shock on the same day. Recorded at Tucson. (Neumann, 1932).

1931, Aug. 19 Valentine, Texas (V) Strong aftershock of intensity VIII event.

1931, Oct. 2 El Paso, Texas III "To-day", El Paso, Texas. Feeble. (Neumann, 1932).

1931, Nov. 3 Valentine, Texas (V) West Texas. Felt at Valentine. Aftershock of August 16 earthquake. Recorded at Tucson.

1935, Dec. 20 Clovis, New Mexico III-V Two Shocks. A tile wall in a creamery was cracked. Another report of wall paper being split (AP news item). (Northrop and Sanford, 1972).

1936, Jan. 8 Carlsbad, N.M.? (IV) Felt by few; press reports some property damage (Neumann, 1938). Newspaper account indicates this earthquake was probably centered near Ruidoso, N.M. (Sanford and Toppozada, 1974).

1936, Aug. 8 El Paso, Texas (III) Weak shock not felt elsewhere (Neumann, 1938).

1936, Oct. 15 El Paso, Texas (III) "Earth tremor" shortly before noon. No details. (Neumann, 1938).

1937, Mar. 31 El Paso, Texas (V) Slight. Felt by many. (Neumann, 1940).

1937, Sept. 30 Ft. Stanton, N.M. V Slight. Awakened many. (Neumann, 1940).

1943, Dec. 27 Tularosa, N.M. IV Rattled windows. (Sanford and Toppozada, 1974).

1949, Feb. 2 Carlsbad, N.M. IV Press reported two distinct shocks which were felt by several. A few people were frightened. Windows, doors, and dishes rattled; houses seemed to shudder momentarily. (Murphy and Ulrich, 1951).

1949, May 23 East Vaughn, N.M. VI Felt over an area of only about 1300 square miles. "Results of a questionnaire coverage indicated the felt area to be a 20-mile strip connecting Pastura with Vaughn and East Vaughn. Maximum intensity VI at the last named place where a few things fell from shelves, loose objects rattled and buildings creaked. Deep rumbling and grinding sounds were heard before and during shock" (Murphy and Ulrich, 1951). Many people were awakened and many were frightened. One person felt the shock while driving a car 20 miles southeast of Vaughn on the highway to Roswell. (Northrup and Sanford, 1972).

1952, May 22 Dog Canyon, New Mexico (about 70 miles northwest of Carlsbad). IV Felt by two in ranch house. Windows, doors, and dishes rattled; house creaked. (Murphy and Cloud, 1954).

1955, Jan 27 Valentine, Texas IV Felt by many. Houses shook (Murphy and Cloud, 1957).

As can be seen from the above data, there have been no earthquakes of epicentral intensity V or greater recorded as occurring within about 200 kilometers of the Los Medanos site when noninstrumental data alone is considered. The strongest earthquake reported to occur within 300 kilometers of the site was the Valentine, Texas event of August 16, 1931. The reported maximum intensity for this shock was VIII on the Modified Mercalli scale (Table 5.2-2). Reports of earthquake intensity for a wide area have been compiled into several isoseismal maps (Neumann, 1932; Sellards, 1933). Intensities in these maps are based on the Rossi-Forel scale which was subsequently abandoned for the Modified Mercalli Scale of 1931. Sanford and Toppozada (1974) have assigned Modified Mercalli intensities on the basis of descriptions of the earthquake effects for this event and plotted the isoseismal map shown in Figure 5.2-2. According to this map the intensity at the site was probably no greater than V. This is the largest known historical site intensity.

Close to the source, the isoseismals are elongated northwest-southeast conforming to the structural grain of the region. Further from the epicenter, the earthquake had higher intensities to the east than west due to lower topographic relief to the east (Sanford and Toppozada, 1974), differences in attenuation, or some other reason. The data to the southwest, in Mexico, are particularly sparse.

Two instrumental locations have been published for this earthquake. The U.S.C.G.S. (Neumann, 1932) places the epicenter at 29.9°N and 104.2°W with an origin time of 11:40:15 GMT. Byerly (1934), who made a detailed instrumental investigation of this earthquake, found the epicenter to be

at 30.9°N and 104.2°W with an origin time of 11:40:21 GMT. Byerly's epicenter, 110 kilometers north of the U.S.C.G.S. epicenter is closer to the region of highest reported intensities and may for this reason be considered the more accurate of the two. Although neither is particularly close to Valentine, Texas, the USCGS and Byerly epicenters bracket this area of max reported intensity fairly well. For the purposes of Figure 5.2-1 and Table 5.2-1, Valentine, Texas, has been adopted for the location of the main earthquake and its aftershocks in agreement with the work of Sanford and Toppozada (1974).

The area over which an earthquake is perceptible can be used to estimate its magnitude (Slemmons et al., 1965; Wiegel, 1970), although this relationship is an empirical one different for different regions of the United States. If a felt area of 4.5×10^5 mi^2 is accepted (1.15×10^6 km^2) as reported by the U.S.C.G.S. (Neumann, 1932) and a magnitude-felt area formula for the central United States and Rocky Mountain region is used (Wiegel, 1970), a magnitude of about 6.4 is calculated for the Valentine, Texas, earthquake. This result appears reasonable and is compatible with the maximum intensity reported for the shock (Sanford and Toppozada, 1974). It is also in good agreement with the estimate of magnitude for this event calculated at Pasadena (Gutenberg and Richter, 1954).

Other earthquakes within 300 kilometers of the site were probably not perceptible or resulted in low intensities in the site area.

5.2.2 Instrumental Data--Regional

As mentioned above instrumental studies of earthquakes in New Mexico began in June 1960 when high-magnification seismographs were placed in operation on the campus of the New Mexico Institute of Mining and Technology at Socorro and by the Atomic Energy Commission at Sandia Base near Albuquerque (Sanford et al., 1972). Most of the early seismic research at Socorro was concentrated on near shocks (Sanford and Holmes, 1961, 1962; Sanford, 1963) because of this initial station distribution

and because information from other stations located in New Mexico and adjacent states was not available in sufficient quantity for a study of the seismicity of the entire state. This situation changed about the beginning of 1962 when stations at Albuquerque and Las Cruces, New Mexico; Payson, Arizona; and Ft. Sill, Oklahoma; began continuous operation.

Detailed reports on the instrumental seismicity of New Mexico as a whole have appeared in a number of publications, principally Sanford (1965), Sanford and Cash (1969), and Toppozada and Sanford (1972). Collectively, these papers cover the interval January 1, 1962, through June 30, 1971. The study of instrumental seismicity in this area, as in any other, evolved over this 11 year period. Not only did more data become available as more seismograph stations began operation, but these data were processed in increasingly sophisticated ways. The ways regional earthquakes have been located and analyzed during this period are summarized below. For a more complete discussion, the reader is referred to the original reports; both those mentioned above and Sanford et al. (1972), Sanford and Toppozada (1974), Sanford (1976a), Sanford (1976b), and Sanford et al. (1976b).

The method used to initially locate the earthquakes during the period January 1, 1962, through June 30, 1964 (Sanford, 1965) was based on the procedure described by Richter (1958). This is an arc intersection procedure where: 1) a trial origin time is estimated from measured S-P intervals, 2) a depth is selected, either 5 kilometers or 10 kilometers, 3) station-epicenter distance is calculated from the P-O (origin time) intervals and a T-D curve (in this instance a graph relating travel time to distance for each of the two depths of focus) and 4) the epicenter is determined from the intersection of the arcs whose radii have just been calculated in step 3) above. If no satisfactory intersection occurs, the process is repeated after adjustment of the origin time estimate. The time-distance curves used by Sanford (1965) in this process were based on a simple crustal model close to the average of those found for the region in previous studies (Tatel and Tuve, 1955; Stewart and Pakiser, 1962;

Romney et al., 1962). The crustal model adopted consisted of a single 39 kilometers thick layer with a P-wave velocity of 6.0 km/sec overlying a half-space with a P-wave velocity of 8.0 km/sec. The two T-D curves, one for a depth of focus of 5 kilometers and one for a 10 kilometers focal depth, were calculated using this model.

For earthquakes occurring between July 1, 1964, and December 31, 1967, a slightly different format was used to present the data (Sanford and Cash, 1969). Whenever available, origin times and epicentral coordinates were taken directly from U.S.C.G.S. reports. Two types of data distributed by the U.S.C.G.S. were consulted; the Monthly Summary series, or where these were not yet published, as for the period October 1966 through December 1967, the Preliminary Determination of Epicenters reports. A majority of the New Mexico earthquakes listed in this period were not located by the U.S.C.G.S., however. When this was the case, events were located precisely as outlined above for the earthquakes of January 1962 through June 1964.

Finally, for initial location of those shocks occurring from January 1968 to June 1971, inclusive, the procedure adopted was identical to that of the previous reporting period except that for those earthquakes located by the New Mexico Institute of Mining and Technology a focal depth of 8 kilometers was used to construct the T-D curves (Toppozada and Sanford, 1972).

The method of assigning magnitudes to the earthquakes of New Mexico has also undergone some evolution. From the start the idea has been to calculate a close analog to the Richter local magnitude (M_L). Magnitude can be expressed by the equation $M_L = \log A - \log A_o$, where A is the maximum trace amplitude (almost always the crustal shear wave, Sg, for local and regional New Mexico earthquakes, Sanford, personal communication, 1978) in millimeters on the seismogram and A_o is the corresponding trace amplitude for a calibration earthquake selected as the standard. The numbers obtained for M_L are dependent on the magnification and frequency response of the seismograph used, and on the

selection of the standard shock. The original Richter scale is based on the Wood-Anderson seismograph, an instrument which records horizontal motion, whose natural period is 0.8 second, and whose static magnification and damping are 2800 and 0.8 critical, respectively. Furthermore, the standard or zero magnitude event is defined such that it would produce a trace deflection of one thousandth of a millimeter when recorded by a Wood-Anderson seismograph at a distance of 100 kilometers.

The direct application of the Richter scale to New Mexico earthquakes was impossible, because none of the available data came from Wood-Anderson seismographs. As an initial best estimate, Sanford (1965) decided to rate the shocks on the basis of the amplitude a Wood-Anderson instrument would produce had it recorded these shocks; that is, maximum trace deflections were first converted to ground displacements, which in turn, were converted to equivalent Wood-Anderson trace amplitudes using the known response characteristics of this instrument. An attempt was made to consider response differences between the actual recording seismograph and the Wood-Anderson seismograph as a function of frequency. The Richter values for A_o were adopted with no attempt to consider possible source or wave transmission differences between those earthquakes occurring in California, where the Richter Scale was developed, and those occurring in New Mexico. Most of the magnitudes were calculated from the maximum SH (or horizontally polarized shear wave) ground motions reported by the station at Las Cruces. When no SH amplitude information was available from the Las Cruces station, magnitude was assigned on the basis of the maximum SV ground motion at Albuquerque. The relation between SV (or vertically polarized shear wave) motion at Albuquerque and magnitude was established from data on shocks detected by both the Las Cruces and Albuquerque stations (Sanford, 1965). This initial attempt to assign magnitudes to New Mexico earthquakes was never intended to be completely accurate but rather to serve as rough indications of the relative strengths of shocks.

Slightly different procedures were followed for magnitudes calculated for the two later reporting periods of July 1964 to December 1967 and January 1968 to June 1971. In these periods three magnitudes are listed: 1) U.S.C.G.S., 2) Albuquerque, and 3) Socorro. Magnitudes assigned by the U.S.C.G.S. (or its later administrative equivalents, such as the National Oceanic and Atmospheric Administration) are body wave magnitudes (m_b) based on the maximum amplitude of the initial P phase. Magnitudes calculated from Albuquerque and Socorro seismograms are based on the amplitudes of the S phases as noted above. For Albuquerque, the maximum SH ground motion was converted to an equivalent Wood-Anderson trace amplitude and the previous procedure was used to obtain an estimate of the equivalent Richter magnitude. A similar procedure was used for Socorro magnitudes, except that for these computations it was necessary to substitute maximum SV motion for maximum SH motion. Checks at the Socorro station indicate SH averages about 1.5 times as large as SV. This correction factor was included in the Socorro magnitudes computations.

Since the initial publication of the 1962-1972 instrumental data (Sanford, 1965; Sanford and Cash, 1969; Toppozada and Sanford, 1972) several additional studies have been undertaken to partially rework this data. Two of these, Sanford and Toppozada (1974) and Sanford et al. (1978), are of particular interest since they deal almost exclusively with earthquakes within 300 kilometers of the Los Medanos site. Sanford and Toppozada (1974) list a total of 34 earthquakes in this area. Of these, 12 appeared in the previously discussed studies, 13 represented new locations by the New Mexico Institute of Mining and Technology not previously published, and the remaining events were taken directly from U.S. Department of Commerce reports, either the Seismological Bulletin or Earthquake Data Reports. An updated version of this listing is presented in Sanford et al (1978). In this update four shocks have been added to the Sanford and Toppozada (1974) tabulation: February 11, 1964; March 3, 1964; October 20, 1964; July 26, 1972. The last of these is most noteworthy because of its proximity to the site. This event will be considered in greater detail in a later subsection. The October 20, 1964

earthquake is included here in conformity with Sanford et al (1978) even though this event apparently falls slightly beyond the 300 kilometers circle specified as the region of interest.

The most significant difference between the 1978 and all previous tabulations is in the magnitudes assigned to the individual earthquakes. The shocks listed in Sanford et al. (1978) have local magnitudes (M_L) substantially lower than those published earlier by the New Mexico Institute of Mining and Technology or the U.S.C.G.S. These revised magnitudes came about because in calculating local magnitudes for single earthquakes, it was noticed that a systematic increase in calculated magnitude occurred with increasing distance from the earthquake. This strongly suggested that more efficient transmission of the phase producing maximum trace amplitude was occurring in New Mexico than would be indicated by an uncritical use of the A_o standard earthquake amplitude attenuation factor of Richter (1958). Therefore, a correction factor for attenuation differences, as well as another correction factor for individual station effects, has been incorporated in the latest magnitude calculations.

Listed in Table 5.2-3 and shown in Figure 5.2-1 are the 38 earthquakes as they appear in Sanford et al. (1978). These data represent the latest and best estimate of all significant parameters associated with those earthquakes occurring within 300 kilometers of the Los Medanos site for the interval January 1, 1961, through December 31, 1972.

5.2.3 Specialized Instrumental Studies--Station CLN

With the publication of Sanford and Toppozada (1974), the first phase of the investigation of southeastern New Mexico seismicity ended. This early phase was concerned with the estimation of seismicity in the Los Medanos area based on careful evaluation of available geologic and seismic data. In early 1974 the emphasis changed. Since at that time no data were available from a station very near the site area itself, it was decided that acquisition of new instrumental data from such a station

would be of immediate value. With the installation of a high-gain seismograph in the site area, the question of the occurrence of low level seismic activity at or near the proposed waste repository could be more meaningfully addressed. Therefore, at the beginning of April, 1974, a single component (vertical) high-gain, continuously recording seismograph station (given the letter designation CLN by the U.S. Geological Survey) was installed in a shack located in a caliche pit very near the proposed nuclear waste disposal site. Analysis and interpretation of the data collected by this station may be found in Sanford et al (1976a), Caravella and Sanford (1977) and Sanford et al (1978). In this section the findings presented in these publications will be briefly discussed.

The essential elements of station CLN are a short-period, vertical seismometer (Earth Sciences Ranger SD 211), an amplifier (Astrodata 120), a film recorder (Earth Sciences RF 220), and a WWVB radio receiver (Specific Products--T60). The recording rate is 1 mm/sec, a speed that can produce high-resolution seismograms of small local and regional earthquakes. At this recording rate, the seismograph requires a film change every three weeks. Otherwise, the station is self-sufficient. Five minutes of the WWVB coded time signal is placed on the record every two hours to assure excellent time control. The ground displacement response of the seismograph has varied slightly over its operating lifetime as the free period and percent critical damping of the seismometer changed. These changes are summarized in Sanford et al. (1978). However, the magnification response of the system has remained essentially constant within the frequency range 4 to 30 Hz. The peak magnification is near 455 thousand times when a factor of 12 for record enlargement during photographic processing is included. This peak occurs near 22 Hz.

For most of the time since the station went into operation on April 5, 1974, the seismograph has performed as expected, except for the changes in response characteristics already mentioned. However, there were times when no records were obtained and when the station was without time signals. Table 5.2-4 lists these periods and the reasons for the breaks

in service. From April 5, 1974, to October 29, 1977, the total reporting period considered in this subsection, the station was in operation 83 percent of the time.

During the April 1974 to October 1977 period, 291 events identifiable as local and regional earthquakes (Sg - Pg $\leq$ 81 seconds, where Sg and Pg are the crustal shear-wave and compressional-wave arrival times) were recorded at station CLN. For a complete list of these events see Sanford et al. (1978, Table 3). For each earthquake the date, arrival time (GMT), and character, whether impulsive or of several phases, are given. The Sg phase amplitudes (from which magnitudes are determined) are also listed. With the aid of additional arrival times from other regional seismograph stations, epicenters for 75 of these 291 events were obtained. This group of 75 events may be further subdivided into those which are fairly well located (49) and those for which only tentative epicentral locations may be given (26). Table 5.2-5 lists the origin times, locations, and magnitudes (and seismograph stations used) for the seismic events whose epicenters are reasonably well known. A map of these epicenters is shown in Figure 5.2-3. Table 5.2-6 lists the remaining events for which there are insufficient data to allow exact locations. For many earthquakes in Table 5.2-6 two epicenters are possible because readings are presently available from only two stations. In this case, the epicenter is listed that is most compatible with the locations of the well-determined events.

Figure 5.2-4 shows histograms of the number of recorded earthquakes versus the Sg-Pg interval in seconds. The upper histogram represents the complete data set at station CLN for all those events whose Sg-Pg interval is less than or equal to 40 seconds. Major peaks in the histogram occur at Sg-Pg intervals of 8 to 13 seconds, 22 to 24 seconds, and 31 to 36 seconds. The middle histogram shows those events in the CLN data set which occurred during local day-time hours (12:00-02:00 GMT), and the bottom histogram those during the local nighttime hours (02:00-12:00 GMT). The similarity in shape of the middle and bottom histograms suggest that explosions from any small number of specific

sources have been largely eliminated from the data set. However, the disproportionate number of events during the day-time hours (7.62 X 10^{-3}/hour) compared to the nighttime hours (5.14 X 10^{-3}/hour) does not rule out the possibility that some cultural sources still exist in the data set.

Because a substantial fraction of the shocks within each of the prominent peaks of the histogram in Figure 5.2-4 are located, speculation on the epicenters for the other shocks is possible. All of the located shocks within the Sg-Pg distance range of 8 to 13 seconds have epicenters within the area from 31.7° to 32.3°N and from 102.8° to 103.2°W. These coordinates bracket a section of the Central Basin Platform centered roughly on the southeastern corner of New Mexico. All of the evidence suggests that all shocks with Sg-Pg times from 8 to 13 seconds are generated within this section of the Center Basin Platform.

Nearly all of the located shocks with Sg-Pg intervals between 22 and 24 seconds have epicenters within the area from 31.5° to 31.85°N and from 102.2° to 102.8°W. The region defined by these coordinates is centered on a section of the Central Basin Platform located about 50 kilometers southeast of the southeastern corner of New Mexico. Most unlocated shocks with Sg-Pg intervals from 22 to 24 seconds are believed to originate from this section of the Central Basin Platform.

The known epicenters for shocks with Sg-Pg intervals from 31 to 36 seconds indicate a number of tectonically active regions are contributing to this peak in the histogram. Notable among these is a region centered on Valentine, Texas, the site of a strong earthquake in 1931 (Sanford and Toppozada, 1974), and much of the Tularosa Basin.

5.2.4 Specialized Instrumental Studies--Central Basin Platform

The first earthquake to be located in the Central Basin Platform from instrumental data occurred on February 3, 1965. This event attracted little attention at first although it was recorded at a number of

regional stations (Socorro, New Mexico; Lubbock, Texas; Ft. Sill, Oklahoma; Vernal, Utah; Las Cruces, New Mexico; El Paso, Texas; and Albuquerque, New Mexico) and was located by the New Mexico Institute of Mining and Technology (Sanford and Cash, 1969). It was not, for example, listed in the Preliminary Determination of Epicenters reports of the U.S.C.G.S.

To learn more about the seismicity of the Central Basin Platform in conjunction with their study of southeastern New Mexico earthquake risk, Sanford and Toppozada (1974) examined the total available record from station FOTX, a Long Range Seismic Measurements (LRSM) station near Ft. Stockton, Texas, in operation from June 21, 1964 to April 12, 1965. Apparently, this is the only high-magnification station (350-400 thousand times at 1 Hz) to have operated for any substantial period within 120 kilometers of the Central Basin Platform before installation of station CLN in 1974. FOTX was in operation at the time of the February 3, 1965 earthquake on the Central Basin Platform. Based on this examination a number of earthquakes believed to have originated in the Central Basin Platform were found including two occurring before the February 3, 1965 event. Prior to examination of the FOTX records these two events on November 8 and 21, 1964 were unknown. All events located by Sanford and Toppozada in the Central Basin Platform during the operation of FOTX - and based primarily on readings from this station - are listed in Table 5.2-7.

The studies by Sanford and Toppozada (1974) suggested earthquake activity on the Central Basin Platform at a level higher than expected, but were not conclusive because of the very small amount of instrumental data available close to this area. About all that could be said at that time was that eight significant earthquakes (see Table 5.2-8) had occurred near the Central Basin Platform between November 1964 and September 1971 ranging in magnitude (new revised estimates as discussed in Section 5.2.2) from 2.5 M_L to 3.2 M_L; that one of these events, August 14, 1966, had an associated maximum intensity of VI on the Modified Mercalli scale; and that a number of smaller earthquakes had apparently occurred

at about the same location during the operating lifetime of station FOTX. The basis for this latter supposition was that all of the measured Sg-Pg intervals on the FOTX seismograms yielded an epicentral distance corresponding to the distance between the FOTX station and the area of activity on the Central Basin Platform. In addition, for some of the stronger shocks, arrival times were available from the Las Cruces station (LCN). The difference between P arrival times at LCN and FOTX was the same (34.7 plus or minus 0.5 sec) for the unlocated shocks as for the located events in November 1964 and February 1965. Thus, it is reasonably certain that the Central Basin Platform has been seismically active since mid-1964. Since the activity rate was roughly the same at the end as at the beginning of the 10-month period for which FOTX records were available, it can be supposed that earthquakes also occurred before mid-1964. If such activity had occurred, it probably would not have been detected on the regional seismograph stations then in existence.

The instrumental coverage of this part of the country has improved markedly in the past several years. The first important improvement took place in the spring of 1974 when station CLN was installed by personnel of the New Mexico Institute of Mining and Technology. Data recorded by this station between April 1974 and the end of October 1977 has already been discussed in detail in subsection 5.2.3. However, it should be mentioned that of the 49 earthquakes recorded during this period by CLN and enough other regional stations to allow accurate location (Sanford et al., 1978), 24 of them occurred within the active parts of the Central Basin Platform. Of the 26 less well located earthquakes of Table 5.2-6 and Figure 5.2-3, 13 of them are thought to belong to the Central Basin Platform area. Thus, for the period of operation of station CLN through October 1977 (which represents the last records so far analyzed from this station) nearly half of the events located within 300 kilometers of the Los Medanos site have occurred within the Central Basin Platform

The most recent advancement in the instrumental coverage of the Central Basin Platform area took place with the initiation of operation of the

Kermit, Texas, seismic array in November 1975. The remainder of this subsection is concerned with discussions of the operation and preliminary findings of this array.

Based on the seismicity information developed by Sanford and Toppozada (1974) the Central Basin Platform was instrumented with an array of seismograph stations encompassing the largest historical events discussed above. The purpose of this array is to study, in some detail, the seismicity of this region which is of interest both because it is important to the evaluation of seismic risk at the Los Medanos site and because secondary petroleum recovery projects have been active in this area for a period roughly coincident with its known seismic activity. It is hoped that ultimately such a study will answer questions fundamental to an evaluation of the implications of Central Basin Platform earthquakes to the tectonism, not only of the platform, but of surrounding regions. Evaluation of the Kermit, Texas, array data has not yet progressed to this point, but some preliminary discussion is possible at this time. The treatment below is largely abstracted from Hays (1977) and Rogers and Malkiel (1978).

The Kermit seismic network currently consists of 10 self-contained radio telemetry systems placed in a grid pattern covering 2200 square kilometers. Each field station is equipped with a single component vertical seismometer and accompanying amplifier-transmitter equipment. The seismometers are Mark Products L-4C's with a natural period of one second and 67 percent critical damping. Typical magnifications range from 25 to 50K near 1 Hz increasing 6dB/octave to 10 Hz. A receiver station is centrally located at the Winkler County Airport at distances from individual stations ranging from 12 to 40 kilometers. The current locations of the 10 array stations are shown in Figure 5.2-5 taken from Rogers and Malkiel (1978). Those stations designated by a three symbol code followed by an "A" represent second locations for these instruments. The moves were usually made to diminish background noise levels or improve foundation conditions. The initial location of these stations may be found in Hays (1977). In general, the effect of unfavorable surface

geology and high cultural noise in this area has posed problems that have resulted in less than optimum station gain for a micro-earthquake study (Rogers and Malkiel, 1978).

Once the signals are placed on the phone lines, recording and timing take place at the National Earthquake Information Center (NEIC) in Golden, Colorado. Signals from the individual stations are put on film (in a 20 channel Develocorder microfilm recorder) and the highest quality station (KT7, see Figure 5.2-5) is simultaneously recorded on a Helicorder visible recorder to provide rapid identification of events of interest. Film recording speed is 3 cm/min and optical enlargement of 20 times permits resolution of plus or minus 0.01 seconds for impulsive arrivals. Direct recording of station WWV also insures correct absolute timing.

The average level of detection within the array is given as magnitude M_{LD}=2.0, where M_{LD} is a magnitude determined from the coda length as discussed in Lee and Lahr (1972). This represents a relatively low array sensitivity due to the surface geology and unfavorable operating environment as previously mentioned. Detection threshold for individual stations varies from a high of M_{LD} = 2.5 in oil fields with sandy surface conditions to a low of M_{LD} = 0.5 along the west edge of the array where low levels of pumping, and caliche "bedrock", allow higher gains to be used. In the discussion below, M_L will be used for M_{LD} wherever the Rogers and Malkiel (1978) data are referenced.

During the current reporting period (November 1975 through July 1977) 407 events have been detected of which 135 have been well enough recorded to be located. These earthquake locations were determined using the hypocenter location program HYPO71 (Lee and Lahr, 1972) and a four layer over a half-space crustal model developed by Stewart and Pakiser (1962) for eastern New Mexico.

Of the 135 located events, 56 occurred within the area of the array. these earthquakes are shown in Figure 5.2-6 and listed in Table 5.2-9. Of these 56 earthquakes, 22 have been located using the readings from only

three stations. This is inadequate to allow hypocentral depth to behave as an unknown in the formal location algorithm so that for all these events an assigned depth of 5 kilometers is used (denoted 5.00* in Table 5.2-9). For an additional 14 events, locations have been accomplished using only four stations. In this case the hypocenter may be fixed deterministically but no redundancy in possible locations exists to allow some estimate of the uncertainty in the formal location. Thus, of the 56 internal, and presumably best located, earthquakes of Table 5.2-9 only 20 are available with an estimate of both depth and hypocentral uncertainty, at least in a formal sense.

An interesting independent estimate of the accuracy with which events have been recently characterized in the Central Basin Platform is provided by a comparison of earthquakes common to both Tables 5.2-9 and 5.2-5. There are only four such events. The majority of those earthquakes appearing in both the Sanford et al. (1978) and Rogers and Malkiel (1978) "well located" data sets are somewhat peripheral to the Kermit array as will be seen below. The location and origin time agreement is very good; differences averaging 0.04 degree and 0.6 seconds respectively. Such modest differences can probably be easily explained by minor model differences and, in the case of the Sanford et al. (1978) data set, focal depth assumptions. However, estimates of local magnitude, M_L, differ significantly. The four events under consideration average over 0.9 magnitude units higher in the Rogers and Malkiel data set than that of Sanford et al. This point is worth keeping in mind.

Table 5.2-10 lists those earthquakes occurring on the periphery of the Kermit array with locations that use readings from at least five array stations. This does not necessarily imply that these events are well located. In fact, many are given a low location quality factor by Rogers and Malkiel (1978). Indeed, these authors do not plot the formal hypocentral positions for earthquakes occurring outside the boundaries of the array but instead outline zones in which these events apparently lie. These zones are meant only to be indicative of the general area where earthquakes appear to be occurring. Both the zone boundaries and formal locations are shown in Figure 5.2-6.

The events listed in Table 5.2-10 may be compared with those in Table 5.2-5 in a manner similar to that discussed above in connection with Table 5.2-9. Of the 51 earthquakes around the periphery of the Kermit, Texas, array as determined by array station readings, 15 also appear in Table 5.2-5. The average origin time difference is greater in this case, being 1.9 sec., and a larger epicenter location difference of 0.1 degree is also present. Again, the most interesting differences are in local magnitude, M_L. As before, the Kermit array data set shows magnitudes consistently higher (in this case 0.84 units higher) than the New Mexico Institute of Mining and Technology values as they appear in Sanford et al. (1978).

Solely to present consistent-looking plots, events listed in Tables 5.2-9 and 5.2-10 and shown in Figure 5.2-6 have been scaled to circumvent this magnitude disparity. That is, the symbol used for a particular earthquake epicenter of magnitude M_L in Figure 5.2-6 is the same as would have been used for a magnitude M_L-0.85 in previous epicenter plots.

All available data through mid-1977 for the Central Basin Platform have now been considered. It is clear that continuing effort in this area will improve the understanding of this seismicity. Before outlining the speculations that have been made based on information to date, it seems appropriate here to briefly summarize this seismicity in very general terms.

There is little doubt that the Central Basin Platform has been seismically active since at least mid-1964. Its activity before this time will likely remain speculative. There is no evidence of historical felt reports for events felt in this area similar to the epicentral intensity = VI earthquake of August 14, 1966, even though local histories and newspapers have now been searched specifically for any such reference (Sanford and Toppozada, 1974). Conclusions as to the lack of previous seismic activity on this basis, however, must be tempered somewhat by the knowledge that this part of western Texas has never had a large population.

Since the first instrumental detection of events in the Central Basin Platform region, the number of recorded earthquakes has been largely a function of the number and sophistication of the seismograph stations available to record them. With the startups of station CLN in 1974, and, more important, with the Kermit array, large numbers of small earthquakes are now being noted that previously would have completely escaped notice. It is now clear that, at least for the last several years and probably for the last decade, the Central Basin Platform has been the most seismically active area within 300 kilometers of the Los Medanos site in terms of number of events.

It is worthwhile here to put the Central Basin Platform activity into perspective. Even though some events near magnitude 0 are recorded (Rogers and Malkiel, 1978), fewer than ten detected events are reported for many months during the operation of the Kermit array. This rate is relatively low compared with the activity rates of some of the more active areas in the eastern U.S. such as Blue Mt. Lake, New York (Sbar et al., 1972), or southeastern Missouri (Stauder et al., 1976). The largest known earthquake to occur in the Central Basin Platform had, by the most recent estimate, a magnitude of less than 3-1/4. It is very difficult to believe that any event very much larger than this (say $M_L \geq 5$) could have escaped instrumental notice during the past 50 years or so. The Valentine, Texas, earthquake of 1931, to the south, for example, had an epicentral intensity of VIII on the Modified Mercalli Scale and was recorded worldwide (Byerly, 1934). The magnitude of this event has been estimated to be 6.4 based on the felt area (Sanford and Toppozada, 1974). The I_o=VI event of August 1966, where I_o is epicentral intensity, has recently been assigned a magnitude somewhat less than 3. In short, the Central Basin Platform has exhibited some activity since mid-1964, but this activity has been of small magnitude. There is no evidence to suggest that moderate or large magnitude events occurred before mid-1964. Within limits imposed by general regional and worldwide seismographic capabilities, there is no evidence to allow a determination of the small magnitude earthquake activity in this area before 1964.

In the remaining discussion, the causes and implications of the Central Basin Platform seismicity, as best these have been determined, are considered. This discussion is speculative since the definitive evidence critical to a unique view of either the causes or implications of these earthquakes does not yet exist. Figure 5.2-6 shows the 107 earthquakes of Tables 5.2-9 and 5.2-10, as well as the approximate boundaries of the Central Basin Platform and a series of pre-Permian faults inferred from drilling. These faults, which are all deeply buried, are taken from 1:9600 scale maps provided by Geomap Corporation to Rogers and Malkiel (1978). From a comparison of fault and epicenter locations it is clearly not possible to associate the earthquakes with known faulting although an alignment of epicenters in the southwest corner of the array appears to occur on a short fault segment. Other events or groups of events appear equally likely to occur in the vicinity of faults as not. In a very general sense, however, it appears that both the eastern and western boundaries are active (Rogers and Malkiel, 1978). The basic conclusion from all instrumental data is that seismic activity is equally likely to occur anywhere along the Central Basin Platform structure as asserted by Sanford et al. (1978) without particular regard to small scale structural details such as individual pre-Permian faults.

Attempts have also been made to relate Central Basin Platform seismicity to secondary oil recovery operations in the area. Both the spatial and temporal association of Central Basin Platform seismicity with secondary recovery projects at oilfields in the area are very suggestive of some cause and effect relationship.

Shurbet (1969) was the first to suggest that seismic activity on the Central Basin Platform is related to water injection for secondary recovery of oil. His suggestion was based on the clearly established association between earthquakes and waste injection into crystalline bedrock at the Rocky Mountain Arsenal near Denver (Healy et al., 1968). Subsequently, a direct association between earthquakes and fluid injection for secondary recovery of oil was established at the Rangely field in northwestern Colorado (Healy et al., 1972). As the fluid pressure builds

up during injection, the effective stress across pre-existing fractures diminishes with an associated decrease in frictional resistance to sliding.

There appears to be a correlation between the number of active waterflood projects and the first known occurrence of earthquakes in 1964. Although waterflood projects began in this area as early as 1944, the number of projects began to increase considerably in the mid-1960's and, on the average, injection pressures have also increased with time (Rogers and Malkiel, 1978). A study of the number of active secondary recovery projects versus time in this area shows a rapid increase in the early 1960's, a peak in 1968, and relative constancy since that time. The increase in secondary recovery activity occurs prior to, but in rough conjunction with, the first occurrence of earthquakes in the area. During the period of operation of the Kermit array, the largest earthquakes recorded have occurred in the vicinity of the Keystone unitized oil field. The Dollarhide unitized field, although outside the boundaries of the array, appears to be one of the most seismically active areas. Other areas of seismic activity occur, however, that are not within the major oil field boundaries, and major secondary recovery fields exist that apparently are not seismically active. Although the evidence is not conclusive, based on this seismicity pattern and the absence of recent geologic faulting within the Central Basin Platform it is believed that the best working hypothesis at this time is that earthquakes are associated with the release of low level residual stress by secondary recovery operations. It is neither proved nor precluded by a consideration of current best estimates of regional stress regime (Hays, 1977) as discussed in a later subsection.

5.2.5 The Events of July 26, 1972 and November 28, 1974

Questions on the tectonism and seismic activity very near or at the site are of great interest. For this reason the single most important seismic event to occur since installation of station CLN at the Los Medanos site has been the earthquake at 03:35:20 GMT on November 28, 1974 (see Table 5.2-5 and Figure 5.2-3). This earthquake, whose most recently estimated

magnitude is 3.6 (Sanford et al., 1978), had an epicenter about 40 kilometers northwest of station CLN. If it is an indication of normal background seismicity in the immediate site area, this event might cause a reevaluation of previous estimates of seismic risk at the Los Medanos site by Sanford and Toppozada (1974) who considered the likely principal sources of site vibratory ground motion to be a major earthquake to the west, no closer than approximately 115 kilometers, and a moderate earthquake in the Central Basin Platform. Because of its potential importance, this event has attracted considerable notice. It was prominently mentioned in two studies (Sanford et al., 1976a; Sanford et al., 1978) and was the main topic of another (Caravella and Sanford, 1977).

As may be seen from Table 5.2-5 the event of November 28, 1974 has been located by the New Mexico Institute of Mining and Technology at about 32.6°N, 104.1°W by using phase readings from six stations. An independent location by the U.S. Geological Survey places this earthquake at 32.3°N, 104.1°W. Both solutions give a virtually identical origin time. At the time of this earthquake, a rockfall and considerable ground cracking were reported at the National Potash Co. Eddy County Mine. The location of this rockfall was 32.55°N, 104.04°W and it occurred within about one minute of the calculated earthquake origin time. In view of this rather remarkable coincidence the question naturally arose as to the cause and effect relationship of the rockfall to the recorded seismic event. The issue was whether the source of this event could be related to a non-tectonic cause such as mine collapse at the Eddy County Mine or if it should be considered a more normal release of accumulated strain energy. Clearly the epicentral uncertainty grossly implied by the two different formal solutions found by the New Mexico Insitute of Mining and Technology and the U.S. Geological Survey allowed actual spatial coincidence of rockfall and seismic disturbance. Therefore it was decided that a more careful location effort would be worthwhile.

As information was being collected for this redetermination effort, it was discovered that a previous rockfall had occurred at the National Potash Co. Eddy County Mine on July 26, 1972. A check of past seismograph

records revealed that a seismic event had been recorded at a number of regional seismograph stations, too. A subsequent location using these readings put this event at 32.6°N, 104.1°W and assigned a magnitude of M_L=2.8 (see Table 5.2-3). Thus this event, although weaker, was found to be located very near the November 28, 1974 event, and study of the individual station records indicated that its coda was of nearly identical character to the later event. Since more records were available for the earlier event, it was decided that a detailed relocation effort would be attempted for it first. The question of the nature of its source was still of primary concern.

The relocation method is described thoroughly in Caravella and Sanford (1977) and will only be outlined here. The origin time was picked by extrapolation to the S-P interval equal zero intercept of a straight line fit of S-P versus P data. Such a procedure, using data from all six stations recording the July 26, 1972 event (LUB, SNM, ALQ, JCT, TUC, and GOL) yielded an origin time of 04:35:40.4;± about 3.3 seconds at the 95 percent confidence level. A similar linear regression using only the first five S-P intervals yielded an origin time of 04:35:43.9 ± about 2.8 seconds at the same confidence level. Ultimately, the five interval origin time was selected because a better location was obtained with it.

To develop a velocity model to use in the relocation effort the following procedure was adopted: seismic wave arrival times from the underground nuclear explosion GNOME were noted. This explosion, which was detonated at 19:00:00 GMT on December 10, 1961, at 32.264°N, 103.866°W (located about 35 km south of the National Potash Co. Eddy County Mine) was recorded by many of the stations noted above (see Romney et al., 1962). From these arrival times, crustal and subcrustal velocities were developed over the ray paths from GNOME to each individual station. In essence, each station was modeled as being underlain by two layers over a half space. The velocity and thickness of the upper layer were assumed known from independent sources (Reddy, 1966; Romney et al., 1962; Wilson et al., 1969; Major, 1975; Shurbet, 1975; Toppozada and Sanford, 1976) and the velocity (and implied critical incidence angles) of the lower (and main)

crustal layer was then found by an iterative technique for each station independently. Subcrustal velocities could then be similarly found. Corrected crustal velocities (layer two) determined in this way ranged from 6.31 km/sec to 6.02 km/sec. Thus lateral inhomogeneity is built into the model.

Using the station-dependent model and the preferred origin time, 95 percent confidence interval arcs were drawn from each station. The results are shown in Figure 5.2-7. As can be seen, the intersecting arcs so constructed define a rather large area of approximately 1900 km^2. Although the Eddy County Mine lies very near this area, other locations within the same area have the same formal likelihood of being the epicentral location.

The November 28, 1974, seismic event was not relocated in the same way. Instead, another fundamental question was asked. That is, could the two events, July 1972 and November 1974, have occurred at the same focus based on existing seismographic evidence. The test applied is that if the events had the same hypocenter, the differences in arrival times of specific phases at common stations should be the same for all stations. As may be seen from Table 5.2-11 this is not the case for the limited data set available.

The difference between the smallest and largest time difference is 1.4 sec. Caravella and Sanford (1977) believe this is too large to be explained by reading errors. The time differences indicate, under this conclusion, that the two events did not have the same hypocenter, even though location uncertainties are such that either of them might, by itself, have occurred at the rockfall site. The time differences can be explained by locating the hypocenter of the November 28, 1974 event about 10 kilometers northwest or southwest of the July 26, 1972 shock (Caravella and Sanford, 1977). At this time, then, best available analysis indicates that both of these small events did not occur at the Eddy County Mine and cannot both be caused by some nontectonic source at that location. In the seismic risk analysis of the next section, therefore, some background earthquake activity in the immediate site area is considered.

5.3 SEISMIC RISK ANALYSIS

In this section, a broad characterization of the site region's seismicity is developed in a way useful for making conservative earthquake-resistant design decisions. This risk analysis is intended to be applicable only to vibratory ground motion resistant design of surface facilities on good foundations. Generalization of the results of this analysis to less idealized conditions, such as design of subsurface facilities for shaking during an earthquake or allowance for poor surface foundation conditions (should they be encountered), may be accomplished at a later time without altering the import of the original analysis. However, it must be emphasized that in this section the risk formally presented is intended to be a meaningful and conservative estimate of proper design values for short-term features of the facility. "Short-term" as used here means time periods on the order of decades. Specifically, it is not believed that any results presented here can be simply extrapolated to periods of tens or hundreds of thousands of years even though formal extrapolations of this kind are possible. This is not a severe handicap in this case. Although the lifetime of the repository will be longer than the limits of applicablility of this risk analysis, the length of time for which vibratory ground motion will be of concern is much shorter (during surface facilities use) and, in fact, falls well within the intent of this analysis.

There are a number of ways to characterize site seismicity in a way useful for rational design against the effects of earthquake associated ground shaking. One measure of the proper design value is the maximum historical site intensity which can be estimated from the historical earthquake record and some intensity attenuation law, whether this law is explicitly or only implicitly considered. As noted in the previous section, the maximum historical intensity at the Los Medanos site is estimated to be less than or equal to V on the Modified Mercalli Intensity Scale (Wood and Neumann, 1931). This characterization of earthquake design motion has the great advantage of being simple and straightforward. It is not, however, generally used for important structures or facilities because it does not

provide a basis for estimating whether future events will result in site intensities exceeding the maximum historical site intensity. This is a serious drawback for areas with a relatively short historic record such as the United States, and especially its western half.

To construct seismic design values for a particular site that go beyond a simple interpretation of a maximum historical measure of ground motion, something more than historical seismicity must be considered. Therefore, the geology of a region is often used in several ways to supplement historic earthquake data. There are several studies that attempt to present a seismic zonation of the United States using both seismic and geologic arguments. The stated intent of one of these (Richter, 1959) is to present a seismic regionalization showing the maximum reasonably expectable intensity during future earthquakes on ground of prevailing character. The Los Medanos site is in a region of intensity VIII according to this study. Algermissen 1969) has developed a Seismic Risk Map that has been closely associated with editions of the Uniform Building Code since 1970 (Uniform Building Code, 1970, 1973, and 1976) and by this association is most directly applicable to an estimate of proper design of structures with lifetimes measured in decades. The Los Medanos site intensity is shown to be V and/or VI in this zonation. Both these seismic risk maps, which were considered for the site region by Sanford and Toppozada (1974), are based on essentially the same data. The differences are due to varying interpretations and intent. That the interpretations are not really very far apart is indicated by a statement by Richter (1959) that an individual structure intended for a lifetime of the order of 30 years might within that life be exposed to shaking of no more than one scale degree below that mapped. Thus, over several decades, the Los Medanos site might reasonably be subjected to shaking at around the V to VII intensity level according to both Richter and Algermissen.

Although based on both historical seismicity and large scale geologic features, the seismic regionalization maps of Richter and Algermissen do not explicitly consider frequency of occurrence of damaging earthquakes. More fundamentally, the subjective decisions implicit in any

characterization of future earthquake ground motion are largely concealed and not subject to scrutiny. Any shifts of emphasis or new geologic or seismic information are, therefore, very difficult to incorporate into such zonations. In recent years, several procedures have been developed that allow formal determination of earthquake design parameters to be made (Cornell, 1968; Cornell and Vanmarke, 1969), and a number of studies incorporating these procedures have been performed (e.g., Cornell and Merz, 1975: Shah et al., 1975; Algermissen and Perkins, 1976). In typical seismic hazard analyses of this kind, the definition of seismicity is made by using geologic and tectonic data as well as observed earthquake locations. The region of study is divided into seismic sources within which future events are considered equally likely to occur at any location. For each seismic source area the rate of occurrence of events above a chosen threshold level is estimated, using the observed frequency of historical events. The sizes of successive events in each source are assumed to be independent and exponentially distributed; the slope of the log-number versus frequency relationship is estimated from the relative frequency of different sizes of events observed in the historical data. This slope, often termed the b value (Richter, 1958), is determined either for each seismic source individually or for all sources in the region jointly. Finally, the maximum possible size of events for each source is determined, using judgment and the historical record (McGuire, 1977).

It is clear from this description that all assumptions, no matter what the level of subjectivity employed in making them, must be made explicit. In addition, this method of determining site-specific earthquake risk may be used for a wide range of geologic and seismic assumptions. In this section, the method of Cornell (1968) will be applied to the question of risk as a function of ground shaking at some prescribed level at the Los Medanos site. Input parameters at each stage of the development will be taken from current best information available in the literature. These input parameters are discussed below in some detail following a general discussion of the mechanics of the Cornell method itself. Finally, several curves showing probablility of maximum ground surface acceleration versus acceleration level, will be presented and discussed for several

different assumptions about the individual source area capabilities. The conclusions that may be drawn from these curves will be considered. It is believed that the data, treated in this way, may be used to arrive at a general preliminary statement of risk from vibratory ground motion that is applicable at the site during its active phase of development and use.

5.3.1 The Method of Cornell

Cornell (1968) developed a method to produce relationships between ground motion parameters, such as peak ground displacement or maximum ground acceleration, and their average return period. The data used include best estimates of average activity levels for various potential sources of earthquakes. Arbitrary geographical relationships are allowed between these potential sources and the site. Cornell provides a technique for integrating the individual influences of these sources into the probability distribution of the ground motion parameter and the average return period then follows directly. The potential sources are modeled geometrically in such a way as to permit a solution of closed analytical form.

In this Section, a calculation is made of the probability that a random peak ground acceleration "A" will exceed a given value "a" once an event of magnitude greater than some threshold level has occurred. Before the method can be used, a geometric model or characterization of the potential earthquake sources must be made. Cornell develops the necessary formulation for point, line, and annular area sources. The geological structure and seismic history of the Los Medanos site do not imply that linear or point source models are appropriate, so use of the technique begins with an approximation of the source regions (Algermissen and Perkins, 1976) by annular segments (see Fig. 5.3-5). As discussed in the next subsection, the annular segments are in all cases believed conservative approximations of the source regions.

Let acceleration be related to Richter magnitude M and hypocentral distance R (in kilometers) by the equation:

$$a = b_1 \exp(b_2 M) R^{-b_3}$$

where a is in units of cm/sec^2 and the values of the constants (b_1, b_2, b_3) are discussed in a later subsection. Then if M and R are assumed to be probabilistically independent within the source areas, the probability of an acceleration A exceeding a given value a can be expressed as:

$$P\left[A \geq a\right] = 1 - F_M(m) = P\left[M \leq (\ln a + b_3 \ln R - \ln b_1)/b_2\right]$$

where F(m) is a distribution function of earthquake magnitudes, which can be calculated using a recurrence relation of the form (Gutenberg and Richter, 1942):

$$\log N = \underline{a} - \underline{b}M$$

where $\underline{a}$ and $\underline{b}$ are constants.

To find the proportion of events having magnitudes in the range $m_o < M < m$ the number of such events ($N_{m_o} - N_m$) is divided by the total total number of events with magnitude greater than m_o

$$F_M(m) = (N_{m_o} - N_m)/N_{m_o} = 1 - \exp\left[-B(m - m_o)\right]$$

where $m_o < m \infty$ and B is used to denote the constant b ln10. However, it is desirable to impose an upper limit on the magnitude of an event that may occur in a given source area, i.e., to specify that $m_o \leq m \leq m_1$. Our cumulative distribution function must now satisfy the boundary condition $F_M(m \geq m_1) = 1$ so:

$$F_M(m) = C\left[1 - \exp\left[-B(m - m_o)\right]\right]$$

where C is a constant such that

$$C = 1/\left[1 - \exp\left[-B(m_1 - m_o)\right]\right] \equiv 1/(1 - k_{m_1})$$

In this case, the probability expression may be rewritten as

$$P\left[A \geq a\right] = 1 - F_M(m) = \left[-k_{m_1} = \exp\left[-B(m - m_o)\right]\right]/(1 - k_{m_1})$$

where $k_{m_1} = \exp\left[-B(m_1 - m_o)\right]$. For values of m less than m_o, $\left[P\ A \geq a\right] = 1$ while for values of $m > m_1$, $P\left[A \geq a\right] = 0$.

Aside from the limits on the range of r due to the inner and outer radii of the annular segment, it is important to note that the condition m_o m m_1 also places limits on the range over which the above probability is valid. Specifically, the condition on m implies, for a given acceleration value a, that:

$$\left[\exp(b_2 m_o/b_3)\right](b_1/a)^{1/b_3} \leq r \leq \left[\exp(b_2 m_1/b_3)\right](b_1/a)^{1/b_3}$$

The lower boundary value of r may be thought of as the distance from the site within which any event of magnitude m or greater will result in an acceleration of a or greater. In other words, the probability is unity that for values of r less than the cutoff value a random acceleration A will exceed the chosen a. The upper boundary is the maximum radius from the site at which an event of magnitude m could have a nonzero probability of causing an acceleration a, given an attenuation law of the proper form. A schematic representation of these limits on r, for a given a, over which the above probability is valid is shown in Figure 5.3-1 (top).

In order to find the cumulative distribution $F_M(m)$ for all possible values of the focal distance and their relative likelihoods, integration over the annular area under consideration is performed:

$$P[A \geq a]_{\text{annular area}} = \frac{1}{2\pi}\int_0^{2\pi}\int_d^{r_o} P[A \geq a]\cdot f_{R,\Theta}(r,\theta)\ dr d\theta$$

where $f_{R,\Theta}(r,\Theta)$ is the probability density function of R, Θ the coordinates of a random focal position within the annulus (see Fig. 5.3-1bottom). Assuming that $f_{R',\Theta}(r,\Theta)$ is independent of Θ, the probability of the source falling within the annular area bounded by X (Fig. 5.1-1bottom) is just the ratio of this area to the total area or

$$F_{R,\Theta}(r,\theta) = \pi(X^2 - \Delta^2)/\pi(\ell^2 - \Delta^2) = (r^2 - h^2 - \Delta^2)/(\ell^2 - \Delta^2)$$

so then

$$f_{R,\Theta}(r,\theta) = \frac{d}{dr} F_{R,\Theta} = 2r/(\ell^2 - \Delta^2)$$

Substituting the expression for $f_{R,\Theta}(r,\Theta)$ into the probability equation and integrating, an expression is found of the form:

$$P[A \geq a]_{ann.} = \frac{2}{\ell^2 - \Delta^2}(1 - k_{m_1})^{-1}[Da^{-B/b_2}\left(\frac{1}{(\gamma-1)d^{\gamma-1}}[1 - (\frac{r_0}{d})^{-(\gamma-1)}]\right) - \frac{k_{m_1}}{2}(r_0^2 - d^2)]$$

where

$$D = b_1^{B/b_2}\exp(Bm_o) \quad : \gamma = Bb_3/b_2) - 1$$

The question of the random number of occurrences in any time period is next considered. It is assumed that for the magnitudes of interest the occurrence of any event is Poissonian, that earthquakes have equal likelihood of occurring anywhere within the source area considered, and that the average occurrence rate, ν per year, is constant in time. The above three assumptions, particularly that of Poissonian distribution of events, are fundamental.

It may then be shown that the probability that $A_{max}(t)$, the maximum value attained by A over a time of t years, will be less than or equal to a is:

$$P\left[A_{max}(t) \leq a\right] = \exp(-p\nu t)$$

where p is the annular area probability, $\left[P\ A \geq a\right]_{ann.}$, calculated above and is the average occurrence rate..

The risk or annual probability that A_{max} will <u>exceed</u> a is

$$1 - P\left[A_{max}(t=1) \leq a\right] = 1 - \exp(-p\nu)$$

Sources near the Los Medanos site will be modelled by angular segments of an annulus. In this case, a simple modification of p in the above exponential is required but the method is otherwise the same.

The average return period, T, of an acceleration equal to or greater than a is defined as the reciprocal of $P\left[A_{max} \geq a\right]$, that is:

$$T(\text{years}) = 1/P\left[A_{max} \geq a\right]$$

Tables of values of annual risk (and average return period) versus values of a can be constructed for each source area near and surrounding the site. The risk at the site arising from all such sources may then be found by combining the results above in the following way:. Consider source areas A, B, and C to be independent in a statistical sense. Then, where $P^{ABC}\left[A_{max} \leq a\right]$ is the familiar probability that the maximum value of A, the peak ground acceleration arising from composite source area ABC, is less than a at the site, is

$$P^{ABC}\left[A_{max} \leq a\right] = P^{A}\left[A_{max} \leq a\right] \bullet P^{B}\left[A_{max} \leq a\right] \bullet P^{C}\left[A_{max} \leq a\right]$$

If it is assumed that all the sources are modeled by annular segments (i.e., not a combination of annular and line sources), then the composite probability of <u>exceeding</u> a in terms of the probability results for the individual areas can be written as

$$P^{ABC}\left[A_{max} \geq a\right] = 1 - P^{ABC}\left[A_{max} \leq a\right]$$

or:

$$P^{ABC}[A_{max} \geq a] = 1 - [(1 - P^{A}[A_{max} \geq a])\cdot(1 - P^{B}[A_{max} \geq a])\cdot(1 - P[A_{max} \geq a])]$$

This equation is the desired formula for combining the previous probability results into a composite curve for "risk" which takes into account influences of all the various source areas near the site.

Thus, given certain input parameters, and estimates of average activity rates for potential sources of earthquakes, Cornell's method offers the means by which to make a quantitative estimate of the seismic risk at a site. Subject to certain fundamental assumptions stated above, the results can be expressed in a form that is easily applied and interpreted.

In the next subsection, the values used for input parameters such as constants of attenuation, and average seismic activity rates for individual source areas, will be discussed. The choice of annular segments approximating the source areas surrounding the site will also be discussed in some detail.

5.3.2 Input Parameters

The first input parameters that must be considered are those having to do with acceleration attenuation as a function of earthquake magnitude and epicentral distance. An unmodified use of Cornell's (1968) hazard analysis method requires, as seen above, a law of the form

$$a = b_1 \exp(b_2 M) R^{-b_3}$$

where a is acceleration in cm/sec^2, M is earthquake magnitude, and R is distance in kilometers. A number of relationships of the above form exist in the literature (Esteva and Rosenblueth, 1964; Seed, et al., 1968; Orphal and Lahoud, 1974). In all these studies, however, the constants b_1, b_2, and b_3 are found for data collected exclusively, or almost exclusively in the western part of the United States and are

therefore applicable there. Recently, several reasons have emerged, both theoretical and empirical, that indicate fundamental differences in acceleration attenuation in the central part of the U.S. For example, it has been demonstrated that the attenuation of body waves (Evernden, 1967) and surface waves (Mitchell, 1973; Nuttli, 1973a) is appreciably lower east of the Rocky Mountains than west. This serves to explain the much larger areas of perceptibility and of damage for central United States earthquakes than for west coast earthquakes of the same magnitude. It is also the source of the reluctance here to use previously published attenuation constants uncritically for this study. With particular reference to attenuation of acceleration, Nuttli (1973b) found that in the central United States the acceleration values of greatest engineering significance may be related to the vector resultants of the vertical and horizontal components of the sustained maximum surface-wave motion rather than to isolated peaks. This is true for ground motion at some distance from the source and for a wide range of magnitudes. The amplitude and shape of the attenuation curve for surface waves (Lg) in the frequency range of interest is known (Nuttli, 1973b) so that the accelerations associated with the Sg/Lg part of the earthquake ground motion coda may be plotted as a function of frequency and epicentral distance (see Nuttli, 1973c, Figure 8) for an event of a given magnitude.

The site area is very close to the western margin of the region of interest in Nuttli's studies so that it is not immediately clear that central United States attenuation laws are more pertinent than their western counterparts. It is believed, however, that there are several reasons for adopting a central United States formula. First, the site geology seems appropriate. The site is near the western boundary of the High Plains physiographic province (Sanford et al., 1976b) which extends eastward well into that part of the continental United States considered the "central U.S." by Nuttli (1973c). Second, there are features of the time histories recorded in the site region that are suggestive of kinship with central United States records. For example, the maximum record motions are almost always in the Sg part of the coda (Sanford, personal communication, 1978) in analogy to central United States Sg/Lg motion.

This feature has the interesting implication that magnitude scales are most naturally developed for this wave in the site region. Third, as mentioned in subsection 5.2.2, recent revision in the method of magnitude determination of events in the source region by stations in this region has been made necessary by the realization that peak record amplitudes have not attenuated with distance as quickly as implied by the uncritical use of Richter's (1958) standard earthquake ground amplitude values. Finally, the observation made by Sanford and Toppozada (1974) that the Valentine, Texas isoseismals apparently encompass more area to the east than to the west of the source is an indication on a very graphic level that attenuation is less in that direction. All these observations, although not rigorously indicative, are at least suggestive of acceleration attenuation in the site region similar to that found appropriate for the central region of the country. For these reasons, it was decided to use such a law for this seismic hazard analysis.

Algermissen and Perkins (1976) found that east of 105°W longitude the Schnabel and Seed (1973) curve developed from western United States data was consistent at about the magnitude 7.6 level with the similarly defined acceleration attenuation curve suggested by Nuttli (1973c) for the central United States out to distances of about 50 kilometers. Beyond this distance, the Nuttli curve attenuates at a slower rate (see Algermissen and Perkins, 1976, Figure 3). Curves applicable to other magnitudes are drawn by Algermissen and Perkins (1976) tangent to the Schnabel and Seed curves, but taking the same general shape as the Nuttli curve. These curves are shown in Figure 5.3-2 for magnitudes of 4.2, 5.2, 5.6, 6.6, 7.6, and 8.5. It is clear that these curves will not fit a single attenuation law of the form desired for simple application of Cornell's (1968) method as discussed in the previous subsection. Such a form requires not only a constant slope for all distances but a constant line spacing for equal magnitude intervals. Neither of these requirements is met by the acceleration attenuation curves taken from Algermissen and Perkins. The task then is to find proper coefficients for a Cornell type attenuation law such that the predicted acceleration so derived for a given magnitude and distance will be conservative

relative to the plotted values taken from Algermissen and Perkins. After some experimentation, the coefficients b_1=17, b_2=0.92, b_3=1.0 were selected (Bickers, 1978). Curves using these values are also shown in Figure 5.3-2 for the same suite of magnitudes. As can be seen from this figure, the model equation with the above constants yields higher accelerations for all values of magnitude and distance than the corresponding Algermissen and Perkins curves and is most closely matched to these curves in the region 10 kilometers $< R <$ 300 kilometers and $5 < M < 6$. This adopted attenuation law, therefore, represents a conservative compromise between the estimated curves of previous authors and the required form of Cornell.

The next feature needed for hazard curve development for the site is some idealization of the regional seismic source areas. Whatever configuration is ultimately chosen for the geometry and location of the source regions affecting the site, the fundamental data are basically regional seismicity and geology. These features of the southeastern New Mexico region have already been evaluated in the literature (Algermissen and Perkins, 1976) with precisely the intent of developing an estimate of maximum acceleration in rock in a probabilistic format. Therefore, it was decided to investigate the feasibility of using these same source zones in the slightly different context of the current hazard evaluation.

As originally defined, the probabilistic estimate of maximum acceleration determined by Algermissen and Perkins (1976) was based primarily on the seismic record; geologic data, primarily distribution of faults, was employed only to a minor extent. In particular, the general principle used by these authors in the construction of seismic source zones was that future earthquake occurrences are assumed to have the same general time rate characteristics as the earthquakes in the past in the same overall region, but that future earthquakes in a particular area might occur over somewhat more extended areas than indicated by historical data. In practice, the seismic source zones were drawn using the following guidelines:

1) Areas of seismicity where shocks of maximum Modified Mercalli intensity V or greater have occurred were considered source zones. (Note that intensity and magnitude are deterministically related by the formula (Gutenberg and Richter, 1942) $M_c = 1.3 + 0.6I_o$ where "M_c is the magnitude corresponding to I_o" (Algermissen and Perkins, 1976). Thus $I_o = V$ is equivalent to $M_c = 4.3$). For any given zone the average distance from the epicenters to the boundary was chosen to be approximately the average separation distance for earthquakes of the maximum intensity found there, when these were sufficiently numerous to establish such a distance. If the maximum intensity earthquake in a source area only occurred once or twice (as in the case of source areas in and near southeastern New Mexico), the distance between earthquakes of the second largest intensity was used.

2) Some zones such as described above were extended to include adjacent areas where evidence of Holocene faulting is present. This type of extension was used in the Great Plains and Southern Rocky Mountains where epicentral clusters could be associated with faults appearing on the tectonic maps of the United States.

3) From 2) above, areas of known Quaternary faulting are generally within source zones, if the faulting is associated with at least low-level historical seismicity. Except as noted above, Quaternary or older faulting not associated with historical earthquakes of Modified Mercalli intensities greater than V or magnitudes greater than 4.0 was not included within source areas.

Using these principles, the seismic source zones of interest to the calculation of hazard at the site as drawn by Algermissen and Perkins are shown in Figure 5.3-3. As seen below, independent studies of regional Quaternary faulting and the more detailed seismicity studies of the last several years do not seriously imply the modification of these source area boundaries with one conceptual exception involving small earthquakes within the immediate site area. This observation is most directly supported by considering the historical seismicity through 1972 as shown

in Figure 5.2-1 in conjunction with the three earthquake source zones of Algermissen and Perkins as shown in Figure 5.3-3. To aid this comparison, the epicenters of the former figure have been drafted on to Figure 5.3-3. It is clear from this superposition that the large majority of significant historical seismicity conforms well with the zonation presented. The location of the Valentine, Texas, earthquake and its aftershocks (if these are formally constrained to share the location of the main event in this sequence), apparently lie slightly to the east of the boundary of the southernmost seismic source zone if the Byerly (1934) location is used. It should be noted, however, that the instrumental location is not well constrained by the data available at the time of Byerly's study and, in particular, the epicentral uncertainty is such that a more southerly or westerly location is equally likely. For example, as may be seen from Figure 5.3-2 both the U.S.C.G.S. instrumental location for this event and the town of Valentine, Texas itself are within the source zone as drawn by Algermissen and Perkins. For the purposes of this risk analysis, the Valentine earthquake and its aftershocks are assumed to have occurred within the southernmost seismic source zone of Algermissen and Perkins.

Of more immediate concern is the scattered residual small magnitude seismicity occurring throughout the site area which cannot be associated with any of the source zones as drawn in Figure 5.3-3. This problem was recognized by Algermissen and Perkins (1976). These authors treated these isolated earthquakes which could not be associated with known faults or tectonic features as seismic background and the same shall be done here. On a nationwide basis these events could have an intensity of VII or less on the Modified Mercalli Scale and were assumed capable of happening over broad areas of the midwest; however they produced acceleration levels below the lowest acceleration contour on their map, because this contour represented the 0.04g level with a 90-percent probability of not being exceeded in a 50-year period (Algermissen and Perkins, 1976). Since acceleration levels for much longer time intervals are of interest in this study, some more explicit treatment of these random events will be necessary, and some explicit source zone including

the site must be considered. This is the conceptual modification of the Algermissen and Perkins study mentioned above.

A simple calculation is adequate to show that it is not necessary to consider any source zone other than the four already mentioned--the three of Figure 5.3-3 and an additional one including the site. The next closest source zone of Algermissen and Perkins is approximately 300 kilometers away from the site and all others are even farther away. Using this distance, the attenuation law considered above and (for the moment) an arbitrary maximum magnitude 7.5 earthquake, the maximum acceleration at the site is slightly less than 0.06g. Thus, such a source zone cannot contribute anything to site accelerations higher than this at any probability level. Furthermore, as will be more forcibly indicated in the next subsection where some actual hazard curves will be discussed, the contributions to probabilities of occurrence from distance source zones even at lower acceleration levels are insignificant when compared to the contributions from the closer zones.

An independent estimate of the appropriateness of the source zones as drawn in Figure 5.3-3 can be obtained from a consideration of faults offsetting Quaternary geomorphic surfaces. This is an independent estimate in the sense that no episode of surface faulting associated with historic seismicity is known in the site region. Nevertheless, Quaternary faulting has often been used as an indicator of the seismic activity of an area over a longer time span than is furnished by the historical seismicity record (e.g. Allen et al., 1965). Sanford and Toppozada (1974) have made an investigation of fault scarps within 300 kilometers of the disposal site, exclusive of the Permian Basin in which the site lies. This investigation consisted primarily of a literature search supplemented by limited reconnaissance of aerial photographs. The study was restricted to fault scarps offsetting Quaternary alluvial surfaces because these are the only fault displacements whose age can be estimated with any certainty. The authors note that tectonic movements in the area may have occurred during the Quaternary along faults cutting older rocks, but detection of recent offsets along such faults are nearly

impossible. Bachman and Johnson (1973) have completed a detailed investigation of the surface features in the Permian Basin which indicates recent fault scarps of a tectonic nature do not exist in this area. Since completion of the Sanford and Toppozada (1974) study, further studies on the existence or nature of fault scarps in the general site region have been actively pursued by Dr. Muehlberger and his students of the University of Texas, Austin (Sanford et al., 1978). To date, the most recent data are consistent with the picture derived from the earlier studies. That is, the Rio Grande Rift and southern Basin and Range provinces have abundant geologic evidence - primarily recent fault scarps - of recent crustal movements (Sanford et al., 1972; Muehlberger et al, 1978) whereas the High Plains, which is the physiographic province of the Permian Salt Basin in the site area, does not. The closest known Quaternary offset is about 125Km from the site.

Shown in Figure 5.3-4 are the faults noted by Sanford and Toppozada (1974) and Muehlberger et al. (1978) superimposed on the Algermissen and Perkins source zones. The references used in construction of these fault traces are Talmage (1934), Reiche (1938), Kelley (1971), Dake and Nelson (1933), King (1948, 1965), Kottlowski (1960), Kottlowski and Foster (1960), and Pray (1961). Also shown is the eastern boundary of the area of investigation of Sanford and Toppozada, that is, the western boundary of the Permian Basin.

It is clear that the Quaternary faults are completely contained within the two western seismic source zones of Algermissen and Perkins. These two zones may be combined under the name "southern Basin and Range--Rio Grande Rift" source zone since they include the parts of those provinces significant to the evaluation of probabilistic acceleration at the site. The reason for combining the two original zones is implied by a comparison of Figures 5.3-3 and 5.3-4. Although the historical seismicity has been of a higher level in the more southerly of the two zones (Algermissen and Perkins assign a maximum intensity of VIII to this southerly zone to correspond to the Valentine, Texas, earthquake and one of only V to the northern zone), the Quaternary fault offset strongly

suggests that to insure conservatism this pattern should be considered a happenstance of the short historical earthquake record. Thus for the purposes of this analysis, the seismic capabilities of the southern zone will be shared by the region to its north. Although only epicenters of earthquakes occurring prior to 1973 are shown in Figure 5.3-3, the implications of more recent activity as they affect the southern Basin and Range--Rio Grande Rift source zone (which will be referred to only as the Rio Grande Rift source zone in the following discussion for brevity) are similar. For example, Figures 5.2-3 and 5.2-4 show that the known epicenters for shocks between April 1974 and November 1977 with Sg-Pg intervals at station CLN from 31 to 36 seconds occur in apparently historically active regions, notably centered around Valentine, Texas and much of the Tularosa Basin. That is, they occur precisely in the Rio Grande Rift source zone as defined above.

One important implication of these studies is that the easternmost of the three Algermissen and Perkins source zones, that corresponding to the post-1964 seismic activity around Wink, Texas, on the Central Basin Platform, is based on seismic evidence alone. This activity was discussed in detail in subsection 5.2.4. For the purposes of specifying a conservative source zone geometry, the only geometrical issue with regard to the Central Basin Platform source zone, then, is the closest approach of the Central Basin Platform relative to the source zone used to model it. Shown in Figure 5.3-4 is an outline of the buried Central Basin Platform as it appears in Rogers and Malkiel (1978). It may be easily seen that the closest approach to the site of the Algermissen and Perkins Central Basin Platform seismic source zone implies its use is adequate. Therefore, this zone, as drawn, will be used for the model to be developed. The general model will consist of three source zones:

1) The Rio Grande Rift zone drawn by combining the western source zones as discussed above.

2) The Central Basin Platform zone as shown in Figure 5.3-4.

3) A site source zone centered at the site and with a radius to be specified below.

There are two purely geometrical issues to be resolved. The first involves specifying a focal depth for the events in each of the source zones. The second is really an exercise in adapting the irregular zones, as shown, to Cornell's method much as it was necessary to adapt the form of the attenuation law.

There is little doubt that the focal depths of earthquakes in the site region should be considered shallow. As we saw in subsection 5.2.2, early instrumental locations were achieved using an arc intersection method employing travel-time-distance curves calculated from a given crustal model and the assumption that focal depths were either 5 kilometers, 10 kilometers, or for later calculations, 8 kilometers. Good epicentral locations could generally be obtained under these assumptions. Confidence in calculated or assumed focal depths is greatly increased, of course, if at least one recording station is situated not much farther away from the epicenter than the focal depth. This situation is not generally realized for New Mexico region earthquakes but several specialized studies for which this criterion has been satisfied are suggestive. For an approximately two-year period beginning in June 1960, several hundred natural microearthquakes having S-P intervals of less than 2.3 seconds were recorded by high-magnification seismographs west of Socorro, New Mexico (Sanford and Holmes, 1962). Rather detailed studies of the depths of these events indicated hypocenters ranging from 2.7 to 6.3 kilometers. More recently, and nearer to the site, preliminary data from the Kermit, Texas, array indicate focal depths ranging from very near the surface down to about 10 kilometers although only about 20 percent of the events are located at depths greater than about 3.7 kilometers (Rogers and Malkiel, 1978). For the formal instrumental location procedure with array data, an initial trial hypocenter at 5 kilometers depth is used by these authors.

Within the range discussed - that is, focal depths of from 0 to 10 kilometers - the issue of selecting a proper depth for the probabilistic acceleration analysis at this site is clearly important only in the site source zone itself. For example, the difference in hypocentral distance - the distance to be used in the acceleration attenuation formula - for a closest approach event in the Central Basin Platform is only 1.93 kilometers in this depth range assuming that the closest approach of this source zone is 25 kilometers as is indicated by Figures 5.3-3 or 5.3-4. This is clearly the greatest difference of this kind outside the site source zone. Within the site source zone the selection of focal depth can be, formally, very important simply because the form of the attenuation law used asymptotically approaches infinite acceleration at very small distances. This is certainly not mechanically realistic and is not the intent of the empirical fitting process to an attenuation law of this form. There is some empirical evidence that the rate of increase of peak acceleration with decreasing hypocentral distance becomes less as the zone of energy release is approached. This is the case for example, for the Parkfield and San Fernando, California earthquakes of 1966 and 1971, respectively (see Page et al., 1972, Figures 4 and 6). Some empirical acceleration attenuation curves make use of this property in extrapolating to the vicinity of energy release. Most importantly for our purposes here, the attentuation curves of Schnabel and Seed (1973) are constructed in this manner and it is these curves that form the basis for near-source acceleration as a function of magnitude used by Algermissen and Perkins (1976). Since it is the intent here to follow these authors insofar as conservatism allows, it was decided to use a focal depth of 5 kilometers in all source zones of this study including that of the site. For smaller hypocentral distances, the form of the attenuation law adopted here deviates significantly from that suggested by Algermissen and Perkins in such a way as to severely exaggerate the importance of very small but very close shocks in the estimation of probabilistic acceleration at the site pertinent to design. This may be seen from Figure 5.3-2.

The manner in which the irregular source zone geometry of Figures 5.3-3 and 5.3-4 may be adapted to the method of Cornell (1968) is shown in Figure 5.3-5. As has been implied above, the seismicity of the site region is, at best, poorly related to observed faults - whether observed Quaternary faults do not occur, as in the case of the Central Basin Platform source zone (Rogers and Malkiel, 1978) or whether they do, as in the case of the Rio Grande Rift source zone (Sanford et al, 1972). Since the boundaries of the latter zone are so drawn as to be as close or closer than known recent faults, conservatism is served by allowing the largest earthquake postulated for specific faults within the region to occur randomly throughout the region. For these two reasons, lack of apparent fault control and additional conservatism, areal source zones were used (see subsection 5.3.1). Thus the object is to approximate the given source zones by a series of annular segments. This is done in such a way that total source zone area is conserved, and such that excluded area of the Algermissen and Perkins zones is replaced by annular areas closer to the source. Finally, closest approach distances are conserved. These criteria are followed in construction of the pattern in Figure 5.3-5. The site source region is drawn to be centered at the site and to include all area not already in another source zone. The radius of this site source zone will be determined by magnitude restrictions.

With the attenuation law and geometry defined for this hazard analysis, the question of the right recurrence formulas for each source zone is next addressed. A number of empirically fitted curves of the form $\log N = a - bM$ have been published for the site region in a broad sense (Sanford and Holmes, 1962; Algermissen, 1969). As before, N is the number of earthquakes of magnitude greater than or equal to M in some area and over some time period. The constants a and b are determined by fitting the data, usually in a least squares procedure. Although data for any time period may be used, all the formulas considered explicitly here will be normalized to one year. In addition, all formulas will be normalized to source areas of 10^5 square kilometers for ease of comparison. For these broad regional studies, b values around 1.0 have been found.

Several studies published recently regarding the immediate site region are not in good agreement with the previous results. For example, graphs of magnitude versus number of earthquakes for events within 300 kilometers of the site exclusive of shocks from the Central Basin Platform and aftershocks of the 1931 Valentine, Texas earthquake yield recurrence formulas of the form

$$\log N = 1.65 - 0.6M_L \quad \text{per yr per } 10^5 \text{ km}^2$$

using instrumental data only, and

$$\log N = 1.27 - 0.6M_L \quad \text{per yr per } 10^5 \text{ km}^2$$

using both historical and instrumental data (Sanford and Toppozada, 1974). Because the numbers of shocks used to establish the linear portions of these curves is very small (16 and 25, respectively), and the total time intervals over which data were collected is very short (11 and 50 years, respectively), an error in the slope (or b value) is quite possible. In fact, a certain dissatisfaction with these results on the part of Sanford and Toppozada is indicated by their development of alternate curves somewhat arbitrarily defined to have a slope of 1.0 instead of 0.6. Algermissen and Perkins (1976) calculate recurrence curves for a number of their source zones. For example, for source zone 45 (as defined in either Figure 5.3-3 or 5.3-4) they find the equivalent of

$$\log N = 0.53 - 0.52\, M_C \quad \text{per yr per } 10^5 \text{ km}^2$$

while for source zone 43, no formula is found, presumably for lack of data. Clearly, the difficulties of finding meaningful recurrence relations for such a short and areally restrictive interval in a region of low seismicity are formidable. Another problem is also implied by the last two equations. Magnitude M_C in the Algermissen and Perkins

formulation is somewhat vaguely defined, as mentioned above, as the magnitude corresponding to I_o in the equation:

$$M_c = 1.3 + 0.6\ I_o$$

where I_o is maximum intensity on the Modified Mercalli Scale. There seems to be no rigorous and straightforward way to relate this magnitude to the M_L of Sanford and Toppozada. Even the definition of M_L, upon which development of recurrence curves is fundamentally dependent, has been revised in the past few years as was seen in subsection 5.2.2

Fortunately, recent work (Sanford et al., 1976b) allows a preliminary treatment of the data that circumvents the worst of these problems. This recent study is based on eleven years of instrumental seismicity data which have been reinterpreted with respect to magnitude. In addition, recurrence formulas are computed for broad physiographic regions of New Mexico vastly increasing the data base. The criterion used in this current hazard analysis will be to use the Sanford et al. (1976b) recurrence formula for the physiographic province in which an individual source zone occurs with the value scaled down to reflect area differences. For example, Sanford et al. (1976b) find

$$\log N = 2.4 - 1.0\ M_L \quad \text{per yr per } 10^5\ km^2$$

for the High Plains province where the site is located, and

$$\log N = 2.5 - 1.0\ M_L \quad \text{per yr per } 10^5\ km^2$$

for the Basin and Range - Rio Grande Rift region. The area of the High Plains province of interest for this analysis is approximately 3.4 x 10^4 km^2 surrounding the site but exclusive of part of the Central Basin Platform. Thus the proper recurrence formula becomes

$$\log N = 1.93 - M_L \quad \text{Site source zone}$$

Similarly, the part of the Southern Basin and Range - Rio Grande Rift region of interest has been referred to in the above discussion as the Rio Grange Rift source zone and had an area of about 1.15×10^5 km^2. The proper recurrence formula becomes

$$\log N = 2.56 - 1.0\ M_L \quad \text{Rio Grande Rift source zone}$$

This leaves only the Central Basin Platform which is essentially a special case. Although the above two formulas were developed for areas near 2×10^5 km^2 in extent with the increase in confidence therefrom derived, this cannot be done for the Central Basin Platform source zone because it is unique and very limited in area. It, therefore, cannot be treated as simply a scaled-down version of some broader region. Although recent work using data from the Kermit array (Rogers and Malkiel, 1978) is available for this source zone, it was decided to use the recurrence formulation of Sanford et al., (1978) for this hazard analysis both for consistency in approach and because this treatment is the only one to calculate a recurrence formula for this source zone using revised magnitude estimates. Based on the seismicity detected in the Central Basin Platform since the installation of station CLN in April 1975, the cumulative number of shocks versus magnitude may be expressed as

$$\log N = 3.84 - 0.9\ M_L \quad \text{per yr per } 10^5\ km^2$$

Assuming that the active portion of the Central Basin Platform had an area of 8×10^3 km^2 during this period (Sanford et al, 1978) the proper recurrence relation becomes:

$$\log N = 2.74 - 0.9\ M_L \quad \text{Central Basin Platform source zone}$$

These are the recurrence relationships used in the current hazard analysis for the site.

One feature of several of these recurrence formulas is apparent: that is, they are very similar when normalized to equal source areas. This is

somewhat surprising in that the geologic indications of recent tectonism vary from source zone to source zone. One way in which the seismic and geologic data may be reconciled is to impose some upper limit on the magnitude of the earthquake that can occur in the geologically quiet areas that is less than the maximum magnitude event that can occur in source zones with evidence of Quaternary tectonism in the form of fault offset. This will be discussed in a later section but is mentioned here as a preface to the final aspect of source region characterization necessary to perform a hazard analysis: that is, maximum magnitude event within each source zone.

It is clear that a simple consideration of maximum historical magnitude within each of the three source zones as specified above will not be adequate to assure conservatism. This is particularly true of the northern part of the Rio Grande Rift source zone (Zone 43 of Algermissen and Perkins, 1976) where a maximum historical intensity of only V is known. As discussed above, the fault scarps in this area, particularly along the margins of the San Andres and Sacramento Mountains, indicate the strong possiblity that major earthquakes have occurred in this region within the past 5×10^5 years. The length of the faulting in these two areas (about 60 to 100 kilometers) suggests earthquakes comparable in strength to the Sonoran earthquake of 1887 (Sanford and Toppozada, 1974). This major earthquake (M=7.8) produced 80 kilometers of fault scarp with a maximum displacement of about 8.5 m extending southward from the U.S. - Mexico border at about 109°W longitude. Sanford and Toppozada (1974) assume that a similar event is possible in the future west of a line in good agreement with the eastern boundary of the Rio Grande Rift zone as shown in Figure 5.3-5. This eclipses the more southerly Valentine, Texas, earthquake whose magnitude has been variously estimated to be 6.1 (Algermissen and Perkins, 1976) and 6.4 (Sanford and Toppozada, 1974). For the purposes of this analysis, a maximum magnitude event of 7.5 will be assumed able to occur anywhere within the Rio Grande Rift source zone in general agreement with Sanford and Toppozada.

Selection of maximum magnitude events for the site source zone and the Central Basin Platform source zone is more difficult. Algermissen and Perkins (1976) assign a maximum historical intensity of VI to the Central Basin Platform. This is presumably the earthquake of August 14, 1966 which has been assigned this intensity in United States Earthquakes, 1966 (Von Hake and Cloud, 1968). On the basis of this intensity and the empirical relationship of Gutenberg and Richter (1942):

$$M = 1.3 + 0.6\ I_o$$

a maximum magnitude event of 4.9 has been selected for the Central Basin Platform by Algermissen and Perkins (1976) as appropriate for their probabilistic acceleration analysis. The magnitude scale was designed to give some indication of the elastic energy released at the earthquake source, and in this context, the 4.9 value above is almost certainly an exaggeration of the energy really released during this particular earthquake. This conclusion is based on both macroseismic and instrumental evidence. For example, one of the descriptions of this shock was, "Like a stick of dynamite being detonated several hundred feet away" (Von Hake and Cloud, 1968). This and a general consideration of felt effects are consistent with the contention that this earthquake has been assigned a relatively high epicentral intensity primarily because it occurred very near a population center. In addition, several magnitudes have been published for this earthquake (U.S.C.G.S. - 3.4; Sanford et al. 1978 - 2.8) which are substantially lower than the 4.9 value used by Algermissen and Perkins.

The maximum instrumental magnitude for an event in the Central Basin Platform source zone is open to some debate because of the apparently different application of magnitude scale by various agencies for this region. The largest earthquake in this region before installation of station CLN had a magnitude less than 3.25 according to the most recent calculations at New Mexico Institute of Mining and Technology (Sanford et al., 1978). Between 1974 and October 1977, during the operation period of CLN for which data is currently available, a number of earthquakes

have been located by Sanford and his colleagues, none of which have been assigned magnitudes greater than 3.2. In the Rogers and Malkiel (1978) study of data from the recently established Kermit array, events with magnitudes approaching 4 are listed. However, as was stated in subsection 5.2.4, a direct comparison of magnitudes for earthquakes listed in both the New Mexico Institute of Mining and Technology and Kermit array data sets shows that events are routinely assigned magnitudes almost one unit higher in the latter listing. Therefore, the maximum historical magnitude earthquake in the Central Basin Platform Source Zone is still a matter for conjecture although some value between 3.0 and 4.0 is most likely.

The features of this source zone that might bear on its possible maximum magnitude are the lack of recent geologic evidence of tectonism, and the high activity rate which may or may not be directly associated with secondary oil recovery efforts. Sanford and Toppozada (1974) conjecture that the maximum magnitude might be 6.0 for this source zone, and in this study of hazard their example will be followed for one set of calculations. Because this value may be exceptionally conservative, an alternate maximum magnitude of 5.0 is also considered.

With regard to the site source zone, there is even less indication that significant magnitude events are reasonably likely. There is no Quaternary fault offset (Bachman and Johnson, 1973) and seismic activity is low. However, recent studies (Caravella and Sanford, 1977) have shown that some level of background seismicity must currently be considered for the site area if conservatism is to be served. Apparently, an earthquake which may be tectonic in origin and with a magnitude of 3.5 has occurred within the site source zone itself (see subsection 5.2.5). Two maximum magnitudes were considered in the hazard analysis of this section: 4.5, that is the maximum historical event plus one magnitude unit; and 5.0, a rather ad hoc attempt to consider additional conservatism in general agreement with the size of a random event possible in the central United States and not associated with a particular source zone (Algermissen and Perkins, 1976).

All the parameters necessary to perform a probabilistic acceleration hazard calculation for the Los Medanos site after the method of Cornell (1968) have now been presented and discussed. In the next subsection the results of these calculations are considered.

5.3.3 Results

The basic results are shown in Figures 5.3-6 and 5.3-7. These are plots of the probabilities that the maximum annual acceleration will exceed some specified acceleration versus the specified acceleration. For example, in Figure 5.3-6, Curve 1, which shows the contribution to risk at the site due to earthquakes in the Rio Grande Rift source zone as shown in Figure 5.3-5, indicates that the probability that the maximum acceleration at the site from this source zone in any one year will exceed 0.05g is approximately 1.8×10^{-5} or 1.8 in one hundred thousand. Probabilities are similarly found for other values of acceleration.

In both Figures 5.3-6 and 5.3-7, six curves are shown. Curve 1 is the same in both figures and represents the probabilistic maximum acceleration distribution for the Rio Grande Rift source zone as described above. Curves 2 and 2' are also the same in both figures, representing the risk from the site source zone when its maximum magnitude is 5.0 and 4.5, respectively. Curve 3 in each figure is the risk distribution from earthquakes in the Central Basin Platform source zone. In Figure 5.3-6, the maximum magnitude event in this zone is assumed to be 6.0 while in Figure 5.3-7 it is given a value of 5.0. Finally, curves 4 and 4' are the total probabilistic maximum accelerations at the site from all source areas combined. For example, Curve 4 in Figure 5.3-6 is the risk at the site assuming the geometric and recurrence properties, and the acceleration attenuation, of the last subsection and a maximum magnitude of 6.0 in the Central Basin Platform source zone and 5.0 in the site source zone.

Probabilities for accelerations below 0.03g have not been calculated. This is because of a feature of the method used. For a given source geometry and minimum magnitude, the lower limit of validity of probabilistic acceleration is fixed (see Figure 5.3-1top) such that $a \geq a'$.

$$a' = 17 \exp 0.92\, m_o\, d^{-1}$$

where m_o is the minimum magnitude and d is minimum distance to any source zone. For the worst case, d = 5 km. The value for m_o, 2.4, is the same for all source zones and is derived from an estimate of the smallest earthquakes recorded uniformly throughout the state of New Mexico (Sanford et al., 1978). Substituting these values into the above expression results in $a' = 30.9$ cm/sec^2 or $a' = 0.03g$.

There are several interesting features that may be derived from a comparison of the four curves, 4 and 4' in both Figures 5.3-6 and 5.3-7. First, it may be noted that in spite of the greater conservatism exercised in the selection of model parameters for this study than in the Algermissen and Perkins (1976) study--on which so much of the current risk evaluation depends--the basic conclusion of Algermissen and Perkins that the site is in an area with less than one chance in ten that an acceleration of 0.04g will be exceeded in any 50 year period is in very good agreement with the results shown in Figures 5.3-6 and 5.3-7. To see this it may be noted that the return period for the Algermissen and Perkins study is about 475 years. For the slightly more conservative curves of Figure 5.3-6, the maximum accelerations at this return period are around 0.045g while in Figure 5.3-7 they are 0.035g.

Secondly, it is interesting to note that under the assumptions of the previous section the significance of the Rio Grande Rift source zone to the total risk at the site is relatively small at all acceleration levels. Because of the earthquake recurrence relationships for the various source zones, this will be true at lower acceleration levels no matter what assumptions are made about the maximum magnitudes in the site

and Central Basin Platform source zones. At higher acceleration levels, this will be true unless the lowest maximum magnitude proper for the site source zone is lower than the 4.5 value considered here. Although probabilities are low at all site acceleration levels from the Rio Grande Rift source zone, the maximum acceleration at the site from a 7.5 shock at a distance of 115 kilometers using the attenuation law of subsection 5.3.2 is 0.15g. This is slightly greater than the 0.1g acceleration assumed to be the maximum at the site in previous studies (Sanford and Toppozada, 1974).

In the case of the Central Basin Platform source zone, a comparison of the two figures shows an interesting phenomenon. For the case where 6.0 is the maximum magnitude event, probabilities are largely controlled by earthquakes in this source zone up to accelerations of around 0.1g. For higher accelerations, the site source zone is more important. If 5.0 is a better maximum magnitude shock in the Central Basin Platform, its significance as a source of risk is completely eclipsed by the site source zone itself at all acceleration levels.

Perhaps the most universal feature of all four total risk curves is their dominance by the site source zone at higher accelerations. If the probabilities at which these higher acceleration levels occur are thought to be of interest, it is the assumptions that are made about the immediate site area that are most critical.

It is believed that the presentation in this section gives the broadest possible assessment of seismic risk at the site in a way that shows explicitly the assumptions used and, to a small extent at least, the effect of varying some of these assumptions. Acceleration is not the only parameter of design significance, of course, so that a plot of its probability is not the whole story even if such a plot is completely accurate.

5.4 SEISMOLOGICAL DATA AND SITE REGION TECTONISM

In previous sections the historical record of seismicity in the site region has been explored as well as the way this record, when combined with very general geologic arguments, can be used to estimate risk levels attached to various possible seismic design acceleration values. In this section the extent to which this seismological data may be used to draw inferences of a longer term nature is considered. The interval over which seismological data can be collected is still very brief; the total available earthquake record, and especially that fraction of it representing the period of instrumental observation, covers a period of time that is very short compared to the total geologic time scale. Thus, a comparison of the regional tectonism derived from a study of geologic processes and structures, with that derived from a study of earthquakes, involves a question of consistency: that is, are the characteristics of regional earthquakes consistent with known geologic structures and the large-scale stresses thought to have been active in their evolution?

Implicit in this concept of tectonics is the definition of tectonic earthquake that is used in this section. The subject of tectonics as it is used here is structural geology. Tectonic earthquakes are those believed to be associated with faulting. This is taken to exclude minor shocks due to less important causes (Richter, 1958). As mentioned in subsections 5.2.4 and 5.2.5 it is not clear that the detected earthquakes in either the site source zone or the Central Basin Platform are tectonic under this definition. There seem to be few geologic structures in either area that would lead one to expect significant tectonism either now or for vast times in the past. Nevertheless, conservatism suggests that these events should be considered tectonic at this stage of our knowledge, and this assumption was made for the seismic risk analysis of the previous section.

Seismology, in the context of tectonism, will be considered below under two general headings: implications about the regional stress regime from focal mechanism solutions, and implications about regional activity from

historic recurrence statistics. Although earthquakes are sometimes used to delineate specific active structures in a way important to discussions of regional tectonism this will not be attempted here, primarily because even in areas with recent faulting, such as occur in the southern Basin and Range province, or in areas with sophisticated seismic array location capabilities as in the Central Basin Platform, the known earthquakes are simply not well correlated with specific geologic structures on a detailed scale.

The ultimate association of seismic and geologic processes is derived from the observation that the structural behavior of an element of the earth's crust is often associated with the release of elastic strain energy in the form of earthquakes. The nature of this association itself, however, may be far from simple. This is especially true of small earthquakes whose characteristics are derived from processes taking place in a very small volume of a crust that, in this context, must be considered very inhomogeneous. As was seen in Section 5.2, the latest calculations show that only one instrumentally located earthquake within 300 kilometers of the site (the Valentine, Texas, event) has exceeded magnitude 4.6. Similarly, within 300 kilometers of the site but outside the Rio Grande Rift source zone as defined in Section 5.3 no earthquake has exceeded magnitude 3.5. This should be kept in mind throughout this section. It may also be noted that most empirical experience in relating tectonic features to seismicity, or vice versa, has been gathered in regions that are much more active than the site region. This too was mentioned in Section 5.2 and is made very clear by comparing earthquake recurrence statistics for the site region with similar statistics for an area such as California. The picture presented by a comparison of seismologic with structural geologic data appears confused for the site region. At least these two data sources are not consistent in the same way or to the same degree that is found in other regions characterized by larger historical earthquakes. It is premature to attempt a reconciliation here, if indeed one is necessary, so that in this section existing evidence (although often only preliminary) is outlined and briefly discussed.

5.4.1 Regional Stress Orientation

The catalog of published crustal stress measurements in the Los Medanos region is a short one. It consists of three focal mechanism solutions and one in situ hydrofracture determination. Another in-situ stress measurement was quoted recently in connection with west Texas studies (Rogers and Malkiel, 1978), but this measurement is some distance to the east, on the Llano uplift. In this very limited data collection, there is little agreement, and none should necessarily be expected since the measurements come from different structural blocks.

The earliest indication of the stress regime for a point within the general Los Medanos site region (when defined as it has been in this chapter as within 300 kilometers of the site) comes from an analysis of first motion polarities from the Valentine, Texas, earthquake of August 16, 1931. In his study of this event Byerly (1934), carefully noted the polarity, azimuth, and epicentral distances of waves at all stations recording this earthquake. He concluded that the observed polarity pattern could be explained by normal movement on a shallow fault striking N35°W, and dipping very steeply to the west. He also noted that certain stations did not fit this pattern and attributed most of these discrepancies to difficulties in observing the true first arrival, which was apparently lost in the noise at these stations. Fortunately, all polarity readings were listed in Byerly's paper for this earthquake, which was recorded at distances ranging from 5.8° to 104.8°. Applying the recent techniques of stereographic projection to Byerly's data, Sanford and Toppozada (1974) obtained an independent but very similar solution shown in Figure 5.4-1a. This solution indicates predominantly dip-slip motion along a normal fault striking N40°W and dipping 74° southwest, or motion of a similar nature on a fault striking N19°W and dipping 18° northeast. The first possibility is preferred because of the structural fabric of the epicentral region with which it is consistent. The inconsistent polarity readings are those noted previously by Byerly. It is worth mentioning that the regional stresses implied by this solution (P-axis or axis of maximum compressive

stress striking N51°E and plunging 62° to the northeast and T-axis or axis of least compressive stress striking S61°W and plunging 28° to the southwest) are the only ones for this region that are incontrovertibly of some tectonic significance.

The remaining two focal mechanism solutions available at this time for the site region have been very recently determined from data recorded at the Kermit array. One solution is a composite of data from three small earthquakes that occurred within a 7-day period in January 1976 and is reproduced from Rogers and Malkiel (1978) in Figure 5.4-1b. The other solution is from a single earthquake on April 26, 1977, in the same area as the other three near array station KT5 (see Figure 5.2-5) and is reproduced, also from Rogers and Malkiel, in Figure 5.4-1c. These are the only events occurring during array operation that have produced a sufficient number of clear first motion polarities to allow focal mechanism solutions.

The earthquakes from which the composite solution of Fig. 5.4-1bottom was derived occurred on January 19, 22, and 25, 1976 and had U.S.G.S. assigned magnitudes of 3.47, 2.83, and 3.92, respectively. It has already been noted in Section 5.2 that these magnitudes appear to be almost a unit larger than those most recently calculated for shocks in this area by Sanford and his colleagues at the New Mexico Institute of Mining and Technology. The preferred fault plane, based on the geologic structure of the Central Basin Platform, strikes N19°W and dips to the west at 53°. The sense of fault motion is that of normal faulting. Similarity to the solution for the Valentine earthquake is clear. The data for the April 1977 event do not fit this type of solution and do not permit a unique mechanism to be obtained. Normal, thrust, and strike-slip mechanism are possible. The normal solution shown in Figure 5.4-1c is the only one considered by Rogers and Malkiel to be relatively consistent with the composite mechanism and the regional tectonics.

The tectonic significance of these last two focal mechanisms is confused by their occurrence in an area where both active fluid withdrawal and

injection are taking place. This confusion is apparently not lessened by considering the in situ stress data. Hydrofracture data from a well in Howard County, Texas to the east (Fraser and Pettit, 1962) indicate a tension axis that trends south-southeast. Overcoring data from Hooker and Johnson (1969) even further to the east in Burnet County, Texas, on the Llano uplift show reversion to a southwest trend for the tension axis. According to Rogers and Malkiel (1978), both the Howard and Burnet County data show a horizontal axis of maximum compression. This is in disagreement with the focal mechanisms, for which the greatest compressive stress is steeply plunging. Also, von Schonfeldt et al. (1973) have indicated that the greatest principal stress in this area is a vertically oriented, overburden induced compressive stress because hydrofracture experiments generally produce vertical fractures in Texas, except in some shallow wells (Hays, 1977). In the face of such a variety of interpretations, it is premature to speculate on the significance, or lack of it, of these data. Any such speculation will have to wait on the collection of new data or additional analysis of existing information.

5.4.2 Tectonism and Earthquake Recurrence Relations

In Section 5.2 the seismicity of the Los Medanos site region was studied. It was noted that most of the activity of recent years had occurred in the Central Basin Platform in two particular areas located such that Sg-Pg intervals at station CLN very near the site were 8 to 13 seconds and 22 to 24 seconds (Sanford, et al. 1978). Another group of epicenters for shocks with Sg-Pg intervals from 31 to 36 seconds were found by these authors to occur in several tectonically active regions to the southwest and west of the site—notably near Valentine, Texas, and in much of the Tularosa Basin. These three Sg-Pg intervals account for the most important peaks on the histogram appearing in Figure 5.2-5. Earthquakes at other distances contribute a general background occurrence level also apparent in this histogram. At least some of these events are known to have occurred in the general site region and not in association with either the Central Basin Platform or the Rio Grande Rift source

zones of the previous section. This characterization of the regional seismicity is interesting because there is abundant geologic evidence for recent tectonic activity for the source zones to the west and none for the Central Basin Platform.

This situation can be described more quantitatively by considering earthquake recurrence statistics. Relations of the form logN=a-bM for the three source zones of Section 5.3 have already been shown. These formulas, taken from Sanford et al. (1976b) and Sanford et al. (1978) may be normalized to equal time intervals and areas for comparison (assuming such a comparison is meaningful) to give:

$$\log N = 2.5 - M_L \quad \text{Rio Grande Rift zone}$$

$$\log N = 2.4 - M_L \quad \text{High Plains Province}$$

$$\log N = 3.84 - 0.9\, M_L \quad \text{Central Basin Platform}$$

where in each case the formulas give the number of occurrences, N, of events with magnitude M_L or greater per year in a 10^5 km^2 area. It is clear that if these relations truly indicated some measure of tectonic activity in effect for a long time period the relative tectonic importance of these areas would be in conflict with that implied by the geologic data. This is particularly true for the Central Basin Platform activity.

Several explanations have been offered to resolve this conflict (Sanford et al., 1978). One is that a recent change in regional stress may be responsible. In this view, the tectonic implications of very recent seismicity are preferred to those of the geologic record. The other extreme possibility is that the observed recent seismicity, especially in the Central Basin Platform, has little bearing on tectonism in the sense normally used in connection with magnitude recurrence relations. Thus, the geologic implications to past and recent (and, by extrapolation, future) tectonism are preferred to those of recent seismicity. Finally,

there is an intermediate position which attempts reconciliation of both the geologic and seismic data by prescribing some particular mode of crustal behavior in the High Plains physiographic province and the Central Basin Platform. The only explicit property of this mode of behavior is that large magnitude earthquakes do not occur; hence, extrapolation of the recurrence formulas above to large magnitudes is fundamentally inaccurate.

The first possibility, that the regional geology of the High Plains province and Central Basin Platform is in essence misleading, is the least satisfactory. There does not seem to be any implication of recent regional stress changes in the more active areas of New Mexico. Sanford et al. (1972) performed calculations comparing the implications to tectonic activity of recent fault offset in the Rio Grande Rift (where recent is defined as less than 4×10^5 years old) with similar implications from recurrence statistics both from historical earthquakes and from microearthquake studies (Sanford and Singh, 1968). These calculations show that if the fault scarps are less than 4×10^4 years old, the seismicity obtained is compatible with the historical earthquake activity in the Socorro region. If the age span of the fault scarps is increased to about 2×10^5 years, the seismicity becomes close to that indicated by the microearthquake studies. It may also be noted here that the focal mechanism solution obtained for the Valentine, Texas, earthquake is consistent with the sense of fault motion implied by the geologic structure of that area.

Using similar types of arguments some limits can be placed on how recently the change in stress postulated for the High Plains province and the Central Basin Platform must have taken place. Consider that part of the High Plains province designated as the site source zone in Section 5.3. Then the recurrence relation is, after Sanford et al. (1976b):

$$\log N = 1.93 - M_L$$

The use of this formula in an uncritical way leads to the conclusion that an earthquake of magnitude greater than or equal to 7.0 should occur in this zone on the average of once in about 10^5 years. Such an earthquake would certainly leave physical evidence of fault offset. If the High Plains province of New Mexico is taken as a whole, a similar earthquake would be expected on the average of once in slightly over 2×10^4 years. Assuming that earthquake occurrence is distributed as a Poisson process, it can be concluded that an earthquake of magnitude 7.0 or greater has a 63 percent likelihood of occurring in a given 2×10^4 year period and that it has a 90 percent likelihood of occurring in a given 2×10^5 year period. Nevertheless, no evidence is known of fault offset suggesting earthquakes of this size anywhere in the High Plains during comparable or longer time periods. Thus, if there have been changes in regional stress that are responsible for the observed conflict between geologic and seismic data, these changes probably have taken place more recently than within the last 2×10^4 to 2×10^5 years.

A similar calculation may be applied to the Central Basin Platform. In this case on the basis of seismic evidence the recurrence interval for a magnitude 7.0 earthquake is about 3500 years. As in the High Plains, there is no geologic evidence for such an earthquake. Thus, the geologic and seismic evidence appear to contradict one another unless the current seismicity is the result of a tectonic stress change that took place within the last several thousands or tens of thousands of years. The implications of recurrence intervals for large earthquakes developed from short term seismic data should not form the basis for rationally discarding contradicting geologic evidence.

The second possibility as it is presented here applies only to the Central Basin Platform. That is, the recurrence statistics for earthquakes in this small area are not related to tectonism in the usual sense of this concept and should not be used for tectonic implications of long time intervals. The principal support for this view is outlined in Sanford and Toppozada (1974). Basically, it has been postulated that the earthquakes on the Central Basin Platform are related to massive fluid

injection for secondary recovery of oil. Both the spatial and temporal association of this seismicity with these secondary recovery projects are very suggestive. This has already been discussed in greater detail in subsection 5.2.4 and will not be repeated here. The wide variety of hypotheses regarding the stress field in the area of the Central Basin Platform neither preclude nor prove any causal relationship between the earthquakes and secondary recovery operations (Hays, 1977), but, the widely observed phenomenon of increased seismic activity during fluid injection (Healy et al., 1968; Healy et al., 1972) argues strongly against the uncritical extrapolation of short term magnitude recurrence formulas under the present conditions.

The third possibility, that the geologic and seismic data are not really in conflict, is the most satisfying from a philosophical viewpoint. It is certainly simpler to derive meaningful conclusions about the physical properties of a system that is not changing than about one that is. It has already been mentioned that such consistency exists for the Rio Grande Rift, at least in gross terms. A similar reconciliation might be possible for the High Plains province or the Central Basin Platform by restricting the maximum magnitude of an earthquake that can occur in either the High Plains physiographic province or the Central Basin Platform.

The simplest restriction that can be applied to the magnitude of shallow seismic events that have occurred in the past is imposed by the size or absence of observed faulting. An argument of this type has been used above in considering the questions of recent stress regime changes. In very general terms, it is believed that where recent geologic faulting exists, even in the absence of observed large magnitude earthquakes, conservatism requires that such seismic activity should be anticipated (Allen et al., 1965; Sanford et al., 1972); that is, to a high level of confidence, large recent faults in an area imply large magnitude earthquakes must be considered there. The converse argument, that large magnitude shallow earthquakes always produce episodes of large scale shallow faulting is even more widely believed. This assertion appears so

absolute because the definitions of "large" earthquake and "large-scale" faulting have been left purposely vague. A more empirically useful statement might be that the largest recent fault offsets (in terms of both fault length and fault displacement) that are found in an area under a given set of geologic conditions and after an adequate search impose an upper limit on the magnitudes of past earthquakes.

The general relation between magnitude of shallow-focus earthquakes and size or volume of the deformed region and the length and amount of displacement of activated surface faults has long been recognized (Tsuboi, 1956; Richter, 1958). Tocher (1958) developed an early empirical relation between magnitude and fault length, and between magnitude and the product of fault length and maximum displacement. Many subsequent refinements have been formulated by adding additional data points (Iida, 1959 and 1965), applying the method to specific areas, as for southern California (Albee and Smith, 1966), and by refining the source data either for the western United States (Bonilla, 1967 and 1970; Bonilla and Buchanan, 1970) or for the world (Ambraseys and Tchalenko, 1968; Bonilla and Buchanan, 1970). Various dislocation models have been proposed by seismologists (Aki, 1967; Brune, 1968; Chinnery, 1969; King and Knopoff, 1968 and 1969; Press, 1967; and Wyss and Brune, 1968) one of which (King and Knopoff, 1968) was used by Sanford et al. (1972) in connection with fault offset-magnitude comparisons in the Rio Grande Rift as discussed above. A recent recompilation and reconsideration of fault offset data has been performed by Slemmons (1977). He finds, for North America data and faulting of all types that

$$\log D = -4.47 + 0.67M$$

$$\log L = 1.61 + 0.44M$$

where both D (fault displacement) and L (fault length) are in meters. Using these formulas, fault lengths of 6.46, 10.72, 17.78, 29.51, 48.98, and 81.28 kilometers are found for magnitudes from 5.0 to 7.5 in half magnitude increments. The respective displacements are 0.08, 0.16, 0.35,

0.77, 1.66, and 3.59 meters. Thus, if an area has been mapped so well that no fault of length about 18 kilometers and maximum displacement of about 1/3 meter could escape notice in strata of a given age, then it could be maintained that no event of magnitude greater than or equal to 6.0 had occurred in that area in the time since formation of the strata. Explicit statements of the kind necessary about the minimum observable fault are not generally available in the literature. If it is assumed that the conclusion of Bachman and Johnson (1973), that no recent fault scarps of a tectonic nature exist in the Permian Basin, is applicable at the scale of the minimum observable fault associated with a magnitude 6.0 earthquake, then the conflict between the geologic and seismic recurrence data is resolved. That is, the recurrence data may not be extrapolated beyond magnitude 6.0. Arguments of this type, although they are clearly over-simplified and depend on relationships between magnitude and fault offset derived from widely scattered data, are of interest at least for purposes of comparison with similiar studies made in other areas.

A more complete treatment of this type would have to address the issue of regional deformation. This involves not only the offset associated with a single earthquake but the deformation implied by summing the effects of all earthquakes. If total strain energy released as seismic waves is calculated from the magnitude recurrence relations, estimates of total available strain energy and total implied steady state deformation may be derived. These are both dependent on the maximum magnitude event allowed, since significant strain and most of the energy are associated with the larger events (Richter 1958). Thus, general deformation rates may be derived as a function of maximum magnitudes, and observed deformation rates may be used to infer an acceptable maximum magnitude for the region over which deformation is observed. Unfortunately, application of this type of analysis is subject to more complication and uncertainty than a simple fault argument. It seems clear, however, that deformation of a type that would be associated with accumulation and release of elastic strain energy has not been very important in the Permian Basin for very long periods of time.

Although other explanations cannot be precluded, it seems that the most reasonable interpretations of seismic implications to tectonism at this time are:

1) Observed geologic and seismic data are in general agreement in the Rio Grande Rift and Southern Basin and Range zones and that future significant earthquakes can be expected there.

2) The current level of activity on the Central Basin Platform is probably related to fluid injection for secondary recovery of oil. This fluid injection makes it unwise to question the geologic data of the area solely on the basis of this high seismic activity level (see Chapter 10).

3) The geologic data, principally the lack of recent geologic faulting, and the seismic data for the High Plains province, in which the site lies, can probably be reconciled by imposing a maximum magnitude limit on the earthquakes that may occur here.

5.5 SUMMARY

Non-instrumental and regional instrumental studies of earthquakes prior to 1972 in southeastern New Mexico indicate that the most significant sources of earthquakes were the Central Basin Platform region near Kermit, Texas, and the area about 200 km or more west and southwest of the site (Rio Grande Rift Zone). The strongest earthquake reported to occur within 300 km is the intensity VIII Valentine, Texas, event of August 16, 1931, at a distance of approximately 210 km. The closest shock (as of 1972) reported from these studies was a magnitude 2.8 event on July 26, 1972, about 40 km northwest of the site. The record from regional studies of events west and southwest of the WIPP site 200 km or more is consistent with the record of Quaternary faulting in that area.

Instrumental studies near the WIPP site since 1974 and near Kermit, Texas, since late 1975 have recorded additional evidence of the seismic activity for the site and region. The pattern obtained from near the site is similar to that from regional studies; about one-half of the located events in the data set occur on the Central Basin Platform while most of the rest occur to the west and southwest of the site in the Rio Grande Rift Zone. The data set also includes three events within about 40 km of the WIPP site since 1972. Two events have been assigned magnitudes of 2.8 and 3.6; the third event (from 1978) has only preliminary data available.

Data reported for the Central Basin Platform from the Kermit, Texas, array continue to show that location as the most active seismic area within 300 km of the site in terms of number of events. The largest earthquake known to occur in the Central Basin Platform had, by the most recent estimate, a magnitude of less than 3-1/4. The activity appears equally likely to occur anywhere along the Central Basin Platform structure without particular regard to small scale structural details such as pre-Permian buried faults. The spatial and temporal coincidence of this seismicity with secondary petroleum recovery projects suggest a close relationship, but this has not yet been satisfactorily established. The lack of known Quaternary faults from the seismically active region of the Central Basin Platform is suggestive that large magnitude earthquakes are not occuring or have not occurred within the recent geologic past in the area.

Analysis of the regional and local seismic data indicate that the 1000 year acceleration is less than or equal to 0.06 g and the 10,000 year acceleration is less than or equal to 0.1 g for all models tried. Probabilities at which higher acceleration levels occur depend almost exclusively on the assumptions made about the seismic potential of the immediate site area.

5.6 REFERENCES

Aki, K., 1967, Scaling law of seismic spectrum: Jour. Geophysical Res., v. 72, p. 1217-1231.

Albee, A.L. and Smith, J.L., 1966, Earthquake characteristics and fault activity in southern California: Engineering Geology in Southern California, R. Lung and R. Proctor, eds., Associated Engineering Geologists, Glendale, Calif., p. 9-33.

Algermissen, S.T., 1969, Seismic risk studies in the United States: Fourth World Conf. on Earthquake Engineering, Santiago, Chile, p. 14-27.

Algermissen, S.T., and Perkins, D.M., 1976, A probabilistic estimate of maximum ground acceleration in the contiguous United States: U.S. Geol. Surv. Open-file report 76-416, p. 1-45.

Allen, C.R., St. Amand, P., Richter, C.F., and Nordquist, J.M., 1965, Relationship between seismicity and geologic structure in the southern California region: Seismol. Soc. Am. Bull., v. 55, p. 753-797.

Ambraseys, N. and Tchalenko, J., 1968, Documentation of faulting associated with earthquakes, Part I: Unpublished Manuscript, Dept. of Civil Eng., Imperial College of Science, London.

Bachman, G.O., and Johnson, R.B., 1973, Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico: U.S. Geol. Surv. Open-file report, 4339-4.

Bickers, G., 1978, "WIPP acceleration attenuation curves": Bechtel Interoffice Memorandum, dated Jan. 30, to J. Litehiser.

Bonilla, M.G., 1967, Historic surface faulting in continental United States and adjacent parts of Mexico: U.S. Geol. Surv. Open-file report.

Bonilla, M.G., 1970, Surface faulting and related effects in earthquake engineering: Earthquake Engineering, Prentice-Hall, Englewood Cliffs, p. 47-74.

Bonilla, M.G., and Buchanan, J.M., 1970, Interim report on worldwide historic surface faulting: U.S. Geol. Surv. Open-file report.

Brune, J.N., 1968, Seismic moment, seismicity and the rate of slip along major fault zones: Jour. Geophysical Res., v. 73, p. 777-784.

Byerly, P., 1934, The Texas earthquake of August 16, 1932: Seismol. Soc. Am. Bull., v. 24, p. 81-89.

Caravella, F.J., and Sanford, A.R., 1977, An analysis of earthquakes north of the Los Medanos site on July 26, 1972 and November 28, 1974: New Mexico Institute of Mining and Technology, Report to Sandia Laboratories, Contract No. 03-6223/GTK.

Chinnery, M.A., 1969, Earthquake magnitude and source parameters: Seismol. Soc. Am. Bull., v. 59, p. 1969-1982.

Coffman, J.L., and von Hake, C.A., (eds.), 1973, Earthquake history of the United States, U.S. Dept. Commerce, Publication 41-1, Revised edition (through 1970), Nat. Oceanographic and Atmospheric Admin., Washington, D.C.

Cornell, C.A., 1968, Engineering seismic risk analysis: Seismol. Soc. Am. Bull., v. 58, p. 1583-1606.

Cornell, C.A., and Merz, H.A., 1975, Seismic risk analysis of Boston: Jour. Struct. Dov., Am. Soc. Civil Eng., v. 10, p. 2027-2043.

Cornell, C.A., and Vanmarke, E.H., 1969, The major influences on seismic risk: Fourth World Conf. on Earthquake Engineering, Santiago, Chile, p. 69-83.

Dake, C.L., and Nelson, L.A., 1933, Post-Bolson faulting in New Mexico: Science, v. 78, p. 168-169.

Esteva, L., and Rosenblueth, E., 1964, Espectros de Temblores a Distancias Moderas y Grandes: Bol. Soc. Mex. Ing. Sism, v.2, p. 1-18.

Evernden, J.F., 1967, Magnitude determination at regional and near-regional distances in the United States: Seismol. Soc. Am. Bull., v. 57, p. 591-639.

Fraser, C.D., and Pettit, B.E., 1962, Results of a field test to determine the type of induced formation fracture: Jour. Petrol. Tech., v. 14, p. 463-466.

Gutenberg, B., and Richter, C.F., 1942, Earthquake magnitude, intensity, energy, and acceleration: Seismol. Soc. Am. Bull., v. 32, p. 163-191.

Gutenberg, B., and Richter, C.F., 1954, Seismicity of the Earth and Associated Phenomena: Princeton Univ. Press, p. 1-310.

Hays, W.W., 1977, Progress report on the Central Basin Platform seismic study - April 1, 1976 through November 15, 1976: Report to ERDA and Sandia Laboratories.

Healy, J.H., Rayleigh, C.B., Brodehoeft, J.C., and Byerlee, J.D., 1972, Seismic activity related to fluid injection (abs.): Society of Exploration Geophysicists, 42nd Annual Meeting, Program, p. 15.

Healy, J.H., Rubey, W.W, Griggs, O.T., and Rayleigh, C.V., 1968, The Denver earthquakes: Science, V. 161, p. 1301-1310.

Hooker, V.B., and Johnson, C.F., 1969, Near-surface horizontal stresses, including the effects of rock anistropy: U.S. Bur. Mines Rept. of Inv. 7224, p. 1-29.

Iida, K., 1959, Earthquake energy and earthquake fault: Nagoya Univ., Jour. Earth Science, v. 7, p. 98-107.

Iida, K., 1965, Earthquake magnitude, earthquake fault and source dimensions: Nagoya Univ., Jour. Earth Science, v. 13, p. 115-132.

Kelley, V.C., 1971, Geology of Pecos country, southeastern New Mexico: New Mexico Bureau Mines and Mineral Resources, Mem. 24, p. 1-69.

King, C.Y. and Knopoff, L., 1968, Stress drop in earthquakes: Seismol. Soc. Am. Bull., v. 58, p. 249-257.

King, C.Y. and Knopoff, L., 1969, A magnitude-engergy relation for large earthquakes: Seismol. Soc. Am. Bull., v. 59, p. 269-273.

King, P.B., 1948, Geology of the southern Guadalupe Mountains, Texas: U.S. Geol. Surv. Prof. Paper 215.

King, P.B., 1965, Geology of the Sierra Diablo region, Texas: U.S.Geol. Surv. Prof. Paper 480, p. 1-179.

Kottlowski, F.E., 1960, Reconnaissance geologic map of Las Cruces thirty-minute quadrangle: New Mexico Bureau Mines and Mineral Resources, Geol. Map 14.

Kottlowski, F.E., and Foster, R.W., 1960, Road log - second day - Las Cruces to Hembrillo Canyon in San Andres Mountains: Roswell Geol. Soc. Guidebook, p. 34-74.

Lee, W.H.K., and Lahr, J.C., 1972, HYP071 - A computer program for determining hypocenter, magnitude, and first motion pattern of local earthquakes: U.S. Geol. Surv. Open-file report, p. 1-100.

McGuire, R.K., 1977, Effects of uncertainty in seismicity on estimates of seismic hazard for the east coast of the United States: Siesmol. Soc. Am. Bull., v. 67, p. 827-848.

Major, M., 1975, Private communication cited in Caravella and Sanford, 1977.

Mitchell, B.J., 1973, Radiation and attenuation of Rayleigh waves from the southeastern Missouri earthquake of October 21, 1965: Jour. Geophys. Research, v. 78, p. 886-899.

Muehlberger, W.R., Belcher, R.C., and Goetz, L,K., 1978, Quaternary faulting in Trans-Pecos Texas: Geology, v. 6, p. 337-340.

Murphy, L.M., and Cloud, W.K., 1954, United States earthquakes 1952: U.S. Dept. Commerce, Coast and Geodetic Survey, Washington, D.C.

Murphy, L.M. and Cloud, W.K., 1957, United States earthquakes 1955: U.S. Dept. Commerce, Coast and Geodetic Survey, Washington, D.C.

Murphy, L.M., and Ulrich, F.P., 1951, United States earthquakes 1951, United States earthquakes 1949: U.S. Dept. Commerce, Coast and Geodetic Survey, Washington, D.C.

Neumann, R., 1932, United States earthquakes 1931: U.S. Dept. Commerce, Coast and Geodetic Survey, Washington, D.C.

Neumann, F., 1938, United States earthquakes 1936: U.S. Dept. Commerce, Coast and Geodetic Survey, Washington, D.C.

Neumann, F., 1940, United States earthquakes 1937: U.S. Dept. Commerce, Coast and Geodetic Survey, Washington, D.C.

Neumann, F., and Bodle, R.R., 1932, United States earthquakes 1930: U.S. Dept. Commerce, Coast and Geodetic Survey, Washington, D.C.

Northrop, S.A., and Sanford, A.R., 1972, Earthquakes of northeastern New Mexico and the Texas Panhandle, in Guidebook of Eastern-central New Mexico: New Mexico Geol. Soc. 23rd Field Conf., p. 148-160.

Nuttli, O.W., 1973a, Seismic wave attenuation and magnitude relations for eastern North America: Jour. Geophys. Research, v. 78, p. 876-885.

Nuttli, O.W., 1973b, The Mississippi Valley earthquakes of 1811 and 1812 - intensities, ground motion and magnitudes: Seismol. Soc. Am. Bull., v. 63, p. 227-248.

Nuttli, O.W., 1973c, Design earthquakes for the central United States: Misc. Paper S-73-1, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, p. 1-45.

Orphal, D.L., and Lahoud, J.A., 1974, Prediction of peak ground motion from earthquakes: Seismol. Soc. Am. Bull., v. 64, p. 1563-1574.

Page, R.A., Boore, D.M., Joyner, W.B., and Coulter, H.W., 1972, Ground motion values for use in the seismic design of the Trans-Alaska pipeline system: U.S.G.S. Circular 672, p. 1-23.

Pray, L.C., 1961, Geology of the Sacramento Mountains escarpment, Otero County, New Mexico: New Mexico Bureau Mines and Mineral Resources, Bull. 35, p. 1-133.

Press, F., 1967, Dimensions of the source region for small shallow earthquakes: Proceedings, VESIAC Conf. on the Source Mechanism of Shallow Seismic Events, VESIAC Rept. 7885-1-X, p. 155-164.

Reddy, R.S., 1966, Crustal structure in New Mexico: M.S. Thesis, New Mexico Institute of Mining and Technology, Socorro, New Mexico, p. 1-45.

Reiche, P. 1938, Recent fault scarps, Organ Mountain destrict, New Mexico: Am. Jour. Sci., v. 36, p. 400-444.

Richter, C.F., 1958, Elementary Seismology: W.H. Freeman & Co., San Francisco, 768 p.

Richter, C.F., 1959, Seismic regionalizaton: Seismol. Soc. Am. Bull., v. 49, p. 123-162.

Rogers, A.M., and Malkiel, A., 1978, A study of earthquakes in the Permian Basin, Texas - New Mexico: draft of a U.S. Geol. Surv. report for open-file.

Romney, C., Brooks, B.G., Mansfield, R.H., Cardes, D.S., Jordan, J.N., and Gordon, D.W., 1962, Travel times and amplitudes of principal body phases recorded from GNOME: Seismol. Soc. Am. Bull., v. 52, p. 1057-1074.

Sanford, A.R., 1963, Seismic activity near Socorro: N. Mex. Geol. Soc., Guidebook, Fourteenth field conference, The Socorro Region, p. 146-151.

Sanford, A.R., 1965, An instrumental study of New Mexico earthquakes: New Mexico Bureau of Mines and Mineral Resources, Circ. 78, p. 1-12.

Sanford, A.R., 1976a, Seismicity of the Los Alamos region based on seismological data: Los Alamos Scientific Laboratory, LA-6416-MS Informal Report, p. 1-9.

Sanford, A.R., 1976b, Seismicity of the Tualarosa Basin: in, A Preliminary Economic Feasibility Study for Establishment of an Energy-Water Complex in the Tularosa Basin, WRRI Report No. 068, New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces, New Mexico p. 84-93.

Sanford, A.R., Budding, A.J., Hoffman, J.P., Alptekin, O.S., Rush, C.A., and Toppozada, T.R., 1972, Seismicity of the Rio Grande Rift in New Mexico: New Mexico Bureau Mines and Mineral Resources, Circ. 120, p. 1-19.

Sanford, A.R., and Cash, D.J., 1969, An instrumental study of New Mexico earthquakes July 1, 1964, through Dec. 31, 1967: New Mexico Bureau Mines and Mineral Resources, Circ. 102, p 1-7.

Sanford, A.R., and Holmes, C.R., 1961, Note on the July 1960 earthquakes in central New Mexico: Seismol. Soc. America Bull., v. 51, p. 311-314.

Sanford, A.R., and Holmes, C.R., 1962, Microearthquakes near Socorro, New Mexico: Jour. Geophys. Res., v. 67, p. 449-4459.

Sanford, A.R., Johansen, S.J., Caravella, F.J., and Ward, R.M., 1976a, A report on seismic recording at the Los Medanos area of southeastern New Mexico, 1974-1975: New Mexico Institute of Mining and Technology, Oak Ridge Operations Contract No. AT-(40-1)-4582.

Sanford, A.R., Sandford, S., Caravella, F.J., Merritt, L., Sheldon, J., and Ward, R.M., 1978, A report on seismic studies of the Los Medanos area in southeastern New Mexico: New Mexico Institute of Mining and Technology, Report to Sandia Laboratories, Contract No. 03-6233.

Sanford, A.R., and Singh, S., 1968, Minimum recording times for determining short term seismicity from microearthquake activity: Seismol. Soc. Am. Bull., v. 58, p. 639-644.

Sanford, A.R., and Toppoazda, T.R., 1974, Seismicity of proposed radioactive waste isolation disposal site in southeastern New Mexico: New Mexico Bureau Mines and Mineral Resources, Circ. 143, p. 1-15.

Sanford, A.R., Toppozada, T.R., Ward, R.M., and Wallace, T.C., 1976b, The seismicity of New Mexico 1962 through 1972: Geol. Soc. Am. Abstracts With Programs v. 8, p. 625.

Sbar, M.L., Armbruster, J., and Aggerwal, Y.P., 1972, The Adirondack, New York, earthquake swarm of 1971 and tectonic implications: Seismol. Soc. Am. Bull. v. 62, p. 1303-1318.

Schnabel, P.B., and Seed, H.B., 1973, Accelerations in rock for earthquakes in the western United States: Seismol. Soc. Am. Bull., v. 63, p. 501-516.

Seed, H.B., Idriss, I.M., and Kiefer, R.W., 1968, Characteristics of rock motions during earthquakes: Earthquake Eng. Res. Center, Rept. no. 68-5.

Sellards, E.H., 1933, The Valentine, Texas, earthquake: Univ. Tex. Bull. no. 3201, p. 113-138.

Shah, H.C. Mortgat, C.P., Kiremidjian, A., and Zsutty, T.C., 1975, A study of seismic risk for Nicaragua: Rept. 11, Dept, of Civil Eng., Stanford Univ., Stanford, California.

Shurbet, D.H., 1969, Increased seismicity in Texas: Texas Jour. Sci., v. 21, p. 37-41.

Shurbet, D.H., 1975, Private communication cited in Caravella and Sanford, 1977.

Slemmons, D.B., 1977, Faults and earthquake magnitude: U.S. Army Engineer Waterways Experiment Station, Miscellaneous Paper s-73-1.

Slemmons, D.B., Jones A.E., and Gimlett, J.I., 1965, Catalog of Nevada earthquakes, 1852-1960: Seismol. Soc. Am. Bull., v. 55, p. 537-583.

Stauder, W., Kramer, M., Fisher, C., Shaefer, S., and Morrissey, S.T., 1976, Seismic characteristics of southeast Missouri as indicated by a regional telemetered microearthquake array: Seismol. Soc. Am. Bull., v. 66, p. 1953-1964.

Stewart, S.W., and Pakiser, L.C., 1962, Crustal structure in eastern New Mexico interpreted from the GNOME explosion: Seismol. Soc. Am. Bull., v. 52, p. 1017-1030.

Talmage, S.B., 1934, Scarps in Tularosa valley, New Mexico: Science, v. 79, p. 181-183.

Tatel, H.E., and Tuve, M.A., 1955, Seismic exploration of a continental crust: Geol. Soc. Am., Spec. Paper 62, p. 35-50.

Tocher, D., 1958, Earthquake energy and ground breakage: Seismol. Soc. Am. Bull., v. 48, p. 147-153.

Toppozada, T.R., and Sanford, A.R., 1972, Instrumental study of New Mexico earthquakes January 1968 through June 1971: New Mexico Bureau Mines and Mineral Resources, Circ. 126, p. 1-6.

Toppozada, T.R., and Sanford, A.R., 1976, Crustal structure in central New Mexico interpreted from the Gasbuggy explosion: Seismol. Soc. Am. Bull., v. 66, p. 877-886.

Tusboi, C., 1956, Earthquake energy, earthquake volume, aftershock area, and strength of the earth's crust: Physics of the Earth Jour. (Tokyo), v. 4, p. 63-66.

Uniform Building Code, 1970, 1973, 1976 editions, International Conference of Building Officials, Whittier, California.

Von Hake, C.A., 1975, Earthquake history of New Mexico: Earthquake Info. Bull, v. 7, No. 3, p. 23-26.

Van Hake, C., and Cloud, W.K., 1968, United States earthquakes 1966: U.S. Dept. Commerce, Coast and Geodetic Survey, Washington, D.C.

Von Schonfeldt, H.A., Kehle, R.O., and Gray, K.E., 1973, Mapping of stress field in the upper earth's crust of the United States: Final Tech. Rept. to U.S. Geol. Surv. under Contract No. 14-08-0001-122278, p. 1-40.

Wiegel, R.L., (ed.), 1970, Earthquake Engineering: Prentice-Hall Inc., Englewood Cliffs, N.J., p. 1-518.

Wilson, E.D., Moore, R.T., and Cooper, J.R., 1969, Geologic Map of Arizona: Arizona Bureau of Mines, Tucson, Arizona, Scale 1:500,000.

Wood, H.O., and Neumann, F., 1931, Modified Mercalli intensity scale of 1931: Seismol. Soc. Am. Bull., v. 21, p. 277-283.

Wyss, M. and Brune, J.N., 1968, Seismic movement, stress, and source dimensions for earthquakes in the California - Nevada region: Jour. Geophysical Res., v. 73, p. 4681-4694.

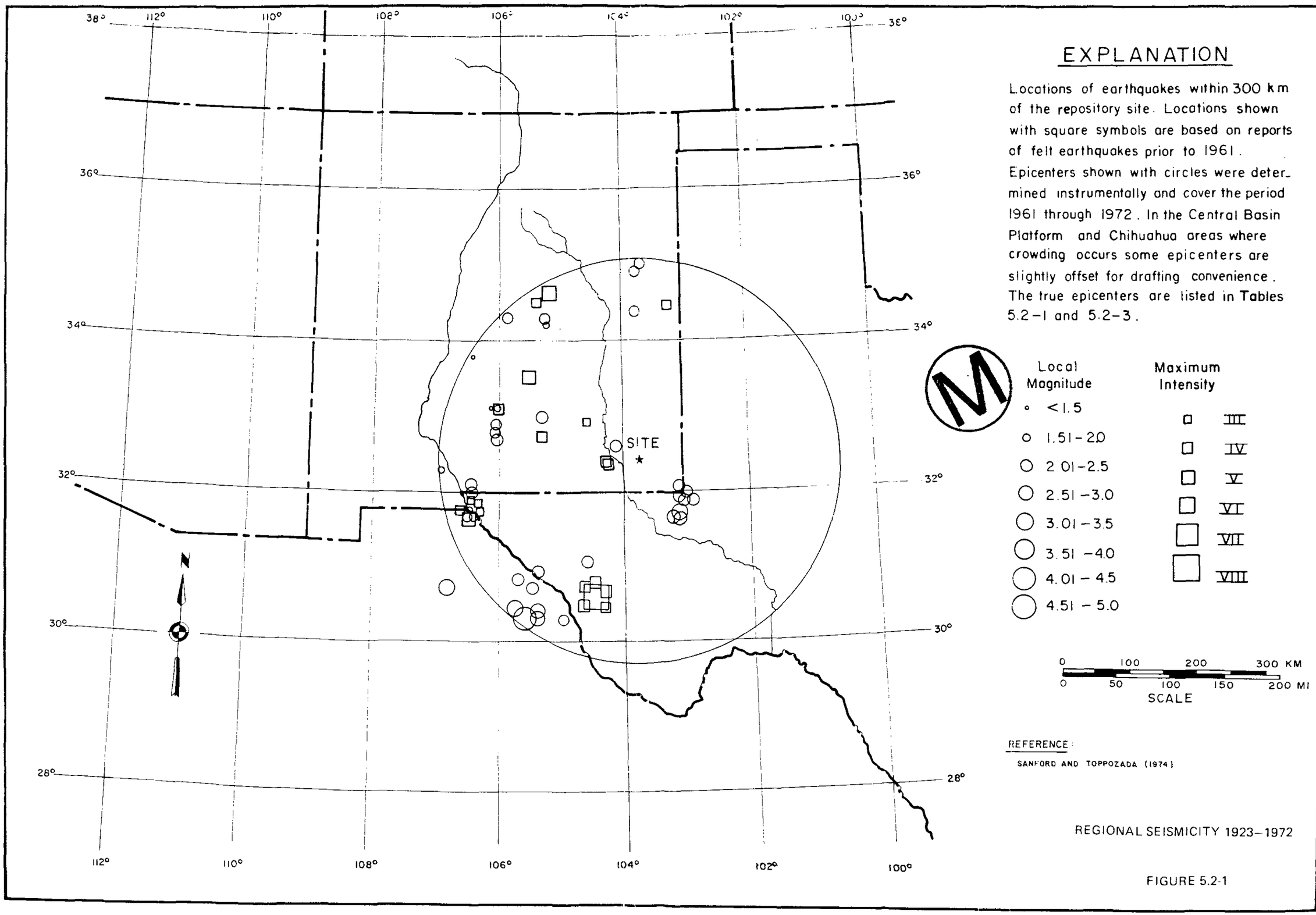

REGIONAL SEISMICITY 1923–1972

FIGURE 5.2-1

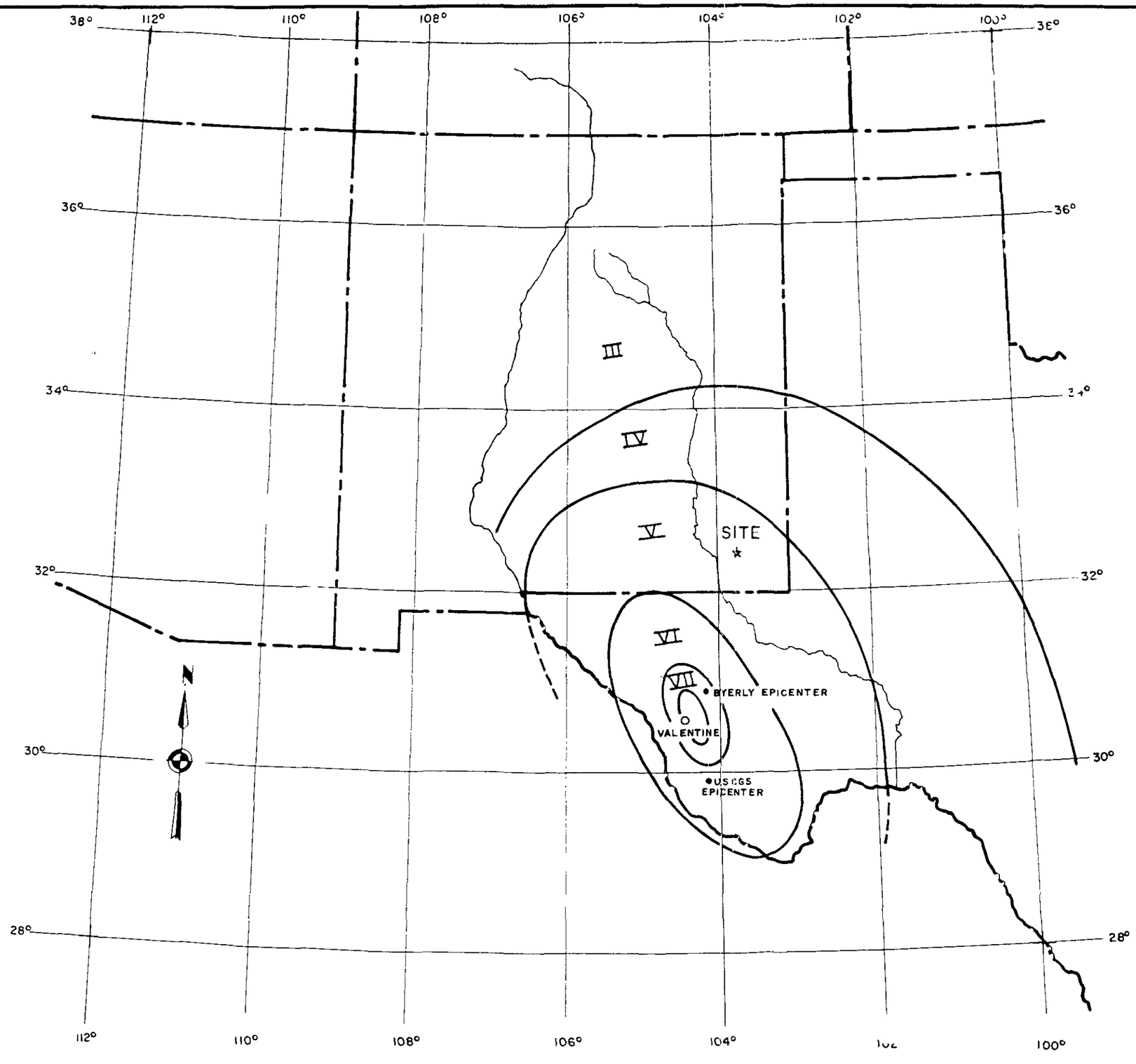

EXPLANATION

Isoseismal map for the Valentine, Texas earthquake of August 16, 1931 (after Sanford and Toppozada, 1974). Intensities are in the Modified Mercalli scale of 1931 (see Table 5.2-2). Also shown are the instrumental epicenters for this earthquake as determined by the U.S.C.G.S. (Neumann, 1932) and Byerly (1934).

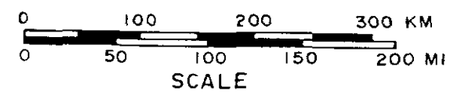

VALENTINE, TEXAS EARTHQUAKE ISOSEISMALS

FIGURE 5.2-2

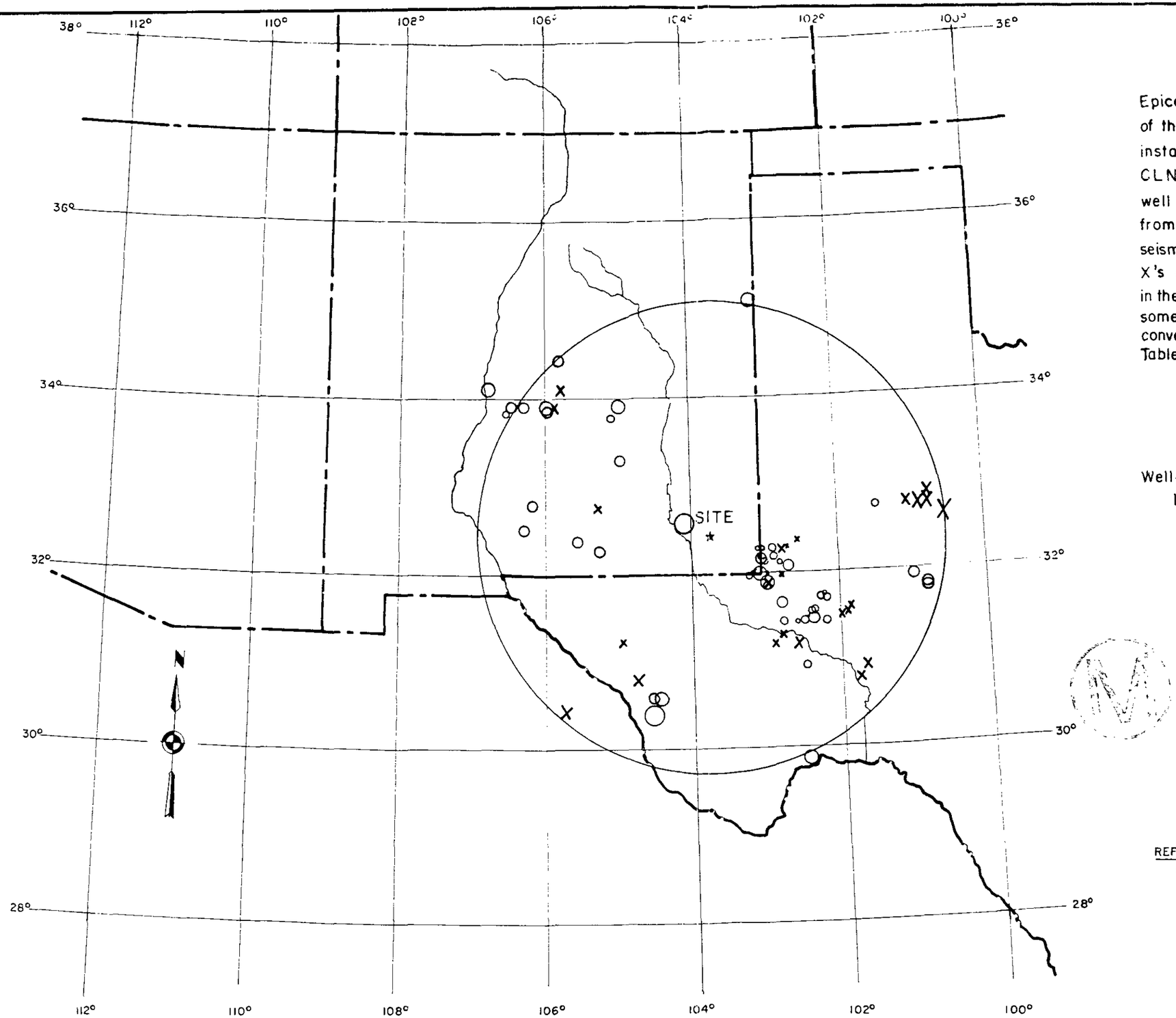

EXPLANATION

Epicenters of earthquakes within 300 km of the repository site located after the installation, and with the help, of Station CLN. Epicenters shown as circles are well located using phase arrival times from at least three and usually many more seismographic stations. Epicenters shown as X's are only tentative locations as explained in the text. In areas where crowding occurs some epicenters are slightly offset for drafting convenience. The true epicenters are listed in Tables 5.2-5 and 5.2-6.

Well-Determined Locations	Local Magnitude	Tentative Locations
∘	<1.5	×
∘	1.51 – 2.0	×
○	2.01 – 2.5	X
○	2.51 – 3.0	X
○	3.01 – 3.5	X
○	3.51 – 4.0	X
○	4.01 – 4.5	X

0 100 200 300 KM
0 50 100 150 200 MI
SCALE

REFERENCE:
SANFORD et al (1978)

EARTHQUAKES LOCATED AFTER INSTALLATION OF STATION CLN

FIGURE 5.2-3

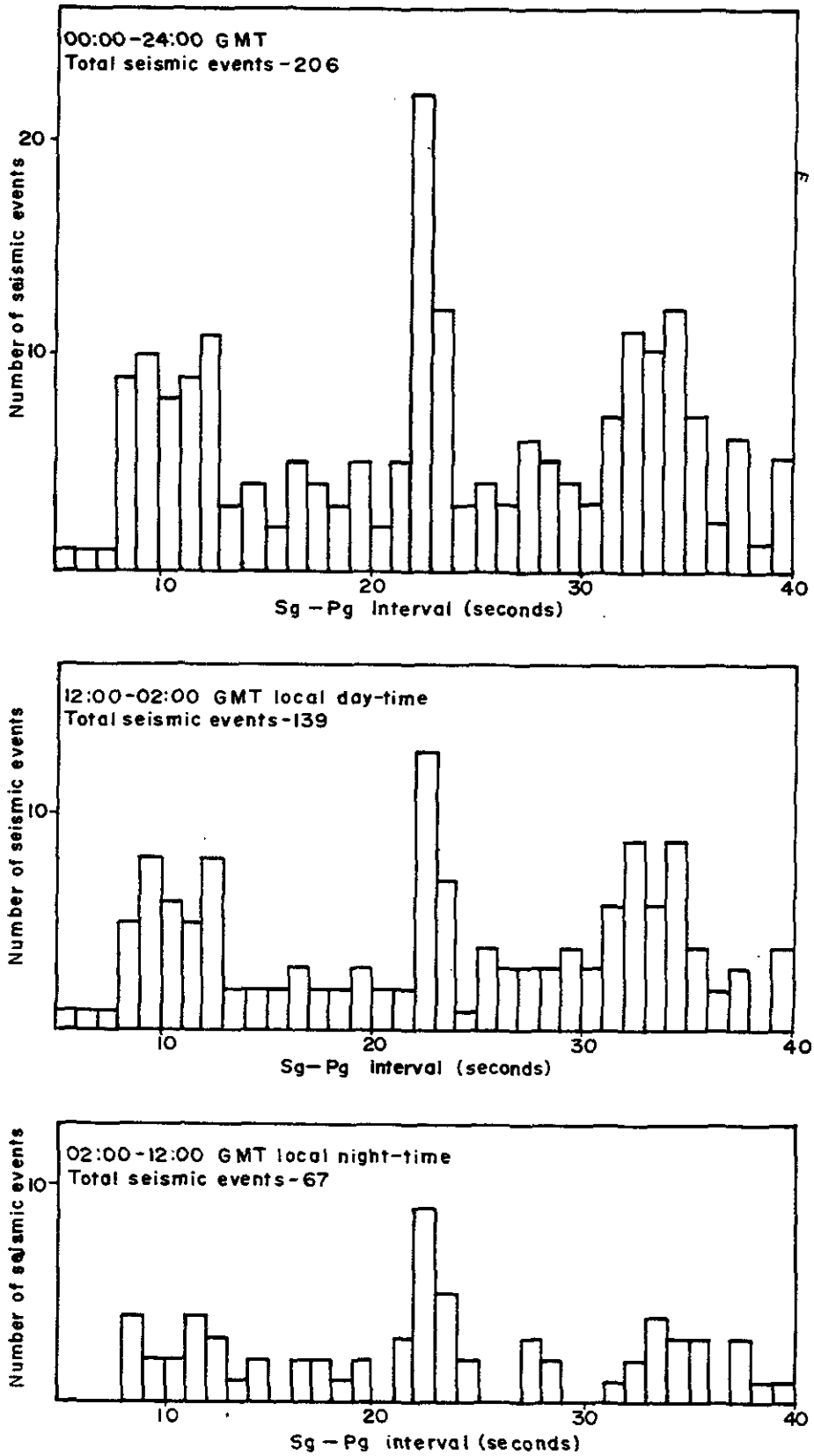

EXPLANATION

Histograms of the number of earthquakes versus Sg-Pg interval for data collected at station CLN from April 5, 1974 to October 29, 1977. Total number of events in top frame is separated into two subsets in the lower frames.

REFERENCE:

Sanford et al., 1978

EVENT-DISTANCE HISTOGRAMS

FIGURE 5.2-4

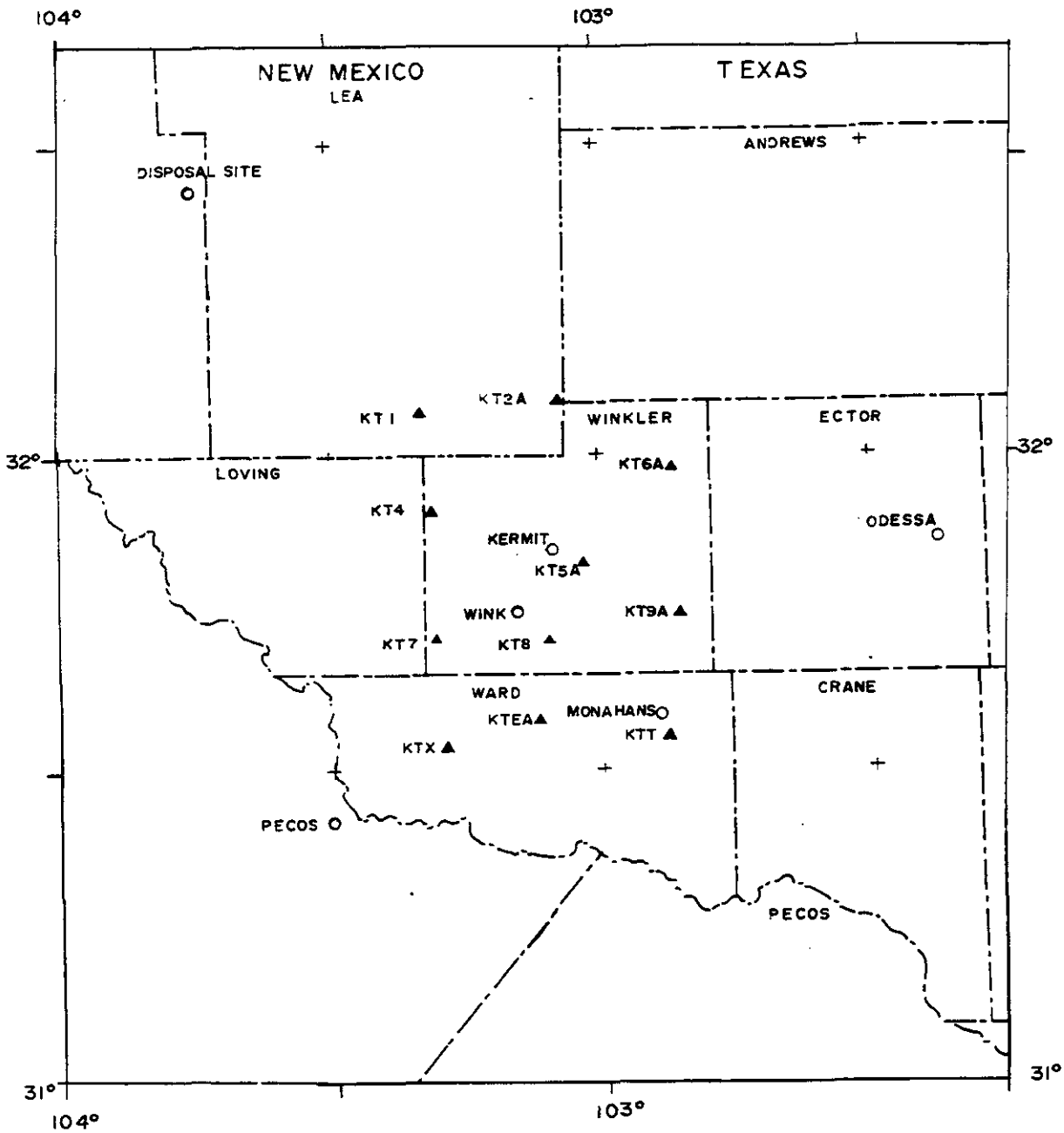

Current seismograph station locations in the Kermit array shown in relation to surrounding cultural features (from Rogers and Malkiel, 1978). Stations with an addended A have been moved from their original sites.

KERMIT ARRAY CONFIGURATION

FIGURE 5.2-5

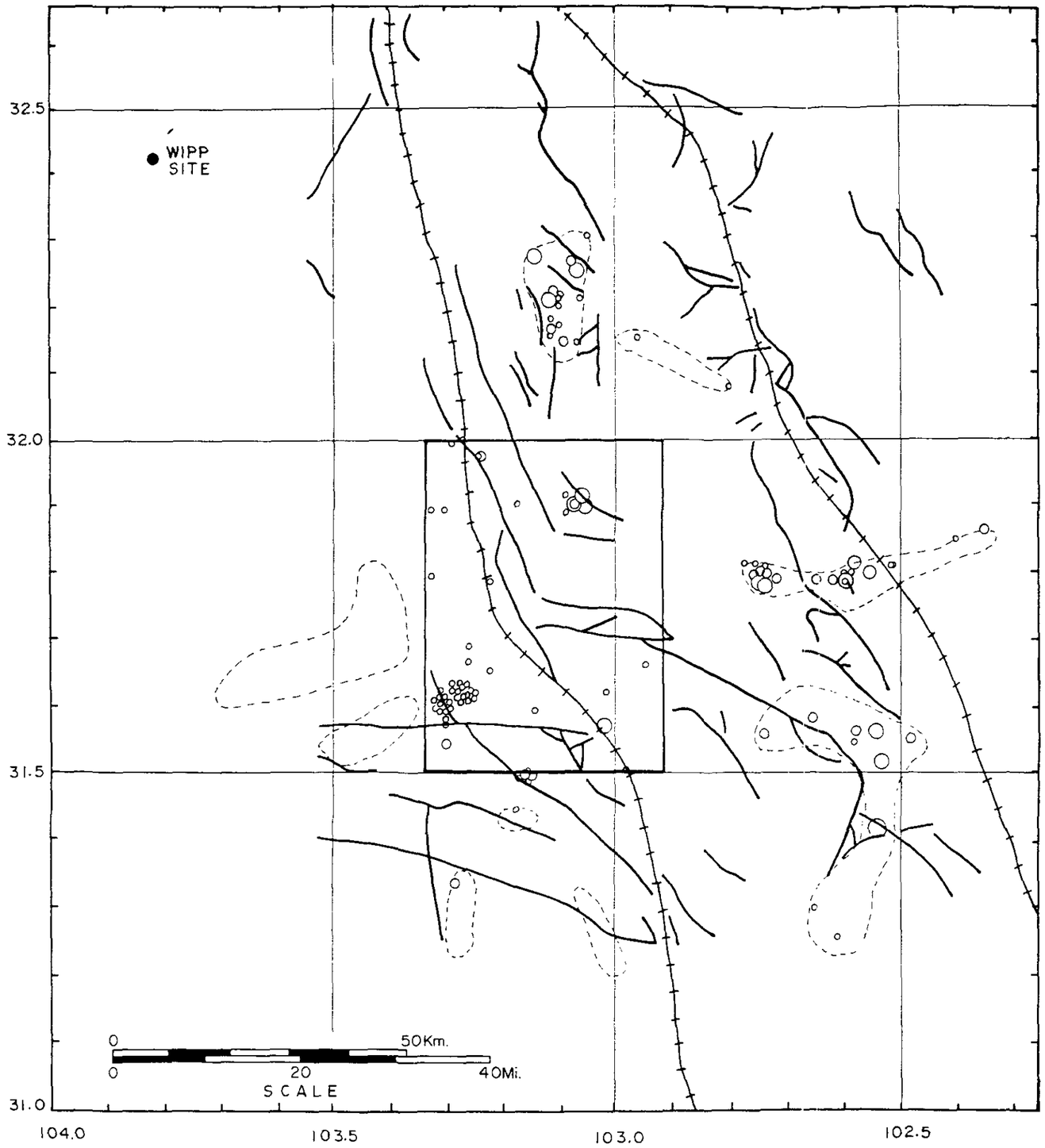

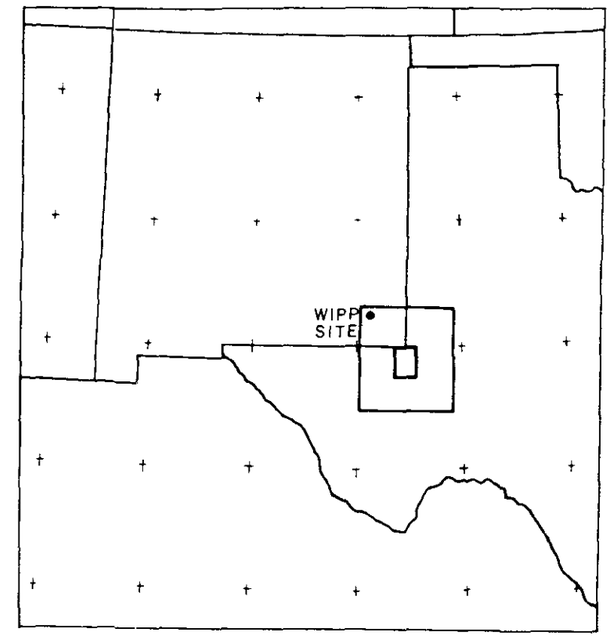

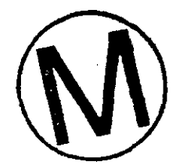

EXPLANATION

Earthquakes located using the Kermit array network. All located events within the array, denoted by the small rectangular area in the map to the left, are shown as well as those shocks on the array's periphery located by five or more array stations. The light dashed lines enclose peripheral epicenters whether or not they satisfy the five station criterion. Solid lines are pre-Permian faults, and the cross hatched lines the boundary of the Central Basin Platform both after Rogers and Malkiel, 1978. The regional location map above shows both the total map area to the left and the Kermit array limits in a large scale context.

Magnitude

- ≤ 2.35
- 2.36 – 2.85
- 2.86 – 3.35
- ≥ 3.36

REFERENCE:
ROGERS AND MALKIEL (1978)

EVENTS LOCATED USING KERMIT ARRAY DATA

FIGURE 5.2-6

46

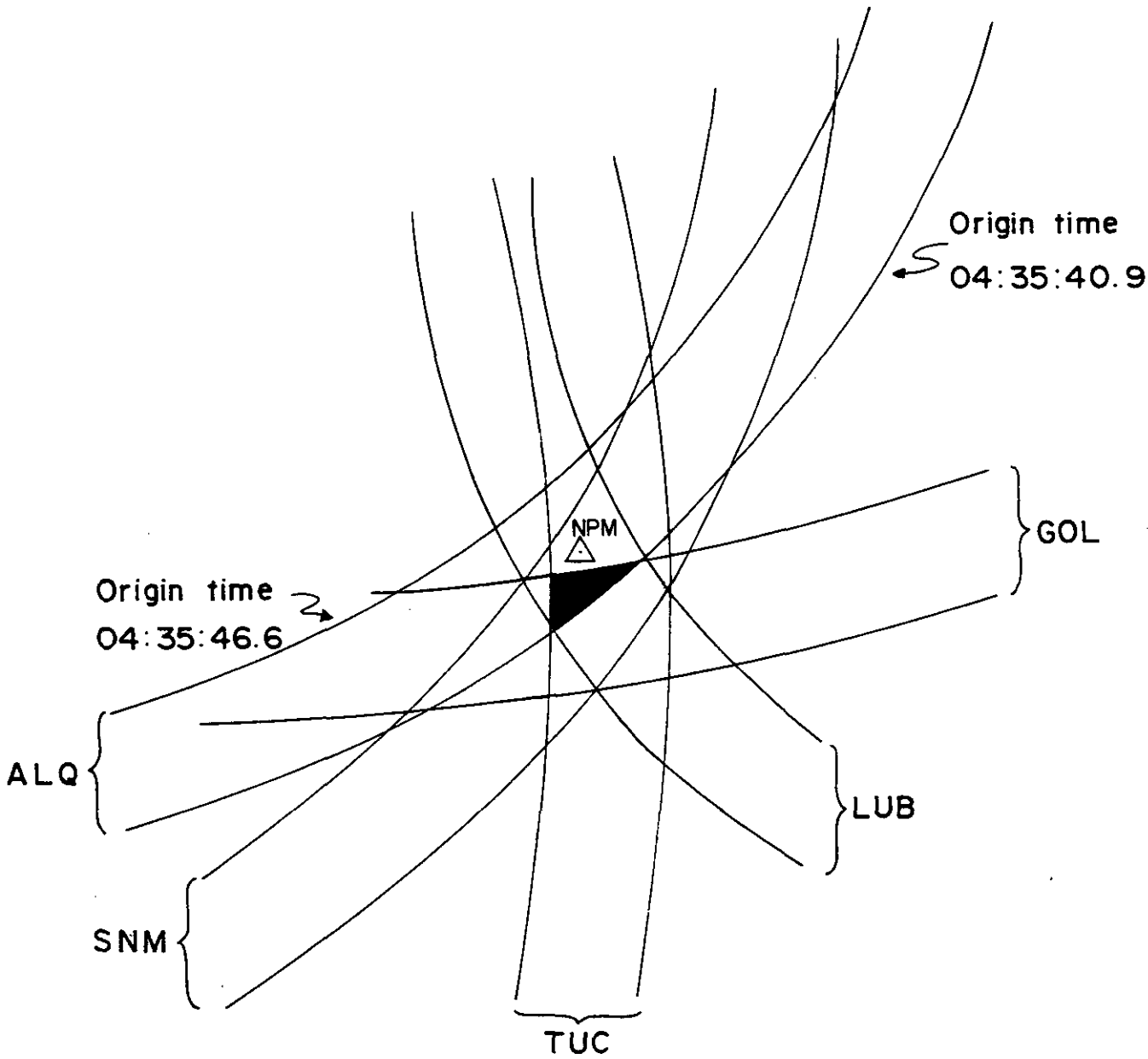

EXPLANATION

The area defined by arc intersections using the 95% confidence intervals for the origin time. NPM is the National Potash Company Eddy County Mine location. All arcs shown are for Pg waves. Actual area of mutual intersection is shaded.

REFERENCE: Caravella and Sanford, 1977.

LOCATION UNCERTAINTY
FOR THE JULY 26, 1972 EVENT

FIGURE 5.2-7

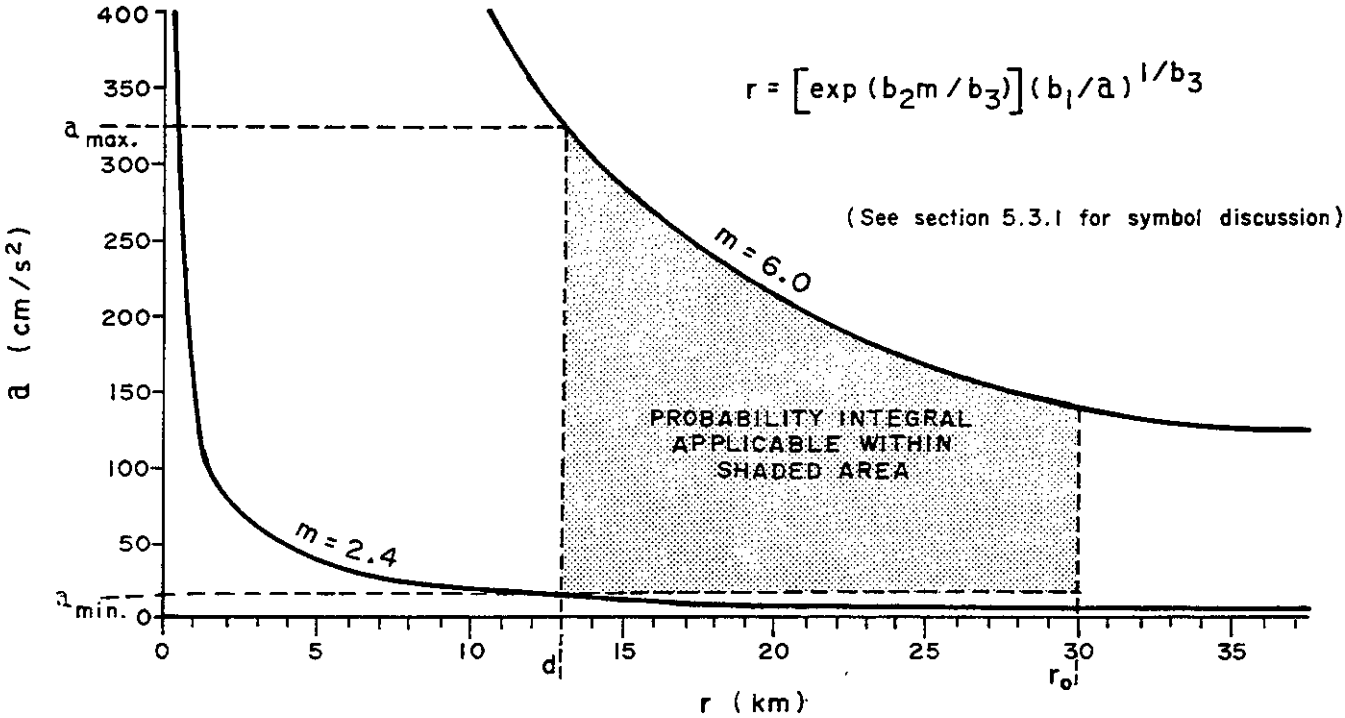

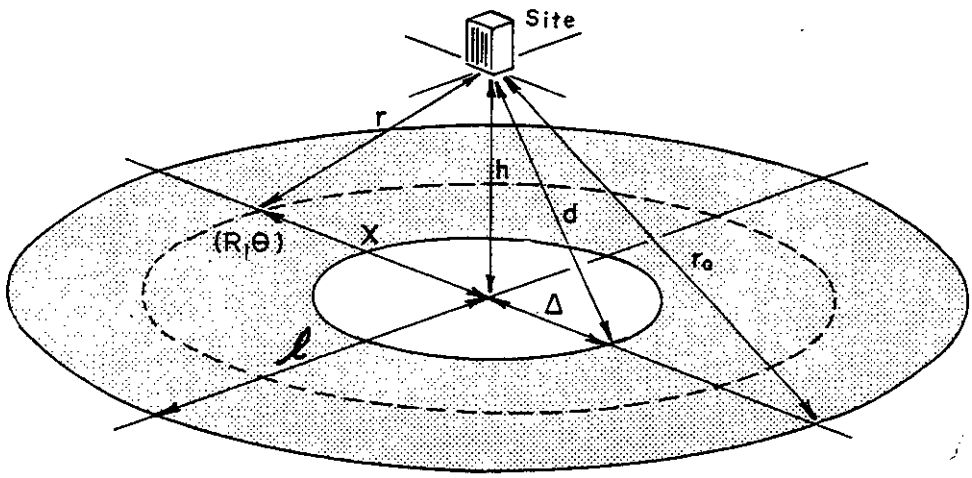

EXPLANATION

TOP - geometric and attenuation law constraints on limits of integration for the annular area probability integral. The shaded region represents values over which the probability is valid.

BOTTOM - schematic of annular source area showing variables of integration.

(After Cornell, 1968).

PARAMETERS FOR THE DETERMINATION OF PROBABILISTIC ACCELERATION

FIGURE 5.3-1

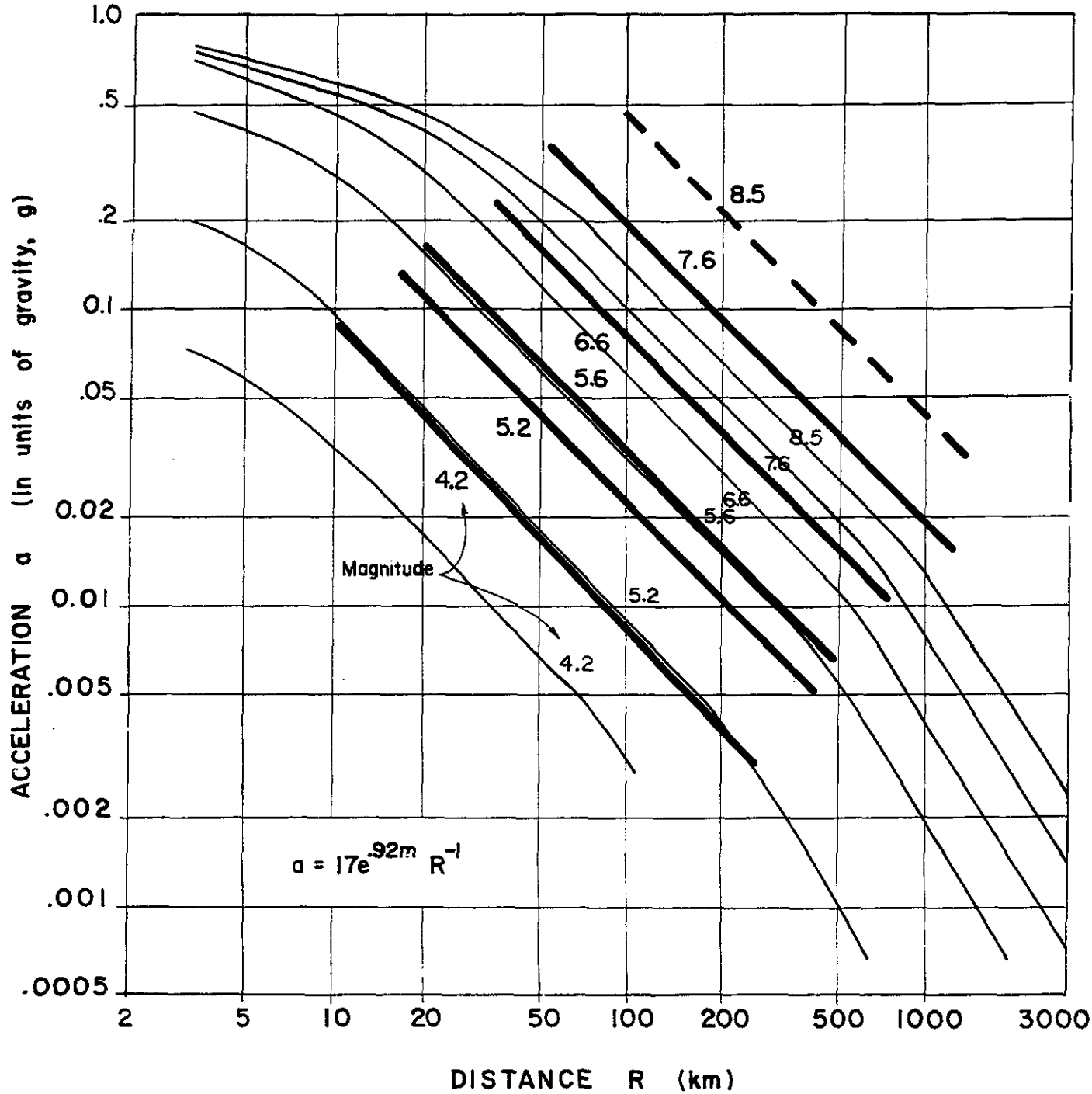

EXPLANATION

Comparison of acceleration attenuation curves for areas of the United States east of 105°W longitude after Algermissen and Perkins (1976) (light lines) with those used in the site hazard analysis of this report (heavy lines). The equation for the recommended attenuation curves is shown in the inset.

M RECOMMENDED ATTENUATION CURVES

FIGURE 5.3-2

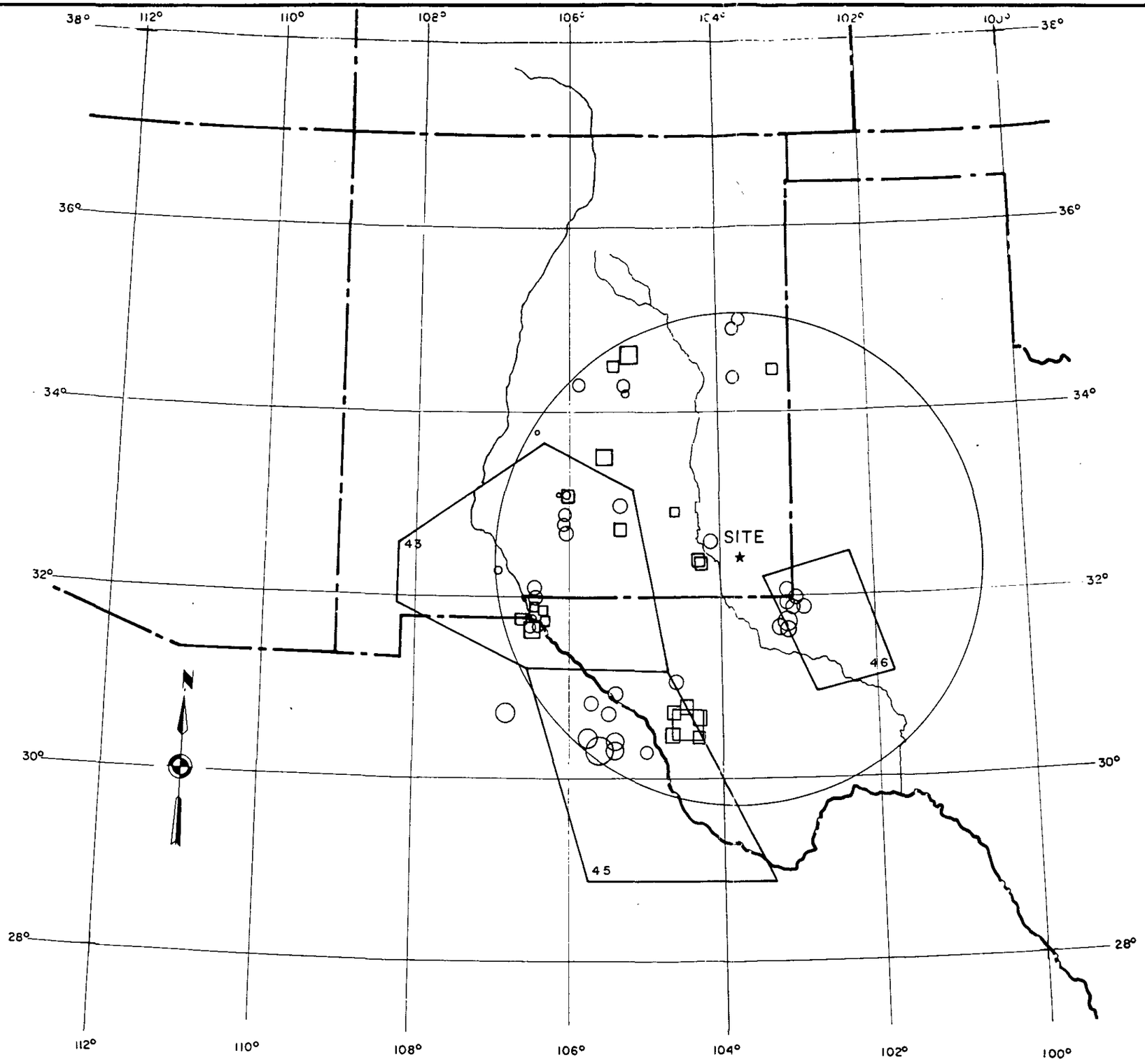

EXPLANATION

Seismic source zones are taken from Algermissen and Perkins (1976). The numbering of the three zones shown is in conformity with that study. For purposes of discussion Zones 43 and 45 are the Southern Basin and Range-Rio Grande rift source zones (northern and southern region respectively). Zone 46 is the Central Basin Platform source zone. Earthquake epicenters are exactly as shown in Figure 5.2-1 of this report. All information concerning them may be found in the explanation for that figure.

M

0 100 200 300 KM
0 50 100 150 200 MI
SCALE

SEISMIC SOURCE ZONES

FIGURE 5.3-3

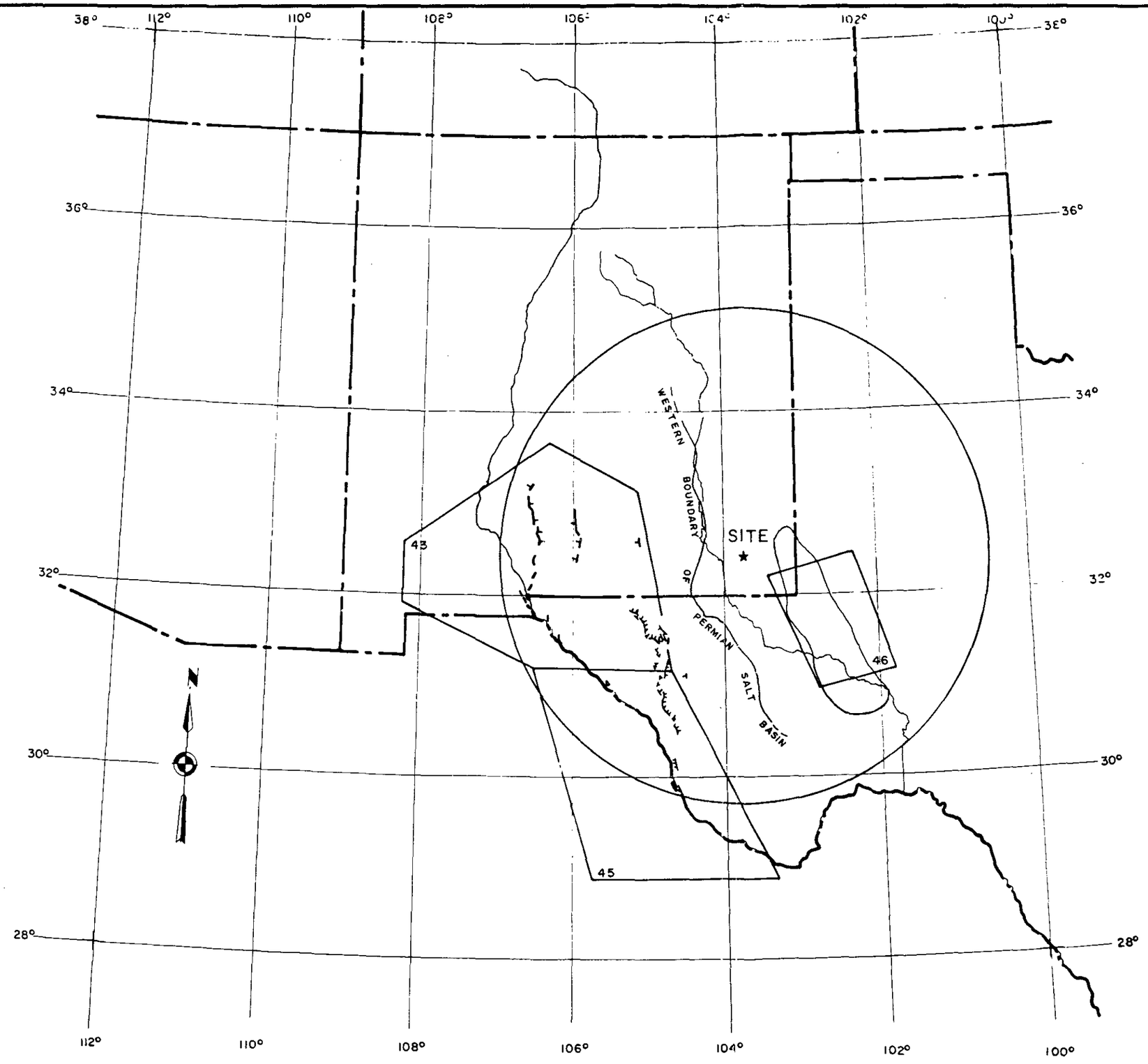

EXPLANATION

Seismic source zones are as shown in Figure 5.3-3 of this report. Plotted Quaternary faulting features are taken from Sanford and Toppozada (1974; Fig. 6) and Muehlberger et al (1978; Fig. 2). The western boundary of the Permian Salt Basin is taken from Figure 6 of Sanford and Toppozada (1974). The outline of the Central Basin Platform shown is taken from Rogers and Malkiel (1978).

0 100 200 300 KM
0 50 100 150 200 MI
SCALE

STRUCTURAL FEATURES IN THE SITE REGION

FIGURE 5.3-4

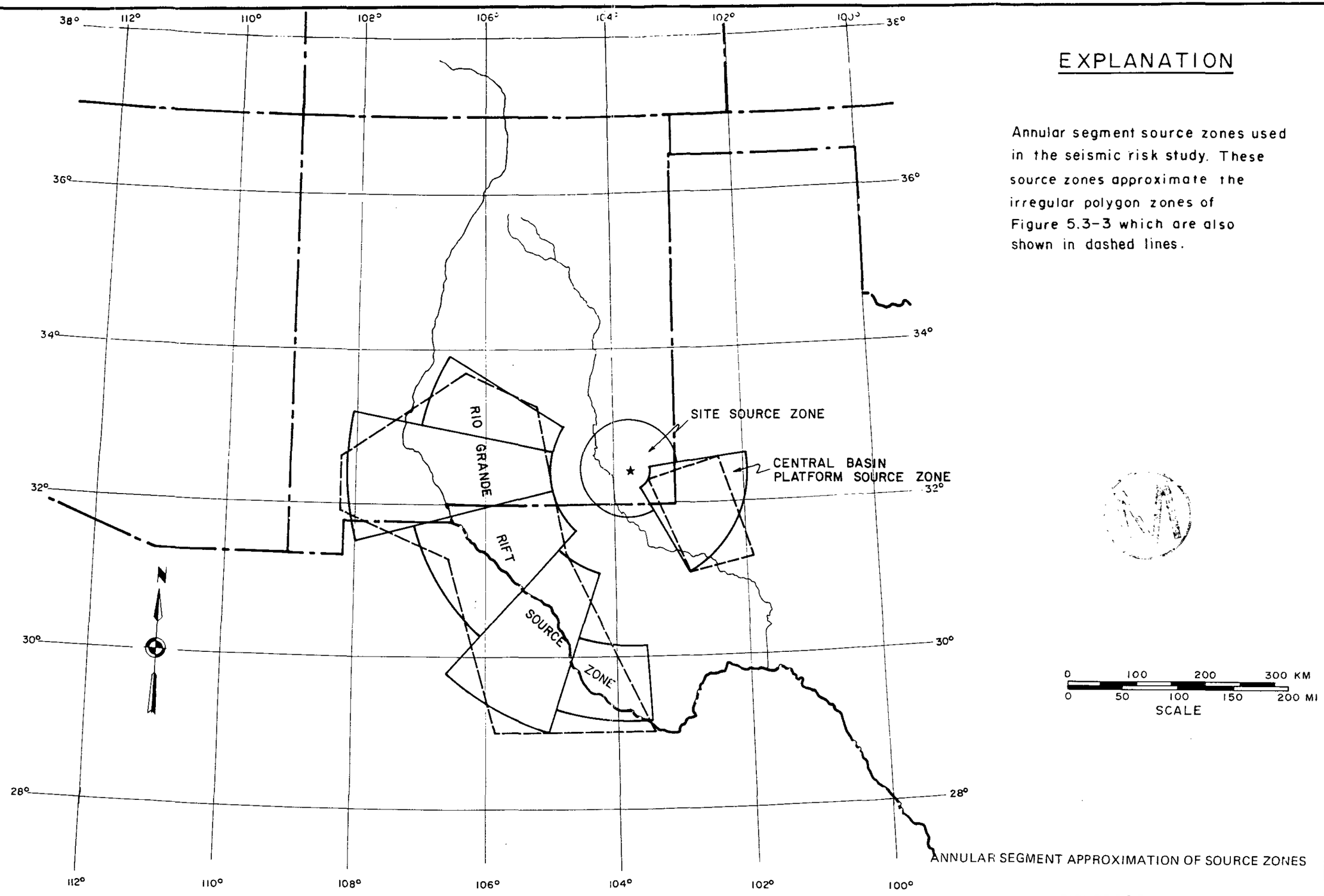

EXPLANATION

Annular segment source zones used in the seismic risk study. These source zones approximate the irregular polygon zones of Figure 5.3-3 which are also shown in dashed lines.

ANNULAR SEGMENT APPROXIMATION OF SOURCE ZONES

FIGURE 5.3-5

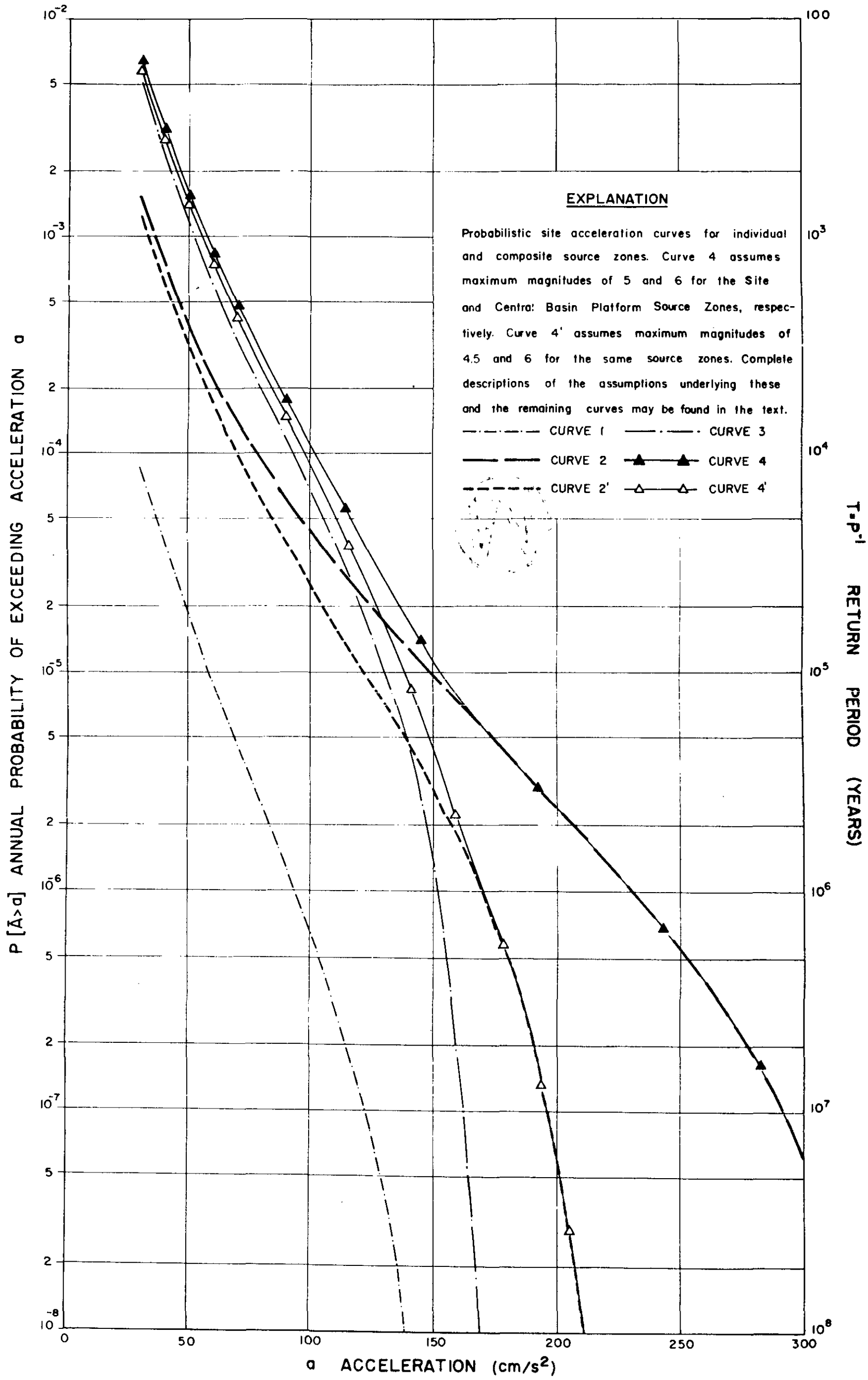

ACCELERATION PROBABILITY CURVES – SET 1

FIGURE 5.3-6

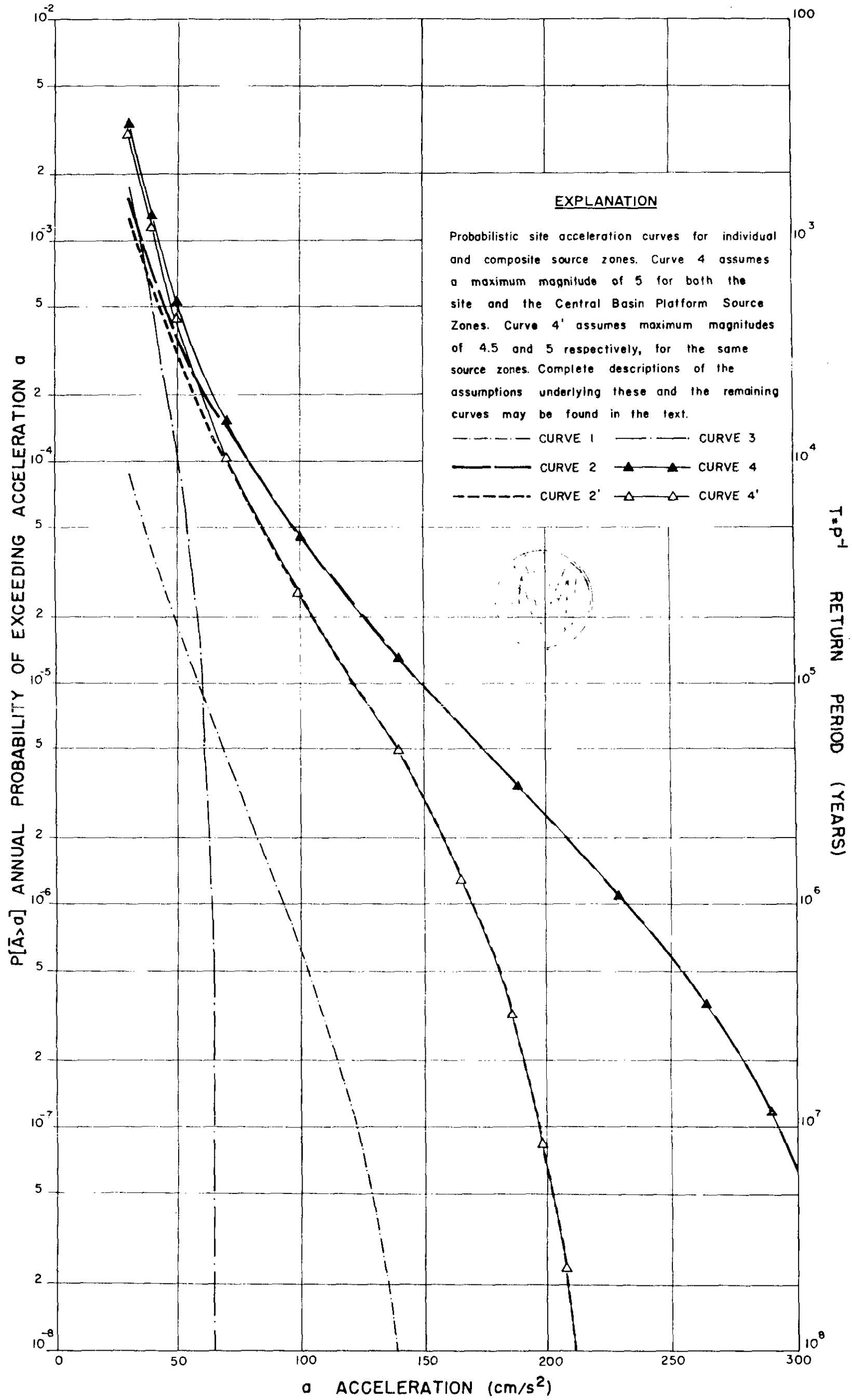

ACCELERATION PROBABILITY CURVES – SET 2

FIGURE 5.3-7

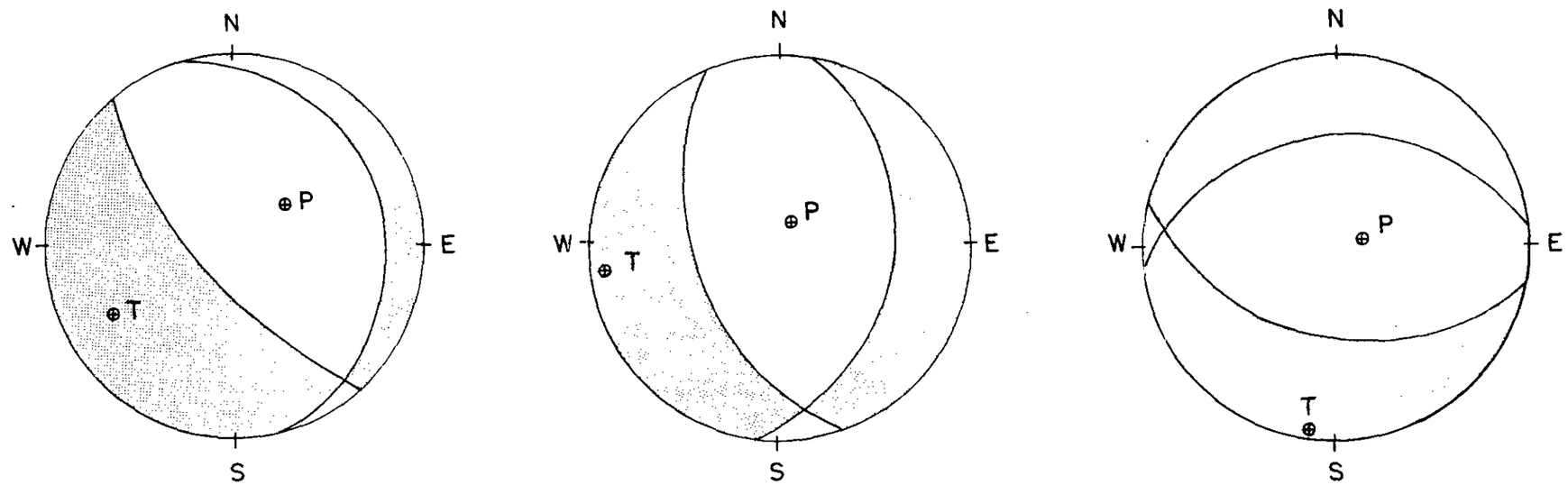

a b c

EXPLANATION

Plots of lower focal hemisphere projections of P-wave polarities for a) the August 16, 1931 Valentine, Texas earthquake, b) a composite solution for three small earthquakes on the Central Basin Platform which occurred in January, 1976, and c) one possible solution for an earthquake in the same area of the CBP ocurring on April 26, 1977. P is the maximum and T the minimum compressive stress axes for each solution.

M

REGIONAL FOCAL MECHANISM SOLUTIONS

FIGURE 5.4-1

Table 5.2-1

EARTHQUAKES OCCURRING BEFORE 1961 AND CENTERED WITHIN 300 KILOMETERS OF THE SITE

DATE Yr/Mo/Day	ORIGIN TIME (GMT)	LOCATION	INTENSITY	DISTANCE (km)
23/03/07	04:03	El Paso, Tex.	V	260
26/07/17	22:00	Hope and Lake Arthur, N.M.	III	90
30/10/04	03:25	34.5°N 105.4°W	(IV)	280
31/08/16	11:40	Valentine, Tex.	VIII	210
31/08/16	19:33	Valentine, Tex.	(V)	210
31/08/18	19:36	Valentine, Tex.	V	210
31/08/19	01:36	Valentine, Tex.	(V)	210
31/10/02	?	El Paso, Tex.	(III)	260
31/11/03	14:50	29.9°N 104.2°W	(V)	295
35/12/20	05:30	34.4°N 103.2°W	III-IV	230
36/01/08	06:46	Carlsbad, N.M.	(IV)	40
36/08/08	01:40	El Paso, Tex.	(III)	260
36/10/15	~18:00	El Paso, Tex	(III)	260
37/03/31	22:45	El Paso, Tex.	(IV)	260
37/09/30	06:15	Ft. Stanton, N.M.	(V)	200
43/12/27	04:00	Tularosa, N.M.	IV	220
49/02/02	23:00	Carlsbad, N.M.	(IV)	40
49/05/23	07:22	34.6°N 105.2°W	IV	280
52/05/22	04:20	Dog Canyon, N.M.	IV	158
55/01/27	00:37	Valentine, Tex.	IV	210

MODIFIED MERCALLI INTENSITY SCALE OF 1931

[Abridged]

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rock noticeably. (IV to V Rossi-Forel scale.)

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale.)

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars. (VIII Rossi-Forel scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars. (VIII+ to IX Rossi-Forel scale.)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+Rossi-Forel scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel scale.)

XI. Few, if any (masonry), structures remain standing. Bridges destroyed, Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

INSTRUMENTALLY LOCATED EARTHQUAKES WITHIN 300 KM
OF THE LOS MEDANOS SITE: 1962-1972

DATE Yr/Mo/Day	ORIGIN TIME GMT	LOCATION Lat N/Long W		MAGNITUDE M_L
69 May 12	08:26:18	32.0	106.4	3.0
69 May 12	08:49:16	32.0	106.4	2.6
69 Jun 1	17:18:24	34.2	105.2	2.0
69 Jun 8	11:36:02	34.2	105.2	2.4
69 Oct 19	11:51:34	30.8	105.7	2.8
71 Jul 30	01:45:50	31.7	103.1	3.1
71 Jul 31	14:53:48	31.6	103.1	3.2
71 Sep 24	01:01:54	31.6	103.2	3.0
72 Feb 27	15:50:04	32.9	106.0	2.3
72 Jul 26	04:35:44	32.6	104.1	2.8
72 Dec 9	05:58:39	31.7	106.4	2.2
72 Dec 10	14:37:50	31.7	106.5	2.2
72 Dec 10	14:58:02	31.7	106.5	1.8

INSTRUMENTALLY LOCATED EARTHQUAKES WITHIN 300 KM
OF THE LOS MEDANOS SITE: 1962-1972

DATE Yr/Mo/Day	ORIGIN TIME GMT	LOCATION Lat N	LOCATION Long W	MAGNITUDE M_L
62 Mar 3	18:16:47	33.8	106.4	1.2
62 Mar 6	09:59:10	31.1	104.6	3.0
64 Feb 11	09:24:10	34.4	103.7	2.5
64 Mar 3	01:26:27	35.0	103.6	2.2
64 Jun 18	20:20:18	33.1	106.1	1.2
64 Jun 19	05:28:39	33.1	106.0	1.7
64 Oct 20	00:53:00	30.7	106.8	3.1
64 Nov 8	09:26:00	31.9	103.0	2.7
64 Nov 21	11:21:24	31.9	103.0	2.5
65 Feb 3	19:59:32	31.9	103.0	3.0
65 Apr 13	09:35:46	30.3	105.0	2.5
65 Aug 30	05:17:30	31.9	103.0	2.6
66 Aug 14	15:25:47	31.9	103.0	2.8
66 Aug 17	18:47:21	30.7	105.5	2.9
66 Aug 19	04:15:44	30.3	105.6	4.6
66 Aug 19	08:38:21	30.3	105.6	3.6
66 Sep 17	21:30:13	34.9	103.7	2.2
66 Nov 26	20:05:41	30.9	105.4	2.6
66 Nov 28	02:20:57	30.4	105.4	3.3
66 Dec 5	10:10:37	30.4	105.4	3.3
67 Sep 29	03:52:48	32.3	106.9	2.0
68 Mar 9	21:54:26	32.7	106.0	2.9
68 Mar 23	11:53:39	32.7	106.0	2.3
68 May 2	02:56:44	33.0	105.3	2.6
68 Aug 22	02:22:26	34.3	105.8	2.1

Table 5.2-4

INTERRUPTIONS IN OPERATION OF SEISMOGRAPH STATION CLN.

From		To		Cause
Time	Date	Time	Date	
Records were not obtained for the following periods:				
08:34	April 29, 1974	20:39	May 1, 1974	Recorder ran out of film.
13:13	May 18, 1974	07:03	May 19, 1974	Developing error.
07:18	May 31, 1974	13:32	June 12, 1974	Operating error changing film.
03:31	June 20, 1974	15:47	June 25, 1974	Developing error.
08:08	Sept 1, 1974	07:05	Sept. 2, 1974	Ran out of film.
17:09	Sept. 27, 1974	21:35	Sept. 28, 1974	Ran out of film.
03:23	Dec. 24, 1974	19:20	Jan. 5, 1975	Film broke.
07:37	May 28, 1975	18:08	June 7, 1975	Galvanometer light burned out.
20:23	June 21, 1975	18:20	July 4, 1975	Film broke.
17:50	Oct. 12, 1975	19:16	Oct. 26, 1975	Programmer-chronometer removed for repair.
19:31	Nov. 8, 1975	23:22	Jan. 12, 1976	Loss of power from thermal-electric generator.
12:40	Nov. 20, 1976	19:35	Jan. 17, 1977	Failure of voltage regulator on thermal-electric generator.
19:35	May 23, 1977	18:49	June 4, 1977	Film advance inoperative.
19:18	Sept. 13, 1977	18:20	Sept. 17, 1977	Film advance inoperative.
22:20	Oct. 6, 1977	18:47	Oct. 8, 1977	Film advance inoperative.
Station was operating without internal time for the following periods:				
22:01	May 1, 1974	07:18	May 31, 1974	Programmer-chronometer malfunction.
23:55	Aug. 18, 1974	23:55	Sept. 1, 1974	" " "
22:30	Nov. 28, 1974	03:23	Dec. 24, 1974	" " "

Table 5.2-5

WELL DETERMINED EPICENTRAL LOCATIONS
FOR
EARTHQUAKES AFTER INSTALLATION OF STATION CLN

DATE Yr/Mo/Day	ORIGIN TIME	LOCATION Lat°N/Long°W		DISTANCE to CLN (km)	CLN MAGNITUDE
74/08/26	07:33:22.0	34.4	105.8	305.9	2.4
74/09/26	23:44:08.5	32.8	106.2	235.8	2.4
74/10/15	10:07:57.9	33.9	106.5	316.9	2.3
74/11/01	10:45:49.6	33.8	106.6	314.9	2.0
74/11/12	02:31:57.3	31.9	100.8	288.9	2.5
74/11/12	07:14:28.5	31.9	100.8	273.7	2.2
74/11/21	16:22:58.6	32.5	106.3	240.3	2.4
74/11/21	18:59:05.8	32.1	102.7	105.7	2.1
74/11/22	08:54:05.1	32.8	101.5	213.6	2.0
74/11/22	14:11:13.2	33.8	105.1	211.7	1.9
74/11/28	03:35:20.5	32.6	104.1	43.1	3.6
75/02/02	20:39:22.6	35.1	103.1	317.3	2.7
75/07/25	08:11:40.0	29.9	102.5	309.8	2.8
75/08/01	07:27:47.3	30.4	104.6	239.3	3.9
75/10/10	11:16:55.9	33.3	105.0	160.4	2.1
76/01/10	01:49:57.0	31.7	102.8	123.4	2.1
76/01/14	07:01:31.5	34.1	106.8	353.7	2.6
76/01/19	04:03:30.4	31.9	103.0	93.8	2.4
76/01/22	07:21:57.8	31.9	103.0	89.1	2.0
76/01/25	04:48:27.5	32.0	103.1	80.2	2.9
76/01/28	07:37:48.5	32.0	101.0	262.9	2.4
76/03/18	23:07:04.8	32.2	102.9	77.9	1.6
76/03/20	16:15:58.0	32.2	103.1	63.8	1.4
76/03/27	22:25:22.0	32.2	103.1	64.1	1.8

Table 5.2-5 (Continued)

DATE Yr/Mo/Day	ORIGIN TIME	LOCATION Lat°N/Long°W		DISTANCE to CLN (km)	CLN MAGNITUDE
76/04/01	14:46:58.0	33.9	106.0	275.5	2.6
76/04/06	18:09:00.2	33.9	105.0	208.6	2.7
76/04/18	03:48:18.5	33.9	106.0	271.2	2.1
76/04/21	08:40:05.5	32.3	102.9	81.4	1.7
76/05/03	06:52:59.0	32.4	105.6	182.4	2.4
76/05/06	17:18:23.8	32.0	103.2	71.9	1.8
76/05/21	13:17:35.0	32.3	105.3	149.0	2.2
76/06/15	02:19:58.3	31.6	102.4	158.4	1.7
76/06/15	08:50:20.0	31.5	102.4	164.0	2.1
76/08/10	09:03:11.6	31.8	102.2	158.0	1.4
76/08/10	10:15:13.8	31.8	102.2	166.0	1.7
76/08/25	01:27:48.5	31.5	102.5	156.3	1.8
76/08/26	15:22:12.7	31.8	102.2	160.8	1.7
76/08/30	11:51:25.2	31.5	102.6	145.9	1.4
76/08/30	13:07:47.5	33.9	106.3	297.8	2.3
76/08/31	12:46:22.4	31.5	102.8	130.6	1.9
76/09/05	10:39:45.7	32.2	102.8	93.8	1.4
76/09/17	02:47:46.9	32.2	103.1	62.7	2.1
76/09/19	10:40:46.4	30.6	104.5	222.9	3.0
76/10/14	11:02:59.7	32.3	103.1	63.9	0.9
76/10/22	05:06:11.8	31.5	102.2	176.2	2.0
76/10/23	12:51:36.9	31.6	102.4	161.6	1.6
76/11/03	23:24:14.7	31.0	102.5	199.3	1.8
77/01/29	09:40:43.5	30.6	104.6	220.0	2.1
77/02/10	01:22:49.4	32.3	103.1	60.2	1.0

Table 5.2-6

TENTATIVE EPICENTRAL LOCATIONS FOR
EARTHQUAKES AFTER INSTALLATION OF STATION CLN

DATE Yr/Mo/Day	ORIGIN TIME	LOCATION Lat°N/Long°W		DISTANCE TO CLN (km)	CLN MAGNITUDE
74/08/17	07:35:18	30.4	105.8	300	3.5
76/03/20	12:42:20	31.2	105.0	180	2.3
76/04/01	14:40:26	34.1	105.8	280	2.8
76/04/01	14:51:17	33.9	105.9	270	2.8
76/05/04	15:05:40	32.0	103.2	70	1.9
76/05/08	11:46:38	32.0	102.8	100	1.8
76/05/11	23:04:38	32.3	102.8	90	1.9
76/05/26	11:52:26	32.4	102.6	110	1.7
76/06/14	23:29:50	31.6	101.9	200	2.3
76/06/16	14:05:12	31.6	101.9	200	2.3
76/08/05	22:23:29	30.8	101.8	260	3.0
76/08/25	01:21:01	32.8	101.1	260	2.8
76/09/10	23:17:48	30.9	101.7	260	2.8
76/10/13	19:11:06	32.0	103.0	90	1.5
77/03/14	10:10:22	32.9	100.8	290	3.5
77/03/19	21:27:49	31.3	102.8	160	2.2
77/03/20	07:54:05	32.3	102.8	90	2.3
77/04/12	23:18:27	31.2	102.6	170	2.9
77/04/16	06:44:22	31.2	102.9	160	2.1
77/04/17	21:47:07	31.5	102.0	190	2.1
77/04/26	09:03:05	31.9	103.0	100	2.6
77/06/07	23:01:17	32.7	100.6	300	4.5
77/06/08	00:51:29	32.8	100.8	280	4.0
77/06/17	03:37:05	32.8	100.9	270	3.9
77/08/03	02:11:48	32.8	105.3	150	2.5
77/08/21	03:01:16	30.8	104.8	210	3.4

Table 5.2-7

Central Basin Platform earthquakes recorded at Ft. Stockton Station (FOTX) from June 21, 1964 through April 12, 1965*

Date Yr/Mo/Day	FOTX-P Arrival Time GMT	FOTX-S-P Interval Secs.	LC-P Arrival Time GMT
64/06/22	07:07:47	14	07:08:22
64/07/13	12:20:03	14	
64/07/13	16:18:17	14	
64/07/19	02:34:16	13	
64/08/14	14:56:37	14	14:57:11
64/09/07	13:42:36	14	13:43:10
64/09/08	22:06:20	15	
64/09/11	12:33:08	14	
64/11/08	09:26:19	S**	09:26:53
64/11/16	02:06:05	15	
64/11/17	08:05:14	14	
64/11/18	10:20:30	14	
64/11/19	11:39:59	14	
64/11/19	11:40:30	14	
64/11/21	11:21:42	S**	11:22:17
64/11/23	03:30:18	14	
64/11/25	23:18:43	14	
64/11/26	00:03:13	14	
64/11/27	16:29:53	14	16:30:28
64/11/28	23:46:55	14	
64/12/01	20:59:50	13	
64/12/01	06:49:47	13	
64/12/05	23:09:43	14	
64/12/07	06:24:12	14	
64/12/07	06:31:40	14	
64/12/08	17:16:02	14	
64/12/13	19:19:19	13	
64/12/14	15:20:26	14	
64/12/26	00:08:29	14	
65/01/08	14:01:13	14	
65/01/12	20:35:19	14	
65/01/12	20:49:38	14	
64/01/21	11:51:51	14	
65/02/02	09:59:19	13	
65/02/03	19:59:52	S**	20:00:27
65/03/08	21:00:01	14	
65/03/09	03:46:18	14	
65/04/02	07:30:58	14	

* Listing of shocks restricted to events whose maximum peak to peak amplitudes exceeded 20 mm.

** Earthquake too strong on the seismogram to read S-P interval

Table 5.2-8

EARTHQUAKES IN THE CBP LOCATED WITH REGIONAL STATIONS BETWEEN 1962-1972

DATE Yr/Mo/Day	ORIGIN TIME (GMT)	LOCATION Lat°N/Long°W		MAGNITUDE
64/11/08	09:26:00	31.9	103.0	2.7
64/11/21	11:21:24	31.9	103.0	2.5
65/02/03	19:59:32	31.9	103.0	3.0
65/08/30	05:17:30	31.9	103.0	2.6
66/08/14	15:25:47	31.9	103.0	2.8
71/07/30	01:45:50	31.7	103.1	3.1
71/07/31	14:53:48	31.6	103.1	3.2
71/09/24	01:01:54	31.6	103.2	3.0

Table 5.2-9
EARTHQUAKES LOCATED WITHIN THE
KERMIT ARRAY NOV 75-JUL 77

Date	Origin time	Lat N	Long W	Depth	M_L	#Sta
1976						
Jan 19	04:03:30.4	31.91	103.07	0.12	3.47	6
22	07:21:57.0	31.90	103.08	0.01	2.83	9
25	04:48:27.7	31.90	103.08	0.89	3.92	9
Feb 25	22:22:59.4	31.78	103.23	0.03	-	4
May 03	08:00:40.1	31.99	103.29	5.56	1.96	5
03	11:27:41.8	32.00	103.27	6.54	2.00	5
04	15:05:39.1	31.97	103.24	0.16	2.32	5
06	17:18:23.6	31.97	103.23	6.88	2.59	6
08	11:46:41.8	31.90	103.18	1.17	1.90	6
27	21:16:06.9	31.89	103.30	5.00*	1.60	3
28	16:15:23.6	31.89	103.32	5.00*	1.49	3
Jun 18	16:51:18.4	31.79	103.32	5.00*	1.68	3
Aug 05	18:53:09.2	31.57	103.02	9.29	3.01	4
Sep 05	16:10:27.7	31.61	103.31	5.00*	2.24	3
10	19:18:43.4	31.91	103.09	5.00*	2.25	3
Nov 04	23:27:54.0	31.67	103.26	0.12	1.74	4
05	22:55:30.4	31.65	103.22	5.00*	1.63	3
06	22:30:23.6	31.68	103.26	0.16	1.64	4
Dec 18	18:27:45.7	31.62	103.02	0.17	2.26	6
24	07:34:53.3	31.61	103.30	5.00*	1.45	3
25	12:58:34.9	31.63	103.29	0.41	1.18	4
26	12:15:04.6	31.63	103.26	0.00	1.17	4

Table 5.2-9
EARTHQUAKES LOCATED WITHIN THE
KERMIT ARRAY NOV 75-JUL 77

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
1977						
Jan 08	20:20:27.2	31.50	102.98	5.00*	1.95	3
14	13:33:33.4	31.60	103.31	5.00*	1.12	3
18	04:39:59.5	31.61	103.27	0.52	0.25	4
20	23:01:01.2	31.61	103.27	5.00*	1.75	3
Mar 12	00:05:23.8	31.62	103.29	5.00*	1.90	3
24	10:31:36.3	31.61	103.27	3.93	0.81	4
24	21:13:10.4	31.67	102.95	2.65	1.77	4
29	00:35:34.9	31.62	103.27	3.43	1.67	5
Apr 03	13:48:09.2	31.49	103.17	0.12	2.36	5
03	14:24:07.1	31.49	103.17	0.04	2.43	6
04	00:44:05.3	31.48	103.17	0.29	2.37	5
04	04:35:56.8	31.50	103.17	0.41	2.11	6
04	04:47:29.9	31.49	103.17	0.17	1.77	5
04	21:40:16.3	31.59	103.31	5.00*	1.68	3
04	22:55:54.0	31.59	103.30	5.00*	1.77	3
05	19:23:03.2	31.58	103.30	5.00*	1.60	3
06	23:22:30.9	31.59	103.31	5.00*	1.66	3
07	18:56:55.6	31.59	103.30	5.00*	1.67	3
07	22:32:29.3	31.60	103.30	5.00*	1.78	3
09	09:44:39.5	31.62	103.28	4.12	0.64	4
09	11:04:14.2	31.62	103.27	1.80	0.56	4
16	01:21:11.4	31.61	103.30	5.00*	0.51	3
16	06:44:22.0	31.62	103.26	3.91	1.26	4
16	14:38:39.6	31.61	103.25	0.34	0.52	7
17	20:52:38.3	31.63	103.31	5.00*	0.63	3

Table 5.2-9
EARTHQUAKES LOCATED WITHIN THE
KERMIT ARRAY NOV 75-JUL 77

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
18	18:08:24.1	31.61	103.27	6.63	2.14	7
20	12:59:58.7	31.61	103.31	5.00*	0.74	3
23	18:58:46.7	31.59	103.14	0.01	0.69	4
26	09:03:07.3	31.90	103.07	4.02	3.10	8
26	09:05:50.4	31.89	103.09	2.67	1.06	5
May 19	04:25:30.6	31.62	103.26	0.20	1.00	4
Jun 09	11:37:35.4	31.61	103.26	5.00*	1.33	3
29	23:59:46.6	31.54	103.30	0.14	2.76	5
Jul 25	17:45:48.1	31.57	103.30	5.00*	1.27	3

* Focal depths constrained to 5 km

Table 5.2-10

EARTHQUAKES LOCATED AROUND THE PERIPHERY OF THE KERMIT ARRAY BY 5 OR MORE ARRAY STATIONS

Date 1976	Origin time	Lat N	Long W	Depth	M_L	# Sta
Mar 15	02:30:48.3	32.15	102.96	0.12	1.56	5
20	16:15:55.5	32.30	103.05	0.35	1.70	5
27	22:25:21.0	32.21	103.10	0.06	1.49	9
Apr 12	08:02:35.9	32.17	103.11	0.45	2.38	5
21	08:40:07.4	32.21	103.10	0.25	2.53	6
May 01	11:13:40.8	32.27	103.14	9.92	3.04	8
Jun 15	02:20:00.5	31.58	102.65	0.76	2.39	7
15	08:50:20.9	31.55	102.48	6.85	2.67	13
Aug 10	09:03:12.2	31.86	102.35	0.14	2.39	7
10	10:15:18.2	31.80	102.55	0.55	2.87	9
25	01:27:49.3	31.56	102.58	3.89	2.79	9
26	15:22:17.7	31.79	102.59	0.75	3.03	11
31	12:46:21.1	31.56	102.73	7.84	2.78	9
Sep 05	10:39:49.4	32.16	103.11	0.18	1.68	5
17	02:47:45.4	32.21	103.10	0.20	2.98	10
17	03:56:28.9	31.42	102.54	1.66	3.44	7
19	10:23:24.4	32.14	103.09	7.29	2.41	6
Oct 14	11:03:00.1	32.21	103.07	2.74	2.32	6
22	05:06:15.9	31.57	102.54	3.03	2.94	7
25	00:27:04.2	31.81	102.58	6.59	2.95	7
25	10:52:27.3	31.85	102.40	0.17	2.15	5
26	10:44:44.1	31.33	103.28	0.46	2.81	7
Dec 12	23:00:14.0	31.52	102.53	7.59	3.21	11
12	23:25:56.0	31.55	102.58	0.13	2.33	7
19	21:26:16.0	31.79	102.64	0.25	2.61	5

Table 5.2-10
EARTHQUAKES LOCATED AROUND THE PERIPHERY OF THE KERMIT ARRAY BY 5 OR MORE ARRAY STATIONS

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
19	23:54:22.7	32.18	103.11	1.48	2.26	6
19	23:56:46.5	32.26	103.08	1.04	2.85	6
1977						
Feb 10	01:22:50.5	32.17	103.10	2.04	2.03	6
18	14:10:36.8	32.20	103.10	3.89	1.17	5
Mar 05	22:56:10.0	31.30	102.65	2.14	2.35	9
17	15:14:13.3	32.14	103.07	2.21	0.95	6
20	07:54:08.0	32.21	103.10	0.99	2.22	8
23	11:02:51.8	31.81	102.51	4.69	1.93	6
Apr 04	01:47:50.4	31.44	103.18	3.96	2.11	5
07	05:45:39.4	32.24	103.17	1.53	2.91	7
12	23:18:26.4	31.26	102.61	0.21	2.24	9
25	10:12:51.1	32.08	102.80	5.94	1.35	6
28	12:54:36.9	31.81	102.51	0.46	2.16	7
28	12:55:40.5	31.79	102.59	4.21	2.17	7
28	12:57:20.3	31.80	102.59	4.77	1.73	7
28	15:22:37.7	31.79	102.61	3.14	2.46	8
29	03:09:40.4	31.80	102.58	1.25	1.73	6
Jul 11	12:31:55.7	31.79	102.73	2.93	2.74	10
11	13:29:49.8	31.79	102.73	2.49	2.19	9
12	17:06:06.3	31.79	102.71	4.86	2.44	9
18	12:37:30.6	31.80	102.74	0.97	2.90	8
22	04:01:10.1	31.80	102.73	3.42	3.35	8
22	04:18:10.5	31.80	102.73	2.30	2.50	7
22	04:36:51.0	31.81	102.75	0.38	1.67	6

Table 5.2-10

EARTHQUAKES LOCATED AROUND THE PERIPHERY OF THE KERMIT ARRAY BY 5 OR MORE ARRAY STATIONS

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
24	09:23:00.5	31.80	102.73	2.04	2.49	10
26	02:01:09.3	31.81	102.77	0.27	1.45	9

DIFFERENCES IN ARRIVAL TIMES BETWEEN THE EARTHQUAKES ON JULY 26, 1972 AND NOVEMBER 28, 1974

Station	Phase	Earthquake on July 26, 1972	Earthquake on Nov. 28, 1974	ΔT
LUB	Pn	04:36:20.3	03:35:58.25	22.05
ALQ	Pn	04:36:36.8	03:36:13.35	23.45
SNM	Pg	04:36:36.9	03:36:13.85	23.05

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GEOLOGICAL CHARACTERIZATION REPORT
WASTE ISOLATION PILOT PLANT (WIPP) SITE,
SOUTHEASTERN NEW MEXICO

SAND78-1596

VOLUME II

Dennis W. Powers, Steven J. Lambert, Sue-Ellen Shaffer,
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GEOLOGICAL CHARACTERIZATION REPORT

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APPENDICES

GCR CHAPTER 6
HYDROLOGY

6.1 INTRODUCTION

The location of the proposed WIPP site is within the surface water boundaries of the Rio Grande Water Resources Region and the groundwater boundaries of the Unglaciated Central region of the Permian Basin. In addition, the site lies within the boundaries of the Delaware Basin, a portion of the Unglaciated Central region that includes some of the least productive aquifers in the United States. The Delaware Basin is characterized by a semiarid climate with low rainfall and runoff, high evaporation, and frequent strong winds. The proposed site contains neither perennial streams nor surface water impoundment, and the water bearing strata beneath the site do not yield large quantities of water to wells. Shallow wells in the local area are generally used only for watering livestock and typically produce non-potable groundwater with total dissolved solids (TDS) concentrations in excess of 3,000 parts per million (ppm).

Hydrologic studies of the water resources surrounding the site have been supported by universities and state and federal agencies since the late 1930's (Robinson and Lang, 1938; Theis and Sayre, 1942; Hendrickson and Jones, 1952; Bjorklund and Motts, 1959; Nicholson and Clebsch, 1961; Brokaw et al., 1972; Hiss, 1975a). The early studies were primarily concerned with the control of water quality in the Pecos River for agricultural usage downstream from the brine discharge at Malaga Bend (Robinson and Lang, 1938; Hale et al., 1954). The first investigations of hydrogeologic parameters describing the occurrence and flow of groundwater in close proximity to the proposed WIPP location began in the late 1950's with Project Gnome (Cooper, 1962; Gard, 1968; Cooper, 1971).

Hydrologic studies at the site and adjacent site areas have concentrated on defining the hydrogeology and associated salt dissolution phenomena (Griswold, 1977; Lambert and Mercer, 1977; Mercer and Orr, 1977; Mercer and Orr, 1978; Anderson, 1978). These investigations are directed toward a more quantitative evaluation of the salt dissolution process, the

hydrogeologic parameters affecting groundwater movement, and the major elements of surface and groundwater quality affecting water resource use and local ecology. The collection of hydrologic data is projected to continue for several years to provide site-specific information for a detailed safety analysis of the WIPP.

Hydrologic test results to date have been used to make bounding calculations of hypothetical occurrences based upon simplifying assumptions of the physical system. Future measurements obtained from the experimental programs and analysis of the test data will be used to refine the initial bounding calculations and to provide a more detailed description of the physical system and system dynamics. The use of computer models as predictive tools is expected to be closely coordinated with current test results from an established monitoring network. Compatible chemical tracers will be injected directly into the groundwater system as a test of the predictive computer results. Also, the use of chemical tracers during construction phases of the WIPP may provide an early indication of leaky borehole plugs or faulty repository seals, if any, far in advance of radionuclide concentrations in the groundwater system.

6.2 SURFACE WATER HYDROLOGY

The area proposed for the Waste Isolation Pilot Plant (WIPP), located in southeastern Eddy County, New Mexico, lies at an average elevation of 3410 feet above mean sea level (MSL) in the Northern Chihuahuan Desert. Although the area belongs to the drainage basin of the Pecos River, surface drainage patterns at the site are not well defined. Preliminary studies indicated that areal requirements for the surface facilities, underground storage, and safety considerations during the operation of the repository would be as shown in Table 6.2-1 (see also Table 2.1).

6.2.1 Surface Water Features

The Rio Grande Water Resources Region, which includes the Pecos River basin, is an area of 88,968 square miles. The Pecos River basin has a

total drainage area of about 44,535 square miles (approximately 20,500 square miles of which do not contribute to river flow), a maximum basin width of about 130 miles, and an overall length of about 500 miles before combining with the Rio Grande River. The Pecos is generally perennial, except in the reach below Anton Chico and in the reach between Fort Sumner and Roswell, where the low flows percolate into the stream bed. About 60 percent of the annual flow occurs between April and September.

The Pecos River is located west of the site and flows southeast through Carlsbad. At the closest point (river mile 430), the Pecos River is approximately 14 miles west of the WIPP site center. The total drainage area of the river at this location is 19,000 sq. miles. A few small unnamed creeks and draws constitute all tributaries flowing westward of the Pecos River within 20 miles north or south of the site. From the west, the Black River (drainage area of 400 square miles) joins the Pecos at a point approximately 16 miles southwest of the site near river mile 436. The Delaware River (drainage area of 700 square miles) joins the Pecos near river mile 446, and a number of small unnamed creeks and draws join at various points along this reach. Pecos River flow in this reach is regulated by storage in Lake Sumner (river mile 401.9), Lake McMillan (river mile 404.2), Lake Avalon (river mile 407.2) and several other smaller upstream dams that divert water for irrigation. The salient features of the five existing dams on the Pecos River in a reach extending 25 miles upstream and 25 miles downstream of the WIPP site are listed in Table 6.2-2. The approximate slope of the Pecos riverbed in the vicinity of the WIPP site is 4.5 ft/mile (U.S.G.S. Topographic Maps NI 13-11 & NI 13-12).

There are no major lakes or ponds within 10 miles of the WIPP site center. Laguna Gatuna, Laguna Tonto, Laguna Plata and Laguna Toston are lakes located to the north more than 10 miles from the site. All these lakes are at or above elevation 3,450 feet. Therefore, surface runoff from the site would not flow toward any of the lakes to the north. To the west and northwest, Red Lake, Lindsey Lake, Salt Lake, and a few unnamed ponds are located more than 10 miles from the site, between elevations 3,000 and 3,300 feet (U.S.G.S. Topo. Maps, 1:250,000).

Surface water and groundwater withdrawals in the Pecos River basin are listed in Table 6.2-3.

6.2.2 Precipitation Patterns

The nearest station to the WIPP site for which climatological records are available is located at Carlsbad, about 26 miles west of the site, at an elevation of 3,120 feet MSL (U.S. Weather Bureau, 1961). Over a period of more than 71 years (NOAA, 1977), the annual precipitation at Carlsbad ranged from 2.95 inches to 33.94 inches. The average annual precipitation over a period of 30 years (1931-1960) was 12.43 inches (U.S. Weather Bureau, 1961). The average annual precipitation from 1951 to 1974 was 9.78 inches at Artesia (elevation 3320 feet), which is about 48 miles northwest of the WIPP site. At Hobbs (elevation 3615 feet), which is about 44 miles northeast of the site, the average annual precipitation for the period 1951-1974 was 14.29 inches. Interpolation of precipitation data for Carlsbad, Artesia and Hobbs indicates that the average annual precipitation at the site should be approximately 12 inches, which is nearly equal to the average annual precipitation at Carlsbad. Therefore, the precipitation patterns at Carlsbad are assumed to be representative of the conditions at the WIPP site.

Maximum, average, and minimum monthly precipitation at Carlsbad over a period of 30 years (1931-1960) are given in Table 6.2-4. The maximum monthly precipitation, 12.28 inches, occurred in May. With the exception of May and August, when the record minimum monthly precipitation were 0.18 and 0.01 inch, respectively, the record minimum precipitation for all other months has been 0.00 inch. The maximum daily precipitation since 1905 occurred in August, 1916, and was 5.12 inches.

The maximum daily and monthly snowfalls at Carlsbad since 1905 have been 10 inches (December, 1923) and 17.8 inches (February, 1905), respectively (U.S. Weather Bureau, 1961).

In general, summer rain is more abundant than that of other seasons and is caused by thunderstorms generated by the southeasterly circulation of moist air from the Gulf of Mexico. Approximately 75 percent of the total annual precipitation occurs from April through September. Winter rainfall is least abundant and is caused mainly by frontal activity associated with the movement of the Pacific storms across the country from west to east (NOAA, 1977).

6.2.3 Drainage

The site is located between elevations 3,250 and 3,570 feet MSL (Griswold, 1977). General ground slope in the vicinity is approximately 39 feet/mile from the northeast to southwest. Average ground slope from north to south is approximately 13 feet/mile. A topographic and surface water divide (Antelope Ridge) exists approximately 8 miles east of the site center and 4 miles from the exterior boundary of Zone IV (Refer to Table 6.2-1).

In general, the surface in the site vicinity is hummocky and covered by sand dunes. The local slope is poorly defined, and rain collects in pools between sand dunes and evaporates, is transpired, or sinks into the sand. Surface runoff from an area of about 10 sq. miles to the northeast, along with that from the site area, drains through a number of small draws which terminate in unnamed ponds to the southwest. Runoff is typically 0.1 to 0.2 inches annually.

6.2.4 Floods

Historically, floods for the Pecos River are reported to have occurred in 1904, 1905, 1915, 1916, 1919, 1937, 1941, 1942, and 1966 (NOAA, 1977). The earliest flood for which discharge information is available occurred on October 2, 1904, following the failure of Avalon Dam. During this flood, the flow at Avalon gaging station (river mile 406.3) exceeded 90,000 cfs. The corresponding river stage is not available. The river stage at Red Bluff (river mile 459.8) is reported to have reached 28 feet

(gage datum of 2850.05 feet) during this flood. Another major flood occurred on August 7, 1916, when the discharge at Carlsbad Station (river mile 419.1) reached 70,000 cfs.

A third major flood occurred in September, 1919, when the river stage at Malaga gaging station (river mile 432.2) was recorded as 29.4 feet (gage datum of 2895.64 feet). The corresponding discharge was 40,400 cfs. The highest flood of record (through 1976) for the Pecos River occurred on August 23, 1966, when the discharge and stage at Malaga were 120,000 cfs and 42.1 feet, respectively (U.S. Geological Survey, 1976). The minimum surface elevation of the site is more than 310 feet above this maximum historic flood level.

6.2.5 Evaporation and Transpiration

In New Mexico, potential evaporation is much greater than the average annual precipitation. In the southeastern valleys, evaporation from a class A pan is on the order of 110 inches per year. During the warm months, May through October, evaporation in the southeast portion of the state is approximately 73 inches.

The record high temperature at Carlsbad is 112°F (June, 1902). The record low temperature at this station is 7°F (January, 1911). The maximum, average and minimum monthly temperatures at this station over a period of 30 years (1931-1960) are given in Table 6.2-5 (U.S. Weather Bureau, 1961). June, July and August are the warmest (average temperature of 80.7°F) while December and January are the coldest months of the year (average temperature of 44.3°F).

In this type of desert climate, more than 90 percent of all infiltrated water evaporates or transpires. The high rate of evapotranspiration is aided by the frequent winds, the low relative humidity (typically 36 percent during daylight hours), and the high mean annual temperature (61°F).

6.2.6 Infiltration

Soils at the site are generally comprised of sands extending to a depth of as much as 25 feet. Actual sand dunes cover a good portion of the site area. With pervious sand on the surface, infiltration rates are high and probably similar to the 1.6 inch-per-hour intake rate of Harkey Sand Loam (75 percent sand) near Carlsbad (Blaney and Hanson, 1965). Groundwater in the area of the site is more than 50 feet below surface elevations. Because the surface sands are underlain by a caliche layer about 2 to 8 feet thick, percolation of rainfall through the sands to the nearest groundwater would be only a portion of the total infiltration. Most infiltration will return to the atmosphere by evapotranspiration.

6.2.7 Surface Water Quality

Water quality in the Pecos River basin is affected by mineral pollution from natural sources and from irrigation return flows. Springs near the headwaters of the basin below Colonias, New Mexico, are estimated to discharge approximately 707 tons per day of dissolved solids into the Pecos River. Below Lake McMillan, springs flowing into the river are usually submerged and difficult to sample; however, dissolved solids concentrations between 3350 and 4000 ppm have been measured in springs that could be sampled. The chemical quality of these mineral discharges indicates the nonpotable character of the ground water in contributing source beds. Inflow of concentrated brine solutions at Malaga Bend increases the chloride content of the Pecos River by an estimated 370 tons per day (see account by Swenson in Bachman and Johnson, 1973). Time-weighted averages of water quality parameters for three sampling stations on the Pecos River between Carlsbad and Malaga Bend are shown in Table 6.2-6. In general, natural spring flows and irrigation return flows progressively concentrate salts downstream. Further downstream at Red Bluff Reservoir, the water is useable occasionally during high flow periods.

6.3 GROUND WATER HYDROLOGY

Detailed investigations of ground water conditions at the proposed site are being conducted to identify the presence of ground water, to measure ground water quality, and to determine hydraulic conductivity and other characteristics of the stratified rocks. The data will provide a basis for assessment of the continued isolation of the proposed repository from ground water circulation. The thick halite beds of the Salado Formation at the WIPP site are isolated from circulating ground water by beds of low hydraulic conductivity, both above and below the formation. In the vicinity of the proposed site, fresh or potable ground water is not present except in small, isolated, near-surface perched bodies.

Investigations to evaluate the transport of radionuclides by ground water flow in the southeastern New Mexico portion of the Delaware Basin were made by the Water Resources Division of the U.S. Geological Survey for Project Gnome in the late 1950's. Since that time, several studies have been carried out by individual consultants, the U.S. Geological Survey, Oak Ridge National Laboratories, and Sandia Laboratories. These studies have been directed to the specific task of providing a better understanding of the relationship between the proposed waste repository and ground water movement. The following is a description of ground water occurrence and flow as understood from the studies completed to date. Ground water is first described on a regional basis, then the results of site specific studies are reviewed, and, finally, dissolution of salt evaporites is discussed.

6.3.1 Regional Ground Water Conditions

Ground water within the Delaware Basin is predominantly of poor quality, with total dissolved solids concentrations in excess of 3,000 ppm. The only large quantities of potable ground water are found in aquifers west of and along the Pecos River. To the west in the Guadalupe Mountains, many rock units of the basin crop out, and the soluble salts have been leached from the Ochoan evaporites.

Important aquifers of the region are the San Andres Limestone and the Capitan Limestone and related reef limestones. The San Andres is a major source for irrigation waters in the Roswell basin, and other areas to the north and northwest of the site. The Capitan aquifer southwest of the community of Carlsbad is the primary source of municipal water. An important aquifer in the region east of the proposed site is the Ogallala Formation. Unconsolidated alluvium along the Pecos River yields large amounts of relatively fresh ground water in some areas, although it is commonly of marginal quality for drinking purposes.

From the outcrop areas west of the Pecos River, ground water moves eastward. The shallow aquifers, those cut by the Pecos River, discharge to the river, either directly or to alluvium of the river channel. The Capitan aquifer is the oldest permeable formation that may have contact with the river. Ground water in permeable formations older than the Capitan is not directly affected by the river, is present under confined conditions, and migrates eastward into the Delaware Basin.

East of the Pecos River, thick beds of evaporites are present at depth, and brines are common in the underlying permeable formations. Ground water in any of the rock units east of the river in Eddy County is of brackish quality, at best. Fresh meteorically-derived ground water does not flush out the poor quality waters in these aquifers. Consequently, the major utilization of ground water in the central and eastern Delaware Basin is for oil-field flooding. The predominant source of the ground water is the Capitan aquifer.

The shallow aquifers east of the Pecos River are limited in extent, are low yielding, and usually contain water of poor quality. Recharge to these shallow aquifers is presumed to be from precipitation on outcrop areas or from overlying formations, and migration of the water generally follows surface drainage patterns, eventually reaching the Pecos River.

In discussing ground water occurrences in relation to the proposed repository, it is convenient to relate them to the Salado Formation because the Salado and its associated evaporite formations have very low hydraulic conductivities and form a barrier to vertical flow (see Table 9.2.3-1). Aquifers stratigraphically below the Salado are widespread and contain large quantities of brine under confined conditions. Aquifers present above the Salado in the proposed site area are either limited in extent or very low-yielding. This upper ground water is of poor quality (TDS concentrations greater than 3,000 ppm) and occurs under unconfined, as well as confined, conditions.

6.3.2 Hydrology of Rocks Underlying the Salado Formation

The halite beds of the Salado Formation that are proposed for the repository are underlain by thick anhydrite and salt beds of the Castile Formation. They act as an aquiclude, separating the Salado from the underlying sandstones of the Delaware Mountain Group. The sandstones are present at a depth of about 4,200 feet in the site area. The hydraulic conductivity of the sandstones of the Delaware Mountain Group, associated with the relatively high hydraulic conductivity of the shelf-margin facies (the Capitan Limestone) and the shelf facies (which includes the San Andres Limestone) make this group the most important hydrologic system underlying the Salado. The hydrology of these Guadalupian-age rocks has been investigated in detail by Hiss (1975a).

Considerable information derived from hydrocarbon exploration in the basin is available on the hydrologic properties of the formations underlying the Permian evaporites. As reported by Lambert and Mercer (1977), the Delaware Mountain Group is the uppermost of the oil- and gas-producing horizons, which extend to the Ellenburger Group at a depth of about 18,000 feet. Several zones are encountered that contain water, oil, and/or gas that are under sufficient pressure to maintain a potentiometric surface at an elevation above that of the Salado Formation. Some of the zones have sufficient hydraulic conductivity to allow flow rates of several hundred barrels per day. In addition to the

Delaware Mountain Group, the Atoka zone at a depth of about 13,150 feet, and the Strawn (Desmoinesian) zone at about 12,900 feet are other oil and gas production zones that are considered deep aquifers by Lambert and Mercer (1977).

Deep Hydrologic Units. The hydrologic parameters of pre-Guadalupian zones are not as well defined, nor are they as hydrologically significant to the proposed repository as the Guadalupian-age rocks. Nevertheless, a review of them is presented, based primarily on McNeal's (1965) analysis of hydrodynamics of the Permian Basin. He described the potentiometric surfaces of seven zones, using elevations of outcrops where cut by a stream or body of water, static water levels in cable tool holes or water wells, and formation pressures converted to potentiometric surface elevations. McNeal prepared maps showing the regional potentiometric surfaces in terms of fresh water, using density differences of the various brine concentrations and depths of the nearby wells. The three deep hydrologic units reviewed are the Ellenburger Group, the Devonian zone, and the Mississippian- Pennsylvanian zone.

1) Ellenburger Group. The Ellenburger Group consists mainly of chert-bearing limestones and dolomites. It is a widespread unit, covering some 100,000 square miles in southeastern New Mexico and northwestern Texas (McNeal, 1965, Figure 1). The unit is estimated to be 350 feet thick at the proposed site (Lambert and Mercer, 1977) and as much as 1000 feet thick elsewhere in the region. The potentiometric surface compiled by McNeal for the Ellenburger indicates an altitude range from 4,200 feet MSL southwest of the site to less than 1,400 feet MSL in central Texas. In the vicinity of the WIPP site, the ground surface elevation is about 3200 feet MSL. The average gradient of the potentiometric surface is about 8 feet per mile in an easterly direction. Water in the Ellenburger is a brine solution, with a dissolved solids range of 50,000 ppm to more than 200,000 ppm. No water production data are available for this group.

2) Devonian Zone. McNeal's potentiometric surface for the Devonian hydrodynamic zone ranges in altitude from 4,000 feet MSL in the vicinity of the Glass Mountains to 3,200 MSL feet along the Lea County - Texas line. In the Midland Basin, there are nearly hydrostatic conditions at an elevation range of 2,800 to 3,200 feet MSL. A high potentiometric nose extending across southeast Eddy County indicates a potentiometric surface at the proposed site of about 3,700 feet MSL. Salinity of the formation water is less than 50,000 ppm in most of southeast New Mexico. In west Texas, salinity reaches 200,000 ppm in one area.

The Devonian, as inferred from McNeal's potentiometric map, extends throughout southeast New Mexico and northwest Texas. He has included Silurian data in the eastern (Texas) subcrop area. The potentiometric surface generally slopes to the east, and the average gradient appears to be about 7 feet per mile.

3) Mississippian-Pennsylvanian Zone. Mississippian rocks are thin and few data are available on the occurrence of fluids under the Delaware Basin. McNeal (1965) delineated a potentiometric surface for the Mississippian zone of West Texas, but has not extended it into New Mexico.

There are three water-bearing zones in Pennsylvanian age rocks. In ascending order they are the Morrow, the Atoka, and the Strawn (Desmoinesian). Lambert and Mercer (1977, p. III-2) report that the Morrow may be a high pressure, low capacity reservoir with water-production rates ranging from 10 to 20 barrels per day. The Atoka also may be an overpressured reservoir with enough head to yield fluid columns of 3375 to 6552 feet MSL at gradients of 0.47 psi per foot. The water is produced from gas wells at rates ranging from 21.6 barrels per day to as much as 214.4 barrels per day (Texas American's Todd Federal Well No. 1).

Lambert and Mercer (1977) report that several wells have been drill stem tested in the Desmoinesian age Strawn zone and several others have been completed as oil wells. On five drill stem tests, the calculated heads

ranged from 3350 to 6203 feet MSL. Water production was reported to be as much as 416 barrels per day in one drill-stem test, and one well (Phillip's James "E" No. 1) produced an average of 106 barrels per day. A potentiometric surface of the Strawn zone is presented by McNeal (1964, Figure 4), but the only area in the Delaware Basin for which data were available was in the southwestern part of Eddy County. Elevation of levels in that area range from 3,200 feet to 3,800 feet MSL. The gradient is easterly at about 20 feet per mile.

Bone Spring Formation. According to Lambert and Mercer (1977), the Bone Spring Formation (Leonardian Series) can be considered an aquiclude. They report that bottom-hole pressure data from the majority of seven wells tested had insufficient heads to prevent downward movement of shallower water. They suggest the pressure data indicate the formation has a low capacity and contains reservoirs of limited volume.

Guadalupian Age Rocks. The most important aquifers of the Delaware Basin are part of a hydrologic system that incorporates rocks of Guadalupian age. The system comprises three interconnected aquifer groups; the shelf aquifers (including the San Andres Limestone and the Artesia Group), the Capitan aquifer (including primarily the reef deposits - Capitan and Goat Seep Limestones), and the basin aquifers (sands of the Delaware Mountain Group). These aquifers are depositionally juxtaposed, but are distinguished in most areas by contrasting hydraulic conductivities, water salinities, and potentiometric levels. Along the north and northwest interface, hydraulic conductivity of the shelf aquifer, although lower, is near the hydraulic conductivity of the Capitan aquifer. The basin aquifers have the lowest values of hydraulic conductivity, and the Capitan is a discharge point for ground water flows in them. Recharge to these basin aquifers probably occurs in outcrop areas along the west flank of the Delaware Basin. Ground water then moves generally eastward, downdip in the tilted beds. Data on aquifer characteristics, compiled by Hiss (1975a), are summarized in Table 6.3-1. Hydrologic, lithologic, and physical properties of the formations in which these aquifers occur are discussed below.

1) Delaware Mountain Group Aquifer. The Delaware Mountain Group includes, in ascending order, the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations and comprises the basin facies of the system. The combined thickness of these formations ranges from less than 2,000 feet in the southern part of the Delaware Basin to more than 4,000 feet in southwestern Lea and eastern Eddy Counties, New Mexico (Hiss, 1975a).

The Brushy Canyon Formation is as much as 1,000 feet thick and consists chiefly of sandstone with limestone lenses and occasional conglomerate at the base. No wells are known to be extracting water from this formation in Eddy County (Hendrickson and Jones, 1952).

The Cherry Canyon Formation is also as much as 1,000 feet thick and consists of thin-bedded, fine-grained sandstone and some persistent limestone beds. The lower one-fourth of the formation persists as a sandstone tongue striking northwestward into the Guadalupe Mountains which may yield water to some wells and springs in that area (Hendrickson and Jones, 1952).

The Bell Canyon Formation ranges in thickness from 670 to 1,040 feet and consists mainly of sandstone and thin beds of limestone (King, 1948). The formation interfingers to the northwest with the reef limestone of the Capitan Formation, providing the potential hydrologic interconnection of the Guadalupian Age rocks. Large springs near the base of the reef escarpment west of the Pecos River are probably supplied by ground water moving through the upper beds of the Bell Canyon Formation (Hendrickson and Jones, 1952).

An average hydraulic conductivity of 0.016 ft/d (feet per day) and a porosity of 15.65 percent were determined by Hiss (1975a) from analyses of approximately 4,500 samples of rock core cut from the Delaware Mountain Group in Eddy and Lea Counties, New Mexico, and Ward and Winkler Counties, Texas. Hiss also computed a similar hydraulic conductivity from productivity indexes (approximately equivalent to specific

capacities) obtained from an oil company for two wells in the El Mar field located on the boundary between Lea County, New Mexico, and Loving County, Texas.

Hiss (1975a) indicated that similar values of hydraulic conductivity were reported by earlier writers for much of the same part of the Delaware Basin.

Hiss compiled a potentiometric surface map of the Delaware Mountain Group, of which the northern Delaware Basin portion is shown in Figure 6.3-1. The data used by Hiss in compiling the map were taken at different times over a period of about 25 years between the late 1940's and early 1970's. However, he believes the contours are representative of conditions during the period 1960 and 1970. Although some local changes to the potentiometric surface are due to oil and water withdrawals during that period, no data suggest that the regional directional trend has changed. The potentiometric surface data for the brines have been corrected to "fresh-water" density, indicating a potentiometric elevation of 3350 feet MSL in the vicinity of the proposed WIPP site. The hydraulic gradient in the northern portion of the basin dips northeasterly at approximately 15 feet per mile.

Quality of the water in the Delaware Mountain Group is generally poor. An isochlor map compiled by Hiss (1975a, Figure 26) shows a chloride-ion concentration range from 50,000 to 150,000 ppm in the east half of the Delaware Basin. Concentration diminishes to approximately 1,000 ppm southward in the vicinity of the Glass Mountains and northwestward in the vicinity of the Guadalupe Mountains. These are outcrop areas where the Guadalupian Age rocks probably have been recharged by precipitation. However, analyses of water samples taken from the hydrologic system in the vicinity of the repository site indicate that the brine solutions do not contain oxygen and hydrogen isotopes in ratios characteristic of meteoric waters. The relative proportions of O^{18}/O^{16}, and deuterium/hydrogen ratios have probably been altered through interaction with the rock of the formation (Lambert, 1978; see also Chapter 7 of this report).

According to Hiss, recharge to the basin aquifers is through precipitation on the outcrops in the Guadalupe, Delaware, Apache, and Glass Mountains, and from downward leakage through the younger rocks in areas where the overlying soluble Ochoan evaporites have been removed. The potentiometric surface (Figure 6.3-1) indicates water moves north and northeastward, and discharge is to the overlying Capitan and shelf aquifers.

2) Capitan Aquifer. The Capitan Limestone and the underlying Goat Seep Limestone constitute the main body of the Capitan aquifer, which is the reef facies of the Guadalupian rocks. Hiss (1975a) describes the aquifer as a long continuous unit that extends in an arcuate strip along the north and east margins of the basin, with exposures in the Guadalupe and Glass Mountains, as well as the Delaware and Apache Mountains. The thickness of the aquifer ranges from a few hundred to more than 2,000 feet, and the average width is approximately 10 miles (Hiss, 1975a, Figure 11). It is one of the most important aquifers of the region and is a major control in the hydrologic system (Mercer and Orr, 1977).

Relatively few aquifer tests have been performed to measure the hydraulic conductivity of the Capitan aquifer. The data compiled by Hiss (1975a) are summarized in Table 6.3-1. Hiss calculated that the hydraulic conductivity of the Capitan aquifer along the western margin of the Central Basin Platform in Texas and New Mexico ranges from 1 to 25 ft/d and estimated that for most of southern Lea County and for about 15 miles east of the Pecos River valley from Carlsbad it is about 5.0 ft/d. Although Hiss was unable to conduct any aquifer tests in the area west of the Pecos River, he concluded that high production wells, the presence of caverns, and high porosity suggest that the hydraulic conductivity of the Capitan is higher west of the river than east of the river. The hydraulic conductivity is probably very high, as well, in the Glass Mountains, because of numerous small caverns (Hiss, 1975a). The coefficient of transmissivity of the Capitan aquifer along the northern and eastern margins of the Delaware Basin is estimated by Hiss to range from 10,000 ft^2/d (square feet per day) in thick sections to less than 500 ft^2/d in the vicinity of eroded, thin sections of the reef.

The Capitan aquifer receives some recharge by direct infiltration on outcrops in the Guadalupe and Glass Mountains, and probably more by percolation of discharge from the basin and shelf aquifers along the north and east margins of the basin. Water-table conditions exist in the aquifer west of the Pecos River and in the Glass Mountains, but to the north of the Glass Mountains and east of Carlsbad water in the aquifer is confined. Hiss believes that water entering the Capitan aquifer in the Guadalupe Mountains moves northeastward toward Carlsbad where most of the water discharges into the Pecos and Carlsbad Springs. The Pecos River controls the movement of ground water in the Capitan aquifer in the vicinity of Carlsbad, and east to the ground-water divide near the Eddy-Lea County line (figure 6.3-1).

Hiss (1975a) believes that a deep submarine canyon cut into the Capitan Limestone is present near the Eddy-Lea county line, and a hydraulic restriction is formed to constrain the eastward movement of water in the aquifer from the vicinity of the Pecos River. Apparently there is little movement of water between the Pecos River and the Eddy - Lea County line. East of the hydraulic restriction, the potentiometric surface declines with an eastward gradient. Hydrographs of observation wells, established by the U. S. Geological survey in the Capitan aquifer from Carlsbad east and south to the Texas - New Mexico state line have recorded these water level differences. Water levels during the years 1967 through 1972 indicate that from Carlsbad eastward to near the Eddy - Lea County line, the potentiometric surface has remained nearly constant, responding to minor fluctuations of the Pecos River. East of the county line, water levels declined more than 100 feet, at a constant rate, during those 6 years (Hiss, 1975a, Figure 24). The eastward gradient and decline in potentiometric surface are caused primarily by the large withdrawals of water for oil-field water flooding in eastern New Mexico and western Texas (Mercer and Orr, 1977). These withdrawals are apparently the primary discharge from the aquifer at the present time. The similar potentiometric heads and directions of movement of the Capitan and shelf aquifers along the northeast and east sides of the basin (Figure 6.3-1) suggest some discharge from the shelf aquifer also

occurs. In analyzing potentiometric data prior to 1950, when large extractions of water from the Capitan had not developed, Hiss (1975a), concluded that discharge at the time was east, into the shelf aquifers.

Water of good quality, although hard, is available in the Capitan aquifer in the area west of Carlsbad (Hendrickson and Jones, 1952), and apparently in the Glass Mountains. However, in the major portion of the aquifer, east of the Pecos River, quality is poor. Chloride-ion concentration increases from 200 ppm just west of Carlsbad to as much as 23,000 ppm east of the community. Along the east flank of the basin, salinity of Capitan water is significantly lower than that in the adjacent shelf and basin aquifers, ranging from about 1,100 to 5,000 ppm in most wells (Hiss, 1975a, Figure 26).

3) Shelf Aquifers.

The shelf aquifers do not have a direct impact on hydrologic conditions underlying the proposed site because the Capitan aquifer is a hydrologic boundary. Nevertheless, they are in close hydraulic connection with that aquifer, and would apparently accept some discharge from the Capitan, should the extensive pumping from the Capitan be discontinued.

The lowermost unit of the Guadalupian age shelf or "back-reef" facies, known as the San Andres Limestone, extends over much of southeast New Mexico and into northwest Texas. The average thickness of the unit is about 1500 feet. Overlying the San Andres are formations of the Artesia Group. Strata in these formations that yield significant quantities of water are the shelf aquifers. The contact between the Capitan and shelf aquifers is gradational and difficult to differentiate in some areas. In the Pecos River Valley between Carlsbad and Roswell, and to the west of that area, the shelf aquifers are quite porous and yield large quantities of potable water to wells (Hendrickson and Jones 1952). The hydraulic conductivity of the aquifers east of the river and in the Central Basin Platform are significantly less than those to the west, and water quality is poor (Hiss, 1975a).

Measurements of hydraulic conductivity and porosity of core samples of the shelf aquifers were collected by Hiss (1975a) and the data are summarized in Table 6.3-1. It can be seen that the hydraulic conductivities in this area are at least one order of magnitude less than hydraulic conductivities of the Capitan aquifer. Potentiometric levels of the shelf aquifer, shown on Figure 6.3-1, are similar to those of the Capitan aquifer along the east side of the Delaware Basin. In the vicinity of Carlsbad, however, the levels are as much as 200 feet higher than those of the Capitan, suggesting poor interconnection between aquifers in that area.

The major areas of recharge to the shelf aquifers are probably north and west of Carlsbad in the Guadalupe mountains and areas west of the Roswell basin. Water in the shelf aquifers to the north moves either southwestward to the Pecos River, or southeastward onto the Central Basin Platform. Water quality in the shelf aquifers varies considerably from one area to another, but is generally poor east of the Pecos River. Chloride-ion concentrations in excess of 150,000 ppm are indicated by Hiss (1975a, Figure 26) north of the Capitan aquifer and along the east flank of the Delaware Basin. However, a narrow band of better quality water (salinity less than 10,000 ppm) in the San Andres Limestone is indicated to the northeast, between the shelf and the Central Basin Platform.

Castile Formation. The Castile Formation overlies the Delaware Mountain Group and consists predominantly of anhydrite with halite interbeds, and subordinate limestone. Its thickness ranges from 1,300 to 2,000 feet over most of the Delaware Basin. In most of the basin hydraulic conductivity of the Castile is very low so that this formation acts as a confining layer for the underlying Delaware Mountain Group (Mercer and Orr, 1977). However, west of the Pecos River, the salt beds have been removed, hydraulic conductivity of the residuum is higher and water is available to wells (Bjorklund and Motts, 1959).

In the central Delaware Basin, isolated pockets of brine and associated hydrogen-sulfide gas have been encountered by various oil companies in

the Castile, and also in the Sandia Laboratories exploratory hole, ERDA-6 (Mercer and Orr, 1977). High-pressured brines encountered in three oil wells east of the proposed site reportedly have had flow rates as high as 20,000 barrels per day. These brines are present near the top of the formation, suggesting a brine zone, but since no other wells have encountered brines, the zone is apparently not continuous (Rose, 1977). Brine from ERDA-6 further suggests a long isolation time on the order of one million years for that pocket (Barr, Lambert and Carter, 1978).

Salado Formation. Massive beds of halite of the Salado Formation are the intended host rock for the WIPP repository. The formation extends more than 100 miles both north and east of the Delaware Basin and underlies an area of approximately 25,000 square miles (Pierce and Rich, 1962). Formation thickness in the Los Medanos area is 1,976 feet, as measured at ERDA-9, and the depth to the top is 848 feet.

Porosity of the halite is very low and interconnected pores are virtually non-existent. Lack of open fractures is assured because of the high plasticity of the material. As a result, hydraulic conductivity of the beds is effectively zero. As reported by C. L. Jones (1973), microscopic to very small angular cavities in grains of halite contain very minor amounts of brine and gas. Less common are much larger cavities or pockets in the halite beds that contain halite-saturated brine and nitrogenous gas confined under pressure sufficient to produce a "blow-out" when encountered during drilling. Nevertheless, the brine pockets do not appear to be interconnected, but seem to be isolated fluid bodies within the rock.

Because halite is quite soluble, it would readily dissolve if the beds came in contact with circulating, unsaturated solutions. West of the proposed site, where the Salado rises to the surface, progressively less halite is present as a result of leaching by percolating ground water. Where exposures existed, all of the salt has been removed (see Section 4.3.2.).

As discussed in Section 4.3.2., removal of salt from the Salado Formation in the western portion of the basin where it is exposed, or near the surface, has formed a residuum of clay, gypsum and sand. In the Carlsbad area along the Pecos River and to the west, Bjorklund and Motts (1959) report that these clays are dense, and are referred to as "red beds". They suggested that the residue has slowed ground-water infiltration and subsequent salt removal.

Underlying Nash Draw, a salt dissolution zone is present in the residuum at the contact between the Salado and the overlying Rustler Formation. As reported by Mercer and Orr (1977), the dissolution zone extends from the recharge area north of Nash Draw to its termination in the vicinity of Malaga Bend. Water penetrates the overlying units through fractures and solution zones in the recharge area and moves southward along the top salt, and discharges into the Pecos River at Malaga Bend (Figure 6.3-2). The dissolved solids content of the brine at the river has been reported to be in excess of 300,000 ppm. Theis and Sayre (1942) calculated the discharge from the brine aquifer into the Pecos River at Malaga Bend to be about 200 gpm. Hale (in Hale, Hughes, and Cox, 1954) calculated a value of transmissivity of 8,000 ft^2/d from aquifer tests in the area between Malaga Bend and Laguna Grande de la Sal. Apparently, as salt has been progressively leached from the overlying beds, the residuum has developed a base of low hydraulic conductivity, preventing further downward leaching, and the dissolution zone has developed along the same structural control as Nash Draw (Robinson and Lang, 1938).

6.3.3 Hydrology of Rocks Overlying the Salado Formation

Nearly all of the water bearing formations overlying the Salado in the Delaware Basin are of materials with low hydraulic conductivity and which contain limited amounts of poor-quality water. The major hydrologic unit in the area that yields moderate quantities of marginal-quality water to wells is the alluvium of the Pecos River valley. Information on the hydraulic characteristics of these water bearing formations is limited, and only regional descriptions of potentiometric levels and hydraulic conductivity can be established.

Rustler Formation The Rustler Formation extends laterally beyond the limits of the Salado Formation and consists of interbedded anhydrite, dolomite, siltstones, clays, and halite. Two dolomite beds in the formation are water-bearing units, other than the Rustler-Salado contact, discussed above. The thickness of the dolomite beds ranges from 20 to 30 feet; these beds are areally extensive. The Magenta Dolomite is a finely crystalline, dense dolomite, and the Culebra Dolomite is vuggy and commonly associated with some anhydrite. The Magenta transmits only minor amounts of water and is not considered an important aquifer (Lambert and Mercer, 1977).

Although the Culebra Dolomite is areally persistent, yields of water vary considerably from place to place. Cooper and Glanzman (1971) suggested that the variability of yields is related to the size and number of fractures and openings in the dolomite, which in turn, could be related to its depth. In the northern part of Nash Draw, the dolomite is near the surface and is reported to yield as much as 700 gpm. East of Nash Draw, where the dolomite is covered with Triassic and younger rocks, yields are typically at least two orders of magnitude less.

Measurements of the hydraulic properties of the Culebra in the region are scarce, primarily originating from studies related to Project Gnome investigations (Cooper and Glanzman, 1971). Aquifer-performance tests in holes drilled for Project Gnome studies indicate a transmissivity of 460 ft^2/d, an average hydraulic conductivity of 16 ft/d, a storage coefficient of about 10^{-4}, and an average effective porosity of 10 percent.

Mercer and Orr (1977) prepared a map of the potentiometric surface from water levels measured in wells open to the Rustler Formation in the north portion of the Delaware Basin (Figure 6.3-2). The data were taken from several sources and represent a composite of the Culebra and Magenta dolomites, or other zones. However, it is believed that most wells are open to the Culebra dolomite bed because it is the most consistently producing rock in the vicinity.

These data indicate that water in the Rustler Formation moves west and southwestward across the Lea - Eddy County line, and southeastward from the community of Carlsbad toward Nash Draw, and the Pecos River to the south. Only the Magenta is exposed locally on the flanks of Nash Draw, and both the Culebra and the Magenta form the floor of wide sections of Nash Draw in the vicinity of Laguna Grande de la Sal.

A single water well in Lea County is reportedly deep enough to have reached Permian beds (Nicholson and Clebsch, 1961); otherwise no additional information is available on occurrence of water in the Rustler Formation in the area.

The Dewey Lake Redbeds. The youngest formation in the Ochoan Series, the Dewey Lake Redbeds, consists of orange-red siltstone with some mudstone and sandstone. This formation has been removed from the western and southern parts of the Delaware Basin by post-Permian erosion but is present in the subsurface throughout most of the site area. The thickness of the formation varies from about 200 feet to as much as 600 feet (Hiss, 1975a).

The Dewey Lake Redbeds are not an aquifer, although some permeable sand lenses are present and yield small quantities of water to a few wells. Regionally, the beds act as an aquiclude, restricting water at the surface from percolating downward to more permeable units in the underlying Rustler Formation.

Dockum Group. The Dockum Group consists of three formations. In ascending order, they are, 1) the Tecovas Formation, which consists of up to 300 feet of red shale, siltstone, and fine-grained sandstone, 2) the Santa Rosa Sandstone, which is composed of 100 to 650 feet of red, brown, and gray sandstone, and 3) the Chinle Formation equivalent, which consists of up to 1,300 feet of red, maroon, and purple shales and siltstones with lenses of fine-grained red-to-gray sandstone (Hiss, 1975a). The group is present only as a thin wedge in Eddy County, thickening to the east in Lea County and in Texas.

Both the Chinle Formation equilvalent and the Tecovas Formation are present only as thin, isolated remnants in southeastern New Mexico, primarily in Lea County. The few wells drilled into these formations yield small quantities of poor-quality water (Hiss, 1975a). In contrast, the Tecovas and Chinle are not considered aquifers in the Delaware Basin. The Santa Rosa Sandstone is a principal aquifer in several areas, particularly in Winkler and Ward Counties, Texas (Hiss, 1975a). It produces both fresh and saline water, depending on location. The westernmost extent of the Santa Rosa Sandstone is just into Eddy County, as shown in Figure 6.3-3. Water levels in wells open to the Santa Rosa Sandstone, reported by several sources, are the basis of the potentiometric surface by Mercer and Orr (1977) shown in Figure 6.3-3. Wells completed in the Santa Rosa Sandstone have low yields with specific capacities of 0.14-0.2 gpm per foot of drawdown (Nicholson and Clebsch, 1961); the formation porosity is about 13 percent.

Ground water recharge to the Santa Rosa Formation is from precipitation on the outcrop and percolation through sand dunes and the overlying Ogallala Formation to the east (Nicholson and Clebsch, 1961). Movement is generally southwest, but additional recharge apparently occurs along the potentiometric high that trends southwest along the eastern side of Eddy County. Discharge is to underlying formations at the edge of outcrops and reportedly downward through collapse zones such as San Simon Swale.

Ogallala Formation. The High Plains (Llano Estacado) region south of the Canadian River is mantled by the Ogallala Formation, which consists of Pleistocene sediments from 0 to 500 feet thick. South of Mescalero Ridge in Lea County the formation becomes discontinuous, and there are no definite remnants of the Ogallala west of easternmost Eddy County. Recharge to the Ogallala is by direct precipitation on the outcrop and by percolation through overlying sand dunes and alluvium. Nicholson and Clebsch (1961) reported that the saturated thickness of the Ogallala ranges from 25 to 175 feet. This variability can be attributed to the very irregular Triassic surface that underlies it. Movement of water in

the Ogallala is controlled to a great extent by the generally southeastward slope of the underlying Triassic red beds (Mercer and Orr, 1977).

Quaternary Deposits The Gatuna Formation is the oldest known Quaternary formation in the area and fills channels and steep-walled valleys cut primarily into the Dewey Lake red beds and Rustler Formation. In the type section and in the vicinity of Nash Draw where the Gatuna is readily recognizable, it is overlain by an extensive caliche zone that marks the Mescalero surface (Bachman, 1974). East of Nash Draw, there are few outcrops of the formation.

The Gatuna Formation yields limited amounts of water to wells where the water is in isolated gravel and sand lenses. Yields of one to five gpm are small but are usually sufficient for stock and domestic use. Ground water from the Gatuna probably percolates downward into Triassic sandstone or the Rustler Formation (Mercer and Orr, 1977).

Younger quaternary deposits are represented by alluvium. The most extensive alluvial deposits are along the west side of the Pecos River north of Malaga. Isolated patches of alluvium, however, occur along the Pecos to the south. In some areas the thickness is nearly 300 feet, and yields are reported to be as much as 3,000 gpm (Hendrickson and Jones, 1952). The source of water is primarily underflow from west of the Pecos River augmented by leakage from canals and from irrigation return flow.

Alluvium east of the Pecos River is restricted to relatively small closed depressions. Nash Draw and Clayton Basin contain Quaternary alluvium, and, in places such as Laguna Grande de la Sal, contain lake or playa deposits. The thickest alluvial deposits occur within San Simon Swale where they are in excess of 500 feet. Ground water present in the San Simon alluvium may be derived from discharge from the Santa Rosa Sandstone (Mercer and Orr, 1977). The lake and playa deposits often yield some water, although it is generally highly mineralized.

6.3.4 Regional Ground Water Use

Ground water is used in the region for irrigation, municipal supplies, rural domestic supplies, stock watering, a few industrial purposes, and for secondary oil recovery (usually referred to as "oil field flooding"). In southeastern New Mexico and western Texas almost all the ground water produced is used for this latter category. The Capitan aquifer is the largest source, but supplies are also taken from the Santa Rosa Sandstone and the Rustler Formation (Hiss, 1975a).

Demand for water throughout the region has increased steadily over the past three decades and is expected to continue into the 1980's. Production from the Capitan aquifer alone increased from approximately 80,000 acre-feet in 1950 to about 700,000 acre-feet in 1970 (Hiss, 1975a, Figure 38). The increase has been fairly linear over the 20 year period. Most of the increased demand has been for oil-field flooding which began in the early 1950's. The largest amount of pumping for this purpose is in Ward and Winkler Counties, Texas, and is primarily extracted from the Capitan aquifer. The other major source is the San Andres Limestone. According to Hiss (1975a), the cumulative total of water produced from these aquifers for the period 1920-1969, in thousands of acre-feet, is as follows:

	Eddy County	Lea County	West Texas	Total
Industrial	65.4	-	-	65.4
Irrigation	151.0	-	223.7	374.7
Municipal	162.0	-	-	162.0
Secondary Recovery	0.6	2.8	293.0	296.4
TOTAL	379.0	2.8	516.7	898.5

Listed below (in acre-feet) is a summary of usage in Eddy County for the year 1949 (Hendrikson and Jones, 1952) and in Lea County for the year 1954 (Nicholson and Clebsch, 1961). It is reasonable to assume that the quantities reported for industrial, irrigation, municipal, and rural use

have increased a moderate amount. The quantity listed for secondary recovery has increased moderately in southeastern New Mexico and dramatically in west Texas, as noted above.

	Eddy County (1949)	Lea County (1954)
Industrial	4,000	2,710
Irrigation	130,000	2,600
Secondary Recovery	0	40
Rural Domestic/Stock	2,000	450
TOTAL	141,000	6,350

Occurrence of large quantities of potable ground water is restricted to west of the Pecos River, and most of this water is extracted from the Capitan aquifer. Hiss (1975a) reported that the municipal water supplies for the communities of Carlsbad and White's City are obtained from wells completed in the Capitan aquifer. Hiss also reported that water pumped from the Capitan aquifer is used to irrigate about 2,300 acres of farmland in the Pecos River valley, the immediate vicinity of Carlsbad.

In addition, water pumped from the Capitan aquifer at Carlsbad is transported by pipeline to a potash refining plant located about 18 miles east of Carlsbad. Approximately 3,740 acre-feet of water per year was used to refine potash ore during the period 1965-1969.

Oil Field Secondary Recovery. In the early 1950's, the petroleum companies operating in the region initiated a process to recover crude oil that could no longer move to wells under existing reservoir pressure. This secondary recovery technique is one in which water is injected under pressure into the oil-bearing formation to drive the residual oil to the pumping wells. Injection may be into existing depleted wells or into wells constructed specifically for this purpose.

According to Hiss (1975a, Table 15), a cumulative total of nearly 300,000 acre-feet of water has been produced from the Capitan aquifer for

secondary recovery versus a total of about 725,000 acre-feet actually used in the flooding process. The difference of 425,000 acre-feet has been supplied from other sources including the San Andres Limestone and the Ogallala and Rustler Formations. The major areas of extraction for this use are in Ward and Winkler Counties, Texas.

Ground Water Utilization East of the Pecos River, Southeast New Mexico. In this area, small amounts of ground water are used for rural domestic supplies, stock watering, gasoline plants, and gas stripping. The Rustler Formation, the Santa Rosa Sandstone, and the Artesia Group are the principal hydrologic units pumped for those purposes. In the Nash Draw area, relatively large quantities of ground water have been taken from the Rustler Formation for use in potash refining. In the past, considerable amounts were pumped for irrigation in Lea County, but this has apparently been discontinued (Nicholson and Clebsch, 1961).

Gasoline plants use a considerable amount of water for their cooling and boiler systems. Nicholson and Clebsch (1961) report that in Lea County a total of 2400 acre-feet of ground water was used for this purpose in 1959. Gas stripping plants in the area also use water for extracting hydrogen sulfide and carbon dioxide from residual gas. Nicholson and Clebsch (1961) estimated that 150 acre-feet per year is used for this purpose.

In 1972, Cooley (1973, Table 4) inventoried the existing and abandoned wells in a nine-township block in east-central Eddy and west-central Lea Counties, New Mexico. Most of these wells are of low yields and are used mainly for domestic supplies and stock watering. Table 6.3-2 is extracted from the Cooley survey; well locations are shown on Figure 6.3-4.

6.3.5 Ground-Water Occurrence at the Proposed Site

The wells in the vicinity of the site (Figure 6.3-4) indicate that ground water above the Salado Formation is found only in limited quantities, and

is commonly of such poor quality, that it is not usable. Where the quality is marginal, it is utilized for watering stock, and is considered a valuable resource (Nicholson and Clebsch, 1961). Below the Castile Formation, at considerable depth, the Bell Canyon Formation might yield large quantities of water, but it would be brine. Although these units are technically regarded as aquifers, in the following discussion, only the hydrologic characteristics of fluid-bearing zones underlying the proposed site will be described. These zones are not identified as aquifers because an aquifer readily yields good quality water to wells.

Fluid-bearing Zones. The hydrologic exploration at the proposed site performed by the U. S. Geological Survey to date has been directed primarily to the fluid-bearing rocks of the Rustler Formation, and to the Rustler-Salado contact zone. They directly overlie the Salado salt and furnish a potential, although remote avenue for salt dissolution and radionuclide transport (Mercer and Orr, 1978). Additionally, brines in the sands of the underlying Bell Canyon Formation have been tested. These fluids are under sufficient head to allow them to reach the Salado salt. Because the brines are undersaturated, they could dissolve the salt. However, to reach the Salado, these fluids would have to first penetrate the Castile Formation. Permeabilities (or lack of permeability) of the Castile and Salado Formations at the site have been determined by drill-stem tests in two exploratory holes: ERDA No. 9 and AEC No. 8. The tests, summarized by Lambert and Mercer, 1977, Tables 1 and 2, indicate that the two formations are extremely tight. The tests gave no indication of fluid content in either formation.

Other zones that were briefly tested include zones in the Dewey Lake red beds where circulation was lost during drilling, or where hydraulic conductivity was believed to be measurable. However, no appreciable amounts of fluid were encountered (Mercer and Orr, 1978).

When the exploration and testing were completed, Mercer and Orr (1978) made several conclusions concerning the occurrence of fluids in the rocks. These include the following:

Monitoring of fluid-bearing zones in the Rustler Formation indicate that stabilized heads decrease with depth; consequently, potential fluid movement would be downward in rocks above the salt. However, the large head differences between fluid-bearing units within the Rustler indicate little or no vertical connection.

Head distribution determined for the Culebra dolomite indicates fluid movement to the southeast across the site. Gradients range from 7 to 120 ft/mi and vary as a function of hydraulic conductivity.

Head distribution within the Magenta dolomite has been determined only in three holes and indicates fluid movement to the southwest. The hydraulic gradient is 50 ft/mi.

Fluids in the Culebra and Magenta are expected to move primarily along fracture systems, and measurements of the effective porosities and hydraulic conductivities in low-yielding fractured rocks are very difficult to obtain.

Brines were found at some locations along the Rustler-Salado contact, but extremely low yields were measured.

Although evaluation of the testing of Bell Canyon sands is not complete, preliminary results at AEC-8 indicate the potentiometric surface, corrected to fresh-water density, is higher than similarily corrected levels of fluid zones in the Rustler Formation.

Hydrologic Testing. The geologic and geophysical exploration performed at the site provides a detailed understanding of the stratigraphy and structure of the underlying formations. This work was described in previous sections. In coordination with the exploratory drilling, a program of hydrologic testing and monitoring was established. As a result, considerable data on the occurrence of ground water have been collected. The ground-water studies are continuing and the data collected will further our understanding of the site conditions.

In addition to continued monitoring of the existing observation wells, long-term pumping tests to measure vertical connection between zones, and other tests have been planned. Also, some hydrologic information is available from the recently completed ERDA 10 test hole, located approximately 8.5 miles southwest of the proposed site.

One of the major problems faced in this program is the difficulty of measuring hydrologic parameters in materials of extremely low hydraulic conductivity in the field. Thorough testing of even the more permeable zones, such as the Culebra Dolomite, requires long periods of time, as well as close control of the interval being tested. To collect a sufficient quantity of water from these materials for proper water quality sampling requires long periods of time. Recovery of water levels in observation wells to static conditions is very slow; levels in some of the wells on site had not stabilized after more than 12 months of monitoring. Nevertheless, the data collected are sufficient to provide a good measure of the hydraulic characteristics and an understanding of ground-water occurrence at the proposed site. Hydrologic test data as of August, 1978, are available from 9 exploratory holes within the proposed land withdrawal boundary, and from the hole designated AEC 8, which is just outside the boundary, as shown on Figure 6.3-5. The U. S. Geological Survey Water Resources Division has been directing the testing program. A summary of drilling and testing operations is given for each hole in Section 6.4. A full description of the testing program and the data collected is presented in Mercer and Orr, 1978. The following discussion is extracted from that report.

The objectives of the program have been to determine the static head or reservoir pressure, the water-yielding potential (i.e., hydraulic conductivity and transmissivity) of the rock strata, and the chemistry of formation waters. These hydrologic tests are made in the exploratory test holes both during drilling and after the hole has been drilled to total depth.

Five of the test holes were specifically designed for hydrologic testing (H-1, H-2 complex, and H-3); the others were drilled for other purposes as well (potash mineral evaluation and/or geologic exploration) but were adapted for hydrologic testing. After drilling and testing wells H-1 and H-3, triangular arrays H-4, H-5, and H-6 complexes were designed similar to the H-2 complex but with a 100-foot well spacing. The additional sets of triangular arrays (H-4, H-5, and H-6) have been completed recently and testing has started.

The H-series test holes were drilled with air and detergent to avoid the undesirable mudcake that occurs when drilling with gel. This method also allows detection of fluid-producing zones that are encountered during drilling. When detected, some of these zones were tested before completion of drilling for a preliminary estimate of yield. On completion of drilling, geophysical logging was performed in all holes. These logs provided detailed information on lithologic changes, formational characterstics, potential zones of water yield, and borehole diameter changes. These data are used to select intervals to be tested, as well as provide information on hole conditions in the selection of packer seats.

Following logging, each potential zone of water yield was isolated with packers, and a drill-stem test (DST) was conducted. The DST is a temporary well completion designed to furnish hydrologic data, such as representative samples of formation fluid, undisturbed formation pressures, and indications of the formation permeablity, and/or transmissivity. The standard DST, as used in oil-field exploration, was run in test holes AEC 8 and ERDA 9, but in the other tests the procedures were modified. The modification most commonly made was in the method of recording formation pressures. In the standard DST, pressures are recorded throughout the test by a Bourdon-tube pressure recording gage (pressure bomb) located near the bottom of the drill string. Data from this pressure bomb cannot be retrieved until after completion of the test. In the modification DST used in these investigations, the fluid was initially removed from the tubing, and the stabilizing fluid levels

were measured in the drill string. This modification allowed for continuous monitoring throughout the test. Additionally, pressure-monitoring devices were placed above and below packers to determine the degree of isolation of the zone from the rest of the borehole.

The test zones were bailed or swabbed until temperature, conductivity, and density of fluid in the casing stabilized to assure that the fluid was representative of formation fluid. Samples were then collected, treated according to standard U. S. Geological Survey techniques, and chemically analyzed for the major and trace elements and for radiochemistry. Results of these analyses are listed in Table 6.3-3. The geochemistry of these fluids is discussed in Chapter 7.

During the bailing, the volume and rate of fluid withdrawal were monitored. The rate of recovery following withdrawal was measured, and yields from test zones were then calculated. The results of these tests are summarized in Table 6.3-4.

After all potential water zones were tested in the open hole, casing was installed and grouted in all holes except ERDA 9. Selected intervals were perforated for monitoring potentiometric levels, and provision was made for long-term hydrologic testing. Radioactive tracer tests were conducted in some of the holes after they had been cased and perforated to examine the cement-bond for leaks between casing and the borehole wall. These tests also yielded some information on vertical distribution of permeability across the test interval. The perforated zones were then tested for yield by bailing or swabbing, as was done in the open hole, and results are summarized in Table 6.3-4.

When the testing of the cased holes was completed, the holes were prepared as multiple observation wells. The holes are used to monitor potentiometric levels of two separate zones with the use of packers and inner tubing. In some wells, a third zone was perforated, but a bridge plug was set above it, and the zone is not available for periodic

monitoring. Figure 6.3-6 illustrates the method of completing the wells, and Table 6.3-5 indicates the zones monitored at each observation well.

Periodic monitoring of the fluid levels in the wells began after completion of testing. Because of the low yield of the zones tested, considerable time is required after bailing for the recovery of fluid to reach a stabilized level. Most levels had stabilized by October 1977, as indicated in Table 6.3-6. These levels provide a measure of the potentiometric surfaces of the monitored zones, and an indication of hydraulic gradients.

Bell Canyon Formation. During the WIPP hydrologic testing program, cores were taken in the Bell Canyon Formation in exploratory hole AEC 8. Analyses of these cores indicated the presence of two sandstone units whose permeabilities were higher than those of the surrounding rocks. These units are referred to as the lower sand and upper sand; their depths are, respectively, 4,844 to 4,860 feet, and 4,821 to 4,827 feet.

Hydrologic testing of the two sand units was made only in cased, perforated zones. There was no open-hole testing. These tests included formation pressure testing, fluid level monitoring, aquifer yields, recovery rates, water sampling, and geophysical logs. Radioactive tracer logs were also run on this hole. Analysis of the data had not been completed at the time of the report by Mercer and Orr (1978).

After the fluid in the casing had been removed by swabbing to a depth of approximately 4,200 feet, the lower sand yielded 31 gallons of fluid in 166 minutes (average 0.2 gpm), recovering to a depth of 4,095 feet. The zone was then shut-in, and a static formation pressure of 2,037 lbs/in^2 was reached in 44-1/2 hrs. The upper sand was not tested for yield. Static formation pressure was 2,044 lbs/in^2 after 57 hours.

Samples collected from the two sand units indicate that these units contain dense brines. For example, the upper sand contains 189,000 ppm of total dissolved solids, 175,000 ppm of which is sodium chloride

(Mercer and Orr, 1978, p. 80). The major constituents from the analyses are listed in Table 6.3-3. Density of the brines of each zone was determined to be 1.11 gm/cm^3 for the upper sand, and 1.12 gm/cm^3 for the lower sand. These values were used to correct static heads to fresh-water equivalents (Table 6.3-6).

Rustler-Salado Contact. The contact zone between the Rustler and Salado Formations was tested in holes H-1, H-2c, H-3, P-14, P-15, P-17, and P-18.

Both open-hole and cased-hole tests were run on the Rustler-Salado contact in H-1 and H-3, and cased hole tests were run in H-2c, P-14, P-15, P-17, and P-18. Without exception, all tests showed very low yields, typically producing a few gallons per day in the cased holes and only slightly more in the open holes (Table 6.3-4). A yield of 9.1 gallons in a 20-hour period (in H-1) was the highest yield recorded. Based on the collected data, Mercer and Orr (1978, p. 83) calculated transmissivities from the yield data, ranging from 10^{-1} ft^2/day (in P-14) to 10^{-4} ft^2/day (in P-18). Recovery rates in the monitoring wells are so slow that the level had not stabilized in P-18, after 4 months (Table 6.3-6).

Samples were taken from all of the test wells except P-18. Analyses of these samples show that the fluid in the Rustler-Salado contact zone is a saturated brine containing more than 300,000 ppm total dissolved solids (Table 6.3-3).

Culebra Dolomite. The Culebra dolomite was tested in holes H-1, H-2b, H-2c, H-3, P-14, P-15, P-17, and P-18. Logs of these holes indicate that the thickness of this unit is about 28 feet and that its depth ranges from 410 to 940 feet below ground level.

Both open-hole and cased-hole tests were run in the Culebra in H-1 and H-3, and cased hole tests were run in H-2c, P-14, P-15, P-17, and P-18. Yields varied considerably. At P-14, 720 gallons of fluid were bailed with no noticable drawdown, while P-18 produced only 16 gallons of fluid

in 33 days of monitoring. Preliminary transmissivity values calculated by Mercer and Orr (1978) also reflect the variability with values of 140 ft^2/day at P-14, 10^{-1} ft^2/day at H-1, and 10^{-4} ft^2/day at P-18.

Mercer and Orr (1978) reported that fluids in the Culebra have a total dissolved solid range of 23,700 to 118,300 ppm, and a sodium chloride range of 17,900 to 89,200 ppm. The major constituents of samples taken from the Culebra are listed in Table 6.3-3.

Magenta Dolomite. The Magenta Dolomite was tested only in H-1, H-2a, and H-3. In these holes the Magenta is 25 feet thick and the top of the unit is 502 feet below ground level.

Both open-hole and cased-hole modified drill stem tests were run on the Magenta in H-1 and H-3; well number H-2a was constructed as an observation well for the Magenta. The open-hole drill-stem test on the Magenta in H-1 produced only 13 gallons of fluid in 13 hours. A subsequent swabbing of the permeable zone produced 107 gallons of fluid, which indicated higher productivity than the DST displayed. In the cased-hole test, the Magenta zone was bailed constantly until a pumping level of 424 feet (depth) was attained. After bailing was stopped, the fluid level recovered to a depth of 340 feet in 33 days. In H-3, an open hole drill-stem test produced 23 gallons of fluid in 38 hours, but 442 gallons were swabbed from the hole after the DST was discontinued. In the cased hole test, 1 hour of bailing produced 6 feet of drawdown, and recovery was from 405 to 401 feet in 33 days of monitoring. Preliminary transmissivity values computed by Mercer and Orr (1978) range from 40 ft^2/d to less than 1 ft^2/d.

The quality of the Magenta fluids is poor (Table 6.3-3), with a total dissolved solids range of 10,300 to 29,700 ppm. The sodium chloride range is from 6800 to 24,300 ppm.

Salt-Residue Zone. Rocks of the Rustler Formation in which halite beds have been removed by leaching--salt-residue zones--were considered to be

areas for possible fluid retention. A potential zone was identified from geophysical logging and drill stem tests performed in H-1 and H-3. Results show that very little fluid now exists in those zones. In H-1, the suspected zone yielded 11.2 gallons of fluid in 12 hours of monitoring.

6.3.6 Dissolution of Salt in the Permian Evaporites

Features apparently caused by solution and/or subsidence are common in southeastern New Mexico. The extensive karst plain of the Llano Estacado (the High Plains or Caprock region) indicate the prominence or rock solution as a geologic process. Depressions near the WIPP site range from small features no more than a few meters in diameter to large features such as Laguna Grande de la Sal (Salt Lake), 11 miles to the west-southwest of the WIPP site, and Laguna Plata and Laguna Gatuna, 14 miles to the north. Not all depressions in the region, however, have been formed by solution and collapse. Some have been formed by wind action, and others are the result of solution or etching of the caliche. Salt Lake does appear to occupy an area of coalesced collapse dissolution sinks, but Laguna Plata and Laguna Gatuna appear to have formed as solution blowouts in windborne sand deposits.

A report to Sandia Laboratories by R. Y. Anderson was prepared in early 1978. This report served to assemble and summarize available data regarding the dissolution of evaporites in the Delaware Basin. The Anderson (1978) report also proposed a set of working hypotheses for the origin of various dissolution features, in order to guide future Sandia investigations of evaporite dissolution relevant to the potential integrity of the WIPP horizons and adjacent evaporites. In the text that follows, an attempt is made to distinguish available data from working hypothesis, whenever Anderson (1978) is cited.

It has been estimated that as much as 50 percent of the original salt of the Delaware Basin evaporites has been removed (Anderson, 1978) either by surface erosion or by subsurface dissolution and transport by ground

water. These processes have been in progress intermittently through more than 100 million years (Bachman, 1974). At least four erosional periods, in which the removal of salt could have been accomplished, can be recognized. These include: 1) Early Triassic time, 2) Jurassic through Early Cretaceous time, 3) a Late Cretaceous through mid-Tertiary period, and 4) post-Ogallala uplift and erosion.

Of the processes which accomplished the removal, two types of salt dissolution have been recognized in the Delaware Basin. The more familiar dissolution is the removal of salt by waters percolating downward from above (primarily from precipitation falling directly on the ground surface above the salt). The percolating water removes soluble salts, leaving behind a residuum of insoluble material that is referred to as a leached zone (Vine, 1963). The shallow dissolution beneath Nash Draw is such a zone and is apparently the route of lateral migration of the leached salts that discharge into the Pecos River.

A second type of salt dissolution has been recognized as having dissolved salt from somewhere within the body of evaporites, generally resulting in the collapse and lowering of the overlying stratigraphic units. Anderson (1978) recognized the resulting insoluble residue as a blanket dissolution breccia which occurs to the west of the present salt edge in the basin. In addition, deep dissolution phenomena within the evaporites may have developed more localized collapse features that have been recognized around the margin of the basin and within the basin (Maley and Huffington, 1953). The origin of these deep dissolution features and breccias is more problematical than the origin of surface dissolution and the rates of dissolution more difficult to assess. Source of the water to dissolve the salt is hypothetically assumed to be aquifers underlying the salt beds, communicating through fracture systems in the intervening anhydrite beds.

<u>Shallow Dissolution</u>. The depth of shallow dissolution in the evaporites (base of leached zone) is highly irregular, but is usually less than 300 feet in the vicinity of the proposed site (see Section 4.3.2). It is

developed in the western part of the Delaware Basin where the evaporites are exposed, or near the surface. For example, in Nash Draw, where the Rustler Formation is exposed, leaching extends into the Salado, and the permeable residuum contains brine (Vine, 1963). It appears that percolating ground waters move laterally toward Nash Draw, eventually discharging to the Pecos River after becoming saturated with salt.

East of Nash Draw, down dip into the basin, the evaporite formations become progressively deeper, and the present-day top of salt becomes progressively higher in the stratigraphic section. The top of salt is at the top of the Salado Formation about 2 miles west of the center of the proposed site, and becomes progressively higher in the Rustler Formation across the site (Figure 6.3-7, also see Figure 2-6).

Jones (1972) reported the solution front in the Salado Formation to be between 2 and 3 miles west of the center of the site. Bachman (1974) described a thinning of the upper member of the Salado Formation to the west and north that he attributed to a combination of thinning inherent in the original deposition processes and thinning due to subrosion "during the middle and late Cenozoic. West of the line marked "edge of Salado salt" in Figure 6.3-8, there is almost a fourfold reduction in thickness of the upper member of the Salado Formation to as little as 150-170 feet in some places. This is the residue of a 500-foot thick section from which the soluble portions have been leached by circulating ground water. Wherever the upper member of the Salado has been thinned by dissolution, the section of rock between the upper surface of the remaining salt and the top of the formation consists of clay with crudely interlayered seams of broken gypsum (from rehydration of anhydrite) and fine-grained sandstone.

As dissolution progresses and the salts are carried away, voids develop and the residual layer is weakened until it is no longer able to support the overlying material. Slumping of the residue and the associated collapse of the roof can extend to surface elevations, resulting in a

topographic sink. The distinctive pitted topography that results is termed karst. Such topography, in which surface drainage is poorly defined, is extensive in southeastern New Mexico.

Bachman (1974) reported that dolines (that are believed to develop into shallow sinks on the rock surface beneath the soil mantle) are very common, and suggested that the course of the Pecos River southward from Carlsbad to the proximity of the New Mexico-Texas state line lies in a major belt of collapsed sinks. For example, along the east side of the Pecos River, southeast of Carlsbad at Malaga Bend, a linear scarp is believed to have formed along a collapse structure that is now occupied by the river. Other major collapse features mentioned by Bachman include Clayton Basin and Nash Draw. Bachman believes that these features formed as coalescing sinks, probably during Pleistocene time.

Another large depression cited by Bachman is San Simon Sink, located 22 miles east of the proposed site. Shallow dissolution is a factor in the development of this sink, which is apparently still in process. The last recorded collapse in San Simon Sink occurred approximately 40 years ago (Nicholson and Clebsch, 1961). Many sinks along the Pecos River Valley have collapsed in historic time (Bachman, 1974). As recently as 1973 a small collapse sink formed at Lake Arthur, N.M., about 50 miles (80 km) north of Carlsbad.

Deep Dissolution. Large, deep dissolution features filled with Cenozoic sediments overlying the inner margin of the Capitan reef (Figure 6.3-8) were recognized by some of the first geologists working in the Delaware Basin (Maley and Huffington, 1953). The source of water to dissolve the salt was assumed to be the Capitan aquifer.

The extent of large-scale dissolution structures is shown on Figure 6.3-8. The dissolution wedges were identified through varve correlation across the basin in the Castile Formation and recognition of dissolution breccia beds in the western part of the basin (Anderson et al., 1972). These studies suggest that deep dissolution wedges in the Castile

Formation occurred in the lower Salado and upper Castile salt beds (Anderson, 1978). The position of the eastern margin of the western wedge coincides with the location of dissolution features containing deep Cenozoic fill (Figure 6.3-8). The development of these features and the wedge was apparently a complex process. It probably included initial wedge development adjacent to the reef, similar to that seen in the eastern wedge (Anderson 1978), and later combined with shallow dissolution.

The most prominent small-scale, (less than 1 mile across) dissolution features in the vicinity of the Delaware Basin have been described by Vine (1960) as "domal karst features". The subsurface projection of one of these (dome "C") was encountered at the level of the McNutt potash zone by Mississippi Chemical Corporation. It was found to be a chimney in the Salado Formation filled with clay-cemented brecciated rock belonging to strata above the 7th ore zone. There are other erosion-breached domes similar to Vine's dome "C" in the vicinity of Nash Draw. The subsurface expression of the domes, if any, is virtually unknown. A chimney containing cemented rubble (incorrectly termed a "breccia pipe") was encountered in commercial exploratory drilling within the proximity of a low circular hill near the Wills-Weaver Mine, but this chimney was not associated with a breached-dome at the surface. Recent geophysical surveys of the region have revealed that some of these hills, including the "Weaver Pipe" and dome "C", are associated with resistivity lows. Both Vine (1960) and Anderson (1978) have proposed mechanisms for origin of these features, all of which remain to be tested by field investigations of their subsurface structure and composition (see Chapter 10). These mechanisms involve various combinations of differential solution, hydration of anhydrite to gypsum, and salt intrusion. An attempt to reconcile these mechanisms and apply them to the origin of domes near Queen Lake southwest of Nash Draw was made by Reddy (1961).

Anderson believes that the dissolution giving rise to these features is an ongoing process. The proposed site is in an area of the Delaware Basin that is free of regional deep dissolution, but localized features

are present in the vicinity. Nevertheless, the extensive investigation carried out at and near the proposed site, including exploratory holes, ERDA-10, ERDA-11, ERDA-9, and AEC-8, indicate that deep dissolution is not taking place there. ERDA 10 was located and drilled specifically to evaluate the suggestion of Anderson that the absence of Halite III in the Castile south of the WIPP site was due to deep dissolution. Examination of the core revealed no apparent solution residue or collapse breccia; the recently collected data indicate nondeposition rather than dissolution since this was the nearest probable location of regional deep dissolution, its absence implies a lack of threat to the WIPP site from this phenomenon.

Rates of Dissolution. It is evident that dissolution is an active process, and can be expected to continue in the future. The potential hazard to the proposed site by continued dissolution in nearby places such as Nash Draw, 7 to 8 miles west of the site, can be evaluated if the rates of dissolution are known. In relation to human activity, the rate of dissolution is almost immeasureably slow. However, in terms of geologic processes, an attempt to estimate the rate is not altogether impractical. As stated by Bachman (1974): "Active geologic processes have not changed since the close of Tertiary Ogallala time, about 3-4 m.y. (million years) ago. However, the rates of these processes have varied considerably. It is assumed that the rates of these processes will continue to vary and that prediction of future events can be made by assuming that the extremes of past conditions will not be exceeded in the future."

With this in mind, Bachman analyzed the rate of dissolution in Nash Draw since the development of the Mescalero caliche, estimated to be 600,000 years ago. The following summarizes his analysis (Bachman, 1974):

Collapse of the Mescalero caliche along the margins of Nash Draw indicates that this depression has formed, at least in part, since the deposition of the caliche.

Along Livingstone Ridge on the east side of Nash Draw, the Mescalero caliche is undeformed at elevations above 3,300 feet. It dips steeply into the depression along the ridge and occurs at elevations of 3,200 feet, and less, within the depression. Along Quahada Ridge on the west side of Nash Draw the Mescalero is likewise undeformed at elevations about 3,300 feet, but it dips steeply into Nash Draw and occurs as collapsed fractured masses within the depression (NE 1/4 sec. 1, T. 22 S., R. 29 E.).

A cross section through potash exploratory holes in Nash Draw indicates the approximate extent of salt dissolution in the Salado Formation since Mescalero time (Figure 6.3-9).

Nash Draw appears to have subsided between Livingstone and Quahada Ridges as much as 180 feet since Mescalero time. At one locality the surface of Nash Draw is 180 feet below the projected altitude of the Mescalero caliche (See figure 6.3-9). However, the interval between the top of the Salado Formation and the top of marker bed 124 at the same location is 420 feet, or 330 feet less than at Livingston Ridge where relatively little Salado salt has been removed. It is therefore interpreted that about 150 feet of Salado salt was removed before Mescalero time and about 180 feet has been removed since Mescalero time. At another locality, Nash Draw subsided approximatley 160 feet below the projected elevation of the Mescalero caliche while about 120 feet of Salado salt was being removed. There is a discrepancy here of about 40 feet that could be explained by surficial erosion.

Thus, in the area of Nash Draw that subsided 180 feet, the average rate of vertical dissolution over the 600,000 years was about 0.33 feet per 1000 years (Bachman, 1974).

These conclusions are based on the available geologic evidence, but the assumption should not be made that this rate of dissolution is a constant for the region. At least two other factors must be considered in this interpretation, but geologic information is not currently available to permit evaluation of them. The factors are:

Dissolution and subsidence rates probably have not been constant in Nash Draw during the past 600,000 years. A major part of this subsidence may have occurred during periods of high humidity in late Pleistocene (Wisconsin time).

The subsidence in Nash Draw, whenever it occurred in the Pleistocene, is not an average rate for the region. In the area of "the Divide," between Antelope and Livingstone Ridges, the Mescalero caliche is relatively undisturbed and probably no dissolution has occurred there since Mescalero time.

Calculations have also been made of the removal of salt from the Rustler and Salado Formations in Nash Draw based on the rates of discharge of dissolved sodium chloride and calcium sulfate into the Pecos River by brine seeps at Malaga Bend. Active dissolution of halite from the upper part of the Salado Formation occurs in the solution breccia zone at the base of the Rustler Formation in Nash Draw (Brokaw et al. 1972). The brine solution is believed to be recharged by aquifers in the Rustler and above, and its discharge is thought to be primarily at the Malaga Bend brine seeps and the salt lakes in Nash Draw. Piper (1973) calculated that the salts discharged into the Pecos River between Malaga Bend and a point 6 miles (10 km) downstream amount to 310,000 tons (2.8×10^8 kg) of NaCl and 170 tons (1.5×10^8 kg) of $CaSO_4$ each year. This is equivalent to a loss of 0.16 vertical feet of salt section per thousand years, a rate of the same order of magnitude as that calculated from the subsidence of Nash Draw.

An alternative approach of estimating vertical dissolution was used by F.A. Swenson (Bachman and Johnson 1973). He investigated the tonnage of salt dissolved and discharged by springs and streams along the east flank of the basin and found the maximum tonnage for the many subbasins to be 955 tons per square mile of drainage area each year. If the discharge continued at that rate it would mean a vertical dissolution of about 0.5 foot of salt in 1,000 years, provided the dissolution was distributed evenly over the area drained.

A rate of lateral shallow dissolution of salt in the western part of the Delaware Basin has been estimated to be about 6 to 8 miles per million years horizontally (Bachman and Johnson 1973). These estimates were based on the assumption that the salt-bearing Salado Formation extended to the Capitan reef escarpment on the western edge of the basin at the end of Ogallala time. It is now recognized that dissolution of this salt could have occurred at previous times in the past, and the average rate of salt removal by shallow dissolution is believed to be much slower than those estimates which establish an upper bound.

As stated previously, it is estimated that about 50 percent of the original volume of salt has been removed from the Basin. In considering the rate at which the salt was removed, it is generally recognized that much of the erosion and dissolution probably occurred since the beginning of Cenozoic time. This is a period of major uplift and erosion. Anderson pointed out (1978) that the dissolution features are closely associated with Cenozoic and postuplift hydrologic and structural controls. Nevertheless, as early as Jurassic time the basin was tilted and the western portion shown on Figure 6.3-8 was exposed and subject to erosion (Bachman, 1976). The hydrologic and structural conditions were apparently similar at that time to those of the Cenozoic, and the Jurassic climate is recognized to have been wet. Thus, it seems quite likely that the deep dissolution and erosional processes of salt removal could have been significantly accelerated during the Jurassic period.

The rate of deep dissolution is difficult to assess, and Anderson (1978) does not believe that estimates can be made with any degree of confidence, considering the available data. He suggests that if it is assumed that 1) deep dissolution progresses at a constant rate, and 2) that significant dissolution did not begin until after stripping of the Ogallala Formation from the basin (3-4 million years ago), projection of that rate would imply all of the lower Salado salt would be removed in about another million years. However, he does not believe the assumptions are valid.

Deep dissolution, as hypothesized by Anderson, would seem to have been a significant geologic process in Jurassic time, as well as in the Cenozoic. It is apparent that further study of these factors is needed to fully assess the impact on the proposed site. Sandia Laboratories and the U.S. Geological Survey are currently performing studies to provide data which should aid in this evaluation (see Chapter 10).

6.4 HYDROLOGY DRILLING AND TESTING SUMMARY

6.4.1 HOLE NO. H-1

LOCATION: T.22 S., R.31 E., Sec. 29

ELEVATION: 3,403.2 feet (ground level)

DEPTH DRILLED: 848 feet

DATE COMPLETED: June 9, 1976

DRILLING CONTRACTOR: Sonora Drilling Co., Carlsbad, N. Mexico

DRILLING METHOD: Auger 18 inch hole (0-40 feet)
Rotary 7.88 inch hole with air-air/mist (40-731 feet)
Core 4.75 inch hole with air mist (731-842 feet)
Ream 9.88 inch hole (40-848 feet)

CASING RECORD: 10.75 inch O.D. steel surface pipe, (0-40 feet) cemented to surface
7 inch O.D. steel casing (0-848 feet), cemented to surface (cement plug to 797 feet, drilled to 831 feet)

GEOPHYSICAL LOGS: Differential Temperatures
BHC Acoustic
Compensated Densilog
Dual-Laterolog

Micro-Laterolog
Compensated Neutron-Gamma
Sperry-Sun Magnetic Survey

HYDROLOGIC TESTING (OPEN HOLE):

A. 699-842 feet: DST, of Rustler-Salado Contact, 9.1 gallons of water in 20 hours

B. 667-699 feet: DST of Culebra Dolomite, 10.6 gallons of water in 11.5 hours

C. 626-667 feet: DST, of suspected salt residue, 11.2 gallons of water in 12 hours.

D. 562-592: DST of Magenta Dolomite, 13 gallons of water in 13.5 hours; after hole was drilled to 592 feet inflow of 490 gpd was observed.

HYDROLOGIC TESTING (CASED HOLE):

E. 803-837 feet: Perforated zone, Rustler-Salado contact, water level rose from 826.5 to 811 (25 gallons) in 33 days.

F. 675-703 feet: Perforated zone, Culebra Dolomite, fluid level rose from 665 to 406 (416 gallons) in nine days.

G. Tracer, ^{131}I, no annulus leaks, no flow in 694-703 interval, major loss in 675-694 interval, tracer injection rate of 8 gpm, total 1634 gal. injected.

H. 562-590 feet: Perforated zone, Magenta Dolomite, after bailing, water rose from 424.5 to 340.7 feet in 33 days (53 gallons), could not bail below 424 feet.

I. Culebra water level stable at 390 feet depth. (October 1977)

J. Magenta water level stable at 249 feet depth. (October 1977)

DRILLING & TESTING SUMMARY

6.4.2 HOLE NO. H-2a

LOCATION: T.22 S., R.31, E., Sec. 29

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 563 feet

DATE COMPLETED: February 19, 1977

DRILLING CONTRACTOR: Pennsylvania drilling Co., Carlsbad, N. Mexico

DRILLING METHOD: Auger 18 inch hole (0-33 feet)
Rotary 8.75 inch hole with air-air/mist (33-513 feet)
Core 4.75 inch hole with air/mist (513-563 feet)
(cut 2.25 inch diameter core)

CASING RECORD: 10.75 inch O.D. steel casing (C-33 feet) cemented to surface
6.63 inch O.D. steel casing, (0-511 feet), cemented to surface

Geophysical Logs: None. Available from H2C, 90 feet away.

HYDROLOGIC TESTING:

A. 0-188 feet: Stopped drilling after encountering wet zone at 185 feet; interval produced no appreciable fluid in 5 hours

B. 513-563 feet: Open hole, Magenta Dolomite, water rose from 556.8 to 538.7 in one day (22 gallons).

C. Magenta static level at 249 feet, October, 1977

DRILLING & TESTING SUMMARY

6.4.3 HOLE NO. H-2b

LOCATION: T.22 S., R. 31 E., Sec 29

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 661 feet

DATE COMPLETED: February 12, 1977

DRILLING CONTRACTOR: Pennsylvania Drilling Co., Carlsbad, N. Mexico

DRILLING METHOD: Auger 18 inch hole (0-33 feet)
Rotary 8.75 feet hole with air-air/mist (33-611 feet)
Core 4.75 inch hole with air/mist (611-661 feet) (cut 2.25 inch diameter core)

CASING RECORD: 10.75 inch O.D. steel casing (0-33 feet) cemented to surface
6.63 inch O.D. steel casing, (0-609 feet)., cemented to surface

Geophysical Logs: None. Available from H2C, 75 feet away.

HYDROLOGIC TESTING:

A. 611-661 feet: Open hole, Culebra cored interval, water rose from 636.9 to 458.0 feet in one day (260 gallons). Level stable at 352 feet (February 1977)

B. Hole # H-2c was bailed from the Culebra while monitoring H-2b in the Culebra. First response in H2b was detected 50 minutes after bailing of H2C started.

C. 510-538 feet: Perforated zone, Magenta Dolomite, water rose from 560 to 420 feet in one day (210 gallons).

D. Well constructed for monitoring at Culebra Dolomite via tubing and Magenta via annulus. Culebra static level at 351 feet, Magenta static level at 292 feet (perforations may be blocked).

DRILLING & TESTING SUMMARY

6.4.4 HOLE NO. H-2c

LOCATION: T.22 S., R.31 E., Sec 29

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 795 feet

DATE COMPLETED: February 5, 1977

DRILLING METHOD: Auger 18 inch hole (0-33 feet)
Rotary 8.75 inch hole with air/mist (33-743 feet)
Core 4.75 inch hole with air/mist (743-795 feet)
(cut 2.25 inch diameter core)

CASING RECORD: 10.75 inch steel casing (0-33 feet) cemented to surface
6.63 inch O.D. steel casing, (0-742 feet), cemented to surface.

Geophysical Logs: Compensated Densilog
Dual-Laterolog
BHC Acoustilog
Micro-Laterolog

Compensated Neutron-Gamma
4-Arm Caliper
USGS Lithologic-log

HYDROLOGIC TESTING:

A. 743-795 feet: Open hole, Rustler-Salado cored interval produced 14 gallons in 18 days.

B. 624-652 feet: Culebra perforated zone, water rose from 656.4 to 446.6 in one day (310 gallons). Static level at 352 feet. (March 1977)

C. Tracer ^{131}I, no flow below 642 in casing, fluid loss zone was between 631 and 644, especially 640-644 where core indicates pitted and fractured dolomite, tracer injection rate was 8 gpm, total 697 gal. injected.

D. Dual completion monitoring (Rustler-Salado via tubing and Culebra via annulus) shows Culebra stable at 355 feet (October 1977) and Rustler-Salado still recovering at 34 feet per month. (June 1978)

DRILLING AND TESTING SUMMARY

6.4.5 HOLE NO. H-3

LOCATION: T.22 S., R.31 E., Sec. 29

ELEVATION: 3,388.7 feet (ground level)

DEPTH DRILLED: 894 feet

DATE COMPLETED: August 12, 1976

DRILLING CONTRACTOR: Pennsylvania Drilling Co., Carlsbad, New Mexico

DRILLING METHOD: Auger 18 inch hole (0-38 feet)

Rotary 7.88 inch hole with air-air/mist (38-894 feet)

Ream 8.75 inch hole (38-894 feet)

CASING RECORD: 10.75 inch O.D. steel surface pipe (0-38 feet) cemented to surface.
6.63 inch O.D. steel casing, (0-891 feet), cemented to surface (cement plug to 804 feet drilled to 864 feet)

Geophysical Logs: Compensated Densilog
Micro-Laterolog
Dual-Laterolog
BHC Acoustilog
Compensated Neutron-Gamma
Differential Temperature

HYDROLOGIC TESTING (OPEN HOLE)

A. 800-868 feet: DST, Rustler-Salado contact, produced 1.8 gallons of water in 16.5 hours;

B. 672-703 feet: DST, Culebra, produced 2.1 gallons of water in 21.5 hours.

C. 703-780 feet: DST, salt residue, 2 gallons of water in 26 hours.

D. 558-608 feet: DST, Magenta, 23 gallons after 37.5 hours. after developing operation via swabbing.

HYDROLOGIC TESTING (CASED HOLE)

E. 813-837 feet: Perforated Rustler-Salado contact; produced 37 gallons in 32 days.

F. 675-703 feet: Perforated Culebra, bailed hole and monitored, recovery was up to 410 from an initial level of 550 feet (200 gallons in 8 days).

G. Tracer ^{131}I, showed no flow below 696 feet; major fluid losses in intervals 684-692 and 692-695; tracer injection rate was 8 gpm, total injected 450 gal.

H. 562-590 feet: Perforated Magenta, bailed 360 gallons in one hour with 6 feet of drawdown.

I. Dual-completion monitoring (Culebra via tubing and Magenta via annulus) indicate Culebra static level at 404.5 and Magenta static level at 245.1 as of October 1977.

DRILLING & TESTING SUMMARY

6.4.6 HOLE NO. P-14

LOCATION: T.22 S., R.30 E., Sec. 24

ELEVATION: 3,358.1 feet (ground level)

DEPTH DRILLED: 1,545 feet.

DATE COMPLETED: October 3, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Co., Las Cruces, New Mexico

DRILLING METHOD: Rotary 8.75 inch hole with air (0-20 feet)
Rotary 7.88 inch hole with air-air/mist (20-784 feet)
Rotary with air/mist (784-1,168 feet)
Core with brine mud (1,168-1,545 feet)

CASING RECORD: 8.63 inch O.D. steel casing (0-20 feet)
4.50 inch O.D. steel casing, (0-775 feet) cemented to surface, hole plugged back from 1,345 feet to 759 feet with cement.

Geophysical Logs: Gamma
Gamma-Gamma
Neutron
Caliper

HYDROLOGIC TESTING (CASED HOLE)

A. 676-700 feet: Perforated Rustler-Salado, fluid level rose from 730 to 620 feet in one day (75 gallons).

B. 573-601 feet: Perforated Culebra, bailed 720 gallons of water in three hours with no drawdown.

C. Tracer ^{131}I, showed 63 percent fluid loss in interval 583-590, remaining loss in interval 573-583; no loss below 590 feet. Injection rate 7 gpm. Total injected 1634 gal.

D. Dual-completion monitoring (Rustler-Salado via tubing and Culebra via annulus); Rustler-Salado stabilized at 386 feet, Culebra stabilized at 324 feet (October 1977)

DRILLING & TESTING SUMMARY

6.4.7 HOLE NO. P-15

LOCATION: T.22 S., R.31 E., Sec. 31

ELEVATION: 3,309.7 feet (ground level)

DEPTH DRILLED: 1,465 feet

DATE COMPLETED: October 14, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Co., Las Cruces, New Mexico.

DRILLING METHOD: Rotary 8.75 inch hole with air (0-20 feet)
Rotary 7.88 inch hole with air-air/mist (20-515 feet)
Core 4.75 inch hole with air/mist (515-600 feet) (cut 2.25 inch diameter core)
Ream 7.88 inch hole with air/mist (515-637 feet)
Rotary 5 inch hole with air/mist (637-1,038 feet)
Core with brine mud (1,038-1,465 feet)

CASING RECORD: 8.63 inch O.D. steel casing (0-20 feet)
4.50 inch O.D. steel casing, (0-635 feet), cemented to surface, hole plugged back from 1,465 to 600 feet with cement, cement drilled out to 620 feet.

Geophysical Logs: Gamma
Gamma-Gamma
Neutron
Caliper
Spectralog

HYDROLOGIC TESTING:

A. 532-556 feet: Perforated Rustler-Salado contact, fluid rise from 618 to 497 in 42 days (81 gallons).

B. 410-438 feet: perforated Culebra, fluid rose from 496 to 420 feet in one day (50 gallons); 125 gallons in 33 days

C. Dual Completion monitoring (Rustler-Salado via tubing and Culebra via annulus) shows Rustler-Salado static level at 324 feet and Culebra at 308 feet as of October, 1977.

DRILLING AND TESTING SUMMARY

6.4.8 HOLE NO. P-17

LOCATION: T.23 S., R.31 E., Sec. 4

ELEVATION: 3,339.5 feet (ground level)

DEPTH DRILLED: 1,660 feet

DATE COMPLETED: October 26, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Co., Las Cruces, New Mexico.

DRILLING METHOD: Rotary 8.75 inch hole with air (0-20 feet)
Rotary 7.88 inch hole with air-air/mist (20-755 feet)
Rotary with air/mist (755-1,220 feet)
Core with brine mud (1,220-1,660 feet)

CASING: 8.63 inch O.D. steel casing (0-20 feet)
4.50 inch O.D. steel casing, (0-751 feet), cemented to surface, hole plugged back from 1,660 feet to 720 feet with cement, cement drilled out to 731 feet.

Geophysical Logs: Gamma
Gamma-Gamma
Neutron
Caliper

HYDROLOGIC TESTING (CASED HOLE)

A. 702-726 feet: Perforated Rustler-Salado contact; fluid rose from 726 to 622 feet (71 gallons in 73 days).

B. 558-586 feet: Perforated Culebra, single packer set at 683 feet, bailed and monitored for 29 days with fluid rise from 622 to 372 feet.

C. Dual Completion monitoring (Rustler-Salado via tubing and Culebra via annulus) indicates fluctuating levels; problem could be leaking bridge packer or communication in cemented annulus.

DRILLING & TESTING SUMMARY

6.4.9 HOLE NO. P-18

LOCATION: T.22 S., R.31 E., Sec. 26

ELEVATON: 3,478.7 feet (ground level)

DEPTH DRILLED: 1,998 feet

DATE COMPLETED: November 5, 1976

DRILLING CONTRACTOR: Pennylsvania Drilling Co., Carlsbad, New Mexico.

DRILLING METHOD: Rotary 8.75 inch hole with brine mud (0-18 feet)
Rotary 7.88 inch hole with brine mud (18-1139 feet) to casing depth.
Rotary with brine mud (1,139-1,630 feet)
Core with brine mud (1,630-1,998 feet)

CASING RECORD: 8.63 inch O.D. steel casing (0-18 feet)
4.50 inch O.D. steel casing, (0-1, 138 feet), cemented to surface, hole plugged back from 1,998 feet to 1,125 feet with cement.

Geophysical Logs: Gamma
Gamma-Gamma
Neutron
Caliper

HYDROLOGIC TESTING (CASED HOLE)

A. 1076-1100 feet: Perforated Rustler-Salado contact, fluid rise from 1123 to 1073 feet in 73 days (34 gallons)

B. 912-940 feet: Perforated Culebra, bailed and monitored recovery for 33 days with fluid rise from 1045 to 1022 feet (16 gallons).

C. Dual completion (Rustler-Salado via tubing, Culebra via annulus) indicated Rustler-Salado at 755 feet and still recovering as of October, 1977.

DRILLING & TESTING SUMMARY

6.4.10 HOLE NO. AEC-8

LOCATION: T.22 S., R.31 E., Sec. 11

ELEVATION: 3,531.9 feet (ground level)

DEPTH DRILLED: 3,019 feet (1974), deepened to 4,910 feet (1976)

DATE COMPLETED: August 5, 1976

DRILLING CONTRACTOR: Sonora Drilling Co., Carlsbad, New Mexico

DRILLING METHOD: Core, ream, rotary 7.88 inch hole with brine mud (31-3,019 feet)
Core, ream, rotary 7.88 inch hole with brine mud (3,018.5-4,910.5 feet)

CASING RECORD: 8.63 feet O.D. steel casing (0-874 feet), cemented to surface.
5.50 inch O.D. steel casing, (0-4,907 feet), cemented to 880 feet.

Geophysical Logs; Compensated Neutron
Micro-Laterlog
Dual-Laterolog
Gamma

HYDROLOGIC TESTING (CASED HOLE)

A. 4,844-4,860 feet: Perforated lower sand lense of Bell Canyon Formation; fluid level rose from 4126 feet to 4095 feet in 166 minutes (31 gallons).

B. 4,832 - 4,910 feet: Production packer with sentry monitoring device showed formational pressure of 2037 lbs/ in^2 reached in 44.5 hours; fluid density was 1.11 g/cm^3.

C. Tracer ^{131}I, along with temperature logs, indicated major fluid loss in interval 4839 to 4860 feet; minor communication down casing to 4870 feet; tracer injection rate was 14 gpm. Total injected 2289 gal.

D. 4,821-4,827 feet: Perforated upper sand lense of Bell Canyon Formation; single packer set at 4835 feet; swabbed fluid to 2600 feet; pressure monitor installed at 4805 feet; shut-in pressure recovered to 2037 lbs/in^2 in 57 hours, fluid density was 1.12 gm/cm^3,

E. Tracer ^{131}I, showed no upward or downward communication; injection rate at tracer was 11 gpm. Total injected 300 gal. Injection was occurring uniformly in the lower 4 feet of perforations.

F. Dual completion monitoring (lowering sand via tubing and upper sand via annulus) indicate lower sand stablized at 615 feet and upper sand at 560 feet as of November, 1977.

6.5 SUMMARY

The proposed site contains neither perennial streams nor surface water impoundment, and the water bearing strata above and below the evaporite section do not yield large quantities of water to wells. At its closest point, the Pecos River is approximately 14 miles southwest of the WIPP site. Water bearing strata in the local site area at stratigraphic horizons above the proposed repository include the Santa Rosa Sandstone and the Culebra and Magenta members of the Rustler Formation. Hydrologic units below the repository horizons include the Bell Canyon Formation of the Delaware Mountain Group. Ground water velocities vary with porosity, hydraulic conductivity, and head gradient but are typically 0.3 ft/d in the Santa Rosa Sandstone, 0.5 ft/d in the Rustler Formation, and 0.0006 ft/d in the Bell Canyon Formation. Shallow wells in the local area are generally used only for watering livestock and typically produce nonpotable ground water with total solute concentrations in excess of 3,000 ppm.

Natural potentiometric levels of fluids from rocks above and below the evaporites at the WIPP site (from the Rustler and Bell Canyon Formations, respectively) are comparable (about 2950 to 3050 above mean sea level). The head differential between upper and lower units varies within about 200 feet on the periphery of the site, the sign and magnitude of the differential depending upon precise geographic location.

Gentle eastward tilting of the Delaware Basin resulting in the exposure of the Salado Formation to near-surface waters has given rise to the removal of a wedge-shaped mass of soluble salts between the Guadalupe escarpment (30 miles due west of the site), where there remains no rock salt, and a point about 3 miles due west of the site center, where the Salado Formation is intact.

The proposed site is in an area of the Delaware Basin that is free of regional deep dissolution, but localized shallow features are present in the vicinity. A shallow salt dissolution zone (called the "brine aquifer") occurs in Nash Draw at the contact between the Salado and

Rustler Formations. This local shallow dissolution area ranges in width from 2 to 10 miles and has a length of approximately 30 miles. The brine solution flows southwesterly at a rate of about 0.2 ft/d and discharges into the Pecos River at Malaga Bend. The average rate of vertical dissolution has been estimated to be between 0.33 and 0.5 feet per 1,000 years, and the average rate for lateral dissolution has been estimated to be between 6 and 8 miles per million years.

Climatological records show that mean annual precipitation of the site is approximately 12 inches per year. Aided by the low relative humidity (typically 36% during daylight hours) and high mean annual temperature (61°F), most of the annual precipitation returns to the atmosphere through evaporation and transpiration. Runoff is typically 0.1 to 0.2 inches annually.

6.6 REFERENCES

Anderson, R.Y., Dean, W.E., Kirkland, D.N., and Snider, H.I., 1972, Permian Castile varved evaporite sequence West Texas and New Mexico: Geol. Soc. Amer. Bull. v. 83, p. 59-86.

Anderson, R. Y., 1978, Report to Sandia Laboratories on deep dissolution of salt, northern Delaware Basin, New Mexico, January 1978, 98pp.

Anderson, R.Y., and Powers, D. W. (in press). Salt anticlines in the Castile-Salado evaporite sequence, Northern Delaware Basin, New Mexico, Symposium on the Ochoan rocks of southeastern New Mexico and West Texas, Cir. 159, New Mexico Bureau of Mines and Mineral Resources.

Bachman, G.O., and Johnson, R., 1973, Stability of salt in the Permian Salt Basin of Kansa, Oklahoma, Texas and New Mexico: U.S. Geol. Survey Open-file report 4339-4.

Bachman, G.O., 1974, Geologic processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U.S. Geol. Survey Open-file report 74-194.

Bachman, G. O., 1976, Cenozoic deposits of southeastern New Mexico and an outline of the history of evaporite dissolution: U.S. Geol. Survey, Jour. Research v. 4, No. 2, p. 135-149.

Barr, G.E., Lambert, S.J., and Carter, J.A., 1978, Uranium isotope disequilibrium in groundwaters of southeastern New Mexico and implications regarding age-dating of waters. SAND77-1779. IAEA-SM-228/32, Sandia Laboratories, Albuquerque, New Mexico.

Bjorklund, L. J. and Motts, W. S., 1959, Geology and water resources of Carlsbad area, New Mexico: U.S. Geol. Survey Open-file report 59-9.

Blaney, H.F., and Hanson, E.G., 1965, Consumptive use and water requirements in New Mexico: New Mexico state engineer, technical report 32.

Brokaw, Arnold L., Jones, C.L., Cooley, M.E., and Hays, W.H., 1972, Geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico: U.S. Geol. Survey Open-file report 4339-1.

Cooper, J.B., 1962, Ground-water investigations of the Project Gnome area, Eddy and Lea Counties, New Mexico: U.S. Geol. Survey Report REI-802.

Cooper, J. B., and Glanzman, V. M., 1971, Geohydrology of project Gnome site, Eddy County, New Mexico: U.S. Geol. Survey, Prof. Paper 712-A, 24 p.

Gard, L.M., Jr., 1968, Geologic studies, Project Gnome, Eddy County, New Mexico: U.S. Geol. Survey Prof. Paper 589.

Griswold, G. B., 1977, Site selection and valuation studies of the Waste Isolation Pilot Plant (WIPP), Los Medanos, Eddy County, New Mexico: SAND77-0946 Sandia Laboratories, Albuquerque, New Mexico.

Hale, W. E., Hughes, L.S., and Cox, E.R., 1954, Possible improvement of quality of water of the Pecos River by diversion of brine of Malaga Bend, Eddy County, New Mexico: Report of the Pecos River Commission, New Mexico and Texas with U.S. Geol. Survey Water Resources Division.

Hendrickson, G. E., and Jones, R. J., 1952, Geology and ground water resources of Eddy County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Ground-Water Report 3.

Hiss, W.L., 1975a, Stratigraphy and ground-water hydrology of the Capitan Aquifer, southeastern New Mexico and western Texas, unpublished Ph.D. thesis, University of Colorado, Boulder, Colorado.

Hiss, W.L., 1975b, Thickness of the Permian Guadalupian Capitan aquifer, southeast New Mexico and west Texas: New Mexico Bureau of Mines and Mineral Resources, Resource Map 5.

Hiss, W.L., 1975c, Chloride-ion concentration in ground water in Permian Guadalupian rocks, southeast New Mexico and west Texas: New Mexico Bureau of Mines and Mineral Resources, Resource Map 5.

Hiss, W. L., 1976a, Structure of the Permian Ochoan Rustler Formation, southeast New Mexico and West Texas: New Mexico Bureau of Mines and Mineral Resources, Resource Map 7, 1976.

Hiss, W.L., 1976b, Structure of the Permian Guadalupian Capitan Aquifer southeast New Mexico and west Texas: New Mexico Bureau of Mines and Mineral Resources, Resource Map 6.

Jones, C. L., Cooley, M.E., and Bachman, G.O., 1973, Salt deposits of Los Medanos area, Eddy and Lea Counties, New Mexico, U.S. Geol. Survey Open-file report 4339-7.

Kelley, V.C., 1971, Geology of the Pecos country, southeastern New Mexico New Mexico Bureau of Mines and Mineral Resources, Memoir 24.

King, P. B., 1948, Geology of the southern Guadalupe Mountains, Texas: U.S. Geol. Survey Prof. Paper 215.

Lambert, S.J., 1977, The geochemistry of Delaware Basin groundwaters, Sandia Laboratories Report, Albuquerque, New Mexico, SAND77-0420. Report also in New Mexico Bureau of Mines and Mineral Resources, Circ. 159 (1978 - in press).

Lambert, S. J. and Mercer, J. W., 1977, Hydrologic investigations of the Los Medanos area, southeastern New Mexico, 1977: SAND77-1401, Sandia Laboratories, Albuquerque, New Mexico.

Lohman, S.W., 1972, Definitions of selected ground-water terms--revisions and conceptual refinements: U.S. Geol. Survey Water Supply Paper 1988.

Maley, V. C., and Huffington, R. M., 1953, Cenozic fill and evaporite solution in the Delaware Basin, Texas and New Mexico: Geol. Soc. Amer. Bull. v. 64, pp 539-546..

McNeal, R. P., 1965, Hydrodynamics of the Permian Basin Fluids, in subsurface environments symposium: Amer. Assoc. of Petrol. Geologists Memoir No. 4, p. 308-326.

Mercer, J.W., (to be published), Hydrologic tests and observations in the potash-hydro holes P-14, P-15, P-17, and P-18, U.S. Geol. Survey.

Mercer, J.W., and Orr, B. R., 1977, Review and analysis of hydrogeologic conditions near the site of a potential nuclear waste laboratory, Eddy and Lee Counties, New Mexico, U.S. Geol. Survey Open-file report 77-123.

Mercer, J. W., and Orr. B. R., 1978, Geohydrology of the proposed Waste Isolation Pilot Plant, southeastern New Mexico: U.S. Geol. Survey report submitted to DOE (preliminary).

Motts, W.S., 1957, Geology and ground water resources of the Carlsbad area, New Mexico, unpublished Ph.D. Thesis, University of Illinois (Urbana).

Nicholson, Alexander, Jr., and Clebsch, A., Jr., 1961, Geology and ground-water conditions in southern Lea County, New Mexico: Ground-water Report 6, New Mexico Bureau of Mines and Mineral Resources.

NOAA Environmental Data Service, 1977, Climatography of the United States, No. 60, Climate of New Mexico: U.S. Dept. of Commerce, March 1977.

Pettigrew, Richard R. and Assoc., 1977, WIPP conceptual design report (soils and foundation investigation): Prepared for Sandia Laboratories Albuquerque, New Mexico.

Pierce, W. G. and Rich, E. I., 1962, Summary of rock salt deposits in the United States as possible storage sites for radioactive waste materials: U.S. Geol. Survey Bull. 1148, 33-35P.

Piper, A.M., 1973. Subrosion in and about the four-township study area near Carlsbad, New Mexico, ORNL subcontract 3745, Oak Ridge National Laboratory, Oak Ridge, TN.

Reddy, G. R., 1961, Geology of the Queen Lake domes near Malaga, Eddy County, New Mexico: unpublished M.S. Thesis, Univ. of New Mexico.

Robinson, T. W., and Lang, W. G., 1938, Geology and ground water conditions of the Pecos River Valley in the vicinity of Laguna Grande de la Sal, New Mexico, with special reference to the salt content of the river water. N. Mex. State Engineer 12th and 13th Bienn. Repts., p. 77-100.

Rose, Walter, 1977, Development of a conceptual model to explain brine flowage into wells drilled thru the Salado-Castile Formation. Contact in locations such as the ERDA #6 site near Carlsbad in southeastern New Mexico: Report to Sandia Laboratories.

Theis, C.V., and Sayre, A.N., 1942, Geology and ground water, in (U.S.) National Resources Planning Board, 1942, Pecos River Joint Investigation-Reports of the participating agencies: Washington, U.S. Govt. Printing Office, P. 27-38.

U.S. Department of Agriculture, Soil Conservation Service, 1971, Soil survey of Eddy area, New Mexico, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Agriculture, Soil Conservation Service, 1974, Soil survey of Lea area, New Mexico, U.S. Government Printing Office, Washington, D.C.

U.S. Department of Commerce, Weather Bureau, 1952, Mean number of thunderstorm days in the United States, Technical paper No. 19.

U.S. Department of Commerce, Weather Bureau, 1955, Rainfall intensity-duration-frequency curves. Technical paper No. 25.

U. S. Department of Commerce, Weather Bureau, 1969, Severe local storm occurrences, 1955-1967. Technical Memorandum WBTM FCST 12.

U.S. Department of Commerce, Weather Bureau, 1961, Climatological Survey Station, Carlsbad, New Mexico.

U.S. Department of Commerce and U.S. Department of Army, Weather Bureau and corps of Engineers, 1976, Hydrometeorological report No. 33, seasonal variation of the probable maximum precipitation east of the 105th meridian.

U.S. Department of the Interior, 1975, Preliminary regional environmental analysis record potash leasing in southeastern New Mexico: Bureau of Land Management, New Mexico State Office.

U.S. Geological Survey, 1976, Water resources data for New Mexico, water year 1976: U.S. Geol. Survey Water-Data Report NM-76-1.

U.S. Geological Survey Topographic maps, 15 minute series (1:62,500) for Nash Draw and Hat Mesa, New Mexico.

U. S. Geological Survey Topographic Maps, (1:250,000), NI 13-11 (Carlsbad) and NI 13-12 (Hobbs), New Mexico.

Vine, J. D., 1960, Recent domal structures in southeastern New Mexico: Amer. Assoc. Petrol. Geol. Bull., v. 44, no. 12, p. 1903-1911.

Vine, J. D., 1963, Surface geology of the Nash Draw quadrangle, Eddy County, New Mexico: U.S. Geol. Survey Bull. 1141-B.

Wolfe, H.G., editor, 1977a. An environmental baseline study of the Los Medanos Waste Isolation Pilot Plant (WIPP) project area of New Mexico: a progress report: SAND77-7017, Sandia Laboratories, Albuquerque, New Mexico.

Wolfe, H.G., editor, 1977b. An environmental baseline study of the Los Medanos Waste Isolation Pilot Plant (WIPP) project area of New Mexico: a progress report. An addendum: SAND77-7018, Sandia Laboratories, Albuquerque, New Mexico.

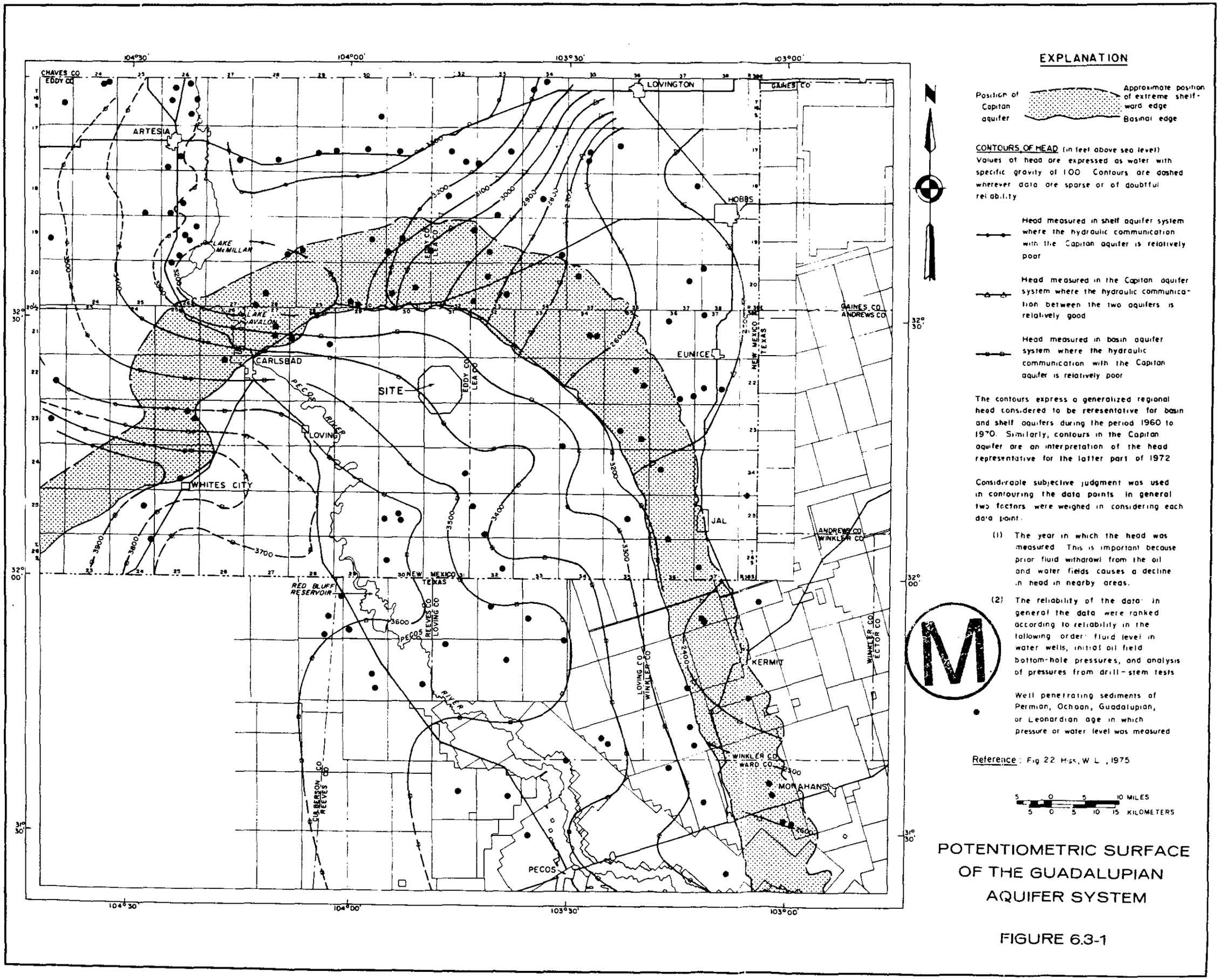

POTENTIOMETRIC SURFACE OF THE GUADALUPIAN AQUIFER SYSTEM

FIGURE 6.3-1

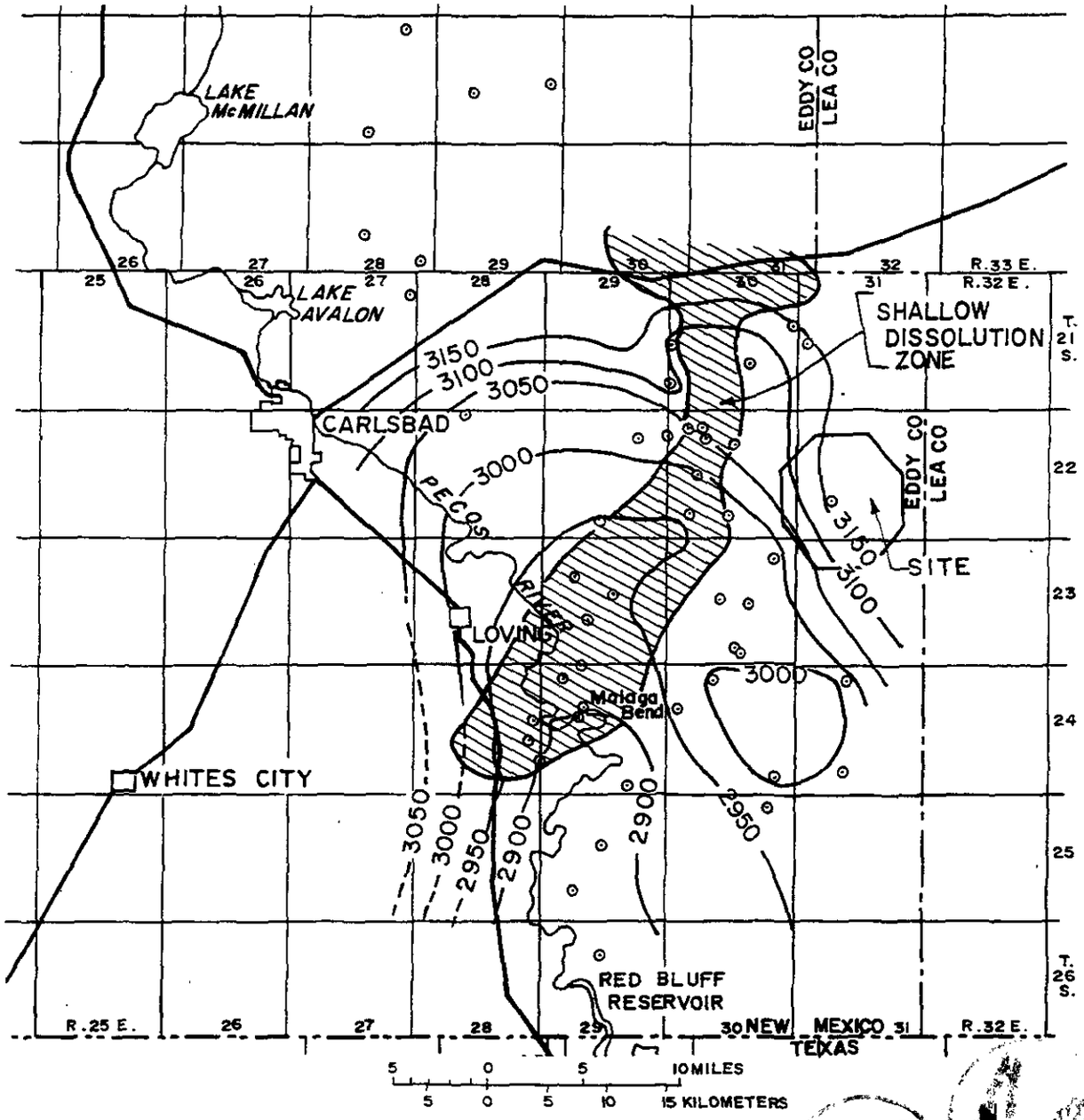

EXPLANATION

⊙ Well or exploratory hole open to the Rustler Formation

3000 -- Potentiometric elevation contour based on water levels measured in wells, 1952–1973. Dashed where approximately located. Datum is mean sea level.

Reference: Figures 5 & 6, U.S.G.S. Open File Rpt. 77-123, 1977

POTENTIOMETRIC SURFACE
RUSTLER FORMATION AND AREAL
EXTENT OF SHALLOW DISSOLUTION ZONE

FIGURE 6.3-2

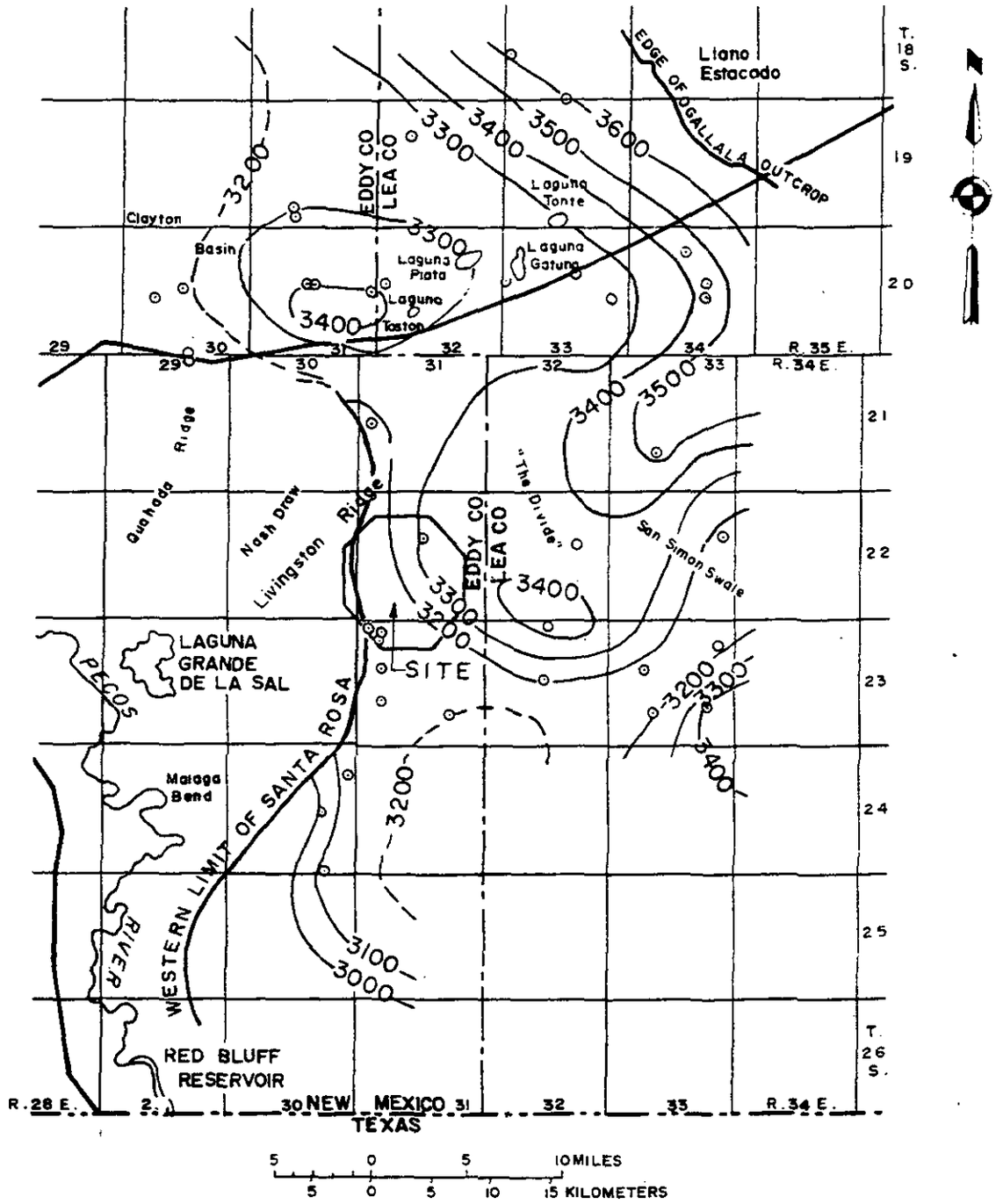

EXPLANATION

⊙ Well open to Triassic rocks

Potentiometric elevation contour, based on water levels measuerd in wells, 1952 – 1973. Dashed where approximately located. Datum is mean sea level.

POTENTIOMETRIC SURFACE
SANTA ROSA SANDSTONE

Reference:

Mercer and Orr, 1977, figure 7.

FIGURE 6.3-3

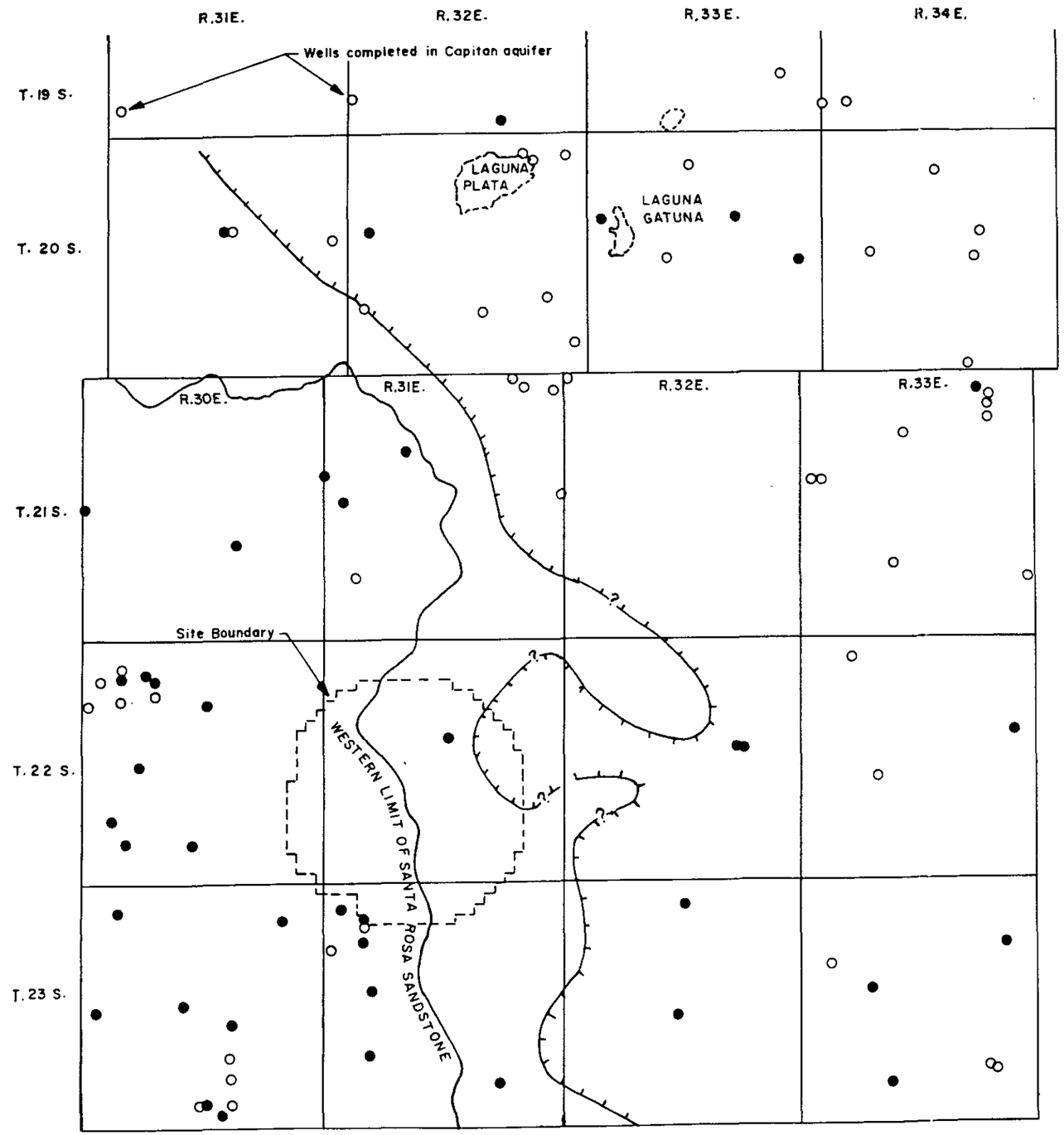

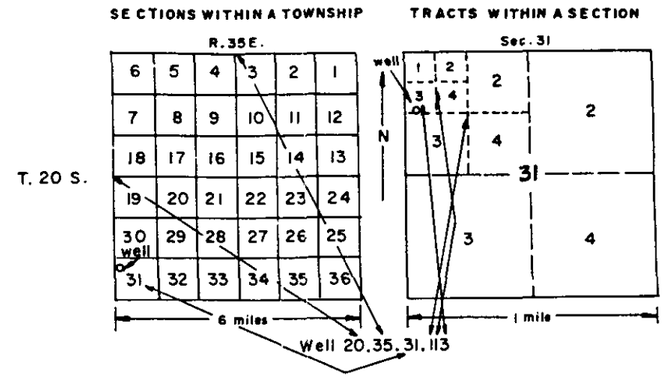

WELL-NUMBERING SYSTEM

The well number consists of four parts separated by periods. The first part is the township number, the second part is the range number, and the third part is the section number. The fourth part of the number consists of three digits which denote the particular 10-acre tract within the section in which the well is located.

EXPLANATION

Approximate western limit of occurrence of ground water in the Santa Rosa Sandstone.

○ Water well completed in surfical deposits or upper sandstone beds of the Chinle Formation.

● Water well completed in lower sandstone beds of the Chinle Formation, Santa Rosa Sandstone, Dewey Lake Redbeds, or Rustler Formation.

NOTE:
See Table 6.3—2 for descriptions of wells.

Reference: USGS Open File Report 4339-7, Jones, C.L., et al, 1973

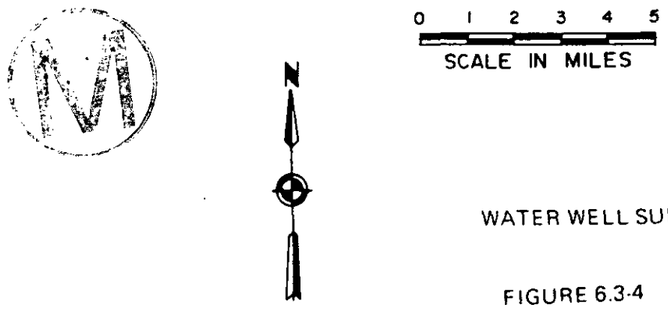

WATER WELL SURVEY

FIGURE 6.3-4

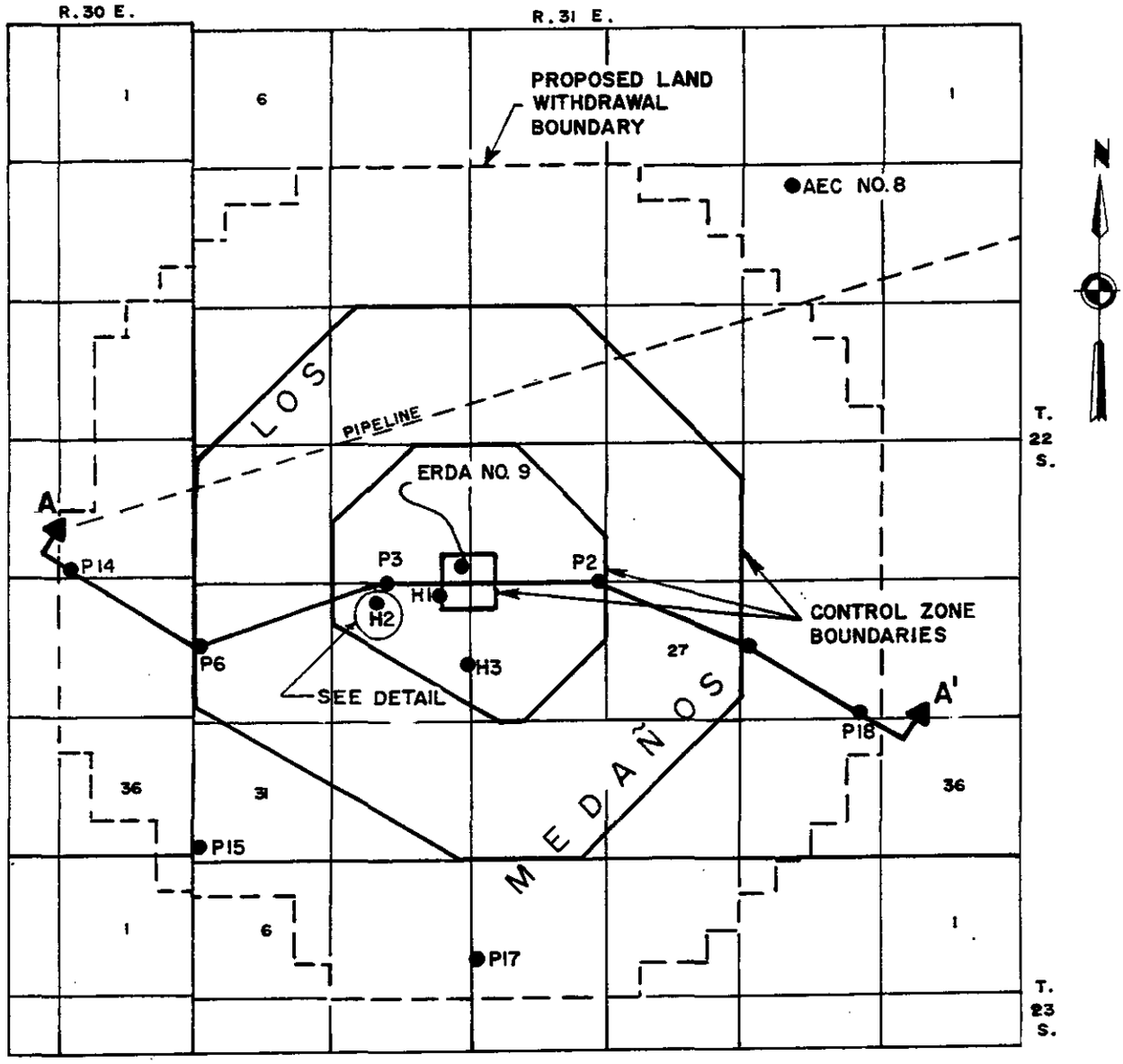

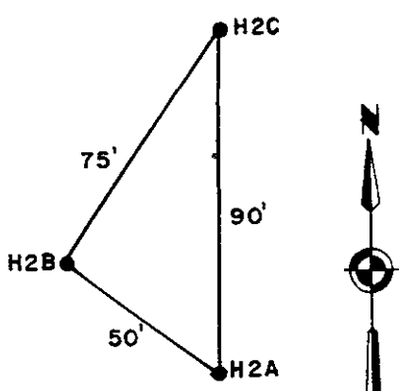

DETAIL

(H2 Configuration)

See figure 6.3-7 for Section A-A'

HYDROLOGIC TEST HOLES

FIGURE 6.3-5

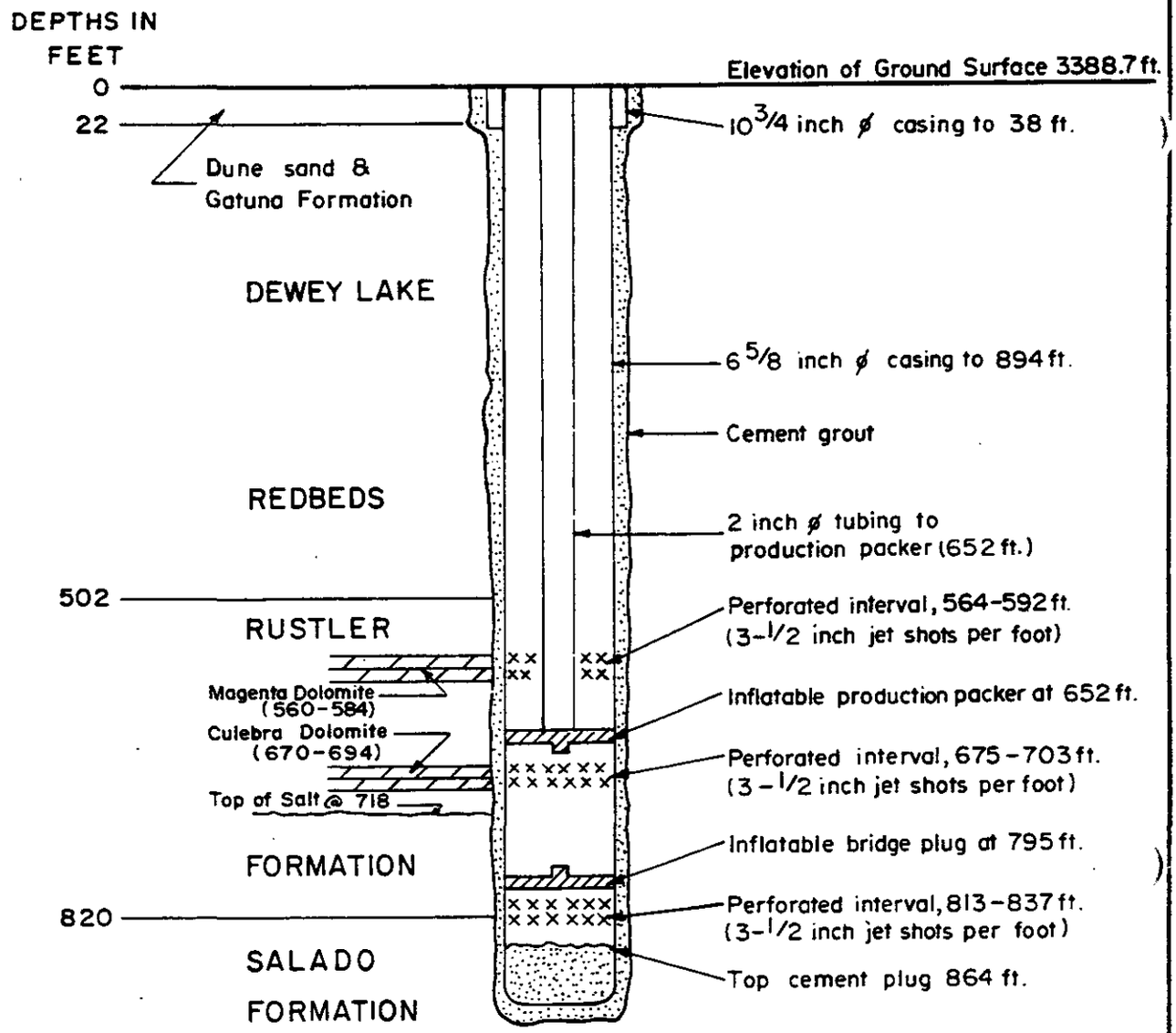

Status October 1977:

Total depth drilled: 894 ft.
Diameter of drilled hole: 9 7/8 inch
Monitoring Culebra through tubing
Monitoring Magenta in annulus
Contact zone not accessible (bridge plug)

CONSTRUCTION OF OBSERVATION WELL

FIGURE 6.3-6

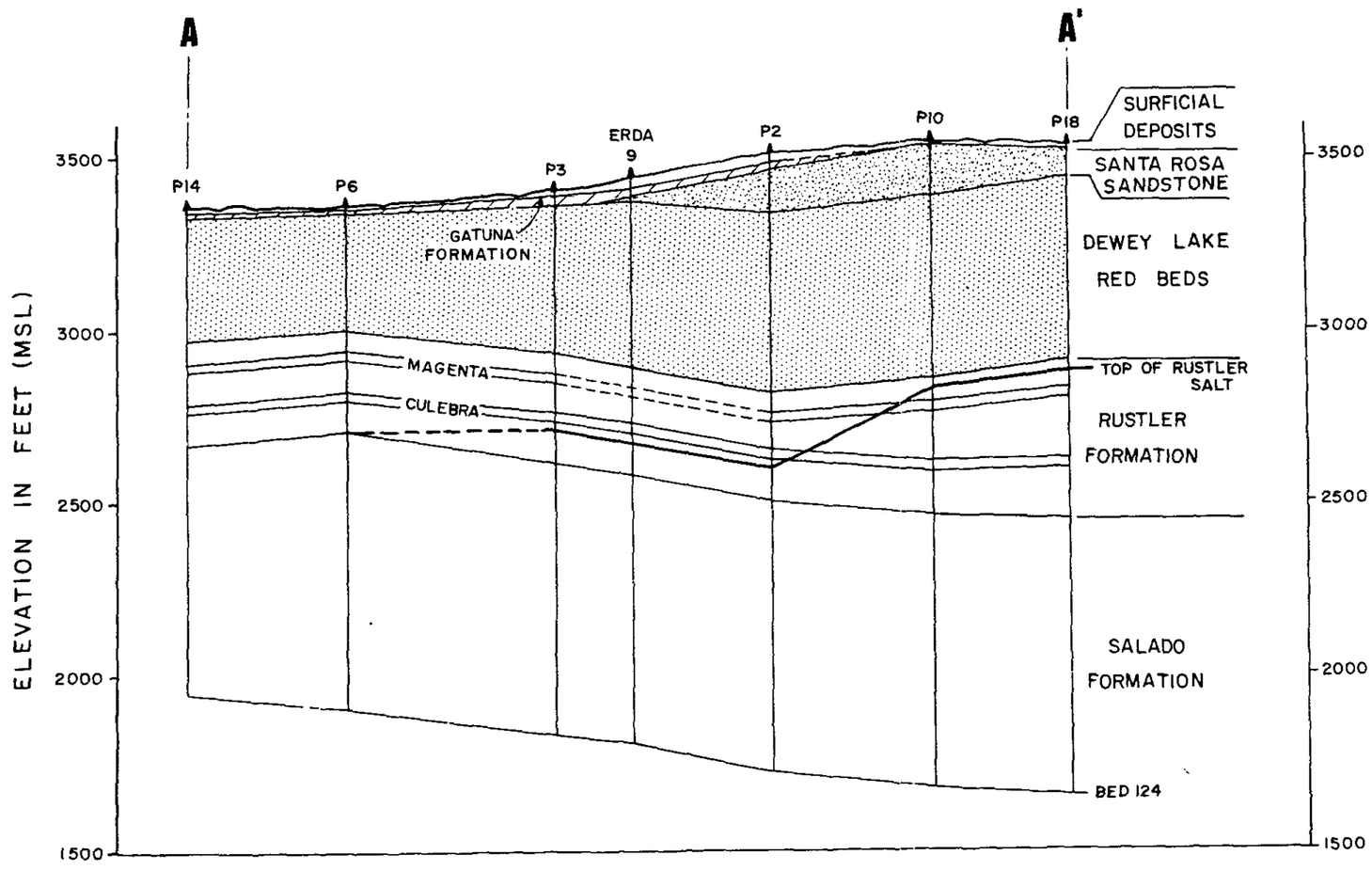

REFERENCES:

Lambert and Mercer, 1978, fig.4, p.I-15

NOTE:

For location of Section see Figure 6.3-5.

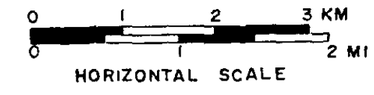

GEOLOGIC SECTION
THROUGH THE LOS MEDANOS AREA

FIGURE 6.3-7

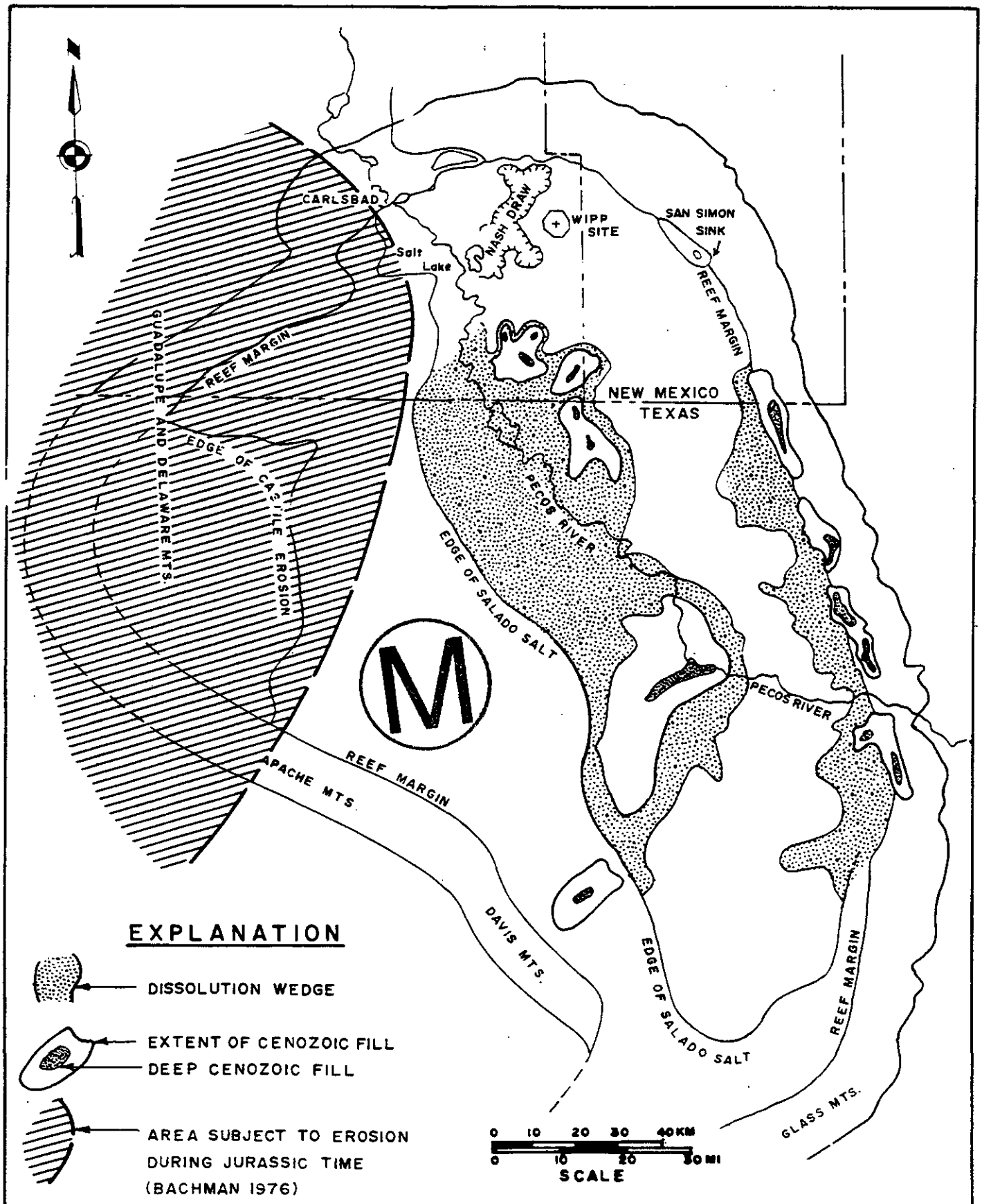

Reference: Based on Figure 1 from Anderson, 1978

DISSOLUTION FEATURES AND EXTENT OF EROSION IN DELAWARE BASIN

FIGURE 6.3-8

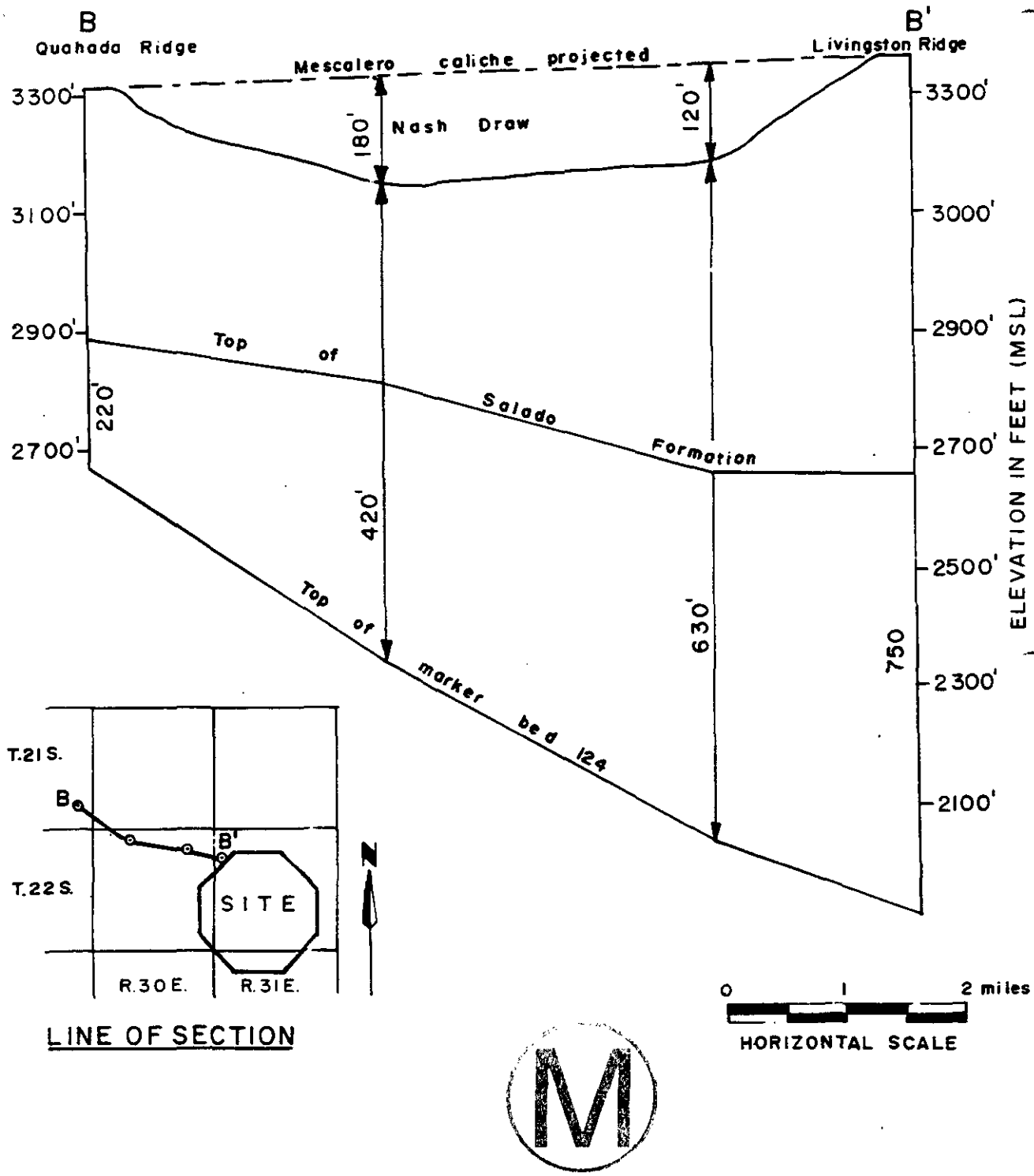

Reference: Fig. 11, USGS Open File Report 74-194, 1974

RELATIONSHIP OF NASH DRAW TO DISSOLUTION IN SALADO FORMATION

FIGURE 6.3-9

Table 6.2-1. AREAL REQUIREMENTS OF THE WIPP SITE

Zone	Zone Use	Approximate Acreage
I	Surface Facilities	60-(100)
II	Underground Storage	1,860
III	1-mile wide zone surrounding Zone II No mining or drilling.	6,230
IV	1-mile wide zone surrounding Zone III. Mining and drilling in conformance with ERDA specifications are allowed.	10,810
	TOTAL	18,960

29.6 square miles

TABLE 6.2-2

SALIENT FEATURES OF MAJOR DAMS UPSTREAM AND

DOWNSTREAM FROM WIPP SITE

Name of Reservoir	River	Drainage Area (sq. mi.)	Type of Dam	Year Completed	Height (ft.)	Max. Storage Capacity (AF)	Purpose
Sumner	Pecos	4,390	earth	1937	143	258,500	Irrigation
McMillan	Pecos	16,990	earth	1908	40	66,600	Irrigation
Avalon	Pecos	18,070	earth	1907	40	36,600	Irrigation
Red Bluff	Pecos	20,720	earth	1937	98	405,000	Irrigation & Hydro-power
Two Rivers	Rio Hondo	963	earth	1963	93	262,221	Flood Control
	Rocky Arroyo	64	earth	1963	116		

TABLE 6.2-3

WATER USE DATA FOR THE PECOS BASIN

Use category	Surface-water and groundwater withdrawals (mgd) 1975[a]
Agriculture	1546
Steam-electricity	12
Manufacturing	0
Domestic	47
Commercial	8
Mining	151
Public lands	4
Fish hatcheries	3
Total	1771

SOURCE: U.S. Water Resources Council, Second National Assessment of Water and Related Land Resources, in press.

[a]The total groundwater withdrawal for 1975 was 1079 mgd.

TABLE NO. 6.2-4

PRECIPITATION AT CARLSBAD, N.M. (in inches)

Period of Record 1931-1960

MONTH	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
Max. Precip	2.31	1.93	4.27	3.99	12.28	6.24	5.48	4.41	7.36	6.13	1.55	2.12	33.94
Av. Precip.	0.44	0.37	0.46	0.54	1.76	1.33	1.56	1.60	1.94	1.61	0.35	0.47	12.43
Min. Precip.	0	0	0	0	0.18	0	0	0.01	0	0	0	0	4.40

SOURCE: U. S. Weather Bureau, 1961.

TABLE NO. 6.2-5

TEMPERATURES AT CARLSBAD, N.M. (in °F)

Period of Record 1931-1960

MONTH	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
Max. Temp	50.4	54.8	61.2	69.1	74.6	83.6	84.2	84.6	80.6	70.8	57.4	52.6	66.3
Av. Temp.	43.8	48.4	54.8	63.3	71.4	79.8	81.4	80.8	74.2	64.1	51.5	44.7	63.2
Min. Temp.	35.2	43.6	47.8	60.1	68.4	73.4	77.4	76.7	70.2	58.2	45.8	37.5	60.3

SOURCE: U. S. Weather Bureau, 1961.

TABLE NO. 6.2-6

WATER QUALITY PARAMETERS (TIME-WEIGHTED AVERAGE)
FOR SAMPLING STATIONS ON THE PECOS RIVER,
OCTOBER, 1975, TO SEPTEMBER, 1976

Station No.	Discharge (cfs)	pH	Dissolved-solids concentration (mg/1) Total	Chloride	Sulfate	Sodium	Calcium
08405000 (Carlsbad)	12	7.7	2,500	531	1100	322	334
08406500 (Near Malaga)	26	7.7	5,390	1690	1820	1030	524
08407000 (Pierce Canyon Crossing)	28	7.5	13,900	6500	2280	4020	551

SOURCE: U. W. Geological Survey, Water-Data Report NM-76-1.

TABLE NO. 6.3-1 AQUIFER CHARACTERISTICS OF THE GUADALUPIAN AGE ROCKS (ADAPTED FROM HISS, 1976, TABLES 6 AND 7)

Geologic Unit	Avg. Hydraulic Conductivity (ft/day)	Average Porosity (%)	No. of samples or tests	
			Conductivity	Porosity
Rock Core Analysis				
Tansill Fm.	0.006	4.23	399	381
Yates Fm.	0.026	9.74	11,287	11,387
Seven River Fm.	0.140	6.56	4,367	4,485
Queen Fm.	0.029	7.79	7,324	7,648
Grayburg Fm.	0.032	7.15	1,971	1,973
Grayburg-San Andres (Und.)	0.033	5.76	7,062	7,313
Glorieta Sandstone	0.027	9.16	3,128	3,115
Delaware Mt. Gp.	0.016	15.65	4,549	4,493
Pumping Tests (San Andres)				
T.20S, R.38E, Sec. 7	0.20		(Drawdown Test)	
Same well as above	0.20		(Recovery Test)	
T.22S, R.37E, Sec. 29	0.30		(Drawdown Test)	
Pumping Tests (Capitan)				
T.21S, R27E, Sec. 5	2.4		(Recovery Test)	
T.21S, R.28E, Sec. 30	16.0		(Recovery Test)	
T.21S, R.34E, Sec. 24	3.0		(Specific Capacity)	
T.21S, R34E, Sec. 14	1.7		(Specific Capacity)	
Same Well	1.9		(Drawdown Test)	
Same Well	1.4		(Recovery Test)	
T.24S, R36E, Sec 4	24.0		(Drawdown Test)	
T.24S, R36E, Sec. 16	7.4		(Specific Capacity)	

TABLE 6.3-2 -- Records of Wells in the Los Medanos Area, New Mexico
(Adapted from Cooley, 1972, Table 4)

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
19.32.34.434	3560	260	--	Dry	9-22-72	QTs, Trc, Trsr(?)	Unused; 3 wells at this locality; no access for entering casing in the other 2 wells.
19.33.26.244	3609	--	6	90.58	9-25-72	QTs, Trc(?)	Electric Submersible; stock.
26.244a	3609	101	--	90.93	9-25-72	QTs, Trc(?)	--
19.34.31.131	3620	53	6	Dry	9-25-72	QTs	Unused; 2 ft. of water in bottom of hole--probably does not represent true water level.
31.232	3632	120R	6	--	9-25-72	QTs, Trc(?)	Windmill; stock; "Hardin Well," no access to enter casing.
20.31.13.412	3440	30	6	1.12	9-18-72	QTs	Unused.
15.130	3460	105	6	62.10	9-18-72	QTs(?), Trsr	Unused.
15.130a	3460	79	6	63.39	9-18-72	QTs(?), Trsr	Unused; 5 wells at this location of which only 1 is an operating well.
15.130b	--	--	--	--	--	QTs(?), Trsr	Windmill; stock.
20.32. 1.312	3510	20	6	Dry	9-22-72	QTs	Unused; deepest of 4 wells at this location, all wells are dry.
24.333	3555	67	5	37.67	9-11-72	QTs	Unused
24.333a	3555	--	--	--	--	QTs(?)	Windmill; stock.
27.144	3545	30	--	23.67	9-18-72	QTs	Unused; no casing present.
36.214	3585	--	--	P43.88	9-18-72	QTs	Windmill; stock; 3 wells at this location at Bingham ranch, well pumping estimated at 2 gallons per minute.

TABLE 6.3-2 (continued)-- Records of Wells in the Los Medanos Area, New Mexico

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
20.33. 4.432	3555	4		Dry	9-22-72	QTs	Unused.
18.123	3521	249	6.5	245.58	9-25-72	Trc	Unused.
21.111	3536	49	6	36.90	9-25-72	QTs	Unused.
24.124	3630	680	12	405.15	9-22-72	Trc, Trsr(?)	Windmill; stock; "West Windmill," watersand at about 300 feet as reported by driller.
20.34. 4.444	3633	200	8	P174.08	10-2-72	Trc	Windmill; stock; "Robert's Well," old oil test drilled before 1930.
14.133	3648	230		190.25	10-2-72	Trc	Windmill; stock.
17.334	3640	220(?)	8	P129.68	10-2-72	Trc	Windmill; stock; "City Service Well," possibly oil test.
22.224	3655	220	12	196.49	10-2-72	Trc	Windmill; stock; "North Well," old oil test
34.432	3770	96	6	89.50	10-2-72	QTs	Windmill; stock.
21.30.18.333	3220	156	6	129.54	9-25-72	Pru	Unused.
22.423	3180	130	6	111.50	9-25-72	Pru	Unused.
21.31. 1.131	3580	30R	6	20.80	9-18-72	QTs	Windmill; domestic & in stock; at Campbell Ranch.
1.241	3600	--	--	--	--	--	"Grave Well."
2.221	3570	35	--	29.80	9-18-72	QTs	Windmill; stock.
7.331	3350	367	14	192.10	9-14-72	Pru, Prc (?)	Unused.
13.244	3600	68	6	Dry	9-13-72	QTs, Trc	Unused.
18.411	3310	--	6	158.32	9-14-72	Pru	Windmill; stock; "New Well."
30.421	3300	176	6	Dry	9-25-72	Pru	Unused.

TABLE 6.3-2 (continued)-- Records of Wells in the Los Medanos Area, New Mexico

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
21.32. 6.111	3598	54R	--	44.00R	9-18-72	QTs	Windmill; domestic & stock; at Allred Ranch; 2 wells at this location.
21.33. 2.231	3810	1150R	--	--	9-22-72	Trsr	Unused; could not pass tape below 550 feet in 1972.
2.420	3770	94	6	79.58	9-22-72	QTs	Windmill; stock.
4.434	3805	147	--	129.66	10-2-72	QTs(?), Trc	Unused.
4.434a	3805	127	--	Dry	10-2-72	QTs(?), Trc	Unused.
18.114	3890	150	--	140.75	9-12-72	QTs	Windmill; stock.
18.114a	3890	175	--	142.88	9-12-72	QTs	Unused.
18.123	3855	--	--	--	9-12-72	QTs(?)	Windmill; stock.
18.123a	3855	145	8	117.30	9-12-72	QTs	Unused.
18.131	3895	11	--	Dry	9-12-72	QTs	Unused.
25.421	3670	67	--	56.58	9-22-72	QTs	Windmill; stock; "West Well."
28.124	3688	210	8	179.00	9-22-72	Trc	Windmill; stock; "Standard Wells," 3 wells at this location.
22.30. 5.431	3120	225	14	53.25	9-19-72	Pru, Prc(?)	Unused.
6.444	3140	176	22	92.40	9-19-72	Pru	Unused.
7.244	3110	58	12	Dry	9-19-72	Pru	Unused.
10.311	3135	68	6	63.70	9-12-72	Pru	Unused; at Crawford Ranch.
20.120	3076	10	5	Dry	9-19-72	QTs, Pru	Unused.
32.111	3010	35	6	32.70	9-19-72	Pru	Unused.
22.31.15.130	3460	--	--	144.07	9-12-72	Trsr(?) Pdl	Windmill; stock.
15.130a	3460	--	--	145.50	9-12-72	Trsr(?) Pdl	Unused.

TABLE 6.3-2 (continued)-- Records of Wells in the Los Medanos Area, New Mexico

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
22.32.14.323	3717	380	--	367.80	9-13-72	Trsr	Jenson Jack; stock; "Comanche Wells."
14.324	3720	380(?)	--	370.40	9-13-72	Trsr	Windmill; stock; "Comanche Wells."
22.33. 5.321	3650	10	6	0.0	9-22-72		Windmill; stock; well on edge of Dagger Lake.
13.231	3515	490	6	388.05	9-21-72	Trc	Windmill; stock; "Roger's Well."
13.231a	3515	400	6	388.05	9-21-72	Trc	Windmill; stock.
20.244	3602	--	--	--	--		Unable to locate well in 1972.
23.30. 2.444a	3250	315	7	257.73	9-20-72	Prc	Windmill; stock; "Little Windmill," well 444 destroyed.
6.424	2980	--	6	0.0	9-20-72	--	Unused; "Nash Well," area flooded by lake.
19.123	3045	--	7	68.55	9-20-72	Prc	Windmill; stock.
21.122	3165	--	5	--	9-20-72	Pru, Prc(?)	Windmill; stock; "Indian Well," no access for water level measurement.
		204	5	179.25	4-6-59	Pru, Prc(?)	
22.234	3210	244	--	227.32	9-20-72	Pru, Prc(?)	Unused.
33.244	3438	696	--	--	--	Pru, Prc	Abandoned; at Gnome Site, plugged 6-25-69, USGS No. 5.
34.133	3413	518	--	433.91	9-25-72	Pru, Prc	Observation; at Gnome Site, USGS No. 4.
				433.67	12-12-61	Pru, Prc	
34.133a	3413	--	--	427.03	9-25-72	Pru, Prc	Unused; at Gnome Site, USGS No. 8.
34.234	3401	568	6	415.70	4-14-62	Pru, Prc	Observation; at Gnome Site, USGS No. 6, drld to 1499' & plugged back to 568'.
34.234a	3402	563	6	418.10	4-16-62	Pru, Prc	Observation; at Gnome Site, USGS No. 7, drld to 1507' & plugged back to 563'.
34.324	3426	567	--	441.67	9-25-72	Pru, Prc	Observation; at Gnome Site, USGS No. 1.
				442.40	9-22-60	Pru, Prc	

TABLE 6.3-2 (continued)-- Records of Wells in the Los Medanos Area, New Mexico

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
23.31. 6.320	3300	213	8	144.72	2-4-59	Pdl	Windmill; domestic.
6.320a	3300	400R	--	--	--	Pdl, Pru	Windmill; domestic; tape will not pass 222' in 1972.
6.444	3310	--	6	106.35	9-20-72	Pdl	Windmill; domestic.
7.240a	3315	--	6	62.27	9-20-72	Pdl	Windmill; stock.
17.310	3305	--	--	--	9-20-72	Pdl, Pru	Windmill; stock.
26.340	3451	--	6	250.47	9-20-72	Pdl	Windmill; stock.
29.113	3335	--	4	139.90	9-20-72	Pdl	Windmill; stock.
23.32. 3.311	3660	550R	8	--	9-13-72	Trsr	Windmill; stock.
3.311a	3660	--	10	204.18	9-13-72	Trsr	Unused.
21.241a	3680	515	--	480.75	9-21-72	Trsr	Windmill; stock.
		550	6	510.00R	4-13-59	Trsr	
23.33.12.312	3530	388	12	351.45	9-21-72	Trsr	Windmill; stock; "Allred Well."
17.423	3702	650(?)	8	504.40	9-21-72	Trc(?), Trsr	Submersible; stock "Graham Wells."
26.421	3645	173	6	165.15	9-21-72	Trc	Windmill; stock; "Tip Top Wells."
26.421a	3645	189	6	P184.00	9-21-72	Trc	Windmill; stock; "Tip Top Wells."
28.334	3675	544(?)	--	500.00R	11-27-53	Trc(?), Trsr	Windmill; stock & domestic; at Brinninstool Ranch, 2 wells at this location, tape will not pass 220' in either well.

Explanations

(1) Geologic source: QTs, surficial deposits; Trc, sandstone beds in the Chinle Formation; Trsr, Santa Rosa Sandstone; Pdl, Dewey Lake Redbeds; Pru, Rustler Formation above Culebra Dolomite Member, including Magenta Dolomite Members; Prc, Culebra Dolomite Member of Rustler Formation.

(2) Altitute: From topograhical maps.

(3) Depth of well: All depths of wells were obtained in 1972; all depths to water in the wells measured in 1972 or before are listed; R, reported depth; P, pumping level; < , than.

TABLE 6.3-3: Water Quality Data (from Table 2, Mercer and Orr, 1978) reported in parts per million

Monitor Well of Sample	Date	pH Units	Temperature (Celsius)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)
Magenta Dolomite										
H-1	5/10/77	7.2	22.0	1,000	460	6,200	840	93	0	3,600
H-2a	2/22/77	8.6	22.0	820	170	2,700	81	74	0	2,400
H-3	5/10/77	8.0	22.5	1,200	480	9,300	250	51	0	3,400
Culebra Dolomite										
H-1	3/17/77	7.3	22.5	820	1,800	29,000	5,600	100	0	11,000
H-2b	2/22/77	8.4	21.5	690	160	2,100	91	59	5	3,000
H-2c	3/16/77	8.1	20.5	680	120	3,600	120	62	0	3,200
H-3	3/17/77	7.4	21.5	1,500	670	19,000	630	115	0	5,700
P-14	3/14/77	6.0	21.5	3,100	760	7,600	600	357	0	1,400
P-15	5/10/77	10.2	21.5	770	63	6,900	1,700	63	24	3,200
P-17	5/10/77	7.4	22.5	1,700	1,600	30,000	120	77	0	5,000
P-18	5/10/77	7.2	24.5	5,600	16,000	9,200	6,200	310	0	980
Rustler-Salado Contact										
H-1	2/22/77	7.9	21.0	13,000	30,000	56,000	17,000	675	0	520
H-2c	2/23/77	5.9	20.5	9,200	25,000	66,000	9,100	199	0	1,300
H-3	2/24/77	7.6	21.5	18,000	25,000	59,000	14,000	467	0	370
P-14	2/24/77	7.2	24.5	570	1,200	120,000	1,300	222	0	10,000
Delaware Sand										
AEC-8	9/22/77	6.0	30.0	10,000	2,500	55,000	860	420	0	240

Table 6.3-3 Continued

Monitor Well	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved Solids (Sum of constitents)	Nitrate* +Nitrate (N)	Ortho* Phosphorus (P)	Boron* (B)	Iron* (Fe)	Manganese* (Mn)
Magenta Dolomite									
H-1	10,000	2.0	1.7	22,200	0.04	0.03	3.3	0.22	0.95
H-2a	4,100	-	6.0	10,300	0.04	0.01	0.22	0.06	<0.05
H-3	15,000	1.8	6.4	29,700	0.08	0.04	13.0	0.04	0.22
Culebra Dolomite									
H-1	49,000	0.8	0.6	97,300	0.03	0.00	18.0	0.79	2.8
H-2b	2,800	2.0	1.7	8,890	0.01	0.03	9.5	0.02	0.2
H-2c	4,700	1.6	3.5	12,500	0.16	0.00	10.0	0.11	0.14
H-3	29,600	0.5	1.2	57,200	0.07	0.00	20.0	0.05	0.12
P-14	20,000	0.9	33	33,700	0.01	0.02	0.7	17	0.5
P-15	11,000	1.2	1.6	23,700	0.04	0.03	4.7	0.1	0.02
P-17	54,000	1.5	1.0	92,500	0.06	0.11	1.7	1.2	3.0
P-18	80,000	1.2	1.0	118,000	0.81	0.40	100.0	0.54	4.5
Rustler-Salado Contact									
H-1	210,000	-	0.0	327,000	0.29	0.00	110	1.5	52
H-2c	200,000	-	2.0	311,000	1.1	0.00	150	2.5	78
H-3	210,000	-	1.0	327,000	0.77	0.00	1.9	1.5	3.8
P-14	180,000	-	2.0	313,000	0.34	0.08	1.7	2.1	3.4
Delaware Sand									
AEC-8	120,000	1.2	3.6	189,000	0.11	0.05	53	23	14.0

* Due to sampling conditions, analyses of NO_3^{-1}, PO_4^{-3}, BO_3^{-3}, Fe^{+2}, and Mn^{+2} are probably no more precise than ±15%. The others have a precision of about ±5%.

TABLE 6.3-4 Fluid Yield From Test Zones
(gallons per day)

Hole No.	Test Interval (depth in ft)	Magenta Dolomite	Culebra Dolomite	Salt Residue Zone in Rustler Fm.	Rustler-Salado Contact	Bell Canyon Sand
	Open hole, drill stem tests (1)					
H-1	562 - 592	23.1				
	626 - 667			22.4		
	667 - 669		22.1			
	669 - 842				10.9	
H-3	558 - 608	14.1				
	672 - 703		2.3			
	703 - 780			1.8		
	800 - 868				2.6	
	Open hole, bailing tests (2)					
H-2a	513 - 563	27				
H-2b	611 - 661		260			
H-2c	743 - 795				0.8(3)	
	Cased hole with perforated interval, bailing tests (2)					
H-1	562 - 590	66				
	675 - 703		46(4)			
	803 - 827				1.0(5)	
H-2b	510 - 538	210				
H-2c	624 - 652		310			

TABLE 6.3-4 (continued) Fluid Yield From Test Zones
(gallons per day)

Hole No.	Test Interval (depth in ft)	Magenta Dolomite	Culebra Dolomite	Salt Residue Zone in Rustler Fm.	Rustler-Salado Contact	Bell Canyon Sand
	Cased hole with perforated interval, bailing tests (2)					
H-3	562 - 590	(8640)(6)				
	675 - 703		200			
	813 - 837				11/32d(8)	
P-14	573 - 601		(5760)(7)			
	676 - 700				75	
P-15	410 - 438		50		2.0/42d(8)	
P-17	558 - 586		170			
	702 - 726				1.0/72d(8)	
P-18	912 - 940		0.5/33d(8)			
	1076 - 1100				0.5/73d(8)	
AEC-8	4844 - 4860					269(9)

NOTES:

(1) Inflows measured over periods ranging from 11.5 to 37.5 hours.
(2) Inflows monotired for periods ranging from 8 days to 217 days. Rate based on inflow during first 24 hours.
(3) Inflow of 14 gallons in 18 days (no other data).
(4) Inflow of 416 gallons in 9 days (no other data).
(5) Average trend after 33 days recovery.
(6) Bailed 360 gallons in 1 hour with 6 feet of drawdown.
(7) Bailed 720 gallons in 3 hours with no drawdown.
(8) Early measurements inconclusive; inflow for period of days (d) indicated.
(9) Recovery measured for only 2.8 hours.

TABLE NO. 6.3-5

OBSERVATION WELLS - MONITORING ZONES

WELL NO. (GROUND ELEV.)	ZONE TESTED	ACCESSIBLE DEPTH	INTERVALS ELEV.
H-1	Magenta	562-590	2841-2813
(3403)	Culebra	675-703	2728-2700
	Rustler-Salado	803-827	2600-2576
H-2a	Magenta	No tests except levels	
H-2b	Culebra	510-538	2867-2839
H-2c	Culebra	624-652	2753-2725
(3377)	Rustler-Salado	743-795	2634-2582
H-3	Magenta	562-590	2837-2799
(3389)	Culebra	675-703	2714-2686
	Rustler-Salado	813-837	2576-2552
P-14	Culebra	573-601	2785-2757
(3358)	Rustler-Salado	676-700	2682-2658
P-15	Culebra	410-438	2900-2872
(3310)	Rustler-Salado	532-556	2778-2754
P-17	Culebra	558-586	2782-2754
(3340)	Rustler-Salado	702-726	2638-2614
P-18	Culebra	912-940	2567-2539
(3479)	Rustler-Salado	1076-1100	2403-2379
AEC-8	Bell Canyon (Upper)	4821-4827	[1289-1295]*
(3532)	Bell Canyon (Lower)	4844-4860	[1312-1328]*

*Elevations in brackets are below mean sea level; all other elevations are above msl. All depths and elevations are given in feet.

TABLE NO. 6.3-6

POTENTIOMETRIC LEVELS
OCTOBER 1977
(Elevation in Feet)

Observation Well	Ground Surface Elevation	Magenta Dolomite	Culebra Dolomite	Rustler-Salado Contact	Delaware Sands "Upper"	Delaware Sands "Lower"
H-1	3,403	3,154	3,013	Not Monitored[1]		
H-2a	3,377	3,128	Not Penetrated	Not Penetrated		
H-2b	3,377	3,081	3,026	Not Penetrated		
H-2c	3,377	Not Screened	3,021	34'/Month[2]		
H-3	3,389	3,141	2,984	Not Monitored[1]		
P-14	3,358	Not Screened	3,034	2,970		
P-15	3,310	Not Screened	3,002	2,975		
P-17	3,340	Not Screened	2,968	2,970		
P-18	3,479	Not Screened	8'/month[2]	40'/month[2]		
AEC-8	3,532	Not Screened	Not Screened	Not Screened	2,927	2,933

NOTES:

[1]The Rustler-Salado contact is accessible, but is temporarily off.

[2]Recovery Rate: Level in tubing had not reached static level in October, 197

GCR CHAPTER 7

GEOCHEMISTRY

7.1 INTRODUCTION

In the context of this Geological Characterization Report, "geochemistry" is taken here to include a description of chemical properties of geologic media presently found in the surface and subsurface environments of southeastern New Mexico in general, and of the proposed WIPP withdrawal area in particular. "Chemical properties of geologic media" might be extended to include a description of present understanding of chemical processes which have taken or are taking place in southeastern New Mexico rocks. This geochemistry chapter of the WIPP Geological Characterization Report does not consider any aspect of artificially-introduced material, temperature, pressure, or any other physico-chemical condition not native to the rocks of southeastern New Mexico. These as-yet hypothetical considerations belong in the realm of interactions between radioactive waste and rock, a subject of the experimental programs initiated as part of the WIPP studies that are not yet completed. Early experimental results of radionuclide interactions with southeast New Mexico rocks and fluids are reported in Chapter 9.

A substantial fraction of this chapter consists of original source material, never before published in any format aside from reports of investigations resulting from research contracts. Much of this material is, however, in the process of being recast so as to be suitable for presentation in various professional forums. Some material has already been so presented.

Information contained herein was offered if the work involved was at a suitable stage of completion so as to allow conclusions to be drawn. Some subjects of investigation related to geochemistry require several years more investigation, even for final site characterization, and are discussed in Chapter 10, "Continuing Studies." Subjects of the present chapter are those which provide background data of relevance to (1)

experimental programs involving radioactive waste and its interaction with geomedia, (2) borehole plugging, (3) the intrinsic physico-chemical stability of southeastern New Mexico rocks in the geologic past, and (4) safety assessment, which is described in other major documents relating to the proposed WIPP. These data include mineralogy, volatile constituents of rocks, the constitution, origin and history of liquids and gases found in rocks, and the lengths of time which have passed since the latest episodes of thermodynamic instability resulting in rock/fluid interactions.

In the absence of a satisfactory theoretically-formulated mathematical model which can accurately predict phase equilibria among complex evaporite minerals, an empirical approach, based on observed assemblages, is adopted here. Such modelling is beyond the scope of this document.

It will be noted that volatile contents of evaporites were determined by three different methods: static heating (Section 7.5.3), thermogravimetric analysis (Section 7.5.2) and counting of fluid inclusions (Section 7.6). Each set of data was collected for a different geochemical purpose, but results from all techniques show comparable amounts of volatile constituents in the evaporites. The most accurate results, however, are probably those derived from static heating.

7.2 THE MINERALOGY OF DELAWARE BASIN EVAPORITES AND RELATED ROCKS OF THE LOS MEDANOS AREA

7.2.1 Introduction

The foregoing sections on geology and stratigraphy have briefly mentioned generalized mineralogies of Delaware Basin rocks of the Los Medanos area. Here it becomes of interest to present a more thorough exposition of mineralogies. This is done for a variety of reasons: (1) mineralogies affect properties of rocks important to physical aspects of mining, (2) soluble minerals in rocks potentially give rise to solutions which can interact with waste and its containers, and (3) minerals in

rocks have various degrees of sorptive affinities for radionuclides and can serve to decrease their mobility. While this section is devoted mainly to an account of the minerals found in the main Ochoan evaporite section (Castile and Salado Formations), mineralogies of some Guadalupian rocks and some rocks above the main evaporite section are included. This information is particularly useful to the consideration of radionuclide mobility in rocks containing substantially more fluid than the evaporites, and is of fundamental importance to in situ experiments involving waste-rock interactions. Also, investigations of fluid inclusions, sources of volatiles, groundwater geochemistry and age-dating of rocks and waters are closely related to mineralogy.

7.2.2 Previous Work

Southeastern New Mexico evaporites have been economically important for many years because they contain the well-known McNutt Potash Zone in the middle part of the Salado Formation. Descriptions of mineralogies of the McNutt and adjacent portions of the Salado have been given in several previous reports covering much of the Permian Basin, and environs of southeastern New Mexico (Brokaw et al., 1972; Jones, 1973; Jones, 1974a; Jones, 1974b; Jones, 1975). A detailed review of the economic mineralogy of the McNutt Potash Zone underlying Los Medanos appears in Chapter 8 of this report. This section on mineralogy has been developed as background critical to mine design, waste-rock-fluid interactions, and other aspects of geochemistry, such as age-dating and radionuclide migration.

7.2.3 Overview of Evaporite Mineralogy

X-ray powder diffraction examination of 50 core samples from ERDA #9 in the center of the study area (Figure 4.1-2) has been completed. Only qualitative information was obtained from these preliminary cores in order to assess mineralogical variations among selected horizons.

As-received cores were crushed and ground to bulk powder to provide a representative sample of that zone, x-ray specimen mounts weres scanned

at 1°/min on a diffractometer equipped with copper x-ray source, graphite monochrometer and scintillation detector.

Eight minerals were identified in the 50 samples:

1.	anhydrite	$CaSO_4$
2.	clay	$Al_2Si_4O_{10}(OH)_2 \quad xH_2O$
3.	halite	$NaCl$
4.	loeweite	$Na_{12}Mg_7(SO_4)_{13} \quad 15H_2O$
5.	magnesite	$MgCO_3$
6.	polyhalite	$K_2Ca_2Mg(SO_4)_4 \quad 2H_2O$
7.	quartz	SiO_2
8.	sylvite	KCl

Their occurrence is given qualitatively in Table 7.1 with a corresponding graphical distribution shown in Figure 7.1. Trace amounts of the potassium minerals sylvite and polyhalite were found in the proposed TRU horizon (2034-2110'), and the high-level horizon (2594-2692') was void of potash.

7.2.4 Mineralogy of Fluid-Bearing Zones in the Rustler Formation and Delaware Mountain Group

Mineralogies of certain fluid-bearing rocks above and below the main evaporite sequence have been determined as background information for radionuclide sorption studies.

Magenta Member, Rustler Formation (AEC No. 8). The Magenta member of the Rustler Formation is largely ferroan dolomite, probably containing minor ankerite which gives rise to the reddish color in weathered outcrops. This rock also contains detrital quartz, and gypsum forms as crystals, filling the vugs in the dolomite, which can be up to several cm across.

Culebra Member, Rustler Formation (AEC No. 8). Like the Magenta, the Culebra member is largely dolomite, with traces of detrital quartz. In addition, small amounts of calcite are found.

Bell Canyon Sandstone (AEC No. 8). The Bell Canyon Formation is the uppermost unit in the Delaware Mountain Group immediately underneath the main evaporite sequence. It is mostly detrital quartz and major feldspar with a matrix of kaolinite and chlorite cemented with calcite and minor amounts of dolomite.

Cherry Canyon Sandstone (Pine Springs Outcrop). Although the Cherry Canyon Formation was not sampled in any WIPP exploratory borehole, its stratigraphic position directly underneath the Bell Canyon made it of interest in preliminary radionuclide sorption measurements. The detrital component is largely quartz, and the cement is mostly dolomite. Minor amounts of albite and microcline contribute to the detrital component, and minor amounts of gypsum and calcite are found in the cement.

7.3 DETAILED CHEMISTRY AND MINERALOGY OF SOLUBLE AND INSOLUBLE COMPONENTS OF THE SALADO FORMATION

7.3.1 Introduction

While this section deals primarily with results obtained from cores from AEC No. 7 and AEC No. 8, exploratory holes three miles northeast of the present study area (Figure 4.1-2), these holes provided material of sufficient lithologic similarity to ERDA No. 9 so as to be of value. The analytical strategy employs a normative-type calculation, in which mineralogical compositions are derived mathematically from bulk chemical compositions. The results of those calculations then can be compared to mineralogies determined petrographically or by x-ray diffraction. This section serves as fundamental background information for the chapters on silicate mineralogy and sources of volatile components within the evaporites.

7.3.2 Materials and Methods

Sample Preparation and Handling. The core samples as received were halved and one-half was retained while the remaining half was crushed and ground. The ground sample was size-distributed as shown in Table 7.2.

The samples were all double-wrapped for storage in plastic bags due to their hygroscopic nature. A portion of the crushed sample weighing approximately 20 grams was accurately weighed and dried in an oven at 70°C for two hours to determine weight loss. The dried sample was then added to 200 ml of distilled water, stirred for 1 hour, and filtered. The filtered material was dried and weighed to determine the insoluble portion of the sample while the filtrate contained the soluble portion of the sample.

Analysis of Soluble Portion. The elements potassium, calcium, magnesium, silicon, iron, aluminum, and strontium were analyzed by standard atomic absorption methods using a Perkin-Elmer 403 Atomic Absorption Spectrophotometer. Sodium, typically difficult to analyze precisely, was analyzed using an Orion Specific Ion Sodium electrode and an Orion Research Model 801 pH meter. Sulfate was determined gravimetrically as barium sulfate; chloride was determined volumetrically by titrating with mercuric nitrate (Vogel, 1961)

Analysis of Insoluble Portion. The insoluble portion was separately analyzed only if the insoluble percentage was greater than 0.5% of the total sample weight. Samples containing less than 0.5% insolubles did not provide sufficient material for analysis, and it was deemed that even a major constituent in such a small percentage of the total would not contribute significantly to the sample behavior. A portion of the water-insoluble material weighing about 100 mg was dissolved in HF, using the following procedure in a teflon-lined high pressure bomb (Bernas, 1968; 1973) obtained from Parr Instruments. Nitric acid (1 ml) was added

to wet the sample and 3 ml of 50% HF were added. The bomb was assembled and placed in a 70°C oven for 2 hours. The contents of the bomb were quantitatively transferred to a polypropylene beaker containing 2.8 g of boric acid and about 30-40 ml deionized water. The boric acid was allowed to dissolve with stirring and the solution diluted to 100 ml in a volumetric flask and stored in a polyethylene bottle. A solution containing all of the matrix material was prepared for use in making standards for the atomic absorption spectrophotometer. All analyses were performed as described in the preceding section. Samples were tested for the presence of carbonates using concentrated HCl but only occasionally was a trace amount detected.

Thermal Analysis. Samples analyzed for weight loss upon heating were ground so that greater than 90% of the sample was smaller than 100 mesh. Each sample was dried for at least 3 days at 65°C in a thermostatically regulated oven. This temperature was chosen to avoid the long-term dehydration of gypsum described elsewhere in this report. Low temperature weight loss (70°C for 2 hours) was used to measure absorbed water. This weight loss is probably higher than for rock distant from the sample collection point owing to absorption of drilling water. Samples of 100 mg weight were heated for differential thermal analysis (DTA) using a Fisher 200A DTA apparatus at a rate of 10°C/min from 25°C to 500°C.

Thermogravimetric analysis was carried out with a Fisher 100A TGA apparatus and a Cahn Model R6 electrobalance at a rate of 5°C/min from 60°C to 500°C using 100 mg of sample material. A few samples were heated to 800°C and are described elsewhere in this subsection.

Results of Analyses. Whole-rock chemical analyses, soluble-insoluble fractions, and weight losses upon heating are presented in Appendix 7.A. These analyses are converted to relative numbers of moles of components by multiplying weight percents by appropriate values of 1000/molecular weight. The results are listed in Appendix 7.B. If the insoluble fraction of a sample exceeds 0.5 weight percent, separate calculations are provided for both the soluble and insoluble fractions of the sample.

7.3.3 Results and Discussion

Distribution of Mineral Phases. Chemical analyses may be used to estimate, semiquantitatively, the amounts of constituent minerals present in a rock. This is accomplished by distributing the quantitatively determined chemical components among mineral phases known qualitatively to be present in the rock. The method was as follows:

The distribution of the total number of moles (Nt) of a given chemical component (c) among the various mineral phases (p) present in a rock is described by the equation

$$Nt,c = \Sigma\ (Np)\ (Nc,p)$$

where:

Nt, c = the total number of moles of the component c in the rock

Np = the total number of moles of each of the mineral phases p in the rock,

Nc,p = the number of moles of the component c in one mole of phase p.

This equation is simply a statement of conservation of mass, indicating that the total amount of a given chemical component must be distributed among the minerals containing that component; this distribution is controlled by the specific chemical compositions of the minerals. An expression of the form of the above equation may be written for each of the components present in a rock sample. For a given rock, one of three conditions are possible for the set of simultaneous equations describing the distribution of all components in that rock:

1) if the number of equations (1 for each component) is equal to the number of unknowns (the moles of each of the phases), an exact solution to the equations may be determined.
2) if the number of components exceeds the number of phases (more equations than unknowns) the system is overdetermined and a solution to the equations may be evaluated by a method such as least squares regression.
3) if the number of components is less than the number of phases (more unknowns than equations), the system is indeterminate.

If either of the first two criteria are met, the chemical composition of the rock can be employed to calculate the quantitative amounts of minerals known, qualitatively, to be present.

An important assumption for the treatment described above is that the chemical composition of all mineral phases is known. This is necessary in order to define Nc,p for all phases in the mass balance equations. If a mineral of variable composition is present in a rock sample (i.e., a solid solution), an additional variable is introduced to the set of equations; that is, the composition of the solid solution. This additional variable may change a set of N equations and N unknowns (condition 1 above) to an indeterminate set containing N + 1 unknowns. If such is the case, it is necessary to employ some additional analytical technique to determine the actual composition of the unknown. On the other hand, if the solid solution is present in a rock meeting condition 2 above, it will suffice to simply introduce two values of Np for the phase; in other words, an unknown for the number of moles of each of the pure end-members of the solid solution present. The composition of the mineral is then defined by the relative number of moles of each of the end-members present.

Qualitative mineralogy may be carried out by a variety of methods such as x-ray diffraction and thin-section analysis in addition to straight-forward examination. The chemical data obtained during this study have been used to attempt to estimate relative amounts of minerals present in the various samples. With only a few exceptions, the rocks are made up essentially of halite, and other mineral phases are present in comparatively minor or trace amounts.

Samples from the Carlsbad boreholes consist of two chemically distinct fractions: (1) water-soluble chlorides and sulfates of sodium, potassium, calcium, and magnesium, and (2) water-insoluble silicates of potassium, magnesium, and aluminum with quartz and iron oxide. Minerals of the first group generally contain stoichiometric compositions, whereas those of the second group exhibit extensive compositional variation. In

the case of the soluble portion, sodium occurs mainly with chloride as halite, while the other cations combine in various proportions with sulfate (and only occasionally chloride) forming minerals such as polyhalite, anhydrite, and kainite. These sulfates are of importance because they contain hydrate water which may be released upon heating. Silicates also undergo dehydration at elevated temperatures, but generally much higher temperatures are required than for the soluble salts because the water must be derived through destruction of hydroxyl groups. Compositions of minerals from these two classes are listed in Table 7.3.

Recognizing that soluble potassium, calcium, and magnesium are combined with sulfate, a semiquantitative estimate of various sulfate phases may be made by plotting the relative numbers of moles of the cations on triangular composition diagrams. The compositions of various stoichiometric mineral phases in the sulfate group are shown on such a diagram in Figure 7.2. No sulfate of potassium alone is common in nature, so sylvite is placed at the potassium apex of the triangle. Also shown on this diagram are the chloride and chloride-sulfate of potassium and magnesium. Not shown on Figure 7.2 are the soluble sulfates containing sodium. After plotting a given sample composition in terms of relative numbers of moles of soluble K_2O, CaO, and MgO, the total number of moles of these cations is compared to the number of moles of sulfate determined analytically; if the two are equal, then the minerals in the rock are estimated using the location of the sample on the diagram. If the cation sum is greater than available sulfate, an appropriate amount of chloride is added to make up the charge balance. Relative amounts of chloride and sulfate are then used in conjunction with the cations to determine appropriate amounts of carnallite, kainite and/or sylvite. If on the other hand, cations are deficient relative to sulfate, then sodium is added to the sulfate group to form bloedite, glaserite and/or glauberite.

The addition of sodium or chloride must be compatible with the relative amounts of these two components in the analysis. Generally, these are

present in such large amounts that a small error in their contents provides sufficient amounts for addition to the potassium-calcium-magnesium-sulfate fraction. In many instances, it is found that when it is necessary to do such addition, the appropriate component (sodium or chloride) is present in excess of the other necessary to form halite. Where such addition is not compatible with the chemical analysis, examination must be made of the insoluble portion of the sample. Where anhydrite-gypsum is present in significant amounts in a sample, the relatively low solubility of $CaSO_4$ (and possibly polyhalite) causes this phase to appear in both the soluble and insoluble fractions.

Minerals of the insoluble fraction consist of quartz, iron oxide, and a variety of clay minerals which are difficult to identify due to fine-grain-size and compositional variability. Iron probably occurs chiefly as either hematite (much of the halite is tinted orange) or an equivalent hydrated form although it may substitute for aluminum to a minor extent in clay minerals.

According to our chemical analyses, the remainder of the insoluble fraction is made up of the components K_2O, Al_2O_3, MgO, and SiO_2. Because the first three of these generally occur combined with the fourth, potential mineralogy of the samples may be evaluated by comparing insoluble analyses to mineral compositions plotted on the compositonal triangle K_2O-Al_2O_3-MgO shown in Figure 7.3. On this diagram, mixed-layer solid solution among potassium and magnesium montmorillonites and seawater-illite is indicated by the shaded area between these three endmember components. It should be noted that the chlorite composition plotted on Figure 7.3 is that which has been observed in present day seawater sediments and evaporites. Relative proportions and amounts of minerals occurring in a given sample are evaluated by distributing potassium, aluminum, and magnesium along appropriate limiting phase compositions. Silica is then distributed among these phases according to stoichiometry, and any excess occurring in the sample analysis is considered to be free quartz.

Halite is by far the most abundant mineral in the soluble fractions of the samples. In only a few cases is halite a minor or trace constituent. Polyhalite and anhydrite/gypsum are accessory minerals in most samples, and in two of these, $CaSO_4$, is a major component. In normative calculations for sulfate deficient samples, kainite and carnallite are included, whereas thenardite, glaserite, bloedite, and kieserite appear in sulfate-excess and balanced samples. These phases are rarely present in more than trace amounts and are calculated to occur in such small quantities as to be insignificant in terms of contributions to hydrate water. Sample 8-1652 (i.e., 1652 feet depth in AEC No. 8) is significantly different from other soluble material in that it is calculated to contain relatively large amounts of the soluble salts sylvite, polyhalite, leonite, and glaserite. The drilling log reports loss of mud at this point, so it is uncertain as to whether a rock is of exotic mineralogy, or one from which certain cations have been leached by moving drilling mud, or one which has exhibited the incongruent solubility of polyhalite, leaving a sample of abnormal chemistry.

Most of the insoluble analyses plot within the triangle bounded by the phases Mg chlorite-K feldspar-talc on Figure 7.3. These minerals are recognized to occur in evaporite sequences which have undergone mild diagenesis ($P < 100$ atm, $T < 100^{\circ}C$), forming as a result of interaction of brine with amorphous aluminosilicate detrital material (Braitsch, 1971). The only other phases calculated to occur in the insoluble fraction are mixed-layer illite-montmorillonite, quartz, and iron oxide. It should be noted that the presence of the mixed layer silicate as well as chlorite and talc may be difficult to establish if they occur in very fine grain size. None of the observed silicate phases undergo dehydration below $500^{\circ}C$, according to the DTA.

<u>Effects of Heating Samples</u>. A number of different responses to heating were exhibited by the samples. Heating to $70^{\circ}C$ was designed to measure absorbed water recognizing that gypsum dehydrates, according to thermochemical data, at about $70^{\circ}C$. In normal differential thermal analysis, gypsum undergoes stepwise dehydration to hemihydrite and

anhydrite at about 150° and 185°C, respectively. Kopp, (University of Tennessee, pers. comm.) has observed that gypsum dehydrates upon fine grinding and prolonged heating at 70°C, hence the observed DTA breakdown is probably a result of kinetic factors. Consequently, samples analyzed using thermogravimetric analysis were powdered and placed in an oven at 70°C for several days prior to analysis of weight loss at elevated temperatures. Samples 7-1171 and 8-2563 both contain major $CaSO_4$, but only the latter showed gypsum-type dehydration. This appears to indicate that sample 7-1171 actually contained anhydrite whereas sample 8-2563 contained gypsum since only 8-2563 showed significant weight loss at 70°C but both analyses summed to near 100%.

Essentially isothermal dehydration was observed over a continuum of temperatures from 100° to 500°C for a large number of samples. In addition, weight loss over a 50° to 100°C span in temperature was observed for most samples, but generally at temperatures above 300°C. These two types of weight loss probably indicate single-mineral dehydration for isothermal loss, and dehydration as a result of mineral-mineral chemical interaction for the weight loss occurring over a large temperature span. Such solid interaction is demonstrated by sample 8-1953 which contains both anhydrite and polyhalite but minimal bloedite. Figure 7.4 shows the DTA curves for pure polyhalite and gypsum. Comparison of these two curves to that of sample 8-1953 shows the 325°C exotherm of polyhalite to be lacking while the lower temperature endotherms of gypsum are present. We suggest the missing polyhalite endotherm is a result of chemical interaction between polyhalite and anhydrite somewhere between 200° and 325°C. Such interaction among evaporite minerals should probably be investigated in some detail in terms of retention of hydrate H_2O.

A few samples were heated to 800°C to get an indication of how much weight might be lost from samples at high temperatures (>500°C). Of the nine samples examined under these "extreme" conditions, four began <u>gaining</u> weight at about 700°C. One sample increased in weight by about 15% between 725° and 800°C. This gain in weight is not a result of

oxidation of iron (eg. Fe^{+2} in chlorite) since sample 8-2050 did not contain any iron. That the gain in weight may be caused by formation of an extremely hygroscopic phase at high temperatures as a result of solid-solid chemical interaction upon heating. Whether or not such a phase forms would undoubtedly depend upon the initial mineralogy of the rock to provide the correct reactant phases since not all sample exhibited this weight gain. The water necessary for this rehydration is probably a result of the fact that the testing laboratory is cooled during the summer months (the analyses were run in early June) by evaporation which results in high relative humidity.

A composite histogram of weight loss of all samples at elevated temperatures is shown in Figure 7.5. The distribution appears to be log-normal with the maximum density near 0.25% weight loss upon heating 500°C. Over half of the samples (56%) show weight loss of 0.5% or less, and only 15 samples exceed 1%. Figures 7.6A and 7.6B are plots of sample weight loss vs depth for the two drill holes. Samples showing more than 1% weight loss upon heating are scattered throughout the depth range but are generally separated by more than one hundred feet of low-water-loss material. There is a broad correlation between higher weight loss and increasing insoluble content of sample, but no clearcut relationship is seen between weight loss and silica content. It is concluded that high temperature weight loss is contributed by both silicate and sulfate minerals. It can be stated in general, however, that samples showing less than 1% weight loss contain less than 10 wt % insoluble material.

7.3.4 Conclusion

Most of the samples showed very little water loss between 200° and 300°C and there were only small water losses at temperatures 200°C and 300°C. As can be seen by examining the data, there are several zones where there is essentially no change in sample behavior with heating to moderate temperatures. These areas show good potential as burial sites for nuclear waste.

7.4 DETAILED PETROLOGY AND SILICATE MINERALOGY OF SOME PERMIAN BASIN ROCKS

7.4.1 Introduction

The purpose of this section is to describe and evaluate the petrologic, mineralogic and geochemical properties of designated core samples, primarily from the ERDA - 9 drill hole and various grab samples exposed in mines and at the surface, in connection with the WIPP (Waste Isolation Pilot Plant) site evaluation.

ERDA - 9 penetrates the Mescalero Caliche, Gatuna Formation Santa Rosa Sandstone, Dewey Lake Red Beds, Rustler Formation, Salado Formation and the uppermost 50 feet of the Castile Formation (Figure 4.3-3). Primary interest is focused on selected intervals within the Salado and uppermost Castile Formations.

The general problems under study are: 1) the genesis of the dominantly evaporite succession with associated silicates and 2) the extent of post-depositional alteration of these sediments. The basic approach (and analytical method) is broadly threefold. First, detailed study of the occurrence and mineralogy of silicates, particularly clay minerals, in the evaporite succession (disaggregation, size fractionation, x-ray diffractometry). Second, bulk chemical analysis of whole rock, water soluble, acid insoluble, and clay size fraction (x-ray fluorescence, atomic absorbtion spectroscopy, other rapid procedures). Third, macroscopic and microscopic petrography (handspecimen and microscope mineral identification, description of form, texture and lithology of mineral associations, and x-ray diffractometry of bulk samples).

7.4.2 Procedure

After core intervals were selected for study, cores were cut lengthwise, mostly in the form of 1/2, less commonly 1/4, of the core. Criteria for selection and additional procedures for analysis of these samples are

described in the following sections on the silicate mineralogy, geochemistry and petrography.

7.4.3 Silicate Mineralogy and Geochemistry

Systematic logging of ERDA - 9 core and accompanying gross mineralogy have been described in Chapter 4. This section is focused on selected segments of the core and examination of the paragenesis of minor constituents, namely the silicate minerals, their composition, and their interpretation in terms of depositional and postdepositional phenomena.

Silicate mineralogy and geochemistry have not been comprehensively studied within the Ochoan rocks and the Permian Basin. Adams (1969) has reported briefly on the occurrences of talc in argillaceous rocks as a part of this extensive study of bromine distribution throughout the section; specialized clay mineral determinations by Grim et al. (1961) and Fournier (1961) have been undertaken on a limited number of samples and with minimal regard to their detailed stratigraphic setting and geneses.

In an effort to provide substantially more complete understanding of the silicates associated with the Permian evaporites, some 70 samples of the ERDA - 9 core ranging from 300 feet below the Salado-Rustler contact (1163.3 foot depth) down to a few tens of feet below the Salado-Castile contact (2867.6 foot depth) were selected. The following criteria were used in the selection: (1) representation of major lithologies; (2) detailed representation of an apparent "cycle" of evaporite deposition which occurs repeatedly through the Salado Formation section; (3) representation of intervals under consideration for waste storage sites; (4) detailed representation of selected polyhalite-anhydrite occurrences toward interpreting the genesis of the unusually abundant polyhalite; and (5) representation of the sequences which may provide data for interpreting postdepositional solution and recrystallization phenomena. In Table 7.4, we list the samples by depth, gross lithology, and stratigraphic position, as well as by character of data obtained; Table 7.5 provides a cross-listing for relating sample number to depth.

Sample Preparation and Analysis. The core was split and one split rebagged for future reference. One to 10 cm segments of the remaining half were selected for analysis (petrographic, mineralogic, and/or chemical) and sectioned off. A 1 cm slab of this was retained for petrographic examination; the remainder was coarsely crushed and a split retained for whole rock analysis. The larger fraction of the sample was leached with excess demineralized water to dissolve the halite host. This was repeatedly centrifuged, decanted, and rewashed to remove all traces of dissolved halite from the residue. The residue was dried, reweighed, and a split suspended in boiling EDTA solution in order to separate the "acid-soluble" salts (sulfate and carbonate minerals) following the procedure of Bodine and Fernalld (1973). Again, after repeated centrifuging, decanting and washing to remove EDTA and to dissolve solid components from the insoluble residue, the suspension was dried and reweighed. Table 7.6 depicts the quantities of sample residues insoluble in water and EDTA. A split of this fraction was resuspended in water, thoroughly disaggregated with an ultrasonic probe, and separated into the $>2\ \mu m$ and $<2\ \mu m$ (effective spherical diameter) fractions by timed gravity settling. Oriented diffractometer mounts of the fine fraction were prepared by pipetting several drops of each suspension onto glass slides and air-drying. Smear (paste) mounts and mounts using the conventional commercial powder mounts were used for the $<2\ \mu m$ insoluble fraction as well as for the other fractions. In addition, pellet or uniformly compressed mounts or "briquettes" of these fractions prepared for x-ray fluoresence were also used for diffraction.

Where sufficient sample was available, normal procedure for the silicate fraction included: (1) diffraction data for the whole EDTA-insoluble fraction using the briquettes or paste mounts; (2) oriented (sedimented) clay-size mounts on glass which were air-dried, glycol saturated, heated to 300°C, and heated to 500°C. Conventional x-ray diffractometer traces were obtained at a scanning speed of $2^{\circ}2\theta$/min with Cu-radiation and a curved crystal monochromator.

X-ray fluorescence work involved briquette mounts using the vacuum-path Norelco fluorescence goniometer with quartz and gypsum analyzing crystals. In this study, standard regression procedures are used along with matrix evaluation for calculating abundances from the raw data. However, at this time the data can only be reported in terms of a unit-slope regression from one standard. Because of the severe errors such a procedure may induce, only "semi-quantitative" chemical results are claimed for this report.

Silicate Mineralogy. The following silicate minerals have been identified in the course of this study; their distribution is given in Table 7.7.

Quartz - Quartz occurs throughout the entire interval of the stratigraphic section analyzed; however, it does not occur in every sample. Quartz is generally fine-grained ($<10\mu m$), subhedral to anhedral, and readily identified in diffraction traces by its very strong peak at 3.34Å and moderate peak at 4.26 Å; interference by the micas and mica-clays with the former and by potash feldspar for the latter only rarely preclude its ready identification.

Illite (mica-clay) - Illite also occurs throughout much of the stratigraphic interval. It is readily observable in diffraction traces with its strong 10Å and 3.34Å peaks and its moderate 5.0Å peak (001, 003, and 003 respectively). All illites observed in the core are dioctahedral as based upon (060) < 1.52 Å and (001, 002, and 003) <1.0, 5.1, and 3.44 Å respectively. Many of the illites contain recognizable but small quantities of interlayered smectite, presumably saponite or other trioctahedral varieties, based on the slight asymmetry of the (001) reflection.

Feldspar - Feldspar occurs frequently, but generally in small quantities, throughout the section and its identification is based principally on one or more diffraction maxima in the 3.17 - 3.30Å range. Unfortunately, its abundance is usually low and when coupled with the presence of other

minerals its diffraction maxima for resolving its composition and its thermal character are not interpretable; both plagioclase and K-feldspar have, on occasion, been recognized.

Chlorite - Chlorite is commonly a minor constituent and its presence is often difficult to establish. With a 14 Å periodicity its maxima can be masked by smectities, various interlayered species, and by the 7 Å minerals, kaolinite and serpentine. In glycol saturated specimens, the 14 Å peak from expandable clays can be removed and at 500°C the 7 Å peak from kaolinite is lost. Even so with only a small amount present in such an assemblage it can remain undetected.

Talc - Talc is rare throughout the core. It is common in the ore zones (Adams, 1969) but appears to be nearly absent from the other lithologies. Talc is identified by very sharp, strong reflections at 9.5 and 3.15 Å (001 and 003); the former is quite distinct from the broad reflection at 9.0 - 9.7 from a regular interlayered chlorite-saponite (corrensite).

Serpentine - Serpentine, like talc, is relatively rare in the section and is confined to the lowermost interval (below 2820.3 and at or below the Salado-Castile contact) in rock salt and anhydrite. Serpentine is identified by strong peaks at ~7.3Å and ~3.6 Å (001 and 002 respectively for a single-layered variety). These maxima are noticeably greater than the 7.0 - 7.2 Å and 3.5 - 3.65 Å reflections attributable to chlorite. In our samples, these larger spacings are characteristically sharp and are not accompanied by the odd (00) reflections of the 14Å minerals.

Expandable Clays - Expandable clays, the smectities, vermiculites, and mixed-layer clays containing either of these constituents, are the dominant clays of the section and are ubiquitous (Table 7.8). We have recognized at least four such clays; however, their definitive identity has not yet been resolved.

a. Saponite (e.g. JS-CS-9 at 1466.9') expands to >16Å with glycol saturation and collapses to < 14Å upon heating, (further heating would yield an ~9.5 Å peak).

b. (?) Illite-saponite (e.g. JL-CS-2 at 1440.5' JL-CS-10 at 1325.3') with an air-dried maximum at 10.2 - 10.3 Å, glycol saturation at 10.0 Å and with or without a less intense shoulder or separate peak at 11.3 - 12.1Å, and collapsing to 9.8Å at 300°C. We have not ruled out a mixed-layer talc saponite identification for this phase.

c. Chlorite-saponite (e.g. MB-CS-21 at 1404.6' and MB-CS-32 at 2541.5') exhibits a 14 Å peak expanding to 15.5Å with glycol saturation and collapse to <14 Å upon heating. The chlorite-vermiculite phase described by Fournier (1961) and Grim et al. (1961) is probably this chlorite-saponite; the expansion with glycol is too great for this to be a chlorite-vermiculite. In some cases the interlaying is random; in others it is regular and produces a distinct superlattice peak (~29Å); in most there is some regularity with a slight shoulder present in the 25-30° 2θ present (these shoulder "maxima" are exceedingly difficult to plot precisely and all contain ±0.3-0.5° 2 θ definition).

Nearly all of the diffraction data in Table 7.8 can be assigned to one of these three clay phases, yet data from several samples are not yet resolved, e.g. MG-CS-13 at 2518.3. It should be noted that smectities are smectite-bearing mixed-layer clays which commonly appear to be "stripped" by the EDTA-dissolution of nonsilicates; they commonly show 12-13.8Å air-dried spacings. However, suspending these clays in $MgCl_2$ or NaCl solutions and then rewashing and redrying restores the appropriate 14-15Å spacing.

In Appendix 7.C, we present a number of the diffraction diagrams illustrating these silicate assemblages.

Distribution of Clay Materials. Some general but tentative observations regarding these minerals throughout the section are:

(1) Serpentine appears to be restricted to the lower 40 feet of the analyzed section; it most commonly occurs in anhydrite and associated rock salt.

(2) Talc is not restricted to assemblages from bitterns as suggested by Adams (1969).

(3) Interlayered illite-saponite (or talc-saponite) appears to be resricted to polyhalite lithologies or adjacent anhydrite. It appears to be absent from clay beds and associated rock salts and from the polyhalite-free remainder of the section.

(4) Expandable clays appear to show somewhat less relative abundance in clay beds (1244.8, 1247.2, 1328.6, 1441.7, and 1468.1 ft.) than in the silicate assemblages from the evaporite rocks.

(5) Furthermore, the mixed-layered clay species in each of these clay seams consists solely of the well developed regularly interstratified chlorite-saponite (corrensite).

7.4.4 Mineralogy of Duval Mine Samples

Several samples of wall-rock were taken from the 4th ore zone (langbeinite level) of the Duval Nash Draw potash mine, about 5 miles west-by-southwest from the study area. These samples include a dark brown clay parting (the DV-4 series) taken from the upper boundary of the 4th ore zone.

Untreated oriented powders were scanned from 2 to 60 degrees two theta. The untreated slide was glycolated by vapor-soaking on a rack in a container filled partially with ethylene glycol. An additional oriented powder was heated at 450°C. Both the glycolated and the heated specimens were scanned from 2 to 3 degrees two theta.

Whole rock samples were analyzed by loading a small amount of randomly oriented rock powder in a Norelco powder holder. This powder was scanned from 5 to 80 degrees two theta and the resulting diffractogram compared to values compiled in the Joint Committee on Powder Diffraction Standards file to determine bulk mineralogic composition. Mineralogic abundances noted were estimates based on comparative peak intensities.

All samples x-rayed (both clays and whole rocks) were scanned with Ni-filtered CuKα radiation. A time constant of two seconds was used with a scintillation counter detector and pulse height analyzer. The goniometer slit system consisted of a divergent and anti-scatter slit of 1 degree and a 0.003 inch receiving slit.

The results for Duval Mine samples appear in Table 7.9. For comparison, "dirty salt" from about 2100 feet depth in ERDA No. 9 has about 8% by weight insolubles.

7.4.5 Chemical Composition

Since appropriate regressions for each component based on several standards have not yet been calculated and matrix effect corrections have not yet been made, the analyses in Table 7.10 must be considered as only semiquantitative. In most cases, most totals are between 85 and 98%; perfectly reasonable totals with the remainder being chiefly water. A few totals exceed 100% and a few others are less than 85%; these are unquestionably in error. These data, however, do illustrate a number of important relations and are compatible with the mineralogic data.

Thus for example, those analyses with high alkali content (JS-CS-2 at 1440.5', JC-CS-6 at 1441.5, MB-CS-27 at 2067.0, MB-CS-31 at 2512.5, MB-CS-13 at 2518.3, MB-CS-10 at 2705.8, and MB-CS-36 at 2758.4) show substantial feldspar with or without abundant mica-clay.

In general, the chemical data support the mineralogic determinations. The silicate fractions are extraordinarily high in MgO (~20-30 wt % MgO)

and correspondingly low in CaO (~1 wt % CaO); Al_2O_3 is low (~8-12 wt % Al_2O_3) for clay mineral assemblages. Thus, except for illite, our clays are trioctahedral with only chlorite containing appreciable Al_2O_3.

7.4.6 Petrography

Petrographic analysis, both macroscopic and microscopic, is used in three ways: first, determination of the mineralogy of samples; second, given the mineralogy of a sample, description of lithology; third, the primary utility of petrographic analysis in this study, description of the texture of the sample. Texture refers to grain or crystal size, shape (habit or form), orientation, relationships (such as nature of contacts between crystals or grains) among different minerals and lithologies.

Macroscopic Petrography.

Sample Preparation and Procedures - Slabs, approximately 1 cm thick, were cut lengthwise using a band saw, from the 1/2 or 1/4 core samples. One face of a remaining core sample was then polished using a sander with various grit sandpapers. The sample was not to be used for silicate mineralogy-geochemistry analysis in order to avoid contamination. The polishing enhanced textural detail. Faces were also polished on some slabs.

Samples were selected from the core in which mineralogy based on macroscopic identification was obscure or uncertain for x-ray diffractometry of the bulk sample. Conventional diffractometry methods, as described previously, were used.

Macroscopic Petrographic Description - The mineralogy, lithology and texture in the polished sections of all the core intervals selected were described. Appendix 7.D is a brief extract from 54 pages of sketches accompanied by textural descriptions of these core intervals. Table 7.11 is a summary of the gross lithology reported largely as macroscopic

mineral identification and core footage. Table 7.11 indicates that macroscopic mineral identifications are generally reliable, especially for coarse-grained minerals, but visual estimation of the relative minerals abundances are less reliable. Estimates of relative abundances based on x-ray diffraction analysis are regarded as "semi-quantitative" and maybe in error, but it is still more reliable because of its greater precision, if not accuracy, compared to visual estimation.

Plates 7.1 through 7.6 are photographs of polished faces of cores or slabs illustrating typical textures. Plate 7.1 shows a variety of shapes of halite in anhydrite. The occurrence as beds or laminae or irregular lenses is inferred to be primary because halite and anhydrite can precipitate jointly or alternately from evaporating seawater. The apparent swallow-tail form of halite in laminated anhydrite is a problem because no primary occurrence of this form of halite is known. The swallow-tail form can occur as a twinned crystal of gypsum, but coprecipitation of gypsum and anhydrite is thermodynamically impossible. One interpretation is primary precipitation of calcium sulfate only as gypsum in the form of rapidly growing swallow-tail twins and finely crystalline aggregates. Then post-depositional alteration of the finely crystalline aggregates to anhydrite takes place, and the twinned crystals alter either directly to halite or first to anhydrite which then alters to halite, with preservation of the primary swallow-tail forms. This interpretation is favored by the almost exclusive dominance of gypsum rather than anhydrite as the primary precipitate in modern environments and lab experiments. Controversial thermodynamic analyses also favor gypsum as the primary precipitate, even metastably.

Plate 7.2 also illustrates occurrence of halite in well laminated anhydrite. This is interpreted as primary coprecipitation of halite and gypsum with these textures followed by post-depositional alteration of gypsum to anhydrite with preservation of primary texture.

Plate 7.3 illustrates an occurrence of halite and polyhalite. The triclinic crystal system of polyhalite is unlikely to produce a rectangular outline in cross section whereas the cubic habit of halite or

the orthogonal morphology of anhydrite would. Thus, the rectangular outline of the polyhalite body suggests post-depositional alteration of anhydrite, (to a lesser extent of halite) to polyhalite as does the occurrence of most polyhalite in irregular masses among halite masses. Thermodynamic and experimental considerations as well as observation of modern evaporites indicate that polyhalite does not precipitate from evaporating seawater.

Plate 7.4 illustrates coarse, relatively pure halite with anhedral, granular texture. The halite contains small crystals of anhydrite, probably a post-depositional alteration product of a primary coprecipitate of halite and gypsum.

Plate 7.5 illustrates another texture of halite in anhydrite with traces of magnesite. As previously indicated, it is believed to result from primary co-precipitation of halite and gypsum with post-depositional alteration of gypsum to anhydrite with preservation of primary texture. Magnesite is not known to precipitate from evaporating seawater but calcite does, suggesting post-depositional alteration of a primary (probably calcium) carbonate to magnesium carbonate.

Plate 7.6 illustrates textures in a dominantly anhydrite rock. The occurrence of the swallow-tail form near the stratigraphic top of the specimen as well as previously related discussions suggest primary precipitation of gypsum followed by post-depositional alteration of anhydrite, which could occur shortly after deposition, with preservation of primary textures.

Microscopic Petrography.

Sample Preparation and Procedure - The 1 cm thick slabs were converted to standard and oversize thin sections following conventional procedures (with the following exceptions) to minimize chemical alteration of the sample. Fluid in contact with the sample was a pure vegetable cooking

oil. Temperatures during the thin sectioning process did not exceed 30°C. Samples were put in dessication jars during impregnation to minimize contact of fluid acetone with the sample.

Microscopic Petrographic Description - Plates 7.7 through 7.12B are photomicrographs of thin sections of rock samples from the Permian Basin of southeast New Mexico. The samples are not from ERDA-9 core but are representative of mineralogies, lithologies and textures commonly encountered in the core.

Plate 7.7 is a photomicrograph of relatively finely crystalline euhedral to subhedral halite. The crystal form, relative clarity (although containing very fine crystals of anhydrite) and occurrence of fluid inclusions as both negative crystals and subspherical forms all suggest little post-depositional alteration with the exception of alteration of primary gypsum to anhydrite.

In Plate 7.8 also dominantly of halite (typical of the rock in Plate 7.4), there is a startling contrast to the texture in Plate 7.7. Crystals in Plate 7.8 are anhedral to subhedral, cloudy, coarser and devoid of fluid inclusions (the apparent void in the lower left was produced by plucking of a cleavage fragment from the specimen during sectioning). Because the texture shown in Plate 7.7 is regarded as indicative of little post-depositional alteration, the texture in Plate 7.8 is considered as indicative of extensive alteration, greater than that required for the postulated gypsum to anhydrite alteration which is also postulated for very fine crystals of anhydrite within the halite in Plate 7.8. These contrasting textures are also apparent in thin sections of carbonate rocks. Bathurst, (1975, especially Chapter 12), deals with recognition of chemically precipitated calcite (analogous to Plate 7.7) versus calcite post-depositionally altered from argonite or some other form of pre-existing calcite (analogous to Plate 7.8). Bathurst uses and builds upon terminology and concepts of the causes and processes of these alterations developed by Folk (1965).

Plate 7.9 shows an occurrence of halite with sylvite. The irregular bodies and irregular contacts of the sylvite (as well as the anhedral nature of the halite and bodies of intimately mixed halite and sylvite) are interpreted to be the product of post-depositional alteration. This interpretation is also favored by the fact that sylvite does not occur as a primary precipitate in the marine evaporite succession.

Plates 7.10A and 7.10B show the irregular and gradational nature of the contact between polyhalite and halite and the concentration of opaques, probably hematite, along the contact. These observations and those discussed under Plate 7.3 are interpreted to be products of post-depositional alteration of either anhydrite or halite to polyhalite.

Plate 7.11 shows the microscopic texture typical of many laminated or banded anhydrites of the Castile and Salado Formations. Neither x-ray diffractometry nor staining techniques have been used to determine the mineralogy of the carbonate. This texture is interpreted as annual varves by Anderson et al. (1972).

Plate 7.12A and 7.12B show dominately massive anhydrite, typical of much of the unlaminated anhydrite in the Salado Formation but atypically cut by a veinlet of gypsum. The rock sample was taken from outcrop and the gypsum veinlet is interpreted to have been produced by alteration of anhydrite to gypsum during uplift and exposure.

The petrographic descriptions and interpretations generally agree with those in the classic and relevant report of Schaller and Henderson (1932).

7.4.7 Interpretations and Tentative Conclusions

1. All of the samples discussed under macroscopic and microscopic petrography exhibit mineralogy, lithology and textures which are indicative of post-depositional alteration of the sediments (dated at 204 million years in Section 7.8). It is believed that fluids

migrating through the sediments are responsible for most of these alterations. Interestingly, the alteration of primary gypsum to anhydrite would liberate abundant volumes of fluid.

2. The abundance of polyhalite and the atypical mineral assemblages (sylvite-langbeinite vs kainite/carnallite-kieserite) of the ore zones suggest either drastic recrystallization or a former primary evaporite depositional environment. The areal extent of the Ochoan rocks and their great thickness coupled with paleogeographic evidence and the marine character of the underlying Permian strata appear to preclude the second alternative. Further evidence of the post-depositional origin of the present assemblage includes the low and highly variable bromine values in the Salado Formation rock salts (Holser, 1966; Adams, 1969). Age dates on K-bearing salts, discussed later in this chapter, further suggest recrystallization shortly after deposition.

3. The general mineralogy and chemistry of the EDTA-insoluble (silicate) fractions of the evaporite beds throughout the Salado and uppermost Castile Formations preclude their detrital origin.

4. The silicate assemblages and their chemistry further supports the hypothesis of post-depositional alteration of these rocks -- at least throughout much of the Salado Formation.
   a. The predominance of smectities (saponite) and trioctahedral smectite-bearing clays suggest relatively immature assemblages. The silicate assemblages of the Zechstein (Permian) of Germany are almost entirely nonsmectitic except for the well-crystallized, well-ordered regular interstratified chlorite-(smectite/vermiculite) mineral corrensite (Fuchtbauer and Goldschmidt, 1969). The Haselgebrige (Permo-triassic) of the Austrian alps similarly contains no smectites nor even smectite-bearing mixed-layered clays (Bodine, 1971), and the same is true for the Silurian salts of New York (Bodine and Standaert, 1977). The development of the unusual illite-saponite/talc/saponite phase with polyhalite suggests immaturity of the silicate

phase with respect to the evaporite phase. Any further phase changes that would take place in the silicate appear to be kinetically inhibited.

b. The variability of the clay assemblages and their lack of correlation with major evaporite lithologies bespeaks strongly of recrystallization accompanying migrating post-depositional pore fluids. Except for the unusual 10.3 Å phase with polyhalite, the only other lithic correlations are: (1) reasonably well crystallized corrensite as the only expandable clay in the discreet clay seams and (2) the occurrence of serpentine in the uppermost Castile Formation. The former is tentatively attributed to the "closed system" nature of the impermeable salzton beds; they were not subject to the attacks by a variety of migrating pore fluids of different composition. The latter relates to the vertical distance between K-Mg-bearing salt beds and the Castile Formation, which essentially comes in contact only with less mobile fluids in equilibrium with halite-anhydrite.

c. It is very tentatively suggested that many of the salzton seams formed through accumulation of silicate debris included in salts which have been dissolved; their association with the soluble K-Mg salt ore zones and with the extensive polyhalite replacement of anhydrite beds appears remarkable and may provide the geometry for the "plumbing system" in which migrating pore fluids circulated. It is also recognized that some of the salzton beds may well represent recrystallized detrital accumulations during periods of no evaporite deposition as suggested by Adams (1969). If migrating groundwaters do flow in some such controlled pattern, ore mineral distribution in each ore zone should reflect this, i.e. remnants of the primary carnallite-kieserite farthest from the source of the brines, enveloped by langbeinite and langbeinite-sylvite assemblages, in turn enveloped by langbeinite and langbeinite-sylvite assemblages, in turn enveloped by sylvite, and finally by barren halite. Similarly polyhalite

crystallization should be at a maximum under the langbeinite-sylvite assemblage within a given "cell" and would likely decrease both away from and toward the lateral pore fluid source.

In summary, substantial evidence has been accumulated that there has been extensive salt recrystallization, most noticeably within the McNutt ore zone. This is considerably less noticeable in the lower Salado and Castile Formations, but may simply reflect the far simpler evaporite mineralogy and persistence of substantially more homogeneous compositions within the pore fluids.

Preliminary computer modeling does, for example, substantiate that a typical primary marine evaporite salt assemblage of carnallite-kieserite-halite can, when under continued attack by migrating halite-gypsum saturated pore fluids flowing down dip in a hypothetical cell, generate a progression of salt facies with remnants of the primary assemblages farthest from the source. Toward the source, the following succession of assemblages would be found: langbeinite-carnallite-halite (or langbeinite-kieserite-halite) then langbeinite-halite, then langbeinite-sylvite-halite facies, then sylvite-halite, culminating toward the source in a barren halite facies. At the same time, the K-Mg rich pore fluids which were generated through ore mineral dissolution and alteration would no longer be in equilibrium with anhydrite; anhydrite would alter to polyhalite until the solution chemistry reached the polyhalite-anhydrite equilibrium composition. The precise thermodynamic conditions and mineralogic reactions which governed these alterations are not known; however, the age of this recrystallization of evaporites has been determined to be in excess of 204 million years. For more details regarding this recrystallization which closely followed deposition, the reader is referred to Section 7.8.

7.5 VOLATILES AND FLUID INCLUSIONS IN MINERALS OF THE SALADO FORMATION

7.5.1 Introduction

Sources of liquids and gases native to the evaporites must be considered. One source is the intergranular fluid to be found in the pore spaces between mineral crystals and lithic fragments. These fluids are discussed in detail in a subsequent section (7.7). Another fluid source is the water of crystallization chemically bound in hydrous minerals. Yet a third source is fluid inclusions inside the mineral crystals themselves, which can behave as separate micro-geochemical systems.

Data presented in the overview Section 7.5.2, and Section 7.5.3 result from heating bulk rock samples to recover all types of fluid. In the major portion of the Salado, the total recovered amounted to less than 0.5 weight percent of the rock. As discussed in the overview section, it was possible to separately identify: (1) loosely-bound volatiles, (2) chemically-bound volatiles, and (3) fluid inclusions.

The sections on mineral sources of water and on fluid inclusions endeavor to place the data in the context of the mineralogy of the rocks serving as hosts for the volatiles. It will be noted that geochemistry in the context of the mineralogy is a pervasive theme in all parts of the geochemistry section of this report. This is true for the sections which follow on groundwater geochemistry and radiometric age-dating also. It will also be noted that the characterization of geochemical properties of solutions in the Salado confirm the qualitative measurements of fluid inclusion solute contents.

This chapter contains considerable data which will assist in the anticipation of short and long term physico-chemical conditions likely to arise during the experiments involving heat-producing radioactive wastes.

7.5.2 Overview of Volatile Contents of Evaporites

Themogravimetric analyses of 35 selected core samples from ERDA No. 9 were made. These were many of the same samples which were qualitatively examined for mineralogy by x-ray diffraction (refer to Section 7.2.3).

These analyses were made by suspending powdered samples from a microbalance while dry nitrogen flowed above the sample. The samples were heated by 5°C/minute until the temperature reached 500°C and were held there until gas evolution had ceased. A hygrometer was inserted downstream to register qualitatively whenever moisture was evolved.

The as-received salt core specimens were massive pieces approximately 4 inches in diameter and 1-2 inches thick. No attempt was made to obtain homogenized samples by powdering the entire piece. Instead nuggets were chiseled from the center of the specimen. The nuggets were crushed and ground to a powder just prior to the weighing and transferring to the microbalance system. A maximum of ten minutes elapsed between the start of crushing and the start of analysis. Thus, the possible loss or gain of moisture prior to testing was minimized. Powdered samples were necessary to minimize decrepitation.

The complete test results are presented in Table 7.12. Figure 7.7 illustrates the typical kinds of weight-loss curves observed. About half the specimens showed 0.5% weight-loss (curve A). Curve B is common with the rapid weight-loss occurring sometimes at 300° and sometimes above 400°C. Some samples show two stages. Only two samples followed curve C, where weight-loss was observed from the beginning of the run. The weight-loss curves for all samples are filed and are available for inspections.

Replicate runs were made in several cases, predominantly those which showed the larger weight-losses, and good agreement, i.e. within 5%, was observed.

All mass-loss is not due solely to water. Only the weight-loss below 300°C can be attributed largely to water; the weight-loss at higher temperatures is in part due to decomposition of carbonates or other volatile-bearing minerals.

Results were correlated with the x-ray diffraction results previously reported in an effort to identify which minerals may be decomposing. No definite conclusions could be reached so selected samples were analyzed for the evolved gases by gas chromatography/mass spectrometry. In particular, this was done for the samples 2302.6, 2516.3, 2658.5, 2786.5 and 2821.0.

The highest weight-loss was experienced by sample 2302.6. Its total ion chromatogram (Appendix 7.E) shows data channel numbers calibrated approximately in terms of temperature. Conspicious peaks occur at 100°C, 250°C and 300°C. Detailed mass spectra are given for 50°C, 100°C, 150°C, 200°C and 250°C; the most prominent mass peak is 18, corresponding to water. At higher temperatures, mass 14 (monoatomic nitrogen) becomes abundant. Even at lower temperatures, mass 28 (diatomic nitrogen) is present.

Sets of peaks separated by 12 mass units, corresponding to carbon, (95, 83, 71; 81, 69, 57, 45) probably represent fragments of hydrocarbons present in the diesel oil which was the lubricant used to core the hole. The contribution of mass 44 (CO_2) to the spectrum is a minimum at 200°C and rises again at higher temperatures. The low-temperature contribution is again probably due to the contaminant diesel oil.

At the highest temperatures, the mass peaks 15, 16, and 17 (CH_3, CH_4, O, OH) are accentuated along with 14, 18, and 28 (N, H_2O and N_2). All the individual ion chromatrograms for mass numbers 14, 18, 19, 20 and 44 have coincidental peaks at about 25°C and 300°C. Water and carbon dioxide are almost continuously evolved over the entire temperature range, but the coincidence of all the peaks for N, H_2O, F(?) and CO_2 (mass peaks 14, 18, 19, and 44, respectively) implies that evolution of

these components at 250°C and 300°C is related to a common source. Since halite decrepitates, releasing its fluid inclusions at about 250°C, those inclusions appear to be the most probable source of volatiles evolved at 250°C. Similarly since polyhalite dehydrates at a temperature slightly above 300°C, fluid inclusions in that mineral might be also released at that temperature (see Section 7.3). A detailed treatment of fluid inclusions appears in a subsequent discussion.

Mass numbers 32, 48, 64 and 80 have sharp coincidental chromatogram peaks at channel 517. These mass numbers most probably represent O_2, SO^{+2}, (possibly O_3 made inside the mass spectrometer) SO_2 and SO_3 released from the sudden decomposition of a sulfate. Similarly mass 36 (HCl) is released in major quantity at this point. All these phenomena occur at a slightly lower temperature than the main 200°C event, and their relationship with that event possibly indicates the presence of a very volatile sulfate phase rapidly decomposing when the halite fluid inclusions begin to rupture. Daughter crystals of gypsum in halite fluid inclusions would indicate a high concentration of sulfate in the inclusions (see subsequent discussion) and such a solution might give rise to the observed sulfur species in the mass spectrum.

The sample with the next greatest total mass loss (2786.5, 3.64%) is considered next. Many of the same features of the chromatograms in Appendix 7.E are observed here as in the previous sample. The main difference is the appearance of a large hump of many volatiles (H_2O, F, N_2, O_2) released at less than 100°C. This is consistent with the occurrence of clay minerals which can absorb various volatiles at surface and interlayer sites. Volatiles would be expected to be weakly bound at these sites. The same hump as before appears at 250°C, incorporating N, H_2O, HF(?), N_2, O_2, HCl, CO_2 and SO^{+2}, but only the postulated SO_2 species appears to be catastrophically released and is probably a product of ionization in the mass spectrometer.

A hump incorporating N, H_2O, HF, N_2, O_2, HCl, CO_2 and SO^{+2} occurs substantially below 300°C. This peak probably corresponds to release of water and other volatiles born of OH and fluid inclusions in the clay minerals, when the clays decompose upon dehydration.

Sample 2516.3 (2.15% mass loss) was unusual in that it contained magnesite. As is seen in the chromatograms in Appendix 7.E, the loss of H_2O and N_2 from various sources provides most of the pattern, which was not sampled at a temperature greater than about 240°C. There is almost a continuum of absorbed O_2 released. The most significant feature of this sample is the high-temperature loss of CO_2, presumably from the decomposition of magnesite.

Finally, the most abundant-type sample is considered: those which have mass losses less than 0.5%. These are characteristic of most of the main evaporite section and contain very little other than halite and anhydrite. Typical examples of these rocks are samples 2658.5 and 2821.0 (Appendix 7.E). The main difference between these two is the apparent larger number of types of volatile sites in the shallower sample. Absorbed N, H_2O, N_2, and O_2 form a large, broad hump at low temperature, with catastrophic release (of fluid inclusions?) of H_2O, N_2, HCl, and CO_2 at higher temperature in 2821.0. In 2658.5, the catastrophic release of H_2O, N_2, HCl, and CO_2 (with possibly some SO^{+2}) appears to occur in smaller episodes as various sets of fluid inclusions are ruptured at higher temperature.

7.5.3 Mineral Sources of Water in the Salado Evaporite Sequence

Introduction. The purpose of this section is to describe the mineralogy and petrologic characteristics of samples taken from two coreholes of the Salado salt from the boreholes AEC Nos. 7 and 8 in Lea and Eddy Counties, near Carlsbad, New Mexico, and the degree to which the evaporite rocks present would dehydrate if subjected to the heat generated by containers of radioactive wastes (radwaste). In a previous study, (Fallis, 1973) the general characteristics of evaporite deposits and their minerals were

described and a detailed mineralogic and petrologic study of two cores from the Hutchinson Salt near Lyons, Kansas, was made. The results at that time indicated that water losses ranging from 0.4 to 19.0 weight % might be anticipated if the surrounding rocks were heated to 100°C.

Sample splits corresponding to ones in this section were also discussed in Section 7.3. A comparison of those results and these is presented in the following section.

Sampling and Sample Preparation. Segments of the original 4 inch (10.2 cm) cores were split in half, lengthwise, for chemical analysis and weight loss determination by thermogravimetric analysis (previous section). Eighty-three samples (coded by core number and depth) arrived wrapped in plastic to reduce the possibility of absorption of moisture during shipping and handling. Core AEC-7 was drilled in Lea County, New Mexico, and core AEC-8 in Eddy County, New Mexico.

Throughout the sample preparation, care was taken to not expose any of the samples to water; however, since it was necessary to cut, grind and sieve various portions of the samples, it was not possible to completely protect them from exposure to moisture in the air. During those periods when samples were not actively being worked upon, they were kept in plastic bags, tightly-stoppered bottles, etc.

Since several different analyses were to be made, it was necessary to obtain representative sample splits which would correspond to each other as closely as possible. A more complete discussion of sample preparation is given in the thesis by Combs. However, for convenience, a brief summary of the methods used in sample preparation is given below:

1. A representative segment of each core sample was chosen and removed by sawing the original core (normal to the axis of the core) with a dry blade, masonry-type saw. This new segment was typically about three inches (8 cm) long.

2. Next, a slice was cut from each core segment (parallel to the axis of the core) with the approximate dimensions 3 x 2 x 1/2 inches (8 x 5 x 1 cm) for use in preparing the thin sections. The sections were prepared by Fred Roberts Petrographic Section Service, Monterey Park, California. They were cut using oil rather than water and mounted with an epoxy cement which was not heated.

3. About one-half of the remainder of each core segment was crushed and sieved, and representative portions selected to be analyzed by x-ray diffraction, x-ray spectroscopy and by static heating methods for water loss determination. (Later, some additional separations were made and portions of the samples selected for bromine analysis using x-ray spectrocopy. These procedures will be described briefly in the following sections.)

Analytical Methods Used in This Study. Several different kinds of analyses were performed on the samples received. The methods used include static weight loss determinations (water loss), mineralogical and petrological analysis, and some chemical analyses using x-ray spectrocopy.

The weight loss determinations were made in essentially the same manner as for samples studied from Lyons, Kansas, and which was reported previously (Fallis, 1973). Splits of the several samples (sample size generally ranged from 1.5 to 2.0 gms and in the 60 to 120 mesh size fraction) were heated to $102 \pm 5^{\circ}C$ for periods ranging from 2 to 42 days. The results of repeated analyses indicated that the precision of weight loss determinations was generally $\pm$ 0.1 to 0.2%. When new sample splits were used, the "precision" dropped to approximately $\pm$ 0.2 to 0.3%. Some data concerning precision are presented in Appendix 7.F.

In addition to the weight loss determinations performed near $100^{\circ}C$, weight loss determinations were also made for several samples which had been heated to $170 \pm 5^{\circ}$ (for 2 days) and $300 \pm 10^{\circ}C$ for (2 to 3 days). The results of the weight loss analyses are reported in Appendix 7.G and discussed in the following section.

Mineralogical and petrological analyses were made using x-ray diffraction and standard petrological techniques. A summary of important mineralogical and petrological data is given in Appendix 7.H and discussed following the next section. The chemical analyses were made using two variants of the x-ray spectrographic method, x-ray fluorescence analysis (wave length dispersive) and x-ray emission spectroscopy (non-dispersive). The chemical analyses were made primarily for bromine, which can be used to aid in the interpretation of the origin of evaporite deposits, and semi-quantitative analyses were made for chlorine, sulfur and iron.

Weight Losses for Cores, AEC NO. 7 and 8. Weight loss data for the samples studied are tabulated in Appendix 7.G and illustrated in Figure 7.8. In general, the weight losses are much less than those found for samples from the site at Lyons, Kansas. The range of weight loss values at 102±5°C for the Carlsbad samples (Salado salt), Cores Nos.7 and 8 was from 0.0 to 3.5% with the majority of samples showing losses less than 0.5%, while the Hutchinson salt, Cores Nos. 1 and 2 was from 0.5 to 19.0%, and most of the samples showed weight losses from 1 to 5%. A plot of approximate range of water loss at 102±5°C to be expected at various depths is shown in Figure 7.9. This is based on data from both Lyons, Kansas and Carlsbad, New Mexico sites.

Based on the results of the various heat treatments, the following conclusions can be drawn concerning the behaviour of the samples from Carlsbad:

1. Samples consisting almost entirely of halite and/or anhydrite show weight losses (up to 300°C) which are typically less than 0.5% and probably less than 0.3%. The final total loss will depend on the amounts of clay minerals and minor hydrated evaporite minerals, such as polyhalite, which are present.

2. Larger water losses (>1% at 102±5°C) are generally associated with the presence of clay minerals (and/or gypsum) in more than trace amounts. The exact losses will depend on

the kinds and amounts of clays present, the temperatures to which they are heated and the length of time for which they are heated.

3. At some temperatures between 170° and 300°C, polyhalite, which is a common accessory mineral constituent in some parts of the Salado salt, will start to break down. It can contribute water to the extent of about 6% of its weight in the rock being heated.

4. Although present in only minor amounts (or absent) in the samples that were analyzed, there are other evaporite minerals such as carnallite, kainite, leonite, etc., near the potash ore zones (the McNutt potash zone at approximately 1600' to 1800').

The weight losses determined in Section 7.3 are compared with these in Appendix 7.G. It should be noted that the earlier data were determined by thermogravimetric analysis; hence, weight losses were not determined at any fixed temperatures but at the actual temperatures at which the decompositions were detected. In order to make the data more comparable, the previous data were rearranged and weight losses taking place within certain temperature ranges were combined. The reader is referred to Section 7.3 for the specific temperatures at which weight losses occurred. It should also be noted that the two sets of data are not directly comparable, since the weight losses of this section were accomplished by heating under static heating conditions for periods of 2 or more days, while the previous data were obtained under dynamic conditions (much more rapid heating). As a general rule, the decomposition temperature of any given mineral will be higher under conditions of dynamic heating rather than static heating.

Even so, there is generally good agreement between the two sets of data which were obtained by different investigators using different techniques. Most minor discrepancies can be explained on the basis of

differences in the methods of analysis. Only a few real discrepancies seem to exist (such as for sample at 1697 in Core #7). This is to be expected since each group rceived different halves of the core and since Section 7.3 involved sample splits of the entire core segment while this work involved only a sample split corresponding to the portion of the core used in preparing the thin section. Since there are both vertical and lateral variations in mineral content within the cores, samples might occasionally have been analyzed which were mineralogically different.

The rocks being considered at the proposed WIPP site, New Mexico, appear to be much more favorable than those from Lyons, Kansas. Even so, some mineral water is still present and is apt to be released during the period when the rocks are heated by the waste containers. It will be important to determine the maximum temperatures to be reached, the volume of rock which will be heated, and the probable maximum volume of water which will be released.

Mineralogy and Petrology of Cores No. 7 and 8. In some respects the mineralogy and petrology of the core samples from Carlsbad are similar to those of the core samples from Lyons. Both cores were taken through evaporite sequences and hence encountered sedimentary sequences containing typical saline minerals such as halite, anhydrite and polyhalite. In addition, clay minerals, magnesite, gypsum, quartz, feldspar, carnallite, celestite (?), glauconite and kainite (?), were detected in smaller amounts. The presence of any of the other less common evaporite minerals in the samples studied is uncertain. In general, they only occur in such small amounts and/or such fine grain sizes that positive identification was not possible using the diffractometer and petrographic miscroscope. In Section 7.3 it was noted that several of these less common minerals are apparently present in many of the samples analyzed. Readers of this section should be aware that the analyses are based on the actual minerals observed (modal analysis) in thin section as supplemented by X-ray diffraction while the analyses presented in Section 7.3 were done by computer manipulation of the chemical analyses determined for each sample (normative analysis). Such

normative analyses can be quite useful, especialy when working with very fine grained or glassy materials. However, it should be noted that normative analyses may generate mineral assemblages which do not agree with the actual minerals present, as was pointed out in section 7.3.

Summaries of the mineralogic and petrologic features of the individual samples studies are presented in Appendix 7.H. For the reader's convenience, some general comments about the mineralogy and petrology of these samples are presented below. An excellent study of the mineralogy and petrology of the rocks in this region is given by Schaller and Henderson, 1932. Brief description of the major minerals noted in the Carlsbad samples follow.

Halite. Most of the halite is colorless and shows excellent cubic cleavage. These features, coupled with less low relief and isotropic optical character, make its identification easy. Sometimes the halite is colored red or orange by minute inclusions of hematite (or other iron oxides) or other minerals such as polyhalite. The grain size showed a wide range, from less than 1 mm (fine grained), to greater than 1 cm (coarse grained). Grains between 1 mm and 1 cm are considered to be medium grained.

Because halite fractures and cleaves so readily, it is difficult to determine whether the numerous breaks observed in thin sections were already present at depth or whether they developed during the coring operation, shipping, handling, thin section preparation, etc. More fractures are noted at the outer margins of each of the thin sections. However, some of them must have occurred prior to the taking of the core because they are filled (at least in part) with other minerals, petroliferous material, etc. In several cases fracture zones could be traced across the entire width of a thin section.

Inclusions (liquid, solid and gas) are common in the halite. During the preparation of some samples hydrogen sulfide (gas) was released. In many cases the inclusions are oriented with respect to the cubic crystal

planes. These oriented inclusions appear to represent hopper crystals which grew at the water surface in times of quiet water and are inferred to represent deposition from shallow water.

Intergrowths of relatively well-formed, cubic crystals of halite with clay and silt-size minerals are likewise inferred to represent very shallow conditions, perhaps even subaerial exposure for brief period.

"Patches" (regular to irregular, more or less equidimensional areas) and "stringers" (regular to irregular areas which are generally elongated in one direction) of anhydrite, polyhalite, clay and silt-sized minerals are common in halite. Sometimes these patches and stringers follow grain boundaries, but often they cut across grains. Where they follow grain boundaries, they may represent (nearly) simultaneous growth of the halite crystals and smaller amounts of the other mineral phase(s). Where they cut across grains, they presumably represent deposition of the minerals along zones of weakness or along which solutions passed. Enough of this latter material is present to demonstrate that there were opportunities for solutions to migrate through these relatively impermeable rocks, even though it is not possible to determine just how far the solutions actually traveled.

Anhydrite. Anhydrite was recognized on the basis of its relatively high birefringence, differences in relief upon rotation and cleavages at right angles. Normally, anhydrite shows parallel extinction, too, but because of twinning, replacement phenomena, etc., this characteristic was not always useful.

Anhydrite occurs in three major types. "Primary" anhydrite, which is commonly bedded, is very fine grained (much less than 1 mm) and somewhat fibrous in character. It also occurs in coarser-grained crystals and twinned crystals (sometimes over 1 cm long). At least some of these larger crystals appear to be pseudomorphs (replacement) after previously-existing gypsum crystals. Sometimes, very small amounts of questionable gypsum are noted nearby, perhaps as a result of partial

rehydration of the anhydrite. Finally, there are more or less isolated crystals and crystal clusters of anhydrite which occur in patches and stringers within the halite or are intergranular with halite. These may be associated with polyhalite and/or clay and silt-sized minerals. This type of anhydrite is thought to be authigenic (formed in place from fluids contained in the pores of the rock or passing through the rock).

Anhydrite can be replaced by polyhalite if fluids containing potassium, magnesium and additional sulfate ions are present. Many examples of this replacement were observed.

A few examples of bedded, nodular anhydrite were observed. The nodules may have originally been composed of gypsum which was later replaced by anhydrite. The origin of such bedded nodules is thought by some workers to represent depositions in very shallow water which was periodically exposed (Sabkha facies).

Polyhalite. Polyhalite was recognized on the basis of its relatively low birefringence, inclined extinction and complex twinning. (Unfortunately in some fine-grained material and/or mixtures, polyhalite and anhydrite can be confused because their optical properties of relief and birefringence are almost the same in certain orientations).

Much of the polyhalite observed is rather fine grained (much less than 1 mm in size for the individual cyrstallites) and often fibrous. However, some larger crystals are numerous, isolated crystals and crystal clusters were observed. Polyhalite is often reddish due to iron oxide inclusions, but this is not universally true.

Some of the polyhalite appeared to be a bedded form associated primarily with halite and lesser anhydrite. Polyhalite also is found replacing anhydrite and associated with nearby patches and stringers of clay and silt-sized minerals. Whether the clay, etc., provided some of the ions necessary for formation of polyhalite or just acted as a pathway for solutions passing through the rock cannot be determined.

Minor Minerals. Minor minerals were identified on the basis of their optical properties and X-ray diffraction analyses, which were occasionally aided by information contained in the well logs for the cores. Just a few brief comments for each mineral are given here.

Clay minerals. Overall, much less clay is present in the samples from Carlsbad than was present in the Lyons samples. X-ray diffraction peaks attributed to clay minerals were noted in nine samples from Core #7 and in fourteen samples from Core #8. Based on the X-ray patterns and peaks noted at approximately 7, 10, 11.5, 14 and 15 angstroms, major clay minerals present include illite, chlorite, mixed-layer clays and possibly some kaolinite.

Magnesite. Although well-crystallized magnesite was not detected in thin sections, some very fine-grained, relatively high birefringent phase was noted in some thin sections and magnesite peaks were detected in some thin sections and magnesite peaks were detected in a number of X-ray patterns. Schaller and Henderson (1932) stated that many of the clays in the samples they studied were magnesitic. The common association of polyhalite with clay and silt-sized minerals may be due in part to the magnesium ions in the magnesitic shales and clays.

Gypsum. Gypsum is monoclinic and in thin section has low birefringence and low, negative relief. Twins ("swallowtail") are fairly common. Well-crystallized gypsum was detected in only one thin section among the samples studied. In addition, several of the sections contained small amounts of questionable gypsum in association with anhydrite and/or polyhalite. However, the amounts present were much less than 1% and could not be confirmed by X-ray diffraction.

Quartz and feldspar. These minerals are present in two forms, as detrital (silt and very fine sand-sized) material deposited along with the clays, and also as authigenic minerals which formed in or near patches and stringers of clay and silt-sized minerals.

Sylvite. A few thin sections contain small amounts of sylvite which was recognized on the basis of its distinctive reddish purple color (due to iron oxide inclusions) and lower relief than halite. Most of the sylvite observed was associated with polyhalite as well as with halite. There were no samples from the sylvinite (mixed halite and sylvite) zones. Adams (1967) reported that not all sylvite is colored; however, in the thin sections studied, the distinctive color was useful in locating the small amounts present.

Carnallite. Only one section contains detectable carnallite. This mineral was suspected on the basis of nearby carnallite as noted in the well log. Its high negative relief and "metallic" luster due to inclusions were used to confirm its presence.

Celestite (?). In two or three thin sections some isolated spear-shaped crystals and clusters of crystals with relatively high relief were noted. Although no positive identification could be made, it is suspected that these are celestite, which is the most common strontium mineral present in evaporite deposits.

Glauconite. A few greenish, rounded grains of glauconite were noted, generally associated with the clay and silt-sized minerals. Not enough of this material was present to attempt to determine its origin or source.

Kainite(?). Kainite (?) was observed in only one thin section. It is a monoclinic mineral with moderate birefringence and negative relief.

Summary and conclusions. The results of this study indicate that the Salado Salt in the samples received is composed primarily of fine to coarse-grained halite with polyhalite, anhydrite, and clay minerals. Other minerals detected in small amounts include gypsum, magnesite, quartz, feldspar, sylvite, carnallite, celestite (?), glauconite, and kainite(?). It should be noted that the samples received for analysis were selected from halite-rich zones in most cases; hence, some of the rarer evaporite minerals such as kieserite, langbeinite, leonite,

bischofite, etc., noted by Schaller and Henderson (1932) were not detected either because they were absent from the specimens analyzed or present in amounts too small (or too fine grained) to identify.

There is much petrographic evidence that the Salado salt was deposited in rather shallow water and may have been exposed subaerially at times. This evidence includes the presence of numerous hopper crystals (which can develop at the air-water interface of quiet, shallow seas) and the intergrowth of euhedral grains of halite with clay and silt-sized minerals, anhydrite, and polyhalite. The latter texture can develop in an exposed, mud-flat type environment. Previous workers, such as Anderson, et al. (1972), have concluded that the underlying, Castile Formation was deposited in deep water, perhaps as much as 2100' (650 m) deep. Hence, there must have been a major change in environmental conditions between the deposition of Castile and that of the Salado.

Petrographic evidence also suggests that local fluids native to the Salado have been able to move through the Salado salt (during recrystallization) along beds and seams of clay and silt, and to a lesser degree along fractures (see Section 7.8). These paths are now marked by entrapped fluid inclusions, zones of altered minerals and zones along which new minerals have been deposited.

Water loss determinations for over eighty samples from cores #7 and #8, indicate a range of water loss (upon heating to $102 \pm 5^{\circ}C$) from 0.0 to 3.5%, which is considerably below the water losses for samples from Lyons, Kansas. It whould be noted that the samples from the Lyons site came from much shallower depths than those from the Carlsbad area. In the section on weight losses, the ranges of dehydration to be anticipated with respect to depth are shown graphically. It appears that the ranges determined for the relatively shallow Lyons site merge with the ranges determined for the deeper Carlsbad site.

Most of the dehydration water at relatively low temperatures (near $100^{\circ}C$) appears to come from clay minerals, although gypsum may make a

contribution for samples taken at shallow depths. At higher temperatures, polyhalite will start to contribute to the dehydration of water. This dehydration takes place somewhere between 170° and 300°C. Pure polyhalite rock can lose up to 6% water. In general, the purer halite beds have weight losses below 0.3 to 0.5%.

As far as can be determined from the samples available for study, the rock units present in the Salado salt seem to release much less water when dehydrated than do the rocks of the Hutchinson salt from Lyons. Hence, the site near Carlsbad would seem to be more favorable (in so far as dehydration water goes) than Lyons. However, these rocks are not totally without water, and most units will lose from 0.0 to 0.3% water when heated and some units may lose up to 3.5% water.

Finally, it was noted during the preparaton of some of the samples that H_2S (and possibly some natural gas) was released when the samples were crushed. No H_2S was detected mass spectrometrically (previous section), which probably attests to a sensitivity of the human nose for H_2S that is unapproachable even with the most sophisticated available instrumentation.

7.6 FLUID INCLUSIONS IN CORE SAMPLES FROM ERDA NO. 9

7.6.1 Introduction

Fluid inclusions in the host rock are of interest to several aspects of nuclear waste disposal. First, determination of their origin and nature may provide insight into the complex sequence of processes and events from original deposition of the salt through to the present; such insight may well be of value in site evaluation. Second, fluid inclusions provide one source of water (and other volatiles) that would certainly aid in the corrosion and eventual breach of the waste containers, and subsequent leaching of the waste itself. Third, fluid inclusions, and their reaction under the thermal pulse from hot wastes, could have an effect on important physical properties of the hot host rock, such as deformation rates and particularly melting.

7.6.2 Samples Studied

Most samples studied were taken from ERDA core No. 9, and came from the following footage intervals:

From	To
1799.0	1799.5
1902.0	1902.3
2065.0	2065.4
2095.1	2095.5
2272.4	2272.7
2391.0	2391.3
2611.5	2611.8
2658.7	2659.0
2760.0	2760.2
2820.8	2821.2
2058.8	2059.0
2070.4	2070.6
2606.5	2606.9
2617.2	2617.7
2626.7	2627.0
2659.0	2659.2
2665.0	2665.1
2692.4	2692.6
2699.8	2700.0

In addition to the above "representative" samples, four nonrepresentative samples from ERDA No.9 were selected because they contained plainly visible large inclusions, suitable for special tests:

2061.2 - 2061.6
2064.5 - 2065.0
2614.7 - 2615.0
2518.5 - 2619.0

In order to test certain sample preparation and inclusion extraction procedures with no loss of important core, two pieces of core from AEC 8 were also picked:

2059.5 - 2059.8

2462.0 - 2462.9

In the Kerr-McGee potash mine, Lea County, New Mexico, northwest of the WIPP site a 4-m igneous dike has cut potash ore beds. As this represents a natural simulation of some of the heat effects of canister storage, it is instructive to examine the fluid inclusions in samples taken at measured distances from this dike:

MB-77-8	White halite 1-2 cm from dike
MB-76-3	Barren salt 0.2 m from dike
MB-76-4	"Ore" horizon 2.5 m from dike
MB-76-5	"Ore" -21 m from dike

Of these samples, the field evidence indicates that only MB-77-8 has been molten. The others show some mineralogical effects of the heating, but as sedimentary structures are preserved, they have presumably not melted (M. Bodine, personal communication).

7.6.3 Sample Preparation

Sections. A thick slice was cut from each sample using a diamond saw and ethyl alcohol lubricant. One side was fine ground with an alcohol slurry of abrasive (1200 grit), ultrasonically cleaned in alcohol, mounted on glass with cold-setting epoxy resin, and cured in 16 hrs. at room temperature. The section was then ground down on a lap, using an alcohol slurry, to 3-8 mm thickness (depending on opacity) and then polished by finer abrasives, ending with either 1200 grit or 0.3 μm Al_2O_3. Plates with fine-ground surfaces were examined using a matching silicone oil or saturated brine and coverglass. Coarse cleavages could be examined directly, without polishing.

A small section (~ 2 X 4 cm) was cut first, perpendicular to the core axis (when nature of sample permitted orienting), then one or more larger plates (5 X 8 cm) were cut parallel with the core axis.

Coarse water-soluble residues. 100- to 150- gram samples were dissolved in tap water at room temperature with frequent stirring. The solution was decanted frequently to remove dissolved salts and finely divided solids such as clays.

7.6.4 Methods of study

Petrographic Examination. All slides and preparations were examained with the petrographic microscope, but phases present other than halite were not determined due to the short time available and the redundancy with extensive mineralogical work by others. Most examination time was spent on finding and characterizing the nature, size, frequency and distribution of the fluid inclusions.

Considerable time was spent determining the volume of fluid inclusions in the plates, through counts of representative portions. This determination was based on measurements with a graduated ocular (calibrated with a stage micrometer) and several assumptions. First, the inclusions were considered to be cubes (based on observation); one edge was measured and then the volume calculated. Larger inclusions (~ 1mm edge length) that were obviously not cubes were estimated from the summation of a series of smaller cubes. Second, since bubbles were very rare (only about 0.1% of the inclusions), and small (~ 1% of inclusion volume), they were ignored. Third, most inclusions in these samples were of one or the other of two types (essentially the same as the types "A" and "B" discussed in a later section on Results), and any given small portion of salt contained only one type. As the bulk of the sample in any plate could be characterized easily into these two types the approximate volume percent of the samples for each type could be estimated. A ~500 mm^3 volume of the plate was then selected from each type, visually estimated to be representative of that type in that plate, and the volume percent of inclusions determined in it by measurement and counting, using a transparent grid template at 500X. The total volume percent of inclusions was then calculated from the weighted average. The weight percent of inclusion fluid was calculated, assuming the salt to have a density of 2.2 and the brine to be 1.3 g/cm^3. Large numbers of very tiny inclusions were estimated from counts and estimates of small

but visually representative volumes. Although the relative errors involved in this step are large, the total contribution by these small inclusions, even though they are extremely abundant, was very small. Most of the fluid found was present as a small number of large inclusions that could be measured more accurately. All inclusions over 200 μm (edge length) in the count volume were measured. The overall measurement error in volume percent of inclusions present is believed to be on the order of ±5% of the value stated for a given plate. Other variables, particularly rare, still larger, centimeter-sized inclusions that were opened during coring or sample preparation (and hence not counted), and the large difference between different plates from the same sample, introduced much larger errors.

Heating Stage. The liquid in inclusions trapped as homogenous fluid at above surface temperature shrinks on cooling, forming a bubble that provides a measure of the amount of differential shrinkage of liquid and host crystal. As the bubbles in the inclusions were small, relatively little heating was needed to cause homogenization. Hence a new heating stage was set up, consisting of a bath of silicone oil with an electric immersion heater and thermometer. Temperature equilibration was achieved through convection and frequent stirring. The individual runs were approximately 2-3 hrs. in length. Many inclusions that had no bubble as received developed one on cooling the silicone to $\sim -6^{\circ}C$ with solid CO_2. On subsequent heating this bubble would decrease in volume but persist as a very small bubble at room temperature. Heating was done on the stage of a low power binocular microscope, since the inclusions were large and scattered.

Freezing stage. The depression of the freezing point of the fluid in an inclusion (i.e., the "freezing temperature") is a function of the composition of the fluid. Using this techique under the microscope can permit a quick measure of the salinity of 10^{-10} g of fluid, a far smaller sample than can be measured by any other method. Metastable supercooling is common, so most inclusions had to be cooled to very low temperatures (three hours in CO_2-acetone at -78° or even LN_2 at $-196^{\circ}C$) to cause freezing. Subsequent slow warming of the sample while

surrounded by rapidly circulating refrigerated acetone of known temperature under the microscope permits recording the temperature of disappearance of the various solid phases formed on freezing (salts, hydrates, and ice), under equilibrium conditions.

If an inclusion is frozen completely to a mixture of solids, with no liquid, it becomes rather opaque. On warming, the first melting wets the crystal interfaces, suddenly making the mass more translucent, and permitting recrystallization to coarser crystals with time. This is called the "first melting temperature." It ranges from -21°C for pure NaCl solutions to -51°C for $CaCl_2$ solutions.

Crushing stage. If a host crystal containing an inclusion with a bubble is surrounded by a fluid and gradually crushed while under the microscope so that the behavior of the bubble can be observed, the presence of noncondensable gas in the bubble, and its pressure, can be determined. The test is only crudely quantitative in terms of pressure (based on the volume precent expansion), but it is extremely sensitive as a detector of small amounts of gas. Less than one billion molecules of gas can be detected readily. Numerous cleavage fragments of salt containing various types of inclusions were crushed on several models of crushing stages to determine the amount and pressure of any noncondensable gases present.

Coarse water-soluble residues. These were studied in oil immersion mounts in hopes that some of these phases were sufficiently coarse to contain fluid inclusions that would provide data on their conditions of formation.

Decrepitation. A portion of the core weighing approximately 100 g was split out with a rock splitter; where possible the outside core surface was avoided, due to the probability of physical deformation and resultant leakage of incluions. This piece was wrapped loosely in aluminum foil, weighed, and heated to the run temperature (150-250°C) over a period of 8 hours to avoid thermal shock, held at run temperature for 3-4 days, cooled and reweighed to determine weight loss. Following this the homogenization temperature range was redetermined for a series of

inclusions that appeared, on petrographic examination, to be representative. Crushing tests were also repeated on the heated samples to detect the presence of noncondensable gases under pressure.

7.6.5 Results of Petrographic Examination

Inclusions type A. This is the most abundant type by far. It consists of slightly rounded cubic cavities (Plates 7.13 and 7.14) filled with liquid and generally no other phase, except for rare tiny vacuum (shrinkage) bubbles that comprise $\sim 1\%$ by volume of those inclusions having bubbles. Only about 0.1% of the inclusions have bubbles, usually the larger inclusions only, but there are exceptions (see below). Type A inclusions occur as dense irregularly shaped clouds of randomly distributed but crystallographically oriented inclusions (e.g., Plate 7.16). In such dense arrays, individual inclusions are rarely over 20μm on an edge (Plate 7.18), few are $> 5\ \mu m$, and most are in the range 0.5-2.0 μ m, with the highest concentrations in the smallest sizes (Plate 7.19). Estimates of the maximum number of such inclusions, based on counts of representative volumes, show about one inclusion per 100 μm^3, or 10^{10} per cm^3. If these are assumed to average one μm^3 in volume, such cloudy halite would contain about one volume percent of fluid.

In addition to these irregular clouds, abundant type A inclusions occur in crystallographically arranged (cubic) planes and zones in the host halite, frequently with parallel inclusion-free zones (Plates 7.13 and 7.14).

In some zones type A inclusions grade into more sparsely distributed but larger inclusions ($\leq 100\ \mu m$), as seen in Plates 7.14 and 23-24. These coarser inclusions may represent incipient recrystallization of the host. The distinction between these larger type A inclusions and type B (next section) may seem inexact, but actually there is little overlap.

Inclusion type B. Type B inclusions, although far less abundant than type A, carry most of the inclusion fluid in these samples, since they are much larger ($\geq$ 100 μ m to several millimeters). Although large, many have no bubble as found (Plate 7.20), but may develop one if cooled slightly ($\sim -7^{o}C$) and warmed back to room temperature. They are generally irregular if large ($\geq$ 500 μ m) and are more nearly euhedral negative cubes if smaller (Plates 7.15 and 7.17). They occur as single isolated inclusions in otherwise almost optically clear halite, and as dense groups of many inclusions, in part interconnected with tubular extensions (Plate 7.15).

The host halite for type B inclusions may occasionally have cloudy wisps of type A inclusions, but they are never immediately adjacent to a large inclusion (Plates 7.15 and 7.17). These features suggest that salt originally containing only clouds of "primary" type A inclusions has been partly or completely recrystallized to form coarser crystals of clear salt with type B inclusions. This interpretation is supported by the grain size of the host salt, which is almost always coarser in those parts of a sample containing type B inclusions (see Table 7.13 in next section on weight percent of fluid). The boundary between cloudy primary and clear recrystallized salt is sometimes curved (Plate 7.16). If it were straight, it might not be possible to distinguish it from a primary growth zone boundary between fast cloudy and slow clear growth. Most areas of type A occur as irregular masses within single crystals of mainly recrystallized halite (Plates 7.15 and 7.17).

Relatively few samples, particularly sample 1902.2, show birefringent crystals of an unidentified phase inside what appear otherwise to be type B inclusions. These are equant to bladed crystals of moderately high birefringence ($\sim$ 0.06) and moderate index of refraction (but well above that of the surrounding brine). Many are twinned (Plates 7.25 and 7.26), and when prismatic or bladed, the extinction positions are strongly inclined to the crystal elongation. As the distribution of these crystals is irregular, and as a similar birefringent phase occurs in some of the same samples (Plate 7.27) the occurrence in the inclusions might be interpreted as accidental trapping of solids present at the time of

trapping of the inclusions. All 10 inclusions in one group in sample 1902.2 (Plate 7.27) contain these crystals, in roughly the same amount (estimated at ~ 5% by volume), thus suggesting that they are true daughter crystals, formed by precipitation from the trapped fluid. Another plane of inclusions in this same sample, only 400 μ m away, contains only liquid (Plate 7.28) so it is concluded that the fluids present during recrystallization changed in composition with time.

Inclusions Type C. This type is similar to type B in size, shape, and occurrence, but rarer, and differs only in containing a relatively larger gas bubble, of variable volume, but > 1% by vol. (Plate 7.29). A larger gas bubble can originiate by several processes -- leakage, necking down, higher temperature of trapping, or primary gas. The gas bubbles in these inclusions are found to be under pressure (see "Results of crushing stage studies"), so it is believed that such inclusions have trapped a mixture of gas and liquid (i.e., primary gas). In some (e.g., Plate 7.30), such inclusions have apparently formed by a refilling of an earlier type B inclusion with a gas-liquid mixture along a crack.

Inclusion Type D. This type occurs in curving planes outlining some of the individual crystal boundaries (Plates 7.31 and 7.32). It was probably full of fluid under natural conditions, but as the grain boundary permitted leakage and desiccation, these are now full of gas (presumably air).

7.6.6 Weight Percent of Fluid

A summary of the results of measurements of the volume percent of fluid in the inclusions is given in Table 7.13. In calculating these volumes some simplifying assumptions had to be made, in addition to those mentioned in Section 7.6.5. For simplicity the host salt volume counted was categorized as type A or B on the basis of the maxiumum size of inclusions it contained. If these were $\leq$ 1 mm, it was called type A. This division is not the same as given in the descriptions of type A and B inclusions, where ~ 100 μ m inclusions are considered as probably indicative of recrystallization, but this has little effect on the results, since on the average, over 90% of the fluid is present as type B

inclusions > 1mm in about 30% of the volume of the salt. Table 7.13 shows that these samples now contain a total of from 0.17 to 2.86% fluid by volume, and average 0.61. These values correspond to 0.1 to 1.7 weight percent fluid as extremes, and average 0.36 weight percent. These results are compatible with those reported in Sections 7.5.2 and 7.5.3.

These values have a measurement error of about ± 5% of the amount found. Much larger, however, is the variability introduced by the samples themselves. Thus three parallel plates were cut at ~ 3-cm intervals through samples 2272, and yielded 1.23, 0.36, and 0.20 volume percent fluid.

Even more important to consider is the bias inherent in these measurements due to substantial and unpreventable loss of inclusions. Examination of the cores showed some centimeter-sized cavities, the sites of former fluid inclusions. No inclusion this size could possibly be included in our count since the plates counted had to be <1 cm in thickness to be translucent. In addition, in situ all natural intergranular porosity in these salt beds was possibly full of fluids. The type D inclusions found represent probably only a trivial part of the total in situ water content present as such "imperfectly sealed fluid inclusion." Large scale in situ porosity tests would be needed to evaluate this variable.

7.6.7 Results of Heating Stage Studies

Only 35 inclusions were run, as listed in Table 7.14. These are mostly from type B inclusions. Some of these inclusions had to be cooled to below room temperature to nucleate a bubble before the run (Plates 7.20, 33 and 34). Why some very tiny inclusions have vapor bubbles (Plate 7.36), yet many large ones have persisted metastably as stretched liquid (i.e., one phase) is puzzling. The data are too sparsely distributed to determine whether the range of values (20.4 to 45.5°C) represents a real difference between samples. One group of inclusions in sample 2821 with birefringent daughter crystals showed no change in the crystals on heating to 24.5°C.

7.6.8 Results of Freezing Stage Studies

Inclusions in NaCl have a special type of behavior on freezing, as a result of reaction of the water of the inclusions with the walls to form the new incongruently-melting phase hydrohalite ($NaCl.2H_2O$), at temperatures below +0.15°C. As a result, the inclusion enlarges and becomes full of birefingent crystals upon being held at low temperatures. Evidence of this expansion remains on warming to room temperature. Furthermore, the volume resulting from expansion to form ice is frequently larger than the original volume of the inclusion, and the inclusion's walls crack to relieve the pressure (Plate 7.35).

The freezing data are summarized in Table 7.15. If the solution present is simply NaCl and H_2O, the last crystal of hydrohalite will melt at +0.15°C, assuming equilibrium has been obtained (which is an extremely slow process for this phase). Although only relatively few large type B inclusions were run, many smaller type A inclusions were also watched at the same time. None were found to have either first melting at -21° or freezing at +0.15°C, so none consist of essentially pure NaCl solutions. Much hydrohalite formed in these inclusions, but as there were birefringent crystals (generally with birefringence less than that of hydrohalite) that persisted well above +0.15°C, the last solid is a phase other than hydrohalite, and the solutions must contain significant quantities of materials other than NaCl (Plate 7.37). This is also very evident from the first melting temperatures.

7.6.9 Results of Crushing Stage Studies

Bubbles in types B and D inclusions from several samples were examined on the crushing stage. All disappeared immediately on opening, indicating that they consist of water vapor (at ~ 20 mm pressure), and hence collapse at one atmosphere. The bubbles in several type C inclusions showed considerable expansion, however, indicating gas under pressure. Thus the bubble in the inclusions shown in Plate 7.38 expanded 270% by volume on opening (Plate 7.39), indicating that nearly three atmospheres of noncondensable gas is present. The composition of this gas is unknown at present.

A previously unrecorded inclusion deformation phenomenon was also observed in some inclusions that were in a sample that was under uniaxial stress on the crushing stage at room temperature but had not been broken to release the inclusions. These inclusions developed a scalloped pattern along the corners (Plate 7.40), presumably due to solution at points of stress concentration and redeposition elsewhere. This pattern developed over a relatively few minutes at effectively constant stress. At least some volume change occurred in this process, since the bubble in the inclusion disappeared at constant temperature.

7.6.10 Results of Study of Coarse Water-Insoluble Residues

The weight percent of such residues ranged from 0.005% (sample 2391 to 0.3% (sample 2821). Unfortunately, however, although there were a variety of phases present in the residues, none of the crystals contained visible fluid inclusions. Some samples emitted a petroliferous odor and showed oily films on the water surface during leaching; it is not known whether these represent contamination from the oil-based drilling mud used in part of the coring, or natural oil in the samples (as is present in other salt deposits, as integranular films and inclusions). No oil inclusions were seen in this work.

7.6.11 Decrepitation Tests

These tests were run only on the last nine samples of the first 19. A summary of the test data and results is given in Table 7.16. On examination of the material after the decrepitation tests, several general features were evident. The nature of the test is such that systematic inclusion counts before and after the test on the same sample are impossible. It was obvious that although most of the larger inclusions had decrepitated, and were empty, many small inclusions ($\leq \sim 100\ \mu m$) had not. These small inclusions appear perfectly normal in distribution, but almost all had developed appreciable vapor bubbles (Plate 7.41), with a vapor/liquid ratio that is obviously higher after heating than that present in two-phase inclusions before heating. Only the 150°C sample still had inclusions without bubbles; a few 10-20 μ m one-phase liquid inclusions were found there. All three samples showed some "steam" inclusions - cubic negative crystals with fillets of liquid

in the corners. No gas under pressure was found in any of the heated inclusions. In most cases, the weight losses increase with increasing run temperature; the several exceptions are probably a result of nonhomogeneous distribution of inclusion in the sample aliquots taken.

Homogenization temperatures were determined on two-phase inclusions remaining in the samples after the decrepitation tests. The results are given in Table 7.17, along with the volume percent of vapor phase, estimated from measurements of bubble diameters.

7.6.12 Study of Suite of Samples from Kerr-McGee

The three samples closest to the lamprophyre dike (See Chapter 3) yielded usable inclusions. (Sample MB-76-5 was too fine grained and opaque to be usable by the sample preparation techniques used here, and will not be considered futher in this report.) In all three samples about 15% of the small inclusions ($< \sim 20$ μm) were without bubbles as received. Most inclusions in all three samples were normal, two-phase inclusions with a small bubble. Homogenization temperatures were determined on a representative group of these two-phase inclusions in each, with results as shown in Table 7.18.

Freezing runs were made on inclusions in two of these samples. In both cases the first melting temperatures were well below that of a pure $NaCl-H_2O$ system ($< -28^oC$ for MB-77-8 and $< -31.0^oC$ for MB-76-4). On warming, the last solid phase to dissolve in both samples was an unidentified phase, presumably a hydrate other than $NaCl \cdot 2H_2O$. This dissolved at +11 to $+18^oC$ (MB-77-8) and at +4 to $+7.2^oC$ (MB-76-4).

One 75- μm inclusion was found in MB-77-8 that yielded an entirely different freezing behavior. This inclusion contains a single homogenous fluid at room temperature, presumed to be gas (Plate 7.43a). On cooling to the range -70 to -75^oC this inclusion develops a number of grains of an unidentified solid (Plate 7.43f). On warming to about -68^oC, a liquid/vapor meniscus becomes visible (Plate 7.43e), with solid grains

still present. The last of these grains disappears at $\sim -56^{\circ}C$ (Plate 7.43d); on further warming the liquid/gas meniscus becomes faint (Plate 7.43c) and the two homogenize, by expansion of the liquid, at $-20.9^{\circ}C$ (Plate 7.43b). This behavior is difficult to interpret in terms of composition. CO_2 has its triple point at $-56^{\circ}C$, in exact agreement with the disappearance of the solid phase at $-56^{\circ}C$ observed here, but obviously the inclusions cannot contain just CO_2, as there is liquid present at a lower temperature. The nature of the mixture of gases can only be guessed at this time.

The crushing tests in the Kerr-McGee mine samples were most revealing. The normal, small-bubble inclusions contain a vacuum bubble (i.e., water vapor at ~ 20 mm presure). Many inclusions that either had a very large bubble or appeared to contain gas only, from all three samples, were found to contain either vacuum (Plates 7.44 and 7.45), or a partial vacuum (Plates 7.46 and 7.47). These are probably from the trapping of bubbles of steam, with or without some noncondensable gas and brine. All three samples also contained a few inclusions with gas under greater than atmospheric pressure. These inclusions were one-phase as first observed, and except under special circumstances, it is not possible to distinguish between a vacuum, dense gas, or even liquid, in such single inclusions. It is only on crushing, when these inclusions formed bubbles of noncondensable gas in the surrounding fluid, that the internal pressure became evident. By measuring the size of the inclusions before crushing, and the diameter of the bubbles evolved, we obtain a crude measure of the internal pressure, assuming each unit volume expansion corresponds to one bar pressure. In a few inclusions, the contents changed to a two-phase, liquid + vapor system during the expansion (Plate 7.48), but usually the pressure release was too sudden to reveal if there was a transient two-phase condition. The volume expansion varies for different inclusions, from 30- to 40-fold (Plates 7.49 and 7.50) to a maxiumum of perhaps 100-fold (Plate 7.51). As the immersion medium used is an oil in which methane is probably readily soluble, this gas is more likely CO_2, since the bubbles dissolve in the oil very slowly.

Interpretation of the data from the Kerr-McGee mine samples is difficult at this time. The presence of an inclusion filled with a dense CO_2-rich (?) gas in sample MB-77-8, (in halite that was probably molten at the time of intrusion of the dike) is not unexpected, since there is a small amount (0.2-2%) of magnesite in the adjoining rock (M. Bodine, personal communication). The dike shows no evidence of carbonate alteration, however, and there is a problem in explaining the presence of inclusions of low-temperature, gas-free brine, apparently pure steam, and dense CO_2 in the same sample. Formation of these types at different times is obviously required, but there is no other indication of differences in conditions or time of origin.

The temperature at which the dense gas inclusion was trapped is of interest. Although the melting point of pure NaCl is 800°C, other materials present here in the potash ore zone (such as KCl) will lower this temperature. If we assume that the gas inclusion contains pure CO_2, the -21°C homogenization indicates a filling density of about 1.03 g/cm^3 (Roedder, 1965). Combining this with the estimate of confining pressure of ~ 38 MPa (380 bars) yields an obviously erroneous "trapping temperature" of 0°C. The several inconsistencies and difficulties in interpretation of the data from the Kerr-McGee samples cannot be resolved until additional studies are made.

7.6.13 Discussion

Geological Significance. Several aspects are evident from these various results. First, the fluids in all the inclusions, both type A in primary salt crystals and type B in recrystallized salt, are strongly saline brines, with significant amounts of other salts present in addition to NaCl. These brines differ from one inclusion to another, indicating that a range of fluids has been present at various times in these beds, but no inclusions with simple NaCl solutions were found, as are found in other salt beds and as might be expected if pure salt beds have been fractured in the presence of meteroically-derived (fresh) ground water. The original deposition of salt occurred from highly-concentrated brines, and

presumably all waters that have passed through these samples since have had dissolved in them amounts of other minerals in addition to NaCl. Such fluids have caused extensive recrystallization of the salt, and presumably other mineralogical changes, so that little of the original salt texture remains. Second, at some stage in this recrystallization, gas-liquid mixtures were present in the pores of these beds. Third, this recrystallization occurred at near-surface temperatures (20-45°C). Fourth, the movement of these fluids must have been slow, as the evidence of extensive inclusion metastability indicates very clean solutions, free from the solid nuclei present in most fast-moving near-surface waters.

The fluids from which the salt crystals making up these beds originally crystallized were exceedingly saline brines with much material other than NaCl in solution, as shown by the freezing data on primary inclusions in hopper salt. These hopper crystals appear to have grown on the surface and then to have sunk, as described by Dellwig (1955). All but about 1% of this original hopper salt texture has been eliminated by recrystallization at some unknown later time, yielding coarser, clearer crystals of salt, and presumably gross changes in the mineral assemblage other than halite. Some of the clear salt surrounding the chevron structures may represent crystallization of these hopper nuclei on the bottom of the basin, but most is believed to be from recrystallization. This recrystallization occurred in the presence of exceedingly saline brines and with much material other than NaCl in solution. The brine may have been composed essentially of fluids from the primary fluid inclusions, released during the recrystallization. It was trapped as large inclusions in the recrystallized salt and comprised the bulk of the liquid now present in the samples as studied in the laboratory. Although the salt beds now appear dry to the eye, the samples contain 0.1 to 1.7 weight % fluid as examined, and may contain more in situ. At some stage or stages early in the history of these beds, the fluids present in these rocks varied in composition. (See section 7.7) A very few were saturated with organic gases such as methane and actually contained bubbles of a separate gas phase. Others contained additional salts in solution, resulting in the precipitation of various crystalline solids

from the liquid within inclusions in halite. The relative time sequence of these various fluids is not known, and most inclusions have neither methane nor crystalline solids. The latest episode of any recrystallization has been dated at 204 million years, slightly younger than Permian.

Homogenization temperatures of inclusions in recrystallized salt range from 20.4 to 45.5°C. During burial, creep from recrystallization in a salt bed with intergranular films of solution should result in the hydrostatic pressure on fluids (during trapping in a crystal) being essentially equal to the lithostatic pressure. If an overburden of 5000 ft. (1524 m) is assumed to have been present during the recrystallization, the maxiumum pressure (lithostatic) would have been ~ 38 MPa (380 bars). There are no PVT data on the specific fluids present in the inclusions, but if the data on a 25-percent NaCl solution are used, this pressure would suggest a maximum pressure correction of 36°C (Potter, 1977), and hence trapping (i.e., recrystallization) temperatures of 56-82°C. However, the true pressure correction may be lower, particularly since the fluids are more saline than 25-percent NaCl. Thus there is a drop of 12°C in the pressure correction on changing from 20-percent NaCl to 25-percent NaCl.

The presence of smooth planes of primary hopper salt inclusions of various sizes, separated by planes of inclusion-free salt, with the plane orientation horizontal, proves that these minute inclusions have not moved measurably since deposition, although they have been in a geothermal gradient presumably similar to that of the present for about 225 m.y.

The widespread occurrence of metastable phenomena in these inclusions, even in some large ones, suggests that fluid flow in the past through these beds has been very slow. Also, the fact that <u>all</u> inclusions that have been frozen prove to contain bitterns, and none was found with just $NaCl-H_2O$ solution, proves that at no time during the history of these samples did ground water, saturated <u>only</u> with respect to NaCl, ever penetrate into these particular samples.

Nuclear Waste Disposal Significance. The most signficant aspects at this stage in the study are as follows: First, the amount of fluid water solution now present in the samples as fluid inclusions averages 0.36 weight percent. Second, although noncondensable gases are present under pressure in some inclusions, the total amount is very small. Third, the inclusions change dimensions signficantly within minutes at room temperatures when the host crystal is subjected to uniaxial stress; this might suggest more rapid movement of inclusions in a thermal gradient if simultaneously under stress, as in mine pillars. Fourth, and possibly most significantly, the distribution of primary inclusions indicates that they have not moved visibly (i.e., less than a few micrometers at most), in the 225 million years since they formed, yet they have been in the small but finite geothermal gradient all this time. All fluid inclusions can be expected to move when placed in a thermal gradient. Since there is usually a thermal coefficient of solubility, material will dissolve on one wall and precipitate on the other. The rate of movement is a complex function of numerous variables (including inclusion size), but the temperature coefficient of solubility is probably the most limiting parameter in the case of NaCl. In the pure system $NaCl-H_2O$, the solubility change per 100g H_2O is low, only 0.03gm/^{o}C in the range of 0-100°C. This increases by approximately a factor of two at the elevated temperatures expected near the wastes. This coefficient is comparable in the $NaCl-MgCl_2-H_2O$ system.

All these aspects will now be treated in expanded detail.

Amount of Water in the Beds. Although this is the most important single datum that might be obtained from inclusion studies, fluid inclusion counting can provide only approximate values. The nature of the samples and the necessary sample preparation are such that there is a bias toward low values built into these data. Superimposed on this uncertainty in accuracy is poor precision in the measurement, due to variability of the sample material. For example, adjacent slabs of the same sample showed a five-fold range. It is probable that precisely calibrated neutron logs, reflecting the amount of hydrogen in the beds, give a more accurate

evaluation of the total water present, since they would effectively integrate over a much larger sample and would include the effects of the liquid-filled intergranular cavities which these tests miss.

One important aspect of the inclusions on the properties of the salt is the effect of the constitutents present on the lowering of the temperature of melting, and on the amount of liquid present at any given temperature. In this connection it is important to note that the inclusions' fluid is not water, but a strong bittern with probably significant quantities of magnesium ions. This will certainly affect the temperature coefficient of solubility of NaCl in these liquids, and will have important effects on the vapor pressure of these liquids (see below).

Corrosive Gases in the Inclusions. Although gas analyses by mass spectrometry are still to be made on the inclusion fluids, it is evident from the crushing studies that the inclusions in these samples, at least, contain very little noncondensable gases. Although hydrogen sulfide was found as an important constituent of gases in a gas pocket in another drill hole, (ERDA-No. 6, Section 7.7), there can be very little, if any, in these inclusions. The human nose is a rather sensitive detector of H_2S, ordinarily responding to a minimum of $\sim 10^{-10}$g. No odor of H_2S was detected during preparation of these samples, when relatively large volumes of inclusion liquid were exposed to the air. Gases such as HCl formed within the inclusions or by reactions of inclusion fluids with other minerals during heating, and under intense gamma radiation, may be a much more important cause for corrosion than those now present in the inclusions.

Effects of Water on Physical Properties of the Salt. The intergranular porosity in these salt beds, <u>in situ</u>, possibly contains some aqueous solution. Such fluids will tend to be squeezed out of the salt beds over geological time as recrystallization along grain boundaries and other processes permit compaction, just as the residual water in a sandstone is eliminated during the formation of a quartzite. Such flow will occur, however, only if there is an escape route for the fluid to take. As

pointed out very aptly by Baar (1977), there is much evidence from high pressure fluid pockets that salt rocks in situ are generally impermeable at depths exceeding about 300 m. It may well be that under such conditions, which preclude further "dewatering", the fluid in these intergranular films is still able to migrate short distances, enough to permit it to coalesce into "pockets", perhaps at points of slightly reduced pressure, just as a plastic shale will flow to the crest of folds in firmer rocks. These "pockets" might be represented in part as the short-lived seeps observed in potash mines.

Even if the intergranular liquid were to be removed completely, yielding a polycrystalline texture with salt crystals in true contact with each other, there is no driving force to remove the fluid inclusions from within the individual halite crystals. If such a salt bed is deformed to the point of rupture of salt crystals, any inclusions along the rupture will provide water to "lubricate" the fracture and hence lower the apparent strength of the rock. Although one might expect that a new fracture would preferentially follow planes of inclusions, as from the healing of former fractures, Gerlach and Heller (1966) have shown that the salt recrystallized in the vicinity of such a healed fracture is actually stronger than the adjacent unrecrystallized salt, and new fractures could not be made through the inclusions. Actually, most of the fluid in inclusions in the Carlsbad salt is in large, apparently randomly arrayed inclusions in recrystallized salt, and examination of fractures through such samples suggests that cracks induced in the laboratory experiments reported here have preferentially taken routes through such inclusions.

One example of the surprising effects of inclusion fluids on the properties of salt crystals is found in the behavior of fluid inclusions in single crystals of salt under uniaxial stress (Plate 7.40). Under these conditions, fluid inclusions visibly change shape, and volume, within a few minutes, at room temperature. This is a new inclusion phenomenon, never reported before.

Evidence of Previous Solution Movement in These Beds. The fluid inclusion evidence obtained so far on solution movements is encouraging in that it indicates at most only very slow movement, and suggests that part of the fluids now present in these beds may even be nearly Permian in age. The lack of any pure $NaCl-H_2O$ inclusions also argues against any previous sudden inrush of groundwater that could be trapped as inclusions in halite before it had time to acquire a full complement of other salts.

Movement of Inclusions in a Thermal Gradient. All fluid inclusions should move when the host crystal is placed in a thermal gradient. The nature and rate of such movement has been the subject of numerous studies, since it is of consequence in the chemical industry. Wilcox (1968) summarizes this extensive work (citing 111 references). Similar migration of inclusions is also an important cause for degradation of laser crystals grown at high temperatures by the Czochralski technique (Hopkins et al., 1976). Most liquid inclusions move up the thermal gradient, but if the vapor bubble is large relative to the liquid, and particularly if boiling occurs, the movement may be in the reverse direction (Wilcox, 1969; Anthony and Cline, 1972; Chen and Wilcox, 1972). The rate of movement is independent of inclusion size in many systems, but strongly (and directly) dependent on inclusion size in others (Wilcox, 1969); there may be a threshold size below which no movement occurs ($\sim 10\ \mu m$ in KCl; Anthony and Cline, 1971a). Large inclusions may break up during movement (Wilcox, 1968; Anthony and Cline, 1973). Many factors may affect the rate of migration, even in a given host, including gravity, composition, surface tension, inclusion shape, crystal anisotropy and imperfections, presence of a foreign gas, etc. In salt, since the thermal coefficient of solubility is small at surface temperatures, but increases greatly with increase in temperature, the rate of movement in a given gradient can be expected to increase with increase in ambient temperature. Higher ambient temperature also increases the travel rate by increasing the solubility, the diffusion coefficient, and the interface kinetics, and the increase in rate was found to be particularly striking in NaCl (Wilcox, 1968, p. 20). The

fact that the inclusions in Carlsbad salt have not moved measurably during geological time in the geothermal gradient is perhaps an indication of exceedingly slow rate, or perhaps a result of a very weak driving force.

Accurate prediction of behavior of in situ inclusions in the thermal gradient around a canister in salt cannot be obtained at this time, as there are too many uncontrolled variables. Since most inclusions at Carlsbad contain no bubble or only a very small bubble, they will move toward the canister, as was shown to occur at Project Salt Vault (Holdoway, 1974). The rate of this movement will depend most particularly on the inclusion size, the ambient temperature of the grain, the temperature gradient, and the temperature coefficient of solubility of NaCl in the particular inclusion fluid involved. The average distance that an inclusion must travel before it intersects a grain boundary will vary with the grain size of the salt, but seldom would be over 1 cm.

What can be expected when the inclusion reaches a grain boundary? Anthony and Cline (1971b) showed that grain boundaries in crystal aggregates tend to trap migrating droplets, but Anthony and Sigsbee (1971) showed that gas bubbles (10-50 μm) migrating in polycrystalline camphor could cross grain boundaries. However, migrating bubbles were observed to drag grain boundaries when the bubble concentration on the grain boundary was large. In Project Salt Vault, Holdoway (1974) says only that "little migration across grain boundaries appears to have occurred." Obviously, if a grain boundary is very tight, a large inclusion could cross it without effect. But if the grain boundary is composed of different material, the fluid could spread out along it as a film. Any such film should act as an inclusion, with material diffusing across it away from the heat source.

The behavior of an inclusion migrating to the wall of an open cavity (e.g., that holding the canister) will be different. On contacting the cavity, Anthony and Cline (1974) and Wilcox (1968, 1969) have shown that

some evaporation occurs, a vapor bubble forms, the inclusion seals itself, and now that it has a large bubble, it reverses direction and moves back the way it came, this time going down the gradient.

Decrepitation Release of Liquid Inclusions. In view of the expected slow migration rates of liquid inclusions in the thermal gradients established by the canisters, it seems probable that release of inclusion fluid by decrepitation will be an important process. An individual inclusion, if it is assumed to have rigid walls, to contain 25-percent NaCl solution, and to homogenize at 40°C, will develop 70.0 MPa (700 bars) internal pressure when heated to 100°C, and 200 MPa (2000 bars) at 200°C (Potter, 1977). However, salt cannot stand such internal pressures without yielding. Even a strong, hard mineral such as quartz starts to decrepitate when the internal pressure in its fluid inclusion reaches 80 ± 3 MPs (800 ± 3 bars) (Khetchikov and Samoilovich, 1970), and halite can be expected to decrepitate when the internal (inclusion) pressure reaches four times the yield stress for monolithic halite, under no confining stress (Cline and Anthony, 1971).

When Carlsbad halites were heated, some of the inclusions decrepitated in part causing the samples to fragment, and yielding an average weight loss of 0.13% (150°C), 0.22% (200°C), and 0.73% (250°C). This means that this much volatiles left the system. More inclusion fluid may well have been exposed, and merely lost water until its concentration of salts was such that the vapor pressure of H_2O at that temperature was less than one atmosphere. Salts in solutions in these brines (including materials other than NaCl as well) have effects on the vapor presure and hence on any vapor transport.

In addition to those inclusions that decrepitated, however, many inclusions remain sealed as liquid inclusions in the sample after heating, albeit in a changed form. These have permanently deformed their walls to form a larger chamber, and now have a much larger shrinkage bubble, proportional to the amount of expansion. (Why some decrepitate and others expand is at present unanswered; residual stresses in the host

crystal may be involved.) This expansion phenomenon is not new - it has been reported at various times in the past. It is the net result of several volume changes during heating of the inclusion. On heating, the host salt expands, enlarging the cavity as well. This effect is small, yielding a cavity volume increase of only 1.2% from 40 to 140°C. The fluid in the inclusion dissolves more salt from the walls on heating; the net volume effect of this (generally a decrease; i.e., an increase in cavity volume) will vary widely with the composition of the solution. Thermal expansion of the brine would develop high pressures if the walls were rigid, but instead, in the presence of liquid, the inclusion walls frequently just expand. The amount of expansion is roughly proportional to the temperature of heating, i.e., the inclusion fluid streches the walls until its internal pressure drops just below that needed to cause further stretching at that temperature. Nucleation of a vapor phase may even occur (Geguzin and Dzyba, 1973), in which case loss of water to the expanding vapor phase also helps to limit the expansion. Some of the thermodynamic variables of the process have been modeled by Cline and Anthony (1971) for the pure halite system.

7.7 THE GEOCHEMISTRY OF DELAWARE BASIN GROUNDWATERS IN RELATION TO THEIR HOST ROCKS

7.7.1 Introduction

Geochemical studies of waters found in Permian and younger rocks of the Delaware Basin (Southeast New Mexico, West Texas) have assumed a new importance in recent years. This began in 1975 when Sandia Laboratories, in cooperation with the United States Energy Research and Development Administration undertook studies of the suitability of Delaware Basin evaporite deposits for the long-term storage of radioactive wastes generated by the national nuclear defense program.

In particular, three aspects of fluid geochemistry have bearing on an understanding of the geology of the area:

1. Rock history - the relationships between dissolution features and nearby fluids which may have dissolved evaporites.

2. Fluid history - evidence of rock/fluid interactions preserved in fluid chemistry, indicating the complexities of fluid movement.

3. Fluid origins - the ultimate sources of fluids which have participated or have potential for participating in dissolution of evaporites.

Many of the waters considered here were bailed from preexisting wells with the assistance of the United States Geological Survey, between December, 1975, and June, 1976. In addition, boreholes for subsurface exploration of Los Medanos (the ERDA study area) tapped some fluid producing zones. These holes include ERDA No. 6,. which at a depth of 2711 feet produced saturated brine associated with H_2S-rich gas from the Castile Formation. In this hole, stratigraphic marker beds were found several hundred feet above their expected positions (Anderson and Powers, 1978). Nine holes penetrating the Rustler Formation have facilited hydrological testing and sampling of Rustler waters. Finally, samples of waters were collected from pools in Carlsbad Caverns. Table 7.19 is an inventory of water samples, together with their collection locations. New Mexico locations are given in Figure 7.10, showing their distribution with respect to the Capitan Limestone.

Three geochemical approaches will be followed in this subchapter. Each approach will consider a few examples of various "types" of water:

1. Solute chemistry - dissolved solids content.

2. Thermodynamics - equilibia and non-equilibria of a fluid-gas system.

3. Stable isotope ratios - variations in deuterium and oxygen - 18 content.

7.7.2 Data

Analytical results for the 29 waters are given in Table 7.20. Solute analyses are expressed in mg/l, performed according to APHA (1971) methods, with modifications by Collins (1975). Analyses by Martin Water Laboratories have a precision of about ± 5 to 10%; others ± 3% (Table 7.19).

Stable isotope analyses were made according to Epstein and Mayeda (1953) and Bigeleisen et al (1952), and are reported in " δ " notation as deviation of the D/H or $^{18}O/^{16}O$ ratio from the corresponding ratio of Standard Mean Ocean Water (SMOW) (Craig, 1961b, Epstein and Mayeda, 1953), in parts per thousand (‰, "per mille") for example:

$$\delta D = \frac{(D/H)\ \text{sample} - (D/H)\ \text{SMOW}}{(D/H)\ \text{SMOW}} \times 1000$$

The precision of $\delta\ ^{18}O$ values is better than ± 0.1‰ and that of δ D is better than ± 1‰ .

Solutes. In this discussion "fresh water" is taken to contain less than 3000 mg/l total dissolved solids (TDS), and is potable at least to local cattle. "Brackish water" refers to TDS contents between 3000 and 30000 mg/l. Brines are waters containing more than 30000 mg/l TDS. According to these definitions, number 1, probably 18 and 26 through 29 (Table 7.19) are fresh waters, found in the Capitan and Santa Rosa Formations. Numbers 2, 6, 11, 17, 22, 24 and probably 19 through 21 are brackish, and include most Rustler waters, one Capitan and one Castile. The fresh and brackish waters contain the solutes expected to be found in carbonate and anhydritic or gypsiferous aquifers. All the other waters are brines, and include the Salado, Morrow, Delaware (Bell Canyon) waters, two Castile, one Capitan, and even two Rustler waters; these Rustler samples came from the Culebra dolomite member, adjacent to halite-bearing parts of the Rustler Formation.

Brines are treated in the most detail here, since their presence has implications regarding either their representation of original evaporite mother-liquors, or their solutes having been derived through rock-water interaction. Their geochemical complexity cannot be understood from solute chemistry alone, and a brine occurrence in a particular rock unit does not necessarily imply that the brine has interacted with its host rock.

The chloride/bromide ratios, where obtainable, of all the brines were between 430 and 900, compared to 292 for modern sea water (Collins, 1975). If the Permian Basin water had a Cl/Br ratio similar to that of sea water, as suggested by Holser (1963) for fluid inclusions in Kansas salt, then these Delaware Basin brines do not contain "original" Permian water as a major component. Since halite crystallizing from sea water selectively excludes bromide from the NaCl lattice, halite has a Cl/Br greater than 300 (Adams, 1969), as would brine resulting from the dissolution of halite. Hence, the sodium chloride in these brines has been dissolved from rocks, but not necessarily the rocks in which the brines were found.

Rather than discuss abundances of individual ions in brine solutions, it is more instructive to consider solute ions combined as solids which might be expected to precipitate from solution upon complete evaporation. Following the crystallization sequences compiled by Braitsch (1971), not only some similarities will be noted between the resulting normative mineral assemblages, but also some significant differences. Waters 16, 9, and 14 (Salado, Bell Canyon, Castile) will be presented as examples.

Water from the Duval Mine Vent Hole is similar to the other potash mine seeps (Numbers 3, 4 and 5) all of which are saturated solutions. Table 7.21 shows the relative proportions of minerals expected to precipitate from this solution. This assemblage is similar to that expected to precipitate from sea water, even though the relative proportions are different (note the overwhelming preponderance of carnallite). In view

of the incongruent dissolution of polyhalite resulting in a calcium-poor solution, this brine is what one would expect for water which has dissolved a potash deposit. Note the presence of normative borax, an evaporite mineral not commonly reported in the Carlsbad potash district (cf. Jones, 1975).

Waters from the more saline portions of the Capitan aquifer (numbers 11, 12 and 13) contain the normative assemblage dolomite-anhydrite-kainite(or carnallite)-halite±sylvite, in various proportions, and are also indicative of solutes obtained by dissolution of adjacent evaporites.

Water number 9, from the Bell Canyon Formation, is examined in Table 7.22. The solution is calcium-rich, as indicated by the less common minerals tachyhydrite and antarcticite. These two minerals are not known to precipitate from sea water, and together with a magnesium deficit distinguish this water from a simple solution of primary evaporites. Graf et al. (1966), have given attention to the origin of calcium chloride waters, and emphasized shale ultrafiltration as an explanation. Other possibilities include diagenetic reactions in which magnesium in solution displaces calcium in carbonates to form dolomite, or in which Mg-rich sheet silicates are formed, having given up more easily replaceable cations such as Na and Ca (Grim, 1968), which were present in the original minerals (kandites and smectities). Mg-rich sheet silicates are present in the Ochoan evaporites overlying the Bell Canyon (see subsection 7.4). Since brine number 9 is a saturated solution, and since calcite, not dolomite is the prevalent carbonate mineral of the Bell Canyon, neither dolomitization nor shale ultrafiltration (which tends also to produce a low-Ca water, which has not yet been found) appears to be a satisfactory model for the in situ evolution of Bell Canyon brine. The sulfate deficiency could have arisen from biogenic degradation of sulfate. The most likely explanation for the in situ Ca-enrichment is ion exchange. This brine probably did not originate in the Bell Canyon, but its solutes probably came from nearby evaporites.

Waters 8 and 10 have a much lower TDS content than does 9, but otherwise yield most of the same minerals. The high strontium content of all three could be taken to indicate that these waters have indeed participated in the recrystallization of carbonates, but probably not within the Delaware Mountain Group of sandstones, which includes the Bell Canyon Formation. According to the Sr/Ca studies of Oxburgh et al. (1959), this solution would have been in equilibrium with a calcite containing about 4000 ppm Sr, a value too high for most natural calcites and dolomites. The Sr in solution could easily have come from the diagenetic alteration of aragonite outside the Bell Canyon.

On July 30, 1975, borehole ERDA No. 6 produced saturated brine (number 14, Table 7.19) and H_2S-rich gas (0.16 cubic feet STP per gallon) from a fractured, gray, laminated Castile anhydrite unit 2711 feet below the surface. Similar phenomena in the Castile have been reported by oil companies, but with an order of magnitude more gas. The analysis of one other such brine (Shell Bootleg, number 15 in Table 7.19) is given in Table 7.20, and is quite similar to the ERDA No. 6 brine. The solutes are resolved in Table 7.23, and aside from thenardite and LiCl (resulting from an almost economic concentration of lithium) are similar to the case of the dissolved potash deposit. Na_2SO_4 has been previously reported in subsurface brines (Reeves, 1963), and thenardite is known to precipitate from local surface lakes. Lithium is a common component of evaporites formed near igneous rocks, but the nearest igneous rock is several kilometers away (Calzia and Hiss, 1978). The brine is sodium-rich and magnesium poor. Once again in terms of ion exchange, a loss of evaporite-derived magnesium into silicates, which give up sodium, appears to be the mechanism here, although this need not have taken place in the Castile. Such like processes may account both for magnesium depletion in the solution and the formation of magnesium silicates in the evaporite sequence.

Thermodynamics. The ERDA No. 6 gas and brine are the only fluids which lend themselves to multiphase thermodynamic considerations. The gas amounted to 1.22 liters (STP) per liter of liquid, and consisted of

55% CO_2, 28% H_2S, 15% CH_4, 1.5 N_2 and 0.5% C_2H_6, determined mass spectrometrically. The H_2S is not saturated in the solution, even in the light of the salting-out effect of high TDS content (Randall and Failey, 1927), and amounts only to 0.02 molal. In order to examine the role of sulfur in this system (the only multivalent element common to both liquid and gas phases) a predominance area diagram (cf. Garrels and Christ, 1965), was constructed for the system S-O-H with the variables pH and oxygen partial pressure, and with total sulfur equal to 0.36 molal (approximating the sulfate and H_2S in solution). The resulting diagram is Figure 7.11, for the field-temperature of 25°C. The field-measured pH is 6.3, and samples of the brine containing dissolved H_2S were observed to precipitate elemental sulfur upon standing at atmospheric conditions. The diagram shows that at pH 6.3, the sulfur field occurs between the sulfate and H_2S fields. Thus, the diagram correctly predicts the oxidation of H_2S to sulfur, and the sulfate and H_2S cannot be in thermodynamic equilibrium with one another at pH < 7. Unfortunately, the oxidation potential was not measured, and the precise position of the ERDA No. 6 system on the diagram is not known. The most probable origin of the H_2S is biogenic reduction of sulfate, an ion abundant in the surrounding rocks as anhydrite as well as in solution. Kuznetsov et al (1963), have indicated that bacteria such as Desulfovibrio aestuarii can exist in saturated NaCl solutions, although their activity is inhibited by bivalent cations, which are not prevalent in the ERDA No. 6 brine.

Stable Isotopes. Analysis of water samples for their $^{18}O/^{16}O$ and D/H ratios has been found to be a useful method of identifying the source of water molecules, and to some degree identifying the types of interactions the water has undergone in the presence of other phases.

Figure 7.12 is a δ D versus $\delta\ ^{18}O$ plot for Delaware Basin groundwaters. Most of the earth's meteoric waters have isotopic compositions which fall between the lines described by the equations:

$$\delta D = 8 \ \delta^{18}O + 5 \text{ (Epstein } \underline{et} \ \underline{al}\text{., 1965; 1970)}$$

and

$$\delta D = 8 \ \delta^{18}O + 10 \text{ (Craig, 1961a).}$$

These lines are included in Figure 7.12, and the area between them is labelled "Meteoric Field."

Most of the points in Figure 7.12 lie in or near the meteoric field. Except for Carlsbad Caverns, a $\delta^{18}O$ value of -7‰ and a δD value of -50‰ appears to be a good approximation to local meteoric water in the Delaware Basin. The Caverns are part of the hydrologic system independent of the rest of the Capitan. Their enrichment in D and ^{18}O reflects the water's origin from air mass conditions different from those which produce other Basin rains.

Bracketing the cluster of meteoric points are two dashed lines whose intervening field is labelled "evaporation." This field is the trajectory of isotopic compositions that the meteoric waters would follow during evaporation. The trajectory slope is 5, according to Craig et al. (1963). The few points that lie in or near the evaporation field (4 Rustler and 1 Castile) may indeed have suffered partial evaporation prior to infiltration, but definitely originated as metoric water.

The dashed line through the origin, also of slope 5, is the trajectory of isotopic compositions of evaporating sea water. This line is also valid for the evaporation of warm-climate coastal meteoric waters ($\delta^{18}O \approx -2‰$, $\delta D \approx -10‰$, as indicated by the intersection of this line with the meteoric field. Such waters were postulated by Holser (1963; 1966) to have been potential contributors to the Delaware Basin. The figure shows that the waters of positive $\delta^{18}O$ values are not the products of partial evaporation either of Delaware Basin water or of modern meteoric water. This conclusion is the same as that drawn from the Cl/Br ratios.

The environments in which the Salado, Morrow and Delaware (Bell Canyon) waters were found involved a rock/water ratio that was very large, as deduced from the low productivity of these reservoirs. Consequently, any interaction involving isotopic exchange between these waters and host rocks would tend to alter the isotopic composition of the water toward δ D and $\delta^{18}O$ values consistent with equilibrium isotopic fractionation between water and minerals in the rock. Calcite in the Bell Canyon Sandstone had a $\delta^{18}O$ value of +25.1‰, a value only slightly less than typical marine carbonate. This implies only minor isotopic alteration of easily exchanged carbonate oxygen in the rock through the action of water, and indicates lack of calcite-water isotopic equilibrium in the Bell Canyon. The oxygen and hydrogen in clay minerals are known to be readily exchangeable with water (O'Neil and Kharaka, 1976). The Delaware, Morrow and Salado waters have isotopic compositions that are suggestive of at least partial isotopic exchange between local meteoric waters and clay minerals in the sediments, in which the mineral/water ratio was very large (cf. Savin and Epstein, 1970) for at least several thousand years. Other mineral sources of exchangeable oxygen and hydrogen are fluid inclusions, whose stable isotopes have yet to be studied, and the water of crystallization of many evaporite minerals. The potash seep waters may have interacted with hydrous minerals. However, gypsum-water is the only such mineral-water system for which the $^{18}O/^{16}O$ and D/H fractionation factors are known.

None of the waters have resulted directly from the dehydration of gypsum to form anhydrite. If ERDA No. 6 were such a water, the point marked "G" in Figure 7.12 would be the isotopic composition of the water from which that gypsum precipitated (using the gypsum-water fractionation factors of Fontes and Gonfiantini, 1967). "G" is not consistent with evaporating Delaware Basin water, whose anticipated δ D - $\delta^{18}O$ trajectory was discussed above. The isotopic composition of ERDA No. 6 brine is consistent with an approach to isotopic equilibrium between water and clay minerals, not necessarily in the Castile. Its isotopic exchange, together with its history of cation exchange, has resulted in a brine whose history appears to be similar to that of oil field brines of Alberta and the Gulf Coast (cf. Clayton et al., 1966).

7.7.3 Summary

Many types of rock/fluid interactions are evident in the geochemistry of groundwaters found in the Delaware Basin. It is not possible to completely characterize these interactions from solutes or stable isotopes alone, nor through a study of water alone without a similar study of rock. In addition to fresh and brackish waters, which have acquired solutes from their host rocks, the brines have here illustrated three examples of various types of rock/fluid interactions:

1. dissolution of evaporites (saline Capitan waters).

2. dissolution of evaporites with isotopic exchange between fluid and rock (Salado potash seeps).

3. dissolution of evaporites, isotopic exchange, and cationic exchange (Delaware, Morrow and ERDA No. 6 waters).

The latter two types indicate more profound interaction than the first, since these involve changes in the water molecules themselves.

No original Permian waters could be identified. If much of the evaporite section has been recrystallized, as Holser (1963) suggests, not even the fluid inclusions are expected to preserve such waters.

7.8 RUBIDIUM-STRONTIUM SYSTEMATICS OF THE SALADO FORMATION, SOUTHEASTERN NEW MEXICO

7.8.1 Introduction

One of the important reasons for studying bedded salt deposits for a radioactive waste repository is to determine their intrinsic geological stability and to understand the behavior of alkali and alkaline earths in such a system assuming leakage of isotopes such as ^{90}Sr and ^{137}Cs.

If it can be demonstrated that such isotopes are likely to be retained at or very near the possible leakage area, then the potential danger of such leakage is minimized. Alternately, if it is found that there has been widespread migration of alkali and alkaline earth elements in the prospective storage sites, then these sites may be unfavorable for retention of ^{90}Sr, ^{137}Cs, etc. assuming leakage occurs. Furthermore, if the latest episode of diagenetic evaporite recrystallization can be dated, arguments can be made for the geochemical requilibration of the evaporite assemblage into a thermodynamically stable configuration, reducing the liklihood of such events in the future.

To address this problem the WIPP study area and nearby sites were chosen for investigation, utilizing the well-established Rb-Sr geochronologic method of age determinations. This method is especially well suited for addressing alkali and alkaline earth retention and/or migration because of the species involved and its simplicity. Because of geochemical similarities (ionic radii, ionization potential, charge) Rb can be used as an analogue for Cs, and ^{90}Sr will behave as any other Sr isotope. Hence the Rb-Sr ages will allow, in theory, meaningful interpretation of the stability of the Salado Formation in terms of Rb and Sr retention and/or migration.

The basic age equation is:

$$T = \frac{(^{87}Sr/^{86}Sr)_m - (^{87}Sr/^{86}Sr)_o}{(^{87}Rb/^{86}Sr)_m \ (\lambda)}$$

where:

T = age in years

$(^{87}Sr/^{86}Sr)_m$ = measured isotopic ratio normalized to $(^{86}Sr/^{88}Sr) = 0.1194$ (the average abundance ratio in the earth)

$(^{87}Sr/^{86}Sr)_o$ = initial isotopic ratio before $^{87}Rb\ (\beta^-)\ ^{87}Sr$ radiogenic decay (R_o) occurs.

$(^{87}Rb/^{86}Sr)_m$ = measured isotopic ratio (calculated from Rb/Sr ratio).

(λ) = decay constant for ^{87}Rb = 1.42×10^{-11}/y.

The $(^{87}Sr/^{86}Sr)_m$ term is the sum of

$$(^{*87} + {}^{87}N)_{Sr/^{86}Sr}$$

where *87 and ^{87}N refer to radiogenic and normal mass 87 respectively.

The initial ratio $(^{87}Sr/^{86}Sr)_o$ can either be assumed, determined by measurements on Rb-free phases formed at T =0, or determined by extrapolation from an isochron (i.e. line of slope $e^{T\lambda} - 1$ along which all samples of the same age and initial ratio but with different Rb/Sr ratios will fall; see Faure and Powell, 1972). The last of these choices is considered the most reliable due to natural variations of the initial ratios in nature, even from supposedly uniform, Rb-free, reservoirs.

7.8.2 Previous Work

K-Ar dating of evaporites has been shown by numerous investigators to be extremely risky (see discussion in Faure, 1977) due to loss of radiogenic ^{40}Ar by diffusion and other processes. Some K-Ar ages have beeen attempted for salts from the WIPP study area at Los Medanos (Shell Dev. Co.; 1973). For sylvites, minimum dates from 18 ± 8 to 74 ± 8 m.y. were obtained while two langbeinite-sylvite mixtures yielded nearly identical dates of 137 ± 8 and 147 ± 8 m.y. Only one very pure langbeinite (18%K) yielded a date of 245 ± 10 m.y.; this date is in excellent agreement with the 225-240 m.y. age range assigned to the Late Permian evaporites of the Castile and Salado formations.

The only other officially reported work is that by E. L. Tremba (1973; unpub. Ph.D. dissertation) in which he reports widely scattered data for evaporites from the Los Medanos area. Tremba's (1973) work was not directed toward problems of local alkali or alkaline earth migration, however, and composite samples were commonly taken which would, in

effect, mask any such local effects. He reports two model Rb-Sr dates of 241 ± 23 m.y. and 208 ± 8 m.y. respectively for (1) a K-ore zone from the Saunders Mine and (2) two separate aliquots of a water-soluble K-ore. An initial ratio of 0.7077 was used in both cases. For water soluble samples from mine faces within the Saunders Mine, Tremba reports a 129 ± 5 m.y. isochron but, without adequate justification, one point (#3SS) is omitted from the isochron calculation. As a model age for this one point yields an apparent model date of 330 m.y. (R_o = 0.708), then the significance of the 129 ± 8 m.y. date, based on only 4 of 5 samples, is difficult to interpret.

Similarly, five samples from Tremba's core 184, first ore zone, yield an apparent isochron date of 120 ± 28 m.y. but with an extremely high initial ratio of 0.7226 ± 0.0092. The argument is made that the two 120 to 129 m.y. isochrons can be explained by some type of Cretaceous "rehomogenization event". This interpretation can be criticized because 27 low-K samples from core 184 yield a mean $(^{87}Sr/^{86}Sr)_m$ = 0.7077 ± 0.0001; and any hypothesized rehomogenization event must explain how selective parts of the core can be affected whereas others are not. For example, Tremba argues that recrystallization involving polyhalite may have taken place at approximately 120 m.y. ago at which time the initial ratio was increased by rehomogenization to above 0.72; yet the data in Table 7.24 yield at least one sample (ERDA-9, 1759.1-1759.8) with $^{87}Sr/^{86}Sr_m$ = 0.7064. Furthermore, if one uses the individual points for Tremba's 129 m.y. isochron and assumes an initial ratio of 0.7077 (based on his data), a range in model dates results from about 185 m.y. to 100 m.y. (not counting sample EV-13 with a very low $^{87}Rb/^{86}Sr$ ratio). The reason for this apparent scatter is unanswered by Tremba's work.

7.8.3 Analytical Procedure

Sample Preparation. Samples studied thus far have been core segments from WIPP exploratory holes. The core segments were about four inches in diameter and ranged in length from 4 to 12 inches. These samples first

were trimmed by air saw to remove all outer surfaces that may have contacted drilling brines or been otherwise contaminated. Only the remaining prism of rock was retained for analysis; the outer portions were stored for possible use in the future.

Enough of the remaining inner portions were ground to -100 mesh to produce approximately 200 g of rock powder. About 30 g of this powder was quartered out and saved for whole rock analysis.

Separation of Water-Insoluble From Water-Soluble Material. The concentration of water-insoluble residue in a sample was determined during the separation of the soluble from the insoluble material. Approximately 60 g of powdered sample, weighed to the nearest 0.01 g, was placed in a 250 ml glass centrifuge tube together with about 175 ml of distilled and deionized H_2O. The bottle was then capped and the mixture shaken vigorously for about 3 minutes, centrifuged for 15 minutes and decanted into S and S 576 filter paper. This procedure was repeated with 175 ml of H_2O followed by a third leaching of 150 ml of H_2O.

The resulting solution was transferred into a Pyrex 600 ml beaker, which was placed on a 150°C hotplate until no more liquid remained. The salt residue was then quantitatively removed from the beaker, weighed, and stored for analysis.

Separation of the < 2 Micron Fraction. The < 2 micron fraction was separated from the insoluble residue remaining from the above procedure. The insoluble residue was repeatedly washed and centrifuged until a disperson of the clay-sized material was obtained. The washed slurry was then put into 1000 ml cylinders for gravity settling. The length of time necessary for settling was calculated from the equation noted by Folk (1968). Fractions finer than 2 microns were siphoned off after the proper length of time had passed. A portion of the < 2 micron fraction was used for oriented slides (for x-ray diffraction analysis); the remainder was dried, ground to -100 mesh and used for Rb-Sr isotopic and other geochemical analyses.

X-ray Diffraction Analysis of Clay and Evaporite Minerals. Thus far, identification of clay minerals has been based solely on x-ray diffractograms, obtained from a Norelco wide range diffractometer. Untreated oriented powders were scanned from 2 to 60 degrees two theta. The untreated slide was glycolated by vapor-soaking on a rack in a container filled partially with ethylene glycol. An additional oriented powder was heated to 450°C. Both the glycolated and the heated specimens were scanned from 2 to 30 degrees two theta.

Whole rock samples were analyzed by loading a small amount of randomly oriented rock powder in a Norelco powder holder. This powder was scanned from 5 to 80 degrees two theta and the resulting diffractogram compared to values compiled in the Joint Committee on Powder Diffraction Standards file to determine bulk mineralogic composition. Mineralogic abundances noted were estimates based on comparative peak intensities.
All samples x-rayed (both clays and whole rocks) were scanned with Ni-filtered CuK radiation. A time constant of two seconds was used with a scintillation counter detector and pulse height analyzer. The goniometer slit system consisted of a divergent and anti-scatter slit of 1 degree and a 0.003 inch receiving slit.

Rb-Sr Isotopic Analysis. Procedures for the dissolution of samples for Rb-Sr isotopic analyses varied dependent on the samples mineralogic composition. All samples were first weighed accurately and placed into a 100 ml teflon evaporating dish; the amount of sample to be dissolved was determined to ensure at least 10 mg Sr and Rb would be in solution. The sample was then spiked with ^{84}Sr and ^{87}Rb solutions. Samples which contained silicate minerals were dissolved with 30 ml reagent grade HF and 3 ml vycor distilled $HClO_4$ on a hot plate. Samples containing only water soluble material were dissolved with 50 ml of distilled and deionized H_2O and 10 ml of vycor distilled 6N HCl. Samples containing large amounts of sulfate minerals were first dissolved in aqua regia and then treated with HF and $HClO_4$.

After complete dissolution of the powder and evaporation of all HF and $HClO_4$, the samples were digested with 25 ml of H_2O and 25 ml of HCl.

The mixture was then reduced to about 5 ml by slow evaporation and allowed to cool overnight. After cooling the solution was filtered through S and S #576 filter paper and loaded onto the top of a chromatography column charged with sulfonated polystyrene, a chromatographic grade cation exchange resin.

The column was washed with 2N HCl repeatedly while the effluent was flame tested for cationic composition. Rb and Sr fractions were collected at the appropriate intervals indicated by the flame test. The collected fractions were subsequently dried, redissolved and transferred to precleaned quartz microvials. The microvials, containing the samples, were fused, cooled and stored for mass spectrometric analysis.

All Rb and Sr concentrations were determined by standard isotope dilution techniques. All Rb and Sr isotopic ratios were measured using a 23 inch, 90 degree sector, solid source, single filament Nuclide mass spectrometer equipped with an electrometer and strip-chart recorder.

7.8.4 Results

Samples for the present study were provided from Sandia Laboratories drill cores AEC-8, ERDA--6, and ERDA 9 drill cores. Samples were studied for their Rb-Sr systematics by mass spectrometer and (Table 7.24, 7.25), mineralogy by x-ray diffraction (Table 7.26). Additional geochemical studies are planned (i.e., rare earth elements, by instrumental neutron activation analysis).

Samples have been divided into whole rocks, water soluble portions, and the minus-two micron fractions. This approach varies significantly from Tremba's (1973) approach in that he worked with water soluble and total water insoluble fractions; the latter were not treated for separation of authigenic from allogenic fraction. This will be discussed later.

Whole rocks may yield uncertain results due to the unknown nature of water insoluble fractions within them. Similarly, the water soluble fractions are meaningful only if the nature of the water insoluble

fraction is studied. This last point can best be addressed by detailed study of the clay-size (minus-two micron), authigenic minerals common to evaporites.

(1) Whole rocks: the water insoluble content of whole rocks varies from less than 1 percent to 32 percent, with a mean of 6.5 percent if sample Dv-4D (clay rich) is omitted. The basic mineralogy of these samples is a halite rich assemblage with some samples rich in sylvite and/or polyhalite as well. Langbeinite-rich samples are rare. The Rb-Sr isochron for eleven samples is shown in Figure 7.13. The date of 132 m.y. must be considered very approximate as nine of the eleven samples plot essentially on the ordinate. Of these last eleven, nine are used to yield a reasonable estimate of initial ratio = 0.7081 $\pm$ 0.0005 (in agreement with Tremba's 1973 value of 0.7077).

(2) Water soluble samples: in working with water soluble samples the assumption is made that ions released into solution will not be absorbed onto the surface of the insoluble material. This is probably true only if the insoluble material consists of allogenic quartz, feldspars, etc. but <u>not</u> clay minerals. An isochron for five water soluble samples yields an apparent date of 206 m.y. with R_o = 0.7084 (Figure 7.14). While this date is not unreasonable for the Permian-Triassic boundary, it is slightly low.

(3) Minus-two micron fraction: the authigenic clay minerals which one might predict for an evaporite sequence are present in this fraction (Table 7.26). Of interest is that this material is (a) authigenic as demonstrated by the x-ray diffraction work and (b) is also the dominant part of the water insoluble fraction. Thus the apparent

isochron date (Figure 7.15) of 325 m.y. needs explanation. If one remembers that many of the clay partings in the potash mines are interpreted as being of aeolian origin, then it is very likely that such aeolian clay minerals will, in part, reflect their provenance. This has been noted before by Hurley et al. (1962) for minus-two micron clay minerals from the Bermuda Rise. Of interest here is that our 325 m.y. date (Figure 7.15) is virtually identical with Tremba's (1973) 331 m.y. date for total water-soluble material.

7.8.5 Discussion

There are several ways to treat the data gathered so far. First a composite of whole rocks, water soluble and minus-two micron size clay minerals yields an isochron date (Figure 7.16) of 165 $\pm$ 20 m.y. with R_o = 0.7115. This date must be interpreted as a minimum due to the fact that the best estimate of R_o is 0.7081 $\pm$ 0.0004 according to the data presented in Table 7.24.

It is also apparent that the whole rocks by themselves are, in general, too halite-rich and possess Rb/Sr ratios which are too low for isochron work. When to this is added the uncertainty introduced by the insoluble material mixed with possible pre-T_s (i.e. time of sedimentation) material smaller than two microns, plus some detrital feldspar, quartz, etc., then the whole rocks can be assumed to be unsuitable for the isochron work.

If the clay minerals in the minus-two micron fraction are aeolian, pre-T_s material may account for the pre-Permian date of 325 m.y. (Figure 7.15). Similarly, since the clay mineralogy (Table 7.26) is very typical of evaporite clay minerals, then an alternate explanation is that these clay minerals have acted as local sinks for some $^{*87}Sr$ presumably remobilized during and after lithification and diagenesis. A lower age limit for this event is set by the 206 m.y. date from the water soluble fraction.

When only the water soluble and minus-two micron clay mineral fractions are considered together, a 204 m.y isochron (Figure 7.17) results with R_o = 0.7137. This date is only somewhat lower than the Permian-Triassic boundary and can safely be interpreted as a minimum due to the high initial ratio (0.7137). This interpretation assumes, however, that the clay minerals equilibrated with the evaporite medium (i.e. salts plus brine plus remnant sea water) at the time of sedimentation and this point remains to be unequivocally demonstrated.

Many of the above mentioned uncertainties will almost certainly be resolved by additional samples now in various stages of analysis for Rb-Sr systematics plus additional samples not yet treated. Furthermore, scanning electron microscope studies are planned to help resolve the problems of aeolian versus non-aeolian authigenesis hypotheses regarding clay mineral occurrences. Finally, rare earth element (REE) data, when complete, will greatly enhance understanding of the evaporite-insoluble material systematics of the Los Medanos area.

7.8.6 Concluding Statements

These data are of importance to he WIPP in the Los Medanos area because: (1) *Widespread recent rehomogenization of radiogenic* ^{87}Sr *would be* obvious if consistently high $^{87}Sr/^{86}Sr$ ratios were determined either from Rb-poor phases or by extrapolation from all samples with high Rb/Sr to the ordinate (Figures 7.13-7.17). This is not the case, and in fact values for whole rocks yield a mean of 0.7081, and several isochrons yield extrapolated values from approximately 0.709 to 0.713. The entire set of data argues against large amounts of radiogenic ^{87}Sr-enriched brine, having been formed post-200 m.y. ago, subsequently leaving its imprint in the recrystallized minerals. (2) the Rb-Sr isochron based on water soluble fractions and clay minerals, Figure 7.17 yields a date of 204 m.y. This date, in view of R_o = 0.7137 (i.e. higher than 0.7084), must be interpreted as a minimum date pending further analyses. (3) The clay minerals (Table 7.26) are of special interest in that they are typical of evaporite clay minerals formed during evaporite diagenesis,

yet they have been interpreted as aeolian. If they are aeolian, then some mixture of kaolinite-montmorillonite-illite would be expected rather than the saponite-chlorite-montmorillonite-serpentine-talc-illite assemblage noted. Since the clay minerals yield (Figure 7.15) a pre-sedimentation apparent date of 325 m.y. with high R_o (0.7123), then it is possible that these clays acted as local sinks for radiogenic ^{87}Sr (and Rb?) released during early diagenesis from roughly 235 m.y to 204 m.y.; such an interpretation is consistent with the data obtained to date. Tremba (1973) has argued for some mid-Cretaceous "rehomogenization event" at about 120 m.y. ago but inspection of his data coupled with these data do not support such an hypothesis. (4) REE are especially sensitive as geochemical tracers and forthcoming data, coupled with continued Rb-Sr and other work, should permit resolution of some of the problems concerning alkali and alkaline earth retention/migration in the geologic past at the Los Medanos site.

7.9 URANIUM ISOTOPE DISEQUILIBRIUM IN GROUNDWATERS OF SOUTHEASTERN NEW MEXICO AND IMPLICATIONS REGARDING AGE-DATING OF WATERS

7.9.1 Introduction

History. Regional exploration of bedded salt deposits for a radioactive waste repository in the Delaware Basin (Permian, New Mexico) included boreholes into the evaporites and associated rocks. These rocks contained various amounts of fluids, already described (Lambert, 1978). Although the halite deposits of the Ochoan Epoch are the prime target of consideration for waste storage, the older rocks of the Guadalupian Epoch are included in the present study, because of the Capitan reef, a body of cavernous limestone which encircles the Basin. The Capitan not only is the dominant rock in the Carlsbad Caverns, but also supplies potable water to the city of Carlsbad. Therefore, it is appropriate to consider possible connections between the Capitan and accumulations of water found in pockets in the evaporites. Brine and gas pockets are known to occur in the Carlsbad district potash mines and in the Castile Formation (anhydrite and halite) underlying the Salado Formation.

One exploration hole, ERDA No. 6, drew national attention (Boffey, 1975), when it encountered an accumulation of saturated NaCl brine laced with Na_2SO_4, accompanied by H_2S-rich gas at 826 m below the surface. Discovery of this artesian fluid, together with bedding-plane dips in the host Castile Formation exceeding 70°, led to abandonment of that particular site. Geophysical investigations showed that this and other occurrences of brine and gas were associated with closed structure contours drawn for the Castile formation. These structures, restricted to a narrow strip of evaporites near the reef have been termed "salt anticlines" (Anderson and Powers, 1978). Core from the fluid-producing zone of ERDA No. 6 consisted of gray laminated anhydrite whose fractures were filled with massive crystalline white anhydrite (Plate 7.52). While isolated fluid accumulations are not rare in evaporites, the possible use of the region for radioactive waste disposal requires attention to the origin of this particular type of accumulation. In the extreme cases, the fluid originates directly from water from the Capitan Reef, or the water was entrapped in the Castile Formation at the time for evaporite deposition in the Permian. In the first case, the water would have an age little older than Capitan waters. In the second case, the water would be in excess of 230 million years old.

Implications. Indeed, the very presence of the ERDA No. 6 accumulation of fluid poses several questions:

1. How long has the water been confined in the pocket?
2. Does the time of the water's intrusion correspond to any significant known geologic events?
3. What is the source of the water?
4. How long has this pocket been disconnected from nearby aquifers such as the Capitan Reef, if it ever was connected?
5. What are the limits to rates of influx (if any) or recharge and discharge (if any) of this fluid pocket?
6. To what degree does the ERDA No. 6 occurrence (or any other in the area) represent a flowing system?
6. Which radiometric clock should be used to age-date the water and what should be taken as initial conditions for age-dating?

7.9.2 Analytical Approach

General Geochemistry of Groundwaters. A number of groundwaters from the Delaware Basin have been characterized in terms of their general geochemistry with respect to their host rocks (Lambert, 1978). In terms of solutes, all waters from below the fresh-saline interface in the Capitan were similar to each other. In addition all shallow ($\leq$ 300 m depth) waters were similar to one another and all deep ($\geq$ 1000 m depth) waters were similar to one another. The ERDA No. 6 water was unique in its solute content, indicative of profound disequilibrium between solution and host rock and also between solution and associated gas phase.

In terms of D/H and $^{18}O/^{16}O$ ratios, Capitan and shallow waters all are similar and are of meteoric origin. (Carlsbad Caverns waters are also of meteoric origin, but are not related to other waters in the Capitan.) Deep water stable isotope ratios are similar to one another, and are not characteristically meteoric. ERDA No. 6 has uniquely non-meteoric isotopic ratios among those of Delaware Basin waters. No waters were found which represent original evaporite mother-liquor.

Experimental Procedures. In spite of the evidence that this fluid has experienced profound interactions with rock (Lambert, 1978), radioisotopes were examined to establish that the ERDA No.6 fluid was not of relatively recent origin. Plutonium concentration was determined by isotope dilution employing a spike of ^{244}Pu. The actual measurement was made on a three-stage thermal emission solid source mass spectrometer equipped with pulse counting for ion detection. The instrument has a very high abundance sensitivity (10^7) and low background, allowing for the determination of precise isotopic ratios on small samples amounting to 0.1 to 1 nanograms of plutonium. The plutonium concentration of the ERDA No. 6 brine was found to be less than 10^{-15} grams per gram, corresponding to the lower limit of analytical detectability. The absence of plutonium suggests the brine has been isolated at least since 1945, a date corresponding to the first atmospheric detonation of nuclear weapons.

Carbon 14 was measured in the CO_2, which amounted to 55% of the total gas collected from ERDA No. 6. Carbon 14 content was counted in a gas proportional detector whose efficiency was calibrated with the NBS oxalate standard. The result was the same as the background, which was about 2 counts per minute in a 1.5 liter detector at 2 atmospheres pressure. From this it was concluded either that the brine is older than about 30,000 years or possibly that carbonates in the host rock have diluted the carbon in the system with non-radioactive carbon.

The disequilibrium of the activity of ^{234}U relative to ^{238}U in natural waters has been attractive as an indicator of the age of groundwaters (Osmond and Cowart, 1976). ^{234}U and ^{238}U are related by the decay scheme:

$$^{238}_{92}U \xrightarrow[4.5 \times 10^9 a]{\alpha} {}^{234}_{90}Th \xrightarrow[24d]{\beta^-} {}^{234}_{91}Pa \xrightarrow[1\ min]{\beta} {}^{234}_{92}U \qquad (1)$$

It has been proposed that excess ^{234}U builds up in confined waters as an aging effect as a result of the alpha-recoil of ^{234}Th, which ejects ^{234}Th out of the host rock crystal lattice into the water (Kigoshi, 1971; Kronfeld et al., 1975). From a knowledge of decay constants and initial activity ratio α_0 ($\alpha = \lambda_{234} N_{234} / \lambda_{238} N_{238}$), the time of confinement is calculated. It cannot be assumed, however, that the earth's natural abundance ratio, $\alpha = 1.00$, is a priori valid for a confined rock-water system. The water carried in with it an initial uranium concentration and original activity ratio, α_0. The water ultimately comes to thermodynamic equilibrium with its host rock and may leach or even deposit ^{234}U and ^{234}Th. Uranium concentrations and α-ratios of rocks and waters in this study were determined by isotope dilution mass spectrometry, described above. Figure 7.18 shows the locations of principal water samples of this study. Table 7.27 shows uranium conentrations and values of α for various waters.

7.9.3 Results and Discussion

The overleaf of Plate 7.52 shows the variations of U content and α in anhydrite of rock core taken from the zone which produced fluid in ERDA No. 6 (826 m, 2709 ft depth). Table 7.27 shows that in ERDA No. 6, both U concentration and α vary with time, until U concentration falls asymptotically to about 2 parts in 10^9, and α rises asymptotically to about 1.35. In the early part of a several-hour flow test, water samples were found to be contaminated with drill mud and spallations from metal pipe. By 1400 hours not only had the uranium reached steady state values, but the iron concentration had fallen from 260 parts in 10^6 (1130 hours) to a steady value of 5 parts in 10^6 (1400 hours), indicating the flushing out of drilling-introduced contaminants. Thus, the later samples are probably representative of the fluid accumulation.

The total variation in α among all water samples is relatively small (1.2 to 5.2). In contrast, absolute uranium content in the waters of Table 7.27 varies by more than two orders of magnitude. Similarly, rock material illustrated in Plate 7.52 shows a wide variation in U content: 1 to 2 parts in 10^6 for "original" laminated gray anhydrite down to 20 to 30 parts in 10^9 in the secondary white anhydrite fracture filling only a few centimeters away.

7.9.4 Applicaton of the Uranium Isotope Disequilibrium Model

If N_2 is the amount of ^{234}U present in a phase, and N_1 is the amount of ^{238}U, the change in ^{234}U content with time in the brine is

$$\left(\frac{dN_2}{dt}\right)_{brine} = \lambda_1 N_1 - \lambda_2 N_2 + Q_1 + Q_2, \qquad (2)$$

in which Q_1 is the rate of release of ^{234}Th (the parent of ^{234}U) from the rock, Q_2 is the rate of release of ^{234}U from the rock and λ_1 and λ_2 are decay constants for ^{238}U and ^{234}U, respectively.

Release rates Q_1 and Q_2 can be modeled in the fashion of Kigoshi (1971), who studied the release of ^{234}Th from zircon powder. He gave the accumulated activity of ^{234}Th in solution after time t as

$$(\lambda_{Th}\ N_{Th})_{brine} = 1/4\ L\ S\rho\ (N_{238}\ \lambda_1)_{rock}\ (1 - e^{-\lambda_{Th} t}), \tag{3}$$

in which λ_{Th} is for ^{234}Th, L is the recoil distance of ^{234}Th in decay scheme (1) above, S is the surface area of parent rock, ρ is its density, and N_{238} is expressed as the number of ^{238}U atoms per gram of rock. Thus, the activity of ^{234}Th in the brine is related to the activity of ^{238}U in the rock by a proportionality constant, and, of course, the time-dependent term. When t >> 24 days, (3) can be approximated as

$$(\lambda_{Th}\ N_{Th})_{brine} \approx f_1 \cdot (\lambda_1\ N_1)_{rock}, \tag{4}$$

in which f_1 is now the leach fraction of ^{234}Th, incorporating 1/4 L S ρ in (3). In general, ^{238}U activities in rock and coexisting brine will not be equal, but will be related by a distribution coefficient r, which is theoretically an equilibrium constant, neglecting the kinetics of dissolution and precipitation:

$$(\lambda_1\ N_1)_{rock} = r\ (\lambda_1\ N_1)_{brine} \tag{5}$$

In actual fact, the time required to achieve chemical equilibrium between rock and brine might be very long relative to the half-life of ^{234}Th. Q_1 now becomes

$$Q_1 = r \cdot f_1 \cdot (\lambda_1\ N_1)_{brine} \tag{6}$$

Similarly, the amount of ^{234}U released is dependent on the decay of its precursor ^{238}U, and on the equilibrium ratio r, and on the leach fraction for ^{234}U, f_2:

$$Q_2 = r \cdot f_2 \cdot (\lambda_1\ N_1)_{brine} \tag{7}$$

In addition, some fraction, f_3, of the ^{238}U will be leached from the rock,

$$\lambda_1 N_1 = r \cdot f_3 \cdot (\lambda_1 N_1)_{brine} + (\lambda_1 N_1)_{brine} \quad (8)$$

Now, equation (2) becomes:

$$\left(\frac{dN_2}{dt}\right)_{brine} = (\lambda_1 N_1)_{brine} \left[1 + r\ (f_1 + f_2 + f_3)\right] - \lambda_2 N_2 \quad (9)$$

If f is defined as a composite leach fraction $(f_1 + f_2 + f_3)$, the solution to (9) is:

$$N_2(t) = \frac{\lambda_1}{\lambda_2-\lambda_1}(1+fr)N_1(t)+N_1(t=0) \quad \frac{\lambda_2 N_2(t=0)}{\lambda_1 N_1(t=0)} \quad \frac{\lambda_1}{\lambda_2}(1+fr) \quad e^{-\lambda_2 t} \quad (10)$$

which allows us to express the solution in terms of $\alpha = \frac{\lambda_2 N_2}{\lambda_1 N_1}$:

$$\alpha_{brine} = \frac{\lambda_2}{\lambda_2-\lambda_1}(1 + fr) + \left[\alpha_o - \frac{\lambda_2}{\lambda_2-\lambda_1}(1 + fr)\right] e^{-(\lambda_2-\lambda_1)t} \quad (11)$$

and since $\lambda_2 >> \lambda_1$

$$\alpha_{brine} \approx 1 + fr + \left[\alpha_o - 1 + fr\right] e^{-\lambda_2 t} \approx \alpha_b \quad (12)$$

The corresponding equation for the rock is:

$$\left(\frac{dN_2}{dt}\right)_{rock} = \lambda_1 (1 - f) (N_1)_{rock} - \lambda_2 (N_2)_{rock} \quad (13)$$

Since for a closed system, the $^{234}U/^{238}U$ equilibrium activity ratio is 1.000, the solution to (13) is:

$$N_2(t)_{rock} = \frac{\lambda_1}{\lambda_2-\lambda_1}(1 - f)N_1(t)_{rock} + \frac{\lambda_1}{\lambda_2} N_1(0)_{rock} e^{-\lambda_2 t} \quad (14)$$

$$- \frac{\lambda_1}{\lambda_2-\lambda_1} N_1(0)_{rock} (1 - f) e^{-\lambda_2 t}$$

which in terms of α is

$$\alpha_{rock} = \frac{\lambda_2}{\lambda_2-\lambda_1}(1 - f) + e^{-(\lambda_2-\lambda_1)t} - \frac{\lambda_2}{\lambda_2-\lambda_1}(1 - f)\ e^{-(\lambda_2-\lambda_1)t} \tag{15}$$

The approximation $\lambda_2 >> \lambda_1$ reduces the equation (15) to

$$\alpha_{rock} \approx 1 - f + f\ e^{-\lambda_2 t} \approx \alpha_r \tag{16}$$

Let us now assume that the geochemical conditions (i.e. U content and α) observed in the ERDA No. 6 rock-fluid assemblage represent equilibrium conditions. This requires the mutual consistency of equations (12) and (16), and that

$$f = \frac{(\alpha_o - 1)\ (\alpha_r - 1)}{\alpha_b - \alpha_o + r\ (\alpha_r - 1)}\ . \tag{17}$$

Anhydrite found in the veins is the most recently formed phase in the core, and using the U values from 1709.4 white anhydrite (U = 33 parts in 10^9, α = 1.04); Plate 7.52 overleaf), and the averages of the last two ERDA No. 6 brines in Table 7.27, (U = 2.01 parts in 10^9, α = 1.35) equation (17) gives rise to the plot in Figure 7.19. Note the prominent singularity at α_0 = 2.01, and that $\alpha_0 \leq 1.971$ at f = 1 (corresponding to 100% leaching, and $\alpha_0 \geq 2.052$ at f = -1 (corresponding to all the uranium in the rock having precipitated from the brine).

Solving equation (12) for t, we obtain an expression for the age of the brine:

$$t = \frac{\ln\left(\frac{\alpha_b - 1 - fr}{\alpha_o - 1 - fr}\right)}{-\lambda_2}. \tag{18}$$

For values of $\alpha_0 \leq 1.971$, negative ages result. Only for values of $\alpha_0 \geq 2.052$ are realistic ages obtained. This result implies that there has been minimal leaching from the rock. Furthermore, it suggests rather that precipitation of uranium has occured from brine to rock which is consistent with reducing conditions implied by the presence of H_2S.

Clearly, the amount of precipitation which has occurred (negative leaching) is related to the original α_0 at the time of closure of the rock fluid system.

Values of α for nearby waters in the Capitan limestone (Table 7.27) which by proximity afford a possible source of water for the ERDA No. 6 brine pocket, are mostly in excess of 1.35. In addition, the ERDA No. 6 brine is not saturated in $CaSO_4$ (Lambert, 1978), and is not likely to have been responsible for the precipitation of substantial amounts of vein anhydrite. Furthermore, the limited volume of the brine pocket (Griswold, 1977) could not realistically be expected to dissolve and reprecipitate anhydrite in veins to the extent observed in the core. Therefore, the α_0 of the ERDA No. 6 brine must have been larger than 2.052, with very little interaction with the reservoir rock.

7.9.5 Model Ages Based on No Leaching

Values of α and α_0 will in this model allow an age determination of a water to be made. The highest α value thus far determined is 14.2, the result of isotope dilution mass spectrometry performed on a sample from Israel supplied by J. Kronfeld, which gave an α value of 10.1 $\pm$ 1.6 by alpha-spectroscopy (Kronfeld et al., 1975). In addition, the occurrence of waters elsewhere in the Delaware Basin (Table 7.27 suggests that a reasonable α_0 value might be 5.14 (in the Capitan limestone), the highest thus far found in the Basin. If the ERDA No. 6 brine represents water escaped from the Capitan, and its α_0 was on the order of 5, Figure 7.19 shows that its interaction with the ERDA No.6 reservoir rock (fractured Castile anhydrite) precipitated less than 6% of the rock's uranium from the brine.

Neither total concentration nor isotopic composition of uranium in the ERDA No. 6 brine was inherited through interaction with the Capitan limestone, for the ERDA No. 6 brine contains substantially more uranium that the Capitan waters (Table 7.27) presently do. Likewise, uniformity in the stable isotope composition of Capitan waters (Lambert, 1978) shows

that the peculiar stable isotope composition of ERDA No. 6 water cannot have arisen by interaction with the Capitan limestone. Composition of stable and unstable isotopes in ERDA No. 6 brine might have arisen from interaction between water and rocks encountered by the water if it moved from the Capitan to its ERDA No. 6 environment.

In its simplest form, equation (18), under conditions of no interaction between ERDA No. 6 brine and its reservoir rock, reduces to:

$$t = \frac{\ln\left(\frac{\alpha_b - 1}{\alpha_o - 1}\right)}{-\lambda_2} \tag{19}$$

which very nearly corresponds to the combination of the solutions to the equations

$$\frac{dN_1}{dt} = -\lambda_1 N_1$$

$$\frac{dN_2}{dt} = -\lambda_2 N_2 + \lambda_1 N_1$$

for which

$$t \approx \frac{\ln\left(\frac{\alpha_b - 1}{\alpha_o - 1}\right)}{-\lambda_2 + \lambda_1} \tag{20}$$

The above conclusions allow limits to be assigned to the age of confinement of the ERDA No. 6 brine, and also to ages of waters in the Capitan. Equation (20) differs from equation (19) only by the approximation that

$$\frac{\lambda_2}{\lambda_2 - \lambda_1} \approx 1,$$

since $\lambda_2 = 2.806 \times 10^{-6}\ a^{-1}$ for ^{234}U
and $\lambda_1 = 1.537 \times 10^{-10}\ a^{-1}$ for ^{238}U.

Figure 7.20 shows the family of curves obtained from equation (20), using observed values of α from Table 7.29, and various values for α_0. The model ages indicated on Figure 7.19 for the ERDA No. 6 brine are less

than those in Figure 7.20 because 4 to 5 percent interaction between brine and rock (uranium precipitation) involves loss of uranium from solution by means other than radioactive decay. There is no evidence for any degree of chemical equilibrium between ERDA No. 6 rock and fluid. If we realistically limit f (Figure 7.19) to have a value between -0.02 and -0.50, the minimum age of the ERDA No. 6 occurrence is 570,000 years (α_0 = 6). In actual fact, as the data of Kronfeld et al. (1975) suggest, maximum α_0 values are universally in the range 10 to 15, and the age is between 800,000 and 1,000,000 years. According to the no-interaction model, (Figure 7.20), if water escaped from the Capitan (α_0 = 5.14) into the brine pocket, this must have occurred at least 880,000 years ago. The highest α_0 value (14.2) confirmed by isotope dilution mass spectrometry gives an age of 1,300,000 years.

If the Carlsbad area (near the Pecos River) is a major recharge area for much of the Capitan reef, and if Carlsbad water (α_0 = 5.14) is the basis for age-dating other waters in the Capitan, ages between 300,000 and 1,100,000 years are obtained. The maximum α_0 (14.2) would imply that Capitan waters are at least 400,000 years old.

7.9.6 Implications and Conclusions

A mathematical model based upon analytical data has showed that the ERDA No. 6 occurrence of brine can be age-dated by the uranium-disequilibrium method. Combinations of leach fractions and ages were derived, and the interaction between rock and fluid was indicated to be minimal. If the brine pocket was once connected to the Capitan Reef, the most productive aquifer in the region, such connection was severed at least 500,000 years ago, and probably more than 900,000 years ago. The brine pocket has been stagnant ever since, and there is little evidence to indicate that chemical equilibrium has been established among the solid, liquid and gaseous phases involved in the brine pocket.

Even though the α value of the ERDA No. 6 brine was close to those of nearby metoric waters taken from the northern apex of the Capitan Reef, these α values are far removed from those of more remote meteorically-derived saline Capitan waters from the east and west arms of the reef (Carlsbad No. 7 and Shell No. 28). In fact, the remote waters appear to be younger than apex waters (Hackberry and Middleton), implying the groundwater flow in the reef is indeed toward the apex and recharge is in the east and west part of the reef.

Fresh and saline Capitan Reef waters have retained their meteoric D/H and $^{18}O/^{16}O$ ratios, even though the ages of some of them are comparable to that of ERDA No. 6. Although reef apex waters and ERDA No. 6 brine are radiometrically similar, the solutes and stable isotopes of ERDA No. 6 reflect a more profound rock/fluid interaction than Capitan waters have experienced. This interaction, however, is more likely to have taken place in rocks between the Capitan and the brine pocket than in the brine pocket itself.

The ERDA No. 6 reservoir rock has not replenished ^{234}U to the brine in spite of long contact. Furthermore, uranium mobility into the white recrystallized anhydrite from the gray laminated anhydrite from the gray laminated anhydrite was shown to be very low in this anoxic environment.

Dating by the uranium-disequilibrium method is not necessarily dependent on a closed system, and bounds on ages can be assigned. Requirements for $^{234}U/^{238}U$ dating include: α values of fluid and rock, leach rate, and knowledge of a value for original activity ratio, α_0 . The α value for the rock is necessary to evaluate the degree of rock-fluid disequilibrium. The leach rate might be negligible even in a closed system. A unique solution to an age-dating problem, however, requires knowledge of initial conditions, just as in case of the well-established uranium-lead and carbon 14 age-dating techniques.

7.10 SUMMARY

Geochemical investigations of the WIPP site have been undertaken to characterize and quantify the mineralogy and petrology of the Delaware Basin evaporites and associated non-evaporites, volatile constituents and fluid inclusions native to the evaporites, the geochemistry of groundwaters native to the rocks, and the lengths of time that the evaporites and groundwaters have existed in their present environments. While these investigations have utilized a number of techniques of analytical chemistry, the choice and analysis of samples, together with interpretations of results, are carried out in the context of the WIPP geology.

The most common mineral in the Permian (Ochoan) Salado Formation, which is proposed for radioactive waste emplacement, is halite. Some of the halite contains minor amounts of anhydrite, and traces of trioctahedral clays and detrital minerals. Locally throughout the Salado Formation marker beds of anhydrite and polyhalite occur at intervals of a few tens of meters. Local accumulations of potassium and magnesium sulfates occur in the McNutt potash zone in the upper part of the Salado.

The petrographic textures, geochronology, and the presence of minerals which are not primary precipitates of sea water, such as sylvite and polyhalite, indicate that much of the evaporite section last underwent recrystallization more than 200 million years ago, shortly after Permian deposition. The trace clay mineral fraction of the rock salt has efficiently entrapped and held radiogenic strontium for at least the last 200 million years. The aqueous solutions involved in this recrystallization were not in communication with fluids outside the evaporite section.

Volatiles presently occur in the evaporite section as the chemically-combined water of crystallization, hydroxyl-groups bound in sheet silicates, short-lived seeps exposed in mines, and as physically-entrapped inter- and intracrystalline fluid inclusions. The

total volatiles recovered from rock salt heated to 600°C typically amount to less than 0.5 weight percent (about 1.5% by volume). In addition to water, traces of nitrogen, CO_2 and contaminants from the coring operation are recovered from subsurface evaporite cores taken from boreholes. The fluid inclusions appear to have been entrapped at 20 to 45°C, and contain NaCl, $MgCl_2$ and minor amounts of other solutes. Fluid inclusions not affected by recrystallization have not moved in the ambient geothermal gradient since the Permian deposition.

Isolated pockets of aqueous solutions now found in the evaporites have no geochemical relationship to surface-derived meteoric waters or to groundwaters above and below the evaporites; neither do they represent original evaporite mother liquors. Such pockets probably are relics of the post-depositional recrystallization which took place more than 200 million years ago, at which time they might have inherited their geochemically distinct solute assemblages and stable isotope compositons.

Stable isotope and solute content studies of meteorically-derived groundwaters west of the WIPP site and peripheral to the Delaware Basin indicate that simple uptake of solutes from rocks with which they have come in contact did not alter their meteoric isotope ratios. Thus, waters participating in active dissolution of salt, which has not occurred in the Salado Formation at the WIPP site, could be readily identified by their geochemistry.

The origin and age of an artesian brine pocket in the Castile Formation, northeast of the WIPP site was evaluated by a uranium isotope disequilibrium model. It was concluded that this accumulation (encountered in borehole ERDA No. 6) has no connection with any other known groundwaters, and has been in its present environment for at least 880,000 years.

7.11 REFERENCES

Adams, S. S., 1967, Bromine in the Salado Formation, Carlsbad potash district, New Mexico: Unpublished Ph.D. Dissertation, Harvard University, 202 pp.

Adams, S. S., 1969, Bromine in the Salado Formation, Carlsbad potash district, New Mexico: New Mexico Bur. Mines Min. Res. Bull. 93, 112 p.

American Public Health Association, 1971, Standard methods for the examination of water and wastewater (13th ed.): APHA, Am. Water Works Assn., Water Pollution Control Fed: Washington, D. C.

Anderson, R. Y., Dean, W. E., Kirkland, D. W., and Snider, H. I., 1972, Permian Castile varved evaporite sequence, West Texas and New Mexico: Bull. Geol. Soc. Amer., v. 83, p. 59-86.

Anderson, R. Y., and Powers, D. W., 1978, Salt anticlines in the Castile-Salado evaporite sequence, northern Delaware Basin, New Mexico: N. Mex. Bur. Mines Min. Res. Circ. 159, in press.

Anthony, T. R. and Cline, H. E., 1971a, Thermal migration of liquid droplets through solids: Jour. Applied Physics, v. 42, no. 9, p. 3380-3387.

Anthony, T. R. and Cline, H. E., 1971b, The interaction of liquid droplets with a grain boundary in large accelerational fields: Philosop. Mag., v. 24, no. 189, p. 695-703.

Anthony, T. R. and Cline, H. E., 1972, The thermomigration of biphase vapor-liquid droplets in solids: Acta Metallur., v. 20, p. 247-255.

Anthony, T. R. and Cline, H. E., 1973, The stability of migrating droplets in solids: Acta Metallur., v. 21, p. 117-122.

Anthony, T. R., and Cline, H. E., 1974, Thermomigration of liquid droplets in salt, in Fourth Symp. on Salt, v. 1, A. H. Cougan, ed.: Cleveland, Ohio, Northern Ohio Geol. Soc., p. 313-321.

Anthony, T. R. and Sigsbee, R. A., 1971, The thermomigration of spherical bubbles through a transparent polycrystalline solid: Acta Metallur., v. 19, p. 1029-1035.

Baar, C. A., 1977, Applied salt-rock mechanics 1; the in-situ behavior of salt rocks: Elsevier Sci. Pub. Co., Amsterdam, 283 pp.

Bathurst, R. G. C. 1975, Carbonate Sediments and their Diagenesis, 2nd ed. Elsevier Scientific Publishing Company, New York, N.Y., 658 pp.

Bernas, B., 1968, New method for decomposition and comprehensive analysis of silicates by atomic absorption spectrophotometry: Anal. Chem. v. 40, p. 1682-1686.

Bernas, B., 1973, Acid pressure decomposition device for interference-free AA analysis: Amer. Lab., v. 5, no. 8, p. 41.

Bigeleisen, J., Perlman, M.L., and Prosser, H.C., 1952, Conversion of hydrogenic materials to hydrogen for isotopic analysis: Anal. Chem., v. 24, p. 1356-1357.

Bodine, M. W., Jr. 1971, Alteration of basic volcanic rocks by marine hypersaline brines, Hallstatt, Upper Austria: (Abstract), Geol. Soc. Am. Abstr., v. 3, p. 509.

Bodine, M. W., Jr. and Fernalld, T. H. 1973, EDTA dissolution of gypsum, anhydrite, and Ca-Mg carbonates: J. Sediment. Petrol. v. 43, p. 1152-1156.

Bodine, M. W., Jr. and Standaert, R. R., 1977, Chlorite and illite compositions from Upper Silurian rock salts, Retsof, New York: Clays and Clay Minerals, v. 25, p. 57-71.

Boffey, Philip M., 1975, Radioactive waste site search gets into deep water: Science, v. 190, p. 361.

Braitsch, O., 1971, Salt deposits -- their origin and composition, trans. P. J. Bureck and A. E. M. Nairn: Springer-Verlag, Heidelberg, p. 1-297.

Brokaw, A. L., Jones, C. L., Cooley, M. E., and Hays, W. H., 1972, Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico: U.S. Geologic Survey open-file report 4339-1, 86 pages.

Calzia, J. P., and Hiss, W. L., 1978, Petrographic character and extent of an Oligocene basaltic dike system, northern Delaware Basin, New Mexico: N. Mex. Bur. Mines Min. Res. Circ. 159, in press.

Chen, K. H., and Wilcox, W. R., 1972, Boiling and convection during movement of solvent inclusions in crystals: Indust. Eng. Chem. Fundamentals, v. 11, no. 4, p. 563-565.

Clayton, R. N., Friedman, I., Graf, D. L., Mayeda, T. K., Meents, W. F., and Shimp, N. F., 1966, The origin of saline formation waters, I. Isotopic Composition: Jour. Geophys. Res., v. 71, p. 3869-3882.

Cline, H. E., and Anthony, T. R., 1971, Vaporization of liquid inclusion (sic) in solids: Philosoph. Mag., v. 24, p. 1483-1494.

Collins, A. G., 1975, Geochemistry of oilfield waters: Elsevier Scientific Publishing Company, Amsterdam, p. 1-496.

Craig, Gordon, L. I., and Horibe, Y., 1963, Isotopic exchange effects in the evaporation of water, I. Low-temperature experimental results: Jour. Geophys. Res., v. 68, p. 5079-5087.

Craig, H., 1961a, Isotopic variations in meteoric waters: Science, v. 133, p. 1702-1703.

Craig, H., 1961b, Standard for reporting concentrations of deuterium and oxygen - 18 in natural waters: Science, v. 133, p. 1833-1834.

Dellwig, L. F., 1955, Origin of the Salina salt of Michigan: Jour. Sed. Petrology, v. 25, p. 83-110.

Epstein, S., and Mayeda, T., 1953, Variaton of ^{18}O content of waters from natural sources: Geochim. Cosmochim. Acta, v. 4., p. 213-244.

Epstein, Sharp, R. P., and Gow, A. J., 1965, Six-year record of oxygen and hydrogen isotope variations in South Pole firn: Jour. Geophys. Res., v. 70, p. 1809-1814.

Epstein, 1970, Antarctic ice sheet: Stable isotope analyses of Byrd station cores and interhemispheric climatic implications: Science, v. 168, p. 1570-1572.

Fallis, S. M., 1973, Mineral sources of water and their influence on the safe disposal of radioactive wastes in bedded salt deposits: Unpublished Master's Thesis, University of Tennessee, Knoxville, 61 pp.

Faure, G., and Powell, J. L., 1972, Strontium isotope geology: Springer-Verlag, New York, 188 p.

Faure, G., 1977, Principles of Isotope Geology: J. Wiley & Sons, Inc., New York, 464 p.

Folk, R. L., 1965, Some Aspects of Recrystallization in Ancient Limestones, in L. C. Pray and R. C. Murray (eds.): Soc. Econ. Paleontologists and Mineralogists, Spec. Pub. 13, p 14-48.

Folk, R. L., 1968, Petrology of sedimentary rocks: Hemphill's, Austin, Texas, 170 p.

Fontes, J., and Gonfiantini, R., 1967, Fractionment isotopique de l'hydrogene dans l'eau de cristallisation du gypse: C. R. Acad. So. Paris, Ser. D., v. 265, p. 4-6.

Fournier, R. O., 1961, Regular interlayered chlorite-vermiculite in evaporite of the Salado Formation, New Mexico: U.S.G.S., Prof. Paper 424-D, p. 323-327.

Fuchtbauer, H. and Goldschmidt, H., 1969, Die Tonminerale der Zechsteinformation: Beitr. Mineral. Petrogr. v. 6, p. 320-345.

Garrels, R. M., and Christ, C. L., 1965, Solutions, minerals, and equilibria: Harper and Row, New York, p. 1-450.

Geguzin, Ya. E., and Dzyuba, A. S., 1973, Study of liquid inclusions in rock salt crystals in the entire range of their existence: Kristallografiya, v. 18, no. 7, p. 800-807 (in Russian; English abstract in Fluid Inclusion Research -- Proceedings of COFFI, v. 7, p. 62).

Gerlach, Hansludwig, and Heller, Siegfried, 1966, Uber Kunstliche Flussigkeitseinschusse in Steinsalzkristallen: Deutsche Gesell. Geol. Wiss., Reihe B., Mineralogie und Lagerstattenforschungen, Bd. 11, Heft 2, p. 195-214.

Graf, D. L., Meents, W. F., Friedman, I., and Shimp, N. F., 1966, The origin of saline formation waters, III. Calcium chloride waters: Illinois State Geol. Surv. Circ. 397, p. 1-60.

Grim, R. E., 1968, Clay Mineralogy (Second Edition), McGraw-Hill Book Company, New York, p. 1-596.

Grim, R. E., Droste, J. B., and Bradley, W. F., 1961, Diffraction data of a regular mixed layered clay mineral in an evaporite, in Eighth Natl. Conference on Clay and Clay Minerals: Pergamon Press, Inc., New York, p. 228-236.

Griswold, G. B., 1977, Site selection and evaluation studies of the Waste Isolation Pilot Plant (WIPP), Los Mendanos, Eddy County, New Mexico: Sandia Laboratories, SAND77-0946.

Hiss, W.L., 1975, Stratigraphy and ground-water hydrology of the Capitan aquifer, southeastern New Mexico and west Texas: unpublished ph.D. thesis, University of Colorado, Boulder, 396 p.

Holdoway, K. A., 1974, Behavior of fluid inclusions in salt during heating and irradiation, in Fourth Symp. on salt, v. 1, A. H. Coogan, ed.: Northern Ohio Geol. Soc., Cleveland, Ohio, p. 303-312.

Hopkins, R. H., Seidensticker, R. G., and Stewart, A. M., 1976, Degradation of Czochralski silicate oxyapatite crystals by the thermomigration of liquid drops: Jour. Crystal Growth, v. 33, p. 223-231.

Holser, W. T., 1963, Chemistry of brine inclusions in Permian salt from Hutchison, Kansas in J. L. Rau (ed.), Symposium on salt: Northern Ohio Geological Society, Cleveland, Ohio, p. 86-103.

Holser, 1966, Bromide geochemistry of salt rocks in J. L. Rau (ed.), Second Symposium on Salt: Northern Ohio Geological Society, Cleveland, Ohio, p. 248-275.

Hurley, P. M., Heezen, B. C., Pinson, w. H., and Fairbairn, H. W., 1963, K-Ar age values in pelagic sediments of North Atlantic: Geochim. Cosmochim. Acta, v. 27, p. 393-399.

Jones, C. L., 1973, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico, with sections on Ground-water Hydrology, by M. E. Cooley, and Surficial Geology, by G. O. Bachman: U.S. Geological Survey open-file report 4339-7, 67 pages.

Jones, C. L., 1974a, Salt Deposits of the Clovis-Portales Area, East-Central New Mexico: U.S. Geological Survey open-file report 74-60, 22 pages.

Jones, C. L., 1974b, Salt Deposits of the Mescalero Plains Area, Chavez County, New Mexico: U.S. Geological Survey open-file report 74-190, 21 pages.

Jones, C. L., 1975, Potash Deposits in Part of Los Medanos Area of Eddy and Lea Counties, New Mexico: U.S. Geological Survey open-file report 75-407, 37 pages.

Khetchikov, L. N., and Samoilovich, L. A., 1970, The possibilities of the decrepitation method in mineral thermometry: Akad. Nauk S.S.S.R., Izvest., Ser. Geol., 1970, no. 7, p. 92-98 (in Russian; translated in Fluid Inclusion Research — Proceedings of COFFI, v. 3, 1970, p. 94-100).

Kigoshi, Kunihiko, 1971, Alpha-recoil thorium-234: dissolution into water and the uranium-234/uranium-238 disequilibrium in nature: Science, v. 173, p. 47.

Kronfeld, J., Gradsztajn, E., Muller, H.W., Raddin, J., Yaniv, A., Zach, R., 1975, Excess ^{234}U: an aging effect in confined waters: Earth Planetary Sci. Letters, v. 27, p. 342.

Kuznetsov, S. I., Ivanov, M. V., and Lyalikova, N. N., 1963, Introduction to geological microbiology (transl. P. T. Broneer): McGraw-Hill Book Company, New York, p. 1-245.

Lambert, S. J., 1978, The geochemistry of Delaware Basin groundwaters: New Mexico Bur. Mines and Min. Res. Circ. 159, in press.

O'Neil, J. R., and Kharaka, Y. K., 1976, Hydrogen and oxygen isotope exchange reactions between clay minerals and water: Geochim. Cosmochim. Acta, v. 40, p. 241-246.

Osmond, J.K., and Cowart, J.B., 1976, The theory and uses of natural uranium isotopic variations in hydrology: Atomic Energy Review, v. 14, p. 621.

Oxburgh, V. M., Segnit, R. E., and Holland, H. D., 1959, Coprecipitation of strontium with calcium carbonate from aqueous solutions (abstr.): Bull. Geol. Soc. Amer., v. 70, p. 1653.

Potter, R. W., II, 1977, Pressure corrections for fluid-inclusion homogenization temperatures based on the volumetric properties of the system $NaCl-H_2O$: J. Research U.S. Geol. Survey, v. 5, no. 5, p. 603-607.

Randall, M., and Failey, C. F., 1927, The activity coefficient of gases in aqueous salt solutions: Chem. Rev., v. 4, p. 271-284.

Reeves, C. C., Jr., 1963, Subterranean natural brines produce sodium sulphate in West Texas: Ground Water, v. 1, p. 35-36.

Roedder, E., 1965, Liquid CO_2 inclusions in olivine bearing nodules and phenocrysts from basalts: Amer. Min., v. 50, p. 1746-1782.

Savin, S. M., and Epstein, S., 1970, The oxygen and hydrogen isotope geochemistry of clay minerals: Geochim. Cosmochim. Acta, v. 34, p. 25-42.

Schaller, W. T. and E. P. Henderson, 1932, Mineralogy of drill cores from the potash field of New Mexico and Texas: U. S. Geol. Surv. Bull. No. 833, 124 pp.

Shell Exploration and Production Research Center, 1973, Potassium-Argon dates on Permian potash minerals from southeastern New Mexico: Isochron/West, No. 6, p. 37.

Tremba, E. L., 1973, Isotope geochemistry of strontium in carbonate and evaporite rocks of marine origin: unpub. Ph.D. dissertaton, Ohio State Univ., 185 p.

Vogel, A. I., 1961, A Textbook of Quantitative Inorganic Analysis: 3rd Ed., John Wiley and Sons, Inc., N.Y., p. 462.

Wilcox, W. R., 1968, Removing inclusions from crystals by gradient techniques: Indust. Eng. Chem., v. 60, no. 3, p. 13-23.

Wilcox, W. R., 1969, Anomalous gas-liquid inclusion movement: Indust. Eng. Chem., v. 61, no. 3, p. 76-77.

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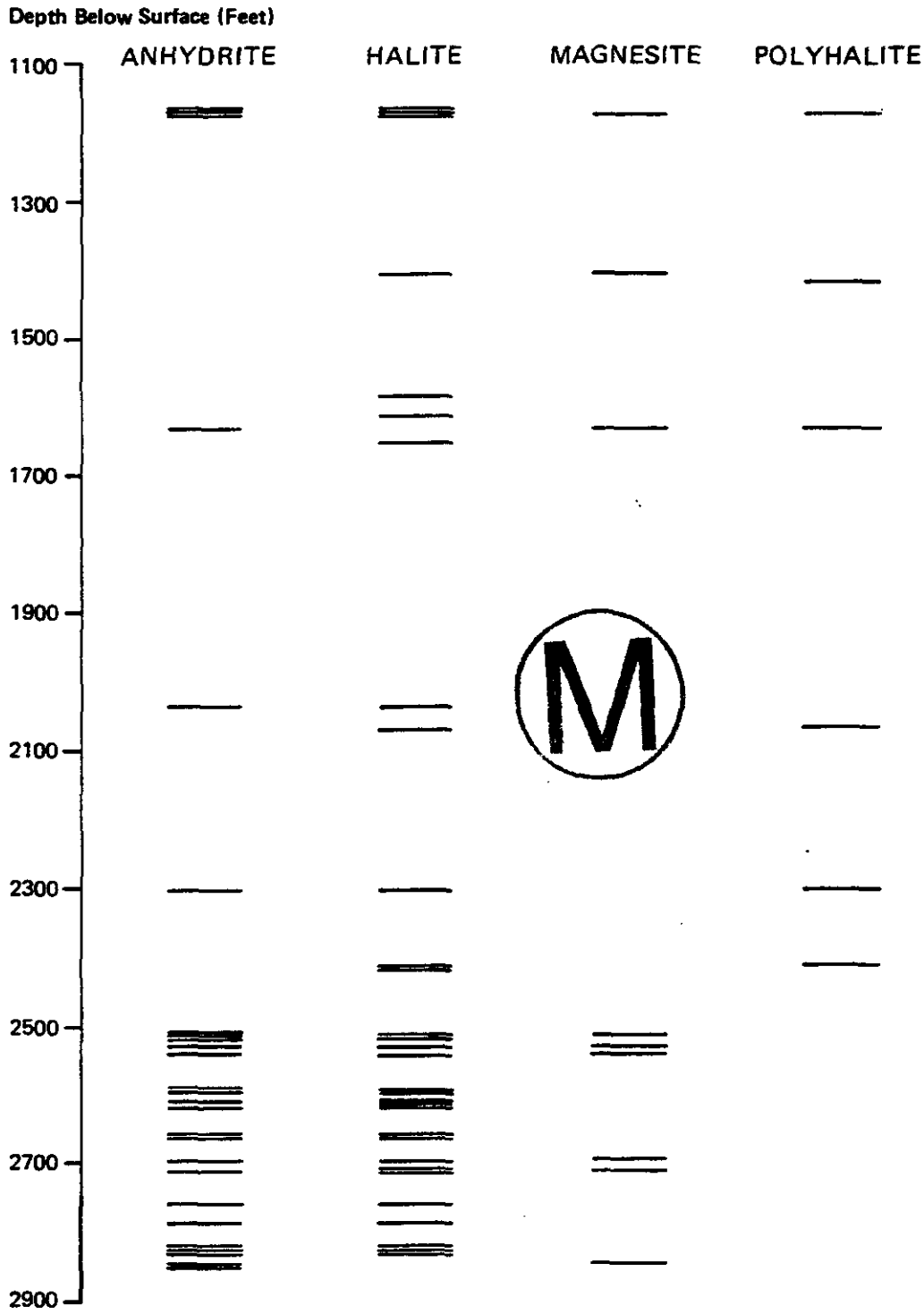

FIGURE 7.1

DISTRIBUTION OF MINERALS IN ERDA #9 CORE SAMPLES

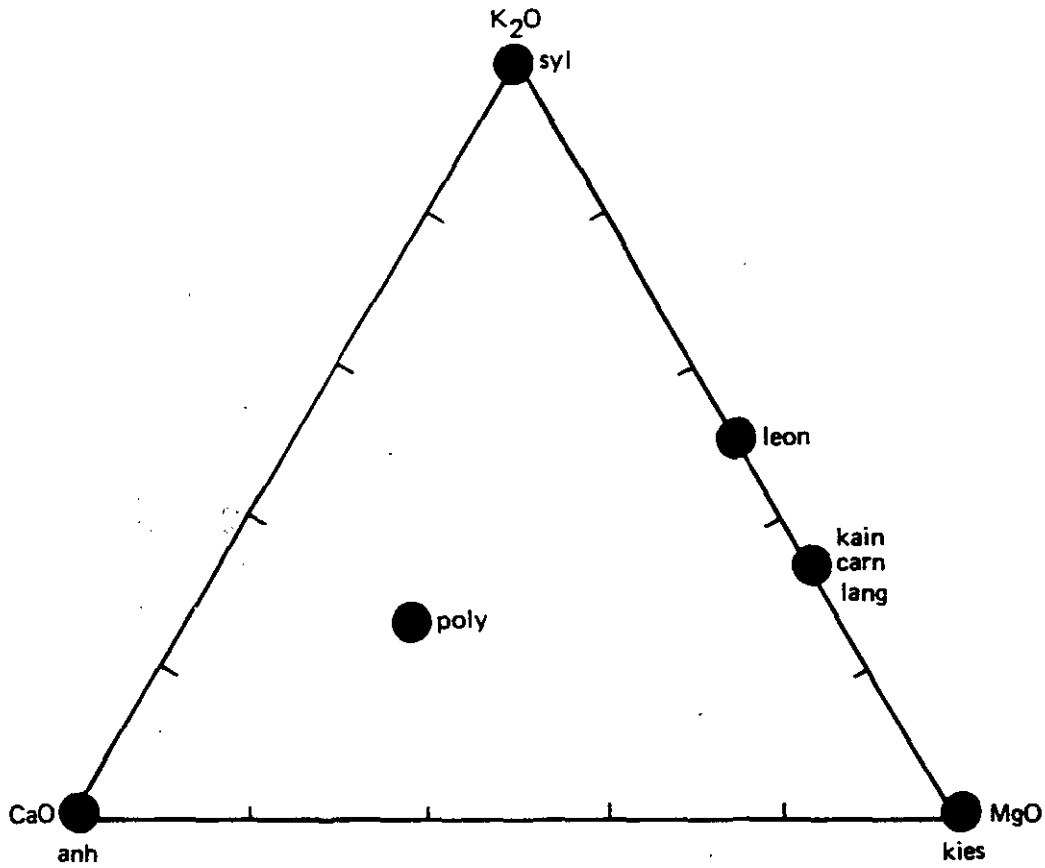

FIGURE 7.2

TRIANGULAR COMPOSITION DIAGRAM OF

SOLUBLE SULFATE-GROUP MINERALS

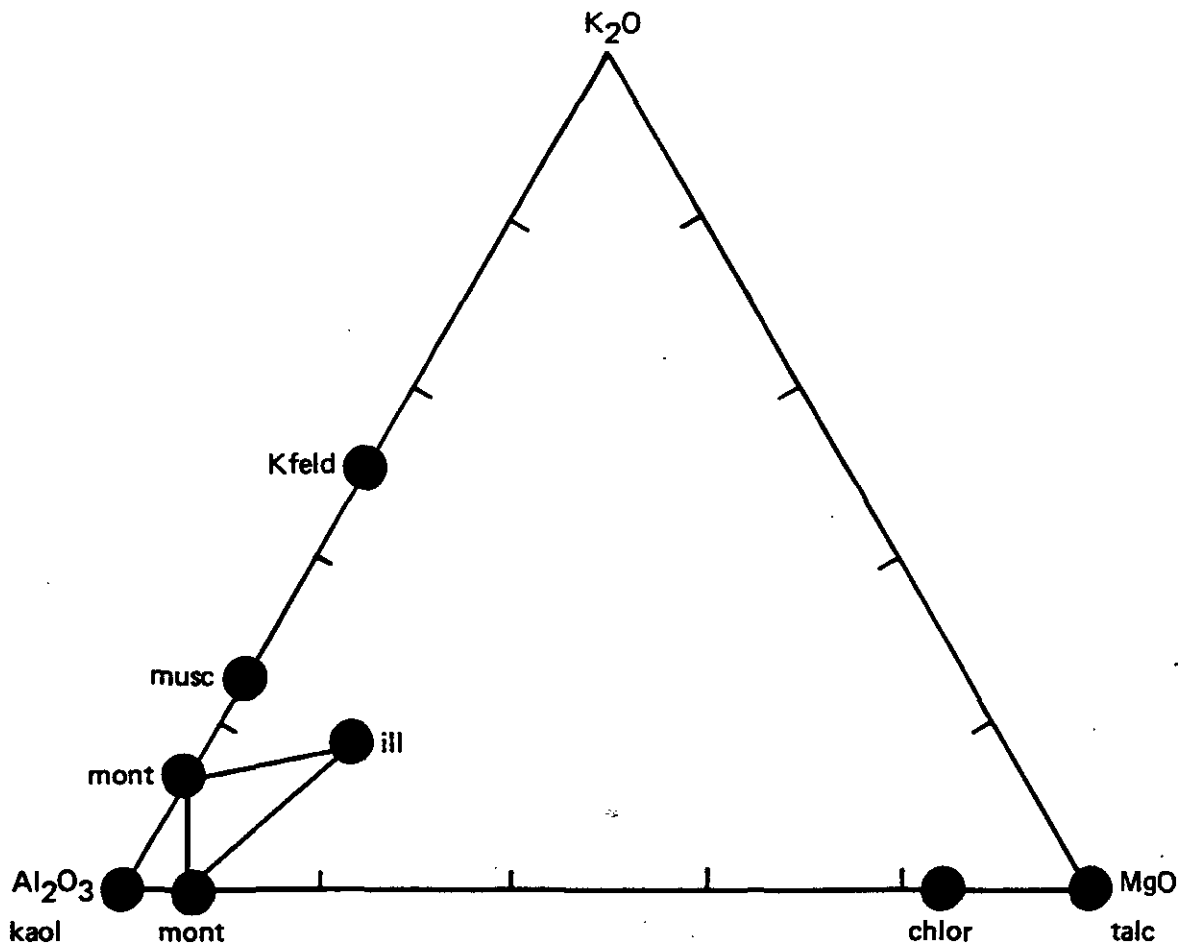

FIGURE 7.3

TRIANGULAR DIAGRAM OF

INSOLUBLE SILICATE-GROUP MINERALS

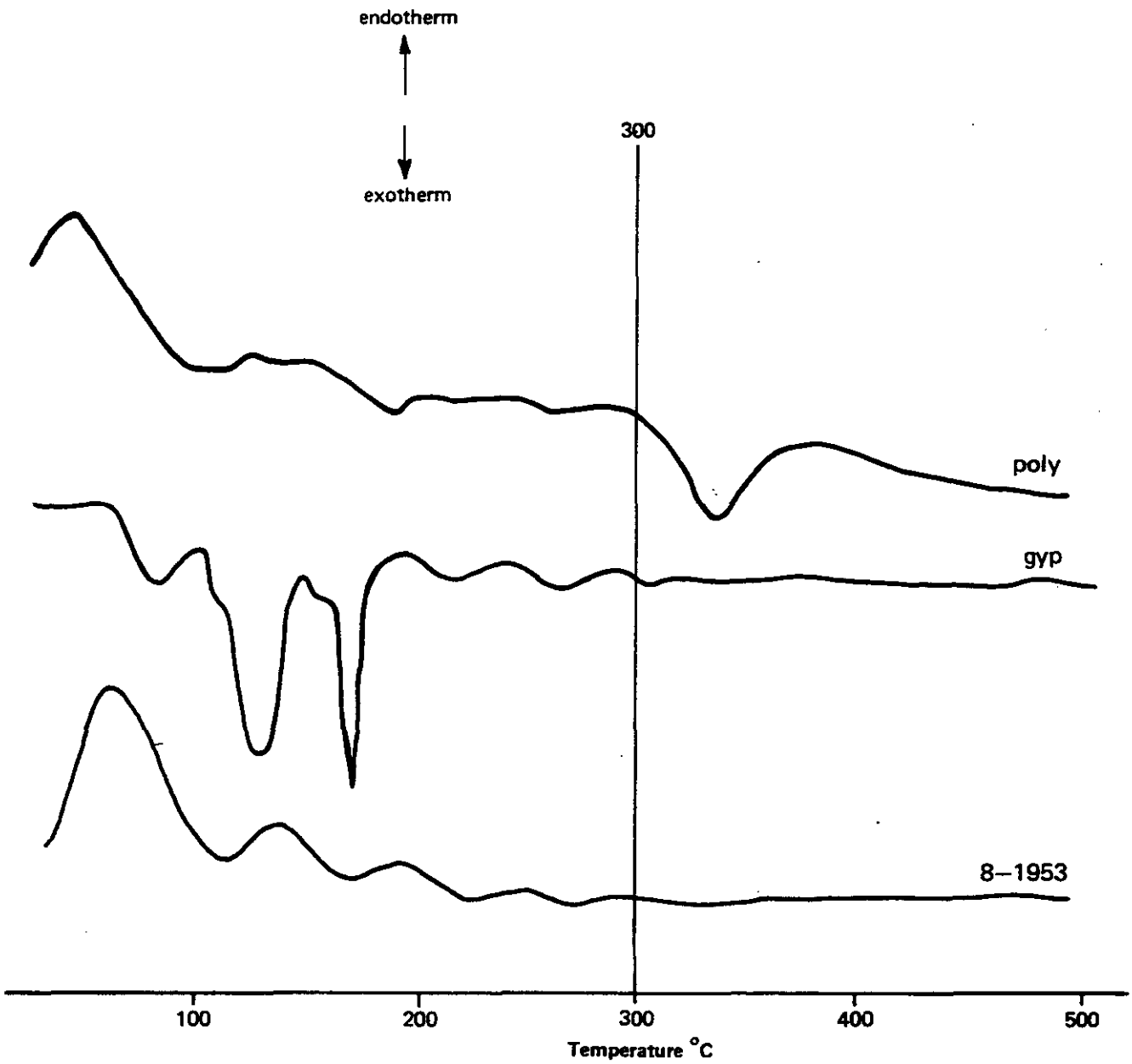

FIGURE 7.4

DIFFERENTIAL THERMAL ANALYSIS CURVES

FOR GYPSUM AND POLYHALITE

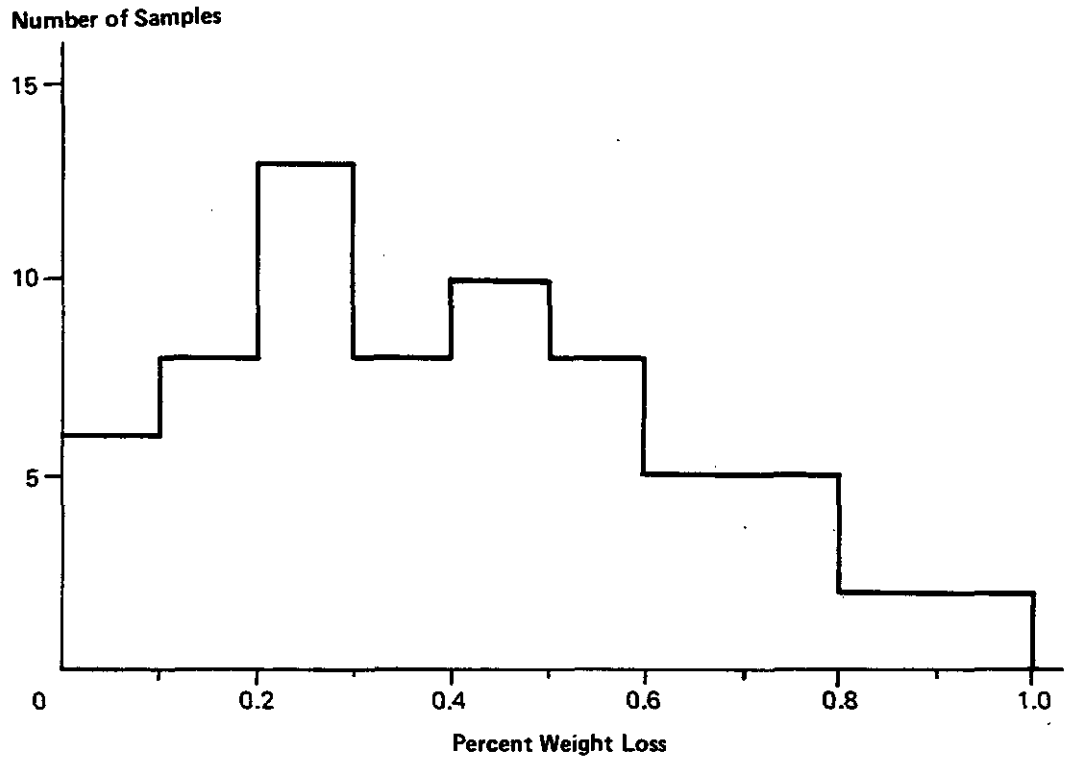

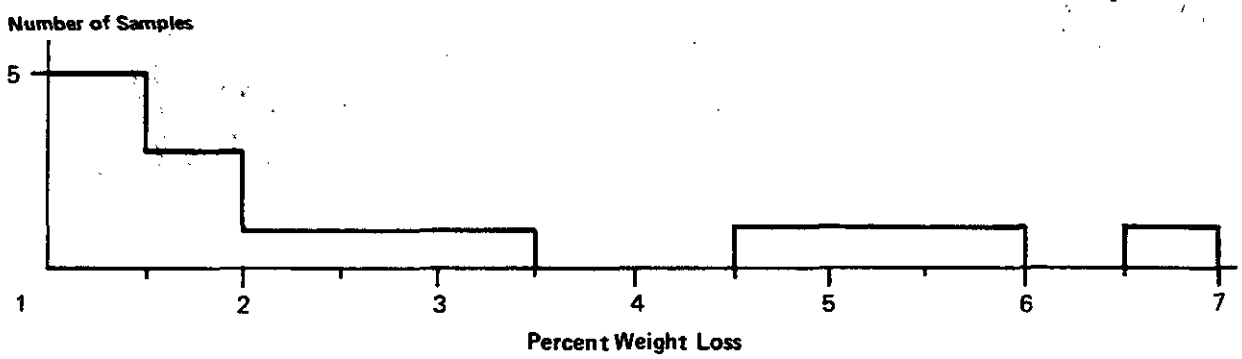

FIGURE 7.5

TOTAL WEIGHT LOSSES AT ELEVATED TEMPERATURES

(500°C) FOR CORES FROM AEC NOS. 7 AND 8

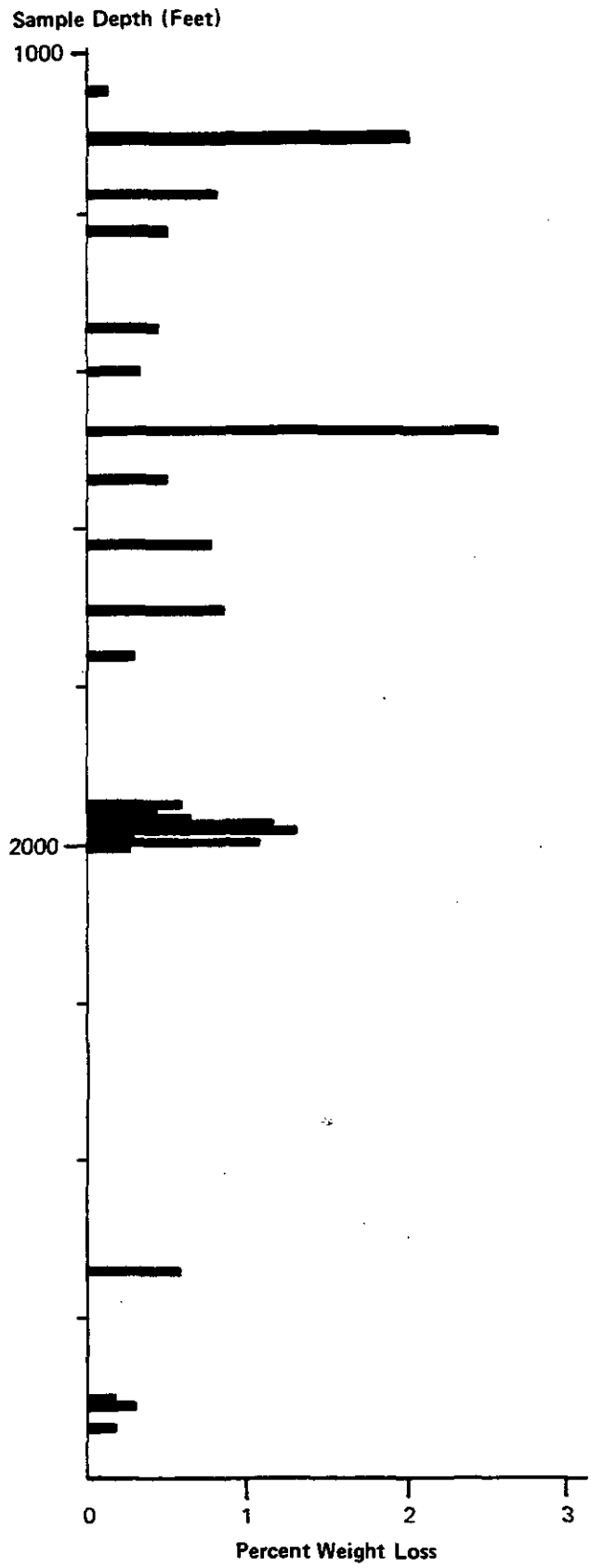

FIGURE 7.6A

AEC NO. 7 SAMPLE WEIGHT LOSSES VS. DEPTH

AT ELEVATED TEMPERATURES (500°C)

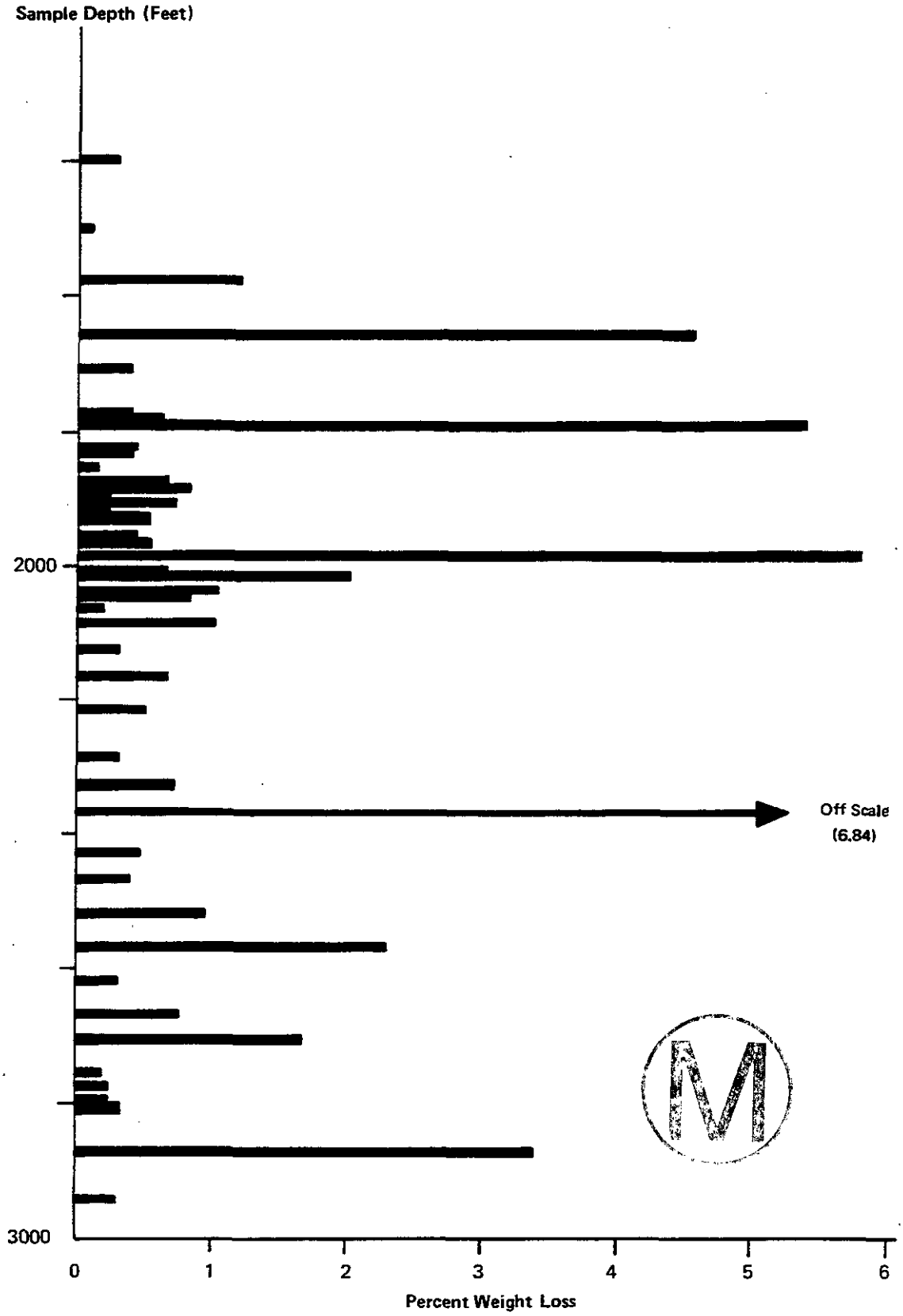

FIGURE 7.6B

AEC NO. 8 SAMPLE WEIGHT LOSSES VS. DEPTH

AT ELEVATED TEMPERATURES (500°C)

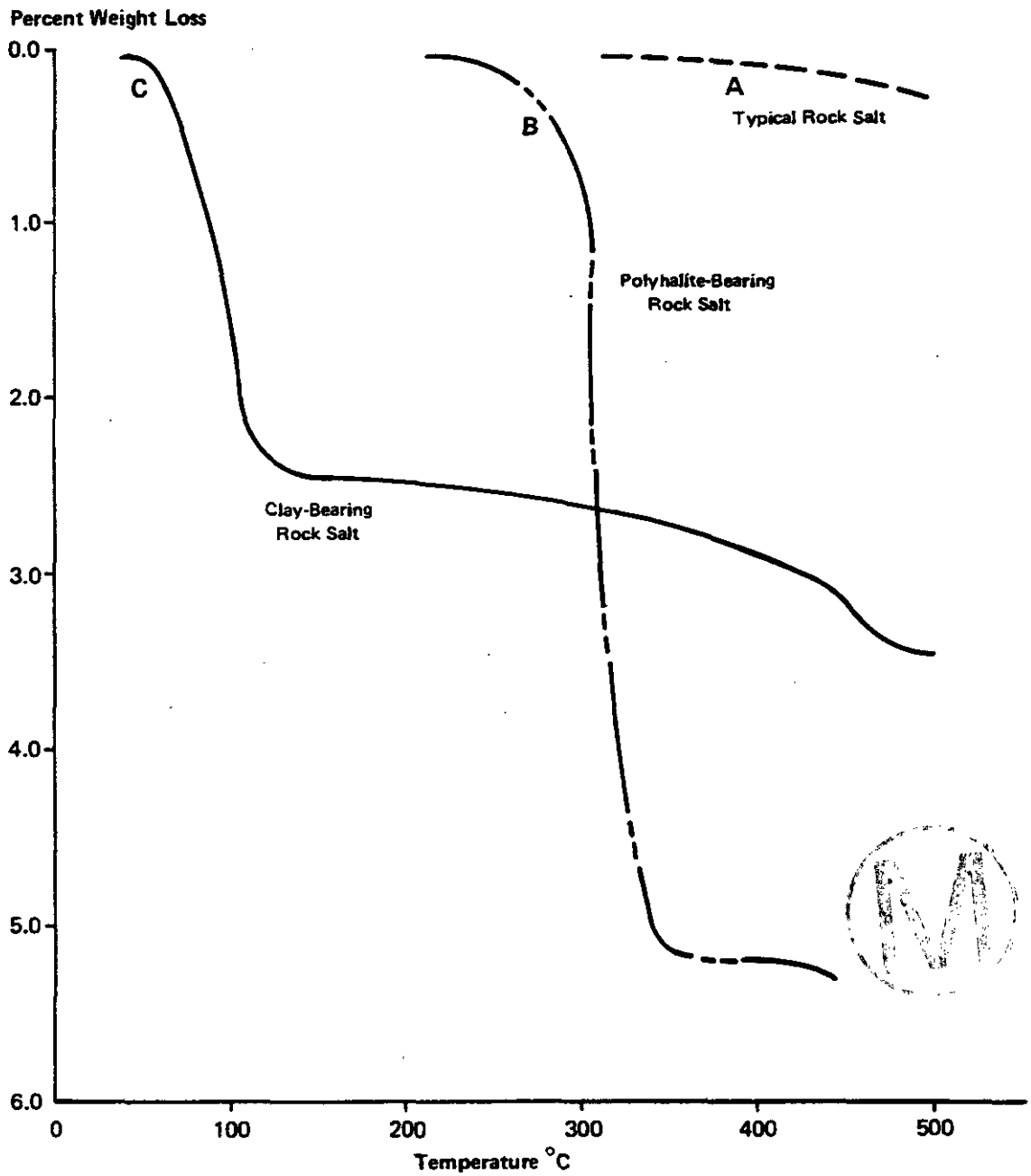

FIGURE 7.7

TYPICAL WEIGHT-LOSS CURVES FOR ERDA #9 EVAPORITE CORE

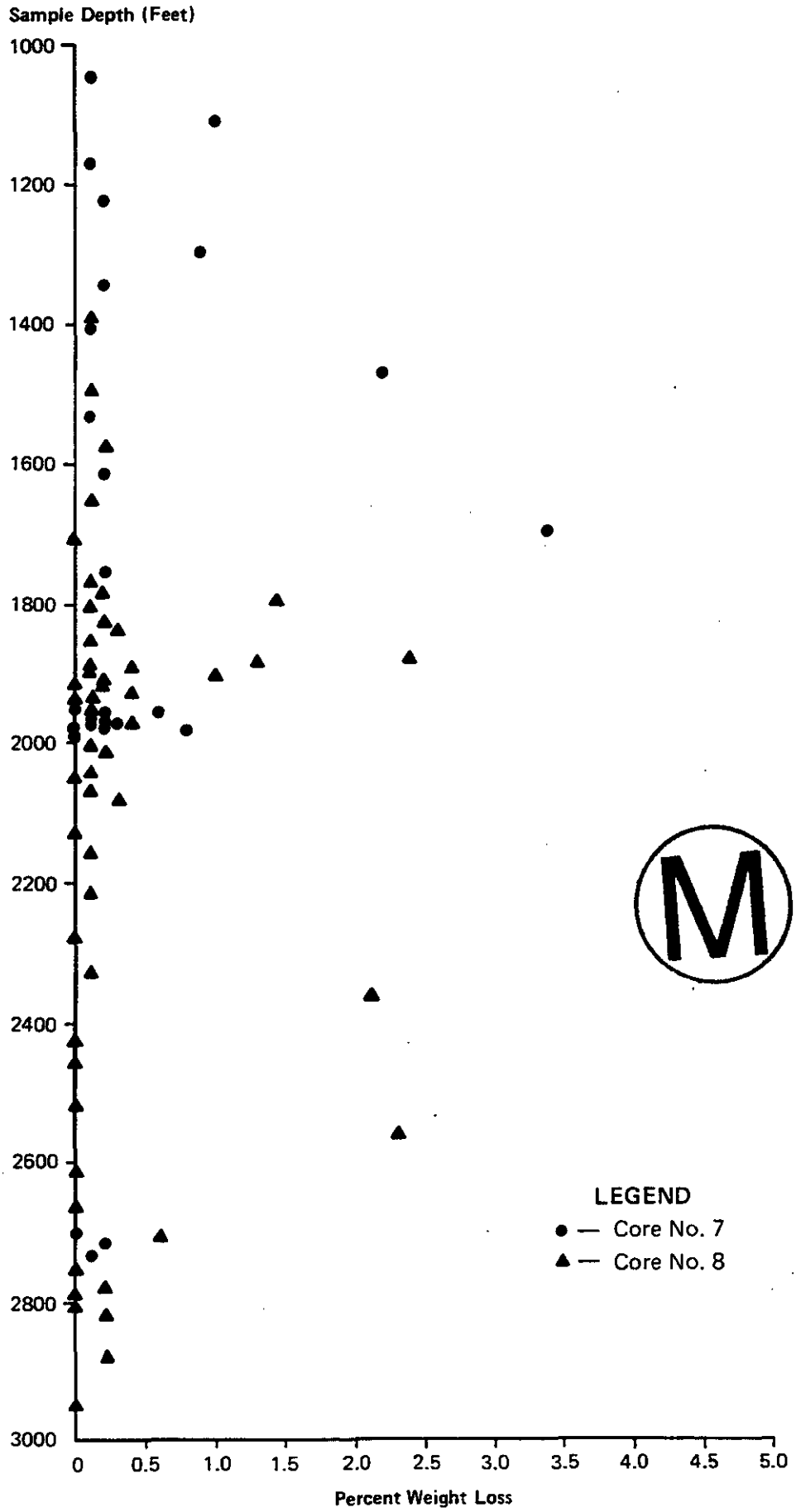

FIGURE 7.8 WEIGHT LOSS DATA FOR SAMPLES (102±5°C)

FROM CORES NO. 7 AND NO. 8 NEAR CARLSBAD, NEW MEXICO

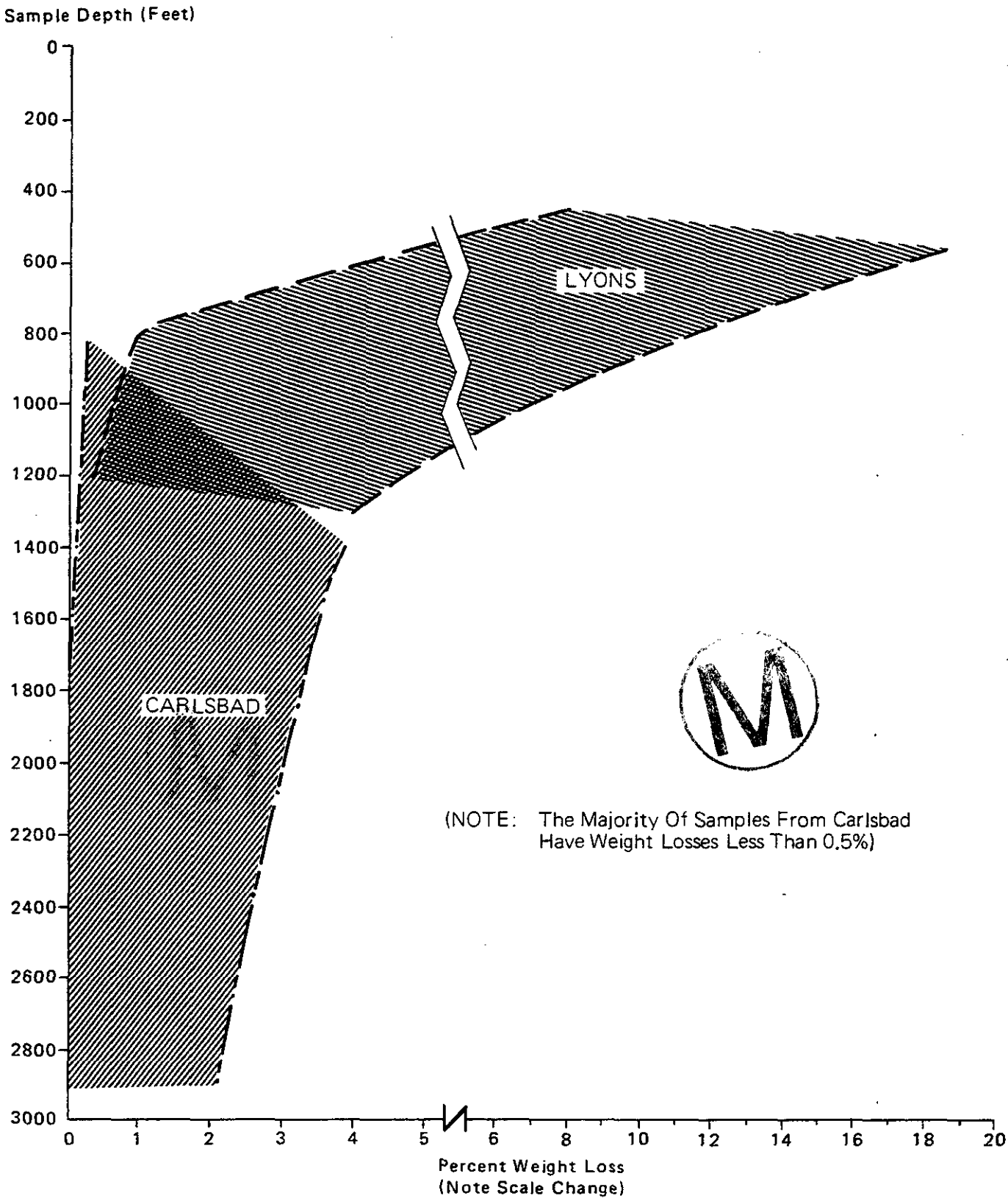

FIGURE 7.9 APPROXIMATE RANGE OF WEIGHT LOSS TO BE EXPECTED At 102 + 5°C VS. DEPTH FOR SAMPLES FROM LYONS, KANSAS AND CARLSBAD, NEW MEXICO

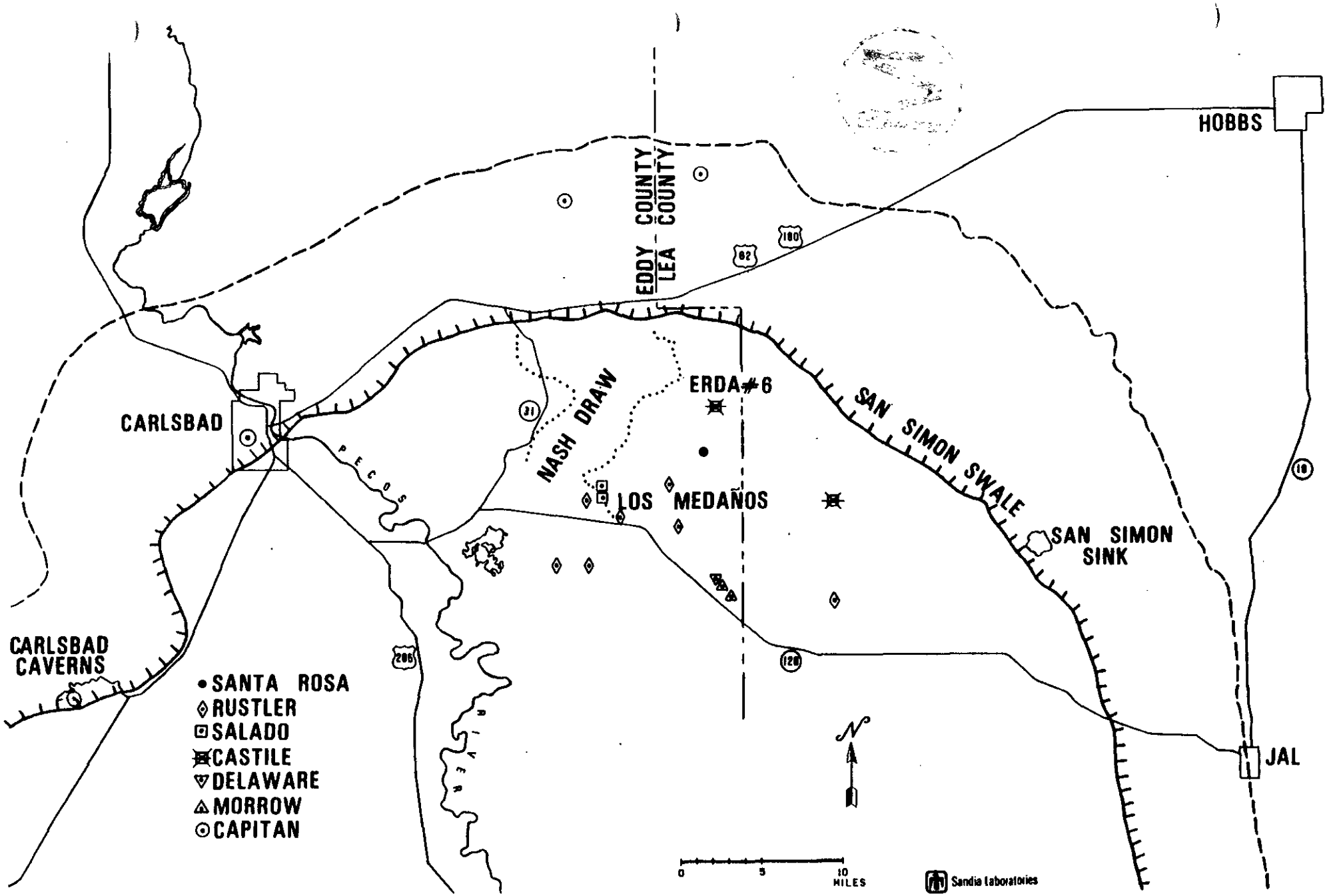

FIGURE 7.10 Map of the New Mexico portion of the Delaware Basin, showing locations of water sampling points in this study. The solid hachured line is the basinward margin of the Capitan Reef; the dashed line is the shelfward edge.

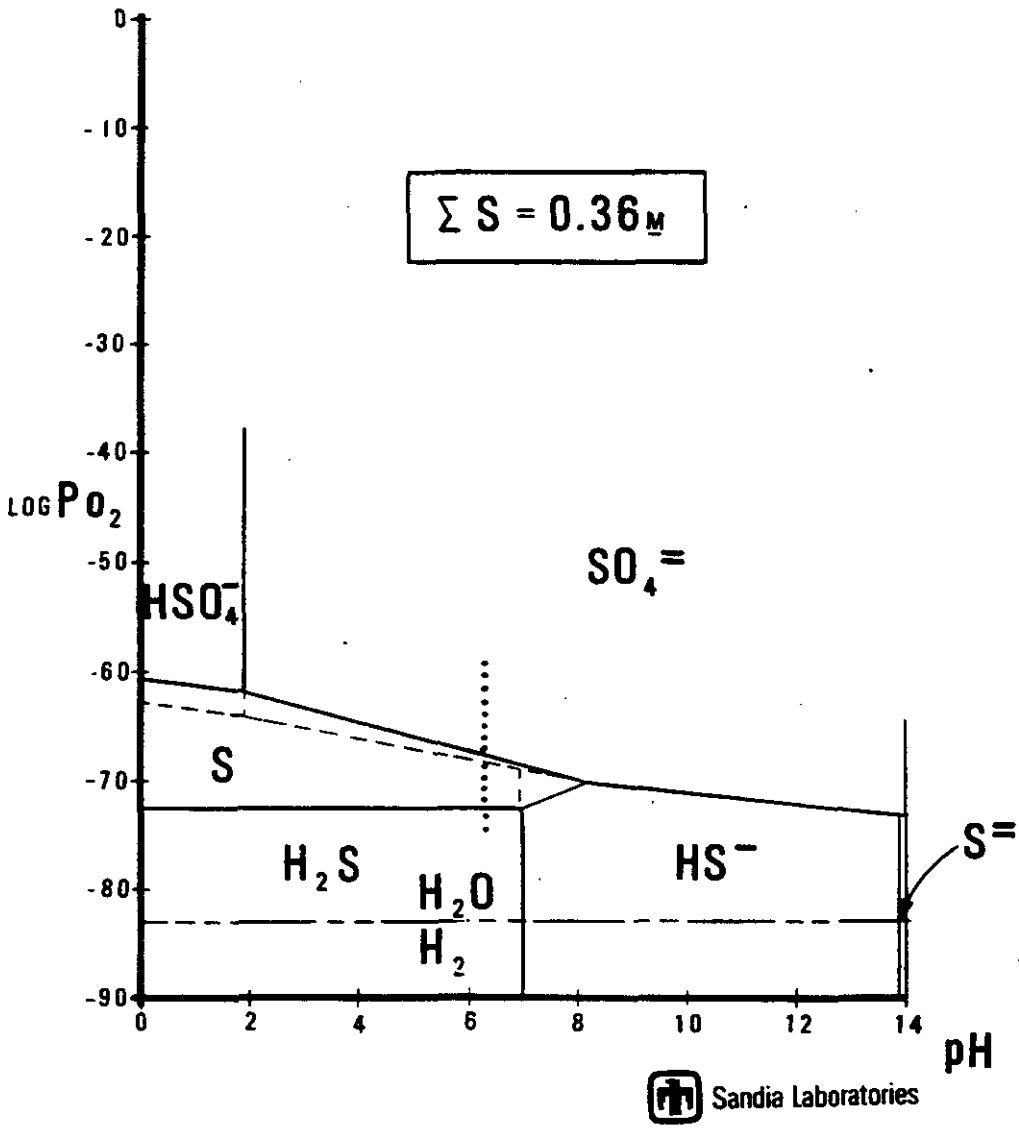

FIGURE 7.11 Predominance area diagram, oxygen partial pressure versus pH, for the System S-O-H at 25°C, 1 atmosphere and total sulfur concentration of 0.36m. Dashed lines are metastable extensions of boundaries. Dotted line represents the field-measured pH of ERDA No. 6, 6.3.

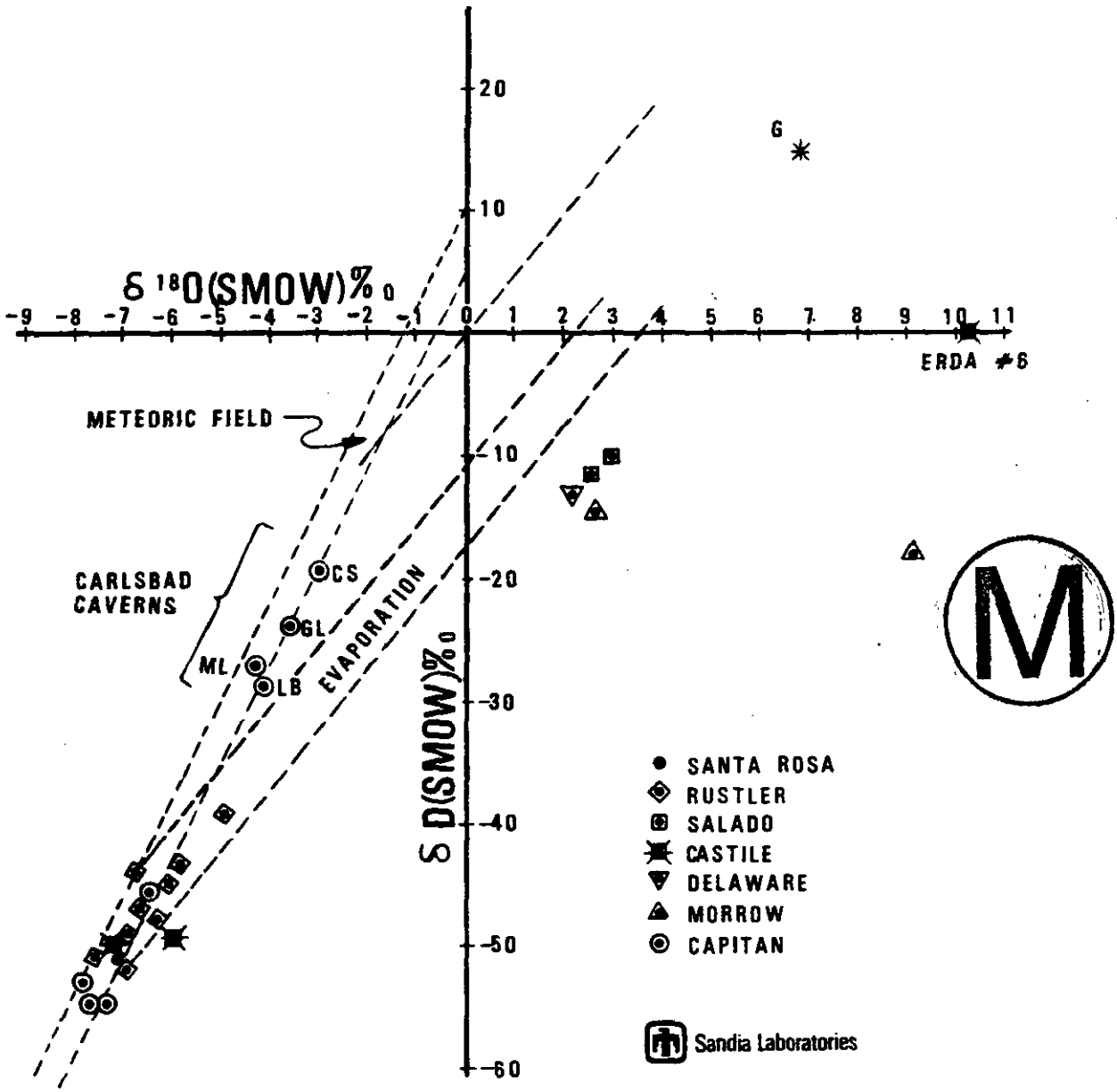

FIGURE 7.12 Stable isotope compositions, δD versus $\delta^{18}O$, for Delaware Basin groundwaters. Relationships are shown for meteoric waters, evaporating meteoric and sea waters. Hypothetical evaporite mother-liquor for gypsum (G) is shown for the case in which ERDA No. 6 is taken to be the water of crystallization for that gypsum.

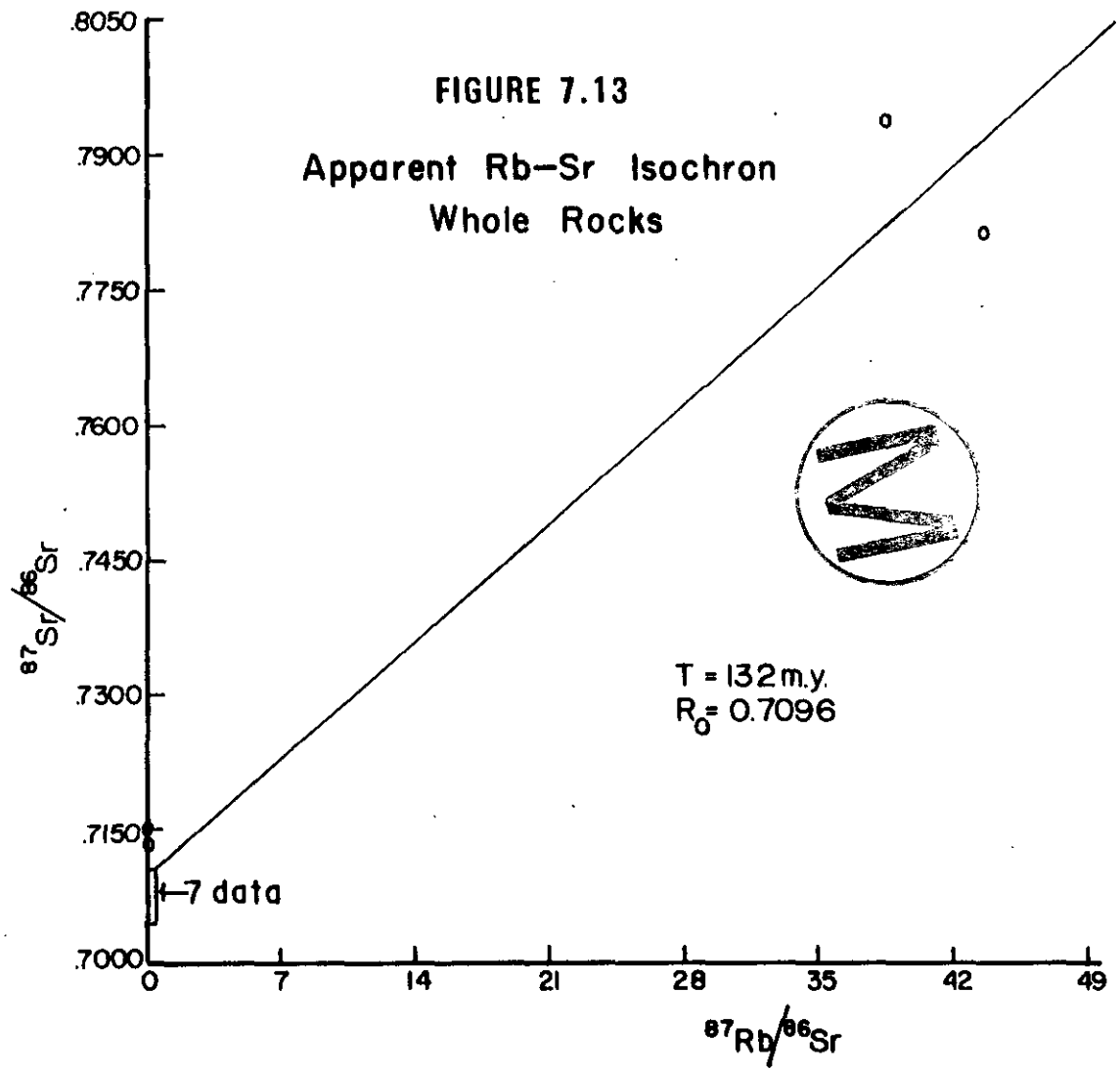
FIGURE 7.13
Apparent Rb–Sr Isochron
Whole Rocks
T = 132 m.y.
R_0 = 0.7096
7 data
.8050
.7900
.7750
.7600
.7450
.7300
.7150
.7000
0
7
14
21
28
35
42
49
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$

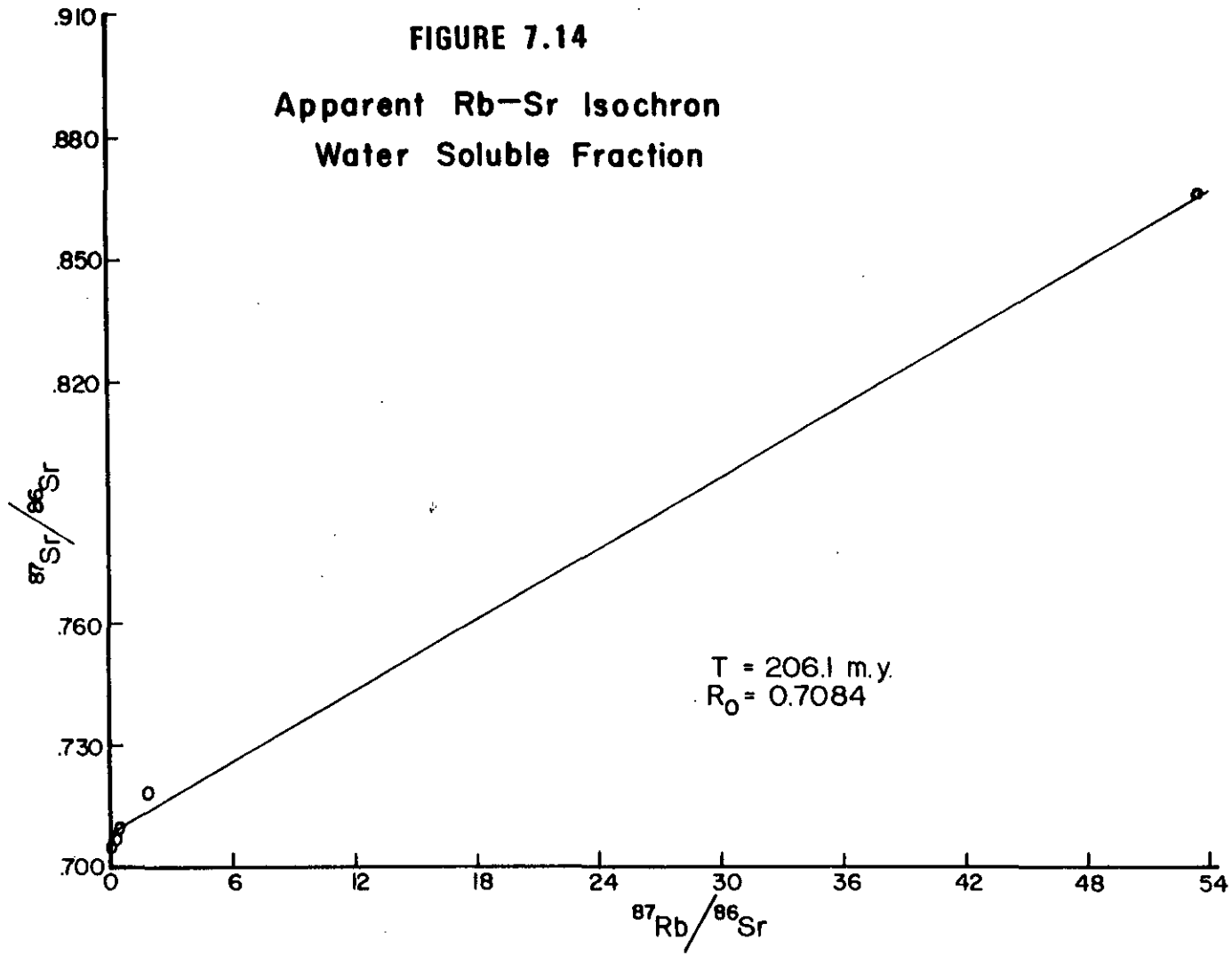
FIGURE 7.14
Apparent Rb—Sr Isochron
Water Soluble Fraction
T = 206.1 m.y.
R_0 = 0.7084
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$
.910
.880
.850
.820
.760
.730
.700
0
6
12
18
24
30
36
42
48
54

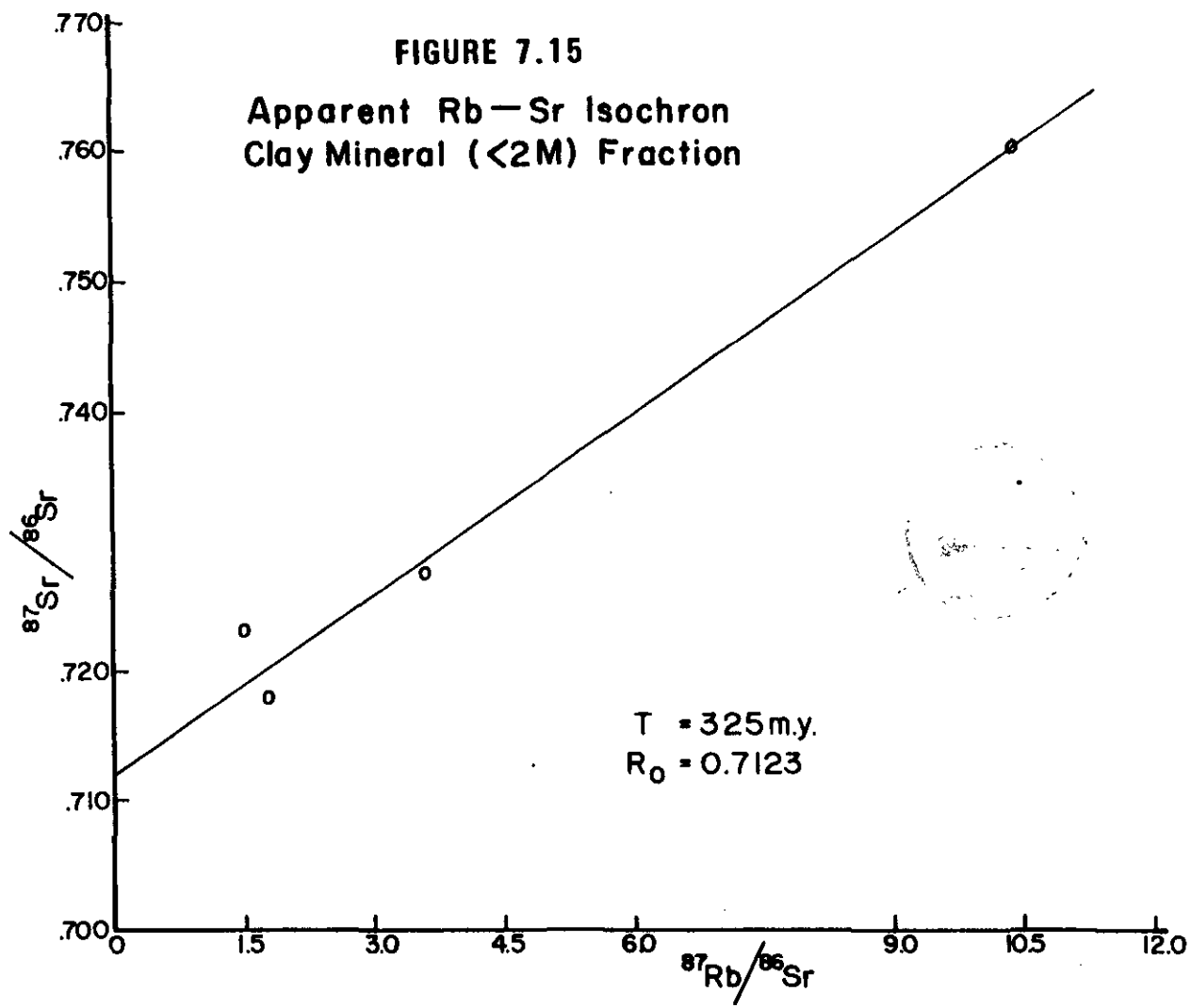
FIGURE 7.15
Apparent Rb—Sr Isochron
Clay Mineral (<2M) Fraction
T = 325 m.y.
R_0 = 0.7123
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$
.770
.760
.750
.740
.720
.710
.700
0
1.5
3.0
4.5
6.0
9.0
10.5
12.0

FIGURE 7.16

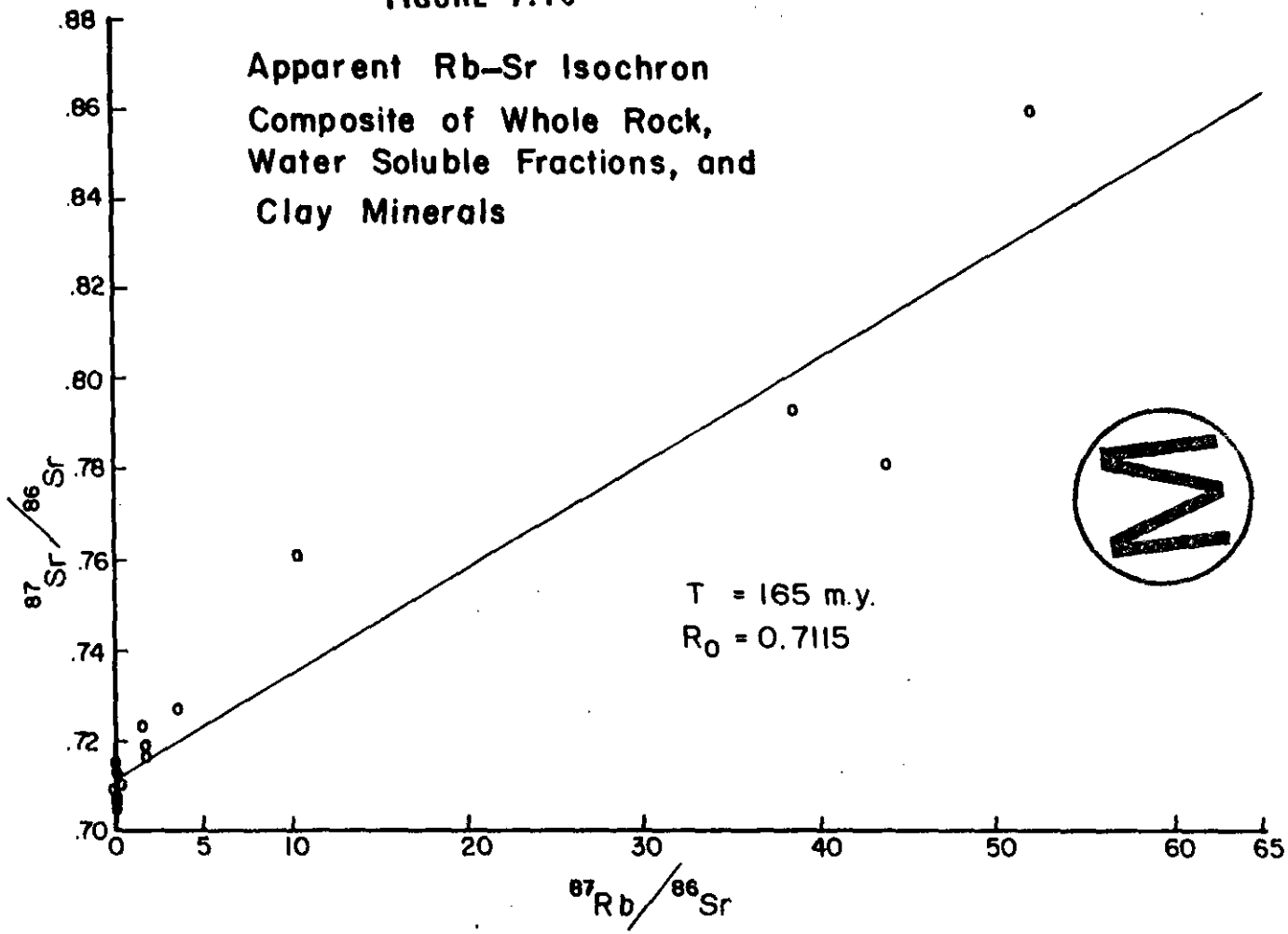
Apparent Rb–Sr Isochron
Composite of Whole Rock,
Water Soluble Fractions, and
Clay Minerals
T = 165 m.y.
R_0 = 0.7115
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$
.88
.86
.84
.82
.80
.78
.76
.74
.72
.70
0
5
10
20
30
40
50
60
65

FIGURE 7.17

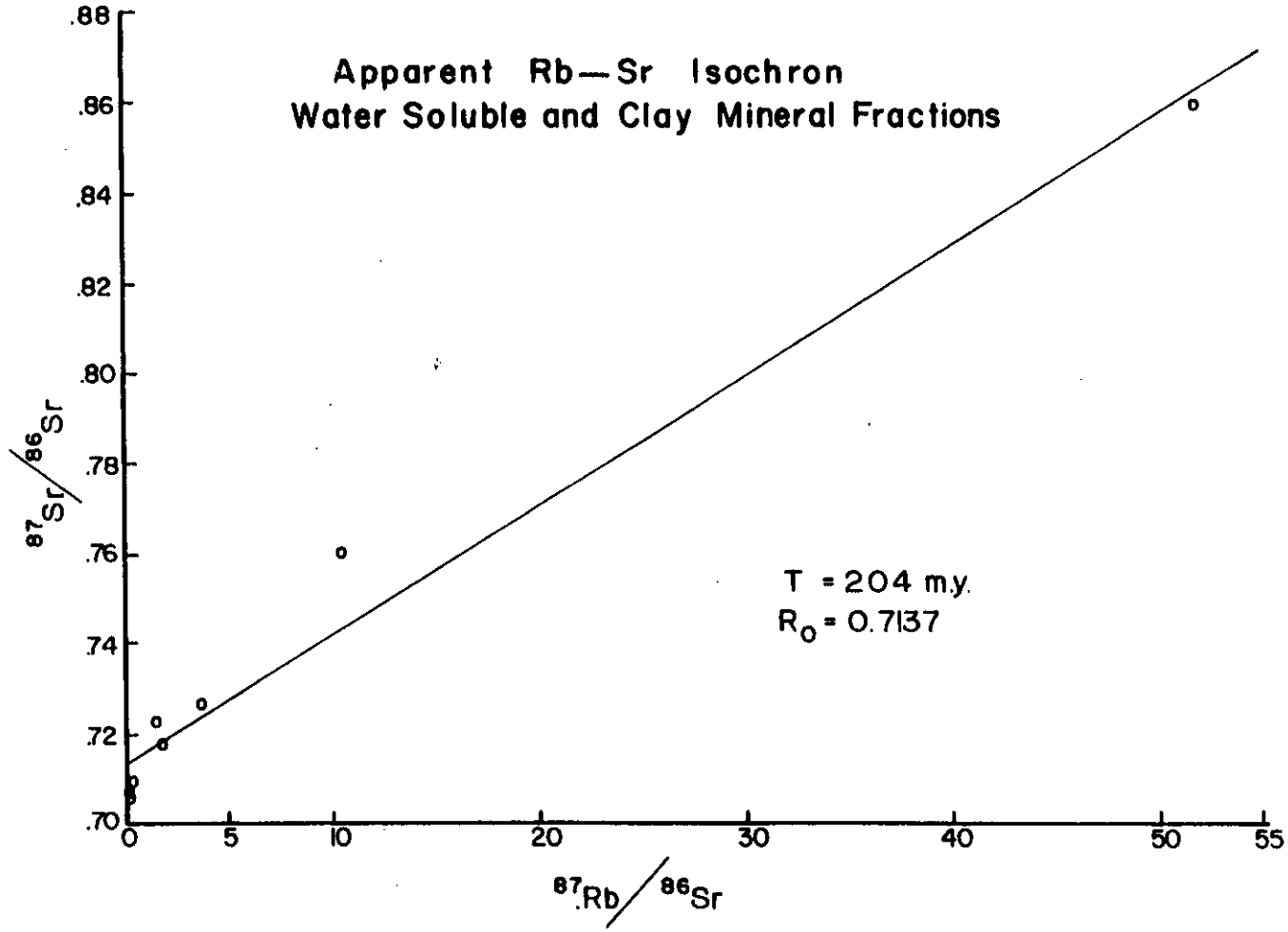
Apparent Rb—Sr Isochron
Water Soluble and Clay Mineral Fractions
T = 204 m.y.
R_o = 0.7137
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$
.88
.86
.84
.82
.80
.78
.76
.74
.72
.70
0
5
10
20
30
40
50
55

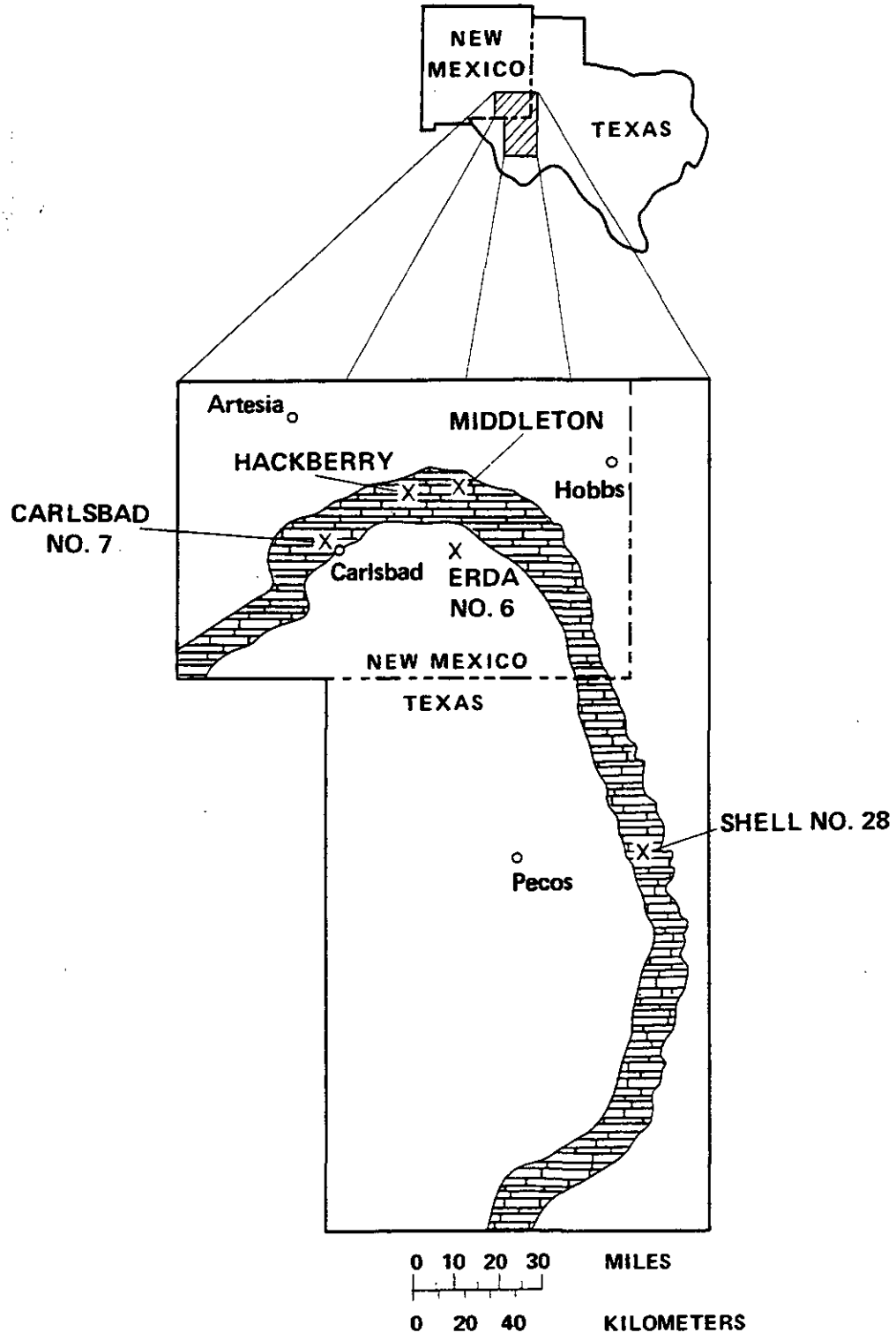

FIGURE 7.18 Map of a portion of the Delaware Basin (southeast New Mexico, west Texas) showing locations of holes whose fluids are sampled for $^{234}U/^{238}U$-disequilibrium age-dating. The brick-pattern shows the surface projection and outcrop of the capitan reef limestone. (from Hiss, 1975)

FIGURE 7.19 Graph of the equation $f = \frac{(\alpha_0 - 1)(\alpha_r - 1)}{\alpha_b - \alpha_0 + r(\alpha_r - 1)}$

for the ERDA No. 6 assemblage of rock and brine, in which $r = 16.42$, $\alpha_r = 1.04$, $\alpha_b = 1.35$.

Uranium disequilibrium ages for the brine are shown according to the equation

$$t = \frac{\ln\left(\frac{\alpha_b - 1 - fr}{\alpha_0 - 1 - fr}\right)}{-\lambda_2}$$

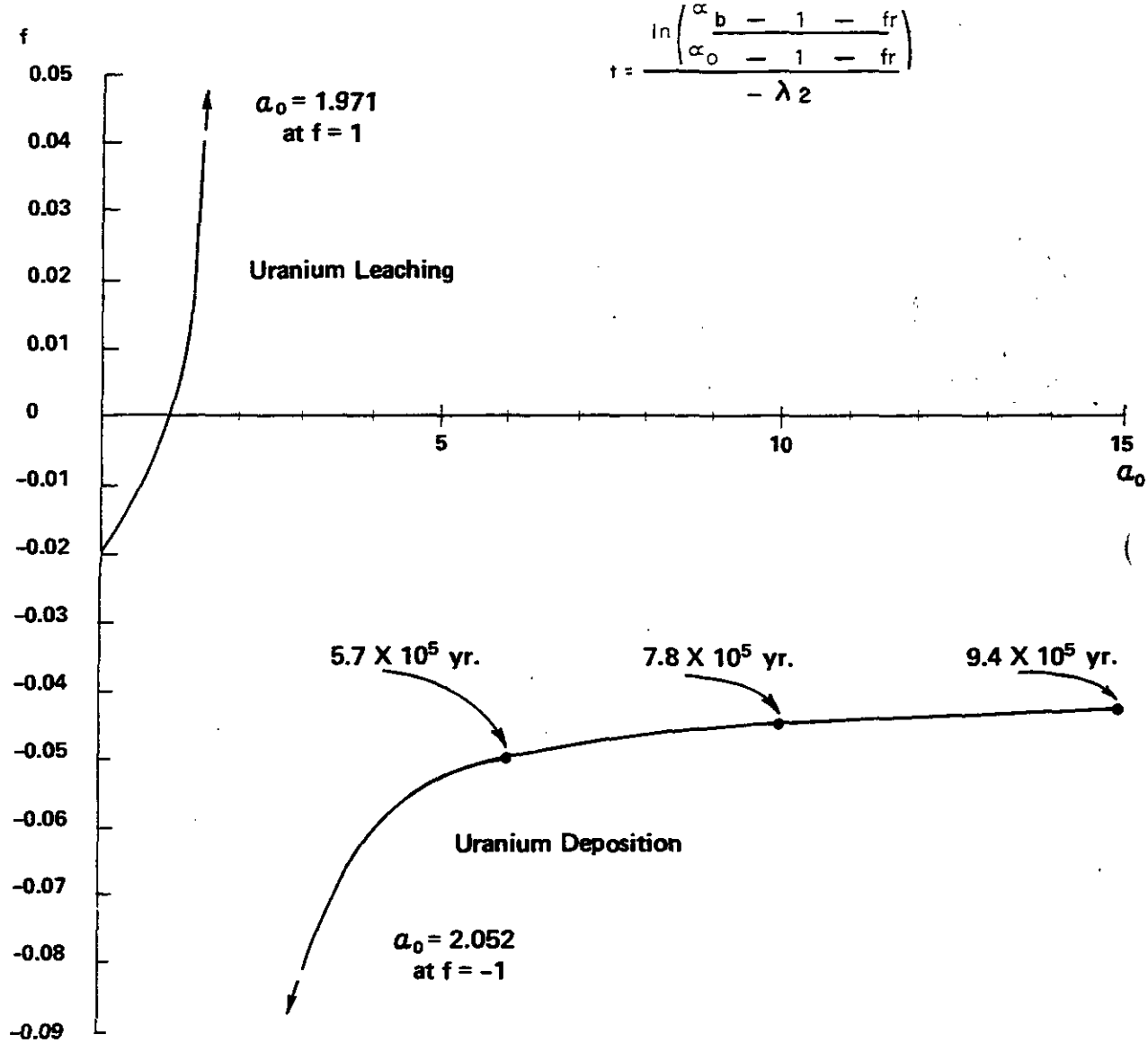

Note that the ERDA No. 6 assemblage is indicative of uranium deposition ($f < 0$) rather than uranium leaching.

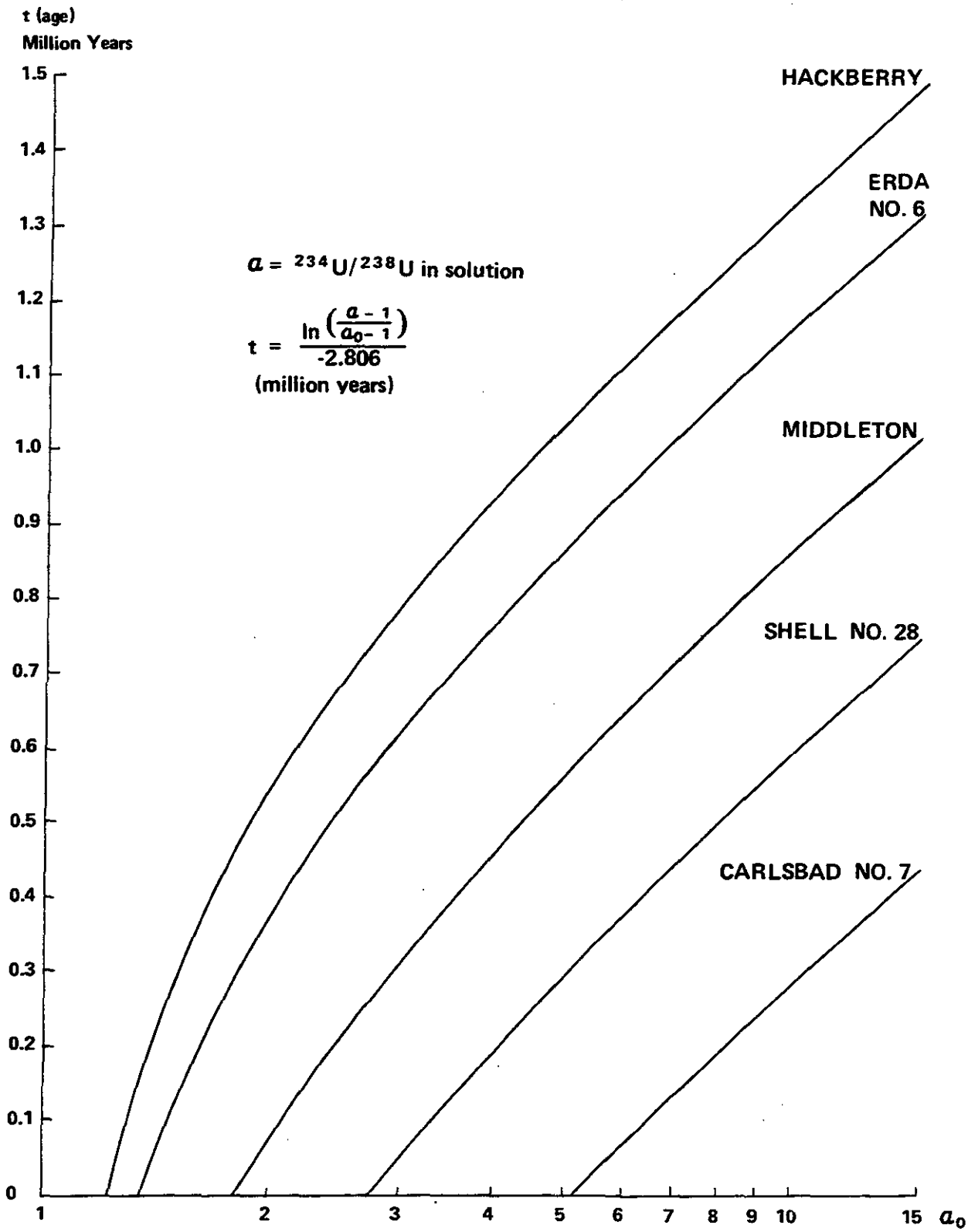

FIGURE 7.20 Uranium disequilibrium ages as a function of original $^{234}U/^{238}U$ ratio, for Delaware Basin groundwaters. These curves are derived from a model involving no exchange or uranium between rock and water.

TABLE 7.1. MINERAL CONTENT OF ERDA #9 CORE SAMPLES (M=MAJOR, T=TRACE).

ERDA 9
CORE #

(DEPTH IN FEET)	ANHYDRITE	CLAY	HALITE	LOEWEITE	MAGNESITE	POLYHALITE	QUARTZ	SYLVITE
1162.7	T	.	M	.	.	.	.	.
1165.7	M	.	M	.	.	.	.	.
1168.0	M	.	T	.	.	.	.	.
1168.8	.	.	M	.	.	.	.	.
1172.8	.	.	M	.	.	M	.	.
1173.4	M	.	.	.	M	.	T	.
1174.1	.	.	M	.	.	M	.	.
1405.7	.	.	M	.	T	.	.	.
1418.8	.	.	.	.	.	M	.	.
1584.0	.	.	M	.	.	.	.	.
1610.0	.	.	M	.	.	.	.	.
1632.4	M	.	.	.	M	.	.	.
1632.8	.	.	.	.	.	M	.	.
1648.5	.	.	M	T	.	.	.	.
2034.7	M	.	M	.	.	.	T	.
2035.7	T	.	M	.	.	.	.	T
2036.3	.	.	M	.	.	.	.	.
2065.0	.	.	M	.	.	.	.	.
2067.5	.	.	M	.	.	T	.	.
2302.6	M	.	T	.	.	M	.	.
2413.7	.	.	M	.	.	M	.	.
2414.2	.	.	M	.	.	M	.	.
2415.6	M	.	M	.	.	.	.	.
2512.0	M	.	M	.	.	.	.	.
2516.3	M	.	M	.	T	.	.	.
2518.8	M	.	.	.	.	.	.	.
2528.7	M	.	.	.	T	.	.	.
2529.0	M	.	T	.	.	.	.	.
2538.5	M	.	.	.	T	.	.	.

TABLE 7.1. MINERAL CONTENT OF ERDA #9 CORE SAMPLES (M=MAJOR, T=TRACE), continued

ERDA 9
CORE #

(DEPTH IN FEET)	ANHYDRITE	CLAY	HALITE	LOEWEITE	MAGNESITE	POLYHALITE	QUARTZ	SYLVITE
2541.0	.	.	M	.	.	.	.	.
2542.0	.	.	M	.	.	.	.	.
2593.2	M	.	.	.	.	.	.	.
2594.5	.	.	M	.	.	.	.	.
2597.0	T	.	M	.	.	.	.	.
2608.9	T	.	M	.	.	.	.	.
2614.7	.	.	M	.	.	.	.	.
2619.6	T	.	M	.	.	.	.	.
2658.5	M	.	M	.	.	.	.	.
2663.3	T	.	M	.	.	.	.	.
2696.4	M	.	M	.	T	.	.	.
2706.5	.	.	M	.	.	.	.	.
2711.9	T	.	M	.	T	.	.	.
2759.0	T	.	M	.	.	.	.	.
2768.5	M	T	M	.	.	.	.	.
2820.7	M	.	M	.	.	.	.	.
2820.6	T	.	M	.	.	.	.	.
2821.0	T	.	M	.	.	.	.	.
2826.5	T	.	M	.	.	.	.	.
2845.3	M	.	.	.	T	.	.	.
2848.8	M	.	.	.	.	.	.	.

TABLE 7.2

Size Distribution of Ground Samples

Mesh	% of Sample *
>20	5.2
20-28	8.8
28035	19.9
35-65	57.0
65-100	6.1
100-200	2.9
<200	0.2

*Total ≠ 100 due to rounding

TABLE 7.3

Listing of Minerals Named in Subsection 7.3

Mineral Name	Chemical Composition
Anhydrite	$CaSO_4$
Bloedite	$Na_2\ Mg(SO_4)_2 \cdot 4H_2O$
Carnallite	$K\ Mg\ Cl_3 \cdot 6\ H_2O$
Chlorite	$Mg_5Al_2Si_3O_{10}(OH)_8$
Glaserite	$K_3Na(SO_4)_2$
Glauberite	$Na_2Ca(SO_4)_2$
Gypsum	$CaSO_4 \cdot 2H_2O$
Halite	$NaCl$
Illite	$K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2$
Iron Oxides (FEOX)	$Fe_2O_3 \cdot XH_2O$
Kainite	$KMgCl\ SO_4 \cdot 11/4\ H_2O$
K-Feldspar	$K\ Al\ Si_3O_8$
Kieserite	$MgSO_4 \cdot H_2O$
Langbeinite	$K_2Mg_2\ (SO_4)_3$
Leonite	$K_2Mg(SO_4)_2 \cdot 4\ H_2O$
Montmorillonite	$Mg_{0.16}\ Al_{2.33}\ Si_{3.67}\ O_{10}(OH)_2$
Polyhalite	$K_2Mg\ Ca(SO_4)_4 \cdot 2\ H_2O$
Quartz	SiO_2
Sylvite	KCl
Talc	$Mg_3\ Si_4\ O_{10}\ (OH)_2$
Thenardite	$Na_2\ SO_4$

TABLE 7.4

ERDA No. 9 Samples Chosen for Silicate Mineralogy

Depth (ft)	Sample	Gross Lithology	Stratigraphic Position
1163.3-1163.6	MB-CS-18	Rock salt	SALADO Fm.
1165.1	MB-CS-16	Anhydrite	
1166.17	MB-CS-17	o Anhydrite	
1167.5	MB-CS-1	Anhydrite	
1168.31	MB-CS-6	Anhydrite w/ halite	
1169.4-1169.5	MB-CS-19	Rock salt	
1172.9	MB-CS-5	Polyhalite	
1173.7-1173.8	MB-CS-20	Rock salt	
1242.5	JL-CS-24	Rock salt	
1242.9-1243.1	JL-CS-18	Polyhalite w/ halite	
1243.6-1243.7	JL-CS-27	Polyhalite w/ halite	
1244.2-1244.5	JL-CS-15	Rock salt w/ polyhalite	
1244.5-1244.8	JL-CS-16	Polyhalite w/ halite and clay	
1244.8	JL-CS-12	o Clay	
1245.0-1245.3	JL-CS-20	Rock Salt	
1246.7-1247.1	JL-CS-21	Rock Salt	
1247.1-1247.2	JL-CS-5	o Clay	
1325.2-1325.4	JL-CS-10	o Polyhalite w/ anhydrite veins	
1327.0-1327.2	JL-CS-23	Polyhalite	
1327.7-1327.8	JL-CS-26	Polyhalite w/ halite	
1328.2-1328.4	JL-CS-25	Polyhalite w/ halite and clay	
1328.6	JL-CS-3	o Clay	
1328.7-1329.8	JL-CS-17	Rock Salt	

TABLE 7.4, continued

Depth (ft)	Sample	Gross Lithology	Stratigraphic Position
1404.6-1404.7	MB-CS-21	Rock Salt	11th ore zone
1418.2	MB-CS-7	Anhydrite with clay seam	
1418.6	MB-CS-8	Polyhalite	marker bed 117
1440.4-1440.6	JL-CS-2	o Polyhalite w/ halite	
1441.0-1441.3	JL-CS-6	o Polyhalite	
1441.7	JL-CS-4	o Clay	
1466.4-1466.6	JL-CS-11	o Polyhalite w/ clay	
1466.8-1467.1	JL-CS-9	o Polyhalite w/ clay	
1467.7-1468.1	JL-CS-22	Rock salt w/ clay	
1468.1	JL-CS-14	o Clay	
1535.6-1535.8	JL-CS-8	Polyhalite w/ anhydrite	
1536.5	JL-CS-7	Anhydrite	
1536.5-1536.6	JL-CS-19	Polyhalite w/ clay	
1537.8-1537.9	JL-CS-18	o Polyhalite w/ anhydrite	
1584.4-1584.5	MB-CS-22	Rock salt	near 5th ore zone
1609.5-1609.8	MB-CS-23	Rock salt	
1649.4-1649.6	MB-CS-24	Rock salt	near 4th ore zone
2034.5	MB-CS-14	Anhydrite	
2035.6-2035.9	MB-CS-25	Rock salt	
2036.5-2036.7	MB-CS-26	Rock salt	
2037.3	MB-CS-4	o Anhydrite	

TABLE 7.4, continued

Depth (ft)	Sample	Gross Lithology	Stratigraphic Position
2065.3-2065.4	MB-CS-29	Rock salt	
2066.1	MB-CS-28	Rock salt	
2067.0	MB-CS-27	o Rock salt	
2414.8	MB-CS-30	Rock salt	~16 ft above marker bed 143
2512.5	MB-CS-31	o Rock salt	
2517.9	MB-CS-12	Anhydrite)	
2518.3	MB-CS-13	o Anhydrite)	
		)	Cowden Anhydrite
2528.0	MB-CS-11	Anhydrite)	
2541.2-2541.9	MB-CS-32	o Rock salt	
2608.9-2609.5	MB-CS-33	Rock salt	
2615.9-2616.4	MB-CS-41	Rock salt	
2616.4-2616.8	MB-CS-34	Rock salt	
2617.2-2617.7	MB-CS-35	Rock salt	
2705.2-1705.6	MB-CS-37	Rock salt	
2705.8	MB-CS-10	o Rock salt	

TABLE 7.4, *continued*

Depth (ft)	Sample	Gross Lithology	Stratigraphic Position
2758.2-2758.6	MB-CS-36	o Rock salt	
2819.1-2819.6	MB-CS-39	o Rock salt	
2820.2	MB-CS-15	o Anhydrite	
2820.3	MB-CS-2	Anhydrite	
2821.1-2821.7	MB-CS-38	Rock salt	
2827.3-2827.5	MB-CS-40	o Rock salt	
			2829
2846.0	MB-CS-9	o Anhydrite	
2848.4	MB-CS-3	o Anhydrite	CASTILE Fm.
2867.4-2867.6	MB-CS-42	Anhydrite	

o Samples subjected to semi quantitative analysis (see Table 7.10).

TABLE 7.5

Core depths of samples selected for mineralogic-geochemical analysis.

Sample	Depth (ft)
MB-CS-1	1167.5
-2	2820.3
-3	2848.4
-4	2037.3
-5	1172.9
MB-CS-6	1168.3
-7	1418.2
-8	1418.6
-9	2846.0
-10	2705.8
MB-CS-11	2528.0
-12	2517.9
-13	2518.3
-14	2034.5
-15	2820.2
MB-CS-16	1165.1
-17	1166.2
-18	1163.3-1163.6
-19	1169.4-1169.5
-20	1173.7-1173.8
MB-CS-21	1404.6-1404.7
-22	1484.4-1584.5
-23	1609.5-1609.8
-24	1649.4-1649.6
-25	2035.6-2035.9
MB-CS-26	2036.5-2036.7
-27	2067.0
-28	2066.1
-29	2065.3
-30	2414.8

Sample	Depth (ft)
MC-CS-36	2758.2-2758.6
-37	2705.2-2705.6
-38	2821.1-2821.7
-39	2819.1-2818.6
-40	2827.3-2827.5
MC-CS-41	2615.9-2616.4
-42	2867.4-2867.6
JL-CS-1	1441.5
-2	1440.4-1440.6
-3	1328.6
-4	1441.7
-5	1247.1-1247.3
JL-CS-6	1441.0-1441.3
-7	1536.5
-8	1535.6-1535.8
-9	1466.8-1467.1
-10	1325.2-1325.4
JL-CS-11	1466.4-1466.6
-12	1244.8
-13	1467.5
-14	1468.1
-15	1244.2-1244.5
JL-CS-16	1244.5-1244.8
-17	1328.7-1329.8
-18	1537.8-1537.9
-19	1536.5-1536.6
-20	1245.0-1245.3

TABLE 7.5, continued

Core depths of samples selected for mineralogic-geochemical analysis.

Sample	Depth (ft)
MB-CS-31	2512.5
-32	2541.2-2541.9
-33	2608.9-2609.5
-34	2616.4-2616.8
-35	2617.2-2617.7

Sample	Depth (ft)
JL-CS-21	1246.7-1247.1
-22	1467.7-1468.1
-23	1327.0-1327.2
-24	1242.5-1242.8
-25	1328.2-1328.4
JL-CS-26	1327.7-1327.8
-27	1343.6-1343.7
-28	1242.9-1243.1

TABLE 7.6

Quantities of water-leach and EDTA-leach residues in samples from the ERDA-9 core. Sulfate lithologies (anhydrites and polyhalites) and salztons were not subjected to water leach.

Hole Depth (ft)	Sample Number	Bulk wt. (g)	LEACH RESIDUES (Percent of bulk) WATER	EDTA	EDTA Residue wt. (g)	Lithology
1163.5	MB-CS-18	1820	0.005	neg	neg+	rock salt
1165.1	MB-CS-16	40	>90	0.11	.043	anhydrite
1166.2	MB-CS-17	1229	>90	0.20	2.33	anhydrite
1167.5	MB-CS-1	38	>90	0.074	0.027	anhydrite
1168.3	MB-CS-6	358	>75	0.23	0.81	anhydrite
1169.4	MB-CS-19	209	0.36	0.005	0.011+√	rock salt
1172.9	MB-CS-5	40	>90	0.13	0.050	polyhalite
1173.7	MB-CS-20	259	0.012	neg	neg+	rock salt
1242.5	JL-CS-24	655	1.89	*	*	rock salt
1242.9	JL-CS-28	200	>75	0.76	1.52	polyhalite
1243.6	JL-CS-27	200	>75	0.60	1.21	polyhalite
1244.4	JL-CS-15	537	0.013	0.003	0.018	rock salt
1244.6	JL-CS-16	400	>75	1.13	4.51	polyhalite
1244.8	JL-CS-12	#	>90	>90	8.40	salzton
1245.1	JL-CS-20	400	6.18	1.15	4.60	rock salt
1246.8	JL-CS-21	747	0.21	*	*	rock salt
1247.2	JL-CS-5	#	>90	>90	2.70	salzton
1325.3	JL-CS-10	641	29.8	0.26	1.68	rock salt
1327.0	JL-CS-23	350	>75	0.25	0.89	polyhalite
1327.8	JL-CS-26	200	>75	0.30	0.61	polyhalite
1328.3	JL-CS-25	200	>75	1.13	2.26	polyhalite
1328.6	JL-CS-3	#	>90	>90	1.46	salzton
1328.7	JL-CS-17	1765	0.18	0.12	2.09	rock salt

TABLE 7.6, continued

Hole Depth (ft)	Sample Number	Bulk wt. (g)	LEACH RESIDUES (Percent of bulk) WATER	EDTA	EDTA Residue wt. (g)	Lithology
1404.6	MB-CS-21	244	2.5	1.0	2.43	rock salt
1418.2	MB-CS-7	40	>90	20.80	8.32	anhydrite
1418.6	MB-CS-8	1120	>90	0.62	6.94	polyhalite
1440.5	JL-CS-2	200	>75	0.83	1.66	polyhalite
1441.2	JL-CS-6	600	>75	0.13	0.80	polyhalite
1441.7	JL-CS-4	#	>90	>90	2.92	salzton
1466.5	JL-CS-11	400	>75	0.42	1.67	polyhalite
1466.9	JL-CS-9	200	>75	3.99	7.97	polyhalite
1467.9	JL-CS-22	860	4.17	1.22	10.5	rock salt.
1468.1	JL-CS014	#	>90	>90	3.30	saltzon
1535.7	JL-CS-8	400	>75	0.44	1.76	polyhalite
1536.5	JL-CS-7	320	>75	2.63	8.41	anhydrite
1536.6	JL-CS-19	360	>75	0.37	1.33	polyhalite
1537.8	JL-CS-18	400	>75	0.55	2.19	polyhalite
1584.4	MB-CS-22	248	0.53	0.42	1.20+√	rock salt
1609.6	MB-CS-23	473	0.037	0.017	0.081	rock salt
1649.5	MB-CS-24	176	1.6	1.1	1.90+√	rock salt
2034.5	MB-CS-14	104	>90	3.9	4.07	anhydrite
2035.7	MB-CS-25	891	0.23	0.009	0.078+√	rock salt
2036.6	MB-CS-26	810	0.23	0.025	0.20+√	rock salt
2073.3	MB-CS-4	145	>90	5.0	7.28	anhydrite
2065.3	MB-CS-29	1085	0.18	0.11	1.17+√	rock salt
2066.1	MB-CS-28	220	3.3	1.5	3.38	rock salt
2067.0	MB-CS-27	229	2.8	0.83	1.90	rock salt
2414.8	MB-CS-30	421	36.3	0.049	0.21	rock salt

TABLE 7.6, continued

Hole Depth (ft)	Sample Number	Bulk wt. (g)	LEACH RESIDUES (Percent of bulk) WATER	EDTA	EDTA Residue wt. (g)	Lithology
2512.5	MB-CS-31	1073	1.79	0.074	0.074	rock salt
2517.9	MB-CS-12	40	>90	0.024	0.010+	anhydrite
2518.3	MB-CS-13	586	>90	0.55	3.20	anhydrite
2528.0	MB-CS-11	40	>90	0.23	0.094	anhydrite
2541.5	MB-CS-32	891	0.70	0.21	1.83	rock salt
2609.2	MB-CS-33	901	0.043	0.015	0.14+✓	rock salt
2616.2	MB-CS-41	811	0.165	0.076	0.62+✓	rock salt
2616.6	MB-CS-34	660	0.071	0.004	0.027+✓	rock salt
2617.5	MB-CS-35	1015	1.17	0.18	1.83	rock salt
2705.4	MB-CS-37	638	13.3	0.65	4.14	rock salt
2705.8	MB-CS-10	450	>90	2.2	9.87	anhydrite
2758.4	MB-CS-36	421	6.6	0.77	3.25	rock salt
2819.3	MB-CS-39	982	2.2	0.27	2.65	rock salt
2820.2	MB-CS-15	520	>90	0.82	4.25	anhydrite
2820.3	MB-CS-2	640	>90	0.59	3.79	anhydrite
2821.4	MB-CS-38	916	1.25	0.039	0.36	rock salt
2828.7	MB-CS-40	920	1.22	0.13	1.17	rock salt
2846.0	MB-CS-9	200	>90	1.2	2.45	anhydrite
2848.4	MB-CS-3	656	>90	0.90	5.93	anhydrite
2867.5	MB-CS-42	240	>90	0.85	2.04	anhydrite

* Water-leach and EDTA-leach dissolutions of this sample not complete.
# ample is hand-picked fragment of saltzto
+ eported as containing "negligible insolu residue" Table 7.7.
✓ A subsequent second dissolution of a substantially greater quantity of

TABLE 7.7

Relative Abundances of minerals in EDTA-insoluble residues.

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	<2 μm fraction of residue il	ch	serp	talc	exp
MB-CS-18	1163.5	Negligible insoluble residue								
MB-CS-16	1165.1	XX	--	--	X	X	a	--	--	XX
MB-CS-17	1166.2	XX	x	--	XX	x	a	--	--	XX
MB-CS-1	1167.5	--	--	--	XX	X	--	--	--	XX
MB-CS-6	1168.3	XX	x	--	XX	x	a	--	--	XX
MB-CS-19	1169.4	Negligible insoluble residue								
MB-CS-5	1172.9	XX	--	--	x	x	--	--	--	XX
MB-CS-20	1173.7	Negligible insoluble residue								
JL-CS-12	1244.8	XX	x	--	XX	X	X	--	--	X
JL-CS-5	1247.2	XX	x	--	XX	XX	X	--	--	X
JL-CS-10	1325.3	a	--	--	XX	--	--	--	--	XX
JL-CS-3	1328.6	XX	X	--	XX	X	X	--	--	X

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	<2 μm fraction of residue il	ch	serp	talc	exp
MB-CS-21	1404.6	XX	a	--	XX	x	x	--	X	XX
MB-CS-7	1418.2	--	x	--	XX	XX	X	--	--	X
MB-CS-8	1418.6	--	a	x	XX	x	x	--	--	XX
JL-CS-2	1440.5	X	XX	a	XX	a	a	--	--	XX
JL-CS-6	1441.2	X	XX	X	XX	XX	X	--	--	X
JL-CS-4	1441.7	--	X	--	XX	XX	X	--	--	X
JL-CS-11	1466.5	--	x	X	XX	XX	X	--	--	X
JL-CS-9	1466.9	XX	x	x	X	XX	X	--	--	XX
JL-CS-14	1468.1	X	X	--	XX	XX	X	--	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	< 2 μm fraction of residue il	ch	serp	talc	exp
JL-CS-8	1535.7	--	X	x	XX	XX	x	--	--	XX
JL-CS-7	1536.5	a	--	--	XX	--	--	--	--	XX
JL-CS-18	1537.8	X	--	x	XX	XX	x	--	--	X
MB-CS-22	1584.4	Negligible insoluble residue								
MB-CS-23	1609.6	XX	X	x	XX	XX	X	--	--	XX
MB-CS-24	1649.5	Negligible insoluble residue								
MB-CS-14	2034.5	XX	--	--	x	x	x	--	--	XX
MB-CS-25	2035.7	Negligible insoluble residue								
MB-CS-26	2036.6	Negligible insoluble residue								
MB-CS-4	2037.3	XX	--	--	X	x	x	--	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	< 2 μm fraction of residue il	ch	serp	talc	exp
MB-CS-29	2065.3	Negligible insoluble residue								
MB-CS-28	2066.1	XX	a	--	XX	a	a	--	--	XX
MB-CS-27	2067.0	XX	X	x	XX	x	x	--	--	XX
MB-CS-30	2414.8	XX	X	--	X	a	x	--	--	XX
MB-CS-31	2512.5	X	--	a	XX	x	x	--	--	XX
MB-CS-13	2518.3	X	x	--	XX	a	a	--	--	XX
MB-CS-11	2528.0	--	--	--	XX	--	--	--	--	XX
MB-CS-32	2541.5	X	a	--	XX	X	X	--	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	< 2 μm fraction of residue il	ch	serp	talc	exp
MB-CS-33	2609.2	Negligible insoluble residue								
MB-CS-41	2616.2	Negligible insoluble residue								
MB-CS-34	2616.6	Negligible insoluble residue								
MB-CS-35	2617.5	XX	X	a	XX	XX	X	--	--	XX
MB-CS-37	2705.4	XX	X	a	X	XX	X	--	--	XX
MB-CS-10	2705.8	XX	X	a	X	X	x	--	--	XX
MB-CS-36	2758.4	XX	X	a	X	XX	X	--	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue				< 2 μm fraction of residue				
		qtz	feld	hem	clay	il	ch	serp	talc	exp
MB-CS-39	2819.3	XX	X	--	X	XX	x	--	--	XX
MB-CS-15	2820.2	XX	--	--	XX	--	a	--	XX	X
MB-CS-2	2820.3	a	X	--	XX	XX	--	--	--	XX
MB-CS-38	2821.4	--	--	--	XX	--	--	XX	--	XX
MB-CS-40	2827.4	--	--	--	XX	--	--	XX	--	XX
MB-CS-9	2846.0	a	--	a	XX	--	--	XX	--	XX
MB-CS-3	2848.4	--	--	--	XX	--	--	X	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	< 2 μm fraction of residue il	ch	serp	talc	exp
MB-CS-42	2867.5	--	--	--	XX	--	x	X	--	X

Minerals: qtz = quartz; feld = feldspar; hem = hematite; il = illite; ch = chlorite; serp = serpentine; exp = expandable (smectite-bearing).

Relative abundances: XX = dominant constituent; X = major constituent; x = minor constituent; a = accessory constituent. All abundances based on relative intensities of major diffraction maxima.

TABLE 7.8

Low-angle diffraction maxima (Å) of expandable clays in the < 2 μm fraction of the EDTA-insoluble residues.

Sample	Depth (ft)	Air-dried	Glycol-saturated	375°C (> 1hr)	500°C (> 1hr)
MB-CS-16	1165.1	14.5	n.d.	n.d.	n.d.
MB-CS-17	1166.2	13.8, 30.5	15.5, 32.7	13.8, (29.4)	13.6, (25.2)
MB-CS-1	1167.5	14.5	n.d.	n.d.	n.d.
MB-CS-6	1168.3	14.5, (25.2)	15.5, (35.3)	13.6, 31.6	13.2, 11.8, (27.6)
MB-CS-5	1172.9	14.3	n.d.	n.d.	n.d.
JL-CS-16	1244.6	13.8, 29.4	15.5, 11.2, 31.6	n.d.	n.d.
JL-CS-12	1244.8	13.6, 29.4	15.5, 31.5	13.6	13.2
JL-CS-20	1245.1	13.8, (30.5)	15.5, 34.0	n.d.	n.d.
JL-CS-5	1247.2	14.5, 30.5	15.5, 11.2, 31.6	14.3	13.6
JL-CS-10	1325.3	10.2	10.4, (12.1)	9.8	9.8, 11.0-11.9
JL-CS-3	1328.6	14.0, 30.5	15.5, 11.2, 31.6	14.5, (31.6)	12.6-14.7, (22.21)
MB-CS-21	1404.6	13.8, 31.6	15.8, 34.0	13.8, (32.7)	13.4, (29.4)
MB-CS-7	1418.2	13.8, (30.5)	n.d.	n.d.	n.d.
MB-CS-8	1418.6	13.4	15.5, (34.0)	13.6, (27.6)	11.6, (27.6)

TABLE 7.8, continued

Low-angle diffraction maxima (Å) of expandable clays in the < 2 μm fraction of the EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	Air-dried	Glycol-saturated	375°C (> 1hr)	500°C (> 1hr)
JL-CS-2	1440.5	10.3	10.2, 11.8	9.8	n.d.
JL-CS-6	1441.2	10.7, 13.6, (29.4)	11.3, 15.5, (31.6)	10.2, 13.0-14.3	10.0
JL-CS-4	1441.7	13.8, 31.6	15.5, 31.6	13.8, (29.4)	13.2
JL-CS-11	1466.5	13.8, 11.2, (30.5)	15.2, (32.7)	13.6, (26.0)	n.d.
JL-CS-9	1466.9	14.7	16.1	13.8	13.8
JL-CS-22	1467.9	14.1, 31.6	15.5, 34.0	n.d.	n.d.
JL-CS-14	1468.1	13.6, 30.5	15.5, 32.7	13.6	13.2
JL-CS-8	1535.7	10.3, 13.6	9.4, 11.5, 16.1	9.8, 13.6	9.7
JL-CS-7	1536.5	10.3	9.3, 11.3	9.9	9.8
JL-CS-18	1537.8	14.3, 32.7	15.8, 34.0	n.d.	n.d.
MB-CS-23	1609.6	12.3	n.d.	n.d.	n.d.
MB-CS-14	2034.5	13.8, 30.5	15.2, 31.6	14.0, 11.9, (31.6)	11.9, 13.2, 29.4
MB-CS-4	2037.3	13.5	15.5, 31.6	13.2, (28.5)	13.0

TABLE 7.8, continued

Low-angle diffraction maxima (Å) of expandable clays in the < 2 μ m fraction of the EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	Air-dried	Glycol-saturated	375°C (> 1hr)	500°C (> 1hr)
MB-CS-28	2066.1	14.5, 30.5	15.5, 31.6	14.0, (29.4)	13.6, (30.5, 22.1)
MB-CS-27	2067.0	14.7, 29.4	16.7, 32.7	14.0, (29.4)	12.6, (26.0)
MB-CS-30	2414.8	13.8, 11.8, (29.4)	15.8, 12.8, (31.6)	13.8, 11.6, (24.5)	11.6, (26.0)
MB-CS-31	2512.5	12.6	n.d.	n.d.	n.d.
MB-CS-12	2517.9	12.8, 31.6	15.5, 31.6	n.d.	n.d.
MB-CS-13	2518.3	12.6, 26.0	17.0, 25.2	13.2, (26.8)	12.3, 10.3, 26.0
MB-CS-11	2528.0	13.2	n.d.	n.d.	n.d.
MB-CS-32	2541.5	13.8, 29.4	15.5, 31.5	13.4, (26.8)	14.2, (31.6)
MB-CS-35	2617.5	13.8, (29.4)	16.7, 32.7	13.8, (26.8)	12.6, 27.6
MB-CS-37	2705.4	14.5, 30.5	16.4, 34.0	13.8, (29.4)	12.5
MB-CS-10	2705.8	13.4	16.7, (35.3)	14.3, (30.5)	14.3, 11.8, (27.6)
MB-CS-36	2758.4	14.0, 29.4	16.4, 32.7	13.8, (29.4)	12.5, (29.4)

TABLE 7.8, continued

Low-angle diffraction maxima (Å) of expandable clays in the < 2 μm fraction of the EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	Air-dried	Glycol-saturated	375°C (> 1hr)	500°C (> 1hr)
MB-CS-39	2819.3	14.5, 29.4	16.1, 31.6	14.5	13.6, (22.0)
MB-CS-15	2820.2	11.6, (26.8)	14.7, (27.6)	11.6, (24.5)	11.6, (26.8)
MB-CS-2	2820.3	14.5	----	10.4	9.8-17.7
MB-CS-38	2821.4	14.7	----	13.8	13.8
MB-CS-40	2827.4	14.7, 11.3	17.0	14.7	n.d.
MB-CS-9	2846.0	12.3, (24.5)	17.0, (28.5)	10.0 - 13.6, (29.4)	13.4
MB-CS-3	2848.4	12.3, (24.5)	17.3, (27.6)	12.63, (27.6)	11.6, (24.5)
MB-CS-42	2867.5	11.8	17.7	14.7	----

n.d. - data not yet determined

Values in parentheses, e.g. (30.5) represent diffraction maximum present only as shoulder.

TABLE 7.9

Mineralogy of Duval Mine Samples
4th Ore Zone

A. Evaporites

Mine Wall Samples	Halite	Sylvite	Polyhalite	Langbeinite
DV-1A	t	-	VA	-
DV-1B	VA	VA	-	-
DV-1C	VA	-	VA	t
DV-1D	VA	VA	t	-
DV-2A	A	VA	-	t
DV-2B	VA	-	A	-
DV-4A	A	-	VA	t
DV-4B	VA	-	-	-
DV-4C	VA	-	-	t
DV-4D	VA	-	-	t
DV-4E	t	t	-	VA
DV-5A	VA	-	-	-
DV-5B	VA	A	t	-

B. 2 Micron Fractions (Silicates)

Mine Wall Samples	Chlorite	Saponite	Chlorite-Saponite	Illite	Talc	Serpentine	Insoluble Residue (Wt. %)
DV-4B	t	-	VA	VA	t	A	15.7
DV-4C	-	-	VA	VA	t	A	12.3
DV-4D	t	t	VA	A	-	t	32.3
DV-5A	t	t	VA	A	t	A	10.3

VA : very abundant
A : abundant
t : tract
- : not detected

TABLE 7.10

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	MB-CS-17	JL-CS-12	JL-CS-5	JL-CS-10	JL-CS-3	JL-CS-2	JL-CS-6	JL-CS-4
Depth (ft)	1166.2	1244.8	1247.1	1325.3	1328.6	1440.5	1441.2	1441.7
Lithology+	Anhydr.	Clay	Clay	Polyhal.	Clay	Polyhal.	Polyhal.	Clay
Weight Percent								
SiO_2	59.	50.	50.	59.	52.	56.	45.	38.
TiO_2	.8	.9	1.2	.2	1.4	.4	.7	1.4
Al_2O_3	12.	13.	15.	12.	15.	6.2	2.5	18.
FeO@	1.2	2.4	3.8	1.3	3.2	5.3	14.	4.5
MgO	20.	25.	20.	32.	18.	20.	15.	19.
CaO	.01	.01	.04	.002	.008	.02	.03	.06
Na_2O	1.2	1.2	1.0	1.0	.5	2.4	1.4	1.6
K_2O	1.8	2.3	3.0	.3	3.3	2.9	2.0	4.6

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	MB-CS-17	JL-CS-12	JL-CS-5	JL-CS-10	JL-CS-3	JL-CS-2	JL-CS-6	JL-CS-4
Depth (ft)	1166.2	1244.8	1247.1	1325.3	1328.6	1440.5	1441.2	1441.7
Lithology+	Anhydr.	Clay	Clay	Polyhal.	Clay	Polyhal.	Polyhal.	Clay
Atom Proportions (al = 1.0)								
Si	4.2	3.2	2.9	4.3	3.0	7.6	15.	1.8
Ti	.04	.04	.05	.01	.06	.04	.2	.05
Al	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Fe	.07	.13	.18	.08	.15	.61	4.0	.17
Mg	2.1	2.3	1.7	3.5	1.6	4.0	7.4	1.3
Na	.16	.15	.11	.14	.06	.64	92	.14
K	.16	.19	.22	.03	.24	.51	.87	.27

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	JL-CS-11	JL-CS-9	JL-CS-14	JL-CS-18	MB-CS-4	MB-CS-27	MB-CS-31	MB-CS-13
Depth (ft)	1466.5	1467.0	1468.1	1537.8	2037.3	2067.0	2512.5	2518.3
Lithology+	Polyhal.	Polyhal.	Clay	Polyhal.	Anhydr.	Halite	Halite	Anhydr.
Weight Percent								
SiO_2	34.	42.	41.	43.	54.	65.	41.	54.
TiO_2	.6	.6	1.2	.6	.8	1.0	.9	.4
Al_2O_3	10.	9.0	14.	8.8	12.	14.	14.	7.0
FeO@	23.	3.7	3.3	8.2	3.7	4.7	N.D.	2.1
MgO	19.	29.	22.	21.	21.	9.3	18.	22.
CaO	.005	.005	.001	.03	.002	.02	.02	.04
Na_2O	1.3	.4	1.6	1.2	1.0	3.9	2.2	2.7
K_2O	2.9	2.6	4.1	2.0	1.5	4.1	2.6	2.5

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	JL-CS-11	JL-CS-9	JL-CS-14	JL-CS-18	MB-CS-4	MB-CS-27	MB-CS-31	MB-CS-13
Depth (ft)	1466.5	1467.0	1468.1	1537.8	2037.3	2067.0	2512.5	2518.3
Lithology+	Polyhal.	Polyhal.	Clay	Polyhal.	Anhydr.	Halite	Halite	Anhydr.
Atom proportions (Al = 1.0)								
Si	2.9	3.9	2.5	4.2	4.0	3.9	2.5	6.2
Ti	.04	.04	.05	.04	.04	.04	.04	.03
Al	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Fe	1.7	.29	.17	.66	.23	.23	--	.20
Mg	2.4	4.0	2.0	3.1	2.3	.83	1.7	3.8
Na	.21	.07	.19	.22	.14	.45	.26	.60
K	.31	.31	.32	.25	.14	.31	.21	.37

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	MB-CS-32	MB-CS-10	MB-CS-36	MB-CS-39	MB-CS-15	MB-CS-40	MB-CS-9	MB-CS-3
Depth (ft)	2541.5	2705.8	2758.4	2819.3	2820.2	2827.4	2846.0	2848.4
Lithology+	Halite	Halite	Halite	Halite	Anhydr.	Halite	Anhydr.	Anhydr.
Weight Percent								
SiO_2	37.	61.	70.	67.	52.	33.	42.	44.
TiO_2	.8	.8	.8	.8	.1	.3	.2	.2
Al_2O_3	13.	12.	12.	12.	3.4	5.0	3.1	3.6
$FeO^{@}$	3.4	4.4	3.4	3.3	.7	1.4	2.6	1.5
MgO	30.	17.	11.	13.	33.	29.	35.	37.
CaO	.002	.01	.1	.06	.007	1.0	.003	.003
Na_2O	1.0	2.9	2.3	2.1	1.6	.9	2.6	1.9
K_2O	1.7	1.8	1.4	1.8	.6	.9	3.3	.7

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	MB-CS-32	MB-CS-10	MB-CS-36	MB-CS-39	MB-CS-15	MB-CS-40	MB-CS-9	MB-CS-3
Depth (ft)	2541.5	2705.8	2758.4	2819.3	2820.2	2827.4	2846.0	2848.4
Lithology+	Halite	Halite	Halite	Halite	Anhydr.	Halite	Anhydr.	Anhydr.
Atom proportions (Al = 1.0)								
Si	2.5	4.5	5.1	4.7	13.	5.6	11.	10.
Ti	.04	.04	.04	.04	.02	.04	.04	.04
Al	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Fe	.19	.27	.21	.19	.15	.20	.59	.30
Mg	2.8	1.8	1.2	1.3	12.	7.3	14.	13.
Na	.13	.41	.33	.29	.77	.30	1.4	.87
K	.15	.17	.13	.16	.19	.19	1.1	.21

* Calculated from 1:1 linear regression; matrix effects and other than unit regression slope not yet included.

\+ Anhydr. = anhydrite; polyhal. = polyhalite.

@ Total iron as FeO.

...BLE 7.11

Mineralogy of Cores from ERDA No. 9

Core Footage	Gross Lithology (listed in decreasing order of abundance, lower case indicates (trace amount)	Bulk Mineralogy by X-ray Diffraction
1168.1	Anhydrite Halite Magnesite	Anhydrite Magnesite
1168.55	Anhydrite Halite Polyhalite	Anhydrite Halite Polyhalite
1173.5	Halite "Brown Material"	Halite Polyhalite trace 12A° (expandable) clay
1173.5	silty claystone or anhydrite	Anhydrite Polyhalite
1584.4	Halite "brown material" anhydrite	Halite polyhalite
1649.7	Halite polyhalite anhydrite	Halite polyhalite
2066.8	Halite '"brown material"	Halite Anhydrite quartz magnesite trace 10A° clay (illite) trace 14A° clay (chlorite)

TABLE 7.11, continued

Mineralogy of Cores from ERDA No. 9

Core Footage	Gross Lithology (listed in decreasing order of abundance, lower case indicates (trace amount)	Bulk Mineralogy by X-ray Diffraction
2067.4	see 2066.8	Halite polyhalite quartz? trace 12A° (expandable) clay
2302	Polyhalite "White Material"	Anhydrite Polyhalite
2414.7	Polyhalite Halite Anhydrite	Halite Polyhalite
2415.0	see 2414.7	Polyhalite Anhydrite
2415.4	see 2414.7	Anhydrite
2529.5	Anhydrite magnesite?	Anhydrite Halite Magnesite
2538.5	Anhydrite Halite	Anhydrite Halite
2619.5	Halite anhydrite or magnesite	Halite Anhydrite
2820 B	Anhydrite Halite magnesite	Anhydrite Halite

BLE 7.12

Weight Losses Observed Upon Heating of ERDA No. 9 Cores

Specimen No. (depth)	Total Weight-Loss (%)	Mass-Loss (%) At Mean Temperature Ranges		
		100°C	300°C	450°
2034.7	1.60	0.70	0.36	.057
2035.7	0.20	----	----	----
2065.0	0.35	----	----	----
2067.5	0.52	----	----	----
2302.6	5.40	----	5.10	0.17
2413.7	1.38	----	1.00	----
2414.2	3.13	----	2.90	----
2415.6	0.10	----	----	----
2512.0	0.14	----	----	----
2516.3	2.15	----	----	1.55
2518.8	0.32	----	----	----
2528.7	2.12	----	----	1.52
2529.0	3.12	----	----	2.94
2538.5	1.55	----	----	1.20
2542.0	6.39	----	6.19	0.20
2593.2	1.47	----	----	1.20
2594.5	0.36	----	----	----
2597.0	0.37	----	----	----
2608.9	0.17	----	----	----
2614.4	0.13	----	----	----
2619.6	0.22	----	----	----
2658.5	0.48	----	0.10	0.17
2663.3	0.50	----	----	0.29
2696.4	1.12	----	----	0.80
2706.5	0.37	----	----	----
2711.9	0.47	----	----	0.21
2759.0	0.28	----	----	----
2786.5	3.64	2.27	----	0.90
2820.7A	0.36	----	----	0.17
2820.6B	0.35	----	----	0.12
2821.0	0.40	----	0.19	----
2826.5	0.36	----	0.27	----
2845.3	1.42	----	----	1.21
2848.8	0.86	----	----	0.53

TABLE 7.13

Data on the volume percent of fluid now present in the salt cores from ERDA No. 9.

Depth interval (feet)	Type Sampled	Volume sampled (mm^3)	Approx. grain size (mm)	Fraction of total slide	Fluid % by vol.	Total % by vol., whole slide
1799.0-1799.5	B	500	5 to 10	1/4	1.66	
	A	500	1 to 5	3/4	0.17	0.54
1902.0-1902.3	B	500	2 to 8	1/5	0.866	
	A	500	0.5 to 3	4/5	0.11	0.26
2065.0-2065.4	B	500	20 to 50	5/6	3.4	
	A	500	20 to 50	1/6	0.20	2.86
2095.1-2095.5	B	500	3 to 15	1/10	2.58	
	A	500	3 to 15	9.10	0.039	0.29
2274.4-2272.7	(B	470	10 to 15	1/2	2.29	
	(A	470	5	1/2	0.17	1.23
" "	(B	510	5 to 7	2/5	0.86	
	(A	510	1 to 3	3/5	0.02	0.36
" "	(B	520	5 to 7	1/3	0.55	
	(A	520	1 to 3	2/3	0.02	0.20
2391.0-2391.3	B	460	10 to 15	1/10	1.17	
	A	460	3 to 10	9/10	0.12	0.22
2611.5-2611.8	B	530	5 to 25	1/5	0.79	
	A	530	2 to 5	4/5	0.015	0.17
2658.7-2659.0	B	360	5 to 10	1/4	1.18	
	A	360	2 to 8	3/4	0.039	0.32

TABLE 7.13, continued

Data on the volume percent of fluid now present in the salt cores from ERDA No. 9.

Depth interval (feet)	Type Sampled	Volume sampled (mm^3)	Approx. grain size (mm)	Fraction of total slide	Fluid % by vol.	Total % by vol., whole slide
2760.0-2760.2	B	460	5 to 8	1/5	0.96	0.40
	A	460	3 to 5	4/5	0.27	
2820.8-2821.2	B	490	3 to 8	1/4	0.87	0.45
	A	490	2 to 5	3/4	0.31	

TABLE 7.14

Homogenization temperatures (°C) of two-phase liquid + gas inclusions from ERDA No. 9 core (numbers of inclusions run given in parentheses)

Depth interval	Homogenization temperatures
1799.0-1799.5	20.5(1), 21.0(1), 25(3)
1902.0-1902.3	25.1(1)
2065.0-2065.4	(none)
2095.1-2095.5	25.6(2), 34.5(1), 44.0(1), 45.5(2)
2272.4-2272.7	41.25(1), 42.5(1), 42.6(3)
2391.0-2391.3	23(4), 39(1)
2611.5-2611.8	(none)
2658.7-2659.0	43.0(1), 43.25(1), 43.5(1), 44(2), 45.0(1)
2760.0-2760.2	20.4(1), 21.6(1), 21.8(2)
2820.8-2821.2	22.5(1), 23.0(1), 25.5(1)

TABLE 7.15

Summary of freezing data (°C), mainly on type B inclusion in samples from ERDA No. 9 core

Depth	First melting temp.	Freezing temp.	Notes
1799	<-31.9	> +10	~20% liquid at -31.9
1902	<-32	> +10	
2095	<-28.4	+15	~20-25% xls at 0°C
"	-32.2	"	
2272	<-32.8	+11.8	~50% xls at 0°C
2391	<-26.1	> +12.8	
2760	<-32	> +12.7	

TABLE 7.16

Test data and weight loss (in %) from decrepitation tests. Roman numerals indicate amount of sample breakup after run: I - unbroken; II - broken into 2 or 3 pieces; III - broken into more than 3 pieces.

	Temperature, °C		
Core interval (ft)	150	200	250
2058.8 - 2059.0	0.16 II	0.23 II	0.76 III
2070.4 - 2070.6	0.16 II	0.12 I	0.35 III
2606.5 - 2606.9	0.02 I	0.24 II	0.95 III
2617.2 - 2617.7	0.06 I	0.30 I	0.62 II
2626.7 - 2627.0	0.19 I	0.28 I	1.04 III
2659.0 - 2659.2	0.14 I	0.13 I	0.59 III
2665.0 - 2665.1	0.19 I	0.18 I	0.75 III
2692.4 - 2692.6	0.06 I	0.26 I	0.83 III
2699.8 - 2700.0	0.19 I	0.24 II	0.65 III
Average	0.13	0.22	0.73
Heating schedule (hours)			
Room T to run T	7	9.5	8
Hold at run T	79	95	79
Run T to room T	~9	~9	~10

TABLE 7.17

Temperature of homogenization and volume % vapor of two-phase inclusions in salt of samples after decrepitation tests.

Decrepitation run temp. (°C)	Homogenization temp. (°C) Minimum	Homogenization temp. (°C) Maximum	Number of inclusions runs	Volume % vapor phase; avg. for ~25 inclusions
150	90	120	16	0.8
200	110	180	21	1.8
250	180	273	28	5.0

Note: Birefringent crystals, present in some of these inclusions, do not disappear during homogenization runs.

TABLE 7.18

Temperature of homogenization of two-phase inclusions in salt from near dike in Kerr-McGee mine, Lea County, New Mexico.

Sample no.	Distance from dike (m)	Temp. of homogenization (°C)		Number of inclusions run
		Minimum	Maximum	
MB-77-8	0.01 - 0.02	71	116	7
MB-76-3	0.2	60	110	6
MB-76-4	2.5	85	88*	9

* Two birefringent crystals remained unchanged, and a cubic crystal (KCl ?) dissolved at 82°C. (See Plate 7-42 for a similar inclusion.)

TABLE 7.19

INVENTORY OF FLUIDS SAMPLED FOR GEOCHEMICAL STUDIES
OF DELAWARE BASIN GROUNDWATERS

Sample No.	Sample Name	Formation Sampled	Location	Solutes	Stable Isotopes	Solute *Analyst
1	Carlsbad City #7	Capitan	T22S-R26E-S1	X	X	M
2	Duval Mine/Collector Ring	Rustler	T22S-R30E-S33	X	X	M
3	Duval Mine/Seep-BT26	Salado	T22S-R30E-S33	X	X	S
4	Duval Mine/Seep-BT48	Salado	T22S-R30E-S33	X	X	M
5	Duval Mine/Seep-BT58	Salado	T22S-R30E-S33	X		M
6	James Ranch	Rustler	T23S-R31E-S5	X	X	M
7	Fairview	Rustler	T23S-R32E-S36	X	X	M
8	Todd State 36-1	Morrow	T23S-R31E-S36	X	X	M
9	Todd Federal 26-4	Bell Canyon	T23S-R31E-S26	X	X	M
10	Todd Federal 26-1	Morrow	T23S-R31E-S26	X	X	M
11	Shell No. 28	Capitan	PSL Blk 74-S34(Texas)	X	X	M
12	Middleton	Capitan	T19S-R32E-S21	X	X	M
13	Hackberry	Capitan	T19S-R31E-S31	X	X	M
14	ERDA #6	Castile	T21S-R31E-S35	X	X	S
15	Shell Bootleg	Castile	T22S-R32E-S36	X		Sh
16	Duval Mine/Vent Hole	Salado	T22S-R30E-S33	X		M
17	UNM Pokorny	Castile	PSL Blk 61-S3(Texas)	X	X	M
18	Smith Livingston Ridge	Santa Rosa	T22S-R31E-S15		X	
19	Indian	Rustler	T23S-R30E-S21		X	
20	Mobley	Rustler	T23S-R30E-S19		X	
21	Mobley #3	Rustler	T23S-R30E-S2		X	
22	H1-Magenta	Rustler	R22S-R31E-S29	X	X	U
23	H1-Culebra	Rustler	T22S-R31E-S29	X	X	U
24	H3-Magenta	Rustler	T22S-R31E-S29	X	X	U
25	H3-Culebra	Rustler	T22S-R31E-S29	X	X	U
26	Green Lake	Capitan	Carlsbad Caverns		X	
27	Mirror Lake	Capitan	Carlsbad Caverns		X	
28	Longfellow's Bathtub	Capitan	Carbsbad Caverns		X	
29	Celery Stalk Pool	Capitan	Carlsbad Caverns		X	

* Analysts:
M - Martin Water Laboratories
S - Sandia
Sh - Shell
U - U.S. Geological Survey

TABLE 7.20

GEOCHEMICAL ANALYSES OF DELAWARE BASIN GROUNDWATERS
(Solutes in mg/l)

No.	pH	$\delta^{18}O$ ‰	δD ‰	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	Br^{-}	SO_4^{+}	HCO_3^{-}	TDS	Other Information
T 1	7.2	- 7.9	-54	74	29	8	1	10	0	72	285	474	NO_3:5
2	7.4	- 6.4	-48	1100	280	3600	405	6400	0	2500	122	14380	Sr:30
3	5.5	+ 3.0	-10	640	55400	27500	3000	236500	305	3650	1090	355085	BO_3:660
4	5.4	+ 2.6	-12	500	62600	44400	30250	251500	530	3300	1170	395000	BO_3:840
5	5.5			520	62000	46300	30250	250000	582	3100	1170	395000	BO_3:990
6	7.6	- 5.0	-40	590	175	68	5	400	0	1570	190	3240	NO_3:225
7	7.6	- 7.1	-53	590	200	120	3	142	0	2140	130	3350	
8	6.4	+ 2.7	-15	1600	240	11300	500	20600	23	300	380	35600	Sr:240
9	7.1	+ 2.2	-13	27600	6075	76700	1700	18500	410	210	215	295400	Sr:1750
10	6.6	+ 9.2	-18	4880	920	28700	200	55400	90	30	300	92400	Sr:1750
11	7.1	- 7.7	-56	940	280	2280	57	3900	0	2400	550	11300	
12	7.4	- 7.5	-55	1100	570	10600	330	17050		3720	300	33800	Sr:64
13	6.0	- 6.5	-46	2200	1680	68700	2950	110800		5150	132	192000	Sr:140,Fe:312
14	7.3	+10.3	0	130	350	112000	5100	186100	240	16000	1310	321000	BO_3:650,Li:160
15	7.7			550	1860	124500		185000		16800	1480	330700	
16	5.8			1260	38500	49000	52500	241500	385	3600	700	388650	BO_3:1160
17	1.6	- 6.0	-50	190	100	200	18	2700	0	570	0	3800	
18		- 7.2	-52										
19		- 6.3	-46										
20		- 6.9	-44										
21		- 5.9	-44										
22	7.4	- 6.8	-48	890	270	5700	70	8000		3900	92	18922	
23	7.6	- 7.0	-50	780	280	9400	190	12000		7400	105	30155	
24	7.4	- 7.3	-53	760	190	4200	100	5800		2600	1150	14800	
25	7.4	- 7.0	-53	1500	720	19000	450	33000		5200	88	60000	
26		- 3.6	-24										
27		- 4.3	-28										
28		- 4.2	-29										
29		- 3.0	-20										

TABLE 7.21

DUVAL MINE VENT HOLE WATER #16

One liter of solution might be expressed as the following amounts of common evaporite minerals:

0.006 moles	(1 gm)	$CaMg(CO_3)_2$	Dolomite
0.026 moles	(4 gm)	$CaSO_4$	Anhydrite
0.012 moles	(3 gm)	$KMgClSO_4 \cdot 11/4H_2O$	Kainite
1.343 moles	(370 gm)	$KMgCl_3 \cdot 6H_2O$	Carnallite
0.224 moles	(46 gm)	$MgCl_2 \cdot 6H_2O$	Bischofite
0.005 moles	(2 gm)	$Na_2B_4O_7 \cdot 10H_2O$	Borax
2.121 moles	(121 gm)	$NaCl$	Halite

TABLE 7.22

TODD FEDERAL 26-4 WATER #9

One liter of solution might be expressed as the following amounts of common evaporite minerals:

0.10 moles	(52 gm)	$CaMg_2Cl_6 \cdot 12H_2O$	Tachyhydrite
0.04 moles	(4 gm)	$KMgCl_3 \cdot 6H_2O$	Carnallite
0.59 moles	(129 gm)	$CaCl_2 \cdot 6H_2O$	Antarcticite
3.34 moles	(195 gm)	NaCl	Halite

TABLE 7.23

ERDA 6 WATER #14

One liter of solution might be expressed as the following amounts of common evaporite minerals:

0.003 moles	(1 gm)	$CaMg(CO_3)_2$	Dolomite
0.009 moles	(1 gm)	$MgCO_3$	Magnesite
0.011 moles	(3 gm)	$KMgClSO_4 \cdot 11/4H_2O$	Kainite
0.130 moles	(9 gm)	KCl	Sylvite
0.155 moles	(22 gm)	Na_2SO_4	Thenardite
0.048 moles	(14 gm)	LiCl	?
4.521 moles	(265 gm)	NaCl	Halite

TABLE 7.24

Rb-Sr Data for Evaporites from the Salado Formation

A. Whole Rocks

Core hole Interval	$(^{87}Sr/^{86}Sr)_N$	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$
AEC-8				
1622.4-1622.9	0.7056	5.0	112.4	0.13
1636.6-1637.1 (sylvite rich portion)	0.7816	120.1	8.0	43.77
1645.0-1645.3	0.7150	0.40	48.2	0.02
1671.2-1671.8	0.7097	5.6	39.8	0.41
1715.4-1715.7	0.7089	0.07	90.9	0.02
1762.0-1762.3	0.7099	1.3	37.9	0.10
1782.2-1782.4	0.7137	0.30	5.7	0.15
ERDA-9				
1404.8-1405.8	0.7934	67.1	5.1	38.41
1648.5-1649.0	0.7079	0.47	44.7	0.03
1759.1-1759.8 (polyhalite rich portion)	0.7064	4.9	793.5	0.02
ERDA-6				
1421.0-1421.7	0.7095	0.60	156.2	0.01

B. Water Soluble Portions

ERDA-8				
1607.0-1608.0	0.7173	26.7	44.7	1.73
ERDA-9				
1408.8-1405.8	0.8601	70.8	4.0	51.87
1709.0-1709.5	0.7094	0.99	8.5	0.34
1713.6-1714.0	0.7072	2.0	34.1	0.17
1772.0-1772.4	0.7067	1.5	57.7	0.07

C. $<$2 Micron Fractions (Clays)

AEC-8				
1607.0-1608.0	0.7229	42.9	82.2	1.51
1671.2-1671.8	0.7273	43.9	35.2	3.62
ERDA-9				
1404.8-1405.8	0.7608	84.5	23.6	10.40
1772.0-1772.4	0.7181	29.4	48.1	1.76

TABLE 7.25

% Insoluble Residue in Whole Rock

Core hole Interval	Insoluble Residue (percent)
AEC-8	
1607.0-1608.0	9.0
1610.8-1611.3	9.0
1622.4-1622.9	2.0
1636.6-1637.1	3.7
1645.0-1645.3	0.8
1671.2-1671.8	11.3
1715.4-1715.7	1.1
1782.2-1782.4	12.5
ERDA-9	
1404.8-1405.8	7.2
1621.9-1622.2	0.8
1633.6-1634.1	0.4
1648.5-1649.0	2.1
1652.8-1653.1	0.3
1709.0-1709.5	1.1
1713.6-1714.0	18.2
1759.1-1759.8	0.7
1772.0-1772.4	12.6

TABLE 7.26

Mineralogical Data

Core hole Interval	Halite	Sylvite	Polyhalite	Langbeinite
A. Whole Rocks (Evaporite Mineralogy by XRD)				
AEC-8				
1607.0-1608.0	VA	VA	-	-
1610-8-1611-3	VA	A	-	-
1622.4-1622.9	VA	A	-	-
1636.6-1637.1	VA	VA	t	-
1645.0-1645.3	VA	t	-	-
1671.2-1671.8	VA	t	t	-
1715.4-1715.7	VA	t	-	-
1762.0-1762.3	VA	t	-	-
1782.2-1782.4	A	A	A	t
ERDA-9				
1404.8-1405.8	A	t	VA	VA
1621.9-1622.2	VA	t	-	-
1633.6-1634.1	VA	t	-	-
1648.5-1649.0	VA	A	-	-
1652.8-1653.1	VA	t	-	-
1709.0-1709.5	VA	A	-	-
1713.6-1714.0	VA	A	-	-
1759.1-1759.8	VA	A	t	-
1772.0-1772.4	VA	A	t	-
ERDA-6				
1421.0-1421.7	VA	t	-	-

TABLE 7.26, continued

Mineralogical Data

Core hole Interval	Halite	Sylvite	Polyhalite	Langbeinite

B. 2 Micron Fractions (Clays, Minerals)

Core Hole Interval	Chlorite	Saponite	Chlorite/ Saponite	Illite	Talc	Serpentine
AEC-8						
1607.0-1608.0	-	-	VA	A	t	A
1610.8-1611.3	t	-	A	A	-	A
1622.4-1622.9	-	-	t	A	A	t
1636.6-1637.1	-	-	A	VA	t	t
1645.0-1645.3	t	-	A	A	t	A
1671.2-1671.8	-	-	VA	A	-	t
1715.4-1715.7	A	-	t	VA	-	VA
1762.0-1762.3	t	t	-	A	A	t
1782.2-1782.4	A	-	t	VA	VA	A
ERDA-9						
1404.8-1405.8	-	-	A	VA	t	A
1648.5-1649.0	A	-	A	VA	VA	VA
1713.6-1714.0	-	-	VA	A	A	VA
1772.0-1772.4	-	-	VA	A	t	A
ERDA-6						
1421.0-1421.7	-	-	t	t	VA	t

VA: very abundant
A: abundant
t: trace
-: not detected

TABLE 7.27

URANIUM CONCENTRATIONS AND ISOTOPIC RATIOS IN DELAWARE BASIN WATERS

Sample	U Concentration	$\alpha(^{234}U/^{238}U)$	$\delta^{18}O$ (SMOW)‰	δD (SMOW)‰
Shell	0.60 parts in 10^9	2.75	-7.7	-56
Middleton	0.54 parts in 10^9	1.81	-7.5	-55
Hackberry	0.02 parts in 10^9	1.22 ± 0.05	-6.5	-46
Carlsbad 7	0.05 parts in 10^9	5.14	-7.9	-54
ERDA 6 1140 hr.	89 parts in 10^9	1.11 ± 0.04		
ERDA 6 1212 hr.	4.8 parts in 10^9	1.26 ± 0.05		
ERDA 6 1445 hr.	2.14 parts in 10^9	1.37 ± 0.07	+10.3	0
ERDA 6 1520 hr.	1.88 parts in 10^9	1.33 ± 0.07		
ERDA 6 Drill Mud	67.2 parts in 10^9	1.19		
Brine Lake (Mud Ingredient)	56.3 parts in 10^9	2.04		

Arrows in these photographs point stratigraphically upward.

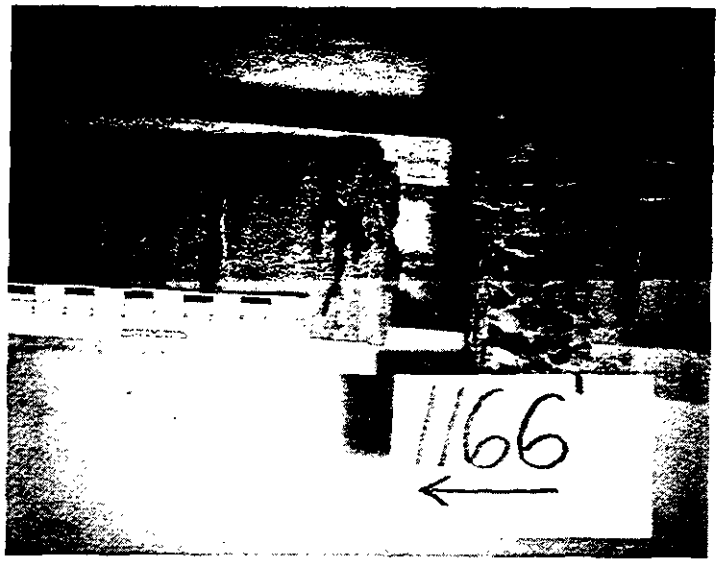

Plate 7.1. Core footage: 1165.4 to 1177.1 ft. (including 0.1 ft. gap) Brownish halite in gray anhydrite. Halite occurs as a thin bed at top of specimen, then as irregular lenses and thin laminae, finally as vertically elongate crystals, some with "swallow tail" form, near bottom of specimen. Locally horizontal laminae occur within the anhydrite due either to color change of the anhydrite or laminae of magnesite.

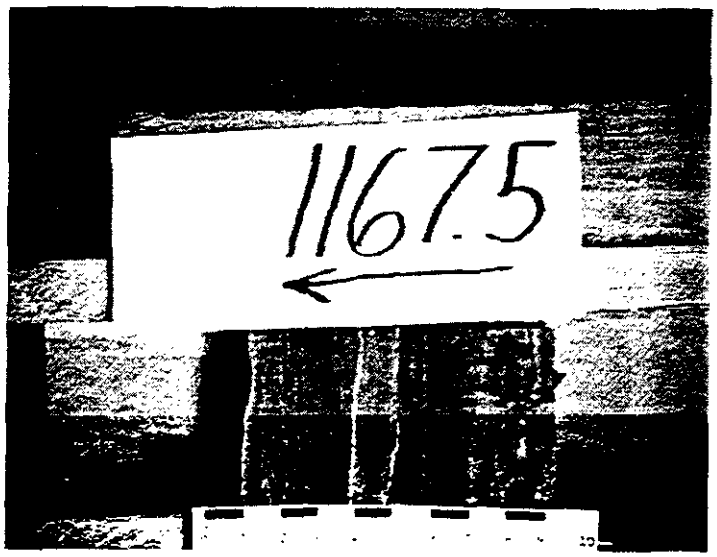

Plate 7.2. Core footage: 1167.5 ft. Dominantly light to dark gray, laminated anhydrite with thin, locally discontinuous, laminae of white magnesite and brownish, elongate halite oriented perpendicular to convex-upward, discontinuous laminae of light gray to white anhydrite.

Plate 7.3. Core footage: 2065.8 to 2066.6 ft. Dominantly clear to milky white halite crystals, approximately 10 mm in size, and reddish brown to pinkish brown polyhalite. Note rectangular outline of polyhalite body stratigraphically above the first 6 in 2066; but most polyhalite occurs around halite crystal boundaries below 2066 label.

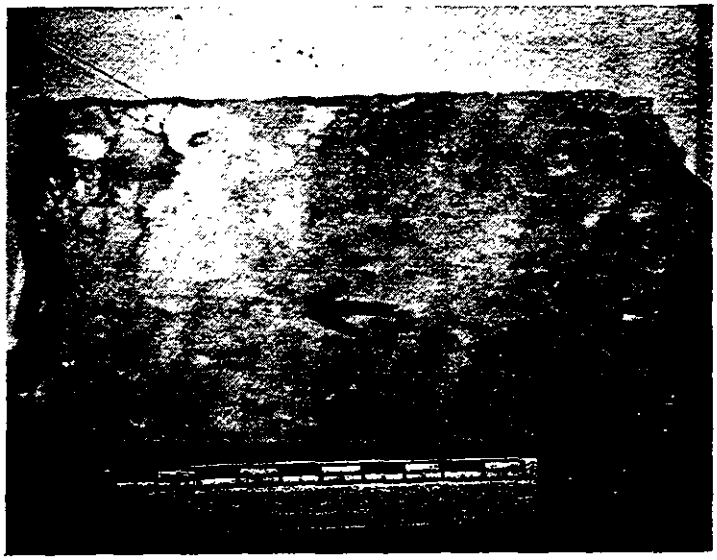

Plate 7.4. Core footage: 2615.0 to 2615.6 ft. Dominantly coarse (ranging from 3 to 40, average 20 mm in size) halite crystals, some with cubic form but most anhedral, locally separated by microcrystalline white anhydrite.

Plate 7.5. Core footage: 2705.8 ft. Coarse, ranging from 2 to 15 mm, light gray to black halite in white microcrystalline anhydrite and rare 1 to 2 mm bodies of pure white magnesite.

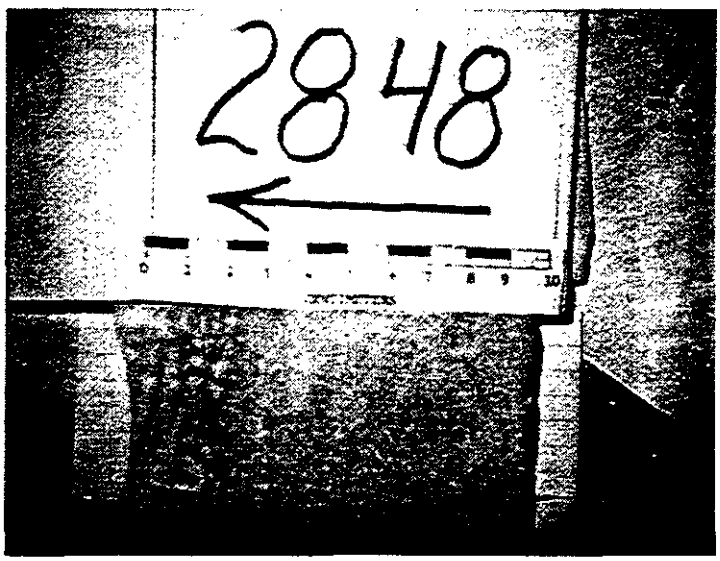

Plate 7.6. Core footage: 2848 ft. Varicolored (white and all shades of gray) anhydrite, some crystals near stratigraphic top of sample exhibit "swallow tail" form.

Plate 7.7. Photomicrograph (25X, plane light) of halite: many euhedral (cubic) to subhedral, relatively clear crystals locally containing fluid inclusions. Crystal size ranges from 0.5 to 1.5 mm. Compare with Plate 7.8.

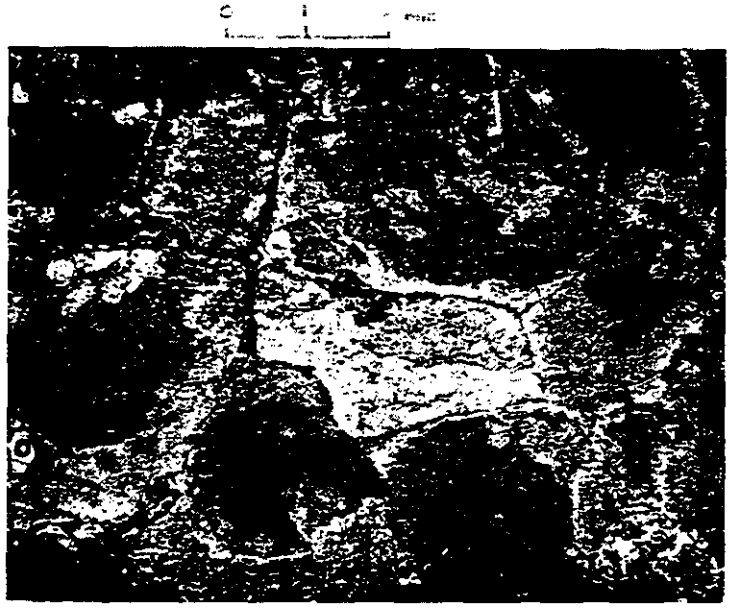

Plate 7.8. Photomicrograph (10X, plane light) of halite: subhedral to anhedral, cloudy crystals devoid of fluid inclusions. Crystal size ranges from 1.5 to 4.5 mm.

Plate 7.9. Photomicrograph (10X, plane light) of sylvite (reddish, translucent to black, opaque in photo) and halite: halite anhedra size ranges from 0.4 to 5 mm. Two subhedra dominantly of sylvite occur within halite anhedra, one subhedron/anhedron of mixed sylvite and halite occurs within a coarse halite subhedron, but most sylvite occurs as anastomosing bodies having gradational contacts with halite between halite anhedra.

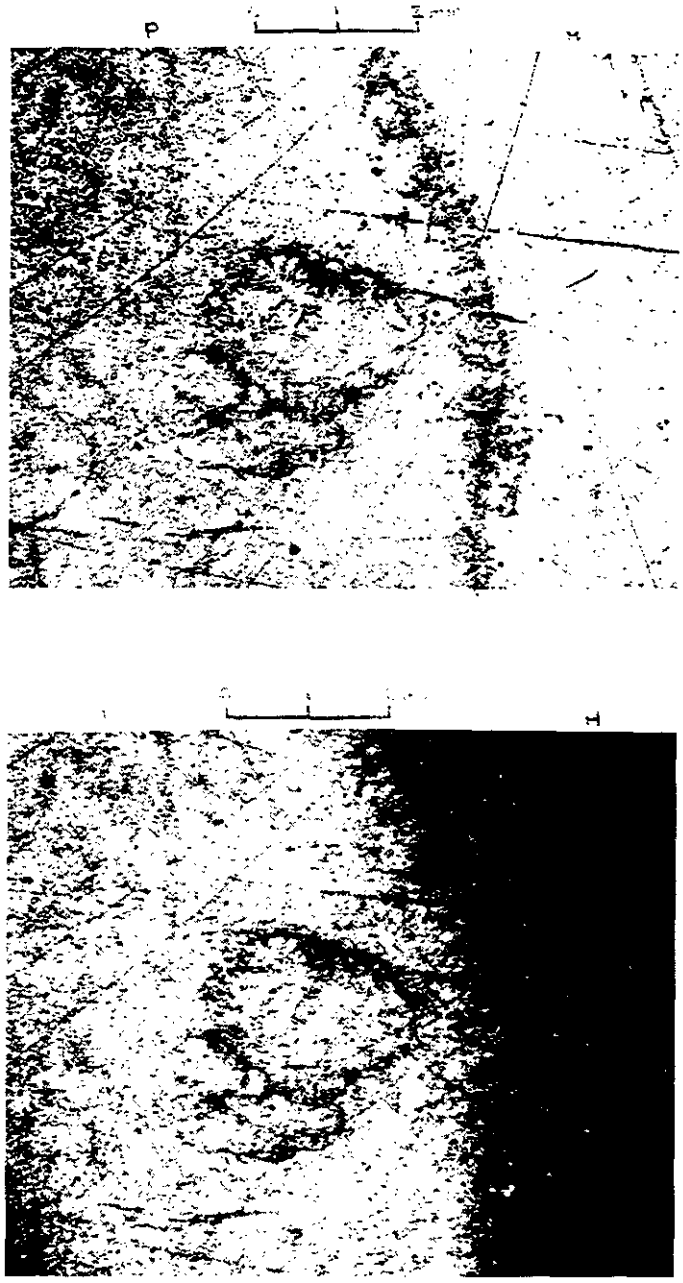

Plates 7.10A and 7.10B. Photomicrographs (10X, plane light in 7.10A, crossed nicols in 10B) of polyhalite (P) and halite (H): Polyhalite occurs as a cloudy anhedron (pinkish in hand specimen) locally containing smaller anhedra which are apparent due to concentrations of opaque (black in the photo, red under microscope reflected light) material, probably hematite. Concentrations of hematite also occur along the contact of polyhalite with halite which becomes extinct (black in 10B) under crossed nicols. The contact is irregular and gradational.

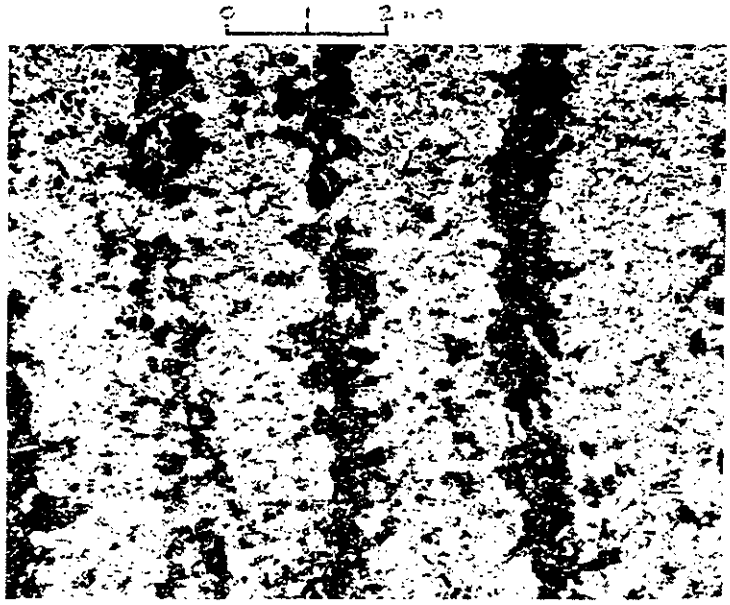

Plate 7.11. Photomicrograph (10X, plane light) of laminated anhydrite and calcium or magnesium carbonate: Dark thin laminae (approximately 1 mm thick) of dominantly carbonate anhedra separate thin laminae (approximately 2 mm thick) of dominantly anhydrite anhedra.

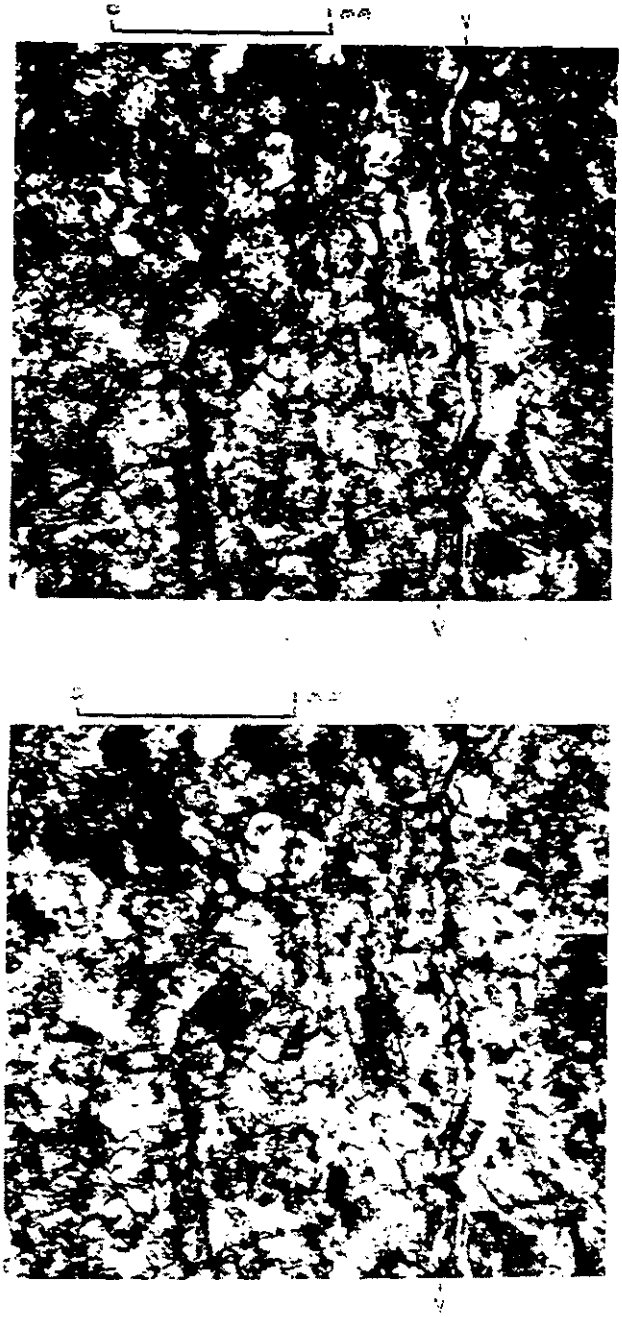

Plates 7.12A and 7.12B. Photomicrographs (25X, plane light in Plate 7.12A, crossed nicols in Plate 7.12B) of anhydrite with veinlet (V) of gypsum. Anhydrite occurs as a mosaic of 0.04 to 0.4 mm anhedra and subhedra with high order interference colors in 12B. Veinlet somewhat discontinuous, is more apparent in 12A and consists of very elongate irregular anhedra of relatively clear gypsum with lower order interference colors than the anhydrite in 12B. The veinlet is approximatedly stratigraphically horizontal and is 0.06 mm thick, the width of a single elongate gypsum anhedron.

Plate 7.13 Group of dark unrecrystallized zones in essentially inclusion-free single crystal of halite of sample 2065. For detail on central area see Plate 7.14.

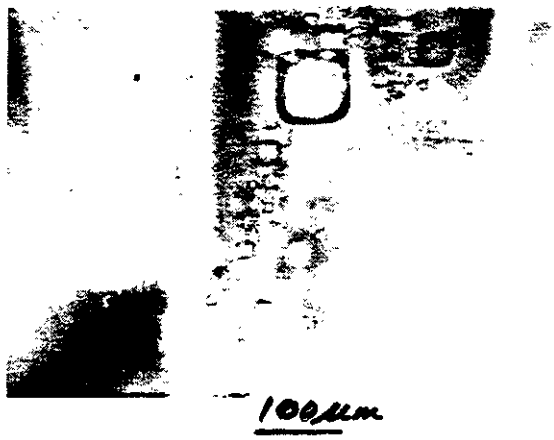

Plate 7.14 Detail of area in Plate 7.13 showing sharp crystallographically controlled boundaries of inclusion-rich zones (type A). Such boundaries may represent primary crystallization features rather than recrystallization fronts.

Plate 7.15 Recrystallized part of sample 2065 with large numbers of type B inclusions with small bubbles (e.g., see arrow) and some dark, cloudy unrecrystallized portions (details in Plate 7.16).

Plate 7.16 One of the dark areas in Plate 7.15 showing dense cloud of primary type A inclusions with some primary banding (arrow), and sharp but curving (solution?) contact with crystallographically parallel but almost inclusion-free recrystallized salt (at top).

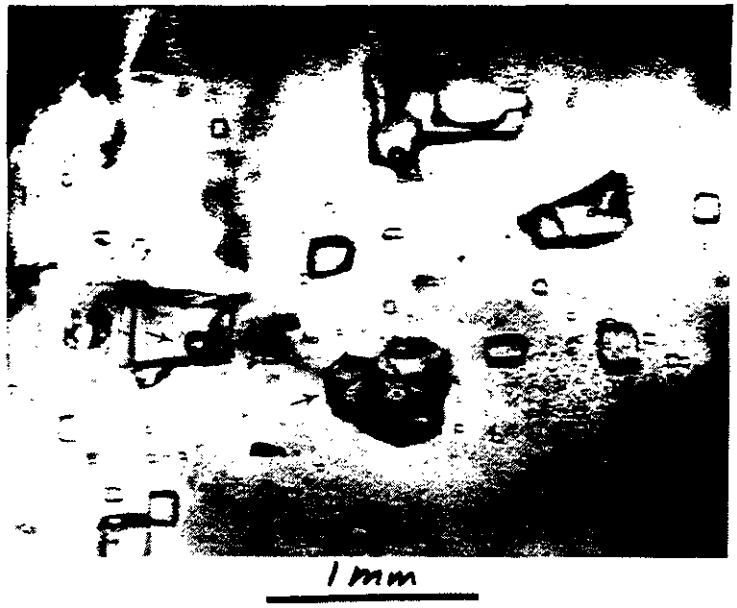

Plate 7.17 Coarsely recrystallized part of sample 2760, with many large type B inclusions, each with bubbles (arrows). Dark clouds are masses of unrecrystallized salt with large numbers of tiny type A primary inclusions (see Plates 7.18 and 7.19).

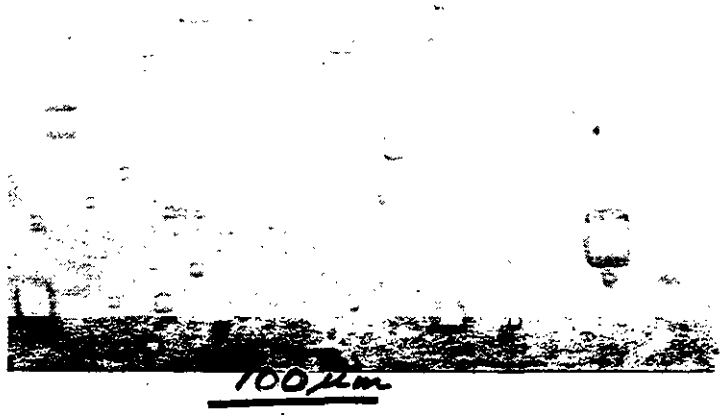

Plate 7.18 Detail of one of the cloudy areas in Plate 7.17, showing high concentration of tiny type A inclusions. Most of these inclusions are < 1μm (see Plate 7.19).

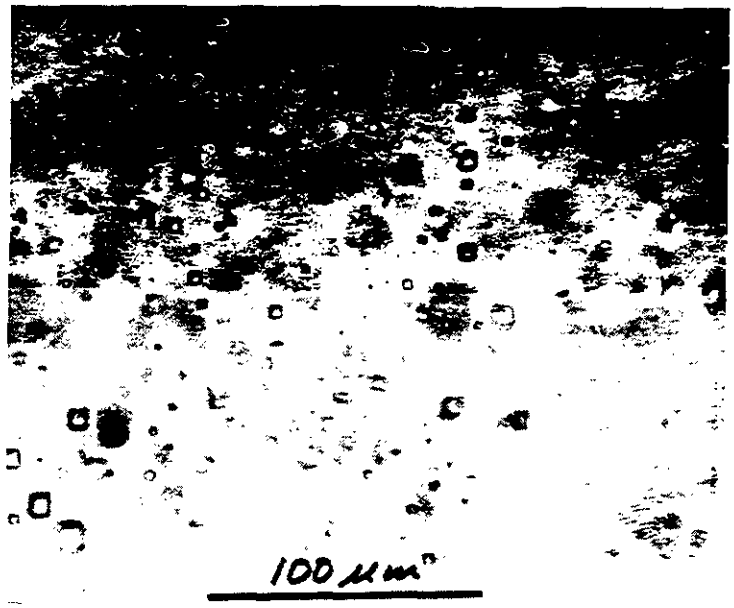

Plate 7.19 Detail of portion of Plate 7.18 that is relatively free of larger inclusions. The smallest inclusions are ≈ 0.5μm. All are type A. None of these inclusions contain a bubble.

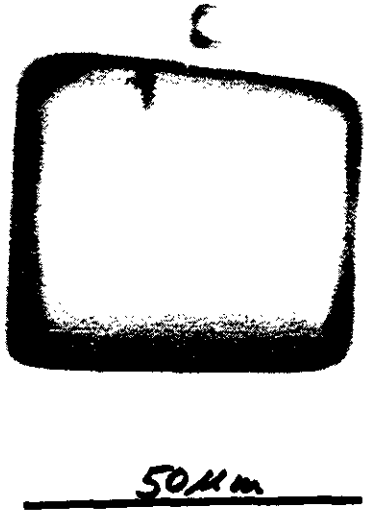

Plate 7.20 Inclusion in sample 2272.5 that contains only liquid, with no bubble, even though fairly large. Type B.

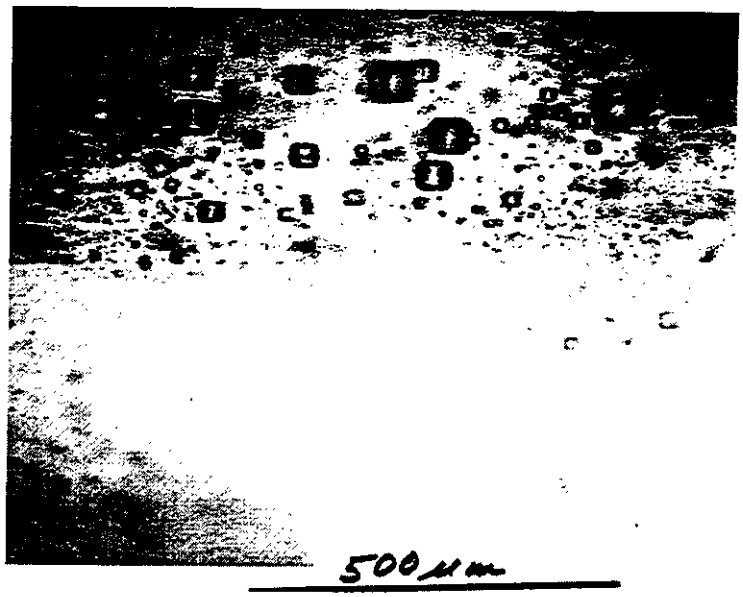

Plate 7.21 Unrecrystallized part of sample 1902 showing primary cubic growth zone feature, delineated by a cloud of tiny type A primary inclusions.

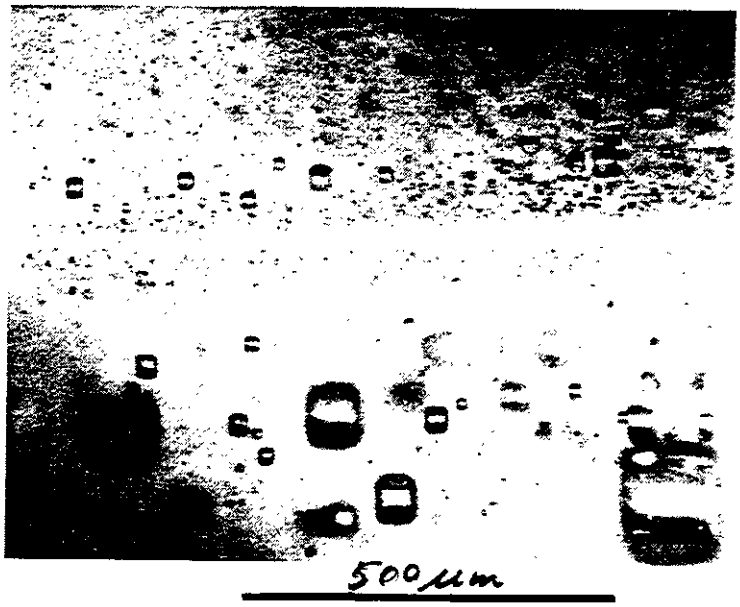

Plate 7.22 Unrecrystallized part of sample 1902 showing thin inclusion-free zone through dense cloud of tiny type A primary inclusions.

Plate 7.23 Oval grain of salt from sample 2760 containing unrecrystallized core with tiny type A primary inclusions. See Plate 7.24 for detail. Top of core is shown by arrow.

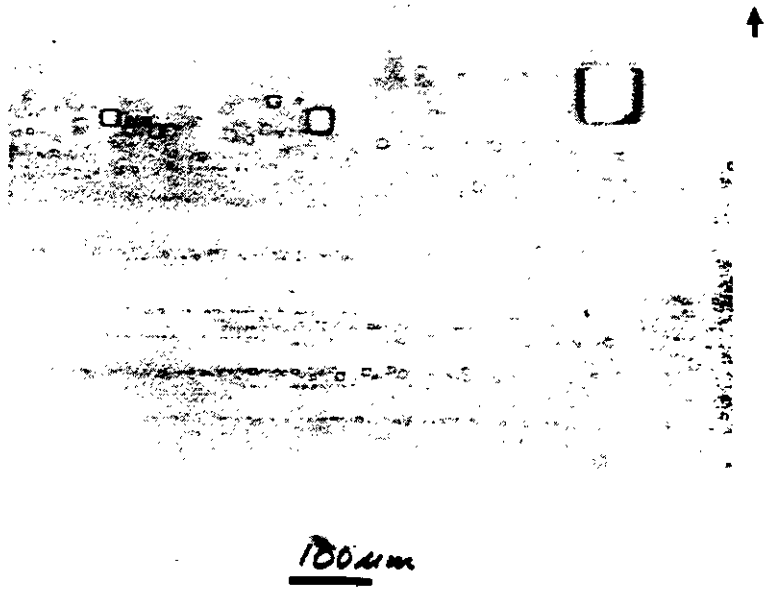

Plate 7.24 Enlgarged view of right central portion of Plate 7.23, showing extremely fine banding of primary type A inclusions, with inclusion-free zones between. Top of core is shown by arrow.

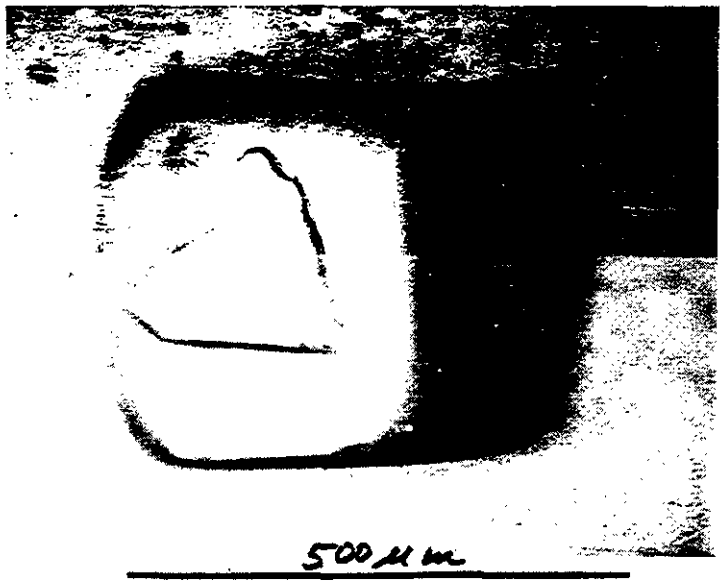

Plate 7.25 Inclusion (type B) in sample 1902 showing twinned birefringent daughter crystal of unidentified phase.

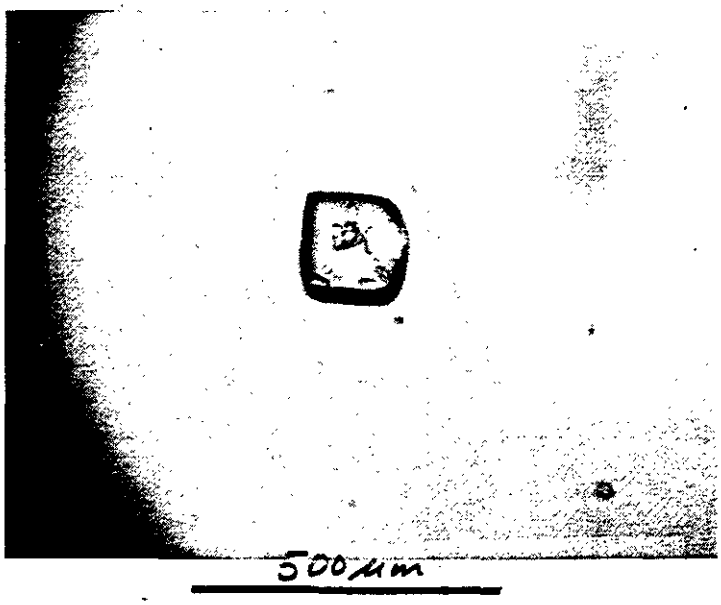

Plate 7.26 Daughter crystals of unidentified phase in type B inclusion in sample 1902.2, with partly crossed polarizers. Note twinning in largest crystal. Many inclusions in this same sample have no daughter crystal or just a few tiny crystals (see Plate 7.28).

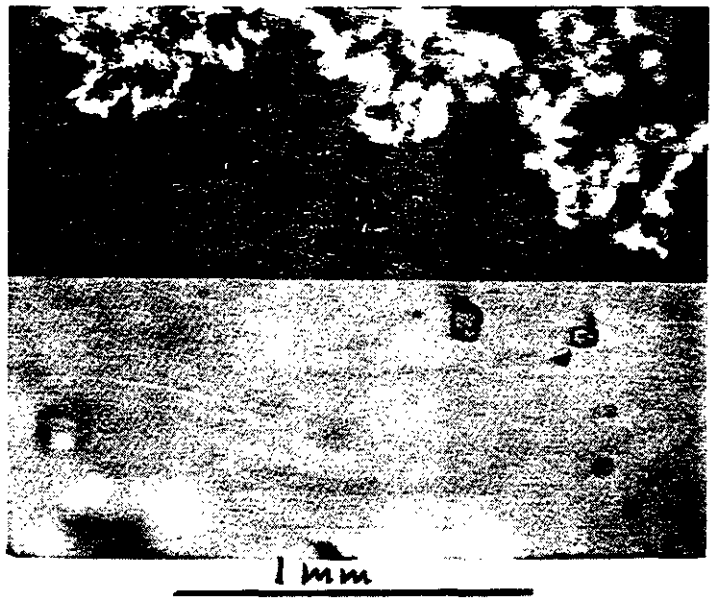

Plate 7.27 Plane of type B liquid inclusions each with a large number of unidentified bladed birefringent daughter crystals, just 400 µm below another plane of inclusions with no daughter crystals (Plate 7.28). Inclusion in Plate 7.26 with daughter crystals is similar in phase ratio but not in same plane (out of focus in lower left here). Sample 1902.2 partly crossed polarizers; birefringent mass embedded in salt crystal at top may be the same phase.

Plate 7.28 Plane of liquid type B inclusions, several with bubble, but without daughter crystals, about 400 µm above a plane of type B inclusions with a large number of unidentified daughter crystals (Plate 7.27). This lower plane is visible but out of focus. Sample 1902.2. Inclusion of Plate 7.26 is visible in lower left.

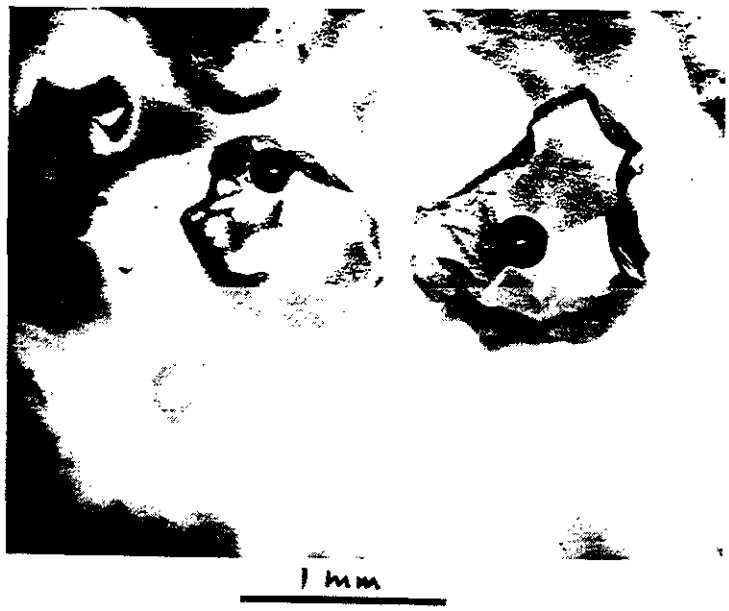

Plate 7.29 Large irregular type C inclusions in sample 2065 with "too large" bubbles.

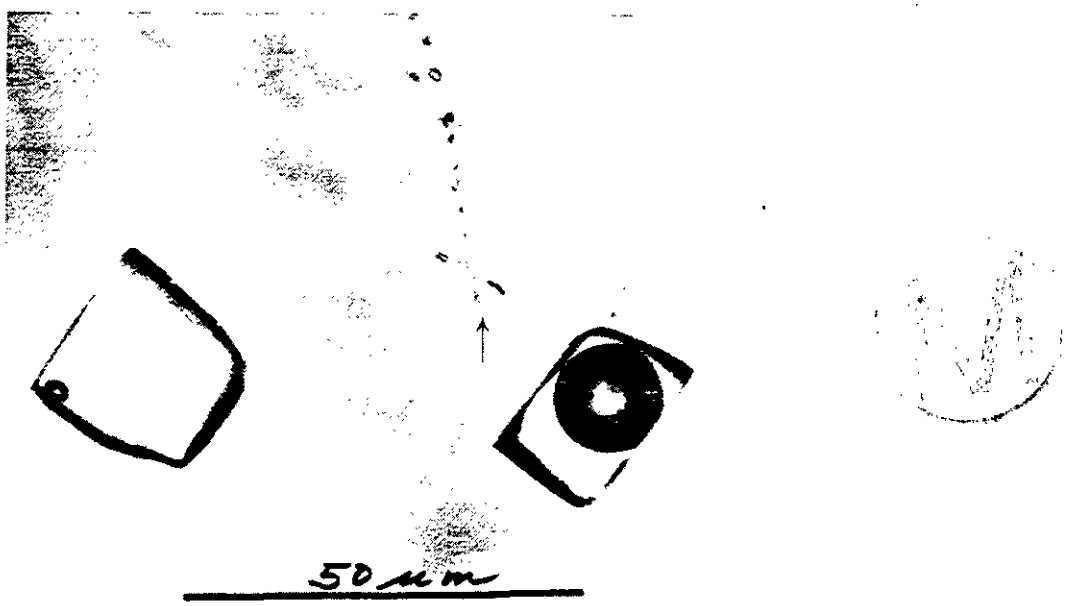

Plate 7.30 Pair of inclusions in sample 1902. The one on left (Type B) with small bubble is typical of those in this sample; that on right (Type C) is on a healed fracture (see arrow) and has apparently been opened and the original fluid replaced with a gas-rich mixture under pressure.

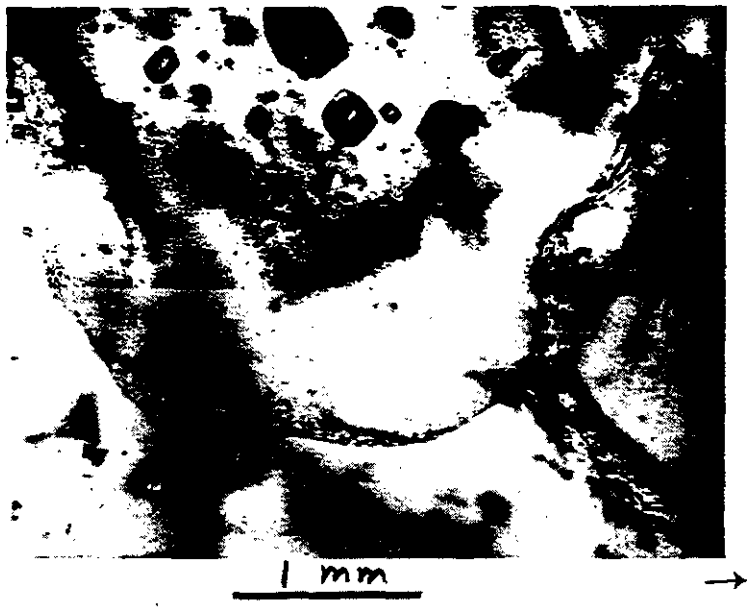

Plate 7.31 Single crystal of salt in sample 2760 with curving planes, outlined by type D inclusions, separating it from adjacent grains. Note also large type B inclusions and mass of tiny type A primary inclusions in central core of crystal. Sample has probably undergone two stages of recrystallization (see text). Top of core is shown by arrow.

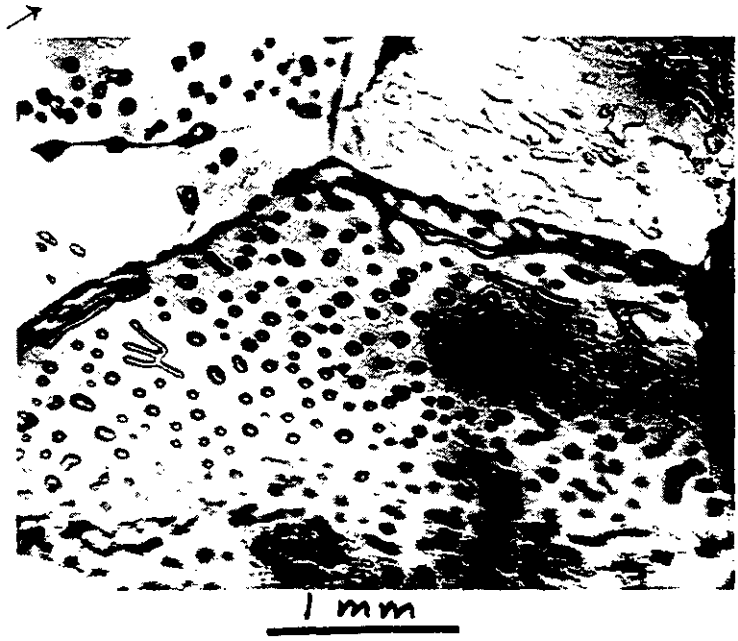

Plate 7.32 Fluid inclusions (gas; type D) on interface between recrystallized salt crystals in sample 2760. Note 120° junction. Top of core is shown by arrow.

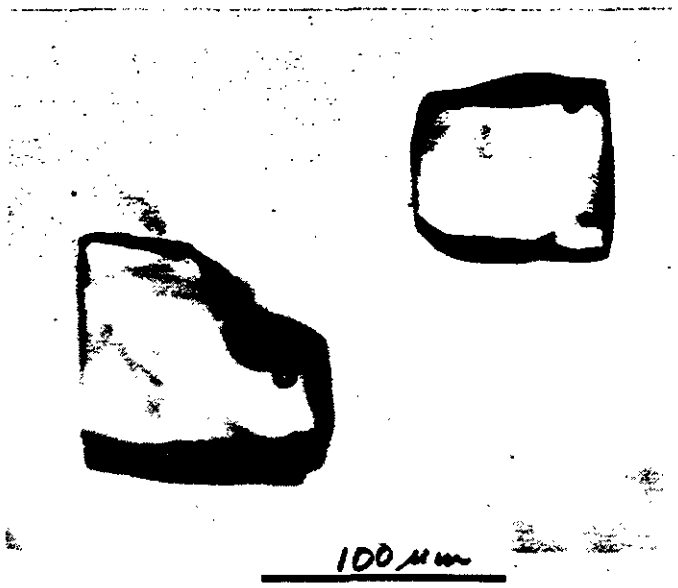

Plate 7.33 Large type B inclusions in sample 1799.1 homogenizing at 20.5°C (lower left) and 21°C (upper right). Photographed at ≈ 19°C.

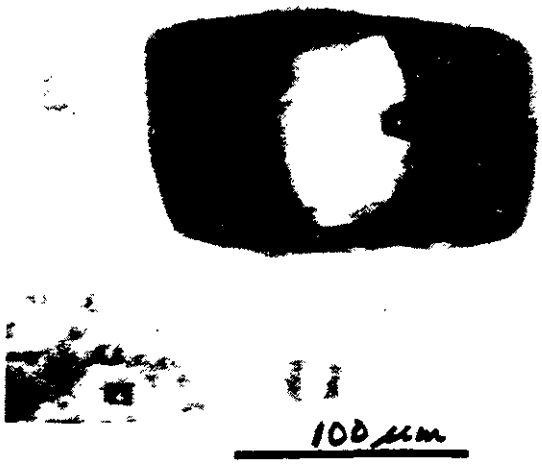

Plate 7.34 Large type B inclusion in sample 2760.1 homogenizing at 20.5°C. Photographed at ≈ 19°C.

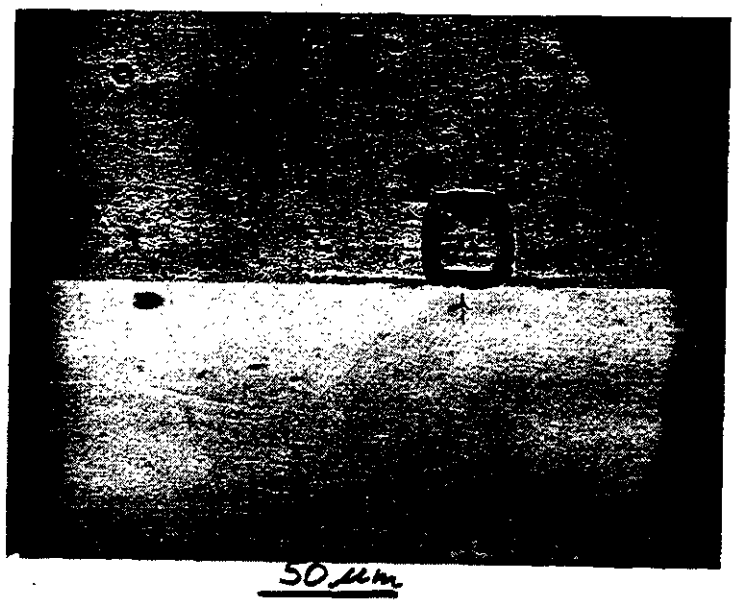

Plate 7.35 Inclusion (type B) in sample 1902 after freezing run, showing horizontal crack formed by expansion on freezing, that is now a plane of tiny secondary fluid inclusions; larger bubble than originally was present (due to volume increase); and rounded halo of tiny inclusions formed during freezing run (arrows), as a result of water in inclusion reacting with halite of walls to form $NaCl \cdot 2H_2O$, thus increasing inclusion volume. See text.

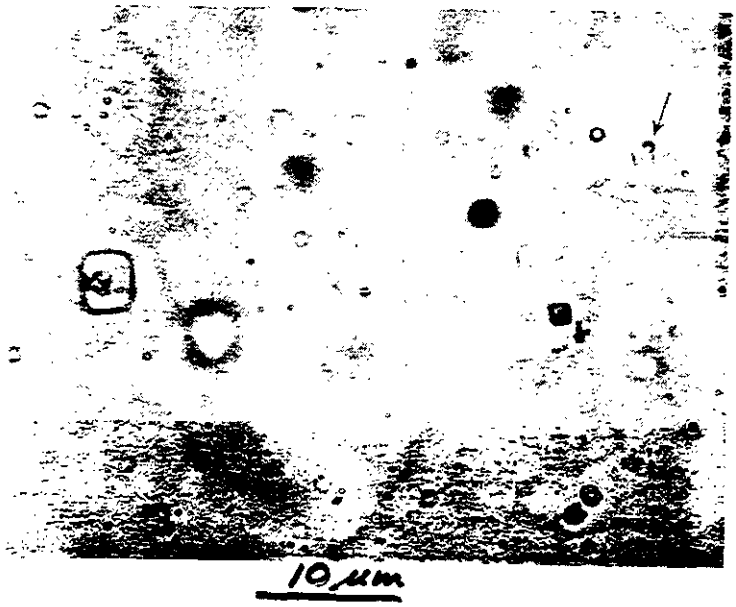

Plate 7.36 Minute primary inclusion in unrecrystallized salt from sample 1902 at high magnification (1560 X). The inclusion in upper right is about 1.8 μm on an edge, and contains a bubble of <0.5μm. Resolution of bubble is poor as it is generally in rapid motion even with an IR filter in optical system and exposures must be long. Many inclusions with no bubble area are ≈ 0.5μm on an edge.

Plate 7.37 Sequence of photographs of type B inclusions in sample 2095.3 taken at the temperatures indicated during a freezing run. At -75.5°C the inclusions contain a partly opaque mixture of solid grains of ice and salts. No change was visible on warming to -34.5°C, but at -32.2°C the mixture suddenly became more translucent and the grain size started to increase, indicating first melting. Extensive melting occurred around -4°C, and the remaining crystals decreased to ≈ 20-25% at 0°C. These were probably a hydrate but not all Nacl $2H_2O$, since a few were present at +12°, and the last dissolved at +15°C. The room temperature photo was taken after the run. The bubble size varies with phases present and temperature.

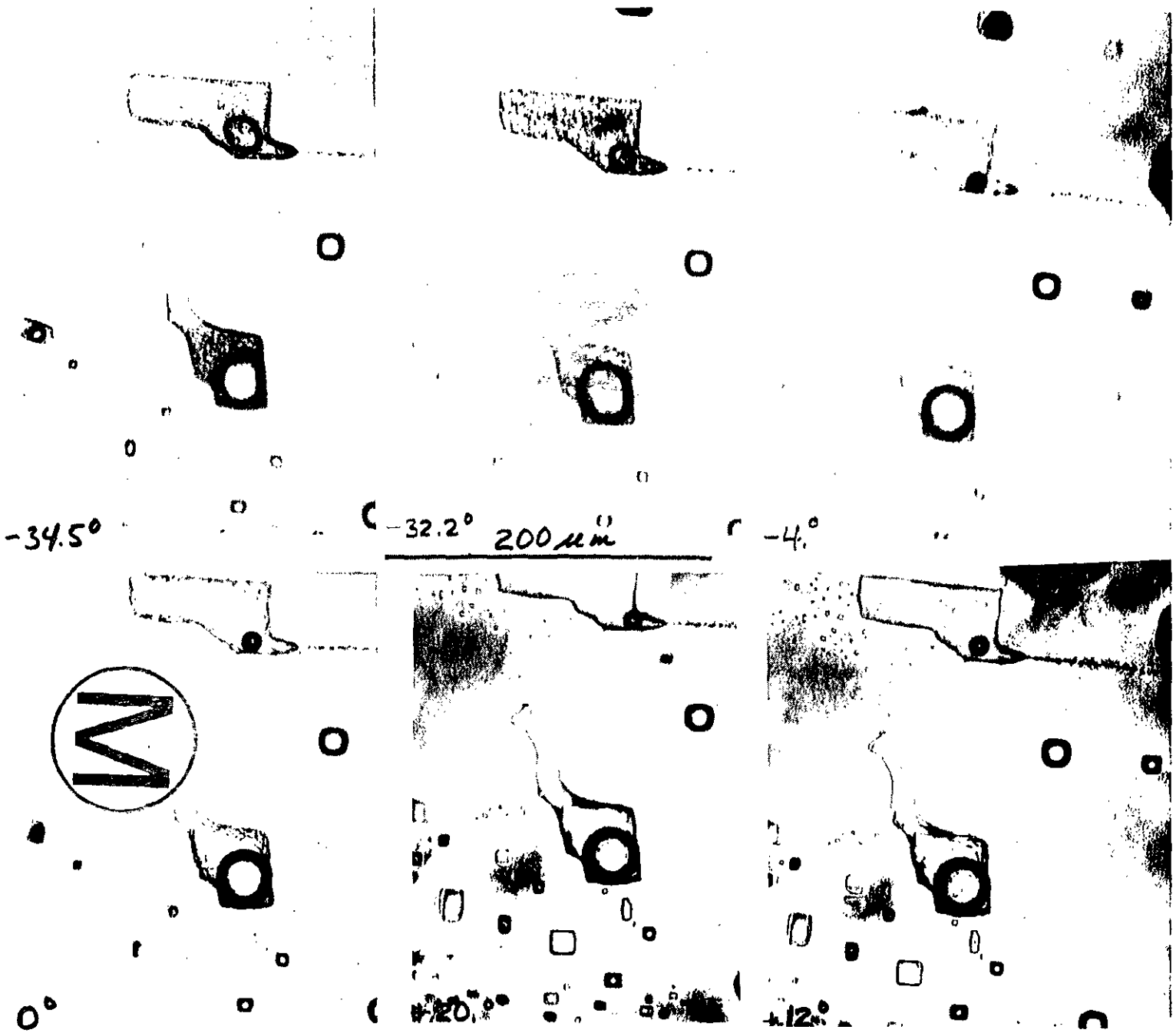
-34.5°
-32.2°
200 μm
-4.°
0°
+20.°
+12°

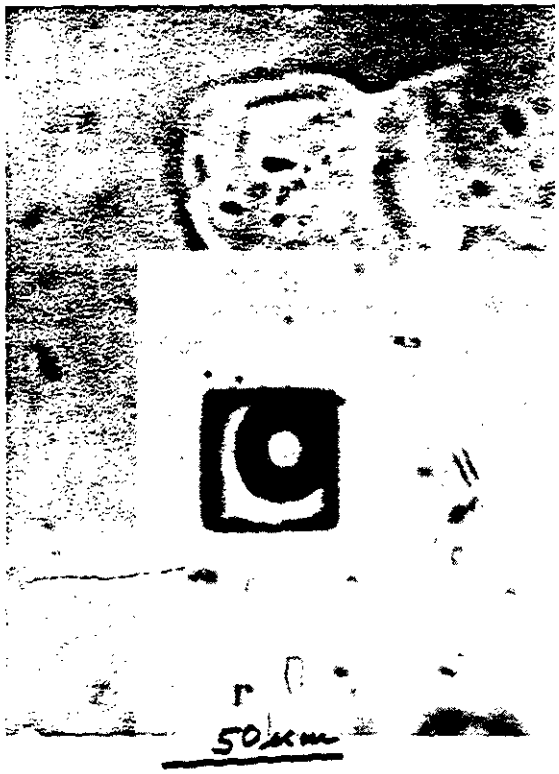

Plate 7.38 Inclusion from sample 2760, as found, with large bubble, viewed on crushing stage. The bubble contains gas under pressure (see Plate 7.39).

Plate 7.39 Same inclusion as seen in Plate 7.38, on crushing stage, after fracture has reached it. The bubble has expanded approximately 270% (vol) on pressure release.

Plate 7.40 Sequence of photographs of inclusion in sample 2760 on crushing stage. A shows the inclusion as found. The sample was then stressed and immediately cracked (at right in B), but the area of inclusion was still under stress, since changes took place along edges of inclusion during next 10 minutes at constant stress (photo B). After 16 minutes at constant stress (C) changes are more pronounced and bubble is smaller; after 18 minutes bubble is gone (D).

In each of the following plates, the length of the scale bar is 100 μm.

Plate 7.41 (Photo 1) Group of small primary hopper-growth inclusions in ERDA-9 sample 2699.8-2700.0, after 250°C decrepitation run. These inclusions probably had no bubble originally, and now have one as a result of plastic deformation of the host salt. They now homogenize at temperatures as high as 273°C (Table 7.17).

Plate 7.42 (Photo 2) Solid phases (daughter crystals?) in inclusion in Kerr-McGee mine sample MB-76-4. The small rod-like crystal has parallel extinction, and the large cubic(?) crystal (KCl?) appears isotropic.

Plate 7.43 (Photo 3) Dense gas inclusion in Kerr-McGee mine sample MB-77-8, photographed at the approximate temperatures indicated (°C). See text, subchapter 7.5.

Plates 7.44 and 7.45 (Photos 4 and 5) Steam inclusions (arrows) in Kerr-McGee mine samples MB-76-3 (7.44) and MB-77-8 (7.45), now containing essentially vacuum, before (a) and after (b) being intersected by a fracture during crushing tests. The surrounding oil has filled the inclusions completely in (b).

Plates 7.46 and 7.47 (Photos 6 and 7) Gas inclusions in Kerr-McGee mine sample MB-77-8 containing gas at less than one atmosphere pressure, before (a) and after (b) being intersected by a fracture during crushing tests.

Plate 7.48 (Photo 8) High pressure gas inclusion in Kerr-McGee mine sample MB-76-4 before (a) and after (b) being intersected by a fracture during crushing.

Plates 7.49, 7.50 and 7.51 (Photos 9, 10, and 11) High pressure gas inclusions in Kerr-McGee mine samples MB-77-8 (7.49 and 7.51) and MB-76-3 (7.50), before (a) and after (b) being intersected by a fracture during crushing. The approximate volume expansion is 30-fold in 7.49, 40-fold in 7.50, and 100-fold in 7.51. Two bubbles formed in 7.49, and one in 7.50 (arrows).

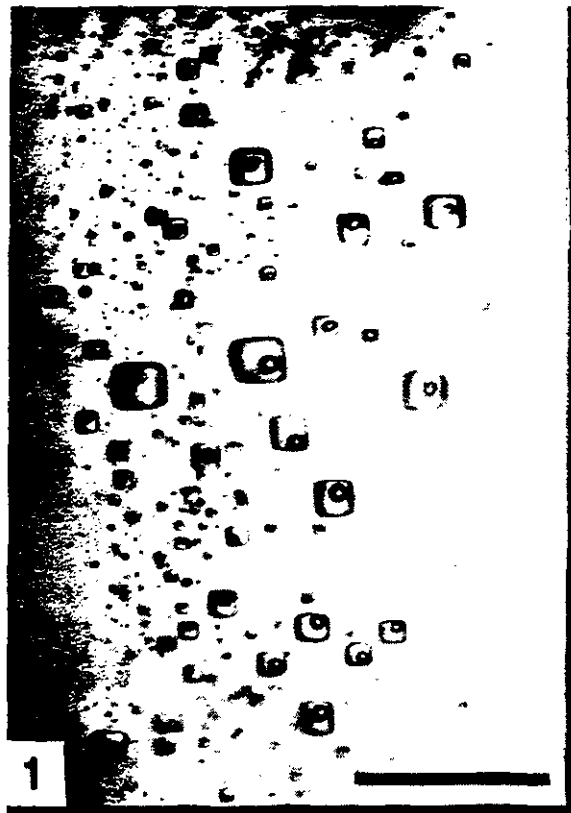
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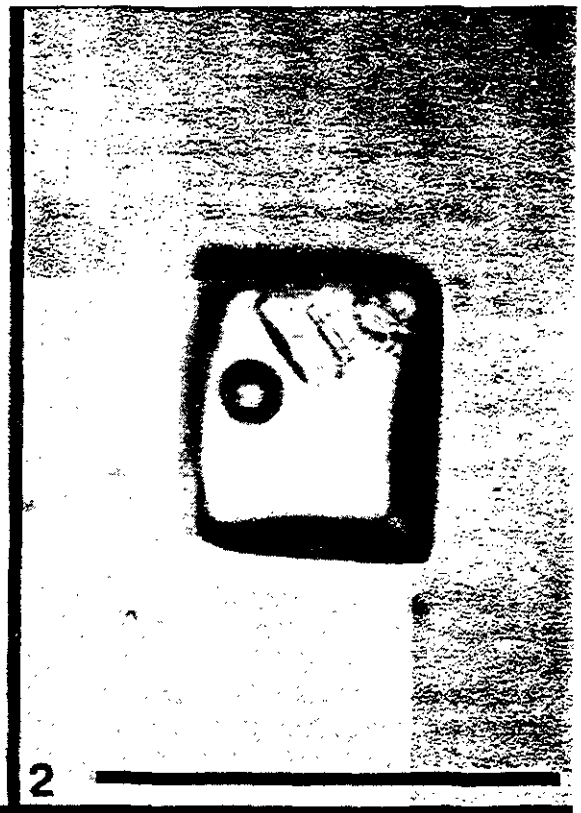
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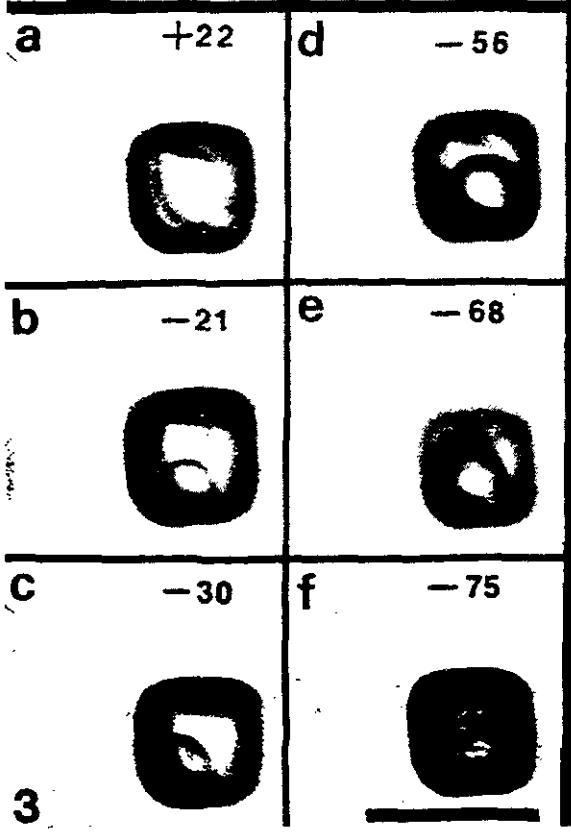
a +22
b −21
c −30
d −56
e −68
f −75
3

a
b
4

a
a
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b
M

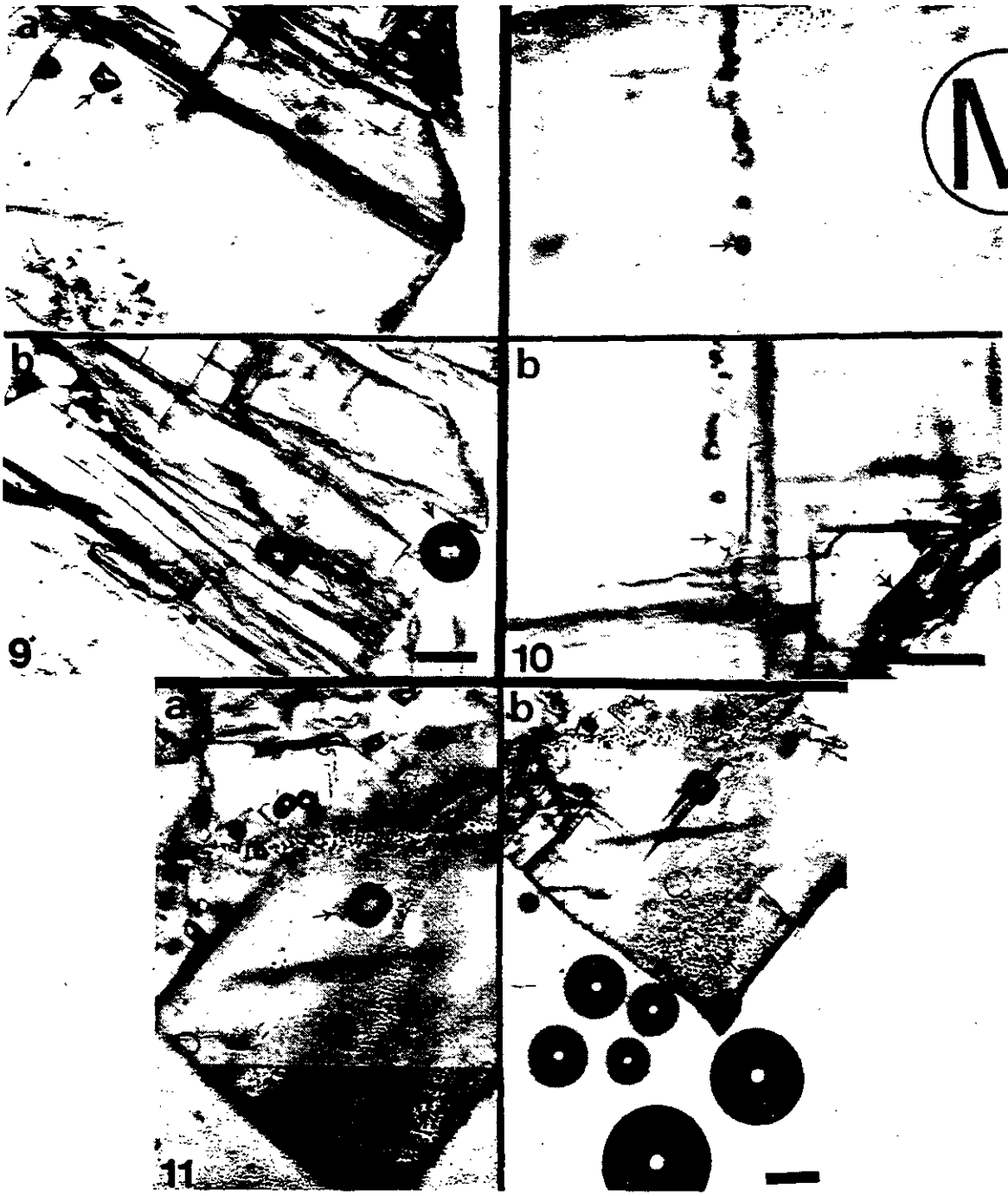
a
b
9
a
b
10
a
b
11

M

PLATE CAPTION

Plate 7.52 and Overleaf: Core fragments from Castile anhydrite serving as host rock for the ERDA No. 6 brine reservoir. Depths of origin, uranium contents and $^{234}U/^{238}U$ ratios are given in the overleaf for various parts of the core fragments.

TOTAL U	α ($^{234}U/^{238}U$)	DEPTH (Ft.)
19.2 ppb	1.09	2708
1.61 ppm	1.02	2709.4
33 ppb	1.04	
2.17 ppm	1.04	2709.9

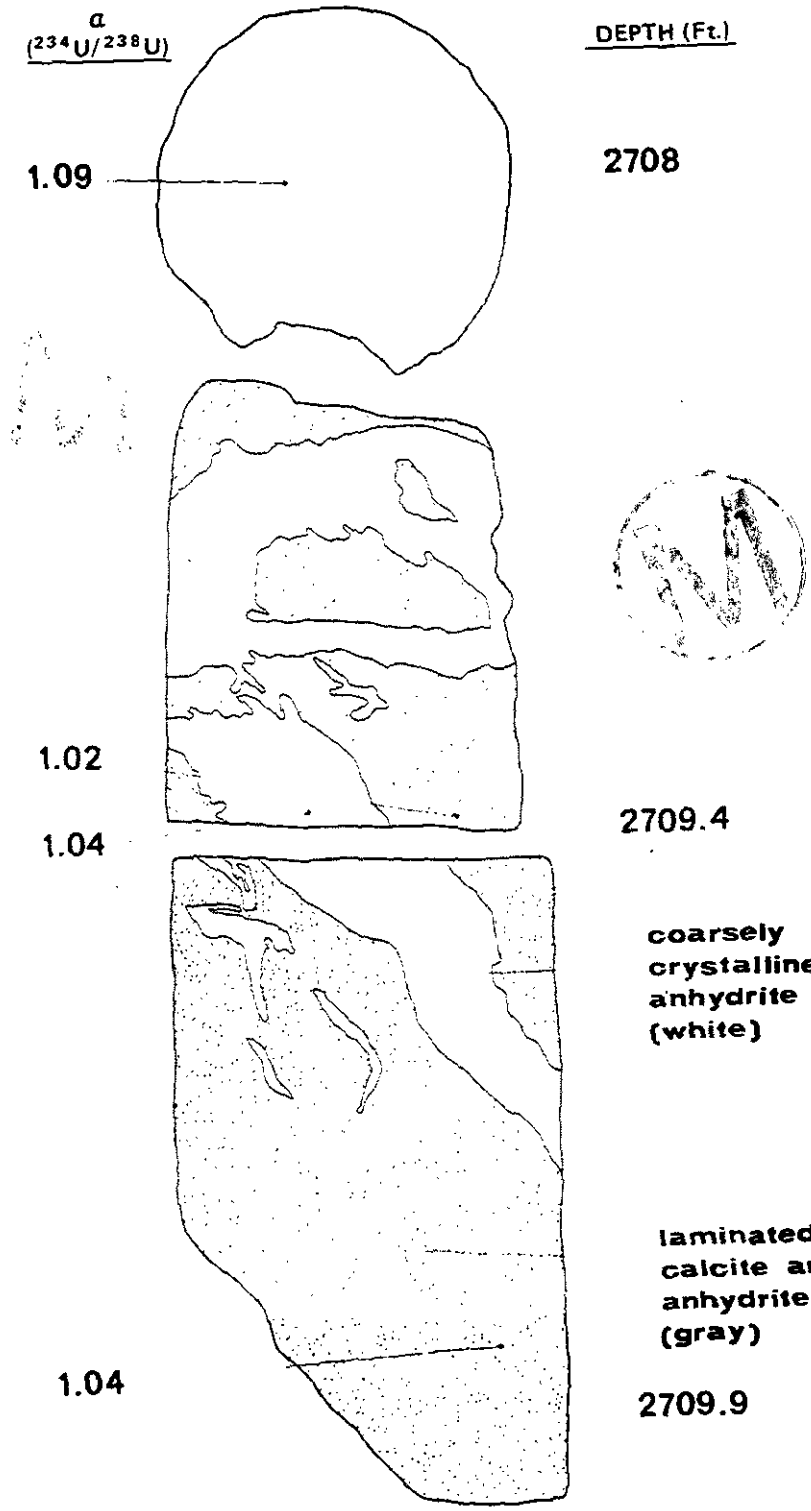

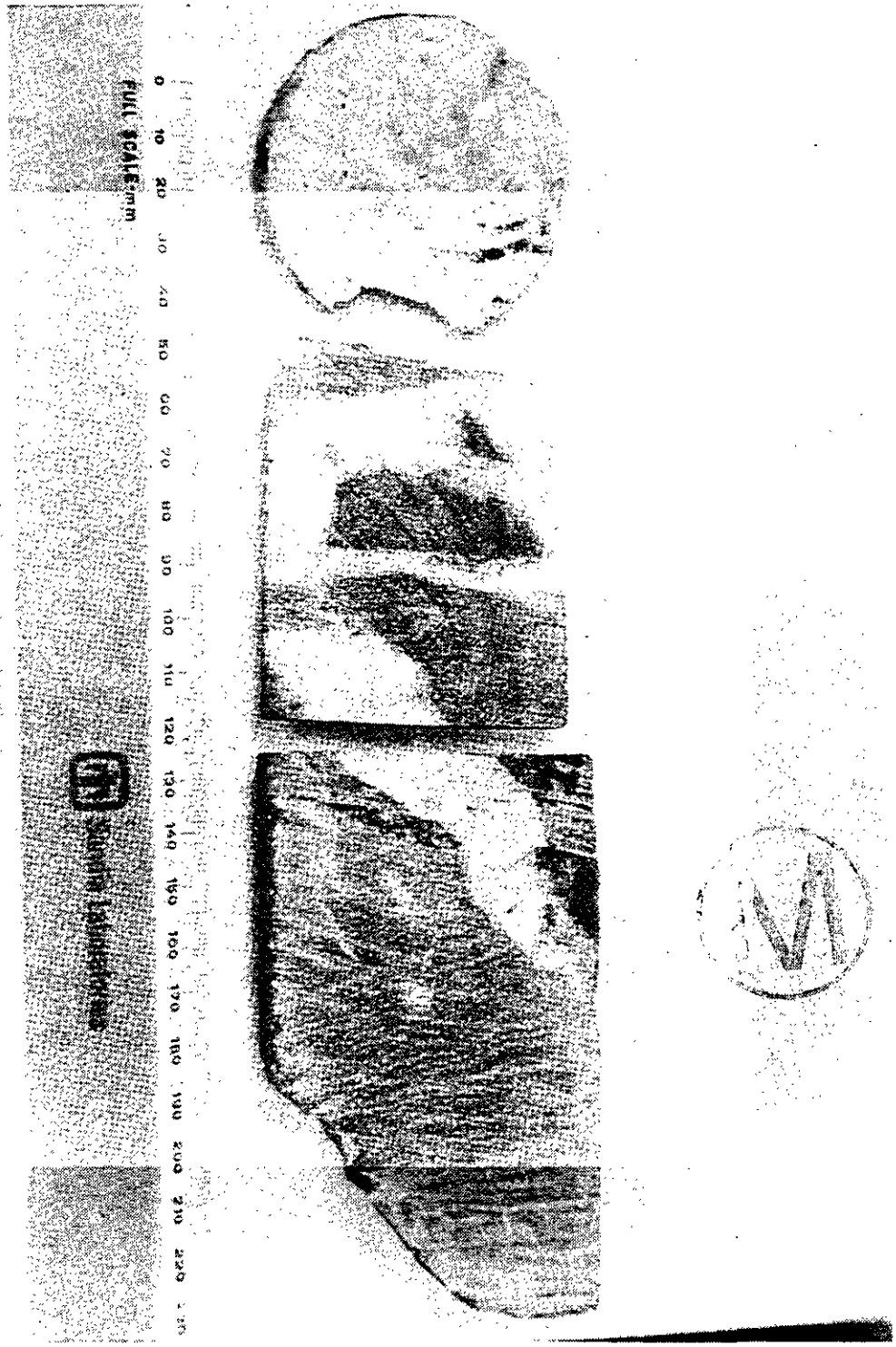
FULL SCALE mm
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230
Scale 1 mm = 1 mm

PLATE 7.52

GCR CHAPTER 8

RESOURCES

8.1 INTRODUCTION

The northern portion of the Delaware Basin is known for production of potassium salts and fluid hydrocarbons. An effort was made to select a location for the WIPP that would minimize conflict with these resources. It is likely, however, that some of these potash and hydrocarbon resources underlie the site. The extent of potash mineralization has been fairly well established because the potash mining industry has released information concerning their exploratory drilling in the area. Those findings were supplemented by information from 21 additional holes drilled by the Department of Energy. Site selection criteria described in Chapter 2 prescribe that the site be no closer than one mile from a deep drill hole. This means that the potential hydrocarbon resource must be evaluated by inference utilizing subsurface information from surrounding areas. An investigation was also carried out to determine the significance of other possible industrial minerals such as caliche, gypsum, salt, uranium, sulfur, and lithium at or very near the WIPP site. Table 8-1 summarizes the principal findings of resource studies. Only potash and natural gas are considered to be significant exploitable deposits as shown in Table 8-2. The economic resources denied in Zones I-III are shown in Table 8-3.

8.2 ORGANIZATIONS INVOLVED IN RESOURCE EVALUATION, AND THEIR REPORTS

Numerous contractors representing both government and private companies were engaged in the resource evaluation at the WIPP site. An outline of work accomplished during this phase of the site characterization is given in Table 8-4.

The listed studies quantify in-place resources and evaluate what portion of those resources would be extractable. A legal determination is now under way to establish values to the various mineral and oil and gas

lease holders within the site area. However, these studies deal with the present value of specific land tracts and as such are not pertinent to site chacterization.

8.3 POTENTIAL RESOURCES IN RELATIONSHIP TO STRATIGRAPHY AT THE WIPP SITE

Resource evaluation at the WIPP site took into consideration the existing stratigraphy of the site area. Each formation was evaluated for mineral deposits that were either known or that could exist based on the characteristics of the sediments present.

A stratigraphic column is given in Table 8-5 that indicates where in the geologic section specific types of deposits are considered to have a reasonable likelihood of occurrence. The table briefly describes the character, thickness, and median depth of each formation.

8.4 RESOURCE DESCRIPTION BY SPECIFIC COMMODITIES

The description of resources commences with the shallowest formation and proceeds down the stratigraphic column to the Precambrian.

8.4.1 Caliche

A thin layer of caliche (a whitish, calcium carbonate-rich material) underlies most of the site area. Exposures are normally obscured by dune sand, but it has been estimated that the caliche blanket covers approximately 80% of the site area. The average thickness is 4.3 feet, and the total resource has been estimated at 185 million tons (Siemers et al., 1978). The quality of caliche as determined by insoluble content (ranging from 21 to 69%) appears to be typical for caliche for this region.

Caliche is often used to surface dirt roads in southeast New Mexico. Small quarries dot the landscape, and several provided material for road construction to various drill locations within the WIPP site. This is the sole use for caliche in this region. Caliche is so extensive in this region that it can not be considered as either a limited resource or one that has significance to road construction of surrounding areas if land is withdrawn for the WIPP site.

8.4.2 Uranium

Uranium could occur in sediments such as those of the Gatuna, Santa Rosa or Dewey Lake Formations. However, no significant occurrence of uranium has been found within the Delaware Basin. Reducing environments favoring uranium deposition are absent as evidenced by the lack of organic debris, pyrite or humates in these formations. No signal indicative of economic or even marginal uranium concentrations was observed on gamma ray logs of the 36 holes drilled through these beds during site evaluation. The conclusion is that significant uranium deposits are most unlikely, even in beds which are considered to be the most favorable.

8.4.3 Gypsum

Dissolution of salt from the Rustler Formation has occurred over much of the site area. Waters accompanying this dissolution have caused partial conversion of anhydrite within the Rustler to gypsum. The conversion is not complete, however, and it is doubtful that high-quality gypsum would be persistent in any single bed. The maximum amount that could be present, assuming an aggregate thickness of 40 feet, amounts to 1.3 billion tons (Siemers et al., 1978). The quality and bed thickness are inferior to those in beds west of the WIPP site. Still farther west and south, extensive outcrops of high quality gypsum of the Castile Formation occur. The nearby availability of superior quality gypsum that can be mined by open pit methods leads to the conclusion that gypsum in the Rustler Formation can not be considered a likely economic resource.

8.4.4 Halite (Salt)

Halite is the dominant constituent of the Ochoan evaporites. The shallowest salt is in the Rustler, but dissolution of this formation has removed much of the Rustler salt except in the southeast quadrant of the WIPP site. On the other hand, salt beds persist under the site in the Salado and Castile Formations. The thickest and purest salt beds in the region are in the Castile. The State Bureau of Mines and Mineral Resources estimated 118 billion tons of salt in the Salado within the WIPP boundary (Siemers et al., 1978). The Castile Formation would add approximately 80 billion tons of additional salt resource.

As with gypsum and caliche, the immense halite deposits are not considered to have economic significance because of the prevalence of these deposits throughout the general area and the existence of adequate supplies closer to areas where salt is in demand.

8.4.5 Sulfur

A significant deposit of native sulfur is being exploited by the Frasch process approximately 50 miles south of the WIPP site in northeastern Culberson County, Texas. The occurrence is associated with brecciated and carbonatized anhydrite beds of the Castile Formation. Considerable exploration has been under way since discovery of the Culberson deposit, but that exploration has been aligned along the southern and western parts of the Delaware Basin where the Castile Formation either lacked halite during deposition or the halite has been removed by dissolution. The genesis of the deposits is believed to depend on a combination of bacterial action, induced fracture permeability and a source of hydrocarbons (presumably from upward escape of natural gas or crude oil along fractures from the Delaware Mountain Group). The closest analogy to such a setting in the northern part of the Delaware Basin and the vicinity of the WIPP site would be either "breccia pipes" or H_2S-laden brine reservoirs. Careful attention was given in selecting the WIPP site to avoid such structures; further investigation has not revealed any such structures, therefore, no sulfur deposits are expected.

8.4.6 Lithium

Lithium occurs in a concentration of 140 mg/L in a saturated brine reservoir that was encountered during the drilling of ERDA 6. The hole was located 2 miles northeast of the outer boundary of the WIPP site. A similar reservoir was found in the Belco Hudson Federal No.1 gas well 1/4 mile outside Zone IV on the southwest side of the site. No analyses were done for lithium in the latter well, but both reservoirs were at equivalent stratigraphic positions (middle Castile), contained H_2S, and were fully saturated brines. The concentration of 140 ppm lithium in ERDA 6 verges on being economically extractable if the reservoir is of sufficient size. Griswold (1977) estimated the reservoir volume at ERDA 6 to be on the order of 100,000 to 1 million bbl. If reservoirs are limited to this size, they would not warrant development. At current market price the in-place value of the lithium would not exceed $1 million.

There has been a deliberate attempt to locate the WIPP site in an area free of brine reservoirs in the Castile. Extensive seismic surveys have been run across the area to ensure that no anomalous structures occur in the Castile Formation. The occurrences at ERDA 6 and at the Belco well are associated with complex anticlinal structures and are easily recognizable on seismic survey traces.

8.4.7 Potash

Method of Evaluation. Sylvite (KCl) and langbeinite ($K_2Mg_2(SO_4)_3$) exist under portions of the WIPP site (see Figures 8.2, 8.3, 8.4). Although an attempt was made to avoid such deposits during the site selection process, it was not possible to do so completely because other site selection factors such as avoiding deep oil and gas test wells and the desire for uniform and thick salt beds at reasonable depth took precedence.

The potash evaluation commenced in August, 1976, after the site was chosen for detailed characterization. When chosen, the site was located mostly outside the Known Potash Area defined by the Conservation Division of the U.S. Geological Survey. Considerable potash exploratory drilling had been done on the flanks of the site area by private industry, but it is a requirement that the results of that drilling be held in confidence by the USGS. However, Sandia Laboratories contacted each mining company that had drilled in the vicinity and was granted access to the drill records on a private basis. These records indicated that deposits of commercial quality probably extended into the site area. The Department of Energy (then ERDA) authorized an exploratory drilling program to evaluate the potash deposits within the WIPP site. Technical direction of this exploratory drilling program was given to the USGS. The drilling program commenced in August and was completed by the end of November, 1976.

The Roswell, New Mexico, office of the Conservation Division of the USGS was given the task of determining potash resources by combining the results of DOE-sponsored drilling with records of drilling in the vicinity of the site. Findings have been reported by John et al. (1978).

The DOE also engaged the services of the U.S Bureau of Mines (USBM) to evaluate the extent to which the resources defined by the USGS could be produced at a profit using existing mining and beneficiation practices. The results of the study have been reported by the USBM (1977). The essential conclusion was that langbeinite in the 4th ore zone could be profitably mined in the northeast quadrant of the WIPP site. A band of sylvite, contained mostly within the 10th ore zone on the north and west sides of the sites, verged on being economically exploitable. Profitable mining of the sylvite would require a higher price for muriate (KCl) than current market value ($52/ton versus a current price of $43/ton).

<u>Description of the Potash Exploration Drilling Phase</u>. Figure 8-1 is a map showing a land block, centered on the WIPP site, that measures 8 miles on a side. This land block constitutes the area investigated by

the USGS and USBM. All locations of drill holes are shown from which information was available as to the depth, thickness, grade, and mineral suite of ore beds. Note that a different symbol is used to denote holes drilled by DOE from those drilled by mining companies. Examination of the distribution of hole locations reveals that the drilling plan directed by the USGS included testing the entire WIPP area on a spacing of not less than one hole per square mile. The objective was to completely cover the site area following industry practice for reconnaisance exploration. The density of the holes is judged to be quite adequate for resource appraisal.

Drilling closely followed standard industry practices (Jones, 1978). Rotary techniques were used from the surface down to a point just above the uppermost ore zone. Drilling operations were then converted to coring using a brine saturated with potassium chloride as the drilling fluid. Core recovery was excellent in all 21 holes. The core recovered was examined, and zones of interest were "split" for chemical analysis. Routine check analyses were done by an independent laboratory. All cores, including the remaining half of sample splits and sample rejects (excess after assay), have been permanently stored.

The results of the analyses of the 21 exploratory holes are attached as Appendix 8A. Included in the list are hole AEC 8 (drilled at the old ORNL site) and 17 holes for which information is available for release either by permission of the mining company involved or because the lease or permit on which the hole was drilled has expired.

Calculation of Potash Resource Distribution, Volume and Grade. As previously stated, calculation of the in-place volume and grade was undertaken by the Roswell office of the Conservation Division of the USGS. Technical assistance was also provided by the Special Projects Branch of the USGS.

There are 61 exploratory holes in the 8 x 8 mile land block shown in Figure 8-1. Ore intercept information was available to the USGS on all

of these holes. Thus, while their calculations used all available data, some specific information pertaining to 22 industry drilled holes is not reported in Appendix 8A to protect proprietary information of individual companies as they so requested.

The reserve calculation commenced with assigning depth intercepts to significant mineralization within the various ore zones. There are 11 such ore zones within the McNutt member of the Salado Formation (see *Figure 4.3-3b*). The next step consisted of extrapolating continuity of individual ore zones between holes. The final step was to calculate the volume and grade for continuous blocks of mineralization. In addition, the Conservation Division utilized criteria they have established for classifying resources as either measured, indicated, unevaluated, or barren. The criteria are:

Measured potash reserves - Tonnage is computed from dimensions revealed in workings and drill holes. The grade is computed from the results of detailed sampling and analyses. A minimum of three data points in any one ore zone meeting quality and thickness standards, no more than 1 1/2 miles (2.4 km) apart, have been used to delineate measured reserves.

Indicated potash reserves - Tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout.

Unevaluated potash areas - Tonnage and grade have not been computed due to low density drilling and sampling, but are surrounded by measured and (or) indicated reserves.

Barren and/or minor potash mineralization areas - Subeconomic resources that would require a substantially higher market value or a major cost-reducing technology for economical production.

Subeconomic resources also include other bittern minerals not presently being recovered.

Potash resources were then quantified at three minimum grade and thickness levels. Standard conditions for each class are shown in Table 8.6.

The intermediate conditions, termed "lease", conform with established policy of the Department of Interior that any area known to contain potash mineralization meeting or exceeding that standard and located on Federal land can be acquired only through competitive bid. The standard is based on judgment along with recognition that ores as low as these grades have been successfully treated from time to time at one or more of the potash refineries in the Carlsbad district. The conditions termed "high" are roughly equivalent to the grade of langbeinite and sylvite ores currently being mined in the district.

Results of the USGS Resource Estimate. The essential results of the USGS resource calculations are best shown by three consecutive maps (Figures 8-2, 3 and 4) which commence with the lowest resource grade standards and progress to the highest. For simplicity, measured and indicated resources were combined. The majority of the resource meets the criteria for "measured" because the entire WIPP site has been drilled on one mile centers. The resource maps do not segregate the several mineralized ore zones, and at times they are "stacked", e.g. the 4th and 10th may be mineralized in the same area in plan even though they are stratigraphically separated by about 180 feet.

Most of the WIPP site area is underlain by potash resources that meet the low standards. No significant planimetric change occurs on raising the standard to lease grades. However, at the high standard, which is roughly equivalent to the current standard of producing mines, the WIPP is nearly clear of potash deposits of interest (particularly Zones I-III). Mining operations may be allowed in Zone IV, the outer boundary of the WIPP site, under controlled conditions.

As grade standards are increased, the potash resources reduce, at more rapid rate on a mass weight basis than on a planimetric basis. Table 8-7 lists the tonnage of by ore zone, type, and location by Zone boundaries within the WIPP site.

For ease in interpretation, the data in Table 8-7 has been charted on Figures 8-5 and 8-6 for langbeinite and sylvite resources, respectively. The USGS recognized the 4th ore zone (langbeinite) and the 10th (mainly sylvite) as the two major mineralized ore zones in the WIPP site area (John et al., 1977). At lease grade, the 4th ore zone contains 115.4 million tons of langbeinite resource, of which only 24 million tons (21%) lies inside the outer boundary of Zone III. At the higher grade (8% K_2O as langbeinite) the tonnage under the WIPP reduces to 59 million tons, of which only 14.6 million tons (25%) lies inside the outer boundary of Zone III.

The 10th ore zone contains mostly sylvite, but a mixed assemblage containing both langbeinite and sylvite exists on the east side of the withdrawal area. At present only one operator in the Carlsbad district has a refinery capable of handling such ores. This operator is the leaseholder over part of this mixed ore zone. However, the langbeinite in the 10th ore zone would be difficult to beneficiate according to the USBM study (USBM, 1977, p.103). Therefore, the 10th ore zone is considered to be viable only for its sylvite content. With this restriction, the 10th ore zone contains 53.5 million tons of ore at lease standard under the entire WIPP site, of which 30.4 million tons (57%) are located within the outer boundary of Zone III. At the high standard, the total tonnage reduces to 38.8 million tons, of which only 9.8 million tons (25%) are inside Zone III.

Results of the USBM Valuation of Potash Resources. The USBM has performed an economic assessment of the potash resources that were defined by the USGS. The USBM study included beneficiation testing to determine the amenability of the various mineral assemblages to refining into marketable products. The USBM engineers visited most of the mines in the district to gather data concerning mining and refining techniques, power consumption, water use, etc. Then, knowing the location and grade

of potash deposits in the WIPP site area, they devised conceptual designs of various mining and processing facilities that would provide both the highest profit and efficient recovery of marketable products from the potash deposits. The approach followed what private industry would do in an evaluation of a potash prospect. No restriction was placed as to where physical mining could be done, or problems related to land acquisition or permitting. Resources adjacent to the WIPP site were considered in the mine development plans. In all, the USBM conceived 12 different conceptual plans for exploiting potash in this area. Each plan, called a mining unit, was evaluated leading to a conclusion that 8 were worthy of full cost analysis. The full findings have been reported by the USBM (1977).

The USBM concluded that only one mining unit (Unit B-1) could be considered economic under existing market conditions and technology (see Table 8.8).

Unit A-1 almost meets the economic requirement of 15% rate of return on invested capital set by the USBM. To make it viable one needs a price of $52.04 per ton of muriate without any increase in production costs. Muriate is currently selling at $43.40 for standard grade containing 62% K_2O (Source: July 1978 issue of Engineering and Mining Journal); however, the price for muriate has exceeded $60 per ton in the past.

Data within the USBM report indicate that the langbeinite resources associated with the Unit B-1 that lie within the boundary of WIPP amount to 48.46 million tons, of which only 13.33 million tons (27.5%) lie inside the outer boundary of Zone III. For Unit A-1 the corresponding numbers are 27.41 million and 0.9 million tons.

Summary of Conclusions Concerning Potash Resources in the WIPP Site. The site contains economically mineable reserves of langbeinite and possibly sylvite. If total rights withdrawal is a requirement to satisfy waste isolation, then the relevant quantities of potash resources are much greater than if mining is allowed in the Zone IV, the outer buffer zone. The relevant quantities are presented in Table 8-9.

The USGS has estimated that potash resources in southeast New Mexico (excluding the WIPP site) that meet lease standards are on the order of 5000 million tons of combined sylvite and langbeinite ores. Therefore, total withdrawal of potash lease rights at the WIPP site would account for about 7% of those resources; withdrawal of Zone I, II, and III rights would account for about 2%. No data are available for the Carlsbad potash district regarding what percentage of these resources would meet the standards deemed by the USBM to be mineable under today's conditions. In addition, the principal potash resource at the WIPP site consists of langbeinite. No estimates, either by USGS or USBM standards, are available for this ore alone. The Carlsbad district is the only area mining langbeinite in the free world. Langbeinite equivalent is produced in quantity, however, by combining sulfates of potassium and magnesium obtained from brine lakes. When the site was initially selected, most of the WIPP lay outside the Known Potash Area, however the 21 hole drilling program conducted as part of the WIPP potash evaluation resulted in discoveries sufficient to warrant expansion of that boundary (see Figure 8-1). The expansion conforms with USGS policy that potash resources meeting the lease standard must be placed within the enclave.

8.4.8 Hydrocarbons

Method of Evaluation. The WIPP site selection criteria dictated that deep drill holes (defined as those that penetrate through the Ochoan) be excluded from Zones I, II, and III. The objective was to maintain a one mile buffer between deep holes and Zone II, the zone in which waste is to be stored. This particular criterion is restrictive, because much of the Delaware Basin has been penetrated by wildcat test holes with an average density of about one hole per square mile. The present site is one of the few remaining portions of the Delaware Basin in New Mexico which will satisfy the criterion pertaining to deep holes. The absence of extensive drilling is due in part to the great depth (greater than 10,000 feet) to potentially favorable gas formations. In addition, potash deposits north and west of the site area precluded oil and gas exploration in those directions. Federal and State regulations have set aside potash

ineralized areas to protect underground mining operations from accidental entrance of methane gas. Therefore, most of the WIPP site is untested for deep reservoirs that might contain crude oil and natural gas. The evaluation must rely on projection of surrounding subsurface geologic information into the site area. There are four petroleum test holes in Zone IV of the WIPP site. Three holes tested the Delaware sands and were unproductive. The fourth was a deep gas test (15,000 feet) that was also unproductive.

The State Bureau of Mines and Mineral Resources performed a regional evaluation of the hydrocarbon resources in southeast New Mexico which was then used to further evaluate a four township area centered on the original ORNL site (Foster, 1974). This report is useful for the current WIPP site because, as indicated in Figure 8-7, the present site is still within the area studied.

Data contained in Foster's report provide a basis for estimating total hydrocarbon resources that might underlie the site area. By using a statistical approach, Foster arrived at a possible hydrocarbon content for each potential productive zone, commencing with the "Ramsey Sand," down to the top of the Precambrian basement. The Ramsey, the first potential pay zone, is located in the upper part of the Delaware Mountain Group. The lowest zones he considered to be potentially productive were dolomitic reservoirs in the Silurian/Devonian. His estimate was based on full development of any prospective area; therefore, total resources were estimated rather than the economics associated with their extraction. His resource estimate was based on the premise that geologic conditions beneath the site were as favorable as elsewhere in the study area and that each potential zone beneath an untested section would contain a proportionate share of the statistical average of hydrocarbons for that zone. The average was derived from success ratios and a conservative estimate of primary recovery of hydrocarbons as established by past exploration, development and production.

A consulting petroleum engineering firm, Sipes, Williamson and Aycock, Inc (SW&A), was engaged by Sandia Laboratories to conduct an economic evaluation of hydrocarbons in the site area. Based on known drilling costs and market conditions, they made a judgment as to what portion and which formations under the site were worthy of testing. The basic criterion was reasonable prospect for discovery with an economic reward to the operator of at least 10% return on his investment plus full recovery of costs. The essential conclusion of the SW&A study was that the Morrow unit has a high potential for successful discovery of natural gas. All other formations present were considered too high a risk to be the objective of a prudent wildcat test. Naturally, once a Morrow well was drilled it could encounter shallower productive pay zones, but the odds of such happening were deemed too speculative to be considered in the overall economics. The full findings of this study have been reported by Keesey (1976).

Structure maps of several horizons beneath the Ochoan evaporites have been compiled from seismic surveys that were either purchased from existing surveys or conducted as part of the WIPP site study. While the main purpose of these seismic surveys has been to understand the geologic aspects of the site area, they are also valuable for interpretation of potential hydrocarbon reservoirs. These structure maps were not available to Foster for his 1974 study, but they were to SW&A during their 1976 evaluation. The seismic studies have been reported by McMillan (1976) and G. J. Long & Associates (1976). Updated structural interpretations based on later seismic studies are now available. The recent changes have had little impact on the overall hydrocarbon evaluation.

Total Hydrocarbon Resources at the WIPP Site. The New Mexico Bureau of Mines study forms the basis of the evaluation of the total hydrocarbon resources in the site area (Foster, 1974). We assume there is a reasonable probability that Foster's estimated resources could exist under the site. However, this probably represents the upper bound of exploitable hydrocarbons.

The validity of the resource estimate rests on the subsurface geology and statistical probability. The geologic setting under the Ochoan evaporites is considered to be quite typical for this portion of the Delaware Basin; therefore the chance of finding oil or gas should approximate what has been found in similar areas near the site which have been more fully tested. However, since it is a regional statistical approach, it is possible that much more or much less than the average expected resource would be found if the site was actually drilled. The hydrocarbon evaluation is not as definitive as that for potash, which was actually confirmed by exploratory drilling. This would be self-defeating in the case of the deeper hydrocarbon resources since the area was selected to avoid such deep drill holes.

Foster's evaluation (Foster, 1974) took into account the occurrence of all known oil and gas accumulations in much of southeast New Mexico (Figure 8-7). The statistical base encompassed about 42 full townships equivalent to almost 1 million acres. The reserves for each oil pool or gas reservoir were estimated from the standpoint of actual or, where possible, projected production. Areas were then classed as developed or undeveloped based on the density and depth of drilling. From these data, Foster (1974) then determined the expected resource per section of land by assuming that the success of future drilling would have the same success ratio as in the past. A coincident assumption was that, while past wildcat drilling avoided the current WIPP site, the past economic incentive for drilling was low. Also, drilling restrictions pertaining to the Known Potash Enclave have prevented drilling, particularly on the west side of the WIPP area. There were more attractive areas available throughout the basin that satisfied the availability of private venture for exploration capital. These past constraints do not enter into the hydrocarbon potential estimates because the characterization of the site must take into consideration the long-term needs for mineral resources.

Figure 8-8 is taken from Foster (1974). Formations that he considered as potentially productive are shown opposite the stratigraphic column of sedimentary rocks underlying the Ochoan evaporites. Table 8-10 then

shows the potential resource he assigned to the various specific intervals but which were composited to more gross intervals. Further explanation is required pertaining to "wildcat" and "acreage" assignment of reserves.

The acreage method tests the success ratio of producing acreage versus the acreage considered to have been tested by wildcat drilling. The wildcat method considered a field, regardless of the number of wells in that field, as a single discovery. A success ratio was then determined by dividing the number of wildcat discoveries by the number of dry holes that were drilled to that formational depth. The acreage method normally results in a higher success ratio and, therefore, higher reserve estimates. In-place hydrocarbon resources for each zone within the WIPP site can be readily calculated from Foster's data by combining his estimate of in-place hydrocarbon resources per section (640 acres) with the known area for each zone of the WIPP site. The acreage method was used to prepare Table 8-11.

While the quantities given in Table 8-11 may appear large, they are brought into perspective by stating that all of the nearby region, i.e., the area studied by Foster, would contain 51 times the resource quantity under the WIPP site. The factor is simply the ratio of the total area evaluated by Foster (1512 square miles) divided by the area of the WIPP site (29.62 square miles). In addition, if hydrocarbon development is allowed in Zone IV, e.g., by deviated drilling, then the resource that would be withdrawn is reduced in proportion to the excluded area, i.e., from 29.62 square miles down to 12.73 square miles for a 43% reduction in restricted resources. The hydrocarbon resources remaining in Zones I, II, and III would account for only 0.84% of the total hydrocarbon resources Foster has estimated in the area immediately surrounding the WIPP site.

Estimate of the Economically Recoverable Hydrocarbon Resources. Sipes, Williamson, and Aycock, Inc. (SW&A) estimated the potentially economic hydrocarbon resources (Keesey, 1976). Their approach was to review the

existing geologic information pertaining to the area in and around the site and then to determine if the probability of oil and gas occurrences justified the risk of drilling and completing a well. The base area studied by SW&A consisted of a 20 x 20 mile block centered on the WIPP site (Figure 8-7). All available data were evaluated on each test that had been drilled within this 400 square mile area, with particular emphasis placed on deliverability and recoverable reserves.

SW&A found that 60 wells in this area were producing oil and/or gas from reservoirs in the Delaware Mountain, Bone Spring, Wolfcamp, Strawn, Atoka and Morrow. With the exception of the Atoka and Morrow, all other zones were considered as presenting too high a risk to justify the cost of wildcat drilling. Furthermore, even though an Atoka reservoir is being produced from a well located near the southwest corner of the WIPP site, SW&A concluded that that particular reservoir is being effectively drained by the single well. Offset drilling would enhance recovery rate but not total recovery.

The Morrow was considered to be worthy of testing, because of the high success ratio of wells drilled to that formation in the area around the site. Of 26 wells drilled to sufficient depth to test the Morrow, 23 were successfully completed as gas wells. A study of these wells revealed that the projected ultimate recovery ranged from insignificant to as much as 5.20 billion cubic feet (bcf) of natural gas. From the distribution of recoveries they concluded that the average successful Morrow well would recover 2.074 bcf of gas. This is in fair agreement with Foster's estimate for Pennsylvanian gas wells; he estimated 3.2 bcf per Morrow gas well if spaced at 320 acres per well.

Drilling and completion costs were then estimated for wells drilled to the Morrow (approximately 14,000 ft.). The estimate was $1.4 million. Using discounted cash flow analysis and the expected delivery rate and current gas price ($1.42 per 1,000 cu. ft. with 4% yearly escalation) they concluded that if a well produced 0.7 bcf over its lifetime it would

recover costs. Since the average well was more than twice this production, it was apparent that drilling in the site area could be justified.

Use was then made of the structure map on a limestone reflector horizon in the Morrow based on data from seismic surveys (Figure 8-9) (Long, 1976). Tentative drilling sites were picked with weight given to the flanks of anticlines because local experience indicates that productive sand lenses would more likely occur at such localities. A total of 20 drill sites was selected (Figure 8-9). In favorable structural areas wells were placed on a spacing of 320 acres per well. This spacing is standard practice for wells of this depth in New Mexico. Depending on proximity to producing wells and structural favorability, the 20 wells were ranked as proven, probable or possible. The proven category was limited to locations that would offset producing wells in the Los Medanos field. Two locations were designated as proven, nine as probable, and nine as possible.

The ultimate recovery of wells was adjusted to take into account the risk factor associated with wildcat drilling. Proven wells were assigned production of 2.07 bcf, probable wells 1.64 bcf, and possible wells 1.33 bcf per well for the southwest quadrant of the WIPP site. The estimated reserves for locations in other parts were placed at 2.09 bcf for probable and 1.67 bcf for possible reserves. No locations could be considered as proven. The higher reserves assigned to these locations were considered justifiable because shallower pay zones may be discovered on the way down to the Morrow. This calculation yielded a total reserve of 36.85 bcf of natural gas under the WIPP site (Table 8-12). Some distillate would accompany this gas production. Foster (1974) estimated that Pennsylvanian gas is accompanied by 14,950 barrels of distillate per bcf of natural gas produced. Therefore, the 36.85 bcf of reserve under the site should be expected to be accompanied by 550,900 bbl distillate.

Of the 20 drilling sites selected, 7 lie in Zone IV, 2 of which are ranked as proven, 4 as probable, and 1 as possible. The aggregate

reserve of these 7 wells is 13.38 bcf of natural gas and 200,000 bbl of distillate. If drilling is allowed into Zone IV these hypothetical reserves could be recovered. The net balance that would be non-recoverable because of restrictions on drilling in Zones I, II, and III is 23.47 bcf of natural gas and 350,000 bbl of distillate.

Summary of Conclusion Concerning Hydrocarbon Resources. Table 8-13 summarizes the findings of the New Mexico Bureau of Mines resource study and the SW&A economic evaluation of the part of those resources considered attractive enough to be developed by the petroleum industry at 1977 prices and drilling costs.

The hydrocarbon resources remaining under the WIPP, if Zone IV is developed, amount to about 0.84% of that projected by Foster for the vicinity of the WIPP site. The total economic reserve, including Zone IV, amounts to approximately 90 days production of dry gas from southeast New Mexico.

8.4.9 Metalliferous Deposits in the Precambrian

Even the deepest oil/gas test near the WIPP site has not penetrated deep enough to encounter the Precambrian basement. A regional survey of test holes has been done by Foster and Stipp (1961). The basement may consist of slightly metamorphosed rhyolites and tuffs known as the Panhandle Volcanic Complex (Flawn, 1954). Such rocks hold potential for sulfide deposits. Geophysical techniques (induced polarization or electromagnetics) have a detection capability scarcely exceeding 1000 feet, while the Precambrian is at median depth of 18,000 feet beneath ground level at the WIPP site. No evaluation, therefore, is feasible for sulfide deposits. The depth is greater by a factor of almost two over the deepest mines in the world. Therefore, resources in the basement rocks, should they exist, are not likely to be attractive targets for exploitation.

8.5 SUMMARY

Potassium salts and fluid hydrocarbons are the only two resources thought to be economically significant in the WIPP site area. The depth, volume and richness of the deposits are the principal factors which will determine when and if they might be exploited by a free-enterprise system. Such economic evaluation has been conducted and reported in the WIPP Environmental Impact Statement. Because economic aspects change, they are not so relevant to site characterization as they are to assessing the impacts of constructing the WIPP facility. Hence, in this chapter, amounts and types of resources will be discussed rather than their present economic value. The principal findings of resource studies are summarized in Table 8-1.

If reasonable technologic and economic restraints are considered for extracting, processing and marketing the resources then both the amounts and types of exploitable deposits are greatly reduced. Only potash and natural gas are considered to be significant in this respect (see Table 8.2). Even these reduced quantities should be considered as upper estimates because of these assumptions: 1) complete mineral lease ownership by a single company and 2) no conflict between the simultaneous development of the shallow potash deposits and the deep gas reservoirs.

Economic resources are further reduced by allowing the mining of potash and recovery of oil and gas by deviated drilling in Zone IV, the outer buffer zone. If this is the case, then economic resources lying in the inner zones are limited to those given in Table 8-3.

Caliche, salt, and gypsum are also present, but the abundance of these minerals throughout the region leads to the conclusion that land withdrawal for the WIPP will have little effect on present or future requirements for them. Consideration was also given to the possible presence of uranium in redbed-type sediments that overlie the evaporites. The conclusion is that no significant uranium deposit exists. Lithium occurs in a brine reservoir within the Castile Formation

northeast of the present site and may be present in a similar reservoir to the southwest. However, care has been taken to avoid such brine reservoirs within the site area. Consideration was also given to the possible existence of metalliferous deposits in the Precambrian basement under the site. However, the depth (about 18,000 feet below the ground surface) to Precambrian rocks would preclude mining even if mineral concentrations were present. No geologic or geophysical evidence exists to suggest that deposits are any more likely in the basement rock of the WIPP area than elsewhere in the region.

8.6 REFERENCES

Flawn, P. T., 1954, Summary of Southeast New Mexico Basement Rocks: Guidebook of Fifth Field Conference, New Mexico Geological Society, p 114-116.

Foster, R. W., 1974, Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste: Open-file report, New Mexico Bureau of Mines and Mineral Resources (work done under Contract No. AF(40-1)-4423 to ORNL).

Foster, R. W. and Stipp, T. F., 1961, Preliminary Geologic and Relief Map of the Precambrian Rocks of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 57.

Griswold, G. B., 1977, Site Selection and Evaluation Studies of The Waste Isolation Pilot Plant (WIPP), Los Medanos, Eddy County, New Mexico: SAND77-0946, Sandia Laboratories.

John, C. B., Cheeseman, R. J., Lorenz, J. C. and Millgate, M. L., 1978, Potash Ore Reserves in the Proposed Waste Isolation Pilot Plant Area, Eddy County, New Mexico: U. S. Geol. Surv. Open-file report 78-828.

Jones, C.L., 1978, Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico: U.S. Geol. Surv. Open-file report 78-592.

Keesey, J. J., 1976, Hydrocarbon Evaluation Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico: Sipes, Williamson and Aycock, Inc., Vols. I and II.

G. J. Long and Associates, Inc., 1976, Interpretation of Geophysical Data, Los Medanos and Vicinity: Report to Sandia Laboratories.

McMillan, C., 1976, Los Medanos Area: Permian Exploration Co., Report to Sandia Laboratories.

Siemers, W. T., Hawley, J. W., Rautman, C., and Austin, G., 1978, Evaluation of the Mineral Potential (excluding hydrocarbons, potash and water) of the Waste Isolation Pilot Plant Site, Eddy County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Report to Sandia Laboratories.

U. S. Bureau of Mines, 1977, Valuation of Potash Occurrences Within the Waste Isolation Pilot Plant Site in Southeastern New Mexico: Prepared for the ERDA.

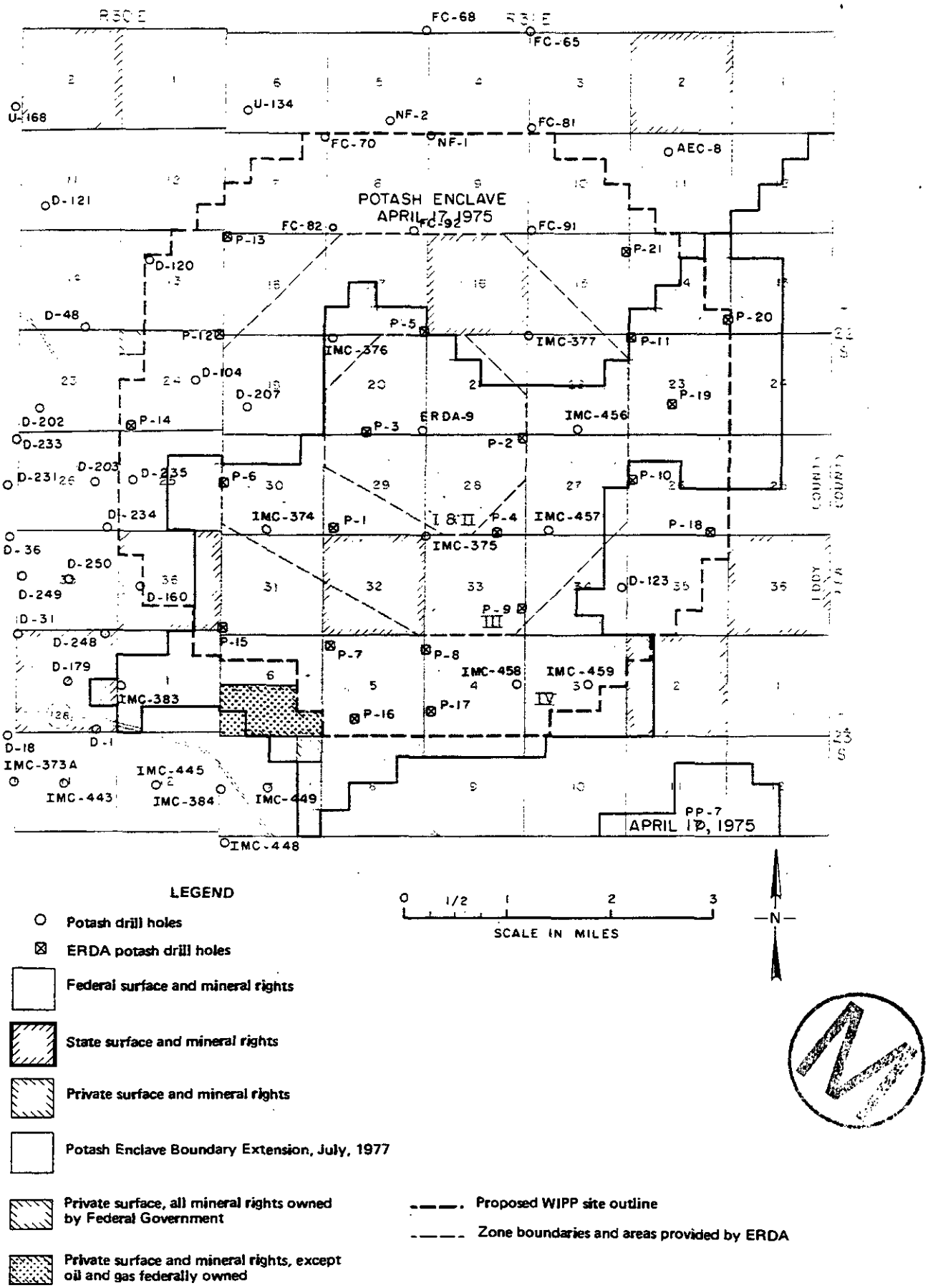

FIGURE 8-1
LOCATION OF POTASH EXPLORATION DRILL HOLES
IN THE VICINITY OF WIPP SITE

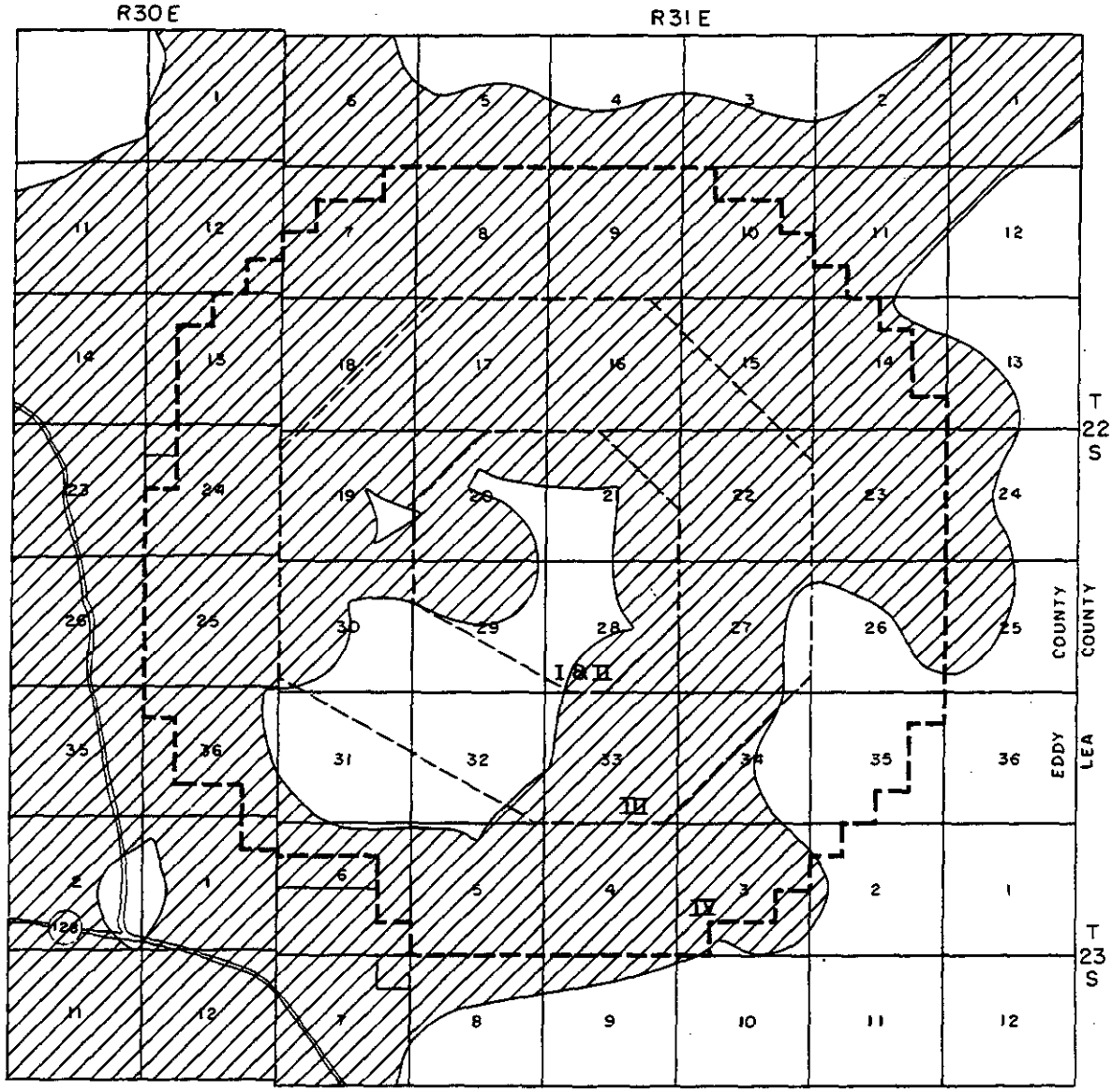

Data provided by USGS Conservation Division and ERDA

0 1/2 1 2 3
SCALE IN MILES

N

LEGEND

Proposed WIPP site outline

Zone boundaries and areas provided by ERDA

Measured and indicated mineralization

Measured and indicated mineralization are at a cut off of 3% K_2O as langbeinite or 8.0% K_2O as sylvite *or equivalent grade of mixed langbeinite-sylvite* occurring in a minimum 4-foot interval

FIGURE 8-2 LOW STANDARD POTASH RESOURCES

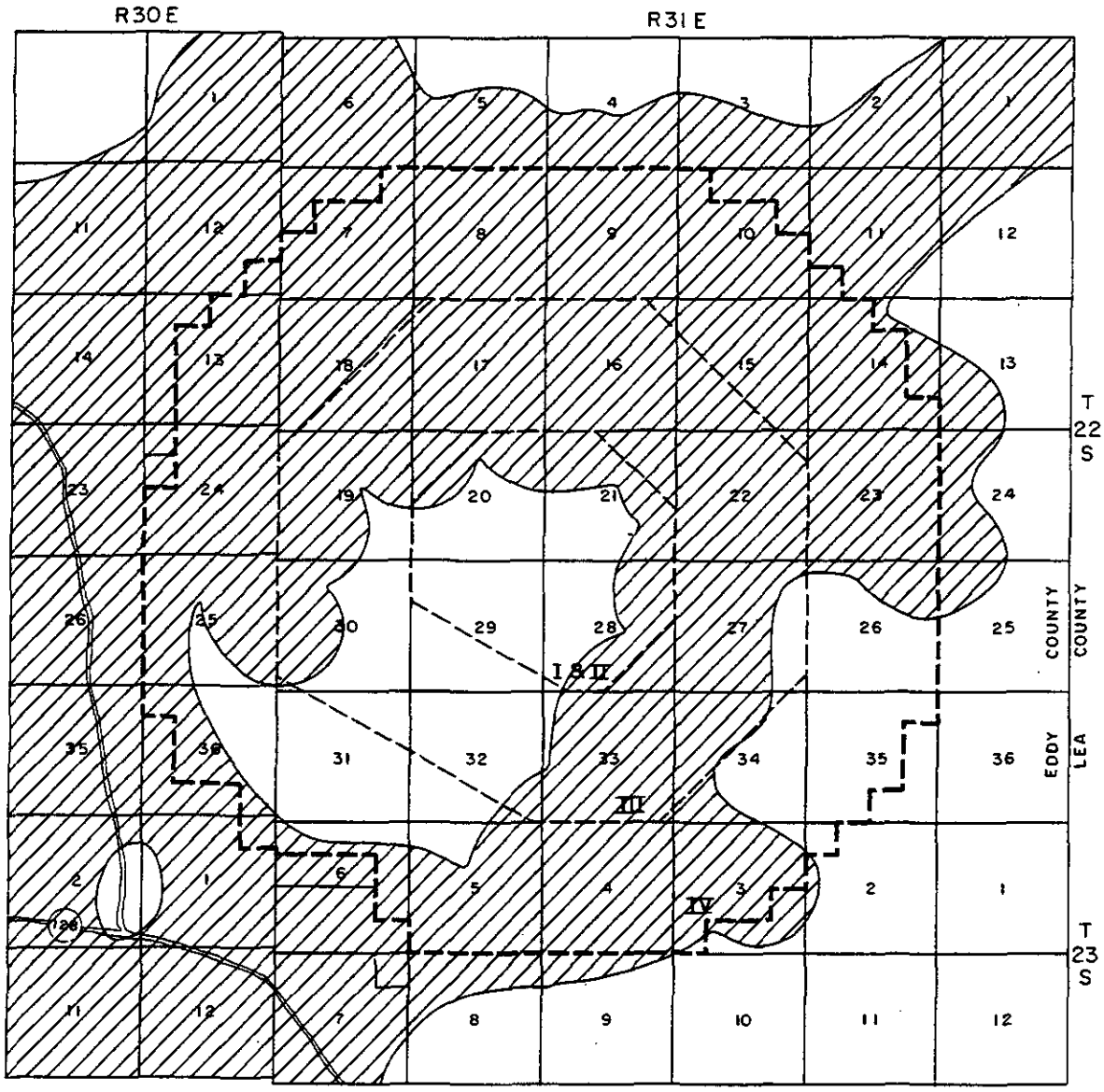

Data provided by USGS Conservation Division and ERDA

0 1/2 1 2 3
SCALE IN MILES

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LEGEND

Proposed WIPP site outline

Zone boundaries and areas provided by ERDA

Measured and indicated mineralization

Measured and indicated mineralization are at a cut off of 4% K_2O as langbeinite or 10.0% K_2O as sylvite or equivalent grade of mixed langbeinite-sylvite occurring in a minimum 4-foot interval

FIGURE 8-3 LEASE STANDARD POTASH RESOURCES

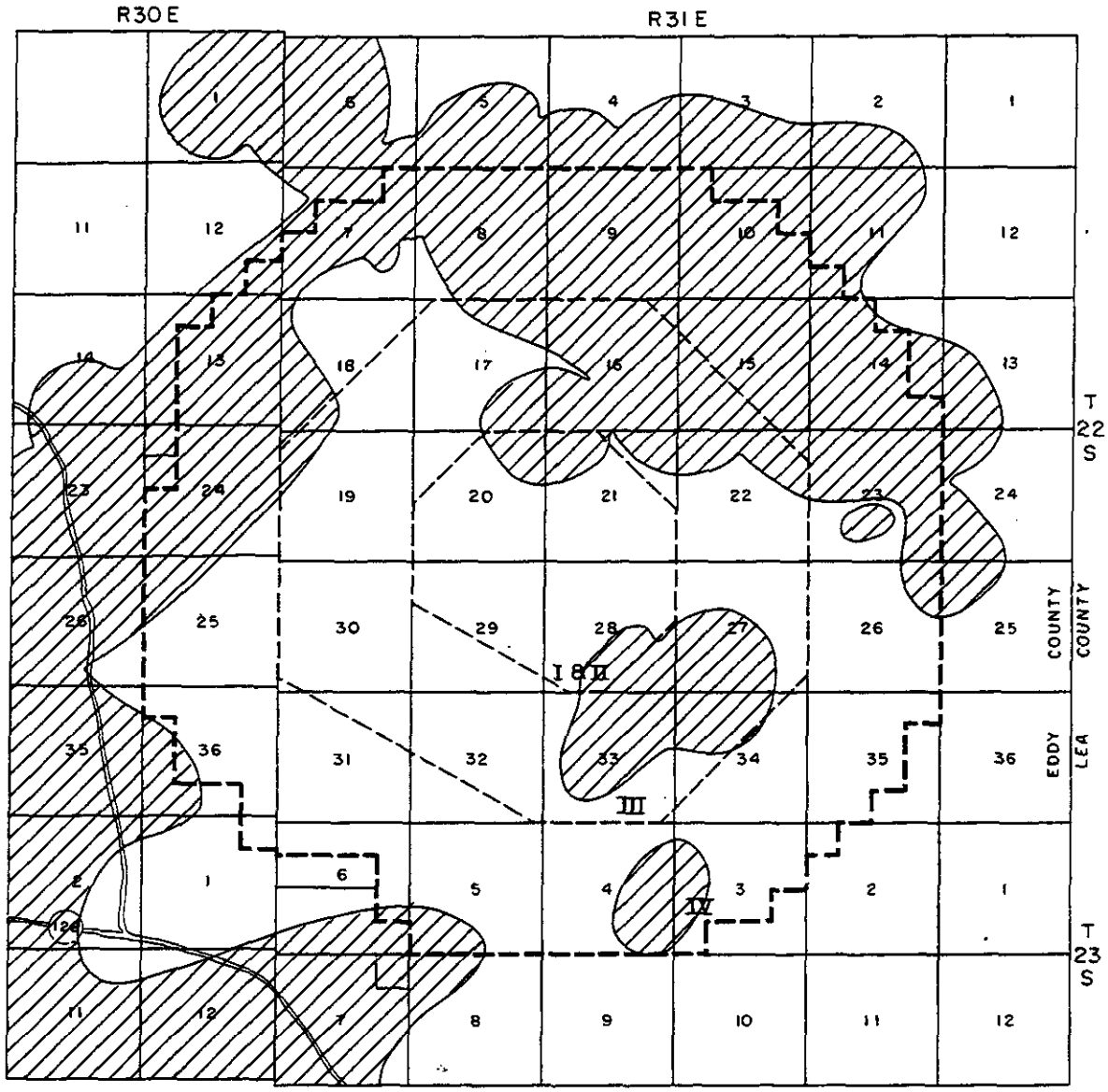

Data provided by USGS Conservation Division and ERDA

0 1/2 1 2 3
SCALE IN MILES

N

LEGEND

Proposed WIPP site outline

Zone boundaries and areas provided by ERDA

Measured and indicated mineralization

Measured and indicated mineralization are at a cutoff of 8% K_2O as langbeinite or 14.0% K_2O as sylvite or equivalent grade of mixed langbeenite-sylvite occurring in a minimum 4-foot interval

FIGURE 8-4 HIGH STANDARD POTASH RESOURCES

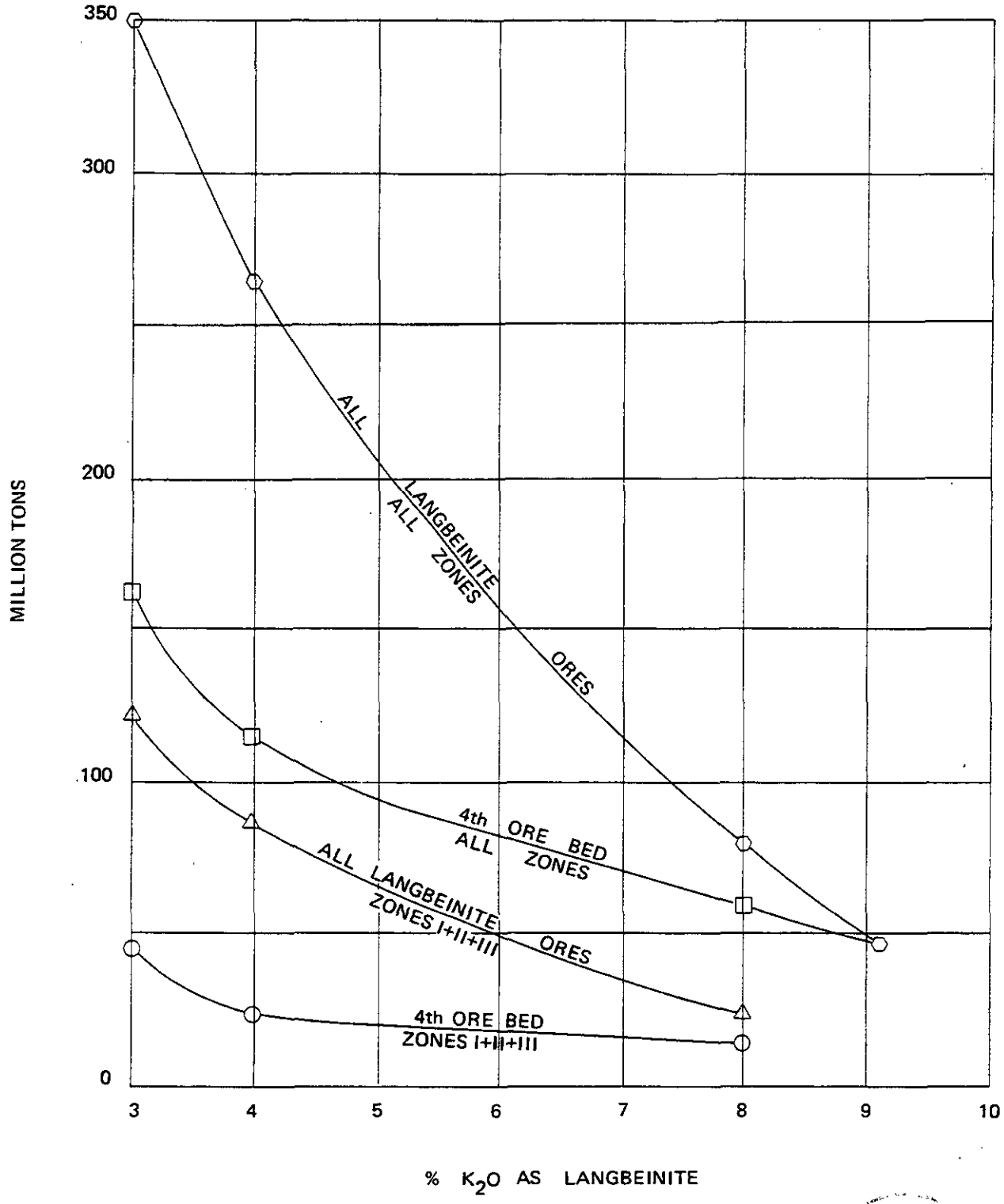

FIGURE 8-5. LANGBEINITE RESOURCES

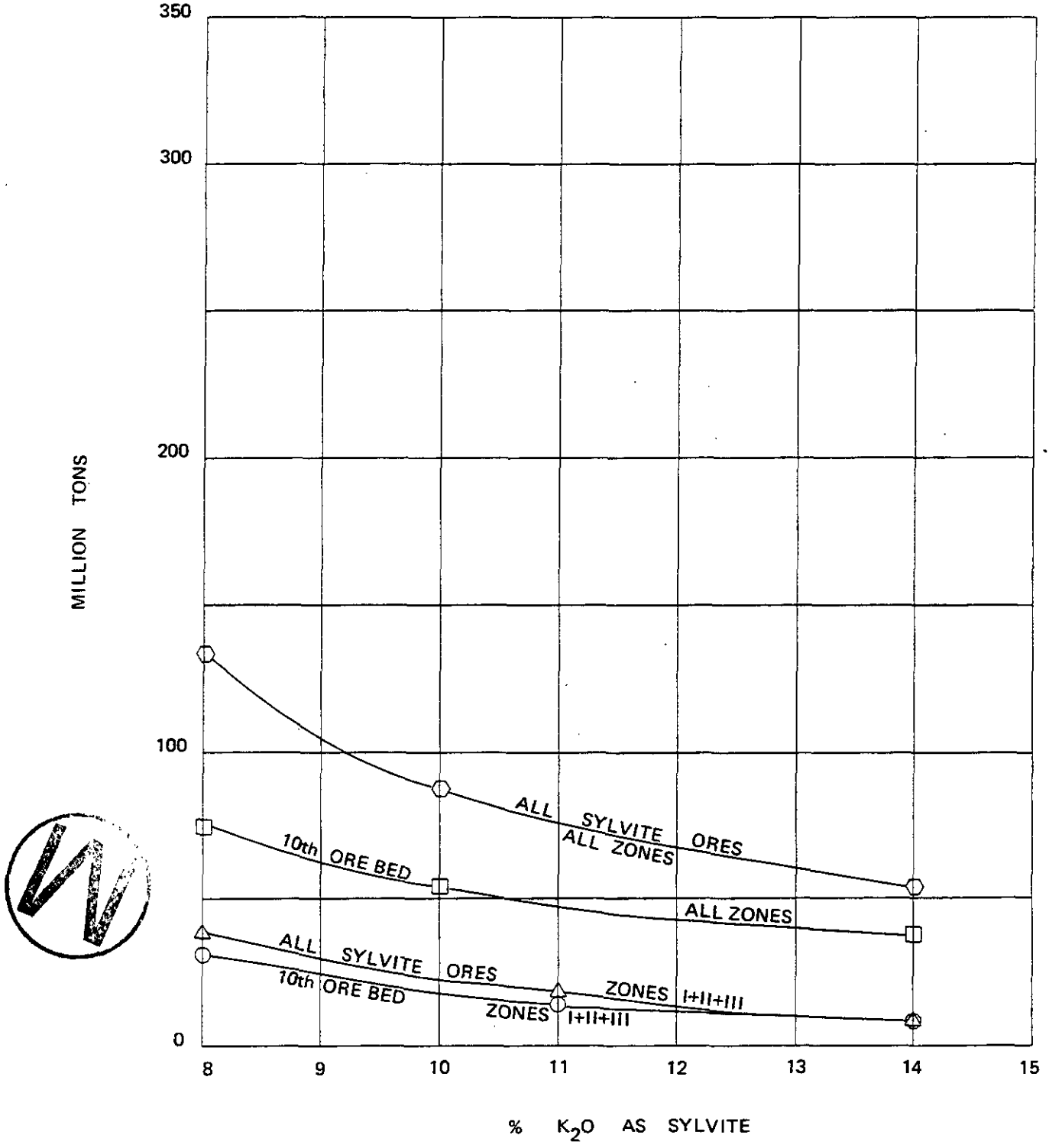

FIGURE 8-6. SYLVITE RESOURCES

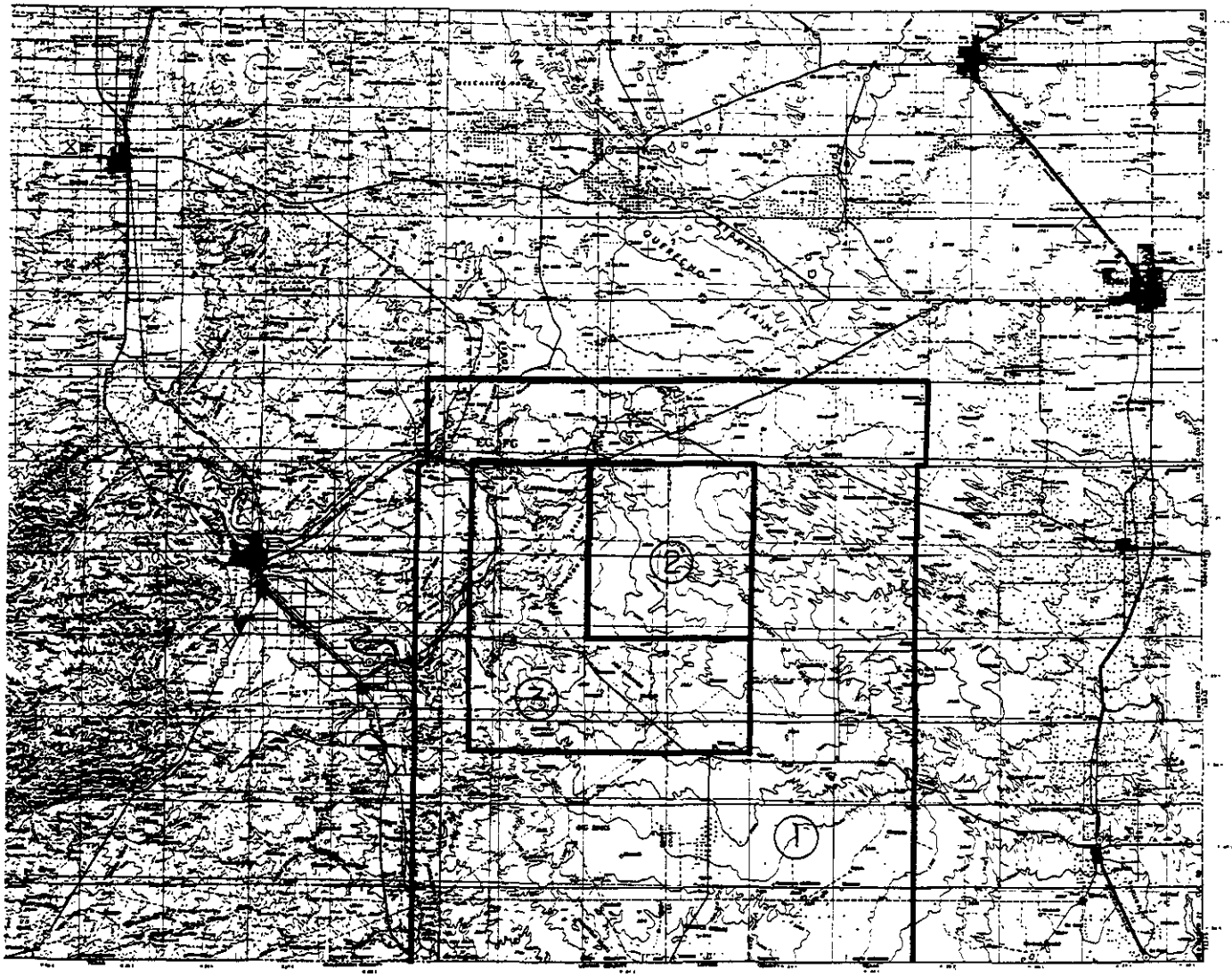

(1) NEW MEXICO BUREAU OF MINES STUDY AREA

(2) NEW MEXICO BUREAU OF MINES DETAILED STUDY CENTERED ON OLD ORNL SITE

(3) SIPES, WILLIAMSON AND AYCOCK STUDY AREA CENTERED ON WIPP SITE

FIGURE 8-7

LOCATION OF HYDROCARBON RESOURCE STUDY AREAS

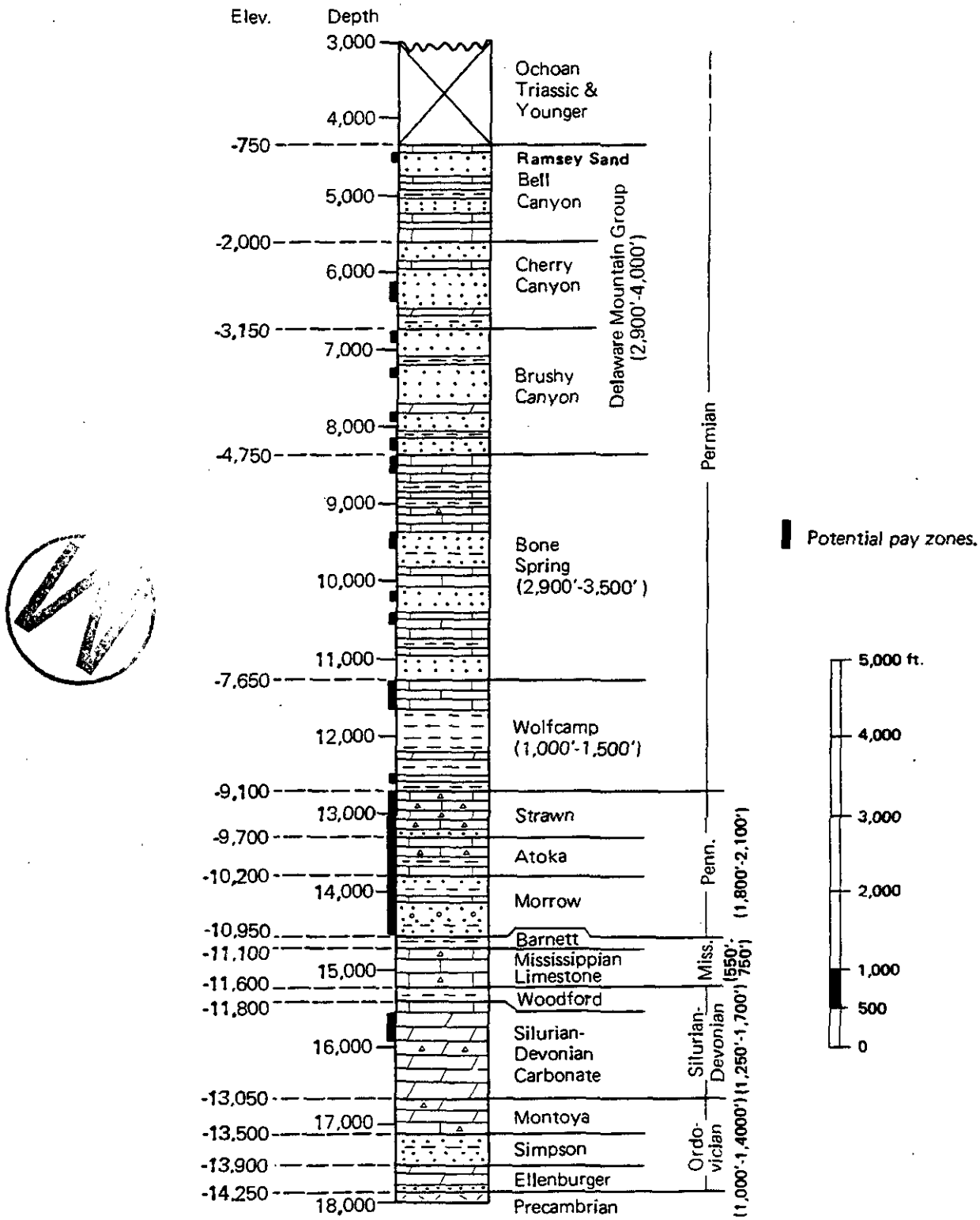

FIGURE 8-8. GEOLOGIC COLUMN AND POTENTIAL HYDROCARBON RESERVOIRS (ADAPTED FROM FOSTER, 1974)

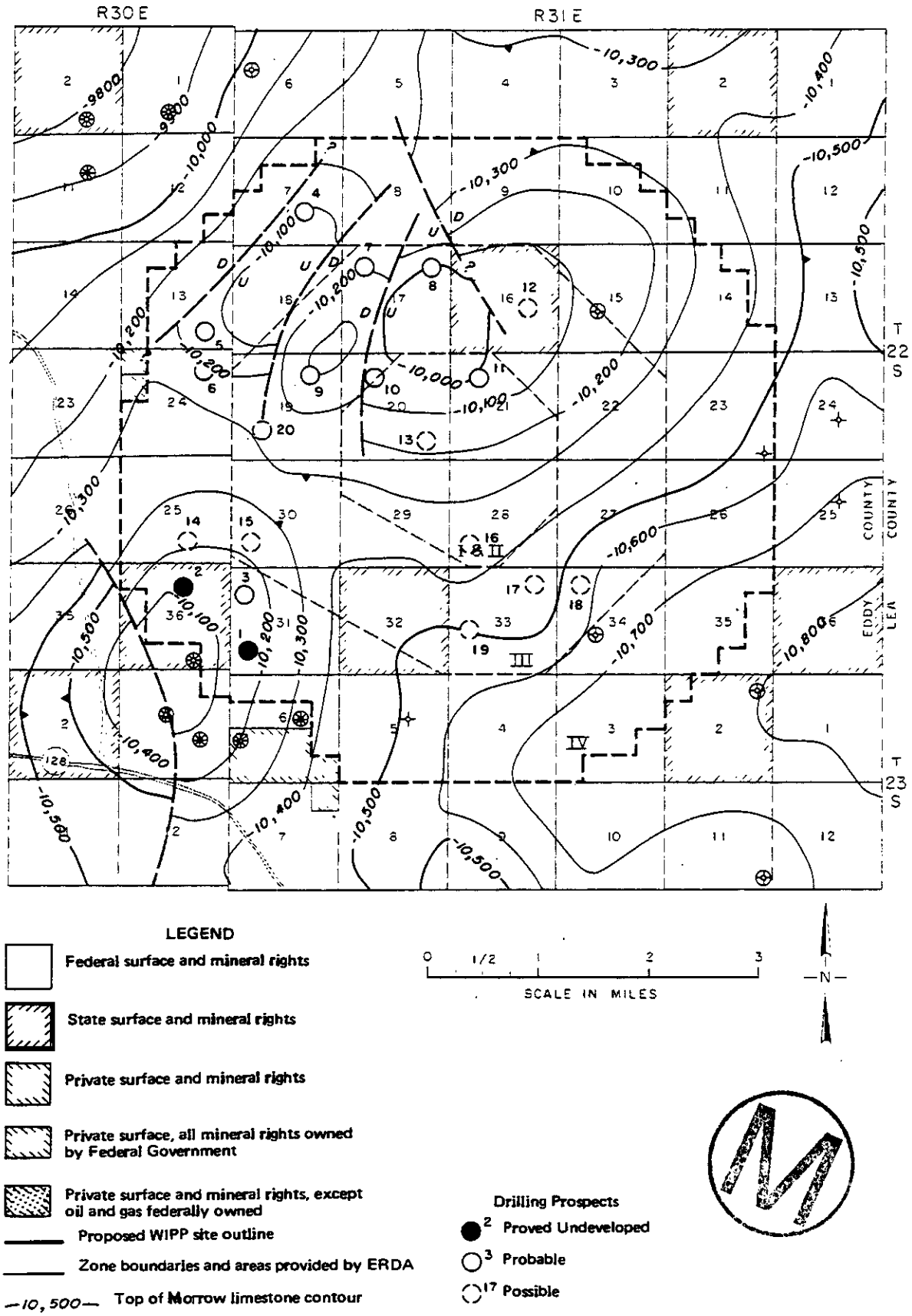

FIGURE 8-9

HYPOTHETICAL DRILLING SITES TO DEVELOP POTENTIAL MORROW GAS RESERVOIRS

TABLE 8-1

TOTAL ESTIMATED RESOURCES AT WIPP SITE

Resource	Quantity	Depth	Richness
Caliche	185×10^6 tons	at surface	21-69% Insol.
Gypsum	1.3×10^9 tons	300-1,500 feet	Pure to mixed
Salt	198×10^9 tons	500-4,000 feet	Pure to mixed
Sylvite	88.5×10^6 tons	1600 feet	11.8 K_2O
Langbeinite	264.8×10^6 tons	1800 feet	6.10 K_2O
Crude Oil	37.7×10^6 bbls	4,000-20,000 feet	31-46° API
Natural Gas	490×10^9 cu. ft.	4,000-20,000 feet	1100 BTU/cu ft
Distillate	5.72×10^6 bbls	4,000-20,000 feet	53-56° API

TABLE 8-2

POTENTIAL ECONOMIC RESOURCES AT WIPP SITE

Resource	Quantity	Depth	Richness
Sylvite	27.43×10^6 tons	1,600 feet	13.33% K_2O
Langbeinite	48.46×10^6 tons	1,800 feet	9.11% K_2O
Natural Gas	36.85×10^9 cu ft	14,000 feet	1,100 BTU/cu ft
Distillate	0.55×10^6 bbls	14,000 feet	53° API

TABLE 8-3

ECONOMIC RESOURCES WITHIN ZONE I, II AND III AT WIPP SITE

Resource	Quality	Depth	Richness
Langbeinite	10×10^6 tons	1,800 feet	10% K_2O
Natural Gas	20×10^9 cu ft	14,000 feet	1,100 BTU/cu ft
Distillate	132×10^3 bbls	14,000 feet	53° API

TABLE 8-4

ORGANIZATIONS RESPONSIBLE FOR RESOURCE EVALUATION AND KEY REPORTS CONCERNING RESOURCES

Organization	Responsibility	Reports
U.S. Geol Surv.	Potash Resources as related to ore grade and volume	John et al. (1978) Jones (1978)
U.S. Bur. of Mines	Determination as to what extent the potash resources reported by U.S.G.S could be economically mined and refined under today's technology and market	USBM (1977)
N.M. Bur. of Mines	Definition of resources and economics for caliche, salt, gypsum, brine, sulfur and uranium	Siemers et al. (1978)
N.M. Bur. of Mines	Oil and gas resources of a four township area which includes the WIPP site	Foster (1974)
Sipes, Williams and Aycock, Inc.	Determination of the economic viability of hydrocarbons under the WIPP site	Keesey (1976)
G.J. Long & Assoc. Inc., Permain Exploration Co.	Intrepretation of structure of Paleozoic sediments beneath Ochoan evaporites. These studies were useful in evaluation of hydrocarbons	Long (1976), McMillan (1976)

Table 8-5

POTENTIAL RESOURCES CORRELATED WITH STRATIGRAPHY

Formation	Thickness (ft)	General Character	Potential Resources	Evaluation
Mescalero Sand	0-15	Dune sand, fine grained	None	No resource
Caliche	0-5	Limestone, chalky	Caliche (in road construction)	Caliche is abundant throughout the area
Gatuna	0-375	Sandstone and siltstone	Uranium	Conditions apparently were oxidizing during deposition, and no uranium is apt to occur in the vicinity
Santa Rosa Sandstone		Sandstone	Uranium	Conditions apparently were oxidizing during deposition, and no uranium is apt to occur in this vicinity
Dewey Lake	487	Siltstone and sandstone some claystone	Uranium	Minor occurrences have been reported outside the WIPP site area. Gamma ray logs of 36 holes drilled within the site area showed no anomalies.
Rustler	310	Anhydrite and rock salt with subordinate dolomite, sandstone, claystone and polyhalite	Gypsum and salt	Abundant throughout the area, no advantage for site resources.
Salado	1976	Rock salt with subordinate anhydrite, polyhalite, potassium ores sandstone, and magnesite	Potassium salts, salt and gypsum	Langbeinite and sylvite occur in commercial quantities

Table 8-, (Continued)

Formation	Thickness(ft)	General Character	Potential Resources	Evaluation
Castile	1400	Anhydrite and rock salt with subordinate limestone	Sulfur, salt, lithium in brine reservoirs	Salt is abundant throughout the area. Lithium concentration in brine is subeconomic today. Care has been taken to exclude brine reservoirs from site. Conditions and structures for sulfur deposits not known to exist at site.
Delaware Mtn. Group	3800	Fine grained sandstone (possibly a siltstone), shale, limestone, and dolomite	Oil and associated gas. Most favorable zone is the Ramsey sand	Reservoirs may exist, but small in comparison with the Morrow Formation
Bone Spring	3400	Limestone, fine-grained sandstone, and black shale	Oil and associated gas	Reservoirs may exist, but are small in comparison to the Morrow Formation
Wolfcamp (Hueco)	1480	Limestone, black shale, red or green shale, sandstone, and conglomerate	Oil and gas	Reservoirs may exist, but are small in comparison to the Morrow Formation
Strawn	300	Limestone, oolitic limestone and gray to black shale	Oil and associated gas	Reservoirs may exist, but are small in comparison to the Morrow Formation
Atoka	640	Limestone, oolitic limestone and gray to black shale	Natural gas	Commercial gas is being produced from near site. Atoka reservoirs are restricted in size, therefore, small likelihood of existence under the site
Morrow	1300	Limestone, oolitic limestone, gray to black shale, and sandstone	Natural	Commercial quantities of gas probably exist

Table 8-5 (Continued)

Formation	Thickness (ft)	General Character	Potential Resources	Evaluation
Mississippian	740	Black, angillaceous shale, black calcareous shale or shaly limestone, some sandstone	None	None likely
Siluro Ordovician	2100	Limestone, dolomite, chert, shale, black shale with rounded quartz grain inclusions, and small amounts of sandstone	Oil and gas. Most favorable zone is beneath the Woodford Shale	Oil and gas may be present in anticlinal situations
Precambrian		Not tested with in the WIPP site locality. Regional inference is that it consists of acidic volcanics or metasediments	Sulfide deposits	Considered too deep to exploit.

References: Siemers et al., 1978; Foster, 1974.

TABLE 8-6
STANDARD CONDITIONS FOR POTASH RESOURCES

Class	Type Ore	% K_2O	Thickness, ft
Low	Langbeinite	3	4
	Sylvite	8	4
Lease	Langbeinite	4	4
	Sylvite	10	4
High	Langbeinite	8	4
	Sylvite	14	4

Reference: John et al, 1978.

Table 8-7

POTASH RESOURCES, TONS x 10^6

I. Sylvite Ores

Ore Zone	Low Grade			Lease Grade			High Grade		
	I+II+III	IV	Total	I+II+III	IV	Total	I+II+III	IV	Total
10	30.4	44.4	74.8	16.5	37.2	53.7	9.8	28.9	38.7
9	3.7	6.6	10.3	1.2	4.8	6.0	--	0.7	0.7
8	5.0	43.1	48.1	1.0	27.8	28.8	--	13.7	13.7
Total	39.1	94.1	133.2	18.7	69.8	88.5	9.8	43.3	53.1

II. Langbeinite Ores

Ore Zone	Low Grade			Lease Grade			High Grade		
	I+II+III	IV	Total	I+II+III	IV	Total	I+II+III	IV	Total
10	25.0	30.6	55.6	24.6	24.8	49.4	9.7	0.9	8.8
5	11.6	14.6	26.2	10.9	13.3	24.2	--	1.6	1.6
4	46.5	114.5	161.0	24.0	91.4	115.4	14.6	44.4	59.0
3	14.6	19.9	34.5	9.6	16.0	25.6	--	--	--
2	24.2	49.5	73.7	18.7	31.5	50.2	1.9	7.9	9.8
Total	121.9	229.1	351.0	87.8	177.0	264.8	24.4	54.8	79.2

III. All Ores

Ore Zone	Low Grade			Lease Grade			High Grade		
	I+II+III	IV	Total	I+II+III	IV	Total	I+II+III	IV	Total
10	55.4	75.0	130.4	41.1	62.0	103.1	17.7	29.8	47.5
9	3.7	6.6	10.3	1.2	4.8	6.0	--	0.7	0.7
8	5.0	43.1	48.1	1.0	27.8	28.8	--	13.7	13.7
5	11.6	14.6	26.2	10.9	13.3	24.2	--	1.6	1.6
4	46.5	114.5	161.0	24.0	91.4	115.4	14.6	44.4	59.0
3	14.6	19.9	34.5	9.6	16.0	25.6	--	--	--
2	24.2	49.5	73.7	18.7	31.5	50.2	1.9	7.9	9.8
Total	161.0	323.2	484.2	106.5	246.8	353.3	34.2	98.1	132.3

Reference: John et al., 1978.

Table 8-8

ECONOMIC POTASH RESOURCES, TONS x 10^6

Mining Unit	Products	Recoverable Ore in Mining Unit	Recoverable Ore in WIPP Site	Percent in Zones I,II,III	Price[1] that Provides a 15 Percent ROR[2], $
B-1	Langbeinite	79.78	48.46	27.5	35.00
	Sulphate			27.5	88.50
A-1	Muriate	57.60	27.41	3.2	52.04
D-2	Langbeinite	87.93	23.57	0.7	36.51
	Sulphate			0.7	92.31
A-2	Muriate	98.32	51.80	7.6	61.73
C-2	Muriate	57.19	36.49	54.2	61.74
D-3	Langbeinite	140.27	42.45	23.5	42.26
	Sulphate			23.5	106.86
C-3	Muriate	70.64	52.87	57.5	67.52
A-3	Muriate	135.02	73.77	14.9	70.28

[1]Market price assuming no increase in production costs. Estimated weighted average annual price per ton of product, f.o.b., Carlsbad, New Mexico, used for evaluation.

[2]Rate of return

Reference: U.S. Bureau of Mines, 1977.

Table 8-9

SUMMARY OF POTASH RESOURCES, 10^6 TONS

	In Place Resources (USGS Study)				Mineable Today (USBM Study)	
	Lease Standard		High Standard			
	Langbeinite	Sylvite	Langbeinite	Sylvite	Langbeinite	Sylvite
Total Withdrawal	264.8	88.5	79.2	53.1	48.46	27.41*
Mining Permitted in Zone IV	87.8	18.7	24.4	9.8	13.35	0.9

*The USBM does not consider the sylvite contained in Unit A-1 to be mineable under today's market. To do so would require the price for muriate to be $52.04 per ton, or the investor must be willing to accept a rate of return less than 15%.

Table 8-10

POTENTIAL HYDROCARBON RESOURCES
EXPECTED IN VARIOUS FORMATIONS WITHIN THE DELAWARE BASIN

Stratigraphic Unit	Rating: Geological Oil	Rating: Geological Gas	Rating: Statistical Oil	Rating: Statistical Gas	P.O.F.	Production Estimate Section (640 Acres): Acreage Oil (bbls)	Acreage Assoc. Gas (MCF)	Acreage Dist. (bbls)	Acreage Gas (MFC)	Wildcat Oil (bbls)	Wildcat Assoc. Gas (MFC)	Wildcat Dist. (bbls)	Wildcat Gas (MCF)	Adjusted Rating Oil	Adjusted Rating Gas
Ramsey	IV		V		62	472,350	756,324			75,052	120,141			IV	
Delaware Mtn. Gp.	II		II		21	51,686	19,546			34,462	13,029			II	
Bone Spring	III		IV		39	193,952	379,738			88,170	172,610			III	
Wolfcamp	III	III	II	II	23	20,800	228,462	32,544	633,984	20,475	224,953	19,530	383,969	III	III
Pennsylvania	III	V	III	V	88	265,455				299,788	1,784,799	94,596	6,441,672	IV	IV
Mississippian	I	I	I	I	14										
Silurian/ Devonian	III	III	IV	IV	72	1,368,330	656,676	36,720	4,244,310	343,422	164,804	36,562	4,225,491	I	IV
Ordovician	I	II	I	III	63										

Table 8-10 (Continued)

	Adjusted Production Estimate Section (640 Acres): Oil (bbls)	Acreage Assoc. Gas (MCF)	Acreage Dist. (bbls)	Acreage Gas (MFC)	Wildcat Oil (bbls)	Wildcat Assoc. Gas (MFC)	Wildcat Dist. (bbls)	Wildcat Gas (MCF)
Ramsey	472,350	756,324			75,052	120,141		
Delaware Mtn. Gp.	25,843	9,773			17,231	6,515		
Bone Spring	145,464	284,804			66,128	129,458		
Wolfcamp	15,600	171,347	24,408	475,488	15,356	168,715	14,648	287,979
Pennsylvanian	265,455	1,580,826	132,440	8,857,200	299,788	1,784,799	118,245	8,052,090
Mississippian								
Silurian Devonian	342,083	164,169	36,720	4,244,310	85,856	41,201	36,562	4,225,495
Ordovician								
	1,266,795	2,967,243	193,568	13,576,998	559,411	2,250,829	169,455	12,565,558

	Ratings	Calculated %
I:	Very low	25
II:	Low	50
III:	Moderate	75
IV:	High	100
V:	Very High	125

Taken from: R. W. Foster, 1974

Table 8-11

IN PLACE HYDROCARBON RESOURCES AT WIPP SITE*

Formation	Zone I+II+III			Zone IV			Total		
	Oil (bbls)	Nat. Gas (C.F.) ($\times 10^9$)	Dist. (bbls)	Oil (bbls)	Nat. Gas (C.F.) ($\times 10^9$)	Dist. (bbls)	Oil (bbls)	Nat. Gas (C.F.) ($\times 10^9$)	Dist. (bbls)
Ramsey	6.0×10^6	9.6		8.0×10^6	12.8		14.0×10^6	22.4	
Delaware Group	3.3×10^5	0.1		4.4×10^5	0.2		7.7×10^5	0.3	
Bone Spring	1.9×10^6	3.6		2.5×10^6	4.8		4.4×10^6	8.4	
Wolfcamp	2.0×10^5	8.2	3.1×10^5	2.6×10^5	10.9	4.0×10^5	4.6×10^5	19.1	7.1×10^5
Pennsylvanian	3.4×10^6	132.9	1.7×10^6	4.5×10^6	176.3	2.2×10^6	7.9×10^6	309.2	3.9×10^6
Mississippian									
Silurian/ Devonian	4.4×10^6	56.1	4.7×10^5	5.8×10^6	74.5	6.3×10^5	10.2×10^6	130.6	1.1×10^6
Ordovician									
Total	16.2×10^6	210.5	2.5×10^6	21.5×10^6	279.5	3.2×10^6	37.7×10^6	490.0	5.7×10^6

* Based on Adjusted Production Estimate per Section (640 acres), Acreage method, Table 8-10. WIPP site contains 29.6 square miles or sections.

TABLE 8-12
ESTIMATE OF ECONOMIC HYDROCARBON RESOURCES AT WIPP SITE

Well Number	Natural Gas (BCF) Zone I, II, III			Natural Gas (BCF) Zone IV			Natural GAS (BCF) Total		
	Proven	Probable	Possible	Proven	Probable	Possible	Proven	Probable	Possible
1	---	---	---	2.07	---	---	2.07	---	---
2	---	---	---	2.07	---	---	2.07	---	---
3	---	---	---	---	1.64	---	---	1.64	---
4	---	---	---	---	2.09	---	---	2.09	---
5	---	---	---	---	2.09	---	---	2.09	---
6	---	---	---	---	2.09	---	---	2.09	---
7	---	2.09	---	---	---	---	---	2.09	---
8	---	2.09	---	---	---	---	---	2.09	---
9	---	2.09	---	---	---	---	---	2.09	---
10	---	2.09	---	---	---	---	---	2.09	---
11	---	2.09	---	---	---	---	---	2.09	---
12	---	---	1.67	---	---	---	---	---	1.67
13	---	---	1.67	---	---	---	---	---	1.67
14	---	---	---	---	---	1.33	---	---	1.33
15	---	---	1.33	---	---	---	---	---	1.33
16	---	---	1.67	---	---	---	---	---	1.67
17	---	---	1.67	---	---	---	---	---	1.67
18	---	---	1.67	---	---	---	---	---	1.67
19	---	---	1.67	---	---	---	---	---	1.67
20	---	---	1.67	---	---	---	---	---	1.67
	---	10.45	13.02	4.14	7.91	1.33	4.14	18.36	14.35
		Total	23.47		Total	13.38		Total	36.85
	Plus Distillate 350,900 BBLS			Plus Distillate 200,000 BBLS			Plus Distillate 550,960 BBLS		

Reference: Keesey, 1976.

TABLE 8-13
SUMMARY OF IN-PLACE AND ECONOMIC HYDROCARBON RESOURCES AT THE WIPP

	IN PLACE RESOURCES (NMBM STUDY)			ECONOMIC RESOURCES (SW&A STUDY)		
	Zone I,II,III	Zone IV	Total	Zone I,II,III	Zone IV	Total
Crude Oil 10^6BBLS	16.2	21.5	37.7	---	---	---
Natural Gas 10^9CUFT	210.5	279.5	490	23.47	13.38	36.85
Distillate 10^6BBLS	2.5	3.2	5.7	0.35	0.20	0.55

GCR Chapter 9

SPECIAL STUDIES

9.1 INTRODUCTION

The special studies presented in Chapter 9 cover issues of particular interest because the site is being characterized for radioactive waste isolation (the WIPP). The first special study presented is that of determining the thermophysical behavior of Southeastern New Mexico (SENM) rocks for mine design and the effects of heat-producing wastes, if placed in the WIPP. The second special study is to determine the site-specific sorptive capacities of SENM rocks for radionuclides flowing with SENM groundwaters. Characterization of the sorptive capacities of SENM rocks is required for safety assessment analysis of hypothetical failure events, not for site selection. Both of these studies are by no means complete and are continuing. The information presented here is an indication of the status of these studies in midyear 1978. Tabulations of test data are left to the references and future reports on specific subjects.

9.2 THERMOPHYSICAL PROPERTIES

9.2.1 Introduction

The thermophysical properties of New Mexico rock salt are being investigated to support the structural mine design and to evaluate the overall stability of bedded salt for the WIPP. A goal of this program is to develop constitutive relations which can be used in design and long-term stability calculations, commonly by finite element analyses (Dawson and Tillerson, 1977). Specific concerns are the stability of the facility during its life, the influence of ground motions on waste retrieval capabilities, and the effect of waste emplacement on the long term containment potential. The program was initiated in 1975.

Rock salts are weak, anelastic geological materials. They exhibit nonlinear response under practically all loading conditions at temperatures and pressures normally encountered in mining. Since salt

can experience large strains prior to failure, openings even at very shallow depths have been known to completely close and heal (Baar, 1977).

In long-established active mining districts, careful in situ observations and measurements have provided a basis for making reasonably reliable predictions of room deformation and failure (Baar, 1977). Some of this knowledge is applicable to the WIPP, although it cannot be directly applied to the WIPP because the behavior of rock salt is dependent upon the site, facility design, temperature and time involved. The rock mechanics program considers the particular problems posed by the longevity of the WIPP and by the unusual combination of mechanical and thermal loading anticipated in the repository.

Laboratory experiments have been severely criticized by some for not realistically representing in situ conditions, (Baar, 1977). However, laboratory experiments on rock salt are a useful step in material characterization, to establish limits of behavior. Ultimately, laboratory and in-situ test data coupled with modeling should lead to representative descriptions of material and structural behavior. As the WIPP is developed, in situ monitoring should enhance the validity of laboratory and modeling results.

The thermophysical behavior of rock salt has been modeled through various approaches, (e.g., Bradshaw and McClain, 1975; Fossum, 1977; Langer, 1967; Mraz, 1978; St. John, 1978; Serata, 1966, 1968, 1970; Serata and Cundey, 1978; Thompson and Ripperger, 1964; Thoms et al., 1973; Wahi et al., 1978). A widely accepted model which can translate laboratory data into a prediction of in situ salt behavior has not been developed.

Three broad areas were studied to identify the relative and site specific importance of various southeast New Mexico rock salt thermophysical properties. These three areas of study consist of: 1) petrography relevant to physical and mechanical properties, 2) general physical properties (density, moisture content, resistivity, etc.), and 3) thermal-mechanical properties (quasi-static and creep parameters).

Petrographic studies were conducted on mineralogically characterized core from AEC 7, AEC 8 and ERDA 9 to investigate structural petrographic changes between natural and experimentally-deformed samples (Callender & Ingwell, 1977). Identification of failure mechanisms by petrographic analyses will assist in selecting models to describe rock behavior.

Physical properties being measured for selected core include density, moisture content, porosity, permeability, electrical resisitivity, ultrasonic velocity, and thermal conductivity. Additional gas and brine permeability measurements are in progress at Sandia both on experimentally undeformed and deformed samples.

The following mechanical properties are being measured: uniaxial compressive strength, indirect (Brazilian) tensile strength, stress-strain behavior and ultimate stress in quasi-static triaxial compression, elastic moduli, principal strain ratios, elastic limit ("yield" stress), and creep rates. Additional tests address the effects of specimen machining, specimen aging due to stress relief during and after core retrieval, and specimen size, all of which could limit the field applicability of laboratory-determined results. The influence of sample size may be partially inferred from published data (e.g., Uhlenbecker, 1968; Dreyer, 1972; Szeki, 1978).

The data base for physical and thermal properties determined from core from the WIPP study area is still being compiled, and tests are continuing. Moreover, most of the results obtained to date pertain to rock salt alone, as opposed to other members of the stratigraphic column above and below the proposed repository horizons.

9.2.2 Petrography

Approximately 35 samples of experimentally undeformed and deformed salt were macroscopically and microscopically examined for mineralogy, fabric, and induced structure by J.F. Callender and T. Ingwell of the University of New Mexico (1977). Mineralogy of rock salt from southeast New Mexico has been described in detail in Chapter 7.

Between the depths of 1,000 and 2,000 feet, the samples are predominantly halite (NaCl) (range 47-98 percent) with lesser amounts of anhydrite ($CaSO_4$) (range 0-15 percent), polyhalite ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$) (range 0-18 percent), and clay and silt (range 0-44 percent). Halite is usually present in the core, except in samples from anhydrite layers and polyhalite seams. Anhydrite, clay and silt are generally present, while polyhalite occurs less commonly. Detailed stratigraphy of the WIPP study area is presented in the ERDA 9 corehole lithologic log, Figure 4.3.3.b.

Fabric In general, the undeformed rock salt specimens do not show well-developed linear or planar fabrics, aside from uncommonly-observed bedding. Locally, however, halite crystals show a faint to strong elongation, probably due to readjustment to local stresses. Certain fabric features within the cores may presumably have important local effects on salt deformation. These features include bubble trains, hopper crystals, cleavage, glide planes, grain boundaries, and clay zones (Callender and Ingwell, 1977).

Bubble trains are commonly aligned along cleaveage traces or grain boundaries in halite. The bubbles generally contain fluid, although some may also be gas or partially solid-filled (see section 7.6). Fracturing in experimentally deformed cores locally follows the bubble trains, and they are likely the site of small-scale structural weaknesses within halite. Once such fractures heal, the zones they followed become stronger than before (section 7.6) Hopper crystals, generally filled with clay, also tend to grow and be aligned along halite cleavage planes. In a number of samples, small-scale fracturing, induced by sample preparation or by disturbance during the coring operation in the field, is associated with zones of hopper crystals.

Cleavage, and fracture related to cleavage, is observed in halite. In euhedral, generally recrystallized, halite, the cleavage direction and grain boundary are coincident. In these cases, deformation along trends parallel to grain boundaries should certainly be facilitated. Similar relations, though less common, exist in subhedral halite. Translation

glide in halite is an important dislocation mechanism and has been described in the literature (c.f., Buerge, 1930; Clabaugh, 1962). Two glide planes, (110) and (001), have been recognized in both undeformed and deformed salt.

In summary, a local concentration of discrete fabric elements (e.g., hopper crystals, bubble trains) may be as statistically significant as planar or linear elements (such as bedding, cleavage alignment, or elongation) for the structural evaluation of the core, and local zones in deformed salt may play an important role in establishing fracture patterns.

Fracture. Analyses of fracture patterns in salt to date have been complicated by induced fracture during sample preparation and the field coring procedures used to obtain samples. The recognition of these induced fractures is generally fairly straightforward; however, the persistent question of local induced fracture arises during detailed study, and is a problem which cannot be easily resolved. Fortunately for the petrographer, many fractures are filled with clay, anhydrite, and polyhalite; these filled fractures give some insight into patterns in material before laboratory testing since they are clearly not a result of sample handling.

In general, fracture in undeformed salt core is relatively minor and is commonly associated with cleavage or grain boundary adjustments. It appears that fractures may have remained open at some stages of diagenesis for a sufficiently long period of time to be filled by sulfate or other solutions. A few unusual fracture geometries have been noted: en echelon fractures, generally with their major trend parallel to cleavage; circular fractures commonly around hopper crystals; fracture refraction across grain boundaries; jog and kink fractures; and fracture and local extension along glide planes. The number of fractures observed in the laboratory resulting from relief of the in situ confining stresses is unknown. Clay, anhydrite, and polyhalite have apparently flowed in some undeformed samples. Perhaps the best evidence for this statement is

local well-defined linear fabric in polyhalite and anhydrite, and the inclusion of halite in clay along grain boundaries.

In samples severely deformed by laboratory testing, fracture patterns are easily observed. In one sample a well-defined zone of cleavage and glide-plane fracture developed at about 40° to the compressional axis. Apparently, a network of interconnected fractures has been established in this zone which respects neither grain boundaries nor grain size. In contrast, another sample suggests that local fabric elements, particularly clay-rich zones, may affect fracture geometry and that planar fracture fabrics may not be as well-developed in clay-rich samples.

Fracturing of halite can be generated in the laboratory at relatively low confining pressures ($\leq$ 1500 psi) and moderately high strains (5 to 12 percent); this fracturing induces a fracture porosity in the material. At higher confining pressures, rock salt displays ductile behavior and it is difficult to induce fracturing. The position of the fracture pattern observed in the laboratory is related to both the stress direction and the local fabric elements. In addition, the crystal lattice of halite permits, through defects and crystallographic constraints (c.f., Hirth and Lothe, 1968), a complex dislocation system to develop.

9.2.3 Physical Properties

Measurements of physical properties of rock salt pertinent to the design of the WIPP have been conducted by several investigators. Some representative data are summarized in Table 9.2.3-1.

Density and Resistivity. Measurements were made on full dimension (4-1/2 inch diameter) core. The density determinations were performed following conventional laboratory procedures for determing bulk rock densities utilizing the buoyancy method. Commercial grade kerosene was used for buoyancy measurements. Direct current resistivity determinations were made using current densities of less than 0.20 microamperes per square centimeter (Elliot, 1976), and by downhole geophysical measurements (Griswold, 1977).

Volatile Mass Loss. Total volatiles, including water, were obtained by heating samples of Salado salt from the proposed repository levels to 300°C in several stages. Static weight loss determinations were made at each stage of heating (Kopp & Combs, 1975) and were reported in section 7.5.3.. In addition, thermogravimetric analyses were made by suspending powdered samples from a microbalance while dry nitrogen flowed over the sample. The samples were heated at 5°C/minute until the temperature reached 500°C and held there until gas evolution had ceased (see section 7.5.2 for details and data).

Permeability. Gas permeability of SENM rock salt has been measured for pressures up to 5000 psi and at room temperature to determine the tightness of the host rock to any gases evolved in the WIPP. The data developed by Sutherland (1978), are for argon gas at confining pressures to 2000 psi. A plot of permeability test results is shown on Figure 9.2.3-1. Sutherland's data demonstrate the influence of confining pressure (crack closure and healing) on permeability. Preloading of samples to near lithostatic confining pressures is required to obtain reproducible data in laboratory experiments. Other gases (air, nitrogen, argon) were measured by Core Labs (1977), Terra Tek (1978), and Shelby (1978). The Core Labs' tests followed API standards, however, they did not allow for crack healing. Shelby tested single crystal NaCl. The results of these measurements illustrate the following:

(1) There is no correlation between measured permeabilities for as-received (stress-relieved) core samples;

(2) Samples behave as if they are "healing" when subjected to a confining pressure on the order of their original in situ pressure (illustrated on Figure 9.2.3-1).

(3) After an initial "healing" or "consolidation" period, the polycrystalline samples tested by Sutherland (1978) and Terra Tek (1978) have measured permeabilities of less than 0.05 microdarcys (the limit of resolution of their permeability measurement systems);

(4) There is little or no gas flow through the salt single crystals (less than 1 picodarcy) in the single crystal test apparatus of Shelby (1978). Therefore, the preferred flow channels through a core sample are believed to be along crystalline boundaries.

Thermal Conductivity. The thermal conductivity of several rock salt samples from core of AEC 8 were determined by a longitudinal heat flow apparatus. This apparatus was designed specifically for use with geologic core sections. Constant power is supplied to a heater at one end of the specimen until thermal equilibrium is established. The heat flux transducer and thermocouple outputs are then recorded allowing the thermal conductivity to be calculated from the readings (Acton, 1977). A plot of test results is shown on Figure 9.2.3-2.

Sonic Pulse Velocity. Measurements of compressional wave velocity were made both on laboratory samples (Kent and Wawersik, 1976) and by down hole geophysical methods (Griswold, 1977). Laboratory measurements were made both parallel and perpendicular to the core axis. No signficant variations (less than 0.02 Km/sec) were observed between the axial and transverse values of twenty measurements. The laboratory data were within 15% of the downhole geophysical values.

Summary of Data. Some physical properties are summarized in Table 9.2.3-1. In addition, permeability data are plotted on Figure 9.2.3-1 and thermal properties are shown in Figure 9.2.3-2. The experimental data are presented in the referenced documents.

9.2.4 Thermomechanical Properties

Introduction. It is the goal of laboratory stress-strain tests to develop constitutive relations which can be used in structural calculations. As the program progresses, a combination of finite element calculations using data obtained in the laboratory, empirical mine design methods and in-situ validation studies will serve to evaluate, in detail, certain aspects of the final WIPP design.

To achieve a valid and practical description of the behavior of rock salt from experiments in the laboratory, several programs are being conducted. These are: (1) Measurement of the mechanical response of SENM rock salts and other nearby rocks (e.g., anhydrite) over the domain of stresses and temperatures which may be expected in the WIPP; (2) Development of general models based on test results that are applicable to differing stress deformation and/or temperature histories; (3) Determination of mechanisms governing salt response in sufficient detail to allow the extrapolation of laboratory measurement in time; and finally (4) Establishment of relationships between laboratory samples of rock salt and salt masses in-situ.

This report summarizes the first series of laboratory tests, consisting primarily of short term "quasi-static" tests. These tests served to compare the response of WIPP salt with rock salts from other horizons and locations and to effectively scope the rock behavior for planning the long term creep tests. It is recognized that short term test behavior may be only partially indicative of long term behavior. Not all of the data developed is presented, particularly where detailed information has been published elsewhere. Instead, test values have been selected which are felt to best represent the behavior of the WIPP rock salt. Too few repetitive tests have been performed thus far to determine statistical significance of the data. This is due to the long times required to perform tests and the limited amount of rock salt core available to this test program from specific horizons of interest to WIPP.

A deliberate attempt was made to encompass a broad range of parameter variations including confining pressure and principal stress difference, i.e., mean stress and deviator stress, as well as temperature, time, loading rate, loading path, handling history, and specimen size. These variations covered a wider spectrum than might ordinarily be required to support the design of conventional mines or solution cavities. The approach is predicated on the unusual combination of anticipated mechanical and thermal loadings associated with WIPP. The experimental program plan also tried to address specific questions, for example,

concerning the effect of loading path, which were raised by critics of conventional quasi-static experiments in the past (Baar, 1977).

Testing was primarily conducted on rock salt samples from three horizons in the Salado Formation. The two horizons at 2,100+ feet and 2,600 to 2,700 feet represent the relatively pure halite from the proposed contact-handling (CH) and remote-handling (RH) levels, while the third horizon at 1,900 feet was chosen for study because it is clay rich salt.

The testing program through the summer of 1978 was generally divided into two segments, quasi-static tests and creep tests. Quasi-static properties were generated over a range of loading rates from d/dt $(\sigma_1 - \sigma_3)$ of 150 to 215 psi/min (RE/SPEC Inc. data, Gnirk et al., 1973, Hansen and Mellegard, 1977) to loading rates of 30 to 60 psi/min (Sandia data, Wawersik, 1977, 1978c). The 30 psi/min loading rate was chosen to match that of published data (Dreyer, 1972, Menzel and Schreiner, 1977). Creep tests were carried over a range of confining pressure $0 \leq \sigma_3 \leq$ 3,000 psi, deviator stresses $1{,}500 \leq (\sigma_1 - \sigma_3) \leq 6{,}000$ psi, and temperatures of $24^{\circ} \leq T \leq 100^{\circ}C$ with a duration of up to 70 days. These loading rates were arbitrarily chosen as a means of scoping the behavior of SENM rock salt under conditions that may be encountered in the WIPP.

<u>Apparatus, Experiments, Capabilities, and Data Handling</u>. To support the determination of material properties of WIPP site rocks, a new triaxial facility was developed (Wawersik et al., 1976). Based on earlier experience (Wawersik and Brown, 1973; Gnirk et al., 1973; Wawersik, 1975), the present apparatus has the following capabilities.

> The apparatus accepts cylindrical specimens up to 4-1/4 inches diameter by 8.5 inches in length to accomodate the coarse grain size or rock salt.
>
> The system has a pressure rating of 10,000 psi; this is adequate to perform variable load path tests, for example, in triaxial compression, in triaxial extension, at constant maximum compression, etc.

The equipment is suitable to conduct both quasi-static tests and creep experiments.

Specimens can be heated uniformly to approximately 250°C in short-term tests and to 200°C to 220°C in long-term experiments.

Controlled, known temperature gradients can be applied for studies of fluid migration.

The equipment provides access to both specimen ends for possible venting or for measurements of pore pressure and permeability and for application of pore pressure, etc.

It provides both axial and radial deformation measurements. For uniform lateral deformation, this combination of strain measurements yields shear and volumetric strains.

The apparatus is equipped with multiple feed-throughs for use of instrumentation inside the pressure vessel.

Normally, hydrostatic and deviatoric loading are decoupled so that the hydrostatic response of all specimens can be defined and, more importantly, so that linear and bulk thermal expansion measurements can be determined as a function of temperature and pressure.

The apparatus and procedures allow for large, relatively unrestrained sample deformation.

Details of the test equipment (ranges, calibration procedures and precisions) are discussed elsewhere (Wawersik, 1975; Wawersik et. al., 1977; Wawersik, 1978a).Material and Test Specimens - The rock salt studied was machined from 4-1/4 inch diameter core obtained from zones at depths of 1,900 feet, 2,100 feet and 2,600 to 2,700 feet. Sample machining consisted of cylindrical and flat-end grinding following documented procedures which were designed to minimize the thickness of any shatter zones at the specimen surfaces. Alternatively, specimens were obtained by means of standard coring tools. Final specimen dimensions were nominally 2 inches or 4 inches in diameter, with a

length-to-diameter ratio of at least two. After machining, the cylindrical surfaces of all samples were coated with a protective layer of RTV silastic.

Quasi-static Rock Salt Properties. Quasi-static testing was conducted on WIPP salt under hydrostatic pressures to 5,000 psi. Deviatoric loading tests were performed to 3000 psi confining pressure and to temperatures of 200°C. Variables of interest were: pressure (confining pressure, mean stress), principal stress difference (deviator stress), time (loading rate), temperature and load path. A separate study of the role of the intermediate principal stress will also be initiated. The importance of the foregoing variables was suggested by prior mine measurements and by existing laboratory data (for example Schmidt, 1937; U.S. Corps of Engineers, 1963; Le Comte, 1965; Hofer and Thoms, 1968; Schlichta, 1969; Carter and Heard, 1970; Bradshaw and McClain, 1971; Dreyer, 1972; Heard, 1972, Serata et al., 1972; Kern, 1973; Menzel and Schreiner, 1977; Baar, 1977).

The term quasi-static is used in the conventional sense to denote a fixed slow rate of loading. To avoid misunderstandings and undue generalizations of these data, it is emphasized that most quasi-static experiments were carried out at particular loading rates, e.g., 30 psi/min. It is important to realize that any data concerning the mechanical behavior of WIPP rock salt under different loading conditions must be inferred with proper regard to the time-dependent nature of the material (Wawersik and Hannum, 1978).

Quasi-static data available to date include approximately 75 uniaxial compression and indirect Brazilian tension tests at ambient temperature on core from drill holes AEC 7 and 8 (Hansen and Gnirk, 1975). These experiments were performed under the direction of Oak Ridge National Laboratory prior to June, 1975. They include approximately 20 experiments on anhydrite and 5 tests on polyhalite. More recent quasi-static data include approximately 50 tests on selected specimens from the potential WIPP repository horizons (Wawersik et al., 1976;

Hansen, 1977; Hansen and Mellegard, 1977, Wawersik and Hannum, 1978). Samples were machined from core of drill holes AEC 7 and ERDA 9. Emphasis was placed on the response of rock salt from the storage horizon at 2600 feet because of the added complexities of elevated temperatures if heat producing wastes are placed in WIPP.

Selected representative mechanical properties in uniaxial compression and indirect tension are listed in Table 9.2.4-1.

Quasi-static Triaxial Properties - Representative triaxial data are listed on Table 9.2.4-2 for a range of confining pressures and temperatures. Note that both tables 9.2.4.1 and 9.2.4-2 list secant moduli (stress/total strain) and principal strain ratios ($\varepsilon_3/\varepsilon_1$) rather than the elastic constants, that is, Young's modulus, E, and Poisson's ratio. To calculate the intrinsic elastic constants it is necessary to separate the nonelastic portion from the total deformation or to move through stress states where elastic response dominates. This was accomplished for New Mexico rock salt recently during unload/reload cycles.

The constants obtained were $4.55 \times 10^6 \leq \varepsilon \leq 5.2 \times 10^6$ psi and $0.17 \leq \nu \leq 0.24$ (Wawersik and Hannum, 1978). These values agree to within 15% with those which were determined from borehole geophysical data.

During initial deviatoric loading in the laboratory, nearly all deformation of WIPP salt was nonelastic (Wawersik and Hannum, 1978). The actual magnitude of this nonelastic deformation is likely to be sensitive to the magnitude of the deviatoric stress which the core experienced during drilling (Wawersik and Hannum, 1978), associated core damage and subsequent core "relaxation" during core storage and handling. Combinations of these factors probably account for the variations in secant moduli and principal strain ratios in tables 9.2.4-1 and 9.2.4-2.

It is common practice in engineering to plot triaxial test data in the form of Mohr's circles at the ultimate stress. The plots are made in the

stress space (σ,T) where σ and T denote normal and shear stresses, and an envelope is drawn tangent to the circles representing the ultimate shear stress of any value of confining pressure.

When the data from Tables 9.2.4-1 and 9.2.4-2 are plotted, three Mohr's circles which are normal for SENM rock salt are obtained in Figure 9.2.4-2A in stress space (σ,T) . The ultimate stresses can be approximated by a straight line (Coulomb) envelope of the form $T = C + \sigma \tan \phi$. In conventional engineering terminology, C is called the cohesion and ϕ , the angle of internal friction. In this case, at ambient temperatures, rock salt from the 2,700 foot level has an apparent cohesion of approximately 1,000 psi and an angle of internal friction of 33°. Similar data for other rocks are being used for mine pillar design. However, it should be recognized that the validity of these ultimate stress analyses rests on two assumptions: (1) failure is independent of the intermediate principal stress, and (2) failure is defined solely in terms of stresses and independent of strain, strain rate and time. Both of these assumptions are currently being evaluated for rock salt.

In contrast to other rocks, it is important to remember that rock salt undergoes large deformations long before the ultimate stress is reached. Since these deformations can exceed 15% even at ambient temperature, it is conceivable that a practial failure condition might incorporate a maximum deformation criterion. To illustrate this case, a Coulomb envelope was constructed (Figure 9.2.4-2B) which defines the stress magnitudes at an arbitrarily chosen constant value of strain ($\varepsilon_1 = 2.5\%$). This value is the average strain at the ultimate stress of samples tested in uniaxial compression at ambient temperature and a loading rate of 30 psi/min. It can be seen that Figure 9.2.4-2B is different from the ultimate stress envelope in Figure 9.2.4-2A. Clearly, the shapes of the Mohr envelopes are highly dependent on failure criteria. The values obtained also depend on the manner in which the Mohr's envelope is drawn. In Figure 9.2.4-2A, a "best fit" straight line tangent to the circles was drawn; while in B, a parabola was drawn tangent to the circles.

Detailed Quasi-static Stress-Strain Relationships. Elastic constants, ultimate stresses, and stress or strain envelopes are useful for conventional failure stability analyses where rock is treated either as an elastic or as an elastic-plastic material. While such analyses have proven valuable in combination with careful engineering judgement, they are not always accurate. In view of the time-dependent nature of rock salt it is especially important that design calculations be based on a more comprehensive constitutive model. To initiate the development of such a model, detailed short-term quasi-static stress strain observations were made to identify the effects of pressure, deviatoric stress, (shear stress), temperature, and loading history. The influence of time as a discrete parameter is mainly considered in creep experiments.

Deviatoric Loading at Constant Confining Pressure. Deviatoric loading at constant confining pressure is the process of increasing the principal stress difference (deviator stress) from an initial state of hydrostatic compression. It is a necessary condition to induce substantial salt flow.

Typical quasi-static deviatoric loading data are shown in Figures 9.2.4-3 through 9.2.4-15. The key to these curves indicates sample depth in feet and (confining pressure in ksi and temperature in degree C). These stress strain curves depict complete continuous experimental records which indicate the manner in which all specimens were loaded. Deviator stress was applied incrementally rather than continuously. Actual force was raised quickly by some predetermined amount and then held constant for between 4 and 15 minutes while axial and lateral strains ε_1 and ε_2 $(= \varepsilon_3)$ were monitored in time. The stepwise loading procedure made it relatively easy to control the mean applied loading rate while monitoring time dependent strains during load hold periods with a minimum of experimental error (Wawersik and Hannum, 1978). In most figures, these details of loading are omitted. As illustrated by the curve for sample 9-2601 in Figure 9.2.4-3, where smooth fits are made to the endpoints of each step in the actual stress strain record. Note that large changes in specimen cross sectional area at constant force during

all load hold intervals lead to considerable decreases in principal stress difference with time (Wawersik et al., 1977, 1978c). Conventional plots ($\sigma_1 - \sigma_3$) versus ε_1 such as Figure 9.2.4-3 relate the present data to virtually all similar results for rock salt in the literature (for example, Schmidt, 1937; Heard, 1972; Dreyer, 1972, Menzel and Schreiner, 1977).

Considering Figures 9.2.4-3 through 9.2.4-6, three observations are particularly noteworthy.

1. Laboratory specimens of New Mexico rock salt have an initial elastic limit close to zero. Furthermore, this initial elastic limit appears to be the same following all hydrostatic pressure histories up to 5000 psi (Wawersik and Hannum, 1978).

2. Pressure appears to have a considerable effect on all properties of New Mexico rock salt except the elastic constants (Wawersik and Hannum, 1978). Specifically pressure controls the strain magnitudes, the ultimate stress and the relationships between the principal strain (Figures 9.2.4-5 and 9.2.4-6). Pressure effects are particularly evident at ($\sigma_1 - \sigma_3$) greater or equal 1200 psi.

3. New Mexico rock salt subjected to quasi-static laboratory compression can undergo substantial dilatancy which is associated with cataclasis, i.e., microfracturing. The magnitudes of the observed volume changes were significant particularly at low confining pressure and amounted to sizeable fractions of the observed shear strains near the ultimate stress (Wawersik and Hannum, 1978). Isovolumetric conditions of deformation are approached only at 3000 psi confining pressure. However, data at elevated temperature demonstrate that even comparatively minor amounts of dilatancy can have a considerable effect on the rate at which New Mexico rock salt deforms (Wawersik and Hannum, 1978).

Elevated Temperature Data. Elevated temperature experiments were carried out in two groups. First, the influence of temperature was considered at fixed confining pressures, for example, 500 psi (Figs. 9.2.4-7, 8 and 9). Then, the effect of pressure was evaluted at 200°C (Figs. 9.2.4-10, 11 and 12). As expected (Bradshaw and McClain, 1971; Heard, 1972: Dreyer, 1972), temperature reduced the ultimate stress and increased the ductility (Fig. 9.2.4-7). Increasing the temperature is qualitatively equivalent to increasing confining pressure at ambient temperature. Cataclastic effects with considerable dilatancy are suppressed in favor of deformation modes which proceed at constant, or nearly constant, volume (Figs. 9.2.4-8 and 9.2.4-9). (Wawersik and Hannum, 1978)

Influence of Loading History. Effects of loading history are noted in several studies in the literature (for example, Schmidt, 1937; Sereta et al., 1972; Baar, 1977). To consider such effects, three sets of experiments were performed early in the experimental program. First, the influence of differing hydrostatic loading histories was tested. The results indicated no measurable effects on the behavior of rock salt from southeastern New Mexico during subsequent deviatoric loading (Wawersik and Hannum, 1978).

In the second group of experiments, quasi-static strains were measured as a function of load path in a conscious effort to separate the influences of load path and loading history as much as possible. The load paths employed are shown in Figure 9.2.4-15. They consist of:

1. Conventional triaxial tests at constant confining pressure (load path I).

2. Triaxial loading at constant mean stress ($\sigma m = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3)$ load path II).

3, Deviatoric loading at approximately constant maximum compression (load path III).

Figure 9.2.4-13 also identifies one test which combined load path III and I passing through points A, D, E, G, and H (Wawersik and Hannum, 1978). Table 9.2.4-3 provides a comparison of strains at several common stress states of Figure 9.2.4-13 with the strains ε_1 and ε_3 are numerically greatest along the path of constant confining pressure (load path I). The smallest ε_1 and ε_3 were obtained along the path of maximum pressure, either confining pressure or mean stress (load path III) (Wawersik and Hannum, 1978).

To evaluate load history even further, a third set of tests was performed. In these experiments, one sample was deformed in three successive stages at 3000, 500, and again at 3000 psi confining pressure. The response of this specimen was then compared with the strain behavior of individual samples which had been loaded deviatorically at 3000 psi and 500 psi confining pressure (Wawersik and Hannum, 1978). The results of the latter tests are shown in Figures 9.2.4-14 and 9.2.4-15. Notice particularly, that the stress strain record for the third load cycle of sample 7-2740.5 does not immediately converge to the stress strain records of specimens 7-2745 and 9-2601.5. Differences in results are obviously due to the influence of loading history (Wawersik and Hannum, 1978).

Interpretation of Quasi-static Data - In view of the quasi-static testing to date, as illustrated in the figures, the following observations were made repeatedly and establish broad guidelines which should be observed in modeling the thermomechanical behavior of New Mexico rock salt up to fracture and/or massive flow (ε_1 greater or equal 20%).

Rock salt from SENM in the laboratory is nonlinear under all loading conditions with an initial elastic limit ($\sigma_1 - \sigma_3$) approximately zero. Its intrinsic elastic properties can be evaluated accurately only in load/unload/reload cycles provided restrictions are imposed either on the loading (strain) rate or on the range of deviator stresses. However, given comparatively nonelastic strains, the intrinsic elastic behavior does not appear to be very important.

In the low confining pressure domain $\sigma_3 \leq 3000$ psi, rock salt behavior depends strongly on pressure and temperature. Both dependencies are reflected in ductility, ultimate stresses and in the variation between maximum and minimum principal strains or in the variations between volumetric strains and shear strains (Figures 9.2.4-4, 5, 8, 11, and 15).

A brittle mode of deformation (microfracturing) dominates rock salt deformation at ambient temperature, low confining pressure, and deviator stress in excess of approximately 1000 to 1500 psi. Accordingly, the overriding pressure effect under these conditions is pressure dependent dilatancy (Figures 9.2.4-4, 6 and 9). Brittle fracture, including creep fracture, i.e., macroscopic collapse and loss in load bearing ability are possible. At low (less than 1,000 to 1,500 psi) deviator stress, high temperature, and/or high pressure, salt deformation proceeds in a predominantly ductile manner at nearly constant volume. Particularly at high temperatures, pressure does not appear to further influence the nature of the governing deformation mechanisms. This is indicated by a pressure invariance (Figure 9.2.4-11) of the relationship between maximum and minimum compressive strains (shear and volumetric strains). However, observed differences in induced strain rate at a fixed loading rate but different confining pressures indicate that pressure influences the rate at which the governing deformation mechanisms, cataclastic or ductile flow, proceed.

It is recognized that available quasi-static stress strain data do not necessarily describe the properties of New Mexico rock salt over long periods of time. However, for lack of other information, quasi-static tests have been used to define the matrices of future creep experiments and to anticipate phenomena which might occur during creep. For example, emphasis is being placed on triaxial creep experiments as opposed to uniaxial tests. Simultaneous measurements are being made of both volumetric strains and shear strains in creep. Similar tests are not conducted routinely elsewhere and the apparatus to perform these tests is at the state-of-the-art in experimental rock mechanics.

<u>Creep of Rock Salt</u> Creep tests on rock salt are continuing to evaluate the long-term time-dependent behavior of New Mexico rock salt. Since August, 1977, two sets of triaxial creep tests have been performed on core from drill holes AEC 7 and ERDA 9, emphasizing the interval of 2600 to 2800 feet depth. Experiments were carried out over the range

$$0 \leq \sigma_3 \leq 3000 \text{ psi}, \; 1500 \leq (\sigma_1 - \sigma_3) \leq 6000 \text{ psi}, \text{ and } 24^\circ \leq T \leq 130^\circ C.$$

Results indicate that in principle WIPP salt can undergo both transient and steady state creep. Furthermore, limited data suggest that steady state creep rates lie in the range from 10^{-10} sec^{-1} to 10^{-7} sec^{-1}, depending strongly on stress state and temperature. Steady state creep may have to be considered in WIPP design calculations; it was not included in earlier wastes repository analyses which were conducted in conjunction with in situ experiments during Project Salt Vault, Kansas (Bradshaw and McClain, 1971).

To evaluate the nature of transient creep of the WIPP salt, 34 tests were carried out on NX sized (two inch nominal diameter) core. Tests durations vary between 0.5 and 500 hours (Hanson, 1977, and Hanson and Mellegard, 1977). Initial efforts served to evaluate the significance of transient creep on the possible repository conditions, to establish upper (conservative) bounds for steady state creep rates at relatively low deviator stress and temperature, and to test the applicability of a pillar creep formula which has been widely used (Bradshaw and McClain, 1971):

$$E(t) = A(\sigma_1 - \sigma_3)^a T^b t^c \qquad (9.1)$$

The results of present transient creep data demonstrate significant pressure effects which are consistant with all quasi-static observations but are not predicted by equation 9.1.

Beyond that, however, at least one block of data appears to support equation 9.1 which in its generalized form is:

$$\varepsilon = F_1(p)F_2(\sigma_1-\sigma_3)F_3(T)F(\text{strain or time}) \quad (9.2)$$

Work is now in progress to estimate the error magnitudes which are associated with the use of equation 9.2 even under restricted conditions, e.g., $(\sigma_1 - \sigma_3) \leq 2{,}500$ psi and $\sigma_3 \leq 1{,}000$ psi. To accomplish this, numerical simulations are compared with the results of independent laboratory experiments which combine multiple creep runs with intermittent short-term stress variations at two different temperatures.

Time Dependent Fracture. To determine the long term strength of New Mexico rock salt, two approaches are being take. First, long-term laboratory creep tests are conducted to establish a relationship between strength and time. Obviously such tests are time consuming. Second, failure times may be calculated from creep flow and from estimates of the amount of nonelastic strain at the point of fracture. The nonelastic failure strain can be estimated by means of an empirical procedure which establishes a relationship between creep, time dependent fracture and quasi-static post failure characteristics (Wawersik, 1972). If this technique is applied to New Mexico rock salt, it appears that the range of stable creep prior to fracture at ambient temperature is:

$$\varepsilon_1 \leq 2.5 \text{ to } 6\% \text{ at } \sigma_3 = 0 \text{ psi}$$

$$\varepsilon_1 \leq 17 \text{ to } 20\% \text{ at } \sigma_3 = 500 \text{ psi}$$

Substantially greater stable creep occurs at $\sigma_3 = 3000$ psi confining pressure (Wawersik 1977). On Figure 9.2.4-18, photographs of core samples from ERDA #9 are shown that were deformed during triaxial testing (Hansen and Mellegard, 1977). Notice the large amount of strain test Numbers 6 and 7 have undergone without apparent major physical damage.

Applicability of Laboratory Measurements. Several investigations are underway to define the qualitative and quantitative applicability of laboratory experiments on WIPP salt to in-situ design predictions. Apart from numerical validation studies, measurements are in progress to determine the relaxation of core after drilling and to assess whether rock salt is damaged during field coring, recovery and storage. The latter efforts are supported by repeated tests on specimens with known laboratory stress histories to further define the effects of stress history, aging and specimen machine. In addition, numerical simulation are being conducted to balance the magnitude of deviatoric loading of salt core during drilling.

9.2.5 Summary and Conclusions

Data from the petrographic and physical properties studies show the WIPP horizon rock salt has low moisture content ($< 0.5\%$), is essentially impermeable ($< 5 \times 10^{-8}$ darcy) and has a high thermal conductivity ($\simeq 5.75$ watts/m^{o}k). These properties along with the studies of fabric and fracture indicate this rock salt is ideally suited from a physical standpoint for the storage of high temperature nuclear waste.

The initial elastic limit is close to zero for rock salt for any confining pressure. Although strengths for rock salt are substantial (unconfined compressive strength to 3700 psi and modulus to 2×10^{6} psi) the load bearing ability is dependent on time, temperature and confining pressure.

It has been shown that rock salt can experience large creep strains (25%) prior to loss of load bearing capacity. Gradual creep is an acceptable feature in the design of underground openings in rock salt as it allows the structure to close without a sizeable reduction in bearing strength and without the physical damage which is associated with fracture.

Laboratory testing is continuing to develop a constitutive model to describe the behavior of SENM rocks. The model will be used in computer codes to study the structural response of the geologic media to WIPP.

9.3 RADIONUCLIDE SORPTION ON WIPP ROCKS

9.3.1 Introduction

An important mechanism in retarding nuclide movement in groundwater is sorption. In the following discussion, this term will be used to encompass all mechanisms pertinent to interaction between nuclides and geomedia which include ion exchange, adsorption, and precipitation.

The ability of rocks to adsorb radionuclides and hinder their migration away from a geologic repository for radioactive waste is not a factor in site selection criteria (Chapter 2). Also, since sorptive affinity is not a fundamental invariant property of a rock sample, such as is mineralogy or total volatile content, radionuclide sorption properties were not discussed in Chapter 7 (Geochemistry). Nevertheless, quantification of rocks' affinities for radionuclide sorption, however, is NOT a generic problem which can be solved simply for all rocks. Since the only rational approach to the problem is to conduct experiments to determine radionuclide sorption properties for site-specific rocks and site-specific aqueous solutions, preliminary results of such experiments are reported as special studies. The results of special studies of radionuclide sorption are entirely dependent upon experimental conditions, just as in the measurement of quasistatic mechanical properties.

In some safety assessment modeling scenarios described for the escape of radionuclides from WIPP repository horizons, groundwters contact and leach the waste form, and eventually find their way out of the salt deposit into the surrounding rock and mineral strata. During this exit, the nuclide-bearing liquid would contact clay-containing halite in the repository horizon, polyhalite formations, anhydrite formations, and

finally the sandstone and dolomite formations which are the bounds of the evaporites. To a rough approximation, the concentration per unit mass of a given nuclide, sorbed on a solid mineral phase C_{solid} can be related to the concentration per unit volume, in the liquid phase C_{liquid}, by the relation:

$$C_{solid} = KC_{liquid}$$

where K is generally known as the distribution coefficient, Kd, with units of ml/g. The use of the term Kd implies an equilibrium condition for a given reaction which is both instantaneous and reversible. In the interaction of a nuclide with a complex mineral assemblage, neither condition may apply and the nuclide sorption observed can result from one or more sorption phenomena on one or more phases. To prevent confusion in nomenclature, the term Kd is used in this report, but with the understanding that what is being measured is a sorption coefficient which applies only to the system described and for the particular set of conditions used in making the measurement. Thus, the measurement of "Kd" does not reflect a fundamental thermodynamic property of rocks and/or solutions; it is rather a function of the experiment in which it is measured.

Ideally, sorptive affinities for radionuclides would be measured in situ in the geological formation of interest using long path lengths and available groundwater. This is not generally feasible and must be supplanted with data generated in a laboratory. Most of this section is an extract of SAND78-0297, "Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) site in New Mexico" by R. G. Dosch and A. W. Lynch. It provides the results of a series of laboratory Kd measurements for various radionuclides and samples of different geological media from the vicinity of the WIPP site, and a discussion of the conditions used in making the measurements. The nuclides chosen for study have either a high potential for leaching and/or migration, a high radiotoxicity, or a chemistry similar to that of a nuclide with these properties. They included ^{137}Cs, ^{85}Sr, ^{131}I, ^{125}Sb, ^{144}Ce, ^{152}Eu, ^{153}Gd, ^{106}Ru, ^{243}Am, ^{244}Cm and ^{238}Pu.

A given set of conditions including pH, Eh, particle size, nuclide concentrations, and brine and/or groundwater simulant composition was defined prior to starting the work and maintained throughout. The Kd values reported are considered to be a set of preliminary baseline data for use in evaluating the effects of changes in those conditions which will undoubtedly be necessary as more information about the WIPP site itself and interactions of the waste forms with bedded salt become available.

The results of some parametric studies with lanthanide elements are also given. Significant differences in Kd's were observed as a result of varying pH and nuclide concentrations, and from the addition of trace quantities of organic contaminants to simulant solutions.

9.3.2 Geological Media

Sample Selection. The geological samples used in this work were taken from four inch diameter core samples from AEC #8 and ERDA #9 boreholes. (See Chapters 4 and 7 for descriptions of stratigraphy and mineralogy.) These include three samples from various rock formations (including the water-bearing rocks above and below the evaporites), four halite samples from the Salado Formation, and samples of polyhalite and Cowden anhydrite also from the Salado Formation.

The selection of the geological media for study was based on both the hydrology of the WIPP site and surrounding area and on a reasonable scenario for radionuclide transport from a bedded salt repository. The Magenta, Culebra, and Bell Canyon formations represent actual or potential aquifers.

Any path to the biosphere for water which may have contacted and leached a waste form would involve migration through halite formations, and also through anhydrite and polyhalite strata interspersed in the halite. Thus, these materials, along with the clay contained in the halite, are included in this study as they represent potential barriers to nuclide migration.

Sample Preparation. Culebra, Magenta, Bell Canyon, polyhalite, and anhydrite samples were reduced to a powder prior to use. Clays from the halite samples were obtained by dissolving core samples in deionized water, filtering and washing the insoluble residue, and drying at ambient temperature in air or vacuum.

9.3.3 Brine and Groundwater Simulants

The bulk of the Kd measurements reported herein were done using simulated brines and groundwater of the compositions given in Table 9.3-1. The Brine A composition is based on that expected in an aqueous solution in contact with potash deposits found in the vicinity of the WIPP site. The Brine B composition is typical of water in contact with halite deposits in the repository horizons. The groundwater Solution C composition is based on analyses of shallow groundwaters from the Los Medanos area (Lambert, 1978) above the evaporites and is intended to represent an "average" composition.

In determining Kd values for halite particles, saturated brines prepared from the particular core sample from which the halite had been taken were used as the liquid phase.

9.3.4 Solution Chemistry

Solutes. The use of simulated brines became necessary as both naturally occurring brines and core samples from repository horizons are currently available in very limited quantities. Simulants do offer the advantage of providing a reproducible matrix which allows for direct comparison of Kd data generated in different laboratories.

Potential problems in using simulants could arise from the absence of trace constituents which may be present in natural waters. If these are common inorganic species, the effect on Kd's would probably be negligible. However, trace quantities of organic compounds or dissolved gases such as hydrogen sulfide could produce significant changes in Kd

values should they tend to form stable complexes with some nuclides. The effect of trace quantities of organics which may be introduced into the repository as radwaste is being addressed and is discussed in Section 9.3.8.

Oxidation Potential. In aqueous migration from a deep geologic storage site, nuclides would most likely encounter both anoxic and aerobic conditions, in that order, as the biosphere is approached. The potential effect on Kd values could be many orders of magnitude; however, this should be limited to nuclides such as U, Np, and Pu which may undergo oxidation-reduction reactions in the potential range encountered.

Oxidizing conditions have been used to date as they are believed to produce the "worst case" with respect to migration, i.e., the higher valence states of the previously mentioned actinides tend to have lower Kd's, and they will be encountered in any scenario leading to contamination of the biosphere.

Hydrogen Ion Activity. The effect of the pH is believed to be extremely important in both the solution chemistry and the adsorption mechanism involved in the Kd for a given geological media. Problems encountered in determining Kd values in systems where solution pH is varying are discussed in Section 9.3.8. Changes in the adsorption characteristics of clays, oxides, and some zeolite materials as a function of pH are well documented (Amphlett, 1964).

The initial pH values of 6.5, 6.5 and 7.5 for Brine A, Brine B and solution C simulants, respectively, were chosen as being representative of field pH measurements of natural brines and groundwaters in the Los Medanos area.

Radionuclide Concentation. Ideally, a distribution coefficient should be independent of concentration. This condition usually exists only over a narrow concentration range and, therefore, nuclide concentrations should be chosen which are somewhat representative of those expected in a

repository. The problem lies in the fact that little or no data exists to aid in estimating leaching rates under conditions expected after closure of a repository. These include glass or other waste forms at elevated temperature (70-200°C) and lithostatic pressure (2000 psi) in contact with "wet" salt or brine. Another presently unknown variable is the effect of radiolysis on leaching mechanisms and rates. Available leaching data primarily result from laboratory leaching experiments with simulated waste in distilled water at ambient temperature.

In order to simplify both sampling and counting operations in the initial work, an activity of approximately 1 μCi/ml was used for all determinations unless stated otherwise. The corresponding nuclide concentrations based on the suppliers' analyses of the isotopes used are listed in Table 9.3-2.

Unless otherwise stated, all distribution coefficient measurements were made using a single nuclide in the brines or groundwater to eliminate competing ion effects. The effect of the nuclide concentration on Kd's is of concern and some initial work in this regard is presented in Section 9.3.8.

9.3.5 Experimental Procedures

Apparatus, Sample Size and Sampling. Samples of rock, clay, anhydrite, polyhalite, or halite were weighed directly into polyethylene dropping bottles volumes of doped brine or groundwater were added. The ratio of liquid to solid was typically in the range of 30 to 35. Due to limited quantities of the clay samples, higher ratios (50-150) were used in experiments with clays.

The bottles were sealed by placing a piece of polyethylene film over the opening and replacing the bottle top. Agitation was provided by orbital, reciprocating, or wrist-action shakers. Samples for analysis were taken by replacing the polyethylene film with a 0.8 μ pore size Gelman filter, tightening the dropping bottle top down over the filter, and squeezing

the bottle to force 0.5 to 1.0 ml volumes into pre-weighed polyethylene vials. Quantitative volumes were determined from weight and density measurements. The filters were replaced with polyethylene film and the agitation continued.

Portions of all "feed" solutions were put in identical polyethylene dropping bottles, agitated, and sampled at the same time and in the same manner. The activity in the filtered "feed" samples were used as the initial solution activity in the Kd calculations.

Analyses. The activity in solutions containing ^{137}Cs, ^{85}Sr, ^{106}Ru, ^{131}I, ^{125}Sb, ^{152}Eu, ^{144}Ce, or ^{153}Gd was determined by x-ray spectroscopy. A Harshaw 3" x 3" NaI(Tl) scintillation crystal or an Ortec VIP Series Coaxial Ge(Li) solid state detector was used. Data was accumulated and processed by a PDP-11/20 computer system. ^{99}Tc beta activity was measured using a mica end-window Geiger tube or by liquid scintillation counting. Alpha activities were determined by liquid scintillation counting. Since only relative activities are needed to determine Kd's, units of cpm/ml were used in all calculations.

Equilibration Time. Samples of fission product nuclides were generally taken after 14-20 and 30-35 day equilibration periods. In some instances, more frequent sampling was done. Variation in Kd's between the two sampling times were generally within a factor of two and are believed to result from changes in concentration due to adsorption on container walls, filters, or pH changes in both the sample and feed solutions rather than from rock-nuclide sorption kinetics.

Equilibration times of 170 days were used in the actinide experiments. This extended period was dictated by delays in acquiring laboratory facilities rather than by experimental design.

9.3.6 Kd Data

The results of Kd measurements using the conditions described in previous sections are given in Tables 9.3-3 through 9.3-11. Each table represents a different geological sample and contains th Kd's determined for the various brine/groundwater-nuclide combinations listed and a pH range including the initial feed pH and final sample pH values. The Kd ranges given for the fission product nuclides include two or more measurements made during the course of the experiment. Error associated with these measurements is certainly the most significant at the high ($>10^4$) and low (<1) ends of the Kd range, where background to signal ratios are high or calculations are based on small differences in large numbers. Two-to-fivefold variations of Kd's between duplicate analyses in these regions were not uncommon. Another obvious source of uncertainty is sampling, both in picking a section of core to represent a geological formation and in taking small samples to represent the core. The magnitude of error due to heterogeneity in a given core sample is unknown, as multiple samples were not used in this survey.

9.3.7 Discussion of Kd Data

Cesium. Cesium adsorption from brines "A" and "B" on Culebra and Magenta samples, representing a potential aquifer region overlying the repository horizons, is minimal or non-existent with Kd's ranging from 0 to 2. Adsorption from groundwater C is slightly higher (Kd's from 4 to 10). In the potential aquifer underling the repository, the Bell Canyon Formation, Cs adsorption is significantly higher in the groundwater "C" simulant than in brine "B". This trend tends to support an ion exchange mechanism for Cs adsorption.

Similar results are observed on the samples associated with the repository horizons, with the exception of the polyhalite sample, which did not adsorb Cs from any of the solutions used.

Strontium. The adsorption of Sr on the rock samples from potential aquifer regions was very low with a Kd of 5 being the highest value observed in both brines and groundwater simulant.

Of the materials associated with the repository horizons, only the polyhalite sample showed any appreciable adsorption of Sr from the brine solutions that would be associated with the region.

The interstitial clay in the halite formation shows no tendency to adsorb Sr from the brine solutions (Tables 9.3-6 and (.3-9), and this may be attributed in part to the relatively high concentration of stable Sr used in the simulants. However, the same behavior was observed in an experiment where a brine prepared by dissolving a halite core and doped with < 0.3 ppm ^{85}Sr was cycled through a column of the halite particles from the same core (Tables 9.3-1 and 9.3-11). In this case, only a slight reduction in Sr activity was observed (which may have resulted from adsorption on the glass column or Tygon tubing used to circulate the brine), while ^{144}Ce was quantitatively removed by the halite.

Europium, Gadolinium and Cerium. These nuclides have been grouped together for discussion because their chemistries are very similar, particularly with respect to hydrolysis, and secondly, because they exhibited similar behavior in their interactions with the geomedia from the WIPP site.

With the exception of polyhalite samples, Kd's of greater than 10^3 for these nuclides were observed on all the geological samples with which they were contacted. Any interpretation of these data with respect to mechanism or comparison of the effects of different brines or geological media is difficult because of the contribution of hydrolysis and subsequent precipitation to the overall adsorption observed in the experiments.

For example, the polyhalite sample which was singled out as having Kd's of less than 10^3 for these nuclides (Table 9.3-7), also had final pH values which were lower than the rock or clay samples. Thus, the

apparent difference in Kd's may be a hydrolysis effect rather than be related to the polyhalite. The effect of hydrolysis is further discussed in Section 9.3.8.

Technetium and Iodine. Both of these nuclides are expected to exist as anionic species in natural groundwaters or brines and were used in the form of pertechnetate, TcO_4, and iodide, I, in this work.

Natural ion exchangers typically exhibit extremely low anion capacities, particularly in neutral or basic solution. In this work, the only material which showed significant adsorption of pertechnetate and iodide was a clay sample taken from a halite core (Table 9.3-9). The adsorption was observed in Brine A and groundwater C, but neither species appeared to be adsorbed from Brine B. The relatively high concentration of Tc used may have far exceeded the anion exchange capacity of some or all of the samples and this possibility is being investigated.

Ruthenium and Antimony. Difficulty was encountered in preparing the doped "A", "B", and "C" solutions due to the high concentrations of stable Ru and acid (4NHCl) in the ^{106}Ru solution used. Adjustment of pH after doping resulted in precipitation of > 95% of the Ru. The final feed solutions were estimated to contain approximately 0.10 μCi/ml of ^{106}Ru in "B" and "C" or 25 ppm total Ru.

General trends observed in the Kd measurements include: 1) higher Kd's for the clay minerals than for the rock samples, 2) higher Kd's in simulants "B" and "C" than observed in "A". The latter effect may be the result of brine composition, but more likely is a hydrolysis effect as the final equilibrium pH of "B" and "C" is higher than that in the "A" brine.

Antimony was added to the group of nuclides being studied late in this work, and there are not sufficient data available on which to base any general statements.

Actinides. The actinides used in this work were supplied as Am(III), Cm(III), and Pu(IV) solutions and used at face value. No attempts were made to determine the Pu species present in the simulant solutions after doping. The nominal activity of the actinides in the solutions used in this work was 1 μCi/ml, however, the final activities in the "feed" solutions were lower. The doping was done by adding the isotope solutions to containers and evaporating to dryness at room temperature. The brines or groundwater solutions were then added to the containers and the solutions were set aside for several days. The amount of isotope used was sufficient to provide an activity of 1.0 μCi per milliliter of solution if the entire amount was dissolved.

In general, the actinide concentrations in groundwater "C" at a pH of 7.3-7.4 are greater than those in the brine solutions in the 6.9-7 pH range. This is particularly true for ^{244}Cm, where the concentrations are 2 to 3 orders of magnitude lower in the brine solutions.

Kd values for the actinides of 300 or greater are observed for all the geological samples if the halite Kd's are based on weight of insoluble material rather than the weight of the total halite sample. In general, the Kd values in the groundwater "C" are higher than in Brine "B" which could result from hydrolysis due to higher pH in the "C" solutions; however, there are some cases where this Kd order is reversed.

The reasonably good agreement between the Kd values for the clay samples (Table 9.3-6) and the halite containing interstitial clay particles (Tables 9.3-5 and 9.3-11) suggests that the halite in the vicinity of the repository can serve as a barrier to actinide migration.

9.3.8 Parametric Effects

pH and Nuclide Concentration Effects on Kd. The first investigation into the contribution of the pH of the aqueous phase and effect of nuclide concentration on the sorption coefficient involved ^{152}Eu sorption from brines A and B and groundwater C on samples from the Magenta and Culebra Formations.

The experimental procedure used was the same as that described previously, except two blank samples of each feed solution were included instead of one. At the end of a two week equilibration period, the pH of the samples and feed solutions were measured. One of the feed B and C solutions was then adjusted so that its pH was equal to that observed in sample solutions containing that feed. A sodium carbonate solution was used for the pH adjustment, which was done over a period of three days. By the time analytical samples of the adjusted feeds were taken, the pH of some of them had increased and was higher than the corresponding sample. The pH of the Brine A feeds was not adjusted as the final values were the same as those in the samples.

The pH of the adjusted feeds decreased significantly during the first three months, probably due to adsorption of atmospheric carbon dioxide (Garrels and Christ, 1965). The pH of the solutions contacting the rock also varied with some increasing and others decreasing; however, the change was consistent within a given set of samples containing the same rock and solution.

Distribution coefficients calculated from both the feed activities and pH adjusted feed activities after two week and three month periods are listed in Table 9.3-12.

Europium is apparently more soluble in Brine A than in Brine B at the same pH or in the C composition at higher pH. The effect of adjusting the pH in B and C solutions definitely resulted in hydrolysis and formation of some species which did not pass through a 0.8μ filter. It is also of interest that significant decreases in activity in the pH-adjusted feeds were observed for all Eu concentrations used.

<u>The Effect of Trace Organic Contaminants of Kd's of ^{152}Eu, ^{153}Gd and ^{144}Ce</u>. One of the concerns in estimating migration rates of radionuclide in aqueous media is the ionic form of the nuclide of interest. Experiments have shown that the simple ionic forms of most polyvalent cations interact quite readily with geologic media from the

WIPP site via ion exchange or other sorption phenomena. These interactions serve to retard the movement of the ionic species relative to the aqueous matrix containing them.

The extent of the nuclide-geologic media interaction can be significantly altered by changes in the ionic form of the nuclide. Examples of such changes are redox reactions which may result in species of zero or negative charge types and reactions with available inorganic or organic ligands to form complex species with different chemical properties. One such change in properties might be enhanced mobility over that of the bare ion.

Investigations of the sorption changes due to complexation between organic ligands and radionuclides have been initiated by Robert T. Paine of the University of New Mexico. One source of organic ligands which may be present in large quantities in the repository is the plywood used in containers for shipping TRU waste. Samples of these containers are being refluxed in synthetic Brine B at 70°C, the maximum temperature expected in the transuranic (TRU) waste horizon in the repository. The initial samples of this brine, subsequently referred to as B*, were taken after 5 weeks of refluxing.

Although no significant physical degradation of the plywood was observed after this time period, chemical leaching did occur as evidenced by the coffee brown appearance of the brine. Gas chromatograph-mass spectrometer analysis of the brine indicated the presence of organic material, but identificaton was inconclusive. Infrared spectroscopy was used to examine carbon tetrachloride and benzene-acetone extracts from the brine. The extracted organic material fell into the general class of esterified rosin compounds, but no specific indentification was possible. Qualitative observation indicated that the brine contained extremely small amounts of organic material. Neither solvent system extracted the colored species from the brine.

The effect of plywood extract on lanthanide distribution coefficients (Kd's) was determind by measuring Kd's for ^{153}Gd, ^{144}Ce and ^{152}Eu between five geologic media from the WIPP site and the brine B* containing the plywood extract, and comparing these values with Kd's obtained in identical experiments using pure Brine B. The results are given in Table 9.3-13.

Although both the B and B* brines were doped initially with the same concentrations of tracers, there is a significant difference in the activity of the final samples taken. This could result from adsorption on the polyethylene containers or hydrolysis and subsequent filtration of hydrated oxides of the tracer elements through the 0.8 μ filters. In either case, the effect occurs to a significantly lesser extent in the brine B*, which is probably the result of interaction between the tracers and some ligand extracted from the plywood to form complexes which are less susceptible to hydrolysis.

The difference in Kd values could also result from complex formation. The complexing ligand may be a rosin derivative, many of which form very stable compounds with heavy metals. It may also be the species which causes the brown coloration of the brine. Observation of the analytical samples taken from the brine B* samples showed that the clay material had completely decolorized the brine. The other materials decolorized the B* samples to varying degrees, as given below in order of decreasing color intensity remaining in solution:

Feed > Magenta > Culebra ≈ Bell Canyon > Cowden > Clay solution

Similar work will be done using extracts which are being prepared from other organic materials expected to be associated with TRU waste such as rubber gloves, swipes, detergents, etc. Based on lanthanide results, an experimental matrix will be designed to study the actinide elements.

<u>The Effect of Oxidation State on Radionuclide Sorption</u>. An additional approach to understanding the behavior of actinides under site specific conditions in WIPP is the study of the behavior of various oxidation

states of the actinides (particularly plutonium) in the presence of various components of the WIPP strata. This work is being performed at Argonne National Laboratory by Sherman Fried and Arnold Friedman.

Relatively concentrated solutions of actinides (0.01 M) whose oxidation states were determined by inspection of their optical absorption spectra were prepared and allowed to react with saturated WIPP brines, and with rocks from the WIPP site. Since it was assumed that in the final stages of a WIPP repository oxygen might be absent in the rock salt, the preparations were made in vacuo to identify species present under such conditions.

Solutions of plutonium were prepared in such a way that samples sealed in optical absorption cells at approximately 10^{-6} atmosphere of O_2 could be examined from time to time to observe changes in absorption peaks (if any) and thus determine the stability of the particular oxidation state as a function of time.

In the case of plutonium preparations, the isotope ^{242}Pu was employed. This was done to minimize radiolysis effects (specific activity Pu^{242} = 4.5×10^3 d/m/μg vs. $1/15 \times 10^5$ d/m/μg for ^{239}Pu). It is felt that while the behavior of plutonium in these concentrated solutions may be substantially different than tracer Pu migrating in an aquifer where the radiation field will be much less, it is nevertheless a good approximation to the conditions immediately in the vicinity of the canister when an amount of radioactivity has just leached out.

The various oxidation states of Pu were prepared by electrolytic means or oxidation by ozone as the case required, in order to avoid the introduction of extraneous ions which might affect the results.

The solutions of Pu compounds ($PuCl_3$, $PuCl_4$, and PuO_2Cl_2) were prepared directly in the absorption cell. The concentrations were generally of the order of 0.01 M. In a typical case, 4 ml of saturated WIPP brine "A" (Table 9.6-1) was introduced into the optical cell and

evaporated to dryness in a stream of nitrogen. After this operation, the proper amount of Pu compound was pipetted in the cell and evaporated to dryness with the salts from the WIPP brine.

The cell was attached to the vacuum line and evacuated until the pressure was $\sim 10^{-6}$ atm. De-aerated water was then distilled under vacuum until the amount of solution equals that which originally pipetted into the cell.

These samples of various Pu compounds were examined from time to time observing any changes in intensity or wavelength of absorption peaks corresponding to the oxidation state in question.

The resulting samples prepared for measurement of changes in intensity of the optical absorption spectra are Pu(III), Pu(IV) and Pu(VI) in water, and in saturated WIPP brine solution.

No definite changes in absorption peaks corresponding to changes in oxidation state were observed. The Pu(IV) solutions were so dilute, because of precipitation from the hydrolysis of Pu(IV), that little or no characteristic absorption peaks could be observed at all. The Pu(III) solutions, whose absorption peak is at about 6000 Å, also showed little or no detectable change over the time interval of the experiment (2-4 months).

The Pu(VI) as PuO_2Cl_2, surprisingly, is insoluble in saturated WIPP brine. The level of solubility is so small that no absorption peaks could be seen at all. In order to be sure that this case is not one of very slow rate of solution, the sealed absorption cells are being rotated with periodic abosorption spectrum determinations.

Some absorption studies have already been carried out with Pu(IV) and Am(III) on anhydrite and dolomite from the WIPP site (see previous sections).

Work is presently underway with the Argonne National Laboratory Analytical Chemistry Group to develop procedures for the determination of the oxidation potential of WIPP salt, dolomite and anhydrite slurries, particularly those employing oxidation-reduction indicators.

Crude reaction rates and K_D values of Pu(III) and Am(III) with Magenta and Culebra dolomites in waters that have been equilibrated with the individual rock are in the table.

Rock Type	Radionuclide	Reaction Time (hr)	K_D
Magenta (gypsiferous dolomite)	Pu	50	41
	Am	400	47
Culebra (silty dolomite	Pu	1	19
	Am	1	84

It should be understood that these reaction rates are crude and that the K_D values are somewhat indeterminable because of varying quantities of radionuclides "plating out" on the walls of the containers. These experiments will be repeated as a function of temperature. Since these determinations were made on tablets of rock of known dimensions, the surface absorption coefficients can be calculated, these perhaps being more applicable to migration along fissures and cracks, where the surface absorption coefficient is

$$S_c = \frac{\text{activity/ml liquid}}{\text{activity/cm}^2 \text{ solid}}$$

The installation of a controlled atmosphere box has made it possible to study the absorption of the various oxidation states of Pu without the perturbing effects of atmospheric oxygen.

9.3.9 Summary

A survey of the potential of geological media from the vicinity of the Waste Isolation Pilot Plant site in Southeastern New Mexico for retardation of radionuclide migration via an aqueous carrier has been completed. Solution simulants representing water in equilibrium with potash minerals or halite zones and a typical groundwater were spiked with radionuclides and contacted with geological samples to obtain sorption coefficients, Kd's. The samples were taken from potential aquifers above and below the repository horizons and from bedded salt deposits in the repository horizons. The nuclides chosen for study represent those with a high potential for leaching and/or migration, high radiotoxicity, or those with a chemistry similar to nuclides with the aformentioned properties. They included ^{137}Cs, ^{85}Sr, ^{131}I, ^{99}Tc, ^{125}Sb, ^{144}Ce, ^{152}Eu, ^{153}Gd, ^{106}Ru, ^{243}Am, ^{244}Cm and ^{238}Pu.

A very general summation of the Kd results in brine simulants is as follows: Anionic species, TcO_4^- and I^-, showed little or no tendency to adsorb on any of the geological media (Kd's ≤ 1), with the possible exception of a clay material from a halite stratum (Kd < 5). Cs and Sr Kd's were also generally less than 1, but values in the range of 10-20 were observed on several minerals. Ru Kd's ranged from 25 to $>10^3$, depending on the brine and geological materials. The lanthanide and actinide Kd's were typically $> 10^3$, with only polyhalite showing significantly lower adsorption.

In the groundwater simulant, Tc and I showed the same behavior. The Kd's of the other nuclides were slightly higher, particularly those of Cs and Sr. This would be expected if the sorption were due to an ion exchange mechanism, but, in the case of the lanthanides and actinides, may also result from an increased contribution of hydrolysis to the Kd due to the higher pH of the groundwater simulant.

Important parameters in Kd measurements include solid sample form, simulant compositon, Eh and pH, and radionuclide concentration. In the Kd survey measurements, an initial set of these parameters was selected and, wherever possible, was used throughout the work. Parametric studies with Eu involving pH, trace organic constituents in the simulant solutions, and radionuclide concentrations have shown that significant differences in Kd's can be observed by varying any of those parameters.

A general observation which can be made from data obtained to date is that a Kd represents an empirical value for nuclide adsorption, which includes the effects of physical adsorption, ion exchange, and hydrolysis or other precipitation processes. The utility of a given Kd value is unambiguous only for that set of conditions used in making the measurement. Kd information which is used in modeling radionuclide migration should be in the form of a range of values generated in parametric studies under the variety of conditions postulated for a specific repository site.

For the WIPP site, rock salt, anhydrite, polyhalite and water-bearing dolomites and sandstones show an affinity for radionuclide sorption. Sorptive capacity as measured by batch Kd experiments generally expressed $Kd > 0$. Even small values of Kd ($0 < Kd < 1$) are effective in retarding the movement of radionuclides in groundwater.

9.4 REFERENCES

Acton, R.V., 1977, Thermal conductivity of SE New Mexico rocksalt and anhydrite: unpublished Sandia Laboratories preliminary report.

Amphlett, C.B., 1964, Inorganic Ion Exchangers, Elsevier, Amsterdam.

Baar, C.A., 1977, Applied Salt-Rock Mechanics 1: Elsevier Scientific, New York.

Bradshaw, R.L. and McClain, W.C., 1971, Project Salt Vault, a demonstration of the disposal of high-activity solidified waste in underground salt mines: Oak Ridge National Laboratories #4555.

Buerger, M.J., 1930, Translation-gliding in crystals of the NaCl structural type: Am. Mineralogist, v. 15, p. 174-187; p. 226-238.

Callender, J.F. and Ingwell, T., 1977, Structural Petrology of Undeformed and Experimentally Deformed Halite samples from USERDA Site #7 and #9, Report, SAND78-7076, Department of Geology, University of New Mexico.

Carter, N.L. and Heard, H.C., 1970, Temperature and rate dependent deformation of halite: Amer. Jour. Sci. 269, 193.

Clabaugh, P.S., 1962, Petrofabric study of deformed salt: Science, v. 136, p. 389-391.

Core Laboratories, 1977, Special core analysis study for Sipes, Williamson and Aycock, unpubl. consulting report to Sandia Laboratories by Sipes, Williamson and Aycock, Inc.

Dawson, P.R. and Tillerson, J.R., 1977, Comparative evaluations of the thermomechanical responses for three high level waste canister emplacement alternatives: Report, SAND77-0388, Sandia Laboratories.

Dreyer, W.E., 1974, Results of recent studies on the stability of crude oil and gas storage in salt caverns. 4th Symp. on Salt, A. H. Coogan, Ed.

Dreyer, W., 1972, The Science of Rock Mechanics: Trans. Tech. Publ. Cleveland, Ohio.

Elliot Geophysical Company, 1976, A laboratory investigation of the density and resisitivity physical properties of drill core sample ERDA #9: consulting report to Sandia Laboratories.

Fossum, A.F., 1977, On the structural behavior of progressively mined solution cavities in salt, Journal of Applied Mechanics, v. 44, Series E, No. 4, p. 565-570.

Garrels, R.M. and Christ, C.L., 1965, "Solutions, Minerals and Equilibria," Freeman, Cooper & Co., San Francisco.

Gnirk, P.F., Pariseau, W.G., Russel, J.E., Wawersik, W.R., and Hovland, H.V., 1973, Analysis and evaluation of the rock mechanics aspects of the proposed salt mine repository: Report, RSI-005, RE/SPEC, Inc.

Griswold, G.B., 1977, Site selection and evaluation studies of the waste isolation pilot plant (WIPP), Los Medanos, Eddy County, New Mexico: Sandia Laboratories report 77-0946, Albuquerque, New Mexico.

Hansen, F.D. 1977, Triaxial Quasi-Static Compression and Creep Bahavior of Bedded Salt from Southeastern New Mexico: Technical Memorandum Report RSI-0055, For Sandia Laboratories, Albuquerque, New Mexico.

Hansen, F.D., and Gnirk, P.F., 1975, Design Aspects of Radioactive Waste Repository: III Uniaxial Quasi-static and Creep Properties of the Site Rock, Tech. Memorandum Report RSI-0029.

Hansen, F.D. and Mellegard, K.D., 1977, Creep behavior for bedded salt from southeastern New Mexico at elevated temperatures: Tech Memo to Sandia Laboratory, RSI-0062, Albuquerque, New Mexico.

Heard, H.C., 1972, Steady-state flow in polycrystalline halite at pressure of 2 Kb: Geophys. Monograph Series, p. 16, 191, 1972.

Hirth, J.P. and Lothe, H., 1968, Theory of dislocations: New York, McGraw-Hill, 780 p.

Hofer, K.H. and Thomas, K., 1968, Triaxial tests on rock salt: Int. J. Rock Mech. Min. Sci., 5, 195.

Kent, D., and Wawersik, W.R., 1976, Laboratory velocity measurements on rock salt core samples: Sandia Laboratories interoffice memo, Albuquerque, New Mexico.

Kopp, O.D., and Combs, D.W. 1975, Mineral sources of water in evaporite sequences, Report, ORNL subcontract No. 3670, Dept. of Geol. Sci., Univ. of Tennessee.

Lambert, S.J., 1977, "The Geochemistry of Delaware Basin Groundwaters," SAND77-0420.

Langer, M., 1969, Rheologie der Gesteine, Z deutsch. geol. Ges., 119.

Le Comte, P., 1965, Creep of rock salt: J. Geol., 73, 469.

Levy, H.B., 1972, "On Evaluating the Hazards of Groundwater Contamination by Radioactivity from An Underground Nuclear Explosion," Lawrence Livermore Laboratory Rept. UCRL-51278.

Menzel, W. and Schreiner, W., 1977, Zum Geomechanischen verhalten von steinsalz verschiedener lagerstatten der DDR, Teil II: das Verformungsverhalten: Neue Bergbautechnik, 7, 585.

Mraz, D., 1978, Theoretical predictions confirmed by in-situ rock behavior in a deep potash mine: in 19th U.S. Rock Mechanics Symp., ed Y.S. Kim, Reno, Nevada.

Russel, J.E., 1978, A Creep Model for Rock Salt, Fifth Int. Salt Symps., Hamburg, Germany.

Schlichta, P.J., 1969, Growth, deformation, and defect structure of salt crystals: Geol. Soc. Am., Sp. Paper 88, 598.

Schmidt, W., 1937, Festigkeit and Verfestigung von Steinsalz: Zeitschr. Angew. Min., 1., 1.

Serata, S., 1966, Continuum theory and model of rock salt structure: in second symposium on salt, ed Jon L. Rau, Cleveland, Ohio.

Serata, S., 1968, Application of continuum mechanics to design of deep potash mines in Canada: Int. J. Rock Mech. Min. Sci., 5:293-314.

Serata, S., 1970, Prerequisites for application of finite-element method to solution cavities and conventional mines: in Third Symposium on Salt, ed., J.L. Rau and L.F. Dellwig, Cleveland Ohio.

Serata, S., 1972, The Serata stress control method of stabilizing undergound openings: Proc. 7 Can. Rock Mech. Symp. Edmonton, March 1971, pp. 99-118.

Serata, S., and Cundey, T.E., 1978, Rheological method of salt county design for underground storage of solid liquid, and gaseous matters: in 19th U.S. Symp. on Rock Mech. ed. Y.S. Kim, Reno, Nevada.

Serata, S., Sakuri, S., and Adachi, T., 1972, Theory of aggregate rock behavior based on absolute three-dimensional testing (ATT) of rock salt: in Basic and Applied Rock mechanics, Proc. 10th U.S. Symp. Rock Mech., K.E. Gray (ed.), AIME.

Shelby, J.E., 1978, Permeability of Sodium Cloride: Sandia Laboratories interoffice memo, Albuquerque, New Mexico.

St. John, C.M., 1978, Computer models and the design of underground radioactive waste repositories, M.I.T. Special Summer Session on Rock Engineering, June 1978.

Sutherland, H.J., 1978, Permeability of SENM rock salt: Sandia interoffice memo, Albuquerque, New Mexico.

Szeki, A, 1978, Influence of Volume on Creep Behavior of Rocksalt Pillars, Fifth. Int. Salt Sympos., Hamburg, Germany.

Terra Tek Inc., 1978, Gas permeabilities of SENM salt: consulting memo to Sandia Laboratories, Albuquerque, New Mexico.

Thompson, E., and Ripperger, E.A., 1964, An Experimental Technique for the Investigation of the Flow of Halite and Sylvinite, Proc. 6th Symp. Rock Mech., E.M. Spokes and C.R. Christiansen, eds., AIME.

Thoms, R.L., Char, C.V., and Bergeron, W.J., 1973, Finite Element Analysis of Creep in Rock-Salt Pillar Models, Proc. 14th, Symp. Rock Mech., H.R. Hardy and R. Stefanko eds., AIME.

Uhlenbecker, F.W., 1968, Verformungsmessungen in der Grube und erganzende Laboruntersuchungen auf dem Kaliwerk Hattorf (Werra-Revier) im Hinblick auf eine optimale Festlegung des Abbauverlustes bei grobtmoglicher Sicherheit der Grubenbaue, PhD Thesis, TH Clausthal.

U.S. Corps. of Engineers, 1963, Project Dribble, Petrographic examination and physical tests of cores, Tatum Salt Dome, Mississippi: Army Engineers Waterway Experiment Station, Techn. Rep. No. 6-614.

Wahi, K.K., Maxwell, D.F., Hofmann, 1978, Explicit finite-difference simulations of Project Salt Vault: in 19th U.S. Rock Mech. Symp., ed. Y.S. Kim, Reno, Nevada.

Wawersik, W.R. and Brown, W.S., 1973, Creep Fracture of Rock, Techn. Report UTEC 73-197, Univ. of Utah,

Wawersik, W.R., 1975, Technique and apparatus for strain measurements on rock in constant confining pressure experiments. Rock Mech. v. 7, 231.

Wawersik, W.R., 1977, Sandia Laboratories Albuquerque, New Mexico, Inter office memos, August and November.

Wawersik, W.R., 1978a, Large specimen triaxial apparatus for rock testing to 70 MPa confining pressure and 225°C: to be published.

Wawersik, W.R., 1978b, Effects of pressure, deviator stress and temperature on transient creep of rock salt at low confining pressure: AGU, Vol 59 No. 4, Apr. 78 p. 376.

Wawersik, W.R., 1978c, Sandia Laboratories, Albuquerque, New Mexico, Inter Office Memo, January.

Wawersik, W.R., Callender, J.F., Weaver, R., and Dropek, R.K., 1976, Preliminary determination of mechanical properties on rock salt from southeastern New Mexico. Pre-Proc., 17th U.S. Symp. Rock Mech., Univ. Utah Exp. St..

Wawersik, W.R. and Hannum, D.W., 1978, Mechanical behavior of New Mexico rock salt in triaxial compression up to 200°C: 5th Int'l Salt Symp. Hamburg, Germany, June 1978.

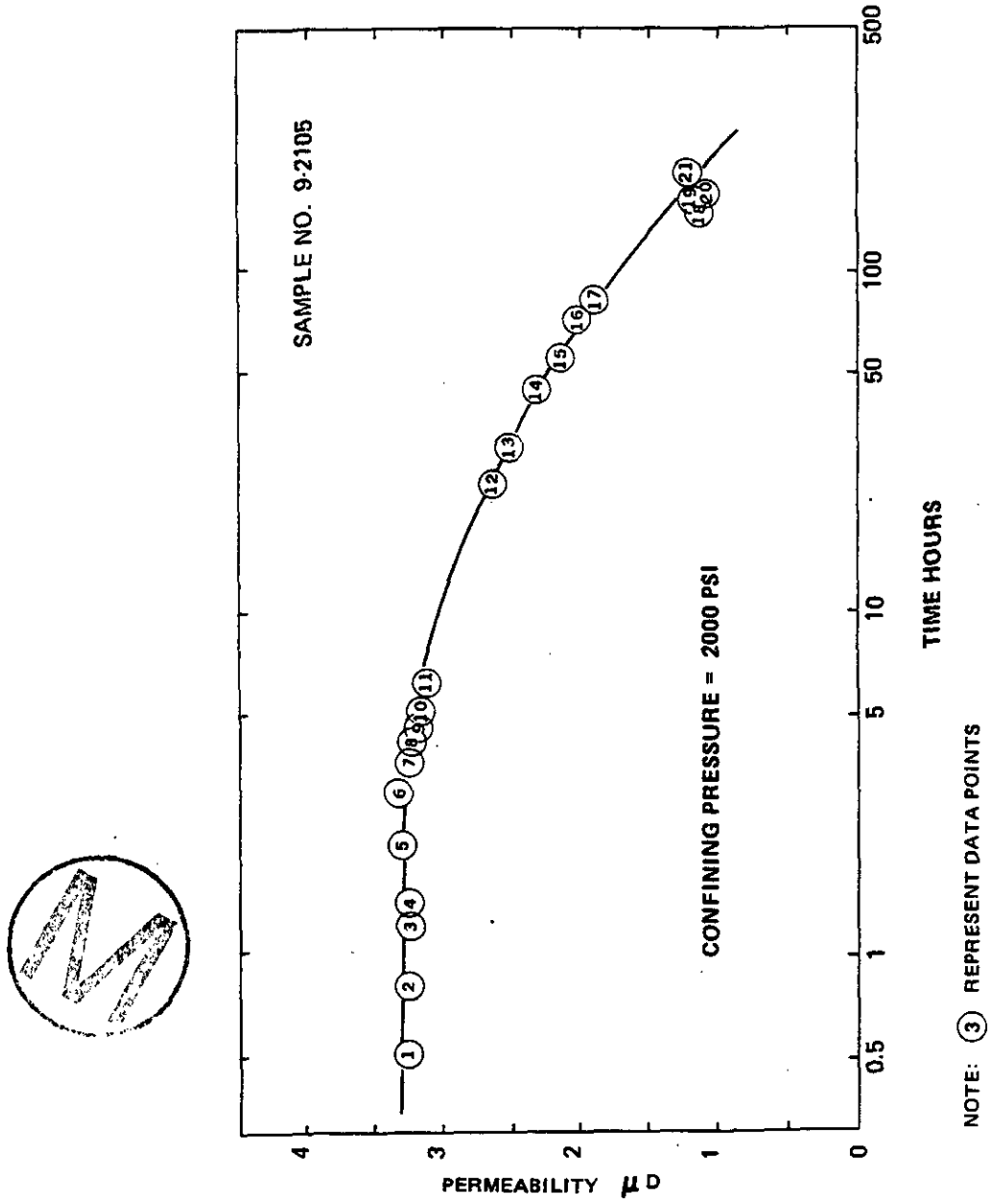

ARGON PERMEABILITY OF ROCK SALT SAMPLE AT 2000 PSI CONFINING PRESSURE

FROM: SUTHERLAND, 1978

FIGURE 9.2.3-1

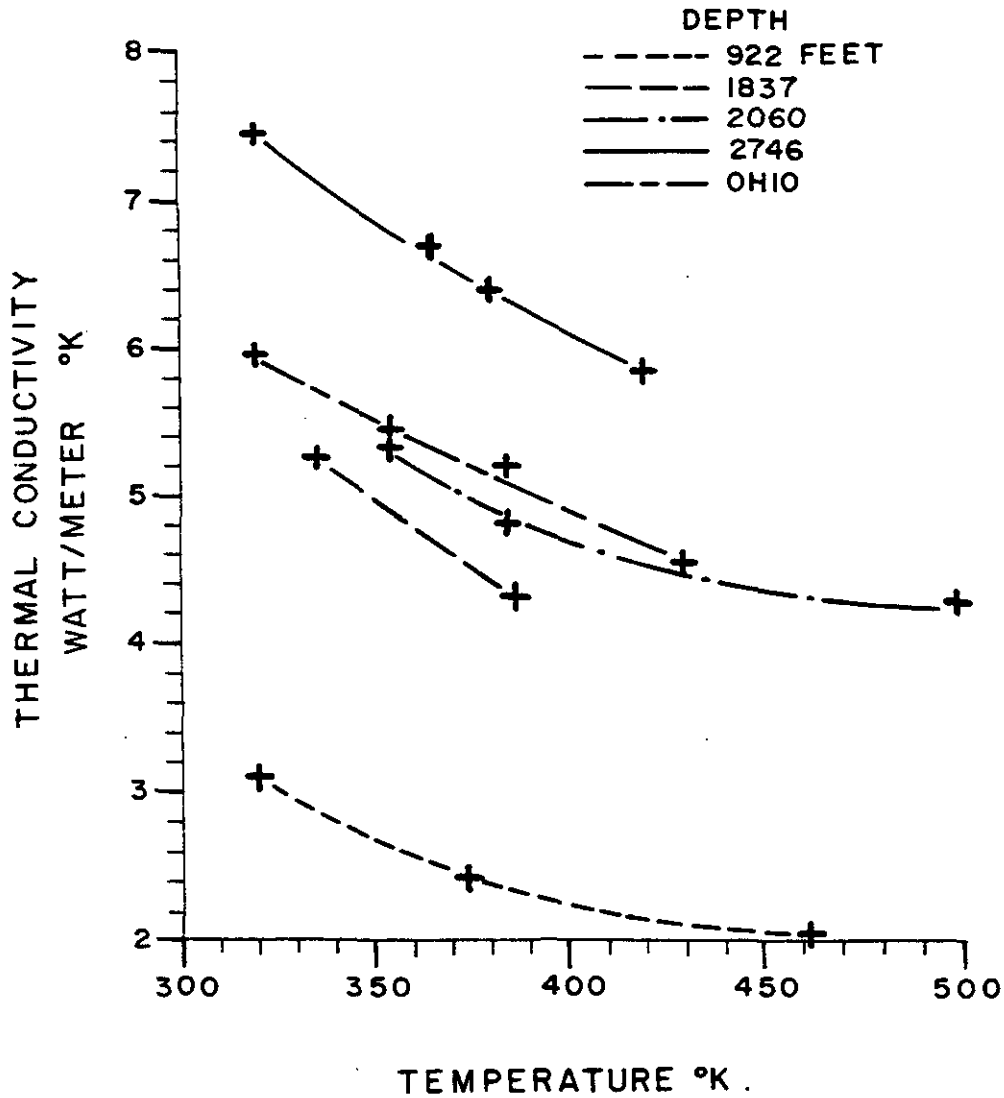

THERMAL CONDUCTIVITY OF ROCKSALT CORE SECTIONS CONTAINING 50% OR MORE HALITE, WELL AEC 8

From: Acton, 1977

FIGURE 9.2.3-2

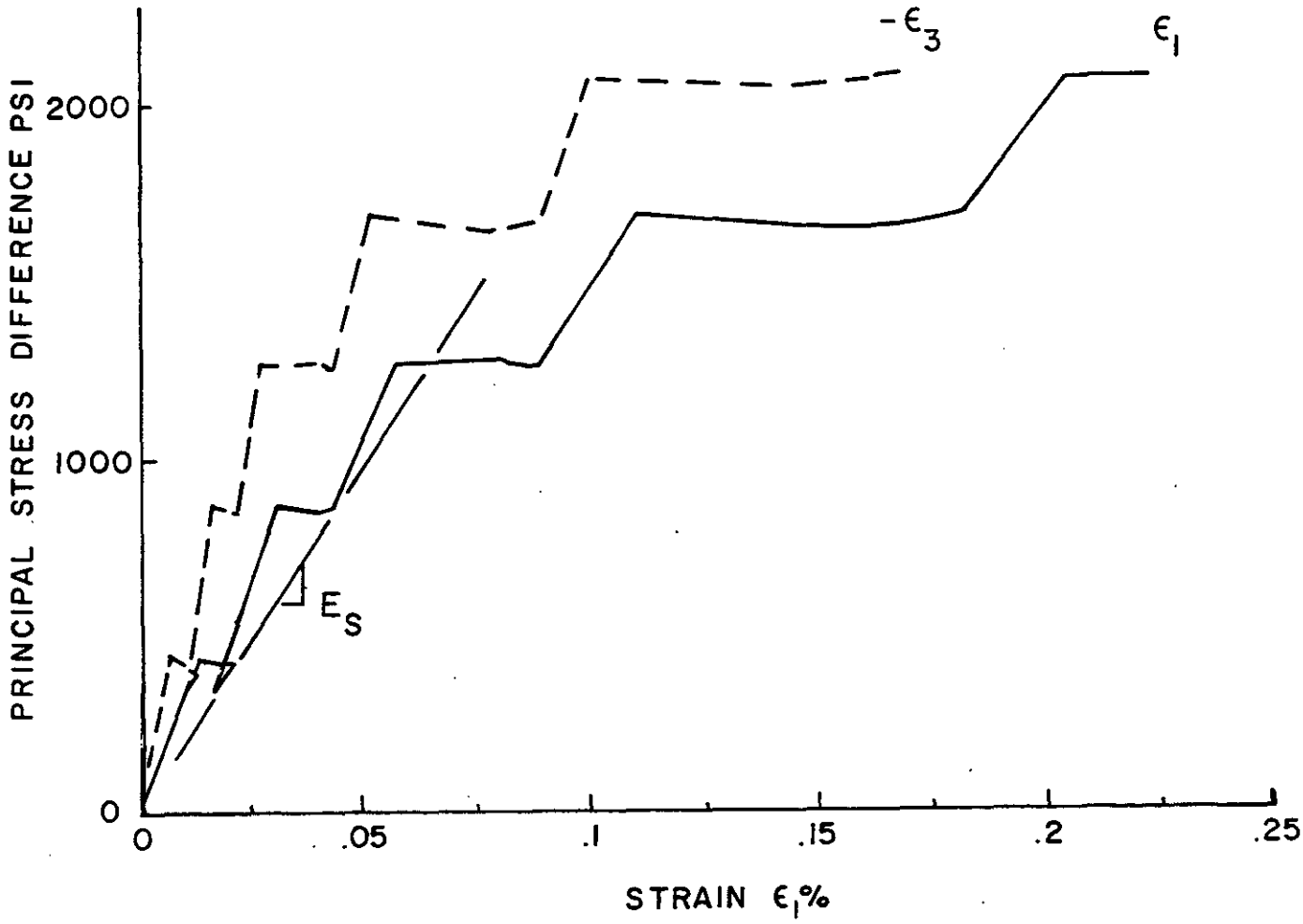

KEY

7-2745 (3.0, 23)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)

TRIAXIAL STRESS-STRAIN CURVES IN REGIME OF SMALL PRINCIPAL STRESS DIFFERENCES AND STRAIN

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-1

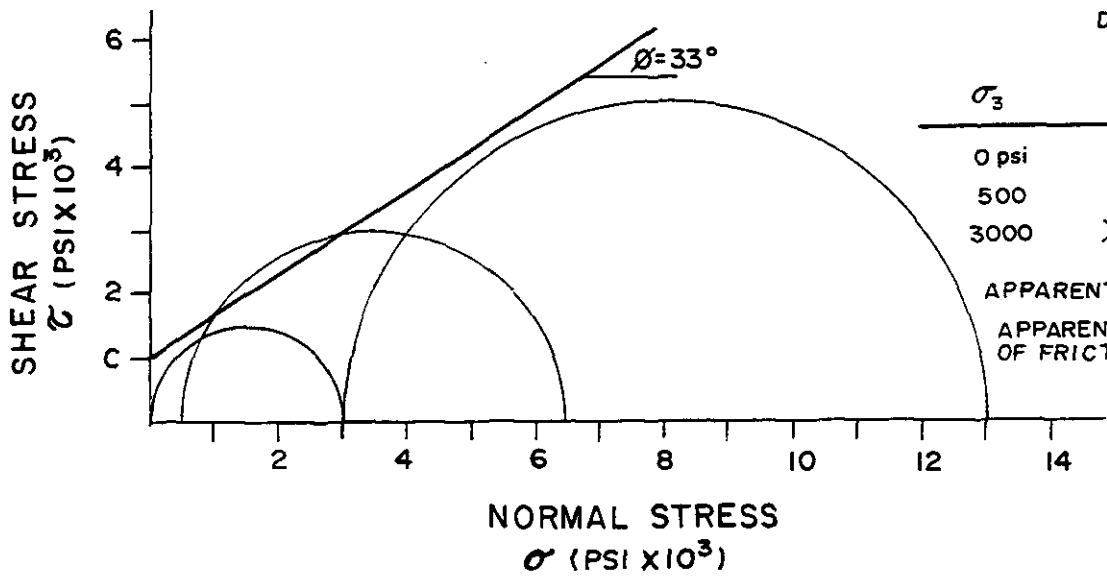

CONFINING PRESSURE σ_3	PRINCIPAL STRESS DIFFERENCE $(\sigma_1 - \sigma_3)$	AXIAL STRAIN AT FAILURE ε_1
0 psi	3000psi	2.5%
500	6000	15
3000	>10,000	>20

APPARENT COHESION C=1000psi

APPARENT ANGLE OF FRICTION Ø = 33°
T = 23°

A. MOHR'S ENVELOPE AT ULTIMATE STRENGTH

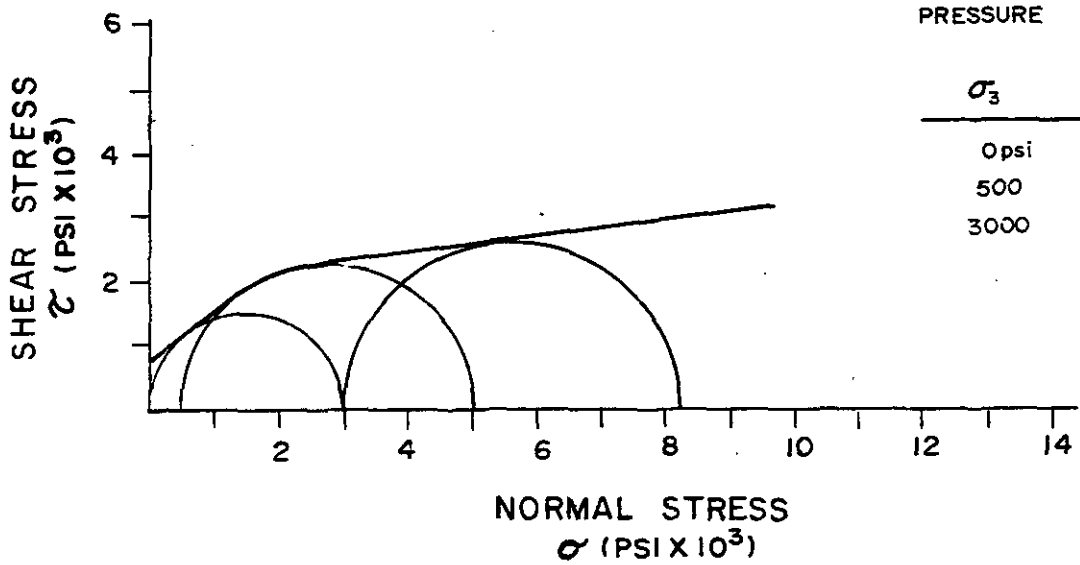

CONFINING PRESSURE σ_3	PRINCIPAL STRESS DIFFERENCE $(\sigma_3 - \sigma_1)$	AXIAL STRAIN ε_1
0psi	3000psi	2.5%
500	4500	2.5
3000	5250	2.5

T = 23°

B. MOHR'S ENVELOPE AT CONSTANT STRAIN

NOTES:

1. THE SAME TEST DATA WERE USED TO GENERATE BOTH ENVELOPES. (TABLE 9 III, 9 IV; WAWERSIK, 1977)
2. THESE QUASI-STATIC PROPERTIES DO NOT ACCOUNT FOR ANY STRENGTH DETERIORATION WITH TIME.

FIGURE 9.2.4-2

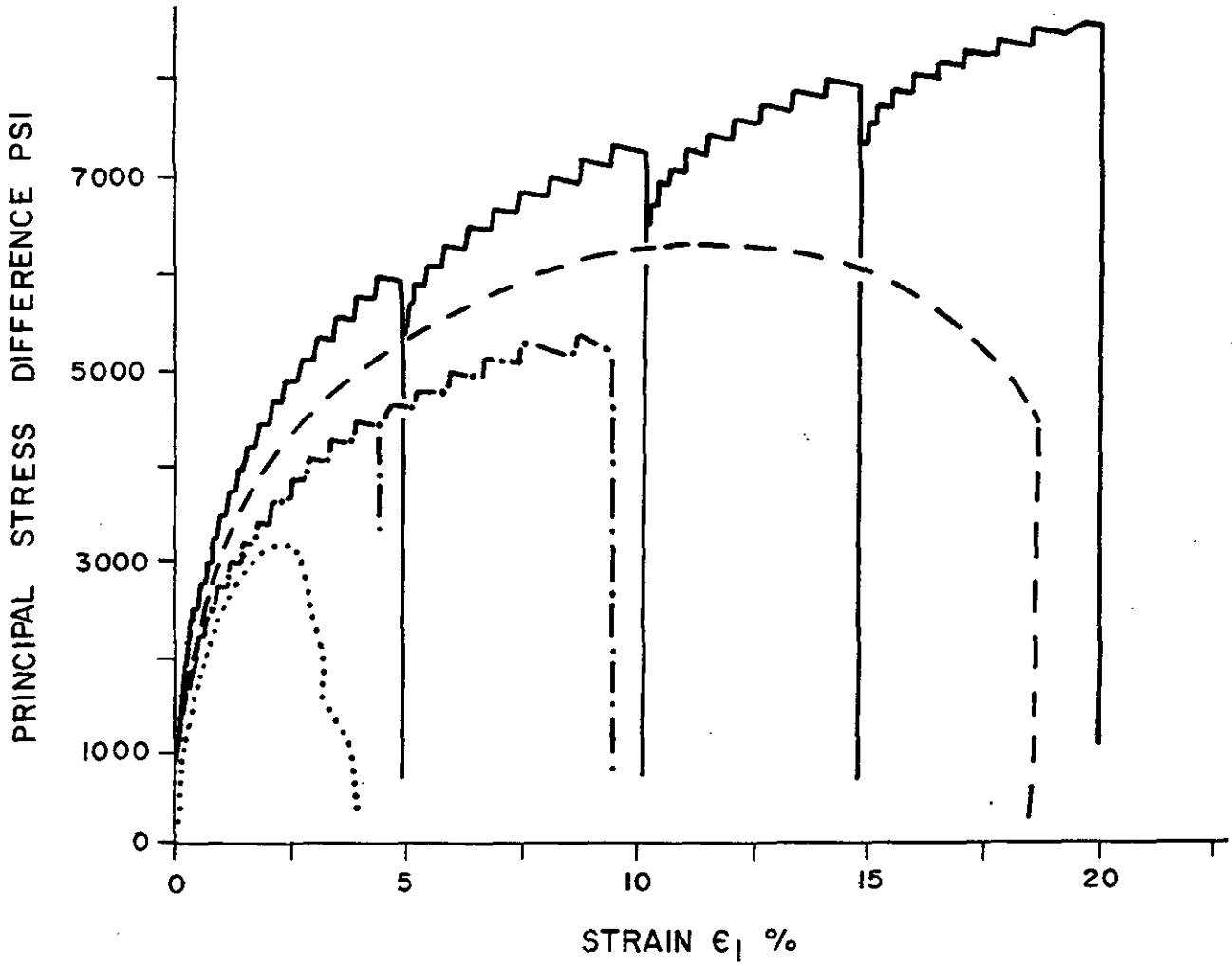

KEY

- ····· 9-2676 (0, 23)
  Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
- — · — 7-2837 (.25, 23)
- — — 9-2601 (.50, 23)
- ——— 9-2601.5 (3.0, 23)

CONVENTIONAL QUASI-STATIC TRIAXIAL STRESS-STRAIN DATA AT AMBIENT TEMPERATURE

EFFECT OF PRESSURE

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-3

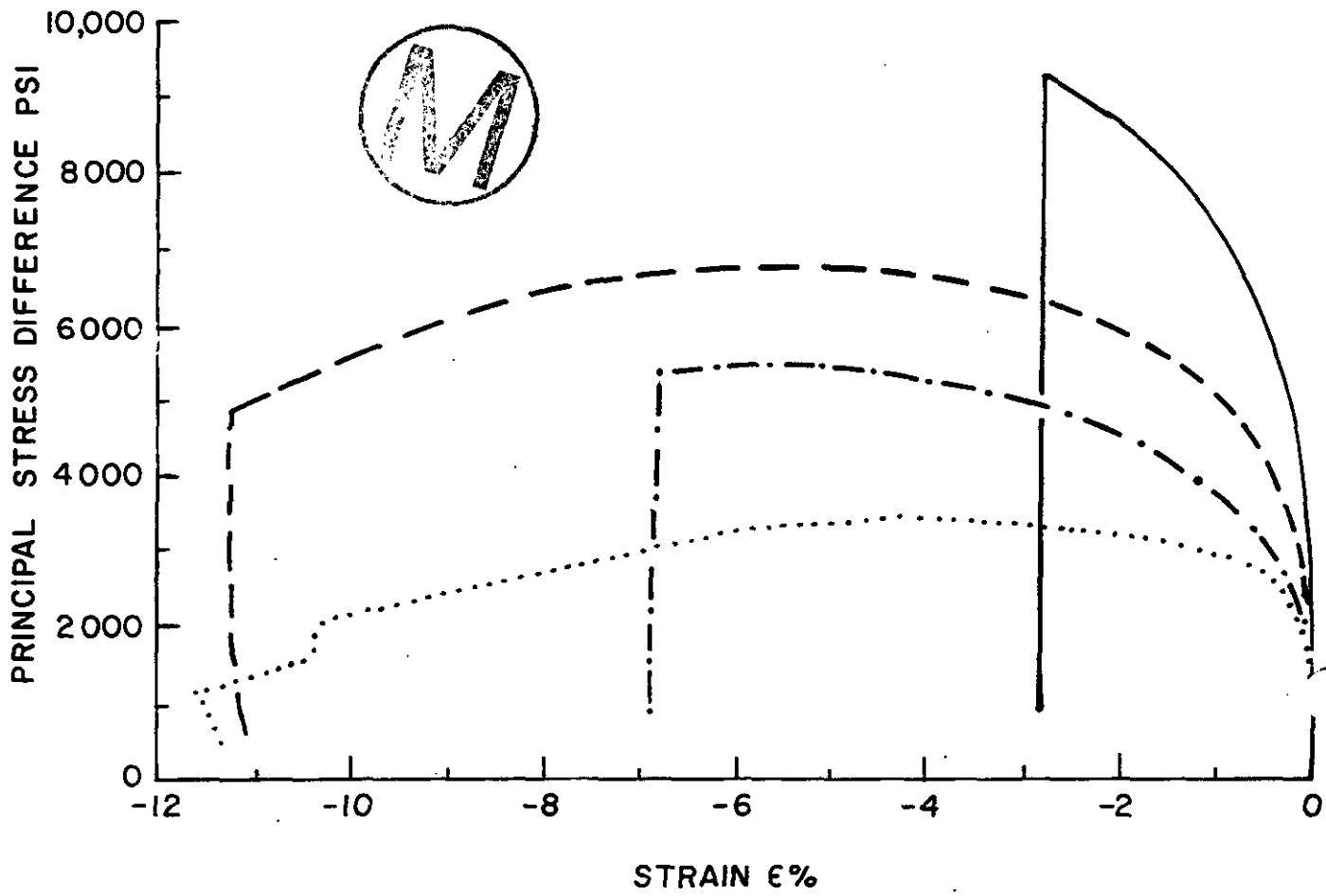

KEY

- ····· 9-2676 (0, 23)
  Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
- —·— 7-2837 (.25, 23)
- — — 9-2601 (.50, 23)
- ——— 9-2601.5 (3.0, 23)

PRINCIPAL STRESS DIFFERENCE VS. VOLUMETRIC STRAIN FOR TEST OF FIGURE 9.2.4-3

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-4

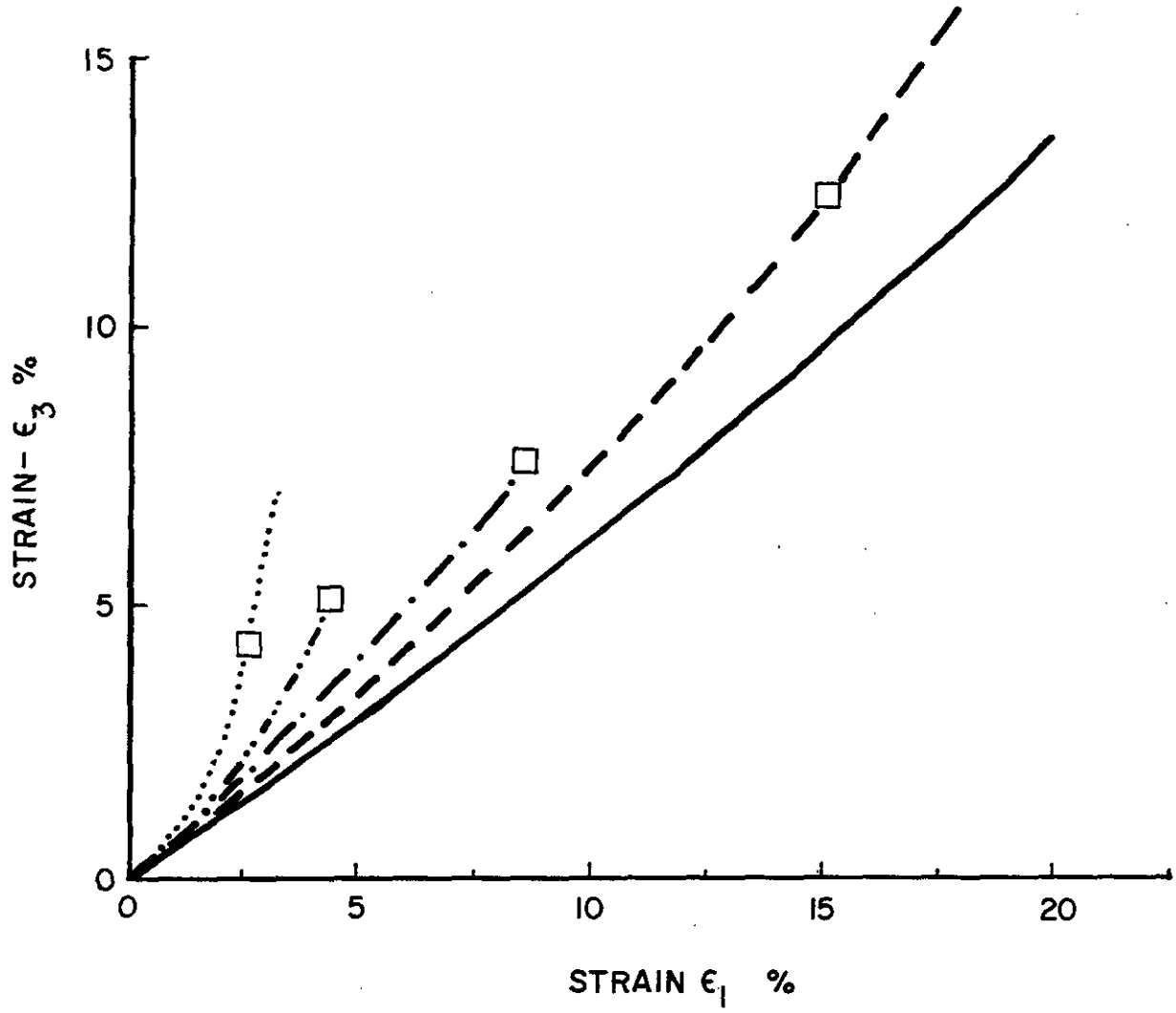

KEY

·····	9-2676 (0, 23)
	Hole No. — Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
—··—	9-2689 (.10, 23)
—·—	7-2837 (.25, 23)
— —	9-2601 (.50, 23)
———	9-2601.5 (3.0, 23)

NOTE: Open squares identify approximate strains at ultimate stresses.

TRIAXIAL VARIATION OF LATERAL STRAIN VS. AXIAL STRAIN FOR TEST OF FIGURE 9.2.4-3

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-5

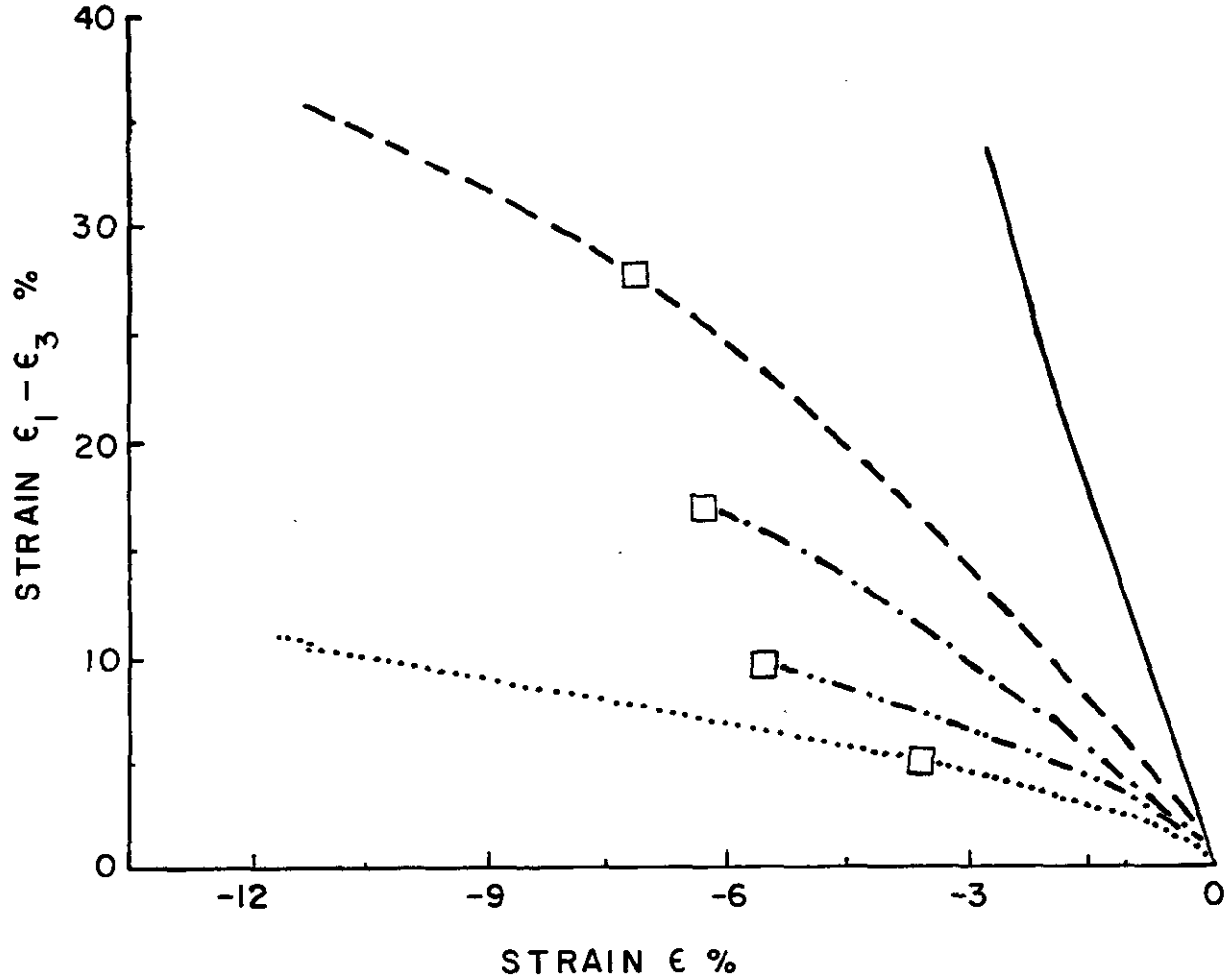

KEY

- 9-2676 (0, 23)
  Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
- 9-2689 (.10, 23)
- 7-2837 (.25, 23)
- 9-2601 (.50, 23)
- 9-2601.5 (3.0, 23)

NOTE: Open squares identify approximate strains at ultimate stresses.

TRIAXIAL VARIATION OF SHEAR STRAIN VS VOLUMETRIC STRAIN FOR TESTS OF FIGURE 9.2.4-3

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-6

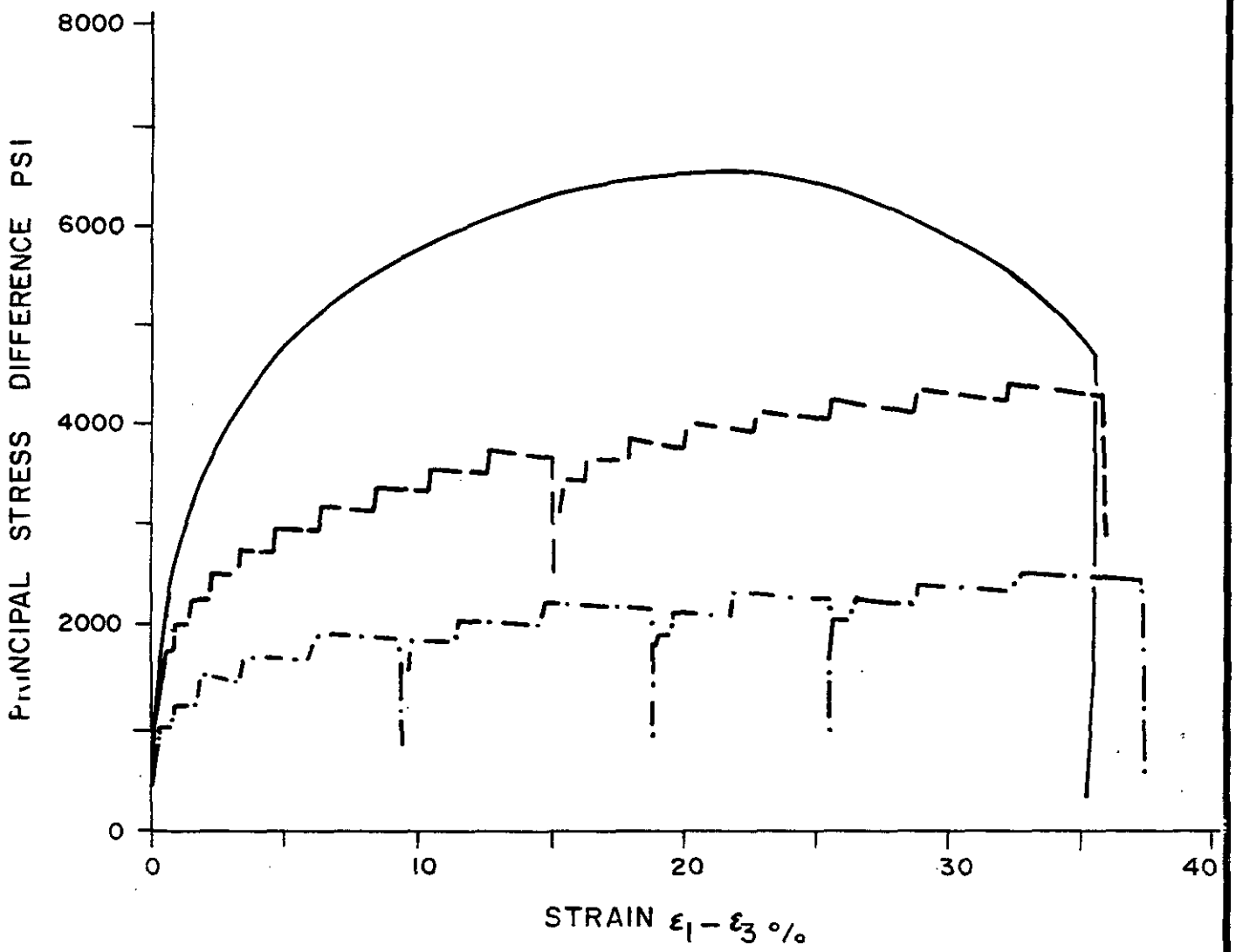

KEY

9-2601 (.50, 23)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
9-2673.4 (.50, 100)
9-2604 (.50, 200)

TRIAXIAL STRESS-STRAIN CURVES AS A FUNCTION OF TEMPERATURE AT CONSTANT CONFINING PRESSURE

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-7

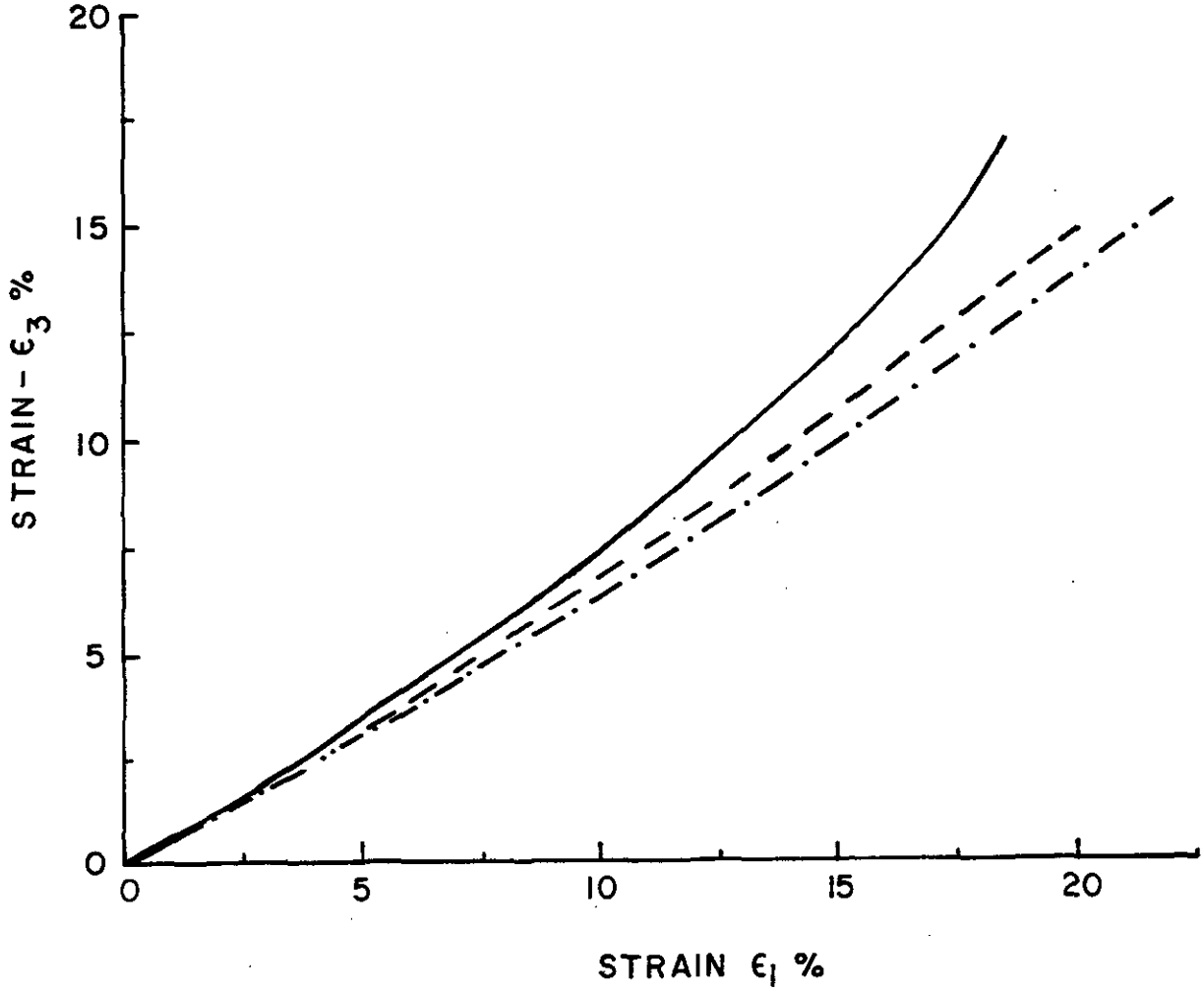

KEY

9-2601 (.50, 23)
Hole No. — Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
9-2673.4 (.50, 100)
9-2604 (.50, 200)

VARIATION OF LATERAL VS. AXIAL STRESS FOR TESTS OF FIGURE 9.2.4-7

From: Wawersik and Hannum, 1978

FIGURE 9.2.4 - 8

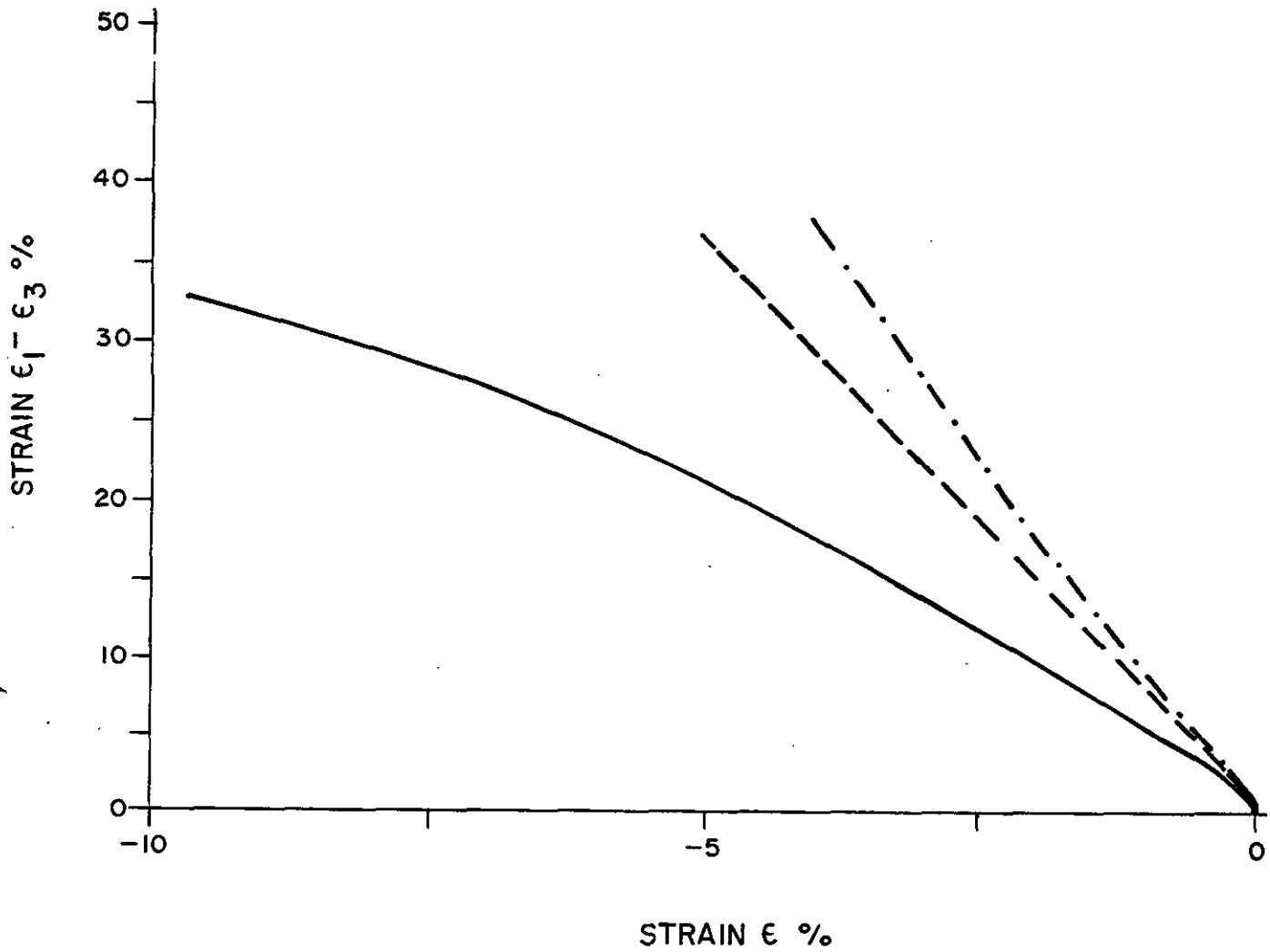

KEY

9-2601 (.50, 23)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
9-2673.4 (.50, 100)
9-2604 (.50, 200)

VARIATION OF SHEAR-STRAIN VS. VOLUMETRIC STRAIN FOR TESTS OF FIGURE 9.2.4-7

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-9

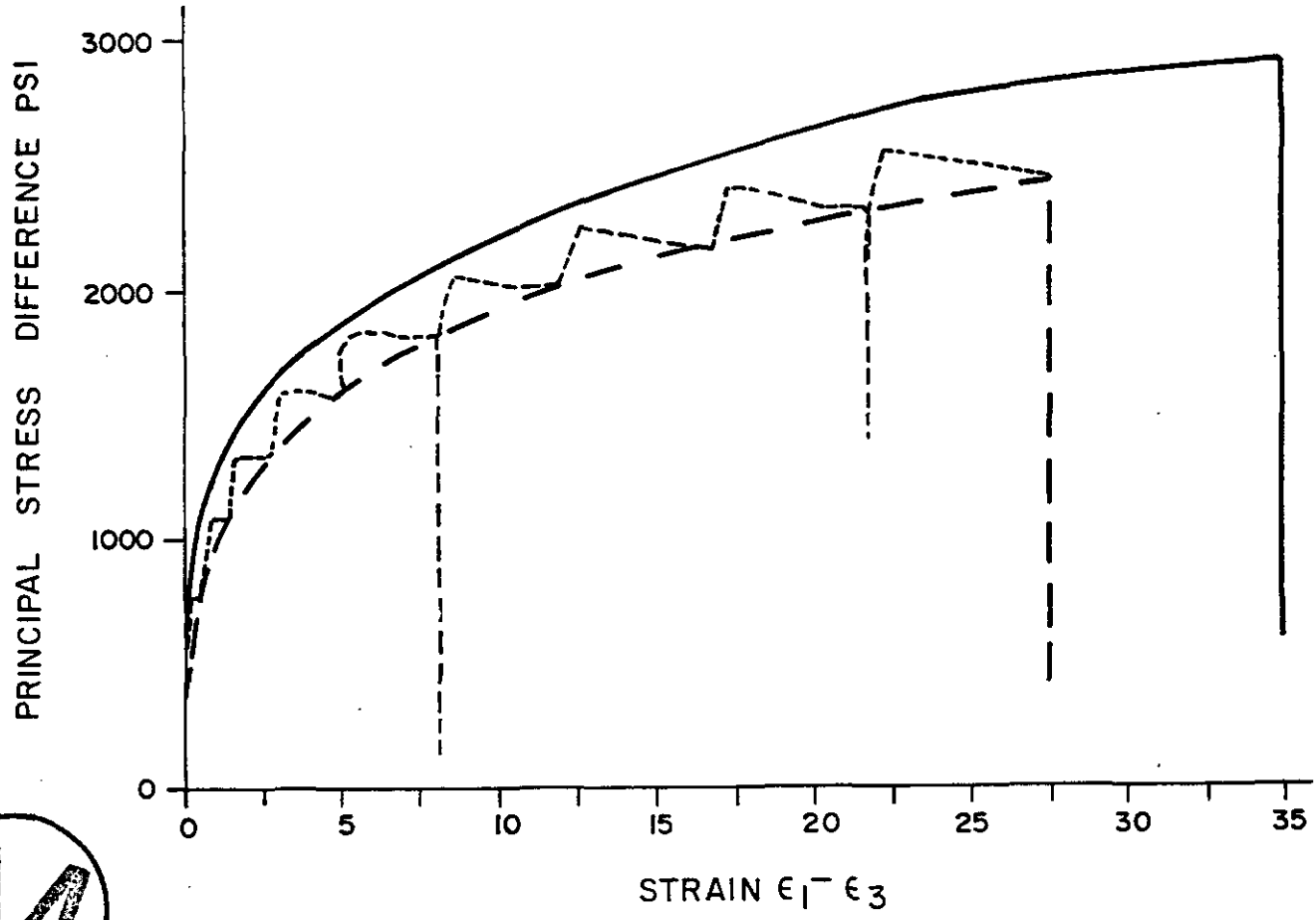

KEY

7-2740 (.50, 200)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
7-2744 (3.0, 200)
Actual load path

TRIAXIAL STRESS STRAIN CURVES AS A FUNCTION OF CONFINING PRESSURE AT 200°C

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-10

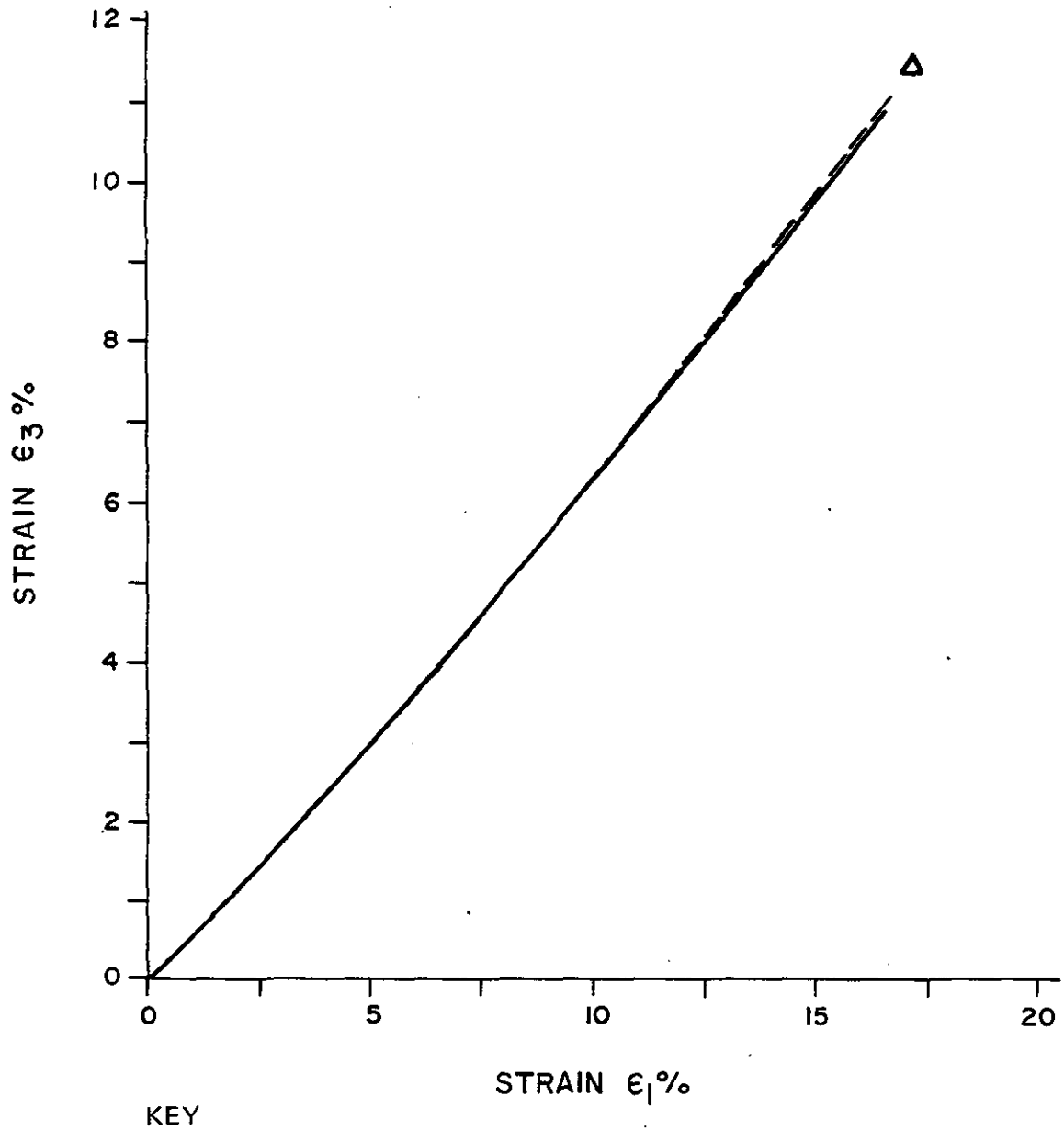

KEY

△ 7-2836 (0, 200)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)

——— 7-2740 (.50, 200)

– – – 7-2744 (3.0, 200)

VARIATION OF LATERAL STRAIN VS. AXIAL STRAIN FOR TESTS OF FIGURE 9.2.4-10

(PLUS ONE ADDITIONAL TEST IN UNIAXIAL COMPRESSION)

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-11

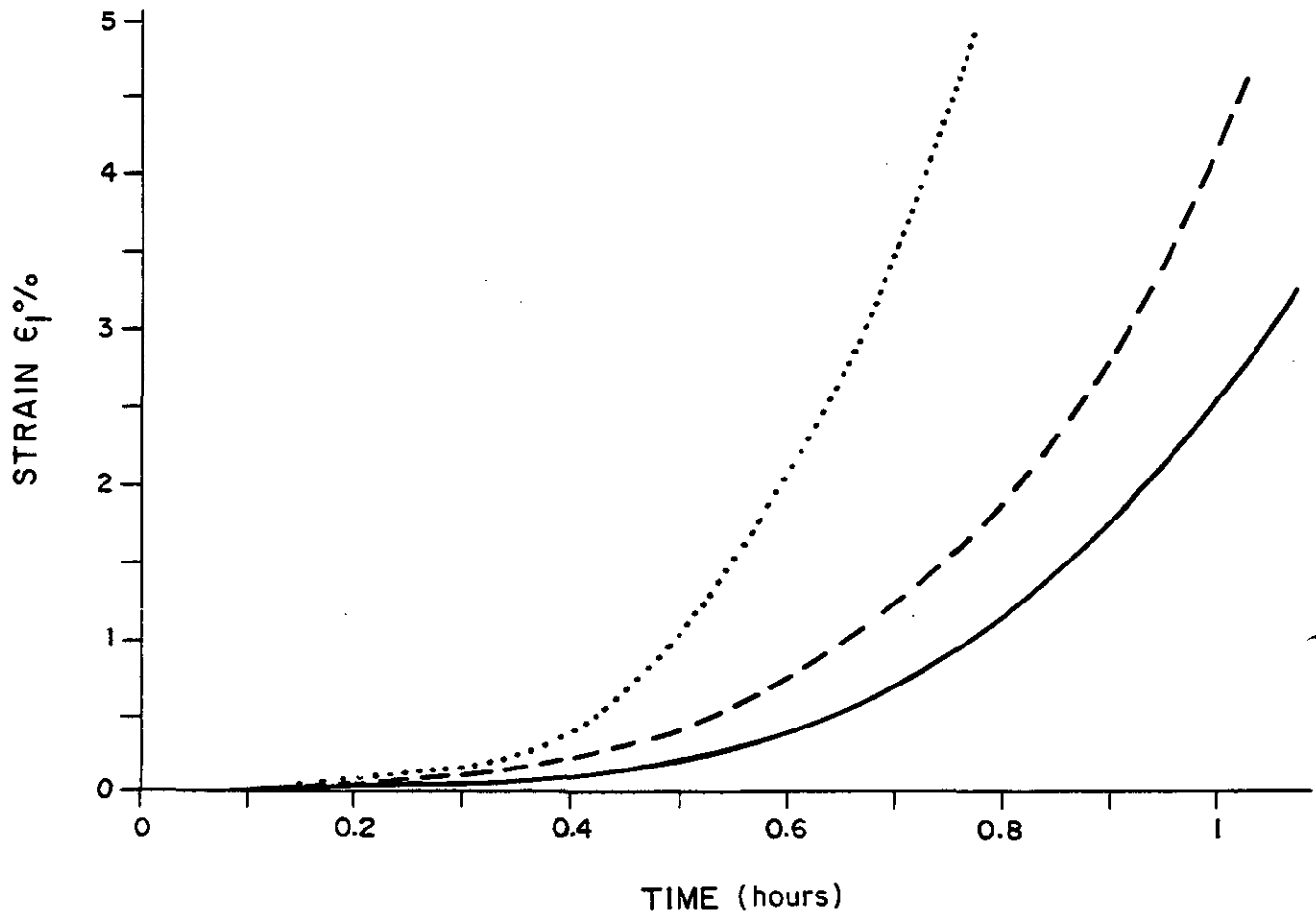

KEY

..... 7-2836 (0, 200)
Hole No. — Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
— — 7-2740 (.50, 200)
——— 7-2744 (3.0, 200)

AXIAL STRAIN VS. TIME FOR TEST OF FIGURES 9.2.4-10 AND 9.2.4-11

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-12

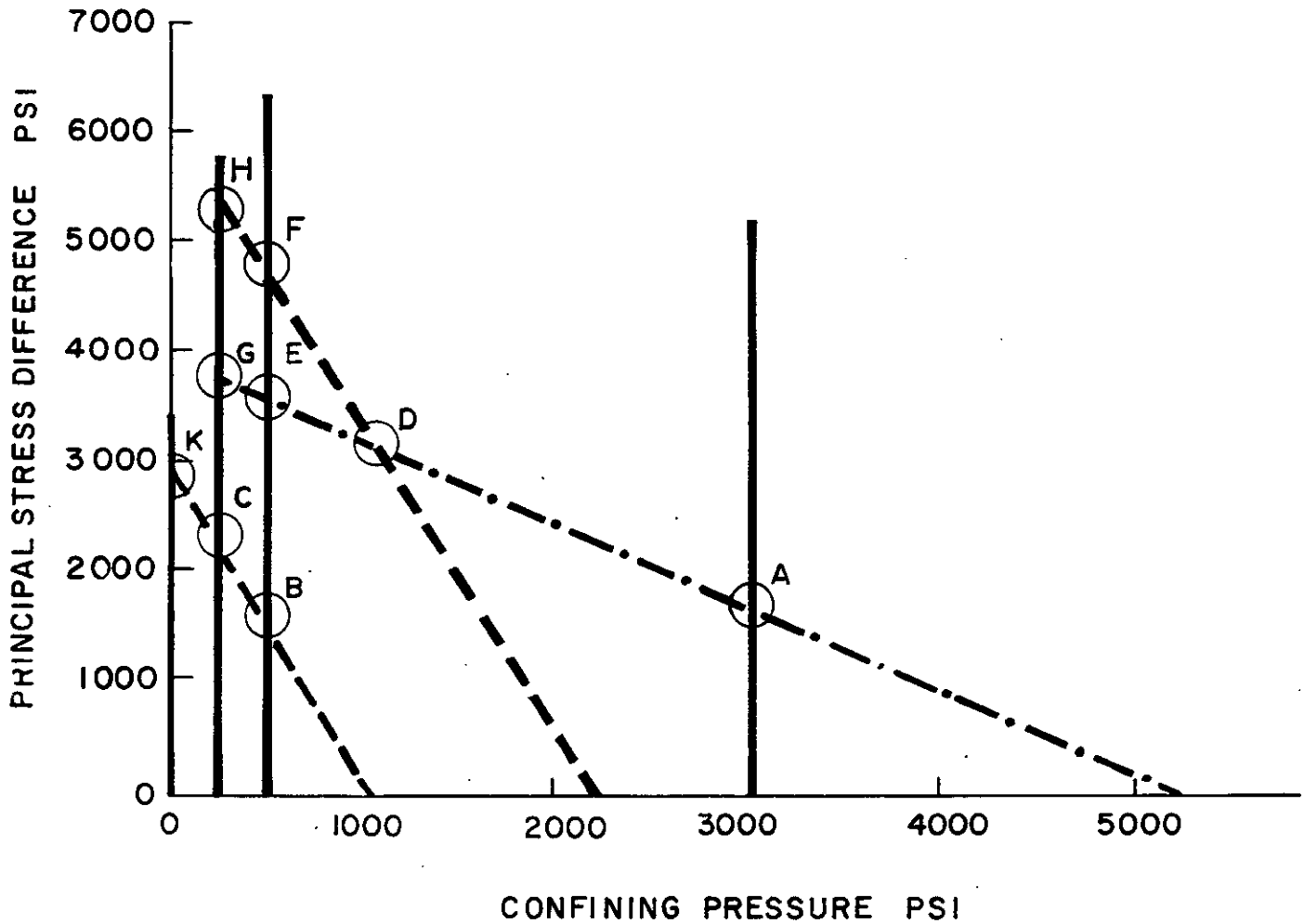

KEY

Load Path I ($\sigma_2 = \sigma_3$ = const.)

Load Path II (σ_m = const.) $\sigma_m = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$

Load Path III ($\sigma_1 \approx$ const.)

NOTE: See table 9.2.4-3 for tabulated data.

MAP OF THREE NON-PROPORTIONAL LOAD PATHS AND COMMON STRESS STATES (POINTS A THROUGH K)

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-13

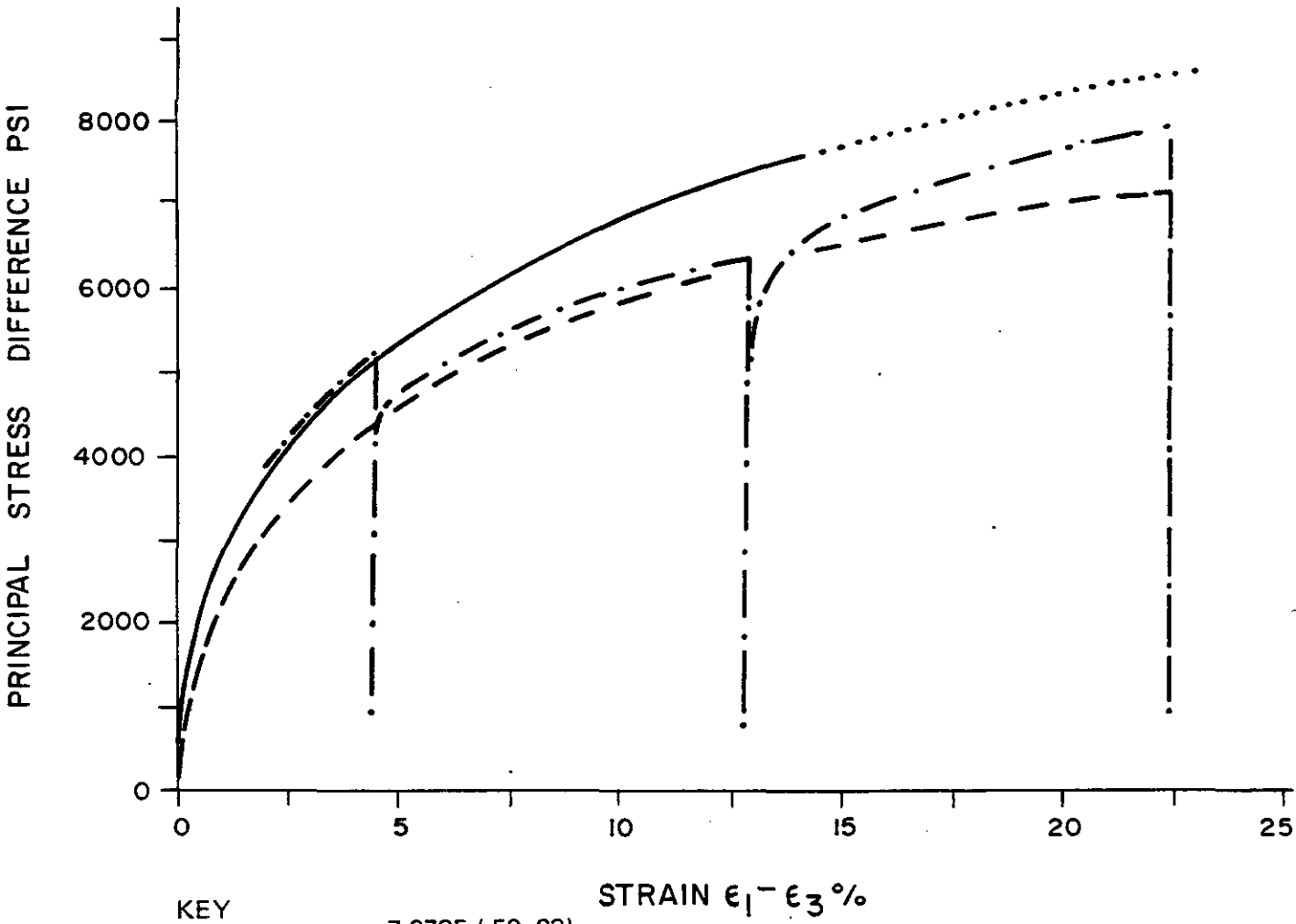

KEY

- — — — 7-2725 (.50, 23)
  Hole No. — Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
- ——— 7-2745 (3.0, 23)
- —·— 7-2740.5 (3.0/.50/3.0, 23)
- ····· 9-2601.5 (3.0, 23)

NOTE: The partial code 3.0/.50/3.0 identifies prevailing confining pressures between $(\sigma_1 - \sigma_3) = 0$ and first unload/reload cycle, first and second unload/reload cycle, and between second unload/reload cycle and final unloading trace.

STRESS-STRAIN CURVES FOR SAMPLE SUBJECTED TO ONE OR MORE CONFINING PRESSURES

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-14

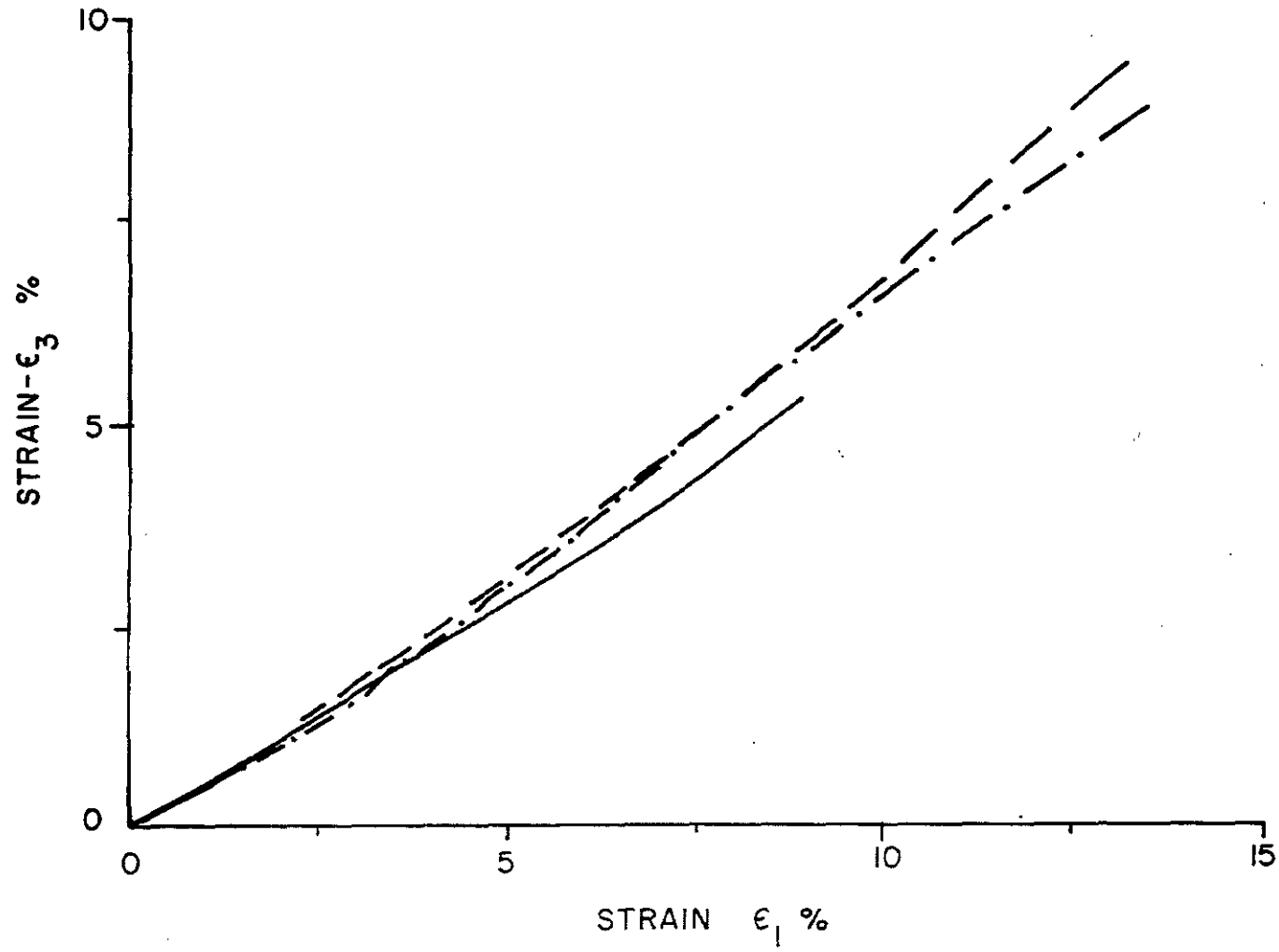

KEY

— — 7-2725 (.50, 23)
Hole No. — Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
——— 7-2745 (3.0, 23)
—·— 7-2740.5 (3.0/.50/3.0, 23)

VARIATION OF LATERAL STRAIN VS. AXIAL STRAIN FOR TESTS OF FIGURE 9.2.4-14

From : Wawersik and Hannum, 1978

FIGURE 9.2.4-15

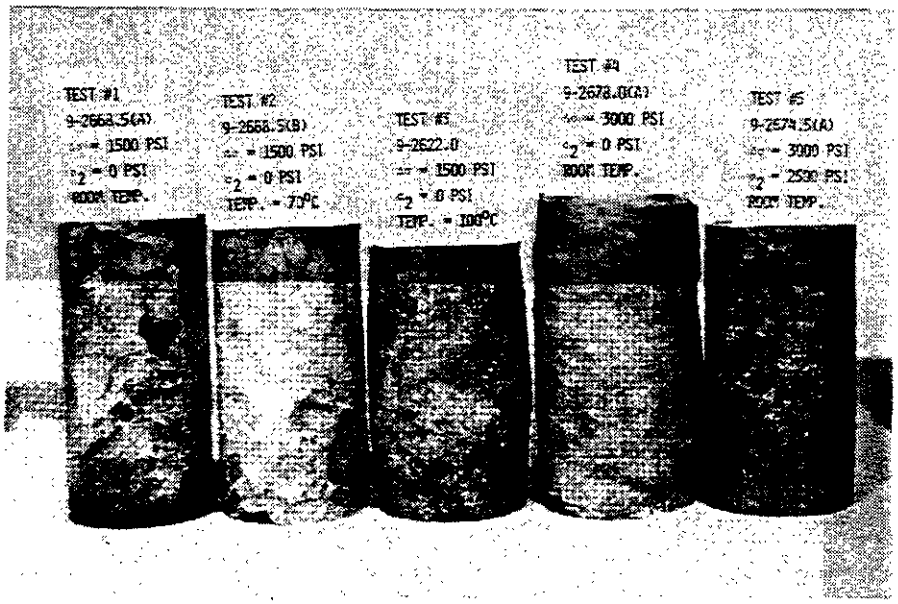

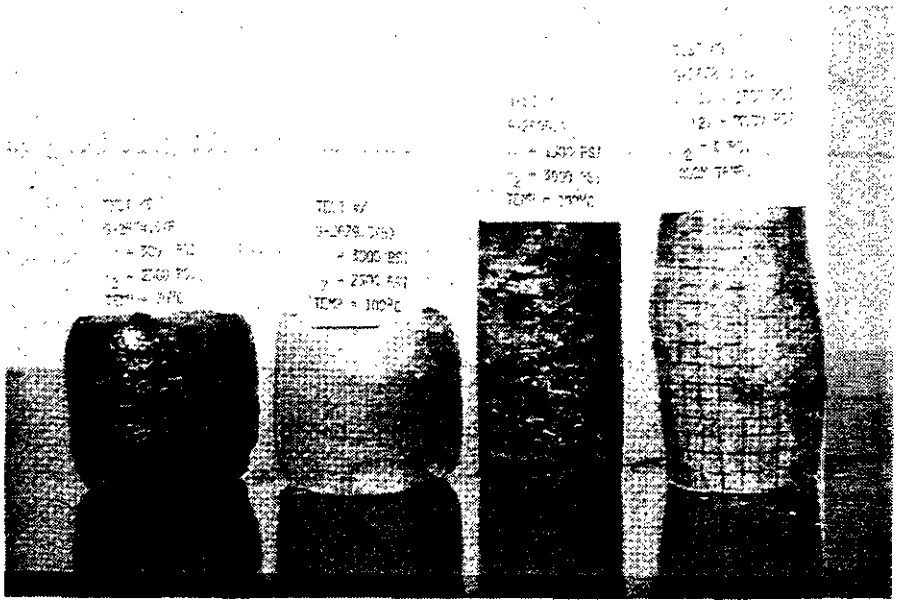

DEFORMED CORE SAMPLES OF ROCK SALT
FROM DRILL HOLE ERDA #9

FROM: HANSEN and MELLEGARD, 1977

FIGURE 9.2.4–16

Table 9.2.3-1: Physical properties of rock from WIPP study area

Material	Depth (ft)	Density (gm/cc)	Avg. Porosity (Range) (%)	Mass (Moisture) Loss (% to $\leq 300^{o}C$)	Resistivity in Ohm Meters	Avg. Air Permeability (Range) in (md)[2]	(P) Wave[3] Velocity (Km/sec)
Rock Salt	2000-2100	2.18	0.4 (0.1-0.8)	N[1] - 1.0	58,100	0.01 (0.0003-0.17)	(4.42-4.62)
Rock Salt	2600-2700	2.18	0.5 (0.3-0.7)	N - 0.4	(4,900-230,000)	-	-
Anhydrite		2.80	-	-	-	-	-
Polyhalite	-	2.70	-	-	-	-	-
Siltstone	-	2.26	-	-	-	-	-

[1]N - None Measured

[2]Core Labs Data; see also Figure 9.2.3-1

[3]Note: P Wave velocities determined in the lab agree to 15% with those measured downhole on borehole ERDA 9 (Griswold, 1977).

Table 9.2.4.-1 - Representative unconfined mechanical properties of rock salt from the WIPP study area

Material	Drillhole/ Approx. Depth (ft)	Uniax. Compr. Strength (psi)	Strain at failure percent	Brazilian Tensile Strength (psi)	Initial Elastic Limit $(\sigma_1 - \sigma_3)$ (psi)	Secant Modulus $x10^6$ (psi)	Principal Strain Ratio	Principal Strain Ratio, $\varepsilon_3/\varepsilon_1$ at Failure
Rock Salt	AEC 7,8/1900	2450	$\geq$ 1.7	200	$\leq$ 750	1.94	0.33	-
Rock Salt	AEC 7,8/2700	3700	3.6	240	$\leq$ 750	1.94	0.34	-
Rock Salt	ERDA 9/2100	2400	1.6	-	< 200	-	-	1.6
Rock Salt	ERDA 9/2700	3300	2.9	-	< 200	-	-	2.1

Note: Loading rates - $30 \leq \frac{d}{dt}(\sigma_1 - \sigma_3) \leq 215$ psi/min

1 Megapascal (MPa) equals about 145 psi
Symbols < and > denote experimental uncertainty.

Table 9.2.4-2 - Representative triaxial compression data for rock salt from the WIPP study area

Drillhole/ Depth (ft)	Confining Pressure (psi)	Temp. (°C)	Ultimate (max) Princ. Stress Diff. (psi)	Ultimate (max) Strain, ε_1 Percent	Initial Elastic Limit $(\sigma_1 - \sigma_3)$ (psi)	Secant Modulus $x10^6$ (psi)	Principal Strain "Poissons'" Ratio	Max. Obs. Princ. Strain Ratio
ERDA 9/2100	500	23	6000	12	$\leq$100	2.7	0.20	- 0.72
ERDA 9/2100	3000	23	> 9000	>20	$\leq$100	2.7	0.20	- 0.65
ERDA 9/2600-2700	500	23	6300	15	$\leq$100	2.7	0.20	- 0.80
ERDA 9/2600-2700	3000	23	> 8900	>20	$\leq$100	2.7	0.20	- 0.67
AEC 7/2700-2800	500	23	> 6200	>13	$\leq$100	2.7	0.21	- 0.71
AEC 7/2700-2800	500	100	≈ 4200	$\geq$18	$\leq$100	-	-	- 0.69
AEC 7/2700-2800	500	200	≈ 2400	>17	$\leq$100	2.4	-	- 0.68
AEC 7/2700-2800	300	200	> 2750	>17	$\leq$100	-	-	-
ERDA 9/2600	500	200	> 2500	>22	$\leq$100	-	-	- 0.68

Note: Loading rate $d/dt\ (\sigma_1 - \sigma_3)$ = 30 to 60 psi/min.

Table 9.2.4-3 Deviatoric Load Path Data For Figure 9.2.4-13

Reference Point In Figure 15	Load Path	$(\sigma_1 - \sigma_3)$ PSI	$\sigma_2 = \sigma_3$ PSI	σm PSI	ε_1 %	$-\varepsilon_3$ %
A	I	1600	2970	3550	0.17	0.07
	III	1640	3020	3570	0.075	0.05
B	I	1520	520	1015	0.357	0.175
	II	1500	520	1015	0.3	0.168
C	I	2200	260	1040	o.782	0.441
	II	2250	250	1015	0.769	0.476
D	II	3190	1120	2180	1.35	0.786
	III	3150	1120	2160	0.73	0.454
E	I	3540	520	1670	1.38	0.828
	II	3580	510	1700	1.12	0.705
F	I	4700	490	2090	4.04	2.434
	II	4740	510	2120	3.92	2.430
G	I	3840	250	1490	2.486	1.85
	III	3780	250	1500	1.49	1.01
H	I	5240	250	1990	8.58	7.81
	III & I	5140	260	2000	6.41	5.46
	II	5320	276	2070	5.71	3.79
K	I	2950	0	990	1.49	1.47
	II	2950	15	1000	1.58	1.19

Table 9.3-1

REPRESENTATIVE BRINES/SOLUTIONS FOR WIPP EXPERIMENTATION

Ion	Brine "A" (mg/liter) (± 3%)	Brine "B" (mg/liter) (± 3%)	Solution "C" (mg/liter) (± 3%)
Na^+	42,000	115,000	100
K^+	30,000	15	5
Mg^{++}	35,000	10	200
Ca^{++}	600	900	600
Fe^{+++}	2	2	1
Sr^{++}	5	15	15
Li^+	20	-	-
Rb^+	20	1	1
Cs^+	1	1	1
Cl^-	190,000	175,000	200
SO_4^{--}	3,500	3,500	1,750
B (BO_3^{---})	1,200	10	-
HCO_3^-	700	10	100
NO_3^-	-	-	20
Br^-	400	400	-
I^-	10	10	-
pH (adjusted)	6.5	6.5	7.5
specific gravity	1.2	1.2	1.0

Table 9.3-2

Nominal Concentration of Nuclides Used in Kd Measurements

Nuclide	Concentration, ppm
^{137}Cs	0.012
Stable Cs	1.0
^{85}Sr	0.03 - 0.3
Stable Sr	5 - 15
^{106}Ru	2500
^{99}Tc	59
^{152}Eu	0.1 - 1.0
^{144}Ce	3×10^{-4}
^{131}I	5×10^{-5}
^{153}Gd	0.2 - 2.0
^{125}Sb	≤ 0.01
^{243}Am	5.4
^{244}Cm	0.012
^{238}Pu	0.058

Table 9.3-3

Distribution Coefficients on Samples From the Magenta Dolomite

Fission Product
Distribution Coefficients

	pH range	Cs	Sr	I,Tc	Eu,Gd	Ru
Brine A	6.5 - 6.9	< 1	1	0 - 1.5	$> 5 \times 10^3$	40-50
Brine B	6.5 - 7.5	< 1	1	< 1	$> 5 \times 10^3$	500-600
Sol'n C	7.5 - 8.2	4	5	0 - 1.5	$> 10^4$	400-550

Actinide
Distribution Coefficients

	pH range	Pu	Am	Cm
Brine B	6.5 - 7.8	5.4×10^3	3.1×10^2	1.3×10^3
Sol'n C	7.5 - 8.2	2.4×10^3	2.4×10^3	4.2×10^4

Table 9.3-4

Distribution Coefficients on Samples From the Culebra Dolomite

Fission Product
Distribution Coefficients

	pH range	Cs	Sr	I,Tc	Eu,Gd	Ru
Brine A	6.5 - 6.9	< 1	< 1	< 1	$> 10^4$	25 - 35
Brine B	6.5 - 7.6	1-2	1-2	< 1	$> 10^4$	640 - 660
Sol'n	7.5 - 8.2	7-10	4-5	< 1	$> 10^4$	240 - 400

Actinide
Distribution Coefficients

	pH range	Pu	Am	Cm
Brine B	6.5 - 7.8	2.1×10^3	2.6×10^3	1.2×10^4
Sol'n C	7.5 - 8.3	7.3×10^3	2.2×10^4	1.1×10^5

Table 9.3-5

Distribution Coefficients on Halite From The 2056' Horizon of ERDA #9 Borehole

Actinide Distribution
Coefficients [1]

pH range	Pu	Am	Cm
7.0 - 7.1	17	306	354
	(1.0×10^4)	(1.8×10^5)	(2.1×10^5)

1) The Kd values in parentheses were calculated from the weight of water insoluble material in the halite. The lower values are based on the total weight of halite taken.

Table 9.3-6

Distribution Coefficients on Samples of Clay From The 2186.6' Horizon of AEC #8 Borehole

Fission Product Distribution Coefficients

	pH range	Cs	Sr	I,Tc	Gd,Eu	Ru
Brine A	6.5 - 7.0	< 1	< 1	< 2	> 2.5×10^3	150-180
Brine B	6.5 - 7.7	4-6	< 1	< 1	> 10^4	> 2×10^3
Sol'n C	7.5 - 7.8	80-120	3-6	< 1	> 10^4	> 1×10^3

Actinide Distribution Coefficients

	pH range	Am	Pu	Cm
Brine B	6.5 - 8.0	1.1×10^3	4×10^4	1.9×10^4
Sol'n C	7.5 - 8.4	3.5×10^3	1.8×10^5	4.2×10^5

Table 9.3-7

Distribution Coefficients on Samples of Polyhalite From the 2304' Horizon of ERDA #9 Borehole

Fission Product Distribution Coefficients

	pH range	Cs	Sr	Eu,Ce [1]	Sb	Tc
Brine A	6.5 - 7.0	< 1	5-10	10-20	< 1	< 1
Brine B	6.5 - 7.2	< 1	19-22	430-700, 50-55	0.9-1.5	< 1
Sol'n C	7.5 - 7.6	< 1	35-40	100-200, 40-60	3-4	< 1

1) Where two ranges of values are given, the first refers to Eu and the second to Ce.

Table 9.3-8

Distribution Coefficients on Sample of Cowden Anhydrite From the 2562' Horizon of AEC #8 Borehole

Fission Product Distribution Coefficients

	pH range	Gd,Eu,Ce
Brine B	6.5 - 7.9	$> 10^3$

Actinide Distribution Coefficients

	pH range	Am	Pu	Cm
Brine B	6.5 - 7.9	2.9×10^2	6.7×10^3	4.2×10^3
Sol'n C	7.5 - 8.2	2.2×10^3	7.7×10^4	1.8×10^5

Table 9.3-9

Distribution Coefficients on Samples of Clay from the 2725' Horizon of AEC #8 Borehole

Fission Product
Distribution Coefficients

	pH range	Cs	Sr	Eu,Gd [1]	Tc,I [1]	Ru
Brine A	6.6 - 7.0	4-9	< 1	$> 10^3$, $2.8\text{-}4 \times 10^2$	3.5-4.5, 0-3.5	90-120
Brine B	6.7 - 7.4	3-6	< 1	$> 10^4$	< 1	$> 10^3$
Sol'n C	7.5 - 8.0	34-40	30-45	$> 10^4$, $> 3 \times 10^3$	0.7-1.5, 0.5-4	$> 10^3$

Actinide
Distribution Coefficients

	pH range	Am	Pu	Cm
Brine B	6.5 - 7.8	310	7.2×10^4	2.7×10^3
Sol'n C	7.4 - 8.4	2.3×10^3	4.0×10^4	1.6×10^5

1) Where two ranges of values are given, the first refers to the first element listed and the second range is for the second element listed.

Table 9.3-10

Distribution Coefficients on Samples of Bell Canyon Formation

Fission Product
Distribution Coefficients

	pH range	Cs	Sr	Eu	Sb	Tc
Brine B	6.5 - 7.4	14-16	< 1	$> 10^4$	5-8	< 1
Sol'n C	7.5 - 7.9	130-140	1-5	$> 10^4$	20-25	< 1

Table 9.3-11

Distribution Coefficients on Halite Samples From the 2611' Horizon of ERDA #9 Borehole

Column Experiment

Column Bed: 7.5 g of Halite in 1 cm diameter column

Solution: Saturated Halite Solution, 200 ml

Flow: 1 Bed volume/min.

Time (days)	% of Initial Activity in Solution	
	^{85}Sr	^{144}Ce
0	100	100
1	98.0	26.7
4	96.8	0.9
8	98.4	0

Actinide Distribution Coefficients(1)

pH range	Am	Pu	Cm
7.0 - 7.3	11	59	56
	(3.8×10^3)	(2.11×10^4)	(2×10^4)

(1) The Kd values in parentheses were calculated using the weight of water insoluble material in the clay. The lower values are based on the weight of halite taken.

Table 9.3-12

^{152}Eu Distribution Coefficients (Kd's)

Rock	Simulant	Nominal ^{152}Eu(μCi/ml)	Kd(1) 2 week	Kd(1) 3 month	Kd(2) 2 week	Kd(2) 3 month
Culebra	A	0.01	$1.7x10^4$	$1.5x10^4$	--	--
"	A	0.1	$3.6x10^4$	$2.1x10^4$	--	--
"	A	1.0	$1.8x10^4$	$4.3x10^4$	--	--
"	B	0.01	$3.4x10^3$	$1.6x10^3$	--	$7.6x10^3$
"	B	0.1	$1.1x10^4$	$3.6x10^3$	--	$1.3x10^3$
"	B	1.0	$3.7x10^3$	$3.9x10^3$	$8.8x10^2$	$1.4x10^3$
"	C	0.01	$2.8x10^4$	$1.3x10^4$	--	$1.1x10^4$
"	C	0.1	$2.7x10^4$	$2.6x10^4$	--	$1.9x10^4$
"	C	1.0	$2.0x10^4$	$1.4x10^4$	$1.2x10^3$	$9.6x10^3$
Magenta	A	0.01	$1.4x10^4$	6×10^3	--	--
"	A	0.1	$1.9x10^4$	$2.0x10^4$	--	--
"	A	1.0	$1.2x10^4$	$1.4x10^4$	--	--
"	B	0.01	$2.8x10^3$	$8.6x10^2$	--	4×10^2
"	B	0.1	$8.3x10^3$	$3.7x10^3$	--	$1.3x10^3$
"	B	1.0	$1.1x10^3$	$1.2x10^3$	$3.5x10^2$	$4.0x10^2$
"	C	0.01	$2.0x10^4$	$1.7x10^4$	--	$1.3x10^4$
"	C	0.1	$3.6x10^4$	$2.2x10^4$	--	$1.6x10^4$
"	C	1.0	$1.4x10^4$	$1.5x10^4$	$7.7x10^2$	$1.3x10^4$

(1) Kd based on activity in feed solutions.

(2) Kd based on activity in pH adjusted feed solutions.

Table 9.3-13

Comparison of ^{153}Gd, ^{144}Ce, and ^{152}Eu Kd's in Brine B and Brine B* Containing Plywood Extract

14 Day Equilibration

Sample	Brine	^{153}Gd cpm/ml	^{153}Gd Kd	^{152}Eu cpm/ml	^{152}Eu Kd	^{144}Ce cpm/ml	^{144}Ce Kd
Feed	B	24,200	-	20,230	-	5,120	-
Feed	B*	38,090	-	38,090	-	7,080	-
Culebra	B		4.2×10^3		9.9×10^3		1.5×10^3
"	B*		6.3×10^2		6.6×10^2		6.0×10^2
Magenta	B		2.5×10^3		3.4×10^3		1.4×10^3
"	B*		6.5×10^1		7.0×10^1		1.1×10^2
Bell Canyon	B		3.4×10^3		3.4×10^3		3.2×10^3
"	B*		1.3×10^2		1.5×10^2		2.3×10^2
Cowden	B		2.6×10^3		2.2×10^4		2.2×10^3
"	B*		3.7×10^2		4.0×10^2		5.1×10^2
High Clay	B		6.8×10^3		8.5×10^4		1.2×10^3
"	B*		8.7×10^3		2.8×10^4		2.5×10^3

28 Day Equilibration

Sample	Brine	^{153}Gd cpm/ml	^{153}Gd Kd	^{152}Eu cpm/ml	^{152}Eu Kd	^{144}Ce cpm/ml	^{144}Ce Kd
Feed	B	23,260	-	20,170	-	4,800	-
Feed	B*	33,350	-	35,210	-	5,910	-
Culebra	B		4.3×10^3		8.3×10^3		3.3×10^3
"	B*		2.1×10^3		1.8×10^3		1.3×10^3
Magenta	B		3.5×10^3		2.5×10^3		$\geq 10^4$
"	B*		1.4×10^2		1.6×10^2		2.5×10^2
Bell Canyon	B		4.2×10^3		2.7×10^3		3.2×10^3
"	B*		1.5×10^2		1.7×10^3		3.2×10^2
Cowden	B		$\geq 10^5$		5.4×10^3		1.8×10^3
"	B*		4.7×10^2		4.8×10^2		5.3×10^2
Hi Clay	B		6.5×10^3		8.7×10^3		6.1×10^3
"	B*		1.9×10^4		3.2×10^4		5.9×10^3

GCR CHAPTER 10
CONTINUING STUDIES

10.1 INTRODUCTION

Continuing studies for the WIPP primarily encompass those geological processes that need to be understood in order to more quantitatively assess the safety of converting the WIPP to a repository. The processes of importance are tectonic, geochemical, hydrologic, and climatic. The studies indicated within this chapter generally relate to these major processes. In addition, a few studies indicated in this chapter relate to minor continuing efforts of site characterization. This chapter will serve to enumerate issues which remain to be addressed relevant to the safety of converting WIPP to a repository. It is not intended here that specific plans and schedules be presented.

The organization of Chapter 10 follows that of previous chapters.

10.2 SITE SELECTION

In line with the differentiation made in Chapter 2 between site selection, site characterization, and site confirmation, the activities of site selection and site characterization are nearly complete. The confirmation of the WIPP site for a repository will necessitate the continuing studies indicated in Sections 10.3 through 10.9.

10.3 REGIONAL GEOLOGY

Continuing studies of the regional geology focus mainly on the processes of tectonics and climate through studies of paleoclimates and various manifestations of past tectonic activity.

10.3.1 Paleoclimatology

The purpose of paleoclimatic studies in southeastern New Mexico is to develop the local timing and magnitude of past climatic changes and their relation to observed geology to help assess the possible effects of future changes on a repository.

The primary method of paleoclimatic study is to examine cores of Pleistocene or Recent sediments for fauna and flora which are indicative of past climatic conditions. In addition, organic matter or ash falls may, if suitable, be dated radiometrically to provide time control.

Studies of paleoclimate are underway with preliminary analysis of core taken in San Simon Sink from borehole WIPP 15. Fauna and flora are being separated from the sediment for paleontological analyses, and suitable organic material is being separated for radiocarbon analysis. These studies of the San Simon material will be completed in 1979 to yield an initial profile of climatic changes. Further coring in other locations may be undertaken at that time, if necessary, to supplement the record. The final stage of this study will be to integrate the local climatic changes into the information about regional climates and to determine the relationship between climatic changes and related processes such as subsurface salt dissolution and resultant subsidence (see Section 10.6).

10.3.2 Regional Tectonic Studies

The purpose of various studies of regional tectonics is to assess the long-term effects of tectonic forces on a repository.

Several studies together contribute to information about regional tectonics and include the seismological studies discussed in Section 10.5.

LANDSAT. A preliminary examination of LANDSAT photos has been completed and is reported in Chapter 3. In addition, the WIPP site and surrounding regions will be re-examined in 1979 with more sophisticated image

enhancement to determine the presence and location of more subtle lineaments. Field evaluation of the interpretations will be undertaken as required.

Leveling Surveys. Releveling of some existing first-order vertical control lines was carried out in 1977, and about 300 km of new lines were established. These new lines, some of which traverse Nash Draw and the WIPP site, will be periodically releveled to establish a data base for separating regional tectonic effects from local effects perhaps due to dissolution (see Section 10.6).

West Texas Salt Flats Graben. Releveling and seismology studies indicate active tectonic displacement on the west Texas salt flats graben. Seismic reflection records will be examined and test coring conducted in 1979 to determine if the sediments will yield a record of tectonic disturbance that will contribute to information about the tectonic forces likely to affect a repository located in the Delaware Basin.

10.4 SITE GEOLOGY

The purpose of continuing studies of site geology are to refine the data base for assessment of the safety of a repository there, and to contribute some additional details of site characterization. The methods and studies as such are quite varied.

10.4.1 Geologic Mapping

Geologic mapping continues on the WIPP site and in the area, particularly under a study of the stability of the WIPP site. This study, being conducted by the USGS, is concerned with mapping caliche and related sediments to provide more conclusive data on the length of time the area has been stable, and the rates at which areas around the site have been disturbed.

10.4.2 Aeromagnetic Survey

A very high resolution aeromagnetic survey will be initiated during FY79 to examine the WIPP site and several special features. The survey of the site will primarily be to determine if any dikes have intruded the evaporites at the site since dikes might form a pathway for fluid flow. Several of the domal features mentioned in Chapters 3, 4, and 6, two of which are considered to be breccia pipes, will be examined to determine if a magnetic signature is associated with disturbance of the magnetic red beds. The tool, if proven applicable, might then be used for prospecting to support continuing studies of breccia pipes as indicated in 10.6.

10.5 SEISMOLOGY

The purpose of continuing seismological studies is to provide data for facility design and to expand the data base contributing to an understanding of tectonic processes affecting a repository in the Delaware Basin. Seismological studies are supported by arrays of stations near points of interest.

10.5.1 Near-Site Activity

The careful characterization of near-site background activity, as indicated in Chapter 5, is the dominant seismic issue affecting the WIPP site. Station CLN has been operating near the site since 1974, and continues to operate. It is planned to augment this station so that at least three stations will be operating at the site to better define near-site seismicity.

10.5.2 Central Basin Platform

An array of stations has been operating near Kermit, Texas, since 1976 to evaluate the seismic activity on the Central Basin Platform and to explore the relationship, if any, between this activity and the massive

fluid injection for secondary oil recovery operations occurring in that area. This array will continue to operate both for this purpose and because the assessment of seismic activity at the WIPP site may partly depend on an understanding of the relationship between fluid injection and seismic activity should injection occur in oil fields near the site.

10.6 CONTINUING STUDIES IN HYDROLOGY

10.6.1 Introduction

Hydrology is a major consideration when examining the feasibility for locating a nuclear waste disposal site. Two factors are directly related to hydrology: (1) the geologic stability of the formation in which the waste products will be stored, and (2) the occurrence of water as a transport medium for radionuclides. Unsaturated waters migrating along the surfaces of the salt beds will dissolve salt; therefore, an examination of magnitude and direction of fluid flow and fluid chemistry in formations above and below the salt is necessary. Additionally, the direction and rate of fluid movement both above and below the storage horizon should be evaluated to predict the movement of radionuclides should they be accidentally discharged into the aquifers.

10.6.2 Purpose of Hydrologic Testing

Two hydrology-related questions are to be answered in evaluating the suitability of the proposed WIPP site.

1. What is the geologic stability of the Salado Formation?

2. Should the primary containment barrier (the salt) fail or an accident occur, where and how rapidly will radionuclides be transported by groundwater?

Three factors need to be investigated to examine the integrity of the Salado within the site: (1) the Rustler-Salado contact is to be examined

geophysically and petrologically within the WIPP area to determine if dissolution is presently occurring, (2) the dissolution front (as defined by the edge of the shallow dissolution zone in the Nash Draw) needs to be located more precisely, (3) the estimated rate of dissolution is to be refined.

The hydraulic gradients and rates of fluid movement in the series of fluid bearing zones that overlie the Salado require further definition. Estimates of concentrations of aqueous species (and when and where they might appear) may then be refined for specific safety-assessment modeling scenarios describing radionuclide escape into these groundwater systems and migration out of the area. In addition, formations which do not presently contain water but exhibit some degree of permeability are to be tested to see what rates of movement would be, should they contain water or other fluids at some later time.

10.6.3 Direction and Rate of Fluid Migration

If radionuclides were to reach fluid bearing zones in the Rustler, they would be transported away from the site by the groundwater system. To evaluate the impact of such an accident on the surrounding area, hydraulic gradients and hydraulic conductivities of fluid bearing zones overlying the salt beds will be determined or modified. Data for these determinations will be acquired by pumping tests on hydrologic test holes or measurements of the recovery time of fluid levels in bailed holes. Tracer tests will be conducted where they may contribute useful information.

A series of hydrologic tests is planned in holes placed near the periphery of the proposed land withdrawal area. After additional testing of some existing holes, control points for the potentiometric surfaces and for hydraulic conductivities will have been established for the periphery with a spacing of 2 to 3 miles. These data will allow construction of more detailed potentiometric surface maps for the site area. The potentiometric contours will be meshed with the results from

the Nash Draw program to the west. Consequently, the potentiometric surface and hydraulic conductivity data required for modeling efforts of long-term safety assessment will be obtained for an area extending from the northeast part of the study area to Malaga Bend on the Pecos River (an area of about 200 square miles).

The borehole plugging program requires data from both laboratory and *in situ* permeability measurements. These permeability measurements, both in the evaporites and in aquifers, will provide additional data for the safety assessment work.

10.6.4 Dewey Lake Redbeds

The Rustler Formation and the shallow dissolution zone in Nash Draw have demanded the attention of this program because they are fluid-bearing. The Dewey Lake Redbeds are also of some significance since fluids are present in sandstone lenses. Although the redbeds are only locally saturated, two possibilities exist for additional water to enter the formation: a climatic change to a high rainfall period, or migration of fluids from below into the redbeds.

Tests in two types of holes are being considered: existing holes, and at least one new hole specifically designed for Dewey Lake testing. The casing in existing holes will be perforated opposite permeable zones as identified from analyses of logging and drilling records.

The standard hydrologic testing procedures will allow calculation of the transmissivity of fluid bearing strata in the Dewey Lake Redbeds or other permeable zones that might be expected to contain fluids at some future time.

10.6.5 Long-Term Monitoring

The peripheral hydrologic test holes, which now include four potash holes, will be configured for long-term monitoring. This long-term

monitoring may show what changes are taking place in the hydraulic gradients which in turn may indicate increased or decreased flow, and variations in rates of recharge or discharge. Moreover, depending on the extent of the monitoring system, a warning network for information on fluid threats to the integrity of the repository is obtained.

The Dewey Lake Redbed hole(s) can be monitored to detect fluid movement that may not be present except during high precipitation cycles of long or short duration.

The test holes drilled in Nash Draw would be monitored to detect changes in the hydrologic regime along the Rustler-Salado contact. Because the Culebra is the main producer of water west and south of the WIPP area, it is desirable to monitor this fluid-bearing strata to determine its relationship with the shallow dissolution zone and to provide additional data for modeling the safety assessment modeling scenarios.

10.6.6 Surface Hydrology

Surface hydrology must be examined climatologically with the aid of surface mapping. Records of annual rainfall and intensity and duration of storms (particularly high intensity, 24 hour, 50 and 100 year recurring storms) are available. This information, in conjunction with surface mapping (from aerial photographs, topographic maps, or both) of contributory drainage will provide the basis to estimate amounts of runoff and amounts of infiltration in the study area. Because of the high evapotranspiration and the caliche layer below surficial sands, infiltration estimates are expected to be only a small portion of the calculated recharge.

Photogrammetric and field mapping is planned to locate and describe springs which may issue from the Dewey Lake Redbeds or the shallow dissolution zone. Several springs are suspected to be located west of the site, and discharge measurements could aid in the identification of the formations from which they issue. Geochemical monitoring of many

such springs, including the Malaga Bend seeps and the Pecos River salt load, will add to this overall understanding of hydrologic system dynamics.

10.6.7 Overview of Deep Hydrologic Testing

Three objectives for deep aquifer testing to complement the site-specific shallow aquifer investigations in the WIPP study area are:

(1) To obtain static bottom-hole pressure measurements in the deep aquifer zones, for the refinement of previous estimates of local potentiometric surfaces, hydraulic gradients, and hydraulic conductivities.

(2) To determine the bounds of the formational reservoirs.

(3) To obtain fluid samples for geochemical analyses.

Three wells suitable for hydrologic testing (Badger, Cabin-Baby, Cotton-Baby) are located within the site area. Each well will have to be re-entered and plugged, in accordance with methods now under study, or maintained as monitoring wells. Deep hydrologic data will be developed from these well to obtain site-specific information on the Delaware zones. Testing outside the study area involves two additional wells (AEC No. 8 and ERDA No. 6).

10.6.8 Long-Term Monitoring of Deep Wells

A number of wells could be equipped for long-term monitoring of the Delaware zone to show what changes, if any, are taking place in the hydraulic gradient, which in turn indicate fluid movement in the reservoir. Periodic fluid samples can be obtained to identify increased flow or chemical changes in the ground water system.

10.6.9 Continuing Studies in Salt Dissolution and Overburden Subsidence

Program Objectives. The program of investigation of dissolution and subsidence has four fundamental purposes, and one special-case consideration:

1. To correlate surficial collapse features and deposits with subsurface dissolution, in order to develop criteria for an evolutionary pattern of collapse.

2. To characterize subsurface dissolution products adjacent to the WIPP site.

3. To determine the behaviour of fluids in dissolution products adjacent to the WIPP site.

4. To analyze potential impacts of evolution of dissolution products at and near the WIPP site with respect to repository breachment and radionuclide transport.

The special case is to determine the nature of subsidence over mines in salt, and its effects on the overlying groundwater system.

An elaboration of these purposes follows.

Nash Draw Investigations. Nash Draw is believed to have originated by some combination of surface erosion and subsidence following subsurface dissolution. If the process of formation is overwhelmingly erosion, then the potential for removal of overburden at the WIPP site is probably about the same as it has been in Nash Draw. If, however, the process is overwhelmingly dissolution of salt and subsequent collapse of the overburden, the potential extension of Nash Draw toward the WIPP by dissolution will be more quantitatively described. At present, there is no conclusive way of defining an instantaneous rate of growth of Nash Draw toward the WIPP site; therefore, the only alternative is to

understand the processes which have resulted in Nash Draw, and incorporate their implications into the mathematical modeling efforts directed toward safety assessment involving the WIPP site in general, and radionuclide escape and migration in particular.

First, the Nash Draw program is a series of core holes, which will be geophysically logged. This operation will obtain data to serve three purposes: 1) reveal the subsurface of Nash Draw stratigraphy at carefully chosen points, 2) reveal the relationships between the subsurface structure and surface features and deposits, 3) reveal how much halite and anhydrite (or gypsum) has been removed by dissolution.

Second, the Nash Draw program is a source of geologic material for petrographic and geochemical examination. Examination of thin sections of recovered rock will allow the mineralogy of dissolution products to be determined, i.e. identification of what was dissolved and what remains. Mineralogy and textures of dissolution residues and cemented collapse fill can then be compared with those of dissolution features sampled in other programs, such as the one to investigate the cemented rubble chimneys (often called "karstic domal features" or "breccia pipes"). Geochemical analyses of core materials for trace constituents will reveal their degree of interaction with groundwaters, and possibly an age of formation. Also, permeabilities to fluids can be obtained from cores.

Third, the Nash Draw core holes will become a series of hydrology test holes. The brine flow underlying Nash Draw has been attributed responsibility for much of the dissolution and collapse observed today. The safety assessment scenarios for radionuclide escape and migration involve movement from WIPP into Rustler Formation waters into the shallow dissolution zone and out at Malaga bend on the Pecos River. It behooves us to understand the hydrologic relationships between the shallow dissolution zone and the Rustler water-bearing rocks in Nash Draw in order to verify that models of radionuclide transport are representative of the physical system.

Cemented Rubble Chimney Investigations. One of the "karstic domal features" described by J. D. Vine (called Hill "C") was encountered at the level of the McNutt potash zone by Mississippi Chemical Corporation. It was found to be a chimney in the Salado Formation filled with clay-cemented brecciated rock belonging to strata above the McNutt. Similarly a breccia-filled chimney was encountered in drilling near a circular hill near the Wills-Weaver Mine. There are numerous other erosion-breached domes such as Vine's Hill "C" in the vicinity of Nash Draw; the subsurface expression of them, if any, is virtually unknown. It is desirable that a hole be drilled to a depth at which no more brecciated rock is found. Hydrologic observation (including water sampling and static water-level measurements) in fluid-bearing zones of the structure itself and in "bedrock" and in nearby rocks will help to determine the degree of hydraulic connection of the structure with aquifers of regional extent.

Petrographic analyses of recovered core will allow comparisons to be made with dissolution products recovered from Nash Draw investigations, described previously. Such material also lends itself to geochemical analyses for the determination of rock-water interaction history and age. Similarly, fluid analyses will provide an indication of how the fluids have interacted with their host rocks, helping to determine the processes at work in such structures.

Since modeling of radionuclide escape and migration must take into account fluid movement, cemented rubble chimneys should be evaluated for their potential as paths for such movement. They should also be evaluated as members of the evolutionary pattern of dissolution and collapse features, and might be generically related to the development of Nash Draw. Consequently, it is desirable to measure *in situ* the permeability of the structure. In addition, the hydrologic relationships between the chimney and surrounding rocks should be understood in order to formulate a complete hydrologic model for risk assessment.

Mine Subsidence Investigations. The potash producers in southeastern New Mexico mine in two stages -- the primary recovery which leaves rooms separated by large pillars, and the secondary recovery in which they may "rob the pillars" and ultimately remove almost 95% of the ore. Second-mining requires abandonment almost immediately thereafter, because there is no longer a large enough local pillar system to hold up the roof. And so, the roof slowly sags, and subsidence is propagated to the surface.

While investigations of subsidence over mines do not bear directly on the four program objectives, mining is certainly a particular cause of subsidence and perhaps an indirect agent for initiating dissolution. If subsidence over a mine causes fracturing of water bearing rocks above, locally increased permeability might allow circulation of groundwater to underlying evaporites through the fractures to start dissolution.

The amount of subsidence and its potential for enhancement of salt dissolution of the Salado Formation over the WIPP if the McNutt potash zone were to be mined is unknown. If this subsidence program were to lead to a satisfactory means to predict subsidence and its effects, in particular dissolutioning, the control zone restrictions currently prescribed around the WIPP could possibly be relaxed. It is possible that minor subsidence will occur over the closed WIPP mine because it will not be possible to backfill the repository to the same packing density as original rock. Therefore, it is desirable to evaluate the effect of mining and subsequent subsidence on the local groundwater system in the subsiding overburden.

10.6.10 Modeling of Regional Hydrology

Hydrologic modeling has one basic objective, to support risk assessment work by describing the movement of fluids in this region in as much detail as possible. The movement of fluids affects the expected period of integrity of the repository and the movement of radionuclides from the repository. To fulfill this objective, the modeling emphasizes several

aspects. The first aspect is interpretation and explication of the data collected in field programs designed to delineate the regional flows. The second is to suggest where data are insufficient and more field or laboratory work is required. The third aspect is the simulation of experiments which cannot be performed in the field. Two examples for simulations are: consequences of perturbations to regional flow patterns caused by the existence of a repository, and consequences of changes in regional flow patterns due to alterations in rainfall patterns or due to man's activities.

The fourth aspect is prediction of the movement and concentrations of radionuclides consistent with fluid movement determined in part by the release scenarios developed for WIPP.

Implementation is based on the modification and use of certain 2-D and 3-D computer codes available for hydrologic modeling. Code verification based on field data already collected is in process. Supporting laboratory programs designed to provide parameters as absorption coefficients, permeabilities, etc., are already underway.

10.7 CONTINUING STUDIES IN GEOCHEMISTRY

10.7.1 Introduction

Detailed accounts of geochemical data reported in Chapter 7 have provided the pressing need of fundamental information for (1) conceptual design of WIPP operational facilities, and (2) formulation of site-specific process scenarios to be used in the consequence safety assessment effort. An evaluation of the available data has shown that the completed studies are not entirely sufficient to support WIPP experimental programs. These programs include borehole plugging, laboratory rock mechanics, in-mine rock mechanics, in-mine heater experiments, in-mine high-level waste emplacement experiments, laboratory waste-rock interaction experiments, radionuclide transport through rocks, and waste encapsulation studies.

In addition, the long-term safety assessment effort has lacked information about geological processes associated with so-called "geological anomalies" such as igneous dikes and cemented rubble chimneys.

10.7.2 Mineralogy and Petrology

The data concerning assemblages of evaporite minerals in the Salado Formation which were presented in Chapter 7 have addressed the types of minerals found and their relative (qualitative) abundances. While this has been useful in selection of candidate horizons for waste emplacement, it has been of limited use to the quantitative measurements of thermal and physical properties of evaporite rocks (see Chapter 9).

It has been found that a small change in the quantitative mineralogical proportions in a rock sample has a large non-linear effect on thermal properties, for example. Chapter 7, together with its executive summary in Chapter 1, has pointed out the variability in the mineralogical composition of rocks in the Permian evaporite section.

In addition, quantitative mineralogy and petrology is required for development of materials to be used in the plugging of shafts and boreholes. The long-term thermodynamic stability of a grout plug, for example, cannot be evaluated without an intimate knowledge of mineral phases in both grout and rock, so that free energy calculations can be made for degradation reactions which might occur between the two. Compatibility of grout with rock and groundwater will be an essential factor requiring thorough evaluation to provide confidence in the long-term sealing of boreholes and shafts which penetrate from surface to repository horizons.

10.7.3 Volatiles Characterization

Chapters 7 and 9 have alluded to the variability in volatile content of evaporites and how the variation affects fundamental rock properties. Chapter 7 has addressed the volatile component in detail mostly in view

of mass loss experienced by heated rock. The entire mass loss cannot be ascribed to water alone. Indeed, Chapter 7 briefly addressed the chemical species which were found in a few selected rock samples, and even so, considerable variation was observed. Experiments are planned to simulate high-level-waste-canister heat in a potash mine, in order to quantize the devolatilization products. Unambiguous interpretations of the experimental results derived therefrom require an understanding of the volatile components native to the rock before heating begins. Furthermore, the interpretations also require an understanding of the fundamental differences between potash ore zones and actual repository zones, since the results of devolatilization in one will certainly not be directly applicable to the other without taking into consideration the native differences.

10.7.4 Origins of Evaporite Assemblages

It was pointed out in Chapter 7 that many of the evaporite mineral assemblages observed in the Permian section cannot have precipitated from a seawater-like solution. Furthermore, the thermodynamic properties of some minerals, such as the almost ubiquitous polyhalite, are virtually unknown. Similarly its mode of origin is entirely unknown, and has been long regarded wholly as a product of recrystallization, commonly replacing anhydrite.

The present assemblages not only contain non-primary evaporite minerals, but also have a magnesium deficiency relative to other evaporites in the world. The sink for this magnesium presumably lost during recrystallization has not been identified. The observations of Chapter 7 urge that a thermodynamic understanding of the environments and processes of evaporite recrystallization be sought. In this way the water loss that the evaporites have experienced (during recrystallization) can be estimated, and confidence can be gained regarding what mineralogical changes (if any) are likely to take place in response to waste emplacement.

The techniques used in deducing the origins of evaporite assemblages include chemical quantitative analyses of minerals, petrographic paragenetic examination, and stable isotope, radioisotope and trace element analyses.

10.7.5 Igneous Dike

In Chapter 4, there was mention of a northeast-trending igneous dike intruding the evaporites on the west side of Nash Draw west of the WIPP study area. The characterization of the dike was based on the Yeso Hills and Kerr-McGee mine occurrences, together with an aeromagnetic survey. In order to come to an understanding of the marginal effects (i.e., dike-salt-fluid interactions), the following pursuits are recommended:

1. Collection and study of additional samples from farther away from the Kerr-McGee dike occurrence.
2. Determination of:
   a. K-Ar ages of the alteration micas in the dikes
   b. Drilling angle holes with coring at appropriate intervals, to sample the dike and the effects of the dike upon the host rock system.

The dike appears to be a natural laboratory experiment involving high-temperature interactions among salts, groundwaters, and "alien" mineralogies such as emplaced waste would also represent.

10.7.6 Trace Elements and Age-Dating

A continued effort is desirable in age-dating and trace element studies, in order to support investigative efforts contemplated for the so-called "geologic anomalies." The activities are, specifically:

1. Chemical and isotopic study of exposed collapse structure in underground workings of Mississippi Chemical Mine.

a. If waters have percolated through this structure in very recent times then this may be reflected in oxygen isotopic study of grain coatings, etc. Rb-Sr studies of clay minerals should give an indication of Rb, Sr and ($^{87}Sr/^{86}Sr$) redistribution relative to clay minerals removed from the collapse structure.

b. Scanning electron microscope/microprobe study of grain boundaries: supplemented by instrumental neutron activation analysis (INAA) for adsorbed elements (alkalies, alkaline earths, rare earth elements).

c. Rare Earth Elements (REE) distribution in all primary and secondary phases most likely to have been affected by solutions.

2. REE (and other key trace element) abundance in major facies of drill core from WIPP site. At present trace element data are very sporadic and obtained by different techniques so that real differences due to analytical precision and accuracy are suspect. Detailed INAA study of various phases from the same stratigraphic horizons over a wide lateral extent are desirable to establish realistic background data for the REE (i.e. because the REE are commonly used as analogues for the transuranics) so that REE data from dike-salt contact zones and elsewhere can be proprly assessed. If the REE distribution is extremely variable then local variations due to solution, recrystallization, contact effects will be difficult to interpret; if the REE show a more or less uniform distribution pattern and abundance then such effects can be closely scrutinized.

3. Dike-evaporite contact effects. Samples from the lamprophyre dike (T = ~ 35 MYBP) which is observed in the underground workings of the Kerr-McGee Mine offers a unique chance to examine the effects of a local, high temperature source in contact with several evaporite phases.

10.7.7 Reef and Back-Reef Waters

There is at present some degree of confusion surrounding the source and discharge of water in the Capitan Reef surrounding the Delaware Basin. Chapter 7 has shown that the greater portion of the water in the Reef cannot have come from direct infiltration into outcrops in the Guadalupe and Glass Mountains, nor from rocks in the Basin. Therefore, the relationships between the Reef and its lagoonal facies (back-reef) stratigraphic equivalents are likely source and sink candidates. These relationships are best deduced by combinations of stable isotope, uranium isotope, and solute analyses of reef and back-reef waters. An extensive water-sampling of these areas is required for this. The results of this geochemical mapping of regional groundwater flow would be used in the long-term safety assessment modelling effort and the final publication of the regional groundwater mathematical model.

10.7.8 Future Work on Fluid Inclusions

In addition to the obvious necessity of making studies on samples from the actual strata to be used for high level waste storage, a variety of approaches need to be explored. Fluid inclusions near the waste canisters might decrepitate in the thermal pulse; the conditions under which this will occur can and should be explored experimentally. (studies are continuing of inclusions in a suite of salt samples collected at various distances from a dike penetrating the salt horizons; this provides a natural analog.) The identification of the daughter minerals in some inclusions, and their thermal behavior, as well as bubble movement in a thermal gradient, will provide additional compositional information. The gases released on crushing or heating should be explored, as well as the leakage of gases (or water) out of inclusions. This would be pertinent both for interpretation of K/Ar ages and in corrosion problems. The actual chemical composition of the larger inclusions and their isotopic composition (particularly H/D and O^{16}/O^{18}) can be determined by existing methods. This would help in

understanding the complex sequence of interactions of pore (and inclusion) fluid with the original salt beds to yield the present mineralogy.

10.8 RESOURCES

Sandia Laboratories has no continuing studies of resources at the WIPP site.

10.9 SPECIAL STUDIES

10.9.1 Purpose. The objective of thermophysical and radionuclide sorption studies on SENM rocks is to determine their characteristics as required by the structural mine design, *in situ* experimental, and long-term safety analyses programs. As with other continuing studies, these special studies are a means to an end, not an end in themselves.

10.9.2 Thermophysical Properties

Scope. A continuing assessment of the thermophysical properties of SENM rocks is envisioned because of the broad range of questions posed about radioactive waste isolation. These problems range from the plasticity of salt to the migration of brine in salt; many are not answered by a cursory investigation. Establishing a data base, for instance, for the analyses of long-term creep, is time consuming. It is not anticipated that evaluation of physical rock properties will be pivotal in mine, experiment or repository design; however, that is intrinsically impossible to guarantee. Such evaluations may very well be pivotal in considerations of retrievability of high-level waste experiments, in which high temperatures tend to accelerate creep. Thus, physical rock property determinations, such as the micromechanics of rock deformation, are a prudent pursuit to provide additional confidence in geologic isolation.

Continuing Studies. The primary object of the continuing experimental rock mechanics program is to understand and model the thermomechanical behavior of the WIPP salt. This will be accomplished through studies of transient creep data at pressures exceeding 1500 psi and at a principal stress difference less than 2000 psi where there is a paucity of data. In addition, petrographic investigations will continue to identify the governing deformation mechanisms.

Other studies relevant to the long-term stability of the WIPP include measurements of gas and brine permeabilities on previously deformed core and measurements of gas permeabilities at elevated temperatures. Studies are also planned in the area of thermal expansion coefficients and brine migration in salt under thermal gradients. Migration of fluid inclusions is being given attention, because of the brine's corrosive potential and because the capacity of fluid inclusions to carry radionuclides through rock salt is not known.

Rock mechanic programs will also be initiated to determine the mechanical properties of the WIPP site rock other than rock salt. These studies will be directed toward the engineering performance and construction characteristics of the non-salt rock which will influence the design and construction of shafts to the repository levels.

Mineralogic and petrographic studies will be conducted on core to support the physical rock properties determinations as required. This information is required to determine the phase systems in the rocks being investigated. A similar set of studies support the geochemical analyses, Chapter 7. The variations in mineral assemblage, grain size, fluid inclusion content, and petrofabric which have been observed in evaporite rocks have also given rise to variations in physical properties, which could only qualitatively be taken into account in the investigations reported here.

The arbitrary separation of mineralogical and physical rock properties from geology and hydrology that has often occurred in other studies is

being avoided in the comprehensive studies being performed for the WIPP. The relations of rocks found at the proposed repository horizons to those found in an *in situ* test bed located elsewhere (e.g., nearby potash mine) are being evaluated. Quite possibly, mineralogic and fabric changes may cause discrepancies in results from one site to another.

10.9.3 Radionuclide Sorption Properties

Scope. A continuing assessment of WIPP rocks ability to inhibit the migration of radionuclides away from the repository is envisioned to augment the batch Kd determinations, which were used in preliminary calculations of radionuclide travel time in site-specific escape scenarios. A realistic approach to safety assessment requires data to be generated (mostly in the laboratory) under simulated physiochemical conditions anticipated in subsurface evaporites and related rocks of southeast New Mexico. The laboratory experiments in radionuclide migration would ultimately be evaluated by SENM field experiments involving the emplacement and observation of movement of non-radioactive tracers which are chemically analogous to radionuclides.

Continuing Studies. Whereas previous "Kd" measurements reflect the degree to which radionuclide soprtion on rocks takes place in static, closed systems, scenarios involving the entrainment of radionuclides in moving groundwater imply that a variety of physiochemical conditions will be encountered in the subsurface.

Now that the radionuclides of interest have been identified, different oxidation states of those radionuclides which might give rise to different mobilities in WIPP environments will next be identified. Investigations of effects on sorption of parameters such as pH, radionuclide concentration in solution, and oxidation potential will then proceed with the oxidation states of species of interest. These parameterization experiments will culminate in the simulation of radionuclide migration in flow-through experiments involving actual WIPP rocks and solutions, at the anticipated physiochemical conditions.

Appendix 7.A (Ref. sec. 7.3)

Whole Rock Chemical Analyses, Soluble-Insoluble Fractions, Mineralogy, and Weight Losses upon Heating.

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1044.2 FEET

SOLUBLE = 99.72 %
INSOLUBLE = 0.28 %

COMPONENT	WT %
SO3	0.55
NA	38.56
NA2O	0.0
K	0.03
K2O	0.0
MGO	0.04
CAO	0.43
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	60.40
WEIGHT LOSS ON HEATING	
70	0.10
HI TEMP	0.0
TOTAL	100.39

MAJOR: HAL
MINOR: ANH
TRACE: CARN

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1107.5 FEET

SOLUBLE = 69.47 %
INSOLUBLE = 30.53 %

COMPONENT	WT %
SO3	20.88
NA	20.28
NA2O	6.63
K	0.0
K2O	4.48
MGO	4.57
CAO	1.84
SIO2	8.30
FE2O3	0.27
AL2O3	1.24
CL	30.78
WEIGHT LOSS ON HEATING	
70	0.12
125	0.10
200	0.40
350-400	1.37
TOTAL	101.26

MAJOR: HAL
MINOR: POLY, LANG, KFELD, TALC, QTZ
TRACE: CHLOR, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1171.5 FEET

SOLUBLE = 37.10 %
INSOLUBLE = 62.90 %

COMPONENT	WT %
SO3	39.73
NA	12.56
NA2O	0.88
K	1.91
K2O	0.0
MGO	0.70
CAO	25.13
SIO2	0.63
FE2O3	0.06
AL2O3	0.0
CL	18.87
WEIGHT LOSS ON HEATING	
70	0.14
300-400	0.58
425	0.08
TOTAL	101.27

MAJOR: HAL, ANH
MINOR: POLY
TRACE: SYL, BLOED, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1221.0 FEET

SOLUBLE = 99.51 %
INSOLUBLE = 0.49 %

COMPONENT	WT %
SO3	2.02
NA	38.79
NA2O	0.0
K	0.06
K2O	0.0
MGO	0.10
CAO	0.88
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	58.31
WEIGHT LOSS ON HEATING	
70	0.30
100-200	0.14
375-425	0.07
TOTAL	101.17

MAJOR: HAL
MINOR: ANH
TRACE: POLY, LANG, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1343.0 FEET

SOLUBLE = 99.74 %
INSOLUBLE = 0.36 %

COMPONENT	WT %
SO3	0.99
NA	38.60
NA2O	0.0
K	0.35
K2O	0.0
MGO	0.15
CAO	0.66
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.40
WEIGHT LOSS ON HEATING	
70	0.27
300-350	0.16
TOTAL	100.95

MAJOR: HAL
MINOR: ANH, POLY
TRACE: QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1402.5 FEET

SOLUBLE = 99.97 %
INSOLUBLE = 0.03 %

COMPONENT	WT %
SO3	0.11
NA	39.67
NA2O	0.0
K	0.06
K2O	0.0
MGO	0.06
CAO	0.02
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	59.78
WEIGHT LOSS ON HEATING	
70	0.19
400-500	0.12
TOTAL	100.04

MAJOR: HAL
MINOR:
TRACE: POLY

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1468.5 FEET

SOLUBLE = 93.66 %
INSOLUBLE = 6.34 %

COMPONENT	WT %
SO3	2.88
NA	34.44
NA2O	0.0
K	0.37
K2O	0.07
MGO	1.85
CAO	0.19
SIO2	2.15
FE2O3	0.24
AL2O3	0.07
CL	53.61
WEIGHT LOSS ON HEATING	
70	1.27
100-150	0.36
175	0.10
250	0.07
375	0.34
400-500	0.45
TOTAL	98.46

MAJOR: HAL
MINOR: KAIN, KIES
TRACE: POLY, KFELD, TALC, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1534.0 FEET

SOLUBLE = 99.86 %
INSOLUBLE = 0.14 %

COMPONENT	WT %
SO3	1.67
NA	36.10
NA2O	0.0
K	0.52
K2O	0.0
MGO	0.22
CAO	0.64
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	57.76
WEIGHT LOSS ON HEATING	
70	0.22
200	0.01
400-500	0.24
TOTAL	97.53

MAJOR: HAL
MINOR: POLY
TRACE: KAIN, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1615.0 FEET

SOLUBLE = 98.69 %
INSOLUBLE = 1.31 %

COMPONENT	WT %
SO3	4.56
NA	35.06
NA2O	0.0
K	1.05
K2O	0.0
MGO	0.71
CAO	1.47
SIO2	0.23
FE2O3	0.04
AL2O3	0.07
CL	55.95
WEIGHT LOSS ON HEATING	
70	0.34
100	0.09
350-400	0.37
TOTAL	99.94

MAJOR: HAL
MINOR: POLY, KAIN
TRACE: CHLOR, MONT

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1698.0 FEET

SOLUBLE = 95.35 %
INSOLUBLE = 4.65 %

COMPONENT	WT %
SO3	0.58
NA	36.47
NA2O	0.0
K	0.06
K2O	0.07
MGO	1.20
CAO	0.34
SIO2	2.07
FE2O3	0.25
AL2O3	0.61
CL	58.35
WEIGHT LOSS ON HEATING	
70	0.82
350	0.03
TOTAL	100.85

MAJOR: HAL
MINOR: ANH, CARN, KIES
TRACE: POLY, ILL, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1755.0 FEET

SOLUBLE = 99.60 %
INSOLUBLE = 0.40 %

COMPONENT	WT %
SO3	0.65
NA	38.12
NA2O	0.0
K	0.23
K2O	0.0
MGO	0.13
CAO	0.08
SIO2	0.02
FE2O3	0.0
AL2O3	0.0
CL	59.54
WEIGHT LOSS ON HEATING	
70	0.19
200	0.04
300-400	0.05
TOTAL	99.45

MAJOR: HAL
MINOR:
TRACE: LEON, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1952.5 FEET

SOLUBLE = 99.30 %
INSOLUBLE = 0.70 %

COMPONENT	WT %
SO3	3.18
NA	37.14
NA2O	0.0
K	0.75
K2O	0.03
MGO	0.54
CAO	0.79
SIO2	0.34
FE2O3	0.03
AL2O3	0.05
CL	57.00
WEIGHT LOSS ON HEATING	
70	0.14
350-450	0.44
TOTAL	100.43

MAJOR: HAL
MINOR: POLY
TRACE: LEON, CHLOR, KFELD, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1954.0 FEET

SOLUBLE = 97.46 %
INSOLUBLE = 2.54 %

COMPONENT	WT %
SO3	0.73
NA	37.94
NA2O	0.0
K	0.18
K2O	0.06
MGO	0.56
CAO	0.52
SIO2	1.34
FE2O3	0.09
AL2O3	0.23
CL	58.38
WEIGHT LOSS ON HEATING	
70	0.32
350-400	0.09
TOTAL	100.44

MAJOR: HAL
MINOR: POLY
TRACE: ANH, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1957.5 FEET

SOLUBLE = 99.16 %
INSOLUBLE = 0.84 %

COMPONENT	WT %
SO3	1.72
NA	38.38
NA2O	0.0
K	0.36
K2O	0.01
MGO	0.41
CAO	2.18
SIO2	0.37
FE2O3	0.04
AL2O3	0.11
CL	59.00
WEIGHT LOSS ON HEATING	
70	0.20
300-400	0.12
TOTAL	102.90

MAJOR: HAL
MINOR: ANH
TRACE: POLY, CHLOR, KFELD, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1961.0 FEET

SOLUBLE = 99.10 %
INSOLUBLE = 0.90 %

COMPONENT	WT %
SO3	0.49
NA	39.14
NA2O	0.0
K	0.21
K2O	0.01
MGO	0.25
CAO	0.19
SIO2	0.42
FE2O3	0.04
AL2O3	0.08
CL	58.83
WEIGHT LOSS ON HEATING	
70	0.07
100	0.16
150-200	0.16
TOTAL	100.05

MAJOR: HAL
MINOR: POLY
TRACE: CHLOR, KFELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1967.0 FEET

SOLUBLE = 99.94 %
INSOLUBLE = 0.06 %

COMPONENT	WT %
SO3	3.03
NA	39.58
NA2O	0.0
K	0.90
K2O	0.0
MGO	0.23
CAO	0.94
SIO2	0.0
FE2O3	0.01
AL2O3	0.0
CL	58.74
WEIGHT LOSS ON HEATING	
70	0.20
300-350	0.28
450-500	0.65
TOTAL	104.62

MAJOR: HAL
MINOR: POLY
TRACE: FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1969.0 FEET

SOLUBLE = 98.05 %
INSOLUBLE = 1.95 %

COMPONENT	WT %
SO3	0.32
NA	38.76
NA2O	0.0
K	0.08
K2O	0.0
MGO	0.22
CAO	0.08
SIO2	0.15
FE2O3	0.02
AL2O3	0.04
CL	60.60
WEIGHT LOSS ON HEATING	
70	0.43
100	0.08
400-500	0.20
TOTAL	100.98

MAJOR: HAL
MINOR:
TRACE: ANH, KAIN, CHLOR, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1973.0 FEET

SOLUBLE = 98.63 %
INSOLUBLE = 1.37 %

COMPONENT	WT %
SO3	0.26
NA	38.46
NA2O	0.0
K	0.06
K2O	0.03
MGO	0.53
CAO	0.07
SIO2	0.66
FE2O3	0.01
AL2O3	0.13
CL	59.58
WEIGHT LOSS ON HEATING	
70	0.19
170	0.07
380	0.02
450+	0.12
TOTAL	100.19

MAJOR: HAL
MINOR: POLY, KIES
TRACE: KAIN, CHLOR, FKELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1975.0 FEET

SOLUBLE = 99.93 %
INSOLUBLE = 0.07 %

COMPONENT	WT %
SO3	0.19
NA	38.93
NA2O	0.0
K	0.06
K2O	0.0
MGO	0.07
CAO	0.09
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	60.38
WEIGHT LOSS ON HEATING	
70	0.17
400-500	0.07
TOTAL	100.03

MAJOR: HAL
MINOR:
TRACE: ANH, KAIN

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1978.5 FEET

SOLUBLE = 91.07 %
INSOLUBLE = 8.93 %

COMPONENT	WT %
SO3	2.82
NA	32.52
NA2O	1.96
K	0.44
K2O	0.13
MGO	2.62
CAO	0.98
SIO2	2.89
FE2O3	0.37
AL2O3	1.06
CL	51.89
WEIGHT LOSS ON HEATING	
70	0.36
200	0.04
300-400	0.17
450-550	1.10
TOTAL	99.35

MAJOR: HAL
MINOR: POLY, CHLOR
TRACE: ANH, LANG, BLOED, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1983.0 FEET

SOLUBLE = 100.00 %
INSOLUBLE = 0.0 %

COMPONENT	WT %
SO3	1.11
NA	36.00
NA2O	0.0
K	0.61
K2O	0.0
MGO	0.40
CAO	0.46
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.20
WEIGHT LOSS ON HEATING	
70	0.29
125	0.03
275	0.05
350-400	0.14
TOTAL	98.30

MAJOR: HAL
MINOR: DOLY, KAIN
TRACE: QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1986.5 FEET

SOLUBLE = 99.71 %
INSOLUBLE = 0.29 %

COMPONENT	WT %
SO3	0.17
NA	38.20
NA2O	0.0
K	0.04
K2O	0.0
MGO	0.03
CAO	0.21
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	60.66
WEIGHT LOSS ON HEATING	
70	0.10
TO 500	0.0
TOTAL	99.71

MAJOR: HAL
MINOR: ANH, POLY
TRACE: KAIN, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1993.5 FEET

SOLUBLE = 99.55 %
INSOLUBLE = 0.45 %

COMPONENT	WT %
SO3	2.96
NA	38.25
NA2O	0.0
K	1.68
K2O	0.0
MGO	0.79
CAO	2.30
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	53.81
WEIGHT LOSS ON HEATING	
70-	0.19
100	0.05
350-400	0.80
TOTAL	101.28

MAJOR: HAL
MINOR: POLY
TRACE:

TOTAL ANALYSIS

HOLE # 7
DEPTH = 2537.0 FEET

SOLUBLE = 91.43 %
INSOLUBLE = 8.57 %

COMPONENT	WT %
SO3	46.62
NA	0.93
NA2O	4.93
K	0.90
K2O	0.0
MGO	13.02
CAO	4.37
SIO2	13.98
FE2O3	1.13
AL2O3	3.26
CL	2.63
WEIGHT LOSS ON HEATING	
70	0.47
100	0.09
TO 500	0.0
HI TEMP	8.68
TOTAL	109.56

MAJOR: ANH
MINOR: HAL, KIES
TRACE: BLOED, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 2703.0 FEET

SOLUBLE = 98.97 %
INSOLUBLE = 1.03 %

COMPONENT	WT %
SO3	1.46
NA	38.36
NA2O	0.0
K	0.02
K2O	0.01
MGO	0.26
CAO	0.79
SIO2	0.25
FE2O3	0.06
AL2O3	0.05
CL	58.89
WEIGHT LOSS ON HEATING	
70	0.24
150	0.03
550	0.12
TOTAL	100.54

MAJOR: HAL
MINOR: ANH
TRACE: POLY, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 2716.3 FEET

SOLUBLE = 99.63 %
INSOLUBLE = 0.37 %

COMPONENT	WT %
SO3	0.44
NA	39.44
NA2O	0.0
K	0.01
K2O	0.0
MGO	0.01
CAO	0.18
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	61.00
WEIGHT LOSS ON HEATING	
70	0.22
350	0.04
TOTAL	101.72

MAJOR: HAL
MINOR: ANH
TRACE: POLY, TALC

TOTAL ANALYSIS

HOLE # 7
DEPTH = 2736.0 FEET

SOLUBLE = 99.67 %
INSOLUBLE = 0.33 %

COMPONENT	WT %
SO3	0.42
NA	39.75
NA2O	0.0
K	0.01
K2O	0.0
MGO	0.06
CAO	0.51
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.88
WEIGHT LOSS ON HEATING	
70	0.08
TO 450	0.03
TOTAL	101.08

MAJOR: HAL
MINOR: ANH
TRACE:

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1391.5 FEET

SOLUBLE = 98.99 %
INSOLUBLE = 1.01 %

COMPONENT	WT %
SO3	1.14
NA	39.34
NA2O	0.0
K	0.31
K2O	0.02
MGO	0.27
CAO	0.53
SIO2	0.40
FE2O3	0.27
AL2O3	0.10
CL	58.07
WEIGHT LOSS ON HEATING	
70	0.04
110	0.03
350-400	0.19
TOTAL	100.71

MAJOR: HAL
MINOR: POLY
TRACE: CHLOR, ILL, QTZ, FLUX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1495.3 FEET

SOLUBLE = 99.83 %
INSOLUBLE = 0.17 %

COMPONENT	WT %
SO3	1.12
NA	38.00
NA2O	0.0
K	0.12
K2O	0.0
MGO	0.13
CAO	1.62
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.97
WEIGHT LOSS ON HEATING	
70	0.05
200	0.03
TOTAL	101.22

MAJOR: HAL
MINOR:
TRACE: CARN

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1573.0 FEET

SOLUBLE = 97.72 %
INSOLUBLE = 2.28 %

COMPONENT	WT %
SO3	5.11
NA	34.63
NA2O	0.0
K	0.18
K2O	0.02
MGO	1.71
CAO	0.45
SIO2	0.02
FE2O3	0.0
AL2O3	0.01
CL	54.11
WEIGHT LOSS ON HEATING	
70	0.04
100	0.20
160	0.09
350-450	0.85
TOTAL	97.42

MAJOR: HAL
MINOR: (?) POLY, KIES
TRACE: (?) ILL

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1652.0 FEET

SOLUBLE = 48.61 %
INSOLUBLE = 51.39 %

COMPONENT	WT %
SO3	51.04
NA	4.07
NA2O	4.24
K	18.59
K2O	0.99
MGO	4.58
CAO	3.93
SIO2	0.35
FE2O3	0.07
AL2O3	0.04
CL	7.35
WEIGHT LOSS ON HEATING	
70	0.09
300+	4.43
TOTAL	99.77

MAJOR: HAL
MINOR: POLY-(?) SYL, LEON, GLAS
TRACE: ILL, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1705.0 FEET

SOLUBLE = 99.71 %
INSOLUBLE = 0.29 %

COMPONENT	WT %
SO3	1.18
NA	38.79
NA2O	0.0
K	0.35
K2O	0.0
MGO	0.17
CAO	0.44
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	58.64
WEIGHT LOSS ON HEATING	
70	0.15
170	0.02
400-500	0.15
TOTAL	100.19

MAJOR: HAL
MINOR:
TRACE: POLY

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1770.0 FEET

SOLUBLE = 98.79 %
INSOLUBLE = 1.21 %

COMPONENT	WT %
SO3	1.95
NA	35.75
NA2O	0.33
K	0.56
K2O	0.02
MGO	0.55
CAO	1.75
SIO2	0.48
FE2O3	0.0
AL2O3	0.12
CL	57.29
WEIGHT LOSS ON HEATING	
70	0.09
170	0.06
400	0.20
TOTAL	99.15

MAJOR: HAL
MINOR: ANH, KAIN
TRACE: ILL, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1787.0 FEET

SOLUBLE = 99.43 %
INSOLUBLE = 0.57 %

COMPONENT	WT %
SO3	3.01
NA	37.24
NA2O	0.0
K	0.69
K2O	0.01
MGO	0.54
CAO	0.70
SIO2	0.21
FE2O3	0.03
AL2O3	0.04
CL	58.00
WEIGHT LOSS ON HEATING	
70	0.32
100	0.04
300-400	0.23
TOTAL	101.06

MAJOR: HAL
MINOR: POLY, KAIN
TRACE: CHLOR, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1794.5 FEET

SOLUBLE = 75.34 %
INSOLUBLE = 24.66 %

COMPONENT	WT %
SO3	0.70
NA	29.75
NA2O	1.16
K	0.42
K2O	0.63
MGO	6.65
CAO	0.04
SIO2	7.80
FE2O3	0.46
AL2O3	1.91
CL	45.14
WEIGHT LOSS ON HEATING	
70	0.44
150	0.27
425+	4.70
TOTAL	100.07

MAJOR: HAL
MINOR: CARN, CHLOR, KFELD, TALC, QTZ
TRACE: POLY, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1804.0 FEET

SOLUBLE = 99.74 %
INSOLUBLE = 0.26 %

COMPONENT	WT %
SO3	0.28
NA	39.43
NA2O	0.0
K	0.06
K2O	0.0
MGO	0.04
CAO	0.70
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.94
WEIGHT LOSS ON HEATING	
70	0.02
200	0.05
TOTAL	100.79

MAJOR: HAL
MINOR: ANH
TRACE: CARN

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1829.0 FEET

SOLUBLE = 99.03 %
INSOLUBLE = 0.97 %

COMPONENT	WT %
SO3	0.02
NA	39.87
NA2O	0.0
K	0.05
K2O	0.02
MGO	0.29
CAO	0.01
SIO2	0.29
FE2O3	0.04
AL2O3	0.08
CL	58.81
WEIGHT LOSS ON HEATING	
70	0.16
200	0.23
TOTAL	99.87

MAJOR: HAL
MINOR:
TRACE: ANH, CARN, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1838.0 FEET

SOLUBLE = 97.53 %
INSOLUBLE = 2.47 %

COMPONENT	WT %
SO3	0.80
NA	37.58
NA2O	0.0
K	0.26
K2O	0.10
MGO	0.48
CAO	0.05
SIO2	0.13
FE2O3	0.16
AL2O3	0.27
CL	58.38
WEIGHT LOSS ON HEATING	
70	0.39
TO 500	0.0
TOTAL	98.60

MAJOR: HAL
MINOR:
TRACE: POLY, SLY, LEON, CHLOR, KFELD, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1856.7 FEET

SOLUBLE = 99.96 %
INSOLUBLE = 0.04 %

COMPONENT	WT %
SO3	2.70
NA	36.08
NA2O	0.0
K	1.62
K2O	0.0
MGO	0.03
CAO	1.56
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	56.66
WEIGHT LOSS ON HEATING	
70	0.07
350	0.03
TOTAL	98.79

MAJOR: HAL
MINOR: ANH, SYL, POLY
TRACE:

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1875.0 FEET

SOLUBLE = 70.94 %
INSOLUBLE = 29.06 %

COMPONENT	WT %
SO3	0.42
NA	25.64
NA2O	0.0
K	0.31
K2O	2.28
MGO	9.55
CAO	0.63
SIO2	15.30
FE2O3	1.23
AL2O3	3.00
CL	40.92
WEIGHT LOSS ON HEATING	
70	0.22
125-200	0.42
TOTAL	99.92

MAJOR: HAL
MINOR: CARN, KFELD, TALC
TRACE: POLY, CHLOR

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1884.0 FEET

SOLUBLE = 80.58 %
INSOLUBLE = 19.42 %

COMPONENT	WT %
SO3	3.76
NA	27.10
NA2O	0.0
K	6.98
K2O	1.80
MGO	5.09
CAO	1.66
SIO2	9.02
FE2O3	0.60
AL2O3	1.99
CL	44.06
WEIGHT LOSS ON HEATING	
70	0.36
350-400	0.44
TOTAL	102.86

MAJOR: HAL
MINOR: ANH, CARN, KFELD, TALC, FEOX
TRACE: CHLOR

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1890.0 FEET

SOLUBLE = 99.98 %
INSOLUBLE = 0.02 %

COMPONENT	WT %
SO3	0.77
NA	36.78
NA2O	0.0
K	0.10
K2O	0.0
MGO	0.10
CAO	0.95
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	59.33
WEIGHT LOSS ON HEATING	
70	0.05
300-400	0.08
TOTAL	100.18

MAJOR: HAL
MINOR:
TRACE: ANH, CARN

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1894.3 FEET

SOLUBLE = 95.43 %
INSOLUBLE = 4.57 %

COMPONENT	WT %
SO3	0.12
NA	37.90
NA2O	0.0
K	0.06
K2O	0.13
MGO	0.74
CAO	0.03
SIO2	2.43
FE2O3	0.20
AL2O3	0.43
CL	57.78
WEIGHT LOSS ON HEATING	
70	0.30
TO 500	0.0
TOTAL	100.12

MAJOR: HAL
MINOR: QTZ
TRACE: ANH, CARN, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1898.5 FEET

SOLUBLE = 98.53 %
INSOLUBLE = 1.47 %

COMPONENT	WT %
SO3	0.55
NA	38.81
NA2O	0.71
K	0.07
K2O	0.01
MGO	0.26
CAO	0.12
SIO2	0.45
FE2O3	0.02
AL2O3	0.07
CL	57.97
WEIGHT LOSS ON HEATING	
70	0.16
TO 500	0.0
TOTAL	99.20

MAJOR: HAL
MINOR:
TRACE: POLY, BLOED, CHLOR, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1900.0 FEET

SOLUBLE = 99.96 %
INSOLUBLE = 0.04 %

COMPONENT	WT %
SO3	3.20
NA	38.14
NA2O	0.0
K	0.98
K2O	0.0
MGO	0.47
CAO	0.39
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	57.60
WEIGHT LOSS ON HEATING	
70	0.17
300-400	0.64
TOTAL	101.63

MAJOR: HAL
MINOR: LEON
TRACE: POLY

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1905.0 FEET

SOLUBLE = 96.98 %
INSOLUBLE = 3.02 %

COMPONENT	WT %
SO3	0.20
NA	38.67
NA2O	0.0
K	0.13
K2O	0.03
MGO	0.93
CAO	0.45
SIO2	0.91
FE2O3	0.14
AL2O3	0.25
CL	57.91
WEIGHT LOSS ON HEATING	
70	0.36
375	0.26
TOTAL	100.24

MAJOR: HAL
MINOR:
TRACE: POLY, CHLOR, KFELD, TALC

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1910.0 FEET

SOLUBLE = 99.02 %
INSOLUBLE = 0.98 %

COMPONENT	WT %
SO3	0.53
NA	39.64
NA2O	0.0
K	0.0
K2O	0.30
MGO	0.31
CAO	0.44
SIO2	0.34
FE2O3	0.04
AL2O3	0.08
CL	59.04
WEIGHT LOSS ON HEATING	
70	0.06
375	0.04
TOTAL	100.82

MAJOR: HAL
MINOR: POLY
TRACE: ANH, CHLOR, KFELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1913.1 FEET

SOLUBLE = 97.71 %
INSOLUBLE = 2.29 %

COMPONENT	WT %
SO3	0.06
NA	38.48
NA2O	0.0
K	0.06
K2O	0.05
MGO	0.55
CAO	0.01
SIO2	0.91
FE2O3	0.13
AL2O3	0.21
CL	59.27
WEIGHT LOSS ON HEATING	
70	0.11
120	0.03
260	0.03
400+	0.04
TOTAL	99.94

MAJOR: HAL
MINOR:
TRACE: KAIN, CHLOR, KFELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1916.2 FEET

SOLUBLE = 99.85 %
INSOLUBLE = 0.15 %

COMPONENT	WT %
SO3	0.92
NA	38.48
NA2O	0.0
K	0.21
K2O	0.0
MGO	0.13
CAO	0.44
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	57.71
WEIGHT LOSS ON HEATING	
70	0.13
250	0.02
350-400	0.10
TOTAL	98.29

MAJOR: HAL
MINOR: POLY
TRACE: ANH

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1923.0 FEET

SOLUBLE = 98.30 %
INSOLUBLE = 1.70 %

COMPONENT	WT %
SO3	1.06
NA	38.03
NA2O	0.0
K	0.05
K2O	0.08
MGO	0.09
CAO	0.20
SIO2	0.60
FE2O3	0.10
AL2O3	0.16
CL	58.43
WEIGHT LOSS ON HEATING	
70	0.19
300	0.06
450+	0.24
TOTAL	99.29

MAJOR: HAL
MINOR: POLY
TRACE: KAIN, CHLOR, ILL, KFELD, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1930.0 FEET

SOLUBLE = 98.99 %
INSOLUBLE = 1.01 %

COMPONENT	WT %
SO3	2.81
NA	35.71
NA2O	0.08
K	1.03
K2O	0.01
MGO	0.46
CAO	0.20
SIO2	0.18
FE2O3	0.07
AL2O3	0.04
CL	56.74
WEIGHT LOSS ON HEATING	
70	0.05
350-400	0.42
TOTAL	97.80

MAJOR: HAL
MINOR: POLY
TRACE: LEON, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1933.0 FEET

SOLUBLE = 99.62 %
INSOLUBLE = 0.38 %

COMPONENT	WT %
SO3	0.78
NA	38.03
NA2O	0.0
K	0.15
K2O	0.0
MGO	0.09
CAO	0.65
SIO2	0.01
FE2O3	0.01
AL2O3	0.0
CL	59.61
WEIGHT LOSS ON HEATING	
70	0.19
200	0.09
TOTAL	100.19

MAJOR: HAL
MINOR: ANH, POLY, KAIN
TRACE: QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1938.0 FEET

SOLUBLE = 99.86 %
INSOLUBLE = 0.14 %

COMPONENT	WT %
SO3	2.91
NA	35.63
NA2O	0.0
K	0.68
K2O	0.0
MGO	0.84
CAO	1.02
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	59.45
WEIGHT LOSS ON HEATING	
70	0.13
125	0.14
275	0.05
350-400	0.17
TOTAL	101.16

MAJOR: HAL
MINOR: POLY, KAIN
TRACE:

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1953.2 FEET

SOLUBLE = 99.91 %
INSOLUBLE = 0.09 %

COMPONENT	WT %
SO3	2.30
NA	39.50
NA2O	0.0
K	0.30
K2O	0.0
MGO	0.42
CAO	1.23
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	57.63
WEIGHT LOSS ON HEATING	
70	0.05
250	0.05
375	0.03
425	0.29
TOTAL	101.90

MAJOR: HAL
MINOR: ANH, POLY
TRACE: BLOED, TALC

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1967.0 FEET

SOLUBLE = 95.13 %
INSOLUBLE = 4.87 %

COMPONENT	WT %
SO3	1.25
NA	35.99
NA2O	2.73
K	0.57
K2O	0.09
MGO	1.21
CAO	0.41
SIO2	0.76
FE2O3	0.10
AL2O3	0.20
CL	57.52
WEIGHT LOSS ON HEATING	
70	0.28
190	0.04
400-500	0.20
TOTAL	101.35

MAJOR: HAL
MINOR: POLY, KAIN, TALC
TRACE: CHLOR, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1986.0 FEET

SOLUBLE = 36.72 %
INSOLUBLE = 63.28 %

COMPONENT	WT %
SO3	60.87
NA	0.36
NA2O	5.83
K	0.0
K2O	26.07
MGO	1.83
CAO	5.12
SIO2	0.54
FE2O3	0.17
AL2O3	0.85
CL	0.15
WEIGHT LOSS ON HEATING	
70	0.07
300-400	5.81
TOTAL	107.67

MAJOR: (?) GLAS, ANH, LEON
MINOR:
TRACE: HAL, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2006.0 FEET

SOLUBLE = 99.50 %
INSOLUBLE = 0.50 %

COMPONENT	WT %
SO3	2.37
NA	37.59
NA2O	0.0
K	1.03
K2O	0.0
MGO	0.31
CAO	0.06
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	57.17
WEIGHT LOSS ON HEATING	
70	0.20
350-400	0.29
450	0.13
475	0.04
TOTAL	99.70

MAJOR: HAL
MINOR: KAIN, BLOED
TRACE: POLY, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2017.0 FEET

SOLUBLE = 95.20 %
INSOLUBLE = 4.80 %

COMPONENT	WT %
SO3	0.62
NA	35.66
NA2O	0.0
K	0.06
K2O	0.04
MGO	0.53
CAO	1.02
SIO2	2.02
FE2O3	0.28
AL2O3	0.70
CL	57.09
WEIGHT LOSS ON HEATING	
70	0.22
100	0.02
300-400	0.17
ORGANIC	1.59
TOTAL	100.02

MAJOR: HAL
MINOR: ANH
TRACE: SYL, CAIN, CHLOR, FEOX, ILL

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2039.0 FEET

SOLUBLE = 98.94 %
INSOLUBLE = 1.06 %

COMPONENT	WT %
SO3	5.50
NA	35.02
NA2O	0.0
K	1.56
K2O	0.03
MGO	0.70
CAO	1.58
SIO2	0.27
FE2O3	0.07
AL2O3	0.05
CL	54.01
WEIGHT LOSS ON HEATING	
70	0.21
100	0.05
300-400	0.49
425	0.27
TOTAL	99.81

MAJOR: HAL
MINOR: POLY, KAIN
TRACE: KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2050.0 FEET

SOLUBLE = 28.61 %
INSOLUBLE = 71.39 %

COMPONENT	WT %
SO3	54.99
NA	8.00
NA2O	4.90
K	0.05
K2O	0.04
MGO	0.31
CAO	7.10
SIO2	0.33
FE2O3	0.0
AL2O3	0.0
CL	12.44
WEIGHT LOSS ON HEATING	
70	0.11
475	0.68
TOTAL	88.95

MAJOR: ANH
MINOR: HAL
TRACE: QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2068.0 FEET

SOLUBLE = 98.84 %
INSOLUBLE = 1.16 %

COMPONENT	WT %
SO3	2.49
NA	37.41
NA2O	0.0
K	0.08
K2O	0.01
MGO	0.31
CAO	0.89
SIO2	0.38
FE2O3	0.05
AL2O3	0.07
CL	55.99
WEIGHT LOSS ON HEATING	
70	0.04
250	0.10
TOTAL	97.82

MAJOR: HAL
MINOR: ANH, TALC, BLOED
TRACE: POLY, CHLOR, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2084.0 FEET

SOLUBLE = 92.00 %
INSOLUBLE = 8.00 %

COMPONENT	WT %
SO3	2.64
NA	34.46
NA2O	1.87
K	1.02
K2O	0.19
MGO	1.48
CAO	0.73
SIO2	2.07
FE2O3	0.25
AL2O3	0.37
CL	52.19
WEIGHT LOSS ON HEATING	
70	0.17
140	0.05
350-400	0.27
450-550	0.22
TOTAL	97.98

MAJOR: HAL
MINOR: CHLOR, TALC, QTZ
TRACE: KFELD, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2130.0 FEET

SOLUBLE = 99.61 %
INSOLUBLE = 0.39 %

COMPONENT	WT %
SO3	2.31
NA	37.79
NA2O	0.0
K	0.42
K2O	0.0
MGO	0.25
CAO	0.75
SIO2	0.03
FE2O3	0.0
AL2O3	0.0
CL	57.16
WEIGHT LOSS ON HEATING	
70	0.11
125	0.07
350-400	0.10
TOTAL	99.38

MAJOR: HAL
MINOR: POLY
TRACE: ANH, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2162.0 FEET

SOLUBLE = 98.90 %
INSOLUBLE = 1.10 %

COMPONENT	WT %
SO3	1.56
NA	36.77
NA2O	0.55
K	1.23
K2O	0.03
MGO	0.65
CAO	0.93
SIO2	0.23
FE2O3	0.06
AL2O3	0.05
CL	59.99
WEIGHT LOSS ON HEATING	
70	0.14
300-400	0.48
TOTAL	102.67

MAJOR: HAL
MINOR: ANH, POLY, SYL
TRACE: KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2217.0 FEET

SOLUBLE = 99.78 %
INSOLUBLE = 0.22 %

COMPONENT	WT %
SO3	0.0
NA	39.14
NA2O	0.0
K	0.07
K2O	0.0
MGO	0.02
CAO	0.12
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.75
WEIGHT LOSS ON HEATING	
70	0.04
300-400	0.40
TOTAL	99.77

MAJOR: HAL
MINOR:
TRACE: ANH, POLY, SLY, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2280.0 FEET

SOLUBLE = 100.00 %
INSOLUBLE = 0.0 %

COMPONENT	WT %
SO3	0.39
NA	37.91
NA2O	0.0
K	0.12
K2O	0.0
MGO	0.09
CAO	0.25
SIO2	0.02
FE2O3	0.0
AL2O3	0.0
CL	60.23
WEIGHT LOSS ON HEATING	
70	0.19
350	0.08
TOTAL	99.28

MAJOR: HAL
MINOR: ANH, CARN
TRACE: POLY, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2326.0 FEET

SOLUBLE = 95.44 %
INSOLUBLE = 4.56 %

COMPONENT	WT %
SO3	0.18
NA	37.83
NA2O	0.0
K	0.06
K2O	0.03
MGO	1.39
CAO	0.17
SIO2	1.15
FE2O3	0.12
AL2O3	0.25
CL	57.93
WEIGHT LOSS ON HEATING	
70	0.11
100-150	0.03
450+ MIN	0.56
TOTAL	99.81

MAJOR: HAL
MINOR: TALC
TRACE: HAL, CARN, CHLOR, FLOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2366.3 FEET

SOLUBLE = 31.37 %
INSOLUBLE = 68.63 %

COMPONENT	WT %
SO3	47.32
NA	0.62
NA2O	3.76
K	0.0
K2O	10.67
MGO	6.40
CAO	3.37
SIO2	10.68
FE2O3	0.01
AL2O3	1.57
CL	1.17
WEIGHT LOSS ON HEATING	
70	0.43
200-375	4.81
375-500	1.60
TOTAL	92.41

MAJOR:
MINOR: KAIN, KFELD, TALC, QTZ
TRACE: HAL, SYL

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2427.5 FEET

SOLUBLE = 99.36 %
INSOLUBLE = 0.64 %

COMPONENT	WT %
SO3	2.58
NA	39.42
NA2O	0.0
K	0.01
K2O	0.01
MGO	0.05
CAO	0.35
SIO2	0.10
FE2O3	0.01
AL2O3	0.01
CL	59.88
WEIGHT LOSS ON HEATING	
70	0.03
300-400	0.40
TOTAL	102.85

MAJOR: HAL
MINOR: ANH
TRACE: POLY, BLOED, KFELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2460.0 FEET

SOLUBLE = 99.21 %
INSOLUBLE = 0.79 %

COMPONENT	WT %
SO3	1.14
NA	38.75
NA2O	0.0
K	0.03
K2O	0.01
MGO	0.20
CAO	0.62
SIO2	0.19
FE2O3	0.03
AL2O3	0.06
CL	57.00
WEIGHT LOSS ON HEATING	
70	0.17
125	0.05
350	0.08
450	0.07
TOTAL	98.40

MAJOR: HAL
MINOR: ANH
TRACE: KAIN, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2519.6 FEET

SOLUBLE = 99.36 %
INSOLUBLE = 0.64 %

COMPONENT	WT %
SO3	0.17
NA	40.42
NA2O	0.0
K	0.02
K2O	0.0
MGO	0.01
CAO	0.03
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	60.31
WEIGHT LOSS ON HEATING	
70	0.08
480	0.06
TOTAL	101.74

MAJOR: HAL
MINOR:
TRACE: POLY

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2563.0 FEET

SOLUBLE = 7.11 %
INSOLUBLE = 92.89 %

COMPONENT	WT %
SO3	40.59
NA	1.47
NA2O	6.06
K	0.05
K2O	0.54
MGO	14.73
CAO	24.37
SIO2	6.25
FE2O3	0.96
AL2O3	1.86
CL	1.05
WEIGHT LOSS ON HEATING	
70	1.87
100-150	0.19
175	0.07
450+ MIN	0.11
TOTAL	100.17

MAJOR: ANH
MINOR: CHLOR, KEELD, TALC, FEOX
TRACE: HAL, LANG

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2615.5 FEET

SOLUBLE = 99.74 %
INSOLUBLE = 0.26 %

COMPONENT	WT %
SO3	0.86
NA	38.58
NA2O	0.0
K	0.05
K2O	0.0
MGO	0.02
CAO	0.58
SIO2	0.0
FE2O3	0.01
AL2O3	0.0
CL	59.37
WEIGHT LOSS ON HEATING	
70	0.21
300-350	0.06
TOTAL	100.00

MAJOR: HAL
MINOR: ANH
TRACE: POLY, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2665.5 FEET

SOLUBLE = 99.08 %
INSOLUBLE = 0.92 %

COMPONENT	WT %
SO3	0.98
NA	38.68
NA2O	0.0
K	0.02
K2O	0.01
MGO	0.22
CAO	0.35
SIO2	0.23
FE2O3	0.04
AL2O3	0.06
CL	59.14
WEIGHT LOSS ON HEATING	
70	0.25
400-500	0.48
TOTAL	100.46

MAJOR: HAL
MINOR: ANH, CHLOR
TRACE: POLY, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2706.0 FEET

SOLUBLE = 98.75 %
INSOLUBLE = 1.25 %

COMPONENT	WT %
SO3	1.13
NA	37.09
NA2O	0.64
K	0.03
K2O	0.03
MGO	0.19
CAO	0.68
SIO2	0.27
FE2O3	0.27
AL2O3	0.07
CL	58.60
WEIGHT LOSS ON HEATING	
70	0.16
300	0.05
380	0.75
400+	0.70
TOTAL	100.66

MAJOR: HAL
MINOR: ANH
TRACE: POLY, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2758.0 FEET

SOLUBLE = 99.22 %
INSOLUBLE = 0.78 %

COMPONENT	WT %
SO3	1.70
NA	37.20
NA2O	0.83
K	0.08
K2O	0.01
MGO	0.18
CAO	1.14
SIO2	0.06
FE2O3	0.01
AL2O3	0.02
CL	58.07
WEIGHT LOSS ON HEATING	
70	0.11
250	0.05
TOTAL	99.46

MAJOR: HAL
MINOR: ANH
TRACE: POLY, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2779.0 FEET

SOLUBLE = 99.62 %
INSOLUBLE = 0.38 %

COMPONENT	WT %
SO3	1.09
NA	37.41
NA2O	0.0
K	0.01
K2O	0.0
MGO	0.03
CAO	1.80
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	58.53
WEIGHT LOSS ON HEATING	
70	0.21
HI TEMP	0.0
TOTAL	99.46

MAJOR: HAL
MINOR: CARN, ANH
TRACE:

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2794.0 FEET

SOLUBLE = 99.79 %
INSOLUBLE = 0.21 %

COMPONENT	WT %
SO3	0.99
NA	37.86
NA2O	0.0
K	0.02
K2O	0.0
MGO	0.01
CAO	0.68
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	60.58
WEIGHT LOSS ON HEATING	
70	0.18
HI TEMP	0.0
TOTAL	100.53

MAJOR: HAL
MINOR: ANH
TRACE: POLY

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2802.5 FEET

SOLUBLE = 99.55 %
INSOLUBLE = 0.45 %

COMPONENT	WT %
SO3	1.76
NA	38.39
NA2O	0.0
K	0.02
K2O	0.0
MGO	0.01
CAO	0.22
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	58.19
WEIGHT LOSS ON HEATING	
70	0.10
170	0.02
375	0.02
TOTAL	99.18

MAJOR: HAL
MINOR: ANH
TRACE: BLOED, POLY

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2809.0 FEET

SOLUBLE = 99.09 %
INSOLUBLE = 0.91 %

COMPONENT	WT %
SO3	2.02
NA	38.56
NA2O	0.0
K	0.01
K2O	0.01
MGO	0.04
CAO	1.09
SIO2	0.04
FE2O3	0.0
AL2O3	0.01
CL	59.70
WEIGHT LOSS ON HEATING	
70	0.15
150-200	0.09
400	0.24
TOTAL	101.96

MAJOR: HAL
MINOR: ANH
TRACE: POLY, BLOED, POLY, KFELD, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2820.5 FEET

SOLUBLE = 99.46 %
INSOLUBLE = 0.54 %

COMPONENT	WT %
SO3	1.67
NA	38.42
NA2O	0.0
K	0.01
K2O	0.0
MGO	0.03
CAO	0.29
SIO2	0.06
FE2O3	0.0
AL2O3	0.0
CL	58.50
WEIGHT LOSS ON HEATING	
70	0.18
400+	0.18
TOTAL	99.34

MAJOR: HAL
MINOR: THEN, ANH
TRACE: POLY, TALC

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2879.0 FEET

SOLUBLE = 96.41 %
INSOLUBLE = 3.59 %

COMPONENT	WT %
SO3	4.15
NA	32.65
NA2O	0.93
K	0.02
K2O	0.01
MGO	0.13
CAO	1.54
SIO2	0.13
FE2O3	0.01
AL2O3	0.01
CL	55.79
WEIGHT LOSS ON HEATING	
70	0.06
TO 500	0.0
500+	3.31
TOTAL	98.74

MAJOR: HAL
MINOR: GLAUB, ANH
TRACE: POLY, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2948.0 FEET

SOLUBLE = 97.32 %
INSOLUBLE = 2.68 %

COMPONENT	WT %
SO3	5.34
NA	37.30
NA2O	0.0
K	0.01
K2O	0.01
MGO	0.03
CAO	0.79
SIO2	0.06
FE2O3	0.01
AL2O3	0.0
CL	55.51
WEIGHT LOSS ON HEATING	
70	0.20
150	0.02
450	0.02
500	0.02
TOTAL	99.32

MAJOR: HAL
MINOR: GLAUB, ANH
TRACE: LANG, TALC, QTZ, FEOX

Appendix 7.B (Ref. sec. 7.3)

Whole Rock Chemical Analyses in Soluble and

Insoluble Fractions & Moles times 1000

HOLE # 7
DEPTH = 1044.2 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.55	6.87
NA	38.56	1677.25
NA2O	0.0	0.0
K	0.03	0.77
K2O	0.0	0.0
MGO	0.04	0.99
CAO	0.43	7.67
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.40	1703.81

	HOLE # 7 DEPTH = 1107.5 FEET SOLUBLE 69.47 WT % OF TOTAL		HOLE # 7 DEPTH = 1107.5 FEET INSOLUBLE 30.53 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	9.24	115.41	11.63	145.27
NA	20.28	882.12	0.0	0.0
NA2O	0.0	0.0	6.63	106.97
K	0.0	0.0	0.0	0.0
K2O	3.70	39.28	0.77	8.17
MGO	2.24	55.57	2.33	57.80
CAO	1.61	28.71	0.23	4.10
SIO2	0.0	0.0	8.30	138.13
FE2O3	0.0	0.0	0.27	1.69
AL2O3	0.01	0.10	1.24	12.16
CL	30.78	868.26	0.0	0.0
SUBTOTAL	67.86 %		31.40 %	
MEASURED =	69.47		30.53	

	HOLE # 7 DEPTH = 1171.5 FEET SOLUBLE 37.10 WT % OF TOTAL		HOLE # 7 DEPTH = 1171.5 FEET INSOLUBLE 62.90 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	1.92	23.98	37.81	472.27
NA	12.56	546.32	0.0	0.0
NA2O	0.0	0.0	0.88	14.20
K	1.91	48.85	0.0	0.0
K2O	0.0	0.0	0.0	0.0
MGO	0.47	11.66	0.23	5.71
CAO	1.65	29.42	23.48	418.69
SIO2	0.01	0.17	0.62	10.32
FE2O3	0.0	0.0	0.06	0.38
AL2O3	0.0	0.0	0.0	0.0
CL	18.87	532.30	0.0	0.0
SUBTOTAL	37.39 %		63.08 %	
MEASURED =	37.10		62.90	

HOLE # 7
DEPTH = 1221.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	2.02	25.23
NA	38.79	1687.26
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.10	2.48
CAO	0.88	15.69
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.31	1644.85

HOLE # 7
DEPTH = 1343.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.99	12.37
NA	38.60	1678.99
NA2O	0.0	0.0
K	0.35	8.95
K2O	0.0	0.0
MGO	0.15	3.72
CAO	0.66	11.77
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.40	1675.60

HOLE # 7
DEPTH = 1402.5 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.11	1.37
NA	39.67	1725.53
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.06	1.49
CAO	0.02	0.36
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.78	1686.32

	HOLE # 7 DEPTH = 1468.5 FEET SOLUBLE 93.66 WT % OF TOTAL		HOLE # 7 DEPTH = 1468.5 FEET INSOLUBLE 6.34 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.98	12.24	1.89	23.61
NA	34.44	1498.04	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.37	9.46	0.0	0.0
K2O	0.0	0.0	0.07	0.74
MGO	0.52	12.90	1.32	32.75
CAO	0.18	3.21	0.01	0.18
SIO2	0.03	0.50	2.12	35.28
FE2O3	0.0	0.0	0.24	1.50
AL2O3	0.0	0.0	0.07	0.69
CL	53.61	1512.27	0.0	0.0
SUBTOTAL	90.13 %		5.72 %	
MEASURED =	93.66		6.34	

HOLE # 7
DEPTH = 1534.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	1.67	20.86
NA	36.10	1570.25
NA2O	0.0	0.0
K	0.52	13.30
K2O	0.0	0.0
MGO	0.22	5.46
CAO	0.64	11.41
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.76	1629.34

HOLE # 7
DEPTH = 1615.0 FEET

SOLUBLE
96.69 WT % OF TOTAL

HOLE # 7
DEPTH = 1615.0 FEET

INSOLUBLE
1.31 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	3.58	44.72	0.98	12.24
NA	35.06	1525.01	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	1.05	26.85	0.0	0.0
K2O	0.0	0.0	0.0	0.0
MGO	0.69	17.12	0.02	0.50
CAO	1.39	24.79	0.08	1.43
SIO2	0.03	0.50	0.21	3.49
FE2O3	0.0	0.0	0.03	0.19
AL2O3	0.0	0.0	0.07	0.69
CL	55.95	1578.28	0.0	0.0
SUBTOTAL	97.75 %		1.39 %	
MEASURED =	98.69		1.31	

	HOLE # 7 DEPTH = 1698.0 FEET SOLUBLE 95.35 WT % OF TOTAL		HOLE # 7 DEPTH = 1698.0 FEET INSOLUBLE 4.65 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.58	7.24	0.0	0.0
NA	36.47	1586.34	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.06	1.53	0.0	0.0
K2O	0.0	0.0	0.07	0.74
MGO	0.28	6.95	0.92	22.82
CAO	0.33	5.88	0.01	0.18
SIO2	0.04	0.67	2.03	33.78
FE2O3	0.0	0.0	0.25	1.57
AL2O3	0.0	0.0	0.61	5.98
CL	58.35	1645.98	0.0	0.0
SUBTOTAL	96.11 %		3.89 %	
MEASURED =	95.35		4.65	

HOLE # 7
DEPTH = 1755.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.65	8.12
NA	38.12	1658.11
NA2O	0.0	0.0
K	0.23	5.88
K2O	0.0	0.0
MGO	0.13	3.23
CAO	0.08	1.43
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.54	1679.55

HOLE # 7
DEPTH = 1952.5 FEET

SOLUBLE
99.30 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.03	37.85
NA	37.14	1615.49
NA2O	0.0	0.0
K	0.75	19.18
K2O	0.0	0.0
MGO	0.42	10.42
CAO	0.78	13.91
SIO2	0.01	0.17
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	57.00	1607.90
SUBTOTAL	99.14 %	
MEASURED =	99.30	

HOLE # 7
DEPTH = 1952.5 FEET

INSOLUBLE
0.70 WT % OF TOTAL

WT %	MOLES
0.15	1.87
0.0	0.0
0.0	0.0
0.0	0.0
0.03	0.32
0.12	2.98
0.01	0.18
0.33	5.49
0.02	0.13
0.05	0.49
0.0	0.0
0.71 %	
0.70	

	HOLE # 7 DEPTH = 1954.0 FEET SOLUBLE 97.46 WT % OF TOTAL		HOLE # 7 DEPTH = 1954.0 FEET INSOLUBLE 2.54 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.73	9.12	0.0	0.0
NA	37.94	1650.28	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.18	4.60	0.0	0.0
K2O	0.0	0.0	0.06	0.64
MGO	0.17	4.22	0.39	9.68
CAO	0.51	9.09	0.01	0.18
SIO2	0.02	0.33	1.33	22.13
FE2O3	0.0	0.0	0.09	0.56
AL2O3	0.0	0.0	0.23	2.26
CL	58.38	1646.83	0.0	0.0
SUBTOTAL	97.93 %		2.11 %	
MEASURED =	97.46		2.54	

HOLE # 7
DEPTH = 1957.5 FEET

COMPONENT	SOLUBLE 99.16 WT % OF TOTAL WT %	MOLES	INSOLUBLE 0.84 WT % OF TOTAL WT %	MOLES
SO3	1.32	16.49	0.41	5.12
NA	38.38	1669.42	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.36	9.21	0.0	0.0
K2O	0.0	0.0	0.01	0.11
MGO	0.24	5.95	0.17	4.22
CAO	2.18	38.87	0.0	0.0
SIO2	0.03	0.50	0.35	5.82
FE2O3	0.0	0.0	0.04	0.25
AL2O3	0.0	0.0	0.10	0.98
CL	59.00	1664.32	0.0	0.0
SUBTOTAL	101.51 %		1.08 %	
MEASURED =	99.16		0.84	

HOLE # 7
DEPTH = 1961.0 FEET

SOLUBLE
99.10 WT % OF TOTAL

HOLE # 7
DEPTH = 1961.0 FEET

INSOLUBLE
0.90 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.49	6.12	0.0	0.0
NA	39.14	1702.48	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.21	5.37	0.0	0.0
K2O	0.01	0.11	0.01	0.11
MGO	0.07	1.74	0.18	4.47
CAO	0.19	3.39	0.0	0.0
SIO2	0.01	0.17	0.42	6.99
FE2O3	0.0	0.0	0.04	0.25
AL2O3	0.0	0.0	0.08	0.78
CL	58.83	1659.52	0.0	0.0
SUBTOTAL	98.95 %		0.73 %	
MEASURED =	99.10		0.90	

HOLE # 7
DEPTH = 1967.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	3.03	37.85
NA	39.58	1721.62
NA2O	0.0	0.0
K	0.90	23.02
K2O	0.0	0.0
MGO	0.23	5.71
CAO	0.94	16.76
SIO2	0.0	0.0
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	58.74	1656.98

HOLE # 7
DEPTH = 1969.0 FEET

SOLUBLE
98.05 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.32	4.00
NA	38.76	1685.95
NA2O	0.0	0.0
K	0.08	2.05
K2O	0.0	0.0
MGO	0.11	2.73
CAO	0.08	1.43
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.60	1709.45
SUBTOTAL	99.96 %	
MEASURED =	98.05	

HOLE # 7
DEPTH = 1969.0 FEET

INSOLUBLE
1.95 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.11	2.73
0.0	0.0
0.14	2.33
0.02	0.13
0.04	0.39
0.0	0.0
0.31 %	
1.95	

HOLE # 7
DEPTH = 1973.0 FEET

SOLUBLE
98.63 WT % OF TOTAL

HOLE # 7
DEPTH = 1973.0 FEET

INSOLUBLE
1.37 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.26	3.25	0.0	0.0
NA	38.46	1672.90	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.06	1.53	0.0	0.0
K2O	0.0	0.0	0.03	0.32
MGO	0.13	3.23	0.40	9.92
CAO	0.06	1.07	0.01	0.18
SIO2	0.03	0.50	0.62	10.32
FE2O3	0.0	0.0	0.01	0.06
AL2O3	0.0	0.0	0.13	1.28
CL	59.58	1680.68	0.0	0.0
SUBTOTAL	98.58 %		1.20 %	
MEASURED =	98.63		1.37	

HOLE # 7
DEPTH = 1975.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.19	2.37
NA	38.93	1693.35
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.07	1.74
CAO	0.09	1.60
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.38	1703.24

HOLE # 7
DEPTH = 1978.5 FEET

SOLUBLE
91.07 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.74	34.22
NA	32.52	1414.53
NA2O	0.0	0.0
K	0.44	11.25
K2O	0.0	0.0
MGO	0.37	9.18
CAO	0.96	17.12
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	51.89	1463.75
SUBTOTAL	88.92 %	
MEASURED =	91.07	

HOLE # 7
DEPTH = 1978.5 FEET

INSOLUBLE
8.93 WT % OF TOTAL

WT %	MOLES
0.08	1.00
0.0	0.0
1.96	31.62
0.0	0.0
0.13	1.38
2.25	55.82
0.02	0.36
2.89	48.09
0.37	2.32
1.06	10.40
0.0	0.0
8.76 %	
8.93	

HOLE # 7
DEPTH = 1983.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	1.11	13.86
NA	36.00	1565.90
NA2O	0.0	0.0
K	0.61	15.60
K2O	0.0	0.0
MGO	0.40	9.92
CAO	0.46	8.20
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.20	1669.96

HOLE # 7
DEPTH = 1986.5 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.17	2.12
NA	38.20	1661.59
NA2O	0.0	0.0
K	0.04	1.02
K2O	0.0	0.0
MGO	0.03	0.74
CAO	0.21	3.74
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.66	1711.14

HOLE # 7
DEPTH = 1993.5 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	2.96	36.97
NA	38.25	1663.77
NA2O	0.0	0.0
K	1.68	42.97
K2O	0.0	0.0
MGO	0.79	19.60
CAO	2.30	41.01
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	53.81	1517.91

HOLE # 7
DEPTH = 2537.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	46.62	582.31
NA	0.93	40.45
NA2O	4.93	79.54
K	0.90	23.02
K2O	0.0	0.0
MGO	13.02	323.00
CAO	4.37	77.92
SIO2	13.98	232.65
FE2O3	1.13	7.08
AL2O3	3.26	31.97
CL	2.63	74.19

HOLE # 7
DEPTH = 2703.0 FEET

SOLUBLE
98.97 WT % OF TOTAL

HOLE # 7
DEPTH = 2703.0 FEET

INSOLUBLE
1.03 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.73	9.12	0.74	9.24
NA	38.36	1668.55	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.02	0.51	0.0	0.0
K2O	0.0	0.0	0.01	0.11
MGO	0.06	1.49	0.20	4.96
CAO	0.78	13.91	0.01	0.18
SIO2	0.04	0.67	0.21	3.49
FE2O3	0.01	0.06	0.05	0.31
AL2O3	0.0	0.0	0.05	0.49
CL	58.89	1661.21	0.0	0.0
SUBTOTAL	98.89 %		1.27 %	
MEASURED =	98.97		1.03	

HOLE # 7
DEPTH = 2716.3 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.44	5.50
NA	39.44	1715.53
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.18	3.21
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	61.00	1720.73

HOLE # 7
DEPTH = 2736.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.42	5.25
NA	39.75	1729.01
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.06	1.49
CAO	0.51	9.09
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.88	1689.14

HOLE # 8
DEPTH = 1391.5 FEET

SOLUBLE
98.99 WT % OF TOTAL

HOLE # 8
DEPTH = 1391.5 FEET

INSOLUBLE
1.01 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	1.07	13.36	0.07	0.87
NA	39.34	1711.18	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.31	7.93	0.0	0.0
K2O	0.0	0.0	0.02	0.21
MGO	0.21	5.21	0.06	1.49
CAO	0.52	9.27	0.01	0.18
SIO2	0.0	0.0	0.39	6.49
FE2O3	0.0	0.0	0.27	1.69
AL2O3	0.0	0.0	0.10	0.98
CL	58.07	1638.08	0.0	0.0
SUBTOTAL	99.52 %		0.92 %	
MEASURED =	98.99		1.01	

HOLE # 8
DEPTH = 1495.3 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	1.12	13.99
NA	38.00	1652.89
NA2O	0.0	0.0
K	0.12	3.07
K2O	0.0	0.0
MGO	0.13	3.23
CAO	1.62	28.89
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.97	1691.68

HOLE # 8
DEPTH = 1573.0 FEET

SOLUBLE
97.72 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.40	42.47
NA	34.63	1506.31
NA2O	0.0	0.0
K	0.18	4.60
K2O	0.0	0.0
MGO	1.65	40.93
CAO	0.29	5.17
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	54.11	1526.38
SUBTOTAL	94.26 %	
MEASURED =	97.72	

HOLE # 8
DEPTH = 1573.0 FEET

INSOLUBLE
2.28 WT % OF TOTAL

WT %	MOLES
1.71	21.36
0.0	0.0
0.0	0.0
0.0	0.0
0.02	0.21
0.06	1.49
0.16	2.85
0.02	0.33
0.0	0.0
0.01	0.10
0.0	0.0
1.98 %	
2.28	

HOLE # 8
DEPTH = 1652.0 FEET

SOLUBLE
48.61 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	19.80	247.31
NA	4.07	177.03
NA2O	0.0	0.0
K	18.59	475.45
K2O	0.0	0.0
MGO	4.12	102.21
CAO	0.19	3.39
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	7.35	207.33
SUBTOTAL	54.12 %	
MEASURED =	48.61	

HOLE # 8
DEPTH = 1652.0 FEET

INSOLUBLE
51.39 WT % OF TOTAL

WT %	MOLES
31.24	390.21
0.0	0.0
4.24	68.41
0.0	0.0
0.99	10.51
0.46	11.41
3.74	66.69
0.34	5.66
0.07	0.44
0.04	0.39
0.0	0.0
41.12 %	
51.39	

HOLE # 8
DEPTH = 1705.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	1.18	14.74
NA	38.79	1687.26
NA2O	0.0	0.0
K	0.35	8.95
K2O	0.0	0.0
MGO	0.17	4.22
CAO	0.44	7.85
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.64	1654.16

HOLE # 8
DEPTH = 1770.0 FEET

SOLUBLE
98.79 WT % OF TOTAL

HOLE # 8
DEPTH = 1770.0 FEET

INSOLUBLE
1.21 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	1.78	22.23	0.17	2.12
NA	35.75	1555.02	0.0	0.0
NA2O	0.0	0.0	0.33	5.32
K	0.56	14.32	0.0	0.0
K2O	0.0	0.0	0.02	0.21
MGO	0.52	12.90	0.03	0.74
CAO	1.75	31.21	0.0	0.0
SIO2	0.01	0.17	0.47	7.82
FE2O3	0.0	0.0	0.0	0.0
AL2O3	0.0	0.0	0.12	1.18
CL	57.29	1616.08	0.0	0.0
SUBTOTAL	97.66 %		1.14 %	
MEASURED =	98.79		1.21	

HOLE # 8
DEPTH = 1787.0 FEET

SOLUBLE
99.43 WT % OF TOTAL

HOLE # 8
DEPTH = 1787.0 FEET

INSOLUBLE
0.57 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	3.01	37.60	0.0	0.0
NA	37.24	1619.84	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.69	17.65	0.0	0.0
K2O	0.0	0.0	0.01	0.11
MGO	0.40	9.92	0.14	3.47
CAO	0.70	12.48	0.0	0.0
SIO2	0.01	0.17	0.21	3.49
FE2O3	0.0	0.0	0.03	0.19
AL2O3	0.0	0.0	0.04	0.39
CL	58.00	1636.11	0.0	0.0
SUBTOTAL	100.05 %		0.43 %	
MEASURED =	99.43		0.57	

HOLE # 8
DEPTH = 1794.5 FEET

SOLUBLE
75.34 WT % OF TOTAL

HOLE # 8
DEPTH = 1794.5 FEET

INSOLUBLE
24.66 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.70	8.74	0.0	0.0
NA	29.75	1294.04	0.0	0.0
NA2O	0.0	0.0	1.16	18.72
K	0.42	10.74	0.0	0.0
K2O	0.0	0.0	0.63	6.69
MGO	0.44	10.92	6.20	153.81
CAO	0.03	0.53	0.01	0.18
SIO2	0.02	0.33	7.78	129.47
FE2O3	0.0	0.0	0.46	2.88
AL2O3	0.0	0.0	1.91	18.73
CL	45.14	1273.34	0.0	0.0
SUBTOTAL	76.50 %		18.15 %	
MEASURED =	75.34		24.66	

HOLE # 8
DEPTH = 1804.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.28	3.50
NA	39.43	1715.09
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.04	0.99
CAO	0.70	12.48
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.94	1690.83

HOLE # 8
DEPTH = 1829.0 FEET

COMPONENT	SOLUBLE 99.03 WT % OF TOTAL WT %	MOLES	INSOLUBLE 0.97 WT % OF TOTAL WT %	MOLES
SO3	0.02	0.25	0.0	0.0
NA	39.87	1734.23	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.05	1.28	0.0	0.0
K2O	0.0	0.0	0.02	0.21
MGO	0.06	1.49	0.23	5.71
CAO	0.01	0.18	0.01	0.18
SIO2	0.01	0.17	0.29	4.83
FE2O3	0.0	0.0	0.04	0.25
AL2O3	0.0	0.0	0.08	0.78
CL	58.81	1658.96	0.0	0.0
SUBTOTAL	98.83 %		0.67 %	
MEASURED =	99.03		0.97	

HOLE # 8
DEPTH = 1838.0 FEET

SOLUBLE
97.53 WT % OF TOTAL

HOLE # 8
DEPTH = 1838.0 FEET

INSOLUBLE
2.47 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.80	9.99	0.0	0.0
NA	37.58	1634.62	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.26	6.65	0.0	0.0
K2O	0.0	0.0	0.10	1.06
MGO	0.11	2.73	0.37	9.18
CAO	0.05	0.89	0.0	0.0
SIO2	0.01	0.17	0.12	2.00
FE2O3	0.0	0.0	0.16	1.00
AL2O3	0.0	0.0	0.27	2.65
CL	58.38	1646.83	0.0	0.0
SUBTOTAL	97.19 %		1.02 %	
MEASURED =	97.53		2.47	

HOLE # 8
DEPTH = 1856.7 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	2.70	33.72
NA	36.08	1569.38
NA2O	0.0	0.0
K	1.62	41.43
K2O	0.0	0.0
MGO	0.03	0.74
CAO	1.56	27.82
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	56.66	1598.31

HOLE # 8
DEPTH = 1875.0 FEET

SOLUBLE
70.94 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.42	5.25
NA	25.64	1115.27
NA2O	0.0	0.0
K	0.31	7.93
K2O	0.0	0.0
MGO	0.33	8.19
CAO	0.43	7.67
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	40.92	1154.30
SUBTOTAL	68.06 %	
MEASURED =	70.94	

HOLE # 8
DEPTH = 1875.0 FEET

INSOLUBLE
29.06 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
2.28	24.20
9.22	228.73
0.20	3.57
15.29	254.45
1.23	7.70
3.00	29.42
0.0	0.0
31.22 %	
29.06	

HOLE # 8
DEPTH = 1884.0 FEET

COMPONENT	SOLUBLE 80.58 WT % OF TOTAL WT %	MOLES	INSOLUBLE 19.42 WT % OF TOTAL WT %	MOLES
SO3	3.76	46.96	0.0	0.0
NA	27.10	1178.77	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	6.98	178.52	0.0	0.0
K2O	0.0	0.0	1.80	19.11
MGO	1.44	35.72	3.65	90.55
CAO	1.65	29.42	0.01	0.18
SIO2	0.01	0.17	9.01	149.94
FE2O3	0.0	0.0	0.60	3.76
AL2O3	0.0	0.0	1.99	19.52
CL	44.06	1242.88	0.0	0.0
SUBTOTAL	85.00 %		17.06 %	
MEASURED =	80.58		19.42	

HOLE # 8
DEPTH = 1890.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.77	9.62
NA	38.78	1686.82
NA2O	0.0	0.0
K	0.10	2.56
K2O	0.0	0.0
MGO	0.10	2.48
CAO	0.95	16.94
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.33	1673.62

HOLE # 8
DEPTH = 1894.3 FEET

SOLUBLE
95.43 WT % OF TOTAL

HOLE # 8
DEPTH = 1894.3 FEET

INSOLUBLE
4.57 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.12	1.50	0.0	0.0
NA	37.90	1648.54	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.06	1.53	0.0	0.0
K2O	0.0	0.0	0.13	1.38
MGO	0.08	1.98	0.66	16.37
CAO	0.03	0.53	0.0	0.0
SIO2	0.0	0.0	2.43	40.44
FE2O3	0.0	0.0	0.20	1.25
AL2O3	0.0	0.0	0.43	4.22
CL	57.78	1629.90	0.0	0.0
SUBTOTAL	95.97 %		3.85 %	
MEASURED =	95.43		4.57	

HOLE # 8
DEPTH = 1898.5 FEET

SOLUBLE
98.53 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.55	6.87
NA	38.81	1688.13
NA2O	0.0	0.0
K	0.07	1.79
K2O	0.0	0.0
MGO	0.08	1.98
CAO	0.11	1.96
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.97	1635.26
SUBTOTAL	97.60 %	
MEASURED =	98.53	

HOLE # 8
DEPTH = 1898.5 FEET

INSOLUBLE
1.47 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.71	11.46
0.0	0.0
0.01	0.11
0.18	4.47
0.01	0.18
0.44	7.32
0.02	0.13
0.07	0.69
0.0	0.0
1.44 %	
1.47	

HOLE # 8
DEPTH = 1900.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	3.20	39.97
NA	38.14	1658.98
NA2O	0.0	0.0
K	0.98	25.06
K2O	0.0	0.0
MGO	0.47	11.66
CAO	0.39	6.95
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.60	1624.82

HOLE # 8
DEPTH = 1905.0 FEET

SOLUBLE
96.98 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.20	2.50
NA	38.67	1682.04
NA2O	0.0	0.0
K	0.13	3.32
K2O	0.0	0.0
MGO	0.10	2.48
CAO	0.44	7.85
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.91	1633.57
SUBTOTAL	97.45 %	
MEASURED =	96.98	

HOLE # 8
DEPTH = 1905.0 FEET

INSOLUBLE
3.02 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.03	0.32
0.83	20.59
0.01	0.18
0.91	15.14
0.14	0.88
0.25	2.45
0.0	0.0
2.17 %	
3.02	

HOLE # 8
DEPTH = 1910.0 FEET

SOLUBLE
99.02 WT % OF TOTAL

HOLE # 8
DEPTH = 1910.0 FEET

INSOLUBLE
0.98 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.53	6.62	0.0	0.0
NA	39.64	1724.23	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.0	0.0	0.0	0.0
K2O	0.29	3.08	0.01	0.11
MGO	0.10	2.48	0.20	4.96
CAO	0.44	7.85	0.0	0.0
SIO2	0.01	0.17	0.33	5.49
FE2O3	0.0	0.0	0.04	0.25
AL2O3	0.0	0.0	0.08	0.78
CL	59.04	1665.44	0.0	0.0
SUBTOTAL	100.05 %		0.66 %	
MEASURED =	99.02		0.98	

HOLE # 8
DEPTH = 1913.1 FEET

SOLUBLE
97.71 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.06	0.75
NA	38.48	1673.77
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.06	1.49
CAO	0.0	0.0
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.27	1671.93
SUBTOTAL	97.94 %	
MEASURED =	97.71	

HOLE # 8
DEPTH = 1913.1 FEET

INSOLUBLE
2.29 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.05	0.53
0.48	11.91
0.0	0.0
0.90	14.98
0.13	0.81
0.21	2.06
0.0	0.0
1.77 %	
2.29	

HOLE # 8
DEPTH = 1916.2 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.92	11.49
NA	38.48	1673.77
NA2O	0.0	0.0
K	0.21	5.37
K2O	0.0	0.0
MGO	0.13	3.23
CAO	0.44	7.85
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.71	1627.93

HOLE # 8
DEPTH = 1923.0 FEET

SOLUBLE
98.30 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.10	1.25
NA	38.03	1654.20
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.05	1.24
CAO	0.08	1.43
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.43	1648.24
SUBTOTAL	96.75 %	
MEASURED =	98.30	

HOLE # 8
DEPTH = 1923.0 FEET

INSOLUBLE
1.70 WT % OF TOTAL

WT %	MOLES
0.95	11.87
0.0	0.0
0.0	0.0
0.0	0.0
0.08	0.85
0.03	0.74
0.12	2.14
0.59	9.82
0.10	0.63
0.16	1.57
0.0	0.0
2.03 %	
1.70	

HOLE # 8
DEPTH = 1930.0 FEET

SOLUBLE
98.99 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.81	35.10
NA	35.71	1553.28
NA2O	0.0	0.0
K	1.03	26.34
K2O	0.0	0.0
MGO	0.33	8.19
CAO	0.19	3.39
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	56.74	1600.56
SUBTOTAL	96.81 %	
MEASURED =	98.99	

HOLE # 8
DEPTH = 1930.0 FEET

INSOLUBLE
1.01 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.08	1.29
0.0	0.0
0.01	0.11
0.13	3.23
0.01	0.18
0.18	3.00
0.07	0.44
0.04	0.39
0.0	0.0
0.52 %	
1.01	

HOLE # 8
DEPTH = 1933.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.78	9.74
NA	38.03	1654.20
NA2O	0.0	0.0
K	0.15	3.84
K2O	0.0	0.0
MGO	0.09	2.23
CAO	0.65	11.59
SIO2	0.01	0.17
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	59.81	1687.17

HOLE # 8
DEPTH = 1938.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	2.91	36.35
NA	35.63	1549.80
NA2O	0.0	0.0
K	0.68	17.39
K2O	0.0	0.0
MGO	0.84	20.84
CAO	1.02	18.19
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.45	1677.01

HOLE # 8
DEPTH = 1953.2 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	2.30	28.73
NA	39.50	1718.14
NA2O	0.0	0.0
K	0.30	7.67
K2O	0.0	0.0
MGO	0.42	10.42
CAO	1.23	21.93
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.63	1625.67

HOLE # 8
DEPTH = 1967.0 FEET

SOLUBLE
95.13 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.25	15.61
NA	35.99	1565.46
NA2O	0.0	0.0
K	0.57	14.58
K2O	0.0	0.0
MGO	0.23	5.71
CAO	0.40	7.13
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.52	1622.57
SUBTOTAL	95.96 %	
MEASURED =	95.13	

HOLE # 8
DEPTH = 1967.0 FEET

INSOLUBLE
4.87 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
2.73	44.05
0.0	0.0
0.09	0.96
0.98	24.31
0.0	0.0
0.76	12.65
0.10	0.63
0.20	1.96
0.0	0.0
4.86 %	
4.87	

HOLE # 8
DEPTH = 1986.0 FEET

SOLUBLE
36.72 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	22.99	287.16
NA	0.36	15.66
NA2O	0.0	0.0
K	0.0	0.0
K2O	14.68	155.84
MGO	0.62	15.38
CAO	0.87	15.51
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	0.15	4.23
SUBTOTAL	39.67 %	
MEASURED =	36.72	

HOLE # 8
DEPTH = 1986.0 FEET

INSOLUBLE
63.28 WT % OF TOTAL

	WT %	MOLES
	37.88	473.15
	0.0	0.0
	5.83	94.06
	0.0	0.0
	11.39	120.91
	1.20	29.77
	4.25	75.78
	0.54	8.99
	0.17	1.06
	0.85	8.34
	0.0	0.0
	62.11 %	
	63.28	

HOLE # 8
DEPTH = 2006.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	2.37	29.60
NA	37.59	1635.06
NA2O	0.0	0.0
K	1.03	26.34
K2O	0.0	0.0
MGO	0.31	7.69
CAO	0.06	1.07
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.17	1612.69

HOLE # 8
DEPTH = 2017.0 FEET

SOLUBLE
95.20 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.55	6.87
NA	35.66	1551.11
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.08	1.98
CAO	0.96	17.12
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.09	1610.44
SUBTOTAL	94.42 %	
MEASURED =	95.20	

HOLE # 8
DEPTH = 2017.0 FEET

INSOLUBLE
4.80 WT % OF TOTAL

WT %	MOLES
0.07	0.87
0.0	0.0
0.0	0.0
0.0	0.0
0.04	0.42
0.44	10.92
0.06	1.07
2.01	33.45
0.28	1.75
0.70	6.87
0.0	0.0
3.60 %	
4.80	

HOLE # 8
DEPTH = 2039.0 FEET

SOLUBLE
98.94 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	4.88	60.95
NA	35.02	1523.27
NA2O	0.0	0.0
K	1.56	39.90
K2O	0.0	0.0
MGO	0.50	12.40
CAO	1.57	28.00
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	54.01	1523.55
SUBTOTAL	97.54 %	
MEASURED =	98.94	

HOLE # 8
DEPTH = 2039.0 FEET

INSOLUBLE
1.06 WT % OF TOTAL

WT %	MOLES
0.62	7.74
0.0	0.0
0.0	0.0
0.0	0.0
0.03	0.32
0.21	5.21
0.01	0.18
0.26	4.33
0.07	0.44
0.05	0.49
0.0	0.0
1.25 %	
1.06	

HOLE # 8
DEPTH = 2050.0 FEET

SOLUBLE
28.61 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.92	48.96
NA	8.00	347.98
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.02	0.50
CAO	0.55	9.81
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	12.44	350.92
SUBTOTAL	24.98 %	
MEASURED =	28.61	

HOLE # 8
DEPTH = 2050.0 FEET

INSOLUBLE
71.39 WT % OF TOTAL

WT %	MOLES
51.08	638.02
0.0	0.0
4.90	79.06
0.0	0.0
0.04	0.42
0.29	7.19
6.55	116.80
0.33	5.49
0.0	0.0
0.0	0.0
0.0	0.0
63.19 %	
71.39	

HOLE # 8
DEPTH = 2068.0 FEET

SOLUBLE
98.84 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.49	31.10
NA	37.41	1627.23
NA2O	0.0	0.0
K	0.08	2.05
K2O	0.0	0.0
MGO	0.03	0.74
CAO	0.87	15.51
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	55.99	1579.41
SUBTOTAL	96.89 %	
MEASURED =	98.84	

HOLE # 8
DEPTH = 2068.0 FEET

INSOLUBLE
1.16 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.28	6.95
0.02	0.36
0.37	6.16
0.05	0.31
0.07	0.69
0.0	0.0
0.80 %	
1.16	

HOLE # 8
DEPTH = 2084.0 FEET

SOLUBLE
92.00 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.05	25.61
NA	34.46	1498.91
NA2O	0.0	0.0
K	1.02	26.09
K2O	0.0	0.0
MGO	0.35	8.68
CAO	0.72	12.84
SIO2	0.01	0.17
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	52.19	1472.21
SUBTOTAL	90.81 %	
MEASURED =	92.00	

HOLE # 8
DEPTH = 2084.0 FEET

INSOLUBLE
8.00 WT % OF TOTAL

WT %	MOLES
0.59	7.37
0.0	0.0
1.87	30.17
0.0	0.0
0.19	2.02
1.13	28.03
0.01	0.18
2.07	34.45
0.24	1.50
0.37	3.63
0.0	0.0
6.47 %	
8.00	

HOLE # 8
DEPTH = 2130.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	2.31	28.85
NA	37.79	1643.76
NA2O	0.0	0.0
K	0.42	10.74
K2O	0.0	0.0
MGO	0.25	6.20
CAO	0.75	13.37
SIO2	0.03	0.50
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.16	1612.41

HOLE # 8
DEPTH = 2162.0 FEET

SOLUBLE
98.90 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.31	16.36
NA	36.77	1599.39
NA2O	0.0	0.0
K	1.23	31.46
K2O	0.0	0.0
MGO	0.45	11.16
CAO	0.93	16.58
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.99	1692.24
SUBTOTAL	100.68 %	
MEASURED =	98.90	

HOLE # 8
DEPTH = 2162.0 FEET

INSOLUBLE
1.10 WT % OF TOTAL

WT %	MOLES
0.25	3.12
0.0	0.0
0.55	8.87
0.0	0.0
0.03	0.32
0.20	4.96
0.01	0.18
0.23	3.83
0.06	0.38
0.05	0.49
0.0	0.0
1.38 %	
1.10	

HOLE # 8
DEPTH = 2217.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.0	0.0
NA	39.14	1702.48
NA2O	0.0	0.0
K	0.07	1.79
K2O	0.0	0.0
MGO	0.02	0.50
CAO	0.12	2.14
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.75	1685.47

HOLE # 8
DEPTH = 2280.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.39	4.87
NA	37.91	1648.98
NA2O	0.0	0.0
K	0.12	3.07
K2O	0.0	0.0
MGO	0.09	2.23
CAO	0.25	4.46
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.23	1699.01

HOLE # 8
DEPTH = 2326.0 FEET

INSOLUBLE
4.56 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.0	0.0
NA	0.0	0.0
NA2O	0.0	0.0
K	0.0	0.0
K2O	0.03	0.32
MGO	1.31	32.50
CAO	0.03	0.53
SIO2	1.14	18.97
FE2O3	0.12	0.75
AL2O3	0.25	2.45
CL	0.0	0.0
SUBTOTAL	2.88 %	
MEASURED =	4.56	

	HOLE # 8 DEPTH = 2366.3 FEET SOLUBLE 31.37 WT % OF TOTAL		HOLE # 8 DEPTH = 2366.3 FEET INSOLUBLE 68.63 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	16.19	202.22	31.13	388.83
NA	0.62	26.97	0.0	0.0
NA2O	0.0	0.0	3.76	60.66
K	0.0	0.0	0.0	0.0
K2O	7.47	79.30	3.19	33.86
MGO	2.77	68.72	3.63	90.05
CAO	0.16	2.85	3.21	57.24
SIO2	0.01	0.17	10.67	177.57
FE2O3	0.0	0.0	0.01	0.06
AL2O3	0.0	0.0	1.57	15.40
CL	1.17	33.00	0.0	0.0
SUBTOTAL	28.39 %		57.17 %	
MEASURED =	31.37		68.63	

HOLE # 8
DEPTH = 2427.5 FEET

SOLUBLE
99.36 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.22	27.73
NA	39.42	1714.66
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.31	5.53
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.88	1689.14
SUBTOTAL	101.85 %	
MEASURED =	99.36	

HOLE # 8
DEPTH = 2427.5 FEET

INSOLUBLE
0.64 WT % OF TOTAL

WT %	MOLES
0.36	4.50
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.04	0.99
0.04	0.71
0.09	1.50
0.01	0.06
0.01	0.10
0.0	0.0
0.56 %	
0.64	

HOLE # 8
DEPTH = 2460.0 FEET

SOLUBLE
99.21 WT % OF TOTAL

HOLE # 8
DEPTH = 2460.0 FEET

INSOLUBLE
0.79 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	1.14	14.24	0.0	0.0
NA	38.75	1685.52	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.03	0.77	0.0	0.0
K2O	0.0	0.0	0.01	0.11
MGO	0.03	0.74	0.17	4.22
CAO	0.62	11.06	0.0	0.0
SIO2	0.0	0.0	0.19	3.16
FE2O3	0.0	0.0	0.03	0.19
AL2O3	0.0	0.0	0.06	0.59
CL	57.00	1607.90	0.0	0.0
SUBTOTAL	97.57 %		0.46 %	
MEASURED =	99.21		0.79	

HOLE # 8
DEPTH = 2519.6 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.17	2.12
NA	40.42	1758.16
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.03	0.53
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.31	1701.27

HOLE # 8
DEPTH = 2563.0 FEET

SOLUBLE
7.11 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.49	18.61
NA	1.47	63.94
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.07	1.74
CAO	0.60	10.70
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	1.05	29.62
SUBTOTAL	4.73 %	
MEASURED =	7.11	

HOLE # 8
DEPTH = 2563.0 FEET

INSOLUBLE
92.89 WT % OF TOTAL

	WT %	MOLES
SO3	39.10	488.38
NA	0.0	0.0
NA2O	6.06	97.77
K	0.0	0.0
K2O	0.54	5.73
MGO	14.66	363.68
CAO	23.77	423.86
SIO2	6.25	104.01
FE2O3	0.96	6.01
AL2O3	1.86	18.24
CL	0.0	0.0
SUBTOTAL	93.20 %	
MEASURED =	92.89	

HOLE # 8
DEPTH = 2615.5 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.86	10.74
NA	38.58	1678.12
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.02	0.50
CAO	0.58	10.34
SIO2	0.0	0.0
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	59.37	1674.75

HOLE # 8
DEPTH = 2665.5 FEET

SOLUBLE
99.08 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.98	12.24
NA	38.68	1682.47
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.35	6.24
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.14	1668.27
SUBTOTAL	99.19 %	
MEASURED =	99.08	

HOLE # 8
DEPTH = 2665.5 FEET

INSOLUBLE
0.92 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.21	5.21
0.01	0.18
0.22	3.66
0.04	0.25
0.06	0.59
0.0	0.0
0.55 %	
0.92	

HOLE # 8
DEPTH = 2706.0 FEET

SOLUBLE
98.75 WT % OF TOTAL

HOLE # 8
DEPTH = 2706.0 FEET

INSOLUBLE
1.25 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	1.12	13.99	0.01	0.12
NA	37.09	1613.31	0.0	0.0
NA2O	0.0	0.0	0.64	10.33
K	0.03	0.77	0.0	0.0
K2O	0.0	0.0	0.03	0.32
MGO	0.01	0.25	0.18	4.47
CAO	0.68	12.13	0.0	0.0
SIO2	0.01	0.17	0.27	4.49
FE2O3	0.0	0.0	0.27	1.69
AL2O3	0.0	0.0	0.07	0.69
CL	58.60	1653.03	0.0	0.0
SUBTOTAL	97.54 %		1.47 %	
MEASURED =	98.75		1.25	

HOLE # 8
DEPTH = 2758.0 FEET

SOLUBLE
99.22 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.70	21.23
NA	37.20	1618.10
NA2O	0.0	0.0
K	0.08	2.05
K2O	0.0	0.0
MGO	0.01	0.25
CAO	1.14	20.33
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.07	1638.08
SUBTOTAL	98.20 %	
MEASURED =	99.22	

HOLE # 8
DEPTH = 2758.0 FEET

INSOLUBLE
0.78 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.83	13.39
0.0	0.0
0.01	0.11
0.17	4.22
0.0	0.0
0.06	1.00
0.01	0.06
0.02	0.20
0.0	0.0
1.10 %	
0.78	

HOLE # 8
DEPTH = 2779.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	1.09	13.61
NA	37.41	1627.23
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.03	0.74
CAO	1.80	32.10
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.53	1651.06

HOLE # 8
DEPTH = 2794.0 FEET

TOTAL

COMPONENT	WT %	MOLES
SO3	0.99	12.37
NA	37.86	1646.80
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.68	12.13
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.58	1708.89

HOLE # 8
DEPTH = 2802.5 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	1.76	21.98
NA	38.39	1669.86
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.22	3.92
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.19	1641.47

HOLE # 8
DEPTH = 2809.0 FEET

SOLUBLE
99.09 WT % OF TOTAL

HOLE # 8
DEPTH = 2809.0 FEET

INSOLUBLE
0.91 WT % OF TOTAL

COMPONENT	WT %	MOLES	WT %	MOLES
SO3	2.02	25.23	0.0	0.0
NA	38.56	1677.25	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.01	0.26	0.0	0.0
K2O	0.0	0.0	0.01	0.11
MGO	0.01	0.25	0.03	0.74
CAO	0.96	17.12	0.13	2.32
SIO2	0.0	0.0	0.04	0.67
FE2O3	0.0	0.0	0.0	0.0
AL2O3	0.0	0.0	0.01	0.10
CL	59.70	1684.06	0.0	0.0
SUBTOTAL	101.26 %		0.22 %	
MEASURED =	99.09		0.91	

HOLE # 8
DEPTH = 2820.5 FEET

SOLUBLE
99.46 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.30	16.24
NA	38.42	1671.16
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.10	1.78
SIO2	0.03	0.50
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.50	1650.21
SUBTOTAL	98.37 %	
MEASURED =	99.46	

HOLE # 8
DEPTH = 2820.5 FEET

INSOLUBLE
0.54 WT % OF TOTAL

WT %	MOLES
0.37	4.62
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.25
0.19	3.39
0.03	0.50
0.0	0.0
0.0	0.0
0.0	0.0
0.60 %	
0.54	

HOLE # 8
DEPTH = 2879.0 FEET

SOLUBLE
96.41 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.17	27.10
NA	32.65	1420.18
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.59	10.52
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	55.79	1573.77
SUBTOTAL	91.25 %	
MEASURED =	96.41	

HOLE # 8
DEPTH = 2879.0 FEET

INSOLUBLE
3.59 WT % OF TOTAL

WT %	MOLES
1.97	24.61
0.0	0.0
0.93	15.00
0.0	0.0
0.01	0.11
0.12	2.98
0.95	16.94
0.12	2.00
0.01	0.06
0.01	0.10
0.0	0.0
4.12 %	
3.59	

HOLE # 8
DEPTH = 2948.0 FEET

SOLUBLE
97.32 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.41	42.59
NA	37.30	1622.45
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.54	9.63
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	55.51	1565.87
SUBTOTAL	96.79 %	
MEASURED =	97.32	

HOLE # 8
DEPTH = 2948.0 FEET

INSOLUBLE
2.68 WT % OF TOTAL

WT %	MOLES
1.92	23.98
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.02	0.50
0.25	4.46
0.05	0.83
0.01	0.06
0.0	0.0
0.0	0.0
2.26 %	
2.68	

Appendix 7.C (Ref. sec. 7.4)

Selected x-ray diffraction traces of EDTA-insoluble residues from the ERDA-9 core.

I-2. MB-CS-42: Serpentine and saponite; the sharp maxima at 12.2 and 24.5°2θ are basal spacings of serpentine's 7Å periodicity. The broad peak at 7.25°2θ (air-dried) becomes a broad weak shoulder at ∿5°2θ upon glycol saturation and is saponite.

A. <2μm EDTA-insoluble residue, air-dried.
B. Bulk EDTA-insoluble residue, glycol-saturated.

I-3. MB-CS-15: Talc and smectite (saponite); sharp peaks at 9.5 and 28.5°2θ are basal spacings of talc's 9.5Å periodicity; they do not shift with glycol-saturation. The broad low-angle peak again is saponite; accessory amounts of serpentine also present.

A. <2μm EDTA-insoluble residue, air-dried.
B. Bulk EDTA-insoluble residue, glycol-saturated.

I-4. MB-CS-17: Regularly interstratified mixed-layer chlorite-saponite (corrensite); distinct strong superlattice reflection at 2.9°2θ (air-dried) which expands to 2.7°2θ with glycol-saturation. The peak at 6.4°2θ (air-dried) expands to 5.6°2θ.

A. <2μm EDTA-insoluble residue, air-dried.
B. <2μm EDTA-insoluble residue, glycol-saturated.

I-5. JL-CS-9: Randomly interstratified mixed-layer chlorite-saponite; air-dried peak at 6.1°2θ expands to 5.5°2θ with glycol saturation. Illite (8.7, 17.6, and 26.6°2θ), minor serpentine (12.3 and 13.1°2θ), and minor feldspar (27.4°2θ) also present.

A. <2μm EDTA-insoluble residue, air-dried.
B. <2μm EDTA-insoluble residue, glycol-saturated.

I-6. MB-CS-13: Saponite; reflections at 6.1 and 27.3°2θ which expand to 5.2° 2θ upon glycol saturation. A small quantity of a regularly interstratified mixed-layer clay (small superlattice peak at 2.4°2θ) also present.

A. <2μm EDTA-insoluble residue, air-dried.
B. <2μm EDTA-insoluble residue, glycol saturated.

I-7. JL-CS-2: Randomly interstratified mixed-layer clay, either talc-saponite or illite-saponite; single strong maximum at 8.6°2θ becomes pronounced doublet at 9.6 and 7.6°2θ with glycol saturation.

A. <2μm EDTA-insoluble residue, air-dried.
B. <2μm EDTA-insoluble residue, glycol-saturated.

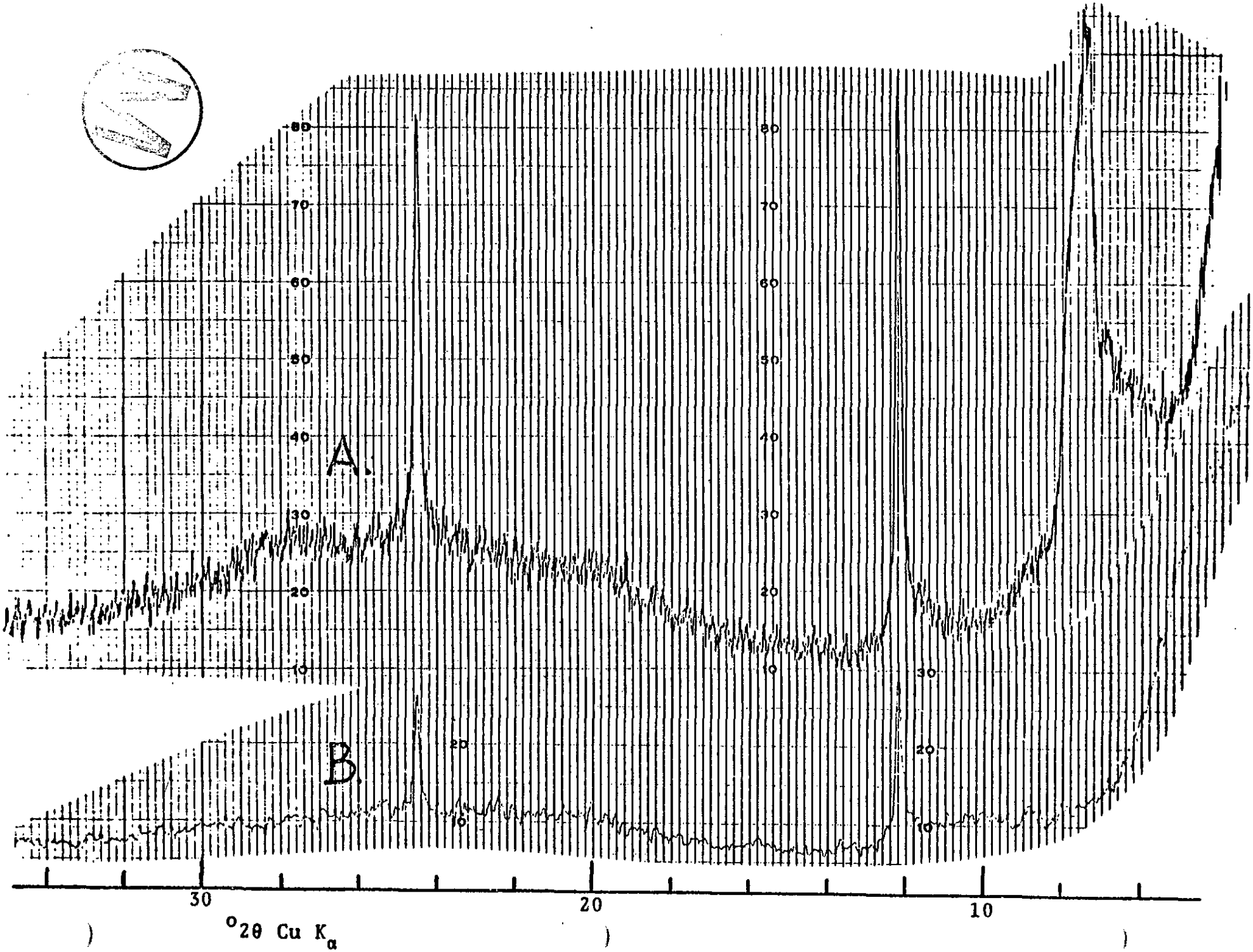
A
B
80
70
60
50
40
30
20
10
30
20
10
°2θ Cu Kα

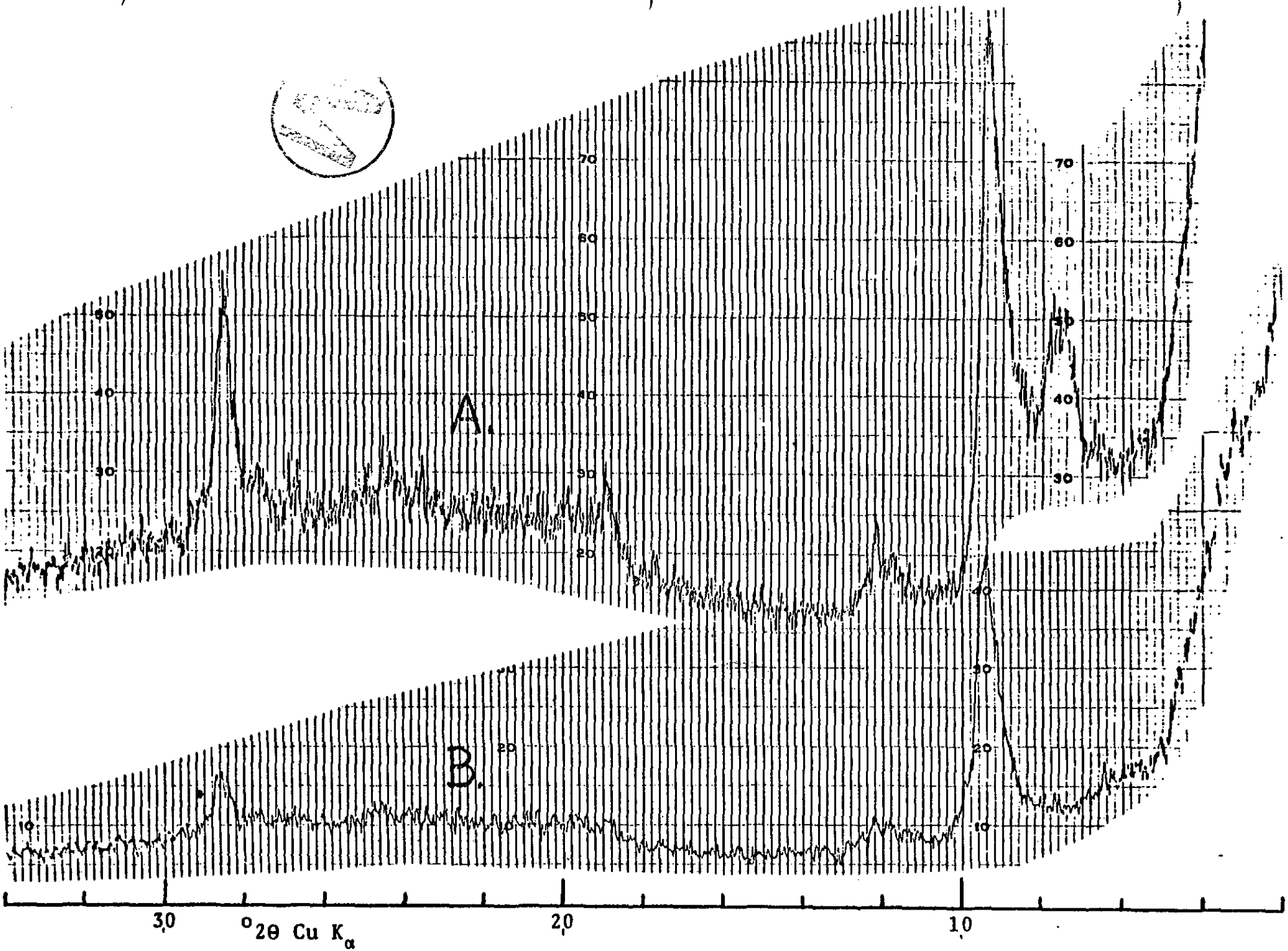
A.
B.
70
60
50
40
30
20
10
30
20
10
°2θ Cu Kα

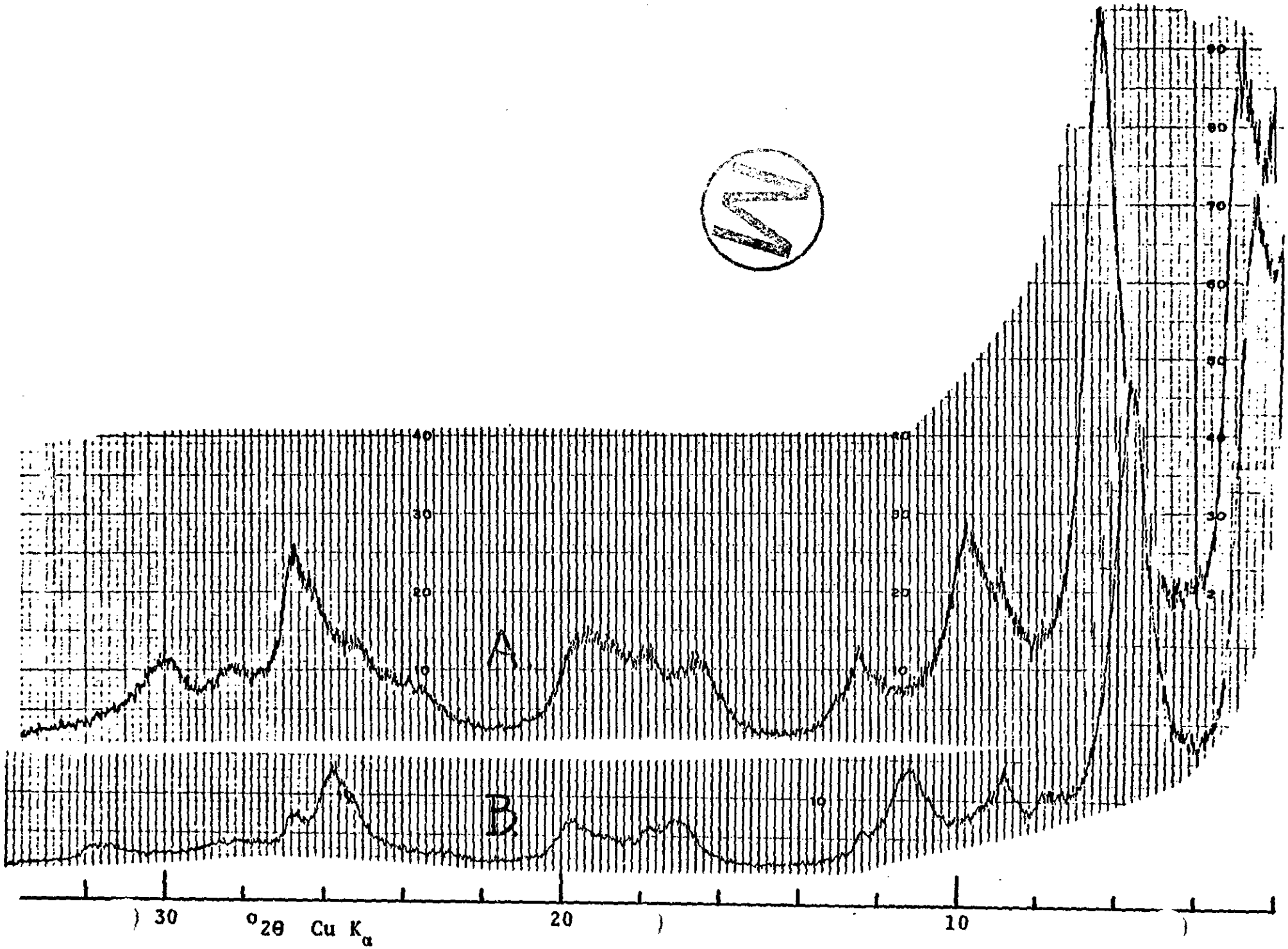
A
B
30
20
10
°2θ Cu Kα

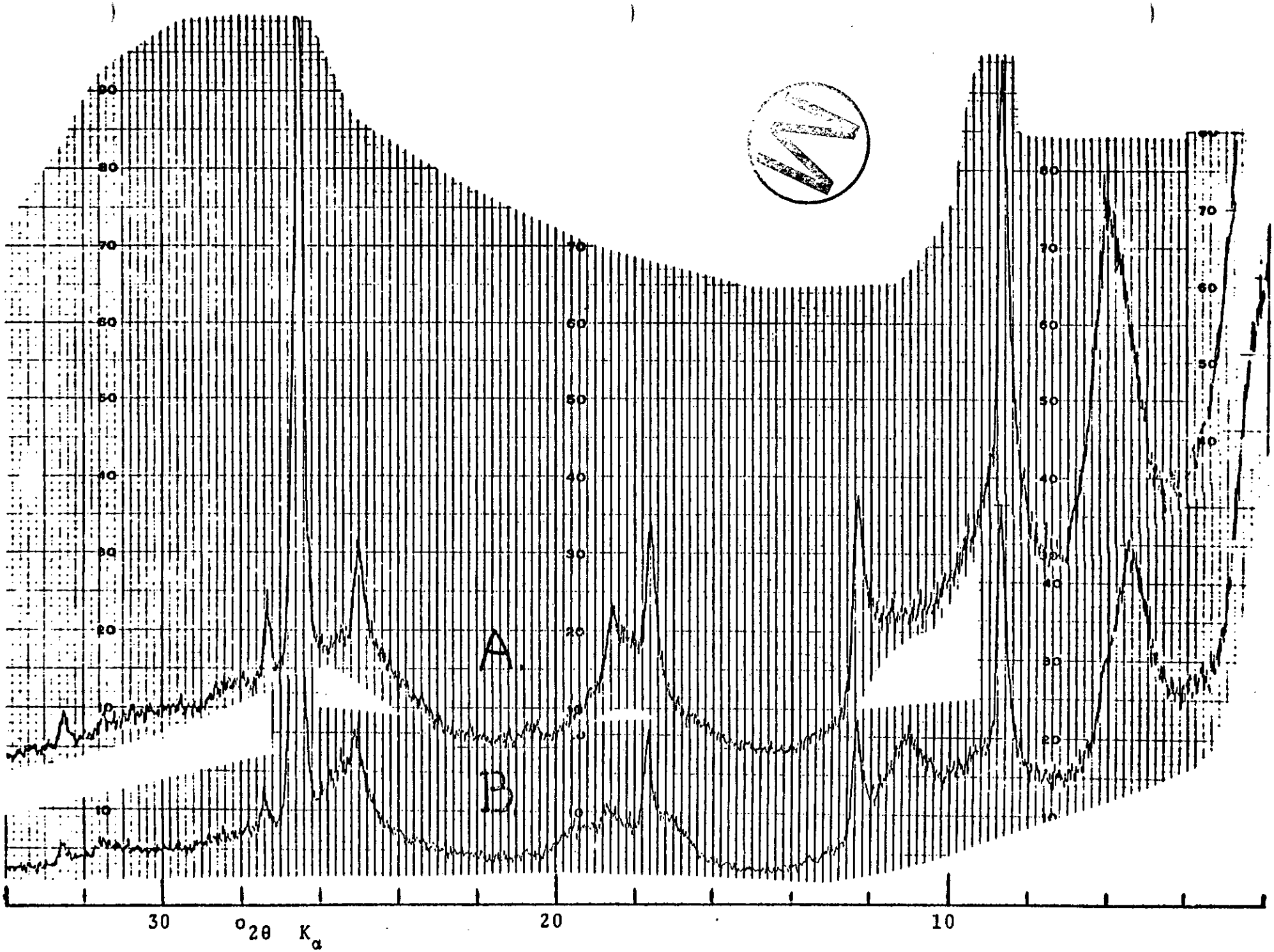
A
B
30
20
10
$^{o}2\theta$ K_{α}

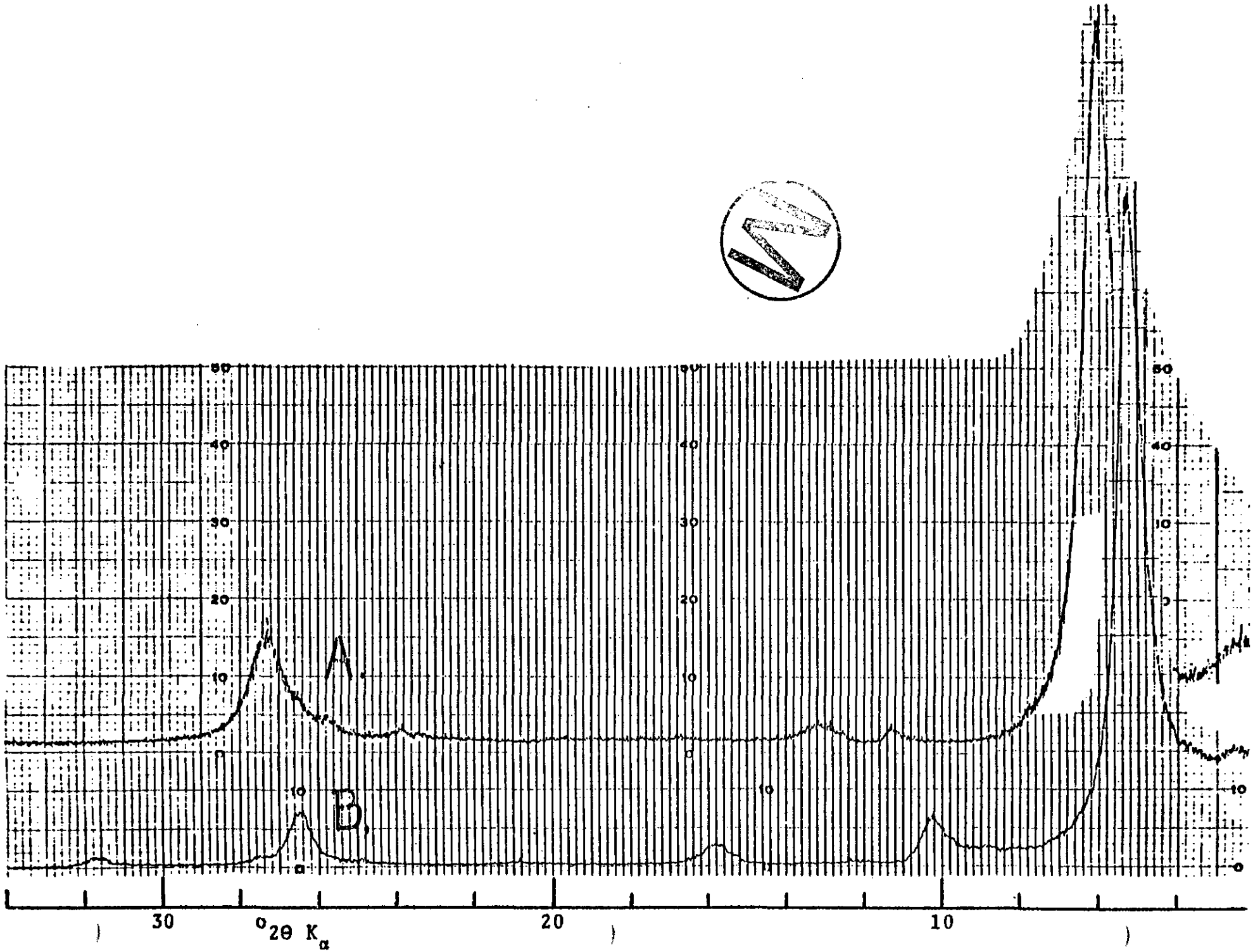
A
B
50
40
30
20
10
0
30
20
10
$^{o}2\theta$ K_{α}

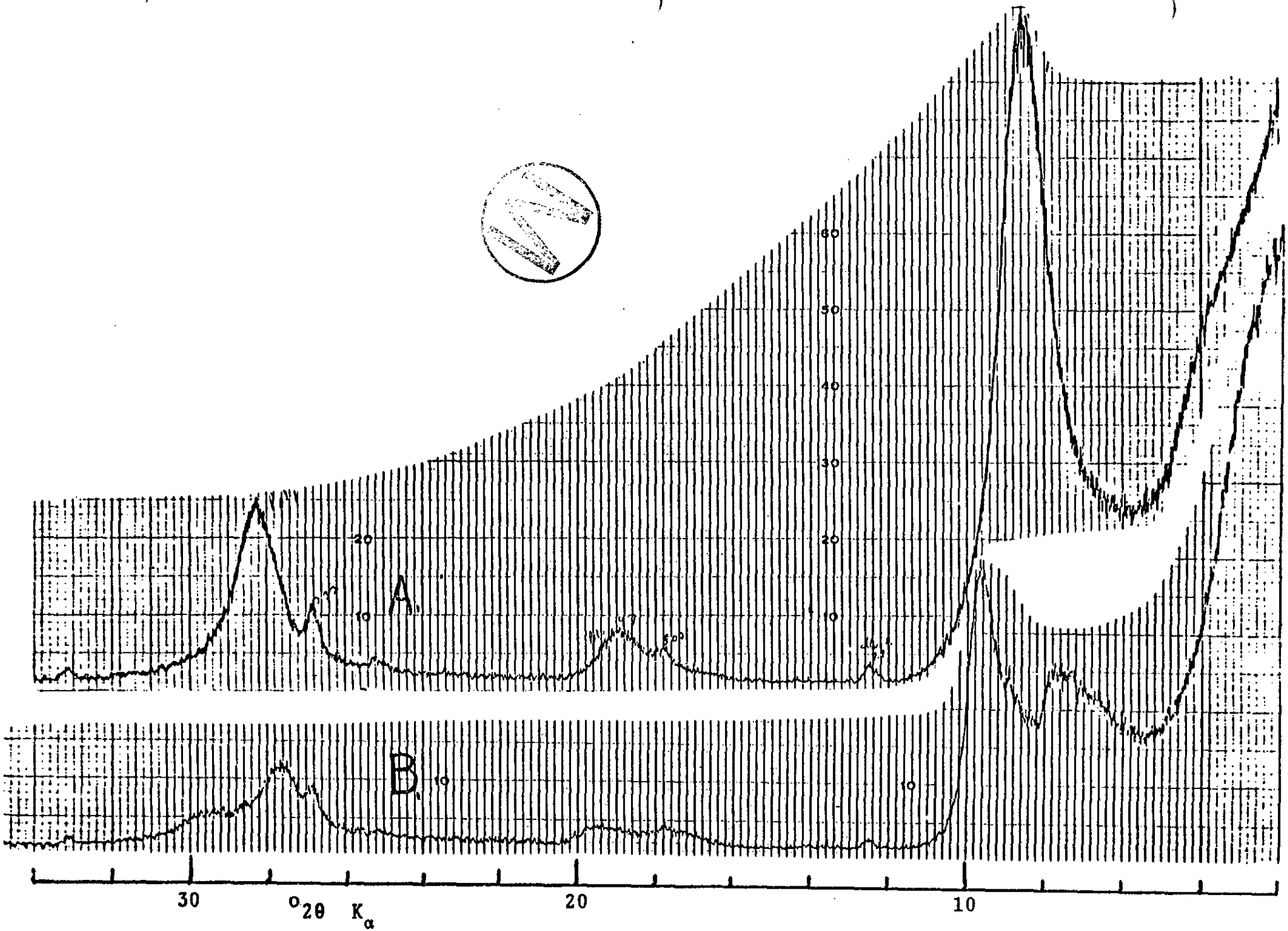
60
50
40
30
20
10
A
B
10
30
20
10
$^{o}2\theta$ K_{α}

APPENDIX 7.D (Ref. sec. 7.4)

Core Footage (Sandia Core Photo #), Informal Lithology and Detailed Macroscopic Core Description

FI in left column indicates abundant fluid inclusions.

† just to left of right column indicates description incorporates stratigraphic variation within that interval.

Abbreviations and Meanings used in Core Description (right column)

anhy or anhyd	anhydrite
ave	average
brwn	brown
dom	dominant
fg	fine grained or finely crystalline
inc	increasing
irreg	irregular
L	length
lams	laminae or laminations
lite or lt	light
loc	local or locally
max	maximum
repl	replacement
struc	structure
thk	thick or thickness
W	Width
w/	with
Xtals or Xtalline	crystals or crystalline
μX	microcrystalline

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
1162.7 (27) 1163.7	Halite	lite brwn, clear, anhedral Xtals (1cm), sharp Xtal boundaries of halite minor 1-4mm thk, lenses of lite gray, μX, anhydrite rimmed with polyhalite
1165.2 (28) 1166.6	Anhydrite w/ halite "crystal growth"	dominantly gray, μX anhydrite w/ slight color banding (gray-lite gray) with: lenses (1/2 to 1 cm thk.) of brown, clear to opaque, poorly defined anhedral Xtals of halite layers (1 to 4 cm thk) of vertically elongate (L/W=2 to 3, L=2mm to 3 1/2 cm), locally swallow-tail, Xtals of halite
1167.3 (28) 1168	Banded Anhydrite	banding of dominantly gray, μX anhydrite laminae (5-10mm thk) with white, thin (<1mm) laminae of μX magnesite locally a few anhedral (some swallow tail) Xtals of halite, locally vertically elongate or radiating
1168 (29) 1168.25	Anhydrite	similar to 1165.2 - 1166.6 but including laminae (~1mm thick) of magnesite
1168.25 (29) 1169.9	brick-red Polyhalite and Halite	dominantly anhedral (rare euhedral) 1/2 cm Xtals of halite, clear to cloudy with red, μX polyhalite between and in halite crystals
1172.6 (30) 1173.5	Banded Polyhalite	prominant banding but mineralogy obscure - "brown mineral" typically opaque, microcrystalline or massive halite, orange to orange brown poorly bounded anhedra ~1/2 cm - silty claystone or anhydrite? locally contorted banding

Core Footage (Sandia Phote #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
1173.5 (31) 1174.7	Halite	halite - clear to red, anhedral Xtals (ave 1/2 cm, max 2 cm) red from polyhalite stain; minor anhydrite
1404.7 (103) 1405.7	11th ore zone (leonite, kainite?)	polyhalite (± halite?) white & cloudy to blood red, massive w/ irreg. patches of dark gray claystone and irreg patches of pale yellow mineral (kainite-leonite?) massive patches are both vertically and horizontally elongate
1418 (106-107) 1418.8	Marker Bed 117, polyhalite plus mud	dominantly massive red polyhalite (w/ microscopic granular texture) laminations 1/2 to 1 1/2 cm thk alternating w/ clay laminae (<2mm thk) which are black & wavy [near 1418 - claystone w/ poor horizontal fissility plus "brown mineral" which looks like halite but has bitter taste]
1584 (160) 1584.9	5th ore zone, very dirty	dominantly halite - clear anhedra ~1 cm (max 2 cm) locally stained by "brown mineral" μXtalline coatings & locally patches a few mm in size; minor patches of gray μX anhydrite
1609.1 (168) 1610.3	Clear Halite (~2 ft above polyhalite)	dominantly halite - brwn (due to polyhalite stain?) indistinct anhedral about 1 1/2 cm; minor evenly dispersed polyhalite stain, and patches (~2mm) of gray material (anhydrite or clay?)
1632 (175) 1632.8	Mudstone	near top: banded anhydrite - claystone; anhydrite dark gray, μX - laminae up to 2mm thk, locally vertically elongate masses or Xtals; claystone lite grey, laminae from 1/2mm to 1/2 cm (thk inc. upward) near base: polyhalite w/ gray clay

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
1648.5 (180-181) 1649.7	4th ore zone halite, bloedite, vanthoffite	dominantly halite - lite brown anhedra ~3/4 cm locally red, μXtal polyhalite as stain & repl. of halite - some lenses and Xtal coatings of gray μX anhydrite?
2034.3 2037.3	Halite	↑ dominantly halite: finely crystalline & clayey near top - coarsely crystalline & banded anhydrite &/or polyhalite near center - finely crystalline & banded ↑ w/ anhydrite near base
2065.2 2067.6	Halite	dominantly coarsely Xtalline (~2 cm) clear, anhedral halite w/ patches, lenses & stains of "brown material" (polyhalite, carnallite, glauberite?) loc w/ radiating acicular texture
2301.6 (384) 2302.7	lite colored Polyhalite	dominantly red, μX polyhalite - locally crinkly flakes & irreg. patches of white fg. material
2413.6 FI (418-419) 2415.7	pure & impure Polyhalite	↑ dominantly poorly thickly banded polyhalite w/ sub-equal lenses of anhydrite & halite polyhalite: pinkish brown to red, μX halite: med. to coarsely Xtal, usually anhedral but some euhedra, typically clear anhydrite: layers, lenses and interXtalline patches, ↑ gray, μX, locally brown
2512 (450) 2512.5	dirty Halite	dominantly halite-gray, clear to cloudy, anhedral, 1 cm Xtal; minor light gray anhydrite as interXtalline patches.
2515.6 (452+) 2519.2	typical massive Cowden Anhy.	↑ (halite above 2516.9) faintly banded gray, μX, anhydrite w/ wispy lenses of magnesite ↑ very minor halite

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
2527.7 (456+) 2529.2	typical laminated Cowden Anhy.	laminations of gray, μX, anhydrite - lam up to 1 1/2 cm (some needle like & loc radiating into magnesite) white, opaque μX magnesite lams, wavy, <1mm to 3mm thk
2538.5 (459) 2539.4	base of Cowden Anhy.	top: faintly banded (color) μX anhydrite, minor patches of halite ↑ dominantly coarsely Xtalline (~1 cm) clear, anhedral halite w/ lenses & interXtalline anhydrite base: similar to middle but halite Xtal size decreases to ~1mm
2541 (460) 2542.5	dirty halite just below Cowden	dominantly halite - gray, clear to cloudy, anhedral Xtals (ave 1 cm, <1mm to 3 cm) minor anhydrite (or magnesite?) - interXtalline patches (1 or 2 cm by 2mm)
2606.5 2608.8	Halite	dominantly halite - typically clear but some cloudy, white to gray anhedra typically ~1 cm but three 3 cm thk zones of ave size ~2mm which tend to be gray; minor anhydrite - interXtalline gray, μX
2614.7 2615.6	Halite	dom. halite - clear white euhedra & subhedra, most anhedra, ave 2 cm (<1mm to 4 cm); minor anhydrite - lt gray to white, μX, interXtalline
2615.9 FI 2619.5	Halite	↑ 15.9 - 16.5 dom halite - clear, white to gray, anhedra, ave 2 cm (1/2 - 6 cm) w/ v minor gray-white, μX, interXtalline anhyd or magnesite 16.5 - 18.4 dom halite - clear to cloudy, white to gray anhedra, ave 1 cm (<1mm - 2 cm) locally "chevron struc" within (& across) Xtals w/ minor gray-white, μX, interXtalline anhyd or magnesite ↑ 18.4 - 19.5 similar to 15.9 - 16.5

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
(2705.7) 2704.8 (509) (2706.8) 2706.5	mottled Anhy & Halite	dominantly halite - coarsely Xtalline (1 to 1 1/2 cm) anhedral, clear to white cloudy cut at ~45° by zones more finely Xtalline halite and mixed w/ up to 30% interXtalline gray, μX, anhydrite (w/ minor magnesite)
2758 (526) 2759.3	dirty Halite	dom halite - light to dk gray, anhedra, ave ~1 cm (<1mm to 3 cm) w/ minor anhydrite - dk gray, μX (but some microlites) as interXtall material
2819.1 (545) 2819.8	clean Halite, slightly banded	dom halite - cloudy, white to lt. gray, anhedral; faint banding by ave Xtal size variation from 1/2 to 1 cm, finer Xtalline tends to be whiter; minor thin horizontal lenses (rare patches), white, μX (rare microlites)
2819.9 (545) 2820.9A	see above	dom anhydrite - lt gray to dk gray (locally banded), μX; subordinate halite - irreg lenses & patches (frequently thin & horiz elongate) unusually sharp contacts between anhydrite & halite
2820 B (545-546) 2820.6B	see above	same as 19.9 - 20.9A except anhydrite locally brown and may contain magnesite
2820.6B (546) 2821.9	see above	dom halite - cloudy, white, anhedral, ave 1 cm (<1mm to 2 cm); very rare lense of wh to lt gray, μX anhydrite possibly w/ magnesite
2826.5 2827.5	dirty Halite	dom halite - poorly developed banding from clear, to cloudy white, to opaque dk gray, anhedral crystals ave 1/2 - 1 cm some magnesite (or anhydrite) - thin irreg seams & wavy lams (both horiz), white, μX

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
2845.6 2846.4	massive light Anhydrite (in Castile)	dom anhydrite - mottled from clear to white & cloudy to gray to dk gray sub. magnesite - thin seams and irreg patches, μX
2847.8 2849.1	banded light Anhydrite	dom anhydrite - banded from clear, to white & cloudy, to gray to dk gray, to black; clear tends to occur in laminae & lenses, locally "enterolithic" contortions and w/ smooth lower contacts & irreg "swallow-tail" upper contacts; subordinate magnesite

Appendix 7.E (Ref. sec. 7.5)

Gas Chromatograms and Mass Spectra
of Volatiles from Selected Samples
of Core from ERDA No. 9

Mass spectra are reported as intensity (normalized to the highest mass peak) as a function of mass/charge ratio (in atomic mass units).
Gas chromatograms are reported as intensity of elution peaks (normalized to the highest elution peak) as a function of relative elution time (in arbitrary units).

SALT SAMPLE 2302.6

TOTAL ION CHROMATOGRAM X6

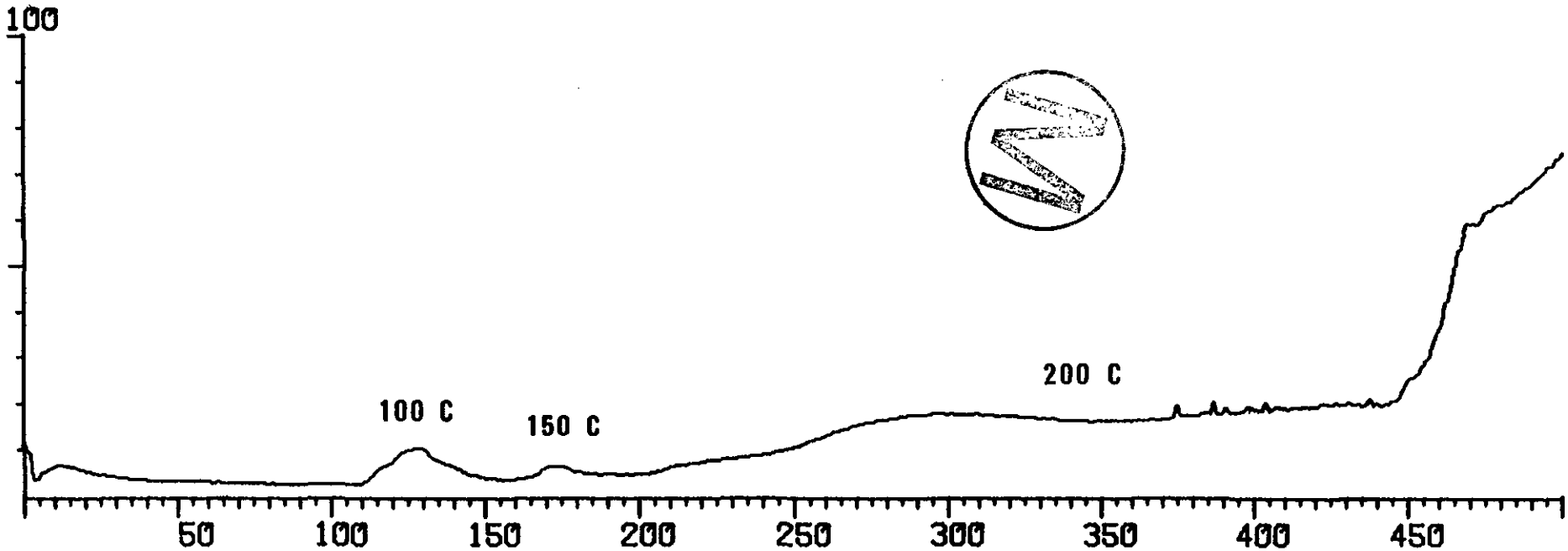

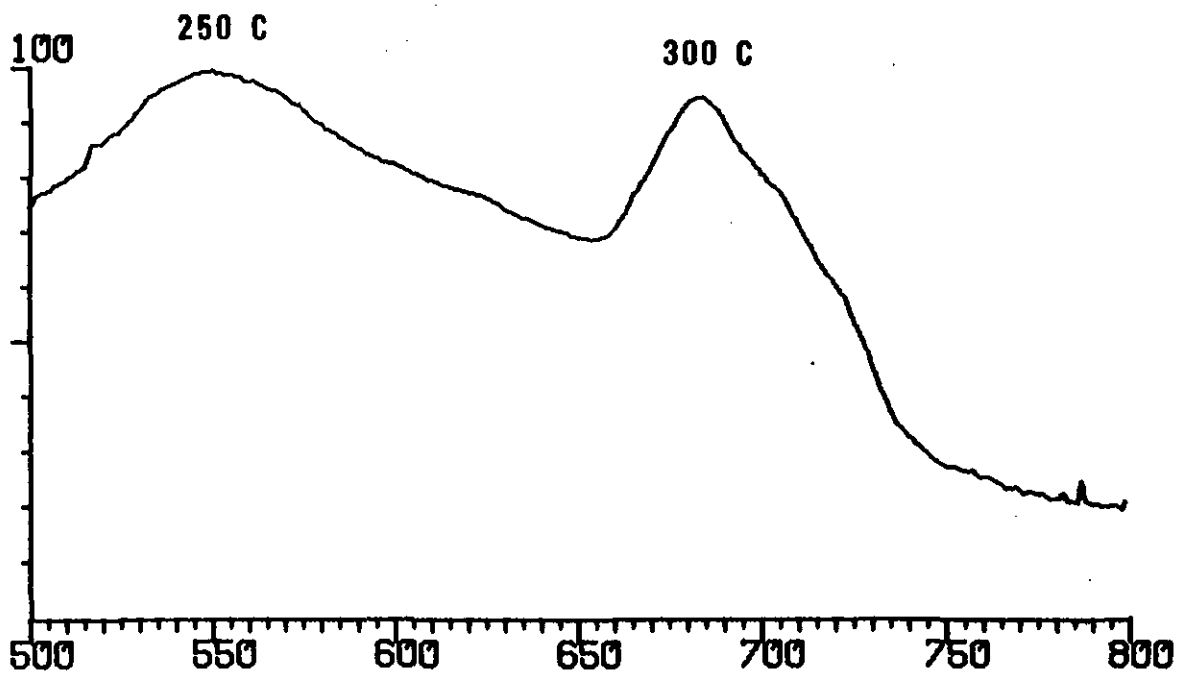

SALT SAMPLE 2302.6

12 MASS SPECTRA 50C X3

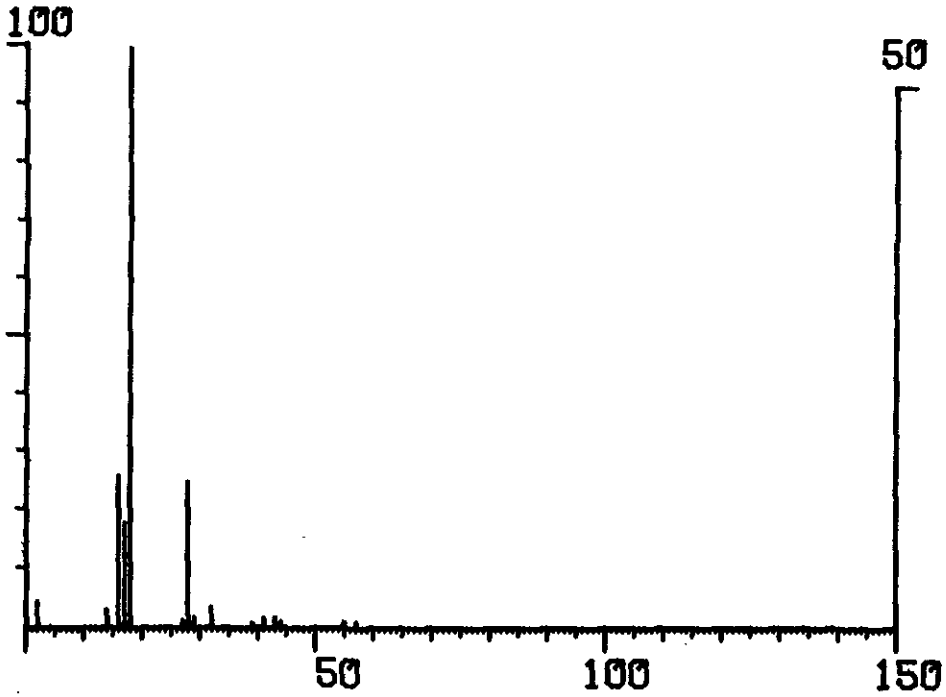

SALT SAMPLE 2302.6

128 MASS SPECTRA 100C X3

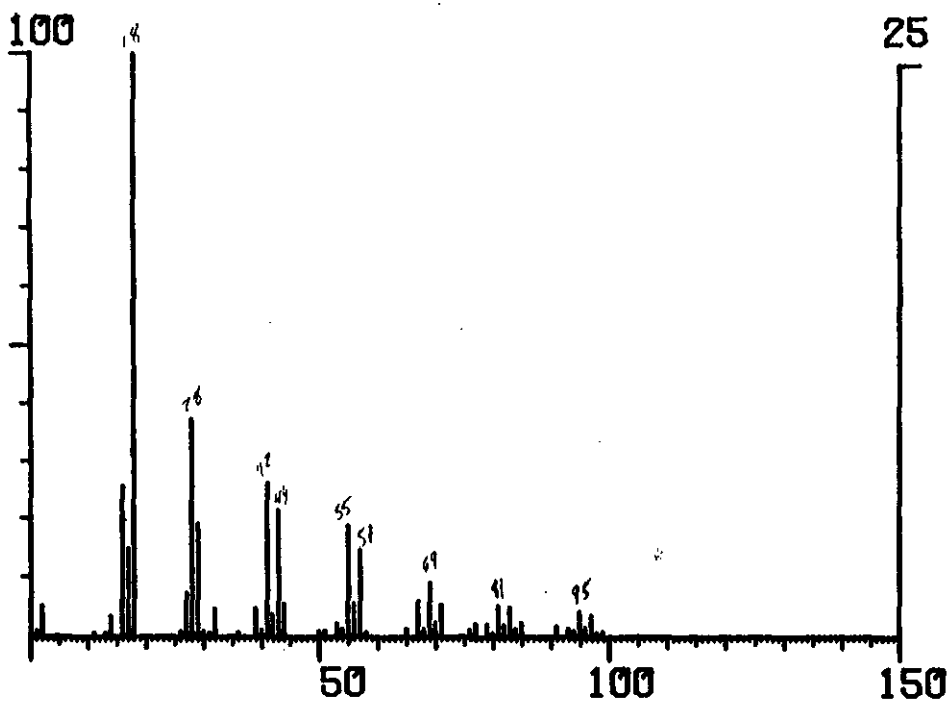

SALT SAMPLE 2302.6

\# 174 MASS SPECTRA 150C X3

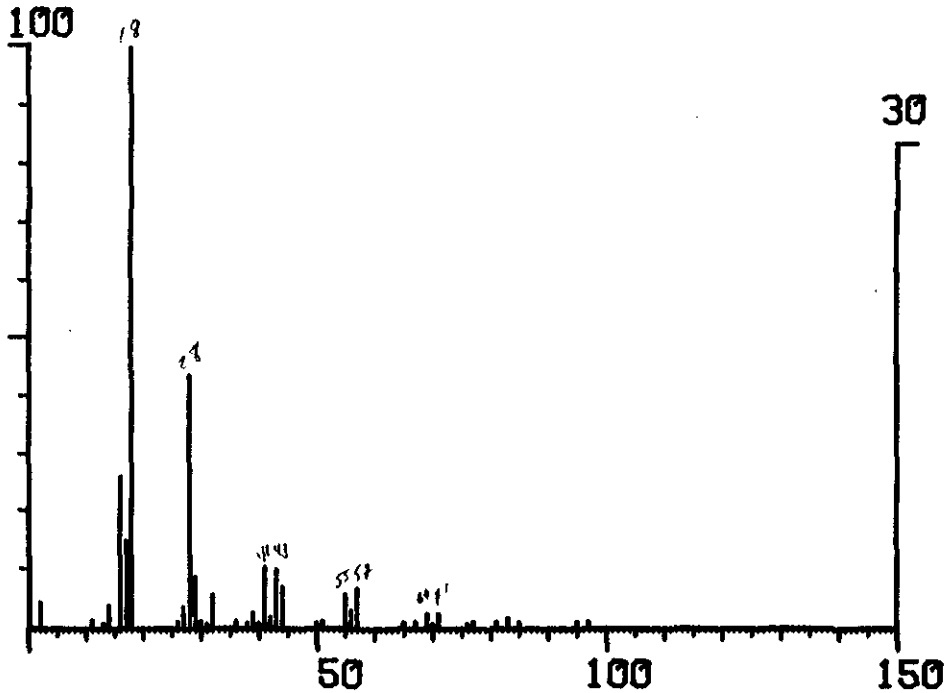

SALT SAMPLE 2302.6

\# 297 MASS SPECTRA 200C X4

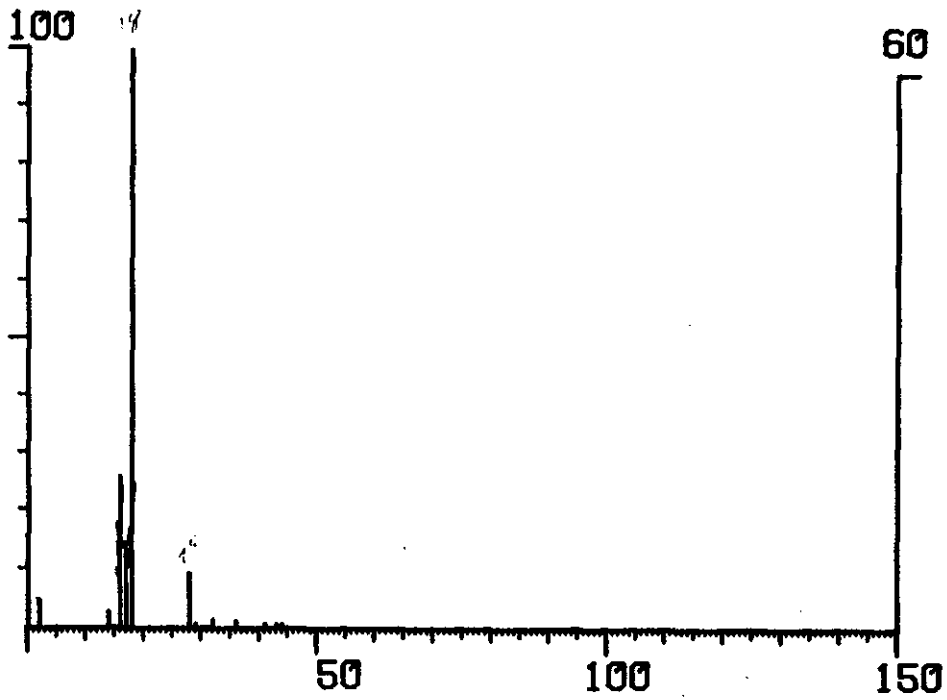

SALT SAMPLE 2302.6

550 MASS SPECTRA 250C X4

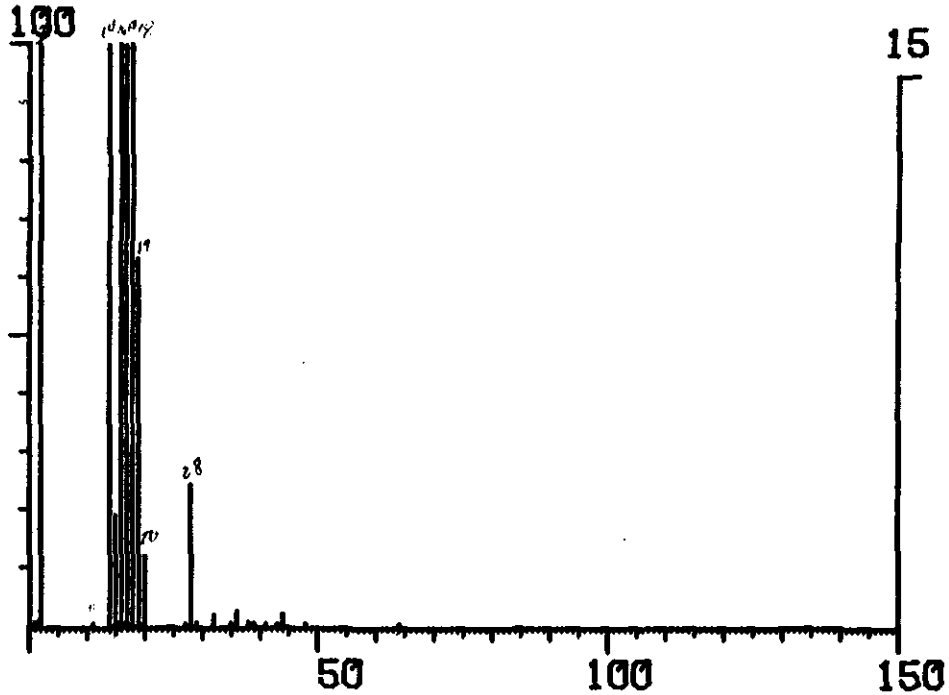

SALT SAMPLE 2302.6

686 MASS SPECTRA 300C X4

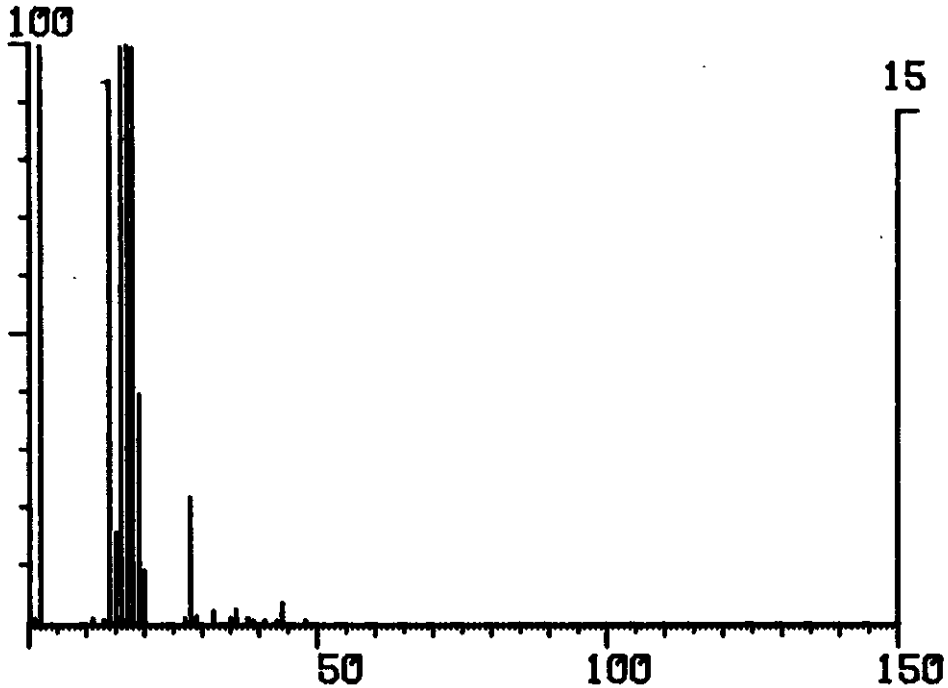

SALT SAMPLE 2302.6

MASS 14 SEARCH X5

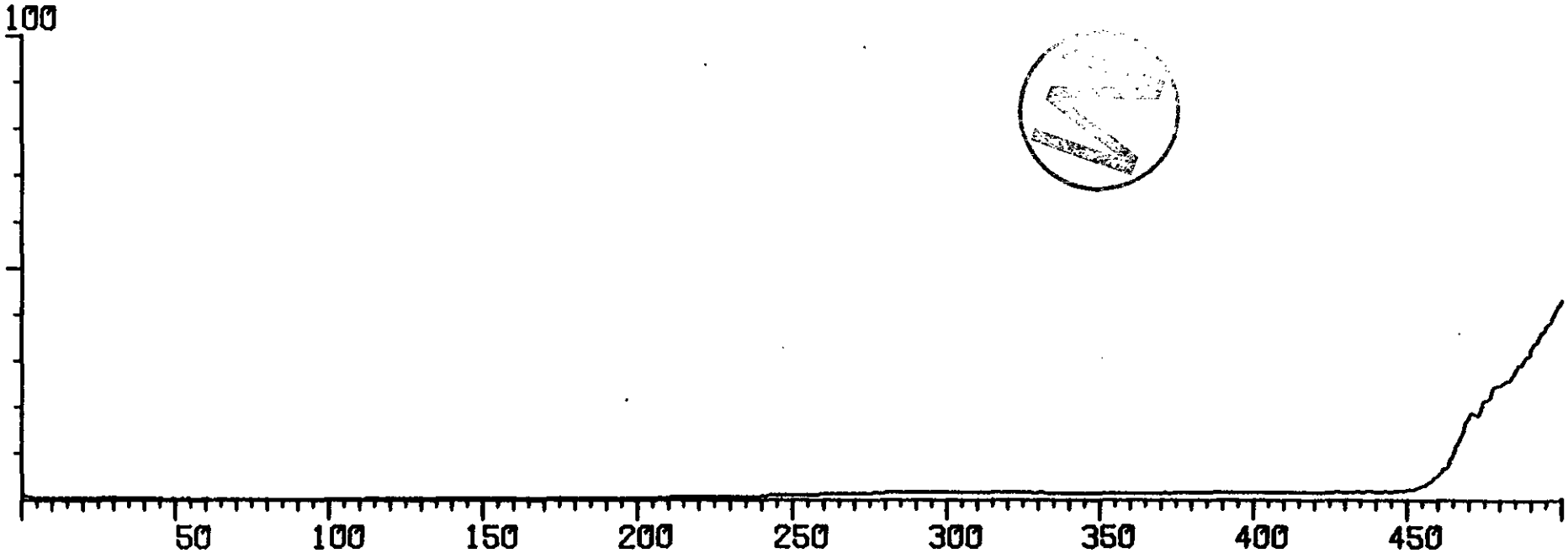

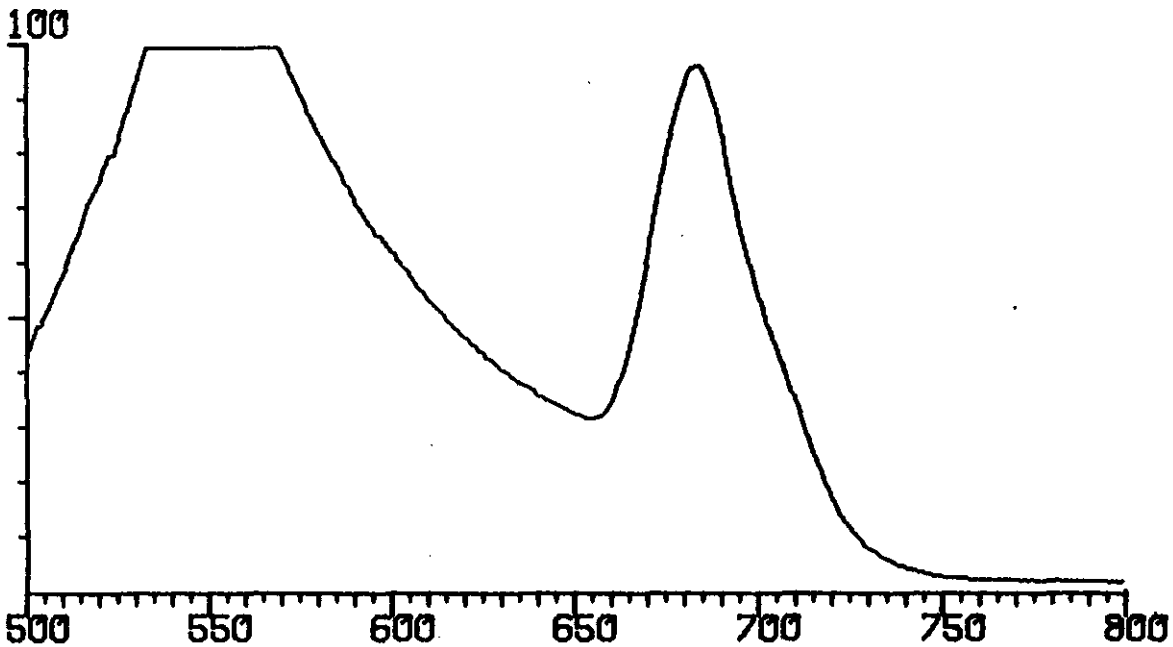

SALT SAMPLE 2302.6

MASS 18 SEARCH X4

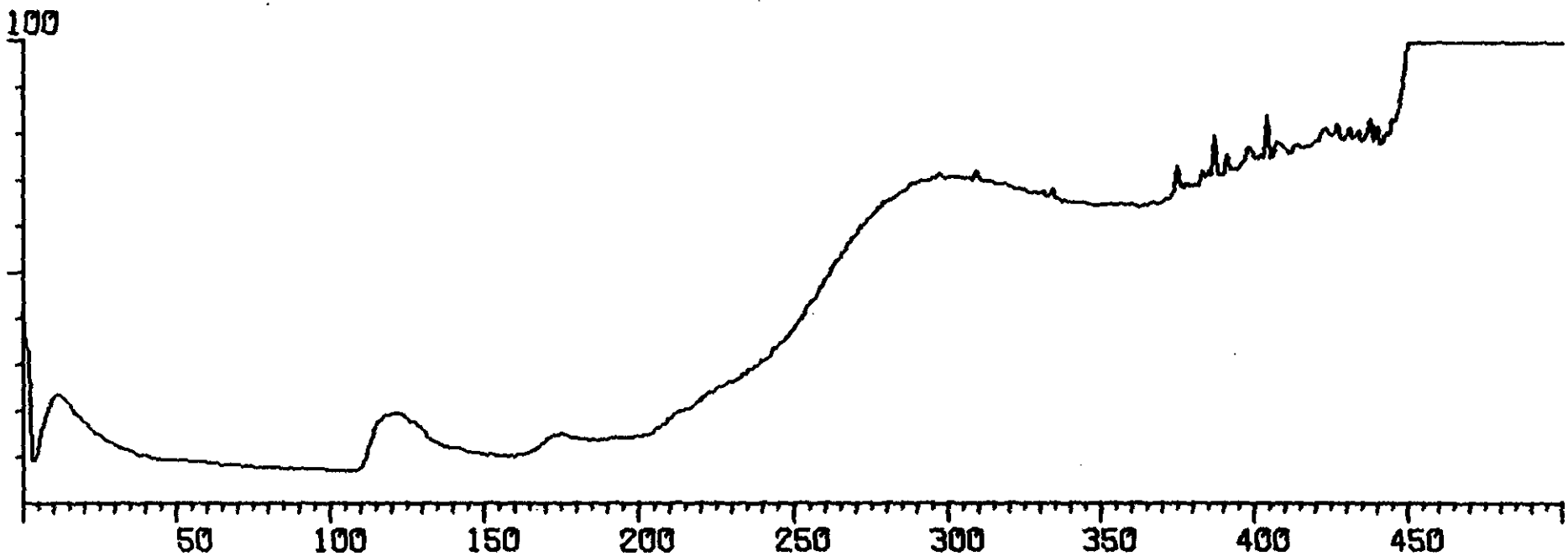

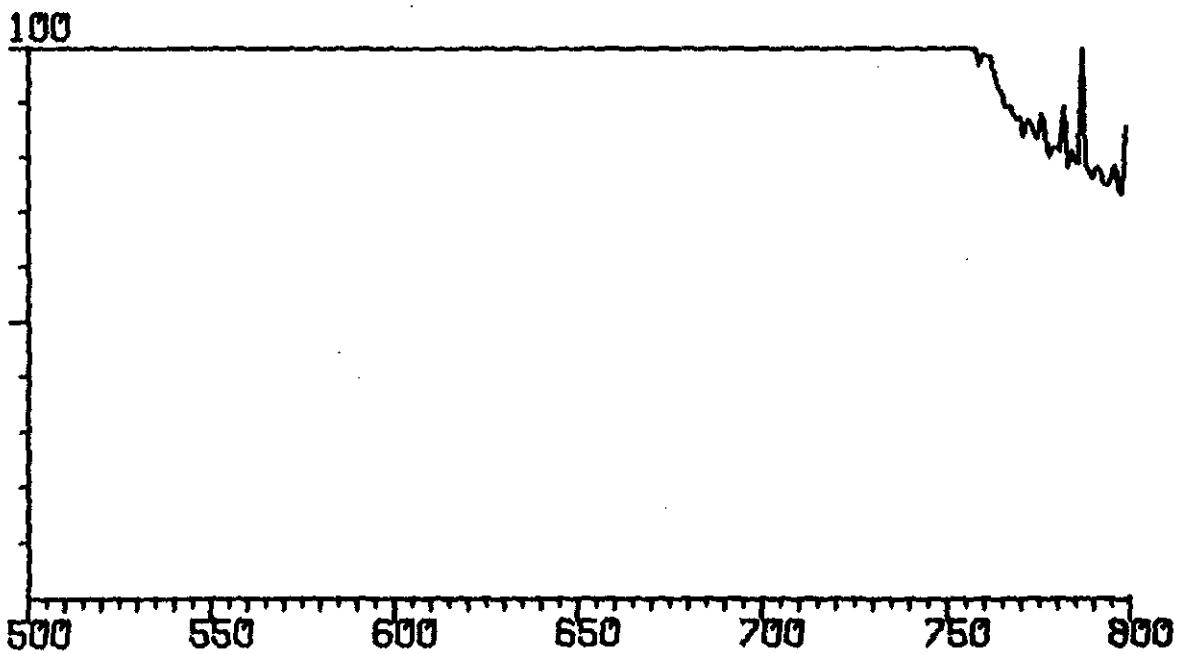

SALT SAMPLE 2302.6

MASS 19 SEARCH X4

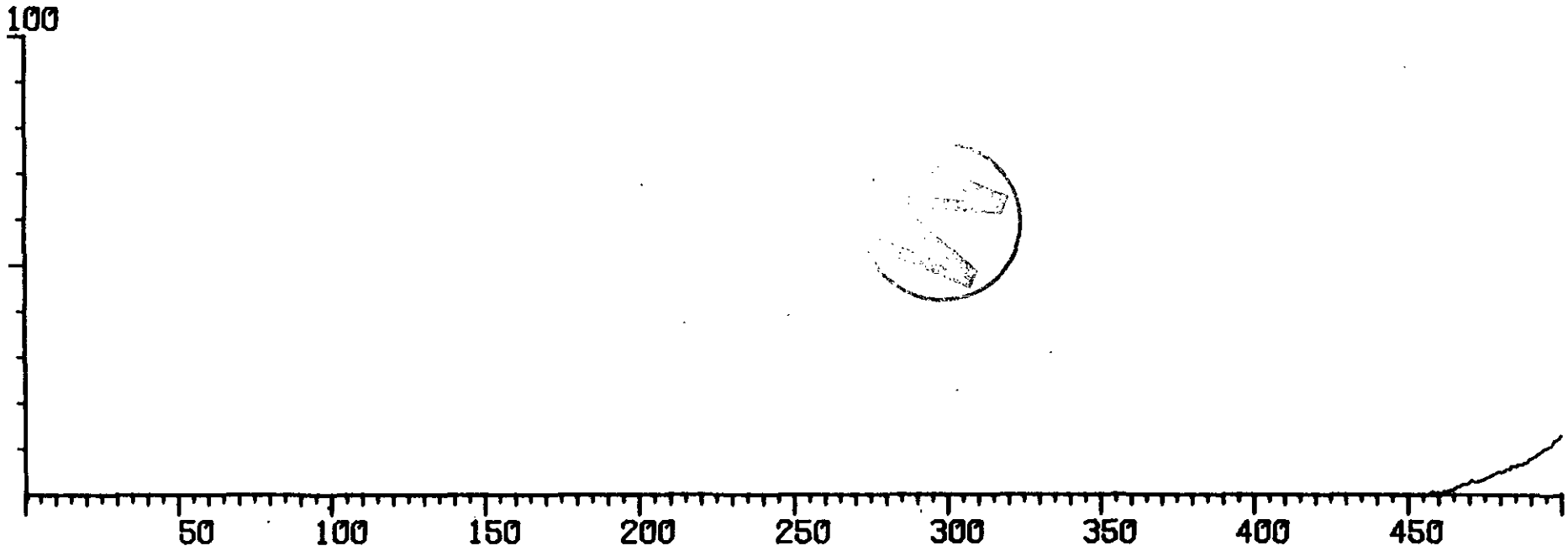

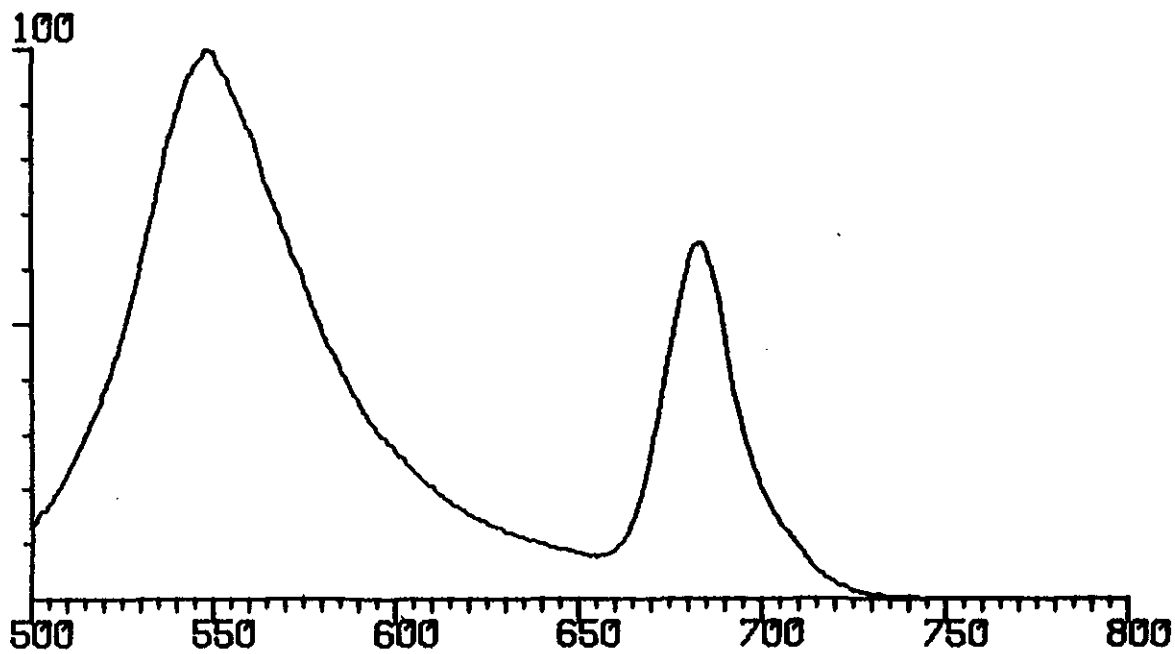

SALT SAMPLE 2302.6

MASS 20 SEARCH X3

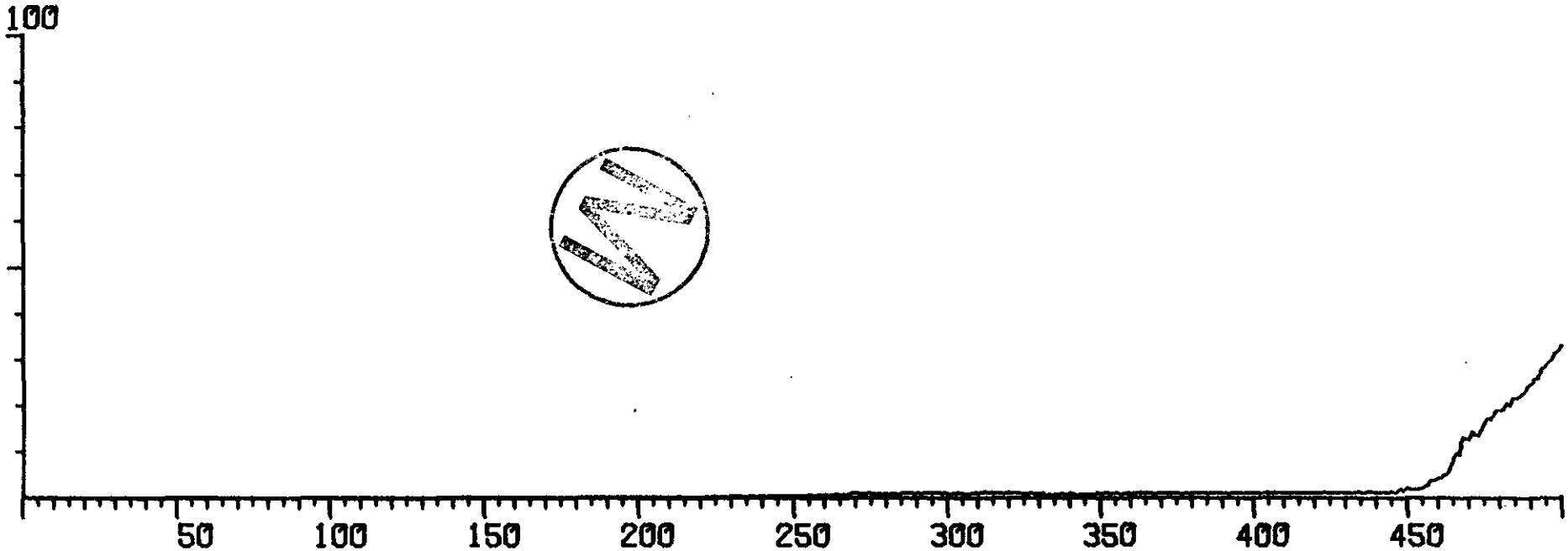

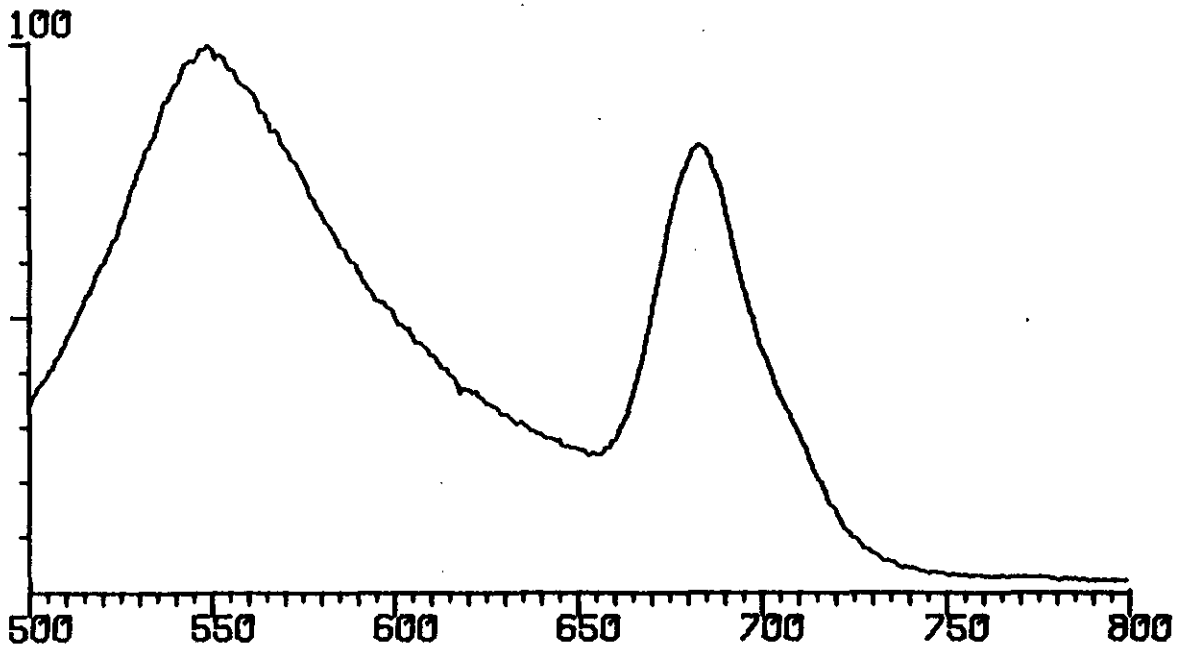

SAL. SAMPLE 2302.6

MASS 32 SEARCH X2

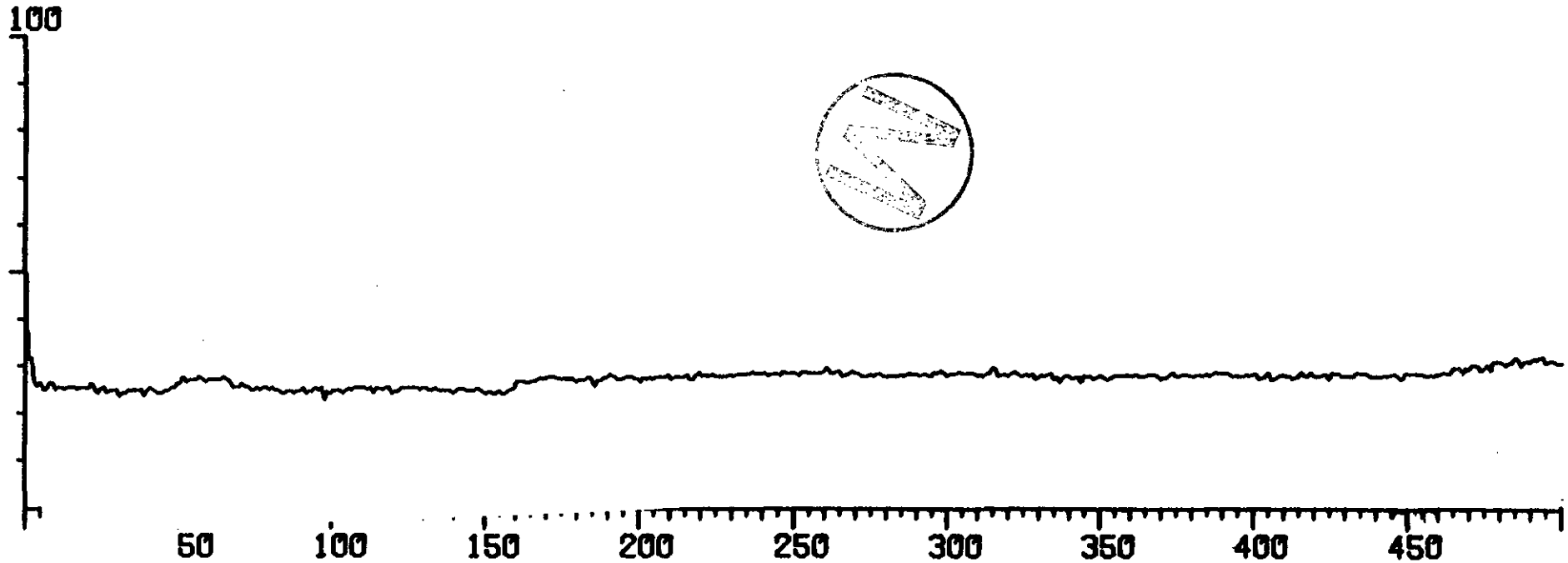

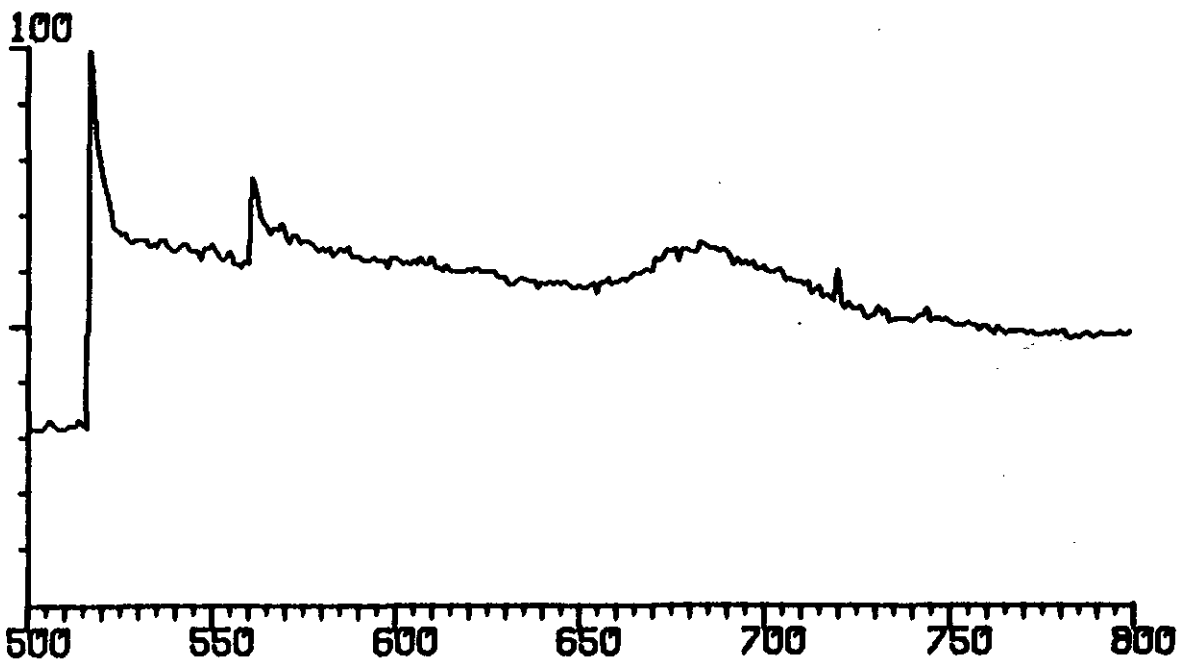

SALT SAMPLE 2302.6

MASS 36 SEARCH X2

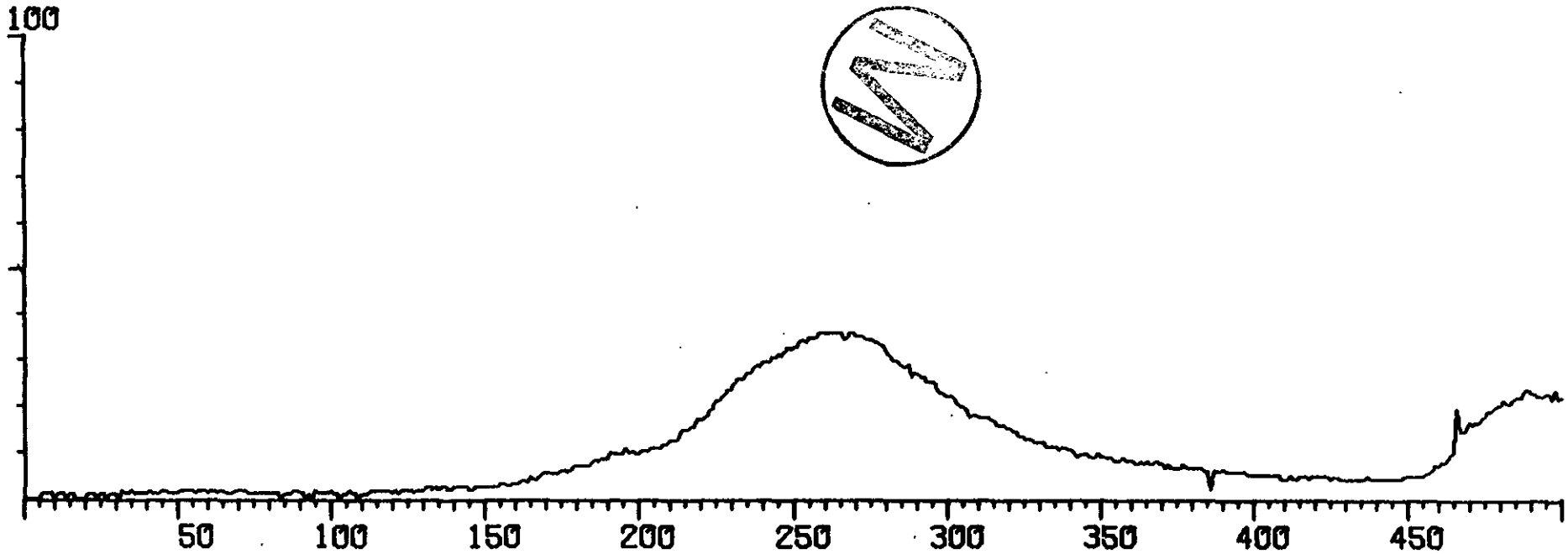

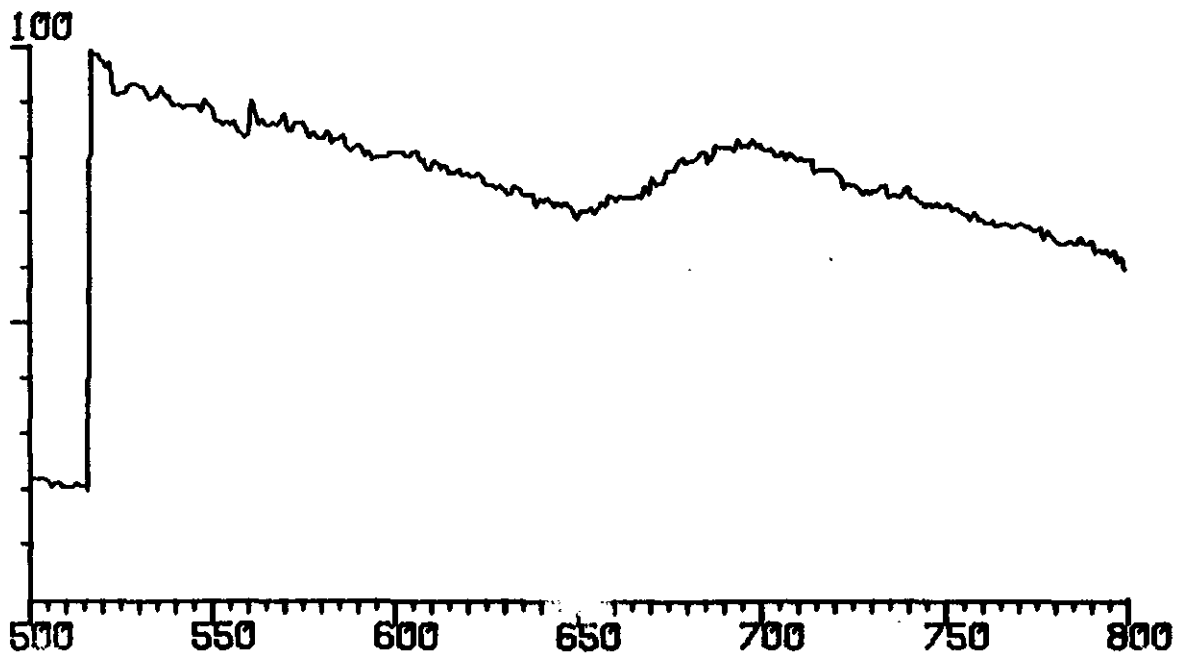

SALT SAMPLE 2302.6

MASS 44 SEARCH X2

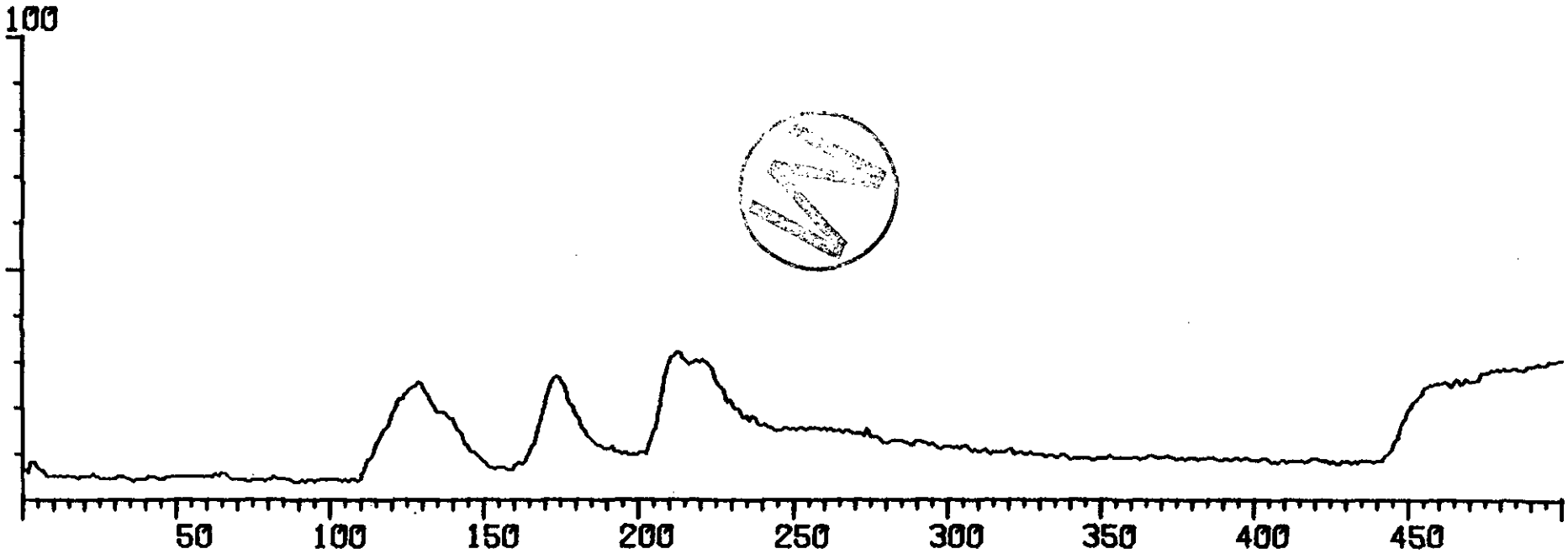

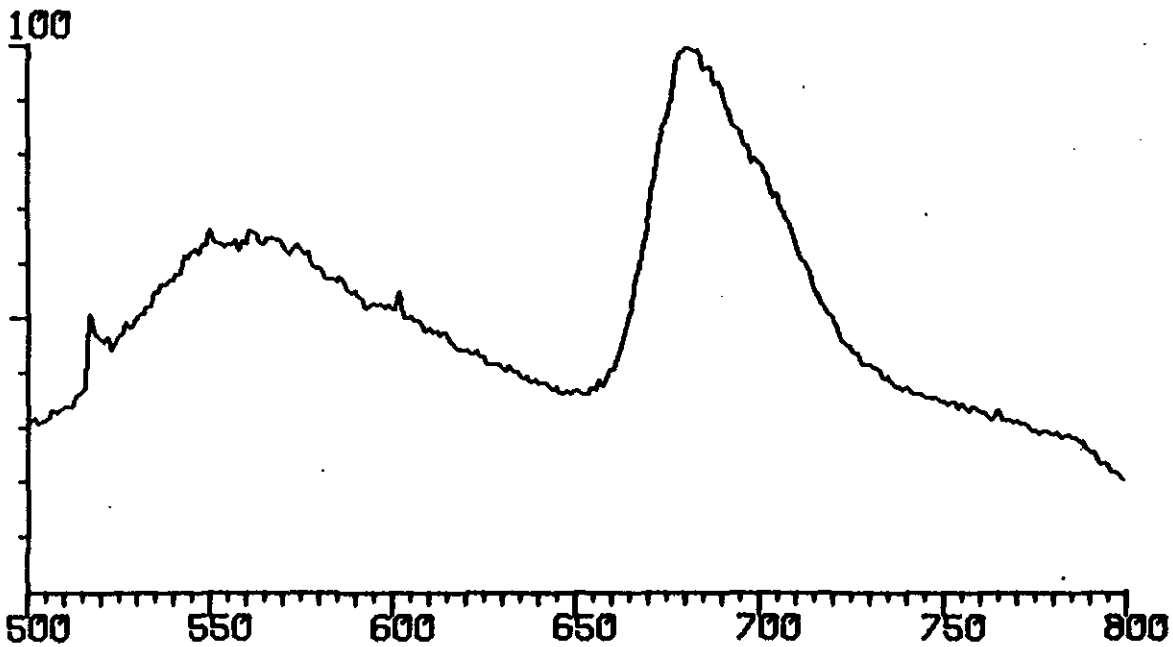

SALT SAMPLE 2302.6

MASS 48 SEARCH X1

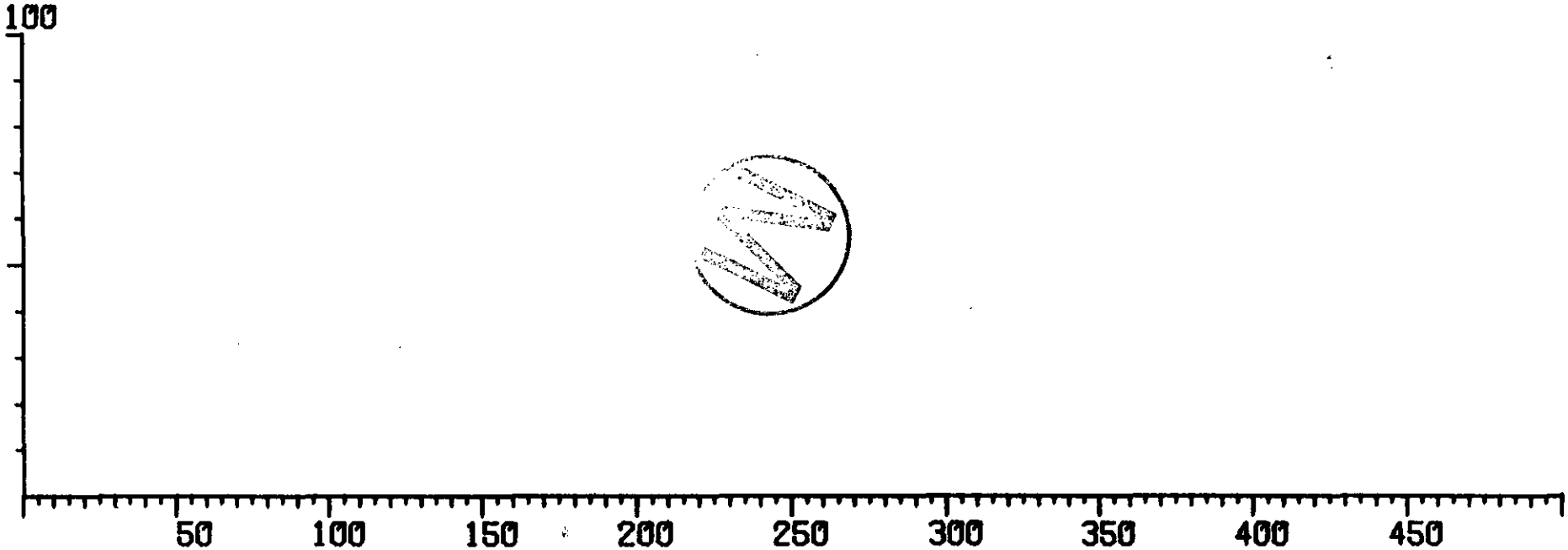

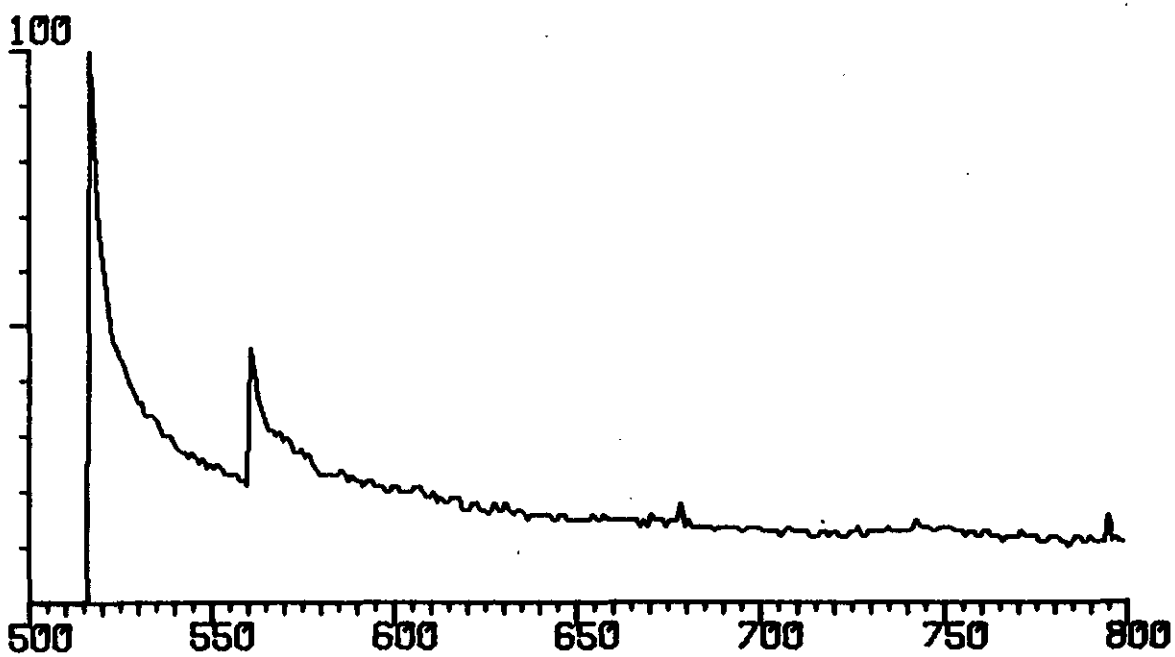

SALT SAMPLE 2302.6

MASS 80 SEARCH X1

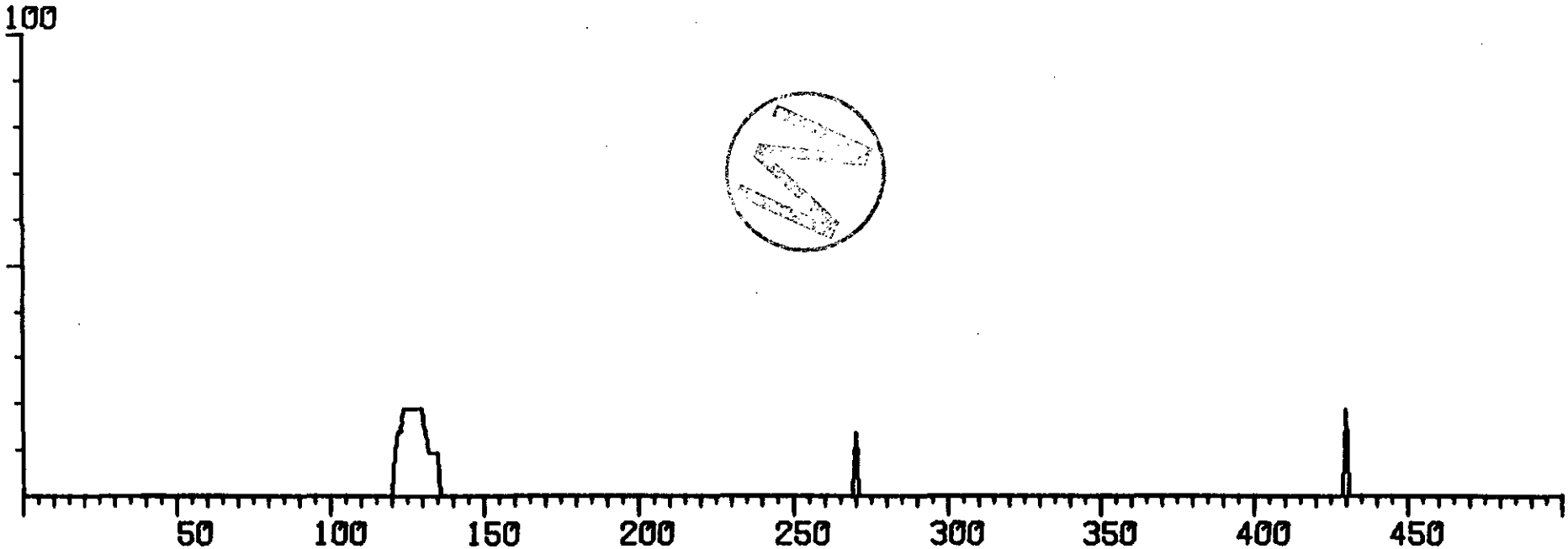

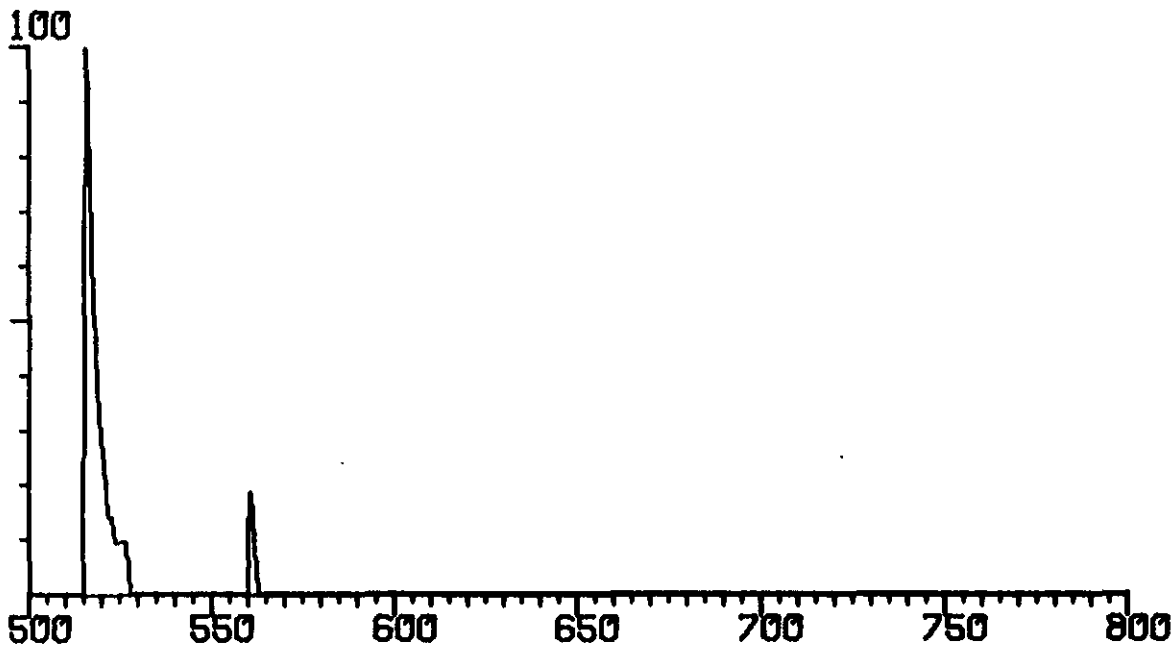

SALT SAMPLE 2302.6

MASS 64 SEARCH X1

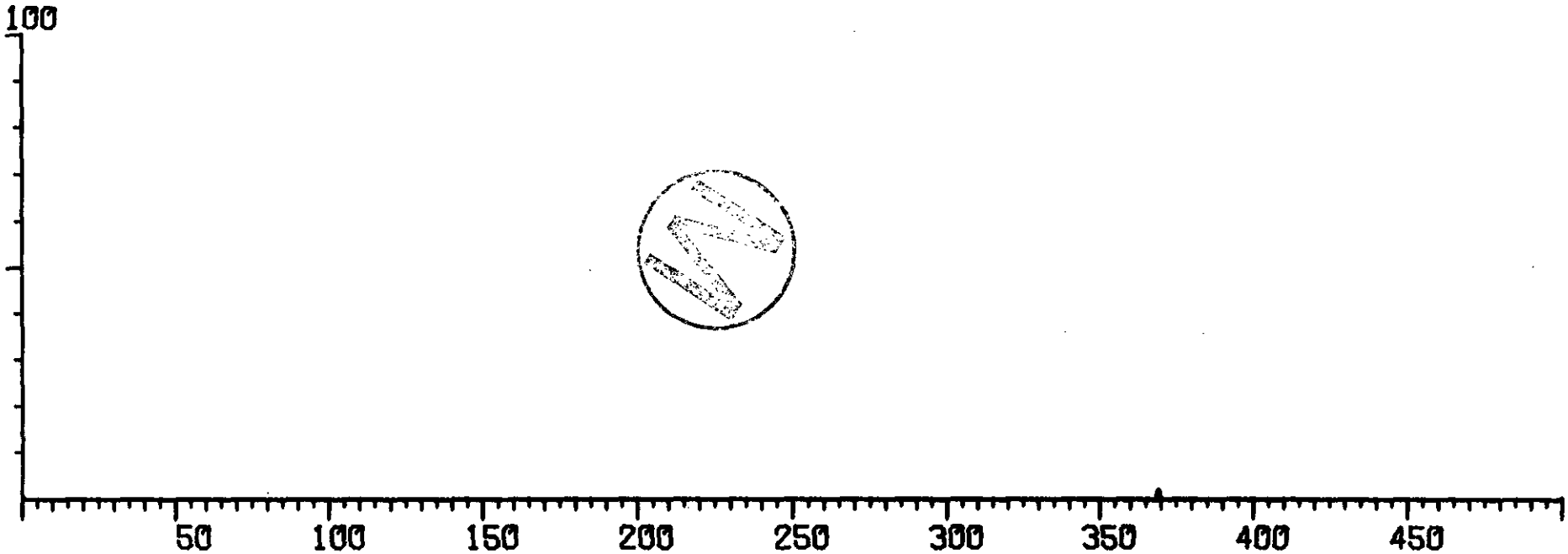

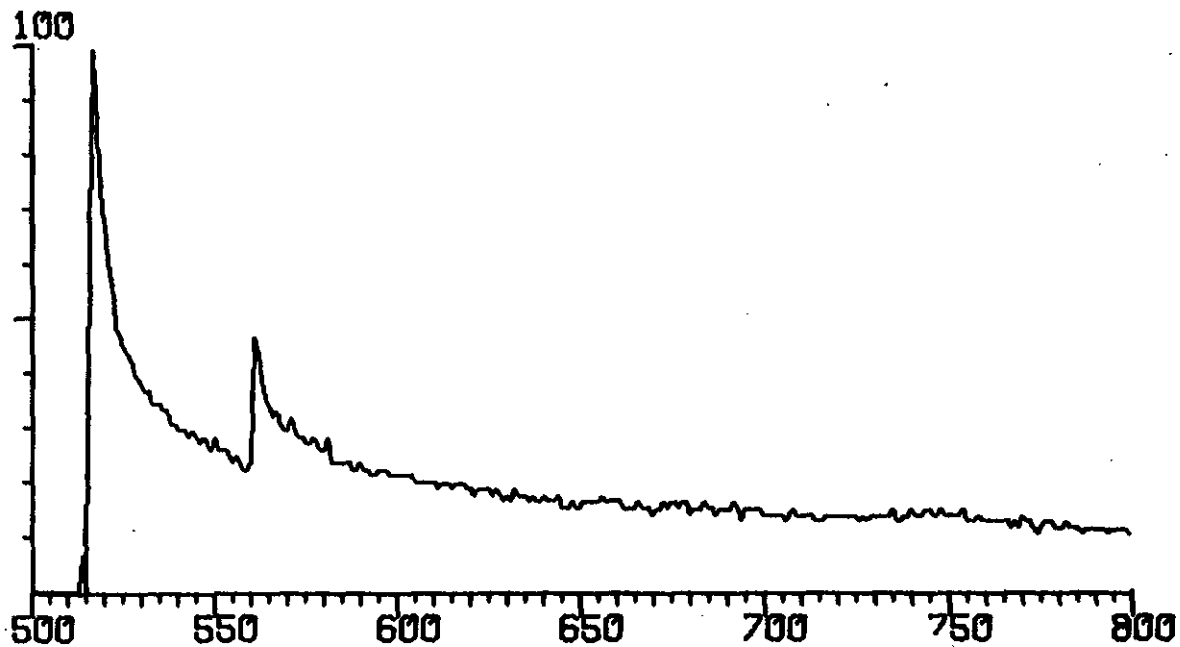

SALT SAMPLE 2516.3

MASS 18 SEARCH X3

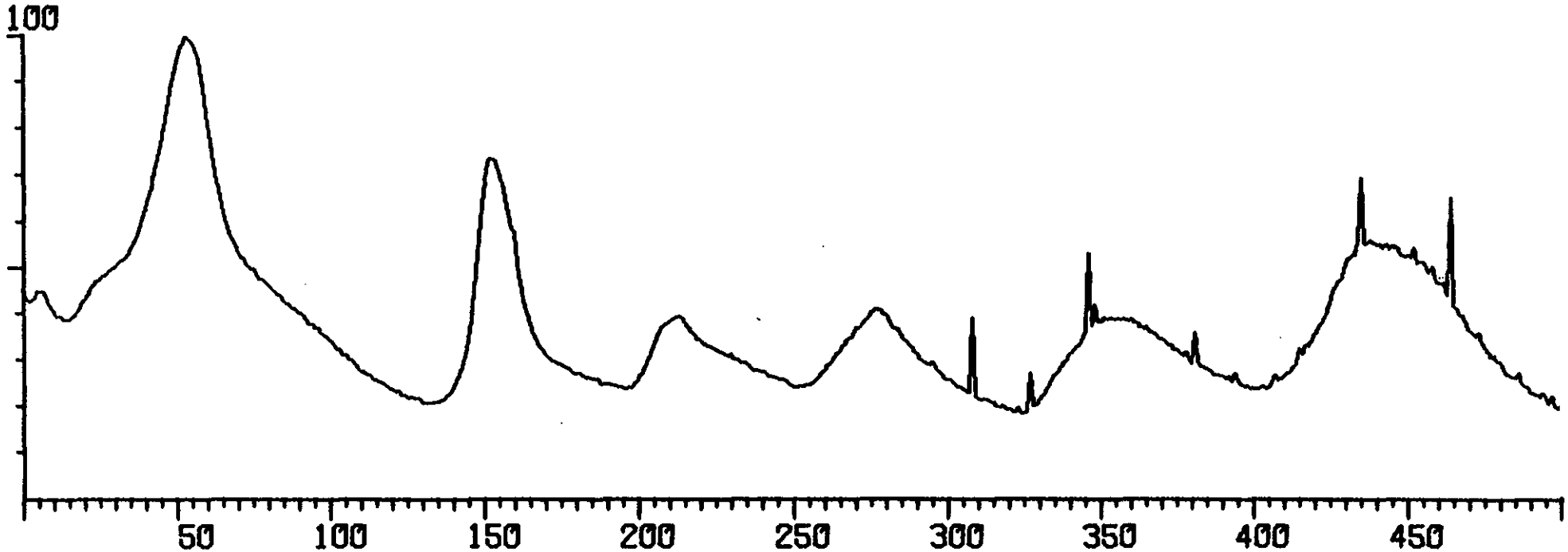

SALT SAMPLE 2516.3

MASS 28 SEARCH X3

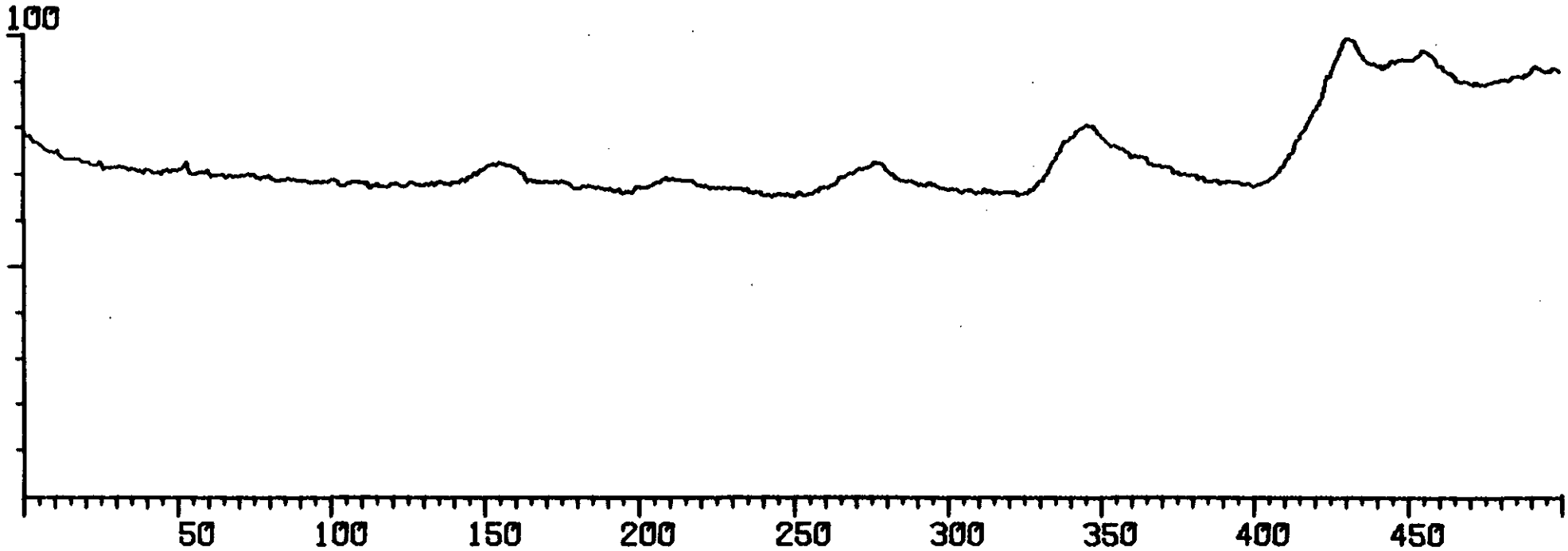

SALT SAMPLE 2302.6

517 CH 517 - CH 522 X1

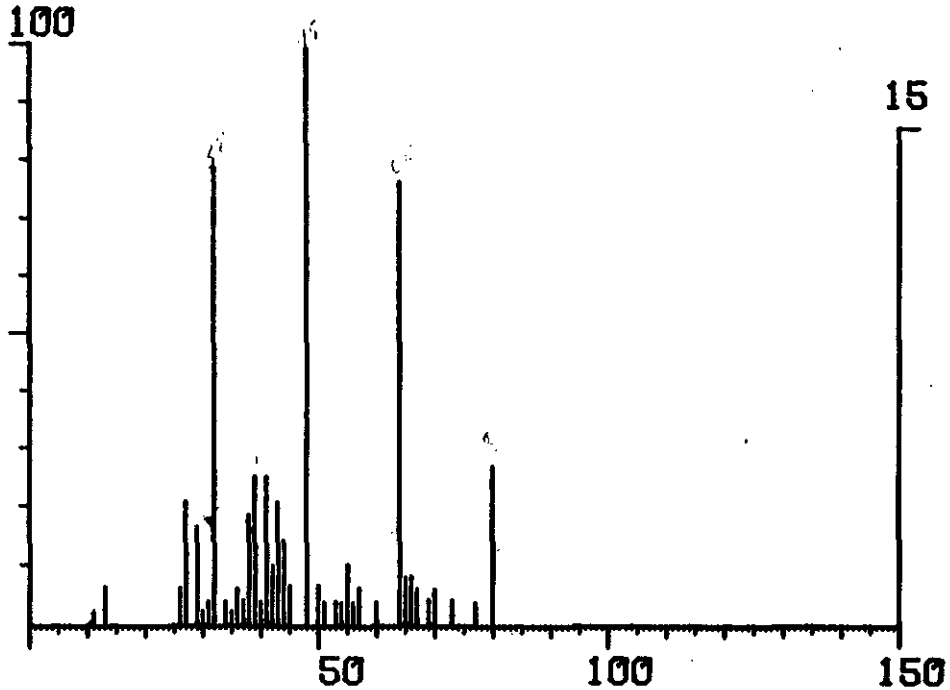

SALT SAMPLE 2516.3

TOTAL ION CHROMATOGRAM

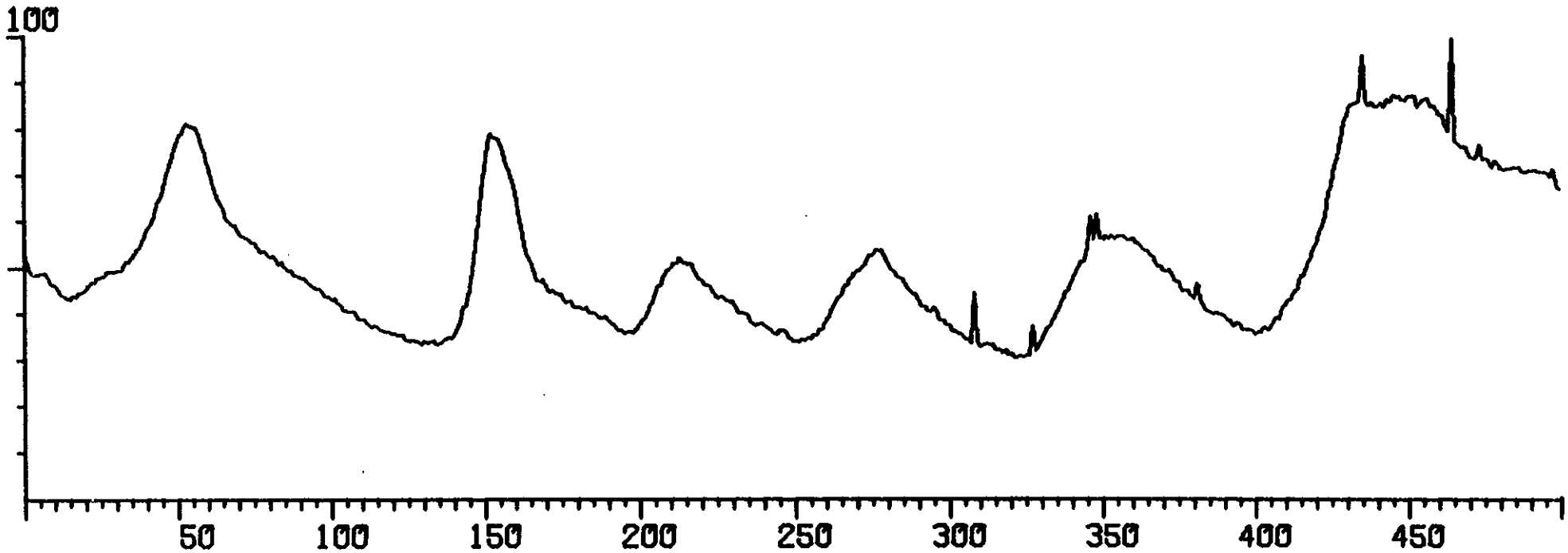

SALT SAMPLE 2516.3

MASS 32 SEARCH X2

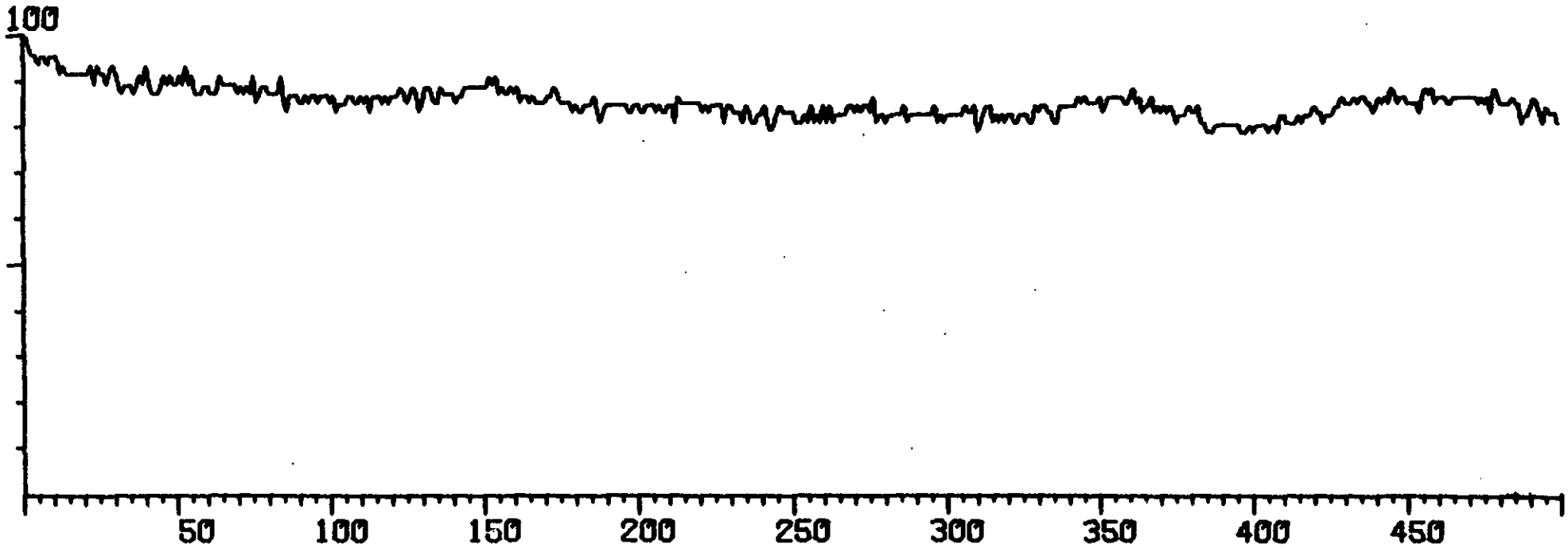

SALT SAMPLE 2516.3

MASS 36 SEARCH X2

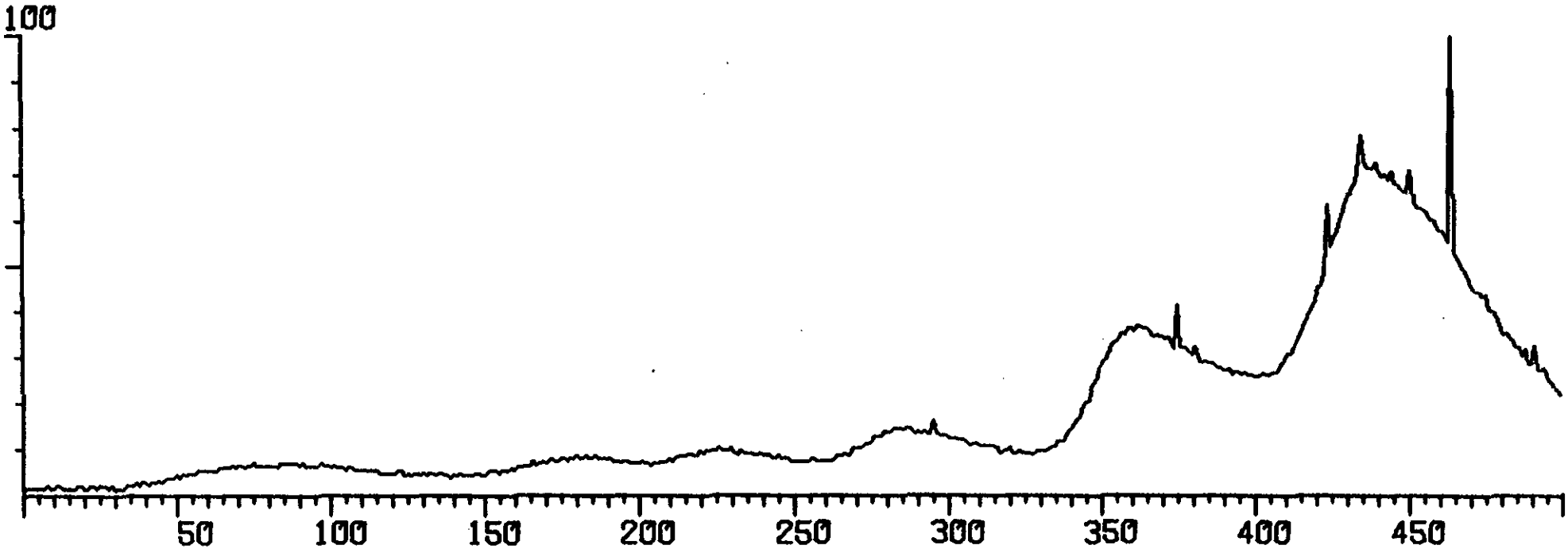

SALT SAMPLE 2516.3

MASS 44 SEARCH X3

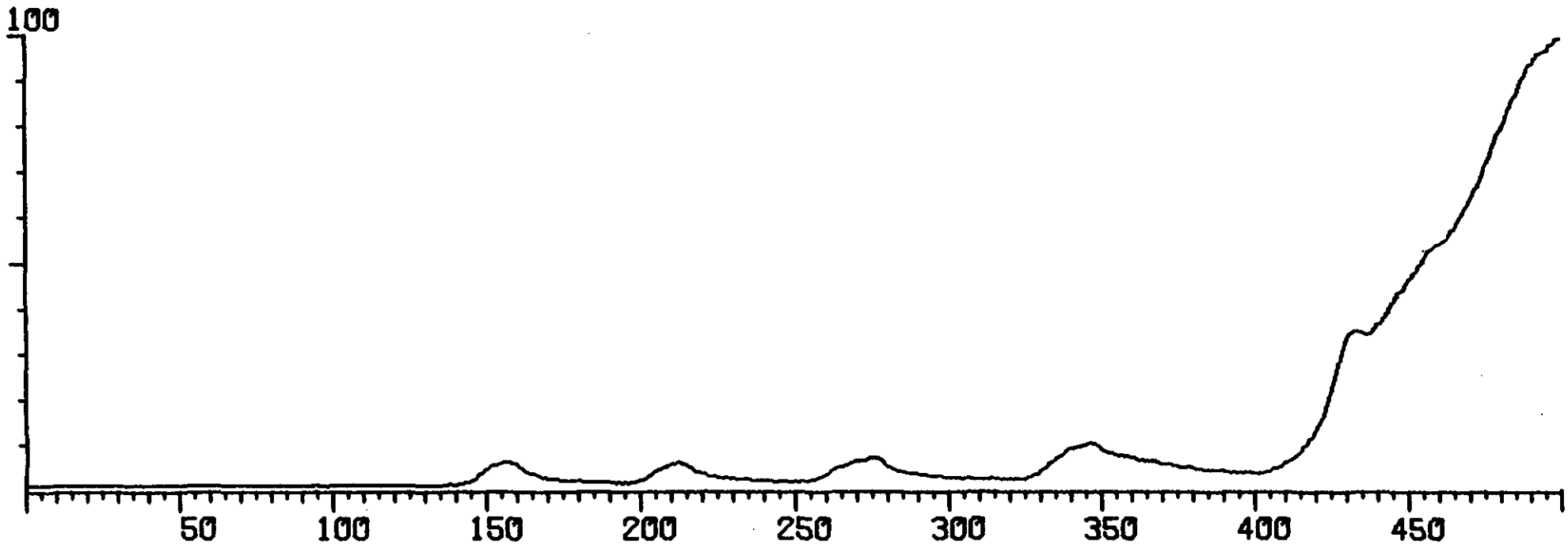

SALT SAMPLE 2516.3

MASS 48 SEARCH X1

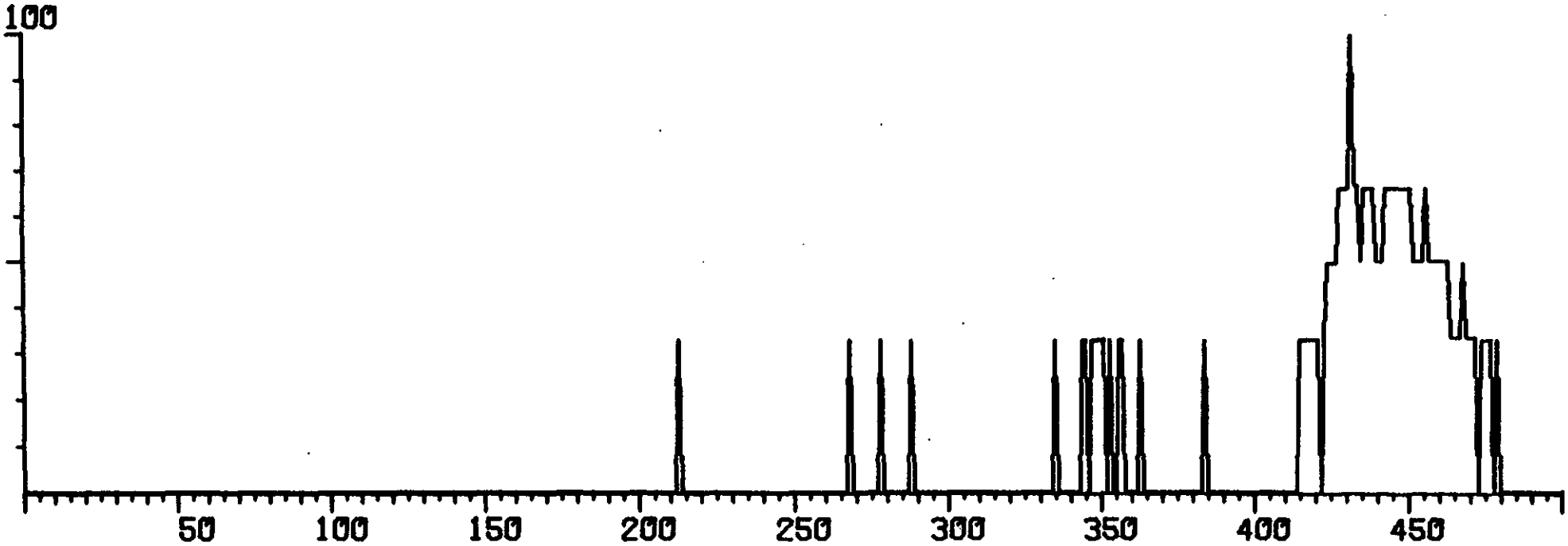

SALT SAMPLE 2658.5

TOTAL ION CHROMATOGRAM

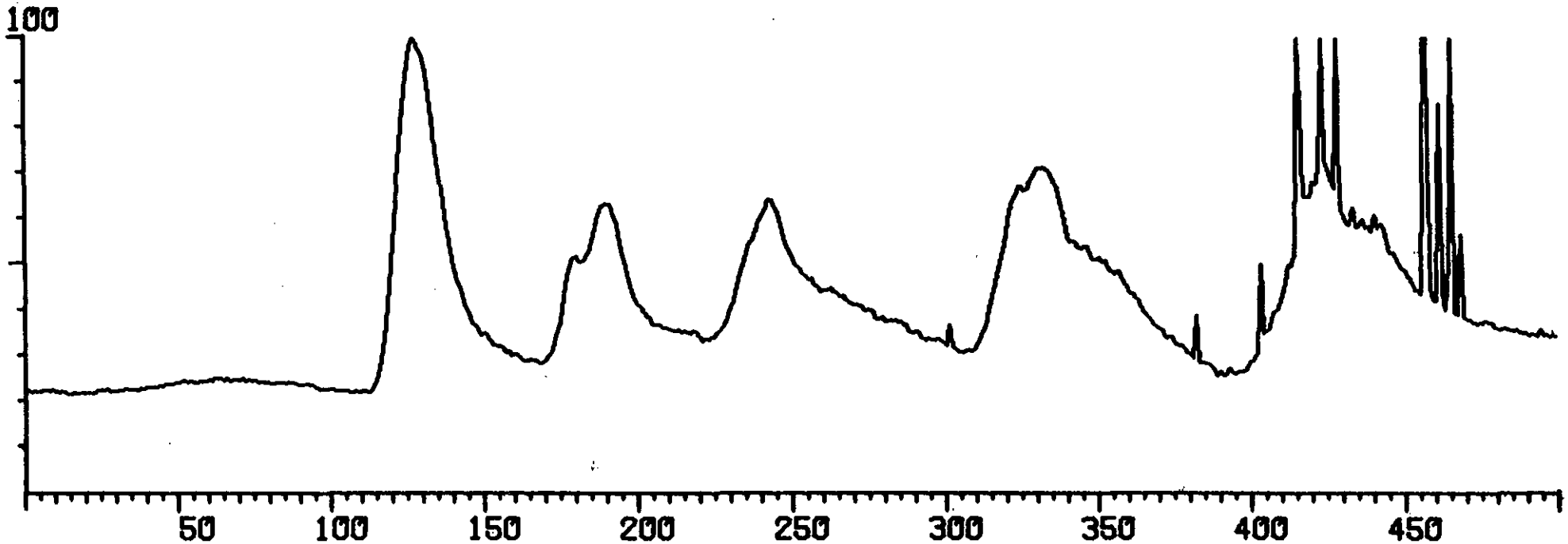

SALT SAMPLE 2658.5

MASS 14 SEARCH X1

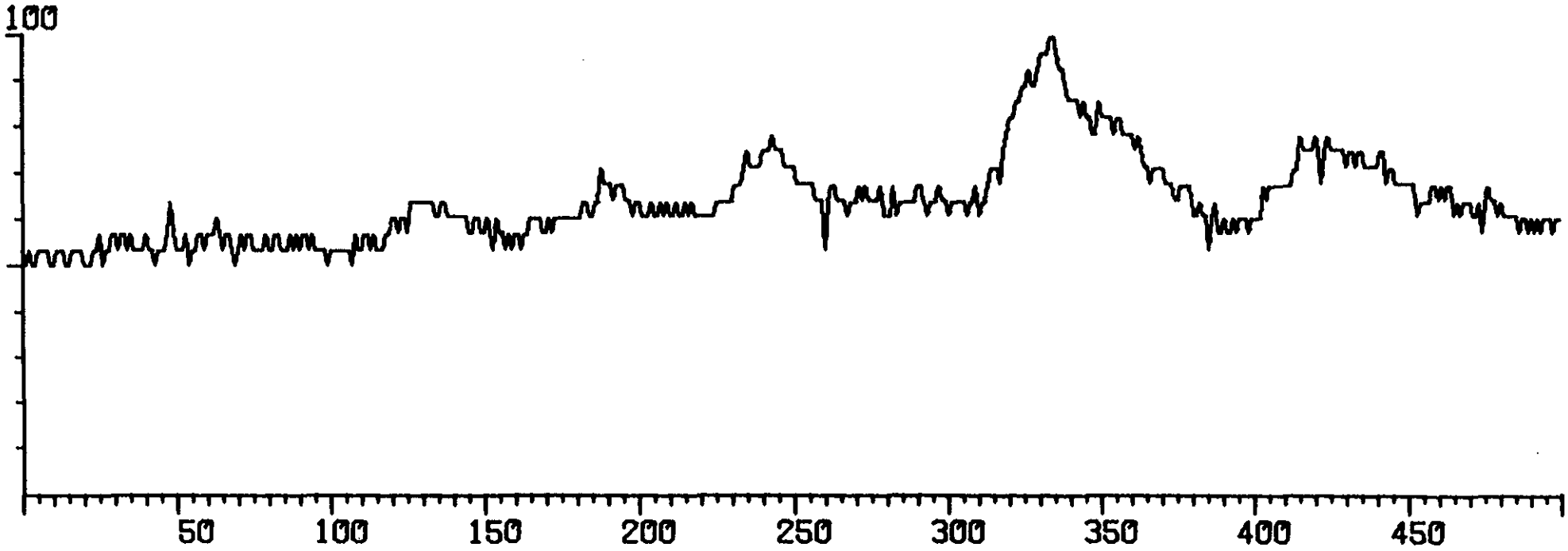

SALT SAMPLE 2658.5

MASS 18 SEARCH X4 (CH 127 = 100%)

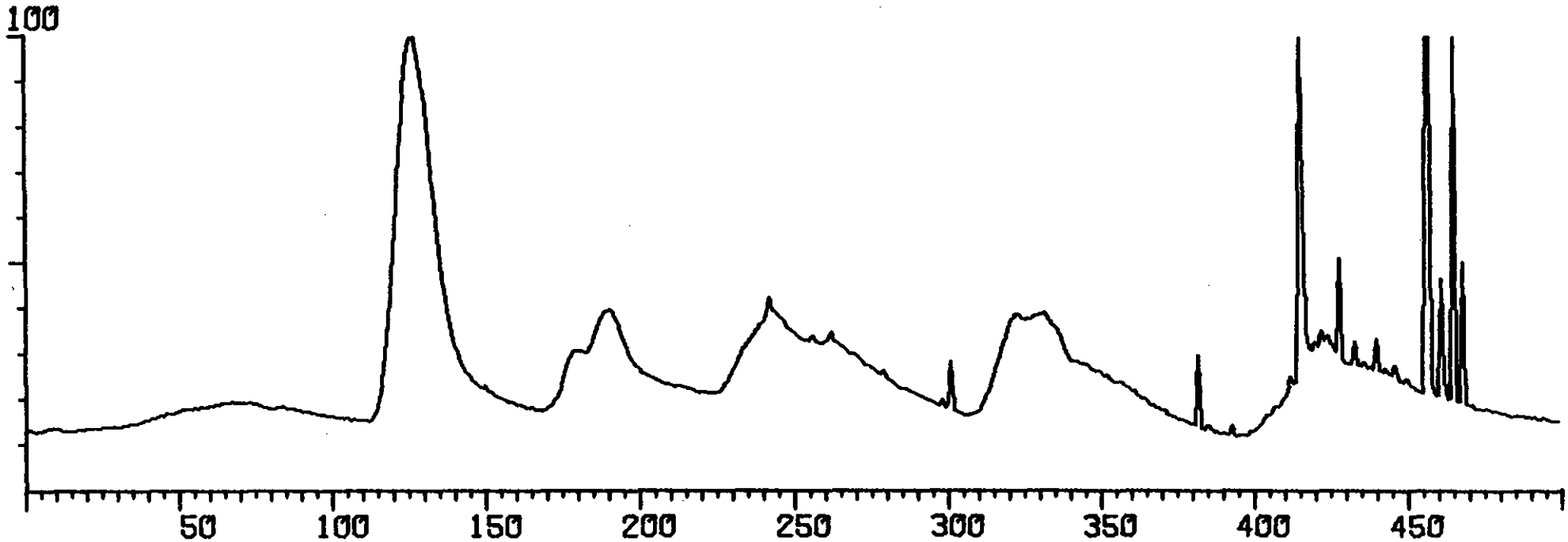

SALT SAMPLE 2658.5

MASS 28 SEARCH X3

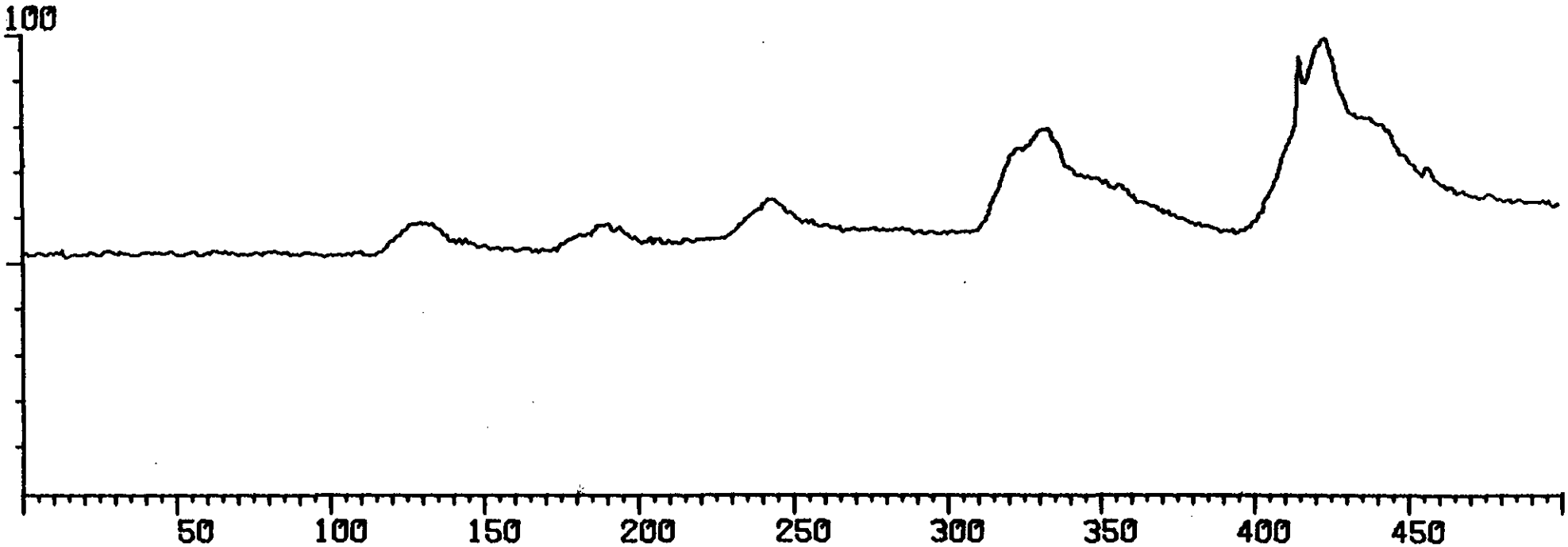

SALT SAMPLE 2658.5

MASS 32 SEARCH X1

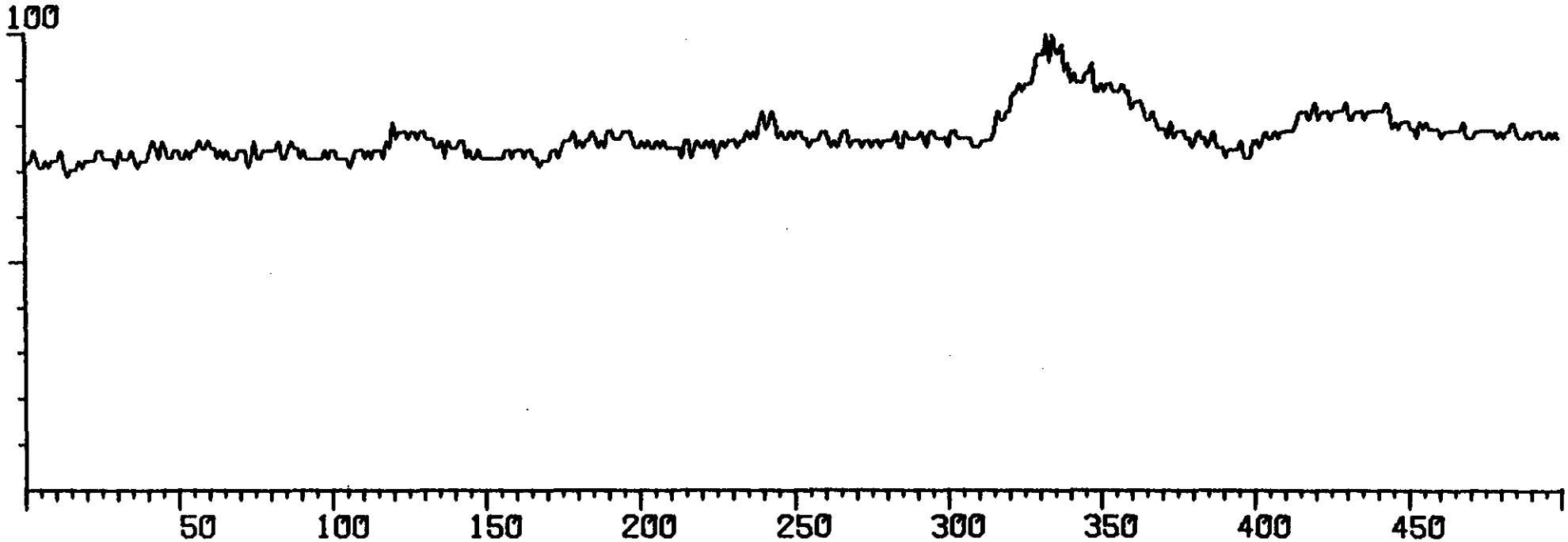

SALT SAMPLE 2658.5

MASS 36 SEARCH X2 (CH 415 = 100%)

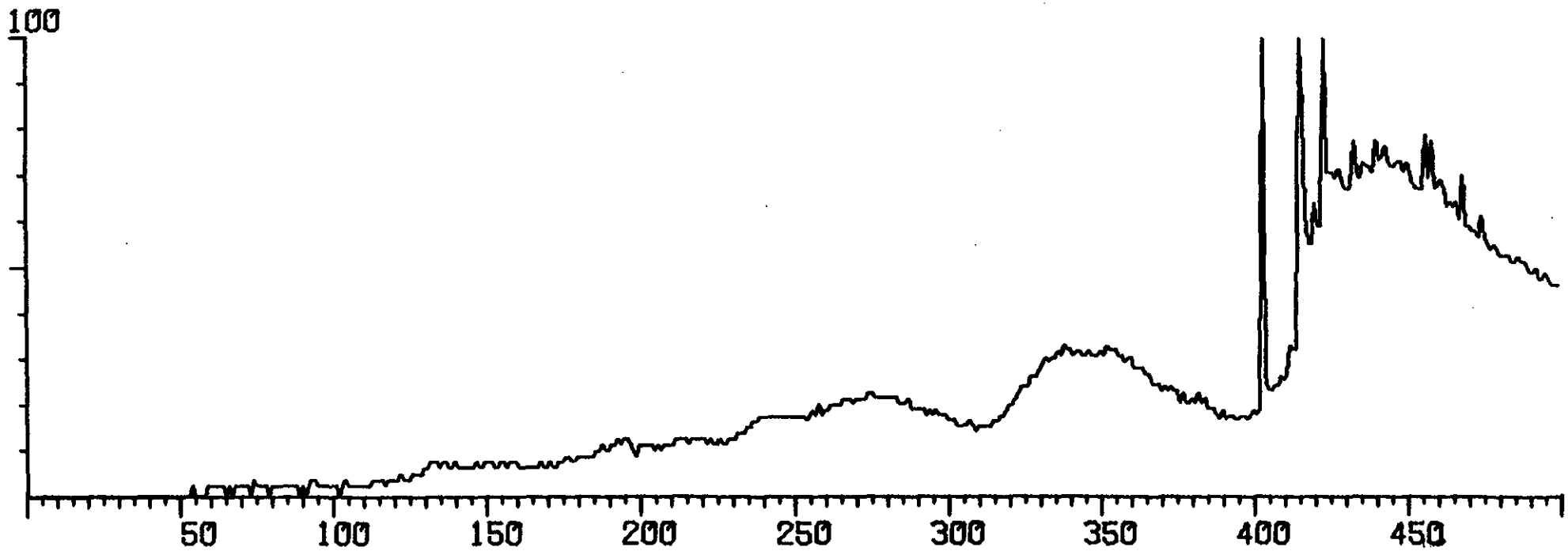

SALT SAMPLE 2658.5

MASS 44 SEARCH X2

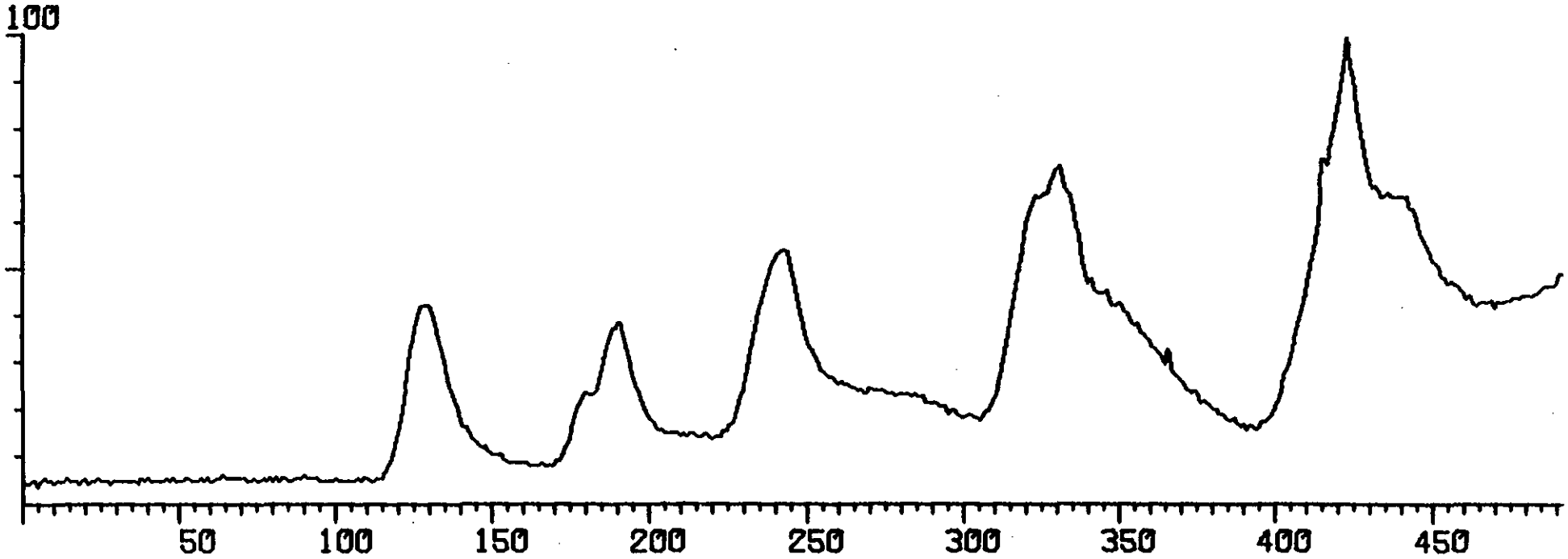

SALT SAMPLE 2658.5

MASS 48 SEARCH X1

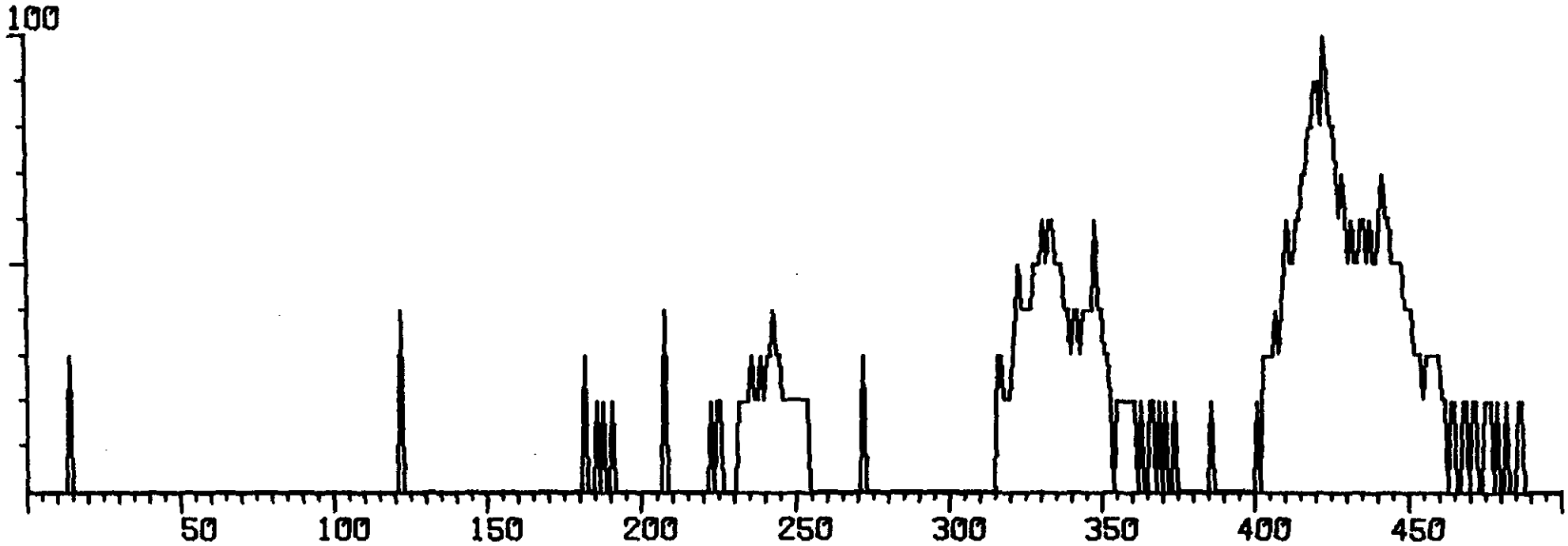

SALT SAMPLE 2786.5

TOTAL ION CHROMATOGRAM

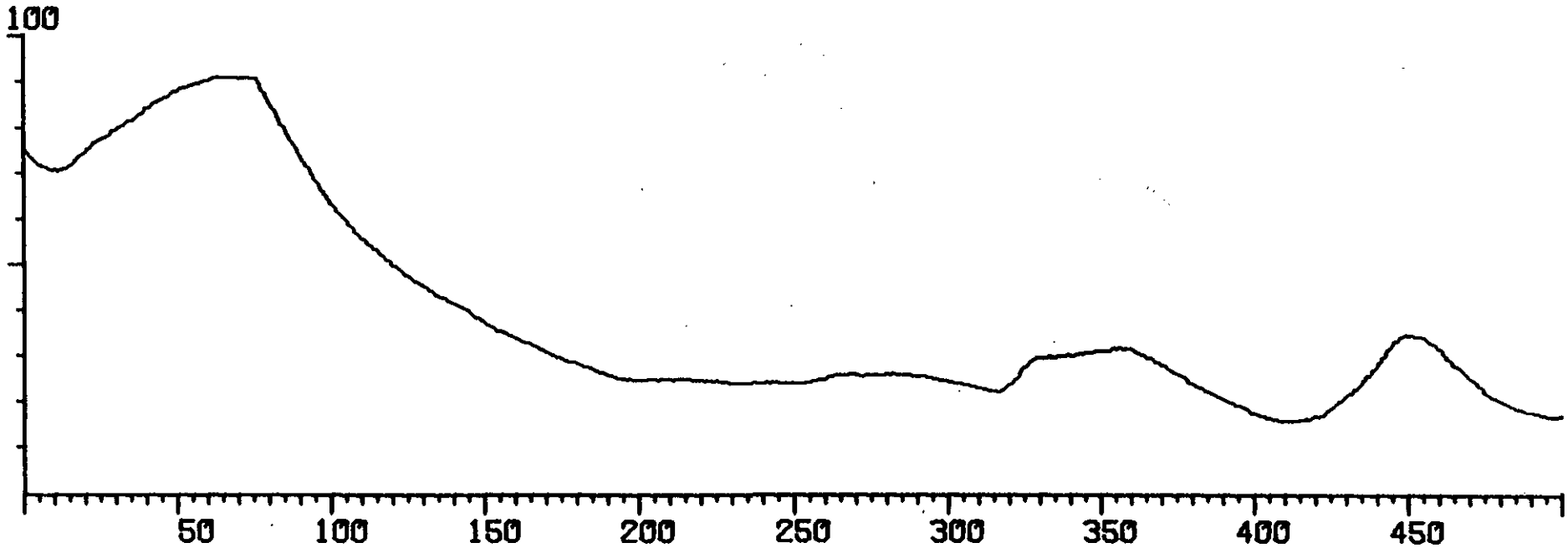

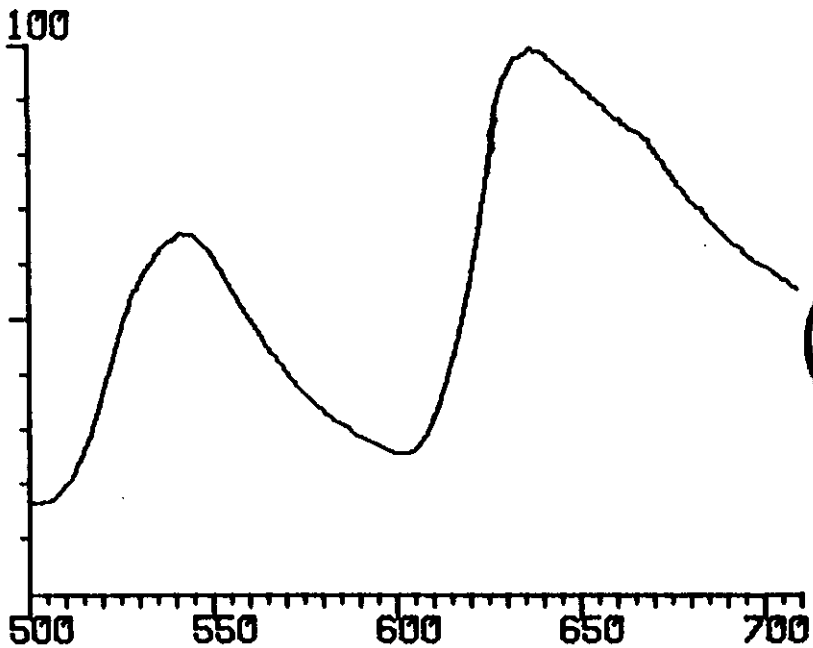

SALT SAMPLE 2786.5

MASS 14 SEARCH X1

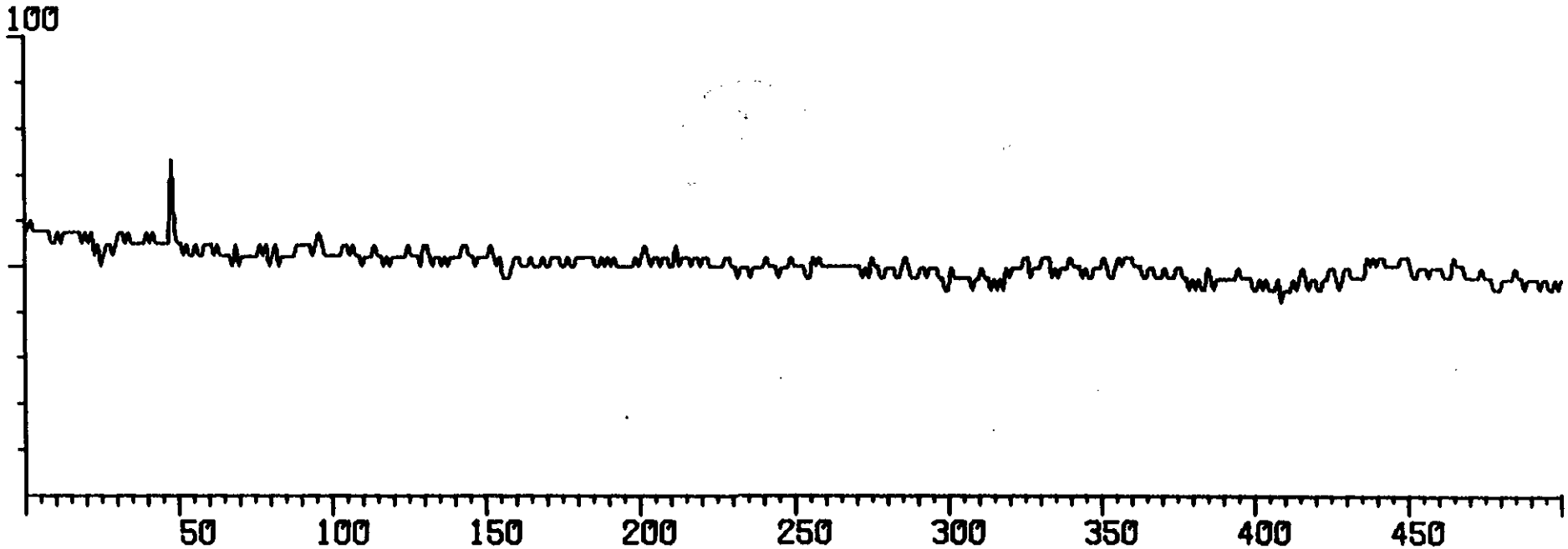

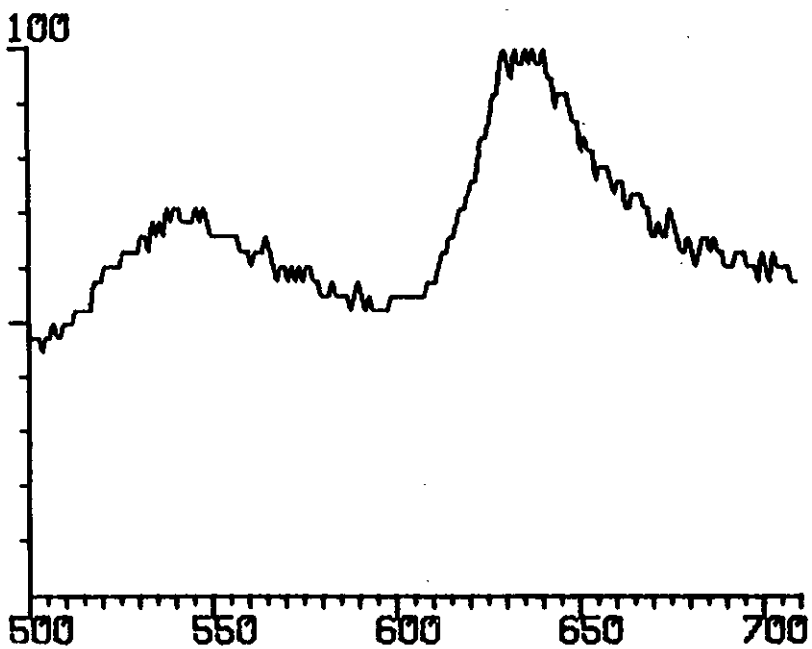

SALT SAMPLE 2786.5

MASS 18 SEARCH X4

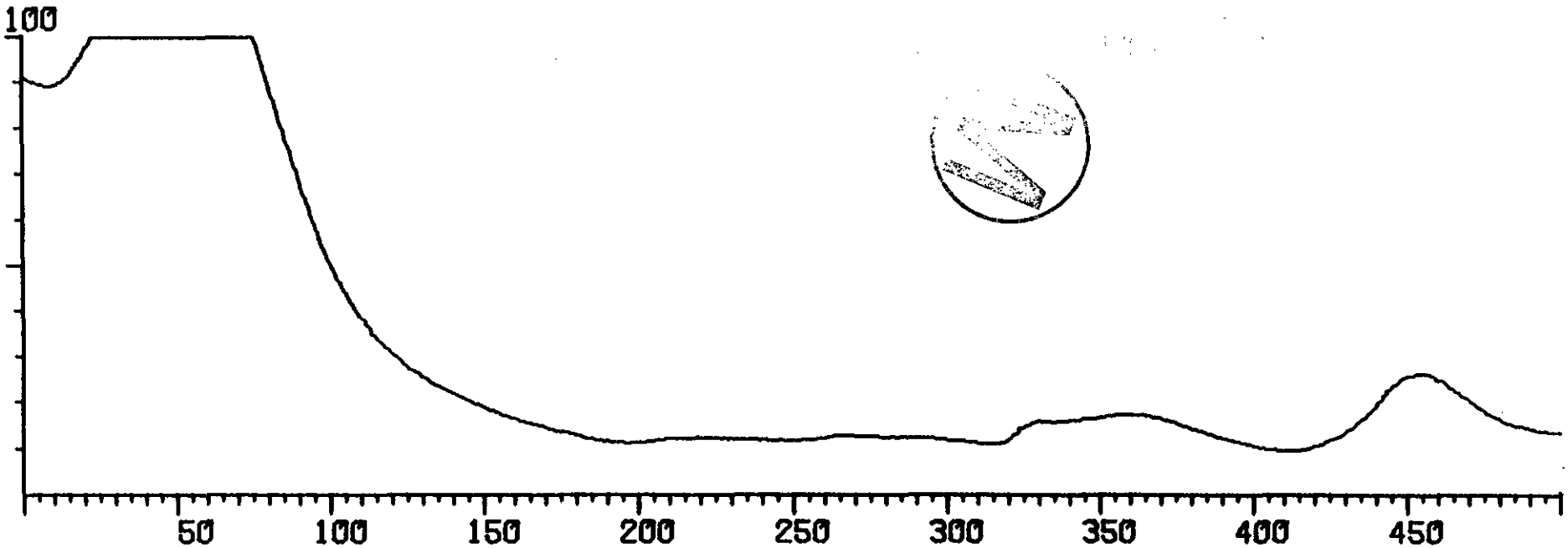

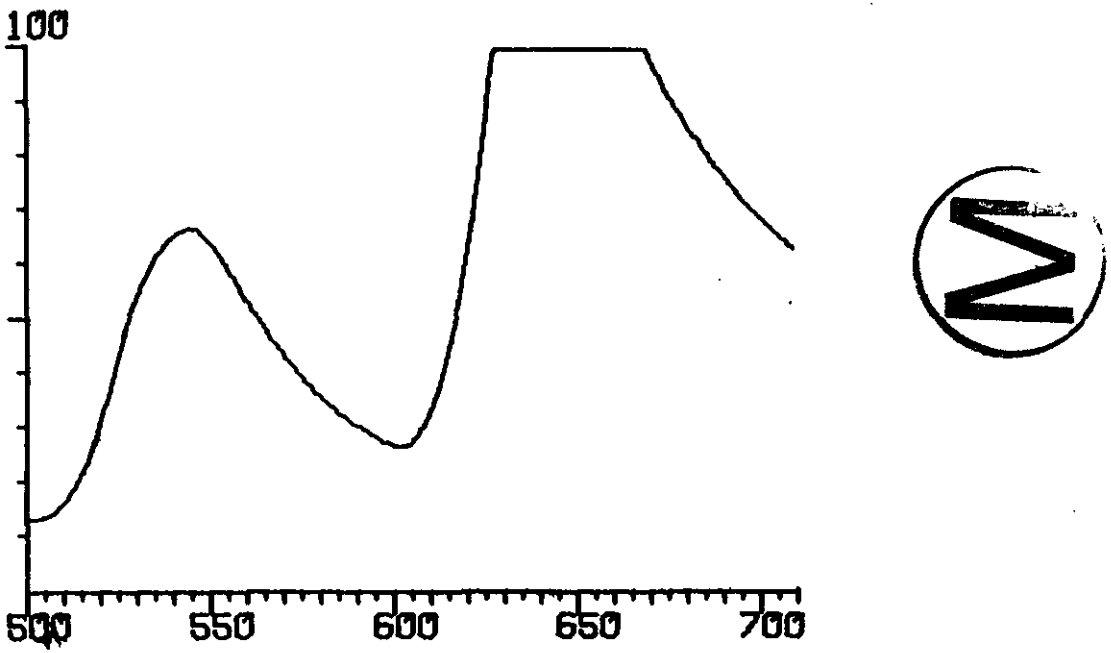

SALT SAMPLE 2786.5

MASS 19 SEARCH X1

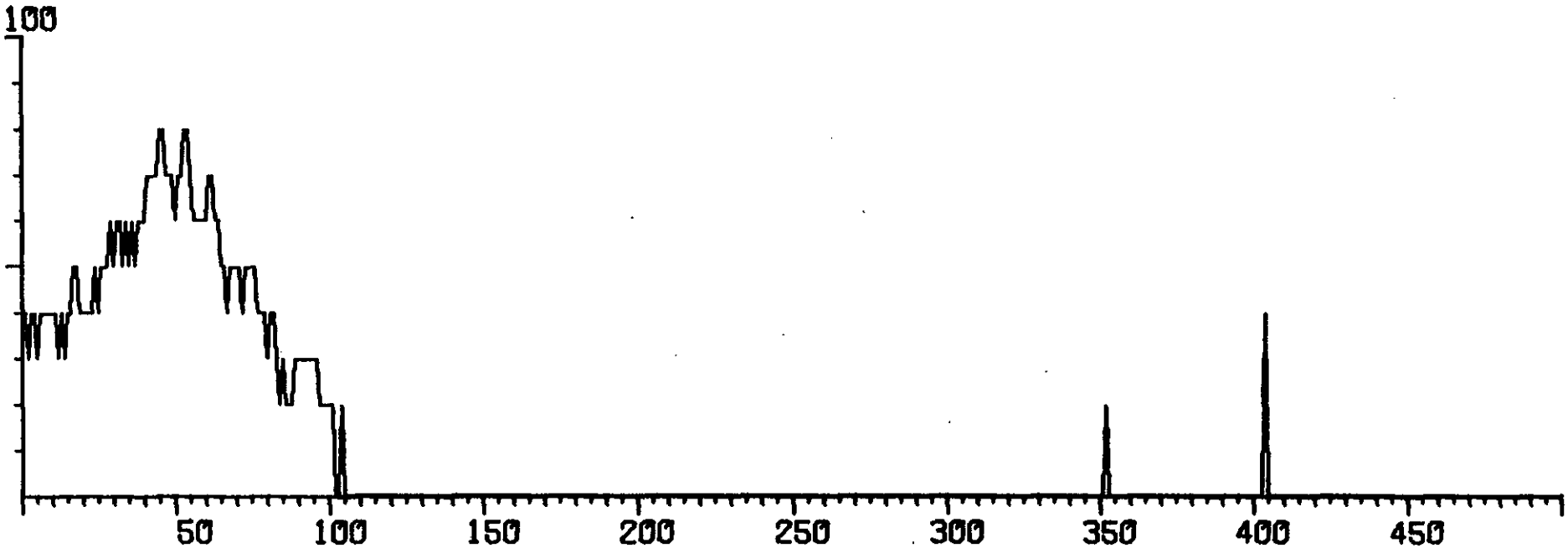

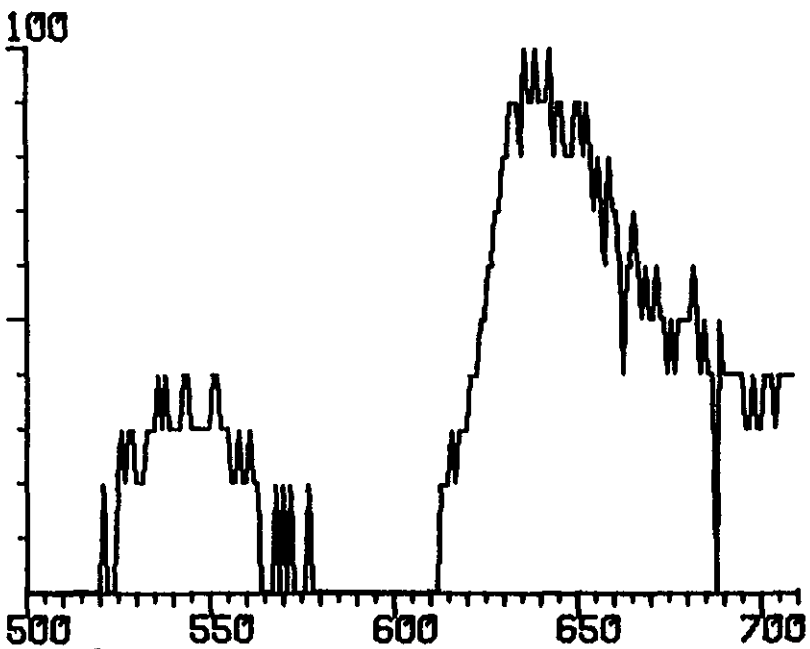

SAL1 SAMPLE 2786.5

MASS 28 SEARCH X3

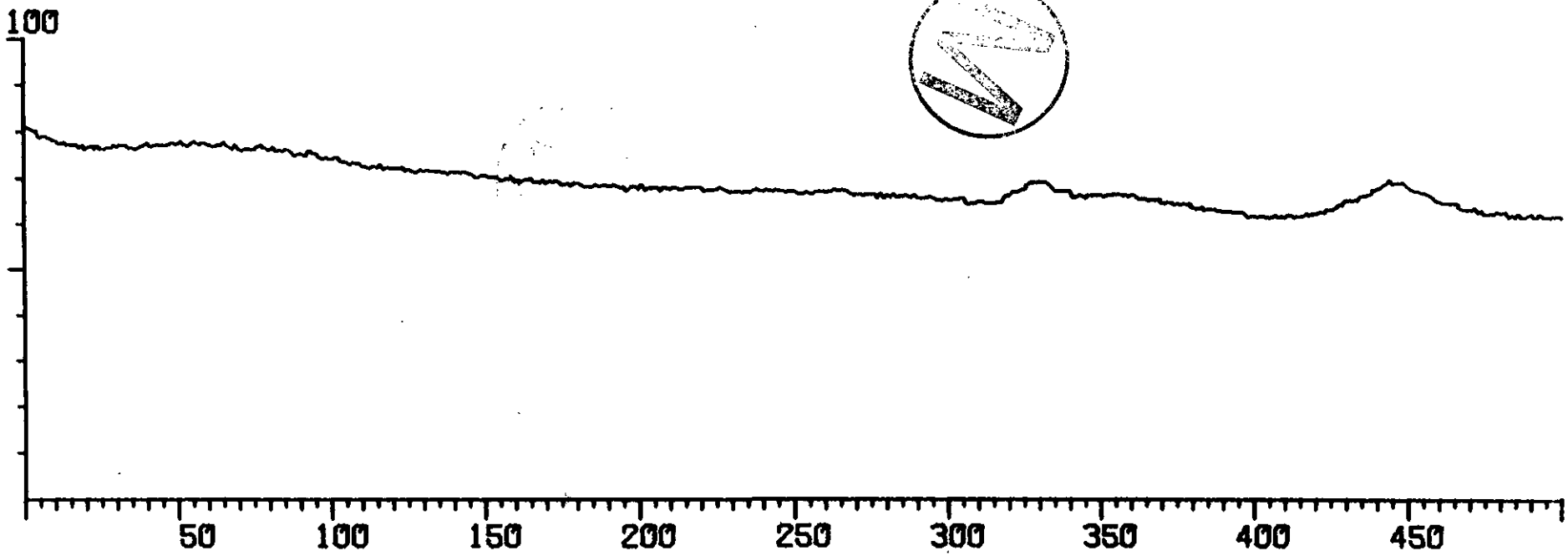

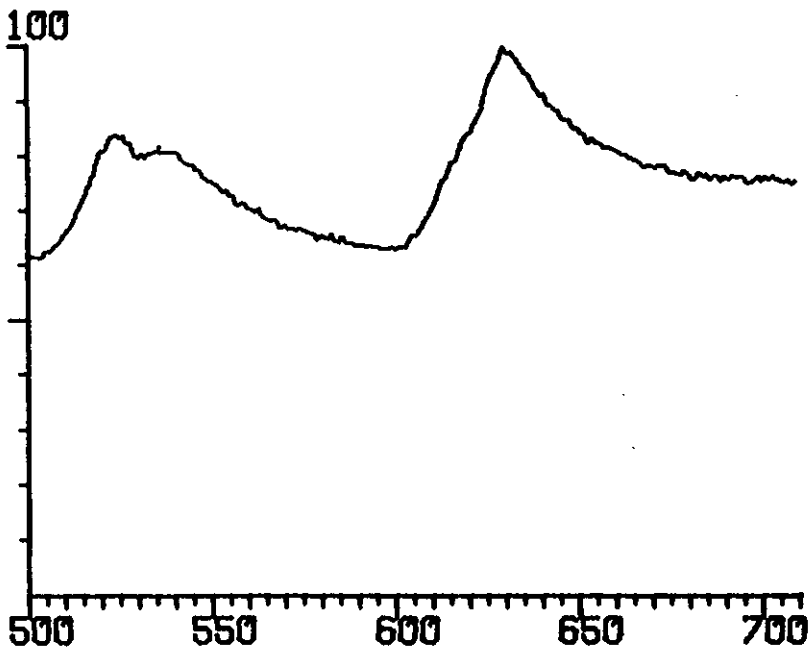

SALT SAMPLE 2786.5

MASS 32 SEARCH X1

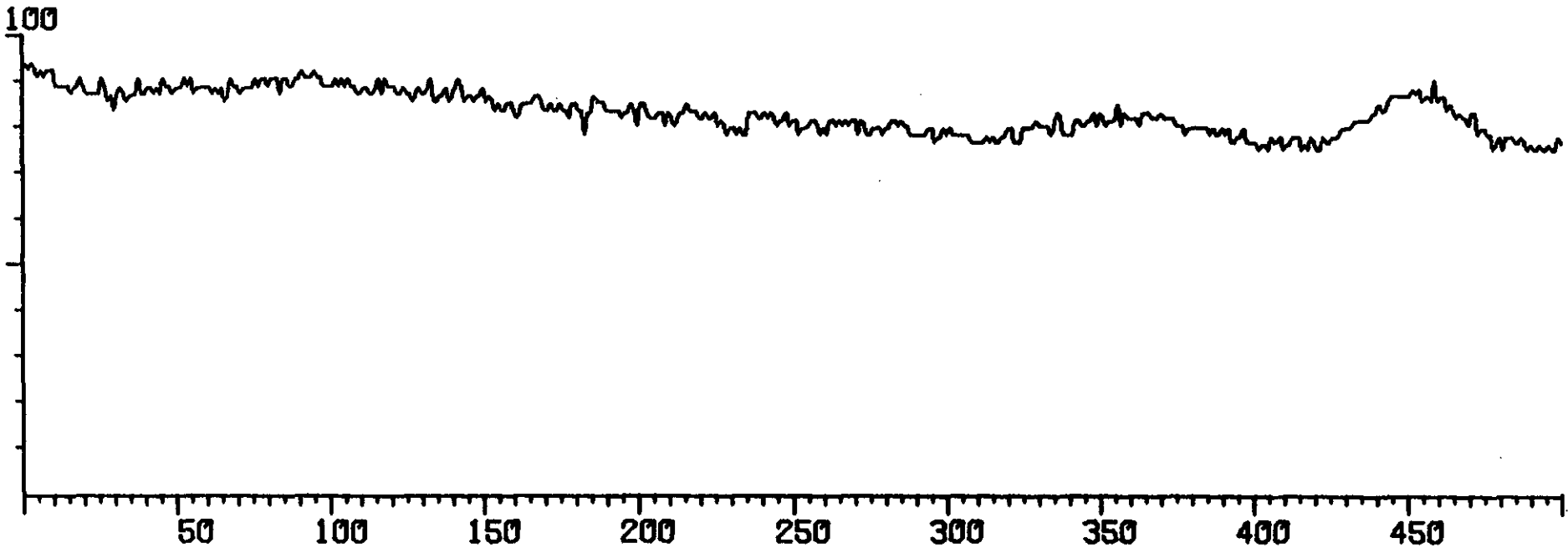

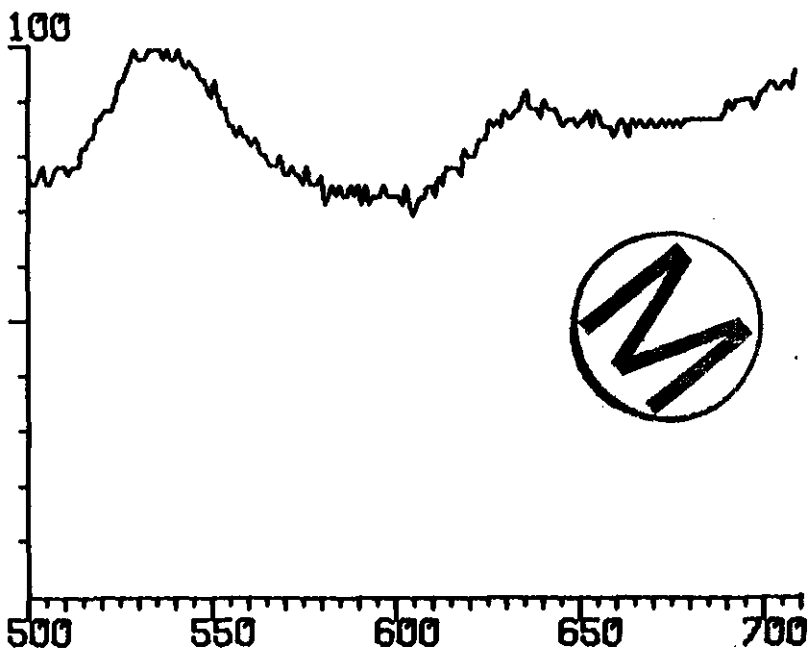

SALT SAMPLE 2786.5

MASS 36 SEARCH X2

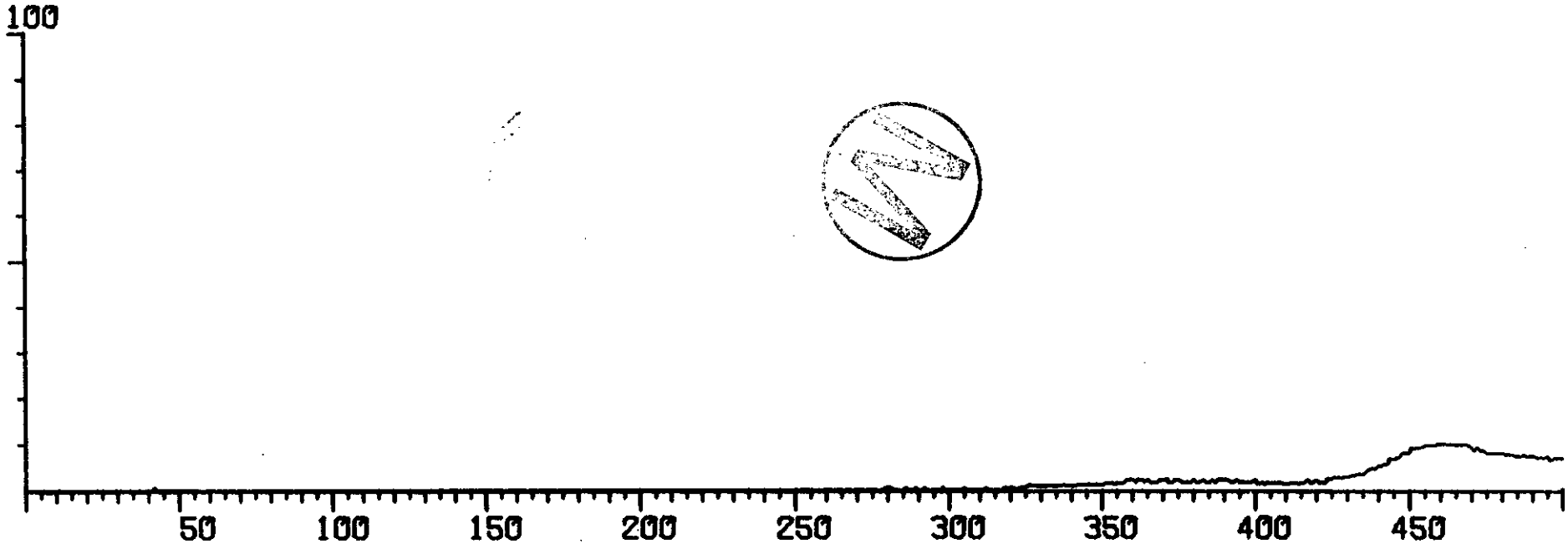

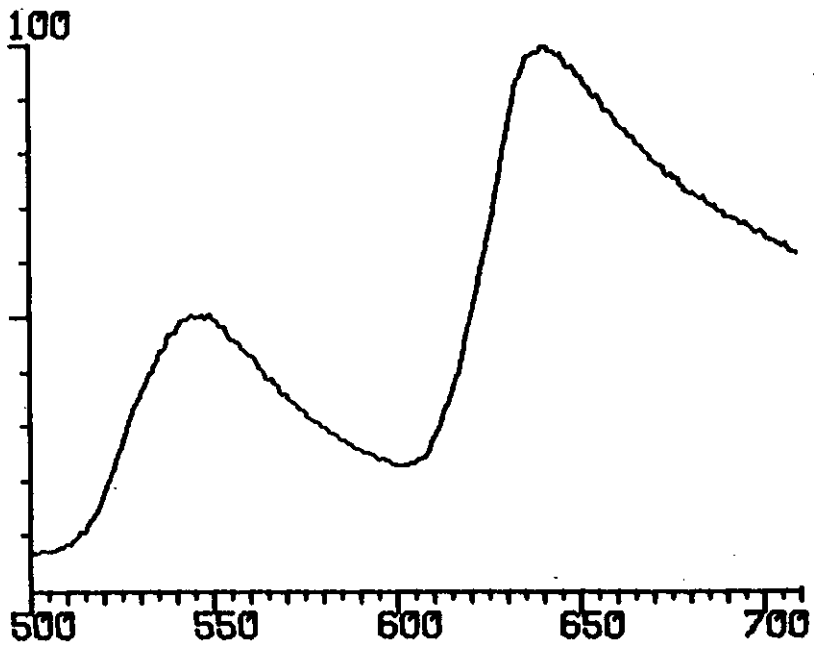

SALT SAMPLE 2786.5

MASS 44 SEARCH X2

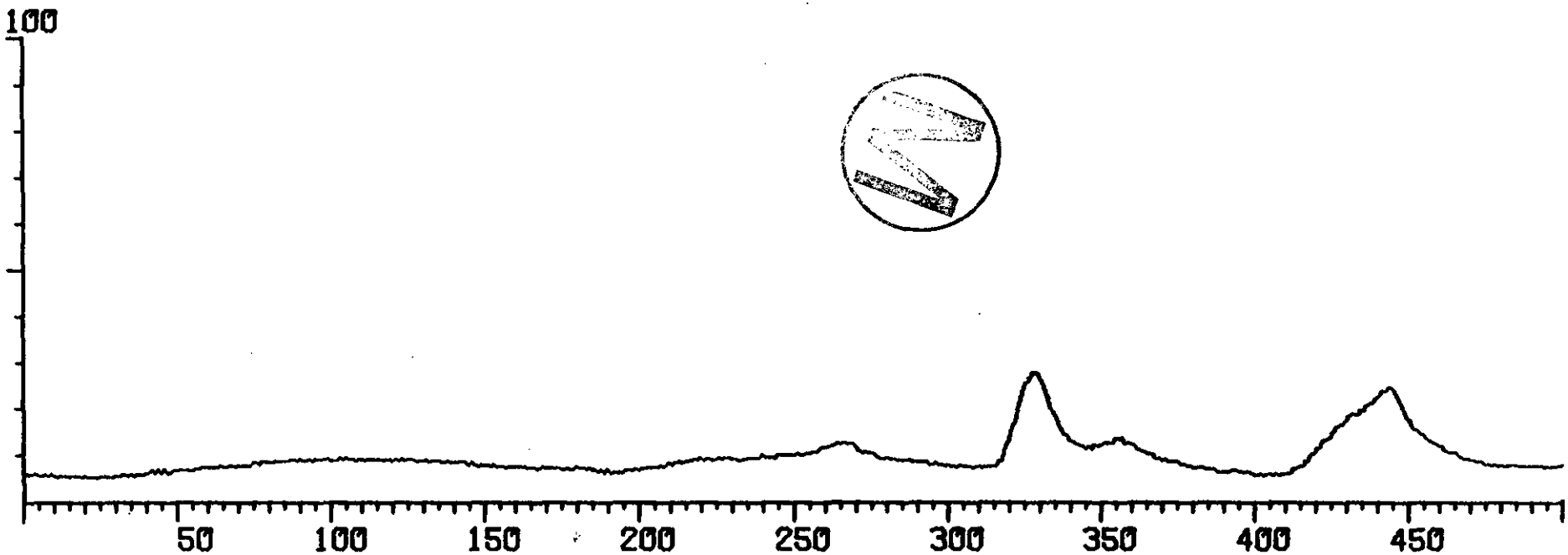

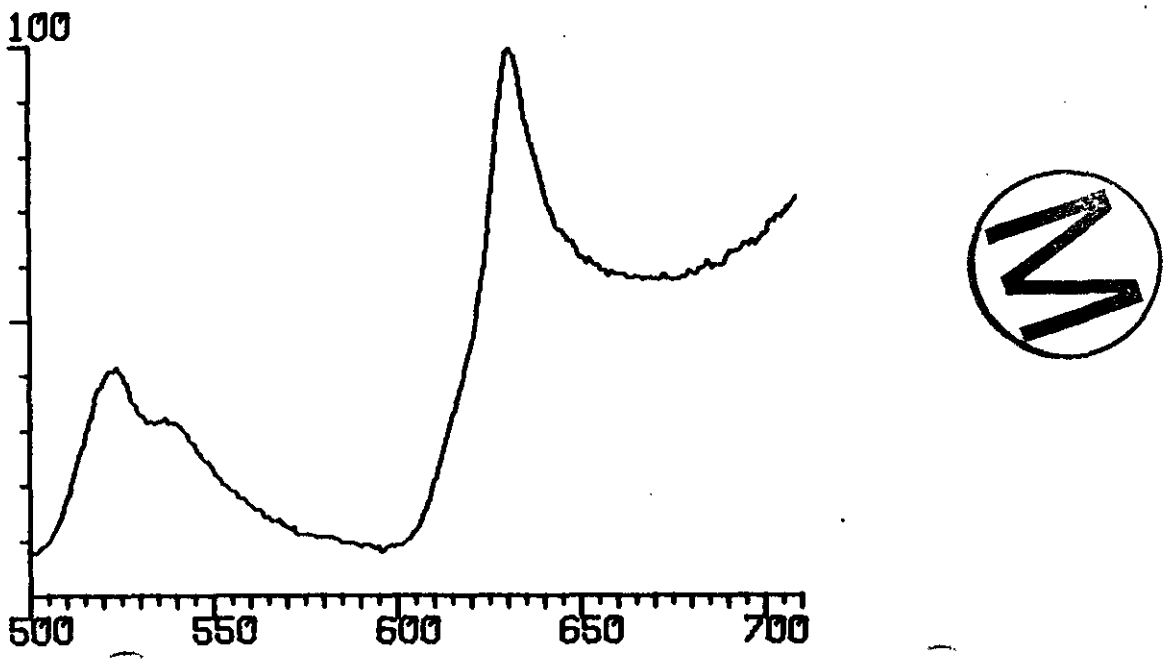

SALT SAMPLE 2786.5

MASS 48 SEARCH X1

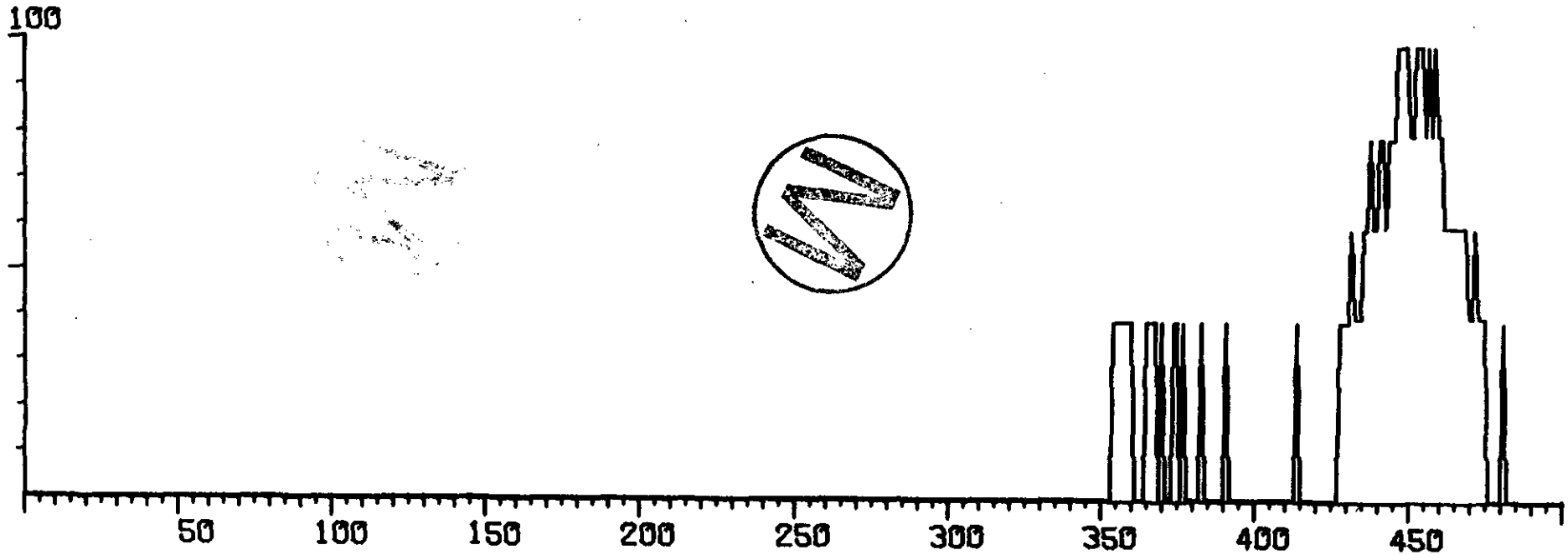

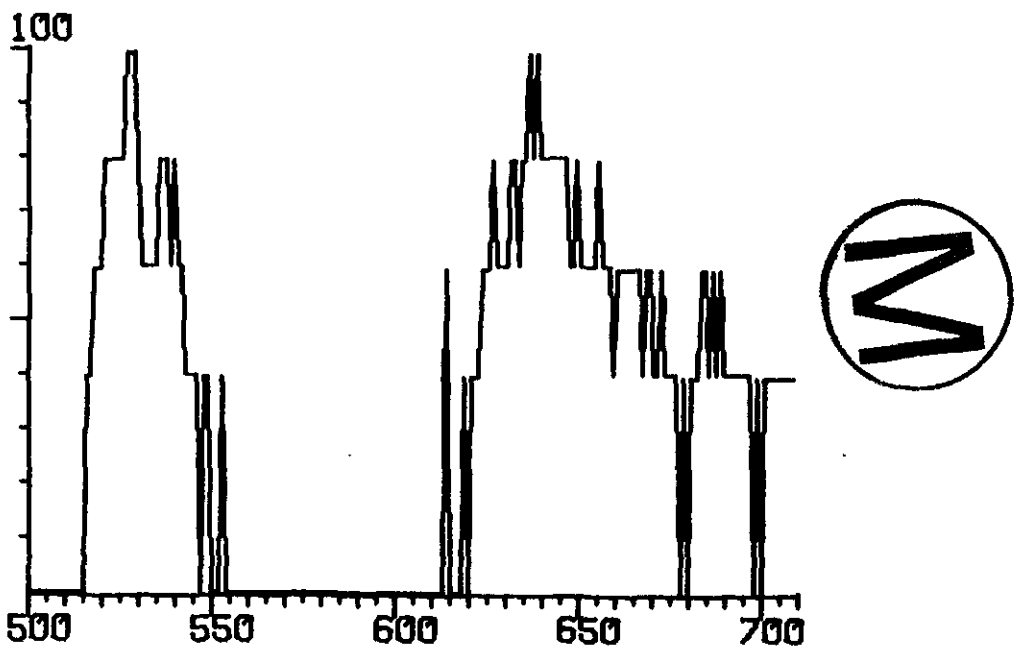

SALT SAMPLE 2821.0

TOTAL ION CHROMATOGRAM

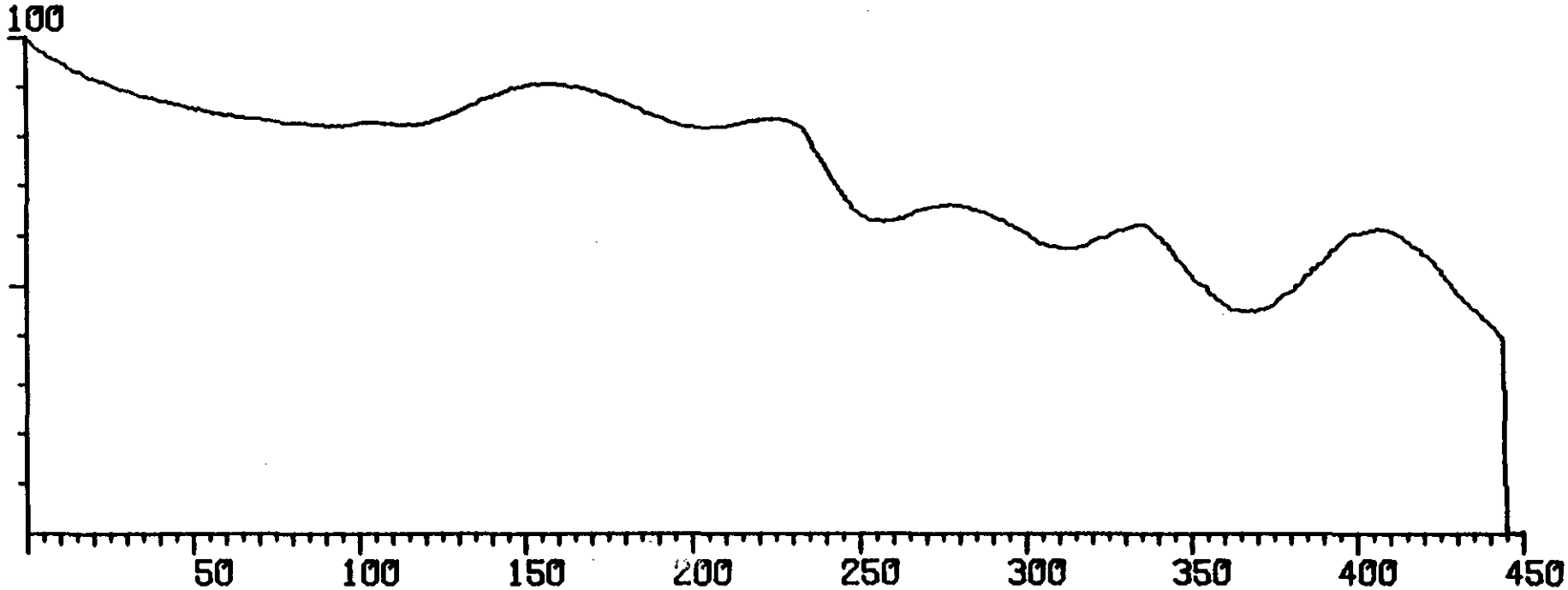

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MASS 14 SEARCH X3

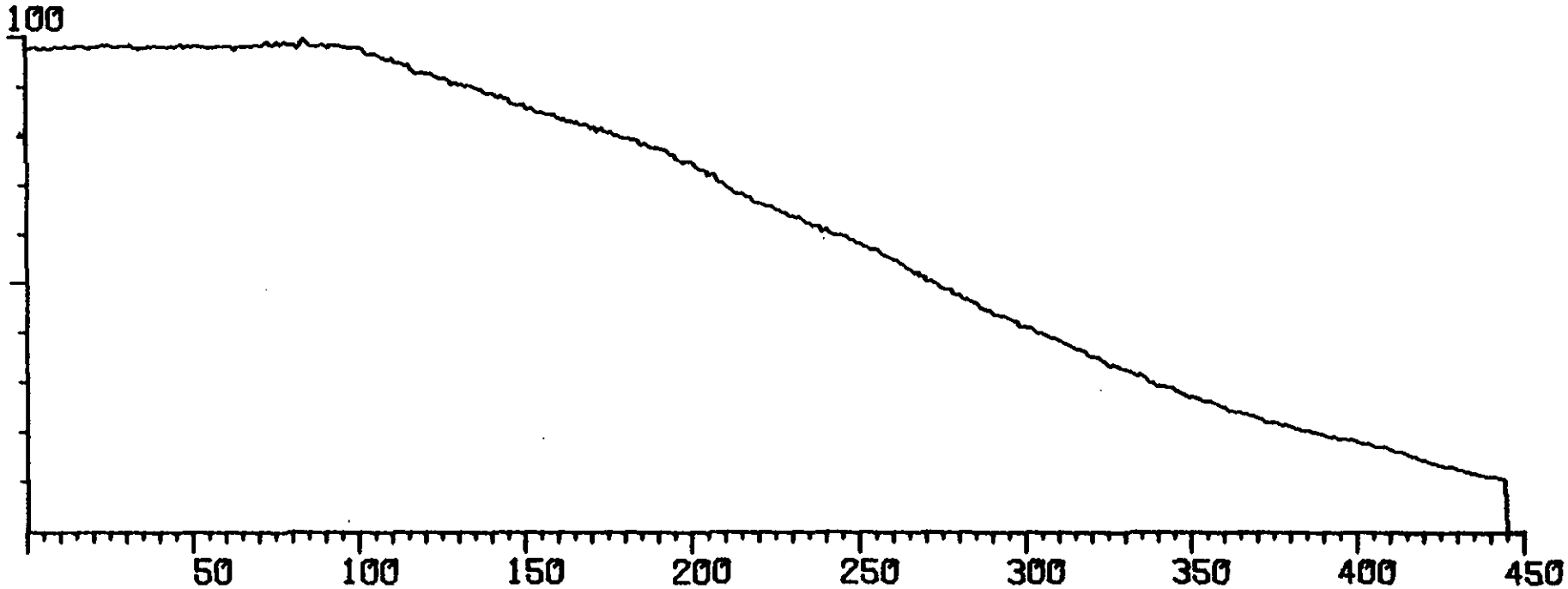

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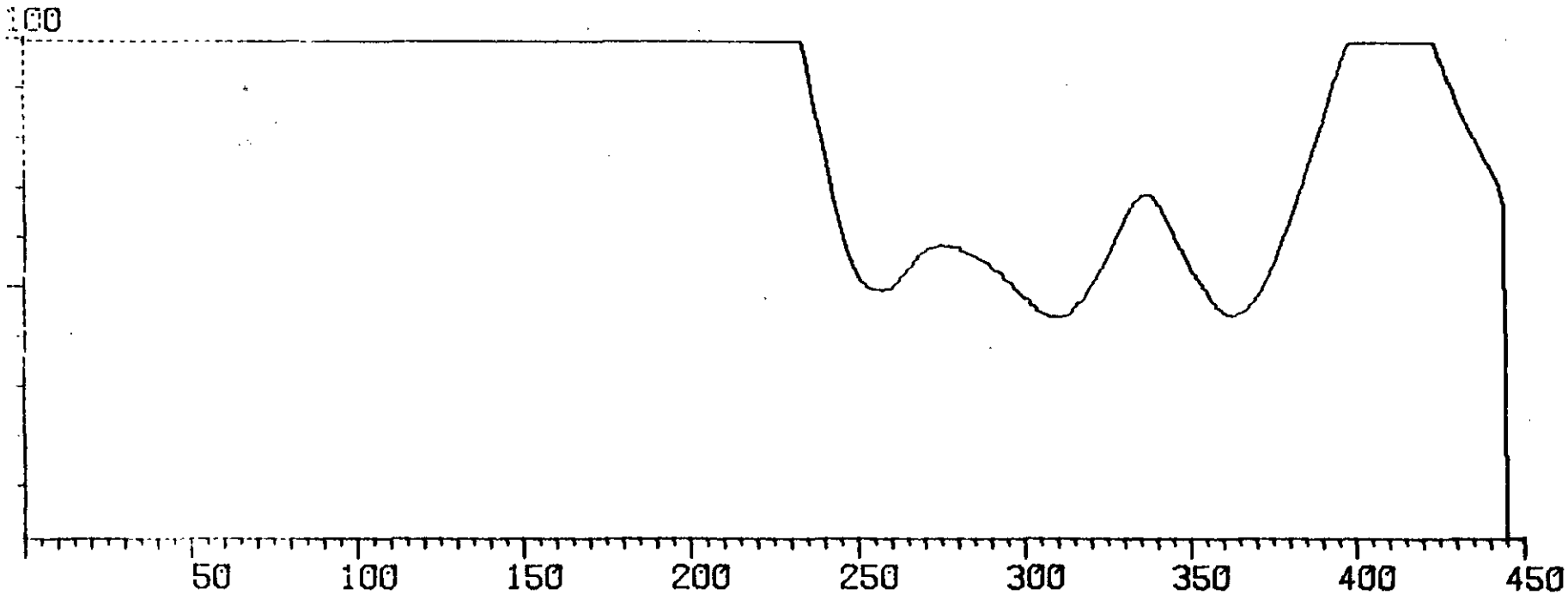

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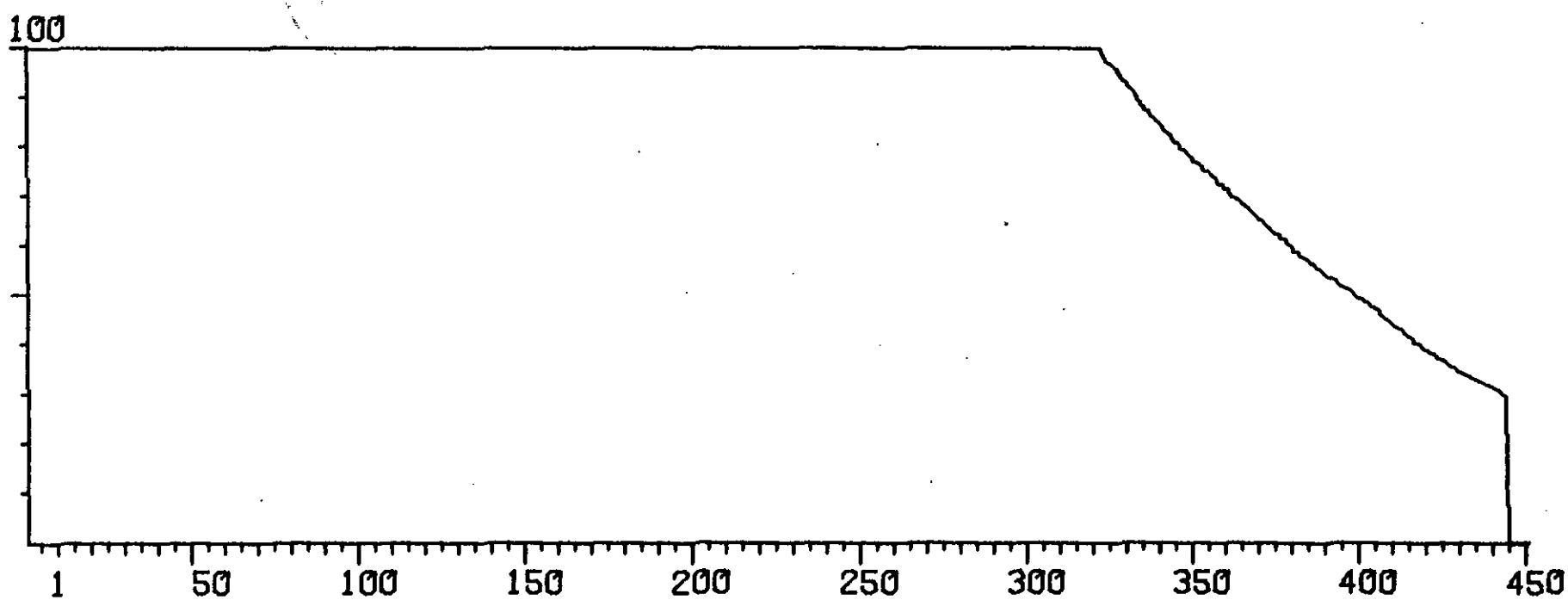

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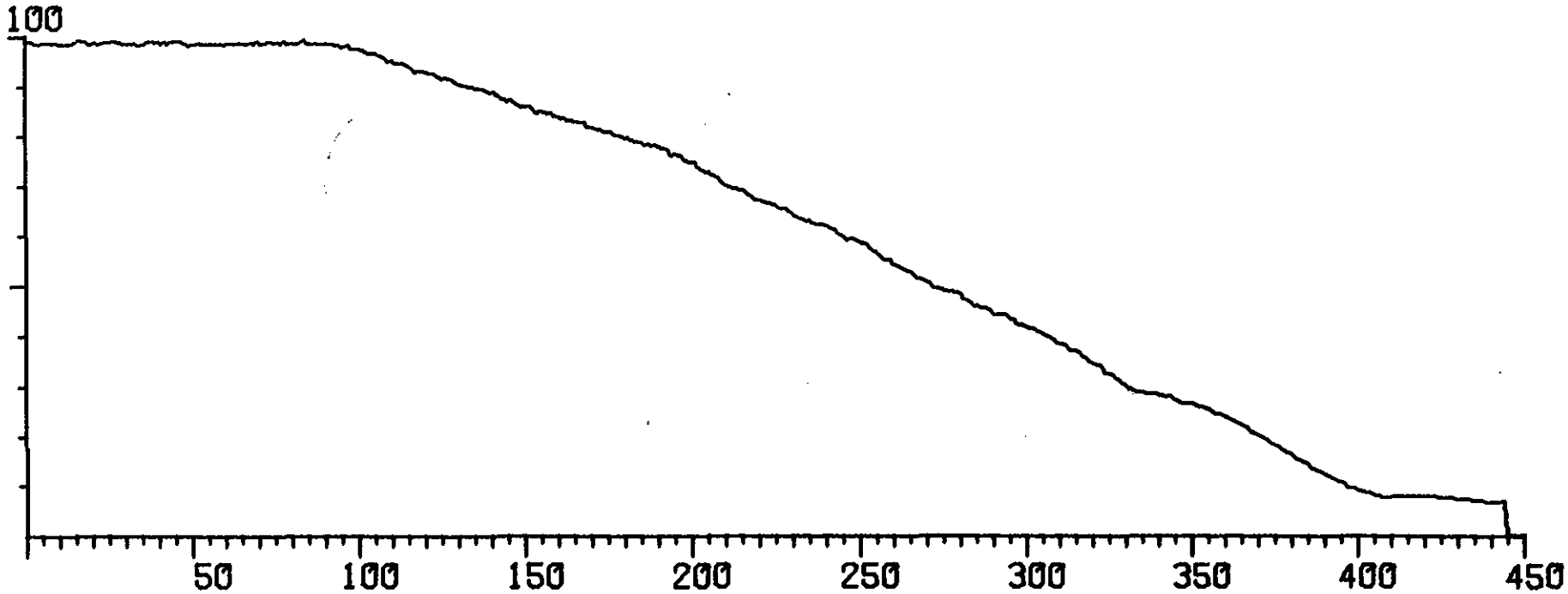

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MASS 36 SEARCH X2

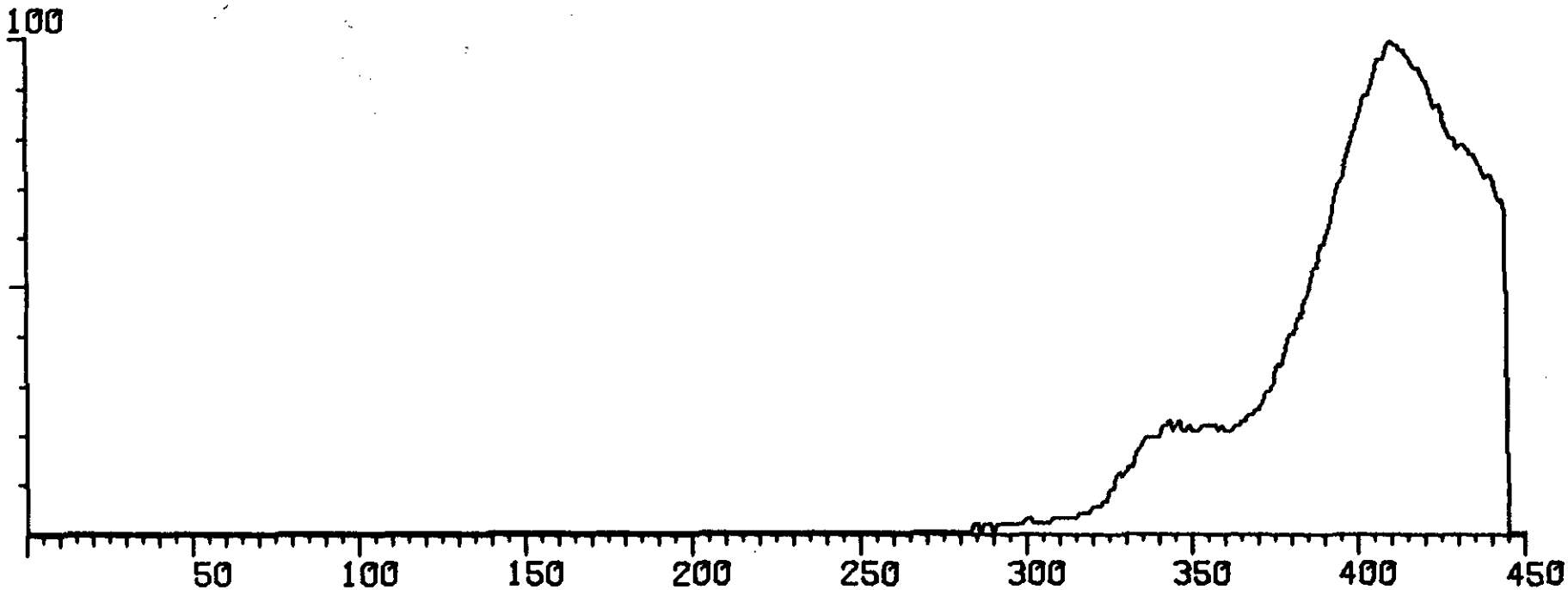

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MASS 44 SEARCH X2

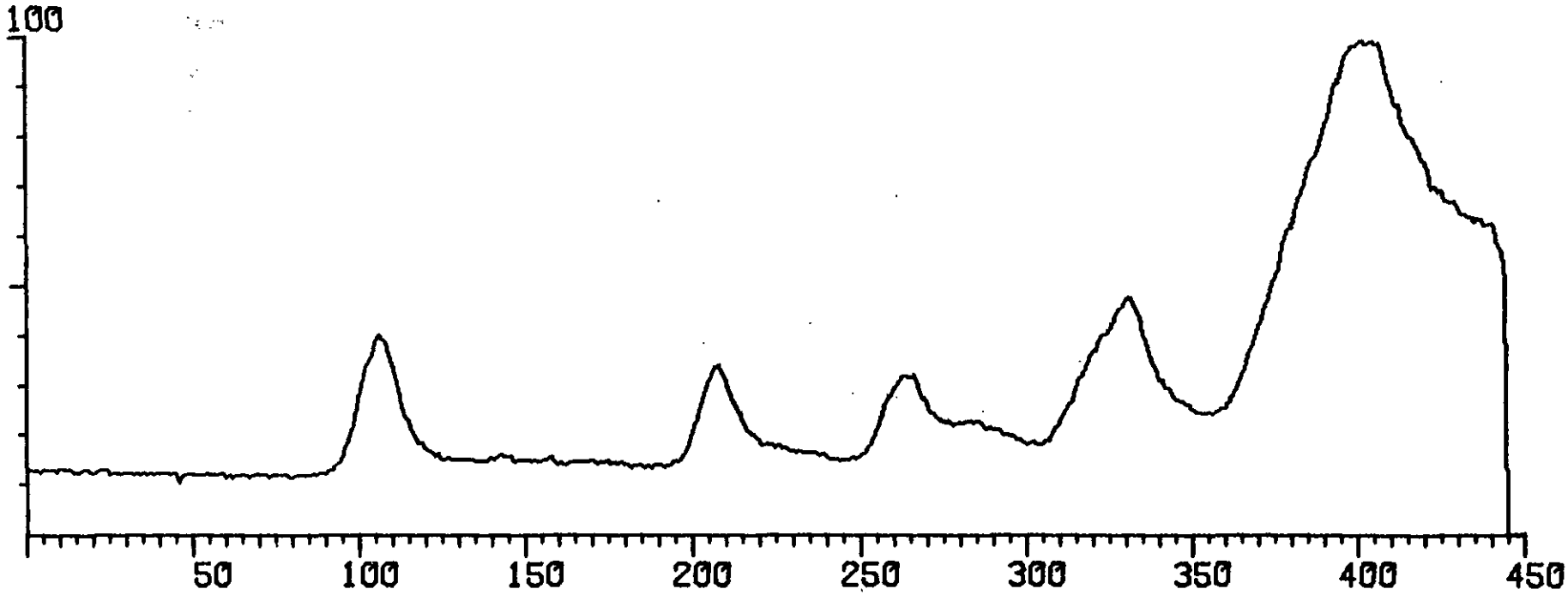

APPENDIX 7.F. Analytical Precision. (Ref. Sec. 7.5)

1. General statement concerning sample sizes, weighing errors, etc.

The sample weights used in this study ranged from approximately 0.5 to 2.5 grams, but typically were from 1.5 to 2.0 grams. The sample bottles were weighed before each new batch of samples was prepared, and both the sample bottles and the combined sample bottle and sample were weighed two times or more. Replicate weighings errors should result in a precision of no worse than ±0.1 to 0.2 weight %.

2. Results of triplicate analyses on selected samples.

Triplicate analyses were performed on separate splits taken from the sample vial using different initial sample weights each time. The results are tabulated below:

Sample	Weight Losses Determined (Wt. %)			Mean to Nearest 0.1%
7-1044	0.1	0.1	0.3	0.2
7-1296	1.3	0.9	1.3	1.2
8-1794	1.2	1.4	1.2	1.3
8-1986	0.0	0.0	0.1	0.0
8-2563	2.0	2.3	1.9	2.1
8-2616	0.0	0.0	0.0	0.0

The results of these analyses indicate that most weight losses determined from replicate samples (taken from the same sample bottle) fall within ±0.2 to 0.3 of the mean value. Because of vertical and lateral variation in mineral content typical of sedimentary rocks the range anticipated for different samples of the same core would be larger, but it is not possible to estimate the precision under such non-reproducible conditions. In the case of relatively uniform samples (such as some halite or anhydrite beds) the precision might be anticipated to remain fairly good. On the other hand, samples which contain varying amounts of clays or other hydrous minerals might be expected to show much larger variations in their weight losses upon heating.

APPENDIX 7.G. Weight Loss Data for Cores #7 and #8, Carlsbad, New Mexico, Including Comparisons with the Data of Section 7.3. (Ref. Sec. 7.5)

1. Core #7.

Sample (ft)	Depth (m)	Weight Losses at 102 ± 5°C (Wt.%)	@70°C	Data from Section 7.3 To 200°C	To Above 400°C
1044	318.2	0.1	0.10	0.10	0.10
1107	337.4	1.0	0.12	0.22	1.99
1171	356.9	0.1	0.14	0.14	0.80
1221	372.2	0.2	0.30	0.44	0.51
1342	409.0	0.2	0.27	0.27	0.43
1402	427.3	0.1	0.19	0.19	0.31
1468	447.4	2.2	1.27	1.73	2.59
1533	467.3	0.1	0.22	0.23	0.47
1615	492.3	0.2	0.34	0.43	0.80
1697	517.2	3.4	0.82	0.82	0.85
1755	534.9	0.2	0.19	0.23	0.28
1952	595.0	0.0	0.14	0.14	0.58
1954	595.6	0.6	0.32	0.32	0.41
1958	596.8	0.2	0.20	0.20	0.32
1960	597.4	0.1	0.07	0.39	0.39
1967	599.5	0.1	0.20	0.20	1.13
1969	600.2	0.2	0.43	0.51	0.71
1973	601.4	0.3	0.19	0.26	0.40
1975	602.0	0.2	0.17	0.17	0.24
1978	602.9	0.8	0.36	0.40	1.67
1983	604.4	0.0	0.29	0.32	0.51
1986	605.3	0.0	0.10	0.10	0.10
1993	607.5	0.0	0.19	0.24	1.04
2702	823.6	0.0	0.24	0.27	0.39
2716	827.8	0.2	0.22	0.22	0.26
2736	833.9	0.1	0.08	0.08	0.11

APPENDIX 7.G. Weight Loss Data, Continued.

2. Core #8

Sample (ft)	Depth (m)	Weight Losses at 102 ± 5°C (Wt.%)	Data from Section 7.3 @70°C	To 200°C	To Above 400°C
1391	424.0	0.1	0.04	0.07	0.26
1495	455.7	0.1	0.05	0.08	0.08
1573	479.5	0.2	0.04	0.33	1.18
1652	503.5	0.1	0.09	0.09	4.52
1705	519.7	0.0	0.15	0.17	0.32
1769	539.2	0.1	0.09	0.15	0.35
1787	544.7	0.2	0.32	0.36	0.59
1794	546.8	1.4	0.44	0.71	5.41
1804	549.9	0.0	0.02	0.07	0.07
1829	557.5	0.1	0.16	0.39	0.39
1838	560.2	0.3	0.39	0.39	0.39
1857	566.0	0.1	0.07	0.07	0.10
1875	571.5	1.2	0.22	0.64	0.64
1884	574.2	0.9	0.36	0.36	0.80
1890	576.1	0.1	0.05	0.05	0.13
1894	577.3	0.4	0.30	0.30	0.30
1899	578.8	0.1	0.16	0.16	0.16
1900	579.1	0.1	0.17	0.17	0.81
1905	580.6	1.0	0.36	0.36	0.62
1911	582.5	0.2	0.06	0.06	0.10
1913	583.1	0.2	0.11	0.14	0.21
1916	584.0	0.0	0.13	0.13	0.25
1923	586.1	0.1	0.19	0.19	0.49
1930	588.3	0.4	0.05	0.05	0.47
1933	589.2	0.1	0.19	0.28	0.28
1938	590.7	0.0	0.13	0.27	0.49
1953	595.3	0.1	0.05	0.10	0.42
1967	599.5	0.5	0.28	0.32	0.52
1986	605.3	0.0	0.07	0.07	5.81

APPENDIX 7.G. Weight Loss Data, Continued.

2. Core #8

Sample (ft)	Depth (m)	Weight Losses at 102 ± 5°C (Wt.%)	Data from Section 7.3 @70°C	To 200°C	To Above 400°C
2006	611.4	0.1	0.20	0.20	0.66
2017	614.8	0.2	0.22	0.24	0.41
2039	621.5	0.1	0.21	0.26	1.02
2050	624.8	0.0	0.11	0.11	0.79
2068	630.3	0.1	0.04	0.04	0.14
2084	635.2	0.3	0.17	0.22	0.71
2130	649.2	0.0	0.11	0.18	0.28
2162	659.0	0.1	0.14	0.14	0.62
2217	675.7	0.1	0.04	0.04	0.44
2280	694.9	0.0	0.19	0.19	0.27
2326	709.0	0.1	0.11	0.14	0.70
2366	721.2	1.9	0.43	0.43	6.84
2427	739.7	0.0	0.03	0.03	0.43
2460	749.8	0.0	0.17	0.22	0.37
2519	767.8	0.0	0.08	0.08	0.14
2563	781.2	2.3	1.87	2.13	2.24
2616	797.4	0.0	0.21	0.21	0.27
2666	812.6	0.0	0.25	0.25	0.73
2707	825.1	0.6	0.16	0.16	1.66
2758	840.6	0.0	0.11	0.11	0.16
2779	847.0	0.2	0.21	0.21	0.21
2793	851.3	0.0	0.18	0.18	0.18
2803	854.4	0.0	0.10	0.12	0.14
2809	856.2	0.0	0.15	0.24	0.48
2821	859.8	0.2	0.18	0.18	0.36
2879	877.5	0.2	0.06	0.06	3.37
2948	898.6	0.1	0.20	0.22	0.26

APPENDIX 7.G. Weight Loss Data, Continued.

3. Weight losses determined at higher temperatures for selected samples from Core #8.

Sample (ft)	Depth (m)	Weight Losses 102 ± 5°C	(± 0.1 to 0.2 Weight %) 170 ± 5°C	300 ± 10°C
1804	549.9	0.0	0.0	0.2
1829	557.5	0.1	0.2	0.4
1875	571.5	1.2	1.8	2.2
1884	574.2	0.9	1.0	1.5
1923	586.1	0.1	0.1	0.2
1967	599.5	0.5	0.5	1.4
2050	624.8	0.0	0.0	0.7
2366	721.2	1.9	2.0	7.4
2948	898.6	0.1	0.0	0.2

Note: In this set of weight loss determinations, one split from each sample selected was heated to successively higher temperatures.

APPENDIX 7.H. Mineralogy and Petrology of Core #7 and #8.

I. Abbreviations used.

Minerals In the summaries which follow the approximate amounts of the minerals present are indicated by upper and lower case letters. AN + MAJOR (> 25%); An + Minor (5 to 25%); an = trace (< 5%. Often less than 1%)

AN	=	Anhydrite	HA	=	Halite
CAR	=	Carnallite	KAIN	=	Kainite
CEL	=	Celestite	PH	=	Polyhalite
CSSM	=	Clay and silt-sized minerals (often magnesitic)	QTZ	=	Quartz
			SYL	=	Sylvite
FELD	=	Feldspar(s)			
GLAU	=	Glauconite			
GYP	=	Gypsum			

Grain Sizes

fg	=	Fine grained (< 1 mm)
mg	+	medium grained (1 mm to 1 mm)
cg	=	coarse grained (> 1 cm)

With the exception of halite, which shows a wide range of grain sizes, most of the minerals observed are fine grained.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

2. Core #7

Depth (ft)	Description
1044	cg HA with An and cssm in patches and stringers. An also in isolated crystals and crystal clusters.
1107	fg to mg HA with mg gyp which is partially replaced by An. fg to mg ph in patches and stringers along with cssm.
1171	Appears macroscopically bedded. Primarily vuggy AN. Voids filled with radial ("starbursts") of ph and also with ha and cssm.
1221	cg HA. Patches and stringers filled with ph (radial in part) and an. Some evidence of ph replacing an.
1296	mg to cg HA with Cssm, ph and possibly some an in patches and stringers. Some of the Cssm appears intergranular among HA crystals. May represent subaerial deposition.
1342	mg to cg HA with ph and cssm in patches and stringers.
1402	mg HA. ph (radial in part) and an in patches and stringers and as crystal clusters.
1468	mg HA with much intergranular Cssm. Possibly represents subaerial deposition. Trace an and ph as isolated crystals and crystal clusters. Some authigenic quartz and feldspar.
1533	mg to cg HA with poorly preserved hoppers. Ph in patches and stringers, some possibly intergranular with HA. Trace Cssm associated with the Ph.
1615	mg to cg HA with hoppers. fg to mg An and ph in patches and stringers. ph appears to be replacing An, some of which may be psuedomorphic after gypsum.
1697	Appears to be macroscopically bedded. Large, nodular masses of AN (possibly pseudomorphic after gypsum nodules) with voids filled with Cssm, Ph, ha and syl. Ph associated with Cssm; syl associated with Ph.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

2. Core #7, continued

Depth (ft)	Description
1755	mg to cg Ha with poorly preserved hoppers. ph and an in patches and stringers. ph replaces an in part. Perhaps a little syl is present.
1952	Appears macroscopically bedded. mg to cg HA with hoppers. Ph and an in patches, stringers and as isolated crystals and clusters. Ph replacing an in part.
1954	mg to cg HA with Cssm in patches and stringers. Some Cssm is intergranular with HA. May represent subaerial deposition. Some isolated crystals and clusters of ph associated with Cssm.
1958	mg to cg HA. cssm in patches and stringers. (Some cssm may be intergranular). ph and possible an in patches and stringers associated with cssm and also in isolated crystals and clusters.
1960	Possibly macroscopically bedded. fg to cg HA with hoppers. Intergranular Cssm with associated authigenic qtz and feld. May represent suberial deposition. Some isolated crystals and clusters of ph and an.
1967	mg to cg HA with poorly preserved hoppers. ph in patches and stringers shows some evidence of flow or deformation. A few isolated crystals and clusters of an.
1969	fg to cg HA with poorly preserved hoppers. Intergranular Cssm with associated authigenic qtz and feld. Isolated crystals and clusters of an and lesser ph.
1973	cg HA with very few patches and stringers of cssm, ph and even some ha crystals.
1975	cg HA with ph, cssm and an in patches and stringers. ph appears to be replacing an. ph associated with cssm.
1978	mg to cg HA with intergranular Cssm and ph. May represent subaerial deposition. Some ph in patches and stringers and as isolated crystals and clusters. Some ph is mg. Isolated crystals of an are associated with the ph.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

2. Core #7, continued

Depth (ft)	Description
1983	mg to cg HA with hoppers. Ph and an in patches and stringers Ph replacing an.
1986	mg to cg HA with small amounts of ph, an and cssm in patches and stringers.
1993	cg HA with hoppers. Ph and an in patches and stringers. (Some Ph and an may be intergranular). Ph appears to replace an.
2702	mg to cg HA with An and cssm in patches and stringers.
2716	mg to cg HA with hoppers. an and cssm in patches and stringers, some possibly intergranular with HA. May represent subaerial deposition.
2736	mg to cg HA with hoppers. An and cssm in patches and stringers, some possibly intergranular with HA. May represent subaerial deposition.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8

Depth (ft)	Description
1391	cg HA with ph and possibly some an in patches and stringers.
1495	mg to cg HA with hoppers. Ph associated with cssm in patches and stringers. Some may be intergranular. Ph shows evidence of flowage or deformation.
1573	Appears macroscopically bedded. mg to cg HA with Ph and fg to mg An in large patches. Ph appers to be replacing An.
1652	Appears macroscopically bedded. fg to mg AN with Ph. mg Ha in patches or voids. Some syl associated with Ph. Algal laminations may be present in the An.
1705	fg to cg HA with hoppers. Ph in patches and stringers; some may be intergranular. Small amount of an associated with Ph.
1769	mg to cg HA with poorly preserved hoppers. fg to mg Ph in patches and stringers and intergranular with HA. In part, Ph appears to be replacing HA. Some gyp (?) may be present in very small amounts. There also may be trace amounts of cel (?).
1787	mg to cg HA with hoppers. Ph in patches and stringers and some intergranular with HA. Some mg, acicular an crystals and mg, acicular cel (?) crystals noted. There may be a small amount of gyp (?) present in this slide.
1794	Appears macroscopically bedded. fg to mg HA with hoppers. CSSM is intergranular with HA. May represent subaerial deposition. Also noted: a few isolated ph crystals, some authigenic qtz and feld, and a trace of glau (?).
1804	fg to cg HA with poorly presrved hoppers. CSSM is intergranular with HA. May represent subaerial deposition. ph in isolated crystals and cluters.
1829	cg HA with hoppers. Cssm in patches and stringers and some intergranular. Possible subaerial deposition. Trace of ph.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
1838	fg to mg HA with poorly preserved hoppers. Cssm intergranular with HA. Ph and An in patches and stringers and associated wtih the Cssm. May represent subaerial deposition.
1857	cg HA with poorly preserved hoppers. ph along stringers.
1875	Apperas macroscopically bedded. fg to mg HA intergranular with CSSM. May represent subaerial deposition. Isolated crystals and clusters of ph and fg to mg an. Traces of authigenic qtz and feld.
1884	fg to mg HA with hoppers, intergranular with CSSM. May represent subaerial deposition. Some isolated crystals and clusters of fg to mg an (some may be pseudomorphic after gyp). Possible trace of syl.
1890	mg to cg HA with hoppers. ph and an in patches and stringers.
1894	mg to cg HA with poorly preserved hoppers. ph and an in patches and stringers. cssm in patches and stringers with authigenic qtz and feld.
1900	fg to cg HA with hoppers. Ph, An and cssm in patches and stringers and some intergranular with HA. May represent subaerial deposition. Some Ph appears to be deformed or to have flowed.
1905	mg to cg HA with patches and stringers and some intergranular Cssm. (May represent subaerial deposition). Scattered, isolated crystals of ph and an.
1910	mg to cg HA with poorly preserved hoppers. Ph, an and cssm intergranular with HA and in patches and stringers. Ph apperas to be replacing an.
1911	mg to cg HA with hoppers. Ph, An and cssm in patches and stringers, some intergranular with HA. (May represent subaerial deposition). Ph appears to be replacing an.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
1913	fg to cg HA with intergranular Cssm. Inclusions of ha in Cssm. May represent subaerial deposition. Isolated crystals of ph. A few authigenic grains of qtz and feldspar.
1916	cg HA with poorly preserved hoppers. ph and an in patches and stringers.
1923	fg to cg HA with intergranular Cssm. May represent subaerial deposition. ph and an in patches and stringers and as isolated crystals. Trace authigenic feld.
1930	mg to cg HA with poorly presrved hoppers. Ph and an in patches and stringers, some as isolated crystals. cssm in patches and stringers. Possible trace gyp (?).
1933	cg HA with hoppers. cssm, ph and an in patches and stringers. Small amounts of authigenic qtz and feld (?).
1938	cg HA with poorly preserved hoppers. Ph and an in patches and stringers.
1953	fg to mg HA with hoppers. Cssm intergranular with HA and in patches and stringers. May represent subaerial deposition. Isolated crystals and clusters of ph and an.
1967	fg to cg HA with hoppers. Cssm intergranular with HA and in patches and stringers. May represent subaerial deposition. Isolated crystals and clusters of ph and an.
1986	Appears cross-bedded. PH with mg AN. Ph appeas to be replacing AN. Some fine laminations may be algal lamination or traces of cssm seams. ha in patches or filling void places.
2006	fg to cg HA with hoppers. Ph and an in patches and stringers. Trace of syl associated with Ph.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
2017	mg to cg HA with hoppers. Ph and an in patches and stringers. Ph appears to be replacing an. cssm in patches.
2039	mg to cg HA with hoppers. Ph and an with cssm in patches and stringers. Much of the Ph is radial. Ph appears to be replacing an.
2050	mg AN with numerous inclusions. AN apperas to be replacing ha with former cubic crystal outlines preserved.
2068	fg to cg HA. Patches and stringers and intergranular An, cssm and possible ph (?). May represent subaerial deposition.
2084	fg to cg HA with much intergranular Cssm, ph and poissible an (?). May represent subaerial deposition. Some Ha crystals appear to be growing in the Cssm.
2130	fg to mg HA with intergranular An and minor cssm. Some ph (?) may be replacing An.
2162	cg HA with intergranular Cssm and Ph. May represent subaerial deposition. Trace of an associated with Ph. Trace of syl associated with Ph.
2217	cg HA with patches and stringers of Ph and an. Some Ph radial and replacing an. Possible syl associated with Ph.
2280	fg to cg HA with patches and stringers of Ph and an. POssible trace of kain (?).
2326	fg to cg HA with poorly preserved hoppers. Cssm intergranular with HA. May represent subaerial deposition. Isolated crystals and clsuters of ph and an. Trace authigenic feld (?).
2366	Possibly macroscopically bedded. fg, radial PH with minor an. cssm scattered throughout.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
2427	fg to cg HA with poorly preserved hoppers. An and cssm in patchers, stringers, and intergranular with HA. May represent subaerial deposition, in part. Possible fossil (bryozoan) fragment.
2460	mg to cg HA with hoppers. Patches, stringers, and intergranular An and cssm. mg an in isolated crystals and clusters along the margins of the patches and stringers.
2519	mg to cg HA with poorly preserved hoppers. Patches, stringers and intergranular an ofter associated with cssm. May represent subaerial deposition.
2563	Possibly macroscopically bedded. Nodular AN with patches of Cssm. Possible mudcrack or burrow along one edge of slide normal to the bedding.
2616	fg to mg HA with poorly preserved hoppers. An intergranular with HA and as patches and stringers. May represent subaerial deposition.
2666	fg to cg HA with poorly preserved hoppers. Patches, stringers, and intergranular Cssm and an. May represent subaerial deposition.
2707	cg HA with hoppers. Patches and stringers of Cssm and an.
2758	fg to mg HA with poorly preserved hoppers. An associated wtih cssm in patches, stringers (some intergranular). May represent subaerial deposition. Some An in isolated crystals.
2779	fg to cg HA with hoppers. An and cssm in patches stringers and intergranular with HA. May represent subaerial deposition.
2793	fg to cg HA with trace evidence of hoppers. Intergranular AN and cssm. May represent subaerial deposition. Patches and stringers of An. Traces of ph and authigenic qtz (?).

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
2803	fg to cg HA with hoppers. Intergranular An and cssm. Some An in patches with possible ph (?). A few large, isolated crystals of An. May represent subaerial deposition.
2809	fg to mg HA with trace evidence of hoppers. An and cssm in patches, stringers and as intergranular material. May represent subaerial deposition.
2821	mg to cg HA with hoppers. Intergranular An and cssm. Some An in patches and stringers. May represent subaerial deposition.
2879	Possible macroscopic evidence of bedding. fg to mg HA with hoppers. Patches and stringers of An and cssm. POssible trance of ph (?). An unknown minerals with lower birefringence and positive relief was observed. Also present are some large, isolated crystals of An.
2948	Possible macroscopic evidence of bedding. mg to cg HA with hoppers. Some patches and stringers of An present. Some may be nodular (?) (possibly pseudomorphic after gyp). a few isolated crystals of ph (?) were noted.

APPENDIX 8A

Analyses of Potash for Department of Energy
(then ERDA) and Industry Boreholes in the WIPP Area

Source is Table 3, John et al., 1978

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral*

[Drill-hole no., Drill-hole designations. P, Energy Research and Development Administration; FC, Farm Chemical Res. Dev. Corp; IMC, International Minerals and Chemical Corp; NFU, Farmers Edu. and Coop. Union of America; D, Duval Sulphur and Potash Co.; U, U.S. Potash Co., Inc. Arc, arcanite; Bs, bischofite; Bl, bloedite; C, carnallite; Gl, glaserite; Gu, glauberite; Ka, kainite; Ki, kieserite; L, langbeinite; Le, leonite; Lo, loewite; S, sylvite; Va, vanthoffite]

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
P-1	5	9	1440.47-1441.35	0.88	8	76	---	15.0	Tr/Ka[1]	3.4/L	
	5	10	1441.35-1442.30	0.95	9	86	---	4.4		1.0/L	
	5	11	1442.30-1443.50	1.20	---	79	---	---	14.0/Ka Tr/Bl[1]	---	
	5	12	1443.50-1444.35	0.85	---	95	---	2.34	---	0.53/L	
	5	13	1444.35-1445.30	0.95	1	79	---	17.07	---	3.87/L	4.83-1.67/L
P-2	10	14	1627.15-1628.35	1.20	1	39	---	39.9	1.9/Ka 5.0/Le	9.05/L	
	10	15	1628.35-1629.52	1.17	1	46	---	43.1	2.6/Ka 0.5/Le	9.78/L	2.37-9.41/L
	4	5	1802.70-1804.00	1.30	1	39	---	38.0	12.9/Ka	8.6/L	
	4	6	1804.00-1805.00	1.00	6	80	---	---	---	---	
	4	7	1805.00-1805.85	0.85	5	89	---	---	---	---	
	4	8	1805.85-1806.30	0.45	6	60	---	20.0	4.0/Ka 3.7/Le	4.54/L	3.60-3.67/L
	2	1	1833.08-1834.00	0.92	2	79	---	4.4	1.9/Ka	3.14/L	
	2	2	1834.00-1834.50	0.50	---	38	---	52.9	0.5/Ka	12.0/L	1.42-6.26/L
P-3	4	3	1596.30-1597.60	1.30	2	72	---	24.7	0.5/Ka	5.6/L	
	4	4	1597.60-1598.70	1.10	2	62	---	18.6	0.5/Ka	4.22/L	
	4	5	1598.70-1599.53	0.83	34	38	---	23.4	---	5.31/L	3.23-5.06/L
P-4	10	2	1572.60-1574.97	2.37	1	56	46.0	---	---	29.40/S	
	10	3	1574.97-1576.17	1.20	4	64	27.6	---	---	17.48/S	
	10	4	1576.17-1577.77	1.60	3	86	7.0	---	---	4.32/S	
	10	5	1577.77-1578.69	0.92	4	64	28.0	---	---	17.46/S	6.09-18.66/S
P-5	10	6	1546.69-1548.65	1.96	6	65	28.0	---	---	18.28/S	
	10	7	1548.65-1549.66	1.01	4	76	13.3	---	---	8.42/S	
	10	8	1549.66-1551.40	1.74	3	60	21.0	---	---	13.41/S	
	10	9	1551.40-1552.75	1.35	2	65	14.5	---	---	9.14/S	6.06-13.2/S
P-6	4	12	1476.00-1477.45	1.45	6	74	---	22.0	1.0/Ki	5.01/L	
	4	13	1477.45-1478.37	0.92	1	83	2.0	8.0	6.0/Ki	1.90/L 1.26/S	
	4	14	1478.37-1480.00	1.63	3	84	---	12.0	---	2.78/L	4.00-3.39/L
	2	18	1510.50-1511.32	0.82	1	37	2.0	54.0	6.0/Ki	12.31/L	
	2	19	1511.32-1512.10	0.78	---	53	---	47.0	---	9.65/L	
	2	20	1512.10-1513.05	0.95	7	79	3.0	1.0	8.6/Ka	0.19/L	2.55-6.18/L
P-7	4	2	1479.73-1481.20	1.47	2	65	1.0	29.0	---	6.53/L	
	4	3	1481.20-1480.00	1.80	---	89	2.0	3.0[4]	---	0.75/L[4]	
	4	4	1483.00-1483.48	0.48	3	69	2.0	3.8	5.7/Ka 1.0/Le 1.0/Bl	3.8/L	3.75-3.41/L
P-8	10	2	1363.70-1365.00	1.30	---	52	29.0	25.0	---	18.45/S 5.62/L	
	10	3	1365.00-1366.72	1.72	1	46	3.0	45.0	4.0/Ka 2.0/Le	10.3/L 1.65/S	
	10	4	1366.72-1368.05	1.33	1	86	---	14.0	---	8.23/L	4.35-6.74/L 4.35-6.17/S mixed ore equivalent: 4.35-9.2/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of intervals (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
P-9	10	8	1522.56-1523.41	0.85	1	42	7.0	48.0	0.67/Ka	4.73/S 10.8/L	
	10	9	1523.41-1524.07	0.66	1	93	2.0	---	3.0/Ki	0.96/S	
	10	10	1524.07-1524.70	0.63	2	17	7.0	63.37	---	4.42/S 14.37/L	
	10	11	1524.70-1526.04	1.34	3	95	---	1.10	---	0.24/L	
	10	12	1526.04-1526.74	0.70	2	65	---	31.31	---	7.1/L	4.18-5.63/L 2.14-3.48/S mixed ore equivalent: 4.18-6.34/L
	4	17	1703.65-1705.23	1.58	2	70	---	28.70	---	6.51/L	
	4	18	1705.23-1705.65	0.42	1	89	---	6.80	3.0/Ka	1.55/L	2.00-5.47/L
P-10	11	1	1650.38-1651.22	0.84	6	89	1.8	---	1.0/Ka	1.13/S	
	11	2	1651.22-1652.03	0.81	7	81	6.1	---	2.0/Ki	3.83/S	
	11	3	1652.03-1653.83	1.80	5	85	7.7	---	1.0/Ki	4.85/S	3.45-3.70/S
	11	4	1653.83-1654.58	0.75	6	94	---	---	---	---	
P-11	11	2	1601.90-1603.56	1.66	---	56	5.0	---	3.60/Ki 1.0/C	3.34/S	
	11	3	1603.56-1604.64	1.08	3	61	2.0	---	31.0/Ka 3.0/C	1.48/S	
	11	4	1604.64-1605.38	0.74	4	84	3.0	---	7.0/Ka 2.0/C	2.20/S	3.48-2.52/S
	10	7	1670.70-1671.84	1.14	1	71	19.0	8.0	1.0/Ki	12.0/S 1.82/L	
	10	8	1671.84-1673.42	1.58	2	66	10.0	18.0	1.0/Ki	6.32/S 3.98/L	
	10	9	1673.42-1674.70	1.28	3	71	16.7	---	1.0/Ki	10.53/S	4.00-9.29/S 2.72-3.07/L mixed ore equivalent: 4.00-14.51/S
	9	14	1688.72-1689.60	0.88	3	76	22.0	---	---	13.74/S	
	9	15	1689.60-1690.89	1.29	1	64	36.9	---	---	23.30/S	
	9	16	1690.89-1691.95	1.06	1	71	21.3	---	2.0/C	13.43/S	
	9	17	1691.95-1693.28	1.33	2	92	2.0	---	1.0/C	1.24/S	4.56-12.73/S
	4	19	1840.60-1842.35	1.75	1	58	---	40.0	5.0/Ki	9.14/L	
	4	20	1842.35-1843.40	1.05	4	76	5.0	4.9	---	1.11/L 2.98/S	2.80-6.0/L
	2	22	1868.67-1870.28	1.61	1	38	2.0	60.0	2.0/Ki	13.65/L	
	2	23	1870.28-1871.10	0.82	---	54	5.0	45.0	1.0/Ki	13.53/L	
	2	24	1871.10-1872.30	1.20	---	27	---	58.3	8.0/Ka Tr/Bl&Lo[1]	13.24/L	3.63-13.49/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent): Polyhalite	Halite	Sylvite	Langbeinite	Other minerals	K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
P-12	10	2a	1344.97-1345.27	0.3	4	36	62.3	---	1.0/Ki	39.38/S	
	10	2b[4]	1345.27-1345.90	0.63	---	10	24.0[2]	---	59.0/Ki	15.08/S	
	10	3	1345.90-1346.95	1.05	1	59	18.0	---	18.0/Ki	11.39/S	
	10	4	1346.95-1348.90	1.95	3	64	18.0	---	19.0/Ki	11.36/S	
	10	5	1348.90-1349.91	1.01	7	44	20.0	---	8.6/Ki 8.7/Ka	12.63/S	
	10	6	1349.91-1350.80	0.89	3	67	16.0[3]	---	2.0/Ka	10.42/S	5.83-13.29/S
	8	14	1390.19-1390.97	0.78	4	80	15.5	---	---	9.77/S	
	8	15	1390.97-1392.66	1.69	7	88	7.0	---	---	4.12/S	
	8	16	1392.66-1394.29	1.63	4	88	10.3	---	---	6.47/S	
	8	17	1394.29-1394.90	0.61	8	51	35.5	---	---	22.42/S	4.71-8.24/S
	4	21	1520.00-1521.55	1.55	1	22	23.0	45.0	9.0/Ki	14.47/S 10.13/L	2.39-7.08/L
	4	22	1521.55-1522.39	0.84	10	48	7.0	6.0	16.0/Ka 10.0/Le	1.44/L 4.42/S	2.39-10.94/S mixed ore equivalent: 4.00-8.23/L
	3	26	1533.50-1535.05	1.55	---	40	11.0	49.0	---	7.0/S 8.59/L	
	3	27	1535.05-1535.59	0.54	34	86	1.0	8.0	1.0/Ki	1.80/L 0.62/S	3.51-5.98/L
	3	28	1535.59-1537.01	1.42	2	47	10.0	21.0	---	4.72/L 6.32/S	3.51-5.74/S mixed ore equivalent: 3.51-8.27/L
	2	34	1549.79-1550.65	0.86	3	85	---[4]	11.0	2.42/L	0.54/L	
	2	35a	1550.65-1551.29	0.64	---	20	5.0	70.0	1.0/Ka Tr/Le[1]	15.93/L	
	2	35b	1551.29-1551.61	0.32	---	21	5.0	30.0	18.0/Ka 19.0/Le 17.0/Bl	12.48/L	1.82-8.05/L
P-13	10	29	1318.02-1319.00	0.98	1	46	49.5	---	---	31.32/S	
	10	30	1319.00-1320.22	1.22	1	62	17.0	2.0	15.0/Ki	10.92/S	
	10	31	1320.22-1320.88	0.66	3	97	---	---	---	---	
	10	32[4]	1320.88-1321.87	0.99	1	30	20.0	10.0	30.0/Ki 10.0/Ka	12.6/S 2.27/L	3.85-14.67/S
	9	36	1334.82-1336.38	1.56	2	94	2.0	---	---	1.12/S	
	9	37	1336.38-1337.32	0.94	2	62	34.8	---	---	21.99/S	
	9	38	1337.32-1338.64	1.32	---	90	3.8	---	---	2.41/S	3.82-6.7/S
	8	21	1359.65-1360.63	0.98	2	67	30.2	---	---	19.13/S	
	8	22	1360.63-1361.70	1.07	8	80	9.14	---	---	4.97/S	2.05-11.74/S
	4	2	1480.20-1481.73	1.53	2	82	2.0	9.0	3.0/Ki	2.03/L	
	4	3	1481.73-1482.78	1.05	1	63	---	33.2	0.4/Le	7.53/L	3.53-4.06/L
	4	4	1482.78-1483.73	0.95	1	64	---	7.0	7.0/Bl	1.59/L	

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
	3	8	1493.23-1493.88	0.65	2	86	---	7.0	---	1.59/L	
	3	9	1493.88-1494.58	0.70	---	15	---	53.0	---	12.06/L	
	3	10	1494.58-1495.50	0.92	3	86	---	10.0	---	2.21/L	2.27-5.07/L[5] 4.00-2.88/L[5]
P-14	10	2	1255.24-1255.64	0.40	---	41	57.0	---	---	36.03/S	
	10	3	1255.64-1257.56	1.92	---	41	57.0	---	---	36.06/S 8.84/S	
	10	4	1257.56-1259.07	1.51	3	64	14.0	18.0	Tr/Ka[1]	3.99/L	
	10	5	1259.07-1260.15	1.08	4	74	7.0	22.0	---	4.36/S 4.88/L	
	10	6	1260.15-1261.05	0.90	2	55	12.0[6]	---	16.0/Ka	6.21/S	5.81-18.47/S 2.59-4.36/L mixed ore equivalent: 5.81-23.33/S
	5	10	1364.44-1366.11	1.67	5	74	5.0	15.0	1.0/Ka	3.35/L 3.00/S	
	5	11	1366.11-1367.86	1.75	3	83	---	19.0	Tr/Ka[1]	4.3/L	
	5	12[6]	1367.86-1369.26	1.40	1	80	---	13.0	Tr/Ka[1]	3.03/L	4.82-3.60/L 1.67-3.0/S mixed ore equivalent: 4.82-4.02/L
	4	18	1440.79-1441.98	1.19	4	46	6.0	38.5	---	8.74/L 3.99/S	
	4	19	1441.98-1442.84	0.86	5	95	---	---	---	---	
	4	20	1442.84-1443.98	1.14	16	56	4.0	23.0	Tr/Le 2.0/Ka	5.22/L 2.53/S	
	4	21	1443.98-1444.61	0.63	3	88	---	11.0	---	2.50/L	3.82-4.69/L 3.19-2.39/S
P-15	4	7	1371.94-1372.81	0.87	6	76	---	25.0	---	5.59/L	
	4	8	1372.81-1374.77	1.96	8	89	---	4.0	---	1.00/L	
	4	9	1374.77-1375.80	1.03	9	64	---	28.0	---	6.30/L	3.86-3.45/L
	2	13	1399.66-1400.38	0.72	3	64	---	32.0	4.0/Ka	7.18/L	
	2	14	1400.38-1401.51	1.13	---	78	---	17.0	3.0/Ka 3.0/Le	4.28/L	1.85-5.41/L
P-16	10	4	1301.94-1302.57	0.63	3	93	0.7	4.0	---	0.47/S 0.89/L	
	10	5	1302.57-1303.91	1.34	3	79	---	21.0	---	4.77/L	
	10	6	1303.91-1304.39	0.48	---	61	---	34.0	8.1/Ka 8.0/Le Tr/Ki[1]	7.77/L	2.45-4.63/L
	4	10	1476.76-1478.40	1.64	---	36	2.0	53.0	Tr/Ka&Le[1]	12.01/L 1.26/S	
	4	11	1478.40-1478.95	0.55	2	86	---	8.7	---	1.98/L	2.19-9.49/L
	4	12	1490.12-1491.00	0.88	1	83	1.0	14.1	---	4.94/L	
	4	13	1491.00-1491.56	0.56	0	39	7.0	19.7[7]	---	4.40/L 4.12/S	
	4	14	1491.56-1492.64	1.08	7	79	---	12.0	---	2.75/L	
	4	15	1492.64-1493.89	1.25	2	56	3.0	31.0	6.0/Le 2.0/Ka	7.05/L 2.09/S	3.77-4.93/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
P-16	2	19	1526.90-1528.00	1.10	1	51	1.0	42.0	2.0/Ka	9.05/L	1.10-9.60/L
P-17	10	2	1365.60-1367.20	1.6	1	27	---	68.8	---	15.61/L	
	10	3	1367.20-1368.45	1.25	3	76	---	12.6	2.0/Ka	2.67/L	
	10	4	1368.45-1369.70	1.25	3	44	---	6.64	30.0/Le 9.0/Ka	1.51/L	4.10-7.43/L
	4	8	1542.90-1543.68	0.78	---	48	---	38.0	13.0/Le Tr/Ka[1]	8.62/L	
	4	9	1543.68-1544.46	0.78	---	43	---	53.0	3.0/Le	12.03/L	1.56-10.33/L
	2	18	1591.39-1592.71	1.32	1	44	---	46.0	1.0/Ka	10.46/L	
	2	19	1592.71-1594.21	1.50	4	83	---	2.4	2.0/Ka	0.53/L	2.82-5.18/L
P-18	10	3	1728.40-1728.78	0.38	1	41	33.0	35.0	---	22.83/S 7.94/L	
	10	4	1728.78-1730.45	1.67	3	86	9.0	---	---	5.61/S	
	10	5	1730.45-1731.49	1.04	6	80	0.72	---	---	0.45/S	
	10	6	1731.49-1732.29	0.80	4	74	0.81	---	---	0.51/S	3.89-4.86/S 0.38-7.94/L mixed ore equivalent: 3.89-6.8/S
P-19	10	7	1741.80-1742.35	0.55	1	55	6.70	36.0	---	4.23/S 8.24/L	
	10	8	1742.35-1743.72	1.37	1	26	2.0	59.0	---	1.20/S 13.39/L	
	10	9	1743.72-1745.09	1.37	4	81	1.0	15.0	---	0.62/S 3.40/L	
	10	10	1745.09-1746.00	0.91	2	53	---	30.0	8.4/Le 2.0/Ka	9.21/L	4.20-8.03/L
	4	21	1925.20-1925.90	0.70	1	74	---	11.0	12.0/Ki	2.50/L	
	4	22	1925.90-1926.70	0.80	1	27	---	57.0	2.0/Ka 9.0/Ki	12.93/L	
	4	23	1926.70-1927.94	1.24	2	62	---	3.6	5.0/Ka Tr/Le[1]	0.82/L	2.74-4.79/L
	2	26	1956.40-1957.36	0.96	6	64	1.0	16.0	15.0/Ki	3.74/L	
	2	27	1957.36-1958.71	1.35	1	29	---	65.0	Tr/Ka[1]	14.83/L	
	2	28	1958.71-1959.21	0.50	0.5	61	---	25.0	Tr/Ka[1]	5.72/L	2.81-9.42/L
P-20	10	2	1725.00-1726.15	1.15	2	72	21.2	Tr/L[4]	---	13.43/S	
	10	3	1726.15-1728.10	1.95	4	64	7.0	35.0	---	4.42/S 8.01/L	
	10	4	1728.10-1729.62	1.52	3	60	28.0[6]	---	6.0/Ka	17.69/S	1.95-8.01/L
	10	5	1729.62-1731.48	1.86	3	60	34.0	---	---	21.48/S	6.51-14.03/S mixed ore equivalent: 6.51-20.03/S
	4	10	1898.80-1900.45	1.65	5	53	1.0	37.0	5.0/Ka	8.35/L	
	4	11	1900.45-1901.77	1.32	16	85	---	1.3	---	0.30/L	
	4	12	1901.77-1903.35	1.58	10	74	---	17.7	---	4.0/L	4.55-4.5/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
P-20	2	14[4]	1925.08-1926.30	1.22	3	95	---	0.88	---	0.2/L	
	2	15	1926.30-1927.75	1.45	1	61	---	35.5	---	8.05/L	2.67-4.46/L
P-21	10	2	1644.03-1644.84	0.81	4	80	17.0	---	---	10.82/S	
	10	3	1644.84-1646.00	1.16	4	81	11.8	---	2.0/Ki	7.46/S	
	10	4	1646.00-1646.33	0.33	1	28	20.2[6]	---	42.0/Ki	12.76/S	
	10	5	1646.33-1647.20	0.87	1	41	25.5	---	18.0/Ki	16.14/S	
	10	6	1647.20-1648.22	1.02	1	62	29.5[2]	---	1.0/Ki	18.66/S	
	10	7	1648.22-1649.23	1.01	3	64	31.3	---	---	19.81/S	5.20-14.37/S
	8	15	1685.17-1686.48	1.31	0	55	45.0	---	---	28.4/S	
	8	16	1686.48-1687.20	0.72	4	83	6.0[6]	---	---	3.72/S	
	8	17	1687.20-1688.24	1.04	5	92	3.0	---	---	1.95/S	
	8	18	1688.24-1688.77	0.53	4	95	0.8	---	---	0.52/S	
	8	19	1688.77-1690.19	1.42	6	86	9.9	---	---	6.24/S	
	8	20	1690.19-1691.26	1.07	8	90	1.0	---	---	0.75/S	
	8	21	1691.26-1692.40	1.14	3	65	33.0	---	---	21.16/S	
	8	22	1692.40-1693.34	0.94	5	65	13.0	---	---	8.18/S	8.17-10.24/S
	4	24	1809.90-1811.50	1.60	0	31	3.0	64.0	2.5/Ka 3.9/Le	14.60/L	1.92-14.69/L
	4	25	1811.50-1811.82	0.32	0	18	5.0[2]	54.66	9.0/Ka 10.60/Le	15.12/L	4.00-7.05/L[5]
	4	30	1815.51-1816.10	0.59	11	51	5	27.0	9.0/Ki	6.08/L	
	4	31	1816.10-1817.25	1.15	3	42	5	44.0	8.0/Ka	9.95/L	1.74-8.64/L, 4.00-3/76/L[5]
AEC-8	10	10	1589.10-1589.70	0.60	1	85	5	---	5/Ki 2/An	2.97/S	
	10	11	1589.70-1591.70	2 00	---	43	16	---	40/Ki	10.32/S	
	10	12[6]	1591.70-1592.20	0 50	---	37	24	---	6/C 30/Ki	15.16/S	
	10	13[6]	1592.20-1594.50	2 30	---	49	32	---	0.1/An 7/C 9/Ka 0.9/An	20.31/S	
	10	14	1594.50-1594.70	0 20	---	38	4	---	51/C 9/Ka 1/Ki 0.1/An	2.34/S	
	10	15[6]	1594.70-1595.50	0.80	2	85	3	---	4/C 2/Ki 9/Ka 0.9/An	2.18/S	6.4-12.33/S
	4	2	1752.70-1753.40	0.70	---	95	---	4	---	0.86/L	
	4	3	1753.40-1754.00	0.60	1	69	2	33	3/Ka	7.39/L	
	4	4	1754.00-1755.00	1.00	---	33	2	68	2/Ka	13.90/L	
	4	5	1755.00-1756.70	1.70	---	24	---	69	3/Le	15.38/L	4-11.27/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
FC-70	10	2	1377.67-1379.00	1.33	2	65	11.2[6]	---	20.0/Ki	7.11/S	
	10	3	1379.00-1381.00	2.00	2	51	39.1[6]	---	1.0/Ki	24.72/S	
	10	4	1381.00-1382.00	1.00	2	64	19.4[6]	---	3.0/C 3.0/Ki	12.29/S	4.33-16.44/S
	9	6	1391.50-1393.00	1.50	1	53	28.00	---	---	17.74	1.5-17.74/S
	8	7	1415.08-1415.75	0.67	2	70	25	---	Tr/Ki[1]	16.10/S	
	8	8	1415.75-1416.50	0.75	5	89	2	---	Tr/Ki[1]	1.35/S	
	8	9	1416.50-1418.00	1.50	2	97	1	---	1.0/Ka Tr/Ki[1]	0.57/S	
	8	10	1418.00-1419.50	1.50	3	91	3	---	---	1.62/S	
	8	11	1419.50-1420.42	0.92	2	80	16	---	1.0/Ka Tr/Ki[1]	10.04/S	
	8	12	1420.42-1421.50	1.08	1	71	16	---	1.0/Ka	10.21/S	6.42-5.5/S
	5	16	1466.00-1467.58	1.58	---	72	---	19.6	---	4.43/L	
	5	17	1467.58-1469.00	1.42	1	53	---	40.7	---	9.22/L	
	5	18	1469.00-1469.67	0.67	1	70	---	24.2	---	5.49/L	3.67-6.48/L
	4	19	1529.92-1531.42	1.50	1	36	---	52.6[6]	---	11.93/L	
	4	20	1531.42-1532.42	1.00	---	45	---	33.0[6]	---	7.42/L	2.5-10.13/L
FC-81	8	7	1564.17-1564.92[8]	0.75	2	58	36.6	---	2.0/C	23.16/S	
	8	8	1564.92-1566.13	1.21	2	79	15.3	---	4.0/C	9.71/S	
	8	9	1566.13-1567.38	1.25	5	66	8.9	6.1	10.0/C	5.62/S 1.38/L	3.21-11.26/S 3.21-0.54/L mixed ore equivalent: 3.21-12.61/S
	4	10	1687.00-1688.21	1.21	---	20	---	74.0	4.0/Ka Tr/Va[1]	16.71/L	
	4	11	1688.21-1689.46	1.25	1	25	---	67.0	Tr/Va[1]	15.31/L	2.46-16.0/L
	2	15	1712.88-1714.46	1.58	1	40	---	56.0	2.2/Le	12.7/L	
	2	16	1714.46-1715.46	1.00	---	65	---	30.3	3.0/Ka Tr/Le[1]	6.9/L	
	2	17	1715.46-1716.00	0.54	4	45	---	42.8	Tr/Le[1]	9.71/L	3.12-10.4/L
FC-82	5	1	1541.42-1541.79	0.37	---	17	---	72.2	2.0/Le 6.0/C	16.34/L	
	5	2	1541.79-1542.29	0.50	---	85	7.0	7.2	---	1.63/L	
	5	3	1542.29-1543.96	1.67	2	5	---	49.8	4.0/Lo 20.9/C	11.3/L	
	5	4	1543.96-1544.50	0.54	1	59	5.0	20.0	Tr/Le[1]	4.54/L	3.08-9.37/L
	4	5	1613.42-1615.08	1.66	---	17	---	63.0	9.3/Ki Tr/Lo[1]	14.3/L	
	4	6	1615.08-1615.92	0.84	1	48	0.7	12.8	17.7/Le 12.0/Ki	2.9/L	2.5-10.52/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent): Polyhalite	Halite	Sylvite	Langbeinite	Other minerals	K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
FC-82	3	7	1624.33-1625.58	1.25	2	57	---	31.1	3.5/Bl 3.7/Ka	7.06/L	
	3	8	1625.58-1627.00	1.42	2	67	---	29.9	0.6/C	6.78/L	
	3	9	1627.00-1627.75	0.75	1	28	---	62.2	Tr/Bl[1] 5.0/Gl	14.11/L	3.42-8.49/L
FC-91	4	34	1712.25-1712.66	0.42	1	18	---	50.0	11.0/Ka 7.5/Le 6.0/Ki	11.35/L	
	4	35	1712.66-1713.08	0.42	---	62	---	---	5.0/Ka 3.4/Ki	---	
	4	36	1713.08-1714.17	1.08	1	25	---	64.6	5.0/Ki	14.66/L	
	4	37	1714.17-1714.75	0.58	2	32	---	58.7	5.0/Ka 1.3/Ki	13.32	
	4	38	1715.75-1715.75	1.00	20	38	---	47.0	5.0/Ka Tr/Gu[1]	10.66	
	4	39	1715.75-1716.33	0.58	6	31	---	54.0	6.2/Ka 4.0/Gl 1.2/Ki	12.25/L	4.08-11.3/L
	4	40	1718.66-1719.42	0.75	3	81	---	8.0	3.0/Ka 9.0/Bs	1.82/L	
	4	41	1719.42-1720.75	1.33	2	37	---	59.5	---	13.5/L	
	4	42	1720.75-1722.00	1.25	---	60	---	37.08	Tr/Gu 3.4/Bs	8.41/L	
	4	43	1722.00-1722.58	0.58	---	71	---	13.5	0.4/Ka 6.0/Bs Tr/Gu[1]	3.06/L	3.91-8.08/L
	2	44	1742.75-1743.25	0.50	---	15	---	62.0	8.8/Ka Tr/Va[1]	14.07/L	
	2	45	1743.25-1744.25	1.00	---	47	---	30.5	10.0/Ki 10.0/Va	6.92/L	
	2	46	1744.25-1745.00	0.75	---	61	---	1.0	3.2/Ka 10.1/Ki 24.0/Va Tr/Gu[1]	0.73/L	2.25-6.44/L
FC-92[9]	8	5	1604.92-1606.04	1.12	1	51	47	Tr[1]	Tr/C[1]	29.0/S	
	8	6	1606.04-1606.50	0.46	---	50	49	Tr[1]	Tr/C[1]	31.0/S	
	8	7	1606.50-1606.75	0.25	---	60	29	1	5.7/C	18.5/S	1.83-28/S
	4	57	1740.66-1741.58	0.92	1	51	---	46.7	---	10.6/L	
	4	58	1741.58-1742.25	0.66	1	36	---	61.0	---	13.85/L	
	4	59	1742.25-1743.25	1.00	1	36	---	61.2	0.1/Ki	13.89/L	
	4	60	1743.25-1744.08	0.83	1	34	---	61.3	---	13.91/L	
	4	61	1744.08-1745.00	0.92	2	38	---	48.8	1.8/Ki	11.07/L	4.33-12.6/L
	2	62	1769.42-1770.08	0.66	1	42	---	55.4	3.0/Va	12.57/L	
	2	63	1770.08-1771.42	1.33	1	51	---	45.7	2.0/Va 1.0/Arc	10.37/L	
	2	64	1777.42-1772.08	0.66	---	39	---	33.0	17.0/Va 8.0/Ki 1.0/Gu	7.49/L	
	2	65	1772.08-1772.38	0.5	---	73	---	1.5	14.0/Va 1.0/Gu	0.34/L	3.16-8.64/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent): Polyhalite	Halite	Sylvite	Langbeinite	Other minerals	K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
IMC-374	4	8	1430.70-1432.10	1.40	6	86	0.7	2.0	0.7/Ki 0.3/Ka	0.46/L 0.44/S	
	4	9	1432.10-1433.10	1.00	13	68	1.0	6.4	1.35/Le	1.46/L 0.63/S	2.4-0.88/L 2.4-0.51/S
IMC-375	4	7	1627.90-1629.00	1.10	2	78	---	6.6	2.0/Ka	1.50/L	
	4	8	1629.00-1630.50	1.50	4	70	2.0	13.2	2.0/Le 1.0/Ka	3.0/L 1.3/S	2.5-2.46/L 1.5-1.3/S
IMC-376	10	2	1427.00-1427.70	0.7	---	60	38.4	---	---	24.3/S	
	10	3	1427.70-1428.30	0.6	---	98	0.2	---	---	0.1/S	
	10	4	1428.30-1429.20	0.9	1	96	0.4	---	---	0.26/S	
	10	5	1429.20-1431.00	1.8	2	86	11.2	---	---	7.1/S	4.0-7.52/S
	5	13	1528.00-1528.90	0.9	2	89	1.0	2.8	---	0.63/L	
	5	14	1528.90-1530.90	2.0	0	45	---	51.3	1.0/Le	11.65/L	3.7-6.5/L
	5	15	1530.90-1531.70	0.8	2	93	1.0	1.05	---	0.25/L	(4.0-6.03/L)[5]
NFU-1[10]	8		1536.25-1540.17	3.92	---	---	---	---	---	19.67/S	3.92-19.67/S
	4		1646.75-1649.08	2.33	---	---	---	---	---	11.96/L	2.33-11.96/L
NFU[10]	10		1441.08-1445.17	4.08	---	---	---	---	---	0.8/S	4.08-0.8/S
	8		1479.80-1483.80	4.00	---	---	---	---	---	9.1/S	4.0-9.1/S
	4		1598.50-1602.70	4.20	---	---	---	---	---	13.1/L	4.2-13.1/L
D-120[10]	10		1248.30-1249.80	1.50	---	---	---	---	---	31.63/S	
	10		1249.80-1251.10	1.30	---	---	---	---	---	10.4/S	
	10		1251.10-1252.50	1.40	---	---	---	---	---	7.34/S	4.2-15.3/S
	4		1419.60-1421.30	1.70	---	---	---	---	---	13.8/S	2.2-10.7/S
	4		1421.30-1421.80	0.50	---	---	---	---	---	0.5/S	2.2-7.5/L mixed ore equivalent: 2.2-29.45/S
D-48[10]	10		1236.60-1240.60	4.00	---	---	---	---	---	---	4.0-11/S 4.0-2.1/L (visual estimate)
	8		1280.52-1289.78	9.26	---	---	---	---	---	---	9.26-17.37/S
	4		1414.20-1416.20	2.00	---	---	---	---	---	---	2.0-8.8/L (visual estimate)

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
D-207	10	24	1358.60-1359.60	1.00	4	87	5	---	2/Ka	3.34/S	
	10	25	1359.60-1360.20	0.60	4	89	5	1	2/Ka	3.34/S 0.25/L	
	10	26	1360.20-1360.60	0.40	1	75	4	1	6/Ka	0.31/L	
	10	27[4]	1360.60-1361.20	0.60	1	47	6	16	5/Ka	3.79/S 3.70/L	
	10	28	1361.20-1361.80	0.60	2	69	2	9	2/Ka	2.04/L	
	10	29	1361.80-1362.30	0.50	7	62	5	10	7/Ka	3.34/S 2.31/L	
	10	30	1362.30-1363.10	0.80	6	83	4	---	1/C 3/Ka	2.66/S	4.5-2.54/S 2.7-1.8/L mixed ore equivalent: 4.5-5.24/S
	4	33	1533.10-1533.50	0.40	2	53	36	7	---	1.51/L 22.74/S	
	4	34	1533.50-1533.80	0.30	4	86	2	11	---	2.43/L	
	4	35	1533.80-1534.40	0.60	2	85	1	2	---	0.50/L	
	4	36	1534.40-1534.70	0.30	3	95	---	4	---	0.85/L	
	4	37	1534.70-1535.00	0.30	2	74	4	1	3.0/Ki	0.14/L	
	4	38	1535.00-1539.80	4.80	6	87	2	4	---	0.85/L	6.7-0.90/L 0.4-22.74/S mixed ore equivalent: 6.7-1.44/L
	3	44	1545.90-1546.30	0.40	1	66	---	32.0	0.74/Le	7.2/L	
	3	45	1546.30-1546.66	0.30	1	11	---	73.2	9.0/Ki	16.6/L	
	3	46	1546.66-1548.00	1.40	2	62	---	30.3	3.8/Le	6.89/L	
	3	47	1548.00-1548.60	0.60	1	43	---	54.7	---	12.4/L	2.7-9.24/L
	2	52	1552.20-1553.00	0.80	11	83	---	5.0	---	1.05/L	
	2	53	1553.00-1553.20	0.20	11	45	---	41.5	2.0/Le	9.41/L	
	2	54	1553.20-1553.60	0.40	4	81	---	15.8	---	3.59/L	
	2	55	1553.60-1554.00	0.40	1	47	---	49.4	1.32/Le	11.19/L	
	2	56	1554.00-1554.80	0.80	18	86	1.4	8.8	---	2.0/L 0.9/S	2.6-3.94/L Tr/S[4]
D-104[10]	10		1340.40-1341.70	1.30	---	---	---	---	---	---	
	10		1341.70-1343.20	1.50	---	---	---	---	---	---	
	10		1343.20-1344.00	0.80	---	---	---	---	---	---	
	10		1344.00-1344.70	0.70	---	---	---	---	---	---	6.0-5.5/S
	10		1344.70-1346.40	1.70	---	---	---	---	---	---	3.2-4.71/L mixed ore equivalent: 6.0-11.78/S
	8		1391.10-1392.00	0.90	---	---	---	---	---	---	
	8		1392.00-1395.30	3.30	---	---	---	---	---	---	
	8		1395.30-1396.30	1.00	---	---	---	---	---	---	5.2-10.8/S
	4		1519.90-1522.80	2.90	---	---	---	---	---	---	2.9-9.4/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
D-104[10]	3		1527.50-1528.90	1.40	---	---	---	---	---	---	1.4-5.0/L
	3		1528.90-1530.50	1.60	---	---	---	---	---	---	2.9-11.4/S mixed ore equivalent: 2.9-6.66/L
	2		1539.50-1540.20	1.20	---	---	---	---	---	---	1.2-15.0/L
U-134[10]	10		1319.58-1321.25	1.69	3	---	6.0	---	2.0/Ka 0.7/C	3.79/S	
			1321.25-1322.83	1.58	2	---	---	---	12.5/Ka	17.22/S	3.27-10.28/S
	8		1361.10-1362.17	1.08	---	---	---	---	---	---	
	8		1362.17-1364.50	2.33	---	---	---	---	---	---	
	8		1364.50-1366.50	2.00	---	---	---	---	---	---	6.33-7.89/S
	8		1366.50-1367.42	0.92	---	---	---	---	---	---	(4.0-12.5/S)[5]
	5		1406.75-1409.42	2.66	---	---	---	---	---	14.44/L	
	5		1409.42-1410.00	0.58	---	---	---	---	---	8.03/L	
	5		1410.00-1411.66	1.66	---	---	---	---	---	7.05/L	4.9-11.2/L
	4		1471.66-1474.00	2.33	---	---	---	---	---	8.54/L	2.33-8.54/L
	3		1484.91-1487.33	2.42	---	---	---	---	---	3.6/L	
	3		1487.33-1490.25	2.92	---	---	---	---	---	1.86/L	
	3		1490.25-1491.33	1.08	---	---	---	---	---	8.7/L	6.42-3.7/L[3]

*Values in table for percent mineral and K_2O equivalent are not consistent owing to independent rounding of assays and conversion factors by numerous authors and investigators.

1 Trace amount; equals 0 to 2.0 percent
2 Incomplete dissolution of sample
3 5.9 percent insolubles, by weight
4 Incomplete or unreliable assay
5 Grade adjusted to 4-foot interval
6 High insoluble content
7 7.1 percent potassium assay used
8 Outside of the ERDA area by 300 feet, included due to influence
9 Raw data unavailable; these are company figures
10 Company interval data; raw data unavailable; no sample numbers assigned

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix GENII

M

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

WIPP PA User's Manual PREGENII, WIPP User's Manual GENII

M

WIPP PA

User's Manual

for

PREGENII, Version 6.21

Document Version 1.00

WPO # 27763

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1.0 INTRODUCTION

PREGENII creates input for the GENII-A code by translating data from CAMDAT and a user-supplied PREGENII text input file. PREGENII accesses a radionuclide database that provides information for converting solute concentrations to activity.

This document serves as a User's Manual for PREGENII, as used in the 1996 WIPP PA calculation. As such, it describes the code's purpose and function, the user's interaction with the code, and the models and methods employed by the code. Examples of user-accessible input and output files are included for the user's convenience.

1.1 Software Identifier

Code Name: PREGENII, A pre-processor for input to GENII-A
WIPP Prefix: GI1
Version Number: 6.21, 4-22-96
Platforms: FORTRAN 77 for OpenVMS AXP, version 6.1, on DEC Alpha

1.2 Points of Contact

1.2.1 Code Sponsor

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1.2.2 Code Consultant

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2.0 FUNCTIONAL REQUIREMENTS

R.1 PREGENII accurately transforms radionuclide inventories from input CDB files to desired GENII-A inventory.

R.2 PREGENII produces an ASCII input file for the GENII-A computer code.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

In order to run the PREGENII code successfully, the user will need a basic knowledge of

- undergraduate-level engineering, mathematics, and physics
- open VMS
- Digital Command Language
- Sandia's CAMDAT database.

To understand how PREGENII is used to configure and run GENII-A, the user should be familiar with the GENII-A code System (Radiation Shielding Information Center, 1995; Napier et al., 1988; WPO # 27751 [the GENII-A User's Manual produced for the WIPP PA QA project]) and the principal potential WIPP exposure routes to humans (which are explained below in Section 4.0).

4.0 DESCRIPTION OF THE MODELS AND METHODS

GENII-A is an implementation of the GENII 1.485 Environmental Radiation Dosimetry Software System (Radiation Shielding Information Center, 1995). PREGENII provides the necessary input to GENII-A so that GENII-A can compute resulting radiological effects on humans from a nuclear waste repository through the following six principal exposure routes or pathways through the biosphere:

1. **Contaminated stockpond, water-stock cattle, man (rancher).** Contaminated brine from an exploratory drillhole leaks into an aquifer and its groundwater is pumped into a stockpond. Livestock drink exclusively from this pond and ranchers consume the livestock.

2. **Contaminated cuttings, man (driller).** Individuals operating the exploratory drill that penetrates the WIPP repository are, because of their proximity to drilling operations, exposed externally to (1) contaminated soil from the drilling mud pit and (2) drilling samples that they examine.

3. **Contaminated stockpond, dust-air transport, man (farm family).** Contaminants from a dried stockpond (contaminated with radionuclides migrating through the groundwater, as explained in pathway 1) are suspended in an air plume that deposits the contamination onto a nearby farm. The contaminated crops and livestock from this farm are consumed by humans.

4. **Contaminated drilling-mud pit, dust-air transport, man (farm family).** Contaminants from a dried drilling-mud pit are suspended in an air plume that deposits the contamination onto a nearby farm. The contaminated crops and livestock from this farm are consumed by humans.

5. **Contaminated lake (drinking water, aquatic activities, fishing, irrigation).** Contaminated water from an exploratory drillhole leaks into an aquifer and its groundwater reaches a lake. Humans are contaminated by drinking water from the lake, fishing from the lake, aquatic activities in the lake, and by consuming crops irrigated by contaminated lake water.

6. **Contaminated well water (drinking water, irrigation).** Contaminated water from an exploratory drillhole leaks into an aquifer and its groundwater reaches a well. Humans are contaminated by drinking desalinated water from the well and consuming crops irrigated by contaminated well water.

While GENII-A models the above physical processes, PREGENII is predominantly a data formatting program. PREGENII is primarily a keyword-driven preprocessing program that creates an ASCII input control file that the GENII-A program can use to perform WIPP PA simulations of radionuclide exposure pathways to humans. Additionally, PREGENII reformulates concentrations from transport or cuttings calculations to make them compatible with GENII-A expectations; see the PREGENII RD/VVP documentation for details.

PREGENII also incorporates a suspension model that calculates how contaminated dust from either a dried stockpond or a dried drilling-mud pit is suspended in the air. The results of PREGENII's suspension calculation are treated as a source term by GENII, which calculates the transport of the suspended, contaminated dust from the source. PREGENII's suspension model is based on the following expression from US DOE (1980):

$$\hat{Q} = K_r \rho_s A_s \Delta x_s U \tag{1}$$

where

$\hat{Q}$ = the flux rate (kg/s)
K_r = resuspension constant (s^2/m^3)
ρ_s = density of surface soil available for resuspension (kg/m^3)
A_s = surface area of soil available for resuspension (m^2)
Δx_s = depth of soil available for resuspension (m)
U = mean wind speed (m/s)

The resuspension factor K_r is taken to be 1.0×10^{-13}, which is applicable in semi-arid environments (US DOE, 1980).

The option also exists to use PREGENII to calculate χ/Q, the ratio of ground-level concentrations (Ci/m^3) to source strength (Ci/s) (US DOE, 1980):

$$\chi/Q = \frac{2.0}{3.0(2\pi)^{1/2}\sigma_y \sigma_z U} \tag{2}$$

σ_y = $0.11D\left(1.0+10^{-4}D\right)^{-1/2}$ (dispersion coefficient)

σ_z = $0.08D\left(1.0+2.0\times10^{-4}D\right)^{-1/2}$ (dispersion coefficient)

D = downwind transport distance (m)

U = mean wind speed (m/s)

The expressions for σ_y and σ_z, provided above, represent slightly unstable lower atmospheric conditions typical of the desert in the southwestern United States and are, therefore, considered appropriate for this analysis (US DOE, 1980).

5.0 CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

PREGENII processes input for the GENII-A version of GENII. Data for determining the biosphere inventory exists in a CAMDAT file. PREGENII expects this data to be located in specified analysis variables (specific units as described in Section 7.1). PREGENII does not give the user access to a complete set of GENII capabilities (e.g., scenarios involving stack release from nuclear power plants.) Instead, PREGENII gives the user the GENII-A capabilities required for performing WIPP PA calculations, as explained in Section 4.0. PREGENII expects the concentrations from the input CDBs to be located in specified analysis variables and to have specific units (see Section 7.1).

6.0 USER INTERACTIONS WITH THE SOFTWARE

The user runs PREGENII as a preprocessor for GENII-A to produce each of the GENII-A input control files corresponding to an *n*-vector sample space. As the computational flow diagram (Figure 1) shows, radionuclide concentration input to PREGENII can come from WIPP PA codes that simulate the direct route to the accessible environment (CUTTINGS code sequence), or from the WIPP PA codes that simulate the indirect route to the accessible environment (BRAGFLO, NUTS/PANEL, SECOFL, and SECOTP code sequences). (Pathways 2 and 4 listed in Section 4.0 use output from the CUTTINGS code sequence; pathways 1 and 3 listed in Section 4.0 use output from the BRAGFLO, NUTS/PANEL, SECOFL, and SECOTP code sequences. Calculations for pathways 5 and 6 are not shown in Figure 1 because they are not used in WIPP PA.)

6.1 Interactive Execution

The user can execute PREGENII interactively by typing the following line (followed by a carriage return) at the VMS "$" prompt:

```
RUN WP$PRODROOT:[GI.EXE]PREGENII_PA96.EXE
```

A banner scrolls down the screen and then the following information describing the file definitions is printed on the screen:

```
*****************************************************************************

PREGENII_TEST_NODBG expects the following files:
   1) Input first CAMDAT File vector
   2) Input Text File
```

```
3) Input Generic Radioisotope Database
4) Output GENII Input File
5) Output Diagnostics/Debug File (optional)
```

****

Subsequent questions in the procedure file request names for the above five files, described briefly below:

1. **Input computational database, CAMDAT, (.CDB) files.** These are the family of CAMDAT database files that contain, for each of the sampled vectors, the initial radionuclide (actinide) concentrations in either contaminated groundwater (output of ALGEBRACDB from the indirect-route-to-accessible-environment simulation shown in Figure 1) or from drilling operations (output of CUTTINGS from the direct-route-to-accessible-environment simulation shown in Figure 1). The name of the first .CDB file is specified. See Section 7.1 for more information on the input computational database files.

2. **PREGENII ASCII input control file.** This file, which contains the commands that establish how GENII-A will be run for the *n*-vector sample space corresponding to a given pathway, is the human interface to the GENII-A code sequence. This file is described extensively in Section 7.2.

3. **Input generic radioisotope database file.** This file contains information that characterizes the radionuclide isotopes, such as half-life, specific activity, and mass. The same input generic radioisotope database is used for all sample vector calculations. See Section 7.3 for more information on this file.

4. **GENII-A ASCII input control files.** These files, which are PREGENII output files, are the GENII-A ASCII input control files created by PREGENII to run GENII-A for each of the sampled vectors. There is a one-to-one correspondence between these files and the .CDB files. See Section 9.1 for more information on the GENII-A input control files.

5. **Output PREGENII diagnostics file.** This is a diagnostics/debug file containing information about the PREGENII run for the *n*-vector sample space. It is an optional file, but it must be specified if the user wants to take advantage of error reporting. See Section 9.2 for more information on this file.

6.2 Execution via Command File

Alternatively, the user may use a command file to execute PREGENII. A sample command file, GI1_TEST_PCA.COM in this example, follows:

```
------------------- GI1_TEST_PCA.COM follows --------------------
$! -----
$! MODULE:       GI1_TEST_PCA.COM
$! PURPOSE:      RUN TEST CASES FOR PREGENII USING THE PRODUCTION EXE
$! DATE:         15-JAN-1996
$! AUTHOR:       E. J. DECOTEAU
$! -----
$  SET NOON
$  START_DIR = F$ENVIRONMENT("DEFAULT")
$  EXE_SRC  :== $WP$PRODROOT:[GI.EXE]PREGENII_PA96.EXE
$  SET DEFAULT WP$TESTROOT:[GI1.TEST]
$! -----
$  DEFINE  GI1_CDB$INP GI1_TEST1_R001.CDB
$  DEFINE  GI1_UIF$INP GI1_TEST1_UIF.INP
$  DEFINE  GI1_RDB$INP GI1_TEST1_RDB.INP
$  DEFINE  GI1_TRN$OUT GI1_TEST1_TRN_R001.INP
$  DEFINE  GI1_DBG$OUT GI1_TEST1_DBG.OUT
$  EXE_SRC GI1_CDB$INP GI1_UIF$INP GI1_RDB$INP GI1_TRN$OUT GI1_DBG$OUT
$! -----
$  SET DEFAULT 'START_DIR
$  EXIT.
```

Note that the above command file specifies the names of Files 1 through 5 as `GI1_TEST1_R001.CDB`, `GI1_TEST1_UIF.INP`, `GI1_TEST1_RDB.INP`, `GI1_TEST1_TRN_R001.INP`, and `GI1_TEST1_DBG.OUT`, respectively. (For user's convenience, these filenames appear in bold type in the above sample command file.) Once the command file is written and stored, the user simply types an "@" followed by the name of the command file, which in this case would be:

```
@ GI1_TEST_PCA.COM
```

THIS SAMPLE COMPUTATIONAL FLOW DIAGRAM *IS NOT NECESSARILY* THE FLOW USED IN THE 1996 WIPP PA CALCULATION. IT IS *INCLUDED SOLELY FOR ILLUSTRATIVE PURPOSES.*

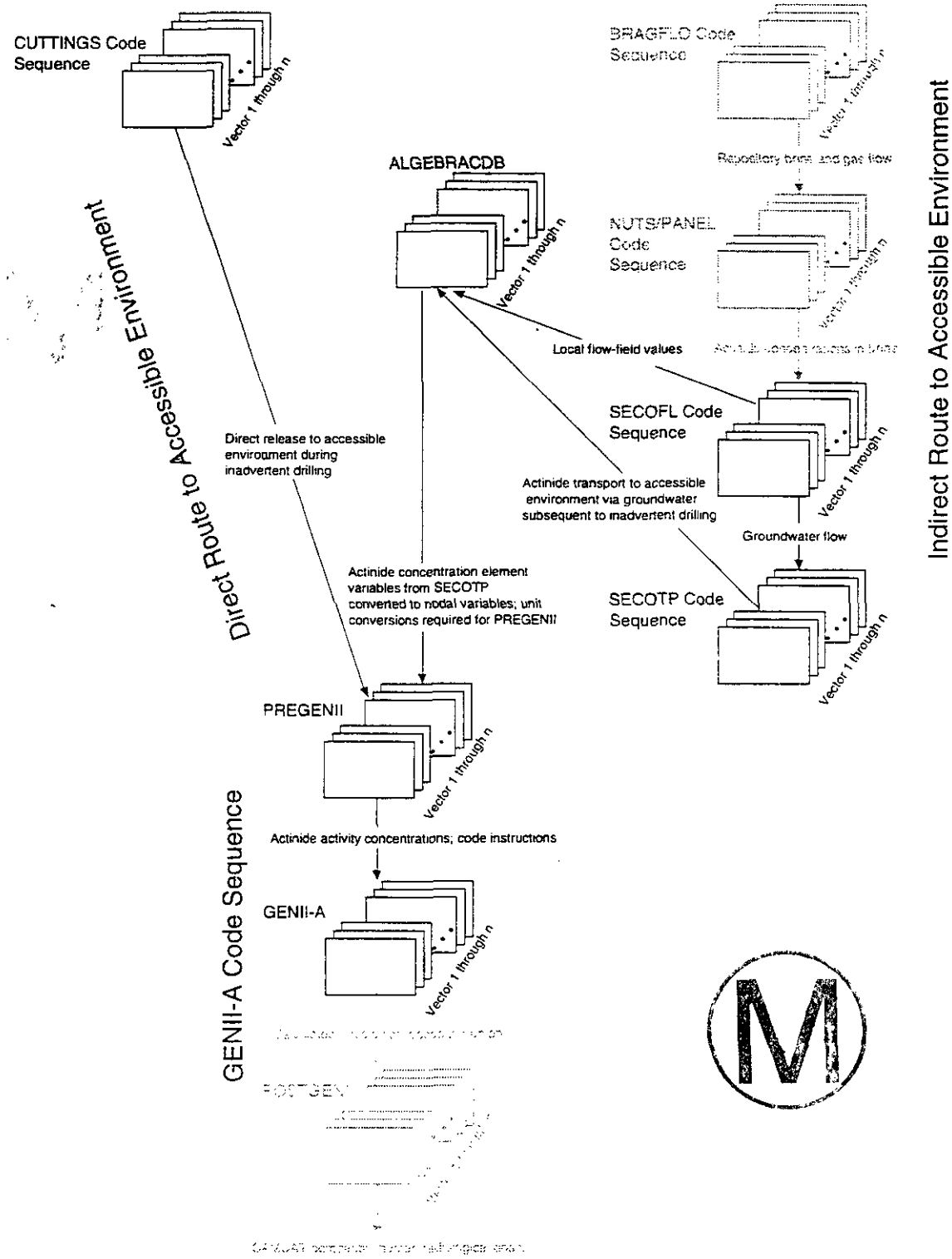

Figure 1. Sample computational flow diagram for PREGENII.

7.0 DESCRIPTION OF INPUT FILES

7.1 Input Computational Database File

The input computational database (.CDB) file follows the CAMDAT format. The CAMDAT format is described in detail in the *Programmer's Manual for CAMCON: Compliance Assessment Methodology Controller*, Sections 6.1 and 6.2 (Rechard et al., 1993). CAMDAT files are not user readable. Data from these files can be plotted using a compatible plotting package and examined using GROPE.

Data required to exist in the input computational database are listed below:

- radioisotopic concentrations saved as appropriate analysis variables (The groundwater concentrations must be nodal analysis variables using the units kg [solute]/m^3 [fluid]; the excavated (drilling) concentrations must be global variables using the units total curies per radionuclide as provided by the CUTTINGS code.)

- the LHS-sampled biosphere-relevant parameters saved as material properties or attributes (e.g., brine concentration, contaminated fraction of animal drinking water, water drinking rates)

- flow field velocities nodal analysis variables as supplied by SECOFL2D.

7.2 PREGENII ASCII Input Control File

The PREGENII ASCII input control file consists of keywords that correspond to the exposure pathway explained in Section 4.0.

The format of the PREGENII input control file follows the standard format established for CAMCON input files as stated in the *User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller*, Version 3.0, Section 2.9.4 (Rechard, 1992). The input file contains keywords, denoted by a leading asterisk (*), and parameters associated with the keywords that can function as secondary keywords or have input values associated with them.

User input must be read from the ASCII input control file. The general format for the PREGENII input control file is shown below. (Optional input is enclosed in square brackets ("[]".)

```
                    *major_keyword [keyword_flags], &*
    [keyword-specific data, &
        .
        .
    ]
[*major_keyword, &
```

* Unless otherwise noted, ampersands (&s) should be provided at the end of each line.

```
        .
        .
    ]
        .
        .
        .
```

Comments can be added to the ASCII input control file. Comments are preceded by an exclamation point (!), as illustrated below:

```
        .
        .
        .
! list the variables which will be sampled, GENII name=CAMDAT name
*LHS_SAMPLES, &
        .
        .
        .
```

Sample input control files for three of the exposure pathways listed in Section 4.0 are provided in Appendix A (contaminated stockpond, water-stock cattle, man [rancher]), Appendix B (contaminated cuttings, man [driller]), Appendix C (contaminated drilling-mud pit, dust-air transport, man [farm family]), and Appendix D (contaminated dried stockpond, dust-air transport, man (farm family). The user can refer to these sample input files to find out which keywords and parameter values should be specified for a given exposure pathway.

A description of the PREGENII keywords and their options follows.

7.2.1 Keyword/Parameter Summary

The following summarizes use of all PREGENII keyword and parameter cards. Detailed descriptions of the keywords and their associated parameters, in the order presented in this listing, are found in Section 7.2.2.

```
-----------------------------------------------------------------

    *PATHWAY, &
     PATH=[DRILL,FARM,LAKE,STOCK,WELL], SCENario=[E1,E2,E1E2] or [CH,RH], &
     WASTE_forms=[value], VECTORS=[value], TIME_INT=[value], &
     LOCations=[value], SOURCE=[WATER,CUTTINGS]

    ---------------------------------------------------------------

    *ARRAY_CAMDAT, &
     TYPE=[GLOBAL,NODE], ROOT=[array or variable name], &
     LENGTH_root=[value], I_LOC=[value], J_LOC=[value], K_LOC=[value], &
     NODE_loc=[value], TIME_SOLution=[value], TOLER=[value], &
     UNITS_Time=[SECONDS,YEARS], INTERP=[LINEAR,NEAR], &
     NUMBER_points=[value]
```

```
-----------------------------------------------------------------

*STOCK_WELL, &
 AQUIFER_AREA=[value], NUMBER_COWS=[value], RATE_DRINK=[value], &
 POTABILITY=[value], PUMP_DURATION=[value], &
 BRINE=[variable name or value], FLOW=[variable name or value]

-----------------------------------------------------------------

*SUSPEND, &
 DENSITY=[value], RATE_coeff=[value], AREA=[value], WIND=[value], &
 DISTANCE_FARM=[value], RADIUS=[value], DEPTH=[value]

-----------------------------------------------------------------

*NUCLEAR, &
 CONC_cut=[value], NUM_nucs=[value], NUCLides=[PU239,PA231,NP237...]

-----------------------------------------------------------------

*DRILLer, &
 DENSITY=[value], DEPTH_BOREhole=[value], &
 RADIUS_Borehole=[value], RADIUS_Chip=[value]

-----------------------------------------------------------------

*LAKE, &
 VOLUME_LAKE=[value], DEPTH=[value], CATCH=[value], PRECIP=[value], &
 TIME_FLOW=[value], UNITS_Time=[SECONDS,YEARS], &
 FLOW=[variable name or value]

-----------------------------------------------------------------

*WELL, &
 AQUIFER_AREA=[value], TIME_FLOW=[value], UNITS_Time=[SECONDS,YEARS], &
 FLOW=[variable name or value]

-----------------------------------------------------------------
*REPORT, &
  COMMITted, ORGANS, NUCLIDES, PATHS

-----------------------------------------------------------------

*SCENARIO, &
  FAR_FIELD/NEAR_FIELD, CHRONIC/ACUTE, &
  INDIVIDUAL/POPULATION=[GRID or value], &
  TRANSPORT=[GROUNDWATER,SURFACE,AIR,NONE], INVENTORY=[RELEASE,BASIC]

-----------------------------------------------------------------

*TRANSPORT

 AIR_TRANSPORT, OPTION=[USE_CHI_OVER_Q,SELECT,SPECIFY], JOINTFRE, &
 USE_CHI_GRID, CHI_OVER_Q=[value], SECTOR=[value], RELEASE_DIST=[value], &
 RELEASE_HEIGHT=[value]

 SURFACE_WATER, MIX_MODEL=[LAKE,RIVER,USER]
```

```
END_TRANSPORT

-----------------------------------------------------------------

*EXPOSURE, &
 DRINKING, ANIMAL_consumption, PLANT_consumption, AQUATIC_consumption, &
 INHALATION, EXTERNAL_GROUND, FINITE_PLUME, INFINITE_PLUME, &
 DOSE_PERIOD=[value], COMMIT_PERIOD=[value], INTAKE_PERIOD=[value], &
 PERIOD_AIR_DEPosition=[value], &
 UNITS_ACTivity=[CURIES,MILLICURIES,MICROCURIES,PICOCURIES,BECQUERELS], &
 UNITS_SURface=[CUBIC_METERS,SQUARE_METERS,KILOGRAMS], &
 PLUME_TIME_EXPosure=[value], SOIL_TIME_EXPosure=[value], &
 SAMPLE_TIME_EXPosure=[value], BOAT_TIME_EXPosure=[value], &
 SWIM_TIME_EXPosure=[value], SHORE_TIME_EXPosure=[value], &
 TIME_IRRIgation=[value], RATE_IRRIgation=[value], &
 TIME_INHALation=[value], AREA_EXTernal_source=[value] &
 AREA_EXAmination=[value]

-----------------------------------------------------------------

*FLAGS, &
 PRODUCTION=[POPULATION,FOOD,GRID], WATER_TREATMENT=[YES,NO], &
 WATER_IRRIgation=[GROUNDWATER,SURFACE], &
 WATER_DRINK=[GROUNDWATER,SURFACE], RESIDENTial, GRID_POPulation

-----------------------------------------------------------------

*SOIL_DATA, &
 ROOTS_Upper_soil=[value], &
 SOIL_Model= [MASS_LOAD,ANSPAUGH,NO_RESUSPENSION], &
 SOIL_DILUTION_FACTOR=[value], DEPTH_TOP_Soil=[value], &
 SOIL_OVER=[value], MASS_LOAD=[value], EXTERNAL_Source=[value]

-----------------------------------------------------------------

*INGESTION

 SOIL_INGESTION=[value]

 WATER_consumption, TREAT=[YES,NO], HOLDup_time=[value], &
 TRANSit_time=[value], CONSumption_rate=[value]

 AQUATIC_consumption=[FISH,MOLLus,CRUSt,PLANts], &
 TRANSit_time=[value], PRODuction=[value], HOLDup_time=[value], &
 CONsumption_rate=[value]

 PLANT_consumption=[FRUIt,GRAIns,LEAF,ROOts], &
 GROW_time=[value], RATE_IRRIgation=[value], TIME_IRRIgation=[value], &
 YIELD=[value], PRODuction=[value], HOLDup_time=[value], &
 CONSumption_rate=[value]

 ANIMAL_consumption=[BEEF,EGGs,MILK,POULtry], &
 CONSumption=[value], HOLDup_time=[value], PRODuction=[value] ,&
 CONTAMINATED_H2O=[value]

 FRESH_FEED=[BEEF,MILK] FRACtion=[value], GROW_time=[value], &
 RATE_IRRIgation=[value], TIME_IRRIgation=[value], YIELD=[value], &
 STORAGE=[value]
```

```
 STORED_FEED=[BEEF,POULTRY,MILK,EGGs], FRACtion=[value], &
 GROW_time=[value], RATE_IRRIgation=[value], &
 TIME_IRRIgation=[value], YIELD=[value], STORAGE=[value]

 END_INGESTION_INPUT
-----------------------------------------------------------------

*LHS_SAMPLES, &
 BIOSPHERE=[region name in CDB file], &
 HUMAN_DRINKING_WATER=H2O_DRNK, . . .*
-----------------------------------------------------------------

*END
```

7.2.2 Keyword/Parameter Detailed Description

A complete listing and explanation of the keywords and associated parameters for PREGENII follows. Note that the user is required to type in only the uppercase letters. For example, the keyword `*DRILLer` can be specified by simply typing "`*DRILL`."

UNLESS OTHERWISE NOTED, THE VALID RANGE FOR KEYWORD PARAMETERS THAT ARE ASSIGNED NUMERICAL VALUES IS ANY POSITIVE NUMBER GREATER THAN ZERO (i.e., RANGE > 0).

UNLESS OTHERWISE NOTED, ONLY ONE VALUE OR NAME CAN BE SPECIFIED FOLLOWING A `PARAMETER=` STATEMENT.

FOR PARAMETER STATEMENTS OF THE TYPE `PARAMETER1/PARAMETER2`, ONLY ONE PARAMETER CAN BE SPECIFIED.

FOR `PARAMETER=` STATEMENTS, DEFAULT VALUES ARE ENCLOSED IN GREATER THAN/LESS THAN BRACKETS (E.G., `WASTE_forms=<1>`). IF NO DEFAULT VALUE IS PROVIDED, THE WORD "NO DEFAULT" IS ENCLOSED IN GREATER THAN/LESS THAN BRACKETS (E.G., `PATH=<no default>`).

---

* List would include all PREGENII variables in CAMDAT that are LHS sampled.

FOR PARAMETER1/PARAMETER2 STATEMENTS, DEFAULT PARAMETERS ARE INDICATED WITHIN GREATER THAN/LESS THAN BRACKETS (E.G., CHRONIC/ACUTE <default=CHRONIC>). IF NO DEFAULT VALUE IS PROVIDED, NO TEXT FOLLOWS THE PARAMETER1/PARAMETER2 STATEMENT.

7.2.2.1 *PATHWAY

The *PATHWAY keyword defines an exposure pathway along with a PA scenario, intrusion time, and number of exposure locations, using the following parameters:

PATH=<no default>
Pathway descriptor for origin of contaminants: DRILL, FARM, LAKE, STOCK, WELL for drill cuttings, farm (atmospheric source), lake, stockpond, or water well, respectively. Only one pathway descriptor can be specified.

SCENario=<no default>
The WIPP PA scenario descriptor; used for informational purposes only. Example specifications include: intrusion through repository panel into an underlying pressurized brine pocket (E1), intrusion through repository into underlying dry rock (E2), or a combination of the two previous events (E1E2), or in the case of the drilling pathway, the waste type: contact handled waste (CH) or remote handled waste (RH).

WASTE_forms=<1>
The number of different waste-forms or parcels; range is any integer greater than 0.

VECTORS=<1>
The number of vectors (i.e., independent samples[1]); range is any integer greater than 0.

TIME_INT=<no default>
Time of borehole intrusion, in years following decommissioning of repository.

LOCations=<no default>
Number of exposure locations; range is any integer greater than 0 up to a maximum value.

SOURCE=<no default>
How radionuclides transported: by water (WATER) or drilling cuttings (CUTTINGS).

---

[1] The Waste Isolation Pilot Plant performance assessments use Latin hypercube sampling methods to generate independent samples of parameter values from the distributions developed in the first step of a Monte Carlo analysis; see, for example, Section 4.2.2 of Rechard [1995] for details. Because each "independent sample" contains a complete set of parameter values required for running a single calculation, it is often referred to as a "vector" in the WIPP PA literature; hence, the parameter VECTORS=.

7.2.2.2 *ARRAY_CAMDAT

The *ARRAY_CAMDAT keyword specifies information about the location of concentration data in the CAMDAT database. A description of the parameters for this keyword follows.

TYPE=<no default>
The type of CAMDAT array; i.e., GLOBAL, or NODE, for global or nodal, respectively. NOTE: PREGENII expects groundwater concentrations to be nodal (analysis) variables where concentrations are expected to be kg/m^3 per radionuclide; however, driller excavations come from global variables, where the units are curies per radionuclide released due to drilling events.

ROOT=<no default>
The root name of the CAMDAT array containing the concentrations.

LENGTH_root=<no default>
This is the character length of the ROOT described above. Its value is limited by the fact that CAMDAT names are limited to eight characters maximum. Because radioisotopes need six characters to uniquely identify them, LENGTH can be 0, 1, or 2, although 0 implies no other variables of that type exist in CAMDAT.

I_LOC=<no default>
The i-line locations of nodes where nodal array data reside.

J_LOC=<no default>
The j-line locations of nodes where nodal array data reside.

K_LOC=<no default>
The k-line locations of nodes where nodal array data reside.

NODE_loc=<no default>
The node index numbers of nodes where nodal array data reside. The location of nodal array data is specified using either NODE_loc or I_LOC, J_LOC, and K_LOC.

TIME_SOLution=<no default>
The time (at the time step) in the CAMDAT database that concentrations are retrieved. The units of time for TIME_SOLution are specified by UNITS_Time.

TOLER=<no default>
The time tolerance about TIME_SOLution values for including candidate CAMDAT analysis time steps.

UNITS_Time=<no default>
The units of time for TIME_SOLution values. The choices are SECONDS or YEARS.

INTERP=<no default>
Selects alternative interpolation schemes for times of CAMDAT analysis data that are within TOLER of TIME_SOLution; i.e., linear interpolation (LINEAR), or nearest point (NEAR). Note: If times are not within specified time tolerance value, no concentrations will be found.

NUMBER_points=<no default>
Number (maximum) of time points allowed for retrieval from CAMDAT that satisfy being within TOLER of TIME_SOLution. These points become candidates for use in interpolation. Note: First NUMBER_points encountered as time increases will be used.

7.2.2.3 *STOCK_WELL

A description of the parameters for specifying stockwell (i.e., stockpond) characteristics, which follow the *STOCK_WELL keyword, follows.

AQUIFER_AREA=<no default>
The cross-sectional area of the aquifer passing through the node where fluid (brine) flux is calculated. NOTE: the area specified by this parameter is normal to flow.

NUMBER_COWS=<no default>
The number of stock cattle supplied by the stockpond; range is any integer greater than 0.

RATE_DRINK=<no default>
The rate (cubic meters per year) at which the individual cattle drink from the stockpond.

POTABILITY=<no default>
Maximum acceptable specific density of brine for cattle drinking water; range is any real number equal to or greater than 1 (i.e., the specific density of pure water). This value corresponds to what is commonly called "minimum water potability."

PUMP_DURATION=<no default>
The fraction of a year that the stock pump is operating; range is any real positive number equal to or less than 1.

BRINE=<no default>
The name of the variable containing the specific density of brine found in the Culebra at the point of extraction; range is any real number equal to or greater than 1. (Must be a nodal analysis variable.) Alternatively, it can be a real value input by the user, which overrides the value in the CDB file.

FLOW =<no default>
The name of the variable containing the Darcy flow rate. (Must be a nodal analysis variable.) Alternatively, it can be a real value input by the user, which overrides the value in the CDB file.

7.2.2.4 *SUSPEND

A description of the parameters for suspension of particulates from soil to air, which follow the *SUSPEND keyword, follows.

DENSITY=<no default>
The mean density of the soil being resuspended (kg/m^3). This is ρ_s discussed in Equation 1.

RATE_coeff=<no default>
The coefficient for the resuspension rate. This is the resuspension constant K_r (s^2/m^3) discussed in Equation 1.

AREA=<no default>
Area over which suspension occurs (m^2).

WIND=<no default>
The mean wind speed (meters per second) over the area of suspension. This is U discussed in Equation 1.

DISTANCE_FARM=<no default>
Distance between the farm and the source (D for σ_y and σ_z in Equation 2).

RADIUS=<no default>
The radius (in meters) of a hypothetical borehole.

DEPTH=<no default>
The depth (in meters) of the soil which can be resuspended. This is Δx_s discussed in Equation 1.

7.2.2.5 *NUCLEAR

A description of the parameters for radionuclides, which follow the *NUCLEAR keyword, follows.

CONC_cut=<no default>
Minimum cutoff for concentrations of radionuclides used for creating GENII-A input (kg/m^3). (Used exclusive of NUM_NUCS, NUCLIDES=<no default>).

NUM_nucs=<no default>
Number of nuclides by explicit designation to use (no minimum cut-off); range is any integer greater than 0.

NUCLides=<no default>
Names of nuclides by explicit designation to use. Name is formed by concatenation of element symbol and nuclide atomic mass number followed by the letter M if it is a metastable state (no spaces); e.g., PU239, PA231, NP237 . . . The user should verify that the number of nuclides specified in the name list following NUCLides= agrees with the number specified by NUM_nucs=.

7.2.2.6 *DRILLer

A description of the parameters for the *DRILLer keyword, which indicates data specific to the driller pathway, follows.

DENSITY=<no default>
The mean density of the chip examined by the driller, in kg/m^3.

DEPTH_BOREhole=<300.0>
The depth of the borehole, in meters. For WIPP PA calculations, the depth of the borehole is assumed to equal the depth of the repository.

RADIUS_Borehole=<no default>
The radius of the drilled borehole, in meters.

RADIUS_Chip=<no default>
The radius of a hypothetically spherical chip, in meters.

7.2.2.7 *LAKE

A description of the parameters for lake exposure scenarios, which follow the *LAKE keyword, follows.

VOLUME_LAKE=<no default>
The volume of the lake in cubic meters.

DEPTH=<no default>
The depth of the lake in meters.

CATCH=<no default>
The catchment area divided by lake area [unitless].

PRECIP=<no default>
Precipitation in meters per year.

TIME_FLOW=<no default>
The duration of flow into the lake from the contaminated aquifer, in the units specified by UNITS_Time.

UNITS_Time=<no default>
The units of time for TIME_FLOW values. The choices are SECONDS or YEARS.

FLOW=<no default>
The variable name containing the volumetric flow rate (m^3/unit time specified by UNITS_Time) in CAMDAT. Alternatively, it can be a real value input by the user, which overrides the value in CAMDAT.

7.2.2.8 *WELL

A description of the parameters for farm-well exposure pathways, which follow the *WELL keyword, follows.

AQUIFER_AREA=<no default>
The cross-sectional area of the aquifer, in square meters, providing Darcy flow is being used (see FLOW=, below). NOTE: the area specified by this parameter is normal to flow. If flow is volumetric (see FLOW=, below), then AQUIFER_AREA=<1.0>.

TIME_FLOW=<no default>
The duration of flow into the well from the contaminated aquifer, in the units specified by UNITS_Time.

UNITS_Time=<no default>
The units of time for TIME_FLOW values. The choices are SECONDS or YEARS.

FLOW=<no default>
The variable name containing either the volumetric flow rate (m^3/unit time specified by UNITS_Time) in CAMDAT or Darcy flow rate (m/unit time specified by UNITS_Time) in CAMDAT. A real value can instead be input by the user, which overrides the value in CAMDAT. When flow is volumetric, AQUIFER_AREA=<1.0> (see AQUIFER_AREA=, above).

7.2.2.9 *REPORT

The *REPORT keyword is followed by one or more of the following parameters specifying how GENII-A outputs results:

COMMITted
Indicates annual effective dose equivalent will be output from GENII-A run. This is a default setting that does not have to be explicitly specified.

ORGANS
Indicates dose by organ will be output from GENII-A run.

NUCLIDES
Indicates dose by nuclide (or radioisotope) will be output from GENII-A run.

PATHS
Indicates dose by various allowed paths (e.g., ingestion, inhalation, external) will be output from GENII-A run.

7.2.2.10 *SCENARIO

The *SCENARIO keyword is followed by the following parameters that characterize the exposure pathway to humans.

FAR_FIELD/NEAR_FIELD <default=FAR_FIELD>
Indicates whether far- or near-field exposure.

CHRONIC/ACUTE <default=CHRONIC>
Indicates whether exposure is chronic or acute.

INDIVIDUAL/POPULATION= <default=INDIVIDUAL>
Indicates whether exposure is to an individual (INDIVIDUAL) or a population (POPULATION=), where the choices for POPULATION are GRID (use a population grid) or the number of persons in the exposed population or critical group.

TRANSPORT=<GROUNDWATER>
Indicates the mode of transport to where exposure occurs; may be 1) groundwater (GROUNDWATER), 2) surface water (SURFACE), 3) air (AIR), or 4) NONE. Note: NONE indicates that the *TRANSPORT keyword is omitted. (*TRANSPORT parameters are not required when there is no transport; nor are they always required when the mode of transport is GROUNDWATER.)

INVENTORY=<BASIC>
Indicates whether radioisotope concentrations are transported (in GENII-A) to exposure location (RELEASE) or are assumed to be at exposure location (BASIC).

7.2.2.11 *TRANSPORT

The *TRANSPORT keyword is followed by the following parameters that characterize how radionuclides are transported.

AIR_TRANSPORT
Indicates air transport parameters, listed immediately below, follow.

OPTION=<no default>
Indicates which of the four air transport options are to be used by GENII-A, as specified in the AIR TRANSPORT section of the GENII-A input control file:

```
====AIR TRANSPORT=======================,================SECTION 1=*
                  0-Calculate PM
          Option: 1-Use chi/Q or PM value
                  2-Select MI dist & dir
                  3-Specify MI dist & dir
```

OPTION=USE_CHI_OVER_Q corresponds to Option 1; OPTION=SELECT corresponds to Option 2; OPTION=SPECIFY corresponds to Option 3. If OPTION= is not specified in the PREGENII input control file, Option 0 is selected, which means that the plume model is calculated by PREGENII.

JOINTFRE
If JOINTFRE is specified, then joint frequency meteorological data will be used in GENII-A to calculate the ratio of ground-level concentrations to the source strength. If JOINTFRE is not specified, then either USE_CHI_GRID or CHI_OVER_Q (described below) must be specified.

USE_CHI_GRID
If USE_CHI_GRID is specified, then a χ/Q grid provided by GENII-A will be used by GENII-A to calculate the above ratio.

CHI_OVER_Q=<0.0>
If CHI_OVER_Q is specified, the plume is semi-infinite. The value for χ/Q is either (1) directly calculated for GENII-A as explained in Section 4.0 (CHI_OVER_Q=CALCULATE), or (2) χ/Q is assigned a value greater than zero (CHI_OVER_Q=value).

SECTOR=<no default>
Specifies the direction of the receptor. Can take on any value between 1 and 16; 1=south, 5=west, 9=north, 13=east, with other integers in this range representing intermediate directions. For example, 16=south-south-east.

RELEASE_DIST=<no default>
Distance from release point to receptor (m).

RELEASE_HEIGHT=<89.0>
For joint frequency data, indicates the height (m) above ground level where data taken.

SURFACE_WATER
Indicates surface water transport parameters, listed immediately below, follow.

MIX_MODEL=<no default>
Indicates the mix model, for surface water, to be used in GENII-A; choices are 1) lake (LAKE), 2) river (RIVER), or 3) user (USER).

END_TRANSPORT
Signifies the end of the *TRANSPORT parameters.

7.2.2.12 *EXPOSURE

A description of the parameters and values for exposure to radionuclides, which follow the *EXPOSURE keyword, follows.

DRINKING
Indicates exposure by drinking water.

ANIMAL_consumption
Indicates exposure by ingesting animal products.

PLANT_consumption
Indicates exposure by ingesting plant food (vegetables, fruits, grains, roots).

AQUATIC_consumption
Indicates exposure by eating aquatic food (e.g., fish).

INHALATION
Indicates exposure occurs from breathing.

EXTERNAL_GROUND
Indicates that groundshine (exposure to radiation coming directly from contaminated soil) occurs.

FINITE_PLUME
Indicates that there is exposure to (immersion in) a finite plume.

INFINITE_PLUME
Indicates that there is exposure to (immersion in) an infinite plume.

DOSE_PERIOD=<no default>
Period of dose due to exposure (years).

COMMIT_PERIOD=<50.0>
Period of dose commitment (years).

INTAKE_PERIOD=<1.0>
Period of intake of contaminated radionuclides (years).

PERIOD_AIR_DEPosition=<0.0>
Number of years of deposition from the air to the soil prior to exposure.

UNITS_ACTivity=<BECQUERELS>
Units of activity (CURIES, MILLICURIES, MICROCURIES, PICOCURIES, or BECQUERELS).

UNITS_SURface=<SQUARE_METERS>
Surface soil units (CUBIC_METERS, SQUARE_METERS , or KILOGRAMS).

PLUME_TIME_EXPosure=<no default>
Time of exposure to radioactive plume in atmosphere (hours).

SOIL_TIME_EXPosure=<no default>
Time of exposure to contaminated soil (hours).

SAMPLE_TIME_EXPosure=<no default>
Time of exposure to contaminated sample (hours).

BOAT_TIME_EXPosure=<no default>
Time of exposure to water while boating (hours).

SWIM_TIME_EXPosure=<no default>
Time of exposure to water while swimming (hours).

SHORE_TIME_EXPosure=<no default>
Time of exposure to water while on shore (hours).

TIME_IRRIgation=<no default>
Time of irrigation (months).

RATE_IRRIgation=<no default>
Rate of irrigation (inches per year).

TIME_INHALation=<no default>
Time of inhalation (hours).

AREA_EXTernal_source=<no default>
Total area of contaminated ground surface (square meters).

AREA_EXAmination=<no default>
Cross-sectional area of contaminated sample examined (square meters).

7.2.2.13 *FLAGS

The user uses the *FLAGS keyword to set some of the flags (or switches) that are needed for the exposure configuration, as specified below.

PRODUCTION=<no specification>
Indicates atmospheric production option; choices are population weighted (POPULATION), food weighted (FOOD), or production grid (GRID). If none of the above are chosen, input defaults to uniform production.

WATER_TREATMENT=<NO>
Flag indicating whether water is treated before use (YES or NO).

WATER_IRRIgation=<no default>
Source of the water used for irrigation (groundwater or surface water, GROUNDWATER or SURFACE, respectively).

WATER_DRINK=<no default>
Source of the water used for drinking (groundwater or surface water, GROUNDWATER or SURFACE, respectively).

RESIDENTial
Indicates residential irrigation.

GRID_POPulation
Indicates to use the population grid stored in FILENAMES.DAT.

7.2.2.14 *SOIL_DATA

A description of soil-related parameters, which follow the *SOIL_DATA keyword, follows.

ROOTS_Upper_soil=<no default>
This is the fraction of roots in the upper soil; range is any real positive number equal to or less than 1.

SOIL_Model=<NO_RESUSPENSION>
The soil model chosen for resuspension; may be MASS_LOAD, ANSPAUGH, or NO_RESUSPENSION. The factor for estimating the amount of resuspended material can be based on a time-dependent Anspaugh function (ANSPAUGH); alternatively, it can be calculated from atmospheric mass loading involving the mass loading of soil in air (MASS_LOAD) (g/m^3); NO_RESUSPENSION indicates that resuspension is not modeled.

SOIL_DILUTION_FACTOR=<no default>
This is the deep soil/surface soil dilution factor for manual redistribution due to farming activities.

DEPTH_TOP_Soil=<no default>
This is the depth of top soil available for resuspension (cm); this parameter must be specified if SOIL_Model=ANSPAUGH.

SOIL_OVER=<0.15>
Depth of overburden (m).

MASS_LOAD=<no default>
This is the mass load factor (g/m^3), this parameter must be specified if SOIL_Model= MASS_LOAD.

EXTERNAL_Source=<no default>
Area of external source surrounding soil (m^2).

7.2.2.15 *INGESTION

A description of ingestion-related parameters, which follow the *INGESTION keyword, follows.

SOIL_INGESTION Parameters
SOIL_INGESTION=<0.5>
Indicates amount of soil ingestion (kg/year).

WATER_consumption Parameters
WATER_consumption
Indicates that water consumption parameters, listed immediately below, follow.

TREAT=<NO>
Indicates whether drinking water treated (YES) or not (NO).

HOLDup_time=<no default>
Indicates holdup time (days) from source to consumption.

TRANSit_time=<no default>
Indicates transit time (days) from source to consumption.

CONSumption_rate=<730.0>
Indicates human consumption rate (liters/year).

AQUATIC_consumption Parameters

AQUATIC_consumption=<no default>
Indicates aquatic source of food is fish/mollusks/crustaceans/plants (FISH, MOLLus, CRUSt, or PLANts, respectively). Only one of these is indicated per input line. NOTE: Aquatic consumption parameters must be repeated for each aquatic food source.

TRANSit_time=<1.0 for FISH, MOLLus, CRUSt; 24.0 for PLANts>
Indicates transit time from aquatic source to consumption (hours).

PRODuction=<0.0>
Indicates production in kg/year.

HOLDup_time=<0.0>
Indicates holdup time from aquatic source to consumption (days).

CONSumption_rate=<0.0>
Indicates consumption rate in kg/year.

PLANT_consumption Parameters

PLANT_consumption=<no default>
Indicates terrestrial plant source of food is fruit/grain/leafy/root (FRUIt, GRAIns, LEAF, or ROOts, respectively). Only one of these is indicated per input line. NOTE: Plant consumption parameters must be repeated for each plant type.

GROW_time=<90.0>
Indicates growing time before harvest (days).

RATE_IRRIgation=<40.0>
Indicates rate of irrigation (inches/year).

TIME_IRRIgation=<6.0>
Indicates duration of irrigation in months/year.

YIELD=<2.0, 0.8, 1.5, or 4.0 for FRUIt, GRAIns, LEAF, or ROOts, respectively>
Indicates yield of crop in kg/m^2 of farmland.

PRODuction=<14.0 for FRUIt, LEAF, ROOts; 180.0 for GRAIns>
Indicates production in kg/year.

HOLDup_time=<64.0, 72.0, 15.0, or 140.0 for FRUIt, GRAIns, LEAF, or ROOts, respectively>
Indicates holdup time in days.

CONSumption_rate=<330, 80.0, 64., or 50.0 for FRUIt, GRAIns, LEAF, or ROOts, respectively>
Indicates consumption rate in kg/year.

ANIMAL_consumption Parameters

ANIMAL_consumption=<no default>
Indicates terrestrial animal source of food is beef/poultry/milk/eggs (BEEF, EGGs, MILK, or POULtry, respectively.) Only one of these is indicated per input line. NOTE: Animal consumption parameters must be repeated for each animal food source.

CONSumption=<70.0, 20.0, 230.0, or 8.5 for BEEF, EGGs, MILK, or POULtry, respectively>
Indicates consumption rate in kg/year.

HOLDup_time=<34.0, 18.0, 4.0, or 34.0 for BEEF, EGGs, MILK, or POULtry, respectively>
Indicates holdup time in days.

PRODuction=<0.0>
Indicates production in kg/year.

CONTAMINATED_H2O=<0.5>
Amount of contaminated water consumed by animals as a fraction of total water consumed by animals.

FRESH_FEED Parameters

FRESH_FEED=<no default>
Indicates fresh feed for beef-producing (BEEF) or milk-producing (MILK) animals. NOTE: Fresh feed parameters must be repeated for each fresh food source.

FRACtion=<0.75>
Fraction of contaminated feed that is fresh; range is any value between 0 and 1.

GROW_time=<45.0 or 30.0 for BEEF or MILK, respectively>
Grow time for fresh animal feed (days).

RATE_IRRIgation=<0.0>
Indicates rate of irrigation (inches/year) for fresh feed.

TIME_IRRIgation=<0.0>
Indicates duration of irrigation (months/year) for fresh feed.

YIELD=<2.0 or 1.5 for BEEF or MILK, respectively>
Amount of fresh feed produced (kg/m^2) per unit area of soil.

STORAGE=<100.0 or 0.0 for BEEF or MILK, respectively>
Storage time of fresh feed (days).

STORED_FEED Parameters
STORED_FEED=<no default>
Indicates stored feed for beef-producing (BEEF), poultry-producing (POULtry), milk-producing (MILK), or egg-producing (EGGs) animals. NOTE: Stored feed parameters must be repeated for each stored food type.

FRACtion=<0.25, 1.0, 0.25, or 1.0 for BEEF, POULtry, MILK, or EGGs, respectively>
Fraction of contaminated feed that is stored; range is any value between 0 and 1.

GROW_time=<90.0, 90.0, 45.0, or 90.0 for BEEF, POULtry, MILK, or EGGs, respectively>
Grow time for stored animal feed (days).

RATE_IRRIgation=<40.0 for BEEF, 0.0 for POULtry, MILK, and EGGs>
Indicates rate of irrigation (inches/year) for stored feed.

TIME_IRRIgation=<6.0 for BEEF, 0.0 for POULtry, MILK, and EGGs>
Indicates duration of irrigation (months/year) for stored feed.

YIELD=<0.8, 0.8, 2.0, or 0.8 for BEEF, POULtry, MILK, or EGGs, respectively>
Amount of stored feed produced (kg/m^2) per unit area of soil.

STORAGE=<180.0, 180.0, 100.0, or 180.0 for BEEF, POULtry, MILK, or EGGs, respectively>
Storage time of stored feed (days).

END_INGESTION_INPUT Marker
END_INGESTION_INPUT
Signifies the end of the *INGESTION parameters.

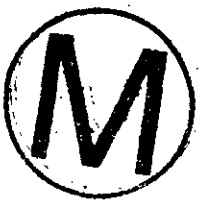

7.2.2.16 *LHS_SAMPLES

BIOSPHERE=<biospher>
Biosphere name of region (block) in CDB file where sampled variables located.

Variables that are sampled in CAMDAT for the biosphere are listed following the BIOSPHERE= parameter statement.

The following format is used: [PREGENIIname=CAMDATname].

7.2.2.17 *END

The *END keyword indicates that this is the end of the input file.

7.3 Input Generic Radioisotope Database (.RDB) File

This input file contains the following generic information on the radionuclide isotopes that could reach man on an exposure pathway from the WIPP:

- daughter product
- half-life (seconds and years)
- atomic weight (grams per mole)
- activity conversion factor (Ci per kg)
- EPA release limit (in 10^6 curies or megacuries if half life > 20 years)
- waste unit (not used in WIPP PA)
- decay mode.

A listing of the input generic radioisotope database is provided in Appendix E.

8.0 ERROR MESSAGES

PREGENII aborts execution and outputs a variety of messages to the screen and/or the diagnostics/debug output file when input errors occur. A listing of these error messages follows.

- One of the following messages is output when memory errors are detected:

```
(ADDMEM) - REAL array size errors detected ***
(ADDMEM2) - REAL array size errors detected ***
(ADDMEM3) - REAL array size errors detected ***
(ADDMEM) - REAL array memory errors detected ***
(ADDMEM) - CHARACTER array size errors detected ***
(ADDMEM1) - CHARACTER array size errors detected ***
(MEMADJ) - REAL DYNAMIC MEMORY ALLOCATION ERRORS ***
(MEMADJ) - Invalid REAL dynamic array indices detected ***
(MEMADJ) - Invalid CHARACTER dynamic array indices detected ***
(MEMADJ2) - REAL DYNAMIC MEMORY ALLOCATION ERRORS ***
(MEMADJ3) - REAL DYNAMIC MEMORY ALLOCATION ERRORS ***
(MEMADJC) - CHARACTER DYNAMIC MEMORY ALLOCATION ERRORS ***
(MEMADJC2) - CHARACTER DYNAMIC MEMORY ALLOCATION ERRORS ***
(MEMADJC3) - ### CHARACTER ### DYNAMIC MEMORY ALLOCATION ERRORS ***
```

If any of the above messages are displayed, the user should contact the code sponsor.

- The following messages are output when a required file cannot be found, opened, or closed:

```
Error calling DBSETUP
Error opening input CAMDAT file . . .
Error closing input CAMDAT file . . .
```

If any of the above messages are displayed, the user should verify that the required file names have been supplied and that the files are in the correct format.

- The following message is output if no brine concentration or fluid flow nodal variable is found:

```
WARNING, no BRINE CONCENTRATION nodal variable found'
WARNING, no FLUID FLOW nodal variable found'
```

If the above message is displayed, the user should supply this variable in the input CDB file or in the user input file.

- The following messages are output if there is an error in reading parameters supplied by the user in the PREGENII input-control file:

```
(RDAQUA) - Errors reading aquifer parameters ***
(RDNUCD) - Errors reading Nuclear (in air) parameters ***
(RDPATH) - Errors reading pathway parameters ***
(RDPGCD) - Read ERRORS encountered reading PREGENII input text file ***
(RDRILL) - Errors reading driller parameters ***
(RDSUSP) - Errors reading suspension (in air) parameters ***
(READ_EXPOSURE) - Errors reading exposure parameters ***
(READ_FLAGS) - Errors reading flags parameters ***
(READ_INGESTION) - Errors reading INGESTION input parameters ***
(READ_REPORT) - Errors reading Report defintion ***
(READ_SCEN) - Errors reading Scenario defintion ***
(READ_SOIL) - Errors reading SOIL input parameters ***
(READ_TRANSPORT) - Errors reading transport parameters ***
(RSTOCK) - Errors reading stockpond parameters ***
```

If any of the above messages are displayed, the user should check the indicated parameter specification in the PREGENII input control file.

- The following messages are output if there is an error in reading keywords supplied by the user in the PREGENII input-control file:

```
*** BAD AQUIFER KEYWORD = ...
*** MAY BE BAD CDB-array KEYWORD = ...
*** BAD CDB-array KEYWORD = ...
*** BAD NUCLEAR DATA KEYWORD = ...
*** POSSIBLE BAD PATHWAY KEYWORD = ...
*** BAD SUSPEND KEYWORD = ...
*** UNKNOWN KEYWORD = ...
*** BAD ingestion KEYWORD = ...
*** Unknown soil_ data  KEYWORD = ...
*** UNKNOWN TRANSPORT KEYWORD = ...
```

If any of the above messages are displayed, the user should check the indicated keyword specification in the PREGENII input control file.

- The following message is output when a problem is encountered reading a CDB-array parameter:

```
(RDARRD) - Errors reading CDB-array parameters in RDARRD***
```

If the above message is displayed, the user should check the input CDB file and the input control file for errors.

- The following messages are output if there is a problem with reading CAMDAT variables:

```
**** ERROR reading input CAMDAT time values ****
*** ERROR reading input CAMDAT HISTORY variable values ***
*** ERROR reading input CAMDAT GLOBAL variable values ***
*** ERROR reading input CAMDAT NODAL variable values ***'
*** ERROR reading input CAMDAT ELEMENT variable values ***'
```

If any of the above messages are displayed, there may be a problem with the input control file or the CDB file.

- The following message is output when PREGENII encounters problems with the generic nuclear database input file:

```
FINDFIT--too many nucs on curies data file
FINDFIT - too many vectors read on file
Isotopic name mismatch in FINDFIT
Isotopic name mismatch in FINDFIT
Can not find . . . in GENERIC NUCLEAR DATABASE
Cannot find some radioisotopes in GENERIC library; see debug file
```

If the above message is displayed, the user should contact the person responsible for this database.

- If there is a problem with the LHS parameters, the following message is displayed:

```
Exceeded max number of LHS parameters, check LHS.INC
```

As the message indicates, the user should check the LHS include file.

- The following messages indicate problems with interpolation:

```
Warning, exceeding specified number of interpolation points
inside range of specified times, may lead to poor
interpolation, time= ...

Warning, insufficient number of interpolation points inside
range of specified times, may lead to interpolation problems
```

```
Specified extraction time bracket is outside or excludes CDB
analysis times
```

If these messages are encountered, the user should examine the time step and interpolation parameters following the `*ARRAY_CAMDAT` keyword in the PREGENII input control file.

9.0 DESCRIPTION OF OUTPUT FILES

9.1 GENII-A ASCII Input Control File

The GENII-A ASCII input control file, output by PREGENII, acts as an input control file for GENII-A. Appendices F, G, H, and I provide sample GENII-A ASCII input control files corresponding to the following exposure pathways[2]:

1. contaminated stockpond, water-stock cattle, man (rancher) (Appendix F)
2. contaminated cuttings, man (driller) (Appendix G)
3. contaminated drilling-mud pit, dust-air transport, man (farm family) (Appendix H)
4. contaminated dried stockpond, dust-air transport, man (farm family) (Appendix I).

The contents of the files in Appendices F, G, H, and I are specified by the PREGENII input control files contained in Appendices A, B, C, and D, respectively.

9.2 PREGENII Diagnostics/Debug File

The diagnostics/debug file contains run-time information for the run of PREGENII corresponding to the sampled vector. A listing of a sample diagnostics/debug file is provided in Appendix J.

10.0 REFERENCES

Napier, B.A., R.A. Peloquin, D.L. Strenge, and J.V. Ramsdell. 1988. *GENII - The Hanford Environmental Radiation Dosimetry Software System, Volume 1: Conceptual Representation and Volume 2: Users' Manual.* PNL-6584, Richland, Washington: Pacific Northwest Laboratory.

Radiation Shielding Information Center. 1995. *GENII 1.485 Environmental Radiation Dosimetry Software System, March 1995.* Oak Ridge, Tennessee: Oak Ridge National Laboratory.

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[2] The sample files provided in this user's manual are not necessarily indicative of those used for the WIPP PA calculations.

Rechard, R.P. 1995. *An Introduction to the Mechanics of Performance Assessment Using Examples of Calculations Done for the Waste Isolation Pilot Plant Between 1990 and 1992.* SAND93-1378, Albuquerque, NM: Sandia National Laboratories.

Rechard, R.P., Ed. 1992. *User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller, Version 3.0.* SAND90-1983, Albuquerque, NM: Sandia National Laboratories.

Rechard, R.P., A.P. Gilkey, H.J. Iuzzolino, D.K. Rudeen, K.A. Byle. 1993. *Programmer's Manual for CAMCON: Compliance Assessment Methodology Controller.* SAND90-1984, Albuquerque, NM: Sandia National Laboratories.

U.S. DOE (U.S. Department of Energy). 1980. Final Environmental Impact Statement: Waste Isolation Pilot Plant. DOE/EIS-0026. Washington, DC: U.S. Department of Energy.

11.0 APPENDICES

Note

The sample files and displays provided in the appendices that follow are examples *only*. They *are not necessarily* the files used for the 1996 WIPP PA regulatory calculation.

Appendix A: Sample PREGENII Input Control (.INP) File for Contaminated Stockpond, Water-Stock Cattle, Man (Rancher) Pathway

```
*PATHWAY, &
   VECTORS=2, PATH='STOCK',SCEN=E1E2,TIME_INT=1000.0,LOC=1,&
   SOURCE=WATER
*ARRAY_CAMDAT, &
   TYPE='NODE', ROOT='C_', LENGTH_ROOT=2, &
   I_LOC=10 J_LOC=10, K_LOC=7, &
   TIME_SOLUTION=3.157E11, &
   TOLER=1.0E9, UNITS_TIME=SECONDS, INTERP=NEAR, NUMBER_POINTS=1
*STOCK_WELL, &
   AQUIFER_AREA=1.0, &
   NUMBER_COWS=25, RATE_DRINK=10.0, POTABILITY=1.007, PUMP_DURATION=0.6,&
   BRINE=1.0, FLOW=1.0
*NUCLEAR, &
   NUM_NUCS=11, NUCLIDES=PU239,PA231,NP237,'U233','U234','U235',&
   'U236','U238',SE79,TC99,'I129'
*REPORT, &
   COMMITTED, NUCLIDES, PATHS
*SCENARIO, &
   FAR_FIELD, CHRONIC, INDIVIDUAL, TRANSPORT=GROUNDWATER, INVENTORY=BASIC
*EXPOSURE, &
    ANIMAL_INGESTION, &
   DOSE_PERIOD=1.0, COMMIT_PERIOD=50.0, INTAKE_PERIOD=1.0, &
   UNITS_ACTIVITY=PICOCURIES, UNITS_SURFACE=CUBIC_METERS
*FLAGS, &
   WATER_TREATMENT=NO, WATER_IRRIG=GROUNDWATER
*INGESTION
   ANIMAL_CONSUMPTION=BEEF, CONSUMPTION=100.0, HOLDUP=50.0, PRODUCTION=110.0,&
                            CONTAMINATED_H2O=1.0
   ANIMAL_CONSUMPTION=POULTRY, CONSUMPTION=80.0, HOLDUP=10.0, &
                            PRODUCTION=120.0, &
                            CONTAMINATED_H2O=1.0
   ANIMAL_CONSUMPTION=MILK, CONSUMPTION=50.0, HOLDUP=10.0, PRODUCTION=120.0,&
                            CONTAMINATED_H2O=1.0
   ANIMAL_CONSUMPTION=EGGS, CONSUMPTION=60.0, HOLDUP=10.0, PRODUCTION=120.0,&
                            CONTAMINATED_H2O=1.0
   FRESH_FEED=BEEF, FRACTION=0.5, GROW_TIME=45, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=2.0, STORAGE=20.
   STORED_FEED=BEEF, FRACTION=0.5 GROW_TIME=45, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=2.0, STORAGE=100.
  END_INGESTION_INPUT
! list the variables which will be sampled, GENII name=CAMDAT name
*LHS_SAMPLES, &
 HUMAN_DRINKING_WATER=H2O_DRNK
*END
[End of file]
```

Appendix B: Sample PREGENII Input Control (.INP) File for Contaminated Cuttings, Man (Driller) Pathway

```
*PATHWAY, &
   WASTE_FORMS=1,VECTORS=1, PATH='DRILL',SCEN=E1E2,TIME_INT=1000.0,LOC=1,&
   SOURCE=CUTTINGS
*ARRAY_CAMDAT, &
   TYPE='GLOBAL', ROOT='C_', LENGTH_ROOT=2, &
   TIME_SOLUTION=7.25007E3, &
   TOLER=1.0E2, UNITS_TIME=YEARS, INTERP=NEAR, NUMBER_POINTS=1
*NUCLEAR, &
   NUM_NUCS=11, NUCLIDES=PU239,PA231,NP237,U233,U234,U235,&
   U236,U238,SE79,TC99,I129
*DRILL, &
  DENSITY=1.4E3, RADIUS_CHIP=0.05, RADIUS_BOREHOLE=0.1775
*REPORT, &
   COMMITTED, NUCLIDES, PATHS
*SCENARIO, &
   NEAR_FIELD, CHRONIC, INDIVIDUAL, TRANSPORT=NONE, INVENTORY=BASIC
*EXPOSURE, &
   EXTERNAL_GROUND, &
   DOSE_PERIOD=1.0, COMMIT_PERIOD=50.0, INTAKE_PERIOD=1.0, &
   UNITS_ACTIVITY=PICOCURIES, UNITS_SURFACE=SQUARE_METERS, &
   PLUME_TIME_EXPOSURE=3700.0, SOIL_TIME_EXP=0.0, &
   SAMPLE_TIME_EXP=1.0, &
   AREA_EXTERNAL_SOURCE=0.0, AREA_EXAMINATION=7.854E-3
*SOIL_DATA, &
   SOIL_MODEL=NO_RESUSPENSION,SOIL_DILUTION_FACTOR=0.5, DEPTH_TOP_SOIL=10.0
! list the variables which will be sampled, GENII name=CAMDAT name
*LHS_SAMPLES, &
 HUMAN_DRINKING_WATER = H2O_DRNK
*END
[End of file]
```

Appendix C: Sample PREGENII Input Control (.INP) File for Contaminated Drilling-Mud Pit, Dust-Air Transport, Man (Farm Family) Pathway

```
*PATHWAY, &
   WASTE_FORMS=1,VECTORS=1, PATH='FARM',SCEN=E1E2,TIME_INT=1000.0,LOC=1,&
   SOURCE=CUTTINGS
*ARRAY_CAMDAT, &
   TYPE='GLOBAL', ROOT='C_', LENGTH_ROOT=2, &
   TIME_SOLUTION=7.25007E3, &
   TOLER=1.0E2, UNITS_TIME=YEARS, INTERP=NEAR, NUMBER_POINTS=1
*NUCLEAR, &
   NUM_NUCS=11, NUCLIDES=PU239,PA231,NP237,U233,U234,U235,&
   U236,U238,SE79,TC99,I129
*DRILL, &
  DENSITY=1.4E3, RADIUS_CHIP=0.05, RADIUS_BOREHOLE=0.1775
*REPORT, &
   COMMITTED, NUCLIDES, PATHS,ORGANS
*SCENARIO, &
   FAR_FIELD, CHRONIC, POPULATION=GRID, TRANSPORT=AIR, INVENTORY=RELEASE
*SUSPEND, &
   DENSITY=1.4E3, RATE_COEFF=1.0E-13, WIND_SPEED=3.7, DEPTH=.01, AREA=22.98
*TRANSPORT
! No continuation afer *TRANSPORT!!!
   AIR_TRANSPORT,JOINTFRE,SECTOR=16, &
                  RELEASE_DIST=5.3E4,RELEASE_HEIGHT=1.0
END_TRANSPORT
*EXPOSURE, &
   EXTERNAL_GROUND, FINITE_PLUME, INHALATION, ANIMAL, PLANT, &
   DOSE_PERIOD=1.0, COMMIT_PERIOD=50.0, INTAKE_PERIOD=1.0, &
   UNITS_ACTIVITY=CURIES, UNITS_SURFACE=SQUARE_METERS, &
   PLUME_TIME_EXPOSURE=8766.0, &
   TIME_INHALATION=8766.0, &
   AREA_EXTERNAL_SOURCE=1000.0, AREA_EXAMINATION=7.854E-3
*FLAGS, &
 PRODUCTION=POPULATION
*SOIL_DATA, &
   SOIL_MODEL=ANSPAUGH, DEPTH_TOP=2.0
*INGESTION
   PLANT_CONSUMPTION=LEAF,GROW_TIME=60,RATE_IRRI=10.0,TIME_IRRI=6.0,&
                           YIELD=50.0,PRODUCTION=120.0,HOLDUP=20.0, &
                           CONSUMPTION=60.0
   PLANT_CONSUMPTION=ROOTS,GROW_TIME=70,RATE_IRRI=10.0,TIME_IRRI=6.0,&
                           YIELD=50.0,PRODUCTION=100.0,HOLDUP=50.0, &
                           CONSUMPTION=60.0
   PLANT_CONSUMPTION=FRUIT,GROW_TIME=80,RATE_IRRI=10.0,TIME_IRRI=6.0,&
                           YIELD=60.0,PRODUCTION=130.0,HOLDUP=10.0, &
                           CONSUMPTION=90.0
   PLANT_CONSUMPTION=GRAIN,GROW_TIME=90,RATE_IRRI=10.0,TIME_IRRI=6.0,&
                           YIELD=40.0,PRODUCTION=110.0,HOLDUP=60.0, &
                           CONSUMPTION=80.0
   ANIMAL_CONSUMPTION=BEEF, CONSUMPTION=100.0, HOLDUP=50.0, PRODUCTION=110.0,&
                           CONTAMINATED_H2O=1.0
   ANIMAL_CONSUMPTION=POULTRY, CONSUMPTION=80.0, HOLDUP=10.0, &
                           PRODUCTION=120.0, &
                           CONTAMINATED_H2O=1.0
   ANIMAL_CONSUMPTION=MILK, CONSUMPTION=50.0, HOLDUP=10.0, PRODUCTION=120.0,&
                           CONTAMINATED_H2O=1.0
```

```
   ANIMAL_CONSUMPTION=EGGS, CONSUMPTION=60.0, HOLDUP=10.0, PRODUCTION=120.0,&
                            CONTAMINATED_H2O=1.0
   FRESH_FEED=BEEF, FRACTION=0.5, GROW_TIME=45, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=2.0, STORAGE=20.
   STORED_FEED=BEEF, FRACTION=0.5 GROW_TIME=45, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=2.0, STORAGE=100.
  END_INGESTION_INPUT
! list the variables which will be sampled, GENII name=CAMDAT name
!*LHS_SAMPLES, &
! HUMAN_DRINKING_WATER = H2O_DRNK
*END
[End of file]
```

Appendix D: Sample PREGENII Input Control (.INP) File for Contaminated Dried-Stockpond, Dust-Air Transport, Man (Farm Family) Pathway

```
*PATHWAY, &
   WASTE_FORMS=1,VECTORS=1, PATH='FARM',SCEN=E1E2,TIME_INT=1000.0,LOC=1,&
   SOURCE=WATER
*ARRAY_CAMDAT, &
   TYPE='NODE', ROOT='C_', LENGTH_ROOT=2, &
   I_LOC=10, J_LOC=10, K_LOC=7, &
   TIME_SOLUTION=3.157E11, &
   TOLER=1.0E9, UNITS_TIME=SECONDS, INTERP=NEAR, NUMBER_POINTS=1
*STOCK_WELL, &
   AQUIFER_AREA=1.0, &
   NUMBER_COWS=25, RATE_DRINK=10.0, POTABILITY=1.007, PUMP_DURATION=0.6,&
   BRINE = 1.0, FLOW=1.0
*NUCLEAR, &
   NUM_NUCS=11, NUCLIDES=PU239,PA231,NP237,U233,U234,U235,&
   U236,U238,SE79,TC99,I129
*REPORT, &
   COMMITTED, NUCLIDES, PATHS, ORGANS
*SCENARIO, &
   FAR_FIELD, CHRONIC, TRANSPORT=AIR, INVENTORY=RELEASE
*SUSPEND, &
   DENSITY=1.5E3, RATE_COEFF=1.0E-13, WIND_SPEED=3.7, DEPTH=.01, AREA=728.5
*TRANSPORT
! No continuation afer *TRANSPORT!!!
   AIR_TRANSPORT,CHI_OVER_Q=CALCULATE,OPTION=USE_CHI_OVER_Q,RELEASE_DIST=5.3E4
END_TRANSPORT
*EXPOSURE, &
   EXTERNAL_GROUND, INFINITE_PLUME, INHALATION, ANIMALS, PLANTS, &
   DOSE_PERIOD=1.0, COMMIT_PERIOD=50.0, INTAKE_PERIOD=1.0, &
   UNITS_ACTIVITY=CURIES, UNITS_SURFACE=SQUARE_METERS, &
   PLUME_TIME_EXPOSURE=8766.0, SOIL_TIME_EXPOSURE=2920.0, &
   TIME_INHALATION=8766.0, PERIOD_AIR_DEP=100.0
*FLAGS, &
 PRODUCTION=POPULATION
*SOIL_DATA, &
   SOIL_MODEL=MASS_LOAD, MASS_LOAD=1.5E3, ROOTS_UPPER=0.5
*INGESTION
   PLANT_CONSUMPTION=LEAF,GROW_TIME=60,RATE_IRRI=10.0,TIME_IRRI=6.0,&
                           YIELD=50.0,PRODUCTION=120.0,HOLDUP=20.0, &
                           CONSUMPTION=60.0
   PLANT_CONSUMPTION=ROOTS,GROW_TIME=70,RATE_IRRI=10.0,TIME_IRRI=6.0,&
                           YIELD=50.0,PRODUCTION=100.0,HOLDUP=50.0, &
                           CONSUMPTION=60.0
   PLANT_CONSUMPTION=FRUIT,GROW_TIME=80,RATE_IRRI=10.0,TIME_IRRI=6.0,&
                           YIELD=60.0,PRODUCTION=130.0,HOLDUP=10.0, &
                           CONSUMPTION=90.0
   PLANT_CONSUMPTION=GRAIN,GROW_TIME=90,RATE_IRRI=10.0,TIME_IRRI=6.0,&
                           YIELD=40.0,PRODUCTION=110.0,HOLDUP=60.0, &
                           CONSUMPTION=80.0
   ANIMAL_CONSUMPTION=BEEF, CONSUMPTION=100.0, HOLDUP=50.0, PRODUCTION=110.0,&
                           CONTAMINATED_H2O=1.0
   ANIMAL_CONSUMPTION=POULTRY, CONSUMPTION=80.0, HOLDUP=10.0, &
                           PRODUCTION=120.0, &
                           CONTAMINATED_H2O=1.0
   ANIMAL_CONSUMPTION=MILK, CONSUMPTION=50.0, HOLDUP=10.0, PRODUCTION=120.0,&
```

```
                                CONTAMINATED_H2O=1.0
   ANIMAL_CONSUMPTION=EGGS, CONSUMPTION=60.0, HOLDUP=10.0, PRODUCTION=120.0,&
                                CONTAMINATED_H2O=1.0
   FRESH_FEED=BEEF, FRACTION=0.5, GROW_TIME=45, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=2.0, STORAGE=20.
   FRESH_FEED=MILK, FRACTION=0.4, GROW_TIME=30, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=5.0, STORAGE=10.
   STORED_FEED=BEEF, FRACTION=0.5 GROW_TIME=45, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=2.0, STORAGE=100.
   STORED_FEED=POULTRY, FRACTION=0.6 GROW_TIME=20, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=6.0, STORAGE=60.
   STORED_FEED=MILK, FRACTION=0.6 GROW_TIME=30, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=5.0, STORAGE=50.
   STORED_FEED=EGGS, FRACTION=0.6 GROW_TIME=25, RATE_IRRIGATION=10.0, &
                    TIME_IRRIGATION=6.0, YIELD=3.0, STORAGE=40.
  END_INGESTION_INPUT
! list the variables which will be sampled, GENII name=CAMDAT name
!*LHS_SAMPLES, &
! HUMAN_DRINKING_WATER = H2O_DRNK
*END
```

Appendix E: Input Generic Radioisotope Database

GENERIC RADIOISOTOPE DATA BASE:

Radio-isotope	Daught.	Half-life (Seconds)	Half-life (Years)	Atomic Wt. (Kg/Mole)	Act. Conv. (Ci/Kg)	EPA Release Limit	Waste Unit	Decay-Mode
H3	HE3	3.8950E+08	1.2343E+01	3.0000E-03	9.6534E+06	10000000.	10000000.	BETA
HE3	Stable	1.0000E+38	1.0000E+38	3.0000E-03	0.0000E+00	10000000.	10000000.	STABLE
C14	N14	1.8070E+11	5.7262E+03	1.4000E-02	4.4589E+03	100.	10000000.	BETA
N14	Stable	1.0000E+38	1.0000E+38	1.4000E-02	0.0000E+00	10000000.	10000000.	BETA
AR36	Stable	1.0000E+38	1.0000E+38	3.6000E-02	0.0000E+00	10000000.	10000000.	STABLE
AR39	K39	8.4830E+09	2.6882E+02	3.9000E-02	3.4095E+04	10000.	10000000.	BETA
AR42	K42	1.4010E+09	4.4396E+01	4.2000E-02	1.9170E+05	10000.	1000000000.	BETA
CL36	AR36	9.4920E+12	3.0079E+05	3.6000E-02	3.3010E+01	10000.	10000000.	BETA
K39	Stable	1.0000E+38	1.0000E+38	3.9000E-02	0.0000E+00	10000000.	10000000.	STABLE
K41	Stable	1.0000E+38	1.0000E+38	4.1000E-02	0.0000E+00	10000000.	10000000.	STABLE
K42	CA42	4.4500E+04	1.4102E-03	4.2000E-02	6.0353E+09	10000000.	10000000.	BETA
CA41	K41	4.4150E+12	1.3991E+05	4.1000E-02	6.2315E+01	10000.	10000000.	E_CAPTURE
CA42	Stable	1.0000E+38	1.0000E+38	4.2000E-02	0.0000E+00	10000000.	10000000.	STABLE
CR51	V51	2.3930E+06	7.5832E-02	5.1000E-02	9.2426E+07	10000000.	10000000.	E_CAPTURE
V51	Stable	1.0000E+38	1.0000E+38	5.1000E-02	0.0000E+00	10000000.	10000000.	STABLE
FE55	MN55	8.5150E+07	2.6983E+00	5.5000E-02	2.4086E+06	10000000.	10000000.	E_CAPTURE
MN55	Stable	1.0000E+38	1.0000E+38	5.5000E-02	0.0000E+00	10000000.	10000000.	STABLE
CO59	Stable	1.0000E+38	1.0000E+38	5.9000E-02	0.0000E+00	10000000.	10000000.	STABLE
CO60	NI60	1.6620E+08	5.2667E+00	6.0000E-02	1.1312E+06	10000000.	10000000.	BETA
NI59	CO59	2.3650E+12	7.4944E+04	5.9000E-02	8.0840E+01	10000000.	10000000.	E_CAPTURE
NI60	Stable	1.0000E+38	1.0000E+38	6.0000E-02	0.0000E+00	10000000.	10000000.	STABLE
NI63	CU63	3.0270E+09	9.5923E+01	6.3000E-02	5.9150E+04	10000.	1000000000.	BETA
CU63	Stable	1.0000E+38	1.0000E+38	6.3000E-02	0.0000E+00	10000000.	10000000.	STABLE
BR79	Stable	1.0000E+38	1.0000E+38	7.9000E-02	0.0000E+00	10000000.	10000000.	STABLE
SE79	BR79	2.0500E+12	6.4962E+04	7.9000E-02	6.9651E+01	10000.	10000000.	BETA
KR85	RB85	3.3766E+08	1.0700E+01	8.5000E-02	3.3930E+04	10000000.	10000000.	BETA
RB85	Stable	1.0000E+38	1.0000E+38	8.5000E-02	0.0000E+00	10000000.	10000000.	STABLE
RB87	SR87	1.4820E+18	4.6963E+10	8.7000E-02	8.7487E-05	10000.	10000000.	BETA
SR87	Stable	1.0000E+38	1.0000E+38	8.7000E-02	0.0000E+00	10000000.	10000000.	STABLE
SR89	Y89	4.3630E+06	1.3826E-01	8.9000E-02	2.9049E+07	10000000.	10000000.	BETA
SR90	Y90	9.1890E+08	2.9119E+01	9.0000E-02	1.3639E+05	10000.	1000000000.	BETA
Y89	Stable	1.0000E+38	1.0000E+38	8.9000E-02	0.0000E+00	10000000.	10000000.	STABLE
Y90	ZR90	2.3040E+05	7.3011E-03	9.0000E-02	5.4398E+08	10000000.	10000000.	BETA
Y91	ZR91	5.0550E+06	1.6019E-01	9.1000E-02	2.4521E+07	10000000.	10000000.	BETA
ZR90	Stable	1.0000E+38	1.0000E+38	9.0000E-02	0.0000E+00	10000000.	10000000.	STABLE
ZR91	Stable	1.0000E+38	1.0000E+38	9.1000E-02	0.0000E+00	10000000.	10000000.	STABLE
ZR93	NB93M	4.82[illegible]13	1.5290E+06	9.3000E-02	2.5138E+00	10000.	10000000.	BETA
ZR95	NB95	5.5[illegible]06	1.7518E-01	9.5000E-02	2.1479E+07	10000000.	10000000.	BETA
NB93	Stable	1.0000E+38	1.0000E+38	9.3000E-02	0.0000E+00	10000000.	10000000.	STABLE
NB93M	NB93	4.2890E+08	1.3591E+01	9.3000E-02	2.8279E+05	10000000.	10000000.	GAMMA
NB94	MO94	6.4020E+11	2.0287E+04	9.4000E-02	1.8744E+02	10000.	10000000.	BETA
NB95	MO95	3.0370E+06	9.6239E-02	9.5000E-02	3.9097E+07	10000000.	10000000.	BETA
NB95M	NB95	3.1180E+05	9.8806E-03	9.5000E-02	3.8081E+08	10000000.	10000000.	GAMMA
MO94	Stable	1.0000E+38	1.0000E+38	9.4000E-02	0.0000E+00	10000000.	10000000.	STABLE
MO95	Stable	1.0000E+38	1.0000E+38	9.5000E-02	0.0000E+00	10000000.	10000000.	STABLE
RU99	Stable	1.0000E+38	1.0000E+38	9.9000E-02	0.0000E+00	10000000.	10000000.	STABLE
TC99	RU99	6.7170E+12	2.1286E+05	9.9000E-02	1.6963E+01	1000000.	10000000.	BETA
RH103M	RH103	3.3670E+03	1.0670E-04	1.0300E-01	3.2526E+10	10000000.	10000000.	GAMMA
RH103	Stable	1.0000E+38	1.0000E+38	1.0300E-01	0.0000E+00	10000000.	10000000.	STABLE
RH106	PD106	2.9800E+01	9.4433E-07	1.0600E-01	3.5710E+12	10000000.	10000000.	BETA
RU103	RH103M	3.3940E+06	1.0755E-01	1.0300E-01	3.2267E+07	10000000.	10000000.	BETA
RU106	RH106	3.1810E+07	1.0080E+00	1.0600E-01	3.3453E+06	10000000.	10000000.	BETA
PD106	Stable	1.0000E+38	1.0000E+38	1.0600E-01	0.0000E+00	10000000.	10000000.	STABLE
PD107	AG107	2.0500E+14	6.4962E+06	1.0700E-01	5.1425E-01	10000.	10000000.	BETA
AG107	Stable	1.0000E+38	1.0000E+38	1.0700E-01	0.0000E+00	10000000.	10000000.	STABLE
AG110M	CD110	2.1590E+07	6.8417E-01	1.1000E-01	4.7497E+06	10000000.	10000000.	BETA
CD110	Stable	1.0000E+38	1.0000E+38	1.1000E-01	0.0000E+00	10000000.	10000000.	STABLE
CD113	IN113	2.9330E+23	9.2944E+15	1.1300E-01	3.4034E-10	10000.	10000000.	BETA
CD113M	IN113	4.2890E+08	1.3591E+01	1.1300E-01	2.3274E+05	10000000.	10000000.	BETA
CD115M	IN115M	3.8530E+06	1.2210E-01	1.1500E-01	2.5457E+07	10000000.	10000000.	BETA
IN113M	IN113	5.9690E+03	1.8915E-04	1.1300E-01	1.6724E+10	10000000.	10000000.	GAMMA
IN113	Stable	1.0000E+38	1.0000E+38	1.1300E-01	0.0000E+00	10000000.	10000000.	STABLE
IN115M	IN115	1.6150E+04	5.1178E-04	1.1500E-01	6.0735E+09	10000000.	10000000.	GAMMA
IN115	SN115	1.6080E+23	5.0956E+15	1.1500E-01	6.0999E-10	10000.	10000000.	BETA
SN113	IN113	9.9450E+06	3.1515E-01	1.1300E-01	1.0038E+07	10000000.	10000000.	E_CAPTURE
SN115	Stable	1.0000E+38	1.0000E+38	1.1500E-01	0.0000E+00	10000000.	10000000.	STABLE
SN119M	SN119	2.5320E+07	8.0237E-01	1.1900E-01	3.7437E+06	10000000.	10000000.	GAMMA
SN119	Stable	1.0000E+38	1.0000E+38	1.1900E-01	0.0000E+00	10000000.	10000000.	STABLE
SN121M	SN121	1.7340E+09	5.4949E+01	1.2100E-01	5.3762E+04	10000.	1000000000.	BETA
SN121	SB121	9.7420E+04	3.0871E-03	1.2100E-01	9.5692E+08	10000000.	10000000.	BETA
SN123	SB123	1.1160E+07	3.5365E-01	1.2300E-01	8.2175E+06	10000000.	10000000.	BETA
SN126	SB126	3.1540E+12	9.9947E+04	1.2600E-01	2.8384E+01	10000.	10000000.	BETA
SB121	Stable	1.0000E+38	1.0000E+38	1.2100E-01	0.0000E+00	10000000.	10000000.	STABLE
SB123	Stable	1.0000E+38	1.0000E+38	1.2300E-01	0.0000E+00	10000000.	10000000.	STABLE
SB124	TE124	5.2010E+06	1.6481E-01	1.2400E-01	1.7490E+07	10000000.	10000000.	BETA
SB125	TE125M	8.7350E+07	2.7680E+00	1.2500E-01	1.0331E+06	10000000.	10000000.	BETA
SB126	TE126	1.0710E+06	3.3939E-02	1.2600E-01	8.3589E+07	10000.	10000000.	BETA
SB126M	SB126	1.1400E+03	3.6125E-05	1.2600E-01	7.8530E+10	10000.	10000000.	BETA
TE124	Stable	1.0000E+38	1.0000E+38	1.2400E-01	0.0000E+00	10000000.	10000000.	STABLE
TE125	Stable	1.0000E+38	1.0000E+38	1.2500E-01	0.0000E+00	10000000.	10000000.	STABLE
TE125M	TE125	5.0110E+06	1.5879E-01	1.2500E-01	1.8008E+07	10000000.	10000000.	GAMMA
TE126	Stable	1.0000E+38	1.0000E+38	1.2600E-01	0.0000E+00	10000000.	10000000.	STABLE

TE127	I127	3.3660E+04	1.0667E-03	1.2700E-01	2.6387E+09	10000000.	10000000.	BETA
TE127M	TE127	9.4180E+06	2.9845E-01	1.2700E-01	9.4308E+06	10000000.	10000000.	GAMMA
TE129	I129	4.1760E+03	1.3233E-04	1.2900E-01	2.0939E+10	10000000.	10000000.	BETA
TE129M	TE129	2.9030E+06	9.1993E-02	1.2900E-01	3.0121E+07	10000000.	10000000.	GAAMMA
I127	Stable	1.0000E+38	1.0000E+38	1.2700E-01	0.0000E+00	10000000.	10000000.	STABLE
I129	XE129M	4.9510E+14	1.5689E+07	1.2900E-01	1.7661E-01	1000.	10000000.	BETA
XE129M	XE129	6.9120E+05	2.1903E-02	1.2900E-01	1.2651E+08	10000000.	10000000.	GAMMA
XE129	Stable	1.0000E+38	1.0000E+38	1.2900E-01	0.0000E+00	10000000.	10000000.	STABLE
BA134	Stable	1.0000E+38	1.0000E+38	1.3400E-01	0.0000E+00	10000000.	10000000.	STABLE
BA135	Stable	1.0000E+38	1.0000E+38	1.3500E-01	0.0000E+00	10000000.	10000000.	STABLE
BA136M	Stable	1.0000E+38	1.0000E+38	1.3600E-01	0.0000E+00	10000000.	10000000.	STABLE
BA136	Stable	1.0000E+38	1.0000E+38	1.3600E-01	0.0000E+00	10000000.	10000000.	STABLE
BA137M	BA137	1.5310E+02	4.8516E-06	1.3700E-01	5.3779E+11	10000000.	10000000.	GAMMA
BA137	Stable	1.0000E+38	1.0000E+38	1.3700E-01	0.0000E+00	10000000.	10000000.	STABLE
BA138	Stable	1.0000E+38	1.0000E+38	1.3800E-01	0.0000E+00	10000000.	10000000.	STABLE
BA140	LA140	1.1010E+06	3.4890E-02	1.4000E-01	7.3180E+07	10000000.	10000000.	BETA
CS134	BA134	6.5030E+07	2.0607E+00	1.3400E-01	1.2945E+06	10000000.	10000000.	BETA
CS135	BA135	7.2530E+13	2.2984E+06	1.3500E-01	1.1520E+00	10000.	10000000.	BETA
CS136	BA136	1.1320E+06	3.5872E-02	1.3600E-01	7.3270E+07	10000000.	10000000.	BETA
CS137	BA137M	9.4670E+08	3.0000E+01	1.3700E-01	8.6971E+04	10000.	1000000000.	BETA
CE140	Stable	1.0000E+38	1.0000E+38	1.4000E-01	0.0000E+00	10000000.	10000000.	STABLE
CE141	PR141	2.8080E+06	8.8983E-02	1.4100E-01	2.8490E+07	10000000.	10000000.	BETA
CE142	BA138	1.5780E+24	5.0005E+16	1.4200E-01	5.0340E-11	10000000.	10000000.	STABLE
CE144	PR144	2.4560E+07	7.7828E-01	1.4400E-01	3.1895E+06	10000000.	10000000.	BETA
LA140	CE140	1.4500E+05	4.5949E-03	1.4000E-01	5.5567E+08	10000000.	10000000.	BETA
PR141	Stable	1.0000E+38	1.0000E+38	1.4100E-01	0.0000E+00	10000000.	10000000.	STABLE
PR143	ND143	1.1720E+06	3.7140E-02	1.4300E-01	6.7305E+07	10000000.	10000000.	BETA
PR144	ND144	1.0370E+03	3.2861E-05	1.4400E-01	7.5538E+10	10000000.	10000000.	BETA
PR144M	ND144	4.3200E+02	1.3690E-05	1.4400E-01	1.8133E+11	10000000.	10000000.	BETA
ND142	Stable	1.0000E+38	1.0000E+38	1.4200E-01	0.0000E+00	10000000.	10000000.	STABLE
ND143	Stable	1.0000E+38	1.0000E+38	1.4300E-01	0.0000E+00	10000000.	10000000.	STABLE
ND144	CE140	6.6230E+22	2.0988E+15	1.4400E-01	1.1827E-09	10000000.	10000000.	STABLE
ND145	CE141	1.8930E+24	5.9987E+16	1.4500E-01	4.1095E-11	10000000.	10000000.	STABLE
ND146	Stable	1.0000E+38	1.0000E+38	1.4600E-01	0.0000E+00	10000000.	10000000.	STABLE
ND147	PM147	9.4870E+05	3.0063E-02	1.4700E-01	8.0884E+07	10000000.	10000000.	BETA
PM146	ND146	1.7450E+08	5.5297E+00	1.4600E-01	4.4275E+05	10000000.	10000000.	BETA
PM147	SM147	8.2790E+07	2.6235E+00	1.4700E-01	9.2686E+05	10000000.	10000000.	BETA
PM148	SM148	4.6400E+05	1.4704E-02	1.4800E-01	1.6426E+08	10000000.	10000000.	BETA
PM148M	SM148	3.5680E+06	1.1307E-01	1.4800E-01	2.1361E+07	10000000.	10000000.	BETA
SM146	ND142	3.2480E+15	1.0293E+08	1.4600E-01	2.3787E-02	1000.	10000000.	ALPHA
SM147	ND143	3.3430E+18	1.0594E+11	1.4700E-01	2.2954E-05	1000.	10000000.	ALPHA
SM148	Stable	1.0000E+38	1.0000E+38	1.4800E-01	0.0000E+00	1000.	10000000.	ALPHA
SM149	ND145	3.1560E+23	1.0001E+16	1.4900E-01	2.3988E-10	1000.	10000000.	ALPHA
SM151	EU151	2.8380E+09	8.9933E+01	1.5100E-01	2.6322E+04	10000.	1000000000.	BETA
SM152	Stable	1.0000E+38	1.0000E+38	1.5200E-01	0.0000E+00	10000000.	10000000.	STABLE
EU151	Stable	1.0000E+38	1.0000E+38	1.5100E-01	0.0000E+00	10000000.	10000000.	STABLE
EU152	SM152	4.2040E+08	1.3322E+01	1.5200E-01	1.7652E+05	10000000.	10000000.	BETA
EU153	Stable	1.0000E+38	1.0000E+38	1.5300E-01	0.0000E+00	10000000.	10000000.	STABLE
EU154	GD154	2.7750E+08	8.7937E+00	1.5400E-01	2.6395E+05	10000000.	10000000.	BETA
EU155	GD155	1.5640E+08	4.9562E+00	1.5500E-01	4.6531E+05	10000000.	10000000.	BETA
EU156	GD156	1.3120E+06	4.1576E-02	1.5600E-01	5.5113E+07	10000000.	10000000.	BETA
GD152	SM148	3.4080E+21	1.0800E+14	1.5200E-01	2.1775E-08	10000.	10000000.	ALPHA
GD153	EU153	2.0910E+07	6.6262E-01	1.5300E-01	3.5258E+06	10000000.	10000000.	E_CAPTURE
GD154	Stable	1.0000E+38	1.0000E+38	1.5400E-01	0.0000E+00	10000000.	10000000.	STABLE
GD155	Stable	1.0000E+38	1.0000E+38	1.5500E-01	0.0000E+00	10000000.	10000000.	STABLE
GD156	Stable	1.0000E+38	1.0000E+38	1.5600E-01	0.0000E+00	10000000.	10000000.	STABLE
DY160	Stable	1.0000E+38	1.0000E+38	1.6000E-01	0.0000E+00	10000000.	10000000.	STABLE
TB160	DY160	6.2470E+06	1.9796E-01	1.6000E-01	1.1285E+07	10000000.	10000000.	BETA
ER166	Stable	1.0000E+38	1.0000E+38	1.6600E-01	0.0000E+00	10000000.	10000000.	STABLE
HO166M	ER166	3.7840E+10	1.1991E+03	1.6600E-01	1.7958E+03	10000.	10000000.	BETA
HF174	Stable	1.0000E+38	1.0000E+38	1.7400E-01	0.0000E+00	1000.	10000000.	ALPHA
HF178M	HF178	9.7760E+08	3.0979E+01	1.7800E-01	6.4823E+04	10000.	1000000000.	GAMMA
HF178	Stable	1.0000E+38	1.0000E+38	1.7800E-01	0.0000E+00	10000000.	10000000.	STABLE
HF182	TA182	2.8380E+14	8.9933E+06	1.8200E-01	2.1839E-01	10000.	10000000.	BETA
TA182	W182	9.9360E+06	3.1486E-01	1.8200E-01	6.2377E+06	10000000.	10000000.	BETA
W182	Stable	1.0000E+38	1.0000E+38	1.8200E-01	0.0000E+00	10000000.	10000000.	STABLE
PB206	Stable	1.0000E+38	1.0000E+38	2.0600E-01	0.0000E+00	10000000.	10000000.	STABLE
PB207	Stable	1.0000E+38	1.0000E+38	2.0700E-01	0.0000E+00	10000000.	10000000.	STABLE
PB208	Stable	1.0000E+38	1.0000E+38	2.0800E-01	0.0000E+00	10000000.	10000000.	STABLE
PB209	BI209	1.1710E+04	3.7108E-04	2.0900E-01	4.6090E+09	10000000.	10000000.	BETA
PB210	BI210	7.0370E+08	2.2300E+01	2.1000E-01	7.6331E+04	10000.	1000000000.	BETA
PB211	BI211	2.1660E+03	6.8638E-05	2.1100E-01	2.4681E+10	10000000.	10000000.	BETA
PB212	BI212	3.8300E+04	1.2137E-03	2.1200E-01	1.3892E+09	10000000.	10000000.	BETA
PB214	BI214	1.6080E+03	5.0956E-05	2.1400E-01	3.2780E+10	10000000.	10000000.	BETA
TL207	PB207	2.8620E+02	9.0694E-06	2.0700E-01	1.9040E+11	10000000.	10000000.	BETA
TL208	PB208	1.8420E+02	5.8371E-06	2.0800E-01	2.9441E+11	10000000.	10000000.	BETA
TL209	PB209	1.3200E+02	4.1829E-06	2.0900E-01	4.0887E+11	10000000.	10000000.	BETA
TL210	Stable	1.0000E+38	1.0000E+38	2.1000E-01	0.0000E+00	10000000.	10000000.	BETA
BI208	Stable	1.0000E+38	1.0000E+38	2.0800E-01	0.0000E+00	10000000.	10000000.	E_CAPTURE
BI209	Stable	1.0000E+38	1.0000E+38	2.0900E-01	0.0000E+00	10000000.	10000000.	STABLE
BI210	PO210	4.3300E+05	1.3721E-02	2.1000E-01	1.2405E+08	10000000.	10000000.	BETA
BI211	TL207	1.2840E+02	4.0689E-06	2.1100E-01	4.1635E+11	10000000.	10000000.	ALPHA
BI212	PO212	3.6330E+03	1.1513E-04	2.1200E-01	1.4646E+10	10000000.	10000000.	BETA
BI213	PO213	2.7390E+03	8.6796E-05	2.1300E-01	1.9335E+10	10000000.	10000000.	BETA
BI214	PO214	1.1940E+03	3.7837E-05	2.1400E-01	4.4146E+10	10000000.	10000000.	BETA
PO210	PB206	1.1960E+07	3.7900E-01	2.1000E-01	4.4912E+06	10000000.	10000000.	ALPHA
PO211	PB207	5.1600E-01	1.6352E-08	2.1100E-01	1.0360E+14	10000000.	10000000.	ALPHA
PO212	PB208	3.0500E-07	9.6651E-15	2.1200E-01	1.7445E+20	10000000.	10000000.	ALPHA
PO213	PB209	4.2000E-06	1.2309E-13	2.1300E-01	1.2609E+19	10000000.	10000000.	ALPHA
PO214	PB210	1.6430E-04	5.2065E-12	2.1400E-01	3.2082E+17	10000000.	10000000.	ALPHA
PO215	PB211	1.7820E-03	5.6406E-11	2.1500E-01	2.9475E+16	10000000.	10000000.	ALPHA

PO216	PB212	1.5000E-01	4.7534E-09	2.1600E-01	3.4815E+14	10000000.	10000000.	ALPHA
PO218	PB214	1.8300E+02	5.7991E-06	2.1800E-01	2.8275E+11	10000000.	10000000.	ALPHA
AT217	BI213	3.2300E-02	1.0236E-09	2.1700E-01	1.6093E+15	10000000.	10000000.	ALPHA
AT218	BI214	2.0000E+00	6.3378E-08	2.1800E-01	2.5872E+13	10000000.	10000000.	ALPHA
RN219	PO215	3.9600E+00	1.2549E-07	2.1900E-01	1.3007E+13	10000000.	10000000.	ALPHA
RN220	PO216	5.5600E+01	1.7619E-06	2.2000E-01	9.2217E+11	10000000.	10000000.	ALPHA
RN222	PO218	3.3040E+05	1.0470E-02	2.2200E-01	1.5379E+08	10000000.	10000000.	ALPHA
FR221	AT217	2.8800E+02	9.1264E-06	2.2100E-01	1.7722E+11	10000000.	10000000.	ALPHA
FR223	RA223	1.3080E+03	4.1449E-05	2.2300E-01	3.8672E+10	10000000.	10000000.	BETA
RA223	RN219	9.8790E+05	3.1306E-02	2.2300E-01	5.1203E+07	10000000.	10000000.	ALPHA
RA224	RN220	3.1620E+05	1.0020E-02	2.2400E-01	1.5926E+08	10000000.	10000000.	ALPHA
RA225	AC225	1.2790E+06	4.0530E-02	2.2500E-01	3.9197E+07	10000000.	10000000.	BETA
RA226	PB210	5.0490E+10	1.6000E+03	2.2600E-01	9.8854E+02	1000.	10000000.	BETA
RA228	AC228	1.8150E+08	5.7516E+00	2.2800E-01	2.7258E+05	10000000.	10000000.	BETA
AC225	FR221	8.6400E+05	2.7379E-02	2.2500E-01	5.8025E+07	10000000.	10000000.	ALPHA
AC227	TH227	6.8710E+08	2.1774E+01	2.2700E-01	7.2321E+04	10000.	1000000000.	BETA
AC228	TH228	2.2070E+04	6.9938E-04	2.2800E-01	2.2417E+09	10000000.	10000000.	BETA
TH227	RA223	1.6170E+06	5.1241E-02	2.2700E-01	3.0731E+07	10000000.	10000000.	ALPHA
TH228	RA224	6.0370E+07	1.9131E+00	2.2800E-01	8.1951E+05	10000000.	10000000.	ALPHA
TH229	RA225	2.3160E+11	7.3392E+03	2.2900E-01	2.1268E+02	1000.	10000000.	ALPHA
TH230	RA226	2.4300E+12	7.7004E+04	2.3000E-01	2.0183E+01	100.	10000000.	ALPHA
TH231	PA231	9.1870E+04	2.9113E-03	2.3100E-01	5.3152E+08	10000000.	10000000.	BETA
TH232	RA228	4.4340E+17	1.4051E+10	2.3200E-01	1.0965E-04	100.	10000000.	ALPHA
TH234	PA234M	2.0820E+06	6.5977E-02	2.3400E-01	2.3153E+07	10000000.	10000000.	ALPHA
PA231	AC227	1.0340E+12	3.2766E+04	2.3100E-01	4.7225E+01	1000.	10000000.	ALPHA
PA233	U233	2.3330E+06	7.3930E-02	2.3300E-01	2.0751E+07	10000000.	10000000.	BETA
PA234	U234	2.4120E+04	7.6434E-04	2.3400E-01	1.9986E+09	10000000.	10000000.	BETA
PA234M	U234	7.0200E+01	2.2246E-06	2.3400E-01	6.8668E+11	10000000.	10000000.	BETA
U232	TH228	2.2710E+09	7.1966E+01	2.3200E-01	2.1409E+04	1000.	10000000.	ALPHA
U233	TH229	5.0020E+12	1.5851E+05	2.3300E-01	9.6785E+00	1000.	10000000.	ALPHA
U234	TH230	7.7160E+12	2.4451E+05	2.3400E-01	6.2474E+00	1000.	10000000.	ALPHA
U235	TH231	2.2210E+16	7.0381E+08	2.3500E-01	2.1612E-03	1000.	10000000.	ALPHA
U236	TH232	7.3890E+14	2.3415E+07	2.3600E-01	6.4686E-02	1000.	10000000.	ALPHA
U237	NP237	5.8320E+05	1.8481E-02	2.3700E-01	8.1610E+07	10000000.	10000000.	BETA
U238	TH234	1.4100E+17	4.4681E+09	2.3800E-01	3.3613E-04	1000.	10000000.	ALPHA
U240	NP240M	5.0760E+04	1.6085E-03	2.4000E-01	9.2593E+08	10000000.	10000000.	BETA
NP236	PU236	8.1000E+04	2.5668E-03	2.3600E-01	5.9008E+08	10000000.	10000000.	BETA
NP237	PA233	6.7530E+13	2.1400E+06	2.3700E-01	7.0480E-01	1000.	10000000.	ALPHA
NP238	PU238	1.8290E+05	5.7959E-03	2.3800E-01	2.5913E+08	10000000.	10000000.	BETA
NP239	PU239	2.0350E+05	6.4487E-03	2.3900E-01	2.3192E+08	10000000.	10000000.	BETA
NP240	PU240	3.9000E+03	1.2359E-04	2.4000E-01	1.2051E+10	10000000.	10000000.	BETA
NP240M	PU240	4.4400E+02	1.4070E-05	2.4000E-01	1.0586E+11	10000000.	10000000.	BETA
PU236	U232	8.9910E+07	2.8492E+00	2.3600E-01	5.3161E+05	10000000.	10000000.	ALPHA
PU237	NP237	3.9140E+06	1.2403E-01	2.3700E-01	1.2160E+07	10000000.	10000000.	ALPHA
PU238	U234	2.7690E+09	8.7747E+01	2.3800E-01	1.7116E+04	100.	10000000.	ALPHA
PU239	U235	7.5940E+11	2.4065E+04	2.3900E-01	6.2150E+01	100.	10000000.	ALPHA
PU240	U236	2.0630E+11	6.5374E+03	2.4000E-01	2.2782E+02	100.	10000000.	ALPHA
PU241	AM241	4.5440E+08	1.4399E+01	2.4100E-01	1.0300E+05	10000000.	10000000.	ALPHA
PU242	U238	1.1880E+13	3.7647E+05	2.4200E-01	3.9235E+00	100.	10000000.	ALPHA
PU243	AM243	1.7840E+04	5.6533E-04	2.4300E-01	2.6020E+09	10000000.	10000000.	ALPHA
PU244	U240	2.6070E+15	8.2613E+07	2.4400E-01	1.7733E-02	1000.	10000000.	ALPHA
PU246	AM246M	9.3740E+05	2.9705E-02	2.4600E-01	4.8916E+07	10000000.	10000000.	BETA
AM240	NP236	1.8288E+05	5.7953E-03	2.4000E-01	8.1105E+15	10000000.	10000000.	ALPHA
AM241	NP237	1.3640E+10	4.3224E+02	2.4100E-01	3.4314E+03	100.	10000000.	ALPHA
AM242	CM242	5.7670E+04	1.8275E-03	2.4200E-01	8.0825E+08	1000.	10000000.	ALPHA
AM242M	AM242	4.7930E+09	1.5189E+02	2.4200E-01	9.7249E+03	1000.	10000000.	ALPHA
AM243	NP239	2.3240E+11	7.3645E+03	2.4300E-01	1.9974E+02	100.	10000000.	ALPHA
AM246M	CM246	1.5000E+03	4.7534E-05	2.4600E-01	3.0569E+10	10000000.	10000000.	BETA
AM246	CM246	2.4300E+03	7.7004E-05	2.4600E-01	1.8870E+10	10000000.	10000000.	BETA
CM242	PU238	1.4070E+07	4.4586E-01	2.4200E-01	3.3128E+06	10000000.	10000000.	ALPHA
CM243	PU239	8.9880E+08	2.8482E+01	2.4300E-01	5.1646E+04	1000.	10000000.	ALPHA
CM244	PU240	5.7150E+08	1.8110E+01	2.4400E-01	8.0892E+04	10000000.	10000000.	ALPHA
CM245	PU241	2.6810E+11	8.4958E+03	2.4500E-01	1.7173E+02	1000.	10000000.	ALPHA
CM246	PU242	1.4920E+11	4.7280E+03	2.4600E-01	3.0733E+02	1000.	10000000.	ALPHA
CM247	AM243	4.9200E+14	1.5591E+07	2.4700E-01	9.2821E-02	1000.	10000000.	ALPHA
CM248	PU244	1.0700E+13	3.3907E+05	2.4800E-01	4.2508E+00	1000.	10000000.	ALPHA
CM250	PU246	2.1760E+11	6.8955E+03	2.5000E-01	2.0735E+02	1000.	10000000.	ALPHA
CF249	CM245	1.1060E+10	3.5048E+02	2.4900E-01	4.0959E+03	1000.	10000000.	ALPHA
CF250	CM246	4.1310E+08	1.3091E+01	2.5000E-01	1.0922E+05	10000000.	10000000.	ALPHA
CF251	CM247	2.8320E+10	8.9743E+02	2.5100E-01	1.5869E+03	1000.	10000000.	ALPHA
CF252	CM248	8.3250E+07	2.6381E+00	2.5200E-01	5.3768E+05	10000000.	10000000.	ALPHA
BK250	CF250	1.1600E+04	3.6759E-04	2.5000E-01	3.8897E+09	10000000.	10000000.	BETA

Appendix F: Sample GENII-A Input Control (.INP) File for Contaminated Stockpond, Water-Stock Cattle, Man (Rancher) Pathway

```
====GENII Input file=========8-Jul 88==================SECTION 2=====
Demonstration of CAMCON PREGENII/GENII interface
This GENII-A input file was Created on 04/01/96 at 11:51:16
OPTIONS==========================DEFAULT============
F    Near-field scenario?
F    Population dose?
F    Acute release?
     Maximum Individual data set used
                                  Complete
TRANSPORT OPTIONS============Section
 F                     Air Transport
 F           Surface Water Transport
 F     Biotic Transport (near-field)
 F     Waste Form Degradation (near)

REPORT OPTIONS=====================
 T              Report AEDE only
 T        Report by radionuclide
 T             Report by pathway
 F      Report debug diagnostics
                             Complete
EXPOSURE PATHWAY OPTIONS===== Section
 F         Finite plume, external
 F       Infinite plume, external
 F               Ground, external
 F           Recreation, external
 F              Inhalation uptake
 F       Drinking water ingestion
 F        Aquatic foods ingestion
 F    Terrestrial foods ingestion
 T       Animal product ingestion
 F     Inadvertent soil ingestion

INVENTORY ##############################################

 1   Invertory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 2   Surface soil source units (1- m2  2- m3  3- kg)
 11  Number of nuclides in source term

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally
     --------|-----------------------|-----------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water *
     nuclide |/yr     /yr     /m3    |/L      /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                                    0.0E+00
     PA231                                                    5.4E-25
     NP237                                                    3.3E-23
     U 233                                                    2.8E-24
     U 234                                                    6.0E-22
     U 235                                                    3.9E-29
     U 236                                                    4.0E-25
     U 238                                                    0.0E+00
     SE79                                                     1.6E-24
     TC99                                                     8.5E-04
     I 129                                                    1.5E-06

     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /l      /kg    |
     --------|------- ------- ------- -------|

TIME ##########################################

   1. Intake ends after (yr)
  50. Dose calc. ends after (yr)
   1. Release ends after (yr)
   0. No. of years of air deposition prior to the intake period
   0. No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ######################################

0          Definition option: 1-Use population grid in filePOP.IN
     0                        2-Use total entered on this line

NEAR-FIELD SCENARIOS ##########################################################

           Prior to the beginning of the intake period: (yr)
0            When was the inventory disposed?  (Package degradation starts)
0            When was LOIC?  (Biotic transport starts)
0.0000     Fraction of roots in upper soil (top 15 cm)
0.0000     Fraction of roots in deep soil
0.0000     Manual redistribution: deep soil/surface soil dilution factor
```

```
.000E+00   Source area for external dose modification factor (m2)
.000E+00   Source area for close examination dose factor (m2)
TRANSPORT ##############################,#####################################
          ====AIR TRANSPORT=====================,=================SECTION 1e*
                 0-Calculate PM
 0        Option: 1-Use chi/Q or PM value
                 2-Select MI dist & dir
                 3-Specify MI dist & dir
.000E+00   Chi/Q or PM value
  0        MI sector index (1=S)
.000E+00  MI distance from release point (m)
   89.00  Release height (m)
T          Use jf data, (T/F) else chi/Q grid

          ====SURFACE WATER TRANSPORT=========================SECTION 2=====
 0        Mixing ratio model: 0-use value, 1-river, 2-lake
  0.00   Mixing ratio, dimensionless
.000E+00 Average river flow rate for: MIXFLG=0 (m3/s) MIXFLG=1,2 (m/s)
  0.00   Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:

EXPOSURE##########################################################################

          ====EXTERNAL EXPOSURE=================================SECTION 5=====
          Exposure time (hours):
   0.0      Plume (hr)
   0.0      Surrounding soil contamination duration (hr)
   0.0      Examined soil contamination duration (hr)
 0.150      Soil overburden depth (m)
   0.0      Swimming (hr)
   0.0      Boating (hr)
   0.0      Shoreline activities (hr)
     0      Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin
   0.0      Transit time for release to reach aquatic recreation (hr)
   0.0      Average fraction of time submersed in acute cloud (hr/person hr)

          Residential irrigation:
F        Consider: (T/F)
 1       Source: 1-ground water
                 2-surface water;  3-derived
  0.0    Application rate (in/yr)
 0.0     Duration (mo/yr)

          ====INHALATION=========================================SECTION 6=====
   0.0    Hours of exposure to contamination per year
0          0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.000E+00    pension      Mass loading factor (g/m^3)   Top soil available (cm)

          ====INGESTION POPULATION=============================SECTION 7=====
 2         Atmospheric production option
.000E+00   0-Use food-weighted chi/Q, (kg-sec/m^3), enter value on this line
           1-Use population-weighted chi/Q
           2-Use uniform production
           3-Use chi/Q and production gridss (PRODUCTION will be overridden)
    0      Population ingesting aquatic foods, 0 defaults to total (person)
    0      Population ingesting drinking water, 0 defaults to total (person)
F          Consider dose from food exported out of region (default=F)

          Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                    3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F         Salt water? (default is fresh)

              DRINKING WATER (Humans)
          --------------------
1       SOURCE (see above)
F       TREATMENT? T/F
   0.0 HOLDUP/TRANSIT(da)
 730.0 CONSUMPTION (L/yr)

          USE        TRAN-  PROD-     -CONSUMPTION-
          ?   FOOD   SIT    UCTION    HOLDUP  RATE
          T/F TYPE   hr     kg/yr     da      kg/yr
          --- ------ -----  -------   ------  -----
          F   FISH     1.0  0.0E+00    0.00    0.0
          F   MOLLUS   1.0  0.0E+00    0.00    0.0
          F   CRUSTA   1.0  0.0E+00    0.00    0.0
          F   PLANTS   1.0  0.0E+00    0.00    0.0

          ====TERRESTRIAL FOOD INGESTION=========================SECTION 9=====

          USE        GROW   --IRRIGATION--          PROD-    --CONSUMPTION--
          ?   FOOD   TIME   S RATE   TIME   YIELD   UCTION   HOLDUP   RATE
          T/F TYPE   da     * in/yr  mo/yr  kg/m2   kg/yr    da       kg/yr
          --- ------ - -----  -----  -----  -------  -------  -------  -----
          T   LEAF V 90.00  1  40.0   6.0     1.5     0.0      14.0     15.0
          T   ROOT V 90.00  1  40.0   6.0     4.0     0.0      14.0    140.0
          T   FRUIT  90.00  1 40.00   6.0     2.0     0.0      14.0     64.0
          T   GRAIN  90.00  1  40.0   6.0     0.8     0.0     180.0     72.0
```

```
      ====ANIMAL PRODUCTION CONSUMPTION=================SECTION 10****

                ---HUMAN----  TOTAL   DRINK   -------------STORED FEED--------------
USE             CONSUMPTION   PROD-   WATER   DIET  GROW  -IRRIGATION--        STOR-
?    FOOD       RATE  HOLDUP  UCTION  CONTAM  FRAC- TIME  S RATE  TIME   YIELD AGE
T/F  TYPE       kg/yr   da    kg/yr   FRACT.  TION   da   * in/yr mo/yr  kg/m3 da
---  ------     ------ -----  ------  -------  ----  ----  - ----- -----  ----- -----
T    BEEF       100.0  50.0  110.00    1.00  0.50 45.00  1  10.0   6.0   2.00 100.0
T    POULTRY     80.0  10.0  120.00    1.00  1.00 90.00  1   0.0   0.0   0.80 180.0
T    MILK        50.0  10.0  120.00    1.00  0.25 45.00  1   0.0   0.0   2.00 100.0
T    EGG         60.0  10.0  120.00    1.00  1.00 90.00  1   0.0   0.0   0.80 180.0
                                               -------------FRESH FORAGE------------
     BEEF                                      0.50 45.00  1  10.0   6.0   2.00  20.0
     MILK                                      0.75 30.00  1   0.0   0.0   1.50   0.0

##########################################################################################
[End of file]
```

Appendix G: Sample GENII-A Input Control (.INP) File for Contaminated Cuttings, Man (Driller) Pathway

```
====GENII Input file*********8-Jul 88==================SECTION 2=====
Demonstration of CAMCON PREGENII/GENII interface
This GENII-A input file was Created on 04/01/96 at 11:51:16
OPTIONS*****************************DEFAULT=====*******
T    Near-field scenario?
F    Population dose?
F    Acute release?
     Maximum Individual data set used
                                  Complete
TRANSPORT OPTIONS==========Section
 F                    Air Transport
 F           Surface Water Transport
 F     Biotic Transport (near-field)
 F     Waste Form Degradation (near)

REPORT OPTIONS=====================
 T              Report AEDE only
 T        Report by radionuclide
 T            Report by pathway
 F      Report debug diagnostics
                                  Complete
EXPOSURE PATHWAY OPTIONS===== Section
 F         Finite plume, external
 F       Infinite plume, external
 T               Ground, external
 F           Recreation, external
 F              Inhalation uptake
 F       Drinking water ingestion
 F        Aquatic foods ingestion
 F    Terrestrial foods ingestion
 F       Animal product ingestion
 F     Inadvertent soil ingestion

INVENTORY ##############################################

 1   Invertory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 1   Surface soil source units (1- m2  2- m3  3- kg)
 11  Number of nuclides in source term

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally
     --------|-----------------------|-------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil    Soil    Water   Water *
     nuclide |/yr     /yr     /m3    |/L      /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239                                   2.7E+07
     PA231                                   5.2E+07
     NP237                                   2.5E+06
     U 233                                   6.5E+08
     U 234                                   8.8E+07
     U 235                                   4.0E+05
     U 236                                   7.8E+06
     U 238                                   9.2E+03
     SE79                                    4.2E+06
     TC99                                    1.1E+08
     I 129                                   3.4E+05

     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /l      /kg    |
     --------|------- ------- ------- -------|

TIME ##########################################

   1. Intake ends after (yr)
  50. Dose calc. ends after (yr)
   1. Release ends after (yr)
   0. No. of years of air deposition prior to the intake period
   0. No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ######################################

0          Definition option: 1-Use population grid in filePOP.IN
     0                        2-Use total entered on this line

NEAR-FIELD SCENARIOS ##########################################################

           Prior to the beginning of the intake period: (yr)
0            When was the inventory disposed?  (Package degradation starts)
0            When was LOIC?  (Biotic transport starts)
0.0000     Fraction of roots in upper soil (top 15 cm)
0.0000     Fraction of roots in deep soil
0.5000     Manual redistribution: deep soil/surface soil dilution factor
```

```
.000E+00   Source area for external dose modification factor (m2)
.785E-02   Source area for close examination dose factor (m2)
TRANSPORT ##############################.#################################
          ====AIR TRANSPORT=======================.==============SECTION 1=*
                 0-Calculate PM
 0        Option: 1-Use chi/Q or PM value
                 2-Select MI dist & dir
                 3-Specify MI dist & dir
.000E+00   Chi/Q or PM value
  0       MI sector index (1=S)
.000E+00  MI distance from release point (m)
   89.00  Release height (m)
T         Use jf data, (T/F) else chi/Q grid

          ====SURFACE WATER TRANSPORT==========================SECTION 2=====
 0        Mixing ratio model: 0-use value, 1-river, 2-lake
  0.00   Mixing ratio, dimensionless
.000E+00 Average river flow rate for: MIXFLG=0 (m3/s) MIXFLG=1,2 (m/s)
  0.00   Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:

EXPOSURE##########################################################################

          ====EXTERNAL EXPOSURE==================================SECTION 5=====
          Exposure time (hours):
3700.0      Plume (hr)
   0.0      Surrounding soil contamination duration (hr)
   1.0      Examined soil contamination duration (hr)
 0.150      Soil overburden depth (m)
   0.0      Swimming (hr)
   0.0      Boating (hr)
   0.0      Shoreline activities (hr)
     0      Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin
   0.0      Transit time for release to reach aquatic recreation (hr)
   0.0      Average fraction of time submersed in acute cloud (hr/person hr)

          Residential irrigation:
F        Consider: (T/F)
 0       Source: 1-ground water
                 2-surface water;  3-derived
  0.0    Application rate (in/yr)
 0.0     Duration (mo/yr)

          ====INHALATION=========================================SECTION 6=====
   0.0    Hours of exposure to contamination per year
0          0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.000E+00    pension      Mass loading factor (g/m^3)   Top soil available (cm)

          ====INGESTION POPULATION==============================SECTION 7=====
 2         Atmospheric production option
.000E+00   0-Use food-weighted chi/Q, (kg-sec/m^3), enter value on this line
           1-Use population-weighted chi/Q
           2-Use uniform production
           3-Use chi/Q and production gridss (PRODUCTION will be overridden)
    0      Population ingesting aquatic foods, 0 defaults to total (person)
    0      Population ingesting drinking water, 0 defaults to total (person)
F          Consider dose from food exported out of region (default=F)

           Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                     3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====

F          Salt water? (default is fresh)

              DRINKING WATER (Humans)
          --------------------
0       SOURCE (see above)
F       TREATMENT? T/F
   0.0 HOLDUP/TRANSIT(da)
   0.0 CONSUMPTION (L/yr)

          USE        TRAN-  PROD-    -CONSUMPTION-
          ?   FOOD   SIT    UCTION   HOLDUP  RATE
          T/F TYPE   hr     kg/yr    da      kg/yr
          --- ------ -----  -------  ------  -----
          F   FISH     1.0  0.0E+00    0.00    0.0
          F   MOLLUS   1.0  0.0E+00    0.00    0.0
          F   CRUSTA   1.0  0.0E+00    0.00    0.0
          F   PLANTS   1.0  0.0E+00    0.00    0.0

          ====TERRESTRIAL FOOD INGESTION=========================SECTION 9=====

          USE        GROW   --IRRIGATION--          PROD-    --CONSUMPTION--
          ?   FOOD   TIME   S RATE   TIME   YIELD   UCTION   HOLDUP   RATE
          T/F TYPE   da     * in/yr  mo/yr  kg/m2   kg/yr    da       kg/yr
          --- ------ - ----- ------  -----  -------  -------  -------  -----
          T   LEAF V 90.00  0  40.0   6.0     1.5     0.0      14.0     15.0
          T   ROOT V 90.00  0  40.0   6.0     4.0     0.0      14.0    140.0
          T   FRUIT  90.00  0 40.00   6.0     2.0     0.0      14.0     64.0
          T   GRAIN  90.00  0  40.0   6.0     0.8     0.0     180.0     72.0
```

====ANIMAL PRODUCTION CONSUMPTION==========SECTION 10====

USE ? T/F	FOOD TYPE	---HUMAN---- CONSUMPTION RATE kg/yr	HOLDUP da	TOTAL PROD- UCTION kg/yr	DRINK WATER CONTAM FRACT.	----------STORED FEED---------- DIET FRAC- TION	GROW TIME da	-IRRIGATION-- S *	RATE in/yr	TIME mo/yr	YIELD kg/m3	STOR- AGE da
T	BEEF	70.0	34.0	0.00	0.50	0.25	90.00	0	40.0	6.0	0.80	180.0
T	POULTRY	8.5	34.0	0.00	0.50	1.00	90.00	0	0.0	0.0	0.80	180.0
T	MILK	230.0	4.0	0.00	0.50	0.25	45.00	0	0.0	0.0	2.00	100.0
T	EGG	20.0	18.0	0.00	0.50	1.00	90.00	0	0.0	0.0	0.80	180.0
						----------FRESH FORAGE----------						
	BEEF					0.75	45.00	0	0.0	0.0	2.00	100.0
	MILK					0.75	30.00	0	0.0	0.0	1.50	0.0

##
[End of file]

Appendix H: Sample GENII-A Input Control (.INP) File for Contaminated Drilling-Mud Pit, Dust-Air Transport, Man (Farm Family) Pathway

```
====GENII Input file=========8-Jul 88==================SECTION 2=====
Demonstration of CAMCON PREGENII/GENII interface
This GENII-A input file was Created on 04/01/96 at 11:51:16
OPTIONS=========================DEFAULT===========
F    Near-field scenario?
T    Population dose?
F    Acute release?
     Maximum Individual data set used
                                   Complete
TRANSPORT OPTIONS============Section
 T                     Air Transport
 F           Surface Water Transport
 F     Biotic Transport (near-field)
 F     Waste Form Degradation (near)

REPORT OPTIONS=====================
 T              Report AEDE only
 T        Report by radionuclide
 T            Report by pathway
 F      Report debug diagnostics
                                 Complete
EXPOSURE PATHWAY OPTIONS===== Section
 T         Finite plume, external
 F       Infinite plume, external
 T               Ground, external
 F           Recreation, external
 T              Inhalation uptake
 F       Drinking water ingestion
 F        Aquatic foods ingestion
 T    Terrestrial foods ingestion
 T       Animal product ingestion
 F     Inadvertent soil ingestion

INVENTORY ***********************************************

 4   Invertory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 1   Surface soil source units (1- m2  2- m3  3- kg)
 11  Number of nuclides in source term

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally
     --------|-----------------------|-------------------------------------|
     Release |        Surface Buried |        Surface Deep    Ground  Surface|
     Radio-  |Air     Water   Waste  |Air     Soil     Soil   Water   Water |
     nuclide |/yr     /yr     /m3    |/L      /unit    /m3    /L      /L    |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239    1.4E-06
     PA231    2.7E-06
     NP237    1.3E-07
     U 233    3.3E-05
     U 234    4.5E-06
     U 235    2.1E-08
     U 236    4.0E-07
     U 238    4.7E-10
     SE79     2.2E-07
     TC99     5.7E-06
     I 129    1.8E-08

     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /l      /kg    |
     --------|------- ------- ------- -------|

TIME ***********************************************

   1. Intake ends after (yr)
  50. Dose calc. ends after (yr)
   1. Release ends after (yr)
   0. No. of years of air deposition prior to the intake period
   0. No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ************************************

1          Definition option: 1-Use population grid in filePOP.IN
     0                        2-Use total entered on this line

NEAR-FIELD SCENARIOS ************************************************************

           Prior to the beginning of the intake period: (yr)
0            When was the inventory disposed?  (Package degradation starts)
0            When was LOIC?  (Biotic transport starts)
0.0000     Fraction of roots in upper soil (top 15 cm)
0.0000     Fraction of roots in deep soil
0.0000     Manual redistribution: deep soil/surface soil dilution factor
```

```
.100E+04   Source area for external dose modification factor (m2)
.785E-02   Source area for close examination dose factor (m2)
TRANSPORT ##############################,#####################################
          ====AIR TRANSPORT=====================,================SECTION 1=*
                 0-Calculate PM
 0        Option: 1-Use chi/Q or PM value
                  2-Select MI dist & dir
                  3-Specify MI dist & dir
.000E+00   Chi/Q or PM value
 16        MI sector index (1=S)
.530E+05  MI distance from release point (m)
   1.00   Release height (m)
T          Use jf data, (T/F) else chi/Q grid

          ====SURFACE WATER TRANSPORT==========================SECTION 2=====
 0        Mixing ratio model: 0-use value, 1-river, 2-lake
  0.00   Mixing ratio, dimensionless
.000E+00 Average river flow rate for: MIXFLG=0 (m3/s) MIXFLG=1,2 (m/s)
  0.00   Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:

EXPOSURE#######################################################################

          ====EXTERNAL EXPOSURE=============================SECTION 5=====
          Exposure time (hours):
8766.0      Plume (hr)
   0.0      Surrounding soil contamination duration (hr)
   0.0      Examined soil contamination duration (hr)
 0.150      Soil overburden depth (m)
   0.0      Swimming (hr)
   0.0      Boating (hr)
   0.0      Shoreline activities (hr)
     0      Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin
   0.0      Transit time for release to reach aquatic recreation (hr)
   0.0      Average fraction of time submersed in acute cloud (hr/person hr)

          Residential irrigation;
F        Consider: (T/F)
 0       Source: 1-ground water
                 2-surface water;  3-derived
  0.0   Application rate (in/yr)
 0.0    Duration (mo/yr)

          ====INHALATION=====================================SECTION 6=====
8766.0    Hours of exposure to contamination per year
2          0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.200E+00    pension      Mass loading factor (g/m^3)   Top soil available (cm)

          ====INGESTION POPULATION=========================SECTION 7=====
 1         Atmospheric production option
.000E+00   0-Use food-weighted chi/Q, (kg-sec/m^3), enter value on this line
           1-Use population-weighted chi/Q
           2-Use uniform production
           3-Use chi/Q and production gridss (PRODUCTION will be overridden)
    0      Population ingesting aquatic foods, 0 defaults to total (person)
    0      Population ingesting drinking water, 0 defaults to total (person)
F          Consider dose from food exported out of region (default=F)

          Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                    3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION========SECTION 8====

F         Salt water? (default is fresh)

              DRINKING WATER (Humans)
          -------------------
0       SOURCE (see above)
F       TREATMENT? T/F
   0.0 HOLDUP/TRANSIT(da)
 730.0 CONSUMPTION (L/yr)

          USE        TRAN-  PROD-    -CONSUMPTION-
          ?   FOOD   SIT    UCTION   HOLDUP  RATE
          T/F TYPE   hr     kg/yr    da      kg/yr
          --- ------ -----  -------  ------  -----
          F   FISH     1.0  0.0E+00   0.00    0.0
          F   MOLLUS   1.0  0.0E+00   0.00    0.0
          F   CRUSTA   1.0  0.0E+00  80.00    0.0
          F   PLANTS   1.0  0.0E+00  80.00    0.0

          ====TERRESTRIAL FOOD INGESTION=====================SECTION 9=====

          USE        GROW   --IRRIGATION--          PROD-    --CONSUMPTION--
          ?   FOOD   TIME   S RATE   TIME   YIELD   UCTION   HOLDUP   RATE
          T/F TYPE   da     * in/yr  mo/yr  kg/m2   kg/yr    da       kg/yr
          --- ------ - ----- ------  -----  -------  ------------
          T   LEAF V 60.00  0  10.0   6.0    50.0    120.0     20.0     60.0
          T   ROOT V 70.00  0  10.0   6.0    50.0    100.0     50.0     60.0
          T   FRUIT  80.00  0 10.00   6.0    60.0    130.0     10.0     90.0
          T   GRAIN  90.00  0  10.0   6 0    40.0    110.0     60.0     80.0
```

```
====ANIMAL PRODUCTION CONSUMPTION=================SECTION 10====

            ---HUMAN---- TOTAL   DRINK   -------------STORED FEED-------------
USE         CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--        STOR-
?   FOOD    RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME   YIELD AGE
T/F TYPE    kg/yr   da   kg/yr  FRACT.  TION   da   * in/yr mo/yr  kg/m3 da
--- ------  ------ ----- ------ -------  ----  ----  - ----- -----  ----- -----
T   BEEF     100.0  50.0 110.00    1.00  0.50 45.00  0  10.0   6.0   2.00 100.0
T   POULTRY   80.0  10.0 120.00    1.00  1.00 90.00  0   0.0   0.0   0.80 180.0
T   MILK      50.0  10.0 120.00    1.00  0.25 45.00  0   0.0   0.0   2.00 100.0
T   EGG       60.0  10.0 120.00    1.00  1.00 90.00  0   0.0   0.0   0.80 180.0
                                           -------------FRESH FORAGE------------
    BEEF                                   0.50 45.00  0  10.0   6.0   2.00  20.0
    MILK                                   0.75 30.00  0   0.0   0.0   1.50   0.0

##########################################################################
[End of file]
```

Appendix I: Sample GENII-A Input Control (.INP) File for Contaminated Dried Stock Pond, Dust-Air Transport, Man (Farm Family) Pathway

```
===GENII Input file=========8-Jul 88=================SECTION 2=====
Demonstration of CAMCON PREGENII/GENII interface
This GENII-A input file was Created on 04/01/96 at 11:51:16
OPTIONS=========================DEFAULT============
F    Near-field scenario?
F    Population dose?
F    Acute release?
     Maximum Individual data set used
                                  Complete
TRANSPORT OPTIONS============Section
 T                  Air Transport
 F            Surface Water Transport
 F     Biotic Transport (near-field)
 F     Waste Form Degradation (near)

REPORT OPTIONS=======================
 T              Report AEDE only
 T        Report by radionuclide
 T             Report by pathway
 F      Report debug diagnostics
                                  Complete
EXPOSURE PATHWAY OPTIONS===== Section
 F         Finite plume, external
 T       Infinite plume, external
 T              Ground, external
 F           Recreation, external
 T              Inhalation uptake
 F       Drinking water ingestion
 F        Aquatic foods ingestion
 T    Terrestrial foods ingestion
 T       Animal product ingestion
 F     Inadvertent soil ingestion

INVENTORY ##############################################

 4   Invertory input activity units: (1-pCi  2-uCi  3-mCi  4-Ci  5-Bq)
 1   Surface soil source units (1- m2  2- m3  3- kg)
 11  Number of nuclides in source term

     --------|----Release Terms------|----------Basic Concentrations---------|
     Use when|  transport selected   |  near-field scenario, optionally
     --------|-----------------------|---------------------------------------|
     Release |         Surface Buried |         Surface Deep    Ground  Surface|
     Radio-  |Air      Water   Waste  |Air      Soil    Soil    Water   Water  |
     nuclide |/yr      /yr     /m3    |/L       /unit   /m3     /L      /L     |
     --------|------- ------- -------|------- ------- ------- ------- -------|
     PU239    0.0E+00
     PA231    3.8E-35
     NP237    2.3E-33
     U 233    2.0E-34
     U 234    4.2E-32
     U 235    0.0E+00
     U 236    2.8E-35
     U 238    0.0E+00
     SE79     1.1E-34
     TC99     6.0E-14
     I 129    1.0E-16

     --------|----Derived Concentrations-----|
     Use when|   measured values are known   |
     Release |Terres. Animal  Drink   Aquatic|
     Radio-  |Plant   Product Water   Food   |
     nuclide |/kg     /kg     /l      /kg    |
     --------|------- ------- ------- -------|

TIME ##########################################

   1. Intake ends after (yr)
  50. Dose calc. ends after (yr)
   1. Release ends after (yr)
 100. No. of years of air deposition prior to the intake period
   0. No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) ######################################


0          Definition option: 1-Use population grid in filePOP.IN
     0                        2-Use total entered on this line

NEAR-FIELD SCENARIOS ##########################################################

           Prior to the beginning of the intake period: (yr)
0            When was the inventory disposed?  (Package degradation starts)
0            When was LOIC?  (Biotic transport starts)
0.5000     Fraction of roots in upper soil (top 15 cm)
0.0000     Fraction of roots in deep soil
```

```
0.0000      Manual redistribution: deep soil/surface soil dilution factor
.000E+00    Source area for external dose modification factor (m2)
.000E+00    Source area for close examination dose factor (m2)
TRANSPORT ******************************,*************************************
            ====AIR TRANSPORT=======================,==============SECTION 1=====
                    0-Calculate PM
 1          Option: 1-Use chi/Q or PM value
                    2-Select MI dist & dir
                    3-Specify MI dist & dir
.249E-07    Chi/Q or PM value
  0         MI sector index (1=S)
.530E+05    MI distance from release point (m)
   89.00    Release height (m)
T           Use jf data, (T/F) else chi/Q grid

            ====SURFACE WATER TRANSPORT==========================SECTION 2=====
0           Mixing ratio model: 0-use value, 1-river, 2-lake
 0.00    Mixing ratio, dimensionless
.000E+00 Average river flow rate for: MIXFLG=0 (m3/s) MIXFLG=1,2 (m/s)
  0.00    Transit time to irrigation withdrawl location (hr)
          If mixing ratio model > 0:

EXPOSURE*************************************************************************

            ====EXTERNAL EXPOSURE==============================SECTION 5=====
            Exposure time (hours):
8766.0        Plume (hr)
2920.0        Surrounding soil contamination duration (hr)
   0.0        Examined soil contamination duration (hr)
 0.150        Soil overburden depth (m)
   0.0        Swimming (hr)
   0.0        Boating (hr)
   0.0        Shoreline activities (hr)
     0        Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin
   0.0        Transit time for release to reach aquatic recreation (hr)
   0.0        Average fraction of time submersed in acute cloud (hr/person hr)

            Residential irrigation:
F         Consider: (T/F)
 0        Source: 1-ground water
                  2-surface water;  3-derived
  0.0     Application rate (in/yr)
  0.0     Duration (mo/yr)

            ====INHALATION=====================================SECTION 6=====
8766.0      Hours of exposure to contamination per year
1             0-No resus-  1-Use Mass Loading          2-Use Anspaugh model
.150E+04      pension      Mass loading factor (g/m^3)   Top soil available (cm)

            ====INGESTION POPULATION==========================SECTION 7=====
 1           Atmospheric production option
.000E+00     0-Use food-weighted chi/Q, (kg-sec/m^3), enter value on this line
             1-Use population-weighted chi/Q
             2-Use uniform production
             3-Use chi/Q and production gridss (PRODUCTION will be overridden)
    0        Population ingesting aquatic foods, 0 defaults to total (person)
    0        Population ingesting drinking water, 0 defaults to total (person)
F            Consider dose from food exported out of region (default=F)

          Note below: S* or Source: 0-none, 1-ground water, 2-surface water
                                    3-Derived concentration entered above
          ==== AQUATIC FOODS / DRINKING WATER INGESTION========SECTION 8====

F           Salt water? (default is fresh)

               DRINKING WATER (Humans)
            --------------------

0       SOURCE (see above)
F       TREATMENT? T/F
   0.0 HOLDUP/TRANSIT(da)
 730.0 CONSUMPTION (L/yr)
```

USE ? T/F	FOOD TYPE	TRAN-SIT hr	PROD-UCTION kg/yr	-CONSUMPTION- HOLDUP da	RATE kg/yr
F	FISH	1.0	0.0E+00	0.00	0.0
F	MOLLUS	1.0	0.0E+00	0.00	0.0
F	CRUSTA	1.0	0.0E+00	0.00	0.0
F	PLANTS	1.0	0.0E+00	0.00	0.0

```
            ====TERRESTRIAL FOOD INGESTION=======================SECTION 9=====
```

USE ? T/F	FOOD TYPE	GROW TIME da	S *	--IRRIGATION-- RATE in/yr	TIME mo/yr	YIELD kg/m2	PROD-UCTION kg/yr	--CONSUMPTION-- HOLDUP da	RATE kg/yr
T	LEAF V	60.00	0	10.0	6.0	50.0	120.0	20.0	60.0
T	ROOT V	70.00	0	10.0	6.0	50.0	100.0	50.0	60.0
T	FRUIT	80.00	0	10.00	6.0	60.0	130.0	10.0	90.0

```
T   GRAIN  90.00  0  10.0   6.0    40.0    110.0      60.0     80.0

====ANIMAL PRODUCTION CONSUMPTION==================SECTION 10====

          ---HUMAN---- TOTAL   DRINK   -------------STORED FEED-------------
USE        CONSUMPTION  PROD-   WATER   DIET  GROW  -IRRIGATION--        STOR-
   FOOD   RATE  HOLDUP UCTION  CONTAM  FRAC- TIME  S RATE  TIME   YIELD AGE
T/F TYPE   kg/yr   da    kg/yr  FRACT.  TION   da   * in/yr mo/yr  kg/m3 da
-- ------ ------ ----- ------ -------  ----  ----  - ----- -----  ----- -----
T   BEEF    100.0  50.0 110.00    1.00  0.50 45.00  0  10.0   6.0   2.00 100.0
T   POULTRY  80.0  10.0 120.00    1.00  0.60 20.00  0  10.0   6.0   6.00  60.0
T   MILK     50.0  10.0 120.00    1.00  0.60 30.00  0  10.0   6.0   5.00  50.0
T   EGG      60.0  10.0 120.00    1.00  0.60 25.00  0  10.0   6.0   3.00  40.0
                                         -------------FRESH FORAGE------------
   BEEF                                 0.50 45.00  0  10.0   6.0   2.00  20.0
   MILK                                 0.40 30.00  0  10.0   6.0   5.00  10.0

*****************************************************************************
```

Appendix J: Sample Diagnostics/Debug File

```
PREGENII C-2.10VV (06/28/95)                                    12/05/95 11:44:24

     PPPPPP   RRRRRR   EEEEEEE   GGGGG   EEEEEEE  N    NN    IIII     IIII
     PP   PP  RR   RR  EE       GG   GG  EE       NN   NN     II       II
     PP   PP  RR   RR  EE       GG       EE       NNN  NN     II       II
     PPPPPP   RRRRRR   EEEEE    GG       EEEEE    NN N NN     II       II
     PP       RRRRR    EE       GG  GGG  EE       NN  NNN     II       II
     PP       RR  RR   EE       GG   GG  EE       NN   NN     II       II
     PP       RR   RR  EEEEEEE   GGGGG   EEEEEEE  NN    N    IIII     IIII

                A pre-processor program for input to GENII

                      PREGENII Version 2.10VV
                  Version Date 06/28/95  QA Level C
                      Written by Ron D. McCurley
                     Sponsored by Ron D. McCurley

                      Run on 12/05/95 at 11:44:24
                  Run on ALPHA AXP BEATLE OpenVMS V6.1

          ***********************************************************

          Prepared for
          Sandia National Laboratories
          Albuquerque, New Mexico 87185-5800
          for the United States Department of Energy
          under Contract DE-AC04-76DP00789

          ***********************************************************

                                  Disclaimer
                                  ----------

          This computer program was prepared as an account of work
          sponsored by an agency of the United States Government.
          Neither the United States Government nor any agency thereof,
          nor any of their employees, nor any of their contractors,
          subcontractors, or their employees, makes any warranty,
          express or implied, or assumes any legal liability or
          responsibility for the accuracy, completeness, or usefulness
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          manufacturer, or otherwise, does not necessarily constitute
          or imply its endorsement, recommendation, or favoring by the
          United States Government, any agency thereof or any of their
          contractors or subcontractors.  The views and opinions
          expressed herein do not necessarily state or reflect those
          of the United States Government, any agency thereof or any
          of their contractors or subcontractors.

          ***********************************************************

*****************************************************************************

FILE ASSIGNMENTS:
-----------------
Input first CAMDAT File vector:
   U1:[RDMCCUR.PREGENII.TEST]TEST_R001.CDB;3
      Written on 08/24/95 12:20:19
Input Text File:
   U1:[RDMCCUR.PREGENII.TEST]PREGENII_STOCK.INP;9
      Written on 12/05/95 11:43:41
Input Generic Radioisotope Database:
   C3:[CAMCON.CUTTINGS]GENERIC.RDB;1
      Written on 07/29/94 16:01:40
Output GENII Input File:
   U1:[RDMCCUR.PREGENII.TEST]GENII_STOCK_R001.INP
Output Diagnostics/Debug File:
   U1:[RDMCCUR.PREGENII.TEST]PREGENII.DBG
Read report specifications
Read scenario specifications
Reading exposure parameters
 *** UNKNOWN KEYWORD = 1.0  ***
 *** UNKNOWN KEYWORD = 50.0  ***
 *** UNKNOWN KEYWORD = 1.0  ***
 *** UNKNOWN KEYWORD = PICOCURIES  ***
 *** UNKNOWN KEYWORD = CUBIC_METERS  ***
 *** UNKNOWN  KEYWORD = IRRIGATION_DURATION  ***
 *** UNKNOWN  KEYWORD = 6.0  ***
 *** UNKNOWN  KEYWORD = NO  ***
```

```
*** UNKNOWN  KEYWORD = GROUNDWATER  ***

    ---------------------------------------------------
              268507 more words allocated by DYNMEM
              Total allocated is     268507
    ---------------------------------------------------

 NVARHI =          0
 NVARGL =          0
 NVARND =         12
 NVAREL =          4
 NVARHI =          0
 NVARGL =          0
 NVARND =         12
 NVAREL =          4
 NVARHI =          0
 NVARGL =          0
 NVARND =         12
 NVAREL =          4
 NVARHI =          0
 NVARGL =          0
 NVARND =         12
 NVAREL =          4

    ---------------------------------------------------
              599958 more words allocated by DYNMEM
              Total allocated is     868465
    ---------------------------------------------------

Specified number of interpolation times and extraction time are not compatible with CDB times--automatically reducing number of
interpolation times to          1

    ---------------------------------------------------
              300120 more words allocated by DYNMEM
              Total allocated is    1168585
    ---------------------------------------------------

*****************************************************************************
(RGRDB)
Solution interpolated to value at nearest time  3.1560401E+11
        CONCENTRATION DATA AT NODE    5761
U1:[RDMCCUR.PREGENII.TEST]TEST_R001.CDB
 UNITS= PICOCURIES/LITER (DRINKING WATER)
 Radioisotope with name PU239   has negligible concentration in CAMDAT CDB
 Radioisotope with name U238    has negligible concentration in CAMDAT CDB
Specified number of interpolation times and extraction time are not compatible with CDB times--automatically reducing number of
interpolation times to          1
Solution interpolated to value at nearest time  3.1560401E+11
        CONCENTRATION DATA AT NODE    5761
U1:[RDMCCUR.PREGENII.TEST]TEST_R002.CDB
 UNITS= PICOCURIES/LITER (DRINKING WATER)
 Radioisotope with name PU239   has negligible concentration in CAMDAT CDB
 Radioisotope with name U 238   has negligible concentration in CAMDAT CDB
```

Appendix K: Review Forms

This appendix contains review forms for the PREGENII User's Manual.

NOTE: Copies of the User's Manual Reviewer's Forms are available in the Sandia WIPP Central Files.

WIPP PA

User's Manual

for

GENII-A, Version 2.10

Document Version 1.00

WPO # 27751

November 13, 1995

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1.0 INTRODUCTION

1.1 Document Purpose

This document serves as a user's manual for GENII-A, as used in the 1996 WIPP PA calculation. As such, it describes the code's purpose and function, the user's interaction with the code, and the models and methods employed by the code. Examples of user-accessible input and output files are included for the user's convenience.

The GENII-A code, which runs on a DEC Alpha platform, duplicates a subset of the executables from the original GENII program (Radiation Shielding Information Center, 1995). Because a published conceptual representation and user's manuals for GENII already exist (Napier et al., 1988 [Volumes 1 and 2]), an important purpose of this user's manual (WPO # 27751) is to point the user to the discussions in Napier et al. pertinent to the 1996 WIPP PA calculation. It is recommended that the user have a copy of Napier et al., available from the Sandia WIPP Central Files, while reading this user's manual (WPO # 27751).

1.2 Software Identifier

Code Name:	GENII-A, a DEC Alpha-platform implementation of GENII, the second generation of the Hanford environmental dosimetry computer codes compiled in the Hanford Environmental Dosimetry System.
WIPP Prefix:	GI2
Version Number:	2.10, 1/16/96
Platforms:	FORTRAN 77 for OpenVMS AXP, version 6.1, on DEC Alpha

1.3 *Points of Contact*

1.3.1 Code Sponsor

Leo J. Rahal
Geo-Centers, Inc.
2201 Buena Vista Drive, S.E.
Albuquerque, NM 87106
Voice: (505) 766-9629
Fax: (505) 766-9125

1.3.2 Code Consultant

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2.0 FUNCTIONAL REQUIREMENTS

The functional requirements for GENII-A are listed below:

R.1 GENII-A reads pathway and nuclide inventory input data.

R.2 GENII-A calculates doses for acute releases.

R.3 GENII-A calculates doses for chronic releases.

R.4 GENII-A calculates doses for air transport of radionuclides with or without meteorological input data.

R.5 GENII-A calculates doses for finite plume air immersion.

R.6 GENII-A calculates doses for infinite plume air immersion.

R.7 GENII-A calculates doses for external gound exposure.

R.8 GENII-A calculates doses for animal product ingestion with or without irrigation option.

R.9 GENII-A calculates doses for terrestrial food ingestion with or without irrigation option.

R.10 GENII-A calculates doses from dairy product ingestion with or without irrigation option.

R.11 GENII-A calculates doses from aquatic food ingestion.

R.12 GENII-A calculates doses from drinking water ingestion.

R.13 GENII-A calculates doses for far-field release.

R.14 GENII-A calculates doses for near-field release.

R.15 GENII-A calculates doses for lake or river surface water transport.

R.16 GENII-A calculates doses from external recreational exposure including boating, swimming, and external shoreline exposure.

R.17 GENII-A calculates doses from handling radioactive samples.

R.18 GENII-A calculates individual dose.

R.19 GENII-A calculates population dose using population distribution data.

R.20 GENII-A calculates doses from inhalation of airborne radionuclides.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

In order to run the GENII-A code successfully, the user will need a basic knowledge of

- Open VMS
- Digital Command Language
- Sandia's CAMDAT database.

To understand the theoretical portions of this manual (and the theoretical portions of the user manual by Napier et al. [1988]) and understand and interpret the results of GENII-A, the user should have a working knowledge of

- scenario development
- biosphere transport of radionuclides
- some knowledge of radionuclide decay processes and
  - radionuclide/organ interactions
  - radiation interactions with organic matter

An undergraduate degree in science or engineering is also recommended. The user should also have some knowledge of the original GENII program and its user manuals (Napier et al., 1988; Radiation Shielding Information Center, 1995). (The original GENII program, because it can run on an IBM PC platform, is sometimes called PC-GENII.).

4.0 DESCRIPTION OF THE MODELS AND METHODS

4.1 Program Modules

While GENII is composed of seven linked computer codes and their associated data libraries, GENII-A makes use of only five of them, as Figure 1 shows. Note that the `ENVIN` module has been renamed `GENII`[1] and that `GENII` calls `ENV` and `DOSE`.

Aside from the above name and hierarchy changes, a minor modification was made to the GENII code allowing a combined dose calculation from a spherical radioactive source (hand-held by the driller) and the ground surface exposure dose from a nearby source of radionuclides spread over a

[1] This program module should not be confused with GENII, GENII-A's predecessor. To prevent confusion, this program module (and all program modules) are written in a Courier font: `GENII`.

specified surface area. This capability is an option and can be selected through appropriate input data.

The following should also be noted:

- Only static outputs from EXTDF and INTDF are used by GENII-A; in other words, the boxes labeled EXTDF and INTDF in Figure 1 represent static data files, not program modules that are exercised when GENII-A is run. (EXTDF and INTDF are described in Sections 3.5 and 3.6 of Volume 1 of Napier et al., 1988 and Sections 3.3 and 3.4 of Volume 2 of Napier et al., 1988.) These modules are discussed below.

- Some modification to input formatting was made along with the deletion of unused parameters and the addition of new parameters for the sample exposure option mentioned above.

- Another addition was the inclusion of the requirement to indicate the number of nuclides in the GENII-A input file.

4.1.1 GENII

The ENVIN portion of GENII

- controls the reading of the input control text (.INP) file prepared by PREGENII (see computational flow discussion in Section 6.0 and input control file discussion in Section 7.2)

- organizes the input for the environmental transport and exposure module, ENV

- prepares the data transfer files that are used as input by ENV

- outputs the run input parameters report (i.e., the output input echo file) (Section 9.3).

Details on ENVIN are provided in Volume 1 of Napier et al. (Section 3.2).

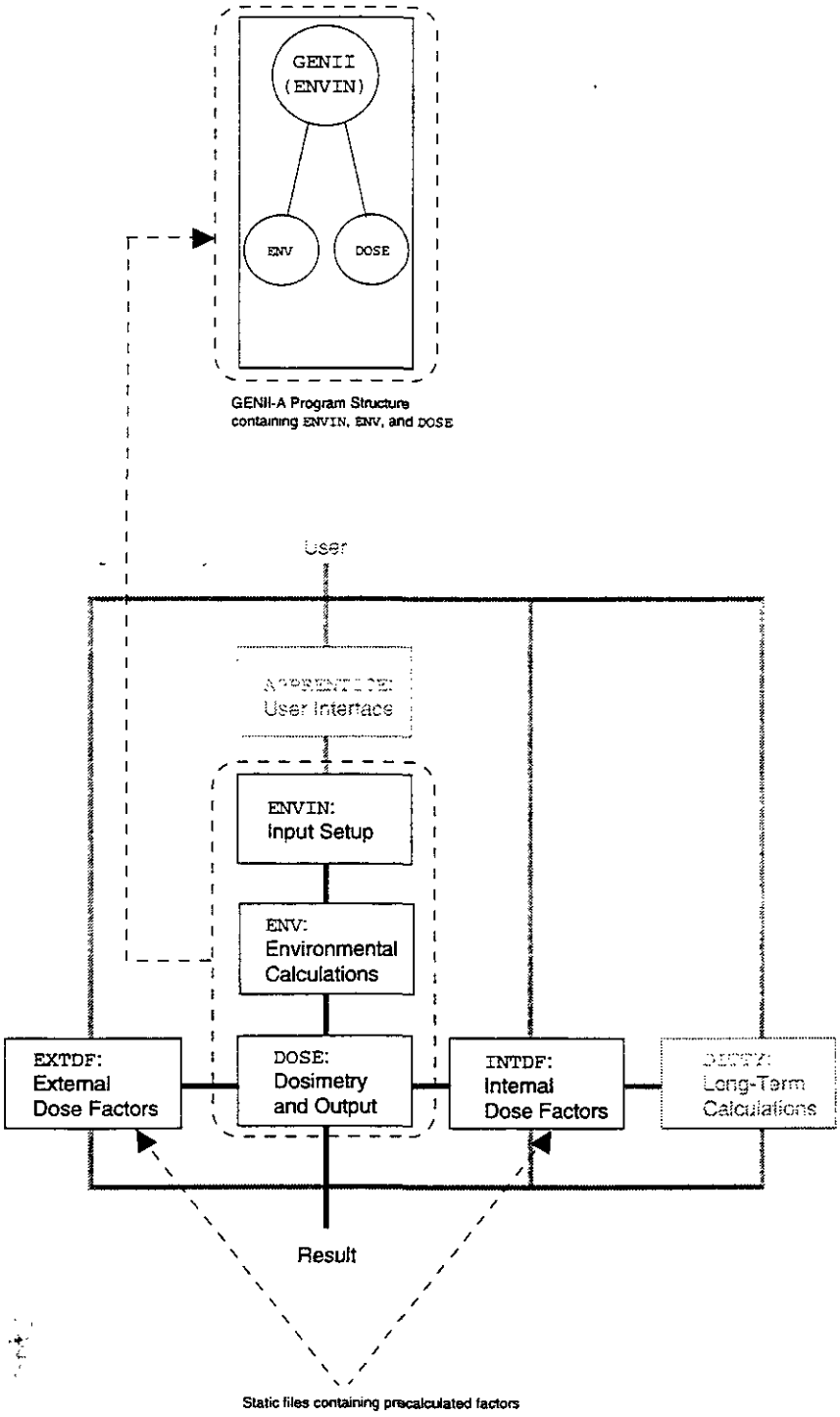

Figure 1. GENII-A implementation of GENII. (Faded portions of figure not used by GENII-A.)

4.1.2 ENV

ENV calculates environmental transfer, uptake, and human exposure to radionuclides that result from the chosen pathway for the defined source terms, as described in Volume 1 of Napier et al. (1988) (Section 3.3). The intermediate information that ENV calculates on annual media concentrations and intake rates are written to data transfer files that are input to DOSE.

4.1.3 DOSE

GENII-A uses DOSE to compute concentrations and intake through the following six principal exposure routes or pathways through the biosphere:

1. **Contaminated stockpond, water-stock cattle, man (rancher).** Contaminated brine from an exploratory drillhole leaks into an aquifer and its groundwater is pumped into a stockpond. Livestock drink exclusively from this pond and ranchers consume the livestock.

2. **Contaminated cuttings, man (driller).** Individuals operating the exploratory drill that penetrates the WIPP repository are, because of their proximity to drilling operations, exposed externally to (1) contaminated soil from the drilling mud pit and (2) drilling samples that they examine.[2]

3. **Contaminated stockpond, dust-air transport, man (farm family).** Contaminants from a dried stockpond (contaminated with radionuclides migrating through the groundwater, as explained in pathway 1) are suspended in an air plume that deposits the contamination onto a nearby farm. The contaminated crops and livestock from this farm are consumed by humans.

4. **Contaminated drilling-mud pit, dust-air transport, man (farm family).** Contaminants from a dried drilling-mud pit are suspended in an air plume that deposits the contamination onto a nearby farm. The contaminated crops and livestock from this farm are consumed by humans.

5. **Contaminated lake (drinking water, aquatic activities, fishing, irrigation).** Contaminated water from an exploratory drillhole leaks into an aquifer and its groundwater reaches a lake. Humans are contaminated by drinking water from the lake, fishing from the lake, aquatic activities in the lake, and by consuming crops irrigated by contaminated lake water.

---

[2] *It is to be noted that this option will not be exercised for the WIPP PA calculations since it was not included* in the test cases for the QA series. The exposure of the driller will be determined from two separate calculations, one involving exposure from a ground plane source (mud pit) and the second from handling the spherical source. In this way each contribution can be examined separately. These test cases have been included in the QA series.

6. **Contaminated well water (drinking water, irrigation).** Contaminated water from an exploratory drillhole leaks into an aquifer and its groundwater reaches a well. Humans are contaminated by drinking desalinated water from the well and consuming crops irrigated by contaminated well water.

The 1996 WIPP PA calculation is limited to the above six principal exposure routes.

DOSE reads the annual intake and exposure rates defined by ENV and converts them to radiation dose. The calculation of external dose is done with precalculated factors from EXTDF, and the calculation of internal dose is done with precalculated factors from INTDF.

GENII-A uses DOSE to calculate the following for each radionuclide:

- inhalation effective dose equivalent
- ingestion effective dose equivalent
- external dose
- internal effective dose equivalent
- annual effective dose equivalent.

All values are reported in dose equivalent units of rem. A 50-year dose commitment is assumed. The effective dose equivalent (EDE) combines the 1-year external dose and the internal dose over a 50-year period with an assumed 1-year intake period, as shown in Figure 2, multiplied by appropriate weighting factors for nuclides and organs. The internal effective dose equivalent equals the sum of the ingestion and inhalation dose. Further details on DOSE are provided in Volume 1 of Napier et al., 1988 (Section 3.4).

Note that an additonal dose calculation capability has been added to GENII-A: the spherical source exposure calculation, which utilizes the external exposure algorithm provided in DOSE with the appropriate dose convergence factors. See Section 7.1.5 for details.

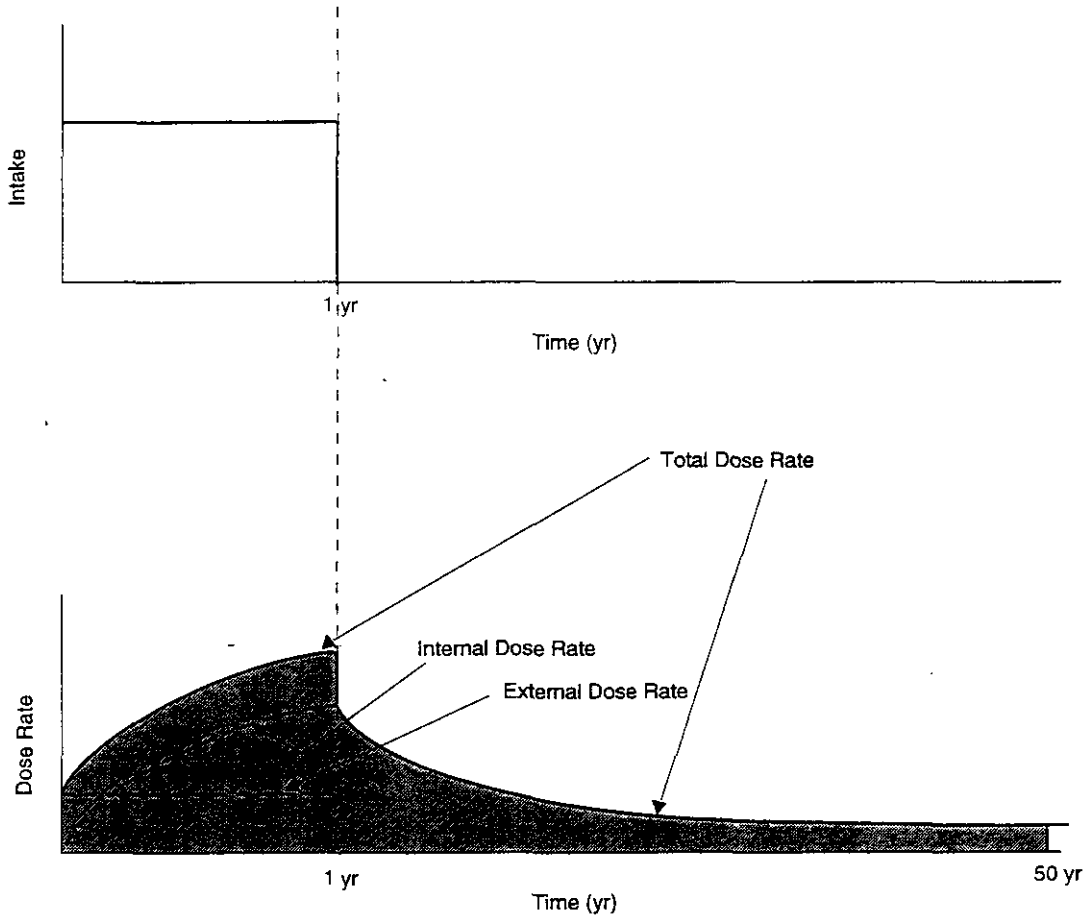

$$\text{Committed Dose} = \int_{0\,yr}^{50\,yr} (\text{Total Dose Rate})\, dt$$

Figure 2. Committed dose from 1-year internal and external exposure plus extended internal dose (from Figure 3.2 of Volume 1 of Napier et al., 1988)

4.2 Mathematical Representations

The mathematical models and algorithms used by GENII are discussed in detail in Chapter 4.0 of Volume 1 of Napier et al. (1988). To understand the theory upon which GENII-A is based, the reader should read the following portions of Chapter 4.0 of Napier et al.:

- Section 4.1, Internal Dosimetry
- Section 4.2, External Dosimetry
- Section 4.3, Atmospheric Dispersion
- Section 4.4, Air Submersion
- Section 4.5, Surface Water Transport Models
- Section 4.6, Soil Contamination Model
- The following subsections in Section 4.7, Terrestrial Exposure Pathways:
  - Subsection 4.7.1, Inhalation
  - Subsection 4.7.2, Drinking Water Ingestion
  - Subsection 4.7.4, Crop Ingestion — Chronic Exposures
  - Subsection 4.7.5, Animal Product Ingestion — Chronic Exposures
  - Subsection 4.7.7, External Exposure

4.3 Solution Techniques

The GENII package of computer codes is written in standard FORTRAN 77 using a Lahey compiler. Most routines are simple algebraic solutions, and no special logic is employed. One exception is the set of Bateman differential equations used by `DOSE` to calculate radioactive decay and generation of daughter products; the Bateman equations are solved in subroutine `CHAIN` using a chain decay solver. Another exception is `INTDF`, which is not run when GENII-A is exercised. (The same static output from `INTDF` is used for all GENII-A runs; see Section 4.1.)

5.0 CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

5.1 Capabilities

GENII-A, as used for the 1996 WIPP PA calculation,

- calculates radiation doses for chronic releases
- evaluates the following exposure pathways—soil (surface source), air (semi-infinite cloud and finite cloud geometries), inhalation pathways, and ingestion pathways
- inputs measured concentrations of the source term in specified environmental media
- provides an interface for external calculation of atmospheric dispersion
- identifies target populations by distance and direction for individuals and populations.

5.2 *Limitations*

The following limitations and assumptions are discussed in the noted parts of Napier et al., 1988:

- The internal dosimetry model does not account for elimination of material leaving a target organ (Volume 1, Subsection 4.1.1).
- All iodine decay products (isotopes of the noble gas xenon) are assumed to be stable or to escape the body before decaying (Volume 1, Subsections 4.1.3 and 4.1.4).
- Tritiated water is assumed to be uniformly distributed among the soft tissues at any time following intake, where it is retained with a biological half time of 10 days (Volume 1, Subsection 4.1.6).
- All intakes of carbon-14 are assumed to be completely and instantaneously absorbed (Volume 1, Subsection 4.1.6).
- For chains with daughters with very short half-lives, the decay energy is assigned to the parent (Volume 1, Subsection 4.1.7).
- Simple atmospheric dispersion modeling is used (Volume 1, Section 4.3 and Subsection 4.3.7).
- The derivation of the atmospheric dispersion models explicitly includes the assumptions that the release is from a point source and that the effluent travels in a straight line once it is released (Volume 1, Subsection 4.3.7).
- The surface water models make the following limiting assumptions: constant flow depth; constant downstream or longshore velocity; straight river channel; constant lateral dispersion coefficient; continuous point discharge release of effluents; constant river width (Volume 1, Section 4.5).
- The quantity of activity from contaminated soil brought to the surface by animals is assumed to be uniformly distributed in the surface soil and available for entry into plant and animal product pathways in subsequent years (Volume 1, Section 4.6.3).

- There is no measurable decrease in the the Anspaugh resuspension factor (used for calculating inhalation exposure) after about 17 years (Volume 1, Subsection 4.7.1).

- Inadvertent ingestion of water during bathing is neglected (Volume 1, Subsection 4.7.2).

- Because interception of materials in irrigation water (i.e., the fraction of radionuclides deposited within a unit area that ends up on vegetation surfaces) is not well understood, a default value of 0.25 is used (Volume 1, Subsection 4.7.4).

- The concentrations of tritium or carbon-14 in environmental media (soil, plants, and animal products) are assumed to have the same specific activity as the contaminating medium (Volume 1, Subsection 4.7.9).

6.0 USER INTERACTIONS WITH THE SOFTWARE

GENII-A is run for each input control file generated by PREGENII corresponding to a *n*-vector sample space. As the computational flow diagram (Figure 3) shows, radionuclide concentration processed by PREGENII can originate from WIPP PA codes that simulate the direct route to the accessible environment (CUTTINGS code sequence), or from the WIPP PA codes that simulate the indirect route to the accessible environment (BRAGFLO, NUTS/PANEL, SECOFL, and SECOTP code sequences). (Pathways 2 and 4 listed in Subsection 4.1.3 use output from the CUTTINGS code sequence; pathways 1 and 3 listed in Subsection 4.1.3 use output from the BRAGFLO, NUTS/PANEL, SECOFL, and SECOTP code sequences.)

6.1 Interactive Execution

The user can execute GENII-A interactively by typing the following two lines (each followed by a carriage return) at the VMS "$" prompt:

```
DEFINE GI2_DFL$DEF WP$TESTROOT:[GI2.DAT]
RUN WP$PRODROOT:[GI.EXE]GENII-A.EXE
```

A banner scrolls down the screen and then the following information describing the file definitions is printed on the screen:

```
*******************************************************************************

GENII-A expects the following files:
   1) Input Text File
   2) Input Filenames File
   3) Output dose file
   4) Output input echo file
   5) Output Diagnostics/Debug File (optional)

*******************************************************************************
```

THIS SAMPLE COMPUTATIONAL FLOW DIAGRAM *IS NOT NECESSARILY* THE FLOW USED IN THE 1996 WIPP PA CALCULATION. IT IS *INCLUDED SOLELY FOR ILLUSTRATIVE PURPOSES.*

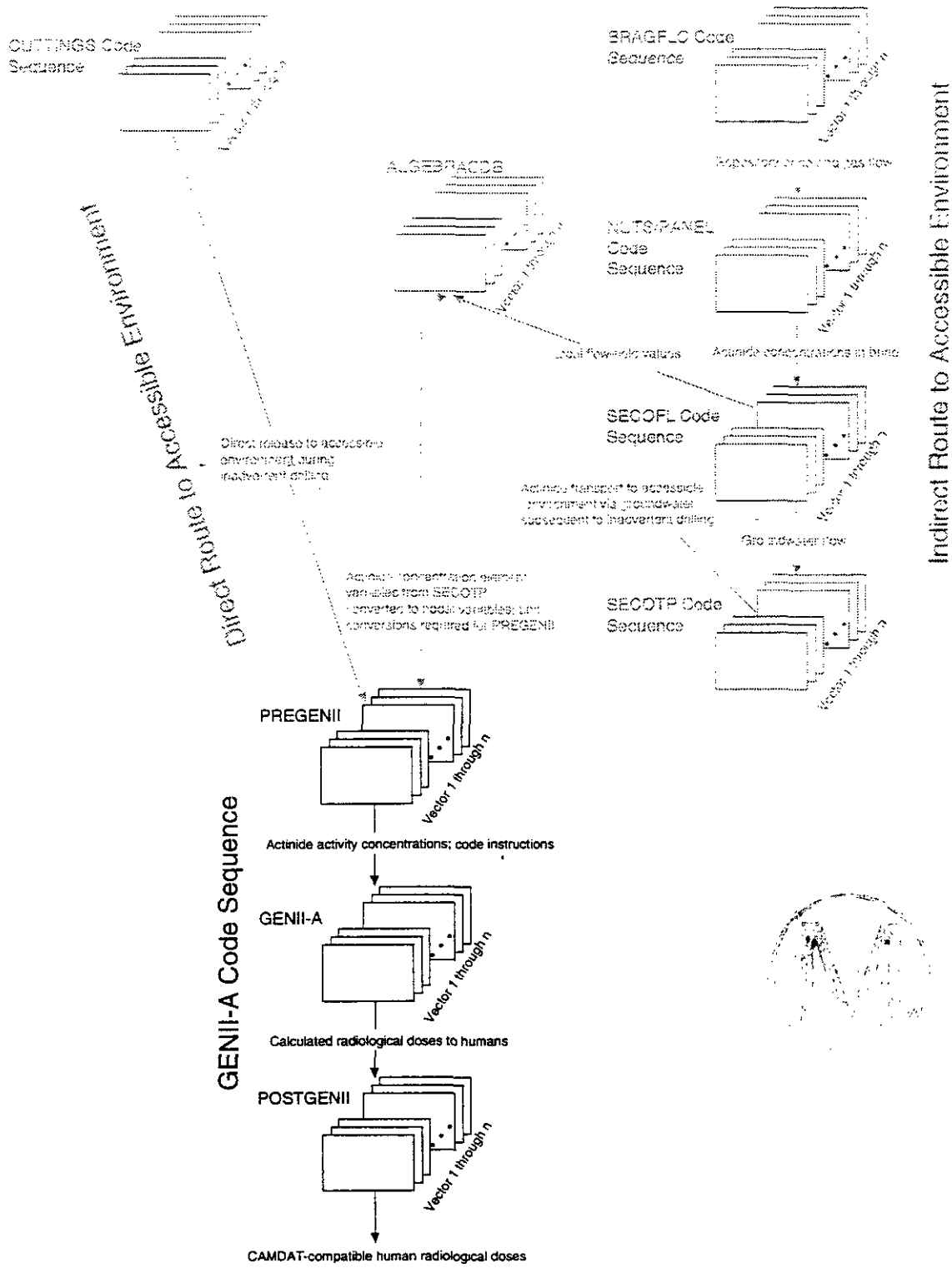

Figure 3. Sample computational flow diagram for GENII-A.

Subsequent questions in the procedure file request names for the above five files, described briefly below:

1. **Input text (.INP) file.** *This is the ASCII input control file output by PREGENII* (Figure 3) to run GENII-A for the sampled vector. See Section 7.1 for more information on this file.

2. **Input filenames (.DAT) file.** This file contains the names of the data files, input files, output files, and buffers required to run GENII-A. See Section 7.2 for more information on this file.

3. **Output dose (.OUT) file.** This file contains the results of the GENII-A calculation for the sampled vector; it is read by POSTGENII (see Figure 3). See Section 9.1 for more information on this file.

4. **Output input echo (.OUT) file.** This file, referred to in Napier et al. (1988) as the run input parameters report, contains a listing of parameters input to GENII-A for the sampled vector. See Section 9.2 for more information on this file.

5. **Output diagnostics/debug (.OUT) file.** This output file contains information about the GENII-A run for the sampled vector. It is an optional file, but it must be specified if the user wants to take advantage of error reporting. See Section 9.3 for more information on this file.

6.2 Execution via Command File

Alternatively, the user may use a command file to execute GENII-A. A sample command file (SAMPLE.COM) follows:

```
! ----
! MODULE:          SAMPLE.COM
! PURPOSE:         RUN A CASE THROUGH GENII-A USING A COM FILE
! DATE:            22-DEC-1995
! AUTHOR:          USER NAME
! ----
  SET NOON
  START_DIR = F$ENVIRONMENT("DEFAULT")
  EXE_SRC :== $WP$PRODROOT:[GI.EXE]GENII-A.EXE
  DEFINE  GI2_DFL$DEF WP$TESTROOT:[GI2.DAT]
  DEFINE  GI2_FND$INP GI2_DFL$DEF:GI2_FILENAME.DAT
  SET DEFAULT WP$TESTROOT:[GI2.TEST]
! ----
  DEFINE  GI2_TRN$INP GI2_TEST1_TRN.INP
  DEFINE  GI2_TRN$OUT GI2_TEST1_TRN.OUT
  DEFINE  GI2_ECO$OUT GI2_TEST1_ECO.OUT
  DEFINE  GI2_DBG$OUT GI2_TEST1_DBG.OUT
  EXE_SRC GI2_TRN$INP GI2_FND$INP GI2_TRN$OUT GI2_ECO$OUT GI2_DBG$OUT
! ----
  SET DEFAULT 'START_DIR
```

```
EXIT
```

Note that the the above command file specifies the names of Files 1 through 5 as `GI2_TEST1_TRN.INP`, `GI2_FILENAME.DAT`, `GI2_TEST1_TRN.OUT`, `GI2_TEST1_ECO.OUT`, and `GI2_TEST1_DBG.OUT`, respectively. (For user's convenience, these filenames appear in bold type in the above sample command file.) Once the command file is written and stored, the user simply types an "@" followed by the name of the command file, which in this case would be:

```
@SAMPLE.COM
```

7.0 DESCRIPTION OF INPUT FILES

7.1 ASCII Input Control (.INP) File

The GENII-A ASCII input control file (File 1 introduced in Section 6.1) contains the input specifications required to exercise GENII-A. This input file is referred to as GENII.IN by Napier et al. (1988) and is described line by line in Volume 2 (Section 3.2) of that publication.

A higher-level description of the GENII-A ASCII input control file, as used for the 1996 WIPP PA calculation, follows. In addition, a sample input control file, along with a detailed line-by-line description of the sample file, is provided in Appendix A.

By examining the sample input control file in Appendix A, one can see that the GENII-A input control file consists of seven major fields:

- options
- inventory
- time
- far-field scenarios
- near-field scenarios
- transport
- exposure.

A description of these fields follows. The sample input control file provided in Appendix A can be used as a guide while reading this description. This sample input control file is not necessarily indicative of one which will be used for the 1996 WIPP PA calculation.

7.1.1 Options

7.1.1.1 General

GENII-A allows for either near- or far-field scenarios. Far-field scenarios are for processes involving release of radioactive material into a wide environment. Near-field scenarios focus on possible doses to an individual at a particular location. For the 1996 WIPP PA calculation, the contaminated cuttings, man (driller) exposure pathway (described in Subsection 4.1.3 of this user's manual) is near-field; the remaining five pathways (also described in Subsection 4.1.3) are far-field.

GENII-A can be commanded to calculate either individual doses (for representative members of a critical group) or population doses (collective doses to regional populations or subpopulations). For the 1996 WIPP PA calculation, individual doses are calculated for all pathways.

For the 1996 WIPP PA calculation, GENII-A is limited to chronic releases; acute releases are not modeled.

"Maximum Individual data set used" indicates a conservative approach to selection of individual dose calculation parameters used for inhalation, ingestion, and external exposure. These conservative parameters are in line with the "critical group" requirement.

7.1.1.2 Transport

For the 1996 WIPP PA calculation, only one of the four transport options is ever invoked: the air transport option, which is used for the two dust-air transport pathways. As Figure 3 shows, groundwater transport for the stockpond pathway is handled by the SECO family of WIPP PA codes, and transport up the borehole to the drilling site is handled by the CUTTINGS family of WIPP PA codes. Sources from these calculations are deposited at the location of the scenario as basic concentrations.

7.1.1.3 Report

For all pathways considered for the 1996 WIPP PA calculation, the following report options are used:

- Dose is reported as committed dose equivalent (CDE), the committed dose from one year of exposure over a 50-year period (see Figure 2), appropriately weighted for each organ.
- Dose is reported for each radionuclide.
- Dose is reported by exposure pathway.
- The debug report is not printed on the screen.

7.1.1.4 Exposure Pathway

The following exposure pathways are exercised for the 1996 WIPP PA calculation:

- finite plume, external
- infinite plume, external
- ground, external
- inhalation uptake
- terrestrial foods ingestion
- animal product ingestion
- sample exposure.

7.1.2 Inventory

The inventory field specifies the input activity units, surface soil units, and the number of nuclides in the source term.

The inventory field also requires specification of the source term as a release term, basic concentration, or derived concentration. Release terms are sources to air or water or concentrations in buried wastes. The WIPP dust-air transport pathways specify an air release term. Basic concentrations can be entered when the transport steps are calculated outside of GENII-A. Basic concentrations are used for the WIPP groundwater and drilling cuttings pathways.

7.1.3 Time

Values provided to the time field allow specification of length of exposure, period for which dose commitment is calculated, length of time during which release occurs, and the time of air or irrigation water deposition prior to the intake period. For the 1996 WIPP PA calculation, the intake and release times are typically assumed to be one year, the dose calculation covers a 50-year period, and no air or irrigation water deposition is assumed to occur before the intake period.

7.1.4 Far-Field Scenarios

For the 1996 WIPP PA calculation, the dust-air pathways are considered far-field scenarios. Only individual doses are calculated.

7.1.5 Near-Field Scenarios

For the 1996 WIPP PA calculation, values can be provided for the following parameters in the near-field scenarios input field:

- "Manual redistribution: deep soil/surface soil dilution factor." A value is specified for the drilling cuttings pathway because drilling a borehole involves physical disruption that mixes deeply buried waste.

- "Source area for external dose modification factor." The value corresponding to this parameter is the area of the contaminated surface; a value is required for the dust-air transport pathways.

- "Source area for close examination dose factor." The GENII-A code has the capability to calculate exposure from a spherical hand-held source and a ground plane. The user has the option to implement either or both of these capabilities:

  - In order to implement the spherical source exposure option, the following input parameters are needed: The "Source area for close examination dose factor" should be set equal to 1250 square meters, and the soil overburden depth should be set to 0.15 meters in the "External Exposure" input field in order to flag within the code the appropriate area modification factor and dose calculation factor, respectively. Additionally, a value must be set for the "Examined soil contamination duration" (hours).

  - The input for the ground plane exposure consists of the area over which the radionuclides are spread in addition to the exposure time to the ground plane area and the distance from that source.

  The exposure times may not necessarily be equal for the two sources (spherical source and ground plane). When the selection is made to calculate exposure from a ground plane together with that from the spherical source, the program combines the two exposures into one and outputs the result as the external dose. If only one pathway is selected (spherical or ground plane), then the external exposure for that pathway will appear as the external dose. When the combined calculation is made, the basic concentration is input in the "Deep Soil" column under "Basic Concentrations."

7.1.6 Transport

7.1.6.1 Air Transport

The 1996 WIPP PA calculation requires that the plume model be calculated by PREGENII, meaning that the "0=Calculate PM" model is selected. When the pathway is dust-air, PREGENII can provide either

- a grid of precalculated χ/Q values and a matching grid of population that GENII-A cross-multiplies to create a population-weighted χ/Q

- joint frequency distribution in place of the χ/Q grid.

WIPP PA

User's Manual

for

GENII-A, Version 2.10

Document Version 1.00

WPO # 27751

November 13, 1995

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1.0 INTRODUCTION

1.1 Document Purpose

This document serves as a user's manual for GENII-A, as used in the 1996 WIPP PA calculation. As such, it describes the code's purpose and function, the user's interaction with the code, and the models and methods employed by the code. Examples of user-accessible input and output files are included for the user's convenience.

The GENII-A code, which runs on a DEC Alpha platform, duplicates a subset of the executables from the original GENII program (Radiation Shielding Information Center, 1995). Because a published conceptual representation and user's manuals for GENII already exist (Napier et al., 1988 [Volumes 1 and 2]), an important purpose of this user's manual (WPO # 27751) is to point the user to the discussions in Napier et al. pertinent to the 1996 WIPP PA calculation. It is recommended that the user have a copy of Napier et al., available from the Sandia WIPP Central Files, while reading this user's manual (WPO # 27751).

1.2 Software Identifier

Code Name:	GENII-A, a DEC Alpha-platform implementation of GENII, the second generation of the Hanford environmental dosimetry computer codes compiled in the Hanford Environmental Dosimetry System.
WIPP Prefix:	GI2
Version Number:	2.10, 1/16/96
Platforms:	FORTRAN 77 for OpenVMS AXP, version 6.1, on DEC Alpha

1.3 Points of Contact

1.3.1 Code Sponsor

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2.0 FUNCTIONAL REQUIREMENTS

The functional requirements for GENII-A are listed below:

R.1 GENII-A reads pathway and nuclide inventory input data.

R.2 GENII-A calculates doses for acute releases.

R.3 GENII-A calculates doses for chronic releases.

R.4 GENII-A calculates doses for air transport of radionuclides with or without meteorological input data.

R.5 GENII-A calculates doses for finite plume air immersion.

R.6 GENII-A calculates doses for infinite plume air immersion.

R.7 GENII-A calculates doses for external gound exposure.

R.8 GENII-A calculates doses for animal product ingestion with or without irrigation option.

R.9 GENII-A calculates doses for terrestrial food ingestion with or without irrigation option.

R.10 GENII-A calculates doses from dairy product ingestion with or without irrigation option.

R.11 GENII-A calculates doses from aquatic food ingestion.

R.12 GENII-A calculates doses from drinking water ingestion.

R.13 GENII-A calculates doses for far-field release.

R.14 GENII-A calculates doses for near-field release.

R.15 GENII-A calculates doses for lake or river surface water transport.

R.16 GENII-A calculates doses from external recreational exposure including boating, swimming, and external shoreline exposure.

R.17 GENII-A calculates doses from handling radioactive samples.

R.18 GENII-A calculates individual dose.

R.19 GENII-A calculates population dose using population distribution data.

R.20 GENII-A calculates doses from inhalation of airborne radionuclides.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

In order to run the GENII-A code successfully, the user will need a basic knowledge of

- Open VMS
- Digital Command Language
- Sandia's CAMDAT database.

To understand the theoretical portions of this manual (and the theoretical portions of the user manual by Napier et al. [1988]) and understand and interpret the results of GENII-A, the user should have a working knowledge of

- scenario development
- biosphere transport of radionuclides
- some knowledge of radionuclide decay processes and
  - radionuclide/organ interactions
  - radiation interactions with organic matter

An undergraduate degree in science or engineering is also recommended. The user should also have some knowledge of the original GENII program and its user manuals (Napier et al., 1988; Radiation Shielding Information Center, 1995). (The original GENII program, because it can run on an IBM PC platform, is sometimes called PC-GENII.).

4.0 DESCRIPTION OF THE MODELS AND METHODS

4.1 Program Modules

While GENII is composed of seven linked computer codes and their associated data libraries, GENII-A makes use of only five of them, as Figure 1 shows. Note that the `ENVIN` module has been renamed `GENII`[1] and that `GENII` calls `ENV` and `DOSE`.

Aside from the above name and hierarchy changes, a minor modification was made to the GENII code allowing a combined dose calculation from a spherical radioactive source (hand-held by the driller) and the ground surface exposure dose from a nearby source of radionuclides spread over a

[1] This program module should not be confused with GENII, GENII-A's predecessor. To prevent confusion, this program module (and all program modules) are written in a Courier font: `GENII`.

specified surface area. This capability is an option and can be selected through appropriate input data.

The following should also be noted:

- Only static outputs from EXTDF and INTDF are used by GENII-A; in other words, the boxes labeled EXTDF and INTDF in Figure 1 represent static data files, not program modules that are exercised when GENII-A is run. (EXTDF and INTDF are described in Sections 3.5 and 3.6 of Volume 1 of Napier et al., 1988 and Sections 3.3 and 3.4 of Volume 2 of Napier et al., 1988.) These modules are discussed below.

- Some modification to input formatting was made along with the deletion of unused parameters and the addition of new parameters for the sample exposure option mentioned above.

- Another addition was the inclusion of the requirement to indicate the number of nuclides in the GENII-A input file.

4.1.1 GENII

The ENVIN portion of GENII

- controls the reading of the input control text (.INP) file prepared by PREGENII (see computational flow discussion in Section 6.0 and input control file discussion in Section 7.2)

- organizes the input for the environmental transport and exposure module, ENV

- prepares the data transfer files that are used as input by ENV

- outputs the run input parameters report (i.e., the output input echo file) (Section 9.3).

Details on ENVIN are provided in Volume 1 of Napier et al. (Section 3.2).

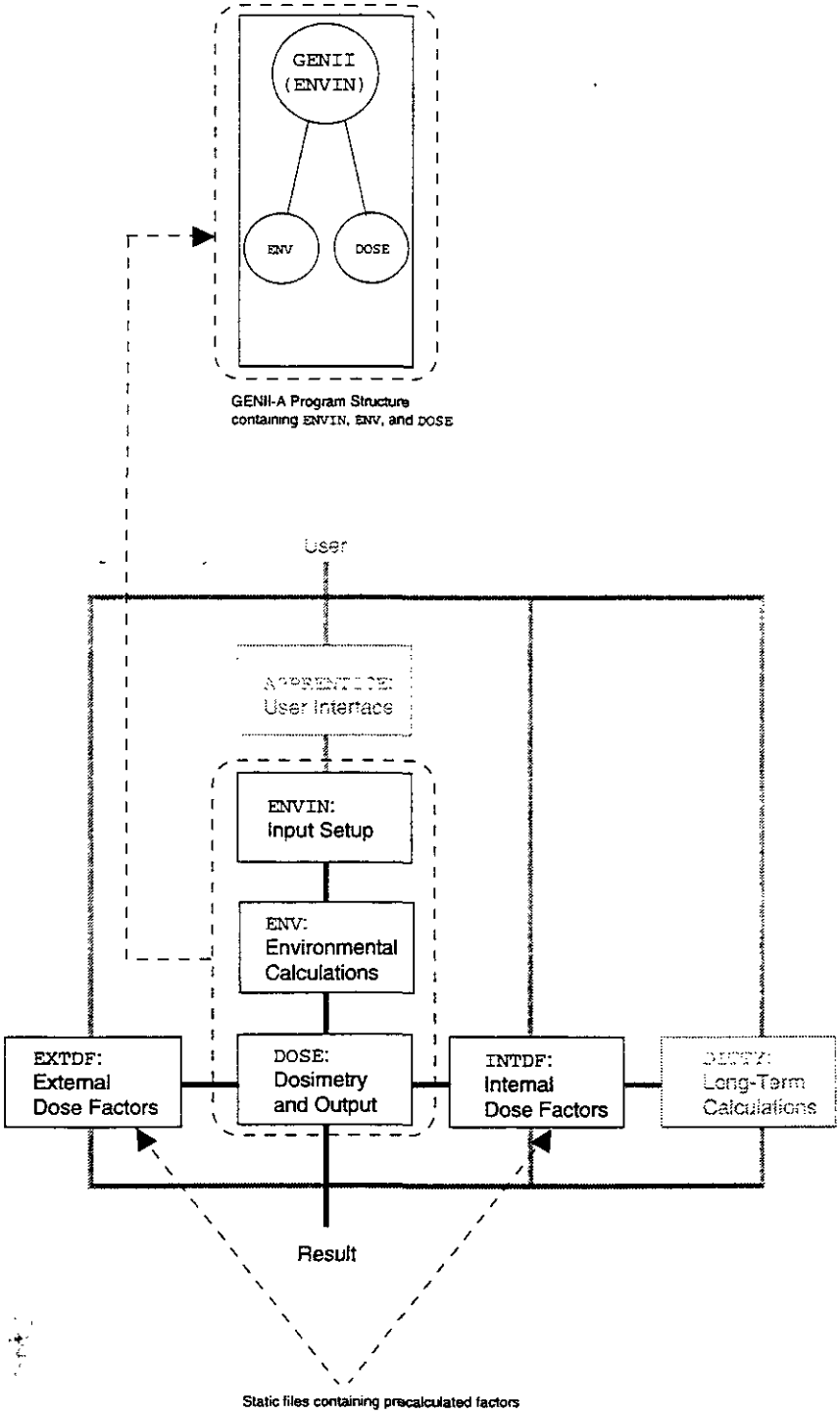

Figure 1. GENII-A implementation of GENII. (Faded portions of figure not used by GENII-A.)

4.1.2 ENV

ENV calculates environmental transfer, uptake, and human exposure to radionuclides that result from the chosen pathway for the defined source terms, as described in Volume 1 of Napier et al. (1988) (Section 3.3). The intermediate information that ENV calculates on annual media concentrations and intake rates are written to data transfer files that are input to DOSE.

4.1.3 DOSE

GENII-A uses DOSE to compute concentrations and intake through the following six principal exposure routes or pathways through the biosphere:

1. **Contaminated stockpond, water-stock cattle, man (rancher).** Contaminated brine from an exploratory drillhole leaks into an aquifer and its groundwater is pumped into a stockpond. Livestock drink exclusively from this pond and ranchers consume the livestock.

2. **Contaminated cuttings, man (driller).** Individuals operating the exploratory drill that penetrates the WIPP repository are, because of their proximity to drilling operations, exposed externally to (1) contaminated soil from the drilling mud pit and (2) drilling samples that they examine.[2]

3. **Contaminated stockpond, dust-air transport, man (farm family).** Contaminants from a dried stockpond (contaminated with radionuclides migrating through the groundwater, as explained in pathway 1) are suspended in an air plume that deposits the contamination onto a nearby farm. The contaminated crops and livestock from this farm are consumed by humans.

4. **Contaminated drilling-mud pit, dust-air transport, man (farm family).** Contaminants from a dried drilling-mud pit are suspended in an air plume that deposits the contamination onto a nearby farm. The contaminated crops and livestock from this farm are consumed by humans.

5. **Contaminated lake (drinking water, aquatic activities, fishing, irrigation).** Contaminated water from an exploratory drillhole leaks into an aquifer and its groundwater reaches a lake. Humans are contaminated by drinking water from the lake, fishing from the lake, aquatic activities in the lake, and by consuming crops irrigated by contaminated lake water.

---

[2] *It is to be noted that this option will not be exercised for the WIPP PA calculations since it was not included* in the test cases for the QA series. The exposure of the driller will be determined from two separate calculations, one involving exposure from a ground plane source (mud pit) and the second from handling the spherical source. In this way each contribution can be examined separately. These test cases have been included in the QA series.

6. **Contaminated well water (drinking water, irrigation).** Contaminated water from an exploratory drillhole leaks into an aquifer and its groundwater reaches a well. Humans are contaminated by drinking desalinated water from the well and consuming crops irrigated by contaminated well water.

The 1996 WIPP PA calculation is limited to the above six principal exposure routes.

DOSE reads the annual intake and exposure rates defined by ENV and converts them to radiation dose. The calculation of external dose is done with precalculated factors from EXTDF, and the calculation of internal dose is done with precalculated factors from INTDF.

GENII-A uses DOSE to calculate the following for each radionuclide:

- inhalation effective dose equivalent
- ingestion effective dose equivalent
- external dose
- internal effective dose equivalent
- annual effective dose equivalent.

All values are reported in dose equivalent units of rem. A 50-year dose commitment is assumed. The effective dose equivalent (EDE) combines the 1-year external dose and the internal dose over a 50-year period with an assumed 1-year intake period, as shown in Figure 2, multiplied by appropriate weighting factors for nuclides and organs. The internal effective dose equivalent equals the sum of the ingestion and inhalation dose. Further details on DOSE are provided in Volume 1 of Napier et al., 1988 (Section 3.4).

Note that an additonal dose calculation capability has been added to GENII-A: the spherical source exposure calculation, which utilizes the external exposure algorithm provided in DOSE with the appropriate dose convergence factors. See Section 7.1.5 for details.

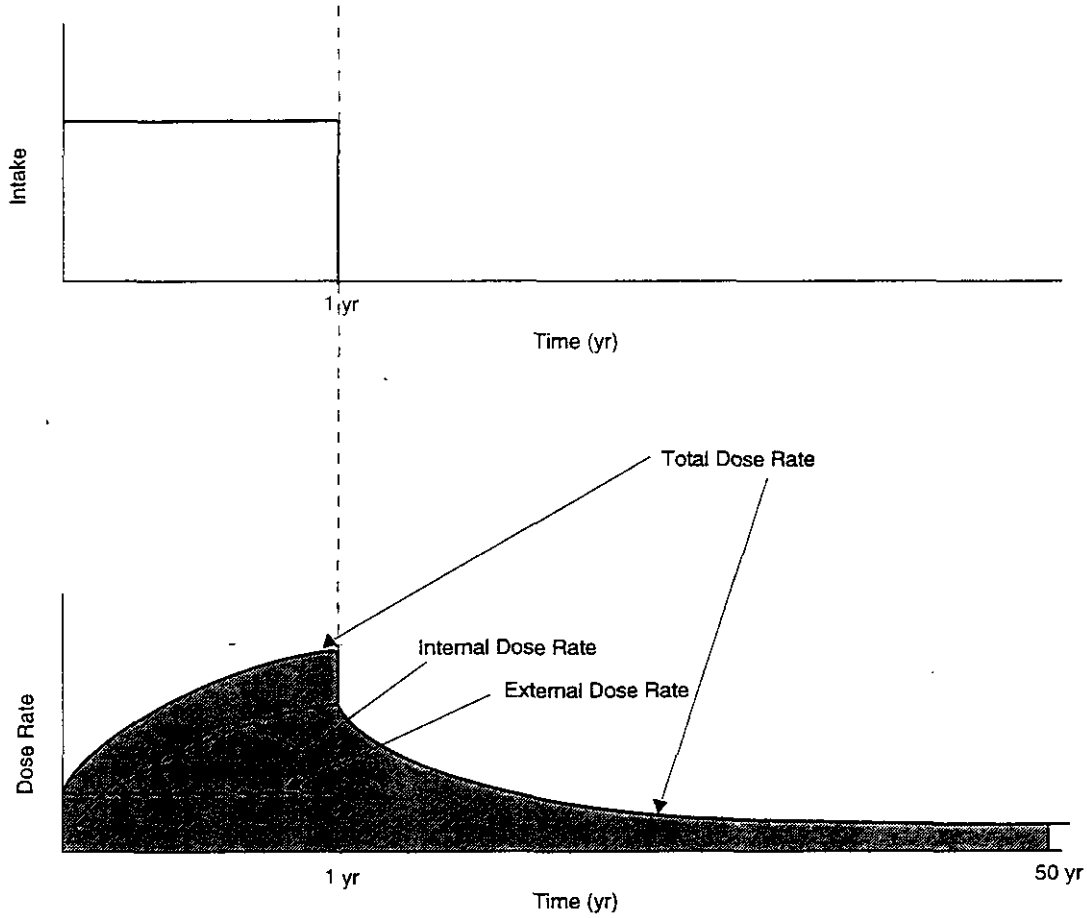

$$\text{Committed Dose} = \int_{0\,yr}^{50\,yr} (\text{Total Dose Rate})\, dt$$

Figure 2. Committed dose from 1-year internal and external exposure plus extended internal dose (from Figure 3.2 of Volume 1 of Napier et al., 1988)

4.2 Mathematical Representations

The mathematical models and algorithms used by GENII are discussed in detail in Chapter 4.0 of Volume 1 of Napier et al. (1988). To understand the theory upon which GENII-A is based, the reader should read the following portions of Chapter 4.0 of Napier et al.:

- Section 4.1, Internal Dosimetry
- Section 4.2, External Dosimetry
- Section 4.3, Atmospheric Dispersion
- Section 4.4, Air Submersion
- Section 4.5, Surface Water Transport Models
- Section 4.6, Soil Contamination Model
- The following subsections in Section 4.7, Terrestrial Exposure Pathways:
  - Subsection 4.7.1, Inhalation
  - Subsection 4.7.2, Drinking Water Ingestion
  - Subsection 4.7.4, Crop Ingestion — Chronic Exposures
  - Subsection 4.7.5, Animal Product Ingestion — Chronic Exposures
  - Subsection 4.7.7, External Exposure

4.3 Solution Techniques

The GENII package of computer codes is written in standard FORTRAN 77 using a Lahey compiler. Most routines are simple algebraic solutions, and no special logic is employed. One exception is the set of Bateman differential equations used by `DOSE` to calculate radioactive decay and generation of daughter products; the Bateman equations are solved in subroutine `CHAIN` using a chain decay solver. Another exception is `INTDF`, which is not run when GENII-A is exercised. (The same static output from `INTDF` is used for all GENII-A runs; see Section 4.1.)

5.0 CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

5.1 Capabilities

GENII-A, as used for the 1996 WIPP PA calculation,

- calculates radiation doses for chronic releases
- evaluates the following exposure pathways—soil (surface source), air (semi-infinite cloud and finite cloud geometries), inhalation pathways, and ingestion pathways
- inputs measured concentrations of the source term in specified environmental media
- provides an interface for external calculation of atmospheric dispersion
- identifies target populations by distance and direction for individuals and populations.

5.2 *Limitations*

The following limitations and assumptions are discussed in the noted parts of Napier et al., 1988:

- The internal dosimetry model does not account for elimination of material leaving a target organ (Volume 1, Subsection 4.1.1).
- All iodine decay products (isotopes of the noble gas xenon) are assumed to be stable or to escape the body before decaying (Volume 1, Subsections 4.1.3 and 4.1.4).
- Tritiated water is assumed to be uniformly distributed among the soft tissues at any time following intake, where it is retained with a biological half time of 10 days (Volume 1, Subsection 4.1.6).
- All intakes of carbon-14 are assumed to be completely and instantaneously absorbed (Volume 1, Subsection 4.1.6).
- For chains with daughters with very short half-lives, the decay energy is assigned to the parent (Volume 1, Subsection 4.1.7).
- Simple atmospheric dispersion modeling is used (Volume 1, Section 4.3 and Subsection 4.3.7).
- The derivation of the atmospheric dispersion models explicitly includes the assumptions that the release is from a point source and that the effluent travels in a straight line once it is released (Volume 1, Subsection 4.3.7).
- The surface water models make the following limiting assumptions: constant flow depth; constant downstream or longshore velocity; straight river channel; constant lateral dispersion coefficient; continuous point discharge release of effluents; constant river width (Volume 1, Section 4.5).
- The quantity of activity from contaminated soil brought to the surface by animals is assumed to be uniformly distributed in the surface soil and available for entry into plant and animal product pathways in subsequent years (Volume 1, Section 4.6.3).

- There is no measurable decrease in the the Anspaugh resuspension factor (used for calculating inhalation exposure) after about 17 years (Volume 1, Subsection 4.7.1).

- Inadvertent ingestion of water during bathing is neglected (Volume 1, Subsection 4.7.2).

- Because interception of materials in irrigation water (i.e., the fraction of radionuclides deposited within a unit area that ends up on vegetation surfaces) is not well understood, a default value of 0.25 is used (Volume 1, Subsection 4.7.4).

- The concentrations of tritium or carbon-14 in environmental media (soil, plants, and animal products) are assumed to have the same specific activity as the contaminating medium (Volume 1, Subsection 4.7.9).

6.0 USER INTERACTIONS WITH THE SOFTWARE

GENII-A is run for each input control file generated by PREGENII corresponding to a *n*-vector sample space. As the computational flow diagram (Figure 3) shows, radionuclide concentration processed by PREGENII can originate from WIPP PA codes that simulate the direct route to the accessible environment (CUTTINGS code sequence), or from the WIPP PA codes that simulate the indirect route to the accessible environment (BRAGFLO, NUTS/PANEL, SECOFL, and SECOTP code sequences). (Pathways 2 and 4 listed in Subsection 4.1.3 use output from the CUTTINGS code sequence; pathways 1 and 3 listed in Subsection 4.1.3 use output from the BRAGFLO, NUTS/PANEL, SECOFL, and SECOTP code sequences.)

6.1 Interactive Execution

The user can execute GENII-A interactively by typing the following two lines (each followed by a carriage return) at the VMS "$" prompt:

```
DEFINE GI2_DFL$DEF WP$TESTROOT:[GI2.DAT]
RUN WP$PRODROOT:[GI.EXE]GENII-A.EXE
```

A banner scrolls down the screen and then the following information describing the file definitions is printed on the screen:

```
*******************************************************************************

GENII-A expects the following files:
   1) Input Text File
   2) Input Filenames File
   3) Output dose file
   4) Output input echo file
   5) Output Diagnostics/Debug File (optional)

*******************************************************************************
```

THIS SAMPLE COMPUTATIONAL FLOW DIAGRAM *IS NOT NECESSARILY* THE FLOW USED IN THE 1996 WIPP PA CALCULATION. IT IS *INCLUDED SOLELY FOR ILLUSTRATIVE PURPOSES.*

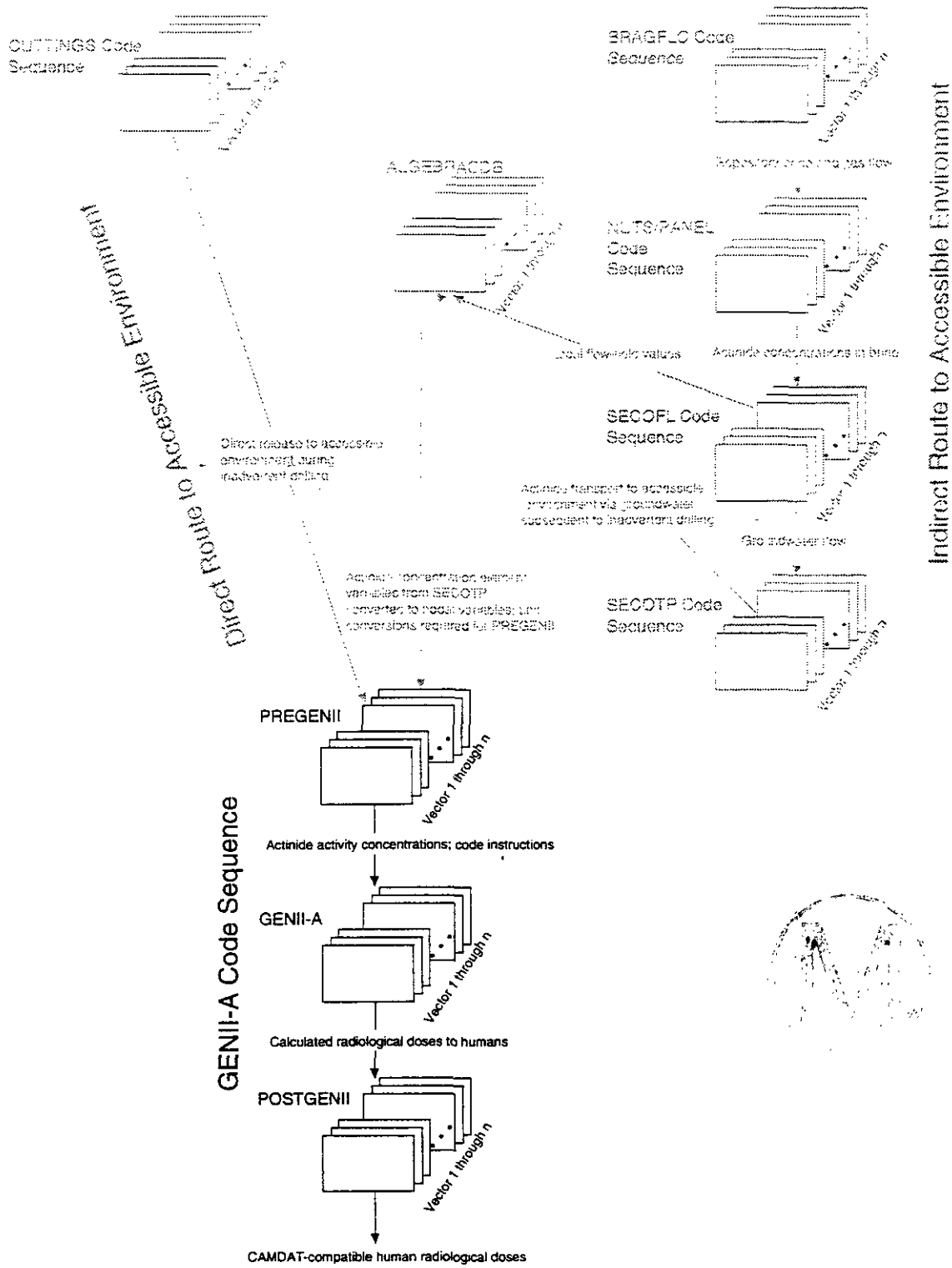

Figure 3. Sample computational flow diagram for GENII-A.

Subsequent questions in the procedure file request names for the above five files, described briefly below:

1. **Input text (.INP) file.** *This is the ASCII input control file output by PREGENII* (Figure 3) to run GENII-A for the sampled vector. See Section 7.1 for more information on this file.

2. **Input filenames (.DAT) file.** This file contains the names of the data files, input files, output files, and buffers required to run GENII-A. See Section 7.2 for more information on this file.

3. **Output dose (.OUT) file.** This file contains the results of the GENII-A calculation for the sampled vector; it is read by POSTGENII (see Figure 3). See Section 9.1 for more information on this file.

4. **Output input echo (.OUT) file.** This file, referred to in Napier et al. (1988) as the run input parameters report, contains a listing of parameters input to GENII-A for the sampled vector. See Section 9.2 for more information on this file.

5. **Output diagnostics/debug (.OUT) file.** This output file contains information about the GENII-A run for the sampled vector. It is an optional file, but it must be specified if the user wants to take advantage of error reporting. See Section 9.3 for more information on this file.

6.2 Execution via Command File

Alternatively, the user may use a command file to execute GENII-A. A sample command file (SAMPLE.COM) follows:

```
! ----
! MODULE:          SAMPLE.COM
! PURPOSE:         RUN A CASE THROUGH GENII-A USING A COM FILE
! DATE:            22-DEC-1995
! AUTHOR:          USER NAME
! ----
  SET NOON
  START_DIR = F$ENVIRONMENT("DEFAULT")
  EXE_SRC :== $WP$PRODROOT:[GI.EXE]GENII-A.EXE
  DEFINE  GI2_DFL$DEF WP$TESTROOT:[GI2.DAT]
  DEFINE  GI2_FND$INP GI2_DFL$DEF:GI2_FILENAME.DAT
  SET DEFAULT WP$TESTROOT:[GI2.TEST]
! ----
  DEFINE  GI2_TRN$INP GI2_TEST1_TRN.INP
  DEFINE  GI2_TRN$OUT GI2_TEST1_TRN.OUT
  DEFINE  GI2_ECO$OUT GI2_TEST1_ECO.OUT
  DEFINE  GI2_DBG$OUT GI2_TEST1_DBG.OUT
  EXE_SRC GI2_TRN$INP GI2_FND$INP GI2_TRN$OUT GI2_ECO$OUT GI2_DBG$OUT
! ----
  SET DEFAULT 'START_DIR
```

```
EXIT
```

Note that the the above command file specifies the names of Files 1 through 5 as `GI2_TEST1_TRN.INP`, `GI2_FILENAME.DAT`, `GI2_TEST1_TRN.OUT`, `GI2_TEST1_ECO.OUT`, and `GI2_TEST1_DBG.OUT`, respectively. (For user's convenience, these filenames appear in bold type in the above sample command file.) Once the command file is written and stored, the user simply types an "@" followed by the name of the command file, which in this case would be:

```
@SAMPLE.COM
```

7.0 DESCRIPTION OF INPUT FILES

7.1 ASCII Input Control (.INP) File

The GENII-A ASCII input control file (File 1 introduced in Section 6.1) contains the input specifications required to exercise GENII-A. This input file is referred to as GENII.IN by Napier et al. (1988) and is described line by line in Volume 2 (Section 3.2) of that publication.

A higher-level description of the GENII-A ASCII input control file, as used for the 1996 WIPP PA calculation, follows. In addition, a sample input control file, along with a detailed line-by-line description of the sample file, is provided in Appendix A.

By examining the sample input control file in Appendix A, one can see that the GENII-A input control file consists of seven major fields:

- options
- inventory
- time
- far-field scenarios
- near-field scenarios
- transport
- exposure.

A description of these fields follows. The sample input control file provided in Appendix A can be used as a guide while reading this description. This sample input control file is not necessarily indicative of one which will be used for the 1996 WIPP PA calculation.

7.1.1 Options

7.1.1.1 General

GENII-A allows for either near- or far-field scenarios. Far-field scenarios are for processes involving release of radioactive material into a wide environment. Near-field scenarios focus on possible doses to an individual at a particular location. For the 1996 WIPP PA calculation, the contaminated cuttings, man (driller) exposure pathway (described in Subsection 4.1.3 of this user's manual) is near-field; the remaining five pathways (also described in Subsection 4.1.3) are far-field.

GENII-A can be commanded to calculate either individual doses (for representative members of a critical group) or population doses (collective doses to regional populations or subpopulations). For the 1996 WIPP PA calculation, individual doses are calculated for all pathways.

For the 1996 WIPP PA calculation, GENII-A is limited to chronic releases; acute releases are not modeled.

"Maximum Individual data set used" indicates a conservative approach to selection of individual dose calculation parameters used for inhalation, ingestion, and external exposure. These conservative parameters are in line with the "critical group" requirement.

7.1.1.2 Transport

For the 1996 WIPP PA calculation, only one of the four transport options is ever invoked: the air transport option, which is used for the two dust-air transport pathways. As Figure 3 shows, groundwater transport for the stockpond pathway is handled by the SECO family of WIPP PA codes, and transport up the borehole to the drilling site is handled by the CUTTINGS family of WIPP PA codes. Sources from these calculations are deposited at the location of the scenario as basic concentrations.

7.1.1.3 Report

For all pathways considered for the 1996 WIPP PA calculation, the following report options are used:

- Dose is reported as committed dose equivalent (CDE), the committed dose from one year of exposure over a 50-year period (see Figure 2), appropriately weighted for each organ.
- Dose is reported for each radionuclide.
- Dose is reported by exposure pathway.
- The debug report is not printed on the screen.

7.1.1.4 Exposure Pathway

The following exposure pathways are exercised for the 1996 WIPP PA calculation:

- finite plume, external
- infinite plume, external
- ground, external
- inhalation uptake
- terrestrial foods ingestion
- animal product ingestion
- sample exposure.

7.1.2 Inventory

The inventory field specifies the input activity units, surface soil units, and the number of nuclides in the source term.

The inventory field also requires specification of the source term as a release term, basic concentration, or derived concentration. Release terms are sources to air or water or concentrations in buried wastes. The WIPP dust-air transport pathways specify an air release term. Basic concentrations can be entered when the transport steps are calculated outside of GENII-A. Basic concentrations are used for the WIPP groundwater and drilling cuttings pathways.

7.1.3 Time

Values provided to the time field allow specification of length of exposure, period for which dose commitment is calculated, length of time during which release occurs, and the time of air or irrigation water deposition prior to the intake period. For the 1996 WIPP PA calculation, the intake and release times are typically assumed to be one year, the dose calculation covers a 50-year period, and no air or irrigation water deposition is assumed to occur before the intake period.

7.1.4 Far-Field Scenarios

For the 1996 WIPP PA calculation, the dust-air pathways are considered far-field scenarios. Only individual doses are calculated.

7.1.5 Near-Field Scenarios

For the 1996 WIPP PA calculation, values can be provided for the following parameters in the near-field scenarios input field:

- "Manual redistribution: deep soil/surface soil dilution factor." A value is specified for the drilling cuttings pathway because drilling a borehole involves physical disruption that mixes deeply buried waste.

- "Source area for external dose modification factor." The value corresponding to this parameter is the area of the contaminated surface; a value is required for the dust-air transport pathways.

- "Source area for close examination dose factor." The GENII-A code has the capability to calculate exposure from a spherical hand-held source and a ground plane. The user has the option to implement either or both of these capabilities:

  - In order to implement the spherical source exposure option, the following input parameters are needed: The "Source area for close examination dose factor" should be set equal to 1250 square meters, and the soil overburden depth should be set to 0.15 meters in the "External Exposure" input field in order to flag within the code the appropriate area modification factor and dose calculation factor, respectively. Additionally, a value must be set for the "Examined soil contamination duration" (hours).

  - The input for the ground plane exposure consists of the area over which the radionuclides are spread in addition to the exposure time to the ground plane area and the distance from that source.

  The exposure times may not necessarily be equal for the two sources (spherical source and ground plane). When the selection is made to calculate exposure from a ground plane together with that from the spherical source, the program combines the two exposures into one and outputs the result as the external dose. If only one pathway is selected (spherical or ground plane), then the external exposure for that pathway will appear as the external dose. When the combined calculation is made, the basic concentration is input in the "Deep Soil" column under "Basic Concentrations."

7.1.6 Transport

7.1.6.1 Air Transport

The 1996 WIPP PA calculation requires that the plume model be calculated by PREGENII, meaning that the "0=Calculate PM" model is selected. When the pathway is dust-air, PREGENII can provide either

- a grid of precalculated χ/Q values and a matching grid of population that GENII-A cross-multiplies to create a population-weighted χ/Q

- joint frequency distribution in place of the χ/Q grid.

7.1.6.2 Surface Water Transport

Surface water transport is not a pathway used for the 1996 WIPP PA calculation.

7.1.7 Exposure

7.1.7.1 External Exposure

For the 1996 WIPP PA calculation, PREGENII can provide values for the following parameters:

- Plume exposure time — length of exposure per year to chronic atmospheric plumes. Plume exposure time is specified for the dust-air pathway. If the pathway is not dust-air, any value assigned to this parameter is neglected.

- Examined soil contamination duration — length of time the driller inspects the contaminated sample. A value is provided for this parameter for the drilling pathway. This parameter specifies the exposure time to the examined sample.

- Soil overburden depth — This parameter is used as a flag when set to 0.15 m to obtain the dose conversion factor for sample exposure. Other values can be used for scenarios not including sample exposure.

7.1.7.2 Inhalation

In the WIPP PA dust-air pathways, PREGENII must provide the following:

- the number of hours of exposure to contamination per year

- the type of resuspension model (none, mass loading, or Anspaugh)

The mass loading and Anspaugh models are explained in Volume 1 of Napier et al., 1988 (Subsection 4.7.1).

7.1.7.3 Ingestion Population

PREGENII specifies one of two options dealing with plant and animal food production:

- Option 1, use same χ/Q value distribution as used for the population (Section 7.1.6.1), essentially assuming the source of food and the people are co-located (used for the dust-air pathways)

- Option 2, assume that the food is produced uniformly throughout an 80-km grid (used for the stockpond pathway)

7.1.7.4 Aquatic Foods/Drinking Water Ingestion

While aquatic foods are not considered for the 1996 WIPP PA calculation, drinking water ingestion may be. If it is exercised, the source would be ground water (Option 1), it would have to be treated, and holdup/transit and consumption parameters would be specified.

7.1.7.5 Terrestrial Food Ingestion

PREGENII provides values for terrestrial food ingestion parameters here. See page 3.25 of Volume 2 of Napier et al. (1988) for details.

7.1.7.6 Animal Production/Consumption

PREGENII provides values for animal production and consumption parameters here. See pages 3.25 and 3.26 of Volume 2 of Napier et al. (1988) for details.

7.2 Input Filenames File

A sample input filenames file is provided in Appendix B. The input filenames file contains the names of the external data, input, and output files and their corresponding unique logical unit numbers (left column of Appendix B). Further information on this file is provided in Volume 2 of Napier et al. (1988) on pages 2.34 through 2.36.

8.0 ERROR MESSAGES

GENII-A generates an alphabetical list of error messages that are written to the diagnostics/debug file (Section 9.3). There are five error types:

1. **Warnings.** These messages are informational only; no action is necessary.

2. **Scenarios errors.** These errors often occur when there is a problem with an input file. The code attempts to identify scenario incompatibilities and stop execution of the program so that the user may make corrections before exposure and dose calculations are performed. The user should carefully check and correct any inconsistencies in the input file.

3. **Program errors.** The sponsor should be notified if a program error message is displayed.

4. **Scenario/file errors.** These errors indicate a problem with auxiliary input files.Users should refer to Sections 2.2.1 through 2.2.12 of Napier et al. (1988), Volume 2 for assistance in determining the cause of scenario/file errors.

5. **Program/file errors.** The sponsor should be notified if a program/file error message is displayed. Program/file errors usually indicate that the user, in attempting to expand the application of GENII-A for research purposes, has made incorrect changes to data files

used by the code. The user should check file format and usage as presented in Section 2.3 of Napier et al. (1988), Volume 2.

Error outputting by GENII is thoroughly documented in Appendix B of Napier et al. (1988), Volume 2. Especially useful is the alphabetical list of messages contained in Table B.1 in Appendix B of Napier et al. (1988), Volume 2. The user should follow the specific guidance provided in that table when recovering from errors.

9.0 DESCRIPTION OF OUTPUT FILES

9.1 Output Dose File

The output dose file contains the actual dose calculation results. The sample output dose file provided in Appendix C, a representative GENII-A output dose file, consists of

- the effective dose equivalent summary calculation, from which individual organ doses may be obtained, and a summary table of the dominant organ, dominant exposure pathway[3], and dominant radionuclide (see listing in Appendix C titled Page C.4)
- the dose assembly matrix (defined in Figure 3.6 of Volume 1 of Napier et al., 1988), from which the annual dose, effective dose equivalent, cumulative dose, and maximum annual dose may be obtained (see listing in Appendix C titled Page C.5)
- the dose contribution by exposure pathway (see listing in Appendix C titled Page C.6)
- the dose contribution by radionuclide (see listing in Appendix C titled Page C.7 through Page C.10)
- the dose contribution by radionuclide as a function of ingestion, inhalation, and external exposure (see listing in Appendix C titled Page C.11 and Page C.12)

9.2 Output Input Echo File

The output input echo file (see Appendix D for a sample listing) is the quality assurance output portion. The input values and scenario description flags are repeated to allow checking of the calculation assumptions.

9.3 Output Diagnostics/Debug File

The output diagnostics/debug file (see Appendix E for a sample listing) contains the file assignments and any error messages generated during the run.

---

[3] Here "exposure pathway" refers to mechanisms within the the five exposure pathways described in Section 4.1.2.

10.0 REFERENCES

Napier, B.A., R.A. Peloquin, D.L. Strenge, and J.V. Ramsdell. 1988. *GENII - The Hanford Environmental Radiation Dosimetry Software System, Volume 1: Conceptual Representation and Volume 2: Users' Manual.* PNL-6584, Richland, Washington: Pacific Northwest Laboratory.

Radiation Shielding Information Center. 1995. *GENII 1.485 Environmental Radiation Dosimetry Software System, March 1995.* Oak Ridge, Tennessee: Oak Ridge National Laboratory.

11.0 APPENDICES

Note

The sample files and displays provided in Appendices A through E are examples *only*. They *are not necessarily* the files used for the 1996 WIPP PA regulatory calculation.

Appendix A: Annotated Sample GENII-A Input Control (.INP) File

A.1 Line-by-Line Annotation

An example of the GENII-A file is presented in Section A.2. A line-by-line description of the parameters and options that are defined in GENII-A, along with the code variable names, is provided below.

Line 1:	File identifier line for the GENII-A file. See B. Napier et al. Vol. 2 page 3.7 for more detail.
Line 2:	Title line for the specific input case. (Name of the specific input file copied into GENII-A.)
Line 3:	Creation date.
Line 4:	OPTIONS header line.
Line 5:	Near-field or far-field scenario option flag. See B. Napier et al. Vol. 2 pp. 3.7 to 3.9 for more detail.
Line 6:	Population or individual dose calculation flag, POPDOS. See B. Napier et al. Vol. 2 pg. 3.9 for more detail.
Line 7:	Acute or chronic release flag, ACUTE. See B. Napier et al. Vol. 2 pg. 3.9 for more detail.
Line 8:	This line contains a reminder of the type of individual exposure parameters used for inhalation, ingestion, and external exposure. See B. Napier et al. Vol. 2 pg. 3.9 for more detail.
Lines 9 to 10:	Header line for transport pathway options.
Line 11:	Atmospheric transport flag, AIR. See B. Napier et al. Vol 2. pg. 3.10 for more detail.
Line 12:	Surface water transport flag, SWAT.
Line 13:	Biotic transport flag (only activated for near-field scenarios with subsurface contamination), BIOT. Inoperative in GENII-A version.
Line 14:	Waste form degradation flag (only activated for near field scenarios with buried wastes), BURWAS. Inoperative in GENII-A version.
Line 15 to 16:	Report Options header.

Line 17:	Flag for type of dose calculation, OUTEDE. See B. Napier et al. Vol 2. pg. 3.10 for more detail.
Line 18:	Flag to provide report of exposure by radionuclide, OUTRAD.
Line 19:	Flag to provide report of exposure pathway, OUTPTH.
Line 20:	Flag to provide debugging output, DEBUG. See B. Napier et al. Vol 2. pg. 3.11 for more detail.
Lines 21 to 22:	Header line for exposure pathway options.
Line 23:	Flag to activate finite plume external exposure pathway, FINITE. See B. Napier et. al Vol. 2 pg. 3.11 for more detail.
Line 24:	Infinite plume external exposure flag, AIREXT.
Line 25:	Soil exposure external exposure flag, GROUND.
Line 26:	Aquatic recreation (swimming, boating, shoreline) exposure flag, RECRE.
Line 27:	Inhalation exposure flag, INHAL.
Line 28:	Drinking water ingestion exposure flag, DRINK.
Line 29:	Aquatic foods ingestion exposure flag, AQFOOD.
Line 30:	Terrestrial foods (crops) ingestion exposure flag, TFOOD.
Line 31:	Animal product (meat, milk, eggs) ingestion exposure flag, ANFOOD.
Line 32:	Inadvertent soil ingestion model exposure flag, SLING.
Lines 33 to 35:	Inventory editing header.
Line 36:	Selection of radionuclide inventory activity units, IUNIT. See B. Napier et al. Vol. 2 pg. 3.12 for more detail.
Line 37:	Selection of surface soil inventory units- the source may be entered in terms of area, volume, or mass, SOLUNT.
Line 38:	Number of nuclides in source term.
Lines 39 to 46:	Inventory editing headers. See B. Napier et al. Vol. 2 pg. 3.12 for more detail.

Lines 47 to 54:	Inventories of radionuclides may be entered here for release or basic concentrations. See B. Napier et al. Vol. 2 pg. 3.12 for more detail.
Lines 55 to 60:	Derived concentration editing header. Inventories of derived concentrations of radionuclides may be entered following this header. See B. Napier et al. Vol. 2 pgs. 3.12 and 3.13 for more detail (not listed in sample listing shown in Section A.2).
Lines 61 to 63:	Time editing header. See B. Napier et al. Vol. 2 pg. 3.13 for more detail.
Line 64:	Length of time over which the intake occurs (time from "Intake Begins" to "Intake Ends." See B. Napier et al. Vol. 2 pg. 3.13 for more detail.
Line 65:	Dose commitment.
Line 66:	Length of time over which release occurs during exposure (time from " Intake Begins" to "Release Stops"), RELEND. If the AEDE ONLY options has been selected for the reports, only one year will be used.
Line 67:	Length of time prior to time "Intake Begins" that inventory atmospheric release was initiated (the early portion of the "Release Period"), BEFAIR, yr.
Line 68:	Length of time prior to time "Intake Begins" that inventory surface water release and irrigation were initiated (the early portion of the "Release Period") , BEFIRR, yr.
Line 69 to 71:	Far-field scenario parameter editing header.
Line 72:	To calculate population doses, you will be asked to input consumption/ exposure parameters for an average individual in the population. See B. Napier et al. Vol. 2 pg. 3.14 for more detail. In this sample file, the number "1" corresponds to the case where the number of people will be read from POP.IN.
Line 73:	If only the total population is being used, enter it on this line, POPIN, persons. In this sample file, the number "2" on Line 72 corresponds to this selected option.
Lines 74 to 77:	Near-field scenario editing header. B. Napier et al. Vol. 2 pg. 3.14 for more detail.
Line 78:	The length of time prior to the time "Intake Begins" that the inventory "Disposal" was initiated, BEFORE, yr.

Line 79: The length of time prior to the time that "Intake Begins" that Loss of Institutional Control (LOIC) occurred, allowing biotic transport to begin, LOIC, yr. Inoperative in GENII-A version.

Line 80: A two-compartment model of plant roots is allowed. Root fractions are used in regular plant concentration model. The upper soil fraction is entered on this line, RF1. See B. Napier et al. Vol. 2 pg. 3.15 for more detail.

Line 81: The deep soil root fraction is entered on this line, RF2.

Line 82: For scenarios involving physical disruption that mixes deeply buried waste with surface soil, a "Manual Redistribution" factor is available, MANULR. See B. Napier et al. Vol. 2 pg. 3.15 for more detail.

Line 83: A simple geometric model of dose rate reduction for small surface areas is provided. Enter the area of the contaminated surface on this line in square meters, FRSIZ.

Line 84: The flag used to initiate the spherical sample calculation is set to 1250.

Line 85: Transport editing header.

Line 86: Air transport editing header.

Lines 87 to 90: A number of options are available to determine air concentration from releases. The option is selected by specifiying a parameter XOQOPT on line 88 of this field. See B. Napier et. al. Vol.2 pgs. 3.15 to 3.18 for more detail.

Line 91: Input chi/Q or population-weighted chi/Q, if used, goes on this line, XOQI, sec /m^3 or person-sec/m^3.

Line 92: Sector index for the location of the Maximum Individual, MIDIR. See B. Napier et al. Vol. 2 pg. 3.18 for more detail.

Line 93: Distance of Maximum Individual from the release point, meters, MIDIST. See B. Napier et al. Vol. 2 pg. 3.18 for more detail.

Line 94: Stack height or effective stack height, SHITE, m.

Line 95: Flag for use of joint frequency data, as defined by XOQOPT, JFIN.

Lines 96 to 97: Surface Water Transport editing header. See Napier et al. Vol. 2 pg. 3.19 for more detail.

Line 98: Indicator for which mixing ratiio model to use. MIXFLG. See Napier et al. Vol. 2 pg. 3.19 for more detail.

Line 99:	Input mixing ratio MIXFLG=0, MIXR.
Line 100:	Average river flow rate, SWFLOW. For MIXFLG=0, the units are m^3/s; for MIXFLG=1 or 2, the units are m/s.
Line 101:	Transit time to irrigation withdrawal location, SWTT, h.
Line 103:	Exposure editing header.
Line 104:	External exposure editing header.
Line 105:	Header for the exposure time for plume.
Line 106:	Length of external exposure (per year) to chronic atmospheric plumes, HRPLUM, h.
Line 107:	Length of external exposure per year to soil contamination, HRGRD, h.
Line 108:	Length of external exposure to spherical sample (hours).
Line 109:	Depth of soil over source. This parameter is also used when spherical sample calculation is implemented, in which case 0.15 m is specified.
Line 110:	Length of time spent per year swimming in contaminated water, HRSWIM, h.
Line 111:	Length of time spent by individuals (per year) boating, HRBOAT, h.
Line 112:	Length of time spent by individuals exposed in shoreline activities, HRSHOR, h.
Line 113:	Index for type of shoreline at the exposure location, SHRTYP. See B. Napier et al. Vol.2, pg. 3.22 for more detail.
Line 114:	Travel time of water from the release point to the recreational exposure point, RECTT, h.
Line 115:	For the acute air submersion model, the fraction ot total plume travel time that the individual spends in the plume, FRCLOD.
Lines 116 to 117:	Irrigation header.
Line 118:	Irrigation flag, RESIRR (T or F).
Lines 119 to 120:	Irrigation source selection, IRRSR (1=groundwater, 2=surface water).

Line 121:	Irrigation application rate, RIRR (in/yr).
Line 122:	Irrigation time in months/year, IRTIMR.
Line 123:	Inhalation editing header. See B. Napier et al. Vol.2, pg. 3.22 for more detail.
Line 124:	Hours per year an individual spends exposed to contaminated air from either chronic plumes or from resuspension. HRINH, h.
Line 125:	Flag for activating resuspension models, IRES. See B. Napier et al. Vol.2, pg. 3.22 for more detail.
Line 126:	If IRES =1, the mass loading factor XMLF, g/m^3. If IRES =2 , the depth of the top layer of soil that is available for resuspension AVALSL, cm.
Lines 127 to 128:	Ingestion Population editing header. See B. Napier et al. Vol.2, pp. 3.22 to 3.23 for more detail.
Line 129:	Option selection for food production, FOQOPT. (Called "Atmospheric production" option because air transport of particulates is involved through the chi/Q factor.)
Line 130:	If FOQOPT =0 , then the food-weighted chi/Q is entered on this line, FOQ, $kg\text{-}sec/m^3$.
Lines 131 to 133:	Editing information.
Line 134:	The number of people ingesting the aquatic food harvest, AQUPOP, persons, if different than the total population. See B. Napier et al. Vol.2, pg. 3.23 for more detail.
Line 135:	The number of people drinking water from the contaminated source, DWPOP, persons, if different than the total population. See B. Napier et al. Vol.2, pg. 3.24 for more detail.
Line 136:	An option is available to consider the total population of foods in the assessment area. The flag for this option is on this line, EXPORT. See B. Napier et al. Vol.2, pg. 3.24 for more detail.
Lines 137 to 139:	Aquatic Food/Drinking Water editing header.
Line 140:	Flag for consideration of freshwater or marine bioaccumulation factors for the aquatic food pathways, ISALT.
Lines 141 to 142:	Drinking Water editing header.

Line 143:	Because GENII-A allows simultnaeous consideration of several sources of contamination (surface water and ground water), you need to indicate which source is to be used for drinking, DWSRC. See Napier et al. Vol.2, pp. 3.24 and 3.25 for more detail.
Line 144:	Flag to indicate whether drinking water is treated through a water treatment facility, DWTRET.
Line 145:	Holdup /transit time for drinking water before use (decay), HOLDDW; days.
Line 146:	Drinking water consumption rate, DWUSAG; liters/year.
Lines 147 to 155:	For each of the aquatic food types you select with the flag in the first column (AQF), several parameters must be entered. See B. Napier et al. Vol.2, pg. 3.24 for more detail.
Lines 156 to 161:	Terrestrial food ingestion editing header.
Line 162 to 165:	Input of terrestrial food parameters. See B. Napier et al. Vol.2, pg. 3.25 for more detail.
Line 166 to 173:	Animal production consumption editing header.
Line 174 to 180:	For each of the animal products you may select (flag ANF), several parameters must be entered to define the conditions under which the products are produced. See B. Napier et al. Vol.2, pp. 3.25 to 3.26 for more detail.

A.2 Sample Listing

```
1  ====GENII  Input  file=========10   -Oct  95==================SECTION  2=====
2                        test file sample3 genii alpha
3                            Created on 12 Oct-95
4  OPTIONS=========================DEFAULT============
5  F     Near-field scenario?
6  T     Population dose?
7  T     Acute release?
8        Maximum Individual data set used
9                                    Complete
10 TRANSPORT  OPTIONS============Section
11  T                        Air Transport
12  F              Surface Water Transport
13  F       Biotic Transport (near-field)
14  F       Waste Form Degradation (near)
15
16 REPORT  OPTIONS=======================
17  T          Report AEDE only
18  T          Report by radionuclide
19  T          Report by pathway
20  F          Debug Report
21                                  Complete
22 EXPOSURE  PATHWAY  OPTIONS=====  Section
23  F           Finite plume, external
24  T           Infinite plume, external
25  T                 Ground, external
26  F             Recreation, external
27  T                Inhalation uptake
28  F         Drinking water ingestion
29  F          Aquatic foods ingestion
30  T    Terrestrial foods ingestion
31  T       Animal product ingestion
32  F       Inadvertent soil ingestion
33
34 INVENTORY  ##############################################
35
36  4    Inventory input activity units: (1-pCi   2-uCi   3-mCi   4-Ci   5-Bq)
37  0    Surface soil source units (1- m2   2- m3   3- kg)2
38  8    Number of nuclides in source term
39
40        --------|----Release Terms------|----------Basic Concentrations---------|
41       Use when|   transport selected    |   near-field scenario, optionally
42        --------|-----------------------|-------------------------------------|
43       Release |          Surface Buried |          Surface Deep     Ground   Surface|
44       Radio-  |Air      Water    Waste  |Air      Soil      Soil     Water
45       nuclide |/yr      /yr      /m3    |/L       /unit    /m3      /L       /L      |
46        --------|------- ------- -------|------- ------- ------- ---------------
47       SM153     2.8E-04
48       EU154     6.8E-06
49       EU155     7.0E-06
50       EU156     7.8E-04
51       CO60      1.2E-06
52       CR51      2.9E-06
53       FE59      2.5E-06
54       FE55      3.0E-05
55 --------|----Derived  Concentrations-----|
56       Use when|    measured values are known    |
57       Release |Terres. Animal   Drink    Aquatic|
58       Radio-  |Plant   Product  Water    Food   |
59       nuclide |/kg     /kg      /l       /kg    |
60        --------|------- ------- ------- -------|
```

```
61
62 TIME  ##########################################
63
64    1. Intake ends after (yr)
65   50. Dose calc. ends after (yr)
66    1. Release ends after (yr)
67    0  No. of years of air deposition prior to the intake period
68    0  No. of years of irrigation water deposition prior to the intake period
69
70 FAR-FIELD  SCENARIOS  (IF  POPULATION  DOSE)  ######################################
71
72 2            Definition option: 1-Use population grid in filePOP.IN
73 1                          2-Use total entered on this line
74
75 NEAR-FIELD  SCENARIOS  ##########################################################
76
77              Prior to the beginning of the intake period: (yr)
78 0               When was the inventory disposed?  (Package degradation starts)
79 0               When was LOIC?  (Biotic transport starts)
80 0.0000      Fraction of roots in upper soil (top 15 cm)
81 0.0000      Fraction of roots in deep soil
82 0.0          Manual redistribution: deep soil/surface soil dilution factor
83 0.0          Source area for external dose modification factor (m2)
84 0.0          Source area for close examination dose factor (m2)
85 TRANSPORT  ##############################,#####################################
86            .     ====AIR TRANSPORT=======================,================SECTION 1=====
87                        0-Calculate PM
88 1           Option: 1-Use chi/Q or PM value
89                        2-Select MI dist & dir
90                        3-Specify MI dist & dir
91 6.8E-03    Chi/Q or PM value
92 0           MI sector index (1=S)
93 .000E+00   MI distance from release point (m)
94  1.0        Release height (m)
95 F           Use jf data, (T/F) else chi/Q grid
96
97                ====SURFACE WATER TRANSPORT==========================SECTION 2=====
98  0           Mixing ratio model: 0-use value, 1-river, 2-lake
99  0           Mixing ratio, dimensionless
100  0.00       Average river flow rate for: MIXFLG=0 (m3/s) MIXFLG=1,2 (m/s)
101  0.0        Transit time to irrigation withdrawl location (hr)
102             If mixing ratio model > 0:
103 EXPOSURE#######################################################################
104                ====EXTERNAL EXPOSURE==============================SECTION 5=====
105             Exposure time (hours):
106   0.        Plume (hr)
107  2920.0     Surrounding soil contamination duration (hr)
108  0.0        Examined soil contamination duration (hr)
109  0.0        Soil overburden depth (m)
110  0.0        Swimming (hr)
111  0.0        Boating (hr)
112  0.0        Shoreline activities (hr)
113  0.0           Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin
114  0.0           Transit time for release to reach aquatic recreation (hr)
115  1.0        Average fraction of time submersed in acute cloud (hr/person hr)
116
117             Residential irrigation;
118 T          Consider: (T/F)
119 0          Source: 1-ground water
120                    2-surface water
121 0.0       Application rate (in/yr)
122 0.0       Duration (mo/yr)
123                ====INHALATION=========================================SECTION 6=====
```

```
124 2920.0       Hours of exposure to contamination per year
125   0.0         0-No resus-  1-Use Mass Loading            2-Use Anspaugh model
126   0.0         pension       Mass loading factor (g/m^3)   Top soil available (cm)
127
128                 ====INGESTION POPULATION==========================SECTION 7=====
129  1              Atmospheric production option
130 .000E+00       0-Use food-weighted chi/Q, (kg-sec/m^3), enter value on this line
131                 1-Use population-weighted chi/Q
132                 2-Use uniform production
133                  3-Use chi/Q and production gridss (PRODUCTION will be overridden)
134 0              Population ingesting aquatic foods, 0 defaults to total (person)
135 0              Population ingesting drinking water, 0 defaults to total (person)
136 F               Consider dose from food exported out of region (default=F)
137                Note below: S* or Source: 0-none, 1-ground water, 2-surface water
138                                          3-Derived concentration entered above
139                ==== AQUATIC FOODS / DRINKING WATER INGESTION=========SECTION 8====
140 F             Salt water? (default is fresh)
141                   DRINKING WATER (Humans)
142                 -------------------
143 2          SOURCE (see above)
144 T          TREATMENT? T/F
145 1.0        HOLDUP/TRANSIT(da)
146 730.0      CONSUMPTION (L/yr)
147
148              USE          TRAN-  PROD-     -CONSUMPTION-
149              ?   FOOD     SIT    UCTION    HOLDUP  RATE
150              T/F TYPE     hr     kg/yr     da      kg/yr
151              --- ------   -----  -------   ------  -----
152              F   FISH      0.0   1.5E+04    1.00   40.0
153              F   MOLLUS     1.0  0.0E+00    0.00    0.0
154              F   CRUSTA     1.0  0.0E+00    0.00    0.0
155              F   PLANTS     1.0  0.0E+00    0.00    0.0
156 ====TERRESTRIAL FOOD INGESTION=======================SECTION 9=====
157
158              USE          GROW    --IRRIGATION--            PROD-     --CONSUMPTION--
159              ?   FOOD     TIME    S RATE    TIME     YIELD  UCTION    HOLDUP    RATE
160              T/F TYPE     da      * in/yr   mo/yr    kg/m2  kg/yr     da        kg/yr
161              --- ------   -  -----  -----    -----    -------  ------------
162              T   LEAF V 90.00  0  0.0       0.0      1.5    0.0E+0    14.0      15.0
163              T   ROOT V 90.00  0  0.0       0.0      4.0    0.0E+0    14.0      140.0
164              T   FRUIT  90.00  0  0.00      0.0      2.0    0.0E+00   14.0      64.0
165              T   GRAIN  90.00  0  0.0       0.0      0.8    0.0E+0    180.0     72.0
166
167                ====ANIMAL PRODUCTION CONSUMPTION===================SECTION 10====
168
169                ---HUMAN---- TOTAL    DRINK    -------------STORED FEED-------------
170 USE          CONSUMPTION  PROD-    WATER    DIET  GROW  -IRRIGATION--          STOR-
171 ?    FOOD    RATE  HOLDUP UCTION   CONTAM   FRAC- TIME  S RATE  TIME    YIELD AGE
172 T/F  TYPE    kg/yr  da    kg/yr    FRACT.   TION  da   * in/yr mo/yr   kg/m3 da
173 --- ------ ------ ----- ------ -------  ----  ----  - ----- -----  ----- -----
174 T    BEEF     70.0  34.0   0.00    0.0    0.0  90.00  0   0.0   0.0   0.80  0.0
175 T    POULTRY  8.5   34.0   0.00    0.0    0.0  90.00  0   0.0   0.0   0.80  0.0
176 T    MILK    230.0   4.0   0.00    0.0    0.0  45.00  0   0.0   0.0   2.00  0.0
177 T    EGG      20.0  18.0   0.00    0.0    0.0  90.00  0   0.0   0.0   0.80  0.0
178                                                 -------------FRESH FORAGE-----------
179      BEEF                                     0.00 45.00  2   0.0   0.0   2.00 100.0
180      MILK                                     0.00 30.00  2   0.0   0.0   1.50   0.0
181
182 ##############################################################################
183
```

Appendix B: Input Filenames File

```
FILENAME.DAT;18
 2        HOME$ROOT:[GENII.FILES]RMDLIB.DAT
 3        HOME$ROOT:[GENII.FILES]METADATA.DAT
 4        HOME$ROOT:[GENII.FILES]RMDBYELE.DAT
 8        HOME$ROOT:[GENII.FILES]FTRANS.DAT
 9        HOME$ROOT:[GENII.FILES]BIOAC1.DAT
10        HOME$ROOT:[GENII.FILES]GRDF.DAT
11        HOME$ROOT:[GENII.FILES]ENV.IN
12        HOME$ROOT:[GENII.FILES]DOSSUM.DAT
13        HOME$ROOT:[GENII.FILES]ENV.OUT
14        HOME$ROOT:[GENII.FILES]DOSE.OUT
15        HOME$ROOT:[GENII.FILES]INTDF.OUT
16        HOME$ROOT:[GENII.FILES]CDEINC.OUT
17        HOME$ROOT:[GENII.FILES]DITTY.OUT
18        HOME$ROOT:[GENII.FILES]INTDF.IN
19        HOME$ROOT:[GENII.FILES]DITTYQA.OUT
20        HOME$ROOT:[GENII.FILES]CDE.OUT
21        HOME$ROOT:[GENII.FILES]MEDIA.OUT
22        HOME$ROOT:[GENII.FILES]DEFAULT.IN
23        HOME$ROOT:[GENII.FILES]JOINTFRE.IN
24        HOME$ROOT:[GENII.FILES]CHIQ.IN
25        HOME$ROOT:[GENII.FILES]PLUMDRF.DAT
26        HOME$ROOT:[GENII.FILES]ENERGY.DAT
27        HOME$ROOT:[GENII.FILES]POP.IN
28        HOME$ROOT:[GENII.FILES]GENII2.OUT
30        HOME$ROOT:[GENII.FILES]DSFCT30.DAT
31        HOME$ROOT:[GENII.FILES]WATREL.IN
32        HOME$ROOT:[GENII.FILES]AIRREL.IN
33        HOME$ROOT:[GENII.FILES]DITTY.IN
34        HOME$ROOT:[GENII.FILES]ISOLIB.DAT
35        HOME$ROOT:[GENII.FILES]EXTDF.IN
36        HOME$ROOT:[GENII.FILES]EXTDF.OUT
37        HOME$ROOT:[GENII.FILES]DOSINC.OUT
38        HOME$ROOT:[GENII.FILES]GAMEN.DAT
39        HOME$ROOT:[GENII.FILES]DOSEQA.OUT
40        HOME$ROOT:[GENII.FILES]DOSINC.DAT
41        HOME$ROOT:[GENII.FILES]SEE.IN
42        HOME$ROOT:[GENII.FILES]FOODPROD.IN
44        HOME$ROOT:[GENII.FILES]SEERPT.OUT
45        HOME$ROOT:[GENII.FILES]SEE1.DAT
46        HOME$ROOT:[GENII.FILES]SEE2.DAT
47        HOME$ROOT:[GENII.FILES]SEE3.DAT
48        HOME$ROOT:[GENII.FILES]WORK.BUF
49        HOME$ROOT:[GENII.FILES]WORK2.BUF
50        HOME$ROOT:[GENII.FILES]WORK3.BUF
[End of file]
```

Appendix C: Sample Output Dose File

```
-----------------------------------------------------------------------------
                        GENII-A Dose Calculation Program
                           (Version 2.10 15-Dec-95)

 Case title:        Demonstration of CAMCON PREGENII/GENII interface

 Executed on:  01/19/96 at 12:22:33                                Page C.  4
-----------------------------------------------------------------------------

            Release period:                    1.0
            Uptake/exposure period:            1.0
            Dose commitment period:           50.0
            Dose units:                   Person rem


                      Committed                  Weighted
                         Dose      Weighting       Dose
        Organ        Equivalent   Factors      Equivalent
     -------------   ----------   --------     ----------
        Gonads         1.2E-01    2.5E-01      3.0E-02
        Breast         1.1E-01    1.5E-01      1.6E-02
        R Marrow       2.8E-01    1.2E-01      3.4E-02
        Lung           2.0E-01    1.2E-01      2.4E-02
        Thyroid        2.0E+02    3.0E-02      6.1E+00
        Bone Sur       2.3E+00    3.0E-02      6.8E-02
        Liver          3.7E-01    6.0E-02      2.2E-02
        LL Int.        9.9E-02    6.0E-02      5.9E-03
        Stomach        9.7E-02    6.0E-02      5.8E-03
        UL Int.        9.3E-02    6.0E-02      5.6E-03
        S Int.         9.0E-02    6.0E-02      5.4E-03
     ---------------------------------------------------
     Internal Effective Dose Equivalent          6.3E+00
     External Dose                               3.3E-02
     ---------------------------------------------------
     Annual Effective Dose Equivalent            6.3E+00


     ---------------------------------------------------
     Controlling Organ:                          Thyroid
     Controlling Pathway:                        Ing
     Controlling Radionuclide:                   I 129
     ---------------------------------------------------
     Total Inhalation EDE:                       1.6E-01
     Total Ingestion EDE:                        6.1E+00
     ---------------------------------------------------
-----------------------------------------------------------------------------
                        GENII-A Dose Calculation Program
                           (Version 2.10 15-Dec-95)

 Case title:        Demonstration of CAMCON PREGENII/GENII interface

 Executed on:  01/19/96 at 12:22:33                                Page C.  5
-----------------------------------------------------------------------------

 Release period:                                                     1.0
 Uptake/exposure period:                                             1.0
 Dose commitment period:                                            50.0
 Dose units:                                                    Person rem


              Dose Commitment Year
                   1         2         3     ...
             ____________________________
 Internal  : |
 Intake    : |
 Year:     3 |                     0.0E+00    ...
           | |                        +
           2 |           0.0E+00   0.0E+00    ...                Internal
           | |              +         +                         Effective
           1 | 5.5E+00 + 6.0E-01 + 6.8E-02 + ...  =  6.3E+00   Dose
                                                                Equivalent
                 ||        ||        ||
 Internal                                                       Cumulative
 Annual        5.5E+00 + 6.0E-01 + 6.8E-02 + ...  =  6.3E+00   Internal
 Dose                                                           Dose
                  +         +         +                 +
 External
```

Annual Dose	3.3E-02	0.0E+00	0.0E+00	...	3.3E-02	
	||	||	||		||	
Annual Dose	5.6E+00 +	6.0E-01 +	6.8E-02 +	... =	6.3E+00	Cumulative Dose
					5.6E+00	Maximum Annual Dose Occurred In Year 1

GENII-A Dose Calculation Program
(Version 2.10 15-Dec-95)

Case title: *Demonstration of CAMCON PREGENII/GENII interface*

Executed on: 01/19/96 at 12:22:33 Page C. 6

Release period:	1.0
Uptake/exposure period:	1.0
Dose commitment period:	50.0
Dose units:	Person rem

Committed Dose Equivalent by Exposure Pathway

Pathway	Lung	Stomach	S Int.	UL Int.	LL Int.	Bone Su	R Marro	Testes
Inhale	1.1E-01	4.9E-03	5.0E-03	5.7E-03	6.6E-03	2.1E+00	1.7E-01	3.3E-02
Leaf Veg	2.2E-03	2.5E-03	2.1E-03	2.5E-03	3.5E-03	1.4E-02	3.6E-03	2.2E-03
Oth. Veg	1.4E-02	1.4E-02	1.4E-02	1.4E-02	1.6E-02	3.6E-02	1.9E-02	1.4E-02
Fruit	6.0E-03	6.2E-03	5.9E-03	6.2E-03	6.8E-03	1.4E-02	7.9E-03	5.9E-03
Cereals	2.1E-02	2.2E-02	2.1E-02	2.2E-02	2.2E-02	3.7E-02	2.7E-02	2.1E-02
Meat	1.4E-02	1.4E-02	1.4E-02	1.4E-02	1.5E-02	1.7E-02	1.7E-02	1.4E-02
Poultry	1.4E-03	1.4E-03	1.4E-03	1.4E-03	1.4E-03	1.7E-03	1.7E-03	1.4E-03
Cow Milk	2.6E-02	2.9E-02	2.5E-02	2.5E-02	2.5E-02	3.1E-02	3.2E-02	2.4E-02
Eggs	2.6E-03	2.7E-03	2.6E-03	2.6E-03	2.6E-03	3.2E-03	3.3E-03	2.6E-03
Total	2.0E-01	9.7E-02	9.0E-02	9.3E-02	9.9E-02	2.3E+00	2.8E-01	1.2E-01

Pathway	Ovaries	Muscle	Thyroid	Kidneys	Liver	Spleen
Inhale	3.3E-02	4.9E-03	1.1E+00	1.5E-02	3.6E-01	1.0E-08
Leaf Veg	2.2E-03	3.0E-03	1.2E+01	2.0E-06	2.0E-03	6.5E-10
Oth. Veg	1.4E-02	1.5E-02	2.4E+01	3.4E-06	3.4E-03	1.1E-09
Fruit	6.0E-03	6.5E-03	7.6E+00	1.1E-06	1.1E-03	3.6E-10
Cereals	2.1E-02	2.2E-02	1.2E+01	1.8E-06	1.9E-03	2.2E-11
Meat	1.4E-02	1.5E-02	1.1E+01	1.7E-07	4.8E-06	7.3E-15
Poultry	1.4E-03	1.4E-03	4.5E-03	3.1E-08	4.2E-09	4.9E-17
Cow Milk	2.5E-02	3.5E-02	1.3E+02	1.0E-06	4.2E-07	3.1E-13
Eggs	2.6E-03	2.7E-03	1.2E+00	6.1E-08	5.0E-07	6.9E-16
Total	1.2E-01	1.1E-01	2.0E+02	1.5E-02	3.7E-01	1.2E-08

External Dose by Exposure Pathway

Pathway	
Plume	3.3E-02
Sur Soil	1.3E-04
Total	3.3E-02

GENII-A Dose Calculation Program
(Version 2.10 15-Dec-95)

Case title: *Demonstration of CAMCON PREGENII/GENII interface*

Executed on: 01/19/96 at 12:22:33 Page C. 7

Release period:	1.0
Uptake/exposure period:	1.0
Dose commitment period:	50.0
Dose units:	Person rem

Committed Dose Equivalent by Radionuclide

Radionuclide	Lung	Stomach	S Int.	UL Int.	LL Int.	Bone Su	R Marro	Testes
H 3	1.8E-02	1.8E-02	1.8E-02	1.8E-02	1.8E-02	2.2E-02	2.3E-02	1.8E-02
C 14	5.8E-02	5.8E-02	5.8E-02	5.8E-02	5.8E-02	7.2E-02	7.3E-02	5.8E-02
KR 85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
SR 90	8.5E-07	9.1E-07	1.4E-06	8.0E-06	3.3E-05	8.8E-04	3.9E-04	4.9E-07

Y 90	1.1E-07	1.9E-06	4.4E-06	2.2E-05	5.4E-05	8.5E-10	8.3E-10	2.8E-11
NB 95	1.3E-07	1.6E-08	2.6E-08	5.1E-08	1.1E-07	1.4E-08	1.1E-08	2.4E-09
RU 103	5.1E-06	3.0E-07	5.2E-07	1.5E-06	3.9E-06	1.2E-07	1.8E-07	7.5E-08
RH 103M	2.2E-09	1.2E-08	8.0E-09	4.6E-09	7.8E-10	4.8E-10	5.7E-11	2.5E-11
RU 106	3.3E-02	3.9E-04	6.6E-04	2.8E-03	8.2E-03	2.2E-04	2.4E-04	1.9E-04
SB 125	3.7E-05	2.7E-06	5.0E-06	1.4E-05	3.8E-05	5.6E-06	2.1E-06	6.5E-07
TE 125M	7.9E-08	3.0E-07	6.3E-07	2.8E-06	7.8E-06	2.2E-05	2.0E-06	6.5E-08
I 129	1.4E-02	1.9E-02	1.2E-02	1.2E-02	1.2E-02	1.5E-02	1.6E-02	1.1E-02
I 131	1.0E-06	2.5E-06	3.6E-07	3.6E-07	3.4E-07	1.4E-06	7.4E-07	3.0E-07
XE 131M	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
CS 134	4.3E-06	4.8E-06	5.6E-06	5.2E-06	5.6E-06	4.2E-06	4.8E-06	5.2E-06
CS 137	1.4E-05	1.5E-05	1.5E-05	1.5E-05	1.5E-05	1.4E-05	1.4E-05	1.5E-05
PM 147	1.2E-04	5.1E-07	1.3E-06	7.4E-06	2.3E-05	3.4E-05	2.7E-06	1.9E-10
SM 147	2.8E-17	5.9E-18	1.5E-17	8.5E-17	2.7E-16	1.1E-14	8.9E-16	1.3E-20
PB 212	5.2E-02	9.6E-04	1.1E-03	1.5E-03	1.6E-03	1.1E-01	9.3E-03	9.1E-04
BI 212	8.8E-03	9.3E-05	7.8E-05	6.5E-05	4.8E-05	6.5E-04	7.3E-05	4.3E-05
PU 238	8.7E-04	2.5E-07	5.6E-07	3.1E-06	9.1E-06	9.4E-02	7.6E-03	1.3E-03
U 234	9.5E-04	4.9E-08	6.9E-08	2.3E-07	6.2E-07	1.6E-05	1.0E-06	3.6E-08
U 238	8.5E-04	4.5E-08	6.3E-08	2.1E-07	5.9E-07	1.4E-05	9.5E-07	3.1E-08
TH 234	8.1E-10	8.0E-09	2.0E-08	1.2E-07	3.4E-07	1.7E-10	1.5E-10	1.9E-11
PA 234	2.0E-13	1.0E-11	1.9E-11	4.1E-11	3.3E-11	3.6E-13	1.1E-12	3.2E-13
PU 241	3.6E-05	2.6E-07	4.2E-07	1.7E-06	4.3E-06	2.1E-01	1.6E-02	3.1E-03
U 237	8.7E-12	9.3E-11	2.5E-10	1.1E-09	3.0E-09	1.2E-11	1.9E-11	4.0E-12
AM 241	2.9E-03	1.2E-06	2.2E-06	1.1E-05	3.2E-05	3.6E-01	2.8E-02	5.0E-03
PU 237	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
NP 237	3.2E-13	7.8E-14	1.8E-13	9.9E-13	2.9E-12	1.8E-09	1.5E-10	1.3E-11
PA 233	1.4E-16	1.1E-14	2.9E-14	1.3E-13	3.7E-13	4.0E-15	2.6E-15	7.7E-16
PU 239	1.1E-02	3.1E-06	7.0E-06	3.7E-05	1.1E-04	1.4E+00	1.1E-01	1.9E-02
U 235	3.1E-05	2.1E-09	2.5E-09	8.1E-09	2.4E-08	5.1E-07	3.3E-08	1.2E-09
TH 231	7.2E-12	7.0E-11	1.7E-10	7.0E-10	1.3E-09	1.0E-11	2.8E-12	2.1E-13
PA 231	1.2E-15	3.2E-15	7.7E-15	4.2E-14	1.3E-13	1.8E-10	1.4E-11	1.9E-16
AC 227	2.8E-18	2.5E-18	3.5E-18	1.8E-17	9.0E-17	7.9E-13	6.3E-14	9.3E-15
TH 227	1.1E-18	1.4E-17	3.5E-17	2.1E-16	7.8E-16	5.9E-16	4.8E-17	1.2E-18
FR 223	3.7E-19	4.0E-19	3.7E-19	3.7E-19	3.7E-19	4.0E-18	5.0E-19	3.7E-19

GENII-A Dose Calculation Program
(Version 2.10 15-Dec-95)

Case title: Demonstration of CAMCON PREGENII/GENII interface

Executed on: 01/19/96 at 12:22:33 Page C. 8

Release period: 1.0
Uptake/exposure period: 1.0
Dose commitment period: 50.0
Dose units: Person rem

Committed Dose Equivalent by Radionuclide

Radionuclide	Ovaries	Muscle	Thyroid	Kidneys	Liver	Spleen
H 3	1.8E-02	1.8E-02	1.8E-02	0.0E+00	0.0E+00	0.0E+00
C 14	5.8E-02	5.9E-02	5.8E-02	0.0E+00	0.0E+00	0.0E+00
KR 85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
SR 90	4.9E-07	4.9E-07	4.9E-07	0.0E+00	0.0E+00	0.0E+00
Y 90	3.1E-11	2.8E-11	2.8E-11	0.0E+00	8.2E-10	0.0E+00
NB 95	2.3E-08	8.7E-09	6.0E-09	8.3E-09	0.0E+00	1.2E-08
RU 103	3.4E-07	1.5E-07	1.1E-07	0.0E+00	0.0E+00	0.0E+00
RH 103M	4.3E-11	2.8E-11	2.5E-11	0.0E+00	0.0E+00	0.0E+00
RU 106	2.0E-04	1.9E-04	1.9E-04	0.0E+00	0.0E+00	0.0E+00
SB 125	3.5E-06	1.2E-06	7.6E-07	0.0E+00	2.7E-06	0.0E+00
TE 125M	2.2E-07	7.6E-08	6.5E-08	0.0E+00	0.0E+00	0.0E+00
I 129	1.2E-02	2.7E-02	2.0E+02	0.0E+00	0.0E+00	0.0E+00
I 131	3.3E-07	1.0E-06	3.7E-03	0.0E+00	0.0E+00	0.0E+00
XE 131M	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
CS 134	4.2E-06	4.2E-06	4.2E-06	0.0E+00	0.0E+00	0.0E+00
CS 137	1.4E-05	1.4E-05	1.4E-05	0.0E+00	0.0E+00	0.0E+00
PM 147	2.3E-10	2.4E-10	2.0E-10	0.0E+00	8.9E-06	0.0E+00
SM 147	1.3E-20	1.3E-20	1.3E-20	0.0E+00	3.1E-15	0.0E+00
PB 212	9.1E-04	9.1E-04	9.1E-04	7.5E-03	1.4E-02	0.0E+00
BI 212	4.3E-05	4.3E-05	4.3E-05	7.0E-03	0.0E+00	0.0E+00
PU 238	1.3E-03	4.9E-08	4.8E-08	0.0E+00	1.7E-02	0.0E+00
U 234	3.6E-08	3.6E-08	3.6E-08	6.4E-06	0.0E+00	0.0E+00
U 238	3.2E-08	3.3E-08	3.3E-08	5.8E-06	0.0E+00	0.0E+00
TH 234	2.3E-10	2.7E-11	2.4E-12	0.0E+00	3.3E-11	0.0E+00
PA 234	4.5E-12	6.7E-13	2.5E-14	1.1E-12	8.0E-13	0.0E+00
PU 241	3.1E-03	2.0E-07	8.4E-08	0.0E+00	3.2E-02	0.0E+00
U 237	6.3E-11	6.0E-12	9.3E-14	1.0E-11	0.0E+00	0.0E+00
AM 241	4.9E-03	4.9E-07	2.8E-07	0.0E+00	6.4E-02	0.0E+00
PU 237	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
NP 237	1.3E-11	1.3E-14	9.7E-15	0.0E+00	7.9E-11	0.0E+00
PA 233	9.2E-15	9.9E-16	1.8E-17	1.2E-15	8.8E-16	0.0E+00
PU 239	1.9E-02	6.0E-07	5.9E-07	0.0E+00	2.4E-01	0.0E+00
U 235	1.3E-09	1.6E-09	1.4E-09	2.1E-07	0.0E+00	0.0E+00
TH 231	7.7E-12	5.4E-13	2.2E-14	0.0E+00	4.3E-13	0.0E+00
PA 231	4.0E-16	3.0E-16	2.5E-16	1.7E-14	1.1E-14	0.0E+00
AC 227	9.5E-15	1.8E-18	9.7E-19	0.0E+00	1.8E-13	0.0E+00
TH 227	2.5E-18	1.2E-18	1.0E-18	0.0E+00	9.3E-18	0.0E+00

FR 223	3.9E-19	3.7E-19	3.7E-19	0.0E+00	0.0E+00	0.0E+00

GENII-A Dose Calculation Program
(Version 2.10 15-Dec-95)

Case title: Demonstration of CAMCON PREGENII/GENII interface

Executed on: 01/19/96 at 12:22:33 Page C. 9

Release period: 1.0
Uptake/exposure period: 1.0
Dose commitment period: 50.0
Dose units: Person rem

Committed Dose Equivalent by Radionuclide

Radionuclide	Lung	Stomach	S Int.	UL Int.	LL Int.	Bone Su	R Marro	Testes
RA 223	9.0E-17	1.4E-16	1.9E-16	6.9E-16	1.9E-15	8.2E-15	5.7E-16	9.0E-17
Total	2.0E-01	9.7E-02	9.0E-02	9.3E-02	9.9E-02	2.3E+00	2.8E-01	1.2E-01

GENII-A Dose Calculation Program
(Version 2.10 15-Dec-95)

Case title: Demonstration of CAMCON PREGENII/GENII interface

Executed on: 01/19/96 at 12:22:33 Page C. 10

Release period: 1.0
Uptake/exposure period: 1.0
Dose commitment period: 50.0
Dose units: Person rem

Committed Dose Equivalent by Radionuclide

Radionuclide	Ovaries	Muscle	Thyroid	Kidneys	Liver	Spleen
RA 223	9.0E-17	9.0E-17	8.2E-17	0.0E+00	0.0E+00	0.0E+00
Total	1.2E-01	1.1E-01	2.0E+02	1.5E-02	3.7E-01	1.2E-08

GENII-A Dose Calculation Program
(Version 2.10 15-Dec-95)

Case title: Demonstration of CAMCON PREGENII/GENII interface

Executed on: 01/19/96 at 12:22:33 Page C. 11

Release period: 1.0
Uptake/exposure period: 1.0
Dose commitment period: 50.0
Dose units: Person rem

Radio-nuclide	Inhalation Effective Dose Equivalent	Ingestion Effective Dose Equivalent	External Dose	Internal Effective Dose Equivalent	Annual Effective Dose Equivalent
H 3	2.7E-03	1.5E-02	0.0E+00	1.8E-02	1.8E-02
C 14	8.9E-04	5.6E-02	0.0E+00	5.7E-02	5.7E-02
KR 85	0.0E+00	0.0E+00	3.3E-02	0.0E+00	3.3E-02
SR 90	1.7E-05	5.8E-05	2.9E-10	7.6E-05	7.6E-05
Y 90	2.6E-08	4.9E-06	1.5E-08	4.9E-06	4.9E-06
NB 95	2.4E-08	1.4E-08	1.6E-08	3.8E-08	5.4E-08
RU 103	7.7E-07	3.5E-07	2.3E-07	1.1E-06	1.4E-06
RH 103M	4.0E-10	1.4E-09	1.0E-10	1.8E-09	1.9E-09
RU 106	4.0E-03	7.2E-04	4.4E-05	4.8E-03	4.8E-03
SB 125	5.5E-06	4.3E-06	5.3E-06	9.7E-06	1.5E-05
TE 125M	1.1E-09	1.7E-06	4.8E-09	1.7E-06	1.7E-06
I 129	3.3E-02	6.1E+00	7.6E-05	6.1E+00	6.1E+00
I 131	2.6E-06	1.1E-04	3.1E-07	1.1E-04	1.1E-04
XE 131M	0.0E+00	0.0E+00	2.1E-11	0.0E+00	2.1E-11
CS 134	1.8E-07	4.3E-06	1.8E-07	4.5E-06	4.7E-06
CS 137	5.1E-07	1.3E-05	3.0E-07	1.4E-05	1.4E-05
PM 147	1.7E-05	1.8E-06	9.4E-11	1.9E-05	1.9E-05
SM 147	7.5E-17	5.7E-16	0.0E+00	6.5E-16	6.5E-16
PB 212	1.2E-02	4.7E-09	5.9E-06	1.2E-02	1.2E-02
BI 212	1.5E-03	1.1E-10	5.1E-05	1.5E-03	1.6E-03
PU 238	5.1E-03	1.2E-04	1.8E-11	5.2E-03	5.2E-03
U 234	1.1E-04	8.0E-07	2.2E-12	1.2E-04	1.2E-04
U 238	1.0E-04	7.3E-07	1.2E-12	1.0E-04	1.0E-04
TH 234	1.2E-10	2.9E-08	4.6E-10	3.0E-08	3.0E-08

PA 234	9.3E-16	7.7E-12	7.0E-11	7.7E-12	7.8E-11
PU 241	1.1E-02	2.5E-04	1.4E-15	1.1E-02	1.1E-02
U 237	1.6E-12	2.9E-10	3.2E-14	2.9E-10	2.9E-10
AM 241	1.9E-02	4.5E-04	6.3E-09	1.9E-02	1.9E-02
PU 237	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
NP 237	3.3E-12	7.8E-11	8.8E-20	8.1E-11	8.1E-11
PA 233	1.2E-19	3.5E-14	3.7E-14	3.5E-14	7.2E-14
PU 239	7.4E-02	1.8E-03	2.7E-10	7.6E-02	7.6E-02
U 235	3.7E-06	2.7E-08	6.7E-11	3.7E-06	3.7E-06
TH 231	2.2E-12	1.3E-10	4.0E-12	1.3E-10	1.4E-10
PA 231	1.8E-14	7.1E-12	2.7E-16	7.2E-12	7.2E-12
AC 227	0.0E+00	4.5E-14	7.7E-21	4.5E-14	4.5E-14
TH 227	0.0E+00	8.7E-17	6.7E-18	8.7E-17	9.4E-17

GENII-A Dose Calculation Program
(Version 2.10 15-Dec-95)

Case title: Demonstration of CAMCON PREGENII/GENII interface

Executed on: 01/19/96 at 12:22:33 Page C. 12

Release period: 1.0
Uptake/exposure period: 1.0
Dose commitment period: 50.0
Dose units: Person rem

Radio-nuclide	Inhalation Effective Dose Equivalent	Ingestion Effective Dose Equivalent	External Dose	Internal Effective Dose Equivalent	Annual Effective Dose Equivalent
FR 223	0.0E+00	4.8E-19	4.0E-20	4.8E-19	5.2E-19
RA 223	0.0E+00	5.4E-16	1.8E-17	5.4E-16	5.6E-16

Appendix D: Sample Output Input Echo File

```
-----------------------------------------------------------------------------
                        GENII-A Dose Calculation Program
                           (Version 2.10 15-Dec-95)

 Case title:        Demonstration of CAMCON PREGENII/GENII interface

 Executed on:  01/19/96 at 12:22:33                                Page     1
 -----------------------------------------------------------------------------

          This is a far-field (wide-scale release, multiple site) scenario.
          Release is chronic
          Dose to exposed population of  3.409E+05

          THE FOLLOWING TRANSPORT MODES ARE CONSIDERED
               Air

          THE FOLLOWING EXPOSURE PATHS ARE CONSIDERED:
               Finite plume, external
               Ground, external
               Inhalation uptake
               Terrestrial foods ingestion
               Animal product ingestion

          THE FOLLOWING TIMES ARE USED:
               Intake ends after (yr):                  1.0
               Dose calculations ends after (yr):      50.0
               Release ends after (yr):                 1.0

========== FILENAMES AND TITLES OF FILES/LIBRARIES USED ======================

 Input file name:       sample1  is name of GENI
 GENII Default Parameter Values (28-Mar-90 RAP)
 Radionuclide Master Library - Long Times  (23-July-93 PDR)
 PNL Food Transfer Factor Library (by Z, with Fr&Os 7/19/93 PDR)
 External Dose Factors for GENII-Sphere source modification BAN 5/19/
 Worst-Case Solubilities, Yearly Dose Increments (23-Jul-93 PDR)
 EXTGAM - Gamma Energies by Group for Finite Plume (13-May-90 RAP)
 200 Area Population (Sommer, Rau, and Robinson, PNL-4010)
 200 AREA - 89 M - Pasquill A - F (1983 - 1987 Average)

==============================================================================

          -------- ----Release Terms------
          Release          Surface Buried
          Radio-   Air     Water   Source
          nuclide  Ci/yr   Ci/yr   Ci/m3
          -------- ------- ------- -------
          H 3      7.0E+01 0.0E+00 0.0E+00
          C 14     1.0E+00 0.0E+00 0.0E+00
          KR85     7.0E+04 0.0E+00 0.0E+00
          SR90     2.0E-04 0.0E+00 0.0E+00
          NB95     1.0E-05 0.0E+00 0.0E+00
          RU103    2.0E-04 0.0E+00 0.0E+00
          RU106    2.0E-02 0.0E+00 0.0E+00
          SB125    1.0E-03 0.0E+00 0.0E+00
I 129    5.0E-01 0.0E+00 0.0E+00
          I 131    2.0E-04 0.0E+00 0.0E+00
          CS134    1.0E-05 0.0E+00 0.0E+00
          CS137    4.0E-05 0.0E+00 0.0E+00
          PM147    1.0E-03 0.0E+00 0.0E+00
          PB212    2.0E-02 0.0E+00 0.0E+00
          BI212    1.0E-01 0.0E+00 0.0E+00
          U 234    2.0E-06 0.0E+00 0.0E+00
          U 235    7.0E-08 0.0E+00 0.0E+00
          U 238    2.0E-06 0.0E+00 0.0E+00
          PU238    3.0E-05 0.0E+00 0.0E+00
          PU241    3.0E-03 0.0E+00 0.0E+00
          AM241    1.0E-04 0.0E+00 0.0E+00
          PU239    4.0E-04 0.0E+00 0.0E+00

========== AIR TRANSPORT ======================================================
          Joint frequency data input.
8.9E+01   Stack height (m)
0.0E+00   Stack flow (m3/s)
0.0E+00   Stack radius (m)
0.0E+00   Effluent temperaure (degrees C)

========== EXTERNAL EXPOSURE ==================================================
 8.8E+03  Hours of exposure to plume
 2.9E+03  Hours of exposure to ground contamination

========== INHALATION =========================================================
 8.8E+03  Hours of inhalation exposure per year
          Resuspension not considered
```

========== INGESTION POPULATION ==========

1 Atmospheric production definition: 1 - Use population-weighted chi/Q
Food production in region assumed to equal consumption.

========== TERRESTRIAL FOOD INGESTION ==========

FOOD TYPE	GROW TIME d	S *	--IRRIGATION-- RATE in/yr	TIME mo/yr	YIELD kg/m2	PROD-UCTION kg/yr	--CONSUMPTION-- HOLDUP d	RATE kg/yr
Leaf Veg	90.0	0	0.0	0.0	1.5		14.0	1.5E+01
Oth. Veg	90.0	0	0.0	0.0	4.0		14.0	1.4E+02
Fruit	90.0	0	0.0	0.0	2.0		14.0	6.4E+01
Cereals	90.0	0	0.0	0.0	0.8		180.0	7.2E+01

========== ANIMAL FOOD INGESTION ==========

FOOD TYPE	---HUMAN---- CONSUMPTION RATE kg/yr	HOLDUP d	TOTAL PROD-UCTION kg/yr	DRINK WATER CONTAM FRACT.	DIET FRAC-TION	STORED FEED---------- GROW TIME d	S *	-IRRIGATION-- RATE in/yr	TIME mo/yr	YIELD kg/m3	STOR-AGE d
Meat	7.0E+01	34.0		0.00	0.3	90.00	0	0.0	0.0	0.80	180.0
Poultry	8.5E+00	34.0		0.00	1.0	90.00	0	0.0	0.0	0.80	180.0
Cow Milk	2.3E+02	4.0		0.00	0.3	45.00	0	0.0	0.0	2.00	100.0
Eggs	2.0E+01	18.0		0.00	1.0	90.00	0	0.0	0.0	0.80	180.0
----------FRESH FORAGE----------											
Meat					0.75	45.0	0	0.0	0.0	2.00	100.0
Cow Milk					0.75	30.0	0	0.0	0.0	1.50	0.0

==========

Input prepared by: _____ Date: _____

Input checked by: _____ Date: _____

==========

Appendix E: Sample Diagnostics/Debug File

```
GENII-A C-2.10 PROD PA96 01/16/96                                01/19/96 12:22:33

          GGGGG   EEEEEEE  N    NN    IIII     IIII            AAAAA
         GG   GG  EE       NN   NN     II       II            AA   AA
         GG       EE       NNN  NN     II       II            AA   AA
         GG       EEEEE    NN N NN     II       II    -------  AAAAAAA
         GG  GGG  EE       NN  NNN     II       II            AA   AA
         GG   GG  EE       NN   NN     II       II            AA   AA
          GGGGG   EEEEEEE  NN    N    IIII     IIII            AA   AA

                A program for generating doses, GENII

                      GENII-A Version C-2.10
                        Revised 12-15-95
                  Written by Bruce Napier et al
                      Sponsored by Leo Rahal

                    Run on 01/19/96 at 12:22:33
                  Run on ALPHA AXP BEATLE OpenVMS V6.1
            Using GENII-A_PA96 PROD PA96 built 01/16/96

          ************************************************************

          Prepared for
          Sandia National Laboratories
          Albuquerque, New Mexico 87185-5800
          for the United States Department of Energy
          under Contract DE-AC04-76DP00789

          ************************************************************

                                Disclaimer
                                ----------

          This computer program was prepared as an account of work
          sponsored by an agency of the United States Government.
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          expressed herein do not necessarily state or reflect those
          of the United States Government, any agency thereof or any
          of their contractors or subcontractors.

          ************************************************************

*****************************************************************************

FILE ASSIGNMENTS:
-----------------
Input Text File:
   WP$TESTROOT:[GI2.TEST]GI2_TEST1_TRN.INP;1
      Written on 11/21/95 14:15:12
Input Filenames File:
   WP$TESTROOT:[GI2.DAT]GI2_FILENAME.DAT;1
      Written on 10/19/95 14:42:19
Output dose file:
   WP$TESTROOT:[GI2.TEST]GI2_TEST1_TRN.OUT
Output input echo file:
   WP$TESTROOT:[GI2.TEST]GI2_TEST1_ECO.OUT
Output Diagnostics/Debug File:
   WP$TESTROOT:[GI2.TEST]GI2_TEST1_DBG.OUT
CHECK:  stack release not set, stack height set to 89.0
REDSET:  Internal dose factors not found for XE131M
```

Appendix F: Review Forms

This appendix contains review forms for the GENII-A User's Manual.

NOTE: Copies of the User's Manual Reviewer's Forms are available in the Sandia WIPP Central Files.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix GTMP

M

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Geotechnical Monitoring Plan

M

WP 07-1, Rev. 1

Waste Isolation Pilot Plant Geotechnical Engineering Quality Assurance Program

Cognizant Section: Geotechnical Engineering

Approved By: C E Lowrey

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WIPP GEOTECHNICAL ENGINEERING QA PROGRAM

WP 07-1, Rev. 1

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List of Attachments

Attachment	Title
1	Room 1, Panel 1, Roof Support Instrumentation Inspection Data Sheet

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WIPP GEOTECHNICAL ENGINEERING QA PROGRAM

WP 07-1, Rev. 1

List of Acronyms

C&C - Consultation and Cooperation
DOE - Department of Energy
EES - Excavation Effects Survey
EPA - Environmental Protection Agency
LTCs - Local Termination Cabinets
MOC - Managing and Operating Contractor
QA - Quality Assurance
PRS - Project Records Storage
RIDS - Records Inventory and Disposition Schedule
SNL - Sandia National Laboratories
SPDV - Site Preliminary Design Validation
TDR - Time Domain Reflectometry
TRU - Transuranic
WID - Waste Isolation Division
WIPP - Waste Isolation Pilot Plant
WP - WIPP Procedure
WPSO - WIPP Project Site Office

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WIPP GEOTECHNICAL ENGINEERING QA PROGRAM

WP 07-1, Rev. 1

Change History

Pages iv, vi, vii, viii, 4-8, Att. 1 (add information for RCRA required inspections of Room 1, Panel 1, roof support instrumentation) - 07/15/93; Pages i, ix, and x - 06/10/94

06-10-94

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FOREWORD

This document is a quality assurance project plan (QAPjP) applying to WID environmental data operations (EDOs). As such, its purpose is to define the applicability of the WID quality management system, as described in WP 13-1, to the specific technical activities described within the scope of this plan. Implementation of this plan shall be in accordance with, and subject to the requirements of the quality assurance requirements as prescribed in WP 13-1. Independent assessment of the effectiveness of the activities described in this plan shall be scheduled and performed by the WID Q&RA Department.

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1.0 INTRODUCTION

The WIPP Geotechnical Engineering Program is designed to (1) provide geologic information necessary to establish a high level of understanding of site characteristics and (2) provide assessments of the stability and performance of underground openings. The Geotechnical Engineering Program currently consists of the following three activities:

1. Geomechanical Monitoring Program
2. Geology Program
3. Excavation Effects Program

These programs are implemented and controlled by individual program plans and operating procedures. The program plans are included in Sections 3 through 5.

1.1 Geomechanical Monitoring Program

The Geomechanical Monitoring Program monitors for geotechnical parameters with geomechanical instruments installed in the shafts and drifts of the WIPP facility. Geomechanical instrumentation found in the shafts and the underground presently includes: tape extensometer stations, convergence meters, borehole extensometers, piezometers, embedment strain gages, stress gages, inclinometers, load cells, and crackmeters.

The instrumentation system provides data on the WIPP geotechnical performance design for design validation, routine evaluation of the safety and stability of excavation, and of the short-term and long-term behavior of underground openings. Data on the stability and closure of underground excavations are used to identify areas of potential instability and allow for remedial action to be taken in a timely manner.

1.2 Geology Program

The activities associated with the Geology Program include geologic and fracture mapping, maintenance of a geologic (core) sample storage facility, seismic monitoring and evaluation, and other special activities that are performed on an as-needed basis. The purpose of the Geology Program is to provide input to help confirm the suitability of the site to contain and isolate TRU radioactive waste.

1.3 Excavation Effects Program

The Excavation Effects Program was initiated to gain a better understanding of fracture development around excavations in salt. The program consists of routine inspections of selected borehole arrays. These observations help to detect and quantify the occurrences of discontinuities such as fractures and bed separations, which result from the excavation of the underground openings.

Technical implementation of these programs is controlled by the Field Program Plans that are discussed in Sections 3 through 5 and the unique operating procedures listed in Table 1-1.

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Table 1-1

WIPP GEOTECHNICAL AND GEOSCIENCES PROCEDURES MANUAL

Geomechanical Monitoring Program Plan WP 07-3

WP 07-301	Manually Acquired Geomechanical Instrument Data
WP 07-302	Automatically Acquired Geomechanical Instrument Data
WP 07-303	Geomechanical Instrument Data Processing
WP 07-304	Installing Convergence Reference Points
WP 07-305	Installing Multiposition Borehole Rod Extensometers
WP 07-306	Installing Rock Bolt Load Cells
WP 07-307	Installing Convergence Meters
WP 07-312	Manually Reading Wire Convergence Meters
WP 07-313	Operation of Gyra-Vib Separator Salt Screening Plant
WP 07-315	Data Collection from Boreholes for Excavation Effects Monitoring
WP 07-410	WIPP BSEP Collection and Inflow Measurements
WP 07-413	Brine Chemistry Sampling and Analyses

Geology Program Plan WP 07-5

WP 07-501	Geologic and Fracture Mapping of the Facility Horizon Drifts
WP 07-502	Geologic Rock Core Logging
WP 07-503	Geologic Mapping of Shafts
WP 07-504	WIPP Project Core Storage, Handling, and Distribution

Excavation Effects Program

WP 07-315	Data Collection from Boreholes for Excavation Effects Monitoring

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2.0 QUALITY ASSURANCE REQUIREMENTS

The objective of Section 2.0, Quality Assurance Requirements, is to establish the specific quality assurance requirements associated with the Geotechnical Engineering QA Program. Those quality assurance requirements are driven by, and are supplemental to, WP 13-1, WID Quality Assurance Program Description, and implementing WIPP Quality Assurance procedures.

The basic 18 requirements that are defined in ASME NQA-1-1989, Quality Assurance Program Requirements for Nuclear Facilities, and their application to the Geotechnical Engineering QA Program are discussed in the following sections.

2.1 Organization

2.1.1 Organizational Structure

The organizational structure of the WID is described in Section 2.0 of WP 13-1. The Geotechnical Engineering Program is the responsibility of the Engineering department.

2.1.2 Quality Assurance Responsibilities for the Geotechnical Engineering QA Program

Quality Assurance provides independent oversight of the Geotechnical Engineering Program to verify that quality objectives are defined and achieved. The Quality Assurance Manager reports directly to the WID General Manager, and is therefore sufficiently removed from the cost and schedule concerns of Geotechnical Engineering. The Quality Assurance Manager has been delegated authority and given organizational freedom by the WID General Manager to access work areas, identify quality problems, initiate or recommend corrective actions, verify implementation of corrective actions, and to ensure that work is controlled or stopped until adequate disposition of an unsatisfactory condition has been implemented. The independence and delegated authority of the Quality Assurance Manager ensures that objective independent assessments of the quality of the performance of the Geotechnical Engineering Program can be achieved.

It is the responsibility of the Geotechnical Engineering Manager to ensure that basic qualifications for Geotechnical Engineering personnel are met. A spectrum of expertise ranging from basic qualifications to specialized knowledge in different areas of engineering would be expected among the Geotechnical Engineering staff. The essential levels of qualification required for Geotechnical Engineering personnel follows:

- Engineer (Sr. Level): The required technical capabilities are basic engineering skills and knowledge of project budgeting, scheduling and regulatory agreements, procurement, and dealing with subcontractors (B.S. degree in a technical field plus eight years experience). The person must demonstrate an ability to plan, coordinate, and manage a broad range of engineering activities given only general objectives and minimal direction and to coordinate engineering activities and designs with other site participants. The engineer should be innovative in dealing with constantly changing budgets, schedules, and priorities.

- Associate Engineer: The required technical capabilities are in areas of mechanical design and equipment maintenance (B.S. degree and two

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years experience preferred). The person must demonstrate good organizational abilities with the capability to develop and maintain an equipment control and maintenance program and an understanding of safety-related activities.

- Senior Technician: The required technical capabilities include an academic or high school diploma, and a minimum of four or five years technical experience, with a minimum of two years as an engineering technician. The person must be capable of providing guidance and work assignments to lower classified technicians and have the ability to exercise judgement, initiative, and interpretation to achieve desired results. This individual must also demonstrate the ability to work reliably and efficiently with little or no supervision after receiving training.

- Technician: The required technical capabilities include a high school diploma or equivalent. Two years of field experience is preferred. This individual must demonstrate the ability to learn a wide variety of tasks, work reliably and efficiently with little or no supervision after receiving training, and demonstrate manual dexterity applicable to handling various types of mechanical equipment.

The Geotechnical Engineering Manager ensures that position descriptions for assigned Geotechnical Engineering personnel are adequately prepared and shall include position purpose, principal responsibilities, nature of work, and scope.

The Geotechnical Engineering Manager conducts an annual performance review of personnel according to Westinghouse requirements for personnel review.

New Geotechnical Engineering personnel selected to perform geotechnical activities shall have experience or training that corresponds with the scope and complexity of the activities. Personnel shall be well informed of the technical objectives and requirements of applicable codes and Quality Assurance Program elements that are to be employed.

Formal training shall be conducted as required by a subject matter expert qualified under WP 14-TR3308 in geotechnical instrumentation. On-the-job training shall be included in the training to the extent necessary to gain first-hand experience and a qualification card. The qualification card shall be prepared by the subject matter expert or cognizant Geotechnical Engineering personnel responsible for new employee qualification. Qualification cards shall be retained in Technical Training department files.

NOTE: No employee shall be allowed to conduct an unsupervised specific Geotechnical Engineering activity without a qualification card on the specific activity by a subject matter expert in Geotechnical Engineering.

The performance of qualified personnel shall be evaluated and documented every three years. The Geotechnical Engineering Manager shall determine the need for retraining of Geotechnical Engineering personnel.

The need for retraining may be noted by Quality Assurance during any surveillance or audit or during a periodic review initiated by the cognizant professional or Geotechnical Engineering Manager.

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The Geotechnical Engineering Manager ensures that documents detailing all staff training are up to date and properly filed. Copies of all training records shall be given to the Training department.

2.1.3 Engineering Responsibilities and Authorities

The Geotechnical Engineering Manager and staff are responsible for achieving and maintaining quality in the Geotechnical Engineering Program. Job descriptions shall be maintained for the Geotechnical Engineering Manager, professional, technical, and administrative staff positions. The Manager of Geotechnical Engineering reports to the Manager of Advanced Repository Technology and has responsibility for the design and implementation of the Geotechnical Engineering QA Program, including the following areas:

- Preparation and approval of technical plans and the Quality Assurance section and the technical sections of the Geotechnical Engineering QA Program
- Development and approval of specific WIPP procedures for the conduct of Geotechnical Engineering activities
- Establishment of minimum qualification criteria and training requirements for all program personnel
- Review and approval of programmatic reports and documents
- Preparation of the budget and schedules for the Geotechnical Engineering department
- Determination of the effect of, and the appropriateness of reporting nonconformances, and providing the appropriate documentation for any reporting
- Notification of Geotechnical Engineering and Quality Assurance personnel of nonconformances and changes that could affect the quality of work

Geotechnical Engineering shall review and approve all Geotechnical Engineering Program data prior to release.

For each technical program, the Geotechnical Engineering Manager may appoint a Geotechnical Engineering Cognizant Engineer, who will have the following responsibilities:

- Direction of the Geotechnical Engineering Program per written approved procedures
- Initiation and review of programmatic plans and procedures
- Review and evaluation of instrumentation data
- Preparation and review of programmatic reports
- Ensuring that appropriate readings are collected and analyzed
- Ensuring that adequate technical support is provided to the Quality Assurance department when required, during audits of vendor facilities

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The Geotechnical Engineering Manager designates one or more associate engineers or technicians who will be responsible for the following items:

- Collecting instrumentation readings
- Assisting the cognizant engineer in the preparation and maintenance of appropriate data sheets and documentation
- Monitoring equipment operability status
- Reporting equipment malfunctions
- Reporting nonconformances to the cognizant engineer or Geotechnical Engineering Manager
- Initiating data checks
- Conducting field activities in accordance with written procedures

2.2 Quality Assurance Program

The WIPP Geotechnical Engineering QA Program is governed by WP 13-1. The Quality Assurance Program used by the WID is described in Section 2.0 of WP 13-1. Steps to ensure quality shall be incorporated, as needed, in the technical procedures used for Geotechnical Engineering activities. The Geotechnical Engineering Manager, or assigned designee, is responsible for developing and maintaining the Geotechnical Engineering QA Program and Geotechnical Engineering procedures. In accordance with the Sections 2.0 and 3.0 of WP 13-1, Geotechnical Monitoring is a Quality Code I activity.

2.3 Design Control

The Design Control requirements are described in Section 3.0 of WP 13-1. The Geotechnical Engineering Program will adhere to all applicable portions of these requirements when performing design activities.

2.4 Procurement Document Control

Procurement shall be carried out in accordance with the appropriate policies and procedures, as outlined in Section 4.0 of WP 13-1 and WP 15-609, Planning, Preparation, and Processing of Purchase Requisitions and Purchase Requisition Change Notices. WP 13-1 and WP 15-609 require specification of a quality code and design class, and concurrence by the Quality Assurance department with procurement documents. The requester shall also specify which Quality Assurance clauses, from the checklist in WP 15-609, are applicable to each Geotechnical Engineering procurement. Technical requirements for procured items and services shall be developed and specified in procurement documents. If deemed necessary, procurement documents shall require suppliers to have an adequate quality assurance program to ensure that required characteristics are attained.

2.5 Instructions, Procedures, and Drawings

Provisions and responsibilities for the preparation and use of instructions and procedures are outlined in the Section 5.0 of WP 13-1. Quality-affecting activities performed by, or on behalf of the Geotechnical Monitoring Program shall be performed in accordance with written plans or approved procedures. They

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shall contain the applicable provisions outlined in Section 9.0, paragraph 2.1.1, of WP 13-1. WIPP general procedures for procurement, document control, and Quality Assurance auditing currently exist and shall be utilized.

Technical procedures shall be developed for each quality-affecting function performed for Geotechnical Monitoring. The procedures shall include in-process and final quality controls and documentation requirements. The procedures shall be as detailed as required and include, when applicable, quantitative or qualitative acceptance criteria to determine that activities have been satisfactorily accomplished. Procedures shall be developed in accordance with existing WIPP procedures. The standard format used for procedure preparation is outlined in WP 15-101, Preparing, Revising, Reviewing, and Canceling Procedures.

2.6 Document Control

Requirements for the control of documents are outlined in Section 6.0 of WP 13-1. Controls ensure that the latest approved versions of procedures are used in performing geotechnical monitoring functions, and that obsolete materials are removed from work areas.

Geotechnical Engineering shall establish documented procedures that define the preparation, approval, and issue requirements for documents which are being used for Geotechnical Engineering activities. As a minimum, the procedures shall include:

- Identification of the required document format
- Identification of the individuals or organization responsible for the preparation, review, approval, and distribution of documents
- Provisions for documents to be reviewed by appropriate WID technical support departments
- Provisions for Quality Assurance review and approval of all quality-related documents
- Provisions for document changes other than obvious typographical errors to be controlled in the same manner as the original document

Geotechnical Engineering is responsible for documentation of the following:

- Engineering Calculations Briefs: Geotechnical Engineering data used in calculations is sometimes acquired from previous reports. The results of work must be completely documented to provide evidence of source, work performance, and quality.
- Field Investigations, Testing and Sampling: Geotechnical Engineering shall document project name, participating personnel, date, time, calibrated equipment used, activity location, and when necessary, unusual conditions encountered. As part of field investigations, photographs in color may be taken for documentation.
- Laboratory Testing: Geotechnical Engineering is responsible for documenting initial data, collected data, and the results of laboratory test plans. Each test document shall include:

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- Project name
- Type of observation
- Identification of test personnel
- Testing date
- Identification of calibrated equipment used
- Identification and description of sample(s) tested
- Test data and any subsequent data reduction
- Test results in the form of tables and curves
- Action taken in connection with any deviation noted
- Person evaluating test results
- Results and acceptability

2.7 Control of Purchased Material, Equipment, and Services

Policy requirements and associated responsibilities for the control of purchased material, equipment, and services are outlined in Section 7.0 of WP 13-1. Measures shall be taken, in accordance with current WIPP procurement policies and procedures, to ensure that procured items and services shall conform to specified requirements. These measures will generally include one or more of the following:

- Evaluation of the supplier's capability to provide items or services in accordance with requirements, including the previous record in providing similar products or services satisfactorily
- Evaluation of objective evidence of conformance, such as supplier submittals
- Examination and testing of items or services upon delivery

These methods shall be adequate to ensure quality in the majority of procurements. If it is determined that additional measures are required to ensure quality in a specific procurement, additional steps may be provided for procurement documents and implemented by Geotechnical Engineering staff and/or the Quality Assurance department. These additional assurances may include source inspection and audits or surveillance at the supplier's facilities.

2.8 Identification and Control of Items

Measures used to ensure that only correct and accepted items are used at the WIPP are outlined in Section 8.0 of WP 13-1. All items that potentially affect the quality of the Geotechnical Engineering Program shall be identified and controlled to ensure that only accepted items are used.

Geotechnical Engineering is responsible for the identification and control of geologic samples stored in accordance with WP 07-504, WIPP Project Core Storage, Handling, and Distribution.

Engineering will be specifically responsible for the identification and control of geologic samples. The geologic samples will be stored in a secure facility and an up-to-date database will be maintained to identify and control the samples. Traceability will be maintained in accordance with ASME NQA-1-1989, 8S-1, Supplementary Requirements for Identification and Control of Items.

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2.9 Control of Processes

Section 9.0 of WP 13-1 outlines the requirements and responsibilities for control processes. Measures employed to ensure that standard processes and special processes performed by the WID or their suppliers are accomplished under controlled conditions and in accordance with applicable safety analysis reports, regulations, codes, standards and specifications, as outlined in WP 13-1. The Geotechnical Engineering Manager, or designee, is responsible for maintaining a general schedule of geotechnical activities and for revising the schedule as needed to ensure that the program objectives are satisfied.

2.10 Inspection

An outline of the inspection program applied to the WIPP site is contained in Section 10 of WP 13-1. Inspections of geotechnical monitoring items shall be performed and documented as required and defined in implementing procedures, both upon receipt and while in service. The Quality Assurance department is responsible for the inspection of equipment upon receipt at the WIPP site.

Geotechnical Engineering may assist the Quality Assurance department during the inspection of equipment upon arrival at the WIPP site. Performance checks for the Geotechnical Engineering Program are designed to determine the acceptability of purchased items, and to assess degradation that occurs during use.

2.11 Test Control

Section 11.0 of WP 13-1 outlines the requirements and responsibilities for the control of tests. Testing or experimental/monitoring activities carried out for Geotechnical Engineering programs shall be performed in accordance with written plans or procedures which shall contain the following provisions, as applicable:

- Scope and/or definition or purpose
- Prerequisites such as calibrated instrumentation and supporting data; adequate test equipment and instrumentation, including accuracy requirements; completeness of item to be tested; suitable and controlled environmental conditions; and provisions for data collection and storage
- Instructions for performing the test
- Any mandatory inspection and/or hold points to be witnessed by the WID or other designated representatives
- Acceptance and rejection criteria
- Methods of documenting or recording test data
- Requirements for qualified personnel
- Evaluation of test results by authorized personnel

Test or experimental/monitoring procedures prepared by other project participants (e.g., Sandia National Laboratories) used as WID procurement documents will be reviewed to ensure that the documents are complete and the tests described by the documents are adequate to determine that the involved equipment, systems, or structures are operationally acceptable.

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Computer program testing activities that effect quality-related activities performed by the WID or their suppliers shall be accomplished in accordance with written test plans or procedures. Examples of computer program testing are standard design analysis, sampling data reduction, Central Monitoring System, and experimental data processed by computer.

Test requirements and acceptance criteria shall be provided or approved by the organization responsible for the design or use of the program to be tested unless otherwise designated. Required tests, including (as appropriate) verification tests, hardware integration tests, and in-use tests, shall be controlled.

Test requirements and acceptance criteria shall be based upon applicable design or other pertinent technical documents.

Verification tests shall demonstrate the capability of the computer program to produce valid results for test problems encompassing the range of permitted usage defined by the program documentation. Acceptable test problems solutions are as follows:

- Hand calculations
- Calculations using comparable proven programs
- Empirical data and information from technical literature

For programs used for operational control, testing shall demonstrate required performance over the range of operation of the controlled function or process.

Depending on the complexity of the computer program being tested, testing may range from a single test of the completed computer program to a series of tests performed at various stages of computer program development to verify correct translation between stages and proper working of individual modules, followed by an overall computer program test.

Regardless of the number of stages of testing performed, verification testing shall be sufficient to establish that test requirements are satisfied and that the computer program produces a valid result for its intended function.

Test problems shall be developed and documented to permit confirmation of acceptable performance of the computer program in the operating system. Test problems shall be run whenever the computer program is installed on a different computer, or when significant hardware or operating system configuration changes are made. Periodic in-use manual or automatic self-check routines shall be prescribed and performed for those applications where computer failures or drift can affect required performance.

Test procedures or plans shall specify the following, as applicable:

- Required tests and test sequence
- Required ranges of input parameters
- Identification of the stages at which testing is required
- Criteria for establishing test cases

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- Requirements for testing logic branches
- Requirements for hardware integration
- Anticipated output values
- Acceptance criteria
- Reports, records, standard formatting, and conventions
- Personnel qualification
- Changes to procedures require the same review and approval requirements as the initial release of the procedure

Verification test records shall identify the following:

- Computer program tested
- Computer hardware used
- Test equipment and calibrations, where applicable
- Date of test
- Tester of data recorder
- Simulation models used, where applicable
- Test problems
- Results and acceptability
- Action taken in connection with any deviations noted
- Person evaluating test results

In-use test results shall identify the following:

- Computer program tested
- Computer hardware used
- Test equipment and calibrations, where applicable
- Date of test
- Tester or data recorder
- Acceptability

Procurement documents shall specify the appropriate test requirements for WID suppliers and subcontractors. When specified in the procurement document, suppliers or subcontractors shall be required to submit test plans and/or procedures to the WID for review and approval. Geotechnical Engineering representatives shall, when specified in the procurement document, witness supplier/subcontractor test activities.

2.12 Control of Measuring and Test Equipment

Measuring and test equipment shall be controlled and calibrated to ensure continued accuracy of instrumentation data. Results of calibrations, maintenance, and repair shall be documented. Calibration records shall identify the reference standard and the relationship to national standards or nationally accepted measurement systems. Records shall be maintained to track uses of measuring and test equipment. If measuring and test equipment is found out of calibration tolerances, the equipment shall be tagged and its use ceased until corrections are made. An evaluation shall be made and the effects upon previous results shall be documented. The evaluation shall be approved by the Geotechnical Engineering Manager, and corrective measures shall be taken as needed.

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It is the responsibility of the site calibration laboratory to maintain records of the calibration status of all geomechanical measuring and test equipment. Equipment is administered in accordance with applicable portions of WP 10-003, Instrumentation Control and Calibration. Calibration reports and operability test data are maintained by the WIPP Calibration Lab. Any out-of-tolerance condition is evaluated for potential impact on the validity of data. Impact evaluation and corrective actions are initiated per specific Geotechnical Engineering QA Program instructions. An out-of-tolerance condition may require a nonconformance report to be initiated according to Section 15.0 of WP 13-1.

2.13 Handling, Storage, and Shipping

Requirements necessary to ensure that the handling, storage, and shipping of waste material, equipment and components, including spare parts, are outlined in Section 13.0 of WP 13-1. Geotechnical Engineering is responsible for identifying critical, sensitive, perishable, or high-value items that require the preparation of detailed procedures to control the handling, cleaning, storage, preservation, and shipping of geomechanical materials, equipment, or spare parts.

It is the responsibility of Geotechnical Engineering to store, handle, and distribute geologic samples in accordance with WP 07-504.

2.14 Inspection, Test, and Operating Status

Measures to ensure that required inspections and tests are performed are outlined in Section 14.0 of WP 13-1. Controls shall be implemented in accordance with documented procedures to ensure that items are not used prior to passing required inspections and tests. The status shall be identified on the items or on documents traceable to the items. Items that have not been accepted shall be identified as such and stored separately from accepted items. The operational status of equipment shall be identified on the equipment or on the equipment list. Faulty equipment shall be tagged and, if practicable, physically segregated from the work area.

2.15 Control of Nonconforming Conditions/Items

Section 15.0 of WP 13-1 describes the system for ensuring that appropriate measures are established to control nonconforming conditions.

Nonconforming items/conditions connected to the Geotechnical Engineering Program can be identified by the following:

- Geotechnical Engineering personnel during the performance of field operations, supervision of subcontractors, and preparation and verification of data reduction processing and numerical analyses
- Laboratory personnel during the preparation for and performance of laboratory testing, calibration of equipment, and quality control activities
- Quality Assurance personnel during the performance of audits and other Quality Assurance activities

Equipment that does not conform to specified requirements shall be controlled to prevent its use. Faulty items shall be tagged and segregated. Repaired

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equipment shall be subject to the original acceptance inspections and tests prior to use.

The Geotechnical Engineering Manager is responsible for:

- Evaluation and documentation of a nonconformance
- Ensuring that nonconformances detected for items within Geotechnical Engineering are identified, tagged, segregated, reported, and processed, in accordance with established procedures
- Providing disposition for nonconforming conditions identified with Geotechnical Engineering
- Review and approval of proposed disposition of nonconformances, as required

2.16 Corrective Action

Requirements for the development and implementation of a system to determine, document, and initiate appropriate corrective actions after encountering conditions adverse to quality are outlined in Section 16.0 of WP 13-1. Conditions adverse to acceptable quality shall be documented and reported in accordance with corrective action procedures, and corrected as soon as practical. Immediate action shall be taken to control work performed under conditions adverse to acceptable quality, and its results, to prevent degradation in quality.

The Geotechnical Engineering Manager, or designee, shall investigate any deficiencies in Geotechnical Engineering activities to determine if there is an underlying root-cause and take corrective actions, if necessary. All such actions shall be documented and reported to the Quality Assurance department.

2.17 Quality Assurance Records

Section 17.0 of WP 13-1 outlines the policy regarding the identification, preparation, collection, storage, maintenance, disposition and permanent storage of Quality Assurance records. The Geotechnical Engineering Manager, or designee, is responsible for the preparation and distribution of Geotechnical Engineering reports in accordance with appropriate DOE orders, policies, and directives.

Records to be generated in the Geotechnical Engineering QA Program shall be specified by procedure. From this, a master list of records shall be developed and maintained. This master list of records shall identify those records determined to be Quality Assurance and shall be included on the Geotechnical Engineering RIDS. The Quality Assurance records shall document the results of the Geotechnical Engineering Program implementing procedures and shall be sufficient to demonstrate that all quality-related aspects are valid. The records shall be identifiable, legible, and retrievable in accordance with DOE/WIPP 89-013, WIPP Project Records Management Handbook, and Quality Assurance record procedures.

While in the custody of the Geotechnical Engineering department, the records shall be protected from loss and damage by procedures requiring backups of electronic records and multiple copy storage. Geotechnical Engineering will coordinate with Project Records Services (PRS) for both periodic and perpetual transfer of records to PRS. It shall also ensure that copy machine-readable

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Quality Assurance records are transferred to more permanent media, either while in the custody of Geotechnical Engineering personnel or immediately upon accession by PRS.

Geotechnical Engineering is responsible for the core library in the core storage building. Records will be maintained of all core library activities. This includes additions to the core library, removal of any material from the core library, any tests performed on the core, a record of people who examine the core on site, and any other alterations made to the core.

Geotechnical Engineering Program procedures are administered by the Geotechnical Engineering Manager in accordance with guidance provided by WP 15-030, Records Management. Records will be transferred to PRS for permanent filing, as outlined in DOE/WIPP 89-013.

2.18 Audits and Independent Assessment

Provisions and responsibilities for quality assurance-type audits are outlined in Section 18.0 of WP 13-1. Periodic independent audits of the Geotechnical Engineering Program shall be scheduled, planned, and performed to verify that work is performed in accordance with specified requirements. The audits shall be administered and led by the Quality Assurance department. Audit teams shall not include members of the Geotechnical Engineering staff. The audits and independent assessments shall be performed in accordance with Quality Assurance auditing procedures.

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3.0 TECHNICAL PROGRAMS

The Geotechnical Engineering Technical Programs define the investigations currently being carried out by Westinghouse Electric Corporation, MOC for the WIPP, to evaluate the geotechnical performance of the underground facility. The data from the program are needed to demonstrate the safe disposal of TRU waste both in the short-term (during the operational life of the facility) and in the long-term to demonstrate that the facility, following decommissioning, will satisfy the appropriate federal regulations governing isolation of the waste. The data are used to provide confidence in the operational effectiveness and safety of the underground operations, for design validation, to support site characterization and performance assessment activities, and to support activities required for research and technological development. The collection of the geotechnical data is also necessitated by the C&C Agreement with the state of New Mexico that stipulates continuing studies of the site geology, and the need to satisfy EPA regulations for repository performance (40 CFR 191).

Two main WIPP contractors, SNL and Westinghouse, share responsibility for performing activities at the WIPP site in the area of geotechnical engineering. The contractors perform their tasks under the direction of the DOE-WIPP Project for site characterization, performance assessment, and technology development. They plan and execute experiments that are carried out in the WIPP. Westinghouse carries out routine geotechnical monitoring to ensure that the facility operates safely and that data is available to make decisions for managing and performing engineering and operational activities. Additionally, Westinghouse assists SNL in the collection and analysis of certain geotechnical data and also provides engineering support for the SNL Experimental Program, when requested. Each contractor is responsible for particular tasks and has assembled a group or project team to perform the necessary work. The contractors subcontract some support services, such as drilling and hydrologic testing. The overall Geotechnical Engineering QA Program is complex and diverse, and requires that the two major contractors work closely together in order to define needs and to avoid duplications of effort.

Field activities have been organized into three programs that cover the following:

- Data collection from geomechanical instrumentation (rock mechanics)
- Data from surveys of fracture development
- Geology

Each field program is controlled by a program plan that describes the general scope of the investigation, its methodology, and Quality Assurance requirements. The technical programs are discussed in Chapter 4.0.

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4.0 DESCRIPTIONS OF TECHNICAL PROGRAMS

4.1 Geology Program

4.1.1 Introduction

The Geology Program is one of three technical programs being carried out under the Geotechnical Engineering Program to collect data on the geotechnical performance of the underground facility. Information from the Geology Program is used to document the existing geology conditions and characteristics and to monitor for changes resulting from the excavations. Activities associated with this program include geologic and fracture mapping, the maintenance of a facility for the storage of geologic samples (Core Library), seismic monitoring and evaluation, and other special activities that are performed on an as-needed basis.

This program plan describes the general scope of the investigation, its methodology, and Quality Assurance requirements. The plan has been prepared in accordance with the requirements listed in Section 11.0 of WP 13-1. The plan will be updated periodically to reflect additions and changes to the program.

The data needs for the analyses performed in the different Geotechnical Engineering programs that comprise the overall program are interrelated. Therefore, data collected under one field program may be used for analyses associated with other programs.

4.1.2 Background

The Los Medanos area has been examined since 1974 to assess site capability for isolation of radioactive waste. The present site for the WIPP was selected in 1976 and has been under continuous investigation since that time as a site for containment and isolation of TRU radioactive waste. As the geology will form the principal barrier in the isolation of the waste from the accessible environment, the Geology Program has provided important data for site characterization and was integral to the decision to proceed with design and construction of the facility.

The site geology has been mainly characterized by subsurface investigations, and approximately 80 boreholes drilled specifically for the WIPP. Local to regional geology studies have used data from as many as 600 industry and WIPP boreholes.

Initially, detailed characterization of the geology within the site boundaries was hindered by the undesirability of drilling exploratory boreholes from the surface into the proposed disposal horizon in the salt beds, 2150 feet below the surface. The boreholes would intercept aquifers in the stratigraphic sequence overlying the salt deposit and could create open pathways from the surface. From these, water bearing units into future waste storage areas or into the buffer zone around the waste area. This initial characterization of the site geology relied heavily on the use of noninvasive geophysical techniques such as seismic reflection; gravity, magnetic, and resistivity surveys in conjunction with data correlated and interpreted from perimeter surface boreholes. In addition to field studies, and as samples have become available, laboratory studies of the geochemistry, physical properties, petrology and mineralogy of the local strata have been conducted. Site selection and preliminary geologic characterization are described in Geologic Characterization Report (Powers. et. al., 1978) and in the Final Environmental Impact Statement (DOE, 1980).

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To provide actual data on underground conditions, the Site and Preliminary Design Validation Program was initiated. The program was completed in 1983 and provided extensive geologic characterization of drifts and shafts. The information from the program established confidence in site suitability and was the basis for the decision to proceed with construction of the WIPP facility.

4.1.3 Program Purpose

The purpose of the current Geology Program is to confirm the suitability of the site based on continuing field activities.

4.1.4 Program Scope

Specific activities associated with the Geology Program are designed to accomplish the following:

- Provide additional site geological characterization based on mapping excavations and logging of cores
- Develop and interpret a database on mineralogy, chemistry and textural features characteristic of dissolution residues and compare the data to regular and irregular depositional features and fabrics
- Develop and interpret a database on subsidence induced by mining and integrate the results with WIPP subsidence models
- Derive a model that describes the hydrogeology of the Rustler Formation based on geologic, hydrologic, and geochemical data
- Monitor the local seismicity using a series of surface based seismographs. As part of this activity, analyses will be performed to determine if any correlation of seismic events with mining or petroleum recovery operations can be established

4.1.5 Methodology

The methodology for performing the activities associated with the Geology Program is described in this section. Tasks performed on a routine basis are carried out according to the approved procedures detailed in the Geotechnical and Geosciences Procedures Manual. Tasks which are in development or are not expected to be performed routinely are performed in accordance with individual plant work requests which supplement this program plan. Plant work requests may also be used to coordinate interrelated or complex activities between the Geotechnical Engineering field programs.

4.1.5.1 Routine Activities

The following activities of the Geology Program are performed on a routine basis:

- SEISMIC MONITORING - Seismic monitoring and evaluation is carried out by the New Mexico Institute of Mining and Technology, a subcontractor to Westinghouse
- GEOLOGIC MAPPING - Geologic mapping is performed in newly excavated areas and when the cognizant engineer or Geotechnical Engineering Manager deems it necessary. All geologic mapping is performed in

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accordance with WP 07-501, Geologic and Fracture Mapping of the Facility Horizon Drift, or WP 07-503, Geologic Mapping of Shafts. The mapping results are documented in the annual Geotechnical Field Data and Analysis Reports and in appropriate topical reports.

All drifts and rooms in which geologic mapping was not conducted are visually inspected by the cognizant engineer, or designee, within three months of excavation to verify that the exposed rock units are laterally continuous and similar to those exposed in the mapped areas of the facility. These inspections are documented and maintained in the Geotechnical Engineering files. Any unusual features are reported in the annual Geotechnical Field Data and Analysis Reports.

- FRACTURE MAPPING - Fracture mapping is performed at locations selected by the cognizant engineer and/or Geotechnical Engineering Manager. Fracture mapping is carried out by the cognizant engineer, or designee, in accordance with appropriate sections of WP 07-501.

- CORE LIBRARY OPERATIONS - Geotechnical Engineering maintains a repository for geologic samples that have been determined necessary for long-term storage. Based on requirements for site characterization and evaluation, DOE-WPSO determines which geologic samples are to be retained. WP 07-504, WIPP Project Core Storage, Handling, and Distribution, defines the proper methods for maintaining the sample repository. The procedure includes methods for the submittal of core to the Core Library, maintenance of the core storage facility (inventory, handling, and distribution), authorization for access to view the core on site, and authorization to remove samples from the library.

  Records are maintained of all Core Library activities which include submittal of samples to the Core Library, removal of samples from the Core Library, type of testing performed on the core, a record of people who had access to the core on site, and any other alterations made to the core.

4.1.6 Other Activities of the Geology Program

4.1.6.1 Brine Sampling and Evaluation

Brine Sampling involves brine collection and analysis to monitor the origins, hydraulic characteristics, extent, and composition of brine occurrences at the WIPP.

Boreholes designated for brine sampling are located at various locations throughout the WIPP underground. Brine collection is carried out in accordance with approved procedures.

Data collected is issued annually in the Brine Sampling and Evaluation Report.

4.1.6.2 Plant work requests will be initiated for non-routine Geology Program activities to ensure that the activity will be completed as planned. These plant work requests will provide specific details to describe the activity and methods and equipment required to complete the activity.

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Complete or ongoing activities that are not considered routine activities of the Geology Program include geologic mapping of the air intake, exhaust, and waste handling shafts. A test plan was developed for each of these activities to ensure that all the necessary steps to complete the activity were carried out. The test plans for each of these activities are included in the work plans referenced in Section 5.0 of this program plan.

4.1.7 Data Handling

Raw data, logs, and data records collected through the Geology Program are considered permanent records and shall be handled accordingly. QA Records generated as a result of Geology Program activities include: core logs, fracture maps, geologic maps, seismic reports. All raw data, logs, and data records will be transferred to PRS according to the requirements of WP 15-030.

Raw data collected for the Seismic Monitoring and Evaluation activity is directly transmitted to the New Mexico Institute of Mining and Technology. Quarterly data and analysis reports on the seismic data are prepared by the New Mexico Institute of Mining and Technology and submitted to Geotechnical Engineering. Copies of the quarterly seismic reports are transmitted to other project participants and to PRS in accordance with the RIDS for Geotechnical Engineering.

4.1.8 Quality Assurance

Policies and practices that apply to the Geology Program that will provide confidence in the quality of the data generated and samples collected are described in Section 2.0 of this program plan.

4.2 Geomechanical Monitoring Program

4.2.1 Introduction

The Geomechanical Monitoring Program consists of monitoring geomechanical instruments in the shafts and drifts of the WIPP facility. Geomechanical instrumentation presently installed in the shafts and underground includes tape extensometers points, convergence meters, borehole extensometers, piezometers, embedment strain gages, stress gages, inclinometers, load cells and crackmeters. The instrumentation is sufficiently sensitive that small changes in rock displacements and rock stresses can be detected.

The instrumentation system has provided data on the WIPP design for design validation, routine evaluation of safety and stability of excavations, and for developing initial interpretations of long-term behavior of underground openings. From an operational point of view, the data relating to the identification of areas of potential instability allow for remedial action to be taken in a timely manner. For long-term behavior, repository performance will rely heavily on the extrapolation of in-situ data, taken over a few years, to predict thousands of years of repository performance.

The information on the geomechanical monitoring is documented in the Geotechnical Field Data Reports prepared by Architect/Engineer, Bechtel, (DOE, 1986a) from 1982 to 1986 and by Westinghouse subsequent to 1987. Geotechnical data is also contained in the Design Validation Final Report (DOE, 1986b) which documents the performance of the facility during the Site and Preliminary Design Validation Program.

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This program plan describes the general scope of the investigation, its methodology, and Quality Assurance requirements. The plan has been prepared in accordance with requirements listed in Section 11 of WP 13-1. Where tasks are performed on a routine basis, they are carried out according to approved procedures that are detailed in the Geotechnical and Geosciences Procedure Manual. Where tasks are in the development stage or are not expected to be performed routinely, the specific steps in the performance of the monitoring activity will be detailed in test plans.

Plant work requests may also be used to coordinate interrelated or complex activities from the field programs. The data needs for the analyses performed in the Geomechanical Monitoring Program are interrelated and data collected under one field program may be used for analyses associated with other programs.

4.2.2 Background

As site characterization progressed and design activities began, the engineering performance of the rocks at the WIPP became important for both the design of the operating facility and the assessment of its long-term performance. Of special significance are the time-dependent properties of the salt. SNL has carried out extensive experimental work to establish an appropriate, constitutive relationship for salt that can predict its in-situ, mechanical performance. Because these experiments were incomplete when design of the underground facility started, facility design was based on empirical information from potash mines, available rheological parameters derived from the laboratory testing of rock samples, engineering evaluations, and numerical analyses. To validate the design, field data from geomechanical instrumentation were used to determine actual mechanical performance of the shafts and excavations at the facility horizon.

4.2.3 Program Purpose

The purpose of the Geomechanical Monitoring Program is to determine the actual geomechanical performance of the underground excavations at the WIPP. Data on stability and closure are needed for operational considerations and for performance assessment.

4.2.4 Program Scope

The activities associated with the Geomechanical Monitoring Program are designed to:

- Maintain and augment the geomechanical instrumentation system in the WIPP underground and upgrade the automatic data acquisition system as necessary
- Monitor geomechanical instrumentation on a regular basis and maintain a current database of instrument readings
- Evaluate the geomechanical instrumentation data and prepare regular reports that document the data and analyses describing the stability and performance of underground openings
- Recommend corrective or preventative measures, if needed, to ensure excavation stability, safe operation of the facility, and an acceptable time frame for possible waste retrieval

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- Provide predictions, as needed, of the performance of the underground excavations based on instrumentation data and supplemented by analytical studies

4.2.5 Methodology

The process by which geomechanical monitoring is initiated may vary. It may be part of operational excavation monitoring, research test support, or test termination. However, the process of proper documentation and analysis is common to all.

The installation and monitoring of the geomechanical instruments are governed by approved procedures detailed in the Geotechnical and Geosciences Procedure Manuals.

Instruments which have been installed underground are monitored automatically by a surface datalogger or read manually. The purpose of each type of instrument and monitoring technique is provided in Table 4-1.

4.2.5.1 Data Acquisition

Geomechanical instrumentation data is remotely acquired by the geomechanical datalogging system or manually by geotechnical engineering technicians. Manually acquired data is collected on a quarterly basis at minimum; however, more frequent readings may be collected as determined by the cognizant engineer or cognizant manager. Automatically acquired data is collected on a monthly basis, at minimum, although more frequent readings may be collected as necessary.

4.2.5.2 Geomechanical Datalogging System

The geomechanical datalogging system consists of a surface computer and LTCs located at various locations underground. The surface computer is used to access the LTCs by means of programs and polling devices installed in the LTCs. All data received is then stored in the Geomechanical Instrumentation System Database. Installation of LTCs is performed in accordance with Specification No. E-P-309, Instrument Cabinets and Panels.

4.2.5.3 Instrumentation

Geomechanical instruments are installed in accordance with approved procedures and the following specifications:

E-P-246	Pull Boxes and Terminal Boxes - Enclosures
E-Q-281	Instrumentation Cables
E-P-244	Cable Terminations
E-P-309	Instrument Cabinets and Panels

Instruments are installed at various locations based on specific monitoring requirements for various locations underground. The locations, monitoring required, and instruments used is provided in Table 4-1.

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TABLE 4-1
GEOMECHANICAL MONITORING INSTRUMENTATION

LOCATION	INSTRUMENT USED	MONITORED
Salt Handling, Waste and Exhaust Shafts	Piezometers	Groundwater pressure behind the shaft liner and key at the waterbearing Magenta and Culebra Dolomite Members.
	Extensometers	The Unnamed Upper and McNutt members of the Salado Formation in the lower unlined portion of the shafts.
	Earth Pressure Cells and Strain Gages	Horizontal stress between the concrete key and the Salado Formation as the creep effects load on the concrete structure.
Salt Handling and Waste Shaft Stations	Tape Extensometer Points	Roof to floor closure and rib to rib closure.
	Multiple Point Borehole Extensometers	Fracture separation in the rock strata.
	Rockbolt Load Cells	Tensile loads in rockbolts.
Main Access Drifts	Tape Extensometer Points	Roof to floor and rib to rib closure rates in intersections and midpillar locations.
	Multiple Point Borehole Extensometers	Fracture of separation in the rock strata.
	Crackmeters	Fracture or separation in the rock.
Waste Storage Panel	Multiple Point Borehole Extensometers	Fracture of separation in the rock strata.
	Tape Extensometer Points, Wire Convergence Meters	Roof to floor and rib to rib closure rates. Where access is restricted remotely read convergence meters are installed.
	Rockbolt Load Cells	Tensile loads in rockbolts.
Site Preliminary Design Validation Test Rooms	Multiple Point Borehole Extensometers	Fracture separation in the rock strata.
	Tape Extensometer Points	Roof to floor and rib to rib closure rates.
	Stressmeters	Monitor stress changes from all directions in the anhydrite bed.
	Inclinometers	Monitor borehole movement in rock strata.
	Wire Convergence Meters	Roof to floor closure rates. Due to restricted access they are read remotely.

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4.2.5.4 Data Analysis and Dissemination of Data

The frequency of data analysis on geomechanical data is based upon the requirements established in WP 02-9, Final Safety and Analysis Report. A completed data analysis is performed on an annual basis, at a minimum. The results of the analyses are published annually in the Geotechnical Field Data and Analysis Report.

An assessment of convergence measurements and geotechnical observations is made after each round of measurements. The results of this assessment are distributed to affected underground operations, engineering, and safety managers. Data analysis may be performed on a more frequent basis, as recommended by the cognizant engineer or cognizant manager.

Although geomechanical instrumentation data is published annually under an approved distribution list, data may be released to external sources with consent from the DOE-WPSO.

4.2.5.5 Calibration

Measuring equipment used to read geomechanical instruments are calibrated by Westinghouse Calibration Lab, in accordance with WP 10-003. Frequency of calibration is based on manufacturer recommendations upon receipt of the measuring device at the WIPP site. Calibration records are maintained by the Westinghouse Calibration Lab. Copies are kept on file in Geotechnical Engineering on an "information only" basis.

4.2.5.6 Routine Activities

Tasks that are in the development stage or are not expected to be performed routinely are detailed in plant work requests.

Maintenance is performed on an as-needed basis. When an instrument is damaged or erroneous readings are suspected, the instrument is physically inspected and evaluated for repairs or replacement. If repair efforts are unsuccessful, that instrument is documented as malfunctioning and monitoring is discontinued until the instrument has been replaced. If it is determined by Geotechnical Engineering that replacement is not necessary, the instrument is not replaced. 07-15-93

Monitoring and inspection of Room 1, Panel 1 is performed on a weekly basis by Geotechnical Engineering. Visual inspections are made during weekly data collection from manually read instrumentation. These inspections will check the physical condition of the instrumentation, junction boxes and cabling for damage, corrosion and loose parts. Any unusual observations or deterioration are documented on the GIS field data sheets and the cognizant engineer is notified of existing conditions. 07-15-93

The performance of the remotely read instrumentation in Room 1, Panel 1 is evaluated by the cognizant engineer on a weekly basis. The evaluation results are reported, on a weekly basis, to the Project Control Group set up to evaluate the performance of Room 1, Panel 1 and the supplemental roof support system. This evaluation is used to determine whether the geomechanical instrumentation and data acquisition system is performing as anticipated and is documented on a Room 1, Panel 1, Roof Support Instrumentation Inspection Data Sheet (Attachment 1).

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Maintenance on borehole extensometers is performed during an annual resetting activity. Resetting increases the rod lengths of those extensometers that have had a displacement of more than two inches since the last reset. This extends the useful life of the instrument and enables maintenance to be performed as well. 07-16-93

The appropriate procedures for the installation, calibration, and monitoring of these instruments are presented in the Geotechnical and Geosciences Procedure Manuals. Additional instrumentation may be installed as needs arise. 07-15-93

4.2.5.7 Other Activities of the Geomechanical Monitoring Program

A test plan will be developed, for activities in a developmental stage, that will include or reference the appropriate procedures to ensure that all necessary steps to complete the activity are carried out. These test plans will detail specific plans which describe instrument characteristics, locations, procedures, etc.

4.2.6 Data Handling

Raw data, logs, and records collected from geomechanical instrumentation under the Geotechnical Engineering Program are considered permanent records. QA records generated as a result of Geomechanical Monitoring Program activities include: Field Data Sheets, Initial Data Sheets, and Extensometer Reset Data Sheets. Permanent records are transferred to PRS in accordance with the Geotechnical Engineering RIDS. All geomechanical instrumentation data collected are reported in the annual Geotechnical Field Data and Analysis Report.

A listing of each geomechanical instrument, its location, and its fieldtag identification is located in the Rock Mechanics Program File. This listing is updated on an annual basis, at a minimum. Also included in the list is the criteria under which each instrument was installed. Reference to specific instrumentation and instrument location, can be found on Drawing No. 74-V-001-W, Location of GIS Instrumentation, Termination Boxes and Termination Box LTC 17 Schematic. This drawing is updated whenever a new instrument has been added to the geomechanical instrumentation system.

4.2.7 Quality Assurance

All aspects of the Geomechanical Monitoring Program activities shall conform to the requirements described in Section 2.0, of this manual and the Geotechnical and Geosciences Procedure Manuals.

4.3 Excavation Effects Program

4.3.1 Introduction

The Excavation Effects Program is being conducted to provide necessary information on the structural behavior of the salt rock around the excavated openings. A variety of techniques are used at the WIPP to monitor fracturing. These include borehole surveys, geologic fracture mapping, resistivity surveys, ground-probing radar, and evaluation of geomechanical instrumentation.

Excavation effects data acquired from borehole surveys and nondestructive geophysical techniques are used to supplement geomechanical data and geological

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observations to detect and quantify the occurrences of discontinuities such as fractures and separations.

This program describes the scope of the investigation, the methodology, and Quality Assurance requirements. The plan has been prepared in accordance with Section 11.0 of WP 13-1.

4.3.2 Background

During the underground Site and Preliminary Design Validation Program, there were indications that fractures were developing in the floors of excavations. These observations resulted in the initiation of a survey of boreholes throughout the underground. This survey, together with visual observations of excavation surfaces, showed that fracturing was occurring throughout the facility both in the roof and floor, and to a lesser extent in the ribs. This behavior was not entirely unexpected and has been previously observed in evaporite mines (Baar, 1977). In general, the fracturing at the WIPP has been discovered in the floors of excavations before being discovered in the roofs.

Following development of the fractures at the WIPP, a maintenance program was put into effect in mid-1986 to study fracturing and separation in the roof and floor. In 1986, thirty borehole arrays were drilled for the specific purpose of determining the distribution of fracturing around the underground facility. These holes are inspected annually, when access is available. The annual inspection of these holes is referred to as the EES. Other open holes in the facility can also be inspected periodically, although not as part of the EES.

4.3.3 Program Purpose

Boreholes are inspected to assess the nature of fracturing surrounding excavations in the underground facility at the WIPP. An understanding of fracturing around excavations will aid in evaluating underground stability in the short-term during operations and, in the long-term, for the design and construction of permanent bulkhead seals.

4.3.4 Program Scope

The activities associated with the Excavation Effects Program include scheduled borehole inspections, geologic observations, and geophysical methods. The program is designed to:

- Perform regular surveys of observation boreholes in the underground to monitor the propagation and development of fractures
- Conduct regular fracture mapping of the underground to identify surface fracture features and their evolution over time. Fracture mapping is performed under the Geology Program; however, data collected is also used for the Excavation Effects Program
- Evaluate additional techniques for monitoring fracture development within the salt and implement them as required
- In association with other Geotechnical Engineering programs, evaluate data and proposed mechanisms to explain the development of fractures at the WIPP

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4.3.5 Methodology

The methodology for performing the activities associated with the Excavation Effects Program is described in this section. Borehole fracture surveys and fracture mapping are performed on a routine basis and are carried out in accordance with approved procedures and detailed in the site Geotechnical and Geosciences Procedure Manuals. Other activities which are in the developmental stage or are not performed routinely are conducted in accordance with plant work requests.

4.3.5.1 Borehole Surveys

Thirty-six arrays of three to six boreholes were drilled for the EES at various locations in the underground (Excavation Effects Array Locations, Table 4-2). The arrays were laid out in similar configurations so that results from one location could be readily compared to results from other locations. The holes are an average of nine feet long. The center holes, at most arrays, were drilled to a 3 inch diameter to allow the use of borehole cameras. The majority of the holes were drilled to 1-7/8 inch diameter.

Open boreholes not specifically included in the EES are of varying diameter and depth. These holes are not inspected annually, but can be inspected when additional information is required in that area.

Boreholes are physically examined using a scratcher probe rod. The boreholes are initially drilled to depths between 6 feet and 12 feet and are inspected annually in accordance with WP 07-315.

4.3.5.2 Data Collection

Data is collected using an aluminum probe rod which consists of a flattened nail less than 1/16 inch wide attached at a right angle to one end. Fractures are identified by scratching the nail along the sides of the borehole while applying moderate pressure. Fractures are located where the nail catches at the same depth on all sides of the borehole wall.

4.3.5.3 Fracture Mapping

Fracture mapping is a routine activity performed under the Geology Program; however, collected data is also used under the Excavation Effects Program. Fracture mapping is described in detail in Section 4.1.5 of this manual.

4.3.5.4 Other Activities of the Excavation Effects Program

For each of these activities, a test plan is developed that will include or reference the appropriate procedures to ensure that all necessary steps to complete the activity are carried out.

4.3.5.4.1 Time Domain Reflectometry (TDR) Monitoring

TDR monitoring encompasses the installation of TDR cables and subsequent data collection and analysis. TDR methods supply information on subsurface fracture location and size.

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TABLE 4-2
EXCAVATION EFFECTS ARRAY LOCATIONS

ARRAY	OPENING DIMENSIONS (HxW)(ft.)	EXCAVATION DATE	LOCATION	DATE DRILLED
1	13 x 33	04/83	Test Room 4, N1175	05/15/86
2	13 x 33	04/83	Test Room 4, N1264	05/16/86
3	13 x 33	04/83	Test Room 4, N1361	05/16/86
4	13 x 33	04/83	Test Room 3, N1198	05/15/86
5	13 x 33	04/83	Test Room 3, N1243	05/15/86
6	13 x 33	04/83	Test Room 3, N1312	05/15/86
7	13 x 33	03/83	Test Room 2, N1147	05/21/86
8	13 x 33	03/83	Test Room 2, N1231	05/21/86
9	13 x 33	04/83	Test Room 1, N1159	05/21/86
10	13 x 33	04/83	Test Room 1, N1275	05/21/86
11	12 x 25	(Floor Lowered 4 ft 12/83)	N1110, W02	05/30/86
12	12 x 14	02/83	N1430, E140	06/05/86
13	8 x 14	01/84	N1110, E439	06/20/86
14	12 x 14	02/84	N1430, E875	06/05/86
15	12 x 25	02/83	N626, W02	06/20/86
16	8 x 14	02/83	N305, E147	07/15/86
17	12 x 32	10/82	Salt Handling Shaft Station, N28	05/30/86
18	20 x 35	06/82 (Roof Raised 3 ft 08/87)	Salt Handling Shaft Station, S24	06/04/86
19	20 x 35	06/82 (Roof Raised 3 ft 08/87)	Salt Handling Shaft Station, S56	06/03/86
20	15 X 25	12/82 (Floor Lowered 5/84)	S592, E155	07/10/86
21	12 x 20	07/85	S700, E66	07/08/86
22	12 x 14	05/84,07/84	S700, E300	07/08/86
23	12 x 14	07/84	S1190, E229	07/09/86
24	15 x 25	12/84; 08/85; 06/84	S1300, E155	07/09/86

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TABLE 4-2 Continued
EXCAVATION EFFECTS ARRAY LOCATIONS

ARRAY	OPENING DIMENSIONS (HxW)(ft.)	EXCAVATION DATE	LOCATION	DATE DRILLED
25	15 x 25	12/82 (Floor Lowered 5/84)	S1129, E155	07/09/86
26	08 x 25	01/83	S2205, E154	07/16/86
27	12 x 14	03/83	N1430, E1555	07/11/86
28	12 x 20	03/83 (Floor Lowered 4/83	N1110, W432	07/16/86
29	15 x 25	12/82 (Floor Lowered 11/85)	S1700, E155	07/10/86
30	8 x 14	02/84	N1110, E1303	07/11/86
31	12 x 14	03/84	N1420, E1375	03/08/91
32	12 x 14	03/84	N1420, E1470	03/07/91
33	13 x 33	03/84	N1420, E1110	03/06/91
34	13 x 33	02/87	E720, S1688	04/26/91
35	13 x 33	02/87	E720, S1775	04/26/91
36	13 x 33	02/87	E720, S1865	04/26/91

NOTES:

1. Nominal hole depth is 9 feet but some holes are shorter due to low drift roof or drilling difficulties.

2. One roof and one floor hole of each array were generally drilled 3 inches in diameter to accommodate use of the borehole camera if desired. Other holes were drilled 1-7/8 inches in diameter. Existing holes were used where possible.

3. Observations were made using a probe consisting of a nail attached perpendicular to the end of a rod.

4. Holes at Array 13 were drilled to only 6 to 6.5 feet depth due to low drift roof. No roof holes were drilled at Arrays 16 and 26 due to low drift roof.

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TDR monitoring consists of rock mass movements which deform a grouted coaxial cable causing a change in cable capacitance and thereby, a reflected wave form occurs when voltage is applied to the cable via the Tektronix cable tester. By monitoring changes in the reflected waveforms, it is possible to monitor the rock mass deformation.

TDR installations are currently located only in the SPDV Test Rooms. No WIPP procedure has been developed, and until a procedure is deemed appropriate, work involving TDR monitoring will be governed by an approved test plan.

4.3.5.4.2 Resistivity Surveys

The resistivity technique currently used at WIPP by Geotechnical Engineering is a direct method which requires a series of lead electrodes to be installed in regular grids of shallow boreholes on the excavation surface being investigated. The electrodes are connected to a transmitting power supply. Current is applied to selected electrodes and the voltage drop is measured at other nearby electrodes. The spacing of electrodes and the selection of which electrodes are energized during a measurement depend on the location and the information desired. Data may be collected manually with a voltmeter or automatically with a computerized datalogger on a monthly basis.

4.3.5.4.3 Ground-Probing Radar Surveys

Ground-probing radar is a technique used at the WIPP to investigate fracturing within the salt rock. Contrasts in dielectric constant along the travel path of a transmitted electromagnetic signal produce reflections from subsurface interfaces. The length of the time between signal generation and receival of the reflected signal is used to provide images of fracturing within the rock mass. The depth of investigation depends upon the frequency of the electromagnetic signal and the conductivity of the salt rock.

4.3.6 Data Handling

Raw data, logs, and data records collected through the Excavation Effects Program are considered permanent records and are handled accordingly. QA records generates us a result of EEP activities include: Field Data Sheets. All raw data, logs, and data records will be documented in the Field Data and Analysis Reports and transferred to PRS in accordance with WP 13-030.

4.3.7 Quality Assurance

All aspects of the Excavation Effects Program activities shall conform to the requirements established in Section 2.0 of this manual.

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5.0 REFERENCES

40 CFR 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes

ASME NQA-1-1989, Quality Assurance Program Requirements for Nuclear Facilities

Drawing No. 74-V-001-W, Location of GIS Instrumentation, Termination Boxes and Termination Box LTC 17 Schematic

DOE/WIPP 89-013, WIPP Project Records Management Handbook

Rock Mechanics Program File No. 78010

SAND 80-7096, Seismicity in the Area of the Waste Isolation Pilot Plant (WIPP)

Specification No. E-P-244, Cable Terminations

Specification No. E-P-246, Pull Boxes and Terminal Boxes - Enclosures

Specification No. E-P-309, Instrument Cabinets and Panels

Specification No. E-Q-281, Instrumentation Cables

Work Plan of Geotechnical Activities in the Waste and Exhaust Shafts at the WIPP Facility

Work Plan for the Geologic Mapping in the Air Intake Shaft at the WIPP Facility

WP 02-9, Final Safety Analysis Report

WP 07, Geotechnical and Geosciences Procedures Manuals

WP 07-501, Geologic and Fracture Mapping of the Facility Horizon Drifts

WP 07-503, Geologic Mapping of Shafts

WP 07-504, WIPP Project Core Storage, Handling, and Distribution

WP 10-003, Instrument Control and Calibration

WP 13-1, WID Quality Assurance Program Description

WP 14-TR3308, On-The-Job Training

WP 15-609, Planning, Preparation, and Processing of Purchase Requisitions and Purchase Requisition Change Notices

WP 15-030, Records Management

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WP 15-101, Preparing, Revising, Reviewing, and Canceling Procedures

WP 15-103, Document Control

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

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Appendix GWMP

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Groundwater Surveillance Program Plan

WP 02-1 Rev. 3
GROUNDWATER SURVEILLANCE PROGRAM PLAN

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GROUNDWATER SURVEILLANCE PROGRAM PLAN

1.0 INTRODUCTION

This is the controlling document for the Waste Isolation Pilot Plant (WIPP) Groundwater Surveillance Program (GSP). The GSP is administered as part of the WIPP Environmental Monitoring Program by the Environmental Monitoring (EM) Section of the Environment, Safety and Health (ES&H) Department.

2.0 REFERENCES

DOE Order 5400.1, General Environmental Protection Program

DOE/EH 0173T, Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance

Groundwater Protection Management Program Plan

WP 02-3, Environmental Procedures Manual

WP 10-AD, WIPP Maintenance Administrative Procedures Manual

WP 12-1, Waste Isolation Pilot Plant Safety Manual

WP 12-107, Hazard Communication Program

WP 13-1, WID Quality Assurance Program Description

WP 15-6, Purchasing Policies and Procedures Manual

WP 15-PR, Records Management Plan

3.0 RESPONSIBILITIES

The overall organizational structure of the Westinghouse WID is described in Part I, Section 1 of the Quality Assurance Program Description (QAPD). The GSP is the responsibility of the ES&H Department. The GSP is conducted by the EM Section of this department.

The EM manager assumes responsibility for the overall design and implementation of the GSP including the following areas:

- Development and approval of specific procedures for the conduct of all GSP activities.
- Establishment of minimum qualification criteria and training requirements for all program personnel.
- Review and approval of programmatic reports.

- Oversight of appropriate levels of cooperation and consultation between the EM Section and the state of New Mexico regarding environmental monitoring.

- Preparation of the QA section of the GSP Plan.

The EM manager and staff are responsible for achieving and maintaining quality in the GSP. Job descriptions will be maintained for the EM manager, professional, technical, and administrative staff positions. All GSP data shall be reviewed and approved by the EM manager, or designee, prior to release.

The EM manager appoints a GSP Team Leader (TL), assigning the following responsibilities to the TL:

- Direct GSP per written approved procedures.

- Initiate review of programmatic plans and procedures.

- Review and evaluate sample data.

- Prepare and review programmatic reports.

- Assure that appropriate samples are collected and analyzed.

- Assure that adequate technical support is provided to the Quality and Regulatory Assurance (Q&RA) Department, when required during audits of vendor facilities.

The EM manager designates one or more scientists, engineers, or technicians who will be responsible for the following items:

- Collection and subsequent distribution of samples.

- Preparation and maintenance of appropriate data sheets and sample tracking documentation.

- Monitoring of equipment operability status.

- Reporting of equipment malfunctions.

- Reporting of nonconformance to the TL or EM manager.

- Overseeing of quality control checks of data.

- Conducting field activities in accordance with written procedures.

The Q&RA manager provides independent oversight of the GSP, via the assigned cognizant Q&RA engineer, to verify that quality objectives are defined and achieved. The Q&RA manager ensures objective, independent assessments of GSP quality performance. The Q&RA manager has been delegated authority and given organizational freedom by the WID General Manager to access work areas, identify quality problems, initiate or recommend corrective actions, verify implementation of corrective actions, and ensure that work is controlled or stopped until adequate disposition of an unsatisfactory condition has been implemented.

The EM manager assures that basic qualifications for GSP personnel are carried out in accordance with Section 2 of the QAPD.

The EM manager assures that position descriptions for assigned GSP personnel are adequately prepared. Each position description will include position purpose, principal responsibilities, nature of work; and scope.

The EM manager and/or TL assures that training is performed on an individual basis to maintain an acceptable level of proficiency by all new or temporary GSP staff and by all permanent GSP staff.

New GSP employees are required to review pertinent program documentation, become familiar with applicable procedures, and complete appropriate qualifications prior to undertaking any unsupervised GSP task. To become qualified to perform a specific task or series of tasks, an employee must demonstrate subject knowledge and practical skills and become certified in performing the task(s) by a board-certified subject matter expert (SME). Employees who have not completed the appropriate qualification card will not be allowed to conduct unsupervised GSP activities.

The EM manager, TL, or task SME may determine the need for retraining of GSP personnel. Retraining may be noted by Q&RA during any surveillance or audit or during a periodic review initiated by the EM manager, TL, or SME.

The EM manager assures that documents detailing all staff training are current and properly filed. Copies of training records shall be on file in the WID Technical Training Section.

4.0 GSP QUALITY ASSURANCE PLAN

4.1 Introduction

This section is the quality assurance (QA) plan for the WIPP GSP. The objective of this QA plan is to establish the specific QA requirements associated with the GSP. The GSP currently consists of two activities: the Water Quality Sampling Program (WQSP) and the Water Level Monitoring Program (WLMP). Technical implementation of each specific activity is controlled by an individual program plan and unique operating procedures. The GSP provides a mechanism for addressing the following:

4.1.1 Department of Energy (DOE) Order 5400.1

Chapter 3 of the DOE Order 5400.1, General Environmental Protection Program, states that "... all Department of Energy (DOE) sites will conduct a groundwater protection management program." The order requires each DOE site to provide for the design and implementation of a groundwater monitoring effort that supports resource management and complies with applicable environmental laws and regulations.

4.1.2 DOE/EH 0173T

DOE/EH 0173T, Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance, states that:

> It is the policy of DOE to conduct effluent monitoring and environmental surveillance programs that are adequate to determine whether the public and the environment are adequately protected during DOE operations and whether operations are in compliance with DOE and other applicable Federal, State, and local radiation standards and requirements. It is also DOE policy that Departmental monitoring and surveillance programs be capable of detecting and quantifying unplanned releases and meet high standards of quality and credibility. It is DOE's objective that all DOE operations properly and accurately measure radionuclides in their effluent and in ambient environmental media.

4.1.3 Resource Conservation and Recovery Act (RCRA)

By virtue of a Groundwater Monitoring Waiver, prepared under 40 CFR 265, the WIPP Project is not required to monitor groundwater to comply with the U.S. Environmental Protection Agency (EPA) RCRA. The WIPP GSP provides a basis for future compliance to the RCRA, as well as any other groundwater protection-related regulations, should the need arise.

4.1.4 Final Environmental Impact Statement (FEIS) Commitments

Section J.2.2 of the FEIS states that "...long-term groundwater sampling and water level monitoring will be conducted as part of the WIPP Environmental Monitoring Program."

4.1.5 Future Land Use Decisions

Data collected from the program will aid in making future groundwater-land use decisions (i.e., designing long term and passive institutional controls for the site).

This QA plan is driven by, and is supplemental to, both the WID QAPD, WP 13-1, and implementing WIPP Q&RA procedures.

4.2 GSP Quality Assurance Requirements

The following specific Q&RA requirements are unique to the GSP.

4.2.2 Quality Assurance Program

This plan is governed by the following documents: WP 13-1, WID Quality Assurance Program Description; and WP 02-3, Environmental Procedures Manual. Steps to ensure quality are incorporated, as needed, in the technical procedures used for groundwater surveillance activities. The EM manager or assigned designee is responsible for developing and maintaining this QA plan and groundwater surveillance procedures.

In accordance with the WID QAPD, Part I, Section 1, groundwater surveillance data activities are classified as Quality Code II.

4.2.3 Design Control

The design control requirements used by Westinghouse at the WID are described in Part II, Section 6 of the QAPD. The GSP will adhere to all applicable portions of these requirements when performing design activities.

4.2.4 Procurement Document Control

Procurement is carried out in accordance with WID procurement policies and procedures, as outlined in Part II, Section 7 of the QAPD, and WP 15-6, Purchasing Policies and Procedures Manual. Both documents require specification of a quality code and design class and concurrence by the Q&RA Department with procurement documents. Technical requirements for procured items and services are developed and specified in procurement documents. If deemed necessary to ensure attainment of the required characteristics, procurement documents may require suppliers to have an adequate QA program.

4.2.5 Instructions, Procedures, and Drawings

Provisions and responsibilities for the preparation and use of instructions and procedures at the WIPP are outlined in Part II, Section 4 of the QAPD. Quality-affecting activities performed by or on behalf of groundwater surveillance are required to be performed in accordance with documented and approved procedures.

Technical procedures have been developed for each quality-affecting function performed for groundwater surveillance. The technical procedures unique to the GSP are contained in the procedures section of this manual. The procedures are as detailed as required and include, when applicable, quantitative or qualitative acceptance criteria to determine that activities have been satisfactorily accomplished.

Procedure requirements are in accordance with Section 4 of WP 13-1. Procedures will be prepared in accordance with applicable technical writer's guides.

4.2.6 Document Control

Requirements for the control of documents are outlined in Part II, Section 4 of the WID QAPD. Controls ensure that the latest approved versions of procedures are used in performing groundwater surveillance functions and that obsolete materials are removed from work areas.

4.2.7 Control of Purchased Material, Equipment and Services

WIPP policy requirements and associated responsibilities for the control of purchased material, equipment, and services are outlined in Part II, Section 7 of the QAPD. In accordance with current WIPP procurement policies and procedures, measures will be taken to ensure that procured items and services conform to specified requirements. These measures will include one or more of the following:

- An evaluation of the supplier's capability to provide items or services in accordance with the requirements, including the history of providing similar products or services satisfactorily.
- An evaluation of objective evidence of conformance, such as supplier submittal (i.e., QA plan).
- An examination and testing of items or services upon delivery.

If it is determined that additional measures are required to ensure quality in a specific procurement, additional steps may be provided in procurement documents and implemented by groundwater surveillance staff and/or the Q&RA Department. These additional assurances may include source inspection and audits or surveillance at the supplier's facilities.

4.2.8 Identification and Control of Items

Measures to ensure that only correct and accepted items are used at the WIPP are outlined in Part II, Section 8 of the QAPD. All items that potentially affect the quality of the GSP are uniquely identified and controlled to ensure that only accepted items are used.

Equipment is administered in accordance with WP 10-AD, WIPP Maintenance Administrative Procedures Manual. Calibration reports test data are maintained by the EM Department. Any "out-of-tolerance" condition is evaluated for potential impact on the validity of data. Impact evaluation and corrective actions are initiated per specific GSP instructions.

4.2.9 Control of Processes

All process control requirements of the QAPD are met by the GSP.

4.2.10 Inspection/Surveillance

Inspection and surveillance activities are conducted as outlined in Part II, Section 10 of the QAPD. The Q&RA Department is responsible for performing the applicable inspections and surveillance on the scope of work. Performance checks are performed by groundwater surveillance personnel as specified by the appropriate procedures, and by WID metrology laboratory personnel. Performance checks for the GSP are designed to determine the acceptability of purchased items and to assess degradation that occurs during use.

4.2.11 Test Control

Part II, Section 8 of the WID QAPD outlines the requirements and responsibilities of the WID for the control of tests. Tests to be performed for the GSP fall into two general categories: tests of items upon receipt and in service, and operability checks of equipment.

All tests are performed in accordance with documented and approved plans and/or procedures. Testing or experimental/monitoring plans or procedures contain the following provisions as applicable:

- Scope and/or definition or scope.
- Prerequisites such as calibrated instrumentation and supporting data; adequate test equipment and instrumentation, including accuracy requirements; completeness of item to be tested; suitable and controlled environmental conditions; and provisions for data collection and storage.
- Instructions for performing the test.
- Mandatory inspection and/or hold points to be witnessed by the WID or other designated representatives.
- Acceptance and rejection criteria.
- Methods of documenting or recording test data.
- Requirements for qualified personnel.
- Evaluation of test results by authorized personnel.

4.2.12 Control of Monitoring and Data Collection Equipment

Monitoring and Data Collection (M&DC) equipment is controlled and calibrated according WP 10-AD, WIPP Maintenance Administrative Procedures Manual, to ensure continued accuracy of groundwater surveillance data. Results of calibrations, maintenance, and repair are documented. Calibration records identify the reference standard and the relationship to national standards or nationally accepted measurement systems. Records are maintained to track uses of M&DC equipment. If M&DC equipment is found to be out of tolerance, the equipment is tagged and its use ceased until corrections are made. An evaluation shall be approved by the EM manager and corrective measures will be taken, as needed.

4.2.13 Handling, Storage, and Shipping

Handling, storage, packaging, and shipping of groundwater samples are controlled in accordance with WP 10-AD, WIPP Maintenance Administrative Procedures Manual. Proper documentation is prepared and maintained for each sample to minimize damage, loss, deterioration, and extraneous exposures.

4.2.14 Inspection and Acceptance Testing

Measures used by the WID to ensure that required inspections and tests performed are outlined in Part II, Section 8 of the WID QAPD. Controls are implemented in accordance with documented procedures to ensure that items are not used prior to passing required inspections and tests. The status is identified on the items or on documents traceable to the items. Items that have not been accepted are identified as such and stored separately from accepted items. The operating status of equipment is identified on the equipment or on the equipment list. Faulty equipment is tagged and, if practicable, physically segregated from the work area.

4.2.15 Control of Nonconforming Conditions

Part II, Section 8 of the WID QAPD describes the system used at the WIPP for ensuring that appropriate measures are established to control nonconforming conditions. Nonconforming conditions connected to the GSP are identified in and controlled by documented procedures. Equipment that does not conform to specified requirements is controlled to prevent use. The disposition of defective items is documented on records traceable to the affected items. Prior to final disposition, faulty items are tagged and segregated. Repaired equipment is subject to the original acceptance inspections and tests prior to use.

4.2.16 Corrective Action

Requirements for the development and implementation of a system to determine, document, and initiate appropriate corrective actions after encountering conditions adverse to quality at the WIPP are outlined in Part I, Section 3 of the QAPD. Conditions

adverse to acceptable quality are documented and reported in accordance with corrective action procedures and corrected as soon as practical. Immediate action will be taken to control work performed under conditions adverse to acceptable quality, and its results, to prevent degradation in quality.

The EM manager or designee investigates any deficiencies in groundwater surveillance activities to determine if there is an underlying root cause. All such actions are documented and reported to the Q&RA Department.

4.2.17 Quality Assurance Records

Part I, Section 4 of the QAPD outlines the policy used at the WIPP regarding identification, preparation, collection, storage, maintenance, disposition, and permanent storage of QA records. The EM manager or designee is responsible for the preparation and distribution of records in accordance with appropriate DOE Orders, policies, and directives.

Records to be generated in the GSP are specified by procedure. QA records are identified. This is the basis for the labeling of records as "QA" on the EM Records Inventory and Disposition Schedule (RIDS).

QA records document the results of the GSP implementing procedures and are sufficient to demonstrate that all quality-related aspects are valid. The records will be identifiable, legible, and retrievable in accordance with WP 15-PR, WID Records Management Plan, and QA record procedures.

While in the custody of the GSP group, the records shall be stored in a UL listed, one-hour fire-resistant cabinet. The EM manager shall coordinate with WIPP Project Records Services (PRS) for both periodic and perpetual transfer of records to PRS.

4.2.18 Assessments

Provisions and responsibilities for assessments are outlined in Part III, Sections 9 and 10, of the QAPD. Periodic, independent assessments of the GSP shall be scheduled, planned, and performed to verify that work is performed in accordance with specified requirements. The Independent Assessment Section has the responsibility and oversight authority for appraising GSP activities for compliance with applicable environmental statutes. Assessment teams will not include members of the GSP staff. Assessments are performed in accordance with applicable assessment procedures.

5.0 GSP WATER QUALITY SAMPLING PLAN

5.1 Scope

This section of the WIPP GSP Plan serves as the controlling document for the WQSP. The WQSP is a subprogram of the GSP.

The WQSP was initiated in January 1985. The objective of the program is to collect representative and reproducible groundwater samples from water-bearing zones in the area of the WIPP site. The purpose of the program is to provide defensible data for meeting the requirements of site characterization, performance assessment, regulatory compliance, and permitting. A program plan that defined the basic structure and operational activities of the program was initially developed by Colton and Morse (1985). The program plan was replaced in 1987 by WP 07-2, Waste Isolation Pilot Plant Water Quality Sampling Manual. In 1991 the WQSP manual was replaced by WP 02-1, Waste Isolation Pilot Plant Groundwater Monitoring Program Plan and Procedures Manual.

5.1.1 General

From 1984 to 1990, the WQSP was designed to characterize the physical and chemical characteristics of representative groundwater samples occurring within and immediately surrounding the WIPP site. Various wells were serially sampled, three times each, to determine the representative character of the groundwater present at each location. Data collected were supplied to the ES&H Department and used to develop a baseline of water quality data as part of the Radiological Baseline Program. A nonradiological database was developed to support the background water quality characterization report. Data were also supplied to and used by Sandia National Laboratories (SNL) for site characterization and performance assessment. By the close of 1990, the groundwater of interest had been characterized, and the objective of the program shifted from characterization to surveillance.

On October 1, 1988, the ES&H Department assumed responsibility for the WQSP. Water quality sampling activities were coordinated with the Environmental Monitoring Program.

Collection of groundwater quality data continues to assist the DOE in meeting performance assessment, regulatory compliance, and permitting requirements. The data also provide:

- Radiological and nonradiological water quality input to the WIPP Environmental Monitoring Program.
- A means to comply with future groundwater inventory and monitoring regulations.
- Input for making land-use decisions (i.e., designing long-term active and passive institutional controls for the site).

Groundwater exists both above and below the WIPP repository, but no hydrologic continuity exists between the repository and the groundwater. Groundwater below the repository occurring in the sandstones of the Delaware Mountain Group (Powers, et al., 1978) is isolated by bedded salt deposits in the lower part of the Salado Formation and

in the underlying Castile Formation. Groundwater below the repository is not being monitored as part of this program.

Groundwater above the repository is being monitored. Groundwater exists in both the Dewey Lake Formation and the Rustler Formation. Zones monitored for background characterization within the Rustler are the Culebra and the Magenta members. These zones appear to be dolomite units isolated from one another by impermeable units. With the exception of excavated shafts at WIPP, these zones are isolated from the repository excavations by bedded salt deposits in the upper two thirds of the Salado Formation.

Postbackground surveillance is focused on the Culebra because it is the primary flow path within the Rustler formation. Databases are maintained for the Magenta so that if the need arises surveillance of the Magenta can be resumed.

The Culebra is areally persistent, but quantity and quality of water vary considerably from place to place. The dolomite is vuggy, fractured, and commonly associated with anhydride (Lambert and Mercer, 1977). The Culebra has a low hydraulic conductivity. It is a fractured unit that is best modeled as a dual-porosity media. Water yields are small and saline (Powers et al., 1978).

The Magenta is finely crystalline and dense. Like the Culebra, the Magenta has a low hydraulic conductivity through fractures and contains limited amounts of poor quality water (Powers et al., 1978).

The Dewey Lake Redbeds consist of orange-red silt stone, mud stone, and some sandstone. The Dewey Lake Redbeds do not form an aquifer, but some permeable sand lenses are present and those yield limited quantities of fresh water to a few private wells in the area around the WIPP site (Powers et al., 1978). One such sand lens has been identified within the WIPP boundary and is scheduled for surveillance as part of the WQSP.

5.2 Surveillance Well Construction

Many of the WIPP surveillance wells were drilled and completed prior to 1980. As the WIPP Project progressed, additional monitoring wells were completed in the vicinity of the site. Drilling of the bulk of WIPP surveillance wells began in 1976 and continued into 1988.

In general, all of these wells were drilled as part of the geologic site characterization and resource evaluation programs. Most WIPP surveillance wells were drilled and completed using oil field techniques. Surveillance wells at the site have been completed, generally, using two types of installations. One installation requires drilling the well to some depth below the base of the Culebra and then casing the well to the bottom of the hole. The interval of the Culebra or Magenta is then perforated to allow access to the formation for testing or sampling purposes. The second type of installation consists of drilling the hole to a depth just above the top of the Culebra,

installing well casing to the bottom of the drilled hole, and coring or drilling through the Culebra interval, leaving the Culebra interval open to the formation.

These types of well completions presented problems in collecting undisturbed and representative samples from the water-bearing units. The open-hole completions have, in some cases, resulted in sediments below the Culebra being exposed in the sampling interval. In some cases, these sediments are rich in halite or other evaporite minerals, causing the water chemistry in the well bore and the water-bearing unit surrounding the well to be altered. Often, during drilling and completion of surveillance wells, fluids containing fresh water, saturated brine, and drilling fluids containing petroleum products have been introduced into the well bore. In some cases, these fluids were left standing in the well bore for extended periods of time, resulting in contamination of the surrounding formation (Crawley 1988).

Standard oil field steel well casings have been used during completion of the WIPP surveillance wells. This type of casing is easily corroded by the brackish to brine water found in the WIPP area. Based on serial sampling results, it appears that the products of well casing corrosion migrate from the well bore into the formation, resulting in a halo or plume of groundwater with altered chemistry surrounding the surveillance wells. Obtaining a representative sample has required that the surveillance wells be pumped for long periods of time to remove the contamination.

Well drilling and completion techniques such as those described above are usually not used for installation of monitoring wells employed in RCRA or other groundwater sampling programs, due to the likelihood of aquifer contamination. These practices required that the WQSP use extensive groundwater pumping in order to obtain uncontaminated water samples.

The difficulty in obtaining representative groundwater samples, due to the design of the wells used by the WQSP, necessitated the use of a serial sampling technique. Serial sampling and the associated equipment are discussed later in this section.

Seven observation wells were completed after the baseline was established using EPA recommended drilling methods and casing materials that have the potential to meet RCRA monitoring standards. Six of the wells were completed in the Culebra; one well in the Dewey Lake formation. Two years of sampling are scheduled prior to the anticipated receipt of waste. The data gathered from these wells will be compared to the existing database and the existing background data will be appended as appropriate.

The configuration of the seven new observation wells may well preclude the necessity to perform serial sampling. However, sampling of a portion of the older surveillance wells may be necessary in years to come. Therefore, a discussion of serial sampling techniques is included in this document.

5.3 Sampling Program Description

The WQSP has employed two types of sampling procedures at the WIPP: serial sampling and final sampling.

5.3.1 Serial Sampling

Serial sampling is the collection of sequential samples for the purpose of determining when the water chemistry stabilizes or reaches a steady state. Ideally, when the water chemistry stabilizes, it is assumed that the chemistry is representative of the native formation fluid, and a final sample is collected. However, in reality, serial sampling leads to the collection of water samples with reproducible chemistries which may or may not be representative of the undisturbed groundwater. The water samples may still be impacted by well construction practices and effects from the installation of downhole pumping and sampling equipment.

During the background characterization phase of the WQSP serial sample, field parameters were monitored on a daily basis. After completion of the background characterization phase, monitoring of serial sample parameters was modified by pumping each well for 48 hours prior to the start of serial sampling then comparing the serial sampling analysis results to the average last day serial sample results for previous sampling rounds. A 95 percent confidence interval was established for comparison standards.

The field analytical parameters found to be the most useful in identifying a steady state condition of the water chemistry include chloride, divalent cations (hardness), and alkalinity, which are analyzed by classic wet chemistry bench methods (titration). Total iron has also been found to be a useful indicator and is analyzed using spectrophotometric methods. Other serial sampling parameters analyzed in the field include measurement of pH, Eh, temperature, specific conductance, and specific gravity. Procedures for collection and analysis of serial samples are processed, approved, and maintained by the site documentation process.

5.3.2 Final Samples

Final groundwater samples are collected once evidence from serial sampling indicates that the pumped groundwater has reached a chemical steady state. Final samples are forwarded to a contract analytical laboratory for analysis.

Final samples are collected in the appropriate type of container for the specific analysis to be performed. For each parameter analyzed, a sufficient volume of sample is collected to satisfy the volume requirements of the analytical laboratory. This includes an additional volume of sample water necessary for maintaining quality control standards. All final samples are treated, handled, and preserved as required for the specific type of analysis to be performed. Details about sample collection, preservation, and volumes required for individual types of analyses are found in the applicable procedures generated, approved, and maintained by the site documentation process.

Splits of the final sample are provided to oversight agencies and WIPP stakeholders as requested by the DOE. A split of the sample is also placed in storage within the ES&H Environmental Sample storage area and held until final reports from the contract analytical laboratory have been evaluated and approved. When the final laboratory report has been approved the samples are removed from storage and destroyed.

Detailed protocols, in the form of procedures, assure that samples are collected in a consistent and repeatable fashion. Procedures applicable to water quality sampling are generated, approved, and maintained by the site documentation process.

The serial sampling process will probably not be needed with the wells completed specifically for water quality sampling. However, during the first two years of sampling, the wells will be serially sampled using an abbreviated method. It is anticipated that changes in the water chemistry from stagnated to representative will occur within the first 24 hours of the purging process. Whereas, this change usually occurred over a seven-day period with the old wells.

During the first two or three years of sampling, these wells will be serially sampled with the first sample being analyzed as soon as possible after the pump is turned on and daily there after for a period of four days or until the field parameters (chloride, divalent cations, alkalinity and iron) stabilize. Eh, pH, and conductance will be monitored continuously by using a flow cell with ion-specific electrodes and a real-time readout. After two years of sampling data have been accumulated, a decision will be made to determine if the serial sampling process can be eliminated. If serial sampling is removed from the water quality sampling well protocol, the decision to collect samples will be based on the number of well bore volumes purged and the results of continuous monitoring of temperature, Eh, pH, and conductance.

5.4 Groundwater Pumping and Sampling Systems

The water-bearing units at the WIPP are highly variable in their ability to yield water to surveillance wells. The Culebra, the most transmissive hydrologic unit in the WIPP area, exhibits transmissivities that range many orders of magnitude across the site area and has been the primary focus of the GSP. The Magenta has a lower transmissivity and yields very small quantities of water to wells. Because the water-yielding characteristics of the hydrologic units at the WIPP are variable, different types of pumping equipment are used during water quality sampling activities.

The groundwater pumping and sampling systems used to collect a groundwater sample are designed to provide continuous and adequate production of water so that a representative groundwater sample can be obtained. The wells used for water quality sampling vary in yield, depth, and pumping lift. These factors affect the duration of pumping as well as the equipment required at each well. Based upon expected yields, the wells monitored at WIPP can be divided into three categories according to flow rate: (1) high flow rate of 10 to 25 gallons per minute (gpm); (2) medium flow rate or 1 to 10 gpm; and (3) low flow rate of less than 1 gpm.

The high and medium flow rate wells may use a submersible pump-packer assembly. The low-volume wells may require a gas-driven piston pump-packer assembly. A discussion of the different pump-packer equipment is provided below.

The type of pumping and sampling system to be used in a well depends primarily on the aquifer characteristics and well construction. For example, if well construction is such that it yields contamination to the aquifer (i.e., metal casing) a packer is normally recommended to minimize purging time. If the aquifer yields adequate water to the well to be classified a high or medium production well, a submersible electric pump may be used. However, if the well is completed with the water-bearing unit uncased, a gas piston pump may be needed to minimize stress to the formation walls to prevent collapse of the formation.

Wells that are completed to water quality standards are cased and screened through the production interval with materials that do not yield contamination to the aquifer or allow the production interval to collapse under stress. An electric, submersible pump installation without the use of a packer is an acceptable installation in this instance.

The largest amount of discharge from the submersible pump takes place from a discharge pipe. In addition to this main discharge pipe a dedicated nylon sample line, running parallel to the discharge pipe, is also used. Flow through the pipe is regulated on the surface by a flow control valve and/or variable speed drive controller. Cumulative flow is measured using a totalizing flow meter. Flow from the discharge pipe is routed to a discharge tank for disposal.

The dedicated nylon sampling line is used to collect the water sample that will undergo analysis. By using a dedicated nylon sample line, the water is not contaminated by the metal discharge pipe. The sample line branches from the main discharge pipe a few inches above the pump. Flow from the sample line is routed into the sample collection area. Flow through the sample collection line is regulated by a flow-control valve. The sample line is insulated at the surface to minimize temperature fluctuations.

A gas-driven pump and sampling system can be used on any volume well. When used, the pump intake is set at a predetermined depth near or in the production zone. The pumping rate is adjusted to maintain the water level in the well above the pump intake.

The flow rate for gas driven pumps is controlled by regulating the air pressure on the pump intake or by a flow control valve. Water is continuously discharged into a water storage tank. Detailed protocol for assembling, installing, and controlling pumping and sampling systems is found in the procedures generated, approved, and maintained by the site documentation process.

5.5 Pressure Monitoring Systems

Regardless of which pump is used when sampling a well that was drilled for the geologic site characterization and resource evaluation program, a packer is used to isolate the pump intake from contaminated well-bore fluid that exists in the well above

the sampling zone. If the packer seal is not good, contaminated water from above the packer can leak into the formation water being sampled and bias analytical results. If the packer has a good seal the pressure above the inflated packer should remain constant.

Pressure above the packer is monitored using transducers and/or bubblers to verify that the seal on the packer is good. Pressure below the packer is monitored to ensure that water levels do not fall below the pump intake. Periodic checks of the pressures are conducted during field sampling to verify packer seal integrity. These field checks are recorded on Field Activity Log Forms.

Wells drilled to water-quality specifications do not require the installation of a packer because sample biases due to well construction deficiencies are not present. However, pressures will be monitored in the formation to maintain water level above the pump intake. Procedures governing the installation and use of pressure monitoring devices are generated, approved, and maintained by the site documentation process.

5.6 Sample Analysis

The mobile field laboratory provides a work place for conducting field sampling and analyses. The laboratory is positioned near the wellhead, is climate controlled, and contains the necessary equipment, reagents, glassware, and deionized water for conducting the various analyses.

Two types of water samples are collected: serial samples and final samples. Serial samples are taken at regular intervals and analyzed in the mobile laboratory for various physical and chemical parameters (called field parameters). The serial sample data are used to determine the chemical steady state conditions of the groundwater, as a direct function of the volume of the water being pumped from the well. Interpretation of the serial sampling data enables the TL to make a determination of when steady state conditions are attained in the pumped groundwater.

Final samples are collected when the serially sampled field parameters have achieved a steady state. If one or more of the field parameters do not stabilize, and there is reason to believe it will not, the TL may choose to collect the final sample regardless of this instability in the field parameter(s).

The objective of the serial sampling effort is to obtain representative water samples in a reproducible manner. By definition, a representative groundwater sample is a sample of undisturbed groundwater. A groundwater sample is considered to be representative of the undisturbed groundwater only if it is chemically identical to the undisturbed groundwater (i.e., completely unaltered by the effects of drilling, postdrilling processes and reactions, and sampling procedures). Obtaining a representative groundwater sample is a theoretical ideal. For example, the redox potential of the aquifer groundwater, Eh, is likely to change as a result of pressure decreases (gas loss) and contamination by atmospheric oxygen that occurs during the sampling process. The ratios between the different oxidation states of a multivariant element may change, and

the total concentration of that element may also change during sampling due to precipitation.

To determine how close the pumped groundwater is to being representative, a comparison is made by monitoring the same selected field parameters which were used to initially define the background characteristics of the water. When these parameters appear stable, then the determination is made that the water sample is representative. Stability is usually defined as ± 5 percent of the average of preceding parameter measurements made on the final day of sampling for previous rounds.

When stability has been determined, a final sample is collected. The final sample is considered to be as representative a sample of the undisturbed groundwater as can possibly be obtained considering the analytical and technical means at hand.

5.6.1 Serial Samples

Serial samples are collected and analyzed in the mobile laboratory to detect and monitor the chemical variation of the groundwater as a function of the volume of water pumped. The purpose of implementing this rigorous serial sampling and analysis program is to ascertain when the pumped groundwater has reached a chemical steady state. Once serial sampling begins, the frequency at which serial samples are collected and analyzed is left to the discretion of the TL. The serial sampling frequency is based upon the site-specific conditions existing at each well, but usually is performed a minimum of three times during a sampling round.

The three field parameters of temperature, Eh, and pH are determined by either an "in-line" technique, using a self-contained flow cell, or an "off-line" technique, in which the samples are collected from a nylon sample line at atmospheric pressure. The iron, divalent cation, chloride, alkalinity, specific conductance, and specific gravity samples are collected from the nylon sample line at atmospheric pressure.

New polyethylene containers are used to collect the serial samples from the nylon sample line. Serial sampling water collected for solute and specific conductance determinations is filtered through a 0.45 µm filter membrane using a stainless steel, in-line filter holder. Filtered water is used to rinse the sample bottle prior to serial sample collection. Unfiltered groundwater is used when determining temperature, pH, Eh, and specific gravity. Sample bottles are properly identified and labeled.

The filtered sample collected for solute analyses is immediately analyzed for iron and alkalinity, as these two solution parameters are extremely sensitive to changes in the ambient water-sample pressure and temperature. The sample aliquot needed for the other chemical parameter analyses may be taken from a second filtered sample bottle. Temperature, pH, and Eh, when not measured in a flow cell, are measured at the approximate time of serial sample collection; these samples are collected from the unfiltered sample line.

Experience gained from the serial sampling of wells has shown that samples to be analyzed for chloride and divalent cations can be stored for one week prior to analysis with confidence that the analytical results will not be altered.

Upon completion of the collection of the final sample suite, the serial sample bottles accrued throughout the duration of the pumping of the well are discarded. No serial sample bottles will be reused for sampling purposes of any sort. However, serial samples may be archived for a period of time depending upon the need. Procedures for sample collection and analysis are generated, approved, and maintained by the site documentation process.

5.6.2 Final Samples

The final sample is collected once the pumped groundwater has achieved a chemically steady state. A serial sample is also collected and analyzed for each day of final sampling. Sample preservation, handling, and transportation methods are designed to maintain the integrity and representativeness of the final samples.

Prior to collecting the final samples, the collection team must consider the analyses to be performed so that proper shipping or storage containers can be assembled.

Final samples are sent to contract laboratories and analyzed for general chemistry, radionuclides, metals, and selected volatile organic compounds that are specific to the waste anticipated to arrive at WIPP. Gases and redox-couples were analyzed during the baseline study, but these data are not needed for environmental monitoring and are no longer obtained on a routine basis.

Water samples are collected at atmospheric pressure using either the filtered or unfiltered nylon sampling lines branching from the main sample line. The samples are collected in new and unused glass and plastic containers.

Before the final sample is taken, all plastic and glass containers are rinsed with the pumped groundwater, either filtered or unfiltered, dependent upon analysis protocol. When the rinsing procedure is completed, the final sample is collected.

5.7 Sample Preservation, Tracking, Packaging and Transportation

Many of the chemical constituents that are measured are not chemically stable and need to be preserved. Samples requiring acidification are treated with either high purity hydrochloric acid, nitric acid, or sulfuric acid (ULTREX or equivalent), depending upon the standard method of treatment required for the particular parameter suite.

The procedure used by the contract laboratory to which the samples are being sent prescribes the type and amount of preservative which should be used. This information is recorded on the Final Sample Checklist for use by field personnel when final samples are being collected.

The sample tracking system at WIPP uses uniquely numbered Chain of Custody Forms and Request for Analysis Forms. The primary consideration for storage or transportation is that samples must be analyzed within the prescribed holding times for the parameters of interest. Procedures for sample tracking and preservation are generated, approved, and maintained by the site documentation process.

The prescribed transport temperature for the organic samples is four degrees Celsius. This temperature must be maintained until the sample reaches the contracted laboratory.

Insulated shipping containers packaged with reusable blue ice are used to keep the samples cool during transport to the contract laboratory. Hold times for specific analytical parameters require samples to be shipped by express air freight. The coolers are packaged to meet Department of Transportation and International Air Transportation Association commercial carrier regulations.

5.8 Quality Assurance, Records Management and Document Control

All aspects of quality assurance, records management, and control of documents generated as a result of WQSP are governed by the QAPD; WP 15-PR, Records Management Plan; and implementing procedures generated, approved, and maintained by the site documentation process.

A chemistry laboratory notebook is maintained in the mobile laboratory to record the overall conditions at the well, the analytical difficulties or problems experienced, and any information which may be pertinent to future interpretation and scientific use of the field data. The original notebook is kept in the field laboratory. A copy of the notes made for each sampling round is kept in a fire-resistant file cabinet.

All field data collected are organized into a data book. The typical field data book contains the following:

- A copy of all of the notes entered into the laboratory notebook concerning the sampling round.
- A copy of all chain of custody forms and request for analysis forms used to distribute the final samples.
- A copy of the completed final sample checklist.
- A copy of all standardization forms.
- A hard copy printout of all computer data entries.
- A copy of all of the Serial Sampling Report Forms submitted for the sampling round.

- A copy of all worksheets used to prepare the data for entry into the computer.
- A written summary report containing a description of the well completion data, a brief summary of serial sampling results, and general observations.
- A copy of all Field Sketch Plan Forms.
- A copy of all Field Activity Log Forms.
- A computer printout of all data logger information, if a data logger was used.
- Validated Check Print copies of all data sheets.

A contract laboratory data book is made for each contract laboratory used to analyze samples from a particular well. The contract laboratory data book contains at a minimum:

- A copy of the contract laboratory analytical report.
- A copy of the computer data generated.

Data collected as a result of WQSP activities are summarized and reported on an annual basis in the Site Environmental Report. Raw data are stored in fireproof cabinets in the EM Section for a period of two years and then turned over to PRS for storage in accordance with the RIDS.

5.9 Calibration Requirements

The equipment used to collect data for the WQSP is to be calibrated in accordance with WP 10-AD, WIPP Maintenance Administrative Procedures Manual. The metrology laboratory is responsible for calibrating needed equipment on schedule, in accordance with written procedures. The EM Section is responsible for maintaining current calibration records for each piece of equipment.

6.0 WATER LEVEL MONITORING PLAN

6.1 Scope

This section of the WIPP GSP serves as the controlling document for the WLMP. The WLMP is a subprogram of the GSP. The quality assurance activities of the WLMP are in strict accordance with the QAPD and the quality assurance implementing procedures specific to environmental monitoring are found in WP 02-3, Environmental Monitoring Procedures Manual.

Water level monitoring will continue through the postoperational phase of the WIPP. This plan addresses the activities of the WLMP during the preoperational and operational phases of the WIPP. Postoperational activity plans will be formulated at a

later date and will address the objectives of water level monitoring as required at the time of decommissioning.

6.2 Introduction

This program will continue the collection and documentation of water level data initiated by the U.S. Geological Survey (Richey, 1987) and SNL (Stensrud et al., 1988) as part of the WIPP Site Characterization Program.

As currently planned, water level measurements will be conducted using hydrologic test wells that were constructed for the site characterization and WQSP. These test wells are distributed geographically both within and surrounding the WIPP site. The frequency of measurement is subjectively defined by the need to record the dynamic nature of the potentiometric surface through time.

On October 1, 1988, the ES&H Department assumed responsibility for Groundwater Level Monitoring Activities. At that time a WLMP plan was still being developed. In June of 1989, an initial plan was finalized entitled WP 07-2, WIPP Water Level Monitoring Program Plan, IT Corp. (June 1989). WP 07-2 was subsequently replaced in 1990 by WP 02-1, Groundwater Monitoring Program Plan and Procedures Manual.

Collection of groundwater-level data assists the DOE in meeting performance assessment, regulatory compliance, and permitting requirements. These data also provide:

- Data collection as required by the Environmental Monitoring Plan.
- A means to fulfill commitments made in the FEIS.
- A means to comply with future groundwater inventory and monitoring regulations.
- Input for making land use decisions, (i.e., designing long-term active and passive institutional controls for the site).
- Assistance in understanding any changes to readings from the water-pressure transducers installed in each of the shafts to monitor water conditions behind the liners.
- An understanding of whether or not the horizontal and vertical gradients of flow are changing over time.

6.3 Objective

The objective of the WLMP is to extend the documented record of water-level fluctuations in the Culebra and Magenta members of the Rustler Formation in the vicinity of the WIPP facility. Water-level data will also be collected from wells

completed in other water-bearing zones overlying and underlying the WIPP repository horizon when access to those zones is possible. This includes, but is not limited to, the Bell Canyon Formation, the Forty Niner member of the Rustler, the contact zone between the Rustler and Salado Formations, and the Dewey Lake Red Beds, when access to these zones is possible.

The scope of the program is subject to change depending upon the following:

- Data trends
- Performance assessment program needs
- Environmental Monitoring Program needs
- Regulatory compliance needs

Water level measurements will be taken monthly in at least one accessible completed interval at each available well pad. At well pads with two or more wells completed in the same interval, quarterly measurements will be taken in the redundant wells.

Water level monitoring will continue through the life of the WIPP Project. It may be deemed necessary to temporarily increase the frequency of monitoring to effectively document naturally occurring or artificial perturbations that may be imposed on the hydrologic systems at any point in time. This will be conducted in selected key wells by increasing the frequency of the manual water-level measurements or by monitoring water pressures with the aid of electronic pressure transducers and remote data-logging systems.

One of the postulated contaminate pathways to the biosphere in the event of a release is believed to be in the water-bearing zones of the Rustler Formation, more specifically, the Magenta and Culebra members. The Culebra is believed to be the more conductive of the two (Mercer, 1983) and has received the most attention in site characterization studies. Other water bearing zones in the vicinity of the WIPP site, in which a limited number of hydrologic test wells have been completed, include the Dewey Lake Red Beds, the Rustler/Salado Contact, the Forty Niner Member of the Rustler, and the Bell Canyon Formation. All of the above listed zones will be monitored as part of this program plan, subject to availability.

Water level fluctuations of confined water bearing units may result from a variety of hydrologic phenomena (Freeze and Cherry, 1979) and (Davis and DeWeist, 1966). These include:

- Changes in groundwater storage (e.g., groundwater recharge)
- Changes in atmospheric pressure
- Deformation of the water bearing zone (e.g., earthquakes and earth tides)

- Disturbances within or adjacent to a well (e.g., groundwater pumping and shaft construction)

Interpretation of water level measurements and corresponding fluctuations over time is complicated at the WIPP by spatial variation in fluid density both vertically in well bores and areally from well to well. To monitor the hydraulic gradients of the hydrologic flow systems at the WIPP accurately, actual water level measurements and the densities of the fluids in the well bores must be known. When both of these parameters are known, equivalent freshwater heads can be calculated. The concept of freshwater head is discussed in Lusczynski (1961) where the following definition is provided:

> Fresh water head at a given point in groundwater of variable density is defined as the water level in a well filled with fresh water from that point to a level high enough to balance the existing pressure at that point. Fresh water heads define hydraulic gradients along a horizontal.

A discussion explaining the calculation of freshwater heads from midformation depth at WIPP can be found in Haug, et al. (1987).

A Pressure Density Survey Program (PDSP) has been conducted to determine the actual variation in density gradients existing in the test wells. The PDSP measured the actual midformation pressures of the Culebra. Data from this program have identified those wells in which some adjustment to measured water level values must be accounted for in order to calculate the measured water levels accurately in terms of equivalent freshwater heads.

6.4 Field Methods

To obtain an accurate groundwater level measurement, a calibrated water level measuring device is lowered into a test well and the depth to water is recorded from a known reference point. When using an electrical conductance probe, the depth to water can be determined by reading the appropriate measurement markings on the embossed measuring tape when the alarm is activated at the surface. Specific procedures regarding the specific activities governing the Water Level Monitoring Program are generated, approved, and maintained by the site documentation process.

6.5 Records and Document Control

All incoming data will be processed in a timely manner to assure data integrity. The data management process for water level measurements begins with completion of the field data sheets. Date, time, tape measurement, equipment identification number, calibration due date, initial of the field personnel, and equipment/comments are recorded on the field data sheets. If, for some unexpected reason, a measurement is not possible (i.e., a test is under way that blocks entry to the well bore), then a notation as to why the measurement was not taken is recorded in the comment column. Personnel also use the comment column to report any security observations (i.e., well lock missing).

Data recorded on the field data sheets and submitted by field personnel are subject to guidelines outlined in WP 02-3, Environmental Procedures Manual. The data are entered onto a computerized worksheet. The worksheet calculates water level in both feet and meters relative to the top of casing and also relative to mean sea level.

A check print is made of the worksheet printout. The check print is used to verify that data taken in the field is properly reported on the database printout. A minimum of 10 percent of the spreadsheet calculations are randomly verified on the check print to ensure that calculations are being performed correctly. If errors are found, the worksheet is corrected. The data contained on the computerized worksheet are translated into a database file. A printout is made of the database file. The data each month are then compiled into report format and transmitted to the appropriate agencies as requested by the DOE.

A computerized database file is maintained for all groundwater level data. Monthly and quarterly data are appended into a yearly file. Upon verification that the yearly database is free of errors, it is appended into the project database file. A printed copy of the project database is maintained in the ES&H EM fire-resistant storage area current through December of the preceding year.

6.6 Reporting

Data collected from this program are reported in the Annual Site Environmental Report (ASER). The ASER includes all applicable information that may affect the comparison of water level data through time. This information will include but is not limited to:

- Well configuration changes that may have occurred from the time of the last measurement (i.e., plug installation and removal, packer removal and reinstallation, or both; and the type and quantity of fluids that may have been introduced into the test wells).

- Any pumping activities that may have taken place since publication of the last annual report (i.e., water quality sampling, hydraulic testing, and shaft installation or grouting activities).

6.7 Calibration Requirements

The equipment used in taking groundwater level measurements is to be calibrated in accordance with WP 10-AD, WIPP Maintenance Administrative Procedures Manual. The WID metrology laboratory is responsible for calibrating needed equipment on schedule, in accordance with written procedures. The EM Section is responsible for maintaining current calibration records for each piece of equipment.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix HYDRO

M

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area

GEOHYDROLOGY OF THE PROPOSED WASTE ISOLATION PILOT PLANT SITE, LOS MEDAÑOS AREA, SOUTHEASTERN NEW MEXICO

By Jerry W. Mercer

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4016

Prepared in cooperation with the

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Albuquerque, New Mexico

1983

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

In this report figures for measurements are given in inch-pound units only. The following table contains factors for converting to International System (S.I.) units.

Multiply inch-pound units	By	To obtain S.I.units
foot	0.3048	meter
foot per mile	0.1894	meter per kilometer
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
gallon per minute	0.06309	liter per second
ton (short)	0.09072	megagram
pound per square inch	0.07031	kilogram per square centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer
inch	25.4	millimeter

Chemical concentrations are given only in metric units—milligrams per liter, micrograms per liter, picocuries per liter, or milliequivalents per liter. Liquid densities are given only in metric units—grams per cubic centimeter.

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level." NGVD of 1929 is referred to as sea level in this report.

GEOHYDROLOGY OF THE PROPOSED WASTE ISOLATION PILOT PLANT SITE, LOS MEDAÑOS AREA, SOUTHEASTERN NEW MEXICO

By Jerry W. Mercer

ABSTRACT

Geohydrologic data have been collected in the Los Medaños area at the U.S. Department of Energy's proposed Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico since 1975 as part of a study evaluating the feasibility of storing defense-associated nuclear wastes within the bedded salt of the Salado Formation of Permian age. Drilling and hydrologic testing have identified three principal water-bearing zones above the Salado Formation and one below that could potentially transport wastes to the biosphere if the proposed facility were breached. The zones above the Salado are the contact between the Rustler and Salado Formations and the Culebra and Magenta Dolomite Members of the Rustler Formation of Permian age. The zone below the Salado Formation consists of channel sandstones in the Bell Canyon Formation of the Permian Delaware Mountain Group.

Determinations of hydraulic gradients, directions of flow, and hydraulic properties were hindered because of the negligible permeability of the water-bearing zones. Special techniques in drilling, well completion, and hydraulic testing have been developed to determine the hydrologic characteristics of these water-producing zones.

Data collected from drill-stem tests in test wells penetrating the Bell Canyon Formation indicate that the brines associated with the unit usually occur in relatively isolated channel sandstones that are permeable (hydraulic conductivities ranging from 7×10^{-3} to 5×10^{-2} foot per day) but grade vertically and laterally into siltstones and shales with little permeability. Potentiometric-surface maps (as equivalent freshwater heads) show flow in the Bell Canyon Formation to be laterally across the basin to the northeast, but the movement probably is extremely slow. The dissolved ions in the brines of the Bell Canyon are predominantly sodium and chloride with dissolved-solids concentrations ranging from 180,000 to 270,000 milligrams per liter.

The Rustler Formation contains the principal water-bearing zones identified at the WIPP site, and thus were the most extensively studied. Calculations from pumping, slug, and pressure-pulse tests indicate that the transmissivities of the individual units vary laterally within as well as between the individual beds. The Culebra Dolomite Member is the most persistent and productive hydrologic unit in the WIPP site area and also has the greatest variability of hydraulic properties. This variability results from the size and number of fractures, which in turn are related to the degree of evaporite dissolution within the Rustler Formation. Transmissivities calculated for the Culebra in Nash Draw immediately west of the WIPP site range from 18 to 1,250 feet squared per day, whereas they range from 1×10^{-3} to 140 feet squared per day at the WIPP site. Potentiometric-surface maps (as equivalent freshwater heads) indicate flow in the Culebra Dolomite Member of the Rustler Formation at the WIPP site to be southerly, eventually flowing southwestward to Nash Draw. Determination of flow directions, however, may be affected significantly by directional differences in permeability along fractures. The dominant dissolved ions are sodium and chloride, with calcium, magnesium, potassium, and sulfate being other major ions present. Hydrochemistry studies indicate an increase of mineralization of water from west to east along with a decrease in circulation of the flow system. The dissolved-solids concentrations range from 2,950 to 239,000 milligrams per liter.

The Magenta Dolomite Member is the uppermost hydrologic unit. Water in this unit either occurs in thin silt beds and silty dolomite or in fractures where extensive evaporite dissolution has occurred in the Rustler Formation. Transmissivities calculated for the Magenta in Nash Draw range from 53 to 375 feet squared per day, whereas they range from 4×10^{-3} to 1×10^{-1} foot squared per day at the WIPP site. Potentiometric-surface maps (as equivalent freshwater heads) indicate flow in the Magenta to be westward toward Nash Draw where the flow direction is then controlled by the evaporite dissolution in the Rustler. The water is brackish to briny. The dominant dissolved ions are sodium and chloride with calcium, magnesium, potassium, and sulfate being other major ions. Dissolved-solids concentrations range from 5,000 to 261,000 milligrams per liter.

The least productive water producing zone is at the contact between the Rustler and Salado Formations where brine occurs either in an evaporite residuum or in clays along bedding planes. The residuum is concentrated along Nash Draw and is most extensive between Malaga Bend on the Pecos River 10 miles southwest of the proposed WIPP site and Salt Lake where transmissivities are as large as 8,000 feet squared per day. North of Salt Lake in Nash Draw the transmissivities range from 2×10^{-4} to 8 feet squared per day; transmissivities at the WIPP site range from 3×10^{-5} to 5×10^{-2} foot squared per day. Potentiometric surface maps (as freshwater equivalent heads) indicate flow in the contact zone to the southwest across the WIPP site toward Nash Draw. The dissolved solids in the brines at the Rustler-Salado contact are predominantly sodium chloride with dissolved-solids concentrations ranging from 41,500 to 412,000 milligrams per liter. Large potassium and magnesium ion concentrations in the eastern part of the site may indicate restricted circulation of the brines.

The relative static heads or formation pressures of the hydrologic units in the Rustler decrease with depth; that is, static heads are the highest in the Magenta and the lowest at the contact zone between the Rustler and Salado. In the WIPP site area, the presence of relatively impermeable interbeds of halite and anhydrite probably restricts vertical movement between units. The Rustler Formation is probably recharged in Bear Grass Draw about 20 miles northwest of the WIPP site and in Clayton Basin which is about 12 miles northwest of the WIPP site. The major discharge occurs at Malaga Bend on the Pecos River.

INTRODUCTION

The U.S. Geological Survey, at the request of the U.S. Department of Energy, is investigating the geohydrology of the proposed Waste Isolation Pilot Plant (WIPP) site in an area known as Los Medaños, 30 miles east of Carlsbad, New Mexico (fig. 1). Geohydrologic data have been collected from this area by the U.S. Geological Survey intermittently since 1972 and on a continuous basis since 1975.

The WIPP is a project of the Department of Energy and is proposed as a radioactive-waste storage facility to be placed at a depth of approximately 2,150 feet in the bedded salts of the Permian Salado Formation. The WIPP is planned to demonstrate disposal technology for transuranic wastes. After a period of "pilot" operation in a waste retrievable mode, it is expected WIPP will be converted into a facility for permanent storage of transuranic wastes (Powers, 1981, p. 119).

The characteristics of the regional geohydrologic systems associated with the WIPP site need to be defined because of the potential for transport of radionuclides to the biosphere by ground water in the event the storage facility is breached. Another equally important aspect of the WIPP site is the geologic stability of the formation in which the wastes will be placed. Because the formation of concern is easily dissolved halite, the inherent stability of the formation is directly related to the hydrologic regime within and around the formation and needs to be studied in detail.

At the WIPP site, water-bearing zones above and below the salt section could affect stability as well as potentially transport radionuclides. Because some of these water-bearing zones are more likely to be involved than others, the degree of certainty required in the definition of flow paths, velocity of ground water, quality of water, and other characteristics is different for some zones than others.

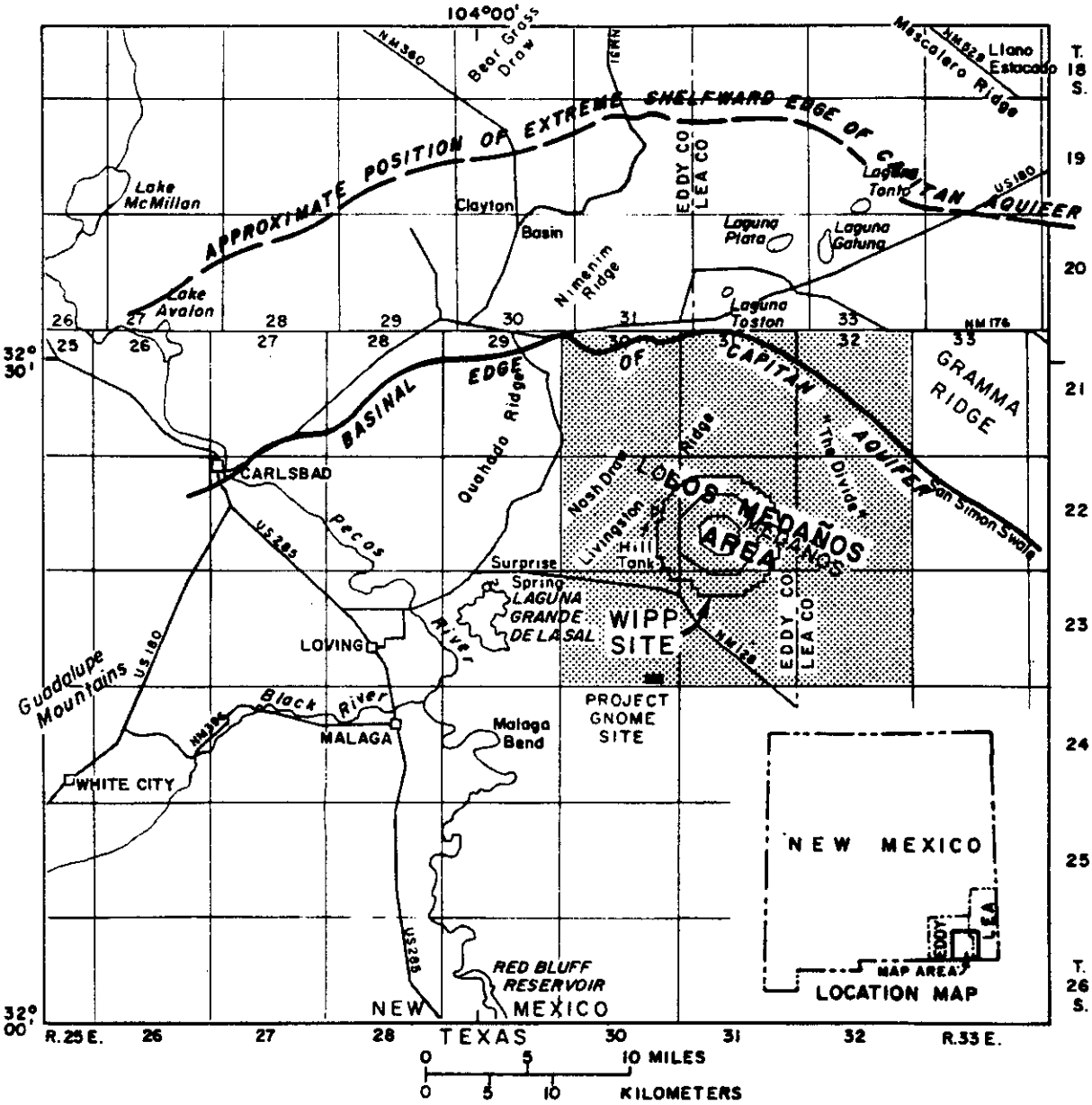

Figure 1.--Location of Los Medaños area and the proposed Waste Isolation Pilot Plant (WIPP) site.

Purpose and scope

This report discusses the ground-water systems and the interpretation of test results in the water-bearing zones above and below the proposed facility. Hydrologic data used in these analyses were collected during 7 years beginning in 1975 and were from 33 test holes drilled for, or converted to, hydrologic test holes. The study included: the determination of potential ground-water flow boundaries; potentiometric heads; ground-water chemistry; and hydraulic properties obtained through pumping, slug, pressure-pulse, and tracer tests.

The hydrologic investigation is part of a comprehensive study related to site characterization and validation conducted on behalf of the U.S. Department of Energy by Sandia National Laboratories. The hydrologic studies were conducted by the U.S. Geological Survey and were designed to supplement the technical site-characterization program performed by Sandia.

Location and areal extent

The study area of approximately 800 square miles is located within the northern part of the Delaware Basin in eastern Eddy and western Lea Counties, New Mexico and includes all or part of Tps. 20-24 S., Rs. 29-33 E. (fig. 1). The WIPP site is approximately in the center of the study area and covers about 54 square miles, encompassing almost all of T. 22 S., R. 31 E. (fig. 1). It is outlined in figure 1 by a proposed exclusion boundary, or buffer zone, surrounding the area of the proposed facility.

The WIPP site is in an area referred to as Los Medaños. Los Medaños is part of a gently sloping terrain that rises eastward from the Pecos River to the "caprock" of the Llano Estacado. The topographic relief generally is less than 50 feet with the surface area covered with sand dunes. Vegetation consists of mesquite, scrub oak, and other plants typical of the northern Chihuahuan desert. The average annual precipitation is 11 to 13 inches, while evaporation from surface water exceeds 98 inches per year. The primary land use is cattle grazing. Potash is being mined in the area to the north and west; petroleum exploration and development recently has become quite intensive.

The major topographic features in the area include two depressions called Nash Draw and Clayton Basin. Nash Draw is the larger, being 4 to 6 miles wide and 15 to 18 miles long, extending southward through the western part of the area (fig. 1). These features are believed to be formed by solution-subsidence and collapse, having then been extensively modified by erosion. Neither Nash Draw nor Clayton Basin have external surface drainage.

Los Medaños area is drained by the Pecos River, the only perennial stream in the region. The Pecos drainage system trends southeastward through the western margin of the study area and is at its closest point 10 miles from the WIPP site.

Laguna Grande de la Sal (Great Salt Lake), a large salt lake in the southern end of Nash Draw, contains water most of the time. Numerous small lakes and playas contain water only after intense rains, whereas small permanent tailing ponds, resulting from potash mining, occupy several of the smaller closed depressions.

Previous investigations

The Delaware Basin geology in southeastern New Mexico has been studied extensively during the past 40 years, especially since the increase in oil and gas exploration. Prior to the establishment of the WIPP project, however, relatively little study was devoted to the Permian formations (above the Bell Canyon Formation), which include the evaporites of concern. Lang (1937) was one of the first to discuss these rock units and topographic features in the area; however, the most intensive geologic work prior to the WIPP project was done by C. L. Jones and others in connection with the U.S. Geological Survey's study of the potash deposits of the Carlsbad area. Reports were prepared by Jones (1954, 1959, 1972), Jones and Madsen (1959), and Jones, Bowles, and Bell (1960). The other significant geologic studies concentrating on this sequence of rocks were related to the Gnome experiment (an underground nuclear test) and include work by Vine (1963), Cooper (1960, 1961, 1962a, and 1962b), and Gard (1968). Numerous recent geologic papers concerned with the WIPP site investigations have been published and are included as references in this report and also are included in a report published by Sandia National Laboratories (Powers and others, 1978).

The first detailed hydrologic work in the area was conducted by Robinson and Lang (1938) during studies of the occurrence of brine springs in the Malaga area during 1937-38. Additional work was performed in the Malaga Bend area from 1938 to 1941; the results of this work, particularly that of Theis and Sayre (1942), was published in the "Reports of the participating agencies, the Pecos River Joint Investigation." Further detail on the Malaga Bend saline problem was added by Hale (1945a, 1945b, 1961), Hale and Clebsch (1958), Hale, Hughes, and Cox (1954), Cox and Kunkler (1962), Cox and Havens (1965), and more recently, Havens and Wilkins (1980) and Kunkler (1980). The regional occurrence of ground water in the area was discussed in Hendrickson and Jones (1952) and Nicholson and Clebsch (1961). Hiss (1976) made an extensive contribution to the hydrology of the Capitan Reef in a dissertation prepared while working with the U.S. Geological Survey. Others that made contributions to an understanding of the Capitan Reef include Bjorklund and

Motts (1959), Halpenny and Greene (1966), and Motts (1968). Associated with the Project Gnome investigations, contributions by Cooper (1961, 1962a, 1962b), Cooper and others (1962), and Cooper and Glanzman (1971) have greatly added to an understanding of the geohydrology of the Rustler Formation.

Recent investigations related to hydrologic characteristics of the WIPP site began with a review of the geology and hydrology of the Carlsbad potash area (Brokaw, Jones, Cooley, and Hays, 1972) and a review of the Los Medanos area (Jones, Cooley, and Bachman, 1973). A review of the regional hydrology of the WIPP site area was presented by Mercer and Orr (1977), while detailed hydrologic studies are included in an interim data report by Mercer and Orr (1979) and in a paper by Mercer and Gonzalez (1981).

The dissolution in the WIPP area is complex and has been considered in studies of the Cenozoic history of the area by Bachman (1973, 1974, 1976, 1980, and 1981). These studies added greatly to an understanding of the hydrologic systems in the area. Additional interpretations of dissolution have been prepared by Lambert (1982) and Anderson (1978, 1981).

Method of investigation

The objective of the hydrologic program was to define the hydrologic characteristics of the flow path of the ground-water system that could potentially transport wastes to the biosphere. Hydrologic information required to define the flow-path characteristics included static heads or reservoir pressures, the magnitude and direction of ground-water flow, and the chemical characteristics of the water that may have an effect on dissolution or on chemical interactions with rocks along the flow path.

The lack of very permeable rocks and the consequent lack of existing wells within the WIPP study area necessitated the development of a comprehensive drilling and testing program. This program included test holes for both site-specific geohydrologic studies and regional studies. Seventy-one test holes were drilled during WIPP studies; of these, 26 were specifically for hydrologic testing (H series) and 13 of the 45 geologic test holes were later used or converted for hydrologic testing (table 1, fig. 1A). These holes range in depth from 154 to 4,910 feet. Because the water-producing zones had little permeability and consequently would require months of recovery time and testing, special techniques in drilling, well completion, and hydraulic testing were developed to determine the hydrologic characteristics of the water-producing zones (Basler, 1983).

The air-rotary method was used to drill two types of holes specifically designed for hydrologic testing: (1) Holes were drilled, cased, cemented, and then perforated at the selected test zone; (2) three closely spaced holes were drilled in a complex, each cased down to a specific test interval. Each of these holes in the second type then was completed by coring to total depth

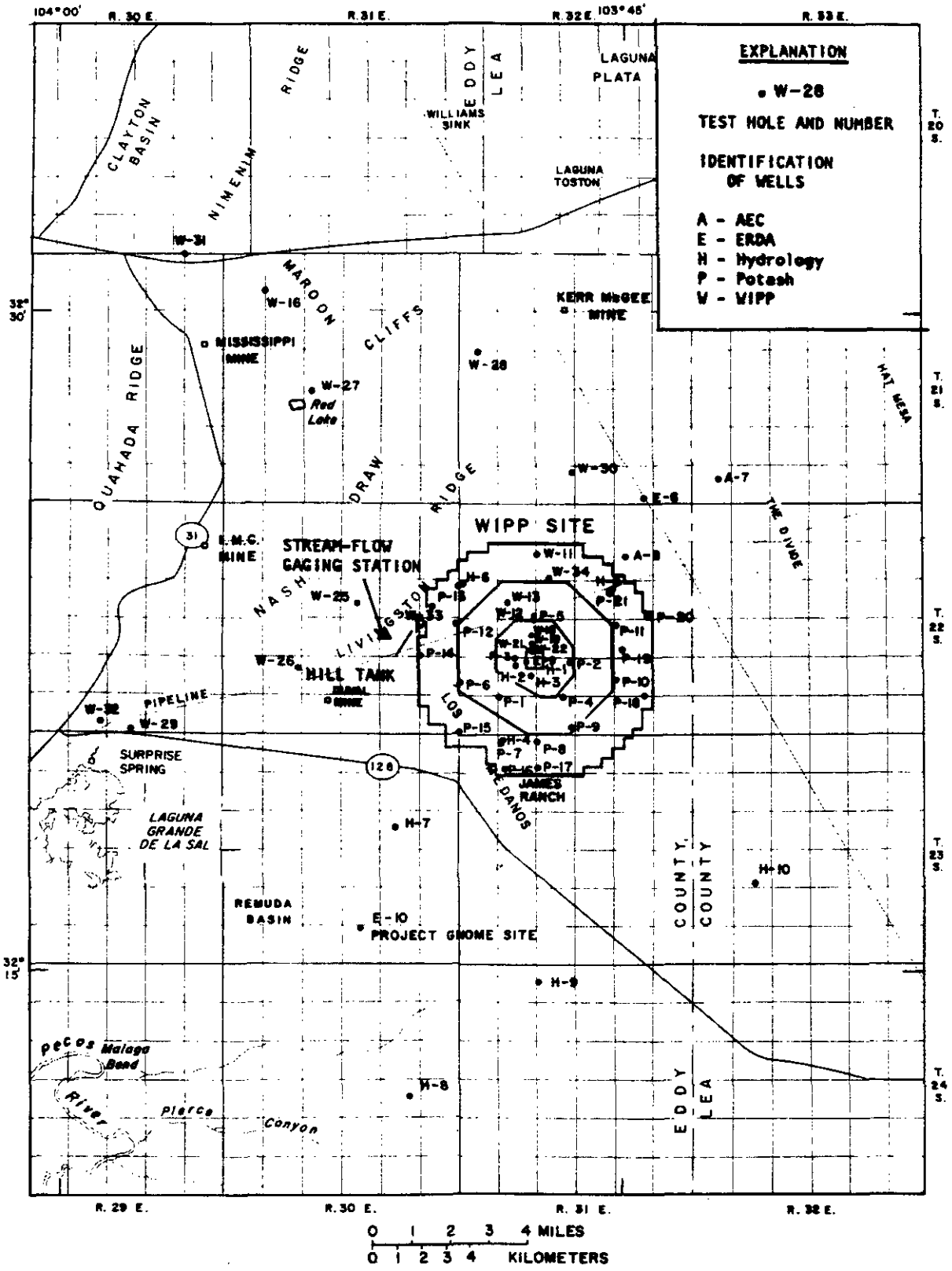

Figure 1a.--Location of test holes at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

through the zone of interest, leaving an open-hole interval for testing. The three-hole complex proved to be the most commonly used and most effective design (Mercer and Gonzalez, 1981, p. 126). The casing-cementing-perforating method continued to be used in the geologic test holes, some of which later were converted to hydrologic holes.

Testing equipment designed for the WIPP geohydrologic studies used hydraulically inflated packers to isolate specific horizons and pressure transducers to measure changes in pressure head. Withdrawal, injection-slug, and pressure-pulse tests were conducted in the zones with little permeability, and standard aquifer tests were conducted in zones with greater permeability. These data were analyzed by methods discussed by Cooper, Bredehoeft and Papadopulos (1967), Lohman (1972), and Bredehoeft and Papadopulos (1980). A detailed discussion of the methods used, including data and data analyses, are not included in this report; however, this information is available in previous reports (Mercer and Orr, 1979; Mercer, Davis, Dennehy and Goetz, 1981; Mercer and Gonzalez, 1981; Dennehy and Mercer, 1982; and Dennehy, 1982).

During the investigation, water levels were measured periodically in about 40 wells. The geology of the water-bearing units was interpreted by use of formation cuttings, cores, and geophysical logs. In addition, water samples were collected from 52 selected intervals in 40 wells. Complete analyses of these samples are included in the data reports and selected analyses are included in table 2 of this report. Other hydrologic data from previous reports were used extensively in this report.

Acknowledgments

This investigation was funded by the U.S. Department of Energy, a cooperative effort of the U.S. Geological Survey and Sandia National Laboratories. Field operations support was directed by Robert Statler of Sandia National Laboratories, and scheduling and direction of support operation were the efforts of W. E. Cunningham, D. L. Bradley, Wayne Laney, and Matthew Wilson of Fenix and Scisson, Inc. Technical reviews and assistance in program development were provided by Wendell Weart, Dennis Powers, Les Hill, and Don Gonzalez of Sandia. Special acknowledgment is made to the U.S. Geological Survey personnel who assisted in the hydrologic studies in the field, primarily C. L. Jones, R. P. Snyder, G. O. Bachman, and R. K. DeWees. James Basler was responsible for most of the data collection and for the design of instrumentation for testing low permeability; data analyses and assistance in data collection were handled by Kevin Dennehy and Jane Wells.

GEOLOGIC SETTING

Sedimentary rocks of the Delaware Basin that outcrop within the WIPP site area range in age from Permian to Quaternary (table 3). The oldest rocks crop out to the west and successively younger rocks are to the east. Detailed stratigraphy primarily is based on information obtained from drill holes because the rocks generally are covered by Quaternary caliche and semi-stabilized and active dune sand. Seventy-one holes ranging in depth from 154 feet to 4,910 feet have been drilled for geologic and hydrologic investigations. Rocks penetrated in these test holes mainly consist of Permian sandstones, evaporites, and red beds, but they also include some Triassic sandstone and Tertiary and Quaternary deposits.

The oldest and deepest formations studied are included in the Guadalupian Delaware Mountain Group which forms the basin floor for the Ochoan evaporite sequence. The margins of the basin are delineated by an encircling Guadalupian reef complex consisting of the Capitan Limestone and equivalent carbonate units, which is not present under the site but nonetheless is important hydrologically. The Ochoan Series within the basin predominantly is halite and anhydrite, but also contains potash, limestone, dolomite, and fine-grained clastics. The Ochoan Series, in ascending order, includes the Castile, Salado, and Rustler Formations and the Dewey Lake Red Beds. The units above the Dewey Lake Red Beds consist of the Triassic Chinle Formation and the Santa Rosa Sandstone, small outliers of the Tertiary Ogallala Formation, and discontinuous bolson deposits of the Quaternary Gatuña Formation. A thin caliche caprock of Holocene age extends across most of the study area and locally is overlain by a shifting mantle of semi-stabilized dune sands. Holocene alluvium is present along the Pecos River.

Late Tertiary subsidence of the Delaware Basin was followed by regional uplift that caused eastward tilting of the beds in the basin. This structural deformation was later modified by local subsidence and karst development in Nash Draw, Clayton Basin and the Malaga Bend area due to near-surface salt dissolution in the Permian evaporites.

STRATIGRAPHY

Delaware Mountain Group

The Delaware Mountain Group is part of the Guadalupian Series deposited during the Permian age and mainly is composed of fine-grained clastic rocks with a few thin limestone and shale beds. The group is divided, in ascending order, into the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. The Delaware Mountain Group is underlain by the Bone Spring Formation of Leonordian age, which consists of basinal siltstone, chert, and dark limestone. The Ochoan Series overlies the Delaware Mountain Group and

principally consists of evaporites with increasing quantities of red mudstone and siltstone in the younger rocks. The following table lists the formations and their respective thicknesses from the Richardson and Bass, No. 1 Regan H. Legg well (T. 22 S., R. 30 E., sec. 27) and the Clayton W. Williams, Jr., Badger Unit Federal well (T. 22 S., R. 31 E., sec. 15) near the WIPP site.

	Legg well	Badger Unit well
Bell Canyon Formation	1,415 feet	961
Cherry Canyon Formation	1,050 feet	1,047
Brushy Canyon Formation	1,605 feet	1,936

Detailed descriptions of these formations can be found in publications by King (1948), Newell and others (1953), Hayes (1964), and Sullivan (1979). The Bell Canyon Formation is the closest water-bearing rock unit underlying the proposed WIPP facility. For this reason, the stratigraphy and hydrologic characteristics of this formation are described in detail in this report.

The Brushy Canyon Formation and Cherry Canyon Formation are composed mostly of siltstone or shales and thin fine-grained sandstone with a few thin limestone beds. Conglomerate and coarser grained sandstone are found only in the Brushy Canyon Formation (Harms, 1974). These units also interfinger with their reef-facies equivalents, the Goat Seep Limestone and San Andres Limestone (fig. 2).

Bell Canyon Formation--Stratigraphic relationships of the Bell Canyon Formation are of importance when studying the hydrology of the Delaware Mountain Group. The Bell Canyon is the fore-reef facies deposited in the Delaware Basin (Watson, 1979, p. 7). The Capitan Limestone is the reef facies equivalent to the Bell Canyon and interfingers with the Bell Canyon along the basin margin (fig. 2). The upper part of the Bell Canyon Formation was studied using cores from three test holes drilled near the WIPP site -- ERDA-10, AEC-7, and AEC-8. The stratigraphic subdivisions used in the WIPP study are shown in figure 3 and are those informal members described by Grauten (1965).

Olds and Hays sandstone members: The Olds sandstone member is separated from the underlying Hays sandstone (informal units) in most places by a shaly bed (Grauten, 1965, p. 298-299). The Olds and Hays have laminated and clean sandstones facies, and they both produce some hydrocarbons in the Delaware Basin.

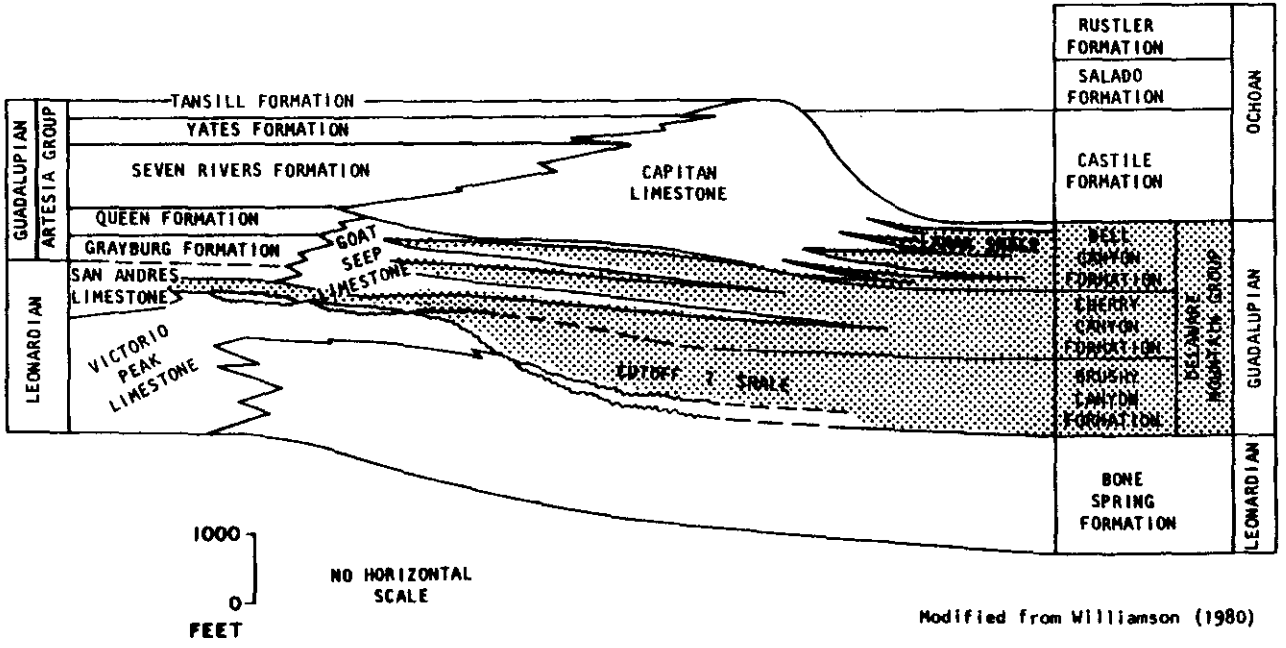

Figure 2.--Generalized stratigraphic section showing the relationships of the Guadalupian reef complex to those of the Delaware Mountain Group, southeastern New Mexico.

SYSTEM	SERIES	GROUP	FORMATION	MEMBER OR ZONE
PERMIAN	OCHOAN		CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN GROUP	BELL CANYON	LAMAR SHALE MEMBER TRAP MEMBER RAMSEY SANDSTONE MEMBER FORD SHALE MEMBER OLDS SANDSTONE MEMBER HAYS SANDSTONE MEMBER (INFORMAL UNITS)
			CHERRY CANYON	
			BRUSHY CANYON	
	LEONARDIAN		BONE SPRING LIMESTONE	

Modified from Grauten (1965)

Figure 3.--Stratigraphic relationships of the Delaware Mountain Group, Texas and New Mexico.

Ford shale member: The Ford shale member overlies the Olds sandstone member (informal unit) in the Delaware Basin. It consists of two 2-foot-thick beds of black shale separated by a 6-foot-thick laminated siltstone, forming one of the most important markers used in exploration for hydrocarbons in the Bell Canyon Formation (Grauten, 1965, p. 298).

Ramsey sandstone member: The Ramsey sandstone member (informal unit) overlies the Ford member throughout the study area. As described by Grauten (1965 p. 295), the Ramsey sandstone member has two main facies: (1) A laminated, shaly siltstone, interlaminated with black shale, and (2) A clean, very fine-grained sandstone with crossbeds of laminated, limy, shaly siltstone or very fine-grained sandstone. This stratigraphic sequence is common in many of the units in the lower parts of the Delaware Mountain Group. An important characteristic of the Ramsey is that, in most instances, the clean sandstones grade laterally into laminated siltstone with negligible permeability, thus creating stratigraphic traps where hydrocarbons and other fluids may accumulate. The Ramsey is the main oil and gas producing unit of the Bell Canyon Formation.

Trap member: The Trap member (informal unit) overlies the Ramsey sandstone member and consists of an interlaminated shaly siltstone and shale sequence, the laminae of siltstone and shale being very thin (Grauten, 1965, p. 295). Some writers (Watson, 1979, p. 4) refer to this member as the upper laminated Ramsey. The Trap usually is very thin, averaging only 5 to 10 feet.

Lamar shale member: The uppermost member is the Lamar shale (informal unit), commonly referred to as the "Lamar lime". It is composed of a very dark, silty shale; in some places beds of hard, black, very shaly limestone are present. Throughout the Delaware Basin, the thickness of the Lamar is 25 to 30 feet.

Guadalupian reef complex

The Guadalupian reef complex, specifically the Capitan aquifer as defined by Hiss (1980, p. 289), is a lithosome that includes the Capitan and Goat Seep Limestone and most or all of the Carlsbad facies of Meissner (1972). It also includes shelf-margin carbonate banks or stratigraphic reefs in the upper part of the San Andres Limestone where these cannot be readily distinguished from the Goat Seep Limestone and Carlsbad facies. Generally, the units discussed are of Permian Guadalupian age and comprise a reef complex that was deposited along the margin of the Delaware Basin in a continuous, narrow, arcuate belt.

The units are composed mostly of limestones, dolomites, reef breccias (Capitan Limestone), and massive dolomites (Goat Seep Dolomite). The complex includes facies transitions composed of shelf-edge dolomites and thin interbedded sandstones (Carlsbad facies), along with chert and dolomite (San Andres Limestone). Terrigenous clastics are notably absent in this sequence of rocks (Meissner, 1972). A more detailed description of lithologic relationships in the "reef complex" described above can be found in Hiss (1976), Meissner (1972), Motts (1968), Newell and others (1953), and Silver and Todd (1969).

Ochoan Series

The Ochoan rocks studied at the WIPP site are composed of extensive evaporite deposits that filled the Delaware Basin and extended across the Guadalupian reef zone during Permian time. The Ochoan Series is represented, in ascending order, by the Castile, Salado, and Rustler Formations, and the Dewey Lake Red Beds. The Ochoan is entirely of marine origin, but it has two dissimilar parts -- a thick lower section of evaporites and a thin upper section of red beds (Jones, 1973, p. 7). The lower section, containing extensive deposits of halite and anhydrite, includes the Castile, Salado, and Rustler Formations, whereas the upper section is composed of the Dewey Lake Red Beds. The Dewey Lake is composed entirely of red sandstone, siltstone, and some shale. The sequence probably forms a protective cover that has retarded the dissolution and removal of the soluble salts in the lower evaporite units (Jones, 1954, p. 107). Among the lower evaporite units, the Castile and Rustler contain more anhydrite and carbonate than the Salado. In the area of the WIPP site, these anhydrites have formed protective barriers that have retarded the upward or downward movement of meteoric water into the salt-rich Salado Formation. The Ochoan sequence conformably overlies the Guadalupian Bell Canyon Formation and unconformably underlies the Triassic Santa Rosa Sandstone.

The WIPP geotechnical studies have generated intense interest in these rocks, not only because the halite of the Salado is to be the location for the proposed facility, but also because the evaporites could be barriers to fluid migration should the facility be breached. Numerous discussions of detailed stratigraphy by various authors can be found in documents published for the area (Vine, 1963; Hayes, 1964; Gard, 1968; Jones, 1954, 1973, 1978; Powers, Lambert, Shaffer, Hill, Weart, 1978; and Bachman, 1973, 1974, 1980, 1981); therefore, stratigraphic discussions in this paper will be limited to those deposits that may affect the hydrologic system at the WIPP site.

Castile Formation.—The Castile Formation, the basal unit in the Ochoan evaporite sequence, consists principally of anhydrite, calcite-banded anhydrite, and halite with some limestone and sandstone. As originally defined by Richardson (1904), it included all the evaporites between the Delaware Mountain Group and the Rustler Formation; however, present usage follows that of Lang (1935), who divided the Castile into two formations: the anhydrite-rich Castile below and the halite-rich Salado above.

Extensive outcrops of the Castile Formation are present in the western part of the Delaware Basin. The formation, where it is exposed, is devoid of halite and the anhydrite primarily has been altered to gypsum by weathering.

The contact between the Castile Formation and the overlying Salado Formation is conformable and gradational, but, nonetheless, generally is defined as the horizon at which dominant anyhdrite below changes to halite above (Jones, 1973, p. 10).

Salado Formation.—The Salado Formation, differentiated from the Castile by Lang (1935, p. 267), principally consists of halite in thick seams interbedded with anhydrite, polyhalite,and glauberite. The upper contact of the Salado is the distinct conformable contact between halite and the gray siltstone and sandstone of the lower part of the Rustler Formation. The Salado is the principal salt formation being investigated at WIPP because the proposed facility would be built in selected salt horizons of this unit. Additionally, the Salado Formation is important because parts of it (McNutt Potash zone) in eastern Eddy and western Lea Counties are mined for potash minerals. A discussion related to potash evaluation can be found in Jones (1978).

Jones (1975, p. 12) describes three divisions within the Salado near the WIPP site: the lower member (1,040-1,154 feet thick), the McNutt potash zone (357-375 feet thick), and the upper member (468-504 feet thick). The lower member consists largely of clayey halite interbedded with thin seams of anhydrite and polyhalite, as well as some thin-bedded siltstones and sandstones. The lithology of the McNutt potash zone, while similar to the clayey halite of the lower member, includes sylvite and langbeinite, which are both economically important potash salts. The upper member is composed of clayey halite interbedded with minor anhydrite and polyhalite. A layer of residuum which lies immediately on top of the Salado in certain areas is considered to be residue from evaporite dissolution and is considered in this report to be part of the lower part of the Rustler Formation.

Throughout the Salado Formation, the principal lithologic types are repeated in a type of rhythmic depositional cycle that consists in ascending order of a clastic, a sulfate, a halite, and a mixed halite-clastic stratum (Jones, 1954, p. 110). Jones (1973, p. 13) interprets these rock sequences to "...represent a fundamental sedimentation unit or evaporite cyclothem."

Rustler Formation.--The Rustler Formation, named by Richardson (1904), is the youngest unit in the Ochoan evaporite sequence. The Rustler is a key marker bed of the upper Permian in Texas and New Mexico. Hydrologically this unit is one of the most extensively investigated units at the WIPP site because it contains the most productive water-bearing units in the study area.

In the vicinity of the WIPP site, Vine (1963, p. B-14) has described a five-fold division of the Rustler (fig. 4). The division includes: (1) At the base, an unnamed unit of clayey siltstone and very fine-grained sandstone with thin interbeds of anhydrite and halite in its upper part; (2) the Culebra Dolomite Member, a unit of thin-bedded, solution-pitted, finely crystalline dolomite; (3) the Tamarisk Member, anhydrite with a single thin interbed of unconsolidated clayey silt (residuum from a thick seam of halite and associated polyhalite and halitic siltstone); (4) the Magenta Dolomite Member, a unit of thinly cross-laminated, fine-grained dolomite; and (5) the Forty-Niner Member, anhydrite with a single thin interbed of unconsolidated clayey silt (residuum from a much thicker seam of clayey and silty halite). The dolomite units are not only hydrologically important but are distinctive marker beds throughout the Delaware Basin (Adams, 1944, p. 1614).

The upper contact of the Rustler Formaton is represented by a distinct lithologic change, going from anhydrite to siltstone, sandstone, or shale. The discordance and hiatus between the Rustler and overlying Dewey Lake Red Beds probably are not very great.

Dewey Lake Red Beds.--The Dewey Lake Red Beds overlie the Rustler Formation in the WIPP area. This sequence was named by Page and Adams (1940) for a sequence of rocks composed of siltstone and claystone with thin lenticular beds of sandstone. As observed in many of the cores from the test holes drilled at the WIPP site, almost all of the siltstone and claystone are intruded by horizontal and crisscrossing veins of selenite. The Dewey Lake is thin bedded and contains numerous greenish-gray spots. Many of the bedding surfaces contain mud cracks and ripple marks. The Dewey Lake Red Beds range in thickness from 345 to 541 feet across the WIPP site. An erosional unconformity marks the contact between the Dewey Lake Red Beds and the overlying Santa Rosa Sandstone of Late Triassic age.

Upper Triassic rocks

Santa Rosa Sandstone.--Triassic rocks of the WIPP area, included in the Dockum Group, consist of the Santa Rosa Sandstone of Darton (1922). The Santa Rosa is only present in the eastern one-half of the WIPP site (fig. 5), having been removed by erosion in the west. At the WIPP site, the Santa Rosa consists of medium-to coarse-grained, micaceous sandstone and conglomerate with interbeds of siltstone and mudstone.

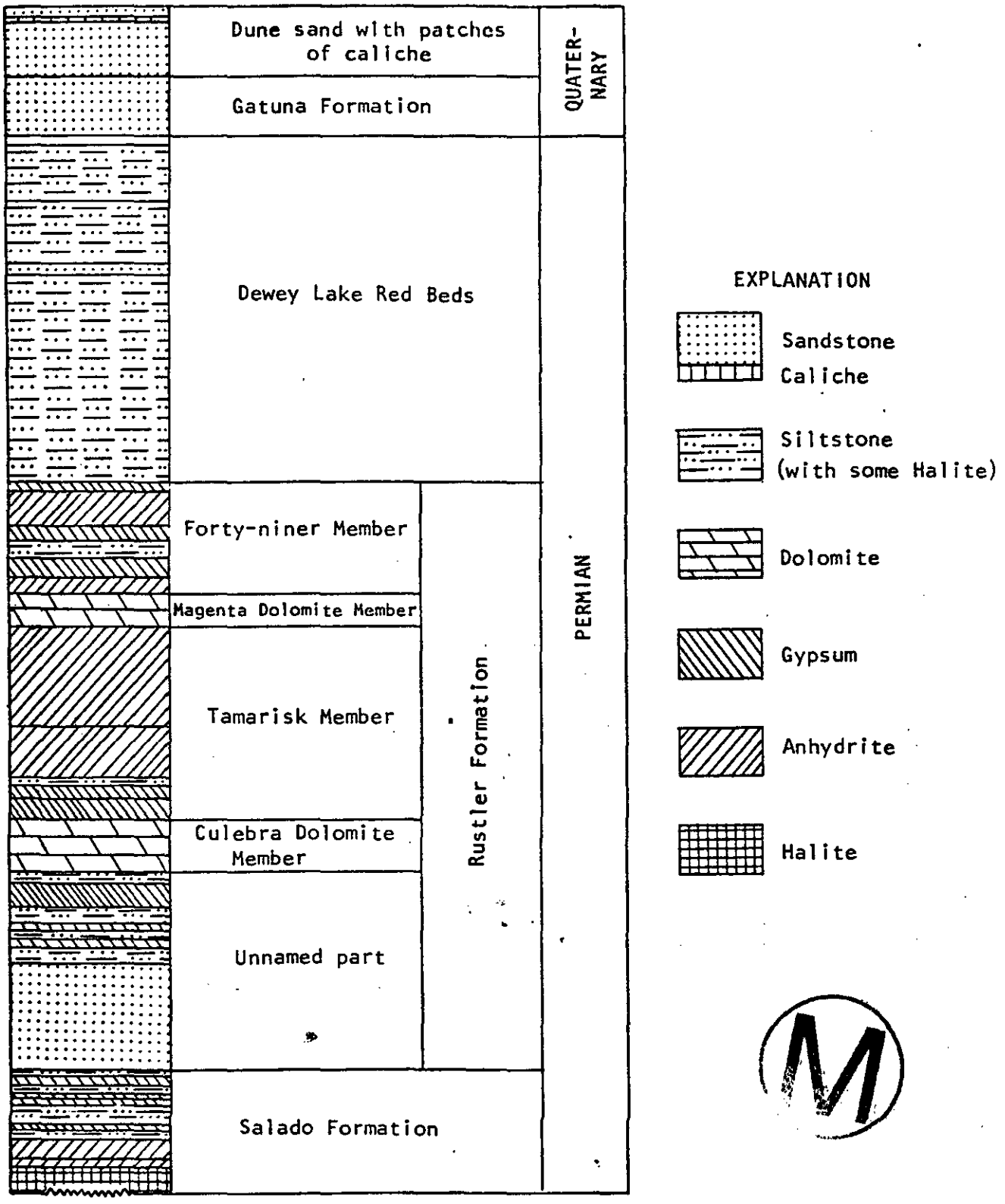

Figure 4.--The five subdivisions of the Rustler Formation in Nash Draw, Eddy County, New Mexico.

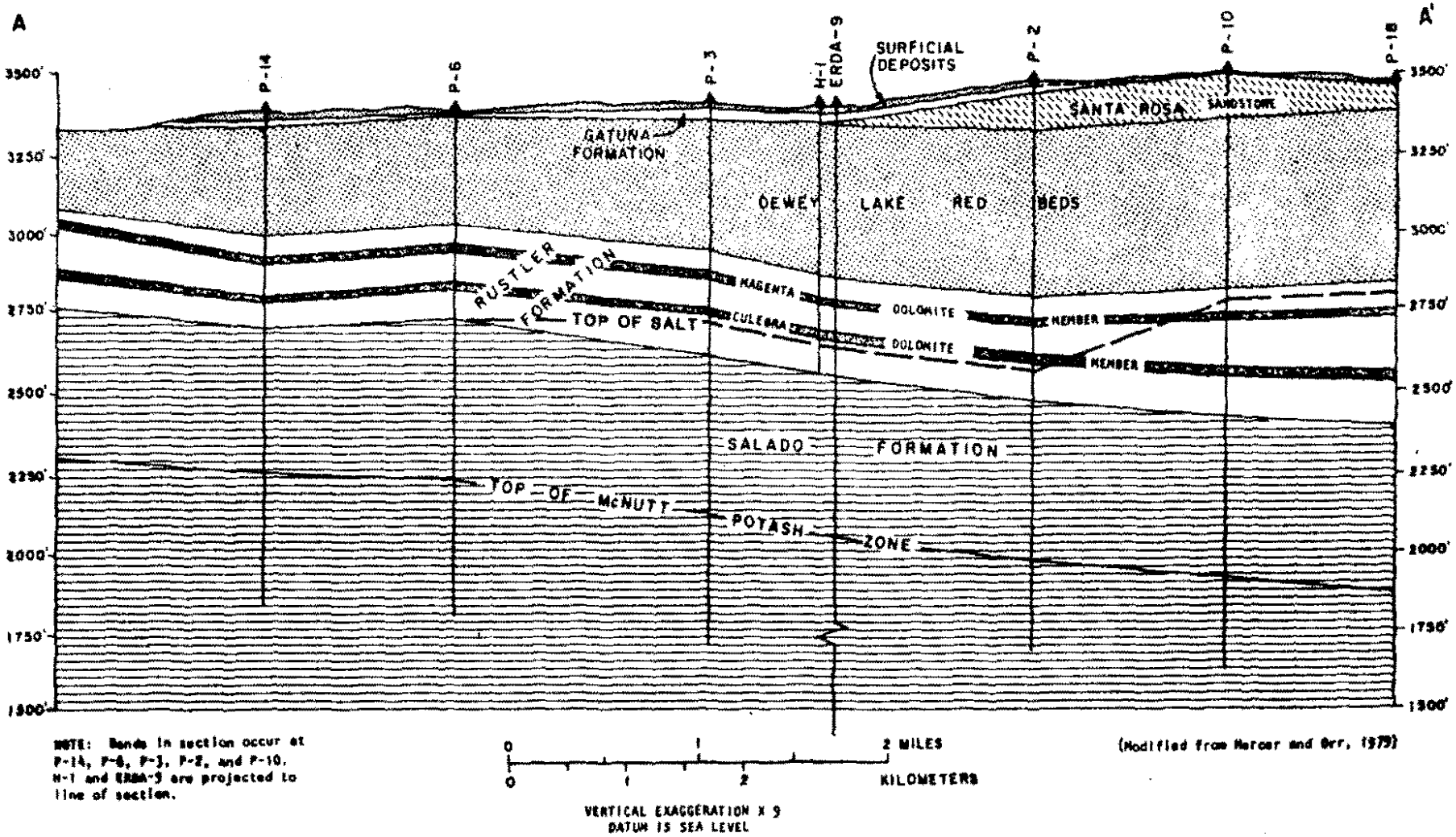

Figure 5.--Geologic section across the proposed Waste Isolation Pilot Plant (WIPP) site.

The Santa Rosa Sandstone in most of the area is truncated by a nodular to laminar limestone of middle Pleistocene age, informally called the Mescalero caliche by Bachman (1974, p. 31). In the area east of the WIPP site, the Santa Rosa may be overlain by the Triassic Chinle Formation or a Chinle equivalent.

Chinle Formation.--The uppermost unit present in the Triassic Dockum Group is the Chinle Formation or an equivalent, which, although not present at the WIPP site, was penetrated in the H-10 test hole drilled 4 miles southeast of the WIPP site (fig. 1A). The Chinle Formation at the H-10 test hole was described as a dominantly shaly mudstone interspersed with greenish-gray mudstone and lenses of sandstone and conglomerate. Anderson (1981, p. 7) discusses the presence of as much as 230 feet of Triassic Chinle Formation in test well WIPP-15 in San Simon Swale which is 10 miles east of the WIPP site. According to Nicholson and Clebsch (1961, p. 35), confusion exists due to lithologic similarities between the Chinle and Santa Rosa, which they believe cannot be separated. In fact, Bachman (1980, p. 26) believes that there is little justification to even extend these formation names into southeastern New Mexico and that the sequence should be simply referred to as Triassic or Dockum Group undivided. Although problems in nomenclature have been created concerning the Triassic Chinle Formation, this report retains the formation names and uses them, at least in the vicinity of the WIPP site.

Tertiary and Quaternary rocks

Tertiary and Quaternary deposits in the vicinity of the WIPP site include the Ogallala Formation of Miocene age, the Gatuña Formation of Pleistocene age, and sands, playa deposits, caliche, and alluvium of Holocene age. These units cover the surface of nearly the whole region and lie unconformably on older rocks.

Ogallala Formation.--The Ogallala Formation of Miocene age is the oldest record of Cenozoic depositional history and climate preserved in southeastern New Mexico (Bachman, 1980, p. 34). Although the Ogallala is well exposed along Mescalero Ridge, at Hat Mesa, Gramma Ridge, and at the Divide (fig. 1 and 1A), Bachman (1980, p. 34) indicated that the Ogallala Formation could not be recognized west of San Simon Swale towards the WIPP site except for a few thin outliers near the Divide.

In southeastern New Mexico, the Ogallala Formation generally is described as a well-sorted, windblown sand with minor poorly-sorted stream deposits and carbonate pans usually capped by a rather resistant layer of well-indurated caliche. Bachman (1980, p. 35) reports that even though the upper surface is relatively smooth, the irregular surface on which it was deposited has resulted in irregular thicknesses for the Ogallala.

Gatuña Formation.—The Gatuña Formation is the oldest known Quaternary formation in the study area and probably the thickest though the least extensive. The Gatuña was named by Robinson and Lang (1938, p. 84-85) and occurs as discontinuous bolson-type deposits in channels and depressions, possibly related to solution within the Salado and Rustler Formations. Bachman (1976, p. 140) describes a reference section of the Gatuña in the vicinity of Gatuña Canyon that consists of sandstone, siltstone, and conglomerate, with the conglomeratic beds containing pebbles of quartz and quartzite reworked from Triassic conglomerates.

Mescalero caliche.—The Mescalero caliche, an informal stratigraphic unit named for the Mescalero Plain (a broad geomorphic surface in southeastern New Mexico), occurs east of the Pecos River and west of the High Plains (Bachman, 1976, p. 141). The caliche is a well-lithified alluvial deposit of chalky, finely crystalline limestone. The caliche caps the geomorphic surface and lies with angular unconformity on the underlying Gatuña and older formations; its lower part commonly engulfs large masses of older bedrock.

Alluvium and other surficial deposits.—There are no through-flowing streams in the immediate area of the WIPP site; therefore, there are no recent stream deposits of any magnitude. Surficial deposits are composed mostly of locally-derived materials deposited by sheet wash. In some parts of the area such as Nash Draw, the surficial deposits include gypsum and dolomite fragments derived from the Rustler Formation as well as caliche fragments from the Mescalero caliche. There are small intermittent streams and collapse features that, although they may be discontinous, do contain alluvial sand and silt that is locally conglomeratic.

Hummocky surficial deposits of dune sand cover almost the entire WIPP site. The sand, locally known as the Mescalero sand (Vine, 1963, p. B-36), is fine to medium grained, with the grains predominantly angular to subrounded. Although the sand may occur as dune ridges, most of it is present on the flats and is generally stabilized by mesquite and other vegetation.

The most extensive deposits of true alluvium in the vicinity of the WIPP site are present along the west side of the Pecos River north of Malaga Bend. Isolated patches of alluvium are present to the south of Malaga Bend, but these are not very extensive.

Alluvium east of the Pecos is localized and present in depressions, as in Clayton Basin and Nash Draw. The thickest alluvial deposits, however, were found in San Simon Swale 10 miles east of the WIPP site, where drilling at WIPP-15 penetrated about 547 feet of fill (Sandia National Laboratories and the University of New Mexico, 1981, p. 7).

Maley and Huffington (1953) and Cooper (1962, p. E152) have described several structural features in the study area as thick accumulations of alluvium that fill deep solution depressions. Nicolson and Clebsch (1961, p. 46-47) describe similar collapse structures in southern Lea County. These studies show that alluvial deposits underlie an area of 150 square miles east of the Pecos River in Eddy County, New Mexico, and extend southward into western Texas (fig. 6). Maley and Huffington (1953, pl. 1) indicate more than 1,400 feet of fill at the center of this area near the New Mexico-Texas State line, but Cooper's investigations show that, at least in New Mexico, the thickness probably does not exceed 1,000 feet. Lithologic descriptions from logs of several holes drilled into the fill indicate the material to be sands separated by somewhat thicker interbeds of silt and clay.

Other surficial material in the WIPP site area includes the fill associated with playas. This material generally consists of alluvium and eolian sands reworked by lake waters but may also contain reworked gypsum as well as precipitated gypsum and chlorides, as is present at Laguna Grande de la Sal. Some playas may contain perennial lakes, such as Laguna Grande de la Sal; others may be dry most of the year.

GROUND-WATER HYDROLOGY

This report presents an appraisal of potential boundaries to the ground-water flow system in the vicinity of WIPP site and includes an evaluation of hydraulic flow paths from the facility to the proposed major discharge area at Malaga Bend. The hydrologic regime both above and below the facility needs to be examined in order to characterize the flow system in the WIPP site study area, particularly when the host medium for the storage facility consists of easily dissolved halite. Therefore the studies were divided into shallow hydrologic investigations (above salt), and deep hydrologic investigations (below salt). The phases of the shallow and deep hydrologic investigations included: the geology of the area, the stratigraphic location of the geohydrologic units and the occurrence of water in them, the hydraulic factors that govern ground-water movement from areas of recharge to areas of discharge, and the chemical quality of water and possible reactions with the host rocks.

The fundamental principles governing the occurrence and movement of ground water have been discussed in detail in textbooks and numerous publications, for example Meinzer (1923a and b), Tolman (1937), and Lohman (1972). The interested reader is referred to these publications and others for a more detailed discussion of this subject.

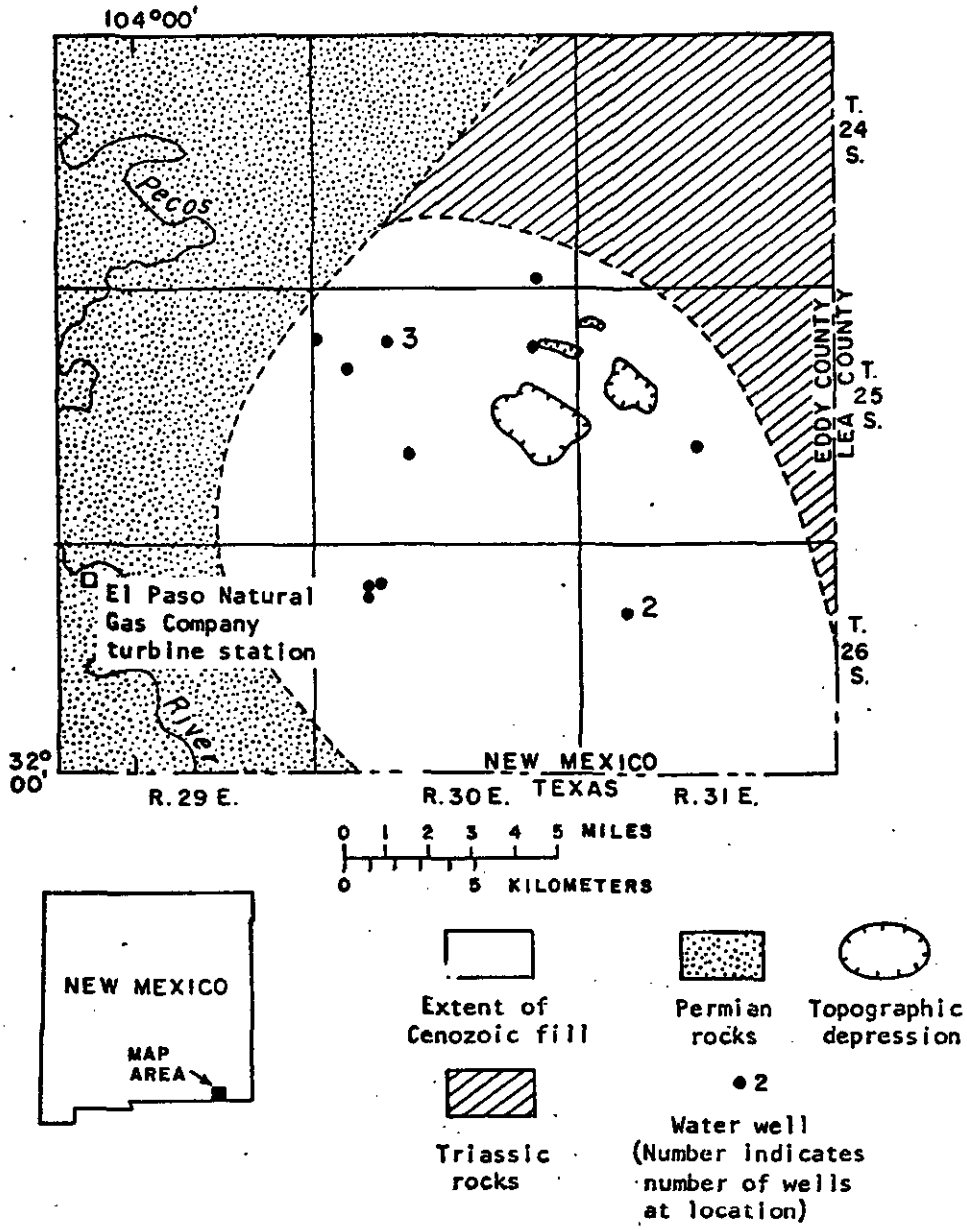

From Cooper (1962)

Figure 6.--Generalized subsurface extent of Cenozoic fill in southeastern Eddy County, New Mexico.

The terminology for hydraulic properties of ground-water systems has caused some confusion in the past. For example, the use of permeability and hydraulic conductivity interchangeably has led to much of the confusion, especially between ground-water hydrologists and petroleum engineers. In this paper hydraulic conductivity will be used when referring to the water-transmitting characteristic of the material in quantitative terms. The definition of hydraulic conductivity used here is the one described in Lohman (1972, p. 6) and is a replacement for the older term, "coefficient of permeability." "A medium has a hydraulic conductivity of unit length per unit time if it will transmit in a unit time a unit volume of ground water at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head through the unit length of flow." In this report permeability will be used as a qualitative term to refer in a general way to the ability of a rock to transmit fluid. The "permeability" commonly used by petroleum engineers will be the "intrinsic permeability" described by Lohman (1972). The "intrinsic permeability" is a property only of the medium and is independent of the nature and properties of the fluid contained in it.

Transmissivity is a term used in this report that also needs definition. As defined by Lohman (1972, p. 6), transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is both a property of the aquifer and of the confined liquid. The transmissivity is equal to the average hydraulic conductivity times the thickness of the aquifer. The term "aquifer" is not used in its formal sense in this report. Formal usage defines an aquifer as a geologic formation or group of formations or a part of a formation that is capable of yielding economic quantities of water to a pumped well or to springs. The use of the term aquifer in reference to most water-bearing zones at WIPP would be misleading. More appropriately these zones will be referred to as "hydrologic units" or "water-bearing zones" in this report.

Ground water exists under hydrostatic pressure and its movement generally is from places of higher potential or hydraulic head to places of lower potential or hydraulic head. The hydraulic head, at any point, is usually expressed as the elevation above a fixed datum (usually sea level) to which water will rise in a tightly cased hole. Differences in hydraulic head in feet of water within a hydrologic unit and the resulting slope of the profile is called the hydraulic gradient.

Rates of movement between any two points in a water-bearing unit depends on the difference in hydraulic head, the distance between the points, the effective porosity of the unit, and the hydraulic conductivity.

The distribution of water levels measured in wells in selected hydrologic units is illustrated by contours on maps; in confined ground-water systems, these maps are referred to as potentiometric-surface maps. The potentiometric surface is the elevation to which water will rise in tightly cased wells that penetrate confined hydrologic units; the

imaginary surface thus defined is used to picture the areal extent and movement of ground water as well as to qualitatively define any permeability changes within the unit. In some instances potentiometric-surface maps can be useful for predicting directions of ground-water flow. In general, the primary direction of water flow in porous media is at right angles to the potentiometric-surface contours. However, in cases of fracture flow, as occurs locally at the WIPP site, the direction of movement is most affected by directional differences in permeability or fracture orientation. Thus, the actual direction may have little or no relationship to the movement inferred from the regional potentiometric-surface contours. Where extensive fracturing has occurred, the flow could actually be almost parallel to the indicated gradient. Earlier maps constructed for the WIPP study area have failed to distinguish between water levels of different hydrologic units. Present potentiometric maps distinguish the three water-bearing units and show equivalent freshwater head differences in excess of 100 feet between units.

Potentiometric-surface maps for the WIPP study area need to include effects from variations in water chemistry within the individual water-bearing zones. These variations create density differences that hinder determination of representative static-pressure heads. A potentiometric-surface map constructed strictly on the existing water levels, without appropriate density correction, may lead to erroneous conclusions when efforts are made to determine flow direction from this potentiometric gradient. Various methods of correction were studied, as described in Bond (1972), Hubbert (1953), and Jorgensen and others (1982). However, it was determined for this report that the water levels would be adjusted to a common density of 1.0 (freshwater equivalent) by methods similar to those described in Hiss (1976). Because the units are almost horizontal, this method is believed to give reasonable values for general directions of flow (the Hiss method is not accurate for dipping beds). Larger errors can occur in hydraulic head calculations, adjusted for density, when thick water-bearing beds are present (not the case at the WIPP site), and especially when density varies in the vertical direction as well as in the horizontal direction. The hydrologic units at the WIPP site include thin water-bearing beds where density variations are primarily lateral, not both lateral and vertical.

As ground water moves along the flow system from recharge areas to areas of discharge, its chemical quality is altered by a variety of geochemical processes. As the ground water moves along the flow path, the concentrations of dissolved solids probably increase, especially if the water comes in contact with easily dissolved halite and other evaporite rocks.

Large concentrations of dissolved solids were found in most of the water samples collected from the hydrologic units studied at WIPP; in most instances the ground water would be classified as moderately to very saline (3,000 to 35,000 milligrams per liter of dissolved solids) to brines (more than 35,000 milligrams per liter of dissolved solids). The concentrations of

the major chemical constituents are directly related to the interaction of the host rocks with the water, which moves slowly through them because of restricted circulation. Interpretation of hydrochemical analyses from these rocks has aided in the understanding of the hydrologic mechanisms at work in the rocks below and above the proposed storage horizon. To facilitate an understanding of these mechanisms, discussions of the water chemistry in this report are included with the hydrologic discussions of the individual units. Although the geochemical complexity of the ground water in the WIPP area cannot be completely understood from the chemistry of the dissolved ions alone, it does provide a qualitative insight into the chemical history of these waters and some of the complexities associated with ground-water movement.

Hydrology of the Delaware Mountain Group

Geohydrologic characteristics.--The lithology of the Delaware Mountain Group has been described previously in detail. It is predominantly a fine-grained, silty sandstone with interbeds of black shale and black limestone. The basinal deposits are composed, in ascending order, of the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. The Delaware Mountain Group crops out in the southern Guadalupe Mountains and in the Delaware Mountains in Texas. The maximum thickness of the Delaware Mountain Group is in the central part of the Delaware Basin where its thickness exceeds 4,000 feet. The Delaware Mountain Group either pinches out or interfingers with the several stages of reef growth on the basin edge (fig. 2).

A structure-contour map (fig. 7) on top of the Lamar shale member (informal unit of the Bell Canyon Formation) of the Delaware Mountain Group shows two main types of structural provinces -- monoclinal in the west and anticlinal in the east, southeast, and the southwest (Grauten, 1965, p. 299). The Lamar shale has a general eastward dip of about 75 to 100 feet per mile.

The Cherry Canyon and Brushy Canyon Formations produce only minor quantities of oil and gas; most of the oil and gas comes from sandstone in the upper part of the Bell Canyon Formation. The oil fields developed in the upper part of the Bell Canyon do not usually occur in any pronounced structual feature that could account for the trap. Oil, gas, and water probably occur in relatively clean elongated "channel" sandstones that are porous and permeable but grade vertically and laterally into relatively impermeable siltstones and laminated shales. These rocks form permeability barriers, thus creating stratigraphic traps. The Cherry Canyon Formation contains less oil and gas, not only because of a lack of favorable structural features such as are found in the Bell Canyon, but also because of a large proportion of siltstone and increased cementation that decrease the permeability. Similarly the Brushy Canyon Formation probably contains little oil or gas because of lesser permeability from increased cementation (Berg, 1979, p. 89). Berg also concludes that the greater permeabilities found in the upper sandstones of the Bell Canyon sandstones probably result from the shallower depth and lesser cementation.

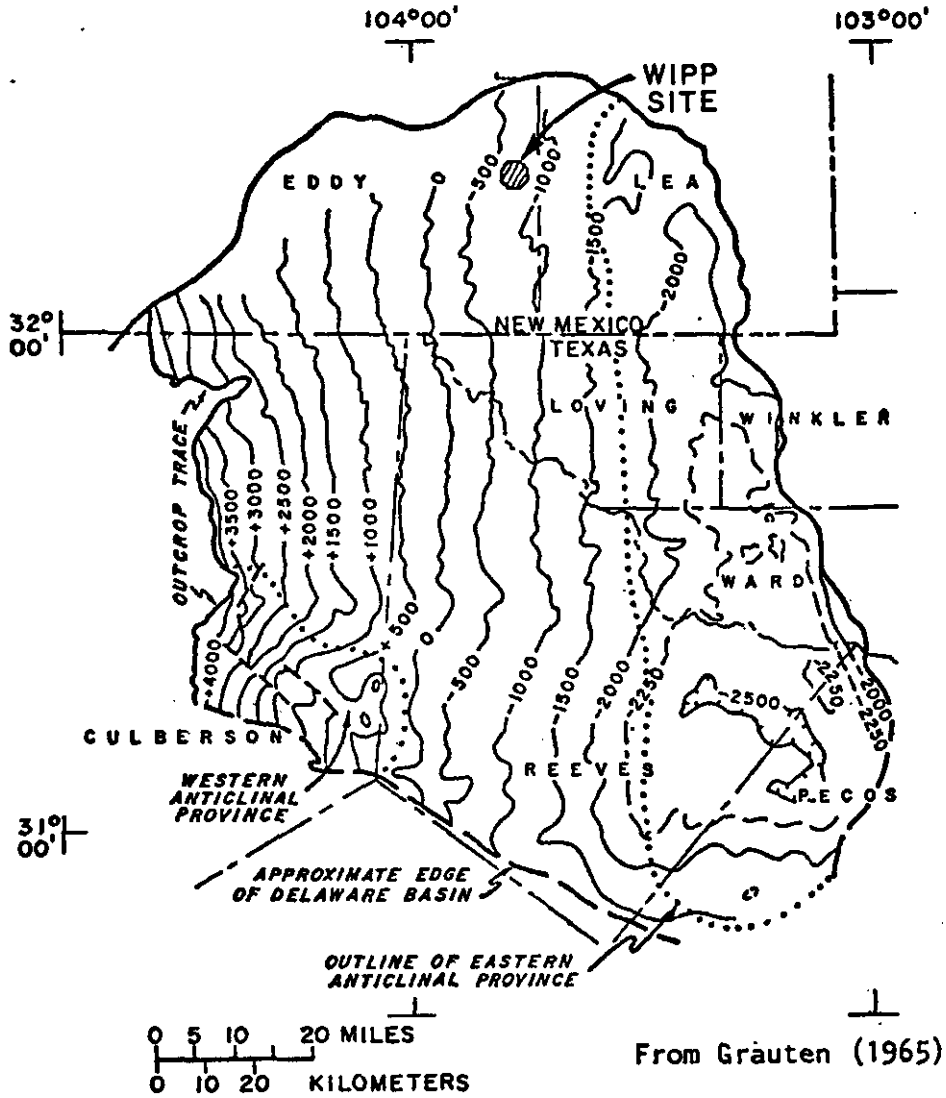

EXPLANATION

1500 STRUCTURE CONTOUR--Shows altitude of top of Delaware Mountain Group. Dashed where approximately located. Contour intervals 250 and 500 feet. Datum is sea level.

Figure 7.--Generalized structure contours on top of the Lamar shale (informal unit, Delaware Mountain Group) in the Delaware Basin, New Mexico and Texas.

Data for a regional analysis of the hydrologic characteristics of water-bearing units within the Delaware Mountain Group are sparse due to the depth, the salinity of the water, and the overall lack of permeability of these rocks. Early studies (Grauten, 1965, and Sullivan, 1979) of the Delaware Mountain Group concluded that the Lamar shale at the top of the Bell Canyon Formation plus the several thousand feet of dense anhydrite and salt of the overlying Castile Formation would probably form an effective confining bed over the Bell Canyon Formation. These confining beds, if they were not fractured, would restrict water from migrating upward from the Bell Canyon Formation to dissolve the salt of the Salado Formation and would also restrict movement of fluids downward from the proposed facility horizon to the Bell Canyon Formation. Since these studies, interpretations of the potential for upward movement of fluids from the Bell Canyon into the overlying evaporites (Anderson, 1978, 1981) has created a need for a re-evaluation of the hydrologic system of the Delaware Mountain Group.

This study is restricted to the upper part of the Bell Canyon Formation because it is the closest water-bearing zone below the evaporites and contains the most porous sandstones of the Delaware Mountain Group. The hydrologic system of the Delaware Mountain Group, as defined by the available data, probably is confined to the upper 600 feet of the Bell Canyon Formation; individual sandstone units in any one area probably are no thicker than 45 to 60 feet.

Based on drill-stem tests conducted on the Bell Canyon Formation and from data from previous studies, it became apparent that earlier studies (Mercer and Orr, 1977; Hiss, 1976) that indicated that the Delaware Mountain Group is a uniform hydrologic unit were in error. Numerous studies of oil reservoirs indicate that the sandstones of the upper part of the Bell Canyon are present as narrow, sinuous channels that grade laterally into less permeable shales and siltstones. These channel sandstones may be covered with siltstone and locally are poorly connected hydrologic units. Though studies of geophysical logs may indicate that it is continuous, each major sandstone body is composed of many individual sandstone beds that are either separated by siltstone or have different degrees of cementation (Williamson, 1979, p. 71). Grauten (1965) describes the apparently continuous sands of the Ramsey Sandstone actually to be composed of three or more separate sublenses of porous sandstone separated by relatively impermeable siltstone beds, each sublens to be virtually separated hydraulically from the others. The entire system is confined by overlying beds with negligible permeability; in the case of the sandstones of the Ramsey member, the overlying Trap and Lamar shale members form a very effective seal (Grauten, 1965, p. 302). As a result, vertical permeability within these sandstone units is very small. This very small vertical permeability is indicated by data from a drill-stem test in test well AEC-8 where two sandstone units, separated by a siltstone unit 16 feet thick, were individually tested (Mercer and Orr, 1979, p. 133). The water levels for the upper and lower sandstones stabilized at 553 and 568

feet below ground level. Extensive evaluation of drill-stem tests in other wells throughout the basin found that differences of this magnitude are common. These differences indicate that confining beds between the sandstones are so poorly connected that they cause hydraulic head differences of 15 feet in sandstone lenses only 16 feet apart.

The hydraulic properties of the upper part of the Bell Canyon have been compiled from several sources including drill-stem tests at the WIPP site (table 4) and selected oil-field production data. The following discussion also includes the average values for hydraulic properties published in the Delaware Mountain Group Symposium (Sullivan, 1979) for reservoirs at which oil, gas, and water are present and includes the values for the hydraulic properties for the permeability barriers of siltstone and shale.

The primary porosity of the upper Bell Canyon sandstones (generally the Ramsey) is intergranular and generally ranges from 20-28 percent. The permeabilities of these sandstones in the Ramsey range from 14 to 90 millidarcy (Berg, 1975) although permeability may be greater locally. The siltstones and shaly siltstones forming the permeability barriers generally have porosities ranging from 10 to 20 percent with a permeability usually less than 0.1 millidarcy. A good example of this type of stratigraphy is shown in the cross section across the El Mar oil field in Loving County, Texas (fig. 8).

The unknown factor in this analysis is the degree to which the sandstones are interconnected on a regional scale. If the siltstone barriers also are present on a regional scale, the permeability values given for the sandstones are probably too large, and calculated rates of movement are also too large. The permeability barriers; however, are present locally.

Three test holes (AEC-7, AEC-8, and ERDA-10) were drilled into the upper part of the Bell Canyon Formation and were hydraulically tested to evaluate the deep water-bearing units in the Bell Canyon Formation in the vicinity of the WIPP site. Several sand stringers that were identified from the geophysical logs and cores were permeable enough to test and contained brine. These zones included an upper and lower sand in test hole AEC-8 (probably pre-Ramsey), a series of sandstones in test hole ERDA-10 (Ramsey and pre-Ramsey), and sandstone in test hole AEC-7 (Ramsey). Although test holes AEC-8 and ERDA-10 are only about 14 miles apart and the sandstones tested are about the same depth below the top of the Bell Canyon, they may not be in good hydraulic connection because they appear to be channel sandstones. Test hole AEC-7 penetrated similar sandstones at a shallower depth.

The tests were conducted using standard and modified drill-stem-test procedures (Mercer and Orr, 1979) which test primarily the horizontal hydraulic conductivity. From analyses of the hydraulic data (table 4), the hydraulic conductivities of the sandstones were 4.0×10^{-2} foot per day for the zone tested in test hole AEC-7, 2.0×10^{-2} and 7.0×10^{-3} foot per day for the two zones tested in test hole AEC-8; and 5×10^{-2} foot per day for

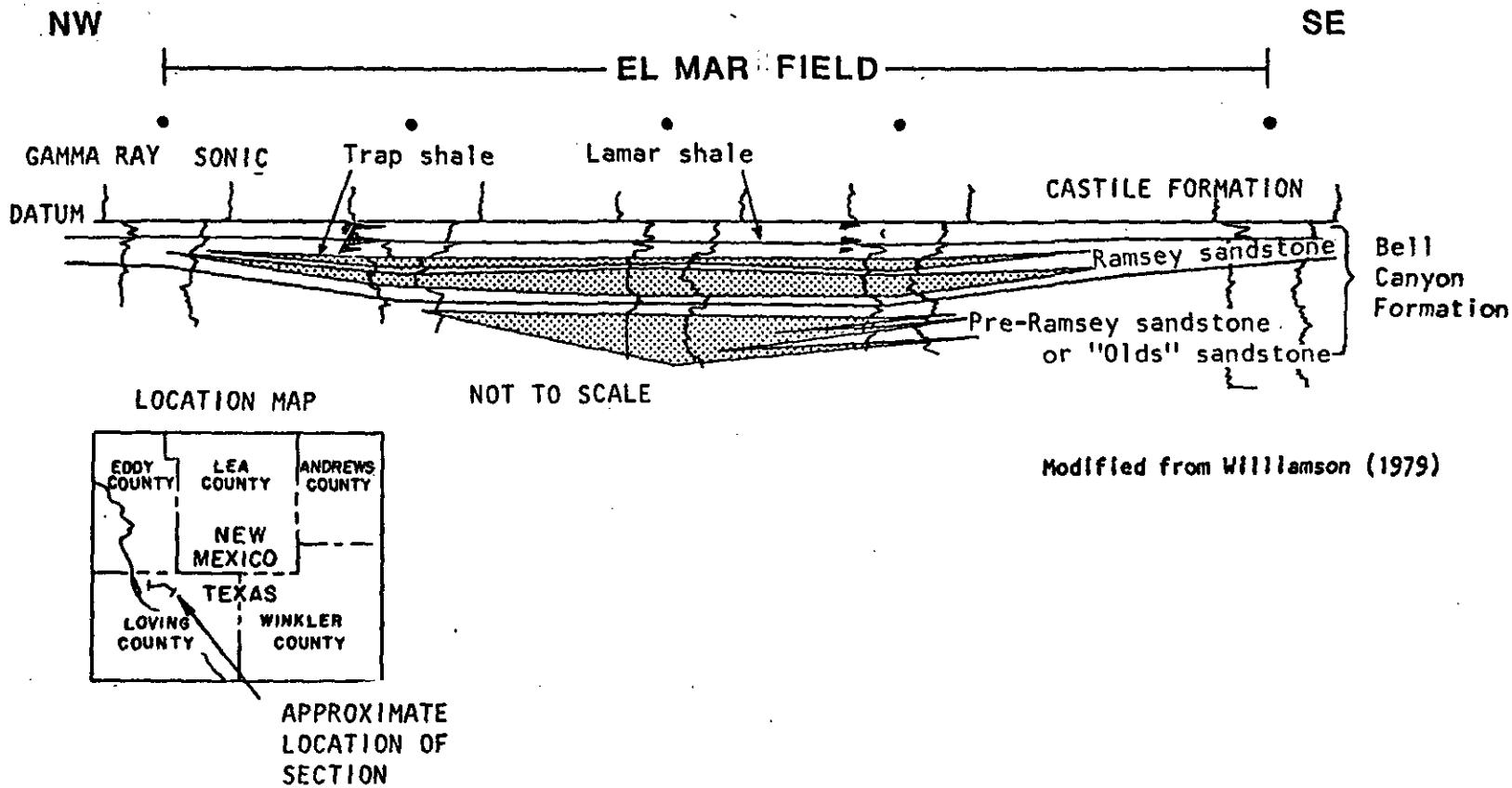

Figure 8.--Generalized geologic section across the El Mar Field, Loving County, Texas.

the zone tested in ERDA-10. The Lamar shale also was tested in the three holes to evaluate the effectiveness of the zone as a confining bed which would restrict upward movement of fluids, assuming the unit is not fractured. The tests of the Lamar shale yielded values of hydraulic conductivity of 2.0×10^{-6} foot per day in test hole AEC-8 and 4.0×10^{-4} foot per day in test hole ERDA-10. In AEC-7, the Lamar shale was evaluated to determine its effectiveness as a confining bed, but it had such negligible permeability it could not be tested. These permeability values for the upper sandstone of the Bell Canyon were within the range of permeability values reported by various oil companies for the sandstones and shales of the Delaware Mountain Group throughout the basin. These tests also indicated that the head in the upper part of the Bell Canyon Formation, although it extends above the lower part of the Rustler Formation, is still less than the heads in Rustler Formation. Therefore, the potential is for downward movement if these zones were interconnected. The head was also lower when converted to freshwater-equivalent.

Ground-water movement.--Several studies have produced potentiometric-surface maps for the Delaware Mountain Group; however, because most of the pressure-head information comes from the upper part of the Bell Canyon, these maps probably are most representative of that zone. The common procedure during oil exploration is to run a drill-stem test on a zone that (from geophysical logs) appears to have the greatest porosity along with some associated permeability. Because of the lack of lateral continuity in many of the sandstones tested in the upper part of the Bell Canyon, less reliable data are available than would be expected from the number of wells shown on an oil and gas map.

Hiss (1976) and McNeal (1965) have constructed potentiometric-surface maps for the upper part of the Bell Canyon Formation, and the maps generally are similar even though Hiss's map only covers the northern part of the Delaware Basin. Both of these maps were constructed after adjusting hydraulic head data to a freshwater datum to account for variations in brine density. In the WIPP characterization study, available oil-field drill-stem tests, production tests, and water analyses were coupled with data collected from the deep test holes AEC-7, AEC-8, and ERDA-10 near the WIPP site to construct a potentiometric-surface map. The base map developed by Hiss (1976) was used and new information was corrected for density as described by Hiss and incorporated in a new map. The new contour map duplicated Hiss's map with very little modification (fig. 9).

The potentiometric gradient of the upper part of the Bell Canyon is nearly parallel with the regional structural trend. Water apparently enters the unit in the western part of the basin, perhaps in the Delaware and Guadalupe Mountains, and moves northeastward across the basin at a hydraulic gradient ranging from 25 to 40 feet per mile. The rate of water movement in the sandstone is probably very slow because it is assumed to be restricted by negligible hydraulic conductivity of the intervening siltstones. Although

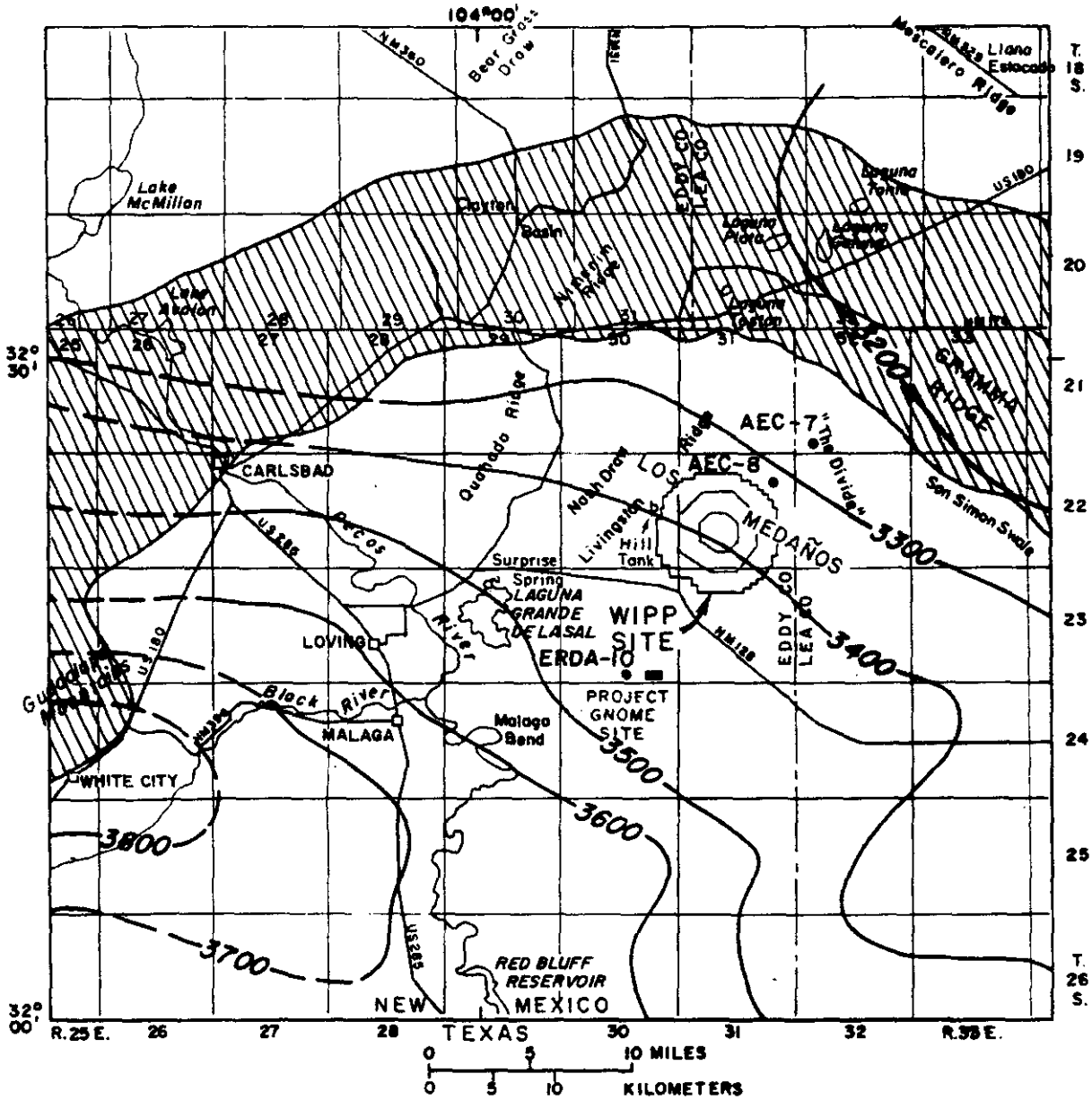

Figure 9.--Potentiometric surface of the hydrologic unit in the upper part of the Bell Canyon Formation (Delaware Mountain Group) at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

the Capitan aquifer of Hiss (1976) abuts and overlies the Delaware Mountain Group along the basin margins, the lithologic and hydrologic characteristics of the Capitan aquifer and Delaware Mountain Group (in particular the upper part of the Bell Canyon Formation) are quite different (Hiss, 1980, p. 289). The hydraulic conductivity of the Delaware Mountain Group is several orders of magnitude less than that of the Capitan aquifer; this fact, coupled with differences in quality of water, would indicate that only a relatively small quantity of water in the Delaware Mountain Group, if any, would move into the Capitan aquifer. Data from tests of the upper part of the Bell Canyon Formation in test holes AEC-7, AEC-8, and ERDA-10 fit with the regional trend. Fluid density and permeability variations and discontinuity of the upper sandstone units in the Bell Canyon preclude detailed site-specific analyses by means of the potentiometric-surface map.

Hydrochemistry.—Generally, the waters in the upper part of the Bell Canyon Formation are brines in which sodium and chloride are the predominant ions (table 5). The "clean" sandstones near the outcrop of the Ramsey sandstone of the Bell Canyon appear to be saturated with relatively freshwater (Grauten, 1965, p. 303). As the water moves across the Delaware basin, however, the salinity of the water increases; locally dissolved-solids concentrations of more than 300,000 milligrams per liter occur in the structural trough of the basin (McNeal, 1965, p. 317). Concentrations of dissolved solids in brines sampled during the testing of the upper part of the Bell Canyon at the WIPP site ranged from 180,000 milligrams per liter in test hole AEC-8 to 270,000 milligrams per liter in test hole ERDA-10 (table 2). The abundance of calcium, magnesium, sodium, and potassium cations, the presence of chloride and sulfate as the major anions, and the measured low hydraulic conductivity support the concept of extensive brine-rock interaction as the water moves slowly northeastward across the basin. Detailed information on the composition of the water from the Bell Canyon in test holes AEC-7, AEC-8, and ERDA-10 is included in table 2.

Hydrology of the Guadalupian reef complex

Geohydrologic characteristics.—In general, the position and dimensions of the Guadalupian reef complex which contains the Capitan aquifer, as defined by Hiss (1976, 1980) and as used in this report, closely agree with the location of the Capitan and Goat Seep Limestones and carbonate banks of the Carlsbad facies of Meissner (1972). It also includes shelf-margin carbonates and the upper part of the San Andres Limestone. Although the Capitan aquifer is one of the most productive aquifers in southeastern New Mexico, it is present in the subsurface, at the closest, some 10 miles north of the proposed WIPP facility. Here the Capitan aquifer is generally composed of a relatively "clean" carbonate with low insoluable residue, especially near the forereef edge.

This report is concerned with the section of the Capitan aquifer that parallels the northern and eastern margins of the Delaware Basin in an arcuate strip that extends from the Guadalupe Mountains southwest of Carlsbad to the Glass Mountains near Fort Stockton, Texas. The width of the Capitan aquifer in this strip ranges from 10 to more than 14 miles (Hiss, 1976, p. 141). In the subsurface, the forereef edge is relatively abrupt and abuts against the sediments of the basin (fig. 10). Approximately 1,200 feet of vertical relief along the forereef edge was detected in two oil test holes drilled a few hundred feet apart (horizontal distance) in sections 5 and 9, T. 22 S. R. 33 E. in Lea County (Hiss, 1976, fig. 18). The backreef edge of the Capitan aquifer is much more irregular. The thickness of the unit is quite variable. A maximum thickness of nearly 2,400 feet is present about 13 miles northeast of Carlsbad.

Hiss (1976, p. 90) reported that thickness of more than 1,500 feet has been observed in 49 percent of the wells that penetrate the Capitan aquifer in New Mexico. He also discussed the presence of submarine canyons that eroded into the reef in Eddy and Lea Counties, New Mexico, which decrease the overall thickness of the aquifer by one-half or more. These features all have a bearing on the occurrence and movement of water in the reef complex.

Hiss (1976, p. 198) calculated the hydraulic conductivity of the Capitan aquifer along the eastern margin of the Delaware Basin in Texas and New Mexico to range from 1 to 25 feet per day; average values for the aquifer in southern Lea County and east of the Pecos River valley at Carlsbad are about 5 feet per day. Although no values of hydraulic conductivity are available for the Capitan aquifer west of Carlsbad, Motts (1968, p. 295) indicates that yields of developed wells are from 1,000 to 4,000 gallons per minute. He also indicates from his studies that the occurrence and movement of water in the Capitan aquifer is controlled primarily by lithofacies changes. Permeabilities are greatest in coarser grained rather than finer grained detrital carbonates and in calcareous rather than dolomitic rocks. This association also is borne out by the work of Hiss.

Ground-water movement.—Water in the Capitan aquifer is under water-table conditions southwest of the Pecos River at Carlsbad, but to the north and east where the aquifer is entirely in the subsurface, artesian conditions prevail. Hiss (1976, p. 296) indicates that water entering the Capitan aquifer system in the Guadalupe Mountains moves eastward toward Carlsbad where most of the water discharges into the Pecos at Carlsbad Springs. He concludes that a deep, incised submarine canyon near the Eddy-Lea County line forms a hydraulic restriction that constrains the eastward movement of water from the vicinity of the Pecos River. Apparently there is little movement of water between the Pecos River and this restriction (fig. 11). However, east of this restriction the regional potentiometric surface, represented by the hydraulic head in the aquifer, has been changed significantly in response to withdrawal of both ground water and petroleum, especially during the last 50 years (Hiss, 1980, p. 294).

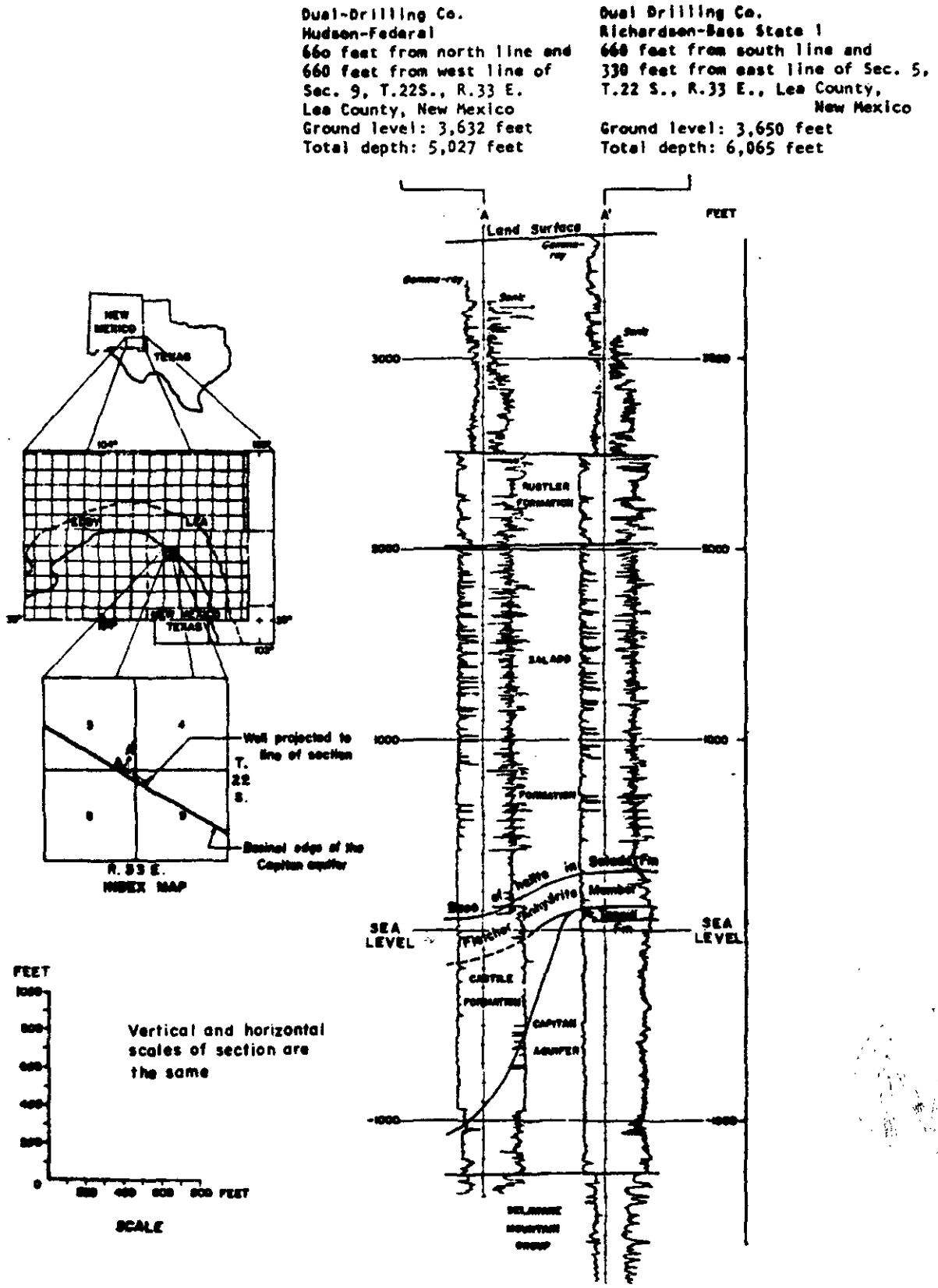

Modified from Hiss (1976)

Figure 10.--Steepness of the basinal edge of Capitan aquifer, Lea County, New Mexico.

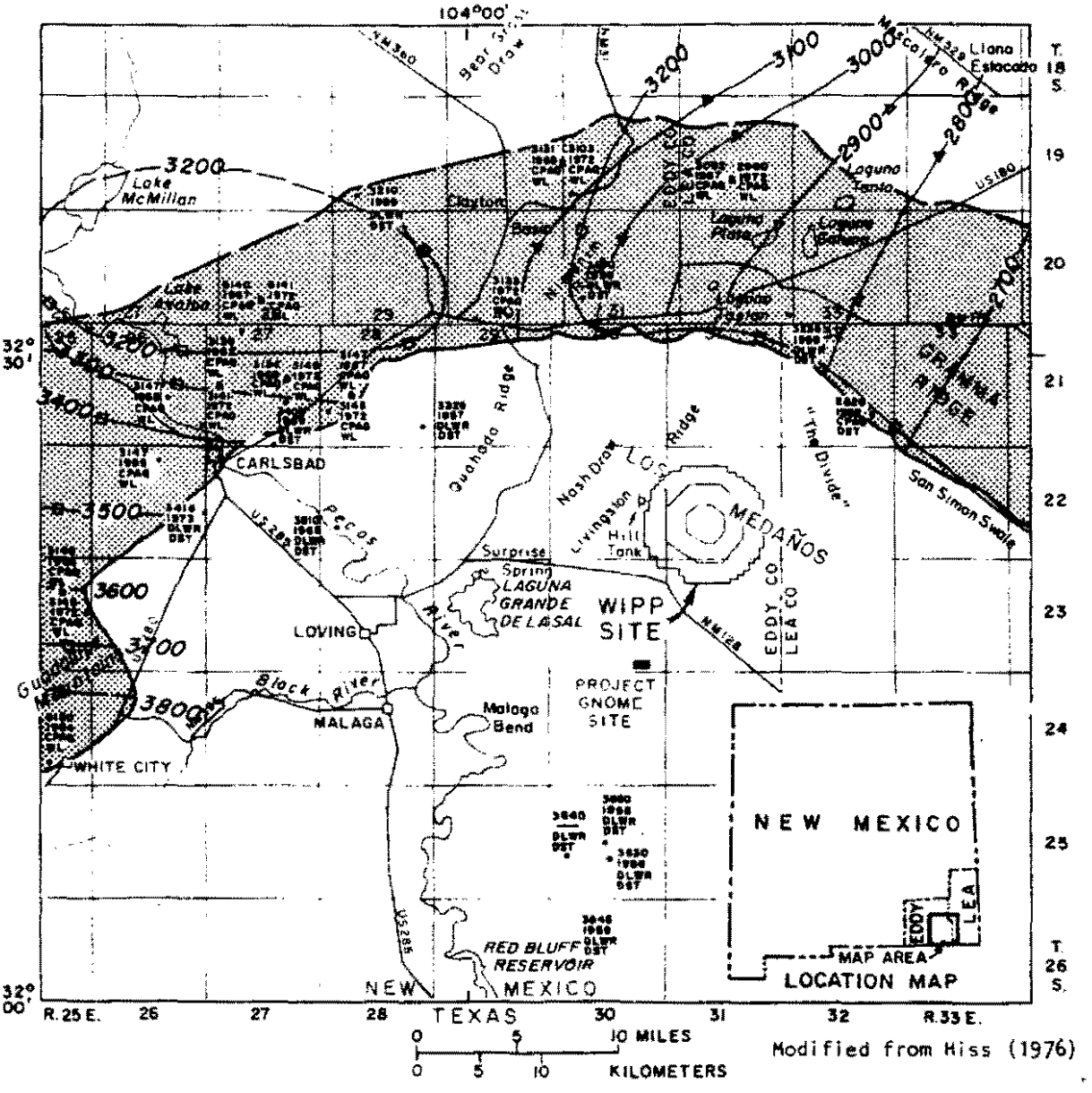

Modified from Hiss (1976)

Figure 11.--Potentiometric surface of the Capitan aquifer in the vicinity of the proposed Waste Isolation Pilot Plant (WIPP) site.

EXPLANATION

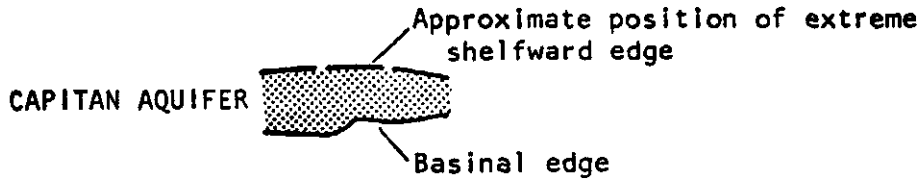

2800 —△——△— HEAD MEASURED IN THE CAPITAN AQUIFER AND SHELF AQUIFER SYSTEM WHERE HYDRAULIC CONNECTION BETWEEN THE TWO AQUIFERS IS RELATIVELY GOOD.

3200 —□——□— HEAD MEASURED IN DELAWARE MOUNTAIN GROUP WHERE THE HYDRAULIC CONNECTION WITH THE CAPITAN AQUIFER IS RELATIVELY POOR.

Contours are dashed wherever data are sparse or of doubtful reliability. Contour interval 100 feet. Datum is sea level.

The contours express a generalized regional head considered to be representative for the Delaware Mountain Group during 1960 to 1970. Similarly, contours in the Capitan aquifer are an interpretation of the head representative for the latter part of 1972.

Considerable subjective judgment was used in contouring the data points. In general, two factors were weighed in considering each data point;

(1) The year in which the head was measured. This is important because prior fluid withdrawal from the oil and water fields causes a decline in head in nearby areas.

(2) The reliability of the data. In general, the data were ranked according to reliability in the following order: Fluid level in water wells, initial oil field bottom-hole pressures, and analysis of pressures from drill-strem tests.

DATA POINT

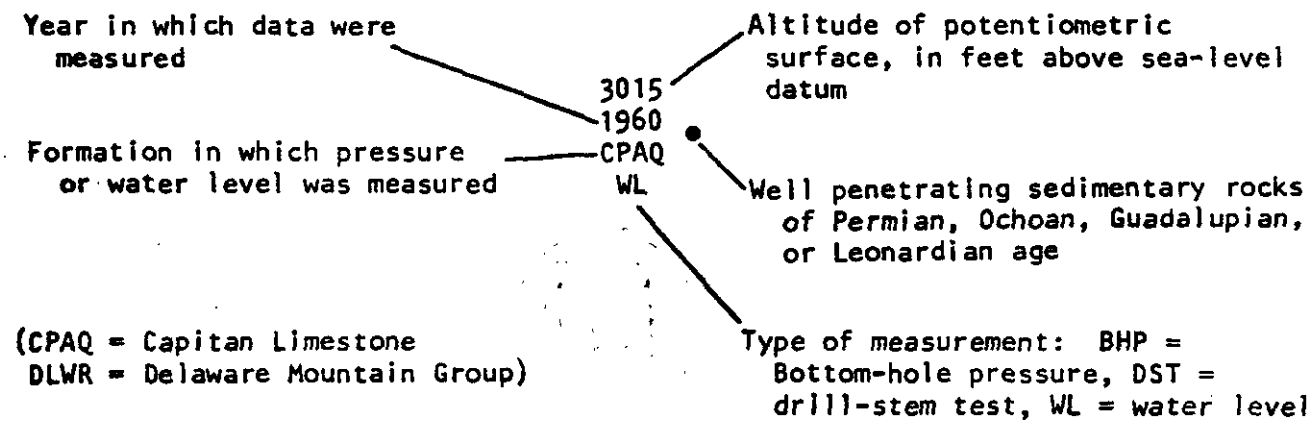

(Values of head are expressed as water with a density of 1.000 gram per cubic centimeter).

In summary, the Capitan aquifer system is unique hydrologically in that it forms a long narrow arcuate belt composed of very permeable rocks. Rocks with little permeability adjoining and underlying the Capitan aquifer control the movement of water. Lateral movement into the basin is prevented by the nearly impermeable anhydrites of the Castile Formation, while downward movement is controlled by the higher hydraulic head in the relatively impermeable Delaware Mountain Group. The shelf-aquifer system (Hiss, 1976) to the west and east of the Pecos River is interconnected with the Capitan aquifer, but the relatively lesser permeability of the shelf-aquifers (one to two orders of magniture less than that of the Capitan) restricts hydraulic connection.

Hydrochemistry.—There is an extensive discussion of the chemical composition of ground water associated with the Capitan aquifer in Hiss (1976, p. 208). In general, the water with relatively small chloride-ion concentrations is present in the Capitan aquifer throughout the region where the rocks have the greatest permeability; conversely, the water with the largest concentrations is present in rocks with the least permeability. The slightly saline water found in the Capitan aquifer and backreef rocks in southeastern New Mexico and western Texas probably is a result of selective displacement of the original brines by freshwater moving from the Glass and Guadalupe Mountains into formations with the regionally greatest transmissivity (Hiss, 1976, p. 210). Moderately saline waters are found in the Capitan aquifer in eastern Eddy County, especially in the area of the apparent hydraulic restriction near the Eddy-Lea County line.

Hydrology of the Castile Formation

Geohydrologic characteristics.—The Castile Formation, consisting of thick anhydrite beds with thin interbeds of salt, lies between the Delaware Mountain Group and the overlying Salado Formation. It is almost completely confined within the Delaware Basin (Oriel, Myers, and Crosby, 1967), the only evaporite unit so restricted. Generally, the Castile averages between 1,500 and 1,850 feet in thickness except in west-central Ward County, Texas, southeast of the WIPP site where it reaches a maximum thickness of more than 2,100 feet (Adams, 1944, p. 1,604). Based on data from test holes drilled during site-characterization investigations at the WIPP site, the Castile is 1,518 feet thick in test hole AEC-7, 1,377 feet thick in test hole AEC-8, and 1,492 feet thick in test hole ERDA-10.

Extensive outcrops of the Castile are present in the western part of the Delaware Basin, in south-central Eddy County, New Mexico, and southward into Texas. The upper anhydrite beds have been altered to gypsum in the area of outcrop and contain solution features.

Very little hydraulic data are available from the Castile Formation. In the salt zones, the presence of water is restricted because the salt does not readily maintain primary porosity, solution channels, or open fractures. The same characteristics are inherent in the anhydrite, with the exception that if developed, fractures may remain open temporarily. Anhydrite hydrates to gypsum in the presence of slightly saline water. Hydration usually is accompanied by a 64-percent expansion in volume, which possibly could seal the fractures and prevent further water migration.

Drill-stem tests were conducted in the Castile Formation during drilling of test holes AEC-7, AEC-8, and ERDA-10 (Lambert and Mercer, 1977). The permeabilities of the anhydrites and salt interbeds were neglibible and in most tests could not be determined with conventional testing methods. However, based on the sensitivity of the test equipment, a conservative estimate for a hydraulic conductivity of the sections tested would be equal to or less than 1×10^{-8} foot squared per day.

In most of the basin, the Castile evaporites act as a barrier or confining layer for water moving in the upper part of the Bell Canyon Formation of the Delaware Mountain Group. It has been suggested that movement of fluids upward from the Bell Canyon Formation through the Castile evaporites could develop a flow path for deep dissolution of the overlying Salado salts and subsequently develop dissolution features referred to as "breccia pipes" (Anderson, 1978, 1981). Anderson also suggested that the upward moving water would, as the concentration of dissolved salts increased, begin to move back downward due to a density differential. This concentrated brine, it is postulated, would move back down through the fracture system in the Castile to discharge into the Bell Canyon Formation. Anderson is concerned that these features could develop at or near the WIPP site.

For this density flow mechanism to work, an extensive fracture system would have to develop through the anhydrites of the Castile. Detailed studies of logs and cores from drill holes in the vicinity of the WIPP site have failed to identify such a fracture system or any other evidence that would indicate water has moved vertically through the evaporite sequence. In fact, to date (1983), no dissolution feature that has been identified within the basin has extended down as deep as the Castile Formation.

The hypothesis also requires that the upper part of the Bell Canyon Formation would be capable of transmitting these saturated brines away from the density-flow systems. The minimal permeability of sands in the Bell Canyon Formation probably would preclude removal of the volume of salt-bearing brines suggested by the hypothesis, even in the time intervals suggested.

Appreciable quantities of water have been reported in the Castile Formation along the western side of the Delaware Basin, but only in weathered zones near the outcrop. Anhydrites in these areas have been altered to

gypsum, forming solution channels and cavities. These cavities are filled with silt and broken blocks of gypsum and act as reservoirs for ground water. Water is used locally for stock watering, but usually has large concentrations of dissolved solids.

Isolated pockets of brine and associated hydrogen sulfide have been penetrated by test holes of various oil companies and during site-characterization investigations at the WIPP site. These occurrences have been discussed in several reports resulting from these investigations (Griswold, 1980; Register, 1981). In general, these pressurized brines are present in a fractured anhydrite bed in the Castile. The brines, in all known instances, are associated with structual features as determined by seismic methods and appear isolated and not part of an interconnected hydrologic system as determined by testing. Geochemical studies by Lambert (1978) show the Castile brine present in ERDA-6 test hole to be chemically and isotopically distinct from indigenous fluids in rocks above and below the Castile. Presently (1982), the Department of Energy is conducting a program that will test the brines extensively, so any further speculation here on the genesis of these brine pockets probably would be premature. The testing is being conducted on test holes ERDA-6 and WIPP-12 and includes standard drill-stem tests and constant head-variable discharge flow tests.

Another dissolution feature that would require the extensive development of a hydrologic system in the Castile is the regional breccias that Anderson (1978) has described in the Castile Formation. These breccias, he postulated, are present in the subsurface at stratigraphic horizons corresponding to major halite beds; the proposed source of the water is the Capitan reef system. As discussed by Bachman (1980), a well-developed flow system would be required over an extended period of time for such extensive lateral dissolution to take place. During careful examination of geophysical logs Bachman could not find a hydraulic system that was in the Castile Formation; in fact, he indicates that the halite beds have never been in close proximity with the Capitan reef system. Bachman proposes instead that the halites were deposited in individual and discrete sub-basins within the large Delaware Basin. The dissolution breccia zones described by Anderson would correspond to areas outside these sub-basins where halite was not deposited. To complete the circulation system, Anderson's (1981, p. 143) theory relies on fracture communication through the evaporites into the Bell Canyon Formation to drain off the brine: as discussed earlier, evidence for this flow mechanism is lacking.

Ground-water movement.—No regional flow system is present within the Castile Formation; the brine appears to occur in isolated pockets. Within the outcrop areas, some localized flow systems have developed in places where anhydrites have been hydrated to gypsum and localized recharge can occur through solution channels and cavities.

Hydrology of the Salado Formation

The Salado Formation consists predominantly of halite with minor beds of anhydrite, polyhalite, clastic rocks, (sandstones and siltstones), and potash minerals. The massive halite beds within the Salado are intended to be the host geologic medium for the WIPP facility.

The Salado is from 1,700 to 2,000 feet thick in most of the area underlying the WIPP site; it is 1,976 feet thick at test hole ERDA-9. Thicknesses may range from as little as 1,200 feet in the northeast to as much as 2,310 feet in deformationally thickened masses in the central part of the area (Jones, 1973, p. 11-18). Jones reports that in the western part of the study area variations in thickness of the Salado are complex and may be quite large. Their complexity and size are believed to reflect a combination of geologic factors involving: (1) Gradual thinning northward in response to changes in deposition patterns during the Ochoan; and (2) rapid thinning westward in response to increased dissolution.

West of the study area, where the Salado is near the surface, most of the halite has been removed by dissolution; in the northwest, where it at one time extended over the buried Guadalupian reef complex, it is absent. Dissolution in the Salado and overlying evaporites has been responsible for development of many shallow and surficial solution related features. Within Nash Draw and possibly in Clayton Basin, solution has been removing halite from the uppermost part of the Salado Formation.

In the WIPP site area, a clay bed with broken gypsum and some fine-grained sandstone is present at the contact of the upper part of the Salado Formation with the overlying Rustler Formation. Jones (1973, p. 20) describes this clay as a subsurface saprolite (a residue concentrated through dissolution of clayey halite and other clay-bearing evaporites by percolating ground water). The residue thins to the east and grades into and intertongues with halite; to the west, it thickens and crops out along the Pecos River. Jones (1973, p. 20) indicates that the practice of assigning this unit to the Rustler Formation by many geologists should be discontinued because the residue is clearly part of the Salado Formation. From a geological standpoint, this unit may be more properly placed with the Salado Formation; however, as a hydrologic unit it is more easily included with the Rustler Formation. For a more detailed discussion of dissolution and time of dissolution, reference is made to reports by Jones (1973) and Bachman (1973; 1980).

The occurrence of water in the Salado Formation is restricted because the halite does not readily maintain primary porosity, solution channels, or open fractures. During drilling of test holes at the WIPP site and during investigations for potash mining operations, no evidence of circulating water was observed in the Salado.

The hydraulic conductivity of the halite in the Salado Formation has been measured in test hole AEC-7 (Peterson, Lagus, Broce, and Lie, 1981); and these tests indicate that the halite has some measurable permeability. The tests were conducted using compressed-air injection into a zone of halite that was isolated by inflatable packers. The flow of air into the formation was measured, and the flow rates were interpreted in terms of formation permeabilities (intrinsic permeability as defined by Lohman, 1972) and porosities. The formation property values were determined based on the assumption that the halite bed could be modeled as an ideal unsaturated porous medium with a porosity of 0.001. Stressing the assumptions they used and cautioning the indiscriminant use of the values obtained to model fluid particle velocity and fluid penetration distances, Peterson, Lagus, Broce, and Lie (1981, p. 52) reported values of permeability (assuming a porosity of 0.001 and a measured well depth of 2,269 feet) of 12 and 21 microdarcies. This depth corresponds to the proposed depth for the WIPP facility. They conclude that the measured in-situ permeability of the halite may be greater than the true value because of formation discontinuities such as microfractures of the borehole wall created by drilling.

As previously discussed, the Salado Formation does not have active circulation of water; however, small pockets of brine have been penetrated during mining and drilling operations. Pockets of gas (nonflammable) and "air" have been penetrated at various depths during drilling of several stratigraphic test holes at the WIPP site. The air or gas was under sufficient pressure to cause unloading (blowouts) of the drilling fluid from the borehole.

Hydrology of the Rustler Formation

The Rustler Formation in the WIPP site area has been divided into five members that are in ascending order: an unnamed lower member, the Culebra Dolomite Member, an anhydrite called the Tamarisk member (Vine, 1963) that is partly altered to gypsum, the Magenta Dolomite Member, and an upper anhydrite called the Forty-niner member (Vine, 1963) (fig. 4). The Tamarisk and Forty-niner members also contain halite in areas where dissolution has not been active. The Magenta and Culebra Dolomite Members at the WIPP site are the most significant units from a hydrologic standpoint and consequently were the most extensively studied.

The Culebra Dolomite Member consists of 25 to 30 feet of microcrystalline dolomite. It characteristically contains many small spherical cavities that range from 2 to 20 millimeters in diameter (fig. 12) and may be partly filled with secondary gypsum and calcite. Although many cavities are open, they do not appear to be interconnected except along fractures. Vine (1963, p. B-14) considers these cavities to be either a primary or a diagenetic phenomenon and not related to weathering in outcrops or secondary solution in the subsurface. In the subsurface, the Culebra is bounded above by anhydrites, which may contain gypsum as thick rinds along

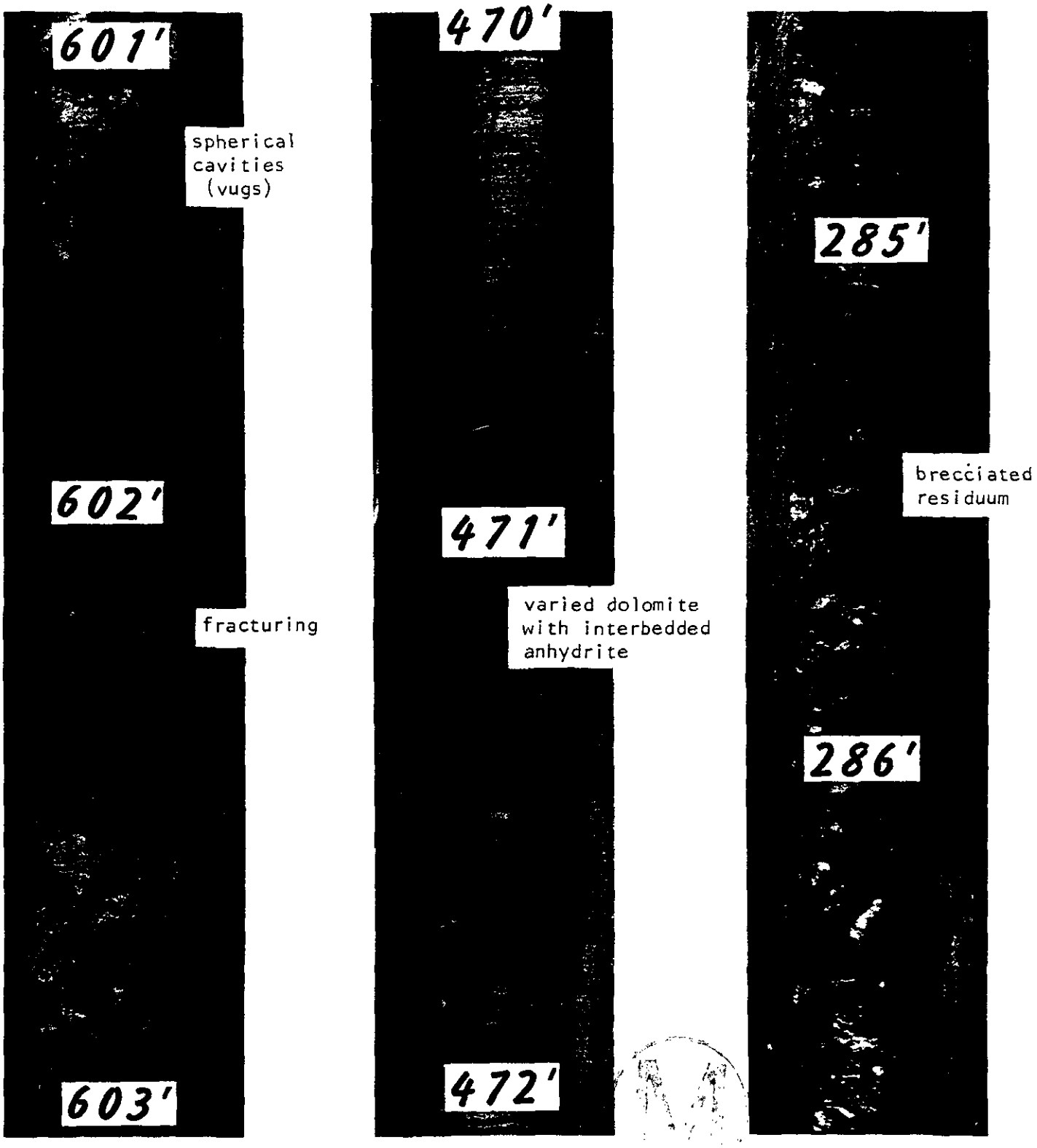

H-8C
Culebra Dolomite Member

H-8A
Magenta Dolomite Member

H-7C
Rustler-Salado contact residuum

NOTE: Numbers on columns indicate feet below land surface.

Figure 12.--Core sections from hydrologic units of the Rustler and Salado Formations.

the contact with the dolomite. These gypsum rinds probably are formed by the movement of water through the dolomite. Underlying the Culebra there is either a clayey halite or a clayey residue, depending on whether the halite has undergone dissolution. Dissolution and removal of this halite bed is directly associated with subsidence, fracturing and the occurrence of permeable zones in the Culebra. In the outcrops, the dolomite may be also locally brecciated or deformed by dissolution collapse.

The Magenta Dolomite Member (fig. 12) ranges in thickness from 20 to 30 feet and is characterized by alternating wavy laminae of silty dolomite and anhydrite (altered in places to gypsum). The dolomite is detrital in origin and is bounded above and below by anhydrite, which may be altered to gypsum along the contact with the dolomite.

A layer of residuum underlies the Rustler Formation in Nash Draw and geologically probably is part of the Salado Formation, but for hydrologic purposes it is considered part of the Rustler Formation. It is a unit composed of clay with crudely interlayered seams of broken gypsum and fine-grained sandstone (Jones, 1973, p. 20) (fig. 12). The clay is considered to be the result of dissolution of clayey halite and other evaporites in the upper part of the Salado. The clay, gypsum, and sandstone comprise a distinctive sequence referred to as the Rustler-Salado residuum. Because it is formed by dissolution, the residuum is quite variable in thickness, especially in Nash Draw. The unit thins eastward, grading into and intertonguing with the halite from which it originated. The residuum thickens westward and crops out at places along the Pecos River.

Exposures of the Rustler along the Pecos River and in Nash Draw are locally deformed, creating an irregular outcrop pattern. This deformation is caused by collapse of the harder, less soluble beds resulting from differential dissolution within the anhydrite, gypsum, and halite of the Rustler and the upper part of the Salado. Generally, the dolomite members are not as susceptible to dissolution as the evaporites; consequently the dolomites are present throughout most of the area. The dolomites commonly are slumped and form draped features in outcrops along Nash Draw, while in other areas they may be broken into discontinuous blocks.

In some areas of Nash Draw, dissolution and erosion has been so extensive that the Magenta and Culebra Dolomite Members are virtually in contact, whereas in a normal stratigraphic sequence they would be separated by as much as 150 feet of red beds and anhydrite. Other evidence of dissolution in the Rustler can be found throughout Nash Draw as indicated by the development of sinkholes and other types of karst topography. Bachman (1981) presents a detailed discussion of these types of near-surface dissolution features. Nash Draw is separated by a low topographic divide from Clayton Basin to the north (fig. 1). A similar type of genesis, that of dissolution collapse accompanied by erosion, also is postulated for this feature.

There has been extensive dissolution of the Rustler Formation in the Malaga Bend area, causing the development of karst mounds (Bachman, 1980, p. 74). As described by Bachman, these mounds and other similar features appear to be controlled more by surficial dissolution in the Rustler Formation than deep-seated geologic processes.

Eastward from the Pecos River, especially east of Nash Draw where the Rustler Formation is covered and protected by the Dewey Lake Red Beds and younger rocks, structures are less chaotic and the Rustler attains a more regular character. In fact, detailed stratigraphy, lithology, and estimates of thickness are obtainable only from drill holes. The geologic section (fig. 5) eastward from Nash Draw identifies the lateral extent of the dissolution front in the Rustler. The structure of the rocks indicates a relatively simple homoclinal dip to the east.

The Rustler Formation ranges in thickness from 300 feet in test hole P-14 at the western edge of the WIPP site to more than 460 feet in P-18 near the southeastern edge of the site. The increase of 160 feet in thickness between P-14 and P-18 may provide an approximate measure of the minimum thickness of halite that is, by dissolution, missing at test hole P-14. The thickness of the Rustler Formation is 330 feet in the northeast part of the study area near test hole AEC-7. Jones (1973, p. 23) believes the difference in formation thickness between the southeast and northeast corners of the area may be depositional in origin because the formation is more thickly bedded in the southeast near test hole P-18. The theory for depositional variation in thickness is enhanced because evaluation of cores from test holes in these areas show no evidence of the dissolution residues common in other areas where the Rustler is thinner. The varying thicknesses shown by a thickness map of the Rustler (fig. 13) represent both changes resulting from dissolution as well as those resulting from the depositional history. This becomes important when describing the hydrologic system because the areas of dissolution have an important bearing on the hydraulic properties of the Rustler Formation and associated rocks.

The hydrologic units of the Rustler Formation have been among the most extensively studied rocks at the WIPP site for two reasons: (1) They are the most productive;and (2) They directly overlie the Salado Formation and could provide a potential avenue for halite dissolution and consequently a means for transporting radionuclides from the proposed repository. Based on a previous study (Mercer and Orr, 1979), the most areally extensive water-bearing units have been identified as the the Culebra Dolomite Member, the Magenta Dolomite Member, and the Rustler-Salado contact residuum. Locally, water also may be found in some of the altered anhydrite units and at places in residue zones where halite has been leached. These occurrences usually are limited to Nash Draw and appear to be discontinous.

A discussion of the hydraulic characteristics logically leads to the division of the study area into two parts: (1) the Nash Draw area southward to Malaga Bend on the Pecos River; and (2) the WIPP site area proper, east of Nash Draw.

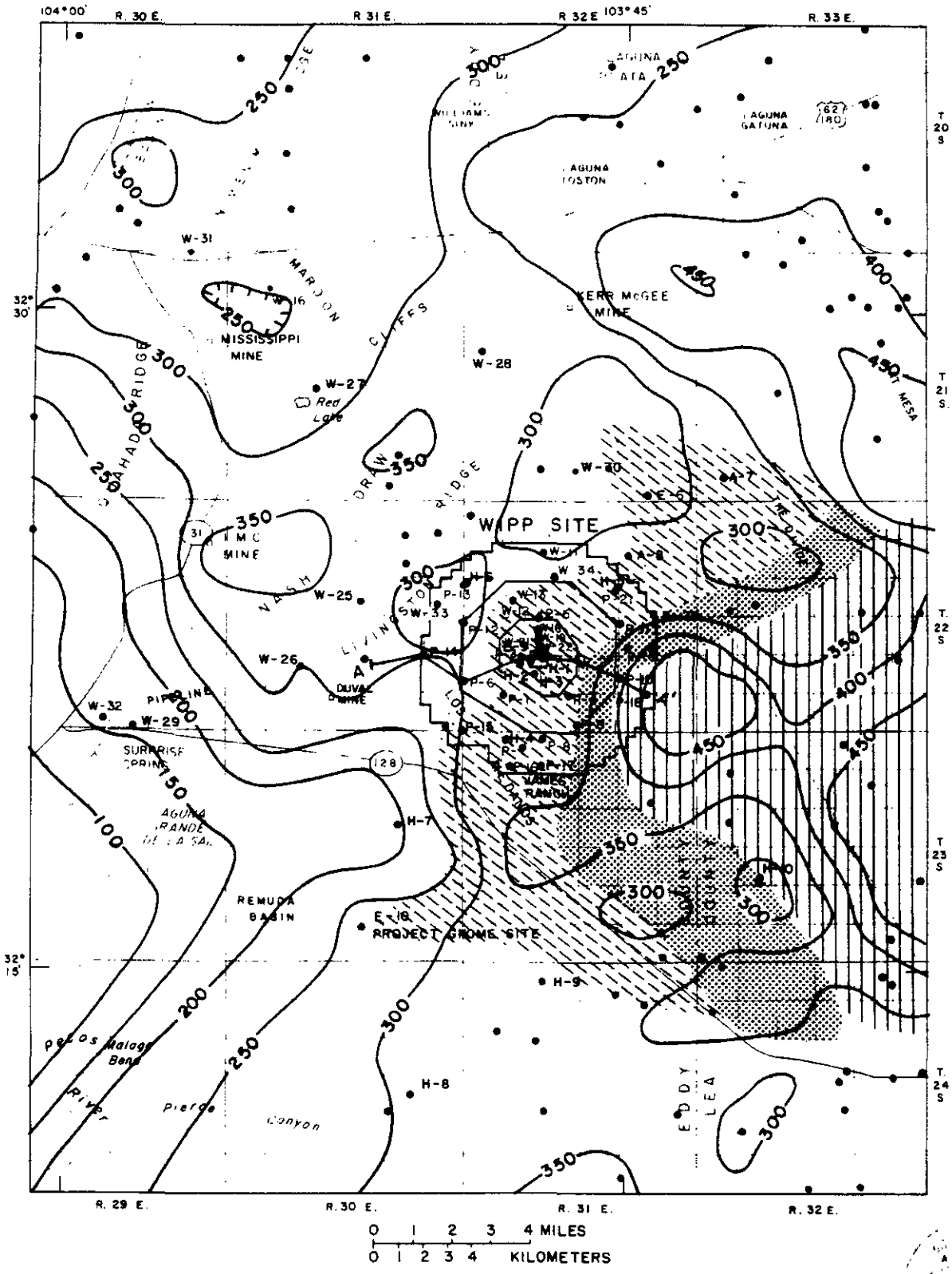

Figure 13.--Presence of halite beds and thickness of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

EXPLANATION

(FOR FIGURE 13)

PRESENCE OF HALITE BEDS IN THE RUSTLER FORMATION

- Above and below both Magenta and Culebra Dolomite Members
- Above and below Culebra Dolomite Member
- Below Culebra Dolomite Member
- None

A ——— A'

LINE OF GEOLOGIC SECTION

—400—

LINE OF EQUAL THICKNESS OF RUSTLER FORMATION--Dashed where approximately located. Interval 50 feet.

•

DRILL HOLE

NOTE: See figure 5 for section showing top of halite in Rustler Formation.

The hydrologic flow system in Nash Draw is very complex and probably is controlled by geologic factors that caused development of the feature itself. Bachman (1980, p. 52) proposes the process of "solution-and-fill," which was discussed by Lee (1925) as the process responsible for the development of Nash Draw. Bachman describes the process whereby near-surface dissolution occurs as surface and ground water penetrates soluble rocks through joint systems and related fractures. The fractures are widened, developing cavities that either collapse (forming sinks) or subside (causing disruption of the more resistant beds). Collapse and subsidence commonly have been observed in Nash Draw. Arroyos actually disappear along fractures into caves in the gypsum.

Hydrology of the Rustler-Salado contact residuum--Brine in the Rustler-Salado contact residuum, immediately above the top of the salt in the vicinity of Nash Draw, was first described by Robinson and Lang (1938) and referred to as the "brine aquifer." Robinson and Lang (1938, p. 86) suggested that the structural conditions that caused the development of Nash Draw also might control the occurrence of the brine; thus, the "brine aquifer" boundary may coincide with the topographic surface expression of Nash Draw. Their studies show the brine to be concentrated along a strip 2 to 8 miles wide and about 20 miles long (figure 14). Data from the test holes they drilled indicates that the residuum (containing the brine) ranges in thickness from 10 to 60 feet and averages about 24 feet. Hydraulic properties determined by Hale, Hughes, and Cox (1954, p. 22) were computed primarily for the area between Malaga Bend on the Pecos River and Laguna Grande del la Sal. They calculated a value of transmissivity of 8,000 feet squared per day and estimated the potentiometric gradient to be 1.4 feet per mile. In this area, the "brine aquifer" apparently is part of a continuous hydrologic system as evidenced by the coincident fluctuation of water levels in the test holes (as far as Laguna Grande de la Sal) with irrigation pumping rates along the Pecos River (Hale, Hughes, and Cox, 1954, p. 22).

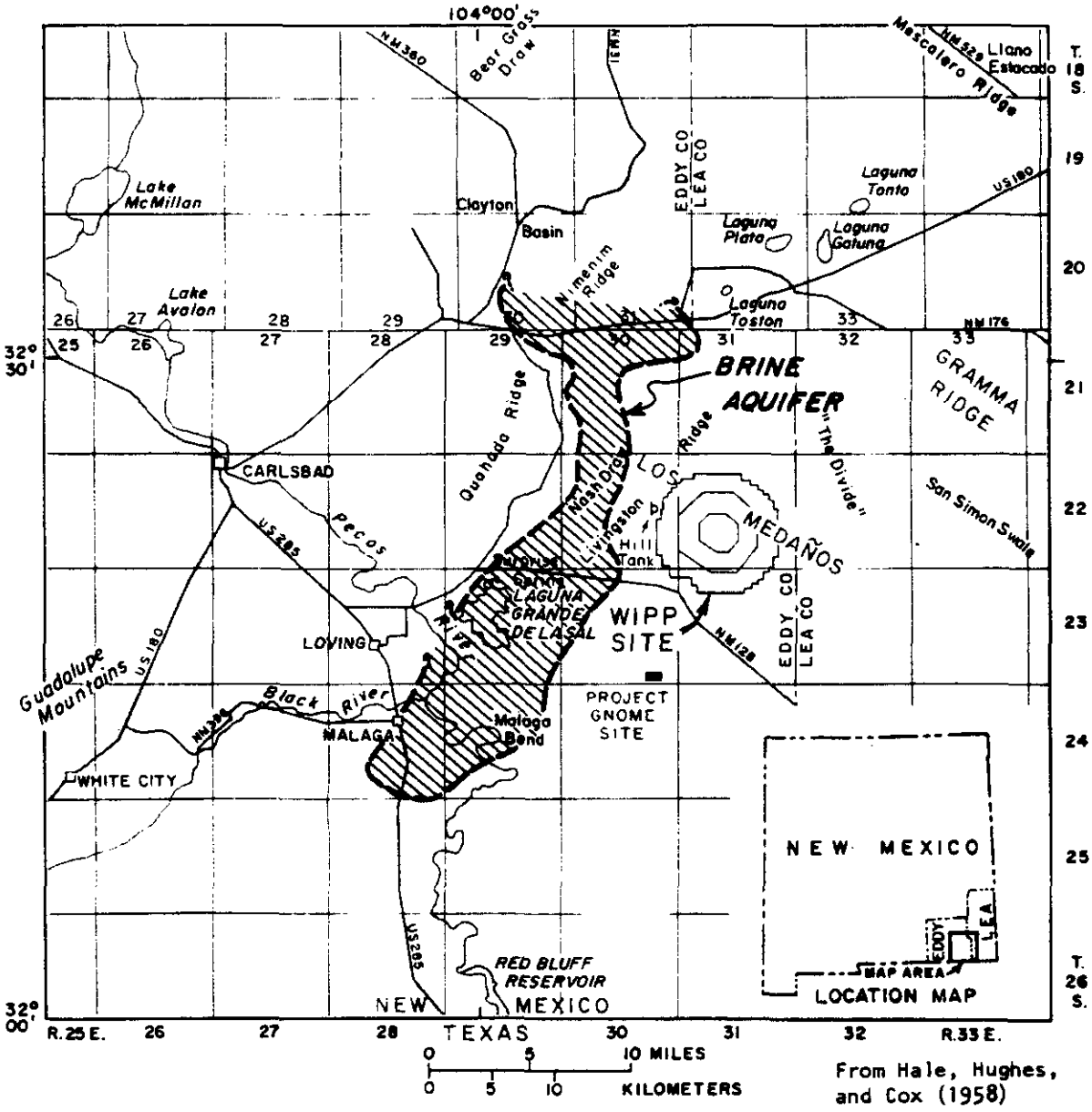

From Hale, Hughes, and Cox (1958)

Figure 14.--Approximate areal extent of the "brine aquifer" near the proposed Waste Isolation Pilot Plant (WIPP) site.

In conjunction with the "brine aquifer" study, Robinson and Lang (1938) also made a study of Laguna Grande de la Sal and the area between it and Malaga Bend to determine if brine in the lake was a source of recharge to the system. They determined, at the time of their study, that the sources of the water in the lake were precipitation and surface drainage, ground water inflow from upper units above the "brine aquifer", and effluent from the U.S. Borax and Chemical Company operation. Since that time, the U.S. Borax and Chemical Company plant has been closed; however, there still may be some inflow from mining activities that take place further north in Nash Draw. Robinson and Lang identified several factors that led to their conclusion that the lake and underlying "brine aquifer" were not connected, these factors were: (1) Test holes drilled into the hydrologic units under the lake contained water with a different chemical composition and a much lesser chloride concentration; and (2) Water levels in the fill indicated movement toward the lake and not away from it (in fact, the hydraulic heads were above the lake level in most test holes). Theis and Sayre (1942, p. 71) supported their conclusion because they found water levels in the lake to be high in winter and low in summer, whereas the hydraulic head in the "brine aquifer" is high in the irrigation season and low between seasons.

Discharge of ground water into Laguna Grande de la Sal and probably into the fill is by the flow of springs and seeps, particularly along the northern end. The largest of these springs was indentified by Robinson and Lang (1938 p. 95) and called Surprise Spring (SW¼ NE¼ SW¼ sec. 4, T. 23 S., R. 29 E.), which was reported to discharge 115 to 125 gallons per minute. More recent WIPP studies indicate that the spring and accompanying seeps now discharge over such a broad area that accurate measurements of flow could not be made. This increase in the areal extent of the discharge area indicates an increase in discharge probably resulting from the effects of effluent added by mining activities since Robinson and Lang's (1938) studies. The discharge of the spring probably comes from the cavernous gypsum of the Tamarisk Member of the Rustler Formation even though alternative sources, the Culebra Dolomite Member or the Rustler-Salado contact residuum, have been proposed. Data from more recent WIPP investigations would indicate that the water chemistry and hydraulic-head information identify the source of the water to be something other than the Culebra or the residuum. Analyses of water samples from the Culebra Dolomite Member and Rustler-Salado contact residuum in test hole WIPP-29 (fig. 1A) near Surprise Spring indicate a considerable difference in both sodium and chloride concentrations when compared to Surprise Spring. There is 2.5 times more calcium in the water discharging from Surprise Spring. Additionally, hydraulic-head data from a potash test hole drilled by Amoco in Laguna Grande de la Sal (T. 23 S., R. 29 E., sec. 4) shows the Culebra to have a hydraulic head about 21 feet above lake level, indicating a confined system although there maybe some minor upward leakage. The Culebra was confined under about 40 feet of gypsum mud and flowed at a rate of approximately 20 gallons per minute when first penetrated during drilling activities. This evidence indicates that neither the water present in the Culebra Dolomite Member nor in the Rustler-Salado residuum is in good hydraulic connection with the brine from the Spring flowing into Laguna Grande de la Sal and that the most likely source is from the Tamarisk Member.

In the northern one-half of Nash Draw, the approximate outline of the "brine aquifer" (Rustler-Salado contact residuum) as described by Robinson and Lang (1938) (fig. 14) has been supported by drilling associated with the WIPP geotechnical studies. These studies also indicate that the main differences in areal extent occur along the eastern side where the boundary is very irregular and in places (test holes P-14 and H-7) extends further east than previously indicated by Robinson and Lang.

Other differences from the earlier studies include the variability in thickness (table 1) of residuum as seen in test holes W-25 to W-29. These holes indicate thicknesses ranging from 11 feet in test hole W-26 to 108 feet in test hole W-29 in Nash Draw compared to 8 feet in test hole P-14 east of Nash Draw. The specific geohydrologic mechanism that has caused dissolution to be greater in one area than in another is not apparent although a general increase in chloride concentration in water from the north end to the south may indicate the effects of movement down the natural hydraulic gradient (table 2).

The historical data concerning hydraulic properties collected from the Rustler-Salado contact residuum are concentrated in the area from north of Laguna Grande de la Sal south to Malaga Bend. The data discussed in this report and collected for the WIPP regional hydrologic studies are from the Nash Draw area generally north of Laguna Grande de la Sal to the Maroon Cliffs, west to Quahada Ridge and east of Nash Draw (including the WIPP site) to The Divide (fig. 1).

A potentiometric-surface map for the hydrologic unit of the Rustler-Salado contact residuum is based on data from both the Rustler-Salado contact residuum of Nash Draw and the residual brine at the contact of the Rustler and Salado Formations east of Nash Draw in the WIPP site area. The map data are adjusted for the effects of variations in water chemistry, which create density differences. As discussed under the methods of investigation, the static heads represented by water levels in the wells were adjusted to a common density of 1.00 (freshwater equivalent, table 6). The potentiometric-surface map, representing freshwater equivalent heads, is shown in figure 15. The contours on this map represent the approximate values of static head and show the variance in gradients between Nash Draw and the area of the WIPP site. The average hydraulic gradient in Nash Draw is about 10 feet per mile; in contrast, at the WIPP site the average gradient is 39 feet per mile. This difference reflects the changes in transmissivity which are as much as five orders of magnitude greater in Nash Draw. The transmissivity determined from aquifer tests in test holes completed in the Rustler-Salado contact residuum of Nash Draw, including test holes P-14 and H-7C (table 7), ranges from 2×10^{-4} foot squared per day at test hole W-27 to 8 feet squared per day at test W-29. This is in contrast to the WIPP site proper where transmissivities range from 3×10^{-5} feet squared per day at test hole P-18 and H-5C to 5×10^{-2} feet squared per day at test hole P-14.

The potentiometric-surface map of the hydrologic unit of the Rustler-Salado contact residuum gives evidence that there are two areas of considerably different permeability. The zone of greater permeability is associated with the residuum (brine aquifer) of Nash Draw, where flow is primarily through associated fractures and the intergranular spaces of the clay and gypsum. In contrast, brine underlying the WIPP site east of Nash Draw occurs in a zone of minute permeability along the contact between the Salado Formation and the overlying Rustler Formation (bedding-plane flow).

As stated earlier, potentiometric-surface maps can be useful in showing the areal variations in hydraulic gradient from which a general trend in movement can be inferred. Inspection of the potentiometric-surface map for the hydrologic unit of the Rustler-Salado contact residuum indicates that the apparent ground-water flow is southwest across the WIPP site towards Nash Draw and then south-southwest down Nash Draw toward Malaga Bend (fig. 15).

Although caution should be used in making interpretations of the hydraulic-head distribution in the WIPP site for the hydrologic unit of the Rustler-Salado contact residuum, the inferred flow direction probably is valid. Static-head interpretations of the Rustler-Salado contact residuum within the area of the WIPP site are complicated by variations in water chemistry and its effects on density and by the great length of time required during testing to establish static conditions in test holes because of the minute permeabilities.

The calculations of the rate of movement of water in the Rustler-Salado contact residuum are complicated by the variations in permeabilities as well as in the hydraulic gradient. The rate of movement of 0.2 foot per day was calculated by Hale and Clebsch (1958, p. 11) for the residuum (brine aquifer) south of Laguna Grande de la Sal. Assuming, as they did, an average effective porosity of 0.2, an average hydraulic conductivity of 0.15 foot per day, and a hydraulic gradient of 10 feet per mile, the flow rate for the section from Maroon Cliffs to Laguna Grande de la Sal would be 0.002 foot per day, assuming that the residuum behaves as a uniform porous medium. Although the hydraulic characteristics of the Rustler-Salado contact residuum are variable, this rate probably is a conservative value. The rate of movement in the Rustler-Salado contact residuum at the WIPP site has not been determined because the hydraulic properties are extremely variable and because of the lack of a valid value for the effective porosity. Water-quality data, in particular the large concentrations of magnesium and potassium, indicate an extremely slow rate of movement with long periods of rock-water contact.

The area of recharge suggested by Lang (Robinson and Lang, 1938, p. 86) is in the area of Bear Grass Draw (T. 18 S., R. 30 E.), some 30 miles north of Malaga Bend. He suggests that water percolating into the ground may pass into the truncated lower part of the Rustler Formation and then migrate south and east into Nash Draw, gradually dissolving salt in the Salado Formation. Data from WIPP regional studies indicate a hydraulic gradient from the north

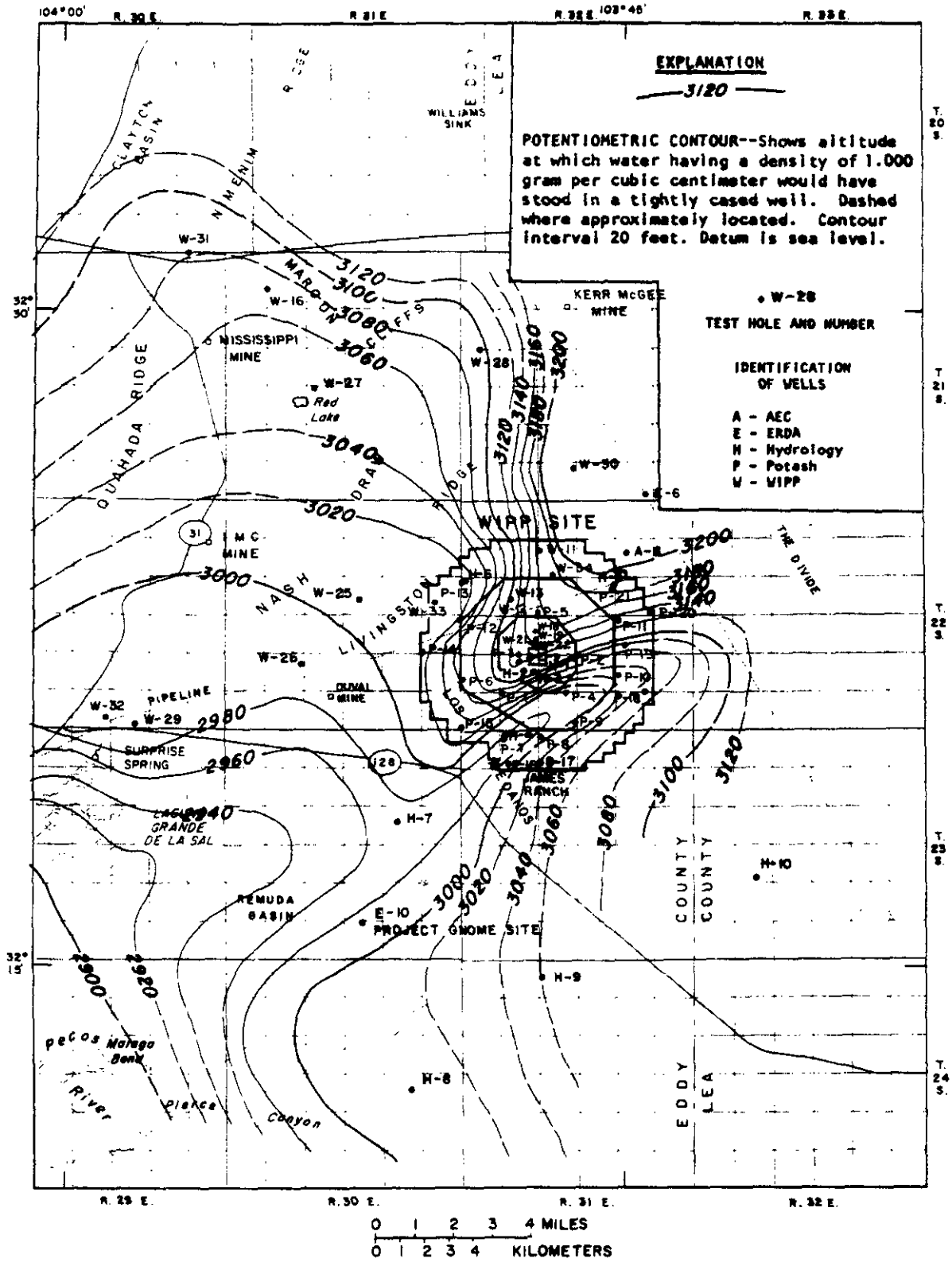

Figure 15.--Adjusted potentiometric surface of the Rustler-Salado contact residuum (1982 at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

and that the Bear Grass Draw area may be a possible area of recharge. There also is a possibility of some recharge occurring in Clayton Basin and Nash Draw.

Hale, Hughes, and Cox (1958, p. 23) believed the Rustler-Salado contact residuum discharges to the alluvium near Malaga Bend on the Pecos River. Because the confining beds in this area probably are fractured due to dissolution and collapse of the evaporites, the brine (under artesian head) moves up through these fractures into the overlying alluvium and then discharges into the Pecos River. Theis and Sayre (1942, p. 69) estimated that the discharge rate was about 200 gallons per minute and that in the Malaga Bend area about 342 tons of sodium chloride per day were discharged to the river, presumably all coming from the "brine aquifer".

Although the potentiometric-surface map (fig. 15) indicates a potentiometric high to the east of the WIPP site, there is not sufficient data to determine its origin. Suggestions have been made that there could be leakage from the overlying Culebra in this area; however, to accomplish this leakage the water would have to move through 80 feet of clay and silt and a 25-foot-thick anhydrite bed. Drilling at the WIPP site has not revealed any fractured anhydrite that could increase the vertical permeability, allowing water to move into the Rustler-Salado contact residuum, nor is there any indication that the water has altered the anhydrite to gypsum. Additionally, the hydraulic-head difference between the two hydrologic units (tables 6 and 9), as much as 400 feet in test hole H-1, coupled with the water-quality difference (table 2), would tend to indicate the zones are isolated and confined systems. The apparent high at test hole H-5 could be due to the conversion of the dense brine to equivalent freshwater head.

Evidence for very slow ground-water movement is found in the water quality, especially in the magnesium concentrations. Large magnesium concentrations appear to be indicative of an environment in which ground-water flow is extremely slow and there has been extensive interaction between the water and its host rock. Large concentrations of magnesium, ranging from 21,000 milligrams per liter in water from test hole H-6 to 82,000 milligrams per liter in water from test hole H-5, were present in most of the test wells in the eastern part of the WIPP site (table 2). Aquifer tests at these test holes were characterized by minute transmissivities (table 7). To the west, approaching the more developed part of the flow system of the Rustler-Salado contact residuum in Nash Draw, the magnesium concentrations decreased by 1 to 2 orders of magnitude (fig. 16). Magnesium concentrations of 1,200 milligrams per liter in water from test hole P-14 and 350 milligrams per liter in water from test hole P-15 may indicate the eastern boundary of the more developed Rustler-Salado flow system. Magnesium concentrations are as little as 430 milligrams per liter in water from test hole H-8; other values range from 910 milligrams per liter in water from test hole H-7 to 3,200 milligrams per liter in water from test hole W-25. Based on the chemical analyses, the magnesium concentration in the brine could be used to outline the zone of active circulation (fig. 16) (see hydrochemistry section on the Rustler Formation).

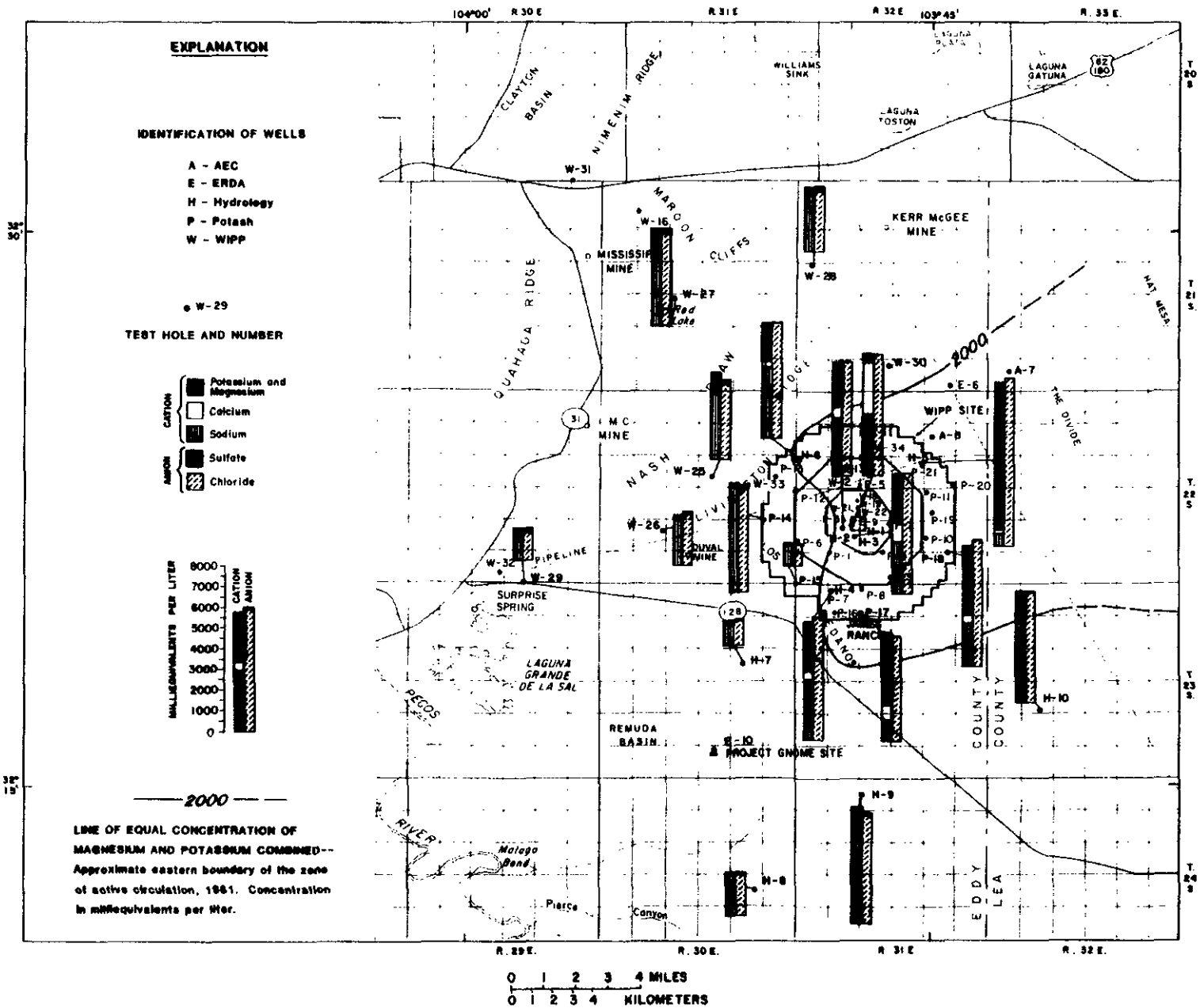

Figure 16.--Concentrations of major chemical constituents in water from the Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

Water at the Rustler-Salado contact, or in the residuum, contains the largest concentrations of dissolved solids in the WIPP area, ranging from 41,500 milligrams per liter in test hole H-1 to 412,000 milligrams per liter in test hole H-5C. These waters are classified as brines. The areal distribution of major chemical constituents in water is shown in figure 16. The general chemical composition of the brine collected from the Rustler-Salado contact residuum also is listed in table 2; the major dissolved cations and anions are listed in table 8 and expressed in milligrams per liter, milliequivalents per liter, and percentage composition.

The dissolved mineral constituents in the brine largely consist of sulfates and chlorides of calcium, magnesium, sodium, and potassium; the major constituent is sodium chloride. Concentrations of the other major ions vary according to the spatial location of the sample and probably are directly related to the interaction of the brine and the host rocks and reflect as a residence time within the rocks. Residence time of the brine depends upon the transmissivity of the rock. For example, the presence of large concentrations of potassium and magnesium in water is correlated with minimal permeability and a relatively undeveloped flow system.

The dissolved-solids, magnesium, and potassium concentrations of the ground water increase from west to east in the WIPP area. An arbitrarily chosen line of equal concentration representing 2,000 milligrams per liter of potassium and magnesium combined (fig. 16) approximates a dividing line between zones of generally small concentrations to the west and rapidly increasing concentrations to the east. This same line, when viewed in terms of values of transmissivity, represents a division between areas of minute transmissivity (less than 1×10^{-3} foot squared per day) and areas of greater transmissivity (more than 1×10^{-1} foot squared per day). This line indicates a division between the more developed flow system with accompanying evaporite dissolution and the minimally developed flow system in which ground-water movement, if any, is restricted to openings along bedding planes. A general lack of residuum to the east of this line, which indicates dissolution of the underlying Salado halite has not occurred, is further evidence that this area is not part of the more developed flow system.

Hydrology of Culebra Dolomite Member of the Rustler Formation--The Culebra Dolomite Member of the Rustler Formation ranges from 25 to 30 feet in thickness and is the most persistent and productive hydrologic unit in the area. In the WIPP site, the Culebra is a vuggy, finely crystalline dolomite that is present below the thick anhydrite of the Tamarisk Member, which in Nash Draw is mostly altered to gypsum. Water in the dolomite usually is present in fractures and is confined by the overlying gypsum or anhydrite and the underlying clay and anhydrite beds. The water may be under water-table conditions in the area south of Laguna Grande del la Sal where the Culebra has been subjected to solutional activity that has caused the confining beds to be extremely fractured and altered.

The structural character of the Culebra is related directly to the degree of dissolution. In Nash Draw, the Rustler Formation has undergone considerable deformation due to dissolution of parts of the evaporites and removal of halite from the underlying halite beds of the Salado. The effects of dissolution can be seen in some areas where large discontinuous blocks of Culebra are near the surface and have steep, erratic dips. In other areas, the Culebra is continuous and forms draped features. The Culebra crops out along the Pecos River in the Malaga Bend area. In those parts of the area east of Nash Draw where the Rustler is overlain by the Dewey Lake Red Beds and younger deposits, the dissolution effects have not been nearly as great and the structure of the Culebra is relatively regular.

In the WIPP site area there is a structural high clearly shown by contours drawn on the top of the Culebra Dolomite Member (Jones, Cooley and Bachman, 1973, p. 50). These contours outline an anticline in the northeastern part of T. 22 S., R. 32 E.; the anticline plunges to the southeast across the central part of the township. Excluding other minor structural irregularities, the overall gentle dip of the Culebra is to the east.

Hydraulic properties of the Culebra Dolomite Member, as determined by testing, vary considerably from place to place and appear to be related to the size and number of fractures and the size of the fracture openings. As previously mentioned, these fractures and openings are related to the degree of evaporite dissolution occurring either in the Rustler or the upper part of the underlying Salado Formation. The potentiometric-surface map, representing equivalent freshwater heads (table 9), is shown in figure 17.

The contours on the map indicate a variability in gradient as well as flow direction for different parts of the region. The gradient variability may reflect lateral variations in permeability within the Culebra Dolomite Member caused by local differences in the number and spacing of fractures. The flow direction may be variable. This variability may be caused by differences in fracture orientation in areas of greater permeability. The gradient in Nash Draw northeast of test hole W-29 is about 16 feet per mile, whereas, southwest of test hole W-29 it is 5 feet per mile. The gradients in the WIPP site area vary considerably, generally being about 7 feet per mile in the central part and 20 feet per mile in the northern and southern parts. The contours also indicate a potentiometric high near test hole H-5, which may reflect the effects of the conversion of brine density to freshwater head. The broad area south of WIPP, where gradients appear to be extremely flat, may represent the transition from an area of fractured dolomite to that of a fractured and disrupted unit created by the extensive dissolution in the Nash Draw area.

Calculated values of transmissivity for the Culebra are based on the assumption of flow in porous media; because flow probably takes place along fractures, these values need to be used with care. It is believed, however, that the porous-media assumption should approximate flow conditions in the

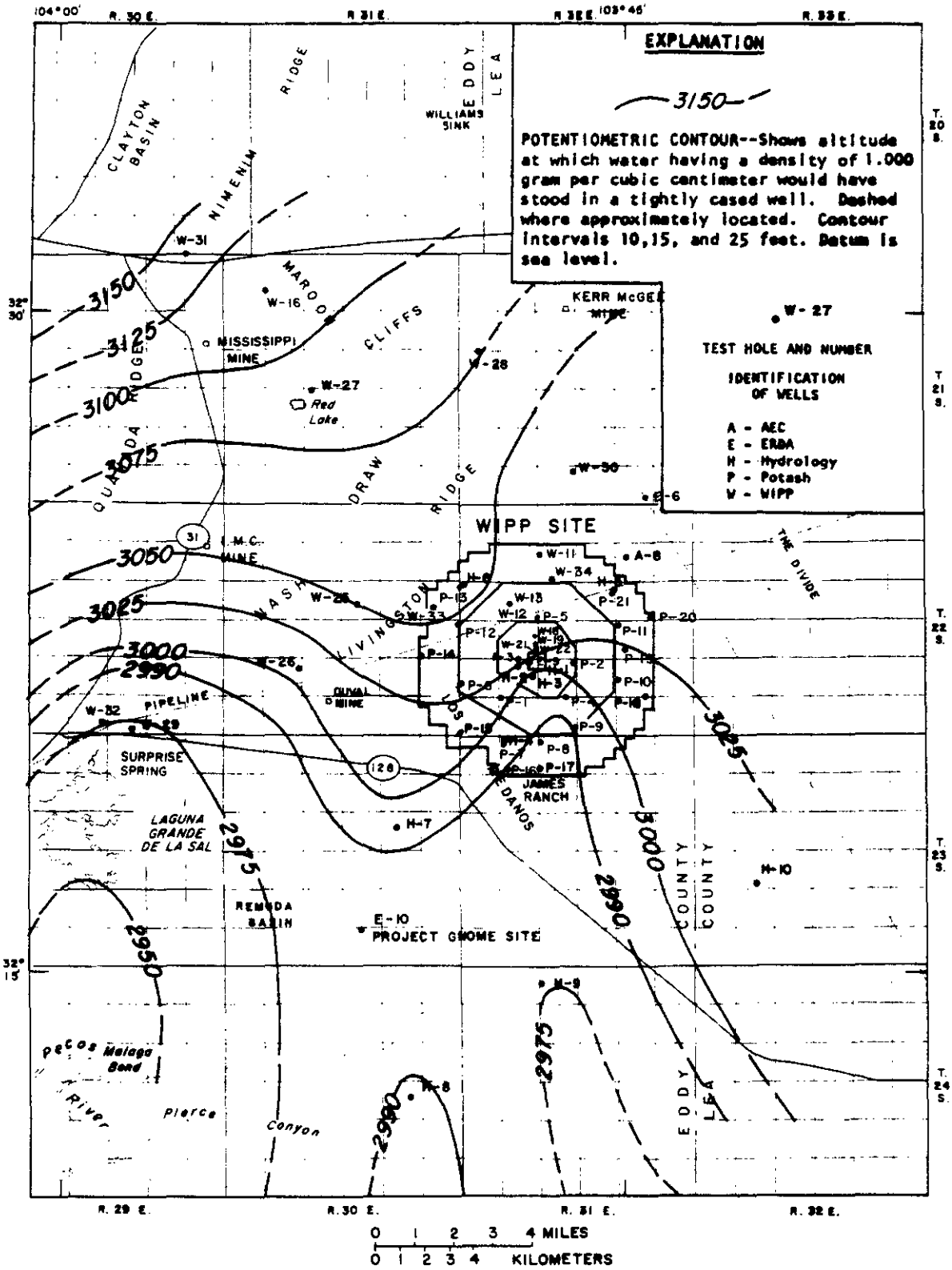

Figure 17.--Adjusted potentiometric surface of the Culebra Dolomite Member of the Rustler Formation (1982) at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

Culebra because the dolomite is thin and the fractures probably are closely spaced (fig. 18). Although the fracturing shown in figure 18 is associated with halite removal on the outcrop, areas of halite dissolution in the subsurface probably have similar fractures. Values of transmissivity for tests from 20 of the test holes drilled during WIPP investigations are included in table 7.

Transmissivities calculated for the Culebra in Nash Draw range from 18 feet squared per day (Gonzalez, 1983) on the north end at test hole W-28 to 1,250 feet squared per day at test hole W-26 west of the WIPP site. These compare with a value of 535 feet squared per day calculated for the Culebra at the Project Gnome site (fig. 1A) (Cooper, 1962a, p. 37).

Hydraulic properties also were determined by laboratory tests of samples of the Culebra Dolomite Member taken from the Project Gnome shaft. One sample from a depth of 505 feet had a total porosity of 14.4 percent and an effective porosity of 7.8 percent, while a sample from 515 feet had a total porosity of 13.7 percent and effective porosity of 11.1 percent. The average effective porosity of 10 percent compares with the 12 percent value obtained by Grove and Beetem (1971) for a tracer test conducted on the Culebra in the same area.

Transmissivities calculated for the Culebra Dolomite Member in the WIPP site area range from 1×10^{-3} foot squared per day at test hole P-18 to 140 feet squared per day at test hole P-14 and generally are less than 1 foot squared per day (table 7). Most of these values are several orders of magnitude less than those in Nash Draw. Smaller transmissivities probably signify that less dissolution has occurred in the halite beds below the Culebra and upper part of the Salado Formation. Greater permeability has been noted where a silty residue is present immediately below the Culebra. This residue results from dissolution of a clayey halite bed below the Culebra, which caused subsidence and fracturing in the dolomite.

Transmissivity values calculated from tests in two test holes in the WIPP site area are much larger than the average; these test holes are H-6B, with a transmissivity of 73 feet squared per day, and P-14, with a transmissivity 140 feet squared per day. Both of these test holes are on the western side of the WIPP site along Nash Draw. Geologic data from cores from these test holes indicate that the large transmissivity values may be related to localized dissolution in the Rustler Formation or upper part of the Salado Formation. Although not expressed topographically at the surface, these large values may indicate an eastward subsurface extension of the geologic processes that formed Nash Draw. Approximately 8 feet of residuum was penetrated at the base of the Rustler in test hole P-14 and about 2 feet of residuum was penetrated in test hole H-6B. The transmissivity of the Rustler-Salado contact residuum in these test holes also is the largest in the WIPP site area. A similar occurrence was found south of the WIPP site in test hole H-8B where the transmissivity was calculated to be 16 feet squared

Figure 18.--Outcrop of Culebra Dolomite Member of Rustler Formation where removal of underlying halite has caused fracturing.

per day and in test hole H-9B where the value was 231 feet squared per day (table 7). Because of these large values of transmissivity it also is possible, as in the case of test holes H-6B and P-14, that the geologic processes active in Nash Draw also may be occurring here.

When the distribution of halite beds in the Rustler Formation (fig. 13) is compared to the distribution of transmissivity across the WIPP site, it appears that dissolution of the halite in the lower part of the Rustler Formation is related to the permeability changes in the Culebra Dolomite Member. As these halite beds below the Culebra are dissolved, subsidence occurs, creating fractures in the dolomite which open up and allow movement of water. No fractures were noted in the overlying anhydrite in cores from most of the WIPP site test holes; thus, the Culebra is assumed to be effectively isolated from overlying water-producing zones east of the site, however, west of the site fracturing may create some interconnection. It is generally accepted that the extensive dissolution in the Rustler Formation in Nash Draw is responsible for the permeability increases in the Culebra in this area.

The direction of ground-water movement in fractured rock, such as the Culebra Dolomite Member, is affected by directional differences in hydraulic conductivity (anisotropy); consequently, the regional direction of flow may have little or no relationship to the localized direction of flow indicated by the contours on the potentiometric-surface map. In Nash Draw the Culebra hydrologic unit is so extensively fractured that there may not be directional differences in hydraulic conductivity. Based on this premise and an inspection of the potentiometric-surface map, the flow trend in Nash Draw generally is southward toward Malaga Bend. Local flow paths in the area of the WIPP site, however, may not be as easy to determine. Because it was concluded that the ground-water flow in the Culebra at the WIPP site was in fractures, it became evident that further studies of the ground-water system were needed. Therefore, several hydrologic test holes penetrating the Culebra at the WIPP site were selected by project personnel for site-specific tracer and aquifer tests. These tests will determine the degree of anisotropy, effective porosity (for rate calculations), dispersivity, and transmissivity. The study is being conducted by Sandia National Laboratories and is in progress at the time of this report (1983); thus, any further evaluation of the flow system would be premature.

Based on water-quality data (table 2), hydraulic head differences (tables 7, 9, and 10), and analyses of cores taken from the hydrologic test holes in the WIPP site area, probably no effective vertical connection exists between the Culebra Dolomite Member and the underlying and overlying hydrologic units. In test hole H-3 near the site center, the stabilized hydraulic head in the Culebra is 155 feet lower than that in the overlying Magenta Dolomite Member and is 480 feet higher than the hydraulic head in the underlying hydrologic unit of the Rustler-Salado contact residuum. In the northwest part of the WIPP site at test hole H-6, the hydraulic head difference between the Culebra and Magenta is only 2 feet, however,

differences in the sodium and chloride concentrations in the water from the two units at test holes H-6A and H-6B indicate that vertical flow probably is very small. The dissolved sodium concentration in water from the Culebra was 18,000 milligrams per liter compared to 1,100 milligrams per liter in the Magenta; the chloride concentration was 28,000 milligrams per liter in the Culebra and 1,200 milligrams per liter in the Magenta.

In test hole W-25 in the north part of Nash Draw, the static-head difference between the Culebra and Magenta is 4 feet; the sodium concentration in the Culebra was 5,100 milligrams per liter and in the Magenta it was 3,100 milligrams per liter, whereas the chloride concentration in the Culebra was 8,300 milligrams per liter and in the Magenta it was 5600 milligrams per liter. These minimal hydraulic head differences and similar sodium and chloride concentrations, along with similar values of transmissivity (Culebra, 270 feet squared per day; and Magenta, 375 feet squared per day), suggest localized vertical interconnection in the north end of Nash Draw.

From test hole W-29 south to Malaga Bend, places probably exist where the Rustler-Salado contact residuum and Culebra may be interconnected (the Magenta has been stripped by erosion); however, data are insufficient in this area to verify this possibility. A geochemical study to quantify the degree of interconnection currently (1983) is being conducted by Sandia National Laboratories.

The Culebra was unsaturated in the ERDA-6 and AEC-7 test holes to the northeast of the site. Similar information has been reported for the area along Quahada Ridge west of Nash Draw. These data may identify permeability boundaries in the Culebra Dolomite to the west and northeast.

The potentiometric-surface contours shown in figure 17 indicate a recharge area for the Culebra Dolomite to the north and northwest of Nash Draw. Like the hydrologic unit of the Rustler-Salado contact residuum, one potential area of recharge would be in the vicinity of Bear Grass Draw (T. 18 S., R. 30 E.), where the beds of the Rustler are truncated and downward percolating water could enter the Culebra. Although conclusive data are lacking, some recharge may be occurring in the area of Clayton Basin, where dissolution and collapse have disrupted beds in the Rustler Formation.

The discharge from the Culebra Dolomite Member probably is in the area south of Laguna Grande de la Sal near Malaga Bend, where the Culebra and overlying beds are significantly fractured. The ground water in this area probably is under water table or slightly confined conditions with flow eventually discharging to the Pecos River. Some potential discharge to the Cenozoic deposits has been suggested to the east of Nash Draw (Tps. 25 and 26 S., RS. 30 and 31 E.) (Cooper, 1962b, p. E152); however, if the discharge does occur, it is probably minimal. The currently (1983) available data are not sufficient in this area to draw any positive conclusions; therefore future studies may be warranted.

Use of water from the Culebra Dolomite is quite limited because of the variability of yields and the marginal water quality. Where the water quality is acceptable, water from the Culebra is used for stock watering, but rarely for domestic purposes.

The dissolved solids in waters associated with the Culebra Dolomite Member range in concentration from 2,950 milligrams per liter at test hole H-8B to 239,000 milligrams per liter at test hole W-29; the water quality from test hole W-29 may be affected by effluent from the mining activities in Nash Draw. The water is classified as being slightly saline to brine.

The areal distribution of major chemical constituents in water from the Culebra is represented by bar graphs in figure 19. The general chemical composition of the water collected from the Culebra is listed in table 2. Major dissolved cations and anions, expressed in milligrams per liter, milliequivalents per liter, and percentage composition are presented in table 8.

The dissolved mineral constituents in the water from the Culebra consist largely of sulfates and chlorides of calcium, magnesium, sodium and potassium; the major constituents are sodium and chloride. The other predominant ions depend on the areal location of the water within the Culebra. The hydraulic characteristics of the Culebra have a bearing on the residence time of the water in the rocks; the residence time affects the concentration and type of dissolved constituents in the water. The potassium and magnesium concentrations are related to the transmissive characteristics of the rocks and the rate of circulation.

The mineralization of water in the Culebra increases from west to east across the WIPP area; the combination of potassium and magnesium also increases (fig. 19). An arbitrarily chosen line of equal concentration representing 100 milligrams per liter of potassium and magnesium combined (fig. 19) approximates not only a dividing line between active and restricted circulation systems, but also approximately coincides with a line to the east of which halite is present in the Rustler Formation below the Culebra and to the west of which the halite beds have been removed by dissolution. As previously mentioned, the removal of these halite beds has caused an increase in the transmissivity of the dolomite. Although not as obvious in the Culebra as at the Rustler-Salado contact residuum, this line divides the area into zones where transmissivities generally are greater than 1 foot squared per day to the west and are generally less than 1 foot squared per day to the east. Even though this division is arbitrary, it does relate the water chemistry to the existing ground-water flow system.

Hydrology of Magenta Dolomite Member of the Rustler Formation--The Magenta Dolomite Member of the Rustler Formation is a persistent and distinctive clastic carbonate bed with thin laminae of anhydrite. The Magenta ranges in thickness from 20 to 30 feet and is present throughout most of the study area. The Magenta is the uppermost water-producing horizon in the Rustler

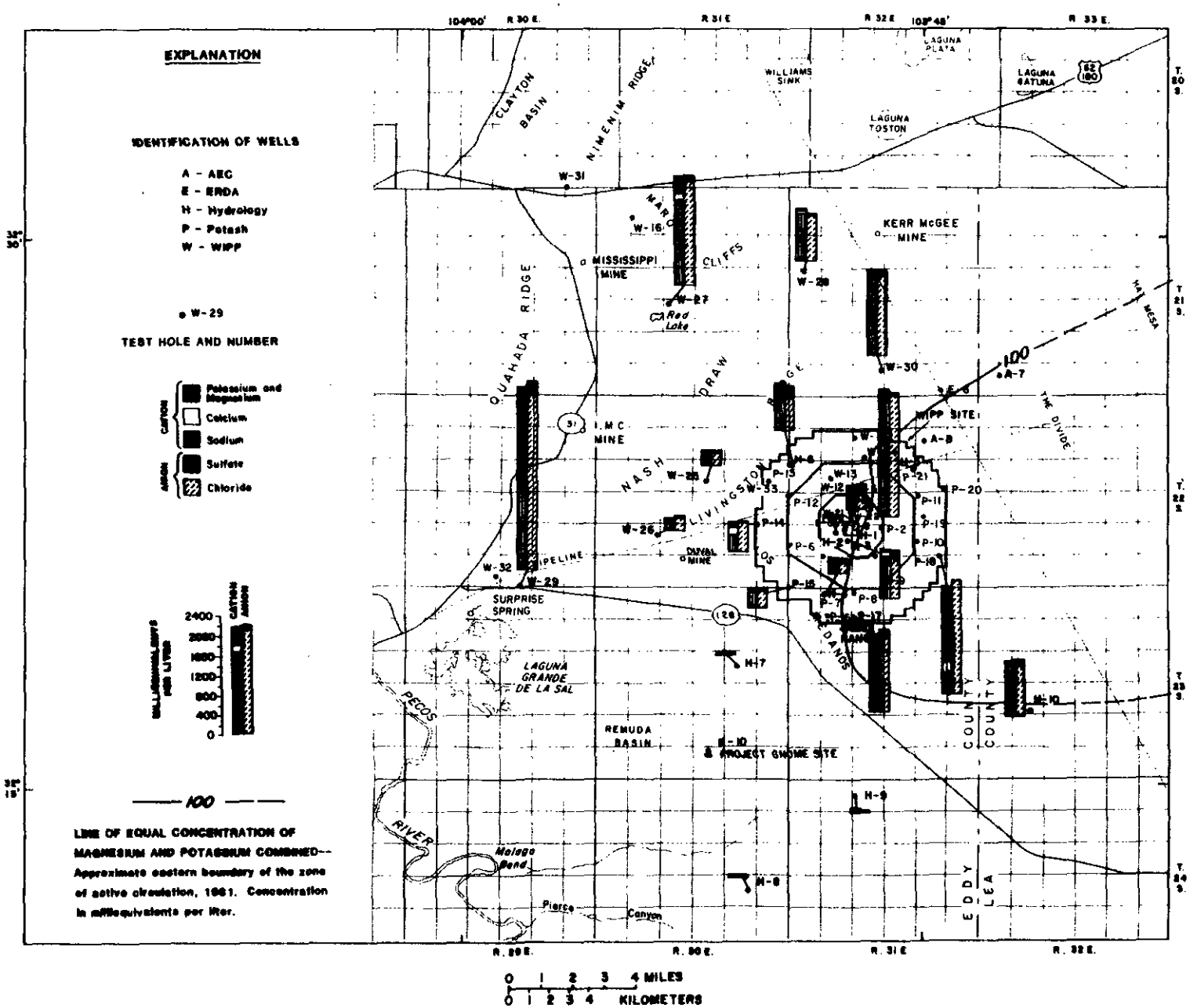

Figure 19.--Concentrations of major chemical constituents in water from the Culebra Dolomite Member of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

Formation. Stratigraphically, it occurs between the thick anhydrite beds of the Tamarisk and Forty Niner Members (fig. 4). Water, when present, usually occurs in the thin silt beds or silty dolomite but also has been found along bedding planes between rock units and in fractures. The Magenta, where it was tested, was always under confined conditions except where it was extensively fractured and altered. In test holes H-7A, W-26, and W-28 the dolomite was virtually unsaturated and was extensively fractured; the underlying anhydrite was fractured and in places altered to gypsum. The water formerly present in the Magenta in this area probably drained through the fractures into the underlying units.

The structure of the Magenta Dolomite, particularly in Nash Draw, is related to the presence or absence of evaporite dissolution. The Magenta in the northern and central parts of Nash Draw and along the eastern boundary is present in the subsurface as a relatively continuous bed; however, in the vicinity of test hole W-29 and south to Malaga Bend, most of the Magenta has been stripped by erosion. There are isolated blocks scattered throughout this area; the Magenta is present along the sides of karst sinks and in other collapsed features as breccia. The breccia mounds shown on Bachman's (1980) maps, particularly in T. 22 S., R. 29 E., sections 33 and 34, are excellent examples of this type of occurrence. These same features were described by Vine (1963, p. B-41) as domal structures.

Outcrops of the Magenta are present along the western side of Nash Draw below Quahada Ridge. Although relatively continuous, they do show effects of weathering and are quite fractured and are not saturated. A reasonable conclusion is that the dissolution responsible for the formation of Nash Draw fractured the Magenta and brecciated the underlying anhydrite, subsequently draining the water into lower units. These fractures later were filled with secondary minerals. Evidence for this type of occurrence can be found in the cores taken from test holes in the area. An isolated occurrence of spring remnants was found along Livingston Ridge (Bachman, 1981, p. 5). These spring deposits are represented by a northeast-trending alignment of gypsite mounds (east 1/2 of sec. 15, T. 22 S., R. 30 E.). The spring deposits are believed by Bachman to have resulted from the evaporation of sulfate-bearing water that had drained from the surface through fractures in the Rustler Formation, particularly in the vicinity of test hole W-33. An additional source for the water could be from subsurface drainage from the fractured Magenta.

To the east of Nash Draw, in the vicinity of and including the WIPP site, the Magenta generally dips gently to the east.

Although some flow along Livingston Ridge may be in fractures, the core samples and hydraulic tests at the WIPP site indicate the flow in the Magenta probably is within the silt beds and the silty dolomite, with some minor flow along bedding planes. Fracture flow probably is predominant in Nash Draw.

The potentiometric map (fig. 20), representing freshwater equivalent heads (table 10), indicates a flow system with some variability in permeability across the WIPP site. The contours show the gradient across this area to be about 16 feet per mile on the eastern side and steepening to about 32 feet per mile along the western side near the boundary of Nash Draw. This steepening of gradient may reflect the drainage of ground water from the Magenta into lower units through the fractures associated with Nash Draw dissolution activity or may only reflect a decrease in permeability. The gradient in Nash Draw of 13 feet per mile indicates a more uniform permeability than at the WIPP site. The Magenta, as an identifiable continuous bed, is not present below the central part of Nash Draw because erosion has removed it and the beds overlying the Rustler Formation down to the Tamarisk Member.

Values of transmissivity for the Magenta Dolomite Member are included in table 7. In Nash Draw, these values range from 53 feet squared per day in test hole W-27 to 375 feet squared per day in test hole W-25; the large values probably are the result of increased permeability in fractured rock. The transmissivity calculated for test hole W-25 is the largest value recorded in the region for the Magenta; this test probably was affected by vertical leakage along fractures that connect with the underlying Culebra. The Magenta is unsaturated in test hole W-26 as a consequence of fracturing caused by dissolution in lower beds. These fractures drained water from the unit; however, core analyses have indicated that these fractures were later filled with gypsum. Evaluation of the core from test hole W-28 indicated that bedding-plane partings and fractures were filled with gypsum, which would significantly decrease the permeability; vertical fracturing was not as evident as in test hole W-26. The Magenta also was unsaturated in test hole H-7A at the margin of Nash Draw south of the WIPP site. The ground water at test hole H-7A also probably drained into lower units; the subsequent alteration of the rocks considerably decreasing the vertical permeability. The core showed that this dolomite has been altered extensively to a partly cemented dolomite mud with the thin anhydrite beds having been altered to gypsum. Like the other cores, secondary filling of gypsum sealed the fractures.

Hydraulic tests for the Magenta in the WIPP site area were conducted in seven test holes; transmissivity values from these tests ranged from 4×10^{-3} foot squared per day in test hole W-30 to 3×10^{-1} feet squared per day in test hole H-6A (table 7). Hydraulic tests from the regional test holes south of the site showed that the transmissivity ranged from 6×10^{-3} foot squared per day in test hole H-8A to 1.0 foot squared per day in test hole H-9A (table 7).

The contours on the potentiometric-surface map for the Magenta Dolomite Member (fig. 20) indicate that water moves westward across the WIPP site towards Nash Draw, where it probably flows through fractures into lower units. In the northeast end of Nash Draw, the water flow generally is to the southwest, probably moving down through fractures into lower units in the central part of the draw.

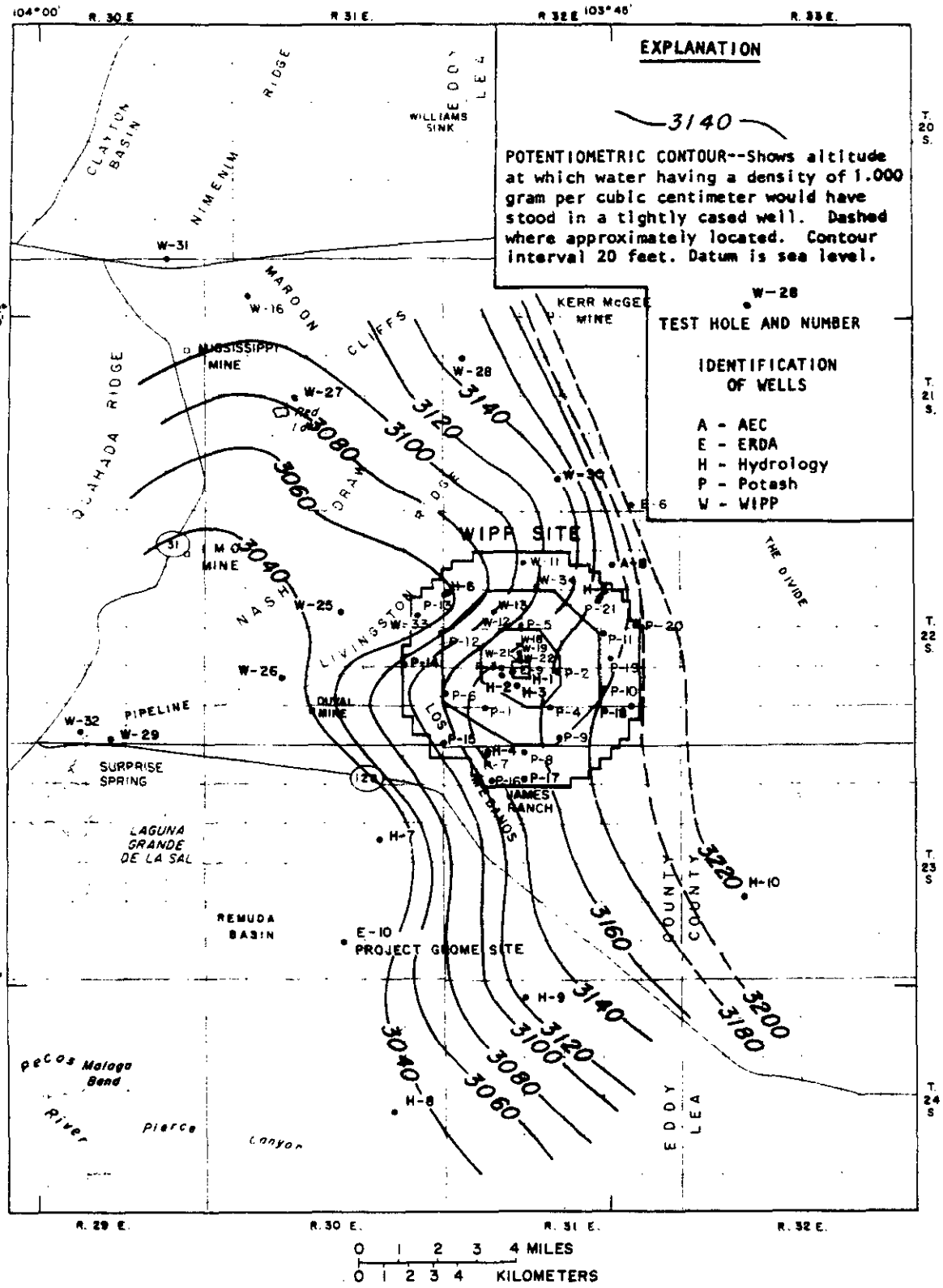

Figure 20.--Adjusted potentiometric surface of the Magenta Dolomite Member of the Rustler Formation (1982), at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

The static heads and water-quality analyses indicate isolation of the Magenta from other units in the area east of Nash Draw and east and south of test hole H-6. The hydraulic head differences between units in this area range from 115 feet in test hole H-2 to 155 feet in test hole H-3 (tables 6, 9, and 10). Static-head variations in Nash Draw vary from 8 feet in test hole W-27 and 4 feet in test hole W-25 to 72 feet in test hole W-28; W-28 probably is anomalous for Nash Draw. It is expected that some hydraulic connection does exist between zones in all the other Nash Draw test holes. The water quality in the Culebra and Magenta hydrologic units in test holes W-25 and W-27 (table 2) is very similar, indicating the possibility of hydraulic connection between these units.

Recharge for the Magenta probably takes place outside of the WIPP area, as it does for the other hydrologic units in the Rustler Formation. The most likely area is to the north in the vicinity of Bear Grass Draw and possibly in Clayton Basin. An inspection of the contours on the potentiometric-surface map indicates the possiblity of recharge to the east of the WIPP site. This apparent recharge is believed to be the effect of either the corrections made for variable water quality (and its density effect on the static-head calculations) or the locally steep gradients that result from decreased permeability to the east.

Discharge of water from the Magenta Dolomite in Nash Draw probably takes place in one of two ways, either by moving into lower units such as the Culebra or into cavernous zones in the Forty-niner Member, which has been altered by dissolution. The ultimate area of discharge would be into the brecciated area in the Rustler near Malaga Bend and then into the Pecos River.

The dissolved solids in water associated with the Magenta Dolomite Member of the Rustler Formation range in concentration from 5,030 milligrams per liter in test hole H-9A to 261,000 milligrams per liter in test hole H-10A. The water is classified as being saline to briny (table 2). The areal distribution of major chemical constituents is represented by bar graphs in figure 21. The major dissolved cations and anions in water collected from the Magenta Dolomite are expressed in table 8 in milligrams per liter, milliequivalents per liter, and percentage composition.

As is characteristic of the other hydrologic units in the Rustler Formation, the dissolved mineral constituents in the Magenta consist largely of sulfates and chlorides of calcium, potassium, magnesium, and sodium; the major constituents by percentage are sodium and chloride.

The relationship between the magnesium and potassium concentrations and the hydraulic properties of the hydrologic unit of the Magenta Dolomite Member is not as well defined as in other units, but does exist. The mineralization of the water and the combined concentrations of magnesium and potassium in the Magenta increase from the northwest to the southeast. The unusually large degree of mineralization in the water at test hole W-27 may

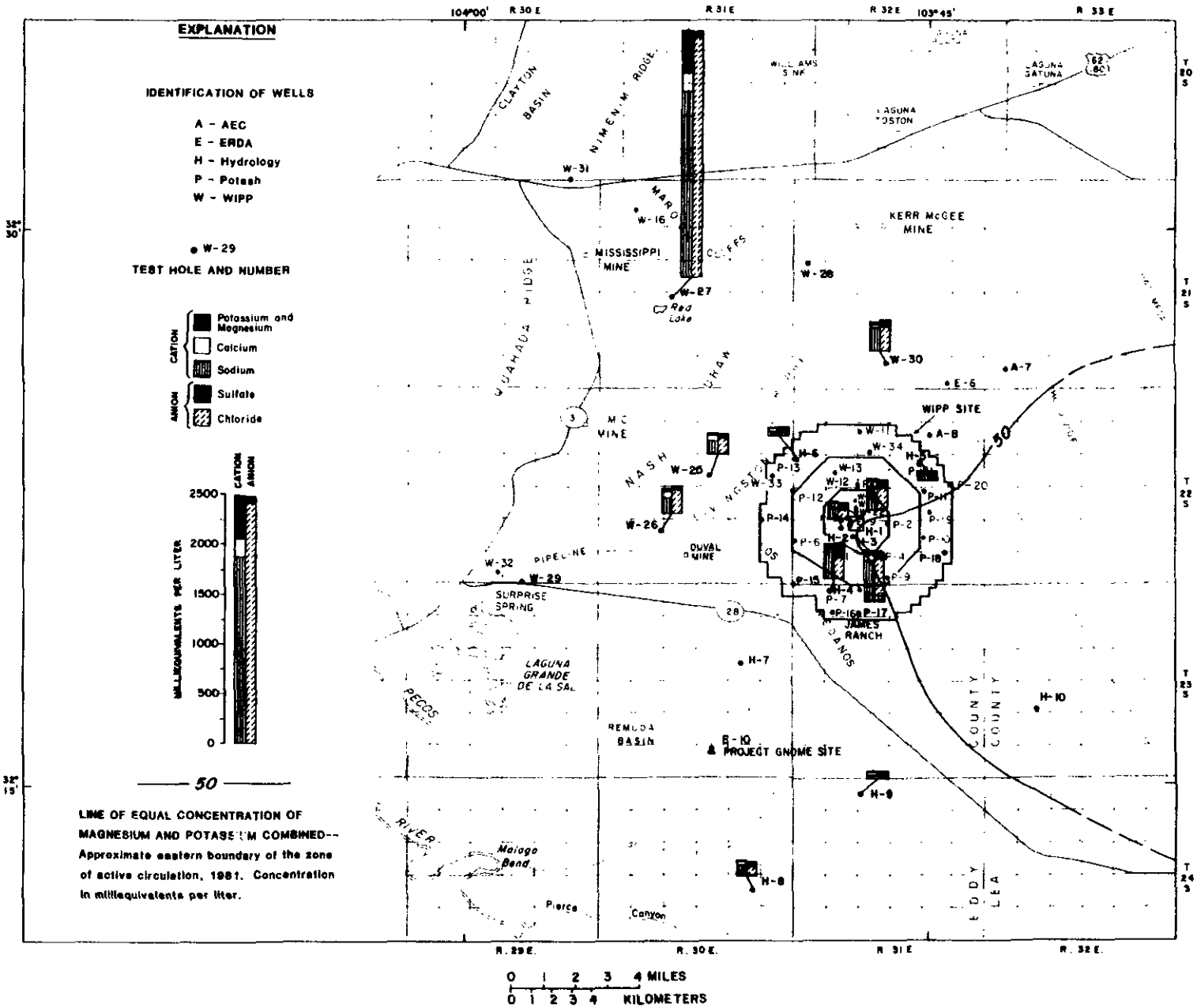

Figure 21.--Concentrations of major chemical constituents in water from the Magenta Dolomite Member of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant (WIPP) site.

be caused by a relatively well developed hydraulic connection between the Magenta and other rock units that contain highly mineralized water.

The arbibrarily chosen line of equal concentration representing 50 milligrams per liter of potassium and magnesium combined (fig. 21) indicates a division between a relatively well developed flow system and one in which circulation is restricted. Although not as well defined as in the case of the Culebra, the line does indicate the area in which halite has been removed from below the Magenta (halite removed to the northwest, halite present to the southeast). The effects of the fracturing resulting from the halite removal on the hydraulic properties of the Magenta are not as pronounced as in the Culebra.

Hydrology of the Dewey Lake Red Beds

Geohydrologic characteristics--The Dewey Lake Red Beds comprise the youngest rocks in the Ochoan sequence at the WIPP site and mark an abrupt change in the depositional environment. This change was from predominantly evaporitic deposits in the Rustler to a deltaic sequence of alternating thin, even beds of siltstone and mudstone with lenticular interbeds of fine-grained sandstone. Nearly all the siltstone and mudstone are veined with selenite gypsum in the cores. The Dewey Lake dips gently eastward, increasing in thickness from 350 feet in test hole P-14 to 546 feet in test hole P-18 (fig. 5). The Dewey Lake Red Beds are separated from the overlying Triassic Santa Rosa Sandstone by an erosional unconformity east of test hole ERDA-9; west to Livingstone Ridge (along Nash Draw), the Dewey Lake is overlain by the Gatuna Formation and other Cenozoic deposits. The thickness of the formation decreases to the west where it was thinned by post-Permian erosion. The Dewey Lake in Nash Draw has been almost completely removed, in places being present only in sinks and other features fractures. The Dewey Lake crops out in low bluffs along the north and east sides of Nash Draw. Because of its characteristically minimal permeability, it does not contain significant quantities of ground water.

Drilling during areal geohydrologic evaluation did not identify a continuous zone of saturation within the Dewey Lake Red Beds; however, localized zones of permeability were detected. In the geologic test holes, the presence of these zones was indicated by minor losses of circulation during drilling. Detailed data collected during air-drilling of the hydrologic test holes (Mercer and Orr, 1979) did identify minor zones of saturation, particularly in several of the thin lenticular sands in the upper part of the Dewey Lake at test holes H-1, H-2, and H-3.

In most instances, the only indication of ground water was the presence of moist cuttings. In test hole H-2C an attempt was made to test the moist sands present at a depth of 185 feet. After monitoring the zone for 5 hours, very little water had entered the hole and the test was stopped (Mercer and

Orr, 1979, p. 58). Geologic data from the wells at the WIPP site indicate the sands to be lenticular, pinching out laterally. Where water is present, it probably is perched or semiperched, and its occurrence is very localized, probably depending to a great extent on locally favorable conditions for recharge.

The Dewey Lake has not normally been found to yield water to wells; however, several wells used for domestic and stock purposes at the James Ranch could possibly be completed in one of these lenticular sands. These wells in T. 23 S., R. 31 E., sections 6 and 7, range in depth from 94 to 212 feet (Cooper and Glanzman 1971, p. A-16). These wells either have saline water or small yields; geologic data indicate they are completed in the upper part of the Dewey Lake. Just east of this area there is an extensive, thick, active area of sand dunes, which could be a recharge area for these water-bearing sand units. No other wells in the area are known to produce water from the Dewey Lake.

Ground-water movement--Recharge of sand units in the Dewey Lake could result from localized conditions, as in the James Ranch area, or could occur by downward percolation of water through fractures or along bedding planes in the mudstone and siltstone. Discharge towards deeper zones through existing fractures or through dissolution of the gypsum veinlets is minor. The Dewey Lake is a protective cover that retards dissolution of evaporites in the Rustler Formation. If the groundwater penetrated to the top of the Rustler Formation in the WIPP site, then the upper anhydrite should be altered to gypsum. Cores and geophysical logs do not indicate that this alteration is present except where the Dewey Lake is thin or absent. Ground-water movement within the Dewey Lake is restricted owing to the perched character of the water in these lenticular sands.

Upper Triassic - Santa Rosa Sandstone

Geohydrologic characteristics--The Santa Rosa Sandstone, present only in the eastern one-half of the WIPP site, overlies the Dewey Lake Red Beds (fig. 5). The Santa Rosa crops out at the north end and along the east side of Nash Draw. The Santa Rosa consists of a fine- to coarse-grained sandstone with interbeds of siltstone and mudstone; it ranges in thickness from a featheredge west of test hole ERDA-9 to 176 feet in test hole H-10. To the west of test hole ERDA-9, the Santa Rosa has been removed by erosion. Throughout most of the area, the Santa Rosa is covered by surficial Cenozoic deposits; however, in test hole H-10, the sandstone is overlain by 392 feet of unsaturated Triassic Chinle Formation.

In the WIPP site area, the Santa Rosa Sandstone was tested in two test holes, H-5 and H-10. Although the Santa Rosa Sandstone is reported to be a principal aquifer in southwestern Lea County (Nicholson and Clebsch, 1961, p. 57), water was only present in the lower part of the formation in test hole H-5. Air drilling was used to identify the presence of water. Although an attempt was made to test the zone, the only reliable data collected were from a water sample from which the chemical composition of the water was determined (table 2). The water was under water-table conditions and was present in a sandstone immediately overlying the Dewey Lake Red Beds. In test hole H-10, the Santa Rosa was monitored during air drilling and no indication of water was found. Several wells east of the WIPP site have been reported to be obtaining water from the Santa Rosa, but yields are reported to be small. According to geophysical logs, a well in T. 22 S., R. 31 E., sec. 15, just west of test hole H-5, was completed in the lower part of the Santa Rosa; however, well yields were reported to be very small.

Ground-water movement--The Santa Rosa probably is recharged by precipitation in the area where it is overlain by permeable Cenozoic deposits, especially in the eastern part of the WIPP site. The water moves downward until it is impeded by the relatively impermeable Dewey Lake Red Beds and then probably moves down the structual dip to the east. Where it lies beneath the Chinle Formation, the water that is found in the Santa Rosa probably is under confined conditions. Small quantities of water probably discharge locally into the Dewey Lake through fractures and along bedding planes. Nicholson and Clebsch (1961, p. 57) believe that further to the east ground-water movement in the Santa Rosa is controlled by the collapse features of San Simon Swale. Nicholson and Clebsch show the pressure gradients to be toward the Swale.

Tertiary and Quaternary rocks

Of the Tertiary and Quaternary rocks in the vicinity of the WIPP site, the Gatuña Formation of Pleistocene age and the playa deposits and alluvium of Holocene age are the only units that contain water. The volume of water in these sediments is quite small.

The Ogallala Formation of Miocene age is an aquifer north and east of the area; however, along The Divide near the WIPP site, it occurs in isolated outliers no more than 60 feet thick. These outliers generally are unsaturated.

The Mescalaro caliche of Holocene age is a well lithified calcium carbonate and functions more as a barrier to downward movement of water than as a ground-water reservoir. The Mescalero caliche covers most of the WIPP site area although it is not present in Nash Draw.

Gatuña Formation--The Gatuña Formation is present as discontinuous bolson-type deposits. In the WIPP site area, the Gatuña is represented by several tens of feet of poorly sorted silt, clay, and sandstone that may grade downward into conglomeratic sandstone containing clasts of siltstone and sandstone (Jones, 1978, p, 10). Of the post-Tertiary rocks in the study area, the Gatuña Formation is the thickest and least extensive; characteristic of its erratic distribution, the Gatuña is absent in some test holes and is more than 100 feet thick in others (143 feet in test hole H-8, for example). Where it does occur at the WIPP site, it is generally no thicker than 46 feet (table 1). In most areas, the Gatuña is overlain by the Mescalero caliche.

Because of its erratic distribution, there is no known continuous saturated zone within the Gatuña Formation. Although Cooper and Glanzman (1971, p. A-10) have reported that there were some limited occurrences of water in the Gatuña in the Project Gnome area, no water was found during the drilling at the WIPP site. If water is present in places, it probably would be perched in sandstone lenses overlying the less permeable Dewey Lake Red Beds.

During foundation tests in the central part of the WIPP site, 30 exploration holes were drilled to test the hydraulic conductivity of the Gatuña. Packer permeability tests in these holes were conducted using injected water; these tests indicated that the hydraulic conductivity generally ranged from less than 3×10^{-3} to 1.9 feet per day; one value of 5.1 feet per day was noted (Register, 1981, p. 8). No indication of water was found in any of these holes.

Water movement in the Gatuña apparently is restricted by the discontinuous "perched" zones and the sporadic occurrence of the unit. Recharge to the Gatuña probably is by local downward percolation of precipitation, especially in areas where rain water is ponded on the surface. This recharge probably is hindered by the caliche cover in the WIPP site area. Discharge probably is locally to phreatophytes although some water may percolate downward into lower zones, particularly in the eastern part of the study area where the Gatuña overlies the Triassic Santa Rosa Sandstone.

Surficial deposits and alluvium--In the main part of the study area there are no through-flowing streams; the "alluvium," here referred to as surficial deposits, is composed of locally derived material deposited by sheet wash or from discontinuous arroyos. These surficial deposits are present almost everywhere in the region and usually are only a veneer over the underlying bedrock. Exceptions exist where deposits are concentrated in depressions created by dissolution of underlying rocks.

The only stream-deposited alluvium in areas near the WIPP site is along the Pecos River, mostly along the west side of the river north of Malaga Bend. This alluvium is composed of sand, gravel, silt, and clay and is as much as 200 feet thick. One of the most notable features of the alluvium is its large variation in thickness, which probably is caused by the alluvium

filling the depressions created by dissolution of underlying rocks (Hale, Hughes, and Cox, 1954, p. 20). South of Malaga Bend, the alluvium is present in isolated patches, which may be as much as 150 feet thick but generally average about 50 to 75 feet.

Playas within the study area are reported to contain alluvium and eolian sands that have been reworked by shallow lake waters (Vine, 1963, p. B-35). Playa deposits consist of silt, sand, and gypsum sand; the thickest deposits exceed 55 feet at Laguna Grande de la Sal (Robinson and Lang, 1938, p. 85). The gypsum and other materials deposited in the other playas in Nash Draw are similar to those at Laguna Grande de la Sal, but the deposits are not as thick.

Windblown sands are common throughout most of the area east of Nash Draw. The sands are only a few feet thick except where they have been concentrated by wind into dunes. The greatest concentration of dunes is located east of James Ranch, where they may have a localized effect on the hydrology.

No wells in the WIPP site area are known to produce water from the surficial deposits or from the windblown sands; however, where these deposits are thickest, they may contain localized perched zones of ground water. The sand dunes east of James Ranch are very permeable; however, evapotranspiration probably removes most of the downward percolating water.

The playa deposits are known to contain water, but the water generally has such large salt concentrations that it is unusable. Robinson and Lang (1938, p. 95) reported the water associated with the Laguna Grande de la Sal playa was under a slight artesian head.

The alluvium associated with the Pecos River, especially north of Malaga Bend, is a productive aquifer. Transmissivities in the alluvium vary considerably, but calculations made by Bjorklund and Motts (1959, p. 191) average 13,600 feet squared per day; the hydraulic conductivity probably averages 116 feet per day. The average hydraulic conductivity, however, could be misleading; lime-cemented conglomerates in the alluvium may greatly increase the value because of solution channels. Detailed data for the alluvium can be found in studies by Hale, Hughes, and Cox (1954) and Bjorklund and Motts (1959). South of Malaga Bend, the alluvium is less extensive and more variable in thickness, so average hydraulic properties are more difficult to determine.

Water associated with the surficial deposits and windblown sand probably is perched or semiperched; consequently, the occurrence of water is spotty and greatly dependent on local conditions. Recharge takes place in areas of surface ponding, and discharge moves downward through fractures and joints into more permeable zones. In several trenches dug through sand dunes at the WIPP site, the sand was found to be unsaturated and no perched water was found. The significant evapotranspiration rate in the area and the relatively impermeable underlying beds (caliche and siltstone) probably preclude large volumes of water moving downward.

The water in the playa deposits usually is localized, and water movement is restricted. The water table in the area around the playas slopes inward toward the playas, indicating water in the fill is moving into the playa and being discharged by evaporation. The source of the water is partly from recharge from precipitation and partly from ground-water inflow from springs (Robinson and Lang, 1938, p. 94).

Recharge to the alluvium is from several sources. Near Carlsbad water moves from the Guadalupian Reef complex to the alluvium. In the south near Malaga Bend, adjacent Permian geologic units, such as the Rustler, recharge the alluvium. Infiltration from precipitation and from streams, canals, and applied irrigation water also are sources of recharge to the alluvium. The alluvium near Malaga Bend is the most likely discharge area for water flow from hydrologic units associated with the WIPP site. The alluvium in this area probably would be the zone of contact with the biosphere if there should be a breach of the facility and a release of radionuclides. Water moving through the alluvium generally flows toward the Pecos River and then southwestward toward the Red Bluff Reservoir. Because the thick accumulations of sediment have been derived, to a great extent, from evaporites and fine-grained clastic rocks, the permeability of the alluvium is probably minimal, resulting in fairly low flow velocities (Hale and Clebsch, 1958, p. 15). However, localized zones of greater permeability may be present, especially where semiconsolidated alluvium is fractured. North of Malaga Bend, wells drilled into the alluvium vary in yield, but the yields are large enough to be used for irrigation.

The occurrence of water in the Tertiary and Quaternary rocks in the WIPP area generally is quite variable and is restricted to the area south of the WIPP site. The quality of ground water characteristically ranges from fresh to saline, although in isolated areas near playas it may be quite briny.

The only hydrologic unit that contains large volumes of water is the alluvium along the Pecos River. Although not specifically investigated during this study, it has been discussed in some detail in previous reports about the area (Hendickson and Jones, 1952; Hale, Hughes and Cox, 1954; and Bjorklund and Motts, 1959). The discussion in this report will be restricted to the hydrochemistry of ground water in the alluvium in the area around Malaga Bend.

Generally, the chemical composition of the water in the alluvium near Malaga Bend is affected by brine inflow from the Permian rocks to the east, downward percolation of relatively fresh water from irrigation, and local dissolution of evaporites. This mixing has caused changes in the overall quality of the water, with dissolved constituents dominated by sodium and chloride. Hale, Hughes, and Cox (1954, p. 40) reported that the chloride concentration in the water in the alluvium increases with depth and a saturated brine is present in the lower part of the fill. The overall ionic composition of the water is similar to the ground water from the other hydrologic units, predominantly consisting of chlorides and sulfates of calcium, magnesium, sodium and potassium.

SURFACE-WATER HYDROLOGY

There are no permanent streams or bodies of surface water present within the WIPP site; therefore, the potential for surface-water transport of waste is only treated briefly in this report. The purpose of these investigations was to relate surface water as a source or discharge point of flow from the ground-water system and as a potential part of the pathway for radionuclides if the WIPP facility were breached.

The Pecos River is a perennial stream and is the major drainage for the region around WIPP. The Pecos River is located west-southwest of the WIPP site and, at its closest point, is 10 miles from the outer exclusion boundary of the WIPP site. Most local tributaries originate in the Guadalupe Mountains, to the west of the Pecos. East of the Pecos, including Los Medaños and the WIPP site, the surface drainage is almost undeveloped. The closest major drainage to the WIPP site is Nash Draw; however, it is a closed drainage area with no surface outlet to the Pecos River. The land surface of the WIPP site is very hummocky and contains numerous small topographic depressions, which generally contain what little surface runoff takes place. A surface-water gaging station was established near Hill Tank (fig. 1A) on an unnamed arroyo draining from the WIPP site to Nash Draw (in sec. 24, T. 22 .S., R. 30 E.). During 4 years, only one flow occurred and it was of such short duration that it could not be measured. Apparently surface runoff from the WIPP site is minimal; most surface water is lost to evapotranspiration.

The most significant effect of surface water on the hydrology of the WIPP site takes place at Malaga Bend on the Pecos River where water from the Rustler Formation discharges to the river. Additional data on the Pecos River and the regional surface-water conditions are included in the report by Powers, Lambert, Shaffer, Hill, and Weart (1978).

SUMMARY AND CONCLUSIONS

The WIPP site is proposed as a mined repository for defense associated radioactive waste at depth of approximately 2,150 feet in bedded salts of the Permian Salado Formation. The characteristics of the geohydrologic systems at the WIPP site need to defined because of the potential for transport of radionuclides to the biosphere by ground water in the unlikely event the storage facility is breached.

The sedimentary formations in the WIPP site area that contain water are present both below and above the halite of the Salado Formation. The formations of concern range in age from Permian to Quaternary. About 70 test holes have been drilled as part of the geologic and hydrologic site characterization.

The major water-bearing zones below the Salado Formation that have been identified during hydrologic investigations, are the fine-grained sandstones of the Bell Canyon Formation of the Delaware Mountain Group. In addition, isolated pockets of pressurized brine have been found in fractures in the anhydrite of the Castile Formation. Investigations to date (1983) indicate that these zones are isolated from units either above or below the Castile. The water-bearing zones of concern above the Salado Formation include a zone composed of the residue from evaporite dissolution at the contact between the Rustler and Salado Formations, and the Magenta and Culebra Dolomite Members of the Rustler Formation. Water in Tertiary and Quaternary sediments is perched in isolated sands.

The Guadalupian reef complex is a major hydrologic unit in the area and forms a long arcuate belt around the margins of the Delaware Basin in which the WIPP site is located. Lateral movement of water away from the reef is restricted by the minimally permeable anhydrites of the Castile Formation.

In the upper part of the Bell Canyon Formation, the brines usually are present in relatively isolated permeable channel sandstones, which have hydraulic conductivities ranging from 7×10^{-3} to 5×10^{-2} foot per day. These channel sandstones grade vertically and laterally into siltstones and shales that have negligible permeability; hydraulic conductivities usually are less than 2×10^{-6} foot per day. Siltstones and shales overlying these channel sandstones restrict upward movement of water to the minimally permeable anhydrites of the Castile Formation. Potentiometric-surface maps indicate water movement across the basin to the northeast; however, the rate of movement is extremely slow. Also, when compared to the hydraulic heads in the units overlying the evaporites, the general movement would be down; that is heads decrease with depth.

Water-bearing units in the Delaware Mountain Group probably are restricted to the upper 600 feet of the Bell Canyon Formation; the individual permeable sandstone beds are no thicker than 45-60 feet. The dissolved ions in the brines of the Bell Canyon in the WIPP site area are predominantly sodium and chloride; dissolved-solids concentrations range from 180,000 to 270,000 milligrams per liter.

The hydrologic units of the Rustler Formation are the principal water-bearing units above the Salado Formation in the WIPP site vicinity and thus have been the most extensively studied. Water-bearing units in the Rustler Formation include the residues (residuum) from evaporite dissolution at the contact between the Rustler and Salado Formations and the Culebra Dolomite and Magenta Dolomite Members.

Brine at the Rustler-Salado contact "brine aquifer of Robinson and Lang (1938) is present either in a clay residuum bed or along the bedding planes between these units. The residuum is common along Nash Draw and is most extensive between Laguna Grande de la Sal and Malaga Bend, where transmissivities are as large as 8,000 feet squared per day. In the northern

end of Nash Draw, transmissivities range from 2 x 10^{-4} foot squared per day in test hole W-27 to 8 feet squared per day in test hole W-29; in the WIPP site proper, transmissivities range from 3 x 10^{-5} foot squared per day at test holes H-5C and P-18 to 5 x 10^{-2} foot squared per day at test hole P-14. The ground-water flow in the eastern part of the site primarily is along bedding planes. Density-corrected potentiometric-surface maps indicate flow is southwest across the WIPP site towards Nash Draw at a gradient of 39 feet per mile and then south-southwest down Nash Draw to Malaga Bend on the Pecos River at a gradient of about 10 feet per mile. The dissolved ions in the brines of the Rustler-Salado contact residuum are predominantly sodium and chloride; dissolved-solids concentrations range from 41,500 milligrams per liter at test hole H-1 to 412,000 milligrams per liter at test hole H-5C. Large concentrations of dissolved potassium and magnesium in ground water in the eastern part of the study area indicate restricted flow and extensive interaction between the ground water and its host rock.

The Culebra Dolomite Member of the Rustler Formation is the most persistent and productive hydrologic unit in the WIPP vicinity. Its hydraulic properties vary considerably from place to place primarily as a result of the size and number of fractures and openings. These fractures are related to the degree of evaporite dissolution within the Rustler that causes subsidence and collapse of the overlying dolomite. The most extensive evaporite dissolution and fracturing are present in Nash Draw. Transmissivities calculated for the Culebra in Nash Draw range from 18 feet squared per day at test hole W-28 to 1,250 feet squared per day at test hole W-26. At the WIPP site east of Nash Draw, transmissivities range from 1.0 x 10^{-3} foot squared per day at test hole P-18 to 140 feet squared per day at test hole P-14. Density-corrected potentiometric-surface maps indicate that flow at the WIPP site is to the south at a hydraulic gradient that ranges from 7 to 20 feet per mile; the flow is then to the southwest to Nash Draw where gradients range from 16 feet per mile in the north end to less than 5 feet per mile near Malaga Bend. Flow directions may be affected significantly by directional differences in permeability in the dolomite. In Nash Draw, the Culebra Dolomite is extensively fractured and flow is virtually south to a discharge area at the Pecos River near Malaga Bend.

Water in the Culebra is slightly saline to briny; dissolved-solids concentrations range from 2,950 milligrams per liter at test hole H-8B to 239,000 milligrams per liter at test hole W-29. Dominant dissolved ions are sodium and chloride; other ions include sulfate, potassium, calcium, and magnesium. Not only does the mineralization of the water generally increase from west to east across the site, but so do the concentrations of potassium and magnesium. This change indicates a decrease in circulation along the eastern side of the WIPP site. This restricted circulation is caused by a decrease in permeability within the Culebra Dolomite Member.

The Magenta Dolomite Member is the uppermost hydrologic unit in the Rustler Formation. Water is present in the area of the WIPP site, usually in thin siltstone beds or silty dolomite and less commonly in fractures. In Nash Draw, the occurrence of water in the Magenta Dolomite Member is variable

because of localized drainage from the unit that results from the chaotic structure created by extensive evaporite dissolution. In the southern end of Nash Draw, the Magenta has been completely removed by erosion. Transmissivities calculated for the Magenta Dolomite in the northern end of Nash Draw range from 53 feet squared per day at test hole W-27 to 375 feet squared per day at test hole W-25; these relatively large values result from the increased permeability in the fractured rock. The transmissivity in the vicinity of the WIPP site ranges from 4×10^{-3} foot squared per day at test hole W-30 to 3×10^{-1} foot squared per day at test hole H-6A. The movement of ground water in the site area, as estimated from density-corrected potentiometric-surface maps, is west toward Nash Draw at a gradient of as much as 32 feet per mile and then southwest in Nash Draw at a gradient of 13 feet per mile.

The flow in the Magenta Dolomite Member eventually moves downward through fractures into lower units. The water in the Magenta is saline to briny; concentrations of dissolved solids range from 5,030 milligrams per liter at test hole H-9a to 261,000 milligrams per liter at test hole H-10A. Dissolved mineral constituents of the water include sulfates and chlorides of magnesium, potassium, and calcium, the major percentages being sodium and chloride. Larger magnesium and potassium concentrations in the eastern part of the site may indicate restricted circulation in the Magenta.

The relative static heads or formation pressures of the hydrologic units in the Rustler Formation decrease with depth; that is, hydraulic heads are highest in the Magenta and lowest at the Rustler-Salado contact. There appear to be two regional flow systems; one in the area around the proposed WIPP site and one in Nash Draw. In the WIPP site area, the presence of impermeable interbeds of halite and anhydrite and the differences in static head and water quality probably indicate restricted vertical hydraulic connection between units; however, in Nash Draw, where dissolution and subsidence are more common, hydraulic connection between units probably exists. Recharge for the Rustler units probably is to the north of Nash Draw near Bear Grass Draw; the major discharge takes place at Malaga Bend on the Pecos River.

REFERENCES

Adams, J. E., 1944, Upper Permian Ochoa series of Delaware Basin of west Texas and southeastern New Mexico: American Association of Petroleum Geologists Bulletin, v. 28, no. 11, p. 1596-1625.

Anderson, R. Y., 1978, Deep dissolution of salt, northern Delaware Basin, New Mexico: Consultants report to Sandia Laboratories, 106 p.

_____, 1981, Deep-seated salt dissolution in the Delaware Basin, Texas and Mexico: New Mexico Geological Society, Special Publication no. 10, p. 133-145.

Anderson, R. Y., Dean, W. E., Jr., Kirkland, D. W.; and Snider, H. I., 1972, Permian Castile varved evaporite sequence, west Texas and New Mexico: Geological Society of America Bulletin, v. 83, p. 59-86.

Bachman, G. O., 1973, Surficial features and late Cenozoic history in southeastern New Mexico: U.S. Geological Survey open-file report, 32 p.

_____, 1974, Geological processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U.S. Geological Survey Open-File Report 74-194, 81 p.

_____, 1976, Cenozoic deposits of southeastern New Mexico and an outline of the history of evaporite dissolution: U.S. Geological Survey Journal of Research, v. 4, no. 2, p. 135-149.

_____, 1980, Regional geology and Cenozoic history of Pecos region, southeastern New Mexico: U.S. Geological Survey Open-File Report 80-1099, 116 p.

_____, 1981, Geology of Nash Draw, Eddy County, New Mexico: U.S. Geological Survey Open-File Report 81-31, 8 p.

Basler, J. A., 1983, Instrumentation used for hydraulic testing of potential water-bearing formations at the Waste Isolation Pilot Plant site in southeastern New Mexico: U. S. Geological Survey open-file report 83-144, 30 p.

Berg, R. R., 1979, Reservoir sandstones of the Delaware Mountain Group, southeast New Mexico, in Permian Basin Section-Society of Economic Paleontologists and Mineralogists Publication 79-18, p. 75-95.

Bjorklund, L. J., and Motts, W. S., 1959, Geology and water resources of the Carlsbad area, New Mexico: U.S. Geological Survey open-file report, 322 p.

Bond, D. C., 1972, Hydrodynamics in deep aquifers of the Illinois Basin: Illinois State Geological Survey Circular 470, 50 p.

Bredehoeft, J. D., and Papadopulos, S. S., 1980, A method for determining the hydraulic properties of tight formations: Water Resources Research, v. 16, no. 1, p. 233-238.

Brokaw, A. L., Jones, C. L., Cooley M. E., and Hays, W. H., 1972, Geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico: U.S. Geological Survey Open-File Report 4339-1, 86 p.

Cooper, H. H., Jr., Bredehoeft, J. D., and Papadopulos, S. S., 1967, Response of a finite-diameter well to an instantaneous charge of water: Water Resources Research, v. 3, no. 1, p. 263-269.

Cooper, J. B., 1960, Geologic section from Carlsbad Caverns National Park through Project Gnome, Eddy County, New Mexico: U.S. Geological Survey TEI-767.

_____, 1961, Test holes drilled in support of ground-water investigations Project Gnome, Eddy County, New Mexico: U.S. Geological Survey TEI-786, 116 p.

_____, 1962a, Ground-water investigations of the Project Gnome area, Eddy and Lea Counties, New Mexico: U.S. Geological Survey TEI-802, 67 p.

_____, 1962b, Ground water in Cenozoic fill in collapsed structures, southeastern Eddy County, New Mexico, in Short papers in geology, hydrology, and topography 1962: U.S. Geological Survey Professional Paper 450-B, p. E152-153.

Cooper, J.B., and others, 1962, Hydrologic and geologic studies for Project Gnome, preliminary report: U.S. Geological Survey Project Gnome Report PNE-130P, 54 p.

Cooper, J. B., and Glanzman, V. M., 1971, Geohydrology of Project Gnome site, Eddy County, New Mexico, in Hydrology of nuclear test sites: U.S. Geological Survey Professional Paper 712A, 24 p.

Cox, E. R., and Havens, J. S., 1961, Evaluation of the Queen Lake Depression, Eddy County, New Mexico, as a storage basin for brine: U.S. Geological Survey open-file report.

_____, 1965, A progress report on the Malaga Bend Experimental Salinity Alleviation Project, Eddy County, New Mexico: U.S. Geological Survey open-file report, 91 p.

Cox, E. R., and Kunkler, J. L., 1962, Feasibility of injecting brine from Malaga Bend into the Delaware Mountain Group, Eddy County, New Mexico: U.S. Geological Survey open-file report, 69 p.

Darton, N. H., 1922, Geologic structure of parts of New Mexico: U.S. Geological Survey Bulletin 726E, p. 173-275.

Dennehy, K. F., 1982, Results of hydrologic tests and water-chemistry analyses, wells H-6A, H-6B, and H-6C at the proposed Waste Isolation Pilot Plant site, southeastern New Mexico: U.S. Geological Survey Water-Resources Investigations, 82-8, 68 p.

Dennehy, K. F., and Mercer, J. W., 1982, Results of hydrologic tests and water-chemistry analyses, wells H-5A, H-5B, and H-5C at the proposed Waste Isolation Pilot Plant site, southeastern New Mexico: U.S. Geological Survey Water-Resources Investigations 82-19, 83 p.

Gard, L. M., Jr., 1968, Geologic studies, project Gnome, Eddy County, New Mexico: U.S. Geological Survey Professional Paper 589, 33 p.

Gonzalez, D. D., 1983, Ground-water flow in the Rustler Formation, Waste Isolation Pilot Plant site, southeast New Mexico: Sandia National Laboratories Report SAND 82- 1012, Albuquerque, New Mexico, 47 p.

Grauten, W. F., 1965, Fluid relationships in Delaware Mountain Sandstone, in Fluids in subsurface environments: American Association of Petroleum Geologists Memoir 4, p. 294-308.

Griswold, G., 1980, Geotechnical consideration for radiological hazard assessment of WIPP: Report of State of New Mexico Environmental Evaluation Group, EEG-6.

Grove, D. B., and Beetem, W. A., 1971, Porosity and dispersion constant calculations for a fractured carbonate aquifer using the two well tracer method: Water Resources Research, v. 7, no. 1.

Hale, W. E., 1945a, Ground-water conditions in the vicinity of Carlsbad, New Mexico: New Mexico State Engineer 16th and 17th Biennial Report, p. 195-250.

_____, 1945b, Ground-water conditions in the vicinity of Rattlesnake Springs, Eddy County, New Mexico: New Mexico State Engineer Technical Report 3, 54 p.

_____, 1961, Availability of ground water in New Mexico, in Sixth annual New Mexico water conference, November 1-2, 1961, New Mexico State University, New Mexico: p. 11-22.

Hale, W. E., and Clebsch, Alfred, Jr., 1954, Preliminary appraisal of ground-water conditions in southeastern Eddy County and southwestern Lea County, New Mexico: U. S. Geological Survey TEM-1045, 23 p.

Hale, W. E., Hughes, L. S., and Cox, E. R., 1958, Possible improvement of quality of water of the Pecos River by diversion of brine at Malaga Bend, Eddy County, New Mexico: Pecos River Commission, New Mexico and Texas, and U.S. Geological Survey, 43 p.

Halpenny, L. C., and Greene, D. K., 1966, Water rights and water supply, city of Carlsbad, investigation of present situation and future requirements: Water Development Corporation, Tucson, Arizona, 85 p.

Havens, J. S., and Wilkins, D. W., 1980, Experimental salinity alleviation at Malaga Bend of the Pecos River, Eddy County, New Mexico: U.S. Geological Survey Water-Resources Investigations 80-4, 65 p.

Harms, J. C. 1974, Brushy Canyon Formation, Texas: Geological Society of America Bulletin, v. 85, p. 1763-1784.

Hayes, P. T., 1964, Geology of the Guadalupe Mountains, New Mexico: U.S. Geological Survey Professional Paper 446, 69 p.

Hendrickson, G. E., and Jones, R. S., 1952, Geology and ground-water resources of Eddy County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Ground-Water Report 3, 169 p.

Hiss, W. L., 1976, Stratigraphy and ground-water hydrology of the Capitan aquifer, southeastern New Mexico and west Texas: University of Colorado, Boulder, Ph.D. thesis, 396 p.

_____, 1980, Movement of ground water in Permian Guadalupian aquifer systems, southeastern New Mexico and western Texas; in Trans-Pecos Region: New Mexico Geological Society, 31st Field Conference, p. 289-294.

Hubbert, M. K., 1953, Entrapment of petroleum under hydrodynamic conditions: American Association of Petroleum Geologists Bulletin, v. 37, no. 8, p. 1957-2026.

Jones, C. L., 1954, The occurrence and distribution of potassium minerals in southeastern New Mexico, in Guidebook to southeastern New Mexico: New Mexico Geological Society, 5th Field Conference, p. 107-112.

_____, 1959, Thickness, character, and structure of upper Permian evaporites in part of Eddy County, New Mexico: U.S. Geological Survey Trace Element Memorandum TEM-1033, 19 p., 2 figs.

_____, 1972, Permian Basin potash deposits, southwestern United States, in Geology of saline deposits: Geologie deposits saline, UNESCO, Earth Science Services, no. 7, p. 191-201.

Jones, C. L., 1973, Salt deposits of Los Medaños area, Eddy and Lea Counties, New Mexico, with sections on Ground-water hydrology by M. E. Cooley, and Surficial geology by G. O. Bachman: U.S. Geological Survey open-file report, 67 p.

_____1975, Potash resources in part of Los Medaños area of Eddy and Lea Counties, New Mexico: U.S. Geological Survey Open-File Report 75-407, 37 p.

_____, 1978, Test drilling for potash resources, Waste Isolation Pilot Plant Site, Eddy County, New Mexico: U.S. Geological Survey Open-File Report 78-592, 2 vols., 431 p.

Jones, C. L, Bowles, C. G., and Bell, K. G., 1960, Experimental drill hole logging in potash deposits of the Carlsbad District, New Mexico: U.S. Geological Survey open-file report, 25 p.

Jones, C. L., and Madsen, B. M., 1959, Observations on igneous intrusions in late Permian evaporites, southeastern New Mexico: Geological Society of America Bulletin, v. 70, p. 1625-1626.

Jones, C. L., Cooley, M. E., and Bachman, G. O., 1973, Salt deposits of Los Medaños area, Eddy and Lea Counties, New Mexico: U.S. Geological Survey Open-File Report 4339-7, 67 p.

Jorgensen, D. G., Gogal, Tony, and Signor, D. C., Determination of flow in an aquifer containing-variable density water: Ground Water Monitoring Review, Spring, 1982, p. 40-45.

King, P. B., 1948, Geology of the southern Guadalupe Mountains, Texas: U.S. Geological Survey Professional Paper 215, 188 p.

Kunkler, J. L., 1980, Evaluation of the Malaga Bend salinity alleviation project, Eddy County, New Mexico: U.S. Geological Survey Open-File Report 80-1111, 31 p.

Lambert, S. J., 1978, Geochemistry of Delaware Basin ground waters, in Geology and mineral deposits of Ochoan rocks in Delaware Basin and adjacent areas: New Mexico Bureau of Mines and Mineral Resources, Circular 159, p. 33-38.

_____, 1982, Interim report--dissolution of evaporites in and around the Delaware Basin, southeastern New Mexico and west Texas: Sandia National Laboratories Report SAND 82-0461, Albuquerque, New Mexico, 171 p.

Lambert, S. J., and Mercer, J. W., 1977, Hydrologic Investigations of Los Medaños area, southeast New Mexico, 1977: Sandia National Laboratories Report SAND 77-1401, Albuquerque, New Mexico, 56 p.

REFERENCES-Continued

Lang, W. B., 1935, Upper Permian formations of Delaware Basin of Texas and New Mexico: American Association of Petroleum Geologists Bulletin, v. 19, no. 2, p. 262-270.

_____1937, Permian formations of the Pecos valley of New Mexico and Texas: American Association of Petroleum Geologists Bulletin, v. 21, p. 833-898.

_____, 1938, Geology of the Pecos River between Laguna Grande de la Sal and Pierce Canyon, in 12th and 13th biennial reports: New Mexico State Engineer, p. 80-86.

Lee, W. T., 1925, Erosion by solution and fill, in Contributions to geography in the United States: U.S. Geological Survey Bulletin 760-C, p. 107-121.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Maley, V. C., and Huffington, R. M., 1953, Cenozoic fill and evaporite solution in Delaware Basin, Texas and New Mexico: Geological Society of America Bulletin, v. 64, no. 5, p. 539-546.

McNeal, R. P., 1965, Hydrodynamics of the Permian Basin, in Fluids in subsurface environments -- a symposium: American Association of Petroleum Geologists Memoir 4, p. 308-326.

Meinzer, O. E., 1923a, The occurrence of ground water in the United States, with a discussion on principles; U.S. Geological Survey Water-Supply Paper 489, 321 p.

_____, 1923b, Outline of ground-water hydrology, with definitions: U.S. Geological Survey Water-Supply Paper 494, 71 p.

Meissner, F. F., 1972, Cyclic sedimentation in middle Permian strata of the Permian Basin, West Texas and New Mexico, in Cyclic sedimentation in the Permian Basin: West Texas Geological Society Publication 72-60, p. 203-232.

Mercer, J. W., Davis, Paul, Dennehy, K. F., and Goetz, C. L., 1981, Results of hydrologic tests and water-chemistry analyses, wells H-4A, H-4B, and H-4C at the proposed Waste Isolation Pilot Plant site, southeastern New Mexico: U.S. Geological Survey Water-Resources Investigations 81-36, 92 p.

Mercer, J. W., and Gonzalez, D. D., 1981, Geohydrology of the proposed Waste Isolation Pilot Plant in southeastern New Mexico, in Environmental geology and hydrology in New Mexico: New Mexico Geological Society Special Publication no. 10, p. 123-131.

Mercer, J. W., and Orr, B. O., 1977, Review and analysis of hydrogeologic conditions near the site of a potential nuclear-waste repository, Eddy and Lea Counties, New Mexico: U. S. Geological Survey Open-File Report 77-123, 35 p.

Mercer, J. W., and Orr, B. O., 1979, Interim data report on the geohydrology of the proposed Waste isolation Pilot Plant site, southeast New Mexico: U.S. Geological Survey Water-Resources Investigations 79-98, 178 p.

Motts, W. S., 1968, The control of ground-water occurrence by lithofacies in the Guadalupian reef complex near Carlsbad, New Mexico: Geological Society America Bulletin, v. 79, no. 3, p. 283-298.

Newell, N. D., Rigby, J. K., Fischer, A. G., Whiteman, A. J., Hickox, J. E., and Bradley, J. S., 1953, the Permian reef complex of the Guadalupe Mountains region, Texas and New Mexico--a study in paleoecology: W. H. Freeman & Co., San Francisco, 236 p.

Nicholson, Alexander, Jr., and Clebsch, Alfred, Jr., 1961, Geology and ground-water conditions in southern Lea County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Ground-water Report 6, 120 p.

Oriel, S. S., Myers, D. A., and Crosby, E. J., 1967, West Texas Permian Basin region, in McKee, E. D., and Oriel, S. S., eds., Paleotectonic investigations of the Permian System in the United States: U.S. Geological Survey Professional Paper 515, p. 17-60.

Page, L. R., and Adams, J. E., 1940, Stratigraphy, eastern Midland Basin, Texas, in Deford, R. K., and Lloyd, E. R., eds., West Texas - New Mexico symposium, pt. 1: American Association of Petroleum Geologists Bulletin, v. 24, no. 1, p. 52-64.

Papadopulos, S. S., Bredehoeft, J. D., and Cooper, H. H., Jr., 1973, On the analysis of "slug test" data: Water Resources Research, v. 9, no. 4, p. 087-1089.

Peterson, E. W., Lagus, P. L., Broce, R. D., and Lie, K, 1981, In situ permeability testing of rock salt: Sandia National Laboratories Report SAND 81-7073, Albuquerque, New Mexico, 65 p.

Powers, D. W., 1981, Geologic investigations of the WIPP site—overview and issues, in Environmental geology and hydrology in New Mexico: New Mexico Geological Society, Special Publication no. 10, p. 119-122.

Powers, D. W., Lambert, S. J., Shaffer, S. E., Hill, L. R., and Weart, W. D., editors, 1978, Geological characterization report, Waste Isolation Pilot Plant (WIPP) site, southeastern New Mexico: Sandia Laboratories Report SAND78-1596, Albuquerque, New Mexico, two volumes.

Register, J. K., 1981, Brine pocket occurrences in the Castile Formation, southeastern New Mexico: Report to the Department of Energy, TME 3080, 14 p.

Richardson, G. B., 1904, Report of a reconnaissance in Trans-Pecos Texas, north of Texas and Pacific Railway: Texas University Mineralogical Survey Bulletin 9, and Texas University Bulletin 23, 119 p.

Robinson, T. W., and Lang, W. B., 1938, Geology and ground-water conditions of the Pecos River valley in the vicinity of Laguna Grande de la Sal, with special reference to the salt content of the river water, in 12th and 13th biennal reports: New Mexico State Engineer, p. 77-100.

Sandia National Laboratories and University of New Mexico, 1981, Basic data report for drillhole WIPP 15 (Waste Isolation Pilot Plant--WIPP): Sandia National Laboratories Report SAND79-0274, Albuquerque, New Mexico, 80 p.

Silver, B. A., and Todd, R. G., 1969, Permian cyclic strata, northern Midand and Delaware Basins, west Texas and southeastern New Mexico: American Association of Petroleum Geologists Bulletin, v. 53, no. 11, p. 2223-2251.

Sullivan, Neil M., editor, 1979, Guadalupian Delaware Mountian Group of west Texas and southeast New Mexico: Permian Basin Section--Society of Economic Paleontologists and Mineralogists Publication 79-18, 244 p.

Theis, C. V., and Sayre, A. N., 1942, Geology and ground water, in U.S. National Resources Planning Board, 1942, Pecos River Joint Investigation --Reports of the participating agencies: Washington, U.S. Government Printing Office, p. 27-75.

Tolman, C. F., 1937, Ground Water: McGraw-Hill Book Company, Inc, New York and London, 593 p.

Vine, J. D., 1963, Surface geology of the Nash Draw quadrangle, Eddy County, New Mexico: U. S. Geological Survey Bulletin 1141-B, p. B1-B46.

REFERENCES-Concluded

Watson, W. G., 1979, Inhomogeneities of the Ramsey Member of the Permian Bell Canyon Formation, Geraldine Ford Field, Culberson and Reeves Counties, Texas, in Guadalupian Delaware Mountain Group of west Texas and southeast New Mexico: Permian Basin Section--Society of Economic Paleontologists and Mineralogists Publication 79-18, p. 2-38.

Williamson, C. R., 1979, Deep-sea sedimentation and stratagraphic traps, Bell Canyon Formation (Permian) Delaware Basin, in Guadalupian Delaware Mountain Group of west Texas and southeast New Mexico: Permian Basin Section--Society of Economic Paleontologists and Mineralogists Publication 79-18, p. 39-74.

Table 1. Geologic and hydrologic data from test holes drilled at and near the proposed Waste Isolation Pilot Plant site

[FNL, from north line; FEL, from east line, FSL, from south line; FWL, from west line; Sec., Section; T, Township; R, Range; units, in feet below land surface]

Test hole	Altitude, in feet above sea level	Location				Depth of rock			
		Sec.	T.	R.	Distance, in feet, from section lines	Surficial deposits	Gatuna Formation	Santa Rosa Formation	Dewey Lake Red Beds
H-1	3397.71	29	22S	31E	623.31FNL 1082.75FEL	0-15	15-35	N.P.,(Not Present)	35-502
H-2A	3377.85	29	22S	31E	726.17FNL 1698.43FWL	0-14	14-38	N.P.	38-457
H-2B	3377.68	do			695.57FNL 1660.57FWL	do	do	N.P.	do
H-2C	3377.75	do			637.15FNL 1708.62FWL	do	do	N.P.	do
H-3	3389 48	29	22S	31E	2085.30FSL 138.1FEL	0-4	4-22	N.P.	22-502
H-4A	3332.91	5	23S	31E	545.89FNL 720.00FWL	0-13	13-29	N.P.	29-315
H-4B	3332.76	do			498.47FNL 632.54FWL	do	do	N.P.	do
H-4C	3333.54	do			446.36FNL 717.89FWL	do	do	N.P.	do
H-5A	3506.15	15	22S	31E	1093.12FNL 184.33FEL	0-8	N.P.(Not Present)	8-225	225-732
H-5B	3505.97	do			1006.80FNL 234.21FEL	do	N.P.	do	do
H-5C	3506.37	do			1006.47FNL 134.20FEL	do	N.P.	do	do
H-6A	3347.26	18	22S	31E	283.80FNL 274.93FWL	0-12	12-38	N.P.	38-427
H-6B	3347.57	do			195.61FNL 322.15FWL	do	do	N.P.	do
H-6C	3347.93	do			280.61FNL 374.81FWL	do	do	N.P.	do
H-7A	3163.55	14	23S	30E	2495.04FNL 2492.35FWL	0-5		N.P.	57-87
H-7B	3163.63	do			2565.8FNL 2563.45FWL	do	do	N.P.	do
H-7C	3163.48	do			2591.93FNL 2467.51FWL	do	do		do
H-8A	3433.0	23	24S	30E	1962.61FNL 1486.59FEL	0-4 4-10 Mescalero Caliche	10-153	N.P.	153-399
H-8B	3433.8	do			1994.76FNL 1405.39FEL	do	do	N.P.	do
H-8C	3433.0	do			2059.39FNL 1470.14FEL	do	do	N.P.	do
H-9A	3405.4	4	24S	31E	2392.14FNL 138.92FWL	0-5	5-25	N.P.	24-455
H-9B	3405.6	do			2391.04FNL 283.63FWL	do	do	N.P.	do
H-9C	3405.9	do			2479.06FNL 188.02FWL	do	do	N.P.	do
H-10A	3686.52	20	23S	32E	433.04FSL 2068.91FEL	0-9	9-90	90-482 Chinle 482-658	658-1204
H-10B	3687.01	do			484.54FSL 1984.84FEL	do	do	do	do
H-10C	3686.88	do			384.54FSL 1981.84FEL	do	do	do	do

Depth of rock							
Rustler Formation	Magenta Dolomite Member of Rustler Formation	Culebra Dolomite Member of Rustler Formation	Top of Salado Formation	Top of salt in Salado Formation	Top of McNutt potash zone	Top of Castile Formation	Test hole depth in feet
502-824	563-589	676-699	824	731(R)			856
457-	515-543						563
457	515-543	623-645	N.P.				661
457-764	515-543	623-645	764	676(R)			795
502-821	559-584	672-694	821	823(S)			894
315-	375-400						415
315-	377-402	498-522					529
315-626	377-403	490-516	626	?			661
732-	783-810	897-920					824
732-	785-805	897-920 5b					925
732-1041	788-812	899-924	1041				1076
427-	492-511						525
427-	492-511	604-627					640
427-721	490-514	604-627	721	723.4(S)			741
87-283	117-140						154
87-283	117-140	237-283					286
87-283	117-140	237-273.5	283	405(S)			420
399-	466-488	5A					505
399-	466-488	588-614					624
399-733	466-488	588-614	733	798(S)			808
455-	523-554						559
455-	523-554	647-677					708
455-791	523-554	647-677	791	791(S)			816
1204-	1256-1280						1318
1204-	1256-1280	1360-1391					1398
1204-1501	1256-1280	1360-1391	1501	1501(S)			1538

Table 1. Geologic and hydrologic data from test holes drilled at and near the proposed Waste Isolation Pilot Plant site — Continued

Test hole	Altitude, in feet above sea level	Location: Sec. T. R.	Location: Distance, in feet, from section lines	Depth of rock: Surficial deposits	Depth of rock: Gatuna Formation	Depth of rock: Santa Rosa Formation	Depth of rock: Dewey Lake Red Beds
P-1	3345.1	29 22S 31E	328FSL 552FWL	0-10	10-40	N.P.	40-358
P-2	3479.4	28 22S 31E	121FNL 171FEL	0-18	18-38	38-164	164-690
P-3	3382.7	20 22S 31E	104FSL 2154FWL	0-10	10-41	N.P.	41-468
P-4	3443.8	28 22S 31E	149FSL 1485FEL	0-8	N.P.	8-93	99-609
P-5	3470.9	17 22S 31E	186FSL 160FEL	0-13	N.P.	13-146	146-623
P-6	3354.1	30 22S 31E	2509FNL 195FWL	0-8	8-18	N.P.	18-357
P-7	3332.0	5 23S 31E	514FNL 393FWL	0-11	11-45	N.P.	45-312
P-8	3338.6	4 23S 31E	640FNL 92FWL	0-11	9-39	N.P.	39-391
P-9	3411.5	33 22S 31E	1493FSL 126FEL	0-11	N.P.	11-66	66-562
P-10	3509.3	26 22S 31E	2341FNL 323FWL	0-8	N.P.	8-151	151-686
P-11	3503.9	23 22S 31E	156FNL 183FWL	0-9	N.P.	9-224	224-745
P-12	3373.6	24 22S 30E	165FNL 198FEL	0-8	N.P.	N.P.	8-461
P-13	3345.2	18 22S 31E	110FNL 147FWL	0-12	12-38	N.P.	38-427
P-14	3359.6	24 22S 30E	309FSL 613FWL	0-10	10-42	N.P.	42-387
P-15	3309.5	31-22S 31E	411FSL 190FWL	0-11	11-32	N.P.	32-231
P-16	3317.9	5 23S 31E	939FSL 1647FWL	0-14	14-32	N.P.	32-316
P-17	3335.9	4 23S 31E	1356FSL 398FWL	0-14	14-46	N.P.	46-382
P-18	3477.2	26 22S 31E	139FSL 733FEL	0-9	N.P.	9-87	87-628
P-19	3545.1	23 22S 31E	1652FSL 2335FWL	0-8	N.P.	8-232	232-758
P-20	3552.7	14 22S 31E	801FSL 79FEL	0-6	N.P.	6-261	261-780
P-21	3509	15 22S 31E	859FN. 130FEL	0-8	N.P.	8-225	225-734
ERDA-6	3540.2	35 21S 31E	2152FSL 910FEL	0-17	17-42	42-71	71-536
ERDA-9	3418.86	20 22S 31E	267.23FSL 176.74FEL	0-15	15-42	42-51	51-538
ERDA-10	3371.2	34 23S 30E	200FNL 2327FEL	0-5	5-151	N.P.	151-366
AEC-7	3654.00	31 21S 32E	2040FNL 2040FEL	0-12	N.P.	12-112	112-662
AEC-8	3531.5	11 22S 31E	935FNL 1979FWL		?	31-165	165-660

Depth of rock							
Rustler Formation	Magenta Dolomite Member of Rustler Formation	Culebra Dolomite Member of Rustler Formation	Top of Salado Formation	Top of salt in Salado Formation	Top of McNutt potash zone	Top of Castile Formation	Test hole depth in feet
358-677	423-448	538-565	677	597(R)	1191-1583		1591.0
690-1008	748-773	857-883	1008	906(R)	1506-1883		1895.0
468-786	529-553	642-665	786	688(R)	1287-1668		1676.0
609-930	662-686	775-802	930	826(R)	1446-1853		1857.0
623-947	686-711	804-827	947	350(R)	1428-1785		1830.6
357-659	417-443	537-560	659	661(S)	1162-1560		1573.0
312-630	373-398	496-522	630	562(R)	1155-1566		1575.0
391-715	450-474	563-588	715	606(R)	1237-1652		1660.0
562-881	617-644	734-757	881	778(R)	1401-1796		1796.0
686-1086	757-781	931-957	1086	712(R)	1594-1983		2010.8
745-1058	798-823	912-938	1058	958(R)	1550-1917		1943.1
461-749	519-543	633-656	749	752(S)	1226-1597		1598.4
427-721	490-514	604-627	721	725(S)	1201-1547		1577.3
387-687	453-477	573-595	687	695(S)	1158-1510		1545.0 Mercer 79, pg 82
231-542	294-321	413-435	542	460(R)	1057-1453		1465.0 Mercer 79, pg 77
316-646	376-401	500-523	646	552(R)	1174-1585		1585.0
382-715	438-463	558-583	715	602(R)	1234-1648		~~1660.7~~ 1660 Mercer 79, pg 78
628-1088	704-730	909-938	1088	654(R)	1604-2087		~~2000.5~~ 1998 Mercer 79, pg 78
758-1117	814-839	967-997	1117	890(R)	1621-2011 projected		2000.0
780-1103	839-866	953-979	1103	1002(R)	1604-1977		1994.5
734-1043	788-812	899-924	1043	944(R)	1526-1887		1916.5
536-815	595-621	710-735	815	815(S)		2401	2775
538-848	596-620	704-727	848	750(S)	1350-1730	2824	2876.6
366-628	366-385	476-504	628	678(S)		2337 3829(D)	4418
662-991	733-759	870-896	991	930(R) 1000(S)		3004 4522(D)	4721
660-985	715-738	833-859	985	985(S)		2966 4343(D)	4910

Table 1. Geologic and hydrologic data from test holes drilled at and near the proposed Waste Isolation Pilot Plant site — Concluded

Test hole	Altitude, in feet above sea level	Location					Depth of rock			
		Sec.	T.	R.	Distance, in feet, from section lines		Surficial deposits	Gatuna Formation	Santa Rosa Formation	Dewey Lake Red Beds
WIPP-11	3426.07	9	22S	31E	711.70FNL	394.08FWL	0-13	13-29	29-161	161-663
WIPP-12	3471.53	17	22S	31E	147.9FSL	83.91FEL	0-9	N.P.	9-155	155-628
WIPP-13	3405.43	17	22S	31E	2565.68FSL	1730.59FWL	0-13	N.P.	13-66	66-517
WIPP-15	3269.34	18	23S	35E	2426FNL	1793FWL			543-2726 (Chinle)	
WIPP-16	3383	5	21S	30E	2355FSL	140FWL	(0-1148)Rubble?			
WIPP-18	3456.47	20	22S	31E	983.58FNL	11.45FEL	0-9	N.P.	9-138	138-613
WIPP-19	3433.13	20	22S	31E	2987.34FSL	12.68FEL	0-14	N.P.	14-96	96-589
WIPP-21	3417.00	20	22S	31E	1551.08FSL	11.74FEL	0-12	12-39	39-73	73-560
WIPP-22	3425.83	20	22S	31E	2544.45FSL	11.94FEL	0-20	20-25	25-80	80-573
WIPP-25	3212.51	15	22S	30E	1852.72FSL	2838.1FEL	0-10	N.P.	N.P.	10-232
WIPP-26	3151.91	29	22S	30E	2232.27FNL	12.2FEL	0-10	N.P.	N.P.	N.P.
WIPP-27	3177.17	21	21S	30E	89.79FNL	1485.03FWL	0-79		N.P.	79-153
WIPP-28	3346.76	18	21S	31E	98.72FNL	2400.99FEL	0-12	N.P.	N.P.	12-215
WIPP-29	2976.99	34	22S	29E	406.62FSL	1827.54FEL	0-12	N.P.	N.P.	N.P.
WIPP-30	3427.54	33	21S	31E	667.5FNL	177.41FWL		N.P.	N.P.	0-449
WIPP-31	3401.43	35	20S	30E	422.54FSL	1762.24FWL		N.P.	0(Breccia)	38(Breccia)
WIPP-32	3023.00	33	22S	29E	1673FSL	29FEL				
WIPP-33	3323.00	13	22S	30E	1762FSL	2427FWL	0-40			40-398
WIPP-34	3433.00	9	22S	31E	202FSL	2000FWL	0-11		11-154	154-657
B-25	3408.74	20	22S	31E	N 9414.91 E 6693.11* *N.M. State Coordinates		0-10 10-14 Mescalero Caliche	14-34.7	34.7-44.8	44.8-533

Depth of rock							
Rustler Formation	Magenta Dolomite Member of Rustler Formation	Culebra Dolomite Member of Rustler Formation	Top of Salado Formation	Top of salt in Salado Formation	Top of McNutt potash zone	Top of Castile Formation	Test hole depth in feet
663-951	727-750	844-867	951	951(S)		2330	3580.6
628-955	672 ~~690~~-715	810-835	954 ~~955~~	857(R) 955(S)		2727	2777.8 SAND82-2336
517-844	565 ~~564~~-583	703-726 ~~701-724~~	346 ~~844~~	774(R) 918(S)			3856 ~~1025~~ SEWARD, SAND82-1880
							810.5
1148-1300+	1189-1199	1153-1176					1300
613-928	672-696	787 ~~786~~-808	928	829(R) 928(S)			1060 SEWARD, SAND79-0275
589-894	647-672	756-779 ~~777~~	~~894~~ 895	894(S)			1038 SAND79-0276, SEWARD
560-868	618-642 ~~641~~	729-753	868	770(R) 868(S)			1045 SAND79-0277, pg 11
573-883	630-654	742-764	~~883~~ 885	785(R) 884(S)			~~1490~~/452 Seward, SAND79-0278
232-565	302-328	447-472	565	600(S)			~~695~~ 651 SAND79-0279 pg 9; Note: discre between pg
10-309	70-99	186-209	309	320(S)			503 Seward pg 22, SAND79-0280 pg
153-416	175-193 ~~176-194~~	292-318	421 ~~416~~	508(S)			592 SAND79-0281
215-531.0	285-310	420-446	531	589 (S)			801
N.P.	N.P.	12-42	143	251(S)			376
449-749	513-537	631-654	749	749(S)			913
750(Breccia)	1981(Breccia)		N.P.				1981
0-166	19-36	61-90	166-390				390
398-675	449-468	550-578	657-840				840
657-973	718-741	834-860	973-1820+				1820
533-842.9	592.7-617	704.1-728	842.9				901

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolaiton Pilot Plant site

[GEOLOGIC UNIT: 231SNSR, Santa Rosa Sandstone; 313BLCN, Bell Canyon Formation; 312RSLRL, Rustler-Salado residuum; 312CLBR, Culebra Dolomite Member; 310MGNT, Magenta Dolomite Member. GM/ML AT 20 C: Grams per millimeter at 20 degrees Celsius; MG/L: milligrams per liter; UG/L: micrograms per liter; PCI/L: picocuries per liter.]

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-5C	78-05-24	231SNRS	--	--	200	240	--	.36	--	150
AEC-7	79-04-28	313BLCN	1.130	--	43	--	--	--	--	35000
AEC-8	77-09-27	313BLCN	1.060	6.3	--	--	--	--	--	--
ERDA-10	77-09-29	313BLCN	1.165	7.7	90	110	0	3.1	.2	19000

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-5C	150	56	51	280	25	120	530	1.2	11.0	890	1200
AEC-7	35000	9700	2600	55000	970	110000	1800	1.4	14.0	76000	180000
AEC-8	--	--	--	--	--	--	--	--	--	--	230000
ERDA-10	19000	5300	1300	89000	720	150000	2400	0.3	3.4	20000	270000

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-1	77-02-23	312RSLRL	--	7.9	554	675	0	.29	--	160000
H-2C	77-02-23	312RSLRL	--	5.9	163	199	0	1.1	--	130000
H-3	77-02-23	312RSLRL	--	7.6	383	467	0	.77	--	150000
H-4C	79-03-16	312RSLRL	--	--	1	1	0	.27	--	130000
H-5C	79-05-16	312RSLRL	--	--	180	300	--	--	--	340000
H-6C	79-04-09	312RSLRL	--	--	1	--	--	--	--	97000
H-7C	80-03-20	312RSLRL	1.048	6.8	35	--	--	.03	--	10000
H-8C	80-09-06	312RSLRL	--	7.6	21	--	--	.00	.6	4800
H-9C	80-05-20	312RSLRL	1.202	7.0	24	--	--	1.1	--	6800
H-10C	80-05-19	312RSLRL	1.198	6.3	53	--	--	.84	--	49000
P-14	77-02-24	312RSLRL	--	7.2	182	222	0	.34	--	6400
P-15	79-04-03	312RSLRL	--	--	45	--	--	--	--	3400
P-17	79-05-11	312RSLRL	--	--	650	--	--	.04	--	200000
P-18	80-05-20	312RSLRL	1.260	6.0	400	--	--	.06	.0	290000
WIPP-25	80-03-19	312RSLRL	1.173	7.2	80	--	--	.04	--	15000
WIPP-26	80-03-18	312RSLRL	1.078	8.5	160	--	--	.05	--	12000
WIPP-27	80-05-21	312RSLR	1.205	7.8	25	--	--	.17	--	6300
WIPP-28	80-03-20	312RSLRL	1.140	7.0	230	--	--	.03	--	13000
WIPP-29	80-03-18	312RSLRL	1.068	7.3	130	--	--	.23	--	10000
WIPP-30	80-03-19	312RSLRL	1.201	7.0	320	--	--	.04	--	12000

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-1	160000	13000	30000	56000	17000	210000	520	--	<.1	110000	480000
H-2C	130000	9200	25000	66000	9100	200000	1300	--	2.0	150000	450000
H-3	150000	18000	25000	59000	14000	210000	370	--	1.0	1900	--
H-4C	130000	8300	27000	66000	8600	210000	1400	1.7	1.3	360000	--
H-5C	340000	2100	82000	14000	21000	290000	2000	<.1	1.6	67000	--
H-6C	97000	4200	21000	80000	8000	200000	2000	1.0	1.4	200000	--
H-7C	10000	2600	910	22000	210	41000	2900	.8	7.2	3100	--
H-8C	4700	1200	430	46000	660	70000	5300	.4	.8	1300	--
H-9C	6300	1300	870	130000	1200	190000	2600	.1	3.8	19000	--
H-10C	49000	1500	11000	100000	4000	190000	3300	.7	3.2	120000	--
P-14	6200	570	1200	120000	1300	180000	10000	--	2.0	1700	350000
P-15	3300	770	350	24000	1400	38000	2800	1.3	1.3	3700	--
P-17	200000	15000	40000	23000	8800	150000	1200	3.8	15	880	--
P-18	290000	31000	51000	20000	16000	250000	280	2.3	3.2	160000	--
WIPP-25	15000	650	3200	90000	2400	130000	12000	.0	2.6	35000	--
WIPP-26	12000	2700	1300	52000	1000	88000	7600	.0	2.5	30000	--
WIPP-27	4700	900	610	130000	390	230000	8400	.2	2.5	9400	--
WIPP-28	13000	750	2700	71000	2800	120000	5200	.2	3.5	38000	--
WIPP-29	10000	850	2000	32000	1000	49000	12000	.9	3.5	21000	--
WIPP-30	11000	850	2300	120000	1500	170000	7000	.0	3.5	77000	--

Table 2.--Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	SELE-NIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DIS-SOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DIS-SOLVED, RADON METHOD (PCI/L)	URANIUM DIS-SOLVED, EXTRAC-TION (UG/L)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)
H-1	77-02-23	312RSLRL	<1	--	--	16000	160	64	.02	<6300
H-2C	77-02-23	312RSLRL	<1	--	--	8400	91	4.8	2.4	<5000
H-3	77-02-23	312RSLRL	1	--	--	12000	26	51	.06	<6000
H-4C	79-03-16	312RSLRL	<1	<7500	3.3	8900	<.4	340	1.2	<11000
H-5C	79-05-16	312RSLRL	1	<13000	.7	15000	.6	310	<.04	<19000
H-6C	79-04-09	312RSLRL	1	<7500	.9	6800	<.7	280	<.04	<11000
H-7C	80-03-20	312RSLRL	--	<950	--	<580	--	65	1.9	<1400
H-8C	80-09-06	312RSLRL	--	<1800	--	<1100	--	18	.04	<2600
H-9C	80-05-20	312RSLRL	--	<5400	--	7600	--	.31	.45	<8000
H-10C	80-05-19	312RSLRL	--	<5600	--	7200	--	10	.37	<8200
P-14	77-02-24	312RSLRL	1	--	--	<2000	2.3	15	1.3	<3700
P-15	79-04-03	312RSLRL	<1	<1000	<.3	1300	<.4	.59	.08	<1500
P-17	79-05-11	312RSLRL	<1	<7500	6.8	13000	2.8	340	<.02	<11000
P-18	79-05-11	312RSLRL	<1	<8800	<.3	9800	<.4	11	.05	<13000
WIPP-25	80-03-19	312RSLRL	--	<5200	--	<3600	--	2.7	.29	<7700
WIPP-26	80-03-18	312RSLRL	--	<3200	--	<1700	--	12	5.2	<4700
WIPP-27	80-05-21	312RSLR	--	<1200	--	<7100	--	2.4	.07	<1800
WIPP-28	80-03-20	312RSLRL	--	<4100	--	<2700	--	3.6	2.7	<6000
WIPP-29	80-03-18	312RSLRL	--	<1100	--	740	--	1.2	2.0	<1600
WIPP-30	80-03-19	312RSLRL	--	<7500	--	<4500	--	98	<.01	<11000

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	290	12000	120
H-2C	190	6700	76
H-3	68	9600	21
H-4C	4.9	8100	<.4
H-5C	1.1	14000	.6
H-6C	1.3	6200	<.7
H-7C	--	<590	--
H-8C	--	<1100	--
H-9C	--	<7200	--
H-10C	--	<6900	--
P-14	6.3	<1600	1.9
P-15	<.4	1200	<.4
P-17	10	12000	2.5
P-18	<.4	8800	<.4
WIPP-25	--	<3800	--
WIPP-26	--	<1800	--
WIPP-27	--	<15000	--
WIPP-28	--	<2800	--
WIPP-29	--	730	--
WIPP-30	--	<4500	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site – Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-1	76-06-02	312CLBR	--	7.6	86	105	0	--	.0	3100
H-2B	77-02-22	312CLBR	--	8.4	57	59	5	.01	--	2400
H-3	77-03-17	312CLBR	--	7.4	94	115	0	.07	--	6500
H-4B	78-12-14	312CLBR	--	7.6	48	59	--	.02	--	2200
H-5B	78-12-19	312CLBR	--	6.8	34	41	--	.01	--	8700
H-6B	78-12-20	312CLBR	--	7.3	85	--	--	.02	--	7000
H-7B	80-03-20	312CLBR	1.001	7.0	100	--	--	.40	--	2000
H-8B	80-02-11	312CLBR	1.000	7.3	61	--	--	.95	--	2100
H-9B	80-02-05	312CLBR	--	7.3	90	--	--	.13	--	2100
H-10B	80-03-21	312CLBR	1.045	8.3	37	--	--	.01	--	8100
P-14	77-03-14	312CLBR	--	6.0	290	357	0	.01	--	11000
P-15	79-04-11	312CLBR	--	--	100	--	--	--	--	3100
P-17	77-05-10	312CLBR	--	7.4	63	77	0	.06	--	11000
P-18	77-05-10	312CLBR	--	7.2	254	310	0	.81	--	80000
WIPP-25	80-08-14	312CLBR	1.014	7.3	370	--	--	.67	.8	3300
WIPP-26	80-08-18	312CLBR	1.013	6.9	130	--	--	3.5	.0	4400
WIPP-27	80-08-22	312CLBR	1.094	6.4	150	--	--	4.0	.0	16000
WIPP-28	80-08-21	312CLBR	1.044	6.4	670	--	--	.09	10	4900
WIPP-29	80-08-20	312CLBR	1.178	6.1	210	--	--	.02	.0	26000
WIPP-30	80-08-13	312CLBR	1.072	6.8	74	--	--	1.2	.0	6300

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-1	3000	780	280	9400	190	12000	7400	5.1	2.7	2400	--
H-2B	2300	690	160	2100	91	2800	3000	2.0	1.7	9500	9700
H-3	6400	1500	670	19000	630	29600	5700	.5	1.2	20000	62000
H-4B	2200	180	430	5800	180	7500	4000	1.9	5.2	19000	--
H-5B	8700	360	1900	53000	1400	86000	610	1.4	2.1	36000	--
H-6B	6900	1200	970	18000	500	28000	3800	1.5	8.5	9500	--
H-7B	1900	590	130	210	1.4	350	1900	1.4	39	780	--
H-8B	2100	570	170	82	4.7	57	2000	2.4	19	580	--
H-9B	2000	580	150	210	1400	320	2000	3.0	26	780	--
H-10B	8100	1600	1000	21000	520	36000	5600	1.3	1.5	13000	--
P-14	11000	3100	760	7600	600	20000	1400	.9	33	700	38000
P-15	3000	780	280	29000	7200	48000	7000	1.6	.6	5200	--
P-17	11000	1700	1600	30000	120	54000	5000	1.5	1.0	1700	97000
P-18	80000	5600	16000	9200	6200	80000	980	1.2	1.0	100000	420000
WIPP-25	3000	920	250	5100	.9	8300	2400	1.4	29	1900	--
WIPP-26	4300	1200	340	3600	2.0	8200	2300	1.5	20	1800	--
WIPP-27	16000	3100	2000	39000	100	77000	3900	.5	13	1900	--
WIPP-28	4300	1200	470	21000	4.0	30000	3200	1.1	28	5400	--
WIPP-29	25000	810	5700	79000	150	140000	13000	.7	11	1300	--
WIPP-30	6300	1100	870	37000	8.2	64000	2800	.5	1.5	23000	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Continued

WELL	DATE OF SAMPLE	GEOLOGIC UNIT	SELENIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DISSOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DISSOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DISSOLVED, RADON METHOD (PCI/L)	URANIUM DISSOLVED, EXTRACTION (UG/L)	GROSS ALPHA, DISSOLVED (UG/L AS U-NAT)
H-1	79-03-13	312CLBR	<1	<200	<.3	410	<.4	1.7	.16	<290
H-2B	77-02-22	312CLBR	2	--	--	120	110	4.6	--	330
H-3	77-03-17	312CLBR	2	--	--	850	<.4	57	.09	<880
H-4B	78-12-14	312CLBR	<1	--	--	310	--	67	2.9	720
H-5B	78-12-19	312CLBR	<1	2700	--	1100	--	290	1.0	4000
H-6B	78-12-20	312CLBR	5	--	--	<420	--	6.6	4.3	<1200
H-7B	80-03-20	312CLBR	--	<38	--	19	--	.98	9.7	<56
H-8B	80-02-11	312CLBR	--	62	<.3	<19	<.4	3.4	7.4	91
H-9B	80-02-05	312CLBR	--	--	--	<25	--	7.3	34	<100
H-10B	80-03-21	312CLBR	--	<1100	--	<590	--	29	.08	<1600
P-14	77-03-14	312CLBR	1	--	--	790	<.4	68	<.01	<390
P-15	79-04-11	312CLBR	4	<1300	<.3	4700	<.4	11	2.2	<1900
P-17	77-05-10	312CLBR	1	--	--	1300	<.4	84	.10	2900
P-18	77-05-10	312CLBR	<1	--	--	7700	.5	190	.33	<4800
WIPP-25	80-08-14	312CLBR	--	<200	--	<170	--	17	6.1	<290
WIPP-26	80-08-18	312CLBR	--	<260	--	<220	--	18	12	<380
WIPP-27	80-08-22	312CLBR	--	<1800	--	6300	--	79	4.9	<2600
WIPP-28	80-08-21	312CLBR	--	<1100	--	<1100	--	40	1.3	<1600
WIPP-29	80-08-20	312CLBR	--	<7500	--	18000	--	17	18	<11000
WIPP-30	80-08-13	312CLBR	--	<880	--	<660	--	64	.29	<1300

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DISSOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	<.4	390	<.4
H-2B	380	97	88
H-3	<.4	710	<.4
H-4B	--	290	--
H-5B	--	1000	--
H-6B	--	<390	--
H-7B	--	19	--
H-8B	<.4	<18	<.4
H-9B	--	<23	--
H-10B	--	<610	--
P-14	<.4	620	<.4
P-15	<.4	4300	<.4
P-17	<.4	1000	<.4
P-18	<.4	6100	.5
WIPP-25	--	<160	--
WIPP-26	--	<210	--
WIPP-27	--	6100	--
WIPP-28	--	<1000	--
WIPP-29	--	17000	--
WIPP-30	--	<600	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Continued

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	DENSITY (GM/ML AT 20 C)	PH (UNITS)	ALKA-LINITY FIELD (MG/L AS CACO3)	BICAR-BONATE FET-FLD (MG/L AS HCO3)	CAR-BONATE FET-FLD (MG/L AS CO3)	NITRO-GEN, NO2+NO3 DIS-SOLVED (MG/L AS N)	SULFIDE TOTAL (MG/L AS S)	HARD-NESS (MG/L AS CACO3)
H-1	76-06-04	310MGNT	--	7.4	75	92	0	--	.0	3300
H-2A	77-02-22	310MGNT	--	8.6	61	74	0	.04	--	2700
H-3	77-05-10	310MGNT	--	8.0	42	51	0	.08	--	5000
H-4A	78-12-14	310MGNT	--	8.0	52	63	--	.01	--	2200
H-5A	78-12-14	310MGNT	--	7.8	41	50	--	.01	--	1300
H-6A	78-12-20	310MGNT	--	7.3	42	51	--	.03	--	2000
H-8A	80-02-12	310MGNT	1.006	9.3	26	--	--	.06	--	2200
H-9A	80-02-05	310MGNT	1.003	8.5	35	--	--	.02	--	2100
H-10A	80-03-21	310MGNT	1.175	7.1	0	--	--	.03	--	17000
WIPP-25	80-09-04	310MGNT	1.010	7.5	150	--	--	.64	1.2	3300
WIPP-27	80-07-24	310MGNT	1.080	6.8	57	--	--	.32	--	11000
	80-09-20	310MGNT	--	6.5	180	--	--	.40	1.8	17000
WIPP-30	80-09-24	310MGNT	--	8.8	62	--	--	.00	.0	2400

WELL	HARD-NESS, NONCAR-BONATE (MG/L CACO3)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	SULFATE DIS-SOLVED (MG/L AS SO4)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	BORON, DIS-SOLVED (UG/L AS B)	SOLIDS, RESIDUE AT 105 DEG. C, DIS-SOLVED (MG/L)
H-1	3300	890	270	5700	70	8000	3900	2.8	1.3	2200	--
H-2A	2700	820	170	2700	81	4100	2400	--	6.0	220	12000
H-3	4900	1200	480	9300	250	15000	3400	1.8	6.4	13000	32000
H-4A	2100	210	410	7000	130	7500	7000	2.5	6.4	13000	--
H-5A	1300	240	170	1500	53	880	3200	2.8	9.0	11000	--
H-6A	2000	520	160	1100	46	1200	2700	1.4	7.7	2500	--
H-8A	2200	870	17	2400	84	3500	2100	.7	.9	3100	--
H-9A	2000	550	170	800	28	750	2700	1.8	3.3	2600	--
H-10A	17000	2500	2600	93000	510	160000	2700	1.3	1.9	3900	--
WIPP-25	3100	910	240	3100	.8	5600	1900	1.5	25	1900	--
WIPP-27	11000	1100	1900	34000	1800	61000	9400	.0	1.7	26000	--
	17000	3600	2000	43000	10000	85000	2900	.4	13	230	--
WIPP-30	2400	690	170	5500	190	8700	3200	1.9	.7	12000	--

Table 2.—Selected chemical and radiochemical analyses of water from test holes at and near the proposed Waste Isolation Pilot Plant site — Concluded

WELL	DATE OF SAMPLE	GEO-LOGIC UNIT	SELE-NIUM, TOTAL (UG/L AS SE)	GROSS ALPHA, DIS-SOLVED (PCI/L AS U-NAT)	GROSS ALPHA, SUSP. TOTAL (PCI/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS CS-137)	GROSS BETA, SUSP. TOTAL (PCI/L AS CS-137)	RADIUM 226, DIS-SOLVED, RADON METHOD (PCI/L)	URANIUM DIS-SOLVED, EXTRAC-TION (UG/L)	GROSS ALPHA, DIS-SOLVED (UG/L AS U-NAT)
H-1	77-05-10	310MGNT	1	--	--	940	<.4	170	.60	<400
H-2A	77-02-22	310MGNT	1	--	--	69	2.6	6.1	.80	<160
H-3	77-05-10	310MGNT	7	--	--	330	<.4	44	--	550
	79-05-10	310MGNT	1	<420	.3	1300	.4	10	.24	<620
H-4A	78-12-14	310MGNT	<1	--	--	<100	--	9.3	.08	<320
H-5A	78-12-14	310MGNT	<1	--	--	53	--	17	1.0	160
H-6A	78-12-20	310MGNT	1	--	--	43	--	11	6.7	110
H-8A	80-02-12	310MGNT	--	<140	<.3	130	<.4	1.9	.08	<200
H-9A	80-02-05	310MGNT	--	--	--	<38	--	9.4	.15	<150
H-10A	80-03-21	310MGNT	--	<5300	--	<3500	--	480	<.10	<7800
WIPP-25	80-09-04	310MGNT	--	<160	--	<140	--	12	8.4	<230
WIPP-27	80-07-24	310MGNT	--	--	--	1900	--	12	--	--
	80-09-20	310MGNT	--	<2000	--	6000	--	24	5.8	<2900
WIPP-30	80-09-24	310MGNT	--	<300	--	<200	--	26	.02	<440

WELL	GROSS ALPHA, SUSP. TOTAL (UG/L AS U-NAT)	GROSS BETA, DIS-SOLVED (PCI/L AS SR/YT-90)	GROSS BETA, SUSP. TOTAL (PCI/L AS SR/YT-90)
H-1	<.4	790	<.4
H-2A	12	55	2.0
H-3	<.4	260	<.4
	.4	1200	.4
H-4A	--	<92	--
H-5A	--	48	--
H-6A	--	39	--
H-8A	<.4	130	<.4
H-9A	--	<35	--
H-10A	--	<3600	--
WIPP-25	--	<130	--
WIPP-27	--	1800	--
	--	5800	--
WIPP-30	--	<190	--

Table 3.--*Stratigraphic summary of rock units of Permian (Guadalupian and Ochoan) and younger age underlying the proposed Waste Isolation Pilot Plant site and adjacent areas*

Age			Rock unit		Thickness (feet)	Description
Quaternary	Holocene		Alluvium and sand of Mescalero surface		0-19	Dune sand, uniformly fine grained, light-brown to reddish-brown
						UNCONFORMITY
			Mescalero caliche		0-5	Limestone, chalky, includes fragments of underlying rock
						UNCONFORMITY
	Plein-to-cene (?)		Gatuna Formation		0-32	Sandstone and siltstone, poorly indurated, dominantly reddish-orange
						UNCONFORMITY
Triassic	Late Triassic		Chinle Formation		0-800	Mudstone, shaly with lenses of sandstone and conglomerate
			Santa Rosa Sandstone		0-255	Sandstone, medium- to coarse-grained, commonly cross-stratified, gray and yellowish-brown, contains conglomerate and reddish-brown mudstone
						UNCONFORMITY
Permian	Ochoan		Dewey Lake Red Beds		250-541	Siltstone and sandstone, very fine to fine-grained, reddish-orange to reddish-brown, contains interbedded reddish-brown claystone, small-scale lamination and cross-stratification common
						UNCONFORMITY
			Rustler Formation		298-462	Anhydrite and halite with subordinate dolomite, sandstone, claystone, and polyhalite; includes Magenta Dolomite and Culebra Dolomite Members
			Salado Formation		2,000±	Halite with subordinate anhydrite, polyhalite, potash ores, sandstone, and magnesite
			Castile Formation		1,300±	Anhydrite and halite with subordinate limestone
	Guadalupian	Guadalupian reef complex	Delaware Mountain Group	Bell Canyon Formation	1,000±	Sandstone, brown and gray, with minor limestone and shale
				Cherry Canyon Formation	1,000±	Sandstone, gray and brown, with limestone and minor shale
				Brushy Canyon Formation	1,000±	Sandstone, gray, with brown and black shale and brown limestone

Modified from Bachman, 1980

Table 4.—Summary of drill-stem tests at test holes AEO-7, AEO-8, and ERDA-10, upper Bell Canyon Formation, in the vicinity of the proposed Waste Isolation Pilot Plant site

Test number	Date of test	Tested interval, in feet below	Type of test	Hydrostatic pressure, in pounds per square inch (gage)		Flow period in minutes	Bottom hole flowing pressure, in pounds per square inch (gage)		Shut-in period, in minutes	Bottom hole shut-in pressure, in pounds per square inch (gage)		Calculated hydraulic conductivity, in feet per day	Static bottom hole pressure (extrapolated), in pounds per square inch (gage)	Fluid density, in grams per cubic centimeter
				Initial	Final		Initial	Final		Initial	Final			
Test Hole AEO-7														
1	4-23-79	4520-4583 (Lamar)	Standard	2,841	2,462	30 120 360	30 23 25	23 23 21	60 360 480	23 23 21	23 25 23	Insufficient Data to Make Calculation	-	-
2	4-27-79	4609-4714 (Ramsey)	Standard	2,547	2,531	25 60 120	127 460 861	395 804 1,270	60 120 335	395 804 1,270	1,814 1,808 1,839	4×10^{-2}	1,883	1.130
3	4-28-79	4493-4714 (Upper Bell Canyon)	Standard	2,479	2,466	10 60 120	120 352 770	314 717 1,188	60 120 350	314 717 1,188	1,764 1,737 1,768	4×10^{-2}	1,811	1.130
Test Hole AEO-8														
1	8-15-77	4844-4800 (pre Ramsey lower sand)	Modified	-	-	-	-	-	-	-	-	2×10^{-2}	2,037	1.147
2	9-27-77	4821-4827 (upper sand)	Modified	-	-	-	-	-	-	-	-	7×10^{-3}	2,044	1.060
7	7-24-76	4304-4405 (Lamar)	Standard	2,445	-	30 58	13 24	18 32	121 748	18 32	1,761 1,788	2×10^{-6}	1,813	-
Test Hole ERDA-10														
9	9-19-77	3860-3927 (Lamar)	Standard	2,083	2,054	30 120 480	51 75 112	58 106 215	120 360 240	58 106 215	1,708 1,684 1,511	4×10^{-4}	1,783	-
10	9-29, 30-77	4127-4430 (Ramsey)	Modified	-	-	-	-	-	-	-	-	5×10^{-2}	1,820	1.165

Table 5.—Major cations and anions in water from test holes AEC-7, AEC-8, and ERDA-10 completed in the upper part of the Bell Canyon Formation, in the vicinity of the proposed Waste Isolation Pilot Plant site

[meq/L, milliequivalent per liter; mg/L, milligrams per liter; percent, percentage composition]

Test Hole AEC-7

Cations												Anions					
Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
9,700	484	7.7	2,600	213.9	3.4	55,000	2,392.5	37.8	970	24.8	0.4	110,000	3,103.1	49	1,800	37.5	0.6

Test Hole AEC-8

Cations												Anions					
Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
10,000	499	8.1	2,500	205.7	3.3	55,000	2,392.5	38.6	860	22	.4	120,000	3,068.4	49.5	240	5	.1

Test Hole ERDA-10

Cations												Anions					
Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
5,300	264.5	3.1	1,300	106.9	1.3	89,000	3,871.5	45.3	720	18.4	.2	150,000	4,231.5	49.5	2,400	50	.6

Table 6.—Measured and density-corrected water levels in selected test holes completed in the Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site

Test Hole	Altitude of land surface, in feet above sea level	Water level		Density, in grams per cubic centimeter	Freshwater equivalent corrected water level	
		Feet below land surface	Altitude, in feet above sea level		Feet below land surface	Altitude, feet above sea level
H-2c	3,397.7	343	3,035	1.225	258	3,140
H-4c	3,333.5	411	2,923	1.215	365	2,969
H-6c	3,347.9	410.5	2,937	1.210	345	3,003
H-7c	3,163.5	205.7	2,958	1.048	197	2,967
H-8c	3,433.0	463	2,970	1.129	421	3,012
P-14	3,359.6	389	2,971	1.126	351	3,009
P-15	3,309.5	313.9	2,996	1.160	278	3,032
P-17	3,335.9	365	2,971	1.193	297	3,039
W-25	3,212.5	238.4	2,974	1.093	206	3,007
W-26	3,151.9	191.7	2,960	1.189	168	2,984
W-27	3,177.2	192	2,985	1.207	126	3,051
W-28	3,346.8	303	3,044	1.152	259	3,088
W-29	2,977	17.6	2,959	1.129	+12	2,989
W-30	3,427.5	307	3,121	1.204	218	3,210

Table 7.—Values of transmissivity and storage coefficient for water-bearing zones in the Rustler Formation penetrated by selected test holes at and near the proposed Waste Isolation Pilot Plant site

[Transmissivity is expressed in feet squared per day]

Test hole	Magenta Dolomite Member		Culebra Dolomite Member		Rustler-Salado Contact	
	Transmissivity	Storage	Transmissivity	Storage	Transmissivity	Storage
H-1	0.05	–	0.07	10^{-4}	0.0003	–
H-2a	.01	10^{-4}				
H-2b			0.4	10^{-9}		
H-2c					0.0001	–
H-3	.1	10^{-5}	19.0	–	0.0003	10^{-4}
H-4a	.06	10^{-6}				
H-4b			0.9	10^{-9}		
H-4c					0.0006	10^{-4}
H-5a	.1	10^{-5}				
H-5b			0.2	10^{-5}		
H-5c					.00003	10^{-3}
H-6a	.3	10^{-5}				
H-6b			73.0	–		
H-6c					.003	10^{-6}
H-7a	Dry	–				
H-7b			1000+	–		
H-7c					0.73	–
H-8a	.006	10^{-5}				
H-8b			16.0	–		
H-8c					0.003	–
H-9a	1.0	10^{-9}				
H-9b			231	–		
H-9c					0.0002	–
H-10a	0.01	10^{-3}				
H-10b			0.07	10^{-4}		
H-10c					0.00009	–
P-14			140	–	0.05	–
P-15			0.07	10^{-4}	0.0004	–
P-17			1.0	10^{-6}	0.0002	10^{-4}
P-18			0.001	–	0.00003	10^{-5}
W-25	375	–	270	–	5.0	10^{-3}
W-26	Dry	–	1250	–	0.4	–
W-27	53	–	650	–	0.0002	–
W-28	Dry	–	18	–	0.87	–
W-29	Not present		1000	–	8	–
W-30	0.004	–	0.3	10^{-4}	0.2	10^{-4}

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site

[meq/L, milliequivalent per liter; mg/L, milligrams per liter; percent, percentage composition]

	Cations												Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole H-1																		
*Magenta	890	44.4	7.1	270	22.2	3.6	5,700	248	39.8	70	1.8	0.3	8,000	225.7	36.2	3,900	81.2	13
*Culebra	780	38.9	4	280	23	2.4	9,400	408.9	42.2	190	4.9	.5	12,000	338.5	35	7,400	154.1	15.9
*Rustler-Salado	13,000	648.7	5.4	30,000	2467.8	20.7	56,000	2,436	20.4	17,000	434.7	3.6	210,000	5924.1	49.7	520	10.8	.1
Test Hole H-2A																		
*Magenta	820	40.9	12	170	14	4.1	2,700	117.5	34.5	81	2.1	.6	4,100	115.7	34	2,400	50	14.7
Test Hole H-2B																		
*Culebra	690	34.4	12.2	160	13.2	4.7	2,100	91.4	32.3	91	2.3	.8	2,800	79	27.9	3,000	62.5	22.1
Test Hole H-2C																		
*Rustler-Salado	9,200	459.1	4.1	25,000	2056.5	18.2	66,000	2,871	25.4	9,100	232.7	2.1	200,000	5,642	50.2	1,300	27.1	.2
Test Hole H-3																		
*Magenta	1,200	59.9	6.0	480	39.5	3.9	9,300	404.6	40.3	250	6.4	.6	15,000	423.2	42.1	3,400	70.8	7.1
*Culebra	1,500	74.9	3.9	670	55.1	2.9	19,000	826.5	42.9	630	16.1	.8	29,600	835	43.3	5,700	118.7	6.2
*Rustler-Salado	18,000	898.2	7.6	25,000	2056.1	17.4	59,000	2566.5	21.7	14,000	358	3	210,000	5924.1	50.2	370	7.7	.1

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – Continued

	Cations												Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole H-4A																		
*Magenta																		
	210	10.5	1.5	410	33.7	4.8	7,000	304.5	42.9	130	3.3	.5	7,500	211.6	29.8	7,000	145.7	20.5
Test Hole H-4B																		
*Culebra																		
	180	9	1.5	430	35.4	5.9	5,800	252.3	42.3	180	4.6	.8	7,500	211.6	35.5	4,000	83.3	14
Test Hole H-4C																		
*Rustler-Salado																		
	8,300	414.2	3.5	27,000	2,221	19	66,000	2,871	24.6	8,600	219.9	1.9	210,000	5924.1	50.7	1,400	29.1	.2
Test Hole H-5A																		
*Magenta																		
	240	12	6.5	170	14	7.6	1,500	65.3	35.5	53	1.4	.7	880	24.8	13.5	3,200	66.6	36.2
Test Hole H-5B																		
*Culebra																		
	360	18	.4	1,900	156.3	3.2	53,000	2305.5	46.5	1,400	35.8	.7	86,000	2426.1	48.9	810	16.9	.3
Test Hole H-5C																		
*Rustler-Salado																		
	2,100	104.8	.6	82,000	6745.3	41.6	14,000	609	3.8	21,000	537	3.3	290,000	8180.9	50.4	2,000	41.6	.3
Test Hole H-6A																		
*Magenta																		
	520	25.9	14.6	160	13.2	7.4	1,100	47.9	26.9	46	1.2	.7	1,200	33.9	19	2,700	56.2	31.5
Test Hole H-6B																		
*Culebra																		
	1,200	59.9	3.3	970	79.8	4.4	18,000	783	43.4	500	12.8	.7	28,000	789.9	43.8	3,800	79.1	4.4
Test Hole H-6C																		
*Rustler-Salado																		
	4,200	209.6	1.9	21,000	1727.5	15.3	80,000	3,480	30.8	8,000	204.6	1.8	200,000	5,642	49.9	2,000	41.6	.4

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – *Continued*

Cations												Anions					
Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole H-7A																	
*Magenta (Dry)																	
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Test Hole H-7B																	
*Culebra																	
590	29.4	29.7	130	10.7	10.8	9.1	18.5	9.2	1.4	0.03	0.1	350	9.9	10	1,900	39.6	40
Test Hole H-7C																	
*Rustler-Salado																	
2,600	129.7	5.4	910	74.9	3.1	22,000	957	40.1	210	5.4	.2	41,000	1156.7	48.5	2,900	60.4	2.4
Test Hole H-8A																	
*Magenta																	
870	43.4	14.8	1.4	.9	.5	2,400	104.4	35.5	84	2.1	.7	3,500	98.7	33.6	2,100	43.7	14.9
Test Hole H-8B																	
*Culebra																	
570	28.4	31.8	170	14	15.7	82	3.6	4	4.7	.1	.1	57	1.6	1.8	2,000	41.6	46.6
Test Hole H-8C																	
*Rustler-Salado																	
1,200	59.9	.2	430	35.4	.8	46,000	2001	47.7	660	16.9	.4	70,000	1974.7	47	5,300	110.3	2.6
Test Hole H-9A																	
*Magenta																	
550	27.4	17.8	170	14	18.2	800	34.8	22.6	28	.7	.1	750	21.2	13.7	2,700	56.2	36.4
Test Hole H-9B																	
*Culebra																	
580	28.9	21.2	150	12.3	9	210	9.1	6.7	1,400	35.8	26.2	320	9	6.6	2,000	41.6	30.5

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – Continued

	Cations												Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole H-9C																		
*Rustler-Salado																		
	1,300	64.9	.1	870	71.6	.6	130,000	5,665	50.5	1,200	30.7	.3	190,000	5359.9	47.8	2,600	54.1	.5
Test Hole H-10A																		
*Magenta																		
	2,500	124.7	1.4	2,600	213.9	2.4	93,000	4045.5	45.1	510	13	.1	160,000	4513.6	50.3	2,700	56.2	.6
Test Hole H-10B																		
*Culebra																		
	1,600	79.8	3.6	1,000	82.3	3.7	21,000	913.5	41.1	520	13.3	.6	36,000	1015.6	45.7	5,600	116.6	5.2
Test Hole H-10C																		
*Rustler-Salado																		
	1,500	74.9	.7	11,000	904.9	8.1	100,000	4,350	38.8	4,000	102.3	.9	190,000	5359.9	47.8	3,300	68.7	.6
Test Hole P-14																		
*Culebra																		
	3,100	154.7	13.4	760	62.5	5.4	7,600	330.6	28.6	600	15.3	1.3	20,000	564.2	48.8	1,400	29.2	2.5
*Rustler-Salado																		
	570	28.4	.3	1,200	98.7	.9	120,000	5,220	48.9	1,300	33.2	.3	180,000	5077.8	47.6	10,000	208.2	2
Test Hole P-15																		
*Culebra																		
	770	38.4	5	63	5.2	.7	6,900	300.2	39.3	1,700	43.5	5.7	11,000	310.3	40.6	3,200	66.6	8.7
*Rustler-Salado																		
	770	38.4	1.7	350	28.8	1.3	24,000	1,044	45.8	1,400	35.8	1.6	38,000	1,072	47.1	2,800	58.3	2.6
Test Hole P-17																		
*Culebra																		
	1,700	84.6	2.6	1,600	131.6	4.1	30,000	1,305	41.4	120	3.1	.1	54,000	1,523	48.3	5,000	104.1	3.3

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site – Continued

Cations												Anions					
Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole P-17 – Continued																	
*Rustler-Salado																	
15,000	748.5	7.2	40,000	3290.4	31.7	23,000	1000.5	9.6	8,800	22.5	2.2	180,000	5077.8	50	1,200	25	.2
Test Hole P-18																	
*Culebra																	
5,600	279.4	6.3	16,000	1316.2	29.7	9,200	400.2	9	6,200	158.5	3.5	80,000	2256.8	50.9	98	20.4	0.5
*Rustler-Salado																	
10,000	499.8	4.1	37,000	3043.6	25	48,000	2,088	17.2	12,000	306.8	2.5	220,000	6,206	57.1	480	10	.1
Test Hole W-25																	
*Magenta																	
910	45.4	11.4	240	19.7	5	3,100	134.9	33.9	0.8	.02	.1	5,600	158	39.7	1,900	39.6	10
*Culebra																	
920	45.9	8	250	20.6	3.6	5,100	221.9	38.7	.9	.02	.1	8,300	234.1	40.6	2,400	50	8.7
*Rustler-Salado																	
650	32.4	.4	3,200	263.2	3.2	90,000	3,915	47.8	2,400	61.4	.7	130,000	3667.3	44.8	12,000	250	3.1
Test Hole W-26																	
*Magenta (Dry)																	
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Culebra																	
1,200	59.9	11.4	340	28	5.3	3,600	156.6	29.9	2	.05	.1	8,200	231.3	44.2	2,300	47.9	9.1
*Rustler-Salado																	
2,700	134.7	2.6	1,300	106.9	2.1	52,000	2,262	43.8	1,000	25.6	.5	88,000	2482.5	48	7,600	158.2	3.1
Test Hole W-27																	
*Magenta																	
3,600	179.6	3.6	2,000	164.5	3.3	43,000	1870.5	38	10,000	255.7	5.2	85,000	2397.9	48.7	2,900	60.4	1.2

*Hydrologic unit

Table 8.—Major cations and anions in water from the Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member, and Rustler-Salado contact residuum at and near the proposed Waste Isolation Pilot Plant site — Concluded

	Cations												Anions					
	Calcium			Magnesium			Sodium			Potassium			Chloride			Sulfate		
	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent	mg/L	meq/L	percent
Test Hole W-27 – Continued																		
*Culebra	2,700	134.7	3.3	1,740	143.1	3.5	38,500	1674.8	40.8	714	18.3	.4	73,300	2069.8	50.3	3,300	68.7	1.7
*Rustler-Salado	1,160	57.9	.6	1,040	85.6	.9	102,000	4437.3	48.8	2,570	65.7	.7	154,000	4344.3	47.7	5,190	108.1	1.2
Test Hole W-28																		
*Magenta (Dry)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Culebra	1,200	59.9	3.1	470	38.7	2	21,000	913.5	47.4	4	.1	.1	30,000	846.3	44	3,200	66.6	3.5
*Rustler-Salado	615	30.7	.5	2,070	170.3	2.8	65,000	2877.5	45.7	2,070	52.9	.8	102,000	2877.4	46.5	11,000	229.1	3.7
Test Hole W-29																		
*Not present	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
*Culebra	698	34.8	.5	3,750	308.5	4.2	67,600	2940.6	40.2	12,700	324.7	4.4	123,000	3469.8	47.6	11,200	232.2	3.2
*Rustler-Salado	850	42.4	1.3	2,000	164.5	5.1	32,000	1,392	42.7	1000	25.6	.8	49,000	1382.3	42.4	12,000	250	7.8
Test Hole W-30																		
*Magenta	690	34.4	5.7	170	14	2.3	5,500	239.3	39.6	190	4.9	.1	8700	245.4	40.6	3,200	66.6	11
*Culebra	1,010	50.4	1.5	804	66.1	2	35,500	1544.3	45.7	888	22.7	.7	56,500	1593.9	47.1	5,050	105.1	3.1
*Rustler-Salado	850	42.4	.4	2,300	189.2	1.8	120,000	5,220	50	1,500	38.4	.4	170,000	4,795	45.9	7,000	145.7	1.4

*Hydrologic unit

Table 9.—Measured and density-corrected water levels in selected test holes completed in the Culebra Dolomite Member of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant site

Test Hole	Altitude of land surface, in feet above sea level	Water level		Density, in grams per cubic centimeter	Freshwater equivalent corrected water level	
		Feet below land surface	Altitude, in feet above sea level		Feet below land surface	Altitude, feet above sea level
H-1	3,397.7	382.5	3,015	1.016	378	3,020
H-2b	3,377.7	348.7	3,029	1.012	345	3,033
H-3	3,389.5	397.0	2,992	1.024	289	3,000
H-4b	3,332.9	340.8	2,992	1.024	237	2,996
H-5b	3,505.9	485.2	3,021	1.106	439	3,067
H-6b	3,347.6	298.8	3,049	1.040	287	3,061
H-7b	3,163.6	170.2	2,993	1.001	170	2,993
H-8b	3,433.8	443.7	2,990	1.0035	443	2,991
H-9b	3,405.6	425.8	2,980	1.002	426	2,980
H-10b	3,687	697.8	2,989	1.044	667	3,020
P-14	3,359.6	320.1	3,040	1.018	316	3,044
P-15	3,309.5	305.4	3,004	1.080	295	3,014
P-17	3,335.9	367.3	2,967	1.082	348	2,986
P-18	-	-	-	-	-	-
W-25	3,212.5	165	3,048	1.010	162	3,051
W-26	3,151.9	146	3,006	1.013	145	3,007
W-27	3,177.2	105	3,072	1.094	85	3,092
W-28	3,346.8	277	3,070	1.044	270	3,077
W-29	2,977	8.2	2,969	1.178	2	2,975
W-30	3,427.5	412	3,016	1.072	395	3,033

Table 10.—Measured and density-corrected water levels in selected wells completed in the Magenta Dolomite Member of the Rustler Formation at and near the proposed Waste Isolation Pilot Plant site

Test Hole	Altitude of land surface, in feet above sea level	Water level		Density, in grams per cubic centimeter	Freshwater equivalent corrected water level	
		Feet below land surface	Altitude, in feet above sea level		Feet below land surface	Altitude, feet above sea level
H-1	3,397.7	246.50	3,151	1.021	240	3,158
H-2a	3,377.9	233.07	3,145	1.012	230	3,148
H-3	3,389.5	238.30	3,151	1.010	234	3,155
H-4a	3,332.9	189.3	3,144	1.017	186	3,147
H-5a	3,506.2	344.5	3,162	1.008	342	3,165
H-6a	3,347.3	289.8	3,056	1.007	287	3,059
H-7a	-	-	-	-	-	-
H-8a	3,433.0	405.1	3,028	1.008	404	3,029
H-9a	3,405.4	282.0	3,123	1.004	281	3,124
H-10a	3,686.5	586.8	3,100	1.171	469	3,218
W-25	3,212.5	159.0	3,054	1.010	158	3,055
W-27	3,177.2	102.0	3,075	1.095	93	3,084
W-28	3,346.8	202.8	3,144	1.048	198	3,149

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix IRD

M

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Implementation of the Resource Disincentive in 40 CFR § 191.14(e) at the WIPP

M

DOE/WIPP 91-029
Revision 1.0
June 1993

IMPLEMENTATION OF THE RESOURCE DISINCENTIVE IN 40 CFR Part 191.14(e) AT THE WASTE ISOLATION PILOT PLANT

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LIST OF ACRONYMS

ADM	Action Description Memorandum
AEC	Atomic Energy Commission
AECL	Atomic Energy Commission Limited (Canada)
BLM	Bureau of Land Management
BMI	Battelle Memorial Institute (Columbus, Ohio)
BNWL	Battelle Northwest Laboratory
C&C	Consultation and Cooperation Agreement
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
DOE	Department of Energy
DOE-WPIO	U.S. Department of Energy Waste Isolation Pilot Plant Project Integration Office
DOE-WPO	U.S. Department of Energy Waste Isolation Pilot Plant Project Office (now DOE-WPSO)
DOE-WPSO	U.S. Department of Energy Waste Isolation Pilot Plant Project Site Office
EEG	Environmental Evaluation Group
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
ESAB	EPA Scientific Advisory Board
FEIS	Final Environmental Impact Statement
FSAR	Final Safety Analysis Report
FSEIS	Final Supplement Environmental Impact Statement
GCR	Geologic Characterization Report
IAEA	International Atomic Energy Agency
NAS	National Academy of Sciences
NEPA	National Environmental Policy Act
NMBM&MR	New Mexico Bureau of Mines and Mineral Resources
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
RDR	Resource Disincentive Requirement
ROD	Record of Decision
SAR	Safety Analysis Report
SNL	Sandia National Laboratories
SPDV	Site and Preliminary Design Validation
TRU	Transuranic
USBM	United Stated Bureau of Mines

LIST OF ACRONYMS
(continued)

USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant
WPIO	See DOE-WPIO
WPO	See DOE-WPO
WPSO	See DOE-WPSO

1.0 INTRODUCTION

1.1 Purpose

In 1986, the U.S. Department of Energy (DOE) Waste Isolation Pilot Plant (WIPP) Project Office (WPO) (DOE-WPO) prepared a strategy[1] for complying with the Environmental Protection Agency's (EPA's) Standards for the management of transuranic (TRU) waste.[2] Section 3.2.2.2 of the DOE's report addressed compliance with the Assurance Requirements found in 40 CFR §191.14[3]. One of the Assurance Requirements addresses the selection of repository sites that contain recoverable natural resources. The requirement, referred to as the Resource Disincentive Requirement, reads as follows:

> *Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be included shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.*[4]

The DOE states, in the strategy document, that the "*natural resources requirement has been addressed during the course of the WIPP Project. A finding will be prepared to show that the favorable characteristics of the disposal site compensate for the greater likelihood of disturbance because of the presence of natural resources.*"[5] This position was developed based on both EPA and Environmental Evaluation Group (EEG) comments to the draft of the compliance strategy. Specifically, the EPA stated, with regard to the comparison of favorable characteristics and resources, that the "*two factors must not only be 'weighed' and 'summarized', but a finding must be documented that the favorable characteristics compensate for the greater likelihood of WIPP being disturbed because of the presence of the natural resources.*"[6] Likewise, the EEG stated that "*something more than a 'summarized' discussion will be needed*" and that they expect "*a detailed report*

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[1] Westinghouse Electric Corp., 1989.

[2] U. S. Environmental Protection Agency, 1985a.

[3] U.S. Environmental Protection Agency, 1985a, pp. 38086.

[4] U.S. Environmental Protection Agency, 1985a, p. 38086.

[5] Westinghouse Electric Corp., 1989, pp. 35-36.

[6] U.S. Environmental Protection Agency, 1987.

analyzing the valuable and rare resources available at WIPP compared to any favorable characteristics."[7]

This document addresses 40 CFR §191.14 (e). The approach is to first summarize the development of the resource requirement to provide a proper perspective for evaluation of WIPP compliance. In addition, a summary of the discussions regarding resources at the WIPP is provided to demonstrate the extent to which the topic has been discussed between the DOE and various oversight groups. Finally, the process of selecting the WIPP site as a repository is shown to be in compliance with the resource disincentive requirement.

This report recognizes that in 1987, 40 CFR 191 was vacated and remanded by the First Circuit Court (National Resources Defense Council, et al. v. United States Environmental Protection Agency, et al.). The DOE believes that when a new standard is promulgated, the Assurance Requirements of 40 CFR 191 will remain intact, and therefore need to be addressed by the WIPP. In the second modification to the Consultation and Cooperation (C&C) Agreement with the state of New Mexico, it is stated that "*DOE agrees to continue its performance assessment planning as though the provisions of 40 CFR Part 191 effective November 19, 1985, remain applicable*"[8]

This report documents that the site selection process for the WIPP facility did indeed comply with the natural resource disincentive requirement in 40 CFR §191,14(e) at the time selected and therefore complies with the standard at this time. Thus, it shall be shown that it is reasonably certain that the WIPP site provides better **overall protection** than **practical alternatives** that were available when the site was selected. It is important to point out here, and it will be discussed later in the report, that the resource disincentive requirement is a preliminary siting criterion that requires further evaluation of sites that have resources (i.e, hydrocarbons, minerals and groundwater) in the vicinity or on the site. This further evaluation requires that for sites that do have resources, a qualitative determination must be made that the site will provide better **overall protection** than **practical alternatives**. The purpose of this report is not to provide a quantitative evaluation for selection of the WIPP site. A further discussion on the difference between the qualitative analysis required under 40 CFR §191.14(e) and the quantitative analysis under other sections of 40 CFR 191 is provided in §2.1 of this report.

1.2 Background

When the Congress of the United States enacted the National Environmental Policy Act (NEPA) of 1969, they recognized the conflict over the management of natural resources. Congress mandated that federal agencies find a balance between the social, economic, and other requirements of present and future generations of Americans and the critical importance of restoring and maintaining environmental quality. Federal agencies are required by the law to "*achieve a balance between population and resource use...*"[9] In

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[7] Environmental Evaluation Group, 1987.

[8] U.S. Department of Energy, 1987, p. 5.

[9] U. S. Congress, 1969.

this regard, federal agencies must provide statements which address "*Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.*"[10] The vehicle for documenting the consideration of resource conflicts and the commitment of resources is the Environmental Impact Statement (EIS) prepared for a federal project.

For waste repositories, such as the WIPP, consideration of "resource conflicts" in the decision making process, as required by the NEPA, is multifaceted. Of course, consideration must be given to the resources consumed by the construction and operation of the facility (e.g., building materials, fuels, and land resources). These considerations are the most common resource commitments that federal agencies address in their EISs. In addition to these, resources associated with the WIPP must be considered from two additional aspects. First, there are denied resources. These are resources that cannot be developed because such development may conflict with the long-term goal of waste isolation. Second, there are the risks associated with resource attractiveness. That is, resources associated with the location may be attractive to future generations, who may elect to exploit them, and thereby create the potential for a release of waste into the biosphere.

Resource attractiveness concerned the EPA when they promulgated the natural resources assurance requirement in 40 CFR 191.[11] Compliance with this part of 40 CFR 191 is the subject of this paper.

In 1985, nearly ten years after the Los Medanos site was identified for a transuranic (TRU) waste facility, the EPA issued federal regulations establishing criteria for the management and disposal of radioactive waste. These standards included limited guidelines regarding the selection of a site for a radioactive waste repository. These regulations are contained in 40 CFR 191 and consist of two subparts: Subpart A, "Environmental Standards for Management and Storage"; and Subpart B, "Environmental Standards for Disposal." Subpart B contains an assurance requirement that has the purpose of discouraging the location of disposal sites where minable resources are available.[12] The requirement is referred to as the Resource Disincentive Requirement (RDR).

The following sections of this report include a discussion of the development of the resource disincentive provision in the EPA's standard, including a discussion of WIPP specific issues associated with resources (Section 2.0); a brief description of the WIPP Project (Section 3.0); an overview of the WIPP site selection process, including a summary of the documentation that resources were considered in the WIPP Project decision-making process by the DOE (Section 4.0); and conclusions regarding the DOE's compliance with the RDR (Section 5.0).

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[10] U.S. Congress, 1969, Title I, Sec. 102, (2), (C), (v).

[11] U. S. Environmental Protection Agency, 1985a, §191.14(e), p. 38086.

[12] U.S. Environmental Protection Agency, 1985a, p. 38086.

2.0 DEVELOPMENT OF THE STANDARD

Nearly every federal entity associated with radioactive waste isolation has established natural resource conflicts as an important consideration in the selection of repository sites. Donna Goad, the author of EEG-1[13], summarized the criteria stated by the Atomic Energy Commission (AEC), the Energy Research and Development Administration (ERDA), the DOE, the Nuclear Regulatory Commission (NRC), the United States Geological Survey (USGS), the Oak Ridge National Laboratory (ORNL), Battelle Institute (BMI and BNWL), Sandia National Laboratories (SNL), the National Academy of Sciences (NAS), the Atomic Energy Commission Limited (AECL) (Canada), and the International Atomic Energy Agency (IAEA). Ms. Goad's discussion is presented in Appendix A. The criteria can be summarized by the following two statements:

> Selecting sites with natural resources may result in the denial of access to important raw materials.
>
> Selecting sites with natural resources may lead to future disturbance of the geological/hydrological system through exploration or production, including direct intrusion into the repository.

2.1 Development of the EPA Resources Assurance Requirement

The EPA took the recommendations of these technical experts to heart when they promulgated the proposed 40 CFR 191 rules.[14] This is evident by the "prohibition" type statement that the EPA included in the proposed rule. It is as follows:

> *(f) Disposal systems shall not be located where there has been mining for resources or where there is a reasonable expectation of exploration for scarce or easily accessible resources in the future. Furthermore, disposal systems shall not be located where there is a significant concentration of any material which is not widely available from other sources.*[15]

In the preamble to the proposed standard, the EPA explained the application of the requirement by way of a comparison. On one hand the EPA points out that salt domes may have numerous uses such as salt production, oil storage, and others. Many of these uses would be in conflict with the long-term goals of waste isolation. On the other hand, the EPA cites salt bed structures as being of much less concern because bedded salt deposits are much more common. In addition, the EPA stated that they "*particularly seek comment on this provision because it could rule out sites which might otherwise be advantageous in meeting all of our other requirements.*"[16]

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[13] Environmental Evaluation Group, 1979.

[14] U. S. Environmental Protection Agency, 1982.

[15] U.S. Environmental Protection Agency, 1982, §191.14(f), p. 58205.

[16] U.S. Environmental Protection Agency, 1982, p. 58201.

Among the comments that the EPA received regarding the resource disincentive assurance requirement were written comments from the EEG[17] and testimony to the EPA's Science Advisory Board (ESAB) by a representative of the WIPP Project.[18]

In their comments, the EEG ties the natural resources assurance requirement to the "*...important concept that human intrusion is perhaps the most likely cause of significant repository releases and that the probability of human intrusion and the expectation of resource presence are interrelated to some extent.*"[19] The EEG goes on to point out that the restrictive wording in the requirement should be changed to allow more discretion in evaluating this requirement. The EEG states that there are two parts to the issue. These are the loss of the resources to society and the health and safety issues associated with the attractiveness of the resources. The EEG suggests that the first part "*is perhaps best handled by the NEPA process,*"[20] and that it may be possible to address the second part by evaluating "*the increased probability of human intrusion that would result from the presence of known mineral resources and use this in the decision-making process.*"[21]

The WIPP Project testimony to the ESAB expressed concern that the restrictions in the requirements "*could be construed to rule out most bedded and domed salt formations for permanent isolation of radioactive wastes, since such areas frequently contain hydrocarbons and other useful resources.*"[22] The testimony goes on to point out that human intrusion scenarios "*have been analyzed in the WIPP Final Environmental Impact Statement (FEIS), the WIPP Safety Analysis Report (SAR), and the analysis of a brine release from beneath the site as a result of human intrusion (Reference 2). The results project no significant impact on the public health and safety.*"[23] The WIPP Project recommended to the ESAB that resources "*should be considered in safety and environmental assessments of a potential site and should be discussed in an Environmental Impact Statement (EIS) or licensing document, but should not be arbitrarily specified as part of a standard, regulating releases from nuclear waste repositories.*"[24]

The ESAB formed a working group to address the Assurance Requirements. In a draft report, made available to the WIPP during an ESAB meeting in July 1983, the working

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[17] Environmental Evaluation Group, 1983a.

[18] WIPP Project, 1983.

[19] Environmental Evaluation Group, 1983a, p. 6.

[20] Environmental Evaluation Group, 1983a, p. 6.

[21] Environmental Evaluation Group, 1983a, p. 7.

[22] WIPP Project, 1983, pp. 2-3.

[23] WIPP Project, 1983, p. 3.

[24] WIPP Project, 1983, pp.3-4.

group indicates their thinking regarding the resource disincentive.[25] In their report, the working group recommends that the EPA allow for an analysis to demonstrate "*that the overall safety of the repository would not be jeopardized by the presence of the resources.*"[26] In their rationale for the modification to the Assurance Requirements, the working group acknowledged that the two concerns still exist (resource denial and resource attractiveness); however, the mere presence of natural resources should not automatically cause the site to be eliminated, particularly if other characteristics of the site are favorable. The group points out that "*it may be possible by suitable engineering techniques to recover the resources without disturbing a nearby repository or to mitigate the effects of potential human intrusion. The site and engineered barriers should be seen as a system, and a single weakness in a site should not automatically foreclose use of it, if the remaining characteristics are highly favorable and can compensate for the weakness.*"[27] The working group recommended the modified language that was ultimately incorporated into the final rule.

The ESAB had two findings with regard to the natural resources assurance requirement. These are as follows:

> *Finding 27:* "*We recommend that EPA not preclude consideration of a potential site because natural resources are at or near the site, but rather should note that the presence of such resources is a highly unfavorable factor which should be included in the site evaluation.*"
>
> *Finding 28:* "*No site type should be precluded on the basis of site characteristics alone. Consideration of all factors, including engineered barriers, transportation, availability of utilities and labor, etc., may lead to different choices amongst acceptable sites and isolation technologies than those dictated by site characteristics alone.*"[28]

In response to these findings, the EPA, for the most part, agreed with the recommendations. Their rationale is a follows:

> *Response (Findings 27 and 28): Because of the inherent uncertainties in the site selection and evaluation process, and because of the desirability of evaluating a variety of alternatives to increase the chances of achieving exceptional environmental protection, the Agency now agrees that automatically precluding a potential site because of one disadvantage is not desirable. At the same time, the Agency still believes that proximity to important or unique resources is a serious problem because of the potential for unplanned human intrusion, since institutional controls cannot be counted on over these periods of time to prevent such intrusion. Therefore the Agency has modified the assurance requirement in the final rule to*

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[25] Assurance Requirement Working Group, 1983.

[26] Assurance Requirements Working Group, 1983, p. 7.

[27] Assurance Requirements Working Group, 1983, p. 8.

[28] U.S. Environmental Protection Agency, 1985b.

indicate that proximity to resources should be considered a serious disadvantage, but not an outright prohibition, for site selection.[29]

In the preamble to the final rule, the EPA reiterated their logic with regard to the purpose of the requirement. They state that "*this assurance requirement has been revised in the final rule to identify resource potential as a disincentive but not as an outright prohibition for site selection.*"[30] The EPA also commented that this assurance requirement wording "*implies a qualitative comparison, because the Agency is not aware of quantitative formulas comprehensive enough to provide adequate comparisons to govern site selection.*"[31] In order to qualify this statement, the EPA points out that it is not enough to merely identify a few site features that might be more favorable. Instead, the EPA expects that **sites with resources would be used only "*if it is reasonably certain that they would provide better overall protection than the practical alternatives that are available.*"**[32] Thus, this becomes the ultimate test under the resource disincentive requirement (RDR).

It is important to note at this point that all quantitative analyses will be performed under other aspects of 40 CFR 191 (i.e., the containment requirements and other provisions of Subpart B) and not under 40 CFR §191.14(e). Any comparison of the overall protection afforded by one site to the overall protection of another, for purposes of compliance with §191.14(e), should be done on a purely qualitative basis. As stated in §1.1, the resource disincentive requirement is a preliminary siting criteria. Thus, its primary purpose is to distinguish between potentially acceptable and potentially unacceptable sites. It is then the purpose of the containment requirements, the other assurance requirements, the individual protection requirements and the groundwater protection requirements to determine the ultimate acceptability of the site as a disposal system for radioactive wastes.

2.2 Comments Relative to Resources at the WIPP Site

There has been significant discussion regarding the resources that exist beneath and in the vicinity of the WIPP site. This discussion is presented under four topics in the following paragraphs. These are (1) site characterization and the preparation of the initial NEPA documentation of the WIPP site; (2) the development of the DOE resource policy, including the WIPP Natural Resources Study; (3) the information and conclusions from the Site and Preliminary Design Validation (SPDV) program; and (4) supplemental NEPA documentation, including the Final Supplement Environmental Impact Statement (FSEIS).

[29] U.S. Environmental Protection Agency, 1985b, p. 2-16.

[30] U.S. Environmental Protection Agency, 1985a, p. 38081.

[31] U.S. Environmental Protection Agency, 1985a, p. 38081.

[32] U.S. Environmental Protection Agency, 1985a, p. 38081.

2.2.1 Site Characterization and the Preparation of the Environmental Impact Statement

Consideration of the resources at the WIPP site was part of the WIPP program from the outset. These evaluations date back to 1974[33] and include evaluations of potash,[34,35,36] caliche, salt, brine, sulfur, uranium, gypsum,[37] and hydrocarbons.[38,39,40] A summary of these results is presented in the Geological Characterization Report (GCR) for the WIPP site prepared by SNL in 1978.[41] The WIPP site characterization activity was conducted to collect the information needed to evaluate the location relative to the site selection criteria established for the WIPP site. (A summary of the site selection process and the appropriate references for the criteria is included in Chapter 3.0.) The specific site selection factor, with regard to natural resources is stated in the GCR as follows:

> *Natural Resources - Unavoidable conflict of the repository with actual or potential resources will be minimized to the extent possible.*[42]

The GCR presents the following conclusions with regard to the resources at the WIPP site:

> *Potassium salts and fluid hydrocarbons are the only two resources thought to be economically significant in the WIPP site area.*
>
> *If reasonable technologic and economic restraints are considered for extracting, processing and marketing the resources, then both the amounts and types of exploitable deposits are greatly reduced. Only potash and natural gas are considered to be significant in this respect.*
>
> *Caliche, salt, and gypsum are also present, but the abundance of these minerals throughout the region leads to the conclusion that land withdrawal for the WIPP will have little effect on present or future requirements for them.*

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[33] New Mexico Bureau of Mines, 1974.

[34] U.S. Geological Survey, 1978a.

[35] U.S. Geological Survey, 1978b.

[36] U.S. Bureau of Mines, 1977.

[37] New Mexico Bureau of Mines and Mineral Resources, 1978.

[38] Sipes, Williamson, and Aycock, 1976.

[39] G.J. Long and Associates, 1976.

[40] Permian Exploration Co., 1976.

[41] Sandia National Laboratories, 1978.

[42] Sandia National Laboratories, 1978, p. 2-20.

Consideration was also given to the possible presence of uranium in the redbed-type sediments that overlie the evaporites. The conclusion is that no significant uranium deposit exists.

Lithium occurs in a brine reservoir within the Castile formation northeast of the present site and may be present in a similar reservoir to the southwest. However, care has been taken to avoid such brine reservoirs within the site area.

Consideration was also given to the possible existence of metalliferous deposits in the Precambrian basement under the site. However, the depth (about 18,000 feet below the ground surface) to Precambrian rocks would preclude mining even if mineral concentrations were present.[43]

The GCR became the principal source for the natural resource evaluation in Section 7.3.7 of the FEIS.[44] The Record of Decision (ROD), which resulted from the FEIS, documents that the DOE concluded, based on the information available at the time, and based on a comparison of alternatives, that the "*environmental impacts predicted for Alternative 2 are generally small and the Los Medanos site appears acceptable for long-term disposal of TRU waste with minimal risk of any release of radioactivity to the environment. There is no indication that an alternative site for the demonstration would pose reduced risk.*"[45]

Publication of the FEIS and the ROD stimulated considerable additional discussion with regard to natural resources. This discussion served the purpose of providing additional public comment and clarification with regard to the impacts due to resource denial and resource attractiveness. The DOE's responses to comments on the FEIS were published in two separate reports. In the first, the DOE responded to five consolidated comments from four organizations. The most significant of these had to do with the DOE's plans regarding the outermost WIPP control zone (Control Zone IV), and the potential radiation risks associated with future mining. These comments and responses follow:

1. *Comment:*

The New Mexico EEG and the Southwest Research and Information Center stated that the DOE should clarify the restrictions it plans to place on gas recovery from Control Zone IV and from deviated drilling beneath the inner control zones. Furthermore, clarification is needed relative to the possibility of potash mining at the site. The EEG questioned the DOE confidence that such activities can be conducted without disturbing the integrity of the site. The EEG believes they should be party to decisions related to resource extraction at the site.

[43] Sandia National Laboratories, 1978, pp. 8-20 to 8-21.

[44] U.S. Department of Energy, 1980.

[45] U.S. Department of Energy, 1981a, p. 9163.

Response:

The DOE recognizes that the language in the FEIS describing resource recovery at the WIPP is tentative. Detailed programs for resource recovery have not yet been formulated. However, to mitigate the adverse impacts of resource denial at the site, the DOE has committed to the policy of allowing maximum resource recovery at the site consistent with protection of site integrity. For purposes of environmental impact analyses, the scenarios discussed in the WIPP waste isolation assessment (FEIS Section 9.7) bound the potential consequences of resource extraction at the Los Medanos site in the long term. These scenario results demonstrate that the consequences of future events, including resource extraction, are acceptably small. The New Mexico EEG will be involved in future decisions regarding resource extraction at the Los Medanos site through their review of documented analyses.

2. *Comment:*

The New Mexico EEG emphasized the need to quantify potential radiation risks of resource extraction at the Los Medanos site. The SRIC stated that the potash mining at the site may lead to subsidence with water intrusion into the salt.

Response:

For purposes of environmental impact analysis, the scenarios presented in the WIPP long-term waste isolation assessment (FEIS Section 9.7) bound the potential consequences of resource extraction at the Los Medanos site. These analyses present a consequence rather than a risk assessment; the assumption is that the probability of occurrence is unity and the event will occur. The results of these analyses demonstrate that the consequences of resource extraction beyond the period of institutional control are insignificant.[46]

In the second report, the EEG raised an additional question regarding the interpretation of the data in the FEIS. In addition, a new issue surfaced with regard to the loss of revenues from royalties normally paid to the state of New Mexico. The comments and responses are reproduced below.

1. *Comment:*

The EEG stated that the DOE must provide more detailed information on the future control of the mineral hydrocarbon resources at or near the WIPP site. In addition, the EEG requested that the DOE provide the results of the hazard analyses that led to the conclusion that resources at the site can be safely extracted.

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[46] U.S. Department of Energy, 1981b, pp. 14-16.

Response:

The DOE recognizes that the FEIS language describing resource recovery at the WIPP site is tentative. Detailed programs for resource recovery have not yet been formulated; however, to mitigate the potential adverse impacts of resource denial at the site, the DOE has committed to the policy of allowing maximum resource recovery at the site consistent with the protection of site integrity. Final plans for resource recovery will be developed after in-situ data are acquired through the SPDV program.

For purposes of environmental impact analyses, the postulated breaching events discussed in the WIPP long-term isolation assessment (FEIS Section 9.7) bound the potential effects of breaching due to resource extraction at the Los Medanos site in the long term. This assessment provides a consequence (rather than risk) assessment; the assumption is made that the probability of occurrence is unity and the event will occur. The results of the consequence analysis demonstrate that the effects of future events, including resource extraction beyond the period on institutional control, are acceptably small.

2. *Comment:*

The EEG challenged the FEIS statement that very little potash exists above the WIPP (Zone II) itself stating that this assertion conflicts with data provided in the SAR. Specifically, SAR Figure 2.7-6 (i.e., the general lithology of the ERDA-9 core) states that the McNutt member of the Salado Formation at the site "contains potassic rock rich in sylvite, langbeinite, and other hydrous minerals." The EEG also stated the FEIS Figure 9-1 would suggest that at least one third of Control Zone II contains lease-grade sylvite.

Response:

As indicated in the FEIS Table 9-19, the sylvite resources within the WIPP inner control zones are considered subeconomic by the U.S. Department of the Interior, Bureau of Mines; significant resources are present but these are not classifiable as reserves. Lithologically, these deposits are potassic minerals, but they do not constitute economic mineral reserves. Accordingly, the lithological descriptions given in SAR Figure 2.7-6 are not inconsistent with the FEIS statements concerning the lack of sylvite reserves within the inner control zones at the WIPP site. FEIS Figure 9-1 is a composite map of mineralization in various ore zones that include lease-grade deposits of both sylvite and langbeinite. As indicated in Table 9-19, there are significant langbeinite reserves within the inner control zones at the WIPP site.

3. *Comment:*

The New Mexico Commissioner of Public Lands expressed concern that New Mexico could forego an estimated hydrocarbon royalty reserve of about $5 million and potash royalty reserve of about $15 million. These losses could be mitigated by a land exchange between the federal government and the state.

Response:

If current expectations are realized, resource recovery could occur without affecting the integrity of the WIPP and royalties would not be lost. Furthermore, the BLM [Bureau of Land Management] and the state are currently negotiating an exchange of federal lands for the state lands located within the site areas. The DOE expects that this exchange will be effected to the satisfaction of the site.[47]

2.2.2 DOE Resource Policy and the WIPP Natural Resources Study

Preparation of the FEIS caused the DOE to rethink its natural resource policy with regard to the control and possible denial of extractable minerals at the WIPP site. The DOE committed to the state of New Mexico to perform a study on the possible effects of recovering natural resources present at the WIPP site.[48] As a basis for conducting this study, called the Natural Resources Study,[49] the DOE issued an interim policy statement on resource recovery at the WIPP.[50] This interim policy reiterated the DOE's commitment to "*maximize the opportunity for resource recovery at the WIPP Site, consistent with the requirements to isolate the emplaced radioactive wastes from the biosphere.*"[51] The interim policy established by the department prohibited resource development in all control zones, pending the analysis completion to determine the possible radiation dose consequences resulting from resource development in Control Zone IV. The DOE committed to issue a revision to its natural resources policy in accordance with the results of the Natural Resources Study. The conclusions from this study are as follows:

The conclusion of this study is that activities related to potash and hydrocarbon resource extraction and solution mining from within (and outside of) Control Zone IV, using currently available and applicable technology, will not compromise the integrity of the WIPP waste emplacement facility and increase the likelihood of a breaching event.

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[47] U.S. Department of Energy, 1981c, pp. 9-10.

[48] U.S. District Court, 1981.

[49] Westinghouse Electric Corp., 1982a.

[50] U.S. Department of Energy, 1981d.

[51] U.S. Department of Energy, 1981d.

Specific conclusions drawn from this study follow:

- *The DOE policy for natural resource recovery is only important when considering communication events that could occur during the time period when this policy is in effect. After the loss of institutional controls, the types and magnitudes of events that could occur, such as those analyzed in the SAR, are fundamentally independent of former resource recovery restrictions at the site. Considering waste decay and geosphere transport rates, the DOE resource recovery policy has little influence on the time of waste isolation before a plausible waste-release event could occur and/or on the radiation dose consequences of such an event.*

- *The disturbances induced by potash exploration and conventional mining or solution mining in Control Zone IV are physically too far removed to affect the integrity of the WIPP facility. Breaching the waste storage area by these activities is not credible and induced changes in host rock hydraulic conductivity are not discernible.*

- *Exploration and production of hydrocarbons from within Control Zone IV likewise would not affect the waste emplaced in the WIPP facility. The extent of disturbance induced by production stimulation in the form of hydrofracing or acidizing is controlled by the specific design and execution of this operation. Evaluations of what can be considered typical operations, as discussed in this report, indicate no impact to the integrity of the WIPP facility.*

- *The communication events, including the types of breaching mechanisms, flow paths, and driving forces analyzed in the WIPP SAR, are applicable to current resource extraction technology in Control Zone IV and beneath Control Zones I, II, and III (for hydrocarbons). The SAR events represent, in fact, the potential effects of developing resources within the area of the WIPP facility itself, after institutional controls are lost.*

In summary, the DOE could reevaluate its interim policy to prudently allow resource recovery in Control Zone IV. This is supported by an evaluation of the consequence analyses for resource extraction, as discussed in this report, and the additional consideration that any resource recovery operation will be reviewed by the Bureau of Land Management (BLM) (for surface claims) and the Minerals Management Service (for underground claims) prior to its implementation. In this fashion, any planned activities will be evaluated on a case-by-case basis to ensure that the integrity of the WIPP facility will not be jeopardized.[52]

Subsequent to the publication of the Natural Resources Study, the DOE issued a revision to their policy on resource recovery. In this revision,[53] the DOE relinquished any resource development control over Zone IV. This policy is included as Appendix B. The criterion that the DOE used in developing this policy is that permanent denial resources should be

[52] Westinghouse Electric Corp., 1982, pp. 64-65.

[53] U.S. Department of Energy, 1982a.

limited to those areas in which extraction activities could potentially lead to measurable effects on the WIPP facilities or whose protection is needed for institutional considerations. All extraction activities that would not lead to measurable effects are allowable under the policy.[54]

Both the EEG and the Governor's Task Force commented on the interim policy, the Natural Resources Study, and the revised interim policy. These comments served to focus the policy and to clarify issues such as the extent and authority of DOE control of lands outside the WIPP site boundary. The EEG stated that they were "*generally satisfied with the revised Policy Statement*"; however, they requested that they be notified if anyone seeks to develop resources within one mile of the WIPP site boundary.[55]

The governor's office responded with the preparation of a report entitled Natural Resources at the Waste Isolation Pilot Plant (WIPP) Site. This report was compiled by the Subcommittee on Natural Resources at the WIPP site, a subcommittee formed by the Radioactive Waste Consultation Task Force.[56] The thrust of the state's report was the assessment of the resources that potentially exist at the WIPP site, and an estimate of the economic impacts associated with their denial. The summary addressed three issues, all of which dealt with resource denial. These were:

1. Exchange of State Trust Lands Within the WIPP Site Boundary for Federal Lands.

2. Compensation for Loss of Potential Revenues From State Trust Lands Within the WIPP Site Boundary.

3. Compensation for the Loss of Potential Revenues From Withdrawn Federal Lands.[57]

Finally, natural resource development was addressed in the first modification to the C&C Agreement between the DOE and the state of New Mexico.[58] This modification included a ban on resource development within the WIPP site boundary during the construction and operation of the WIPP facility, and allowed for the development of hydrocarbons beneath the WIPP site, provided they were accessed from outside the WIPP site boundary and that entry within the WIPP site boundary occurred below 6,000 feet. In addition, the agreement requires the DOE to reconsider the resources policy at least one year before decommissioning to determine necessary changes for long-term control of the site. Further discussion of the resources policy resulted in a second modification of the C&C Agreement and the imposition of the policy as it exists today. In this modification, the

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[54] U.S. Department of Energy, 1982a.

[55] Environmental Evaluation Group, 1983b.

[56] New Mexico Energy and Minerals Department, 1984.

[57] New Mexico Energy and Minerals Department, 1984, pp. 28-31.

[58] U.S. Department of Energy, 1984.

DOE agreed to the following language:

> D. *The DOE will not permit subsurface mining, drilling, or resource exploration unrelated to the WIPP Project on the WIPP site during facility construction, operation, or after decommissioning. This prohibition also precludes slant drilling under the site from within or outside the site.*[59]

2.2.3 Resource Issues Addressed During the SPDV

In 1981, the DOE initiated a program to provide confirmation of the characteristics of the then-proposed WIPP site. The program included the construction of shafts and tunnels at the location selected for the facility. Data collected during this investigation, referred to as the SPDV program, was to be used in making a decision regarding the full construction of the WIPP facility.[60] In a subsequent revision to the program plan, the SPDV was expanded to include stratigraphic studies in the vicinity of the site with the intent of issuing basic data reports on drill holes in the vicinity of the site.[61] The SPDV activity was summarized in a report that covered all site selection activities up to and including the SPDV. The report, which was prepared by SNL, included a section regarding natural resources, since natural resources were among the site selection criteria used for evaluation of the WIPP site. The summary report states the natural resources criterion as follows:

> 14.1 *The site should be located so that losses of natural resources are reduced to acceptable levels, which shall be determined by the value of the resources and the alternative sources for these commodities.*[62]

The conclusion drawn in the summary document is that the WIPP site is qualified with respect to the criterion on natural resources. The rationale for drawing this conclusion is stated as follows:

> *In summary, some potash resources may be denied by present restrictions, but occurrences of potash and its possible attraction for future generations does not present a breach threat to the WIPP. Natural gas resources are not denied by present restrictions, but their possible presence and the overall geologic setting makes drilling through the WIPP a more likely occurrence than in a nonsedimentary geologic setting. Possible drilling breaches of the WIPP confinement integrity have been analyzed and shown to result in relatively benign consequences. It is therefore concluded that the site should not be ruled unacceptable because of potential resource conflicts; this potential is outweighed and compensated by the*

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[59] U.S. Department of Energy, 1987.

[60] Westinghouse Electric Corp., 1980.

[61] Westinghouse Electric Corp., 1982b.

[62] Sandia National Laboratories, 1983, p. 12.

very favorable hydrologic regime at the WIPP.[63]

The DOE published the results of the SPDV in a report inviting the public to provide comments that the DOE would use in making its decision on full WIPP construction.[64] Comments from the public and the state of New Mexico were handled separately by the DOE. In the volume summarizing the public's comments, the DOE discussed nine comments and provided responses.[65] For the most part, these comments dealt with the concerns of resource denial and resource attractiveness. In several of the responses, the DOE reiterated the fact that the decision-making process implemented through the FEIS did satisfy the requirements for evaluating the amounts of resources, the impacts of resource denial, the attractiveness to future generations, and a comparison of alternatives. The DOE did commit to working out arrangements with the BLM to assure that the DOE receives notification of resource development proposals in the vicinity of the WIPP site.[66] In the second volume of comments and responses, the DOE addressed input from the state of New Mexico.[67] As with the public's comments, the DOE was asked to clarify the issues of resource denial and resource attractiveness. In addition, the DOE was requested to comment on the topic of compensation for denied royalties that would normally be given to the state in the event minerals were mined. The DOE's responses on the first two topics were consistent with its previous positions, namely that the issues were adequately considered in the FEIS and were part of the decision-making process. With regard to resource attractiveness, the DOE pointed out that "*studies by both the DOE and the EEG (U.S. DOE, 1980; Woolfolk, 1982; Channell, 1982) show that future human intrusion in search of mineral resources will not significantly impact public health and safety.*"[68] Regarding resource denial, the DOE defined acceptable levels of loss of natural resources as "those levels at which the loss is exceeded by the expected benefits of the existence and operation of the WIPP. The extent of loss of natural resources that would be expected...is described in the WIPP FEIS. The result of the comparison indicating that the losses are acceptable was presented by issuance of the ROD to proceed with the WIPP Project (46 FR 9162)."[69] Finally, with regard to compensation to the state of New Mexico for lost revenues from foregoing future mineral production, the DOE responded that the issue "*merits further discussion.*" Further, the DOE adds that "*the State should recognize that very significant revenues that will be received for the engineering, construction, and operation of the WIPP facility in the state of New Mexico. These will*

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[63] Sandia National Laboratories, 1983, p. 25.

[64] U.S. Department of Energy, 1983a.

[65] U.S. Department of Energy, 1983b, pp. 3-16 to 3-19.

[66] U.S. Department of Energy, 1983b, p. 3-17.

[67] U.S. Department of Energy, 1983c, pp. 3-17 to 3-19, 6-3, 7-3.

[68] U.S. Department of Energy, 1983c, p. 3-81.

[69] U.S. Department of Energy, 1983c, p. 3-81.

likely far surpass the mineral revenue lost."[70]

The EEG published their own analysis of the results of the SPDV program.[71] In this report, the EEG devoted a chapter to the natural resources at the WIPP. They considered the subject very broadly, including the nature and extent of resources, a discussion of important criteria and standards, the DOE interim resource policy, and the potential effect of resource removal. The EEG focused their attention on the resource denial and the resource attractiveness concerns. In Chapter 2 of their report,[72] the EEG concludes for several reasons that caliche, halite, and gypsum are not of concern with regard to repository integrity. Likewise, lithium from brines is unlikely to be competitive on the world market. Even if it were of interest, it is bounded by other resource extraction scenarios. The EEG concluded that both potash and hydrocarbons represented denied resources that could be attractive for future development. In Chapter 3 of their report,[73] the EEG addresses the proposed EPA standard (see Section 2.1 above) and the NRC standards with regard to natural resources. Both agencies consider the presence of resources to be a potentially adverse condition. The EEG concluded that "*the WIPP site appears to have adverse conditions by virtue of the natural resources. It was on this basis that the EEG recommended that the DOE indicate its plans for control of exploration and recovery of the resources, and analyze the consequences of such exploration and recovery.*"[74] With regard to the DOE interim resource recovery policy, discussed in Chapter 4 of the EEG's report, the report states that "*the State intends to negotiate with BLM to obtain notification from BLM of any applications for mining activity within 1 mile of the Zone III boundary. Upon notification, EEG plans to evaluate such proposals and provide appropriate comments, if any, to BLM and DOE, concerning the potential effects on the repository horizon.*"[75] The EEG also raised the issue that the DOE did not consider the production of either halite or lithium as viable resources. Both, according to the EEG, are "*unlikely*" to be produced as resources and both are "*bounded*" by existing analyses.[76] In their Conclusions and Recommendations chapter, the EEG recommended that the mining of potash in Control Zones I, II, and III be "*banned indefinitely*" to minimize the possible future risk to the repository.[77] With regard to natural gas, however, the EEG concluded that "*the removal of natural gas does not present any radiological problems*" since natural

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[70] U.S. Department of Energy, 1983c, p. 7-3.

[71] Environmental Evaluation Group, 1983c.

[72] Environmental Evaluation Group, 1983c, pp. 94-107.

[73] Environmental Evaluation Group, 1983c, p. 98-100.

[74] Environmental Evaluation Group, 1983c, p. 100.

[75] Environmental Evaluation Group, 1983c, p. 101.

[76] Environmental Evaluation Group, 1983c, p. 103.

[77] Environmental Evaluation Group, 1983c, p. 142.

gas could be recovered using slant drilling techniques.[78]

The National Academy of Sciences (NAS) Panel on the WIPP produced a report at the end of the SPDV program.[79] The panel examined the body of information available with regard to potash and hydrocarbon. They credit the release of Zone IV for resource development as a major step in eliminating what appeared to be a "*major flaw in the case for site suitability.*"[80] The panel accepted the conclusion in the Natural Resources Study that the consequences of resource development should not be serious as long as the exploitation is limited to Zone IV and with the "*proviso that each proposal to develop resources should be carefully examined, with the burden of proof as to its safety, made the responsibility of the proposer.*"[81] Consequently, the NAS concluded that "*the presence of hydrocarbon and potash resources at the WIPP site is not a seriously adverse feature... .*"[82]

2.2.4 Natural Resource Considerations in NEPA Documentation Subsequent to the FEIS

Subsequent to the publication of the FEIS, there were three separate occasions where the DOE addressed the topic of natural resources in NEPA documentation. First, in 1982, the DOE prepared an environmental analysis to address an ambitious cost reduction program of the WIPP Project.[83] A part of the analysis included the proposal to release Control Zone IV for resource exploitation. The basis used in this environmental analysis was the Natural Resources Study. This environmental analysis formalized the DOE decision-making process for the release of the resources in Control Zone IV. DOE's NEPA Office reviewed the proposed actions with regard to cost reductions, including the proposed release of Control Zone IV and the revised DOE resource recovery policy. It concluded that the "*proposals would result in no new potential for significant environmental impacts from that described in the EIS for the WIPP facility as currently designed, and in fact, should result in an overall decrease in the potential for environmental impacts.*"[84]

The second NEPA review occurred after the completion of the SPDV and was conducted in support of the decision to proceed with full facility construction. Public comments were solicited regarding the results of the SPDV as discussed above. Based on the results and the comments, the DOE prepared an Action Description Memorandum (ADM) for full

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[78] Environmental Evaluation Group, 1983c, p. 142.

[79] National Academy of Sciences, 1984.

[80] National Academy of Sciences, 1984, p. 8.

[81] National Academy of Sciences, 1984, p. 11.

[82] National Academy of sciences, 1984, p. xii.

[83] U.S. Department of Energy, 1982b.

[84] U.S. Department of Energy, 1982c.

facility construction.[85] In Section III of the ADM, the topics of natural resource denial and natural resource attractiveness were addressed. In both cases, the DOE points out that the changes since the publication of the FEIS have resulted in no increases in risks or impacts. The DOE/NEPA office stated after their review of the ADM that "*we have determined, after consultation with the Office of General Council, that there are no significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts, within the meaning of NEPA and the Council on Environmental Quality (CEQ) regulations. Additional investigations since issuance of the WIPP Final EIS, including the SPDV activities, have generally confirmed the understanding of site characteristics and environmental impacts presented in the Final EIS...we concur with the proposed decision to proceed with the full WIPP facility construction based on available information.*"[86]

The topic of natural resources was included in the SEIS.[87] The SEIS examined new information regarding the facility and provided an opportunity for the DOE to obtain public comment regarding the implementation of a Test Phase for the WIPP Project. No new information was presented with regard to natural resources. However, by the time the SEIS was published, the DOE and the state of New Mexico had agreed to the language in the second modification to the C&C Agreement whereby the DOE would not allow any resource development at the WIPP site during construction, operations, or after decommissioning.[88] In general, the public comment on the SEIS, with regard to resources, requested further clarification of DOE land management policy, including the future regulation of resource development.[89] The SEIS did provide an update of the consequence analysis regarding the impacts of an inadvertent human intrusion into the repository related to resource development. Under some of the assumptions, the results exceeded the allowable EPA standard; in other cases, compliance was demonstrated. The uncertainty associated with these calculations were, in part, instrumental in the DOE's decision to proceed with the Test Phase as a means of addressing the uncertainty. An additional SEIS will be performed, prior to the initiation of the Disposal Phase, to evaluate the effects of intrusion into the repository motivated by resource development. If the impacts exceed the applicable environmental standards, alternative approaches to disposal (such as waste processing) will be evaluated.

2.3 Summary

The development of the RDR has involved a significant amount of discussion and thought, both scientific and nonscientific. The final version of the requirement does not automatically eliminate any sites that may contain resources. Instead, it provides the implementing agency with the opportunity to demonstrate that the favorable conditions of

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[85] U.S. Department of Energy, 1983d.

[86] U.S. Department of Energy, 1983e.

[87] U.S. Department of Energy, 1990a.

[88] U.S. Department of Energy, 1990a, p. 7-3.

[89] U.S. Department of Energy, 1990a, Vol. 3, pp. 193-195.

the site outweigh the potential increased risk associated with using the site. This demonstration involves a qualitative comparison of the risks associated with the site and the alternatives to using the site.

Concern for both resource denial and resource attractiveness has been evident in the technical and decision-making documents that the DOE has prepared for the WIPP site on the topic of natural resources. These documents have undergone a significant amount of public scrutiny, which served to focus the issues of resources. Two basic concerns have emerged: resource denial and resource attractiveness. The DOE's policy with regard to resource denial has been evolutionary, to the extent that initial restrictions have proven to be unnecessary, based on analysis in the Natural Resources Study. Consequently, the DOE has reduced the amount of denied resources significantly since the publication of the FEIS. With regard to resource attractiveness, the DOE has performed analyses to assess the impacts of unintentional disruption of the WIPP facility as the result of resource development. As the DOE's understanding of the facility, the surrounding geological and hydrological systems, and the waste has increased, the need for additional information has increased, and is to be addressed during the Test Phase. The DOE has obtained control over the surface and subsurface above 6,000 feet by successfully eliminating all mineral leases that could potentially lead to problems with the long-term isolation capability of the facility. In addition, the Congress has recently permanently withdrawn the land for the operation of the WIPP.

The following chapters discuss the qualitative comparison that was performed in the FEIS[90] prepared for the WIPP. Key to this comparison was the evaluation of the societal impacts of resource denial and the increased risks associated with the potential for human intrusion. Furthermore, the latter consideration is the subject of an ongoing assessment being prepared for the WIPP facility. Updates to the analysis in the FEIS were published in the SEIS.[91] In addition, SNL has the responsibility to complete the performance assessment required under other parts of 40 CFR 191. These performance assessments consider the risks associated with a human intrusion motivated by resource exploitation.[92]

It is important to note that the WIPP site was selected before the Assurance Requirements were issued in either proposed or final form. Consequently, it is not possible to reconstruct a compliance approach that is directed specifically at the EPA's standards. Instead, it is the purpose of the following sections to demonstrate that the extent to which the DOE considered resources was sufficient and that the intent of these requirements has been met. Furthermore, the decision to use the WIPP facility as a final disposal facility has not been made and will not be made until the DOE can demonstrate that even with increased risks associated with resource attractiveness, the site can meet the environmental protection requirements in 40 CFR 191.

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[90] U.S. Department of Energy, 1980.

[91] U.S. Department of Energy, 1990a.

[92] Sandia National Laboratories, 1990a.

3.0 THE WIPP PROJECT

3.1 Location

The WIPP facility is located in Eddy County, New Mexico, 26 miles east of Carlsbad (Figure 1). The WIPP site boundary encompasses 16 square miles (10,240 acres) located in an area known as the Los Medanos (the dunes). It consists of Sections 15-22 and 27-34 of Township 22 South, Range 31 East.[93] The area originally withdrawn for the WIPP facility covered 18,960 acres and was organized into four control zones (Figure 2).[94] The control zones were established so that the containment integrity of the salt beds used for disposal could be protected from mining and resource exploitation activities.[95] In 1982, a decision was made by the DOE to release control of the outermost control zone, effectively reducing the WIPP site boundary to the configuration in Figure 3.[96] As the result of an agreement with the state of New Mexico,[97] resource exploitation that could be harmful to the WIPP facility is not allowed within the 10,240 acres that lie within the WIPP site boundary.

3.2 WIPP Mission

Public Law 96-164 defines the WIPP mission as "*a defense activity...for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission.*"[98] The DOE is responsible for all aspects of the WIPP Project.

3.3 Overview of the WIPP Project

From 1973 to 1975 a site selection program was conducted to locate a site, within the Carlsbad area of eastern New Mexico, that would be suitable for a radioactive waste repository. During this period, there were no federal regulations that established criteria for selecting a radioactive waste repository site, but there were informal criteria.[99,100,101] These informal criteria were used to evaluate several candidate sites.

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[93] U.S. Department of Interior, 1991.

[94] U.S. Department of Energy, 1980, p. 8-4.

[95] Oak Ridge National Laboratory, 1973a.

[96] U.S. Department of Energy, 1982c.

[97] U.S. Department of Energy, 1987.

[98] U.S. Congress, 1979.

[99] Oak Ridge National Laboratory, 1973a.

[100] Sandia National Laboratories, 1978.

The Los Medanos site was selected for the WIPP Project. Appendix D of the FEIS summarizes the site selection criteria that were specifically applied to the selection of the location of the WIPP facility. These are included in this report as Appendix C.[102]

Upon selection of the Los Medanos site, a site characterization program was initiated.[103] Extensive studies (geophysical surveys, borehole corings, etc.) were conducted to verify that the site was as adequate as the criteria indicated. At the same time, in accordance with the NEPA, aspects of how the WIPP would impact the environment were evaluated. The results of these studies are summarized in the WIPP FEIS, a two-volume document issued in 1980.[104]

In 1981, the DOE decided to proceed with the WIPP Project, as authorized, at the Los Medanos site.[105] With this decision, mining at the WIPP facility commenced and the SPDV program was initiated.[106] The SPDV program provided additional proof of the favorable characteristics of the site as a mined geological repository.[107]

On June 28, 1983, the DOE rendered the decision to proceed with full construction of the WIPP facility.[108] As construction proceeded, the DOE continued to evaluate the geotechnical and hydrological characteristics of the site. In 1988, the impact of the human intrusion scenario on the site was reevaluated by SNL based on new information regarding the transmissivity of fluids in the Rustler Formation, the expected quantities of brine that could collect in the repository before closure, and the gas permeability of the in-situ salt. Based on this new information, and uncertainties surrounding the selection of model parameters for numerically evaluating the long-term performance of the repository, the DOE decided to initiate a Test Phase for the WIPP. The Test Phase was to provide an opportunity for the DOE to evaluate certain waste characteristics under controlled experimental conditions.[109,110,111,112] The NEPA documentation for the Test Phase

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[101](...continued)
[101] U.S. Department of Energy, 1980.

[102] U.S. Department of Energy, 1980, Volume 2, Appendix D, pp. D-1 to D-10.

[103] Sandia National Laboratories, 1978.

[104] U.S. Department of Energy, 1980.

[105] U.S. Department of Energy, 1981a.

[106] Westinghouse Electric Corp. 1980.

[107] Sandia National Laboratories, 1983.

[108] U.S. Department of Energy, 1983e.

[109] U.S. Department of Energy, 1990b.

[110] Sandia National Laboratories, 1990b.

was completed in 1990.[113] The DOE currently expects to begin the Test Phase experiments in the last quarter of 1993.

[111](...continued)
[111] Sandia National Laboratories, 1990c.

[112] Sandia National Laboratories, 1990d.

[113] U.S. Department of Energy, 1990a.

4.0 WIPP SITE SELECTION AND NATURAL RESOURCES

4.1 Summary of Site Selection Activities

As stated in §2.1, the ultimate test for site suitability under the resource disincentive requirement is that sites with resources present would be used only "*if it is reasonably certain that they would provide better overall protection than the practical alternatives that are available*".[114] This section sets forth the site selection process for the WIPP and how that process complied with the resource disincentive requirement.

As will be discussed, the WIPP site selection process consisted of four distinct stages. An important aspect to keep in mind when going through this process is the comparison to practical alternatives requirements mentioned in the standard. It will be shown that at each stage of the site selection process practical alternatives were analyzed, and with the elimination of the various alternatives, the Los Medanos site in southeastern New Mexico was ultimately selected as the most favorable site of all of the practical alternatives.

4.1.1 General Description of the Site Selection Process Used to Select the WIPP Facility Location

A deductive-reasoning process was used to select the WIPP site. This process has been described as four distinct stages.[115] The following is a summary of the process.

STAGE 1: In stage 1, a geologic media, which in this case is salt, was selected and geographic regions that contain this media were identified. This was accomplished by gathering and evaluating existing information concerning rock types and geographic availability. A set of desirable criteria was established and a list of the most favorable regions was developed.

STAGE 2: In stage 2, a careful study of the literature relevant to stage 1 was performed to narrow down the number of regions identified in stage 1. Once a region was selected, candidate sites within the region were chosen. Selection criteria were used to compare the sites. Those sites which satisfied the most criteria were selected for further evaluation. Typically, resource conflict considerations are applied on a broad scale at this stage of site selection.

STAGE 3: In stage 3, the candidate sites identified in stage 2 undergo further investigations which cover geology, hydrology, archaeology, historical surveys, demography, and biology. The results of all the site evaluations were compared, and the site that best met the selection criteria (the Los Medanos site) was selected for Site Characterization. At this stage, the type and amount of resources were considered in detail.

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[114] U. S. Environmental Protection Agency, 1985a, p. 38081.

[115] U.S. Department of Energy, 1980, p. 2-7.

STAGE 4: In stage 4, a detailed full system analysis was performed. Full-system refers to the specific geologic environment, the waste forms, the plant design, and the potential failure modes in respect to radiation safety and environmental impacts.

Typically, the results of all of the studies performed to select and characterize the site are summarized in an EIS prepared in accordance with the NEPA. The EIS was made available to all interested parties. Public comments were incorporated into the decision that determines whether or not to proceed with the project, as defined, at the location selected.

4.1.2 Selection of Salt as a Disposal Media

The rationale for preferring salt as the disposal medium for nuclear waste, in general, and for the WIPP facility, specifically, resulted from two decades of repository program activities. In 1955, the NAS National Research Council (NAS-NRC) was asked by the AEC to examine the issue of permanent disposal of radioactive waste. In a report published in 1957,[116] the committee stated that it was "*convinced that radioactive waste can be disposed of safely*" and concluded that "*the most promising method of disposal of high level waste at the present time seems to be in salt deposits.*"[117]

Salt was determined to be the most promising disposal medium because of its unique thermal and physical properties. Salt has a relatively high thermal conductivity, which serves to rapidly conduct heat away from waste. Salt has favorable plastic, or creep, properties which permit sizeable strains to be absorbed without fractures.[118] The existence of large salt deposits demonstrates isolation from circulating groundwaters for long periods of geologic time. The depositional nature and preservation of large salt deposits demonstrate regional stability for long periods of geologic time.

From 1957 to 1961, the AEC sponsored research at the ORNL on the suitability of salt as a disposal medium for defense generated radioactive waste.[119] In 1962, the USGS completed a study that summarized rock salt deposits in the United States as possible storage sites for radioactive waste.[120]

In 1963, an existing salt mine in Lyons, Kansas, was selected for further study. The ORNL began a large-scale field program known as Project Salt Vault. Simulated wastes (irradiated fuel elements), supplemented by electric heaters, were placed in the mine for observation.

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[116] National Academy of Sciences, 1957.

[117] National Academy of Sciences, 1957, pp. 3-4.

[118] Oak Ridge National Laboratory, 1973a, p. 3.

[119] U.S. Department of Energy, 1980, p. 2-6.

[120] U.S. Geological Survey, 1962.

Conclusions made from the studies that took place from 1963 to 1970 were favorable and, in 1970, the Lyons site was selected by the AEC as a potential location for a radioactive waste repository. The NAS endorsed this recommendation. However, subsequent studies identified some technical problems and, in 1972, the integrity of the site was judged to be unacceptable. There were too many drill holes in the area that could not be positively located, and solution mining, which was taking place nearby, was experiencing unexplainable water losses.[121]

Table 4-1 provides a comparison of the geologic media considered for the WIPP.[122] As stated in the FEIS, "*salt is the best understood of all candidate geologic media with respect to its possible use as a waste-repository medium, and it offers advantages in thermal properties and plasticity. It is found in many places in the United States.*"[123] Therefore, of the disposal media considered for the WIPP site (limestone, shale, and salt), salt was selected the best of the practical alternatives.

4.1.3 Selection of Eastern New Mexico

The WIPP site selection process began in 1973, when the AEC, ORNL, and the USGS began seeking a repository site to replace the site abandoned in Lyons, Kansas. A nationwide survey was conducted to locate a region that contained a salt deposit suitable for use as a repository.[124,125,126,127,128,129,130]

Of the areas in the United States underlain with bedded salt, the Salina Basin in portions of New York, Pennsylvania, West Virginia, Ohio, Michigan, and southern Ontario, and the Permian Basin including parts of Kansas, Oklahoma, Texas, Colorado, and New Mexico, were considered for further study under the waste management program.[131] The Permian Basin was eventually selected over the Salina Basin. The reason for this was

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[121] U.S. Department of Energy, 1980, p. 2-7.

[122] U. S. Department of Energy, 1980, p. A-4.

[123] U. S. Department of Energy, 1980, p. A-5.

[124] U.S. Geological Survey, 1962.

[125] U.S. Geological Survey, 1973a.

[126] U.S. Geological Survey, 1973b.

[127] U.S. Geological Survey, 1973c.

[128] U.S. Geological Survey, 1973d.

[129] U.S. Geological Survey, 1973e.

[130] U.S. Geological Survey, 1974a.

[131] U. S. Department of Energy, 1980, p. 3-9.

because potential areas in the Salina Basin were *"much more densely populated, the land is more intensively used, and the complex hydrologic characteristics are likely to be much more difficult to define and evaluate."*[132] Thus of the alternatives in bedded salt, the Permian Basin was determined to the best of the practical alternatives.

The most promising region identified within the Permian Basin was located in the Delaware Basin of eastern New Mexico. This region was selected because the salt is shallow and flat. Although the Delaware Basin is a known oil and gas producer, the eastern New Mexico area is not very productive, and has not been subjected to a lot of drilling.[133] Selection of this area of the Delaware Basin was consistent with the criterion of avoiding locations in known oil and gas production trends. Thus, of the alternatives in the Permian Basin, eastern New Mexico was considered to the best of the practical alternatives.

4.1.4 Selection of the Carlsbad Area

An extensive literature study was performed to locate an area in eastern New Mexico for further evaluation. Three areas in eastern New Mexico were chosen for further study: (1) the Carlsbad area;[134] (2) the Clovis-Portales area;[135] and (3) the Mescalero Plains of Chaves County.[136]

The Clovis-Portales area was disqualified because the salt being studied was too shallow and clayey. The Mescalero Plains area was disqualified because of excessive resource development (oil production) in the area. The Carlsbad area, in the northern portion of the Delaware Basin, was ultimately selected as the best of the practical alternatives.[137]

4.1.5 Selection of the Los Medanos Site

Site selection efforts within the Carlsbad area were initiated in 1972 by ORNL, the USGS, and the AEC. A plan issued by ORNL, in October of 1973,[138] states that resource-high areas should be avoided. Specifically, the plan states:

> *Significant quantities of potash ore and extensive deposits of oil and gas occur in selected localities of southeastern New Mexico. To preclude conflicts of interest in the economic development of the region, the rocks underlying the study area should*

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[132] U. S. Department of Energy, 1980, p. 3-10.

[133] U.S. Department of Energy, 1980, p. 2-10.

[134] U.S. Geological Survey, 1972.

[135] U.S. Geological Survey, 1974b.

[136] U.S. Geological Survey, 1974c.

[137] U.S. Department of Energy, 1980, p. 2-10.

[138] Oak Ridge National Laboratory, 1973b.

preferably have a low potential for oil and gas development and should not contain extensive high-grade potash ores.[139]

Appendix D of the WIPP FEIS[140] lists the criteria used to select the Los Medanos site, and explains how well the WIPP site fares against these criteria (see Appendix C of this paper). These criteria evolved through the selection and abandonment of a Project Salt Vault in Lyons, Kansas.

The first site selected for characterization within the Carlsbad area (ORNL site) had to be abandoned. It was centered on Sections 10 and 11 of Township 22 South, Range 31 East. Characterization studies showed that (1) rock strata were much shallower than expected; (2) beds showed severe distortion; (3) structural dips were as high as 75 degrees; (4) the site contained leasable grades of potash (AEC Nos. 7 and 8); and (5) a pocket of pressurized brine was encountered at a depth of 2,710 feet within the Castile Anhydrite.[141,142]

It was determined that the site was located too close to the Capitan Reef. Structural influence by the reef caused the actual geologic character to vary from the predicted geologic behavior.[143] Extensive drilling would have been required to thoroughly document the structure of the site, which is contrary to the principle of minimizing the number of holes drilled into the repository.

In late 1975, the USGS and the Energy Research and Development Administration (ERDA) went back to stage 2 of the site selection process, and began looking for an alternative location within the Carlsbad Area of the Delaware Basin. Site selection criteria and characterization factors were revised to include knowledge gained from several studies.[144,145,146,147,148,149] These revised criteria are referred to as stage 2 siting

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[139] Oak Ridge National Laboratory, 1973a, p. 3.

[140] U.S. Department of Energy, 1980, Vol. 2, Appendix D.

[141] U.S. Department of Energy, 1980, p. 2-10.

[142] Sandia National Laboratories, 1978.

[143] U.S. Geological Survey, 1973d.

[144] Oak Ridge National Laboratory, 1974a.

[145] U.S. Geological Survey, 1973b.

[146] Oak Ridge National Laboratory, 1973c.

[147] U.S. Geological Survey, 1975.

[148] Oak Ridge National Laboratory, 1974b.

[149] Sandia National Laboratories, 1978, p. 2-11.

criteria.[150] The following is an abbreviated listing of the most restrictive stage 2 siting criteria:[151,152]

1. Avoid areas that are within one mile of any borehole that extends through the Ochoan evaporites and into the Delaware or deeper formations. (This automatically assures that a site will not be located over an existing oil or gas field.)

2. Salt of high purity at a depth between 1,000 and 3,000 feet.

3. Avoidance of areas where dissolution had advanced to the top of the Salado or deeper levels, by establishing a distance of one mile or more from dissolution fronts at the top of the Salado.

4. Avoidance of possible salt deformation in a belt six miles wide basin-ward from the Capitan Reef.

5. Avoidance of pronounced known anticlinal structures.

6. Avoidance of known oil and gas trends.

7. Avoidance of the known potash enclave above the repository and minimize conflict with the known enclave in the buffer zone.

Only two of the proposed alternatives withstood the stage 2 siting criteria. Alternative I, the Los Medanos site, was selected as the preferred location because seismic data indicated that the site was in a syncline, making the accumulation of oil, gas, and geopressurized brines less favorable. Alternative II was located adjacent to shallow oil fields where water flooding for secondary recovery was a possibility.[153]

Selection of the Los Medanos site did not prove that the "perfect" site had been selected. The selection criteria used, however, was sufficient to establish that the site selected was adequate, safe, and acceptable.[154] An effort was made to avoid resource-rich areas. This goal could not be completely satisfied by the Los Medanos site. Thus the Los Medanos site was selected as the best of the practical alternatives for the location of a waste repository.

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[150] Sandia National Laboratories, 1978, p. 2-22.

[151] Sandia National Laboratories, 1978, pp. 2-21 and 2-22.

[152] Sandia National Laboratories, 1977.

[153] Sandia National Laboratories, 1978, pp. 2-22 and 2-23.

[154] Sandia National Laboratories, 1978, p. 2-15.

The site contains potential economic quantities of both potash and hydrocarbons.[155] These resources will be discussed subsequently.

4.2 Resources at the WIPP Site

The language in the EPA's resource disincentive defines resources[156] that are of interest to include "*minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems.*"[157] Accordingly, the following discussion centers on the specific resources defined in the standard. This includes a discussion of hydrocarbon resources, which include oil, gas, and distillate; minerals, which include potash, halite, and construction materials such as sand, gravel, and caliche; and groundwater.

4.2.1 Hydrocarbons

The New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) conducted a hydrocarbon resource study in southeastern New Mexico under contract to the ORNL.[158] The NMBM&MR study was based on the known reserves[159] of crude oil and natural gas in the region and on the probability of discovering new reserves. A fundamental assumption of this study was that the WIPP area has the same potential for resources as the much larger region. The estimates do not take into account the economic value or the recoverability of the hydrocarbons. The NMBM&MR estimated that each section (640 acres) could contain 1.266 million barrels of oil, 16.544 billion cubic feet of gas, and 0.193 million barrels of distillate.[160] The SNL hired a consulting firm to prepare an estimate of the hydrocarbon reserves (economically producible resources) within the area.[161] Since there were no resource wells within the inner three control zones at the WIPP site, the study relied on information gained from nearby exploration. The study was updated just prior to the publication of the draft EIS for the WIPP. Based on the updated study, the reserve estimates in Table 4-1 were projected.[162]

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[155] U.S. Department of Energy, 1980, p. 8-8.

[156] The term "resources" means concentrations of materials in a form that makes their extraction currently or potentially feasible.

[157] U.S. Environmental Protection Agency, 1985a, p. 38086.

[158] New Mexico Bureau of Mines, 1974.

[159] The term "reserves" applies to resources that can be extracted profitably by existing techniques and under present economic conditions.

[160] U.S. Department of Energy, 1980, pp. 7-68 to 7-70.

[161] Sipes, Williamson, and Aycock, 1976.

[162] Sipes, Williamson, and Associates, 1979.

In order to gain control over the development of hydrocarbons within the WIPP site area, the DOE acquired the oil and gas leases within all the WIPP control zones. These acquisitions were necessary to keep the salt beds intact.[163] The only leases that are still intact are in Section 31. These leases only allow the production of resources by entry below 6,000 feet. The upper 6,000 feet of the leases were taken by the DOE through condemnation in 1979. This action was consistent with the developing policy on resource recovery.[164] Current policy would not allow any resource development inside the WIPP site boundary.[165] Table 4-2 puts the resources and the reserves into perspective. This table has been modified from Table 9-14 in the FEIS[166] to include the differentiation between the resources in the inner three control zones and those in Control Zone IV.

4.2.2 Mineral Resources

A comprehensive discussion of the nonhydrocarbon mineral resources affected by the WIPP site is included in the FEIS[167] and is based on information gathered for the GCR.[168] The conclusion in these documents is that the principal mineral resources that underlie the WIPP facility are caliche, gypsum, salt, lithium from brines, sylvite, and langbeinite. Potassium salts (sylvite and langbeinite), which occur in strata above the repository, are the only mineral resources of practical significance and are considered to be economically extractable (that is, reserves).[169,170]

When the Los Medanos site was initially screened for the WIPP Project, it was thought that the facility was positioned outside of the Known Carlsbad Potash District, and would therefore have a minimal impact on potash resources.[171] Information from studies

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[163] U.S. Department of Energy, 1980, pp. 8-8 to 8-10.

[164] U.S. Department of Energy, 1982a.

[165] U.S. Department of Energy, 1987.

[166] U.S. Department of Energy, 1980, p. 9-19.

[167] U.S. Department of Energy, 1980, Chapters 7, 8, and 9.

[168] Sandia National Laboratories, 1978.

[169] U.S. Department of Energy, 1980, p. 9-18.

[170] Environmental Evaluation Group, 1983, pp. 95-98.

[171] U.S. Department of Energy, 1980, p. 2-15.

conducted after site selection[172,173,174] has caused an enlargement of the Known Carlsbad Potash District to include most of the Los Medanos site.[175]

Table 4-3 illustrates the significance of the amount of potash mineral resources that cannot be mined or extracted because of the WIPP site. The mineral of greatest interest is langbeinite, which is used to manufacture a fertilizer. Denying the exploitation of langbeinite resources on the WIPP site does impact regional and national resources. Langbeinite is a relatively rare evaporite mineral that is found in commercial quantities only in the Carlsbad area and in eastern Europe. It contains soluble potassium, magnesium, and sulfur.[176]

The chief importance of langbeinite is as a fertilizer. It is desirable for soils which require soluble potassium, magnesium, and sulfur, but which cannot tolerate chlorine. The principle beneficial ingredient is potassium sulfate. Some langbeinite is sold as a refined mineral but some is mixed with sylvite to produce potassium sulfate.[177]

Substitutes for the principal beneficial ingredient of langbeinite (potassium sulfate) are available. Some langbeinite produced from Carlsbad is transformed into potassium sulfate by a base-exchange process between langbeinite and sylvite. Potassium sulfate can also be produced by a reaction between sylvite and sulfuric acid. Potassium sulfate is present in the brine water of the Great Salt Lake, Utah, and is now being exploited commercially.[178]

The supply of langbeinite in the Carlsbad potash area is exhaustible. It is projected that langbeinite operations will last another 28 years if reserves are considered, and 46 years if resources are considered. The WIPP Project originally excluded the mining or extraction of resources from 18,960 acres. In 1982, the DOE issued a revised Interim Policy Statement on Resource Recovery at the WIPP Site.[179] This policy states that "*the extraction of potash outside Control Zone III is allowable.*"

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[172] U.S. Geological Survey, 1978a.

[173] U.S. Bureau of Mines, 1977.

[174] Agricultural and Industrial Minerals, 1978.

[175] U.S. Department of Energy, 1980, p. 2-15.

[176] U.S. Department of Energy, 1980, p. 9-21.

[177] U.S. Department of Energy, p. 9-24.

[178] U.S. Department of Energy, 1980, pp. 9-14 to 9-25.

[179] U.S. Department of Energy, 1982a.

4.2.3 Groundwater

Groundwater in the area of the WIPP site has been studied extensively and the results of the studies have been summarized both in the WIPP FEIS[180] and the WIPP Final Safety Analysis Report (FSAR).[181] The following are the principal tasks that were conducted to evaluate the groundwater in the vicinity of the WIPP:

> A review of available data and literature resulting from potash, oil and gas, and Pecos River investigations was conducted.
>
> Hydrologic testing was performed in 52 exploration holes.
>
> Extensive field testing programs were conducted, including drill stem tests, flow tests, pump tests, and packer tests.
>
> Water samples from specific rock units have been laboratory tested for physical and chemical parameters.

The studies that were performed confirmed that groundwater exists both above and below the facility horizon. Below the facility horizon, groundwater is found in the Bell Canyon Formation. This groundwater is of very poor quality and, for the most part, can be considered a brine.[182] Groundwater above the facility horizon is found only in limited quantities, and is usually of such poor quality that it is not usable.[183,184,185]

At some locations, the water is of marginal quality and is used for watering livestock. The "Barn Well" (located 5.5 miles south-southeast of the WIPP site) supplies drinking water to a local ranch from the Dewey Lake Red Beds Formation.[186]

The WIPP does not impact any irreplaceable groundwater as defined by 40 CFR 191.14(e), which states that groundwaters are either irreplaceable because (1) "*no reasonable alternative source of drinking water is available for substantial populations*"; or (2) it is "*vital to the preservation of a unique and sensitive ecosystem.*"[187] No substantial population is affected by the WIPP site, and alternative supplies of drinking water are

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[180] U.S. Department of Energy, 1980, Section 7.4.

[181] Westinghouse Electric Corp., 1990.

[182] Sandia National Laboratories, 1978, p. 6-29.

[183] Westinghouse Electric Corp., 1987.

[184] Westinghouse Electric Corp., 1986.

[185] Westinghouse Electric Corp., 1988.

[186] Westinghouse Electric Corp., 1988.

[187] U.S. Environmental Protection Agency, 1985, p. 38086.

available from the wells 30 miles north of the WIPP site which are completed in the Ogallala Formation.[188]

4.3 WIPP Ecosystems

The terrestrial ecology of the WIPP site is characteristic of areas where rainfall is the limiting factor for vegetation. The area lies within a transition zone between the Chihuahuan Desert and the southern Great Plains. As a result, the area shares the floral characteristics of both areas. There are no endangered plant species known to occur within the WIPP site area.[189] Thirty-nine species of mammals have been observed in the area. None are on the threatened or endangered species list.[190] A total of 122 birds have been observed. None are on the endangered species list.[191]

With regard to the impacts on the ecological resources, the FEIS points out that the ecosystems found at the WIPP are not unique. No endangered species of plants or animals are known to inhabit the WIPP site or the vicinity of the site. The area contains vegetation and soil types that are common throughout the region. No unique species or populations have ever been identified at the site.[192]

[188] Westinghouse Electric Corp., 1990, p. 2.5-1.

[189] U.S. Department of Energy, 1980, pp. 7-3 to 7-7.

[190] U.S. Department of Energy, 1980, p. 7-7.

[191] U.S. Department of Energy, 1980, p. 7-8.

[192] U.S. Department of Energy, 1980, pp. 9-14 to 9-15.

5.0 CONCLUSIONS

In 1981, the DOE decided that the available data, as summarized in the FEIS,[193] supported a decision to proceed with the WIPP project through facility construction. As documented by this paper, the information that the DOE used to make this decision evolved from site selection and site characterization activities, which included resource considerations in compliance with the resource disincentive requirements.

During the site selection process, the Los Medanos site was compared against several other candidate sites. An established list of selection criteria (which included resource considerations) was used to compare candidate sites, and the Los Medanos site best met the selection criteria. Based on the favorable characteristics of the Los Medanos site (good hydrological characteristics, salt medium, moderate depth, salt thickness, low population density, lack of significant economic conflicts, and others),[194] the decision was made to proceed with full construction and operation for the Test Phase. These favorable characteristics more than compensate for the possibility that the site will be disturbed in the future because of the presence of natural resources. The decision for full operations as a permanent disposal facility will be rendered only if the EPA guidelines for radioactive waste isolation are met.

In conclusion, the preliminary site selection intent of the RDR in 40 CFR 191(e) has been met for the WIPP facility. Resource conflicts were given adequate consideration, including extensive public comment. The conclusion is that the favorable characteristics of the site uniquely qualify it for a repository for defense TRU waste. These characteristics more than compensate for the likelihood of a future disturbance.

[193] U.S. Department of Energy, 1980.

[194] Sandia National Laboratories, 1983.

LIST OF REFERENCES

Agricultural and Industrial Minerals, 1978, Resource Study for the Waste Isolation Pilot Plant, Eddy County, New Mexico, 1978, Agricultural and Industrial Minerals, Inc., San Carlos, CA.

Assurance Requirement Working Group, 1983, Report of the Assurance Requirement Working Group, Third Draft, by Dr. Robert Budnitz, Dr. Konrad Krauskopf, Dr. Terry R. Lash, Chair, and Dr. David Okrent, July 20, 1983, contained in Trip Report Number DA:83:0343 prepared by W.Baer, Westinghouse Electric Corp, Albuquerque, NM, July 29, 1983. (Westinghouse Electric Corp. is now in Carlsbad, NM.)

Environmental Evaluation Group, 1979, Goad, Donna, A Compilation of Site Selection Criteria, Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, EEG-1, Environmental Evaluation Group, Santa Fe, NM, June, 1979. (the EEG is now located in Albuquerque and Carlsbad, NM).

Environmental Evaluation Group, 1983a, Comments of the Environmental Evaluation Group on Environmental Protection Agency Proposed Rule 40 CFR Part 191 Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, May 3, 1983, contained in a letter from Robert H. Neill, Director, EEG, to Dr. Glenn L. Sjoblom, Director, Office of Radiation Programs, Environmental Evaluation Group, Santa Fe, NM (the EEG is now located in Albuquerque and Carlsbad, NM).

Environmental Evaluation Group, 1983b, Letter dated January 21, 1983 from Robert H. Neill, Director, Environmental Evaluation Group to Mr. Joseph M. McGough, Project Manager of WIPP, U. S. Department of Energy, Environmental Evaluation Group, Santa Fe, NM (the Environmental Evaluation Group is now located in Albuquerque and Carlsbad, NM).

Environmental Evaluation Group, 1983c, Neill, R.H., J.K. Channell, L. Chatuverdi, M. S. Little, K. Rehfeldt, and P. Spiegler, Evaluation of the Suitability of the WIPP Site, EEG-23, May, 1983, Environmental Evaluation Group, Santa Fe, NM (the Environmental Evaluation Group is now in Albuquerque and Carlsbad, NM).

Environmental Evaluation Group, 1987, EEG Comments of Waste Isolation Pilot Plant Compliance Plan for 40 CFR 191, DOE-WIPP 86-013, contained in a letter from Robert H. Neill, Director, Environmental Evaluation Group to Mr. Jack B. Tillman, Project Manager, WIPP Project Office, U.S. Department of Energy, Carlsbad, NM.

Long, G.J. and Associates, 1976, Interpretation of Geophysical Data, Los Medanos and Vicinity, 1976, report to Sandia National Laboratories, Albuquerque, NM.

National Academy of Sciences, 1957, The Disposal of Radioactive Waste on Land, Report of the Committee on Waste Disposal of the Division of Earth Sciences, Publication 519, National Academy of Sciences/National Research Council, Washington, D.C.

New Mexico Bureau of Mines, 1974, Foster, R. W., Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste: Open-file Report, 1974, New Mexico Bureau of Mines, Socorro, NM.

New Mexico Bureau of Mines and Mineral Resources, 1978, Siemers, W. T., J. W. Hawley, C. Rautmen and G. Austin, Evaluation of the Mineral Potential (Excluding Hydrocarbons, Potash and Water) of the Waste Isolation Pilot Plant Site, Eddy County, New Mexico, 1978, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

New Mexico Energy and Minerals Department, 1984, Natural Resources at the Waste Isolation Pilot Plant Site, a Report of the Energy and Minerals Department Task Force on Natural Resources, January 1984, attached to a letter dated January 30, 1984, from Paul Biderman, Secretary, Energy and Minerals Department, state of New Mexico to Raymond G. Romatowski, Manager, Albuquerque Operations Office, U.S. Department of Energy, Albuquerque, NM.

National Academy of Sciences, 1984, Review of the Scientific and Technical Criteria for the Waste Isolation Pilot Plant (WIPP), 1984, National Academy of Sciences, Washington, D.C.

Oak Ridge National Laboratory, 1973a, Site Selection Factors for the Bedded Salt Pilot Plant, ORNL-TM-4219, 1973, Oak Ridge National Laboratory, Oak Ridge, TN.

Oak Ridge National Laboratory, 1973b, Oak Ridge National Laboratory, 1973b, Program Plan for the Development of the Bedded Salt Pilot Plant, ORNL-TM-4233, 1973, Oak Ridge National Laboratory, Oak Ridge, TN.

Oak Ridge National Laboratory, 1973c, Piper, A. M., Suberosion In and About the Four Township Study Area Near Carlsbad, ORNL Subcontract 3745, 1973, Oak Ridge National Laboratory, Oak Ridge, TN.

Oak Ridge National Laboratory, 1974a, Claiborne, H. C., and F. Gera, Potential Containment Failure Mechanisms and Their Consequences at a Radioactive Waste Repository in Bedded Salt in New Mexico, ORNL-TM-4369, 1974, Oak Ridge National Laboratory, Oak Ridge, TN.

Oak Ridge National Laboratory, 1974b, Foster, R.W., Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste, ORNL Open-File Report, Contract No. AF(40-1-4423), 1974, Oak Ridge National Laboratories, Oak Ridge, TN.

Permian Exploration Co., 1976, McMillan, C., Los Medanos Area, 1976, report to Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories, 1977, Griswold, G. B., Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medanos, Eddy County, New Mexico, SAND77-0946, 1977, Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories, 1978, Powers, D. W., S. J. Lambert, S. E. Shaffer, L. R. Hill, and W. D. Weart (eds.), 1978, Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, Two Volumes, SAND78-1596, Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories, 1983, Weart, W. D., Summary of Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability, SAND83-0450, March, 1983, Sandia National Laboratories, Albuquerque, NM., p. 12.

Sandia National Laboratories, 1989, Bertram-Howery, S. G. and R. L. Hunter, Plans for Evaluation of the Waste Isolation Pilot Plant's Compliance with EPA Standards for Radioactive Waste Management and Disposal, SAND88-2871, 1989, Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories, 1990a, Bertram-Howery, S. G., M. G. Marietta, R. P. Rechard, P. N. Swift, D. R. Anderson, B. L. Baker, J. E. Bean, Jr., W. Beyeler, K. F. Brinster, R. V. Guzowski, J. C. Helton, R. D. McCurley, D. K. Rudeen, J. D. Schreiber, and P. Vaughn, Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December, 1990, SAND90-2347, Sandia National Laboratories, Albuquerque, NM (Note: SNL publishes annual status reports on the progress being made on performance assessment.)

Sandia National Laboratories, 1990b, Molecke, M. A., Test Plan: WIPP Bin-Scale CH TRU Waste Tests, SAND90-1974, January 1990, Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories, 1990c, Molecke, M. A. and A. R. Lappin, Test Plan Addendum #1: Waste Isolation Pilot Plant Bin-Scale CH TRU Waste Tests, SAND90-2082, December, 1990, Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories, 1990d, Molecke, M. A., Test Plan: WIPP In-Situ Alcove CH TRU Waste Tests, January 1990, Sandia National Laboratories, Albuquerque, NM.

Sipes, Williamson, and Associates, 1979, Keesey, J. J., Evaluation of Directional Drilling for Oil and Gas Reserves Underlying the WIPP Site Area, Eddy County, New Mexico, 1979, Sipes, Williamson, and Associates, Midland, TX.

Sipes, Williamson, and Aycock, 1976, Keesey, J. J., Hydrocarbon Evaluation, Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico, Vol. I and II, 1976, Sipes, Williamson and Aycock, Midland, TX.

U.S. Bureau of Mines, 1977, Valuation of Potash Occurrences Within the Waste Isolation Pilot Plant Site in Southeastern New Mexico, 1977, United States Bureau of Mines Report to the Energy Research and Development Administration, Washington, D.C.

U. S. Congress, 1969, National Environmental Policy Act of 1969, Pub. L. 91-190, 42 U.S.C. 4321-4347, January 1, 1970 as amended by Pub. L. 94-52, July 3, 1975 and Pub. L. 94-830, August 9, 1975, United States Congress, Washington, D.C., Title I, Sec. 101, (b), (5).

U.S. Congress, 1979, Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980, Public Law 96-164 (S. 673), Title II - General Provisions, Waste Isolation Pilot Plant, Delaware Basin, New Mexico, Sec. 213, Approved December 29, 1979, U. S. Congress, Washington, D.C.

U.S. Department of Energy, 1980, Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026, October, 1980, U.S. Department of Energy, Washington, DC, pp. 7-60 to 7-77.

U.S. Department of Energy, 1981a, Waste Isolation Pilot Plant (WIPP); Record of Decision, 46 FR 9162, January 28, 1981, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1987, Second Modification to the Agreement for Consultation and Cooperation, August 4, 1987, signed by the Department of Energy and the state of New Mexico. Available from the U.S. Department of Energy, Carlsbad, NM.

U.S. Department of Energy, 1981b, DOE Responses to Comments on the WIPP Final Environmental Impact Statement, WIPP-DOE-81, January, 1981, U.S. Department of Energy, WIPP Project Office, Albuquerque, NM (the WIPP Project Office is now known as the WIPP Project Site Office and is located in Carlsbad, NM), pp. 14-16.

U.S. Department of Energy, 1981c, DOE Responses to Comments on the WIPP Final Environmental Impact Statement, Supplement, WIPP-DOE-81A, April, 1981, U.S. Department of Energy, WIPP Project Office, Albuquerque, NM (the WIPP Project Office is now known as the WIPP Project Site Office and is located in Carlsbad, NM), pp. 9-10.

U.S. Department of Energy, 1981d, Interim Policy Statement by U.S. Department of Energy, Resource Recovery at the Waste Isolation Pilot Plant Site, contained in a letter dated November 3, 1981, from J. M. McGough, Project Manager, WIPP Project Office to Dr. George S. Goldstein, Chairman, Governor's Task Force on WIPP, U.S. Department of Energy, WIPP Project Office, Albuquerque, NM (the WIPP Project Office is now known as the WIPP Project Site Office and is located in Carlsbad, NM).

U.S. Department of Energy, 1982a, DOE Revised Interim Policy Statement on Resource Recovery at the WIPP Site, contained in a letter dated December 23, 1982 from J. M. McGough, Project Manager, WIPP Project Office to Dr. George S. Goldstein, Chairman, Radioactive Task Force, WIPP Project Office, Albuquerque, NM (the WIPP Project Office is now known as the WIPP Project Site Office and is in Carlsbad, NM).

U.S. Department of Energy, 1982b, Environmental Analysis, Waste Isolation Pilot Plant (WIPP), Cost Reduction Proposals, WIPP-DOE-136, July, 1982, U.S. Department of Energy, WIPP Project Office, Albuquerque, NM (the WIPP Project Office is now known as the WIPP Project Site Office and is in Carlsbad, NM).

U.S. Department of Energy, 1982c, Review of the Environmental Analysis for the Cost Reduction Proposals for the Waste Isolation Pilot Plant (WIPP) Project, July, 8, 1982, letter from William A. Vaughn, Assistant secretary, Environmental Protection, Safety and Emergency Preparedness, to Herman E. Roser, Assistant Secretary for Defense Programs, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1983a, Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program, WIPP-DOE-161, March, 1983, U.S. Department of Energy, WIPP Project Office, Albuquerque, NM (the WIPP Project Office is now known as the WIPP Project Site Office and is in Carlsbad, NM).

U.S. Department of Energy, 1983b, DOE Responses to the Public's Comments on "Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program," (WIPP-DOE-161), WIPP-DOE-173, June 1983, U.S. Department of Energy, WIPP Project Office, Albuquerque, NM (the WIPP Project Office is now known as the WIPP Project Site Office and is in Carlsbad, NM), pp. 3-16 to 3-19.

U.S. Department of Energy, 1983c, DOE Responses to the State of New Mexico's Comments on "Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program," (WIPP-DOE-161), WIPP-DOE-174, June 1983, U.S. Department of Energy, WIPP Project Office, Albuquerque, NM (the WIPP Project Office is now known as the WIPP Project Site Office and is in Carlsbad, NM), pp. 3-17 to 3-19, 6-3, 7-3.

U.S. Department of Energy, 1983d, Action Description Memorandum (ADM) for Determination to Proceed with Full Waste Isolation Pilot Plant (WIPP) Construction, June, 24, 1983, attached to a letter from Herman E. Roser, Assistant Secretary for Defense Programs, to William A. Vaughn, EP-1, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1983e, National Environmental Policy Act (NEPA) Review of the Waste Isolation Pilot Plant (WIPP) Site and Preliminary Design Validation (SPDV) Program, June 28, 1983, letter from William A. Vaughn, Assistant Secretary, Environmental Protection , Safety and Emergency Preparedness, to Herman E. Roser, Assistant Secretary for Defense Programs, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1984, First Modification to the July 1, 1981 "Agreement for Consultation and Cooperation" on the WIPP by the State of New Mexico and U.S. Department of Energy, November 1984, available from the U.S. Department of Energy, Carlsbad, NM.

U.S. Department of Energy, 1990a, Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026-FS, January 1990, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy, 1990b, WIPP Test Phase Plan: Performance Assessment, DOE/WIPP 89-011, Rev. 0, April 1990, U.S. Department of Energy, Carlsbad, NM.

U.S. Department of Interior, 1991, Land Withdrawal, Waste Isolation Pilot Plant Project; New Mexico, Public Land Order 6826, 56 FR 3038, January 28, 1991, Bureau of Land Management, New Mexico State Office, Santa Fe, NM.

U.S. District Court, 1981, Stipulated Agreement in Civil Action No. 81-0363 JB, State of New Mexico v. The United States Department of Energy, July 1, 1981, filed with the U.S. District Court, Albuquerque, NM, Appendix B, Item 6.

U. S. Environmental Protection Agency, 1982, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Proposed Rule, 40 CFR Part 191, 47 FR 58196, December 29, 1982, U. S. Environmental Protection Agency, Washington, D.C.

U. S. Environmental Protection Agency, 1985a, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule, 40 CFR 191, 50 FR 38084, Sept. 19, 1985, U. S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency, 1985b, High Level and Transuranic Radioactive Wastes, Response to Comments for Final Rule, Volume II, EPA 520/1-85-024-2, August 1985, U.S. Environmental Protection Agency, Washington, D.C., p. 2-16.

U.S. Environmental Protection Agency, 1987, Comments on the draft Waste Isolation Pilot Plant (WIPP) Compliance Plan for 40 CFR 191, May 22, 1987, contained in a letter from Sheldon Meyers, Director, Office of Radiation Programs, U.S. Environmental Protection Agency to Mr. Grover A. Smithwick, Principal Deputy Assistant Secretary, Environment, Safety and Health, Department of Energy, Washington, D.C.

U.S. Geological Survey, 1962, Pierce, W. G., and E. I. Rich, Summary of Rock Salt Deposits in the United States as Possible Storage Sites for Radioactive Waste Materials, USGS Bulletin 1948, 1962, U.S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1972, Brokaw, A. L., C. L. Jones, M. E. Cooley, and W. H. Hays, Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico, USGS Open-File Report 72-49, 1972, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1973a, Anderson, R. E., D. H. Eargle, and B. O. Davis, Geology and Hydrologic Summary of Salt Domes in Gulf Coast Region of Texas, Louisiana, Mississippi, and Alabama, USGS Open-File Report 4339-2, 1973, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1973b, Bachman, G. O., Geologic Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico, USGS Open-File Report 4339-4, 1973, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1973c, Hite, R. J., and S. W. Lohman, Geologic Appraisal of Paradox Basin Salt Deposits for Waste Emplacement, USGS Open-File Report 4339-6, 1973, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1973d, Jones, C. L., M. E. Cooley, and G. O. Bachman, Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico, USGS Open-File Report 4339-7, 1973, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1973e, Mytton, James W., Two Salt Structures in Arizona; The Supai Salt Basin and Luke Salt Body, USGS Open-File Report 4339-3, 1973, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1974a, Ekren, E. B., Geologic and Hydrologic Considerations for Various Concepts of High-Level Radioactive Waste Disposal in Conterminous United States, USGS Open-File Report 74-158, 1974, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1974b, Jones, C. L., Salt Deposits of the Mescalero Plains Area, Chaves County, New Mexico, USGS Open-File Report 74-190, 1974, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1974c, Jones, C. L., Salt Deposits of the Clovis-Portales Area, East-Central, New Mexico, USGS Open-File Report 74-60, 1974, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1975, Jones, C. L., Potash Resources in part of Los Medanos area of Eddy and Lea Counties, New Mexico, USGS Open-File Report 75-407, 1975, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1978a, John, C. B., R. J. Cheeseman, J. C. Lorenz, and M. L. Millgate, Potash Ore Reserves in the Proposed Waste Isolation Pilot Plant Area, Eddy County, Southeastern New Mexico, U.S.G.S. Open-File Report 78-828, 1978, U. S. Geological Survey, Washington, D.C.

U.S. Geological Survey, 1978b, Jones, C. L., Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico, U.S.G.S. Open file Report 78-592, 1978, U. S.Geological Survey, Washington, D.C.

Westinghouse Electric Corp., 1980, Little, C. C., F. J. Gurney and D. S. Bell, A Description of the Site and Preliminary Design Validation Program for the WIPP Site, TME 3063, October 1980, Westinghouse Electric Corporation, Albuquerque, NM (Westinghouse Electric Corp. is now in Carlsbad, NM).

Westinghouse Electric Corp., 1982a, Brausch, L. M., A. K. Kuhn, and J. K. Register, Natural Resources Study, Waste Isolation Pilot Plant, Southeastern New Mexico, TME 3156, September 1982, Westinghouse Electric Corp, Albuquerque, NM (Westinghouse Electric Corp. is now in Carlsbad, NM).

Westinghouse Electric Corp., 1982b, Hart, J. S. and J. K. Register, A Description of the Site and Preliminary Design Validation Program for the WIPP Site, Revision 1, TME 3063, Rev. 1, November 1982, Westinghouse Electric Corporation, Albuquerque, NM (Westinghouse Electric Corp. is now in Carlsbad, NM).

Westinghouse Electric Corp., 1986, Uhland, D. W. and W. S. Randall, Annual Water Quality Data Report, DOE/WIPP 86-006, 1986, Westinghouse Electric Corp., Carlsbad, NM.

Westinghouse Electric Corp., 1987, Uhland, D. W., W. S. Randall, and R. C. Carrasco, Annual Water Quality Data Report, DOE/WIPP 87-007, 1987, Westinghouse Electric Corp., Carlsbad, NM.

Westinghouse Electric Corp., 1988, Randall, W. S., M. E. Crawley, and M. L. Lyon, Annual Water Quality Data Report, DOE/WIPP 88-006, 1988, Westinghouse Electric Corp., Carlsbad, NM.

Westinghouse Electric Corp., 1989, Waste Isolation Pilot Plant, Compliance Strategy for 40 CFR Part 191, DOE/WIPP 86-013, March 17, 1989, Westinghouse Electric Corp., Carlsbad, NM.

Westinghouse Electric Corp., 1990, Final Safety Analysis Report, Waste Isolation Pilot Plant, WP 02-9, Westinghouse Electric Corporation, Carlsbad, NM. Groundwater is discussed in Section 2.5.

WIPP Project, 1983, Testimony on Proposed 40 CFR 191, EPA Science Advisory Board, July 1983, contained in a letter from W. Baer, Manager, Safety Assessment, Westinghouse Electric Corp. to Mr. J. M. McGough, Project Manager, WIPP Project Office, letter number WD:83:01588, dated July 20, 1983, Westinghouse Electric Corporation, Albuquerque, NM (Westinghouse Electric Corporation is now located in Carlsbad, NM).

FIGURES

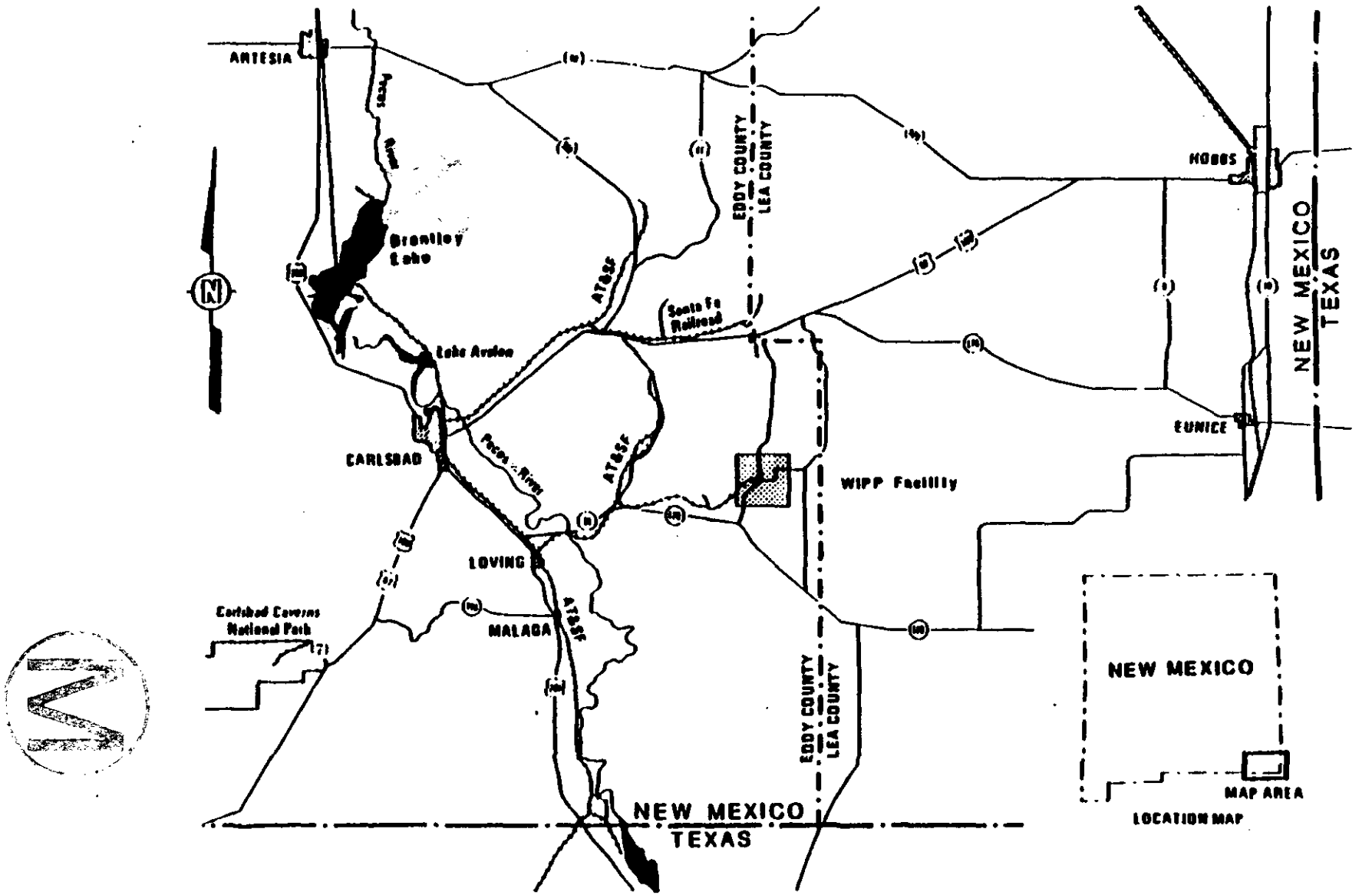
ARTESIA
Brantley Lake
Lake Avalon
CARLSBAD
Pecos River
Carlsbad Caverns National Park
LOVING
MALAGA
ATSF
Santa Fe Railroad
EDDY COUNTY
LEA COUNTY
WIPP Facility
HOBBS
EUNICE
NEW MEXICO
TEXAS
NEW MEXICO
MAP AREA
LOCATION MAP
FEDERAL HIGHWAY
STATE HIGHWAY
0 5 10 KILOMETERS
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SCALE
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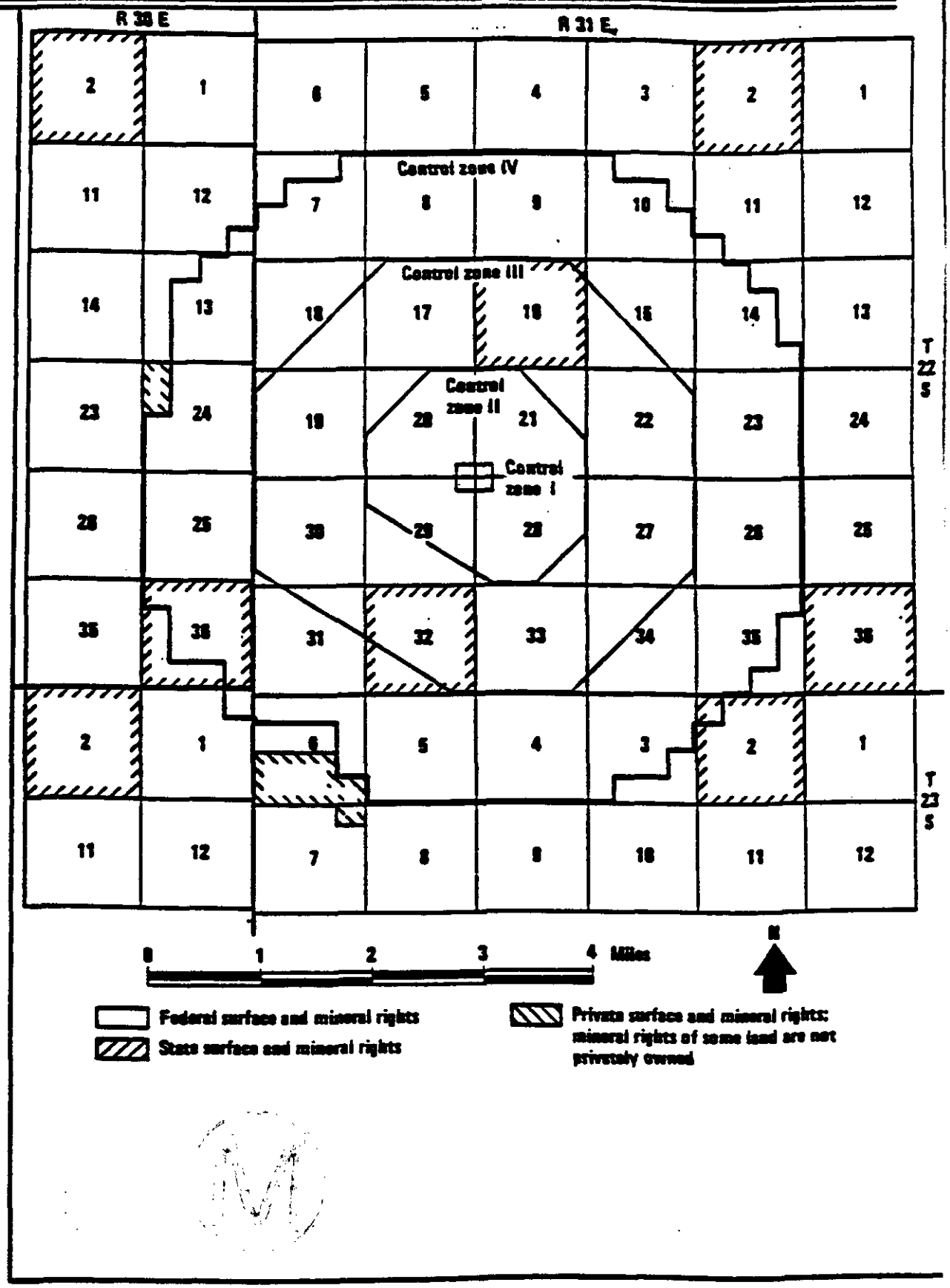

FIGURE 2 ORIGINAL CONTROL ZONES AT THE WIPP SITE

IMPLEMENTATION OF THE RESOURCE DISINCENTIVE IN 40 CFR PART 191.14(e) AT THE WASTE ISOLATION PILOT PLANT

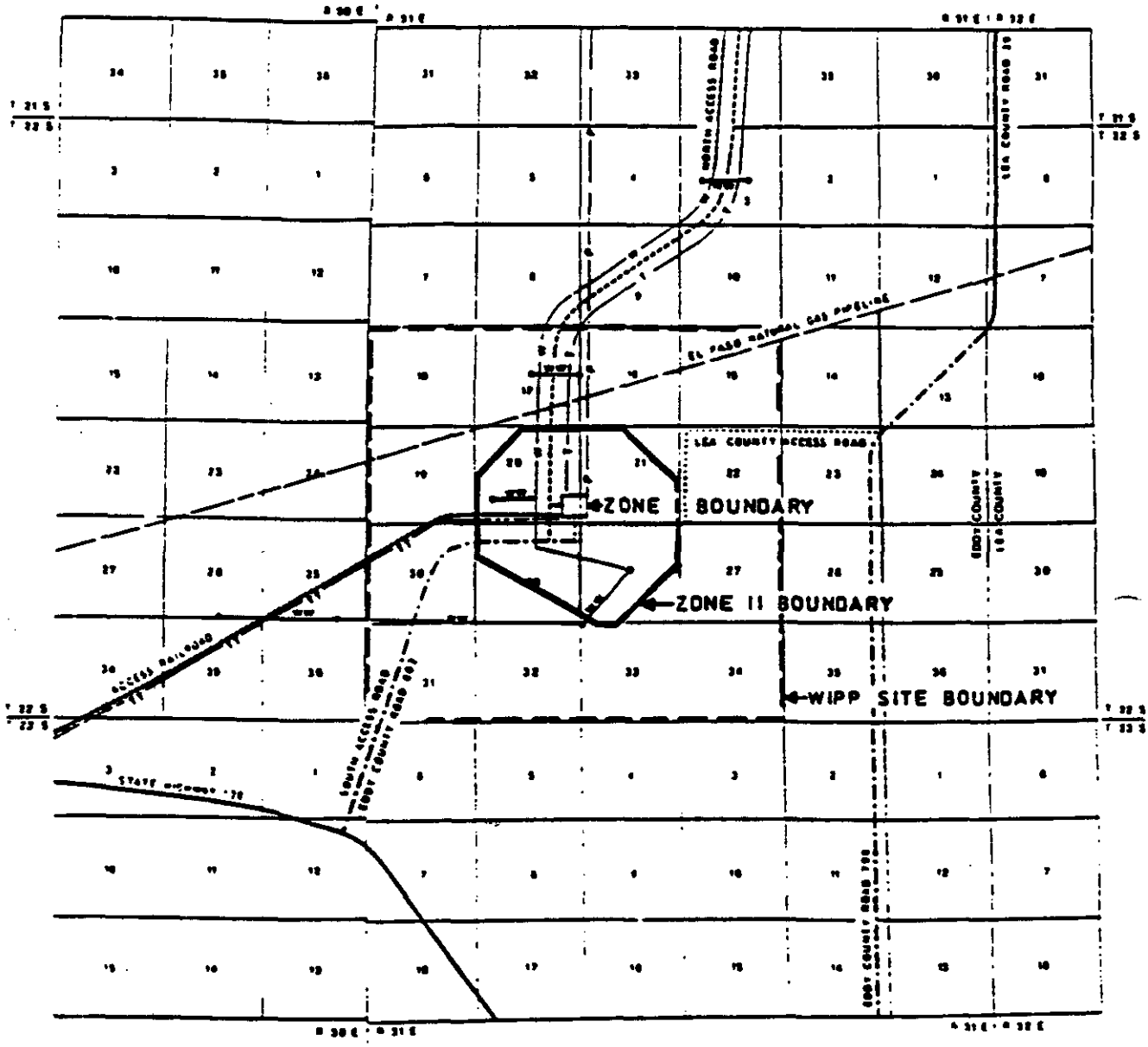

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FIGURE 3 CURRENT WIPP FACILITY BOUNDARIES

M

TABLES

Table 4-1. Comparison of Geologic Media Considered for the WIPP Facility

Property	Salt	Basalt or Granite	Shale
BASIC PROPERTIES			
Plasticity	High	None	Variable
Solubility	High	Very low	Very low
Sorptive Capacity	Low (depends on impurities)	Fair	High
Compressive Strength	Moderate	High	Moderate
Thermal Diffusivity	High	Low	Low
Thermal stability against chemical decomposition	High	High; potential dewatering of clay in basalt	High; potential dewatering of clay
IN-SITU PROPERTIES			
Porosity	0.5%, interstitial	1%, cracks	5-30%, cracks
Permeability	Essentially none	Decreases with depth	Very low
Water presence	Isolated from flowing groundwater	Present, open to flowing groundwater	Present, open to flowing groundwater
Corrosiveness of indigenous fluid	High	Low to moderate	Low to moderate
Tectonic stability	Very stable	Very stable areas can be found	Very stable areas can be found
Geologic structure	Relatively simple areas can be found	Fracture systems often complex	Like salt
Hydrology	Moderately difficult to characterize	Difficult to characterize	Difficult to characterize
PRACTICAL MATTERS			
Availability	Good	Good	Good
Need to use explosives	No	Yes	Possibly
Understanding of medium for repository use	Well studied	Not well studied	Not well studied
Waste rock	Reuse some; pile needs protection from erosion and runoff	Reuse some; pile probably does not need protection	Reuse some; pile needs protection but less that salt
Mathematical modeling	Relatively simple; well developed	Relatively complex; not fully developed	Relatively complex; not fully developed

Source: U. S. Department of Energy, 1980, p. A-4.

Table 4-2. Hydrocarbon Reserves and Resources at the WIPP Site

	Condensate (bbl)			Gas (10^6 ft^3)		
CATEGORY	ZONES I,II,III	ZONE IV	CATEGORY TOTAL	ZONES I,II,III	ZONE IV	TOTAL
Proved but undeveloped reserves	0	81,758	81,758	0	11,610	11,610
Probable reserves	11,640	9,822	21,462	9,050	10,094	19,144
Possible reserves	14,169	1,135	15,304	12,002	1,866	13,868
Total reserves	25,809	92,715	118,524	21,052	23,570	44,622
Unassigned reserves and resources			272,319			39,352
Grand total			390,843			83,974

Source: U.S. Department of Energy, 1980, p. 7-74.

Table 4-3. Summary of the Impacts of Hydrocarbon Resource Denial

RESOURCES

DEPOSIT	SITE TOTAL	REGION	UNITED STATES	WORLD
Natural Gas (bill. ft^3)	490	25,013	855,000	N/A
Control Zones I-III	211	0.8 %	0.025 %	
Control Zone IV	279	1.1 %	0.033 %	
Distillate (mill. barrels)	5.72	293	N/A	N/A
Control Zones I-III	2.46	0.84%		
Control Zone IV	3.26	1.11%		
Crude Oil (mill. barrels)	37.5	1915	200,000	N/A
Control Zones I-III	16.12	0.84%	0.008 %	
Control Zones IV	21.38	1.12%	0.0006%	

RESERVES

DEPOSIT	SITE TOTAL	REGION	UNITED STATES	WORLD
Natural Gas (bill. $ft.^3$)	44.62	3865	208,800	2,520,000
Control Zones I-III	21.05	0.54%	0.01 %	0.0008%
Control Zone IV	23.57	0.61%	0.011 %	0.0009%
Distillate (mill. barrels)	0.12	169.1	35,500	N/A
Control Zones I-III	0.03	0.02%	0.00008%	
Control Zone IV	0.09	0.06%	0.00024%	
Crude Oil		471.7	29,486	646,000

Source: Based on U.S. Department of Energy, 1980, p. 9-19 and 9-28.

Table 4-4. Summary of Potash Resources at the WIPP Site

RESOURCES

DEPOSIT	SITE TOTAL	REGION	UNITED STATES	WORLD
Sylvite (mill. tons ore)	133.2	4280	8550	850,000
Control Zones I-III	39.1	0.92%	0.46%	0.0046%
Control Zone IV	94.1	2.21%	1.10%	0.01%
Langbeinite (mill. tons ore)	351.0	1140	N/A	N/A
Control Zones I-III	121.9	10.7 %		
Control Zone IV	229.1	20.1 %		

RESERVES

DEPOSIT	SITE TOTAL	REGION	UNITED STATES	WORLD
Sylvite (mill. tons K_2O)	3.66	106	206	11,206
Control Zones I-III	NIL			
Control Zone IV	3.66	3.45%	1.78%	0.33%
Langbeinite (mill. tons K_2O)	4.41	9.3	9.3	N/A
Control Zones I-III	1.21	13.0 %	13.0 %	
Control Zone IV	3.20	34.4 %	34.4 %	

Source: U.S. Department of Energy, 1980, p. 9-19 and 9-28.

APPENDIX A

LIST OF PUBLICATIONS ADDRESSING SITE SELECTION (FROM EEG-1)

1: No. 8

nflict with Natural Resources

1. Should be taken into account/information useful for site selection/evaluation:
   i. to be considered in making criteria - petrographical and mineralogical composition and economic value, p. 12-13; questions regarding salt as host media: often associated with potash and oil and may be an attractive target for exploratory boreholes, p. 9, AECL Canada 1976, E2
   ii. for salt formation, occurences of petroleum, potash mines, oil and gas production, USGS 4339-1, 1972, B2
   iii. Criteria - future value of potash deposits should be considered, p. 70-71; economic development - potash, ranches, oil and gas fields, p. 45, USGS 4339-6, 1973, B4
   iv. study considered oil and gas deposits, potash, p. 20, USGS 74-190, 1974, B9
   v. criteria considered - oil, gas and recreational potential development, p. 2-3, Supplemental Areas, Kn GS 1972, B11
   vi. in geologic study of areas, range of tasks includes natural resource evaluation, including those items relating to people's activities in the subsurface which would alter the natural geologic conditions, p. 22, OWI/ERDA Program Plan for NWTSP 1976, D19
   vii. petroleum, potash, sulfur - may be present near a salt deposit. Necessary to weigh need for rep and the availability of other sites against present and potential need for mineral resources at site.
      - p. 6, OWI/DOE Salt Dep of US 1978, D21
      - p. 48, IAEA SS Factors 1977, E11
   viii. potential for oil and gas - considered since it might attract drilling, ORNL McClain and Boch 1974, D3
   ix. potential sites in salt should be evaluated for potential exploitation and/or contamination of oil, gas, and water resevoirs, and of salt, potash and other valuable or potentially valuable commodities, p. 4.63, HLWM Alternatives, BNWL-1900, 1974, D16
   x. site selection - determine suitability of broad regions in terms of potential for denial of natural resources, p. 13; site evaluation - need detailed definition of distribution of physical properties throughout site (i.e. petrologic and mineralogic features), p. 14; ES aspects of long term risk analysis - need knowledge of processes that affect containment capability: identification of mineral resources that might serve to cause people to penetrate rep, p. 16-17, ESTP USGS and DOE 1979, D24
   xi. events taken into account in risk analysis - human intrusion: gas/oil exploration, mineral exploration, p. 95-103, AD Little, Assessment 1978, C3

2. Formation should not be associated with or be in the immediate vicinity of potentially valuable mineral resources:
   i. no area with present or past history of resource extraction except by surface quarrying should be considered, p. 13-15, NAS/NRC 1978, A1
   ii. to the extent possible, p. 2:10; unavoidable conflict with resources should be minimized to the extent possible (large scale site selection criteria), p. 2:20-21, GCR 1978, D10

iii) p15, Canada AECL 1975, E1

iv) tract considered is most promising since it is 5 miles or more from any center of industrial activity, i.e.gas or oil wells or mines, p 34-35, USGS 4339-7, 1973, B5

v) preferred salt environment -where oil and gas potential is low; unsuitable area - where strata have high oil or gas potential, p 3 USGS 74-158, (B8) 1974; p 4.4, HLWM Alternatives, BWNL - 1900, 1974 (D16)

vi) p 21 AEC, Lyons E. S. 1971, D6

vii) Criteria must be met: waste must not be placed in potentially useful mineral deposits, p 13-14, Deep Rock, Klett/Sandra 1974, D8

viii) SS criteria p 12-13, SS WIPP/Sandia 1977, D9

ix) Site should not offer an attractive resource target p 5; actual or potential resource of site should be such that it will not undvely deprive this or future generations of necessary and valuable resources, p 5-6, Nureg 0353, NRC-State Review 1977, C4

x) Would make site more favorable, p 6, OWI/DOE Salt Dep of US 1978, D21

xi) p 3-4, ORNL, Program Plan for BSPP 1973, D1

xii) Avoid areas where mineral resources are "known to abound" and where resources were "worked out" in formation below rep, Kehnemyi, Battelle M, 1979, D23

xiii) avoid areas of existing production or extensive exploration as much as possible, p 10, mineral potential should be minimal to minimize probability of future operations. p 11, summary, BSPPSS Factors ORNL 1973, D2

xiv) presence of potentially mineable minerals detract from usefulness of host rock for disposal, p 33, IAEA SS Factors 1977, E11

xv) as much as possible - p 5, Brunton & McClain, OWI/ERDA 1977, D20

xvi) de Marsily, etal, Guarantee Isolation? 1977, E5

xvii) p 2-9, 4-73, ES of WM of LWR Cycle, NRC 1976, C8

Reasons:

a. potential source of raw materials that would be denied:

i) p 13-15, NAS/NRC 1978, A1

ii) proposed criteria: actual or potential resource value of site should be such that it will not unduly deprive this or future generations of necessary and valuable resources, p 5-6 NRC State Review, Nureg-0353 1977, C4

iii) p 36-40, EPA State of Geologic Knowledge 1978, C7

iv) waste disposal facilities shall be sited and operated to avoid as much as possible the foreclosure of future options. p 13, NRC - Proposed Goals for RWM, 1978, C9

b. disturbance of hydrological/geological system by boreholes, shafts, fractures, cavities;

i) p 13-15, NAS/NRC 78, A1

ii) p 32 OWI/ERDA, Program Plan for WWTSP 1976, D19

iii) avoidance of areas over "worked out" mineral deposits because of danger of subsidence, Kenhemuyi, Battelle M, 1979, D23

iv) site should be located so that existing subsurface operations would be outside buffer zone and to minimize probability of future operations since current technology makes it difficult to predict what the eventual effects of mechanical or solution mining on rep might be. p 11, BSPPSS Factors ORNL 1973, D2

v) people are now one of the major driving forces for geologic change (erosion, solid movement and water movement for example) p-13, NRC Proposed Goals for RWM 1978, C9

vi) site should be where intrusion of people in a manner that will change conditions is minimal. p 4.5 HLWM Alternatives, BNWL-1900 1974, D16

c. Attract propspection - exploration that might penetrate rep:

i) p 13-15, NAS/NRC 1978, A1

ii) danger of reexploitation of already mined resources; Kehnemuyi, Batelle, M, 1979, D23

iii) minimize probability of future operations within buffer zone, p 11, BSPP SS Factors, ORNL 1973, D2

iv) Must have no natural resources in area that would attract prospection deMarsily, et al, Guarantee Isolation? 1977, E5

v) site should not offer attractive resource target, p 5, NRC, State Review, Nureg 0353, 1977, C4

vi) Recommendations have been presented p IV-57, KBS Rydberg & Winchester 1978, E9

vii) People will seek anything of value and are now one of the major driving forces of geologic change - to the extent predictable, we should design and locate facilities so as to avoid motivation for penetrating disposal volume, p 13 NRC-Proposed Goals for RWM 1978, C9

viii) p 35-40, EPA State of Geologic Knowledge 1978

3. Avoid conflicts with water as a natural resource:

i) esp in arid areas, groundwater is an important commodity - extensive deposits of fresh water above or below site could adversely affect its availability due to public opinion, p c 10-12, ERDA/BNWL, App c 1976, D18
p 41, IAEASS Factors 1977, E11

ii) special care needed if water near site is used by municipalities, industry, agriculture, p 5-6 OWI/DOE Salt Dep of US 1978, D21

iii) avoid areas where groundwater resources are extensively used and/or have potential for significant future development -Kehnemuyi, Battelle M, 1979, D23
-SS Factor, BSPPSS Factors, ORNL 1973, D2
-p 6 Brunton & McClain, OWI/ERDA 1977, D20
-p [illegible] HLWM Alternatives, BNWL-1900 1974, D16

iv) there may be conflict with industrial, recreational, scenic interest in large lakes and streams - p C 10-12, ERDA/BNWL, Alternatives App c 1976, D18
- p 41 IAEA SS Factors 1977, E11
- p 6 Brunton & McClain, OWI/ERDA 1977, D20

4. Waste placed in rep as a natural resource:

i) operation of the rep should not create a potential future source of valuable material; unreprocessed spent fuel elements, potentially highly valuable to future people, should not be placed in non-retrievable storage (temptation to penetrate rep), p 13-15, NAS/NRC 1978, A1

ii) consideration: since uranium ore is limited, it may become desirable to recover unreprocessed fuel rods, so a breach in the rep to recover them could be a serious problem in the future. p 3, p 35-36 State of Geologic Knowledge 1978 EPA, C7

iii) goals for RWM: to the extent predictable, we should design and locate facilities so as to avoid motivation for penetrating the disposal volume. p 13, NRC-Proposed goals for RWM 1978, C9

5. If the rep is located where there are natural resources present or near-by:

i) If possibility exists that some valuable resource is present, it will be necessary to show that credible attempts to recover the resources will not have adverse effects on the effectiveness of the rep, p 5; Proposed criteria: site should have characteristics such that the consequences of unplanned intrusions will be ALARA p 5-6, Nureg 0353, NRC State Review 1977, C4

ii) accidental penetrations should not result in undue hazard. p 2:17 GCR 1978, D10

iii) Resources could be extracted from adjacent regions with proper evaluation and precautions. To be considered in evaluations: compatibility of operations, impact on rep from extraction operations, possibility of contamination of resource by waste. p 48, IAEA SS Factors 1977, E11

iv) "The expectation, but one that cannot yet be guaranteed is that these minerals (at WIPP site in Zone III) may be recovered in decades ahead should they be economically attractive. Certainly the time frame for their development would be within the next century while the rep site is still under administrative control. The small amounts of either resource within zone III would not be of significant interest in the absence of other production in the area." p 10, Letter from Beckner to Schueler, Dec. 1978, D13

v) Rydberg -Though recommendations have been presented that rep be placed in area with no valuable minerals, "it seems probably that a future person, who is capable of mining and drilling to a depth of 500m, also will use instruments capable of detecting radioactivity." p IV-57- KBS Rydberg & Winchester 1978, E9

6. Can we predict the likelihood of intrusion of people into rep in search of resources?

i) Uncertainities are introduced into risk assessments because of uncertainti of probabilities and consequences of human intrusion. p 4-94, ES of WM of LWR Cycle, NRC 1976, C8

ii) Another risk for which no trustworthy probability estimates can be applied-

intrusion at some future date by people in search of minerals (including the uranium and TRU buried in rep) or to satisfy archeological or other curiosity. People's unpredictability far outstrips that of most of the imagined geologic hazards, p. 35-36; as raw materials dwindle there will be an increasingly desperate exploitation of them. What mineral resource exploitation might be like a thousand years from now is impossible to predict - should be considered, p. 36-40, EPA State of Knowledge, 1978, C7

iii. Do we adequately understand how to evaluate current resource conflicts? models tested, applying to specific site (including WIPP), p. 38; Can we estimate the long term effects of future resource conflicts? moderate understanding of principles, developing models, p. 44, ESTP USGS and DOE 1979, D24

REFERENCES

A. National Academy of Sciences/National Research Council:

A1. NAS/NRC 1978 - "Geological Criteria for Repositories for High Level Radioactive Wastes", by the Panel on Geological Site Criteria, Committee on Radioactive Waste Management, August 1978

A2. NAS/NRC Bedded Salt 1970 - "Disposal of Solid Radioactive Wastes in Bedded Salt Deposits ", Committee on Radioactive Waste Management, Nov. 1970

A3. NAS/NRC Implementation of Standards 1979 - "Implementation of Long-Term Environmental Radiation Standards: The Issue of Verification", by the Panel on Implementation Requirements of Environmental Radiation Standards Committee on Radioactive Waste Management, 1979

B. U.S. Geological Survey:

B1. Pierce and Rich, "Summary of Rock Salt Deposits in the U.S. as Possible Storage Sites for Radioactive Waste Materials", Bulletin 1148, 1962

B2. USGS 4339-1, 1972 - Brokaw, Jones, Cooley and Hays, "Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, NM", Open file report 4339-1, 1972

B3. USGS 4339-5, 1973 - Merewether, Sharps, Gill and Cooley, "Shale, mudstc and claystone as potential host rocks for underground emplacement of waste", Open file report 4339-5, 1973

B4. USGS 4339-6, 1973 - Hite and Lohman, "Geologic appraisal of the Paradox Basin Salt Deposits for waste emplacement", Open file report 4339-6, 1973

B5. USGS 4339-7, 1973 - Jones, Cooley and Bachman, "Salt Deposits of the Los Medanos Area, Eddy and Lea Counties, NM", Open File report 4339-7, 1973

B6. USGS 74-60, 1974 - Jones, "Salt deposits of the Clovis-Portales area, East-Central NM," Open file report 74-60, 1974

B7. USGS 74-194, 1974 - Bachman, "Geologic processes and cenozoic history rela to salt dissolution in southeast NM", Open file report 74-194, 1974

B8. USGS 74-158, 1974 - Ekren, Dinwiddie, Mytton, Thordarson, Weir, Hinrichs and Schroder, "Geologic and hydrologic considerations for various concept of high level radioactive waste disposal in the conterminous U.S.", Open file report 74-158, 1974

B9. USGS 74-190, 1974 - Jones, "Salt deposits of the Mescalero Plains area, Chavez County, NM", Open file report, 74-190, 1974

B10. USGS ES Perspectives, 1978 - "Bredehoeft, England, Stewart, Trask and Winograd, "Geologic Disposal of High Level Radioactive Waste - Earth Science Perspectives", Circular 779, 1978

B11. Supplemental Areas, KnGS 1972 - "Preliminary Geological Investigations of Supplemental Radioactive Waste Repository Areas in the State of Kansas", Kansas Geological Survey, Jan. 1972

C. Nuclear Regulatory Commission/Environmental Protection Agency

C1. "Licensing Procedures for Geologic Repositories for High Level Waste", NRC, Proposed general statement of policy, Federal Register, Vol. 43, No. 223, Nov. 17, 1978

C2. EPA Crit for RW/Rec for Fed Guidance, Fed Reg 1978 - "Criteria for Radioactive Wastes/Recommendations for Federal Guidance", Federal Register, Nov. 15,1978, EPA

C3. AD Little Assessment 1978 - Arthur D. Little, Inc., "Subtask D: Assessment of Accidental Pathways/Technical Support for Radiation Standards for High Level Waste Management", Draft, done for EPA, Feb. 1978

C4. NRC State Review Nureg 0353 1977 - "Workshops for State Review of Site Suitability Criteria for High Level Radioactive Waste Repositories: Discussion Group Reports", NRC, Nureg-0353, Oct. 1977

C5. NRC State Review/Analysis, Nureg 0354 1978 - "Workshops for State Review of Site Suitability Criteria for High Level Radioactive Waste Repositories: Analysis and Recommendations", Volume I, Nureg 0354, Feb. 1978

C6. NRC Branch Technical Position 1977 - "Branch Technical Position: HLTWB-1 - Design/Performance Criteria for HL and TRU Waste Repositories", by the HL and TRU Waste Branch, NRC 1977

C7. EPA State of Knowledge 1978, "State of Geologic Knowledge Regarding Potential Transport of High Level Radioactive Waste from Deep Continental Repositories" Report of the Ad Hoc Panel of Earth Scientists, for EPA, 1978, EPA/520/4-78-004

C8. ES of WM of LWR Cycle, NRC 1976 - "Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle: A Task Force Report", NRC Nureg-0116, Oct 1976

C9. NRC Proposed Goals for RWM, 1978 - "Proposed Goals for Radioactive Waste Management", by a group of consultants organized by Sandia, for NRC, May 1978

C10. NRC Info Base for Rep Design 1979 - J.W. Bartlett and C.M. Koplick, Analytica Sciences Corporation, "Information Base for Waste Repository Design, Volume 7: Executive Summary", prepared for NRC, March 1979, NUREG/CR-0495

D. Oak Ridge National Laboratory, Sandia Lab., Battelle Memorial Lab, Battelle Pac Northwest Lab, Atomic Energy Commission, Energy Research and Development Agency, and the Department of Energy:

D1. ORNL Program Plan for BSPP, 1973 - "Program Plan for the Development of the Bedded Salt Pilot Plant", by the staff of the Salt Mine Repository Project, ORNL-TM-4233

D2. ORNL BSPP SS Factors 1973 - "Site Selection Factors for the Bedded Salt Pilot Plant", by the staff of the ORNL Salt Mine Repository Project, May 1973, ORNL-TM-4219

D3. ORNL McClain and Boch, 1974 - McClain and Boch, "Disposal of Radioactive Waste in Bedded Salt Formations", in Nuclear Technology, Vol. 24, Dec, 197

D4. ORNL Gera, Salt Tectonics GSA 1972 - Ferruccio Gera, Federal Repository Project, ORNL, "Review of Salt Tectonics in Relation to the Disposal of Radioactive Wastes in Salt Formations", in Geological Society of Ameri Bulletin, Vol. 83, Dec. 1972

D5. ORNL Gera and Jacobs Considerations for HLWM 1972 - F. Gera and D.G. Jacobs "Considerations in the Long-Term Management of High Level Radioactive Wast ORNL-4762, 1972 Feb.

D6. AEC ES Lyons, 1971 - "Environmental Statement - Radioactive Waste Repositor Lyons, Kansas", AEC, June 1971

D7. Braithwaite and Mollecke, "High Level Waste Canister Corrosion Studies Pertinent to Geologic Isolation", Dec. 1978, Sandia, SAND78-2111

D8. Deep Rock, Klett Sandia 1974 - Klett, "Deep Rock Nuclear Waste Disposal Test: Design and Operation", Sandia, Sept. 1974, SAND74-0042

D9. SSWIPP, Sandia 1977 - George B. Griswold, "Site Selection and Evaluation Studies of WIPP, Los Medanos, Eddy County, NM", Sandia Dec 1977, SAND77-09

D10. GCR 1978 - "Geological Characterization Report - WIPP site, Southeastern New Mexico", Volume I, August 1978, Sandia, SAND 78-1596

D11. Design Criteria, Sandia 1978 - "Design Criteria, WIPP : Revised Mission Concept", Draft Nov. 1978.

D12. "WIPP Conceptual Design Report", June, 1977, SAND 77-0274, Sandia

D13. Letter from E.H. Beckner, Nuclear Waste and Environmental Programs, Sandi to D.T. Schueler, WIPP Project Manager, DOE, Dec. 21, 1978

D14. Burkholder, Cloninger, Baker and Jansen , "Incentives for Partitioning of High Level Waste", BNWL, in Nuclear Technology, Vol. 31, Nov. 1976

D15. H.C. Burkholder, "The Reconcentration Phenomenon of Radionuclide Chain Migration", in Nuclear Waste Management and Transportation Quarterly Progress Report, January through March 1976, BNWL June 1976

D16. HLWM Alternatives, BNWL-1900, 1974 - K.J. Schneider and A.M. Platt, edito "High Level Radioactive Waste Management Alternatives, Volume II", BNWL-1900, May 1974

D17. ERDA/BNWL Alternatives Vol. 4, 1976 - "Alternatives for Managing Waste fr Reactors and Post-fission Operations in the LWR Fuel Cycle, Volume 4: Alternatives for Waste Isolation and Disposal", Report coordinated by BNWL, May 1976, ERDA-76-43

D18. ERDA/BNWL Alternatives App C 1976 - "Alternatives for Managing Wastes fro Reactors and Post-fission Operations in the LWR Fuel Cycle, Volume 5 Appendices", Report coordinated by BNWL for ERDA, May 1976, ERDA 76-

D19. OWI/ERDA Program Plan for NWTSP, 1976 - "National Waste Terminal Storage Pro Management and Technical Program Plan: for the period FY 1976-FY1978", Office of Waste Isolation, Union Carbide Corp. for ERDA, April 21, 1976

D20. Brunton and McClain, OWI/ERDA 1977 - G.D. Brunton and W.C. McClain, "Geological Criteria for Radioactive Waste Repositories", Office of Waste Isolation, Union Carbide Corp., prepared for ERDA, Nov. 28, 1977

D. 21. OWI/DOE Salt Dep of US 1978 - K.S. Johnson and S. Gonzalez, "Salt Deposits in the U.S. and Regional Characteristics Important for the Storage of Radioactive Wastes", Prepared for Office of Waste Isolation, Union Carbide, DOE, March 1978

D22. Desrosiers and Njoku, Risk Limit as Standard, 1978 or 9 - A.E. Desrosiers (BNWL) and E. Njoku (U. of Kansas), "The use of a risk limit as an environmental safety standard for radioactive waste disposal sites", under contract with DOE, 1978 or 1979

D23. Kehnemuyi, Battelle M, 1979 - Muzaffer Kehnemuyi, Battelle Memorial, Office of Nuclear Waste Isolation, "Site Qualifications and Site Selection Criteria for the Geologic Disposal of Nuclear Wastes", paper given at Tucson, AZ conference, Feb 26 - March 1, 1979

D24. ESTP USGS and DOE 1979 - "Earth Science Technical Plan for Mined Geologic Disposal of Radioactive Waste", by the Office of Nuclear Waste Management of DOE and the USGS, Jan. 1979, Draft TID-29018

E. Miscellaneous References

E1. AECL Canada 1975 - P.J. Dyne, "Waste Management in Canadian Nuclear Programs", paper given at the 15th annual International Conference, Canadian Nuclear Association, June 1975. Published by Atomic Energy of Canada Limited, Aug, 1975

E2. AECL Canada 1976 - H.Y. Tammemegi, Whiteshell Nuclear Research Establishment, "Geological Disposal of Radioactive Wastes - The Canadian Development Program" Atomic Energy of Canada Limited, May 1976

E3. McCarthy et al, Waste-rock interactions; Nature 1978 - McCarthy, White, R. Roy, Scheetz, Komarmeni, Smith, D.M. Roy, "Interactions between nuclear waste and surrounding rock", Penn. State U. , in Nature, Vol. 273, No. 5659, May 18, 1978

E4. Dade W. Mueller for the Advisory Committee on Reactor Safeguards, "Review of health physics research administered by the U.S. NRC", in Health Physics, Vol. 35, No. 3-A, Sept 1978

E5. de Marsily et al, Guarantee Isolation? 1977 - de Marsily, Ledoux, Barbreau and Margat, "Nuclear Waste Disposal: Can the Geologist Guarantee Isolation?" in Science, Vol 197, No. 4303, 4 August 1977

E6. Winchester, Long term geochem in crystalline 1978 - J.W. Winchester, Dept. of Oceanography, Florida State U., "Long term Geochemical Interactions of High Active Waste with Crystalline Rock Repository Media", Oct. 1978

E7. Krause and Randl, WM in W. Germany 1972 - H. Krause and R. Randl, "Treatment and Final Disposal of Radioactive Wastes from Fuel Reprocessing in the Federal Republic of Germany - A Survey of Policy and R&D Work", given at the IAEA-European Nuclear Energy Agency Symposium, in Paris, Nov. 27-Dec.1, 1972

E8. Kasperson et al, Handling Hazards 1978 - Fischhoff, Hohenemser, Kasperson Kates, "Handling Hazards", in Environment, Vol. 2, No. 7, Sept. 1978

E9. KBS Rydberg and Winchester 1978 - Rydberg and Winchester, "Disposal of High Active Nuclear Fuel Waste - a Critical Review of the Nuclear Fuel Safe (KBS) Project on Final Disposal of Vitrified High Active Nuclear Fuel Waste", Sweden, Industridepartementet Energikommissionen, DsI 1978:17

E10. T.B. Johansson and P. Steen, "Radioactive Waste from Nuclear Power Plants Facing the Ringhals-3 Decision", Sweden, 1978, Industridepartementet, DsI 1978:36

E11. IAEA SS Factors 1978 - "Site Selection Factors for Repositories of Solid High Level and Alpha-Bearing Wastes in Geological Formations", Technical Report Series, No. 177, International Atomic Energy Agency, 1977, STI/DOC/10/77

APPENDIX B

DOE REVISED INTERIM POLICY STATEMENT

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

DEC 23 1982

Dr. George S. Goldstein
Chairman, Radioactive Task Force
Health and Environment Department
P.O. Box 968
Santa Fe, NM 87503

Dear Dr. Goldstein:

DOE Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site

Enclosed for your use and information is the DOE Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site. Under the terms of this policy statement no potash or other commercial mining in, or commercial drilling from, Control Zones I, II and III will be allowed; however, the DOE will exercise no control over mining or drilling outside Control Zone III. (Control Zone III is being redefined as the area withdrawn for SPDV which is a square containing 16 sections (10,240 acres) surrounding the center of the site.) Additionally, BLM will prohibit permanent inhabitation of Zone IV while the facility is in operation. Hydrocarbon resources below 6000 ft. beneath Control Zones I, II and III can be accessed by deviated drilling from outside the Control Zone III boundary. The DOE will rely on the review of State and Federal regulatory agencies, including the New Mexico Energy and Minerals Department and the U.S. Department of the Interior, Minerals Management Service, to protect the integrity of the WIPP Site boundaries from commercial exploration, mining or other extractive activities. So that the DOE can maintain information on resource recovery near the WIPP Site, the Bureau of Land Management will notify the DOE of any requests for resource recovery permits within one mile of the WIPP Site boundary.

The final DOE policy will be issued when the decision is made regarding retrieval of the waste. Should the DOE decide to retrieve all the radioactive waste, the WIPP Site will become available for complete resource recovery after retrieval and decommissioning are complete.

The initial Interim Policy Statement, which was transmitted to the State of New Mexico on November 3, 1981, was developed to serve as the basis for the performance of the Natural Resources Study. The initial DOE

Interim Policy, as indicated therein, was "temporary denial of all resource extraction within the four control zones of the WIPP Site until the decision is made relative to which, if any, of the emplaced waste will be retrieved." Based on the conclusions of the Natural Resources Study, which was transmitted to the State of New Mexico on October 5, 1982, we have determined that the initial Interim Policy can be revised as indicated above.

Not only does the DOE Revised Policy Statement reflect the conclusions of the Natural Resources Study but it also addresses comments provided by the New Mexico Environmental Evaluation Group on the Policy Statement.

If you require additional information or have questions on this matter, please contact me.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

Enclosure

WIPP:JMM 82-0885/6366A

cc: w/encl:
J. K. Otts, Chairman, Radioactive Waste Consultation Committee, Santa Fe, NM
J. Bingaman, Attorney General, Santa Fe, NM
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DOE REVISED INTERIM POLICY STATEMENT ON RESOURCE RECOVERY AT THE WIPP SITE

The policy of the Department of Energy (DOE) concerning resource recovery at the Waste Isolation Pilot Plant (WIPP) site during facility construction and operation is as follows:

- No potash or other mining excluding that conducted for the WIPP Project will be allowed in WIPP Control Zones I, II, and III.

- No drilling excluding that conducted for the WIPP Project will be allowed from Control Zones I, II, and III.

- Drilling from outside Control Zone III to access locations beneath Control Zones I, II, and III at depths greater than 6,000 feet will be allowed if the planes formed by the downward vertical projections of the Control Zone III boundaries are not penetrated above a depth of 6,000 feet.

- DOE will rely on the review of State and Federal regulatory agencies, including the New Mexico Energy and Minerals Department and the Minerals Management Service, U.S. Department of the Interior, to protect the integrity of the WIPP site boundaries from commercial exploration, mining, and other extractive activities.

- If the DOE decides that all radioactive waste is to be retrieved, the WIPP site will become available for complete resource recovery once retrieval and facility decommissioning is accomplished.

This policy may be re-evaluated after facility decommissioning. The following paragraphs provide a measure of clarification of the rationale used to develop the resource recovery policy.

It is the policy of the DOE to maximize the opportunity for resource recovery at the WIPP site, consistent with the requirements to isolate the emplaced radioactive wastes from the biosphere. Within five years after the first emplacement of each type of TRU waste (i.e., contact and remotely handled), separate decisions will be made about the retrieval of each kind of waste. <u>If the DOE decides that all waste is to be retrieved, the WIPP site will become available for complete resource recovery once retrieval and facility decommissioning are accomplished.</u>

The criterion for the DOE policy is that permanent denial of resources should be limited to those areas in which extraction activities could potentially lead to measurable effects[1] on the WIPP facilities or whose protection is needed to satisfy institutional considerations, all extraction activities that would not lead to measurable effects on the WIPP site are defined as "allowable" under the DOE policy.

Potash (sylvite and langbeinite) and hydrocarbons (natural gas and distillate) comprise the resources present at the WIPP site that are of interest considering the technology and market conditions in the foreseeable future. These resources and the methods available to recover them are described in detail in the FEIS (U.S. Department of Energy, 1980).

---

1 Measureable effects are those influences from extraction activities that could cause the assumptions made in the breach scenario consequence analyses (U.S. Department of Energy, 1980) to be unconservative.

Due primarily to institutional considerations, no potash mining in or commercial exploratory drilling (hydrocarbon or other) from Control Zones I, II, and III will be permitted. A study was conducted to investigate the possible effects of resource recovery within Control Zone IV on the WIPP facility (Natural Resources Study, Brausch et al., 1982). The following paragraphs provide a brief summary of the results and conclusions of that study.

The extraction of potash outside Control Zone III is allowable. Potential methods of mining potash include drill-and-blast, continuous mining, solution mining, shortwall, and longwall techniques. Since mining of potash is allowable, it is not reasonable to prohibit those mining techniques that make such an activity economically viable. To prohibit such activities is, in effect, to preclude mining. Accordingly, extraction ratios can be maximized in any mines developed outside Control Zone III of the WIPP site, consistent with mine safety considerations and other state and federal requirements. Solution mining will be allowable outside Control Zone III. Resource extraction by solution mining may be applied to recovery of sylvite. Solution mining for recovery of langbeinite would be ineffective because langbeinite is less soluble than the surrounding minerals (e.g., halite, sylvite). However, the lack of existing solution mining for sylvite in the Carlsbad potash mining district suggests that solution mining for potash within Control Zone IV may not be feasible.

The recovery of hydrocarbon resources outside Control Zone III is allowable. This activity includes drilling, production stimulation, and, possibly, secondary recovery. Resources located outside Control Zone III may be accessed by vertical drilling; resources located beneath the inner three control zones at depths greater than 6,000 feet may be accessed by drilling vertically outside Control Zone III to a depth of 6,000 feet and then deviating from vertical at the angle required to reach the target resource zone.

If oil or gas is found, it is not reasonable to prohibit those techniques available to the producer that maximize recovery. Enhancing the production from drilled wells by hydraulically fracturing the reservoir rock, acidizing the formation, or other applicable techniques would not be expected to affect the WIPP facility.

These types of production stimulation are used primarily to increase the permeability of the rock that contains the hydrocarbons. Secondary recovery methods (techniques used to enhance or replace the natural driving force that "pushes" the oil to the production well) and tertiary methods (techniques used primarily to decrease the viscosity of heavy crude oils) may also be employed but, because the crude oil resources at the site are not reasonably or economically extractable, these techniques are not expected to be useful unless significant technological advances and adaptations are made.

State and federal regulatory agencies, including the New Mexico Energy and Minerals Department and the Minerals Management Service of the U.S. Department of Interior, are responsible for reviewing proposed mining and hydrocarbon exploration plans to prevent injury to adjacent leases or properties. The DOE will rely on this regulatory review process to protect the integrity of the WIPP site boundary from potash mining and hydrocarbon exploration on adjacent properties. The DOE will provide assistance to these agencies during the review process upon request. In addition, the BLM will notify the DOE of any requests for permits for resource recovery activities within one mile of the WIPP site boundary.

This policy will be modified if changes in institutional requirements occur or if significant new data relevant to the policy are obtained during development and operation of the WIPP facility.

APPENDIX C

FINAL ENVIRONMENTAL IMPACT STATEMENT
APPENDIX D,
SELECTION CRITERIA FOR THE WIPP SITE

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Appendix D

SELECTION CRITERIA FOR THE WIPP SITE

This appendix briefly describes how the geologic, hydrologic, and other characteristics of the WIPP site in southeastern New Mexico meet site-selection criteria and factors. The criteria and factors given here are from the Geological Characterization Report (Powers et al., 1978, pp. 2-15ff) and are based on criteria suggested earlier by the Oak Ridge National Laboratory (ORNL, 1973), the International Atomic Energy Agency (1977), and Brunton and McClain (1977).

The site-selection criteria described here were originally formulated under the expectation that the WIPP would be a repository that would contain spent fuel from nuclear reactors. The heat emitted by spent fuel would have had important effects on the salt in which it was emplaced; for that reason, some of the criteria were specifically intended to insure the safety of spent-fuel emplacement. The WIPP mission no longer includes the disposal of spent fuel or any other high-level waste. Furthermore, the design of the WIPP no longer includes the separate mined cavity for high-level waste called the "lower repository" or the "lower horizon" in the criteria. Accordingly, not all the criteria presented here are applicable to the WIPP under its current mission and design. Because the site was, however, actually selected under these criteria, no effort has been made to revise them for this document.

D.1 GEOLOGIC CRITERION AND SITE-SELECTION FACTORS

The geology of the site will be such that the repository will not be breached by natural phenomena while the waste poses a significant hazard to man. The geology must also permit safe operation of the WIPP repository.

Topography. The terrain must permit access for transportation. The effect on inducing salt flow during excavation must be considered. Surface-water flow and the potential for flooding must be evaluated.

The maximum relief over the WIPP repository is 120 feet. The regional relief is low and easily accommodates the required transportation corridors. The location near a broad surface and groundwater divide will minimize the development of future relief. Differential stress in the salt due to surface relief is not a significant factor in causing deformation in the salt. (See Powers et al., 1978, Sections 3.2 and 4.2.)

Depth. Repository horizons should be deeper than 1000 feet to insure that erosion and consequences of surficial phenomena are not a major concern. The depth of suitable horizons will not exceed 3000 feet to limit the rate of salt deformation around the excavations.

The selected repository bed for heat-producing waste varies between depths of 2750 and 2250 feet over the potential excavation area. The bed for TRU

waste ranges from 2200 to 1800 feet deep through the repository region. These depths are based on interpretations of seismic reflection data. (See Powers et al., 1978, Sections 3.3, 4.3, and 9.2.)

Thickness. The total thickness of the salt deposits should be several hundred feet to buffer thermal and mechanical effects. The desired thickness for the repository bed is 20 feet or more to mitigate the thermal and mechanical effects at nonhalite units.

The halite unit in which the heat-producing waste will be placed is about 100 feet thick. The total thickness of the evaporite section provides about a 1300-foot buffer above and below the repository horizons. This distance to the nearest potential aquifers insures that the thermal effects at these aquifers will be insignificant. (See Powers et al., 1978, Sections 4.3.2 and 9.2.)

Lateral extent. The distance to structural or dissolution boundaries must be adequate to provide for future site integrity. For the Los Medanos area a distance of 5 miles to the Capitan reef and 1 mile to regional Salado dissolution has been established.

From seismic data and drill-hole information, the selected horizons are believed to extend well beyond the repository site. The separations from the deformed salt belt parallel to the Capitan reef and from the natural dissolution fronts are adequate to insure the required site integrity. (See Powers et al., 1978, Sections 3.3, 4.3, and 6.3.)

Lithology. Purity of the salt beds is desirable. Brine in the salt could induce geochemical interactions; pending further investigations, 3% brine is established as a desirable upper limit for the heat-producing waste horizon. Additional geochemical interactions must be considered if significant chemical or mineral impurities are present.

The horizon within the lower Salado that will accommodate the heat-producing wastes averages more than 97% halite from the samples analyzed. Brine content averages less than 0.5%. (See Powers et al., 1978, Sections 4.3 and 7.2 through 7.6.)

Stratigraphy. Continuity of beds, character of interbedding, and nature of beds overlying and underlying the salt are important considerations in the construction of the facility; they are also important in insuring the long-term integrity of the repository.

There are no beds of clay or polyhalite near enough to the lower repository horizon to affect repository construction and operation or to affect the long-term performance of the repository. The significant nonhalite beds adjacent to the heat-producing-waste horizons are principally anhydrite, which has favorable thermal, mechanical, and chemical properties for bounding layers. The upper (TRU-waste) level of the repository can also be located to avoid rock-mechanics instabilities due to interbeds of nonhalite rock. (See Powers et al., 1978, Sections 3.3, 3.4, 4.3, and 4.4.)

Structure. Relatively flat bedding (less than 3 degrees) is desirable for operational purposes. Steep anticlines and major faults are to be avoided.

Seismic-reflection data and drill-hole information have been interpreted as showing relatively flat (less than 1 degree) bedding over most of the 3-square-mile repository horizon. Seismic data do show a small anticline at the northern edge of control zone II. Drilling on this anticline (WIPP-12) has shown that the elevation difference of the repository beds, from ERDA-9 at the center of the repository to WIPP-12, is less than 200 feet, an average of about 2 degrees. Photography, satellite imagery, surface mapping, geophysical techniques, and drilling have been used to search for indications of significant faulting. No post-Permian faults are known to exist in the site area. Seismic indications of faulting in older, deeper rocks do not extend through the Permian evaporite section.

The lack of severe structure and recent faulting satisfactorily meets the desired conditions for this factor. (See Powers et al., 1978, Sections 3.4 and 4.4.)

Erosion. While the depth of the repository reduces concern about erosion, it is desirable to avoid features that would tend to localize or accelerate erosion.

The site is located near a broad surface-water divide, and the local base level is at an elevation of about 2900 feet. Consequently, future erosion will proceed less rapidly over the site than in the established drainage channels. The expected erosion rates will not expose the Salado salt within the required lifetime of the repository. Future climatic changes will not alter this assessment, and glaciation is not expected to be a concern at this location. (See Powers et al., 1978, Sections 3.2.3, 3.6, 4.2, and 6.2.)

Dissolution. Regional and/or local dissolution must not breach the repository while the wastes represent a significant hazard to people. While there are various suggestions for the time a repository should remain isolated from the biosphere, a period of 250,000 years (10 half-lives of plutonium-239) is commonly used to represent the time over which the wastes are significantly hazardous.

Studies by the U.S. Geological Survey indicate that the maximum rate of horizontal progression of the salt-dissolution front in Nash Draw, averaged over the past 500,000 years, has been 6 to 8 miles per million years and less than 500 feet vertically per million years. The nearest active solution front is to the west, in Nash Draw. This is far enough from the site to provide repository isolation for more than 2 million years. (See Powers et al., 1978, Section 6.3.6.)

Subsidence. Subsidence due to dissolution of salt will be avoided when the subsidence adversely affects the repository beds or unduly accelerates the rate of dissolution to the jeopardy of the long-term integrity of the repository.

Subsidence has occurred over the western portion of the WIPP site area because of the natural removal of salt from the Rustler Formation. Hydrologic data from this region indicate that the major aquifers in the Rustler have different potential heads, and thus this regional subsidence has not caused them to be interconnected by permeable fractures. No sinks due to localized solutioning are present at the site.

D.2 HYDROLOGIC CRITERION AND SITE-SELECTION FACTORS

The hydrology of the site must provide high confidence that natural dissolution will not breach the site while the waste poses a significant hazard to man. Accidental penetrations should not result in undue hazards to mankind.

Surface water. Present and future runoff patterns, flooding potential, etc., should not endanger the penetrations into the repository while these openings are unplugged.

Because the site is near a broad surface-water divide, lacks established drainage, and is well above the Pecos River, simple construction techniques will prevent flooding of the repository. (See Powers et al., 1978, Section 6.2.)

Aquifers. For the WIPP, the overlying and underlying aquifers represent a secondary barrier if the salt is breached. Consequently, low permeability and transmissivity are desirable but not mandatory. Accurate knowledge of aquifer parameters is important to construction, decommissioning, and realistic calculation of the consequences of failure scenarios.

Aquifers above and below the repository have low transmissivity. Consequently, flooding of the repository during its operation through shafts or drill holes is not credible. These access points can readily be plugged to prevent water inflow after decommissioning.

The quantity of water carried by the major aquifers above and below the WIPP beds is too small to be useful. Furthermore, the water carries too many salts to be potable or otherwise useful.

The hydrologic parameters of the aquifers do not permit rapid flow of water. The low permeability would limit the flow even if heads were to be modified in future pluvial cycles. (See Powers et al., 1978, Section 6.3.)

Hydrologic transport. For the WIPP, this is a secondary factor that must be evaluated to allow quantitative calculations of the consequences of various failure scenarios. Slow transport of isotopes is acceptable if more critical factors have been satisfied.

Calculations based on various postulated failure scenarios show that the transport of radionuclides through the overlying and underlying aquifers would be so slow that a significant hazard to people would not exist even if the salt beds were breached. The nearest natural discharge point is near Malaga Bend on the Pecos River, over 14 miles away. At the maximum measured rate of water movement, it would take about 1700 years after a breach for the first trace of nonretarded nuclides (i.e., iodine-129) to appear at the Pecos. The long-lived transuranic nuclides would be retarded by the sorption of ions and would not begin to appear at Malaga Bend until 35,000 years after a postulated breach of the salt beds. The concentrations of radionuclides (or possible radiation doses) would never reach significant hazard levels in the Pecos River. (See Powers et al., 1978, Sections 6.3, 9.3, and 10.6.)

Climatic fluctuations. Possible pluvial cycles must be considered in estimating the effects of the hydrologic factors.

The dissolution and erosion rates established as averages over the past 500,000 years include the effects of several past pluvial cycles. It is expected that future cycles would also be shorter than the isolation time sought for the repository. Transport rates under different climates (rainfall) can be estimated by appropriate boundary conditions on the hydrologic model. The low permeability of the major aquifers above the site will not be significantly altered by the climatic changes expected for this area, and the resultant flow in the aquifers will not be grossly altered by changed climatic conditions. (See Powers et al., 1978, Sections 3.6 and 4.5, Chapter 6, and Section 10.3.)

Man-made penetrations. The effect of drill holes and mining operations must be included in evaluating the potential effects of dissolution.

The repository and control zone III are free of preexisting boreholes that extend through the salt, shafts, and mining activity. Any existing or future holes in any of the WIPP zones must be adequately plugged when abandoned.

D.3 TECTONIC STABILITY CRITERION AND SITE-SELECTION FACTORS

Natural tectonic processes must not result in a breach of the site while the wastes represent a significant hazard to people and should not require extreme precautions during the operational period of the repository.

Seismic activity. The frequency and magnitude of seismic activity impact facility design and safety of operation. Low levels of seismicity are desirable, but facility design can accommodate higher levels as well.

The WIPP site is in an area of relatively low seismic activity. The nearest seismic activity has been 10 or more miles north of the site and of small magnitude. It is not known whether the three nearest events were tectonic, related to salt dissolution, or a result of human activity. No faulting has been observed in the area of these seismic events. In any case, they and the potential future events pose no hazard for a properly constructed repository and are no threat to its long-term integrity. (See Powers et al., 1978, Chapter 5 and Section 10.5.)

Faulting and fracturing. While open faults, fractures, or joints are not expected in salt, the more brittle units within and surrounding the salt may support such features that can enhance dissolution and hydrologic transport. Major faults and pronounced linear structural trends should be avoided.

No major structural trends of recent geologic age are known to exist in the site area. The nearest recent faulting observed is on the west side of the Guadalupe Mountains, some 70 miles away. Seismic-reflection data have indicated small faults in deep, old rocks below the Salado Formation. There are no known tectonic faults in post-Permian rocks at the site area. Thousands of miles of drift in the potash mines in the Salado salt have not encountered any open fractures or faults through which groundwater had penetrated.

D.4 PHYSICOCHEMICAL COMPATIBILITY CRITERION AND SITE-SELECTION FACTORS

The repository medium must not interact with the waste in ways that create unacceptable operational or long-term hazards.

Fluid content. The repository bed containing high-level waste should not contain more than 3% brine. The limit for TRU waste has not been established, but the value used for high-level waste is acceptable.

The average brine content of the lower repository is less than 0.5% by weight. The average brine content of the upper repository horizon beds is less than 1% by weight. (See Powers et al., 1978, Sections 7.5 and 10.7.8.)

Thermal properties. To avoid undesirable temperature rises, no major natural thermal barriers should exist closer than 20 feet of the repository horizons.

This is of significance to the lower horizon, where the halite unit of interest is about 100 feet thick. The adjoining beds are anhydrite, which, even though far enough away, has similar thermal conductivity and does not represent a thermal barrier in any case. (See Powers et al., 1978, Section 9.2.3.)

Mechanical properties. The medium must safely support excavation of openings even while thermally loaded. Clay seams and zones of unusual structural weakness should be avoided in the selection of the repository horizon.

The halite bed at the lower level is sufficiently thick and devoid of clay seams that stability of openings will not be a problem for repository operation. Clay seams and polyhalite beds are more common in the area selected for the upper repository level, but construction levels can be located to avoid significant structural stability problems from such nonhalite beds. (See Powers et al., 1978, Section 9.2.4.)

Chemical properties and mineralogy. Beds that are of unusual composition or contain minerals with bound water should not occur within 20 feet of the waste horizon. This will lessen the uncertainties with regard to thermally driven geochemical interactions.

The heat-producing waste horizon is quite pure halite, with more than 97% NaCl. No polyhalite, clay, or other water-bearing minerals occur near this horizon. The upper horizon beds are more than 92% NaCl, with impurities being mostly potassium and magnesium salts and clay. These impurities have no known negative implications for TRU-waste isolation and, in fact, have been shown to absorb radionuclides from brine. (See Powers et al., 1978, Sections 4.3 and 7.2 through 7.5.)

Radiation effects. While no unacceptably deleterious effects are postulated, these phenomena are best quantified in halite, and thus the purer rock salt beds are desired for high-level waste.

Salt-flow anticlines. Major deformation of salt beds by flow can fracture brittle rock and create porosity for brine accumulations. Major anticlines resulting from salt flow should be avoided or evaluated to check on brine presence and anhydrite fracturing.

The only anticlines within the site are relatively minor features. Both have been drilled, however, and the cores show little fracturing or porosity and no accumulation of fluids. These small anticlines will not hinder repository construction or jeopardize its long-term safety. (See Powers et al., 1978, Section 4.4.)

Diapirism. An extreme result of salt flow, this feature will be avoided for WIPP siting.

There are no known or indicated diapirs (salt domes) at the WIPP site. (See Powers et al., 1978, Section 4.4.)

Regional stability. Areas of pronounced regional uplift or subsidence should be avoided since such behavior makes prediction of future dissolution, erosion, and salt flow more uncertain.

Geologic mapping has failed to reveal any indicators of regional instability. Caliche formation and attitude indicate stable conditions in the site region over the last half-million years. The lack of scarps and the natural seismicity are consistent with regional stability. (See Powers et al., 1978, Sections 3.4, 4.4, and 10.3.2.)

Igneous activity. Areas of active or recent volcanism or igneous intrusion should be avoided to minimize these hazards to the repository.

No recent igneous activity is known in the region. Geophysical surveys, mining, and drill-hole intercepts have shown that an intrusive dike exists 9 miles northwest of the site. Radiometric dating shows it to be 35 million years old. No other intrusive features are known to exist in the region. (See Powers et al., 1978, Section 3.5.)

Geothermal gradient. Abnormally high geothermal gradients should be avoided to allow construction in salt at 3000 feet. High gradients may also be indicative of recent igneous or tectonic activity.

The geothermal gradient as determined in the AEC-8 drill hole shows a normal geothermal gradient averaging about 0.58°F per 100 feet. The heat flow is about one heat-flow unit. (See Powers et al., 1978, Section 4.4.1.)

Samples of WIPP salt show no characteristics that would produce undesirable effects under irradiation. The low brine content will limit the amount and effects of radiolytic disassociation of water. (See Powers et al., 1978, Chapter 9.)

Permeability. Salt has a very low permeability. It is necessary to evaluate the permeability only of the interbeds and the surrounding media. Low permeability is desirable, but quantitative limits need not be specified for site selection. Salt permeability to gases may be important in establishing waste-acceptance criteria.

Laboratory measurements on cores show very low permeability. On a large scale, measurements at the WIPP horizons have not been made. Experience in other drill holes (absence of aquifers in salt and presence of small high-pressure gas pockets) would argue for very low in-situ permeability on larger scales. (See Powers et al., 1978, Section 9.2.3.)

Nuclide mobility. This is a secondary factor in siting since confinement by the salt and isolation from water are the basic isolation premises. Ion sorption must be determined to allow quantification of safety analyses and to indicate whether engineered barriers (clay) would be beneficial.

The distributed impurities in the rock salt provide significant ion-sorption capability for many radionuclides. The clay layers in higher salt beds will be still more sorptive. These properties will tend to minimize radionuclide migration due to such local mechanisms as brine migration in thermal gradients. (See Powers et al., 1978, Section 9.3.)

D.5 ECONOMIC AND SOCIAL COMPATIBILITY CRITERION AND SITE-SELECTION FACTORS

The site must be operable at reasonable economic cost and should not create unacceptable impacts on natural resources or the biological and social environment.

Natural resources. Unavoidable conflict of the repository with actual or potential resources will be minimized to the extent possible.

This factor is not well satisfied by the WIPP site. Both hydrocarbons and potash exist in potentially economic quantities within the site. While salt itself may be considered a valuable mineral, its economic potential at the site is very low. Since both potash and hydrocarbons may be recovered from control zone IV, the amounts that may be restricted from development within zones I, II, and III are the critical amounts. These quantities are not large in terms of national supply (even the langbeinite product is synthesized in quantity from brine lakes). These minerals may prove an enticement for future exploration and exploitation. For this reason, studies are under way to examine the effects of recovering the potash ore from above control zone III. Very little potash exists above the repository (zone II) itself. Similarly, once adequate borehole plugging is demonstrated, drilling in zone III could be permitted or the same zones developed from zone IV by slant drilling. The expectation, but one that cannot yet be guaranteed, is that these minerals may

be recovered in the decades ahead should they be economically attractive. Certainly the time frame for their development would be within the next century, while the site is still under administrative control. The small amounts of either resource within zone III would not be of significant interest in the absence of other production in the area. (See Powers et al., 1978, Chapter 8.)

Man-made penetrations. Boreholes or shafts that penetrate through the salt into underlying aquifers will be avoided within 1 mile of the repository. Existing mining activity, unrelated to the repository, should not be present within 2 miles of the repository. Future, controlled mining will be allowable up to 1 mile from the repository. Future studies may permit still closer mining and drilling if properly controlled.

The present site adequately fulfills this present restriction on man-made penetrations. (See Powers et al., 1978, Section 2.3 and Chapter 4.)

Transportation. Transportation should be capable of ready development. Avoidance of population centers by transportation routes is not a factor in the siting of the repository.

The present site meets this requirement and would utilize a spur line of the Santa Fe Railroad now running to the Duval mine.

Accessibility. The site should be readily accessible for transportation and utilities.

The site presents no problems for access by road, railroad, or utility lines.

Land jurisdiction. Siting will be on Federal land to the extent possible.

Of the 18,960 acres to be withdrawn by the DOE if this site is approved, 17,200 are Federal land controlled by the Bureau of Land Management and 1760 acres belong to the State of New Mexico. There are no private lands within the site.

Population density. Proximity to population centers and rural habitats will be considered in siting. A low population density in the immediate site area is desirable.

There are 16 permanent residents within 10 miles of the site. There is a transient population at potash mines. The nearest town is Loving, New Mexico, with a population of 1600. Carlsbad is 26 miles west and has a population of 28,600. Low population is not necessary to siting but, all other factors being equal, is desirable.

Effects on ecology and cultural resources. Major impacts on ecology due to construction and operation should not occur. Archaeological and historic features of significance should be preserved.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix IRES

M

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Intermediate Results

M

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ACRONYMS

DRZ	disturbed rock zone
EPA	U.S. Environmental Protection Agency
FMT	fracture matrix transport
WIPP	Waste Isolation Pilot Plant
LHS	Latin hypercube sample

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APPENDIX IRES

IRES.1 Latin Hypercube Sample Sampled Values and Ranks

Table IRES-1 shows the 57 parameters that were sampled in Latin hypercube sample (LHS). Tables IRES-2, IRES-3, and IRES-4 show the 100 values sampled by LHS for the 57 parameters that were varied in the 1996 performance assessment calculations, replicates #1, #2, and #3, respectively. Tables IRES-5, IRES-6, and IRES-7 show the ranks of the 100 values sampled, replicates #1, #2, and #3, respectively.

Table IRES-1. Parameters Sampled in LHS Code

LHS #	Id #	Material	Material Description	Parameter	Parameter Description	Distribution Type	Units	Mean	Median	Low	High	Standard Deviation
1	2907	STEEL	Generic steel in waste	CORRMCO2	Inundated corrosion rate for steel without CO2 present	UNIFORM	m/s	7.9370E-15	7.9370E-15	0	1.5870E-14	0
2	2823	WAS_AREA	Waste emplacement area and waste	PROBDEG	Prob. of plastics&rubber biodegradation in event of significant microbial gas generation	DELTA	NONE	2.0000E+00	2.0000E+00	0	2.0000E+00	0
3	657	WAS_AREA	Waste emplacement area and waste	GRATMICI	Biodegradation rate, inundated conditions	UNIFORM	mol/kg*s	4.9150E-09	4.9150E-09	3.1710E-10	9.5129E-09	0
4	656	WAS_AREA	Waste emplacement area and waste	GRATMICH	Biodegradation rate, humid conditions relative to inundated rate	UNIFORM	mol/kg*s	6.3420E-10	6.3420E-10	0	1.2684E-09	0
5	2994	CELLULS	Cellulose	FBETA	Factor beta for microbial reaction rates	UNIFORM	NONE	5.0000E-01	5.0000E-01	0	1.0000E+00	0.29
6	671	WAS_AREA	Waste emplacement area and waste	SAT_RGAS	Residual Gas Saturation	UNIFORM	NONE	7.5000E-02	7.5000E-02	0	1.5000E-01	0.04
7	670	WAS_AREA	Waste emplacement area and waste	SAT_RBRN	Residual Brine Saturation	UNIFORM	NONE	2.7600E-01	2.7600E-01	0	5.5200E-01	0.16
8	2231	WAS_AREA	Waste emplacement area and waste	SAT_WICK	Index for computing wicking	UNIFORM		5.0000E-01	5.0000E-01	0	1.0000E+00	0.29
9	2334	CL_L_T1	Lower Salado clay: 0 to 10 years	PRMX_LOG	Log of intrinsic permeability, X-direction	TRIANGULAR	log(m^2)	-1.8867E+01	-1.8301E+01	-2.1000E+01	-1.7301E+01	0.78
10	2470	CONC_T1	Concrete column: 0 to 400 years	PRMX_LOG	Log of intrinsic permeability, X-direction	TRIANGULAR	log(m^2)	-1.8816E+01	-1.8750E+01	-2.0699E+01	-1.7000E+01	0.76
11	2283	ASPHALT	Asphalt column	PRMX_LOG	Log of intrinsic permeability, X-direction	TRIANGULAR	log(m^2)	-1.9667E+01	-2.0000E+01	-2.1000E+01	-1.8000E+01	0.62
12	3133	SHFT_DRZ	Shaft disturbed Rock Zone	PRMX_LOG	Log of intrinsic permeability, X-direction	TRIANGULAR	log(m^2)	-1.5333E+01	-1.5000E+01	-1.7000E+01	-1.4000E+01	0.62
13	2939	SALT_T1	Shaft salt column compacted: time 0 to 10 years	CUMPROB	Cumulative Probability	UNIFORM	NONE	5.0000E-01	5.0000E-01	0	1.0000E+00	0.29
14	2529	SALT_T1	Shaft salt column compacted: time 0 to 10 years	SAT_RGAS	Residual Gas Saturation	UNIFORM	NONE	2.0000E-01	2.0000E-01	0	4.0000E-01	0.12
15	2528	SALT_T1	Shaft salt column compacted: time 0 to 10 years	SAT_RBRN	Residual Brine Saturation	CUMULATIVE	NONE	2.5000E-01	2.0000E-01	0	6.0000E-01	0.18

Table IRES-1. Parameters Sampled in LHS Code (Continued)

LHS #	Id #	Material	Material Description	Parameter	Parameter Description	Distribution Type	Units	Mean	Median	Low	High	Standard Deviation
16	2516	SALT_T1	Shaft salt column compacted: time 0 to 10 years	PORE_DIS	Brooks-Corey pore distribution parameter	CUMULATIVE	NONE	2.5200E+00	9.4000E-01	1.1000E-01	8.1000E+00	2.48
17	544	S_HALITE	Salado halite, intact	POROSITY	Effective porosity	CUMULATIVE	NONE	1.2800E-02	1.0000E-02	1.0000E-03	3.0000E-02	0.01
18	547	S_HALITE	Salado halite, intact	PRMX_LOG	Log of intrinsic permeability, X-direction	UNIFORM	log(m^2)	-2.2500E+01	-2.2500E+01	-2.4000E+01	-2.1000E+01	0.87
19	541	S_HALITE	Salado halite, intact	COMP_RCK	Bulk Compressibility	UNIFORM	Pa^-1	9.7500E-11	9.7500E-11	2.9400E-12	1.9200E-10	0.00
20	591	S_MB139	Salado marker bed 139, intact and fractured	PRMX_LOG	Log of intrinsic permeability, X-direction	STUDENT	log(m^2)	-1.8890E+01	-1.8890E+01	-2.1000E+01	-1.7100E+01	1.20
21	580	S_MB139	Salado marker bed 139, intact and fractured	COMP_RCK	Bulk Compressibility	STUDENT	Pa^-1	8.2630E-11	8.2630E-11	1.0900E-11	2.7500E-10	0.00
22	596	S_MB139	Salado marker bed 139, intact and fractured	RELP_MOD	Model number, relative permeability model	DELTA	NONE	4.0000E+00	4.0000E+00	1.0000E+00	4.0000E+00	0.00
23	598	S_MB139	Salado marker bed 139, intact and fractured	SAT_RBRN	Residual Brine Saturation	STUDENT	NONE	8.3630E-02	8.3630E-02	7.8460E-03	1.7400E-01	0.05
24	599	S_MB139	Salado marker bed 139, intact and fractured	SAT_RGAS	Residual Gas Saturation	STUDENT	NONE	7.7110E-02	7.7110E-02	1.3980E-02	1.9719E-01	0.06
25	587	S_MB139	Salado marker bed 139, intact and fractured	PORE_DIS	Brooks-Corey pore distribution parameter	STUDENT	NONE	6.4360E-01	6.4360E-01	4.9053E-01	8.4178E-01	0.11
26	546	S_HALITE	Salado halite, intact	PRESSURE	Brine far-field pore pressure	UNIFORM	Pa	1.2470E+07	1.2470E+07	1.1040E+07	1.3890E+07	823000.00
27	66	CASTILER	Castile Brine Reservoir	PRESSURE	Brine far-field pore pressure	TRIANGULAR	Pa	1.3600E+07	1.2700E+07	1.1100E+07	1.7000E+07	1245700.00
28	67	CASTILER	Castile Brine Reservoir	PRMX_LOG	Log of intrinsic permeability, X-direction	TRIANGULAR	log(m^2)	-1.2100E+01	-1.1800E+01	-1.4700E+01	-9.8000E+00	1.01
29	61	CASTILER	Castile Brine Reservoir	COMP_RCK	Bulk Compressibility	TRIANGULAR	log(Pa^-1)	-9.8000E+00	-1.0000E+01	-1.1300E+01	-8.0000E+00	0.68
30	3184	BH_SAND	Borehole filled with silty sand	PRMX_LOG	Log of intrinsic permeability, X-direction	UNIFORM	log(m^2)	-1.2500E+01	-1.2500E+01	-1.4000E+01	-1.1000E+01	0.87
31	3194	CASTILER	Castile Brine Reservoir	GRIDFLO	Index for selecting a Brine Pocket	DELTA	NONE	1.6000E+01	1.6000E+01	1.0000E+00	3.2000E+01	0.00
32	3246	BLOWOUT	BRAGFLO Direct Brine Releases	PARTDIA	Logarithm of waste particle diameter in CUTTINGS model	LOGUNIFORM	m	2.3500E-02	2.8000E-03	4.0000E-05	2.0000E-01	0.04
33	2254	BOREHOLE	Borehole and Fill	TAUFAIL	Effective shear strength for erosion (rfail)	UNIFORM	Pa	5.0300E+00	5.0300E+00	5.0000E-02	1.0000E+01	2.90

Table IRES-1. Parameters Sampled in LHS Code (Continued)

LHS #	Id #	Material	Material Description	Parameter	Parameter Description	Distribution Type	Units	Mean	Median	Low	High	Standard Deviation
34	3419	CULEBRA	Culebra member of the Rustler formation	MINP_FAC	Mining Transmissivity Multiplier	UNIFORM	NONE	5.0050E+02	5.0050E+02	1.0000E+00	1.0000E+03	288.40
35	225	GLOBAL	Information that applies globally	TRANSIDX	Index for selecting realizations of the Transmissivity Field	UNIFORM	NONE	5.0000E-01	5.0000E-01	0.0000E+00	1.0000E+00	0.29
36	3262	SOLAM3	Solubility of Americium in oxidation state III	SOLSIM	Solubility in Salado brine, inorganic chemistry controlled by the Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
37	3263	SOLAM3	Solubility of Americium in oxidation state III	SOLCIM	Solubility in Castile brine inorganic with chemistry controlled by Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
38	3265	SOLPU3	Solubility of Plutonium in oxidation state III	SOLSIM	Solubility in Salado brine, inorganic chemistry controlled by the Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
39	3264	SOLPU3	Solubility of Plutonium in oxidation state III	SOLCIM	Solubility in Castile brine inorganic with chemistry controlled by Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
40	3266	SOLPU4	Solubility of Plutonium in oxidation state IV	SOLSIM	Solubility in Salado brine, inorganic chemistry controlled by the Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
41	3389	SOLPU4	Solubility of Plutonium in oxidation state IV	SOLCIM	Solubility in Castile brine inorganic with chemistry controlled by Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
42	3390	SOLU4	Solubility of Uranium in oxidation state IV	SOLSIM	Solubility in Salado brine, inorganic chemistry controlled by the Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
43	3391	SOLU6	Solubility of Uranium in oxidation state VI	SOLSIM	Solubility in Salado brine, inorganic chemistry controlled by the Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37

Table IRES-1. Parameters Sampled in LHS Code (Continued)

LHS #	Id #	Material	Material Description	Parameter	Parameter Description	Distribution Type	Units	Mean	Median	Low	High	Standard Deviation
44	3392	SOLU6	Solubility of Uranium in oxidation state VI	SOLCIM	Solubility in Castile brine inorganic with chemistry controlled by Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
45	3393	SOLTH4	Solubility of Thorium in oxidation state IV	SOLSIM	Solubility in Salado brine, inorganic chemistry controlled by the Mg(OH)2-MgCO3	CUMULATIVE	NONE	1.8000E-01	-9.0000E-02	-2.0000E+00	1.4000E+00	0.37
46	3429	PHUMOX3	Proportionality constant with humic colloids for actinide in oxidation state III	PHUMCIM	Proportionality constant of actinides in Castile brine w/ humic colloids, inorgan	CUMULATIVE	moles/liter	1.1000E+00	1.3700E+00	6.5000E-02	1.6000E+00	0.47
47	3417	GLOBAL	Information that applies globally	OXSTAT	Index for Oxidation Solubilities	UNIFORM	NONE	5.0000E-01	5.0000E-01	0.0000E+00	1.0000E+00	0.29
48	223	GLOBAL	Information that applies globally	CLIMTIDX	Climate Index	CUMULATIVE	NONE	1.3100E+00	1.1700E+00	1.0000E+00	2.2500E+00	0.35
49	3485	CULEBRA	Culebra member of the Rustler formation	HMBLKLT	Culebra Half Matrix-Block Length	UNIFORM	m	2.7500E-01	2.7500E-01	5.0000E-02	5.0000E-01	0.13
50	3487	CULEBRA	Culebra member of the Rustler formation	APOROS	Culebra Advective Porosity	LOGUNIFORM	NONE	2.1000E-03	1.0000E-03	1.0000E-04	1.0000E-02	0.00
51	3486	CULEBRA	Culebra member of the Rustler formation	DPOROS	Diffusive Porosity for Culebra Dolomite	CUMULATIVE	NONE	1.6000E-01	1.6000E-01	1.0000E-01	2.5000E-01	0.04
52	3475	U+6	Uranium VI	MKD_U	Matrix Distribution Coefficient for Uranium	UNIFORM	m^3/kg	1.5000E-02	1.5000E-02	3.0000E-05	3.0000E-02	0.01
53	3479	U+4	Uranium IV	MKD_U	Matrix Distribution Coefficient for Uranium	UNIFORM	m^3/kg	1.0000E+01	1.0000E+01	9.0000E-01	2.0000E+01	5.50
54	3480	PU+3	Plutonium III	MKD_PU	Matrix Distribution Coefficient for Plutonium	UNIFORM	m^3/kg	2.6000E-01	2.6000E-01	2.0000E-02	5.0000E-01	0.14
55	3481	PU+4	Plutonium IV	MKD_PU	Matrix Distribution Coefficient for Plutonium	UNIFORM	m^3/kg	1.0000E+01	1.0000E+01	9.0000E-01	2.0000E+01	5.50
56	3478	TH+4	Thorium IV	MKD_TH	Matrix Distribution Coefficient for Thorium	UNIFORM	m^3/kg	1.0000E+01	1.0000E+01	9.0000E-01	2.0000E+01	5.50
57	3482	AM+3	Americium III	MKD_AM	Matrix Distribution Coefficient for Americium	UNIFORM	m^3/kg	2.6000E-01	2.6000E-01	2.0000E-02	5.0000E-01	0.14

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1

LHS#	Material	Parameter	1	2	3	4
1	STEEL	CORRMCO2	2.297E-15	6.448E-15	1.106E-14	1.249E-14
2	WAS_AREA	PROBDEG	2	0	1	0
3	WAS_AREA	GRATMICI	7.81E-09	9.2E-09	7.863E-09	7.367E-10
4	WAS_AREA	GRATMICH	4.714E-10	8.844E-10	5.903E-10	9.714E-10
5	CELLULS	FBETA	0.6023	0.2903	0.2791	0.7284
6	WAS_AREA	SAT_RGAS	0.001259	0.1096	0.1166	0.06413
7	WAS_AREA	SAT_RBRN	0.4607	0.2286	0.442	0.1831
8	WAS_AREA	SAT_WICK	0.9356	0.4746	0.6929	0.6383
9	CL_L_T1	PRMX_LOG	-17.96	-18.18	-18.23	-17.48
10	CONC_T1	PRMX_LOG	-19.84	-19.64	-19.58	-18.97
11	ASPHALT	PRMX_LOG	-20.35	-19.58	-18.72	-20.14
12	SHFT_DRZ	PRMX_LOG	-15.54	-16.23	-14.69	-14.78
13	SALT_T1	CUMPROB	0.1668	0.1596	0.4195	0.3575
14	SALT_T1	SAT_RGAS	0.0979	0.3888	0.2526	0.2727
15	SALT_T1	SAT_RBRN	0.26	0.2406	0.3225	0.1807
16	SALT_T1	PORE_DIS	0.4861	0.9551	0.6866	6.23
17	S_HALITE	POROSITY	0.01081	0.004985	0.02148	0.01941
18	S_HALITE	PRMX_LOG	-23.4	-21.64	-23.52	-22.12
19	S_HALITE	COMP_RCK	1.514E-10	4.765E-11	1.603E-10	7.344E-11
20	S_MB139	PRMX_LOG	-18.88	-18.83	-19.21	-18.42
21	S_MB139	COMP_RCK	7.67E-11	6.285E-11	1.071E-10	1.09E-11
22	S_MB139	RELP_MOD	1	1	1	1
23	S_MB139	SAT_RBRN	0.09324	0.08087	0.1366	0.06827
24	S_MB139	SAT_RGAS	0.01398	0.04879	0.1072	0.07723
25	S_MB139	PORE_DIS	0.6133	0.6096	0.6832	0.6797
26	S_HALITE	PRESSURE	12010000	12270000	11310000	12960000
27	CASTILER	PRESSURE	14900000	12340000	12380000	11910000
28	CASTILER	PRMX_LOG	-11.02	-11.98	-13.26	-12.42
29	CASTILER	COMP_RCK	-10.82	-10.4	-9.054	-9.112
30	BH_SAND	PRMX_LOG	-12.71	-12.04	-13.15	-13.2
31	CASTILER	GRIDFLO	29	32	9	21
32	BLOWOUT	PARTDIA	0.06034	0.002024	0.1585	0.0001861
33	BOREHOLE	TAUFAIL	0.9258	2.753	3.828	3.421
34	CULEBRA	MINP_FAC	397.7	891.1	955.5	530.7
35	GLOBAL	TRANSIDX	0.357	0.01873	0.8568	0.6144
36	SOLAM3	SOLSIM	-0.1976	-0.3821	-0.8902	0.9657
37	SOLAM3	SOLCIM	-0.391	-0.1461	-0.09575	-1.842
38	SOLPU3	SOLSIM	-0.4834	0.6853	-0.1384	-0.2147
39	SOLPU3	SOLCIM	0.1014	-0.4374	0.8697	-0.05452
40	SOLPU4	SOLSIM	-0.2832	-0.06566	-0.196	-1.09
41	SOLPU4	SOLCIM	-0.08138	0.2441	-1.586	0.606
42	SOLU4	SOLSIM	-0.457	-0.2272	-0.1713	-0.8627
43	SOLU6	SOLSIM	-0.2324	0.03276	0.08097	-0.3385
44	SOLU6	SOLCIM	-0.0111	-0.07551	0.6432	-0.177
45	SOLTH4	SOLSIM	0.5522	-0.4155	-0.199	-0.3565
46	PHUMOX3	PHUMCIM	0.1283	1.429	1.575	0.5214
47	GLOBAL	OXSTAT	0.9977	0.06733	0.9432	0.6761
48	GLOBAL	CLIMTIDX	1.214	2.191	1.973	1.137
49	CULEBRA	HMBLKLT	0.4234	0.06395	0.3044	0.4767
50	CULEBRA	APOROS	0.0001301	0.008438	0.0001923	0.0004559
51	CULEBRA	DPOROS	0.125	0.1049	0.235	0.1069
52	U+6	MKD_U	0.002671	0.0117	0.01405	0.004525
53	U+4	MKD_U	4.848	6.674	2.815	19.37
54	PU+3	MKD_PU	0.3181	0.1667	0.3738	0.3569
55	PU+4	MKD_PU	12.38	8.944	10.04	17.7
56	TH+4	MKD_TH	4.403	8.097	1.814	12.8
57	AM+3	MKD_AM	0.1197	0.3153	0.0739	0.1911

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	5	6	7	8	9	10
1	7.105E-15	9.142E-15	4.761E-15	4.911E-15	1.557E-14	6.568E-15
2	0	0	0	0	1	0
3	1.656E-09	4.389E-09	5.458E-09	5.584E-09	8.129E-09	6.15E-09
4	6.908E-10	6.401E-10	1.125E-10	1.08E-09	1.2E-09	7.519E-11
5	0.3117	0.5607	0.3226	0.5085	0.656	0.5722
6	0.07166	0.1151	0.0393	0.08188	0.006144	0.1363
7	0.09151	0.3899	0.06708	0.4254	0.1806	0.3419
8	0.08241	0.9487	0.6274	0.1544	0.5396	0.8526
9	-20.19	-18.46	-17.6	-17.84	-18.9	-18.51
10	-18	-18.37	-18.33	-19.42	-18.74	-19.29
11	-19.23	-20.01	-20.29	-18.77	-20.44	-19.15
12	-16.66	-16.34	-16.1	-15.38	-15.31	-15.29
13	0.5338	0.7245	0.6629	0.226	0.1812	0.8326
14	0.2706	0.2875	0.2813	0.06421	0.04299	0.1361
15	0.4858	0.1529	0.1242	0.08617	0.1782	0.1143
16	4.046	0.1192	0.6726	6.193	6.548	0.6585
17	0.02417	0.005869	0.02923	0.001218	0.02889	0.009058
18	-21.67	-22.39	-22.72	-21.85	-22.65	-22.88
19	3.553E-11	8.828E-11	1.242E-10	6.165E-11	1.035E-10	1.207E-10
20	-19.18	-19.3	-19.61	-19.4	-19.44	-19.1
21	1.425E-10	1.457E-10	2.01E-10	1.308E-10	1.702E-10	1.093E-10
22	4	4	4	1	4	1
23	0.08703	0.1123	0.06434	0.1256	0.1011	0.03109
24	0.05233	0.07564	0.04548	0.08072	0.08845	0.07537
25	0.709	0.656	0.6404	0.7547	0.6197	0.7863
26	11100000	13000000	12570000	13280000	12230000	11150000
27	12890000	11300000	12560000	11840000	15570000	12160000
28	-12.91	-12.45	-11.26	-11.8	-13.09	-10.88
29	-9.171	-9.714	-9.921	-9.778	-8.874	-10.01
30	-13.86	-12.29	-11.12	-12.32	-11.54	-13.38
31	17	10	14	25	16	17
32	0.001435	0.00006769	0.003107	0.00004855	0.0003968	0.0002952
33	7.828	4.904	4.763	6.32	3.079	1.204
34	324.4	622.6	798.1	118.6	250.3	194.1
35	0.7098	0.5359	0.05519	0.983	0.7561	0.4057
36	0.1593	-0.2835	-0.2347	0.06037	-0.6301	-0.08894
37	-0.3508	-0.131	0.3866	-0.2962	0.2448	-0.002704
38	1.29	-0.2447	-0.1994	0.1444	0.01939	-0.7773
39	-0.01913	0.1141	0.6295	0.05688	-0.06534	0.07417
40	0.8918	-0.4392	-0.2575	-0.2034	0.02398	-0.01516
41	-0.1313	0.1431	0.1403	-0.3727	-0.4151	-0.3906
42	-0.6831	0.08368	-0.3469	0.04341	0.002013	0.1255
43	-0.1239	-0.1353	0.1331	-0.2376	-0.1577	-0.2628
44	-0.1886	-1.078	-0.08139	0.8535	-0.6759	0.1178
45	-0.07243	0.1607	-0.1473	0.3523	-0.01643	-0.0298
46	0.4879	0.182	1.404	0.09101	0.281	1.597
47	0.5603	0.2142	0.2202	0.4481	0.8715	0.9708
48	1.147	2.235	1.019	1.172	1.092	1.806
49	0.2846	0.1536	0.3261	0.101	0.1762	0.1324
50	0.0006328	0.0001228	0.002639	0.003002	0.007133	0.0004813
51	0.1244	0.1299	0.1488	0.1899	0.1118	0.1099
52	0.005594	0.01283	0.007649	0.007031	0.02767	0.003107
53	9.599	2.236	10.36	11.44	7.685	4.919
54	0.3121	0.4509	0.05285	0.02125	0.2665	0.1455
55	16.11	3.196	13.31	13.94	17.47	18.59
56	3.811	16.1	7.056	10.1	16.26	2.796
57	0.4692	0.2336	0.4605	0.4812	0.4626	0.4733

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	11	12	13	14	15	16
1	1.451E-15	1.233E-14	8.047E-16	1.207E-14	9.029E-15	6.126E-15
2	1	1	0	2	2	0
3	2.751E-09	4.199E-09	8.468E-09	5.27E-09	6.627E-09	4.597E-09
4	4.117E-11	1.784E-10	5.062E-10	1.214E-09	7.186E-10	1.231E-09
5	0.8893	0.6985	0.4824	0.8424	0.03712	0.9962
6	0.1205	0.07298	0.1301	0.02233	0.08592	0.1028
7	0.4939	0.1463	0.3824	0.169	0.418	0.2714
8	0.2108	0.7754	0.3892	0.909	0.01272	0.6131
9	-18.12	-17.98	-18.44	-19.1	-19.61	-19.12
10	-18.35	-17.39	-18.84	-19.35	-17.88	-19.38
11	-19.71	-20.05	-19.25	-18.83	-20.69	-19.14
12	-15.49	-14.89	-15.78	-16.14	-14.75	-15.14
13	0.6091	0.4515	0.2538	0.8103	0.764	0.3022
14	0.2576	0.1689	0.1004	0.02677	0.247	0.08531
15	0.5705	0.1911	0.2312	0.3737	0.1984	0.1479
16	0.5205	0.2174	0.3639	0.1359	1.587	0.8442
17	0.007804	0.001774	0.001712	0.01702	0.007113	0.02453
18	-23.84	-22.52	-23.32	-22.17	-21.57	-23.92
19	1.867E-10	9.312E-11	1.541E-10	9.129E-11	3.152E-11	1.894E-10
20	-19.72	-20.11	-19.33	-18.74	-20.28	-18.6
21	1.91E-10	2.75E-10	1.382E-10	4.912E-11	2.418E-10	6.496E-11
22	4	1	1	1	1	1
23	0.138	0.05271	0.06205	0.07412	0.06536	0.04497
24	0.09171	0.07997	0.1144	0.08922	0.1031	0.08424
25	0.6127	0.5611	0.6876	0.7328	0.7141	0.6594
26	13640000	13540000	12790000	11480000	13330000	13700000
27	13460000	11480000	13820000	14100000	12970000	12750000
28	-12.02	-12.66	-13.63	-12.85	-11.92	-12.61
29	-9.753	-9.258	-8.783	-8.724	-10.47	-10.24
30	-12.67	-12.07	-12.82	-12.22	-11.69	-12.84
31	24	28	13	7	6	15
32	0.0007068	0.008348	0.07205	0.01918	0.0001514	0.0038
33	5.23	7.325	9.509	7.024	3.552	6.705
34	5.103	693.7	822.9	284.6	238.1	163.5
35	0.4501	0.4335	0.135	0.2505	0.7455	0.4818
36	-0.0115	-0.1457	-0.3107	-0.2181	-0.02046	0.3333
37	-1.604	-1.489	-0.1542	0.03388	-0.1698	0.7343
38	-0.4233	0.1723	0.504	-0.02029	-0.0983	-0.1759
39	-0.004312	-0.5491	-0.07601	-0.3476	-0.3373	-0.1457
40	-0.8019	1.292	0.1657	-0.03913	-0.06178	0.1405
41	-0.1618	-0.3304	0.258	-0.05741	0.6666	1.287
42	-0.2542	0.3222	-0.1034	-0.6092	-0.9822	0.9713
43	-0.2461	0.9485	-0.09874	0.8764	0.5624	-0.9554
44	-0.4822	-0.2143	0.2257	-0.3144	0.1528	0.2438
45	0.7954	-0.04355	-0.283	0.7317	-0.009254	-0.05335
46	1.434	0.8562	0.6901	0.3261	1.382	1.392
47	0.3461	0.9828	0.8982	0.3243	0.8223	0.7699
48	1.635	1.037	1.005	1.071	1.611	1.205
49	0.3675	0.2574	0.1259	0.2429	0.1931	0.2494
50	0.008813	0.002013	0.00159	0.004476	0.002206	0.000141
51	0.1379	0.1874	0.1688	0.1782	0.1161	0.1159
52	0.02607	0.02524	0.004146	0.01475	0.008279	0.02837
53	7.367	19.89	1.369	18.13	5.338	14.98
54	0.3783	0.2251	0.4363	0.4069	0.1613	0.478
55	19.17	10.37	7.478	6.213	2.427	11.3
56	3.761	8.952	15.63	4.053	9.768	11.11
57	0.2168	0.08853	0.2306	0.3948	0.1377	0.3545

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	17	18	19	20	21	22
1	3.615E-15	6.729E-15	7.422E-15	1.158E-14	1.516E-14	2.906E-16
2	2	1	1	2	0	0
3	7.173E-09	1.11E-09	1.201E-09	5.835E-09	9.411E-09	1.264E-09
4	1.029E-09	3.254E-10	4.123E-10	9.918E-10	8.049E-10	9.777E-10
5	0.4964	0.4701	0.6156	0.1783	0.1346	0.8789
6	0.0921	0.00162	0.1069	0.1254	0.03353	0.0362
7	0.5143	0.1081	0.2845	0.4575	0.1638	0.4008
8	0.2483	0.1217	0.9507	0.2532	0.896	0.1453
9	-18.21	-18.92	-19.52	-18.34	-18.61	-19.79
10	-17.98	-19.47	-17.73	-19.53	-17.62	-17.65
11	-19.42	-19.94	-19.3	-20.64	-19.02	-18.92
12	-14.94	-16.91	-16.02	-14.97	-14.52	-15.32
13	0.4432	0.7109	0.5679	0.5047	0.5989	0.5893
14	0.2655	0.3705	0.09099	0.1757	0.279	0.006904
15	0.5424	0.1392	0.5082	0.031	0.3537	0.4271
16	0.2861	6.989	8.383	3.317	0.7036	5.956
17	0.01145	0.008216	0.02341	0.006488	0.02705	0.02838
18	-21.52	-21.17	-22.94	-21.6	-22.54	-23.11
19	4.888E-11	7.978E-12	1.018E-10	6.152E-11	9.878E-11	1.353E-10
20	-18.63	-18.79	-18.87	-17.94	-19.16	-18.33
21	4.154E-11	6.866E-11	8.052E-11	1.09E-11	1.18E-10	1.09E-11
22	4	4	4	1	1	1
23	0.01922	0.06786	0.06211	0.05082	0.09205	0.1037
24	0.09669	0.1525	0.01398	0.04724	0.1155	0.1177
25	0.5991	0.6278	0.6613	0.6769	0.6058	0.6292
26	11610000	12080000	11380000	11870000	11860000	11570000
27	14430000	12000000	12920000	13430000	13260000	12490000
28	-10.39	-11.22	-12.68	-11.69	-12.18	-12.16
29	-10.36	-10.72	-9.224	-8.892	-10.85	-9.7
30	-11.92	-13.93	-11.08	-13.85	-12.16	-13.18
31	10	22	12	22	31	7
32	0.1989	0.001108	0.0347	0.002436	0.00005323	0.006954
33	1.007	9.272	7.201	1.338	5.053	9.632
34	45.06	217.5	37.43	159	139.8	465.6
35	0.9436	0.782	0.3402	0.2217	0.838	0.2187
36	0.4178	-0.4858	0.01766	0.0008687	0.6779	-0.1514
37	0.1554	0.6574	-0.2538	0.178	0.00804	0.4661
38	0.2078	-1.847	-0.15	0.76	0.7395	-0.1076
39	0.2418	-0.2709	-0.1929	0.8324	0.3545	-0.101
40	0.8414	-0.07628	-0.6662	-0.3454	-0.0805	0.3194
41	-0.1349	-0.227	-0.2313	0.8818	-0.489	-0.02563
42	0.03041	0.0752	-0.05337	-1.66	-0.05717	-0.2989
43	0.155	0.09074	0.3881	0.249	-0.0933	-0.6864
44	-0.1597	0.0777	0.4936	-0.05947	-0.1119	0.03686
45	-0.1308	-0.2069	0.5296	-0.8945	0.8469	-0.1811
46	0.6394	1.424	1.565	1.444	1.147	1.419
47	0.5544	0.9155	0.2374	0.8802	0.07913	0.7796
48	1.188	1.559	2.122	2.072	1.182	2.176
49	0.1211	0.2751	0.4005	0.3148	0.3706	0.07018
50	0.0008503	0.00509	0.006843	0.0001731	0.0003843	0.0004626
51	0.1759	0.174	0.1834	0.1951	0.1553	0.1653
52	0.02478	0.0215	0.01431	0.02971	0.013	0.02378
53	9.922	11.29	13.03	17.4	16.44	13.68
54	0.0445	0.2593	0.2319	0.4033	0.3386	0.0819
55	17.8	6.334	16.2	10.48	12.56	8.808
56	7.58	19.44	17.62	14.88	16.73	7.703
57	0.1478	0.311	0.3896	0.4246	0.2781	0.04295

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	23	24	25	26	27	28
1	4.041E-16	1.376E-14	7.749E-16	1.436E-14	1.415E-14	1.084E-14
2	0	0	0	1	0	0
3	7.446E-09	4.01E-09	3.773E-09	6.503E-09	2.089E-09	3.191E-09
4	3.02E-10	8.486E-10	2.78E-10	9.036E-10	1.22E-09	1.099E-09
5	0.1585	0.5212	0.2855	0.3968	0.1208	0.8542
6	0.1195	0.1472	0.01669	0.1273	0.1452	0.01561
7	0.1576	0.008916	0.2006	0.0624	0.1884	0.1982
8	0.06674	0.2774	0.5431	0.3503	0.1631	0.5634
9	-19.23	-19.91	-18.43	-18.39	-17.9	-18.68
10	-18.38	-19.46	-19.67	-18.17	-18.03	-19.04
11	-20.39	-20.37	-18.19	-18.45	-18.26	-19.57
12	-14.38	-16.29	-15.1	-14.26	-15.77	-15.11
13	0.6176	0.6742	0.4869	0.3274	0.4384	0.1417
14	0.03946	0.07058	0.1412	0.1507	0.2242	0.2293
15	0.1342	0.46	0.08192	0.07746	0.09435	0.1294
16	1.202	0.1941	3.539	0.7198	0.302	1.807
17	0.0101	0.006359	0.01491	0.02645	0.002929	0.00688
18	-23.16	-22.36	-21.21	-21.09	-22.18	-21.72
19	1.41E-10	7.909E-11	1.732E-11	1.387E-11	8.053E-11	4.422E-11
20	-17.12	-18.92	-18.47	-19	-18.15	-18.93
21	1.09E-11	7.861E-11	3.962E-11	8.459E-11	1.728E-11	9.553E-11
22	4	4	1	4	4	4
23	0.1017	0.08259	0.09494	0.1003	0.09399	0.1218
24	0.07789	0.09575	0.01733	0.05644	0.03488	0.08541
25	0.5205	0.7239	0.6745	0.6997	0.6107	0.6582
26	13050000	13830000	13360000	12840000	12300000	13860000
27	11720000	12620000	14530000	14180000	13080000	13610000
28	-12.4	-12.53	-12.48	-12.98	-12.24	-12.05
29	-10.2	-9.992	-9.303	-9.449	-9.538	-9.814
30	-11.39	-12.96	-11.31	-13.62	-11.76	-11.45
31	15	8	5	11	27	16
32	0.08983	0.07022	0.0004595	0.0006004	0.02435	0.003391
33	0.7151	0.5259	4.006	4.298	8.398	6.105
34	369.9	634.2	78.07	929.7	303.7	186.6
35	0.9137	0.3743	0.4907	0.2856	0.8725	0.6254
36	-0.0607	0.7541	0.1729	0.8431	-0.2148	0.2283
37	-0.03141	-0.6808	-0.2793	0.3099	0.05543	-0.07211
38	-0.5774	-0.2311	0.02512	-0.4307	-0.8807	-0.2422
39	0.06717	-0.1375	-0.4207	-0.1511	0.7146	-0.8765
40	0.01149	-0.2424	0.06837	-0.3683	0.1133	0.3893
41	0.1125	-0.3107	0.1222	-0.01294	-0.2401	-0.08663
42	-0.09245	-0.9391	0.2422	-0.01204	-0.2313	-1.438
43	0.4395	-0.3394	-0.8716	-0.1851	-0.2013	0.5339
44	-0.1987	0.7385	-0.8136	-0.2039	-0.4575	1.29
45	-0.1043	-0.08892	-0.8414	0.2386	-0.8209	-1.201
46	0.6075	1.308	0.3213	1.571	1.52	0.9421
47	0.7374	0.03426	0.4807	0.9247	0.4144	0.6187
48	1.177	1.123	1.068	1.176	1.1	1.111
49	0.4718	0.1944	0.1421	0.3004	0.4519	0.4321
50	0.009447	0.00285	0.000694	0.006449	0.001162	0.0008286
51	0.1102	0.1225	0.1891	0.1809	0.1014	0.2446
52	0.02121	0.02872	0.007833	0.001859	0.0008295	0.005178
53	9.427	13.81	2.666	15.67	17.25	5.874
54	0.138	0.1423	0.2791	0.3819	0.07629	0.3529
55	6.838	9.707	16.46	2.704	12.03	16.63
56	6.804	3.092	9.961	10.61	13.45	5.606
57	0.3854	0.2121	0.02192	0.3411	0.1829	0.289

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	29	30	31	32	33	34
1	5.243E-15	1.985E-15	9.926E-15	5.591E-15	5.9E-15	8.443E-15
2	2	2	0	0	0	2
3	5.68E-09	2.414E-09	7.36E-09	3.162E-09	7.986E-09	6.396E-09
4	6.582E-10	3.887E-10	8.127E-10	6.718E-10	4.86E-10	4.688E-10
5	0.06116	0.4001	0.08247	0.7515	0.4389	0.9899
6	0.1175	0.03141	0.09551	0.02858	0.05487	0.06004
7	0.2704	0.04703	0.01245	0.02577	0.2406	0.05246
8	0.8876	0.3745	0.6715	0.4259	0.0006692	0.1909
9	-18.82	-18.09	-19.97	-18.62	-19.19	-20.05
10	-18.22	-18.44	-20.09	-17.21	-18.56	-18.66
11	-19.77	-19.01	-19.3	-20.48	-20.28	-19.6
12	-15.81	-15.16	-14.53	-15.42	-16.36	-15.88
13	0.5475	0.02871	0.9828	0.941	0.4772	0.8625
14	0.3945	0.3609	0.2175	0.3789	0.1447	0.1678
15	0.393	0.2999	0.05253	0.00145	0.3135	0.1647
16	0.5649	5.575	4.78	5.43	2.666	2.964
17	0.02492	0.005312	0.002528	0.01434	0.01991	0.0106
18	-21.4	-23.56	-23.98	-23.51	-22.78	-23.45
19	3.029E-11	1.589E-10	1.92E-10	1.625E-10	1.4E-10	1.67E-10
20	-19.02	-18.3	-18.69	-18.85	-18.02	-19.46
21	1.011E-10	1.09E-11	5.917E-11	7.544E-11	1.09E-11	1.643E-10
22	1	4	4	1	4	1
23	0.1099	0.09857	0.1089	0.05879	0.174	0.08358
24	0.137	0.1082	0.04514	0.06287	0.06092	0.08292
25	0.6185	0.6392	0.5409	0.6177	0.6433	0.637
26	13110000	12400000	12130000	12360000	11960000	13380000
27	13320000	12720000	13490000	14140000	12540000	15030000
28	-11.47	-12.35	-11.66	-11.75	-12.76	-11.56
29	-10.12	-10.26	-9.74	-9.541	-9.504	-9.427
30	-11.74	-12.44	-11.99	-13.27	-12.99	-13.07
31	12	21	1	5	23	32
32	0.02216	0.009177	0.004564	0.01255	0.000141	0.005281
33	6.995	6.269	8.001	9.447	6.524	4.694
34	108.3	757.9	585.5	812.3	25.73	914.8
35	0.1407	0.3905	0.08647	0.5695	0.3274	0.479
36	-0.684	0.5815	0.04501	0.1933	-0.3951	0.8817
37	1.172	0.01786	0.1007	-0.735	-0.4024	0.1915
38	0.06449	0.3771	0.09101	0.1824	-0.2038	-0.2281
39	-0.6638	0.1757	-0.3021	0.2794	0.6998	-0.02619
40	-0.1893	-1.643	-0.05292	-0.1677	-0.1417	0.01614
41	-0.2084	-0.902	-0.4706	-0.2837	-0.1514	-0.1793
42	-0.2153	-0.2447	-1.931	0.4023	-0.13	0.6518
43	-1.738	-0.445	0.6736	-1.373	0.1682	-0.006549
44	0.6578	-0.5252	-0.5648	-0.03729	0.08342	0.1871
45	-0.7726	0.03082	0.2156	-0.1706	-0.03935	-0.5386
46	0.2507	1.341	0.7264	1.168	1.593	0.8
47	0.7284	0.5434	0.8603	0.5284	0.9543	0.2028
48	1.116	1.076	2.007	1.199	1.015	1.202
49	0.3105	0.1463	0.165	0.2144	0.1694	0.1073
50	0.0002683	0.0002833	0.0002459	0.001402	0.0006117	0.0002345
51	0.1199	0.1853	0.1445	0.1573	0.1831	0.127
52	0.02499	0.02815	0.02287	0.005044	0.0145	0.01802
53	12.79	12.72	6.563	6.971	10.84	9.093
54	0.1328	0.2801	0.1918	0.09007	0.4964	0.06028
55	15.93	3.65	17.29	7.8	3.095	11.47
56	11.23	1.939	14.61	1.319	15.51	15.88
57	0.4283	0.3839	0.1645	0.1073	0.1134	0.03309

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	35	36	37	38	39	40
1	3.479E-15	1.553E-14	6.861E-15	1.326E-14	1.316E-14	1.198E-14
2	2	1	2	0	0	1
3	6.98E-09	3.467E-09	6.88E-09	8.686E-09	2.442E-09	4.835E-09
4	5.271E-10	1.077E-09	8.956E-10	9.909E-11	4.04E-10	9.336E-10
5	0.31	0.8911	0.4245	0.9232	0.1119	0.04598
6	0.1492	0.1321	0.06286	0.1458	0.1335	0.01337
7	0.5213	0.4362	0.1405	0.05545	0.3202	0.449
8	0.9939	0.58	0.7522	0.1027	0.5243	0.09056
9	-20.16	-20.27	-17.7	-18.28	-17.57	-19.06
10	-18.61	-18.14	-19.23	-19.61	-19.75	-18.63
11	-19.11	-20.56	-19.18	-19.41	-20.25	-19.68
12	-16.07	-15.2	-15.46	-15.83	-14.95	-14.39
13	0.7066	0.3987	0.2967	0.04036	0.8224	0.6565
14	0.3124	0.03544	0.1041	0.1199	0.2502	0.1542
15	0.02183	0.4127	0.256	0.02656	0.5197	0.4472
16	8.094	7.969	7.836	2.524	3.684	7.213
17	0.02044	0.002242	0.01187	0.02587	0.009223	0.02874
18	-23.66	-21.36	-21.59	-21.87	-23.68	-23.47
19	1.733E-10	2.527E-11	4.224E-11	5.17E-11	1.677E-10	1.495E-10
20	-18.75	-19.04	-18.53	-19.47	-17.1	-19.68
21	6.824E-11	9.223E-11	4.952E-11	1.575E-10	1.09E-11	1.768E-10
22	4	4	1	4	4	4
23	0.09074	0.09814	0.1247	0.06946	0.06994	0.0546
24	0.1117	0.06402	0.08191	0.04183	0.166	0.06234
25	0.6335	0.5095	0.6646	0.5822	0.6382	0.7461
26	13150000	11390000	13750000	12630000	12740000	13240000
27	13110000	13860000	15130000	14430000	15250000	13630000
28	-13.18	-13.42	-10.78	-12.09	-11.28	-13.59
29	-9.334	-9.469	-9.487	-10.3	-10.17	-8.443
30	-12.4	-13.48	-13.36	-13.58	-12.19	-12.63
31	14	21	24	14	26	27
32	0.01732	0.00006158	0.01063	0.01176	0.00008466	0.01338
33	5.397	1.97	4.607	9.071	2.171	8.691
34	141.8	515.4	871.5	412.2	900.2	271.4
35	0.2697	0.0007058	0.8672	0.8098	0.2006	0.5256
36	0.4919	-0.1935	-0.7312	-0.09108	0.639	-0.8085
37	-0.0127	-0.1022	-0.07984	-0.06834	-0.1328	-0.5586
38	-0.3166	-0.0008317	-0.4789	-0.08773	-0.02401	0.1399
39	-0.2226	0.216	-0.2101	-0.2351	-0.05952	0.5071
40	-0.3326	0.1472	-0.2354	0.4393	0.451	-0.1475
41	0.07348	-0.0429	0.5861	0.1975	-0.8776	-0.1222
42	0.6281	0.1662	-0.2075	-0.3924	0.925	0.1882
43	0.9808	-0.465	0.325	-0.1622	0.06336	0.2247
44	-0.1873	-0.1679	-0.6314	-0.932	-0.1085	-0.1517
45	-0.3648	-0.1138	0.9941	0.1796	0.1997	-0.1657
46	0.5378	0.3995	1.224	0.9794	0.1444	0.4366
47	0.2707	0.8592	0.4213	0.5155	0.8392	0.1155
48	1.05	1.036	1.211	1.244	1.224	1.685
49	0.3561	0.1624	0.09395	0.1999	0.05319	0.3351
50	0.00111	0.0002242	0.0004285	0.000106	0.003215	0.0003074
51	0.133	0.1766	0.1074	0.1464	0.1746	0.1138
52	0.0003253	0.01061	0.02336	0.02275	0.00692	0.0156
53	17.71	8.006	11.64	12.52	8.165	2.281
54	0.4946	0.08471	0.1231	0.4845	0.3659	0.3642
55	13.5	10.21	4.378	19.3	11.17	4.037
56	15.35	1.097	2.898	16.47	18.69	11
57	0.288	0.4154	0.1009	0.2015	0.4414	0.06713

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	41	42	43	44	45	46
1	1.614E-15	9.497E-15	1.06E-14	2.124E-15	3.19E-15	5.059E-15
2	0	0	0	0	0	2
3	8.346E-09	9.305E-09	4.663E-09	4.544E-10	6.098E-09	9.771E-10
4	1.178E-09	2.43E-10	6.231E-10	5.188E-10	7.95E-10	7.739E-10
5	0.1895	0.906	0.7612	0.2022	0.78	0.6243
6	0.1382	0.05111	0.1129	0.09357	0.04579	0.09002
7	0.3144	0.3306	0.4331	0.3965	0.4053	0.002974
8	0.3383	0.9675	0.5807	0.413	0.7195	0.4569
9	-19.15	-18.06	-18.87	-19.72	-19.27	-18.4
10	-18.06	-18.86	-18.83	-17.88	-19.94	-19.13
11	-20.23	-20.61	-19.22	-19.38	-20.32	-19.98
12	-14.83	-14.61	-16.45	-15.26	-15.52	-14.93
13	0.2786	0.4229	0.4061	0.133	0.6997	0.7838
14	0.2234	0.08105	0.1967	0.06145	0.3099	0.2078
15	0.1414	0.4551	0.337	0.5545	0.1714	0.2702
16	0.1649	6.494	8.262	0.9238	3.939	0.7921
17	0.02745	0.004443	0.004858	0.0209	0.02292	0.02622
18	-21.82	-22.68	-21.07	-22.76	-23.87	-23.37
19	4.475E-11	1.097E-10	1.229E-11	1.153E-10	1.843E-10	1.562E-10
20	-19.03	-18.66	-18.77	-18.97	-19.25	-17.6
21	9.442E-11	4.568E-11	7.24E-11	9.123E-11	1.134E-10	1.09E-11
22	4	1	1	1	4	1
23	0.09143	0.09977	0.06639	0.05604	0.08868	0.07864
24	0.1126	0.05848	0.0541	0.02654	0.08373	0.08671
25	0.6327	0.6777	0.6685	0.6239	0.7651	0.622
26	12820000	12110000	12890000	11670000	13770000	12250000
27	16250000	11930000	15830000	12180000	12460000	14940000
28	-10.98	-11.63	-12.2	-11.19	-11.08	-10.57
29	-9.649	-10.19	-9.978	-10.6	-10.69	-11.07
30	-12.78	-12.53	-11.43	-12.36	-12.92	-13.96
31	28	9	19	29	12	19
32	0.00007838	0.01602	0.1267	0.006231	0.0006447	0.0008589
33	8.123	9.856	0.227	5.757	5.922	2.252
34	783.4	700.9	659.9	973.8	685.7	294
35	0.07073	0.2989	0.6644	0.4112	0.9572	0.8136
36	-0.8702	-0.1356	-0.2951	0.1471	-0.1722	-1.859
37	-0.896	0.2913	-0.1415	0.9957	0.9175	-1.107
38	0.3294	-0.05209	0.8781	-0.06399	0.8153	0.2505
39	-0.2676	0.3431	-0.1619	-0.1778	0.0401	-1.022
40	-0.6903	-0.1815	0.2821	-0.3148	-0.00644	-0.02937
41	-0.1836	0.9004	-0.7935	0.1015	-0.3402	-0.06853
42	0.2291	0.2201	0.196	-0.7494	-0.1365	-0.04485
43	-0.4158	-0.1414	-0.05778	-0.6189	0.1029	-0.08648
44	0.1396	-0.9833	-0.3279	-0.04426	-1.916	-0.06325
45	-0.4602	-0.1751	0.000152	0.1231	-0.4032	-1.82
46	1.288	1.543	1.529	0.2244	1.508	1.512
47	0.9672	0.1265	0.6274	0.6022	0.7801	0.0442
48	1.875	1.133	2.14	1.124	1.04	1.109
49	0.4781	0.3762	0.4661	0.2634	0.3548	0.4615
50	0.0002005	0.002545	0.0003587	0.005885	0.0003259	0.0005747
51	0.1597	0.2413	0.1866	0.1643	0.1189	0.1814
52	0.008437	0.0089	0.002387	0.001822	0.01947	0.005736
53	18.75	19.17	14.6	16.91	18.94	8.696
54	0.1787	0.02543	0.1074	0.3477	0.06666	0.2864
55	12.77	8.071	2.877	11.84	5.926	13.54
56	18.47	14.11	17.89	17.27	3.243	9.247
57		0.1764	0.1634	[illegible]	0.184	0.4187

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	47	48	49	50	51	52
1	3.028E-15	1.171E-14	4.022E-15	1.527E-14	6.254E-15	5.092E-15
2	0	0	0	2	0	0
3	4.309E-09	3.234E-10	4.922E-09	8.24E-09	6.826E-09	2.99E-09
4	1.262E-09	4.561E-10	6.038E-10	1.06E-09	7.572E-10	5.513E-10
5	0.2639	0.7994	0.7111	0.5551	0.9341	0.3313
6	0.004339	0.1084	0.01387	0.0442	0.1233	0.09775
7	0.3745	0.5047	0.1188	0.4637	0.2188	0.03451
8	0.7476	0.8075	0.6089	0.05461	0.323	0.9145
9	-18.34	-18.81	-18.25	-19.85	-19.44	-19.89
10	-18.12	-19.41	-18.22	-19.07	-20.18	-18.62
11	-18.67	-20.53	-19.62	-19.48	-19.82	-19.06
12	-14.9	-14.63	-14.33	-15.63	-15	-15.09
13	0.6401	0.894	0.2439	0.4963	0.689	0.1739
14	0.1264	0.2012	0.3997	0.2101	0.3826	0.2915
15	0.2079	0.163	0.5226	0.1168	0.5797	0.3347
16	0.2728	1.566	7.319	0.5287	1.395	7.657
17	0.003301	0.008084	0.002273	0.02786	0.004286	0.01915
18	-22.25	-23.14	-22.27	-23.22	-23.08	-22.47
19	9.454E-11	1.475E-10	6.84E-11	1.355E-10	1.279E-10	1.069E-10
20	-19.22	-19.77	-18.5	-19.32	-19.18	-19.37
21	1.344E-10	2.088E-10	3.145E-11	1.344E-10	1.21E-10	1.448E-10
22	4	1	4	1	4	1
23	0.07627	0.07659	0.08789	0.09715	0.08762	0.007846
24	0.06608	0.1046	0.073	0.08134	0.1098	0.1343
25	0.7007	0.5774	0.5966	0.5969	0.6702	0.6887
26	12040000	12330000	12540000	11500000	11040000	13470000
27	13980000	13770000	12690000	12650000	11620000	14660000
28	-11.83	-13.98	-13.49	-12.57	-10.5	-12.85
29	-10.38	-8.497	-8.196	-8.65	-10.04	-9.006
30	-13.76	-13.65	-13.9	-11.1	-11.71	-11.79
31	23	30	6	2	4	24
32	0.06324	0.1344	0.001823	0.002004	0.0005293	0.0007283
33	3.215	4.452	0.05556	1.057	3.692	1.601
34	386.5	125.4	648.6	942.2	773.6	881.3
35	0.09761	0.8282	0.2416	0.6757	0.7326	0.6984
36	-0.03597	-0.5956	-0.1598	0.02706	-0.05126	-1.612
37	-0.1751	-0.02446	0.8083	0.08081	-0.2224	-0.181
38	-0.1268	-0.03579	0.4409	-0.3231	-0.9157	-0.5216
39	-0.4088	-0.6944	-0.0907	-0.2046	0.007828	0.228
40	-0.301	-0.2281	0.08164	0.2219	0.6407	-0.489
41	-0.1026	-0.1143	0.7552	0.0893	-0.01607	0.1895
42	0.2068	-0.6504	-0.0249	-0.01581	-0.07455	-0.03443
43	-0.3031	-0.1166	-0.04534	-1.119	-0.2161	-0.051
44	-0.01514	-0.1037	0.8006	-0.02643	-0.412	-0.1196
45	0.6048	0.2326	0.6945	-0.06694	-0.7154	-0.1355
46	1.54	1.498	1.557	1.494	0.3596	1.093
47	0.4543	0.264	0.3799	0.3153	0.2446	0.9394
48	1.044	1.161	1.023	1.079	1.165	1.228
49	0.4439	0.2305	0.2215	0.2946	0.4828	0.2284
50	0.0001363	0.0005197	0.00569	0.003049	0.0001812	0.00499
51	0.112	0.1141	0.111	0.104	0.1825	0.1732
52	0.02945	0.02216	0.01329	0.006517	0.01864	0.02697
53	8.446	9.223	3.111	4.217	18	7.818
54	0.1016	0.05724	0.442	0.1272	0.4443	0.3433
55	14.27	11.71	18.22	9.229	10.75	10.91
56	5.304	19.8	16.95	13.65	8.909	2.26
57	0.3674	0.1299	0.08201	0.3211	0.2362	0.4516

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	53	54	55	56	57	58
1	1.501E-14	1.113E-14	8.137E-15	1.031E-14	1.759E-15	2.46E-15
2	2	2	1	1	1	1
3	5.775E-09	1.953E-09	3.679E-09	1.579E-09	2.26E-09	3.613E-09
4	7.632E-10	1.244E-10	2.857E-10	3.651E-10	1.113E-09	7.43E-10
5	0.9673	0.1918	0.3861	0.1633	0.7073	0.01942
6	0.0116	0.04127	0.1051	0.02749	0.1044	0.04661
7	0.2479	0.5276	0.5083	0.4857	0.2799	0.345
8	0.5573	0.4653	0.7044	0.4408	0.229	0.846
9	-20.07	-18.77	-20.37	-19.18	-18.95	-20.75
10	-19.31	-19.99	-20.28	-18.71	-18.5	-18.52
11	-18.37	-19.45	-19.84	-20.42	-20.12	-19.93
12	-15.03	-14.88	-14.99	-15.57	-15.34	-15.28
13	0.3703	0.807	0.01727	0.1198	0.9362	0.09485
14	0.1626	0.2964	0.3642	0.04669	0.1143	0.01144
15	0.4179	0.3516	0.005785	0.2934	0.09983	0.2833
16	0.2106	0.4333	0.8051	0.1477	5.193	0.9029
17	0.00579	0.02175	0.0185	0.005412	0.003706	0.005607
18	-23.35	-22.03	-21.22	-23.28	-22.99	-22.61
19	1.559E-10	6.361E-11	1.573E-11	1.316E-10	1.134E-10	1.169E-10
20	-19.06	-18.18	-18.89	-20.01	-21	-18.11
21	9.912E-11	1.09E-11	1.117E-10	2.242E-10	2.75E-10	1.09E-11
22	4	1	1	1	1	4
23	0.04826	0.1029	0.08232	0.08157	0.1203	0.1137
24	0.1019	0.01398	0.09265	0.06501	0.09036	0.09498
25	0.5284	0.6574	0.6735	0.6233	0.6929	0.7048
26	13220000	12510000	13200000	12670000	11240000	11930000
27	12840000	13060000	14280000	13000000	16520000	13800000
28	-10.15	-11.51	-11.87	-11.76	-10.31	-11.45
29	-10.27	-9.794	-9.889	-9.668	-10.9	-9.969
30	-13.3	-11.58	-13.79	-13.98	-12.87	-13.31
31	32	16	8	6	15	25
32	0.00009677	0.0004769	0.02615	0.01436	0.04309	0.03324
33	6.205	8.516	9.801	5.151	1.531	8.419
34	485	833.2	502.3	747.1	867.2	848
35	0.6512	0.1932	0.1665	0.5722	0.4439	0.3128
36	-0.4142	-0.1256	-0.5516	0.5345	0.1795	0.2482
37	0.5212	-0.2167	-0.6367	-0.1225	0.5675	-0.4755
38	-0.04357	0.1604	0.2215	-0.05598	-0.09029	-0.3404
39	-0.1073	-1.425	0.5853	-0.2442	-0.1225	-0.1164
40	-0.2111	0.7045	-0.425	0.106	-1.905	0.1869
41	-0.5324	0.2171	-0.2005	-0.4089	-0.2438	-0.2066
42	-0.3177	1.251	-0.0669	-0.002082	0.06574	0.7748
43	-0.06923	-0.1513	-0.07117	0.007373	0.04834	0.119
44	-0.2391	0.9794	-0.2918	-1.367	0.3086	-0.2704
45	-0.1248	0.1333	0.3392	-0.562	0.1714	-0.2391
46	1.551	1.469	1.486	1.416	0.9772	1.443
47	0.4948	0.805	0.4309	0.9017	0.3561	0.09834
48	1.565	1.167	1.02	1.195	1.143	1.249
49	0.3847	0.3319	0.0816	0.2462	0.2528	0.4115
50	0.00407	0.00121	0.006091	0.007732	0.0007403	0.003591
51	0.1702	0.1089	0.129	0.148	0.1362	0.135
52	0.001118	0.02713	0.007357	0.00616	0.00378	0.029
53	4.432	19.79	17.61	8.842	18.63	10.15
54	0.305	0.3887	0.03176	0.4541	0.4708	0.2616
55	8.474	1.173	18.71	15.75	6.572	8.168
56	14.29	6.008	7.33	8.514	11.68	18.11
57	0.3275	0.4534	0.3258	0.4077	0.3018	0.151

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	59	60	61	62	63	64
1	1.042E-14	1.398E-14	1.261E-14	4.575E-15	9.77E-15	3.838E-15
2	1	0	0	1	0	2
3	9.452E-09	1.714E-09	5.558E-10	4.09E-09	2.544E-09	6.344E-09
4	2.572E-10	1.964E-10	2.22E-10	1.003E-09	1.182E-09	6.791E-10
5	0.02093	0.3758	0.005953	0.8655	0.3561	0.8161
6	0.08051	0.07854	0.007902	0.03835	0.03483	0.1011
7	0.02821	0.2074	0.3009	0.3514	0.1261	0.1336
8	0.9893	0.267	0.8668	0.6419	0.3676	0.02259
9	-18.76	-19.55	-18.52	-19.32	-18.17	-18.54
10	-18.53	-19.1	-19.12	-17.34	-20.51	-19.02
11	-20.22	-20.05	-18.59	-20.11	-20.18	-19.79
12	-15.25	-14	-16.04	-14.85	-16.54	-15.37
13	0.5719	0.969	0.9992	0.1078	0.07862	0.8792
14	0.3079	0.1101	0.02853	0.3585	0.2369	0.003149
15	0.1759	0.4002	0.05706	0.15	0.05007	0.01509
16	5.83	0.5875	4.684	0.8703	2.226	0.7488
17	0.01542	0.004197	0.007514	0.02367	0.002745	0.01822
18	-22.62	-22.85	-22.21	-22.07	-22.8	-21.93
19	9.684E-11	1.009E-10	8.644E-11	7.739E-11	1.311E-10	5.531E-11
20	-18.56	-18.4	-19.56	-17.7	-19.12	-17.89
21	6.36E-11	3.739E-11	1.592E-10	1.09E-11	1.185E-10	1.09E-11
22	1	1	4	4	4	4
23	0.07823	0.04987	0.1155	0.08389	0.09649	0.05677
24	0.09856	0.03703	0.0575	0.05058	0.1296	0.07175
25	0.7157	0.6856	0.5684	0.6506	0.5918	0.604
26	11240000	12650000	12770000	13820000	12470000	12710000
27	12770000	14530000	12240000	12090000	13560000	12260000
28	-13.38	-10.7	-11.34	-11.4	-11.14	-11.93
29	-8.556	-10.63	-10.14	-10.34	-9.879	-8.836
30	-13.59	-11.2	-13.43	-11.85	-11.27	-11.55
31	32	29	18	14	25	27
32	0.03936	0.001562	0.0009411	0.0957	0.07942	0.0002072
33	4.359	9.991	0.4086	7.702	8.911	3.433
34	93.77	82.95	670.2	996.4	540.7	726.2
35	0.1549	0.1768	0.602	0.5937	0.182	0.1007
36	-0.06599	-0.2421	-0.1059	0.05945	0.2139	-0.2597
37	-0.1981	0.7574	-0.3596	-0.4584	-0.05411	-0.04087
38	-1.726	0.1203	0.1138	0.04935	0.6113	-0.07942
39	-0.3701	0.9622	0.08407	0.1488	-0.1838	-1.956
40	0.9825	-0.5153	0.04192	0.1192	-0.1767	-0.9646
41	-0.5895	0.03709	0.318	-0.6982	-0.03415	-1.49
42	-0.4927	-0.1954	0.1491	-0.2104	-0.2414	-0.08116
43	-0.7623	-0.107	-0.924	1.114	-0.454	-0.02523
44	0.1985	-0.08603	-0.2457	0.1732	-0.09665	-0.1652
45	-0.09248	-0.3795	-1.458	-0.486	0.4141	0.2042
46	0.4066	0.7672	1.464	0.7733	1.524	0.8243
47	0.1832	0.3698	0.2814	0.3349	0.3081	0.3913
48	1.104	1.085	1.087	1.73	1.207	1.062
49	0.3878	0.1511	0.09819	0.1889	0.4403	0.4184
50	0.000996	0.0007894	0.0003671	0.0001635	0.008047	0.002371
51	0.1396	0.1667	0.1611	0.1151	0.169	0.1788
52	0.01678	0.01843	0.02403	0.009753	0.01636	0.02457
53	13.31	1.549	6.322	1.172	3.494	5.589
54	0.2499	0.4095	0.331	0.3365	0.4658	0.2001
55	4.815	9.638	16.8	18	3.779	13.05
56	5.738	4.61	13.92	13.72	11.81	9.546
57	0.05053	0.2815	0.3334	0.4983	0.2964	0.1339

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	65	66	67	68	69	70
1	1.289E-14	8.303E-15	7.658E-15	9.64E-15	8.001E-15	5.832E-15
2	1	2	0	1	2	2
3	6.685E-09	7.249E-09	7.678E-09	5.338E-09	2.965E-09	5.086E-09
4	8.251E-10	1.05E-09	9.636E-10	2.076E-10	1.165E-09	2.847E-11
5	0.9762	0.4528	0.342	0.45	0.7499	0.8066
6	0.05066	0.06923	0.08718	0.08308	0.05765	0.02583
7	0.1544	0.5359	0.3613	0.3561	0.2645	0.2529
8	0.4377	0.3493	0.8294	0.04857	0.1703	0.2045
9	-18.49	-17.66	-18.96	-18.68	-19.37	-20.49
10	-19.51	-19.07	-18.8	-18.99	-20.42	-18.77
11	-19.08	-20	-19.86	-19.35	-19.54	-19.5
12	-15.88	-15.95	-16.61	-15.07	-14.45	-15.72
13	0.2358	0.7938	0.8406	0.5298	0.8587	0.05784
14	0.2406	0.1834	0.09409	0.1327	0.3309	0.3402
15	0.562	0.4987	0.2115	0.3621	0.03895	0.4646
16	1.106	4.317	3.167	6.791	0.7785	0.4076
17	0.009627	0.003471	0.01675	0.007893	0.01794	0.001422
18	-23.05	-21.99	-21.49	-23.8	-21.29	-21.98
19	1.265E-10	5.83E-11	3.438E-11	1.8E-10	2.015E-11	6.694E-11
20	-18.37	-18.78	-18.27	-18.68	-19.28	-18
21	1.569E-11	8.81E-11	1.09E-11	5.978E-11	1.288E-10	1.09E-11
22	4	1	1	1	1	1
23	0.06658	0.06359	0.0441	0.0959	0.02601	0.08479
24	0.07015	0.06623	0.0936	0.1059	0.07253	0.05502
25	0.6906	0.7381	0.5482	0.6634	0.5818	0.6654
26	11160000	12930000	13020000	13170000	13080000	13560000
27	14700000	15320000	13370000	13170000	12420000	13530000
28	-12.34	-13.04	-10.06	-13.22	-13.79	-12.96
29	-10.66	-9.858	-11.14	-9.367	-8.964	-8.264
30	-11.66	-13.02	-13.69	-12.12	-11.89	-13.49
31	20	23	4	4	9	26
32	0.0004253	0.0002619	0.05121	0.0001769	0.03021	0.0003556
33	6.46	9.144	6.909	7.511	3.305	2.923
34	264.6	988.9	553.2	498.7	358.7	223
35	0.3321	0.3065	0.6835	0.04069	0.6419	0.5073
36	-0.07775	0.7498	0.1128	-0.4772	-0.1165	0.07574
37	-0.9746	0.1143	-0.4881	-0.1612	-0.522	0.1535
38	-0.1198	-0.7943	-0.1408	-0.3572	-0.1927	-0.2735
39	-0.03885	-0.9203	0.9311	-0.1256	0.7972	0.2026
40	-0.109	-0.0133	0.1785	0.5775	-0.02722	-0.2459
41	0.2302	0.1579	0.4062	0.03509	-0.431	-0.2219
42	-0.146	-0.1761	-0.08577	0.1106	0.8822	0.02375
43	0.1896	0.232	-0.03151	-0.5364	-0.269	0.01462
44	-0.3671	-0.1433	0.2341	-0.3953	-0.001774	0.07081
45	-1.591	-0.2177	1.367	0.1528	0.4919	0.06227
46	1.125	1.548	1.047	1.257	1.066	1.025
47	0.8493	0.257	0.6457	0.6583	0.02529	0.1311
48	1.064	1.771	1.011	1.15	2.038	1.127
49	0.2067	0.4337	0.4917	0.498	0.3471	0.3638
50	0.009767	0.001986	0.001459	0.0004042	0.003918	0.0001009
51	0.103	0.1717	0.1544	0.1619	0.2025	0.121
52	0.01381	0.02231	0.01242	0.01022	0.01596	0.009456
53	7.069	2.579	1.976	3.737	14.34	10.81
54	0.2029	0.1145	0.2902	0.03463	0.4194	0.1587
55	1.682	19.85	4.559	18.45	8.573	1.364
56	4.837	11.45	15.06	18.54	4.184	16.82
57	0.07266	0.2585	0.1731	0.4912	0.2708	0.4372

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	71	72	73	74	75	76
1	1.008E-14	1.295E-15	1.333E-14	1.069E-14	3.754E-15	1.283E-14
2	1	0	0	2	1	2
3	1.794E-09	8.186E-09	8.674E-09	4.797E-09	2.853E-09	9.061E-09
4	3.801E-10	1.316E-10	8.499E-10	1.116E-09	4.282E-10	1.73E-10
5	0.8365	0.9115	0.5435	0.7303	0.2141	0.3614
6	0.1125	0.07677	0.05252	0.1002	0.1405	0.04936
7	0.2351	0.08638	0.4983	0.4206	0.09569	0.2919
8	0.6601	0.7601	0.2917	0.4097	0.7294	0.7936
9	-18.3	-19.34	-19.66	-18.84	-19.04	-18.71
10	-19.88	-18.57	-18.4	-17.71	-19.73	-17.51
11	-19.53	-19.72	-19.47	-19.96	-19.74	-18.53
12	-15.57	-14.68	-15.12	-15.17	-15.47	-16.22
13	0.3696	0.3115	0.6232	0.348	0.7717	0.9203
14	0.2342	0.1945	0.3359	0.3398	0.2937	0.02394
15	0.3048	0.1202	0.1027	0.06486	0.1868	0.4334
16	0.2586	5.768	2.84	4.531	0.8553	4.191
17	0.01237	0.003525	0.001038	0.007336	0.0202	0.002025
18	-22.33	-21.78	-23.21	-23.6	-23.73	-21.32
19	8.459E-11	5.266E-11	1.432E-10	1.642E-10	1.809E-10	1.968E-11
20	-18.55	-19.54	-17.75	-19.65	-18.81	-18.99
21	4.426E-11	1.526E-10	1.09E-11	1.877E-10	8.183E-11	1.058E-10
22	4	1	1	1	4	4
23	0.08604	0.07989	0.09005	0.08029	0.07531	0.0606
24	0.02705	0.01398	0.0671	0.05566	0.03208	0.1235
25	0.6663	0.654	0.5866	0.8418	0.6721	0.631
26	11190000	12180000	11420000	12440000	13300000	13590000
27	14290000	15440000	14370000	12040000	13910000	13740000
28	-14.12	-10.64	-12.29	-11.61	-11.97	-10.92
29	-9.341	-10.76	-9.825	-10.32	-10.15	-10.1
30	-12.61	-11.03	-13.24	-11.3	-13.46	-11.5
31	7	11	8	24	11	1
32	0.01009	0.00009082	0.0002299	0.004268	0.00004178	0.002666
33	2.49	7.557	5.823	0.2882	3.93	5.51
34	937.6	447	207.7	718.9	373.9	450.6
35	0.7627	0.4628	0.9788	0.5535	0.778	0.713
36	-0.3599	-0.021	-0.4417	-0.9475	0.0912	-0.4577
37	-0.05682	-0.8484	-0.08482	-0.1155	0.4272	-0.2481
38	-0.2582	-0.1539	0.04129	0.1054	0.9449	0.2454
39	0.4422	-0.008715	-0.7403	-0.3804	-0.8307	-0.1955
40	-0.9219	0.6961	-1.423	-0.3867	0.5392	-0.8398
41	-1.245	-1.831	-0.0959	-0.0372	-0.3002	0.002755
42	-0.1166	-0.4713	0.5662	0.0593	-0.1559	-0.1638
43	-0.01922	-0.1679	0.1488	-0.3147	-0.007305	-0.1761
44	0.3616	0.1598	0.1277	-0.3787	0.2797	0.02012
45	-0.3204	-0.1018	-0.2352	-0.2878	0.9055	-0.3229
46	0.1094	1.588	0.6948	1.459	1.479	1.372
47	0.6382	0.3896	0.5736	0.4796	0.5877	0.7062
48	1.031	1.096	1.223	1.002	1.103	1.119
49	0.2207	0.138	0.2364	0.2725	0.4075	0.2082
50	0.00215	0.001079	0.004777	0.0009432	0.001842	0.0001847
51	0.1725	0.1005	0.1053	0.1844	0.1657	0.1427
52	0.02934	0.0274	0.01174	0.02184	0.009058	0.02084
53	10.53	15.24	16.66	5.736	3.364	14.22
54	0.06843	0.4603	0.3915	0.4177	0.1206	0.428
55	16.95	15.29	19.01	4.238	5.806	9.339
56	19.92	18.87	1.057	19.3	9.347	12.21
57	0.1434	0.3747	0.06309	0.1581	0.03622	0.3616

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	77	78	79	80	81	82
1	4.214E-15	4.943E-16	1.185E-14	2.845E-15	8.848E-15	7.895E-15
2	2	2	2	1	0	1
3	8.466E-10	7.664E-09	4.512E-09	3.944E-09	5.977E-09	9.258E-10
4	1.148E-09	9.147E-10	3.392E-10	3.509E-10	1.402E-11	5.824E-10
5	0.9474	0.228	0.4606	0.4165	0.5936	0.09411
6	0.06774	0.06551	0.04329	0.131	0.009867	0.1216
7	0.5346	0.4093	0.3345	0.2964	0.3088	0.2244
8	0.9794	0.4834	0.07311	0.6547	0.03048	0.8336
9	-18	-18.58	-18.31	-18.56	-18.16	-20.57
10	-17.47	-18.9	-18.11	-18.92	-18.46	-19.19
11	-20.1	-19.87	-18.89	-18.96	-19.89	-19.63
12	-15.98	-14.46	-14.77	-15.43	-15.41	-14.66
13	0.4691	0.7384	0.2079	0.1916	0.9757	0.06192
14	0.3268	0.07709	0.1851	0.07484	0.3204	0.346
15	0.008922	0.1561	0.07292	0.11	0.4898	0.5877
16	0.3997	4.885	6.968	0.8945	0.4585	0.5553
17	0.01469	0.003013	0.008579	0.01265	0.009751	0.008888
18	-23.75	-21.44	-23.62	-22.31	-21.71	-21.93
19	1.705E-10	3.902E-11	1.781E-10	7.199E-11	5.722E-11	7.097E-11
20	-18.36	-18.7	-19.51	-19.9	-18.96	-19.13
21	1.09E-11	7.044E-11	1.755E-10	2.669E-10	8.352E-11	1.141E-10
22	4	4	1	4	4	4
23	0.106	0.05904	0.03762	0.09237	0.1117	0.07295
24	0.07935	0.04282	0.09695	0.03945	0.08784	0.06812
25	0.6483	0.6444	0.6158	0.5553	0.7082	0.6468
26	11550000	13410000	11460000	13690000	11740000	12910000
27	15410000	12850000	14610000	15670000	15960000	15730000
28	-12.56	-13.53	-12.27	-11.59	-13.12	-12.14
29	-9.062	-9.565	-10.56	-10.08	-9.195	-9.642
30	-11.36	-12.56	-13.11	-13.76	-12.27	-11.16
31	17	21	9	12	20	18
32	0.00004528	0.02162	0.001244	0.00006117	0.04512	0.0002544
33	5.579	7.716	2.663	1.919	7.276	5.668
34	428.2	524.3	802.6	617.5	964.4	606.8
35	0.5897	0.905	0.0347	0.2737	0.5429	0.9205
36	-0.1242	-0.1595	-0.2041	-1.285	-0.2489	0.1336
37	-0.2313	0.6256	-0.4295	0.8837	0.204	-0.1078
38	0.0762	-0.02925	-1.25	-0.693	0.5973	-0.9585
39	0.4517	0.132	-0.2212	1.183	-0.0881	-1.668
40	0.9268	0.2427	-0.08719	0.7636	0.086	-0.1172
41	0.1668	-0.9625	0.0707	-0.001956	0.05863	0.3967
42	-0.7807	-0.4376	-0.4217	-0.1442	-0.1235	-0.3268
43	-0.08267	-1.967	-0.1903	0.7658	-0.0385	-0.3774
44	0.05658	-0.2188	0.2041	0.7767	-0.1337	-0.7676
45	0.0737	-0.2495	-0.000452	-0.6457	0.2692	0.1063
46	1.475	1.377	1.208	0.1963	0.6309	1.453
47	0.5977	0.6836	0.1665	0.01882	0.08302	0.7424
48	1.912	1.745	2.048	1.191	1.666	1.141
49	0.3418	0.3187	0.1728	0.4576	0.4886	0.2815
50	0.004361	0.005398	0.0001539	0.007403	0.001005	0.0002556
51	0.1798	0.132	0.2159	0.1712	0.1673	0.1853
52	0.02644	0.01141	0.01515	0.02555	0.01013	0.01775
53	11.09	16.14	14.75	15.49	19.61	5.143
54	0.2124	0.4733	0.2205	0.3227	0.4897	0.2517
55	7.596	5.467	5.013	5.268	19.54	13.88
56	10.41	14.7	7.863	2.112	3.567	6.091
57	0.2443	0.3766	0.2235	0.1937	0.4007	0.2465

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	83	84	85	86	87	88
1	1.459E-14	7.261E-15	1.134E-14	1.396E-14	9.26E-15	2.655E-15
2	0	0	0	0	0	0
3	6.284E-09	8.807E-09	7.092E-09	8.52E-09	1.501E-09	8.984E-09
4	1.015E-09	3.161E-10	2.307E-10	1.634E-10	4.432E-10	6.191E-10
5	0.6333	0.6818	0.5147	0.6457	0.07191	0.2453
6	0.09727	0.02068	0.004889	0.07372	0.05891	0.08424
7	0.1017	0.3647	0.4732	0.5509	0.5452	0.1312
8	0.8761	0.7305	0.5108	0.4925	0.5098	0.1168
9	-19.74	-19.69	-20.34	-18.73	-19.54	-19.29
10	-17.82	-19.8	-18.95	-18.48	-19.26	-18.25
11	-19.97	-18.86	-20.45	-19.67	-19.32	-18.61
12	-14.84	-14.73	-15.05	-15.19	-15.74	-16.17
13	0.5596	0.9197	0.2143	0.52	0.2852	0.6308
14	0.2635	0.3853	0.1598	0.1883	0.1221	0.3004
15	0.2222	0.09052	0.03535	0.5344	0.01936	0.07162
16	0.6277	0.4941	0.8281	5.169	2.157	0.3506
17	0.01333	0.01733	0.01619	0.02248	0.006061	0.014
18	-21.03	-22.91	-22.49	-23.76	-22.43	-23.88
19	5.972E-12	1.078E-10	1.122E-10	1.72E-10	8.35E-11	1.767E-10
20	-18.9	-19.83	-18.09	-18.22	-18.29	-18.72
21	1.032E-10	2.118E-10	1.09E-11	2.816E-11	1.09E-11	5.283E-11
22	1	4	4	4	1	1
23	0.1184	0.1044	0.07917	0.08546	0.07106	0.07213
24	0.05189	0.08632	0.07655	0.06138	0.1972	0.02232
25	0.6525	0.607	0.6951	0.5642	0.5876	0.573
26	11650000	11900000	11820000	13630000	11330000	11770000
27	11710000	15100000	12580000	14780000	12810000	13020000
28	-11.52	-11.37	-10.51	-11.83	-12.8	-13.78
29	-10.46	-10.03	-10.97	-9.613	-9.847	-9.128
30	-13.52	-12.51	-11.97	-13.73	-11.01	-12.68
31	3	26	13	3	30	31
32	0.0001226	0.1181	0.002903	0.004933	0.0001181	0.04954
33	6.757	5.008	4.09	1.749	2.129	2.561
34	565	51.22	671.9	763.7	854.4	334.8
35	0.5164	0.1188	0.8409	0.7948	0.3824	0.7204
36	0.1041	1.264	-1.235	0.2976	-0.003798	-0.09791
37	0.1289	-0.2396	-0.3367	-0.3168	0.06612	-0.04304
38	-0.173	0.01095	-0.4526	-0.009456	0.1926	-0.07451
39	-0.1735	-0.0346	-0.4975	-0.603	0.1958	-0.47
40	-0.6013	-0.1647	-0.04606	-0.4048	0.2126	-0.4662
41	-0.05304	0.2045	0.5323	-0.7434	-0.1534	0.8008
42	0.3991	-0.1873	-0.3732	-1.116	-0.405	0.1682
43	0.2033	-0.2109	-0.5757	-0.4866	0.1915	0.6124
44	-0.1306	0.1017	0.5182	-0.231	-0.2244	-0.4687
45	-0.1565	-0.9473	0.8884	-0.4688	-0.05961	0.09158
46	1.388	0.8866	0.4821	1.354	1.579	1.407
47	0.4035	0.6993	0.1595	0.178	0.05301	0.6626
48	1.232	1.235	1.157	1.139	1.009	1.185
49	0.4255	0.3795	0.05979	0.2896	0.4022	0.1307
50	0.001278	0.003697	0.001779	0.003384	0.0001135	0.0006862
51	0.2092	0.1868	0.1881	0.1774	0.1607	0.2315
52	0.02632	0.01585	0.002855	0.01746	0.02029	0.02042
53	0.9321	7.449	18.34	9.724	11.93	13.99
54	0.2291	0.04174	0.2726	0.1974	0.2954	0.09315
55	14.76	2.05	15.09	0.9814	14.53	12.35
56	10.82	17.93	13	8.723	1.589	8.271
57	0.1057	0.3594	0.2548	0.4456	0.08624	0.4902

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	89	90	91	92	93	94
1	1.576E-14	8.671E-15	7.552E-15	1.361E-14	5.481E-15	2.949E-15
2	1	1	1	2	0	0
3	1.334E-09	5.536E-09	3.291E-09	2.619E-09	1.973E-09	8.938E-09
4	8.661E-10	5.334E-10	1.246E-09	5.321E-11	7.024E-10	5.644E-10
5	0.2381	0.1402	0.05512	0.6758	0.6616	0.5361
6	0.05636	0.03154	0.08885	0.1432	0.02519	0.06688
7	0.07442	0.1735	0.3201	0.01702	0.1138	0.4769
8	0.3158	0.3928	0.2308	0.6861	0.7809	0.1801
9	-18.03	-19.46	-17.8	-19.4	-18.98	-18.65
10	-18.28	-18.8	-20.1	-19.24	-18.72	-19.16
11	-20.08	-20.88	-20.03	-20.16	-20.77	-20.2
12	-14.81	-15.91	-15.64	-15.23	-16.48	-15.67
13	0.03942	0.2698	0.1286	0.3881	0.9077	0.7482
14	0.05818	0.178	0.3181	0.05067	0.3485	0.2151
15	0.1935	0.06197	0.5964	0.3869	0.2761	0.5452
16	0.4507	1.922	7.557	2.327	0.3832	0.6126
17	0.006585	0.009427	0.02209	0.007214	0.004639	0.02988
18	-23.96	-22.95	-22.57	-22.1	-21.27	-21.13
19	1.851E-10	1.222E-10	1.189E-10	7.486E-11	2.348E-11	9.763E-12
20	-18.44	-19.24	-20.35	-18.95	-18.57	-18.61
21	2.183E-11	1.263E-10	2.75E-10	9.797E-11	3.075E-11	5.426E-11
22	4	4	1	4	1	1
23	0.1063	0.09424	0.07727	0.1474	0.07353	0.08902
24	0.07347	0.05951	0.03364	0.09928	0.07469	0.09082
25	0.7204	0.6533	0.4905	0.6354	0.6416	0.6451
26	13500000	11600000	12040000	12590000	13780000	13440000
27	13950000	16320000	12320000	13150000	14810000	13290000
28	-10.94	-12.72	-11.13	-11.89	-14.22	-11.72
29	-10.53	-9.399	-10.07	-9.928	-9.273	-9.953
30	-12.26	-11.61	-11.82	-11.21	-11.39	-12.75
31	3	28	4	30	2	20
32	0.1462	0.001345	0.002351	0.1716	0.007684	0.0003147
33	1.714	4.206	9.358	2.979	1.36	0.5979
34	13.76	571	318.3	598	178.2	343
35	0.02599	0.9995	0.421	0.9371	0.06998	0.1291
36	-0.328	0.9028	-0.07617	-0.18	-0.2271	0.2148
37	0.221	0.1879	-0.1897	-0.2049	0.1384	-0.2133
38	-0.29	-1.265	-0.2201	0.963	-0.4014	-0.186
39	-0.1588	-0.04709	-0.237	-0.08011	0.03117	0.1618
40	0.2352	-0.1028	-0.4591	-0.1353	-0.1531	-0.1223
41	-0.1904	-0.07373	-0.4597	0.9713	-0.6214	-0.1675
42	0.291	0.8492	0.4707	0.5044	0.1351	-0.03986
43	0.037	0.1221	0.7399	-0.8216	-0.2067	-0.2251
44	-0.02886	0.02778	0.4026	0.59	-0.8688	-0.3433
45	-0.08275	-0.2664	-0.1438	0.04009	0.0137	-0.2087
46	1.535	1.513	1.395	1.437	1.399	1.582
47	0.1024	0.8106	0.5093	0.7152	0.7985	0.1931
48	1.241	1.219	1.082	1.929	1.851	1.058
49	0.0795	0.2696	0.1829	0.3964	0.346	0.05532
50	0.0005933	0.0003008	0.0001197	0.001734	0.0002148	0.002458
51	0.1629	0.1804	0.141	0.1523	0.1519	0.1978
52	0.00125	0.01702	0.01228	0.01089	0.003569	0.01735
53	15.1	4.569	17.03	6.124	15.91	12.02
54	0.3016	0.2389	0.1781	0.1707	0.2412	0.3959
55	15.5	15.01	7.21	14.1	5.501	19.77
56	12.42	5.224	6.334	6.913	4.976	12.58
57	0.2034	0.3457	0.2692	0.2108	0.1242	0.04813

Table IRES-2. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 1 (Continued)

LHS#	95	96	97	98	99	100
1	4.441E-15	1.254E-15	1.486E-14	1.469E-14	9.806E-16	1.097E-16
2	1	0	0	0	0	2
3	3.862E-09	2.24E-09	6.038E-10	5.186E-09	7.499E-09	3.358E-09
4	1.131E-09	8.343E-11	1.423E-10	1.066E-11	7.355E-10	9.434E-10
5	0.1006	0.5822	0.9593	0.2514	0.8278	0.7885
6	0.1278	0.07529	0.1425	0.02273	0.1378	0.01874
7	0.08212	0.2137	0.4866	0.2562	0.3789	0.04031
8	0.3024	0.1398	0.2806	0.5977	0.925	0.8128
9	-18.36	-18.1	-17.93	-17.75	-17.86	-19.01
10	-17.8	-18.68	-17.92	-18.75	-18.91	-19.97
11	-19.8	-19.91	-18.78	-19.76	-20.74	-19.65
12	-15.61	-14.57	-14.6	-15.7	-15.02	-14.22
13	0.7547	0.008287	0.9594	0.08757	0.3333	0.8896
14	0.3748	0.1288	0.3547	0.0529	0.0121	0.01677
15	0.3781	0.04215	0.04482	0.1046	0.2352	0.4721
16	0.2467	0.73	3.489	0.329	0.9366	0.602
17	0.003983	0.00838	0.02545	0.009985	0.01581	0.01306
18	-23.27	-21.38	-21.03	-23.03	-21.79	-21.45
19	1.458E-10	2.83E-11	3.353E-12	1.379E-10	3.701E-11	2.595E-11
20	-18.82	-19.39	-18.65	-18.48	-19.08	-19.09
21	5.565E-11	1.495E-10	3.435E-11	2.378E-11	8.634E-11	1.24E-10
22	1	1	4	1	4	4
23	0.08499	0.0713	0.1292	0.0403	0.0745	0.1075
24	0.07079	0.1195	0.1009	0.126	0.06904	0.1462
25	0.6255	0.6814	0.6488	0.6297	0.6023	0.5928
26	11720000	11080000	12430000	12200000	11290000	11810000
27	16060000	13340000	14050000	14230000	13230000	13690000
28	-12.06	-10.8	-11.31	-13.89	-13.3	-14.46
29	-9.594	-10.52	-10.43	-8.766	-8.611	-8.959
30	-12.9	-12.48	-12.46	-12.08	-13.07	-11.96
31	5	2	27	1	19	18
32	0.001132	0.0008014	0.105	0.0001587	0.006006	0.0001085
33	8.242	0.8188	8.067	8.726	8.841	2.343
34	480.5	67.35	406.2	431.9	258.6	735.7
35	0.9649	0.2315	0.3695	0.8981	0.8898	0.6322
36	-0.3503	0.126	-0.02964	0.3523	-0.1871	-0.04512
37	-0.4213	0.04593	-0.01926	0.0863	0.227	-0.817
38	-0.3877	0.4947	-0.6482	0.238	-0.1606	-0.1126
39	0.1791	-0.4502	-0.3193	0.0212	-0.9811	0.1201
40	0.192	-0.09245	0.04924	-0.746	-0.1281	-0.2153
41	0.7379	-0.1394	-0.107	0.02279	-0.2622	0.4722
42	-0.1933	0.7471	-0.2736	-0.1045	0.09932	-0.5502
43	-0.3698	0.4534	0.2777	-0.1267	-0.3983	0.8417
44	-0.4352	-1.625	-0.2609	0.9484	0.008929	-0.05308
45	0.1098	-0.02363	0.0553	-0.4424	-0.2232	-0.1918
46	1.451	0.5794	0.926	1.484	1.503	1.56
47	0.1422	0.297	0.7575	0.5378	0.006549	0.4603
48	1.053	1.513	1.028	1.238	1.055	1.157
49	0.07646	0.4496	0.1149	0.3204	0.1121	0.08905
50	0.001331	0.001538	0.000344	0.0008874	0.000526	0.0001482
51	0.2227	0.1173	0.1182	0.1174	0.1634	0.1129
52	0.01897	0.02005	0.02359	0.0197	0.004721	0.0005612
53	12.21	3.797	4.125	13.45	1.735	16.19
54	0.1845	0.208	0.3135	0.1499	0.4322	0.1033
55	3.564	1.593	1.866	7.154	2.591	6.707
56	19.08	13.15	6.542	12.11	2.581	17.47
57	0.3505	0.3072	0.2633	0.05751	0.4772	0.4135

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2

LHS#	Material	Parameter	1	2	3	4
1	STEEL	CORRMCO2	2.681E-15	4.002E-15	7.336E-15	1.319E-14
2	WAS_AREA	PROBDEG	2	2	1	2
3	WAS_AREA	GRATMICI	6.003E-09	9.277E-09	3.402E-09	5.008E-09
4	WAS_AREA	GRATMICH	1.214E-09	8.389E-10	1.101E-09	3.64E-11
5	CELLULS	FBETA	0.3166	0.7173	0.4054	0.2284
6	WAS_AREA	SAT_RGAS	0.1032	0.146	0.03963	0.004825
7	WAS_AREA	SAT_RBRN	0.2165	0.4386	0.1844	0.07472
8	WAS_AREA	SAT_WICK	0.8136	0.9899	0.5983	0.2636
9	CL_L_T1	PRMX_LOG	-19.59	-18.01	-19.17	-18.22
10	CONC_T1	PRMX_LOG	-18.39	-18.99	-18.58	-17.42
11	ASPHALT	PRMX_LOG	-19.24	-19.73	-18.91	-20.2
12	SHFT_DRZ	PRMX_LOG	-14.55	-14.6	-14.65	-15.04
13	SALT_T1	CUMPROB	0.1256	0.2631	0.4918	0.2529
14	SALT_T1	SAT_RGAS	0.1999	0.3875	0.3221	0.3948
15	SALT_T1	SAT_RBRN	0.1036	0.3129	0.3967	0.3399
16	SALT_T1	PORE_DIS	0.7288	1.568	4.752	6.721
17	S_HALITE	POROSITY	0.002122	0.0157	0.0232	0.00635
18	S_HALITE	PRMX_LOG	-21.11	-21.37	-21.52	-22.1
19	S_HALITE	COMP_RCK	7.472E-12	2.72E-11	4.081E-11	8.106E-11
20	S_MB139	PRMX_LOG	-19.01	-18.89	-19.1	-19.1
21	S_MB139	COMP_RCK	1.156E-10	6.39E-11	1.073E-10	8.07E-11
22	S_MB139	RELP_MOD	1	4	1	1
23	S_MB139	SAT_RBRN	0.09029	0.09525	0.01177	0.0776
24	S_MB139	SAT_RGAS	0.08968	0.05632	0.06345	0.02071
25	S_MB139	PORE_DIS	0.6701	0.6089	0.652	0.7005
26	S_HALITE	PRESSURE	12490000	11320000	11220000	12090000
27	CASTILER	PRESSURE	13400000	12310000	16590000	12470000
28	CASTILER	PRMX_LOG	-12	-12.18	-10.59	-11.85
29	CASTILER	COMP_RCK	-10.38	-9.459	-11.16	-8.743
30	BH_SAND	PRMX_LOG	-13.17	-11.18	-11.39	-12.65
31	CASTILER	GRIDFLO	19	23	6	17
32	BLOWOUT	PARTDIA	0.01663	0.0383	0.0013	0.00009838
33	BOREHOLE	TAUFAIL	2.715	9.718	6.384	8.999
34	CULEBRA	MINP_FAC	359.6	406.1	793.2	280.2
35	GLOBAL	TRANSIDX	0.6583	0.9762	0.4418	0.1064
36	SOLAM3	SOLSIM	-0.4552	0.01046	0.1076	0.9686
37	SOLAM3	SOLCIM	0.7633	-0.1296	-0.9505	0.02868
38	SOLPU3	SOLSIM	-0.04413	-0.1357	-1.379	-0.1927
39	SOLPU3	SOLCIM	-0.4943	0.2926	0.2395	-0.4617
40	SOLPU4	SOLSIM	1.128	-0.295	0.1322	-0.1586
41	SOLPU4	SOLCIM	0.4518	-0.06731	0.254	-0.09627
42	SOLU4	SOLSIM	-0.3395	-0.3239	-0.144	-0.1593
43	SOLU6	SOLSIM	-1.269	-0.09545	-0.142	-0.1908
44	SOLU6	SOLCIM	0.9115	-0.2874	-0.004202	-0.3898
45	SOLTH4	SOLSIM	-0.3427	-0.7559	0.07263	0.2125
46	PHUMOX3	PHUMCIM	0.494	0.3204	1.406	0.2232
47	GLOBAL	OXSTAT	0.8608	0.3213	0.3082	0.8164
48	GLOBAL	CLIMTIDX	1.046	1.112	1.135	1.152
49	CULEBRA	HMBLKLT	0.4556	0.2946	0.3728	0.4047
50	CULEBRA	APOROS	0.001935	0.0005074	0.0003785	0.0007499
51	CULEBRA	DPOROS	0.1755	0.1342	0.137	0.1299
52	U+6	MKD_U	0.02921	0.006248	0.01165	0.007491
53	U+4	MKD_U	8.524	12.52	6.349	2.666
54	PU+3	MKD_PU	0.4322	0.3538	0.3913	0.1632
55	PU+4	MKD_PU	18.8	2.767	14.42	13.7
56	TH+4	MKD_TH	17.67	12.52	6.236	17.73
57	AM+3	MKD_AM	0.1603	0.4972	0.09537	0.365

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	5	6	7	8	9	10
1	1.107E-14	9.976E-15	1.268E-14	7.488E-15	1.575E-14	8.349E-15
2	1	0	2	1	1	0
3	5.485E-09	6.306E-09	8.961E-09	5.244E-09	9.139E-10	9.382E-09
4	7.784E-10	2.695E-10	1.138E-09	4.255E-10	7.168E-10	3.193E-10
5	0.1087	0.0855	0.8149	0.5794	0.4612	0.1991
6	0.1343	0.1437	0.145	0.007197	0.01856	0.06399
7	0.4596	0.244	0.1539	0.1925	0.2852	0.328
8	0.05398	0.08016	0.6061	0.9429	0.7987	0.4
9	-17.56	-17.98	-18.51	-18.33	-19.01	-20.1
10	-17.51	-18.48	-19.17	-18.12	-18.71	-18.98
11	-19.71	-18.74	-20.31	-19.79	-19.98	-19.83
12	-14.19	-15.82	-16.23	-14.54	-15.61	-14.95
13	0.7196	0.8728	0.9458	0.994	0.172	0.1451
14	0.02619	0.2746	0.1373	0.2512	0.2453	0.07411
15	0.4544	0.1665	0.07884	0.08017	0.4176	0.4689
16	0.7958	0.9632	4.979	0.6085	0.3829	4.442
17	0.008702	0.01739	0.01442	0.005963	0.001135	0.02153
18	-23.57	-23.5	-23.72	-22.7	-23.41	-21.43
19	1.667E-10	1.644E-10	1.716E-10	1.037E-10	1.514E-10	3.355E-11
20	-18.32	-18.16	-18.84	-19.72	-19.3	-19.35
21	1.09E-11	1.09E-11	9.389E-11	2.359E-10	1.323E-10	1.463E-10
22	4	4	1	1	4	4
23	0.0913	0.09863	0.05355	0.1615	0.08117	0.1412
24	0.05461	0.01398	0.08694	0.05846	0.09316	0.09171
25	0.5965	0.6005	0.7266	0.647	0.6541	0.6873
26	12530000	13690000	13710000	12180000	12740000	11440000
27	12790000	13650000	13730000	16130000	12510000	13450000
28	-12.67	-10.23	-11.06	-14.51	-10.79	-12.5
29	-9.694	-10.77	-10.63	-8.165	-9.771	-9.137
30	-12.31	-13.15	-12.95	-12.92	-11.26	-11.62
31	1	3	7	9	8	18
32	0.1245	0.02004	0.00005137	0.0002972	0.0002031	0.006999
33	1.864	3.659	2.207	1.537	0.8694	6.245
34	120	921.1	873.9	286.3	326	452
35	0.3056	0.6326	0.7926	0.3656	0.004732	0.8115
36	0.3318	-0.5231	0.01195	0.03257	-1.452	0.2355
37	-0.4121	-0.3397	-0.2057	0.5368	-0.2783	0.221
38	-0.3202	0.234	-0.3485	-0.03599	-0.02195	0.02997
39	0.1111	-1.702	0.8036	0.1626	-0.1268	-0.05529
40	0.2333	-0.4493	0.3789	0.2185	0.01605	-0.2217
41	-0.4234	0.6659	0.7834	0.8841	-0.5403	0.5865
42	-0.03597	0.05831	-0.2374	0.8365	-0.04351	0.1981
43	-1.696	-0.0983	-0.197	0.2261	-0.2787	-0.9528
44	0.04695	0.6979	-0.05753	0.2286	-0.1222	0.7087
45	0.0209	-0.2358	-0.7807	0.8508	-1.123	-0.8664
46	1.408	1.486	1.336	1.566	1.395	1.371
47	0.5185	0.5685	0.2028	0.4228	0.1625	0.01177
48	1.233	1.072	1.237	1.184	1.064	2.154
49	0.09784	0.2085	0.08498	0.4275	0.2446	0.2571
50	0.004442	0.005319	0.002283	0.0004301	0.0003001	0.006426
51	0.1612	0.1211	0.1052	0.1843	0.1661	0.1137
52	0.009632	0.02864	0.000195	0.01899	0.0007683	0.009021
53	3.126	13.79	10.93	11.18	19.47	5.364
54	0.385	0.04495	0.05336	0.1992	0.3414	0.4188
55	15.91	5.436	7.985	7.453	9.009	11.9
56	19.47	6.69	15.99	13.26	5.458	7.94
57	0.03809	0.231	0.4195	0.2599	0.1383	0.05839

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	11	12	13	14	15	16
1	1.477E-14	1.12E-14	1.084E-14	8.242E-15	1.453E-14	7.781E-15
2	1	0	0	0	0	1
3	6.516E-09	9.492E-09	8.605E-09	7.6E-09	6.897E-09	3.728E-09
4	9.48E-10	1.258E-10	5.642E-10	1.046E-09	2.612E-10	1.473E-10
5	0.1233	0.01151	0.3444	0.4547	0.1858	0.803
6	0.117	0.1263	0.07997	0.02562	0.009961	0.1019
7	0.3257	0.3399	0.2721	0.1706	0.3166	0.156
8	0.5596	0.1855	0.9606	0.5603	0.1704	0.9386
9	-18.37	-19.09	-19.31	-17.68	-19.64	-20.45
10	-20.24	-17.69	-17.79	-19.64	-18.86	-19.02
11	-20.6	-20.16	-19.09	-19.26	-20.43	-20.04
12	-16.06	-15.57	-15.77	-15.35	-14.79	-14.31
13	0.8801	0.3088	0.6232	0.802	0.3842	0.3425
14	0.1411	0.2191	0.2243	0.3453	0.1153	0.2868
15	0.2155	0.2069	0.4786	0.3321	0.02723	0.0515
16	5.253	0.6444	0.7037	0.4682	0.5736	6.142
17	0.009996	0.002494	0.001929	0.007957	0.002262	0.02659
18	-21.67	-22.16	-21.42	-21.28	-22.8	-23.96
19	5.761E-11	6.766E-11	3.282E-11	2.314E-11	1.146E-10	1.894E-10
20	-18.18	-19.18	-18.48	-18.73	-18.76	-18.35
21	1.09E-11	1.269E-10	2.696E-11	7.091E-11	6.844E-11	2.179E-11
22	4	1	4	4	1	1
23	0.06459	0.0504	0.06162	0.0873	0.123	0.05938
24	0.07561	0.06523	0.08826	0.07812	0.07899	0.06412
25	0.4905	0.6104	0.6242	0.7173	0.5656	0.6609
26	13520000	13460000	13070000	11360000	12340000	11570000
27	15150000	14230000	13360000	13740000	13690000	12900000
28	-13.51	-12.66	-11.61	-10.69	-11.34	-12.81
29	-8.397	-9.221	-10.27	-9.784	-10.8	-9.259
30	-11.23	-12.67	-12.35	-12.55	-13.04	-11.58
31	30	9	17	2	32	2
32	0.001487	0.0001188	0.1638	0.0001647	0.0009615	0.0004592
33	8.14	4.205	2.119	7.312	6.832	7.737
34	494	58.72	597.8	862.1	476.9	751.8
35	0.322	0.2499	0.8839	0.3163	0.7282	0.7183
36	-1.931	-0.2012	-1.077	-0.0165	0.2142	-0.9263
37	0.8504	-0.05875	-0.4595	-0.1148	-0.2303	-0.809
38	-0.8552	-1.886	0.417	-0.099	-0.07513	-0.03203
39	-0.1666	0.1394	-0.04817	-0.2549	-0.0293	-0.01193
40	0.9936	-0.491	-1.842	-0.009069	0.6931	0.5933
41	-0.02683	0.07568	0.6276	0.03768	-0.6726	-0.1261
42	-0.1511	-0.3911	0.9301	-0.08065	-0.2157	0.8772
43	-0.04246	-0.0807	-0.2667	0.1384	0.7323	0.5675
44	-0.2631	-0.9179	-0.05336	-0.02142	0.6034	0.7759
45	-0.3663	-0.2377	0.02679	0.2765	-0.5096	0.1828
46	1.017	0.399	1.468	0.2938	1.543	0.8124
47	0.4521	0.6164	0.9344	0.1837	0.4069	0.9517
48	1.094	1.002	1.236	2.186	1.157	1.122
49	0.1961	0.2307	0.4323	0.07941	0.1149	0.3087
50	0.002317	0.003715	0.0002251	0.0007607	0.0004006	0.0001909
51	0.1807	0.1797	0.1804	0.1096	0.163	0.1719
52	0.0111	0.02752	0.005064	0.02904	0.02538	0.01833
53	5.042	17.1	17.45	13.36	4.307	3.423
54	0.4867	0.0787	0.4796	0.3625	0.2393	0.2996
55	17.13	3.124	8.561	11.63	2.296	3.738
56	8.074	16.77	13.94	1.721	13.08	19.39
57	0.07465	0.1349	0.2663	0.3751	0.4863	0.15

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	17	18	19	20	21	22
1	1.685E-15	1.214E-14	1.395E-14	4.483E-15	3.527E-15	1.365E-15
2	0	0	1	0	1	2
3	7.326E-09	8.471E-09	4.175E-09	7.01E-09	9.195E-09	4.428E-09
4	1.624E-10	1.062E-09	1.246E-09	8.816E-10	5.39E-10	9.195E-10
5	0.4358	0.7441	0.03722	0.5899	0.8592	0.78
6	0.03477	0.1421	0.1068	0.09098	0.07262	0.09478
7	0.2408	0.0622	0.1969	0.1093	0.3457	0.01712
8	0.2149	0.5898	0.0706	0.6687	0.8001	0.7389
9	-18.31	-19.51	-19.52	-18.63	-20.28	-20.14
10	-19.54	-18.59	-19.51	-17.23	-18.09	-19.92
11	-19.9	-20.02	-19.58	-20.3	-19.92	-20.67
12	-16	-16.65	-14.95	-15.37	-15.07	-15.96
13	0.5233	0.6543	0.4449	0.9227	0.1873	0.7005
14	0.2948	0.3134	0.05092	0.1532	0.2076	0.365
15	0.05425	0.03276	0.1323	0.4986	0.186	0.5646
16	6.273	3.29	0.2984	0.5805	0.7326	1.583
17	0.007477	0.02117	0.0244	0.003708	0.01623	0.01272
18	-21.59	-21.89	-22.23	-23.18	-23.33	-23.85
19	5.259E-11	4.77E-11	9.138E-11	1.437E-10	1.584E-10	1.809E-10
20	-18.43	-19.22	-19.07	-18.66	-17.79	-19.24
21	5.684E-11	1.099E-10	1.164E-10	5.907E-11	1.09E-11	1.362E-10
22	4	4	4	4	1	1
23	0.05205	0.09598	0.09267	0.06986	0.1292	0.1059
24	0.1018	0.07778	0.1223	0.09743	0.08104	0.04525
25	0.6917	0.667	0.7051	0.5762	0.7087	0.5804
26	12510000	13280000	13420000	11050000	12770000	11820000
27	12160000	11690000	15820000	11950000	15200000	12070000
28	-11.91	-11.22	-12.43	-13.68	-11.18	-13.06
29	-9.371	-9.61	-9.714	-9.064	-9.923	-9.163
30	-12.86	-12.37	-13.3	-13.12	-12.07	-13.54
31	11	15	27	1	19	7
32	0.02673	0.01083	0.0002534	0.0005508	0.003791	0.1084
33	2.245	2.601	8.502	3.798	0.519	6.718
34	968.6	33.14	44.65	665.8	448.1	379.6
35	0.4909	0.3927	0.3426	0.6637	0.02125	0.3702
36	-0.07251	0.5015	-0.08383	-0.4884	-0.9644	-0.4803
37	-1.436	-0.06528	-0.8999	-0.08694	1.279	-0.1451
38	0.261	-0.228	-0.01955	-0.4142	-0.1678	0.5949
39	0.2068	-0.09913	-0.8334	-0.1562	-0.2231	-1.072
40	-0.7472	-0.02447	-0.9388	-0.307	0.1904	-0.234
41	-0.1861	-0.3646	-0.05696	-0.4082	0.2186	-0.2549
42	-0.06391	-0.2024	0.216	-0.3021	-1.777	0.1673
43	0.02593	-0.2942	-0.03269	-0.1105	-0.2413	-0.5563
44	-0.07009	0.03495	-0.1012	0.544	-0.1522	-0.184
45	-0.1066	0.165	-0.1836	-0.2448	-0.1492	-0.06292
46	1.474	1.559	1.444	1.174	1.529	1.54
47	0.06576	0.2852	0.3345	0.2435	0.7994	0.4965
48	1.013	1.857	1.084	1.033	1.77	1.982
49	0.2047	0.3845	0.4228	0.4954	0.1178	0.1492
50	0.0003521	0.005218	0.00111	0.001193	0.0009415	0.0008293
51	0.189	0.1676	0.1749	0.1649	0.1433	0.2052
52	0.02056	0.01693	0.02359	0.01386	0.0112	0.01526
53	2.362	18.1	11.89	7.859	4.551	8.551
54	0.4104	0.433	0.3978	0.4608	0.1233	0.06405
55	16.42	1.192	4.372	10.98	11.33	19.41
56	12.92	17.42	8.614	2.355	4.116	8.991
57	0.06043	0.08748	0.3482	0.4508	0.2751	0.1876

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	23	24	25	26	27	28
1	3.897E-15	6.528E-15	6.924E-15	6.266E-15	5.399E-15	4.122E-17
2	2	0	1	2	1	1
3	8.253E-09	2.878E-09	7.738E-09	6.458E-09	3.551E-09	5.831E-09
4	6.818E-10	5.322E-12	4.515E-10	5.927E-10	7.366E-10	9.123E-10
5	0.6664	0.07061	0.9846	0.0008046	0.8204	0.5203
6	0.08155	0.08508	0.02187	0.1124	0.1286	0.1257
7	0.5468	0.09426	0.4776	0.4729	0.4985	0.02866
8	0.46	0.3959	0.4995	0.6127	0.8463	0.2025
9	-19.38	-19.89	-18.84	-18.35	-19.71	-18.95
10	-19.21	-18.51	-18.49	-19.49	-19.29	-18.39
11	-20.24	-19.81	-19.32	-19.1	-18.56	-18.88
12	-16.47	-15.29	-15.94	-15.44	-14.86	-15.72
13	0.04911	0.5794	0.9307	0.6796	0.9176	0.4242
14	0.3073	0.1247	0.1769	0.1232	0.004699	0.3901
15	0.09943	0.3725	0.1275	0.4254	0.1763	0.3879
16	0.6889	3.472	0.2628	8.362	3.047	2.271
17	0.02067	0.007268	0.02035	0.02693	0.004745	0.005727
18	-21.7	-23.09	-23.04	-23.69	-21.93	-21.96
19	5.459E-11	1.314E-10	1.356E-10	1.558E-10	6.632E-11	6.338E-11
20	-18.39	-17.1	-17.86	-18.64	-18.02	-17.15
21	1.339E-11	1.09E-11	1.09E-11	4.758E-11	1.09E-11	1.09E-11
22	4	4	4	1	4	1
23	0.09917	0.07309	0.08223	0.04187	0.1048	0.09791
24	0.1181	0.03054	0.07546	0.1366	0.08049	0.09645
25	0.5728	0.6504	0.6404	0.7721	0.6818	0.5263
26	11970000	13300000	12120000	12200000	13220000	11870000
27	14830000	14490000	14160000	14700000	11790000	16020000
28	-11.4	-11.71	-13.41	-12.46	-12.16	-13.58
29	-10.24	-10.35	-9.031	-9.109	-9.638	-8.27
30	-13.47	-11.83	-11.52	-11.98	-12.87	-12.21
31	1	12	17	11	13	28
32	0.07547	0.00004225	0.0003748	0.0001353	0.0006317	0.00006322
33	2.445	0.1299	6.434	6.001	9.493	9.62
34	313.8	136.9	834.5	827.1	527.4	269.6
35	0.4797	0.8016	0.406	0.9812	0.5701	0.644
36	0.5781	0.447	-0.001601	-0.1034	1.08	-0.1695
37	-0.2466	0.1526	-0.2275	0.05624	-0.1706	-0.2151
38	0.03883	0.8924	-0.1172	-0.175	-0.6602	0.6938
39	-0.4137	0.3129	-0.2902	-0.4396	-0.09505	0.5536
40	0.7012	0.1995	-0.04458	-0.1743	-0.2229	-0.4324
41	0.08682	-0.1979	-0.3168	-0.8685	-1.233	-0.2174
42	-0.1388	-0.5003	-0.6869	-0.03085	-0.8481	-0.6588
43	0.7785	-0.0127	-0.7171	0.8555	-0.2191	0.6309
44	0.06382	0.09633	-0.6152	-0.3463	0.1938	0.1646
45	0.84	-0.1965	-0.1934	-0.4251	0.1205	0.4005
46	1.302	1.401	0.06894	1.554	1.455	1.514
47	0.5813	0.8394	0.156	0.6531	0.9706	0.08368
48	1.083	1.567	1.2	1.205	1.125	1.214
49	0.4897	0.4493	0.3347	0.2689	0.4186	0.1592
50	0.009141	0.0006175	0.0002009	0.008175	0.0001491	0.0002544
51	0.1409	0.1833	0.1706	0.2407	0.1639	0.1694
52	0.00436	0.01572	0.02637	0.02249	0.004785	0.002482
53	6.599	17.94	13.95	9.897	19.04	17.53
54	0.1389	0.4991	0.1488	0.2079	0.03748	0.05496
55	5.1	11.42	8.793	14.57	19.64	9.14
56	2.134	4.509	14.47	11.37	14.74	3.688
57	0.2185	0.3791	0.2638	0.233	0.2439	0.1468

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	29	30	31	32	33	34
1	9.358E-15	1.475E-14	8.625E-15	1.246E-14	1.136E-14	4.413E-15
2	2	1	0	1	0	0
3	2.988E-09	1.103E-09	8.112E-09	1.272E-09	7.134E-09	8.384E-09
4	5.267E-10	4.055E-10	4.686E-10	5.183E-10	2.311E-10	4.965E-10
5	0.4466	0.4867	0.6588	0.4206	0.3514	0.1465
6	0.1482	0.1049	0.03061	0.1334	0.04095	0.06264
7	0.1335	0.07867	0.4332	0.5072	0.2064	0.4037
8	0.349	0.7463	0.3577	0.7176	0.9753	0.02291
9	-18.87	-18.17	-18.59	-18.56	-18.38	-18.65
10	-19.57	-20.01	-18.55	-17.31	-19.36	-17.58
11	-18.8	-19.69	-18.68	-20.03	-19.19	-19.85
12	-14.89	-16.32	-15.91	-14.73	-15.05	-15.23
13	0.3694	0.1938	0.5194	0.99	0.08869	0.6812
14	0.09951	0.2383	0.1486	0.1166	0.03594	0.3114
15	0.1532	0.1952	0.1756	0.02044	0.5391	0.06267
16	0.2754	2.469	0.5156	3.539	1.754	4.081
17	0.006188	0.01694	0.008029	0.009766	0.02431	0.009304
18	-22.29	-22.18	-23.99	-23.01	-21.54	-22.75
19	7.676E-11	8.781E-11	1.916E-10	1.334E-10	3.029E-11	1.252E-10
20	-18.86	-17.62	-19.02	-18.79	-17.57	-19.84
21	9.171E-11	1.09E-11	1.016E-10	6.037E-11	1.09E-11	2.188E-10
22	4	1	1	4	1	1
23	0.1028	0.101	0.06861	0.0559	0.09317	0.09
24	0.03654	0.0522	0.03992	0.07431	0.08204	0.09861
25	0.6287	0.6056	0.5913	0.6235	0.6359	0.6206
26	11190000	13370000	11540000	12420000	11480000	13550000
27	12200000	12560000	13570000	11870000	12670000	14930000
28	-12.38	-14.01	-12.77	-11.16	-10.36	-14.27
29	-9.828	-9.428	-8.918	-9.914	-10.75	-8.998
30	-13.79	-11.51	-13.1	-13.74	-13.99	-13.56
31	32	28	24	32	8	9
32	0.0001847	0.001863	0.05851	0.002207	0.003058	0.1708
33	0.1757	7.61	9.868	6.167	5.434	6.099
34	846	468.1	770.9	858.2	190.6	226.9
35	0.5854	0.1894	0.2919	0.8417	0.7525	0.2351
36	-0.2501	0.8743	0.1668	0.06907	-0.03376	0.6861
37	0.02055	-0.1499	-0.4803	0.5519	0.1022	0.03637
38	0.1	-0.8199	0.3269	0.08807	-0.3838	-0.1827
39	-0.0376	-0.3238	0.175	-0.1101	0.4343	-0.004585
40	0.5491	-0.3495	0.2618	0.006549	-0.2498	-0.1302
41	-0.945	0.9436	0.03461	-0.04269	-0.1482	-0.2884
42	0.5973	0.4078	0.5393	0.02587	0.9984	0.4883
43	0.144	-0.1236	-0.385	0.1651	-1.785	0.2057
44	-0.2491	0.1408	-0.4968	-0.0901	-0.1987	-0.03213
45	0.672	0.6151	-0.9376	0.239	0.2145	-0.03186
46	0.687	1.502	0.563	0.3556	0.4239	0.119
47	0.6948	0.7626	0.9898	0.3404	0.14	0.6227
48	1.72	1.106	1.188	1.193	1.061	1.514
49	0.1643	0.0708	0.3117	0.2905	0.1359	0.4107
50	0.003427	0.002619	0.002725	0.0001832	0.002896	0.0018
51	0.1848	0.1226	0.2273	0.111	0.1895	0.1189
52	0.005193	0.02077	0.0167	0.01345	0.01926	0.001408
53	15.78	9.608	15.18	5.782	3.608	19.7
54	0.3114	0.3741	0.2941	0.274	0.07004	0.3226
55	6.211	19.51	8.287	2.855	12.14	19.05
56	19.14	9.135	3.078	0.9197	3.369	6.831
57	0.4334	0.4568	0.09758	0.1049	0.1285	0.484

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	35	36	37	38	39	40
1	3.069E-15	1.536E-14	9.613E-15	4.795E-15	1.306E-14	6.713E-15
2	0	0	0	0	2	0
3	8.918E-09	1.711E-09	5.867E-09	5.573E-09	1.412E-09	8.137E-09
4	1.228E-09	1.113E-09	5.494E-10	1.01E-09	1.665E-10	9.856E-10
5	0.3323	0.3274	0.7232	0.6283	0.7081	0.7777
6	0.01455	0.07423	0.1108	0.1398	0.05947	0.03736
7	0.1012	0.1631	0.2317	0.482	0.3668	0.05337
8	0.2274	0.8797	0.6361	0.1133	0.3204	0.2434
9	-18.44	-19.43	-18.51	-17.76	-18.61	-19.92
10	-19.89	-17.88	-18.15	-18.92	-18.04	-18.18
11	-20.48	-19.34	-18.35	-20.82	-20.15	-19.03
12	-14.71	-14.41	-15.43	-14.49	-15.51	-14.74
13	0.6447	0.01637	0.7747	0.4684	0.106	0.008147
14	0.08688	0.1331	0.3426	0.2558	0.378	0.09593
15	0.2468	0.01927	0.05686	0.5284	0.2933	0.3094
16	5.421	5.695	5.622	2.569	5.062	7.229
17	0.008282	0.01212	0.02858	0.001439	0.00846	0.01932
18	-21.36	-22.63	-22.61	-22.25	-23.81	-23.47
19	1.717E-11	1.286E-10	9.697E-11	6.422E-11	1.792E-10	1.489E-10
20	-19.21	-18.98	-20.73	-18.51	-18.87	-19.12
21	1.237E-10	1.003E-10	2.75E-10	2.916E-11	8.994E-11	9.604E-11
22	4	1	1	1	4	4
23	0.1127	0.06605	0.02648	0.08883	0.1148	0.06917
24	0.05531	0.09496	0.0706	0.04198	0.06114	0.09516
25	0.6319	0.6842	0.5825	0.7303	0.7121	0.7064
26	11730000	12680000	12050000	12030000	13730000	11640000
27	12270000	13280000	13230000	16440000	14650000	12820000
28	-12.51	-13.48	-12.08	-12.02	-10.65	-11.67
29	-8.493	-8.645	-10.29	-10.44	-10.6	-10.46
30	-12.8	-13.88	-13.58	-12.61	-12.19	-11.72
31	29	9	24	20	26	10
32	0.00007512	0.03399	0.00004522	0.004145	0.007622	0.00005839
33	0.7131	7.044	4.281	9.556	5.326	8.876
34	907.4	652.8	588	486.3	728.5	3.153
35	0.6171	0.8299	0.08732	0.1696	0.6752	0.2856
36	-0.07889	-0.4354	-0.2166	-0.1565	-0.3829	-0.3166
37	-0.3036	0.008955	-0.5319	-0.1879	-0.1213	-0.0132
38	0.05972	0.2155	-0.0103	0.8084	-0.2364	0.2024
39	-0.1679	0.09128	-0.9581	-0.3647	0.6976	-0.1201
40	-0.95	0.1539	-0.08544	-0.03608	-0.2627	-0.01551
41	0.1675	-0.00939	-0.4895	-0.1572	0.4294	0.3058
42	-0.166	-0.9617	-0.7447	0.01957	-0.1843	0.3709
43	-0.1612	-0.0277	-1.025	-0.7557	-0.3216	0.484
44	0.1772	-0.1786	0.4142	-0.04167	-0.1724	-0.2067
45	0.04558	-0.07238	-0.1136	-0.1721	0.08457	-0.04558
46	0.6931	1.393	0.8826	1.547	1.431	0.6536
47	0.8987	0.7874	0.2771	0.756	0.1443	0.4482
48	1.028	2.094	2.029	1.208	1.911	1.099
49	0.2755	0.0867	0.4335	0.3928	0.4964	0.2432
50	0.004828	0.001035	0.0006861	0.000113	0.004031	0.000958
51	0.1873	0.1254	0.1733	0.1473	0.2142	0.1407
52	0.001596	0.01492	0.006953	0.01244	0.003743	0.01362
53	12.95	14.78	6.874	3.299	5.922	18.76
54	0.2444	0.06071	0.4021	0.2155	0.03427	0.1414
55	9.318	7.039	17.42	1.807	16.03	16.89
56	9.611	7.077	11.65	19.72	11.15	2.846
57	0.2942	0.0407	0.4311	0.3424	0.285	0.2472

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	41	42	43	44	45	46
1	7.853E-16	5.855E-15	6.132E-15	1.334E-14	9.467E-15	1.194E-14
2	1	0	0	1	0	1
3	2.904E-09	3.913E-09	1.944E-09	7.9E-10	1.567E-09	8.006E-09
4	4.724E-10	1.176E-09	1.121E-09	8.2E-10	5.796E-10	1.35E-10
5	0.2308	0.5396	0.06401	0.8895	0.9301	0.9971
6	0.05604	0.003661	0.07694	0.1497	0.07037	0.01711
7	0.0369	0.5165	0.3626	0.172	0.5218	0.3542
8	0.2882	0.5437	0.9584	0.1516	0.3358	0.3142
9	-17.7	-17.41	-19.35	-18.99	-20.04	-18.54
10	-18.81	-19.12	-18.83	-18.44	-18.96	-19.81
11	-19.35	-19	-19.78	-19.13	-20.62	-19.73
12	-14.99	-15.11	-15.26	-15.01	-14.69	-15.09
13	0.05062	0.2905	0.6002	0.38	0.5902	0.3275
14	0.11	0.3567	0.3554	0.319	0.2406	0.2771
15	0.008974	0.1582	0.1962	0.06553	0.5966	0.04452
16	0.3308	2.813	4.371	7.464	0.5384	1.324
17	0.01505	0.003886	0.006858	0.02531	0.02513	0.02273
18	-22.8	-21.06	-23.43	-22.86	-22.85	-21.23
19	1.078E-10	9.721E-12	1.57E-10	1.183E-10	1.123E-10	1.397E-11
20	-17.99	-19.27	-18.59	-18.72	-19.55	-18.62
21	1.09E-11	1.497E-10	4.009E-11	7.481E-11	2.096E-10	3.702E-11
22	4	1	4	1	4	4
23	0.06798	0.06491	0.1218	0.1003	0.06656	0.1081
24	0.1248	0.0734	0.09288	0.1161	0.07991	0.07708
25	0.6278	0.6412	0.6477	0.6175	0.6591	0.6606
26	12820000	12970000	12880000	12310000	13650000	13540000
27	12230000	12750000	13850000	13100000	13200000	12930000
28	-11.69	-12.22	-11.44	-13.33	-11.27	-13.76
29	-10.35	-10.11	-9.846	-8.964	-9.73	-10.03
30	-11.02	-11.05	-11.67	-13.03	-11.17	-13.88
31	21	21	2	5	23	7
32	0.08714	0.0002367	0.001693	0.0006728	0.05097	0.000762
33	3.906	1.162	3.151	1.551	5.027	6.707
34	886.6	74.35	788.8	178.7	543.3	365.6
35	0.09558	0.5424	0.4259	0.1538	0.7698	0.6884
36	-0.1132	-0.3445	0.9412	-0.1185	0.14	-0.3999
37	0.8316	0.1281	-0.0919	-0.1111	-0.2396	-0.4036
38	-0.713	-0.1632	0.3794	-0.4438	-0.05379	0.4551
39	-0.14	-0.18	-0.2336	-0.7878	0.1478	-0.06659
40	-0.1937	0.05813	0.6105	-0.064	0.1661	-0.07262
41	-0.1935	-1.468	-0.3391	0.7281	0.5372	-0.4606
42	0.2309	-0.02241	0.6853	-0.0009286	-0.5863	0.001039
43	-0.1478	-0.06498	-0.205	-0.1758	0.5116	-0.4914
44	-0.2696	0.1807	-0.2166	-0.4745	0.0519	-0.5725
45	0.194	-0.02054	-0.4772	-0.2604	0.5353	-0.2943
46	0.5981	1.576	0.8562	1.379	1.353	1.497
47	0.2175	0.8553	0.006882	0.6033	0.681	0.7036
48	1.18	1.24	1.069	1.02	1.018	1.103
49	0.3186	0.3253	0.214	0.329	0.1101	0.4076
50	0.0001602	0.004347	0.0001266	0.0002462	0.0002102	0.0003387
51	0.2466	0.1874	0.1496	0.1186	0.1855	0.1583
52	0.007925	0.003155	0.02967	0.02009	0.00676	0.02506
53	16.77	9.08	18.64	10.66	16.62	9.223
54	0.2663	0.0203	0.1502	0.2357	0.4164	0.3683
55	5.135	7.74	10.77	8.395	17.92	3.382
56	3.828	6.356	18.48	4.85	8.778	4.602
57	0.2722	0.3585	0.404	0.3883	0.3053	0.1945

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	47	48	49	50	51	52
1	1.236E-14	3.554E-16	4.216E-15	2.738E-15	1.298E-14	9.128E-15
2	0	2	0	1	1	0
3	6.201E-10	3.165E-09	2.423E-09	1.998E-09	1.234E-09	2.262E-09
4	1.077E-09	3.321E-10	2.222E-10	4.428E-10	7.673E-10	1.108E-10
5	0.05104	0.4901	0.472	0.6092	0.3864	0.02198
6	0.04724	0.05132	0.000557	0.1083	0.1005	0.007851
7	0.4152	0.2939	0.3057	0.5342	0.05689	0.1808
8	0.765	0.7521	0.7874	0.8902	0.4408	0.1647
9	-18.2	-18.08	-18.25	-18.79	-19.05	-19.23
10	-18.01	-18.42	-19.73	-18.9	-18.79	-18.89
11	-20.41	-20.13	-19.37	-19.64	-20.09	-19.62
12	-15.01	-14.97	-16.8	-15.15	-14.88	-15.38
13	0.4717	0.1157	0.9559	0.5071	0.7481	0.7251
14	0.2039	0.2237	0.07983	0.08207	0.03974	0.1568
15	0.2178	0.573	0.4081	0.5072	0.5839	0.04092
16	4.125	0.3008	0.8937	0.5027	0.2059	0.7764
17	0.02289	0.01414	0.005122	0.01881	0.0222	0.01806
18	-21.76	-22.97	-21.19	-21.87	-22.06	-21.81
19	4.592E-11	1.167E-10	1.959E-11	4.939E-11	7.973E-11	5.172E-11
20	-18.29	-18.55	-18.91	-20.27	-19.52	-19.31
21	1.09E-11	3.44E-11	9.712E-11	2.621E-10	1.699E-10	1.426E-10
22	1	4	4	1	4	4
23	0.1173	0.07218	0.05653	0.08003	0.06218	0.08274
24	0.08613	0.1104	0.07274	0.1196	0.03697	0.06701
25	0.6573	0.6137	0.6654	0.6182	0.6533	0.6069
26	13200000	12360000	12260000	12460000	12590000	11090000
27	13310000	13950000	12370000	15110000	14560000	13610000
28	-13.8	-12.96	-13.37	-12.11	-11.63	-12.54
29	-8.71	-8.957	-9.808	-10.53	-10.06	-9.503
30	-12.16	-13.38	-13.66	-11.88	-13.93	-11.15
31	22	30	11	5	16	6
32	0.005218	0.0001272	0.006338	0.008628	0.02355	0.03254
33	9.392	0.4413	7.627	6.928	4.566	5.804
34	341.8	503.1	170.7	420.9	914.9	627.5
35	0.5224	0.5589	0.4196	0.1948	0.01215	0.7845
36	-0.6791	-0.2286	-0.11	0.08277	0.2597	0.08889
37	-1.905	-0.6981	-0.0347	0.2612	0.1425	0.1602
38	0.9519	-0.7591	0.1817	0.1539	0.9431	-0.4677
39	0.09656	-0.62	0.0005594	-0.1387	0.1909	-0.7727
40	0.07311	0.1732	0.9192	-0.332	-0.02939	-0.6899
41	-0.1192	-0.02792	0.3501	0.1632	-0.1756	0.137
42	-0.2654	0.09558	-0.1939	-0.171	-0.4245	-0.4819
43	0.1039	-0.4585	0.3582	-0.3113	0.119	0.2354
44	0.2936	-0.7059	-0.4577	-0.07904	-0.2346	-0.2246
45	-0.174	-0.08624	-0.9821	0.9879	-0.225	0.1148
46	1.063	1.526	1.215	1.429	0.9048	1.467
47	0.1224	0.8865	0.5018	0.5904	0.07717	0.3992
48	1.211	2.065	1.169	1.196	1.163	1.147
49	0.274	0.1352	0.4511	0.06517	0.347	0.1796
50	0.002493	0.0004398	0.00218	0.001094	0.009114	0.001399
51	0.1682	0.1002	0.1122	0.199	0.1861	0.1037
52	0.008194	0.01969	0.005784	0.01306	0.01284	0.002936
53	6.245	10.58	15.37	19.88	7.622	3.865
54	0.221	0.2474	0.04221	0.2524	0.2596	0.1583
55	13.46	12.43	9.605	0.9991	14.95	4.808
56	7.384	1.861	14.95	14.45	1.217	15.23
57	0.2518	0.208	0.05176	0.1752	0.4468	0.3286

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	53	54	55	56	57	58
1	8.808E-15	9.717E-15	8.999E-15	1.545E-14	1.355E-14	3.462E-15
2	0	0	2	2	0	2
3	5.678E-09	4.892E-09	4.055E-09	5.101E-09	5.465E-09	4.275E-09
4	8.718E-10	6.266E-10	1.897E-10	2.505E-10	1.187E-09	2.022E-10
5	0.2605	0.2756	0.3781	0.1185	0.8485	0.6938
6	0.05542	0.1142	0.06538	0.06798	0.02006	0.02533
7	0.2516	0.2789	0.001879	0.3914	0.08617	0.04539
8	0.102	0.4786	0.6293	0.6963	0.7078	0.9048
9	-20.54	-20.7	-19.41	-18.97	-19.15	-17.95
10	-20.09	-17.96	-19.2	-19.96	-18.33	-18.54
11	-18.7	-19.97	-19.48	-19.59	-19.46	-18.65
12	-14.43	-15.14	-15.2	-14.61	-15.59	-14.76
13	0.4368	0.218	0.842	0.8267	0.3931	0.8982
14	0.3988	0.09101	0.06057	0.2714	0.3313	0.2614
15	0.2582	0.1487	0.2496	0.1376	0.1281	0.5545
16	0.1956	0.2141	7.938	0.4233	7.837	0.4454
17	0.01766	0.003044	0.00179	0.003182	0.00356	0.006971
18	-22.71	-21.79	-22.57	-21.07	-22.39	-22.66
19	1.221E-10	4.406E-11	9.418E-11	4.849E-12	9.36E-11	1.053E-10
20	-18.27	-18.96	-19.03	-19.56	-18.7	-19.68
21	1.09E-11	1.027E-10	1.1E-10	1.88E-10	6.285E-11	1.73E-10
22	1	1	4	1	4	4
23	0.07389	0.04665	0.08617	0.07363	0.112	0.08491
24	0.08947	0.03259	0.1283	0.09135	0.08314	0.1312
25	0.6861	0.5868	0.5449	0.6209	0.6555	0.6756
26	13820000	13460000	12940000	12860000	12780000	13790000
27	12760000	12940000	14780000	14080000	12670000	14250000
28	-14.15	-13.03	-10.07	-11.73	-10.88	-12.73
29	-8.612	-9.521	-10.91	-9.576	-10.65	-9.48
30	-12.41	-11.09	-13.23	-12.74	-12.13	-13.51
31	27	3	6	3	19	14
32	0.0008651	0.05183	0.01432	0.00241	0.02029	0.001396
33	2.989	8.694	9.935	5.168	2.929	0.7694
34	933.3	645.4	631.2	765.3	735.8	110.4
35	0.1769	0.6932	0.04818	0.9257	0.2005	0.6094
36	0.05518	-0.0933	-0.2487	-0.02767	-0.05007	-0.03923
37	0.1093	0.06521	0.3083	-0.334	-0.661	-0.1553
38	0.731	-0.1393	-0.1239	0.008252	-0.2003	-0.08387
39	0.7587	-0.2407	0.06458	0.04044	0.9601	0.07307
40	-0.5943	-0.388	-0.4101	-0.1083	-0.2397	-0.6289
41	-0.2119	-1.84	-0.4765	1.203	-0.01557	-0.5659
42	-0.2814	0.3367	-0.2305	0.1833	-0.09774	-0.4896
43	-0.4066	-0.06214	-0.2491	-0.172	0.6636	0.0637
44	-0.01526	-0.3291	0.3366	0.09098	-1.164	-0.1566
45	0.3761	0.153	-0.05882	-0.3072	0.004451	-0.3287
46	0.476	1.555	1.492	1.42	1.518	1.44
47	0.8027	0.04419	0.9676	0.913	0.5764	0.2926
48	1.017	2.205	1.08	1.217	1.691	1.244
49	0.2811	0.09305	0.375	0.09979	0.1899	0.05371
50	0.003607	0.004681	0.001364	0.0001413	0.009551	0.0003124
51	0.1087	0.1163	0.117	0.1782	0.1819	0.1378
52	0.01442	0.01755	0.00212	0.01772	0.02651	0.02399
53	7.154	4.431	2.203	19.07	14.55	0.9982
54	0.128	0.1066	0.4406	0.1131	0.4906	0.4754
55	2.07	12.81	4.542	18.47	11.13	9.917
56	16.63	9.395	8.414	1.298	15.5	17.3
57	0.02577	0.2227	0.4136	0.4242	0.4717	0.159

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	59	60	61	62	63	64
1	1.48E-15	2.42E-16	9.056E-16	3.219E-15	1.401E-14	1.565E-14
2	0	1	0	0	0	1
3	4.637E-09	8.723E-09	5.583E-10	7.523E-09	5.291E-09	3.532E-09
4	2.959E-10	1.232E-09	9.7E-10	9.191E-11	8.08E-10	3.896E-10
5	0.2565	0.2044	0.3044	0.752	0.6728	0.9167
6	0.1307	0.05098	0.06724	0.1355	0.0126	0.02959
7	0.4219	0.3832	0.544	0.2114	0.3145	0.443
8	0.9953	0.4507	0.6485	0.1493	0.2908	0.5172
9	-19.12	-18.11	-19.21	-19.83	-18.15	-18.12
10	-19.03	-19.68	-19.11	-18.86	-18.68	-18.27
11	-18.42	-19.88	-19.07	-19.83	-19.15	-19.96
12	-14.84	-15.54	-16.04	-15.23	-15.85	-15.41
13	0.4119	0.02437	0.3568	0.9044	0.2873	0.455
14	0.1814	0.06537	0.03	0.1938	0.07027	0.1636
15	0.02835	0.4836	0.07253	0.4392	0.1073	0.2724
16	0.2379	0.5479	8.22	0.8009	0.3502	0.6688
17	0.01557	0.007743	0.001254	0.001606	0.02891	0.01854
18	-21.72	-23.9	-23.4	-21.63	-21.91	-23.2
19	3.9E-11	1.865E-10	1.536E-10	3.882E-11	5.996E-11	1.388E-10
20	-19.25	-19.41	-19.38	-18.85	-18.06	-18.57
21	1.378E-10	1.404E-10	1.302E-10	7.612E-11	1.09E-11	5.302E-11
22	4	1	4	1	1	4
23	0.1038	0.07176	0.04836	0.07833	0.08377	0.119
24	0.06955	0.02589	0.04584	0.113	0.08321	0.05934
25	0.699	0.65	0.561	0.7442	0.6359	0.4905
26	13860000	13400000	11680000	12230000	12890000	12130000
27	13490000	12340000	13430000	11540000	13050000	12100000
28	-11.3	-11.54	-13.2	-11.8	-11.95	-10.55
29	-10.09	-9.982	-9.194	-10.22	-8.852	-10.99
30	-12.46	-13.96	-13.43	-11.39	-11.95	-12.75
31	23	10	14	29	2	21
32	0.002052	0.0002614	0.0001035	0.004349	0.01197	0.00008655
33	8.592	8.763	3.042	9.054	9.158	5.837
34	577.2	953.3	818.9	603.7	977.9	68.95
35	0.05485	0.03305	0.5668	0.07101	0.4806	0.623
36	-0.2788	-0.1772	-0.2295	-0.01228	0.1903	-0.1392
37	0.2396	-0.04025	-0.01636	-1.603	0.6647	0.1783
38	-0.1488	-1.593	0.1192	0.1702	0.07333	-0.09374
39	-0.2031	0.9467	-0.2846	-1.258	-0.6001	-0.5371
40	-0.529	-0.09373	-0.2043	0.7501	0.413	-1.725
41	-0.04079	-0.1035	0.9755	0.2349	-0.07454	0.05367
42	0.2458	0.06726	-0.4006	-0.09289	-0.819	-0.1122
43	0.9371	0.9914	-0.5147	-0.1277	-0.4359	0.3157
44	-0.06592	0.3981	0.01364	0.003433	-0.7271	0.8652
45	-0.6264	-0.1591	1.079	0.9387	-0.09087	-0.3945
46	0.254	1.569	1.439	1.251	1.584	0.7286
47	0.1732	0.648	0.03857	0.193	0.8211	0.5547
48	1.183	1.131	1.114	1.172	1.248	1.117
49	0.4768	0.3493	0.2494	0.223	0.3689	0.1059
50	0.001224	0.0001697	0.00583	0.007602	0.0001792	0.0003206
51	0.1526	0.1021	0.1698	0.113	0.1829	0.1445
52	0.01012	0.01886	0.02431	0.006541	0.01423	0.009332
53	1.51	12.12	6.682	12.62	11.46	12.19
54	0.197	0.3177	0.1804	0.4426	0.4551	0.07459
55	18.87	1.648	7.941	6.016	7.321	6.653
56	13.64	8.263	18.03	3.441	12.02	10.73
57	0.1886	0.2892	0.3526	0.08509	0.4587	0.06752

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	65	66	67	68	69	70
1	9.71E-16	2.42E-15	7.621E-15	6.246E-16	1.021E-14	1.374E-14
2	0	0	0	2	2	2
3	1.504E-09	3.824E-09	2.533E-09	2.158E-09	4.731E-09	4.777E-09
4	6.152E-10	3.723E-10	8.542E-10	4.627E-11	7.931E-10	5.726E-11
5	0.9674	0.8386	0.1614	0.568	0.511	0.5457
6	0.1216	0.09845	0.07178	0.09671	0.138	0.09417
7	0.1428	0.3932	0.2556	0.3505	0.5373	0.3354
8	0.2558	0.7275	0.8891	0.3708	0.4201	0.5092
9	-18.06	-19.25	-17.91	-17.91	-18.27	-18.28
10	-17.63	-18.76	-19.84	-18.21	-19.38	-18.63
11	-20.51	-19.21	-20.11	-20.06	-19.42	-19.67
12	-15.47	-15.3	-15.17	-14.39	-16.3	-15.62
13	0.7373	0.2463	0.2317	0.4805	0.6637	0.1562
14	0.2351	0.2981	0.1656	0.2644	0.3723	0.1072
15	0.09484	0.1882	0.1437	0.08586	0.1101	0.2647
16	0.8165	0.8806	7.098	0.902	1.993	0.9493
17	0.02979	0.01187	0.006511	0.009034	0.02616	0.02596
18	-21.13	-22.28	-22.41	-21.46	-22.35	-22.55
19	1.211E-11	8.456E-11	9.796E-11	2.881E-11	7.516E-11	1.013E-10
20	-19.07	-18.94	-18.52	-18.44	-20.14	-19.14
21	8.466E-11	8.207E-11	4.999E-11	3.095E-11	2.75E-10	1.276E-10
22	4	4	1	1	1	4
23	0.08138	0.08466	0.08799	0.04041	0.1068	0.05832
24	0.06542	0.01398	0.1417	0.06825	0.06203	0.15
25	0.615	0.6387	0.5566	0.6947	0.5462	0.593
26	13030000	12280000	13340000	13120000	11900000	11180000
27	14320000	14470000	14600000	11780000	13530000	14410000
28	-11.96	-13.18	-12.13	-10.28	-11.12	-11.81
29	-9.544	-9.343	-9.305	-10.57	-10.15	-10.17
30	-12.01	-11.86	-13.77	-13.37	-11.91	-11.29
31	5	8	24	25	12	26
32	0.003547	0.0001503	0.02568	0.06092	0.001735	0.0001976
33	2.368	4.954	2.754	6.597	4.63	4.809
34	569.4	702.6	539.5	26.81	234.6	897.1
35	0.2543	0.2151	0.1292	0.2719	0.06111	0.1145
36	0.04527	-0.1492	0.7799	-0.2134	-0.322	0.1457
37	-0.07629	0.08577	-0.4864	-0.2514	0.6375	-0.04295
38	-0.2449	-0.06017	-0.1043	0.1126	0.2479	1.287
39	0.1233	-0.2179	-0.3969	-0.08143	1.26	0.2271
40	0.1009	-0.06231	-0.1245	0.839	-0.873	-0.1346
41	-0.345	-0.1641	0.1016	0.1885	-0.167	-0.2471
42	0.1123	1.301	-0.1955	-0.2143	-0.1787	-0.02034
43	0.8376	-0.04933	-0.1161	0.05587	0.09118	-0.4748
44	1.384	-0.788	-0.1079	-0.8665	-0.3097	0.1129
45	-0.6975	-1.259	-0.1317	-0.009073	0.139	-0.164
46	0.5261	1.192	0.2199	1.578	1.461	1.506
47	0.9444	0.5366	0.7178	0.1015	0.2261	0.6369
48	1.668	1.056	1.923	1.006	1.13	1.109
49	0.07362	0.05499	0.3391	0.1687	0.3618	0.3597
50	0.0068	0.006232	0.0008322	0.00166	0.0001258	0.007133
51	0.2232	0.1176	0.1539	0.1885	0.1158	0.1018
52	0.02205	0.0006231	0.008693	0.02325	0.02601	0.02564
53	10.36	9.77	9.433	7.585	5.647	17.14
54	0.1324	0.3765	0.3591	0.171	0.4846	0.09052
55	6.569	14.25	6.418	10.32	15.27	13.23
56	10.58	18.12	16.49	10.07	10.36	18.77
57	0.111	0.491	0.3377	0.4709	0.04664	0.3973

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	71	72	73	74	75	76
1	2.307E-15	2.035E-15	1.174E-14	1.274E-14	1.041E-14	7.243E-15
2	1	0	0	0	2	2
3	1.606E-09	4.482E-10	3.173E-09	4.477E-09	2.124E-09	3.629E-09
4	2.068E-10	9.273E-10	6.376E-10	6.02E-10	8.963E-10	7.313E-10
5	0.09795	0.6155	0.8703	0.9009	0.8672	0.5535
6	0.1053	0.06045	0.1157	0.1292	0.05305	0.05757
7	0.1272	0.409	0.2921	0.007353	0.2249	0.4525
8	0.5261	0.8234	0.4308	0.04902	0.03875	0.09121
9	-18.71	-20.17	-19.47	-18.89	-18.03	-20.6
10	-20.19	-18.61	-18.35	-19.24	-18.7	-18.24
11	-19.93	-20.36	-20.28	-19.53	-19.76	-20.21
12	-15.13	-15.67	-16.44	-15.78	-16.09	-16.54
13	0.7565	0.5493	0.2232	0.5518	0.8645	0.1386
14	0.2111	0.3369	0.3639	0.2289	0.04538	0.003778
15	0.4948	0.359	0.1478	0.1225	0.2349	0.2288
16	0.6394	1.012	0.1353	0.844	0.8622	2.68
17	0.01996	0.006671	0.002665	0.005495	0.01345	0.008755
18	-23.34	-22.01	-22.12	-21.27	-21.48	-21.02
19	1.62E-10	7.304E-11	6.948E-11	2.138E-11	5.807E-11	4.574E-12
20	-19.44	-18.82	-17.95	-19.92	-18.33	-18.69
21	1.555E-10	7.772E-11	1.09E-11	1.605E-10	1.09E-11	5.36E-11
22	1	4	4	4	1	4
23	0.1363	0.07618	0.03028	0.07048	0.07576	0.1095
24	0.02862	0.04709	0.1046	0.1148	0.05043	0.0494
25	0.5898	0.6797	0.6127	0.6645	0.8418	0.6339
26	12990000	13260000	11150000	11410000	13180000	12400000
27	14350000	13150000	15620000	15340000	13990000	15890000
28	-10.81	-12.98	-10.95	-12.36	-12.23	-11.05
29	-10.47	-9.656	-9.951	-8.836	-9.971	-10.18
30	-11.7	-13.32	-13.69	-13.64	-12.69	-13.72
31	18	19	25	26	7	14
32	0.0005007	0.00114	0.003181	0.1187	0.0005873	0.00008217
33	5.319	8.372	4.033	7.164	8.094	3.515
34	211.4	332.3	256.5	397.6	244.8	741.8
35	0.8657	0.9345	0.8739	0.5931	0.918	0.3599
36	-0.3587	0.8199	0.6085	-0.8875	-1.526	-0.1816
37	-1.168	0.2283	0.4115	-0.1741	0.9679	-0.863
38	-0.9452	-0.8955	-0.1259	-0.5484	0.1419	-0.3707
39	-0.1931	0.02755	-0.15	0.2202	-0.3058	0.05473
40	0.2469	-1.137	-0.1132	0.2029	-0.7906	-0.1868
41	-0.4302	-0.04942	0.2487	-0.8123	-0.1355	-0.2231
42	-0.1213	-1.59	0.7437	-0.0861	0.08884	-0.1283
43	-0.2247	-0.8683	0.2979	-0.3395	0.0002952	-0.004864
44	-0.1614	-0.1148	-0.1385	0.2204	0.244	-0.9601
45	0.2312	-0.5937	-0.03752	-0.09768	0.7688	0.09712
46	0.1644	1.099	1.036	1.279	0.1911	0.3304
47	0.2372	0.7289	0.3128	0.5434	0.3739	0.355
48	1.769	1.04	1.625	1.034	1.227	1.229
49	0.4793	0.1535	0.2988	0.1282	0.2648	0.2177
50	0.0005639	0.005749	0.000382	0.0002787	0.002779	0.0001019
51	0.159	0.1769	0.1513	0.1561	0.1196	0.1791
52	0.02428	0.0299	0.01643	0.02765	0.01727	0.008925
53	19.38	8.796	5.125	11.23	14.39	8.154
54	0.167	0.4255	0.4073	0.02577	0.4661	0.2902
55	5.591	3.456	15.2	16.21	10.54	16.69
56	5.74	1.544	13.74	14.26	15.8	18.33
57	0.1235	0.4034	0.18	0.4123	0.4651	0.1171

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	77	78	79	80	81	82
1	1.156E-14	1E-14	2.16E-15	2.91E-15	1.057E-14	1.067E-14
2	0	1	0	0	2	0
3	1.84E-09	3.266E-09	6.173E-09	6.279E-09	6.022E-09	7.052E-09
4	1.033E-09	1.079E-09	6.881E-11	8.654E-11	4.094E-10	3.132E-10
5	0.7968	0.6882	0.5075	0.8936	0.9578	0.3633
6	0.12	0.07633	0.04246	0.08271	0.002721	0.1232
7	0.4016	0.1267	0.5082	0.2691	0.2031	0.1128
8	0.1218	0.3036	0.06503	0.133	0.8665	0.777
9	-18.46	-18.42	-19.28	-17.84	-18.8	-18.4
10	-18.29	-17.92	-19.05	-17.74	-19.44	-19.74
11	-18.14	-19.88	-19.63	-18.94	-20	-18.5
12	-15.73	-15.27	-15.08	-15.65	-14.8	-16.21
13	0.5684	0.09619	0.2032	0.2752	0.4079	0.1624
14	0.1018	0.1736	0.1905	0.216	0.01266	0.2563
15	0.4569	0.3674	0.003914	0.5446	0.3516	0.405
16	0.168	0.9328	0.6094	3.945	7.645	3.794
17	0.009147	0.02182	0.01154	0.003361	0.0293	0.01085
18	-23.75	-21.17	-22.95	-23.53	-23.15	-22.03
19	1.784E-10	1.48E-11	1.345E-10	1.475E-10	1.207E-10	8.289E-11
20	-19.77	-18.78	-19.48	-19.04	-18.75	-19.63
21	1.992E-10	6.647E-11	1.541E-10	1.046E-10	6.886E-11	1.919E-10
22	1	1	1	1	1	4
23	0.09453	0.06376	0.08711	0.1167	0.0383	0.08957
24	0.08467	0.06769	0.0576	0.1787	0.01927	0.01398
25	0.6961	0.6295	0.6424	0.5711	0.5982	0.6253
26	11940000	13760000	12570000	13600000	13610000	13120000
27	13830000	11450000	12490000	15020000	15480000	15560000
28	-12.83	-12.88	-12.29	-11.9	-12.9	-10.99
29	-8.536	-9.321	-9.441	-10.4	-8.786	-10.13
30	-12.09	-12.99	-12.59	-12.52	-12.03	-11.55
31	28	12	15	29	31	13
32	0.0008554	0.0003277	0.001057	0.009489	0.1377	0.01728
33	5.658	1.418	7.358	8.003	4.835	1.708
34	129.8	696.2	415	986.9	195.7	292.3
35	0.9556	0.9428	0.8361	0.9663	0.4552	0.9908
36	0.09949	0.2456	-0.7978	-0.5826	-0.2396	0.1658
37	-0.002864	-0.1946	-0.4423	0.08207	-0.186	-0.05502
38	-0.2353	-0.1577	-0.3368	-0.279	-0.4611	0.6234
39	-0.01489	-0.2449	0.5027	-0.07335	0.01565	-0.08543
40	-0.07654	0.03059	-0.09725	0.1133	-0.001618	0.8736
41	0.1509	-0.2015	0.1169	0.2133	-0.1416	-1.674
42	0.6333	0.07799	-0.3162	-0.06125	0.1303	-0.364
43	-0.2103	0.07911	-0.9352	-0.08901	-0.6507	-0.07014
44	-0.5344	-0.01195	0.8179	-0.19	0.552	-0.2113
45	-0.08144	-0.2177	-0.2717	-0.1443	0.301	0.5868
46	1.589	1.6	1.535	0.9815	0.8306	1.141
47	0.5278	0.4339	0.09736	0.7383	0.0205	0.8739
48	1.05	1.093	2.119	1.176	1.14	1.025
49	0.4699	0.4635	0.2559	0.2286	0.3988	0.1999
50	0.001559	0.0001321	0.0004781	0.003125	0.001999	0.001734
51	0.1766	0.1104	0.1356	0.1237	0.1119	0.1075
52	0.004168	0.0103	0.02112	0.01827	0.02153	0.01067
53	1.357	14.85	15.8	12.9	15.58	3.996
54	0.2798	0.3822	0.4703	0.3365	0.313	0.2745
55	3.79	18.19	17.56	17.71	1.855	6.9
56	7.537	12.7	6.606	15.81	16.35	2.586
57	0.2402	0.08094	0.4389	0.1735	0.3923	0.3253

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	83	84	85	86	87	88
1	1.426E-14	1.497E-14	3.705E-15	1.511E-14	6.395E-15	5.074E-15
2	0	2	2	0	0	0
3	6.681E-09	6.758E-09	1.039E-09	7.922E-09	4.212E-09	2.675E-09
4	1.322E-11	9.591E-10	9.9E-10	8.247E-10	7.025E-10	2.883E-10
5	0.5901	0.924	0.9405	0.4123	0.04815	0.6377
6	0.1384	0.1128	0.01506	0.03339	0.03215	0.1195
7	0.2607	0.49	0.2351	0.4539	0.1447	0.1187
8	0.6728	0.2324	0.01595	0.8525	0.3889	0.8343
9	-18.81	-18.76	-19.6	-19.77	-19.98	-17.63
10	-20.13	-18.76	-19.44	-19.27	-17.46	-19.32
11	-20.73	-18.82	-18.43	-19.28	-20.38	-19.53
12	-15.46	-14.52	-14.27	-14.64	-15.22	-14.9
13	0.6314	0.6987	0.7913	0.9726	0.8313	0.5359
14	0.1472	0.04121	0.2828	0.3834	0.3704	0.008084
15	0.3003	0.5191	0.3253	0.4406	0.3818	0.007497
16	2.046	5.949	5.86	0.7628	8.063	4.63
17	0.005571	0.005299	0.004842	0.01369	0.02804	0.004315
18	-22.32	-21.61	-22.52	-23.59	-21.32	-23.31
19	8.953E-11	3.638E-11	1.011E-10	1.615E-10	2.445E-11	1.401E-10
20	-19.61	-18.23	-18.56	-18.13	-19.46	-19.15
21	1.813E-10	1.09E-11	2.409E-11	1.09E-11	1.636E-10	1.205E-10
22	4	1	1	4	1	4
23	0.09198	0.09375	0.1018	0.07684	0.1101	0.1267
24	0.08534	0.1079	0.0509	0.08717	0.06868	0.01398
25	0.7586	0.6029	0.6379	0.6629	0.6781	0.7212
26	11790000	11250000	11720000	11750000	11630000	11130000
27	12580000	12430000	14140000	12700000	13120000	15690000
28	-13.9	-13.14	-10.48	-11.25	-11.87	-12.59
29	-9.248	-9.396	-10.51	-10.11	-10.84	-9.855
30	-11.47	-11.43	-11.8	-13.84	-13.43	-12.24
31	12	15	21	20	31	16
32	0.0003383	0.02998	0.002709	0.06967	0.04463	0.09646
33	1.291	0.6181	5.569	7.454	4.363	3.419
34	947.7	713	805.4	97.86	992.8	201.9
35	0.1446	0.2606	0.3839	0.4687	0.7461	0.5334
36	-0.05621	-0.1598	0.4673	-0.7605	-0.2976	-0.1271
37	0.1805	-0.3599	0.3834	-0.1662	0.7134	-0.379
38	-0.5943	-0.2922	-0.4852	-1.083	-0.4067	-0.06584
39	0.1845	0.7353	-0.1812	-0.719	-0.3867	-0.2005
40	-0.1677	-0.2109	0.0637	-0.04881	0.1242	-0.4148
41	-0.0824	-0.1058	-0.08876	-0.2311	-0.2715	0.0001973
42	0.1327	-0.2268	0.2037	-0.2485	0.1499	-1.5
43	0.12	0.4401	0.04004	1.081	-0.1858	0.188
44	-0.1271	-0.4102	0.1492	-0.412	-1.429	-1.615
45	0.4862	-0.4404	-1.688	0.7407	-0.2146	-0.2033
46	1.421	0.7785	1.512	1.449	1.48	1.412
47	0.9203	0.05173	0.4807	0.4674	0.2635	0.6763
48	1.865	1.55	1.198	1.223	1.074	1.058
49	0.4678	0.4428	0.3886	0.3545	0.1812	0.1259
50	0.0002734	0.00145	0.007295	0.003953	0.0002386	0.0009119
51	0.1737	0.1621	0.1601	0.1149	0.1644	0.1267
52	0.0282	0.0231	0.02472	0.02039	0.005428	0.007702
53	4.802	2.837	16.02	18.31	17.71	16.26
54	0.09563	0.1008	0.2625	0.3061	0.1887	0.4503
55	9.723	4.311	14.8	12.98	1.426	15.66
56	2.776	4.15	13.45	18.9	9.849	6.023
57	0.1663	0.4783	0.02374	0.2128	0.1406	0.03374

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	89	90	91	92	93	94
1	5.292E-15	1.168E-14	1.846E-15	5.121E-15	1.134E-15	6.01E-15
2	0	2	2	0	0	0
3	2.472E-09	7.465E-09	7.627E-10	4.995E-09	6.623E-09	3.532E-10
4	4.821E-10	1.263E-09	1.165E-09	1.196E-09	3.566E-10	6.581E-10
5	0.7389	0.2476	0.21	0.3943	0.1734	0.2982
6	0.09225	0.04855	0.03796	0.04364	0.08951	0.02289
7	0.01409	0.04381	0.4287	0.3772	0.4683	0.3711
8	0.5331	0.9247	0.4118	0.006044	0.6543	0.5749
9	-18.74	-17.87	-19.81	-18.49	-19.67	-18.67
10	-20.35	-18.07	-17.91	-20.44	-18.65	-19.14
11	-20.26	-20.08	-19.55	-20.5	-20.35	-20.56
12	-14.93	-15.86	-16.7	-14.13	-15.68	-16.35
13	0.3356	0.7892	0.6163	0.7671	0.9647	0.3118
14	0.1688	0.3262	0.1289	0.3324	0.0556	0.3025
15	0.09024	0.01584	0.1805	0.1188	0.1709	0.06904
16	0.4067	0.1159	6.497	3.151	6.529	0.357
17	0.00955	0.01066	0.00762	0.01291	0.02746	0.01032
18	-22.91	-23.24	-22.47	-23.64	-22.48	-23.93
19	1.097E-10	1.419E-10	7.145E-11	1.693E-10	1.141E-10	1.859E-10
20	-18.41	-18.61	-18.81	-18.94	-18.46	-18.68
21	1.888E-11	4.681E-11	7.33E-11	8.363E-11	4.337E-11	4.235E-11
22	1	4	1	4	1	1
23	0.007846	0.07458	0.07909	0.061	0.07806	0.146
24	0.0607	0.0713	0.07254	0.1062	0.1027	0.1735
25	0.6449	0.674	0.6893	0.5156	0.6723	0.7848
26	11990000	11600000	12700000	12660000	11280000	11380000
27	15260000	14050000	12630000	12000000	12980000	13170000
28	-12.06	-11.46	-11.37	-10.9	-11.5	-12.26
29	-9.992	-11.05	-9.871	-10.71	-9.742	-9.591
30	-12.28	-11.76	-11.07	-12.82	-12.48	-12.95
31	22	30	25	4	31	4
32	0.195	0.0000724	0.07864	0.000407	0.004975	0.01323
33	0.9618	9.267	3.593	4.526	3.236	3.981
34	388.1	440.5	158.9	88.94	11.13	611.1
35	0.737	0.4323	0.3376	0.8983	0.1357	0.8577
36	0.1958	0.3515	-0.204	-0.191	-0.06511	-0.4153
37	-0.07758	-0.2942	-0.7368	0.9443	0.1909	-0.02608
38	-0.08194	-0.2138	0.05316	0.7755	-0.005759	-0.2197
39	-0.3563	0.6197	-0.02195	0.3859	0.4819	0.8998
40	-1.37	0.04134	-0.3602	-0.1395	-0.2749	0.0844
41	0.1193	-0.001362	-0.1174	0.06063	-0.2395	-0.9299
42	-0.4347	0.04526	0.1574	-0.04886	0.7877	-0.07046
43	-0.03689	-0.8196	-0.1537	-0.3668	-0.236	-0.4114
44	-0.03989	-0.0918	-0.2421	-1.828	0.07154	0.473
45	-1.785	0.177	-0.4482	-0.0001462	-0.4976	-0.02662
46	1.382	1.482	0.09205	0.4383	1.591	0.5455
47	0.2531	0.7793	0.996	0.8498	0.741	0.3854
48	1.593	1.164	2.244	1.814	1.141	1.009
49	0.484	0.2365	0.2876	0.3222	0.1872	0.3028
50	0.0004996	0.001864	0.0006385	0.0005813	0.0005269	0.003304
51	0.1471	0.1909	0.107	0.1295	0.1325	0.1045
52	0.003606	0.01558	0.02833	0.01231	0.0161	0.002417
53	11.61	7.238	1.805	8.223	13.64	14.2
54	0.1201	0.2038	0.1874	0.2258	0.1761	0.3456
55	5.723	13.94	4.136	18.58	15.59	12.64
56	15.15	10.01	5.526	12.2	10.92	11.81
57	0.2022	0.1136	0.3347	0.3016	0.3674	0.3198

Table IRES-3. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 2 (Continued)

LHS#	95	96	97	98	99	100
1	5.668E-15	8.447E-15	7.038E-15	4.747E-15	8.08E-15	1.442E-14
2	1	1	2	0	1	2
3	9.14E-09	7.269E-09	8.79E-09	7.853E-09	2.767E-09	8.537E-09
4	1.015E-09	6.671E-10	7.542E-10	1.146E-09	3.433E-10	6.868E-10
5	0.7607	0.9738	0.6401	0.1545	0.1361	0.2897
6	0.02797	0.08844	0.01064	0.045	0.07861	0.08683
7	0.02409	0.3023	0.5267	0.06927	0.08954	0.4943
8	0.4891	0.918	0.2782	0.6898	0.1984	0.364
9	-18.91	-18.21	-20.3	-18.69	-19.06	-17.78
10	-18.32	-18.74	-19.39	-17.84	-19.6	-19.07
11	-19.44	-20.86	-19.49	-20.18	-18.97	-19.4
12	-15.89	-14.81	-15.33	-15.51	-16.17	-16.13
13	0.8595	0.06296	0.8198	0.5895	0.07099	0.03891
14	0.01654	0.05717	0.2911	0.02377	0.1867	0.351
15	0.1623	0.1132	0.03609	0.2831	0.5913	0.5202
16	6.893	1.194	0.3854	0.1487	0.4798	7.297
17	0.002805	0.004163	0.01647	0.02798	0.02374	0.004507
18	-23.82	-23.25	-23.67	-22.99	-23.1	-23.77
19	1.831E-10	1.682E-10	1.762E-10	1.264E-10	1.454E-10	1.738E-10
20	-19.36	-20.38	-18.98	-19.19	-20	-18.91
21	1.184E-10	2.75E-10	8.91E-11	1.129E-10	2.263E-10	8.702E-11
22	1	1	1	4	1	4
23	0.08565	0.08341	0.08038	0.09652	0.09703	0.05394
24	0.1007	0.1089	0.09957	0.0533	0.1058	0.04255
25	0.644	0.6329	0.6732	0.6036	0.6689	0.7351
26	13840000	13060000	12630000	11840000	11510000	11350000
27	12860000	13900000	14880000	13020000	11360000	13800000
28	-12.32	-11.76	-11.57	-11.59	-12.62	-13.26
29	-10.05	-9.894	-10.32	-10.25	-10.02	-9.666
30	-11.3	-11.65	-13.2	-11.34	-12.42	-13.27
31	16	15	23	26	18	28
32	0.01267	0.00005427	0.007948	0.04077	0.005764	0.1531
33	1.941	8.285	0.3082	1.047	7.888	1.804
34	304.5	670.5	513.8	687.6	143.6	553.8
35	0.7766	0.9058	0.5158	0.5006	0.7015	0.227
36	0.7253	0.2249	-0.1371	-0.6189	-0.04559	0.1239
37	0.2133	-0.09973	-0.5969	-0.2219	-0.1359	0.4714
38	0.2058	0.1582	-0.2536	0.5169	-0.2017	0.01342
39	-0.2118	-1.828	-0.9071	-0.05893	-0.1137	-0.4736
40	0.3153	-0.4723	-0.2013	-0.1494	0.4851	-0.1598
41	0.02334	-0.7293	-0.3833	0.1972	0.8014	-0.6193
42	0.253	-0.1069	-0.008576	-1.065	-0.9023	-0.4622
43	-0.01742	0.1751	-0.1327	0.2003	0.2442	0.02251
44	-0.14	-0.4409	0.1199	-0.3686	0.2093	0.9789
45	0.06085	-0.1249	-0.05171	0.05569	-0.38	-0.1387
46	0.6343	1.135	0.9599	1.385	0.7464	0.9273
47	0.1139	0.4155	0.6652	0.9001	0.4793	0.3611
48	1.088	1.145	1.041	1.049	1.956	1.157
49	0.1474	0.3799	0.06196	0.438	0.1429	0.1716
50	0.000106	0.008498	0.0007012	0.001308	0.0001583	0.000118
51	0.1668	0.1721	0.2137	0.1144	0.2341	0.1823
52	0.02265	0.02682	0.001108	0.02726	0.0119	0.02189
53	2.58	13.23	1.16	10.17	1.907	16.45
54	0.1036	0.2848	0.2269	0.08443	0.3317	0.3487
55	10.2	13.68	12.33	19.89	2.537	17.17
56	5.244	11.52	4.966	16.98	19.83	7.665
57	0.2831	0.07116	0.316	0.384	0.3093	0.2036

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3

LHS#	Material	Parameter	1	2	3	4
1	STEEL	CORRMCO2	7.953E-15	9.879E-15	2.743E-15	6.456E-16
2	WAS_AREA	PROBDEG	0	0	2	2
3	WAS_AREA	GRATMICI	6.519E-09	6.091E-09	3.098E-09	2.999E-09
4	WAS_AREA	GRATMICH	3.241E-10	1.325E-10	7.98E-10	1.457E-10
5	CELLULS	FBETA	0.01927	0.9557	0.8943	0.8093
6	WAS_AREA	SAT_RGAS	0.1283	0.07608	0.1423	0.001877
7	WAS_AREA	SAT_RBRN	0.3501	0.05385	0.3636	0.1118
8	WAS_AREA	SAT_WICK	0.6216	0.9441	0.5362	0.6699
9	CL_L_T1	PRMX_LOG	-20.52	-18.93	-20.2	-18.27
10	CONC_T1	PRMX_LOG	-18.94	-18.18	-18.33	-17.36
11	ASPHALT	PRMX_LOG	-19.32	-19.68	-19.1	-19.83
12	SHFT_DRZ	PRMX_LOG	-14.42	-15.74	-15.42	-15.72
13	SALT_T1	CUMPROB	0.7266	0.2696	0.9293	0.8559
14	SALT_T1	SAT_RGAS	0.2551	0.1385	0.1437	0.08484
15	SALT_T1	SAT_RBRN	0.07056	0.1157	0.5544	0.1847
16	SALT_T1	PORE_DIS	3.015	0.1688	5.662	2.688
17	S_HALITE	POROSITY	0.01484	0.02972	0.01203	0.007851
18	S_HALITE	PRMX_LOG	-22.13	-22.25	-21.94	-23.52
19	S_HALITE	COMP_RCK	7.384E-11	8.516E-11	6.157E-11	1.647E-10
20	S_MB139	PRMX_LOG	-19.1	-17.74	-17.71	-18.47
21	S_MB139	COMP_RCK	1.199E-10	1.09E-11	1.09E-11	1.09E-11
22	S_MB139	RELP_MOD	1	4	1	4
23	S_MB139	SAT_RBRN	0.09602	0.07762	0.06919	0.09706
24	S_MB139	SAT_RGAS	0.0956	0.01741	0.09916	0.09088
25	S_MB139	PORE_DIS	0.7087	0.6092	0.7132	0.5838
26	S_HALITE	PRESSURE	12360000	13600000	12140000	13760000
27	CASTILER	PRESSURE	12130000	14650000	13260000	12560000
28	CASTILER	PRMX_LOG	-12.42	-12.82	-11.37	-13.96
29	CASTILER	COMP_RCK	-10.26	-9.739	-10.31	-8.219
30	BH_SAND	PRMX_LOG	-12.26	-12.13	-12.61	-12.88
31	CASTILER	GRIDFLO	16	19	10	8
32	BLOWOUT	PARTDIA	0.0005864	0.00008167	0.00004835	0.003406
33	BOREHOLE	TAUFAIL	2.732	5.04	1.276	5.441
34	CULEBRA	MINP_FAC	179.7	297.5	494.2	566.6
35	GLOBAL	TRANSIDX	0.9698	0.9147	0.1598	0.8505
36	SOLAM3	SOLSIM	-0.1842	0.08728	0.1006	0.5719
37	SOLAM3	SOLCIM	-0.9465	0.9542	0.4419	0.5122
38	SOLPU3	SOLSIM	0.2175	-0.06066	-0.377	-0.3226
39	SOLPU3	SOLCIM	-0.09942	0.1129	-0.1234	-0.1885
40	SOLPU4	SOLSIM	-0.276	-0.1661	-0.03985	-0.1444
41	SOLPU4	SOLCIM	-0.4476	-0.2044	0.4379	-0.07879
42	SOLU4	SOLSIM	0.3904	0.9371	-1.914	-0.1297
43	SOLU6	SOLSIM	0.4311	-0.3542	-0.1524	-0.5921
44	SOLU6	SOLCIM	0.1536	-0.3176	0.3893	-0.6575
45	SOLTH4	SOLSIM	-0.2302	0.8965	0.1811	-0.06395
46	PHUMOX3	PHUMCIM	1.389	1.581	1.422	1.066
47	GLOBAL	OXSTAT	0.9994	0.9725	0.664	0.05909
48	GLOBAL	CLIMTIDX	1.096	1.093	1.073	1.773
49	CULEBRA	HMBLKLT	0.1704	0.156	0.3472	0.2044
50	CULEBRA	APOROS	0.0002278	0.004572	0.001054	0.0003685
51	CULEBRA	DPOROS	0.1471	0.1702	0.1615	0.1694
52	U+6	MKD_U	0.003078	0.01602	0.02467	0.01009
53	U+4	MKD_U	1.905	3.234	5.17	8.202
54	PU+3	MKD_PU	0.06481	0.3157	0.2455	0.2353
55	PU+4	MKD_PU	3.663	11.43	2.632	4.362
56	TH+4	MKD_TH	6.971	12.8	1.931	18.07
57	AM+3	MKD_AM	0.07562	0.4603	0.3306	0.09583

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	5	6	7	8	9	10
1	1.143E-14	1.574E-14	4.538E-15	8.159E-15	3.155E-15	1.812E-15
2	2	2	0	2	0	0
3	9.476E-09	8.551E-10	2.254E-09	6.986E-09	1.203E-09	1.842E-09
4	4.494E-10	6.968E-10	4.434E-10	4.829E-10	1.094E-09	7.496E-10
5	0.3064	0.6226	0.8885	0.6828	0.475	0.0921
6	0.06837	0.003986	0.08643	0.145	0.0589	0.109
7	0.07943	0.3654	0.4655	0.08395	0.2714	0.02613
8	0.02684	0.3273	0.8747	0.9851	0.3036	0.4179
9	-17.88	-19.95	-19.29	-19.49	-19.14	-20.41
10	-19.15	-18.5	-17.93	-18.59	-18.53	-18.86
11	-19.26	-19.58	-20.08	-19.78	-18.37	-19.59
12	-15.03	-14.68	-14.77	-15.69	-15.53	-15.23
13	0.354	0.9893	0.4975	0.1119	0.4521	0.1943
14	0.05211	0.2625	0.2827	0.03521	0.2749	0.3998
15	0.5963	0.287	0.3433	0.007012	0.07204	0.5044
16	0.7831	2.245	0.642	7.607	0.1486	0.2831
17	0.004336	0.01779	0.02458	0.002689	0.02232	0.004121
18	-23.57	-21.42	-22.61	-22.54	-21.9	-23.25
19	1.688E-10	3.04E-11	1.12E-10	1.005E-10	5.054E-11	1.355E-10
20	-19.42	-19.47	-19.75	-19.32	-18.51	-19.17
21	1.502E-10	1.705E-10	1.719E-10	1.227E-10	4.432E-11	1.107E-10
22	1	4	4	1	1	1
23	0.1155	0.08817	0.02223	0.1619	0.06991	0.1004
24	0.05583	0.07025	0.09387	0.05427	0.04163	0.05636
25	0.6345	0.6816	0.8418	0.6501	0.6607	0.5785
26	13420000	12650000	12210000	12930000	13680000	13150000
27	13980000	15850000	13120000	13720000	12700000	15210000
28	-12.86	-13.58	-12.95	-12.32	-11.64	-10.64
29	-9.214	-8.729	-9.181	-9.89	-10.24	-10.12
30	-12.77	-13.86	-12.42	-13.02	-13.69	-13.54
31	8	21	9	2	22	1
32	0.00007748	0.0001242	0.0938	0.02295	0.08675	0.01601
33	7.179	4.129	1.552	2.223	6.5	5.978
34	736	420.8	664.6	431.3	78.67	335.9
35	0.1869	0.2643	0.1075	0.471	0.515	0.2535
36	0.2229	0.4776	-0.03154	-0.8366	-0.2155	0.1604
37	0.02996	-0.09647	-1.784	0.1647	0.2347	0.3811
38	0.07572	-0.4501	-0.4374	0.1793	-0.239	0.1745
39	-0.1148	0.7351	-0.4933	-0.4349	-0.9389	0.7537
40	1.327	0.05781	0.5228	0.03651	-0.2073	-0.3148
41	-0.02902	-0.0533	-0.3927	0.1191	0.1047	0.1136
42	0.1862	0.2486	-0.2103	-0.1089	0.501	-0.4471
43	-0.1122	-0.2363	0.1666	-0.2439	-0.3244	-0.1692
44	0.4739	-0.1558	-0.2476	-0.1391	0.2346	-0.1
45	-0.06097	0.05749	-0.4249	0.6611	-0.1797	0.1325
46	1.462	1.427	1.206	0.1575	1.417	1.312
47	0.4448	0.6507	0.3905	0.3309	0.3277	0.7714
48	1.209	1.244	1.099	2.178	1.131	1.107
49	0.4009	0.3314	0.3771	0.2083	0.2553	0.05831
50	0.0002063	0.0012	0.002606	0.001514	0.0004681	0.0007821
51	0.115	0.1523	0.1359	0.12	0.1829	0.1507
52	0.006597	0.007028	0.01652	0.01347	0.02709	0.01897
53	7.889	19.57	13.62	15.03	15.92	13.32
54	0.1626	0.07262	0.3889	0.4167	0.1691	0.1901
55	2.617	14.13	17.6	14.79	6.022	12.92
56	14.01	2.593	15.28	9.871	18.76	14.84
57	0.4618	0.1635	0.373	0.05109	0.1691	0.09057

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	11	12	13	14	15	16
1	5.913E-15	1.027E-14	1.068E-14	4.804E-15	3.78E-15	1.214E-14
2	0	2	0	2	0	1
3	6.342E-09	4.354E-09	6.423E-09	3.664E-09	6.783E-09	1.02E-09
4	1.013E-09	4.11E-10	9.007E-10	8.547E-10	1.658E-10	9.008E-11
5	0.1172	0.1469	0.7424	0.901	0.4484	0.7355
6	0.1324	0.1495	0.04304	0.01354	0.0195	0.1292
7	0.2436	0.1701	0.1302	0.4325	0.4431	0.2072
8	0.3145	0.1116	0.7012	0.6942	0.439	0.2411
9	-19.25	-18.52	-19.88	-19.6	-18.64	-19.54
10	-18.97	-19.24	-18.74	-20.23	-19.87	-17.54
11	-20.19	-20.3	-19.07	-20.68	-19.98	-20.04
12	-15.06	-15.51	-15.32	-14.73	-15.39	-15.18
13	0.6798	0.3337	0.634	0.2886	0.09413	0.9673
14	0.3274	0.1199	0.3178	0.2788	0.05617	0.212
15	0.208	0.5316	0.2992	0.1524	0.5148	0.4973
16	7.206	0.2309	0.3907	0.8868	0.3592	3.454
17	0.005557	0.005739	0.01716	0.006074	0.008186	0.007474
18	-21.98	-23.48	-23.59	-22.94	-23.65	-22.86
19	8.988E-11	1.585E-10	1.671E-10	1.282E-10	1.72E-10	1.095E-10
20	-18.99	-18.97	-19.14	-18.4	-19.89	-18.32
21	1.028E-10	9.141E-11	1.311E-10	2.906E-11	1.961E-10	1.09E-11
22	4	1	1	4	4	4
23	0.08257	0.1323	0.09407	0.1188	0.1146	0.03428
24	0.01398	0.08353	0.1711	0.06097	0.06845	0.08555
25	0.6011	0.7236	0.684	0.5984	0.6188	0.6589
26	11990000	11820000	13040000	12950000	11270000	12560000
27	15420000	12050000	12080000	11860000	12500000	13580000
28	-10.55	-12.4	-12.45	-13.57	-14.09	-11.88
29	-10.84	-9.446	-9.475	-9.646	-8.934	-10.05
30	-11.9	-13.65	-12.35	-12.06	-11.61	-11.93
31	30	15	20	29	9	9
32	0.005223	0.000247	0.0003206	0.006205	0.005617	0.03091
33	7.061	9.01	3.467	0.2756	0.05838	6.312
34	653.8	16.83	616.3	549.1	274.5	103
35	0.1336	0.5306	0.9906	0.1773	0.882	0.6857
36	0.1923	0.07107	0.2407	-0.4754	-0.312	-0.16
37	-0.04756	-0.4631	-0.1836	-0.1162	-0.2472	-0.1626
38	-0.8233	-0.1481	-0.9547	-0.7367	-0.5965	0.09985
39	-0.2637	0.03161	0.07049	-0.3556	0.1794	0.2355
40	-0.7769	0.9704	0.3253	0.2156	-0.7174	-0.1975
41	-0.07636	-0.1326	-0.1791	-0.6007	1.287	-0.08762
42	1.085	-0.1486	-0.7589	-0.04144	0.783	0.1155
43	-0.2927	0.154	-0.8426	0.3443	-0.3936	1.105
44	-0.04326	-0.191	-0.8343	0.05702	0.1651	-0.7563
45	-0.7856	-0.2466	-0.1671	-0.09331	0.01352	-0.07216
46	0.5655	1.448	0.4593	1.456	0.9822	0.5995
47	0.6452	0.5012	0.8038	0.6888	0.9571	0.2993
48	1.126	1.626	1.114	1.157	1.024	1.052
49	0.4165	0.2219	0.1639	0.2664	0.4908	0.4669
50	0.009054	0.006472	0.00159	0.000124	0.0006491	0.0001709
51	0.1419	0.2471	0.2178	0.1298	0.1176	0.1014
52	0.01238	0.02901	0.0007269	0.02741	0.02039	0.02269
53	11.59	13.91	7.102	2.592	16.66	4.066
54	0.2636	0.4301	0.4746	0.2753	0.1063	0.2572
55	7.542	12.1	6.544	10.46	16.1	11.63
56	11.3	5.077	5.643	1.073	11.09	19.52
57	0.1304	0.2021	0.1655	0.1848	0.3357	0.1804

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	17	18	19	20	21	22
1	8.494E-15	9.411E-15	1.613E-16	3.408E-16	1.21E-15	1.914E-15
2	0	0	0	0	0	0
3	7.764E-09	8.372E-09	2.19E-09	5.308E-09	4.845E-09	8.261E-09
4	3.59E-10	5.041E-10	8.628E-10	1.05E-09	4.725E-10	5.279E-10
5	0.08729	0.1879	0.7159	0.1606	0.6937	0.2542
6	0.1114	0.01833	0.02527	0.01556	0.03819	0.14
7	0.2409	0.1452	0.3193	0.4402	0.2373	0.4805
8	0.1792	0.3978	0.6526	0.6112	0.8082	0.2326
9	-19.35	-19.85	-18.12	-17.56	-18.75	-19.81
10	-19.49	-17.91	-18.63	-18.25	-19.36	-19.32
11	-20.47	-20.28	-19.39	-20.39	-20.81	-18.77
12	-15.13	-15.57	-14.74	-14.17	-15.9	-16.07
13	0.3763	0.8842	0.8756	0.7854	0.3667	0.666
14	0.01725	0.2085	0.1053	0.1792	0.1441	0.006578
15	0.5381	0.1255	0.1605	0.225	0.482	0.4325
16	3.533	0.9207	6.318	1.011	5.544	0.4465
17	0.01659	0.00281	0.005174	0.02539	0.02799	0.02304
18	-23.16	-22.43	-21.55	-23.4	-21.38	-23.09
19	1.423E-10	8.71E-11	4.254E-11	1.521E-10	1.849E-11	1.443E-10
20	-18.68	-19.35	-19.5	-18.73	-18.77	-18.18
21	6.706E-11	1.439E-10	2.62E-10	5.413E-11	7.004E-11	1.09E-11
22	4	4	4	1	1	1
23	0.0594	0.0689	0.11	0.07587	0.07793	0.1483
24	0.02075	0.09869	0.1094	0.01398	0.07571	0.06771
25	0.6531	0.6158	0.5813	0.6697	0.5374	0.6766
26	13890000	13360000	12710000	13240000	11440000	11090000
27	14540000	13180000	12020000	12840000	12420000	13960000
28	-12.71	-13.5	-10.43	-10.72	-14.18	-13
29	-8.811	-9.871	-10.28	-10.42	-9.161	-8.976
30	-11.8	-12.29	-12.4	-12.69	-12	-13.14
31	12	15	25	8	8	28
32	0.1136	0.001969	0.001061	0.0001411	0.01029	0.0007653
33	3.429	8.154	6.047	2.282	4.846	0.8481
34	484.8	986.8	729.2	396.9	248.2	854.6
35	0.7784	0.05731	0.568	0.3244	0.02932	0.4893
36	0.9254	-0.9949	-0.1774	-0.2581	-0.09243	-0.645
37	0.4751	0.2515	0.1072	-0.08805	-0.06214	0.8556
38	0.06022	-0.1585	-0.4973	-0.112	0.1631	-0.0192
39	-0.4553	-0.1945	-0.3335	0.8528	0.1049	0.054
40	0.9041	0.0348	0.424	-0.03288	-0.01663	0.1083
41	-0.02507	-0.1199	-0.1178	-0.2262	-0.9232	-0.239
42	-0.239	-0.1921	0.193	-0.01583	0.4535	0.9883
43	-0.03954	-0.2282	0.8587	0.5386	0.09131	0.03813
44	-0.8015	-0.2281	-0.453	-0.2068	-0.1741	-0.07838
45	-0.03952	-0.283	0.213	1.29	-0.01878	-0.1141
46	0.1984	1.593	0.2796	1.463	1.16	1.53
47	0.8967	0.6082	0.9615	0.4026	0.3716	0.01315
48	1.112	1.594	1.504	1.565	1.006	1.808
49	0.311	0.09374	0.1146	0.3463	0.1273	0.2951
50	0.000853	0.001137	0.001501	0.0006965	0.003276	0.001035
51	0.1407	0.1142	0.1768	0.1678	0.1893	0.1747
52	0.01402	0.01047	0.00273	0.01714	0.00137	0.02098
53	3.901	14.84	14.16	8.638	16.14	7.469
54	0.09155	0.3066	0.3108	0.04952	0.1334	0.3277
55	5.336	4.626	19.91	17.06	2.834	8.016
56	14.99	3.257	13.88	1.603	11.69	16.42
57	0.2861	0.04303	0.06402	0.3063	0.2229	0.114

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	23	24	25	26	27	28
1	1.28E-14	1.47E-14	9.739E-16	3.537E-15	1.043E-14	4.746E-15
2	0	2	0	0	0	0
3	8.033E-09	5.976E-10	3.359E-10	3.249E-09	8.055E-09	8.41E-09
4	7.683E-10	1.195E-09	1.034E-09	9.331E-10	1.146E-09	6.661E-11
5	0.04544	0.4377	0.2002	0.1318	0.195	0.0009603
6	0.04183	0.07012	0.06456	0.1109	0.1432	0.09474
7	0.2981	0.4193	0.3743	0.009806	0.4133	0.5482
8	0.42	0.3655	0.04916	0.967	0.9015	0.2778
9	-20.26	-18.1	-19.05	-19.22	-18.89	-18.79
10	-19.62	-19.06	-18.84	-18.13	-19.91	-18.38
11	-18.69	-20.72	-19.04	-20.44	-19.8	-19.91
12	-16.05	-15.83	-15.33	-14.32	-15.57	-15.21
13	0.1543	0.8278	0.0699	0.6949	0.2026	0.0593
14	0.1953	0.2456	0.1875	0.3404	0.3729	0.3712
15	0.1316	0.4317	0.4474	0.2452	0.05262	0.1359
16	0.6911	0.2636	6.68	0.3018	5.27	3.863
17	0.01541	0.0011	0.02241	0.002129	0.01948	0.005869
18	-22.2	-23.67	-23.1	-22.65	-22.57	-22.36
19	9.93E-11	1.636E-10	1.2E-10	1.134E-10	1.016E-10	9.345E-11
20	-18.84	-18.81	-19.46	-19.2	-19.25	-17.96
21	7.444E-11	8.647E-11	1.664E-10	1.26E-10	1.32E-10	1.09E-11
22	1	4	1	1	1	4
23	0.0489	0.09507	0.1061	0.07475	0.05264	0.1094
24	0.1309	0.1136	0.0728	0.04452	0.08307	0.13
25	0.5891	0.6057	0.6266	0.6258	0.5652	0.5256
26	12440000	13290000	13390000	11610000	11800000	11700000
27	12750000	12600000	12670000	12190000	11630000	15320000
28	-11.97	-11.95	-13.2	-11.13	-13.43	-11.7
29	-10.3	-10.14	-8.258	-9.826	-9.074	-9.513
30	-13.07	-11.29	-13.4	-11.55	-11.86	-11.1
31	1	20	31	20	27	26
32	0.00006185	0.0001746	0.0003687	0.007873	0.004867	0.01
33	1.831	2.989	9.437	3.093	5.223	7.514
34	788.9	962	240.1	847.6	98.28	714.1
35	0.6333	0.4433	0.3636	0.896	0.6238	0.7311
36	0.6628	-0.2065	-0.1576	-0.1196	0.9685	0.6254
37	-0.1266	-0.1946	-0.7861	0.1197	0.06382	-0.1323
38	-0.01247	0.7825	0.1504	0.1272	0.01526	-0.168
39	-0.5573	-0.3581	-0.3823	-0.09014	0.6233	-0.1625
40	-0.2314	-0.02154	-0.2406	-0.191	0.2423	-0.1069
41	-0.7983	0.1751	-0.1656	-0.193	0.2025	-0.3547
42	-0.1394	-0.2936	-0.1554	0.2071	-0.3922	-0.2748
43	0.9118	0.6538	-0.2032	0.2794	0.0503	-0.2558
44	0.01367	0.1159	-0.572	0.009311	0.06694	-0.3373
45	-0.1927	-0.02643	-0.04429	-0.3657	0.9673	-0.3373
46	0.9511	1.563	1.474	1.544	1.577	0.3646
47	0.275	0.5332	0.4269	0.1214	0.8213	0.3404
48	1.173	1.011	1.188	1.202	2.245	1.063
49	0.4794	0.4086	0.3164	0.2824	0.2874	0.3857
50	0.000292	0.00857	0.0004409	0.001316	0.0003984	0.0003338
51	0.1266	0.1835	0.1171	0.1053	0.1293	0.1858
52	0.01544	0.005119	0.02822	0.011	0.0256	0.02289
53	12.36	8.362	17.97	12.87	9.945	17.58
54	0.4796	0.3462	0.2805	0.3237	0.1787	0.1354
55	16.63	12.94	19.68	11.07	10.78	6.892
56	17.73	18.88	9.465	10.58	15.08	1.276
57	0.2351	0.2281	0.4491	0.4975	0.3225	0.05729

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	29	30	31	32	33	34
1	1.4E-14	1.124E-14	7.869E-15	1.382E-14	1.289E-14	9.281E-15
2	2	0	0	0	0	2
3	1.995E-09	2.9E-09	6.214E-09	6.913E-09	3.721E-09	1.953E-09
4	1.984E-10	2.984E-10	3.722E-10	8.201E-10	6.474E-10	3.371E-10
5	0.2387	0.5838	0.9347	0.9686	0.7529	0.3557
6	0.04542	0.1357	0.1274	0.004693	0.07781	0.05624
7	0.1389	0.2773	0.2495	0.3427	0.1719	0.2258
8	0.9319	0.9992	0.508	0.7578	0.07798	0.5555
9	-17.83	-18.03	-18.8	-18.73	-18.33	-18.36
10	-18.02	-17.39	-18.47	-19.04	-18.75	-19.78
11	-18.67	-19.64	-19.79	-20.33	-19.36	-18.43
12	-15.02	-15.98	-14.45	-14.83	-14.96	-15.49
13	0.607	0.6537	0.622	0.1389	0.02826	0.2144
14	0.2346	0.1993	0.3349	0.1234	0.3509	0.3207
15	0.5901	0.39	0.1381	0.2116	0.2511	0.01285
16	0.5571	0.5177	0.4249	3.272	0.8365	0.1218
17	0.01737	0.01475	0.02113	0.003655	0.02894	0.00773
18	-22.8	-23.13	-22.06	-21.69	-22.2	-23.35
19	1.086E-10	1.402E-10	6.154E-11	4.05E-11	7.069E-11	1.489E-10
20	-18.58	-18.76	-18.67	-18.27	-18.7	-18.21
21	5.553E-11	6.372E-11	4.508E-11	2.287E-11	5.919E-11	3.198E-11
22	1	1	1	1	1	1
23	0.1211	0.07193	0.1064	0.1274	0.09974	0.07953
24	0.08023	0.0387	0.02632	0.1203	0.1064	0.02749
25	0.6561	0.4905	0.6323	0.6964	0.5922	0.6107
26	12250000	13080000	13800000	12020000	11750000	12890000
27	15370000	14220000	13270000	12920000	14510000	12660000
28	-13.03	-11.77	-13.33	-11.71	-12.66	-10.28
29	-8.648	-10.08	-9.558	-9.009	-9.789	-11.21
30	-13.25	-11.52	-12.1	-13.81	-12.62	-11.76
31	23	22	7	4	3	11
32	0.02466	0.003216	0.002173	0.0004526	0.05703	0.0009102
33	6.747	0.8429	7.976	0.6667	8.388	3.85
34	253.2	575.5	795.5	682.2	941.2	645.8
35	0.558	0.6928	0.8051	0.004764	0.1442	0.01901
36	-0.4311	-0.07745	0.04471	0.1441	-0.1319	0.2593
37	-0.4186	-1.325	-0.4935	0.2083	-0.06952	-0.004443
38	-0.07874	-0.5277	-0.07578	-0.002764	-0.1792	-0.1335
39	-0.2181	0.3989	-0.9677	0.2404	-1.984	-0.04522
40	-0.1209	-0.178	0.01401	-0.354	-0.2874	-0.04553
41	-0.1544	-0.5333	0.143	-0.2982	-0.3668	-0.0612
42	0.3145	-0.247	-1.256	-0.9338	0.1462	0.2685
43	0.602	0.2361	-0.1219	0.3834	-0.0284	-0.1872
44	-0.1611	0.8618	-0.002737	0.2115	1.134	-0.4241
45	-0.1206	-0.2627	-0.9019	-0.4918	0.7946	-0.1411
46	1.374	1.387	1.57	1.108	1.436	0.6445
47	0.9169	0.7567	0.3119	0.7688	0.7006	0.549
48	1.213	1.22	1.103	1.118	2.132	1.022
49	0.1076	0.1586	0.32	0.1984	0.3605	0.2513
50	0.0001087	0.001357	0.0001785	0.0002422	0.005481	0.0001645
51	0.1111	0.2032	0.1652	0.1043	0.1641	0.1628
52	0.01525	0.02204	0.009762	0.02861	0.00003962	0.01376
53	9.604	9.762	14.92	12.07	6.787	18.88
54	0.4909	0.2019	0.09935	0.06055	0.3906	0.2698
55	13.38	9.699	18.05	4.953	14.94	18.25
56	10.31	8.986	5.882	12.29	13.1	2.419
57	0.4672	0.3696	0.07958	0.2157	0.1541	0.3844

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	35	36	37	38	39	40
1	7.334E-15	8.263E-15	9.755E-15	1.357E-14	1.324E-14	1.422E-14
2	1	1	2	0	1	2
3	5.538E-09	1.401E-09	7.146E-09	2.409E-09	2.858E-09	1.676E-09
4	6.466E-10	2.515E-10	2.376E-10	1.141E-09	6.075E-10	1.067E-09
5	0.532	0.03561	0.8707	0.8551	0.6511	0.3804
6	0.08952	0.009479	0.09825	0.1458	0.124	0.0399
7	0.523	0.4502	0.4778	0.1629	0.3859	0.01685
8	0.1046	0.2697	0.5159	0.1374	0.8192	0.584
9	-19.47	-18.53	-17.72	-18.61	-18.48	-18.67
10	-18.9	-18	-17.59	-18.37	-20.51	-19.27
11	-19.65	-20.58	-19.28	-20.84	-20.01	-18.64
12	-15.27	-16.25	-15.27	-15.64	-14.83	-15
13	0.898	0.4003	0.1706	0.5835	0.8442	0.5386
14	0.04698	0.2863	0.2404	0.1109	0.0931	0.1634
15	0.0005285	0.05774	0.4943	0.01128	0.2568	0.5227
16	0.138	4.514	0.7262	2.605	0.6618	0.7007
17	0.01832	0.01329	0.01636	0.01136	0.008758	0.02047
18	-21.46	-21.73	-21.8	-23.88	-21.3	-21.15
19	3.475E-11	6.644E-11	5.883E-11	1.827E-10	1.431E-11	1.275E-11
20	-18.13	-18.65	-18.97	-18.94	-18.55	-19.97
21	1.09E-11	4.79E-11	9.347E-11	8.151E-11	1.675E-11	2.75E-10
22	1	1	4	1	4	1
23	0.0865	0.09077	0.09296	0.04644	0.05193	0.09786
24	0.04354	0.03475	0.06441	0.1351	0.07965	0.07889
25	0.6923	0.6574	0.6985	0.5271	0.6137	0.5691
26	13550000	12920000	11630000	12380000	12830000	13020000
27	13850000	11950000	12350000	13660000	11640000	14370000
28	-10.75	-13.78	-10.19	-11.66	-11.5	-12.04
29	-9.719	-8.504	-10.62	-8.833	-9.592	-9.845
30	-11.46	-11.17	-11.37	-12.83	-13.84	-11.03
31	18	11	19	15	10	11
32	0.0002045	0.00724	0.03351	0.00005364	0.001228	0.01122
33	2.352	1.477	1.395	6.169	9.799	0.644
34	635.9	415.8	869.3	461.5	745.1	590.5
35	0.6776	0.4236	0.3148	0.3964	0.453	0.6696
36	-0.2726	0.206	0.7031	-0.2863	-0.02572	-0.8209
37	-1.241	-0.1903	-0.2403	-0.1444	0.6671	-0.1208
38	0.8422	0.631	-0.2694	-0.2309	-0.06578	0.2032
39	-0.02767	-0.1522	-1.193	-1.648	0.004941	0.8414
40	-0.1842	0.1713	-0.2247	-0.1341	0.1528	0.1071
41	0.6647	-0.6554	0.1909	0.9775	-0.4772	0.09075
42	-0.4886	-0.05817	-0.05222	0.8574	0.2271	-0.08665
43	-0.2198	-1.11	-0.1399	0.1836	-0.3847	-0.4332
44	-0.2893	-0.1336	-0.01907	-0.01139	-0.1266	-1.276
45	0.7471	-0.2079	0.4838	0.9047	-0.7604	-0.3767
46	0.5364	1.507	1.551	1.408	0.7545	0.8533
47	0.9378	0.1924	0.02972	0.574	0.9298	0.006197
48	1.543	1.178	1.058	1	1.206	1.167
49	0.2256	0.3039	0.172	0.1839	0.1776	0.4227
50	0.0008304	0.004023	0.0002705	0.0006881	0.0002327	0.002262
51	0.1155	0.1718	0.1489	0.1737	0.2261	0.1557
52	0.002131	0.02008	0.01118	0.02422	0.02808	0.02785
53	17.47	9.286	4.943	4.884	2.155	0.932
54	0.2367	0.444	0.265	0.3832	0.2151	0.04333
55	6.066	19.42	13.77	5.778	12.64	13.51
56	13.47	14.16	6.52	6.13	9.675	4.751
57	0.3464	0.3134	0.07128	0.1467	0.1963	0.04814

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	41	42	43	44	45	46
1	9.094E-15	1.446E-14	1.475E-15	1.558E-14	1.525E-14	3.92E-15
2	0	0	1	0	2	1
3	8.675E-09	6.195E-09	4.737E-09	5.262E-09	7.783E-09	7.608E-09
4	8.416E-10	4.291E-10	1.192E-09	2.092E-10	5.55E-10	5.771E-10
5	0.06931	0.1264	0.3122	0.4971	0.3406	0.4638
6	0.02937	0.0003789	0.09201	0.1149	0.0933	0.04802
7	0.3272	0.013	0.3214	0.4974	0.1947	0.5436
8	0.2216	0.9788	0.6061	0.526	0.8571	0.6734
9	-19.18	-19.59	-20.73	-17.88	-20.1	-18.41
10	-18.2	-20.17	-18.91	-18.94	-17.17	-18.09
11	-20.37	-19.85	-18.91	-19.17	-20.25	-20.05
12	-16.02	-15.61	-14.85	-16.53	-14.54	-15.15
13	0.3193	0.6443	0.2791	0.8004	0.9196	0.7452
14	0.2491	0.08327	0.09114	0.3019	0.2017	0.3152
15	0.03572	0.1943	0.4501	0.3279	0.1485	0.02761
16	1.8	0.9074	2.913	4.781	0.8289	0.8788
17	0.007	0.02692	0.01076	0.001617	0.02194	0.002516
18	-22.73	-22.81	-22.52	-22.34	-23.31	-21.09
19	1.066E-10	1.18E-10	9.64E-11	7.884E-11	1.575E-10	8.186E-12
20	-18.07	-18.43	-18.86	-20.38	-19.78	-19.02
21	1.09E-11	1.09E-11	8.047E-11	2.75E-10	2.2E-10	1.181E-10
22	4	4	4	4	4	1
23	0.09643	0.06603	0.06046	0.08995	0.1042	0.05808
24	0.09305	0.1475	0.08448	0.03211	0.08743	0.09219
25	0.5071	0.6435	0.629	0.6878	0.6079	0.6296
26	12670000	11670000	11520000	13520000	11190000	11570000
27	14770000	12850000	13880000	13140000	13460000	15590000
28	-12.1	-10.03	-12.77	-10.87	-12.36	-11.92
29	-9.996	-10.68	-9.033	-10.52	-9.681	-9.12
30	-13.77	-12.03	-11.41	-13.28	-11.14	-13.62
31	14	24	3	2	28	5
32	0.001752	0.01514	0.0001078	0.002303	0.01853	0.002665
33	7.422	7.743	4.709	2	6.904	0.9768
34	132.4	40.83	155.1	5.237	68.79	25.27
35	0.1689	0.292	0.1233	0.1935	0.03888	0.9039
36	-0.5823	-0.3266	-0.009351	0.08199	-0.708	-1.513
37	-0.9042	-0.2796	-0.8736	-0.2355	0.7645	0.5676
38	-0.9023	0.3339	-1.419	-1.943	-0.166	0.04882
39	1.243	-0.4266	-0.05499	-0.1874	-0.619	-0.6772
40	-0.1173	0.5721	-0.09708	0.2321	0.1573	0.1359
41	0.8648	-0.01637	-0.1319	0.03492	0.7934	-0.7363
42	-0.2309	0.7049	-0.0797	0.001767	-0.7042	-0.1987
43	0.07454	-0.1297	-0.9515	0.0008706	-0.004225	-1.452
44	-0.08891	0.1248	-0.3789	-0.07292	-0.05204	-0.222
45	0.02998	-0.2119	-0.11	0.3378	-0.2392	0.4319
46	0.8233	1.537	1.523	0.7105	0.2398	1.535
47	0.285	0.1048	0.3699	0.03701	0.6272	0.1718
48	1.123	1.724	2.011	1.243	1.229	1.064
49	0.2122	0.3801	0.2596	0.2002	0.1233	0.3521
50	0.0003101	0.0001884	0.002957	0.002475	0.003585	0.0001326
51	0.1105	0.1795	0.1009	0.184	0.1681	0.1806
52	0.01062	0.006313	0.004558	0.001578	0.01634	0.02327
53	1.389	15.37	4.389	12.66	16.95	10.5
54	0.2174	0.1238	0.4978	0.1433	0.07812	0.2878
55	19.51	10.84	3.792	15.32	12.21	5.516
56	15.77	12.53	3.974	3.665	16.22	15.93
57	0.2617	0.2204	0.4784	0.4411	0.4222	0.4054

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	47	48	49	50	51	52
1	1.137E-14	1.261E-14	1.479E-14	6.484E-15	8.718E-16	2.439E-15
2	0	2	0	0	2	1
3	4.085E-09	4.377E-09	5.598E-09	4.649E-09	5.925E-09	9.351E-09
4	1.057E-09	9.796E-10	5.919E-10	6.735E-10	8.063E-10	9.438E-10
5	0.2189	0.0711	0.8183	0.6638	0.5285	0.7688
6	0.09138	0.08841	0.01336	0.04721	0.07897	0.1131
7	0.03475	0.4864	0.2676	0.06701	0.4621	0.04339
8	0.452	0.7208	0.3371	0.06347	0.6812	0.4659
9	-18.63	-19.07	-20.57	-19.64	-18.25	-18.31
10	-18.51	-17.8	-17.65	-19.2	-18.63	-17.87
11	-20.63	-19.51	-19.44	-19.72	-19.45	-18.97
12	-15.17	-14.11	-14.95	-16.11	-15.66	-14.91
13	0.2526	0.01141	0.3867	0.8348	0.2318	0.5474
14	0.3662	0.1656	0.1143	0.1893	0.2672	0.2908
15	0.1746	0.3056	0.3935	0.1791	0.5512	0.4644
16	0.9387	6.171	6.882	3.189	6.008	0.4932
17	0.007245	0.005455	0.02834	0.001807	0.02438	0.003471
18	-21.93	-21.01	-23.41	-21.06	-22.64	-22.68
19	5.429E-11	3.185E-12	1.551E-10	5.995E-12	9.47E-11	1.222E-10
20	-19.08	-18.87	-18.92	-19.33	-18.6	-17.85
21	1.222E-10	7.345E-11	8.351E-11	1.381E-10	3.515E-11	1.09E-11
22	4	1	1	4	4	4
23	0.1114	0.03466	0.08537	0.08675	0.07312	0.06452
24	0.05331	0.07499	0.01398	0.08568	0.04689	0.05856
25	0.6723	0.622	0.5545	0.5872	0.6035	0.6451
26	12620000	13840000	11140000	11980000	12810000	11770000
27	12620000	13040000	11470000	16160000	14920000	12230000
28	-11.27	-13.94	-11.46	-13.77	-11.6	-12.54
29	-10.09	-9.275	-9.477	-9.243	-9.413	-8.926
30	-14	-13.16	-12.16	-13.61	-13.51	-13.01
31	17	13	7	23	32	14
32	0.0001862	0.0002643	0.05061	0.1329	0.000819	0.001546
33	5.558	8.643	8.718	4.554	5.251	3.171
34	451.8	938.8	887.2	478.9	312.8	284.8
35	0.9776	0.7181	0.8346	0.924	0.7078	0.04559
36	-0.1991	-0.3689	-0.3861	0.03166	-0.776	-0.1408
37	0.2456	-0.03728	-0.1755	-0.3263	-0.5322	-0.7476
38	0.1129	-0.4114	0.2484	-0.02432	0.8896	-0.3197
39	-0.5503	-0.009923	0.1333	-0.8826	-0.1437	-0.823
40	-0.9101	0.07396	-0.4788	-0.2491	0.6009	-0.4397
41	0.2283	0.3652	-0.1985	-0.1471	0.6108	0.5951
42	0.1031	0.08676	-1.201	-0.2051	-0.3412	0.1341
43	-0.01929	0.8411	-0.2301	0.1345	-0.06267	-0.5325
44	-0.2748	-0.3581	0.581	0.6109	0.317	-0.8997
45	-0.5448	0.1151	0.5198	-0.2203	-1.159	-0.356
46	1.34	1.401	0.4903	1.487	1.014	1.51
47	0.09318	0.3883	0.4321	0.8105	0.748	0.7974
48	1.167	1.181	1.15	1.237	1.142	1.149
49	0.4851	0.2617	0.4108	0.1334	0.3739	0.3067
50	0.0009815	0.0004931	0.001219	0.0003629	0.0005076	0.0005953
51	0.119	0.196	0.2402	0.1895	0.1638	0.1817
52	0.00576	0.004077	0.02455	0.02043	0.001085	0.01805
53	10.81	11.71	19.42	8.798	6.907	12.99
54	0.1084	0.3691	0.1877	0.08425	0.2244	0.4257
55	2.143	7.912	9.273	9.419	4.336	4.755
56	1.397	12.12	4.262	7.665	5.474	7.94
57	0.4458	0.3495	0.3616	0.4937	0.1577	0.03756

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	53	54	55	56	57	58
1	1.225E-14	2.105E-15	3.265E-15	1.166E-14	5.514E-15	5.254E-15
2	0	1	0	1	2	0
3	5.379E-09	9.033E-09	6.706E-09	8.521E-09	5.185E-09	3.366E-09
4	1.843E-10	3.83E-10	2.262E-10	9.951E-10	4.039E-10	7.803E-10
5	0.2728	0.9948	0.5787	0.3216	0.8672	0.4216
6	0.07473	0.02821	0.04972	0.03335	0.1048	0.07983
7	0.429	0.4232	0.2118	0.2542	0.3361	0.1535
8	0.562	0.6396	0.8466	0.1521	0.01269	0.3486
9	-17.91	-20.3	-18.7	-17.45	-18.92	-18.5
10	-19.29	-19.44	-18.15	-20.15	-17.47	-19.97
11	-18.32	-19.23	-19.94	-19.48	-19.54	-20.54
12	-15.44	-15.1	-14.5	-15.78	-16.4	-15.11
13	0.4863	0.7394	0.7692	0.9981	0.2264	0.4184
14	0.3376	0.3914	0.3842	0.206	0.02189	0.1309
15	0.4185	0.4597	0.1995	0.1416	0.08777	0.1704
16	0.8584	5.091	4.685	1.162	0.5976	0.3193
17	0.004587	0.004951	0.01986	0.02953	0.01861	0.02003
18	-22.97	-22.76	-21.87	-21.44	-22.1	-22.29
19	1.321E-10	1.154E-10	5.713E-11	2.692E-11	6.841E-11	7.1E-11
20	-19.25	-19.65	-18.34	-19.67	-19.39	-18.62
21	1.133E-10	1.54E-10	2.13E-11	1.927E-10	1.464E-10	5.05E-11
22	4	1	1	1	1	1
23	0.06691	0.07687	0.1406	0.0433	0.06536	0.05667
24	0.09772	0.06669	0.1972	0.06613	0.09026	0.1022
25	0.641	0.5595	0.7048	0.5957	0.6637	0.6677
26	11400000	11410000	13720000	13120000	12520000	11310000
27	15080000	13600000	16330000	13390000	13900000	16610000
28	-12.57	-11.35	-11.07	-12.26	-11.75	-13.07
29	-9.106	-11.05	-10.68	-8.586	-10.17	-9.952
30	-11.98	-13.72	-11.68	-11.43	-12.93	-13.42
31	14	30	19	12	25	5
32	0.0002855	0.001145	0.1058	0.03848	0.1558	0.07388
33	4.389	1.863	5.868	2.45	2.835	1.698
34	892.3	217.2	605.9	191.5	365.5	918
35	0.5016	0.7649	0.3898	0.7291	0.8703	0.7909
36	-0.4017	0.3416	0.05751	-0.1004	-0.1512	-0.00309
37	0.6083	-0.0344	-0.3106	0.7103	0.1835	-0.4724
38	1.157	0.2765	0.3527	-0.2488	0.0244	-0.3009
39	0.2744	-0.1551	-0.2144	-0.1291	0.1969	-0.3117
40	-0.3894	0.7811	0.2509	-0.2095	0.08886	-0.0715
41	0.2904	0.05915	0.9062	-0.06426	0.01232	0.8349
42	-0.2515	-0.1005	0.166	-0.8122	0.1249	-0.4179
43	0.2251	0.09568	-0.4629	-0.06064	0.712	0.06808
44	-0.4945	-0.4648	0.5098	0.184	0.9627	-1.593
45	0.2192	0.1927	0.2779	-0.3118	-0.4423	-0.0004511
46	0.8108	0.8776	1.161	1.451	1.38	0.7957
47	0.4508	0.1627	0.8825	0.5821	0.3074	0.04352
48	1.081	1.044	1.676	1.191	1.086	1.225
49	0.07773	0.3398	0.4713	0.3917	0.1883	0.2201
50	0.0006069	0.002837	0.005744	0.005834	0.0001198	0.005015
51	0.1882	0.1385	0.1721	0.1029	0.1619	0.2137
52	0.008013	0.008153	0.02988	0.01747	0.007351	0.02942
53	5.543	7.285	8.113	18.2	4.191	17.24
54	0.4705	0.3638	0.3327	0.4192	0.1294	0.2308
55	10.22	13.93	11.28	9.676	15.73	16.36
56	1.809	19.25	10.16	2.05	3.832	13.23
57	0.4251	0.2964	0.4354	0.1418	0.1391	0.206

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	59	60	61	62	63	64
1	7.243E-15	1.239E-14	4.343E-15	1.176E-14	5.815E-15	1.31E-14
2	0	0	1	1	1	2
3	1.465E-09	5.061E-09	4.602E-09	1.717E-09	2.119E-09	9.313E-09
4	7.357E-10	6.26E-10	1.234E-09	1.127E-10	1.23E-09	1.085E-09
5	0.2629	0.8404	0.9752	0.9182	0.2977	0.7003
6	0.006547	0.1018	0.08259	0.1345	0.03528	0.0221
7	0.3132	0.1901	0.06487	0.09067	0.4566	0.108
8	0.776	0.009421	0.8627	0.7659	0.578	0.1656
9	-18.24	-19.42	-18.58	-18.85	-18.87	-18.2
10	-19.17	-18.3	-19.57	-19.73	-17.96	-19.08
11	-19.42	-19.97	-20.14	-19.75	-19.93	-19.87
12	-14.62	-14.92	-16.32	-15.46	-15.15	-15.77
13	0.186	0.04272	0.9399	0.1224	0.4388	0.684
14	0.2289	0.2223	0.1555	0.3948	0.07204	0.3567
15	0.1072	0.07874	0.3771	0.09357	0.3583	0.05071
16	6.646	0.4607	7.867	8.068	0.6204	5.464
17	0.01892	0.02587	0.006642	0.009999	0.006886	0.02639
18	-23.84	-21.29	-23	-21.1	-23.31	-23.98
19	1.856E-10	1.665E-11	1.301E-10	1.14E-11	1.614E-10	1.907E-10
20	-18.81	-17.11	-18.54	-19.05	-18.68	-18.16
21	7.682E-11	1.09E-11	3.943E-11	1.094E-10	6.128E-11	1.09E-11
22	1	4	1	1	4	4
23	0.08475	0.08124	0.1126	0.08129	0.08336	0.09255
24	0.06935	0.1164	0.101	0.0468	0.06231	0.05975
25	0.6311	0.6224	0.6519	0.6546	0.639	0.7004
26	12290000	12170000	13000000	11850000	11360000	13480000
27	16010000	12980000	13640000	14160000	12800000	13000000
28	-10.99	-10.49	-12.16	-12.23	-11.24	-12.08
29	-10.16	-10.57	-9.759	-9.338	-10.89	-10.01
30	-13.26	-12.2	-11.49	-12.36	-13.56	-13.89
31	25	25	11	16	3	27
32	0.00004708	0.02618	0.0459	0.0000685	0.1698	0.1486
33	2.089	0.4896	9.384	3.76	9.806	3.712
34	117.9	443.4	535	812.1	581.4	501
35	0.64	0.6157	0.9351	0.9845	0.4348	0.6586
36	-0.116	-0.1044	0.8772	-1.303	-0.04792	-0.464
37	0.3066	0.1708	-0.2168	-0.4295	-0.07717	-0.05475
38	-0.1872	-1.727	-1.008	-0.866	0.002	-0.2585
39	-0.0311	0.3268	-0.01806	0.9733	0.902	0.5714
40	-0.588	0.3968	-1.589	0.8847	0.7471	-0.08613
41	-0.008851	0.1405	0.06964	-0.2833	0.2212	-0.2313
42	-0.9887	-0.00516	0.07124	0.4182	-0.4032	-0.1824
43	0.1939	0.2462	-0.3077	-0.7463	-1.573	0.7961
44	0.1919	-0.4434	0.1335	0.2848	0.0301	-0.3492
45	-1.474	-1.839	-0.03095	-0.2012	0.06639	-0.2244
46	1.559	0.7283	0.1177	1.345	1.514	1.288
47	0.5517	0.1556	0.1858	0.6303	0.4118	0.7824
48	1.918	2.201	1.223	1.008	1.03	1.037
49	0.3955	0.08715	0.4524	0.2304	0.1201	0.2977
50	0.003654	0.0009528	0.0001007	0.003842	0.0003825	0.009659
51	0.2232	0.1368	0.1586	0.1114	0.1203	0.1579
52	0.005328	0.004516	0.00354	0.02515	0.01167	0.02639
53	2.701	13.76	14.36	18.4	6.333	10.84
54	0.4051	0.3598	0.2975	0.3946	0.3996	0.4831
55	13.27	8.62	15.08	7.707	5.13	10.37
56	18.57	10.67	6.407	14.57	14.44	8.649
57	0.02035	0.4756	0.319	0.06136	0.2669	0.4325

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	65	66	67	68	69	70
1	1.438E-14	4.815E-16	3.411E-15	2.239E-15	7.643E-15	1.192E-14
2	0	2	0	0	2	1
3	7.908E-09	8.225E-09	4.201E-09	3.538E-09	7.094E-09	2.766E-09
4	7.24E-10	5.578E-11	6.718E-10	7.001E-10	9.259E-10	5.856E-12
5	0.9464	0.6186	0.5928	0.7956	0.1559	0.6427
6	0.1474	0.06737	0.05126	0.03613	0.01149	0.03023
7	0.4068	0.2969	0.003514	0.1375	0.5152	0.05865
8	0.4499	0.4869	0.2097	0.08634	0.8304	0.03236
9	-18.22	-18.99	-18.96	-19.41	-19.01	-18
10	-18.69	-20	-18.45	-19.01	-18.71	-18.28
11	-18.57	-20.02	-19.86	-19.06	-18.51	-20.13
12	-14.47	-16.51	-16.16	-15.62	-16.68	-14.69
13	0.5525	0.7067	0.7125	0.7954	0.8157	0.106
14	0.09602	0.3541	0.06892	0.2279	0.3792	0.1016
15	0.1654	0.1169	0.1583	0.04022	0.3465	0.03637
16	1.643	8.312	0.5318	0.7453	0.478	7.453
17	0.003907	0.009426	0.002053	0.002303	0.008436	0.009204
18	-23.92	-22.87	-21.2	-22.91	-23.9	-23.78
19	1.865E-10	1.268E-10	2.326E-11	1.205E-10	1.771E-10	1.712E-10
20	-18.48	-18.71	-18.9	-18.63	-18.28	-19.58
21	5.168E-11	6.525E-11	9.844E-11	4.273E-11	1.09E-11	1.627E-10
22	4	1	4	1	4	1
23	0.07084	0.07332	0.007846	0.08736	0.05484	0.07112
24	0.05788	0.05272	0.0365	0.0717	0.06513	0.03928
25	0.5519	0.789	0.694	0.6784	0.6729	0.7383
26	12320000	13640000	11490000	13150000	11220000	11050000
27	14060000	13740000	13430000	12310000	15000000	14810000
28	-13.14	-12.01	-13.69	-11.84	-12.9	-12
29	-9.366	-9.606	-8.698	-10.07	-9.298	-9.973
30	-11.59	-11.07	-12.73	-11.64	-12.75	-11.95
31	24	20	24	24	2	6
32	0.0002227	0.0003488	0.006954	0.0001639	0.0005447	0.004398
33	7.873	9.995	2.633	8.42	9.214	8.852
34	350.3	803.9	557.6	908.1	994.1	528
35	0.33	0.2227	0.08236	0.4167	0.8458	0.582
36	-0.2351	-0.4839	0.1816	-0.5508	-0.4253	0.01981
37	-0.2259	-0.02748	-0.3441	-0.3716	-0.1703	-0.2074
38	-0.09045	-0.2247	0.6758	-0.03269	-0.4652	-0.1954
39	-0.06797	0.149	0.2114	0.03675	-0.7627	-0.1051
40	-0.1522	-0.055	0.005222	0.8042	0.1865	-0.4172
41	-1.317	0.5158	0.3069	-0.22	-0.4094	-0.9903
42	-0.3721	-0.1323	-0.06612	-0.2218	0.5813	-0.09152
43	-0.213	0.9996	0.1076	-0.7946	0.5849	-0.01099
44	-0.1994	-0.1474	0.776	0.841	-0.2102	-0.2565
45	-0.7078	-0.3033	-0.05137	0.1296	0.04148	0.1653
46	0.6783	1.586	0.1944	0.9091	0.6181	1.219
47	0.2325	0.06108	0.8738	0.1342	0.8666	0.7366
48	1.214	1.186	2.074	1.237	1.77	1.196
49	0.3346	0.06624	0.4571	0.4322	0.2909	0.2355
50	0.001694	0.0001539	0.0005371	0.009309	0.004923	0.001435
51	0.1485	0.1728	0.1822	0.1657	0.1094	0.154
52	0.02238	0.0171	0.02342	0.008711	0.02697	0.01876
53	13.31	18.78	6.076	1.212	5.452	1.782
54	0.0251	0.2909	0.4648	0.09349	0.02262	0.3531
55	15.95	8.188	16.82	14.42	8.927	3.492
56	19.85	16.07	9.296	2.894	4.481	8.112
57	0.2545	0.3576	0.02916	0.4104	0.1905	0.2837

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	71	72	73	74	75	76
1	7.589E-15	1.01E-14	1.553E-14	1.499E-14	2.651E-15	8.875E-15
2	2	0	0	1	0	2
3	9.426E-10	3.985E-09	2.493E-09	7.402E-09	4.696E-10	1.267E-09
4	3.519E-10	1.162E-09	2.841E-10	1.257E-09	5.6E-10	1.634E-10
5	0.4518	0.3345	0.4882	0.1063	0.02834	0.6778
6	0.1372	0.03208	0.05278	0.1218	0.1073	0.1196
7	0.1263	0.4741	0.5094	0.3551	0.07414	0.5403
8	0.3825	0.2194	0.1825	0.7811	0.6477	0.5936
9	-18.29	-17.79	-18.17	-18.43	-18.38	-20.11
10	-18.68	-18.25	-19.1	-17.84	-17.72	-19.64
11	-20.33	-19.73	-20.42	-18.98	-19.22	-20.49
12	-16.12	-15.36	-15.96	-15.3	-15.91	-14.64
13	0.3938	0.3471	0.7501	0.5116	0.5977	0.4268
14	0.1708	0.3467	0.1494	0.06342	0.3085	0.3823
15	0.267	0.5699	0.3615	0.2881	0.02153	0.3158
16	1.376	3.791	4.988	8.406	6.524	0.5585
17	0.00832	0.02137	0.007505	0.01259	0.02864	0.004726
18	-23.74	-21.69	-23.22	-22.39	-22.31	-23.72
19	1.82E-10	4.749E-11	1.455E-10	8.062E-11	9.053E-11	1.735E-10
20	-18.89	-18.37	-19	-17.94	-19.19	-18.53
21	7.858E-11	1.501E-11	9.23E-11	1.09E-11	1.281E-10	3.817E-11
22	4	1	1	4	4	1
23	0.08584	0.08063	0.07544	0.09119	0.1044	0.05543
24	0.0869	0.06339	0.07225	0.06183	0.1077	0.1058
25	0.5929	0.7252	0.6655	0.6447	0.7065	0.6897
26	12590000	12470000	11540000	12530000	11900000	13500000
27	14390000	11760000	12890000	13510000	12510000	13800000
28	-10.9	-12.68	-10.96	-12.78	-12.48	-13.15
29	-10.78	-10.34	-10.61	-9.627	-9.578	-8.412
30	-13.92	-12.45	-12.65	-13.73	-12.52	-12.98
31	29	10	31	29	21	23
32	0.0132	0.002426	0.0007121	0.01755	0.00006046	0.1882
33	0.2168	4.814	4.986	1.126	4.138	3.565
34	970.9	42.46	950.2	828.1	836.3	270.7
35	0.5266	0.86	0.4628	0.3503	0.07995	0.09798
36	0.006817	-0.1898	-0.2447	0.2287	0.1295	0.1163
37	-0.3026	-0.009628	-0.151	0.09237	0.1966	0.8208
38	0.5251	0.4637	-0.3454	0.1352	-0.2219	0.09266
39	0.08936	-0.2997	-0.2261	-0.1723	0.1691	0.51
40	0.2083	-0.25	-0.159	-0.06482	-0.00439	-1.982
41	-1.97	0.2493	0.4708	-0.4249	0.1566	-0.1029
42	-0.3253	0.0782	0.05351	0.0204	-0.02469	0.8337
43	-0.1628	-0.1086	-1.835	-0.6549	-0.07248	-0.4912
44	-1.226	0.04471	-0.5304	0.7156	-0.065	0.09595
45	0.3634	0.1479	-0.4554	0.006903	-0.1356	-0.1563
46	1.439	0.4393	1.499	1.04	0.08294	0.9531
47	0.8393	0.4671	0.982	0.1125	0.2151	0.2401
48	2.129	1.96	2.046	1.033	1.07	1.921
49	0.4412	0.06266	0.1481	0.2706	0.442	0.4256
50	0.0002181	0.006952	0.0001429	0.00184	0.0001488	0.007899
51	0.1033	0.1072	0.1252	0.1442	0.1848	0.1879
52	0.005552	0.02189	0.01486	0.0193	0.01775	0.0006021
53	19.85	16.93	3.538	11.81	9.01	3.138
54	0.2059	0.2474	0.2519	0.4092	0.1524	0.1173
55	1.277	1.585	17.47	18.43	1.075	9.902
56	6.804	17.48	19.8	8.74	19.17	5.83
57	0.1018	0.0305	0.3114	0.4522	0.4883	0.2361

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	77	78	79	80	81	82
1	5.684E-15	2.902E-15	7.134E-15	6.143E-15	1.377E-14	1.281E-15
2	0	1	1	0	0	2
3	7.569E-09	8.779E-09	8.731E-09	2.554E-09	3.345E-09	4.958E-09
4	1.105E-09	1.255E-09	8.285E-10	3.698E-11	1.179E-09	2.073E-11
5	0.3976	0.3746	0.9885	0.05919	0.7841	0.5081
6	0.06422	0.1307	0.02683	0.1176	0.06163	0.07147
7	0.04497	0.117	0.2019	0.1032	0.5299	0.1558
8	0.2902	0.4759	0.128	0.09569	0.9253	0.5433
9	-18.35	-18.15	-18.56	-18.68	-19.19	-19.96
10	-19.35	-17.69	-18.83	-18.77	-19.5	-19.53
11	-19.12	-20.55	-19.99	-19.71	-20.09	-20.2
12	-14.28	-16.81	-15.08	-14.99	-16.59	-16.27
13	0.0313	0.3058	0.078	0.864	0.1664	0.3292
14	0.1811	0.3318	0.1738	0.05082	0.0115	0.3077
15	0.1803	0.3701	0.2755	0.5806	0.1893	0.4763
16	7.094	0.579	0.6455	1.904	0.9697	0.2171
17	0.009569	0.02506	0.01302	0.003008	0.01173	0.0264
18	-23.51	-22.45	-21.64	-21.59	-22.16	-21.99
19	1.385E-10	1.037E-10	5.342E-11	3.708E-11	7.809E-11	6.348E-11
20	-20.74	-19.84	-19.07	-17.43	-18.93	-19.28
21	2.75E-10	1.841E-10	1.05E-10	1.09E-11	9.65E-11	1.418E-10
22	4	1	4	4	1	1
23	0.04099	0.07386	0.07889	0.08945	0.118	0.09192
24	0.07364	0.1412	0.1035	0.1132	0.04971	0.04893
25	0.6795	0.7313	0.6353	0.6596	0.6691	0.6177
26	13440000	12070000	13620000	12330000	12730000	12850000
27	14130000	14880000	14690000	13530000	14100000	12960000
28	-11.55	-11.33	-12.19	-12.52	-11.58	-11.21
29	-10.73	-10.19	-9.937	-10.38	-10.35	-9.867
30	-11.19	-11.35	-12.48	-11.24	-11.26	-12.92
31	31	5	6	18	13	28
32	0.05571	0.0006356	0.00004025	0.00009562	0.02862	0.002941
33	1.227	4.451	6.519	7.005	9.144	5.33
34	767.3	184.4	360.1	89.63	306.3	384.1
35	0.2451	0.285	0.2352	0.7548	0.5907	0.3006
36	-0.03893	-0.1339	-0.1677	-0.8944	-1.115	-0.07485
37	0.2224	-0.01986	-0.5833	1.342	-0.06384	0.0541
38	-0.03669	-0.0542	0.951	-0.6971	0.2285	-0.205
39	-0.2429	0.1276	-0.09037	-0.05567	-0.2484	-1.273
40	-0.2192	0.06696	-0.1266	-0.6136	-0.4024	-0.5088
41	0.07404	-1.73	-0.2129	-0.3095	-0.04816	-0.4954
42	-0.1709	-0.1229	0.6324	-0.8483	-0.225	-1.569
43	-0.6866	-0.8958	-0.3676	-0.1767	0.1692	-0.02392
44	-0.05582	-0.1081	-0.1117	0.2188	-0.9497	0.4448
45	0.09033	-0.6321	-0.3954	0.07701	-0.569	0.1036
46	1.375	1.134	0.2697	1.477	0.3836	0.3008
47	0.7195	0.9452	0.4903	0.8439	0.5103	0.2589
48	1.162	1.056	1.146	1.079	1.156	1.199
49	0.06979	0.1504	0.278	0.4352	0.2462	0.1377
50	0.0001941	0.000287	0.004518	0.004249	0.0008993	0.006131
51	0.1867	0.1711	0.1668	0.1185	0.1234	0.1065
52	0.02544	0.006797	0.01215	0.01414	0.01177	0.01974
53	6.521	10.24	18.53	19.7	4.59	1.562
54	0.2081	0.07637	0.148	0.4352	0.4877	0.3196
55	6.69	18.64	15.48	18.9	1.938	11.86
56	11.48	8.522	12.71	7.338	3.031	17.27
57	0.3916	0.2088	0.4841	0.2995	0.243	0.3966

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	83	84	85	86	87	88
1	4.983E-15	6.652E-15	9.666E-15	8.618E-15	6.195E-15	5.164E-15
2	1	0	2	1	1	1
3	5.958E-09	8.957E-09	7.214E-09	4.545E-09	5.674E-10	7.323E-09
4	6.102E-10	8.926E-10	1.024E-09	4.472E-11	1.208E-09	4.596E-10
5	0.2468	0.2878	0.7211	0.1795	0.9242	0.6399
6	0.126	0.07295	0.06105	0.01657	0.1055	0.04492
7	0.184	0.09499	0.2823	0.2199	0.4001	0.1775
8	0.829	0.3746	0.8949	0.4006	0.05233	0.4918
9	-17.64	-17.94	-18.47	-18.06	-17.75	-19.08
10	-19.71	-19.46	-18.44	-18.99	-19.38	-18.56
11	-19.69	-19.88	-19.61	-20.11	-19.19	-18.79
12	-14.57	-14.36	-16.44	-14.94	-14.88	-16.21
13	0.9755	0.9074	0.08239	0.5207	0.4784	0.4684
14	0.2931	0.07971	0.2363	0.02564	0.3627	0.06523
15	0.02951	0.08381	0.4157	0.2352	0.06652	0.1205
16	0.2096	0.7793	1.57	4.315	0.341	2.146
17	0.02375	0.008678	0.001474	0.003768	0.005077	0.006472
18	-21.75	-21.33	-21.13	-21.27	-22.02	-21.51
19	4.923E-11	2.129E-11	9.179E-12	2.471E-11	7.608E-11	2.754E-11
20	-19.03	-18.38	-18.03	-18.45	-18.75	-19.3
21	9.978E-11	2.638E-11	1.09E-11	1.09E-11	6.071E-11	1.364E-10
22	4	1	4	1	4	1
23	0.09893	0.1241	0.06277	0.08367	0.1073	0.07832
24	0.07792	0.06983	0.0882	0.09596	0.1034	0.07472
25	0.6858	0.6242	0.7706	0.6129	0.5993	0.638
26	11350000	12420000	11930000	11670000	11100000	12050000
27	13220000	15710000	13310000	11840000	13090000	12400000
28	-14.62	-11.79	-12.21	-10.62	-13.39	-11.53
29	-8.564	-9.775	-9.526	-10.97	-9.31	-10.55
30	-13.97	-11.73	-11.3	-13.13	-11.01	-13.32
31	31	22	30	17	13	32
32	0.000424	0.06209	0.00134	0.0001182	0.01237	0.004004
33	6.658	8.071	5.716	4.312	7.296	5.728
34	774.4	228.3	694.9	323.8	146.3	200.9
35	0.2065	0.2714	0.8257	0.9598	0.7817	0.1154
36	0.1361	0.413	0.3644	0.8496	-0.01625	-0.3505
37	0.009855	-1.509	-0.2098	-0.6813	0.1339	-0.1588
38	0.1917	-0.1391	0.4437	-0.1269	-0.09921	-0.3585
39	-0.134	0.2221	0.4926	-0.4724	0.07346	-0.06979
40	-0.46	-0.1039	-0.964	-0.3287	0.1907	-1.251
41	-0.03688	-0.8551	-0.0001582	-0.1713	-0.2567	-0.3291
42	-0.6039	-0.02841	0.03962	0.03107	-0.3212	-0.4433
43	-0.4156	-0.05333	0.1261	-0.2785	0.2054	0.01666
44	-0.1206	-0.2376	-0.2359	0.08151	-0.02839	-1.99
45	-0.1619	0.5574	-0.1031	-0.1487	-0.01072	0.2455
46	0.0952	1.494	1.52	0.5287	1.467	1.545
47	0.2672	0.2279	0.5276	0.3504	0.6122	0.8542
48	1.074	1.035	1.992	1.134	1.852	1.174
49	0.09681	0.3599	0.07389	0.05154	0.3686	0.4963
50	0.0003186	0.001742	0.003335	0.007463	0.0002514	0.002345
51	0.1162	0.1785	0.1754	0.1227	0.1428	0.2366
52	0.002448	0.008882	0.01316	0.0267	0.01284	0.0092
53	5.832	7.683	14.65	2.986	11.1	11.28
54	0.3019	0.3717	0.1551	0.1958	0.1753	0.04766
55	16.41	2.279	17.76	3.249	1.401	3.96
56	10.01	17.09	13.52	8.223	15.43	7.518
57	0.2791	0.1174	0.3799	0.3558	0.3883	0.3382

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	89	90	91	92	93	94
1	9.021E-15	4.058E-15	1.34E-14	4.278E-15	1.059E-14	1.52E-14
2	1	0	0	0	0	1
3	5.746E-09	3.835E-09	9.083E-09	1.1E-09	4.12E-09	6.629E-09
4	2.79E-10	9.566E-10	2.627E-10	1.237E-10	7.71E-11	8.83E-10
5	0.7725	0.4155	0.5471	0.839	0.6006	0.3602
6	0.09708	0.02399	0.08224	0.1213	0.09947	0.008478
7	0.3774	0.3044	0.3864	0.5044	0.03292	0.3952
8	0.356	0.9171	0.1435	0.9563	0.7412	0.7984
9	-19.13	-18.44	-19.76	-17.6	-18.09	-19.73
10	-18.06	-18.66	-18.61	-19.11	-19.69	-18.8
11	-18.82	-19.33	-18.86	-19.49	-18.95	-20.21
12	-15.49	-14.78	-15.05	-15.88	-14.81	-15.4
13	0.7746	0.007888	0.5702	0.2433	0.1415	0.2993
14	0.2979	0.0134	0.2561	0.1256	0.159	0.2701
15	0.01829	0.09126	0.2169	0.3302	0.06129	0.1452
16	4.244	0.1953	0.4152	0.758	7.976	0.2653
17	0.01026	0.001194	0.009027	0.016	0.009755	0.006309
18	-23.95	-23.62	-21.61	-21.24	-23.05	-21.81
19	1.892E-10	1.768E-10	3.61E-11	3.265E-11	1.351E-10	4.577E-11
20	-19.54	-19.12	-20.26	-20.12	-17.1	-19.15
21	1.77E-10	1.063E-10	2.422E-10	2.251E-10	1.09E-11	8.842E-11
22	4	4	4	4	1	4
23	0.09442	0.06154	0.1009	0.06381	0.04669	0.1025
24	0.1111	0.1177	0.1273	0.1242	0.0764	0.01398
25	0.6361	0.7609	0.6464	0.5745	0.6745	0.7489
26	13830000	13190000	13270000	13720000	11300000	12110000
27	12770000	14600000	11240000	14270000	12460000	15570000
28	-13.25	-12.62	-11.09	-11.43	-11.9	-11.82
29	-9.7	-8.874	-9.916	-10.47	-9.989	-10.21
30	-12.56	-12.25	-13.05	-13.37	-13.45	-11.83
31	4	32	27	17	6	18
32	0.0005114	0.009184	0.07056	0.04295	0.07961	0.0001555
33	3.242	7.612	9.592	9.646	8.525	8.212
34	60.47	166.9	873.3	674.1	129.3	377.9
35	0.3774	0.8143	0.3499	0.06003	0.4958	0.5463
36	0.1668	-0.2429	-0.05537	-0.06674	-0.0888	0.5031
37	-0.254	0.1487	-0.1057	-0.1002	0.0979	0.02091
38	0.9431	-0.6123	-0.04627	-0.1082	0.703	-0.4083
39	-0.07745	-0.03769	0.6738	-0.004034	-0.4063	-0.2037
40	-1.1	-0.05978	-0.3718	-0.009883	0.6589	0.129
41	-0.1437	-1.152	-0.2439	0.04418	0.1887	-0.1831
42	0.2254	-0.06964	0.1722	-0.18	-0.6223	-0.4731
43	-0.1552	-0.09479	-0.04306	-0.1895	-0.2008	-0.1321
44	-0.182	0.6711	-0.09479	-0.04011	-0.3974	0.09043
45	-0.9908	0.2324	0.1769	-0.08896	-0.1856	-0.1251
46	1.556	0.4157	1.416	1.406	1.492	1.265
47	0.2082	0.1421	0.4826	0.4735	0.5977	0.6762
48	1.692	1.047	1.018	1.231	1.04	1.137
49	0.1904	0.3266	0.4048	0.474	0.4473	0.4922
50	0.0004289	0.002664	0.002072	0.003089	0.0007502	0.0001314
51	0.1601	0.1134	0.1081	0.1323	0.1123	0.1977
52	0.02938	0.02143	0.02397	0.02594	0.00188	0.01575
53	5.975	16.21	15.63	3.575	9.325	10.3
54	0.3492	0.1158	0.3786	0.4415	0.05709	0.4583
55	8.902	12.44	7.315	3.172	18.78	6.302
56	3.551	10.86	16.82	7.113	4.611	17.58
57	0.1761	0.1011	0.08265	0.2932	0.2496	0.1238

Table IRES-4. 100 Values Sampled by LHS for 57 Parameters That Were Varied in the 1996 Performance Assessment Calculations, Replicate 3 (Continued)

LHS#	95	96	97	98	99	100
1	1.692E-15	5.358E-17	6.899E-15	1.103E-14	1.083E-14	6.684E-15
2	1	2	1	0	1	2
3	1.558E-09	9.208E-09	5.686E-09	3.469E-09	2.706E-09	7.537E-10
4	9.648E-10	5.414E-10	5.156E-10	3.142E-10	1.121E-09	7.225E-10
5	0.8223	0.4013	0.51	0.5698	0.5564	0.2252
6	0.05467	0.1164	0.08533	0.1032	0.1381	0.05708
7	0.5286	0.4913	0.3377	0.2899	0.2603	0.2287
8	0.2555	0.711	0.1903	0.8849	0.2891	0.7382
9	-20.01	-17.98	-19.36	-19.3	-19.68	-18.82
10	-18.39	-18.81	-20.35	-19.23	-20.1	-19.85
11	-19.38	-20.17	-19.96	-20.23	-19.57	-18.2
12	-14.89	-14.6	-14.65	-15.24	-15.35	-15.82
13	0.9504	0.6114	0.943	0.442	0.5031	0.5672
14	0.03725	0.02845	0.2175	0.0006224	0.1347	0.04174
15	0.1116	0.1021	0.5613	0.09796	0.4051	0.04532
16	3.999	0.805	2.449	0.3778	5.926	7.392
17	0.01086	0.01362	0.0142	0.02726	0.02329	0.003174
18	-23.45	-22.49	-23.8	-23.25	-21.5	-23.03
19	1.474E-10	8.411E-11	1.796E-10	1.523E-10	4.414E-11	1.244E-10
20	-19.22	-19.6	-18.8	-19.4	-19.09	-18.85
21	1.159E-10	2.03E-10	8.492E-11	1.559E-10	1.009E-10	7.117E-11
22	4	4	4	4	4	1
23	0.08897	0.08211	0.01187	0.06797	0.1341	0.1018
24	0.05152	0.07774	0.08234	0.0942	0.08131	0.08926
25	0.6202	0.6494	0.6485	0.6632	0.7166	0.6412
26	11170000	11890000	13220000	12180000	12780000	13340000
27	15890000	12280000	14310000	15160000	14440000	13350000
28	-10.8	-11.01	-11.19	-12.3	-11.43	-12.13
29	-10.48	-10.42	-10.8	-10.03	-9.804	-9.398
30	-11.69	-13.47	-12.83	-13.2	-12.58	-12.2
31	16	1	13	26	4	4
32	0.001571	0.0211	0.0009522	0.00008888	0.003756	0.127
33	7.368	6.355	2.882	8.916	3.97	0.4135
34	407.4	920.8	512	704.6	756.5	630.3
35	0.6076	0.9494	0.5754	0.7405	0.4036	0.2191
36	1.184	-0.2124	-1.977	0.7768	-0.2271	-0.05822
37	0.9451	0.07435	-0.643	-0.3993	0.04691	-0.3914
38	0.5912	-0.1245	0.04215	-0.1922	-0.08493	-0.2141
39	-0.1775	0.4416	0.01427	0.164	-0.2333	-0.2714
40	0.4984	-0.822	-0.4888	-0.1726	-0.8857	-0.08076
41	-0.1062	-0.09064	-0.7188	0.7046	-0.4451	0.001216
42	0.6941	-0.04813	-0.01328	-0.5224	-0.1602	-0.117
43	0.4853	-0.07916	-0.4814	-0.1018	0.02445	-0.08376
44	-0.1729	-0.02291	0.9481	0.1684	-0.6903	0.2395
45	-0.4652	-1.714	0.6183	-0.0791	0.8485	-0.8468
46	1.394	1.433	0.3386	1.599	1.585	1.482
47	0.6961	0.7262	0.07831	0.08721	0.5625	0.9068
48	1.105	1.884	1.249	1.13	1.089	1.016
49	0.1418	0.4639	0.08157	0.1026	0.2435	0.1093
50	0.002146	0.001952	0.0001126	0.006697	0.0005747	0.008105
51	0.1338	0.1783	0.1866	0.1129	0.1766	0.1813
52	0.0212	0.01448	0.01852	0.00772	0.00934	0.003802
53	15.48	12.55	19.21	17.84	2.273	16.4
54	0.4555	0.3388	0.4473	0.03914	0.0332	0.1678
55	17.29	14.56	7.142	8.458	19.11	1.679
56	2.732	18.09	11.86	5.244	16.73	18.44
57	0.2719	0.418	0.2557	0.1079	0.1264	0.4027

Table IRES-5. Ranks of 100 Values Sampled, Replicate 1

LHS#	Material	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	STEEL	CORRMC	15	41	70	79	45	58	30	31	99	42	10	78	6	77	57	39	23	43	47	73
2	WAS_AREA	PROBDEG	88	26	63	26	26	26	26	26	63	26	63	63	26	88	88	26	88	63	63	88
3	WAS_AREA	GRATMICI	82	97	83	5	15	45	56	58	85	64	27	43	89	54	69	47	75	9	10	61
4	WAS_AREA	GRATMIC	38	70	47	77	55	51	9	86	95	6	4	15	40	96	57	98	82	26	33	79
5	CELLULS	FBETA	61	30	28	73	32	57	33	51	66	58	89	70	49	85	4	10	50	48	62	18
6	WAS_AREA	SAT_RGA	1	74	78	43	48	77	27	55	5	91	81	49	87	15	58	69	62	2	72	84
7	WAS_AREA	SAT_RBR	84	42	81	34	17	71	13	78	33	62	90	27	70	31	76	50	94	20	52	83
8	WAS_AREA	SAT_WIC	94	48	70	64	9	95	63	16	54	86	22	78	39	91	2	62	25	13	96	26
9	CL_L_T1	PRMX_LO	89	79	77	100	7	65	98	93	45	63	82	88	66	37	20	36	78	44	23	72
10	CONC_T1	PRMX_LO	11	16	18	42	85	74	73	23	54	28	72	98	48	26	89	25	86	21	92	19
11	ASPHALT	PRMX_LO	15	59	92	25	75	33	17	91	11	78	52	30	74	89	4	79	67	38	73	5
12	SHFT_DRZ	PRMX_LO	36	10	84	80	2	8	14	44	48	49	38	74	25	13	82	58	71	1	17	69
13	SALT_T1	CUMPRO	17	16	42	36	54	73	67	23	19	84	61	46	26	82	77	31	45	72	57	51
14	SALT_T1	SAT_RGA	25	98	64	69	68	72	71	17	11	35	65	43	26	7	62	22	67	93	23	44
15	SALT_T1	SAT_RBR	58	56	66	46	86	39	32	22	45	29	97	48	54	72	50	37	93	35	89	8
16	SALT_T1	PORE_DIS	22	50	34	86	71	1	33	85	88	32	24	7	15	2	55	43	11	91	10	66
17	S_HALITE	POROSIT	53	23	79	74	86	28	99	2	98	45	38	5	4	68	34	87	54	41	84	31
18	S_HALITE	PRMX_LO	20	79	16	63	78	54	43	72	45	38	6	50	23	62	82	3	83	95	36	80
19	S_HALITE	COMP_RC	79	24	84	38	18	46	65	32	54	63	98	48	80	47	16	99	25	3	53	31
20	S_MB139	PRMX_LO	51	54	29	79	30	24	12	19	18	35	9	4	22	61	3	70	68	57	52	94
21	S_MB139	COMP_RC	47	39	64	10	79	81	92	75	87	65	91	99	78	32	96	41	29	43	49	10
22	S_MB139	RELP_MO	26	26	26	26	76	76	76	26	76	26	76	26	26	26	26	26	76	76	76	26
23	S_MB139	SAT_RBR	66	46	97	27	56	88	22	95	77	4	98	12	19	35	23	8	2	26	20	11
24	S_MB139	SAT_RGA	3	19	83	51	22	49	17	55	65	48	69	54	88	66	80	60	74	98	3	18
25	S_MB139	PORE_DIS	29	26	78	76	89	60	48	97	33	99	28	8	80	94	90	63	21	38	64	74
26	S_HALITE	PRESSUR	34	44	10	68	3	69	54	79	42	4	92	88	62	16	81	94	21	37	12	30
27	CASTILER	PRESSUR	83	17	18	7	34	1	23	6	92	12	51	2	61	67	36	29	75	9	35	50
28	CASTILER	PRMX_LO	85	52	15	37	23	36	79	60	19	89	51	30	8	24	55	31	97	80	29	64
29	CASTILER	COMP_RC	6	19	84	82	80	56	45	53	89	39	54	77	91	93	16	27	21	8	78	88
30	BH_SAND	PRMX_LO	43	66	29	27	5	57	96	56	83	21	45	65	40	60	78	39	70	3	98	6
31	CASTILER	GRIDFLO	90	99	28	65	52	31	43	77	49	52	74	87	40	21	18	46	31	68	37	68
32	BLOWOUT	PARTDIA	86	47	98	19	43	7	52	3	27	24	34	63	89	73	16	54	100	39	80	49
33	BOREHOLE	TAUFAIL	9	28	38	34	79	49	48	64	31	12	53	74	96	71	36	67	10	93	72	13
34	CULEBRA	MINP_FA	40	90	96	54	33	63	80	12	25	20	1	70	83	29	24	17	5	22	4	16
35	GLOBAL	TRANSID	36	2	86	62	71	54	6	99	76	41	46	44	14	26	75	49	95	79	35	23
36	SOLAM3	SOLSIM	35	20	6	99	77	26	30	69	11	51	62	43	24	32	61	86	88	14	65	64
37	SOLAM3	SOLCIM	20	42	50	1	22	45	87	25	84	63	2	3	41	66	39	94	77	93	27	78
38	SOLPU3	SOLSIM	14	93	44	33	100	28	35	76	65	9	18	78	90	61	49	38	81	1	42	95
39	SOLPU3	SOLCIM	72	17	97	56	61	73	92	68	54	70	63	13	53	22	23	43	84	26	36	96
40	SOLPU4	SOLSIM	26	54	35	4	97	17	27	34	66	61	8	100	77	58	55	75	96	53	11	22
41	SOLPU4	SOLCIM	52	84	2	92	45	76	75	21	18	20	40	23	85	55	93	10	44	31	30	97
42	SOLU4	SOLSIM	16	31	39	7	10	71	22	67	64	74	27	86	49	12	5	99	66	70	56	2
43	SOLU6	SOLSIM	30	66	70	23	46	44	75	29	41	27	28	98	49	97	91	5	77	71	87	84
44	SOLU6	SOLCIM	62	53	92	38	36	4	52	97	10	73	14	33	82	24	76	84	41	70	89	55
45	SOLTH4	SOLSIM	91	18	35	22	53	77	42	87	61	59	95	57	26	94	62	56	45	34	90	6
46	PHUMOX3	PHUMCIM	3	63	95	18	17	5	58	1	9	100	64	31	24	11	53	55	23	62	93	67
47	GLOBAL	OXSTAT	100	7	95	68	57	22	23	45	88	98	35	99	90	33	83	77	56	92	24	89
48	GLOBAL	CLIMTIDX	65	99	91	41	45	100	6	52	28	86	80	12	2	22	79	62	57	77	96	95
49	CULEBRA	HMBLKLT	83	4	57	95	53	24	62	12	29	19	71	47	17	43	32	45	16	51	78	59
50	CULEBRA	APOROS	6	97	15	33	41	5	72	74	93	35	98	66	61	83	68	8	47	86	92	12
51	CULEBRA	DPOROS	29	5	98	7	28	32	44	90	13	10	37	87	61	73	20	19	70	68	81	91
52	U+6	MKD_U	9	39	47	15	19	43	26	24	93	11	87	85	14	50	28	95	83	72	48	100
53	U+4	MKD_U	21	31	11	97	46	7	50	56	36	22	34	100	3	91	24	74	48	55	64	87
54	PU+3	MKD_PU	63	31	74	71	61	90	7	1	52	27	75	43	87	81	30	96	6	50	45	80
55	PU+4	MKD_PU	61	43	48	88	80	13	65	69	87	93	96	50	35	28	8	55	89	29	81	51
56	TH+4	MKD_TH	19	38	5	63	16	80	33	49	81	10	15	43	78	17	47	54	35	98	88	74
57	AM+3	MKD_AM	21	62	12	36	94	45	92	97	93	95	42	15	44	79	25	70	27	61	78	85

Table IRES-5. Ranks of 100 Values Sampled, Replicate 1 (Continued)

LHS#	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
1	96	2	3	87	5	91	90	69	34	13	63	36	38	54	22	98	44	84	83	76	11	60	67	14	21	32	20	74	26
2	26	26	26	26	26	63	26	26	88	88	26	26	26	88	88	63	88	26	26	63	26	26	26	26	26	88	26	26	26
3	99	11	78	41	38	68	20	32	59	23	77	31	84	67	73	35	72	92	24	50	88	98	48	2	63	8	44	1	51
4	64	78	24	67	22	72	97	87	52	31	65	53	39	37	42	85	71	8	32	74	93	20	50	41	63	62	100	36	48
5	14	88	16	53	29	40	13	86	7	41	9	76	44	99	31	90	43	93	12	5	19	91	77	21	78	63	27	80	72
6	23	25	80	99	12	85	97	11	79	21	64	20	37	41	100	89	42	98	90	9	93	35	76	63	31	61	3	73	10
7	30	73	29	2	37	12	35	36	49	9	3	5	44	10	95	80	26	11	59	82	57	60	79	72	74	1	68	92	22
8	90	15	7	28	55	36	17	57	89	38	68	43	1	20	100	58	76	11	53	10	34	97	59	42	72	46	75	81	61
9	58	15	32	12	67	69	91	55	48	84	11	57	33	10	8	6	96	75	99	38	35	85	46	17	31	68	71	49	76
10	95	94	71	22	15	79	84	39	78	69	6	100	63	58	61	80	31	17	13	59	83	47	49	88	9	34	81	24	77
11	83	86	13	14	100	97	99	60	48	84	72	9	18	58	80	7	77	68	19	53	20	6	76	69	16	35	93	8	57
12	92	47	96	9	61	98	26	60	24	57	91	42	7	22	15	54	40	23	70	95	78	88	6	51	37	72	73	87	97
13	60	59	62	68	49	33	44	15	55	3	99	95	48	87	71	40	30	5	83	66	28	43	41	14	70	79	65	90	25
14	70	2	10	18	36	38	57	58	99	91	55	95	37	42	79	9	27	30	63	39	56	21	50	16	78	52	32	51	100
15	70	79	34	83	21	20	24	33	75	63	14	1	65	42	6	77	57	7	90	81	36	82	68	95	43	59	51	41	91
16	35	84	52	5	68	36	12	56	27	81	76	80	62	64	98	97	96	61	69	92	4	87	99	48	70	40	10	54	93
17	93	96	51	30	63	92	11	33	88	24	9	61	75	52	77	7	55	90	46	97	94	20	22	78	83	91	13	40	8
18	49	30	28	55	94	97	61	76	87	15	1	17	41	19	12	89	81	71	11	18	73	44	98	42	5	21	59	29	58
19	51	70	74	41	8	6	42	22	15	83	100	85	73	87	91	12	21	26	88	78	23	57	5	60	96	82	49	77	35
20	32	83	99	48	77	42	89	47	41	84	64	53	92	17	60	39	74	16	100	10	40	66	59	44	26	98	28	8	75
21	69	10	10	48	28	52	20	58	61	10	37	46	10	86	42	56	33	84	10	89	57	31	45	55	67	10	76	93	25
22	26	26	76	76	26	76	76	76	26	76	76	26	76	26	76	76	26	76	76	76	76	26	26	26	76	26	76	26	76
23	64	80	78	49	69	76	67	93	86	74	85	16	100	50	62	73	94	28	29	13	63	75	24	14	59	42	38	39	58
24	89	90	52	73	5	26	11	61	96	84	16	33	30	58	86	34	57	14	99	32	87	28	23	7	59	63	36	81	45
25	24	39	3	93	73	85	27	62	32	47	5	31	50	45	43	2	66	14	46	96	42	75	69	36	98	34	86	12	19
26	29	19	71	99	82	64	45	100	73	48	39	47	33	83	74	13	95	56	60	78	63	38	65	23	96	43	36	46	53
27	45	21	5	25	77	69	40	55	47	28	52	68	22	85	41	62	87	74	88	56	98	8	95	13	20	84	65	59	27
28	45	46	38	34	35	21	43	50	72	39	65	62	27	69	17	12	91	48	78	9	86	66	44	81	84	94	58	4	11
29	5	57	28	40	75	69	65	51	33	26	55	64	66	70	74	68	67	24	30	98	59	29	41	12	9	2	20	97	100
30	62	28	87	35	90	13	75	85	76	53	67	25	34	31	54	18	22	15	61	46	41	49	86	55	36	2	8	12	4
31	96	21	46	24	15	33	84	49	37	65	2	15	70	99	43	65	74	43	80	84	87	28	58	90	37	58	70	93	18
32	4	61	91	88	29	32	76	53	75	64	56	68	15	58	72	6	66	67	9	69	8	71	95	60	33	37	87	96	45
33	51	97	7	5	40	43	84	61	70	63	80	95	66	47	54	20	46	91	22	87	82	99	2	58	60	23	32	45	1
34	14	47	37	64	8	93	31	19	11	76	59	82	3	92	15	52	88	42	91	28	79	71	66	98	69	30	39	13	65
35	84	22	92	38	50	29	88	63	15	40	9	57	33	48	27	1	87	81	21	53	8	30	67	42	96	82	10	83	25
36	93	42	55	95	78	96	33	83	10	91	67	80	19	97	89	36	9	50	92	8	7	44	25	76	39	1	58	12	40
37	64	89	59	10	26	86	68	53	100	65	72	9	19	80	62	49	52	54	44	12	6	85	43	99	98	4	38	60	96
38	94	48	12	30	66	17	7	29	69	87	71	79	34	31	24	63	15	51	60	75	86	56	97	54	96	85	45	58	88
39	87	49	69	44	18	42	94	7	11	78	25	85	93	60	31	82	33	30	55	90	27	86	40	38	67	4	19	10	50
40	52	86	64	29	69	21	73	87	36	2	56	39	43	65	23	76	30	88	89	42	10	37	85	24	63	59	25	31	70
41	14	60	73	24	74	62	29	51	33	6	15	26	42	38	70	57	91	80	7	46	37	98	8	72	22	54	49	47	95
42	55	25	50	6	84	62	30	3	32	28	1	88	45	93	92	77	34	20	98	79	83	82	80	9	44	57	81	11	60
43	50	10	88	22	7	37	35	90	2	17	93	3	78	63	99	15	86	40	69	82	18	43	55	11	72	51	25	47	57
44	47	67	35	94	8	34	16	100	93	13	12	58	71	79	37	39	11	6	48	42	75	5	23	57	1	54	61	49	96
45	96	37	48	51	7	84	8	4	9	66	82	39	58	13	21	47	99	79	80	40	16	38	64	74	19	1	92	83	93
46	42	61	21	48	10	94	83	34	8	49	26	43	99	29	19	13	45	36	4	15	47	88	85	7	80	81	87	78	91
47	8	78	74	4	49	93	42	62	73	55	87	53	96	21	28	86	43	52	84	12	97	13	63	61	79	5	46	27	38
48	55	98	54	37	21	53	30	34	35	23	92	60	5	61	15	11	64	74	68	82	88	40	97	38	13	33	14	49	8
49	72	5	94	33	21	56	90	85	58	22	26	37	27	13	69	25	10	34	1	64	96	73	93	48	68	92	88	41	39
50	30	34	99	73	43	91	54	46	22	23	20	58	40	19	53	18	32	2	76	25	16	71	28	89	26	38	7	36	88
51	48	57	11	27	89	77	2	100	25	83	41	49	80	30	34	71	8	42	69	16	50	99	85	56	24	78	14	17	12
52	44	80	71	96	27	7	3	18	84	94	77	17	49	61	1	36	78	76	23	52	29	30	8	6	65	20	99	74	45
53	82	67	45	68	10	78	86	27	63	62	30	32	53	43	89	38	57	61	39	8	94	96	72	84	95	41	40	44	12
54	67	13	25	26	54	76	12	70	24	55	36	15	100	9	99	14	22	97	73	72	34	2	19	69	10	56	17	8	88
55	62	42	32	47	82	10	59	83	79	15	86	37	12	56	66	49	19	97	54	17	63	38	11	58	27	67	71	57	91
56	83	36	31	12	48	51	66	25	55	6	72	3	77	79	76	2	11	82	94	53	92	70	89	86	13	44	24	99	85
57	54	5	77	41	1	67	34	57	86	76	31	19	20	3	56	83	17	38	88	10	16	33	30	2	35	84	73	23	13

Table IRES-5. Ranks of 100 Values Sampled, Replicate 1 (Continued)

LHS#	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	97	40	33	95	71	52	65	12	16	66	89	80	29	62	25	82	53	49	61	51	37	64	9	85	68	24	81	27	4	75	18
2	88	26	26	88	88	63	63	63	63	63	26	26	63	26	88	63	88	26	63	88	88	63	26	26	88	63	88	88	88	88	63
3	87	71	30	60	18	37	14	22	36	10	16	3	42	25	66	70	76	81	55	29	52	17	86	91	49	28	96	6	80	46	40
4	84	60	44	61	10	23	29	88	59	21	16	18	80	94	54	66	83	76	17	92	3	30	11	68	89	34	14	91	73	27	28
5	56	94	34	97	20	39	17	71	2	3	38	1	87	36	82	98	46	35	45	75	81	84	92	55	74	22	37	95	23	47	42
6	30	83	66	8	28	71	19	70	32	54	53	6	26	24	68	34	47	59	56	39	18	75	52	36	67	94	33	46	44	29	88
7	85	40	7	45	96	93	88	51	63	6	38	55	64	23	25	28	98	66	65	48	46	43	16	91	77	18	53	97	75	61	54
8	6	33	92	56	47	71	45	23	85	99	27	87	65	37	3	44	35	83	5	18	21	67	77	30	41	73	80	98	49	8	66
9	14	25	13	9	50	4	34	43	1	51	21	62	29	80	61	64	97	42	54	27	3	74	28	19	47	39	53	87	59	73	60
10	38	4	60	27	7	3	56	66	65	64	36	35	99	1	40	20	37	50	41	2	52	10	62	70	93	14	96	97	46	82	44
11	64	45	82	98	66	44	12	26	39	21	31	95	27	23	47	81	34	43	70	61	63	62	51	65	37	50	96	28	42	87	85
12	32	67	62	65	75	68	34	46	50	52	10	16	76	4	45	21	19	3	63	94	28	35	85	59	56	39	11	18	93	81	41
13	50	69	18	38	81	2	12	94	10	58	97	10	11	8	88	24	80	85	53	86	6	37	32	63	35	78	93	47	74	21	20
14	53	96	73	41	75	92	12	29	3	77	28	8	90	60	1	61	46	24	34	83	86	59	49	84	85	74	6	82	20	47	19
15	30	98	67	78	69	2	62	25	61	44	76	15	38	13	4	96	88	52	71	10	84	64	31	26	17	47	80	3	40	19	28
16	25	53	95	6	19	41	3	79	47	83	28	75	45	59	38	51	73	65	89	39	18	9	82	63	74	44	72	17	77	90	46
17	95	19	73	27	80	72	25	16	26	64	18	37	85	10	71	48	14	67	39	70	3	56	15	1	36	76	6	62	12	43	57
18	26	31	52	22	66	93	24	34	47	46	39	60	65	40	69	32	67	84	7	91	68	56	75	27	14	10	90	9	86	13	57
19	71	67	55	81	33	7	69	59	61	50	52	45	40	68	28	66	30	17	94	10	34	44	27	75	86	95	9	89	20	93	37
20	23	31	21	38	88	50	5	1	90	72	80	13	97	34	95	81	58	86	65	25	93	73	14	96	11	56	43	82	63	15	6
21	77	71	80	60	10	66	95	99	10	40	27	85	10	70	10	19	54	10	38	74	10	30	83	10	90	50	63	10	44	88	97
22	26	76	26	76	26	26	26	26	76	26	26	76	76	76	76	76	26	26	26	26	26	76	26	26	26	76	76	76	76	26	76
23	72	57	1	9	79	48	47	92	89	41	10	90	51	71	15	25	21	7	70	3	52	55	44	61	45	37	18	82	17	5	65
24	56	85	95	79	3	70	35	67	72	76	12	27	20	94	43	41	37	71	82	44	24	8	3	38	25	9	92	53	15	75	13
25	20	70	81	4	61	72	35	83	87	91	79	10	56	17	23	82	95	6	65	13	67	68	59	15	10	71	41	54	51	30	7
26	17	1	86	77	52	76	58	8	32	7	57	61	98	51	59	5	67	70	75	72	89	6	40	14	50	80	90	18	84	15	93
27	26	3	79	32	39	71	37	100	60	30	76	14	11	54	15	80	89	49	43	19	53	72	91	73	10	63	58	90	33	78	93
28	32	96	25	99	71	57	61	98	73	13	92	76	74	82	54	40	20	100	16	6	22	3	93	41	67	53	88	33	10	42	68
29	94	37	85	25	52	46	58	4	42	96	11	32	22	47	90	10	48	1	72	86	99	73	7	50	23	31	34	83	63	13	35
30	97	77	74	24	81	7	1	38	23	14	94	20	72	92	82	79	33	11	63	71	17	47	99	26	91	19	84	89	48	30	9
31	5	12	74	99	49	24	18	46	77	99	90	55	43	77	84	61	70	12	12	28	80	21	33	24	74	33	2	52	65	28	37
32	46	31	35	11	30	77	70	82	79	81	44	38	92	90	20	28	23	85	18	78	26	65	10	21	55	1	50	2	74	41	5
33	11	37	16	62	86	98	52	15	85	44	10	4	77	90	35	65	92	69	75	33	29	25	76	59	3	39	55	56	78	27	19
34	95	78	89	49	84	51	75	87	85	10	9	67	100	55	73	27	99	56	50	36	23	94	45	21	72	38	46	43	53	81	62
35	68	74	70	66	20	17	58	45	32	16	18	61	60	19	11	34	31	69	5	65	51	77	47	98	56	78	72	59	91	4	28
36	66	56	2	18	45	13	90	79	84	54	29	48	68	81	27	52	94	73	15	47	70	21	60	17	5	71	16	46	41	34	3
37	70	31	37	90	32	11	46	91	15	35	95	21	16	56	58	5	73	14	40	13	76	55	7	51	47	88	28	30	92	17	97
38	23	6	13	57	77	82	55	50	22	2	74	73	68	92	52	46	8	43	21	36	26	27	41	67	72	98	84	70	59	4	10
39	34	64	83	48	3	91	28	46	47	21	99	71	76	37	1	58	6	98	45	95	81	88	62	9	20	8	35	89	75	32	100
40	82	92	14	33	94	18	72	1	79	99	13	67	74	38	5	48	62	78	91	60	28	6	93	3	20	90	7	98	84	51	95
41	71	61	79	13	82	35	19	28	34	12	67	86	10	59	3	83	77	88	66	17	32	4	1	50	58	25	64	78	5	69	63
42	61	53	59	24	100	54	63	69	95	14	35	76	33	29	52	42	38	51	73	97	65	47	15	91	68	41	40	8	17	18	43
43	4	32	56	54	42	53	64	68	73	9	48	6	100	16	60	79	83	59	13	26	65	61	39	76	24	62	38	52	1	36	95
44	60	18	46	29	99	25	3	86	26	80	51	28	78	50	40	21	43	83	19	63	69	87	77	74	20	85	65	68	32	81	95
45	54	10	44	46	75	86	12	78	29	50	20	3	14	88	81	2	32	100	76	89	69	24	49	30	25	98	23	70	28	63	11
46	77	12	40	90	72	76	60	35	66	14	27	71	28	84	30	41	89	38	46	39	37	2	98	25	70	74	51	73	52	44	6
47	32	25	94	50	81	44	91	36	10	19	37	29	34	31	40	85	26	65	66	3	14	64	39	58	48	59	71	60	69	17	2
48	24	50	69	78	51	7	59	44	75	32	26	27	83	63	19	20	85	4	46	93	39	10	29	67	1	31	36	89	84	94	58
49	55	97	40	75	63	8	44	46	81	76	23	11	31	87	82	35	86	99	100	67	70	38	20	42	50	80	36	65	60	28	91
50	75	13	85	81	55	90	95	44	78	50	45	29	11	96	69	100	65	59	31	80	1	67	52	84	49	64	14	82	87	10	94
51	4	79	67	63	9	31	43	36	35	38	59	52	18	62	74	3	65	47	53	93	26	66	1	6	82	58	40	75	33	95	64
52	22	63	90	4	91	25	21	13	97	56	62	81	33	55	82	46	75	42	35	54	32	98	92	40	73	31	70	89	38	51	86
53	18	90	37	19	99	88	42	93	49	65	4	29	2	14	25	33	9	6	15	71	52	51	76	83	26	13	70	54	80	73	77
54	23	89	68	60	77	3	91	94	51	48	82	65	66	93	38	39	20	57	4	84	29	11	92	78	83	21	85	41	95	42	64
55	44	52	53	40	2	94	78	30	39	21	46	84	90	16	64	5	100	20	92	41	3	85	76	95	18	26	45	36	24	22	23
56	67	42	8	71	27	34	40	57	91	26	20	69	68	58	46	21	56	75	93	18	84	100	95	1	97	45	60	50	73	37	7
57	63	46	90	65	91	64	81	59	28	7	55	66	100	58	24	11	50	32	99	53	87	26	74	9	29	4	72	47	75	43	37

Table IRES-5. Ranks of 100 Values Sampled, Replicate 1 (Continued)

LHS#	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	56	50	92	46	72	88	59	17	100	55	48	86	35	19	28	8	94	93	7	1
2	26	63	26	26	26	26	26	26	63	63	63	88	26	26	63	26	26	26	26	88
3	62	7	65	93	74	90	13	95	12	57	33	26	19	94	39	21	4	53	79	34
4	2	46	81	25	19	13	35	49	69	43	99	5	56	45	90	7	12	1	58	75
5	60	10	64	69	52	65	8	25	24	15	6	68	67	54	11	59	96	26	83	79
6	7	82	65	14	4	50	40	57	38	22	60	96	17	45	86	51	95	16	92	13
7	56	41	19	67	86	100	99	24	14	32	58	4	21	87	15	39	89	47	69	8
8	4	84	88	74	52	50	51	12	32	40	24	69	79	19	31	14	29	60	93	82
9	81	2	16	18	5	52	22	30	86	24	94	26	41	56	70	83	90	95	92	40
10	68	32	90	12	43	67	29	76	75	51	5	30	55	33	91	57	87	53	45	8
11	41	56	36	88	10	54	71	94	29	1	32	24	2	22	46	40	90	49	3	55
12	43	86	77	83	64	55	27	12	79	20	31	53	5	30	33	90	89	29	66	99
13	98	7	56	92	22	52	29	64	4	27	13	39	91	75	76	1	96	9	34	89
14	81	87	66	97	40	48	31	76	15	45	80	13	88	54	94	33	89	14	4	5
15	87	99	53	23	9	92	5	18	49	16	100	74	60	94	73	11	12	27	55	85
16	21	26	31	23	42	78	58	14	20	57	94	60	16	30	8	37	67	13	49	29
17	49	44	59	69	66	82	29	60	32	47	81	35	21	100	17	42	89	50	65	58
18	77	70	100	37	51	8	53	4	2	35	48	64	92	96	25	88	99	33	74	85
19	29	36	2	56	58	90	43	92	97	64	62	39	11	4	76	14	1	72	19	13
20	45	33	49	7	91	87	85	62	78	27	2	46	71	69	55	20	67	76	37	36
21	51	68	62	94	10	23	10	34	21	73	99	59	24	35	36	82	26	22	53	72
22	76	76	26	76	76	76	26	26	76	76	26	76	26	26	26	26	76	26	76	76
23	87	33	91	81	43	54	30	32	83	68	40	99	34	60	53	31	96	6	36	84
24	64	39	21	62	50	31	100	6	46	29	10	77	47	68	42	91	78	93	40	97
25	88	53	57	25	84	9	16	11	92	58	1	44	49	52	37	77	55	40	22	18
26	25	66	22	31	28	91	11	26	87	20	35	55	97	85	24	2	49	41	9	27
27	96	94	4	86	24	81	31	38	64	99	16	42	82	46	97	48	66	70	44	57
28	18	47	70	75	95	59	26	7	87	28	83	56	2	63	49	90	77	5	14	1
29	79	60	17	38	3	61	49	81	14	71	36	44	76	43	62	15	18	92	95	87
30	58	95	16	50	68	10	100	44	59	80	73	93	88	42	37	51	52	64	32	69
31	61	55	8	80	40	8	93	96	8	87	12	93	5	61	15	5	84	2	58	55
32	83	22	14	94	51	57	13	84	97	42	48	99	62	25	40	36	93	17	59	12
33	73	57	68	50	41	18	21	26	17	42	94	30	14	6	83	8	81	88	89	24
34	97	61	57	6	68	77	86	34	2	58	32	60	18	35	48	7	41	44	26	74
35	55	93	52	12	85	80	39	73	3	100	43	94	7	13	97	24	37	90	89	64
36	28	75	72	100	4	85	63	49	23	98	53	38	31	82	22	74	59	87	37	57
37	81	48	74	29	23	24	69	57	82	79	36	34	75	33	18	67	61	71	83	8
38	91	5	39	64	16	62	80	53	25	3	32	99	19	37	20	89	11	83	40	47
39	51	2	39	59	14	12	80	15	41	57	29	52	66	77	79	16	24	65	5	74
40	71	47	12	40	57	19	81	15	83	49	16	44	41	46	80	50	68	9	45	32
41	68	87	56	81	90	9	41	96	36	53	16	99	11	39	94	43	48	65	27	89
42	46	23	87	37	21	4	19	78	85	96	89	90	75	58	36	94	26	48	72	13
43	58	20	81	33	12	14	80	92	67	74	94	8	34	31	21	89	85	45	19	96
44	44	9	45	72	90	30	31	15	59	66	88	91	7	22	17	2	27	98	64	56
45	85	72	41	5	97	15	55	71	52	27	43	67	65	33	73	60	68	17	31	36
46	22	69	54	32	16	50	96	59	86	82	56	65	57	97	68	20	33	75	79	92
47	9	75	41	70	16	18	6	67	11	82	51	72	80	20	15	30	76	54	1	47
48	81	43	70	71	48	42	3	56	73	66	25	90	87	18	16	76	9	72	17	47
49	98	52	84	74	3	54	79	18	7	49	30	77	66	2	6	89	15	61	14	9
50	51	21	56	79	63	77	3	42	39	24	4	62	17	70	57	60	27	48	37	9
51	60	84	94	86	88	72	51	97	54	76	39	46	45	92	96	21	23	22	55	15
52	34	60	88	53	10	59	68	69	5	57	41	37	12	58	64	67	79	66	16	2
53	98	23	1	35	92	47	58	69	75	20	85	28	79	59	60	16	17	66	5	81
54	98	49	44	5	53	37	58	16	59	46	33	32	47	79	35	40	62	28	86	18
55	98	68	73	7	75	1	72	60	77	74	34	70	25	99	14	4	6	33	9	31
56	14	28	52	90	64	41	4	39	61	23	29	32	22	62	96	65	30	59	9	87
57	80	48	18	71	49	89	14	98	39	68	52	40	27	6	69	60	51	8	96	82

Table IRES-6. Ranks of 100 Values Sampled, Replicate 2

LHS#	R#	Mat	Par	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	2	STEEL	CORRMC	17	26	47	84	70	63	80	48	100	53	94	71	69	52	92	50	11	77	88	29
2	2	WAS_AREA	PROBDEG	88	88	63	88	63	26	88	63	63	26	63	26	26	26	26	63	26	26	63	26
3	2	WAS_AREA	GRATMICI	62	98	34	52	57	66	95	54	7	99	68	100	91	80	72	38	77	89	42	73
4	2	WAS_AREA	GRATMIC	96	67	87	3	62	22	90	34	57	26	75	10	45	83	21	12	13	84	99	70
5	2	CELLULS	FBETA	32	72	41	23	11	9	82	58	47	20	13	2	35	46	19	81	44	75	4	59
6	2	WAS_AREA	SAT_RGA	69	98	27	4	90	96	97	5	13	43	79	85	54	18	7	68	24	95	72	61
7	2	WAS_AREA	SAT_RBR	40	80	34	14	84	45	28	35	52	60	59	62	50	31	58	29	44	12	36	20
8	2	WAS_AREA	SAT_WIC	82	99	60	27	6	9	61	95	80	41	56	19	97	57	18	94	22	59	8	67
9	2	CL_L_T1	PRMX_LO	21	87	34	77	99	88	62	72	40	9	70	37	29	97	19	4	73	23	22	57
10	2	CONC_T1	PRMX_LO	70	41	62	98	96	67	33	81	55	42	3	93	91	16	47	40	19	61	20	100
11	2	ASPHALT	PRMX_LO	75	50	87	22	52	91	16	47	35	44	6	24	81	74	11	31	40	33	59	17
12	2	SHFT_DRZ	PRMX_LO	90	89	86	65	99	24	10	91	33	71	15	35	26	46	80	97	17	3	70	45
13	2	SALT_T1	CUMPROB	13	27	50	26	72	88	95	100	18	15	89	31	63	81	39	35	53	66	45	93
14	2	SALT_T1	SAT_RGA	50	97	81	99	7	69	35	63	62	19	36	55	57	87	29	72	74	79	13	39
15	2	SALT_T1	SAT_RBR	26	65	75	68	82	42	20	21	78	84	52	51	85	67	7	13	14	9	34	88
16	2	SALT_T1	PORE_DIS	36	54	76	89	40	50	77	29	16	74	79	32	35	21	27	85	86	66	11	28
17	2	S_HALITE	POROSITY	7	65	84	30	43	69	62	28	1	79	50	9	6	39	8	92	36	78	87	16
18	2	S_HALITE	PRMX_LO	97	88	83	64	15	17	10	44	20	86	78	62	87	91	40	2	81	71	60	28
19	2	S_HALITE	COMP_RC	3	13	21	42	87	86	90	54	79	17	29	35	16	11	60	99	27	24	47	75
20	2	S_MB139	PRMX_LO	42	50	35	36	84	89	54	9	24	22	88	31	76	61	59	82	79	28	38	66
21	2	S_MB139	COMP_RC	68	40	64	49	10	10	57	96	76	81	10	73	23	44	42	21	36	65	69	37
22	2	S_MB139	RELP_MO	26	76	26	26	76	76	26	26	76	76	76	26	76	76	26	26	76	76	76	76
23	2	S_MB139	SAT_RBR	62	69	2	40	63	74	12	100	46	98	22	10	19	57	94	17	11	70	65	29
24	2	S_MB139	SAT_RGA	67	26	33	6	24	3	63	28	71	69	49	35	65	52	53	34	79	51	92	75
25	2	S_MB139	PORE_DIS	70	26	57	86	19	21	93	53	59	80	2	27	36	91	9	64	82	68	87	12
26	2	S_HALITE	PRESSURE	51	10	7	37	53	93	94	40	60	15	87	85	72	12	46	19	52	79	84	1
27	2	CASTILER	PRESSURE	49	16	100	20	31	56	58	98	22	51	87	70	48	59	57	34	12	4	95	8
28	2	CASTILER	PRMX_LO	52	45	94	58	29	99	84	1	91	35	10	30	67	92	76	26	55	80	37	8
29	2	CASTILER	COMP_RC	20	68	1	92	57	7	11	100	53	81	98	78	25	52	6	76	72	61	56	83
30	2	BH_SAND	PRMX_LO	28	94	87	46	57	29	35	37	92	80	93	45	56	49	32	81	39	55	24	30
31	2	CASTILER	GRIDFLO	59	71	17	52	2	9	21	28	24	55	93	28	52	6	99	6	33	46	84	2
32	2	BLOWOUT	PARTDIA	71	81	41	11	95	73	3	24	20	61	43	13	98	17	38	29	77	66	22	31
33	2	BOREHOLE	TAUFAIL	27	98	64	90	19	37	22	15	9	63	82	42	21	73	69	78	23	26	85	38
34	2	CULEBRA	MINP_FAC	36	41	80	28	12	93	88	29	33	46	50	6	60	87	48	76	97	4	5	67
35	2	GLOBAL	TRANSID	66	98	45	11	31	64	80	37	1	82	33	25	89	32	73	72	50	40	35	67
36	2	SOLAM3	SOLSIM	16	64	73	99	86	13	65	66	3	83	1	35	4	61	81	6	53	90	51	14
37	2	SOLAM3	SOLCIM	95	45	5	66	18	22	34	90	26	82	97	55	16	47	30	8	3	54	6	51
38	2	SOLPU3	SOLSIM	57	44	3	36	24	83	22	58	60	66	7	1	88	49	53	59	85	31	61	18
39	2	SOLPU3	SOLCIM	14	85	84	16	73	2	96	77	45	56	40	75	57	27	59	62	81	49	7	41
40	2	SOLPU4	SOLSIM	100	25	75	41	83	16	87	82	65	32	99	14	1	62	93	91	9	60	6	24
41	2	SOLPU4	SOLCIM	89	54	85	50	18	93	95	97	13	91	60	70	92	67	10	45	37	21	55	19
42	2	SOLU4	SOLSIM	22	23	43	41	58	68	29	96	57	80	42	20	98	52	32	97	54	34	82	25
43	2	SOLU6	SOLSIM	3	50	43	36	2	49	35	82	26	5	57	52	27	75	94	91	66	25	59	48
44	2	SOLU6	SOLCIM	98	25	63	20	67	93	55	83	46	94	27	6	56	60	92	95	53	66	49	90
45	2	SOLTH4	SOLSIM	22	9	70	81	65	30	8	97	4	7	21	29	66	85	13	79	48	77	37	28
46	2	PHUMOX3	PHUMCIM	17	10	58	7	59	76	49	93	56	51	37	13	72	9	88	29	73	92	67	43
47	2	GLOBAL	OXSTAT	87	33	31	82	52	57	21	43	17	2	46	62	94	19	41	96	7	29	34	25
48	2	GLOBAL	CLIMTIDX	14	34	41	46	70	22	72	56	20	97	29	1	71	98	48	37	4	87	26	10
49	2	CULEBRA	HMBLKLT	91	55	72	79	11	36	8	84	44	47	33	41	85	7	15	58	35	75	83	99
50	2	CULEBRA	APOROS	65	36	29	44	83	87	68	32	24	91	69	79	18	45	31	15	28	86	53	54
51	2	CULEBRA	DPOROS	70	34	36	32	52	26	6	82	58	16	77	75	76	10	54	65	89	60	69	57
52	2	U+6	MKD_U	98	21	39	25	33	96	1	64	3	31	37	92	17	97	85	62	69	57	79	47
53	2	U+4	MKD_U	40	61	29	10	12	68	53	54	98	24	22	85	87	66	18	14	8	91	58	37
54	2	PU+3	MKD_PU	86	70	78	30	77	6	7	38	67	84	98	13	96	72	46	59	82	87	79	92
55	2	PU+4	MKD_PU	94	10	71	68	79	24	38	35	43	58	85	12	41	57	8	15	82	2	19	53
56	2	TH+4	MKD_TH	88	61	28	89	98	31	80	65	24	37	38	84	69	5	64	97	63	87	41	8
57	2	AM+3	MKD_AM	30	100	16	72	4	44	84	50	25	8	12	24	52	74	98	28	9	15	69	90

Table IRES-6. Ranks of 100 Values Sampled, Replicate 2 (Continued)

LHS#	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
1	23	9	25	42	44	40	35	1	59	93	55	79	72	28	20	97	61	31	83	43	5	37	39	85	60	76	78	3	27
2	63	88	88	26	63	88	63	63	88	63	26	63	26	26	26	26	26	26	88	26	63	26	26	63	26	63	26	88	26
3	97	45	87	28	81	67	36	60	30	9	85	11	75	88	94	16	61	58	12	86	29	40	18	6	14	84	4	31	23
4	43	73	54	1	36	47	59	72	42	32	37	41	19	40	97	88	44	80	14	78	38	93	89	65	46	11	85	27	18
5	86	79	67	8	99	1	83	53	45	49	66	43	36	15	34	33	73	63	71	78	24	54	7	89	94	100	6	50	48
6	49	64	55	57	15	75	86	84	99	70	21	89	28	42	10	50	74	94	40	25	38	3	52	100	47	12	32	35	1
7	63	4	100	18	87	86	91	6	25	15	79	92	38	74	19	30	42	88	67	10	7	94	66	32	95	65	76	54	56
8	81	74	47	40	50	62	85	21	35	75	36	72	98	3	23	88	64	12	33	25	29	55	96	16	34	32	77	76	79
9	6	8	27	13	47	71	17	43	46	80	59	60	69	56	66	25	63	95	58	12	96	100	28	41	10	61	79	84	76
10	82	9	31	65	66	21	28	71	18	7	63	99	26	95	10	89	80	44	84	79	50	35	49	68	43	12	85	69	14
11	39	4	20	46	72	80	95	88	90	53	93	32	77	43	10	71	99	2	25	83	70	84	48	79	5	51	12	26	69
12	63	18	5	49	19	41	76	28	74	8	20	83	64	52	84	95	42	93	37	82	68	60	51	67	85	61	66	69	1
13	19	71	5	58	94	68	92	43	37	20	52	99	9	69	65	2	78	47	11	1	6	30	61	38	60	33	48	12	96
14	52	92	77	32	45	31	2	98	25	60	38	30	9	78	22	34	86	64	95	24	28	90	89	80	61	70	51	56	20
15	47	96	25	72	32	79	45	74	39	49	44	6	93	16	56	5	15	92	62	64	3	40	50	17	100	12	53	97	77
16	37	55	34	67	9	100	64	59	10	60	24	68	56	71	80	82	81	61	78	92	13	63	73	94	25	53	72	12	46
17	66	57	77	35	76	93	21	27	29	68	40	49	86	47	41	56	97	3	42	74	63	17	33	89	88	82	83	61	23
18	23	5	77	31	32	11	69	68	57	61	1	33	82	42	89	46	47	59	7	18	41	99	19	38	39	93	75	35	94
19	83	95	28	68	71	81	34	32	40	45	100	69	15	65	8	67	50	33	94	78	56	4	82	62	58	6	23	61	9
20	96	27	81	100	95	67	92	99	52	97	41	57	98	7	29	43	1	75	51	34	93	25	70	62	14	68	85	73	48
21	10	77	19	10	10	32	10	10	56	10	61	38	10	94	72	60	99	24	55	58	10	82	28	46	93	27	10	26	59
22	26	26	76	76	76	26	76	26	76	26	26	76	26	26	76	26	26	26	76	76	76	26	76	26	76	76	26	76	76
23	96	82	75	33	48	7	81	73	79	77	27	14	66	61	88	24	3	59	89	28	26	23	93	76	25	84	91	32	15
24	56	16	90	9	48	96	55	74	11	22	13	47	57	76	25	72	42	14	31	73	93	46	70	89	54	50	62	86	45
25	89	13	11	56	48	98	77	4	39	24	17	35	44	33	41	78	14	94	90	88	38	49	54	31	62	63	61	29	67
26	61	28	33	80	38	41	77	30	6	82	18	49	16	89	25	58	36	35	95	22	63	68	65	45	92	88	76	47	43
27	88	10	82	76	69	80	6	97	13	23	54	7	27	84	15	46	45	99	79	32	14	29	62	40	44	35	47	64	18
28	81	19	74	63	12	36	46	9	38	4	27	82	97	2	34	11	49	51	93	65	64	44	73	14	78	7	6	22	13
29	44	80	27	22	84	82	60	99	50	70	88	45	8	85	97	94	24	18	12	17	21	34	49	86	55	38	93	87	51
30	65	16	18	73	83	68	38	60	7	84	31	9	1	15	41	4	14	47	61	76	100	99	78	33	95	5	62	21	12
31	59	21	2	37	52	33	40	87	99	87	74	99	24	28	90	28	74	62	81	31	65	65	6	14	71	21	68	93	33
32	54	93	89	1	27	15	33	6	18	46	86	48	51	99	8	80	2	55	62	5	91	21	44	34	84	35	58	14	60
33	5	68	25	1	65	60	95	97	2	76	99	62	55	61	7	71	43	96	54	89	39	12	32	16	51	67	94	4	77
34	45	38	32	14	84	83	53	27	85	47	78	86	19	23	91	66	59	49	73	1	89	8	79	18	55	37	35	51	17
35	3	38	48	81	41	99	58	65	59	19	30	85	76	24	62	83	9	17	68	29	10	55	43	16	77	69	53	56	42
36	5	15	91	88	63	49	100	39	27	97	78	69	59	93	52	17	32	41	20	24	47	22	98	46	75	19	10	31	48
37	100	43	28	76	31	68	39	33	65	42	15	91	72	67	24	64	13	36	46	62	96	74	50	48	29	19	1	10	59
38	39	91	67	97	47	38	11	93	72	8	86	71	20	37	69	82	62	96	29	80	10	40	87	17	56	89	99	9	79
39	31	4	18	86	25	17	50	91	58	23	78	48	88	63	39	71	5	21	93	46	43	38	30	8	76	54	72	11	64
40	79	30	94	80	57	38	31	17	90	22	85	64	28	45	5	76	51	58	27	61	36	68	92	54	77	53	70	78	98
41	82	27	71	35	24	7	4	32	5	98	66	57	42	25	78	62	14	41	88	86	36	3	23	94	90	16	46	59	87
42	1	78	44	13	10	59	7	11	91	88	90	66	99	89	40	5	9	65	37	87	83	60	93	63	12	64	27	72	36
43	29	12	95	62	10	97	32	92	76	46	20	77	1	81	40	60	4	9	23	89	42	54	34	38	90	14	72	16	87
44	42	37	69	72	11	22	80	77	28	75	14	51	35	59	78	38	88	57	39	34	26	79	32	15	68	12	85	10	16
45	42	54	96	35	36	18	74	88	93	92	6	84	82	59	67	53	47	39	71	57	80	61	15	27	90	25	38	51	5
46	85	87	48	57	1	90	69	82	24	79	20	12	14	3	25	55	32	89	64	23	21	95	31	52	50	78	39	84	45
47	80	50	59	84	16	66	98	9	70	77	99	35	14	63	90	79	28	76	15	45	22	86	1	61	69	71	13	89	51
48	85	92	25	78	61	62	38	65	83	32	57	58	19	76	9	95	93	63	89	30	54	73	21	7	6	31	64	94	51
49	16	23	98	89	64	49	82	25	26	5	59	54	20	81	51	9	86	77	100	43	60	62	37	63	14	80	50	19	90
50	49	46	99	40	16	96	9	21	77	71	72	14	74	63	85	51	42	3	81	50	11	82	6	20	17	27	70	33	67
51	40	93	39	81	64	99	55	62	83	27	97	12	90	24	86	29	67	43	95	38	100	87	44	23	84	49	61	1	14
52	38	51	15	53	88	75	16	9	18	70	56	45	65	5	6	50	24	42	13	46	27	11	99	67	23	84	28	66	20
53	20	41	30	90	69	48	95	88	78	46	75	26	15	99	64	73	32	13	27	94	84	43	93	52	83	44	28	51	76
54	22	10	25	100	27	40	4	8	61	74	58	53	11	64	47	9	80	41	3	26	52	1	28	45	83	73	42	48	5
55	55	97	22	56	42	72	99	44	28	98	39	11	59	96	45	33	87	5	80	84	23	36	52	40	90	13	66	61	46
56	17	43	7	19	72	55	73	15	96	44	12	1	13	32	46	33	57	99	54	11	16	29	93	21	42	20	34	6	74
57	54	35	42	75	51	45	47	27	87	91	17	18	23	97	58	5	86	68	56	48	53	71	81	77	60	37	49	40	7

Table IRES-6. Ranks of 100 Values Sampled, Replicate 2 (Continued)

LHS#	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	18	82	58	56	62	57	98	86	22	10	2	6	21	89	99	7	16	49	4	65	87	15	13	75	81	66	46	73	64	14	19
2	63	63	26	26	26	88	88	26	88	26	63	26	26	26	63	26	26	26	88	88	88	63	26	26	26	88	88	26	63	26	26
3	19	10	22	59	50	41	53	56	44	47	92	3	79	55	35	13	39	25	21	48	49	15	2	32	46	20	37	17	33	64	65
4	35	61	9	69	50	15	20	94	16	24	98	77	8	64	31	49	30	68	4	63	5	17	74	51	48	71	58	82	86	6	7
5	61	39	3	27	28	38	12	85	70	26	21	31	76	68	92	97	84	17	57	52	55	10	62	88	91	87	56	80	69	51	90
6	73	67	6	37	77	44	46	14	17	88	34	45	91	9	20	82	66	48	65	92	63	71	41	78	87	36	39	81	51	29	56
7	97	11	33	46	51	1	71	16	9	77	70	99	39	57	81	26	72	47	64	98	61	24	75	53	2	41	82	73	23	93	49
8	90	45	17	11	48	63	70	71	91	10	46	65	15	30	52	26	73	89	38	43	51	53	83	44	5	4	10	13	31	7	14
9	50	39	32	3	1	26	42	35	89	36	83	33	14	81	82	85	31	90	91	75	74	53	7	24	45	86	2	65	67	30	93
10	45	51	46	6	86	32	8	73	64	39	15	36	48	57	76	94	52	11	78	25	59	4	60	72	30	56	77	75	87	38	92
11	55	28	57	92	36	64	58	65	94	98	41	82	45	78	37	8	76	27	30	67	54	38	14	18	61	49	21	100	42	56	86
12	57	75	44	94	58	55	88	34	81	77	36	16	53	23	43	39	48	56	96	9	32	59	30	6	25	14	4	27	50	62	31
13	51	75	73	44	22	85	83	40	90	42	3	36	91	29	46	74	25	24	49	67	16	76	55	23	56	87	14	57	10	21	28
14	21	10	40	100	23	16	68	83	66	46	17	8	49	18	41	59	75	42	67	94	27	53	85	91	58	12	1	26	44	48	54
15	89	98	11	58	38	57	35	33	95	8	86	19	80	27	60	24	48	36	22	28	59	87	70	37	31	55	54	83	71	1	94
16	23	6	39	5	7	97	19	96	20	8	26	99	41	14	33	42	45	91	47	57	49	31	51	2	43	44	62	4	48	30	70
17	73	81	71	70	12	5	13	15	34	64	38	2	4	98	72	100	55	31	45	91	90	75	32	10	25	59	44	46	80	54	14
18	72	65	73	43	74	48	98	54	45	76	4	21	79	70	27	96	58	53	85	55	49	22	67	63	92	84	100	9	95	36	16
19	25	41	26	64	22	49	2	48	55	20	98	80	19	31	72	5	44	51	14	39	53	85	38	36	10	30	1	93	7	70	77
20	3	15	23	86	45	40	13	63	10	26	19	20	53	91	71	37	46	74	78	4	33	18	55	94	6	83	64	8	58	16	39
21	97	87	80	10	62	66	90	39	88	78	79	75	47	10	34	52	50	33	25	99	74	84	48	10	85	10	35	92	41	83	63
22	26	76	76	26	26	76	26	76	76	76	26	76	26	26	76	76	76	26	26	26	76	26	76	76	76	26	76	26	26	26	26
23	44	20	49	35	8	55	34	87	53	80	31	9	42	51	92	47	52	58	6	83	16	97	38	4	30	37	85	68	21	56	90
24	91	12	37	66	10	94	68	58	95	41	7	17	87	59	29	36	3	97	39	32	98	8	18	81	88	20	19	60	38	27	100
25	32	58	25	79	15	5	34	60	74	85	55	8	96	45	2	30	47	7	83	6	18	16	76	28	66	100	43	84	40	50	10
26	50	55	2	98	86	67	64	62	97	10	83	23	42	66	39	70	44	81	73	31	5	69	78	4	14	75	48	32	96	54	90
27	86	77	55	30	36	81	67	26	71	52	17	50	3	39	11	72	75	78	5	53	74	73	42	93	90	65	96	61	2	21	85
28	48	66	33	3	20	100	62	89	28	77	70	16	60	54	95	53	17	47	98	83	59	90	21	87	39	43	85	25	24	41	56
29	14	36	66	95	65	4	63	10	67	35	41	79	28	89	3	64	73	75	13	31	30	16	59	43	90	42	29	96	74	69	19
30	71	3	96	54	97	26	43	63	17	52	2	20	88	69	42	67	72	8	22	70	91	77	23	11	13	44	10	64	34	48	50
31	14	49	17	84	9	17	9	59	42	71	31	42	90	6	65	14	24	74	77	37	81	55	59	77	81	21	42	87	37	46	90
32	64	75	79	37	85	70	49	74	42	47	23	12	56	67	10	53	16	76	87	45	19	30	40	52	94	32	9	36	25	39	65
33	70	46	58	30	87	100	52	29	8	86	88	31	91	92	59	24	50	28	66	47	48	53	84	41	72	81	35	57	14	74	80
34	43	92	63	94	65	64	77	74	11	58	96	82	61	98	7	57	71	54	3	24	90	22	34	26	40	25	75	13	70	42	99
35	20	2	79	18	70	5	93	21	61	6	4	57	8	49	63	26	22	13	28	7	12	87	94	88	60	92	36	96	95	84	97
36	70	85	71	68	50	28	60	56	58	26	38	30	62	79	43	67	42	95	33	23	76	21	96	92	7	2	37	72	84	8	12
37	85	75	77	73	69	86	23	11	41	84	58	61	2	93	78	53	71	14	27	92	57	4	83	88	38	99	7	63	35	17	70
38	76	98	15	94	43	46	64	35	51	42	2	74	78	70	50	28	55	48	73	84	100	5	6	45	13	75	21	30	41	23	26
39	44	80	9	95	29	69	67	99	70	34	98	26	3	12	13	74	32	19	52	100	83	36	66	42	82	24	68	61	28	90	53
40	23	59	10	12	20	19	48	29	11	13	50	34	95	88	2	72	55	46	96	7	44	84	4	47	81	8	37	52	66	49	73
41	77	38	75	33	1	15	100	61	12	58	49	99	83	53	68	22	40	72	79	39	28	17	56	84	8	44	31	76	34	73	81
42	39	18	15	26	86	30	79	49	14	84	69	19	50	8	47	73	100	35	33	38	61	46	2	94	51	71	45	92	70	24	55
43	24	73	83	19	55	28	39	93	69	98	99	13	45	17	86	96	56	47	68	71	15	31	7	85	22	64	63	33	70	6	51
44	52	30	31	61	23	86	71	4	41	54	87	65	64	9	97	100	8	48	7	24	73	40	47	44	82	84	5	13	62	96	36
45	99	31	73	87	76	55	24	64	23	11	41	10	98	50	19	10	3	45	62	75	40	83	12	58	49	95	72	52	32	26	43
46	63	33	71	16	91	77	61	83	66	8	94	65	46	97	26	18	44	6	96	70	80	4	40	38	47	5	11	98	100	86	36
47	60	8	40	81	5	97	92	58	30	18	65	4	20	83	56	95	54	72	11	23	64	24	73	32	55	38	36	53	44	10	74
48	59	49	45	5	99	24	66	82	74	55	40	35	52	75	36	81	17	90	2	39	33	84	12	80	11	68	69	16	28	96	53
49	4	66	29	52	10	73	12	32	1	95	67	45	39	71	13	6	2	65	27	70	69	96	24	56	18	48	38	94	92	46	40
50	52	98	58	78	84	57	8	100	25	55	12	89	95	13	26	92	90	47	61	5	93	38	88	30	23	73	1	60	7	34	75
51	92	85	4	9	20	21	73	78	37	46	3	63	15	80	41	96	22	47	88	19	2	50	72	45	48	25	74	71	11	35	28
52	44	43	10	49	59	7	60	89	80	34	63	82	22	48	32	74	2	29	78	87	86	81	100	55	93	58	30	14	35	71	61
53	100	36	16	33	19	7	96	72	1	4	59	31	62	56	60	50	47	45	35	25	86	97	42	23	55	71	38	3	74	79	63
54	49	50	29	23	19	88	20	99	95	37	63	34	89	91	12	24	75	71	32	97	15	31	85	81	2	93	57	55	76	94	66
55	1	74	21	7	63	20	92	54	48	95	4	37	27	34	31	30	70	29	50	76	65	25	14	75	81	51	83	16	91	88	89
56	71	2	76	83	45	40	3	77	86	67	39	90	14	59	52	51	91	82	49	50	94	26	4	68	70	78	92	35	62	30	79
57	33	89	65	2	43	83	85	95	29	36	57	70	14	92	10	19	99	67	94	6	79	22	80	34	82	93	21	46	13	88	32

Table IRES-6. Ranks of 100 Values Sampled, Replicate 2 (Continued)

LHS#	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	67	68	90	95	24	96	41	32	34	74	12	33	8	38	36	54	45	30	51	91
2	88	26	26	88	88	26	26	26	26	88	88	26	26	26	63	63	88	26	63	88
3	63	74	70	71	8	83	43	26	24	78	5	51	69	1	96	76	93	82	27	90
4	33	25	2	76	79	66	56	23	39	100	92	95	29	52	81	53	60	91	28	55
5	96	37	60	93	95	42	5	64	74	25	22	40	18	30	77	98	65	16	14	29
6	2	83	93	76	11	23	22	80	62	33	26	30	60	16	19	59	8	31	53	58
7	37	21	48	89	43	83	27	22	3	8	78	69	85	68	5	55	96	13	17	90
8	87	78	68	24	2	86	39	84	54	93	42	1	66	58	49	92	28	69	20	37
9	49	68	48	51	20	16	11	98	52	92	15	64	18	55	44	78	5	54	38	94
10	23	13	5	53	22	29	97	27	2	83	88	1	58	34	74	54	24	90	17	37
11	34	96	3	89	97	73	13	62	19	29	60	9	15	7	66	1	63	23	85	68
12	79	11	40	92	98	87	54	73	72	22	2	100	29	7	21	78	47	38	12	13
13	41	17	64	70	80	98	84	54	34	79	62	77	97	32	86	7	82	59	8	4
14	4	65	37	11	71	96	93	3	43	82	33	84	14	76	5	15	73	6	47	88
15	69	76	63	90	66	81	73	2	23	4	46	30	43	18	41	29	10	61	99	91
16	95	69	58	84	83	38	98	75	18	1	87	65	88	15	90	52	17	3	22	93
17	99	53	26	24	22	60	96	19	48	52	37	58	94	51	11	18	67	95	85	20
18	29	66	56	80	50	14	90	24	37	26	52	13	51	3	6	25	12	34	30	8
19	63	43	46	18	52	84	12	73	57	74	37	89	59	97	96	88	92	66	76	91
20	60	11	12	87	72	90	17	32	80	69	56	47	77	65	21	2	44	30	5	49
21	43	91	89	10	22	10	86	71	20	31	45	51	30	29	70	99	54	67	95	53
22	26	76	76	26	26	76	26	76	26	76	26	76	26	26	26	26	26	76	26	76
23	5	60	64	67	78	39	86	95	1	36	43	18	41	99	54	50	45	71	72	13
24	5	3	61	84	21	64	40	3	30	43	44	83	80	99	78	85	77	23	82	15
25	20	37	97	22	46	65	75	92	52	73	81	3	71	99	51	42	72	23	69	95
26	91	74	27	8	24	26	21	3	34	20	59	57	9	13	99	71	56	29	17	11
27	91	92	24	19	68	28	41	94	89	66	25	9	37	43	33	63	83	38	1	60
28	23	86	5	18	96	79	57	32	50	72	75	88	71	42	40	61	69	68	31	15
29	91	32	77	71	15	33	5	48	40	2	47	9	54	62	37	46	23	26	39	58
30	66	82	85	86	74	6	19	59	58	75	98	40	51	36	90	79	27	89	53	25
31	96	40	37	46	65	62	96	49	68	93	77	12	96	12	49	46	71	81	55	87
32	96	72	26	78	50	88	83	92	100	7	90	28	57	69	68	4	63	82	59	97
33	49	17	13	6	56	75	44	34	10	93	36	45	33	40	20	83	3	11	79	18
34	20	30	95	72	81	10	100	21	39	44	16	9	2	62	31	68	52	69	15	56
35	46	100	15	27	39	47	75	54	74	44	34	90	14	86	78	91	52	51	71	23
36	29	77	55	40	89	9	25	45	80	87	34	36	54	18	94	82	44	11	57	74
37	37	56	79	21	87	40	94	20	52	25	9	98	80	60	81	49	12	32	44	89
38	16	92	12	25	14	4	19	54	52	33	68	95	63	32	81	77	27	90	34	65
39	65	51	79	94	37	10	20	35	22	92	60	87	89	97	33	1	6	55	47	15
40	63	97	39	33	69	56	74	18	3	67	21	43	26	71	86	15	35	42	89	40
41	43	2	52	48	51	30	26	64	74	63	47	69	29	6	65	9	20	80	96	11
42	74	21	75	31	81	28	76	3	17	67	77	56	95	53	85	48	62	4	6	16
43	11	53	74	88	67	100	37	79	58	8	41	21	30	18	61	78	44	80	84	65
44	91	33	45	19	76	18	3	2	58	50	29	1	70	89	43	17	74	21	81	99
45	86	91	89	17	2	94	33	34	1	78	16	63	14	60	69	46	56	68	20	44
46	30	42	62	28	81	68	74	60	53	75	2	15	99	19	22	41	35	54	27	34
47	3	88	93	6	49	47	27	68	26	78	100	85	75	39	12	42	67	91	48	37
48	42	8	88	77	60	67	23	18	79	50	100	86	43	3	27	44	13	15	91	47
49	78	34	93	88	76	68	30	17	97	42	53	61	31	57	22	74	3	87	21	28
50	66	62	22	59	94	80	19	48	35	64	41	39	37	76	2	97	43	56	10	4
51	13	8	68	53	51	18	56	30	42	91	7	31	33	5	59	66	94	17	98	79
52	72	36	94	77	83	68	19	26	12	52	95	41	54	8	76	90	4	91	40	73
53	77	17	21	11	80	92	89	81	57	34	5	39	67	70	9	65	2	49	6	82
54	62	54	16	17	51	60	36	90	21	39	35	43	33	68	18	56	44	14	65	69
55	6	32	47	18	73	64	3	78	26	69	17	93	77	62	49	67	60	100	9	86
56	81	9	10	18	66	95	47	27	75	48	25	60	53	58	23	56	22	85	100	36
57	78	64	31	96	1	41	26	3	38	20	66	59	73	63	55	11	62	76	61	39

Table IRES-7. Ranks of 100 Values Sampled, Replicate 3

LHS#	R#	Mat	Par	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	3	STEEL	CORRMCO2	51	63	18	5	73	100	29	52	20	12	38	65	68	31	24	77	54	60	2	3
2	3	WAS_AREA	PROBDEG	26	26	88	88	88	88	26	88	26	26	26	88	26	88	26	63	26	26	26	26
3	3	WAS_AREA	GRATMICI	68	63	31	30	100	6	22	73	10	17	66	44	67	37	71	8	81	88	21	55
4	3	WAS_AREA	GRATMICH	26	11	63	12	36	55	35	39	87	60	80	33	72	68	14	8	29	40	69	83
5	3	CELLULS	FBETA	2	96	90	81	31	63	89	69	48	10	12	15	75	91	45	74	9	19	72	17
6	3	WAS_AREA	SAT_RGAS	86	51	95	2	46	3	58	97	40	73	89	100	29	10	14	87	75	13	17	11
7	3	WAS_AREA	SAT_RBRN	64	10	66	21	15	67	85	16	50	5	45	31	24	79	81	38	44	27	58	80
8	3	WAS_AREA	SAT_WICK	63	95	54	67	3	33	88	99	31	42	32	12	71	70	44	25	18	40	66	62
9	3	CL_L_T1	PRMX_LOG	3	43	7	75	91	12	30	23	35	4	31	62	13	20	56	22	28	14	82	99
10	3	CONC_T1	PRMX_LOG	44	79	73	99	34	66	87	62	64	47	42	30	54	3	10	96	21	88	60	76
11	3	ASPHALT	PRMX_LOG	72	54	80	45	74	59	29	48	98	58	23	17	81	4	35	31	10	18	68	13
12	3	SHFT_DRZ	PRMX_LOG	95	27	42	28	65	85	81	29	36	53	63	37	48	83	44	55	59	34	82	99
13	3	SALT_T1	CUMPROB	73	27	93	86	36	99	50	12	46	20	68	34	64	29	10	97	38	89	88	79
14	3	SALT_T1	SAT_RGAS	64	35	36	22	14	66	71	9	69	100	82	30	80	70	15	54	5	53	27	45
15	3	SALT_T1	SAT_RBRN	18	29	95	47	100	61	68	2	19	89	51	92	63	39	90	88	93	32	41	54
16	3	SALT_T1	PORE_DIS	64	4	82	62	40	59	31	95	3	11	92	8	17	46	15	67	68	48	86	51
17	3	S_HALITE	POROSITY	63	100	56	39	19	70	87	10	81	18	26	27	68	29	40	36	67	11	24	89
18	3	S_HALITE	PRMX_LOG	63	59	69	16	15	87	47	49	71	25	68	18	14	36	12	39	28	53	82	21
19	3	S_HALITE	COMP_RCK	38	44	32	86	88	15	58	52	26	71	46	83	87	67	90	57	74	45	21	79
20	3	S_MB139	PRMX_LOG	35	96	97	77	18	16	9	23	75	31	43	45	33	80	6	84	65	21	15	61
21	3	S_MB139	COMP_RCK	70	10	10	10	82	87	88	72	30	66	62	55	75	24	92	10	42	80	97	35
22	3	S_MB139	RELP_MOD	26	76	26	76	26	76	76	26	26	26	76	26	26	76	76	76	76	76	76	26
23	3	S_MB139	SAT_RBRN	70	40	28	72	90	58	3	100	29	76	49	96	67	92	89	4	17	27	86	38
24	3	S_MB139	SAT_RGAS	73	5	77	68	25	42	71	24	14	26	3	59	99	30	39	61	6	76	85	3
25	3	S_MB139	PORE_DIS	89	26	90	14	43	77	100	56	64	12	22	92	78	20	32	62	58	30	13	70
26	3	S_HALITE	PRESSURE	47	90	39	96	84	57	42	67	93	74	34	28	71	68	8	54	100	82	59	78
27	3	CASTILER	PRESSURE	12	79	45	23	65	95	41	58	28	88	91	10	11	7	21	54	77	43	9	32
28	3	CASTILER	PRMX_LOG	37	25	75	4	24	9	22	40	66	93	95	38	36	10	3	57	28	11	97	92
29	3	CASTILER	COMP_RCK	26	55	23	100	78	92	79	46	27	33	5	69	68	59	87	37	91	47	25	18
30	3	BH_SAND	PRMX_LOG	58	63	47	38	41	5	53	33	11	16	71	12	56	65	80	70	74	57	54	44
31	3	CASTILER	GRIDFLO	49	58	30	24	24	65	27	5	67	2	92	46	62	89	27	27	37	46	78	24
32	3	BLOWOUT	PARTDIA	32	9	3	53	8	14	92	75	91	71	58	22	25	60	59	79	94	46	39	15
33	3	BOREHOLE	TAUFAIL	27	51	13	55	72	41	16	22	65	60	71	91	35	3	1	63	34	82	61	23
34	3	CULEBRA	MINP_FAC	18	30	50	57	74	43	67	44	8	34	66	2	62	55	28	11	49	99	73	40
35	3	GLOBAL	TRANSIDX	97	92	16	86	19	27	11	48	52	26	14	54	100	18	89	69	78	6	57	33
36	3	SOLAM3	SOLSIM	37	71	72	91	82	89	59	7	32	77	80	69	84	15	24	40	98	5	38	27
37	3	SOLAM3	SOLCIM	5	99	88	90	66	50	1	77	83	87	57	16	37	47	28	40	89	85	73	51
38	3	SOLPU3	SOLSIM	82	55	20	23	70	16	17	79	29	78	8	42	5	9	12	72	69	41	14	47
39	3	SOLPU3	SOLCIM	49	73	46	36	47	94	14	17	6	95	27	66	69	22	79	83	16	35	23	97
40	3	SOLPU4	SOLSIM	26	40	58	43	100	68	90	67	34	24	9	99	86	82	10	35	98	66	88	59
41	3	SOLPU4	SOLCIM	16	34	88	52	59	56	20	74	72	73	53	44	38	12	100	51	60	46	47	31
42	3	SOLU4	SOLSIM	87	98	1	45	79	84	33	48	90	16	100	42	9	58	95	73	29	36	80	61
43	3	SOLU6	SOLSIM	88	22	42	12	47	29	77	28	23	39	25	76	7	86	19	100	58	31	97	90
44	3	SOLU6	SOLCIM	76	24	87	11	89	41	28	43	83	49	57	36	7	68	77	9	8	31	16	34
45	3	SOLTH4	SOLSIM	30	97	79	54	55	68	18	93	38	75	8	28	39	50	65	53	58	26	81	100
46	3	PHUMOX3	PHUMCIM	55	96	62	39	70	63	44	4	61	48	20	67	16	69	36	21	6	99	9	71
47	3	GLOBAL	OXSTAT	100	98	67	6	45	66	40	34	33	78	65	51	81	69	96	30	90	61	97	41
48	3	GLOBAL	CLIMTIDX	29	28	22	85	63	74	30	98	40	33	38	80	35	48	8	16	34	79	76	78
49	3	CULEBRA	HMBLKLT	27	24	67	35	78	63	73	36	46	2	82	39	26	49	98	93	59	10	15	66
50	3	CULEBRA	APOROS	18	84	52	29	16	54	71	60	34	45	98	91	61	5	41	12	47	53	59	43
51	3	CULEBRA	DPOROS	42	63	52	62	18	46	35	25	80	45	39	100	95	32	22	2	38	17	72	60
52	3	U+6	MKD_U	11	54	83	34	22	24	56	45	91	64	42	97	3	92	68	76	47	35	10	58
53	3	U+4	MKD_U	6	13	23	39	37	98	67	75	79	66	56	69	33	9	83	17	16	73	70	41
54	3	PU+3	MKD_PU	10	62	47	45	30	11	77	83	32	36	51	86	95	54	18	50	15	60	61	7
55	3	PU+4	MKD_PU	15	56	10	19	9	70	88	73	27	63	35	59	30	51	80	57	24	20	100	85
56	3	TH+4	MKD_TH	32	63	6	90	69	9	76	47	94	73	55	22	25	1	54	98	74	13	68	4
57	3	AM+3	MKD_AM	12	92	65	16	93	30	74	7	32	15	24	38	31	35	66	34	56	5	10	60

Table IRES-7. Ranks of 100 Values Sampled, Replicate 3 (Continued)

LHS#	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
1	8	13	81	93	7	23	66	30	89	71	50	88	82	59	47	53	62	86	84	90	58	92	10	99	97	25	72	80	94
2	26	26	26	88	26	26	26	26	88	26	26	26	26	88	63	63	88	26	63	88	26	26	63	26	88	63	26	88	26
3	50	87	84	4	1	32	85	89	19	29	65	72	38	18	57	12	75	23	28	15	91	64	49	54	82	80	41	45	58
4	38	42	61	95	82	74	91	6	16	24	30	65	52	27	51	20	19	90	48	85	67	34	94	17	44	46	84	78	47
5	70	26	5	44	21	14	20	1	24	59	94	97	76	36	54	4	88	86	66	39	7	13	32	50	35	47	22	8	82
6	26	94	28	47	44	74	96	64	31	91	85	4	52	38	60	7	66	98	83	27	20	1	62	77	63	33	61	59	9
7	43	88	55	76	68	2	75	100	26	51	46	63	32	41	95	82	87	30	70	4	60	3	59	91	36	99	7	89	49
8	81	24	43	37	5	97	91	28	94	100	51	76	8	56	11	27	52	14	82	59	23	98	61	53	86	68	46	73	34
9	51	15	6	83	39	32	45	50	93	86	49	52	72	70	24	61	96	58	64	55	34	21	1	92	9	68	57	38	2
10	25	27	17	38	48	81	9	71	84	98	67	39	53	12	46	85	95	72	1	29	78	4	45	43	100	82	65	91	94
11	2	91	92	3	83	11	46	40	93	56	47	15	70	97	55	6	73	1	33	94	14	44	87	78	19	30	5	62	66
12	21	15	16	23	47	97	35	54	66	18	94	78	69	38	51	10	50	31	77	67	17	33	76	4	91	58	56	100	70
13	37	67	16	83	7	70	21	6	61	66	63	14	3	22	90	41	18	59	85	54	32	65	28	81	92	75	26	2	39
14	37	2	49	62	47	86	94	93	59	50	84	31	88	81	12	72	61	28	24	41	63	21	23	76	51	79	92	42	29
15	86	80	33	79	81	56	14	34	99	74	35	52	57	4	1	15	87	3	58	91	9	49	82	66	38	7	44	64	75
16	81	20	34	9	89	12	79	70	26	24	19	66	43	1	2	74	36	61	33	35	56	47	63	76	42	45	49	85	90
17	95	83	64	1	82	7	74	28	69	62	78	15	98	38	71	59	66	54	44	77	34	93	52	4	80	9	35	25	96
18	88	31	60	11	30	45	48	55	41	29	65	78	61	22	85	76	74	5	90	95	43	40	50	56	24	98	70	100	20
19	9	75	51	85	62	59	53	48	56	73	31	20	36	78	17	34	30	96	7	6	55	61	50	41	82	3	28	1	81
20	58	88	54	55	17	29	26	93	71	59	66	86	63	87	90	67	44	46	72	5	91	79	52	2	8	41	37	51	48
21	43	10	46	53	86	73	76	10	36	40	31	22	37	25	10	32	57	50	20	99	10	10	49	99	94	69	71	45	51
22	26	26	26	76	26	26	26	76	26	26	26	26	26	26	26	26	76	26	76	26	76	76	76	76	76	26	76	26	26
23	41	99	10	69	82	36	12	85	93	32	83	95	75	44	55	62	66	8	11	73	71	24	18	61	80	16	87	5	53
24	49	38	95	88	45	16	58	94	55	12	7	91	83	8	15	10	34	96	54	53	70	98	60	9	64	69	23	48	3
25	5	74	16	24	38	37	9	3	60	1	42	84	17	27	82	61	85	4	29	10	2	50	39	80	25	40	71	34	7
26	15	2	50	80	83	20	27	24	43	72	97	35	25	65	89	66	21	48	63	70	58	22	17	88	6	19	56	99	4
27	19	64	29	24	27	13	3	89	90	70	46	35	76	26	61	8	17	57	4	73	81	33	62	42	51	93	25	39	2
28	2	21	53	54	16	82	12	64	20	61	14	63	30	98	91	6	99	65	71	50	48	100	27	89	39	55	78	5	72
29	80	86	24	32	99	50	83	66	94	35	64	85	52	1	56	97	11	90	62	49	40	10	84	15	58	81	34	76	67
30	67	29	31	91	21	82	72	97	26	83	64	7	46	75	85	95	88	39	6	99	8	66	87	24	96	13	1	28	62
31	24	86	2	62	96	62	83	81	70	67	21	12	8	34	55	34	58	46	30	34	43	74	8	5	86	15	52	40	21
32	66	35	6	18	27	63	57	65	76	52	47	29	86	37	20	62	80	4	41	67	45	70	12	48	73	50	19	23	84
33	49	9	18	30	95	31	52	76	68	8	80	7	84	39	24	15	14	62	98	6	75	78	47	20	69	10	56	87	88
34	25	86	79	97	24	85	10	72	26	58	80	69	95	65	64	42	87	47	75	60	14	4	16	1	7	3	46	94	89
35	3	49	64	45	37	90	63	74	56	70	81	1	15	2	68	43	32	40	46	67	17	30	13	20	4	91	98	72	84
36	50	11	93	34	41	46	99	92	17	52	67	76	45	85	26	81	94	25	60	8	12	23	62	70	10	2	35	21	20
37	55	97	45	35	8	74	69	44	18	3	14	81	53	63	4	36	29	43	93	46	6	26	7	30	95	91	84	58	38
38	77	61	62	95	76	74	65	39	52	13	53	63	38	44	96	92	26	30	54	81	6	86	3	1	40	68	73	18	84
39	72	68	12	21	20	51	92	40	32	87	5	84	1	57	60	42	4	2	64	96	100	18	56	37	11	10	13	62	75
40	61	73	30	60	29	36	84	48	46	38	65	22	25	57	37	78	31	44	76	72	47	91	50	83	77	75	6	70	15
41	6	29	8	78	40	36	81	22	41	13	76	25	21	55	93	11	80	99	15	71	97	61	45	66	95	9	83	87	35
42	89	99	43	25	41	81	20	26	86	28	3	6	76	85	14	55	56	97	83	51	30	94	52	64	10	35	72	71	4
43	71	67	98	93	34	85	68	27	92	83	46	87	59	37	32	4	43	79	20	17	70	45	5	64	63	3	61	96	30
44	38	52	65	73	12	64	69	23	40	97	63	81	100	18	25	44	61	62	45	3	51	74	20	53	56	32	26	21	91
45	61	47	36	60	57	21	99	23	46	27	6	14	95	43	94	34	89	98	9	20	66	33	48	86	29	88	13	73	90
46	42	85	34	93	73	88	95	12	51	54	94	40	65	23	19	80	90	59	27	31	30	87	84	25	7	86	49	57	17
47	38	2	28	54	43	13	83	35	92	76	32	77	71	55	94	20	3	58	93	1	29	11	37	4	63	18	10	39	44
48	2	86	52	4	57	61	100	19	64	66	31	36	97	7	77	54	18	1	62	51	37	83	93	73	69	20	50	55	46
49	18	55	96	80	60	52	53	75	13	25	61	33	70	45	40	57	28	30	29	83	37	74	47	34	17	68	97	48	81
50	76	51	24	97	33	56	31	27	2	57	13	20	87	11	46	81	22	42	19	68	25	14	74	70	78	7	50	35	55
51	89	69	30	81	21	6	31	84	12	93	57	5	56	54	19	65	44	68	97	48	11	75	1	82	61	76	24	91	99
52	5	70	52	17	95	37	86	77	51	74	33	96	1	46	8	67	38	81	94	93	36	21	16	6	55	78	20	14	82
53	80	35	60	40	90	63	48	88	46	47	74	59	31	95	87	44	22	21	7	1	3	76	19	62	85	51	52	57	97
54	24	65	96	68	55	64	34	25	99	38	17	9	78	53	46	89	52	76	41	5	42	22	100	26	13	56	19	73	35
55	11	38	83	64	99	54	52	32	66	47	90	22	74	91	28	97	68	26	62	67	98	53	16	76	60	25	7	37	44
56	57	82	89	95	45	51	75	2	50	43	27	60	64	8	66	70	30	28	46	21	78	61	17	15	81	79	3	59	18
57	43	20	45	44	90	100	64	8	94	73	13	41	28	76	68	62	11	27	37	6	51	42	96	88	84	81	89	69	72

Table IRES-7. Ranks of 100 Values Sampled, Replicate 3 (Continued)

LHS#	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	41	6	16	78	14	21	74	35	34	46	79	28	75	37	83	91	4	22	15	49	76	48	64	98	95	17	56	36	19	45	39
2	26	88	63	26	63	26	63	88	26	26	26	63	63	63	88	26	88	26	26	88	63	88	26	26	63	26	88	26	63	63	26
3	48	61	99	56	95	70	90	53	34	13	52	47	16	20	98	83	86	43	36	74	27	7	40	24	78	2	11	79	93	92	25
4	54	64	75	15	31	18	79	32	62	59	50	98	9	97	86	58	5	53	56	73	1	28	92	23	10	45	13	88	99	66	3
5	67	53	77	28	100	58	33	87	43	27	85	98	92	30	71	95	62	60	80	16	65	46	34	49	11	3	68	40	38	99	6
6	32	53	76	50	19	34	23	70	54	5	68	56	90	24	15	99	45	35	25	8	21	92	22	36	82	72	80	43	88	18	79
7	13	84	8	78	77	39	47	61	28	57	35	12	17	83	20	74	54	1	25	94	11	23	86	93	65	14	98	9	22	37	19
8	7	69	47	57	64	85	16	2	35	78	1	87	77	58	17	45	49	21	9	84	4	39	22	19	79	65	60	30	48	13	10
9	19	76	73	90	5	53	100	44	63	77	25	59	47	46	79	78	41	42	26	40	87	74	94	80	67	69	8	71	81	60	54
10	32	59	89	28	23	80	5	97	8	33	74	18	13	86	37	56	7	68	40	55	75	57	77	36	90	92	16	26	93	49	52
11	51	65	85	99	75	38	64	61	8	67	36	25	49	39	42	95	32	43	82	96	26	16	50	12	84	76	9	79	7	34	52
12	14	30	73	41	61	92	25	7	60	88	72	8	40	57	26	93	5	12	32	2	84	13	45	19	49	20	87	98	1	62	68
13	84	24	55	49	74	77	100	23	42	19	5	94	13	44	69	56	71	72	80	82	11	40	35	76	52	60	43	4	31	8	87
14	48	67	73	85	98	97	52	6	33	58	56	39	99	19	90	25	89	18	57	95	26	43	87	38	16	78	96	46	83	44	13
15	45	94	84	78	83	50	36	22	43	27	20	73	24	70	13	42	30	40	11	69	10	59	97	71	62	6	65	46	72	60	98
16	65	84	23	44	78	75	52	29	13	88	21	96	98	30	80	55	99	25	37	22	94	53	69	77	10	87	27	91	28	32	57
17	5	86	14	20	22	75	99	72	76	73	90	32	50	33	91	17	47	6	8	42	46	41	79	37	57	97	21	48	88	58	12
18	99	46	44	35	42	72	86	64	58	6	91	34	97	23	1	3	38	94	37	4	8	9	77	27	54	57	10	17	52	79	81
19	2	49	64	69	60	29	13	35	37	97	8	68	5	84	100	98	66	11	63	93	89	95	24	76	42	47	91	72	54	27	19
20	22	70	95	27	11	83	10	20	69	56	99	73	39	64	89	76	62	49	68	85	13	50	82	42	94	30	74	1	7	38	98
21	78	26	10	67	83	21	91	81	33	47	10	28	65	39	10	34	41	59	29	10	85	48	19	56	10	74	27	99	90	63	10
22	76	76	76	76	26	26	26	26	26	26	76	26	26	76	76	76	26	76	26	76	26	76	26	26	76	76	26	76	26	76	76
23	56	33	22	25	39	98	7	23	15	52	46	88	47	50	65	30	34	1	57	13	31	54	45	37	63	81	14	6	35	43	60
24	62	18	28	75	37	100	36	67	79	40	89	78	17	32	29	27	22	11	43	35	13	63	33	44	31	84	82	46	97	81	87
25	15	23	52	48	8	87	19	66	68	41	35	57	59	47	86	6	99	83	75	72	95	18	93	67	51	88	81	76	94	44	63
26	33	62	26	13	14	95	73	52	10	44	40	69	29	12	86	45	92	16	75	7	1	55	51	18	53	31	87	85	37	91	46
27	98	84	14	86	55	99	49	63	100	97	37	56	69	31	38	66	59	50	16	85	82	74	5	34	52	22	60	68	83	80	53
28	7	67	33	32	76	84	42	62	19	86	96	46	43	79	49	18	51	8	58	23	52	88	29	87	26	35	17	69	77	45	34
29	77	70	88	82	2	9	95	30	43	31	13	54	73	4	39	72	61	93	36	75	42	7	22	12	60	63	98	8	29	44	20
30	14	17	34	68	10	78	86	36	20	25	60	84	55	15	4	81	98	43	79	42	69	3	52	45	9	50	35	94	89	51	93
31	70	99	43	43	92	58	37	78	15	78	78	34	49	8	83	74	62	74	74	5	18	89	30	96	89	65	70	96	15	18	55
32	96	36	43	24	40	93	81	98	89	2	77	83	7	99	97	21	26	61	17	31	56	69	49	34	72	5	100	85	33	1	11
33	46	53	32	44	19	59	25	28	17	21	5	94	38	99	37	79	100	26	85	93	89	2	48	50	11	42	36	12	45	66	70
34	48	32	29	90	22	61	20	37	92	12	45	54	82	59	51	35	81	56	91	100	53	98	5	96	83	84	27	77	19	36	9
35	93	71	5	51	77	39	73	88	80	65	62	94	99	44	66	34	23	9	42	85	59	53	87	47	36	8	10	25	29	24	76
36	66	9	43	19	86	68	49	42	63	47	48	97	3	57	16	30	14	79	13	18	65	64	36	28	83	74	73	58	44	39	6
37	23	13	9	92	59	24	94	79	15	86	78	32	17	52	56	31	60	22	21	39	34	25	62	42	71	80	96	82	61	12	100
38	60	97	24	100	85	87	28	66	25	37	2	4	7	64	27	50	31	93	59	15	35	90	89	22	75	32	71	58	56	99	10
39	7	43	8	85	41	33	45	80	24	59	86	61	99	98	91	54	76	81	67	9	48	71	25	31	39	78	90	29	74	50	55
40	28	92	17	20	95	85	33	71	53	12	87	2	97	94	51	42	56	64	96	79	18	81	27	41	54	63	1	32	69	45	11
41	42	92	91	85	68	98	54	65	96	62	75	69	26	82	30	3	90	86	32	19	5	1	84	89	18	77	49	70	2	33	24
42	34	22	75	27	49	77	8	74	18	5	63	69	88	19	37	21	44	54	32	91	50	23	70	68	65	60	96	39	46	92	7
43	75	54	13	82	72	16	55	94	69	80	84	24	9	2	95	33	99	73	8	91	62	40	48	1	11	53	14	10	6	21	38
44	92	86	6	14	15	90	79	99	2	80	17	75	85	66	22	35	42	95	96	33	27	4	67	13	94	54	72	55	48	47	82
45	32	4	22	82	80	85	24	17	63	3	1	59	35	69	31	10	25	56	74	67	77	87	76	16	64	44	41	71	11	19	70
46	76	37	81	29	32	43	68	53	28	92	26	3	50	82	47	24	98	5	33	22	45	66	15	79	38	1	35	52	41	8	74
47	82	75	80	46	17	89	59	31	5	56	16	19	64	42	79	24	7	88	14	87	74	84	47	99	12	22	25	72	95	50	85
48	71	43	45	25	14	81	58	26	68	89	99	67	3	9	12	65	56	95	72	84	59	96	91	94	10	21	90	49	17	44	24
49	19	72	58	7	65	94	76	31	38	77	9	90	41	16	56	64	4	91	85	54	42	87	3	22	50	88	84	5	23	51	86
50	28	36	39	40	73	88	89	4	86	79	49	1	80	30	100	62	10	37	99	85	58	17	93	8	64	9	95	15	23	83	82
51	90	55	78	88	37	66	3	53	94	96	36	50	13	26	49	43	67	79	58	10	47	4	8	29	41	83	87	86	64	59	23
52	69	4	61	27	28	100	59	25	99	18	15	12	84	39	88	75	57	79	29	90	63	19	73	50	65	60	2	85	23	41	48
53	42	32	64	25	34	38	91	18	86	10	68	71	92	29	53	65	94	28	2	24	5	100	84	14	58	43	12	30	49	93	99
54	14	43	85	94	72	66	84	23	44	81	71	58	79	80	97	2	57	93	16	1	70	39	48	49	82	28	21	40	12	27	87
55	45	18	21	49	69	55	46	78	81	65	41	75	36	23	50	79	39	84	71	43	14	2	4	87	92	1	48	31	93	77	95
56	36	24	37	5	97	49	7	16	65	93	52	29	72	71	41	100	80	44	11	19	38	31	87	99	42	96	26	56	40	62	34
57	99	29	4	85	58	87	26	25	39	1	95	63	9	52	86	49	71	2	82	36	55	18	3	61	91	98	46	78	40	97	59

Table IRES-7. Ranks of 100 Values Sampled, Replicate 3 (Continued)

LHS#	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	87	9	32	42	61	55	40	33	57	26	85	27	67	96	11	1	44	70	69	43
2	26	88	63	26	88	63	63	63	63	26	26	26	26	63	63	88	63	26	63	88
3	33	51	62	94	76	46	3	77	60	39	96	9	42	69	14	97	59	35	26	5
4	93	2	49	71	81	4	96	37	22	76	21	10	7	70	77	43	41	25	89	57
5	79	51	25	29	73	18	93	64	78	42	55	84	61	37	83	41	52	57	56	23
6	42	48	84	49	41	12	71	30	65	16	55	81	67	6	37	78	57	69	93	39
7	97	29	34	18	52	40	73	33	69	56	71	92	6	72	96	90	62	53	48	42
8	93	55	83	38	90	41	6	50	36	92	15	96	75	80	26	72	20	89	29	74
9	33	11	97	89	65	85	95	37	36	66	16	98	84	17	10	88	27	29	18	48
10	20	19	14	22	69	41	24	63	83	58	61	35	15	51	70	50	2	31	6	11
11	28	22	53	41	57	27	77	90	89	71	88	63	86	21	69	24	37	20	60	100
12	3	9	90	96	6	71	75	11	39	80	64	22	79	43	74	89	86	52	46	24
13	17	33	98	91	9	53	48	47	78	1	58	25	15	30	96	62	95	45	51	57
14	3	77	74	20	60	7	91	17	75	4	65	32	40	68	10	8	55	1	34	11
15	48	85	8	21	77	55	17	31	5	23	53	67	16	37	28	26	96	25	76	12
16	50	7	6	39	54	73	14	58	72	5	18	38	97	10	71	41	60	16	83	93
17	55	92	85	43	3	16	23	31	51	2	45	65	49	30	53	60	61	94	84	13
18	62	67	75	89	96	92	66	83	2	13	80	93	32	73	19	51	7	26	84	33
19	40	33	25	10	4	12	39	14	99	92	18	16	70	23	77	43	94	80	22	65
20	47	25	40	81	92	78	60	24	14	34	3	4	100	32	28	12	57	19	36	53
21	58	79	60	23	10	10	38	77	89	64	96	95	10	54	68	93	52	84	61	44
22	26	26	76	26	76	26	76	26	76	76	76	76	26	76	76	76	76	76	76	26
23	91	64	74	94	20	51	84	42	68	19	77	21	9	79	59	48	2	26	97	78
24	20	19	52	41	65	74	80	47	86	90	93	92	50	3	21	51	57	72	56	66
25	69	31	79	36	98	28	21	46	45	97	53	11	73	96	33	55	54	65	91	49
26	60	64	11	49	32	23	3	36	98	76	79	94	9	38	5	30	77	41	61	81
27	67	36	44	94	47	6	40	18	30	78	1	71	20	92	96	15	72	87	75	48
28	68	80	1	60	44	94	13	70	15	31	83	74	56	59	90	85	81	41	73	47
29	21	48	96	53	65	3	74	14	57	89	45	17	41	28	16	19	6	38	51	71
30	92	37	2	76	90	30	100	23	49	59	32	22	19	73	77	18	40	27	48	61
31	40	86	96	67	92	52	40	99	12	99	83	52	18	55	49	2	40	81	12	12
32	78	51	28	87	42	13	68	55	30	64	88	82	90	16	44	74	38	10	54	95
33	92	54	67	81	57	43	73	58	33	77	96	97	86	83	74	64	29	90	40	4
34	31	39	78	23	70	33	15	21	6	17	88	68	13	38	41	93	52	71	76	63
35	60	31	21	28	83	96	79	12	38	82	35	7	50	55	61	95	58	75	41	22
36	4	53	75	88	87	96	61	22	78	29	56	54	51	90	100	33	1	95	31	55
37	54	68	64	2	33	10	75	41	27	76	48	49	72	65	98	70	11	19	67	20
38	83	34	80	43	88	45	49	21	98	11	57	48	94	19	91	46	67	36	51	33
39	28	3	44	82	89	15	70	53	52	58	93	63	19	34	38	88	65	77	30	26
40	19	13	16	49	5	23	80	3	4	55	21	62	93	74	89	8	14	39	7	52
41	57	14	58	7	63	39	27	23	43	4	28	67	79	37	48	50	10	94	17	64
42	31	2	12	59	67	66	24	17	82	53	78	38	11	15	93	57	62	13	40	47
43	78	60	18	56	74	26	81	65	41	50	57	36	35	44	89	52	15	49	66	51
44	5	88	46	29	30	70	59	1	37	93	50	58	19	71	39	60	98	78	10	84
45	12	72	40	91	49	42	62	84	5	83	78	51	37	45	15	2	92	52	96	7
46	13	10	2	78	83	18	72	89	91	14	60	58	77	46	56	64	11	100	97	75
47	52	26	27	23	53	36	62	86	21	15	49	48	60	68	70	73	8	9	57	91
48	47	60	23	11	92	41	87	53	82	15	6	70	13	42	32	88	75	39	27	5
49	44	20	11	69	6	1	71	100	32	62	79	95	89	99	21	92	8	12	43	14
50	48	90	26	63	77	94	21	69	32	72	66	75	44	6	67	65	3	92	38	96
51	28	7	20	74	70	27	40	98	51	16	9	33	14	92	34	73	85	15	71	77
52	40	66	9	30	44	89	43	31	98	72	80	87	7	53	71	49	62	26	32	13
53	20	4	26	36	72	11	54	55	27	81	78	15	45	50	77	61	96	89	8	82
54	98	63	59	74	29	37	33	6	69	20	75	88	8	92	91	67	90	4	3	31
55	6	58	82	8	89	13	3	17	42	61	34	12	94	29	86	72	33	40	96	5
56	12	86	48	85	67	39	77	35	14	53	84	33	20	88	10	91	58	23	83	92
57	47	79	54	21	75	70	77	67	33	17	14	57	48	22	53	83	50	19	23	80

IRES.2 Shaft Seal Permeabilities

The calculated time-dependent shaft seal permeabilities are contained in Table IRES-8. In the performance assessment realization of the shaft seal system, a disturbed rock zone (DRZ) exists in the Salado formation adjacent to the asphalt, clay, and salt materials. The halite DRZ around the concrete is expected to be effectively healed by 25 years after closure; consequently no DRZ is assumed to exist adjacent the concrete columns. The DRZ is not explicitly represented in the BRAGFLO grid system. For the compliance certification application calculations, seal and DRZ permeabilities are combined into a seal composite permeability. Because the DRZ is transient, seal material permeability will also be transient for those seal components adjacent to a DRZ. The Rustler was not specified to have a DRZ.

The geometry of a DRZ region is assumed to be an annulus with inner radius equal to the effective radius of the shaft and outer radius the outer extent of the DRZ region. A log-linear model of permeability as a function of radial distance is reasonable based upon the field results. Assuming the only significant component of flow is parallel to the direction of the shaft, the effective permeability of a DRZ region is obtained by averaging the permeability in the direction of flow over the annular DRZ region as

$$k_{DRZ} = \frac{1}{A}\iint_A k\,dA$$

where A is the area of the annulus and k is the permeability. Assuming that DRZ permeability varies log-linearly and satisfying $k = k_{in}$ at $r = r_{in}$ (inner radius) and $k = k_{out}$ at $r = r_{out}$ (outer radius) the effective permeability is

$$k_{DRZ} = \frac{2}{r_{out} + r_{in}}\left[k_{out}\left(\frac{r_{out}\ln\left(\frac{k_{out}}{k_{in}}\right) - \Delta r}{\ln^2\left(\frac{k_{out}}{k_{in}}\right)}\right) - k_{in}\left(\frac{r_{in}\ln\left(\frac{k_{out}}{k_{in}}\right) - \Delta r}{\ln^2\left(\frac{k_{out}}{k_{in}}\right)}\right)\right] \quad (1)$$

where Δr is equal to the outer DRZ radius minus the inner DRZ radius, $r_{out} - r_{in}$.

From the DRZ skin permeability, k_{in}, the intact Salado formation permeability, k_{out}, and an estimate of the extent of the DRZ radius, r_{out}, the DRZ effective permeability can be calculated for a given shaft with known r_{in}.

Because the DRZ is adjacent to each of the four shafts and the extent of the DRZ is dependent on each individual shaft radius, the effective DRZ permeability calculation from equation 1 must be performed for all four shafts. Denote this effective permeability as $k_{DRZ,i}$, where i denotes the shaft index. The effective DRZ permeability for the composite shaft system is an area weighted sum of the effective DRZ permeability of each individual shaft:

$$k_{DRZ}A_{DRZ} = \sum_{i=1}^{4} k_{DRZ,i}\, A_{DRZ,i}$$

where

$$A_{DRZ} = \sum_{i=1}^{4} A_{DRZ,i}$$

and the DRZ areas are the area of the annuli $\pi(r_{out}^2 - r_{in}^2)$ for each individual shaft.

If the DRZ were modeled explicitly within the BRAGFLO performance assessment grid, then the effective composite DRZ permeability would be k_{DRZ}. However, the BRAGFLO model further combines the effective DRZ permeabilities with the corresponding seal permeabilities into a composite model permeability. In this case, an approximate effective area-weighted permeability of the combined shaft and DRZ can be calculated as

$$k_{model} = \frac{k_s A_s + k_{DRZ} A_{DRZ}}{A_{model}}$$

where A_{model} is equal to the shaft area A_S

$$A_s = \sum_{i=1}^{4} A_{S,i},$$

which is approximately 1,023 square feet (95 square meters). The value of k_{model} is dependent on shaft material and can be transient in time. This permeability is assigned to the appropriate shaft grid over time for the performance assessment calculation.

The calculated time-dependent shaft seal permeabilities are contained in Table IRES-8.

Table IRES-8. Time-Dependent Shaft Seal Permeabilities Used in BRAGFLO

Shaft Material	Time Period (years)	Intrinsic Permeability (square meters)
Earthen fill	0-10,000	1.000000×10^{-14}
Rustler compacted clay	0-10,000	1.380382×10^{-18}
Asphalt column	0-10,000	8.017980×10^{-17}
Concrete, T1	0-400	1.230269×10^{-19}
Concrete, T2	400-10,000	1.000000×10^{-14}
Upper Salado compacted clay, T1	0-10	9.220170×10^{-17}
Upper Salado compacted clay, T2	10-25	6.057352×10^{-17}
Upper Salado compacted clay, T3	25-50	3.668447×10^{-17}
Upper Salado compacted clay, T4	50-100	1.458055×10^{-17}
Upper Salado compacted clay, T5	100-10,000	1.380382×10^{-18}
Lower Salado compacted clay, T1	0-10	1.122931×10^{-16}
Lower Salado compacted clay, T2	10-25	2.143571×10^{-17}
Lower Salado compacted clay, T3	25-50	1.625464×10^{-18}
Lower Salado compacted clay, T4	50-10,000	1.380382×10^{-18}
Compacted salt column, T1	0-10	6.737940×10^{-16}
Compacted salt column, T2	10-25	5.824235×10^{-16}
Compacted salt column, T3	25-50	5.688506×10^{-16}
Compacted salt column, T4	50-100	1.759959×10^{-19}
Compacted salt column, T5	100-200	1.296823×10^{-20}
Compacted salt column, T6	200-10,000	1.779326×10^{-21}
Bottom clay	0-10,000	1.380382×10^{-18}
Concrete monolith at shaft base	0-10,000	1.000000×10^{-14}

IRES.3 Actinide Solubility

For a complete discussion, please see Appendix SOTERM (Sections SOTERM.3, SOTERM.4, and SOTERM.7). Actinide solubility is modeled using fracture matrix transport (FMT) (See Appendix SOTERM, Section SOTERM.3). The modeled solubilities for each oxidation state are given in Table IRES-9, below:

Table IRES-9. Solubilities of the Oxidation State Analogs, in moles/liter, with MgO Backfill

	Oxidation States			
Brine	**+III**	**+IV**	**+V**	**+VI***
Salado	5.82×10^{-7}	4.4×10^{-6}	2.3×10^{-6}	8.7×10^{-6}
Castile	6.52×10^{-8}	6.0×10^{-9}	2.2×10^{-6}	8.8×10^{-6}

* Not calculated with the FMT model.

Uncertainty in these solubilities is incorporated by sampling a distribution around each solubility. The lower end of the distribution is 1 percent of the modeled solubility; the high end of the distribution is 2,500 percent of the solubility. The sample from the solubility distribution was then applied to the appropriate oxidation state.

An oxidation state analogy related the data for oxidation states to the actinides themselves. Because some actinides can exhibit more than one oxidation state under WIPP conditions, two oxidation state distributions are used in performance assessment, each for half of the realizations (III and IV), as shown in Tables IRES-10 and IRES-11.

Table IRES-10. Lower Oxidation States of the Actinides in the WIPP as used in Performance Assessment

Actinide Element	Oxidation States	
thorium		IV
uranium		IV
neptunium		IV
plutonium	III	
americium	III	
curium	III	

Table IRES-11. Higher Oxidation States of the Actinides in the WIPP as used in Performance Assessment

Actinide Element	Oxidation States			
thorium		IV		
uranium				VI
neptunium			V	
plutonium		IV		
americium	III			
curium	III			

Figure IRES-1 shows the resulting distribution of dissolved concentrations of americium and plutonium, for all performance assessment realizations. Isotopes of plutonium and americium dominate the U.S. Environmental Protection Agency (EPA) unit (Appendix WCA, Section WCA.3). By far the largest fraction of realizations yield concentrations of 10^{-7} to 10^{-6} M.

Figure IRES-1 shows dissolved concentrations only, without the contribution of colloidally sorbed actinides. The contribution of colloids was incorporated by using the proportionality constants given in Table IRES-12. Please see Appendix SOTERM (Section SOTERM.7) for a complete discussion.

Colloid concentration factors were combined with dissolved concentrations according to the following example:

Considering one realization in which Pu is present in Salado brine in the +IV state and has a sampled dissolved concentration of 2.8×10^{-6} M.

The colloidal proportionality constants from Table IRES-12 are:

- humic proportionality constant = 6.3
- microbe proportionality constant = 0.3
- humic cap = 1.1×10^{-5} M
- microbe cap = 2.1×10^{-3} M
- actinide concentration on mineral fragment = 2.6×10^{-8} M
- intrinsic colloid concentration = 1×10^{-9} M

The humic complexed plutonium would be:

Table IRES-12. Colloid Concentration Factors

Actinide Element	Concentration on Mineral Fragments*	Concentration as Intrinsic Colloid*	Proportion Sorbed on Microbes**	Maximum Sorbed on Microbes****	Proportion Sorbed on Humics**		Maximum Sorbed on Humics*
					Salado	Castile	
Th(IV)	2.6×10^{-8}	0.0	3.1	0.0019	6.3	6.3	1.1×10^{-5}
U(IV)	2.6×10^{-8}	0.0	0.0021	0.0021	6.3	6.3	1.1×10^{-5}
U(VI)	2.6×10^{-8}	0.0	0.0021	0.0023	0.12	0.51	1.1×10^{-5}
Np(IV)	2.6×10^{-8}	0.0	12.0	0.0027	6.3	6.3	1.1×10^{-5}
Np(V)	2.6×10^{-8}	0.0	12.0	0.0027	9.1×10^{-4}	7.4×10^{-3}	1.1×10^{-5}
Pu(III)	2.6×10^{-8}	0.0	0.3	6.8×10^{-5}	0.19	1.37***	1.1×10^{-5}
Pu(IV)	2.6×10^{-8}	1.0×10^{-9}	0.3	6.8×10^{-5}	6.3	6.3	1.1×10^{-5}
Am(III)	2.6×10^{-8}	0.0	3.6	NA	0.19	1.37***	1.1×10^{-5}

* In units of moles colloidal actinide per liter
** In units of moles colloidal actinide per mole dissolved actinide
*** A cumulative distribution from 0.065 to 1.60 with a mean value of 1.1 was used
**** In units of moles total mobile actinide per liter
NOTE: The colloidal source term is added to the dissolved source term to arrive at a total source term. Mineral fragments were provided with distributions, but the maximum was used as described in SOTERM 7.1.3. Humic proportionality constants for III, IV, and V were provided with distributions, but only the Castile Am(III) and Pu(III) were sampled.

(2.8×10^{-5} mole per liter)(6.3 moles bioaccumulated per mole) = 1.8×10^{-4} moles per liter

This value, however, exceeds the cap for humic-mobilized plutonium, 1.1×10^{-5} mole per liter. Therefore, in this case, the cap would be used for the humic mobilized actinide concentration.

The microbial mobilized plutonium would be:

(2.8×10^{-5} mole per liter)(0.3 moles adsorbed per mole per liter) = 8.3×10^{-6} moles

which is less than the cap.

The total plutonium concentration for this realization would then be the sum of the dissolved and colloidal actinides:

Dissolved + Humic + Microbe + Mineral + Intrinsic

$$2.8 \times 10^{-5} + 1.1 \times 10^{-5} + 8.3 \times 10^{-6} + 2.6 \times 10^{-8} + 1.0 \times 10^{-9} = 4.7 \times 10^{-5} \text{ mole per liter}$$

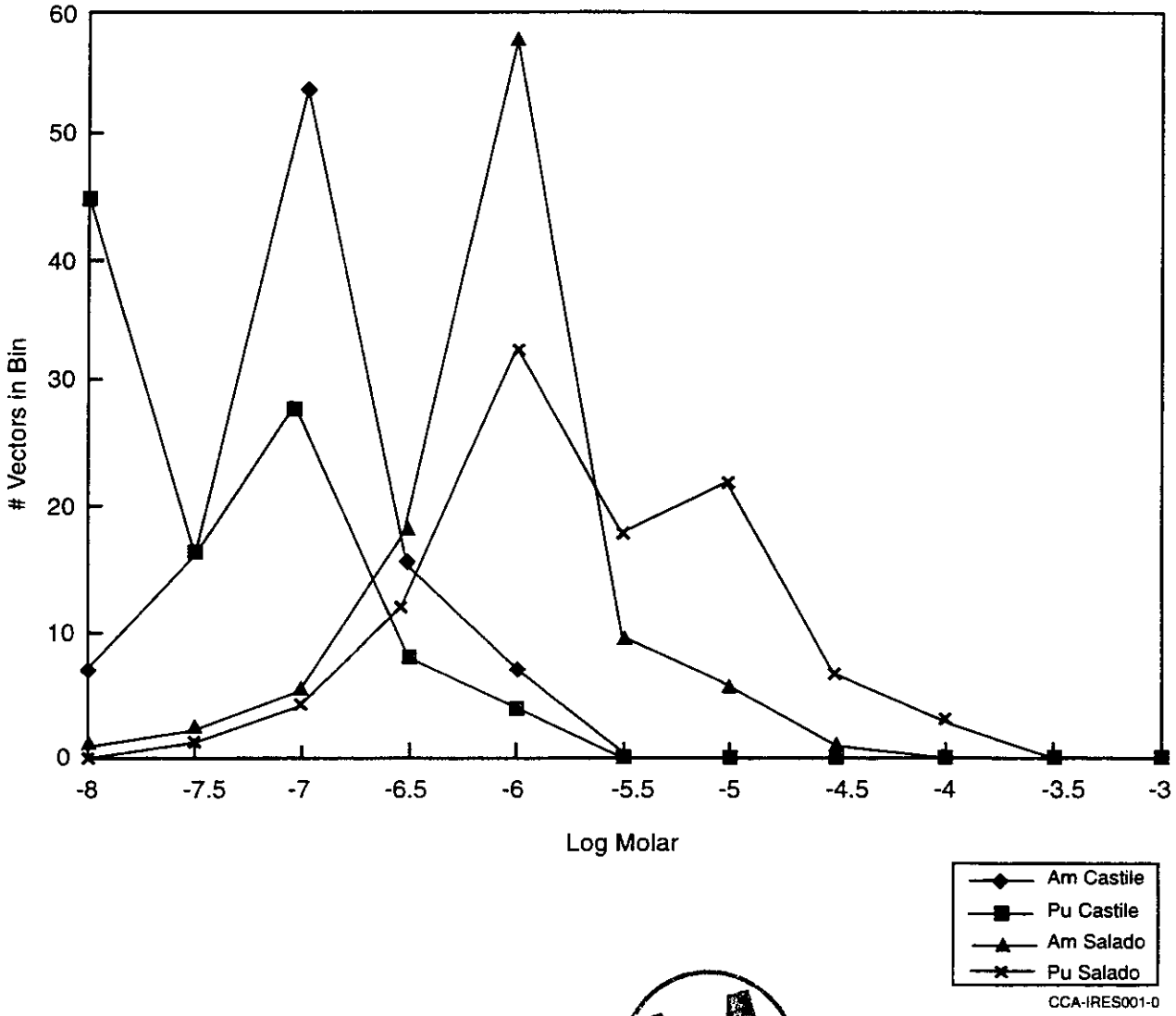

Figure IRES-1. Solubility Distributions, Dissolved Only

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Figure IRES-2 shows mobilized concentrations of Am and Pu that include colloidal sorption. The solubility curves for plutonium in both brines have shifted to higher solubilities, reflecting the proportionality constants in Table IRES-12.

Tables IRES-13 and IRES-14 show the dissolved actinide concentrations for the Castile and Salado, respectively. Tables IRES-15 and IRES-16 show the total (dissolved plus colloidal) actinide concentrations for the Castile for the higher and lower oxidation states, respectively.

Table IRES-13. Castile Dissolved Concentrations

Vector	Solubility, log (moles per liter)				
	AM	PU	U	TH	NP
1	-7.57675	-8.30323	-5.06662	-8.22185	-5.65758
2	-7.33185	-7.62315	-8.22185	-8.22185	-8.22185
3	-7.2815	-9.80785	-4.41232	-8.22185	-5.65758
4	-9.02775	-7.61585	-5.23252	-8.22185	-5.65758
5	-7.53655	-8.35315	-5.24412	-8.22185	-5.65758
6	-7.31675	-7.07165	-8.22185	-8.22185	-8.22185
7	-6.79915	-6.55625	-8.22185	-8.22185	-8.22185
8	-7.48195	-7.12887	-8.22185	-8.22185	-8.22185
9	-6.94095	-8.63695	-5.73142	-8.22185	-5.65758
10	-7.18846	-8.61245	-4.93772	-8.22185	-5.65758
11	-8.78975	-7.19006	-8.22185	-8.22185	-8.22185
12	-8.67475	-8.55225	-5.26982	-8.22185	-5.65758
13	-7.33995	-7.96385	-4.82982	-8.22185	-5.65758
14	-7.15187	-7.53335	-8.22185	-8.22185	-8.22185
15	-7.35555	-7.55525	-4.90272	-8.22185	-5.65758
16	-6.45145	-6.93485	-4.81172	-8.22185	-5.65758
17	-7.03035	-8.35675	-5.21522	-8.22185	-5.65758
18	-6.52835	-8.44885	-4.97782	-8.22185	-5.65758
19	-7.43955	-7.37865	-8.22185	-8.22185	-8.22185
20	-7.00775	-7.34005	-5.11499	-8.22185	-5.65758
21	-7.17771	-6.83125	-8.22185	-8.22185	-8.22185
22	-6.71965	-8.24748	-5.01866	-8.22185	-5.65758
23	-7.21716	-8.10935	-5.25422	-8.22185	-5.65758
24	-7.86655	-7.32325	-8.22185	-8.22185	-8.22185
25	-7.46505	-7.60645	-8.22185	-8.22185	-8.22185
26	-6.87585	-8.23479	-5.25942	-8.22185	-5.65758
27	-7.13032	-6.47115	-8.22185	-8.22185	-8.22185
28	-7.25786	-8.30848	-3.76552	-8.22185	-5.65758
29	-6.01375	-8.43025	-4.39772	-8.22185	-5.65758
30	-7.16789	-9.12385	-5.58072	-8.22185	-5.65758
31	-7.08505	-8.69245	-5.62032	-8.22185	-5.65758
32	-7.92075	-8.50555	-5.09281	-8.22185	-5.65758
33	-7.58815	-8.37325	-4.9721	-8.22185	-5.65758
34	-6.99425	-7.21194	-8.22185	-8.22185	-8.22185
35	-7.19845	-7.40835	-8.22185	-8.22185	-8.22185
36	-7.28795	-8.26475	-5.22342	-8.22185	-5.65758

Table IRES-13. Castile Dissolved Concentrations (Continued)

Vector	Solubility, log (moles per liter)				
	AM	PU	U	TH	NP
37	-7.26559	-7.39585	-8.22185	-8.22185	-8.22185
38	-7.25409	-8.02435	-5.98752	-8.22185	-5.65758
39	-7.31855	-9.09945	-5.16402	-8.22185	-5.65758
40	-7.74435	-6.67865	-8.22185	-8.22185	-8.22185
41	-8.08175	-8.40545	-4.91592	-8.22185	-5.65758
42	-6.89445	-6.84265	-8.22185	-8.22185	-8.22185
43	-7.32725	-9.01535	-5.38342	-8.22185	-5.65758
44	-6.19005	-8.12035	-5.09978	-8.22185	-5.65758
45	-6.26825	-8.56205	-6.97152	-8.22185	-5.65758
46	-8.29275	-8.20775	-8.22185	-8.22185	-8.22185
47	-7.36085	-7.59455	-8.22185	-8.22185	-8.22185
48	-7.21021	-7.88015	-8.22185	-8.22185	-8.22185
49	-6.37745	-7.27645	-8.22185	-8.22185	-8.22185
50	-7.10494	-7.39035	-8.22185	-8.22185	-8.22185
51	-7.40815	-7.17792	-8.22185	-8.22185	-8.22185
52	-7.36675	-8.03235	-5.17512	-8.22185	-5.65758
53	-6.66455	-7.29305	-8.22185	-8.22185	-8.22185
54	-7.40245	-8.00475	-4.07612	-8.22185	-5.65758
55	-7.82245	-6.60045	-8.22185	-8.22185	-8.22185
56	-7.30825	-8.63075	-6.42252	-8.22185	-5.65758
57	-6.61825	-7.30825	-8.22185	-8.22185	-8.22185
58	-7.66125	-7.30215	-8.22185	-8.22185	-8.22185
59	-7.38385	-7.55585	-8.22185	-8.22185	-8.22185
60	-6.42835	-6.22355	-8.22185	-8.22185	-8.22185
61	-7.54535	-7.10168	-8.22185	-8.22185	-8.22185
62	-7.64415	-7.03695	-8.22185	-8.22185	-8.22185
63	-7.23986	-7.36955	-8.22185	-8.22185	-8.22185
64	-7.22662	-9.14175	-8.22185	-8.22185	-8.22185
65	-8.16035	-7.99165	-5.42262	-8.22185	-5.65758
66	-7.07145	-8.10605	-8.22185	-8.22185	-8.22185
67	-7.67385	-7.81565	-4.82142	-8.22185	-5.65758
68	-7.34695	-8.18676	-5.45082	-8.22185	-5.65758
69	-7.70775	-6.38855	-8.22185	-8.22185	-8.22185
70	-7.03225	-6.98315	-8.22185	-8.22185	-8.22185
71	-7.24257	-9.46685	-4.69392	-8.22185	-5.65758

Table IRES-13. Castile Dissolved Concentrations (Continued)

Vector	Solubility, log (moles per liter)				
	AM	PU	U	TH	NP
72	-8.03415	-7.19447	-8.22185	-8.22185	-8.22185
73	-7.27057	-8.31775	-4.92782	-8.22185	-5.65758
74	-7.30125	-7.56615	-8.22185	-8.22185	-8.22185
75	-6.75855	-8.52205	-4.77582	-8.22185	-5.65758
76	-7.43385	-8.21909	-5.0354	-8.22185	-5.65758
77	-7.41705	-8.05505	-4.99894	-8.22185	-5.65758
78	-6.56015	-9.18435	-5.27432	-8.22185	-5.65758
79	-7.61525	-7.40695	-8.22185	-8.22185	-8.22185
80	-6.30205	-6.00275	-8.22185	-8.22185	-8.22185
81	-6.98175	-7.27385	-8.22185	-8.22185	-8.22185
82	-7.29355	-7.82515	-5.82312	-8.22185	-5.65758
83	-7.05685	-7.35925	-8.22185	-8.22185	-8.22185
84	-7.42535	-8.01735	-4.95382	-8.22185	-5.65758
85	-7.52245	-7.68325	-8.22185	-8.22185	-8.22185
86	-7.50255	-7.78875	-8.22185	-8.22185	-8.22185
87	-7.11963	-6.98995	-8.22185	-8.22185	-8.22185
88	-7.22879	-7.42105	-5.52422	-8.22185	-5.65758
89	-6.96475	-7.34455	-8.22185	-8.22185	-8.22185
90	-6.99785	-8.29558	-5.02774	-8.22185	-5.65758
91	-7.37545	-8.68155	-4.65292	-8.22185	-5.65758
92	-7.39065	-7.25055	-4.46552	-8.22185	-5.65758
93	-7.04735	-8.84325	-5.92432	-8.22185	-5.65758
94	-7.39905	-7.02395	-8.22185	-8.22185	-8.22185
95	-7.60705	-7.00665	-8.22185	-8.22185	-8.22185
96	-7.13982	-7.63595	-8.22185	-8.22185	-8.22185
97	-7.20501	-8.32885	-5.31642	-8.22185	-5.65758
98	-7.09945	-8.19906	-4.10712	-8.22185	-5.65758
99	-6.95875	-8.16685	-8.22185	-8.22185	-8.22185
100	-8.00275	-7.06565	-8.22185	-8.22185	-8.22185

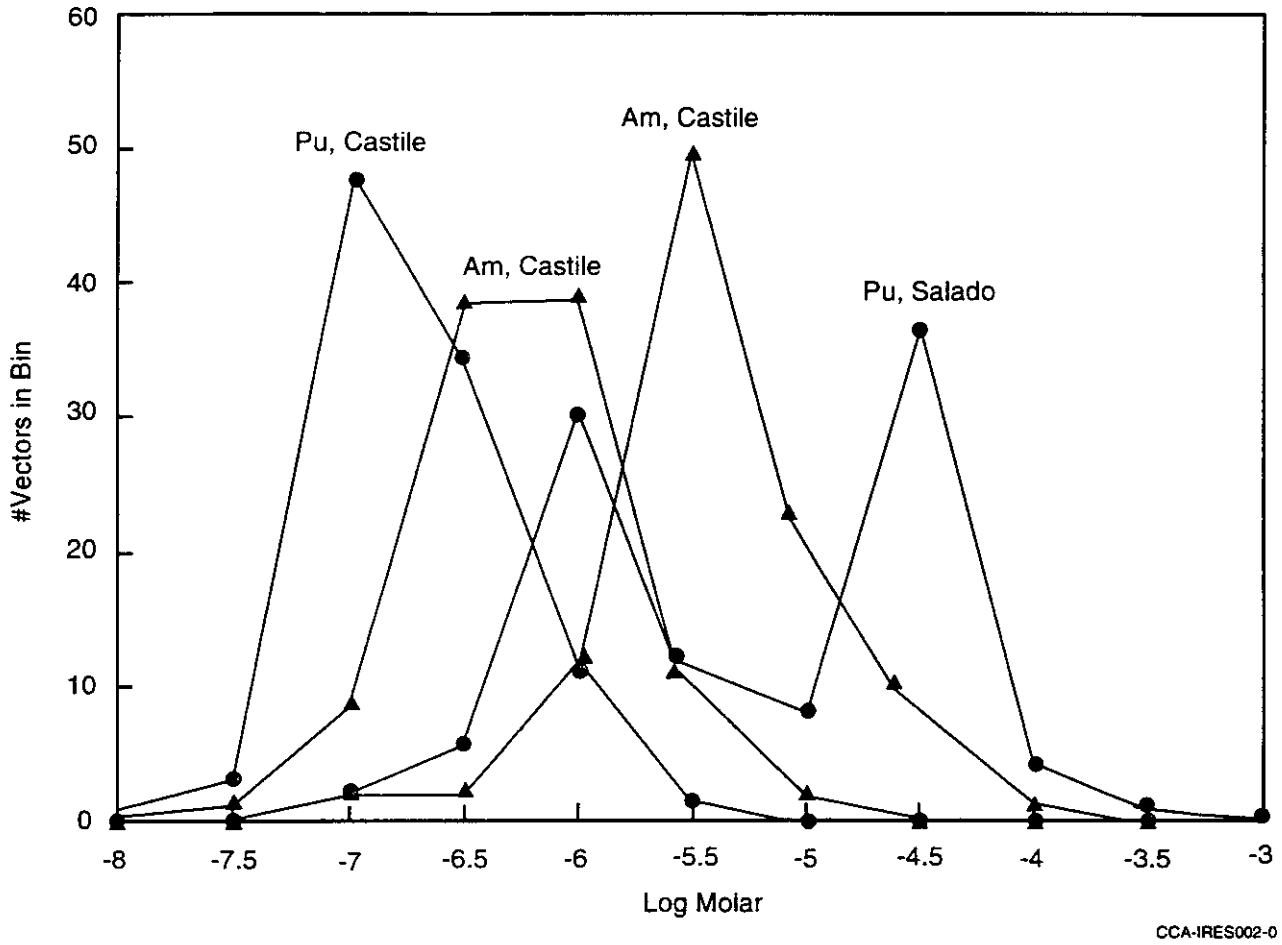

Figure IRES-2. Total Maximum Concentration (Dissolved and Colloidal)

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Table IRES-14. Salado Dissolved Concentrations

Vector	Solubility, log (moles per liter)				
	AM	PU	U	TH	NP
1	-6.43268	-5.63975	-5.29288	-4.80435	-5.63827
2	-6.61718	-5.54978	-5.58375	-5.77205	-5.35655
3	-7.12528	-5.55255	-4.97951	-5.55555	-5.63827
4	-5.26938	-6.44655	-5.39898	-5.71305	-5.63827
5	-6.07578	-4.46475	-5.18438	-5.42898	-5.63827
6	-6.51858	-6.47978	-5.27287	-5.19585	-5.35655
7	-6.46978	-6.43448	-5.70345	-5.50385	-5.35655
8	-6.17471	-6.09068	-5.31314	-5.00425	-5.35655
9	-6.86518	-5.33257	-5.21818	-5.37298	-5.63827
10	-6.32402	-5.37171	-5.32328	-5.38635	-5.63827
11	-6.24658	-6.65838	-5.61075	-4.56115	-5.35655
12	-6.38078	-4.06455	-4.11198	-5.4001	-5.63827
13	-6.54578	-5.19085	-5.15922	-5.63955	-5.63827
14	-6.45318	-6.25537	-5.96575	-4.62485	-5.35655
15	-6.25554	-5.41833	-4.49808	-5.3658	-5.63827
16	-5.90178	-5.21605	-6.01588	-5.4099	-5.63827
17	-5.81728	-4.51515	-4.90548	-5.48735	-5.63827
18	-6.72088	-5.43283	-4.96974	-5.56345	-5.63827
19	-6.21742	-6.38508	-5.40992	-4.82695	-5.35655
20	-6.23421	-5.70195	-4.81148	-6.25105	-5.63827
21	-5.55718	-5.49558	-5.41372	-4.50965	-5.35655
22	-6.38648	-5.03715	-5.74688	-5.53765	-5.63827
23	-6.29578	-5.34506	-4.62098	-5.46085	-5.63827
24	-5.48098	-6.46618	-6.29565	-5.44547	-5.35655
25	-6.06218	-6.20996	-5.11435	-6.19795	-5.35655
26	-5.39198	-5.72485	-5.24558	-5.11795	-5.63827
27	-6.44988	-7.11578	-5.58785	-6.17745	-5.35655
28	-6.00678	-4.96725	-4.52658	-6.55755	-5.63827
29	-6.91908	-5.54585	-6.79848	-6.12915	-5.63827
30	-5.65358	-6.99955	-5.50548	-5.32573	-5.63827
31	-6.19007	-5.40947	-4.38688	-5.14095	-5.63827
32	-6.04178	-5.52425	-6.43348	-5.52715	-5.63827
33	-6.63018	-5.49825	-4.89228	-5.3959	-5.63827
34	-5.35338	-6.46318	-4.70475	-5.89515	-5.35655
35	-5.74318	-6.55168	-4.72845	-5.72135	-5.35655
36	-6.42858	-5.20935	-5.52548	-5.47035	-5.63827
37	-6.96628	-6.71398	-5.56405	-4.36245	-5.35655

Table IRES-14. Salado Dissolved Concentrations (Continued)

Vector	Solubility, log (moles per liter)				
	AM	PU	U	TH	NP
38	-6.32616	-4.91725	-5.22268	-5.17695	-5.63827
39	-5.59608	-4.90555	-4.99712	-5.15685	-5.63827
40	-7.04358	-6.09518	-5.16835	-5.52225	-5.35655
41	-7.10528	-6.04685	-5.47628	-5.81675	-5.63827
42	-6.37068	-6.28717	-5.13645	-5.53165	-5.35655
43	-6.53018	-5.07445	-5.11826	-5.3564	-5.63827
44	-6.08798	-5.67135	-5.67938	-5.23345	-5.63827
45	-6.40728	-5.36299	-4.95758	-5.75975	-5.63827
46	-8.09408	-5.98458	-5.4014	-7.17655	-5.35655
47	-6.27105	-6.36188	-5.14975	-4.75175	-5.35655
48	-6.83068	-6.27087	-6.00695	-5.12395	-5.35655
49	-6.39488	-5.79418	-5.38145	-4.66205	-5.35655
50	-6.20802	-6.55818	-5.37236	-5.42349	-5.35655
51	-6.28634	-7.15078	-5.4311	-6.07195	-5.35655
52	-7.84708	-5.84555	-5.11148	-5.49205	-5.63827
53	-6.64928	-6.27865	-5.67425	-5.48135	-5.35655
54	-6.36068	-4.65205	-5.21178	-5.22325	-5.63827
55	-6.78668	-6.01358	-5.42345	-5.01735	-5.35655
56	-5.70058	-5.25055	-5.05311	-5.91855	-5.63827
57	-6.05558	-6.32537	-5.29081	-5.18515	-5.35655
58	-5.98688	-6.57548	-4.58175	-5.59565	-5.35655
59	-6.30107	-7.96108	-5.84925	-5.44903	-5.35655
60	-6.47718	-6.11478	-5.55195	-5.73605	-5.35655
61	-6.34098	-6.12128	-5.20745	-6.81455	-5.35655
62	-6.17563	-6.18573	-5.56695	-5.84255	-5.35655
63	-6.02118	-5.62378	-5.59795	-4.94245	-5.35655
64	-6.49478	-6.3145	-5.43771	-5.15235	-5.35655
65	-6.31283	-5.46555	-4.87088	-6.94755	-5.63827
66	-5.48528	-7.02938	-5.53265	-5.57425	-5.35655
67	-6.12228	-5.17805	-5.09199	-3.98955	-5.63827
68	-6.71228	-4.77905	-5.59688	-5.20375	-5.63827
69	-6.35158	-6.42778	-4.47435	-4.86465	-5.35655
70	-6.15934	-6.50858	-5.3328	-5.29428	-5.35655
71	-6.59498	-6.27845	-5.0797	-5.67695	-5.63827
72	-6.25608	-6.38898	-5.82785	-5.45835	-5.35655
73	-6.67678	-6.77955	-4.91168	-5.59175	-5.63827

Table IRES-14. Salado Dissolved Concentrations (Continued)

Vector	Solubility, log (moles per liter)				
	AM	PU	U	TH	NP
74	-7.18258	-6.12968	-5.29725	-5.64435	-5.35655
75	-6.14388	-4.81735	-5.06779	-4.45105	-5.63827
76	-6.69278	-6.19635	-5.23658	-5.67945	-5.63827
77	-6.35928	-4.42975	-5.14315	-5.28285	-5.63827
78	-6.39458	-5.11385	-7.02748	-5.60605	-5.63827
79	-6.43918	-7.48508	-5.77825	-5.357	-5.35655
80	-7.52008	-6.92808	-5.50075	-6.00225	-5.35655
81	-6.48398	-5.63778	-5.48005	-5.08735	-5.35655
82	-6.10148	-5.47375	-5.43788	-5.25025	-5.63827
83	-6.13098	-6.40808	-4.95745	-5.51305	-5.35655
84	-4.97108	-5.52125	-5.27138	-6.30385	-5.63827
85	-7.47008	-6.68768	-5.72975	-4.46815	-5.35655
86	-5.93748	-6.24453	-6.47255	-5.82535	-5.35655
87	-6.23887	-6.04248	-5.76155	-5.41616	-5.35655
88	-6.33299	-5.82275	-4.44808	-5.26497	-5.63827
89	-6.56308	-6.52508	-5.06555	-5.4393	-5.35655
90	-5.33228	-5.45935	-4.93838	-5.62295	-5.63827
91	-6.31125	-5.81565	-4.32058	-5.50035	-5.63827
92	-6.41508	-5.49185	-5.88208	-5.31646	-5.63827
93	-6.46218	-5.50965	-5.26718	-5.34285	-5.63827
94	-6.02028	-6.42108	-5.39641	-5.56525	-5.35655
95	-6.58538	-6.62278	-5.54985	-5.24675	-5.35655
96	-6.10908	-5.74038	-4.60945	-5.38018	-5.35655
97	-6.26472	-5.30731	-4.78278	-5.30125	-5.63827
98	-5.88278	-6.10255	-5.18718	-5.79895	-5.63827
99	-6.42218	-6.39568	-5.25723	-5.57975	-5.35655
100	-6.2802	-6.34768	-5.90675	-5.54835	-5.35655

Table IRES-15. Higher Oxidation State for the Castile (Dissolved plus Colloidal)

Vector	Solubility, log (moles per liter)				
	AM	PU	U	TH	oxstat
91	-6.55511	-7.36833	-4.47743	-7.05355	0.5093
38	-6.47261	-7.005	-5.80074	-7.05355	0.5155
32	-7.02124	-7.29475	-4.9123	-7.05355	0.5284
98	-6.29253	-7.12461	-4.04899	-7.05355	0.5378
30	-6.36692	-7.48526	-5.3983	-7.05355	0.5434
17	-6.28855	-7.21879	-5.03441	-7.05355	0.5544
5	-6.75969	-7.21679	-5.06323	-7.05355	0.5603
73	-6.50868	-7.19678	-4.7476	-7.05355	0.5736
75	-5.9642	-7.30239	-4.59579	-7.05355	0.5877
77	-6.58748	-7.02709	-4.81861	-7.05355	0.5977
44	-5.503	-7.0726	-4.91926	-7.05355	0.6022
28	-6.47878	-7.19143	-3.73761	-7.05355	0.6187
43	-6.50239	-7.46425	-5.20203	-7.05355	0.6274
71	-6.52959	-7.5288	-4.51397	-7.05355	0.6382
67	-6.83665	-6.84409	-4.64134	-7.05355	0.6457
68	-6.5384	-7.11669	-5.26913	-7.05355	0.6583
88	-6.41941	-6.50135	-5.34215	-7.05355	0.6626
4	-7.51139	-6.67559	-5.05166	-7.05355	0.6761
78	-5.77686	-7.49524	-5.09333	-7.05355	0.6836
84	-6.63444	-6.9999	-4.77357	-7.05355	0.6993
76	-6.6092	-7.13733	-4.85501	-7.05355	0.7062
92	-6.56612	-6.3431	-4.34358	-7.05355	0.7152
29	-5.32555	-7.2579	-4.29132	-7.05355	0.7284
23	-6.46618	-7.06508	-5.0733	-7.05355	0.7374
82	-6.47638	-6.85178	-5.6386	-7.05355	0.7424
97	-6.43102	-7.20313	-5.13529	-7.05355	0.7575
16	-5.66858	-6.04095	-4.63165	-7.05355	0.7699
22	-5.9304	-7.15498	-4.8383	-7.05355	0.7796
45	-5.47894	-7.32027	-6.72709	-7.05355	0.7801
93	-6.24877	-7.42132	-5.73851	-7.05355	0.7985
54	-6.57471	-6.99066	-4.0217	-7.05355	0.805
90	-6.1936	-7.18389	-4.84736	-7.05355	0.8106
15	-6.53788	-6.62229	-4.72254	-7.05355	0.8223
39	-6.59544	-7.4809	-4.98335	-7.05355	0.8392
65	-7.18326	-6.98099	-5.24107	-7.05355	0.8493
36	-6.54727	-7.16551	-5.04259	-7.05355	0.8592

Table IRES-15. Higher Oxidation State for the Castile (Dissolved plus Colloidal) (Continued)

Vector	Solubility, log (moles per liter)				
	AM	PU	U	TH	oxstat
31	-6.33357	-7.37233	-5.43763	-7.05355	0.8603
9	-6.23271	-7.35131	-5.54783	-7.05355	0.8715
20	-6.20781	-6.42672	-4.93443	-7.05355	0.8802
13	-6.57214	-6.9602	-4.64973	-7.05355	0.8982
56	-6.49236	-7.34886	-6.22362	-7.05355	0.9017
18	-5.74219	-7.26731	-4.79753	-7.05355	0.9155
26	-6.07196	-7.14715	-5.07848	-7.05355	0.9247
52	-6.56755	-7.0108	-4.99442	-7.05355	0.9394
3	-6.45724	-7.55001	-4.30273	-7.05355	0.9432
33	-6.73081	-7.22784	-4.79182	-7.05355	0.9543
41	-7.12623	-7.24505	-4.73572	-7.05355	0.9672
10	-6.36903	-7.3415	-4.75749	-7.05355	0.9708
12	-7.42553	-7.31597	-5.08885	-7.05355	0.9828
1	-6.82016	-7.18837	-4.88617	-7.05355	0.9977

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Table IRES-16. Lower Oxidation State for the Castile (Dissolved plus Colloidal)

	Solubility, log (moles per liter)				
Vector	AM	PU	U	TH	oxstat
99	-6.1567	-7.33641	-7.15607	-7.05355	0.00655
80	-5.61645	-5.81992	-7.15607	-7.05355	0.01882
69	-6.86312	-6.00258	-7.15607	-7.05355	0.02529
24	-6.97334	-6.82132	-7.15607	-7.05355	0.03426
46	-7.243	-7.35234	-7.15607	-7.05355	0.0442
87	-6.30529	-6.49263	-7.15607	-7.05355	0.05301
2	-6.51315	-7.03626	-7.15607	-7.05355	0.06733
21	-6.38965	-6.41129	-7.15607	-7.05355	0.07913
81	-6.24296	-6.88679	-7.15607	-7.05355	0.08302
58	-6.80182	-6.7857	-7.15607	-7.05355	0.09834
89	-6.16029	-6.80902	-7.15607	-7.05355	0.1024
40	-6.93279	-6.40787	-7.15607	-7.05355	0.1155
42	-6.09189	-6.36108	-7.15607	-7.05355	0.1265
70	-6.26103	-6.57074	-7.15607	-7.05355	0.1311
95	-6.75561	-6.5259	-7.15607	-7.05355	0.1422
85	-6.74809	-7.19412	-7.15607	-7.05355	0.1595
79	-6.77766	-6.90219	-7.15607	-7.05355	0.1665
86	-6.67126	-7.15387	-7.15607	-7.05355	0.178
59	-6.63289	-7.12811	-7.15607	-7.05355	0.1832
94	-6.5644	-6.52326	-7.15607	-7.05355	0.1931
34	-6.2417	-6.80713	-7.15607	-7.05355	0.2028
6	-6.59075	-6.81628	-7.15607	-7.05355	0.2142
7	-6.00903	-6.10891	-7.15607	-7.05355	0.2202
19	-6.60194	-6.83326	-7.15607	-7.05355	0.2374
51	-6.65802	-6.86273	-7.15607	-7.05355	0.2446
66	-6.26159	-7.30707	-7.15607	-7.05355	0.257
48	-6.39597	-7.19469	-7.15607	-7.05355	0.264
35	-6.45428	-7.00537	-7.15607	-7.05355	0.2707
61	-6.7017	-6.60959	-7.15607	-7.05355	0.2814
96	-6.39646	-7.15207	-7.15607	-7.05355	0.297
63	-6.42192	-6.83094	-7.15607	-7.05355	0.3081
50	-6.29706	-6.85161	-7.15607	-7.05355	0.3153
14	-6.42801	-7.12714	-7.15607	-7.05355	0.3243
62	-6.82996	-6.6627	-7.15607	-7.05355	0.3349
11	-7.44622	-6.69144	-7.15607	-7.05355	0.3461
57	-5.86351	-6.85704	-7.15607	-7.05355	0.3561
60	-5.693	-5.89878	-7.15607	-7.05355	0.3698
49	-5.58373	-6.74917	-7.15607	-7.05355	0.3799
72	-7.07988	-6.67457	-7.15607	-7.05355	0.3896
64	-6.45855	-7.54466	-7.15607	-7.05355	0.3913
83	-6.25859	-6.84002	-7.15607	-7.05355	0.4035
27	-6.31935	-6.00877	-7.15607	-7.05355	0.4144

Table IRES-16. Lower Oxidation State for the Castile (Dissolved plus Colloidal) (Continued)

	Solubility, log (moles per liter)				
Vector	AM	PU	U	TH	oxstat
37	-6.46603	-6.89128	-7.15607	-7.05355	0.4213
55	-6.92961	-6.13901	-7.15607	-7.05355	0.4309
8	-6.74319	-6.88477	-7.15607	-7.05355	0.4481
47	-6.5324	-7.00332	-7.15607	-7.05355	0.4543
100	-7.05943	-6.56404	-7.15607	-7.05355	0.4603
74	-6.48308	-6.99174	-7.15607	-7.05355	0.4796
25	-6.71071	-7.17312	-7.15607	-7.05355	0.4807
53	-5.86721	-6.76399	-7.15607	-7.05355	0.4948

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix LMP

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Land Management Plan

WASTE ISOLATION PILOT PLANT LAND MANAGEMENT PLAN

DOE/WIPP 93-004

WASTE ISOLATION PILOT PLANT

LAND MANAGEMENT PLAN

DOE/WIPP - 93-004

Reprint 01/31/96

The majority of artworks contained in this Plan were courteously provided by W.E. "Bill" Briggs and C.H. "Chuck" Dyer.

FOREWORD

A prospective land user who has questions regarding elements of land management contained in this plan (see Table of Contents) or wishes to request access to Waste Isolation Pilot Plant (WIPP) lands should contact the U.S. Department of Energy (DOE) at (505) 234-7303 or write the Carlsbad Area Office, P.O. Box 3090, Carlsbad, NM 88221. In the event of an emergency, call the WIPP Central Monitoring Room at 234-8125, 234-8457, or 234-8111.

Prior to submitting requests for land use, the requestor should examine the content of this document to identify those chapters that apply to the components of the respective activity, and provide for the implementation of adherence with WIPP land management edicts provided in this plan. For example, a potential user should read Chapter 2, "Environmental Compliance," to become familiar with the required permitting procedures and corresponding documentation.

It is the goal of the DOE to develop a "user-friendly" document that allows for reliable applications of management goals and objectives required to maintain site integrity, environmental quality and to sustain multiple-land use objectives where appropriate.

Through continual information sharing and timely updates of the Land Management Plan (LMP), the WIPP seeks to encourage improved land management practices based upon sound professional standards. Guidance prescribed by the LMP is useful for proposed activities, external as well as WIPP-related, that could impact lands used in the operation of the WIPP.

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ACRONYMS AND ABBREVIATIONS

APD	Application for Permit to Drill
API	American Petroleum Institute
ASER	Annual Site Environmental Report
AUM	Animal Unit Month
BECR	Biennial Environmental Compliance Report
BFB	Backshift Fire Brigade
BLM	Bureau of Land Management
CAO	Carlsbad Area Office (of the DOE)
CFR	*Code of Federal Regulations*
CMR	Central Monitoring Room
CMRO	Central Monitoring Room Operator
DOE	(United States) Department of Energy
DOE-AL	(United States) Department of Energy Albuquerque Operations Office
DOI	(United States) Department of Interior
EA	Environmental Assessment
EMNRD	(New Mexico) Environment, Minerals, and Natural Resources Department
EOC	Emergency Operation Center
ERO	Emergency Response Organization
ERT	Emergency Response Team
EPA	(United States) Environmental Protection Agency
ER	Environmental Review
ES&H	Environment, Safety and Health
EST	Emergency Services Technician
FEIS	Final Environmental Impact Statement
FLPMA	Federal Land Policy and Management Act
FSM	Facility Shift Manager
GSP	Groundwater Surveillance Program
HAZMAT	Hazardous Materials
IMC	International Minerals and Chemical Corporation
LMC	Land Management Council
LMIP	Land Management Implementation Plan
LMP	Land Management Plan
LUC	Land Use Coordinator
LUR	Land Use Request
LWA	(WIPP) Land Withdrawal Act

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MCF	Thousand Cubic Feet
MOU	Memorandum of Understanding
MSDS	Material Safety Data Sheet
MSHA	Mine Safety and Health Administration of the U.S. Department of Labor
NEPA	National Environmental Policy Act
NMDG&F	New Mexico Department of Game and Fish
NMED	New Mexico Environment Department
ORV	Off-Road Vehicle
OSHA	Occupational Safety and Health Administration of the U.S. Department of Labor
P.L.	Public Law
PPE	Personal Protective Equipment
RCRA	Resource Conservation and Recovery Act
RMP	Resource Management Plan
SEIS	Supplement Environmental Impact Statement
SG	Grassland (Short-grass Prairie)
SHPO	State Historic Preservation Officer
SMA	Special Management Area
SNL	Sandia National Laboratories
SOD	Shin Oak/Dune Habitat
SPDV	Site and Preliminary Design Validation
SRS	Supervisory Realty Specialist
STR	Subcontract Technical Representative
T&E	Threatened and Endangered
TRU	Transuranic
U.S.C	*United States Code*
USF&WS	United State Fish and Wildlife Service
WID	Waste Isolation Division of the Westinghouse Electric Corporation
WLWA	WIPP Land Withdrawal Area
WIPP	Waste Isolation Pilot Plant
WP	WIPP Procedure

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PREFACE

In accordance with Section 4 of the Waste Isolation Pilot Plant (WIPP) *Land Withdrawal Act* (LWA) (Public Law 102-579), the DOE has prepared this Land Management Plan (LMP) as required by the Act. The development of this plan is in concert with the U.S. Department of Interior's (DOI) Bureau of Land Management (BLM) and the state of New Mexico. Changes or amendments to this plan shall be done in consultation with the BLM, the state of New Mexico, and affected stakeholders, as appropriate.

This LMP, as required by LWA, has been prepared to identify resource values, promote the concept of multiple-use management, and identify long-term goals for the management of WIPP lands until the culmination of the decommissioning phase. This plan also provides the opportunity for participation in the land use planning process by the public, as well as local, state, and federal agencies.

This document is a reprint of the LMP which incorporates elements of implementation previously provided in the WIPP *Land Management Implementation Plan* (LMIP) (DOE/WIPP 94-026). This reprint does not revise or amend the intent or scope of the original plan, but merges implementing actions from the LMIP to make the plan more helpful for those desiring to use WIPP lands. An additional reason for developing this reprint was to reduce document volume and redundancies in text, which results in the LMIP being superseded by this LMP.

This plan is prepared through the integration of the WIPP *Land Withdrawal Act* of 1992 (Public Law 102-579), BLM planning regulations (43 CFR 1600) issued under the authority of the Federal Land Policy and Management Act (FLPMA) of 1976, the National Environmental Policy Act (NEPA) of 1969, as amended; and existing Memoranda of Understanding (MOU) among the DOE and local, state and/or federal agencies. The LMP is designed to provide a comprehensive framework for the management and coordination of WIPP land uses during the life of the project. The LMP, and any subsequent amendments, will continue through the decommissioning phase. Moreover, in accordance with section 13 of the WIPP *Land Withdrawal Act,* the DOE will develop, in consultation with the Secretary of the Interior and the State of New Mexico, a plan for the management and use of the WIPP Land Withdrawal Area following the decommissioning of WIPP. This plan must be developed by October 30, 1997.

The guidelines prescribed in the LMP provide for the management and oversight of WIPP lands under the jurisdiction of the DOE in addition to lands outside the WIPP boundary that are used in the operation of the WIPP (e.g., groundwater surveillance well pads outside the withdrawn area). Furthermore, this plan provides for multiagency involvement in the administration of DOE land management actions. Documents referenced in the LMP are available to any person and/or organization desiring to conduct activities on lands under the jurisdiction of the WIPP in addition to those involved in development and/or amending existing land management actions. Documents can be obtained from the U.S.

Department of Energy, Carlsbad Area Office, P.O. Box 3090, Carlsbad, New Mexico 88221.

This LMP envisions and encourages direct communication among stakeholders, including federal and state agencies involved in managing the resources within, or activities impacting the areas adjacent to, the WIPP Land Withdrawal Area (WLWA). It sets forth cooperative arrangements and protocols for addressing WIPP-related land management actions. The DOE recognizes the guidelines for contemporary land management practices that pertain to rational adherence with edicts in the WIPP LWA and all applicable regulatory requirements contained therein. Commitments contained in current permits, agreements, or concurrent MOUs with other agencies (e.g., state of New Mexico, DOI), shall be adhered to when addressing/evaluating land use management activities and future amendments that affect the management of WIPP lands.

This LMP will be reviewed on a biennial basis to assess the adequacy and effectiveness of the document, or as may be necessary to address emerging issues potentially affecting WIPP lands. Affected agencies, groups, and/or individuals may be involved in the review process.

The contents of the LMP focus on management protocols for the following issues: administration of the plan; environmental compliance; wildlife; cultural resources; grazing; recreation; energy and mineral resources; lands/realty; reclamation; security; industrial safety; emergency management; maintenance and work control. Each issue and its complementary planning/management criteria are described in the respective chapters.

CHAPTER 1

ADMINISTRATION OF THE LAND MANAGEMENT PLAN

GREAT SEAL OF THE STATE OF NEW MEXICO

CRESCIT EUNDO

1912

DEPARTMENT OF ENERGY

UNITED STATES OF AMERICA

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF LAND MANAGEMENT

CHAPTER 1

ADMINISTRATION OF THE WIPP LAND MANAGEMENT PLAN

1.0 INTRODUCTION

On October 30, 1992, the WIPP *Land Withdrawal Act* (P.L. 102-579) became law. This Act transferred the responsibility for the management of the WIPP Land Withdrawal Area (WLWA) (see Figure 10.1) from the Secretary of the Interior to the Secretary of Energy. In accordance with sections 3(a)(1) and (3) of the Act, these lands ". . . are withdrawn from all forms of entry, appropriation, and disposal under the public land laws . . ." and are reserved for the use of the Secretary of Energy ". . . for the construction, experimentation, operation, repair and maintenance, disposal, shutdown, monitoring, decommissioning, and other activities, associated with the purposes of WIPP as set forth in Section 213 of the Department of Energy National Security and Military Applications of Nuclear Energy Act of 1980 (P.L. 96-164; 93 Stat. 1259, 1265) and this Act."

As a complement to this LMP, a MOU has been executed between the DOE and the BLM, as required by section 4(d) of the Act. The state of New Mexico was consulted in the development of the MOU and the associated Statement of Work (SOW).

1.0.1 Affected Environment

The WIPP facility, a project of the United States Department of Energy (DOE), was authorized by P.L. 96-164 to provide a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States.

The WIPP Site is located in Eddy County in Southeastern New Mexico. The site is 26 miles east of Carlsbad, New Mexico, in a region known as the Los Medaños, that represents the initial intergradation between the Llano Estacado and the Chihuahuan Desert. This region displays an exceptional diversity of plant and animal inhabitants.

Geographically, the region is regarded as a relatively flat, sparsely inhabited plateau with little surface water. Demographically, there are approximately 26 residents at various locations within 10 miles of the WIPP site. The majority of the local population within 50 miles of the WIPP are concentrated in and around the communities of Carlsbad, Hobbs, Eunice, Jal, and Artesia, New Mexico. The nearest community is the village of Loving,

New Mexico, 18 miles west-southwest of the WIPP. The population of Loving decreased from an estimated 1600 in 1980 to 1240 in 1990 with a current population estimate of 1291. The nearest major populated area is Carlsbad, New Mexico, 26 miles west of the WIPP. The population of Carlsbad decreased from an estimated 25,496 in 1980 to an estimated 24,952 in 1990 with a current estimated population of 26,974. [Population estimates are calculated by subtracting the number of deaths from the number of births and adding net migration.] The transient population within 10 miles of the WIPP is associated with ranching, oil and gas exploration/production, and potash mining. The region is popular for recreation, providing opportunities for hunting, camping, hiking, and bird watching.

1.0.2 Implementation of the WIPP Land Management Plan

WIPP land management authorizations and actions, including budget proposals, will not create conflict with this LMP. Valid existing rights, operations, and activities under existing permits, contracts, cooperative agreements, MOUs, or other instruments for land use are evaluated to assure that the Land Use Request (LUR) process complies with the intent of existing permits and/or agreements.

Actions in the LMP shall be implemented over a period extending through decommissioning phase of the WIPP facility. In some cases, site-specific planning and environmental analyses more detailed than those required by this LMP may be required before an action can be taken.

This LMP will be reviewed biennially and updated as needed to reflect new management direction, program policy, and monitoring results, or to respond to changing congressional mandates. Amendments or revisions to this plan will be developed in consultation with the BLM and the state of New Mexico and promptly submitted to the Congress and the state of NM as required by section 4(e) of the Act.

As implementation of this plan proceeds, proposed land use projects not addressed in this plan will be evaluated in regards to the intent of this plan to determine conformance with the plan's objectives. The Land Management Council (LMC), convened in accordance with prescribed guidelines (Appendix A), shall review all proposals through the LUR process for this purpose, as defined in Chapter 2 of this plan. The LMC will determine if management actions contained in the LUR are provided for specifically in this plan or, if not mentioned, if they are clearly consistent with the terms, conditions, and decisions of the approved plan.

It is not the intent of the DOE to administer surface uses, within the extent of the WIPP Land Withdrawal Area (WLWA), as a WIPP exclusive use area. The goal of the DOE is to manage the surface of the WLWA using traditional multiple land use concepts. Accordingly, land-use restrictions will be minimized to the extent possible.

The subsurface of the WLWA is restricted to exclusive use by the WIPP with the exception of two 320-acre tracts that are leased for oil and gas development below 6000 feet. These subject tracts are identified as Federal Oil and Gas Leases No. NMNM 02953 and NMNM 02953C of Section 31, Township 22 South, Range 31 East. Restrictions pertaining

to subsurface properties are needed to protect the long-term integrity of the WIPP disposal system. In addition, it is the intent of the DOE that, during repository operations, safety and security will be maintained.

In accordance with section 4(c) of the Act, if the Secretary of Energy determines, in consultation with the Secretary of the Interior, that the health and/or safety of the public or the common defense and security require the closure to the public of any road, trail, or other portion of the withdrawal area, the DOE will take whatever action the Secretary determines to be necessary to effect and maintain the closure and shall provide notice (to the public) of such closure.

1.1 OBJECTIVE

The objective of this LMP is to provide the DOE with land management guidelines in addition to establishing criteria for review and implementation of land management decisions. These appraisals allow the DOE to evaluate the effectiveness of multiple-use decisions, and will provide guidance for the evaluation of productivity, condition, quality, or other issues related to land-management actions. Implementation and monitoring plans for each respective land resource are discussed in subsequent chapters of this document.

1.2 PLANNED ACTIONS

Planned actions are those associated with the review and update of this LMP. These are presented to assure timely review and update of the LMP and to establish consistency with current regional land management practices, DOE policy, and congressional directives.

1.2.1 Maintaining the Land Management Plan

The LMP shall be maintained efficiently through timely modifications which document new data, minor changes (e.g., amendments to existing regulations), or corrections, and which have undergone appropriate WIPP document review procedures. These modifications will not expand the scope or level of resource decisions, conditions, or terms prescribed in the LMP.

1.2.2 Updating, Amending, or Revising the Land Management Plan

The LMP may be updated, amended, or revised by the LMC, as described in Appendix A, when considering a proposal or an action that is not addressed by the LMP. Categories of plan changes are discussed below.

1.2.2.1 Updates

This category is used to define activities designated as "low impact" by the LMC. The purpose of this category is to designate proposal(s) that the LMC, in consultation with cognizant regulatory personnel, has identified as not being addressed specifically in the LMP and as not having significant environmental impact. A LUR shall be submitted to the LMC

for status determination. DOE NEPA Compliance Coordinator will assess the project for determination (e.g., DOE/NEPA categorical exclusion). Updates do not require a plan alteration.

1.2.2.2 Amendments

This category is used when preliminary analysis by the LMC indicates that proposal(s) not specifically addressed in the LMP have, or are likely to have, significant environmental impacts that would necessitate the development of an Environmental Assessment (EA). In this case the LMC and/or cognizant regulatory personnel, will evaluate regulatory impacts and possible permit requirements and request a National Environmental Policy Act (NEPA) determination from the DOE. Actions (e.g., document modifications) that are determined, by the LMC, as amendments will require stakeholder notification and subsequent submittal to Congress.

1.2.2.3 Revisions

This category is used when a proposal(s) not specifically addressed in the LMP will have a significant impact. A revision of the LMP may involve the preparation of a new LMP when updates or amendments can no longer keep the existing plan current with existing environmental impact statements (EIS), changing management needs, resource conditions, policies, or regulatory laws. Plan revisions will be considered only after a comprehensive review by the LMC and cognizant regulatory personnel. Revisions will be submitted to Congress, evaluated by all affected stakeholders, and may include formal, public involvement. A revision likely would result in a significant mission or regulatory change and would be conducted in accordance with all pertinent DOE planning policies.

CHAPTER 2

ENVIRONMENTAL COMPLIANCE

Land Withdrawal Act

NEPA FLPMA

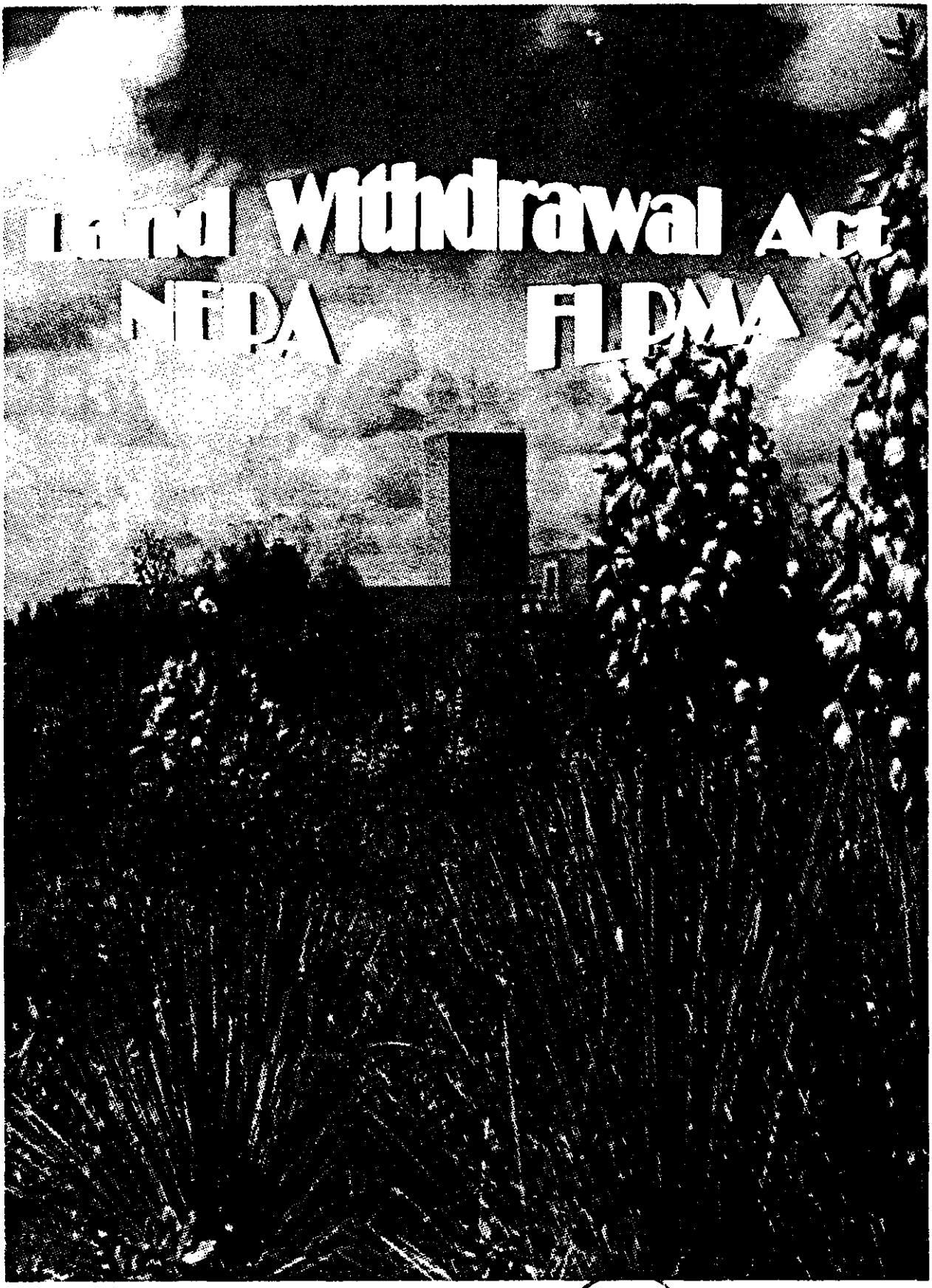

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CHAPTER 2
ENVIRONMENTAL COMPLIANCE

2.0 INTRODUCTION

Parties who desire to conduct activities that have the potential to impact the WIPP Land Withdrawal Area (WLWA), outside the perimeter of the Property Protection Area (see Figure 10.1), must prepare a Land Use Request (LUR) (Appendix B). This includes activities that originate outside the WLWA but will directly affect properties within the WLWA, or on lands outside the WLWA boundary under the jurisdiction of the WIPP. A LUR consists of a narrative description of the project, a completed Environmental Review (ER) (Attachment 1 to Appendix B), and a map depicting the location of the proposed activity. The LUR is used to determine if applicable regulatory requirements have been met prior to approval of a proposed project. A LUR is submitted by any WIPP organization or outside entity wishing to complete any construction rights-of-way, pipeline easements, or similar actions within the WLWA and on lands used in the operation of the WIPP, under the jurisdiction of the DOE.

2.1 OBJECTIVE

The objective of this chapter is to describe the method that the DOE, working in concert with the WIPP Land Use Coordinator (LUC), will use to review and implement regulatory guidelines that govern land use activities related to the WLWA. The DOE is required by various DOE Orders, the consultation and cooperation agreement between the DOE and the State of New Mexico, MOUs, and regulations to evaluate activities that could impact human health or the environment prior to implementation.

2.2 PLANNED ACTIONS

The review and implementation of activity-specific regulatory requirements is initiated by a NEPA review of the activity. NEPA requirements are implemented through the WIPP NEPA Compliance Program. As described below, the ER is used to initiate regulatory reviews. Through the submittal of a LUR and an attached ER, the WIPP NEPA Compliance Coordinator evaluates potential environmental impacts, mitigating actions for the impacts, and potential permit requirements. ERs are evaluated to determine if air, water, hazardous waste, or land use permits are required for the activity. Potential impacts to wildlife and cultural resources are also included in the ER evaluation.

Discussions of environmental regulations that pertain to the WIPP Project are provided in the *WIPP Biennial Environmental Compliance Report* (BECR), and the *WIPP*

Annual Site Environmental Report (ASER). Both documents, available from the LUC on request, provide regulatory compliance applicability and status for federal, state, and local environmental regulations. Land use requestors will find that the BECR and the ASER serve as reliable reference documents for use in better understanding regulatory requirements at the site. Both documents will assist the requestor in identifying regulations that could affect the development of project schedules prior to submittal of the LUR package (to include the ER). LUR submittals are reviewed in accordance with the flow diagram in Figure 2.1 of this document.

2.2.1 National Environmental Policy Act and Land Use within Waste Isolation Pilot Plant Land Withdrawal Area

2.2.1.1 Waste Isolation Pilot Plant Project Requests

LURs associated with WIPP-specific activities are addressed as follows:

1. The requestor will submit to the LUC (see foreword) a LUR (Appendix B) identifying the proposed project.

2. The LUC will provide the requestor with a guide for the proper completion of a LUR (Appendix B). The submittal of a properly completed LUR (containing a completed Environmental Review or ER) is mandatory for obtaining authorization for use of lands contained within the WLWA (excluding the inner Property Protection Area), or lands outside the WLWA boundary used for the operation of the WIPP, managed under the jurisdiction of the DOE (e.g., groundwater surveillance pads, railroad rights-of-way).

2.2.1.2 Land Use Request Review Process

1. The LUC will assign a unique number to the LUR and enter the LUR into a tracking system.

2. The LUC will review the LUR and transmit it, along with any supporting documentation, to the WIPP NEPA Compliance Coordinator for evaluation. The WIPP NEPA Compliance Coordinator will enter the LUR number into the computerized NEPA tracking database.

3. The NEPA Compliance Coordinator will evaluate the submitted LUR for impacts to human health and the environment using screening criteria defined by the CAO (e.g. DOE Order 541.1 *NEPA Compliance Program)* and comparing the proposal to activities evaluated within the WIPP's existing NEPA documents (e.g., WIPP's *Final Supplement Environmental Impact Statement*).

4. In consultation with appropriate cognizant regulatory personnel, the WIPP NEPA Compliance Coordinator will complete a technical review, as required, to address any concerns not completely addressed in the LUR. Items that need to be resolved prior to project initiation will be added to the review in order to

comply with regulatory considerations such as waste minimization, water and air permit requirements, waste management, reclamation requirements, and rights-of-way, in addition to other concerns pertaining to the protection of human health and the environment.

5. The WIPP NEPA Compliance Coordinator review the proposed action against the approved screening criteria for such actions provided by the CAO.

6. If the proposed action is addressed by existing NEPA documentation and other pertinent regulatory approvals have been obtained, the WIPP NEPA Compliance Coordinator will indicate approval and return the package, including the LUR, to the LUC. Subsequently, the LUC may convene the LMC and advise the requestor of regulatory concerns.

7. If the ER is outside the scope of actions previously assessed within WIPP's NEPA documentation, the WIPP NEPA Compliance Coordinator will submit the LUR and ER to the CAO for consideration by the CAO's NEPA Compliance Officer.

8. The WIPP NEPA Compliance Coordinator will inform the requestor of the action of additional requirements for NEPA documentation and an estimated time frame for completion and follow CAO guidance for completion of subject documentation.

9. After the WIPP NEPA Compliance Coordinator has released the LUR (including the completed ER) back to the LUC with the appropriate level of NEPA approval, the LUC will log out the ER signifying the return of the ER to the requestor.

10. If any additional issues remain outstanding, the LUC will coordinate with the requestor to resolve the identified concerns.

11. When the requestor has addressed all concerns contained in the review satisfactorily, the ER, along with review resolution documentation, will be returned to the LUC.

12. The LUC will log in the returned request and indicate final approval of the proposal (this approval may contain contingencies for the implementation of the action, such as avoidance measures for cultural resource sites, etc.).

2.2.2 Project Requests Through the Bureau of Land Management or State Land Office

Requests for projects that involve land uses on BLM, state of New Mexico, and DOE lands will require a "lead agency" determination. Lead agency status regarding projects involving multiple agencies will be determined by existing MOUs (Appendix C) or 40 CFR

1501.5. To this extent the following criteria are used to determine "lead agency" designation:

- Magnitude of respective agency's involvement
- Project approval/disapproval authority
- Expertise concerning the effects of environmental actions
- Duration of agency's involvement
- Sequence of agency's involvement

In the event the DOE receives lead agency designation, guidelines contained in the standards of Subsection 2.2.1 of this document apply.

If either the BLM or the State Land Office for the State of New Mexico is determined to be the lead agency, the LUR review process will be as follows:

1. The BLM or State will direct the requestor to notify the WIPP LUC prior to initiating subject land use activities.

2. The BLM or State Supervisory Realty Specialist (SRS) will oversee the submittal of the requisite EA, as appropriate, and advise the requestor to notify the WID LUC for guidance in the development and submittal of a LUR.

3. A Land Use Request (LUR) (Appendix B) will be submitted in writing to the Land Use Coordinator (LUC) (see foreword) for use of the land within the WLWA (excluding the inner Property Protection Area), or on lands outside the WLWA under the jurisdiction of the WIPP, by a non-WIPP organization.

4. The requestor will contact the BLM or the State Land Office regarding their proposed action.

5. The requestor will provide information to the lead agency to allow an environmental assessment (EA) to be prepared for the proposed project.

6. Upon completion of the draft EA, the BLM or state SRS will transmit the document, along with any supporting documentation, to the LUC for review and comment.

7. The LUC will assign a unique number to the LUR and enter the request for land use into the tracking system.

8. The LUC will review the ER and consult the cognizant WIPP NEPA Compliance Coordinator for environmental regulatory considerations.

9. The WIPP NEPA Compliance Coordinator will convey any regulatory consideration regarding the proposed action to the LUC by way of a technical review.

10. The LUC will append the technical review with any other land use considerations he/she may feel proper and appropriate.

11. If the regulatory considerations detailed in the technical review are significant, the BLM or state SRS will arrange a meeting with the affected requestor. The requestor(s) will be advised of the regulatory concerns of the proposed action.

12. When all regulatory considerations are addressed to the satisfaction of all affected participants, the project may be approved by the DOE Carlsbad Area Office (CAO).

13. The DOE Land Manager will transmit a letter to the BLM or state SRS, approving the proposed project, and will send a courtesy copy to the WIPP LUC.

FLOW CHART FOR LAND USE REQUEST AND NOTIFICATION PROCESS

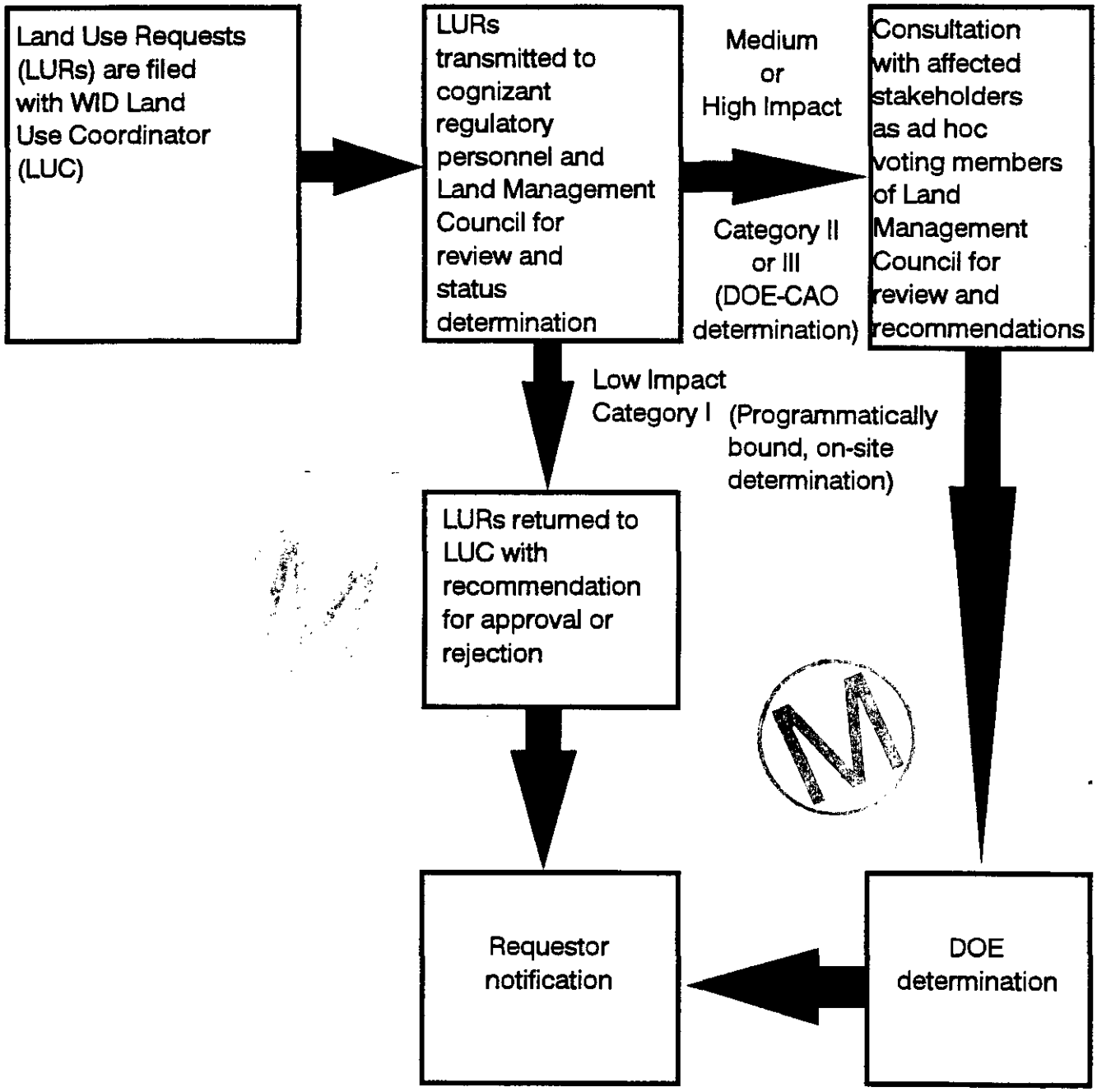

FIGURE 2.1

CHAPTER 3

WILDLIFE

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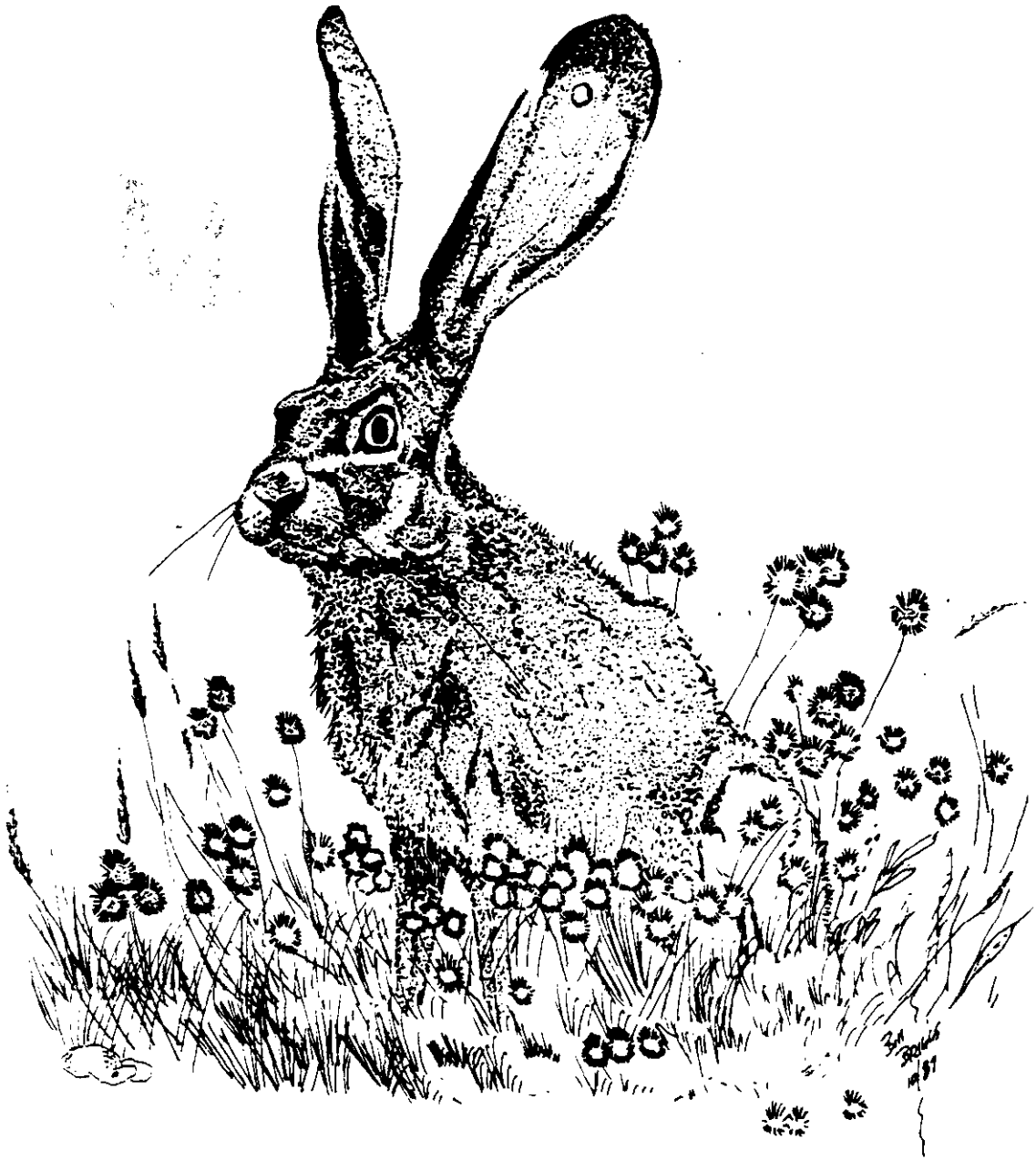

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CHAPTER 3
WILDLIFE

3.0 INTRODUCTION

This chapter is dedicated to planning wildlife investigation and management projects. Recommendations for approaches, potential prospectuses, and proposed investigational plans are discussed. Tools, techniques, and personnel available for conducting investigations and achieving management objectives are examined. These criteria are essential to wildlife objectives for effective planning as it relates to choice, between alternatives, establishment of realistic constraints (e.g., time, funding, manpower), practicality, and expediency in the development of efficient research methodology.

Wildlife within the WLWA shall be given consideration during planning stages of projects involving the disturbance or encroachment of wildlife habitat inside DOE lands by way of the LUR process as described in Chapter 2, "Environmental Compliance." Monitoring and research of specific wildlife populations will occur in accordance with applicable laws, agreements, and regulations subject to funding and personnel constraints.

The WIPP conducts a number of general wildlife management activities. Each activity is mandated and/or supported by state and federal guidelines or by way of commitments created through interagency agreements (e.g., *Raptor Research and Monitoring Interagency Agreement*, Appendix E) and/or MOUs (Appendix C).

Examination of wildlife species in the area reveals significant diversity and complexity. Management of indigenous wildlife incorporates the development of a logical sequence when programming activities. Solutions for problems (e.g., home-range, territoriality of desert mule deer) will serve the implementation of conservation and resource management objectives as they pertain to the management and operation of the WIPP site.

3.0.1 Affected Biological and Wildlife Environment

The wildlife habitat around the WIPP is categorized in accordance with the BLM's standardized habitat sites subsequent to a detailed Integrated Habitat Inventory Classification System. WIPP lands comprise a small part of those lands grouped into major habitat types as described in Appendix L-2 of the *East Roswell Grazing Environmental Impact Statement*. Moreover, habitat types and species inventories were conducted for the DOE during initial site characterization studies as described in the WIPP Biology Program, the *Final Environmental Impact Statement* (FEIS) (DOE/EIS-0026-FS), the Site and Preliminary Design Validation studies, and the *Environmental Monitoring Plan* (DOE/WIPP 92-040).

Wildlife in the vicinity of the WIPP is characterized by a wide variety of insects, amphibians, reptiles, birds, and mammals.

The Chihuahuan desert has long been regarded for its extraordinary diversity of plant and animal communities. The location of the WIPP, situated in the Los Medaños region of the Chihuahuan desert, exemplifies this unusual array of biotic factors. The Los Medaños is located in an area of intergradation between the northern region of the Chihuahuan Desert and the Llano Estacado or Staked Plains. The region is characterized by aeolian and alluvial sedimentation on upland plains that form hummocks, dunes, sand ridges, and swales with the presence of Havard Shin Oak (or shinnery oak) as a prominent foliar factor. Although the abundance of Shin Oak has aided in the stabilization of the dunes, a number of them remain unstable and exhibit distinct signs of shifting. An additional predominant shrub is Honey Mesquite which has invaded what at one time was a short-grass, shinnery oak-dominated landscape.

As with many areas, the shinnery oak community has shifted from a dominant bluestem/grama grassland with varying amounts of shinnery oak, sand sage, and yucca to a composition dominated by Dropseeds, three-awns, and Gramas, with high densities of Plains Yucca, annual forbs, and Mesquite.

According to the Bureau of Land Management's (BLM) Resource Management Plan (RMP), 15 percent of the wildlife species identified in the Resource Area utilize the Shin Oak habitat with 30 percent occupying areas consisting primarily of grass compositions with greater than 75 percent grasses in the description of the potential plant community.

The subtle blend of plant communities with Shin Oak/Dune habitat (SOD) that somewhat dominates Grassland (SG) affords a composition of factors that results in the diverse wildlife population of the Los Medaños.

Wildlife populations are characterized by numerous species of arthropods, amphibians, reptiles, birds, and mammals. Now and then, aquatic mollusks, inhabitants of local stock ponds and livestock drinking units, are observed. Jerusalem crickets (*Stenopelmatus fuscus*) are an example of one order of insects that occupy the locality of the WIPP.

Red-Spotted Toads (*Bufo punctatus)* and New Mexico Spadefoot Toads (*Spea hammondi)* are two examples of no fewer than ten different species of indigenous amphibians. Their significance is seldom recognized until spring or summer rains, at which time they appear in extraordinary numbers.

Reptiles comprise more conspicuous inhabitants due to the diurnal nature of numerous species. Ornate Box Turtles (*Terapene ornata),* Desert Side-Blotched Lizards (*Uta stansburiana),* and Texas Horned Lizards (*Phrynosoma cornutum,* a federal notice-of-review species listed under the Endangered Species Act) represent 3 of approximately 35 distinct species of indigenous reptiles. Moreover, three species of rattlesnake can be encountered in the area.

Bird densities vary according to preferable food and habitat availability. The habitat heterogeneity of the Los Medaños accounts for a wide assortment of bird species that inhabit the area either as seasonal transients or permanent residents. Large numbers of Mourning Dove (*Zenaida macroura*), Pyrrhuloxias (*Cardinalis sinuata)*, and Black-Throated Sparrows (*Amphispiza bilineata*) are frequently observed. A unique desert subspecies of the Northern Bobwhite (*Colinus virginianus*), Scaled Quail (*Callipepla squamata)*, and an occasional Lesser Prairie Chicken (*Typanuchus pallidicinctus)* depict the gallinaceous inhabitants. Due to a scarcity of surface waters in the immediate vicinity of the WIPP, migrating or breeding waterfowl are not considered common.

The area supports a particularly abundant and diverse population of Raptors, or birds of prey. Harris' Hawks (*Parabuteo unicinctus)*, Swainson's Hawks (*Buteo swainsoni)*, and Great Horned Owls (*Bubo virginianus)* illustrate species commonly found nesting in the area. The density of large avian-predator nests has been documented as high as 16 nests per 10 square kilometers, one of the predominant raptor breeding populations in recorded scientific literature.

As is common in desert biomes, Black-Tailed Jackrabbits (*Lepus californicus)* and Desert Cottontails (*Sylvilagus audoboni)* are the most conspicuous mammals. Three species of Ground Squirrel (*Spermophilus spp.)* and numerous other rodents such as Kangaroo Rats (*Dipodomys spp.)* and Cactus Mice (*Peromyscus eremicus)* also occupy the area. Large piles of debris, that may consist of aluminum cans, cow dung and other rubbish (sometimes to a height of nearly five feet), clustered at the base of cactus or large mesquites characterize the houses (or "middens") of the Southern Plains Woodrat (*Neotoma micropus)*. Although specimens rarely exceed weights of 300 grams, several Woodrats that weighed nearly 500 grams have been captured, by WIPP biologists, near the WIPP. Big-game species, such as Desert Mule Deer (*Odocoileus hemionus)* and carnivores such as Coyotes (*Canis latrans)* and Badgers (*Taxidea taxis)* also frequent the area.

The DOE consulted with the USF&WS in 1979 to determine the presence of threatened or endangered species at or near the WIPP site. At that time, the USF&WS listed the Lee Pincushion Cactus (*Coryphantha sneedi* var. *leei),* the Black-Footed Ferret (*Mustela nigripes*), the American Peregrine Falcon (*Falco peregrinus anatum)*, and the Bald Eagle (*Haliaeetus leucocephalus)* as threatened or endangered that could occur on lands within or outlying the WIPP site. However, no critical habitat for endangered species was identified at the WIPP. In 1989, the DOE again consulted with the USF&WS to update the list of threatened and endangered species. The agency has advised the DOE that the list of species provided in 1979 is still valid.

During 1989, the DOE consulted with the NMDG&F regarding the state-listed endangered species in the vicinity of the WIPP. Based on NMDG&F Regulation 657, dated January 9, 1988, the NMDG&F listed seven birds and one reptile in one of two endangerment categories that occur or are likely to occur at the site.

During 1995, the USF&WS transmitted the April 24, 1995, updated list of threatened and endangered species for Eddy and Lea Counties, New Mexico. Accordingly, the list was

disseminated to pertinent WIPP departments for consideration and incorporation into applicable documents. The DOE currently operates under the assumption that activities associated with the operation of the WIPP will have no impact on any threatened or endangered species. Considerations pertaining to protected species are implemented in accordance with this management plan, during the deliberation and administration of projects conducted on WIPP lands.

3.1 OBJECTIVES

The objective of the DOE is to maintain and/or enhance the ecological condition of wildlife habitat within the WLWA.

Decisions regarding the management of wildlife on DOE lands are implemented over time in accordance with the DOE planning and budgeting processes. Priorities will be established for each management program to coordinate sequential implementation.

Implementation of wildlife management objectives shall be in accordance with existing local, state, and federal laws. In addition, it is the DOE's objective to comply with commitments contained in existing MOUs and interagency agreements with separate agencies and to consider the needs of, and the impacts to, native wildlife populations throughout the life of the WIPP (to include decommissioning).

3.2 PLANNED ACTIONS

3.2.1 Raptors

Investigation and management of the raptor resource of the Los Medaños, as it pertains to the WIPP, shall be conducted in accordance with the following:

1. The BLM and the DOE will continue the Raptor Research and Management Program in accordance with Interagency Agreement No. 1422G910-A2-0016 (Appendix E).

2. All land management actions involving intrusion into raptor habitat will take into consideration, prior to project approval, the potential impacts on raptor resources in the area. Documentation identifying potential impacts and proposed mitigation method will be submitted to the cognizant regulatory personnel (WIPP raptor biologist) for status determination (e.g., approval or denial). For example, power lines within the withdrawal will be constructed using acceptable configurations (e.g., BLM specifications) regarded as "raptor safe" by WIPP raptor biologists.

3. All raptor research will be conducted by personnel trained in the science disciplines and will be authorized under state and federal permits to conduct the desired studies. At such time that a study is determined to be counterproductive or too intrusive, it can be terminated, at the discretion of WIPP cognizant

personnel, until such time that a complete evaluation and concurrent disclosure is conducted.

4. The DOE will solicit, contingent on funding, research proposals from educational institutions, non-profit organizations, environmental/scientific groups and/or state agencies (e.g. NMDG&F) who desire to conduct raptor research in the area. These investigations will provide valuable data, function to expand the data gathering network, and project a positive public image for the WIPP by conveying to the general public the positive environmental impacts of the WIPP. Cognizant WIPP personnel (usually the Land Use Coordinator) will serve as supervisors to personnel conducting research and will evaluate research techniques to assess the impacts of the research on the resource. The LMC will reserve the right to suspend a study for evaluation, by the Land Use Coordinator, if evidence reveals that intrusive research activities are having a negative impact upon the environmental resource.

3.2.2 Threatened and Endangered Species

1. Upon identification of habitat within WIPP lands occupied by state or federally listed species, the area will be set aside, posted against unauthorized entry, and routinely monitored. Prior to implementation of proposed projects and/or other activities that may affect special status plant or animal species within the WLWA, expeditious notification (within 30 days of project implementation) of cognizant regulatory agencies (e.g., the NMDG&F, the USF&WS, the Energy, Minerals and Natural Resource Department's Forestry and Resources Conservation Division) will be conducted by WIPP personnel. The DOE will solicit recommendations from said agencies for incorporation into a habitat management plan to be developed and implemented in a timely manner.

2. Federally listed threatened and endangered (T&E) plant and animal species are managed according to USF&WS recovery plans. If a preliminary determination is made during the assessment process that a proposed project could affect T&E habitat, then consultation with USF&WS will be initiated under Section 7 of the *Endangered Species Act* of 1973, as amended. State-listed species will be protected by way of cooperative agreements, joint powers agreements, or MOUs with the NMDG&F, EMNRD Forestry and Resources Conservation Division, or other cognizant regulatory agencies.

3. The DOE will continue to monitor for the presence of T&E species.

4. Cognizant WIPP personnel will continually monitor and maintain, as required, sensitive habitats for T&E species.

3.2.3 Ungulates

1. The DOE will initiate, contingent on funding and manpower, investigations designed to ascertain territories, home ranges, and migration trends of desert

mule deer (*Odocoileus hemionus*). Evaluations of desired food sources by season would benefit WIPP biologists by way of aiding in the determination of seed mixes conducive to the preferences of the local deer herd. Suitable mixes will then be used in reclamation plans.

2. As constraints associated with funding, manpower, and permitting allow, the WIPP will provide monitoring studies into the life histories of wild desert ungulates. These may involve the radio-tagging of deer to evaluate WIPP effects on transient populations. Moreover, this approach would allow scientists to determine the status of the local population pertaining to home-range parameters and migratory movements in response to seasonal activity, livestock forage, and oil and gas exploration.

3. New water developments within the WLWA will be made accessible to wild ungulates. Existing water developments (e.g., livestock watering units) inside the WLWA will be modified (if necessary) to accommodate wildlife needs.

4. Fencing within the WLWA will reflect configurations recommended by the BLM for construction in areas containing wild ungulates.

3.2.4 Small Game

3.2.4.1 Galliformes

1. The DOE will implement, contingent on funding and manpower, analyses into the dynamics of the desert galliforme (quail and prairie chickens) populations. Examination of food preferences, distribution, range, and breeding behavior will be incorporated into the research design.

2. Galliformes, particularly desert quail, comprise one of the more popular recreational pursuits of local hunters and therefore represent a direct pathway to man for environmental contaminants. Available information regarding the life histories of native quail (e.g., scaled quail and desert subspecies of bobwhites) are finite, thus affording WIPP scientists limited parameters for scientific inquiry and management designs. Due to their popularity with sport hunters and their capacity as bioindicators for WIPP radiological analyses, desert quail will be considered a priority for research as funding is made available.

3. New water development within the WLWA will be equipped to facilitate desert galliformes (e.g., bird ramps in livestock waterers). Existing water developments will be modified to facilitate desert galliformes.

4. Reclamation seed mixes will reflect plant species conducive to the needs of native gallinaceous birds.

5. Population densities of the lesser prairie chicken will be determined to assess the need for mitigation actions associated with surface-disturbing activities.

Location and status of booming grounds, or "leks," will be identified each spring. Active leks will be monitored passively to preclude inadvertent disturbances associated with the operation of the WIPP or by members of the general public.

3.2.5 Nongame Species

3.2.5.1 Small Mammals

1. Small mammal population studies will continue as appropriate, with regards to, the WIPP nonradiological environmental sampling protocol as defined in the *Annual Site Environmental Report* (DOE/WIPP 95-2094).

3.2.5.2 Furbearers

1. **Persons wishing to conduct trapping activities within the WLWA shall, at minimum, notify the WIPP Land Use Coordinator (for permission to trap) and the WIPP security force for a briefing regarding safety requirements and conduct while operating on WIPP lands.** Trapping of furbearers in the WLWA will be allowed, however, restrictions will apply. Trapping will be done in accordance with all applicable state and federal laws. Traps shall be well-marked and checked every 24 hours at a minimum. If the presence of traps represents a safety concern, or if the trapper has not complied with stipulations imparted by cognizant WIPP personnel, the traps will be removed immediately. If the presence of traps is determined to be unnecessary by the WIPP LUC, all traps will be removed until such time that the WIPP LUC, in consultation with the LMC and the proper authorities, concludes that trapping may resume.

2. Resident populations of furbearers (e.g., coyotes, foxes, bobcats) will be monitored on an "as needed" basis. Responses to anomalous conditions (e.g., disease) in the furbearer population will be contingent on the severity of the condition (e.g., rabies) and the potential threat it represents to the employees of the WIPP.

3. The deployment of traps utilizing poisons such as cyanide (e.g., M-44s), are strictly prohibited on WIPP lands.

3.2.5.3 Small Birds

1. WIPP personnel will continue to survey resident and transient populations of small birds (e.g., Passeriformes) on an "as needed" basis. Migration trends, habitat preferences, and nesting behavior will be factored into mitigation actions concerning adverse impacts of WIPP operations on protected species.

2. Reclamation efforts will use plant species conducive to the needs of small birds.

3. Water developments and similar hazards (e.g., molasses troughs) within the WLWA will be configured to prevent mortalities of small birds.

4. If the determination is made that the nest of a protected species compromises the normal working operation of the WIPP (e.g., nests built on construction machinery), cognizant WIPP personnel will contact appropriate regulatory agencies (NMDG&F, USF&WS) for guidance regarding response protocol. Nests will remain in place and undisturbed until the determination of legal response protocol.

3.2.5.4 Reptiles

1. The monitoring and management of reptiles will fall primarily under the auspices of T&E management. As of 1993, the area around the WIPP was identified as having habitat favorable for the inhabitation of the Dune Sagebrush Lizard (*Sceloporus arenicolous*), a state-listed species. Moreover, contacts with Texas Horned Lizards (*Phrynosoma cornutum*), a federal notice of review species, are not uncommon on WIPP lands. Therefore, potential impacts to these protected species will be considered during deliberation of land management decisions.

2. All construction projects conducted on WIPP lands will take action in accordance with all applicable state and federal laws pertaining to the mitigation of impacts to habitat conducive to the presence of protected species of reptiles.

CHAPTER 4

CULTURAL RESOURCES

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CHAPTER 4

CULTURAL RESOURCES

4.0 INTRODUCTION

This chapter provides edicts pertaining to the appraisal, documentation, protection, preservation, and chronology of archaeological and historic resources within the 16-section WIPP Land Withdrawal Area. The BLM's *Carlsbad Resource Management Plan* (RMP) is used as guidance for the management of the cultural resources.

4.0.1 Cultural Resources in the Affected Environment

From man's first arrival in the Southwest about 10,000 B.C. to the late 1800s, southeastern New Mexico was inhabited by aboriginal hunters and gatherers who subsisted on various wild plants and animals. These people would have found a number of edible plants throughout the region, including mesquite beans, hackberries, walnuts, acorns, seed-producing grasses, agave and a variety of other succulents. Big and small game, including bison, deer, antelope, rabbits, reptiles, birds, and various invertebrates, could have been hunted or collected in the region.

From approximately 600 A.D. onward, as trade networks were established with Puebloan people to the west, domesticated plant foods and materials, including corn (or maize), beans, squash, and cotton, were acquired in exchange for dried meat, hides, and other products from the Pecos Valley and Plains. The indigenous population may also have practiced horticulture at favorable locales in the area, but only on an intermittent basis, since water for crops would have been scarce and unpredictable much of the time.

In the mid-1500s, the Spanish Conquistadors encountered Jumano and Apachean peoples in the region practicing hunting and gathering and engaging in trade with Puebloans. Later, as the natives acquired horses, and as Europeans began settling the land, this traditional way of life evolved into specialized bison hunting on the Llano Estacado and raiding both Spanish and Puebloan settlements to the west. In the late 1800s, the region was settled by ranchers and farmers.

The WLWA is situated in dune-covered, rolling-plains terrain in the eastern part of the BLM's Carlsbad Resource Area. Known archaeological sites within the area are primarily the remains of prehistoric camps and short-term settlements. These localities are generally marked by hearth features, scattered burned rock, flaked stone projectile points, and cutting and scraping tools, pottery fragments, and groundstone implements. Locations generally represent short-term, seasonal occupations by small, nomadic groups of hunters and

gatherers who utilized the plants and animals in the dune lands east of the Pecos River. In a few cases within the WLWA, sites with evidence of structures have been reported. These sites probably hosted occupations of perhaps several weeks or months.

Many known historical sites in southeastern New Mexico consist primarily of early twentieth century homesteads that failed, or isolated features from late nineteenth and early twentieth century cattle or sheep ranching and military activities. Although the region was part of the Spanish and Mexican colonial empires, no related conquest or settlement sites have yet been identified.

Historic components (more than 50 years old) are rare, but are occasionally noted within the WLWA. These include features and debris related to ranching in the early years of the twentieth century. In addition, more modern ranching debris and facilities such as fence lines are present in the area, including some which are likely still in use. Ranch-related sites which date to the 1940s and 1950s are common in parts of the WLWA. These will be considered historical properties within the next several years and under current law, will have to be treated as such. The majority of the several sites recorded in the area typically include elements which can contribute to their eligibility for the National Register of Historic Places. With few exceptions, cultural properties known or anticipated for the WLWA are significant; they must be identified, recorded, assessed through inventory, and considered in any plan of development for the area.

Compared with most other parts of southeastern New Mexico, the locations and nature of cultural resources within the WLWA can be described relatively well, based on intensive inventory of portions of the area, along with limited excavation and some other work on some sites.

In 1976 four sections comprising the WIPP core area (Sections 20, 21, 28, and 29), along with associated rights-of-way and drilling pads within and outside the WLWA (Nielson 1976, Linnabery 1976) were inventoried by the Agency for Conservation Archaeology (ACA) of Eastern New Mexico University. Additional rights-of-way within and outside the WLWA were inventoried in 1978 and 1979 by ACA (Schermer 1978; MacLennan and Schermer 1979). Sites identified in the core area were relocated and evaluated in 1980 by ACA, and management recommendations for those sites were prepared (Schermer 1980). Subsequently, in accordance with the ACA's recommendations, a number of sites within the WIPP core area were tested for eligibility and/or were excavated as mitigation (Hicks 1981a; 1981b; Lord and Reynolds 1985).

In 1987 Mariah Associates conducted an intensive study of portions of 45 sections surrounding the WIPP facility. Mariah's study included an inventory of 2,460 acres in 15 quarter-section units. Inventoried units were selected so as to be representative of the area as a whole. Within each of the sample units, all cultural resource sites encountered were recorded, certain selected sites were tested, and management recommendations were prepared (Mariah Associates, 1987).

Between 1989 and 1992, several seismic projects associated with oil and gas development provided cultural resource clearances within the WLWA. Numerous inventories

have been conducted outside the withdrawal area, primarily for oil and gas exploration and ranching.

Inventories conducted to date within the withdrawal area have located 59 archaeological sites, along with 91 isolated occurrences (single or few artifacts, or isolated features which can be fully recorded in the field). Sites and isolates identified are almost exclusively prehistoric. Only one site with both prehistoric and historic components has been noted.

Of a total of 10,240 acres in the WLWA, 3,380 acres (37 percent) have been inventoried for cultural resources. The results have been the discovery of one site for every 65 acres surveyed, and one isolate in every 42 acres. Based on this information, and assuming environmental homogeneity and a fairly even distribution of sites, the remaining 6,410 uninventoried acres could contain approximately 99 sites and 153 isolates. The combined results of the several inventories conducted within the WLWA compare well with those from Mariah's 1987 inventory of selected units over a much larger area. Mariah's results show only a slightly higher frequency of cultural resources per acre. In 2,460 acres, 40 sites and 75 isolates were recorded, or one site for every 62 acres and one isolate in every 33 acres.

Of the 40 sites identified and evaluated on the Mariah inventory, 14 appear to be eligible for the National Register of Historic Places, 24 are potentially eligible, and two are not eligible. [Note: A determination of eligibility can be made only after the site has been archaeologically tested.] None of the 75 isolates are considered eligible. While the data from the various researchers cited above are not always consistent with Mariah's explicit data on site significance, it appears that within the WLWA, the majority of sites either are or have the potential to be eligible for the National Register of Historic Places and will require consideration in future land disturbing activities.

Site significance is contingent on the number of manifestations encountered, their diversity in composition, the total number of each type of manifestation, and existing evidence suggesting whether or not a given site is datable. Previous limited cultural inventories indicate that the WLWA represents a potentially significant cultural resource contributor to the discipline of archeology and shall be regarded as such when deliberating land management decisions.

4.1 OBJECTIVES

The objectives of the DOE are to protect and preserve representatives of the full array of cultural resources, within the WLWA, for the benefit of scientific and socio-cultural use by present and future generations. This guidance will ensure that cultural resources are given full consideration in land use planning and management decisions. Planning/management policies pertaining to cultural resources within the WLWA shall be conducted in accordance with guidelines established in Appendix G of this plan.

4.2 PLANNED ACTIONS

The DOE will be responsible for completing cultural resource clearances for DOE-funded activities prior to initiating projects that result in land disturbance by means of the LUR process (see Chapter 2). Cultural resource clearances for actions by outside agencies or organizations, not funded by the DOE, but completed on DOE property, or crossing DOE property, are the responsibility of the outside agency or organization. Clearances will be completed in accordance with DOE standards, to include the guidelines established in this plan, and submitted to the DOE for review.

4.2.1 Cultural Resource Management

The DOE will continue to inventory, evaluate, and manage cultural resources inside the WLWA. In locating, evaluating, and adding properties to the management inventory, the DOE shall consult the *Secretary of the Interior's Standards and Guidelines for Identification and Evaluation*.

4.2.2 Field Surveillance

The WIPP will conduct field surveys in a timely manner relative to agency planning and LURs involving surface disturbance of land within the WLWA. The DOE shall select appropriate strategies to ensure that surveys are completed so that the DOE can carry out its responsibilities under Section 106 of the National Historic Preservation Act and 36 CFR 800, "Protection of Historic and Cultural Properties," before initiating any activity that might damage or disturb historic properties.

4.2.3 Reports on Survey Results

The DOE will provide reports on survey results, both negative and positive, fully documenting the rationale for decisions made in the identification and evaluation of properties. The inclusion of negative data--that is, data on surveys that result in the identification of no historic properties--is important to ensure that redundant surveys will not be performed in the future. Negative data are also needed to improve the reliability of predictive models. When large-scale surveys are conducted within the WLWA, or smaller scale surveys over time result in the accumulation of substantial bodies of survey data about cultural resources within the WLWA, the DOE will prepare reports synthesizing and analyzing the resulting data for use by interested scholars as well as for management purposes. Such analyses should be provided to the State Historic Preservation Officer (SHPO) and other interested parties for review, comment, and incorporation into inventories. The DOE will document current locations and conditions of artifacts, document records, and remains related to historic properties under their jurisdiction or control. In some cases, such as when objects have long been removed from their places of origin, documentation may not be feasible. Documentation should be included as appropriate in identification and evaluation records as well as *National Register* property records.

4.2.4 Report Reviews

The DOE will provide reports to the State Historic Preservation Officer (SHPO) and other interested parties for review, comment, and incorporation into statewide historic resource inventories and for use in reviews under Section 106 of the National Historic Preservation Act when applicable. Such reporting to the state assists the state in maintaining comprehensive inventories while ensuring that state and DOE efforts are coordinated and compatible.

4.2.5 Potentially Eligible Properties

While conducting surveys, the DOE may encounter properties which are potentially eligible for the *National Register* (for Historic Places), but which do not meet the criteria at the time of the survey. For example, properties may be less than 50 years old and not of exceptional significance, consequently they would not meet the *National Register* criteria. If the LMC makes a determination that such properties are likely to become eligible in the future, it is to the DOE's advantage to document them at the time of the survey to facilitate later evaluation and registration. As cultural resources are identified, they will be evaluated in consultation with the New Mexico State Historic Preservation Officer (SHPO) and the BLM to determine their eligibility for listing on the *National Register of Historic Places*.

Sites which are found to be eligible for listing in the *National Register of Historic Places* will be avoided to the maximum extent possible. Where avoidance is not possible, mitigative measures designed to treat the effects of the undertaking will be developed and implemented in consultation with the SHPO and the BLM.

4.2.6 Project Clearances

Any proposed activity involving surface disturbance within the WLWA that has not received archaeological clearance from the LMC will be postponed until such time that an appropriate archaeological investigation is completed and approved.

4.2.7 Management and Record Inventory

The WIPP will create a management inventory and maintain records of identification, using appropriate forms as described in the "Guidelines for Federal Agency Responsibilities" under Section 110 of the National Historic Preservation Act, to include:

1. Description of methods used
2. Identification of lands inspected with data on all properties, both historic and nonhistoric
3. Identification of evaluation methods
4. Identification of sources (informants)
5. Documents produced during research and consultation

4.2.8 Information Disclosure

The DOE will establish guidelines for withholding and disclosing sensitive information regarding locations or character of historic or archaeological properties if it is established by the LMC, in consultation with cognizant professionals, that such disclosure may create a substantial risk, harm, theft, or destruction of such properties. Protocol for restricting information disclosure will be in accordance with the *National Register* Bulletin 29, "Guidelines for Restricting Information on the Location of National Register Properties."

CHAPTER 5

GRAZING

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CHAPTER 5
GRAZING

5.0 INTRODUCTION

This chapter provides guidance pursuant to best management practices of the DOE, on lands contained in the WLWA, as they pertain to traditional livestock use. Grazing within the WLWA operates within the authorization of the Taylor Grazing Act of 1934, the FLPMA, the Public Improvements Rangelands Act of 1973, and the Bankhead-Jones Farm Tenant Act of 1973. The responsibilities of the DOE include supervision of ancillary activities associated with grazing (e.g., wildlife access to livestock water development, assurance that all livestock water developments inside WIPP lands are configured according to regulatory requirements, etc.) and maintenance of an interface with respective allottees. Administration of grazing rights shall be in cooperation with the BLM in accordance with existing MOUs (Appendix C) and the coinciding statement of work (Appendix D) through guidance established in the *East Roswell Grazing Environmental Impact Statement* (BLM 1979).

5.0.1 Grazing within the Affected Environment

The *Land Withdrawal Act* provides for the continuation of grazing practices, within the WLWA, in accordance with applicable grazing laws and policies, including: the Act described as "An Act to stop injury to public grazing lands by preventing overgrazing and soil deterioration, to provide for their orderly use, improvement, and development, to stabilize the livestock industry dependent upon the public range, and for other purposes..." approved June 28, 1934 (43 U.S.C. 315 et seq., commonly referred to as the *Taylor Grazing Act*); title IV of the *Federal Land Policy and Management Act* of 1976 (43 U.S.C. 1751 et seq.); and the *Public Rangelands Improvement Act* of 1978 (43 U.S.C. 1901 et seq., and 43 CFR 4100).

The principles of multiple-use and sustained-yield are basic to the management of this program. Rangelands comprise a substantial portion of the WLWA and provide forage for livestock and valuable wildlife habitats.

The WLWA affects two grazing allotments administered by the BLM: the Livingston Ridge (No. 77027) and the Antelope Ridge (No. 77032) (Figure 13.1).

The Livingston Ridge allotment begins 17 miles east of Carlsbad, New Mexico. The allotment is comprised of 55,581 acres in size and permitted to a livestock rancher operating a year-round cow/calf business. Land ownership is divided between federal, state, and private lands. Acreage distributed by ownership are as follows: (1) 41,608 acres of Federal

ownership (2,880 acres within the WLWA), (2) 13,063 acres of State Trust lands, and (3) 910 acres of private (deeded) land. Although the allotment is 55,581 acres in size, only 5.18 percent of the allotment is situated within the WLWA.

Pasture rotation with some of the pastures being rested for at least a portion of the growing season, is standard management practice for this allotment. Vegetative monitoring studies to collect data on the utilization of the land, and the amount of precipitation by pasture from each study allotment are conducted annually to compare production with consumption. Should vegetative monitoring studies indicate a need for an allotment management plan, a plan will be developed in consultation with the BLM. The allotment is permitted for 6,483 Animal Unit Months (AUMs), which converts to 6.3 acres per AUM. (An AUM is the amount of forage necessary for the sustenance of a cow, or its equivalent, for a period of one month.)

The Antelope Ridge allotment begins 23 miles east of Carlsbad, New Mexico, and contains 77,574 acres. This allotment is permitted to a livestock rancher operating a year-round cow/calf business. Approximately 300 acres (more or less) within the Antelope Ridge allotment contain the WIPP facilities and are posted against trespass (see Chapter 10 *Security* for sector designations) and fenced to prevent grazing. Land ownership of the subject allotment is divided between federal, state, and private (deeded) lands. Acreage distributed by ownership are as follows: (1) 66,757 acres of federal land (7,360 acres within the WLWA), (2) 8,749 acres of State Trust lands, and (3) 2,068 acres of private land. Of the 77,574 acres contained in this allotment, 9.49 percent is within the WLWA.

An allotment management plan has been developed for this allotment by the BLM. The plan includes a seven-pasture rotation system, with some pastures being rested for full years and others receiving growing season rest. The allotment is permitted for 13,236 AUMs which translates to 7.0 acres per AUM.

Both allotments consist of sandy and deep sand range sites. These sites have combined shin-oak/dune (SOD) and grassland (SG) aspects and include grasses such as Gramas (*Bouteloua* spp.), Bluestems (*Andropogon* spp.), and Dropseeds (*Sporobolus* spp.). Other key forage plant species include Havard Shin Oak (*Quercus havardii*) and Fourwing Salt-bush (or Chamiza) (*Atriplex canescens*).

5.1 OBJECTIVES

The objective of the DOE for grazing management is based on the current practices for adjacent public lands. Priorities involve maintaining rangeland resource values on a long-term, sustained-yield basis utilizing vegetative monitoring studies of key forage species as the mechanism by which the need for any potential range management changes would be detected.

5.2 PLANNED ACTIONS

Planned Actions will be administered by the BLM, for the DOE, in consultation with the State of New Mexico and affected county, state, and federal agencies.

5.2.1 Grazing Regulations

The DOE will continue to grant livestock grazing privileges in accordance with historical land uses as regulated by pertinent laws, regulations, and existing agreements (e.g., BLM/DOE MOU) governing livestock use of public lands.

Vegetative monitoring will continue in the WLWA to determine if the goals and objectives of the grazing allotments are being achieved. As a minimum, data on actual livestock use, wildlife use, degree of utilization of key forage species, climatic conditions, and rangeland ecological condition and trend will be collected.

5.2.2 Configuration of Rangeland Improvements

As a result of the WIPP Land Withdrawal Act, all existing and future rangeland improvements (e.g., livestock water developments) within the WLWA belong to the DOE. Therefore, all rangeland improvements within the WLWA will conform with configuration requirements established by the LMC and cognizant regulatory personnel.

New or replacement livestock watering units may have water supplied from the Double Eagle Water System. For connections to the Double Eagle Water System, the allottee will be required to meet the requirements identified in the water line contract with the city of Carlsbad as identified in Subsection 8.2.6.3 of this document. Request submittals will be routed in accordance with Chapter 2 and Appendix B of this document.

5.2.3 Wildlife Access

All rangeland improvements within the WLWA will be made accessible to wildlife. Any improvement that is determined by cognizant personnel to pose an imminent threat to wildlife of the area will be corrected immediately by the responsible party/parties or will be expeditiously removed from service at the expense of the responsible party/parties.

5.2.4 Future Rangeland Improvements

Future rangeland improvements will be initiated through a request to the BLM by the responsible party (requestor). The request will be forwarded by the BLM to the DOE for evaluation by the LMC. The LMC will determine the expediency of the request, make status decisions per the request, and attach necessary stipulations to the request. All requests for rangeland improvements will be completed in accordance with existing MOUs or comparable documents. LMC decisions will be sent to the BLM for incorporation into their response to the requestor. Decisions of the LMC are final and subject to amendment only at the discretion of the LMC. Stipulations (e.g., identification of party/parties responsible for the

installation and/or maintenance of subject improvement) requested by the LMC shall be addressed to the satisfaction of the LMC by the requestor prior to implementation of the request.

5.2.5 Maintenance of Existing Improvements

General maintenance of existing rangeland improvements will be the responsibility of the allottee unless otherwise directed by authority of the LMC. All maintenance will be conducted in accordance with all applicable laws and regulations governing the respective action.

5.2.6 Violations of Existing Agreements

Alleged violations of existing agreements (e.g., MOUs), commitments, and/or existing laws and regulatory requirements will be brought before the LMC for discussion, determination, and resolution. Examples of violations are connections to water developments that do not meet configuration requirements pertaining to existing regulations and/or laws, and fence configurations that do not meet existing requirements and/or laws.

5.2.7 Nonconformance with Grazing Requirements

If evidence suggests that a respective allottee is in nonconformance with existing grazing regulations/requirements on WIPP lands (e.g., exceeding legal AUM allocation), the concern will be submitted, in writing, to the BLM for resolution. Final resolution will be done in consultation and cooperation with the LMC.

5.2.8 Modifications to Improvements

Modifications of existing rangeland improvements (e.g., fence line alterations) may be conducted by the respective allottee. However, the modification will not contradict the management goals and best management practices of the BLM and the WIPP LMP. Requests for modifications must be submitted in writing by the respective allottee to the BLM. The BLM will forward the request to the DOE for review, comments, and determination by the LMC.

5.2.9 Amending Grazing Rights

If the determination is made by the LMC that livestock grazing represents a significant risk to the health and/or safety of WIPP personnel, the integrity of critical T&E or wildlife habitat, or that it poses a risk to the incorporation of best management practices by the LMC, ancillary restrictions and/or guidelines may be imposed on the respective allottee pursuant to their grazing privileges on WIPP lands. If the determination is made by the BLM that a respective allottee has committed three or more incidents of noncompliance pertaining to existing grazing laws and/or restrictions, grazing privileges may be revoked within the WLWA, at the discretion of the LMC, in accordance with all applicable laws and regulations governing the revocation of grazing rights on public lands.

5.2.10 State Notification

The DOE will provide notice to the EMNRD Forestry and Resources Conservation Division upon receipt or development of:

1. Grazing management changes and/or plans proposed for the WLWA;

2. Any report generated from the BLM's and/or DOE's vegetative monitoring program covering the WLWA.

5.2.11 Grazing Fees

Administration of grazing fees shall be conducted in accordance with the provisions of the BLM/DOE MOU (Appendix C).

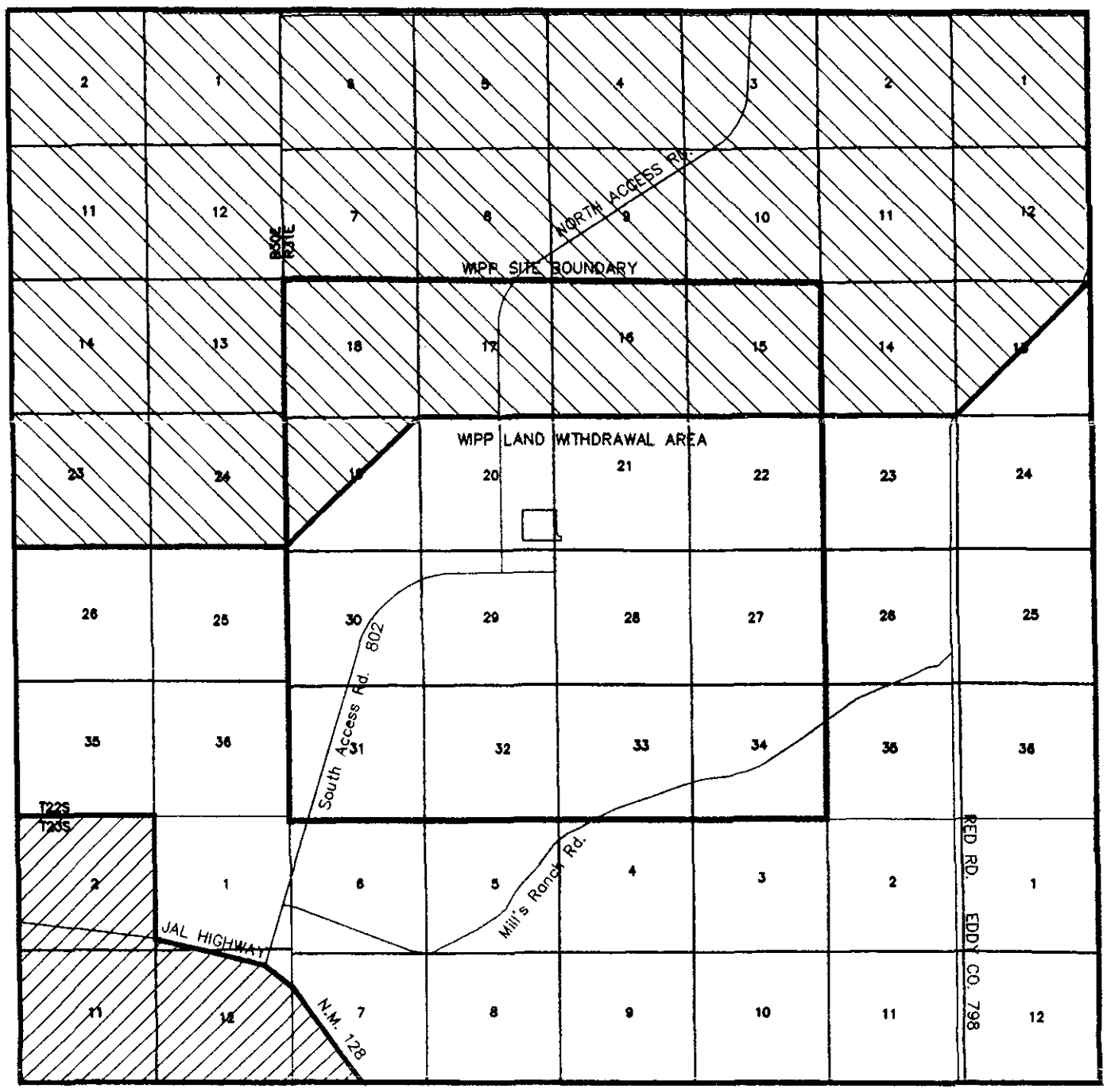

GRAZING ALLOTMENTS IN THE VICINITY OF THE WIPP LAND WITHDRAWAL AREA

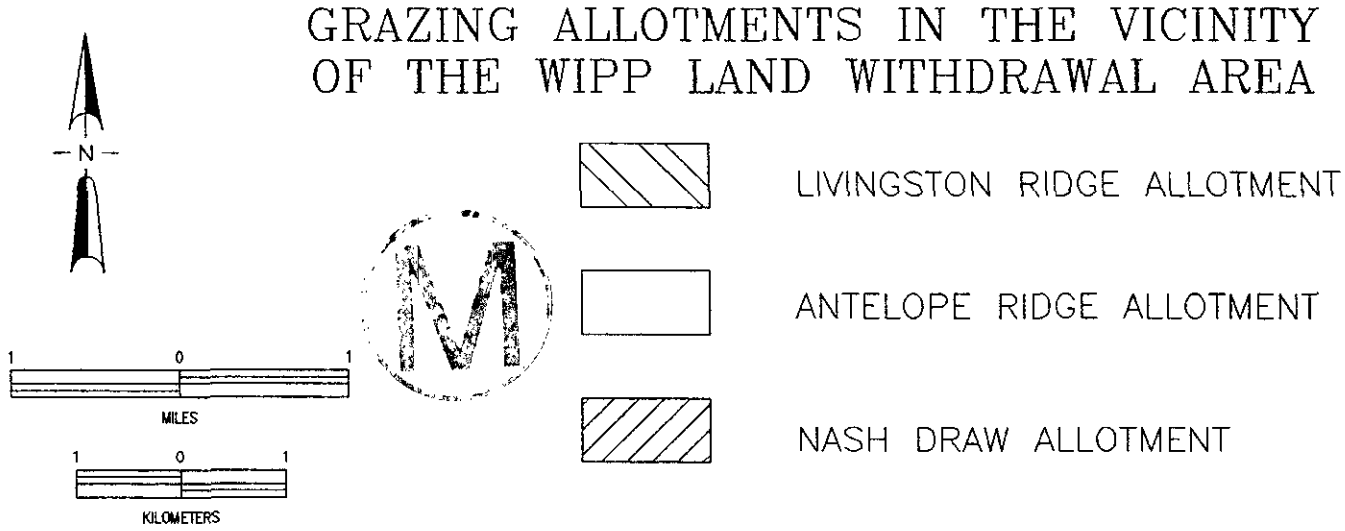

FIGURE 5.1

CHAPTER 6

RECREATION

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CHAPTER 6
RECREATION

6.0 INTRODUCTION

Recreational opportunities will continue in accordance with most traditional land uses. Examples of such land use concepts can be found in the *Carlsbad Resource Area Resource Management Plan and Environmental Impact Statement* (BLM-NM-PT-86-004-4410). Traditional land uses that conflict with the mission of responsible land management practices can be restricted on WIPP lands at the discretion of the DOE in consultation with the LMC and affected stakeholders. Properties posted with DOE "no trespassing" signs are excluded from public use and will be patrolled by WIPP security personnel to prevent unauthorized use. Violators are subject to prosecution in accordance with applicable laws and regulations governing property protection.

6.0.1 Recreation within the Affected Environment

Due to the topography, climatic conditions, and wildlife in the area of the WIPP site, an extensive (non-facility based) variety of recreational opportunities are available to include: hunting for both big and small game animals; camping; horseback riding; hiking; watching wildlife (e.g., bird watching); and sightseeing. The WIPP area contains significant biodiversity (see Chapter 3 *Wildlife)* in addition to historic and prehistoric sites (see Chapter 4 *Cultural Resources)*. These offer rewarding opportunities for scientific study and interpretive recreation.

6.1 OBJECTIVES

The objective of the DOE is to support a range of recreational outdoor activities for all segments of the public, commensurate with demand, access, safety, regulatory requirements, environmental protection, and liability. Visitors have a freedom of choice with minimal regulatory constraint regarding activities outside the boundary of the "Off Limits Area".

6.2 PLANNED ACTIONS

6.2.1 Access

Roads used in the operation of the WIPP are maintained and open to public access, unless otherwise designated. [Note: Roads posted with stipulations denoting alternate designations will be managed in accordance with the posted restrictions.] Roads within the WLWA will enhance recreational opportunities and allow use of WIPP lands. Areas identified as SMAs (e.g., reclamation areas, wildlife habitat) can, at the discretion of the LMC, be removed from access. These areas will be barricaded and/or posted accordingly to prevent unauthorized access.

6.2.2 Off-Road Vehicles (ORVs)

Management of roads and trails within the WLWA is conducted under requisite restrictions. This means that recreational motor vehicle use can be limited or prohibited at certain times, in certain areas, and/or for certain specified purposes to protect the health and safety of the public, environmental quality of the area, or for the common defense and security of the site. These restrictions generally apply to the following:

a. Numbers of vehicles
b. Types of vehicles
c. Time or season of use
d. Permitted or licensed vehicle use only
e. Use of existing roads and/or trails
f. Vehicle use in designated areas (roads/trails)
g. Other restrictions as deemed necessary

The use of ORVs within the WLWA will be limited to existing roads. Exceptions are those projects which are in conjunction with WIPP-related activities and have received proper authorization from the LMC. Trails and primitive roads will be posted with informational signs that clearly communicate restrictions regarding the operation of ORVs. The unauthorized use of ORVs traveling off designated roads, or in posted areas within the WLWA, will be regarded as criminal trespass. Violators are subject to criminal prosecution in accordance with applicable laws and regulations governing property protection.

6.2.3 Visual Resource Management

The DOE implements the BLM's Visual Contrast Rating System to determine the degree to which any proposed projects or other activities within the WLWA would affect the visual quality of the landscape. Using this system, any anticipated unacceptable visual impacts can be mitigated during the planning and design stage.

The DOE aspires to conduct all WIPP-related activities in accordance with visual resource objectives. Proposed activities and projects will be evaluated for consistency with existing laws and best management practices regarding scenic quality. The impacts of each

action will be evaluated by the LMC and affected stakeholders, via ERs, EAs, and/or visual inspections of the proposed site prior to implementation. The ER will analyze the project significance, the visual sensitivity of the affected area, and the project impacts. Stipulations will be attached as appropriate to ensure compatibility of projects with management objectives for visual resources. Painting requirements will be implemented for surface facilities in accordance with existing guidelines (e.g., BLM painting requirements). Activities may be modified, at the discretion of the LMC, to blend with the native landscape.

Prior to commencement of work, contractors and/or subcontractors will be briefed on compliance guidelines for a "start-clean, stay-clean" philosophy. Inspections revealing unclean projects (e.g., excessive trash and debris in and around a work site), or projects that compromise the visual integrity of the surrounding area, will result in the immediate suspension of the project until such time as project cleanliness complies with the standards of this document.

Access to aesthetic visual resources of the WIPP (e.g., bird watching, wildlife photography, wildflower photography, etc.) will be encouraged and supported by cognizant WIPP professionals as time and funding constraints allow. Advocating access by nonconsumptive users reaffirms positive public perception and involvement with the WIPP.

6.2.4 Hunting and Trapping

Hunting inside the WLWA will continue in accordance with applicable traditional land uses, existing New Mexico Department of Game and Fish (NMDG&F) and U.S. Fish and Wildlife Service (USF&WS) regulations, and best management practices regarding the health and safety of WIPP personnel and the protection of the environment. Hunting within areas designated as "no trespassing" is prohibited. Violators are subject to prosecution under existing laws and regulations pursuant to property protection. The DOE after consultation with the BLM and the state of New Mexico, may impose regulations that prohibit or limit hunting or trapping if it is determined that the activity represents a profound safety risk to WIPP personnel and/or the public, creates significant adverse impacts to the environment, represents a potential threat to the integrity of threatened and endangered (T&E) species habitat, and/or threatens the quality of life for isolated wildlife populations residing within the WLWA.

Trapping inside the WLWA will be allowed in accordance with applicable federal and state laws and regulations governing the taking of furbearers. Prerequisites that pertain to trapping on WIPP lands will be implemented in accordance with Subsection 3.2.5.2 of this plan.

6.2.5 Horseback Riding and Hiking

Recreational riding and hiking will be allowed in areas of the WIPP identified as "multiple land use areas." Restrictions such as "No Trespass" zones will apply as with non-DOE users. Except for posted areas, horseback riding and/or hiking by the general public will be encouraged to provide nonmotorized recreational experiences in addition to projecting affirmative relationships with nonconsumptive users.

6.2.6 Camping

Note: Campers are required to check in with the WIPP security inspectors prior to establishing camp.

Camping will be allowed in areas designated as "multiple land use areas" within the WLWA. Names of campers, license numbers of vehicles, camp location, emergency phone numbers, and arrival and expected departure times shall be provided to the security inspectors. Campers must be informed that their camp is subject to random inspections at the discretion of security personnel. At the time of departure, campers will check out with WIPP security personnel. In the event that checkout does not occur, security personnel will deploy to the campsite for determination of camp status (e.g., abandoned, occupied, camper with injuries, vehicle problems, etc.).

Restrictions to inform the general public concerning camping in the WLWA will be posted on signs situated at access points to the area, in local newspapers, and in the state game hunting proclamation.

CHAPTER 7

ENERGY AND MINERAL RESOURCES

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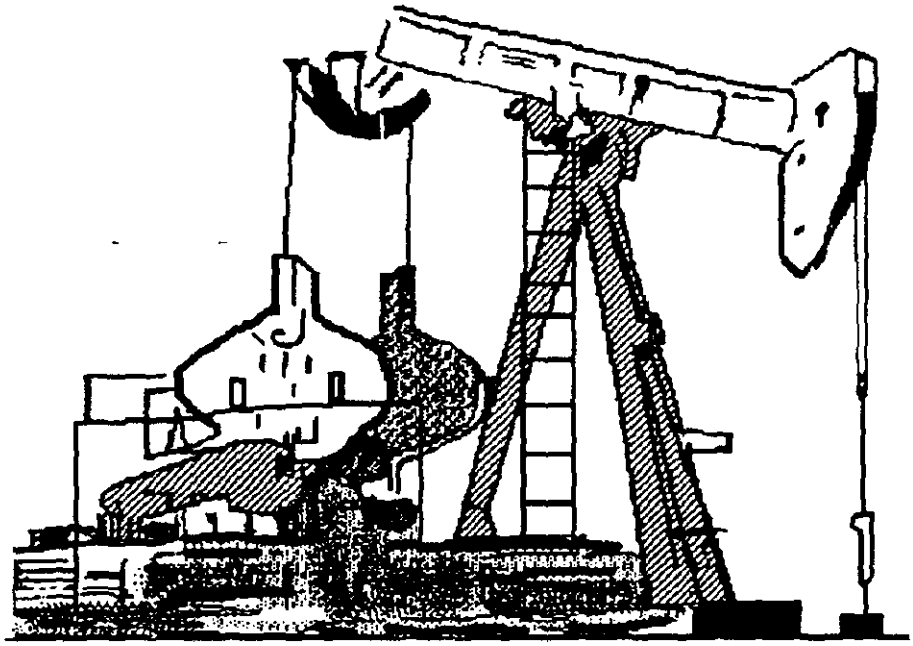

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CHAPTER 7
ENERGY AND MINERAL RESOURCES

7.0 INTRODUCTION

This chapter discusses mineral resources and reserves as they pertain to the judicious management of lands under the jurisdiction of the DOE. This serves as a baseline management document for the determination and analysis of energy and mineral resources in the affected environment.

7.0.1 Mineral Resources in the Affected Environment

Mineable resources known to underlie the WLWA are caliche, gypsum, salt, sylvite, langbeinite, crude oil, natural gas, and distillate. Potassium salts (sylvite and langbeinite), which occur in strata above the repository, and hydrocarbons (e.g., crude oil and natural gas), which occur in strata below the repository, are the only resources of practical significance.

7.0.1.1 Oil and Gas

The oil and gas industry is well established in the Los Medaños region of New Mexico (the vicinity of the WIPP), with producing oil and gas fields, support services, and compressor stations. Nearly all phases of oil and gas activities have occurred in the locality. These phases include seismic exploration, exploratory drilling, field development (comprised of production and injection wells) and other sundry activities associated with hydrocarbon extraction. Oil and gas production was estimated, during 1992, at 60 million barrels of oil and 432 million MCF (thousand cubic feet) gas from the BLM's Carlsbad Resource Area with 12,656 wells identified in Eddy County. Combined with the production from the Roswell Resource Area, Southeast New Mexico accounts for 92 percent of the total oil production and 48 percent of the total gas production from the state of New Mexico. As identified in the Bureau of Land Management's *Oil and Gas Potential Occurrence Zones*, the Los Medaños region is located in a region designated as having a "high potential for oil and gas occurrence." This region, part of the Delaware Basin, is bordered by the Capitan Reef. The majority of hydrocarbon extraction has occurred outside the Basin, within the Reef. Although the Delaware Basin accounts for approximately 32 percent of lands in Eddy County, only 17 percent of oil and gas wells are located within its boundaries. During 1995, oil and gas reserves in the immediate vicinity of the WLWA were evaluated by the New Mexico Bureau of Mines and Mineral Resources (NMBMMR). Results from this evaluation were compiled in a report, *Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site,* March 31, 1995.

7.0.1.2 Potash

Potash minerals are used to produce one of the major ingredients in fertilizers. There are twelve potash ore zones of Permian Age in the Carlsbad Mining District, all in the Salado formation. Detailed descriptions of these ore zones can be found in the *Generalized Columnar Section and Radioactivity Log, Carlsbad Potash District* by C.L. Jones, C.G. Bowles, and A.E. Disbrow (1954). The NMBMMR recently performed an evaluation of the potash resources in the vicinity of the WLWA (NMBMMR 1995).

There are five potash mining and refining operations in the area. These are: Eddy Potash; International Minerals and Chemical (IMC) Fertilizer; Western Ag Minerals; New Mexico Potash; and Mississippi Chemical Corporation. Horizon Potash discontinued operations in April of 1993. That same year, IMC and Mississippi Chemical expanded operations to increase production. According to Bureau of Land Management records, during 1992, these six potash companies produced 84 percent of the potash produced in the United States.

7.0.1.3 Caliche

Caliche, as the term is used in the Southwestern United States, refers to a buff, white, or reddish brown calcareous material of secondary accumulation, commonly found in layers on or near the surface of soils in the arid and semiarid regions. "Calcrete," "duricrust," and "hardpan" are other terms used to describe caliche in its various forms.

Caliche is considered a locally significant construction material due to its compaction properties. Deposits of caliche are frequently used for the construction of well pads, surfacing roads, and as a compacted base-course for buildings and paved roads. Although the caliche profile for the Los Medaños does not compare with the well developed Llano Estacado profile, several pits which produce a high-quality material are located in the vicinity. Access to this caliche, for use by the WIPP, is made available by way of Free Use Permits granted to the DOE by the BLM.

Several historic extraction pits are located within the WLWA. Historic pits within the WLWA are now the property of the DOE and will be managed as components for imminent restoration/reclamation in accordance with Chapter 9 of this plan.

Inasmuch as the LWA prohibits surface or subsurface mining unrelated to the WIPP, within the WLWA, supplementary conditions pertaining to caliche or potash extraction, within this document, are not relevant. Accordingly, text within this chapter will pertain to oil and gas exploration and production only.

7.1 OBJECTIVES

The objective of the DOE with respect to mining and oil and gas production is to ensure that the development of mineral leases does not affect the integrity of the disposal system.

7.2 PLANNED ACTIONS

7.2.1 Provisions

In accordance with Section 4(b)(5) of the LWA, no surface or subsurface mining unrelated to the WIPP Project, or oil or gas production, including slant drilling from outside the boundaries of the WLWA, are permitted at any time (including after decommissioning) on lands on or under the WLWA, with two exceptions. These exceptions are two 320-acre (eight units) leases within the WLWA, below 6,000 feet, which are leased for oil and gas development (Federal Oil and Gas Leases NMNM 02953 and NMNM 02953C) (Figure 6.1). Both tracts, located in T.22 S., R. 31 E., Section 31, prohibit drilling within the first 6,000 feet of the surface. In accordance with the WIPP Land Withdrawal Act, existing rights under these leases will not be affected unless the Administrator of the Environmental Protection Agency (EPA) determines, after consultation with the Secretary of Energy, that the area in question should be purchased.

7.2.2 Surveillance

Surveillance of drilling and mining activity within one mile of the withdrawal boundary will be conducted by the DOE in coordination and cooperation with the BLM and/or the state of New Mexico in accordance with the MOU (Appendix C) and the concurrent statement of work (Appendix D). The BLM and state agencies have agreed to forward APDs and mining and reclamation plans to the DOE for review and comment in determining issuance of any drilling or mining permit within one mile of the WLWA. In addition to those commitments contained in the MOU and statement of work, the DOE shall conduct perimeter surveillance to verify proposed drill locations in accordance with Application for Permit to Drill (APD) submittals and evaluate potential encroachment of ancillary activities associated with producing wells and mines.

7.2.3 Department of Energy Response to Mining Plans and Applications for Permit to Drill

As directed by the existing MOU between the BLM and the DOE, WIPP personnel will receive APDs and mining reclamation plans from the BLM regarding activities proposed to be conducted within one mile of the WIPP site boundary. The DOE will field-verify the proposed locations and respond to the BLM, within 15 days, with DOE stipulations for approval. Companies that file for proposed drilling activities within 330 feet of the WIPP boundary may be required, at the recommendation of the DOE (and in accordance with existing DOE/BLM MOUs), to submit a daily set of drilling logs or "suite" of logs for verification, by the DOE, that the horizontal displacement of the well at no time encroaches on the WIPP site boundary. In the event of encroachment, a trespass condition will exist. The company will be required to cease drilling activities immediately, and plug and seal the region of trespass in accordance with all applicable laws and regulations that govern drilling activities, and to the satisfaction of the DOE, prior to proceeding with completion of the well.

Transmittal of proposed resource extraction applications or mining plans to the DOE by the BLM and/or the appropriate state agencies are formalized through MOUs or similar agreements.

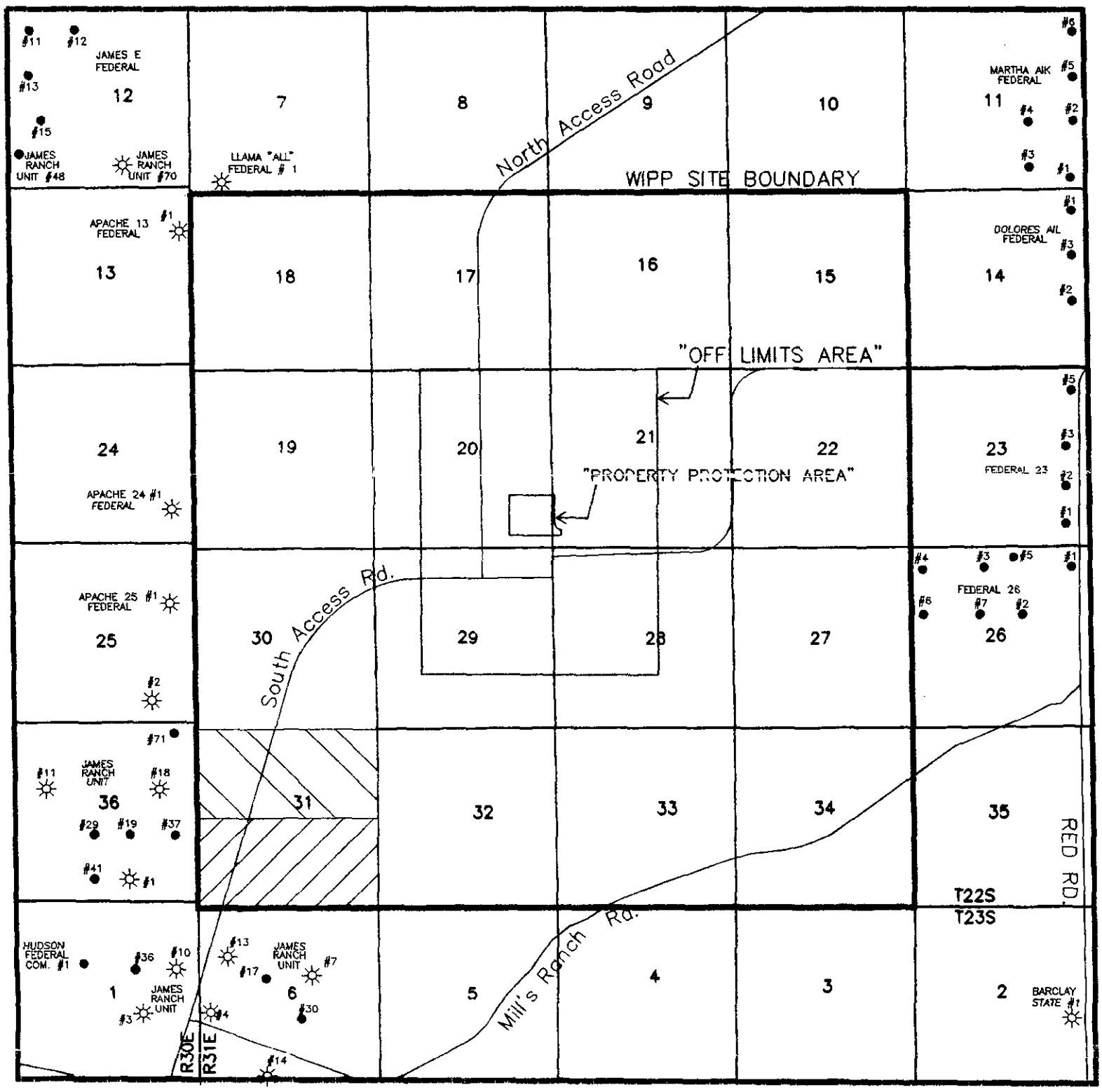

OIL AND GAS WELLS WITHIN ONE MILE OF THE WIPP LAND WITHDRAWAL AREA

1 0 1
MILES

1 0 1
KILOMETERS

● — OIL WELL

☼ — GAS WELL

Note: Production well icons denote well status according to firsthand field observations

FEDERAL LEASE NM-02953-C

FEDERAL LEASE NM-02953

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FIGURE 7.1

CHAPTER 8

LANDS AND REALTY

DEPARTMENT OF ENERGY

UNITED STATES OF AMERICA

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U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF LAND MANAGEMENT

CHAPTER 8
LANDS AND REALTY

8.0 INTRODUCTION

This chapter identifies land use management responsibilities of the DOE as they pertain to general realty issues, access corridors, rights-of-way, and avoidance areas that affect, but are not solely contained within, the WLWA.

8.0.1 Lands and Realty within the Affected Environment

WIPP Lands are relatively well consolidated within the boundaries of the 10,240 acre WLWA. There are, however, additional properties outlying the WLWA boundary, used in the operation of the WIPP, that are managed under the custodial auspices of right-of-way reservations granted (typically) by the Bureau of Land Management or the state of New Mexico. Groundwater monitoring well pads, their access roads, and environmental monitoring sampling stations predominate this property category for lands under the jurisdiction of the WIPP.

Access to the WIPP site is from U.S. Highway 62/180, 13 miles to the north (North Access Road), and from Highway 128, four miles to the south (South Access Road). Rail access to the WIPP site is provided by a rail line connecting with a spur of the Atchison, Topeka, and Santa Fe railroad near the Western Ag-Minerals Nash Draw mine six miles southwest of the site (Figure 9.1).

WIPP lands may be designated, at the discretion of the LMC, as right-of-way corridors or as avoidance areas to protect environmental and social values while optimizing economic efficiency for utilities and transportation facilities. The LMC will identify which lands will be avoided when routing future rights-of-way in order to protect sensitive resource values, and which areas may be designated as corridors. Major rights-of-way used in the operation of the WIPP, in addition to those that existed prior to land withdrawal, were acquired from the BLM. Existing rights-of-way are commonly associated with linear facility development (e.g., power lines, gas lines, water lines).

Development and/or maintenance of adequate access routes within the WLWA represent significant concerns.

8.1 OBJECTIVES

The objective of the DOE is to ensure proper management and maintenance of DOE/WIPP lands and realty (e.g., rights-of-way and access routes), in addition to providing safe and adequate access to the WIPP site while protecting the security of WIPP personnel, lands and realty (e.g., facilities). The DOE will consult with BLM and the State of New Mexico, as appropriate, on future rights-of-way actions needed outside the WLWA.

8.2 PLANNED ACTIONS

8.2.1 Proposals for New Access Routes, Easements, and Rights-of-Way

The DOE will examine, by way of the LMC and in accordance with Chapter 2 of this document, proposals from land users (WIPP and non-WIPP) that impact lands/realty, under the jurisdiction of the DOE to include: new access routes; easements; and rights-of-way when such access will not cause significant adverse impacts to other resources. In addition, the DOE will:

1. Review and comment on applications or proposals received from the BLM for access routes, easements, and rights-of-way affecting, but not solely contained within, the WLWA.

2. Forward to the New Mexico Environment Department (NMED) Hazardous and Radioactive Materials Bureau/DOE Oversight Bureau, within 30 days of receipt from or submittal to the DOI BLM:

   A. Applications or proposals for any access routes, easements, and rights-of-way affecting, but not solely contained within, the WLWA; and

   B. Any DOE comments developed on such applications or proposals.

8.2.2 Utility Development

In general, WIPP lands are available for utility and transportation facility development; however, applicants will be encouraged to locate any new facilities within existing right-of-way corridors. Deviations from existing corridors may be permitted on the basis of the need of the proposal and lack of conflicts with other resource values and uses.

8.2.3 Avoidance Areas

Right-of-way avoidance areas are defined as areas where future rights-of-way may be granted only when no feasible alternative route or designated right-of-way corridor is available. Terms and conditions of right-of-way grants will depend on the sensitivity of the affected resources and existing laws and regulations established as protective measures for the area in question.

8.2.4 Access Permits

The DOE will not grant permits for access when reasonable access already exists. Exceptions may be considered by the LMC only if the requestor presents, to the satisfaction of the LMC, a compelling need. [Note: See Chapter 2, "Environmental Compliance," for permitting protocol.]

8.2.5 Advertising

No commercial advertising signs will be allowed on WIPP lands. Violations will result in prosecution of the violator commensurate with laws governing property protection. Directional and road signs must be authorized by the DOE and must conform with DOE specifications and configurations.

8.2.6 Rights-of-Way, Rights-of-Way Corridors, and Realty Components

Realty components constructed, maintained, and/or utilized in the operation of WIPP, under existing custodial right-of-way reservations include, but are not limited to, the following:

8.2.6.1 North Access Road

The North Access Road is a private road granted, for perpetuity, under right-of-way reservation NM 55676 on August 24, 1983. The North Access Road is approximately 13 miles in length with an easement width of 120 feet. This road is restricted for use by the personnel, agents, and contractors of the DOE on official business related to the WIPP Project, or to personnel, permittees, licensees, or lessees of the BLM. Signs are placed and will be maintained at the turnout of Highway 62/180 stating the restrictions on access. Persons desiring access to Highway 128 should use the Lea County Line Road immediately to the east. Right-of-way NM 55676 was amended on April 22, 1988 to facilitate the construction of livestock fencing along either side of the subject road.

8.2.6.2 South Access Road

Eddy County Road 802 is designated as the South Access Road. This road originates at the turnout of Highway 128 and terminates as the pavement ends at the confluence of Sections 28 and 29 in T.22 South, R.31 East. This is a county road constructed in accordance with BLM Right-of-Way permit NM 46130. Terms for the right-of-way are for ". . . 50 years after the date of grant." The road configuration consists of a right-of-way width of 80 feet, two 12 foot driving lanes, two-to-four foot shoulders, and parallel "bar" ditches. Multiple-use access will be allowed unless it is determined that access by industry or the general public represents a significant safety risk to WIPP personnel. Upon determination, general access on Eddy County Road 802 may be restricted at the boundary of the 1454-acre Off-Limits Area in accordance with DOE Order 5632.6, *Physical Protection of DOE Property and Unclassified Facilities.*

8.2.6.3 Water Service Pipeline

Water service for the WIPP facility is furnished by a water line that originates 31 miles north of the facility. Maintenance and operation of the water line is performed in accordance with the conditions of Contract DE-AC04-86AL24138-M002 between the City of Carlsbad and the DOE under right-of-way reservation NM 53809 issued to the U.S. Army Corps of Engineers acting on behalf of the DOE. The volume capacity of the water line is such that it meets all water requirements for the operation of the WIPP facility, as well as provides the City of Carlsbad with untreated water.

The initial 16-mile segment of the line is a 24 inch diameter line that accommodates the city of Carlsbad deliveries in excess of that required by the WIPP facility. The city of Carlsbad is authorized to use capacity in the initial 16-mile segment that is in excess of 500 gallons per minute, provided that:

- Any such use of the excess capacity by the city of Carlsbad will be without any cost or liability to the DOE.

- The city of Carlsbad will notify the DOE not less than 30 days in advance of the installation of each new tap and/or service capacity commitment which the city of Carlsbad intends to serve from the DOE's line.

- Upon request by the DOE Contracting Officer, the city of Carlsbad will provide a monthly tabulation of deliveries by tap point for the preceding 24 months.

In the final 15-mile (10 inch diameter) segment, the DOE has authorized the 3/4 inch water tap lines to supply water to livestock drinking tanks. Additional tap points may be added from time to time with advance approval of the DOE. Water delivered at such tap points will be metered and billed by the city of Carlsbad consistent with the city of Carlsbad's rates and procedures for providing service to its regular customers.

Future use of the water pipeline within the WLWA will be determined at the time of decommissioning of the WIPP facility.

As specified in Contract DE-AC04-86AL24138-M002, the city of Carlsbad will provide the DOE's water requirements free of consumption charge and maintain the water line, at its expense, during the initial term of the contract and any optional extension terms thereafter. Single maintenance projects involving repairs or replacements that cost in excess of $10,000 will be considered abnormal and will be funded by the DOE, provided that such repairs or replacements are not the result of the fault or negligence of the city of Carlsbad or its customers, and provided further that the city of Carlsbad will first obtain the advance approval of the Contracting Officer (DOE) for any maintenance project requiring the DOE funding. This contract will be renegotiated between the DOE and the city of Carlsbad every five years.

An operating committee, comprised of (no fewer than) two representatives from the DOE and other affected city, county, state, and federal agencies, will be formed. The responsibilities of the operating committee will be:

- To establish standard procedures and practices for the operation and maintenance of the water line.

- To review any technical studies that may be conducted during the term of the contract and keep the Contracting Officer (DOE) and the city of Carlsbad currently advised as to matters needing attention.

8.2.6.4 Access Railroad

Rail access to the WIPP site is provided by a rail line connecting with a spur of the Atchison, Topeka, and Santa Fe railroad near the Western-Ag Minerals Nash Draw Mine six miles southwest of the site (Figure 9.1). This section of rail was constructed under the auspices of right-of-way reservation NM 55699 granted on September 27, 1983, is approximately five miles in length and consists of an adjacent frontage road, in addition to the rail. Both railroad and service road were constructed on an easement width of 150 feet. The railroad and the concurrent easement road will be maintained, in accordance with Chapter 13 of this document, until such time as the determination is made that the rail spur is identified for decommissioning.

8.2.6.5 Transmission Line

The WIPP is serviced by an overhead electrical transmission line that traverses the WLWA for two miles to the north (right-of-way reservation NM 43203) and an additional two miles to the south (right-of-way reservation NM 91163). The southern terminal of the line is approximately five miles south of the WIPP at a location identified as the Southwest Public Service Company's Sand Dune Substation. Access to the power line easement is restricted to WIPP employees and SPS employees. Unauthorized access to the easement is prohibited and will result in DOE response commensurate with property protection (see Chapter 10, *Security*).

8.2.6.6 High-Pressure Gas Line

A twelve-inch, high-pressure, interstate gas line with a corresponding easement road traverses portions of Sections 15, 16, 17, 19, and 20 of the WLWA. Maintenance and operation of the line and the easement road are the proprietary responsibility of the El Paso Natural Gas Company (the owner/operator of the line) under right-of-way reservation LC 060762. The WIPP periodically uses the easement road for access to the east and, therefore, will conduct maintenance activities (as needed and in accordance with WIPP maintenance protocol) (see Chapter 13 *Maintenance and Work Control*) to the road in order to provide adequate and safe access for WIPP vehicles (e.g., emergency response vehicles).

8.2.6.7 Sewage Lagoon

The WIPP sewage lagoon system is a zero-discharge facility consisting of two primary settling lagoons, two polishing lagoons, a chlorination system, and three evaporation basins. The entire facility is lined with 30 mil synthetic liners. The facility is designed to dispose of domestic sewage and site-generated brine waters from observation well pumping and from underground dewatering activities at the site.

The WIPP sewage facility is operated under the New Mexico Discharge Plan (DP-831) and managed in accordance with the EPA sewage sludge regulations (40 CFR 503), the New Mexico Solid Waste Management Regulations (Part 700), the New Mexico Water Quality Control Regulations (3-100), and the WIPP Sewage Sampling Procedure, WP 02-EM1001. These requirements provide guidance for disposal of domestic sewage, site generated brine waters, and site generated non hazardous waste waters.

A determination is made on a case-by-case basis to determine regulatory requirements for onsite or offsite disposal of sewage sludge. Small quantities of sludges generated at the WIPP site have been used as fertilizer and soil stabilizers for WIPP reclamation projects. All sludges are analyzed in accordance with regulatory requirements of 40 CFR 503 before they are applied to the reclamation areas.

8.2.6.8 Groundwater Surveillance Wells

WIPP personnel monitor 65 well bores and their corresponding locations on or in the vicinity of the WIPP site (Figure 13.1). Well depth ranges from approximately 525 feet to 750 feet. These respective well bores are used to conduct surveillance of water elevation (groundwater level) data. In addition, 7 of the 65 wells contribute water characterization data to the Water Quality Sampling Program of the WIPP. These evaluations are used to determine the physical and chemical characteristics and maintain surveillance of groundwater elevation surrounding the WIPP facility, both before and throughout the operational lifetime of the facility. Well locations located beyond the WIPP Site Boundary were constructed and are maintained under the guidelines of existing right-of-way reservations for each respective well. All well locations are periodically inspected, the existing well pads examined, and any nonconformities identified, reported, and dealt with accordingly.

In the event a well is considered inoperative (i.e., no longer needed for groundwater surveillance), the well will be plugged and sealed in compliance with State and Federal regulations in effect at the time. This procedure will apply as each DOE well (e.g., a well within the jurisdiction of the DOE or a well the DOE has assumed responsibility for) becomes abandoned until such time that all commensurate wells are plugged and sealed. Well pads and associated roads will be ripped, leveled, and reseeded in accordance with provisions contained in pertinent permits, agreements, and reclamation requirements identified in this document.

8.2.6.9 Salt Tailings Stockpiles

Salt from the underground mining operations is brought to the surface and stored in a bermed salt pile just north of the surface facilities. The salt storage pile contains approximately 408,000 cubic yards of material, with a capacity to store the estimated 2,116,400 cubic yards of material projected to be excavated during the lifetime of the WIPP project. There is also an inactive storage pile containing roughly 162,000 cubic yards within the DOE Exclusive Use Area, east of the Property Protection Area fence. This pile, referred to as the Site and Preliminary Design Validation (SPDV) pile, resulted from accumulation of material(s) extracted during the drilling of one 12-foot diameter and one 6-foot diameter shaft to the repository depth of 2,150 feet and the initial excavations underground.

Salt from the north stockpile, which is not needed for decommissioning will be disposed of under sections 2 and 3 of the Act of July 31, 1947 (30 U.S.C. 602, 603; commonly referred to as the "Materials Act of 1947"). After disposal of the salt, the stockpile area will be reclaimed in accordance with stipulations for reclamation contained within this document (see Chapter 9 *Reclamation/Environmental Restoration)*.

Disposition of the SPDV stockpile area will be determined after the pile is characterized for material content. As with the north stockpile, reclamation of the SPDV stockpile will be conducted in accordance with reclamation protocol(s) described in this document.

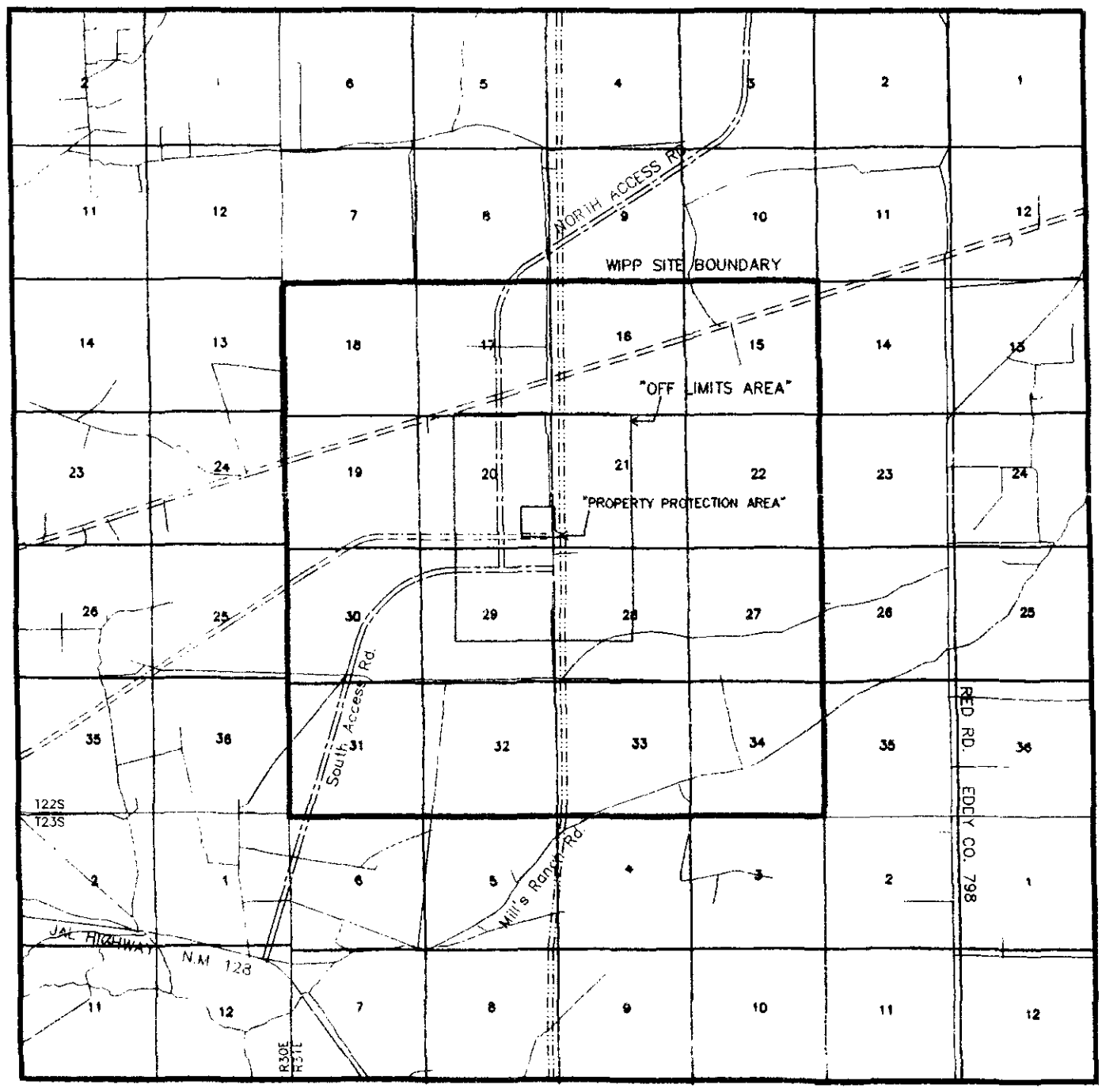

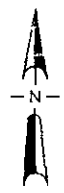

ACCESS AND RIGHTS-OF-WAY FOR THE WIPP SITE

NORTH AND SOUTH ACCESS ROADS

12" INTERSTATE GAS LINE

69 KV OVERHEAD ELECTRICAL TRANSMISSION LINE

RAILROAD

NOTE: WATER AND TELEPHONE LINE RIGHTS-OF-WAY ARE WITHIN THE NORTH ACCESS ROAD RIGHT-OF-WAY

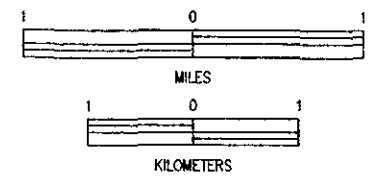

FIGURE 8.1

CHAPTER 9

RECLAMATION/ENVIRONMENTAL RESTORATION

CHAPTER 9
RECLAMATION/ENVIRONMENTAL RESTORATION

9.0 INTRODUCTION

This chapter identifies responsibilities of the DOE pursuant to applicable federal, state, and local environmental regulations to enhance and restore areas affected by the WIPP activities, to include areas disturbed prior to WIPP activities that were accepted as part of the land transfer from the BLM to the DOE. This chapter is designed to be revised as needed and is no way limited, except by law, to revisions based on new techniques for reclamation and new plans which the WIPP may incorporate in the future.

9.0.1 Reclamation in the Affected Environment

WIPP reclamation activities will be conducted in accordance with the *Environmental Protection Implementation Plan* (DOE/WIPP 90-050); DOE Order 5400.1, *General Environmental Protection Program Requirements*; the DOE *Organization Act* (42 U.S.C. 7112); *the Federal Land Policy and Management Act* of 1976 (Public Law 94-579); the *Final Supplement to the Environmental Impact Statement* (SEIS) WIPP (DOE/EIS-0026-FS, January 1990); the *Final Environmental Impact Statement,* (DOE/EIS-0026); and all applicable reclamation requirements by federal laws and regulations, Executive Orders, MOUs, DOE Orders, and state and local laws. These commitments include any unforeseeable future mandates or amendments to existing regulations.

In accordance with this document, the WIPP will implement a contemporary reclamation program and corresponding long-range reclamation plan. As locations are identified for reclamation, WIPP personnel will reclaim these areas by using the best acceptable reclamation practices. Seed mixes used will reflect those species indigenous to the vicinity and priority will be given to those plant species which are conducive to soil stabilization, wildlife, and livestock needs.

Without an active reclamation program, the establishment of stable ecological conditions in arid environments may require decades or centuries to achieve, depending on natural and unnatural disturbance and environmental conditions present during the entirety of the reclamation process. Reclamation activities will reduce soil erosion, increase the rate of plant colonization and succession, and provide habitat for wildlife in disturbed areas. In addition to maintaining the compliance posture of the WIPP with respective external entities, reclamation will ultimately serve to mitigate the effects of WIPP-related activities on affected plant and animal communities.

9.1 OBJECTIVES

The objective of the DOE reclamation program is to return lands used in the operation of the WIPP that are no longer commissioned for WIPP operations to a stable ecological condition. Plant species and topography of the reclaimed area will be conducive to the surrounding ecosystem. It is the intent of the DOE to establish reclamation guidelines for land use requestors.

9.2 PLANNED ACTIONS

The DOE will be responsible for reclaiming lands disturbed by DOE-funded activities. Reclamation for actions by outside agencies or organizations, completed on DOE property, or crossing DOE property, is the responsibility of the outside agency or organization. All reclamation activities must be completed in accordance with the following pertinent guidelines as prescribed by the WIPP LMC:

9.2.1 Timeliness of Reclamation Projects

Reclamation activities will be conducted as soon as is reasonably possible after the determination is made that an area is to be decommissioned. Scheduling of reclamation activities is done with mutual concurrence of the LUC and affected parties as applicable.

9.2.2 Review of Reclamation Activities

DOE will seek review of proposed reclamation activities, in advance, by the BLM and appropriate state agencies to ensure compliance with applicable DOE reclamation commitments. All proposed WIPP reclamation activities will be reviewed and approved by the cognizant reclamation task leader (WIPP LUC) in consultation with cognizant DOE personnel and affected stakeholders (LMC).

9.2.3 Fencing of Reclamation Sites

Reclamation activities include the fencing of the project with prescribed standard BLM fence configurations (e.g., bottom-strand barbless wire 16 inches from the ground, middle-strand barbed wire 26 inches from the ground, and top-strand barbed wire 38 inches from the ground for a three-strand range fence) to deter unauthorized use or grazing by livestock. The fence will remain in place until the determination is made by the LUC that plant succession has progressed to a state of ecological stability suitable to sustain livestock access.

9.2.4 Reclamation Protocol

Reclamation activities will incorporate low-impact, shallow-tillage protocol as often as is reasonably possible. This reclamation technique is preferred to mitigate the loss of ground moisture critical to seed germination.

9.2.5 Prioritization of Reclamation Sites

The LUC will identify and prioritize sites for reclamation (e.g., pads, roads, pits, etc.). Prioritization determinations are made in consultation with the LMC (including affected stakeholders). All projects and/or facilities authorized by previous commitments (e.g., MOUs, cooperative agreements) will be managed by the LUC to project finalization per DOE commitments.

9.2.6 Seed Mixes

All reclamation areas will be sown with seed mixtures that are approved by the Land Use Coordinator. These mixes will reflect plant species indigenous to the area.

9.2.7 Reseeding of Sites

Reclamation sites with plantings that do not germinate within a reasonable time frame, to be determined by the Land Use Coordinator, will be reseeded.

9.2.8 Reclamation and Cultural Resources

Reclamation activities will incorporate mitigation plans regarding any potential adverse impacts to cultural resources imposed directly by reclamation activities, or by ancillary activities associated with reclamation projects.

9.2.9 Decommissioning of the Waste Isolation Pilot Plant

Section 13 of the WIPP *Land Withdrawal Act* requires the DOE to prepare, in consultation with the Secretary of the Interior and the State of New Mexico, a decommissioning plan for the WIPP. This plan must be developed by October 30, 1997. Once decommissioning of the WIPP facility begins, surface structures are to be abandoned, decontaminated, and removed (including support facilities such as power lines). Underground facilities will be decommissioned in accordance with all applicable laws, rules, and regulations in effect at the time. Decommissioning and subsequent surface reclamation activities will be in accordance with existing applicable regulations and pertinent decommissioning plans (e.g., DOE/WIPP 2065, Revision 0, *Safety Analysis Report,* Chapter 10, "Decontamination and Decommissioning").

CHAPTER 10

SECURITY

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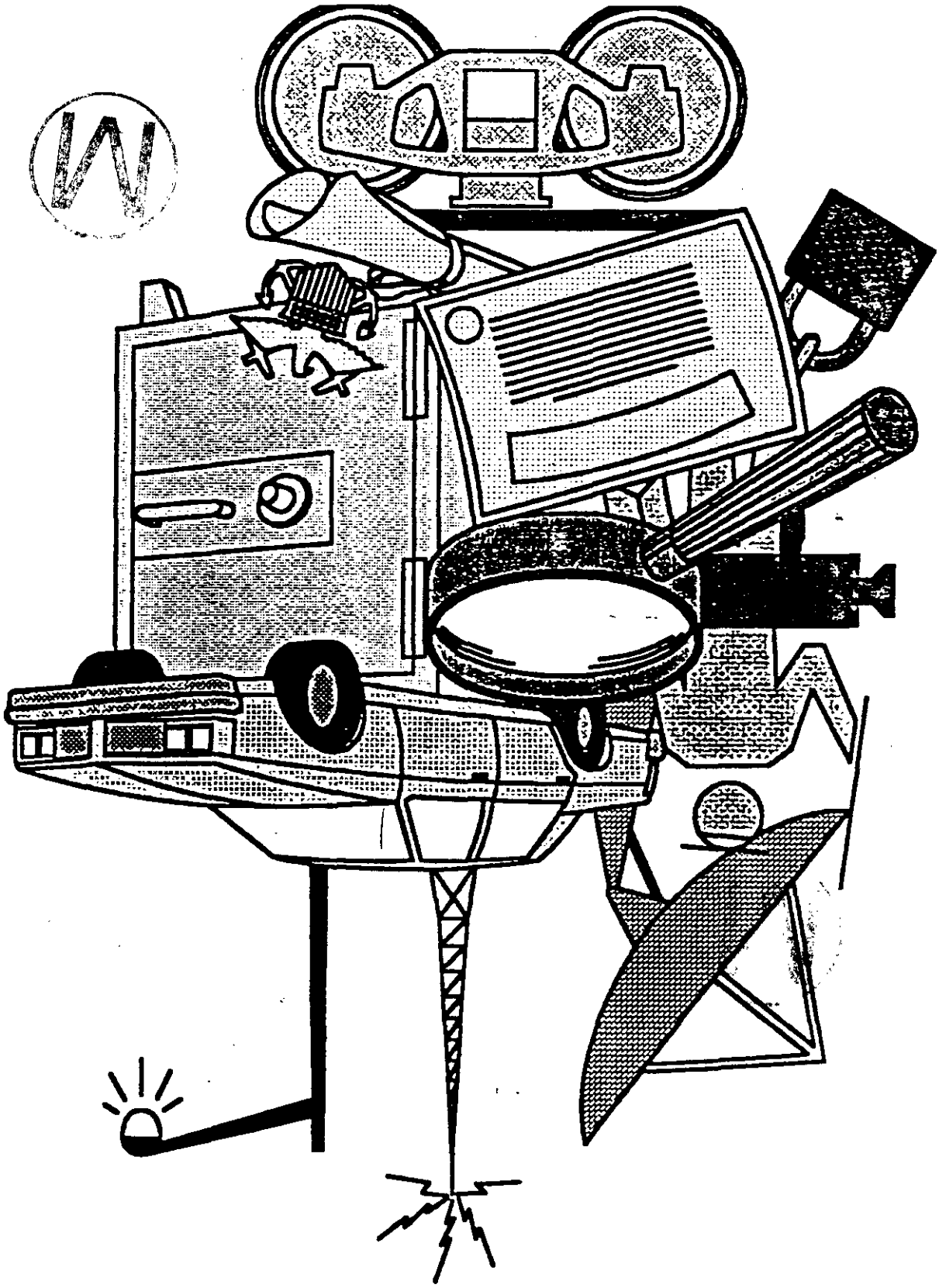

CHAPTER 10
SECURITY

10.0 INTRODUCTION

The security force for the WIPP consists of a staff of security officers, and support personnel on duty 24 hours a day. The WIPP security force maintains field vehicles, which are used several times daily for perimeter inspections.

10.1 OBJECTIVES

Security will be maintained in the classic sense within the Property Protection, Exclusive Use, and Off-Limits areas only. These areas are posted against trespass under the authority of Section 229 of the Atomic Energy Act of 1954, 42 U.S.C. 2278a, and pursuant to the regulations set forth in 10 CFR 860 and DOE Order 5632.6, *Physical Protection of DOE Property and Unclassified Facilities*. Security personnel will evaluate requests for services within the WLWA and make determinations based on DOE direction, manpower, and funding.

The objective of the security force will be limited to observation and reporting. Incidents requiring response or investigation will be referred to the proper legal authorities.

10.2 PLANNED ACTIONS

10.2.1 Property Protection Area

The interior core area of the facility (Figure 10.1) is a land area of approximately 34.16 surface acres surrounded by a chain link fence. This area, formerly identified as "Zone I," is designated as the "Property Protection Area." All access control features are maintained with uniformed security personnel on duty 24 hours a day.

10.2.2 Exclusive Use Area

The Exclusive Use Area (Figure 10.1) is comprised of approximately 277.14 acres within Sections 20, 21, 28, and 29 of Township 22 South, Range 31 East. It is surrounded by a five-strand barbed wire fence and is restricted exclusively for the use of the DOE, its contractors and subcontractors in support of the project. In addition, this area is defined as the point of closest public access for the purposes of performing accident consequences to the general public in the WIPP Safety Analysis Report (SAR). This area is marked by DOE

"No Trespassing" signs and will be patrolled by WIPP security personnel to prevent unauthorized activities or uses.

10.2.3 Off Limits Area

The Off Limits Area (Figure 10.1) is a sector comprised of 1453.9 acres, or 2.2 square miles (more or less), within Sections 20, 21, 28, and 29 of Township 22 South, Range 31 East. This sector is managed as an area wherein unauthorized entry and the unauthorized introduction of weapons and/or dangerous materials (as provided in 10 CFR 860.3 and 860.4) is prohibited. Pertinent prohibitions and subsequent penalties (10 CFR 860.5) are posted at consistent intervals along the perimeter as directed in 10 CFR 860.6. Grazing and public thoroughfare continue until such time that these activities present a threat to the security, safety, and/or environmental quality of the WIPP. This sector will be patrolled by WIPP security personnel to prevent unauthorized activity or use. While the subject sector is posted, the area is not fenced.

10.2.4 Waste Isolation Pilot Plant Land Withdrawal Area

The WIPP Site Boundary distinguishes the perimeter of the 16 section (or 10,240 acres) WIPP Land Withdrawal Area (WLWA). This tract includes properties outlying the Property Protection Area, the Exclusive Use Area, and the Off Limits Area. This sector is designated at points of ingress and egress, as a Multiple Land Use Area, and is managed accordingly. Certain restrictions however do apply. Information regarding land use restrictions is available on request.

10.2.5 Special Management Areas

There are sectors used in the operation of the WIPP (e.g., reclamation sites, well pads, roads, etc.) that are identified as Special Management Areas (SMA). A SMA designation is due to values, resources, and/or circumstances that meet criteria for protection and management under special management designations. Unique resources of value that are in danger of being lost or damaged, sectors wherein ongoing construction is occurring, fragile plant and/or animal communities, sites of archaeological significance, sectors containing imminent risks (safety hazards), or a sector(s) that may receive an unanticipated elevated security status would be suitable for designation as a SMA. Accordingly, the subject sector would receive special management emphasis under this stipulation. SMAs will be posted against trespass and shall be safeguarded commensurate with applicable laws governing property protection. WIPP security personnel will patrol these areas to prevent unauthorized access or use.

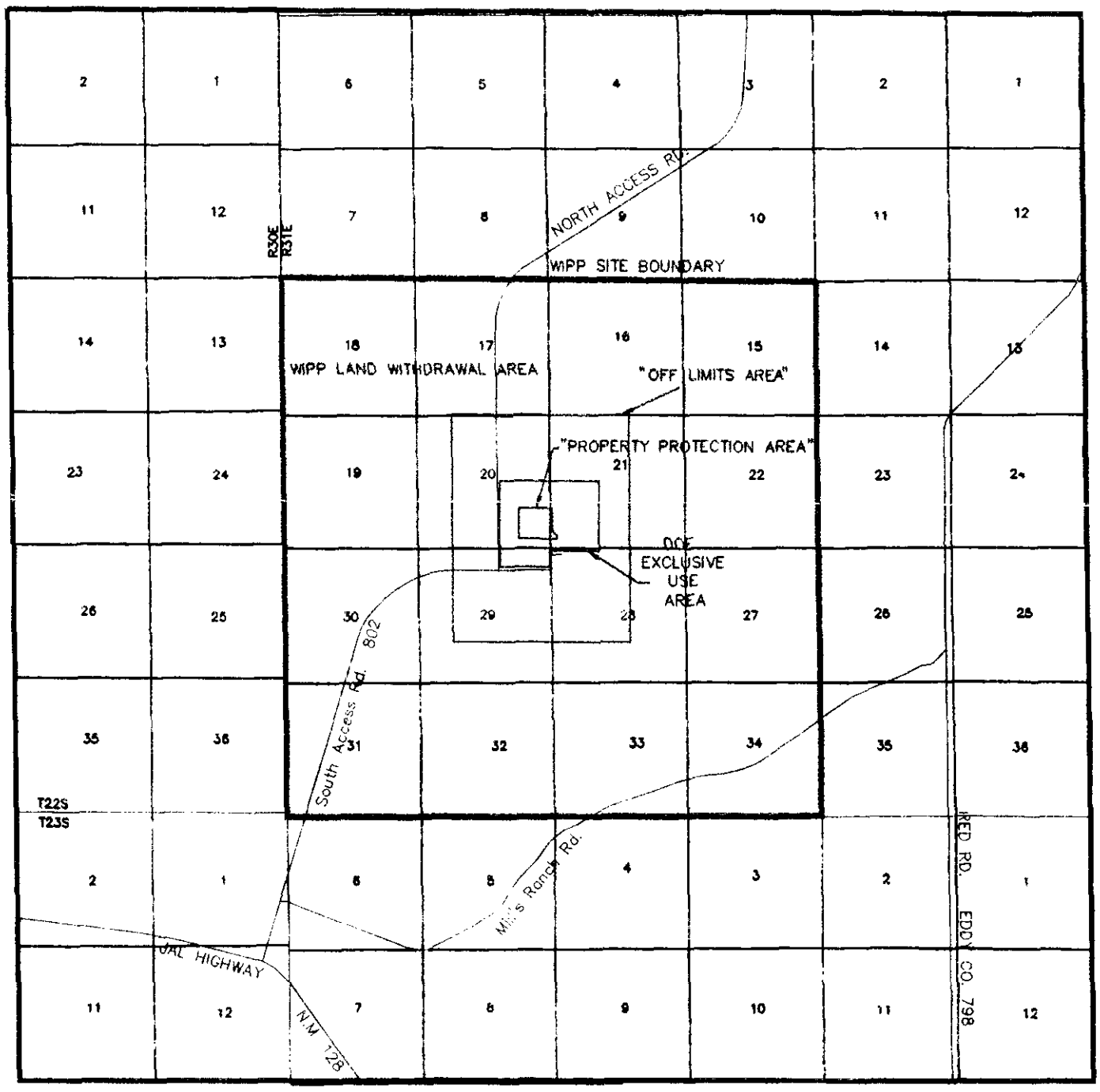

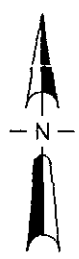

SECURITY ZONES WITHIN
THE WIPP SITE BOUNDARY

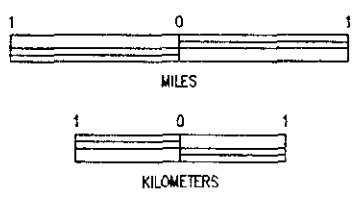

FIGURE 10.1

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CHAPTER 11

EMERGENCY MANAGEMENT

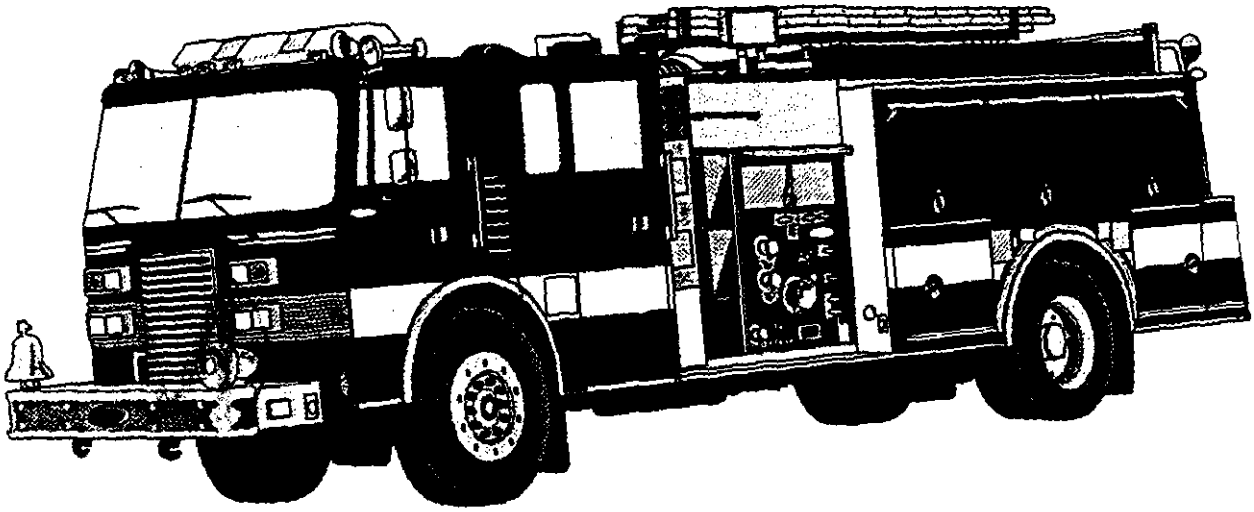

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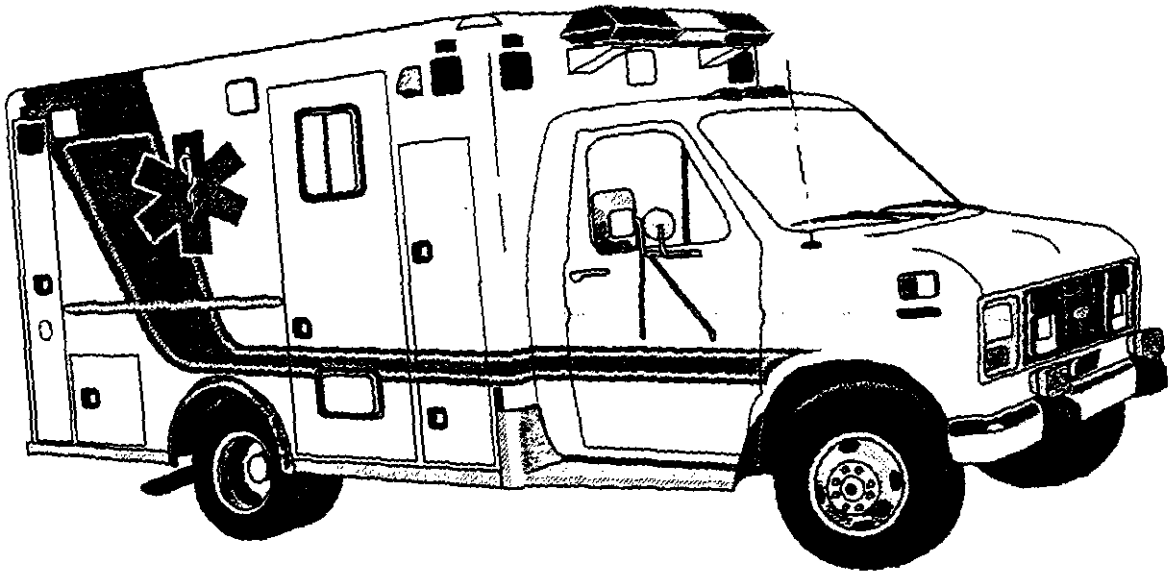

CHAPTER 11
EMERGENCY MANAGEMENT

11.0 INTRODUCTION

In the event of an emergency contact the Central Monitoring Room at 234-8125, 234-8457 or 234-8111.

Preparations have been made to minimize the impacts of an emergency at the WIPP by preparing emergency plans and training for emergency responders.

WP 12-9, *WIPP Emergency Plan and Procedures*, was developed to provide a framework of the responsibilities, capabilities, and authorities for the members of the emergency response organization (ERO). The ERO members, for the purpose of this document, consist of the following personnel/teams:

- Emergency Services Technicians (ESTs)
- Emergency Response Team (ERT)
- Backshift Fire Brigade (BFB)
- Central Monitoring Room Operator (CMRO) (234-8125)
- Facility Shift Manager (FSM)
- RCRA Emergency Coordinators

11.0.1 Emergency Services in the Affected Environment

The WIPP maintains 24-hour readiness in the event of an emergency. Emergency response includes fire fighting capabilities and emergency medical technicians deployed in accordance with existing Mutual Aid Agreements (e.g., with Carlsbad, Hobbs, and Eddy County, New Mexico). Emergency conditions of particular concern to the WIPP are both natural and anthropogenic (man-made). Natural disasters include wind, range fires, lightening, localized flooding, earthquakes, and tornadoes. Anthropogenic emergency conditions include fires, explosions, loss of power, hazardous atmospheres, external disruptions, mine accidents, hazardous emissions, heat stress, and equipment failure.

Plans have been implemented to minimize facility or programmatic impacts during an emergency condition at the WIPP Site. These plans apply to safety and security emergency preparedness and response actions to the following:

- Radiological Emergencies
- Underground Emergencies

- Industrial Emergencies
- Security Emergencies
- National Emergencies
- Continuity of Government Emergencies
- Natural Disaster Emergencies

11.0.2 Responsibilities

11.0.2.1 Emergency Services Technicians/Incident Commander

The EST is responsible for the overall incident command of an emergency until the emergency is mitigated. The EST is in charge of life and/or property threats that lie within the WLWA boundary (i.e., medical, rescue, fire, hazardous materials). The EST may also be activated outside the WLWA boundary by the Facility Shift Manager (FSM) in accordance with existing MOUs. MOUs shall be accommodated at the discretion of the FSM, in accordance with existing facility operations standing instructions, unless an on site emergency takes priority over actions prescribed in the MOU.

11.0.2.2 Emergency Response Team

The ERT is trained to incident-specific response, including, but not limited to, medical/ rescue, fire fighting, release of hazardous materials/waste, and contaminated/injured personnel. The response to any one event by the team shall be in accordance with the applicable federal, state, or local standards and/or guidelines established for that response. The ERT responds to emergencies at the WIPP in accordance with prescribed procedures and training.

11.0.2.3 Backshift Fire Brigade

The BFB is comprised of security personnel. They provide fire, rescue, and medical response support to the EST from 4:00 p.m. until 7:30 a.m., Monday through Friday, and 24 hours a day on Saturday, Sunday, and holidays.

The BFB is trained to respond to fires (on site and off) in accordance with existing MOUs and/or mutual assistance agreements. Personnel of the BFB are trained in accordance with New Mexico Firefighter Level 1 training standards.

11.0.2.4 Central Monitoring Room Operator (CMRO)

The on-shift operator is responsible for Central Monitoring Room (CMR) operations and can be contacted by dialing 234-8125 or 234-8457. The CMRO, who reports directly to the FSM, has the authority and responsibility to activate response personnel and organizations when notified of incidents that require immediate response (e.g., personnel injury, spills, fires, etc.) as directed by existing emergency procedures.

11.0.2.5 Facility Shift Manager (FSM)

This position is staffed 24 hours a day. The FSM is designated as the supervisor responsible for the overall day-to-day operation of the WIPP, including compliance with applicable Technical Safety Requirements and Safety Analysis Report. The FSM is the senior shift representative for WID management. The FSM is in charge of directing plant activities at the WIPP during emergencies until relieved by the Crisis Manager.

11.0.2.6 Resource Conservation and Recovery Act Emergency Coordinator

The RCRA Emergency Coordinator at the WIPP is the Facility Shift Manager during an activation of the RCRA Contingency Plan. Depending on the potential for adverse impacts, the FSM may transfer emergency response responsibilities to the Crisis Manager (e.g. in the event of an EOC activation the role of RCRA Emergency Coordinator is delegated to the Crisis Manager). There shall be a RCRA Emergency Coordinator onsite at the WIPP facility 24 hours a day, seven days a week, with responsibility for coordinating all emergency response measures. Those who are qualified to serve as RCRA Emergency Coordinators are thoroughly familiar with the *WIPP Contingency Plan* (WP 02-12); TRU mixed waste and hazardous waste operations and activities at the WIPP facility; locations of TRU mixed waste and hazardous waste activities; locations on the site where hazardous materials are stored and used; and locations of waste staging and accumulation areas. Persons qualified to act as the RCRA Emergency Coordinator have the authority to commit the necessary resources to implement the *WIPP Contingency Plan*.

11.0.2.7 Emergency Operations Center

The EOC is activated by the FSM when emergency conditions arise that cannot be mitigated without additional resources. The EOC is minimally comprised of a Crisis Manager, a Deputy Crisis Manager, an Operations representative, a Safety representative, and the EOC manager.

11.1 OBJECTIVES

The DOE's facility emergency preparedness objective is designed toward protecting and providing a safe environment for WIPP employees, contractor personnel, visitors, and the members of the general public during emergency situations. These include, but are not limited to wildland fires, radioactive and hazardous material (HAZMAT) accidents, tornadoes, floods, lightening strikes, and earthquakes.

11.2 PLANNED ACTIONS

11.2.1 Fire

The DOE's fire management program is designed to ensure a timely, well-coordinated, and effective response to suppress any wildfires within the WLWA. Once the CMR has been notified of a fire requiring response by emergency personnel, the CMRO will activate the EST, the ERT, and/or the BFB to mitigate the event. This includes activation to the WLWA boundary specified in the LMP.

The ERT/BFB will assemble at the Emergency Services Vehicle Bay to don personal protective equipment (PPE). The on-shift EST shall act as Incident Commander and direct all aspects of the fire response. The EST reports directly to the Facility Shift Manager. Moreover, activation may proceed outside this area as directed by existing MOUs.

11.2.1.1 Strategy

1. The DOE employs full suppression strategy for a wildfire within the WLWA by empowering the WIPP Incident Commander to coordinate fire management activities. The Incident Commander ensures that fire fighting activities adhere to the WIPP Pre-Fire Plans. The WIPP Pre-Fire Plans, kept in the WIPP fire truck and rescue vehicle, identifies entrances, exits, and any potential hazardous materials for each WIPP facility building.

2. Upon detection of a wildfire, within the WLWA, the BLM's Carlsbad Fire Control Officer is notified immediately. Upon arrival at the fire, WIPP personnel assess the situation and determine if additional support will be required. Should support be required, fire fighters from the BLM as well as Carlsbad, Hobbs, and Eddy County, New Mexico may be asked to assist in accordance with established Mutual Assistance Agreements.

11.2.1.2 Resources

The DOE will make a good-faith effort to acquire and maintain, in a state of readiness, the necessary resources to execute full suppression of a wildfire within the WLWA. The WIPP fire truck is intended primarily for protection of the WIPP facilities. This equipment must remain available for its primary objective. If conditions are such that WIPP personnel choose not to commit their forces to wild fires, WIPP Emergency Management personnel shall notify the BLM; and the BLM will coordinate suppression efforts.

11.2.1.3 Reporting

The DOE will provide notice, within 90 days, to the New Mexico Environment, Minerals, and Natural Resources Department (EMNRD)

Forestry and Resources Conservation Division regarding the status of any wildfire or prescribed burn within the WLWA.

11.2.2 Radioactive and Hazardous Materials

The initial response to any radioactive and/or HAZMAT incident is directed to protect human health, safety, and the environment. All such incident responses shall be conducted by personnel wearing the appropriate level of PPE as required by 29 CFR 1910.120 (P).

The ERT provides initial response to spills that cannot be managed by the responsible individual(s). Upon request of the on-duty EST, after a spill has been stabilized, any contamination will be removed by cognizant personnel. If necessary, the WIPP will use other resources (e.g., local fire departments, state police, subcontractors) to mitigate spills.

11.2.2.1 Strategy

The EST has the following duties during a spill of hazardous or radioactive materials.

1. Provide initial incident command of any emergency actions pertaining to releases or spills, radioactive or hazardous materials, or unknown substances.

2. Provide, if no emergency exists, medical surveillance and additional technical support for operations requiring a site-generated hazardous waste worker.

3. Advise the FSM on conditions and progress.

4. Direct all operations involving releases that have the potential to harm responders involved in cleanup activities.

11.2.2.2 Reporting

Complete proper HAZMAT forms as directed by WP 12-ER 4902, *Hazardous Materials Spill Response*. Spills or releases of hazardous materials will be reported to regulatory authorities in accordance with applicable regulations.

CHAPTER 12

INDUSTRIAL SAFETY

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CHAPTER 12

INDUSTRIAL SAFETY

12.0 INTRODUCTION

In the event of an emergency, contact the WIPP Central Monitoring Room at 234-8457, 234-8125, or 234-8111.

The industrial safety requirements for this section cover work performed by subcontractors, work performed on approved easements, work performed by WIPP employees, and recreational activities conducted within the boundaries of the WLWA. This program supplements WIPP policies contained in spill control plans and emergency response plans that relate to safe practices. The types of activities covered by this program include, but are not limited to:

- Construction work, including buildings, annexes, warehouses, storage areas, etc.
- Repairs or alterations
- Equipment installation and servicing
- Routine contract maintenance
- Remediation work
- Scrap and waste removal
- Transportation (i.e., trucking and deliveries)
- Electrical, piping, rigging, roofing, etc.
- Environmental monitoring/land management work

12.1 OBJECTIVES

The objective of the DOE is to provide and maintain a safe environment for any who wish to use WIPP lands. Additionally, the industrial safety program will define, for all WIPP subcontractors and members of the general public who wish to use WIPP lands, the safety and health policies, rules, and guidelines for minimizing unsafe conditions and acts that may result in personal injury and/or property damage. This program will provide a mechanism for subcontractors to communicate their safety and health concerns to WIPP safety and health personnel.

12.2 PLANNED ACTIONS

In order to maintain optimum conditions for a safe environment, the following are prohibited within the WLWA boundary:

- Possession or use of alcoholic beverages
- Possession or use of a controlled substance (e.g., marijuana)
- Discarding refuse/trash within the WLWA

12.2.1 Work Performed by Waste Isolation Pilot Plant Employees

All work performed by WIPP employees should comply with the requirements of the *WIPP Safety Manual*, WP 12-1 (available on request), and other applicable site requirements.

Any activity (e.g., recreational hunting, camping, etc.) that is identified by the DOE as an imminent risk to the health and/or safety of WIPP personnel can, at the discretion of the DOE, be suspended indefinitely on the WLWA. Permanent prohibition of activities resulting in the contradiction and/or subsequent amending of this LMP shall be considered only after a review by the LMC in consultation with affected stakeholders.

12.2.2 Safety Requirements for Subcontractors

When WIPP personnel perform work on the WIPP site or at offsite WIPP locations (e.g., groundwater surveillance well pads), their activities and equipment could affect subcontractor personnel and WIPP employees and property. Consequently, it is necessary that certain safety requirements be followed at all times when such operations are performed.

Work performed within the WLWA, regardless of the point of origin of a purchase requisition (e.g., WID or Sandia National Labs), must comply with existing WIPP site safety requirements. Documentation for work performed on approved easements must be submitted to cognizant WIPP personnel for validation concerning the appropriate Occupational Safety and Health Administration (OSHA) requirements for the type of work to be performed.

Subcontractors who conduct drilling activities (e.g., groundwater monitoring wells) within the WLWA will be held accountable for compliance with American Petroleum Institute (API) Recommended Practices for Occupational Safety for Well Drilling and Servicing Operations, API Recommended Practices 54 (RP54).

12.2.3 Policy

Subcontractors (to include lower-tier subcontractors) must comply with applicable local, state, and federal safety, health, and environmental regulations. The WIPP site representative (e.g., facility, work control, project engineer, or maintenance person in charge) will provide the site safety rules for which the contractor will be held accountable, and shall verify the adherence to these rules by the subcontractor. Site safety rules range from providing proper eye protection to compliance with the lockout/tagout procedures (i.e., project-specific). The WIPP recognizes that the subcontractor may also require its employees to follow specific safety rules which exceed the WIPP rules. These will be acceptable, provided they do not conflict with WIPP site rules.

12.2.4 General Guidelines

Since unsafe practices by subcontractors could expose WIPP employees to injuries and illnesses, a person cognizant of work packages and purchase requisitions will designate a subcontract technical representative (STR). The STR will monitor the practices of the contractor and establish a mechanism to control subcontractor services to assure that such services are performed in a safe manner.

12.2.5 Prior to Commencement of Work

Prior to commencement of work, all subcontractors are required to attend an on site preconstruction and safety conference. Conferences for construction (Davis-Bacon) subcontractors shall be conducted by WID Procurement Services; those for maintenance contractors (non-Davis-Bacon) shall be conducted by the WIPP STR.

12.2.6 Submittals Required by Subcontractors

12.2.6.1 Construction Subcontractors (Davis-Bacon Work)

The *Davis-Bacon Act* (40 U.S.C. 276a-276a-7) is a federal law applicable to federally funded construction work in excess of $2,000, which ensures that workers engaged in such construction work are not paid less than the scale of wages prevailing in the area in which the work is to be performed, as determined by the Department of Labor. Requisitions specify that each subcontractor shall provide WID Procurement Services the following information when bidding a project. This documentation will be reviewed and approved by the WID Industrial Safety Section.

1. Documentation of previous three-year injury experience and a current OSHA 200 Log.

2. Historical information (last three years) on any OSHA citations and other regulatory inspection reports or citations relative to the type of work to be performed.

3. Confirmation of workers' compensation coverage or equivalent, including the experience modification rate and other specific insurance coverage.

4. Copies of written safety policy and programs, which would include (as appropriate) but are not limited to (training requirements and supporting documentation):

   - Hazard communication
   - Respirator protection
   - Respirator fit testing and medical approval
   - Driving powered-industrial trucks
   - Control of hazardous energy systems (lockout/tagout)
   - Confined space entry

- PPE use

(WIPP personnel will have control of lockout/tagout procedures within the core or fenced area and confined space entry procedures within the WLWA.)

5. Copies of the Material Safety Data Sheet (MSDS) for each chemical to be brought inside the WLWA. The MSDS(s) will be reviewed, evaluated, and approved by the WID industrial hygienist or designee before any chemical is permitted on WIPP lands. The contractor is responsible for removal and for cleaning up spills generated by their actions, including costs associated with the cleanup.

6. Written certification that all material handling equipment (e.g., cranes, hoists, powered industrial trucks, chains, slings, spreaders) have been inspected and meet all requirements of Subpart N of both 29 CFR 1910 and 29 CFR 1926.

7. Written job hazard analysis for each phase of the work to be performed.

When specified in the subcontract, contractors are required to supply work plans describing the type of work to be performed, the number of people performing task(s), their emergency action plan, their safety rules, and the names of responsible personnel.

Subcontractor personnel are required to complete the appropriate WIPP training requirements prior to operating any WIPP site equipment, performing unescorted lockout/tagout functions within the fenced area, or entering any area within WIPP lands labeled as a confined space or meeting confined space criteria.

12.2.6.2 Maintenance Contractors (Non-Davis Bacon Work)

Maintenance contractors performing work within WIPP lands without active direction from the WIPP STR shall submit the same documentation required of the Davis-Bacon contractors (see above). When applicable, contractors operating under the direction of the site STR provide, for approval, to the WIPP STR and WID Industrial Safety the following:

1. Written documentation that all electrical hand tools have been tested as defined in OSHA 29 CFR 1926.404 (b).

2. Training records or confirmation of safety training for all employees as defined in OSHA 29 CFR 1926.21. "Safety Training and Education."

3. Copies of MSDSs for each chemical to be brought on site or to the project by the subcontractor.

4. Approved job hazard analysis or work instructions for each segment of work.

12.2.7 Waste Isolation Pilot Plant Responsibilities

12.2.7.1 Waste Isolation Division Procurement Services

WID Procurement Services provides:

1. The WIPP safety rules and procedures for subcontractors (available on request from the LUC).

2. Specific safety requirements for construction subcontractors meeting the Davis-Bacon criteria (available on request from the LUC).

3. Copies of all subcontract purchase requisitions to the WID Industrial Safety Section.

12.2.7.2 Waste Isolation Pilot Plant Subcontract Technical Representative Responsibilities

The WIPP STR shall:

1. Interface with other site groups and subcontractors.

2. Identify potential safety and exposure hazards that may interfere with the subcontractor while on the project.

3. Require mitigating emergency response procedures relative to the scheduled work activities.

4. Initiate stop work orders when OSHA, Mine Safety and Health Administration (MSHA), or the WIPP safety rules are violated and report all stop work orders that impact subcontractors to the cognizant WID Procurement Services representative.

5. Adhere to the existing system for maintenance of records regarding accident investigations, near-miss observations, injuries, and illnesses.

6. Route all maintenance contractor (non-Davis-Bacon) submittals through the WID Environment, Safety and Health (ES&H) Department for approval prior to commencement of work.

12.2.8 Procedure for Reporting Accidents

1. The WIPP site-specific procedure for reporting accidents will be used throughout the WLWA. All accidents involving injury or illness are required to be reported immediately to the CMR (first), the WIPP STR, the WIPP site medical personnel (according to WP 12-918, *Reporting Occurrences in Accordance with DOE Order 5000.3B*), and the individual's manager.

2. Property damage caused by accidents shall be reported to the CMR then to the WIPP STR, who convey the information to appropriate management.

3. Subcontractors are required to post emergency numbers and ensure that such numbers are provided to all employees of lower-tier subcontractors.

4. No off-site authorities are contacted prior to contacting the WIPP STR.

5. Spills, releases to the environment, and other "off-normal" events are to be reported in accordance with WIPP procedures.

6. All information concerning injuries and/or illness involving their employees are required to be recorded on their OSHA 200 Log or other appropriate record.

12.2.9 Subcontractor Safety Procedures

When stipulated in the statement of work, all subcontractors are required to include the following information in their bid package:

1. Medical surveillance and first aid plan

2. Electrical safety program

3. Hearing conservation program

4. Personal protection equipment program

5. Housekeeping program and inspection program

6. Hazardous waste disposal procedures

The statement of work for non Davis-Bacon subcontractors whose employees are under the direction of a WIPP STR is not required to contain the above requirements because employees of such subcontractors are subject to WIPP safety programs.

12.2.9.1 Personal Protective Equipment

Subcontractors are responsible for providing WIPP-approved personal protective equipment (PPE) to their employees. Any employee required to wear respiratory equipment must have prior medical approval from a physician to wear such type of equipment and be trained to wear it properly.

12.2.9.2 Safety Meetings

Subcontractors are required to conduct safety meetings, the frequency of which will depend on the nature of the project, but at a minimum of weekly.

12.2.9.3 Subcontractor Procedures

Procedures of subcontractors will not conflict with the WIPP site-specific procedures. In cases wherein procedures of subcontractors conflict with those of the WIPP, the WIPP STR will seek assistance and guidance from the WID ES&H Department.

12.2.10 Housekeeping Inspections

Subcontractor personnel (including lower-tier subcontractors) are required to conduct daily safety checks of areas where their employees are working. Any unsatisfactory conditions are reported immediately to the WIPP STR. Corrective actions will be taken immediately and documented on a daily safety inspection form.

Refuse and scraps that interfere with work flow and/or create fire hazards are required to be disposed of properly in a timely manner and not allowed to accumulate.

Subcontractors cannot block aisles, walkways, stairs, etc. The WIPP STR shall be notified prior to the erection of any barricades or other efforts by the subcontractor to prevent entry into areas.

CHAPTER 13

MAINTENANCE AND WORK CONTROL

CHAPTER 13
MAINTENANCE AND WORK CONTROL

13.0 INTRODUCTION

Lands used in the operation of the WIPP are listed in one of two categories. The first consists of lands contained within the boundary of the WLWA. Included in this area are roads, groundwater monitoring well pads, reclamation sites, and storage yards. Lands used in the operation of the WIPP outside the WLWA boundary consist primarily of access roads to groundwater well pads and a few isolated reclamation areas. [Note: roads and well pads used in the operation of the WIPP are identified in Figure 13.1.] The maintenance management program for the WIPP facility is consistent with best management practices (e.g., DOE Orders, WIPP procedures) that pertain to the maintenance of properties in a manner that promotes operational safety, worker health, environmental protection and compliance, property asset preservation, and cost effectiveness, while meeting the programmatic mission.

13.1 OBJECTIVES

The DOE maintenance objective (scope) is defined as the preventive, predictive, corrective, and scheduled maintenance activities for facilities, equipment, and support infrastructure necessary to accomplish the WIPP mission.

The WID work control system controls maintenance activities. It ensures that maintenance activities are effective in maintaining safe and reliable facility operation. This system applies to all personnel doing maintenance activities at the WIPP.

The WID work order system is the central component of the control system for maintenance activities at the WIPP. The work order system ensures that jobs are identified, logged, planned, scheduled, performed, tested, and formally accepted and documented in a systematic manner.

13.2 PLANNED ACTIONS

A maintenance training program has been established through the central site training organization. The training organization supports maintenance training programs that meet the intent of established industrial guidelines and address specific WIPP needs.

The infrastructure and equipment of the WIPP is required to be maintained by a proper balance of preventive, corrective, and predictive maintenance; procedures and

standards; and configuration management. Maintenance activities are controlled by the WID work control system to ensure a safe and reliable facility operation. The work order, submitted in accordance with *Work Control Administration* (WP 10-WC3002) and the *Maintenance Operations Instructions Manual* (MOIM), is the fundamental form used in the work order system for:

1. Job planning and analysis
2. Permits
3. Work performance standards
4. Priority system
5. Scheduling
6. Construction program interface
7. Post maintenance/modification testing

Maintenance activities in support of this LMP will be performed to the same criteria as established for the base facility (Property Protection Area). The expanded maintenance work scope as it pertains to land management activities includes, but is not limited to:

1. Maintenance of roads inside the WLWA

2. Maintenance of the WIPP railroad easement and the corresponding frontage road

3. Maintenance of DOE signs inside the WLWA

4. Maintenance of signs outside the WIPP boundary on properties used in the operation of the WIPP (e.g., North Access Road)

5. Maintenance of the North Access Road

6. Construction and maintenance of cattle guards inside the WLWA

7. Construction and maintenance of cattle guards outside the WLWA on roads used expressly for WIPP operations

8. Maintenance and oversight of the WIPP water line in accordance with contractual edicts between the City of Carlsbad and the DOE

9. Construction and maintenance of security/safety fences within the WLWA (e.g., the fence surrounding the Exclusive Use Area, and the fences that parallel the North and South Access Roads, that prevent livestock from wandering on the road) or at remote locations outside the WLWA used in the operation of the WIPP.

10. Construction and maintenance of groundwater surveillance well pads and corresponding access roads inside the WLWA.

11. Construction and maintenance of groundwater surveillance well pads and corresponding access roads outside the WLWA. [Note: roads outside the WLWA, identified as part of the WIPP maintenance work scope are limited to those which are intended exclusively for WIPP-related activities. Road maintenance of existing easements or rights-of-way, not constructed expressly for the WIPP uses but used as convenient access routes for WIPP-related activities, is not the responsibility of the WIPP.]

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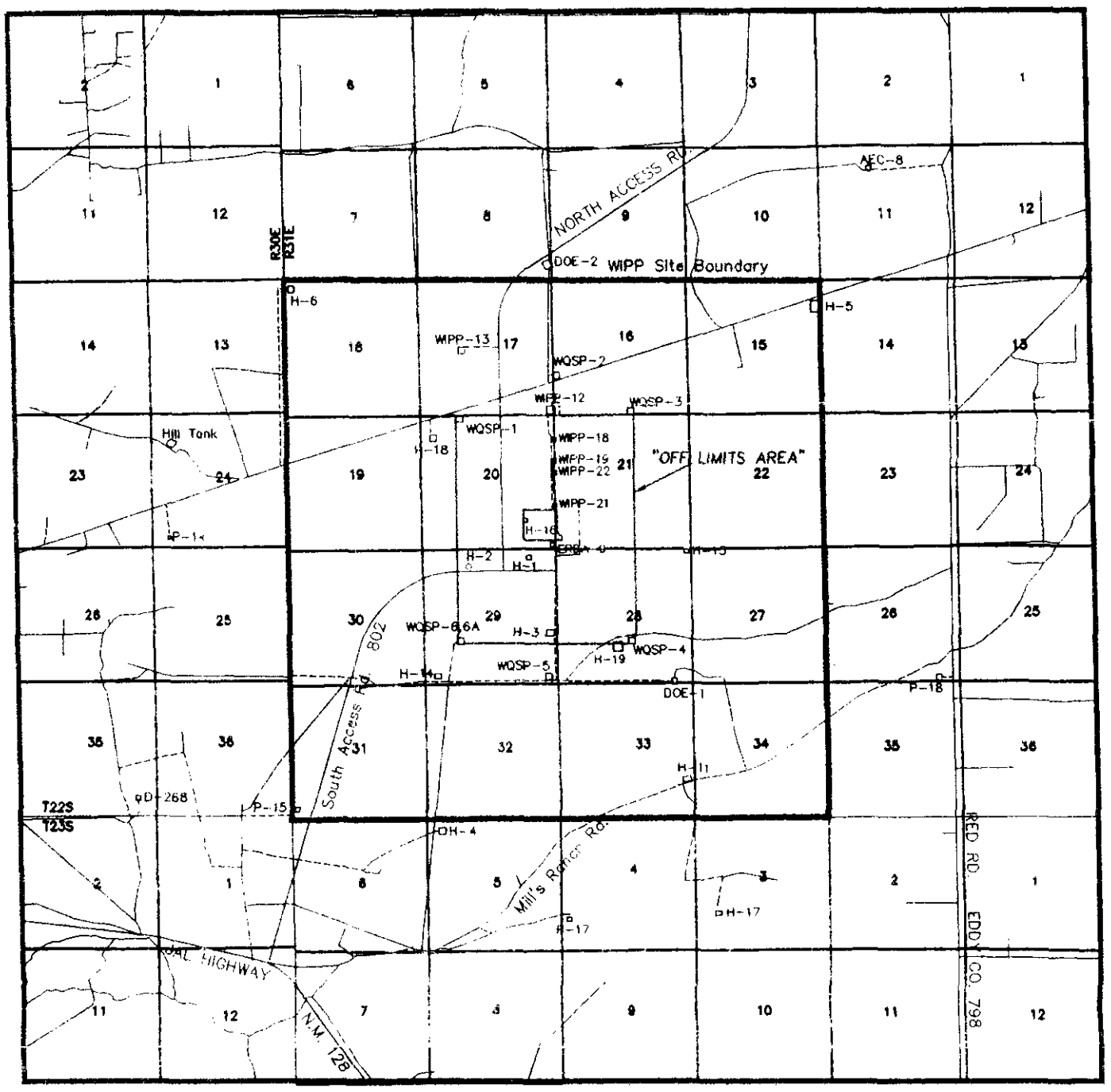

ROADS AND WELL PADS
USED IN THE OPERATION OF WIPP

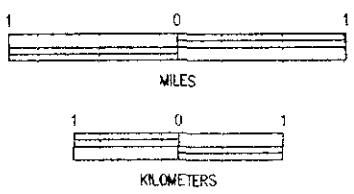

ROADS USED AND MAINTAINED EXPRESSLY FOR WIPP OPERATIONS

OTHER UNIMPROVED ROADS

IMPROVED ROADS

FIGURE 13.1

APPENDIX A

APPENDIX A

LAND MANAGEMENT COUNCIL

Land Management Planning

1.0 SCOPE

The WIPP Land Management Council provides policy guidance to the Department of Energy (DOE) in areas involving coordination of the management and oversight of lands included within the boundaries of the Waste Isolation Pilot Plant (WIPP) Land Withdrawal Area and those lands outside the WIPP boundary used in the operation of the WIPP site. This includes compliance with all applicable regulatory requirements relating to activities which occur or are likely to occur within the boundaries of those lands used in the operation of the WIPP. These include (but are not limited to) regulations referenced in the WIPP Land Management Plan (DOE/WIPP 96-2151), Joint Powers Agreement(s) (JPA), and the U.S. Department of the Interior, Bureau of Land Management (BLM) - DOE Memorandum of Understanding (MOU) incorporating all regulatory requirements and directives contained therein.

2.0 PARTICIPANTS

The Land Management Council shall consist of the following:

DOE Land Management Designee
WID Land Use Coordinator
Affected Stakeholder(s) - as appropriate (see Section 5.0)

3.0 RESPONSIBILITIES

1. Attend LMC meetings.

2. Evaluate and establish positions on issues or proposals brought before the LMC for consideration, and register individual concurrence or nonconcurrence.

3. Participate in matters that are presented to the Council for action.

4. Establish and maintain lines of communication among participants entities which, at any time, may have reason to utilize lands under the jurisdiction of the WIPP site.

5. Obtain recommendations and guidance from appropriate federal and state agencies.

3.0 **Responsibilities** (continued)

6. Provide recommendations and guidance to federal and state agencies as appropriate.

7. Monitor DOE compliance with applicable implementation of new state and/or federal regulatory requirements as they pertain to lands under the jurisdiction of the WIPP project.

8. Review of any unusual occurrences involving potential or existing safety concerns, contamination release, environmental noncompliance, nonconformance(s) with the Safety Analysis Report, and the like as they pertain to land management concerns.

9. Other pertinent issue/policy agenda items.

4.0 OPERATION

1. Convening the LMC by the DOE or the LUC shall occur as issues related to land management arise, as defined in the Land Management Plan.

2. Consideration of issues related to land management will not proceed without prior notification to all members of the LMC (to include affected stakeholders).

3. Decisions by DOE affecting the vested interests or concerns of party/parties identified as "affected stakeholders" will incorporate comments from said parties as voting members of the LMC.

4. The LMC will track all Land Use Requests from inception to project culmination, to include modifications, longevity and/or decommissioning.

5.0 STAKEHOLDERS/KEY EXTERNAL INTERFACES

1. Agency for Conservation Archaeology (ACA)

2. City of Carlsbad, New Mexico

3. Eddy County

4. (New Mexico) Energy, Minerals, and Natural Resources Department (EMNRD)

5. Environmental Evaluation Group (EEG)

6. Forestry and Resources Conservation Division of EMNRD

5.0 STAKEHOLDERS/KEY EXTERNAL INTERFACES (continued)

7. Historic Preservation Division of the Office of Cultural Affairs (OCA)
8. Lea County
9. Mills Ranch, Mr. J. C. Mills, Operator
10. New Mexico Department of Game and Fish (NMDG&F)
11. New Mexico Environment Department (NMED) - DOE/WIPP Oversight
12. (New Mexico) Office of Cultural Affairs (OCA)
13. Oil Conservation Division of the EMNRD (OCD)
14. Sandia National Laboratories (SNL)
15. Smith Ranch, Mr. K. Smith, Operator
16. (New Mexico) State Historic Preservation Officer (SHPO)
17. (New Mexico) State Land Office (SLO)
18. U.S. Department of the Interior, Bureau of Land Management (BLM)
19. U.S. Department of the Interior, U.S. Fish and Wildlife Service (USF&WS)
20. (New Mexico) State Engineer Office
21. U.S. Federal Bureau of Investigation
22. (New Mexico) State Police
23. (New Mexico) Department of Agriculture
24. U.S. Department of Agriculture
25. Carlsbad Area Office (CAO) of the DOE
26. (U.S.) Department of Justice

APPENDIX B

APPENDIX B

GUIDE FOR THE COMPLETION OF A LAND USE REQUEST

Acceptance or denial of a LUR is contingent on the accuracy and completeness of the LUR submittal. A LUR submittal consists of three basic elements or steps. These are:

Step 1: The requestor(s) of specific projects is required to complete a detailed, narrative description of the proposed activities for evaluation by the LUC. The project abstract is required to contain the following:

- Disclosure of the names of all individual(s) and/or companies scheduled to perform the proposed action;
- The intent or purpose of the proposed action;
- Anticipated timelines for completion;
- Impacts on the WIPP that would result if the LUR for the proposed action was denied;
- Alternatives;
- Anticipated environmental impacts;
- Detailed reclamation/restoration plans.

Step 2: The requestor(s) is required to submit a properly completed ER (Attachment 1 to Appendix B).

Step 3: The requestor is required to provide a map (USGS 7.5 topographic, BLM land status, or WIPP generated) depicting the location(s) of the proposed action.

DOCUMENT NAME: _____ (Test Plan, Engineering Document, Etc.)	DOCUMENT No. _____ (If Available)

BRIEF DESCRIPTION: (Include type of action, location, schedule, justification. Use separate attachment if necessary)

ENVIRONMENTAL CONCERNS: Will the project/activity, either during construction or operation result in changes and/or disturbances in the following areas? Check "yes" if the proposed project/activity represents a commitment to a course of actions that would ultimately require a positive response to one or more of the questions below. Provide brief explanations for "yes" responses.

		YES	NO			YES	NO
1.	Air emissions	☐	☐	12.	Outside property protection area	☐	☐
2.	Liquid effluents	☐	☐	13.	Archaeological/cultural resources	☐	☐
3.	Solid waste	☐	☐	14.	Noticeable increase in noise	☐	☐
4.	Hazardous constituents	☐	☐	15.	Radiation/toxic chemical exposures	☐	☐
5.	Radioactive waste	☐	☐	16.	Pesticide/herbicide use	☐	☐
6.	Mixed waste (rad. & haz.)	☐	☐	17.	High energy source/environment	☐	☐
7.	Chemical storage/use	☐	☐	18.	Transportation issues	☐	☐
8.	Petroleum storage/use	☐	☐	19.	Special status species/environment	☐	☐
9.	Asbestos materials	☐	☐	20.	Environment restoration site	☐	☐
10.	Utility system	☐	☐	21.	Other (specify)	☐	☐
11.	Clearing or excavation	☐	☐				

No.	Explanation and qualification of specific "Yes" responses.

Are any waste minimization measures planned for this action? If yes, provide brief description of the measures planned.

CI Printed Name	Signature	Date

*Required only if items 12 13 and/or 20 are checked "YES"

Land Use Coordinator (Printed Name)	Signature	Date

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APPENDIX C

MEMORANDUM OF UNDERSTANDING

BETWEEN

THE U.S. DEPARTMENT OF ENERGY

AND

THE U.S. DEPARTMENT OF INTERIOR

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MEMORANDUM OF UNDERSTANDING
BETWEEN
THE U.S. DEPARTMENT OF ENERGY
AND
THE U.S. DEPARTMENT OF INTERIOR

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MEMORANDUM OF UNDERSTANDING
BETWEEN
THE U.S. DEPARTMENT OF ENERGY
AND
THE U.S. DEPARTMENT OF THE INTERIOR

I. PARTIES

The parties to this Memorandum of Understanding (MOU) are the U.S. Department of Energy (DOE), represented by its Waste Isolation Pilot Plant (WIPP) Carlsbad Area Office, and the U.S. Department of the Interior (DOI), represented by its Bureau of Land Management (BLM), Roswell District Office.

II. BACKGROUND AND PURPOSE

The WIPP is authorized under Section 213 of the DOE National Security and Military Applications of Nuclear Energy Authorization Act of 1980, Public Law (P.L.) 96-164. The WIPP is authorized for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission.

The WIPP Land Withdrawal Act of 1992, P.L. 102-579 ("the LWA"), withdrew 10,240 acres of land in Eddy County, New Mexico, from the operation of the public land laws and reserved those lands for the construction, experimentation, operation, repair and maintenance, disposal, shutdown, monitoring, decommissioning, and other authorized activities associated with the purposes of the WIPP as set forth in Section 213 of P.L. 96-164.

Section 4 of the LWA makes the Secretary of Energy responsible for the management of the withdrawal, consistent with the Federal Land Policy and Management Act of 1976. The LWA directs the Secretary, in consultation with the Secretary of the Interior and the state of New Mexico, to develop a land management plan (DOE/WIPP 93-004) for the use of the withdrawal area until the end of the decommissioning phase. It further directs the Secretary and the Secretary of the Interior to enter into an MOU to implement the management plan.

III. AUTHORITY

This MOU is entered into pursuant to the authority of, and is consistent with, the LWA. Further, it is consistent with and subject to certain other appropriate statutory authorities, including the Department of Energy Organization Act, P.L. 95-91; the Energy Reorganization Act of 1974, P.L. 93-438; and the Economy Act of 1932, as amended by P.L. 98-216.

IV. MANAGEMENT

This MOU envisages direct communication between officials of the DOE and the BLM in consultation with other federal and state land management agencies which are involved in managing the resources within or activities impacting the surrounding areas of the WIPP withdrawal area. This MOU sets forth the cooperative arrangements and procedures for addressing land management within the withdrawal area. These cooperative arrangements and procedures implement the WIPP Land Management Plan for the withdrawal area and are consistent with the WIPP Land Management Plan's concept of multiple-use management.

The responsibilities and duties listed pursuant to this MOU relate to those shared by the DOE and the DOI. For additional land management issues not found in this MOU, consult the WIPP Land Management Plan (DOE/WIPP 93-004).

This MOU will be administered on behalf of the DOE by the Manager, Carlsbad Area Office, P.O. Box 3090, Carlsbad, New Mexico 88221.

This MOU will be administered on behalf of the DOI by the District Manager, Roswell District Office, BLM, P.O. Box 1397, Roswell, New Mexico 88201.

V. FUNDING

The details of the levels of funding to be furnished to one signatory organization by the other will be developed in specific interagency agreements, subject to the availability of funds. This MOU shall not be used to obligate or commit funds or as the basis for the transfer of funds. The DOE and the DOI will provide each other mutual support in budget justification to the Office of Management and Budget and in hearings before the Congress with respect to the programs described in the WIPP Land Management Plan and implemented through this MOU.

VI. RESPONSIBILITIES OF PARTICIPATING PARTIES

A. Cultural Resources

It is the intent of the DOE to manage cultural resources within the withdrawal area pursuant to Sections 106 and 110 of the National Historic Preservation Act, Archaeological Resource Protection Act, Native American Graves Protection and Repatriation Act, and applicable DOE Orders to ensure that scientific and sociocultural use by present and future generations shall not be diminished.

1. The DOE agrees to:

   a. Retain responsibility for management of cultural resources within the withdrawal area.

   b. Inventory and evaluate cultural resources prior to surface-disturbing activities.

c. Use avoidance as the primary mitigation measure.

2. The DOI agrees to:

a. Provide recommendations to the DOE in developing mitigation measures when avoidance of historic property is not possible.

B. Grazing Management

The withdrawal area includes portions of two grazing allotments administered by the BLM. The DOE's intent is to continue current management practices.

1. The DOE agrees to:

a. Retain responsibility for grazing management decisions affecting the two grazing allotments within the withdrawal area.

2. The DOI agrees to:

a. Provide proposed grazing management changes and/or plans to the DOE for review and comment.

b. Provide grazing management of the grazing allotments within the withdrawal area in accordance with applicable grazing laws including the Taylor Grazing Act, the Federal Land Policy and Management Act, and the Public Rangelands Improvement Act.

c. Continue BLM-funded vegetative monitoring program to determine if range management goals and objectives established for the grazing allotments are being achieved. As a minimum, the monitoring program will include collecting data on actual livestock use, wildlife habitat and population trends, degree of utilization of the key forage species, climatic conditions, and rangeland ecological conditions and trends.

C. Wildlife

The DOE intends to manage wildlife habitat within the withdrawal area for ungulates, raptors, upland game, and any special-status plant or animal species occupying the withdrawal area.

1. The DOE agrees to:

a. Retain responsibility for management decisions affecting wildlife habitat and the habitat of any special-status plant or animal species found occupying the withdrawal area.

b. Continue with the BLM and the DOE Interagency Agreement No. 1422G910-A2-0016 - Raptor Research and Management Program.

c. Upon receipt of the draft copy of the recovery plan (see Part 2a. below), the DOE shall review, comment, and transmit the draft copy of the recovery plan back to the BLM within 30 days.

2. The DOI agrees to:

a. Develop a recovery plan in cooperation with the U.S. Fish and Wildlife Service and appropriate state agencies for any threatened or endangered plant and animal species found occupying the WIPP withdrawal area to ensure its success and survival.

b. Continue with the BLM and the DOE Interagency Agreement No. 1422G910-A2-0016 - Raptor Research and Management Program.

c. Consult with the DOE to ensure that any range improvement developments (e.g., installation of livestock watering units) will be designed to accommodate wildlife needs.

D. Fire Management

It is the intent of the DOE to provide a fire management program that will ensure a timely, well-coordinated, and cost-effective response to suppress wildfire within the withdrawal area.

1. The DOE agrees to:

a. Employ full suppression strategy of a wildfire within the withdrawal area by utilizing the WIPP incident commander to coordinate fire management activities.

2. The DOI agrees to:

a. Provide full fire-fighting support within the withdrawal area should the WIPP incident commander request such support.

b. Commit necessary additional fire suppression resources should local BLM fire suppression resources be insufficient. The additional resources to be committed will be negotiated based upon the severity and behavior of the fire.

E. Mining and Gas and Oil Production

It is the intent of the DOE to ensure that mining and gas and oil activities do not encroach upon the withdrawal area. Adherence to this MOU is crucial to protecting the repository from inadvertent human intrusion. The WIPP is an offset owner to all gas

and oil leases adjacent to the withdrawal boundary and will exercise the right to provide input on proposed activities of adjacent offset operators requesting an exception to applicable New Mexico Oil Conservation Division (NMOCD) rules and regulations.

In accordance with Section 4(b)(5)(A) of the LWA, no surface or subsurface mining or oil or gas production, including slant drilling from outside the boundaries of the withdrawal, shall be permitted at any time (including after decommissioning) on lands on or under the withdrawal.

In accordance with Section 4(b)(5)(B) of the LWA, existing rights under Federal Oil and Gas Leases No. NMNM 02953 and No. NMNM 02953C shall not be affected unless the Administrator of the Environmental Protection Agency determines, after consultation with the Secretary of Energy and the Secretary of the Interior, that the acquisition of such leases by the Secretary of Energy is required to comply with the disposal regulations or with the Solid Waste Disposal Act (42 U.S.C. 6901 et seq.).

1. The DOE agrees to:

   a. Coordinate with the BLM to provide input and recommendations in determining a BLM permit issuance for oil and gas extraction and mining activity on federal lands within one mile of the WIPP withdrawal boundary.

   b. Provide the technical expertise to interpret, review, and verify oil and gas activity calculations performed by the BLM.

2. The DOI agrees to:

   a. Forward applications for Permit to Drill and mining and reclamation plans to the DOE for review and comment in determining issuance of any oil and gas extraction or mining permit within one mile of the WIPP withdrawal boundary. The BLM shall resolve any DOE comments prior to approval of such applications and plans.

   b. Include the following as a Special Condition of Approval for oil and gas activity on federal lands at 330 feet or closer to the WIPP withdrawal boundary:

      (1) Ensure that the operator provides the BLM with drill site downhole vertical deviation surveys for each 500-foot drilling interval.

      (2) Provide the technical expertise to calculate well bore deviation at each 500-foot interval of drilling to determine the degree of deviation and forward these results to the DOE for review and verification of calculations.

      (3) Require the operator, in accordance with the NMOCD Rule 111, to perform and provide the BLM a directional survey to establish bottom

hole location on well bores that experience deviation angles of more than five degrees from vertical in any 500-foot interval.

(4) Require the operator to perform and provide the BLM a directional survey to establish bottom hole location on well bores when the total cumulative degrees of displacement, independent of direction, indicate that the well bore could deviate to within 100 feet of the withdrawal boundary. Should the directional survey indicate that deviation is toward the withdrawal boundary, the BLM would require a directional survey at 100-foot intervals until such time as data would indicate that the bottom hole location at total depth would not exceed 10 degrees from vertical or could result in a bottom hole location less than 100 feet from the withdrawal boundary. Should deviation direction continue towards the withdrawal boundary during the BLM monitoring of the 100-foot directional survey intervals, the BLM will require the operator to take corrective measures (e.g., side tracking) or cease drilling activity.

(5) Provide the DOE the directional survey results that establish bottom hole location on well bores that experience deviation angles of more than five degrees from vertical in any 500-foot interval and on well bores when the total cumulative degrees of displacement, independent of direction, indicate that the well bore could deviate to within 100 feet of the withdrawal boundary.

c. Provide the DOE with completion, alternate use, and/or plugging and abandonment reports relevant to drilling, production, injection, and mining activity on federal lands within one mile of the withdrawal boundary.

F. Realty/Lands/Rights-of-Way

Land use management within the WIPP withdrawal boundary is the sole responsibility of the DOE. It is the intent of the DOE to monitor any land use proposal affecting the withdrawal area.

1. The DOE agrees to:

a. Consult with the BLM regarding future DOE right-of-way actions needed outside the withdrawal area.

b. Review and comment on applications and proposals received by the BLM for any land uses affecting, but not solely contained within, the WIPP withdrawal boundary.

c. Submit comments relative to any land uses affecting, but not solely contained within, the WIPP withdrawal boundary to the BLM's Roswell District Manager, or their representative, within 30 days of receipt from the BLM.

2. The DOI agrees to:

   a. Forward applications and proposals for land uses affecting, but not solely contained within. the WIPP withdrawal boundary to the DOE.

   b. Assume responsibility, when designated as the lead agency, for the preparation of the National Environmental Policy Act documentation for land uses affecting, but not solely contained within. the WIPP withdrawal boundary. The BLM shall obtain the review and approval of the DOE (the contributing agency) in regard to the BLM issuance of a Record of Decision.

   c. Incorporate any DOE- and/or WIPP-specific compliance requirements when preparing documentation for land uses affecting, but not solely contained within. the WIPP withdrawal boundary.

G. Reclamation

The DOE intends to return land disturbed by the WIPP activities to a stable ecological state that will assimilate with the surrounding undisturbed ecosystem.

1. The DOE agrees to:

   a. Reclaim land disturbed by the WIPP activities in accordance with the *Environmental Protection Implementation Plan* (DOE/WIPP 90-050); the Federal Land Policy and Management Act, 1976 (P.L. 94-579); the WIPP Final Supplement Environmental Impact Statement (DOE/EIS-0026-FS, Jan. 90); the WIPP Final Environmental Impact Statement (DOE/EIS-0026, Oct. 80); EPA requirements regarding disposal regulations; future Environmental Impact Statements; and land withdrawal requirements.

   b. Consult with the BLM in advance of reclamation activities to ensure compliance with applicable DOE reclamation commitments.

2. The DOI agrees to:

   a. Review DOE-proposed reclamation actions to ensure compliance with applicable DOE reclamation commitments.

VII. PUBLIC INFORMATION COORDINATION

Subject to the Freedom of Information Act. Title 5 U.S.C 552. decisions by either party on disclosure of information to the public regarding projects and programs developed pursuant to this MOU shall be made only after consultation between the parties.

VIII. PATENTS AND TECHNICAL DATA

Appropriate patent and other intellectual property provisions shall be included in interagency agreements and any other agreements entered into by the parties in order to implement this MOU. DOE patent and intellectual property policies shall apply to any such work performed by a contractor (including any subcontractor) which is funded in whole or in part by the DOE. Rights to inventions made by U.S. government employees shall be determined by the employing agency. .

IX. REVIEW, AMENDMENT, AND TERMINATION

The DOE and the DOI, in consultation with other federal and state agencies involved in managing the resources within the withdrawal, shall review the MOU on an annual basis to determine whether it remains current and whether it effectively and appropriately implements the WIPP Land Management Plan for the WIPP withdrawal.

In the event that the DOE and the DOI determine that this MOU should be revised or amended, such revision or amendment shall be accomplished only upon written agreement between the parties. Any revisions or amendments to this MOU shall be developed in consultation with the state of New Mexico.

This MOU may be terminated by mutual agreement of the DOE and the BLM, or by either party upon a 30-day written notice to the other party.

This MOU shall remain in effect until the end of the decommissioning phase of the WIPP, as that phase is defined in the LWA.

X. EFFECTIVE DATE

This MOU shall become effective upon the latter date of signature of the parties.

U.S. DEPARTMENT OF ENERGY

BY: George E. Dale

DATE: July 19, 1994

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

BY: Leslie M. Cone

DATE: July 19, 1994

APPENDIX D

WASTE ISOLATION PILOT PLANT

STATEMENT OF WORK

FOR

THE BUREAU OF LAND MANAGEMENT

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THE BUREAU OF LAND MANAGEMENT

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WASTE ISOLATION PILOT PLANT

STATEMENT OF WORK
FOR
THE BUREAU OF LAND MANAGEMENT

The Bureau of Land Management (BLM) shall perform the following specific tasks identified by the U.S. Department of Energy (DOE) as being necessary to the management of the Waste Isolation Pilot Plant's (WIPP) 16-section withdrawal area.

The parties to this Statement of Work (SOW) are the DOE, represented by its WIPP Carlsbad Area Office, and the U.S. Department of the Interior (DOI), represented by its BLM, Roswell District Office.

This SOW supports the WIPP Land Management Memorandum of Understanding executed between the DOE and the DOI.

This SOW will be administered on behalf of the DOE by the Manager, Carlsbad Area Office, P.O. Box 3090, Carlsbad, New Mexico 88221.

This SOW will be administered on behalf of the DOI by the District Manager, Roswell District Office, BLM, P.O. Box 1397, Roswell, New Mexico 88201.

RESPONSIBILITIES OF THE BLM

A. Cultural Resources

The BLM shall:

1. Provide recommendations to the DOE, within 30 days of request, in developing mitigation measures when avoidance of an historic property area is not possible.

B. Grazing Management

The BLM shall:

1. Provide proposed grazing management changes and/or plans to the DOE for review and comment.

2. Have the responsibility for all traditional administration of range resources afforded under the Taylor Grazing Act, the Federal Land Policy Management Act, and the Public Rangelands Improvement Act. Duties include, but are not limited to, the collection of grazing fees, project design and planning for development of range improvements, and development of Allotment Management Plans.

c. Continue BLM-funded vegetative monitoring program to determine if range management goals and objectives established for the grazing allotments are being achieved. As a minimum, the monitoring program shall include collecting data on actual livestock use, wildlife habitat and population trends, degree of utilization of the key forage species, climatic conditions, and rangeland ecological conditions and trends.

C. Wildlife

The BLM shall:

1. Prepare in cooperation with the U.S. Fish and Wildlife Service and appropriate state agencies a recovery plan for any threatened or endangered plant and animal species found occupying the WIPP withdrawal area to ensure its success and survival.

2. Provide the DOE, within 30 days of report completion, a draft copy of the recovery plan for review and comment.

3. Consult with the DOE to ensure that any range improvement developments (e.g., installation of livestock watering units) will be designed to accommodate wildlife needs.

4. Continue with the BLM and the DOE Interagency Agreement No. 1422G910-A2-0016 - Raptor Research and Management Program.

D. Fire Management

The BLM shall:

1. Provide full fire-fighting support within the withdrawal area should the WIPP incident commander request such support.

2. Commit necessary additional fire suppression resources should local BLM fire suppression resources be insufficient. The additional resources to be committed will be negotiated based upon the severity and behavior of the fire.

3. Negotiate with the DOE for monetary compensation required by the DOI for commitment of fire-fighting resources within the withdrawal area on a case-by-case basis.

E. Mining and Gas and Oil Production

The BLM shall:

1. Forward applications for Permit to Drill and mining and reclamation plans to the DOE within ten days of receipt for review and comment in determining issuance of any drilling or mining permit on federal lands within one mile of the withdrawal boundary. Drilling or mining permits for this area will not be issued by the BLM until DOE recommendations have been received.

2. Include the following as a Special Condition of Approval for oil and gas activity on federal lands at 330 feet or closer to the WIPP withdrawal boundary:

   a. Ensure that the operator provides the BLM with drill site downhole vertical deviation surveys for each 500-foot drilling interval within 48 hours of completion of each 500-foot drilling interval. The BLM will provide the DOE with these drill site downhole vertical deviation surveys within three days.

   b. Provide the technical expertise to calculate well bore deviation at each 500-foot interval of drilling to determine the degree of deviation and forward these results to the DOE within three days for review and verification of calculations.

   c. Require the operator to perform and provide the BLM with a directional survey to establish bottom hole location on well bores when the total cumulative degrees of displacement, independent of direction, indicate that the well bore could deviate to within 100 feet of the withdrawal boundary. Should the directional survey indicate that deviation is toward the withdrawal boundary, the BLM would require a directional survey at 100-foot intervals until such time as data would indicate that the bottom hole location at total depth would not exceed ten degrees from vertical or could result in a bottom hole location less than 100 feet from the withdrawal boundary. Should deviation direction continue towards the withdrawal boundary during the BLM monitoring of the 100-foot directional survey intervals, the BLM will require the operator to take corrective measures (i.e., side tracking) or cease drilling activity.

   d. Require the operator, in accordance with the New Mexico Oil Conservation Division (NMOCD) Rule 111, to perform and provide the BLM a directional survey to establish bottom hole location on well bores which experience deviation angles of more than five degrees from vertical in any 500-foot interval and on well bores when the total cumulative degrees of displacement, independent of direction, indicate that the well bore could deviate to within 100 feet of the withdrawal boundary.

   e. Provide the DOE with the aforesaid directional surveys within three days of receipt and completion, alternate use, and/or plugging and abandonment reports within five days of receipt.

F. Realty/Lands/Rights-of-Way

The BLM shall:

1. Forward applications and proposals for land uses affecting, but not solely contained within, the WIPP withdrawal boundary to the DOE within ten days of the BLM receipt of a completed application.

2. Assume the responsibility, when designated as lead agency, for the preparation of the National Environmental Policy Act documentation for land uses affecting, but not solely contained within, the WIPP withdrawal boundary and any DOE and/or WIPP specific compliance requirements documentation. The BLM shall obtain the review and approv

of the DOE (the contributing agency) of the aforesaid documents in determining issuance of a Record of Decision by the BLM.

3. Incorporate DOE- and/or WIPP-specific compliance requirements when preparing documentation for land uses affecting, but not solely contained within, the WIPP withdrawal boundary.

   These requirements shall include at a minimum:

   a. A safety plan that includes a job hazard analysis

   b. A list of all hazardous materials

   c. A description of methods used to manage and dispose of solid and hazardous waste

   d. Detailed project design drawings to include specific areas of impact

   e. A copy of their threatened and endangered species review (wildlife study)

   f. A copy of the archaeology study

G. Reclamation

The BLM shall:

1. Within ten days of receipt from the DOE, review and comment on the DOE proposed reclamation actions to ensure compliance with applicable DOE reclamation commitments.

U.S. DEPARTMENT OF ENERGY

BY: George E. Dials

DATE: July 21, 1994

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U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

BY: Leslie M. Cone

DATE: July 19, 1994

APPENDIX E

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INTERAGENCY AGREEMENT NO.
between the
DEPARTMENT OF ENERGY
and the
BUREAU OF LAND MANAGEMENT

Raptor Research and Management Program

Agreement No. 1422G910-A2-0016

1.0 BACKGROUND

This Interagency Agreement is pursuant to Appendix 3 of the Memorandum of Understanding (MOU) #NM-6-34, dated October 26, 1990, between the United States Department of Energy (DOE), Waste Isolation Pilot Project (WIPP) Project Site Office (WPSO) and United States Department of Interior Bureau of Land Management (BLM), Roswell District, Carlsbad Resource Area Office (CRA). Appendix 3 prescribes management direction for the maintenance and protection of wildlife resources, including raptors. This Agreement defines the relationship and responsibilities of the BLM and the DOE/WPSO to expand the existing cooperative raptor and wildlife studies. The BLM will provide funding to expand the ongoing raptor/wildlife research program, and to engage in an on-the-ground sharing of resources to accomplish this effort.

The area has been designated as the Los Medanos Raptor Study Area which lies in Eddy and Lea counties of southeastern New Mexico. This is an area identified as having a significantly dense and diverse raptor population. Currently, a raptor research project is being conducted by DOE/WPSO within this area, which encompasses the proposed 16 section withdrawal area for the WIPP site and a large area of outlying land administered by the BLM. These research efforts have been ongoing for the past nine years, and have been funded by the DOE. The research has focused on the gathering of base line biological data, describing the behavior, territoriality, and life history of the Harris Hawk and other species. As a means of continuing and expanding this research program, while maintaining research continuity, the BLM will assist the DOE with funding and provide assistance in the collection of biological data (i.e. species diversity, nesting sites, high use area, etc.) necessary to amend the current CRA Resource Management Plan (RMP), and to develop a new raptor Habitat Management Plan (HMP) for the area.

BEST AVAILABLE COPY

In summary, this cooperative effort will expand the monitoring and research to include potential short and long term impacts to all raptor populations and other wildlife species, and will more effectively focus on the raptor research needs of both agencies necessary to derive specific management direction. The BLM intends to expand the size of the Los Medanos study area, and to establish a raptor advisory committee to assist in the development of protocols and procedures to reduce impacts to wildlife species within the Los Medanos study area. The DOE/WPSO will assist in the development of these research protocols and of future HMPs for the area.

2.0 OBJECTIVES

1. To identify and map active nest sites and high use areas (tree groves, large mesquites w/nests, etc.) within the established boundaries of the Los Medanos study area in order to mitigate potential negative impacts accrued from land surface uses.

2. Establish wildlife management objectives for the area based on the research findings, and incorporate into the Carlsbad RMP amendment.

3. Base line data will be collected for the development of a Los Medanos Raptor HMP which will be initiated starting in FY95.

4. An overall raptor species list will be compiled from these efforts as well. It is already known, based on confirmed sightings, that some endangered species occur within or frequent the Los Medanos study area.

5. To establish an advisory committee for the designated raptor study area, to suggest research protocol, to review research proposals, and to ensure proper research techniques are practiced. However, approval of research proposals will not be the authority of this committee. The BLM and DOE will each assign at least one member to the advisory committee. Other members will include representative(s) from the New Mexico Department of Game and Fish, the US Fish and Wildlife Service, conservation groups, professional raptor research organizations and the interested public.

3.0 STATEMENT OF WORK

A. The DOE/WPSO agree to:

1. Denote active nest sites and high use areas for wildlife on 7.5 minute topographic maps.

2. Monitor population dynamics, focusing mainly on recruitment into the population, and home range size.

3. Monitor behavioral activities of family groups and single mature and immature birds.

4. Band all captured birds in order to track their long range migration through band recovery.

5. Attach radio telemetry to a maximum of 10 birds in FY 92 (as permits allow) to monitor winter and summer range, home ranges and territories, and locate nesting sites and high use areas.

6. Take blood samples from nestling(s) and adult(s) for analysis. The blood will be analyzed for contaminants (i.e. organophosphates, hydrocarbons, radionuclides, etc.).

7. Construct augmentation facility for the release of rehabilitated raptors, working in conjunction with licensed wildlife rehabilitators.

8. Summarize the findings in responsibilities 1-7 which will be the basis for meeting the research needs identified in Part 2.0., Objectives.

9. Provide the CRA, with a yearly summary report of the research findings. This report should include banding records, results of blood sampling, a 7.5 minute topographic map identifying raptor nests and high use areas, and a complete list of all species occupying the Los Medanos study area.

B. The BLM agrees to:

1. Provide 7.5 minute topographic maps associated with the study area.

2. Provide personnel support, when available, to assist with on the ground efforts being conducted by WPSO employees.

3. Provide necessary clearances required for the development of future wildlife habitat enhancement projects. These projects may be established within the proposed 16 section DOE land withdrawal or along Double Eagle water line right-of-way.

4. Share nest location and behavioral information and field note data relevant to the cooperative studies.

4.0 REPORTS

A yearly report summarizing the research findings including notations of active nest sites/high use areas, fledgling success, etc., shall be submitted by DOE/WPSO to the CRA after the monitoring seasons are complete. This report is due at the end of the fiscal year.

5.0 PAYMENT

As monies become available, a percentage of the total BLM allocated funds for this program shall be paid. The method for reimbursement will be via receipt of the SF 1081. The remaining percentage will be paid upon receipt and subsequent approval of the yearly summary report to be submitted at the end of the fiscal year.

The address for submission of the completed forms, progress reports, draft and final reports, etc. is:

Bureau of Land Management
Attn: John Sherman
P.O. Box 1778
Carlsbad, NM 88221

6.0 TERMINATION

This agreement shall become effective upon the date of last signature and shall remain in effect for five consecutive years from that effective date. The agreement shall be reviewed on an annual basis for consideration of the project's effectiveness in meeting the specific goals and to ensure that the requirements still exist.

The BLM may terminate this agreement upon thirty (30) days written notice of such termination. The DOE/WPSO shall be reimbursed for commitments extending beyond the effective date of termination to a date not later than the date upon which the agreement would have expired if not terminated under this paragraph, which the DOE/WPSO, in the exercise of due diligence, is unable to cancel. Payments under this agreement, including payments under this article, shall not exceed the ceiling amount elsewhere specified in this agreement.

7.0 ADMINISTRATION

1. BLM:

The Contracting Officer responsible for this contract is:

Peggy Dabb
New Mexico State Office
P.O. Box 27115
Santa Fe, NM 87502-0115
(505) 438-7638

The Contracting Officer's Representative (COR) will be:

John Sherman
Carlsbad Resource Area
P.O. Box 1778
Carlsbad, NM 88221
(505) 887-6544

2. DOE/WPSO:

The Contracting Officer is:

Ona M. Bellino
U.S. Department of Energy
Contracts and Procurement Division
P.O. Box 5400
Albuquerque, NM 87185
(505) 845-6156

The Project Manager is:

Arlen E. Hunt
Waste Isolation Pilot Plant
WIPP Project Site Office
P. O. Box 3090
Carlsbad, NM 88221
(505) 887-8101

8.0 AUTHORITY

This agreement is entered into pursuant to the Authority of the Economy Act, 31 U.S.C. 1535.

U.S. Department of the Interior
Bureau of Land Management
New Mexico State Office

9/25/92
Larry Woodard, State Director (Date)
New Mexico

U.S. Department of Energy
Waste Isolation Pilot Project
WIPP Project Site Office

Ona M. Bellino 9/25/92
Ona M. Bellino, Contracting Officer (Date)

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APPENDIX F

MEMORANDUM OF UNDERSTANDING

BETWEEN THE

UNITED STATES DEPARTMENT OF ENERGY

AND THE

NEW MEXICO DEPARTMENT OF PUBLIC SAFETY

CONCERNING

MUTUAL ASSISTANCE AND EMERGENCY MANAGEMENT

THIS MEMORANDUM OF UNDERSTANDING (MOU) is between the United States Department of Energy (DOE), represented by the Albuquerque Field Office (AL), and the State of New Mexico (State), represented by the Department of Public Safety (DPS).

WHEREAS, both parties have certain responsibilities for protecting workers, the general public, the environment and property; and

WHEREAS, both parties have developed and maintain capabilities to accomplish these respective responsibilities; and

WHEREAS, both parties recognize that developing and maintaining a program of mutual assistance will enhance each's ability to accomplish their respective responsibilities in a more effective and efficient manner; and

WHEREAS, both parties are willing to enter into this MOU; and

WHEREAS, the DOE is authorized to enter into this agreement by Public Law 95-91; and

WHEREAS; the DPS is authorized to enter into this agreement on the behalf of the State to the extent provided by Section 74-4B-1 et seq., NMSA 1978.

NOW, THEREFORE, it is understood and agreed by the parties as follows:

1. General:

   a. References:

      The DOE Order 5500.1B, EMERGENCY MANAGEMENT SYSTEM

      The DOE Order 5500.2B, EMERGENCY CATEGORIES, CLASSES, AND NOTIFICATION AND REPORTING REQUIREMENTS

      The DOE Order 5500.3A, PLANNING AND PREPAREDNESS FOR OPERATIONAL EMERGENCIES

The DOE Order. 5500.4. PUBLIC AFFAIRS POLICY AND PLANNING REQUIREMENTS FOR EMERGENCIES

The DOE Order. 5000.3A. OCCURRENCE REPORTING AND PROCESSIN OF OPERATIONS INFORMATION

The DOE Order. 5530.3. RADIOLOGICAL ASSISTANCE PROGRAM

The DOE Order. 5530.6. FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER (Draft. dated May 30. 1991)

New Mexico Hazardous Materials Emergency Response Plan and Procedures manual. December 1989.

Radiological Emergency Response Planning and Preparedness. (44 CFR. Part 351)

The DOE Order 5300.1B. TELECOMMUNICATIONS

The DOE National Security Emergency Preparedness (NSEP) Telecommunications Procedural Guide. dated January 10. 1990

The Federal Radiological Emergency Response Plan (50 F. R. 46542. November 8. 1985)

Chapter 74. Article 4B. NMSA 1978. "Emergency Management Act"

Chapter 74. Article 4E. Sections 1 through 9. NMSA 1978 "Hazardous Chemicals Information Act"

Chapter 12. Article 10. Sections 1 through 10. NMSA 1978. "State Civil Emergency Preparedness Act"

b. Definitions:

(1) Sandia National Laboratories (SNL): A DOE facility located on Kirtland Air Force Base (KAFB). operated for the DOE by Sandia Corporation.

(2) Ross Aviation Inc. (ROSS): A DOE facility located on KAFB. from which aircraft are operated for the DOE.

(3) The Inhalation Toxicology Research Institute. (ITRI): A DOE facility located on KAFB. operated for the DOE by the Lovelace Biomedical and Environmental Research Institute.

(4) The Kirtland Area Office (KAO): A DOE facility located on KAFB. which is the DOE office responsible for administering the contracts for ROSS. SNL. and ITRI.

(5) The Waste Isolation Pilot Plant (WIPP): A DOE facility located in Eddy County, New Mexico, operated for the DOE by the Westinghouse Corp.

(6) The Los Alamos National Laboratory (LANL): A DOE facility located in Los Alamos County, New Mexico, operated for the DOE by the University of California.

(7) The AL: The DOE Albuquerque Field Office.

(8) The AL Complex: The complex of buildings located on the corner of H and Pennsylvania streets on KAFB, which houses the AL.

(9) The Los Alamos Area Office (LAAO): The DOE office responsible for administering the contract between DOE and the University of California for the operations of LANL.

(10) Hazardous Materials (HAZMAT) Response: A response to an actual or potential emergency or incident involving hazardous materials.

(11) DOE Emergency Manager: The DOE Emergency manager is the director (DOE or DOE contractor) of the emergency management team in the Emergency Operations Center (EOC) of a DOE facility.

(12) DOE Incident Commander: The DOE Incident Commander is the DOE or DOE contractor on-scene director of emergency operations.

(13) The AL Operations Center: The AL, 24 hour point of contact.

(14) The Department of Public Safety (DPS): The state agency, through the Cabinet Secretary, that has the final authority to administer the provisions of the state Emergency Management Act.

(15) The Emergency Management Bureau (EMB): The organization within the DPS whose function it is to coordinate state planning and responses where more than one state agency is involved, to ensure the citizens of New Mexico are protected from natural and man-made incidents, accidents, and disasters. This entity is also responsible for the state's EOC.

(16) State Emergency Response Officer (ERO): A state police officer trained in hazardous material accident evaluation and emergency response. When the State Hazardous Materials Emergency Response Plan is activated, this

individual serves as a central coordinator to direct response functions of responsible state agencies.

(17) District Emergency Response Officer (ERO): A state police officer trained in hazardous material accident evaluation and emergency response who acts as the on-scene coordinator for accidents/incidents that occur in his/her district.

c. This MOU is entered into on behalf of the DOE by the Manager, AL, and on behalf of the State by the Cabinet Secretary of the DPS, to the extent the DPS is authorized to enter into this agreement by Chapter 74, Article 4B, NMSA 1978.

d. The provisions of this MOU apply to any actual or potential emergency or incident that:

(1) Involves a significant threat to employees of the AL, KAO, SNL, ROSS, LANL, LAAO, WIPP, ITRI, other DOE/DOE-contractor personnel, or the general public;

(2) Involves property under the control or jurisdiction of either the DOE or the State;

(3) Involves a threat to the environment which is reportable to an off-site agency;

(4) Requires the combined resources of the DOE and the State to resolve;

(5) Requires a resource that the DOE has which the State does not have, or a resource that the State has which the DOE does not have, to resolve; or

(6) Involves any other incident for which a joint determination has been made by the DOE and the State that the provisions of this MOU will apply. This determination shall be a joint determination made by the DOE and State ERO on duty, or the Director of the State EOC.

e. **Background:**

The AL has the responsibility for ensuring the safe transportation of DOE special nuclear materials and transuranic waste throughout DOE Radiological Region IV, which encompasses the state of New Mexico.

Radiological Emergency Planning and Preparedness (44 CFR 351) assigns to the DOE the responsibility to provide emergency response resources in the event of a major radiological emergency. Inherent in this responsibility and as delineated in the Federal Radiological Emergency

Response Plan (50 F. R. 46542, November 8, 1985), is the immediate reporting and response to emergency situations which could possibly endanger the safety of the inhabitants or the environment of New Mexico.

The nature of the work at some of the DOE facilities within the state creates the potential for on-site releases that have the potential of adversely affecting non-DOE areas and people. This situation promotes the need for close and professional cooperation between the DOE and State emergency planners and response personnel to effectively control incidents and accidents that might occur.

f. The DOE and the State do hereby expressly waive any and all claims against each other hereto for any loss, damage, personal injury, or death occurring in consequence of the reasonable performance of this MOU.

g. The DOE will coordinate with the DPS on response actions to a radiological accident or any other incidents involving DOE material or personnel.

2. Specific:

a. Emergency Management:

(1) The DPS shall:

Permit qualified and security cleared members of the DOE emergency management community identified by the Office of Emergency Plans and Operations, DOE, AL, access to the State EOC for the purpose of:

(a) Coordinating communications functions:

(b) Evaluating and maintaining communications capabilities:

(c) Participating in exercises:

(d) Link the State's High Frequency (HF) radio communications network with the DOE; and

(e) Assisting the State during radioactive materials accidents that require joint operations or the use of the DOE Radiological Assistance Program (RAP) team.

At the request of the DOE, cordon off segments of the state highway system as may be necessary for the landing of DOE aircraft that are responding to incidents or accidents pursuant to the provisions of this MOU.

During an actual emergency permit DOE access to any appropriate warning networks, if necessary, which the State currently has available or may develop in the future. Specific details and justifications for the needed access will be provided to the State by the DOE at the time of the event.

Retain Incident Command authority for HAZMAT, radiological, or high energy release incidents occurring outside DOE property, utilizing such DOE officials as may be appropriate as advisors.

Maintain liaison with the DOE, through the EMB, regarding State emergency planning, preparedness, and response programs, and provide accurate and timely information to the DOE and public during emergency conditions.

However, the DOE may refuse requests from the State which would impede or interfere with the DOE's ability to meet its statutory responsibilities.

(2) The DOE Shall:

Permit qualified and DOE security cleared members of the State Emergency Management community identified by the EMB access to DOE's EOCs for the purpose of:

(a) Coordinating communications functions;

(b) Evaluating and maintaining communications capabilities;

(c) Participating in exercises;

(d) Coordinating activities on the behalf of the State in the event of a radiological related emergency; and

(e) Coordinating activities on behalf of the State during radioactive Materials accidents that require joint operations or the use of the DOE RAP team.

Pay for DOE security clearances for up to three members of the State Emergency Management community who will have access to the DOE EOCs.

Consult with the DPS in the preparation of emergency assessments and preparedness programs, and provide technical advice and assistance within the scope of the DOE's activities.

Retain control over emergency planning activities relating to radioactive materials as delineated in the

Federal Radiological Emergency Response Plan (50 F. R. 46542, November 8, 1985).

During an actual emergency, permit the State access to any appropriate warning networks, if necessary, which the DOE currently has available or may develop in the future. Specific details and justifications for the needed access will be provided to the DOE by the State at the time of the event.

Participate in the search and recovery operations for nuclear materials, weapons, devices and transuranic waste involved in an incident.

Retain Incident Command authority for hazardous materials, radiation or high energy release incidents occurring on DOE property, utilizing such state officers as may be appropriate as advisors.

Maintain liaison with the EMB regarding DOE emergency planning, preparedness, and response programs, and provide accurate and timely information to the DPS and public during emergency conditions.

Provide equipment and authorizations for all communications required by DOE for DOE/State mutual aid for emergency communications.

However, the State may refuse requests from the DOE which would impede or interfere with the State's ability to meet its statutory responsibilities.

Keep the State notified of all emergency events as specified in e. below.

b. Training:

(1) Annually, the DOE will provide orientation training to State emergency response personnel on the hazards and emergency response procedures of DOE sites. Annually, the State will provide orientation training to DOE emergency response personnel on the hazards and emergency response procedures of the State. Each of the parties will bear the cost of providing training to the other party.

(2) The DPS and AL will inform each other of emergency management training programs that are being conducted that personnel of the other party are eligible to attend.

(3) The DOE will provide to the State and the State will provide to the DOE any training which is mutually agreed upon.

c. HAZMAT Response:

If the State requires support from the DOE to respond to an actual or potential HAZMAT emergency or incident, the State will contact the AL EOC. The DOE will provide such assistance as is mutually agreed upon.

d. DOE-owned or operated aircraft crash response:

In the event a DOE-owned or operated aircraft crashes within the State, the State and/or local jurisdiction will respond. The DOE will notify the State ERO of any hazardous cargo or the need for special security precautions.

e. Notification:

(1) The DOE will promptly notify the DPS of any actual or potential emergency or incident classified at the Alert or higher Emergency classification level, and of any other actual or potential incident which, in the determination of the DOE Emergency Manager or Incident Commander, may impact the State, or for which it is determined that the DPS may need to be informed.

Both the State and the DOE will utilize the hazardous material response levels outlined in DOE Order 5500.2B when notifying each other of potential or actual releases, see (3) below.

(2) The DPS will promptly notify the DOE through the AL EOC of any actual or potential emergency or incident which, in the determination of the State ERO on duty or the Director of the State EOC, may impact the DOE or for which it is determined that the DOE may need to be informed.

(3) For the purpose of notification, the following are the DOE classes of emergencies:

<u>ALERT</u> - An Alert is declared when events are in progress or have occurred which involve an actual or potential substantial degradation of the level of safety of a DOE facility.

<u>SITE AREA EMERGENCY</u> - A Site Area Emergency is declared when events are in progress or have occurred which involve actual or likely major failures of facility functions needed for protection of workers and the public.

<u>GENERAL EMERGENCY</u> - A General Emergency is declared when events are in progress or have occurred which involve actual or imminent catastrophic reduction of facility safety systems

with potential for loss of containment or confinement integrity.

(4) Attached to this MOU is a matrix containing the telephone numbers of both the DOE and the State that shall be used in making all notifications required by this MOU, plus some other telephone numbers relative to DOE and State emergency management. This attachment will be revised annually by the parties identified in g. below.

f. Public Information Coordination:

Consistent with the Freedom of Information Act (5 U.S.C. 552), procedures for the timely release of information to the public regarding any emergency response or preparedness activities under this MOU will be made following consultation between DOE and DPS representatives.

g. Administration:

This MOU will be administered on behalf of DOE by the Area Manager, KAO. Administration on behalf of the DPS will be the Director, EMB.

h. Security:

Except for the necessary access that is allowed to the "Q" cleared members of the State Emergency Management community in conjunction with their participation in the DOE EOCs during emergencies and/or emergency preparedness exercises, nothing in this MOU authorizes access to or disclosure of classified information required to be protected in accordance with federal law or regulations in the interest of national security. DPS agrees to comply with, and to assure that all of its personnel participating in activities under this MOU comply with all applicable security regulations and requirements of the DOE.

i. Other:

(1) Command and Control:

The DOE and the State will use the National Interagency Incident Management System (NIIMS), Incident Command System (ICS), which is the State's standard command and control system, during joint emergency operations.

(2) Nothing in this agreement negates or supersedes any other agreements between the DOE and the State.

3. Anti-Deficiency:

a. Nothing in this MOU commits the DOE to expend funds which have not been authorized by the U. S. Congress.

b. Nothing in this MOU commits the State to expend funds which have not been authorized by the New Mexico State Legislature.

4. Term, Modification and Termination:

a. This MOU will become effective on being signed by the DOE and the DPS.

b. This MOU may be terminated by mutual agreement of the DOE and the DPS, or by either party upon a 30 day written notice to the other party.

c. This MOU will be reviewed annually by the parties identified in g. above and may be modified by written agreement between the DOE and the DPS.

Accepted on behalf of:

The DOE:

Manager
Albuquerque Field Office
Department of Energy

3/3/92
Date

The State:

Cabinet Secretary
Department of Public Safety
State of New Mexico

3-19
Da

Attachment

ATTACHMENT

TO THE

MUTUAL ASSISTANCE AND EMERGENCY MANAGEMENT

MEMORANDUM OF UNDERSTANDING

BETWEEN THE DOE AND THE NEW MEXICO DEPARTMENT OF PUBLIC SAFETY

NOTIFICATION TELEPHONE NUMBERS

		EMERGENCY NOTIFICATION		OTHER
		8 am - 4 pm	Other Hours	
STATE:	ERO *	827-9126	827-9126	
	EOC			827-9236 827-9126 827-9247
	EMB			827-9222 827-9126
DOE:	AL EOC*	845-4667	845-4667	
	KAO Duty Officer	845-0142-1153	845-0142-1153	
	LAAO Duty Officer	FTS 843-6211 Com. 667-6211	FTS 843-7080 Com. 667-7080	
	SNL EOC			845-8150 845-4667
	LANL EOC			FTS 843-621 Com. 667-621 FTS 843-708 Com. 667-708
	WIPP EOC			887-8111 887-8100
	ITRI EOC			844-1169 845-4264
	Ross Dispatch			845-5728 845-5728
	KAO			845-557 845-522

* First Notification

EOC - Emergency Operations Center
EMB - Emergency Management Bureau
ERO - Emergency Response Officer
DOE - Department of Energy
AL - Albuquerque Field Office
ITRI - Inhalation Toxicology Research Institute
SNL - Sandia National Laboratories
WIPP - Waste Isolation Pilot Plant
LANL - Los Alamos National Laboratory
LAAO - Los Alamos Area Office
KAO - Kirtland Area Office

APPENDIX G

IMPLEMENTING REGULATIONS REGARDING CULTURAL RESOURCES

1. Antiquities Act of 1906 (P.L. 59-209);

2. Historic Sites, Buildings, and Antiquities Act of 1935, P.L. 74-292, as amended by P.L. 89-249, P.L. 94-458, and P.L. 96-625;

3. Archeological Recovery Act of 1960, P.L. 86-523, as amended by P.L. 93-291 (The Archeological and Historic Preservation Act of 1974), P.L. 95-625, P.L. 96-205, and P.L. 96-515;

4. Executive Order 11593 (1971);

5. President's Memorandum on Environmental Quality and Water Resources Management (1978); and

6. Archaeological Resources Protection Act of 1979, P.L. 96095, as amended by P.L. 100-555 and P.L. 100-588;

7. National Historic Preservation Act, P.L. 89-665, as amended by P.L. 91-243, P.L. 93-54, P.L. 94-422, P.L. 94-458, P.L. 96-199, P.L. 96-244, P.L. 96-515, and P.L. 101-70

8. 36 CFR 60 - National Register of Historic Places

9. 36 CFR 63 - Determinations of Eligibility for Inclusion in the National Register of Historic Places

10. 36 CFR 65 - National Historic Landmarks Program

11. 36 CFR 78 - Waiver of Federal Agency Responsibilities Under Section 110 of the National Historic Preservation Act

12. 36 CFR 800 - Protection of Historic and Cultural Properties

13. 43 CFR 7 - Protection of Archaeological Resources

Additional Guidance

1. U.S. Department of Energy Order 1324.7 - Departmental History Program

2. U.S. Department of Energy Memorandum - Management of Cultural Resources at Department of Energy Facilities

3. Section 110 Guidelines

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix MASS

M

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Supplemental Information on Modeling Assumptions

M

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ACRONYMS

BSEP	Brine Sampling and Evaluation Program
CCDF	complementary cumulative distribution function
CH	contact-handled
CSH	calcium-silicate-hydrate
DCCA	Draft Compliance Certification Application
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
DSEIS	Draft Supplement, Environmental Impact Statement
EEG	Environmental Evaluation Group
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration
FEIS	Final Environmental Impact Statement
FEP	features, events, and processes
FSEIS	Final Supplemental Environmental Impact Statement
LANL	Los Alamos National Laboratory
LEFM	linear elastic fracture mechanics
LLNL	Lawrence Livermore National Laboratory
MB	marker bed
NAS	National Academy of Sciences
NIST	National Institute of Standards and Technology
ORNL	Oak Ridge National Laboratory
PNL	Pacific Northwest Laboratory
RH	remote-handled
SNL	Sandia National Laboratories
SSBI	Small-Scale Brine Inflow
SWCF	Sandia National Laboratories WIPP Central Files
TDEM	Time Domain ElectroMagnetic
TRU	transuranic
USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant
WQSP	Water Quality Sampling Program

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APPENDIX MASS

MASS.1 Introduction

This appendix presents supplementary information regarding the assumptions, simplifications, or approximations used in the models of this performance assessment of the Waste Isolation Pilot Plant (WIPP). In any topic area in this appendix, relevant issues in the formulation or development of the various types of models (for example, conceptual, mathematical, numerical, or computer code) used for the topic may be discussed. Because extensive discussion of computer codes *per se* is presented in stand-alone appendices, there is redundancy between portions of this appendix and other parts of this application. Additionally, where assumptions, simplifications, or approximations are implemented by way of a choice of the value of a parameter, there may be redundancy in this appendix with Appendix PAR.

Several types of information are presented in this appendix, including memoranda prepared during development of the performance assessment by the U.S. Department of Energy (DOE) personnel and documents associated with modeling assumptions tested during development of the performance assessment process. These are included as attachments in this appendix. These attachments are also maintained as project records in the Sandia National Laboratories (SNL) WIPP Central Files (SWCF).

Section MASS.2 contains a historical perspective of the development of the concepts since 1975 about future WIPP performance. The remainder of this appendix is arranged to provide topical information on the major physical processes and systems introduced in Chapter 6.0 (Section 6.4) and modeled in the performance assessment. Section MASS.3 begins this topical piece with a discussion of general modeling assumptions applicable to the disposal system as a whole, including a table of assumptions made in performance assessment models, with cross-references. In some topical discussions, the information relevant to a particular model is more appropriately included in a different appendix. Where this occurs, the reader is referred to the appendix that contains the relevant information.

MASS.2 Historical Development of WIPP Conceptual Models

Concepts about the processes important to the performance of the WIPP have changed since the DOE's inception, as the DOE and its predecessor agencies refined knowledge and understanding of features of the site and the processes and events that might occur there. Although the understanding of the WIPP site has continuously evolved since the early 1970s, the fundamental conceptual models that shaped projections of the WIPP's performance underwent major refinement three times: in the mid-1970s during site selection; in the late 1970s during surface-based site characterization; and again in the mid-to-late 1980s. Since the late 1980s, the fundamental conceptual model has not changed in any major way. Experimental activities since the late 1980s have led to the level of understanding necessary

for quantitative, probabilistic performance assessments. This section describes the evolution of the DOE's understanding of the processes and events of importance at the WIPP.

Techniques used to evaluate the consequences of radionuclide release from the repository have also changed. Changing the methods used to address the consequences of radionuclide exposure pathways has affected both the types of computational modeling used to evaluate performance and the understanding of the relative importance of the many physical properties of the disposal system. Until 1985, when the U.S. Environmental Protection Agency (EPA) promulgated its radiation protection standard for the management and disposal of spent nuclear fuel, high-level and transuranic wastes, 40 CFR Part 191, the consequences of release were primarily evaluated in terms of human exposure to radionuclides that had reached the biosphere by some mechanism, rather than in terms of any specific or quantitative release criterion. Contaminant transport in the geosphere was not regarded as a problem if humans were not exposed. Two principle pathways were of concern. Direct releases to the surface from a borehole could expose drillers and hypothetical future residents of the region who consumed livestock that grazed nearby. Individuals could also be exposed by drinking water from a contaminated source or by eating livestock watered at a contaminated stock pond. For example, the hypothetical exposed person was someone who drank water and ate fish from the Pecos River near Malaga Bend, a discharge point for contaminated groundwater from the Rustler (DOE 1980, 9 – 128, K23 – K24). (The release of contaminated Rustler groundwater at Malaga Bend is no longer considered plausible.) The consequences of release by diverse transport pathways were treated deterministically and individually. The time period considered for evaluating the effectiveness of the WIPP was usually about a quarter of a million years, roughly ten half-lives of ^{239}Pu, although this time frame was not specified by regulations.

40 CFR Part 191, promulgated in 1985, set release limits at defined boundaries. Therefore, determining possible contamination of areas far from the repository was no longer an objective of consequence modeling. Instead, quantities of actinides released from the disposal system, a defined volume, became the primary measure for assessing performance, although dose calculations to humans were still of interest to many groups and required for certain regulatory criteria. The probabilistic methodology suggested in 40 CFR Part 191 led to an appreciation of the possible interactions among multiple boreholes, assessment of the probabilities of defined events, and formal assessment of the performance impact of uncertainty in estimates of physical quantities. The standard also established a regulatory time period, during which actinide transport and system performance must be modeled. The EPA has become increasingly prescriptive about how the DOE should incorporate the uncertainty associated with projecting human actions into the future (for example, 40 CFR Parts 191 and 194, and the Compliance Application Guidance). In addition, expectations about the quantity and quality of supporting information used to support analyses of repository performance have gradually escalated.

Interactions between the DOE and external groups have played an important role in developing the current understanding of the disposal system performance. Interactions with

the National Academy of Sciences (NAS) and interactions with the Environmental Evaluation Group (EEG) have been the most important of these. Interactions with the state of New Mexico and with the EPA have also contributed. At various times through the years, the DOE has convened expert panels and working groups to obtain advice on certain issues; for example, an expert working group met for many years to advise on the treatment of uncertainty in characterizing the Culebra (Zimmerman and Gallegos 1993).

MASS.2.1 Conceptual Models Used During Site Selection (1975-1976)

The Oak Ridge National Laboratory (ORNL) selected the site for the WIPP in the early 1970s. At that time, the concept of long-term performance of the WIPP was based on an understanding that bedded salt deposits were dry, natural creep of the salt would encapsulate waste, salt had good heat-dissipation properties, and the northern Delaware Basin had predictable geology that was amenable both to repository construction and to predictions of performance. Site-selection criteria were strongly influenced by experience at the abandoned bedded-salt site near Lyons, Kansas, and consequently focused strongly on isolating the repository from potential breach mechanisms associated with resource exploitation and dissolution. Accordingly, buffer zones of two miles between the site and existing deep boreholes and of five miles between the site and any existing potash mines were established as criteria for siting, and interest in fluid flow in aquifers and abandoned boreholes was chiefly related to its potential for dissolving salt in the Salado Formation.

During site selection in the early 1970s, several ideas about the Salado and processes associated with radioactive waste disposal in it were accepted. The formation was known to contain anhydrite layers; the DOE wanted to choose a repository horizon without anhydrite beds in close proximity because they would interfere with creep and waste encapsulation. Project staff recognized that a disturbed rock zone (DRZ) would develop around the repository; but because of salt creep, the long-term effects of the DRZ were assumed to be negligible as the waste was encapsulated and the disturbed salt healed (that is, as its properties became similar once again to those of intact salt). The generation of gas by microbial degradation of waste constituents was recognized as a possible pressure-building mechanism. Because the Salado was thought to be dry, corrosion of steel in the waste was not considered to be important. It was known that intragranular brine inclusions could migrate toward waste as a result of the thermal effects of heat-emitting waste. This possibility for brine migration was of considerable concern because at the time it was intended that the WIPP would have two excavations for waste disposal: one at a shallower horizon for relatively cold transuranic (TRU) waste and one at a deeper horizon for heat-emitting spent nuclear fuel.

The ORNL identified a candidate site northeast of the present WIPP site in 1974. As discussed in Chapter 2.0 and Appendix GCR, drilling of U.S. Energy Research and Development Administration (ERDA)-6 in 1974 at that site revealed steeply dipping beds, missing units, and brine containing hydrogen sulfide near the deeper planned repository depths. The dipping beds and missing units indicated that a level, minable repository horizon free of anhydrite could not be expected. Hydrogen sulfide in the brine posed a potential

hazard to mine workers. Thus, the discovery of the deformed beds and associated brine at the ORNL site changed the concept of uniform evaporite stratigraphy throughout the northern Delaware basin.

The ORNL site was deemed unacceptable, and a search for a new site with acceptable conditions was initiated in late 1975. The new search was conducted by SNL. SNL used selection criteria similar to ORNL's. The present site was identified in December 1975. Examination of petroleum exploration data, primarily seismic reflection surveys, indicated that deformation was limited largely to a zone paralleling the buried Capitan reef. A region in which Castile deformation is absent was identified and borehole ERDA-9 was drilled through the Salado near the center of the proposed site, confirming that its beds were flat-lying and that no brine was present in it or immediately below the potential repository elevations. Consequently, because the site satisfied this and other criteria, it was accepted as suitable in 1976, and site characterization began.

At the end of site selection and with the current site identified, the following concepts were accepted by the DOE and shaped thinking about the consequences of repository development:

- the Salado is dry, with no mobile intergranular liquid,
- intragranular fluid inclusions could migrate in thermal fields,
- gas could be generated by microbial action,
- salt would creep and encapsulate waste,
- there are deformed areas and brine-producing areas in the Delaware Basin evaporites, but the present site was free of deformation and brine at the potential repository horizons, and
- natural dissolution fronts would not threaten the repository, as a result of either vertical or lateral dissolution, for more than 250,000 years.

MASS.2.2 Conceptual Models Developed During Site Characterization and Repository Design (1976-1981)

Experimental activities conducted at the site immediately after site selection focused on characterizing the encapsulation properties of the Salado, the migration of intragranular brine in a thermal gradient, microbial gas generation, and the hydrologic properties of the units above the Salado.

After site selection, interest in fluid flow in water-bearing units of the area shifted from its effects on dissolution to the role of these units as potential pathways for radionuclide release.

The Magenta and Culebra Members of the Rustler Formation and the Rustler-Salado contact zone were recognized from regional experience to be potential pathways. At the time, the relative importance of these units was unknown, so the first tests targeted all three. The Rustler-Salado contact was confirmed to be transmissive in Nash Draw but did not yield significant quantities of water at the site and did not represent a significant pathway for fluid movement for either radionuclide transport or dissolution. The Culebra was more transmissive than the Magenta, and the transmissivities of these units varied by several orders of magnitude. In time, characterization of groundwater pathways for radionuclide release became the principal characterization activity pursued at the WIPP site.

The hydrologic properties of the Salado were characterized by surface testing (drill-stem tests) during this period. These tests indicated measurable permeabilities over substantial thicknesses of the Salado, suggesting that the permeability of the Salado was sufficiently high that gas generated by microbial action would dissipate into the rock without reaching high pressure. Accordingly, the program to characterize gas generation, which had been progressing through the late 1970s, was canceled.

Many repository breach mechanisms by natural processes were postulated during this period, and investigations began to evaluate their likelihood and consequences. These investigations examined volcanism, tectonism, karst hydrology, deep dissolution, and other processes. In time, all such naturally occurring processes for breaching the repository were resolved as not likely to occur or not likely to occur in a manner that would impair WIPP performance.

MASS.2.3 Repository Design

The design of the repository—the dimensions and geometry of the rooms, pillars, and accessways—was conducted by Bechtel, Inc., in the late 1970s. The design sought to ensure long-term encapsulation of the waste by salt creep and to provide enough volume to dispose of the projected 6.2 million cubic feet (176,000 cubic meters) of waste. Given these performance criteria, the physical dimensions of the repository were determined with primary consideration given to mine safety during waste-disposal operations. Because the repository was designed prior to underground access, the basis for the design drew on experience gained from potash mines in the Delaware Basin.

The initial repository design placed the shafts at the south end of the repository, an area for experimental activities north of the shafts, and the waste-disposal region north of the experimental area. From early on, the DOE viewed the WIPP as a research and developmental facility that would conduct experiments that were of interest to a wide variety of disposal programs and concepts. Accordingly, the original purpose of the experimental area was to house experiments to support development of models of rock mechanics and salt creep, experiments on seal behavior, and experiments of interest to high-level waste disposal concepts, such as canister design and fluid-inclusion brine movement. It was not intended at first that the experimental region would support studies of phenomena that had been previously characterized from the surface, such as the permeability of the Salado.

The repository design did not initially include constructed barriers to separate the waste into modules. Early discussions with the NAS oversight panel led to concern that fire in combustible portions of the waste could pose a hazard to mine workers. Modularization of the waste was proposed to enhance mine safety. Because constructing closures is expensive and time-consuming, separating waste at the panel scale was considered the best of several options for balancing concerns about safety, cost, and mine operations.

In November 1981, the WIPP-12 borehole was deepened into the Castile and encountered large quantities of brine that flowed freely into the borehole and to the surface. The discovery of a Castile brine reservoir at WIPP-12 prompted the rotation of the waste panels from their planned location north of the experimental area to south of the shafts, the current configuration, and eventually led to a geophysical program in the 1980s to investigate the possibility of brine reservoirs under the panels. Both the DOE and the EEG conducted consequence analyses of a drilling encounter with a brine reservoir like that at WIPP-12 and concluded that the health consequences were minor (Woolfolk 1982; Channell 1982).

In 1980, Congressional legislation limited the WIPP to the disposal of TRU waste, and plans for a spent-fuel disposal level in the Infra-Cowden salt near the base of the Salado were abandoned. Because TRU waste generates relatively little heat, migration of brine in fluid inclusions was of little concern for the WIPP after 1980, although tests were conducted of this phenomenon because of continued interest in high-level-waste disposal in salt beds elsewhere.

Thus prior to underground access at the WIPP in the early 1980s, several conceptual models shaped the thinking about the performance of the WIPP repository:

- the Salado is dry with no mobile intergranular liquid,
- intergranular fluid inclusions are unimportant,
- the Salado has permeability high enough that gas generated by microbial action will dissipate, and pressure will not build up,
- fluid flow and transport of radionuclides in Salado are negligible,
- natural processes are not likely to release radionuclides,
- the Culebra is the most important unit above the Salado,
- the Culebra hydrology is relatively simple,
- based on available batch K_d measurements and the assumption of porous-medium flow, retardation in Culebra is assumed, and
- WIPP-12 leads to rotation of panels away from encountered brine reservoir.

MASS.2.4 Conceptual Models Developed During Site Characterization and Development (1982 - Present)

The repository horizon was selected in 1982 after the initial shaft was sunk and after design of the repository had been established. The horizon was selected based on the preliminary design of the repository, salt thickness above and below the excavations, and ease of mining. The DOE wanted (a) the mine to be at least 300 feet (91 meters) below the McNutt Potash Zone (hereafter referred to as McNutt) to provide isolation from possible mining, (b) anhydrite bed or clay seams within the back (roof) to be at least 2 to 3 feet (0.6 to 0.9 meters) above the repository to reduce the possibility of roof fall, and (c) the mine to be as shallow as possible to minimize mining costs. The horizon selected between Marker Bed (MB) 138 and MB139 was deemed to best satisfy all of these criteria.

Experiments to investigate rock mechanics and salt creep were started in the initial underground excavations. Some brine was observed seeping into the repository from boreholes drilled upward into the back and collected in downward boreholes. Some brine was also observed on some freshly excavated surfaces. These observations led to significant changes in the conceptual models of WIPP performance.

The concern was raised that the waste would not become encapsulated in a solid mass by salt creep, because brine that had seeped in would impede such consolidation. Information about the rate of brine flow showed that concerns about the waste becoming fluidized were unrealistic because consolidation to a sufficiently low porosity would occur before significant amounts of brine could accumulate. However, a new series of tests was executed to validate beliefs about the hydraulic properties of the Salado that had been based on surface-based testing conducted in the late 1970s. This series of tests included the Small-Scale Brine Inflow, Brine Sampling and Evaluation Program (BSEP), Room Q, in-situ permeability tests, and laboratory flow tests. Some of these test programs continued until their conclusion in 1995.

The in-situ permeability tests showed that intergranular fluids were involved in flow and also demonstrated that the drill-stem tests conducted in the 1970s had overestimated the permeability of the Salado. These results led to the realization in the late 1980s that gas dissipation in the Salado would not be sufficient to avoid the potential for high pressures. Brine seepage into the repository raised the possibility of gas generation by corrosion of steel in addition to microbial gas generation. A new program to characterize gas generation began in the late 1980s.

Because of gas generation and low permeabilities in the far-field Salado, it was thought that high pressure in the repository could induce the Salado to fracture. This topic had been of concern in the 1970s when microbial gas generation was investigated. The renewed concern about gas generation led to a program to investigate hydrofracturing of the Salado interbeds by high pressure, and eventually to the adoption of a fracturing model in performance assessment.

Inadvertent penetration of the repository by deep drilling and the resultant release of radionuclides directly to the surface were treated deterministically in early evaluations of long-term performance. The promulgation of 40 CFR Part 191 made it necessary to consider the possibility of multiple boreholes and their interactions. The combination of brine saturation in the repository and possible high gas pressures led eventually to two new postulated mechanisms for release to the surface—gas spall (release of fine particulates caused by high gas pressures and flows from the waste to the penetrating borehole) and direct brine release to the surface during drilling—in addition to the cuttings and cavings releases that had been modeled previously.

Actinide solubilities were not considered important until the mid-to-late 1980s. Before this time, the DOE's expectation that the repository would be dry made aqueous concentrations seem unimportant. From early on, the DOE had considered adding getters (materials that act to remove radionuclides) to the repository, not so much to control actinide mobility as to assure performance (for example, Tyler et al. 1988). From the mid-to-late 1980s, however, the importance of actinide solubilities has been increasingly recognized in conjunction with the importance of release pathways involving fluid flow from the repository. Direct control of repository chemistry is more effective in controlling actinide solubilities than getters.

Transport of actinides in colloidal forms was recognized as potentially important by the late 1980s, but, because of lack of understanding, no allowance for the possible impact of actinide transport was made in the ranges chosen for actinide solubilities in early performance assessments. The effect of transport of actinides in colloidal forms was not explicitly modeled until the calculations for this application.

From the time of the initial conceptual design and the 1980 Final Environmental Impact Statement (FEIS) (DOE 1980), it was assumed that backfill would be emplaced in the repository to help fill the void space and reduce the magnitude of subsidence in overlying units, in addition to eliminating any potential risk of underground fire propagation. The WIPP Final Safety Analysis Report (DOE 1990) showed that there was no significant chance of fire propagation in the waste disposal region even in the absence of backfill. The Backfill Engineering Analysis Report (Westinghouse Electric Corporation, 1996) showed that addition of backfill would have negligible impact on the subsidence of overlying units. For a time, therefore, backfill was not considered as part of the baseline design for the repository. Recently, the addition of a carefully designed backfill to control chemical conditions in the repository has been shown to have significant benefit in assuring lower actinide solubilities.

Because of the possibility of high gas pressure in the repository and the associated possibility of fracturing of the Salado, it became apparent in the late 1980s that effective isolation of radionuclides from the anhydrite interbeds close to the repository could not be fully assured. Because the anhydrite interbeds were known to be relatively more permeable than the halite-rich horizons of the Salado, recognizing that the DRZ was not likely to heal effectively increased the potential importance of interbeds passing through the DRZ with respect to fluid flow in the Salado.

Panel closures were designed to isolate panels from each other during waste operations. For a time, in recognition of the concept that DRZ healing could not be relied upon to isolate interbeds from the repository and that fluids might flow around panel closures, these closures were essentially assumed not to exist for evaluations of long-term performance. This treatment was unrealistic, however, and the more reasonable idea that panel closures should be modeled with properties similar to those assigned to the imperfectly healed DRZ emerged.

The conceptual design of shaft seals evolved during the 1980s. The long-term ability of the shaft seals to isolate the repository from overlying units had been credited to a salt component to be emplaced throughout much of the Salado. The salt-based component would consolidate under the pressure of salt creep and, over a period of a hundred to several hundred years, would develop properties similar to that of intact salt. However, control of brine flow to the salt seal from upper units was of concern because significant volumes of brine could delay or even prevent creep consolidation of the long-term seal components of crushed salt. The early concepts of shaft construction, which used a concrete and concrete-grout plug to protect the salt component, were not thought to be robust enough to control downward brine flow and, possibly in the long term, might be susceptible to damage by the flow. This concern led to a design and testing program to develop the present shaft seal concept, which is based on the principle that multiple components and multiple materials provide demonstrable protection of long-term components from downward brine flow and support a high level of confidence in the expected behavior of shaft seals.

Test programs in the units above the Salado have been in progress continuously since site selection. The preeminent importance of the Culebra as a lateral pathway for transport has been recognized by the DOE. The Rustler and Salado contact was demonstrated to be unimportant, and the Magenta was demonstrated to have generally lower conductivity than the Culebra and not to have hydraulically significant fractures that could channel flow. Although the Rustler was characterized to some extent throughout its thickness, in the 1980s the interest focused on the Culebra. Transport in the Culebra has been demonstrated to be controlled by the variation in hydraulic conductivity and by interaction between flow in fractures and flow in matrix. Increasingly complex tests were conducted to characterize the Culebra, including multi-well tracer tests and regional pumping tests, culminating in the recent seven-well tracer test conducted at H-19, multiwell retesting at H-11, and distinctive single-well injection and withdrawal tests at both H-19 and H-11. Testing at these localities provided new, high-quality test results at two relatively high-permeability locations in the Culebra. Increasingly complex modeling techniques were used to represent the characterized variability and residual uncertainty in the transmissivity of the Culebra, assisted by review and advice from the Geostatistics Expert Group, a panel convened by the DOE, and INTRAVAL, an international model validation review group. Effective chemical and physical retardation was no longer assumed but became the subject of study, and by the early 1990s several alternative conceptual models had been advanced and were implemented in the preliminary performance assessments (WIPP Performance Assessment Department 1993, 8-27 to 8-56). One of these has since been identified as superior to the others (see Section MASS.15).

In the Dewey Lake, above the Rustler, boreholes occasionally produce groundwater but, because it had long been assumed that groundwater in the Dewey Lake is in discontinuous lenses and that regional flow does not occur, characterizing groundwater in the Dewey Lake was a low priority for the DOE. When performance assessments in 1994 showed that long-term releases to the Dewey Lake are unlikely because the Culebra captures all fluids moving upward through the Rustler in a borehole, further characterization of the Dewey Lake was perceived as unimportant. Recently, the DOE has recognized that a continuous water table may exist in the Dewey Lake, but it is observed only in areas where permeabilities are relatively higher than average. Nevertheless, if releases into the Dewey Lake occur, they will be of little consequence, because, as a red bed, the Dewey Lake has a uniformly distributed and large sorption capacity as the result of the widespread occurrence of both hydrated iron oxides and clays.

In the Castile, geophysical techniques were used to help resolve whether brine reservoirs like that encountered at WIPP-12 might exist under the waste panels. In the late 1980s, these techniques indicated a zone of lower resistivity that can be interpreted as brine. This zone exists under a portion of the waste disposal area.

In addition to experimental programs, the development of probabilistic performance assessments for the WIPP also led to a considerable effort to characterize the consequences of combinations of events and processes. One notable development was the identification of the need to model the effects of multiple intrusions into the repository, some of which might penetrate brine reservoirs, and the possible interactions among these intrusions in a partially saturated repository. This development led to the identification of the scenarios currently in use.

Thus, by the late 1980s, the conceptual model for the disposal system had changed considerably from that of the late 1970s to mid-1980s. Rather than a fairly simple repository horizon that encapsulated waste rapidly and was thereafter relatively stable, as envisioned through 1985, the first WIPP preliminary performance assessment in 1989 recognized that the long-term conditions in the disposal system depended critically on the interplay between various natural, excavation-induced, and waste-related processes, and the final condition depended closely on the relative rates of these processes. Although some changes have occurred since 1989—for example, uncertainty about many aspects of the disposal system has been substantially reduced through experimental programs and some new release processes have been identified and incorporated—the overall conceptual model recognized in the late 1980s remains valid today:

- the waste horizon is not effectively isolated from nearby interbeds,
- the repository is partially to fully saturated with liquid,
- gas generation is closely linked to other processes,

- creep closure occurs but does not assure complete consolidation,
- brine inflow from the Salado is likely,
- high gas pressures in the repository could induce fracturing of Salado interbeds,
- actinide solubilities and colloid actinides are important,
- borehole-repository-brine reservoir intersections are possible,
- multiple intrusions allow the possibility of cross-borehole flow,
- the Culebra is the most transmissive upper unit, and releases through other units are unlikely, and
- Culebra transport is complex, fractures are important, and retardation is sensitive.

This list of the major concepts developed in the late 1980s has driven the selection of subsequent experimental programs and determined the types of modeling done in performance assessment from 1989 onward. Since 1989, details have changed, but the overall concept of long-term performance has remained stable. The models described in Chapter 6.0 (Section 6.4) of this application and further described in this appendix are based on this overall conceptual understanding of disposal system interactions.

MASS.3 General Assumptions in Performance Assessment Models

Several assumptions are applied generally to the disposal system through the conceptual and mathematical models implemented in the major computer codes used in this performance assessment. Several major assumptions are discussed here. A table of general assumptions is also presented in Section MASS.3.4.

MASS.3.1 Darcy's Law Applied for Fluid Flow Calculated by BRAGFLO, SECOFL2D, and SECOTP2D

A mathematical relationship expressing the flux of fluid as a function of hydraulic head gradients applied, commonly known as Darcy's Law, is applied to geologic media for all fluid flow calculations. For details about the specific formulation of Darcy's Law used, refer to Appendix BRAGFLO for the disposal system modeling, and Appendices SECOFL2D and SECOTP2D for Culebra modeling. Darcy's Law is not applied for flow up a borehole that is being drilled (see Section MASS.16.2 and Chapter 6.0, Section 6.4.7.1.1, for more discussion of this topic).

Darcy's Law generally applies for flow models if certain conditions are satisfied: (1) the flow occurs in a porous medium with interconnected porosity, (2) flow velocities are low enough that viscous forces dominate inertial forces, and (3) a threshold hydraulic gradient is exceeded.

Hydraulic tests in the Salado (Beauheim et al. 1991; 1993) were carefully designed to limit the effects of outside influences on the tested interval and provide the best evidence for the controlling flow mechanism in the Salado. The tests influence rock as far as 33 feet (10 meters) from the test zone and are not thought to significantly alter the pretest conditions of most of the tested region. The stratigraphic intervals tested include halite (both pure and impure) and anhydrite with associated clay seams at distances from 3 to 75 feet (1 to 23 meters) from the repository. Because tests close to the repository are within the DRZ, tests farthest from the repository are considered more representative of undisturbed conditions.

The tests are interpreted using potentiometric flow models incorporating Darcy's Law. Successful interpretations using these models are obtained and indicate a continuous porous medium that can be hydraulically characterized with permeability, pore compressibility, and porosity parameters. Tests in pure halite yield ambiguous interpretations, indicating either very low permeability or no flow whatsoever (a potential violation of the applicability of Darcy's Law). However, the effects of the pure halite layers on the performance of the repository have been demonstrated to be small (see below). Thus, the regions of importance to the performance of the repository have been tested, appear to meet the criteria for Darcy flow, and can be assumed to behave as continuous porous media that obey Darcy's Law.

Bear (1972, 125) discusses the balance of viscous and inertial forces in fluid flow. The Reynold's number, Re, is the ratio of inertial to viscous forces. For porous media, Re is calculated as

$$Re = \frac{qd}{\nu} , \qquad (1)$$

where q is the specific discharge in units of length per time, d is some length dimension of the porous matrix, and ν is the kinematic viscosity of the fluid in units of length squared per time ($\nu = \mu/\rho$, where ρ is fluid density and μ is dynamic viscosity). In principle, d is related to the length of elementary channels in the porous medium. Because of the difficulty of establishing this length, however, it is customary to use some measure of the pore grain size for d. Alternatively, Collins (1961) suggests $d = (k/n)^{1/2}$, where k is permeability in units of length squared, and n is porosity. The upper limit for application of Darcy's Law is not exceeded if Re is less than some number between 1 and 10 (Bear 1972, 126).

The specific discharge above which the models of fluid flow might be invalid can be estimated for the WIPP. The maximum d in the BRAGFLO domain, by Collins' method, is approximately 2×10^{-4} centimeters (calculated for the waste disposal region, using an assumed permeability of 1×10^{-12} square meters = 1×10^{-8} square centimeters and an assumed porosity of 0.2). Salado brine has a dynamic viscosity of 2.1×10^{-2} grams per centimeter per second; a

density of 1.22 grams per cubic centimeter, for a kinematic viscosity of 0.017 grams per cubic centimeter per second. Taking Re equal to 1 as the critical indicator, the critical specific discharge is the ratio of ν to d, and has a value approaching 100 centimeters per second. As all specific discharges of brine in the BRAGFLO model are significantly less than this value, viscous forces dominate brine flow in the model and the upper limit of the validity of Darcy's Law is not exceeded.

For gas in the WIPP, assumed to have the properties of hydrogen for this calculation, density is about 8.2×10^{-5} grams per cubic centimeter and dynamic viscosity is about 89.2×10^{-6} grams per centimeter per second, for a kinematic viscosity of about 1.1 square centimeter per second. The critical specific discharge for gas in the BRAGFLO model is greater than 5,000 centimeters per second. In WIPP simulations of gas flow, q for gas remains below this value, indicating that the upper limit for the validity of Darcy's Law for gas is not exceeded.

Bear (1972, 128) proposes that a minimum hydraulic gradient, the threshold hydraulic gradient, exists below which flow in porous media does not occur. The minimum gradient may be required to overcome countercurrents that may occur at very low velocities, or may be required to overcome the slight nonNewtonian behavior of the viscosity of water. In general, this behavior is evident in fine-grained, low permeability rock such as clay. Because the WIPP is situated in the low-permeability Salado, flow may not be able to occur through the Salado unless a minimum hydraulic gradient is exceeded. Testing for a minimum hydraulic gradient is extremely difficult, however, and therefore has not been attempted at the WIPP.

Except for pure halite, Salado intervals tested at the WIPP have responded to hydraulic testing, and test results can be interpreted to high certainty using models based on Darcy's Law without correcting for the existence of minimum hydraulic gradients. This is strong evidence that the standard Darcy's Law is applicable in these units. In hydraulic tests of the pure halite, no hydraulic response to induced pressure change in the test zone was observed. Two explanations are offered for the results observed during the test. Either (1) the pure halite has a permeability low enough that a hydraulic response could not be measured over the duration of the test, or (2) a high threshold gradient for fluid flow exists in pure halite and was not exceeded during the test in rock around the test interval.

Although the reason for the lack of response in pure halite during flow tests is not established conclusively, its behavior can be approximated in continuum models of fluid flow based on Darcy's Law by assigning it an extremely low permeability relative to other rocks units, which effectively prevents flow through the volume that represents pure halite. This technique assumes the gradients calculated during modeling in the pure halite interval will not exceed the threshold gradient for flow, if it exists. For performance assessment modeling, this assumption is sound given that relatively large gradients were imposed on the unit during hydraulic testing and did not induce flow. Christian-Frear and Webb (1996) analyzed the effects of the variation in lithologic types, including pure halite, in a model of the Salado surrounding the repository. In their study, they found that the hydrologic response of the Salado to the presence of the repository was adequately represented by the simplified

stratigraphic representation that is implemented in BRAGFLO. Thus, even though the lack of hydraulic response in pure halite units is not conclusively explained, the hydraulic characterization of pure halite intervals is adequate for an accurate assessment of WIPP performance.

Darcy's Law assumes laminar flow, that is, there is no motion of the fluid at the fluid/solid interface. For liquids, it is reasonable to assume laminar flow under most conditions. For gases at low pressure, however, gas molecules near the solid interface may not have intimate contact with the solid and may have finite velocity, not necessarily zero. This effect, which results in additional flux of gas above that predicted by application of Darcy's Law, is known as the slip phenomenon, or Klinkenberg effect (Bear 1972, 128). A correction to Darcy's Law for the Klinkenberg effect is incorporated into the BRAGFLO model (see Appendix BRAGFLO, Section 4.12, for additional details).

Darcy flow for one and two phases implies that values for certain parameters must be specified. Some principal parameters relate to the properties of the fluid, others to the rock. Fluid properties in the Darcy flow model used for the WIPP are its density, viscosity, and compressibility. Rock properties in Darcy flow models are porosity, permeability, and compressibility (pore, bulk, or rock). In BRAGFLO, other parameters are required to describe the interactions or interference between the two phases present in the model, gas and brine, because they can occupy the same pore space. In the WIPP application of Darcy flow models, compressibility of both the liquid and rock are related to porosity through a dependence on pressure. Fluid density, viscosity, and compressibility are functions of fluid composition, pressure, and temperature. In BRAGFLO, fluid viscosity is a function of pressure, but its density and compressibility are held constant. Fluid composition for the purposes of modeling flow and transport is assumed to be constant.

MASS.3.2 Hydrogen Gas as Surrogate for Waste-Generated Gas Physical Properties in BRAGFLO

The gas phase in the BRAGFLO model is assigned the properties of hydrogen because hydrogen will, under most conditions reasonable for the WIPP, be the dominant component of the gas phase.

Hydrogen gas is produced by the corrosion of steel in the repository by water or brine. Because of the surface area, the total mass of steel emplaced, and the quantity of brine that is reasonably expected to flow into the repository from the Salado, as much as 0.3×10^6 moles of hydrogen per year can be generated in the repository and 2×10^9 total moles of hydrogen (Wang 1995).

Other gases may be produced by processes occurring in the repository. If microbial degradation occurs, a significant amount of CO_2 and CH_4 will be generated by microbial degradation of cellulosics, and, perhaps, plastics and rubbers in the waste. CO_2 produced, however, will react with MgO backfill and cementitious materials to form $MgCO_3$ and

$CaCO_3$, thus resulting in very low CO_2 fugacity in the repository. Although other gases exist in the disposal system, for BRAGFLO calculations it is assumed these gases are insignificant and are not included in the model.

With the average stoichiometry gas generation model, the total number of moles of gas generated will be the same whether the gas is considered to be pure H_2 or a mixture of several gases, because the generation of other gases is accounted for by specifying the stoichiometric factor y. Therefore, considering the moles of gas generated alone, the pressure buildup in the repository will be approximately the same, because the expected gases behave similarly to an ideal gas, even up to lithostatic pressures.

The effect of assuming pure H_2 instead of a mixture of gases (including H_2, CO_2, H_2S and CH_4) on flow behavior, and its resulting impact on the WIPP repository pressure is presented as follows:

Radial flow of a 100 percent saturated rock with nonideal gas is described by Darcy's Law (Amyx et al. 1960):

$$q_b = 1.988\times10^{-5}\left[\frac{T_b z_b}{P_b}\frac{kh\left(P_e^2-P_w^2\right)}{\mu_{avg} z_{avg}\ln\left(\frac{r_e}{r_w}\right)}\right], \tag{2}$$

which can be rewritten:

$$P_e^2-P_w^2 = \frac{q_b}{1.988\times10^{-5}}\left[\frac{P_b}{T_b z_b}\frac{\mu_{avg} z_{avg}\ln\left(\frac{r_e}{r_w}\right)}{kh}\right], \tag{3}$$

where:

q	=	gas flow rate, cubic feet per day at base (reference) conditions
T	=	temperature, K
P	=	pressure, pounds per square inch atmosphere
k	=	permeability, millidarcys
h	=	height, feet
μ	=	viscosity, centipoises
z	=	gas compressibility factor (a function of gas pressure and temperature)
r	=	radius, consistent units

e = external boundary (repository)
w = internal boundary (wellbore)
b = base or reference conditions for gas (temperature, pressure, compressibility factor)
avg = average properties between external and internal boundaries because u and z are functions of pressure which change with time.

This expression is very useful for looking at the relationships of gas properties (specifically μ and z [which is a function of the gas temperature and pressure]) and rock properties (namely k) on defining q and P.

In order to evaluate the effect of gas composition on q and P, a computer program developed by the National Institute of Standards and Technology (NIST) entitled SUPERTRAPP was used (NIST 1992). This computer program allows calculations of gas properties for 116 pure fluids and mixtures of up to 20 components for temperatures to 1,000 K and pressures to 300 megapascals. The computer program currently can evaluate hydrogen, CO_2, and water but does not have the capacity to evaluate brine (Friend and Huber 1994). In analyzing gas flow, it is assumed that CH_4 will behave similarly to CO_2. Because such small quantities of H_2S are anticipated at the WIPP, its impact will be neglected. Therefore, for this evaluation only the impact of CO_2 is considered.

Figure MASS-1 shows the relationship between gas viscosity for various mole fractions of H_2 at pressures of 7 megapascals and 15 megapascals as determined from SUPERTRAPP. The viscosity at 50 percent mole fraction H_2 is 2.3 times greater than for 100 percent mole fraction H_2. As shown in Equation 2, viscosity has an inverse relationship to flow rate and, as shown in Equation 3, a direct relationship to the square of the repository pressure. Hence viscosity differences that would result if gas properties other than those of hydrogen were incorporated would result in a decrease in flow rate and potentially higher pressures.

As shown in Figure MASS-2, the gas compressibility at 50 percent mole fraction H_2 is about 0.9 times that at 100 percent mole fraction H_2. Like viscosity, the gas compressibility factor is inversely related to flow rate and directly related to the square of the repository pressure. Hence changing composition from 100 percent to 50 percent H_2 would result in a slight increase in flow rate and a decrease in pressure. Therefore, the impact of variation in gas compressibility caused by composition is considered minor and so is neglected.

The absolute permeability of the surrounding formation plays a significant part with respect to both flow rate and pressure determinations. Because marker bed permeabilities range over four orders of magnitude (see Appendix PAR, Parameter 20), these primary flow pathways will have a greater influence on pressure and flow rate determinations compared to either uncertainty in viscosity or gas compressibility effects.

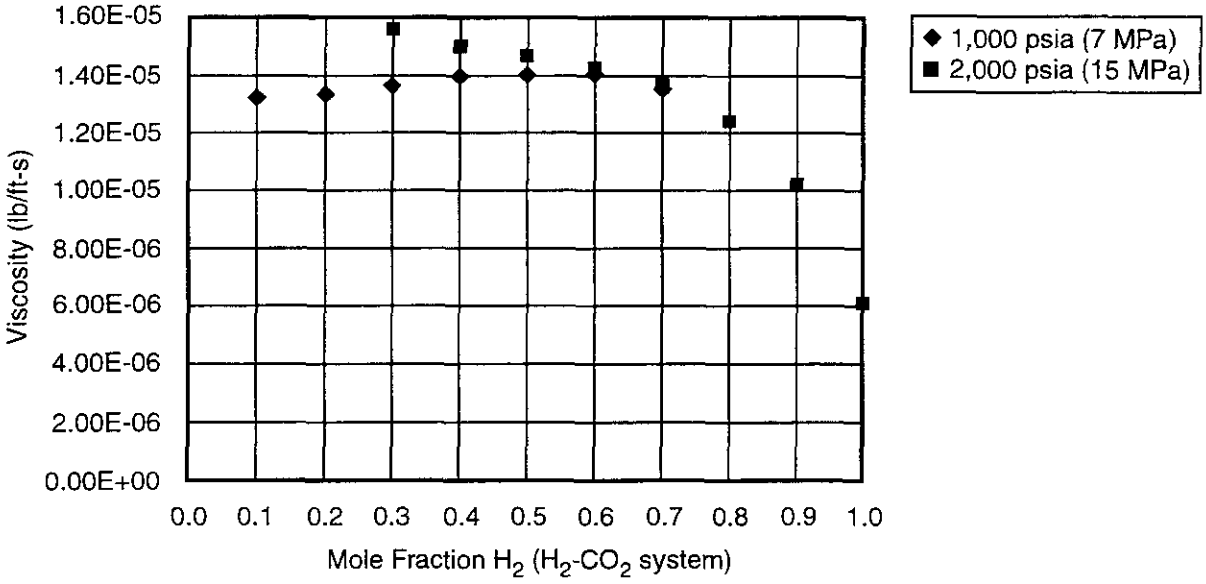

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Figure MASS-1. Gas Viscosity as a Function of Mole Fraction H_2 at 7 Megapascals and 15 Megapascals Pressure

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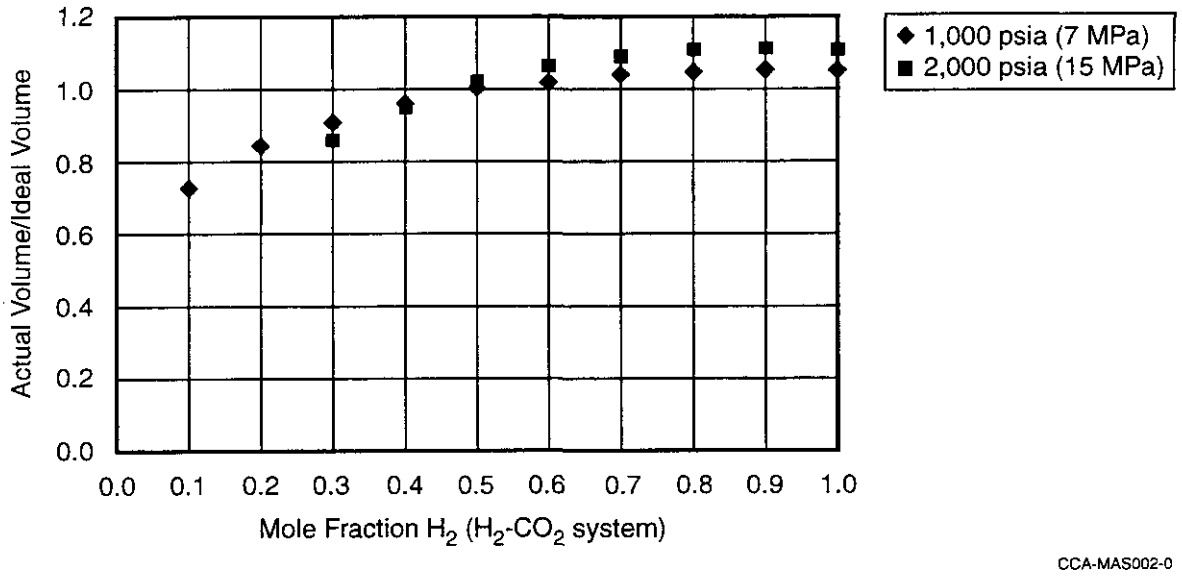

Figure MASS-2. Gas Compressibility as a Function of Mole Fraction H_2

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MASS.3.3 Salado Brine as Surrogate for Liquid Phase Physical Properties in BRAGFLO

BRAGFLO models physical properties for all liquids as Salado brine properties. However, liquid in the modeled region may consist of (1) brine originally in the Salado, (2) liquid introduced in the excavation during construction, maintenance, and ventilation during the operational phase, (3) a very small amount of liquid introduced as a component of the waste, (4) liquid from overlying units, and (5) liquid from the Castile brine reservoir. However, for BRAGFLO modeling it is assumed that the properties of all of these liquids are similar enough to Salado brine properties that the effect of variation in properties that may occur from liquids mixing is negligible. The properties required by BRAGFLO, and the subject of the discussion here, are density, viscosity, and compressibility.

Following repository closure, Salado brine will flow toward the repository at a rate that depends on the properties of the rock and brine, as well as hydraulic gradients. Brine flowing into the repository from the Salado is an important, sometimes dominant, source of liquid in the repository following closure. Because Salado brine is the only important source of brine that is present in all scenarios, it is assumed that the properties of brine important in the BRAGFLO model are the same as those of Salado brine.

During construction of the repository, water was spread for dust control. This water principally consisted of groundwater from the Culebra collected in the sumps and manufactured brine purchased from a local vendor. The physical properties of Salado brine as a surrogate for this Culebra brine are adequate because (1) the two brines have similar original physical properties, (2) the introduced brine will have equilibrated with liquid in the Salado and by dissolution, (3) some of the introduced liquid has evaporated, and (4) the volume introduced is relatively small.

Introduction of liquid through respiration in the repository is also considered insignificant. Because of the dry climate in the region, air drawn in from the surface and circulated through the repository is normally undersaturated in water vapor. In addition, the relative humidity of mine air is less than the equilibrium humidity of water in the mine environment. Thus, this liquid vapor remains in the vapor state until it is removed from the repository through forced circulation up the ventilation shaft.

The density difference among Salado brine, Castile brine, and brine from overlying units is the result of varying dissolved mineral content. Castile brine contains essentially sodium chloride (NaCl), while the Salado brine is saturated with approximately one-half sodium chloride and one-half magnesium chloride. Brine from overlying units is consistently fresher. Densities for WIPP brines were measured and reported by Brush (1990). The specific gravity of Salado and Castile brines are very similar and vary between 1.215 to 1.23 grams per cubic centimeter. Brines from the units above the Salado have lower specific gravity (for example, the specific gravity of Culebra brine is about 1.09 grams per cubic centimeter [WIPP Performance Assessment Division 1991]).

The viscosity of Salado brine is approximately 1.8×10^{-3} cp; for Culebra brine, the viscosity is approximately 1×10^{-3} cp (WIPP Performance Assessment Division 1991). Because of their similar specific gravity, it is expected that the viscosity of Castile and Salado brines is similar.

The ratio of density to viscosity appears in flow equations. The maximum difference of these is close to a factor of two for the three types of brines. Compressibilities range from approximately 2×10^{-10} per pascal for Culebra brine (for this discussion the range is assumed to be similar to that of water) to 2.5×10^{-10} per pascal for Salado brine and 9×10^{-10} per pascal for Castile brine (WIPP Performance Assessment Division 1991). The differences in the physical properties among these brines are considered insignificant with regard to the position of complementary cumulative distribution functions (CCDFs) because the variability of these values is relatively small (factors of two or three, without considering blending effects of mixing), and CCDFs are typically plotted in log-log format with many log cycles. Therefore, these differences are assumed negligible in the performance assessment. (Note that variability in chemical properties of these brines is accounted for, as discussed in Chapter 6.0, Sections 6.4.3.4 and 6.4.3.5, and Appendix SOTERM, Section SOTERM.2.2.1.)

MASS.3.4 Table of General Modeling Assumptions

This section presents Table MASS-1, which lists modeling assumptions used in the performance assessment. Table MASS-1 is a guide to general modeling assumptions used and provides some guidance for integrating the assumptions made with (a) the chapters or appendices in which they are discussed and (b) the code(s) that implement these assumptions. The features, events, and processes (FEPs) discussed in Appendix SCR that are relevant to the assumptions are also indicated. The final column in the table indicates whether the DOE considers the assumption described to be reasonable or conservative. As discussed in Chapter 6.0 (Section 6.5), the DOE has not attempted to bias the overall results of the performance assessment toward a conservative outcome. However, where data or models are infeasible to obtain, or where effects on performance are not expected to be significant enough to justify development of a more complicated model, the DOE has chosen to use conservative assumptions. The designator R (reasonable) in the final column indicates that the DOE considers the assumption to be reasonable based on WIPP-specific data or information, data and information considered analogous to the WIPP disposal system, expert judgment, or other reasoning. The designator C (conservative) indicates the DOE considers the assumption made may overestimate a process or effect that may contribute to releases to the accessible environment. The regulatory designator (Reg) indicates that the assumption is based on regulations in 40 CFR Part 191, criteria in 40 CFR Part 194, or other regulatory guidance.

MASS.4 Model Geometries

This section presents supplementary information on the disposal system geometry presented in Chapter 6.0 (Section 6.4.2), as modeled by the code BRAGFLO, and the Culebra flow and transport geometries used, as modeled by the codes SECOFL2D and SECOTP2D.

Table MASS-1. General Modeling Assumptions

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
MASS.3 Some General Assumptions in Performance Assessment Models				
MASS.3.1 Darcy's Law Applied for Fluid Flow calculated by BRAGFLO, SECOFL2D, and SECOTP2D				
1	BRAGFLO SECOFL2D	Flow is governed by mass conservation and Darcy's Law in porous media. Flow is laminar and fluids are Newtonian.	Saturated groundwater flow Unsaturated groundwater flow Brine inflow	R
2	BRAGFLO	Two-phase flow in the porous media is by simultaneous immiscible displacement.	Fluid flow caused by gas production	R
3	BRAGFLO	The Brooks-Corey or Van Genuchten/Parker equations represent interaction between brine and gas.	Fluid flow caused by gas production	R
4	BRAGFLO	The Klinkenberg effect is included for flow of gases at low pressures.	Fluid flow caused by gas production	R
5	BRAGFLO	Threshold displacement pressure for flow of gas into brine is constant.	Fluid flow caused by gas production	R
6	BRAGFLO SECOFL2D SECOTP2D	Fluid composition and compressibility are constant.	Saturated groundwater flow Fluid flow caused by gas production	R
MASS.3.2 Hydrogen Gas as Surrogate for Waste-Generated Gas Physical Properties in BRAGFLO				
7	BRAGFLO	The gas phase is assigned the density and viscosity properties of hydrogen.	Fluid flow caused by gas production	R
MASS.3.3 Salado Brine as Surrogate for Liquid Phase Physical Properties in BRAGFLO				
8	BRAGFLO	All liquid physical properties are assigned the properties of Salado brine.	Saturated groundwater flow	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.2 Model Geometries MASS.4 Model Geometries				
6.4.2.1 Disposal System Geometry MASS.4.1 Disposal System Geometry as Modeled in BRAGFLO				
	BRAGFLO	The disposal system is represented by a two-dimensional, north-south, vertical cross section.	Stratigraphy Physiography	R
	BRAGFLO	Flow in the disposal system is radially convergent or divergent centered on the repository, shaft, and borehole for disturbed performance.	Saturated groundwater flow Unsaturated groundwater flow	R
	BRAGFLO	Variable dip in the Salado is approximated by a 1° dip to the south.	Stratigraphy	R
	BRAGFLO	Stratigraphical layers are parallel.	Stratigraphy	R
	BRAGFLO	The stratigraphy consists of units above the Dewey Lake, the Dewey Lake, the Forty niner, the Magenta, the Tamarisk, the Culebra, the Unnamed Lower Member, and the Salado (comprising impure halite, MB138, anhydrites a and b [lumped together], and MB139). The dimensions of these units are constant. A Castile brine reservoir is included in all scenarios.	Stratigraphy	R
6.4.2.2 Culebra Geometry MASS.4.3 Historical Context of Culebra Geometries as Modeled in SECOFL2D and SECOTP2D				
	SECOFL2D SECOTP2D	The Culebra is represented by a two-dimensional, horizontal geometry for groundwater flow and radionuclide transport simulation.	Stratigraphy	R
	SECOFL2D GRASPINV	Transmissivity varies spatially. There is no vertical flow to or from the Culebra.	Groundwater recharge Groundwater discharge	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	SECOTP2D	The regional flow field provides boundary conditions for local transport calculations.	Advection	R
6.4.3 The Repository MASS.5 BRAGFLO Geometry of the Repository				
	BRAGFLO	The repository comprises five regions: a waste panel, the panel closures, the remainder of the panels and the access drifts, the operations region, and the experimental region. Also, a single shaft region is modeled, and a borehole region is included for a borehole that intersects the separate waste panel. The dimensions of these regions are constant.	Disposal geometry	R-C
	BRAGFLO	Long-term flow up plugged and abandoned boreholes is modeled as if all intrusions occur into a downdip (southern) panel.	Disposal geometry	C
	BRAGFLO	For each repository region the model geometry preserves design volume.	Disposal geometry	R
	BRAGFLO	Pillars and individual drifts and rooms, and panel closures in the nine lumped panels, are not modeled for long-term performance, and containers provide no barrier to fluid flow.	Disposal geometry	C
	BRAGFLO	The distance from the south end of the modeled waste panel to the modeled shaft is the true distance from the south end of the waste disposal region to the waste handling shaft.	Disposal geometry	R
	BRAGFLO	Long-term flow is radial to and from the borehole that intersects the waste disposal panel during disturbed performance.	Waste-induced borehole flow	R
	BRAGFLO	Panel closures are modeled with the same properties as the surrounding DRZ.	Disposal geometry	C

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.3.1 Creep Closure MASS.6 Creep Closure Appendix PORSURF				
	SANTOS	Creep closure is modeled using a two-dimensional model of a single room. Room interactions are insignificant.	Salt creep Changes in the stress field Excavation-induced changes in stress	R
	SANTOS	Creep closure causes a decrease in room volume which decreases waste porosity. The amount of creep closure is a function of time, gas pressure, and waste matrix strength.	Salt creep Changes in the stress field Consolidation of waste Pressurization	R
	BRAGFLO	Porosity of operations and experimental areas is fixed at a value representative of consolidated material.	Salt creep	R
6.4.3.2 Repository Fluid Flow MASS.7 Repository Fluid Flow				
	BRAGFLO	General assumptions 1 to 8.		See above
	BRAGFLO	The waste disposal region is assigned a constant permeability representative of average consolidated waste without backfill.	Saturated groundwater flow Unsaturated groundwater flow	R
MASS.7.1 Flow Interactions with the Creep Closure Model				
	BRAGFLO	The experimental and operations regions are assigned a constant permeability representative of unconsolidated material and a constant porosity representative of consolidated material.	Saturated groundwater flow Unsaturated groundwater flow Salt creep	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
MASS.7.2 Flow Interactions with the Gas Generation Model				
	BRAGFLO	For gas generation calculations, the effects of wicking are accounted for by assuming that brine in the repository contacts waste to an extent greater than that calculated by the Darcy flow model used.	Wicking	R
6.4.3.3 Gas Generation MASS.8 Gas Generation Appendix WCA				
	BRAGFLO	Gas generation occurs by anoxic corrosion of steel containers, and Fe and Fe-base alloys in the waste, giving H_2, and microbial degradation of cellulosics and, perhaps, plastics and rubbers, giving mainly CO_2 and CH_4. Radiolysis, oxic reactions, and other gas generation mechanisms are insignificant. Gas generation is calculated using the Average Stoichiometry model, and is dependent on brine availability.	Container material inventory Waste inventory Degradation of organic material Gases from metal corrosion	R
	BRAGFLO	The anoxic corrosion rate is dependent on liquid saturation. Anoxic corrosion of steel continues until all the steel is consumed. Steel corrosion will not be passivated by microbially-generated gases CO_2 or H_2S. Brine is consumed by the corrosion reaction.	Brine inflow Gases from metal corrosion Degradation of organic material	R
	BRAGFLO	Laboratory-scale experimental measurements of gas generation rates at expected room temperatures are used to account for the effects of biofilms and chemical reactions.	Effects of biofilms on microbial gas generation Effects of temperature on microbial gas generation Chemical effects of corrosion	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	BRAGFLO	The rate of biodegradation is dependent on the amount of liquid present. It is assumed that biodegradation neither produces nor consumes water. Gas generation by microbial degradation takes place in half the simulations. In half of the simulations with microbial gas generation, microbes consume all of the cellulosics but none of the plastics and rubbers. In the other half of the simulations with microbial gas generation, microbes consume all of the cellulosics and all of the plastics and rubbers. Microbial gas generation will continue until all biodegradable organic materials are consumed if brine is present. The MgO backfill will react with CO_2 and remove it from the gas phase.	Brine inflow Degradation of organic material Waste inventory	R
	BRAGFLO	Gas dissolution in brine is of negligible consequence.	Fluid flow caused by gas production	R
	BRAGFLO	The gas phase is assigned the properties of hydrogen (general assumption 8).	Fluid flow caused by gas production	See above
6.4.3.4 Chemical Conditions in the Repository SOTERM.2 Conceptual Framework of Chemical Conditions				
	NUTS PANEL	Chemical conditions in the repository will be constant. Chemical equilibrium is assumed for all reactions that occur between brine in the repository, waste, and abundant minerals, with the exceptions of gas generation and redox reactions.	Speciation Redox kinetics	R
	NUTS PANEL	Brine and waste in the repository will contain a uniform mixture of dissolved and solid-state species. No microenvironments that influence the overall chemical environment will persist.	Heterogeneity of waste forms Speciation	C

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	NUTS PANEL	For the undisturbed performance and E2 scenarios, brine in the waste panels has the composition of Salado brine. For E1 and E1E2 scenarios, all brine in the waste panel intersected by the borehole has the composition of Castile brine.	Speciation	R
	NUTS PANEL	Chemical conditions in the waste panels will be reducing. However, a condition of redox disequilibrium will exist between the possible oxidation states of the actinide elements.	Redox kinetics Speciation Effects of metal corrosion	R
	NUTS PANEL	The pmH and pCO_2 in the waste panels will be controlled by the equilibrium between brucite and magnesite. (A result of this assumption is low pCO_2 and alkaline conditions).	Speciation Backfill chemical composition	R
6.4.3.5 Dissolved Actinide Source Term SOTERM.3.3 The FMT Computer Code				
	NUTS PANEL	Radionuclide dissolution to solubility limits is instantaneous.	Dissolution of waste	C
	NUTS PANEL	Six actinides (Th, U, Np, Pu, Cm, and Am) are considered for calculations of radionuclide transport of brine. Choice of radionuclides is discussed in Appendix WCA.	Waste inventory	R
	NUTS PANEL	The reducing conditions in the repository will eliminate significant concentrations of Am(V), Pu(V), Pu(VI), and NP(VI) species. Am and Cm will exist predominantly in the III oxidation state, Th in the IV oxidation state. It is assumed that the solubilities and K_ds of Pu, Np, and U will be dominated by one of the remaining oxidation states: Pu(III) or Pu(IV), Np(IV) or NP(V), U(IV) or U(VI).	Speciation Redox kinetics	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	NUTS PANEL	For a given oxidation state, the different actinides exhibit similar chemical behavior and thus have similar solubilities.	Speciation	R
	NUTS PANEL	Organic ligands will not significantly affect solubility.	Waste inventory Dissolution of waste Organic ligands Organic complexation	R
	NUTS PANEL	For undisturbed performance and for all aspects of disturbed performance except for cuttings and cavings releases, radionuclide-bearing compounds are distributed evenly throughout the disposal panel.	Waste inventory Heterogeneity of waste forms	R
	NUTS PANEL	Mobilization of actinides in the gas phase is negligible.	Dissolution of waste	R
	NUTS PANEL	Actinide concentrations in the repository will be inventory limited when the mass of an actinide becomes depleted such that the predicted solubilities cannot be achieved.	Dissolution of waste	R
6.4.3.6 Source Term for Colloidal Actinides				
	NUTS PANEL	Four types of colloids comprise the source term for colloidal actinides; microbes, humic substances, intrinsic colloids, and mineral fragments.	Colloid formation and stability Humic and fulvic acids	R
	NUTS PANEL	The only intrinsic colloids that will form are those of the plutonium Pu(IV) polymer.	Colloid formation and stability	R
	NUTS PANEL	Concentrations of intrinsic colloids and mineral fragment colloids are modeled as constants that were based on experimental observations. Humic and microbe colloid actinide concentrations are modeled as proportional to dissolved actinide concentrations.	Colloid formation and stability	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	NUTS PANEL	The maximum concentration of each actinide associated with each colloid type is constant.	Actinide sorption	R
6.4.4 Shafts and Shaft Seals MASS.12 Shafts and Shaft Seals				
	BRAGFLO	General Assumptions 1 to 8.		See above
	BRAGFLO	The four shafts connecting the repository to the surface are represented by a single shaft with a cross-section and volume equal to the total volume of the four real shafts and separated from the waste by the distance of the nearest real shaft.	Disposal geometry	R
	BRAGFLO	The seal system is represented by nine materials occupying eleven model regions.	Seal geometry Seal physical properties	R
	BRAGFLO	The shaft is surrounded by a DRZ which heals with time. The DRZ is represented through the permeabilities of the shaft system itself, rather than as a discrete zone. The effective permeability of shaft salt, clay and concrete seals are adjusted several times after closure to reflect consolidation and possible degradation. Permeabilities are constant for asphalt and earthen fill components.	Salt creep Consolidation of seals Disturbed rock zone Microbial growth on concrete Chemical degradation of seals Mechanical degradation of seals	R
	BRAGFLO	Concrete shaft components are modeled as if they degrade 400 years after emplacement.	Mechanical degradation of seals	C
	NUTS	Radionuclides are not retarded by the seals.	Actinide sorption Speciation	C

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.5 The Salado MASS.13 Salado				
	BRAGFLO	General Assumptions 1 to 8.		See above
6.4.5.1 Impure Halite MASS.13.1 High Threshold Pressure for Halite-Rich Salado Rock Units				
	BRAGFLO	Rock and hydrologic properties are constant.	Stratigraphy	R
6.4.5.2 Salado Interbeds MASS.13.3 The Anhydrite Interbed Fracture Model				
	BRAGFLO	Interbeds have a fracture-initiation pressure above which local fracturing and changes in porosity and permeability occur in response to changes in pore pressure. A power function relates the permeability increase to the porosity increase. A pressure is specified above which porosity and permeability do not change.	Disruption caused by gas effects	R
	BRAGFLO	Interbeds have identical physical properties; they differ only in position, thickness, and some fracture parameters.	Saturated groundwater flow	R
6.4.5.3 Disturbed Rock Zone MASS.13.4 Flow in the Disturbed Rock Zone				
	BRAGFLO	The permeability of the DRZ is constant and higher than intact Salado. The DRZ porosity is equal to the porosity of impure halite to plus 0.29 percent.	Disturbed rock zone Roof falls Gas explosions Seismic activity Underground boreholes	C-R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.5.4 Actinide Transport in the Salado MASS.13.5 Actinide Transport in the Salado				
	NUTS	Dissolved actinides and colloidal actinides are transported by advection in the Salado. Diffusion and dispersion are assumed negligible.	Advection Diffusion Matrix diffusion	R
	NUTS	Sorption of actinides in the anhydrite interbeds, colloid retardation, colloid transport at higher than average velocities, co-precipitation of minerals containing actinides, channeled flow, and viscous fingering are not modeled.	Actinide sorption Colloid transport Colloid filtration Colloid sorption Fluid flow caused by gas production Fracture flow	R
	NUTS	Radionuclides having similar half lives are grouped as discussed in Appendix WCA.	Radioactive decay and ingrowth	R
	NUTS	Sorption of actinides in the borehole is not modeled.	Actinide sorption	C
6.4.6 Units Above the Salado MASS.14 Geologic Units above the Salado				
	SECOTP2D	Above the Salado, lateral actinide transport to the accessible environment can occur only through the Culebra.	Saturated groundwater flow Unsaturated groundwater fkow Solute transport	R
6.4.6.1 Unnamed Lower Member				
	SECOFL2D BRAGFLO	The unnamed lower member, Tamarisk, and Forty-niner are assumed to be impermeable.	Saturated groundwater flow	C
6.4.6.2 The Culebra MASS.15 Culebra Appendix TFIELD				
	SECOFL2D SECOTP2D	General Assumptions 1, 6, and 8.		See above

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	SECOFL2D SECOTP2D	For fluid flow the Culebra is modeled as a uniform (single-porosity) porous medium. For radionuclide transport a double-porosity model is used (advection in high permeability features and diffusion and sorption in low-permeability features).	Saturated groundwater flow Fracture flow Advection Diffusion	R
	SECOFL2D	The Culebra flow field is determined from the observed hydraulic conditions and estimates of the effects of climate change and potash mining outside the controlled area, and does not change with time unless mining is predicted to occur in the disposal system in the future.	Saturated groundwater flow Climate change Precipitation (for example, rainfall) Temperature Changes in groundwater flow caused by mining	R
	BRAGFLO	The Culebra is assigned a single permeability to calculate brine flow into the unit from an intrusion borehole.	Natural borehole fluid flow Waste-induced borehole flow	R
	SECOFL2D	Gas flow in the Culebra is not modeled. Gas from the repository does not affect fluid flow in the Culebra.	Saturated groundwater flow Fluid flow caused by gas production	R
	BRAGFLO SECOFL2D SECOTP2D	Different thicknesses of the Culebra are assumed for BRAGFLO, SECOFL2D, and SECOTP2D calculations, although the transmissivities are consistent.	Effects of preferential pathways	R
	GRASP-INV	Uncertainty in the spatial variability of the Culebra transmissivity is accounted for by statistically generating many transmissivity fields.	Saturated groundwater flow Fracture flow Shallow dissolution	R
	SECOFL2D BRAGFLO	Potentiometric heads are set on the edges of the regional grid to represent flow in a portion of a much larger hydrologic system.	Groundwater recharge Groundwater discharge Changes in groundwater recharge and discharge Infiltration	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.6.2.1 Transport of Dissolved Actinides in the Culebra MASS.15.2 Dissolved Actinide Transport and Retardation in the Culebra				
	SECOTP2D	Dissolved actinides are transported by advection in high-permeability features and diffusion in low permeability features.	Solute transport Advection Diffusion Matrix diffusion	R
	SECOTP2D	Sorption occurs on dolomite in the matrix. Sorption on clays present in the Culebra is not modeled.	Actinide sorption Changes in sorptive surfaces	C
	SECOTP2D	Sorption is represented using a linear isotherm model.	Actinide sorption Kinetics of sorption	R
	SECOTP2D	The possible effects on sorption of the injection of brines from the Castile and Salado into the Culebra are accounted for in the distribution of actinide K_ds.	Actinide sorption Groundwater geochemistry Natural borehole fluid flow	R
	SECOTP2D	Hydraulically-significant fractures are assumed to be present everywhere in the Culebra.	Advection	C
6.4.6.2.2 Transport of Colloidal Actinides in the Culebra MASS.15.3 Colloidal Actinide Transport and Retardation in the Culebra				
	SECOTP2D	Humic actinides are chemically retarded identically to dissolved actinides and are treated as dissolved actinides.	Advection Diffusion Colloid transport Microbial transport	R
	SECOTP2D	The concentration of intrinsic colloids is sufficiently low to justify elimination from performance assessment transport calculations.		R
	SECOTP2D	Microbial colloids and mineral fragments are too large to undergo matrix diffusion. Filtration of these colloids occurs in high permeability features (which is modeled using a decay approach). Attenuation is so effective that associated actinides are assumed to be retained within the disposal system and are not transported in SECOTP2D.	Microbial transport Colloid sorption	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.6.2.3 Subsidence Due to Potash Mining				
MASS.15.4 Subsidence Caused by Potash Mining in the Culebra				
	SECOFL2D	The effect of potash mining is to increase the hydraulic conductivity in the Culebra by a factor from 1 to 1,000.	Potash mining Changes in groundwater flow caused by mining	Reg.
6.4.6.3 The Tamarisk				
	SECOFL2D BRAGFLO	The Tamarisk is assumed to be impermeable.	Saturated groundwater flow	R
6.4.6.4 The Magenta				
	BRAGFLO	General Assumptions 1 to 8.		See above
	BRAGFLO	The Magenta permeability is set to the lowest value measured near to the center of the WIPP site. This increases the flow into the Culebra.	Saturated groundwater flow	R
	NUTS	No radionuclides entering the Magenta will reach the accessible environment. However, the volumes of brine and actinides entering and stored in the Magenta are modeled.	Solute transport	R
6.4.6.5 The Forty-niner				
	BRAGFLO	The Forty-niner is assumed to be impermeable.	Saturated groundwater flow	R
6.4.6.6 Dewey Lake				
	BRAGFLO	General Assumptions 1 to 8.		See above
	NUTS	The sorptive capacity of the Dewey Lake is sufficiently large to prevent any release over 10,000 years.	Saturated groundwater flow Actinide sorption	R
6.4.6.7 Supra-Dewey Lake Units				
	BRAGFLO	General Assumptions 1 to 8.		See above

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	BRAGFLO	The units above the Dewey Lake are a single hydrostratigraphic unit.	Stratigraphy	R
	BRAGFLO	The units are thin and predominantly unsaturated.	Unsaturated groundwater flow Saturated groundwater flow	R
6.4.7 The Intrusion Borehole MASS.16 Intrusion Borehole				
6.4.7.1 Releases During Drilling				
	CUTTINGS_S BRAGFLO_DBR	Any actinides that enter the borehole are assumed to reach the surface.	—	C
MASS.16.1 Cuttings, Cavings, and Spall Releases during Drilling				
	BRAGFLO PANEL CUTTINGS_S	Future drilling practices will be the same as they are at present.	Oil and gas exploration Potash exploration Oil and gas exploitation Other resources Enhanced oil and gas recovery	Reg.
	CUTTINGS_S	Releases of particulate waste material are modeled (cuttings, cavings, and spallings). Releases are corrected for radioactive decay until the time of intrusion.	Drilling fluid flow Suspension of particles Cuttings Cavings Spallings	R
	CUTTINGS_S	Particle waste shear based on properties of marine clays, considered a worst case	Cavings	C
6.4.7.1.1 Direct Brine Release During Drilling MASS.16.2 Direct Brine Releases during Drilling				
	BRAGFLO PANEL	Brine containing actinides may flow to the surface during drilling. Direct brine release will have negligible effect on the pressure and saturation in the waste panel.	Blowouts	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	BRAGFLO	A two-dimensional grid (one degree dip) on the scale of the waste disposal region is used for direct brine release calculations.	Blowouts	R
	BRAGFLO	Calculation of direct brine release from several different locations provides reference results for the variation in release associated with location.	Blowouts	R
6.4.7.2 Long-Term Releases Following Drilling MASS.16.3 Long-Term Properties of the Abandoned Intrusion Borehole				
	BRAGFLO	Plugging and abandonment of future boreholes are assumed to be consistent with practices in the Delaware Basin.	Natural borehole fluid flow Waste-induced borehole flow	Reg.
6.4.7.2.1 Continuous Concrete Plug through the Salado and Castile				
	BRAGFLO	A continuous concrete plug is assumed to exist throughout the Salado and Castile. Long-term releases through a continuous plug are analogous to releases through a sealed shaft.	Natural borehole fluid flow Waste-induced borehole flow	Reg-R
6.4.7.2.2 The Two-Plug Configuration				
	BRAGFLO	A lower plug is located between the Castile brine reservoir and underlying formations. A second plug is located immediately above the Salado. The brine reservoir and waste panel are in direct communication though an open cased hole.	Natural borehole fluid flow Waste-induced borehole flow	Reg.-R
	BRAGFLO	The casing and upper concrete plug are assumed to fail after 200 years, and the borehole is assumed to be filled with silty-sand like material. At 1,200 years after abandonment the permeability of the borehole below the waste panel is decreased by one order of magnitude as a result of salt creep.	Natural borehole fluid flow Waste-induced borehole flow	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.7.2.3 The Three-Plug Configuration				
	BRAGFLO	In addition to the two plug configuration, a third plug is placed within the Castile above the brine reservoir. This third plug behaves in a similar manner to the lower plug in the two-plug configuration.	Natural borehole fluid flow Waste-induced borehole flow	Reg.-R
6.4.8 Castile Brine Reservoir MASS.18 Castile Brine Reservoir				
	BRAGFLO	The Castile region is assigned a low permeability, which prevents fluid flow. Brine occurrences in the Castile are bounded systems. Brine reservoirs under the waste panels are assumed to have limited extent and interconnectivity, with effective radii on the order of several hundred meters.	Brine reservoirs	R
6.4.9 Climate Change MASS.17 Climate Change				
	SECOFL2D	Climate-related factors are treated through recharge. A parameter called the Climate Index is used to scale the Culebra flux field.	Climate change Temperature Precipitation (for example, rainfall)	R
6.4.10 Initial and Boundary Conditions for Disposal System Modeling				
6.4.10.1 Disposal System Flow and Transport Modeling (BRAGFLO and NUTS)				
	BRAGFLO	There are no gradients for flow in the far-field of the Salado, and pressures are above hydrostatic, but below lithostatic. Excavation and waste emplacement result in partial drainage of the DRZ.	Saturated groundwater flow Brine inflow	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	BRAGFLO	An initial water-table surface is set in the Dewey Lake at an elevation of 3,215 feet (980 meters) above mean sea level. The initial pressures in the Salado are extrapolated from a sampled pressure in MB139 at the shaft and are in hydrostatic equilibrium. The excavated region is assigned an initial pressure of one atmosphere. The liquid saturation of the waste-disposal region is consistent with the liquid saturation of emplaced waste. Other excavated regions are assigned zero liquid saturation, except the shaft which is fully saturated.	Saturated groundwater flow	R
	NUTS	Molecular transport boundary conditions are no diffusion or dispersion in the normal direction across far-field boundaries. Initial actinide concentrations are zero everywhere except in the waste.	Radionuclide decay and ingrowth Solute transport	R
6.4.10.2 Culebra Flow and Transport Modeling (SECOFL2D, SECOTP2D)				
	SECOFL2D	Constant head boundary conditions are set on the far-field boundaries of the regional flow model. Constant head boundary conditions are also set on the boundaries of the local domain, and are derived by interpolating the solution of the regional domain..	Saturated groundwater flow	R
	SECOFL2D	Initial actinide concentrations in the Culebra are zero.	Solute transport	R
6.4.10.3 Initial and Boundary Conditions for Other Computational Models				
	NUTS PANEL BRAGFLO (direct brine release) CUTTINGS_S	Initial and boundary conditions interpolated from previously executed BRAGFLO calculation.		R

Table MASS-1. General Modeling Assumption (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.12 Sequences of Future Events				
	CCDFGF	Each 10,000 year future (random sequence of future events) is generated by randomly and repeatedly sampling: the time between drilling events; the location of drilling events; the activity level of the waste penetrated by each drilling intrusion; the plug configuration of the borehole, and the penetration of a Castile brine reservoir, and by randomly sampling the occurrence of mining in the disposal system.	Oil and gas exploration Potash exploration Oil and gas exploitation Other resources Enhanced oil and gas recovery Natural borehole fluid flow Waste-induced borehole flow	Reg.-R
6.4.12.1 Active and Passive Institutional Controls in Performance Assessment Chapter 7.0				
	CCDFGF	Active institutional controls are effective for 100 years and completely eliminate possibility of incompatible activities. Passive institutional controls are effective for 600 years and reduce rate of incompatible events to 0.01 of the rate during the following uncontrolled period.		Reg.-R
6.4.12.2 Number and Time of Drilling Intrusions				
	CCDFGF	Drilling may occur after 100 years according to a Poisson process.	Loss of records Oil and gas exploration Potash exploration Oil and gas exploitation Other resources	Reg.-R
6.4.12.3 Location of Intrusion Boreholes				
	CCDFGF	The waste disposal region is discretized with 144 regions with the probability of each region being intersected equal. A borehole can penetrate only one region.	Disposal geometry	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.12.4 Activity of the Intersected Waste Appendix WCA				
	CCDFGF	569 waste streams identified for contact-handled (CH)-TRU and all the remote-handled (RH)-TRU waste was grouped (binned) together into one equivalent or average (WIPP-scale) RH-TRU waste stream.	Heterogeneity of waste form	R
6.4.12.5 Diameter of the Intrusion Borehole Appendix DEL				
	CUTTINGS_S	The diameter of the intrusion borehole is constant at 12.25 inches (31.12 centimeters).		Reg.-R
6.4.12.6 Probability of Intersecting a Brine Reservoir				
	CCDFGF	One brine reservoir is assumed to exist below the waste panels. The probability that a deep borehole intersects a brine reservoir below the waste panels is 0.08. Brine reservoirs may be depleted by boreholes drilled in the waste disposal region that do not intersect waste (for example, through intact rock).	Brine reservoirs	R
6.4.12.7 Plug Configuration in the Abandoned Intrusion Borehole				
	CCDFGF	The two-plug configuration has a probability of 0.68. The three-plug configuration has a probability of 0.30. The continuous concrete plug has a probability of 0.02.		Reg.-R
6.4.12.8 Probability of Mining Occurring in the Land Withdrawal Area				
	CCDFGF	Mining in the disposal system occurs a maximum of once in 10,000 years (a 10^{-4} probability per year).		Reg.-R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.13 Construction of a Single CCDF				
	CCDFGF	Deterministic calculations are executed with BRAGFLO, NUTS, SECOFL2D, SECOTP2D, CUTTINGS_S, and PANEL to generate reference conditions. These reference conditions are used to estimate the consequences associated with random sequences of future events. These are in turn used to develop CCDFs.		R
	CCDFGF	10,000 random sequences of future events are generated for each CCDF plotted.		R
6.4.13.1 Constructing Consequences of the Undisturbed Performance Scenario				
	CCDFGF	A BRAGFLO and NUTS calculation with undisturbed conditions is sufficient for estimating the consequences of the undisturbed performance scenario.		R
6.4.13.2 Scaling Methodology for Disturbed Performance Scenarios				
	CCDFGF	Consequences for random sequences of future events are constructed by scaling the consequences associated with deterministic calculations (reference conditions) to other times, generally by interpolation but sometimes by assuming either similarity or no consequence.		R
6.4.13.3 Estimating Long-Term Releases from the E1 Scenario				
	CCDFGF NUTS	Reference conditions are calculated or estimated for intrusions at 100, 350, 1,000, 3,000, 5,000, 7,000, and 9,000 years.	Waste-induced borehole flow	R
	SECOTP2D	Reference behavior for actinide transport in the Culebra is calculated for intrusions at 350 and 1,000 years.	Solute transport	R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
6.4.13.4 Estimating Long-Term Releases from the E2 Scenario				
	CCDFGF NUTS SECOTP2D	The methodology is similar to the methodology for the E1 scenario. For multiple intrusions, the additional source term to the Culebra for the second and subsequent intrusions is assumed to be negligible.	Waste-induced borehole flow Waste inventory	R
6.4.13.5 Estimating Long-Term Releases from the E1E2 Scenario				
	CCDFGF PANEL	The concentration of actinides in liquid moving up the borehole assumes homogeneous mixing within the panel.	Waste-induced borehole flow	C
	PANEL	Any actinides that enter the borehole reach the Culebra.	Waste-induced borehole flow	C
6.4.13.6 Multiple Scenario Occurrences				
	CCDFGF PANEL	The panels are assumed not to be interconnected for long term brine flow.	Saturated groundwater flow Unsaturated groundwater flow	R
6.4.13.7 Estimating Releases During Drilling for All Scenarios				
	PANEL NUTS	Repository conditions will be dominated by Castile brine if any borehole connects to a brine reservoir.	Brine reservoirs Natural borehole fluid flow	R
	CUTTINGS_S	Depletion of actinides in parts of the repository that have been penetrated by boreholes is not accounted for in calculating the releases from subsequent intrusions at such locations.	Waste-induced borehole flow Waste inventory	C
6.4.13.8 Estimating Releases in the Culebra and the Impact of the Mining Scenario				
	CCDFGF SECOFL2D SECOTP2D	Releases from intrusions at random times in the future are scaled from releases calculated at 100 years with a unit source of radionuclides in the Culebra.		R

Table MASS-1. General Modeling Assumptions (Continued)

CCA Section and Appendix	Code	Modeling Assumption	Related FEP in Appendix SCR	Assumption Considered*
	CCDFGF	Actinides in transit in the Culebra when mining occurs are transported in the flow field used for the undisturbed case. Actinides introduced subsequent to mining are transported in the flow field used for the disturbed case (that is, mined case).		R

* R = Reasonable
C = Conservative
Reg. - Based on regulatory guidance
See above - Refers to assumptions 1 through 8 listed at the beginning of this table.

MASS.4.1 Disposal System Geometry as Modeled in BRAGFLO

Overall, the conceptual model of the geometry of the disposal system is that the spatial effects of process interactions can be represented in two dimensions. The geometry used to represent the processes of long-term fluid flow in the Salado, flow between a borehole and overlying units, and flow within the repository (where processes coupled to fluid flow occur, such as creep closure and gas generation), is a vertical cross-section through the repository on a north-south axis. The dimension of this geometry in the direction perpendicular to the plane of the cross-section varies so that spatial effects of certain processes can be better represented, as discussed below.

Three other two-dimensional model geometries are used in performance assessment. For fluid flow and transport modeling in the Culebra, the geometry is a horizontal two-dimensional plane (see Sections 6.4.2 and 6.4.6.2). For modeling brine flow from the intruded panel to the borehole during drilling, the geometry is a two-dimensional, horizontal representation of a waste panel (see Section 6.4.7). For modeling brine flow that might occur between an E-type borehole and other boreholes penetrating the repository, the geometry used is a two-dimensional, horizontal representation of the entire repository (see Section 6.4.13.6). These geometries are mentioned here but not discussed in detail because they are components of other conceptual models requiring geometric assumptions.

The two-dimensional geometry developed for the Salado is based on the assumption that brine and gas flow will converge upon and diverge from the repository horizon. The impact of this conceptual model and its implementation in a two-dimensional grid has been compared to a model that does not make the assumption of convergent and divergent flow (see Attachment 4-1 for additional information). The conceptual model for the Salado includes the slight and variable dip of beds in the vicinity of the repository, which might affect fluid flow.

Above and below the repository, it is assumed that any flow between the borehole or shaft (see Section 6.4.3) and surrounding materials will converge or diverge. With respect to flow in units overlying the Salado, the only purpose of this conceptual model is to determine the quantity (flux) of fluid leaving or entering the borehole or shaft. Fluid movement through the units above the Salado is treated in a different conceptual model (see Section 6.4.6). Below the repository, the possible presence of a brine reservoir is considered to be important, so a hydrostratigraphic layer representing the Castile and a possible brine reservoir in it is included.

MASS.4.2 Historical Context of the Disposal System Geometry

The geometry used in the disposal-system model has seen numerous changes since the 1991 preliminary performance assessment (WIPP Performance Assessment Division 1991), in which undisturbed performance used different geometrical assumptions than for disturbed performance, but all calculations used homogeneous waste regions. In gas and brine migration calculations performed in 1992 prior to the 1992 performance assessment for 40 CFR Part 191 (WIPP Performance Assessment Department 1992a) several different geometries were again used, however some of these explored discretizing the repository into different waste and panel seal regions and explored the impact of the north end of the repository. The 1992 performance assessment calculations used geometries similar in principle to those used for the 1992 gas and brine migration calculations (Sandia WIPP Project 1992; WIPP Performance Assessment Department 1992b).

The current disposal system geometry was chosen to allow simulations for both disturbed and undisturbed scenarios to use the same grid description. The repository regions that contain waste have been divided into two subregions: a panel region and the remainder of the repository. Separating the panel region allows a more detailed representation of an intrusion borehole penetrating a panel. The effects of inter-panel communication can be examined by varying the permeability of the panel closure. In addition, the Culebra and other geologic units extending to the surface are represented. The various shaft seal components are also included in the modeling. The computational grid used in BRAGFLO is identical for all three scenarios, and the distinction between scenarios is facilitated by introducing material changes at specified time intervals. For example, at the time of an intrusion the material properties corresponding to the borehole grid blocks are changed to those properties consistent with the long-term behavior of a borehole and plug system.

MASS.4.3 Historical Context of Culebra Geometries as Modeled in SECOFL2D and SECOTP2D

The geometries used in the SECOFL2D and SECOTP2D Culebra models are chosen to provide a reasonable and realistic basis for two-dimensional simulations of groundwater flow and radionuclide transport through the Culebra. This model, described in Sections 6.4.2 and 6.4.6.2, has been developed over many years. The development of the various modeling domains and assumptions is documented in Section MASS.15.

MASS.5 BRAGFLO Geometry of the Repository

The purpose of this model is to provide a reasonable representation of the geometry of the WIPP repository with respect to the interactions between important processes that occur there.

This conceptual model represents the geometry of the repository for performance assessment. As with the geometry of the disposal system discussed in Chapter 6.0 (Sections 6.4.2.1) and Section MASS.4, the principal process considered in setting up the repository geometry is fluid flow. Several features considered to be important in fluid flow are included in the conceptual model. The first is the overall dimension of the repository along the north-south trend of the cross section, as well as the major divisions within the repository (waste disposal region, operations region, and experimental region). The second is the volume of a single panel, because fluid flow to a borehole penetrating the repository can potentially access only the volume in a waste panel directly and other regions of the repository only by flow through or around a panel closure. The third is the physical dimensions of panel closures separating the single panel and the other major divisions of the repository. In determining the appropriate way to represent these features, the important concepts applied are to preserve dimensions along the axis of the model, interface areas, and volumes excavated.

Notably absent from the conceptual model for the long-term performance of the repository are pillars and individual drifts and rooms. These are excluded from the model for simplicity, and it is assumed that they have either negligible impact on fluid flow processes or, alternatively, that including them in the conceptual model would be beneficial to long-term performance because their presence could make flow paths more tortuous and decrease fluxes. This assumption includes lumping nine of the 10 panels in the waste disposal region into a single region (see Sections 6.4.3 and 6.4.3.2).

The BRAGFLO model of the WIPP disposal system is a two-dimensional array of three-dimensional grid blocks. Each grid block has a finite length, width, height, volume, and surface area for its boundaries with neighboring grid blocks. The BRAGFLO two-dimensional grid is similar to any other two-dimensional grid used to treat flows, except that the grid-block dimension in the direction perpendicular (z-direction) to the plane of the grid varies from block to block as a function of the lateral direction (x-direction). This allows the BRAGFLO grid to treat important geometric aspects of the WIPP disposal system, such as the very small intrusion borehole, the moderate-size shaft, and the larger controlled areas.

MASS.5.1 Historical Context of the Repository Model

Several early models of repository fluid-flow behavior (models of radionuclide migration pathways, gas flow from the disposal area to the shaft, Salado brine flow through panel to borehole, effects of anhydrite layers on Salado brine flow through a panel, and flow from a brine reservoir through a disposal room) are summarized in a 1990 report (Rechard et al. 1990). In the preliminary performance assessment of 1992, all waste was lumped into a single region (WIPP Performance Assessment Department 1993). Because human intrusion

boreholes must be treated in detail for the 1996 performance assessment, it was necessary to model a single waste panel with a borehole surrounded by two-dimensional radial-flaring gridblocks. The remainder of the waste is modeled as the rest of the repository and is separated from the waste panel by a panel closure.

MASS.6 Creep Closure

The model used for creep closure of the repository is discussed in Appendix PORSURF, Chapter 6.0 (Section 6.4.3.1), and Appendix BRAGFLO (Section 4.11).

MASS.7 Repository Fluid Flow

This model represents the long-term flow behavior of liquid and gas in the repository and its interaction with other regions in which fluid flow may occur, such as the Salado, shafts, or intrusion borehole. This model is not used to represent the interaction of fluids in the repository with a borehole during drilling.

There are at least three different alternative models that the DOE evaluated for explaining brine inflow. One conceptual model, the far-field flow model, is for flow from the far field in response to potentiometric gradients through naturally interconnected intergranular pore spaces. There is experimental evidence supporting this model in anhydrite interbeds and some non-anhydrite intervals. Experimental results from very pure halite are ambiguous with respect to this model: results can be interpreted either as very low permeability (near-complete absence of interconnected pore space); or as a lithology in which fluid is not responsive to applied pressure gradients. In the first case, potentiometric flow models can be used effectively with very low permeability values. In the second case, which would imply a conditional exception to the potentiometric flow model, a potentiometric model would not be appropriate for use.

Numerous parameters are necessary to describe flow in terms of potentiometric equations. These include properties describing the rock formation: porosity, permeability, density, rock compressibility; and properties describing fluid flow and fluid interactions: relative permeability, capillary pressure, fluid compressibility, fluid density, and fluid viscosity. Within the conceptual model, few limits are imposed on the spatial variability or functional dependence of these properties. It is known, for example, that the pore structure and composition of the Salado are not uniform, which leads to spatial heterogeneity in rock properties both by layering and within each layer. Fluid properties are known to be functions of pressure, temperature, chemical composition, and saturation.

A second conceptual model, the redistribution model, proposes that interconnected pore spaces do not exist naturally in most lithologic units in the Salado. Interconnected networks form as the result of fracturing and creep around excavations. Potentiometric flow occurs in interconnected networks, but because the interconnectedness is of limited extent, the volume of brine that can flow is severely limited compared to the naturally interconnected case. A

numerical model based on the redistribution concept was developed and applied to the small-scale brine inflow (SSBI) data set (McTigue 1993). The redistribution-based model allowed the use of a more realistic capacitance for the formation response than do far-field flow models with far-field properties.

The third conceptual model for flow, the clay consolidation model, arises from observations made as part of the BSEP. On the basis of observations recorded during more than nine years of underground observations (Deal and Case 1987; Deal and Roggenthen 1989; Deal et al. 1987, 1989, 1991a, 1991b, 1993), this model proposes that the most significant source of brine flowing into the repository is clay layers exposed by excavation. According to the model, (1) clay layers compact and yield brine when stresses are relieved near the excavation and (2) flow through other lithologic units is negligible.

Since definitive data do not exist to reconcile these three alternatives, the DOE has implemented the far-field flow model because it results in a range of variability in brine inflow that covers the other two alternative models. The first principle in the conceptual model for fluid flow in the repository is that gas and brine can be both present and mobile (two-phase flow), governed by conservation of energy and mass and by Darcy's Law for their fluxes (see Appendix BRAGFLO, Sections 4.1 through 4.4). Consistent with typical concepts of two-phase flow, the phases can affect each other by impeding flow caused by partial saturation (relative permeability effects) and by affecting pressure caused by capillary forces (capillary pressure effects).

The flow of brine and gas in the repository is assumed to behave as two-phase, immiscible, Darcy flow (see Appendix BRAGFLO, Sections 4.8 and 4.9). BRAGFLO is used to simulate brine and gas flow in the repository and to incorporate the effects of disposal room closure and gas generation. Fluid flow in the repository is affected by the following factors:

- the geometrical association of pillars, rooms, and drifts; panel closure caused by creep; and possible borehole locations;
- the varied properties of the waste areas resulting from creep closure and heterogeneous contents;
- flow interactions with other parts of the disposal system; and
- reactions that generate gas.

The geometry of the panel around the intrusion borehole is consistent with the assumption that fluid flow there will occur directly toward or directly away from the borehole. The geometry represents a semi-circular volume north of the borehole and a semi-circular volume south of the borehole (representing the assumption of radial flow in a subregion of a two-dimensional representation of the repository). Around the shaft, the assumption of convergent or divergent flow is made, and implemented with a similar gridding technique.

Approximating convergent and divergent flow around the intrusion borehole and the shaft creates two narrow necks in the otherwise fairly uniform width grid in the region representing the repository. In the undisturbed performance scenario and under certain conditions in other scenarios, flow in the repository may pass laterally through these necks. In reality, these necks do not exist. Their presence in the model is expected to have a negligible or conservative impact on model predictions compared to predictions that would result from use of a more realistic model geometry. The time scale involved and the permeability contrast between the repository and surrounding rock are sufficient that lateral flow that may occur in the repository is restricted by the rate at which liquid gets into or out of the repository, rather than the rate at which it flows through the repository.

Gas generation is affected by the quantity of liquid in contact with metal. However, the distribution of fluid in the repository can be only approximated. For example, capillary action can create wicking that would increase the overall region in which gas generation occurs, but this cannot be modeled at the necessary resolution to fundamentally stimulate processes without undesirable effects on the duration of the model simulations. Therefore, as a bounding measure for gas generation purposes, brine in the repository is distributed to an extent greater than actually estimated by the Darcy flow models used and values of parameters chosen.

Panel closures are represented with a permeability of 1×10^{-15} square meters, which is equivalent to the DRZ permeability. This value is considered reasonable as verified by an analysis, which is presented as Attachment 7-1 of this appendix.

Modeling of flow within the repository is based on homogenizing the room contents into relatively large computational volumes. The approach ignores heterogeneities in disposal room contents that may influence gas and brine behavior in the room by causing fluid flow among channels or preferential paths in the waste, bypassing entire regions. Isolated regions could exist for several reasons:

- they may be isolated by low-permeability regions of waste that serve as barriers,
- connectivity with the interbeds may occur only at particular locations within the repository, or
- the repository dip may promote preferential gas flow in the upper regions of the waste.

The adequacy of the homogenization approach was examined in screening analyses DR-1 (Webb 1995) and DR-6 (Vaughn et al. 1995a). To address room heterogeneity, this analysis used an additional parameter in BRAGFLO to specify the minimum active (mobile) brine flow saturation (pseudo-residual brine saturation). Above this saturation, the normal descriptions of two-phase flow apply (that is, either the Brooks and Corey or van Genuchten and Parker relative permeability models). Below this minimum, brine is immobile, although it is available for reaction and may still be consumed during gas-generation reactions. The

assumption of a minimum saturation limit is justified based on the presumed heterogeneity of the waste and the fact that the repository dips slightly. The minimum active brine saturation was treated as an uncertain parameter and sampled uniformly between values 0.1 and 0.8 during the analysis. This saturation limit was applied uniformly throughout the disposal room in order to bound the impact of heterogeneities on flow (Webb 1995; Vaughn et al. 1995a). Results of this analysis showed that releases to the accessible environment in the baseline case (homogenization) are consistently higher.

The experimental and operations regions are represented in performance assessment by a fixed porosity of 18.0 percent and a permeability of 10^{-11} square meters. This combination of low porosity and high permeability will conservatively overestimate fluid flow through these regions and limit the capacity of these regions to store fluids, thus potentially overestimating releases to the environment. This conclusion is based on a screening analysis (Vaughn et al. 1995b) that examined the importance of permeability varying with porosity in closure regions (waste disposal region, experimental region, and operations region). To perform this analysis, a model for estimating the change in permeability with porosity in the closure regions (waste disposal region, experimental region and operations region) was implemented in BRAGFLO. A series of BRAGFLO simulations was performed to determine whether permeability varying with porosity in closure regions could enhance contaminant migration to the accessible environment. Two basic scenarios were considered in the screening analysis, undisturbed performance and disturbed performance. To assess the sensitivity of system performance on dynamic permeability in the closure regions, CCDFs of normalized contaminated brine releases were constructed and compared with the corresponding baseline conditional CCDFs. The baseline model treated permeabilities in the closure regions as fixed values. Results of this analysis showed that the inclusion of dynamic closure of the waste disposal region, experimental region, and operations region in BRAGFLO results in computed releases to the accessible environment that are essentially equivalent to the baseline case.

MASS.7.1 Flow Interactions with the Creep Closure Model

The dynamic effect of halite creep and room consolidation on room porosity is modeled only in the waste disposal region. Other parts of the repository, such as the experimental region and the operations region, are modeled assuming fixed (invariant with time) properties. In these regions, the permeability is held at a fixed high value representative of unconsolidated material, while the porosity is maintained at relatively low values associated with highly consolidated material. It is assumed that this combination of low porosity and high permeability conservatively overestimates flow through these regions and minimizes the capacity of this material to store fluids, thus maximizing the release to the environment. To examine the acceptability of this assumption, a screening analysis (Vaughn et al. 1995c) evaluated the effect of including closure of the experimental region and operations region. In this analysis, consolidation of the experimental region and operations region was implemented in BRAGFLO by relating pressure and time to porosity using a porosity-surface method. The porosity surface for the experimental region and operations region differs from the one used for consolidation of the disposal room and is based on an empty excavation (see Appendix

PORSURF). Results of the screening analysis showed that disregarding dynamic closure of the experimental region is acceptable because it is conservative: lower releases occur when closure of the experimental region and operations region is computed compared to simulations with time-invariant high permeability and low porosity.

MASS.7.2 Flow Interactions with the Gas Generation Model

Gas generation affects repository pressure, which in turn is an important parameter in other processes such as two-phase flow, creep closure, and interbed fracturing. Gas generation processes considered in performance assessment calculations include anoxic corrosion and microbial degradation. Radiolysis is excluded from performance assessment calculations on the basis of laboratory experiments and a screening analysis (Vaughn et al. 1995d) that concluded that radiolysis does not significantly affect repository performance.

In modeling gas generation, the effective liquid in a computational cell is the computed liquid in that cell plus an adjustment to account for the uncertainty associated with wicking by the waste (see Appendix BRAGFLO, Section 7.2.9). Capillary action (wicking) is the ability of a material to carry a fluid by capillary forces above the level it would normally seek in response to gravity. Because the current gas-generation model computes substantially different gas-generation rates depending on whether the waste is wet or merely surrounded by water vapor, the physical extent of wetting could be important. A screening analysis (Vaughn et al. 1995e) examined wicking and concluded that it should be included in performance assessment calculations. The baseline gas-generation model in BRAGFLO accounts for corrosion of iron and microbial degradation of cellulosics. The net reaction rate of these processes depends directly on brine saturation: an increase in brine saturation will increase the net reaction rate by weighting the inundated portion more heavily and the slower humid portion less heavily. To simulate the effect of wicking on the net reaction rate, an effective brine saturation, which includes a wicking saturation contribution, is used to calculate reaction rates rather than the actual brine saturation. To account for uncertainty in the wicking saturation contribution, this contribution was sampled from a uniform distribution that ranged from 0.0 to 1.0 for each BRAGFLO simulation in the analysis.

MASS.8 Gas Generation

This model represents the possible generation of gas in the repository by corrosion of steel and microbial degradation of cellulosics, plastics, and rubbers. Additional discussion of this topic may be found in Appendices WCA (Section WCA.5.1), BRAGFLO (Section 4.13), SOTERM (Section SOTERM.2.2), and SCR (Section SCR.2.5.1).

Gas will be produced in the repository by a variety of chemical reactions—principally those between brine, metals, microbes, cellulosics and similar materials, plastics, and rubber materials—and by liberation of dissolved gases to the gaseous phase. The processes assumed for long-term performance are anoxic corrosion of steel waste containers and metals in the waste and microbial degradation of cellulosics and, perhaps, plastics and rubbers in the waste.

Anoxic corrosion reactions between brine and steel are expected to occur and produce H_2; they are included in the conceptual model. Microbial degradation of cellulosics and perhaps, plastics and rubbers, might occur. If it does, it may produce various gases, primarily CH_4 and CO_2. However, by reaction with the MgO backfill that will be emplaced to control the chemistry of the repository, CO_2 produced by microbial degradation will be rapidly removed from the gaseous phase (see Appendix SOTERM, Section SOTERM.2.2.2, and Chapter 6.0, Section 6.4.3.4). Other gases such as N_2 and H_2S produced by microbial degradation are insignificant in quantity (see Attachment 8-1). Thus the conceptual model for gas generation is that anoxic corrosion of steel will produce H_2; microbial degradation of cellulosics, plastics, and rubbers might occur and might produce other gases, but any CO_2 produced is rapidly removed by reaction with MgO backfill.

In the conceptual model, the rate of gas production in the repository by anoxic corrosion can be limited by several factors. Anoxic corrosion cannot occur unless brine (water) is present and in contact with steel. The corrosion rate is assumed to be dependent on brine saturation. Because anoxic corrosion consumes steel, the rate of gas production can be limited by the quantity of steel left in the repository. Because corrosion is a surface reaction, it proceeds at quantifiable rates per unit surface area of steel. In addition, anoxic corrosion consumes water. Because of these factors, the rate of gas generation in the repository can vary through time as conditions change. It is assumed that anoxic corrosion can occur in the repository as soon as the shafts are sealed.

Microbial degradation of cellulosics, plastics, and rubbers is limited by several factors, chiefly the long-term viability of microbes in the repository. Whether microbes degrade plastics and rubbers is also important. The rate of microbial degradation is dependent on brine saturation. Because of uncertainty, however, it is assumed that there is no effect of microbial degradation on brine (water) content in the repository.

A limited quantity of O_2 will be trapped in the panels after repository closure. However, this O_2 will be consumed quickly by both oxic corrosion and microbial degradation, and the reducing environment will be dominant in the repository over 10,000 years. The contribution of oxic corrosion and biodegradation to overall gas production is negligible. Thus, oxic reactions are not considered in the conceptual model for gas generation.

Addition of an MgO backfill significantly reduces the impact of microbial generation of CO_2 (see Attachment 8-2). As discussed in Section 6.4.3.4, the MgO backfill will react with carbon dioxide produced by microbial degradation and remove it from the gaseous phase.

Because the conceptual model discusses the general processes and interactions assumed to occur without direct reference to the mathematical equations used, no parameters are defined by this conceptual model. The mathematical model used to implement it, the average stoichiometry model, is discussed in Section 6.4.3.3 and Attachment 8-2. The most important parameter in the average stoichiometry model is the rate at which gas generation occurs with brine and steel present, because this is the principal control on the total quantity of gas

generated. The assumptions made about the principal reactions and their stoichiometry are also important, however, because they affect the quantity of gas created per unit quantity of steel and water reacted.

The feedback between the gas generation conceptual model and the repository fluid flow conceptual model is important to understand. Gas generation cannot continue for long with the low initial quantity of liquid present in the waste, as specified by waste acceptance criteria. For gas generation to occur, brine must flow into the repository; for gas generation to be sustained, brine consumed by gas generation must be replenished. Gas generation, however, tends to increase repository pressure and keep brine from flowing into it. Thus the rates at which various processes proceed are important in determining the conditions of the repository. There is important feedback as well between the gas generation model and other conceptual models through pressure effects, such as those calculating creep closure (Section 6.4.3.1), interbed fracturing (Section 6.4.5.2), two-phase flow (Section 6.4.3.2), and the radionuclide release associated with spalling and direct brine release during an inadvertent drilling intrusion (Section 6.4.7).

Single-process laboratory studies of anoxic corrosion of steels and Al-based materials by R. E. Westerman and his colleagues at Pacific Northwest Laboratory (PNL) from November 1989 through September 1995 have shown that the factor with the greatest effect on the rate of H_2 generation by anoxic corrosion is the quantity of brine in WIPP disposal rooms (Attachment 8-2). This is because anoxic corrosion occurs rapidly under inundated conditions, but not at all under humid conditions. The pressure difference between WIPP disposal rooms and the far field and the porosity of the room contents also affect the extent of brine inflow and outflow and, hence, the anoxic-corrosion rate. Because the average stoichiometry model is incorporated in BRAGFLO, gas generation is coupled with brine and gas inflow and outflow. Moreover, because BRAGFLO uses a porosity surface to simulate room closure (Butcher and Mendenhall 1993), it also couples gas generation to room closure. Telander and Westerman (1993) and subsequent studies of anoxic corrosion at PNL have shown that pH, pressure, and the composition of the gaseous phase also affect the H_2-generation rate.

The greatest uncertainty in modeling gas generation in WIPP disposal rooms is whether microbial gas generation will occur and, if so, to what extent it will occur and what its effects will be. The following sources of microbial uncertainty have been described:

- whether microorganisms capable of carrying out the potentially significant respiratory pathways identified by Brush (1990) (denitrification, SO_4^{2-} reduction, and methanogenesis) will be present when the repository is filled and sealed,

- whether these microbes will survive for a significant fraction of the 10,000-year period of performance of the repository,

- whether sufficient H_2O will be present in the waste or brine,

- whether sufficient electron acceptors (oxidants) will be present and available,
- whether enough nutrients, especially N and P, will be present and available,
- whether microbes will consume significant quantities of plastics and rubbers during the 10,000-year period of performance of the repository, and
- the stoichiometry of the overall reaction for each significant respiratory pathway, especially the number of moles of electron acceptors, nutrients, gases, and H_2O consumed or produced per mole of substrate consumed.

With regard to the first five of these uncertainties, it has been concluded that, although significant microbial gas production is possible, it is by no means certain. Therefore, it has been estimated that significant microbial gas generation in WIPP disposal rooms will occur half of the time; and in half of the cases that significant microbial degradation occurs, microbes will consume all of the plastics and rubbers in the repository after they consume all of the cellulosics (Attachment 8-3).

Single-process laboratory studies of microbial consumption of cellulosics by A.J. Francis and his colleagues at Brookhaven National Laboratory from May 1991 through September 1995 showed that if significant microbial activity occurs, the factor with the greatest effect on the microbial gas-generation rate is the quantity of brine in the repository (see Francis and Gillow 1994; Attachment 8-2). This is because microbial gas generation occurs rapidly under inundated conditions, but at much lower rates under humid conditions. Francis and Gillow (1994) also found that inoculation with halophilic microbes from the WIPP site and nearby lakes, amendment with NO_3^- (an electron acceptor), amendment with nutrients, and addition of bentonite (a previously proposed backfill material) affect the rate or extent of microbial gas generation. Other factors that could affect the rate or extent of microbial gas generation, but which Francis and Gillow (1994) did not quantify, are the pH; the dissolved or suspended concentrations of actinides or other heavy metals, which could inhibit or preclude microbial activity; and the concentrations of microbial byproducts, which could inhibit or preclude additional microbial activity. High pressure will not preclude or even inhibit microbial activity significantly, even when it increases to 150 atmospheres (lithostatic pressure at the depth of the repository).

Data summarized by Molecke (1979) imply that radiolysis of cellulosics, plastics, and rubbers will not be a significant, long-term gas-generation process in WIPP disposal rooms. (Radiolysis here refers to α radiolysis, the breaking of chemical bonds by α particles emitted during the radioactive decay of the actinide elements in TRU waste. Because molecular dissociation caused by other types of radiation will be insignificant in a TRU-waste repository such as the WIPP, this discussion considers only α radiolysis.) Based on calculations using the results of laboratory studies of brine radiolysis carried out for the WIPP by Reed et al. (1993) on estimates of the quantities of brine that could be present in the repository after filling and sealing, and on estimates of the solubilities of Pu, Am, Np, Th, and U summarized

by Trauth et al. (1992), it was concluded that radiolysis of H_2O will not significantly affect the overall gas or H_2O content of the repository (see Appendix SCR, Section SCR.2.5.1.3.1).

MASS.8.1 Historical Context of Gas Generation Modeling

The DOE performed laboratory studies of gas generation during the late 1970s to support the development of TRU waste acceptance criteria (Molecke 1978, 1979; Sandia National Laboratories 1979). For the most part, these laboratory studies comprised single-process experiments (one gas-generation process studied at a time) on microbial activity and radiolysis with nonradioactive and some radioactive simulated TRU waste. There was very little work on anoxic corrosion. Based on laboratory measurements on samples obtained by drilling from the surface, the permeability of the Salado appeared to be high enough for rapid migration of gas from the repository, even given the highest gas-generation rates summarized by Molecke (1979). Therefore, the DOE concluded that further studies of gas generation were unnecessary.

In 1987, preliminary performance assessment calculations on the effects of human intrusion identified inflow of intergranular Salado brine as a concern for the long-term performance of the repository. In early 1988, the DOE began to examine the possible effects of processes such as anoxic corrosion of steels and microbial degradation of cellulosics on the H_2O content of WIPP disposal rooms. Brush and Anderson (1989a) concluded that these processes could affect the H_2O content as significantly as brine inflow. Furthermore, they concluded that these processes could also produce significant quantities of gas. Meanwhile, in situ measurements in the WIPP underground workings revealed that the permeability of the Salado was much lower than believed in the late 1970s.

Systems analysis carried out by Lappin et al. (1989) to support the 1990 Supplemental Environmental Impact Statement, which used gas-generation assumptions from Brush and Anderson (1989a, 1989b, and 1989c), the rates-and-potentials gas-production model of Lappin et al. (1989), and new in situ permeabilities, demonstrated that gas would affect the overall performance of the repository if present in significant quantities.

Therefore, the DOE initiated laboratory studies of gas generation in February 1989. These studies have comprised mainly single-process experiments on anoxic corrosion, microbial activity, and radiolysis, mostly with nonradioactive, simulated CH-TRU waste (Brush 1990; Brush et al. 1991a, 1991b, 1993; Reed et al. 1993; Telander and Westerman 1993; Francis and Gillow 1994).

The DOE has also developed two additional gas-generation models since 1989. The WIPP Performance Assessment Division (1991) developed the average stoichiometry gas-generation model and incorporated it into BRAGFLO, which also simulates room closure. Incorporation of the average stoichiometry model into BRAGFLO thus coupled this gas-generation model with the hydrologic and geomechanical models used for performance assessment. The WIPP Performance Assessment Division (1991) and Brush et al. (1994) developed the average

stoichiometry and the reaction-path gas-generation models, respectively, based on the results of the single-process laboratory studies that were restarted in 1989. However, although these laboratory studies considered only one gas-generation process at a time (anoxic corrosion, microbial activity, or radiolysis), they did, at least to some extent, simulate some of the possible interactions between these processes. For example, the study of anoxic corrosion by Telander and Westerman (1993) considered the effects of the microbially produced gases CO_2 and H_2S on corrosion, and Brush et al. (1994) included passivation of steels and other Fe-based metals by CO_2 and H_2S in the reaction-path model.

Work began on the reaction-path gas-generation model in 1992, which includes more gas-generation processes than the average stoichiometry model and the interactions among these processes (Brush et al. 1994). It was recommended to replace the average stoichiometry model in BRAGFLO with the reaction-path model. However, in November 1995, the DOE decided to terminate all work on the reaction-path model and to continue to use the average stoichiometry model in BRAGFLO. The rationale for the decision is documented in Attachment 8-1. The main advantage of the reaction-path model relative to the average stoichiometry model is that the former includes passivation of steels by microbially produced CO_2 and H_2S. However, the results from laboratory studies of anoxic steel corrosion fail to support passivation of steels by CO_2. Therefore, the main advantage of the reaction-path model no longer exists. In addition, the experimental results show that anoxic steel corrosion does not stop at about 70 atm hydrogen pressure as predicted by the reaction-path model. Because of these reasons, the reaction-path model is not used in BRAGFLO calculations.

MASS. 9 Chemical Conditions

Topics in the models used for chemical conditions in the repository are discussed in Appendix SOTERM and Chapter 6.0 (Section 6.4.3.4).

MASS.10 Dissolved Actinide Source Term

Topics in the models used for the dissolved actinide source term in the repository are discussed in Appendix SOTERM, Chapter 6.0 (Section 6.4.3.5), and Appendix SCR (Sections SCR.2.5.2 and SCR.2.5.3).

MASS.11 Colloidal Actinide Source Term

Topics in the models used for the colloidal actinide source term are discussed in Appendix SOTERM (Section SOTERM.6) and Chapter 6.0 (Section 6.4.3.6).

MASS.12 Shafts and Shaft Seals

The conceptual model for the shafts and shaft seals used in the performance assessment has been chosen to provide a reasonable and realistic basis for simulating long-term fluid flow through the shaft seal system and to allow evaluation of the effect that uncertainty about the

long-term properties of the shaft seal system may have on cumulative radionuclide releases from the disposal system. The conceptual model is also discussed in Chapter 6.0 (Section 6.4.4) and Appendix SEAL (Section 2).

The conceptual model of the seals is based on results of detailed numerical models of the shaft seal system design. These models were developed to evaluate the performance of the shaft seal system under a range of conditions. Both fluid flow and structural response of the system have been evaluated. The principal uncertainties associated with the detailed models follow:

- reconsolidation of the crushed salt component,
- construction, permeability, and gas threshold pressure of the clay components, and
- damage, permeability, healing, and character of the Salado and Rustler disturbed rock zones.

These uncertainties are also present in the performance assessment model and have been accounted for in the values specified for seal parameters. The consequences of uncertainty in seal component performance were a primary motivation in the development of the proposed seal system design. Although there is uncertainty in many of the materials and models, the shaft will be completely filled with high density, low permeability materials. The use of multiple materials and components for each sealing function results in a robust system. Time dependency of the performance of seal components is incorporated directly into the model through temporal variation in seal properties.

The processes that can affect the performance of the shaft seals—structural, hydraulic, and coupled structural and hydrological—are discussed in some detail in Appendix SEAL (Sections 7 and 8). Evaluation of these issues required the use of existing structural and both single-and two-phase flow codes. In addition, development of conceptual and numerical models for crushed salt reconsolidation, the disturbed rock zone, and the shaft seal system was required. These models have been reviewed by independent, qualified experts, are well documented, and have been developed within an accepted quality assurance program. Codes used in the analyses include SPECTROM-32 (structural) (Callahan 1994), SWIFT II (single-phase flow) (Reeves et al. 1986), and TOUGH2 (multi-phase flow) (Pruess 1991). These codes were selected for their capability to simulate the processes thought to affect seal performance. They are also well-documented, accepted, and widely used within the scientific community. The codes were modified to implement the conceptual models specific to the seals, and these modifications were made within a program that establishes criteria for assuring software quality.

The BRAGFLO model of the seal system requires consistency with parameters associated with the surrounding system. For example, the permeability of the crushed salt component should always be greater than or equal to that of the intact halite. Similarly, the calculation of the effective halite DRZ permeability requires the permeability of intact halite as input. As

discussed in Appendix SEAL (Section 1.4), procedures in performance assessment have been implemented to ensure these parameter consistency concerns are met.

MASS.12.1 Historical Development of the Shaft Seals

The four shafts into the repository will be sealed after completion of disposal activities at the WIPP. The shaft seal system design has evolved over time (Stormont 1988; Nowak et al. 1990; DOE 1995). The Initial Reference Seal System Design proposed a two component design to achieve a sealing strategy with two phases: concrete and clay seals formed a short-term seal, and a crushed salt seal formed long-term protection. The use of native rock (that is, crushed salt) as a permanent sealing material is considered the most effective means to eliminate the shafts as a preferred pathway for migration of hazardous constituents. Because some interim period must pass for the crushed salt to reconsolidate to sufficiently high densities, short-term seals were proposed as a means to prevent fluid migration during the interim. Estimates of this interim period ranged from 100 to 200 years.

Seal design changes and refinements have been incorporated into the conceptual model of the seals used by the DOE (Bertram-Howery et al. 1990; WIPP Performance Assessment Department 1991; Sandia WIPP Project 1992). Performance assessments conducted prior to 1992 addressed general sealing issues but did not include specific seal components.

Results of the scoping calculations using the DCCA model demonstrated that low-permeability materials were required for the shaft seals (DOE 1995, Appendix D). However, the simplicity of the conceptual model limited the applicability of results to the detailed seal system design.

The shaft seal design for the WIPP is presented in Appendix SEAL (Sections 4 and 5).

MASS.13 Salado

The purpose of this model is to reasonably represent the effects of fluid flow in the Salado on long-term performance of the disposal system. The conceptual model is also discussed in Chapter 6.0 (Section 6.4.5).

Fluid flow in the Salado is considered in the conceptual model of long-term disposal system performance for several reasons. First, some liquid could move from the Salado to the repository because of the considerable gradients that can form for liquid flow inward to the repository. This possibility is important because such fluid can interact with creep closure, gas generation, actinide solubility, and other processes occurring in the repository. Second, gas generated in the repository is thought to be capable of fracturing the Salado interbeds under certain conditions, creating increased permeability channels that could be pathways for lateral transport. The pathway of lateral transport in intact Salado is also modeled, but it is considered unlikely to result in any significant radionuclide transport to the accessible environment boundary.

The fundamental principle in the conceptual model for fluid flow in the Salado is that it is a porous medium within which gas and brine can be both present and mobile (two-phase flow), governed by conservation of energy and mass, and by Darcy's Law for their fluxes (see Appendix BRAGFLO, Sections 4.1 through 4.4). Consistent with typical concepts of two-phase flow, each phase can affect the other by impeding flow because of partial saturation (relative permeability effects) and by affecting pressure by capillary forces (capillary pressure effects). It is assumed that no waste-generated gas is present initially, but gas can enter the interbeds. It is expected that the low permeability of impure and pure halite intervals of the Salado will prevent gas from penetrating because of the expected high capillary pressure for these units.

Some variability in composition exists between different horizons of the Salado. The largest differences occur between the anhydrite-rich layers called interbeds and those dominated by halite. Within horizons dominated by halite, composition varies from nearly pure halite to halite plus several percent other minerals, in some instances including clay (see Chapter 2.0, Section 2.1.3.4). The Salado is modeled as impure halite except for those interbeds that intersect the DRZ near the repository. This conceptual model and an alternative model that explicitly represented all stratigraphically distinct layers of the Salado near the repository (Christian-Frear and Webb 1996) produced similar results.

From other modeling and theoretical considerations, flow between the Salado and the repository is expected to occur primarily through interbeds that intersect the DRZ. Because of the large surface areas between the interbeds and surrounding halite, the interbeds serve as conduits for the flow of brine in two directions: from halite to interbeds to the repository, or, for brine flowing out of the repository, from the repository into interbeds and then into halite. Because the repository is modeled as a relatively porous and permeable region, brine is considered most likely (but not constrained) to leave the repository through MB139 below the repository because of the effect of gravity. Gas is considered most likely (but not constrained) to leave the repository through anhydrite interbeds above the repository.

The effect of gravity may also be important in the Salado because of the slight and variable natural stratigraphic dip. For long-term performance modeling, the dip in the Salado within the domain is taken to be constant and 1 degree from the north to south.

Fluid flow in the Salado is conceptualized as occurring either convergently upon the repository, or divergently from it, as discussed in detail in Section 6.4.2.1. Because the repository is not conceptualized as homogeneous, implementing a geometry for the conceptual model of convergent or divergent flow in the Salado is somewhat complicated and is discussed in Section 6.4.2.1.

The conceptual model for Salado fluid flow has primary interactions with three other conceptual models. The interbed fracture conceptual model allows porosity and permeability of the interbeds to increase as a function of pressure. The repository fluid flow model is directly coupled to the Salado fluid flow model by the governing equations of flow in

BRAGFLO (in the governing equations of the mathematical model, they cannot be distinguished), and it differs only in the region modeled and the parameters assigned to materials. The Salado model for actinide transport is directly coupled to the conceptual model for flow in the Salado through the process of advection.

MASS.13.1 High Threshold Pressure for Halite-Rich Salado Rock Units

A parameter used to describe the effects of two-phase flow is threshold pressure. The threshold pressure is important because it helps determine the ease with which gas can enter a liquid-saturated rock unit. For a brine-saturated rock, the threshold pressure is defined as "equal to the capillary pressure at which the relative permeability to the gas phase begins to rise from its zero value, corresponding to the incipient development of interconnected gas flow paths through the pore network" (Davies 1991, 9).

The threshold pressure, as well as other parameters used to describe two-phase characteristics, has not been measured for halite-rich rocks of the Salado. The Salado, however, is thought to be similar in pore structure to rocks for which threshold pressures have been measured (Davies 1991). Based on this observation, Davies (1991) postulated that the threshold pressure of the halite-rich rocks in the Salado could be estimated if an empirical correlation exists between rocks postulated to have similar pore structure.

Davies developed a correlation between threshold pressure and intrinsic permeability applicable to the Salado halites. (A similar correlation was developed for Salado anhydrites; subsequent testing confirmed that the correlation predicted threshold pressures accurately.) The correlation developed by Davies predicts threshold pressures in intact Salado halites on the order of 20 megapascals or greater (Davies 1991). This threshold pressure predicted by correlation is so high that for all practical and predictive purposes, no gas will flow into intact Salado halites (see Section 6.4.5.1).

Because threshold pressure helps control the flow of gas, and because the greatest volume of rock in the Salado is rich in halite, a high threshold pressure effectively limits the volume of gas that can be accommodated in the pore spaces of the host formation. Thus high threshold pressure is considered conservative as well as realistic, because if gas could flow into the pore spaces of Salado halite, repository pressures could be reduced dramatically.

MASS.13.2 Historical Context of the Salado Conceptual Model

In the 1980 FEIS (documented in Lappin et al. 1989, Table 1-1, 1-7 to 1-8), the Salado was assumed to be a confining bed, containing no circulating groundwater (Lappin et al. 1989, 7 – 87). Brine was thought to be present only in fluid inclusions and hydrous minerals and was assumed not to be present along grain boundaries. Gas permeability was estimated to be adequate to dissipate the volumes of gas potentially generated by the waste. There was no explicit recognition of any differing hydrologic role for the nonhalite interbeds.

Based on the results of early in situ permeability testing, the conceptual model of the Salado had changed by the time of publication of Lappin et al. (1989, Table 1-1, 1-7 to 1-8). Grain boundary brines were known to be present and were distinct compositionally from fluid inclusions. The Salado was interpreted to be brine saturated. The major contribution to fluid flow was interpreted to be movement of grain-boundary fluids, as a result of pore pressure gradients resulting from excavation. Darcy flow, assuming atmospheric boundary conditions within the repository (which was all that could be modeled at the time), probably over-predicted brine inflow. Far-field permeability (not distinguished between halites and anhydrites) was thought to be less than 10^{-21} to 10^{-22} square meters and possibly even effectively zero in undisturbed regions. Because gas would have to displace brines in the Salado, dissipation of significant volumes of gas would be difficult. The combination of gas-generation rates and low permeability would have led to pressures exceeding lithostatic unless these pressures were relieved: numerical models for altered anhydrites did not exist at that time. Except at seal locations, MB139 was thought to be a relatively high-permeability flow path directly under the excavations because of the development of open excavation-related fractures.

In the preliminary performance assessment completed in December 1992 (WIPP Performance Assessment Department 1992, 2-41 to 2-45), anhydrite interbeds provided the dominant pathway for fluid migration because of their relatively high permeability. New test data indicated permeabilities of 10^{-16} to 10^{-21} square meters for anhydrites and 10^{-20} to 10^{-24} square meters for halite. (The DOE interpreted the low ends of these ranges to be far-field permeabilities and the higher ends to results from excavation effects; see Sandia WIPP Project 1992, 2-56 to 2-57). It was newly recognized that there would be coupling between fluid flow, creep closure, and brine-dependent gas generation. No altered-anhydrite model was implemented in this preliminary performance assessment.

In 1994, the DOE concluded that the regional 1-degree stratigraphic dip could have an effect on fluid flow into and out of the repository. An altered-anhydrite model for interbed fracture under elevated gas pressures was implemented. Flow simulations incorporating detailed stratigraphy confirmed that simplifications considering only a lumped impure halite were adequate (Christian-Frear and Webb 1996). The potential for preferential brine outflow caused by channeling, fingering, updip flow, or fracturing was also recognized. Concern about the adequacy of the two-dimensional modeling simplification to provide reasonable estimates of three-dimensional brine inflow and outflow was thought to be potentially important, because of the addition of both dip and altered-anhydrite fracturing models. These concerns led to a number of modeling and analysis efforts to investigate the adequacy of performance assessment assumptions.

In 1995 and 1996, final analyses of the Room Q experiments showed experimental results to be consistent with a Darcy flow model.

MASS.13.3 The Anhydrite Interbed Fracture Model

The purpose of this model is to alter the porosity and permeability of the anhydrite interbeds if their pressure approaches lithostatic, simulating some of the hydraulic effects of fractures with the intent that unrealistically high pressures (much in excess of lithostatic) do not occur in the repository or disposal system. The conceptual model is also discussed in Section 6.4.5.2.

In the 1992 preliminary performance assessment, repository pressures were shown to greatly exceed lithostatic pressure if a large quantity of gas was generated. Pressures within the waste repository and surrounding regions were predicted to be roughly 20 to 25 megapascals. It was expected that fracturing within the anhydrite marker beds would occur at pressures slightly below lithostatic pressure. An expert panel on fractures was convened to develop the conceptual bases for the fracturing within the anhydrite marker beds.

The porosity and permeability increases are conceptualized as occurring vertically throughout the affected interbed; in other words, throughout the porous medium as a whole rather than on discrete portions. This simplification facilitates numerical implementation and execution.

Two parametric behaviors must be quantified in the conceptual model. First, the change of porosity with pressure in the anhydrite marker beds must be specified. This is done with a relatively simple equation, described in Appendix BRAGFLO (Section 4.10), that relates porosity change to pressure change using an assumption that the fracturing can be thought of as increasing the compressibility of interbeds. Parameters in the model are treated as fitting parameters and have little relation to physical behavior except that they affect the porosity change. The second parametric behavior is the change of permeability with pressure, which is incorporated by a functional dependence on the porosity change. It is assumed that a power function is appropriate for relating the magnitude of permeability increase to the magnitude of porosity increase. The parameter in this power function, an exponent, is also treated as a fitting parameter and can be set so that the behavior of permeability increase with porosity increase fits the desired behavior.

The fracture enhancement model assumes fracture propagation is uniform in the lateral direction to flow within the marker beds in the absence of dip. The 1-degree dip modeled in BRAGFLO may affect fracture propagation direction. That is, within the accuracy of the finite difference grid, a fracture will develop radially outward. This would not account for fracture fingering or a preferential fracturing direction; however, no existing evidence supports heterogeneous anhydrite properties that would contribute to preferential fracture propagation. This evidence is discussed in Attachment 13-2.

The maximum enhanced fracture porosity controls the storativity within the fracture. The extent of the migration of the gas front into the marker bed is sensitive to this storativity. The additional storativity caused by porosity enhancement will mitigate gas migration within the marker bed. The enhancement of permeability by marker-bed fracturing will make the gas more mobile and will contribute to longer gas-migration distances. Thus the effects of

porosity enhancement at least partially counteract the effects of permeability enhancement in affecting the gas-migration distances.

Because intact anhydrite is partially fractured, the pressure at which porosity or permeability changes are initiated is close to the initial pressure within the anhydrite. The fracture treatment within the marker beds will not contribute to early brine drainage from the marker bed, because the pressures at these times are below the fracture initiation pressure.

The input data to the interbed fracture model (see Appendix PAR, Table PAR-36) were chosen deterministically to produce the appropriate pressure and porosity response as predicted by a linear elastic fracture mechanics (LEFM) model, as discussed in Mendenhall and Gerstle (1993). Results from this performance assessment show that repository pressures do not exceed the full fracture pressure of approximately 16.5 megapascals, a value slightly higher than lithostatic pressure.

MASS.13.4 Flow in the Disturbed Rock Zone

The conceptual model for the DRZ around the waste disposal, operations, and experimental regions has been chosen to provide a reasonably conservative estimate of fluid flow between the repository and the intact halite and anhydrite marker beds. The conceptual model is also discussed in Section 6.4.5.3 of this application.

The conceptual model implemented in the performance assessment uses values for the permeability and porosity of the DRZ that do not vary with time. A screening analysis examined an alternative conceptual model for the DRZ in which permeability and porosity changed dynamically in response to changes in pressure (Vaughn et al. 1995). This analysis implemented a fracturing model in BRAGFLO for the DRZ. This fracturing model is identical to the existing anhydrite interbed alteration model. In this model, formation permeability and porosity depend on brine pressure as described by Freeze et al. (1995, 2-16 to 2-19) and Appendix BRAGFLO (Section 4.10). This model permits the representation of two important formation alteration effects. First, pressure build-up caused by gas generation and creep closure within the waste will slightly increase porosity within the DRZ and offer additional fluid storage with lower pressures. Second, the accompanying increase in formation permeability will enhance fluid flow away from the DRZ. Because an increase in porosity tends to reduce outflow into the far field, parameter values for this analysis were selected so that the DRZ alteration model greatly increases permeability while only modestly increasing porosity.

Two basic scenarios were considered in the screening analysis by Vaughn et al. (1995), undisturbed performance and disturbed performance. Both scenarios included a 1-degree formation dip downward to the south. Intrusion event E1 is considered in the disturbed scenario and consists of a borehole that penetrates the repository and pressurized brine in the underlying Castile. Two variations of intrusion event E1 were examined, E1 updip and E1 downdip. In the E1 updip event, the intruded panel region was located on the updip (north)

end of the waste disposal region, whereas in the E1 downdip event, the intruded panel region is located on the downdip (south) end of the disposal region. These two different geometries permitted evaluation of the possibility of increased brine flow into the panel region caused by higher brine saturations downdip from the borehole and the potential for subsequent impacts on contaminant migration. To incorporate the effects of uncertainty in each case (E1 updip, E1 downdip, and undisturbed), a Latin hypercube sample size of 20 was used, for a total of 60 simulations. To assess the sensitivity of system performance on formation alteration of the DRZ, conditional CCDFs of normalized contaminated brine releases were constructed and compared with the corresponding baseline model conditional CCDFs that were computed with constant DRZ permeability and porosity values. Based on comparisons between conditional CCDFs, computed releases to the accessible environment were determined to be essentially equivalent between the two treatments.

Preliminary performance assessments considered alternative conceptual models that allowed for some lateral extent of the DRZ into the halite surrounding the waste disposal region and for the development of a transition zone between anhydrites a and b and MB138 (WIPP Performance Assessment Department 1993, Figures 4.1-2 and 5.1.2; Davies et al. 1993; Gorham et al. 1992). The transition zone was envisioned as a region that had experienced some hydraulic depressurization and perhaps some elastic stress relief because of the excavation, but probably no irreversible rock damage and no large permeability changes. Modeling results indicated that including the lateral extent of the DRZ had no significant effect on fluid flow. Communication vertically to MB138 was a potentially important process, however, and the model adopted for the performance assessment conservatively assumes that the DRZ extends upward to MB138 without an intervening transition zone.

MASS.13.5 Actinide Transport in the Salado

The purpose of this model is to represent the transport of actinides in the Salado. This model is also discussed in Section 6.4.5.4.

Actinide transport in the Salado is conceptualized as occurring only by advection through the porous medium described in the Salado hydrology conceptual model. Advection is the movement of material with the bulk flow of fluid. Other processes that might disperse actinides, such as diffusion, hydrodynamic dispersion, and channeling in discrete fractures, are not included in the conceptual model.

Advection is a direct function of fluid flow, which is discussed in the conceptual model for Salado fluid flow.

This application of NUTS treats the transport of radionuclides within all the regions for which BRAGFLO computes brine and gas flow. The brine must pass through some part of the repository at some period in its history to become contaminated. While there, it is assumed to acquire radioactive constituents, which it then transports by advection to other regions outside the repository. NUTS uses BRAGFLO's velocity field, pressures, porosities, saturations, and other model parameters (including geometrical grid, residual saturation, material map, brine

compressibility, and time step) averaged over a given number of time steps (20 for this performance assessment calculation), which it takes as input for its transport calculations. Consequently, the results of NUTS are subject to all the uncertainties associated with BRAGFLO's conceptual model and parameterization, which will not be repeated here. Details of the source term are discussed in Appendix SOTERM.

This application of NUTS disregards sorptive and other retarding effects throughout the entire flow region, even though retardation must occur at some level within the repository, the marker beds, and the anhydrite interbeds, and especially in zones with clay layers or clay as accessory minerals.

This application of NUTS neglects molecular dispersion, which leads to uncertainty. For materials of interest in the WIPP repository system, molecular diffusion coefficients are at a maximum on the order of 4×10^{-10} square meters per second. Thus, the simplest scaling argument using a time scale of 10,000 years leads to a molecular diffusion (that is, mixing) length scale of approximately 33 feet (10 meters), which is negligible compared to the lateral advection length scale of roughly 7,874 feet (2,400 meters) (the lateral distance from the repository to the accessible environment).

This application of NUTS also neglects mechanical dispersion, which leads to additional uncertainty (see Section 6.4.5.4.2). Dispersion is quantified by dispersivities, which are empirical (tensor) factors that are proportional to flow velocity (to within geometrical factors related to flow direction). They account for both the downstream and cross-stream spreading of local extreme values in concentration of dissolved constituents. Physically, the spreading is caused by the fact that both the particle paths and velocity histories of once-neighboring particles can be vastly different because of material heterogeneities characterized by permeability variations. These variations arise from the irregular cross-sectional areas and tortuous nonhomogeneous, nonisotropic connectivity between pores. Because of its velocity dependence, the transverse component of mechanical dispersivity tends to transport dissolved constituents from regions of relatively rapid flow (where mechanical dispersion has a larger effect) to regions of slower flow (where mechanical dispersion has a smaller effect). In the downstream direction, dispersivity merely spreads constituents in the flow direction. Conceptually, ignoring lateral spreading assures that dissolved constituents will remain in the rapid part of the flow field, which assures their transport toward the boundary. Similarly, ignoring longitudinal dispersivity ignores the elongation of a feature in the flow direction, which ignores foreshortening (or lengthening) of arrival times. However, because the EPA release limits are time-integrated measures, the exact times of arrival are unimportant for constituents that arrive at the accessible environment within the assessment period (10,000 years).

Advection is therefore the only transport mechanism considered important, which underscores NUTS' reliance on BRAGFLO. Because the Darcy flows are given to NUTS as input, the maximum solubility limits for combined dissolved and colloidal components are the most important NUTS parameters. They are described in Appendix SOTERM (Section SOTERM.7).

MASS.14 Geologic Units above the Salado

The model for geologic units above the Salado was developed to provide a reasonable and realistic basis for simulations of fluid flow within the disposal system and detailed simulations of groundwater flow and radionuclide transport in the Culebra. The conceptual model for these units is also discussed in Chapter 6.0 (Section 6.4.6) of this application.

The conceptual model used in performance assessment for the geologic units above the Salado is based on the overall concept of a groundwater basin, as introduced in Chapter 2.0 (Section 2.2.1.1) of this application, and developed further in Section MASS.14.2. The computer code SECOFL3D was used to evaluate the effect on regional-scale fluid flow by recharge and rock properties in the groundwater basin above the Salado. However, simpler models for this region are implemented in codes used in performance assessment. For example, in the BRAGFLO model, layer thicknesses, important material properties including porosity and permeability, and hydrologic properties such as pressure and initial fluid saturation are specified, but the model geometry and boundary conditions are not suited to groundwater basin modeling (nor is the BRAGFLO model used to make inferences about groundwater flow in the units above the Salado). In performance assessment the Culebra is the only subsurface pathway modeled for radionuclide transport above the Salado, although the groundwater basin conceptual model includes other flow interactions. The Culebra model implemented in performance assessment includes spatial variability in hydraulic conductivity and uncertainty and variability in physical and chemical transport processes. Thus, the geometries and properties of units in the different models applied to the units above the Salado by the DOE are chosen to be consistent with the purpose of the model.

The groundwater basin model incorporated into the code SECOFL3D is the most general and least limited model available to the DOE for investigating how fluid flow in the units above the Salado is affected by variation in regional rock properties, basin geometries, and boundary conditions (including recharge changes and climate change). This code is used for calculations in support of this application but not in performance assessment *per se*. Studies performed with this code provide support for the performance assessment assumption of a confined Culebra and quantify the possible effects of future change in climate on the performance of the WIPP.

The SECOFL2D and SECOTP2D codes are used directly in performance assessment to model fluid flow and transport in the Culebra. The assumptions made in these codes are discussed in Section 6.4.6.2 and Section MASS.15.

With respect to the units above the Salado, the BRAGFLO model is used only for determination of fluid fluxes between the shaft or intrusion borehole and hydrostratigraphic units. For this purpose, it does not need to resolve regional or local flow characteristics.

The basic stratigraphy and hydrology of the units above the Salado are described in Sections 2.1.3.5 through 2.1.3.10, and Section 2.2.1.4, respectively. Additional supporting

information is contained in Appendices GCR, HYDRO, and SUM. Details of the conceptual model for each unit are described in Sections 6.4.6.1 through 6.4.6.7.

MASS.14.1 Historical Context of the Units above the Salado Model

The model used in the WIPP FEIS in 1980 (documented in Lappin et al. 1989, Table 1-1, 1-14 to 1-16) recognized three water-bearing zones within the Rustler, that is, the Magenta, Culebra, and the Rustler-Salado-interface (Lappin et al. 1989, 7 – 87). The Culebra and Magenta, although known to be separate units, were combined for regional-scale transport modeling into a Rustler aquifer and assigned a uniform hydraulic conductivity, except in Nash Draw. In the modeling, the Rustler aquifer was assumed to be an isotropic porous medium with a uniform porosity of 0.10 (Lappin et al. 1989, Table K-2, K-18). Regional flow was assumed to be toward the southwest, with discharge at Malaga Bend on the Pecos River. Numerical modeling was not able to consider the possible impact of variations in brine density within the Rustler; instead, modeling used an equivalent freshwater head. Steady-state flow directions and rates were assumed. Fluid flow in units above the Rustler was not considered because the limited available information suggested that these units were unsaturated. Units below the Castile were assumed to have no effect on performance and were not included in the analysis.

Several developments had taken place by 1989 (Lappin et al. 1989). Most importantly, interest in fluid flow within the Rustler became strongly focused on the Culebra. The Culebra is at least one order of magnitude more permeable than the Magenta, except in Nash Draw. Modeling by Barr et al. (1983) showed no potential for significant transport or fluid movement through the Magenta, and none of the hydraulic tests in the Magenta shows anything but porous-medium behavior. All other units within the Rustler (unnamed lower member, Tamarisk, Forty-niner) were even less permeable than the Magenta. Testing at DOE-2 had shown that permeability of the lower Dewey Lake was significantly lower than in the Magenta (Beauheim 1986). In the Draft Supplemental Environmental Impact Statement (DSEIS) (DOE 1989) and the December 1992 preliminary performance assessment calculations, all fluid flow and transport was assumed to be concentrated in the Culebra; this was thought to be a conservative approach because it did not allow flow in units in which release to the accessible environment was not possible.

Other important changes were in place by 1989. The potential for vertical fluid flow within the Rustler was recognized, on the basis of limited data, although for flow and transport calculations, the Culebra was assumed to be perfectly confined. Long-term flow transients within the system, related to climate change, were considered to be likely. Finally, the possibility of vertical fluid flow in an open borehole between the Rustler and the Bell Canyon was considered, but it was concluded that such fluid flow would be directed downward and was therefore of no physical or regulatory concern (Lappin et al. 1989).

Use of the groundwater basin conceptual model to gain an understanding of regional flow in the units above the Salado was initiated in a modeling study performed by Davies (1989). He

selected boundaries to coincide with hydrologic features and used geologic data to infer hydraulic conductivity values for areas in which conductivity measurements were not available. Recognizing the three-dimensional nature of the regional groundwater system, Davies oriented two-dimensional simulations in both vertical and horizontal planes. The vertically oriented simulations were performed because it was recognized that the transient nature of the system is related to movement of the water table and the consequent change in the amount of water stored in the rocks. Davies confirmed that the hypothesis that the modern-day flow system might be a transient response to recharge during the last glacial pluvial period (Lambert 1987; Lambert and Carter 1987; Lambert and Harvey 1987) is physically possible. He also concluded that as much as 25 percent of the total inflow to the Culebra could be entering as vertical flux, and that fluid pressures in the Culebra are less than hydrostatic because the Culebra is well connected to the discharge area and poorly connected to the source of recharge. He suggested that the results of his study could be expanded by, among other things, using a fully three-dimensional approach and additional study of the role of long-term transient changes in flow.

As a first step in extending the work of Davies, Corbet and Wallace (1993) developed a fully three-dimensional model with an adaptive upper boundary condition to approximately simulate movement of the water table. These simulations were performed using a version of the United States Geological Survey (USGS) code MODFLOW (McDonald and Harbaugh 1988) that was modified to include seepage faces. The modified MODFLOW model was limited in its capabilities in that it only approximately calculated the position of the water table and did not account for lateral variations in hydraulic conductivity. Nonetheless, the simulation results provided the first information about possible recharge rates at a regional scale and the sensitivity of groundwater flow patterns to changes in recharge. Specifically, the results suggested that rates of recharge to the saturated zone do not exceed several millimeters per year and that flow patterns in confined units are sensitive to small changes, perhaps only a few tenths of a millimeter per year, in rates of recharge.

A new numerical code, SECOFL3D (Knupp 1996), was used to perform the most recent three-dimensional simulations (Corbet 1994; Corbet and Swift 1996 [see Attachment 17-1]). The algorithm implements a rigorous treatment of the free-surface and seepage-face boundary conditions (Bear and Verruijt 1987; Dagan 1989; de Marsily 1986) and is designed to be robust even if extremely large contrasts in hydraulic conductivity are present within the model domain. A moving mesh that adaptively deforms so that its upper surface conforms to the moving water table is used to ensure that the entire computational domain remains saturated.

MASS.14.2 Groundwater-Basin Conceptual Model

The conceptual model that emerged from taking a groundwater-basin approach represents a significant advance in understanding (Section 2.2.1.1). It differs from previous conceptual models in that it includes a description of the geometry of the groundwater basin, the distribution of rock hydraulic properties, and the physical mechanisms that drive groundwater flow. Previous conceptual models were limited to describing current flow conditions. They

provided little basis to extrapolate backward or forward in time or to predict the impact of human-induced disturbances to the hydrologic system.

An objective of groundwater basin modeling was to use numerical simulations to enhance conceptual understanding of the hydrogeology of the Culebra in the context of regional groundwater flow (Corbet and Knupp 1996). A conceptual model is considered to be a qualitative description of the hydrologic processes, the geometry of the hydrogeologic system, the hydrostratigraphy, and the pattern of groundwater flow. In short, a conceptual model is an interpretation of reality. The rest of this section presents aspects of the conceptual model of groundwater flow in the Culebra that was formulated by integrating the previous conceptual understanding with the new information that these numerical simulations provided. Simulation results are incorporated without specifically identifying them as such.

Groundwater flow in the Culebra in the vicinity of the WIPP is a portion of a larger hydrologic system that includes the rock units that overlie the Salado. This system extends laterally well beyond the WIPP site to the boundaries of a groundwater basin. The basin boundary is not fixed in time; the basin is more extensive during dry periods in which the water table is at depth and less extensive during wet periods in which the water table is near to the land surface. The boundaries of the numerical model (Figure 2-29 in Chapter 2.0) approximately represent the basin boundaries for dry periods. These boundaries, therefore, outline the minimum region that must be considered to conceptually understand the evolution of modern-day flow conditions and their extrapolation into the future.

There is a continuous water table across the groundwater basin. It is probably in the Dewey Lake within the WIPP-site boundary. In places the hydraulic conductivity of the Dewey Lake is small enough that groundwater inflow to an open drill hole penetrating the saturated portion of this unit is too slow to be easily observed. It is also possible that some saturated portions of the Dewey Lake might be perched, that is, that they overlie an unsaturated region. Perched regions, if they exist, are part of the percolation process. They might affect the distribution of percolation at the water table but do not directly affect flow in the saturated zone.

A fundamental aspect of the conceptual model that has evolved from groundwater basin modeling is that the groundwater system is dynamic and is responding to the drying of the climate that has occurred since the end of the Pleistocene. Recharge rates at the end of the Pleistocene were sufficient to maintain the modeled water table near the land surface over much of the model domain. Groundwater flow, at that time, was controlled by the intermediate features of the land-surface topography. The gentle east to west slope of the land surface in the vicinity of the WIPP, for example, caused groundwater in the Culebra to flow toward and discharge into Nash Draw. As the amount of moisture available to recharge the groundwater system decreased after the last glacial pluvial period, the elevation of the water table declined. The decline occurred first in areas of high topography. As the water table dropped, groundwater flow began to increasingly reflect the land-surface topography at the scale of the entire groundwater basin. That is, the flow was away from the areas along the north and north-east boundaries of the basin where land-surface elevations are greater than

3,609 feet (1,100 meters) and toward areas below 2,789 feet (850 meters) in the Pecos River valley along the south boundary of the basin.

Dissolution of the upper Salado and associated processes has generated a zoned distribution of hydraulic conductivity at the basin scale. Hydraulic conductivities in the region in which dissolution is assumed to have disrupted stratigraphic layering (zone 1 of Figure MASS-3) are orders of magnitude larger than the region in which the strata are intact (zone 4). A transition interval separates these regions. Flow magnitudes and directions are quite different in these regions. Lateral flow in the intact strata is slow and, regardless of the elevation of the water table, is directed toward the disrupted region in areas that are within about a kilometer of the transition interval. In contrast, flow in the disrupted region is relatively rapid and its direction depends on the elevation of the water table. Flow is toward topographic depressions along the west and south boundaries of the model domain if the water table is near the land surface. Flow is directed toward the portion of the Pecos River valley along the south boundary if the water table is at depth.

Within the region of intact strata, the contrast in hydraulic conductivities plays an important role in determining flow patterns. The Dewey Lake and Triassic rocks are more permeable than the anhydrites at the top of the Rustler. Consequently most of the water that recharges the groundwater basin flows only in these rocks above the Rustler. The rest leaks vertically through the upper anhydrites and is available for flow through the rest of the Rustler. Gradients of hydraulic head along the base of the Dewey Lake provide the driving force for flow in the Rustler.

Groundwater flow in the Rustler is characterized by very slow vertical leakage through confining units and faster lateral flow in conductive units. Specific discharges (flow rates per unit area) in the Culebra are two to three orders of magnitude greater than the vertical specific discharges across the top of the Culebra. However, vertical leakage can contribute a significant portion of the total inflow to portions of the Culebra that are extensive enough that the upper surface is very much larger than the area available for lateral flow. It is difficult to quantify the relative contribution of vertical leakage because the hydraulic conductivity of the anhydrite confining layers at a regional scale is not well known.

As discussed in Chapter 2.0 (Section 2.2.1.4.1.2), studies of the isotopic composition of groundwater above the Salado (for example, Chapman 1986, 1988; Siegel et al. 1991) have generated debate about where and when the groundwater that is currently in the Culebra within the WIPP site was recharged. Conceptually, the sites of recharge can be found in a groundwater basin model by tracing various flowpaths from the WIPP site upstream to the water table. Flow paths were not identified as such as part of the simulation study, but some understanding can be reached by examining a large number of velocity distributions for the Culebra, Magenta, and Dewey Lake and Triassic units. These results suggest that flowpaths would have reached the water table in areas that are north and northeast of the WIPP site. The various flowpaths to the WIPP site would include relatively rapid lateral flow in the conductive units and slow vertical flow through the Rustler confining units. Flow paths that

enter the WIPP site portion of the Culebra by vertical leakage across its upper surface originated outside of the WIPP site but closer to the WIPP site than the flow paths that enter the WIPP site by lateral flow within the Culebra. None of the water in the Culebra within the WIPP site is conceptualized as having been recharged in areas where the Culebra is at or near to the land surface. It is also noted that the travel times along the various flowpaths to the Culebra probably vary greatly. Therefore, the water currently in the Culebra is a mix of water with much different residence times.

The modern-day pattern of groundwater flow has not equilibrated to the present climate. There are two aspects to this disequilibrium. First, the position of the water table has not yet adjusted to past changes in recharge rates. A decrease in recharge that started at the end of the Pleistocene was complete by 8,000 years ago. The water table, however, is still in the process of adjusting to this change in recharge. Second, hydraulic heads in rocks with small conductivities are not adjusted to the current position of the water table. The base-case transient simulation shows, for example, that closed regions of maximum head occur in the Culebra at the present time. These maxima are in regions where the Culebra's conductivity is believed to have been reduced by precipitation of halite in pore space. Groundwater flows out of these regions too slowly for heads to remain in equilibrium with a falling water table. The persistence of these regions of high head delays the transition of the flow field to one that fully reflects the basin-scale topography.

The slow response of the water table to long-term changes in recharge is the dominant aspect of the transient nature of the groundwater system. However, superimposed on long-term changes in the flow system are short-term changes caused by alternating wet and dry periods during the Holocene. Each wet-and-dry cycle results in a rise and fall of the water table. The amount of change in the water table depends on the peak recharge rate and the rock properties. The simulated change is typically 16 to 49 feet (5 to 15 meters). Changes in hydraulic head in the Culebra lag behind changes in the water table and have a smaller amplitude. The overall effect of the Holocene wet periods is to slow the long-term decline of the water table and to superimpose short-term, and relatively small, variations to long-term flow velocities.

The new contributions to the conceptual understanding of the regional hydrogeology of the Culebra resulting from modeling from a groundwater basin perspective include the following:

- The shape and elevation of the water table largely determine rates and directions of groundwater flow in the Culebra.

- Groundwater inflow to the portion of the Culebra within the WIPP site boundary is by a combination of lateral flow within the Culebra and extremely slow vertical leakage from the overlying Tamarisk.

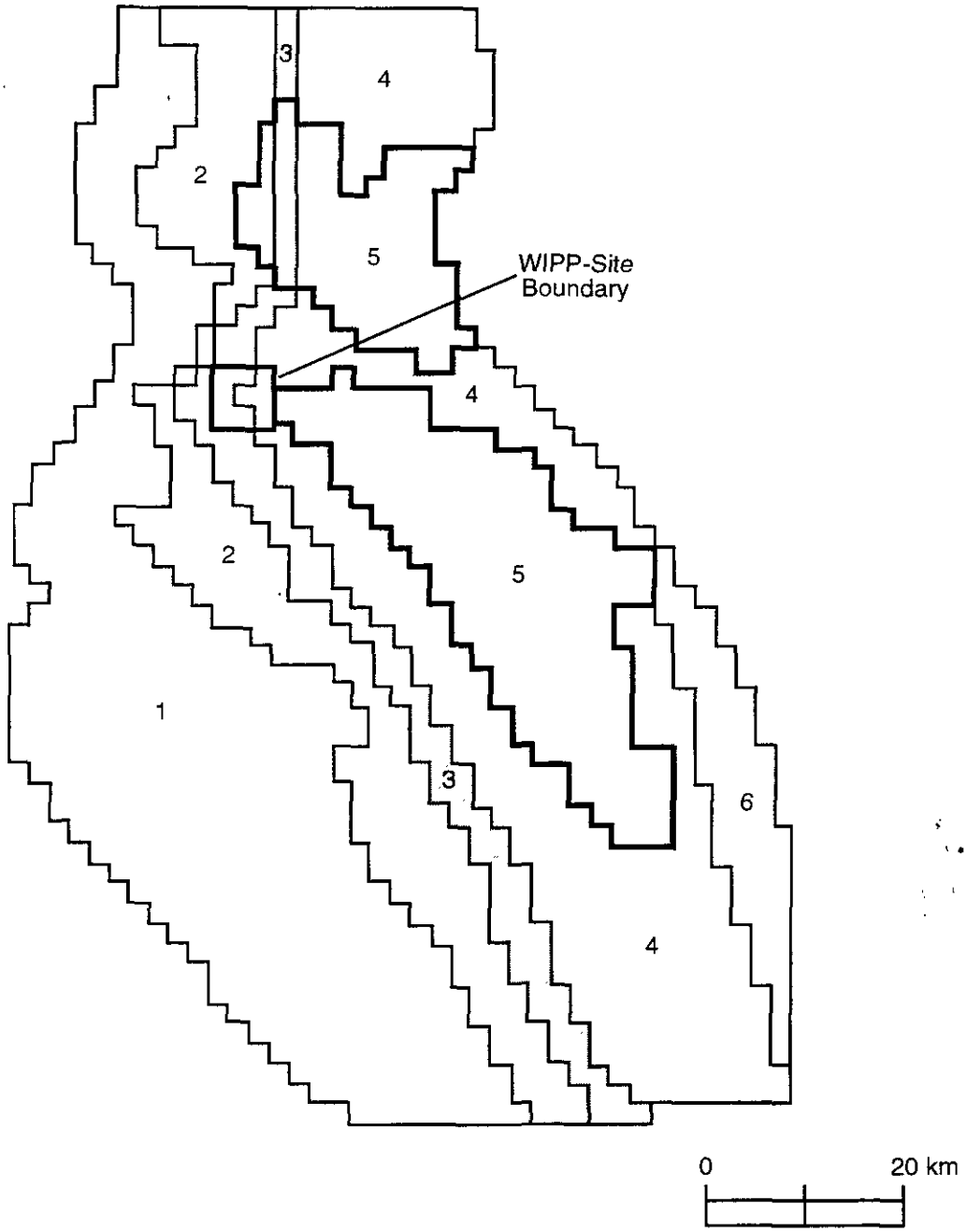

NOTE: Zonation approach used to represent the effects of depositional setting and post-depositional processes. Zone 1 ia a region in which dissolution of the upper Salado has fractured and disrupted overlying strata to the extent that stratigraphic layering is not preserved over long distances. In Zone 2, dissolution of the upper Salado is thought to have fractured the Rustler, but did not disrupt layering. Fractures that predate dissolution of the upper Salado are mostly filled with gypsum. These fracture fillings have been removed in Zone 3. Zone 4 represents intact strata. The region occupied by the halite facies of the mudstone/halite layers is indicated by Zone 5. A graben structure is shown as Zone 6.

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Figure MASS-3. Zonation Approaches Used in SECOFL3D Studies of Regional Groundwater Flow

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- The term recharge refers to a process that occurs at the water table. The inflow to the Culebra originated as recharge distributed over large areas of the groundwater basin. Recharge that eventually reaches the Culebra within the WIPP site does not occur where the Culebra crops out or where overlying confining units have been removed or fractured. The paths that water follows as it flows from the water table to the Culebra at the WIPP site necessarily include vertical leakage across confining layers. The travel time to reach the Culebra varies greatly along the various paths. The travel times are probably thousands or tens of thousands of years.

- Climate change alters recharge rates. Consequently the position of the water table changes and groundwater velocities at depth adjust accordingly.

- Modern-day flow velocities in the Culebra at the WIPP site can be understood and simulated using the groundwater basin conceptual model. The generally north-to-south flow is a result of the modern-day depth of the water table and the basin-scale distribution of hydraulic conductivity. Flow in wetter climates would rotate toward Nash Draw to the west. Flow in the Culebra directed away from Nash Draw is not supported by this model.

- The size and shape of the hydrogeologic system that determines groundwater flow velocities in the Culebra at the WIPP site have been tentatively identified.

MASS.15 Culebra

The conceptual model for groundwater flow in the Culebra (a) provides a reasonable and realistic basis for simulating radionuclide transport in the Culebra and (b) allows evaluation of the extent to which uncertainty about groundwater flow in the Culebra may contribute to uncertainty in the estimate of cumulative radionuclide releases from the disposal system. See Chapter 6.0 (Section 6.4.6.2) for additonal references to other relevant discussions on this conceptual model.

The conceptual model used in performance assessment for groundwater flow in the Culebra treats the Culebra as a confined two-dimensional aquifer with constant thickness and spatially varying transmissivity (see Attachment 15-7). Flow is modeled as single-phase (liquid) Darcy flow in a porous medium.

Basic stratigraphy and hydrology of the units above the Salado are described in Chapter 2.0 (Sections 2.1 and 2.2). Additional supporting information is contained in Appendices GCR, HYDRO, and SUM.

The conceptual model for flow in the Culebra is discussed in Chapter 6.0 (Section 6.4.6.2). Details of the calibration of the transmissivity field, based on available field data, are given in Appendix TFIELD (Section TFIELD.4). Initial and boundary conditions used in the model

are given in Section 6.4.10.2. A discussion of the adequacy of the two-dimensional assumption for performance assessment calculations is included as Attachment 15-7.

The principal parameter used in the performance assessment to characterize flow in the Culebra is an index parameter (the transmissivity index) used to select a single transmissivity field for each Latin hypercube sample element from a set of calibrated fields, each of which is consistent with available data (see Appendix PAR, Parameter 35).

MASS.15.1 Historical Context of the Culebra Model

Since the FEIS in 1980, the model used to describe flow and transport within the Culebra has changed significantly. In the FEIS, the Culebra and Magenta were combined and modeled as one layer referred to as the Rustler aquifers. In the modeling, the Rustler aquifers were assumed to be an isotropic porous medium with a uniform porosity of 0.10 (Lappin et al. 1989, Table K-2, K-18). A uniform transmissivity field was assumed across the model domain except in Nash Draw. Regional flow was assumed to be toward the southwest discharging at Malaga Bend on the Pecos River. (There was no regulatory framework or boundary defined at this time.) Numerical modeling was not able to consider the possible effect of variations in brine density within the Rustler, so modeling used an equivalent freshwater head. Steady-state flow directions and rates were assumed. As for physical-transport characteristics, the Culebra was incorporated into the Rustler aquifers and assumed to be an isotropic, homogeneous porous medium.

Haug et al. (1987) calibrated a flow model to the H-3 pumping test (Beauheim 1987a) and the effects from the excavation of the shafts. Data from numerous new boreholes installed and tested since the 1980 study were included in this model. The boundaries of the model were not much larger than the extent of the WIPP site. Brine densities were also used as a calibration target. The brine densities were assigned at the boundaries and subsequently modified to match the observed fluid densities. Vertical leakage was included in an attempt to calibrate the brine densities. This attempt led to the recommendation that future modeling studies treat the Culebra as a leaky-confined aquifer. The transmissivity field was estimated by kriging and modified by the addition of pilot points, which were located by trial and error. In this model, single- and double-porosity effects on the flow field were investigated. At the regional scale, the use of a double-porosity vs. single-porosity (matrix-only) conceptual model had little effect on the flow field.

A modeling study (LaVenue et al. 1990) conducted to support the DSEIS only slightly modified the conceptual model used by Haug et al. (1987). The differences in the conceptual model were the assumptions that brine density varied spatially but was held constant through time, and vertical leakage was not included. It was assumed that the brine concentrations could be considered to have changed little over the period of time modeled. The boundaries of the 1989 study were much larger than those of the 1987 study, extending approximately 18.6 miles (30 kilometers) north and south and 12.4 miles (20 kilometers) in east and west. The model grid was centered on the WIPP site. The boundaries were selected to include the

region for which head data were available and to minimize the boundary effects during transient simulation of the H-3, WIPP-13, and H-11 pumping tests. Fixed heads were assigned around all four boundaries based upon the regional head values. Transmissivities were estimated by kriging and ranged over seven orders of magnitude in this study. Pilot points were added to modify the transmissivity field during steady-state and transient calibration. Pilot-point locations were selected using an adjoint sensitivity analysis technique. The Culebra transmissivity field was calibrated on the basis of 41 test locations. Transmissivity was recognized to vary by approximately three orders of magnitude within the WIPP site. Modern flow in Culebra was recognized as being predominantly north to south on the WIPP site, and strongly affected by a high-transmissivity zone in the southeastern portion of the WIPP site. Flow was calculated on the basis of a fully confined Culebra and boundary conditions applied at the WIPP site scale. As discussed in Lappin et al. (1989), local flow and transport behavior were affected by fracturing where the transmissivity is greater than approximately 10^{-6} square meters per second. For physical transport, a double-porosity (matrix-diffusion) transport model for off-site transport from waste panels was assumed. Transport parameters were based on best estimates from nonsorbing tracer tests at three locations (Jones et al. 1992). It was assumed that the effective thickness was equal to the total thickness. Contaminant-transport calculations were one-dimensional.

The initial conditions for the Culebra flow field have been taken from the hydrographs of the WIPP boreholes. Prior to excavation of the salt handling shaft, the hydrographs showed little evidence of head change over the ten years preceding the shaft excavations. Head values were selected for each borehole with a hydrograph that preceded shaft excavation or that was located far from the shaft effects on the flow field. These data provided an estimate of the undisturbed head field and were subsequently used as initial conditions for the Culebra model's transient simulation.

In modeling the hydrologic characteristics of the Culebra, SNL (1992-1993) generated multiple transmissivity fields conditioned on hydraulic test data (point transmissivity data and transient head data) and then sampled those fields. This procedure addressed uncertainties in the location-specific values of the Culebra transmissivity. The geologic conceptual model was further revised to indicate that the degree of fracture flow was related to the degree of gypsum cement in the fractures. Contaminant-transport calculations were two-dimensional. The effective thickness of the Culebra was taken to be equal to the total thickness. A range of physical-transport parameters was used, as opposed to best estimates, to address the variability of physical-transport properties within the Culebra. The maximum fracture spacing was assumed to be equal to the total thickness of the Culebra (approximately 26 feet [8 meters]). The fracture spacing used in modeling was a convenient modeling simplification based on the concept of through-going parallel fractures. Representing fracturing in terms of fracture spacing is a mechanism to ensure that the proper surface-to-volume ratios are used in estimating the role of matrix diffusion. Calculations considered the possibility of both single-porosity (fracture-flow-only) and double-porosity (matrix diffusion) behavior.

The main differences between the 1989 and 1992 models were the model boundary locations, boundary conditions, and the geostatistical approach used to develop and modify the transmissivity field (LaVenue and RamaRao 1992). The 1992 model boundaries were rotated 38 degrees east to align with the axis of Nash Draw. This permitted the specification of a no-flow boundary condition along a portion of the western boundary, which was selected to coincide with the axis of Nash Draw. In addition, the northeastern corner of the model was treated as a no-flow boundary because of the low transmissivities in the area and the lack of any nearby regional heads to provide boundary head estimates. Transmissivities were simulated by conditional simulation. Pilot points were automatically located and assigned transmissivity values using an optimization routine during steady-state and transient-state calibration.

By 1994, the model of the Culebra's hydrologic characteristics was unchanged from that of December 1992. For the physical-transport characteristics, double-porosity transport was assumed, but the base case had large fracture spacing, effectively the same as the Culebra thickness. A single block size was assumed in each realization. Calculations still assumed an effective thickness equal to the total thickness.

Since 1994, the model of the Culebra's regional hydrologic characteristics has not changed, although additional large-scale information from pumping at H-19 and small-scale information at Water Quality Sampling Program (WQSP) wells has been incorporated into the calibration. Existing borehole-transmissivity interpretations have been refined. The model of the physical-transport characteristics has changed on the basis of analysis of new data from H-19 and H-11 and reanalysis of previous tests of H-3, H-11, H-6. The Culebra is now conceived of as a fractured porous medium with inherent local variability in the degree and scale of fracturing. Examination of core and shaft exposures has revealed that there are multiple scales of porosity within the Culebra including fractures from microscale to large, vuggy zones, and inter-particle and inter-crystalline porosity. This variability leads to both lateral and vertical variations in permeability. Advection is believed to occur largely through fractures; however, in some areas it may also occur through vugs connected by small fractures and interparticle porosity. Diffusion occurs into all connected porosity. Performance assessment, rather than conceiving of transport in terms of fracture and matrix porosities, conceives the Culebra as being composed of advective and diffusive porosities. Matrix diffusion is still believed to be effective and significant. The effective transport thickness is thought to be less than the total stratigraphic thickness. The available data suggest that the permeability of the upper portion of the Culebra is relatively low. Therefore the DOE has concluded that the Culebra is adequately represented by a double-porosity continuum model on the scale of performance assessment calculations, and it is not necessary to use a discrete-fracture model on this scale.

MASS.15.2 Dissolved Actinide Transport and Retardation in the Culebra

The purpose of this model is to represent the effects of advective transport, physical retardation, and chemical retardation on the movement of actinides in the Culebra. This conceptual model is also discussed in Section 6.4.6.2.1.

The properties of the Culebra have been characterized by direct observation in outcrop, boreholes, and shafts (Holt and Powers 1984, 1986, 1988, 1990), field hydraulic testing and analysis (Beauheim 1987b), field tracer testing and analysis (Attachment 15-6; Jones et al. 1992; Mercer and Orr 1979), and laboratory testing and analysis (Papenguth and Behl 1996a, 1996b). The conceptual model for dissolved actinide transport in the Culebra is based on these observations, tests, and analyses.

The conceptual model for actinide transport in the Culebra has three principal components: advective transport, physical retardation, and chemical retardation. Two types of porosity are present—porosity in which advective transport occurs, and porosity that is relatively inactive in advective transport. This type of behavior is typically referred to as double porosity. Because testing and analysis of the Culebra suggest that its upper portion does not play a significant role in transport, transport is modeled only for the lower portion of the Culebra.

Advective transport refers to the transport of actinides in those pores of the Culebra where the principal fluid flow occurs. This flow primarily occurs in fractures, but may also occur in microfractures connecting vugs in vuggy regions or other portions of the porosity of the Culebra that contain large pore-throat apertures (that is, high permeability regions). This mechanism includes the effects of diffusion and dispersion in advective porosity as well as the movement of actinides with the bulk fluid flow. Advective transport is thought to be controlled by hydraulic gradient, hydraulic conductivity, thickness, and advective porosity.

Physical retardation refers to the process of diffusion from advective porosity into diffusive porosity, that is, those portions of the porosity of the Culebra that are relatively inactive in advective transport. Once in the diffusive porosity, the actinides are no longer carried along by the most rapidly moving liquids, and their rate of movement is controlled by diffusion and sorption. Diffusion can be an important process for effectively retarding solutes by transferring mass from the porosity where advection (flow) is the dominant process into other portions of the rock. The properties that control the diffusion of actinides into the diffusive porosity are the surface area to volume ratio between advective porosity and the diffusive porosity, the tortuosity of the diffusive porosity, and free-water diffusion coefficients (see Attachment 15-3).

Chemical retardation refers to the sorption of actinides on minerals present in the Culebra. The sorption is thought to occur on dolomite grains, but will also occur on clay or other minerals. In the conceptual model, chemical retardation occurs only in the diffusive porosity, and adds to the effects of the physical retardation. The governing properties for sorption are described in a parametric expression of the degree to which dissolved actinides tend to sorb or

remain in solution (in the mathematical model, a K_d for a linear isotherm is used), which requires the concentration of actinides in solution and the abundance of minerals on which sorption can occur (see Attachment 15-1).

Advective porosity is thought to be a small percentage of the total volume of the Culebra involved in transport. This porosity is interconnected and contains high-permeability features such as fractures or vuggy pore structures. In this advective porosity, little actual rock material is considered to exist (in other words, it is the fracture apertures and pore volumes without surrounding rock). In contrast, diffusive porosity makes up the major portion of the Culebra pore volume. It comprises lower-permeability features and most of the rock material. The rate at which diffusion removes solutes from advective porosity is a function of the surface area to volume ratio between the advective and diffusive porosity. For a given geometry of advective porosity assumed in a model (for example, parallel-plate fractures), this surface area to volume ratio can be expressed as a characteristic length which is known as the matrix block length (for example, the thickness of a matrix slab between two parallel-plate fractures).

In summary, the conceptual model for dissolved actinide transport in the Culebra includes two types of porosity: advective porosity associated with high-permeability features of the Culebra, and diffusive porosity associated with lower-permeability features. These two types of porosity are distributed throughout the Culebra and are intertwined on a small scale; hence, mapping their regional extent or boundaries between them is not feasible. Advection, diffusion, and dispersion of dissolved actinides occur within the advective porosity. Diffusion (physical retardation) and sorption (chemical retardation) occur within the diffusive porosity. Advective porosity makes up a small portion of the overall pore volume of the Culebra; diffusion is an important process for transferring mass into other portions of the rock mass where there is a larger surface area for sorption. Because the upper portion of the Culebra has been observed to be relatively inactive in solute transport in tests, it is assumed to be unimportant and is not included in the conceptual model. Attachment 15-6 contains additional information on the transport properties of the Culebra.

Several parameters are referred to or implied in the conceptual model as discussed in Section 6.4.6.2. For transport in advective porosity, the principal parameter is the porosity of the network, but because of links to the Culebra fluid flow model, the hydraulic gradient and hydraulic conductivity largely control the specific discharge calculated by SECOFL2D. Within diffusive porosity, the porosity, tortuosity, and diffusion coefficients for various actinides are important because of their effect on the rate of diffusion. A parameter called matrix block length, a measure of the surface area between the advective and diffusive porosities, is also important. The density of sorbing minerals and their sorption properties, expressed by K_d (the distribution coefficient), are important in chemical retardation.

It is commonly assumed that there should be a relationship between the conductivity of advective porosity and its porosity and distribution, that is, that the fracture permeability, porosity, and aperture or spacing should be correlated. Data collected and analyzed at the

WIPP do not support this assumption. There are no meaningful trends among these parameters for the data that have been collected. Therefore, values of these parameters are not correlated in the performance assessment (see Attachment 15-6, 14; Attachment 15-10).

Transport of actinides in the Culebra is coupled to several other conceptual models. An important coupling is to models for features that can introduce actinides to the Culebra, for example, the exploratory borehole, shafts and shaft seals, and dissolved actinide source term. The most important coupling is to the model for flow in the Culebra. Because transport in the Culebra is one of the last processes to occur along this pathway prior to release, it does not feed back to other conceptual models in any significant manner. In a manner of speaking, this conceptual model falls at the downstream end of the overall disposal system model, and thus has little or no impact on models that come before it.

MASS.15.2.1 Current Studies of Sorption in the Culebra

Several factors affect the sorption of Pu, Am, U, Th, and Np, the elements for which K_d values are required in performance assessment for Culebra transport calculations (Ramsey 1996) including:

- the properties of the sorbents (solids) that will sorb actinides from solution,
- the composition of solutions that currently exist in the Culebra or could enter the Culebra after human intrusion into WIPP disposal rooms,
- the oxidation state of the sorbate (actinide elements) in the Culebra,
- dissolved actinide concentration,
- equilibration time, and
- direction of reaction (sorption versus desorption).

The two most important sorbents in the Culebra are dolomite, a carbonate mineral that constitutes most of the Culebra, and corrensite, an ordered mixture of chlorite and saponite associated with fracture surfaces and dispersed in the matrix (intact rock between the fractures) of the Culebra. Dolomite is important because it is by far the most abundant mineral in the Culebra. Corrensite is important because, although a minor constituent, it sorbs actinide elements more strongly than dolomite. The work of Sewards (1991) and Sewards et al. (1991, 1992) indicates that corrensite is associated with fracture surfaces and dispersed in the matrix at concentrations high enough to increase the retardation of Pu, Am, U, Th, and Np relative to that observed in laboratory studies with dolomite-rich rock. However, the DOE does not include K_ds for clay minerals in the ranges and probability distributions for the matrix K_ds for use in performance assessment calculations because laboratory data for clay-

rich rock under expected Culebra conditions are insufficient at this time. Furthermore, the DOE does not take any credit for sorption by clay minerals associated with fracture surfaces. Omitting K_ds for clays is conservative.

The experimental basis for the ranges and probabilities of matrix distribution coefficients is documented in Attachment 15-1.

MASS.15.2.2 Historical Studies of Sorption in the Culebra

The DOE carried out several laboratory studies of sorption in the late 1970s and early 1980s (Serne et al. 1977; Paine and Dosch 1992; Dosch and Lynch 1978; Dosch 1979, 1980, 1981; Lynch and Dosch 1980; Lynch et al. 1981; Tien et al. 1983). These empirical studies used a variety of sorbents and solutions—including dolomitic, anhydritic, and clay-rich rocks and repository and Culebra brines—and in some cases included the effects of dissolved organics on sorption. The DOE (1980) used some of these results for the 1980 WIPP Environmental Impact Statement (EIS). According to Lappin et al. (1989), the sorption model used by the DOE (1980) included a porous-medium approximation of the Culebra. Lappin et al. (1989) and the DOE Office of Environmental Restoration and Waste Management (1990) also used these results for the 1990 Supplemental EIS. For Pu, Am, U, Th, Np, and Cm, Lappin et al. (1989) and the DOE Office of Environmental Restoration and Waste Management (1990) included sorption by the matrix only, linear sorption isotherms, and instantaneous, reversible equilibrium in their model. For Ra and Pb, however, they assumed linear, instantaneous, reversible sorption by clay minerals in the matrix because there were no data available for sorption of these elements by dolomite.

The DOE and the state of New Mexico formally recognized deficiencies in the early sorption studies. In 1988, the DOE and the state of New Mexico modified the Consultation and Cooperation agreement to require New Mexico concurrence on any K_ds recommended for use in the final performance assessment. Papenguth and Behl (1996b) planned the current program (see below) in part to satisfy that agreement.

Soon after the agreement was reached, the DOE started a mechanistic sorption study, primarily at Stanford University (Lappin et al. 1989; Siegel et al. 1990; Park et al. 1992, 1995). The objective of this study is to develop a surface-complexation model for the sorption of UO_2^{2+} by corrensite, the dominant clay mineral in the Culebra. It is infeasible, however, to use this model in performance assessment calculations for three reasons:

- laboratory data for clay-rich rock under expected Culebra conditions are insufficient at this time to include K_ds for clay minerals in performance assessment calculations;

- the Stanford results pertain only to sorption of U(VI) and its oxidation-state analogs Pu(VI) and Np(VI), none of which will significantly affect the long-term performance of the WIPP; and

- even if sorption of U(VI), Pu(VI), or Np(VI) did affect the long-term performance of the WIPP significantly, it would not be possible to incorporate a surface-complexation model in the Culebra flow and transport codes SECOFL2D and SECOTP2D.

At about the same time that the Stanford mechanistic sorption study began, the DOE convened an expert panel consisting of SNL staff to estimate ranges and probability distributions of K_ds for use in performance assessment. This panel estimated ranges and distributions of actinide K_ds for the Culebra as a whole and for the clay-rich fracture surfaces (Trauth et al. 1992). These values were used for the 1991 and 1992 calculations.

MASS.15.3 Colloidal Actinide Transport and Retardation in the Culebra

The purpose of this model is to represent the effects of colloidal actinide transport in the Culebra. This model is also discussed in Section 6.4.6.2.2 and Attachments 15-2, 15-8, and 15-9.

A particle is referred to as being in the colloidal state when the particle size lies roughly in the range between 1 and 1,000 nanometers. These particles are generally much larger than simple ions, and as a result, the transport behavior of colloids in groundwater systems can be quite different from that of dissolved species. In a groundwater system, colloids are essentially a third phase consisting of a mobile solid that can associate with or contain actinides and potentially increase transport rates slightly relative to the average groundwater velocity.

In the WIPP disposal system, for instance, colloids are often too large to pass through the small pore throats of diffusive porosity. Such colloids will be restricted to the advective portion of the flow system. Colloids may also be less reactive than dissolved actinides with the host rock. Therefore, even though a colloid is small enough to penetrate the diffusive porosity, the retardation coefficient associated with the colloid will in some cases be smaller than the retardation coefficient of the actinide associated with the colloid.

Colloid-facilitated actinide transport has not been included in past performance assessment calculations because of a lack of adequate information to model this phenomenon and demonstrate its impact on compliance (see, for example, SNL, 1992-1993, Vol. 1, 4-12, line 29). Transport of actinides by colloidal particles has been recognized only relatively recently as a phenomenon of potential importance to the performance of nuclear waste repositories (Jacquier 1991; Avogadro and de Marsily 1984). In fact, the study of colloid-facilitated contaminant transport is a relatively new topic to the geosciences in general. Nyhan et al. (1985) was one of the first investigations to demonstrate the potential importance of colloid-facilitated radionuclide transport. Since then, a number of researchers have investigated colloids as a potential transport mechanism (for example, McCarthy and Zachara 1989; Corapcioglu and Jiang 1993; Grindrod 1993; Ibaraki and Sudicky 1995). Grindrod (1993) and Ibaraki and Sudicky (1995) addressed the topic of colloid-facilitated transport through fractured porous media. Consequently, their work is most applicable to the colloid transport problem in the Culebra.

Among the most sophisticated and rigorous numerical models developed are those by van der Lee et al. (1993, 1994) and Bennett et al. (1993). Many of the colloid transport numerical models described in the literature focus on simulating solute transport through fractured media with double porosity flow characteristics, and they have been generalized to include unique features of colloid transport (for example, Hwang et al. 1989; Grindrod and Worth 1990; Light et al. 1990; Smith and Delgueldre 1993; Harmand and Sardin 1994). Some numerical models, such as the population balance model by Travis and Nuttall (1985), assume equilibrium colloid concentrations. That is, the loss of colloidal particles by attachment to the medium wall is compensated by the generation of new colloidal particles by various mechanisms such as condensation and entrainment. The modeling approach developed by Travis and Nuttall (1985) is similar to the double-porosity transport model.

MASS.15.3.1 Experimental Results

As discussed in Section 6.4.6.2.2, the four types of colloids and colloidal sized particles modeled to be introduced to the Culebra are microbes, mineral fragments, humic substances, and actinide intrinsic colloids. To investigate the impact of these four colloid types on radionuclide transport in the Culebra, an experimental program was developed and implemented at SNL with significant contributions from Lawrence Livermore National Laboratory (LLNL), Battelle National Laboratory, Los Alamos National Laboratory (LANL), and Florida State University. The intent of this experimental program was to develop parameter ranges and distributions for the conceptual models discussed above. With the exception of the Pu(IV) polymer, the experimental results indicated that colloid-facilitated actinide transport is not a viable mechanism for actinide transport in the Culebra. Furthermore, the potential amount of Pu(IV) polymer that could be introduced to the Culebra was found to be insignificant with respect to the EPA normalized release limit. Consequently, colloid-facilitated actinide transport was not simulated in the performance assessment.

The experimental results and implications on performance assessment modeling are summarized as follows:

- Mineral fragments and microbes are attenuated so effectively it was deemed unnecessary to include them in the transport calculations (see Attachments 15-8 and 15-9).

- The total potential amount of Pu(IV) polymer introduced to the Culebra was found to be insignificant with respect to the EPA normalized release limit (Attachment 15-8). Therefore, the contribution of Pu(IV) polymer to the integrated discharge was disregarded in the performance assessment.

- Under neutral to slightly basic brine conditions, the presence of humic substances in the brine did not influence the sorption behavior of dissolved actinides. Results indicate that at these geochemical conditions, humic substances were not effective complexants in the presence of dolomite (Attachment 15-8). Therefore, actinides

associated with humic substances are assumed to disassociate upon entering the Culebra.

MASS.15.3.2 Indigenous Colloidal Transport

In an intrusion scenario at the WIPP, as dissolved actinide elements are introduced to the Culebra, it is possible that those dissolved actinides could sorb onto a separate population of indigenous mineral fragments, microbes, and humic substances. The physical and chemical behavior of these newly formed actinide-bearing colloidal particles will be nearly identical to the behavior of colloids introduced from the repository. Microbes and mineral fragments will be rapidly filtered out of the advective flow domain; hence, disregarding the interaction between dissolved actinides and these types of colloids is considered to be a conservative approach. Experimental results indicate that humic substances do not interact with dissolved actinides under the expected Culebra geochemical conditions. Consequently, the quantity of newly formed actinide-bearing humics will be insignificant.

MASS.15.3.3 Alternative Approaches Considered

As discussed above, results of experimental studies show that colloidal actinides are strongly attenuated or present in negligible concentrations, making it unnecessary to include them in performance assessment simulations. The following section describes the three alternative transport conceptual models considered prior to the completion of these experimental results.

After the introduction of colloidal actinides and dissolved actinides into the Culebra, realistically a new equilibrium condition will be established, with the stipulation that the total concentration of actinide must be preserved. As in the repository, quantifying an equilibrium assemblage is not practicable.

Three approaches were considered to quantify colloid-facilitated actinide transport at the WIPP. First, the transport of one or more types of actinide-bearing colloidal particles in the Culebra could be assumed to be instantaneous. In other words, as actinides associated with that type of colloidal particle migrate to the Culebra from the repository, or are generated within the Culebra, the mass of actinides associated with those colloidal particles becomes part of the integrated release of actinides at the accessible environment boundary. This approach can be useful if the concentrations of actinides associated with one or more types of colloidal particles are very low. Treating colloid-facilitated actinide transport as instantaneous, however, is a significant shortcoming, because of the potentially large expected retardation effects of colloidal particles.

Second, SECOTP2D and supporting codes could be used to simulate the effects of one or more of the colloid retardation phenomena (Ramsey 1996). The double porosity advection and diffusion equation solved by SECOTP2D can simulate colloid sorption in the matrix and to the fracture walls. The code can also model colloid filtration using the decay term of the governing equation. For colloids considered too large to diffuse into the matrix, matrix

diffusion can be disabled by setting the matrix tortuosity to zero. This approach was used for some calculations completed in 1994. Specifically, microbes, because of their relatively large size, were excluded from matrix diffusion and limited to advective flow in fractures. Humic substances were allowed to diffuse into intercrystalline pores, but at a reduced rate relative to dissolved actinide species.

This approach requires a number of simplifying assumptions under the presumption they are conservative with respect to the integrated release of radionuclides. The first assumption is that the dissolved concentration will be greatest at the source point and therefore, the concentration of radionuclides associated with colloids will be greatest at the source as well. Second, a radionuclide associated with a colloid is assumed to remain fixed to that colloid throughout the simulation. Given these assumptions, the colloidal actinide concentration is no longer a function of the dissolved actinide concentration, and it is not necessary to solve the dissolved species transport problem and the colloid transport problem simultaneously. As a result, the standard advection diffusion transport equation can be used to predict colloid transport and compute integrated colloid releases. Given the initial concentration of radionuclides sorbed to each specific type of colloid, the integrated colloid release can be converted to an integrated radionuclide release by postprocessing the colloid transport results. Radionuclide decay can also be accounted for in postprocessing.

The third assumption is that colloid-facilitated actinide transport could be quantified by a rigorous numerical modeling code developed for the WIPP. Such a rigorous transport model would address all physical and chemical processes that could affect the movement and fate of the four colloidal particle types, including colloid generation; interactions with solutes, the dispersant, and rock; advection; dispersion; diffusion; filtration; gravitational settling; attachment and detachment; adsorption and desorption; coagulation; flocculation; and peptization. Ideally, permeability reduction caused by pore clogging by colloids, which would affect solute transport as well, would also be considered. Currently available models do not include all of these processes (see Attachments 15-2, 15-8, and 15-9).

The most practical approach to evaluating the transport of colloidal actinides is the second option presented above, using the SECOTP2D code. Where possible, the DOE considered reducing the number of phenomena treated in the transport code and address them in the source term. For example, the effect of ionic strength on colloid stability would have been included in the colloid source term. Retardation of colloidal particles was to be quantified using a retardation factor, and filtration was to be quantified through the decay term.

MASS.15.4 Subsidence Caused by Potash Mining in the Culebra

This model incorporates the effects of potash mining in the McNutt on disposal system performance (see Appendix SCR, Sections SCR.3.2.2 and SCR.3.3.2). 40 CFR Part 194 provides a conceptual model and parts of a mathematical model for these effects. The DOE has implemented the EPA conceptual model to be consistent with EPA criteria and guidance. It is described in Section 6.4.6.2.3 of this application. Additional information on the

implementation of the mining subsidence model is available in Attachments 15-4 and 15-5, and Bertram (1995).

The principal parameter in this model is the range assigned to a factor by which hydraulic conductivity in the Culebra is increased (Attachment 15-4). As allowed in supplementary information to 40 CFR Part 194, it is the only parameter changed to account for the effects of mining.

Mining in the McNutt has been considered in the performance of the WIPP since the original siting activities. Siting criteria for both the site abandoned in 1975 and the current site included setbacks from active mines. (See, for example, Section MASS.2.) The 1980 FEIS for the WIPP (DOE 1980) considered the possibility of an indirect dose arising from the effects of solution mining for potash or halite; it concluded that direct access of waste by solution mining for potash was not likely because of the methods that would be used to control the flow of solvent through the formation. The DOE is not aware of solution mining for potash or other minerals in the Salado within the Delaware Basin at this time.

Mining has been included in scenario development for the WIPP since the earliest work on this topic (for example, Hunter 1989; Marietta et al. 1989; Guzowski 1990; Tierney 1991; and WIPP Performance Assessment Division 1991). These early scenario developments considered both solution and room-and-pillar mining. The focus was generally on effects of mining outside the disposal system. The two primary effects of mining considered were changes in the hydraulic conductivity of the Culebra or other units and changes in recharge as a result of surface subsidence. These mining effects were not formally incorporated into quantitative assessment of repository performance in preliminary performance assessments.

The inclusion of mining in performance assessment satisfies the criteria of 40 CFR Part 194 to consider the effects of this activity on the disposal system.

MASS. 16 Intrusion Borehole

The inclusion of intrusion boreholes in performance assessment adds to the number of release pathways for radionuclides from the disposal system. Direct releases to the surface may occur during drilling as particulate material from cuttings, cavings, and spall are carried to the surface. Also, dissolved actinides may be carried to the surface in brine during drilling. Once abandoned, the borehole presents a possible long-term pathway for fluid flow, such as might occur between a hypothetical Castile brine reservoir, the repository, and overlying units. This topic is also addressed in Chapter 6.0 (Section 6.4.7) and Appendix SCR (Sections SCR.3.2.1 and SCR.3.3.1).

MASS.16.1 Cuttings, Cavings, and Spall Releases during Drilling

The purpose of these models is to estimate the quantity of actinides released directly to the surface during drilling through the repository by three mechanisms: the drillbit boring

through the waste (cuttings), the drilling fluid eroding the walls of the borehole (cavings), and gas movement forcing particulate matter into the circulating drilling fluid (spallings). See Section 6.4.7.1 and references to other appendices cited in that section for additional information. Stochastic uncertainty with respect to parameters relevant to these release mechanisms is addressed in Section 6.4.12.

The conceptual model for cuttings, cavings, and spallings is discussed in three parts because of the differing process by which the three types of material are produced.

Cuttings are materials removed to the surface through drilling mud by the direct mechanical action of the drill bit. The volume of waste removed to the surface is a function of the compacted repository height, the porosity of waste at the time of intrusion, and the drill bit area. The radioactivity of waste removed to the surface is probabilistically determined based on the distribution of waste radioactivity expected in the WIPP.

Cavings are materials introduced into the drilling mud by the erosive action of circulating drilling fluid on the waste in the walls of the borehole annulus. Erosion is driven solely by the shearing action of the drilling fluid (or mud) as it moves up the borehole annulus. Shearing may be caused by either laminar or turbulent flow. Repository pressure effects on cavings, which are negligible, are covered by the spall process.

Spallings are the particulate material introduced into drilling mud by the movement of gas from the waste into the borehole annulus. After the drill bit enters the repository, pressure gradients generated by the flow of gas toward the borehole fracture the waste material, permitting the escaping gas to flow within fractures rather than through a porous matrix. Consequently, the intrinsic permeability of the matrix does not restrict gas flow, and the gas pressure at the borehole entrance to the repository can be assumed to be the initial gas pressure in the repository. The gas flow velocity up the borehole is governed by the isothermal flow of gas in a long tube of a given cross-sectional area, tube roughness, and gas pressure at the borehole entrance. The mass-flow rate of gas in the fractured waste at any radial cross-section is equal to the mass-flow rate up the borehole. Radial gas flow within the fractures in the waste matrix erode and widen the fractures. Erosion is assumed to occur if the fracture gas velocity exceeds a threshold velocity related to the terminal velocity of a waste particle at the fracture surface and to the cohesive strength afforded by moisture in the matrix.

The cuttings model has as a principal parameter the diameter of the drill bit, which according to current practice is constant. This model interacts with the conditions in the repository as calculated by BRAGFLO because the porosity and height of the repository are necessary to calculate the volume of waste removed.

The principal parameters in the cavings model are the properties of the drilling mud, drilling rates, and the shear resistance of the waste. See Appendix PAR (Parameter 33) for details on the sampled parameter used in the cavings model, effective shear resistance to erosion.

The principal parameters in the spallings model are the gas pressure in the repository when it is penetrated and properties of the waste such as particle diameters and erosive properties. Appendix PAR (Parameter 32) provides information on the waste particle diameter, which is a sampled parameter in the spallings model. Because the release associated with spalling is sensitive to gas pressure in the repository, it is strongly coupled to the BRAGFLO-calculated conditions in the repository at the time of penetration. In particular, the spall release may be sensitive to whether the repository has been penetrated previously by another borehole.

Several factors contribute to model uncertainty, principally the undefined nature and complexity of the waste, both in its initial state and during its alteration by chemical and biological processes. Even the most basic information is lacking, such as chemical form, grain size (if the material is granular), partially biodegraded decomposed form, density, cohesion, etc. In the absence of such information, property values typical of surrogate materials are selected to represent the worst case response to the process being investigated (see Appendix PAR, Table PAR-11; Chapter 9.0, Section 9.3.4.4; and Appendix WCA, Section WCA.5.2). In this sense, the model is highly conservative.

Another uncertainty arises from the drilling scenario assumptions for application of the model. There is no consensus about how the driller will act as the drill approaches the waste horizon, that is, whether he will be able anticipate the presence of the gas-filled repository, much less control the drilling process once penetration occurs. In consequence, the conceptual model assumes the worst possible limiting situation, in which the borehole is driven almost instantaneously through the waste by a driller without any knowledge of the existence of the repository, and the driller is unable to control the subsequent gas release.

The scale-up from a model qualified on laboratory samples to the full-scale configuration of a drill penetrating the waste gives rise to another uncertainty, the possibility of improper scaling. However, the adverse effect of improper scaling on the amount of waste released is considered to be negligible because of the conservatism of the material and drilling scenario assumptions.

MASS.16.1.1 Historical Context of Cuttings, Cavings, and Spallings Models

Releases of cuttings and cavings are straightforward and have been considered in performance analyses since the beginning of direct release evaluation. The analytical equations governing erosion (cavings) based on laminar and turbulent flow (Berglund 1992, Section 2.2) have been implemented in the code CUTTINGS_S. Using appropriately selected input based on assumed physical properties of the waste and other drilling parameters, this code calculates the final caved diameter of the borehole that passes through the waste. Although certain features of the analysis, such as whether the flow of the drilling fluid should be modeled as laminar or turbulent and what drilling parameters might be valid near the WIPP repository, have been debated, the basic model has been generally accepted. The amount of material predicted to be released by cavings is small, and therefore this contribution to surface release has never been considered to be critical.

The conceptual model of the release of waste by spalling has been changed several times during its development. Early spall conceptual model development focused on transient unrestrained outgasing leading to the spall (dynamic fracture) of porous cohesive granular media (Berglund 1992, Section 3.3). An experimental program related to model development focused on almost instantaneous depressurization and was limited to a one-dimensional linear sample configuration. The pore pressures required to cause spall or dynamic fracture could be closely approximated using the tensile strength of the porous soil medium (Berglund and Lenke 1995), but the model was complex and could not be directly related to an intrusion event. In addition, although the experimental observations showed fracturing under instantaneous release of gas pressure, sample-preparation factors were largely responsible for the locations of the fractures. The fracture patterns also depended on the one-dimensional nature of the experiments, and the model did not explain how the fractured material was removed.

Subsequently, the dynamic fracture spall model was replaced with a more general three-part model based on the premise that the waste could be removed by any one of three mechanisms: blowout, stuck pipe, and gas-flow assisted erosion (as the result of gas-induced spall). Which mechanism will dominate depends on the permeability and pressure drop at the borehole. Well blowout, an uncontrolled gas release from the well, was considered the dominant mechanism. The two remaining mechanisms, stuck pipe and gas-flow assisted erosion, were not thought to be important because they would occur at waste permeabilities of less than 10^{-16} square meters, much lower than is expected for the waste (1.7×10^{-13} square meters). Consequently, conceptual-model development has focused on the blowout mechanism for removing waste.

Once the DOE concluded that blowout was the principal cause of direct release of waste by spalling, the nature of the gas flow and the entrainment properties of the waste became the focus of subsequent model development. The first model, used in analyses in 1994, was simplistic. Release was defined in this model by how much gas flowed out into the borehole and an assumed amount of solids entrained in it over a prescribed time period. The time limit for release assumed in the calculations was 5 minutes, the time estimated for the driller to close the blowout preventers and start weighting up the drilling mud. Entrainment was a sampled percentage ranging from 0 to 10 percent. Defending the time limit for release was particularly difficult because opinions about how long it would take before the driller controlled the well varied widely. In addition, the model was not self-limiting, in the sense that release would continue for as long as the unchecked gas flow was assumed to continue, and quantification of the entrainment percentage was of concern.

To respond to these concerns, model development for release continued. A more-detailed model was developed based on the observation that a critical entrainment or lofting (terminal) velocity represents a threshold erosion condition. This value of the gas velocity defines whether solid particulate matter is separated from the bulk waste. Once separated, the material is assumed to be entrained in the gas and carried up the borehole to the ground surface (Berglund and Lenke 1995, Section 6.1, 33 – 39). Because gas velocities below this

threshold can remove no solids, the removal process is self-limiting: gas velocity decreases as a function of distance from the borehole, eventually dropping below the entrainment velocity threshold and terminating the process.

The first version of the steady-state model incorporating the terminal velocity release process assumed that gas would flow uniformly through the waste and out the borehole. It was based on the fact that the velocity of the gas decreases with distance from the borehole, because of the symmetry of the gas flow field. The flow velocity is greatest at the borehole boundary and decreases with distance away from it. Therefore, at some point sufficiently remote from the borehole, the gas velocity just equals the critical entrainment (terminal) velocity. All material closer to the borehole was assumed to be eroded and lofted up the borehole, but the gas velocity in all material farther from the borehole was too low to cause erosion. This hypothesis permitted a calculation of how much material would be released in connection with an assumed gas-pressure drop in the waste disposal region.

An experimental program was designed to confirm the model using a test apparatus to simulate gas flow through the waste and up the borehole (Lenke and Berglund 1995). The model-confirmation process was to first experimentally determine the entrainment velocity characteristics of the material, and then apply these data to the model to predict the amount of release expected for various boundary pressures. Boundary pressures were then experimentally applied to the samples in the experimental blowout device, and the amounts of eroded material were determined assuming uniform Darcy flow. The confirmation criterion was that if the measured amount of lofted material was less than the predicted amount of erosion then the model was considered confirmed. Confirmation was never possible, however, because the material release tests revealed that the assumption of uniform gas flow through the waste was not reflected by the response of the material. Instead of formation and expansion of a cavity left behind by eroded material, post-test observations showed that the gas instead created flow channels that increased in thickness as erosion proceeded. Releases were greater than expected because gas velocity in the channels was greater than it would have been had gas flowed through the bulk of the material (Lenke and Berglund 1995, 14). Channel flow was consistent with the heterogeneity of the waste.

The experimental observation of flow-channels formation by erosion forced another iteration in blowout-model development to make the model consistent with material response. The new model is used in performance assessment and is documented in Appendix CUTTINGS (Section 4).

Including a channel-flow mechanism in the model requires either precise definition of the number, geometric configuration, and location of all the channels before they form, which is not technically feasible, or scaling the model results in some manner to reflect the channeling process. The scaling method was adopted, adjusting the predicted releases to agree with experimental release observations. Although the uniform-flow model was independent of experiments, in the sense that release predictions did not require direct data from the tests, a coupling between experimental results and the model was necessary for scaling. This was

accomplished by introducing certain experimentally determined scaling constants into the model (see Appendix CUTTINGS). The model is applied to different gases and solid materials by prescribing well-defined material properties, such as particle size and density, viscosity, and cementation tensile strength. The scaling factors are the only parameters of the model not directly related to geometry or material properties, but they are necessary to represent the way channels for gas flow are likely to develop.

MASS.16.2 Direct Brine Releases during Drilling

This model provides a series of calculations to estimate the quantity of brine released directly to the surface during drilling. Direct brine releases may occur when a driller penetrates the WIPP and unknowingly brings contaminated brine to the surface during drilling. (These releases are not accounted for in the cuttings, cavings and spallings calculations, which model only the solids removed during drilling.) Attachment 16-2 describes the direct brine release model used for this performance assessment. The conceptual model is also discussed in Section 6.4.7.1.1.

Uncertainty in the BRAGFLO direct-brine-release calculations is captured in the 10,000-year BRAGFLO calculations from which the initial and boundary conditions are derived. The model parameters that have the most influence on the direct brine releases are repository pressure and brine saturation at time of intrusion. Brine saturation is influenced by many factors, including Salado and marker bed permeability and gas-generation rates (for undisturbed calculations). For E1 and E2 intrusions, Castile brine-reservoir pressure and volume and abandoned borehole permeabilities influence conditions for the second and subsequent intrusions. Dip in the repository (hence the location of intrusions), two-phase flow parameters (residual brine and gas saturation), time of intrusion, and duration of flow have lesser impacts on brine releases.

MASS.16.2.1 Historical Context of the Direct Brine Release Model

The direct brine release model is a relatively new development in WIPP performance assessments, and this performance assessment is the first one to incorporate this mechanism of release. Prior to using the current model in this performance assessment, several iterations of models were performed. At first, a simplistic cylindrical (radial) BRAGFLO model was used to represent the excavated volume of one intruded panel, but this was inadequate to capture the effects of heterogeneities within the site. This model was replaced with the current repository-scale mesh representing the configuration of the WIPP excavation, accounting for drifts, passageways, closures, pillars and rooms, and formation dip in the waste region. The current mesh reflects the configuration used by the DOE in this application, with flow unaffected by backfill within the panels. In addition, the vertical wellbore flow model is coupled to the BRAGFLO mesh, and the effects of solids removal caused by cavings and spall are examined (CUTTINGS_S code). Boundary conditions can account for two intrusions in a single panel, one of which connects to a brine reservoir.

The assumptions used in the models are based on current drilling practices in the Delaware Basin (see Appendix DEL). The wellbore model description assumes a typical WIPP-area oil or gas well completion, including bit size, casing size and depths, drilling mud, etc. The duration of flow is based on how a present-day driller might react to the pressures and flows predicted by the model when encountering high pressure (see Appendix DEL). The assumptions in the BRAGFLO direct-brine-release model (that is, about permeability, two-phase flow properties, crushed panel height, porosity) match those used in the 10,000-year BRAGFLO and CUTTINGS_S models.

The WIPP two-phase flow code BRAGFLO is used to simulate the direct brine releases during a drilling intrusion. This code is also used to calculate the 10,000-year flow of brine and gas through the WIPP and surrounding rock. However, a different conceptual model has been constructed to represent the excavated rooms, drift passageways, and the salt pillars between them. This refined mesh, or repository scale model, more accurately captures the flow patterns associated with the short-duration direct releases. The suite of software used to calculate direct brine releases is discussed in Appendix CODELINK. The output from the repository-scale direct release model is the volume of brine (cubic meters) released to the surface. The activity of radioisotopes in the brine released is determined using the actinide source term model.

MASS.16.3 Long-Term Properties of the Abandoned Intrusion Borehole

The purpose of the model for the long-term properties of the intrusion borehole is to provide in BRAGFLO the physical properties relevant to fluid flow through a plugged and abandoned borehole that intersects the repository. The model includes several possible plugging and configuration patterns based on current practice in the Delaware Basin (Attachment 16-1). Because plugging practice is closely controlled by state regulations, only the New Mexico portion of the Delaware Basin is considered. Section 6.4.7.2 of this application describes the properties assigned to the boreholes and the types of plug configurations considered in performance assessment.

The conceptual model for long-term flow up a plugged and abandoned borehole addresses the principal parameters in the intrusion borehole model for long-term flow: permeability, porosity, compressibility, and two-phase properties. Because these properties may change with time as the borehole plugs degrade, some types of boreholes have several defined stages for the evolution of borehole properties. No retardation of actinides or other transport-limiting effects in the borehole are assumed.

Permeability, the most important borehole property, changes according to the stage of borehole degradation. The values assigned to other parameters are held constant for all stages and are set consistent with a borehole fill referred to as silty sand, consisting of the material that would naturally slough off the walls of the borehole or the remains of degraded plugs. The porosity of the plugged and abandoned borehole is set at a low value within the porosities expected of materials that will be in the borehole; the low value was chosen because smaller

void volume in the borehole reduces storage in the borehole and slightly increases the total flux of fluids that may pass through it.

Predictions of the time-dependent permeability of plugged boreholes are based on three configurations for borehole plugs and two concepts of how the plug materials will be altered by fluids. The concepts include steel corrosion and concrete degradation. From the outside inward, the conceptual model for borehole plugs envisions concentric circles of ordinary portland cement as grout attaching the casing to the rock, low carbon steel (the casing), and a central disc of ordinary portland cement (the concrete plug). The bulk of the data used to predict the service lives of borehole plugs comes from the open literature on corrosion of low carbon steel and ordinary portland cement and from tabulated thermodynamic data bases.

Predictions of plug performance derived from the conceptual models are sensitive to both chemical and physical parameters. Key areas of uncertainty include the following:

- opened or closed nature of the physical and chemical systems,
- degree to which performance data from generic materials apply to WIPP-specific materials and conditions,
- conditions at the precise locations where WIPP plugs are emplaced, and
- physical dimensions of the plugs.

The conceptual models for predicting the time-dependent permeability of plugged boreholes recognize two types of systems: open and closed. Open systems are ones in which chemical components can be added or subtracted freely, whereas closed systems are ones in which the identity and amount of chemical components available for reaction are constant. In physical models, a closed system maintains a constant volume, while in open systems volume is unconstrained. The principal area of uncertainty in the conceptual models is the definition of the boundary between open and closed space. This boundary is significant because real systems are somewhere between totally open or closed, and open and closed systems result in very different expected performance lives for plugged boreholes.

In chemical systems, a very small addition or release of reacting components is insignificant, but a substantial change can have large effects: in open systems reactions proceed until the supply of reactants is exhausted. In open systems, equilibrium considerations may have little or no significance; hence treatment by equilibrium thermodynamics may be unenlightening. Similarly, in physical systems, a small amount of system expansion will have little effect on internal stresses, but unlimited expansion may cause the system to fail in tension.

MASS.16.3.1 Corrosion

There are many low-carbon-steel alloys, and not all corrode at the same rate in a given environment. However, because of the aggressive corrosion rate selected for the model, steel composition is not thought to introduce significant uncertainty about the rate. Corrosion of the casing steel has been modeled thermodynamically for plugged boreholes. Hydrogen is a common byproduct of corrosion. An equilibrium hydrogen pressure has been calculated for a number of potential reactions, using metallic iron to represent steel and pure water to represent brines. Attainment of equilibrium hydrogen pressure is taken to indicate cessation of corrosion. To reach equilibrium, the system must contain the hydrogen that is generated. The hydrostatic pressure of the brine column has been assumed to confine hydrogen when the pressure exceeds the equilibrium hydrogen pressure calculated for the corrosion reaction of interest.

Reactions most representative of corrosion of steel casing produce iron hydroxide corrosion products. Equilibrium hydrogen pressures for these reactions are exceeded by hydrostatic pressures at depths greater than about 1,100 feet (335 meters). Corrosion of casing above this depth is treated as open; the casing corrodes until the supply of metallic iron is exhausted and the casing disintegrates. Without axial support supplied by the casing, the concrete plug also fails. In contrast, corrosion is assumed to take place in a closed system at depths greater than 1,100 feet (335 meters). Hydrogen is not free to nucleate as a gas and leave the system. Although local perforations in the casing are expected, the casing does not disintegrate. It supports the concrete plugs, and permeability changes in the plugs are attributed to alteration of cement phases by the brine that flows through them.

The greatest uncertainty associated with composition is likely to arise from the thermodynamic calculations used in the model. Pure phases (Fe for steel and H_2O for brine) have been assumed so that hand calculations may be more readily performed. Various reactions and environments have been modeled without directly considering complexities in the chemical system (other than volatiles). Qualitatively, the added complexities are likely to have no substantial consequence on the ability of the brines to dissolve a pathway through the casing. However, system complexities might decrease the equilibrium hydrogen pressures calculated for the corrosion reactions or lead to unexpected reaction products.

Data supporting low-carbon-steel corrosion models come primarily from the literature. The empirical data support the assumption that general corrosion is the dominant mechanism for corrosion under oxic conditions and that pitting will occur under low oxygen (and high pH) or elevated carbon dioxide and hydrogen disulfide conditions. Corrosion rates are a function of the conditions under which corrosion occurs. Published data include rates as rapid as 3 millimeters per year, which is the value assumed in the model. Such rapid rates are not inconsistent with reports in the Delaware Basin of casing failures occurring from corrosion within months to years (Attachment 16-3, B-17). Data from corrosion of steel enshrouded in concrete come from the literature on marine construction and the data base on reinforcing steels. These data support the assumption that steel encased in concrete cannot be assumed to

corrode more slowly than exposed steel. This subject area is discussed in detail in Attachment 16-3 (Section 3.2 and Appendix B).

MASS.16.3.2 Portland Cement Concrete

The cementitious materials used in hydrocarbon exploration are variable. The degree to which oil-field materials might perform differently from the cement mixtures investigated and reported in the literature is unknown. There is no standard mix formulation that specifies plugging cements precisely; the use of generic data is reasonable, because the vagaries of cement composition are implicitly included. The published empirical studies of concrete degradation include a large body of data for reacting solutions ranging from pure water to marine brines. Waters with higher chloride and magnesium contents cause greater reaction. This level of detail has not been factored into the model directly; rather, alteration by brines has been the favored source when extracting information on degradation.

Chemical alteration of cement phases by brine produces new solids with greater molar volumes than the unaltered, hardened cement phase. In a closed physical system, the alteration will lead to decreased internal porosity and consequent decrease in permeability. In an open physical system, alteration will lead to increased internal pore pressures that will eventually exceed the tensile strength of the concrete plug. The result is often seen on concrete sidewalks or other unreinforced concrete structures: without something to restrain expansion, the concrete cracks, increasing its porosity and permeability.

Current plugging practices create configurations that favor each model. Plugs installed to respond to the New Mexico Oil Conservation Division regulation R-111-P approach 2,000 feet (610 meters) in length (State of New Mexico 1988). These plugs are judged to be long enough that they are self-confining. As a result, alteration of R-111-P plugs produces a situation in which performance is indistinguishable from the undisturbed rock. In contrast, plugs emplaced in response to regulations of the U.S. Bureau of Land Management have a mean length near 40 meters. This length is judged to be too short to provide self-confinement; alteration of the concrete results in fracturing and increased porosity and permeability in the plug. The plug length that changes the physical system from open to closed is undetermined. For both chemical and physical model elements, a closed system enhances performance.

Simulation of concrete plug degradation follows a model proposed by Berner (1990), in which the matrix degrades after dissolution and removal of soluble materials such as alkali salts. The model is grounded in empirical observations that concrete alteration sequentially removes excess alkalis, portlandite, and tobermorite or calcium-silicate-hydrate (CSH). Decreased strength attends removal of portlandite.

A critical amount of flow must occur before this degradation threshold is crossed. A volume equivalent to 100 pore volumes has been taken as the critical flow volume, based on values for common compositions of ordinary portland cement concrete (Berner 1990). Also following Berner, the model tracks the amount of flow as pore volumes, reasoning that flow

occurs only through pores and that alteration is therefore limited to the solids that surround the pores. The model does not explicitly account for the strength of the concrete but instead makes the conservative assumption that physical failure occurs suddenly at the onset of chemical attack on CSH, that is, at approximately 100 pore volumes. As a result, initial porosity of the hardened concrete is a key parameter for timing plug degradation.

The initial permeability of hardened cement is directly related to the connected porosity that permits flow to occur. Initial permeability of ordinary portland cement is a strong function of the water:cement ratio of the mix. Higher water contents produce higher porosity and permeability. To simplify the analysis, initial plug permeability has been taken as a constant at 5×10^{-17} square meters. This value lies in the upper range of permeabilities reported for ordinary portland cement and is verified by field measurements made during a single field test of borehole plugging conducted for the DOE (Attachment 16-3, C-4).

The initial permeability of the concrete plug is an important parameter because water must penetrate and flow through the structure before it can alter the hardened plug. The lower the permeability, the longer it takes for 100 pore volumes to pass through the plug. Somewhat paradoxically, the lower the porosity, the smaller the volume of water needed before attack of the CSH begins, because the model decouples the relationship between porosity and permeability by holding permeability constant. In the real world, cement formulations with low water:cement ratios generally produce fewer alkalis and have both lower porosities and lower permeabilities. Less water must pass through the concrete body before onset of CSH degradation, but the lower permeabilities lead to a longer life. The simplified model is conservative: it holds the permeability constant at the upper end of the established range while allowing porosity to vary over the full range commonly encountered in ordinary portland cement. This accommodation reflects better knowledge of permeabilities than porosities in as-emplaced borehole plugs. The range in porosity modeled (5 to 40 percent) can create an order-of-magnitude spread in predicted performance life.

Data supporting the concrete degradation model come primarily from two sources: the international repository literature and journals on concrete construction (for example, dams or bridges). The international literature on repositories contains both models and empirical studies confirming that alteration of concrete will result in decreased porosities and permeabilities in closed systems. Experience for dams confirms this conclusion and confirms the diffusion-driven concrete alteration rates used in the model. The general concrete literature confirms the values of initial permeability and porosity of hardened concrete used in the model.

Observations made on cores recovered from potash mines near the WIPP confirm that alteration of concrete plugs is not extensive after decades of service. Qualitative data have been produced by recovery, microscopic inspection, and leach testing of concrete cores recovered from nearby potash mines. These data establish that plugs placed in boreholes will have low initial permeabilities and that plugs placed in the Salado will form tight interfaces at the borehole-rock interface and will not degrade substantially by contact with formation brines

in the amounts and compositions that might reasonably be expected. Attachment 16-3 (Section 3.3 and Appendices C and D) discusses concrete alteration of plugs and creep closure of boreholes in more detail.

MASS.16.3.3 Borehole Configurations

The conceptual models for borehole plugs examine three basic possibilities: a continuous plug through the evaporite sequence, a plug below the brine reservoir horizon coupled with a plug between the repository and the Rustler, and three or more plugs with at least one intermediate plug between the brine reservoir and the repository and another between the repository and the Rustler. These possibilities represent simplifications of the plugging schemes documented in the 1996 survey (see Chapter 6.0, Sections 6.4.7.2.1 through 6.4.7.2.3, and Attachments 16-1 and 16-3, Section 2.1).

As stated, the basis for these assumptions is a detailed survey of plugging practices in the Delaware Basin. The survey examined the lengths, locations, and intervals plugged, as well as the materials used for construction. The locations of plugs are determined partly by stratigraphic changes and partly by operational considerations during exploration and recovery. Variations in plug length and location affect pressure regimes and flow rates through plugs. The 120-foot (40-meter) length of the plugs is the approximate mean value of approximately 188 plugs in the survey. Minimum lengths prescribed by regulations are 50 feet (15 meters) above plus 50 feet (15 meters) below casing transitions or recovery points. Additional plug lengths sometimes occur for unspecified reasons. When all else is equal, performance life is proportional to plug length. For conservatism, the model does not consider the longer plugs. In the conceptual model, all plugs are taken to be 120 feet (40 meters) long. See Attachment 16-3 (Section 5.0) for a more detailed discussion of plug performance.

The borehole permeability model was assembled beginning in February 1996. Initially, the model considered only the plug configuration stipulated by Oil Conservation Division regulations, but it was subsequently expanded to consider all regulations and practices documented in the New Mexico portion of the Delaware Basin, without specific consideration of their applicability to the WIPP in the future. The model was developed to be straightforward and easy to understand. Use of hand calculations was favored over the use of complex computer codes. As a result, no detailed evaluation of potentially applicable codes was undertaken, and no screening of codes was performed.

The text of the attached report (Attachment 16-3) describing the model and its predictions contains about 40 references with data that support the model. In general, these references support the plug configurations, steel corrosion mechanisms and rates, and concrete alteration processes that underpin the model.

MASS.17 Climate Change

The purpose of this model is to allow quantitative consideration of the extent to which uncertainty about future climate may contribute to uncertainty in estimates of cumulative radionuclide releases from the disposal system. Consideration is limited to conditions that could result from reasonably possible natural climatic changes. The model is not intended to provide a quantitative prediction of future climate, nor is it intended to address uncertainty in system properties other than estimated cumulative radionuclide releases that may be affected by climate change. This model is also discussed in Chapter 6.0 (Section 6.4.9).

As discussed in Appendix CLI, paleoclimatic data from the literature form the basis for reconstructing the climatic variability in southeastern New Mexico since late Pleistocene time, spanning the transition from full glacial conditions in North America (ice sheets as far south as the Northern Great Plains) to the present interglacial period. The wettest and coolest climate at the WIPP corresponded to periods of continental glaciation. During Holocene time (the past 10,000 years), the climate has been predominantly dry, like that of the present, with several wetter episodes.

Future climate at the WIPP may differ in the next 10,000 years from that of the present, but it should be bounded by the extremes of the late Pleistocene glaciation. For the purposes of performance assessment, the DOE assumes that uncertainty about future climate is adequately captured by considering two possible patterns: one in which the Holocene pattern of predominantly dry conditions alternating with wetter conditions continues; and one in which the climate becomes continuously wetter.

Effects of climatic change on the WIPP are limited in the performance assessment model to effects on groundwater flow in the Culebra. Flow (that is, specific discharge in the SECOFL2D model) is increased from its present calibrated value by a sampled factor that ranges from 1.0 to 2.25 to simulate effects of wetter climates. Possible decreases in flow during drier climates are not considered. Justification for limiting the effects of climate change to flow in the Culebra is based on regional three-dimensional modeling that estimates the extent to which changes in recharge will alter the altitude of the water table and in turn affect flow in the Culebra and other units. Maximum recharge rates considered in the analysis result in a simulated water-table altitude at or near the ground surface throughout the region. Other effects of climatic change, including changes in temperature, wind, evapotranspiration, and vegetation, are not modeled explicitly but are qualitatively included in this analysis through the consideration of the effects of varying recharge.

The climate change model is implemented through the use of a single parameter, the Climate Index. This parameter is a dimensionless factor by which the specific discharge in each grid block of the SECOFL2D domain is multiplied. It is a sampled parameter in the performance assessment, with a bimodal distribution ranging from 1.00 to 1.25 and from 1.50 to 2.25. See Corbet (1995) and Attachment 17-1 for a discussion of this distribution.

The climate change model used for performance assessment is predicated on the assumption that climate will change during the next 10,000 years. The extent of this change is uncertain, but it should be bounded by the changes that occurred in the past during the peaks of Pleistocene glaciation. Other conceptual models for climate change are not consistent with present scientific understanding of the Earth's climate or with the EPA's guidance to consider natural processes of climatic change (EPA 1996, 5227-5228). For example, climate could be assumed to remain constant for 10,000 years, but this would be inconsistent with scientific understanding of climate. Alternatively, climate could be assumed to change to conditions unlike any known from the Pleistocene; however, no natural processes are known that could result in such change within 10,000 years.

As discussed in Corbet (1995) and Attachment 17-1, the implementation of climate change in the performance assessment incorporates uncertainty about future climates within the range known from the Pleistocene. Alternative approaches to treating climate change in the performance assessment (that is, varying boundary conditions rather than specific discharge) are discussed in the following section. Past analyses performed using a different approach as part of the 1991 and 1992 preliminary performance assessments suggest that disposal system performance is not sensitive to climate change (Swift et al. 1994, 12).

MASS.17.1 Historical Context of the Climate Change Model

Past changes in climate at the WIPP have been recognized since the earliest site characterization work. As described in Appendix GCR (3-102), Brokaw et al. (1972) and Bachman (1974) interpreted the sedimentary record of the Gatuña, the Mescalero caliche, and the overlying surficial sediments (see Chapter 2.0, Sections 2.1.3.8, 2.1.3.9, and 2.1.3.10) as indicating alternating wetter and drier climates during the Pleistocene. Bachman continued extensive geologic work in the WIPP region throughout site characterization and further documented the sedimentary evidence for Pleistocene climatic change (Bachman 1976, 1980, 1981, 1985, 1987). One borehole, WIPP-15, was drilled in 1978 in San Simon Sink southeast of the WIPP to examine the causes of subsidence in the sink and to obtain paleoclimatic data (SNL and University of New Mexico, 1981). Core from the borehole indicates about 547 feet (167 meters) of total subsidence in the Quaternary. Aquatic fauna and flora from the upper 98 feet (30 meters) of core indicate a wet climate followed by an arid period before the present.

In addition to site-specific geologic evidence, past climatic changes have been inferred by other workers throughout the southwest based on various data. Bachman (1989) prepared an annotated bibliography of relevant information published as of 1984. Swift (see Appendix CLI) prepared a synthesis of Pleistocene climate at the WIPP based on detailed examination of available literature. Swift's analysis forms the basis for the DOE's present understanding of climatic change.

Early interest in the possible effects of climatic change on disposal system performance focused on the possibility that wetter climates might increase rates of salt dissolution. As discussed in Chapter 2.0 (Section 2.1.6.2), and Appendix SCR (Section SCR.1.1.5.1), average

dissolution rates over the past several hundred thousand years include both wet and dry climates and are too low to affect disposal system performance during the next 200,000 years. Questions have also been raised about whether dissolution or precipitation of fracture fillings in the Culebra could occur during climatic changes and alter the rate of radionuclide transport in groundwater. As discussed in Appendix SCR (Section SCR.1.1.5.2), isotopic data from Siegel et al. (1991, 5-53 to 5-57), Chapman (1986), and Lambert (1987) indicate that mineralogical changes from interactions with groundwater have been minimal during late Pleistocene time in the units above the Salado. Future mineralogical changes that might occur during climate changes are therefore also expected to be minimal.

Based on their interpretation of uranium isotope activity ratios and other isotopic data from WIPP area groundwater, Lambert and Carter (1987) and Lambert (1991) proposed that climatic change in the past could have had a significant effect on groundwater flow direction. In their interpretation, wetter conditions during the late Pleistocene recharged the Rustler in the vicinity of Nash Draw, with flow occurring to the southeast. Drier conditions of the Holocene (including the present) resulted in no recharge and a gradual shift in flow directions to those observed at present.

Current understanding of regional groundwater flow is consistent with Lambert and Carter's general observation that flow directions may change with changing climate, but the specifics of their proposal are not supported by regional three-dimensional modeling. Flow in the Rustler during the wet period of the late Pleistocene was probably driven by a higher water table than that of the present and probably followed the local topography from east to west at the WIPP, rather than northwest to southeast. Drier conditions of the Holocene resulted in less, but perhaps not zero, recharge, and the altitude of the water table fell. Flow directions in the Culebra shifted to their present north-to-south direction, reflecting regional topography of the Delaware Basin.

Early assessments of system performance (for example, DOE 1980) did not consider the possibility that climatic change could affect the transport of radionuclides through its effects on groundwater flow. The 1991 preliminary performance assessment for the WIPP contained the first quantitative analysis of the possible effects of climatic change on radionuclide transport through the Culebra (WIPP Performance Assessment Division 1991, 6-35 to 6-43). The effects were approximated by varying heads along a portion of the northern boundary of a two-dimensional flow model for the Culebra. Heads were varied using a function that resulted in three peaks during the next 10,000 years, separated by periods in which heads were lowered to their present values. The maximum head elevations were prescribed by a sampled parameter that, at its largest value, allowed heads to reach the land surface and resulted in the maximum potentiometric gradient across the domain.

The 1992 preliminary performance assessment for the WIPP used an approach similar to that of the 1991 analyses (WIPP Performance Assessment Department 1993, 6-11 to 6-19). Sensitivity analyses performed for both the 1991 and 1992 preliminary performance assessments indicated that cumulative radionuclide releases were not sensitive to the variation

in heads at the northern boundary, conditional on the other assumptions adopted in the preliminary performance assessments (Swift et al. 1994, 9 – 12).

Variations in boundary heads were abandoned for this performance assessment because the regional three-dimensional modeling provided the basis for an approach that was better linked to the near-surface processes of infiltration and recharge and that offered more control over groundwater flow within the controlled area. The degree to which variations in boundary heads affected flow over the repository in previous analyses was in part determined by the location of the boundaries and their distance from the site. Setting boundary conditions closer to the repository could have had a greater effect on flow over the site. Furthermore, restricting changes in boundary heads to a single location restricted the possibility for changes in flow direction.

In addition to work performed to address the treatment of climatic change in this application, additional work was performed using the regional three-dimensional groundwater model to examine the validity of approximating three-dimensional flow in the Rustler with a two-dimensional model of the Culebra. This work indicates that within the controlled area essentially all flow out of the Culebra is lateral. This result, documented by Corbet (1995), provides the basis for applying a scaling factor derived from a three-dimensional model to a two-dimensional model.

MASS.18 Castile Brine Reservoir

The conceptual model for the brine reservoir is included in the performance assessment to estimate the extent to which uncertainty about the existence of a brine reservoir under the waste disposal region may contribute to uncertainty in the estimate of cumulative radionuclide releases from the disposal system. The conceptual model is not intended to provide a realistic approximation of an actual brine reservoir under the waste disposal region: data are insufficient to determine whether such a brine reservoir exists.

The Castile is treated as an impermeable unit in performance assessment and plays no role in the analysis except to separate the Salado from the brine reservoir, that is important in human-intrusion scenarios. Properties of the brine reservoir, including its permeability, porosity, volume, and initial pressure, are chosen to be consistent with available data from borehole penetrations of brine reservoirs in the region.

Basic geologic information about the Castile is given in Chapter 2.0 (Section 2.1.3.3). The hydrology of the known brine reservoirs is discussed in Section 2.2.1.2.2. The treatment of the brine reservoir in the performance assessment is discussed in Chapter 6.0 (Section 6.4.8), which also points to supplementary information included in this application.

The principal parameters used in the brine reservoir model, described in Section 6.4.8, include permeability, porosity, pore compressibility, initial pressure, and two-phase flow properties. These parameters are implemented in the BRAGFLO model and affect the amount and rate of

brine flow up an intrusion borehole. Brine flow up a borehole is also affected by conditions in other regions of the BRAGFLO model, including most directly the permeability of borehole-fill material and fluid pressure in the borehole. The volume of the brine reservoir is treated as an uncertain quantity in the performance assessment.

Attachment 18-4 discusses the estimate of the probability of intercepting a pressurized brine reservoir used in BRAGFLO to develop the brine reservoir volumes. The probabilities described in this memorandum are used to determine the cumulative distribution function for the volume of a Castile brine reservoir. According to the method used, there is a 6/32 probability of a 32,000-cubic-meter brine reservoir (the probability of 0 and 1 reservoirs combined), a 10/32 probability of a 64,000-cubic-meter brine reservoir, a 10/32 probability of a 96-cubic-meter brine reservoir, a 5/32 probability of a 128,000-cubic-meter brine reservoir, and a 1/32 probability of a 164,000-cubic-meter brine reservoir. See Chapter 6.0 (Section 6.4.12.6) for additional discussion of the probability of intercepting a brine reservoir.

MASS.18.1 Historical Context of the Castile Brine Reservoir Model

The FEIS (DOE 1980) acknowledged the possible importance of Castile brine, based largely on the encounter at ERDA-6. However, it concluded that brine probably was not present beneath the WIPP site, based on geologic structure and available well data (including the absence of brine in WIPP-12, prior to deepening). Scenario development for the FEIS considered brine occurrences, but consequences of a brine reservoir were not modeled explicitly. The presence of brine beneath the repository was considered to be extremely unlikely. No natural pathways connecting any brine reservoir with the repository were thought to be present. Boreholes penetrating the repository and any brine reservoir were assumed to be cased, and any flow from a reservoir would, therefore, have no impact (borehole-casing degradation was not considered).

Spiegler (1982) concluded that brine reservoirs, originally at hydrostatic pressure, formed several million years ago, prior to regional-scale erosion and decrease of overburden. He assumed an original connection of the reservoir to the water table and concluded that reservoirs formed (and were presumably isolated) several million years ago.

Spiegler and Updegraff (1983) concluded that the original brines were sea water, but that release of water from gypsum dehydration could not be ruled out. Popielak et al. (1983) agreed that Castile brines were relict or ancient sea water. They estimated a brine-residence time of about one million years, believing that isolation preceded the latest stage of basin tilting.

Popielak et al. (1983) and Faith et al. (1983), on the basis of analyses of brines from the WIPP-12 and ERDA-6 occurrences, concluded that these two reservoirs are isolated occurrences.

Lambert and Carter (1984) hypothesized that there may have been a Pleistocene connection of the reservoirs to the Capitan Limestone, that is, that the brines were originally fresh water. Using several assumptions, they calculated minimum residence times for WIPP-12 and ERDA-6 brines ranging from 360,000 to 880,000 years on the basis of $^{234}U/^{238}U$ activity ratios.

By the time of the Site and Preliminary Design Validation, Borns et al. (1983) concluded that

- reservoirs formed mainly because of gravity tectonics (in response to density inversion of thick halites and anhydrites),
- the WIPP-12 structure (1 percent strain) took a minimum of 10,000 years to form, and
- gravity tectonics were probably continuing, although at a reduced rate, because of decreased overburden over the past few million years.

The conceptual understanding of the origin of reservoirs did not change between the early 1980s and the time of the DSEIS (DOE 1989) and FSEIS (DOE 1990). Brine reservoirs were (and still are) believed to be isolated occurrences. Based on a Time Domain ElectroMagnetic (TDEM) survey over the repository area, Earth Technology Corporation (1988) estimated that a conductive horizon, which could be interpreted to represent Castile brine reservoirs, underlies portions of the waste-emplacement panels (four out of nine soundings directly over the panels). A recent interpretation of this data set is in Attachment 18-5.

For purposes of numerical modeling, hypothetical brine reservoirs were assumed to be radially symmetrical, with an inner highly-fractured zone of high transmissivity, and an outer (less-fractured) zone of moderate transmissivity. The outer zone is surrounded by an infinitely extending anhydrite matrix, representative of intact (unfractured) Castile. The brine-reservoir model produced double-porosity fluid-flow responses. This treatment implicitly assumes that any borehole intersecting an area underlain by a brine reservoir will produce large amounts of brine; the possibility that boreholes could penetrate the highly fractured reservoir, but miss highly conductive fractures, was not considered.

Assuming that the reservoirs are radial, and based on an areal view of wells penetrating the Castile (some of which did and some of which did not encounter a brine reservoir), Reeves et al. (1991) determined that brine reservoirs could be expected to have radii varying from approximately 2,625 to 10,499 feet (800 to 3,200 meters). Deterministic calculations in the DSEIS and FSEIS assumed that any borehole penetrating the WIPP repository would penetrate a Castile brine reservoir, and that this reservoir could be represented by the estimated characteristics of the WIPP-12 brine reservoir.

There was no fundamental change in the conceptual understanding of brine reservoirs in the December 1992 performance assessment. Performance assessment calculations included gas pressurization of the repository, which was not considered in DSEIS calculations. This

pressurization helped delay brine depressurization of the Castile reservoirs. It was estimated that brine underlay 25 to 57 percent of the waste-emplacement panels, with a median of 40 percent. This estimate was based on a contouring of the existing TDEM data, and was implemented as a probability of a given borehole intersecting brine. Any borehole penetrating a reservoir was assumed to produce brine. A broad range of significant reservoir properties (for example, initial pressure, storativity) were sampled probabilistically, without assuming that any reservoir present would be represented by WIPP-12 properties. The WIPP-12 characteristics did, however, fall within the sampled range.

Section 6.4.8 describes the DOE's current model of a fractured Castile brine reservoir, as implemented by performance assessment. The main conceptual change is the idea that, because of the high angle of vertical fracturing in Castile brine reservoirs, many boreholes may penetrate a brine occurrence without penetrating a conductive fracture. Thus, even though the recent interpretation (Attachment 18-5) of the TDEM data suggest that 10 to 55 percent of the waste-panel area may be underlain by one or more brine reservoirs, the probability of a borehole in the panel area encountering brine may be lower. The geostatistical study performed by Powers et al. (Attachment 18-6) indicated an 8 percent probability of a borehole in the panel area encountering Castile brine. This probability is assigned to determine whether deep boreholes are of the E1 or E2 type in the 1996 performance assessment.

REFERENCES

Section MASS.2 References:

Channell, J.K. 1982. *Calculated Radiation Doses form Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine.* EEG-11. The Environmental Evaluation Group, Albuquerque, NM .

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026, U.S. Department of Energy, Washington, DC. WPO 38835, WPO 38838 – 38839.

DOE (U.S. Department of Energy). 1990. *Final Safety Analysis Report.* WP 02-9, Rev. 0, May 1990. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Tyler, L.D., Matalucci, R.V., Molecke, M.A., Manson, DE, Nowak, E.J., and Stormont, J.C. 1988. *Summary Report for the WIPP Technology Development Program for Radioactive Waste.* SAND88-0844, Sandia National Laboratories, Albuquerque, NM. WPO 24040.

Westinghouse Electric Corporation (WEC). 1996. *Backfill Engineering Analysis Report, Waste Isolation Pilot Plant.* Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM. WPO 37909.

WIPP Performance Assessment Department. 1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B.* SAND92-0700/4, Sandia National Laboratories, Albuquerque, NM. WPO 20958.

Woolfolk, S.W., 1982. *Radiological Consequences of Brine Release by Human Intrusion Into the WIPP.* TME-3151, U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM.

Zimmerman, D.A. and Gallegos, D.P. 1993. A Comparison of Geostatistically-Based Inverse Techniques for Use in Performance Assessment Analyses at the WIPP Site: Results from Test Case No. 1. *High Level Radioactive Waste Management, Proceedings from the Fourth Annual International Conference, Las Vegas, Nevada, April 26-30, 1993.* SAND92-2127C, Volume 2, p. 1426 – 1436. American Nuclear Society, La Grange Park, IL, and American Society of Civil Engineers, New York, NY. WPO 27840.

Section MASS.3 References:

Amyx, J.W., Bass, D.M. Jr., and Whiting, R.L. 1960. *Petroleum Reservoir Engineering, Physical Properties.* ISBN 07-001600-3, McGraw-Hill Book Company, New York, NY. (derived from equation 2-33) pp. 78.

Bear, J. 1972. *Dynamics of Fluid in Porous Media.* ISBN 0-486-65675-6, Dover Publications, New York, NY.

Beauheim, R.L., Saulnier, Jr., G.J. and Avis, J.D. 1991. *Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant: First Interim Report.* SAND90-0083, Sandia National Laboratories, Albuquerque, NM. WPO 26003.

Beauheim, R.L., Roberts, R.M., Dale, T.F., Fort, M.D., and Stensrud, W.A. 1993. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report.* SAND92-0533, Sandia National Laboratories, Albuquerque, NM. WPO 23378.

Brush, L.H. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266, Sandia National Laboratories, Albuquerque, NM. WPO 26015.

Christian-Frear, T.L., and Webb, S.W. 1996. *The Effect of Explicit Representation of the Stratigraphy on Brine and Gas Flow at the Waste Isolation Pilot Plant.* SAND94-3173, Sandia National Laboratories, Albuquerque, NM.

Collins, R.E. 1961. *Flow of Fluids Through Porous Materials.* Reinhold, New York, NY.

Friend, D.G., and Huber, M.L. 1994. Thermophysical Property Standard Reference Data from NIST, *International Journal of Thermophysics.* Vol. 15, no. 6, 1279 – 1288.

NIST (National Institute of Standards and Technology). 1992. *Thermophysical Properties of Hydrogen Mixtures Database (SUPERTRAPP): Version 1.0 User's Guide.* U.S. Department of Commerce, National Institute of Standards and Technology Standard Reference Data Program, Gaithersburg, MD.

Wang, Y. 1995. Maximum gas generation rate and maximum quantity of gas generated. Memorandum to P. Chen dated December 21, 1995. SWCF-A W.B.S 1.1.09.1.1 (WPO 36288). Sandia National Laboratories, Albuquerque, NM.

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991 - Volume 3: Reference Data.* SAND91-0893/3. Eds. R.P. Rechard, A.C. Peterson, J.D. Schreiber, H.J. Iuzzolino, M.S. Tierney, and J.S. Sandha. Sandia National Laboratories, Albuquerque, NM.

Section MASS.4 References:

Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters.* SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM. WPO 23529.

WIPP Performance Assessment Department. 1992a. *Long-Term Gas and Brine Movement at the Waste Isolation Pilot Plant: Preliminary Sensitivity Analyses for Post-Closure 40 CFR 268 (RCRA), May 1992.* SAND92-1933, Sandia National Laboratories, Albuquerque, NM. WPO 23513.

WIPP Performance Assessment Department. 1992b. *Preliminary Performance Assessment for the Waste Isolation Pilot Plan, December 1992- Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance.* SAND92-0700/5, Sandia National Laboratories, Albuquerque, NM. WPO 20929.

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991 - Volume 2: Probability and Consequence Modeling.* SAND91-0893/2, Sandia National Laboratories, Albuquerque, NM. WPO 26415.

Section MASS.5 References:

Rechard, R.P., Beyeler, W., McCurley, R.D., Rudeen, D.K., Bean, J.E., and Schreiber, J.D. 1990. *Parameter Sensitivity Studies of Selected Components of the Waste Isolation Pilot Plant Repository/Shaft System.* SAND89-2030, Sandia National Laboratories, Albuquerque, NM. Chapter 5, Summary and Conclusions, pp. 153 - 160. WPO 25946.

WIPP Performance Assessment Department. 1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B.* SAND92-0700/4, Sandia National Laboratories, Albuquerque, NM. Section 4.1, Model Geometry, 4-1, 4-3. WPO 23599.

Section MASS.7 References:

Deal, D.E., and Case, J.B. 1987. *Brine Sampling and Evaluation Program, Phase I Report.* DOE-WIPP 87-008, Westinghouse Electric Corporation, Carlsbad, NM.

Deal, D.E., and Roggenthen, W.M. 1989. "The Brine Sampling and Evaluation Program (BSEP) at WIPP: Results of Four Years of Brine Seepage Data," *Waste Management '89, Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education, Tucson, AZ, February 26-March 2, 1989.* Ed. R.G. Post. University of Arizona, Tucson, AZ. Vol. 1, 405 – 406.

Deal, D.E., Case, J.B., Deshler, R.M., Drez, P.E., Myers, J., and Tyburski, J.R. 1987. *Brine Sampling and Evaluation Program Phase II Report.* DOE-WIPP-87-010, Westinghouse Electric Corporation, Carlsbad, NM.

Deal, D.E., Abitz, R.J., Belski, D.S., Case, J.B., Crawley, M.E., Deshler, R.M., Drez, P.E., Givens, C.A., King, R.B., Lauctes, B.A., Myers, J., Niou, S., Pietz, J.M., Roggenthen, W.M., Tyburski, J.R., and Wallace, M.G. 1989. *Brine Sampling and Evaluation Program, 1988 Report.* DOE-WIPP-89-015, Westinghouse Electric Corporation, Carlsbad, NM.

Deal, D.E., Abitz, R.J., Belski, D.S., Clark, J.B., Crawley, M.R., and Martin, M.L. 1991a. *Brine Sampling and Evaluation Program, 1989 Report.* DOE-WIPP-91-009. Prepared for U.S. Department of Energy by IT Corporation and Westinghouse Electric Corporation. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Deal, D.E., Abitz, R.J., Myers, J., Case, J.B., Martin, M.L., Roggenthen, W.M., and Belski, D.S. 1991b. *Brine Sampling and Evaluation Program, 1990 Report.* DOE-WIPP-91-036. Prepared for U.S. Department of Energy by IT Corporation and Westinghouse Electric Corporation. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Deal, D.E., Abitz, R.J., Myers, J., Martin, M.L., Milligan, D.J., Sobocinski, R.W., Lipponer, P.P.J., and Belski, D.S. 1993. *Brine Sampling and Evaluation Program, 1991 Report.* DOE-WIPP-93-026. Prepared for U.S. Department of Energy by IT Corporation and Westinghouse Electric Corporation. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

McTigue, D.F. 1993. *Permeability and Hydraulic Diffusivity of Waste Isolation Pilot Plant Repository Salt Inferred from Small-Scale Brine Inflow Experiments.* SAND92-1911, Sandia National Laboratories, Albuquerque, NM.

Vaughn, P., Lord, M., and MacKinnon, R. 1995a. "DR-6: Brine Puddling in the Repository due to Heterogeneities." Summary Memo of Record to D.R. Anderson, December 21, 1995, SWCF-A:1.1.6.3. Sandia National Laboratories, Albuquerque, NM. WPO 30795.

Vaughn, P., Lord, M., and MacKinnon, R. 1995b. "DR-7: Permeability Varying with Porosity in Closure Regions." Summary Memo of Record to D.R. Anderson, December 21, 1995, SWCF-A:1.1.6.3. Sandia National Laboratories, Albuquerque, NM. WPO 30796.

Vaughn, P., Lord, M., and MacKinnon, R. 1995c. "DR3: Dynamic Closure of the North End and Hallways." Summary Memorandum of Record to D. R. Anderson, September 28, 1995. SWCF-A:1.1.6.3. Sandia National Laboratories, Albuquerque, NM. WPO 30798.

Vaughn, P., Lord, M., Garner, J., and MacKinnon, R. 1995d. "GG-1: Radiolysis of Brine." Summary Memo of Record to D.R. Anderson, October 10, 1995, SWCF-A:1.1.6.3. Sandia National Laboratories, Albuquerque, NM. Contained in WPO 30791.

Vaughn, P., Lord, M., and MacKinnon, R. 1995e. "DR-2: Capillary Action (Wicking) within the Waste Materials." Summary Memo of Record to D.R. Anderson, December 21, 1995, SWCF-A:1.1.6.3. Sandia National Laboratories, Albuquerque, NM. WPO 30793.

Webb, S. 1995. "DR-1:3D Room Flow Model with Dip." Planning Memo of Record to D.R. Anderson, May 30, 1995. SWCF-A:1.1.6.3. Sandia National Laboratories, Albuquerque, NM. WPO 22494.

Section MASS.8 References:

Brush, L.H. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266, Sandia National Laboratories, Albuquerque, NM. WPO 26015.

Brush, L.H., and Anderson, D.R. 1989a. "Potential Effects of Chemical Reactions on WIPP Gas and Water Budgets," *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* Eds. A.R. Lappin, R.L. Hunter, D.P. Gabber, and P.B. Davies. SAND89-0462, Sandia National Laboratories, Albuquerque, NM. A-3 through A-30. In Appendix A of WPO 24125.

Brush, L.H., and Anderson, D.R. 1989b. "First Meeting of the WIPP PA Source Term Group," *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* Eds. A.R. Lappin, R.L. Hunter, D.P. Gabber, and P.B. Davies. SAND89-0462, Sandia National Laboratories, Albuquerque, NM. A-31 through A-50. In Appendix A of WPO 24125.

Brush, L.H., and Anderson, D.R. 1989c. "Second Meeting of the WIPP PA Source-Term Group," *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* Eds. A.R. Lappin, R.L. Hunter, D.P. Gabber, and P.B. Davies. SAND89-0462, Sandia National Laboratories, Albuquerque, NM. A-51 through A-59. In Appendix A of WPO 24125.

Brush, L.H., Grbic-Galic, D., Reed, D.T., Tong, X., Vreeland, R.H., and Westerman, R.E. 1991a. "Preliminary Results of Laboratory Studies of Repository Chemistry for the Waste Isolation Pilot Plant," *Scientific Basis for Nuclear Waste Management XIV, Materials Research Society Symposium Proceedings, Boston, MA, November 26-29, 1990.* Eds. T. Abrajano, Jr., and L.H. Johnson. SAND90-1031C, Materials Research Society, Pittsburgh, PA. Vol. 212, 893-900. WPO 25093.

Brush, L.H., Molecke, M.A., Lappin, A.R., Westerman, R.E., Tong, X., Black, J.N.P., Grbic-Galic, D., Vreeland, R.E., and Reed, D.T. 1991b. "Laboratory and Bin-Scale Tests of Gas Generation for the Waste Isolation Pilot Plant," *Waste-Generated Gas at the Waste Isolation Pilot Plant: Papers Presented at the Nuclear Energy Agency Workshop on Gas Generation and Release from Radioactive Repositories.* Eds. P.B. Davies, L.H. Brush, M.A. Molecke,

F.T. Mendenhall, and S.W. Webb. SAND91-2378, Sandia National Laboratories, Albuquerque, NM. 2-1 through 2-14. In Chapter 2 of WPO 25381.

Brush, L.H., Molecke, M.A., Westerman, R.E., Francis, A.J., Gillow, J.B., Vreeland, R.H. and Reed, D.T. 1993. "Laboratory Studies of Gas Generation for the Waste Isolation Pilot Plant," *Scientific Basis for Nuclear Waste Management XVI, Materials Research Society Symposium Proceedings, Boston, MA, November 30-December 4, 1992.* Eds. C.G. Interrante and R.T. Pabalan. SAND92-2160C, Materials Research Society, Pittsburgh, PA. Vol. 294, 335-340. WPO 29332.

Brush, L.H., Garner, J.W., and Storz, L.J. 1994. "Development of a Gas-Generation Model for the Waste Isolation Pilot Plant," *Scientific Basis for Nuclear Waste Management XVII, Materials Research Society Symposium Proceedings, Boston, MA, November 29-December 3, 1993.* Eds. A. Barkatt and R.A. Van Konynenburg. SAND93-1145C, Materials Research Society, Pittsburgh, PA. Vol. 333, 241-246. WPO 26689.

Butcher, B.M., and Mendenhall, F.T. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR Part 191, Subpart B.* SAND92-0427, Sandia National Laboratories, Albuquerque, NM. WPO 23356.

Francis, A.J., and Gillow, J.B. 1994. *Effects of Microbial Processes on Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions, Progress Report Through 1992.* SAND93-7036, Sandia National Laboratories, Albuquerque, NM. WPO 10673.

Lappin, A.R., Hunter, R.L., Gabber, D.P., and Davies, P.B., eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* SAND89-0462, Sandia National Laboratories, Albuquerque, NM. WPO 24125.

Molecke, M.A. 1978. *Waste Isolation Pilot Plant Transuranic Wastes Experimental Characterization Program: Executive Summary.* SAND78-1356, Sandia National Laboratories, Albuquerque, NM. WPO 23671.

Molecke, M.A. 1979. *Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation.* SAND79-1245, Sandia National Laboratories, Albuquerque, NM. WPO 26715.

Reed, D.T., Okajima, S., Brush, L.H., and Molecke, M.A. 1993. "Radiolytically-Induced Gas Production in Plutonium-Spiked WIPP Brine," *Scientific Basis for Nuclear Waste Management XVI, Materials Research Society Symposium Proceedings, Boston, MA, November 30-December 4, 1992.* Eds. C.G. Interrante and R.T. Pabalan. SAND92-7283C, Materials Research Society, Pittsburgh, PA. Vol. 294, 431-438. WPO 28639.

Sandia National Laboratories. 1979. *Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP.* Comp. T.O. Hunter. SAND79-1305, Sandia National Laboratories, Albuquerque, NM. WPO 26734.

Telander, M.R., and Westerman, R.E. 1993. *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments, Progress Report for the Period November 1989 Through December 1992.* SAND92-7347, Sandia National Laboratories, Albuquerque, NM. WPO 23456.

Trauth, K.M., Hora, S.C., Rechard, R.P., and Anderson, D.R. 1992. *The Use of Expert Judgment to Quantify Uncertainty in Solubility and Sorption Parameters for Waste Isolation Pilot Plant Performance Assessment.* SAND92-0479, Sandia National Laboratories, Albuquerque, NM. WPO 23526.

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 3: Reference Data.* SAND91-0893/3. Eds. R.P. Rechard, A.C. Peterson, J.D. Schreiber, H.J. Iuzzolino, M.S. Tierney and J.S. Sandha. Sandia National Laboratories, Albuquerque, NM. WPO 26419.

Section MASS.12 References:

Bertram-Howery, S.G., Marietta, M.G., Rechard, R.P., Swift, P.N., Anderson, D.R., Baker, B.L., Bean, Jr., J.E., Beyeler, W., Brinster, K.F., Guzowski, R.V., Helton, J.C., McCurley, R.D., Rudeen, D.K., Schreiber, J.D., and Vaughn, P. 1990. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990.* SAND90-2347, Sandia National Laboratories, Albuquerque, NM.

Callahan, G.D. 1994. *SPECTROM-32: A Finite Element Thermomechanical Stress Analysis Program Version 4.06*, RSI-0531, RE/SPEC Inc., Rapid City, SD. WPO 36814.

DOE (U.S. Department of Energy). 1995. *Conceptual Design for Operational Phase Panel Closure Systems.* DOE-WIPP-95-2057, U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

Nowak, E.J., Tillerson, J.R., and Torres, R.M. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant.* SAND90-0355, Sandia National Laboratories, Albuquerque, NM.

Pruess, K. 1991. *TOUGH2: A General-Purpose Numerical Simulator for Multiphase Fluid and Heat Flow.* LBL-29400, Earth Science Division, Lawrence Berkeley Laboratories, Berkeley, CA.

Reeves, M., Ward, D.S., Johns, N.D., and Cranwell, R.M. 1986. *Theory and Implementation for SWIFT II, The Sandia Waste-Isolation Flow and Transport Model for Fractured Media, Release 484.* SAND83-1159, NUREG/CR-3328, Sandia National Laboratories, Albuquerque, NM.

Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters.* SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM.

Stormont, J.D. 1988. *Preliminary Seal Design Evaluation for the Waste Isolation Pilot Plant.* SAND87-3083, Sandia National Laboratories, Albuquerque, NM.

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991—Volume 1: Methodology and Results.* SAND91-0893/1, Sandia National Laboratories, Albuquerque, NM.

Section MASS.13 References:

Christian-Frear, T.L., and Webb, S.W. 1996, *The Effect of Explicit Representation of the Stratigraphy on Brine and Gas Flow at the Waste Isolation Pilot Plant.* SAND94-3173, Sandia National Laboratories, Albuquerque, NM. WPO 37240.

Davies, P.B. 1991. *Evaluation of the Role of Threshold Pressure in Controlling Flow of Waste-Generated Gas into Bedded Salt at the Waste Isolation Pilot Plant.* SAND90-3246, Sandia National Laboratories, Albuquerque, NM. WPO 26169

Davies, P.B., Webb, S.W., and Gorham, E.D. 1993. "Feedback on 'PA Modeling Using BRAGFLO -- 1992' memo by J. Schreiber, July 14, 1992," pp. A-23 through A-37 in Sandia WIPP Project, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1993. Volume 3, Model Parameters.* SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM.

Freeze, G.A., Larson, K.W., and Davies, P.B. 1995. *Coupled Multiphase Flow and Closure Analysis of Repository Response to Waste-Generated Gas at the Waste Isolation Pilot Plant (WIPP).* SAND93-1986, Sandia National Laboratories, Albuquerque, NM. WPO 29557.

Gorham, E., Beauheim, R., Davies, P., Howarth, S., and Webb, S. 1992. "Recommendation to PA on Salado Formation Intrinsic Permeability and Pore Pressure for 40 Subpart B Calculations, June 15, 1992," pages A-49 through A-65 in Sandia WIPP Project, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1993. Volume 3, Model Parameters.* SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM.

Lappin, A.R., Hunter, R.L., Gabber, D.P., and Davies, P.B., eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* SAND89-0462, Sandia National Laboratories, Albuquerque, NM. WPO 24125.

Mendenhall, F.T., and Gerstle, W. 1993. WIPP Anhydrite Fracture Modeling. Memorandum to Distribution, December 6, 1993. SWCF-A: W.B.S. 1.1.7.1 (WPO #39830). Sandia National Laboratories, Albuquerque, NM. WPO 39830.

Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters.* SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM. WPO 23529.

Vaughn, P., Lord, M., and MacKinnon, R. 1995. S-6: Dynamic Alteration of the DRZ/Transition Zone: Summary Memo of Record to D.R. Anderson, September 28, 1995. SWCF-A (WPO #30798). Sandia National Laboratories, Albuquerque, NM.

WIPP Performance Assessment Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 2: Technical Basis.* SAND92-0700/2, Sandia National Laboratories, Albuquerque, NM. WPO 23528.

WIPP Performance Assessment Department. 1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B.* SAND92-0700/4, Sandia National Laboratories, Albuquerque, NM. WPO 23528.

Section MASS.14 References:

Barr, G.E., Miller, W. B., and Gonzalez, D.D. 1983. *Interim Report on the Modeling of the Regional Hydraulics of the Rustler Formation.* SAND83-0391, Sandia National Laboratories, Albuquerque, NM. WPO 27557.

Bear, J., and Verruijt, A. 1987. *Modeling Groundwater Flow and Pollution.* Dordrecht; Boston, MA: D. Reidel Publishing; Norwell, MA: Sold and distributed in the U.S. and Canada by Kluwer Academic Publishers.

Beauheim, R.L. 1986. *Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-1364, Sandia National Laboratories, Albuquerque, NM. WPO 27656.

Chapman, J.B. 1986. *Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area.* EEG-35, DOE/AL/10752-35, Environmental Evaluation Group, Santa Fe, NM.

Chapman, J.B. 1988. *Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico.* EEG-39, Environmental Evaluation Group, Santa Fe, NM.

Corbet, T.F. 1994. "Evolution of Patterns of Regional Groundwater Flow in Southeastern New Mexico: Response to Post-Pleistocene Changes in Climate," *Abstracts with Programs, 1994 Annual Meeting, The Geological Society of America, October 24-27, 1994.* SAND94-1856A, Seattle, WA. Vol. 26, no. 7, 414. WPO 23733.

Corbet, T.F., and Wallace, M.G. 1993. "Post-Pleistocene Patterns of Shallow Groundwater Flow in the Delaware Basin, Southeastern New Mexico and West Texas," *Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society Forty-fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993.* Eds. D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.W. Austin, and J.M. Barker. SAND93-1318J, New Mexico Geological Society, Socorro, NM. 321-325. WPO 28644.

Corbet, T.F., and Knupp, P.M. 1996. *The Role of Regional Groundwater Flow in the Hydrogeology of the Culebra Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND96-2133, Sandia National Laboratories, Albuquerque, NM.

Dagan, G. 1989. *Flow and Transport in Porous Formations.* Springer-Verlag, New York, NY.

Davies, P.B. 1989. *Variable-Density Ground-Water Flow and Paleohydrology in the Waste Isolation Pilot Plant (WIPP) Region, Southeastern New Mexico.* Open-File Report 88-490, U.S. Geological Survey, Albuquerque, NM. WPO 38854.

de Marsily, G. 1986. *Quantitative Hydrogeology: Groundwater Hydrology for Engineers.* Academic Press, Orlando, FL.

DOE (U.S. Department of Energy). 1989. *Draft Supplement, Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-DS, Department of Energy, Washington, DC. Vols. 1 – 2.

Knupp, P. 1996. "A Moving Mesh Algorithm for 3-D Regional Groundwater Flow with Water Table and Seepage Face," *Advances in Water Resources.* Vol. 19, no. 2, 83-95.

Lambert, S.J. 1987. *Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and Other Nuclides to the Groundwater Hydrology of the Rustler Formation, Southeastern New Mexico.* SAND86-1054, Sandia National Laboratories, Albuquerque, NM. WPO 24475.

Lambert, S.J., and Carter, J.A. 1987. *Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico. I: Principles and Preliminary Results.* SAND87-0388, Sandia National Laboratories, Albuquerque, NM. WPO 24453.

Lambert, S.J., and Harvey, D.M. 1987. *Stable-Isotope Geochemistry of Groundwaters in the Delaware Basin of Southeastern New Mexico.* SAND87-0138, Sandia National Laboratories, Albuquerque, NM. WPO 24150.

Lappin, A.R., Hunter, R.L., Gabber, D.P., and Davies, P.B., eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* SAND89-0462, Sandia National Laboratories, Albuquerque, NM. WPO 24125.

McDonald, M.G., and Harbaugh, A.W. 1988. *A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model.* Open-File Report 83-875, U.S. Geological Survey, Denver, CO.

Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196, Sandia National Laboratories, Albuquerque, NM. WPO 25624.

Section MASS.15 References:

Avogadro, A., and de Marsily, G. 1984. "The Role of Colloids in Nuclear Waste Disposal," *Scientific Basis for Nuclear Waste Management VII, Materials Research Society Symposia Proceedings, Boston, MA, November 14-17, 1983.* Ed. G.L. McVay. North-Holland, New York, NY. Vol. 26, 495-505.

Beauheim, R.L. 1987a. *Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-2311, Sandia National Laboratories, Albuquerque, NM. WPO 28468.

Beauheim, R.L. 1987b. *Interpretations of Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987.* Sandia National Laboratories, Albuquerque, NM. WPO 27679.

Bennett, D.G., Liew, S.K., Nanu, L., Read, D., and Thomas, J.B. 1993. "Modelling Colloidal Transport of Radionuclides Through Porous Media," *High Level Radioactive Waste Management, Proceedings of the Fourth Annual International Meeting, Las Vegas, NV, April 26-30, 1993.* American Nuclear Society, La Grange Park, IL; American Society of Civil Engineers, New York, NY. Vol. 4, 638-645.

Bertram, S.G. 1995. "NS-11: Subsidence Associated with Mining Inside or Outside of the Controlled Area." Summary Memo of Record to D.R. Anderson, December 8, 1995. SWCF-1:1.1.6.3. Sandia National Laboratories, Albuquerque, NM. WPO 30761.

Corapcioglu, M.Y., and Jiang, S. 1993. "Colloid-Facilitated Groundwater Contaminant Transport," *Water Resources Research*. Vol. 29, no. 7, 2216 – 2226.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026, U.S. Department of Energy, Washington, DC. Vols. 1 - 2. WPO 38835, WPO 38839.

DOE (U.S. Department of Energy). 1990. *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026-FS, U.S. Department of Energy Office of Environmental Restoration and Waste Management, Washington, DC. Vols. 1 – 13.

Dosch, R.G. 1979. "Radionuclide Migration Studies Associated with the WIPP Site in Southeastern New Mexico," *Scientific Basis for Nuclear Waste Management, Proceedings of the Symposium on Science Underlying Radioactive Waste Management, Boston, MA, November 28-December 1, 1978*. Ed. G.J. McCarthy. SAND78-1178J, Plenum Press, New York, NY. Vol. 1, 395-398. WPO 29589.

Dosch, R.G. 1980. *Assessment of Potential Radionuclide Transport in Site-Specific Geologic Formations*. SAND79-2468, Sandia National Laboratories, Albuquerque, NM. WPO 28085.

Dosch, R.G. 1981. *Solubility and Sorption Characteristics of Uranium (VI) Associated with Rock Samples and Brines/Groundwaters from WIPP and NTS*. SAND80-1595, Sandia National Laboratories, Albuquerque, NM. WPO 30252.

Dosch, R.G., and Lynch, A.W. 1978. *Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) Site in New Mexico*. SAND78-0297, Sandia National Laboratories, Albuquerque, NM. WPO 28145.

Grindrod, P. 1993. "The Impact of Colloids on the Migration and Dispersal of Radionuclides Within Fractured Rock," *Journal of Contaminant Hydrology*. Vol. 13, no. 1 – 4, 167-181.

Grindrod, P., and Worth, D.J. 1990. *Radionuclide and Colloid Migration in Fractured Rock: Model Calculations*. SKI Technical Report 91:11, Swedish Nuclear Power Inspectorate, Stockholm, Sweden.

Guzowski, R.V. 1990. *Preliminary Identification of Scenarios for the Waste Isolation Pilot Plant, Southeastern New Mexico*. SAND90-7090, Sandia National Laboratories, Albuquerque, NM. WPO 25771.

Harmand, B., and Sardin, M. 1994. "Modelling the Coupled Transport of Colloids and Radionuclides in a Fractured Natural Medium," *Chemistry and Migration Behaviour of Actinides and Fission Products in the Geosphere, Proceedings of the Fourth International Conference, Charleston, SC, December 12-17, 1993.* R. Oldenbourg Verlag, Munich. Vol. 66/67, 691-699.

Haug, A., Kelley, V.A., LaVenue, A.M., and Pickens, J.F. 1987. *Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report.* SAND86-7167, Sandia National Laboratories, Albuquerque, NM. WPO 28486.

Holt, R.M., and Powers, D.W. 1984. *Geotechnical Activities in the Waste Handling Shaft.* WTSD-TME-038, U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1986. *Geotechnical Activities in the Exhaust Shaft.* DOE-WIPP 86-008, U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE-WIPP 88-004, U.S. Department of Energy, Carlsbad, NM.

Holt, R.M., and Powers, D.W. 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant.* DOE-WIPP 90-051, U.S. Department of Energy, Carlsbad, NM.

Hunter, R.L. 1989. *Events and Processes for Constructing Scenarios for the Release of Transuranic Waste from the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND89-2546, Sandia National Laboratories, Albuquerque, NM. WPO 27731.

Hwang, Y., Pigford, T.H., Lee, W.W.-L., and Chambre, P.L. 1989. "Analytic Solution of Pseudocolloid Migration in Fractured Rock," *Transactions of the American Nuclear Society.* Vol. 60, 107-109.

Ibaraki, M., and Sudicky, E.A. 1995. "Colloid-Facilitated Contaminant Transport in Discretely Fractured Porous Media. 1. Numerical Formulation and Sensitivity Analysis," *Water Resources Research.* Vol. 31, no. 12, 2945 – 2960.

Jacquier, P. 1991. "Geochemical Modelling: What Phenomena are Missing?" *Radiochimica Acta.* Vol. 52/53, pt. 1, 495-499.

Jones, T.L., Kelley, V.A., Pickens, J.F., Upton, D.T., Beauheim, R.L., and Davies, P.B. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site.* SAND92-1579, Sandia National Laboratories, Albuquerque, NM. WPO 23504.

Lappin, A.R., Hunter, R.L., Gabber, D.P., and Davies, P.B., eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* SAND89-0462, Sandia National Laboratories, Albuquerque, NM. WPO 24125.

LaVenue, A.M., and RamaRao, B.S. 1992. *A Modeling Approach to Address Spatial Variability Within the Culebra Dolomite Transmissivity Field.* SAND92-7306, Sandia National Laboratories, Albuquerque, NM. WPO 23889.

LaVenue, A.M., Cauffman, T.L., and Pickens, J.F. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite: Volume 1 - Model Calibration.* SAND89-7068/1, Sandia National Laboratories, Albuquerque, NM.

Light, W.B., Lee, W.W.-L., Chambre, P.L., and Pigford, T.H. 1990. "Radioactive Colloid Advection in a Sorbing Porous Medium: Analytical Solution," *Transactions of the American Nuclear Society.* Vol. 61, 81-83.

Lynch, A.W., and Dosch, R.G. 1980. *Sorption Coefficients for Radionuclides on Samples from the Water-Bearing Magenta and Culebra Members of the Rustler Formation.* SAND80-1064, Sandia National Laboratories, Albuquerque, NM. WPO 28223.

Lynch, A.W., Dosch, R.G., and Hills, C.R. 1981. *Migration of Cesium-137 Through a Solid Core of Magenta Dolomite Taken from the Rustler Formation in Southeastern New Mexico.* SAND80-1259, Sandia National Laboratories, Albuquerque, NM. WPO 24234.

Marietta, M.G., Bertram-Howery, S.G., Anderson, D.R. (Rip), Brinster, K.F., Guzowski, R.V., Iuzzolino, H., and Rechard, R.P. 1989. *Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant.* SAND89-2027, Sandia National Laboratories, Albuquerque, NM. WPO 25952.

McCarthy, J.F., and Zachara, J.M. 1989. "Subsurface Transport of Contaminants," *Environmental Science and Technolology.* Vol. 23, no. 5, 496 – 502.

Mercer, J.W., and Orr, B.R. 1979. *Interim Data Report on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico.* Water-Resources Investigations 79-98, U.S. Geological Survey, Albuquerque, NM.

Nyhan, J.W., Drennon, B.J., Abeele, W.V., Wheeler, M.L., Purtymun, W.D., Trujillo, G., Herrera, W.J., and Booth, J.W. 1985. "Distribution of Plutonium and Americium Beneath a 33-yr-old Liquid Waste Disposal Site," *Journal of Environmental Quality.* Vol. 14, no. 4, 501 – 509.

Paine, R.T., and Dosch, R.G. 1992. "Summary of Previously Unpublished Experimental Measurements of Plutonium and Americium Sorption onto Culebra Substrates from Brine B Containing Organic Ligands," *An Evaluation of Radionuclide Batch Sorption Data on Culebra Dolomite for Aqueous Compositions Relevant to the Human Intrusion Scenario for the Waste Isolation Pilot Plant.* C.F. Novak. SAND91-1299, Sandia National Laboratories, Albuquerque, NM. D-1 through D-8. In Appendix D of WPO 26181.

Papenguth, H.W., and Behl, Y.K. 1996a. "Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant." SNL Test Plan TP 96-01, Sandia National Laboratories, Albuquerque, NM. WPO 31337.

Papenguth, H.W., and Behl, Y.K. 1996b. "Test Plan for Evaluation of Dissolved Actinide Retardation at the Waste Isolation Pilot Plant." TP 96-02, Sandia National Laboratories, Albuquerque, NM. WPO 31336.

Park, S.-W., Leckie, J.O., and Siegel, M.D. 1992. *Surface Complexation Modeling of Uranyl Adsorption on Corrensite from the WIPP Site.* Technical Report No. 315, Stanford University Department of Civil Engineering, Palo Alto, CA.

Park, S.-W., Leckie, J.O., and Siegel, M.D. 1995. *Surface Complexation Modeling of Uranyl Adsorption on Corrensite from the Waste Isolation Pilot Plant Site.* SAND90-7084, Sandia National Laboratories, Albuquerque, NM. WPO 29367.

Ramsey, J. 1996. "Culebra Dissolved Actinide Parameter Request." Unpublished memorandum to E. J. Nowak, March 18, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 35269.

Serne, R.J., Rai, D., Mason, M.J., and Molecke, M.A. 1977. *Batch K_d Measurements of Nuclides to Estimate Migration Potentials at the Proposed Waste Isolation Pilot Plant in New Mexico.* PNL-2448, Battelle Pacific Northwest Laboratory, Richland, WA.

Sewards, T. 1991. *Characterization of Fracture Surfaces in Dolomite Rock, Culebra Dolomite Member, Rustler Formation.* SAND90-7019, Sandia National Laboratories, Albuquerque, NM. WPO 23872.

Sewards, T., Williams, M.L., and Keil, K. 1991. "Mineralogy of the Culebra Dolomite," *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Eds. M.D. Siegel, S.J. Lambert, and K.L. Robinson. Sandia National Laboratories, Albuquerque, NM. 3-1 to 3-43. Chapter 3 of WPO 25624.

Sewards, T., Brearly, A., Glenn, R., MacKinnon, I.D.R., and Siegel, M.D. 1992. *Nature and Genesis of Clay Minerals of the Rustler Formation in the Vicinity of the Waste Isolation Pilot*

Plant in Southeastern New Mexico. SAND90-2569, Sandia National Laboratories, Albuquerque, NM. WPO 26157.

Siegel, M.D., Leckie, J.O., Park, S.-W., Phillips, S.L., and Sewards, T. 1990. *Studies of Radionuclide Sorption by Clays in the Culebra Dolomite at the Waste Isolation Pilot Plant Site, Southeastern New Mexico.* SAND89-2387, Sandia National Laboratories, Albuquerque, NM. WPO 17722.

Smith, P.A., and Degueldre, C. 1993. "Colloid-Facilitated Transport of Radionuclides Through Fractured Media," *Journal of Contaminant Hydrology.* Vol. 13, no. 1 – 4, 143 – 166.

SNL (Sandia National Laboratories). 1992 – 1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992.* SAND92-0700, Vols. 1-5, Sandia National Laboratories, Albuquerque, NM. Vol. 1 – WPO 20762, Vol. 2 – WPO 20805, Vol. 3 – WPO 23529, Vol. 4 – WPO 20958, Vol. 5 – WPO 20929.

Tien, P.-L., Nimick, F.B., Muller, A.B., Davis, P.A., Guzowski, R.V., Duda, L.E., and Hunter, R.L. 1983. *Repository Site Data and Information in Bedded Salt: Palo Duro Basin, Texas.* SAND82-2223, Sandia National Laboratories, Albuquerque, NM. WPO 28328.

Tierney, M.S. 1991. *Combining Scenarios in a Calculation of the Overall Probability Distribution of Cumulative Releases of Radioactivity From the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND90-0838, Sandia National Laboratories, Albuquerque, NM. WPO 26030.

Trauth, K.M., Hora, S.C., Rechard, R.P., and Anderson, D.R. 1992. *The Use of Expert Judgment to Quantify Uncertainty in Solubility and Sorption Parameters for Waste Isolation Pilot Plant Performance Assessment.* SAND92-0479, Sandia National Laboratories, Albuquerque, NM. WPO 23526.

Travis, B.J., and Nuttall, H.E. 1985. "A Transport Code for Radiocolloid Migration: With an Assessment of an Actual Low-Level Waste Site," *Scientific Basis for Nuclear Waste Management VIII, Materials Research Society Symposia Proceedings, Boston, MA, November 26-29, 1984.* Eds. C.M. Jantzen, J.A. Stone, and R.C. Ewing. Materials Research Society, Pittsburgh, PA. Vol. 44, 969-976.

van der Lee, J., de Marsily, G., and Ledoux, E. 1993. "Are Colloids Important for Transport Rate Assessment of Radionuclides? A Microscopic Modeling Approach," *High Level Radioactive Waste Management, Proceedings of the 4th Annual International Conference, Las Vegas, NV, April 26-30, 1993.* American Society of Civil Engineers, New York, NY. 646-652.

van der Lee, J., Ledoux, E., and de Marsily, G. 1994. "Microscopic Description of Colloid Transport in Fractured or Porous Media," *Transport and Reactive Processes in Aquifers: Proceedings of the IAHR/AIRH Symposium, Zurich, Switzerland, April 11-15, 1994.* Eds. Th. Dracos and F. Stauffer. A.A. Balkema, Brookfield, VT. 349-355.

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991—Volume 1: Methodology and Results.* SAND91-0893/1, Sandia National Laboratories, Albuquerque, NM.

Section MASS.16 References:

Berglund, J.W. 1992. *Mechanisms Governing the Direct Removal of Wastes from the Waste Isolation Pilot Plant Repository Caused by Exploratory Drilling.* SAND92-7295, Sandia National Laboratories, Albuquerque, NM. WPO 23946.

Berglund, J.W., and Lenke, L.R. 1995. "One Dimensional Experiments of Gas Induced Spall." NMERI Contractor Report NMERI 1995/3. New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, NM. WPO 27589.

Berner, U. 1990. "A Thermodynamic Description of the Evolution of Pore Water Chemistry and Uranium Speciation During the Degradation of Cement," Technical Report 90-12, Paul Scherrer, Villigen, Switzerland.

Lenke, L.R., and Berglund, J.W. 1995. "Blowout Experiments in an Axisymmetric Geometry," New Mexico Engineering Research Contractor's Report, Contract AL-7022, November, 1995. WPO 29181.

State of New Mexico, Oil Conservation Division, Energy, Minerals, and Natural Resources Department. 1988. Application of the Oil Conservation Division Upon Its Own Motion to Revise Order R-111, As Amended, Pertaining to the Potash Areas of Eddy and Lea Counties, New Mexico. Case 9316, Revision to Order R-111-P, April 21, 1988. Santa Fe, NM.

Section MASS.17 References:

Bachman, G.O. 1974. *Geologic Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico.* Open-File Report 74-194, United States Geological Survey, Sandia National Laboratories.

Bachman, G.O. 1976. "Cenozoic Deposits of Southeastern New Mexico and an Outline of the History of Evaporite Dissolution," *Journal of Research, United States Geological Survey.* Vol. 4, no. 2, 135 – 149.

Bachman, G.O. 1980. *Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico.* Open-File Report 80-1099, United States Geological Survey, Denver CO.

Bachman, G.O. 1981. *Geology of Nash Draw, Eddy County, New Mexico.* Open-File Report 81-31. United States Geological Survey, Denver, CO.

Bachman, G.O. 1985. *Assessment of Near-Surface Dissolution At and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND84-7178, Sandia National Laboratories, Albuquerque, NM. WPO 24609.

Bachman, G.O. 1987. *Karst in Evaporites in Southeastern New Mexico.* SAND86-7078, Sandia National Laboratories, Albuquerque, NM. WPO 24006.

Bachman, G.O. 1989. *Annotated Bibliography of Paleoclimate Studies Relevant to the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND89-7087, Sandia National Laboratories, Albuquerque, NM. WPO 24426.

Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hays, W.H. 1972. *Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico.* USGS-4339-1, United States Geological Survey, Denver, CO.

Chapman, J.B. 1986. *Stable Isotopes in the Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area.* EEG-35, Environmental Evaluation Group, Santa Fe, NM.

Corbet, T. 1995. "NS-9: Justification of SECO2D Approximation for PA Transport Calculations." Summary Memo of Record to D.R. Anderson, September 21, 1995. SWCF-A:1.1.6.3. Sandia National Laboratories, Albuquerque, NM. Contained in WPO 30802.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026, U.S. Department of Energy, Washington, DC. WPO 38835, WPO 38838 – 38839.

EPA (U.S. Environmental Protection Agency). 1996. "40 CFR Part 194. Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule," *Federal Register.* Vol. 61, no. 28, 5224 – 5245.

Lambert, S.J. 1987. "Stable-Isotope Studies of Groundwaters in Southeastern New Mexico," *The Rustler Formation at the WIPP Site.* Ed. L. Chaturvedi. EEG-34; SAND85-1978C, Environmental Evaluation Group, Santa Fe, NM. WPO 28418.

Lambert, S.J. 1991. Chapter 4: "Isotopic Constraints on the Rustler and Dewey Lake Groundwater Systems," *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico*. Eds. M.D. Siegel, S.J. Lambert, and K.L. Robinson. SAND88-0196, Sandia National Laboratories, Albuquerque, NM. 5-1 through 5-79.

Lambert, S.J., and Carter, J.A. 1987. *Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico. I. Principles and Preliminary Results*. SAND87-0388, Sandia National Laboratories, Albuquerque, NM.

Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds. 1991. *Hydrochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico*. SAND88-7096, Sandia National Laboratories, Albuquerque, NM. WPO 25624.

SNL (Sandia National Laboratories) and University of New Mexico. 1981. *Basic Data Report for Drillhole WIPP 15 (Waste Isolation Pilot Plant - WIPP)*. SAND79-027, Sandia National Laboratories, Albuquerque, NM. WPO 26960.

Swift, P.N., Baker, B.L., Economy, K., Garner, J.W., Helton, J.C., and Rudeen, D.K. 1994. *Incorporating Long-Term Climate Change in Performance Assessment for the Waste Isolation Pilot Plant*. SAND93-2266, Sandia National Laboratories, Albuquerque, NM. WPO 27827.

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 2: Probability and Consequence Modeling*. SAND91-0893/2, Sandia National Laboratories, Albuquerque, NM. WPO 26415.

WIPP Performance Assessment Department. 1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B*. SAND92-0700/4, Sandia National Laboratories, Albuquerque, NM. WPO 20958.

Section MASS.18 References:

Borns, D. J., Barrows, L.J., Powers, D.W., and Snyder, R.P. 1983. *Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site*. SAND82-1069, Sandia National Laboratories, Albuquerque, NM. WPO 27532.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*. DOE/EIS-0026, U.S. Department of Energy, Washington, DC. Vols. 1-2. WPO 38835, WPO 38838 – 38839.

DOE (U.S. Department of Energy). 1989. *Draft Supplement, Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-DS, Department of Energy, Washington, DC. Vols. 1 – 2.

DOE (U.S. Department of Energy). 1990. *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026-FS, U.S. Department of Energy Office of Environmental Restoration and Waste Management, Washington, DC. Vols. 1 – 13.

Earth Technology Corporation. 1988. *Final Report for Time-Domain Electromagnetic (TDEM) Survey at the WIPP Site.* SAND87-7144, Sandia National Laboratories, Albuquerque, NM.

Faith, S., Spiegler, P., and Rehfeldt, K.R. 1983. *The Geochemistry of Two Pressurized Brines from the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site.* EEG-21, Environmental Evaluation Group, Santa Fe, NM.

Lambert, S.J., and Carter, J.A. 1984. *Uranium-Isotope Disequilibrium in Brine Reservoirs of the Castile Formation, Northern Delaware Basin, Southeastern New Mexico. I. Principles and Methods.* SAND83-0144, Sandia National Laboratories, Albuquerque, NM. WPO 28341.

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant Project, Southeastern New Mexico.* TME-3153, U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad, NM.

Reeves, M., Freeze, G., Kelley, V.A., Pickens, J., Upton, D.T., and Davies, P.B. 1991. *Regional Double-Porosity Solute Transport in the Culebra Dolomite Under Brine-Reservoir-Breach Release Conditions: An Analysis of Parameter Sensitivity and Importance.* SAND89-7069, Sandia National Laboratories, Albuquerque, NM. WPO 24048.

Spiegler, P. 1982. *Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site.* EEG-17, Environmental Evaluation Group, Santa Fe, NM.

Spiegler, P., and Updegraff, D. 1983. *Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12, Based on Stable-Isotope Concentrations of Hydrogen and Oxygen.* EEG-18, Environmental Evaluation Group, Santa Fe, NM.

BIBLIOGRAPHY

Section MASS.4 Bibliography:

Christian-Frear, T.L., and Webb, S.W. 1996. *Effect of Explicit Representation of Detailed Stratigraphy on Brine and Gas Flow at the Waste Isolation Pilot Plant.* SAND94-3173, Sandia National Laboratories, Albuquerque, NM. WPO 37240.

Webb, S.W., and Larson, K.W. 1996. *The Effect of Stratigraphic Dip on Brine and Gas Migration at the Waste Isolation Pilot Plant.* SAND94-0932, Sandia National Laboratories, Albuquerque, NM. WPO 31271.

Section MASS.5 Bibliography:

Marietta, M.G., Bertram-Howery, S.G., Anderson, D.R. (Rip), Brinster, K.F., Guzowski, R.V., Iuzzolino, H., and Rechard, R.P. 1989. *Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant.* SAND89-2027, Sandia National Laboratories, Albuquerque, NM. pp. III-4 through III-16, and pp. IV-2 through IV-49. WPO 25952.

Section MASS.7 Bibliography:

Butcher, B.M., Thompson, T.W., VanBuskirk, R.G., and Patti, N.C. 1991. *Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste.* SAND90-1206, Sandia National Laboratories, Albuquerque, NM.

Section MASS.8 Bibliography:

DOE (U.S. Department of Energy) Office of Environmental Restoration and Waste Management. 1993. *Independent Technical Review of the Bin and Alcove Test Programs at the Waste Isolation Pilot Plant.* DOE/EM-0130T, U.S. Department of Energy, Office of Environmental Restoration and Waste Management, Washington, DC.

Lappin, A.R., Gotway, C.A., Molecke, M.A., Hunter, R.L., and Lorusso, E.N. 1991. *Rationale for Revised Bin-Scale Gas-Generation Tests with Contact-Handled Transuranic Wastes at the Waste Isolation Pilot Plant.* SAND90-2481, Sandia National Laboratories, Albuquerque, NM. WPO 23963.

Molecke, M.A. 1990. "Test Plan: WIPP Bin-Scale CH TRU Waste Tests." Sandia National Laboratories, Albuquerque, NM. WPO 27063.

Molecke, M.A. 1990. "Test Plan: WIPP In Situ Alcove CH TRU Waste Tests." Sandia National Laboratories, Albuquerque, NM. WPO 40317.

Molecke, M.A., and Lappin, A.R. 1990. *Test Plan Addendum #1: Waste Isolation Pilot Plant Bin-Scale CH TRU Waste Tests.* SAND90-2082, Sandia National Laboratories, Albuquerque, NM. WPO 23959

Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters.* SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM. WPO 23529.

Section MASS.13 Bibliography:

Bear, J. 1988. *Dynamics of Fluids in Porous Media.* Reprinted. Dover Publications, Inc., New York, NY.

Bear, J., Tsang, C.F., and de Marsily, G., eds. 1993. *Flow and Contaminant Transport in Fractured Rock.* Academic Press, Inc., San Diego, CA.

Beauheim, R.L., Saulnier, Jr., G.J., and Avis, J.D., 1991, *Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant: First Interim Report.* SAND90-0083, Sandia National Laboratories, Albuquerque, NM. WPO 37240

Beauheim, R.L., Roberts, R.M., Dale, T.F., Fort, M.D., and Stensrud, W. 1993. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant: Second Interpretive Report.* SAND92-0533, Sandia National Laboratories, Albuquerque, NM. WPO 23378.

Domski, P.S., Upton, D.T., and Beauheim, R.L. 1996. *Hydraulic Testing Around Room Q: Evaluation of the Effects of Mining on the Hydraulic Properties of Salado Evaporites.* SAND96-0435, Sandia National Laboratories, Albuquerque, NM. WPO 37380.

Kazemi, H., Merrill, L.S., Porterfield, K.L., and Zeman, P.R. 1976. "Numerical Simulation of Water-Oil Flow in Naturally Fractured Reservoirs," *SPEJ, Society of Petroleum Engineers Journal.* Vol. 16, no. 6, 317 – 326.

Section MASS.14 Bibliography:

WIPP Performance Assessment Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 2: Technical Basis.* SAND92-0700/2, Sandia National Laboratories, Albuquerque, NM. WPO 23528.

WIPP Performance Assessment Department. 1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B.* SAND92-0700/4, Sandia National Laboratories, Albuquerque, NM. WPO 23599.

Section MASS.15 Bibliography:

Guzowski, R.V. 1990. *Preliminary Identification of Scenarios that May Affect the Escape and Transport of Radionuclides From the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND89-7149, Sandia National Laboratories, Albuquerque, NM. WPO 24067.

LaVenue, A.M., Haug, A., and Kelley, V.A. 1988. *Numerical Simulation of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site. Second Interim Report.* SAND88-7002, Sandia National Laboratories, Albuquerque, NM. WPO 28558.

Molecke, M.A. 1983. *A Comparison of Brines Relevant to Nuclear Waste Experimentation.* SAND83-0516, Sandia National Laboratories, Albuquerque, NM. WPO 24500.

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant Project, Southeastern New Mexico.* TME 3153, U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad, NM.

Roache, P.J. 1993. *The SECO Suite of Codes for Site Performance Assessment.* SAND93-7007, Sandia National Laboratories, Albuquerque, NM. WPO 29007.

Siegel, M.D., Robinson, K.L., and Myers, J. 1991. "Solute Relationships in Groundwaters from the Culebra Dolomite and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico," *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Eds. M.D. Siegel, S.J. Lambert, and K.L. Robinson. Sandia National Laboratories, Albuquerque, NM. 6-1 to 6-35. Chapter 2 of WPO 25624.

Section MASS.17 Bibliography:

Bachman, G.O. 1983. *Regional Geology of Ochoan Evaporites, Northern Part of Delaware Basin.* New Mexico Bureau of Mines and Mineral Resources Open File 184, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Corbet, T.F., and Wallace, M.G. 1993. "Post-Pleistocene Patterns of Shallow Groundwater Flow in the Delaware Basin, Southeastern New Mexico and West Texas," *Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993.* Eds. D.W. Love, J.W. Hawley. 321-325.

Swift, P.N. 1993. "Long-Term Climate Variability at the Waste Isolation Pilot Plant, Southeastern New Mexico, USA," *Environmental Management* v. 17, 83-87. (Also published in 1992 with the same title as SAND91-7055, and reproduced in this application as Appendix CLI). WPO 27093.

ATTACHMENTS

Model Geometries (Section MASS.4)

Attachment 4-1
SWCF WPO 30840. FEP Screening Analysis: S1: Verification of 2D-Radial Flaring Using 3D Geometry

Repository Fluid Flow (Section MASS.7)

Attachment 7-1
SWCF WPO 40418 Thompson, T.W. and F.D. Hansen. 1996. "Long Term Performance of Panel Closures." Unpublished memorandum to M.G. Marietta, August 2, 1996. Albuquerque, NM: Sandia National Laboratories.

Gas Generation (Section MASS.8)

Attachment 8-1
SWCF WPO 36290 Brush, L.H., Wang, Y., and Garner, J.W. 1995. "Rationale for Discontinuing the Development of the Reaction-Path Gas-Generation Model." Unpublished memorandum to distribution, November 30, 1995. Albuquerque, NM: Sandia National Laboratories.

Attachment 8-2
SWCF WPO 31943 Wang, Y. and Brush, L. 1996. "Estimates of Gas-Generation Parameters for The Long-Term WIPP Performance Assessment." Unpublished memorandum to Martin S. Tierney, January 26, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 8-3
SWCF WPO 36289 Wang, Y. and Brush, L. 1995. "Input Parameter Value Adjustments for the Average-Stoichiometry Model." Unpublished memorandum to D.R. Anderson, September 20, 1995. Albuquerque, NM: Sandia National Laboratories.

Salado (Section MASS.13)

See also Attachment 4-1

Attachment 13-1
SWCF WPO 30790 Lord, M., Vaughn, P., and MacKinnon, R. 1995. "S-7: GAS EXSOLUTION - Summary Memo of Record." Unpublished memorandum to D. R. Anderson, December 21, 1995. Albuquerque, NM: Sandia National Laboratories.

Attachment 13-2
SWCF WPO 39166 Larson, K. 1996. "Memorandum of Record for meeting held 1/22/96 to discuss symmetry of intact rock properties, possible gas-pressure induced fracture properties, and fluid flow properties around the WIPP." Unpublished memorandum of record to Distribution, June 5, 1996. Albuquerque, NM: Sandia National Laboratories.

Culebra (Section MASS.15)

Attachment 15-1
SWCF WPO 38801 Brush, L.H. 1996. "Ranges and Probability Distributions of K_ds for Dissolved Pu, Am, U, Th, and Np in the Culebra for the PA Calculations to Support the WIPP CCA." Unpublished memorandum to M.S. Tierney, June 10, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 15-2
SWCF WPO 36385 Ramsey, J. 1996. "Numerical Implementation of the Colloid Transport Conceptual Model." Unpublished memorandum to Distribution, April 8, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 15-3
SWCF WPO 37533 Brush, L.H. 1996. "Revised Free-Solution Tracer Diffusion Coefficients (D_{sol}s) for Dissolved Pu, Am, U, Th, Np, Cm, and Ra in Boreholes and the Culebra for Use in the PA Calculations to Support the WIPP CCA." Unpublished memorandum to M.S. Tierney, May 11, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 15-4
SWCF WPO 37455 Larson, K.W. 1996. "Mining Transmissivity Multiplier - Area to be Mined." Unpublished memorandum to M. Wallace, April 25, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 15-5
SWCF WPO 38571 Howard, B.A. 1996. "Future Mining Events in the Performance Assessment." Unpublished letter to M. Marietta, April 3, 1996. Carlsbad, NM: Westinghouse Electric Corporation.

Attachment 15-6
SWCF WPO 37450 Meigs, L. and McCord, J. 1996. "Physical Transport in the Culebra Dolomite." Unpublished memorandum to File, July 11, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 15-7
SWCF WPO 30802 Corbet, T. 1995. "FEP NS-9, Two-dimensional assumption for Culebra Calculations." Unpublished summary memorandum of record, September 21, 1995. Albuquerque, NM: Sandia National Laboratories.

Attachment 15-8
SWCF WPO 38797 Stockman, C.T. 1996. "Treatment of colloids in Culebra transport." Unpublished memorandum to J.C. Helton, June 19, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 15-9
SWCF WPO 38250 Perkins, W.G. 1996. "Calculations of Filtration for Microbial and Mineral Fragment Colloids." Unpublished memorandum to J.L. Ramsey, June 4, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 15-10
SWCF WPO 40484 McCord, J. 1996. "Cross-Correlations for WIPP PA: Culebra Physical Transport Parameters." Unpublished memorandum to K. Larson, September 2, 1996. Albuquerque, NM: Sandia National Laboratories.

Intrusion Borehole (Section MASS.16)

Attachment 16-1
SWCF WPO 38579 Howard, B.A. 1996. "Borehole Plugging in the Delaware Basin." Unpublished letter to M. Marietta, April 4, 1996. Carlsbad, NM: Westinghouse Electric Corporation.

Attachment 16-2
SWCF WPO 39090 Stoelzel, D.M. and O'Brien, D.G. 1996. "Conceptual Model Description for BRAGFLO Direct Brine Release Calculations to Support the Compliance Certification Application." Unpublished report, July 9, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 16-3
SWCF WPO 39624 Thompson, T.W., Coons, W.E., Krumhansl, J.L., and Hansen, F.D. 1996. "Inadvertent Intrusion Borehole Permeability." Unpublished report, July 8, 1996. Albuquerque, NM: Sandia National Laboratories. Filed as an attachment to WPO 39624, 39622, 39626.

Climate Change (Section MASS.17)

Attachment 17-1 (two items)

SWCF WPO 36425 Corbet, T.F. 1996. "Non-Salado Record Package: Culebra Transmissivity Zone: Climate Index." Unpublished memorandum to NWM Records Center, April 24, 1996. Albuquerque, NM: Sandia National Laboratories.

SWCF WPO 37465 Corbet, T. and Swift, P. 1996. "Distribution for the Non-Salado Parameter for SECOFL2D: Climate Index." Unpublished memorandum to M. Tierney, April 12, 1996. Albuquerque, NM: Sandia National Laboratories.

Castile Brine Reservoir (Section MASS.18)

Attachment 18-1

SWCF WPO 37148 Freeze, G. and Larson, K. 1996. "Initial Pressure in the Castile Brine Reservoir." Unpublished memorandum to M. Tierney, March 20, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 18-2

SWCF WPO 37973 Freeze, G. and Larson, K. 1996. "Castile Brine Reservoir Pressure Record Package." Unpublished memorandum to SWCF-A Records Center, May 20, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 18-3

SWCF WPO 37971 Larson, K. and Freeze, G. 1996. "Castile Brine Reservoir Volume Revision." Unpublished memorandum to SWCF-A, May 27, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 18-4

SWCF WPO 37147 Helton, J. 1996. "Addition of Discrete Parameter." Unpublished memorandum to M. Tierney, March 21, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 18-5

SWCF WPO 39121 Borns, D.J. 1996. "Proportion of the waste panel area, WIPP site, that is underlain by brine reservoirs in the Castile Formation as Inferred from Transient Electromagnetic Method (TEM or TDEM) Surveys." Unpublished memorandum to M. Chu, February 20, 1996. Albuquerque, NM: Sandia National Laboratories.

Attachment 18-6

SWCF WPO 40199 Powers, D.W., Sigda, J.M., and Holt, R.M. 1996. "Probability of Intercepting a Pressurized Brine Reservoir Under the WIPP." Unpublished report, July 10, 1996. Albuquerque, NM: Sandia National Laboratories.

Appendix A

Background for Borehole Location Data

Westinghouse Electric Corporation

Not attached.
Available in SWCF.
Kurt Larson 7/12/96.

Appendix B

Location Data and Depth for

Drillholes with Interpreted Geophysical Data

Dennis W. Powers

Not attached.
Available in SWCF.
Kent Larson 7/12/86.

Appendix C

Structural Elevation Data for

Drillholes with Geophysical Data

Dennis W. Powers

Not Attached.
Available in SWCF.
Kurt Larson 7/12/96.

Appendix G

Regional Geological Processes Affecting Rustler Hydrogeology

Dennis W. Powers
and
Robert M. Holt

(report by IT Corporation)

Not Attached.
Available in SWCF.
Kurt Larson 7/12/96

Appendix H

Letter Transmitting Oil Company Responses re Brine Occurrences

Matthew Silva
(Environmental Evaluation Group)

Not Attached.
Available in SWCF.
KURT LARSON 7/12/96.

APPENDIX I

Comparison of Brine Intercept/No-Intercept Sample Semi-Variogram Calculations

Table I-A: Results from UNCERT's VARIO Module

Table I-B: Results from GSLIB's GAM2V Module

Table I-C: Results from VARIOWIN

Not Attached.
Available in SWCF
Kurt Larson
7/12/96

APPENDIX J

Cowden Isopach Sample Semi-Variogram Calculations

Table J-A: Results from UNCERT's VARIO Module

Not Attached.
Available in SWCF.
Kurt LARSON 7/12/96.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

MASS Attachment 4-1

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WFO 30840

INFORMATION ONLY

FEP Screening Analysis

S1: Verification of 2D-Radial Flaring Using 3D Geometry

WBS No. 1.1.6.3 [At time work was initiated, May 1995]

SWCF-A: 1.2.07.3: PA:QA:TSK: S1

ERRATA - February 19, 1996

Palmer Vaughn

Lead Staff Member: Palmer Vaughn
Sandia National Laboratories
Organization 6749

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Teklu Hadgu, Ecodynamics Research Associates
David McArthur, Sandia National Laboratories, Org. 6514
James Schreiber, Science Applications International Corporation

S-1: Verification of 2-D WIPP PA Grid Using 3-D Geometry
Summary Memo of Record

TO: D. R. Anderson

FROM: P. Vaughn

SUBJECT: FEP Screening Issue S-1

DATE: January 26, 1996

STATEMENT OF SCREENING DECISION

FEP Screening Issue S-1 need not be included in future system-level performance assessment calculations.

STATEMENT OF SCREENING ISSUE

The present 2-D WIPP PA grid and lumping of rooms and panels used in the performance assessment (PA) conceptual model need to be justified by comparison to a more detailed representation of the repository, shafts, and surrounding Salado Formation including repository dip. Concerns regarding the current conceptualization include the following:

Results using a 2-D WIPP PA grid need to be compared to those for a 3-D model to establish the reliability of the simplification for identical geometric conditions. This comparison should be performed for a consistent representation of the repository in both cases with the only change being the dimensionality of the model. When dip is included, the problem becomes fully three-dimensional, and the 2-D WIPP PA grid option becomes much more questionable. With the 2-D WIPP PA grid, brine and gas flows are required to occur laterally in the entire element, whereas they may actually only occur in a very limited section.

The objective of the current study is thus to test the performance and adequacy of the 2-D grid by comparing it with a 3-D grid constructed based on the 2-D model.

APPROACH

The first task was construction of a conceptual model to be used for the study. The 2-D PA grid was constructed from a 3-D conceptualization in which rooms, panels, and drifts were first lumped together to form a much-simplified 3-D repository geometry. The 2-D grid is a further simplification that is intended to preserve accessible pore volume. The method is described in detail in Chapter 4 of Volume 4 of the Preliminary Performance Assessment (1992). Construction of the 3-D grid for this study started from the simplified 3-D repository geometry, and the third (east-west) dimension was gridded instead of being lumped into two dimensions.

Currently, the 2-D mesh being used for WIPP Performance Assessment calculations consists of 31 grid blocks in the x-axis and 27 grid blocks in the vertical axis for a total of 837 grid blocks. If we add a third dimension with, say, 31 grid blocks, the total number of blocks in 3-D will be 25,947. This gridding size would require computation times that are prohibitive. Therefore, in order to reduce the size of the problem, and to concentrate on the regions of importance, some simplifications were adopted:

- To concentrate on the repository and waste, the Rustler and Castile formations, and all formations above the Rustler were excluded. Thus the grid includes only the Salado formation.

- Because of symmetry in the north-south-direction, only one half of the problem was considered.

- In the actual repository, connections between the panels are through the seals. Thus, any other connections between the single panel and the rest of the repository were removed. The same procedure was applied to the experimental and operations regions.

The above simplifications do not invalidate the study because all regions of importance to the implementation of the performance measures were included.

A new model of the WIPP site was developed for the current study based on the simplifications described above. The model retains the features of the original grid but some grid blocks are lumped together. These simplifications resulted in reducing the total number of 3-D grid blocks to 2100 (*i.e.*, NX = 21, NZ = 10, NY = 10 for the TOUGH28W run, and NX = 23, NY = 12, NZ = 10 for the 3-D BRAGFLO runs). This modified 3-D grid runs at a reasonable speed for the purpose of the current study. Note that the computation times would still be unreasonable for routine probabilistic runs (see Table 2, Appendix 2 for a comparison of CPU times). Results will be compared with a similarly modified 2-D grid.

After construction of the simplified 2-D and 3-D grids, simulation procedures, as used for the compliance Performance Assessment were conducted. The TOUGH28W code, which is a WIPP version of the code TOUGH2 (Pruess, 1991), was used for the 3-D simulation, and BRAGFLO was used for both 2-D and 3-D simulations. Since TOUGH28W does not currently have the capacity to model gas generation and brine consumption, gas generation was modeled as a constant average source value over the repository. Brine consumption was not included in the simulations. The simulations calculated flow in the WIPP site for a period of 10, 000 years starting from -5 years, the same as in the PA calculations. At -5 years, the WIPP site is at hydrostatic condition except for the excavated regions, which are at 1 atm. pressure. The first 5 years of the simulation (-5 to 0) represent the operational period of the repository, during which some depressurization and brine drainage occurs in the formations surrounding the repository. At time 0, the waste material is placed in the repository, and creep-closure and gas generation are activated. At 100 years, shaft seal material properties are changed. At 1000 years, the intrusion well is activated, and gas generation is stopped. The disturbed option (intrusion well scenario) was selected because it is associated with higher releases to the environment, compared to the undisturbed option. For the current study gas generation is stopped at 1000 years, which means that the maximum pressure for both disturbed and undisturbed scenarios would be the same.

Median values were input for distributed parameters. The simulation was based on two cases of gas generation rates in the repository. The rates were based on the estimated repository gas generation of 1600 moles per drum, reported on page A-11 of Volume 3 of the Preliminary Performance Assessment (1992), and 3200 moles per drum to account for other sources such as plastics and rubber as potential gas generators. The first case (*i.e.*, the base case) used an average gas generation rate in the repository of 1.6 moles per drum per year for 1000 years. The second case used a gas generation rate double that of the first case. The higher rate would include potential gas generation due to plastics and rubber. It will also allow fracturing of the anhydrite layers so that the effect of dip and fracturing on flow were included. Note that all runs included the 1-degree dip.

The results of simulation were to be compared based on the performance measures. The selected performance measures include pressure in the repository (because it is important for blowout and fracturing), and brine out flow at the top of shaft, top of the intrusion well and at the 2.4 km land withdrawal boundary.

RESULTS AND DISCUSSION

A simplified version of the two dimensional WIPP PA grid being used for WIPP PA has been tested against a corresponding three dimensional model. BRAGFLO was used for both 2-D and 3-D simulations, and TOUGH28W was used for the 3-D simulations only. Simulation results were compared for cases with an average repository gas generation rate, and a gas generation rate double the average gas generation rate. The simulation results were plotted and are shown in Figs. 6 to 16 in Appendix 2. The results of Case 2 (*i.e.*, doubled gas generation rate) indicate that a combination of pressure induced fracturing and the 1-degree dip cause flow paths which are different for the 2-D and 3-D grids. Once fracturing occurs, the 3-D model displays an immediate migration of gas primarily out of the west side of the repository into the anhydrite layers, accompanied by brine inflow to the repository. This phenomenon is not seen in the results from the 2-D model, in which the west side of the repository is a no-flow boundary

(see Figs. 12 and 15), which demonstrates that the 2-D and 3-D simulations show local variations. However the results also show that predictions of brine flow to the accessible environment are similar for both grids. The main advantage of the 2-D grid over the 3-D grid is the reduced computation time and storage, allowing an efficient and fast processing of data for the numerous vectors that are required for the probabilistic Performance Assessment calculations. Following is a summarized analysis of the results based on the selected performance measures:

- The amount of brine inflow and outflow at the 2.4 km boundary of the anhydrite layers is low. For Case 1 (*i.e.*, median gas generation rate), the cumulative inflow over the 10,000-year performance period for 2-D BRAGFLO was about 800 kg (0.65 m^3), and outflow was about 400 kg (0.33 m^3). The corresponding 3-D BRAGFLO results show an inflow of about 15,400 kg (12.5 m^3) and outflow of 114 kg (0.093 m^3) at the boundary. For Case 2 (*i.e.*, doubled gas generation rate) the cumulative inflow over 10,000 years for 2-D BRAGFLO was 0.3 kg (2.4 x 10^{-4} m^3), and the cumulative outflow was 8411 kg (6.8 m^3). The corresponding 3-D BRAGFLO results were a cumulative inflow of 15383 kg (12.5 m^3) and a cumulative outflow of 817 kg (0.66 m^3). For both Case 1 and Case 2, the 2-D BRAGFLO results are consistently higher than those of the 3-D. Note that these figures represent only half of the repository, and that the amount of contamination of the brine has not been verified.

- Both 2-D and 3-D results showed that at the top of the shaft there was no brine flow out, but some gas flowed out.

- Both 2-D and 3-D showed that there was no brine flow from panel up the borehole following intrusion.

- The results of repository pressure for both 2-D and 3-D with TOUGH28W and BRAGFLO were in good agreement. Plots for the base gas generation rate shown in Fig. 6 are almost identical. Plots for the doubled gas generation rate (see Fig. 11) are also identical except at the peak, where some differences occur.

BASIS FOR RECOMMENDED SCREENING DECISION

Comparison of outputs of calculations of the simplified 2-D WIPP PA grid and a corresponding 3-D grid, based on the selected input data, showed that results were equivalent for the most part. Although the 3-D grid showed flow details which were not accurately represented with the 2-D grid, the computed releases to the accessible environment for both grids were nearly equivalent. This indicates that, based on the performance measures and the overall uncertainty, the current model being used for WIPP Performance Assessment is sufficient for estimates of calculated releases. Calculations using the 2-D grid are more computationally efficient, which is necessary for the large number of vectors.

CERTIFICATION AND TRAINING

The following individuals were responsible for the calculations and analysis of the FEP screening effort:

T. Hadgu, D. McArthur and J. Schreiber.

Head staff member and reviewers included:

M. Lord, R. MacKinnon and P. Vaughn.

Copies of certification and training of personnel involved in the FEP screening issue S-1 are on file in the SWCF. All staff were trained on QAP's.

CORRESPONDENCE

None

REFERENCES

Butcher, B. M., S. W. Webb, and J. W. Berglund, 1995. *System Prioritization Method-Iteration 2. Baseline Position Paper: Disposal Room and Cuttings Models, Volume 2*, Appendix F. March 28, 1995. Albuquerque, NM: Sandia National Laboratories.

Christian-Frear, T. and Webb, T., 1995. Milestone SH001: Preliminary Comparison of BRAGFLO and TOUGH28W using a WIPP PA Specific Conceptual Model for Undisturbed Conditions.

International Formulation Committee, 1967. *A formulation of the Thermodynamic Properties of Ordinary Water Substance*, IFC Secretariat, Düsseldorf, Germany.

Pruess, K., 1983. *Development of a General Purpose Simulator MULKOM, Annual Report 1982*, Earth Sciences Division, report LBL-15500, Lawrence Berkeley Laboratory.

Pruess, K., 1987. *TOUGH Users' Guide*, Report LBL-20700, Lawrence Berkeley Laboratory, CA.

Pruess, K., 1991. *TOUGH2-A General-Purpose Numerical Simulator for Multiphase Fluid and Heat Flow*, Report LBL-29400, Lawrence Berkeley Laboratory, CA.

WIPP PA (Performance Assessment) Department, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992-Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B*, SAND92-0700/4, Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992-Volume 3: Model Parameters*, SAND92-0700/3, Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department, 1995. *User's Manual for BRAGFLO, Version 3.62ZO*, Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department, 1995. *Software Quality Assurance Notebook for BRAGFLO, Version 3.62ZO*, Albuquerque, NM: Sandia National Laboratories.

APPENDIX 1: Overview of BRAGFLO and TOUGH28W

As stated earlier, both BRAGFLO and TOUGH28W were used to simulate flow in the repository site. Note that the verification of BRAGFLO for QA included comparing output of BRAGFLO with that of TOUGH2 and with analytical solutions of selected problems (see Software Quality Assurance Notebook for BRAGFLO, 1995). In addition, Christian-Frear and Webb (1995) compared results of BRAGFLO and TOUGH28W using a WIPP model with median values for an undisturbed scenario. Both the QA verification work and the comparison of the codes using the WIPP model showed that results of the two codes were very similar. Because of those findings a decision was made to use both codes for the present study. However, it should be pointed out that although both codes solve the same equations of motion, code architecture, solution methods, some fluid properties are not the same. A list of some of the differences is given below.

BRAGFLO is the numerical simulator being used for WIPP PA to study flow in the repository site. It is a two-phase (brine and gas), isothermal finite difference simulator which uses mass balance equations and Darcy's law. The non-linear equations are solved using the Newton-Raphson iterative scheme, and a direct equation solver. The code includes WIPP-specific processes such as pressure induced fracturing, creep closure, gas generation and brine consumption.

TOUGH28W is the WIPP version of TOUGH2 (*i.e.*, TOUGH2 with EOS8) which includes WIPP-specific processes such as pressure induced fracturing and creep closure. TOUGH2 (Pruess, 1991) is a non-isothermal, multiphase flow integral finite difference numerical simulator for porous and fractured media. It assumes Darcy flow. TOUGH2 and the earlier version TOUGH (Pruess, 1987) belong to the MULKOM family of codes (Pruess, 1983). The coupled non-linear equations are solved using the Newton-Raphson iterative scheme, and the code allows a selection of direct and preconditioned conjugate gradient solvers. TOUGH2 includes a number of equation of state (EOS) modules to evaluate fluid properties of different fluids.

Following is a list of some features and differences of the two codes. Note that these differences are as of the present, and that both codes could be modified to include new features.

- BRAGFLO uses brine pressure and gas saturation as primary variables for two-phase flow. The initial conditions in the input require brine saturation. TOUGH28W uses gas pressure, gas saturation and temperature as primary variables, and requires gas saturation initially.

- BRAGFLO uses finite differences while TOUGH28W uses integral finite differences to approximate the partial differential equations of motion. TOUGH28W does not depend on any global coordinate system. However, for the problem at hand, the two methods are equivalent since Cartesian geometry is used.

- BRAGFLO uses a direct equation solver with LU-decomposition. TOUGH28W has a selection of direct and preconditioned conjugate gradient (pcg) solvers. The pcg solvers require less storage and are normally expected to be faster than direct solvers, and so are useful for large problems. In this study, BRAGFLO with its direct solver turned out to be faster by a factor of 4.

- The convergence criteria, tolerances and time step controls are different in the two codes. BRAGFLO uses individual Newton-Raphson convergence criteria for pressure and saturation. TOUGH28W requires separate convergence criteria and tolerance limits for Newton-Raphson and the preconditioned conjugate gradient solvers. In TOUGH28W convergence of Newton-Raphson iterations depends on a general criterion (size of residual), rather than on individual primary variables, as in BRAGFLO.

- There are differences in the evaluation of interface parameters for flow calculation. BRAGFLO employs harmonic averaging of permeabilities, densities, viscosities and interface areas, and upstream weighting of relative permeabilities. TOUGH28W gives the user a choice of weighting methods. For the current simulations options that are close to those of BRAGFLO were selected.

The selected options were upstream weighting of relative permeabilities and viscosity, harmonic weighting of permeability, and arithmetic averaging of density.

- TOUGH28W uses a formatted input which requires input information placed at specified position. BRAGFLO uses unformatted input. The input of BRAGFLO allows simulations to continue to 10,000 years without stopping to change input parameters at selected times. TOUGH28W, on the other hand, needs to be stopped when material properties have to be changed (such as when shaft seal permeability is changed at 100 years).

- BRAGFLO has a set of input and output data processing codes and plotting capabilities. This allows a vastly more efficient analysis of data than currently is available on TOUGH28W. Similar codes have been developed for TOUGH2 but are not available to all users.

- Both codes allow pressure induced fracturing of the anhydrite layers. But the input parameters for fracturing are not the same. For instance, TOUGH28W requires changes in pressure above initial pressure for both initiation and ending of fracturing. In the case of BRAGFLO, the corresponding input parameters are change in pressure above initial pressure for initiation of fracturing, and change of pressure above the initiation pressure for ending fracturing. Note that the setup in TOUGH28W needs modification. Currently, when restarting is done after change of input parameters, the initial pressures are not stored, resulting in new initial pressures. This needs to be changed.

- Both codes allow for creep closure of the excavated areas. Currently, both use data generated by SANTOS (Butcher *et al.*, 1995) based on studies of salt creep. The tabulated data are in the form of Pressure-Time relations, and are used to modify formation porosity. Simulations show that the creep closure option in TOUGH28W slows calculations significantly. Modifications might be required so that the computation speed is improved.

- BRAGFLO computes gas generation and brine consumption due to corrosion and biodegradation. Currently this option is not fully functional on TOUGH28W.

- For capillary pressure and Klinkenberg effect BRAGFLO requires input of individual constants while TOUGH28W uses a combination of the constants. For instance, in the correlation for formation permeability to gas: $k_g = k_w(1 + bk_w^{-a} / p)$, BRAGFLO requires the values of the constants a and b as input while TOUGH28W requires the term bk_w^{-a}. In the case of capillary pressure, the input to TOUGH28W is residual liquid saturation, residual gas saturation, parameter lambda, threshold pressure and maximum pressure. The input to BRAGFLO is the same as the above except for threshold pressure. In BRAGFLO, the threshold pressure is calculated as a function of permeability using: $P_t = a\ k^h$, and the constants a and h are the input parameters. Input parameters are selected so that the sub-models are equivalent in treatment.

- BRAGFLO uses the Redlich-Kwong-Soave equation of state to evaluate gas density. Brine density is calculated based on a constant fluid compressibility. Both gas and liquid viscosities are assumed constant and are required as input. TOUGH28W uses the perfect gas law for gas density. Brine density and liquid and gas viscosities are all dependent on temperature and pressure. Properties of water are obtained from the steam table equations of the International Formulation Committee (1967). To facilitate comparisons with BRAGFLO the equation of brine density used in BRAGFLO has been added to TOUGH28W.

It should be pointed out that comparisons between BRAGFLO and TOUGH2 (commercial version), using selected problems for the verification BRAGFLO, showed similar results (see Software Quality Assurance Notebook for BRAGFLO, 1995).

APPENDIX 2: Discussion of Results

Following is a discussion of results of FEP S-1 for the 2-D and 3-D grids for Cases 1 and 2 using BRAGFLO and TOUGH28W computer codes. CPU times and time steps are given in Table 2.

Case 1: Base Gas Generation Rate

Results of simulation for Case 1 are shown in Figs. 6 to 10. The figures show plots of average gas pressure, gas saturation and porosity in the repository (*i.e.*, Materials 17 and 19 in Figs. 1 and 2); gas mass in place in the repository; cumulative net brine inflow into the repository and cumulative brine outflow from the repository. The plots are results of 2-D and 3-D BRAGFLO, and 3-D TOUGH28W. For Case 1, the pressures were not high enough to cause pressure induced fracturing in the anhydrite layers. The results are mostly in general agreement, as is shown in the figures. The curves for average gas pressure and porosity in the repository (Figs. 6 and 8, respectively) are almost identical. Initially the repository is at atmospheric pressure. As brine flows into the excavated regions, and also due to the generation of gas in the repository, the pressure increases (Fig. 6). At 1000 years, the intrusion well penetrates the repository, which allows gas to escape. As a result the pressure drops. The three curves show almost identical behavior.

Fig. 7 shows simulation results for average gas saturation in the repository. The curves show a similar trend. At time zero, brine continues to flow into the excavated region due to differences in hydrostatic head. Although gas is generated at this time, the effect of the hydrostatic head is more important. In addition, gas escapes through the shaft, as the shaft seal is not placed yet. Thus the gas saturation drops initially. At 100 years, the shaft seal is placed, and the gas saturation stabilizes up to 1000 years. At 1000 years, gas generation is stopped, and gas starts to escape through the intrusion well. In addition, brine flows into the repository. This causes gradual decline of the gas saturation until it drops to its residual value. Note that exactly the same trend is not followed in the individual grid blocks, and that the curves only show average behavior. The three curves are close until about 1500 years but differ in the period 1500 - 7000 years. These differences are also shown in plots of cumulative net brine inflow into the repository (Fig. 10). As shown in Figs. 7 and 10, the plots for 3-D BRAGFLO and 3-D TOUGH28W are closer to one another than to 2-D BRAGFLO. For instance, both curves show full brine saturation at about 8800 years while the prediction of 2-D BRAGFLO is at about 9500 years. Thus these differences may be attributed to differences in prediction of 2-D and 3-D grids. The differences between the 3-D BRAGFLO and TOUGH28W are believed to be due to the differences in the two codes described in Appendix 1.

Fig. 9 shows gas mass in place in the repository. Again, all curves show the same trend. The mass in place increases between 100 and 1000 years due to gas generation. It then drops drastically due to gas withdrawal through the intrusion well and because gas generation is discontinued. The mass in place continues to drop gradually until the immobile quantity is reached. The predictions are slightly different around the peak mass in place, which is probably due to differences in the equations of gas density, among other reasons.

Fig. 10 shows plots of brine net inflow and outflow at the repository. The calculations are based on flow through all boundaries of the Panel and Rest of Repository (see Figs. 1 and 2). Note that a plot of outflow for 3-D TOUGH28W has not been provided because the method of evaluation of the outflow was not the same as in BRAGFLO. 2-D BRAGFLO predicts a maximum outflow of about 3×10^6 kg (2439 m^3) while 3-D BRAGFLO predicts about 4.3×10^6 kg (3496 m^3) at 10,000 years. Fig. 15 shows the corresponding plots for the doubled gas generation case. In the plot, 2-D BRAGFLO predicts maximum brine outflow of about 2×10^6 kg (1626 m^3) whereas 3-D BRAGFLO predicts a slightly higher value of about 2.5×10^6 kg (2032 m^3) at 10,000 years. This potentially contaminated brine flows to the DRZ, where it mixes with a large volume of uncontaminated brine. Some of this mixture of uncontaminated and potentially contaminated brine migrates to the anhydrite layers (mainly to MB139). The amount of brine flow to the halite which has a very low permeability is not significant. The extent to which the brine is contaminated is not known from the BRAGFLO calculations alone. In any case the brine outflow at the 2.4 km anhydrite boundary is very low for both 2-D and 3-D, as shown above. Note also that the calculations did not include brine consumption in the waste due to chemical reactions (*i.e.*, because TOUGH28W did not have this option). According to earlier work, a large portion of the brine inflow to the repository is consumed. Thus the calculations of brine outflow from the repository would have been much lower if brine consumption was included.

One of the reasons for the differences observed in the predictions of the 2-D and 3-D curves is the method of weighting of inter-block parameters. For instance, the flow areas between grid blocks in the 3-D cases are the same while those of the 2-D model are different. Thus, when BRAGFLO applies harmonic weighting on the areas the magnitude of the flux will be different from that of the 3-D cases.

Case 2: Doubled Gas Generation Rate

For this case the gas generation rate of Case 1 was doubled. The objective of this case was to include contributions of gas generation due to plastics and rubber, and also to allow fracturing in the anhydrite layers in order to study its effect on the performance of the 2-D approximation. Doubling the gas generation allowed pressures to build-up and cause pressure induced fracturing in the anhydrite layers. Note that our earlier attempt was to include TOUGH28W for Case 2 calculations. As stated in Appendix 1, currently TOUGH28W does not store initial conditions at time 0, which are required for the pressure induced fracturing model. Thus TOUGH28W could only be used if restarting is avoided. In our attempt to use TOUGH28W we decided to make shaft seal property changes at time 0 (instead of at 100 years), and run 0 - 1000 years without any restarting. Thus, all Case 2 calculations do not have shaft seal property changes at 100 years. Everything else, except for gas generation rate, remained as in Case 1. The above modifications could allow TOUGH28W to run to 1000 years. However since another restarting is required at 1000 years, it was finally decided not to use TOUGH28W for Case 2. Only results of 2-D and 3-D BRAGFLO are compared for this case. Results of simulation are shown in Figs. 11 to 16.

Fig. 11 shows plots of gas pressure vs. time for 2-D and 3-D BRAGFLO. Because of doubling the gas generation rate, the maximum pressure in this case is over 17 MPa for 2-D BRAGFLO compared to 12.5 MPa in Case 1. This caused fracturing in the anhydrite layers, as is evident from the permeability changes observed. The predictions of gas pressure in the repository are nearly the same except at the peak. 2-D BRAGFLO predicts a maximum of about 17.5 MPa while 3-D predicts about 16.5 MPa. In this case, the shaft seal is installed at time zero (as opposed to 100 years for Case 1) and thus gas build-up starts early.

Fig. 12 shows plots of gas saturation. In this case a sharp drop is observed in the predictions of 3-D BRAGFLO earlier than in Case 1. In Case 1 the drop occurred at 1000 years, because the intrusion well penetrated the repository, and gas generation was stopped. In Case 2, in addition to the reasons given for Case 1, fracturing in the anhydrite layers causes the gas saturation to drop. Results of permeability changes demonstrate that fracturing occurs before 1000 years, which explains the drops in saturation shown in Fig. 12. On the other hand, 2-D BRAGFLO shows a gradual drop of saturation, although fracturing has occurred.

The sharp drop in saturation is in line with changes in cumulative net brine inflow into the repository (Fig. 15), and porosity in the anhydrite layers (Fig. 16). This is due to a combination of pressure induced fracturing and the 1-degree dip. A study of the 3-D results shows significant permeability increases in the North-West section of the anhydrite layers. This causes an increased migration of gas out of the repository, which in turn induces an inflow of brine into the repository (see Fig. 15). Note that the maximum fracturing occurs up-dip where the maximum changes in pressure occur. Although 2-D BRAGFLO predicts fracturing in the anhydrite layers, the magnitude of average porosity and permeability changes are different from 3-D (see Fig. 16). In addition, fracturing for 3-D is spread over the 3-D geometry whereas fracturing for 2-D occurs to the south and north only. As a result, changes in saturation and mass movement are not as sharp. Since gas saturation is stopped and the intrusion well is introduced at 1000 years, the effect of fracturing is reduced in the time beyond 1000 years. Once the effect of fracturing subsides the predictions of the two models are similar, which is why the curves are parallel in Figs. 12 and 15. Note that in Case 2 the repository is not brine saturated at 10,000 years.

Fig. 16 shows plots of volume averaged porosity for 2-D and 3-D BRAGFLO. Grid block porosities in all anhydrite layers were volume averaged in the region bounded by the 2.4 km land withdrawal boundary. This analysis may be used as a measure of the fracture porosity enhancement. Note that the analysis is over all anhydrite layers and that local variations were not reported. The extent of fracturing for 2-D is similar to that of 3-D along the North-South axis. For materials MB139 and Anhydrite A and B the fracturing extends to the first anhydrite grid block past the excavated region both in up-dip and down-dip directions. For material MB138, the fracturing extends to the first anhydrite grid block in the down-dip direction, and to two grid blocks in the up-dip direction. In the East-West direction fracturing in the 3-D grid extends over one grid block, except near the North-West corner of the excavated area where more fracturing is observed.

Table 1: Material Properties at Different Simulation Periods

-5 to 0 Years

Material Name	Permeabiliy (m^2)	Porosity	Compres. (1/Pa)	Klinkenberg Factor (MPa)	Lambda	Modified Brooks-Corey Parameters: Resid. Liquid Saturation	Resid. Gas Saturation	Threshold Pressure (Pa)	Maximum Cap. Pressure (Pa)
S-HALITE 12	1.E-21	0.01	8.054E-9	8.341E+0	0.7	0.3	0.2	9.e6	1.E+8
DRZ_1 16	1.E-15	0.01	8.279E-8	8.734E-2	0.7	0.0	0.0	0.0	1.E+24
TRANS_1 14	1.E-15	0.01	8.279E-8	8.734E-2	0.7	0.0	0.0	0.0	1.E+24
S_MB138 13	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
S_ANH_AB 15	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
S_MB139 22	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.2	0.0	1.E+24
SHFT_B_1 2	1.E-10	1.0	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+8
SHFT_LS1 4	1.E-10	1.0	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+8
REPOSIT 17	1.E-10	1.0	0.0	5.067E-3	0.7	0.0	0.0	0.0	1.E+24
PANEL 19	1.E-10	1.0	0.0	5.067E-3	0.7	0.0	0.0	0.0	1.E+24
BACKFILL 20	1.E-10	1.0	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+24
EXP_AREA 21	1.E-10	1.0	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+24

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0 to 100 Years

Material Name	Permeabiliy (m^2)	Porosity	Compres. (1/Pa)	Klinkenberg Factor (MPa)	Lambda	Modified Brooks-Corey Parameters: Resid. Liquid Saturation	Resid. Gas Saturation	Threshold Pressure (Pa)	Maximum Cap. Pressure (Pa)
S-HALITE 12	1.E-21	0.01	8.054E-9	8.341E+0	0.7	0.3	0.2	9.e6	1.E+8
DRZ_1 16	1.E-15	0.01	8.279E-8	8.734E-2	0.7	0.0	0.0	0.0	1.E+24
TRANS_1 14	1.E-15	0.01	8.279E-8	8.734E-2	0.7	0.0	0.0	0.0	1.E+24
S_MB138 13	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
S_ANH_AB 15	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
S_MB139 22	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
SHFT_B_1 2	1.E-12	0.075	1.333E-8	8.938E-3	0.7	0.2	0.2	7.947E+03	1.E+8
SHFT_LS1 4	1.E-12	0.050	1.2E-8	8.938E-3	0.7	0.2	0.2	4.268E+05	1.E+8
REPOSIT 17	5.585E-12	0.6602	0.0	5.067E-3	0.7	0.2	0.2	0.0	1.E+24
PANEL 19	5.585E-12	0.6602	0.0	5.067E-3	0.7	0.2	0.2	0.0	1.E+24
BACKFILL 20	1.E-12	0.075	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+24
EXP_AREA 21	1.E-12	0.075	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+24

100 to 1000 Years

Material Name	Permeabiliy (m^2)	Porosity	Compres. (1/Pa)	Klinkenberg Factor (MPa)	Lambda	Modified Brooks-Corey Parameters: Resid. Liquid Saturation	Resid. Gas Saturation	Threshold Pressure (Pa)	Maximum Cap. Pressure (Pa)
S-HALITE 12	1.E-21	0.01	8.054E-9	8.341E+0	0.7	0.3	0.2	9.e6	1.E+8
DRZ_1 16	1.E-15	0.01	8.279E-8	8.734E-2	0.7	0.0	0.0	0.0	1.E+24
TRANS_1 14	1.E-15	0.01	8.279E-8	8.734E-2	0.7	0.0	0.0	0.0	1.E+24
S_MB138 13	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
S_ANH_AB 15	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
S_MB139 22	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
SHFT_B_1 2	1.E-12	0.075	1.333E-8	8.938E-3	0.7	0.2	0.2	7.947E+03	1.E+8
SHFT_LS1 4	1.E-17	0.050	1.2E-8	3.992E-1	0.7	0.2	0.2	4.268E+05	1.E+8
REPOSIT 17	5.585E-12	0.6602	0.0	5.067E-3	0.7	0.2	0.2	0.0	1.E+24
PANEL 19	5.585E-12	0.6602	0.0	5.067E-3	0.7	0.2	0.2	0.0	1.E+24
BACKFILL 20	1.E-12	0.075	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+24
EXP_AREA 21	1.E-12	0.075	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+24

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1000 to 10,000 Years

Material Name	Permeabiliy (m^2)	Porosity	Compres. (1/Pa)	Klinkenberg Factor (MPa)	Lambda	Modified Brooks-Corey Parameters: Resid. Liquid Saturation	Resid. Gas Saturation	Threshold Pressure (Pa)	Maximum Cap. Pressure (Pa)
S-HALITE 12	1.E-21	0.01	8.054E-9	8.341E+0	0.7	0.3	0.2	9.e6	1.E+8
DRZ_1 16	1.E-15	0.01	8.279E-8	8.734E-2	0.7	0.0	0.0	0.0	1.E+24
TRANS_1 14	1.E-15	0.01	8.279E-8	8.734E-2	0.7	0.0	0.0	0.0	1.E+24
S_MB138 13	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
S_ANH_AB 15	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
S_MB139 22	2.51E-19	0.019	4.121E-9	1.347E+0	0.7	0.2	0.165	0.0	1.E+24
SHFT_B_1 2	1.E-12	0.075	1.333E-8	8.938E-3	0.7	0.2	0.2	7.947E+03	1.E+8
SHFT_LS1 4	1.E-17	0.050	1.2E-8	3.992E-1	0.7	0.2	0.2	4.268E+05	1.E+8
REPOSIT 17	5.585E-12	0.6602	0.0	5.067E-3	0.7	0.2	0.2	0.0	1.E+24
PANEL 19	5.585E-12	0.6602	0.0	5.067E-3	0.7	0.2	0.2	0.0	1.E+24
BACKFILL 20	1.E-12	0.075	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+24
EXP_AREA 21	1.E-12	0.075	0.0	8.938E-3	0.7	0.0	0.0	0.0	1.E+24
WELL	3.161E-13	0.37	0.0	1.307E-2	0.7	0.2	0.0	0.0	1.E+24

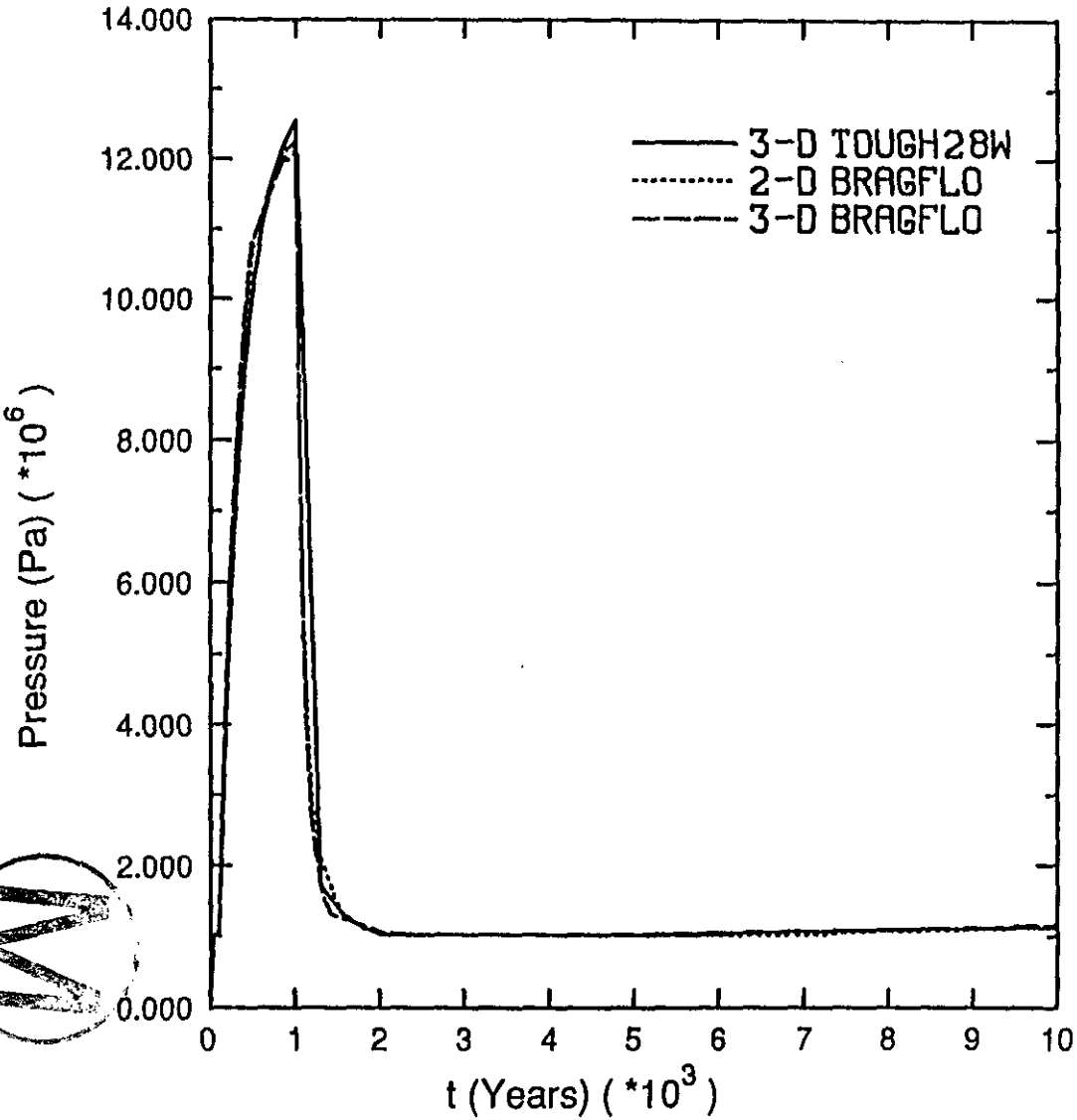

Fig. 6 Average Pressure in Repository - Base Gas Generation rate

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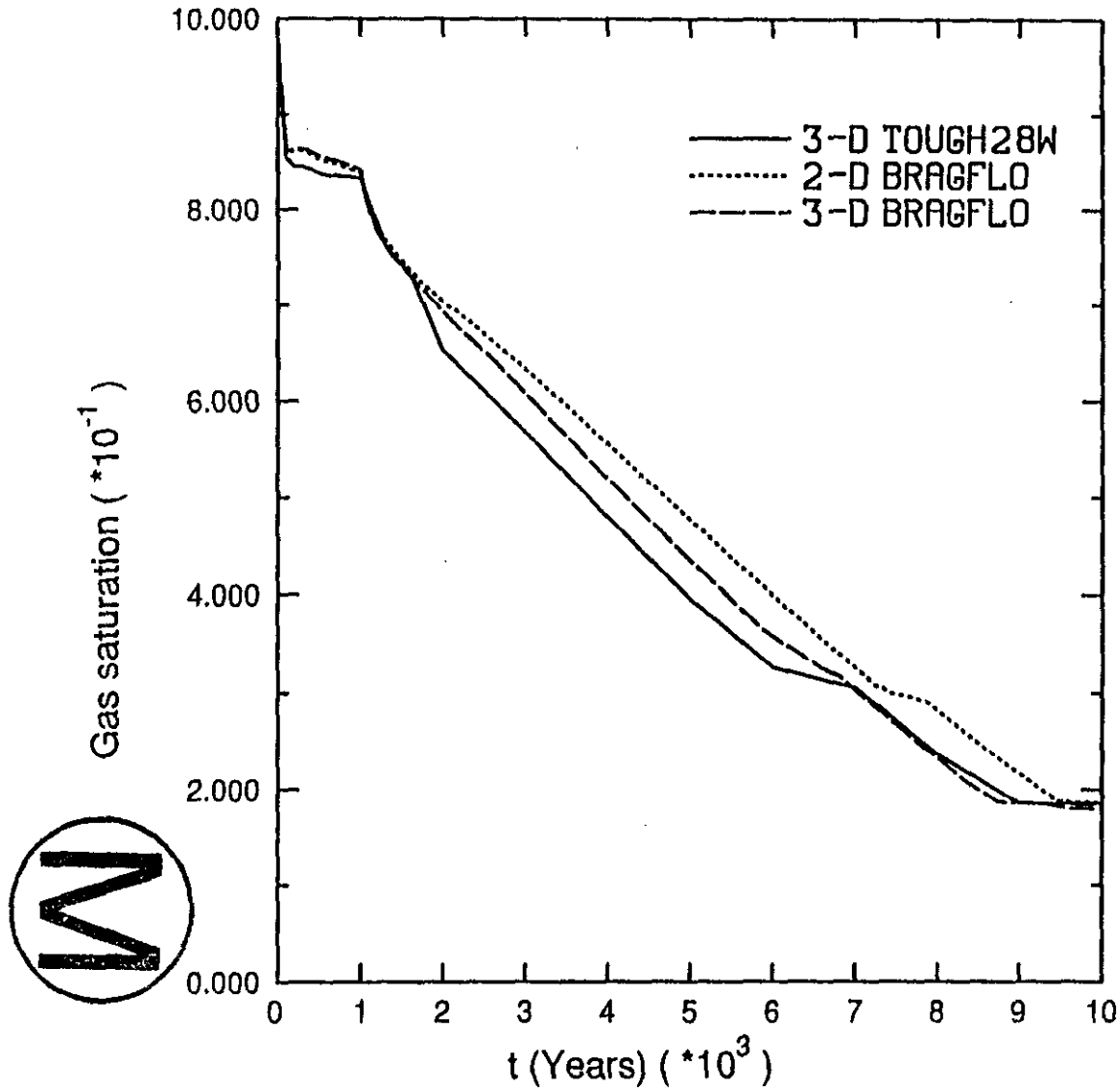

Fig. 7 Average Gas Saturation in Repository - Base Gas Generation rate

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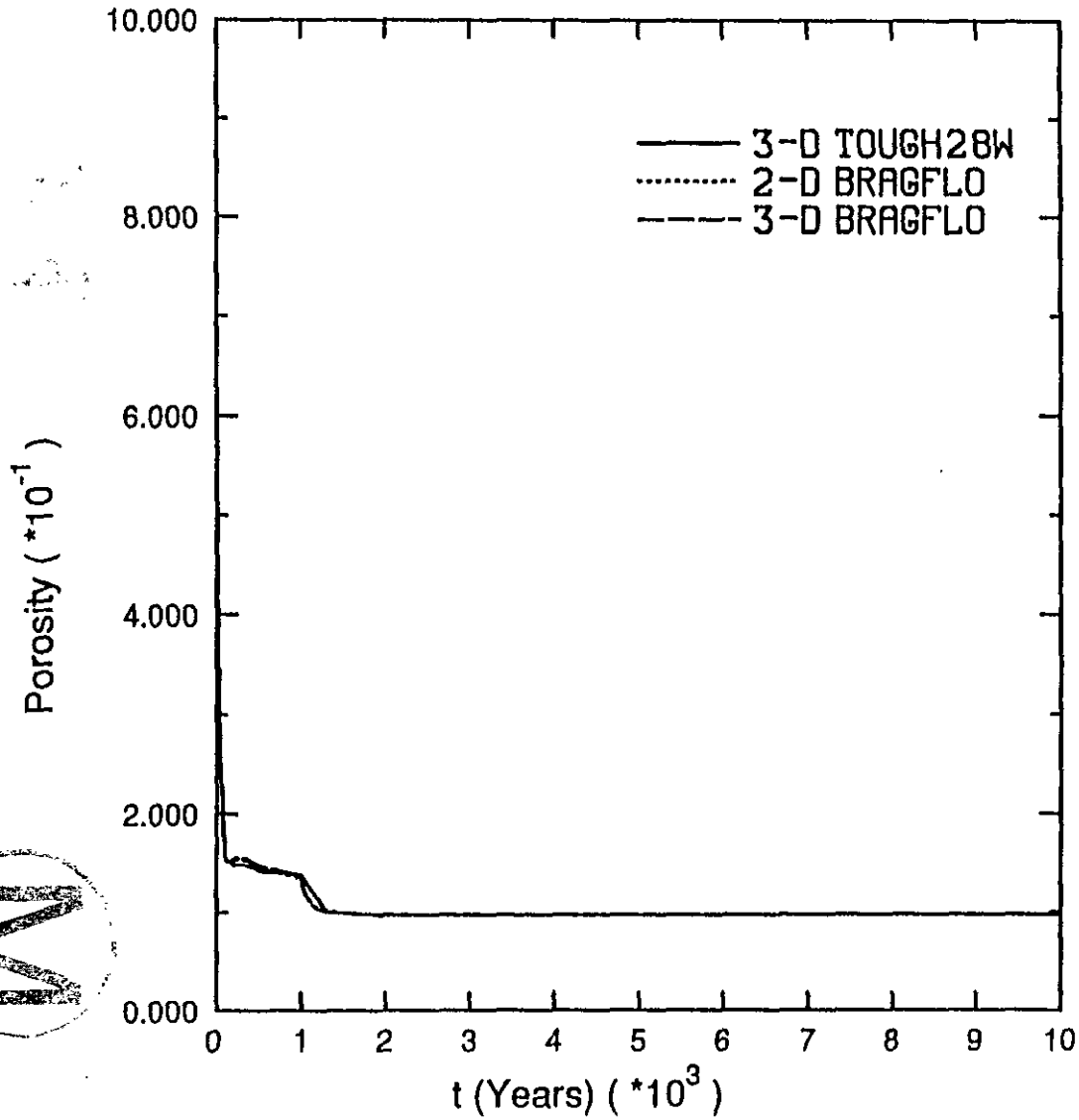

Fig. 8 Average Porosity in Repository - Base Gas Generation rate

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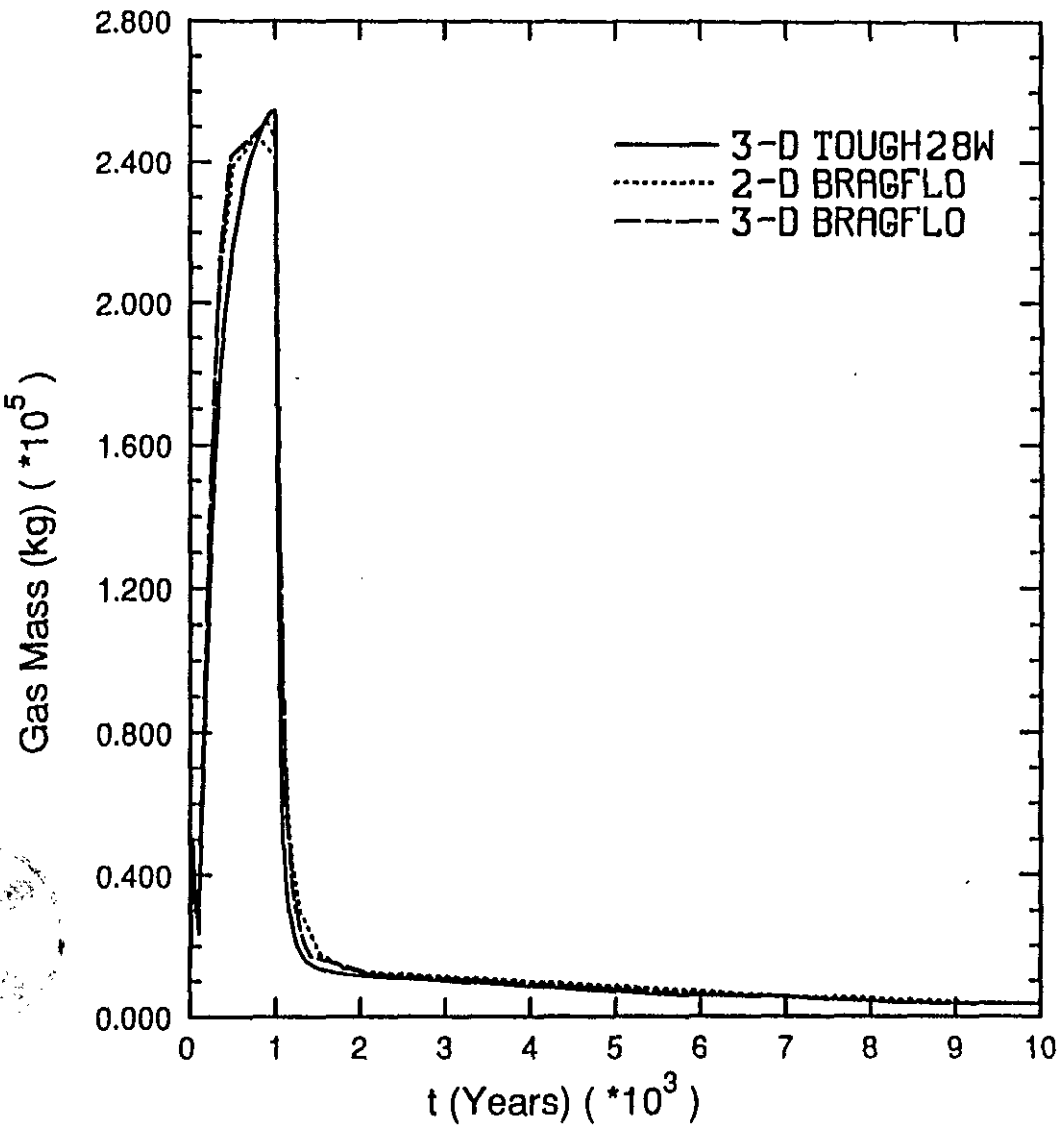

Fig. 9 Gas Mass in Place in Repository - Base Gas Generation rate

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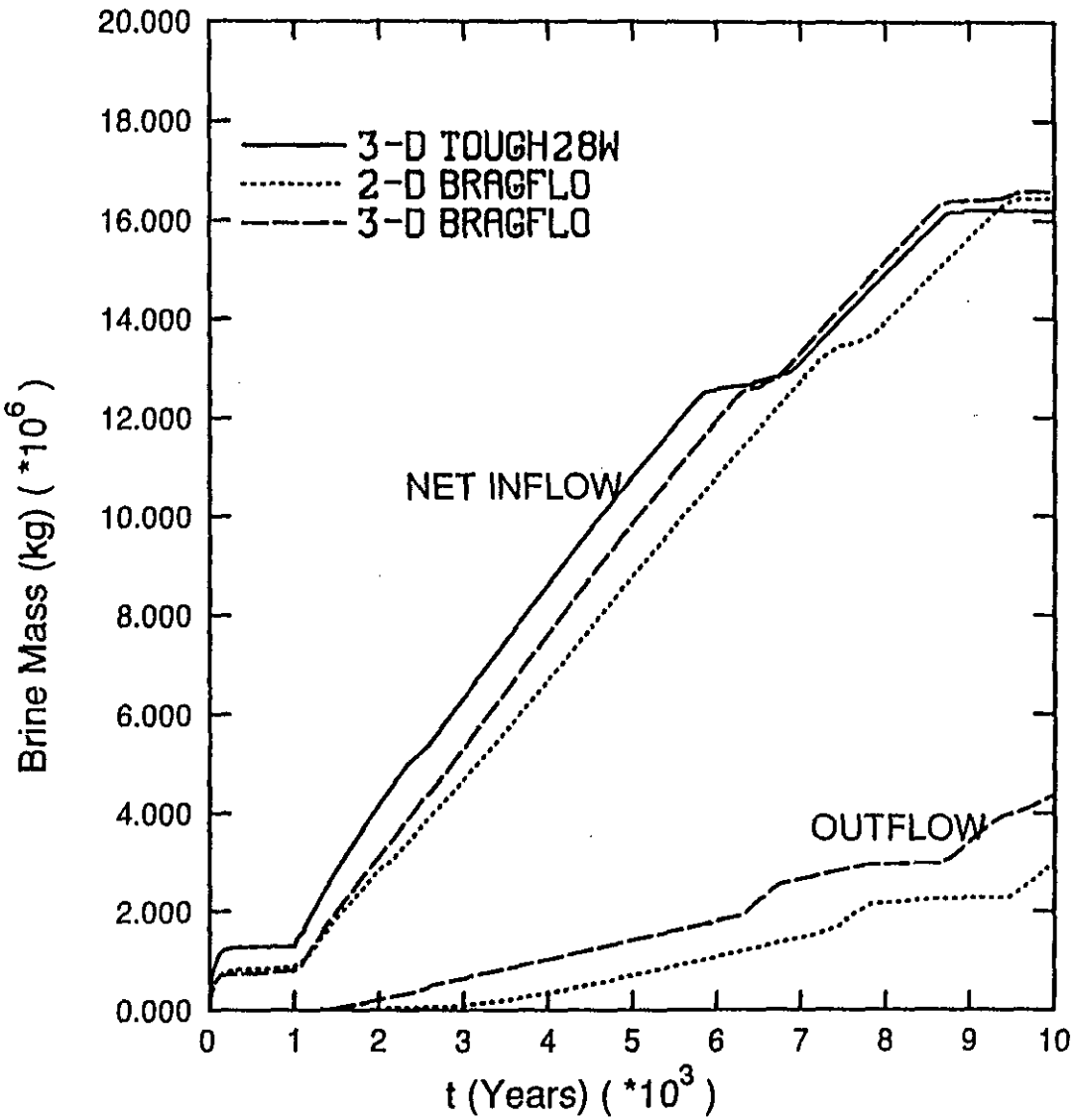

Fig. 10 Cumulative Net Brine In and Outflow at Repo. - Base Gas Generation rate

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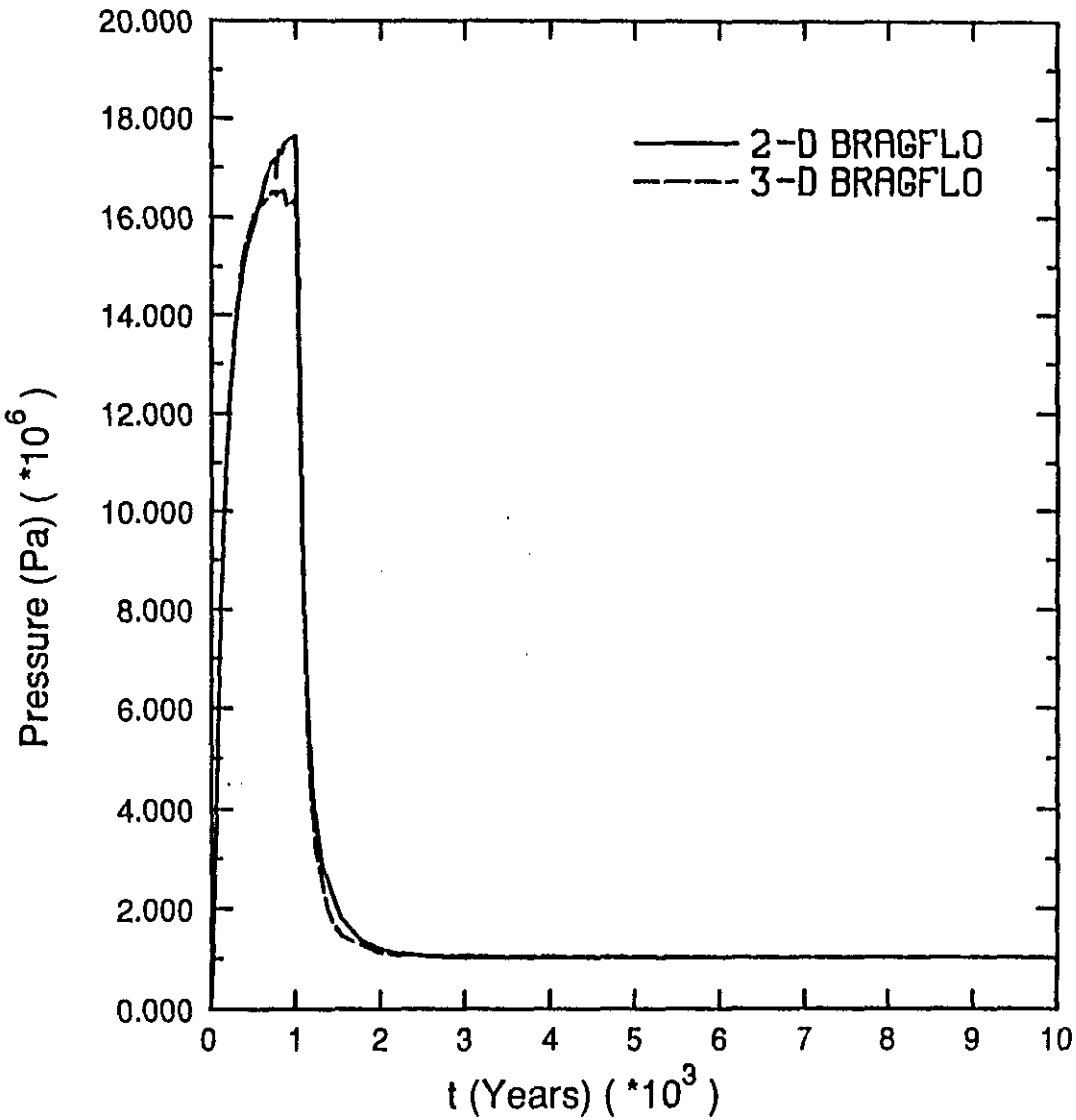

Fig. 11 Average Pressure in Repository - Doubled Gas Generation rate

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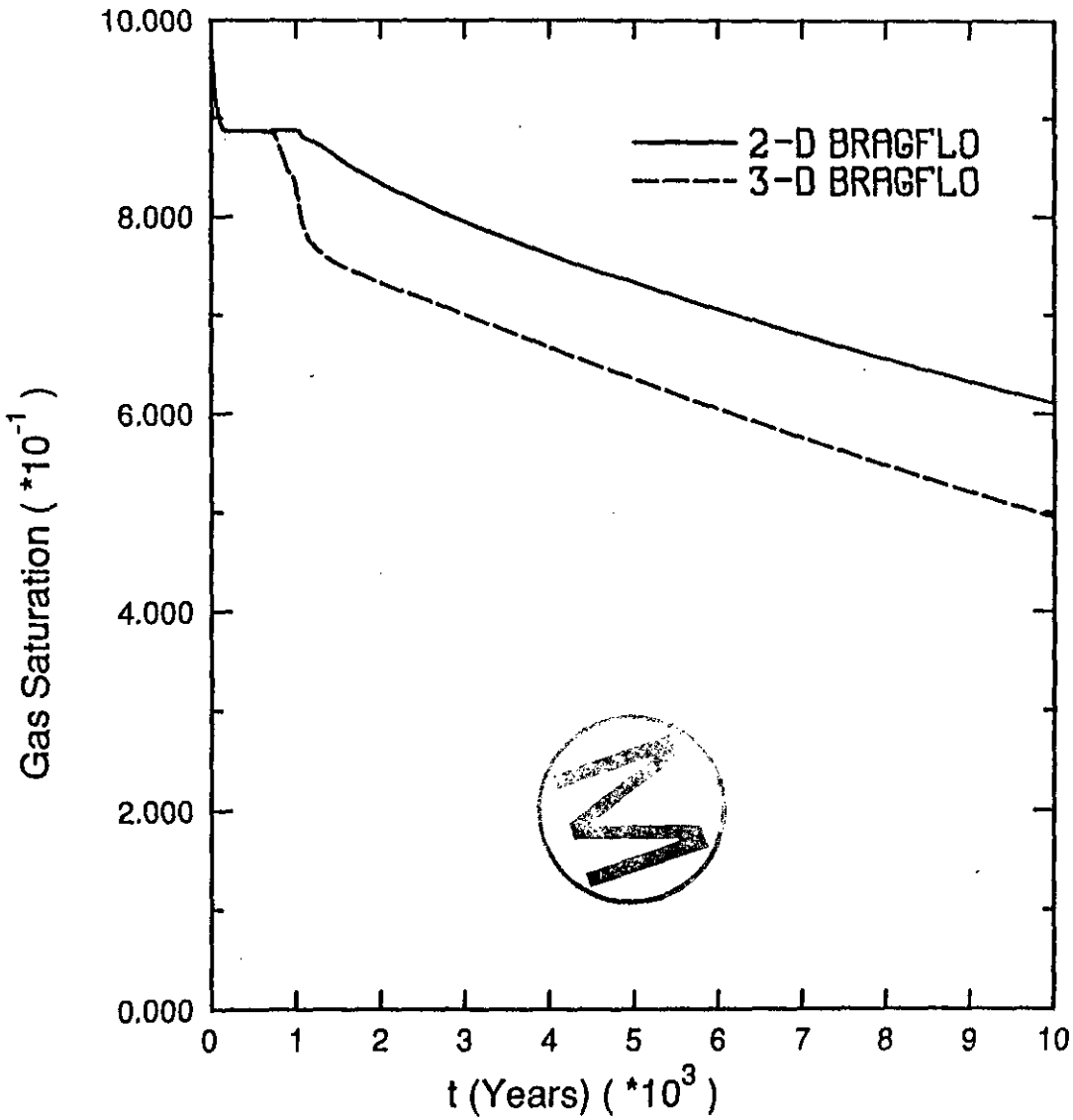

Fig. 12 Average Gas Saturation in Repository - Doubled Gas Generation rate

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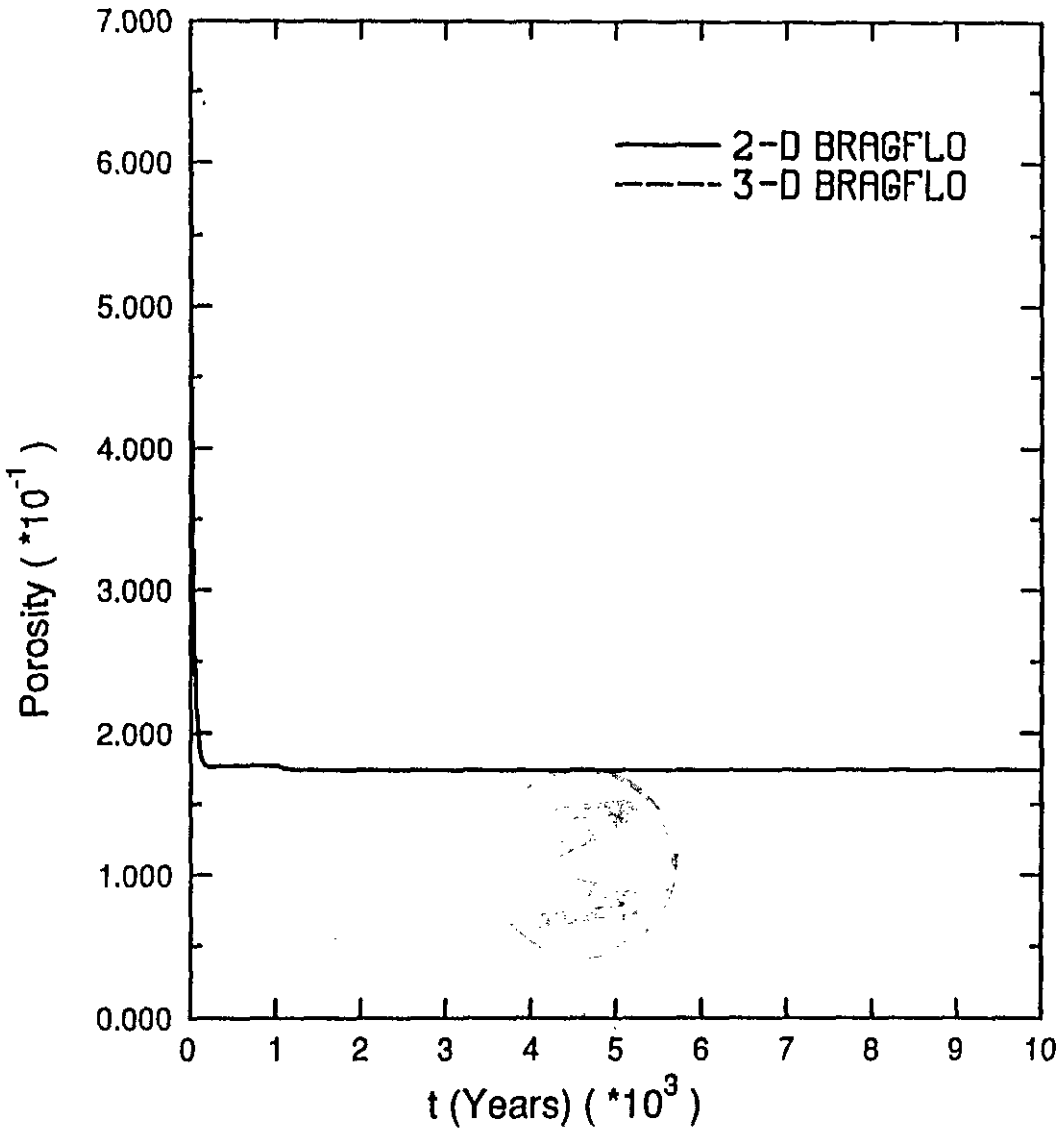

Fig. 13 Average Porosity in Repository - Doubled Gas Generation rate

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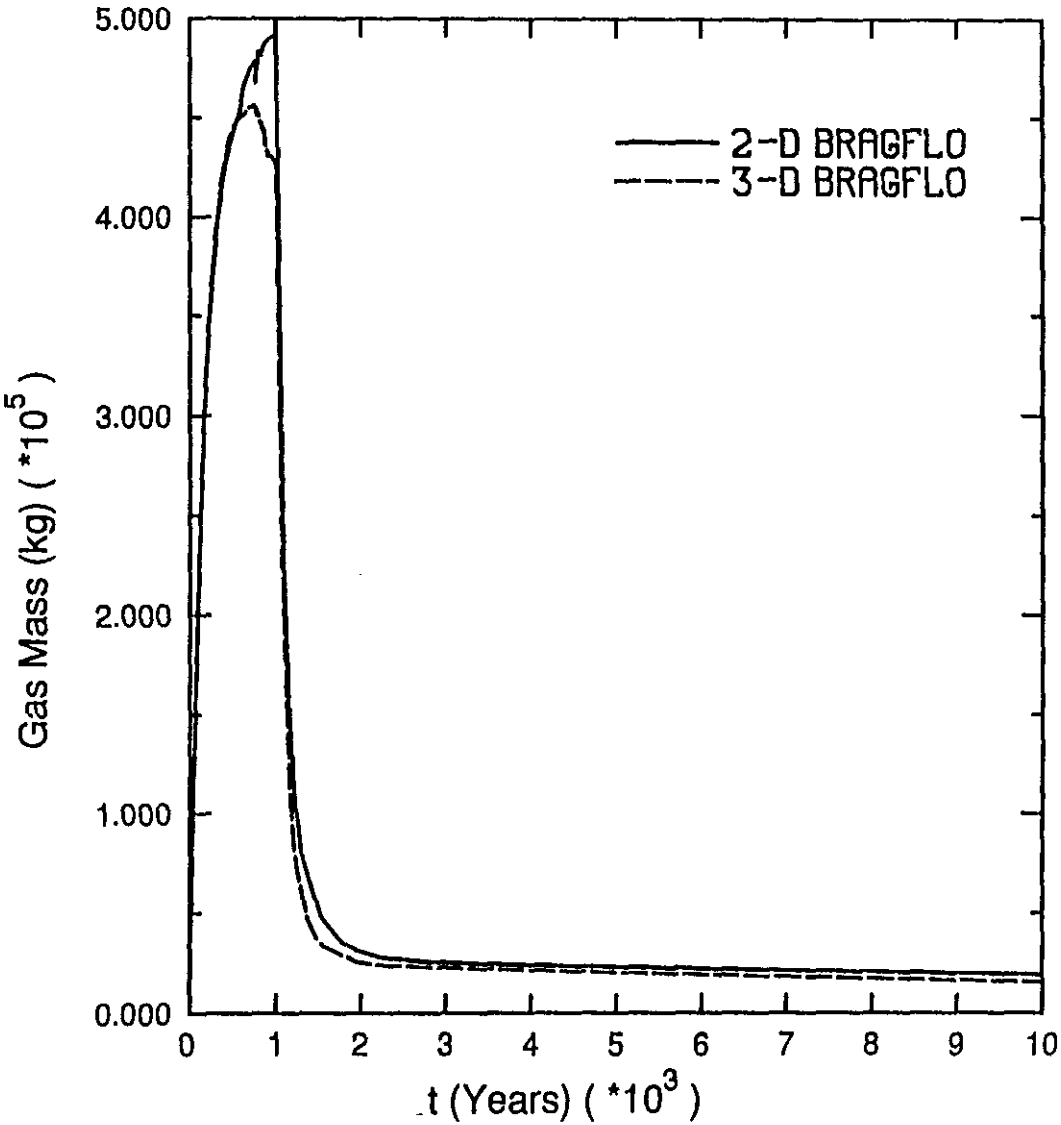

Fig. 14 Gas Mass in Place in Repository - Doubled Gas Generation rate

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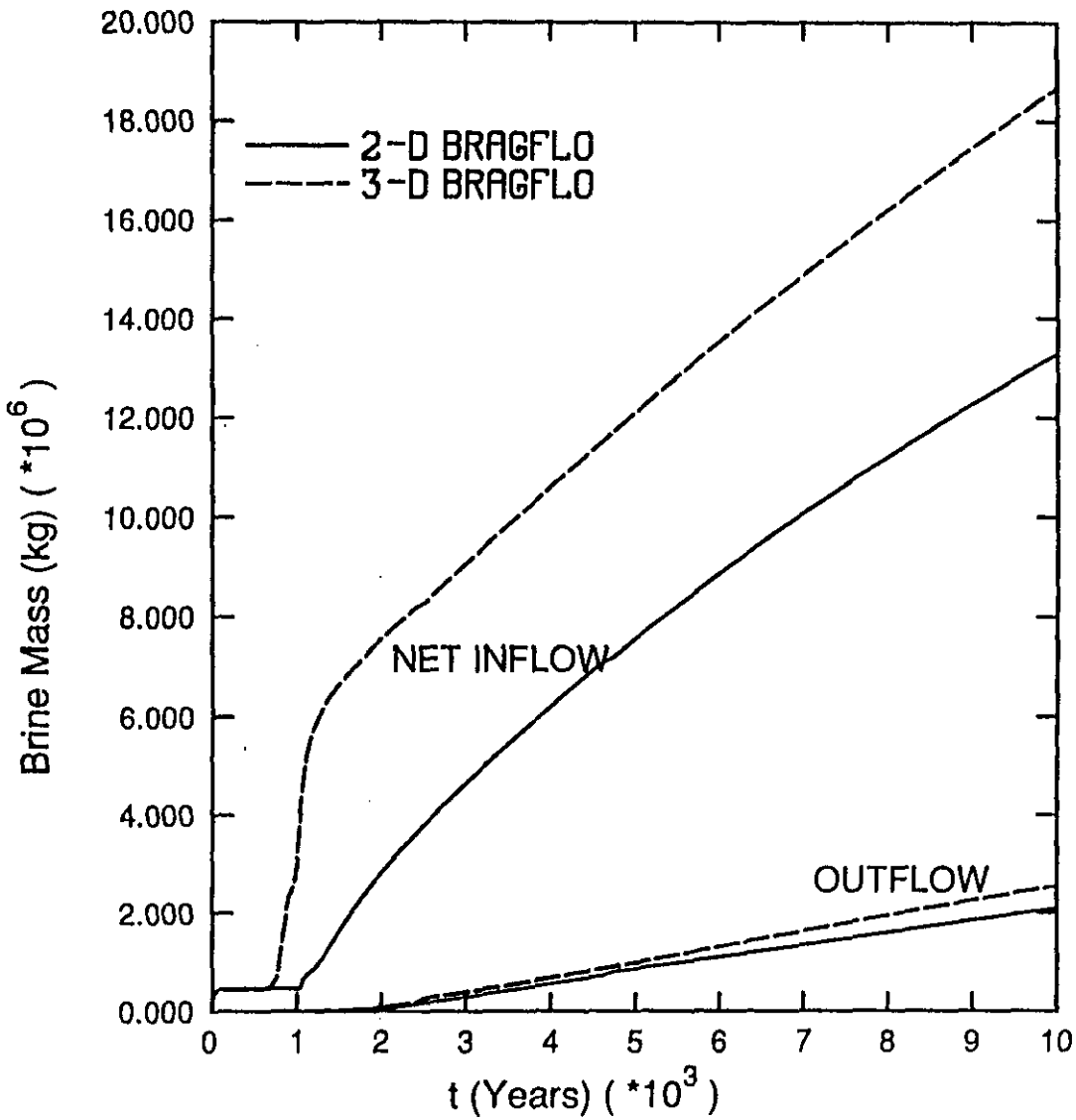

Fig. 15 Cumulative Net Brine In and Outflow at Repo.-Doubled Gas Generation rate

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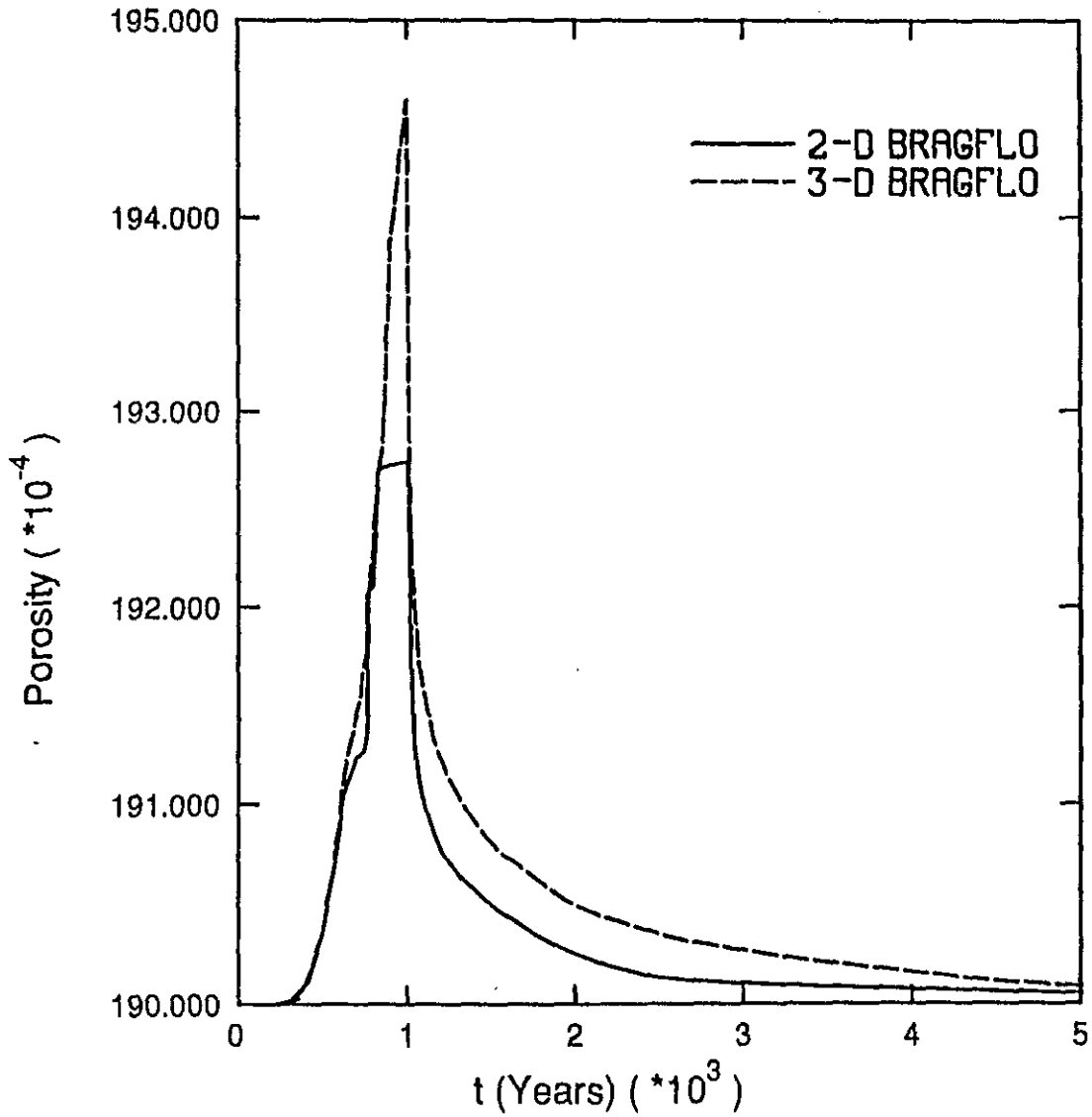

Fig. 16 Average Porosity in Anhydrite Layers - Doubled Gas Generation rate

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

MASS Attachment 7-1

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MEMORANDUM

To: M.G. Marietta

From: T.W. Thompson, F.D. Hansen

Date: August 2, 1996

Subject: Long-term Performance of Panel Closures

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1. INTRODUCTION

After waste has been emplaced in a panel, closures will be built to restrict flow from the panel during the remainder of the operational phase. These closures will include a length of concrete placed in the panel entries. Although it is not the intent of these closures to restrict flow over the regulatory period of 10,000 years, evaluation of their long-term performance characteristics are required to determine their contribution to overall system performance.

Flow of fluids into or out of the panels will be controlled by the conductance of the panel closure, and of the surrounding disturbed rock zone (DRZ). Performance Assessment (PA) calculations use a constant value for DRZ permeability of 10^{-15} m^2, a value which is substantiated in the records package for the waste rooms (FEP: S6). Consideration of the current panel closure designs indicates that they will maintain their structural integrity for the regulatory period. If this is the case, then the concrete element of the closure system will continue to provide resistance to inward deformation of the surrounding salt, and will prohibit growth of the DRZ from its initial state. Since the DRZ will not increase during the regulatory period, and may decrease, the assumption of a constant DRZ permeability is reasonable.

The panel closures have been designed to limit the flow of brine and gas out of the disposal regions during the operational phase, and current designs call for these operational closures to include concrete elements (Figure 1). Although these closures are designed for an operational use, it is expected that they will continue to provide fluid flow restriction during the post-closure phase. The remainder of this memorandum establishes the permeability expectations of the closures, with emphasis on the potential for concrete degradation and increase in permeability. For the purposes of these analyses the concrete elements are taken to have a length of nominally 26 ft (7.9 m) (USDOE, 1996a,b), and to be made of a material chosen so as to be compatible with the environment, such as Salado Mass Concrete (SMC: Sandia, 1996) or a similar mix. Degradation of the concrete may occur by interaction with brine flowing through the plug, or with brines flowing along the plug/salt interface or in the DRZ.

2. CONCRETE PROPERTIES

The initial permeability expected for the concrete panel closures are documented in the materials specification appendix of the Compliance Submittal Design Report (CSDR) (Sandia, 1996a)

developed for the shaft seal system. In addition to conventional engineering properties, the SMC has well documented permeability characteristics, permeabilities having been determined from field tests (Knowles and Howard, 1996) and laboratory studies (Pfeifle et al., 1996). Figure 2, taken from the CSDR, summarizes the available data, and indicates a permeability for as-placed SMC of between $2x10^{-21}$ and $1.8x10^{-17}$ m^2. For calculations performed in this memorandum a value of 10^{-17} m^2 is used, this being at the high end of the values used by PA for the shaft concrete components, and consistent with other data. For example, data on generic portland cement pastes shows that the permeability of oil field concrete plugs is on the order of $1 x10^{-19}$ m^2, while data from the Bell Canyon Test indicate permeabilities for borehole concrete plugs of $5 x 10^{-17}$ m^2 (Petersen and Christensen, 1980; Christensen and Hunter, 1980).

For the purposes of calculating degradation of the concrete member an assumption of porosity is necessary. The expected value is 5 %, which is higher than the 2% estimated by Petersen and Christensen (1980) for the Bell Canyon Test plugs, but is generally consistent with practical experience of field emplaced concrete structures, and is the value for cast in-place SMC given in the CSDR (Sandia, 1996a). An upper limit for porosity is taken as 10%, which is an engineering estimate for concrete, and is used to add a level of conservatism to the calculations.

As noted in the introduction, the concrete closure member is expected to be structurally stable for the regulatory period, and to provide support for the surrounding rock and the DRZ. In this context it can be noted that the unconfined compressive strength of SMC is greater than 4500 psi (30 MPa), and that under the confined state of stress within the closure system the ultimate strength will be greater (Pfeifle et al, 1996). The compressive strength of SMC is sufficient to preclude structural failure of the concrete member in the panel entries.

3. DEGRADATION OF CONCRETE

The solid matrix that makes up concrete is composed almost entirely of amorphous to cryptocrystalline solid phases. These phases are thermodynamically unstable, and with time and exposure to water they alter into more stable and more crystalline assemblages. Thermodynamic calculations conducted by Alcorn et al (1992) have predicted the alteration phases of portland cement due to exposure to a variety of waters and brines as including tobermorite, quartz, gypsum, calcite, clays and zeolite, produced at the expense of soluble and unstable materials such as portlandite. The theoretical alteration assemblage occupies more volume than the original solids. These calculated results have been verified by subsequent experiments in which waters and cement were reacted (Onofrei et al., 1992), and are confirmed, at least partially, from observations made on recovered plugs originally placed decades ago in potash mineral exploratory holes in the Delaware Basin (Bonen, 1996), as well as from evaluations of salt-saturated concrete after six years in the WIPP (Wakeley et al., 1993).

At free surfaces concrete materials are not physically supported and can spall. Long term leaching experiments report that surface diffusion controlled alteration is dependent on the C_3A content of the cement and the Mg and SO_4 content of leachant (Walton et al., 1990). Creation of an alteration rind weakens the concrete and makes it subject to spalling (Wakeley et al., 1994). The mechanism for spalling is that the alteration phases occupy more volume than the original

solids, volumetric expansion increases internal pore pressures until concrete tensile strengths are exceeded and spalling occurs. Short-term, empirical studies of ordinary concrete in brine report alteration rates in the range of 0.7 to 1 mm/year (Atkinson and Hearne, 1990) - These rates are likely to be overestimates because diffusion distance varies as the square root of time. Further details are given in Appendix C of Thompson et al., 1996.

4. DEGRADATION OF CONCRETE PANEL CLOSURES

The concrete elements of the panel closures may degrade in one of two ways, either by flow of brines through the mass of the concrete element, or by flow of brines along the interface.

4.1 Flow Through the Concrete Element

An estimate of the degradation of a concrete closure element may be made based on data on the progression of concrete chemical alteration reported by Berner (1990) for both fresh water and brine leachants (Figure 3). The progression is charted in terms of the volume of water flow, with degradation indicated by a decrease in Ca, increase in SO_4 and increase in SiO_2 in solution (corresponding to removal of silica and sulphate from the concrete) which occurrs at between 100 and 1000 water exchange cycles. This indicates that more than 100 pore volumes of leachants must pass through concrete before there is chemical evidence that the matrix is being significantly attacked. Based on these results, it has been assumed (conservatively) that the concrete closure elements will degrade significantly after 100 pore volumes of water have passed through them. A more detailed discussion of these results is given in Thompson et. al. (1996).

This volume can be converted to performance life by using Darcy's Law and considering the flow of fluids though the plug and the surrounding DRZ. If there is a pressure difference between the panel and the rest of the repository, flow will occur through the panel closure and the surrounding DRZ, with the two elements acting as flow resistors in parallel (Figure 4). If the pressure in the panel is P_1 (Pa) and in the rest of repository is P_2 (Pa), then under brine saturated conditions, the steady state flow rate out of the panels will be Q, where:

$$Q = A*(k'/\mu)*(P_1 - P_2)/L \quad m^3/sec, \qquad (1)$$

where: A is the total flow area of the panel closure plus DRZ (m^2)
L is the flow length (m)
μ is the fluid viscosity (Pa.s)
k' is the composite permeability of the panel closure plus DRZ (m^2).

The composite permeability, k', is given by:

$$k' = (k_d A_d + k_c A_c)/(A_d + A_c), \qquad (2)$$

where: k_d, k_c are the permeabilities of the DRZ and plug closure respectively (m^2)
A_d, A_c are the flow cross-sectional areas of the DRZ and plug closure respectively (m^2).

The flow through the panel closure, q_c, will be:

$$q_c/Q = k_c A_c/(k_d A_d + k_c A_c). \quad (3)$$

The pore volume of the panel closure (V_p) is:

$$V_p = A_c L \phi \text{ m}^3,$$

where ϕ is the porosity. The number of pore volumes (N_p) flowing through the closure in unit time will be:

$$N_p = q_c/V_p \text{ pore volumes/sec},$$

and the time for 100 pore volumes to flow through the closure will be:

$$t_{100} = 100/(N_p * 3.154 \times 10^7) \text{ years}$$

The current design (USDOE, 1996a,b) calls for a length of 7.9 m (26 ft) for the concrete closure, and a cross-sectional area of 15.63 to 24.16 m^2 (4.27 to 6.10 m wide by 3.66 to 3.96 m high). As noted in Section 2 an undegraded concrete permeability of 10^{-17} m^2, and a porosity ranging from 5% to 10% may be assumed. The DRZ around the closure is assumed to have a permeability of 10^{-15} m^2. Based on the BRAGFLO grid (Sandia, 1996b) the DRZ may be assumed to have a height of 11.95 m above the closure and 2.23 m below. It is assumed that the salt DRZ in the pillars at either side of the closure heals due to creep closure onto the rigid concrete. The DRZ flow area may therefore be taken as between 60.55 and 86.50 m^2.

Given these values, the effective permeability of the closure and the DRZ, from equation (2), is between 7.84 and 7.97×10^{-16} m^2, with an effective flow area of 76.18 to 110.66 m^2. When brine flows between the panel and the rest of the repository, from equation (3), only between 0.26 and 0.28 % will flow through the closure, the remainder of the flow will be through the DRZ.

An analysis of calculations made with BRAGFLO (Sandia, 1996b) using a range of parameters, and assuming permeabilities for the closures and DRZ of 10^{-15} m^2, indicates that the maximum cumulative flow between the panel and the rest of the repository for any likely E1 or E2 scenario will be of the order of 10^4 m^3 (Figure 5). With these flows, and the split in flows indicated above, only 26 to 28 m^3 of brine will flow through the concrete closure in 10,000 years. For a porosity range of 5 % to 10 % the maximum cumulative flow through the concrete closure in 10,000 years will therefore be between about 0.6 and 1.2 pore volumes. The same point is made in Figure 6, which shows the cumulative flow with closure permeabilities of 10^{-15} to 10^{-17} m^2. Degradation will be minimal with these flow volumes.

4.2 Flow Along the Interface

Flow along the interface may be more rapid due to the higher permeabilities in the DRZ. A maximum effect of this flow might be estimated to be equivalent to the free surface spall rate of

0.5 to 1 mm/yr. Such a degradation rate is unrealistically high, since the degradation will be controlled by the rate of fluid flow, and total loss of material will not occur in a physically constrained region. However this rate of spall is much less than the expected closure rates (measured at the order of 0.1 to 0.2 ft/yr. or 30 to 60 mm/yr in Panel 1: USDOE, 1996b) so even such a rapid spall rate would be more than compensated for by creep of the salt on the closure. It is therefore concluded that the effect of flow along the interface will be minimal. At most it will lead to an insignificant increase in the DRZ flow area.

5. CONCLUSIONS

It is concluded that the potential flow through the concrete closure is nearly two orders of magnitude too small to cause any significant degradation. Degradation caused by flow in the DRZ adjacent to the concrete will be taken up by creep closure. It is therefore concluded that the panel closures will retain their initial permeability in the post-closure phase. If this permeability is 10^{-17} m^2, then the effective permeability of the DRZ and the closure together will be about $8x10^{-16}$ m^2. An assumption of a permeability of 10^{-15} m^2 for the closure and the DRZ is reasonable.

It is also concluded that since no significant degradation is expected for the concrete members, these will maintain their structural integrity and will provide a rigid support to prevent growth of the DRZ during the regulatory period.

6. REFERENCES

Alcorn, S.R., Coons, W.E., Christian-Frear, T.L., and M.G. Wallace, 1992, "Theoretical Investigations of Grout Seal Longevity," Final Report, Stripa Project TR 92-23, SKB, Stockholm, Sweden.

Atkinson, A., Goult, D.J., and Hearne, J.A., 1985, "An Assessment of the Long-Term Durability of Concrete in Radioactive Waste Management." Materials Research Society Symposium Proceedings: Scientific Basis for Nuclear Waste Management IX, v. 50,pp 239-246.

Berner, U., 1990, "A Thermodynamic Description of the Evolution of Pore Water Chemistry and Uranium Speciation During the Degradation of Cement," Technical Report 90-12, Paul Scherrer, Villigen, Switzerland.

Bonen. D., 1996, "Petrographic Analyses of Concrete and Grout Recovered from the WIPP," The Technological Institute, Northwestern University, Interim Report, January 15, 1996, 9pp.

Christensen, C.L. and Hunter, T.O., (1980) "The Bell Canyon Test Results" SAND80-2414C. Sandia National Laboratory, Albuquerque NM

FEP: S6, "Dynamic Alteartions of the Disturbed Rock Zone/Transition Zone," SWCF:1.1.6.3:PA:NG:TSK:DR2, DR3, DR6, DR7, and S6, Sandia National Laboratories, 1996.

Knowles, M.K., and C.L. Howard, 1996, "Small Scale Seal Test Results," Waste Management '96, Tuscon, AZ.

Onofrei, M., Gray, M., Coons, W.E.., and S.R. Alcorn, 1992, "High Performance Cement Based Grout for Use in a Nuclear Waste Disposal Facility, " Waste Management, v.12, pp. 133-154.

Petersen, E.W., and Christensen, C.L. (1980) "Analysis of Bell Canyon Test Results" SAND80-7044C. Sandia National Laboratories, Albuquerque NM

Pfeifle, T.W., F.D. Hansen, and M.K. Knowles, 1996. "Salt-Saturated Concrete Strength and Permeability," 4th. Materials Engineering Conference, ASCE, Washington, D.C.

Sandia National Laboratories, Repository Isolation Department, 1996a. "Waste Isolation Pilot Plant Shaft Seal Syatem Compliance Submittal Design Report," SAND96-1326, Sandia National Laboratories, Department 6121, Albuquerque, NM

Sandia National Laboratories, 1996b, "Analysis Package for the Salado Flow Calculations (Task 1) of the Performance Assessment Analysis Supporting the Compliance Certification Application," SWCF-A:1.2.07.4.1:PA:QA:CCA:Analysis Package for Salado Flow (Task 1), Sandia National Laboratories, Albuquerque, NM.

Thompson, T.W., W.E. Coons, J.L. Krumhansl, and F.D. Hansen, 1996. "Inadvertent Intrusion Borehole Permeability," Memorandum of Record, July 8, 1996, Sandia National Laboratories, Albuquerque, NM.

Wakeley, L.D., P.T. Harrington and C.A. Weiss, 1993, "Properties of Salt-Satutared Concrete and Grout after Six Years In-situ at the WIPP," SAND93-7019, Sandia National Laboratories, Albuquerque, NM.

Wakeley, L.D., Poole, T.S., and Burkes, J.P., 1994, "Durability of concrete materials in high-magnesium brines," SAND 93-7073

Wakeley, L.D., P.T. Harrington, and F.D. Hansen, 1995, "Variability in Properties of Salado Mass Concrete," SAND94-1495, Sandia National Laboratories, Albuquerque, NM.

Walton, J.C., Plansky, L.E., and Smith, R.W., 1990, "Models for estimation of service life of concrete barriers in low-level waste repositories," NUREG/CR-5542

U.S. DOE (Department of Energy), 1995, "Waste Isolation Pilot Plant Sealing System Design Report," DOE/WIPP-95-3117.

U.S. DOE (Department of Energy), 1996a, "Detailed Design Report for an Operational Phase Panel-Closure System," DOE/WIPP-96-2150.

U.S. DOE (Department of Energy), 1996b, "Final No Migration Variance Petition," DOE/CAO-96-2160.

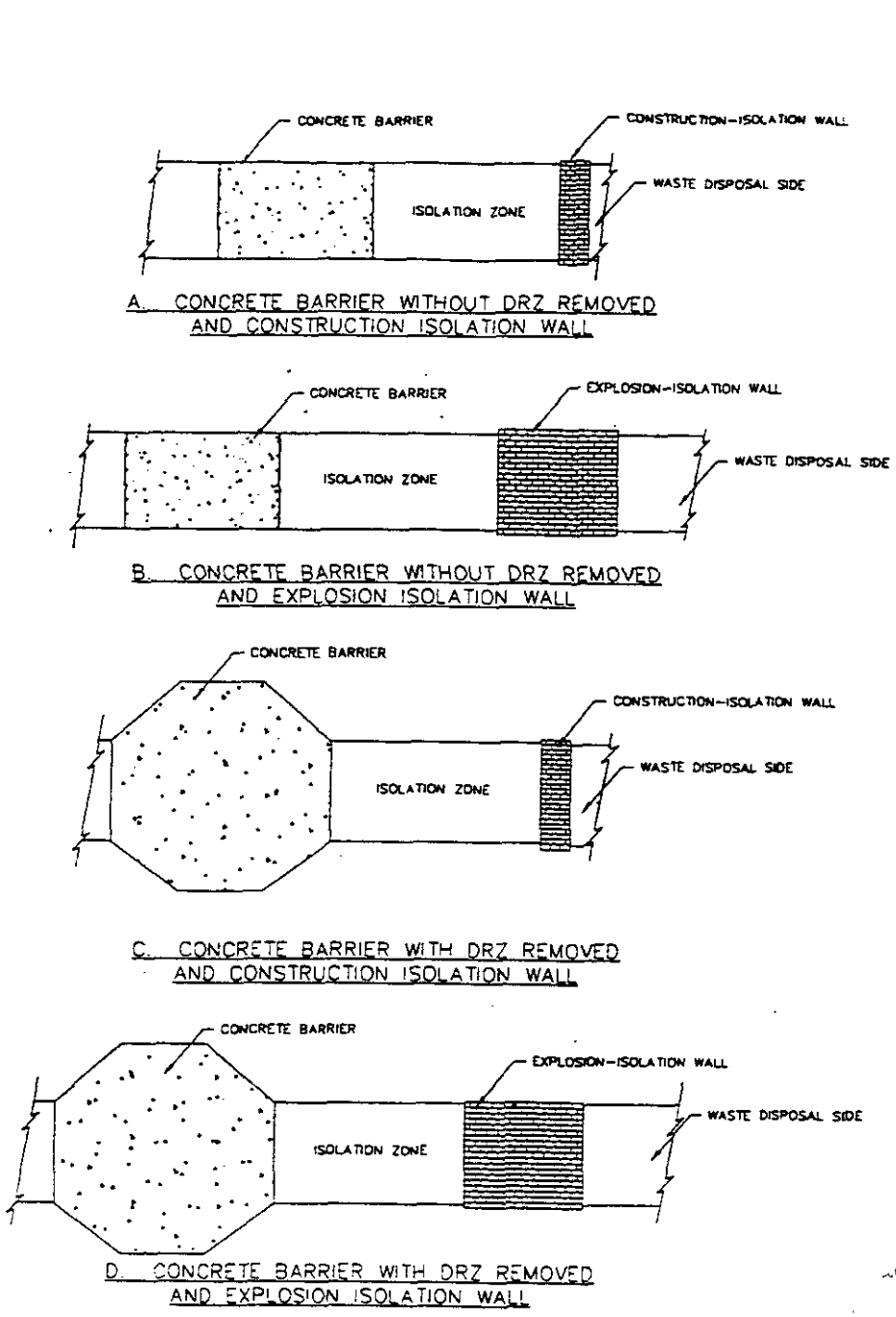

Figure 1: Panel Closure Designs (after USDOE, 1996a)

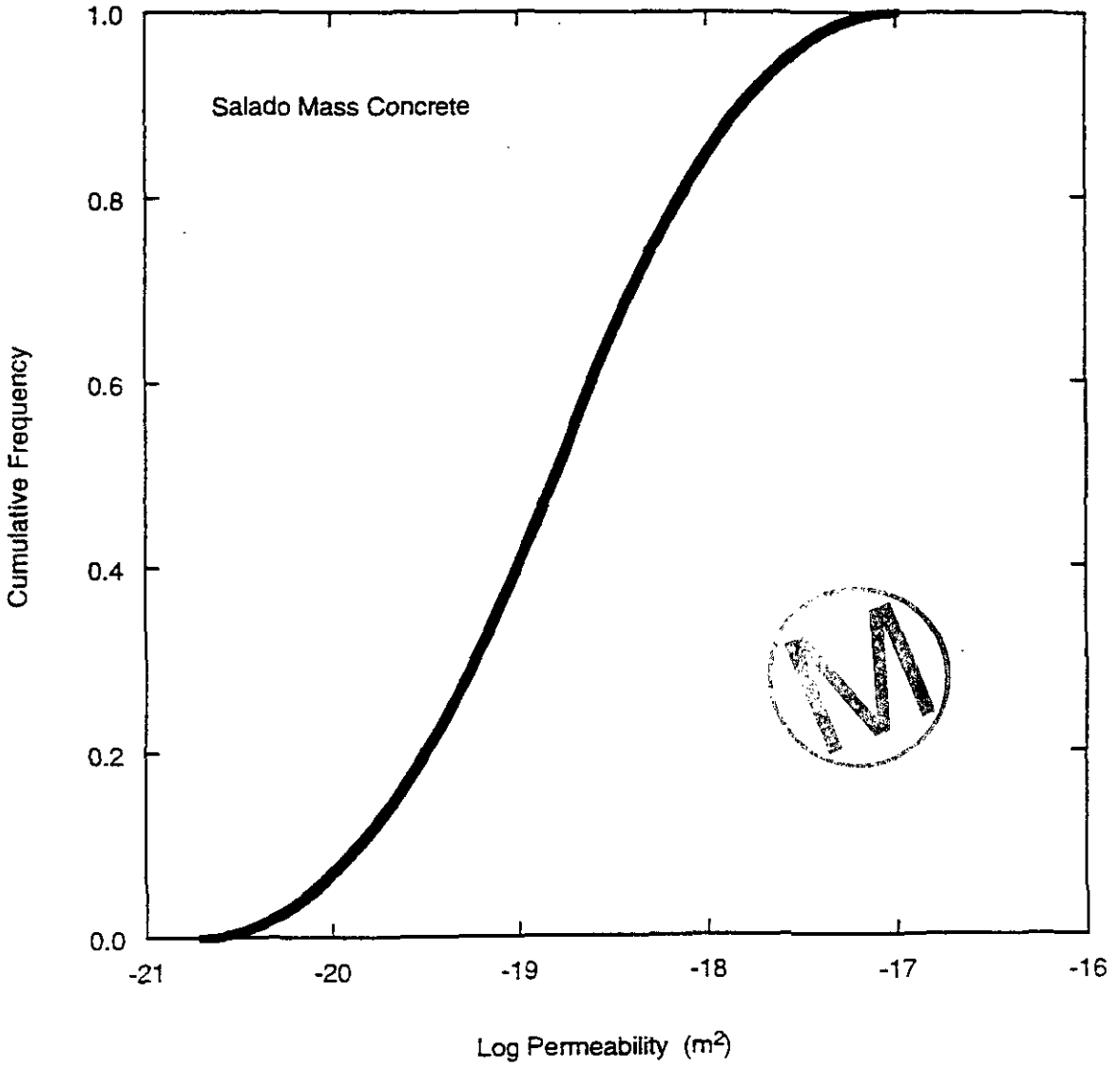

Figure 2: Cumulative Distribution Function for Permeability of SMC (after Sandia, 1996)

Figure c-3 Degradation of "HTS" in standard marl grundwater "MAR". After 6650 cycles calcite is the only solid phase present (T = 25 °C).

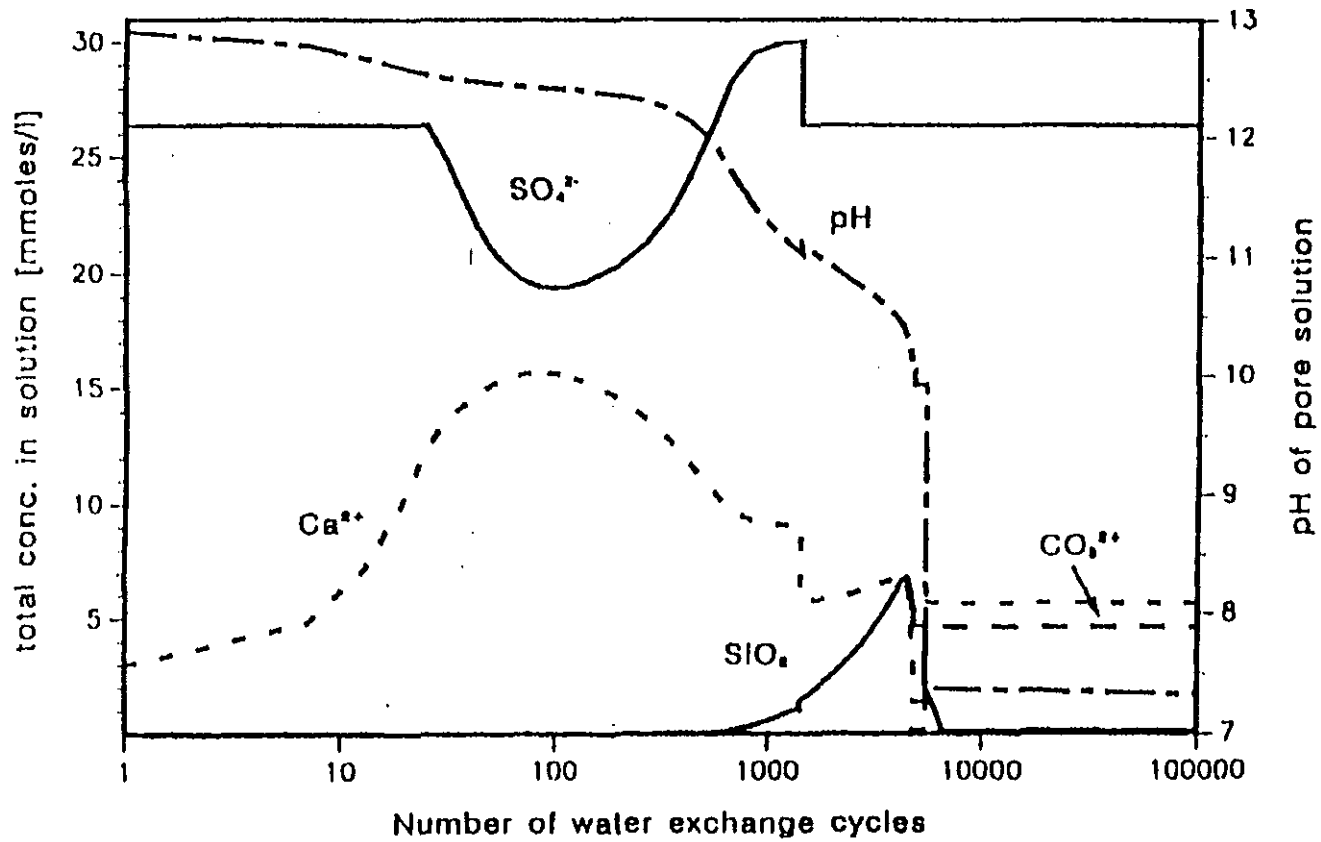

Figure 3: Degradation of Concrete in Brine (after Berner, 1990)

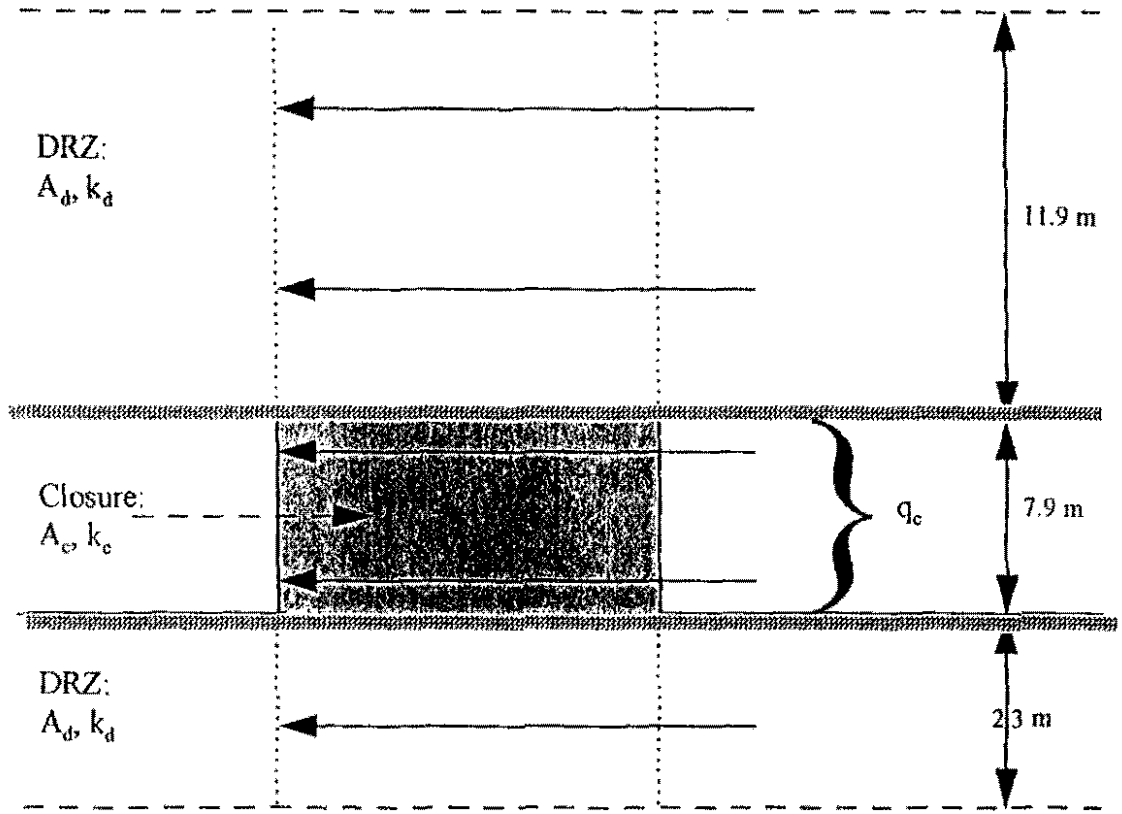

Figure 4: Parallel Flow through the Panel Closure and DRZ

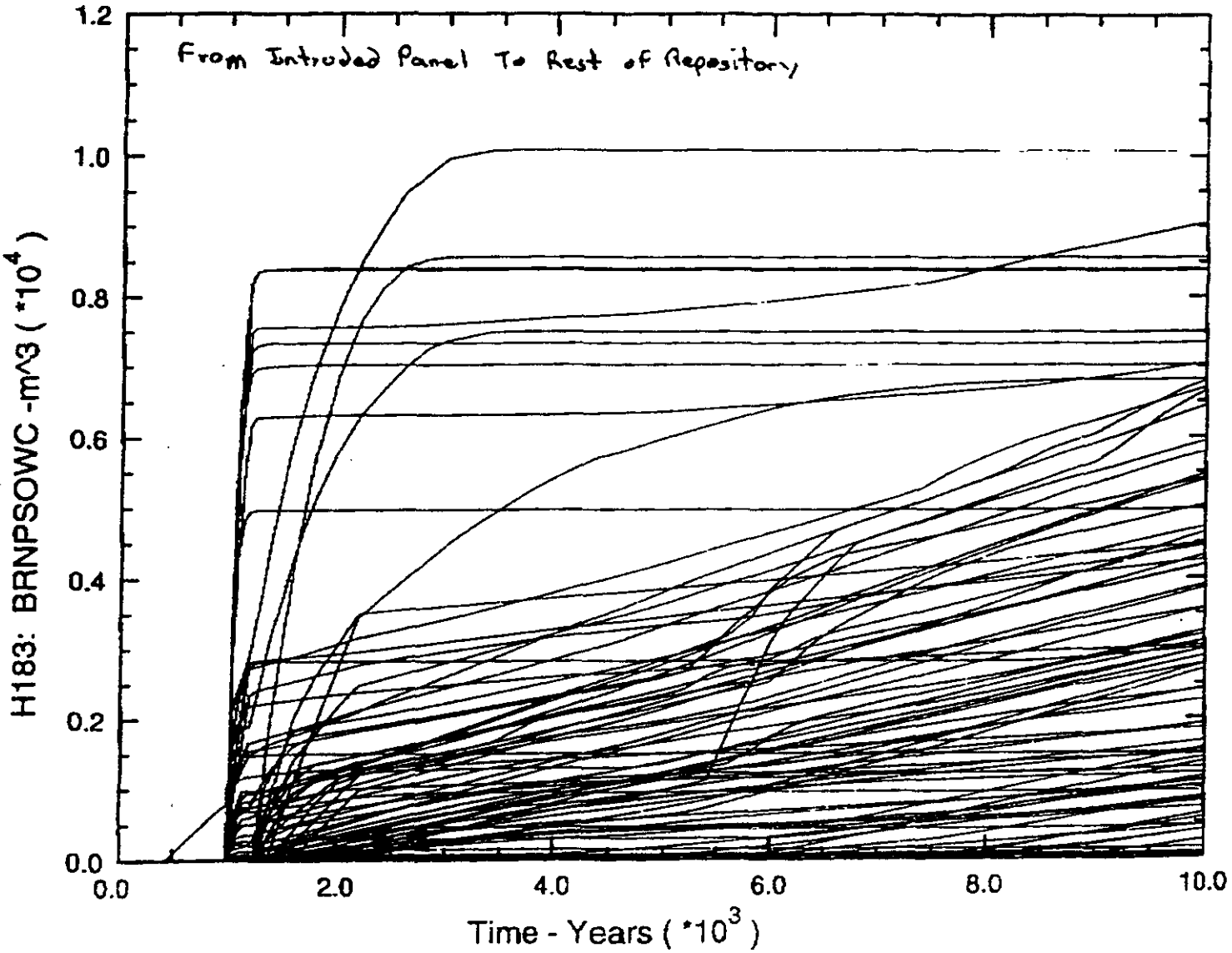

Figure 5: Cumulative flows between a panel and the rest of the repository for an E1 Intrusion at 1000 Years

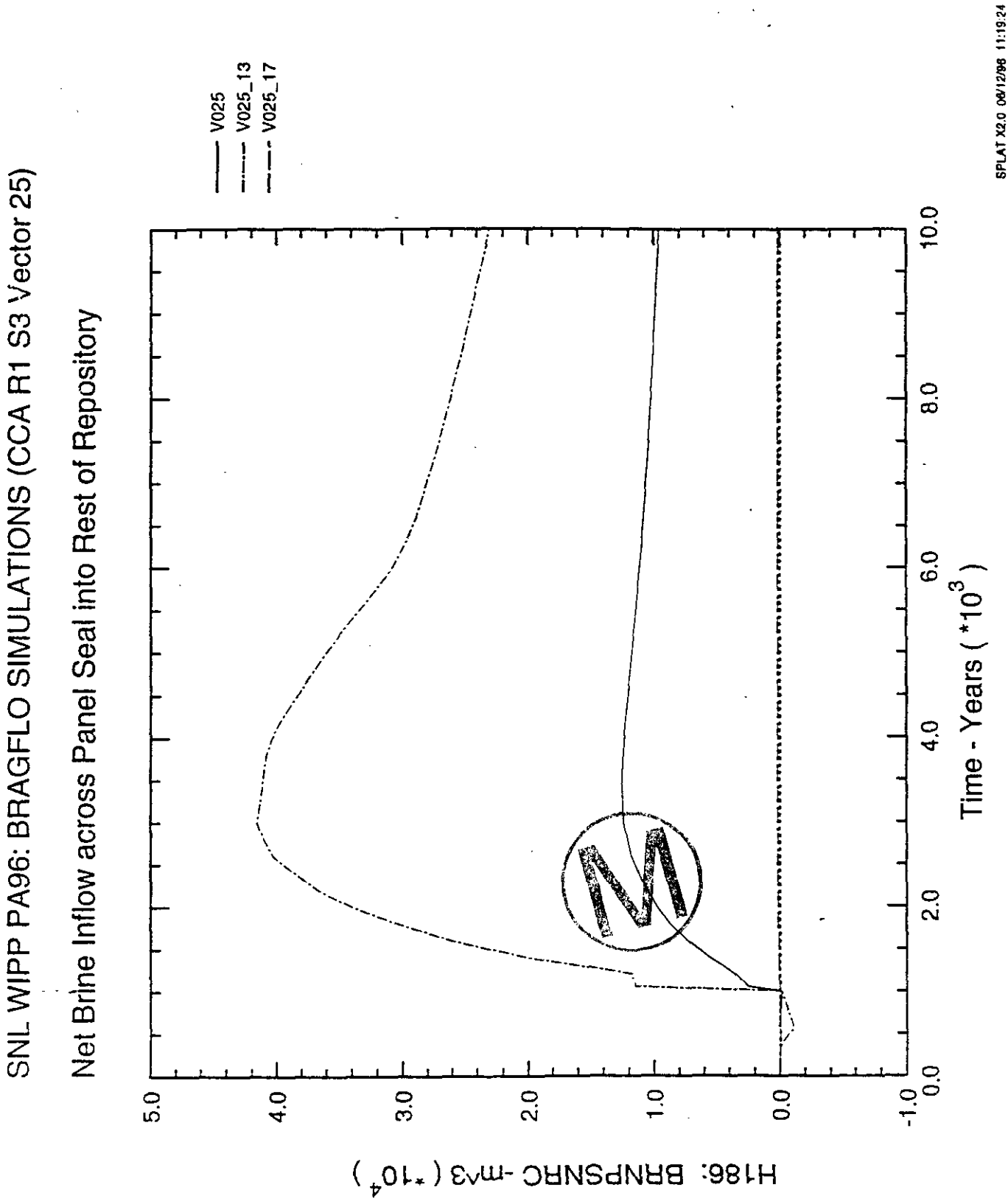

Figure 6: Cumulative flows through the Panel Closures for Permeabilities of 10^{-15} to 10^{-17} m^2. Results shown are for the Maximum Flow Case of Figure 5.

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WP036290

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

INFORMATION ONLY

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date: November 30, 1995

to: M. S. Y. Chu, MS 1335 (Org. 6801)

L. H. Brush

from: L. H. Brush, MS-1341 (Org. 6748), Y. Wang, MS-1341 (Org. 6748), and J. W. Garner, MS-1328 Org. 6749)

subject: Rationale for Discontinuing the Development of the Reaction-Path Gas-Generation Model

We are discontinuing the development of the reaction-path gas-generation model at this time because: (1) we do not need the reaction-path model to obtain parameters for use in Brine and Gas Flow (BRAGFLO) for the 1996 performance-assessment (PA) calculation nor for use in the EQ3/6 calculations to support the Actinide Source Term Program (ASTP); (2) some of the conceptual models upon which the reaction-path model is based are no longer defensible; (3) if additional development of a gas-generation model is necessary in the future, we should use an approach different from that used by Brush et al. (1994) to develop the reaction-path model.

LACK OF NEED FOR THE REACTION-PATH MODEL

The main advantage of the reaction-path model (Brush et al., 1994) relative to the average-stoichiometry gas-generation model currently in BRAGFLO (WIPP Performance Assessment Division, 1991; Sandia WIPP Project, 1992) was that the reaction-path model includes passivation of steels and other Fe-base alloys by microbially produced CO_2 and H_2S, the most important interaction among gas-generation processes observed in laboratory studies of gas generation. Therefore, the reaction-path model predicted significant gas generation from anoxic corrosion of steels and other Fe-base alloys, or from microbial degradation of cellulosics, but not from both of these processes in the same realization. However, PA personnel have incorporated a switch in the average-stoichiometry model that essentially predicts the effects of passivation (gas production from corrosion or microbial activity, but not both). Furthermore, recent results from laboratory studies of anoxic corrosion fail to support passivation of steels by CO_2. These results imply that, although microbial activity can produce *enough* CO_2 to passivate steels and other Fe-base alloys, it probably will not produce CO_2 *fast enough* for passivation (Telander and Westerman, 1993; Francis and Gillow, 1994; Francis et al., in prep.; Telander and Westerman, in prep.). Therefore, the main advantage of the reaction-path model relative to the average-stoichiometry model no longer exists.

Moreover, we can use hand calculations instead of the reaction-path model to obtain parameters for use in BRAGFLO for the 1996 PA calculation and for the EQ3/6 calculations to support the ASTP. The average-stoichiometry model uses the overall reaction

$$CH_2O + \text{unknowns} \rightarrow (y)\text{gas} + \text{unknowns} \qquad (1)$$

We can estimate the stoichiometric factor y independently based on estimates of the quantities of NO_3^- and SO_4^{2-} in the transuranic (TRU) waste to be emplaced in the Waste Isolation Pilot Plant (WIPP) and the experimentally determined corrosion rate for steels (R_c), and rate of microbial consumption of cellulosics (R_m) under inundated conditions. First, we use the rates R_c and R_m to estimate the maximum quantities of steels and cellulosics that will be consumed in 10,000 years:

$$[Fe]_{max} = \min \{[Fe]_i, [Fe]_i \bullet [1 - \exp(-10000*R_c)]\}; \qquad (3)$$

$$[Cell]_{max} = \min \{[Cell]_i, [Cell]_i \bullet [1 - \exp(-10000*R_m)]\} \qquad (2)$$

where $[Fe]_i$ and $[Cell]_i$ are the quantities (in moles) of steels and cellulosics initially present in the repository, and the units of R_c and R_m are both year^{-1}. Next, we calculate the average stoichiometric factor y by distributing $[Cell]_{max}$ into individual microbial respiratory pathways. Consider two extreme cases, corresponding to the maximum and minimum values of y: (1) no reaction of microbially produced CO_2 and H_2S with steels and steel corrosion products; (2) complete reaction of CO_2 and H_2S with steels and steel-corrosion products.

If no CO_2 or H_2S are consumed by reactions with steels and steel-corrosion products, we would expect the maximum quantity of microbial gas production in WIPP disposal rooms and, therefore, the maximum value for y. Microorganisms will consume cellulosics via the following reaction pathways:

$$CH_2O + 0.8H^+ + 0.8\,NO_3^- \rightarrow 1.4\,H_2O + CO_2 + 0.4N_2 \qquad (4)$$

$$CH_2O + H^+ + 0.5SO_4^{2-} \rightarrow H_2O + CO_2 + 0.5H_2S \qquad (5)$$

$$CH_2O \rightarrow 0.5\ CH_4 + 0.5\ CO_2. \tag{6}$$

The maximum value of y can estimated from these reactions by:

$$y_{max} = \{1.4/0.8 \bullet [NO_3^-]_i + 1.5/0.5 \bullet [SO_4^{2-}]_i$$

$$+ [Cell]_{max} - [NO_3^-]_i/0.8 - [SO_4^{2-}]_i/0.5\}/[Cell]_{max} \tag{7}$$

in which $[NO_3^-]_i$ and $[SO_4^{2-}]_i$ are the molar quantities of NO_3^- and SO_4^{2-} initially present in the repository.

If CO_2 and H_2S react with steels and steel-corrosion products, we expect that a significant quantity or, perhaps, all of these microbially produced gases would be consumed, thus forming $FeCO_3$ and FeS. This would result in the minimum value of y. The total gas consumed by those reactions (G) is:

$$G = \min \langle \{[NO_3^-]_i/0.8 + 1.5/0.5 \bullet [SO_4^{2-}]_i$$

$$+ 0.5 \bullet \{[Cell]_{max} - [NO_3^-]_i/0.8 - [SO_4^{2-}]_i/0.5\}, [Fe]_{max} \rangle. \tag{8}$$

The minimum value of y can estimated from these reactions by:

$$y_{min} = \{1.4/0.8 \bullet [NO_3^-]_i + 1.5/0.5 \bullet [SO_4^{2-}]_i$$

$$+ [Cell]_{max} - [NO_3^-]_i/0.8 - [SO_4^{2-}]_i/0.5 - G\}/[Cell]_{max} \tag{9}$$

For each BRAGFLO simulation, the value y should be sampled over $[y_{min}, y_{max}]$. The calculational scheme proposed here would automatically correlate y with waste-inventory estimates as well as with reaction rates. *This scheme would allow us to estimate y independently without having to use the reaction-path model.*

The average stoichiometry model does not predict the types of gases produced by Reaction 1 (see above). However, we can use hand calculations analogous to those

described above to estimate the yield of CO_2 from Reaction 1. We can then use these predictions of the quantity of CO_2 as input to EQ3/6 to calculate total quantity of inorganic C dissolved in WIPP brines, its speciation (CO_2, H_2CO_3, HCO_3^-, and CO_3^{2-}), and the pH of these brines for the ASTP. EQ3/6 is a geochemical software package developed mainly by personnel at Lawrence Livermore National Laboratory (Daveler and Wolery, 1992; Wolery, 1992a; 1992b; Wolery and Daveler, 1992) for use by the Yucca Mountain Project.

We estimate that, *if the conceptual models upon which the reaction-path model is based were defensible (see below),* upgrading the QA status of the reaction-path model to Level A would require about one to two man years of effort. (This effort would comprise preparing a combined Requirements Document and Verification and Validation Plan, a Validation Document, and a User's Manual for this model.) It is hard to envision how we could accomplish these tasks at a time when the WIPP Project is reducing the resources allocated to the Gas Generation Program, yet requiring that we deliver gas-generation data to PA and produce the final reports on the laboratory studies of gas generation two months earlier than originally scheduled. We believe that this effort is unnecessary in view of the fact that we can use hand calculations to obtain parameters for use in BRAGFLO for the 1996 PA calculation and for the EQ3/6 calculations to support the ASTP.

CONCEPTUAL BASIS OF THE REACTION-PATH MODEL

Some of the conceptual models upon which the reaction-path model is based are no longer defensible. Problems or potential problems revealed by reviewers and/or the laboratory studies of gas generation include: (1) the thermodynamically calculated phase boundaries in the model are based on free energies of formation for pure (Mg-free) steel-corrosion products, but at least some of these phases probably include significant quantities of Mg under expected WIPP conditions; (2) high-pressure corrosion studies (Telander and Westerman, 1993; in prep.) imply that the $Fe(OH)_2$-forming corrosion reaction does not stop at about 70 atm as predicted, probably due at least in part to substitution of Mg for Fe in this corrosion product, but perhaps also due to the fact that the crystal structure of this phase is different from that of amakinite, the only $Fe(OH)_2$ polymorph for which the free energy of formation is available; (3) some of the corrosion studies imply that the assumption of instantaneous, reversible equilibrium is invalid.

Because some of the conceptual models on which the reaction-path model is based are probably no longer defensible, significant additional work would be required before the QA status of this model could be upgraded to Level A. Additional laboratory studies would be necessary to: (1) determine the extent of Mg substitution in steel-

corrosion products, especially $Fe(OH)_2$; (2) determine the free energy of formation of $(Fe,Mg)(OH)_2$ and, perhaps, the free energies of formation of other corrosion products that contain significant Mg under expected WIPP conditions; (3) determine the H_2 partial pressure at which steels are in equilibrium with $(Fe,Mg)(OH)_2$; (4) evaluate the assumption of instantaneous, reversible equilibrium. These laboratory studies would require at least several man months and, perhaps, a few man-years of effort. Upon completion of these studies, modification of the reaction-path model to incorporate the results would probably require several man-months of work.

PROPOSED APPROACH FOR ADDITIONAL MODEL DEVELOPMENT

We believe that, to address the problems and potential problems with the conceptual models described above, it would be unwise to continue to pursue the overall approach used by Brush et al. (1994) to develop the reaction-path model. This approach consisted of using the corrosion, microbial, and radiolytic reactions observed during laboratory studies of gas generation as the basis for a simplified reaction-path model that operates independently of other reactions expected in WIPP disposal rooms. These other reactions include dissolution of gases such as CO_2 and H_2S in brines, reactions between brines and other constituents of the waste such as $Ca(OH)_2$ in cementitious materials used to solidify process sludges, mixing of brines during human intrusion, and reactions between brines and evaporite minerals in the surrounding Salado Formation. Brush et al. (1994) decided to use the reaction-path model to simulate the gas-generation reactions, especially passivation of steels and other Fe-base alloys by microbially produced CO_2 and H_2S, and to use models such as EQ3/6 to simulate other reactions expected in the repository.

The approach we favor now would be to incorporate gas-generation reactions into a global (WIPP-disposal-room-scale) model such as EQ3/6 by obtaining Pitzer ion-interaction parameters for the reactants and products of these reactions for which Pitzer parameters do not yet exist. This is, essentially, the approach being used by the ASTP to develop the actinide-source-term model. Because it would require an experimental program similar to the ASTP solubility program, we could only implement such an approach if the Environmental Protection Agency (EPA) specifies that significant additional work on gas generation is required.

Furthermore, we would still need a greatly (computationally) simplified model such as the average-stoichiometry model for use in BRAGFLO. (It would probably be infeasible to couple BRAGFLO and EQ3/6).

ADDITIONAL COMMENTS ON THE REACTION-PATH MODEL

We believe the reaction-path model has been a valuable research tool. It has been a significant asset for planning and interpreting the results of laboratory studies of gas generation. We believe the reaction-path model can continue to be a valuable research tool as long as we do not use any results from this model, either directly or indirectly, for PA calculations or for other compliance-related activities.

We believe the efforts spent on the reaction-path model and the Gas Generation Program, and the resources required for them, were not expended in vain. Because of these efforts, we are much better able to defend the position that gas generation will not adversely affect the performance of the WIPP with respect to EPA regulations for long-term isolation of radioactive and chemically hazardous waste.

REFERENCES

Berner, R.A. 1980. *Early Diagenesis: A Theoretical Approach.* Princeton, NJ: Princeton University Press.

Brush, L.H. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266. Albuquerque, NM: Sandia National Laboratories.

Brush, L.H. 1995. *Systems Prioritization Method - Iteration 2 Baseline Position Paper: Gas Generation in the Waste Isolation Pilot Plant.* Albuquerque, NM: Sandia National Laboratories.

Brush, L.H., J.W. Garner and L.J. Storz. 1994. "Development of a Gas Generation Model for the Waste Isolation Pilot Plant," *Scientific Basis for Nuclear Waste Management XVII, Materials Research Society Symposium Proceedings, Boston, MA, November 29-December 3, 1993.* Eds. A. Barkatt and R.A. Van Konynenburg. SAND93-1145C. Pittsburgh, PA: Materials Research Society. Vol. 333, 241-246.

Daveler, S.A., and T.J. Wolery. 1992. *EQPT, A Data File Preprocessor for the EQ3/6 Software Package: User's Guide and Related Documentation (Version 7.0).* UCRL-MA-110662 PT II. Livermore, CA: Lawrence Livermore National Laboratory.

Francis, A.J., and J.B. Gillow. 1994. *Effects of Microbial Processes on Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions.* SAND93-7036. Albuquerque, NM: Sandia National Laboratories.

Francis, A.J., J.B. Gillow, and M.R. Giles. In prep. *Effects of Microbial Processes on Gas Generation Under Expected WIPP Conditions. Data Report for the Period 1993-1995.*

Froelich, P.N., G.P. Klinkhammer, M.L. Bender, N.A. Luedtke, G.R. Heath, D. Cullen, P. Dauphin, D. Hammond, B. Hartman and V. Maynard. 1979. "Early Oxidation of Organic Matter in Pelagic Sediments of the Eastern Equatorial Atlantic: Suboxic Diagenesis," *Geochimica et Cosmochimica Acta.* Vol. 43, 1075-1090.

Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters.* SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories.

Telander, M.R., and R.E. Westerman. 1993. *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments.* SAND92-7347. Albuquerque, NM: Sandia National Laboratories.

Telander, M.R., and R.E. Westerman. In prep. *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments. Final Report.*

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 3: Reference Data.* SAND91-0893/3. Eds. R.P. Rechard, A.C. Peterson, J.D. Schreiber, H.J. Iuzzolino, M.S. Tierney and J.S. Sandha. Albuquerque, NM: Sandia National Laboratories.

Wolery, T.J. 1992a. *EQ3/6, A Software Package for Geochemical Modeling of Aqueous Systems: Package Overview and Installation Guide (Version 7.0).* UCRL-MA-110662 PT I. Livermore, CA: Lawrence Livermore National Laboratory.

Wolery, T.J. 1992b. *EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0).* UCRL-MA-110662 PT III. Livermore, CA: Lawrence Livermore National Laboratory.

Wolery, T.J., and S.A. Daveler. 1992. *EQ6, A Computer Program for Reaction-Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0).* UCRL-MA-110662 PT IV. Livermore, CA: Lawrence Livermore National Laboratory.

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WPO # 31943

Sandia National Laboratories

Albuquerque, New Mexico 87185-

date: January 26, 1996

to: Martin S. Tierney (6741)

INFORMATION ONLY

Yifeng Wang Larry Brush

from: Yifeng Wang & Larry Brush (Org. 6748)

subject: Estimates of Gas-Generation Parameters for The Long-Term WIPP Performance Assessment

Introduction

Steel corrosion and organic-material biodegradation have been identified as major gas-generation processes in the WIPP repository (Brush, 1995). Gas production will affect room closure and chemistry (Butcher, 1990; Brush, 1990). This memorandum provides the current estimates of gas-generation parameters for the long-term WIPP performance assessment. The parameters provided here include the rates of gas generation under inundated and humid conditions, the stoichiometric factors of gas generation reactions, and the probability of the occurrence of organic material biodegradation (Table 1). To satisfy the quality assurance (QA) requirement (QAP 9-5), we summarize all hand calculations for estimating these parameters in Appendices I and II.

Biodegradation of Organic Materials

Cellulosics, plastics, and rubbers have been identified as the major organic materials to be emplaced in the WIPP repository (DOE/CAO, 1996) and could be degraded by microbes in 10,000 years. Cellulosics has been demonstrated experimentally to be the most biodegradable among these materials (Francis et al., 1995). The occurrence of significant microbial gas generation in the repository will depend on: (1) whether microbes capable of consuming the emplaced organic materials will be present and active; (2) whether sufficient electron acceptors will be present and available; (3) whether enough nutrients will be present and available. Considering uncertainties in evaluation of these factors and also in order to bracket all possible effect of gas generation on the WIPP performance assessment, we assign a 50% probability to the occurrence of significant microbial gas generation.

- *Microbial Reactions*

Microorganism will consume cellulosics mainly via the following reaction pathways in the repository (Brush, 1995):

$$C_6H_{10}O_5 + 4.8\ H^+ + 4.8\ NO_3^- \rightarrow 7.4\ H_2O + 6\ CO_2 + 2.4\ N_2 \quad (1)$$

$$C_6H_{10}O_5 + 6\ H^+ + 3\ SO_4^{2-} \rightarrow 5\ H_2O + 6\ CO_2 + 3\ H_2S \quad (2)$$

$$C_6H_{10}O_5 \rightarrow 3\ CH_4 + 3\ CO_2. \quad (3)$$

We assume that Reactions 1 to 3 will proceed sequentially according to the energy yield of each reaction. Here we ignore the reaction pathways of aerobic respiration, Mn(IV) and Fe(III) dissimilatory reduction, since the quantities of O_2, Mn(IV) and Fe(III) initially present in the repository will be negligible relative to the other electron acceptors. In Reactions 1 to 3, biomass accumulation is also not taken into account. This is because significant biomass accumulation seems unlikely in the WIPP repository and the accumulated biomass, if any, will be recycled by microbes after all biodegradable cellulosics is consumed.

In addition to Reaction (3), methanogenesis may proceed via:

$$4\ H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O. \quad (4)$$

However, this reaction will be ignored in our calculations, because (1) no experimental data are available to evaluate the rate of this reaction and (2) the net effect of this reaction is to reduce the total gas generation and the amount of CO_2 in the repository and, therefore, it is conservative to ignore this reaction in respect of repository pressurization and actinide solubility.

- *Rates of Cellulosics Biodegradation*

The rate of cellulosics biodegradtion was measured by incubating representative cellulose materials (filter paper, paper towels, and tissue) in WIPP brine with microbes enriched from various WIPP environments (Francis & Gillow, 1994; Francis et al., 1995). The incubation experiments were conducted under various conditions: aerobic or anaerobic, inundated or humid, with or without bentonite, amended or unamended with nutrients or NO_3^-. Because the repository is expected to become anoxic shortly after waste emplacement and also because bentonite will not be added as a backfill according to the current waste emplacement plan, we think that the experimental data from anaerobic incubation without bentonite present are most relevant to expected WIPP conditions. Considering that the current experimental data are mostly for denitrification (Reaction 1), but not sulfate reduction (Reaction 2) and methanogenesis (Reaction 3) (Francis & Gillow, 1994; Francis et al., 1995), we assume that the ranges of the rates of cellulosics biodegradation via sulfate reduction and methanogenesis are equal to those observed for denitrification.

We use CO_2 production data to estimate the rates of cellulosics biodegradation. There are two advantages of using CO_2 production data: (1) there are experimental data available on the CO_2 dissolution in WIPP brine (Telander & Westerman, 1995) and, therefore, it is easy to correct the CO_2 production data for gas dissolution (Appendix I); (2) since cellulosics biodegradation did not reach the stage of methanogenesis in the experiments, according to

Reactions 1 and 2, the consumption of one mole carbon of cellulosics will produce one mole of CO_2. This 1:1 relationship is independent of oxidation state of carbon in cellulosics. Therefore, it is rather straightforward to determine the amount of cellulosics biodegraded from the amount of CO_2 produced.

Experimental data show a strong dependence of CO_2 generation on the concentrations of nutrients and nitrate (Francis & Gillow, 1994; Francis et al., 1995). The maximum CO_2 generation was observed in nitrate-and-nutrient-amended samples. In those experiments, after a short lag phase, CO_2 first linearly increased with time and then approached some limiting value as its production rate diminished. If we assume that biodegradation is nitrate- or nutrient-limited, the experimental data can be explained by Michaelis-Menton kinetics (Chapelle, 1993). Michaelis-Menton kinetics, which describes the dependence of microbial reaction rate on substrate concentration, can be expressed by:

$$V = \frac{V_{max} S}{K_s + S} \qquad (5)$$

where V is the microbial reaction rate; V_{max} is the maximum value of the rate; S is the concentration of the limiting substrate; K_s is a constant. Equation (5) states that the microbial reaction rate becomes independent of the substrate concentration, if the latter is high enough, i.e. $S >> K_s$ and $V = V_{max}$. In this circumstance, the reaction product will accumulate linearly with time before the substrate is sufficiently depleted. In other words, in our cases, the linear part of CO_2 vs. time curve will give the estimate of the maximum rate of cellulosics biodegradation.

From the experimental data of Francis & Gillow (1994) and Francis et al. (1995), we estimate the maximum and minimum rates of cellulosics biodegradation under inundated conditions to be 0.3 and 0.01 mole C/kg/year, respectively (Appendix I). The maximum rate is estimated from the data obtained from both NO_3^-- and nutrients-amended experiments, whereas the minimum rate is derived from the data obtained from the inoculated-only experiments without any nutrient and NO_3^- amendment. Under humid conditions, experimental data show no clear correlation between CO_2 production and nutrient concentration. The best estimate of the maximum rate of cellulosics biodegradation under humid condition is 0.04 mole C/kg/year (Appendix I). The minimum of the humid biodegradation rate is set to 0, corresponding to the cases where microbes become inactive due to nutrient and water stress.

- *Biodegradation of Plastics and Rubbers*

The rates of plastics and rubber biodegradation under expected WIPP conditions were

measured by Francis et al.(1995). The experimental data show that plastics and rubbers are much less biodegradable than cellulosics, although the data themselves are not sufficient for us to constrain the long-term biodegradation rate for plastics and rubbers. There are two factor that may potentially increase the biodegradibility of those materials: long time scale and cometabolism. Over a time scale of 10,000 years, plastics and rubbers may change their chemical properties and therefore their biodegradibility. Cometabolism means that microbes degrade an organic compound but do not use it as a source of energy or of their constituent elements, all of which are derived from other substrates (Alexander, 1994). In the WIPP repository, plastics and rubbers, which are resistant to biodegradation, may still be cometabolized with cellulosics and other more biodegradable organic compounds. Because of these uncertainties, we recommend a 50% chance for the biodegradation of plastics and rubbers in the event of significant microbial gas generation. We further suggest lumping plastics and rubbers into cellulosics and applying the ranges of cellulosics biodegradation rate to plastics and rubbers. This treatment is conservative in respect of repository pressurization and actinide solubility. We propose to use the following equation to convert plastics and rubbers to the carbon-equivalent quantity of cellulosics (Appendix I):

$$\text{total cellulosics (kg)} = \text{actual cellulosics (kg)} + 1.7 \text{ plastics (kg)} + \text{rubbers (kg)}. \qquad (6)$$

Anoxic Steel Corrosion

According to current waste inventory estimates, a large amount of steels will be emplaced in the WIPP repository (DOE/CAO, 1996). Those steels will be capable of reacting with the repository brine to form H_2 gas. Both thermodynamic calculations and experimental observations indicate that the H_2 gas can be generated to pressures exceeding the lithostatic pressure at the WIPP horizon, if enough brine enters the repository (Brush, 1990; Telander & Westerman, 1993, 1995). Since the repository will become anoxic shortly after waste emplacement and sealing, we here focus only on anoxic steel corrosion.

- *Steel Corrosion in the Absence of CO_2 and H_2S*

In this case, steel corrosion will follow the reaction (Telander & Westerman, 1993, 1995):

$$Fe + 2\ H_2O \rightarrow Fe(OH)_2 + H_2. \qquad (7)$$

In the Mg-rich WIPP brines (exemplified by Brine A), a significant fraction of Fe in the corrosion product is substituted by Mg. This substitution can substantially increase the stability of the corrosion product. Experimental observations indicate that steel corrosion can still proceed even at an 127 atm H_2 pressure (Telander & Westerman, 1995). Aside from this thermodynamic stability argument, the experimental observations indicate no

essential effect of Mg in the brine on the corrosion rate. As a matter of fact, the corrosion rates measured in Mg-rich Brine A are not significantly different from those measured in Mg-depleted Brine ERDA-6 (Telander & Westerman, 1995).

It was observed in the experiments that the steel corrosion rate decreased with time until some limiting rate was achieved (Telander & Westerman, 1995). Our long-term corrosion rate is estimated from the longest-term data available in a WIPP-relevant Brine A environment. The estimated inundated rate is 0.5 μm/year or 0.07 mole Fe /m^2/year (Appendix II). In addition, the corrosion rate is also found to increase with decreasing brine pH (Telander & Westerman, 1993, 1995). Without addition of CO_2 from microbial reactions, the pH in the repository is unlikely to go below its experimental value, which is about 10 (Telander & Westerman, 1993, 1995). Therefore, we recommend using 0.5 μm/year as the upper limit of inundated corrosion rate for the cases without microbial gas generation. On the other hand, the pH in the repository can be ~2 units higher than its experimental value due to the presence of $Ca(OH)_2$ as a cementious material in the waste, and thus, based on the scaling factor (= 0.01) given by Telander & Westerman (1995), the steel corrosion rate could be as low as 0.005 μm/year. In addition, the experimental work for Source Term Test Program (STTP) at Los Alamose National Laboratory indicates that salt crystallization on steel surface may possibly prevent the steel from corrosion. To include this possibility, we set the minimum inundated steel corrosion rate to 0.

The corrosion rate observed on specimens exposed to humid conditions is negligible, based on essentially non-existent presence of corrosion product and lack of apparent H_2 generation (Telander & Westerman, 1995). Therefore, we set the humid steel corrosion rate to 0.

- *Steel Corrosion in the Presence of CO_2 and H_2S*

In the event of significant microbial gas generation, steel corrosion can proceed via the following reactions in addition to Reaction (7) (Telander & Westerman, 1993, 1995):

$$Fe + CO_2 + H_2O \rightarrow FeCO_3 + H_2 \quad (8)$$
$$Fe + H_2S \rightarrow FeS + H_2. \quad (9)$$

One possible effect of CO_2 and H_2S on steel corrosion is that they may cause passivation of the steel. Steel passivation was observed in the experiments in which large quantities of CO_2 and H_2S were added to the reaction vessels. It usually took place after tens of days and was caused by the formation of a protective layer of $FeCO_3$ or FeS on steel surfaces (Telander & Westerman, 1995). However, we think that this passivation is unlikely to occur under the repository conditions. This is because the microbial production rate of CO_2 and H_2S is too slow and it will take an exceedingly long time period (relative to the experimental time scale) for these gases in the repository to reach their concentration levels required for

passivation under the experimental conditions. The conclusion of no steel passivation under the WIPP repository conditions is consistent with other studies (e.g., Ikeda et al., 1983; Schmitt, 1983). In fact, aside from the previously cited work of Telander & Westerman (1993), total passivation of steel by CO_2 and H_2S in low-temperature solutions has not been reported, though varying degrees of corrosion inhibition have been observed.

In the absence of passivation, the microbial generation of CO_2 and H_2S will increase steel corrosion rates in the repository either by lowering the repository pH or by initiating additional reaction pathways (Reactions 8 and 9) (Telander & Westerman, 1995). We take this effect into account by modifying the sampling range of steel corrosion rate. Obviously, Reactions 8 and 9 will be limited by microbial CO_2 and H_2S production, and therefore the upper limit of the reaction rate can be estimated from the maximum cellulosics biodegradation rate, which is 0.3 mole/kg cellulosics/year, equivalent to 6 μm/year of steel corrosion rate (Appendix II). Thus, in the event of significant microbial gas generation, the upper limit of steel corrosion rate is 6.5 μm/year, the sum of the maximum rates of Reactions 7 through 9. The corresponding lower limit will be kept the same as that estimated for the cases without CO_2 production, i.e. 0.0 μm/year. Under humid conditions, experimental results show a negligible effect of CO_2 and H_2S on steel corrosion (Telander & Westerman, 1995). We thus set the humid corrosion rate to 0.

Stoichiometric Factors in the Average-Stoichiometry Model

In the Average-Stoichiometry Model, which is currently implemented in BRAGFLO, microbial gas generation is represented by the overall reaction:

$$\frac{1}{6}C_6H_{10}O_5 \;+\; \textit{unknown} \;\rightarrow\; y\ \textit{gas} \;+\; \textit{unknown} \qquad (10)$$

and H_2 production due to steel corrosion is described by:

$$Fe + \frac{4+2x}{3}\,H_2O \rightarrow \frac{4-x}{3}\,H_2 + x\,Fe(OH)_2 + \frac{1-x}{3}\,Fe_3O_4. \qquad (11)$$

The stoichiometric factors x and y in Reaction 10 and 11 are estimated as follows.

- *Average-Stoichiometric FactorY in Microbial Reaction*

The stoichiometric factor y depends on the extent of the progress of each individual reaction pathway (Reactions 1 through 3). It can be estimated based on the inventory estimates of the transuranic waste to be emplaced in the Waste Isolation Pilot Plant (DOE/CAO, 1996; Drez, 1996).

First, we estimate the maximum quantities (in moles) of cellulosics and steels that will be potentially consumed in 10,000 years:

$$M'_{cel} = \min \left\{ \frac{6000 M_{cel}}{162},\ 10000 R'_C M_{cel} \right\} \tag{12}$$

$$M'_{Fe} = \min \left\{ \frac{1000 M_{Fe}}{56},\ 1410 R_{c,i} A \right\} \tag{13}$$

with

$$R'_c = \max \left\{ R_{m,i},\ R_{m,h} \right\} \tag{14}$$

A is the total surface area of steel (m^2)

where M_{cel} and M_{Fe} are the quantities (in kg) of cellulosics and steels initially present in the repository; $R_{c,i}$ is the inundated steel-corrosion rate (μm/year); $R_{m,i}$ and $R_{m,h}$ are the sampled rates of cellulosics biodegradation under inundated and humid conditions respectively (mole/kg/year). In Equation (13), we use the factor of 0.141 mole/μm/m^2 to convert steel-corrosion-rate unit from μm/year to mole/m^2/year (Telander and Westerman, 1995). Here, we assume that cellulosics biodegradation and steel corrosion both follow zero order reaction kinetics. Next, we calculate the average stoichiometric factor y by distributing M'_{cel} into individual biodegradation pathways. Consider two extreme cases, corresponding to the maximum and minimum values of y: (1) no reaction of microbially produced CO_2 and H_2S with steel and steel-corrosion products; (2) complete reaction of microbially produced CO_2 and H_2S with steel and steel-corrosion products.

If no CO_2 or H_2S is consumed by reactions with steel and steel-corrosion products, we would expect the maximum quantity of microbial gas production in the repository and therefore the maximum value for y. We assume that Reactions 1 to 3 will proceed sequentially. The maximum value of y can be estimated by averaging the gas-yields for all reaction pathways:

$$y_{\max} = \frac{\frac{8.4 M_{NO3}}{4.8} + \frac{9 M_{SO4}}{3} + \left(M'_{cel} - \frac{6 M_{NO3}}{4.8} - \frac{6 M_{SO4}}{3} \right)}{M'_{cel}} \tag{15}$$

where M_{NO3} and M_{SO4} are the quantities of NO_3^- and SO_4^{2-} (in moles) initially present in the repository.

If CO_2 or H_2S reacts with steel and steel-corrosion products, we expect that a significant quantity or, perhaps, all of these microbially produced gases would be consumed, thus forming $FeCO_3$ and FeS. This would result in the minimum value of y. The total gas consumed by those reactions (G) is:

$$G = \min\left\{\frac{6M_{NO3}}{4.8} + \frac{9M_{SO4}}{3} + \frac{3}{6}\left(M'_{cel} - \frac{6M_{NO3}}{4.8} - \frac{6M_{SO4}}{3}\right),\ M'_{Fe}\right\} \tag{16}$$

The minimum value of y can then be estimated by:

$$y_{\min} = \frac{\frac{8.4M_{NO3}}{4.8} + \frac{9M_{SO4}}{3} + \left(M'_{cel} - \frac{6M_{NO3}}{4.8} - \frac{6M_{SO4}}{3}\right) - G}{M'_{cel}} = y_{\max} - \frac{G}{M'_{cel}} \tag{17}$$

For each BRAGFLO simulation, y will be uniformly sampled over $[y_{min}, y_{max}]$:

$$y = y_{\min} + \beta(y_{\max} - y_{\min}) \tag{18}$$

with $0 \le \beta \le 1.0$. The calculational scheme proposed here automatically correlates y with waste inventory estimates as well as with reaction rates.

The above calculational scheme does not take into account the SO_4^{2-} that will be brought into repository by brine inflow. Based the previous BRAGFLO simulations for undisturbed cases, the total volume of the brine entering the repository in 10000 years is unlikely to be larger than 2.2×10^7 liters, the value corresponding to the case with unrealistically low gas generation and therefore the worst repository flooding. With a typical SO_4^{2-} concentration of 200 mM in WIPP brines (Brush, 1990), we estimate that the amount of SO_4^{2-} brought into the repository by brine inflow would be less than 0.4×10^7 moles. This amount of SO_4^{2-} will increase the fraction of sulfate reduction pathway in total cellulosics biodegradation only by less than 1%. Therefore, neglecting the sulfate brought by brine inflow would introduce an error of no more than a few percents in y values.

• *Average-Stoichiometric FactorX in Steel Corrosion Reaction*

While magnetite (Fe_3O_4) has been observed to form on steel as a corrosion product in low-Mg anoxic brines at elevated temperatures (Telander & Westerman, 1995) and in oxic brine (Haberman & Frydrych, 1988), there is no evidence that it will form at WIPP repository temperatures. If Fe_3O_4 were to form, it would be expected that H_2 would be produced (on a molar basis) in excess of Fe consumed. But, the anoxic corrosion experiments did not show the production of H_2 in excess of Fe reacted. Therefore, we set the stoichiometric factor x to 1.0 in Reaction 11.

Table 1. Gas-Generation Parameters for the Long-Term WIPP Performance Assessment

Parameter	Estimated Value
Probability of occurrence of significant microbial gas generation	50%
Probability of occurrence of plastics and rubber biodegradation in the event of significant gas generation	50%
Rate of inundated cellulosics biodegradation	0.01 - 0.3 mole C/kg/year
Rate of humid cellulosics biodegradation	0.0 - 0.04 mole C/kg/year
Rate of inundated steel corrosion for the cases without microbial gas generation	0.0 - 0.5 μm/year[1]
Rate of humid steel corrosion for the cases without microbial gas generation	0.0 μm/year
Rate of inundated steel corrosion for the cases with microbial gas generation	0.0 - 6.5 μm/year
Rate of humid steel corrosion for the cases with microbial gas generation	0.0 μm/year
Stoichiometric factor x in Reaction 11	1.0
Stoichiometric factor y in Reaction 10	calculated from Eqn. (18)
Factor β in Equation 18	0 - 1.0
NO_3^- initially present in the waste[2]	2.6×10^7 moles
SO_4^{2-} initial present in the waste[2]	6.6×10^6 moles

1. Multiplying 0.141 mole/μm/m^2 will convert the unit of steel corrosion rate from μm/year to mole/m^2/year (Telander & Westerman, 1993). 2. See Appendix I.6.

References

Alexander M. (1994) *Biodegradation and Bioremediation*. Academic Press, NY.

Brush L. H. (1990) *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant*. SAND90-0266, Sandia national Laboratories, Albuquerque, NM.

Brush L. H. (1995) *Systems Priority Method - Iteration 2 Baseline Position Paper: Gas Generation in the Waste Isolation Pilot Plant*. Sandia National Laboratories, Albuquerque, NM.

Butcher B. M. (1990) *Preliminary Evaluation of Potential Engineered Modifications for the Waste Isolation Pilot Plant (WIPP)*. SAND89-3095, Sandia National Laboratories, Albuquerque, NM.

Chapelle F. H. (1993) *Ground-Water Microbiology and Geochemistry*. John Wiley & Sons, NY.

DOE/CAO (1996) *Transuranic Waste Baseline Inventory Report*. (Rev. 2)

Drez P. (1996) Preliminary estimate for SNL/NM performance assessment calculations of nitrate, sulfate, and phosphate content in transuranic solidified wastes destine for disposal in WIPP. CTAC. (memo, 1/26/1996)

Francis A. J & Gillow J. B. (1994) *Effects of Microbial Processes on Gas Generation under Expected WIPP Repository Conditions: Progress Report through 1992*. SAND93-7036, Sandia National Laboratories, Albuquerque, NM.

Francis A. J., Gillow J. B. & Giles M. R. (1995) *Effects of Microbial Processes on Gas Generation under Expected WIPP Repository Conditions: Data Report for the Period 1993 - 1995*. (draft)

Haberman J. H. & Frydrych D. J. (1988) Corrosion studies of A216 Grade WCA steel in hydrothermal magnesium-containing brines. *Scientific Basis for Nuclear Waste Management XI, Materials Research Society Symposium Proceedings, Boston, MA, November 30 - December 3, 1987*. Eds. M. J. Apted and R. E. Westerman. Materials Research Society, Pittsburgh, PA. 112, 761-772.

Ikeda A., Ueda M. & Mukai S. (1983) CO_2 corrosion behavior and mechanism of carbon steel and alloy steel. *Corrosion '83, Anaheim, CA, April 18 - 22, 1983*. Paper no. 45. National Association of Corrosion Engineers, Huston, TX.

Molecke M. A. (1979) *Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation*. SAND79-1245, Sandia National Laboratories, Albuquerque, NM.

Schmitt G. (1983) CO_2 corrosion of steels - An attempt to range parameters and their effects. *Advances in CO_2 Corrosion in the Oil and Gas Industry, Proceedings of the*

Corrosion/83 Symposium, Anaheim, CA, April 18 - 19. Ed. R. H. Hausler. National Association of Corrosion Engineers, Huston, TX. 1, 1-2.

Telander M. R. & Westerman (1993) *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Progress Report for the Period November 1989 through December 1992.* SAND92-7347, Sandia National Laboratories, Albuquerque, NM.

Telander M. R. & Westerman (1995) *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Final Report.* (draft)

Appendix I. Hand Calculations for Estimating Microbial Gas generation Parameters

Name of person performing the calculations: Yifeng Wang, Jan. 26, 1996 Yifeng Wang
Name of person reviewing the calculations: Larry Brush, Jan. 26, 1996 Larry Brush

I.1 Correction for CO_2 Dissolution in the Brine

Data and definition of variables:

- TCO_2: Total CO_2 produced in an incubating experiment (moles)
- n: Measured CO_2 in headspace (moles)
- C_l: Dissolved CO_2 (moles/l)
- V_l: Brine volume = 0.104 (l) (Gillow, per. comm.)
- V_g: Headspace volume 0.046 (l) (Francis & Gillow, 1994)
- P: Partial pressure of CO_2 (atm)
- K: Partition coefficient of CO_2 between brine and gas phase = 0.01 (mole/l/atm) (Telander & Westerman, 1995)
- R: Gas constant = 0.082 (l•atm/mole/K)
- T: Temperature = 303.15 (K)

Assumption: Gaseous CO_2 approximately follows the idea gas law during these experiments.

Calculations:

$$TCO_2 = V_l*C_l + n = K*P*V_l + n = K*V_l*n*R*T/V_g + n = (K*V_l*R*T/V_g + 1)*n = (0.01*0.104*0.082*303.15/0.046 + 1)*n = 1.56*n \text{ (moles).}$$

I.2 Estimate of the Maximum Inundated Cellulosics Biodegradation Rate

Data:

Source: Francis et al. 1995, p. 41, 148-149.
Experimental conditions: anaerobic inoculated, nutrients and nitrate amended

We only take the linear part of CO_2 vs. time curve:

time	CO_2
69 days	6.1 μmol/g of cel.
411 days	163 μmol/g of cel.

Calculations:

(1) Rate = (163 - 6.1)/(411 - 69) = 0.459 micro-moles/g/day = 0.168 mole/kg/year.
(2) Correcting it for dissolved CO_2 (see I.1), we finally have:
maximum rate = 0.168*1.56 = 0.3 mole/kg/year.

I.3 Estimate of the Minimum Inundated Cellulosics Biodegradation Rate

Data:
Source: Francis et al. 1995, p. 148-149.
Experimental conditions: anaerobic, inoculated only,

time	CO_2
0 days	2.1 µmol/g of cel.
1034 days	14.0 µmol/g of cel.

Calculations:
(1) Rate = (14.0 - 2.1)/(1034 - 0) = 0.0115 µmol/g/day = 0.004 mole/kg/year.
(2) Correcting it for dissolved CO_2 (Appendix I.1), we finally have:
minimum rate = 0.004*1.56 = 0.01 mole/kg/year.

I.4 Estimate of the Maximum Humid Cellulosics Biodegradation Rate

Data:
Source: Francis et al. 1995, p. 80.
Experimental conditions: anaerobic, inoculated only;
anaerobic, inoculated and amended

time	CO_2
6 days	(7.7 + 13.3)/2 = 10.5 µmol/g of cel.
415 days	(83.1 + 28.8)/2 = 56 µmol/g of cel.

Calculations:
Maximum rate = (56 - 10.5)/(415 - 6) = 0.11µmol/g/day = 0.04 mole/kg/year.

I.5 Convert Plastics and Rubbers to the Equivalent Quantity of Cellulosics

Data:

Source: Molecke (1979)

Celllulosics: $C_6H_{10}O_5$	M. W. = 162 g/mole
Polyethylene: $(-C_2H_4-)n$	M. W. = 28 g/mole
Polyvinychloride: $(-C_2H_3Cl-)n$	M. W. = 62 g/mole
Neoprene: $(-C_4H_5Cl-)n$	M. W. = 88 g/mole
Hypalon: $(-(C_7H_{13}Cl)_{12}-(CHSO_2Cl)_{17}-]n$	M. W. = 3488 g/mole

Assumption:

Plastics: 80% polyethylene, 20% polyvinychloride
Rubbers: 50% neoprene, 50% hypalon
Based on Molecke (1979).

Calculations:

The P kilograms of plastics and R kilograms of rubbers are equivalent to the Q kilograms of cellulosics, based on carbon equivalence:

$$Q = (0.8*2*162/28/6 + 0.2*2*162/62/6)*P + (0.5*4*162/88/6 + 0.5*101*162/3488/6)*R = 1.7\ P + R \text{ (kilograms)}$$

I.6 Moles of NO_3^- and SO_4^{2-} Initially Present in the Waste

NO_3^- : $1.62x10^6$ kg (Drez, 1996) = $1000/62*1.62x10^6 = 2.6x10^7$ moles
SO_4^{2-} : $6.33x10^5$ kg (Drez, 1996) = $1000/96*6.33x10^5 = 6.6x10^6$ moles

Appendix II. Hand Calculations for Estimating Steel Corrosion Parameters

Name of person performing the calculations: Yifeng Wang, Jan. 26, 1996 Yifeng Wang
Name of person reviewing the calculations: Larry Brush, Jan. 26, 1996 Larry Brush

II.1 Estimate of the Maximum Inundated Steel Corrosion Rate for the Cases without Microbial Gas Generation

Data:

(1) Anoxic corrosion rate obtained from the 12th to 24th month experimental data = 0.71 μm/year (Telander & Westerman, 1993, p. 6-14).

(2) Scaling factor for the long-term rate = 70% (Telander & Westerman, 1995, p. 6 - 19).

Calculation:

The maximum long-term steel corrosion rate = 0.71*70% = 0.5 μm/year.

II.2 Estimate the Maximum Inundated Steel Corrosion Rate for the Cases with Microbial Gas Generation

Data:

Total transuranic waste volume: 1.4×10^5 m^3 (DOE/CAO, 1996)
Drum volume: 0.208 m^3 (DOE/CAO, 1996)
Surface area of steel: 6 m^2/drum (Brush, 1995)
Maximum cellulosics biodegradation rate: 0.3 mole/kg/year (Appendix I.2)
Maximum inundated steel corrosion rate for the cases without microbial gas generation: 0.5 μm/year.
Total cellulosics (including plastics and rubbers): 2.0×10^7 kg (DOE/CAO, 1996; Appendix I.5)
NO_3^- initially present in the waste: 2.6×10^7 moles (Appendix I.6)
SO_4^{2-} initial present in the waste: 6.6×10^6 moles (Appendix I.6)

Assumption:

Reactions 8 and 9 will be limited by microbial CO_2 and H_2S production rate.

Calculations:

(1) Number of drums = $1.4 \times 10^5 / 0.208 = 6.7 \times 10^5$ drums.

(2) Total moles of C in cellulosics = $6 * 2.0 \times 10^7 * 1000/162 = 7.4 \times 10^8$ moles of C.

Molar fraction of cellulosics biodegraded via denitrification = $2.6 \times 10^7 / 7.4 \times 10^8 = 4\%$.

Molar fraction of cellulosics biodegraded via sulfate reduction = $6.6 \times 10^6 / 7.4 \times 10^8 = 1\%$.

(3) Maximum CO_2 and H_2S production rate for the whole repository = $(0.04 + 1.5*0.01 + 0.5*0.95)*0.3*2.0 \times 10^7 = 3.2 \times 10^6$ moles CO2/year.

(4) Total steel surface area = $6*6.7 \times 10^5 = 4.0 \times 10^6$ m^2.

(5) The maximum rate of steel corrosion via Reactions 8 and 9 = $3.2 \times 10^6 / 4.0 \times 10^6$ = 0.8 mole Fe/m^2/year = 6 μm/year.

(6) The upper limit of inundated steel corrosion rate for the cases with microbial gas generation = 0.5 + 6 = 6.5 μm/year.

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3/12/96

Sandia National Laboratories

Albuquerque, New Mexico 87185-

date: February 23, 1996

to: Martin S. Tierney (Org. 6741)

Yifeng Wang Larry Brush

from: Yifeng Wang & Larry Brush (Org. 6748)

subject: Modify the Stoichiometric Factor **y** in BRAGFLO to Include the Effect of MgO Added to WIPP Repository As a Backfill

This memo is supplemental to the previous one (Wang & Brush, 1996). We here request a modification for the calculation of stoichiometric factor y in BRAGFLO, in order to take into account the effect of MgO added to WIPP repository as a backfill. Notice that all gas-generation-parameter values submitted in the previous memo (Wang & Brush, 1996) will not be changed.

The accumulation of CO_2 produced by microbial reactions will decrease pH and thus increase actinide solubility in the repository. In order to improve WIPP performance, MgO will be added to the repository as a backfill to remove CO_2 and buffer pH. The consumption of CO_2 by MgO in the repository can be described by the overall reaction:

$$MgO(c) + CO_2(g) \rightarrow MgCO_3(c). \qquad (1)$$

According to the current waste inventory estimates, the amount of MgO sufficient to remove all CO_2 is estimated to be 4×10^8 moles or 4.5×10^3 m^3, which is about 4% of total transuranic waste volume (See Appendix). The simple thermodynamic calculation (See Appendix) shows that Reaction (1) will buffer the fugacity of CO_2 around 10^{-11} atm. Therefore, as long as sufficient MgO is added, the contribution of CO_2 to total gas pressure will be certainly negligible. This effect will be taken into account in the BRAGFLO calculation simply by modifying the stoichiometric factor **y** in the Average-Stoichiometry model.

The following modification is proposed: CO_2 is no longer taken into account in the derivation of equations (15 -17) in the previous memo (Wang & Brush, 1996). Those equations should be replaced by:

$$y_{\max} = \frac{\frac{2.4M_{NO3}}{4.8} + \frac{3M_{SO4}}{3} + 0.5*\left(M'_{cel} - \frac{6M_{NO3}}{4.8} - \frac{6M_{SO4}}{3}\right)}{M'_{cel}} \qquad (2)$$

$$G = \min\left\{\frac{3M_{SO4}}{3},\ M'_{Fe}\right\} \qquad (3)$$

$$y_{\min} = y_{\max} - \frac{G}{M'_{cel}} \qquad (4)$$

All notations here are the same as those used in Wang & Brush (1996).

References

DOE/CAO (1996) *Transuranic Waste Baseline Inventory Report.* (Rev. 2)

Drever J. I. (1982) The Geochemistry of Natural Waters. Prentice-Hall.

Lide D. R. (1995) Handbook of Chemistry and Physics. CRC.

Wang Y. & Brush L. H. (1996) Estimates of gas-generation parameters for the long-term WIPP performance assessment. Sandia National Lab., Albuquerque, NM. (memo to M. Tierney, 1/26/1996)

Appendix

A.1. How much MgO will be needed?

From Wang & Brush (1996, p. 15), the maximum quantity of CO_2 potentially to be produced in the repository is: 7.4×10^8 moles C * (0.04 + 0.01 + 0.05*0.95) moles CO_2/mole C = 4×10^8 moles of CO_2. According Reaction (1), the amount of MgO sufficient to consume all CO_2 will be 4×10^8 moles. With the molar volume of 11.2 cm^3/mole for MgO (Lide, 1995), the amount of MgO needed in volume will be 4.5×10^3 m^3, about 4% of total waste volume (DOE/CAO, 1996).

A.2. Fugacity of CO_2 buffered by Reaction (1)

The fugacity of CO_2, f_{CO2}, controlled by Reaction (1) can be calculated by

$$\lg f_{CO_2} = \frac{\Delta G}{2.303RT}$$

where ΔG is the free energy change of Reaction (1); R is gas constant (= 1.987 cal/mol/K); T is temperature (= 298.15 K). From the data given by Drever (1982), ΔG is estimated to be -15.32 kcal/mol. f_{CO2} is thus estimated to be $10^{-11.22}$ atm.

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Mifg W 8
3/12/96

Sandia National Laboratories

Albuquerque, New Mexico 87185-

date: February 29, 1996

to: Palmer Vaughn (Org. 6749)

Yifeng Wang Larry Brush

from: Yifeng Wang & Larry Brush (Org. 6748)

subject: An Adjustment for Using Steel Corrosion Rates in BRAGFLO to Reflect Repository Chemical Condition Changes due to Adding MgO as a Backfill

In order to control the repository chemistry, a sufficient amount of MgO will be added to the repository as a backfill. Through chemical reaction, this backfill will practically remove all CO_2 generated by microbial reactions and thus prevent any possibility of CO_2 accumulation in the repository. Therefore, the previously-suggested enhancement of steel corrosion by CO_2 (Wang & Brush, 1996) will be no longer possible. In our previous memo (Wang & Brush, 1996), two set of inundated steel corrosion rates were provided: one is 0.0 to 0.5 μm/year for the cases without CO_2 present and another is 0.0 to 6.5 μm/year for the cases with CO_2 present. *Considering the chemical condition changes due to adding MgO as a backfill, we suggest using the rate of 0 to 0.5 μm/year for* ***all*** *BRAGFLO simulations.*

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WPO 36289

Sandia National Laboratories

INFORMATION ONLY

Albuquerque, New Mexico 87185-1341

date: 9/20/1995

to: D. R. Anderson

Larry Brush

from: Yifeng Wang and Larry Brush, Dept. 6748

subject: Input Parameter Value Adjustments for the Average-Stoichiometry model

In this memo, we summarize the results of the calculation conducted for the comparison of the two existing gas generation models: Average-Stoichiometry model and Reaction-Path model. We demonstrate that the two model are in good agreement with each other in the prediction of total gas generation in the WIPP disposal rooms if more realistic input parameter values are adopted in the Average-Stoichiometry model. Our work thus places confidence in the use of the more simple Average-Stoichiometry model in the WIPP system modeling. Based on the calculation results as well as other considerations, we request two adjustments in sampling input parameter values for the Average-Stoichiometry model: (1) changing the sampling range for the stoichiometric factor of cellulosics biodegradation and (2) assigning a non-zero probability to the occurrence of the biodegradation of plastics and rubbers.

The details of the calculations can be found in the Summary Memorandum of Record (GG-2) for this FEPs activity. BRAGFLO was used with the Average-Stoichiometry model to calculate the history of gas generation in the repository and then this history was compared with that predicted by the Reaction-Path model. Using the Reaction-Path model, we have carried out 10 simulations for the cases including only steel corrosion and 10 more simulations for the cases including both microbial reaction and steel corrosion. For the steel-corrosion-only cases, the total gas generation predicted by the Average-Stoichiometry model falls in the range calculated by the Reaction-Path model. For the cases including both microbial reaction and steel corrosion, however, discrepancies are observed between the two model predictions (Table 1). But, the discrepancies can be minimized by adopting more realistic values for the stoichiometric factor of microbial reaction in the Average-Stoichiometry model. Importantly, based on the experimental data on steel passivation (Telander & Westerman, 1993), the calculation indicates that steels might become passivated shortly after the onset of microbial degradation of cellulosics, implying that microbial production of CO_2 might effectively preclude significant gas generation by steel corrosion. This, therefore, justifies the possible use of a "switch" in the Average-Stoichiometry model to mimics the effect of passivation of steels and other Fe-base alloys. This "switch" would allow only one process, either microbial reaction or steel corrosion, to occur in each calculation.

In the Average-Stoichiometry model, the biodegradation of cellulosics is represented by an overall reaction (WIPP Performance Assessment Division, 1991):

$$CH_2O + \text{unknowns} = y\ \text{gas} + \text{unknowns} \qquad (1)$$

where y is the stoichiometric factor. The value of y is currently sampled over a range of 0 to 1.67. However, our results show that this sampling range is not wholely realistic and usually results in either under- or over-estimating total gas generation in the disposal rooms (Table 1). The actual value of y, we believe, is distributed over a more narrow range.

The stoichiometric factor (y) depends on the reaction pathway of cellulosics degradation and the amount of electron acceptors (such as NO_3^- and SO_4^{2-}) present in the disposal rooms. The abundance of electron acceptors determines the extent to which each individual reaction pathway can proceed. Based on the waste inventory estimates by Storz (1995), the Reaction-Path model predicts that ~10% of cellulose materials will be degraded via denitrification and sulfate reduction:

$$CH_2O + 0.8\ H^+ + 0.8\ NO_3^- = 1.4\ H_2O + CO_2 + 0.4\ N_2 \qquad (2)$$

$$CH_2O + 0.5\ SO_4^{2-} = H_2O + CO_2 + 0.5\ H_2S \qquad (3)$$

and the rest via methanogensis:

$$CH_2O = 0.5\ CH_4 + 0.5\ CO_2 \quad . \qquad (4)$$

In the above reactions, the gas yield per mole of carbon of cellulosics is 1.4 for denitrification, 1.5 for sulfate reduction, and 1.0 for methanogensis. Therefore, if no steel-corrosion effect is considered, the stoichiometric factor (y) should be within a range of [1.0 to 1.2]. 1.5

Now let us take a look at the effect of steel corrosion on the stoichiometric factor (y). A small amount of steel can be corroded before it becomes passivated, in the cases where significant microbial gas generation occurs. As mentioned above, methanogensis is a dominant biodegradation pathway, and thus any small amount of H_2 released from steel corrosion would be quickly consumed by the reaction:

$$CO_2 + 4\ H_2 = CH_4 + 2\ H_2O. \qquad (5)$$

Note that this reaction simply converts CO_2 to an equal amount of CH_4 and leaves the total amount of microbially-generated gas unchanged. Therefore, for a long-term prediction, release of H_2 from metal corrosion does not affect parameter y. One possible minor effect of H_2 on Reaction (1) is caused by the repression of Reaction (4) by Reaction (5), because the latter is energetically more favorable. This is equivalent to reducing the rate of cellulosic biodegradation. This effect is already taken into account by the current sampling range for microbial reaction rate in the Average-Stoichiometry model. The major effect of steel corrosion on parameter y is actually caused by the reactions between the gases generated by microbial reaction and the products of steel corrosion, e.g.:

$$Fe(OH)_2 + CO_2 = FeCO_3 \ . \qquad (6)$$

All of these reactions consume microbially-generated gases (CO_2, H_2S) and thus equivalently reduce the stoichiometric factor (y) in Reaction (1). Due to steel corrosion, y can, therefore, have a value below 1.0. This effect may become significant in the cases with very high steel-corrosion rate but very low microbial reaction rate. According to the Reaction-Path-model calculation, however, it is unlikely for y to go below 0.75 (Table 1).

Table 1. Comparison of the Reaction-Path Model with the Average-Stoichiometry Model in the Prediction of Total Gas Generation in WIPP Disposal Rooms. Listed are only the cases involving significant microbial gas generation. Recommended y values are calculated so as to bring the total amount of gas predicted by the Average-Stoichiometry model to the same levels as calculated by the Reaction-Path model.

vector #	gas predicted by average-stoich. model (10^6 mol)	gas predicted by Reaction-Path model (10^6 mol)	y value used in average-stoich. model	y value recommended
3	1040	623	1.28	0.77
5	1080	1400	0.86	1.12
6	1100	1251	1.00	1.14
7	860	859	1.11	1.10
9	1510	1094	1.61	1.17
12	961	1315	0.83	1.13
15	87	1031	0.08	0.98
17	650	1352	0.53	1.11
19	817	1505	0.61	1.12
20	306	1005	0.34	1.12

In short, by choosing the appropriate y values, the Average-Stoichiometry model is still adequate to predict the total gas generation for the cases with both microbial reaction and steel corrosion involved. From the above discussion, we recommend adjusting the sampling range for the stoichiometric factor (y) to [0.75, 1.2] in the Average-Stoichiometry model. We also recommend the following sampling scheme:

1.5 ?

y: uniform distribution over [1, 1.2] if $g \geq 0.03$
y: uniform distribution over [0.75, 1] if $g < 0.03$

with $g \equiv R_{mic}/\max R_{mic} \bullet (1 - R_{cor}/\max R_{cor})$

where R_{mic} and R_{cor} are respectively the rates of microbial reaction and steel corrosion; max R_{mic} and max R_{cor} are respectively the maximum values of R_{mic} and R_{cor} allowed in their sampling ranges. This sampling scheme correlates the low values of y with the high rates of steel corrosion and the low rates of microbial reaction. Here we want to emphasize that the recommended sampling range could be subjected to a further adjustment as the waste inventory estimates are updated.

In addition, considering the difference between plastics (or rubbers) and cellulosics in biodegradability, we believe that it is more realistic to treat plastics and rubbers separately from cellulosics. We therefore recommend a 50% chance of plastics and rubber biodegradation in the event of significant microbial gas generation. The probability of the occurrence of significant microbial gas generation is recommended to retain the current value, i.e. 50%.

Finally, considering tight time constraints, as to the Average-Stoichiometry model, we recommend: (1) against changing kinetics of anoxic corrosion and microbial reaction from the 0th to the 1st order; (2) against inclusion of aluminum corrosion in the model; (3) retaining the assumption that microbial activity will have no significant effect on the H_2O content of WIPP disposal rooms. Leaving aluminum corrosion out of the model might be justified as follows: First, aluminum will be present only in a small amount relative to Fe alloys in the waste (U.S Department of Energy Carlsbad Area Office, 1994), and thus the effect of aluminum could be limited. Second, in the cases where significant microbial reaction occurs, as discussed above for steels, H_2 released from aluminum corrosion would be consumed quickly by reaction (5) and therefore would not have a significant effect on the long-term prediction of total gas generation. Also, note that the products of aluminum corrosion are unlikely to react with CO_2 and H_2S and thus they would not change the stoichiometric factor (y) in reaction (1).

REFERENCES

Storz L. 1995. Waste inventory estimates for input to the gas generation model. (memo)

Telander M. R. and Westerman R. E. 1993. Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Progress Report for the Period

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

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MASS Attachment 13-1

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WPO 30790

see also
WPO 30791

S-7: GAS EXSOLUTION
Summary Memo of Record

INFORMATION ONLY

TO: D. R. Anderson
M. Lord P Vaughn R MacKinnon
FROM: M. Lord, P. Vaughn, R. MacKinnon

SUBJECT: FEP Screening Issue S-7

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STATEMENT OF SCREENING DECISION

FEP Screening Issue S-7 need not be included in future system-level performance assessment calculations.

STATEMENT OF SCREENING ISSUE

This screening effort evaluates the need for including effects of dissolved gas in future system-level performance assessment calculations. During early time when the waste cavity is filling with brine, dissolved gas in brine may contribute an additional drive mechanism. As brine is drained from the near-waste formations and pressure declines within these formations, gas will be released from the brine resulting in potentially higher pressures. This mechanism may enhance the flow of brine to the waste region. At later time, when gas generation in the waste cavity is the principal drive mechanism, gas will go into solution as the pressure increases. This behavior will result in lower fluid pressures and altered fluid flow.

The impact of gas exsolution on direct releases to the surface during a drilling intrusion into the repository is also considered. Direct releases to the surface may occur during drilling due to cuttings and spallings in the drilling fluid and brine circulation from the repository to the surface in the wellbore. These releases are controlled by the prevailing pressure, permeability, and saturation conditions in the disposal room at the time of intrusion. The effect of dynamic alterations of the DRZ/TZ on these conditions may be important and needs to be evaluated.

APPROACH

The baseline two-phase flow model in BRAGFLO does not account for dissolved gas in brine. To simulate the effects of dissolved gas on fluid flow, a model was implemented to permit gas exsolution and dissolution in brine according to Henry's Law.

A series of BRAGFLO simulations were performed to determine if dissolved gas has the potential to enhance contaminant migration to the accessible environment. Effects of all other FEP issues were disabled in the simulations. Two basic scenarios were considered in the screening analysis, undisturbed performance and disturbed performance. Both scenarios included a 1.0 degree formation dip downward to the south. Intrusion event E1 is considered in the disturbed scenario and consists of a borehole that penetrates the repository and pressurized brine in the underlying Castile Formation. One variation of intrusion event E1 is examined, E1 Down-Dip. In the E1 Down-Dip event the intruded panel region is located on the down-dip (south) end of the repository. Based on FEPs screening analyses of issues DR-2, DR-3, DR-6, DR-7, and S-6, it can be concluded that the E1 Down-Dip configuration yields consistently larger predicted releases to the accessible environment than the E1 Up-Dip configuration. These larger releases are due to higher brine saturations down-dip of the borehole. For this reason, E1 Up-Dip calculations were not performed for this FEP issue. To incorporate the effects of

uncertainty in each case (E1 Up-Dip, E1 Down-Dip, and undisturbed), a Latin hypercube sample size of 20 was used resulting in a total of sixty simulations. To assess the sensitivity of system performance on puddling, conditional complementary cumulative distribution functions (CCDFs) of normalized contaminated brine releases to the Culebra via human intrusion and shaft system, as well as releases to the subsurface boundary of the accessible environment, were constructed and compared to the corresponding baseline model CCDFs. In the baseline model calculations, the effects of all FEP issues were disabled. These comparisons provide direct information about how the inclusion of dissolved gas may influence repository performance. In addition, performance measures are examined for direct releases during drilling due to both cuttings and spallings and brine circulation from the repository to the surface. Potential releases to the surface during drilling are strongly influenced by three drivers, brine pressures, brine saturations, and permeability in the waste disposal area. Spallings, cuttings, and brine releases tend to increase with an increase in each of these drivers. The exception to this trend is that at high brine saturations (or low gas saturations) brine releases tend to decrease because gas volumes become to small to maintain an appreciable gas drive (gas expansion).

RESULTS AND DISCUSSION

CCDFs for releases to the Culebra and subsurface boundary of the accessible environment for E1 Up-Dip, E1 Down-Dip, and undisturbed cases are provided in Figure 5 of Appendix 1. Each figure compares CCDFs of normalized releases predicted by the baseline model and normalized releases predicted with gas exsolution. Note that releases to the Culebra via the shaft and intrusion borehole are shown on the left side of the figure, whereas releases to the subsurface boundary of the accessible environment are presented on the right side of the figure. In both cases (E1 Down-Dip and undisturbed), the gas exsolution curves for releases to the Culebra via the shaft and borehole are very close and consistently below and to the left of the baseline curves for all but a very narrow range of insignificant releases. Similarly, CCDFs for releases to the subsurface boundary via the Marker Beds show that the gas exsolution curves are below and to the left of the baseline CCDFs for all but a very narrow range of insignificant releases. In summary, differences in releases between the baseline and gas exsolution results are minor with the baseline model predicting consistently higher releases.

Performance measures for direct release during drilling, which include maximum, mean, medium, and minimum values of volume averaged brine pressures, brine saturations, porosity, and permeability in the waste region for undisturbed conditions at 100, 1000, and 10000 years, are given in Table 4 of Appendix 1. Comparison of these values with the baseline values given in Table 2 indicate that brine pressures are consistently higher in the baseline case. All other metrics (drivers) are nearly equal between the baseline and gas exsolution cases. In summary, the baseline case is sufficiently conservative (over estimates potential release) with respect to releases due to brine, spalling, and cuttings.

BASIS FOR RECOMMENDED SCREENING DECISION

Based on the CCDFs, the inclusion of gas exsolution in BRAGFLO results in overall lower computed releases to the accessible environment than the baseline case. In addition, gas exsolution has an insignificant effect on waste room conditions relevant to releases due to drilling intrusion. As a result, the baseline model is conservative in its approach of neglecting dissolved gas effects and gas exsolution can be eliminated from consideration in system-level PA calculations.

FIGURE 8. MOLES OF H2 GENERATED DUE TO CORROSION AND BIODEGRADATION

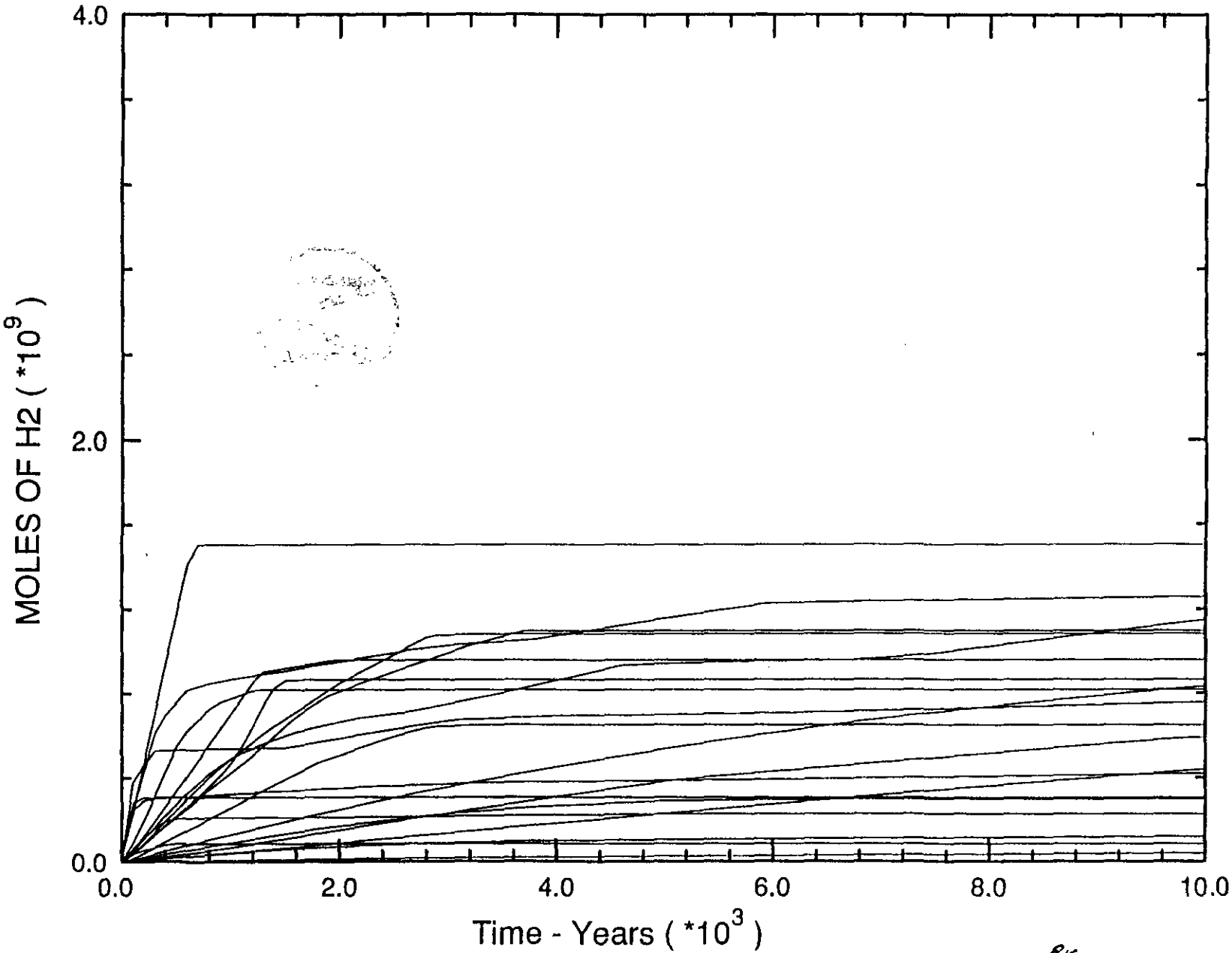

SWCF:1.1.6.3:PA:NG:TSK:G61 and 57
QA
PV 12/22/95
PV 12/22/95

F1:[FEP.RAD.UNDIST]SPLAT_H2.INP;9

SPLAT X2.0 12/22/95 10:47:35

FIGURE 9. MOLES OF H2 DUE TO RADIOLYSIS, CORROSION, AND BIODEGRADATION

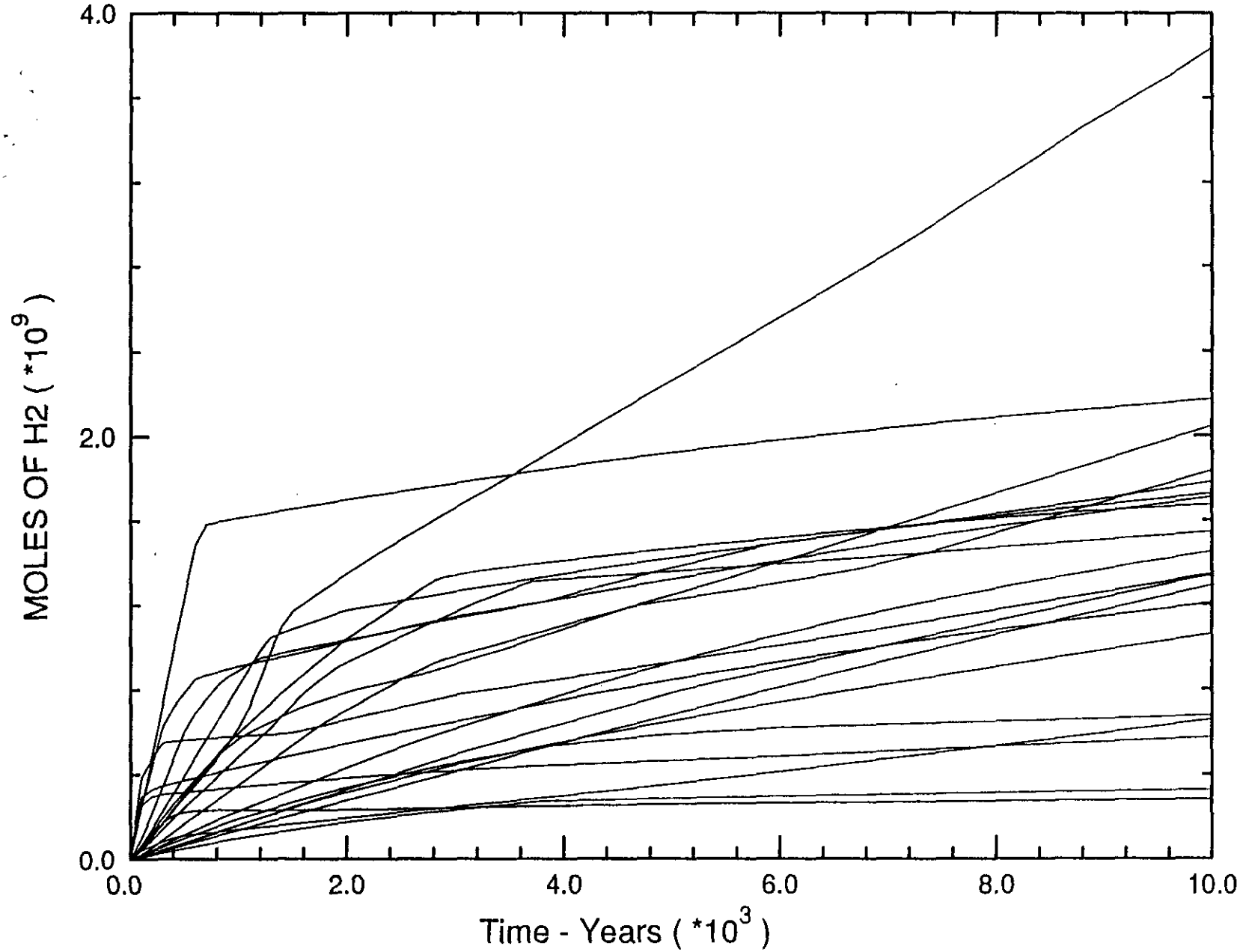

SWCF:1.1.6.3:PA:NG:TSK:GG1 and S7
RJM 12/22/95
QA JC 12/20/95

PV 12/22/95

Table 5. SOLUBILITY LIMITS (mole/m^3)

Th229 (3.0250E-03)	Th330 (3.0250E-03)	Th232 (3.0250E-03)	U233 (1.0003E+03)
U234 (1.0003E+03)	U235 (1.0003E+03)	U236 (1.0003E+03)	U238 (1.0003E+03)
Np237 (1.0300E+01)	Pu238 (7.0000E-01)	Pu239 (7.0000E-01)	Pu240 (7.0000E-01)
Pu241 (7.0000E-01)	Pu242 (7.0000E-01)	Am241 (1.0003E+03)	

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Table 4. Performance Measures For Blowout, Spalling, and Cuttings (Gas Exsolution Model Results)

TIME = 0.100000E+03 years

	BRINE PRESSURE (Mpa)	BRINE SATURATION	POROSITY	PERMEABILITY (m^2)
MIN	0.623238E+06	0.161922E-01	0.128635E+00	0.558470E-11
MAX	0.773898E+07	0.329942E+00	0.300751E+00	0.558470E-11
MEAN	0.258056E+07	0.154919E+00	0.181337E+00	0.558470E-11
MED	0.193918E+07	0.173379E+00	0.162942E+00	0.558470E-11

TIME = 0.100000E+04 years

MIN	0.197624E+07	0.956873E-05	0.646636E-01	0.558470E-11
MAX	0.210255E+08	0.412832E+00	0.258960E+00	0.558470E-11
MEAN	0.970278E+07	0.198533E+00	0.112481E+00	0.558470E-11
MED	0.809752E+07	0.179574E+00	0.975377E-01	0.558470E-11

TIME = 0.100000E+05 years

MIN	0.571118E+07	0.180534E-03	0.819800E-01	0.558470E-11
MAX	0.172035E+08	0.891735E+00	0.257772E+00	0.558470E-11
MEAN	0.856382E+07	0.304707E+00	0.114075E+00	0.558470E-11
MED	0.675711E+07	0.240683E+00	0.971745E-01	0.558470E-11

PV 12/20/95

QA

Table 2. Performance Measures for Blowout, Spalling, and Cuttings (Baseline Model Results)

TIME = 0.100000E+03

	BRINE PRESSURE (Mpa)	BRINE SATURATION	POROSITY	PERMEABILITY (m^2)
MIN	0.646341E+06	0.164512E-00	0.129134E+00	0.558470E-11
MAX	0.781343E+07	0.328766E+00	0.300751E+00	0.558470E-11
MEAN	0.261626E+07	0.159652E+00	0.182226E+00	0.558470E-11
MED	0.197089E+07	0.175252E+00	0.163546E+00	0.558470E-11

TIME = 0.100000E+04

MIN	0.405960E+07	0.144595E-03	0.753411E-01	0.558470E-11
MAX	0.213275E+08	0.829489E+00	0.260317E+00	0.558470E-11
MEAN	0.993771E+07	0.223267E+00	0.114298E+00	0.558470E-11
MED	0.841570E+07	0.185228E+00	0.986526E-01	0.558470E-11

TIME = 0.100000E+05

MIN	0.596549E+07	0.162282E-03	0.831857E-01	0.558470E-11
MAX	0.177650E+08	0.891300E+00	0.259204E+00	0.558470E-11
MEAN	0.904791E+07	0.295925E+00	0.115752E+00	0.558470E-11
MED	0.686144E+07	0.224458E+00	0.106594E+00	0.558470E-11

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

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MASS Attachment 13-2

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UPO 39166

INFORMATION ONLY

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

Memorandum of Record

DATE: June 5, 1996

SUBJECT: Memorandum of Record for meeting held 1/22/96 to discuss symmetry of intact rock properties, possible gas pressure-induced fracture properties, and fluid flow properties around the WIPP

DISTRIBUTION: 2 Copies w/att:
SWCF-A:WBS# 1.1.7.1:PA -Modeling and Analysis - Hydrologic Modeling:NQ:Salado Flow Symmetry

Kurt Larson
7/11/96

On January 22, 1996, a meeting was convened by Dr. Wendell Weart, Dept. 6000, and attended by Dr. Norman Warpinski, Dept. 6114, Dr. Wolfgang Wawersik, Dept. 6117, Dr. Stephen Brown, Dept. 6117, Dr. Peter Davies, Dept. 6115, Dr. Margaret Chu, Dept. 6801, Dr. Palmer Vaughn, Dept. 6749, and Kurt Larson, Dept. 6751. Dr. David Borns, Dept. 6116, was invited but could not attend. The meeting began at 8:30 and was scheduled as open-ended. The group decided a reasonable discussion had been pursued and an ending point reached after 3½ hours.

The meeting was held to discuss whether rock properties, fracture processes, or other evidence indicate that fluid flow in the Salado away from the repository will occur in a preferred direction, and to suggest for use in performance assessment a BRAGFLO model geometry consistent with the conclusion of the discussion. The topic is perceived as critical with respect to estimated performance of the disposal system, so a conservative approach for the sake of bounding the problem is not feasible.

Several packages of supporting information were provided and are attached to this memorandum. Peter Davies prepared and distributed prior to the meeting a packet of nine attachments summarizing previous work on the subject of flow and geometry, Kurt Larson brought a photocopy of stratigraphy in vicinity of the repository from Beauheim et al. SAND92-0533, Kurt Larson brought figures of geometry of present model, Palmer Vaughn brought a handout of the PA fracture model, and Palmer Vaughn brought a figure of pressures in the repository from modeling studies conducted in support of the PA.

An author's draft of this memorandum was submitted to all meeting participants for their review. Reviews were received from Dr. Warpinski and Dr. Wawersik. Their reviews are attached. This current memorandum has

been revised from the draft circulated for review to reflect the concerns and comments made in the reviews received.

Discussion about rock properties focused on whether significant anisotropy exists in the lateral hydraulic properties of interbeds. Discussed were the effects of the depositional environment of the interbeds, uplift and unloading history, geometry and orientation of existing and partially-healed fractures, and the observed heterogeneity of composition, permeability, and porosity. Dr. Brown wondered whether features in the interbeds might have directional components resulting from energy patterns impacting the depositional environment, such as prevailing winds or tides. Wendell Weart answered that his interpretation of Dave Borns' work was that interbeds show no directional trends or fabrics evident from any origin. The group concluded that present knowledge suggests absence of significant anisotropy. However, further work would strengthen this suggestion including two follow-on studies. First, examination of cores from surface boreholes might demonstrate pervasive preexisting subhorizontal fracture systems in Marker Bed 139 (and perhaps other interbeds) throughout the WIPP are representative of site-wide conditions. Second, mapping the thickness of overburden above the repository horizon within the Land Withdrawal Area could confirm that the stresses acting on preexisting fractures are similar over the region of interest for actinide transport. At the request of Dr. Weart, Dr. Borns investigated the suggested issues and has documented results in an attached memorandum. In summary, Dr. Borns, Dr. John Lorenz, and Dr. Dennis Powers examined eight available cores and found vertical or horizontal fractures in six, and found approximately 100 meters increased overburden moving from ERDA-9 eastward across the site.

Discussion about possible directional propagation of fractures induced by high repository pressure focused on results from WIPP-specific experiments, insight from other sites, and theory.

Hydrofrac experiments conducted at the WIPP by Dr. Wawersik and others in Marker Bed 139 and Marker Bed 140 below room C1 show that fractures remained in these interbeds within relatively narrow zones of anhydrite. The zones are basal or within the upper third of the interbed. Fractures propagated easily within these zones. Fractures did not propagate through clay-rich layers. For these small-scale hydrofracs, the maximum fracture opening was on the order of 0.5 cm, with a residual (post-fracturing) opening of 0.02 cm. Fracture extension of at least 30 m was observed. Dr. Wawersik expressed his opinion that (i) all of his hydraulic fracturing were influenced by the presence of room C1 and that generalizations of fracture paths for very long fractures must be carried out cautiously. (ii) Gas driven fractures would remain in the interbeds because the magnitude of the horizontal principal stresses in interbeds tested appeared to be similar to the magnitude of the overburden stress and because preexisting weakness such as partially-healed fractures probably would act as

fracture guides. (iii) Theoretical, fracture-mechanics based analyses leave open the possibility that hydraulically driven fractures, including gas-driven, might curve upward and cross into the overlying salt if the length of a fracture becomes long compared with the depth of the fracture below surface.

The behavior of hydraulically-induced fracturing at other sites and fluid flow through fractures at other sites was discussed. Oak Ridge hydrofrac experiments were discussed as these may be good analogues to possible WIPP behavior. Dr. Wawersik followed up on the Oak Ridge experiments. The Oak Ridge hydrofrac work identified possible parallels (analogues) in the propagation characteristics of horizontal, fluid-driven fractures. Points of particular interest are: (i) the magnitude of in-situ stress states to maintain horizontal fracture growth, (ii) the possible influence of preexisting inclined fractures on horizontal hydraulic fracturing paths, and (iii) the possibility of fracture towards shallower depths and towards the surface as the lengths of the grout-driven fractures became long compared with their depth below surface.

Fracturing experiments in coal fields show that coal fines prevent easy propagation because the fracture tip gets clogged and fractures bifurcate. Such bifurcations may produce multiple fractures. Hydrofracs conducted by the petroleum industry were thought not to be good analogues because in most oil-field applications fractures are oriented vertically rather than horizontally. The Edsel gas storage field in Germany and experiments conducted by Shell in Holland were mentioned because there gas has moved along grain boundaries at high pressures. Specifically, Shell R&D results indicate that grain boundaries in rock salt around storage caverns will open to absorb liquid or gas when the cavern pressure reaches the prevailing lithostatic pressure. If true, such a scenario might create gas storage volume outside of new or reopened fractures in any WIPP interbeds.

Stripa was mentioned. However the relevance of fracture studies there is questionable because Stripa is looking at pre-existing fracture behavior but significant flow in the Salado at WIPP, if it occurs, will be in induced fractures. Dr. Warpinski mentioned that small-scale effects in western gas sands are thought to be insignificant.

It was the consensus of the group that propagating fractures are not likely to have a strong directional component propagating fractures in all directions to a similar distance is energetically more favorable than propagating a fracture or network of fractures in a single direction or limited arc. At the scales of interest for WIPP performance assessment, areas between propagated fractures will tend to be bridged by new fractures before the propagated fractures extend further. It was noted by Dr. Warpinski that vertical fractures created during oilfield operations have extended as far as 1500 feet; Dr.

Warpinski thought that it would be difficult to extend fractures greater than 2000 feet.

Dr. Warpinski advanced three conceptual models for possible conditions in the interbeds. In interbeds that have not been affected by high repository pressure, a network of preexisting fractures, partially healed, controls fluid flow. As pressures rise above the point where alteration begins, two things could happen. Dilation and interconnection of preexisting fractures could occur, resulting in increased porosity and permeability. Creation of new fractured zones and networks could also occur.

The impact of dip was discussed briefly. Dr. Warpinski stated that any dip would likely have an impact on segregation of gas and brine and some impact on the direction of fractures. Palmer Vaughn reported the present PA model incorporating dip and fractures did yield some directionality in fractures and segregation of fluids.

The performance assessment model for incorporating the effect of induced fractures was discussed. Palmer Vaughn introduced the model. The opinion of Dr. Wawersik and Dr. Warpinski was that the parameters in the model should be set such that the effect of a linear elastic fracture mechanics (LEFM) model is mimicked at a pressure slightly above lithostatic. Additionally, it was stated that pressures in the repository greater than a few to several MPa greater than lithostatic were unbelievable on physical grounds - some portion of the system would dilate or fracture if such pressures were attained. Thus the fracture model parameters should be set so the increase in interbed porosity and interbed permeability (i.e., propagation properties) at a pressure a couple or several MPa above lithostatic is sufficient to prevent any additional pressure increase. Kurt Larson and Palmer Vaughn followed up on this with help from Mike Lord (see attachments).

Summary:

- The group concluded that most available evidence and relevant experience rules out strong, obvious effects of anisotropy, and supports radial flow and radial propagation of fractures away from the repository rather than directional propagation of fractures. It was noted that the available evidence is not sufficient to prove that radial flow and propagation of fractures will occur but the preponderance of scientific judgement favored that interpretation.

- The parameters in the interbed fracture model implemented in BRAGFLO should be set such that the effect of a linear elastic fracture mechanics (LEFM) model is mimicked at a pressure slightly above lithostatic. Additionally, the fracture model parameters should set so the system porosity increase and permeability increase (i.e., propagation properties)

at a pressure a couple or several MPa above lithostatic is sufficient to prevent any additional pressure increase. Identification of a parameter set intended to accomplish this has since been completed (see attachments for details).

Attachments: Not Attached in CCA. Available in SWCF. Kurt Larson 8/5/96.

Borns, David J. Memorandum to Wendell Weart, January 19, 1996. The symmetry of flow within Marker Bed 139.

Borns, David J. Memorandum to Wendell Weart, May 30, 1996. Lateral Variability of Fractures and Fracture Susceptibility in the Marker Beds of the Saladao [sic] Formation.

Davies, Peter. Memorandum to Distribution, January 19, 1996. Additional Background Information for Tuesday's Meeting on Salado Brine Outflow.

Vaughn, P. and Fewell, M. Memorandum to Margaret Chu, January 10, 1996. Recommendations on Preferential Flow in the Salado Formation.

Warpinski, N.R. Memorandum to W.D. Weart, March 19,1996. Review of *Salado Flow Geometry Meeting* Summary.

Wawersik, W.R. Memorandum to W.D. Weart, March 25, 1996. Salado Flow Geometry.

Wawersik, W.R. Memorandum to Kurt Larson, February 15, 1996. Fracture and fluid flow in Salado marker beds.

Wawersik, W.R. Memorandum to M.S.Y. Chu, September 14, 1996. Gas-driven fracture development in WIPP - CORRECTION.

Unauthored Attachments:

Parameters describing the variable porosity and permeability within anhydrite material and supporting information.

Plot of pressure versus time in the repository for FEP baseline calculations

Figure 2-3: Salado Formation lithology figure.

Figure 2-2: Detailed stratigraphy near the WIPP facility.

Table A-1: Description of generalized stratigraphy.

Top-down figure of BRAGFLO long-term release mesh. Figure in Section 6 of CCA. Kurt Larson

To-scale side view of BRAGFLO long-term release mesh. Figure in Section 6 of CCA. Kurt Larson.

Copy w/att:

D. Borns	MS 0750	
S. Brown	MS 0751	
M. Chu	MS 1335	
P. Davies	MS 1324	
M. Fewell	MS 1328	
K. Larson	MS 1341	Day File
P. Vaughn	MS 1328	
N. Warpinski	MS 0705	
W. Wawersik	MS 0751	
W. Weart	MS 1337	

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P. Swift	MS 1341
L. Dotson	MS 1341
M. Lord	MS 1328

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Application
for the
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MASS Attachment 16-1

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WPO 38579

WS:96:03106
DA:96:11019

Westinghouse Electric Corporation

Government and Environmental Services Company

Waste Isolation Division

Box 2078
Carlsbad New Mexico 88221

April 4, 1996

INFORMATION ONLY

Mr. Mel Marietta, Manager
WIPP Project Compliance Department
Sandia National Laboratories
115 N. Main Street
Carlsbad, NM 88220

Subject: BOREHOLE PLUGGING IN THE DELAWARE BASIN

Dear Mr. Marietta:

Per our verbal discussion, please find attached summary results of regulatory analyses and records research used to determine plugging and abandonment practices in the Delaware Basin. The results summarized in the attachment are based on actual drilling and plugging records from the Bureau of Land Management and the Oil Conservation Division offices, that are most current and complete sources available.

The plug arrangements, material thicknesses, casing and cement specifications, and associated patterns are summarized by type so as to facilitate developing a conceptual model and probability distribution for time dependent plug performance in the Performance Assessment (PA).

This information will be the basis upon which Mr. B. Thompson of CTAC will provide the PA distribution. The case file for the CTAC work should be added to the detailed records package that supports the summary level conclusions attached here. The detailed records for the attached summary will be provided to you in a few days.

Should you have any questions, please contact Mr. Ross Kirkes of my staff at (505) 234-8145, or myself at 234-8380.

Sincerely,

B. A. Howard, Manager
Long-Term Regulatory Compliance

hmp

Attachments

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BOREHOLE PLUGGING IN THE DELAWARE BASIN

EXPLANATION OF ASSUMPTIONS

The purpose of the Delaware Basin Drilling and Plugging Study was two-fold: 1) to determine the fraction of boreholes currently plugged in the basin; and 2) to provide a basis for the development of a conceptual model for long-term performance of plugged boreholes. This study has not attempted to predict the effectiveness of plugs, but only identify the location and physical characteristics of plugs which might be important to performance assessment.

Guidance in 40 CFR 194 states that "Performance assessments should assume that the permeability of sealed boreholes will be affected by natural processes, and should assume that the fraction of boreholes that will be sealed by man equals the fraction of boreholes which are currently sealed in the Delaware Basin." The rule also states that "...drilling practices will remain as those of today."

Using the guidance above, the following assumptions were used in the study:

1) In determining the fraction of plugged holes, all New Mexico wells in the Delaware Basin which are subject to plugging and abandonment (under the most recent plugging regulations [1988]) were analyzed. This analysis is consistent with the future state assumption provided in the guidance and includes boreholes on both state and federal land. Boreholes in the Texas portion of the Delaware Basin have been excluded by the future states interpretation taken from 40 CFR 194. That is, boreholes in Texas are currently plugged according to Texas state plugging regulations. These regulations are not currently applicable to the WIPP, and therefore will not be applicable in the future. These criteria result in a sample size of 194.

2) Initially, to find an appropriate plugging analogue for the WIPP, the study considered only boreholes on federal land, in the potash enclave, in a barren area that have been drilled and were subject to plugging under the most recent regulations (since 1988). The exclusion of state land from this sample was supported by the argument that WIPP currently resides on land under federal ownership, and therefore falls under plugging and abandonment regulations imposed by the Bureau of Land Management (BLM). In addition, the WIPP is within the potash enclave, but is in a barren area, where potash grades and quantities are not of economic value. This set of bounding conditions appeared to be the most accurate description of an analogue for a borehole which might occur at the WIPP.

Unfortunately, these selection criteria resulted in only one plugged borehole. This situation is due to the fact that drilling in potash areas is not generally allowed by regulators. Interestingly, the single borehole identified was not plugged per the applicable R-111-P requirements; waivers from this requirement are granted due to the fact that in barren areas, there is no potash ore to protect. Clearly, a sample size of one is not adequate to determine plugging practice in the area of interest.

Based on this finding, these criteria were modified to include all boreholes in the New Mexico portion of the Delaware Basin subject to plugging since 1988 under BLM regulations, without regard to potash. After examining the data from these boreholes, it became apparent that there is little variability in plugging procedures for wells on federal land. That is, boreholes on federal land are plugged in a consistent manner regardless of whether or not the borehole is within the potash enclave. Interestingly, one borehole has been identified which does meet the R-111-P requirements, however, it is not within the R-111-P area. Use of these criteria resulted in a sample size of 115.

For completeness, wells plugged on state land since 1988 were added to the sample to help determine any significant differences in plugging practices between state and federal procedures. There have been 73 wells on state land plugged and abandoned since 1988, raising the total sample to 188.

3) For the purposes of this study, only boreholes with depths greater than 2,150 ft were considered. Pressurized brine is assumed to be at depths from 2700 - 3000.

CONCLUSIONS

Frequency

As mentioned, the fraction of plugged boreholes in the Delaware Basin must be known and used for input in performance assessment. Using the sample size of 194, the records reveal 188 plugged and abandoned boreholes, and 6 unplugged boreholes. Of these 6 unplugged boreholes, each have proposals to plug and abandon filed with the appropriate regulatory agency. Westinghouse personnel have field verified and/or verbally communicated with regulatory personnel regarding each of these wells and have noted that 5 of these boreholes have in fact been plugged and abandoned. The records, however, have not been brought up to date. The remaining 1 borehole is merely in the interim period between the proposal to plug and the actual plugging activities. The important point here is that these boreholes have not been forgotten or neglected; they are somewhere along the prescribed regulatory sequence. Once these boreholes are plugged, a final record stating the exact procedure used, composition, location, and length of all plugs emplaced will be filed with the regulatory agency. The study suggests that plugging and abandonment regulations are followed consistently, and that no wells in the basin have been left unplugged since the implementation of the most current regulation. Therefore, it is recommended that performance assessment

assume a 100% plugging frequency. An alternative to this would be to use 99% to ensure that wells that are not captured by the records management system do not invalidate the performance assessment calculations using a 100% frequency.

Configuration

Type I 50

To determine the typical configuration and composition of a borehole plug, the study considered both current drilling and plugging practices. Records of the plugged boreholes have revealed that the surface casing rarely extends beyond 800', and there is almost always a plug at this transition in casing size. It is therefore reasonable to assume by applying current practice to a borehole occurring at WIPP, that there will typically be a surface casing shoe plug below the Culebra (at approximately 800').

Current practice also shows consistent use of the intermediate casing shoe plug. Conversations with drillers have indicated that drilling proceeds relatively quickly through the salt, until the Lamar Limestone is encountered. This formation is a thin unit that lies directly below the Castile formation. When this unit is reached, drilling ceases and the intermediate casing string is installed. It is at this transition in casing size that another plug will be installed upon plugging and abandonment. Drillers have confirmed that this is done without consideration to any pressurized brine that may or may not have been encountered in overlying strata. Therefore, it is reasonable to assume that a borehole at WIPP would typically have an intermediate casing shoe plug near the base of the Castile (at approximately 4000 ft). The location of these two plugs represent the Type I plug.

Type II and III

Other plugging configurations exist in the Delaware Basin. For example, in cases where the production casing is removed upon abandonment, a plug is required at this interval. The depth at which this casing is cut and removed is a function of practicality and economics. If the casing is in sufficient condition to salvage upon abandonment, that portion may be removed. This depth may vary from approximately 4000' to approximately 1200'. Typically, this would occur somewhere within the intermediate casing string. For the purposes of this study, we have called this plug the "stub" or "intermediate plug of significance." Plugs of this type may occur at depths greater than 4000', but have no importance or protective capability with regard to the repository or the hypothetical brine pocket.

The placement of this intermediate plug is of particular interest in generating a conceptual model for the borehole plug. If this plug exists between the repository and the hypothetical brine pocket (2150' - 2700'), some protection may be provided from the infiltration of brine. Plugging configurations such as this are represented by the Type II plug.

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If this intermediate plug is above 2150', it may have the negative effect of directing flow into the repository from the underlying brine pocket. This situation is represented by the Type III plug. Both the Type II and Type III plugging configurations include the upper and lower plugs evident in the Type I plug.

Type IV

In some cases, intermediate plugs in addition to those of Type II have been emplaced. These are represented here as Type IV plugs.

Type V

In very few cases, only a surface plug and a bottom or lower plug is evident. Such configurations meet the minimum regulatory requirements, provided that the borehole did not encounter any water bearing zones. While this would not be the case at the WIPP, they have occurred within the Delaware Basin, and are included here for completeness. This configuration represents the Type V plug.

Type VI

The Type VI plug is a solid cement plug through a significant portion of the salt section. This plug, like the others, may have additional plugs above and below the salt-section plug.

These types are displayed in Figure 1.

(50)

Type I Plugs (BLM)					
	API #	Base of Top Plug	Length	Base of Bottom Plug	Length
1	30-025-30599	670	670	5100	130
2	30-025-31403	837	100	4340	150
3	30-015-25317	436	436	3665	35
4	30-015-26278	1265	200	4050	50
5	30-015-27998	800	154	4490	140
6	30-025-30062	698	100	6165	100
7	30-015-26152	820	75	7250	500
8	30-025-31394	850	104	3870	157
9	30-025-31193	940	142	3410	240
10	30-025-32233	1450	150	5130	430
11	30-025-32871	733	100	5156	200
12	30-015-27972	820	100	4525	345
13	30-015-27760	713	263	4300	300
14	30-015-27959	720	200	4198	300
15	30-025-32231	575	100	5020	120
16	30-015-27225	915	155	2853	137

17	30-015-27522	815	173	2842	100
18	30-015-27523	450	100	3050	221
19	30-015-27966	551	123	3775	221
20	30-015-26446	450	100	2850	100
21	30-025-29302	433	290	3000	220
22	30-025-29540	1100	262	4357	152
23	30-015-26799	408	50	3800	225
24	30-015-21916	946	574	4127	147
25	30-015-05874	847	50	4100	270
26	30-015-21187	770	220	3340	100
27	30-015-24799	1573	183	3814	100
28	30-015-21530	500	100	5763	414
29	30-015-04757	540	240	3260	187
30	30-025-21093	671	81	3131	141
31	30-025-08219	775	361	4650	361
32	30-025-31650	410	100	4365	100
33	30-025-26234	770	191	3429	100
34	30-025-27267	720	100	5358	178

35	30-025-27752	1555	100	5221	220
36	30-015-25405	1108	600	4260	195
37	30-015-20475	715	715	3715	175
38	30-015-20603	800	80	3800	100
39	30-015-23832	850	100	3798	100
40	30-015-25169	425	425	3565	35
41	30-015-25150	450	450	3600	35
42	30-025-28682	659	127	3059	133
43	30-025-31518	925	206	3625	526
44	30-015-23356	525	50	3415	205
45	30-025-29962	710	100	3200	184
46	----------[1]	1000	1000	4765	100
47	30-025-27154	849	100	3600	227
48	---------[1]	390	213	4500	360
49	---------[1]	1029	1029	4500	50
50	---------[1]	1000	1000	4765	100

[1]Records for this well do not include API number, only township, range, and section.

Type I Plugs (State)					
	API #	Base of Top Plug	Length	Base of Bottom Plug	Length
1	30-025-31986	465	115	4250	164
2	30-015-27144	2000	2000	4700	35
3	30-025-30458	608	100	3250	200
4	30-025-31821	778	197	4300	160
5	30-015-26531	666	100	2882	150
6	30-025-27466	1100	100	4900	201
7	30-025-21081	1210	200	4780	100
8	30-025-29127	1000	325	5250	103
9	30-025-29917	1125	125	5300	100
10	30-015-22971	525	225	3375	225
11	30-015-24207	620	254	3103	40

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Type II Plugs (BLM)							
	API #	Base of Top Plug	Length	Base of Intermediate Plug	Length	Base of Bottom Plug	Length
1	30-015-26519	450	162	2367	123	3544	100
2	30-015-26631	452	154	2165	173	3650	100
3	30-015-28020	530	200	2500	200	4050	250
4	30-015-27782	650	200	2800	150	3850	250
5	30-015-21035	808	248	2499	75	3350	35
6	30-015-24341	100	50	[1]	[1]	4582	2082
7	30-015-24033	500	100	2200	100	3175	100
8	30-015-03703	470	292	2781	188	[2]	[2]
9	30-025-27280	520	119	2511	99	5317	155
10	30-015-27322	450	100	2748	200	4775	125
11	30-015-24283	456	132	2571	132	6030	232

[1]Lower plug is of sufficient length to extend into this interval.

[2]This well has a total depth less than 3000', therefore the intermediate plug listed is actually the deepest plug in the borehole.

12	30-015-24902	425	60	2335	54	3625	75
13	30-015-25211	450	450	2300	50	4025	50
14	30-015-24903	425	60	2335	54	3625	100
15	----------[1]	380	380	2455	100	4525	315

[1]Records for this well do not include API number, only township, range, and section.

Type II Plugs (State)							
API #		Base of Top Plug	Length	Base of Intermediate Plug	Length	Base of Bottom Plug	Length
1	30-015-26456	602	135	2314	327	5810	110
2	30-015-26105	450	100	2340 1400	200 100	3343	100
3	30-015-27790	500	100	2183	383	4100	50
4	30-015-26707	650	275	2650	100	2830	100
5	30-015-25864	650	100	2410	100	4680	100
6	30-015-26812	550	90	2375	175	4650	662
7	30-015-26911	370	155	2785	545	3400	35
8	30-015-22330	450	100	2486	304	3342	54
9	30-015-25004	700	200	2300	85	3400	120
10	30-015-24352	570	100	2310	100	3344	50
11	30-015-10358	1260	875	2235	725	3750	120
12	30-015-22954	560	560	2690	300	3600	100
13	30-015-22441	463	218	2461	427	3286	276

14	30-015-22312	1500	950	2500	435	[1]	[1]
15	30-015-24836	369	369	2850	515	3460	364
16	30-015-23301	550	200	2500	200	3584	200
17	30-015-24810	500	402	2600	100	5550	168
18	30-025-28596	650	110	2704	109	4351	221
19	30-015-22352	238	100	2525	100	4300	75
20	30-015-23615	565	100	2814	86	3340	50
21	30-015-23586	800	150	2442	100	3673	100
22	30-015-24061	465	250	2400	40	[1]	[1]

[1]This is a shallow well with a total depth less than 3000'.

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Type III Plugs (BLM)							
	API #	Base of Top Plug	Length	Base of intermediate plug	Length	Base of Bottom Plug	Length
1	31-015-27274	670	100	2050	50	4350	50
2	30-025-31885	682	102	1160	100	4911	175
3	30-025-30691	413	47	1300	162	4666	162
4	30-025-30388	1240	100	1643	100	5177	200
5	30-025-32482	623	50	1150	150	4690	150
6	30-025-30873	650	100	1200	100	4473	196
7	30-015-27044	456	116	2100	131	3960	131
8	30-015-27427	783	150	1814	150	3066	150
9	30-015-24201	545	100	1800 760	100 103	5510	50
10	30-015-26802	450	154	1995	152	3550	100
11	30-015-27678	710	200	1922	125	3280	405
12	30-015-27554	516	100	1150	100	3100	260
13	30-025-25685	685	252	1020	76	3224	184
14	30-025-27557	300	147	900	138	3492	292

15	30-025-31664	700	250	1175	50	4375	258
16	30-015-21126	515	250	1080	100	3950	182
17	30-015-05883	965	68	1465	170	4000	99
18	30-015-05882	928	152	1451	214	4050	99
19	30-015-05869	960	269	2000	100	4100	100
20	30-015-05886	950	118	2050	100	4075	100
21	30-015-25444	1020	55	2880	142	4163	27
22	30-015-25582	870	100	1500	200	3478	100
23	30-105-24978	985	140	2000	61	3360	119
24	30-015-21519	600	150	2000	100	3050	100
25	30-015-01159	690	100	2000	100	3450	100
26	30-025-27753	590	100	1109	100	4965	104
27	30-025-26867	465	100	1200	200	3570	200
28	30-025-08185	775	361	1172	244	4600	434
29	30-025-08214	804	312	1200	150	4403	362
30	30-025-08189	775	361	1170	170	4650	506
31	30-025-08702	747	747	1170	170	4450	436
32	30-025-08205	775	361	1185	100	4506	361

33	30-025-08207	775	325	973	144	4520	578
34	30-025-08215	450	450	1170	495	4385	361
35	30-025-08201	775	325	1195	157	4500	434
36	30-025-28654	300	100	1071	184	2983	145
37	30-015-25273	384	384	1849	209	3000	192
38	30-015-24701	1375	153	3080	253	4616	450
39	30-025-08127	350	98	1237	63	4875	25
40	30-025-08188	818	361	1206	106	4650	578
41	----------[1]	434	434	1610	645	3600	100

[1]Records for this well do not include API number, only township, range, and section.

Type III Plugs (State)							
	API #	Base of Top Plug	Length	Base of Intermediate Plug	Length	Base of Bottom plug	Length
1	30-025-30179	648	170	1200	170	5300	170
2	30-015-26924	310	90EST	2000 1200	525 119	5000	105
3	30-015-26084	608	117	3800	170	5750	351
4	30-015-25578	524	149	1772	100	3089	35
5	30-015-26531	525	125	1350	55	2850	100
6	30-025-08193	400	400	1090	180	4575	50
7	30-105-20759	383	116	2080	244	5200	121
8	30-015-20843	680	170	1982	132	5450	180
9	30-015-20831	280	160	1775	375	5345	550
10	30-015-24476	600	600	2110	110	5700	35
11	30-015-24961	563	150	1981	153	5453	156
12	30-015-21007	425	100	1845	100	3000	100
13	30-015-21551	400	400	2100	410	5533	100
14	30-015-20842	441	441	1949	175	5562	506

15	30-015-23037	425	204	1350	240	3247	50
16	30-015-24045	1177	100	2000	100	5557	265
17	30-015-20728	415	100	2036	156	5296	100
18	30-015-23021	400	125	1800	125	4850	200
19	30-025-27263	300	300	1140	100	5000	147
20	30-025-26958	690	100	1290	100	4500	100
21	30-025-28471	1430	125	3020	80	4300	104
22	30-025-26692	510	100	1410	130	4960	158
23	30-025-27805	[1]	[1]	1500	100	4600	100

[1]Top plug is actually at a depth such that it has been classified as the intermediate plug.

Type IV Plugs (BLM)							
	API #	Base of Top Plug	Length	Base of Intermediate Plug	Length	Base of Bottom Plug	Length
1	30-015-26771	600	100	2650 960	100 100	5940	38
2	30-025-28644	1117	640	2800 1835	100 125	5237	315
3	30-015-21782	600	200	2845 1500	232 162	3400	200
4	30-015-25558	976	38	1587	127	2900	229
5	30-015-22502	419	151	2170 1460	100 100	2400	100

Type IV Plugs (State)							
	API #	Base of Top Plug	Length	Base of Intermediate Plug	Length	Base of Bottom Plug	Length
1	30-015-26069	470	470	3888 3334 2650 1400	246 248 790 217	4445	247
2	30-015-27980	550	150	2700 2450	100 100	3600	100
3	30-015-28268	588	133	1239 2696	100 100	4601	79
4	30-015-25772	418	172	2500 1935 768	50 111 120	2500	50
5	30-015-26266	614	100	2785 1500 825	99 122 100	2785	99
6	30-015-21008	450	450	1990 1400	217 217	2780	237
7	30-015-23833	570	555	2385	256	3024	256
8	30-015-23489	500	190	2450	1300	6165	200

9	30-015-22134	422	81	2050	149	2718	115
10	30-015-23067	458	100	2095 2480	100 100	5000	400
11	30-015-23300	481	100	1220 2509	200 100	6055	50
12	30-015-26899	525	125	1350 2850	50 100	5375	125
13	30-015-24152	450	100	1857	267	3000	570
14	30-015-26470	480	100	2125	299	2325	355

Type V Plugs (BLM)							
	API #	Base of Top Plug	Length	Base of intermediate plug	Length	Base of Bottom Plug	Length
1	30-025-31177	50	50	4000	100	4797	100
2	30-025-31926	50	50	4756 5744	278 100	8740	220
3	30-025-08220	175	175	4430	362	6030	300

Type V Plugs (State)							
API #		Base of Top Plug	Length	Base of intermediate plug	Length	Base of Bottom Plug	Length
0	None found						

Type VI Plugs (BLM)							
API #		Base of Top Plug	Length	Base of Intermediate Plug	Length	Base of Very Long Plug (typically through salt section)	Length
1	30-015-20878	761	170	None	None	3883	2131

Type VI Plugs (State)							
	API #	**Base of Top Plug**	**Length**	**Base of Intermediate Plug**	**Length**	**Base of Very Long Plug** (typically through salt section)	**Length**
1	30-015-26130	449	369	2200 1150	368 382	3250	1035
2	30-015-27701	3000	3000	3000	3000	3000	3000
3	30-025-24238	4736	4736	4736	4736	4736	4736

SUMMARY

Type	BLM	State	Total	Frequency
I	50	11	61	32.5%
II	15	22	37	20.0%
III	41	23	64	34.0%
IV	5	14	19	10.0%
V	3	0	3	1.5%
VI	1	3	4	2.0%
Total	115	73	**188**	100.0%

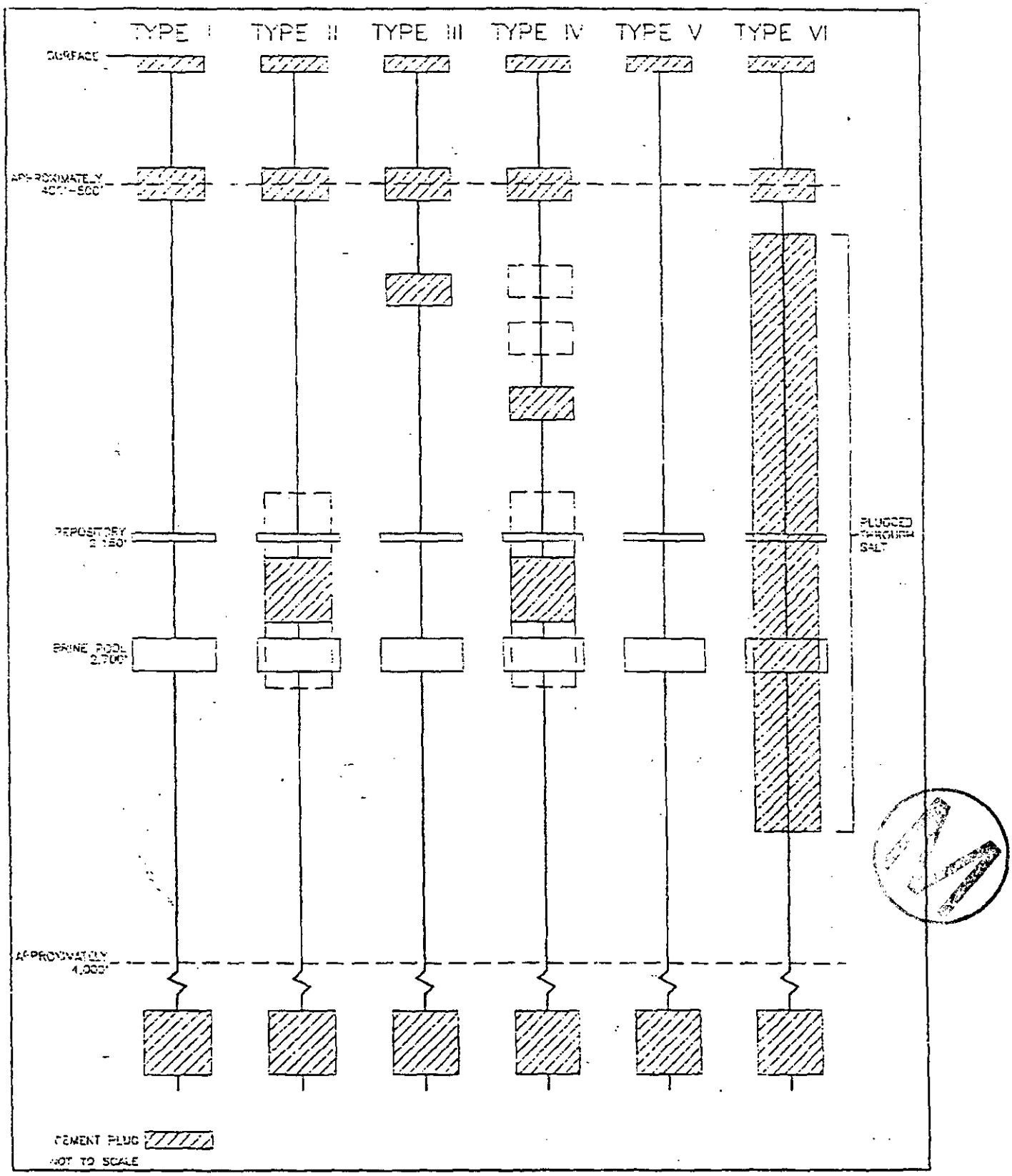

Figure 1

Typical Borehole Plug Configurations in the Delaware Basin

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

MASS Attachment 16-2

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WPO 39090

INFORMATION ONLY

Conceptual Model Description for BRAGFLO Direct Brine Release Calculations to Support the Compliance Certification Application

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July 9, 1996

Model Purpose

This model has been developed to support the Direct Brine Release portion of the 1996 performance assessment (PA) of the WIPP repository site. The calculations will be performed to contribute to the complimentary cumulative distribution function (CCDF), the probability distribution of exceeding normalized cumulative radionuclide releases to the accessible environment, that will become part of the Compliance Certification Application (CCA). Direct brine releases may occur when a future driller penetrates the WIPP and contaminated brine is unknowingly brought to surface during the drilling process. These releases are not specifically accounted for in the cuttings, cavings and spallings calculations (CUTTINGS_S), as that code only models the solids removed during the drilling process. Certain conditions must exist within the waste in order for contaminated brine to flow directly to the surface during a drilling intrusion:

- Pressure in the waste must be greater than that exerted by the column of drilling mud that penetrates a waste panel. Drillers in the Delaware Basin currently use a salt saturated mud while drilling through the Salado, with a specific gravity of 1.23. This corresponds to ~8.0E+06 Pascals at the repository horizon, which is the minimum pressure needed to overcome a static column of drilling mud.

- There must be mobile brine present in the waste panels to flow to the surface. Corrosion and biodegradation processes consume brine and release gasses as by-products, and it is possible for the brine volume in the waste pores to drop below its "mobile" (residual) saturation. It is likely for gas-only flows to occur up a drill hole, but these flows are only of concern for the solids releases (Spalls).

Model Description

The model is set up as a two-dimensional finite difference mesh of 39 X 39 grid blocks to be solved using the BRAGFLO code (hereafter called DBR_BRAGFLO - see Figure 1). The mesh compares to the regional 10,000 year model (hereafter called BRAGFLO) in the following ways:

- The DBR_BRAGFLO mesh is oriented in the areal plane, with the z-dimension (height) one element thick. BRAGFLO is oriented as a cross-section, with multiple layers in height and the thickness (y-dimension) one element thick.
- DBR_BRAGFLO models flow only in the waste area. The BRAGFLO model includes the surrounding geology as well as the entire WIPP excavation (including operations, experimental, and shaft regions).
- Local scale heterogeneities are included in the DBR_BRAGFLO model, including the salt pillars, rooms, panel seals, and passageways which contain waste. These are not fully represented in the BRAGFLO mesh.
- The DBR_BRAGFLO mesh uses constant thickness, while BRAGFLO radially flares the element thickness to account for 3-dimensional volumes in 2-D space.
- The disturbed rock zone (DRZ) is included in both models, but exists above and below the excavated regions in the BRAGFLO model, whereas the DRZ surrounds the waste rooms on the sides for the DBR_BRAGFLO model.
- Both models include one degree formation dip through the excavated regions.

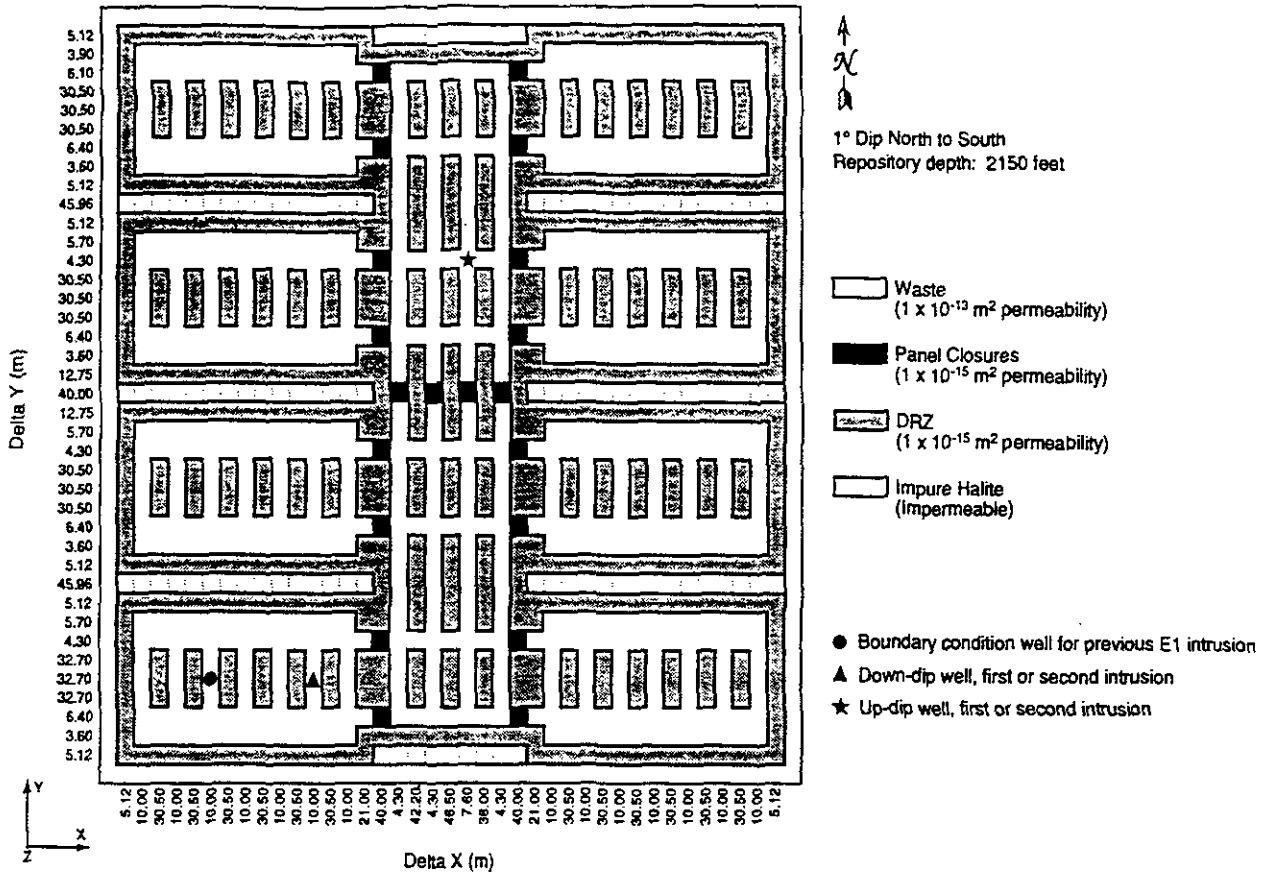

Note: Model cells are not to scale. The actual dimensions of the grid blocks, are indicated along the edge of the diagram.

TRI-6342-5432-1

Figure 1: Direct Brine Release (DBR_BRAGFLO) Mesh

Principal Parameters Defined By Model

The pressure and saturation time-histories for each realization (3 replicates of 5 scenarios of 100 consequences) from the 10,000 year BRAGFLO calculations will provide the basic input needed for the direct brine releases. The pressure and saturation at specified times for each consequence will provide the initial conditions needed for the DBR_BRAGFLO model. These values are also used to calculate the boundary conditions which represent flow up the intrusion borehole.

The input parameters that will be used for the direct brine release calculations will come from four sources: the 10,000 year BRAGFLO output files, the CUTTINGS_S code, the WIPP database and a correlation to simulate flow up the borehole (Figure 2).

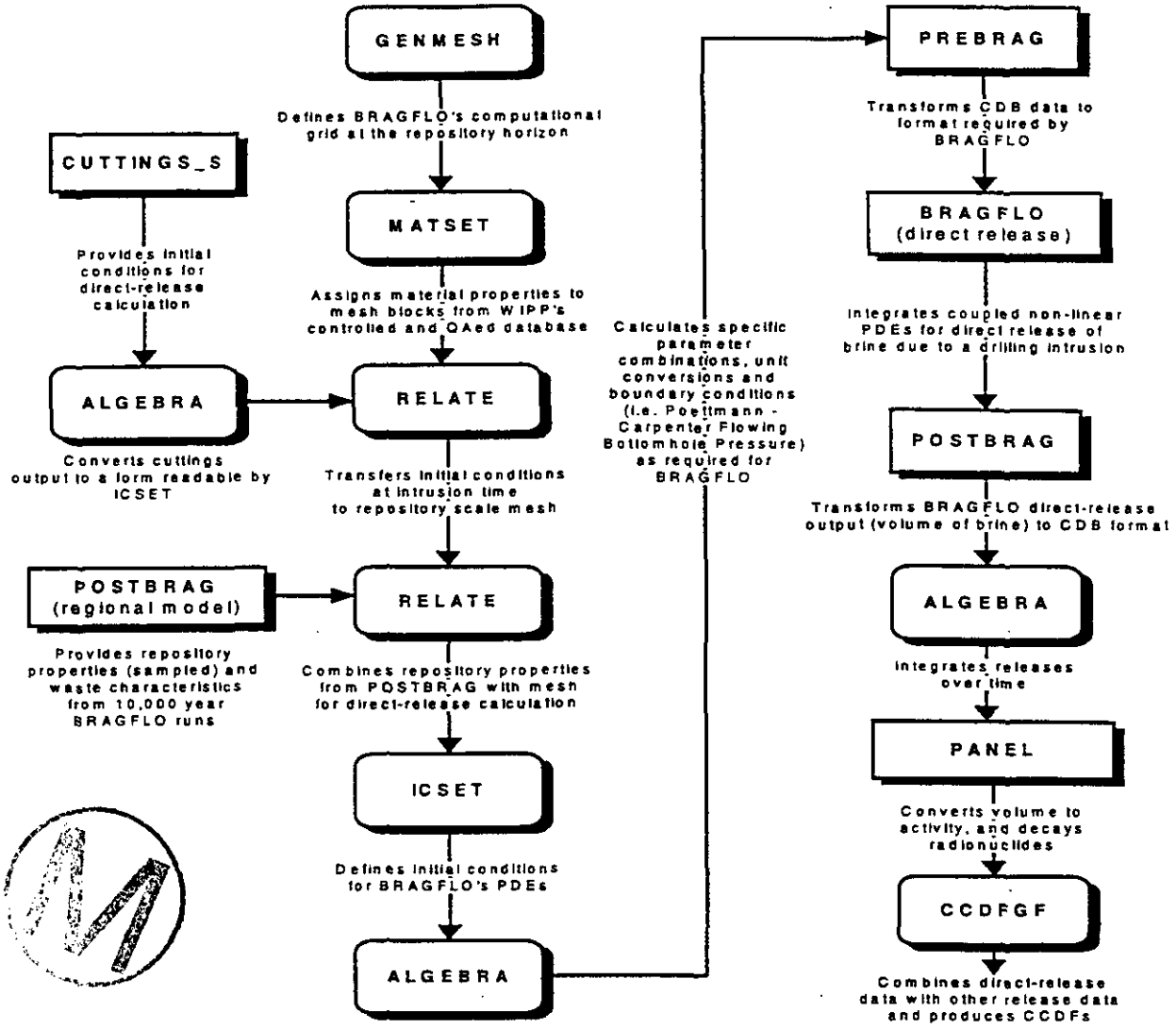

Figure 2: Calculational Flowchart for DBR_BRAGFLO

- The initial brine saturation and pressure, porosity, and crushed panel height within the waste used in the direct release model are determined from the 10,000 year BRAGFLO results, and therefore vary with time. These parameters are calculated by time interpolation in the CUTTINGS_S code, and RELATEd to the direct release model. An intermediate ALGEBRACDB step is required to convert time-history variables to material properties.
- Unsampled material properties which remain constant are read directly from the parameters database (through MATSET).

- Sampled material properties are RELATEd from the 10,000 year BRAGFLO output files.
- The pressure (boundary condition) that drives the wellbore model has been developed from a commonly used petroleum industry multi-phase vertical pipe flow correlation (Poettmann-Carpenter), which is tied to the well deliverability expression used by DBR_BRAGFLO.

The two RELATE steps accomplish the same function as the LHS sequence for the 10,000 year BRAGFLO calculations. DBR_BRAGFLO does not require a separate sampling, as all needed variables are extracted from the previously run BRAGFLO and CUTTINGS_S files. Hence, important flow parameters for the waste region (such as residual brine and gas saturation) are the same for each realization in the BRAGFLO and DBR_BRAGFLO models. The DRZ, panel seal, and halite relative permeability and capillary pressure parameters are set equal to those used in the waste region. This was done to ease the DBR_BRAGFLO computation. The intrinsic permeability of the DRZ and panel seals are the median values read from the database.

The element thickness of the DBR_BRAGFLO mesh is adjusted to equal the crushed room height, which is passed on from the CUTTINGS_S code. This arbitrarily sets all elements in the mesh to the same height, therefore, the porosity in the non-waste regions (DRZ, halite, and seals) are increased proportionally to maintain equal pore volume with the corresponding 10,000 year BRAGFLO regions.

Integration with other PA codes

The DBR_BRAGFLO mesh is coupled to BRAGFLO by subdividing the waste area in BRAGFLO into four regions. Region one represents the farthest up-dip repository grid blocks in BRAGFLO which contain waste. This corresponds roughly to the up-dip quarter of the DBR_BRAGFLO mesh. Region four represents the farthest down-dip section of waste in BRAGFLO, which is the "panel" region in the 1996 CCA mesh. This corresponds to the farthest down-dip quarter of the DBR_BRAGFLO mesh. Similar subdivisions are made for the middle two sections of each grid (Figure 3). Pore-volume averaged brine saturation and pressure within each region of the BRAGFLO model are used to initialize similar regions in the DBR_BRAGFLO mesh at each intrusion time.

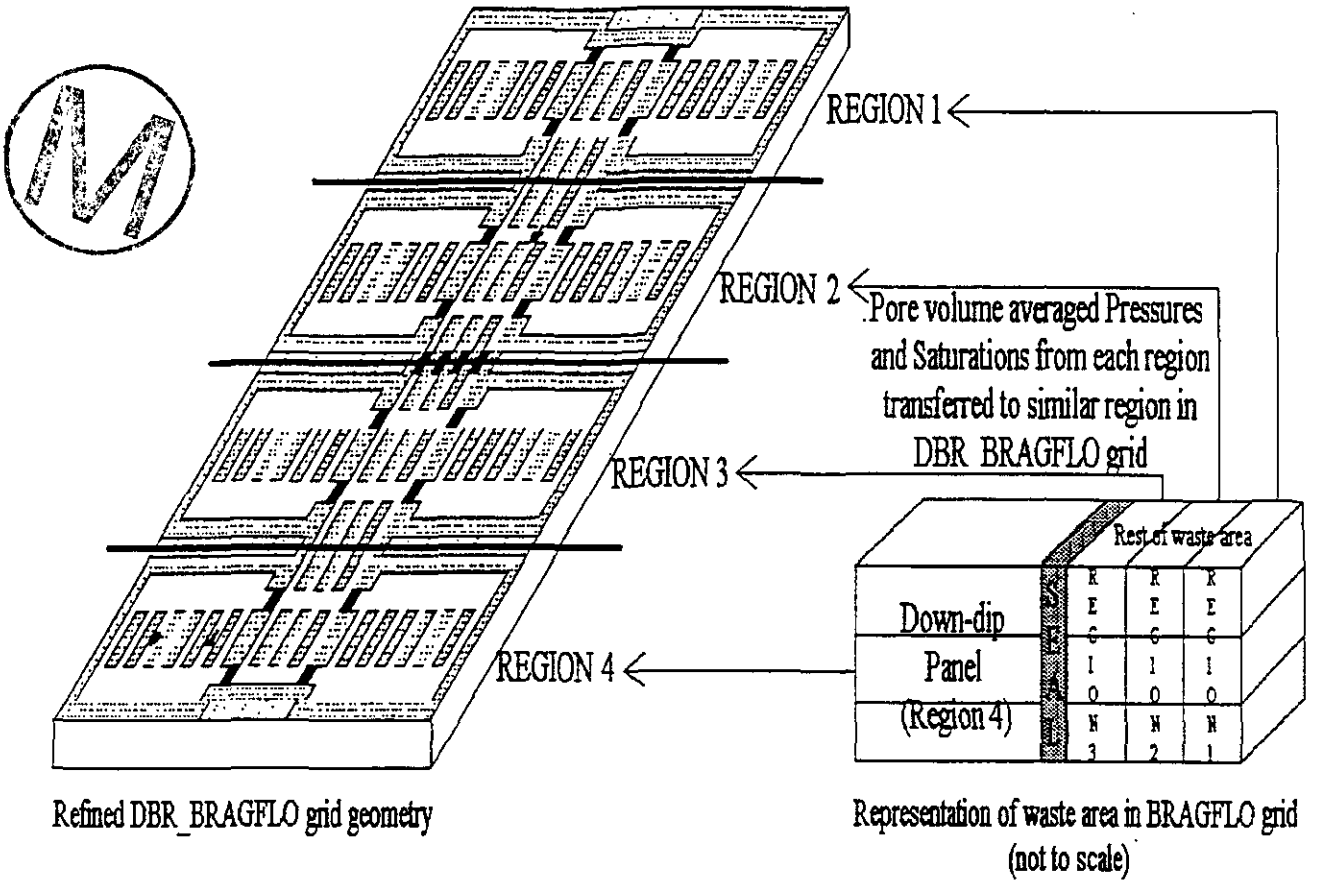

Figure 3: Representation of coupling between the two grids to obtain initial conditions for the DBR_BRAGFLO mesh at each intrusion time

The DBR_BRAGFLO model uses the same intrusion times as is used by the CUTTINGS_S code to provide brine releases for the CCDF generation. Intrusion times differ for each scenario, and two calculations are performed at each time: one for an up dip intrusion, and one for a down dip intrusion. For all subsequent intrusions following an initial intrusion into the Castile brine pocket, the boundary condition well is "turned on" to simulate an abandoned borehole connection to the brine pocket (a more detailed explanation can be found in Appendix A). Since thousands of probabilistic time histories are possible for each replicate-scenario-vector, the actual releases are determined by time interpolating between the given times at which the DBR_BRAGFLO calculations were performed. A more detailed description of how this is accomplished will be provided in the CCDFG code description. A summary of the direct release calculational scheme follows:

- **Scenario 1 (From Undisturbed BRAGFLO runs):** Up dip and down dip first intrusions are modeled at 100, 350, 1000, 3000, 5000, and 10000 years (12 calculations X 100 vectors = 1200 calculations).

- **Scenario 2 (From 350 year first intrusion to brine pocket BRAGFLO runs - E1):** Up dip and down dip second intrusions are modeled at 550, 750, 2000, 4000, and 10000 years (10 calculations X 100 vectors = 1000 calculations).
- **Scenario 3 (From 1000 year first intrusion to brine pocket BRAGFLO runs - E1):** Up dip and down dip second intrusions are modeled at 1200, 1400, 3000, 5000, and 10000 years (10 calculations X 100 vectors = 1000 calculations).
- **Scenario 4 (From 350 year first intrusion, no brine pocket BRAGFLO runs - E2):** Up dip and down dip second intrusions are modeled at 550, 750, 2000, 4000, and 10000 years (10 calculations X 100 vectors = 1000 calculations).
- **Scenario 5 (From 1000 year first intrusion, no brine pocket BRAGFLO runs - E2):** Up dip and down dip second intrusions are modeled at 1200, 1400, 3000, 5000, and 10000 years (10 calculations X 100 vectors = 1000 calculations).
- A total of 5,200 calculations will be performed per replicate, or 15,600 calculations for the 3 replicates to be submitted in the CCA.

The DBR_BRAGFLO is also coupled to the CUTTINGS_S code to account for the possibility of enhanced near wellbore flow due to solids removal. This is accomplished through the use of the skin factor parameter (S) in the DBR_BRAGFLO well deliverability equation, and is included in the determination of flowing bottom-hole pressure.

Flowing bottom-hole pressure using Poettmann-Carpenter wellbore model

Flow up the intrusion borehole during drilling is governed by complex physics dependent on frictional effects and two-phase fluid properties. This phenomena is much studied in petroleum engineering, and many correlations have been developed to predict flow rates and pressures in vertical two-phase pipe flow. The Poettmann-Carpenter approach was chosen to calculate the necessary flowing bottom hole pressures (FBHP) to be used in the DBR_BRAGFLO model. The wellbore is descritized into finite delta lengths of 25 feet, each being described by the diameters of the open hole, drill pipe, drill collars, and casing(s). Note that for the DBR_BRAGFLO model, brine is assumed to flow to surface through the annular area only (between the drill string and open hole). Figure 4 shows the wellbore configuration used for the CCA calculations.

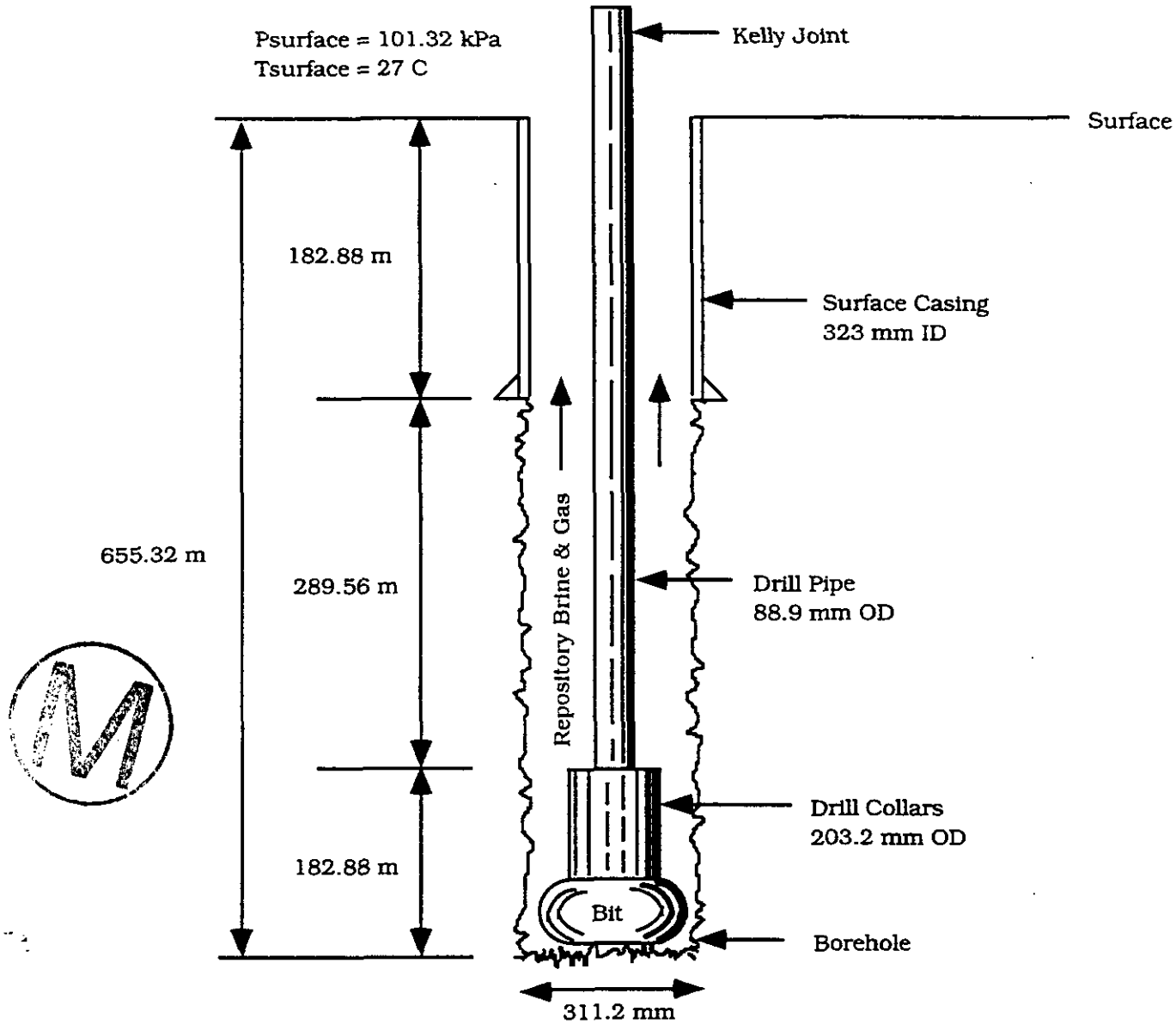

Figure 4: Borehole representation used for Poettmann-Carpenter correlation

The Poettmann-Carpenter model (P-C mod) was chosen because it is easy to implement, accounts for multi-phase frictional effects based on empirical (field) data from flowing wells, and is one of the few correlations that includes annular flow data in its development. To calculate the flowing bottom hole pressures to be used in the CCA calculations, the flow rates used in P-C mod have to match those predicted by the DBR_BRAGFLO well model. Since the fluid saturations and panel pressures are known for each realization at each intrusion time, it is possible to calculate the FBHP iteratively. A starting FBHP is assumed, and the gas and brine flow rates are calculated from the DBR_BRAGFLO well deliverability equation. These flow rates are then used in the P-C mod to determine finite pressure drops up the wellbore to the surface. If the resulting surface flowing pressure does not equal atmospheric, a new FBHP is

assumed and the process repeated until the surface pressure is calculated to within 5% tolerance of atmospheric. A detailed description of the equations used can be found in Appendix B. Figure 5 shows a flowchart of this process.

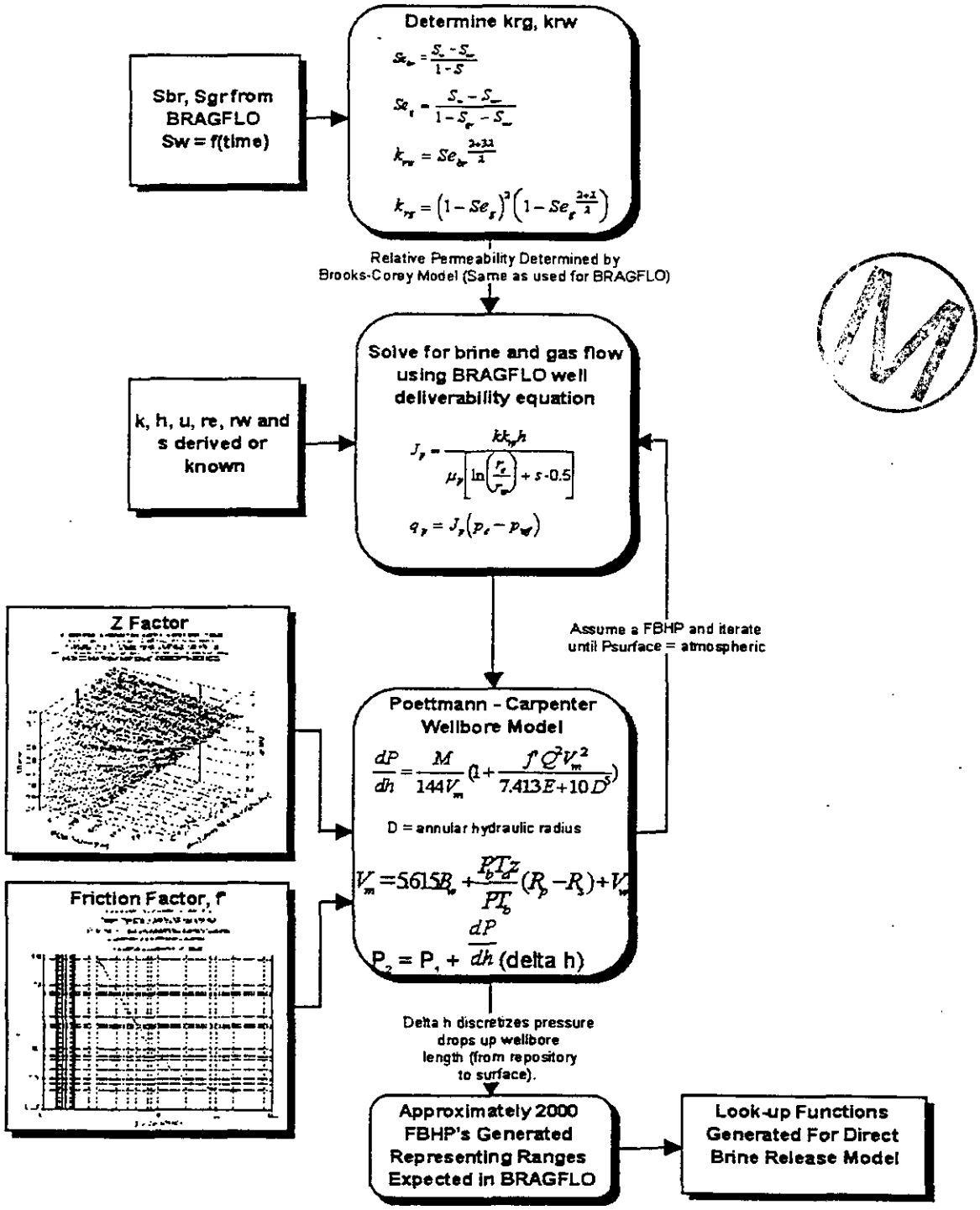

Figure 5: Flowchart of iterative process used to estimate flowing bottom hole pressure in the CCA calculations

An Excel spreadsheet was developed to perform the iterative procedure and create a table of FBHPs based on randomly generated crushed panel heights, initial panel pressures, and residual fluid saturations. These variables are expected to vary with time, or are sampled in the CCA calculations. The resulting (2,000 plus) FBHPs were curve-fitted to three look-up functions, which were used to predict the starting FBHP in the intruded grid block in each DBR_BRAGFLO calculation (the second ALGEBRA step in Figure 2). Skin factor (based on spall removed) was kept at zero and mole fraction Hydrogen was kept at 100% for development of the lookup functions, even though these may vary in the BRAGFLO runs. Ideally, the FBHP should be updated at each time step in the DBR_BRAGFLO calculation, but the current version of BRAGFLO is unable to achieve this. Therefore, the FBHP is held constant for the duration of the direct release flow time period. This is a conservative modeling constraint, since the FBHP should realistically increase with time (thereby reducing flow) as the panel pressure decreases.

Uncertainty in Conceptual Models and a Qualitative Discussion of the Relative Significance of Parameters

The DBR_BRAGFLO model uncertainties are captured in the 10,000 year BRAGFLO calculations from which the initial and boundary conditions are derived. The model parameters that have the most influence on the brine direct releases are repository pressures and brine saturations at time of intrusion. High brine saturations are influenced by many factors, including Salado and marker bed permeability and gas generation rates (for undisturbed calculations). For intrusion scenarios, Castile brine pocket pressures and volumes (E1) and abandoned borehole permeabilities (E1 and E2) influence conditions for the 2nd and subsequent intrusions. Additionally, dip in the repository (hence location of intrusions), two-phase flow parameters (residual brine and gas saturation, etc.), and time of intrusion have lesser impacts on brine releases.

Duration of flow for DBR_BRAGFLO model

The DBR_BRAGFLO model is run for 50 days for each realization that meets the blowout criteria (adequate pressure and saturation). The cumulative brine releases to contribute to the CCDF construction are determined in a post processing step (the last ALGEBRA run in Figure 2) by the following criteria:

- Every realization will accumulate brine for a minimum of three days. This is based on the estimated length of time it will take to drill through the Castile and cement the intermediate casing (see reference No. 10 for a synopsis of current drilling practices in the WIPP area). If there is little or no gas flow associated with the brine flow, current practice is to allow the brine to "seep" into the drilling mud and flow to the mud pits (the "seepage" may even go undetected), until the salt section is cased.
- If there is a significant amount of gas flow associated with the brine releases, it is possible that the driller will lose control of the well. In such cases the brine releases will accumulate until the gas rate drops below a predetermined gas "cut-off" rate. This rate is arbitrarily set by the author at 100 thousand standard cubic feet per day (MSCF/D), and represents a gas flow rate (in oil field units) at which control of the well could be easily be regained.

- Should the gas flow rate continue above the cut-off rate, the brine releases will accumulate for a maximum of eleven days. This is based on the amount of time it took to control the South Culebra Bluff Unit #1 well, which blew out in January, 1978 (see reference No. 3). Eleven days was the response time needed to gather the equipment and personnel necessary to regain control of that well

Model output and integration with CCA results

The output from the repository-scale direct release model is volume of brine (m^3) released to the surface. The number of intrusions into the waste area, location (updip or downdip), and scenario (E1 or E2) are determined stochastically in the CCDFG code for each BRAGFLO realization. The actual brine released directly for each time history is then calculated by linear time interpolation from the DBR_BRAGFLO results. This is combined with output from PANEL (expressed in EPA units) to determine the releases associated with each realization at each intrusion time.

References: Direct Brine Release Model

1. [Amyx, Bass and Whiting, 1960]: Amyx, J. W., Bass, D. M. Jr., and Whiting, R. L., Petroleum Reservoir Engineering, Physical Properties, McGraw-Hill Book Company, ISBN 07-001600-3, 1960, (derived from equation 2-33) pp. 78.

2. [Brill, Beggs, 1986]: Brill, James, P. and Beggs, H. Dale, Two-Phase Flow in Pipes, Fifth Edition, first printing, published by University of Tulsa, 1986, pp. 3-2 and 3-73, 3-74.

3. [Boak, et. al., 1996]: Boak, D.M., Dotson, L., Aguilar, R., Powers, D.W., and Newman, G.: Wellbore Enlargement Investigation: Potential Analogs to the Waste Isolation Pilot Plant During Inadvertent Intrusion of the Repository, In progress, SAND(TBD), Powers memo to Les Hill, pp. A-5

4. [Cornish, 1976]: Cornish, R. E.: "The Vertical Multiphase Flow of Oil and Gas at High Rates", Journal of Petroleum Technology, July, 1976, pp. 825-831.

5. CUTTINGS_S Version 5.02, Berglund, J. W., Lenke, L. R., and Cole, R. A., New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, work in progress.

6. [Ely and Huber, 1992]: Ely, J. F., and Huber, M. L., NIST Thermophysical Properties of Hydrocarbon Mixtures Database (SUPERTRAPP) Software User's Guide, Version 1.0, U. S. Department of Commerce National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg, MD, July 1992.

7. [Friend and Huber, 1994]: Friend, D. G. and Huber, M. L., "Thermophysical Property Standard Reference Data from NIST", International Journal of Thermophysics, Vol. 15, No. 6, November, 1994, pp. 1279 - 1288.

8. [Katz, et. al., 1959]: Katz, D. L., Cornell, D., Kobayashi, R., Poettmann, F. H., Vary, J. A., Elenbaas, J. R., and Weinaug, C. F., Handbook of Natural Gas Engineering, McGraw-Hill Book Company, Inc., 1959, (figure 7.22) p. 326.

9. [Lee, 1982]: Lee, John, Well Testing, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. ISBN 0-89520-317-0, 1982, (equation 1.10), p. 5, (equation 1.19) p. 7.

10. [N.M. Bureau of Mines, 1995]: New Mexico Bureau of Mines & Mineral Resources, Final Report, Evaluation of Mineral Resources at the Waste Isolation Pilot Plant, Volume 3, Chapters IX-XII, Westinghouse Electric Corporation, Waste Isolation Division, Contract No. PO-75-WJJ644145Z, submitted March, 1995, (WPO package No. 37866), Chapters IX and X.

11. [Poettmann and Carpenter, 1952]: Poettmann, F. H., and Carpenter, P. G., "Multiphase Flow of Gas, Oil, and Water through Vertical Flow Strings with Application to the Design of Gas-lift Installations", Drilling and Production Practices, API, 1952, pp. 257-317.

12. [Sanchez, 1972]: Sanchez, M. J.: "Comparison of Correlations for Predicting Pressure Losses in Vertical Multiphase Annular Flow", M. S. Thesis, The University of Tulsa, 1972.

13. [Santos, 1989]: Santos, Otto Luiz Alcantara, "A Dynamic Model of Diverter Operations for Handling Shallow Gas Hazards in Oil and Gas Exploratory Drilling", pH.D. dissertation, LSU, 1989, 284 pp.

14. SAND92-0700/3 UC-721, Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December, 1992, Volume 3: Model Parameters, Sandia WIPP Project, 1992, Albuquerque, New Mexico: Sandia National Laboratories, (chapter 3, figure 3.1-2), p. 3-3.

15. [Welchon, Bertuzzi and Poettmann, 1962]: Welchon, J. K., Bertuzzi, A. F., and Poettmann, F. H. "Wellbore Hydraulics", Chapter 31 in Petroleum Production Handbook, Volume 2, edited by Frick, T. C., and Taylor, R. W., Society of Petroleum Engineers of AIME, 1962, pp. 31-1 to 31-36, (figure 31-6 for annular flow) p. 31-23.

16. WIPP PA User's Manual for BRAGFLO, Version 3.62ZO, WPO 24179, WIPP Central Files, October 3, 1995, (section 4.9) pp. 45-51, (section 7.2.4) pp. 92-96.

APPENDIX A

A1: E1-E2 SCENARIOS

The following definitions for the E1-E2 scenarios are paraphrased from the SPM-2 Decision Aiding Tool, Prepared for the DOE's Waste Isolation Pilot Plant (WIPP) by Sandia National Laboratories, March 31, 1995, Report Volume 1, Glossary (Section 9):

E1 Intrusion Scenario - A characterization of an alternative future state of the WIPP disposal system that models an inadvertent exploratory borehole intersecting the repository and a hypothetical pressurized brine reservoir (pocket) in the underlying Castile formation.

E2 Intrusion Scenario - A characterization of an alternative future state of the WIPP disposal system that models an inadvertent exploratory borehole intersecting the repository but missing the hypothetical brine reservoir.

E1E2 Intrusion Scenario - A characterization of an alternative future state of the WIPP disposal system that models two or more inadvertent exploratory boreholes intersecting the repository, at least one of which hits an underlying brine reservoir. With robust panel seals the boreholes must intersect the same panel, one of which is a previously abandoned well through the brine reservoir. With degraded or failed seals, communication to the abandoned brine pocket well could exist across multiple panels. For the 1996 CCA, panel seals are given a 10^{-15} m^2 permeability, which is robust enough to inhibit short-term (days) brine flow between panels, but can allow significant gas flow through the waste area.

The 1996 CCA calculations treat future abandoned intrusion boreholes the following way:

- The first 200 years after abandonment are characterized by two cement plugs ($5X10^{-17}$ m^2 permeability) across the top of the Salado and bottom of the Castile formations. Between the two plugs, the borehole is treated as corroded, brine-filled pipe open to flow between the brine pocket and WIPP panel.
- From 200 to 1,200 years after abandonment, the cement plugs are assumed to degrade and the entire borehole is filled with debris, with permeability sampled from 10^{-11} to 10^{-14} m^2.
- From 1,200 to 10,000 years after abandonment, the lower section of borehole in the Salado between the WIPP horizon and Castile is assumed to be affected by salt creep, and its permeability is reduced one order of magnitude.

The amount of brine that can flow from the brine pocket, through an abandoned borehole, into a WIPP panel (E1 scenario), and out a nearby (blowout) well in the same panel (E2 scenario) is a function of the following, assuming steady-state flow for the duration of the blowout:

- Castile brine reservoir properties:
    1. Height (h_{BP}) is assumed to be 12.34 meters for all calculations, which is equivalent to that used in the BRAGFLO model
    2. Areal extent expressed as external drainage radius ($r_{e\ BP}$), set equal to 114 meters for all calculations, which corresponds to the highest brine pocket size possible that could fit underneath a single waste panel.
    3. Brine pocket pressure (P_{BP} - Pascals), which is taken from BRAGFLO at the blowout well intrusion time.
    4. The brine pocket permeability (K_{BP} - m^2), which is a sampled parameter obtained from BRAGFLO.
    5. Flowing pressure at the wellbore in the brine pocket ($P_{wf\ BP}$ - Pascals).
- Waste panel properties:
    6. Flowing pressure at the wellbore in the abandoned borehole grid block for boundary condition treatment ($P_{wf\ BC}$ - Pascals).

7. Equivalent radius representing area of abandoned borehole grid block ($r_{e\,BC}$=[(delx*dely)/π]$^{0.5}$, meters)
8. Flowing pressure at the wellbore for the intrusion well ($P_{wf\,BO}$ - Pascals), which is calculated separately using the Poettmann-Carpenter correlation.
9. Wellbore radius (r_w - meters, from bit size parameter off the database) is assumed to be equal for the abandoned wellbore and intrusion borehole.
10. Flow up the abandoned borehole from the brine pocket (Q_{BP} - m^3/s) is assumed to be equal to flow "injection" into the panel (Q_{BC} - m^3/s), for steady state conditions.

E1-E2 Illustrations/Terminology

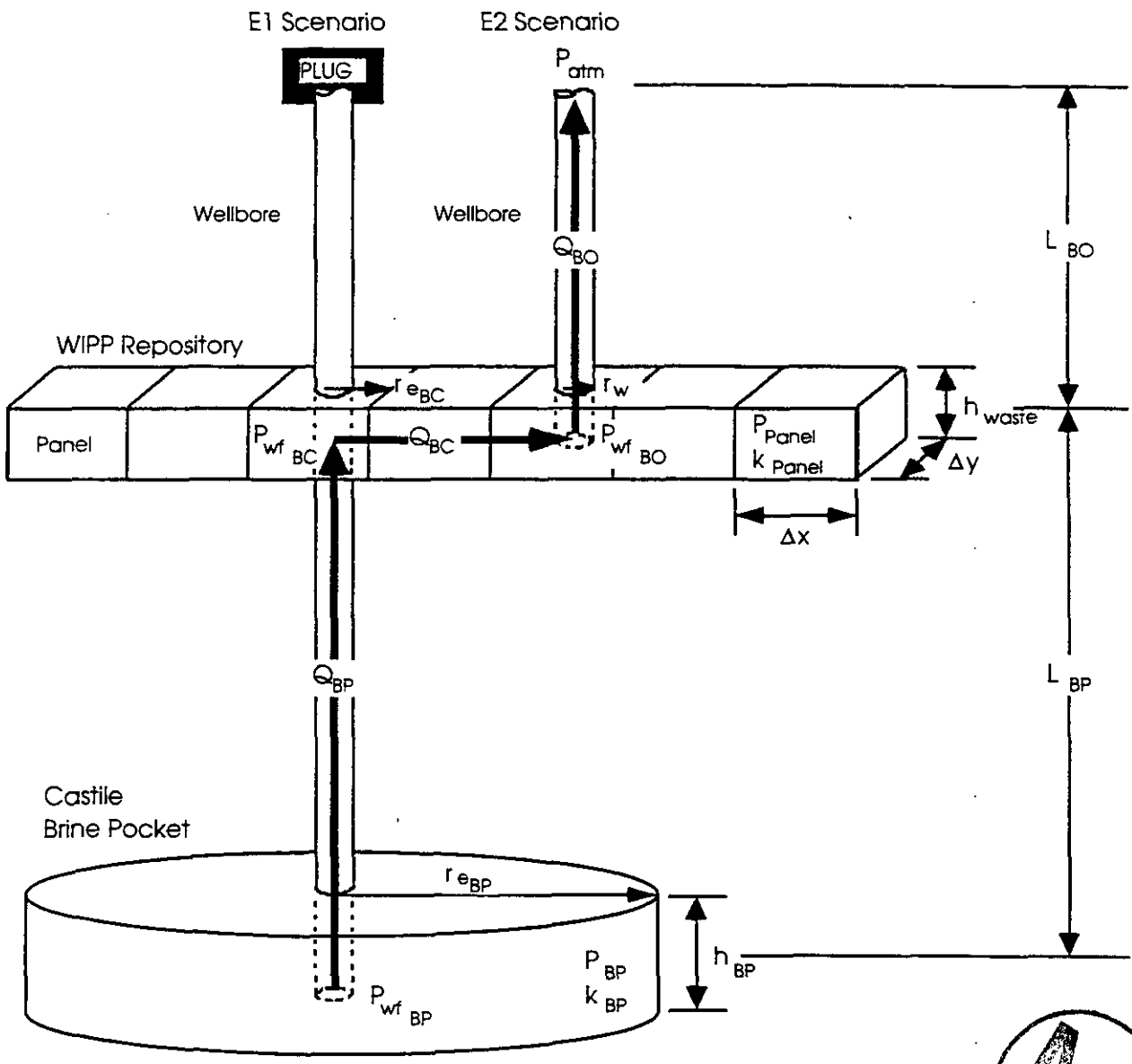

Figure A1: Representation of assumed flow path for E1E2 scenario

A2: THEORETICAL CONSIDERATIONS

A. Frictional Effects

Consider the flow rate necessary to achieve laminar flow from the brine pocket to the repository as depicted by the following:

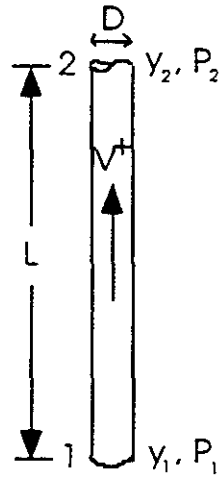

Assuming the flow is positive between location 1 (brine pocket) to 2 (repository panel), the following equation describes linear flow according to Poiselle's Law:

$$\left(\frac{P_1}{\gamma}+y_1\right)-\left(\frac{P_2}{\gamma}+y_2\right)=\frac{32\mu VL_{BP}}{\gamma D^2}$$ [Equation A1]

$$Q=VA, V=\frac{Q}{A}=\frac{4Q}{\pi D^2}$$ [Equation A2]

$$\left(\frac{P_1}{\gamma}+y_1\right)-\left(\frac{P_2}{\gamma}+y_2\right)=\frac{128\mu QL_{BP}}{\gamma\pi D^4}$$

or by separating and combining terms:

$$(P_1-P_2)+\gamma(y_1-y_2)=\frac{128\mu QL_{BP}}{\pi D^4}$$ [Equation A3]

Using the following WIPP properties:

$$\gamma=9.8\frac{m}{\sec^2}*1230\frac{kg}{m^3}=12{,}054\frac{kg}{\sec^2 m^2}=12{,}054\frac{Pascal}{m}$$

$$L_{BP}=y_1-y_2=-247m$$

$$\mu=1.8E-03\,Pascal-\sec$$

For 9 5/8 inch OD casing (8.921 inch ID):

$$D = 0.2266m$$

Substituting these values into Equation A3 results in the following relationship for P_2 as a function of P_1 and Q as follows:

$$P_2 = P_1 - 2.9773E06 - 6.8705E03Q \qquad \text{[Equation A4]}$$

where:
P_1 = Pressure at the brine pocket end of the wellbore (Pa)
P_2 = Pressure at the repository end of the wellbore (Pa)
Q = Poiselle laminar flow rate from the brine pocket to the repository (m^3/sec)

Since Q must be ≥ 100 m^3/sec for frictional forces to have an effect on flow, frictional forces will be neglected in the remainder of the equations developed (6.8705E03*Q = 0).

B. Open Borehole Connection Between Brine Pocket and Repository Panel

For open borehole flow where Q_{BC} is negative for injection:

$$P_{wf_{BC}} = P_{wf_{BO}} - Q_{BC}\left[\frac{\mu \ln\left(\frac{r_{e_{BC}}}{r_w}\right) - 0.5}{k_{waste}h_{waste}(1)}\right] \qquad \text{[Equation A5]}$$

$$P_{wf_{BP}} = P_{wf_{BC}} + 2.9773E06 - 6870Q_{BC} \qquad \text{[Equation A6]}$$

$$Q_{BP} = -Q_{BC} \qquad \text{[Equation A7]}$$

$$Q_{BP} = \left[\frac{k_{BP}h_{BP}(1)}{\mu \ln\left(\frac{r_{e_{BP}}}{r_w}\right) - 0.5}\right]\left(P_{BP} - P_{wf_{BP}}\right) \qquad \text{[Equation A8]}$$

Substituting Equations A6 and A7 into Equation A8:

$$-Q_{BC} = \left[\frac{k_{BP}h_{BP}}{\mu \ln\left(\frac{r_{e_{BP}}}{r_w}\right) - 0.5}\right]\left(P_{BP} - P_{wf_{BC}} - 2.9773E06\right) \qquad \text{[Equation A9]}$$

Substituting Equation A9 into Equation A5:

$$P_{wfBC} = P_{wfBO} + \left[\frac{k_{BP}h_{BP}\left(P_{BP} - P_{wfBC} - 2.9773E06\right)}{\mu \ln\left(\frac{r_{eBP}}{r_w}\right) - 0.5}\right]\left[\frac{\mu \ln\left(\frac{r_{eBC}}{r_w}\right) - 0.5}{k_{waste}h_{waste}}\right]$$

or by separating and combining terms:

$$P_{wfBC} = P_{wfBO} + \left[\frac{k_{BP}h_{BP}\ln\left(\frac{r_{eBC}}{r_w}\right) - 0.5}{k_{waste}h_{waste}\ln\left(\frac{r_{eBP}}{r_w}\right) - 0.5}\right]\left(P_{BP} - P_{wfBC} - 2.9773E06\right) \qquad \text{[Equation A10]}$$

Now define the following to be a constant:

$$Const1 = \left[\frac{k_{BP}h_{BP}\ln\left(\frac{r_{eBC}}{r_w}\right) - 0.5}{k_{waste}h_{waste}\ln\left(\frac{r_{eBP}}{r_w}\right) - 0.5}\right] \qquad \text{[Equation A11]}$$

Substituting Equation A11 into Equation A10 and rearranging gives:

$$P_{wfBC} = \left[\frac{P_{wfBO} + Const1P_{BP} - Const1(2.9773E06)}{(1 + Const1)}\right] \qquad \text{[Equation A12]}$$

Equation A12 is the defining equation for open borehole flow between the brine pocket and repository panel.

C. Sand-filled Connection Between Brine Pocket and Repository Panel

For the sand-filled connection between the brine pocket and repository the borehole flow rate (for linear flow, neglecting drawdown in the brine pocket) according to Darcy's Law is:

$$Q_{BH} = \left\{\frac{k_{BH}A_{BH}\left[\left(P_{wfBC} - P_{BP}\right) + 2.9773E06\right]}{\mu L}\right\} \qquad \text{[Equation A13]}$$

Rearranging terms and solving for Pwf_{BC} gives:

$$P_{wfBC} = \frac{Q_{BH}\mu L}{k_{BH}A_{BH}} + P_{BP} - 2.9773E06 \qquad \text{[Equation A14]}$$

$Q_{BH} = Q_{BC}$ [Equation A15]

Substituting Equation A15 into Equation A14 and rearranging:

$$Q_{BC} = \left(P_{wfBC} - P_{BP} + 2.9773E06\right)\left(\frac{k_{BH}A_{BH}}{\mu L}\right) \qquad \text{[Equation A16]}$$

Substituting Equation A16 into Equation A5:

$$P_{wfBC} = P_{wfBO} + \left[\frac{k_{BH}A_{BH}\ln\left(\frac{r_{eBC}}{r_w}\right) - 0.5}{Lk_{waste}h_{waste}}\right]\left(P_{BP} - P_{wfBC} - 2.9773E06\right) \qquad \text{[Equation A17]}$$

Now define the following to be a constant:

$$Const2 = \frac{k_{BH}}{h_{waste}}\left[\frac{\pi r_w^{\,2}\ln\left(\frac{r_{eBC}}{r_w}\right) - 0.5}{Lk_{waste}}\right] \qquad \text{[Equation A18]}$$

Substituting Equation A18 into Equation A17 and rearranging gives:

$$P_{wfBC} = \left[\frac{P_{wfBO} + Const2P_{BP} - Const2(2.9773E06)}{(1 + Const2)}\right] \qquad \text{[Equation A19]}$$

Equation A20 is the defining equation for sand-filled borehole flow between the brine pocket and repository panel.

A3: CONCLUSIONS

Equations A12 and A19 are the expressions that are used to determine the boundary condition pressure that represents abandoned E1 wells. This "injection" pressure simulates flow into the panel from the brine pocket, and is a function of brine pocket properties and abandoned borehole permeabilities at blowout well intrusion time.

APPENDIX B

B1. FLOWING BOTTOMHOLE PRESSURE ISSUE AND THEORY

The driving force behind expulsion of brine and gas from the WIPP repository to the surface via a wellbore during an uncontrolled blowout is determined by the static panel pressure and flowing bottomhole pressure at the time of intrusion. The flowing bottomhole pressure, defined as the dynamic pressure at the inlet to the wellbore adjacent to the point of entry into the repository, is less than the static pressure due to elevation, friction and acceleration effects. The ability of the well to produce brine and gas is governed by the drop in panel pressure and the productivity index (assuming steady-state flow) by the following well deliverability equation:

$$q_p = J_p\left(p_e - p_{wf}\right) \qquad \text{[Equation B1]}$$

where:

q_p = well flow rate of the produced phase (brine or gas)
J_p = phase productivity index
p_e = phase pressure at the outer boundary of the well drainage area (panel pressure)
p_{wf} = flowing bottomhole pressure

In a radial drainage area where saturation is uniform over the drainage region (which is valid throughout the assumed blowout period), the productivity index, J_p can be determined from Darcy's law:

$$J_p = \frac{kk_{rp}h}{\mu_p\left[\ln\left(\frac{r_e}{r_w}\right) + s + c\right]} \qquad \text{[Equation B2]}$$

where:

k = absolute permeability (assumed to be constant through time at 1.7E-13 m^2)
k_{rp} = relative permeability to phase (based upon the modified Brooks-Corey KRP = 4 model)
h = crushed panel height (calculated from porosity surface)
μ_p = viscosity of fluid phase (assumed to be constant through time for brine, μ_{brine} = 1.8E-03 Pa-sec, and for gas μ_{gas} = 8.92E-06 Pa-sec)
r_e = external drainage radius (which for rectangular gridblock dimensions, r_e is taken as the equivalent areal radius, i.e. for panel dimensions of 10 m by 32.7 m:

$$r_e = \sqrt{\frac{(10)(32.7)}{\pi}} = 10.2023 \text{ m)}$$

r_w = wellbore radius (assumed to be constant through time at 0.1556 m)
c = -0.50 for pseudosteady-state flow
s = skin factor, incorporating well stimulation caused by spallings release

The CUTTINGS_S model can be coupled through the skin factor according to the petroleum engineering well testing relationship:

$$s = \left(\frac{k}{k_{skin}} - 1\right)\ln\left(\frac{r_{skin}}{r_w}\right) \qquad \text{[Equation B3]}$$

where:

s = skin factor
k = absolute permeability
k_{skin} = permeability of an open channel as a result of CUTTINGS_S releases (assumed to be infinite)
r_w = wellbore radius
r_{skin} = effective radius of the wellbore with CUTTINGS_S volume removed

The effective radius of the wellbore can be determined using the total area removed from the CUTTINGS_S model (AreaTotal) by assuming a radius (r_{skin}) such that:

$$AreaTotal = \pi r_{skin}^2 \qquad \text{[Equation B4]}$$

Rearranging Equation B4 to solve for r_{skin} gives:

$$r_{skin} = \sqrt{\frac{AreaTotal}{\pi}} \qquad \text{[Equation B5]}$$

Substituting Equation B5 into Equation B3 and assigning infinity to k_{skin} gives the desired relationship between skin (s) and total area removed according to the CUTTINGS_S model (AreaTotal):

$$s = -1 \ln\left(\frac{\sqrt{\frac{AreaTotal}{\pi}}}{r_w}\right) \qquad \text{[Equation B6]}$$

The relative permeability to a phase (k_{rp}) using the modified Brooks-Corey model (KRP = 4) shown in Equation B2 is defined using the following expressions for brine (br) and gas (g) respectively:

Calculate an effective saturation (Se) for each phase as follows:

$$Se_{br} = \frac{S_w - S_{wr}}{1 - S_{wr}} \qquad \text{[Equation B7]}$$

$$Se_g = \frac{S_w - S_{wr}}{1 - S_{gr} - S_{wr}} \quad \left(0 \le S_{gr} \le 0.15\right) \qquad \text{[Equation B8]}$$

where:

S_w = brine saturation in panel at time of intrusion
S_{wr} = residual brine saturation (sampled parameter, from 0% to 40%)
S_{gr} = critical gas saturation (sampled parameter, from 0% to 15%)

Calculate the relative permeability for each phase as follows:

$$k_{rw} = Se_{br}^{\frac{2+3\lambda}{\lambda}} \qquad \text{[Equation B9]}$$

$$k_{rg} = \left(1 - Se_g\right)^2\left(1 - Se_g^{\frac{2+\lambda}{\lambda}}\right) \qquad \text{[Equation B10]}$$

where:

k_{rw} = relative permeability to brine

k_{rg} = relative permeability to gas

λ = pore size distribution parameter (assumed constant at 2.89 for the waste region)

Sampled parameters in combination with Equations B6, B9 and B10 when used in Equation B2, yield the productivity index for brine and gas. These values are available with the panel pressure at the time of intrusion. The only variable unknown is the flowing bottomhole pressure which when used in the well deliverability equation (Equation B1) gives the expelled brine and gas flow rates. To determine the flowing bottomhole pressure, an iterative procedure is used based upon a petroleum engineering industry multiphase flow correlation developed by Poettmann and Carpenter (for a discussion of the Poettmann and Carpenter technique, refer to section B3). The method begins by assuming a gas composition comprised of hydrogen and carbon dioxide (CO_2 is assumed to be 0 because of its adsorption in the backfill) and a flowing bottomhole pressure less than the panel pressure. With the productivity index computed from Equation B2, flow rates for brine and gas are computed using Equation B1. Using the Poettmann and Carpenter method which takes into account elevation, friction and acceleration impacts on the flowing pressure gradient, a surface pressure is computed. If the surface pressure is equal to atmospheric pressure (101.32 Pa, for a blowout scenario), the iteration ceases using the last flowing bottomhole pressure used. If the surface pressure is not equal to atmospheric pressure, another flowing bottomhole pressure is assumed and the process of computing the brine and gas flow rates and subsequent surface pressure is repeated until the surface pressure is at atmospheric pressure.

B2. RESULTS

Flowing bottomhole pressures (FBHP) were generated using the method described in Section B1 of this report to represent expected ranges of panel pressures, brine saturation, critical gas saturation, panel permeability, crushed panel height and skin factor due to spall releases. These results were then developed into correlations based upon relationships between FBHP versus panel pressure and log of well productivity index (as shown in Figure B1) and FBHP versus panel pressure and log (krg/krw) (as shown in Figures B2 and B3 for brine dominated and gas dominated flow, respectively). The linear fit equations (shown in Figures B1-B3) are used as a "look-up" function in the BRAGFLO Direct Brine Release model to determine FBHP. Figures B4 and B5 demonstrate how the FBHP changes with log (krg/krw) and brine saturation, respectively.

FIGURE B1

FBHP as a Function of Brine Well Index and Panel Pressure (Krg=0, Brine only)

Rank 36 Eqn 1001 z=(a+bx+cy)/(1+dx+ey)
r^2=0.98189816 DF Adj r^2=0.98109617 FitStdErr=1284.2129 Fstat=1437.4399
a=8002577.4 b=821379.75 c=0.024916096
d=0.10264807 e=3.1235777e-09

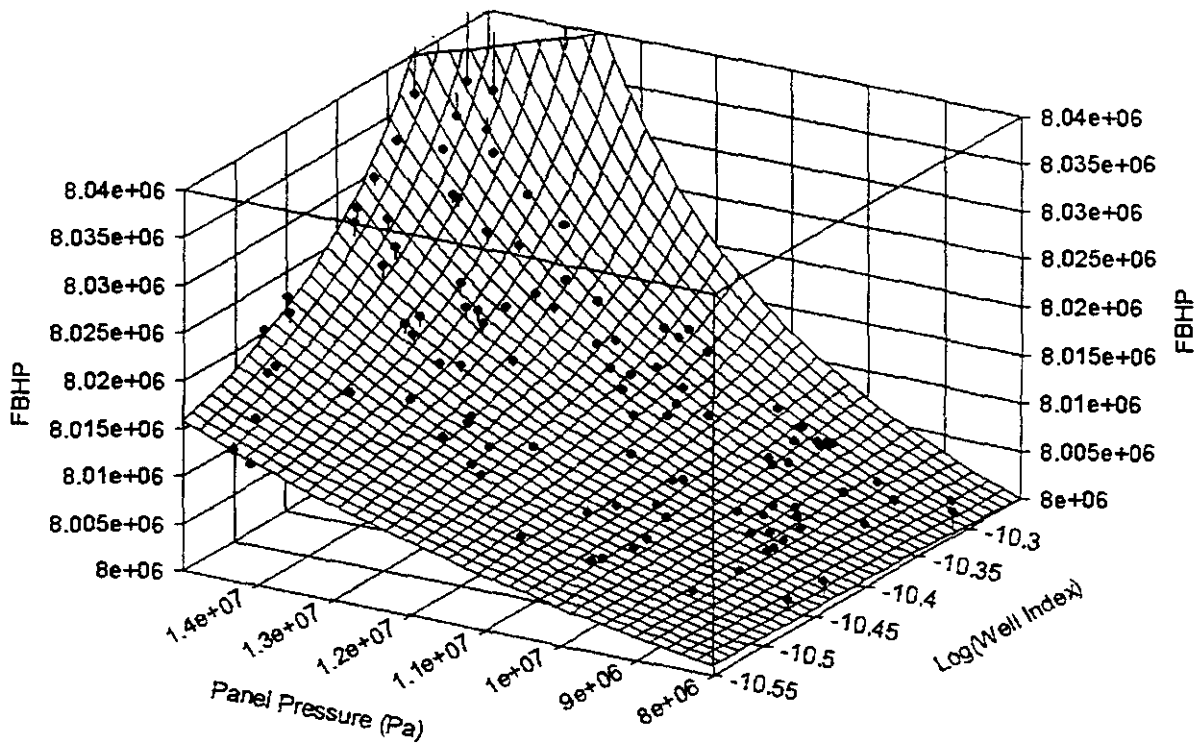

FIGURE B2

FBHP as a Function of Rel Permeabilities and Panel Pressure (brine dominated)

Rank 3 Eqn 1100 $z=(a+bx+cx^2+dx^3+ey)/(1+fx+gx^2+hy)$
r^2=0.99785338 DF Adj r^2=0.99782216 FitStdErr=147128.98 Fstat=36590.213
a=847062.65 b=2788147.9 c=3451058.3 d=-54884.388
e=-0.017079483 f=0.8953597 g=0.54041532 h=-4.9369107e-09

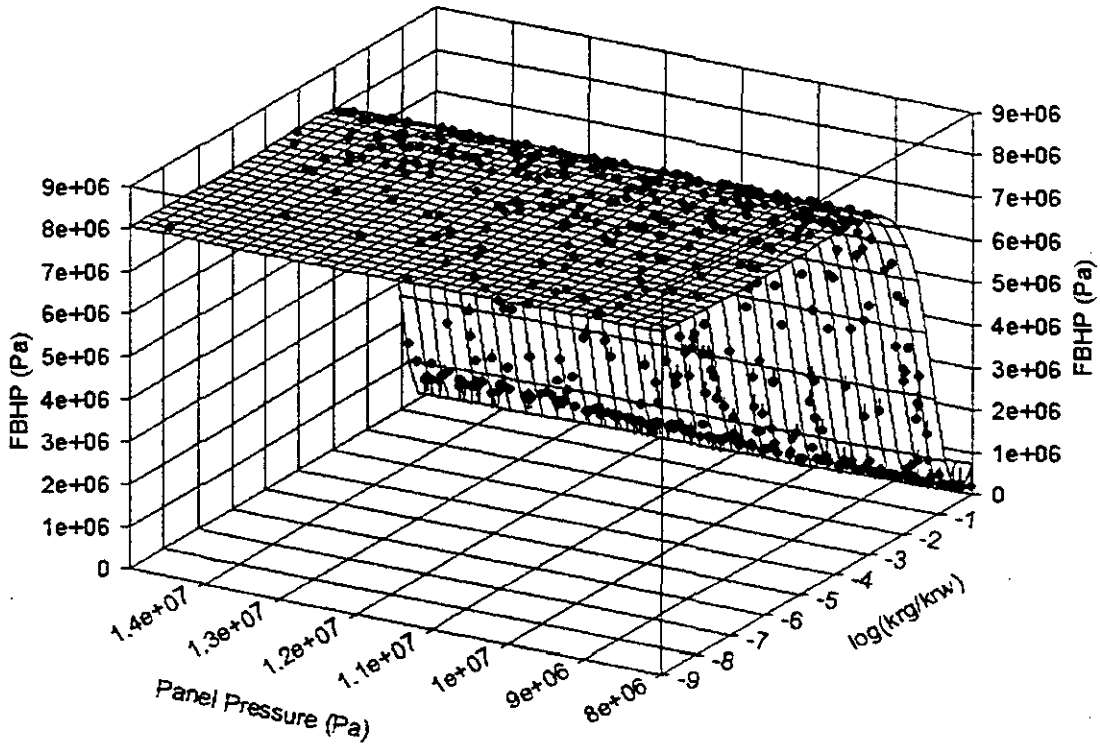

FIGURE B3

FBHP as a Function of Rel Permeabilities and Panel Pressure (gas dominated)

Rank 54 Eqn 151250960 $\ln z = a + bx + cx^{0.5} + de^{x} + ey^{0.5}$

r^2=0.94539889 DF Adj r^2=0.94520677 FitStdErr=11520.361 Fstat=6155.3571

a=8.9214635 b=-0.2274279 c=1.3680586

d=1.8350086 e=0.00045726223

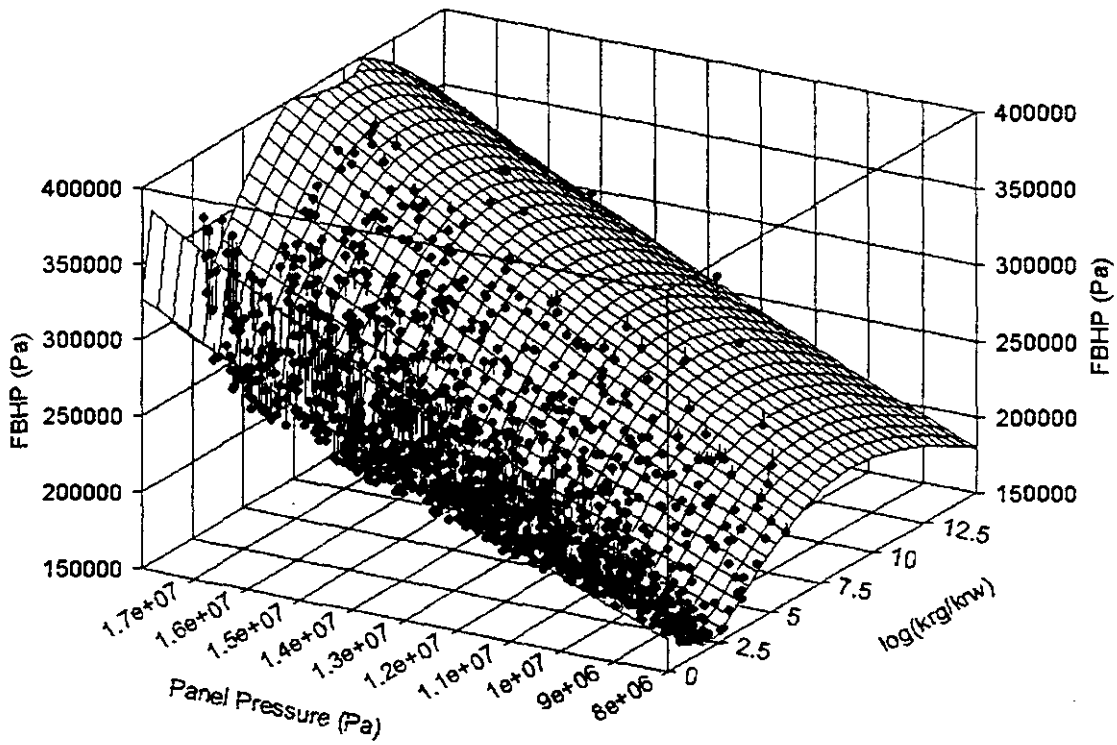

FIGURE B4
FBHP as a Function of log(Krg/Krw)

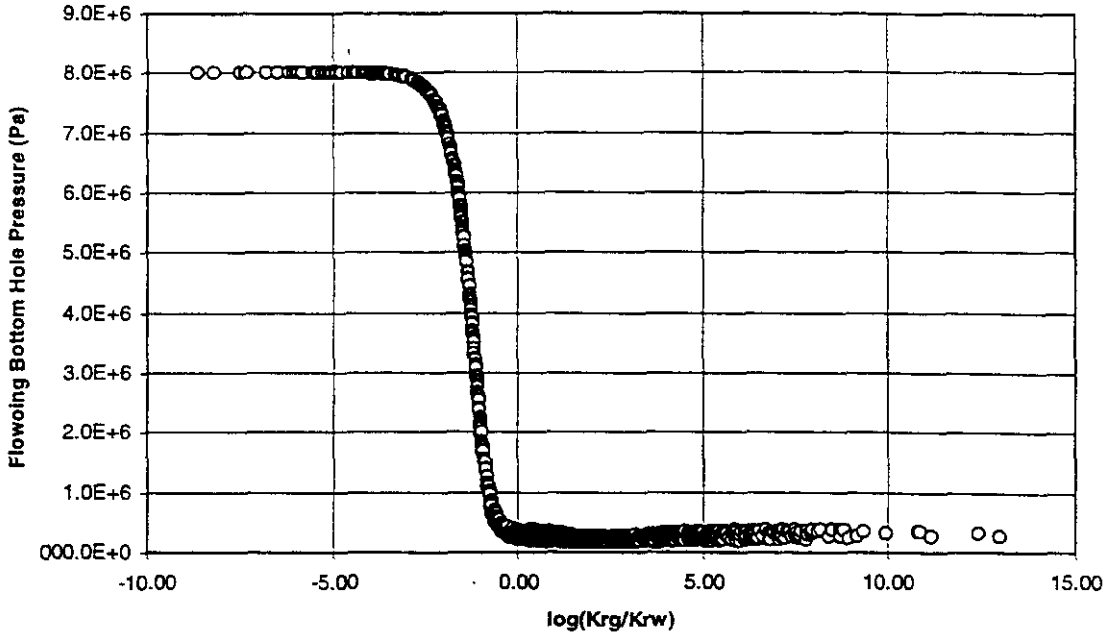

FIGURE B5
FBHP as a Function of Brine Saturation

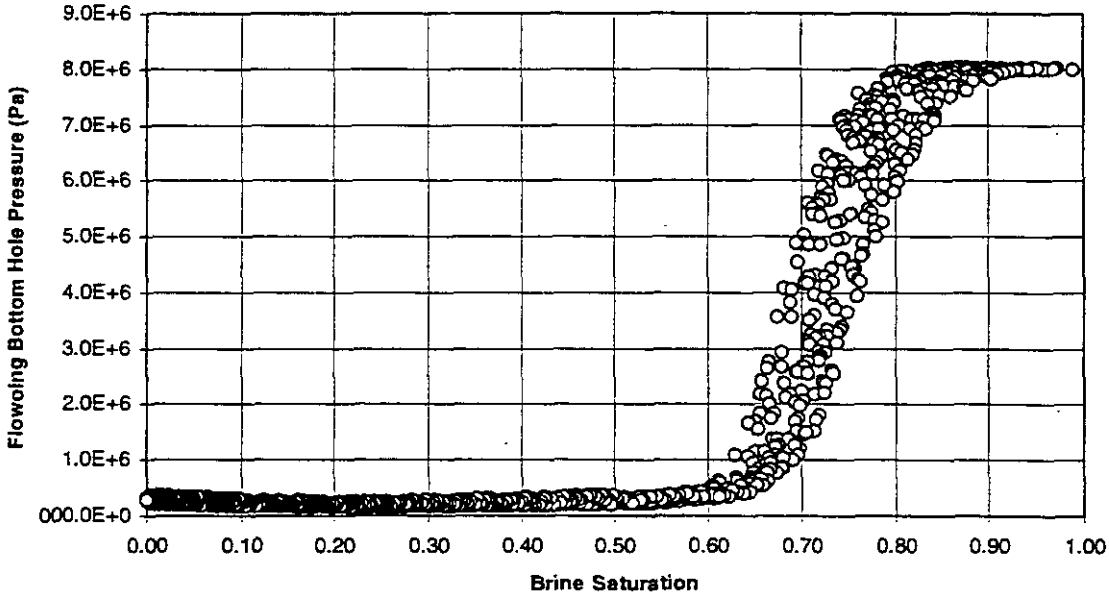

B3. Poettmann and Carpenter Equations

For vertical flow, the general pressure gradient equation can be written as:

$$\frac{dp}{dz} = \left(\frac{dp}{dz}\right)_{el} + \left(\frac{dp}{dz}\right)_{f} + \left(\frac{dp}{dz}\right)_{acc}$$

The total pressure drop is the sum of the pressure drops due to elevation, friction and acceleration, respectively. The pressure drop caused by elevation change depends on the density of the mixture. The pressure drop caused by friction losses requires evaluation of a friction factor. The pressure drop caused by accelerating the fluids is especially important for cases of high flow velocities as would be expected with high pressure gas. The empirical correlations differ in the manner used to calculate the three components of the total pressure gradient.

To calculate the bottom-hole flowing pressure using the method of Poettmann and Carpenter, the following information is required:

$$\frac{dP}{dh} = \frac{M}{144V_m}\left(1 + \frac{f'Q^2V_m^{\,2}}{7.413E+10D^5}\right)$$

where:

$\frac{dP}{dh}$ = pressure gradient (psia/ft)

D = annular diameter [using "hydraulic radius" concept] (ft)
$D^5 = (d_i + d_o)^2(d_i - d_o)^3$

$$V_m = 5.615B_w + \frac{P_bT_az}{PT_b}(R_p - R_s) + V_w$$

V_m = volume of mixed gas and brine at pressure P per barrel of stock-tank liquid, based on the ratio of fluids flowing into and out of the flow string (ft^3/stbl)

R_p = producing gas-liquid ratio (scf/stb)

B_w = formation volume factor of brine = 1 (rbl/stb)

P_b = base pressure at which gas is measured (101.32 Pa)

T_a = average temperature of flow (300.1 °K)

T_b = base temperature at which gas is measured (300.1 °K)

z = compressibility factor of the gas in the annulus at temperature T_a (300.1 °K) and pressure P

Component	Pc (psia)	Tc (deg R)	Tr = Ta/Tc
H2	187.52	59.29	8.94
CO2	1070.23	547.51	0.97
Methane	667.00	342.93	1.55
N2	491.68	227.09	2.33
O2	731.43	278.17	1.90
H2S	1296.64	671.69	0.79

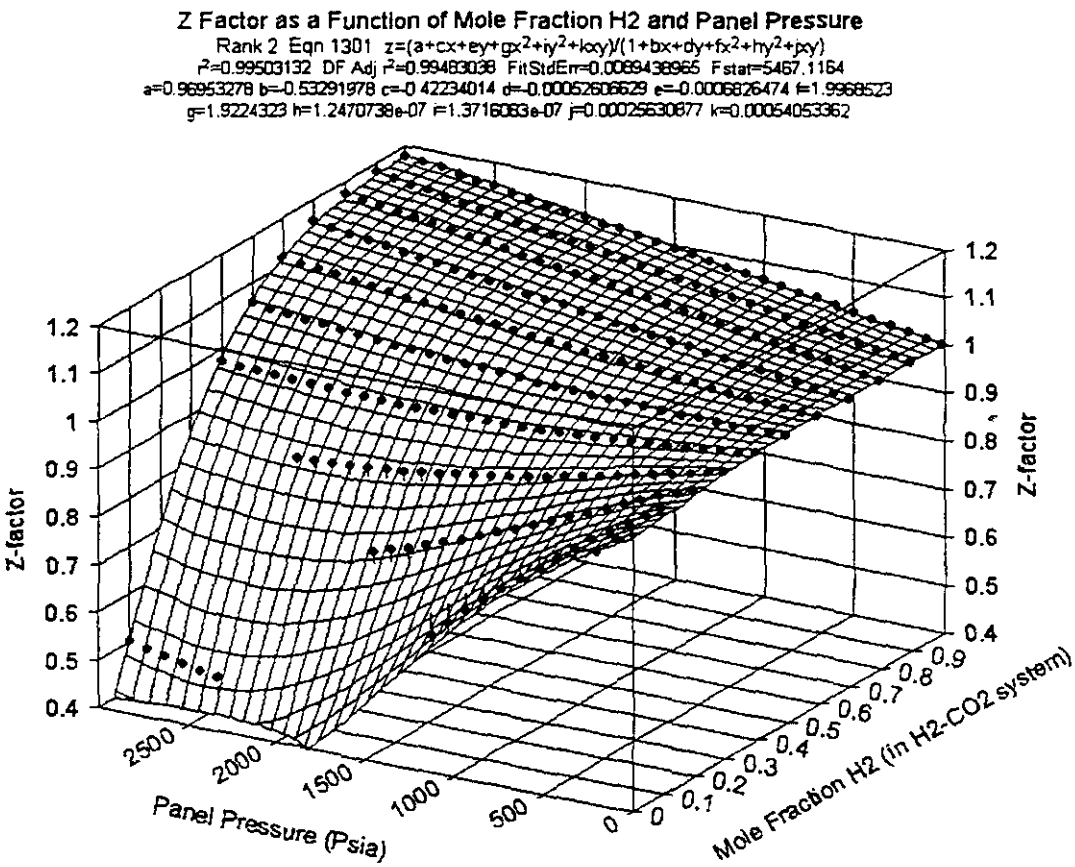

R_s = solution gas-liquid ratio at pressure P (scf/stb) [assumed to be 0]

V_w = cubic feet water produced (scf/stb) [assumed to be 0]

Q = bbl of stock-tank liquid produced per day (bbl/day)

M = $(5.615)(62.4)(G_{sto}) + 0.0764(G_g)(R_p) + 62.4(G_b)(V_w)$

M = total mass of gas and brine, lb, associated with 1 bbl stock-tank liquid flowing into and out of flow string.

G_{sto} = specific gravity of stock-tank oil = 0

G_g = separator gas gravity (air = 1.0) [function of the gas composition, determined with SUPERTRAPP program developed by NIST]

G_b = specific gravity of produced water = 1.23

M will remain constant at any point in the annulus

Defining the flowing density as follows:

$$\rho = \frac{M}{V_m}(lb/ft^3)$$

f' = determined empirically from the work of Poettmann and Carpenter as a function of M, Q & D

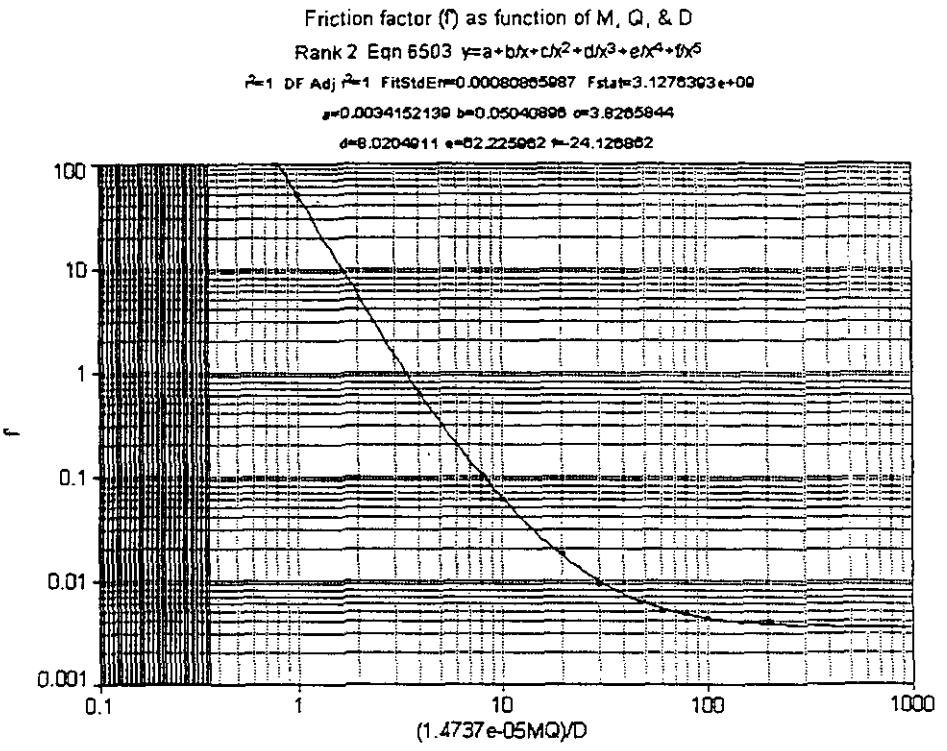

$\frac{dP}{dh}$ is determined from the original expression above so that the new pressure may be obtained by the following:

For delta h increments up the wellbore, $P_2 = P_1 + \frac{dP}{dh}$(delta h)

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

MASS Attachment 16-3

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INFORMATION ON

INADVERTENT INTRUSION BOREHOLE PERMEABILITY

July 8, 1996

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1.0 INTRODUCTION

The inadvertent human intrusion scenario envisions that boreholes may penetrate the Waste Isolation Pilot Plant (WIPP) repository and extend through a pressurized brine reservoir in the Castile Formation. These boreholes represent a potential pathway between the brine reservoirs and the repository, and between the repository and the overlying aquifers of the Rustler Formation or the surface. Estimates of borehole permeability are important inputs to the WIPP Performance Assessments (PA). The boreholes will be plugged on abandonment, and prediction of the time variation of this permeability as the plugs degrade and the boreholes close is also important information for PA. As noted in Appendix A, the borehole permeability model presented here should also be applied when analyzing intrusion into a contaminant plume, as well as when considering whether a borehole that does not penetrate any contaminated zone can affect performance of the disposal system.

A methodology has been developed for predicting this borehole permeability, based upon reviews of current plugging and abandonment practices, technical data and predictive methodologies in the published literature, and data from WIPP-specific tests. Part 194 of Title 40 of the Code of Federal Regulations (40CFR194) requires that the frequency with which holes are plugged, the depths of plugged intervals, and the dimensions and materials used to fabricate the plugs be based on current practice. In this area the authors have relied on a study by the Westinghouse Waste Isolation Division (WID) that defines these current practices (WID, 1996). The methodology and materials properties used to assess the behavior of the boreholes and the plugging materials over time, and thus to make long-term predictions of performance, have been taken principally from the professional literature, or from standard engineering and scientific practices. Borehole plugging field test results and experience reported by oil and gas exploration companies have been used to test the credibility of assumptions and predictions.

This report presents the results of the investigations. The principal results are included in the main body of the report, with supporting calculations and detailed information included in the Appendices. Section 2.0 discusses the current plugging practices in the Delaware Basin, as a

means of identifying the classes of plugged wells to be considered. Related regulatory issues are discussed in Appendix A which was prepared by Sharla Bertram of Sandia National Laboratories. Conceptual models for the plugged holes, and for casing corrosion and cement degradation are described in Section 3.0, with more details being given in Appendices B and C, while Section 4.0 and Appendix D discuss the creep closure of the boreholes and its effect on permeability. Section 5.0 summarizes the predicted behavior of the three classes of well considered, while Section 6.0 includes the overall conclusions of the study.

2.0 CURRENT BOREHOLE PLUGGING PRACTICES

2.1 Available Information

Current borehole plugging practice in the Delaware Basin is specified in well abandonment regulations promulgated by the New Mexico Oil Conservation Division (OCD) and/or the federal Bureau of Land Management (BLM) (See Appendix A for analysis and discussion). The regulations are universally observed, as borne out by a detailed review of actual field practices (WID, 1996). Current regulations and field practices in the Delaware Basin, and specifically in the vicinity of the WIPP, entail plugging boreholes with portland cement based materials (hereafter, "concrete"). The WIPP lies within a portion of the Delaware Basin that contains potash resources, which are protected by both State and Federal regulations. At the Federal level, an area known as the "Secretary's Area" was designated by the Secretary of the Interior in October 1986 as an area within which the BLM should protect potash resources when considering Applications for Permits to Drill (APD's) for oil or gas wells. At the State level similar considerations apply as specified by the NMOCD in July 1985. Within this area, known variously as the Known Potash Leasing Area (KPLA) or the (almost) equivalent R-111-P area, certain regulations apply relative to drilling, completion and plugging of boreholes. In particular, within this area permission to drill may be denied to protect potash, or because of the presence of the WIPP, and between August 1993 and April 1996 this permission was denied by BLM for 63

wells. Where drilling is allowed BLM is required to take account of the State regulations that stipulate special drilling and plugging practices.

These special State regulations came into force in 1988, so any review of current practice must be restricted to wells plugged since that time. The WID survey identified only one well plugged since 1988 in the potash enclave, apparently because drilling is not generally allowed here. For this reason the survey was extended to cover all boreholes in the Delaware Basin which were subject to plugging since 1988 under BLM regulations, a total of 115 wells, and since the practice in federal and state lands were essentially the same, State wells were added to the survey raising the total sample population 188 wells (see Table C-2 in Appendix C).

Based on this population, the number and distribution of concrete plugs in a given plugged and abandoned borehole are variable and somewhat dependent on the practice of individual operators. However, for the purposes of predicting long-term performance, review of the records indicates that current practice on federal lands may be adequately represented using three scenarios: one with two deep plugs, one with at least three deep plugs, and one in which multiple plugs may approximate the OCD requirement for a continuous plug that extends all the way through the host salt formation. Further discussion is given in the following section.

2.2 Borehole Plugging Configurations

The dimensions and locations of the concrete members (plugs) largely determine their predicted performance lives, and can exert significant performance effects on releases from the overall system under human intrusion scenarios. A number of configurations have been used in the Delaware Basin, including:

- a single continuous plug through the evaporite sequence;
- a two plug configuration that contains one plug in the Bell Canyon Formation (below the depth of potential brine reservoirs) plus one plug in the Rustler Formation (between the Culebra aquifer and the repository); and

- a three (or multi-) plug configuration that contains the two plugs described for the two plug configuration, plus an additional plug in the Salado Salt Formation (see Table C-4 in Appendix C).

In addition to the plugs located at depth, all boreholes have surface plugs that extend ~15 m (50') down from the land surface. These shallow plugs are located in surface casings and are primarily intended to prevent debris or biota from entering the hole. For physical support, the concrete elements of the surface plug are keyed into the near-surface geologic media.

All of these configurations have been modeled in this study for completeness, and are discussed in more detail below.

Under OCD regulations for the R-111-P (KPLA) area a continuous plug of salt-saturated cement is required to extend from the top of the Bell Canyon Formation to the top of the Salado Formation (See Figure 1). This long plug is emplaced to ensure that water inflow cannot effect potash reserves. A deeper plug (typically 15 m of concrete on top of a cast iron bridge plug) is assumed to exist no deeper than 2438m (8000 feet), although this deep plug has no effect on borehole performance for this scenario.

Under BLM regulations outside of the KPLA, or where OCD regulations are not adhered to, plugs are required to isolate the top and bottom of the evaporite sequence from waters not saturated with indigenous salts. For practical reasons, plugged intervals tend to be tied to changes in casing diameter, which tend to be related to drilling and production considerations. One change in casing size typically occurs at the top of the Salado, where the large diameter surface casing is changed to a smaller diameter intermediate casing. In boreholes proximate to the WIPP Site, this step-down in casing diameter occurs below water producing zones in the Rustler. In deep holes associated with hydrocarbon production, an additional step-down occurs at the base of the evaporite sequence, defined typically as from the top of the Salado Formation to the bottom of the Castile (Figure 2). At this location the intermediate casing changes into the smaller diameter production string. During production, this production casing string typically extends to

the surface, but is only cemented to above the potential production zones: on abandonment this casing is sometimes cut above the cemented zone and is reclaimed. Typically, the first of these changes (from the surface to the intermediate casing) occurs at or above 245m (800') depth and the second at about 1220m (4000') depth (WID, 1996).

At abandonment, concrete is poured to create plugs which overlap the casing transitions. The plugs are intended primarily to prevent the flow of aqueous media within and around the borehole casing, and are typically about 40m long, centered at the depth where the change in casing diameter occurs. The net effect of this process is that at the WIPP, the minimum plugging arrangement (hereafter, the "two plug configuration") results in upper and lower plugs which isolate the evaporite sequence (Figure 2), with about one-third of the wells being plugged in this way (WID, 1996).

In approximately two-thirds of the sampled wells, one or more intermediate plugs are placed between the Bell Canyon and the Rustler (hereafter, the "three plug configuration"; Figure 3) in addition to the plugs at the base of the Rustler and top of the Bell Canyon. This three plug configuration is associated with holes where hydrocarbon production has occurred, and where a production casing is installed within the intermediate casing. When the production casing is salvaged it is cut and stubbed, and a 40 m thickness of concrete, centered on the stub location, is typically poured to seal off the abandoned production casing that remains in the hole. Near the WIPP, stubbing occurs at a depth averaging ~ 790m (2600'; Westinghouse, 1996) which is above the horizon of the Castile brine reservoirs, but below the repository level. However in some cases, the intermediate plug may lie in the Salado above the repository horizon. For simplicity, this minor occurrence is grouped with the three plug layout.

3.0 CONCEPTUAL MODELS

3.1 General Configuration

Plugged sections of boreholes are assumed to have circular axial cross-sections with alternating layers of concrete plug and steel casing (See Figure 4). In parts of the boreholes which are not plugged, concrete only exists between the casing and the rock, and volumes within the casing are filled with a suspension that contains less than 5% solids in brine. In the borehole plug degradation model, it is assumed that the plugs will fail from a combination of steel casing corrosion and chemical deterioration of the concrete's matrix. The expected performance lives of the different plugs vary because different plugs are located within different hydrologic and chemical environments.

3.2 Conceptual Model for Casing Corrosion

Corrosion of iron-based materials, such as steel, is a complex subject because steel varies in composition, and because the corrosion of steel is highly dependent upon the corrosion environment. For example, the corrosion of different steels under the same conditions can vary by as much as an order of magnitude (e.g., see data in Manfredi 1989). Similarly, the corrosion rate and mechanisms for a given steel will be dependent upon the composition of the corroding medium, including, for example, any volatiles present. Corrosion of steel under oxic conditions is generally much faster than when oxygen is absent (e.g., Escalante et al. , 1990). Corrosion in the presence of hydrogen disulfide gas is aggressive at partial pressures lower than a few atmospheres (Videm and Kvarekval, 1994) and passivated at higher partial pressures (Westerman and Brush, 1996).

Corrosion of borehole casings at WIPP will occur under a number of different environments. Air saturated brine will corrode the casing from the inside-out. De-aired, and in some cases anoxic, formation brines will corrode the casing from the outside-in. None of these borehole

environments is similar to the repository, and borehole casing will not show the slow corrosion rates expected to be experienced by steel drums in the repository (see Brush and Westerman, 1996).

Prediction of the corrosion rates and mechanisms for the steel borehole casing has required a number of simplifications. For example:

- It has been assumed that corrosion data for low carbon steel are generally applicable here. Corrosion rates have been bounded by using corrosion data from experiments conducted in brine under low oxygen conditions with carbon dioxide and hydrogen disulfide present, in de-aired conditions with carbon dioxide (only) present, and under air-saturated conditions.

- Complex gas-steel interactions have been ignored in developing generally applicable conceptual models for casing corrosion, and calculations have only considered the reaction of iron and oxygen.

In the simplified iron-water system, corrosion of the casing occurs as available waters react with the steel to form hydrous solids. While other alteration products are possible, corrosion of iron-based materials is generally assumed to produce goethite (FeOOH) or ferrous hydroxide, $Fe(OH)_2$, and generate hydrogen as a byproduct. The extent of corrosion that may occur is theoretically limited both by the amount of reactants and the partial pressure of hydrogen that is generated. When hydrogen partial pressures build up to ~45 atm at 25 ^{o}C, thermodynamic calculations indicate that iron will no longer react to form goethite (Appendix B), and within the compositional limits of the brine-steel system considered, the corrosion of iron theoretically ceases.

From this analysis, it follows directly that the extent of casing corrosion in a borehole will be affected by the "tightness" of the system. If hydrogen can escape, hydrogen partial pressures will not build up and corrosion will proceed until the supply of either steel or water is exhausted. If the system is gas-tight, then corrosion will be limited. Hydrogen is effectively contained in the

system if the diffusion of hydrogen through the steel and surrounding rock is sufficiently slow that constant composition is effectively maintained. As a gas, hydrogen is notorious for its ability to diffuse rapidly. Escape of hydrogen from the system is virtually assured if hydrogen exists as a gas and perforations in the casing lie adjacent to conductive formations.

Casings are most likely to corrode and perforate adjacent to strata with appreciable conductivity, where brine can be produced (Warner and McConnell, 1990). Thus, when hydrogen is present as a gas and the casing fails from contact with formation brines, the casing is expected to continue corroding until it disintegrates. In contrast, if hydrogen is not present as a gas, or if localized failure of the casing does not coincide stratigraphically with conductive formations, then corrosion is expected to be restrained. In such cases, the casing may perforate locally, but total disintegration and loss of physical integrity is not expected.

3.3 Conceptual Model for Concrete Alteration

After hardening, concrete materials consist of coarse and fine-grained elements. In a simplified sense, aggregate comprises the coarse material while the fine material is generated by the reactions between the cement and the mix water. The permeability of concrete is determined by the connected porosity that exists through the fine-grained matrix. This porosity includes microcracks, intergranular pores, and small voids that contained bleed water or gas prior to curing. The hardened concrete's initial permeability may be related to the ratio of water to cement used when mixing the concrete (e.g. Neville, 1983; See Figure 5). This general relationship holds because excess water leads to increased connected porosity.

The solid phases that form in concrete are primarily a function of the cement composition, the amount and identity of additives and the composition of the mix water. For the purposes of performance calculations, we have assumed that all cementitious materials are based on ordinary portland cement (OPC) with halite saturated mix waters. The crystalline phases that commonly occur in OPC include portlandite, calcium silicate hydrate (CSH) and often ettringite; however, the bulk of the solid is comprised of cryptocrystalline, or amorphous, CSH and silica. The

simplified system may be considered to be portlandite dispersed in a CSH matrix. The solids which make up the concrete will react upon exposure to water. The phases which dissolve and react most readily are alkali salts and portlandite. Dissolution and reaction of portlandite is followed by ettringite (primary and secondary) and then CSH. The alteration phases that are produced include gypsum, calcite, brucite and ultimately clays and perhaps zeolites (Onofrei et al., 1992; Coons and Alcorn,1989).

Alteration of the solid results in a change of the concrete's permeability. This change can be related mathematically to changes in the concrete's porosity (Coons and Alcorn, 1989). In an unconfined system, the porosity of the concrete increases as the volume of water that flows through the concrete increases. There are two reasons for this change. Firstly, the alteration phases occupy more volume than the original concrete phases (e.g. Robie and Waldbaum, 1978), and alteration causes unconfined concrete to crack, thereby increasing porosity and permeability of the mass. Secondly, in an open system, if flow rates are sufficiently high, then dissolution and removal of highly soluble portlandite can outpace deposition of new solids. This process removes mass from the concrete and causes the porosity and permeability of the mass to increase.

In contrast, in a confined system, alteration of the concrete causes the permeability of the mass to decrease. The solid products produced by alteration of concrete occupy more space than the original solid. If the volume of the mass is not allowed to increase (or if the chemical changes occur very gradually), then as new phases are formed, they clog the internal porosity of the mass. This phenomenon has been observed to produce a decrease in average pore size and total porosity which results in decreased permeability (See Figures 6 and 7; Onofrei et al., 1992). The result is an altered concrete mass with a permeability that is lower than the original, unaltered, value (Alcorn et al., 1992). Models for predicting changes in concrete plug permeability require the use of both the confined and open system results. Long plugs will be self-confining and will approximate the closed or constrained system. Short plugs cannot be safely assumed to be self-confining and must be treated more as an open system.

The conceptual model for changes in short plug performance is a step function, with decreases in plug performance occurring as sudden changes that coincide with plug failure. Failure is conservatively taken to occur when a sufficient volume of water has passed through the concrete mass that the CSH matrix undergoes measurable alteration. At this point, it is assumed that the matrix has degraded significantly, and the plug is subject to unconstrained microfracturing and physical failure. The 'critical volume' of water for causing plug failure has been taken as the volume required before breakdown of the CSH matrix is expected to begin. Based on data in Berner (1990), the critical volume has been conservatively assumed to be equal to 100 pore volumes. The time required for this volume to pass through the concrete mass can be calculated from Darcy's Law using site-specific conditions (See Appendix C). For long plugs, decreases in permeability from the initial, as-emplaced concrete values, have not been considered because it is believed that they will result in no effective difference in system performance predictions.

4.0 CREEP-DRIVEN DENSIFICATION OF BOREHOLE DEBRIS

Rocksalt is a medium which flows viscoelastically under applied deviatoric, or shear, stress, with the rate of flow, or creep, increasing as the stresses increase. This flow may be expected to cause increased closure of the boreholes over time.

The salt around a borehole will be subject to stress difference brought about by the presence of the borehole. At some distance from the borehole the salt will be under a uniform lithostatic load, but at the borehole surface the salt will be confined only by any hydraulic gradient from fluids in the borehole or back pressure from plugs. Away from the plugs the salt will creep into the hole at a rate dictated by the depth (and thus the magnitude of the far-field stress) and the back pressure caused by any borehole fill material. Salt is a highly non-linear material, with the creep rate depending on the applied stress to a power of 4.9 (SNL, 1992), so the rate of closure of the borehole is highly dependent on both depth and backpressure. The far-field stress and any fluid backpressure in the hole work against each other, with the far-field stress trying to close the borehole and the fluid pressure tending to open it. Both of these pressures increase with depth, although the far-field lithostatic stress increases more rapidly. Deeper holes therefore tend to

close faster, and holes with an internal fluid pressure will close more slowly than empty holes. One result of this is that only the deepest parts of the borehole, that is those below the repository, will show meaningful closure in the 10,000 year regulatory time period (Appendix D).

In addition to the effects of depth and fluid back-pressure, the closure of the hole is controlled by its geometry. A circular borehole in a uniform stress field is a highly stable configuration, and any additional closure is resisted by the constraint imposed by the shape of the hole. For this reason even the deepest boreholes will not close completely over the 10,000 year regulatory time frame, and permeability effects will only be seen where the holes are filled with a compressible granular material. Thus, at depths below the repository any debris in the borehole will experience compression as the salt creeps inward, leading to a decrease of both the porosity and the permeability of the sediment pile. The amount of permeability decrease will be related directly to the volume of creep closure experienced by the borehole.

Creep closure has been calculated using a "pineapple slice" plane strain model in the Spectrom 32 code, with the MDCF model and WIPP salt parameters (See Appendix D). Only steady state creep was included. Far-field horizontal stresses were estimated at 1 psi/ft depth, with a back-pressure due to a column of brine (density 1.2) to the surface. No back pressure due to consolidating borehole fill was assumed. It has also been assumed that all change in volume is due to loss of pore volume, i.e. the solids are infinitely stiff relative to the borehole fill, and that the Kozeny-Carman relationship for porosity and permeability holds (Bear, 1972; Lambe and Whitman, 1969; Koltermann and Gorelick, 1995).

Given these assumptions changes in the porosity have been calculated that will give rise to an order of magnitude decrease in permeability of the silty sand borehole debris. Calculations have been performed at several depths and times to provide guidance on the rate and locations where permeability changes might be expected (See Figure 8). The calculations indicate that an order of magnitude decrease in permeability will occur if the porosity of the borehole is decreased by between 14 to 23 percent (the range results from the effect of different assumptions for the initial porosity of the debris). At the base of the Salado (850 m depth) 14 percent creep closure will

occur in slightly less than 500 years and 23 percent in about 850 years (See Figure 9). Similarly, at the repository level 14 percent closure will take about 1800 years, and 23 percent over 3500 years.

For the purposes of estimating the performance of a plugged borehole at WIPP, the median of the range of properties is useful. Figure 8 indicates that the median (18%) closure will be realized for a column of about 100 meters in 1000 years. As a result, a creep-induced decrease in the permeability of the silty sand fill below the repository of one order of magnitude is predicted to occur after about 1000 years. Above the repository horizon, pressure gradients are low enough that, given the strong non-linearity of creep rates with applied stress, creep induces no significant change to the fill properties within the period of performance.

5.0 PREDICTED PERFORMANCE

5.1 Continuous Plug Configuration

In this scenario, OCD requires that a continuous concrete plug shall extend through the entire evaporite sequence (Castile plus Salado Formations; See Figure 1). Within the WIPP Site, such a plug would have a length of over 900m (3000 feet) and a volume of more than 20 cubic meters (i.e., more than 50 tons of concrete). The length of the plugged interval and its location in media which will creep tightly around the radius of the plug produce a physically confined system.

In a physically confined system, concrete will maintain very low permeabilities for time periods well in excess of the period of performance (see: Atkinson, 1985, 1986; Alcorn et al., 1992; Berner, 1990; Lagerblad and Tragardh, 1995) The mechanisms that lead to predicted long term performance include the very low initial permeability of the concrete and the fact that alteration of the concrete will lead to filling of the internal porosity that permits flow to occur. The predicted permeability of a steel-cased borehole plugged continuously with concrete through the entire evaporite sequence therefore will be equal to or less than the initial permeability of the hardened

concrete (which is taken to be 5×10^{-17} m^2, as discussed in the following paragraph). It is predicted that this permeability will not experience an effective increase during the 10,000 year period of performance.

These predictions, and the key assumptions concerning the performance of materials that they are based on, are consistent with field and laboratory observations. The initial permeability estimate of hardened concrete is based on field measurements made on test plugs emplaced in the Bell Canyon formation (Christensen and Hunter, 1980; Petersen and Christensen, 1980), and supported by laboratory measurements made on ordinary portland cement grouts (Figure 5; Neville, 1983). Continuous concrete plugs placed through the evaporite sections by potash mining concerns have remained hydraulically tight for decades and show a general lack of concrete alteration (Bonen, 1996). From these findings, and the permeabilities predicted for concrete altered in a confined system, it is concluded that a continuously plugged borehole approximates the isolation capability of the undisturbed geology.

The plug system includes both the grouted steel casing and the internal concrete plug. While the concrete elements are predicted to maintain low permeabilities, it might be argued that corrosion of the steel casing at the rock-steel interface could form a preferred pathway for flow. However, formation of even an incipient annulus is not expected. The most aggressive relevant corrosion rates for carbon steel approach 3mm/yr (Andrade et al., 1990; Manfredi et al., 1989; Videm and Kvarekval, 1994: See Appendix B). The expected length of the continuous plug (900,000 mm), combined with the corrosion rate, the low solubility of iron in brine reservoir fluids (Appendix B), the finite volume of brine assumed (1,000,000,000 liters; Popielak, 1983; Sandia National Laboratories, 1992), and the ability of salt creep to close any small gaps, result in the prediction that corrosion will not create an annular pathway from the Castile, through the repository to the Culebra (See Appendix B).

5.2 Two Plug Configuration

In the two plug configuration, a plug does not separate the hypothesized Castile brine reservoir from the repository (See Figure 2). There is a plug in the Rustler Formation, above the repository, and in the Bell Canyon Formation, below the brine reservoir.

In this scenario connection from the brine pocket to the repository is expected to be essentially instantaneous, since in the first several tens of years the steel casing is projected to perforate locally. The system will not be gas or water tight from this time onward, and interbed permeabilities will control the local release of fluids. Because the transmissivities of local breaches in the casing are expected to be small for 200 years or so, the permeability of the borehole plugs in the Rustler (above the repository) and the Bell Canyon (below the Castile brine reservoir) are expected to be about 5×10^{-17} m^2 for this period. After 200 years the upper casing and the Rustler plug will decay and fail due to aggressive corrosion. Debris from this casing and plug will fill the borehole from the top of the Bell Canyon Plug up to a point above the Rustler with a material equivalent to silty sand (Appendix B), so that the permeability from the brine pocket in the Castile to the Culebra will be in the range 10^{-11} to 10^{-14} m^2, while the permeability of the brine pocket-Bell Canyon flow path remains about 5×10^{-17} m^2. After an additional 1000 years, creep closure causes compaction of the debris and decreases the permeability of the borehole fill below the repository to a range of 10^{-12} to 10^{-15} m^2, while the pathway from the repository to the Culebra remains unchanged at 10^{-11} to 10^{-14} m^2 (Appendix D). After a median time of about 5000 years (See Appendix B for details on the full range), the Bell Canyon plug fails, and the debris pile falls to the bridge plug at 8000 feet, but still extends above the Culebra. From this time onward, the permeability of the entire borehole approximates silty sand, with that below the repository being one order of magnitude less permeable due to creep closure. The bases for this prediction are elaborated upon below, and in Appendices B, C and D.

In the upper reaches of the borehole, (depths less than ~300 m) corrosion of the steel casing will speed the failure of the Rustler Plug. At these shallow depths, total corrosion damage to the steel is expected to be generalized, and much greater than the localized damage expected at greater

depths. This prediction is a result of the lower hydrostatic pressures at shallower depths, which will be insufficient to keep corrosion-generated hydrogen from nucleating as a gas and escaping into the surrounding formations. Loss of this gas substantially removes chemical controls on corrosion, and allows the reaction to proceed until the supply of steel is exhausted, and the upper portions of the casing disintegrate. Laboratory-derived linear corrosion rates (See Figures 10 and 11; Videm and Kvarekval, 1994; Andrade et al., 1990) suggest that localized breaches of the casing may be expected in periods as short as several months to tens of years, which is consistent with oil field experience in the Delaware Basin (Bailey, 1990), so that within decades the borehole casings will not be "gas-tight". Scaling up from these same experiments, extensive corrosion and total disintegration of the casing are expected within less than 200 years.

Loss of the casing will remove physical support for the concrete plug and will expose new concrete surfaces to alteration. Experiments conducted by Waterways Experiment Station indicate that diffusion driven processes result in a spall rate of 0.05 cm/yr from concrete surfaces (Atkinson and Hearne, 1990). In 200 years, radial diffusion would be capable of reducing the diameter of the plug by over 90 percent. As a result, in a practical sense the Rustler Plug is predicted to lose its functionality within about 200 years.

The corrosion products from the casing will be fine-grained materials. Degraded concrete and sloughed rock will also fall into the hole and will likely be coarser material. The debris will comprise a granular fill for the borehole above the Rustler plug. Because of the telescoping geometry of the borehole, the debris pile will extend above the Culebra Dolomite. The permeability of this fill is expected initially to approximate silty sand (10^{-11} to 10^{-14} m^2), and subsequent consolidation by salt creep in lower sections of the borehole will ultimately reduce this conductivity range by an order of magnitude below the repository (See Section 4.0, and Appendix D).

The deeper Bell Canyon plug will degrade more slowly than the Rustler plug. At the depth of the Bell Canyon (~4000 feet), the hydrostatic pressure greatly exceeds the equilibrium hydrogen pressure created by steel corrosion, and hydrogen gas is not expected to nucleate and escape.

The consequence is that corrosion of the casing will be limited to local perforation (pitting failures), and while this corrosion will result in isolated holes in the casing, total disintegration of the casing is not expected to occur within the 10,000 year performance period.

The process that will cause degradation of the Bell Canyon plug will be chemical alteration, due to reaction with water that flows axially through the plug's porosity. As noted above, approximately 100 pore volumes are conservatively taken to be required before chemical reactions significantly attack the concrete's calcium-silicate-hydrate matrix (See Figure 12; Berner, 1990). The comparatively short length of the plug (40 m), and the high hydraulic gradients produced by the pressurized brines, will allow significant volumes of water to pass through and chemically alter the concrete mass of the plugs during time frames of interest. In contrast to the continuous plug configuration discussed above, it may not be reliably assumed that this plug is physically confined. The performance life of the concrete is controlled by water access (See Clifton and Knab, 1989), and chemical degradation of the matrix will allow the concrete mass to fracture and cause the plug to fail. Under the site-specific conditions assumed, the expected performance life of the Bell Canyon plug has a median of 5000 years and a range of from 500 to 50,000 years (See Appendix C). At that time, the permeability of the plug will decrease to that of the consolidated debris.

5.3 Three Plugs

The three plug configuration includes a plug between the brine pocket and the repository. The plugs between a) the brine pocket and the repository (the Salado plug), and b) the repository and the Culebra (the Rustler plug), are expected initially to have permeabilities of 5×10^{-17} m^2 (as is the pathway through the Bell Canyon). Failure of the casing and Rustler Plug are not driven by processes that require connection to the Castile Brine Reservoir, and, as in the two plug configuration, the upper casing and the Rustler plug will fail at around 200 years. In most cases this will cause the predicted permeability from the repository to the Culebra to be that of silty sand. Such a condition will prevail except in those instances when an additional plug is located in the Salado above the repository horizon. When such off-normal plugging occurs, the permeability

above the extra plug will approximate silty sand (10^{-11} to 10^{-14} m^2), but the permeability from the repository to the plug will remain 5×10^{-17} m^2.

At depths below about 1100 feet, the hydrostatic pressure will be high enough to prevent hydrogen gas nucleation. Casing corrosion will be constrained and the plugs will remain physically supported. Nevertheless, pressurized brines may be expected to reach the inside volumes of the unplugged casing beneath the plug in times as short as months to tens of years after abandonment. Predictions of localized perforation are based on linear corrosion by brines with compositions similar to the Castile Brines analyzed by Popielak et al., 1983 (but with reduced partial pressures of hydrogen disulfide, assumed due to atmospheric venting that occurred at the time of drilling). While a concrete cladding *may* slow corrosion, the presence of concrete around the steel *cannot be relied upon* to decrease linear corrosion rates significantly (compare Figure 10 and Figure 11 and see Appendix C). Once the pressurized brines from the Castile gain access to the inside of the casing, a steep hydraulic gradient will be established across the Salado and Bell Canyon plugs, and even with the low initial permeability of the concrete (5×10^{-17} m^2), the gradient is sufficient to drive brine through the plug in appreciable volumes within the 10,000 year period of performance.

The chemical alteration of these concrete plugs, which lack axial confinement, is expected to lead to failure of the plugs and a consequent increase in borehole conductivity. The driving force behind plug failure is that chemical alteration products occupy more volume than the original concrete material. In the continuous plug configuration, this expansion clogged available pores and decreased permeability because the system was physically confined. In the two and three plug configurations, formation of the same alteration phases leads to increased pore pressures and results in fracturing and loss of the physical integrity of the Salado plug.

The Salado plug's initial permeability is estimated to continue for a median time of about 5000 years (with a range of 500 to 50,000 years), when both the Salado and the Bell Canyon plugs are predicted to fail. As noted above, the Rustler plug is expected to have failed at about 200 years, and the portion of the borehole above the intermediate plug will have filled with corrosion and

other debris approximating a silty sand like material. Prior to failure of the intermediate plug, creep will have densified the lower portions of the sediment pile, below the repository. As a result, upon failure of the intermediate plug at 5000 years, the permeability of the brine pocket-repository pathway will be 10^{-12} to 10^{-15} m^2, while the pathways above the repository will approximate silty sand (10^{-11} to 10^{-14} m^2).

5.4 Surface Plugs

Surface plugs will exist in all boreholes and their expected degradation applies equally well to all plugging scenarios. Surface plugs will be located in and around the casing that extends 50 ft downward from the surface. The top 4 to 6 feet of these plugs is keyed into the geologic media, providing a physical support.

The entire mass of the surface plug and associated casing lies above the water table at the site. The casing between the surface plug and the Rustler runs through both saturated and unsaturated media. The casing will corrode quickly in the saturated environments and more slowly in unsaturated zones. Failure of the casing is not expected to cause the surface plug to fail by loss of physical support because of the construction geometry.

The concrete elements of the surface plug will degrade very slowly. No long lasting hydraulic head will drive water to flow through and chemically alter the plug. Degradation beyond surface phenomena (such as freeze-thaw) is expected to be driven by diffusion and evaporation mechanisms. These processes are not expected to alter plug performance to a significant degree during the 10,000 year period of performance.

In summary the section of the borehole above the Rustler plug is expected to have hydraulic properties controlled by the surrounding formations. The control will begin within decades after abandonment due to local perforation of the steel casing; however, limited transmissivity may restrict water flows to small amounts. Total hydraulic control by the host geology is expected

within 200 years, by which time the saturated portion of the casing is expected to disintegrate. Prior to that time the surface plug is taken to have a permeability of 5×10^{-17} m^2.

6.0 SUMMARY AND CONCLUSIONS

Permeabilities have been predicted for borehole plugs as they are likely to exist at the WIPP over long time periods. Borehole plug configurations, dimensions and materials have been estimated from a review of current regulations and practices. Expected changes in performance have been estimated using models and data for steel corrosion and concrete alteration taken from the published literature. Predictions have been calibrated, where possible, by comparing predicted behavior with field observations and measurements.

Plugs are initially expected to have a permeability of 5×10^{-17} m^2. In the continuous plug configurations, this performance remains permanently undiminished. Under alternative plugging configurations, permeabilities associated with different sections of the borehole vary with time. Casing above the Rustler Formation is estimated to completely degrade in about 200 years, and the plug in the Rustler Formatio will fail at this time. This corroded casing and degraded plug will fill the hole with material with a permeability approximating that of silty sand (10^{-11} to 10^{-14} m^2), and over time any of this material below the repository will compress through creep` closure of the borehole to a permeability about one order of magnitude lower. Deeper casing will not corrode so extensively, and the deeper plugs will not fail for an estimated median time of 5,000 years. The predicted changes in borehole performance for the different potential configurations are shown in Figures 13 and 14 and in Tables 1 and 2, and summarized below:

- Continuous Plug: The permeability of the plug remains at 5×10^{-17} m^2 for the whole regulatory period.

- Two Plugs: The permeability between the repository and the surface is 5×10^{-17} m^2 for 200 years and 10^{-11} m^2 to 10^{-14} m^2 after that. Between the Castile and the repository has a very

high permeability for 200 years, values of 10^{-11} to 10^{-14} m^2 up to 1,200 years, and 10^{-12} to 10^{-15} m^2 after that.

- Three Plugs: The permeability between the intermediate plug and the surface is 5×10^{-17} m^2 for 200 years and 10^{-11} m^2 to 10^{-14} m^2 after that. The intermediate plug has a permeability of 5×10^{-17} m^2 for a median time of 5,000 years, and the borehole between the Castile and the repository has values of 10^{-11} to 10^{-14} m^2 for 1,000 more years , and 10^{-12} to 10^{-15} m^2 after that.

Under all scenarios considered, the permeability of the borehole plug system never exceeds that of silty sand (10^{-11} to 10^{-14} m^2).

7.0 REFERENCES CITED

Alcorn, S.R., Coons, W.E., Christian-Frear, T.L., and M.G. Wallace, 1992, "Theoretical Investigations of Grout Seal Longevity," Final Report, Stripa Project TR 92-23, SKB, Stockholm, Sweden.

Aguilar, A., Sagues, A.A., and Powers, R.G. (1990) Corrosion of reinforcing steel in partially submerged concrete slabs: in Corrosion Rate of Steel in Concrete: ASTM, Philadelphia, PA, pp66-85.

Andrade, C., Alonso, M.C. and Gonzalez, J.A. (1990) An initial effort to use the corrosion rate measurements for estimating rebar durability: in Corrosion Rate of Steel in Concrete: ASTM, Philadelphia, PA, pp29-37

Atkinson, A., Goult, D.J., and Hearne, J.A., 1985, "An Assessment of the Long-Term Durability of Concrete in Radioactive Waste Management." Materials Research Society Symposium Proceedings: Scientific Basis for Nuclear Waste Management IX, v. 50,pp 239-246.

Atkinson, A., 1986, "The Time Dependence of pH Within a Repository for Radioactive Waste Disposal.: Report AERE-R 1177, Materials Development Division, Harwell Laboratory, Oxfordshire, England.

Bailey, J., 1990. "Water Level Rises in Culebra Dolomite Monitor Wells," NM State Land Office, Technical Letter Memorandum, August 13, 1990.

Bear, J., 1972, Dynamics of Fluids in Porous Media, Elsevier, New York.

Berner, U., 1990, "A Thermodynamic Description of the Evolution of Pore Water Chemistry and Uranium Speciation During the Degradation of Cement," Technical Report 90-12, Paul Scherrer, Villigen, Switzerland.

Bonen, D., 1996, "Petrographic Analyses of Concrete and Grout Recovered from the WIPP," The Technological Institute, Northwestern University, Interim Report, January 15, 1996, 9pp.

Buiil, M., Revertagat, E., and Oliver, J., 1992, "A model of the attack of pure water or undersaturated lime solutions on cement. in Stabilization and Solidification of Hazardous Radioactive and Mixed Wastes," Special Publication 1123, ASTM, Philadelphia, PA, pp 227-241

Burski, J.L., 1994, "Yates Petroleum et al.v. New Mexico State Office, Bureau of Land Management:" IBLA 92-612 decided November 18,1994.

Christensen, C.L. and Hunter, T.O., (1980) "The Bell Canyon Test Results" SAND80-2414C. Sandia National Laboratory, Albuquerque NM

Clifton, J.R. and Knab, L.I., 1989,"Service Life of Concrete." NUREG/CR-5466 and NISTIR 89-4086; National Institutes of Standards and Technology, Gaithersburg, Maryland.

Coons, W.E. and S.R. Alcorn, 1989, "Estimated Longevity of Performance of Portland Cement Grout Seals," in Sealing of Radioactive Waste Repositories, Conference Proceedings, Braunschweig, Germany, May 22-25, 1989.

Dale, T., and L. D. Hurtado, 1996, "WIPP Air Intake Shaft Disturbed Rock Zone Study," to be presented at 4th. International Symposium on Salt, Montreal, June, 1996.

Escalante, E. and Ito, S. (1990) Measuring the corrosion rate of steel in concrete: in Corrosion Rate of Steel in Concrete: ASTM, Philadelphia, PA, pp86-102.

Freeze, R.A., and J.A. Cherry, 1979, Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Garrels, R.M. and Christ, C.L., 1965, Solutions, Minerals, and Equilibria, Jones and Bartlett, 450p

John Hart and Associates. P.A., 1995, "Review and Comparison of Regulatory Requirements Governing Plugging and Abandonment of Oil and Gas Wells in New Mexico, Texas, Oklahoma, Colorado and Nevada," Report to Westinghouse Waste Isolation Division, March 1995

Kelley, V., Jones, T., and J. Ogintz, 1996, "WIPP Seal System Parameters for PA BRAGFLO Compliance Calculations", Memorandum from Intera to Diane Hurtado, January 15 1996

Knowles, M. K. and C. L. Howard, 1996, "Field and Laboratory Testing of Seal Materials Proposed for the Waste Isolation Pilot Plant," to be presented at the Waste Management Conference, February 1996.

Koltermann, , and Gorelick, 1995, "Conductivity in Sediment Mixtures"

Krumhansl. J. L., 1993, "The accelerated testing of cements in brines," Proc. Am. Ceramic Soc, "Cement-based Materials," April 19-22, 1993, Cincinnati, Ohio, p. 153-164.

Lagerblad, B., and J. Tragardh, 1995, "Conceptual Model for Concrete Long Time Degradation in a Deep Nuclear Waste repository," Swedish Cement and Concrete Institute, TR 95-21, SKB, Stockholm, Sweden, 103pp.

Lambe, T.W., and R.V. Whitman, 1969, Soil Mechanics, Wiley, New York.

Lambert, S.J., and R.L. Robinson, 1984, "Field Geochemical Studies of Groundwaters in Nash Draw, Southeastern New Mexico," SAND83-1122, Sandia National Laboratories, Albuquerque, 1984.

LaVenue, M., 1991, "Anomalous Culebra Water-Level Rises near the WIPP Site," INTERA: Technical Letter Memorandum, January 28, 1991.

Manfredi, C., Mozhi,T.A., and Wilde, B.E., 1989, Corrosion of carbon steel in saturated brine at 150oC- the effects of pH. Corrosion, v. 45 no.2, pp 172-177

Munson, D.E., deVries, K.L., Schiermeister, D.M., deYonge, W.F., and R. L. Jones, 1992, "Measured and Calculated Closures of Open and Brine filled Shafts and Deep Vertical Boreholes in Salt," SAND91-1869, Sandia National Laboratories, Albuquerque, January 1992.

Myers, J., Drez, P, and P. James, 1991, "The Redox State and the Occurrence and Influence of Organics in the Culebra," in Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste isolation Pilot Plant Area, Southeatern New Mexico, Siegel, Lambert and Robinson (eds), SAND88-0196, Sandia National Laboratories, Albuquerque.

Neville, A., 1981, Properties of Concrete, John Wiley and Sons, London.

Onofrei, M., Gray, M., Coons, W.E.., and S.R. Alcorn, 1992, "High Performance Cement Based Grout for Use in a Nuclear Waste Disposal Facility, " Waste Management, v.12, pp. 133-154.

Petersen, E.W., and Christensen, C.L. (1980) "Analysis of Bell Canyon Test Results" SAND80-7044C. Sandia National Laboratories, Albuquerque NM

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellinson, C.T., and R.L. Olsen, 1983, "Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico," Report TME 3153, U.S. Department of Energy, Albuquerque, NM.

Robie,J and Waldbaum, D.J., 1978, "The Thermodynamic Properties of Minerals" American Mineralogic Society. Washington, D.C.

S. M. Stoller Corporation, "Investigation of Borehole Brine Migration in Potash Mines - Phase I and Phase II," Report to Westinghouse Waste Isolation Division, Undated.

Sandia National Laboratories, 1992, "Preliminary Performance Assessment for the WIPP, December 1992, Volume 3: Model Parameters," SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories, 1995, "Status Meeting for the Delivery of Shaft Seal System Parameter Distributions for BRAGFLO (Draft)", December 15, 1995

Sienko, M.J. and Plane, R. A., 1966, Chemistry: Principles and Properties. McGraw-Hill, NY, New York

State of New Mexico, 1988, Minerals and Natural Resources Department, Oil Conservation Division, Order No. R-111-P (April 1988).

U.S. Department of the Interior, 1989, "Inspection and Enforcement Program and Selected Related Management Activities Bureau of Land Management," Office of Inspector General Audit Report, Report No. 90-18, November 1989.

US Department of Energy, 1995, "Waste Isolation Pilot Plant Sealing System Design Report," DOE/WIPP - 3117, October 1995.

Videm, K, Loren, A.M., and J. Kvarekval, 1992, "Passivity, Pitting and Uniform Corrosion of Carbon Steels in Aqueous Sodium Bicarbonate Solutions and in Simulated Oil Well Water Phases," Proc. 12th Scandinavian Corrosion Congress and Eurocorr '92, V1, Corrosion Soc. of Finland, Espoo Finland, pp. 327-336.

Videm, K, and J. Kvarekval, 1995, "Corrosion of Carbon Steel in Carbon Dioxide-Saturated Solutions Containing Small Amounts of Hydrogen Sulfide," Corrosion, V51(4), pp. 260-269.

Wakeley, L. D., Harrington, P. T., and C. A. Weiss, Jr., 1993, "Properties of Salt Saturated Concrete and Grout after 6 Years In-Situ at the WIPP, " SAND93-7019, Sandia National Laboratories, Albuquerque, NM.

Wakeley, L.D., Poole, T.S., and Burkes, J.P., 1994, "Durability of concrete materials in high-magnesium brines," SAND 93-7073

Walton, J.C., Plansky, L.E., and Smith, R.W., 1990, "Models for estimation of service life of concrete barriers in low-level waste repositories," NUREG/CR-5542

Warner, D.L. and McConnell, C.L. (1990) Abandoned oil and gas industry wells-a quantitative assessment of their environmental implications wih emphasis upon the lower Tuscaloosa Sand oil-producing trend of Mississippi and Louisiana. Report to American Petroleum Institute, Health and Environmental Sciences Department and Production Department. Washington, D.C.

Westinghouse Electric Corporation, and John Hart and Associates, 1996, Drilling Requirements and Practices in the Delaware Basin of New Mexico and Texas as Related to Inadvertent Human Intrusion into the Waste Isolation Pilot Plant (WIPP). March 1996 Draft.

Xia, Z., Chou, K.-C., and Szklarska-Smialowska, 1989, Pitting corrosion of carbon steel in CO2-containing NaCl brine. Corrosion; v.45 no. 8 pp 636-642.

SCHEMATIC DIAGRAM FOR A CONTINUOUS PLUG

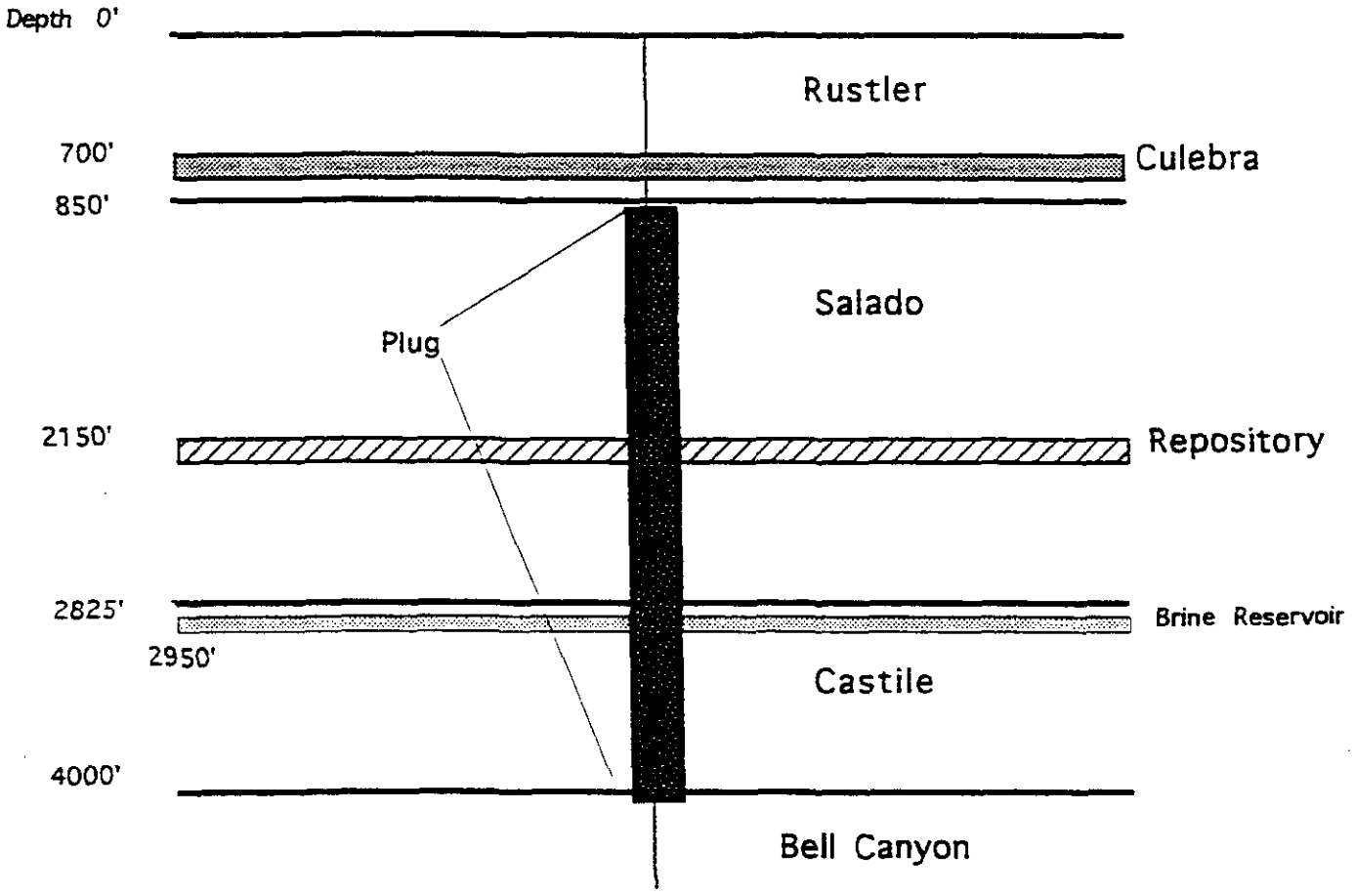

Figure 1

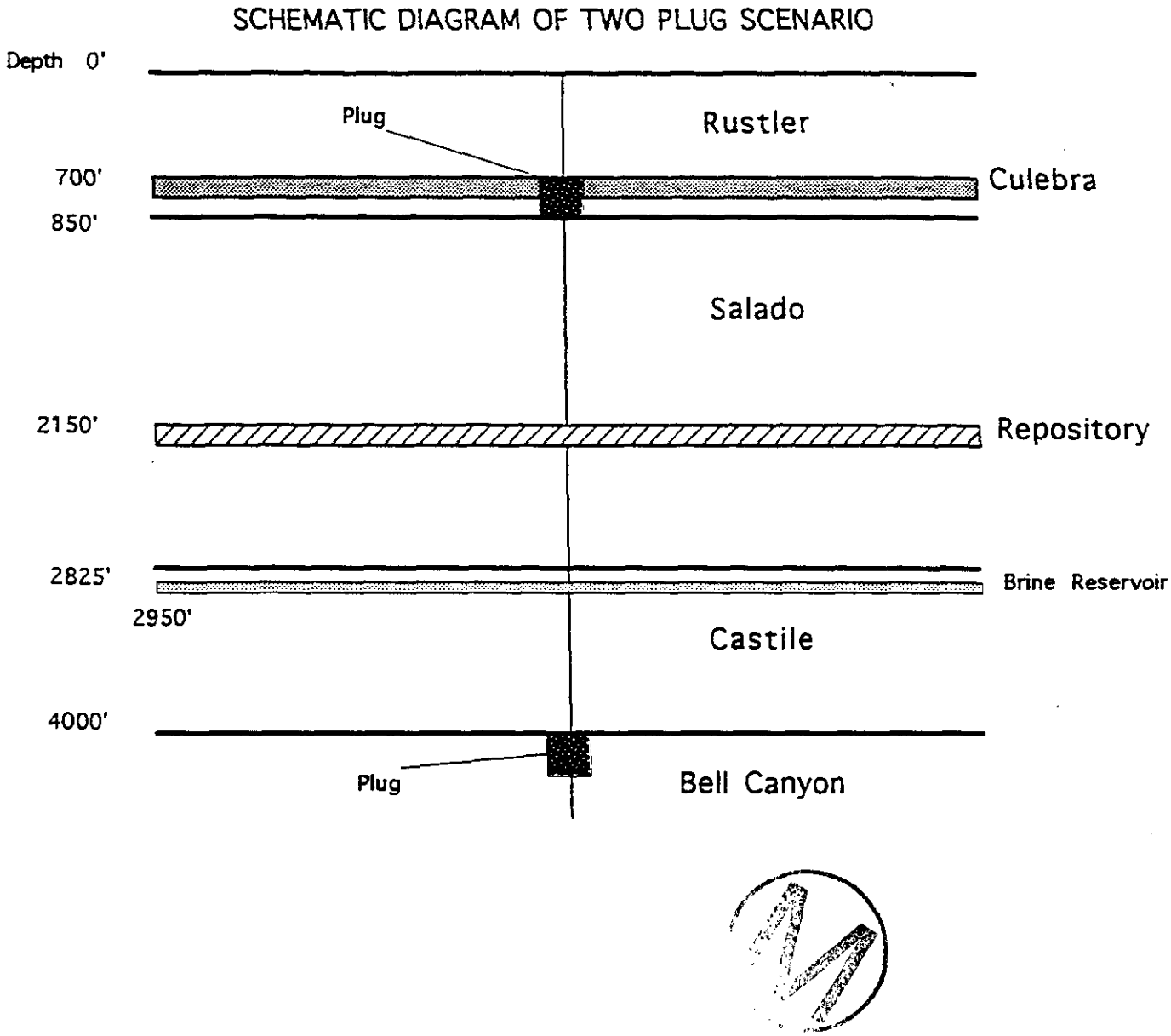
SCHEMATIC DIAGRAM OF TWO PLUG SCENARIO
Depth 0'
Plug
Rustler
700'
Culebra
850'
Salado
2150'
Repository
2825'
Brine Reservoir
2950'
Castile
4000'
Plug
Bell Canyon

Figure 2

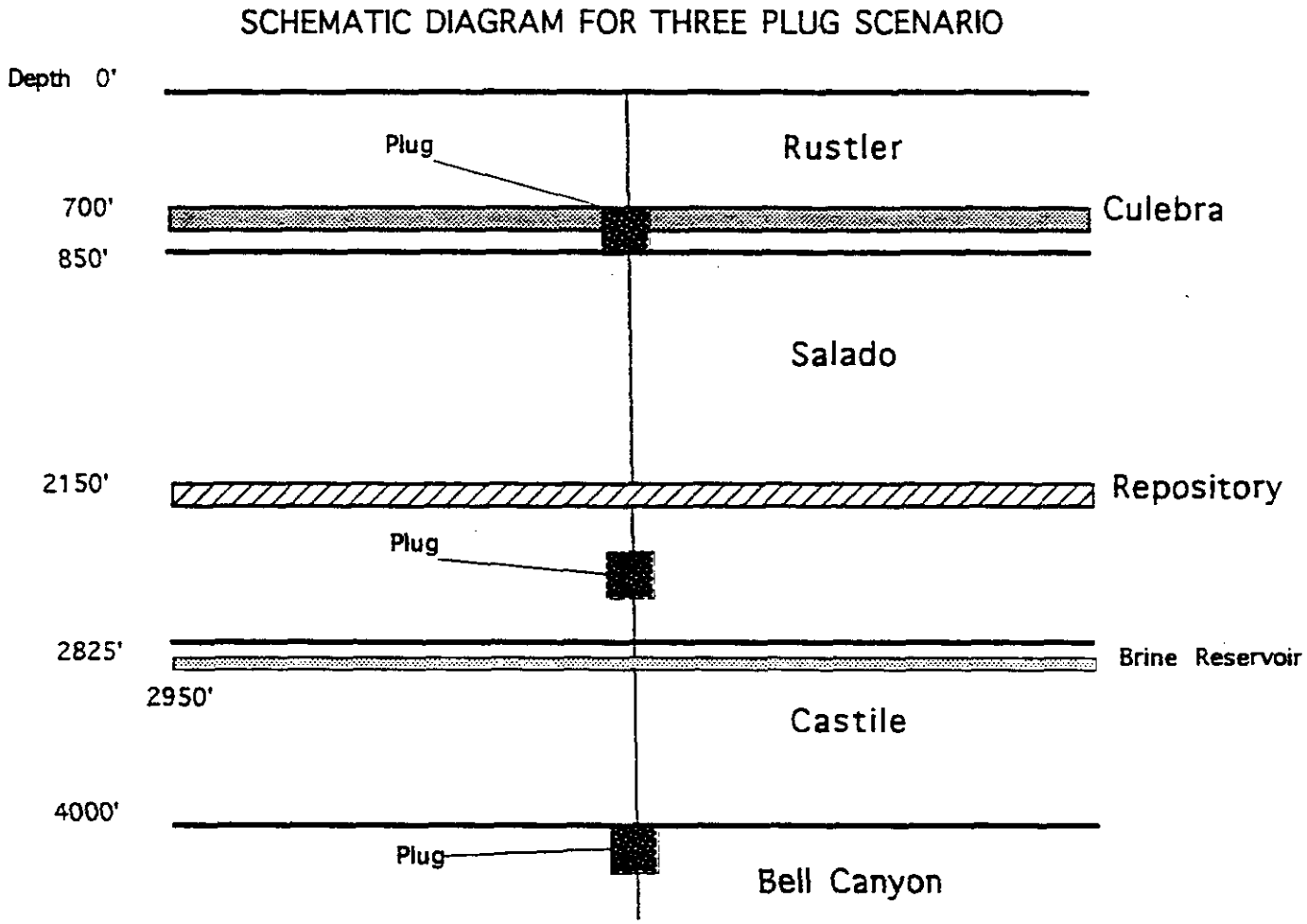
SCHEMATIC DIAGRAM FOR THREE PLUG SCENARIO
Depth 0'
Plug
Rustler
700'
Culebra
850'
Salado
2150'
Repository
Plug
2825'
Brine Reservoir
2950'
Castile
4000'
Plug
Bell Canyon

Figure 3

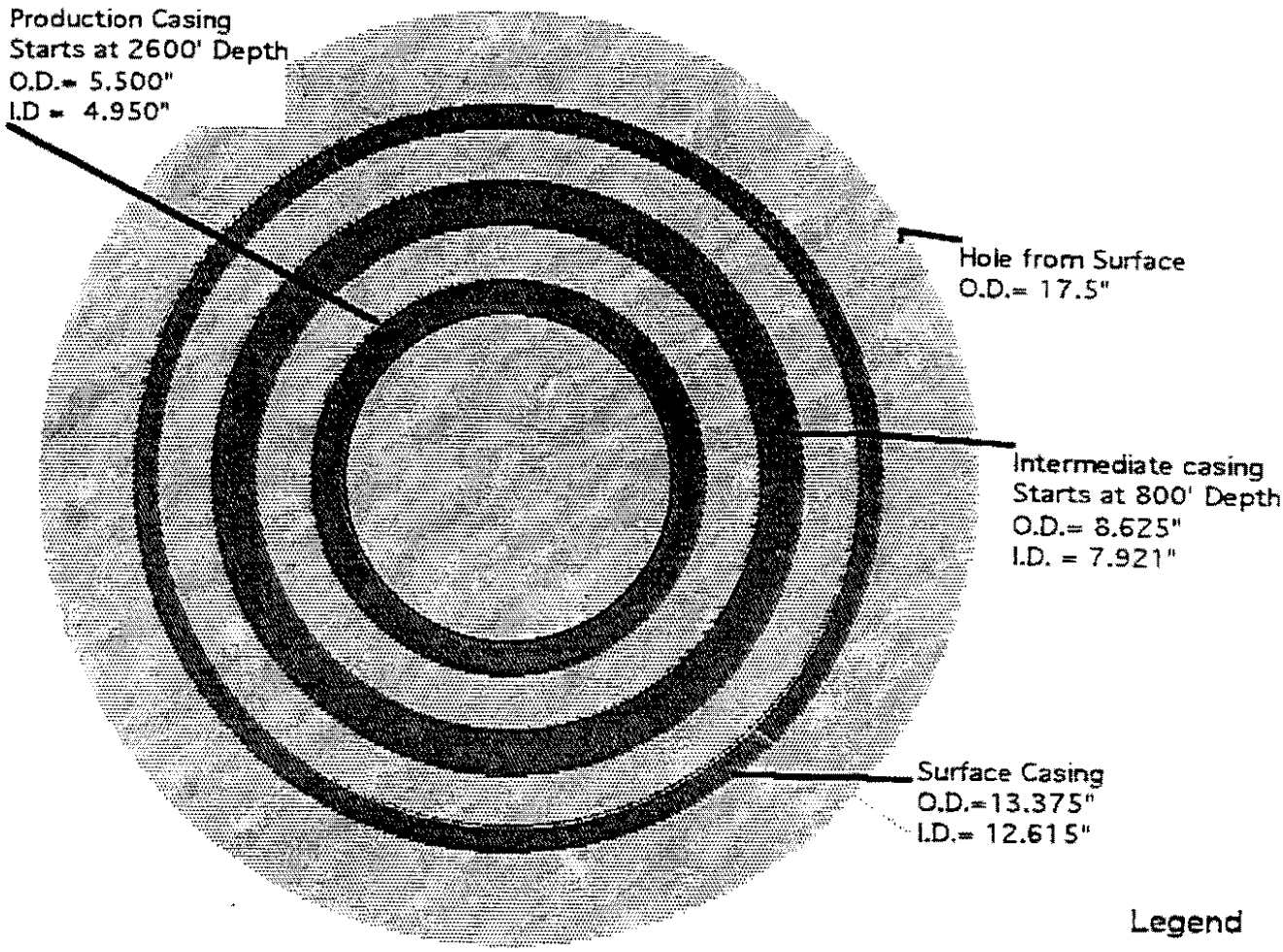

Figure 4: Axial Cross Section of Plugged Borehole

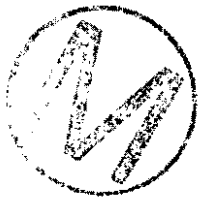

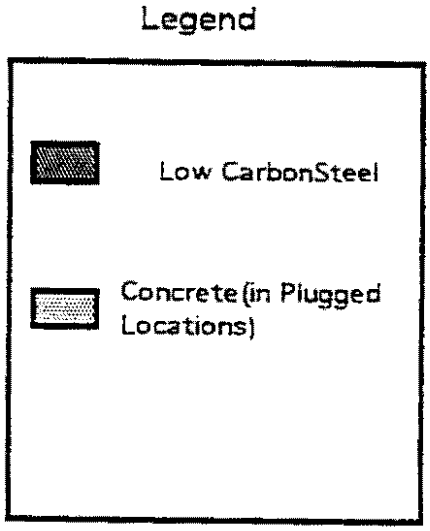

Figure 4

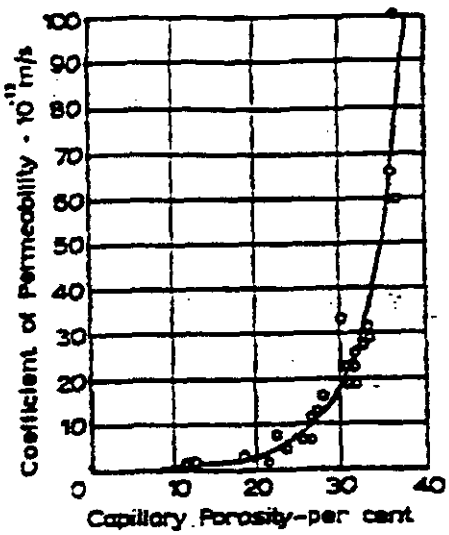

Relation between permeability and capillary porosity of cement pastes (Neville, 1981).

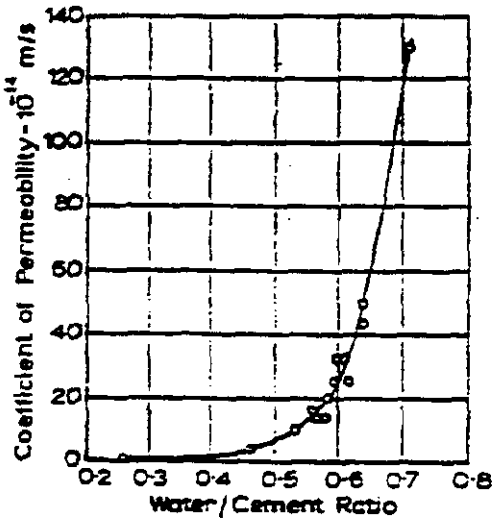

Permeability as a function of water - cement ratio for mature cement pastes (93% of cement hydrated). From Neville, 1981.

Figure 5

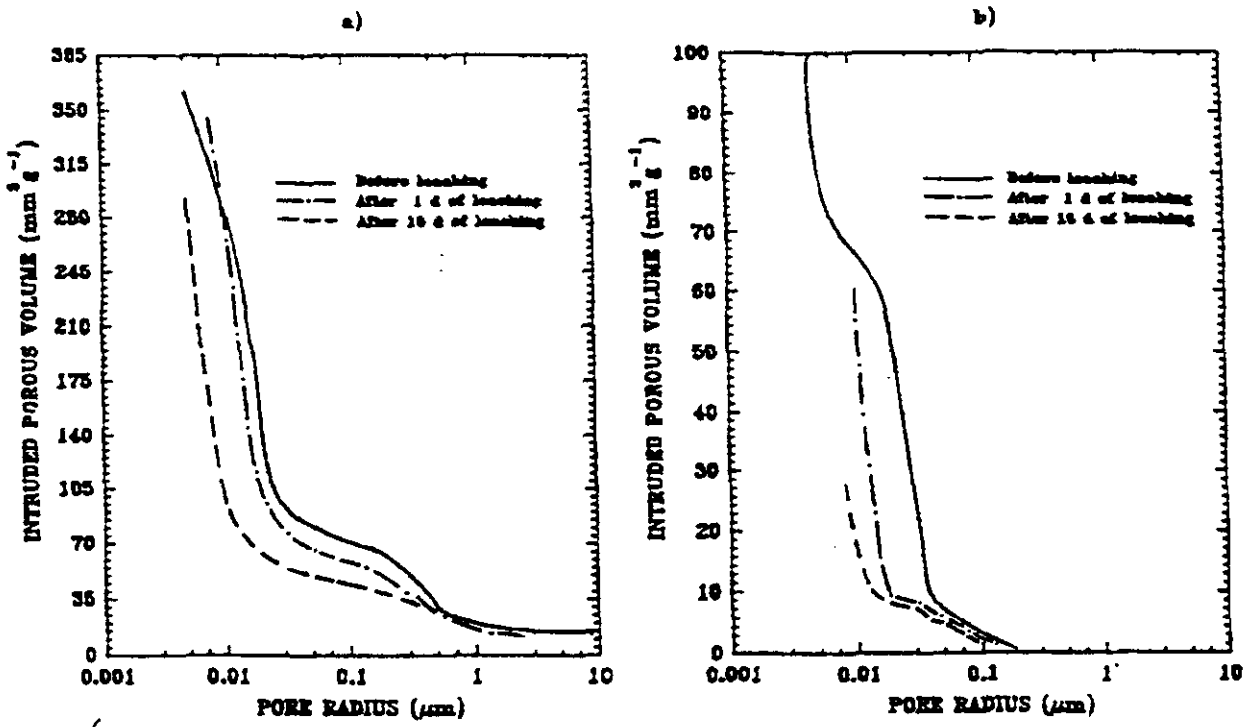

FIG 6 The effect of leaching time on cumulative pore size distribution measured by mercury intrusion porosimetry for: (a) ALOFX -MC grout (MC-500, 0.7/1/10), and (b) reference grout (Type-50, 0.4/1/10).

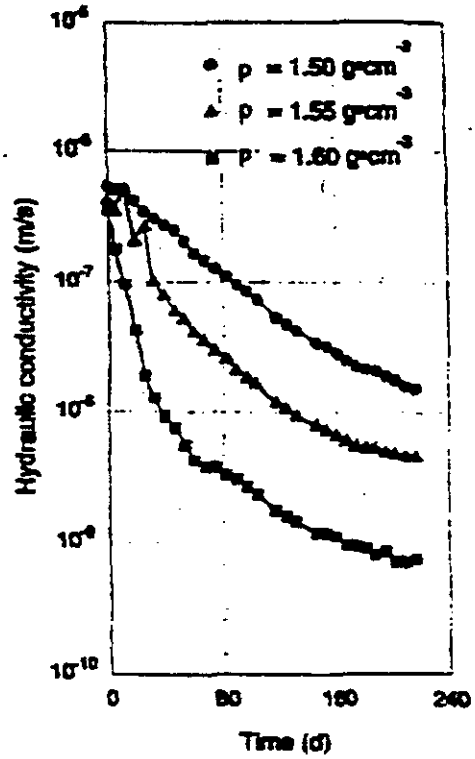

FIG-7 Decreases in hydraulic conductivity measured in crushed, reconsolidated grout as a function of time of exposure to flowing ground water (from Gray, 1992; after Onofrei et al., 1992).

RE/SPEC Inc. CALCULATION SHEET Page 8 of 8

Title Creep Closure of a Brine-Filled Open Borehole in Salt

Calculation No. 326/3.9/01 Engineer MCL Date 3/30/96 Checker _____ Date _____

RSI-325-96-121

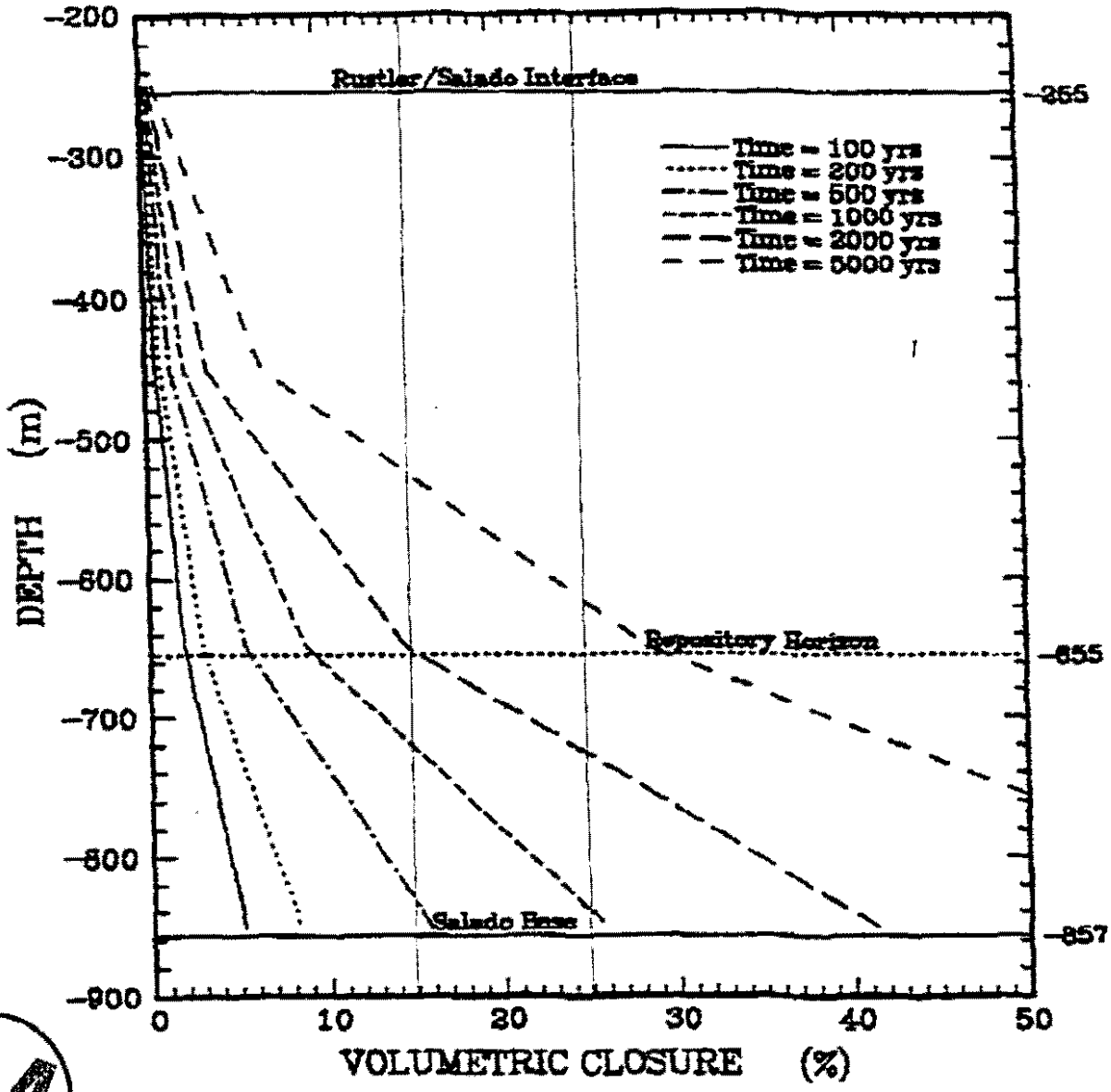

Figure 8. Volumetric Closure as a Function of Depth at Six Representative Times.

— PRELIMINARY —

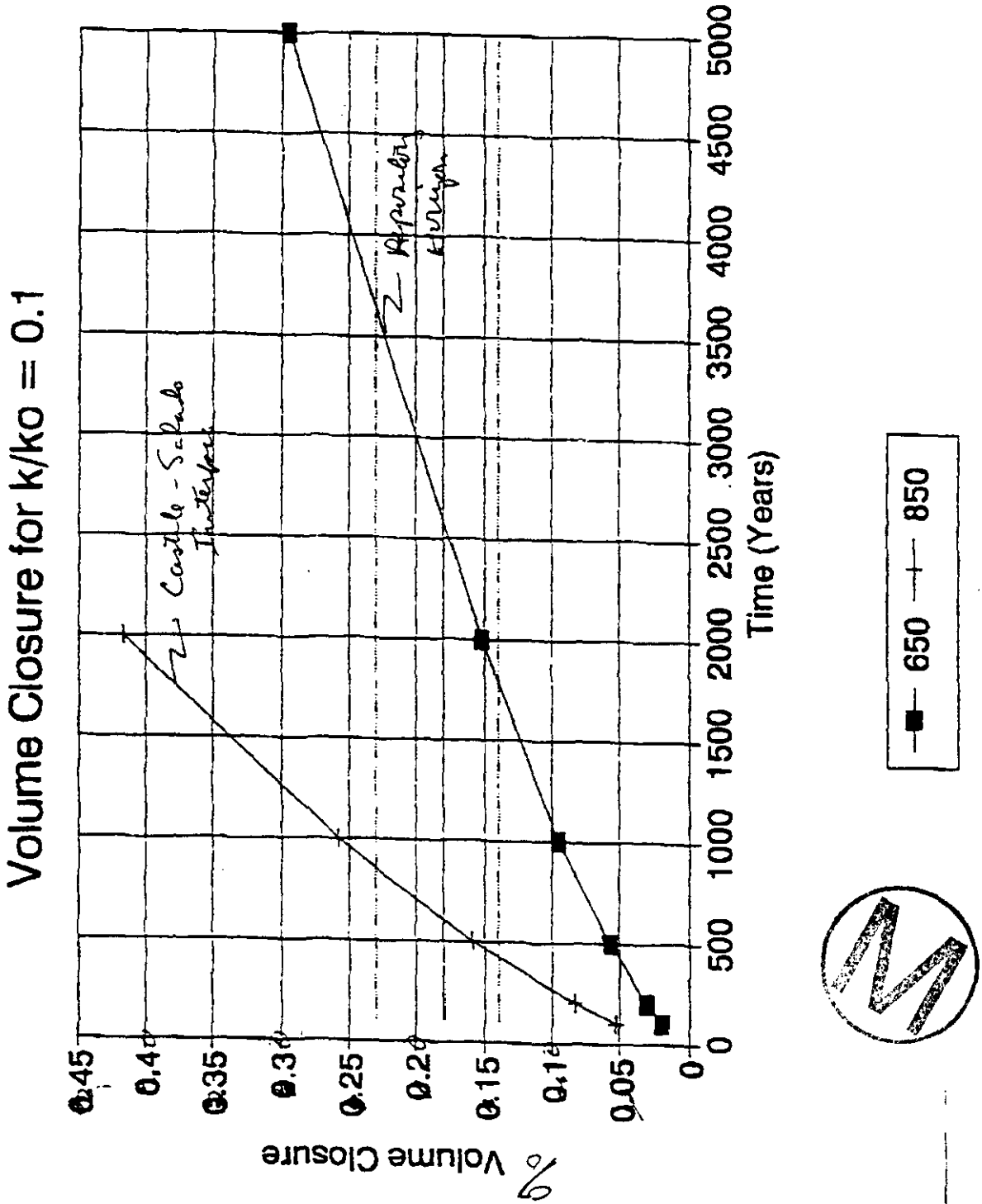
Volume Closure for k/ko = 0.1
Volume Closure
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time (Years)
650
850

Figure 9

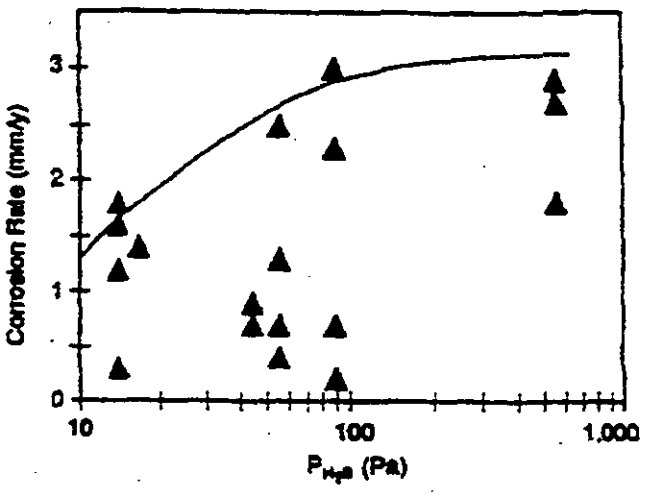

Corrosion rate of low carbon steel in carbon dioxide saturated solutions as a function of the partial pressure of hydrogen disulfide (from Videm and Kvarekval, 1995)

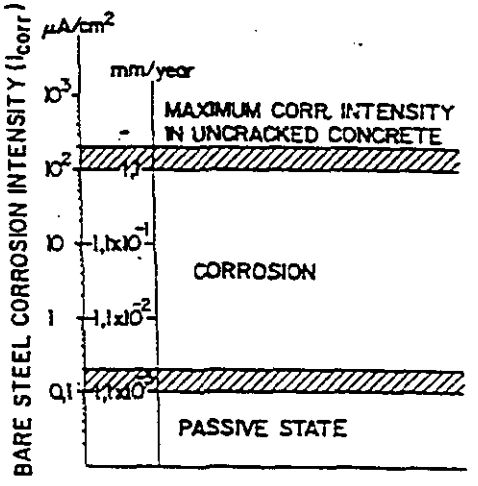

—Values of corrosion intensity in μA/cm² and in mm/year which may be measured in concrete. Below the range 0.1 to 0.2 μA/cm² the amount of corrosion is negligible. Between this range and until 100 to 200 μA/cm², corrosion is active and brown oxides develop. Values above 100 to 200 μA/cm² were never recorded in uncracked concrete.

Figure 10 Degradation of "HTS" in standard marl grundwater "MAR". After 6650 cycles calcite is the only solid phase present (T = 25 °C).

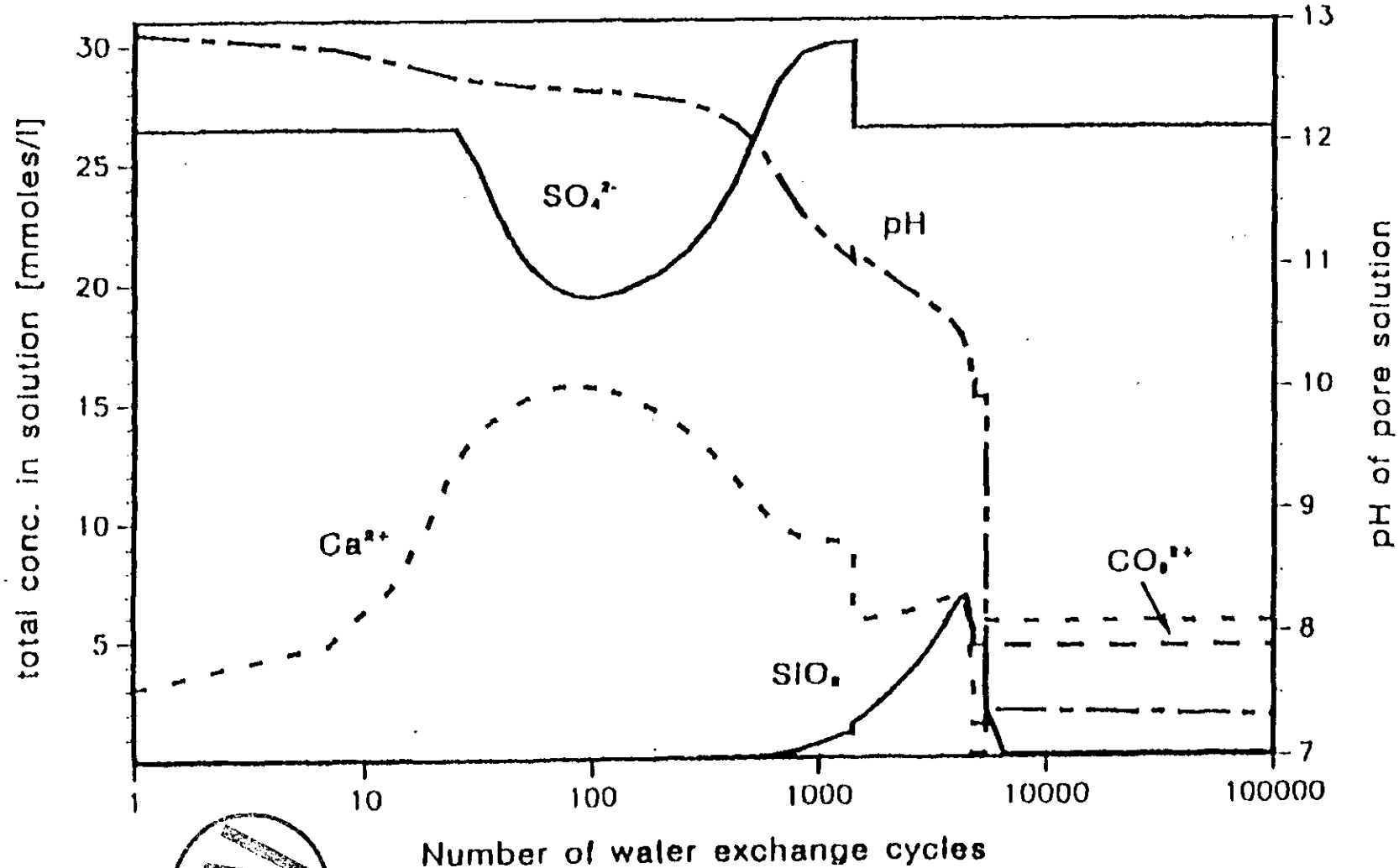

Permeability Changes in a 3 Plug Scenario

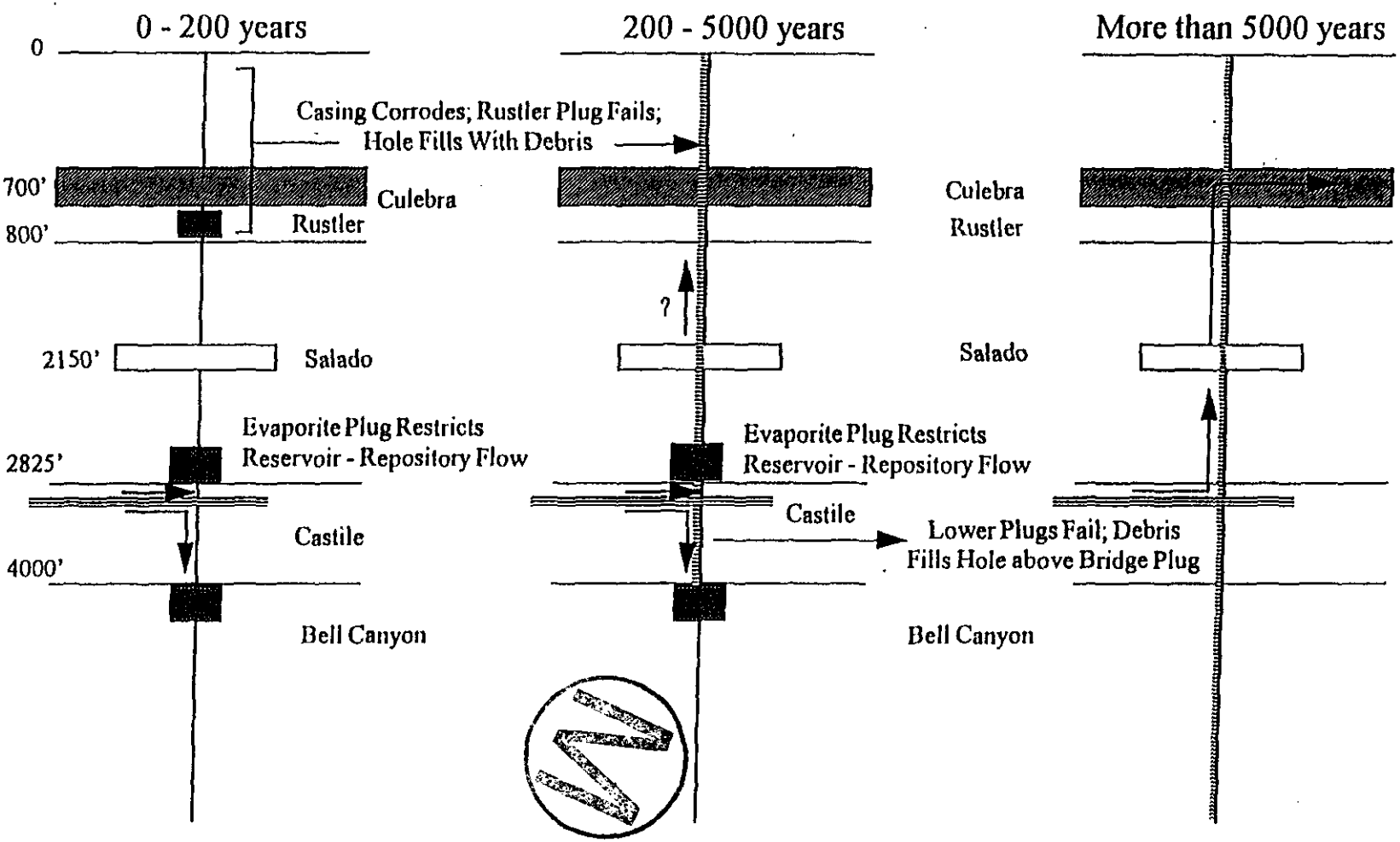

Permeability Changes in a 2 Plug Scenario

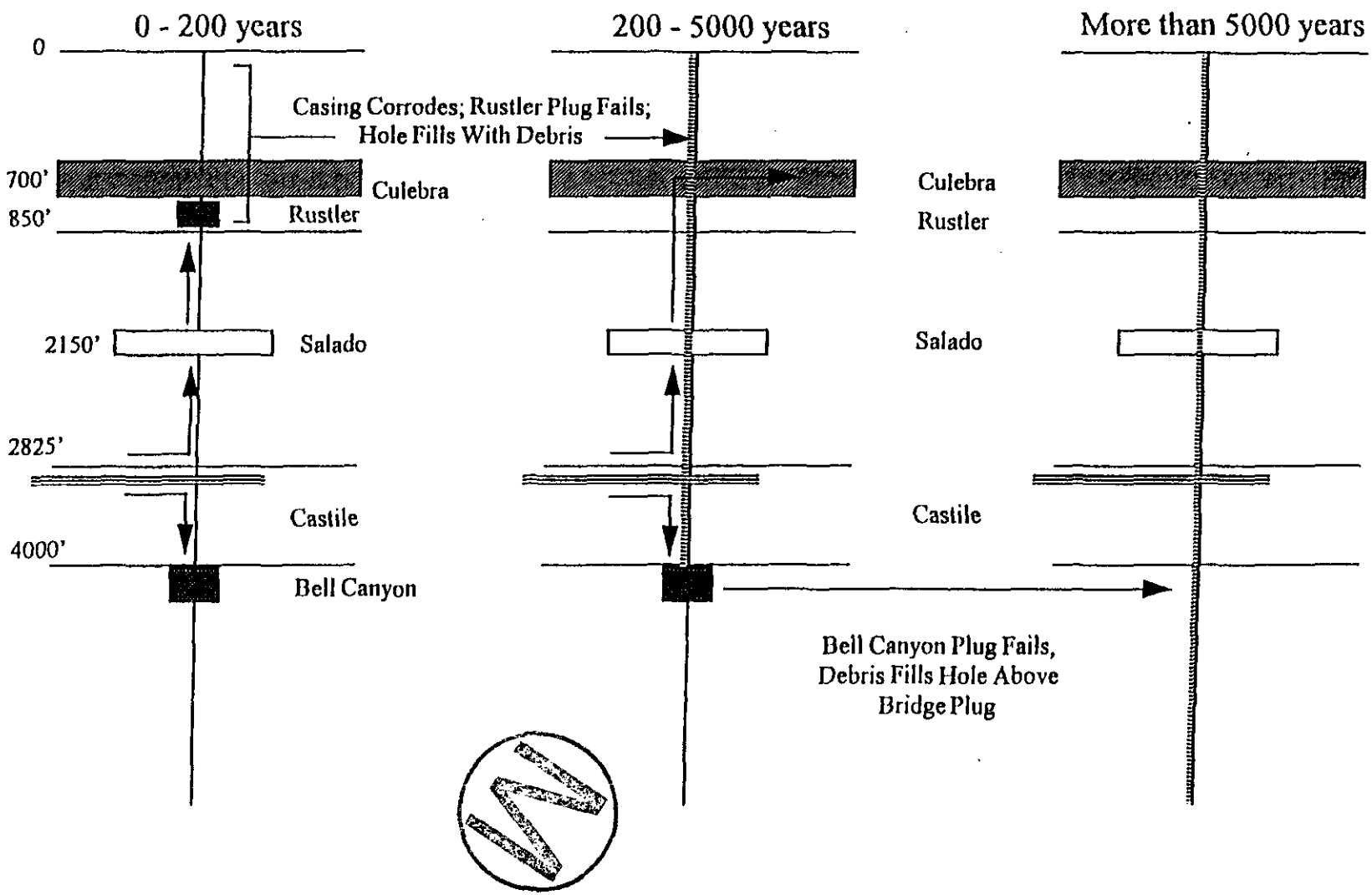

Table 1: Hydraulic Properties of Borehole Plugs as a Function of Time: 2 Plug Scenario

Location of Plugs: Top of Bell Canyon; Bottom of Rustler (Below Culebra)
Length of Plugs: 40 m.

Years After Abandonment	Castile - WIPP Repository	WIPP - Culebra (Rustler Plug)	Culebra - Surface (Surface Plug)	Castile - Bell Canyon (Bell Canyon Plug)
0 - 200	unrestricted	5×10^{-17} m^2	5×10^{-17} m^2	5×10^{-17} m^2
200 - 1200	10^{-11} to 10^{-14} m^2	10^{-11} to 10^{-14} m^2	10^{-11} to 10^{-14} m^2	5×10^{-17} m^2
1200 - 5000	10^{-12} to 10^{-15} m^2	10^{-11} to 10^{-14} m^2	10^{-11} to 10^{-14} m^2	5×10^{-17} m^2
> 5000	10^{-12} to 10^{-15} m^2	10^{-11} to 10^{-14} m^2	10^{-11} to 10^{-14} m^2	10^{-12} to 10^{-15} m^2

Note: Permanent Bridge Plug Assumed at 8,000 feet.

Table 2: Hydraulic Properties of Borehole Plugs as a Function of Time: 3 Plug Scenario

Location of Plugs: Top of Bell Canyon; Between Brine Pocket and Repository; Bottom of Rustler (Below Culebra)
Length of Plugs: 40 m.

Years After Abandonment	Castile - Lower Salado (Salado Plug)	Lower Salado - Repository	Repository - Culebra (Rustler Plug)	Culebra - Surface (Surface Plug)	Castile - Bell Canyon (Bell Canyon Plug)
0 - 200	5×10^{-17} m^2	unrestricted	5×10^{-17} m^2	5×10^{-17} m^2	5×10^{-17} m^2
200 - 1200	5×10^{-17} m^2	10^{-11} to 10^{-14} m^2	10^{-11} to 10^{-14} m^2	10^{-11} to 10^{-14} m^2	5×10^{-17} m^2
1200 - 5000	5×10^{-17} m^2	10^{-12} to 10^{-15} m^2	10^{-11} to 10^{-14} m^2	10^{-11} to 10^{-14} m^2	5×10^{-17} m^2
> 5000	10^{-12} to 10^{-15} m^2	10^{-12} to 10^{-15} m^2	10^{-11} to 10^{-14} m^2	10^{-11} to 10^{-14} m^2	10^{-12} to 10^{-15} m^2

Note: Permanent Bridge Plug Assumed at 8,000 feet.

APPENDIX A:
REGULATORY BASIS FOR CONSEQUENCE ANALYSIS OF BOREHOLES

Sharla G. Bertram
Sandia National Laboratories

This Appendix describes the regulatory framework, then discusses the pertinent requirements from 40 CFR Part 194 for consideration of boreholes. Although the main report focuses on a deep borehole that penetrates the underground repository, the context for borehole analyses is much broader.

A.1 REGULATORY FRAMEWORK

On February 9, 1996, the EPA published "Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations" (40 CFR Part 194, 61 FR 5224-5242). An implicit hierarchy of authority consisting of legislative mandates, regulatory language, and supporting documentation must be considered when applying the rule. The Nuclear Waste Policy Act of 1982, as amended (42 U.S.C. 10101–10270) and the Waste Isolation Pilot Plant Land Withdrawal Act (P.L. 102-579) provide the foundation upon which the implementing regulations, 40 CFR Parts 191 and 194, are based[1]. Supporting documents for 40 CFR Part 194 include:

- the Supplementary Information (SI) published with the final 40 CFR Part 194 (EPA, 1996a),
- the Background Information Document (BID) for 40 CFR Part 194 (EPA, 1996b),
- the Response to Comments Document (RCD) for 40 CFR Part 194 (EPA, 1996c),
- the SI published with the proposed 40 CFR Part 194 (EPA, 1995), and
- the Compliance Application Guide (CAG) (EPA, 1996d).

With respect to the regulations and their supporting documents, the following hierarchy exists:

1. The language found in the regulations (40 CFR Parts 191 and 194) is controlling in all cases, since the regulations bear the "force of law." Where inconsistencies occur between the wording in the regulations and related discussions in the SI, BID, RCD, or the CAG, the regulations always take precedence.

[1] Interpretation of 40 CFR Part 194 requires consideration of 40 CFR Part 191, its technical bases, and the Supplemental Information (SI) published with Part 191 in 1985 (50 FR 38066) and in 1993 (58 FR 66398). The SI's for Part 191 continue to apply except where Part 194 modifies them.

2. The SI ("supporting rationale" or "preamble") published in the *Federal Register* with both the proposed and final rules is, after the regulatory language itself, the most authoritative source for interpreting the rules. In addition, an implicit hierarchy exists between the SI for a proposed rule and the resulting final regulation. In cases where there is no significant change between a proposed requirement and the final requirement, the SI for the proposed rule continues to be applicable. In cases where the proposed rule is changed, the SI for the final rule becomes controlling. This interpretation is supported by the statement in the SI for the final Part 194 which states that "[T]hose sections of the final rule which have remained unchanged since the rule's proposal are also further explained in the notice of proposed rule (60 FR 5766–5791)" (61 FR 5225). The SI for the final Part 194 states at 61 FR 5225 that "[T]he supporting rationale for today's action, found in the following summary and discussion of principal changes, **is further explained** in the Background Information Document and the Response to Comments which accompany today's action" (emphasis added).

3. The EPA publishes, coincidentally with both proposed and final regulations, a BID that is intended to further explain the Agency's considerations in developing the rule. Again, the BID for the final rule takes precedence over the BID for the proposed rule, except where no changes have been made. The BID for the final rule states in its Introduction (EPA, 1996b) that: "[T]he final preamble and regulation to 40 CFR part 194, as they appear in the Federal Register, take precedence over any descriptions or interpretations of the final rule that appear in this document."

4. Upon publication of a final rule, the EPA publishes an RCD, in which the Agency responds to public comments submitted to the Docket regarding the proposed rule. In terms of the hierarchy for Part 194, the RCD (EPA, 1996c) is assumed to take precedence over the BID because the RCD contains no disclaimer regarding status vis-à-vis either the BID or the final rule and preamble. This interpretation is supported by the reference to the RCD and the BID in the SI for Part 194, quoted above.

5. The CAG (EPA, 1996d), published as a companion to the final 40 CFR Part 194, is subsidiary to the rule as well as to all of the other supporting documents. The CAG was issued by EPA as simply a guidance document. The EPA states in a Disclaimer to the CAG that "[T]he CAG is intended solely as guidance. The CAG does not establish compliance criteria or any other binding rights and duties...Any inconsistencies between the CAG and the...final rule are wholly inadvertent and, in all circumstances, the final rule is dispositive of any inconsistencies."

A.2 CONSIDERATION OF BOREHOLES IN 40 CFR PART 194 AND SUPPORTING DOCUMENTS

The final rule requires that boreholes drilled within the controlled area and its vicinity be evaluated in performance and compliance assessments. The rule establishes requirements for consideration of borehole drilling, use, and abandonment in sections 194.32, 194.33, and 194.54. The rule also establishes requirements for consideration of future technological capabilities and practices of humankind in section 194.25 and these requirements must be considered in conjunction with sections 194.32, 194.33, and 194.54. Definitions pertinent to borehole modeling are found in section 194.2 of the rule. This appendix discusses the regulatory basis established by the rule for consequence analysis of boreholes. The likelihood of drilling is not considered here.

A.2.1 Future States Assumptions Applicable to Modeling of Boreholes

Because the rule applies today's conditions to the future, we must first consider the "future states" requirements. The rule states that:

> *§ 194.25 Future state assumptions.*
> *(a) Unless otherwise specified in this part or in the disposal regulations, performance assessments and compliance assessments conducted pursuant the provisions of this part to demonstrate compliance with §191.13, §191.15 and part 191, subpart C shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions.*

This requirement is interpreted to mean that, for the purposes of performance assessments and compliance assessments, that only naturally occurring processes and events will change during the period of regulatory concern. Societal, technological, and economic factors of today can be assumed to be in effect for the entire time period of regulatory concern. Indirect anthropogenic effects on repository performance need not be considered.

The SI (EPA, 1996a) published with the rule states that:

> The Agency recognizes the inherently conjectural nature of specifications on future states and wishes to minimize such speculation in compliance applications. The Agency has found no acceptable methodology that could make reliable predictions of the future state of society, science, languages or other characteristics of future mankind. DOE shall assume that [these] present day conditions will exist in their present state for the entire 10,000-year regulatory time frame.

This means that the economic or societal conditions that would motivate human activities, the technological approaches taken in human activities, and the legal requirements that bound human

activities must all be assumed to remain the same as prevail on the day that the compliance application is submitted to the EPA (considered to be "today"). Considerations of resource exploration and exploitation between today and sealing of the repository shafts should be limited to those activities that are currently occurring in the vicinity of the WIPP and can be expected to continue to occur given today's economic conditions. Laws and regulations of the State of New Mexico and of the U.S. Department of the Interior should be assumed to govern the practices associated with resource exploration and recovery within the New Mexico portion of the Delaware Basin.

A.2.2 Scope of Analysis of Borehole Drilling for Performance Assessment

Conditions for "undisturbed performance" and for "disturbed performance" are established by the rule.

> *§ 194.32 Scope of performance assessments.*
> *(a) Performance assessments shall consider natural processes and events, mining, deep drilling, and shallow drilling that may affect the disposal system during the regulatory time frame.*
> *(c) Performance assessments shall include an analysis of the effects on the disposal system of any activities that occur in the vicinity of the disposal system prior to disposal and are expected to occur in the vicinity of the disposal system soon after disposal. Such activities shall include, but shall not be limited to, existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities.*

The requirement 194.32(c) is interpreted to mean that, for the purposes of performance assessment, activities outside of the Land Withdrawal Area (controlled area) that occur prior to or are initiated before disposal must be evaluated for their possible effects on performance of the disposal system. The effects of any activities, including borehole drilling, completion, and plugging, and all types of resource extraction activities that have occurred or may be initiated prior to shaft sealing, and that can significantly affect radionuclide transport, must be included. These activities are considered to be part of the "undisturbed performance" of the disposal system. Effects of abandoned boreholes must be evaluated over 10,000 years. "Vicinity" means the area adjacent to but outside of the controlled area and extends far enough to include any activities that can affect the disposal system within the 10,000 years of regulatory concern.

The SI (EPA, 1996a) states that:

> In today's final rule, the Agency requires that performance assessments and compliance assessments must include -- among other processes and events -- the effects on the

> disposal system of drilling and all types of resource extraction activities, including inter alia solution mining and fluid injection, that will have occurred prior to the time at which the compliance application is prepared or that may be expected to occur soon afterward based on existing plans and leases for drilling.

This means that analyses of postclosure (after sealing of the repository shaft system) disturbed performance need consider only natural processes and events, mining, deep drilling, and shallow drilling. Preclosure activities are not limited to those required to be considered for postclosure disturbances. Undisturbed conditions that form the base case for the performance assessment must consider the effects on the disposal system over the long term of any human activities that are occurring in the vicinity of the disposal system today. Continued occurrence or initiation of new occurrences of the same activities in the near future must also be considered, if reasonably expected under today's conditions. Activities expected to be under way at the time of shaft sealing should be assumed to continue to their planned completion. The SI (EPA, 1996a) for the final rule recognizes three categories of drilling that have a time component.

> Sections 194.32 and 194.33 of the final rule require that performance assessments include the effects of both deep drilling and shallow drilling, whether such drilling has occurred prior to the time at which the compliance application is prepared, can be reasonably expected to occur in the near future based on existing leases, or can be expected to occur in the future during the 10,000-year regulatory time frame.

Because human activities initiated after shaft sealing will begin more than 30 years from today and the history of such activities covers only 100 years, attempting to project new activities is not reasonable. For this reason, no activities initiated after shaft sealing should be considered for undisturbed performance. "Near future" thus would be defined as the period between today and the time of shaft sealing, but would include completion of ongoing activities (e.g., for the typical "lifetime" of an oil or gas well today).

Projections of human activities for the "near future" need consider only existing leases and plans. Because proprietary plans are not likely to be available, only publicly available information should be considered as plans. Because existence of a lease does not guarantee that resource exploration and exploitation will occur, economic considerations should take precedence over leases and plans in projecting activities.

Both shallow drilling and deep drilling activities must be considered to continue to occur as they are today. Section 194.2 of the rule defines both drilling events. "Deep drilling" denotes those drilling events that reach or exceed a depth 2150 feet below the surface where such drilling occurred. "Shallow drilling" denotes those drilling events that do not reach to a depth 2150 feet below the surface where such drilling occurred.

The requirement in section 194.32(c) defines undisturbed performance, because similar language in 194.54 requires the same considerations, and 194.54 applies to undisturbed performance only.

The RCD (EPA, 1996c) corroborates this interpretation (see Issue 7.D.10): "It is reasonable to assess the undisturbed performance of WIPP to fully consider the realities of the site-specific conditions."

Examining the interaction of boreholes is supported by the language of the SI (EPA, 1996a), which states that "When analyzing the effects of all later boreholes, performance assessments must account for the effect that these existing boreholes will have had on the hydrogeologic properties of the disposal system and on the creation of new pathways for releases."

The SI (EPA, 1996a) indicates three time frames when considering activities that may affect the disposal system: first, occurred prior to the submittal of the Compliance Certification Application (CCA) (i.e., "historical" time); second, expected to occur prior to disposal or soon after disposal i.e., ("near future" time); and third, assumed to occur after disposal (i.e., "future" time). Activities during the first and second time frames are defined by 194.32(a) and 194.32(c) to occur in the **vicinity** of the disposal system (i.e., in the vicinity of the controlled area by DOE's definition of disposal system), and are prevented from occurring within the controlled area during the period of DOE control. It is important to note that only those activities currently taking place in the vicinity of the disposal system need be considered for projection into the near future. Historical activities (e.g., nuclear testing) need not be projected into the near future. It will be necessary for the DOE to determine what human activities will be initiated prior to repository closure, but will end after repository closure (after being carried to the reasonable completion of the activity), and to assess the duration and long-term impacts of those activities. For example, if a permit application for an injection well at a given location is predicted to be submitted to the appropriate regulatory authority by the lessee of the resource prior to repository closure, then the associated fluid injection activity would be projected to its completion for the borehole in question.

Consideration of drilling activities during the third time frame is limited by 194.33 to locations where drilling may affect the disposal system, by 194.33(d) to the act of drilling and the effects of the abandoned borehole (excluding any resource recovery subsequent to drilling), and by the institutional controls (194.41 and 194.43) to some future century when passive institutional controls (PICs) are ineffective. Future human activities are part of disturbed performance and are to be considered in evaluating compliance with the Containment Requirements of 40 CFR Part 191. All "near future" and "future" activities are limited by the Future States requirements (194.25) as discussed in Section A.2.1 above.

The distinction between "near future" and "future" is vague in both the SI and the rule. The rule says consider "near future" activities occurring after disposal. The logical way to define "near future" is to consider the continuation of any activity that is initiated prior to shaft sealing (preclosure) by predicting the end of that activity at some reasonable date after shaft sealing (postclosure). The demarcation between "near future" and "future" is assumed to be the date of shaft sealing (closure). The CAG (EPA, 1996d, Section 194.32) states that:

> The EPA recommends that the terms 'near future' and 'soon after disposal' for oil and gas drilling be considered to consist of the expected lives of the oil and gas fields in existing leases that can reasonably be expected to be developed in the vicinity of the WIPP.

Considerations of resource exploration and exploitation between today and sealing of the repository shafts should be limited to those activities that are currently occurring in the vicinity of the WIPP and can be expected to continue to occur given today's economic conditions, existing leases, and plans. Laws and regulations of the State of New Mexico and of the U.S. Department of the Interior should be assumed to govern the practices associated with resource exploration and recovery. Furthermore, the Future States requirement (194.25(a)) limits consideration of the "near future" to activities that could be undertaken given today's economic conditions, technology, and regulations. For example, the Future States requirement limits this CAG guidance to today's economics regarding the continued exploitation of the target oil or gas "field" for a given lease. If secondary or tertiary recovery are not economic today, they need not be considered.

Hence, drilling activities that are **initiated** subsequent to repository closure should be considered to be future activities and, as such, performance assessments need only consider the impacts of the process of drilling the borehole and the condition of the borehole after abandonment. The impacts of the use of a future borehole are specifically excluded from performance assessments. This concept is supported by the RCD (EPA 1996a, Issue 19.R):

> Section 194.54 limits the scope of compliance assessments to undisturbed scenarios; only existing boreholes and other activities which **occur before disposal** must [be] accounted for in compliance assessments (since such current human activities constitute part of the baseline site characterization) (emphasis added).

The RCD takes precedence over the CAG, as discussed in Section A.1 above.

In the RCD (Issue 12.J.4), EPA states:

> The boreholes resulting from such activities shall be analyzed for their effects on the properties of the disposal system for this entire 10,000-year regulatory time frame. Predictions about the effects of such existing boreholes should be based on the actual characteristics of the boreholes, as far as it is practicable to determine them. Such characteristics would include drilling, completion, and plugging procedures.

A.2.2.1 Constraints on Conditions of the Borehole

The manner in which the DOE must assess the impacts from drilling are specifically addressed in Part 194. Beyond the requirements presented in §194.32, as discussed above, the EPA addresses the consideration of drilling in performance assessments in §194.33.

§ 194.33 Consideration of drilling events in performance assessments.
(a) Performance assessments shall examine deep drilling and shallow drilling that may potentially affect the disposal system during the regulatory time frame.
(b) The following assumptions and process shall be used in assessing the likelihood and consequences of drilling events, and the results of such process shall be documented in any compliance application:
(1) Inadvertent and intermittent drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario.
(c) Performance assessments shall document that in analyzing the consequences of drilling events, the Department assumed that:
(1) Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared. Such future drilling practices shall include, but shall not be limited to: the types and amounts of drilling fluids; borehole depths, diameters, and seals; and the fraction of such boreholes that are sealed by humans; and
(2) Natural processes will degrade or otherwise affect the capability of boreholes to transmit fluids over the regulatory time frame.
(d) With respect to future drilling events, performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole.

This requirement is interpreted to mean that, for the purpose of performance assessment:

(a) All possible locations in the Delaware Basin, both within and outside of the boundary of the Land Withdrawal Area (LWA), must be examined to determine whether either shallow or deep boreholes at particular locations, either alone or in combination with other shallow or deep boreholes, could potentially affect the disposal system, e.g., by modifying ground-water flow and associated phenomena within the disposal system. The vicinity for this analysis is the area within which such drilling can affect the performance of the disposal system during the 10,000 years of regulatory concern.

(b) When considering human actions that directly penetrate the waste, the most severe action that must be analyzed is drilling for natural resources by drill crews who are unaware of the presence and contents of the repository. Both exploratory and developmental drilling must be considered.

(c)(1) Performance assessments should be based on a defensible analysis of current drilling technology and borehole drilling and sealing practices, considering applicable regulations in effect in the Delaware Basin at the time the certification application is prepared. The assessment should be adjusted to realistically reflect the extent to which applicable requirements are actually satisfied. The rate at which boreholes are sealed can be based on the sealing rate since the effective date of pertinent regulations for boreholes (hydrocarbons,

potash, and water each considered separately) within the portion of the Delaware Basin containing similar resources to those in the vicinity of the WIPP. The sealing practice can be based on the practice for boreholes in the vicinity of the WIPP. "Vicinity" can be defined by the extent of the Salado Formation on Federal lands within the Delaware Basin in the State of New Mexico, for the purposes of establishing the sealing-practice data base. A deep borehole can be assumed to remain uncased at the repository horizon for three days during drilling.

(c)(2) The hydraulic conductivity of boreholes can be assumed to change after the hole is abandoned. This property may increase or decrease depending on the drilling practice (presence of casing and sequence of casing and grout), sealing practice (on abandonment) for a particular borehole, and the chemical and mechanical processes affecting the casing, grout, seals, and host rock after the hole is abandoned.

(d) In analyzing **future** boreholes under the Containment Requirements of 40 CFR Part 191, the only effects that need to be considered are the drilling of the borehole and the potential for the subsequently abandoned borehole to act as a pathway for ground-water flow. Any effects on the disposal system resulting from the use of boreholes for any post-drilling activities can be excluded from the analyses.

The effectiveness of borehole seals[2] is required to be assumed to change over time, either degrading or improving, depending on the processes acting on the seals.

Taken together, §§194.25, 194.32, 194.33 and 194.54 require that the DOE assess the impacts of boreholes in three distinct phases. The first phase includes those boreholes abandoned prior to the current regulations (about 1988) requiring specific sealing practices. The types and uses of boreholes that must be considered are those that occurred historically in the Delaware Basin, including the controlled area, and that could affect the long-term performance of the disposal system. Performance assessments and compliance assessments must include the long-term impacts from both plugged and unplugged boreholes in assessing the undisturbed performance of the disposal system. The number of plugged and unplugged boreholes and their uses should be based upon currently available data. In the RCD (EPA 1996c, Issue 12.J.4), EPA states:

> The boreholes resulting from such activities shall be analyzed for their effects on the properties of the disposal system for this entire 10,000-year regulatory time frame. Predictions about the effects of such existing boreholes should be based on the actual characteristics of the boreholes, as far as it is practicable to determine them. Such characteristics would include drilling, completion, and plugging procedures.

The second phase that must be considered in performance assessment and compliance assessment includes boreholes abandoned after 1988 but initiated prior to sealing of the repository shafts.

[2] Sealing includes grouting between the casing and the host rock and grouting inside the casing.

The types and uses of boreholes that must be considered are those that are occurring today in the vicinity of the WIPP. Current field practices are to be assumed for these boreholes (194.33(c)). While both performance assessments and compliance assessments must consider these boreholes in assessing undisturbed performance, they can do so assuming that the holes have been sealed in accordance with the appropriate regulatory guidelines (194.25(a)). The primary distinction between these boreholes and those in the previous phase is that the State of New Mexico Oil Conservation Division (OCD) regulatory requirements (Order R-111-J) on borehole sealing apply to those drilled on State or private lands after 1988. The OCD implementing regulation (Rule 202) states that "before any well is abandoned, it shall be plugged in a manner which will permanently confine all oil, gas, and water in the separate strata originally containing them." Regulations of the U.S. Dept. of the Interior are implemented by the Bureau of Land Management (BLM). Those regulations also stipulate plugging practices, and the BLM strives for consistency with the NM OCD. The BLM regulations have been consistently enforced since about 1990. While these requirements apply to drilling of oil and gas wells, other requirements relating to potash exploration and groundwater protection would also apply to boreholes where appropriate.

The third phase includes those boreholes initiated after the repository has been sealed. These boreholes are assumed to be drilled, completed, and abandoned exactly as those in the second phase, but the EPA considers these "future" boreholes to be disturbed performance and excludes them from compliance assessments (194.54(a)). Part 194 requires that performance assessments must consider future boreholes, but limits the impacts to the effects of drilling and the subsequent condition of the abandoned borehole with respect to the transmission of fluids. Any use of the borehole is excluded from consideration, but the effects on the hydrogeologic state of and possible spread of contaminants through the disposal system resulting from natural or waste- and repository-induced flow into near-miss boreholes and flow through boreholes to units above or below the Salado must be considered in performance assessments.

Once a borehole is drilled and sealed, the borehole will affect the disposal system indefinitely into the future. The specific concerns stated in the SI (EPA, 1996a) are affects on the hydrogeology and the creation of new pathways for radionuclide releases.

> Further, boreholes drilled after closure of the repository shall be assumed to affect the properties of the disposal system for the remainder of the 10,000-year regulatory time frame. When analyzing the effects of all later boreholes, performance assessments must account for the effect that these existing boreholes will have had on the hydrogeologic properties of the disposal system and on the creation of new pathways for releases.

The SI (EPA, 1996a) repeated essentially the same language as section 194.33 with regard to future drilling practices and sealing rates. The proximity of this language on seals to the discussion of future sealing rates indicates that EPA is discussing the future and not the past.

> Section 194.33 requires performance assessments to make several specific assumptions about future deep drilling and shallow drilling. These assumptions include that drilling will

> occur randomly in space and time and may occur at different rates for each resource, and that drilling practices will remain as those of today and may vary depending on the resource. Performance assessments should assume that the permeability of sealed boreholes will be affected by natural processes, and should assume that the fraction of boreholes that will be sealed by man equals the fraction of boreholes which are currently sealed in the Delaware Basin.

Considering the future states requirements, "fraction currently sealed" can be interpreted to mean the fraction of future boreholes sealed under today's State and Federal laws, regulations, and enforcement practices. The SI (EPA, 1996a) further instructs that the analyses must consider affects of drilling for each resource separately. The resources associated with borehole drilling today are water (shallow drilling), potash (shallow exploration drilling), and hydrocarbons (deep drilling).

> The Agency recognizes that drill operators currently employ different techniques in the exploration and development of each resource. Hence, performance assessments shall conduct a separate analysis of the effects that future drilling for each different resource -- the act creating a borehole -- will have on the disposal system. Each separate analysis should set the future rate of drilling for the particular resource equal to the historical rate at which that resource has been drilled for in the Delaware Basin during the past 100 years. The analyses of the consequences of each type of drilling might remain conceptually similar, but vary with regard to assumptions made on size and depth of boreholes, quantity of drilling fluid used, or any other characteristic specific to that type of resource. Analyses of the consequences of future drilling events may be confined only to the drilling activity and the subsequent effect of the borehole's presence and need not include an analysis of extraction and recovery activities which would occur subsequently.

Analyses of consequences of borehole drilling cannot assume that drillers will recognize the hazards associated with drilling into the disposal system, nor can one intrusion be assumed to deter another.

The vicinity within which either shallow or deep drilling must be analyzed can be defined as the area in which the drilling or the abandoned borehole can affect the disposal system within the 10,000 years of regulatory concern. The vicinity for deep drilling is not necessarily the same as the vicinity for shallow drilling. In the RCD (EPA, 1996c, Comment 12.B.1), the EPA states

> In performance assessments, scenarios involving human intrusion anywhere in the Delaware Basin must be analyzed if they could have an effect on the repository, per §194.32(a). Section 194.32 establishes the scope of processes and events that need be considered in performance assessments (PA). The final rule logically limits the scope of PA to those events that may affect the disposal system during the regulatory time frame [§194.32(a)].

The EPA clearly considers penetration of the lithosphere anywhere in the Delaware Basin to be human intrusion. Furthermore, mining is considered to be intrusion, even though the mining being considered does not intersect the repository. The response to comments 12.B.2-12 in the RCD (EPA, 1996c) contains this logic:

> In §194.32 and §194.33 of the final rule, the Agency has provided further clarification on which activities fall within the scope of human intrusion, and, in response to public comments, has modified the terms used to avoid confusion. Section 194.33 of the final rule requires that two types of activities be analyzed—deep drilling and shallow drilling. Deep drilling (referred to as "human intrusion" in the proposed rule) is defined as drilling events in the Delaware Basin that reach or exceed a depth of 2150 feet below the surface (the level of the waste in the disposal system). Shallow drilling (referred to as "human activity" in the proposed rule) is defined as those drilling events in the Delaware Basin that do not reach a depth of 2,150 feel below the surface relative to where such drilling occurred.
>
> Consistent with the changes in defined terms, §194.33 in the final rule is titled *Consideration of drilling events in performance assessments*.... **This clarifies the Agency's intent that neither deep drilling nor shallow drilling events shall be considered in analyses of undisturbed performance of the disposal system (emphasis added)**. The term human intrusion should not be interpreted as being confined to drilling only. The preamble accompanying the final rule explains the various types of drilling activities encompassed by the terms deep and shallow drilling. Further, as discussed in §194.33(c)(1), those ancillary activities which are associated with drilling, such as borehole sealing, are within the scope of this term. In response to public comments, EPA has also required consideration of excavation mining events as described in §194.32(b). The consideration of human intrusion is limited to those events which are made without knowledge of the repository's presence. This type of event would constitute an 'inadvertent intrusion.'

The key to interpreting the requirement in 194.33(b)(1) is the word "severe." No definition for this term is provided in the rule or the SI. "Severe" could mean either enhancing transport of radionuclides out of the engineered facility (repository) or disrupting the geohydrologic conditions within the disposal system. Because 194.32 requires that the performance assessment include effects of mining, which has a much greater impact on the geohydrology of the disposal system than does a borehole, "severe" must refer to enhancing transport of radionuclides from the engineered facility. Based on this rationale, drilling penetrations of the disposal rooms are the most severe human intrusion into the repository that must be included in performance assessment. This does not preclude consideration of a borehole penetrating a plume of radionuclides elsewhere in the disposal system. This conclusion is supported by the EPA's statement in the BID (EPA, 1996b, Section 9.1) that

> These criteria are based on the assumption that inadvertent and intermittent drilling for resources is the most severe scenario to be considered when addressing human intrusion for performance assessment calculations because it provides a direct intersection with the waste and a pathway to the surface. Mining of resources is a very important, though less direct form of a human-initiated process or event.

Subsequent discussions in the BID (sections 9.1 and 9.3.2-4) on shallow drilling corroborate that the analyses must also consider drilling that encounters strata "contaminated with radioactivity from the repository. Therefore, the borehole permeability model should also be applied when analyzing intrusion into a contaminant plume, as well as when considering whether a borehole that does not penetrate any contaminated zone can affect performance of the disposal system

The CAG (EPA, 1996d) states that the compliance application is expected to:

> demonstrate that exploratory and development wells were included in the analysis of inadvertent and intermittent intrusion by drilling for resources and the manner in which they were evaluated.

A.2.2.2 Drilling Practices

The EPA has stated that drilling practices used in the Delaware Basin at the time the application is prepared can be assumed to be the drilling practices for the entire time of regulatory concern. This is consistent with the future states requirements (194.25). The requirement deals with documenting assumptions about drilling activities. The CAG (EPA, 1996d) states that the compliance application is expected to identify:

> current drilling practices in the Delaware Basin; the current drilling practices that affect performance assessments; types and amounts of drilling fluids; borehole depths typically used; borehole diameters typically used; seals typically used; the fraction of boreholes sealed by humans today; and the source(s) of the above information.

Review of the SI, BID, and the RCD for 40 CFR Part 194 leads to the conclusion that the EPA intends that performance assessments realistically address today's practices and conditions in the Delaware Basin.

The SI (EPA, 1996a, p. 5230, Col. 2) states

> Section 194.33 requires performance assessments to make several specific assumptions about future deep drilling and shallow drilling. These assumptions include...that drilling practices will remain as those of today and may vary depending on the resource. Performance assessments...should assume that the fraction of boreholes that will be sealed by man equals the fraction of boreholes that are currently sealed in the Delaware Basin....

In its first set of comments on proposed Part 194 (EPA Air Docket IV-D-10, April 27, 1995), SNL observed that the proposed rule was internally inconsistent in that one section stated that boreholes should be considered to be sealed at a rate representative of the sealing practices for the last 50 years, while another section refers to "current " practices. To resolve the inconsistency, SNL suggested that 194.33 be revised to state that "Boreholes will be sealed **consistent with current drilling practices** in the Delaware Basin." EPA, in its RCD, responded (EPA, 1996c, Issue 12.E) that

> [T]reatment of sealing of boreholes must assume, per section 194.33(c) of the final rule, that borehole depths, diameters, and seals will remain consistent with current practice in the Delaware Basin. In addition, an examination of current practice must be used to determine the fraction of boreholes which are sealed by humans...."

In its supplementary comments on proposed Part 194 (EPA Air Docket No. A-92-56, September 13, 1995), SNL re-iterated the earlier comment, and expanded it further by stating that "[S]ealing practices have improved considerably over the past 50 years, and credit should be allowed for this improvement." "In the context of borehole seals, *current practice* (194.33) and *today* (194.25) should refer to those rules and regulations issued by the State of New Mexico and in effect at the time of the final PA analyses regarding the abandonment and plugging of wells." In response to this comment, EPA in the RCD (EPA, 1996c, Issue 12.J.3) simply re-iterates the content of 194.33(c)(1), but then goes on to state that

> [T]he analyses of current practice must be substantiated in any compliance application, showing references and the factual basis used to establish 'current practice'. The Agency believes that the criteria in the final rule provide adequate direction to DOE.

The EPA in its response does not refer to any specific borehole sealing regulations and requirements. The response noted above does appear, however, to implicitly recognize that such an approach on the part of DOE would be acceptable, if justified.

Section 9 of the BID (EPA, 1996b), "Consideration of Human Intrusion" contains an extensive discussion of drilling and borehole sealing in the Delaware Basin, including State and Federal (BLM) permitting and drilling and casing practices (Sections 9.3.1,1 and 9.3.1.2

respectively). Specifically, Section 9.3.1.4 (Borehole Plugging and Abandonment) relates plugging techniques to BLM and State requirements but observes that:

> [T]he number of unplugged boreholes drilled **prior to the more stringent institutional controls now employed** is unknown, but has been characterizes as 'many' by OCD field personnel...The issue of unsealed or improperly sealed boreholes must also be factored into analysis of repository integrity.

An evaluation, in context, of the contents of Section 9.3.1.4 leads to a reasonable conclusion that, while EPA may be somewhat skeptical about the degree to which boreholes are sealed, the Agency has no fundamental objection to the Department's reliance on the current regulatory constraints imposed on drillers. The application of *current* institutional (i.e., regulatory) controls as input assumptions for PA must, however, be tempered by a realistic assessment of the existing level of compliance in the Basin, i.e., neither 100% effectiveness nor zero compliance with the applicable regulations is realistic.

Section 9.3.1.5 (Human Intrusion Scenarios) of the BID (EPA, 1996b) supports using realistic borehole-sealing assumptions. The first paragraph of the section (quoted in its entirety) follows:

> In addition to the radioactivity release scenarios involving direct transfer of waste to the surface by a borehole which penetrates the repository, several other scenarios involving human intrusion can be theorized. For example, SNL developed a family of scenarios involving boreholes which penetrate the waste and are then plugged above the overlying transmissive Culebra Member of the Rustler Formation. Solubilized waste then moves up the borehole by brines found in the underlying formations and then, **due to the borehole seal**, laterally through the relatively transmissive Culebra towards the WIPP site boundary (SAN92). **The assumption of borehole sealing depth is consistent with the sealing practices in the area and the regulatory requirements.** The assumption is also reasonably analogous to the other geologic systems that were analyzed **so that DOE should be able to defend** the above scenario" (emphasis added).

Thus, the EPA believes that the presence of a surface plug is consistent with their concept for evaluating borehole seals. Furthermore, the reference to "regulatory requirements" indicates that the Agency is prepared to accept a defensible argument that current practice is indeed constrained by the need to comply with applicable sealing requirements.

The EPA states in the SI (61 FR 5230)

> The analyses of the consequences of each type of drilling might remain conceptually similar, but vary with regard to assumptions made on size and depth

> of boreholes, quantity of drilling fluid used, or any other characteristic specific to that type of resource.

Characteristics of deep drilling vary depending on the stratigraphy, particularly on the presence (or absence) of salt and the thickness of the strata overlying the target horizon. For example, sealing practices are dependent on whether the salt section is present. Therefore, basing sealing practices on boreholes where the stratigraphy is similar to the stratigraphy of the Controlled Area is realistic.

The EPA states in the BID (EPA, 1996b, Section 9.3.1.2):

> If the WIPP site were to be penetrated by inadvertent human intrusion, such an event would occur during drilling through the salt section before the intermediate casing is set. Once the intermediate casing is set in place and the annulus between the casing and the borehole wall is sealed with cement, then the possibility of radionuclide contamination reaching the surface will be prevented as long as the casing remains intact. Typically, casing integrity is demonstrated by pressure testing and ultrasonic logging of the cemented section for bonding between the casing and the cement and between the cement and the formation. It is estimated that this critical section of a borehole would remain uncased for no more than three days during drilling.

A.2.2.3 Conditions in the Abandoned Borehole

The language in 194.33(c)(2) establishes two opposite results. Degradation would result in higher hydraulic conductivity than the borehole had when originally abandoned. The phrase, "Or otherwise affect," allows an alternative result that can lower the hydraulic conductivity. Application of 194.33(c)(1) requires consideration of drilling practice and sealing practice to determine the materials in the borehole and whether the hydraulic conductivity of the materials decreases or increases.

The CAG (EPA, 1996d) states that the compliance application is expected to:

> identify the processes that are expected to affect boreholes over time [and] discuss the portions of the borehole over which particular processes are expected to act. For example, creeping of the salt is one process that could affect a borehole in the salt section, while other processes may affect other portions of a borehole[.]" The application is expected to "discuss the effects that natural degradation are expected to have on the capability of boreholes to transmit fluids; and identify the models in which borehole degradation is addressed.

A.2.3 Scope of Analysis of Borehole Drilling for Compliance Assessment

§ 194.54 Scope of compliance assessments.
(b) Compliance assessments of undisturbed performance shall include the effects on the disposal system of:

> *(1) Existing boreholes in the vicinity of the disposal system, with attention to the pathways they provide for migration of radionuclides from the site; and*
> *(2) Any activities that occur in the vicinity of the disposal system prior to or soon after disposal. Such activities shall include, but shall not be limited to: existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities.*

The SI (EPA, 1996a) states that:

> Section 194.54 defines the scope of compliance assessments. Compliance assessments should be conducted of the undisturbed performance of the disposal system, which, by the definition in section 12 of 40 CFR Part 191, denotes that the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.
>
> The Agency recognizes, however, that resource extraction and fluid injection activities which are currently performed in the Delaware Basin can alter the hydrogeologic properties of the initial state of the disposal system. The final rule requires that performance assessments and compliance assessments analyze the effects of all types of fluid-injection and all boreholes which can have an effect on the disposal system and which have been or will have been drilled prior to or soon after disposal. These boreholes shall be assumed to affect the properties of the disposal system for the entire 10,000-year regulatory time frame. Predictions about such future activities shall be strictly limited to the expected use of existing leases.

Compliance assessments of undisturbed conditions for 40 CFR Part 191 section 15 and Subpart C must consider the effects on the disposal system over the long term of any borehole drilling activities that are occurring in the vicinity of the disposal system today. Continued occurrence or initiation of new occurrences of the same activities must also be considered, if expected to occur on existing leases given today's conditions, up until the time of shaft sealing. Activities under way at the time of shaft sealing should be assumed to continue to their planned completion. For the reasons previously given, activities initiated after shaft sealing should not be considered in analyses of as undisturbed conditions. Preclosure borehole drilling-related activities are the same as those required to be considered as the base case for the performance assessment.

References

U.S. EPA, 1995, Proposed Rule 40 CFR Part 194, Criteria for the Certification and re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations, in *Federal Register* Vol. 60, pp. 5776-5791, January, 1995.

U.S. EPA, 1996a, 40 CFR Part 194, Criteria for the Certification and re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations, in *Federal Register* Vol. 61, pp. 5224-5245, February 1996.

U.S. EPA, 1996b, Criteria for the Certification and re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations, Background Information Document for 40 CFR Part 194, EPA 402-R-96-002, January 1996.

U.S. EPA, 1996c, Criteria for the Certification and re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations, Response to Comments Document for 40 CFR Part 194, EPA 402-R-96-001, January 1996.

U.S. EPA, 1996d, Compliance Application Guidance for 40 CFR Part 194, EPA 402-R-95-014, March 1996.

APPENDIX B: CORROSION OF STEEL

B.1 INTRODUCTION

Corrosion of steel is an important process in the performance of boreholes because the holes will be steel cased, and these casings will physically support the concrete plugs used on abandonment. When the steel casing breaches, formation waters can enter and flow within the borehole, except where this flow is inhibited by an effective plug. If the formation waters are pressurized, as they may be for example in the Castile brine pockets, connection with the inside of the borehole will lead to steep hydraulic gradients across plugs, enhanced flow through the concrete, and accelerated concrete degradation. If the casing corrodes to the point where it ceases to provide physical support for the concrete plug, then the plug will be by-passed, and will eventually fail. Flow around the plug will expose an increased surface area for chemical attack which, combined with the plug's loss of physical confinement, will result in rapid disintegration of the concrete element. Deterioration of the steel casing, which is considered in this Appendix is therefore an important element of plug performance, as are the rate and failure associated with concrete degradation which are discussed in Appendix C.

Corrosion is a process which alters metal materials and causes them to lose both density and strength. The mechanisms and rates with which metals corrode vary with the composition and fine structure of the metal, as well as with variations in the corroding environment. Borehole casing material is "steel", which is a term applied to a wide variety of metal alloys that contain iron as a principal ingredient. As a result, there is no unique corrosion rate or mechanism for "steel". Similarly, there is no unique corrosion environment at WIPP. Rather, there are a number of brine environments in which corrosion is expected. Because of these variabilities, the technical approach taken in this document is to make reasonable simplifications to the composition of the reactants (water and steel), and to attempt to set reasonable limits or brackets on those variables that cannot be simplified or defined.

Estimations of steel corrosion have been derived from both calculations and empirical data. Calculations have relied on traditional concepts embodied in equilibrium thermodynamics, while empirical data have been taken from experiments described in the open literature. Both of these methods have their shortcomings, since the thermodynamic calculations assume equilibrium in chemically simplified systems, and the empirical results assume that generic data apply reasonably well to site-specific WIPP conditions. Clearly, neither method alone will result in a highly accurate estimate of borehole casing corrosion at the WIPP. However, the use of both methods, and the comparison of predictions with the experience of oil and gas field developers near the WIPP, and similar practical comparisons, adds confidence that the results described in later sections are reasonable and are expected to be correct within an order of magnitude.

B.2. ORGANIZATION

The sections below contain descriptions of the theoretical calculations (Section B.3) and empirical analyses (Section B.4) performed to evaluate casing corrosion at the WIPP. Each of these section contains several subsections which contain discussions of the details of the method, assumptions employed, deduced results and limitations or cautionary notes that apply to the results. The subsections of Section B.4 include reviews of corrosion experiments conducted under oxic and anoxic conditions. Section B.5 contains a discussion of the findings, including observations that support the reasonableness of deduced results.

B.3 THEORETICAL EVALUATIONS OF STEEL CASING CORROSION AT THE WIPP

Equilibrium thermodynamics provides a basis for establishing some limits on corrosion, including constraints imposed by the equilibrium concentrations of corrosion products, such as the aqueous solubility of iron and the equilibrium fugacity of volatile product species such as hydrogen. In simplified terms, in chemical systems where constituents can neither be added to or removed, reactions cannot ordinarily proceed beyond equilibrium. Thus, if the amount of available water is known, establishing the equilibrium solubility of iron constrains the total mass of iron that can be removed from solid, metallic form. Such a calculation is important to determining if casing can be dissolved to create a vertical pathway from brine reservoirs located in the Castile, through the repository horizon, to an exit pathway in the Culebra. Similarly, establishing the equilibrium hydrogen fugacity helps identify when corrosion of steel is expected to cease in a closed system.

B.3.1 Details of the Thermodynamic Calculation Methods Used

To perform thermodynamic calculations, balanced equations must be written for the relevant reactions and reliable thermodynamic data, such as free energies of formation, must be available. For the materials involved here (aqueous solutions and iron-based alloys), a number of relevant reactions have been hypothesized. The free energy of each reaction was calculated by subtracting the molar free energies of the reactants from the products. The equilibrium constant, K, was calculated from the Nernst equation and the relationship between the free energy of reaction and equilibrium constant ($\Delta G = -2.303$ RTlog K) was used to calculate concentrations of interest. All calculations were performed for a temperature of 25 °C.

The stepwise progression of calculations is shown below:

Step 1, Calculate Free Energy of Reaction:

$$\Delta G(\text{reaction}) = \Delta G(\text{products}) - \Delta G(\text{reactants}) \quad (1)$$

Step 2, Formulating the Equilibrium Constant:

For a reaction $A^a + B^b = C^c + D^d$:

$$K = (C^c)(D^d)/(A^a)(B^b) \quad (2)$$

where items in parentheses are molar concentrations (chemical activities) or partial pressures (fugacities).

Step 3, Relating Free Energy to K:

$$\Delta G(\text{reaction}) = -2.303\ RT \log K; \text{ at } 250C; \quad (3)$$

$$\text{with } \Delta G \text{ in calories } \text{Log } K = \Delta G/1.364 \quad (4)$$

Step 4, Calculating Equilibrium Concentrations of Interest:

Calculate K from Log K and substitute the result into Step 2 (along with other known or assumed concentrations) to calculate the concentration or fugacity of interest.

Thermodynamic data are available in published tabulations and in the open literature. In this investigation, the tabulation available in Geological Survey Bulletin 1452 (Robie and Waldbaum, 1978) has been used as the primary authority. Tabulated data presented as Appendix VIII, Standard Free Energies, Enthalpies and Entropies in "Introduction to Geochemistry" (Krauskopf, 1967) has been used as a secondary source. During calculations, care has been taken not to mix data bases.

B.3.1.1 Calculating the Solubility of Iron in WIPP Formation Waters

The solubility of steel casing in WIPP ground waters is a consideration when investigating whether or not a pathway can be created by corroding and dissolving the casing along its entire length from the Castile brines to the Culebra. In a free flowing system, or a system where free space exists around the dissolving substance, the dissolving surfaces may become isolated from precipitated phases and solubility controls may not impose effective restraint on dissolution. However, in physical situations where flow is very slow or nonexistent, and where dissolving or corroding surfaces are not surrounded by a lot of free space, then solubilities will control the amount of iron that can exist in the aqueous phase, and hence how much can be dissolved. The second situation is a close approximation to the conditions expected at WIPP. At WIPP it is only conceivable that casing corrosion and diffusion could create a hydraulic pathway along the entire length of the casing if the Castile reservoirs possess enough dissolving capacity. If instead of being dissolved and mobilized, iron is simply oxidized (corroded) and left in-place, then the positive volume change in solids that accompanies oxidation will tend to decrease porosities and

permeabilities associated with plugged casing locations. If these WIPP brines cannot dissolve and mobilize enough steel to create a meaningful connection, then kinetic phenomena such as corrosion rates do not need to be examined. In either case, evaluating the solubility of iron in various environments sheds light on water-casing interactions and increases understanding of how plugged boreholes might behave over long time periods.

The solubility of steel in the WIPP ground waters has been calculated after simplifying the chemical system (See Section B.3.2 Assumptions, and Section B.3.4 Limitations)by taking iron metal to represent steel and pure water to represent brine. Balanced equations have been written for the dissolution of iron metal to form a series of potential corrosion products. The concentration of iron in equilibrium with each potential controlling solid (i.e., the iron saturation level associated with each potential solid corrosion product) has been calculated and this value taken to be the potential maximum concentration that could occur in the ground water. The reasonableness of the calculations was assessed by comparing the results with easily established natural limits on the system (such as the stability of water, See Sections B.3.3 and B.5.0 for discussion).

Iron solubilities were calculated for the iron-water system using the following reactions:

(direct oxidation of iron) $(Fe^0) = Fe^{2+} + 2e^-$ (5)

Note that Eq (5) is a partial reaction common to all equilibria examined. The remaining reactions were formulated assuming ferrous iron as the only iron species in solution. Proper arrangement of the partial reactions allows calculation of dissolved quantities controlled by simultaneous contact with iron metal and iron-bearing corrosion phases. Substitution of (Fe^{2+}) into Eq (5) allows the pe^- or Eh to be calculated ($pe^- = -\log e^-$ $pe^-/17 \sim Eh$.)

(Control of dissolved iron concentration by ferrous hydroxide precipitation)

$$(Fe^{2+}) + 2H_2O = Fe(OH)_2 + 2H^+ \quad (6)$$

(Control of dissolved iron concentration by the iron-magnetite buffer)

$$3(Fe^0) + 4\,H_2O = Fe_3O_4 + 8H^+ + e^- \quad (7)$$

(Control of dissolved iron concentration by goethite precipitation)

$$(Fe^{2+}) + 2\,H_2O = FeOOH + 3H^+ + e^- \quad (8)$$

(Control of dissolved iron concentration by ferrous hydroxide precipitation)

$$(Fe^{2+}) + 3\,H_2O = Fe(OH)_3 + 3H + e^- \quad (9)$$

The potential affect of sulfide on iron solubility was calculated using a range of sulfide: sulfate ratios, observed concentrations and pH's and the additional equations:

$$(Fe^{2+}) + 2HS^- = FeS_2 + 2H^+ + e^- \quad (10)$$

$$H_2S = HS^- + H^+ \quad (11)$$

$$Fe^{2+} + HS^- = FeS + H^+ \quad (12)$$

B.3.1.2 Calculating the Equilibrium Hydrogen Fugacity for Potential Corrosion Reactions of Steel Casing in WIPP Waters

In a chemical system where reacting components are not free to enter or leave the system, Le Chatelier's Principal holds, and once equilibrium concentrations are reached, the concentration of reactants and reaction products remains constant. Prior to reaching equilibrium, adding to the concentration of reactants drives the reaction forward while adding to the reaction products inhibits the reaction from proceeding. Combining the definition of equilibrium with LeChatelier's Principal leads to the inference that upon reaching equilibrium among steel, water, and corrosion products, corrosion of the casing will effectively cease. In contrast, in a chemical system where reacting components are free to leave the system, there is no such control on the extent of reaction. Without the buildup of reaction products, LeChatelier's rule implies that the corrosion reaction will proceed aggressively forward and will continue until the supply of either water or casing is exhausted.

Corrosion-produced hydrogen is an important component in the simplified system iron-water. Hydrogen is a corrosion product of all reactions in the simplified system, and as a gas it is highly mobile and capable of escape if flow paths exist. As a result, calculation of the equilibrium hydrogen partial pressure is useful for evaluating whether or not casing corrosion will proceed unchecked, or will be slowed by the approach to equilibrium. If hydrogen nucleates as a gas, it is assumed fugitive from the system and unchecked corrosion may be expected. If confining pressures exceed the hydrogen partial pressure, then hydrogen is not expected to nucleate as a gas and will not be able to flee the system. In such a case, equilibrium relations can be expected to constrain corrosion. The stepwise process used to calculate equilibrium hydrogen partial pressures for relevant corrosion reactions is described below.

Balanced reactions have been written for potential corrosion reactions, and their corresponding free energies have been summed. The equilibrium hydrogen partial pressure has been calculated for each reaction, assuming that water and all solid products are pure phases (See Sections B.3.2 and B.3.4). When the equilibrium hydrogen partial pressure exceeds the confining pressure supplied by the overlying brine column, hydrogen has been taken as a fugitive (or perfectly mobile) species, and corrosion is expected to be unrestrained.

Hydrogen partial pressures were calculated for the simplified iron-water system using the equations below. Note that it is important that hydrogen ions associate to form molecular hydrogen ($2H^+ = H_2$).

$$Fe^0 + H_2O = Fe(OH)_2 + H_2 \quad (13)$$
$$Fe^0 + 4H_2O = Fe_3O_4 + 4H_2 \quad (14)$$
$$Fe^0 + 2H_2O = FeOOH + 3/2\ H_2 \quad (15)$$

The potential effects carbonate and sulfide were evaluated with the reactions:

$$Fe^0 + CO_2 + H_2O = FeCO_3 + H_2 \quad (16)$$
$$Fe^0 + 2H_2S = FeS_2 + 2H_2 \quad (17)$$
$$Fe^0 + H_2S = FeS + H_2 \quad (18)$$

B.3.2 Simplifying Assumptions

Simplifying assumptions are routinely used during thermodynamic calculations because data for materials of the exact composition of interest are rarely available under the conditions of interest. Calculations commonly proceed by approximating the composition of materials, applying various thermodynamic mixing models, and approximating the conditions under which the reactions occur. In addition, thermodynamic calculations often invoke such fundamental concepts as equilibrium and ideality to ground the calculations in rigorous derivations and to simplify mathematical treatment. Assumptions made during theoretical calculations are discussed below.

B.3.2.1 Fundamental Assumptions

Equilibrium: The principals of equilibrium thermodynamics have been applied in all calculations. Equilibrium has been assumed to exist among all components of reactions considered.

Temperature: All reactions are assumed to occur at 298 oK

Ideality: All reactions are assumed to be ideal

Pressure: Reactions are assumed insensitive to pressure

Control: Water is assumed in excess and its constituents, rather than the reacting solids, are assumed to exert control on e.g. pH

B.3.2.2 Assumptions On Composition

The key components when considering the corrosion of borehole casing in WIPP brines are the steel which comprises the casing, and the fluids which represent the corrosive environment. Steel is an iron-based alloy which commonly contains carbon and minor amounts of other metallic elements (Cr, Mo, Va, Bi, Cu etc) to create a specialized material with properties that are well-suited to an intended application. The steel pipe which is commonly used for casing oil and gas boreholes is a low carbon steel (commonly AISI 1045; Westinghouse, 1996). The simplifying assumption applied to steel borehole casing is to represent its composition as pure iron. The potential thermodynamic effects of minor elements in the steel have been neglected.

Brine is an aqueous solution containing high levels of dissolved material. It is acknowledged that the chemical behavior of brine deviates substantially from ideality and that brine is not pure water. To avoid complex mathematics that would require the aid of computers, brine has been taken as pure water. These and other assumptions pertaining to composition are summarized below.

Steel: Steel is assumed to be pure iron

Products: Dissolved iron is assumed to exist as ferrous ion only. Corrosion products are assumed to be pure phases. Solid solution effects have been neglected

Brine: Brine is assumed to be pure water

Volatiles: Water and its components are assumed to comprise the volatile environment except where specifically noted. When other volatile phases are assumed present, they are assumed pure and in equilibrium with water and its components

B.3.3 Calculational Results

Calculational results presented in this section are intended to provide enough detail to support the discussions and conclusions presented in later sections. Each step of a given calculation is not necessarily provided, although narrative summaries are included where these are potentially helpful in understanding the reasoning and methodology. Calculations of iron solubility assuming a number of potential controlling solids are presented first (Section B.3.3.1), followed by calculations of hydrogen pressures associated with related reactions (Section B.3.3.2).

B.3.3.1 Iron Solubility Calculations

As noted earlier, iron solubility calculations are intended to assess whether the possibility exists for corrosion to create a vertical pathway from the Castile Brine Reservoir horizon

(taken to be at a depth of 899 m; Rechard, 1995) to the Culebra aquifer (taken to be at a depth of 216 m). Corrosion along the length of the casing may occur from waters associated with the brine reservoirs, formation waters and aquifers such as the Culebra, as well as the brine introduced inside the casing during abandonment. Waters in the Culebra and Castile have been reported to coexist with hydrogen disulfide and carbon dioxide gases, thereby creating a range of potential corrosion environments (Popielak et al., 1983; Lambert and Robinson, 1984). In the following sections, the potential to dissolve iron in the presence of H_2S gas is examined first, followed by the potential in carbonate and then pure water environments.

The results of the calculations for ternary equilibria involving iron metal, an iron bearing phase and aqueous species can indicate solubilities that may exceed the aqueous solubility of the iron bearing phase alone. In the present analysis, such a result is taken to indicate that dissolution of iron occurs at the iron-water interface, followed by precipitation of the iron-bearing phase at a distance from the interface. This process leads to a conservative result by assuming that dissolution occurs under local equilibrium conditions (the presence of iron) that may not apply in areas where precipitation occurs (the absence of iron). In the calculations discussed here, reactions possessing the lowest free energies are generally considered dominant when more than one reaction is possible. Tests of reasonableness, such as being within the stability field for water or possessing reasonable densities, are used to evaluate the results.

B.3.3.1.1 Sulfide Controlled Solubilities. Sulfide corrosion products found on iron, and for which thermodynamic data are compiled, include pyrite and troilite (See Videm and Kvarekval, 1995; and Robie and Waldbaum, 1978). The solubility of iron metal in equilibrium with water and each of these phases is analyzed here.

Pyrite: Ferrous iron concentrations in equilibrium with pyrite are calculated first for a Salado-like environment and then for the Castile. Oxidation of iron metal, and the aqueous solubility limit of ferrous iron as controlled by the presence of pyrite, may be calculated by using equations (5),and (10).

From Eq(5): $\log K = 13.818 = \log [Fe^{2+}] - 2pe^-$.
From Eq (10): $\log K = -18.494 = \log [Fe^{2+}] + 2\log [HS^-] + 2pH + 2pe^-$

To solve the equation, estimates of the HS^- concentration and pH are required.

Salado: Assuming ideality, the bisulfide concentration in a Salado room seep should be less than ~0.3M (if total sulfur is reported as HS; Rechard, 1995). At pH = 8, substitution of pH and HS^- concentrations and rearrangement and addition of Eq's (5) and (10) yields:

$$Eq(5) + Eq\ (10) = -4.676 = 2\log [Fe^{2+}] - 1.046 + 16; \qquad (19)$$

Hence: $\log [Fe^{2+}] = -9.815$, and $pe^- = -11.816$ (therefore, Eh = -0.699 v)

This result for Eh is below the 1 atm stability field of water, indicating that when iron metal and pyrite coexist, HS must be present at much lower concentrations than assumed here. Taking 0.01M HS as a practical lower limit, the same calculations yield ferrous iron concentrations of :

$$\log[Fe^{2+}] = -8.338, \text{ and } pe^{-} = -11.078 \text{ (therefore, Eh = -0.655 v).}$$

These conditions are still well below the 1 atm stability limit of water.

The lowest theoretical HS- concentration in equilibrium with iron metal, pyrite and water may be calculated and substituted into Eq (10). At the lower stability limit of water, pe^{-} equals pH, and the sulfide concentration is estimated:

From Eq (5): $13.818 = \log [Fe^{2}] - 2(-8)$, so $\log [Fe^{2+}] = -2.18$;
Substituting into Eq (10): $2\log [HS^{-}] = -18.94 - (-2.18)$, so $\log [HS^{-}] = -8.156M$.

At pH = 8, the calculated HS- concentrations are so low that if steel casing corrosion is appreciable in the Salado, it is likely to be controlled by another corrosion reaction.

Castile: The Castile brines have been characterized to the point where calculations are somewhat less parametric and more definitive. Sampling of the gas phase coexisting with brine from borehole WIPP12 showed that H_2S comprises about 20 mole percent of the gas. The minimum pH and pressures associated with the brine reservoir are 6.4 and 14 MPa, respectively. Assuming ideality, fugacity equals partial pressure and may be calculated as:

$$P_i = (P_{tot})\, X; \tag{20}$$

where X is the mole fraction. For H_2S:

$$Pi = (138 \text{ atm})(0.20) = 27.6 \text{ atm}$$

Substituting values for pH and $f H_2S$ into Eq (11) yields

$$-7.997 = \log [HS^{-}] - 6.4 - \log (27.6),$$

so that: $\log [HS^{-}] = -0.56$, or $[HS^{-}] = 0.10M$.

Substituting into Eq (19) and solving for the equilibrium ferrous iron concentration yields:

$$-4.676 - 2\log [HS^{-}] - 2pH = 2\log [Fe^{2+}],$$
$$-4.676 - 2(-0.56) - 2(6.4) = 2\log [Fe^{2+}],$$

and: $\log [Fe^{2+}] = -8.89$ M.

Substituting these ferrous iron concentrations into Eq (5) produces a pe^- of -11.35 or an Eh of -0.67v, still below the 1 atm stability field of water.

Troilite: As an alternative to pyrite, calculations can be performed using troilite (FeS) as the controlling corrosion product (See Videm and Kvarekval, 1995).

$$Fe = Fe^{2+} + 2e^- \qquad \log K = 13.818 \qquad (5)$$
$$Fe^{2+} + HS^- = FeS + H^+ \qquad \log K = 6.055 \qquad (21)$$

Combining Eq's (5) and (21) so that both Fe and FeS control ferrous iron yields:

$$\log K = (13.818) - 6.055 = 7.763 = 2\log [Fe^{2+}] + \log [HS^-] + pH$$

Salado: For Salado brines a practical lower concentration limit of 0.01M may be used for $[HS^-]$ and the pH range 6 to 8 evaluated. The results for log ferrous iron concentrations are 0.88 M at pH = 8 and 1.88 M for pH = 6. The resulting Eh is -0.38v, at pH = 8, which lies within the 1 atm stability field of water.

Castile: For Castile brines, the previously calcuated HS- concentration of 0.70 M and the observed pH of 6.4 were substituted into the equation. The results predict a log ferrous iron solubility of 0.76 M.

B.3.3.1.2 Carbonate Controlled Solubilities: Siderite ($FeCO_3$) is the stable corrosion product of iron following exposure to carbon dioxide-rich brines. The reaction cited by Xia et al. (1989) is reaction of iron with the carbonate ion. The equilibrium ferrous iron concentrations established for these reactions (see Eq 16) are calculated below:

From Eq (5): $\log K = 13.818$,
also: $H_20 + CO_2 = CO_3^{-2} + 2H^+$, $\log K = -18.130$,
and: $Fe^{2+} + CO_3^{-2} = FeCO_3$, $\log K = -10.69$.

Arranging terms and summing yields gives:

$$\Sigma \log K = -13.937 = 2\log [Fe^{2+}] + \log[CO_3] - 2pH$$

Data from brine seeps and brine reservoirs show that CO_3 concentrations are in the range 0.11 to 0.16M (1992 PA). Taking the lower end of the range and substituting yields gives:

$$-13.937 = 2\log[Fe^{2+}] + (-0.796) - 12;$$

so that: $\log [Fe^{2+}] = -0.571$ M

Substitution of $[Fe^{2+}]$ into Eq (5) yields an associated Eh of -0.42 v which approximates the lower stability limit of water.

B.3.3.1.3 Corrosion Controlled by Simple Oxides and Hydroxides (Data from Robie and Waldbaum, 1978): Aqueous oxidation of iron metal can be examined using Eq (5), (6), (7), (8), and (9). Ferrous hydroxide, $Fe(OH)_2$, is a corrosion product (Eq 6) reported by Telander and Westerman (1992), although magnetite (Eq 7) and goethite (Eq 8) are also cited in the literature.

Magnetite Control: Examining the iron-magnetite reaction first, Eq (7) can be written in its component parts as:

From Eq (5): $Fe = Fe^{2+} + 2e^-$, $\log K = +13.818$,
and from Eq (7): $3Fe^{2+} + 4H_20 = Fe_3O_4 + 8H^+$, $\log K = -30.245$.

Rearranging and summing yields gives:

$$\log K = 44.06 = 4\log[Fe^{2+}] + 8pH.$$

At pH=6: $\log[Fe^{2+}] = -0.98$ M;
at pH=8: $\log[Fe^{2+}] = -4.99$ M.

The attending Eh's (calculated by substituting ferrous iron values into Eq 5 and solving for pe^-) are in the range -0.425 to -0.55v. At the reference pH's, these values are near to, but below, the stability field for water.

Ferrous Hydroxide Control (Data from Krauskopf, 1967): The most commonly cited corrosion product for iron is ferrous hydroxide. The corrosion results from reaction of iron with protons and hydroxides of water (Manfredi et al., 1989). Recomposing Eq (8) into its component parts gives:

From Eq (5): $Fe = Fe^{2+} + 2e^-$, $\log K = +14.883$,
from Eq (8): $H_20 = H^+ + OH^-$, $\log K = -13.996$,
and from Eq (8): $Fe^{2+} + 2(OH) = Fe(OH)_2$, $\log K = +14.736$.

Rearranging, balancing (2 waters) and summing gives:

$$\log K = -27.845 = 2\log [Fe^{2+}] - 2pH.$$

At pH = 6: $\log [Fe^{2+}] = -7.923$;
at pH = 8: $\log [Fe^{2+}] = -5.922$.

The attending Eh's are in the range -0.67 to -0.61 v.

Goethite Control (Data from Robie and Waldbaum, 1978): Goethite (See Eq 9) is assumed to form from a corrosion reaction similar to ferrous hydroxide. Following the same procedure as above:

From Eq (5): $Fe = Fe^{2+} + 2e^-$, $\log K = +13.818$,
and from Eq (9): $H_20 = H^+ + OH^-$, $\log K = -13.996$,
and: $Fe^{2+} + (OH) + 1/2\ O_2 = FeOOH$, $\log K = +44.218$.

Rearranging and summing gives:

$$\log K = -43.331 = 2\log[Fe^{2+}] - pH.$$

At pH=6, $\log [Fe^{2+}] = -18.665$;
at pH=8, $\log [Fe^{2+}] = -17.665$.

As with previous calculations, the attending Eh's are calculated to be below the stability field of water.

B.3.3.2 Partial Pressures of Hydrogen Over Controlling Equilibria

A number of different solubilities have the potential to apply to casing corrosion at WIPP. Several relevant reactions have been written and presented in the section above. In reality, complex equilibria will likely be involved and the degree of control exerted will depend on compositional variabilities such as brine composition and over-pressures of coexisting volatile species (e.g. carbon dioxide, hydrogen sulfide, hydrogen etc.).

B.3.3.2.1 Corrosion Inside the Casing: Of the reactions written above, corrosion inside the casing is expected to be closest to the simple iron-water reactions because abundant carbonate and sulfide cannot be assumed to be present in the corroding water. At equilibrium in this system, the corrosion reactions can be recomposed to show hydrogen as a reaction product [See Eq (13)-(18)]. The equilibrium hydrogen fugacity (or partial pressure) can then be calculated as described in Section B.3.1.2.

In this simplified system, the reactions most commonly associated with corrosion are represented in Eq (13) and Eq (15). These reactions also give the lowest free energies, hence they are inferred to be the most stable, and therefore the controlling reactions. The partial pressure of hydrogen associated with these reactions is in the range 40- 45 atm, as shown below.

From Eq (13): $\log K = 1.628 = \log(P_{H2}) - 2\log(P_{H20})$, (Krauskopf, 1967)
$1.628 = \log(P_{H2}) - 2\log(1)$,
$P_{H2} = 42.4$ Atm.

From Eq (15): $\log K = 2.654$ (Krauskopf, 1967) to 2.50 (Robie and Waldbaum, 1978);

For: $\log K = 2.654 = 3/2 \log (P_{H2})$,
$(2.64) \times (2/3) = 1.769 = \log (P_{H2})$,
$P_{H2} = 58.8$ Atm

For: $\log K = 2.50 = 3/2 \log (P_{H2})$,
$(2.50) \times (2/3) = 1.666 = \log (P_{H2})$,
$P_{H2} = 46.4$ Atm

These calculations would seem to suggest that in the simplified system, when corrosion is of concern, the partial pressure of hydrogen will be in the range of 40-50 atmospheres, where the reaction stops. It should be noted, however, that magnetite has infrequently been noted as a corrosion product by some experimenters (See Telander and Westerman, 1992). If magnetite is truly present, and if it is present in quantities sufficient to control reactions, then the hydrogen pressures could be higher. In the simplified system (no solid solutions and unit activity of water), the iron-magnetite reaction is calculated to produce equilibrium hydrogen pressures of the order of 650 atm.

B.3.3.2.2 Corrosion Outside the Casing: Outside the casing, formation waters commonly contain carbonate, and in the Castile reservoirs, sulfide.

Carbonate: If carbon dioxide is assumed continuously present (i.e. there is an inexhaustible supply) at air concentration values (0.033%), then the hydrogen pressure in equilibrium with siderite (see Eq 16) may be calculated to reach 483 atmospheres. It should be noted that the continuous supply of CO_2 may be generated in the repository, with the carbon dioxide supplied by microbial action.

Sulfide: The composition of brines taken from the Castile are reported by Popielak et al., 1983. The maximum documented sulfur concentration is reported as 590 mg/l. This equates to approximately 0.06 moles/l sulfur as HS^-. Summing equations (5) (10) and (11) and substituting for HS^- and pH gives a log hydrogen disulfide fugacity of +0.775 atm at pH = 6 as shown below:

$$\log K = -7.997 = \log [HS^-] - pH - \log f_{H2S} = -0.1.222 - 6 - \log f_{H2S} = +0.775$$

Under these conditions the troilite and pyrite reactions yield extremely high equilibrium hydrogen pressures. For example, from the troilite reaction, $Fe + H_2S = FeS + H_2$, the equilibrium hydrogen pressure is calculated as:

$$\log K = 11.878 = \log f_{H2} - \log f_{H2S}$$
$$\log f_{H2} = 11.878 + 0.775 = 12.65 \text{ Atm.}$$

Thus, equilibrium hydrogen pressures associated with casing corrosion have the potential to range from a low of 40 atm to a high in excess of 1012 atm. The controlling reaction will ultimately be determined by the relative abundance of reactants and the prevailing geochemical environment. For example, Figure B-3 (from Garrels and Christ, 1965) displays the rather limited conditions within redox-pH space where sulfide corrosion products can exist. Figure B-4 shows that siderite (FeCO3) has a somewhat more substantial stability region; however, as carbon dioxide is consumed, the field becomes

dominated by ferrous hydroxide. Accordingly, the equilibrium hydrogen pressure assumed to dominate casing corrosion is derived from the simplified water-iron reactions.

B.3.4 Limitations

The calculations summarized above have utilized a number of assumptions and simplifications (See Section B.3.2). Accordingly, while the results are good indicators of how elements of a plugged borehole will behave, they should not be taken as quantitatively definitive.

Two assumptions central to the calculations are those concerning the reaction of pure phases and equilibrium. For example, water has been assumed to be pure water, while in actuality the corroding solutions will be brines in which the chemical activity may be expected to be somewhat less than 1. This compositional effect will result in underestimates of calculated solubilities and equilibrium hydrogen pressures. Partial or complete compensation of this error may come from having assumed pure solid reaction products, while the iron-bearing minerals assumed as pure solid phases will likely incorporate some degree of solid solution with the iron, e.g., by metals such as magnesium. Similarly, pure iron has been used to approximate steel casing. The free energies of various steels has not been modeled, and the general effect on free energies and equilibrium constants is unknown.

Equilibrium has been assumed throughout the system. Lack of equilibrium may lead to incomplete reaction causing the results of the calculations described here to be overestimates. Lack of equilibrium may also result in a lack of solubility control allowing supersaturated solutions (i.e. higher concentrations) to persist, if they are somehow generated. In addition, the calculations employed here do not account for galvanic effects that might occur across different domains of steel alloys or between passivated portions of the casing and areas that remain unclad by corrosion products.

To address these limitations the calculational results are supplemented with empirical results from experimental corrosion studies between low carbon steel and brines. These are described in the next section.

B.4. RESULTS FROM EMPIRICAL STUDIES INVESTIGATING STEEL CORROSION IN BRINE WITH RELEVANCE TO WIPP

As noted above, while simple thermodynamic calculations are useful, they cannot be relied on to present a complete picture of how casing will corrode under repository conditions. To provide more reality to the theoretical analysis, data has been obtained from the literature from investigations of low carbon steel corrosion in brine environments. Other parameters of interest included volatile environments (air saturated, de-aired, carbon-dioxide and hydrogen sulfide-enriched) and the presence of portland cement materials.

These studies do not determine the steady state composition of ferrous iron in brine. Rather, they investigate the rate at which iron oxidizes and the mechanism through which corrosion occurs.

B.4.1 Corrosion of Low Carbon Steel in Aerated Environments

Corrosion of casings at WIPP may include environments where oxygen is available. Thus, brines put into casings at abandonment will initially be air saturated, and formation waters from shallow depths may be in contact with air to some degree. In either case, the subject of oxic corrosion of low carbon steel casing is relevant.

In the presence of air saturated brines, steel undergoes oxic corrosion. Eq (14) can be recomposed as:

$$2Fe + 3/2\ O_2 + H_20 = 2FeOOH \qquad (22)$$

This reaction is written to describe the consumption of oxygen; however, at equilibrium it is thermodynamically equivalent to Eq (14). Oxic corrosion strips Fe randomly from exposed surfaces. Each surface location has an equal potential for reaction, so the mechanism is called uniform or generalized corrosion. With all other compositional aspects held constant, the presence of oxygen may be the strongest driver for corrosion; however, other species which promote oxidizing environments also contribute substantially.

Acidity: The acidity of the corroding medium can be a very important parameter to corrosion rates of steel. Acid environments are oxidizing environments. Reference to Eq (2) through (12) shows that elevated concentrations of hydrogen ion (e^-) lead to elevated concentrations of ferrous ion [Fe^{2+}]. The effect of pH on oxic corrosion rates of low carbon steel is exemplified by Figure B-1, taken from Manfredi et al., 1989 who performed experiments on low carbon steel in brine at temperatures associated with heat producing nuclear wastes (up to 1500 °C). Moderate temperature elevations of this type generally accelerate kinetic reactions unless reaction mechanisms change, with a 100 °C rise in temperature generally doubling or tripling reaction rates (Sienko and Plane, 1966). These short term elevated temperature experiments therefore simulate more then 100 years of corrosion. The results show that short-term corrosion rates are much higher, by an order of magnitude or more, than the rates likely to occur over long time periods. In addition, the experiments reveal that the pH sensitivity of low carbon steel corrosion rates varies with acidity. In low pH regions (pH= 0 to 3), corrosion rate increases steeply as pH decreases. In contrast, in the more neutral range (pH 4-10) shows a moderate corrosion rate that lacks sensitivity to pH. At higher pH's, corrosion is low and corrosion may be more influenced by local aberrations in chemistry of the steel or surface energies etc.

Effect of Concrete: The presence of concrete complicates the picture somewhat. As a cladding material, concrete has the potential to change the corrosion of low carbon steel

from a generalized to a localized mechanism. This potential is created because concrete adheres to the surface of low carbon steel preventing uniform access of brine, while the concrete is non-uniform with respect to density and composition and can therefore introduce chemical micro-environments. During corrosion of steel by brine in the presence of concrete, oxygen exerts influence on the overall corrosion rate and chloride exerts influence on where corrosion is initiated, since high chloride concentrations initiate corrosion (Andrade et al., 1990). Where oxygenated waters have access to steel surfaces, corrosion rates are higher. Where steel surfaces are in contact with elevated chloride concentrations, more corrosion sites are initiated. Where the corrosion environment includes both saturated and unsaturated areas (dry and wet areas or interfaces), anodic corrosion is especially aggressive (Aguilar et al., 1990). Corrosion rates for low carbon steel surrounded by both dense and cracked concrete are depicted in Figure B-2 (Andrade et al., 1990). For ease of comparison, a conductance of 11mA/cm2 is equal to about 0.1 mm/year. Accordingly, short term corrosion rates reported for concrete encased low carbon steels in aerated brines reach as high as about 11 mm/yr.

B.4.2 Corrosion of Low Carbon Steel In the Presence of CO_2 and H_2S

It is quite likely that the dominant corrosion environment for low carbon steel casing at WIPP will not be an air saturated or oxygen-rich environment. With increasing depth, communication with surface air becomes impossible. With time, air entrained during drilling and abandonment is consumed by corrosion or biota and the environment becomes anoxic. At the WIPP, the gases carbon dioxide and hydrogen disulfide are commonly associated with brine reservoirs (Popielak et al.,1983) and possibly formation waters such as the Culebra (Lambert and Robinson, 1984; Myers, 1991). Accordingly, review of low carbon steel corrosion experiments involving brines and CO_2 and H_2S has been conducted.

In the presence of some oxygen, carbon dioxide- rich brines induce corrosion rates of 1-3 mm/yr in low carbon steel (Andrade et al.,1990). Production of carbonate scale on steel surfaces leads to pitting corrosion as opposed to uniform corrosion. In de-aired experiments with brine and carbon dioxide, corrosion mechanisms and rates are similar (Xia et al.,1989). Early production of $FeHCO_3$ passivates corrosion, but within weeks, the $FeHCO_3$ was converted to the thermodynamically stable $FeCO_3$, passivation ended and corrosion at 1-3 mm/yr resumed (Xia et al., 1989).

In anoxic brine containing hydrogen disulfide, corrosion of low carbon steel is complicated by passivation (Telander and Westerman, 1992). At the onset, corrosion is driven aggressively by the thermodynamic stability of iron sulfides, i.e. iron sulfides are highly favored over iron metal. At elevated partial pressures of hydrogen sulfide, however, a dense sulfide coating (reportedly mackinawite; Videm and Kvarekval, 1995) inhibits access of the corroding medium to the steel surface. As a result, corrosion virtually ceases. At lower partial pressures (below about 5 atm; Westerman personal communication), the passivating sulfide coat does not form.

The combination of hydrogen disulfide and carbon dioxide at low partial pressures creates an environment that is likely to be similar to a Castile brine reservoir that has been vented to the atmosphere. Corrosion of low carbon steel in just such an environment has been investigated (Videm and Kvarekval, 1995). Figure B-3 reproduces their experimental results and shows low carbon steel corrosion in the range of 1-3 mm/yr.

B.5. DISCUSSION OF FINDINGS

B.5.1. Corrosion Rate

The empirical corrosion rates presented for oxic and anoxic conditions, whether or not additional gas species such as carbon dioxide and hydrogen sulfide are present, appear to have an upper range near 1-3 mm/yr (For example, compare Andrade et al., 1990; Aguilar, et al., 1990; Videm and Kvarekval, 1995). These initial rates may slow with time as suggested by Manfredi et al. (1989), and Telander and Westerman (1992), and an uncracked concrete coating will undoubtedly inhibit corrosion (Andrade et al., 1990). It may be argued that better estimates of rates could be obtained from more detailed researching of hydrocarbon steel casing compositions followed by performing site-specific corrosion experiments directly on those compositions. While it is certainly true that corrosion rates can be specified with reasonable accuracy for specific steels in brines of a given chemistry, the uncertainties associated with the variability of corroding environments at WIPP make it more reasonable to adopt the published, upper range for generic low carbon steel in brine as the expected corrosion rate.

The estimated rate of 1-3 mm/yr is a very aggressive rate, but it appears to comport well with oil field observations made during exploration in the Delaware Basin. As reported by the New Mexico State Land Office, corrosive failure of casings in the Salado is common though not pervasive (See Bailey memo in La Venue, 1991). Most commonly, these failures are reported to occur within several years of emplacement of the casing, although breaches within months after emplacement are not unheard of. Setting aside the fact that most failures appear to occur near Nash Draw, where aqueous environments in the Salado and shallower formations will be most oxidizing and corrosive (Lambert and Robinson, 1984; Myers et.al, 1991), as shown below simple division shows that the rate of 1-3 mm/yr would account for most casing failures. The common maximum wall-thickness of the surface casing is about 11 mm, while the common thickness associated with intermediate casing is about 9 mm. The intermediate casing is the pipe that would be placed in the Salado (Westinghouse, 1996), where failures are reported (Bailey, 1991). Dividing 9 mm by several (e.g. three) years would give an annual corrosion rate of 3mm/yr.

This apparent agreement lends confidence to the selection of 3 mm/yr as a conservative but applicable corrosion rate; however, the coincidence does not mean that corrosion will necessarily occur at 3 mm/yr in every environment encountered by the borehole casing.

Corrosion rates measured under repository conditions are on the order of one thousand times slower than rates applied to the casing (Telander and Westerman, 1992). This difference may be due to different compositions of steels and/or corroding environments or to unknown experimental differences between the WIPP-specific and generic investigations. It is with the understanding that a corrosion rate of 1-3 mm/yr represents a conservative, generally applicable rate that this investigation recommends it for predicting borehole plug performance.

B.5.2 Corrosion Mechanism

Corrosion mechanisms are important because some mechanisms strip layers of iron from the surface while others bore through the steel in a focused fashion. Focused mechanisms may result in localized failures even when the corrosion reaction is controlled by a low solubility. Localized failures may have hydraulic consequence without being attended by physical collapse. Generalized mechanisms must be accompanied by appreciable solubilities or very large quantities of corroding media before failure is as significant a concern. Generalized failure will commonly be accompanied by physical collapse.

Two corrosion mechanisms are reported for corrosion of low carbon steel: uniform corrosion (e.g. Manfredi et al, 1989) and pitting corrosion (e.g. Xia et al,1989 ; Videm and Kvarekval, 1995). Uniform corrosion is reported at low and moderate pH's (<10) under oxic and de-aired conditions (Manfredi et al, 1989; Posey and Palko, 1979) and when steel surfaces are not covered with mineral coatings. Pitting corrosion is reported at high pH's (Manfredi et al., 1989)or under elevated partial pressures of carbon dioxide (Xia et al 1989; Videm and Kvarekval 1995), hydrogen disulfide (Videm and Kvarekval, 1995) or when concrete or the degree of saturation create non-uniform corrosion environments (Andrade et al, 1990; Aguilar et al., 1990).

Corrosion mechanisms will operate in two directions. Brine placed inside the casing will corrode from the inside-out, while formation waters in the host rock will corrode from the outside-in. Internal corrosion will proceed in a relatively uniform environment. In contrast, external corrosion may experience great variability due to the cement that attaches the casing to the host rock, i.e. casing cement will inhibit access to steel surfaces to different degrees at different locations.

In addition to axial location, depth may also affect the corrosion mechanism acting on the outside of the borehole casing. Shallower depths are more likely to support oxic corrosion environments and are therefore more likely to experience generalized corrosion. Corrosion at greater depth is more likely to encounter elevated partial pressures of carbon dioxide and hydrogen disulfide, and localized pitting should be more prevalent.

B.5.3 Conceptual Models For Casing Corrosion

Information developed for low carbon steel corrosion has been synthesized with site characteristics and judgment to yield a conceptual model for casing corrosion at WIPP. The model has been assembled based on published corrosion rates and corrosion mechanisms, as well as calculated solubilities and amounts of materials. The casing corrosion model recommended for WIPP is comprised of two sub-models one in which hydrogen is fugitive, and free to leave the system, and another in which hydrogen is confined within the system. These models are described more fully below.

B.5.3.1 Corrosion When Hydrogen Is Fugitive

As noted above, depth is expected to affect corrosion by influencing the oxidation potential of the environment. Depth may also affect whether or not corrosion is thermodynamically limited. Section B.3.3.2 showed that corrosion controlled by formation of iron hydroxides theoretically ceases when hydrogen partial pressures reach 40-45 atm. The weight of the brine column inside the casing creates a confining pressure of this magnitude at depths below about 1100 feet (See Section B-5.4).

Confining pressure determines the ability of a volatile to nucleate as a free phase gas. When the physical confining pressures exceed the pressure of the volatile of interest, the volatile cannot become a free gas and the chemical potential associated with hydrogen can increase. If the confining pressure is less than the volatile's pressure (as it is above ~1100 feet), then the volatile can escape as a gas. When a reacting component can enter or leave the system it is said to be "perfectly mobile" or fugitive. This is relevant to the corrosion process because when hydrogen is fugitive development of back pressure to stop corrosion cannot occur. Corrosion will continue until all the iron is oxidized as long as there is sufficient water.

The most certain volume of water available is the brine placed in the casing at abandonment. The volume of water associated with the casing can be calculated. The dimensions of the intermediate casing are taken to be an O.D of 8.625 in. (0.21908m) and an I.D. of 7.921 in. (0.20119m) (Westinghouse, 1996). In a 1m length of casing, the internal volume is 0.0318 m^3 and the volume of steel is 0.00589 m^3. The molar volume for iron is 7.092 cm^3 (Robie and Waldbaum, 1978). Thus, in one meter of casing there are ~830 moles of iron. The volume of water in that same meter of length is ~ 31.8 liters, or with a molar volume of water of 18.068 cm^3 (Robie and Waldbaum, 1978) about 1756 moles of water per meter of casing length.

Referring to Eq (16) shows that each mole of iron reacts with 2 moles of water to create ferrous hydroxide. Thus, theoretically only 1660 moles of water are required to oxidize all of the iron in the casing. The calculated amount of water present (1756 moles) appears close enough to that theoretically required that assumptions such as ideality etc may be enough to call total corrosion into question. However, additional water is certain to be

present. First, water will exist in the surface casing. Because of its proportions (O.D.= 0.3397m, I.D = 0.3179m) a similar calculation shows that the molar ratio of water to iron in the upper part of the column will be 2.76 (vs 2.11 for the intermediate casing and a requirement of 2.0 for complete oxidation).

In addition to casing water, formation waters may be available to drive corrosion. Brine flows have been reported from shallow Salado interbeds (and attributed as the potential causes for casing failures) in oil field wells (Bailey memo in LaVenue, 1991). As reported by the New Mexico State Land Office, "These water flows are characterized as strong, intermittent and spotty. Not all wells have encountered flows, but when they did, the flows were estimated at 1000-2000 barrels per day. The flows often would last 4-5 days before stopping themselves."

Two points may be made in connection with these reports. Firstly the reports of brine flow and casing failure come from locations closer to Nash Draw than to the site. Near Nash Draw, the Salado contains clastic intervals capable of supplying water at a much higher rate than the interbeds characteristic of the WIPP site. Nevertheless, if the minimum values of 1000 barrels and 4 days are taken, then the drainable volume of the interbed brines could be as high as 480,000 liters□ ,and supply about 26 x 106 additional moles of water. The combination of casing and potential formation brines are therefore more than adequate to oxidize borehole casing completely when hydrogen is fugitive.

In summary, at depths less than 1000 feet, hydrogen gas can nucleate and escape if a pathway exists. Corrosion failures of casing are well-known in these depths (Bailey, 1991) and will almost certainly occur in a matter of years to tens of years. These failures will provide escape paths for gaseous hydrogen and unchecked generalized corrosion can proceed. As a result, steel casings above 1000 feet are expected to corrode entirely and collapse into the hole. The time required for total collapse of the casing is not calculable from known data; however, judgment has been applied in the form of an additional order of magnitude to yield an estimate of about 100-200 years.

The physical characteristics of the corrosion debris are also not amenable to calculation. Corrosion products found on the surfaces of corroding metals are exceptionally fine (micron sized). This knowledge together with the well-known, fine-grained nature of most chemical precipitates, suggests that much of the resulting debris will contain abundant silt-sized or finer material. Not all of the debris will be disaggregated chemical precipitate, however, nor can fine materials formed initially be assured not to agglomerate and cement. These materials will comprise coarser materials, in an undetermined amount. Other material, such as pieces of rusted pipe or concrete may also be present, approximating sand or gravel materials. Collectively, the debris is expected to comprise a mixture of coarse to very fine-grained material and hydraulically resemble silty-sand, as originally proposed by EPA in 40CFR191.

B.5.3.2 Corrosion When Hydrogen Is Contained

At depths greater than about 1000 feet, hydrogen gas will not develop and hydrogen will not be a fugitive species. Because it cannot escape, hydrogen back pressure will build up inside the casing as corrosion produces ferrous hydroxide. Upon reaching the equilibrium hydrogen pressure near 40-45 atm, generalized corrosion in the simplified water-iron system will cease, probably before failure of the casing occurs.

Outside the casing corrosion will be driven by formation brines. Brines are not expected to occur in abundance within the deep Salado at the site; however, large brine reservoirs with volumes as high as 1 x 109 liters (1992 PA) may be encountered in the Castile. These brines are reportedly charged with CO_2 and/or H_2S (Popielak, 1983) and although no compositional data are available for Salado interbed brines, it is reasonable to assume a similar chemistry.

Attack by formation waters will lead to localized failure of the casing due to pitting corrosion. Pitting is almost certain to be the dominant mechanism given that casing concrete will surround the pipe and that carbonate and sulfide phases will form on some steel surfaces. The result of pitting corrosion will be a degraded casing that is locally perforated and has failed hydraulically but which has remained substantially intact physically.

B.5.3.3 Potential For Corrosion To Create Hydraulic Pathways

In inadvertent human intrusion scenarios, steel casing is assumed to intersect Castile Brine reservoirs (899 m depth), the repository (655m depth) and the Culebra aquifer (216 m depth; all depths from 1992 PA). The potential exists for corrosion of the steel to create an open path that hydraulically connects all of these features. Solubility and corrosion rate data have been used to assess this potential.

Dissolution of the entire casing would produce an open annulus in the space previously occupied by the steel. Assuming one billion liters of brine, a bounding calculation was performed to see if simple dissolution was a concern. The removal of iron by dissolution will be determined by the solubility of the most stable phase.

The water source with the greatest volume (hence capacity for dissolution) is an assumed Castile Brine Reservoir with an estimated volume of 109 liters (Popielak et al., 1983). These reservoirs have been observed to emit hydrogen disulfide gas. Brines rich in hydrogen sulfide gas react with iron to form iron sulfides such as troilite, pyrite, and mackinawite (Telander and Westerman, 1992; Videm and Kvarekval, 1995). Thermodynamic data have not been discovered for mackinawite, and estimations have not been performed for that phase. Theoretical Fe 2÷ solubilities controlled by the presence of both troilite and pyrite were calculated in Section 133.3.1.1. Estimates for pyrite (~10-8 M) are used here because the presence of carbonate destabilizes FeS (See Figure B-4) and

Castile brines contain abundant dissolved carbonate and excess carbon dioxide (Popielak et al., 19%)

In a brine reservoir with a volume of one billion liters at a pH near 6, sulfide solubility would limit dissolution and transport of iron to less than 31,000 moles {(10^9 liters) x (10^{-8} moles/liter) = 10 moles}. This amount represents all of the steel in a 1 cm length of casing (10 moles/830 moles of iron per meter of casing). This represents less than 0.5% of the distance between the reservoir and repository horizons. However, removal of 10 moles from the rock-casing interface (only) is not sufficient to create a conductive pathway to the repository.

The solubilities of metastable mackinawite and troilite (both FeS) will be higher than the thermodynamically stable phase, pyrite. However, empirical corrosion experiments where FeS phases are reported as corrosion products indicate that linear corrosion rates will not permit connection of the Castile Brine reservoir horizon and the repository during the 10,000 year period of performance. The corrosion rate selected for the conceptual model is less than 3mm/year. This is a very aggressive rate. The brine reservoirs and the repository are separated by about 250 m (250,000 mm). Using the cited corrosion rate, more than 80,000 years would be required to create a pathway by corrosion along the interface.

An alternative to vertical dissolution from the Castile is vertical dissolution coming from interbed sources that might occur periodically throughout the Salado. In order for such sources to have significance, they must occur every 35 m or less and all must contain sufficient accessible water supplies that dissolution is possible. Without the ability to disperse dissolved material away, corrosion products that might form will clog porosity.

Although it is inconceivable that dissolution and corrosion could combine to create a significant vertical pathway for flow, the capacities are more than enough to create horizontal pathways into the casing. Such pathways are inconsequential when the casing is completely filled with concrete (See Appendix C). Axial degradation may occur, but it will be separated by long columns of intact material that will resist flow and approximate the undisturbed geology.

B.5.4 Volume of Debris Produced by Corrosion

It is assumed that casing above 345 m depth (1131 feet) will disintegrate due to unrestrained corrosion (See Section B-3.3.2). It is also assumed that the corrosion product may be either ferrous hydroxide or magnetite. Corrosion products of steel occupy more volume than the original steel. Using the molar volume for iron to represent steel, Ferrous hydroxide occupies 3.73 times more volume and magnetite occupies 2.1 times more.

The volume of steel in the borehole casing above a depth of 345 m is calculated to be about 4.4.m^3.(Note: 260m of the length is assumed to be surface casing and 85 m is assumed to be intermediate casing). The volume contained by the intermediate (which extends to the top of the Salado) is 0.0059 m^3/m of length.

Conversion of all steel casing to corrosion products produces between 8 and 14.5 cubic meters of debris. This is sufficient to fill 1380-2460 m of casing (up to about 8063 feet). As a result, debris from corrosion in the uppermost part of the casing is sufficient to fill boreholes more than 8000 feet deep from their bottom all the way to the Culebra.

This debris is expected to contain both fine- and coarse-grained materials. Coarse material will be comprised of larger pieces of corroded casing that fall into the hole as a result of physical failure. The fine material will be the result of chemical precipitation of alteration phases. Based on such phenomena as precipitation in marine environments and production of shiny to dull films in corrosion experiments, it is the judgment of the investigators that the fine materials will range in size from microns to silt-sized. The initial permeability of the settled debris is expected to be in the range of 10^{-11} to 10^{-14} m^2.

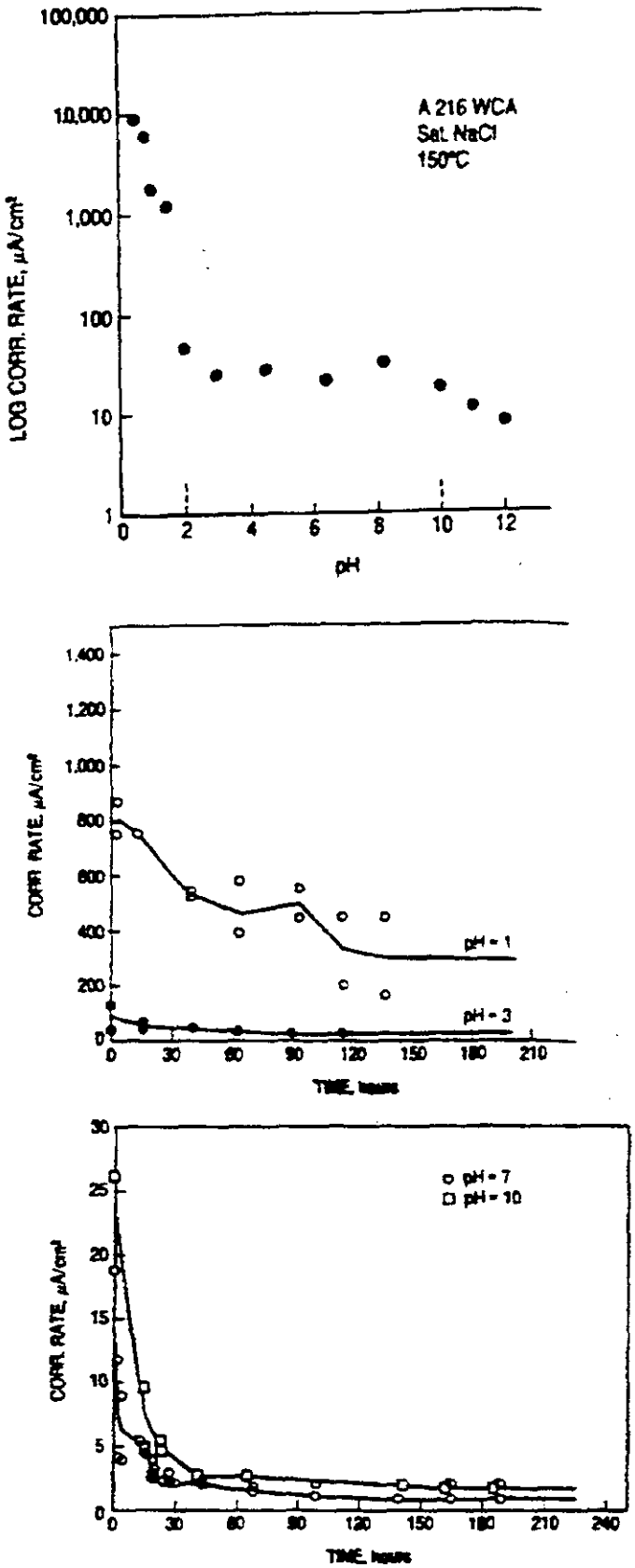

Figure B-1: The effects of pH and time on corrosion rate of low carbon steel

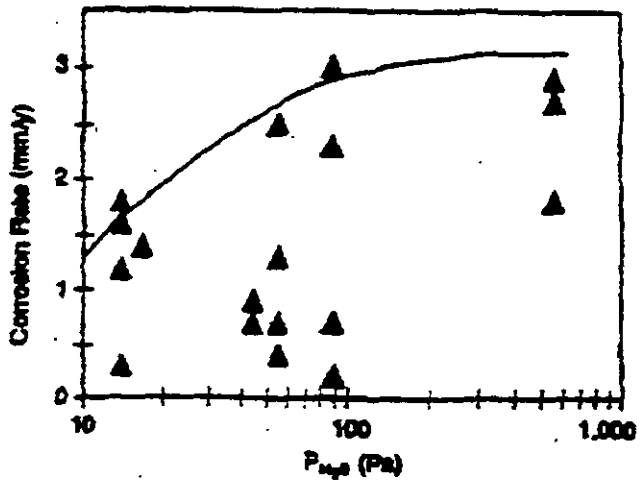

Corrosion rate of low carbon steel in carbon dioxide saturated solutions as a function of the partial pressure of hydrogen disulfide (from Videm and Kvarekval, 1995)

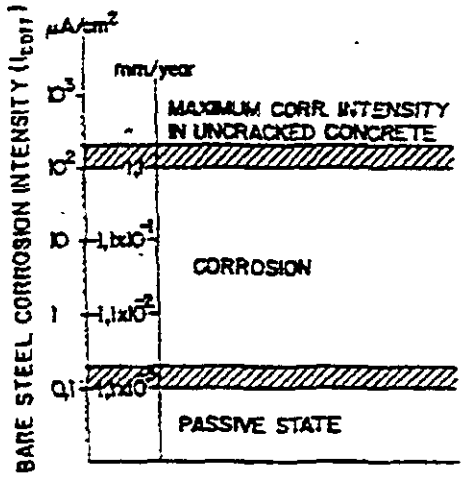

-Values of corrosion intensity in μA/cm² and in mm/year which may be measured in concrete. Below the range 0.1 to 0.2 μA/cm² the amount of corrosion is negligible. Between this range and until 100 to 200 μA/cm², corrosion is active and brown oxides develop. Values above 100 to 200 μA/cm² were never recorded in uncracked concrete.

Figure B.2

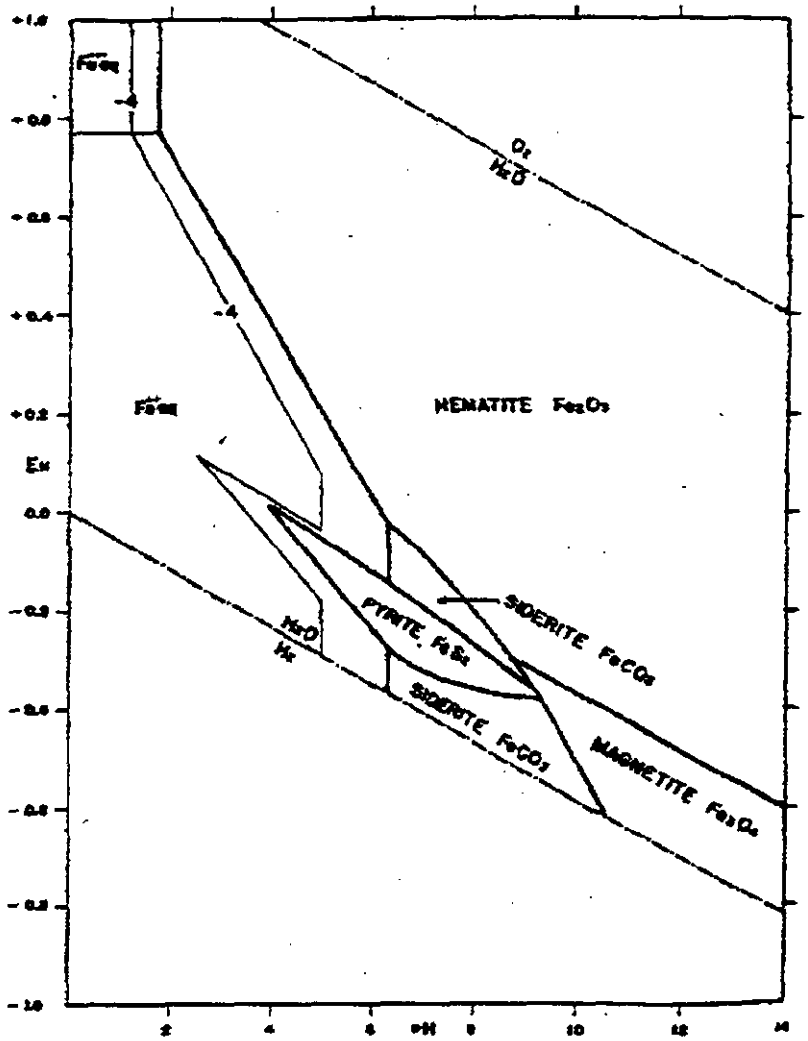

FIG B-3. Stability relations of iron oxides, sulfides, and carbonates in water at 25 °C and 1 atmosphere total pressure. Total dissolved sulfur = 10^{-5}. Total dissolved carbonate = 10^{0}. Note elimination of FeS field by $FeCO_3$ under strongly reducing conditions, and remarkable stability of pyrite in presence of small amount dissolved sulfur.

Figure B.3

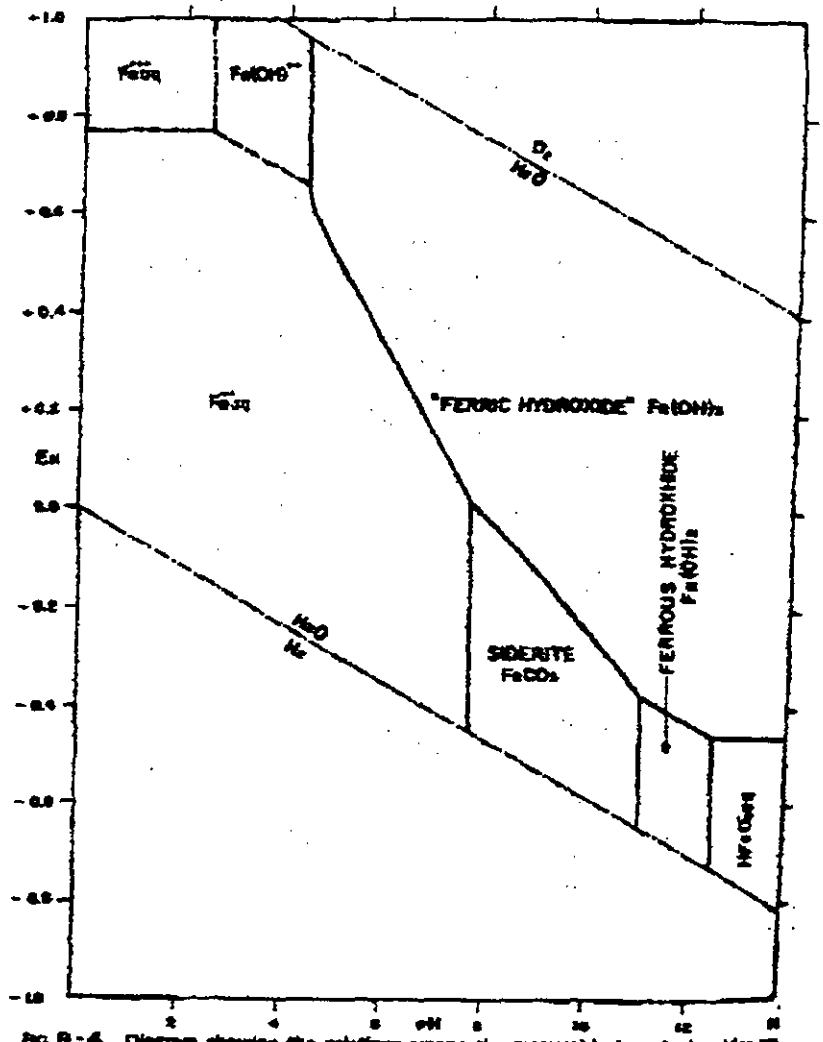

FIG. B-4 Diagram showing the relations among the measurable iron hydroxides and siderite at 25 °C and 1 atmosphere total pressure. Boundary between solids and total activity of dissolved species = 10^{-6}. Total dissolved carbonate species = 10^{-2}. Dashed lines are boundaries between fields dominated by the labeled ion.

Figure B.4

APPENDIX C: DEGRADATION OF CONCRETE

C.1. INTRODUCTION

On permanent abandonment, exploration and production boreholes in the Delaware Basin of New Mexico are filled with steel casing, drilling mud and concrete plugs. This appendix contains descriptions of mud and concrete plug materials (C-2), details of how the concrete materials are expected to alter with time (C-3), an explanation of how the performance life of concrete plugs has been estimated (C-4), a description of the characteristics of alteration products and debris expected from plug degradation (C-5), and a compilation of Delaware Basin plug locations, dimensions and plugged intervals (C-5). Simplifying assumptions have been made for many of the calculations performed. These assumptions and the limitations they impose on the application of the calculations are discussed within each section of the appendix.

Many of the results of the investigation into expected concrete plug performance rely on results from the casing corrosion investigations described in Appendix B, since some form of failure by the casing is a necessary precursor to changes in performance by the concrete plug. Conservative approaches have been used when analyzing the potential for casing failure, and are also used here. As a result, in the authors' scientific opinion, predictions of concrete plug and overall system performance most likely underestimate the expected performance life of borehole plugs.

Competent emplacement of borehole plugs is an underlying assumption of the performance-life analysis described here, so that the theoretical performance life of the plugs is based on the fundamental physical and chemical properties of the plug materials in the expected service environment. With this assumption, plug performance depends primarily on the environment in which the plugs are placed, and the initial permeability and porosity of the plug, as well as the nature of the plug materials.

Conservative site specific data have been used to estimate the former, and experimental data for generic Portland cement concrete have been applied to estimate the latter. The results indicate that plugs placed above about 335 m (1100') will likely disintegrate in one or two hundred years. Plugs placed at greater depths will be much more long-lived. The best estimate for the average performance life of deeper plugs is on the order of 5000 years, with an uncertainty of one order of magnitude.

C.2 PLUGGING SCHEMES USED IN THE DELAWARE BASIN OF NEW MEXICO

A total of 194 boreholes have been drilled and plugged in the New Mexico portion of the Delaware Basin since 1988, when current plugging and abandonment regulations were instituted. During this time interval, no hole is known to have been constructed and abandoned without following the plugging requirements set forth in various regulations (see Appendix A).

Figure C.4 depicts cross-sections of several plugging schemes used in the Delaware Basin of New Mexico. The minimum plugging configuration imposed by BLM regulations (Oil and Gas Order Number 2) requires plugs to isolate the evaporate sequence (Castile + Salado formations). In practical terms in the Delaware Basin, BLM requires placement of at least two plugs with one below and one above the repository. Figure C.4 shows that the minimum standards are met by installing a deep plug (generally placed below horizons associated with the pressurized brine reservoirs in the Castile Formation) along with a shallow plug interposed between the repository and the Culebra, usually at the Rustler-Salado contact. Of the 194 boreholes, 50 are plugged in this manner (See Table C.2).

The maximum plugging configuration consists of a continuous plug throughout the Salado-Castile evaporite sequence. Regulation R-111-P applies to any hole placed in the Known Potash Leasing Area (KPLA), regardless of whether the hole is intended for oil and gas or mineral exploration. The regulation provides protection to mineralized potash areas and workings by requiring a continuous plug so that there is virtually no chance for the flooding of mines either as they are developed or during their operation. All potash exploration holes follow the practices required by R-11-P. There are only four oil and gas boreholes documented to have a continuous plug; however, over 70 applications for oil and gas holes have been denied in the KPLA since 1988 (See Burski, 1994) for fear of creating circumstances that threatened potash reserves or workings.

Between the maximum and minimum plugging schemes lies intermediate ground characterized by multiple plugs. Multiple plugs are placed when: 1) casing is cut and recovered after development, or 2) in the event that unusual circumstances are encountered (e.g., lost circulation, water-production into the casing, casing failure, delivery of excess concrete to the site etc.) .

Figure C.4 depicts several such plugging schemes documented in the Delaware Basin of New Mexico. In these schemes, additional plugs are located in the Salado and/or Castile between (or through) the brine reservoir horizon (located at ~900m depth) and the Culebra (located at ~216 m depth). Table C.2 summarizes the available borehole and plug location/dimension information. For reference, the repository is taken to be located at a depth of 655 m; thus, Basin-wide practice includes installation of intermediate plugs that lie both above and below the reference repository depth. Whether or not current practice would result in plugged intervals above or through the actual repository horizon has not been speculated upon.

C.3 COMPOSITION OF BOREHOLE PLUG ELEMENTS

For the purposes of this report a borehole plug is defined as consisting of the casing, and any material left or emplaced within the casing. Performance of the casing has been discussed in Appendix B. Materials left within the casing include drilling mud and concrete. These elements are described and discussed below.

C.3.1 Drilling Mud

Different types of mud are used at different times in well-development history. A lubricating and hydraulic control mud is used during drilling of the well. At abandonment, plugging mud is placed within the casing to provide a platform for setting internal concrete plugs at desired depths, and to provide a positive fluid pressure to control inflow of formation fluids. The plugging mud remains as a part of the plugging system, and will be referred to hereafter as "mud.".

C.3.1.1 Composition of "Mud"

The BLM regulations in Oil and Gas Order Number 2 require that drilling mud left at abandonment must have a density of 10 pounds per gallon. Density is achieved by mixing mineral solids with brine. A previous investigation (Warner and McConnell, 1990) modeled oil field muds as sodium montmorillonite with water and concluded that after settling "muds" provided significant hydraulic flow resistance. As explained below, this result cannot be translated to the current situation due to the low volume of solids used in the low density muds.

BLM requirements for "mud" density can be achieved with NaCl- saturated brine and a minimum of additional solid material. The density of NaCl brine is about 1.2 g/cm^3, or about 9.6 pounds/gallon. Addition of about 2% by volume sodium montmorillonite satisfies the BLM requirement for 10 pound "mud." A review of plugging practices in the Delaware Basin (Westinghouse, 1996) shows that BLM requirements are met in precisely this manner. Thus, in reality drilling "mud" is brine possessing a somewhat thicker viscosity than ordinary water, but without appreciable hydraulic resistance.

Discussions with drillers and mud companies have resulted in conflicting pictures of the ability of particulates to settle out from "muds." Additives are routinely placed in "muds" to prevent settlement, and there are claims that settlement will be prevented permanently, although "permanent" in the context of normal oil-field operations does no necessarily equate to "permanent" in the regulatory context. There are also anecdotes that relate to difficulties of encountering settled "muds" upon reentering abandoned holes.

The amount of montmorillonite that might settle out of the low density plugging mud will not provide a flow barrier of any consequence. The upper 345 m of casing has an ID of 31.788 cm (12.515"; Westinghouse, 1996) and an associated volume calculated as ~27 m^3. The volume of clay associated with this amount of "mud' would be 0.55 m^3 at 10 ppg. If all this clay were to settle out onto the uppermost plug (which is assumed to be located near the Salado-Culebra contact), at full density the pile would have a permeability on the order of 10^{-15} m^2, but it would extend less than 5 meters. At high hydraulic gradients and without sufficient physical support, the pile would be subject to piping and erosion. If the pile fell into the intermediate casing (ID = 20.12 cm), it would extend a length of less than 10 m or have a higher permeability. The suspicions concerning the ability of the mud to resist flow would remain approximately the same, but there would be an important additional uncertainty. Even if the settled mud column possessed low permeability and could withstand high hydraulic gradients, the pile's location may not lie

between water sources of concern and the Culebra. Because of the small amounts of solids involved, the uncertainties in regard to settled mud location, and the unresolved ability of the "mud" to settle, the current analysis does not rely on settled "mud" to contribute to borehole plug performance.

C.3.1.2 Composition of Oil Field Concrete

Oil field concretes are mixed by adding water, additives and bags of cement. Precise specifications can not be given because practice varies from driller to driller. For example, specifications are written in terms of "sacks of cement." Each sack weighs 94 pounds and can be used to formulate from 1 to 2 ft^3 of concrete slurry (Westinghouse, 1996). For an assumed density for cement of 2.8 g/cm^3, and assuming conservation of volume, the calculated water:cement ratio for oil field cement pastes therefore ranges from ~ 0.3 to ~0.9. BLM requires that plugs intended for evaporite sequences must be mixed with brines saturated in indigenous salts, such as halite. Accordingly, concretes are assumed to be halite saturated.

The type (i.e. composition) of cement used to plug boreholes also varies, Class C oil field cement is highly resistant to sulfate attack, and is specified for use at some depths. Otherwise, Class H oil field cement is used. Because the cement type is variable and because no WIPP-specific experiments have been conducted, generic data from portland cement materials have been used in these analyses.

The initial permeability associated with a generic portland cement paste can be estimated from the water:cement ratio of the mix. This relationship occurs because permeability is intrinsically related to the porosity through which the permeant must move. As cements harden, they undergo water-solid reactions that form phases such as calcium-silicate-hydrate gel, tobermorite, portlandite, and ettringite. These phases form an interlocking network, with trapped porosity between the crystals. The porosity is comprised of microcracks and internal porosity, but in either case, the pore volume was occupied by water prior to the onset of cement reactions. Thus, after hardening the initial permeability is related to the original water:cement ratio. Figure C.1 (Neville, 1983) shows the relationship of permeability to porosity and permeability to water:cement for generic portland cement pastes. From the figure, it can be deduced that the initial permeability of oil field concrete plugs will be on the order of 1×10^{-19} m^2. To account for field emplacement and the increased range of water:cement, an initial permeability on the order of 10^{-17} m^2 has been judged reasonable. Data from WIPP-specific field tests on cement plugs placed in the Castile formation appears to corroborate this estimate. Measured values from these field tests were 5×10^{-17} m^2 (Petersen and Christensen, 1980; Christensen and Hunter, 1980), and, since this value is consistent with those from the water:cement ratio, this is used as the permeability of undegraded concrete.

C.4 CHANGES IN CONCRETE PERMEABILITY AS A FUNCTION OF TIME

The solid matrix that makes up concrete is composed almost entirely of amorphous to cryptocrystalline solid phases. These phases are thermodynamically unstable, and with time and exposure to water they alter into more stable and more crystalline assemblages.

Alcorn et al (1992) used the equilibrium code EQ3NR/EQ6 to predict the alteration phases in portland cement that would occur upon exposure to waters ranging in composition from pure water to saline brines. The predicted alteration phases included tobermorite, quartz, gypsum, calcite, clays and zeolite, produced at the expense of soluble and unstable materials such as portlandite and hydrogarnet. The significance of the calculations is that the theoretical alteration assemblage occupies more volume than the original solids. Recalling that porosity and permeability are related, a theoretical relationship was developed to predict the change in permeability caused by the mineralogic changes:

$$\Delta_k = (k_i) \times 10^{7.39\Delta n} - k_i,$$

where k_i is the initial hydraulic conductivity, and Δ_n is the change in porosity that derives from mineralogic alterations. (Coons, et al., 1989)

This relationship, and the predicted decrease in porosity, indicates that the permeability of a concrete plug will decrease as the plug alters geochemically, assuming that the concrete structure is not allowed to expand its external volume. It is also apparent that the initial permeability of the plug is central to determining its long term performance. If initial permeability is low, then not much change will occur. If initial permeability is high, then there is the potential to observe significant change. It is also important to note that in fast flow ("open") systems, material can be transported out of the system, causing an increase in porosity and permeability. In equilibrium flow systems, permeability should decrease significantly.

These calculated results have been verified by subsequent experiments in which waters and cement were reacted (Onofrei et al., 1992). Consistent with theoretical predictions, the experiments showed consumption of portlandite and apparent production of gypsum, calcite, tobermorite and clay-like materials which were observed as very fine-grained materials filling pores and coating surfaces of the original hardened paste. As a result, the experiments also showed the reduction of porosity and permeability predicted from theory (See Figure C.2), confirming that as time passes in physically confined systems concrete plugs may be expected to improve their performance as hydraulic barriers. This prediction is also confirmed, at least partially, from observations made on recovered plugs originally placed decades ago in potash mineral exploratory holes in the Delaware Basin. Petrographic inspection of the cores reveals some alteration proximate to surfaces where water access has occurred, but shows that original textures and mineralogy (e.g. portlandite) is present at short distances of separation (Bonen, 1995). These observations are consistent with mineralogic alteration of the concrete attending water access, followed by the subsequent inability of water to reach further into the concrete.

By contrast, at free surfaces concrete materials are not physically supported and can spall. Long term leaching experiments report that surface diffusion controlled alteration is dependent on the C_3A content of the cement and the Mg and SO_4 content of leachant (Walton et al., 1990). Creation of an alteration rind weakens the concrete and makes it subject to spalling (Wakeley et al., 1994). The mechanism for spalling is that the alteration phases occupy more volume than the original solids, volumetric expansion increases internal pore pressures until concrete tensile strengths are exceeded and spalling occurs. Short-term, empirical studies of ordinary concrete alteration report alteration rates in the range of 0.7 to 1 mm/year (Atkinson and Hearne, 1990) - These rates are likely to be overestimates because diffusion distance varies as the square root of time. For simplification, the time (i.e. distance) dependence and the effect of compositional changes in the leachant have been neglected when estimating spallation. This is conservative because of the two variables, diffusion is the controlling factor (the composition of the leachant is unimportant if it cannot roach the material being leached). So, for the purposes of estimating concrete plug longevity, the commonly reported leaching rates (0-5 to 1 mm/yr) are assumed equivalent to a spallation rate. Generally, spalling occurs after increments of one to several millimeters of alteration (Atkinson and Hearne, 1990) but this level of detail is inconsequential to the model. Based on this model, axial diffusion driven spallation will reduce the length of a borehole plug by 5-10 m in 10,000 years, while if corrosion produces a hydraulically conductive interface between the plug and the casing, radial diffusion and spallation would reduce the diameter of the plug by half in about 120 years. Such a reduction is judged sufficient to result in physical failure of the plug.

In summary, theoretical calculations and empirical observations show that in physically confined systems chemical alteration of concrete plugs will tend to decrease the plug's permeability. In unconfined and fast flow systems, chemical alteration will tend to increase plug permeability. Borehole plugs will generally receive radial confinement from the borehole and casing wall, however if the casing is removed from around the plug and water sources are present, failure is predicted to occur rapidly (in about 100 years), due to a combination of fast flow and diffusion-driven spallation. Axial (longitudinal) confinement for the plug comes from the plug's internal strength. Short plugs will tend to act as unconfined systems, while longer plugs will be confined, however the minimum length to approximate a fully confined system has not been determined.

C.5 FLOW-DRIVEN FAILURE OF CONCRETE BOREHOLE PLUGS

As noted above, the minimum length a plug must have to be self-supporting and approximate a fully confined system has not been determined. In an attempt to model flow driven failure, the following logic has been employed:

- The concrete plug will lose its functionality when substantial cracking results from the cumulative flow of leachant through the plug

- Cracking will occur because increased pore pressures from alteration are insufficiently offset by the internal strength of the plug's matrix, supplemented by the effects of confinement of the plug

- Substantial cracking will occur when the plug begins to lose its internal strength
- Loss of internal strength will begin when the internal matrix of the concrete is chemically attacked and loses strength
- The internal matrix of the concrete is comprised of calcium-silicate-hydrate (CSH)
- When leachants show evidence that the CSH phase is being attacked, the plug is assumed to fail. Note that concrete materials do not dissolve congruently. The first phases to dissolve are portlandite and alkali salts (Atkinson, 1985). Phases such as ettringite and hydrogarnet likely follow, and then the CSH matrix is attacked.
- Prior to failure, the plug will function with no increases or decreases in permeability caused by changes in porosity

The progression of concrete chemical alteration has been reported by Berner (1990) for both fresh water and brine leachants. The progression is charted in terms of the volume of water flow. Traditionally, geochemical studies plot the progress of alteration in terms of the water: solid ratio. It is clear that the total volume of solid is irrelevant in concrete degradation studies because much of the solid never contacts the flowing leachant. By tracking progressive alteration in terms of the number of pore volumes of water that pass through the concrete, Berner is consistent with the reasoning that only the solid that surrounds the pores interacts with the leachant. His results show that more than 100 pore volumes of leachants must pass through the concrete before there is chemical evidence that the matrix is being attacked (See Figure C.3). Clearly these results will vary somewhat depending on the composition of the leachant and the cement mix formulation.

Based on the above assumptions, and Berner's results, it has been assumed that borehole plug failure will occur after 100 pore volumes of water have passed through the plug. This volume can be converted to performance life by using Darcy's Law and assumptions about the plug's physical characteristics. Thus, for a plug with a cross-sectional area of A (m^3), length of L (m), permeability of k (m^2), and a fluid viscosity of μ (Pa.s), inlet pressure of P1 and outlet pressure of P2 (Pa) the flow rate is:

$$Q = A*(k/\mu)*(P_1 - P_2)/L \quad m^3/sec$$

The pore volume of the plug (V_p) is:

$$V_p = AL\phi \ m^3$$

So:

$$Q = \{(k/\mu)*(P_1 - P_2)/L\}/\{L\phi\} \text{ pore volumes/sec}$$

Breakdown of the structure of the cement matrix is considered to start after 100 pore volumes of flow, or after:

$$t_{100} = 100*L\phi/\{(k/\mu)*(P_1 - P_2)/L\}* 3.154x10^7 \text{ years}$$

If the following values apply to plugs:

$$L = 40 \text{ m},$$
$$k = 5x10^{-17} \text{ m}^3,$$
$$\mu = 1x10^{-3} \text{ Pa.s},$$

then:

$$t_{100} = 1.015x10^5*\phi/(P_1 - P_2) \text{ years},$$

with pressures in MPa.

The porosity of the plug may be taken to range from 5-40 percent, while the pressures controlling the flow will depend on the location. For a plug between the Castile and the repository the pressure below the plug will be equal to the Castile brine reservoir pressure, less any head loss between the reservoir and the base of the plug. The pressure above the plug will equal the repository pressure, plus any head increase between the repository and the plug.

It should be noted that for the purposes of the calculations used here, the relationship between porosity and permeability is not accounted for. This simplifies the calculation but creates the somewhat illogical extension that as the porosity of the plug decreases, less and less water flux is calculated as being needed to cause failure. In the extreme, at zero porosity no flow would be necessary. The significance of this apparent inconsistency is diminished by evaluating a range of porosity that does not include zero. The lower limit of porosity for a borehole plug is judged to be 5 %. This is higher than estimated by Petersen and Christensen (2%; 1980) for the Bell Canyon test plugs, but more consistent with practical experience of field emplaced concrete structures. The upper limit for porosity is taken as 40%. This porosity conservatively reflects coarse grained (e.g. sand) particles in contact (also, see Figure C.1). Given the pressure imposed by the overlying column of water, greater porosities, while possible to engineer, would only occur with difficulty. An engineering estimate for the most likely initial porosity of concrete in a borehole plug is 10%.

C.6 CHARACTERISTICS OF DEBRIS GENERATED BY PLUG FAILURE

The secondary phases created during the chemical alteration of concrete are very fine (See Onofrei et al., 1992 for photomicrographs). These materials commonly clog pores in the concrete and are smaller than 100mm (See Gray, 1993). Spalled material from unloading concrete surfaces is also expected to be fine-grained. As with corrosion products, no knowledge is claimed for how the fine-grained material might agglomerate and/or cement with time.

The volume of debris that can be associated with failure of the uppermost plug is calculated as 2.89 m^3. This figure derives from the assumptions that 20 meters of the uppermost plug lies in the surface casing (ID = 31.788 cm) and 20 meters lies in the intermediate casing (ID = 20.119 cm; See Westinghouse, 1996 for plugging practices and casing dimensions) and that the disaggregated volume will be at least 30% greater than the intact volume. In addition to the volume from the degraded plug itself, the concrete materials used to cement the casing to the rock will contribute debris. The internal diameter of the borehole for the surface casing (OD = 33.973 cm) is taken to be 36.297 cm (Westinghouse, 1996). Assuming the same 30% bulking factor, the volume of degraded cement associated with disintegration of the upper 335 m (See Appendix B) of casing cement is 5.59 m^3.

Collectively, casing and plug cement debris is calculated to have a volume of 7.81 m^3. This volume is sufficient to fill the intermediate casing for a length of over 1300 m. When added to the minimum 8 m^3 of debris generated by casing corrosion, the debris pile is calculated to be at least 2600 m long (about 8800 feet). A debris column of this length is sufficient to fill an exploratory hole from its bottom (or a bridge plug set at 8000 feet depth) to above the Culebra. Thus, in the worst case, if calculations predicting plug performance life are faulty, it is inconceivable that an abandoned oil and gas borehole will perform at a level less than a pathway filled with silty-sand (See 1992 PA and Appendix D). Representative performance lives and permeabilities associated with plugged borehole intervals are summarized in Table C.1. An engineering estimate for initial porosity (10%) has been used for the example calculation.

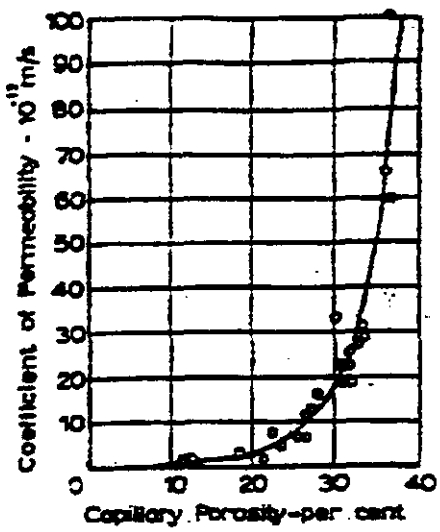

.Relation between permeability and capillary porosity of cement pastes (Neville, 1981).

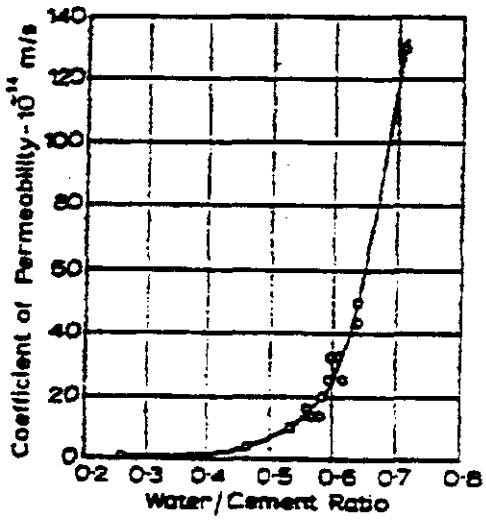

.Permeability as a function of water - cement ratio for mature cement pastes (93% of cement hydrated). From Neville, 1981.

Figure C.1

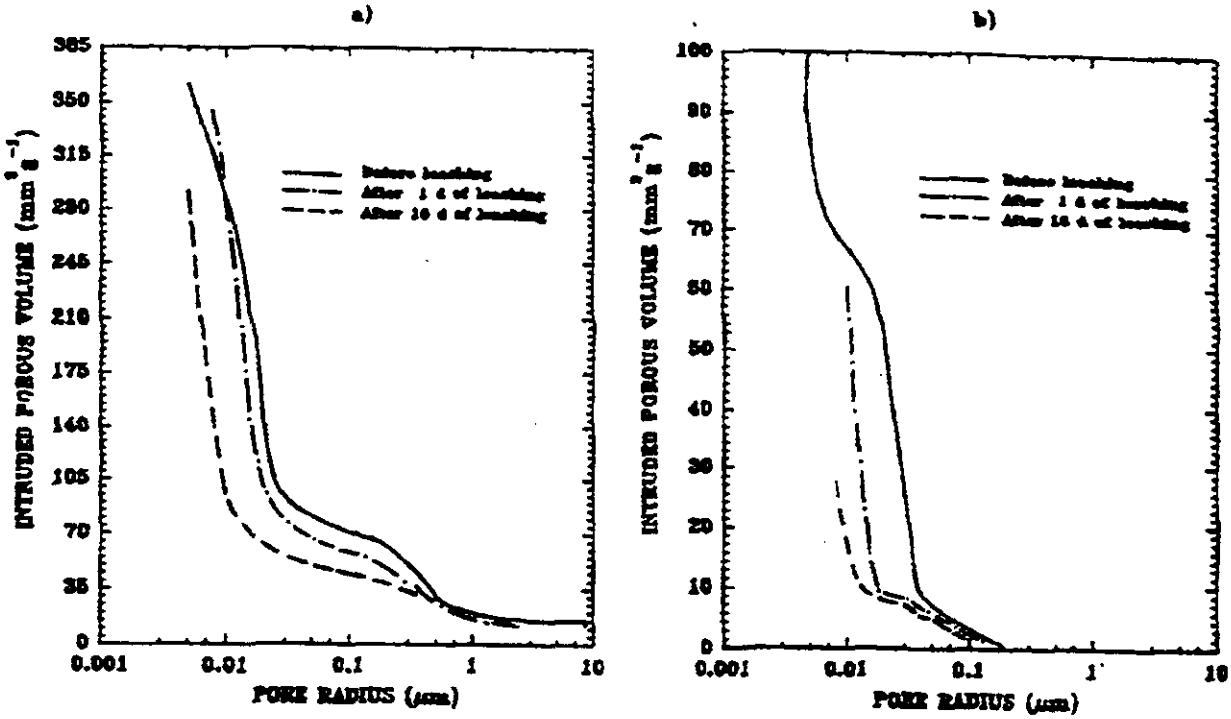

The effect of leaching time on cumulative pore size distribution measured by mercury intrusion porosimetry for: (a) ALOFX -MC grout (MC-500, 0.7/1/10), and (b) reference grout (Type-50, 0.4/1/10).

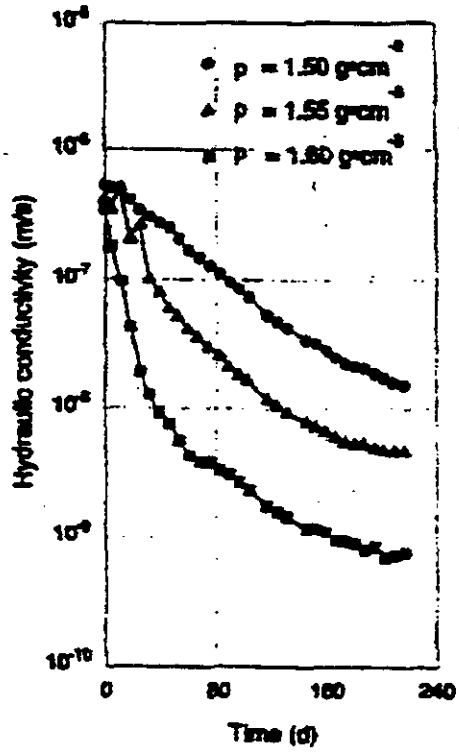

Fig C-2 Decreases in hydraulic conductivity measured in crushed, reconsolidated grout as a function of time of exposure to flowing ground water (from Gray, 1992; after Onofrei et al., 1992).

Figure c-3 Degradation of "HTS" in standard marl grundwater "MAR". After 6650 cycles calcite is the only solid phase present (T = 25 °C).

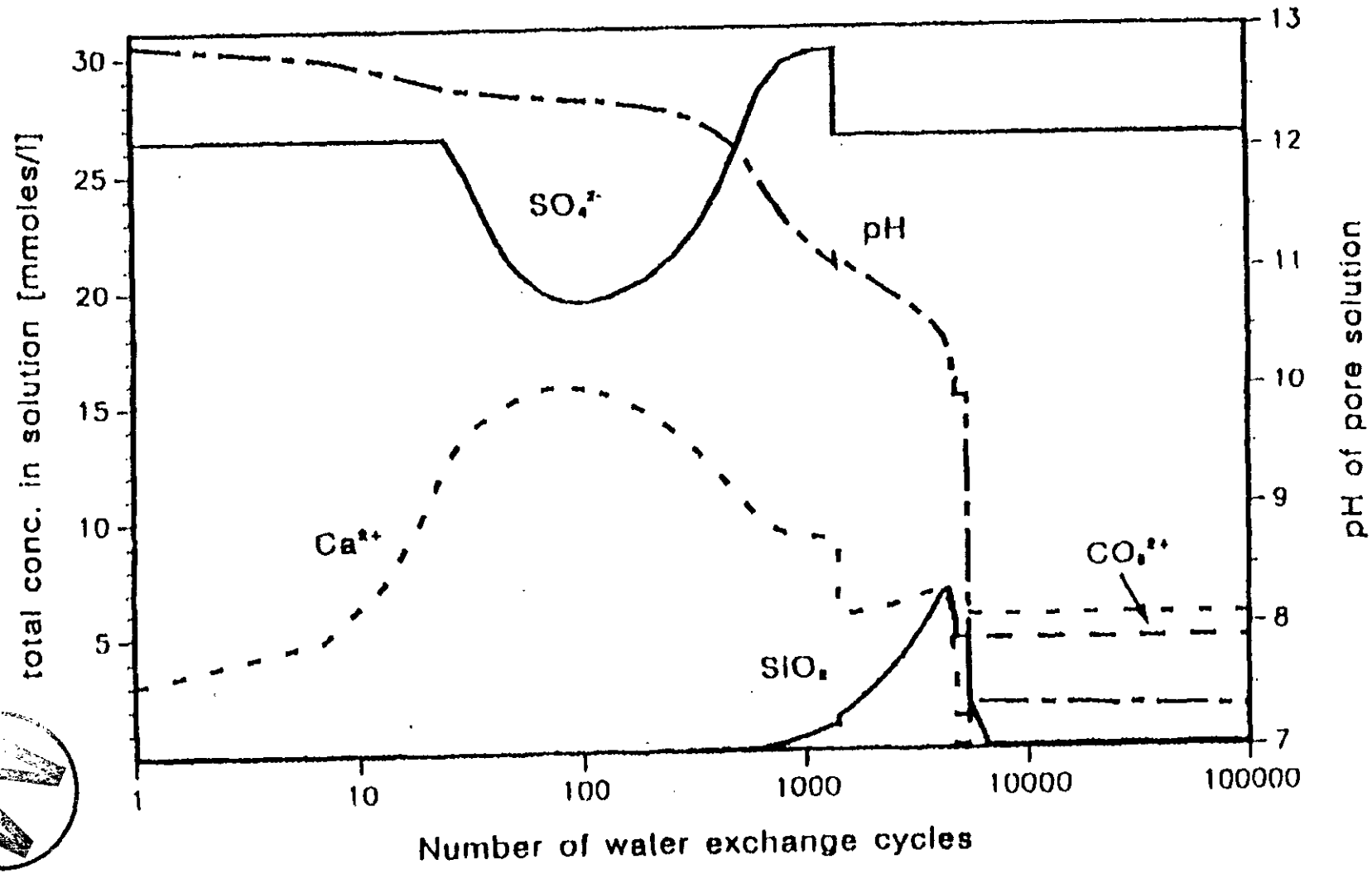

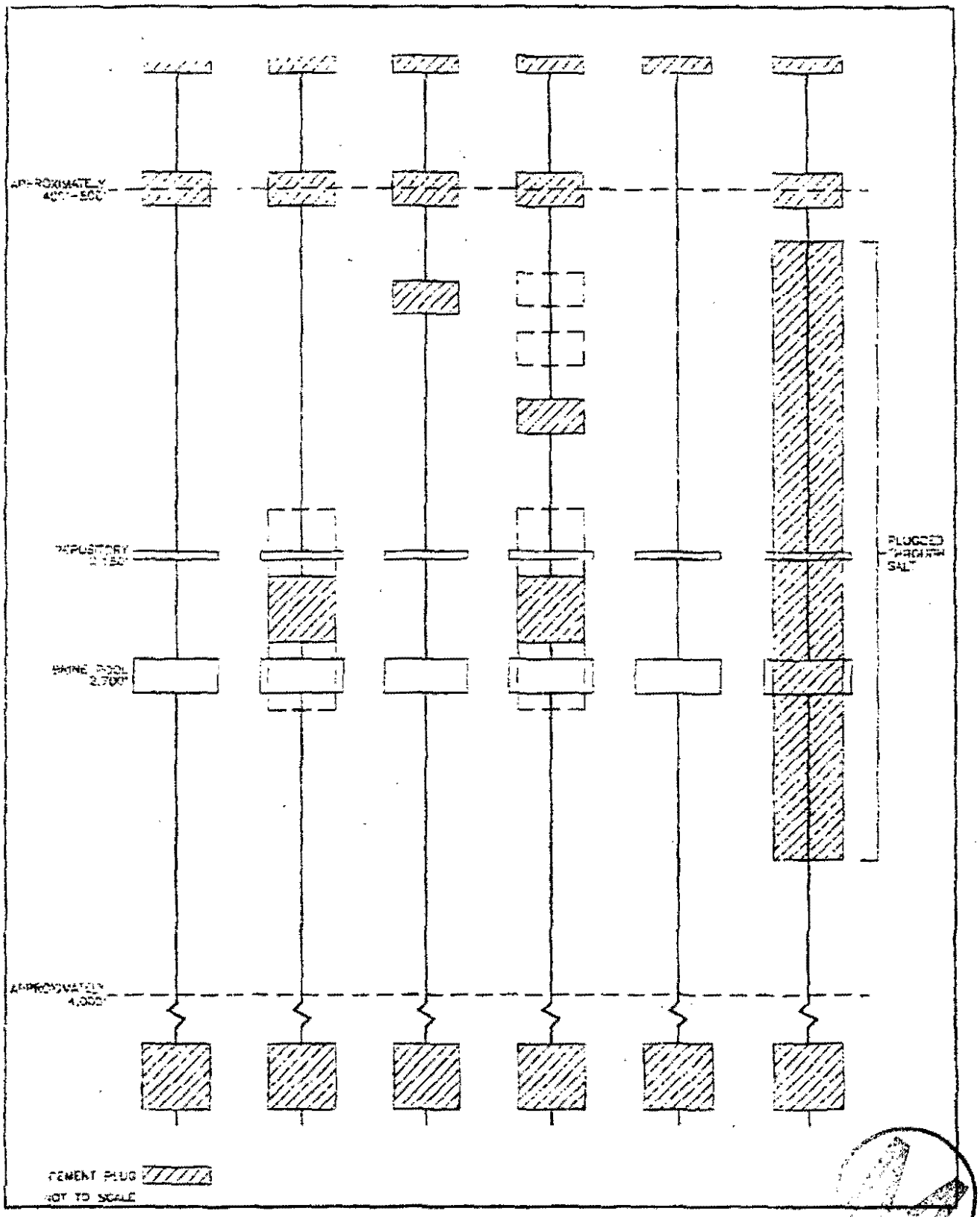

Figure C-4

Typical Borehole Plug Configurations in the Delaware Basin

APPENDIX D: CREEP CLOSURE OF BOREHOLES

D.1. INTRODUCTION

Following disintegration of the upper plug a borehole will become filled with a material whose physical properties, including permeability, will approximate those of a silty-sand. Appendix C.-- has evaluated this material. Over time that portion of the borehole in the salt sections will tend to creep closed, and in so doing will compress the fill material, and may be expected to reduce its porosity and permeability. Analyses have been conducted to evaluate this effect, and have demonstrated that, in the absence of any restraint from uncorroded casing, borehole creep closure will reduce permeabilities in the deeper parts of an intrusion borehole (that is below the repository) by about one order of magnitude in about 1000 years. Closure of the borehole above the repository will be too slow to have any significant effect.

The methodology used for these calculations is to a) calculate the time for a certain amount of borehole closure to occur at various depths, b) equate these closures to porosity reductions and c) relate these porosity reductions to permeability reductions using an appropriate correlation.

D.2. CREEP CLOSURE

Creep closure of the borehole has been calculated by RE/SPEC using a "pineapple slice" plane strain model in the Spectrom 32 code, with the MDCF model and WIPP salt parameters. Only steady state creep was included. Closure calculations were made for 5000 years at depths of 250 m (Top Salado), 450 m, 650 m (Repository) and 850 m (Bottom Salado). Far-field horizontal stresses were estimated at 1 psi/ft depth, with a back-pressure due to a column of brine (density 1.2) to the surface. No back pressure due to consolidating borehole fill is allowed for. Full details of the calculations are included in RE/SPEC's calculation file 325/3.9/01. Results are summarized in Figures D.1 and D.2.

The results, in terms of volumetric closure, are converted to a reduction in porosity for the silty-sand borehole fill as follows:

Deformation is plane strain, so:

$$V/V_o = A/A_o = (a_o + u)^2/a_o^2$$

where: V, V_o are the current and initial borehole volume,
A, A_o are the current and initial borehole cross-sectional area,
a_o is the initial borehole radius,
u is the radial deformation.

If it is assumed that all change in volume is due to loss of pore volume, i.e. the solids are infinitely stiff relative to the borehole fill, then:

$$(1 - \phi)/(1 - \phi_o) = (V_s/V_b)/ (V_s/V_{bo}) = V_{bo}/V_b,$$

D.3. PERMEABILITY - POROSITY

It is assumed that the permeability varies with the porosity, according to the Kozeny-Carman relationship (e.g., Bear, 1972: Lambe and Whitman, 1969: Koltermann and Gorelick, 1995):

$$k = \alpha\, \phi^3/(1 - \phi)^2,$$

so that:

$$k/k_o = (\phi/\phi_o)^3/\{(1 - \phi_o)/(1 - \phi)\}^2.$$

D.4. RESULTS

Figure D.3 shows the volume closure required to give a one order of magnitude reduction in permeability ($k/k_o = 0.1$) for various possible values of initial porosity ,ϕ_o. This indicates that for initial porosities varying between 25% and 40% volume closures of between 14% and 23% are required. For a median initial porosity of 32% a closure of 18% is required. Figure D.1 may then be used to indicate the time required for these volume closures to occur at different depths. At the base of the Salado (850 m) 14% closure will occur in slightly less than 500 years and 23% in about 850 years. At the repository level 14 % closure will take about 1800 years, and 23 % over 3500 years. Figure D.2 indicates that the median (18%) closure will be realized for a column of about 100 metres in 1000 years and almost for the full column beneath the repository in 2000 years.

A number of points should be noted. Firstly the time values given here are calculated assuming that there is no restraint from uncorroded casing, although on the other hand they do assume uniform closure, and neglect the effect of early localized corrosion. Secondly these values take no account of consolidation due to the effect of the overlying borehole fill. Finally the creep closure calculations do not account for back stress from the consolidated fill. This is not unreasonable for the closures used here (up to 23% maximum), but will probably not be reasonable for larger closures. As a result additional closure will be increasingly resisted, making it likely that the one order of magnitude reduction in permeability from the effects of creep used here will not be exceeded with additional time.

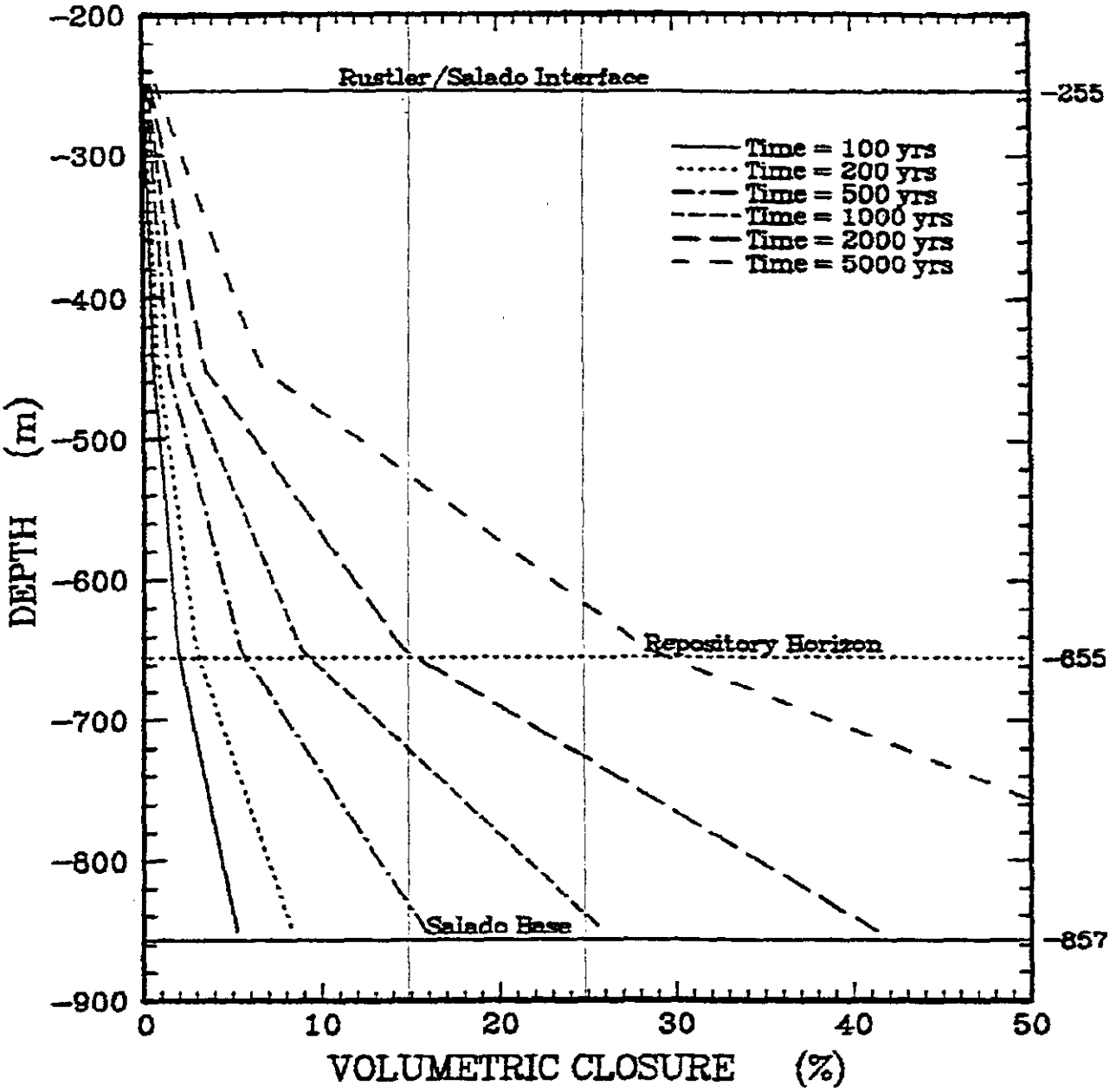

Figure 5. Volumetric Closure as a Function of Depth at Six Representative Times.

— PRELIMINARY —

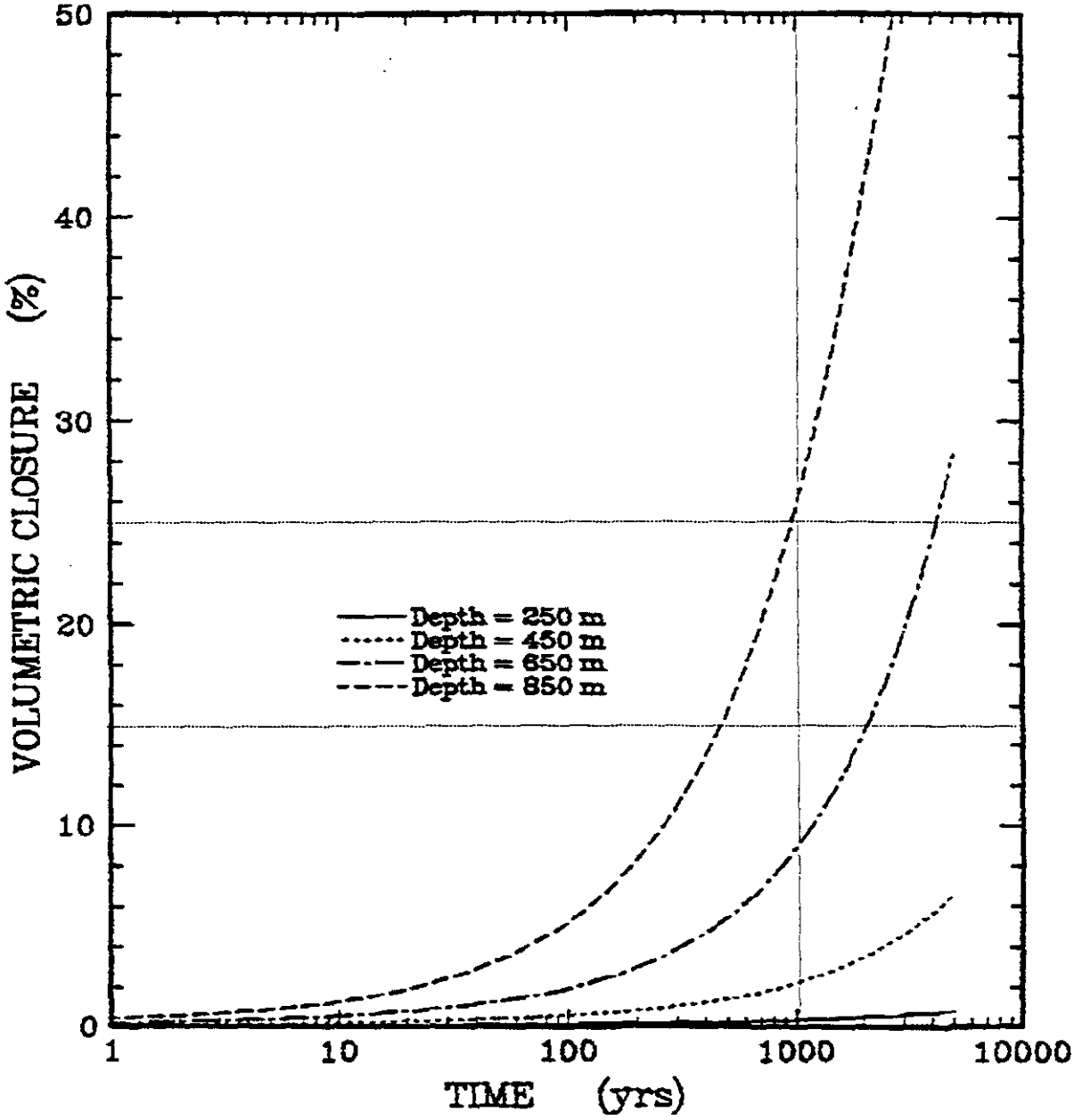

Figure 2. Volumetric Closure as a Function of Time at Four Depths.

— PRELIMINARY —

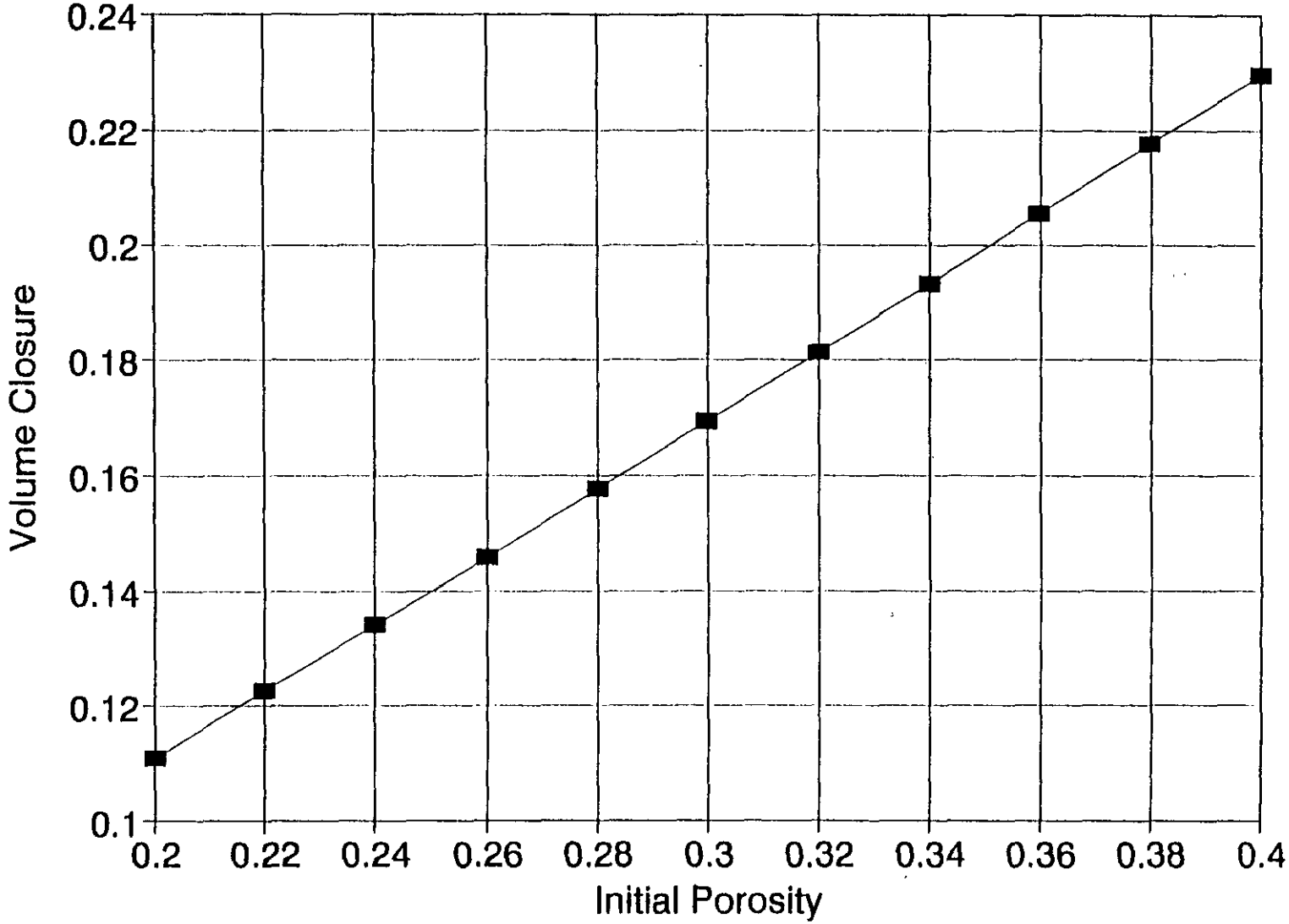
Volume Closure for k/ko = 0.1
Volume Closure
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.2
0.22
0.24
0.26
0.28
0.3
0.32
0.34
0.36
0.38
0.4
Initial Porosity

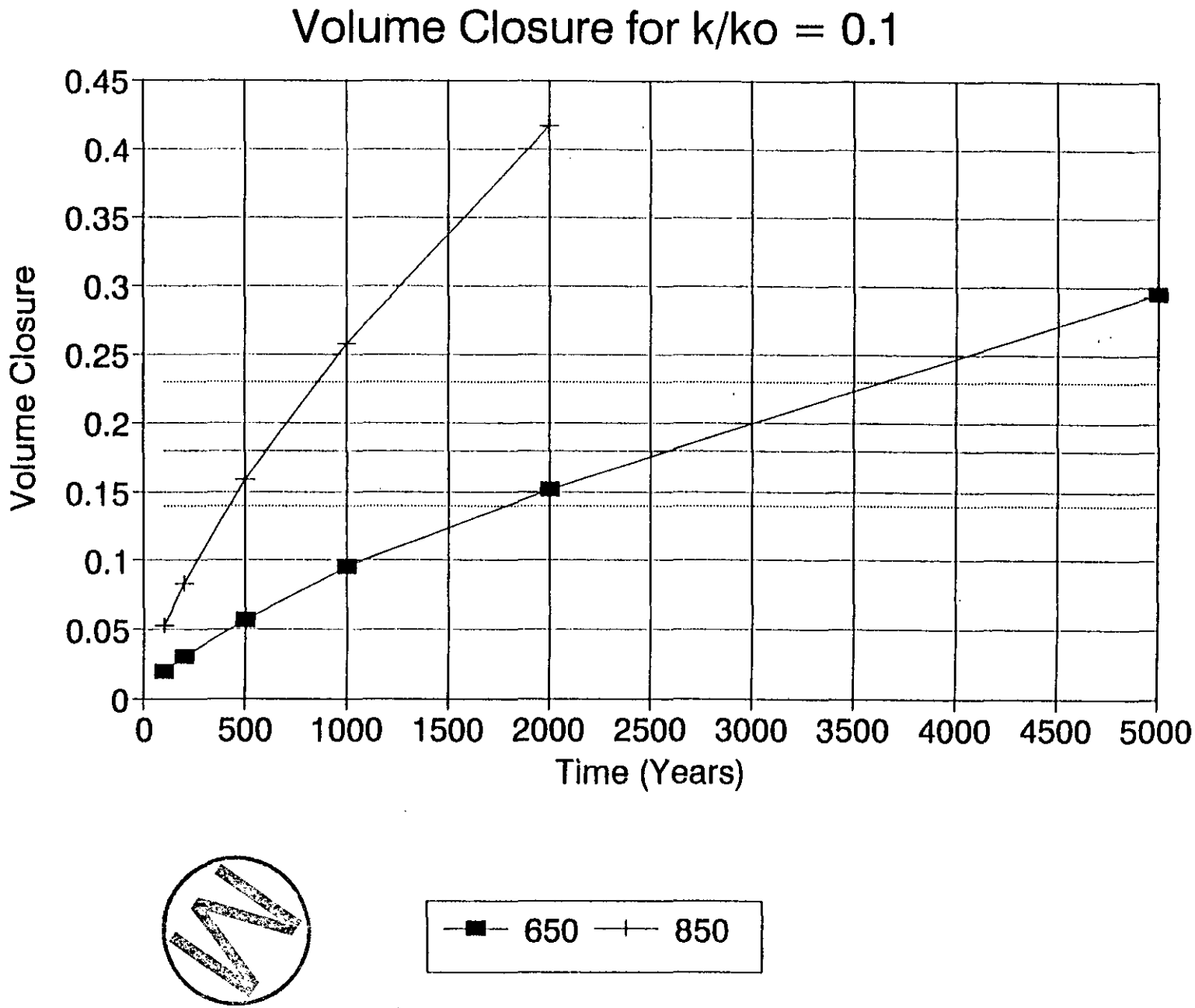
Volume Closure for k/ko = 0.1
Volume Closure
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time (Years)
650
850

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

MASS Attachment 17-1

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36425 see 38365

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

date: April 24, 1996

to: NWM Records Center, SWCF-A:WBS1.2.07.1:PDD:QA: Non-Salado:Culebra Transmissivity Zone:CLIMTIDX/GLOBAL

T Corbet.

INFORMATION ONLY

from: Thomas Corbet, MS-1324 (6115)

subject: Non-Salado Record Package: Culebra Transmissivity Zone: Climate Index

The attached record package contains the parameter value and supporting documentation for the Climate Index (idpram: CLIMTIDX, idmtrl: GLOBAL, id: 223). This record package is supported by several other record packages which will be submitted to the NWM Records Center at a later date (see also "Roadmap" contained in Part 2 of this package).

The information in this record package was collected by Principle Investigators for input to the WIPP Data Entry Form (Form 464) and for use by Performance Assessment personnel making parameter estimates. The record package was prepared in accordance with WIPP Quality Assurance Procedure (QAP) 17-1, WIPP QA Records Source Requirements.

Please call me at 848-0714 if you have any questions.

SWCF-A:WBS 1.2.07.1:PDD:QA:Non-Salado:Culebra Transmissivity Zone:CLIMTIDX/GLOBAL

WPO # 37465
see 39 345

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 12 April 1996

to: M. Tierney, Dept. 6741, MS 1328

from: T. Corbet, Dept. 6115, MS 1324, P. Swift, Dept. 6821, MS 1395

INFORMATION ONLY

subject: Distribution for Non-Salado Parameter for SECOFL2D: Climate Index

parameter description:	Climate Index
idpram:	CLIMTIDX
idmtrl:	GLOBAL
id#:	223

The constructed distribution (subjective) is as follows: the probability density is 3.0 in the interval from 1.0 to 1.25 and the probability density is 0.333 in the interval from 1.5 to 2.25.

The rationale for this distribution and supporting information is contained in the records package: Non-salado Parameters Required for SECOFL2D: Climate Index, SWCF package number 36425. This package will be placed in the records center at a later date.

copy: J. Ramsey, Dept. 6749, MS 1328
A. Lappin, Dept. 6115, MS 1324
SWCF-A:WBS 1.2.07.1:PDD:QA:Non-Salado:Culebra Transmissivity Zone:
CLIMTIDX/GLOBAL

PART 1: ANALYSIS SUMMARY

A. Parameter Identification

parameter description:	Climate Index
idpram:	CLIMTIDX
idmtrl:	GLOBAL
id#:	223

B. Parameter Value

The constructed distribution (subjective) is as follows: the probability density is 3.0 in the interval from 1.0 to 1.25 and the probability density is 0.333 in the interval from 1.5 to 2.25. Consequently, the probability that a sampled value of the Climate Index is in the interval from 1.0 to 1.25 is 0.75, and the probability that a value is in the interval from 1.5 to ~~1.25~~ 2.25 is 0.25.

T Corbet 11 July 1996

C. Scope and Objectives

Scenarios involving one or more intrusion holes consider the possibility that brine carrying radionuclides in solution could flow up an intrusion hole and then flow laterally in the Culebra Dolomite Member to the accessible environment. A change in climate could alter the flow rates and directions of groundwater flow in the Culebra and consequently impact transport of radionuclides to the accessible environment. The performance assessment calculations for the CCA will include the possible effect of climate change on transport in the Culebra by multiplying the magnitude of flow in each realization of the Culebra flow field by a sampled value of the Climate Index. This will uniformly modify flow rates, but not flow directions, in each realization of the Culebra flow-field.

The objective of this analysis is to specify the sample distribution for the Climate Index. This is a constructed subjective distribution because it is not possible to directly measure future changes in climate or their long-term effect on groundwater flow in the Culebra. The rationale for the distribution has two main parts. First we have surveyed the scientific literature to find available information that can be used to infer the annual precipitation rate since the end of the Pleistocene and for the next 10,000 years. Second, we performed a series of numerical simulations to see how various assumed rates and temporal patterns of recharge would impact groundwater flow velocities in the Culebra within the WIPP site.

This parameter records package is in two parts. The remainder of this Part 1 outlines the approach and assumptions used in this analysis (Section D), the results of the numerical simulations (Section E) and finally, in Section F, the rationale for the specified distribution for the Climate Index. Part 2 contains details of the analysis documentation.

D. Approach and Assumptions

Climate Change

Geologic data from southeastern New Mexico and the surrounding region show repeated alternations of wetter and drier climates throughout the Pleistocene, corresponding to global cycles of glaciation and deglaciation. Data from plant and animal remains and paleo-lake levels permit quantitative climate reconstructions for the region only for the last glacial cycle, and confirm the interpretation that conditions were coolest and wettest during glacial maxima (Swift, 1993). The hottest and driest conditions since the last glaciation have been similar to those of the present. Modeling of global circulation patterns suggests that these changes resulted from the disruption and southward displacement of the winter jet stream by the ice sheet, causing an increase in the frequency and intensity of winter storms throughout the American Southwest (COHMAP Members, 1988). Mean annual precipitation 22,000 to 18,000 years ago, when the last North American ice sheet reached its southern limit roughly 1500 km north of the WIPP, was approximately twice that of the present (Figure 1). Mean annual temperatures may have been as much as 5°C colder than at present.

Glacial periodicities have been stable for the last 800,000 years (Milankovitch, 1941; Hays et al., 1976; Imbrie et al., 1984; Imbrie, 1985). Barring anthropogenic changes in the Earth's climate, relatively simple modeling of climatic response to orbital changes in insolation suggests that the next glacial maximum will occur in approximately 60,000 years (Imbrie and Imbrie, 1980). The extent to which unprecedented anthropogenic climate changes may alter this conclusion is uncertain, but presently available models of climatic response to an enhanced greenhouse effect (e.g., Mitchell, 1989; Houghton et al., 1990) do not predict changes of a larger magnitude than those of the Pleistocene. Furthermore, published models do not suggest significant increases in precipitation in southeastern New Mexico following global warming (Washington and Meehl, 1984; Wilson and Mitchell, 1987; Schlesinger and Mitchell, 1987; Houghton et al., 1990).

Relatively shorter-term climatic fluctuations in southeastern New Mexico have occurred throughout the Pleistocene and Holocene with periodicities on the scale of thousands of years (Figure 1). The causes of these nonglacial fluctuations are, in general, unknown, but paleoclimatic data indicate that precipitation may have approached glacial highs for relatively short periods at some times during the Holocene (Swift, 1993). Based on the past record, fluctuations of this sort are possible and perhaps likely during the next 10,000 years.

Numerical Modeling of Groundwater Flow

The overall approach of the numerical modeling was to perform a series of simulations of groundwater flow in the strata overlying the Salado Formation assuming a range of values for the hydraulic properties of the rocks, recharge rates, and changes in recharge rate with time. We examine the simulation results to see how the lateral flow out of the portion of the Culebra within

the WIPP site change over the next 10,000 years. The uncertainty in the hydraulic properties of units other than the Culebra is large and the number of simulations that can be performed is limited. We therefore subjectively select combinations of hydraulic parameters that represent a broad range of possible responses to future changes in recharge.

CONCEPTUAL MODEL

These numerical simulations are based on the widely-accepted concepts of regional groundwater flow in groundwater basins (Hubbert, 1940; Tóth, 1963; Freeze and Witherspoon, 1967). A groundwater basin is a three-dimensional closed hydrologic unit bounded on the bottom by an "impermeable" rock unit (actually a stratigraphic layer with much smaller permeability than the layers above), on the top by the ground surface and on the sides by groundwater divides. The upper boundary of the region of saturated flow is the water table. All rocks in the basin have finite permeability, i.e., hydraulic continuity exists throughout the basin. All recharge to the basin is by percolation of precipitation to the water table and all discharge from the basin is by flow across the water table to the land surface. Here, the term recharge is used as defined by Freeze and Cherry (1979) to mean the entry into the saturated zone of water made available at the water-table surface, together with the associated flow away from the water table within the saturated zone.

Differences in the elevation of the water table across the basin provide the driving force for groundwater flow. The pattern of groundwater flow depends on the lateral extent of the basin, the shape of the water table, and the heterogeneity of the permeability of the rocks in the basin. Water flows along gradients of hydraulic head from regions of high head to regions of low head. The highest and lowest heads in the basin occur at the water table at its highest and lowest points respectively. Therefore groundwater generally flows from the elevated regions of the water table, downward across confining layers (layers with relatively low permeability), then laterally along more conductive layers, and finally upward to exit the basin in regions where the water table (and by association, the land surface) is at low elevations.

The position of the water table moves up and down in response to changes in recharge. The water table can't rise higher than the land surface at any location. Seepage faces develop in areas where recharge is sufficient to maintain the water table at the land surface. It is through the development of seepage faces that the topography of the land surface impacts patterns of groundwater flow. Seepage faces occur only in topographically low areas if recharge is low. In this case, groundwater flow is toward the seepage faces. The portion of a basin that is covered by seepage faces increases as recharge increases. Given a sufficiently humid climate, the entire surface of a groundwater basin is covered by seepage faces. That is, the water table is everywhere close to the land surface. As groundwater flow adjusts to changes in recharge, the rise or fall of the water table is greatest under areas in which the elevation of the land surface is highest.

Climate impacts groundwater flow by changing the amount of moisture that infiltrates and recharges the saturated zone. In our implementation of this conceptual model, changes in

climate are represented as changes in the rate of potential recharge with time. We assume that more recharge occurs during cool wet climates than during hot dry climates.

TOPOGRAPHY AND MODEL BOUNDARIES

The lateral boundary of the numerical model for the WIPP region (Figure 2) coincides with selected topographic depressions and highs on the land surface. The boundary follows Nash Draw and the Pecos River valley to the west and south and the San Simon Swale to the east. The boundary continues up drainages and dissects topographic highs along the northern part of its east side. It is assumed that these boundaries represent groundwater divides whose position remains fixed over the range of past and future climates. There are other groundwater divides within this boundary. The positions of these additional divides might change with time and, in some cases, even their existence might be intermittent. The lower boundary of the model is the top of the Salado Formation and the upper boundary coincides with the land surface.

HYDROSTRATIGRAPHY

Measurements of rock hydraulic properties are available for only a tiny fraction of model area because this area is much larger (it covers approximately 6000 square kilometers) than the region covered by the site characterization. Values for these properties are inferred from geologic observations and conceptual models of how geologic processes have altered hydraulic properties.

The strata above the Salado are layered and there are large differences in the ease at which water can flow through the individual layers. We conceptualize the effect of the layering on groundwater flow in terms of the hydrostratigraphic units (Figure 3) defined by Powers and Holt (1990). A hydrostratigraphic unit comprises one or more adjacent rock layers with similar hydrologic characteristics. The Powers and Holt classification divides the Rustler Formation and overlying strata into 13 hydrostratigraphic units. Those hydrostratigraphic units that are relatively more permeable are referred to here as conductive units and those with very small permeability are called confining layers. The confining layers consist of anhydrite and halite. Dolomite layers form the conductive units. The confining layers are perhaps five orders of magnitude less conductive than the dolomite units. Dividing the Rustler and overlying strata into 10 stratigraphic units is sufficient to represent vertical heterogeneity at the regional scale. A detailed examination, however, would show that each of these units is also vertically heterogeneous. Heterogeneity within a hydrostratigraphic unit effects, for example, the transport of radionuclides along that unit.

The hydrostratigraphic units account for vertical differences in hydraulic properties. Such differences are due to the sedimentary processes that were active as these rocks were deposited. However, the hydrologic properties of these rocks also vary laterally. It is thought that post-depositional geologic processes caused the lateral variations. Those processes that were accounted for in our assignment of hydraulic conductivity values are summarized below.

Salado Dissolution. The top of the Salado Formation has been dissolved over large

areas. This dissolution disrupts and fractures Rustler strata and consequently increases their hydraulic conductivity to varying degrees. In the most extreme case, the Rustler breaks into blocks which rotate and are collapsed downward. In these regions, stratigraphic continuity is disrupted and vertical hydraulic conductivity increases to the extent that the Rustler does not behave hydrologically as a layered system. In other regions in which Salado dissolution is less extensive, stratigraphic continuity is maintained but fracturing increases the hydraulic conductivity of the more brittle carbonate and anhydrite units.

Dissolution of Pore- and Fracture-Filling Minerals. Evaporite minerals (halite, gypsum, or anhydrite) fill much of the pore space and fractures in intact Rustler units. Over portions of the map area, moving groundwaters have dissolved these minerals and have thereby locally increased hydraulic conductivity. For example, dissolution of cements and fracture fillings is thought to be an important control on the pattern of hydraulic conductivity of the Culebra dolomite in the vicinity of WIPP.

Proximity to Halite Deposits. In regions where halite deposits are present in the Rustler, halite replaces gypsum in the rock matrix and fills fractures in units that underlie or overlie the halite deposits. The hydraulic conductivity in units affected by gypsum replacement and fracture filling is possibly as low as that of the halite deposits.

The regions affected by the various geologic processes have been mapped into a series of zones. Figure 4 is a map of the extent of these zones. These zones, along with specification of hydrostratigraphic units, are used to infer the distribution of hydraulic conductivity values in numerical simulations. We use a two-step approach assign hydraulic conductivity values to cells within the numerical model. First an "intact" conductivity value is assigned to each rock type. This value represents the hydraulic conductivity of that rock type before the effect of post-depositional processes. The intact values assigned changed from simulation to simulation; the values used are given in Tables 1 and 2. Second, intact values are adjusted to reflect the impact of the post-depositional process in the zones shown in Figure 4. The amount of adjustment is based on measured values of hydraulic conductivity in each of these zones in the Culebra in the vicinity of the WIPP site. The following adjustments, in units of the logarithm of conductivity (m/s), are applied:

upper Salado dissolution (zone 2), applied to dolomites and anhydrites:	+1.0
dissolution of fracture fillings (zones 2 and 3), applied to dolomites:	+1.5
presence of halite in adjacent layers (zone 5), applied to the Culebra:	-2.0

RECHARGE RATES AND PATTERNS

In dry environments, such as the WIPP site, the fundamental effect of climate change on groundwater flow is to influence the position of the water table. The position of the water table, along with the distribution of the rock's hydraulic conductivity, determine flow directions and rates at depth. For this discussion, the process by which climate moves the water table can be divided into three parts, infiltration, percolation in the unsaturated zone, and recharge to the saturated zone. As discussed below, our model, and therefore the link between climate and groundwater flow, focuses on the last part, recharge to the saturated zone.

Evapotranspiration potential greatly exceeds annual precipitation in southeastern New Mexico and only a small portion of precipitation infiltrates below the root zone. The relationship between the rate and spatial distribution of infiltration and climatic factors is complex. Infiltration depends, for example, on the temporal and spatial pattern of precipitation, soil and plant types, land surface slopes, surface drainage, wind speeds, and air temperature and humidity. We clearly do not know these details about the future environment, nor do we need this information to estimate possible effects of climate on groundwater flow. Our model therefore does not consider the details of the interaction between climatic factors and infiltration.

After infiltration, moisture is available to infiltrate downward toward the water table. The pattern of flow is complex because the unsaturated hydraulic properties of the rocks are highly heterogenous and variable in time. Where the water table is at depth the net movement of water is downward, but the lateral components of flow are such that the spatial pattern of percolation at the water table is different than the pattern at the land surface. It is not possible or necessary to characterize the unsaturated hydraulic properties at the scale of our model, nor do we need this information to estimate possible effects of climate on groundwater flow. Our model does not simulate flow in the unsaturated zone.

In these calculations, changes in climate are represented by changes in potential recharge at the water table. Potential recharge is the maximum amount of moisture available to recharge the saturated zone. Actual recharge is equal to potential recharge in areas where the water table is at depth, but can be less than potential recharge if the water table is near the land surface and a seepage face forms. The spatial and temporal distribution of potential recharge is specified as model input, but the distribution of recharge is a simulation result. We assume that potential recharge varies in time but is spatially uniform over the model domain because of the large uncertainty in its spatial distribution and the relative insensitivity of model results to spatially-varying recharge. The rate of potential recharge used in these simulations should be thought of as the water available to recharge the water table as averaged over the area of a model cell (4 square kilometers) and long periods of time (hundreds of years). This conceptual averaging is consistent with the resolution in modeling natural systems at this scale.

We vary potential recharge so that the hydraulic conditions range from conditions that are similar to those of today (water table at depth) to the limiting conditions that could occur in times of greater recharge (water table near the land surface). The values used for potential recharge are model specific in that they were selected to simulate a range of possible hydrologic conditions.

The validity of the results does not rest on demonstrating that these values are the same as past or future actual values. However, the values used are certainly reasonable. The rates used in these calculations ranged from 0.2 to 2.0 mm/year. The same range was determined by Campbell et al. (1996) using a chloride mass balance method to estimate localized infiltration rates at the WIPP site. They noted that these estimates are in agreement with studies in other similar geologic environments. In addition, we believe that these calculations provide the best possible estimates of the upper limit of recharge over large areas and long periods of time.

Both steady-state and transient calculations were used to evaluate the effects of climate on groundwater flow. Effects are implied from steady-state calculations by comparing results of calculations that differ only in the specified rate of potential recharge. These comparisons represent the maximum effect on flow that a change in recharge from one of the values to the other could have because the time lag in the response is not accounted for. Transient simulations, in contrast, show how the hydrologic system responds as the potential recharge changes with time.

We make two assumptions about past recharge conditions 1) that times of maximum precipitation are also times of maximum recharge and 2) recharge in the late Pleistocene was sufficient to raise the water table to near the land surface. Therefore, recharge sufficient to raise the water table to the land surface was assumed at the start of the transient simulations (i.e., at 14,000 years before present). We refer to this recharge rate as the late Pleistocene recharge rate. The potential recharge was assumed to decrease to zero (the Holocene minimum recharge rate) over 6,000 years. This portion of the recharge function represents the first-order feature of the precipitation record: that the average annual precipitation decreased starting about 14,000 years ago and reached a minimum about 8,000 years ago (Swift, 1993).

The remainder of the recharge function (Figure 5), covering the period from 8,000 years ago until 10,000 years in the future, represents the historical short-term wet periods as well as uncertainty about future precipitation rates and temporal patterns. The historical wet periods are represented by spikes in the recharge function that reach maximum recharge rates (maximum Holocene recharge rates) at 6,000, 4,000, and 2,000 years ago. Each spike has a duration of 1,000 years. We use different rates for the maximum Holocene recharge rate to represent uncertainty in that value but, within a single simulation, assume the same maximum rate for each wet period.

Because of uncertainty about the magnitude and duration of future climatic change, we use two patterns for future recharge. Either pattern is possible, given the present state of knowledge about future climates, but neither is presented here as a prediction of the future state. Rather, the two patterns, and the parameterization of potential recharge within each pattern, provide a distribution that reasonably represents our uncertainty about the effects of possible future climatic change on recharge. Both recharge patterns assume that recharge will be greater at some time in the future than it is at present, and that present recharge is the same as its minimum Holocene value (zero for this analysis, as discussed below). Both recharge patterns also

assume that the dominant effects on climate change during the next 10,000 years will be natural, rather than anthropogenic. In part, this assumption that natural effects will dominate is based on the observation noted in Section D that published model results suggest that if anthropogenic global warming occurs it will not result in an increase in precipitation in southeastern New Mexico. Furthermore, regulatory guidance provided by the EPA indicates that consideration of climatic change should be limited to natural processes (US EPA, 1996, p. 5277).

The first recharge pattern considered in the analysis assumes that recharge will increase from its minimum value at the present to its maximum Holocene value 500 years in the future. Recharge is then held constant after this "step" increase, and this pattern is therefore referred to as the "step pattern" of future recharge. As discussed below, the maximum Holocene value is varied between simulations to characterize uncertainty about the magnitude of the maximum value. Conceptually, the step pattern corresponds to a future in which the climatic patterns of the Holocene are disrupted, and the climate either becomes continuously wetter or the frequency of alternations between wetter and drier climates becomes sufficiently high that the hydrologic response is indistinguishable from that of a continuously wetter climate. Mechanisms that might produce this precipitation pattern and their probability of occurrence are discussed in Section F below.

The second recharge pattern used in this analysis is simply a continuation of the observed pattern of the Holocene, with an oscillatory recharge function with peaks occurring 500, 2,000, 4,000, 6,000, 8,000, and 10,000 years in the future. We refer to this pattern as the Holocene pattern of future recharge. Conceptually, this pattern corresponds to a continuation of the variability of the Holocene, with alternations of wetter and drier climates, and without major, first-order disruptions to the climatic cycles. The probability of occurrence of this pattern is discussed below in Section F.

The values used for the late Pleistocene, Holocene minimum, and Holocene maximum recharge rates for the transient simulations are shown in Table 3. We assume as an initial condition at 14,000 years ago a flow field that had equilibrated to a late Pleistocene recharge rate of 2.0 mm/yr for all the transient simulations. This is a somewhat arbitrary rate that was selected to be large enough to maintain the water table near the land surface for all of the distributions of hydraulic conductivity considered.

Values used for the maximum Holocene rates of potential recharge are 0.2, 0.4, or 0.6 mm/yr. This range is limited to those values that are not so large that they result in unrealistically high simulated heads for the present time. The largest value also results in future conditions similar to those assumed for the late Pleistocene if the step recharge function is used.

The choice to use a value of zero mm/yr for the minimum Holocene recharge rate is also somewhat arbitrary, and is not intended to imply that the actual present recharge rate is zero. For modeling purposes, the only requirement imposed on the minimum Holocene recharge rate is that it is a non-negative number that is sufficiently less than the lowest maximum Holocene value used

(0.2 mm/yr) to result in different flow conditions during the wet and dry Holocene periods. Flow in the transient simulations never approach equilibration with the minimum Holocene recharge rate. The main effect of choosing a value of zero for this rate is to maximize the steepness of the sloped portions of the recharge function, and consequently, to maximize the simulated impact of climate change.

MATHEMATICAL AND NUMERICAL MODEL

The groundwater-flow equations are solved on the saturated domain Ω, which is assumed to be an irregularly-shaped "box" with unknown moving top surface given by the water-table elevation Z_{WT}. The interior equation for the domain Ω is

$$\nabla\cdot\kappa\nabla h = S_s\frac{\partial h}{\partial t} \tag{1}$$

with κ a spatially-dependent conductivity tensor, S_s the specific storage coefficient.

Zero-gradient boundary conditions are assumed on the sides and bottom of the domain. On the top portion of Ω free-surface (or phreatic) boundary conditions are imposed (Bear and Verruijt, 1987; Dagan, 1989; de Marsily, 1986). Because the location of the water-table is not known *à* priori, *two* boundary conditions must be imposed at the water-table:

$$h(x,y,z_{WT},t) = z_{WT}(x,y,t), \tag{2}$$

$$(\kappa\cdot\nabla h + \mathrm{N})\cdot\nabla(h-z) = \omega\frac{\partial h}{\partial t}, \tag{3}$$

with $\mathbf{N} = -\mathbf{R}\nabla z$ being the vertical infiltration rate. The first boundary condition is a statement that the pressure at the water-table surface is atmospheric. The second condition is the kinematic boundary condition (Bear and Verruijt, 1987) that assures that the flux normal to the surface is continuous.

If the recharge flux **N** is independent of time, an equilibrium or "steady-state" water-table develops. This condition physically represents the case of mass balance between fluid injected into the saturated zone by steady recharge and fluid lost due to the presence of seepage faces. For steady-state the SECOFL3D code uses the interior equation

$$\nabla\cdot\kappa\nabla h = 0. \tag{4}$$

The equilibrium water-table position is embodied in the condition $\partial h/\partial t = 0$, which reduces the

kinematic boundary condition to

$$(\nabla\cdot\kappa\nabla h+N)\cdot\nabla(h-z)=0. \tag{5}$$

This equation shows that, to first-order. the equilibrium position reached in steady-state is due to a balance between surface recharge and vertical flow.

An additional complication in modeling free-surface groundwater flow is the need to simulate seepage flow wherein the water-table interacts with the land surface. The appropriate "seepage" boundary condition is (Bear and Verruijt, 1987; de Marsily, 1986):

$$h(x,y,z_{WT},t)=z_{LS}(x,y), \tag{6}$$

which replaces the condition (2). The kinematic condition (3) is not enforced at seepage faces.

The kinematic condition is applied wherever the water-table elevation is below the land surface. If the water-table elevation is the same as the land surface, the kinematic condition may need to be converted to a seepage face. To determine whether the kinematic or the seepage boundary condition should be applied when the elevation of the water-table and the land surface are the same, we compute

$$U=R-(K_{33}+R)\partial h/\partial z+\nabla h\cdot\kappa\nabla h \tag{7}$$

Since $U=\omega\partial h/\partial t$, its algebraic sign indicates whether the water-table is rising or falling at a particular location. If the water-table is at the land surface and $U < 0$ it is assumed that the water-table is freely falling and thus the kinematic condition is called for. If $U \geq 0$ at the land surface, then the water-table is rising and the seepage condition is enforced as a Dirichlet boundary condition in the linearized system.

To solve these equations, the code SECOFL3D transforms the saturated domain onto a moving mesh to accommodate the changes in the domain with time. The transformed equations are then discretized using centered differences on a finite volume, staggered mesh. Because the free-surface flow equations are non-linear, the set of discrete equations must be linearized. This is done by means of a Picard Iteration. Additional details concerning the numerical model are provided by Knupp (1996).

The lateral extent of the model cells is 2 km on a side. This discretization of hydraulic properties is appropriate for the scale of this model but is much less detailed the at the discretization used for distribution of Culebra transmissivity in performance assessment calculations. For this reason, these simulations provide a fundamentally different level of resolution of the flow field than do the performance assessment calculations.

PERFORMANCE MEASURE

The Climate Index increases flow magnitudes by the same factor at all locations within the flow fields used in the PA calculations. The index is applied uniformly because these simulations do not have the resolution to calculate its dependence on position. In order to conserve mass, this condition requires that the total flow across the boundary of an arbitrary closed portion of the flow field change by the same factor. We use this relationship to choose the total lateral flow out (essentially equal to total flow out) of a portion of the Culebra that is approximately within the WIPP-site boundary as the performance measure to base the Climate Index on. This portion of the Culebra is referred to as the Culebra reference volume. The surface trace of the reference volume is a square that is about the same area as the WIPP site but is shifted slightly to the northwest relative to the position of the WIPP site. The UTM coordinates of the corners of the WIPP site are N3585057, E610496; N3585109, E616941; N3578681, E617015; and N3578612, E610566. The UTM coordinates of the surface trace of the reference volume are N~~3586000~~, ~~610000~~E; N~~3586000~~, E~~616000~~; N~~3580000~~, E~~616000~~; and N~~3580000~~, E~~610000~~. 3585000 ▽ Corbet 11 July 1991

E 611000 3585000 617000 3579000 617000 3579000 611000

In analyzing simulation results, we are concerned with how future rates of total lateral flow out of the Culebra reference volume compare to the simulated present rate. We refer to this as the lateral-flow ratio. For transient simulations, this is the ratio of the total lateral flow out of the Culebra reference volume at a given time in the future to that quantity at the simulated present time. For example, Table 7 shows that for transient simulation 30, the rate of lateral flow out of the Culebra reference volume is 3335 m^3/yr at 10,000 years in the future. Table 6 shows that the value for this number is 2107 m^3/yr at the simulated present time. The ratio of these numbers, as indicated in Table 8, is 1.6. This same value would be achieved by uniformly increasing the magnitude of lateral flow within the WIPP site by a factor of 1.6. Steady-state simulations, by definition, do not provide the rate of lateral flow at different times. The lateral-flow ratios for steady-state simulations (Table 5) are the ratios of total lateral flow out of the Culebra for pairs of calculations that differ only in their recharge rate.

SUMMARY OF ASSUMPTIONS

The main assumptions of the modeling approach are:

the groundwater basin conceptual model is applicable,

the lateral boundaries are flow divides (i.e. no-flow boundaries) during the period simulated,

flow in the unsaturated zone can be neglected, and

the flow system was equilibrated to a recharge rate sufficient to maintain the water table near the land surface at the start of the simulations.

E. Modeling Results and Discussion

We performed 54 steady-state and 17 transient simulations (Tables 1 - 3). Results are presented in two formats:

1) As mass balances over the Culebra reference volume.

2) Head values for each hydrostratigraphic unit at the WIPP site are graphed versus time for six of the transient simulations.

Steady-State Results

Table 4 shows the mass balances over the Culebra reference volume for the steady-state simulations. This table shows the rate of total flow across the surface of the reference volume as well as the percent of the total that flows in or out across the top, base, and sides. For example, the amount of simulated vertical leakage across the top of the Culebra reference volume ranges from 1.4 to 97.8 percent of the total inflow. More than 97.4 percent of the outflow from the Culebra reference volume is by lateral flow in all but one of the steady-state simulations.

Table 5 shows the lateral-flow ratios for the 27 pairs of steady-state simulations that differ only in the value of potential recharge Each of these pairs includes a simulation with potential recharge equal to 2.0 mm/yr and a calculation with potential recharge equal to 0.2 mm/yr. The higher rate was sufficient to raise the water table at the center of the WIPP site to the land surface in all cases. In addition, the lower rate was sufficient to raise the water table to the surface in simulations 3, 12, and 21. The lateral-flow ratios for the pairs of steady-state simulations range from 0.7 to 5.5.

We use the vertical differences in head near the center of the WIPP site as an indicator of whether or not a particular set of hydraulic properties could be representative of actual conditions. Figure 6 shows the simulated elevation of the water table and values of hydraulic head in the Magenta and Culebra near the center of the WIPP site for the 27 simulations that assume a recharge rate of 0.2 m/yr. (We use the simulations with the lower recharge rate because these results best approximate actual present-day conditions.) Each graph in this figure presents head profiles from three simulations as a function of anhydrite conductivity. For each value of anhydrite conductivity in each graph, the three data points are the water table (upper point), Magenta head, and Culebra head (lower point). In each of the steady-state calculations, the difference in head between these units decreases as the conductivity of the anhydrite layers increases. Also, the difference in head between units is less than 10 m for all simulations that assume a value of 2×10^{-6} m/s for the conductivity of the Dewey Lake/Triassic rocks.

The simulated differences in head can be compared to observed differences. The actual

difference in fresh-water head between the Culebra and the Magenta is about 40 m. The difference between the head in the Magenta and the estimated position of the water table is 20 m. Using these numbers as guides, those simulations in which hydraulic conductivity of intact anhydrite is $1x10^{-11}$ m/s or the conductivity of the Dewey Lake/Triassic rocks is $2x10^{-6}$ stand out as resulting in unrealistically small differences in head. We have therefore excluded the lateral-flow ratios from these calculations (simulation pairs 1/28, 4/31, 7/34, 8/35, 9/36, 10/37, 13/40, 16/43, 17/44, 18/45, 19/46, 22/49, 25/52, 26/53, and 27/54) from consideration in determining the distribution of the Climate Index.

Transient Results

Vertical profiles of hydraulic head versus time provide an intuitive illustration of the effects of the recharge function on groundwater flow. A series of such graphs are presented in Figures 7, 8, and 9. These simulations use the same hydraulic properties (the properties for transient simulation number 30) and differ only in the pattern of future recharge and the maximum rate of Holocene recharge. In these figures, the upper-most line is the water table and the lower-most line represents head in the Culebra. The seven lines in between show head in the seven hydrostratigraphic units between the Culebra and the Dewey Lake. The order of the head lines is the same as their stratigraphic order.

Figure 7 (top), for example, shows the simulated hydraulic head with time if the maximum Holocene recharge is 0.2 mm/yr and the step pattern is used for future recharge. This graph illustrates several important aspects of the long-term behavior of the hydrologic system. First, the water table remains level for about 4,200 years after the start of the simulation. The water table does not drop even though the rate of potential recharge decreased over this time because over most of the range in change of recharge, the recharge is more than sufficient to maintain the water table at the land surface at WIPP. However, head in the Culebra decreased from the start of the simulation. This shows that flow in the Culebra responds to changes in the regional-scale flow system caused by the water table dropping faster in other parts of the model domain. Once, the water table becomes a free-surface at WIPP, heads in all layers begin to decrease more rapidly.

The overall trend over the first 14,000 years of the simulation was a decrease in the elevation of the water table and the heads in all strata. The water table dropped about 80 m and head in the Culebra dropped about 35 m. This overall trend reflects the decline in the rate of potential recharge from 2.0 to 0.0 mm/yr over the first 6,000 years of the simulation. Superimposed on the trend are short-term increases in heads that correspond to the periodic increases in potential recharge. The times of maximum head lag about 300 years behind the corresponding peaks on the recharge function.

Heads, in this simulation, increase continuously after the simulated present time. This increase represents the flow systems attempt to equilibrate with a recharge rate of 0.2 mm/yr that was assumed to occur for the simulated time period between 500 and 10,000 years in the future. Heads are still increasing at the end of the simulation. Given sufficient time, these heads would

reach the equilibrium elevations of steady-state calculation number 14.

Tables 6 and 7 show the mass balance for the Culebra reference volume at the present time and at 10,000 years in the future respectively. Table 8 shows the lateral-flow ratios at 10,000 years for each of the 17 transient simulations. These numbers range from 0.8 to 2.1. As can be inferred from the graphs of head versus time, the lateral-flow ratio reaches a maximum value at 10,000 years if the step pattern is used for future recharge. This is not the case if the Holocene pattern is used. We have therefore calculated the lateral-flow ratio as a function of time for the six transient simulations that use the Holocene pattern and graphed those results in Figure 10.

Figure 10 (top) shows the lateral-flow ratio for two sets of simulations (41, 42, and 43) that differ only in the value used for maximum Holocene recharge. This time-trace clearly shows the effects of the Holocene wet periods superimposed on the long-term decline of the lateral-flow ratio. The high frequency signature of the wet periods dominate the trend if the maximum Holocene recharge is 0.4 or 0.6 mm/yr. The long-term trend is more important if the recharge rate is 0.2 mm/yr. The lateral-flow ratio is less than 1 over nearly the entire 10,000-year future period at this lower maximum Holocene recharge rate. The trend in the lateral-flow ratio is similar for simulations 44, 45, and 46 (bottom).

F. Rationale for the Distribution for the Climate Index

Future Precipitation

Mechanisms that might produce a climate change corresponding to the step pattern of recharge are speculative. Based on the past climatic record, initiation of a new cycle of global cooling leading eventually to glaciation is possible within the next 10,000 years, and could perhaps disrupt the Holocene climatic patterns of southeastern New Mexico. However, a return to the full-glacial conditions of the late Pleistocene, in which the climate of southeastern New Mexico was affected by a continental ice sheet extending southward into the Great Plains, is not plausible within the next 10,000 years. Temperatures at high latitudes may have fluctuated abruptly during the late stages of the last major interglacial period approximately 120,000 to 110,000 years ago, but it is likely that climatic effects were less at lower latitudes (Dansgaard et al., 1993). Evidence from oxygen isotope ratios in ice cores and gases trapped within them indicates that changes in the total volume of continental ice sheets at the end of the last interglacial period do not correlate with changes in polar temperatures (Raynaud et al., 1993). Consideration of the oxygen isotope record from oceanic sediments suggests that major growth in continental ice sheets did not occur until late in the last glacial period, many tens of thousands of years after the end of the last interglacial (Imbrie et al., 1984). Relatively little is known about precipitation patterns in southeastern New Mexico during the early stages of glacial advance, but, as discussed in Section D, the wettest climate did not occur until the continental ice sheet reached its greatest extent approximately 20,000 years ago (Swift, 1993). Climatic changes near the

WIPP early in a glacial period, before the full growth of the continental ice sheet and the consequent disruption and southward shift of the jet stream, would presumably be less extreme than those of the glacial maximum. Based on these observations, we believe the step recharge function, which represents a radical disruption of the climatic pattern of the Holocene, is relatively unlikely, and we assign it a 0.25 probability of occurrence.

Mechanisms that produce the climatic variability observed in the Holocene are not well understood, but fluctuations analogous to those seen in the precipitation record for southeastern New Mexico (Swift, 1993) are also observed in Greenland ice cores (O'Brien et al., 1995). Solar variability, changes in oceanic circulation patterns, and volcanic activity are all proposed as factors that may have influenced Holocene climatic fluctuations (Stuiver et al., 1995). Causal relationships between these factors and precipitation at the WIPP are not proposed here, and we do not believe it is useful for this purpose to attempt direct prediction of future climate changes. However, based on the observation that there is no basis for assuming that the frequency of any natural factors influencing Holocene climatic variability will change in the next 10,000 years, we believe that it is reasonable to assume that such changes will continue to occur. The Holocene recharge pattern is therefore assigned a 0.75 probability of occurrence.

Effects on Groundwater Flow

In the previous section we presented the rationale for assigning a 0.75 probability to a continuation of the Holocene pattern of recharge to the future and a 0.25 probability to a future recharge pattern that is represented by the step pattern. The objective of this section is to present the rationale for the distribution of the Climate Index for each of the two future recharge patterns.

FUTURE REPRESENTED BY THE STEP RECHARGE FUNCTION

Simulations using the step recharge function for the future show a smooth increase in heads and lateral flow rates in the future. Consequently the lateral-flow ratio reaches its maximum value at the end of the simulation (at 10,000 years). We use this value to represent the future change in lateral flow rates in these simulations.

We first consider the uncertainty in the maximum Holocene recharge rate. Two sets of simulations address this uncertainty. Each set has fixed hydraulic properties and contains simulations assuming values of maximum Holocene recharge of 0.2, 0.4, and 0.6 mm/yr. The first set consists of simulations 30, 37, and 38. The lateral-flow ratios for these simulations are 1.6, 1.7, and 1.6. These ratios show little sensitivity to the maximum rate of Holocene recharge. The second set of simulations, numbers 32, 39, and 40, have lateral-flow ratios of 1.6, 2.1, and 2.1. These simulations show larger ratios for maximum recharge rates of 0.4 and 0.6 mm/yr. The range of values for the lateral-flow ratios for these six simulations is 1.6 to 2.1. In order to reflect what we believe is an appropriate level of resolution for these results, we use 0.25 as the smallest increment of the lateral-flow ratio when specifying its probability distribution. We tentatively assign a distribution ranging from 1.5 to 2.25 with equal probability of all values.

The six simulations on which we have based the tentative distribution consider only two sets of hydraulic properties. We next examine results from a series of 7 simulations (numbers 30, through 36) in which the maximum Holocene recharge is fixed at 0.2 mm/yr but the hydraulic properties are different in each case. The hydraulic properties of the sets were selected to represent an extensive range of possible hydrologic responses. As shown in Table 8, the lateral-flow ratios for these simulations are, in the order of the simulation numbers, 1.6, 1.2, 1.6, 2.0, 1.4, 1.4, and 1.0. These results suggest that the range of lateral-flow ratios is not altered very much if a larger range of hydraulic properties is considered. If anything, these results suggest that the lower limit of the range should be decreased from 1.5 to 1.0. We choose not to alter the tentative distribution to reflect this larger range.

Finally, there are 12 pairs of steady-state simulations that provide additional information about the sensitivity of the lateral-flow ratio to the choice of hydraulic properties. These are the pairs, 2/29, 3/30, 5/32, 6/33, 11/38, 12/39, 14/41, 15/42, 20/47, 21/48, 23/50, and 24/51. The other 15 pairs of steady-state simulations listed in Table 4 have an anhydrite conductivity of 1x 10^{-11} and/or a conductivity of 2 x 10^{-6} m/s for the Dewey lake/Triassic rocks. As noted above, these choices of rock properties result in unrealistically small vertical gradients of head and are therefore not considered to be representative. The lateral-flow ratios for the 12 representative pairs are, in the order listed, 1.4, 1.5, 1.8, 1.1, 1.1, 1.0, 1.1, 1.0, 0.9, 0.7, 1.0, and 0.8. Using a rationale similar to that for the transient simulations for various hydraulic properties, we choose not to modify the tentative distribution for the Climate Index for the step pattern used for future recharge. Therefore, this distribution remains as being uniform between 1.5 and 2.25.

FUTURE REPRESENTED BY THE HOLOCENE RECHARGE FUNCTION

There are 6 transient simulations (numbers 41 through 46) that use the Holocene pattern of future recharge. These differ from simulations (numbers 30, 37, 38, 32, 39, 40) used to determine the Climate Index for the future step recharge function only in the pattern of future recharge; the hydraulic properties and the maximum Holocene recharge rates are the same as in the corresponding simulations.

The Holocene pattern of future recharge results in periodic increases and decreases of future heads and lateral flow rates that correspond to future wet and dry periods. Consequently, the lateral-flow ratio at the end of the simulation is not representative. Instead, of using a value of this ratio at a single time, we have calculated a continuous record of the lateral-flow ratio from the present time until 10,000 years in the future. These records are shown in Figure 10. As discussed above, the lateral-flow ratio is dominated by the effects of wet periods if the Holocene recharge function is assumed. Presumably, future transport of radionuclides in the Culebra would be slightly faster during those time in which lateral flow is faster. Although, these results suggest that a representative future lateral-flow ratio could be as low as 0.9, we will assume 1.0 as the lower range in the specified distribution. We specify a distribution ranging from 1.0 to 1.25 with equal probability of all values for the Holocene recharge function.

G. References

Bear, J. and A. Verruijt, 1987. *Modeling Groundwater Flow and Pollution,* D. Reidel Pub. Co., Dordrecht.

Campbell, A. R., F. M. Phillips, and R. J. Vanlandingham, 1996. Stable isotope study of soil water, WIPP site New Mexico: estimation of recharge to Rustler aquifers. Radioactive Waste Management and Environmental Restoration, v. 20, p. 153-165.

COHMAP (Cooperative Holocene Mapping Project) Members. 1988. "Climatic Changes of the Last 18,000 Years: Observations and Model Simulations," *Science* v. 241, 1043-1052.

Dagan, G., 1989. *Flow and Transport in Porous Formations,* Springer-Verlag, New York.

Dansgaard, W., S.J. Johnsen, H.B. Clausen, D. Dahl-Jensen, N.S. Gundestrup, C.U. Hammer, C.S. Hvidberg, J.P. Steffensen, A.E. Sveinbjornsdottir, J. Jouzel, and G. Bond. 1993. "Evidence for general instability of past climate from a 250-kyr ice-core record," *Nature* v. 364, 218-220.

Freeze, R.A., and J.A. Cherry. 1979. *Groundwater*. Englewood Cliffs, NJ: Prentice-Hall.

Freeze, R.A., and P.A. Witherspoon. 1967. "Theoretical Analyses of Regional Ground Water Flow: 2. Effect of Water Table Configuration and Subsurface Permeability Variation," *Water Resources Research.* Vol. 3, 623-634.

Hays, J.D., J. Imbrie, and N.J. Shackleton. 1976. "Variations in the Earth's orbit: pacemaker of the Ice Ages," *Science* v. 194, 1121-1132.

Houghton, J.T., G.J. Jenkins, and J.J. Ephraums. 1990. *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, New York, NY.

Hubbert, M.K. 1940. "The Theory of Ground-Water Motion," *The Journal of Geology*. Vol. 48, no. 8, pt. 1, 785-944.

Imbrie, J. 1985. "A theoretical framework for the Pleistocene Ice Ages," *Journal of the Geological Society v.* 142:417-432.

Imbrie, J., and J.Z. Imbrie. 1980. "Modeling the climatic response to orbital variations," *Science* v. 207, 943-953.

Imbrie, J., J.D. Hays, D.G. Martinson, A. McIntyre, A.C. Mix, J.J. Morley, N.G. Pisias, W.L. Prell, and J.J. Shackleton. 1984. The orbital theory of Pleistocene climate: support from a

revised chronology of the marine $\delta^{18}O$ record, pp. 269-305, Part 1. In: *Milankovitch and Climate, Proceedings of the NATO Advanced Research Workshop on Milankovitch, Palisades, NY, November 30-December 4, 1982.* A.L. Berger, J. Imbrie, J. Hays, G. Kukla, and B. Saltzman (eds.). D. Reidel Publishing Co., Boston MA.

Knupp, P., 1996. A moving mesh algorithm for 3-D regional groundwater flow with water table and seepage face. Advances in Water Resources, v. 19, n. 2, p. 83-95.

Marsily, G. de., 1986. *Quantitative Hydrogeology,* Academic Press, San Diego, CA.

Milankovitch, M. 1941. *Canon of Insolation and the Ice-Age Problem.* Koniglich Serbische Akademie, Beograd. (English translation by the Israel Program for Scientific Translations; published the United States Department of Commerce and the National Science Foundation, Washington, D.C.).

Mitchell, J.F.B. 1989. "The "Greenhouse Effect" and climate change" *Reviews of Geophysics* v. 27, 115-139.

O'Brien, S.R., P.A. Mayewski, L.D. Meeker, D.A. Meese, M.S. Twickler, S.I. Whitlow. 1995. "Complexity of Holocene Climate as Reconstructed from a Greenland Ice Core," *Science* v. 270, 1962-1964.

Powers, D.W., and R.M. Holt. 1990. "Sedimentology of the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) Site," *Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, Field Trip #14 Guidebook, Geological Society of America 1990 Annual Meeting, Dallas, TX, October 29-November 1, 1990.* Leaders: D.W. Powers, R.M. Holt, R.L. Beauheim, and N. Rempe. Dallas, TX: Dallas Geological Society. 79-106.

Raynaud, D., J. Jouzel, J.M. Barnola, J. Chappellaz, R.J. Delmas, and C. Lorius. 1993. "The Ice Record of Greenhouse Gases," *Science* v. 259, 926-934.

Schlesinger, M.E., and J.F.B. Mitchell. 1987. "Climate model simulations of the equilibrium climatic response to increased carbon dioxide," *Reviews of Geophysics* v. 25, 760-798.

Stuiver, M., P.M. Grootes, and T.F. Braziunas. 1995. "The GISP2 $\delta^{18}O$ Climate Record of the Past 16,500 Years and the Role of the Sun, Ocean, and Volcanoes," *Quaternary Research* v. 44, 341-354.

Swift, P. N. 1993. Long-term climate variability at the Waste Isolation Pilot Plant, southeastern New Mexico, USA. Environmental Management, v. 17. P. 83-97.

Tóth, J. 1963. "A Theoretical Analysis of Groundwater Flow in Small Drainage Basins," *Journal*

of Geophysical Research. Vol. 68, no. 16, 4795-4812.

US EPA (United States Environmental Protection Agency). 1996. "Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations; Final Rule," *Federal Register* v. 61, 5224-5245.

Washington, W.M., and G.A. Meehl. 1984. "Seasonal cycle experiment on the climate sensitivity due to doubling of CO_2 with an atmospheric general circulation model coupled to a simple mixed-layer ocean model" *Journal of Geophysical Research* v. 89, 9475-9503.

Wilson, C.A., and J.F.B. Mitchell. 1987. "A doubled CO_2 climate sensitivity experiment with a global climate model including a simple ocean," *Journal of Geophysical Research* v. 92, 13,315-13,343.

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WPO 37148

INFORMATION ONLY

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

date: March 20, 1996

to: Martin Tierney, MS 1328, Dept. 6741

from: Geoff Freeze, MS 1324, Dept. 6115 (INTERA)
Kurt Larson, MS 1341, Dept. 6751

subject: Initial Pressure in the Castile Brine Reservior

The initial brine pressure in the Castile brine reservoir to be used in BRAGFLO calculations for the 1996 WIPP Compliance Certification Application calculations is specified in this memorandum. The pressure was determined in a meeting held March 19, 1996. In attendance were Rip Anderson, Palmer Vaughn, Jon Helton, Peter Davies, Al Lappin, Peter Swift, Geoff Freeze, and Kurt Larson, and perhaps others. The pressure specified in this memorandum supercedes the pressure specified in an earlier memorandum. The pressures are being changed because the range specified in the earlier memorandum has been considered further and is now thought to be unduly conservative because it is inconsistent with available evidence on the pressures encountered in anhydrite intervals in the region of the WIPP.

The group reached consensus on the approach to be used for determining the pressures, as well as the pressures to be used. These will be described in a separate document that is in preparation at the time of this memorandum.

The pressure in the brine reservoir is to be sampled in the range of 11.1 to 17 MPa (1.11×10^7 to 1.7×10^7 Pa). The distribution is triangular with a mode at 12.7 MPa (1.27×10^7 Pa).

Distribution:
Lori Dotson MS 1341
Kurt Larson Day File
SWCF-A:WBS1.2.07.1:PDD:QA:Non-Salado:PKG#19B:Castile Brine Reservior Pressure (WPO #31072) (2)

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

MASS Attachment 18-2

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WBS 1.2.07.1 WBS 1.2.12
PRD

Package received from Kurt Larson 960528/ww

INFORMATION ONLY

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: May 20, 1996

to: SWCF-A Records Center
SWCF-A:WBS1.2.07.1:PDD:QA:NONSALADO:
PKG#19:CASTILE BRINE RESERVOIR PRESSURE

In Kurt - this has been approved and supersedes the earlier records pkg. 960529/ww

from: Geoff Freeze, INTERA
Kurt Larson, SNL

subject: Castile Brine Reservoir Pressure Record Package

This memo describes a two-step process for assignment of initial fluid pressure in the Castile brine reservoir for use in BRAGFLO simulations. The first step is to examine the relationship between fluid pressures and lithostatic pressures in anhydrite units in the Salado and Castile formations. The second step is to examine observed Castile brine reservoir pressures and adjust them to WIPP-12 depth, representative of the depth of the BRAGFLO Castile brine reservoir. Adjustments assume either a hydrostatic or near lithostatic (as determined in step 1) correction. The resulting adjusted pressures are used to develop a range for use in performance assessment.

Table 1 compares observed (measured and interpreted) Castile brine reservoir fluid pressures with corresponding lithostatic pressures. Observed pressures are from TME-3153 (Table H.1) except where indicated. Lithostatic pressures are from SAND92-0700/3 (based on WIPP-11 density log shown in Figure 2.3-13).

Table 1. Fluid and Lithostatic Pressures for Castile Brine Reservoirs

Location	Fluid Pressure at Reservoir Depth (MPa)	Lithostatic Pressure at Reservoir Depth (MPa)	Fluid Pressure as a % of Lithostatic Pressure
Pogo	17.4	21	83
Tidewater	16.0	22	64
Union	10.1	18	56
H&W Danford 1	7.0	14	50
Bilbrey	11.2	19	59
Culbertson	12.8	21	56
Mascho 1	12.4	21	57
Mascho 2	12.0	21	59
Shell	13.4	22	54
WIPP-12	12.7*	20	64
ERDA-6	14.1	18	78
Belco	14.3	20	72
Gulf Covington	13.6	22	62

* from SAND89-7069, Appendix A

Additional estimates of anhydrite fluid pressure are available from the Salado (SWCF-A:WBS 1.2.07.1:PDD:QA:SALADO:PKG12:Anhydrite Pressure). The lithostatic pressure at the measurement depth is 15 MPa. Interpreted values are 12.9, 12.4, 12.3, 11.1, and 9.4 MPa. The corresponding percentages of lithostatic pressure are 86, 83, 82, 74, and 63, respectively.

For the 18 fluid pressures (13 Castile, 5 Salado), the percentage of lithostatic rages from 50 to 86% with an average value of 67% and a median value of 64%. Based on this data, and on the fact that some of Castile measured pressures are minimum pressures (flow was above ground surface), the maximum fluid pressure in the Castile brine reservoir is assumed to be 85% of lithostatic.

For the 4 locations where measured or interpreted values best represent formation pressure (i.e., not minimums), the measured values are adjusted to reflect formation pressure at the depth of the WIPP-12 reservoir (140 masl). The pressure adjustment requires an assumption about pressure variation with depth in the Castile. Two bounding cases are used, hydrostatic and 85% of lithostatic, with the adjusted pressures calculated as follows:

$$P_a = P + \rho g (h - 140) / 1 \times 10^{-6}$$

where:

P_a = adjusted pressure [Mpa]
P = measured/estimated pressure [Mpa]
ρ = assumed density [kg/m^3]
g = gravitational constant [9.8 N/kg]
h = brine reservoir elevation [masl]

A brine density of 1,240 kg/m^3 (SAND89-7069; p. 2-12) was assumed for the hydrostatic variation, an average formation density of 0.85*2,400 kg/m^3 (SAND92-0700/3; p 4-14) was assumed for the lithostatic variation. The adjusted pressures are shown in Table 2.

Table 2. Adjusted Castile Brine Reservoir Formation Pressures

Location	Pressure at Reservoir Depth (MPa)	Pressure at WIPP-12 Depth with Hydrostatic Adjustment (MPa)	Pressure at WIPP-12 Depth with 85% Lithostatic Adjustment (MPa)
WIPP-12	12.7[b]	12.7	12.7
ERDA-6	14.1[a]	15.5	16.4
Belco	14.3[a]	14.5	14.5
Gulf Covington	13.6[a]	12.1	11.1

[a]from TME-3153, Table H.1
[b]from SAND89-7069, Appendix A

All of these measured and adjusted values should be considered in the range of values used in performance assessment calculations. Because the BRAGFLO brine reservoir is assumed to have

WIPP-12 properties, the best measured value is the interpreted WIPP-12 pressure of 12.7 MPa. Minimum and maximum pressures are 11.1 MPa and 16.4 MPa, respectively. At WIPP-12 reservoir depth 85% of lithostatic pressure (20 MPa) is 17 MPa. Because this value is greater than the maximum value from Table 2, it is used to define the upper end of the brine reservoir pressure range.

Based on the above information, the following distribution is proposed Castile brine reservoir initial pressure:

Distribution:	Triangular
Minimum:	11.1 MPa
Mode:	12.7 MPa
Maximum	17.0 MPa

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WPO 37971

Sandia National Laboratories

INFORMATION ONLY

Albuquerque, New Mexico 87185-1341

Memorandum of Record

date: May 27, 1996

to: SWCF-A:WBS1.2.07.1:PDD:NON-SALADO:PKG#19C:Castile Brine Reservoir Volume (WPO #31082)

from: Kurt Larson Dept. 6822 MS 1341
Geoff Freeze Dept. 6115 INTERA

subject: Castile Brine Reservoir Volume Revision

This memorandum records the rationale for selection of a revised brine volume contained in a hypothetical Castile brine reservoir for the 1996 performance assessment calculations for the Compliance Certification Application. This rationale was developed during a meeting held March 19, 1996, as documented in a memorandum to Martin Tierney from Kurt Larson and Geoff Freeze, March 20, 1996, which was submitted to the same records package as this Memorandum of Record.

The volume of brine in the Castile brine reservoir is used in BRAGFLO, and is one of several parameters necessary for estimating the fluid flow in the intrusion borehole resulting from its penetration of the waste panels and a hypothetical brine reservoir. Discussion of other parameters for the brine reservoir is documented elsewhere. The volume of brine used is based on the conceptual model of brine reservoirs, analogy to a tested brine reservoir penetrated within the land withdrawal area by the WIPP-12 borehole, and consideration of the possible effects of deep boreholes assumed to be drilled in the vicinity of WIPP during the regulatory period.

Brine reservoirs in the northern Delaware Basin are believed to be fractured systems, with predominantly vertical or nearly-vertical fractures, and with those fractures spaced widely enough that a borehole can penetrate through a volume of rock containing a brine reservoir without intersecting any fractures and therefore not produce brine. They usually occur in the upper portion of the Castile, in an interval interpreted to be from 7 to 24 meters thick (Reeves et al., 1991). The interconnectivity of fractures is uncertain. Appreciable brine volumes have been produced from several reservoirs, but there is little direct information on the areal extent of the reservoirs. The WIPP-12 data indicates that fractures in the network have a variety of apertures and permeabilities, and their pressure and brine volume decrease at different rates. Brine occurrences in the Castile behave as reservoirs, i.e., they are bounded systems - rather than as aquifers such as groundwater in the Culebra and Magenta. The average porosity of fractures of the WIPP-12 reservoir from which brine can be

produced, over its areal extent, is approximately 0.008. This porosity is not the porosity of intergranular voids (although that is likely low as well), but rather is the porosity of a fractured network containing some large-aperture fractures and a large volume of (conceptually) non-porous blocks. Thus, the fracture porosity is not distributed evenly through the medium.

The volume contained within the WIPP-12 reservoir has been estimated by a method described in the previous record package specifying reservoir volumes. Using the values and methods specified there, estimated reservoir pore volumes (bulk volume multiplied by porosity) and their areal extent assuming a circular boundary have been calculated, as shown in Table 1.

Table 1: Estimated brine volume (m^3) and effective radius (m) (areal extent assuming a circular boundary) of the brine reservoir encountered at WIPP-12 as a function of interpreted compressibilities and thicknesses.

	$C = 5 \times 10^{-12}$ Pa^{-1}	$C = 1 \times 10^{-10}$ Pa^{-1}	$C = 1 \times 10^{-8}$ Pa^{-1}
7 m thickness	3.2×10^4 m^3 430 m	3.2×10^6 m3 4300 m	6.4×10^7 m^3 19000 m
24 m thickness	3.2×10^4 m^3 230 m	3.2×10^6 m^3 2300 m	6.4×10^7 m^3 10300 m

Table 1 shows that there is uncertainty in both the volume of the brine reservoirs and their areal extent.

The smaller interpreted volumes of the brine reservoir from WIPP-12 are associated with effective radii on the order of several hundred meters. These dimensions are somewhat smaller than the waste panels; this interpretation of the extent of reservoirs is generally but not quantitatively supported by geophysical survey data. The interpreted large volumes are associated with effective radii much larger than the waste panel dimensions, or even the site dimensions. For performance assessment, it is assumed that reservoirs that may exist under the waste panels have limited extent and interconnectivity, with brine volumes consistent with the lower values estimated from the WIPP-12 encounter. The basis for this assumption is discussed in the following paragraphs.

Consistent with regulatory criteria regarding the rate of drilling to be used in performance assessment, it is assumed that 47 deep boreholes may be drilled per square kilometer in the next 10,000 years. Scoping calculations indicate that this drilling rate yields approximately 50-acre spacing of boreholes in the vicinity of the WIPP in 1,000 years, and nearly 5 acre spacing of boreholes at the end of 10,000 years. Even with limited probability of intersecting a brine reservoir, in 1,000 years there should be approximately one intersection per 500 acres, and in 10,000 years approximately 1 intersection per 50 acres. Thus,

penetrations will occur at closely-spaced intervals. In current practice, when a problematic brine reservoir is encountered drillers allow the well to flow until it is safe to continue drilling; total volumes produced and the time allowed for flow vary, depending on the driller and conditions. Even if the driller does continue to drill, the reservoir will be partially depleted by flow that occurs during drilling. Thus, every time a reservoir is penetrated, it is partially depleted. If reservoirs are well-interconnected, they will be penetrated and partially depleted many times during 10,000 years, until at some time penetrating a reservoir no longer produces flow. If reservoirs are poorly-interconnected, regions of undisturbed pressure and volume could persist, although these would have lower producible brine volumes due to their limited extent.

There is an area in which potential brine reservoirs cannot be penetrated and depleted for some time - under the waste panels while passive institutional controls are effective. The passive institutional controls shield a region of the Castile from exploratory drilling. If brine reservoirs are well-interconnected, the sheltered region could be depleted by the effects of multiple penetrations occurring in unprotected areas. If brine reservoirs are poorly-interconnected, they could persevere under undisturbed conditions under the panels. It is considered that there are two reasonable conceptual models consistent with regulatory guidance for the future condition of brine reservoirs in the WIPP region: (1) they are interconnected over large areas and penetrated and partially depleted many times; or (2) they are interconnected over small areas and not affected by the penetrations that occur far away. It is considered that penetrating a undisturbed pressure and volume, smaller reservoir through the waste panels has potentially greater consequences than penetrating a depleted large reservoir. Therefore, the latter model is assumed: brine in the Castile potentially under the waste panels is hydraulically poorly-interconnected (with extent similar to the lower estimates from WIPP-12), not much affected by penetrations occurring far away, and can persevere with pristine conditions until it is penetrated by a borehole drilled within the panel area.

The minimum pore volume of the brine reservoir used in BRAGFLO should be the minimum volume obtained from WIPP-12 analysis, 32000 cubic meters. Because this volume WIPP-12 reservoir is associated with an estimated effective area of about 1/3 of the waste panel area, and because a reservoir with a volume larger than the minimum WIPP-12 volume could reasonably exist under the waste panels, larger reservoir volumes should also be used. A total of five different volumes of brine should be used in performance assessment for determining the consequence of first penetration of a brine reservoir: 32000, 64000, 96000, 128000, and 160000 cubic meters.

Reference:

Reeves, M., G.A. Freeze, V.A. Kelley, J.F. Pickens, D.T. Upton, and P.B. Davies, 1991. Regional Double-Porosity Solute Transport in the Culebra Dolomite under Brine-Reservoir-Breach Conditions: An Analysis of Parameter Sensitivity and Importance. SAND89-7069. Sandia National Laboratories: Albuquerque, N.M.

Copy To:

Peter Swift	MS 1341
Lori Dotson	MS 1341
Kurt Larson	Day File
Rip Anderson	MS 1328
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Peter Davies	MS 1324
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WPO 37147

Sandia National Laboratories

Albuquerque, New Mexico 87185-MS1328

INFORMATION ONLY

date: March 21, 1996

to: Martin Tierney

from: Jon Helton

Jon Helton

subject: Addition of Discrete Parameter

Please add a discrete parameter to the data base that takes on values 1 to 32, with equal probability (i.e., 1/32) assigned to each value. This parameter will be used to select brine pocket fields for use in calculations with BRAGFLO, CCDFGF and GRIDFLO. Possible brine pocket locations (I= 1,2,3,4,5) are shown in Attachment A. A single brine pocket field in designated by a vector of the form (I_1, I_2, I_3, I_4, I_5), where $I_i = 0$ implies the absence of pressurized brine at location i and $I_i = 1$ implies the presence of pressurized brine at location i. The following correspondence exists between the integers 1, 2, ..., 32 and the brine pocket fields:

	1	2	3	4	5	TOTAL # of Brine Pockets
1~	0	0	0	0	0	0
2~	0	0	0	0	1	1
3~	0	0	0	1	0	1
4~	0	0	0	1	1	2
5~	0	0	1	0	0	1
6~	0	0	1	0	1	2
7~	0	0	1	1	0	2
8~	0	0	1	1	1	3
9~	0	1	0	0	0	1
10~	0	1	0	0	1	2
11~	0	1	0	1	0	2
12~	0	1	0	1	1	3
13~	0	1	1	0	0	2
14~	0	1	1	0	1	3
15~	0	1	1	1	0	3
16~	0	1	1	1	1	4
17~	1	0	0	0	0	1
18~	1	0	0	0	1	2
19~	1	0	0	1	0	2
20~	1	0	0	1	1	3
21~	1	0	1	0	0	2
22~	1	0	1	0	1	3
23~	1	0	1	1	0	3
24~	1	0	1	1	1	4
25~	1	1	0	0	0	2
26~	1	1	0	0	1	3
27~	1	1	0	1	0	3
28~	1	1	0	1	1	4
29~	1	1	1	0	0	3
30~	1	1	1	0	1	4
31~	1	1	1	1	0	4
32~	1	1	1	1	1	5

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Attachment A

EN1: Definition of Distribution D_L for Drilling Location

- Discretize repository into finite number of locations
- Define D_L on basis of area associated with each location

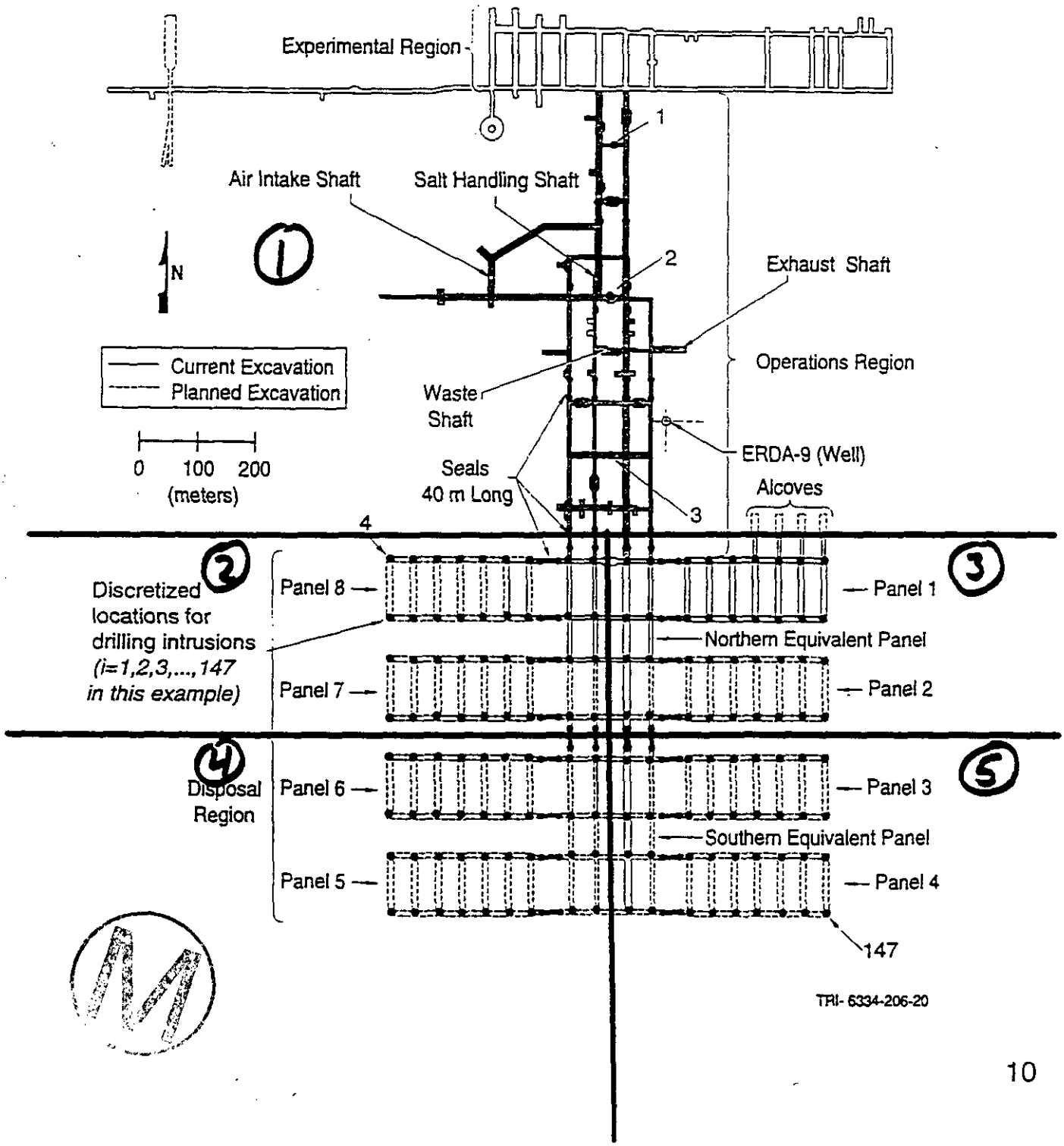

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Application
for the
Waste Isolation Pilot Plant

MASS Attachment 18-5

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WPO 39121

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation
LOCKHEED MARTIN
Albuquerque, New Mexico 87185-0750

INFORMATION ONLY

date: 20 February 1996

to Margaret Chu, Org. 6801/MS-1332

from: David J. Borns, Org. 6116/MS-0750

subject: Proportion of the waste panel area, WIPP site, that is underlain by brine reservoirs in the Castile Formation as Inferred from Transient Electromagnetic Method (TEM or TDEM) Surveys

Reference:
The Earth Technology Corporation, 1988, Final report for time domain electromagnetic (TDEM) surveys at the WIPP Site, Sandia Report, SAND87-7144, Sandia National Laboratories, Albuquerque, NM

In 1987, Sandia National Laboratories and the Earth Technology Corporation conducted a series of 38 time domain electromagnetic (TDEM) soundings at the WIPP Site. Thirty-six (36) of these sounding were taken over an approximately 1x2 km area. These soundings were spaced on a rectangular grid with a separation of 250 m for each station. This area overlaps the surface projection of the WIPP waste panel area at that time (see attached Figure 1).

In brief, the ability of the TEM methods to determine resistivity and depth stems from the field configuration of the method. The transmitter is a square surface loop of insulated wire (500 m on a side for the WIPP surveys) and produces a time varying magnetic field as the current in the loop is turned rapidly on and off. As the current is turned off, electromagnetic induction results in eddy currents in the subsurface. In horizontally layered ground as at WIPP, the eddy currents are horizontally closed rings parallel to the surface. With time after the transmitter loop is turned-off, the currents migrate to greater depth (these can be envisioned as smoke-rings leaving a smoker's mouth). The use of the word, "sounding" for the measurement stems from this migration of the eddy currents. A multicoil receiver lies in the middle of the transmitter loop. This receiver measures the electromotive forces due to the eddy currents which *with time reflect deeper layers in the earth.* In short, the magnitude of the electromotive force measured with increasing time reflects the conductivity at increasing depth. The resulting data aquisition and data analysis obtains a numerical solution for the resistivity distribution with depth that will produce the observed decay in electromotive forces with time (see Fig. 2). These one dimensional inversion matching a model of the resistivity data to the observed data utilize the industry standard ARRTI program of INTERPEX LTD.

From the WIPP measurements, series of one-dimensional inversions were made and profiles of electrical resistivity (or its inverse-conductivity) with depth were made. These profiles indicate whether zones of high electrical conductivity are present at depths of the Castile Formation. The inference is that these zones of high conductivity reflect the presence of brine reservoirs. This inference was supported by taking similar measurements at areas known absence and presence of brine (e.g., boreholes WIPP-12 and DOE-1). The resolution of the method and inversion is discussed by the Earth Technology Corporation (1988). The depth resolution for the method is plus/minus 75 m.

The effect of this resolution is that at the ***minimum depth*** within the range (e.g., minus 75 m) the proportion of brine reservoirs beneath the surface area is ***greater,*** since a ***greater extent*** of the subsurface conductors are above the Bell Canyon Formation (approximately 1200 m depth in the area) and within the Castile Formations. At the ***maximum depth*** in the range (e.g., plus 75 m), the proportion of brine reservoirs is ***less.*** Based on the thirty-six sounding in the waste panel area, I have estimated the possible distribution of brine reservoirs beneath the 2 km^2 area in Table 1.

Table 1: Proportion of the Surface Area above the Waste Panel Area that is Underlain by Brine Reservoir in the Castile Formation

	Minimum Depth/ Maximum Reservoir in Castile Formation	*Mean Calculated Depth/Average Reservoir in Castile Formation*	*Maximum Depth/ Minimum Reservoir in Castile Formation*
Percentage of Area Underlain by Brine Reservoirs	55%	25%	10%

Distribution	Org.	MS
W. D. Weart	6000	1335
K. Larson	6847	1341
SWCF: 0517.201310 "WIPP Regulatory"	6800	1330

WBS RD 7/11/96
SWCF: 1.1.05: Castile Brine Reservoir/waste Panel
CO/CC A: QA:

CO

SWCF WBS 1.2.07.1.3: CO/CC A/APPENDIX MASS/QA: Castile Brine Reservoir

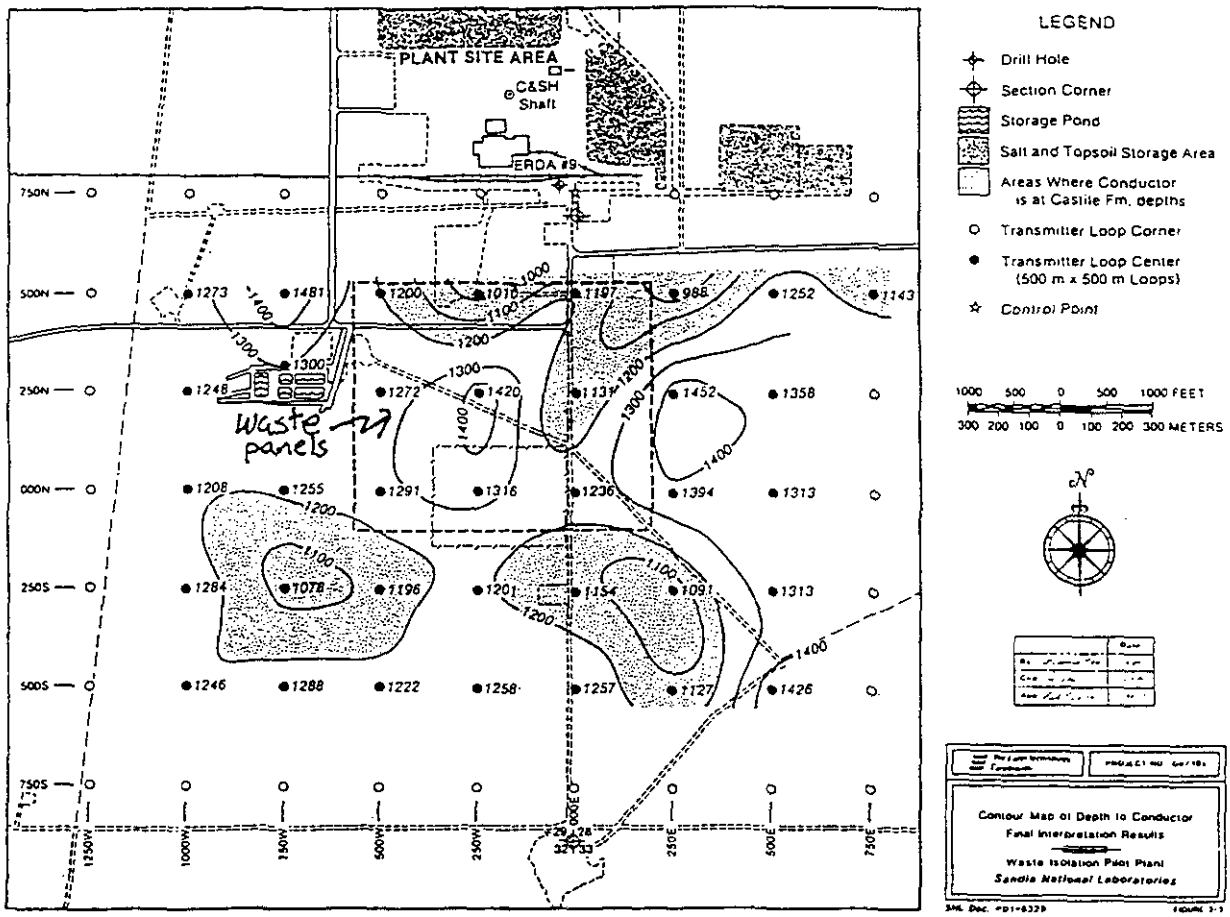

Figure 1. Contour Map of Depth to Conductor from Earth Technology Corporation (1988), *Inner dashed rectangle is the surface projection of the underground waste panels*

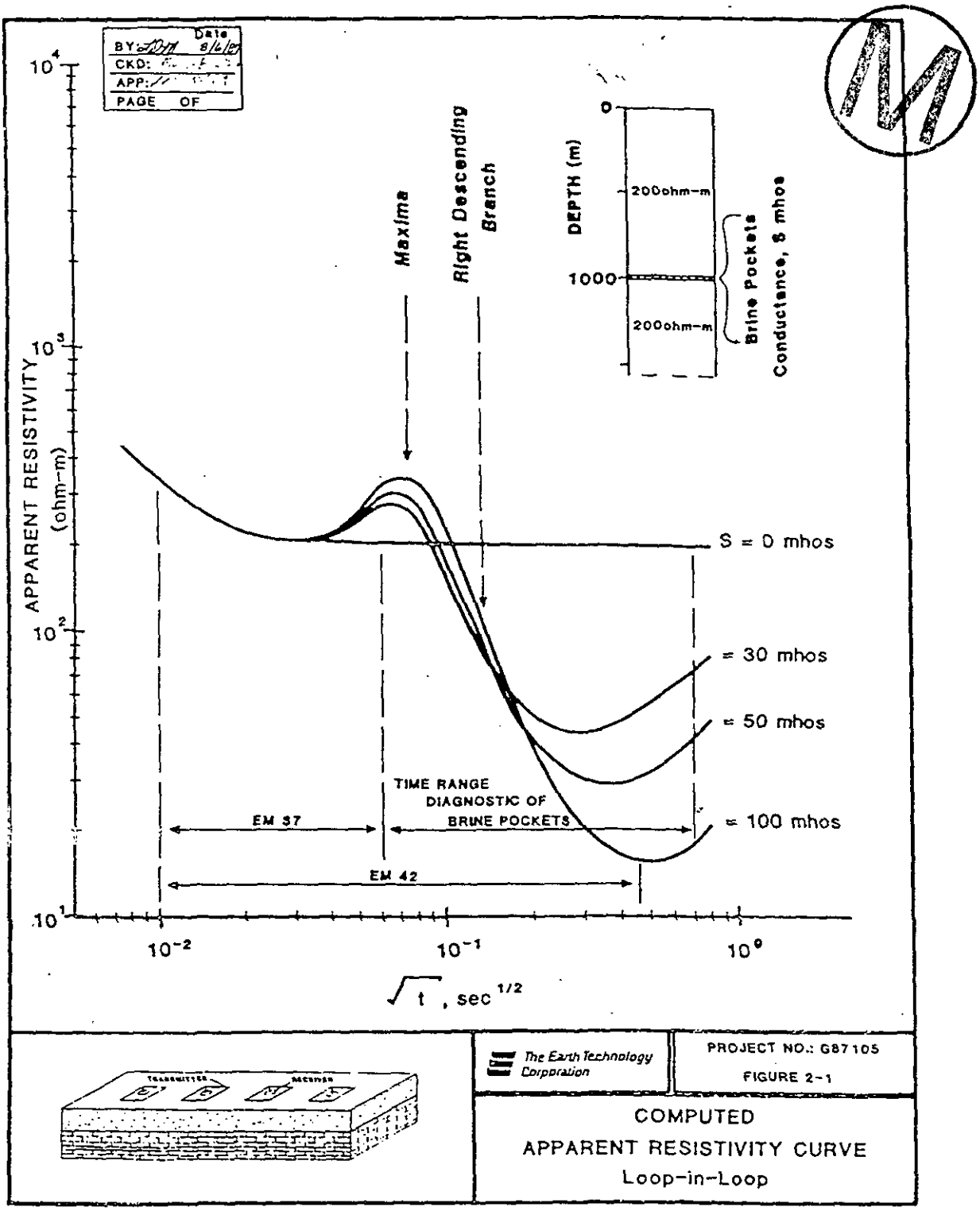

Figure 2. Computed Apparent Resistivity Curve

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Probability of Intercepting a Pressurized Brine Reservoir Under the WIPP

Dennis W. Powers

John M. Sigda

Robert M. Holt

July 10, 1996

ABSTRACT

Twenty-seven drillholes in the Delaware Basin are accepted as showing intercepts of pressurized brine in the Permian Castile Formation. Using an indicator function (brine = 1, no brine = 0) and location data for these and other drillholes in the area around WIPP, semi-variograms were constructed. Parameters from selected semi-variograms were input to an ordinary kriging algorithm to estimate the probabilities of intercepting brine in a drillhole within the Castile Formation beneath the WIPP site. For the area of the disposal panels, the estimated probabilities at computational nodes range between 0.078 and 0.084. For the shaft and access area, probabilities at nodes range between 0.078 and 0.221. Nodes within the experimental area ranged from 0.078 to 0.371. An areally-weighted average for the waste panel area is 0.080.

Structure contour and isopach maps of selected stratigraphic contacts and intervals over part of the nine township area around WIPP show deformed evaporites in areas where most brine occurrences are mapped. No data were obtained from a few drillholes where brine was encountered. The Castile is deformed at WIPP 12, the nearest brine encounter to the WIPP. Stratigraphic data from the Castile are few at WIPP, but there appears to be no significant deformation in the vicinity of the waste panels. This is consistent with generally low probabilities for a drillhole encountering brine as calculated by geostatistical techniques. The estimated thickness from base of Castile to base of Cowden Anhydrite at ERDA 9 is considerably less than the minimum thickness for any known brine encounter, indicating there may be a threshold value for reservoir formation.

1.0 INTRODUCTION

A scenario for the Waste Isolation Pilot Plant (WIPP) includes a drillhole intercept of pressurized brine in the Permian Castile Formation below WIPP underground workings. The analysis of this scenario requires estimates of the probability that a drillhole at WIPP will encounter pressurized Castile brine.

2.0 PURPOSE

This report describes the process that was followed to estimate the probability that a drillhole will intercept brine in the Castile below the underground workings at WIPP. This report also describes how geological data were acquired and analyzed as complementary evidence of the distribution of pressurized Castile brine.

3.0 APPROACH

Several steps were followed to estimate the probabilities of encountering brine in a drillhole:

1) The reported encounters of pressurized brine were listed, including relevant information about location, depth, drillhole name, and stratigraphic basis for assigning the encounter to the Castile.

2) A file of locations of oil and gas drillholes penetrating the Castile compiled by the Compliance Department of Westinghouse was provided by Westinghouse as a database for analysis. AUTOCAD software was used to establish locations and prepare data files for use. (See Appendix A).

3) The UNCERT geostatistics software package was used to prepare semi-variograms utilizing an indicator function (brine report = 1; no brine report =0) and location data for each drillhole. Rbase 5.5 and Excel 4.0 were used to format ASCII data files from AUTOCAD for use by UNCERT.

4) The semi-variograms were evaluated for sensitivity to data cluster effects and classification errors.

5) The ordinary kriging module of UNCERT was used to prepare comparable maps showing the estimated conditional probabilities of intercepting brine and to obtain nodal values for points within three defined areas including the underground workings at WIPP.

6) This analysis report was prepared to show data sources, techniques, estimated conditional probabilities, results and limitations.

Several steps were also followed to analyze how geological features or processes (mainly Castile deformation) are related to the distribution of Castile brine reservoirs:

1) Reported encounters of pressurized brine flow were listed to include information about location, depth, drillhole name, and stratigraphic basis for assigning the encounter to the Castile.

2) Stratigraphic data were derived from geophysical logs for many drillholes around the WIPP site where the geophysical logs were appropriate with respect to depth, location, and log coverage.

3) From the stratigraphic data, subsidiary tables of unit elevations (for structure maps) and thicknesses (for isopach maps) were prepared. These tables were used to prepare maps of structure and thickness for various horizons and intervals, respectively.

4) A general relationship apparently exists between the location of most brine encounters and areas where the Castile evaporites have been significantly deformed from original position. The structure data for the WIPP site are meager for the Castile, though it appears that the area of the waste panel is not significantly deformed.

5) The statistical relationship or association of structure and brine encounters is still being examined, as appropriate data have just been drawn together.

6) This analysis report discusses data sources, techniques, maps, results, and limitations of the geological analysis of the relationship between brine reservoirs and deformation.

3.1 Responsible Staff

The analysis has been conducted by:

Dennis Powers, mainly conducting geological research;

John Sigda, mainly conducting geostatistical analysis; and

Robert Holt, contributing to both geological and geostatistical analyses.

3.2 Schedule and Deliverables

The analysis report includes:

a) the estimated probabilities that a drillhole will encounter pressurized brine under 1) the waste panel area, 2) shaft and access areas, and 3) experimental area.

b) a discussion of the apparent relationship between Castile brine and Castile deformation.

The first request for assistance on this issue came in early February, 1996. An initial approach was outlined and followed before developing the broader analysis approach in April. An initial report and supporting data were scheduled for June 18, with a "final" report and data package required by about July 10, 1996.

4.0 DATA TYPES AND SOURCES

4.1 Geostatistical Analysis

The geostatistical methods used in this analysis for estimating probabilities require two related data sets:

a) a set of locations for drillholes, and

b) an indication of whether each drillhole intercepted Castile brine or not.

The location data set needed to be relatively comprehensive for the area in which brine encounters have been reported. Most of the drillholes that penetrate through most or all of the Castile should be represented. In addition, the data set needed to have a consistent coordinate system (e.g., NM State Plane coordinates) for computational purposes. The coordinates for each drillhole needs to be reasonably accurate relative to nearby drillholes, but long-range accuracy (over several miles) is not expected to be important and was not examined.

Two sources of a location data set were found. Petroleum Information Corporation (PI) maintains a large drillhole data set available for lease/purchase; location coordinates were available as an extra service. Through discussions with the Compliance Department, Westinghouse Electric Corporation, it became apparent that a partial set of drillhole data from PI already been purchased and was being used. L. Madl and D. Hughes provided two subsets of this data set. D. Hughes converted the original PI location data for each drillhole into equivalents to the NM State Plane coordinates (see Appendix A). L. Madl provided files that provided common elements with the location (State Plane coordinates) data and the standard locations (Township/Range system) generally available for geophysical data. We added useful WIPP drillholes not in the database using coordinates provided in Gonzales (1989).

The data set for brine occurrences (Table 4.1-1) was compiled from several sources.

Original studies and reports include Griswold (1977), Register (1981), Popielak et al. (1982), and Chaturvedi (1985). More recent summaries have been provided in unpublished documents by Kehrman (1994) and Silva (1996). Silva obtained summary data from a number of petroleum exploration companies active in the area. In addition, Powers examined files at the Oil Conservation Department (NM) in Artesia and Hobbs, NM, to develop additional data and verify some occurrences. Of the total apparent occurrences, several were eliminated as unlikely, usually because of the combination of 1) insufficient evidence of significant volume and/or pressure, and 2) being in the wrong stratigraphic unit. Twenty-seven reports of brine occurrence were accepted as Castile brine intercepts. The analysis is based on this set of encounters, though we demonstrate later (Section 6.3.2) that it is rather insensitive to adding or dropping encounters in areas where they are more common.

The data set for brine occurrences consists of reports of brine intercepts, which is a proxy for actual occurrences, and "non-reports". There is no requirement that all brine intercepts be reported. Some of the earliest known reports of brine came before modern drilling practices and resulted in loss of control of the drillhole and substantial surface flows. We cannot know if some drillholes intercepted a brine reservoir that went undetected because substantial pressure was depleted by other drillholes. Some companies declined to respond to Silva's survey. Other intercepts may have been quickly controlled, and no report was made or required. We accept the reports accumulated as a reasonable representation of the actual history of brine intercepts. In later discussion, we address alternatives.

Tables 4.1-1 and 4.1-2 include basic information about the drillholes included in this analysis as encountering brine within the Castile. Some excluded drillholes are also reported with justification for deciding they should not be in the data set.

The map area was selected to encompass the locations of all 27 Castile brine occurrences. We tried to make the area as small as practical to minimize the number of drillholes for which there is no report of a brine intercept. For the geostatistical analysis, the total number of drillholes, including appropriate WIPP drillholes, is 354.

4.2 Geological Analysis

The geological methods used in this analysis for understanding the relationship between brine reservoirs and geological features or processes (mainly evaporite deformation) require two related data sets:

a) stratigraphic and reference elevation data from drillholes (Appendix B), and

b) a locations (including State Plane coordinates) for those drillholes.

For most petroleum exploration drillholes in the area around WIPP, one or more geophysical logs have been made that can be purchased or examined. They vary in

Table 4.1-1

Location Data for Drillholes Considered to have Castile Brine

IDnum	T.	R.	Section	from section line (e.g.,n=north)		Drillhole Name
1104	21	31	35	2152s	910e	ERDA 6
1159	22	31	17	148s	84e	WIPP 12
5014	22	31	2	2310s	330e	Pogo State "2" No. 3
5128	23	30	1	1830n	1980w	Belco Hudson Federal No. 1
5275	21	32	31	1980n	660w	Phillips Luke Federal No. 1
5305	21	31	26	1980n	1980w	Pogo Federal No. 1
5306	21	31	35	660n	660w	Union Federal FI No. 1
5307	21	31	36	1980s	660e	Yates Lost Tank "AIS" State No. 1
5308	21	31	36	1980s	1980w	Yates Lost Tank "AIS" State No. 4
5326	22	31	1	660n	1980w	Phillips Molly State No. 1
5327	22	31	1	660n	660w	Phillips Molly State No. 3
5328	22	31	1	660n	1980e	Yates Unocal "AHU" Federal No. 1
5337	22	31	11	660s	1650e	Yates Martha "AIK" Federal No. 3
5338	22	31	11	1980s	1650e	Yates Martha "AIK" Federal No. 4
5339	22	31	12	330n	1650w	Pogo Federal 12 No. 8
5340	22	31	13	1980n	1980w	Texaco Federal Neff 13 No. 5
5348	22	32	5	660n	1580e	Getty Bilbrey Federal No. 1
5365	22	32	15	660s	1650w	Strata Lechuza Federal No. 4
5366	22	32	16	330s	330e	Yates Kiwi "AKX" State No. 1
5382	22	32	25	660n	1980w	Pogo Covington "A" Federal No. 1
5392	22	32	34	660n	1650e	Pogo Red Tank "34" Federal No. 1
5394	22	32	36	330n	1980w	Shell Bootleg Ridge Unit No. 1
5404	22	32	36	660n	660e	Richardson & Bass Tidewater No. 1
5405	22	32	36	1980n	1980e	Culbertson & Irwin Culbertson No. 1
5406	22	29	9	660s	660e	H & W Danford No. 1
5407	22	33	20	660s	1980e	Yates Mascho Cloyd No. 2
5408	22	33	20	660s	660e	Yates Mascho Cloyd No. 1

Data sources for this table include Popielak et al (1983), Register (1981), Kehrman (1994), Silva (1996), and information developed by Powers through visits to OCD offices in Artesia and Hobbs, NM.

Table 4.2-2
Brine Occurrence Depths and Unit Assignments

IDnum	Drillhole Name	Brine Depth (ft)	Depth* Data Source	Unit at Brine depth	Notes
1104	ERDA 6	2711	1,6,8,9	A2?	Uppermost anhydrite; may be A3
1159	WIPP 12	3017	1,7	A3	
5014	Pogo State "2" No. 3	3083	5	A3	May only be gas
5128	Belco Hudson Fed No. 1	2802	1	A3	
5275	Phillips Luke Fed No. 1	3050-57	3,4,5	A3	Lost Tank SWD#1-E
5305	Pogo Fed No. 1	3322	1	A2-A3?	A units coalesce?
5306	Union Fed FI No. 1	2810	1	A3	
5307	Yates Lost Tank "AIS" State No. 1	2970	4	H2-A3	A3-H2 contact 2932
5308	Yates Lost Tank "AIS" State No. 4	3280	4	A2	Uppermost anhydrite? No A3?
5326	Phillips Molly State No. 1	3080	4	A3	
5327	Phillips Molly State No. 3	3023	4	A3	
5328	Yates Unocal "AHU" Fed No. 1	3068	3	A3	
5337	Yates Martha "AIK" Fed No. 3	3311	3,4	H2	A3-H2 contact 3267
5338	Yates Martha "AIK" Fed No. 4	3750, 3745	3,4	H1	H1 from 4170 to 3688
5339	Pogo Fed 12 No. 8	3050	3	A3	
5340	Texaco Fed Neff 13 No. 5	3340	4	A3	
5348	Getty Bilbrey Fed No. 1	3090; 2965-3066	1,5; 4	A3	
5365	Strata Lechuza Fed No. 4	3500	4	H2	H2 from 3700 to 3371
5366	Yates Kiwi "AKX" State No 1	TD(4535) ; 3400; 3360	3;5;4	A3	A3-H2 contact 3430
5382	Pogo Covington "A" Fed No. 1	3600	1,5	A3?	A3 in #5208 from 3385 to ?3650

IDnum	Drillhole Name	Brine Depth (ft)	Depth* Data Source	Unit at Brine depth	Notes
5392	Pogo Red Tank "34" Fed No. 1	3590-4489; 3000	3,5	A3-A1; Salado (3000)	
5394	Shell Bootleg Ridge No. 1	3671	1	A3 probably	A3-H2 not interpreted top A3 at 3466
5404	Tichardson & Bass Tidewater No. 1	3730	1	A3?	Compared to #5397
5405	Culbertson & Irwin Culbertson No. 1	3515	1,5	A3	Compared to #5210
5406	H & W Danford No. 1	1930; 2208	1;5	Cowden? @ 1952; A3 2150-2380	Scout report & NMBMMR well log report interpreted for Castile anhydrites/salt
5407	Yates Mascho Cloyd No. 2	3298; 3362	1;5	A3?	Unit inferred from maps, nearby wells
5408	Yates Mascho Cloyd No. 1	3322; 3362	1;5	A3?	Unit inferred from maps, nearby wells
	BOREHOLES NOT INCLUDED				
5315	Collins & Ware Lincoln Fed. No. 1	2000	3	Upper Salado	MB109 base 1926; top Vaca Triste 2106
5094	Phillips James A No. 9	7529	4	nd	Castile-BC contact at 3658 ft
5276	AEC 7	3918?	2,10	nd	gas blowout after well reached TD 3918

*References for Data Sources of Depths (see Reference list for complete citation):

1. Popielak et al, 1983
2. Register, 1981
3. Kehrman, 1994
4. Silva, 1996
5. Powers notes from OCD offices in Artesia and Hobbs, NM
6. Sandia National Laboratories and US Geological Survey, 1983
7. D'Applonia Consulting Engineers, Inc., 1982
8. Anderson and Powers, 1978
9. Jones, 1981
10. Sandia National Laboratories and D'Appalonia Consulting Engineers, Inc., 1983

Note: All stratigraphic unit assignments were reviewed by Powers based on reexamination of geophysical logs or by inferring units from nearby drillholes and contour maps of relevant units.

type (e.g., acoustic or neutron), drillhole conditions (open/cased), logged interval, and quality, which can be affected by unknowns such as hole diameter behind casing or by equipment development and improvement over the years. Where the geophysical log covers the appropriate interval and is at least partially interpretable, the principal data for geological analysis includes the elevation of the log reference or beginning point (commonly KB or kelly bushing) and the depth from the reference point to various stratigraphic markers.

With these basic data, two additional kinds of useful information are calculated:

structure data - the elevation of any identifiable stratigraphic marker (Appendix C), obtained by subtracting the depth from the reference point elevation, and

isopach (thickness) data - the thickness between any two identifiable stratigraphic markers (Appendix D), obtained by subtracting the depth to the uppermost marker from the depth to the deeper marker.

Both kinds of data are generally plotted on maps and then the elevations of the horizon for structure or the interval thickness values are contoured. The evaporite beds are expected to have been deposited essentially horizontal, and the upper surface of each unit was probably about horizontal when the overlying unit began to be deposited. Many of the units are expected to be reasonably uniform in thickness across significant areas, but there can also be differences if there was differential subsidence during deposition across the area.

The stratigraphic information is interpretive. Geophysical logs obtain data about rock characteristics indirectly. An example is natural gamma, a measurement of the natural radiation of the rocks the drillhole penetrates. The instrument is calibrated to a standard for the industry, and the display is scaled such that 100 API units (one full log cycle) would be the response from a hypothetical average mid-continent North American black shale. In a drillhole through unknown rocks, the natural gamma indicates the total gamma radiation from all sources, and it would be tentatively interpreted in terms of general expectations of the natural gamma of different rock types. Cuttings, other geophysical logs, or cores might be used to supplement the interpretation. In the area of WIPP, the evaporite units are well known in general from many thousands of drillholes and previous studies (e.g. Bachman, 1985), and their geophysical log characteristics are also well known (e.g., Jones et al., 1960; Holt and Powers, 1988; Powers and Holt, 1990). There is little difference in interpretation of the geophysical logs for many studies (see analysis in Appendix C of Powers and Holt, 1995). For this work, the main problem is that most geophysical logs for the Castile were taken in open holes. (See Limitations discussion below - section 5.5.)

The location data in standard township/range form were used to plot drillhole locations on preliminary maps and post values for structure and isopach maps. Such data are available from the geophysical logs and from Midland Map Company ownership maps

used as convenient base map. State Plane coordinates were also assigned to each drillhole with stratigraphic data to examine statistical relationships between structural properties at drillhole locations and reports/nonreports of Castile brine. The statistical studies of this relationship are incomplete at this time.

5.0 CASTILE DEFORMATION

Early in the history of the WIPP project, pressurized Castile brines were considered to be related to deformation of the Castile (e.g., Griswold, 1977; Anderson and Powers, 1978; Register, 1981; Popielak et al., 1983). Popielak et al. (1983) proposed that brine resides in fractures created within anhydrite by deformation and that fewer large fractures provide vigorous initial flow when hit with a drillhole. Borns et al. (1983) reviewed basic information on evaporite deformation in the northern Delaware Basin, considered five hypotheses on the origin of deformation, and concluded that gravity foundering (due to denser anhydrite overlying halite) and gravity sliding were the most likely explanations. Nonetheless, the physical conditions for either mechanism exist over broad areas while deformation is apparently not widespread. Borns et al. (1983) suggest intergranular water may have varied areally, changing rock strength somewhat locally and leading to deformation in these areas. Petrofabrics in the deformed Castile are also consistent with pressure solution and intergranular fluids (e.g., Borns, 1987). It is possible that intergranular fluids contribute directly to deformation and are also the source of the pressurized brines, but this has not been established.

The analysis by Register (1981) reported 10 brine encounters from the 62 drillholes (existing at that time) into the Castile near the WIPP and inferred that nine of the 10 were associated with known anticlinal structures. There has been considerable drilling since 1981; in this section we report structural information from a much larger data base and examine whether we can still conclude that brine reservoirs are associated with Castile deformation.

Our data around Danford well (T.22S., R.29E., sec. 9) are so limited that we draw no conclusions about structure. Our maps for this analysis do not extend to the Danford well.

We use two main forms of structure information: structure contours on selected stratigraphic contacts and maps of thickness (isopachs) of selected intervals. We assume that the evaporites were deposited on generally planar, horizontal surfaces, though we also recognize that there may have been differential subsidence or tilting during some of the deposition. We also begin with a working assumption that most of the units were deposited with a reasonably uniform thickness; regional and local trends can be depositional, compensating for synsedimentary subsidence or tilting.

While the focus is on Castile deformation, we have examined some of the effects on higher units as background. There are two reasons for this. The structure and thickness of higher units help delineate or bound the extent and age range for deformation. In addition, there are many more data points on mid-Salado to Rustler stratigraphic units across the WIPP site. If brine is associated with Castile structure, but the effects of that structure can also be seen in higher units, it may be possible to

better judge the possibilities that brine underlies parts of the WIPP. This possibility had not been adequately tested statistically at this time.

5.1 Methods

Data for structure and isopach maps were managed and computed using Rbase 5.5. Data were posted manually to maps and were contoured by Powers. All data were honored by contouring except some isolated points at the contour value (e.g., 1500) and some values at map edges, particularly along the northeast side of the map area where the Capitan reef underlies the area. Interpolation of values between data points is subjective but is generally roughly scaled. Dashes and dots for contour lines reflect decreasing confidence, generally in areas of fewer data points and at greater distance from data points.

Single hole anomalies that remain generally have not been reconfirmed or resolved with available data. They should be treated with caution at this time.

5.2 Structure Contours

Drillhole locations are identified on Figure 5.1-1 with identification numbers tied to data tables (e.g. ~~Table 4.2-2~~)
Appendix B

5.2.1 General

Over the area south of the study area, the top of the Delaware Mountain Group (DMG) displays relatively uniform strike slightly east of north and dips east about 75-100 ft/mile (about 1 degree) (Borns and Shaffer, 1985, fig. 16). This unit is the "basement" rock for our discussion.

For much of the study area, the DMG (Figure 5.2-1) continues the trends mapped by Borns and Shaffer (1985) for areas south of WIPP. Data for this contact are almost non-existent for the site area. We assume the NNE-SSW strike and modest east dip continues under the site.

In T.22S., R.32E., the contours indicate the DMG dips less than regional dip. Near the eastern edge of the map, some contours may be showing basin margin effects, though we include too few data to be certain.

While there are some differences from areas to the south, these are relatively minor. The structure of the DMG contrasts significantly with upper Castile horizons, as shown below.

Structure contours have been drawn for the top of the middle (A2) and upper A3) anhydrites of the Castile to demonstrate the main Castile features.

5.2.2 Anhydrite 2 (A2) (Figure 5.2-2)

Over the area south of the study area, A2 has strike and dip similar to the DMG (see figure 13 of Borns and Shaffer, 1985). The southern margin of our map study area appears to be the transition area to more complex structure to the north in the study area.

The few data points at the site area show deformation in the northern area and approximately "normal" structure in the southeastern site area (the vicinity of DOE 1). Near the southwest corner of the site, this unit in the Hudson Belco well appears also to be structurally high, though no nearby wells exist west of the Belco well to confirm closure. Near the northwest corner of the WIPP, it appears that the attitude of A2 is changing to more east-west strike. Three holes, each somewhat isolated, indicate structure lows. There are no known brine encounters in the cluster of drillholes near the northwest corner of WIPP

East and northeast of WIPP, A2 has been deformed into a major anticline trending about NW-SE. At least half of the known brine encounters closely relate to this major anticline, and several others are located along subsidiary structures. A structural low in east-central T22S., R.32E., interrupts part of this trend. Along the southeast corner of the map area, structure contours run approximately east-west, normal to the strike further south and west. Three brine encounters are in this area, 200 - 300 ft above projected contours from the south. The Mascho 1 and 2 brine encounters in T.22S., R.33E., are near deformed areas, but data near these wells are few.

Nearly all the brine encounters on the map appear to be related to areas deformed at the A2 level. More than half appear in areas where structural closure is demonstrable or very likely. Most of the rest are in areas where A2 differs considerably from contours projected from the south into the area.

5.2.3 Anhydrite 3 (A3) (Figure 5.2-3)

In this area, the top of A3 is also the top of Castile. Most of the brine encounters are interpreted to flow from the lower part of this bed.

The major structures of A3 and associations with brine encounters are very similar to those described for A2. The top of A3 was uncertain in the Belco well, though other nearby wells indicate some local structure.

5.2.4 Comparison with Culebra Dolomite Member (Rustler Formation)

A recent structure contour map of the Culebra (Powers and Holt, 1995) shows that the main anticlinal structure north and east of WIPP persists to the level of the Culebra. Over the WIPP site, there are limited changes from regional trends that may be difficult to attribute to any process (Powers and Holt, 1995).

5.3 Isopach Information

5.3.1 General

Three intervals were chosen to represent the main value of thickness maps: 1) Castile thickness, 2) the combined thickness of both halite numbers (H1, H2) and anhydrite (A2) between these halites, and 3) the thickness from base of Castile to base of the Cowden Anhydrite (of the Salado Formation). For simplicity, we call the third interval the IsoCowden.

5.3.2 Castile Thickness (Figure 5.3-1)

In areas near the southern margin of the site, the undeformed Castile is generally 1300-1400 ft thick. South and west of the site, isopach data are not very helpful. There may be local relative thickening and thinning near Hudson Belco, but the data are few. Over the site, DOE 2 shows thinning of the Castile; Borns (1987) described deformation features from Castile cores. While other WIPP drillholes at the site show structure, they do not go as deep as the DMG, and we have not inferred thickness in such drillholes for this analysis.

As expected, this map shows a strong thickening trend along the anticline north and east of WIPP. Just northeast of WIPP, there is an apparent minor thickening trend of about NNE-SSW. A localized thin area in east-central T.22S., R.32E. is consistent in location with a structural low along the anticline trend.

The apparent thickening of Castile northeast and east of WIPP is associated with many of the brine encounters. Nonetheless data are not available at several holes with brine, mainly because the DMG was not drilled or we cannot determine the stratigraphic contacts for the relevant beds. Some encounters east of WIPP are around areas of thickening or thinning, but thickness at the brine locations is not greatly different from undeformed areas.

5.3.3 Middle Castile (H1-A2-H2) Interval (Figure 5.3-2)

The main thickening and thinning trends and locations shown by the total Castile isopach are present in this map. There are more site details because more wells penetrated the relevant interval. Some local features show finer detail in this map compared to "smoother" contours for the thicker total Castile map. In "undeformed" areas south of the site, the thickness of the interval is about 600-700 ft.

In the northern part of the WIPP site a few drillholes are available that show the effects of deformation in the "disturbed zone" (see Powers et al., 1978). WIPP 12 and WIPP 11 show thickening, while WIPP 13 is much thinner. In the southeast part of WIPP, drillhole DOE 1 shows a "normal" thickness. The contours in these area are very approximate, and the thickness north of WIPP 12 is expected to be quite variable. While DOE 2 is difficult to interpret, there is almost no halite in the Castile at that location. If A2 was correctly identified, the thickness could be less than 150 ft.

Off the southwest corner of WIPP, there are some limited indications of thickening, but the interval was not definable at Hudson Belco. Off the northwest corner of WIPP, there is northward thickening.

Northeast and east of the site, a thick area trends along the anticlinal structure and zone of thickening for the entire Castile. The thinner area in east-central T.22S., R.32E., displays some apparent "fabric" of local thin zones approximately normal to the trend of the thick zone.

Most of the known brine occurrences can be associated with areas of thickening/thinning of this interval. There are several occurrences where data are inadequate and few where isopach changes are smaller or can be questioned.

5.3.4 IsoCowden (Figure 5.3-3)

This interval is very similar to the total Castile isopach, and it should be because it is the Castile plus the salt (commonly called the InfraCowden) between Castile and Cowden Anhydrite. The main structures are present, though there is some broadening across the main structure of the ERDA 6 anticline.

This map includes some estimated values noted by [ ]. The basis for the estimated values included on the map is provided in Appendix E. [Additional values for the thickness were generated from this map for later analysis in Section 8.0; only values that could be estimated independently from this map were included in this map.] The map was contoured in more detail than some others because this map has the most values, including estimates, of the thickness interval compared to other intervals.

While many of the brine intercepts occur in areas that are near the maximum thickness for the interval, some intercepts are not. While we think that most of the brine intercepts are in areas differing in thickness from regional trends, some are located in the mid-range of thickness for this map area.

5.3.5 Comparison of "Normal" and Thickened Zones

All three isopach maps show similar thickness differences between areas that are undeformed and deformed. This means that the thickening can principally be attributed to the halite members or the combined H1-A2-H2 interval. The basal (A1) and upper (A3) anhydrites included in the total Castile isopach differ much less from normal to deformed areas than does the interval with halite.

In order to examine further the relationship between various thickness intervals and the occurrence of brine, we plotted (Figure 5.3-4) the basic statistics (minimum, maximum, range of $\pm$ 1 standard deviation around the mean) for a number of intervals for comparison. Those intervals are:

IsoA1	top of Bell Canyon to top of A1
IsoH1	top of Bell Canyon to top of H1
IsoA2	top of Bell Canyon to top of A2
IsoH2	top of Bell Canyon to top of H2
H1A2H2	base of H1 to top of H2
IsoCas	top of Bell Canyon to top of Castile (A3)
IsoCow	top of Bell Canyon to base of Cowden Anhydrite
Iso124	top of Bell Canyon to base of MB 124
IsoRus	top of Bell Canyon to base of Rustler Formation
Cashal	sum to H1 and H2 thickness
IsoVT	top of Bell Canyon to base of Vaca Triste Sandstone Mbr
A1-Cow	top of A1 to base of Cowden Anhydrite

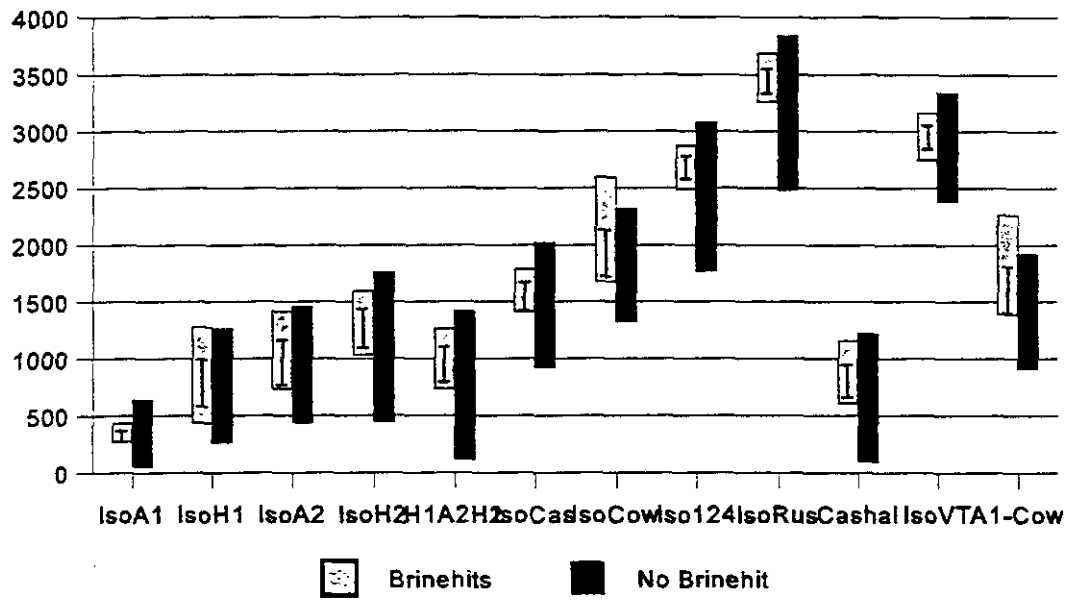

Figure 5.3-4 Color bars show range of thickness for each interval. Bars represent ± 1 standard devation around the mean.

We see that the thickness associated with brinehits tends to be greater than for the other drillholes. Each Cowden interval shows greater thickness for brine hits. The minimum thickness of IsoCow associated with a brine reservoir is 1677 ft; at ERDA 9, near the waste panels, the estimated thickness of the IsoCow is 1532 (± 25) ft. This interval is the most reliable of all listed above with respect to largest number of data points with direct thickness information at any drillhole

This is because the Bell Canyon structure is reasonably well understood and considered to be best for interpolation and because the Cowden could be

interpreted reliably in more wells than the top of Castile. This interval is considered as a possible exclusionary indicator for brine reservoirs under the waste panel. The statistical data are further examined in Section 7.0.

5.4 Summary of Geological Relationship to Brine Encounters

The majority of reported occurrences of Castile brine are clearly associated with areas of deformed evaporites in the Castile. Geological information is too limited for one drillhole (Danford) to determine if the evaporites are deformed at that location. Several drillholes are located in the general area of deformation, but they are not on extreme features. Brine appears to be strongly related to structure in Castile.

Very limited data on the top of the Castile near the WIPP site indicate that there is little, if any, deformation under the waste panel area. From this, we would infer that there is low likelihood of intercepting a brine reservoir in a drillhole through the waste panel area. The thickness of some of the intervals, especially the IsoCowden (base Castile to base Cowden), at the waste panel is estimated to be about 145 ft less than the minimum thickness for this interval at any known brine encounter, suggesting there may be a threshold excluding the panel area as an area to expect brine encounters.

Though the association of brine to structure appears to be strong, we note that most drillholes in areas of structure do not report brine in the Castile. A drillhole that does not intercept brine is not a demonstration that brine does not exist within an area.

5.5 Limitations

Some of the limitations for the geological data are due to the nature of the data. The geophysical logs for this study are dominated by neutron and gamma logs taken through casing in the evaporite section. While many of the stratigraphic "picks" are relatively straightforward, some are not, requiring more subjective decisions based on experience. The posted values for the structure contour and isopach maps do not differentiate between such kinds of data. The contoured maps are themselves a means of checking the likelihood of any individual value by the surrounding values. Single hole anomalies should be reexamined regardless of the apparent quality of the original data.

Another limitation to the geological study is that several of the holes with brine encounters were drilled before modern geophysical logging and have such limited geological data available that we are unable to confidently interpret the stratigraphic horizons and structural features at the drillhole location. Because more reliable data from other drillholes demonstrates that the structure and isopachs can vary over short distances, we have limited our inferences/extrapolations about the structure at these hole locations.

Work has not been completed to examine possible statistical relationships between structure or isopachs and brine encounters. If there is found a relationship strong enough to be helpful, we expect to incorporate this later into a re-evaluation of the

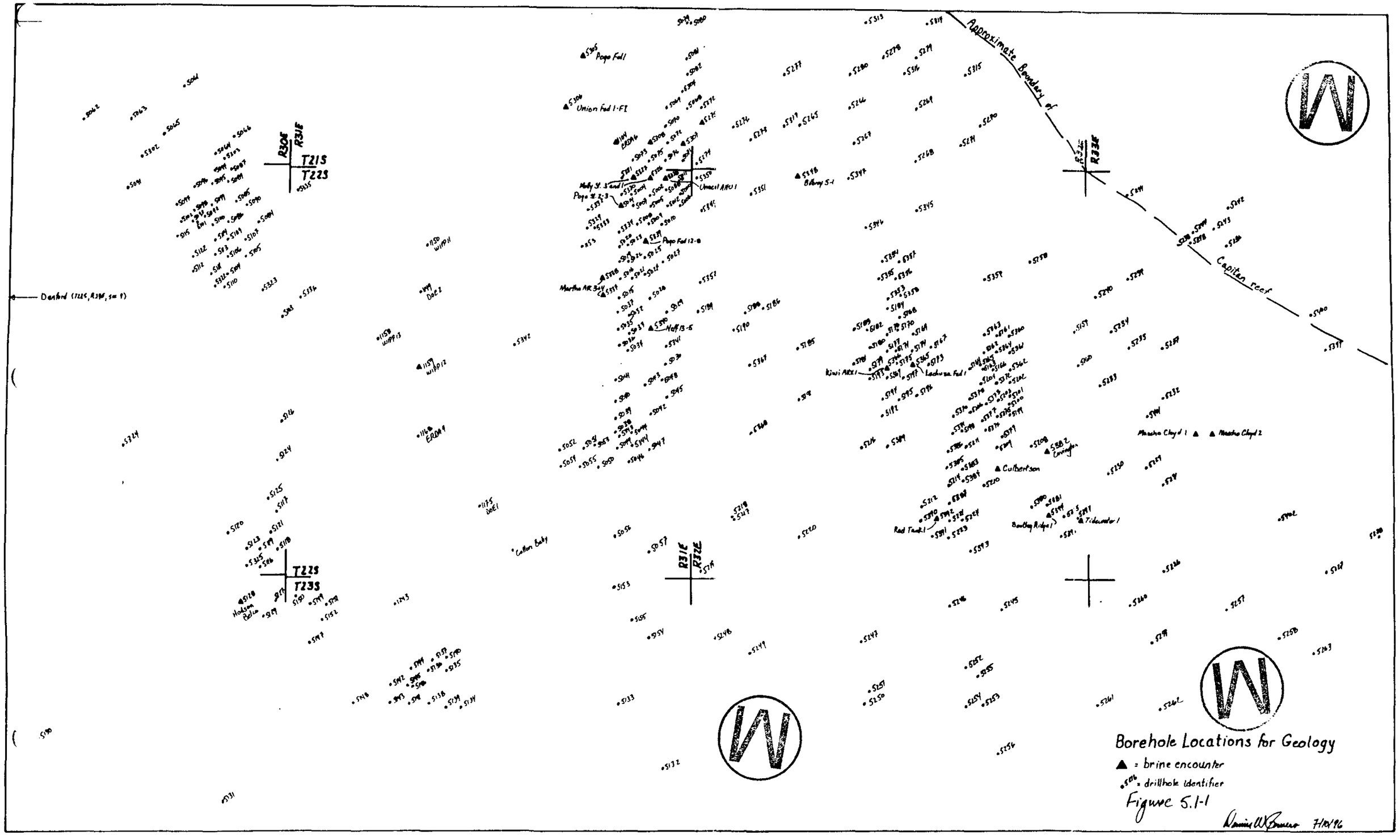
Approximate Boundary of
Capitan reef
R30E
R31E
T21S
T22S
T23S
R32E
Dunford (T22S, R30E, sec 9)
Pogo Fed
Union Fed 1-E1
Molly St. Sand 1
Pogo St. E-3
Unocal AFU 1
Bilbrey S-1
Pogo Fed 12-8
Martha AK 3-4
Neff 13-5
Kiwi AKU 1
Lechuza Fed 1
Culbertson
Red Tank 1
Bentley Ridge 1
Tidewater 1
Mesaho Chayd 1
Mesaho Chayd 2
Hudson Delta
Cotton Baby
Borehole Locations for Geology
▲ = brine encounter
= drillhole identifier
Figure 5.1-1
7/10/96

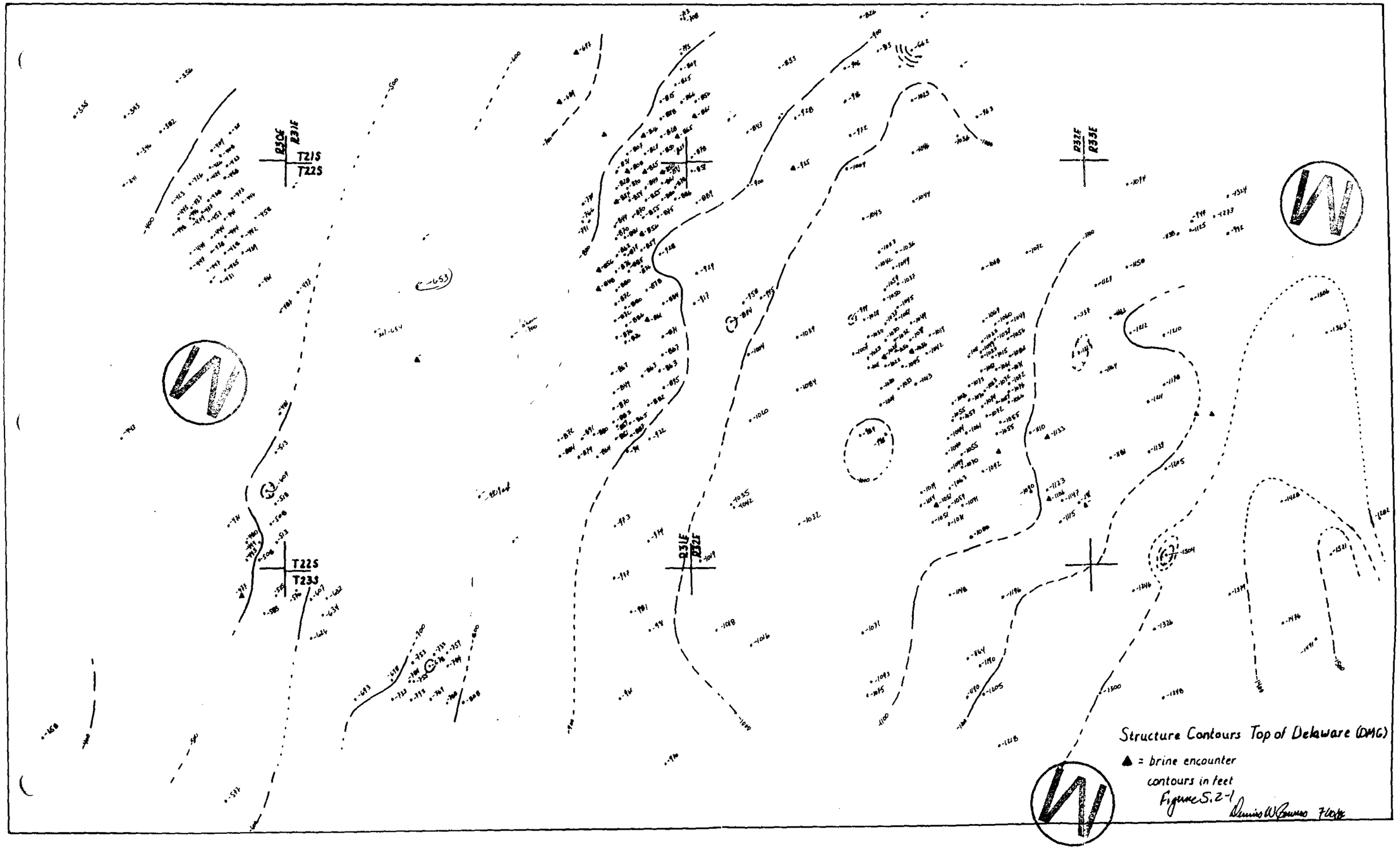

Structure Contours Top of Delaware (DMG)

▲ = brine encounter

contours in feet

Figure S.2-1

Dennis W. Powers 7-10-78

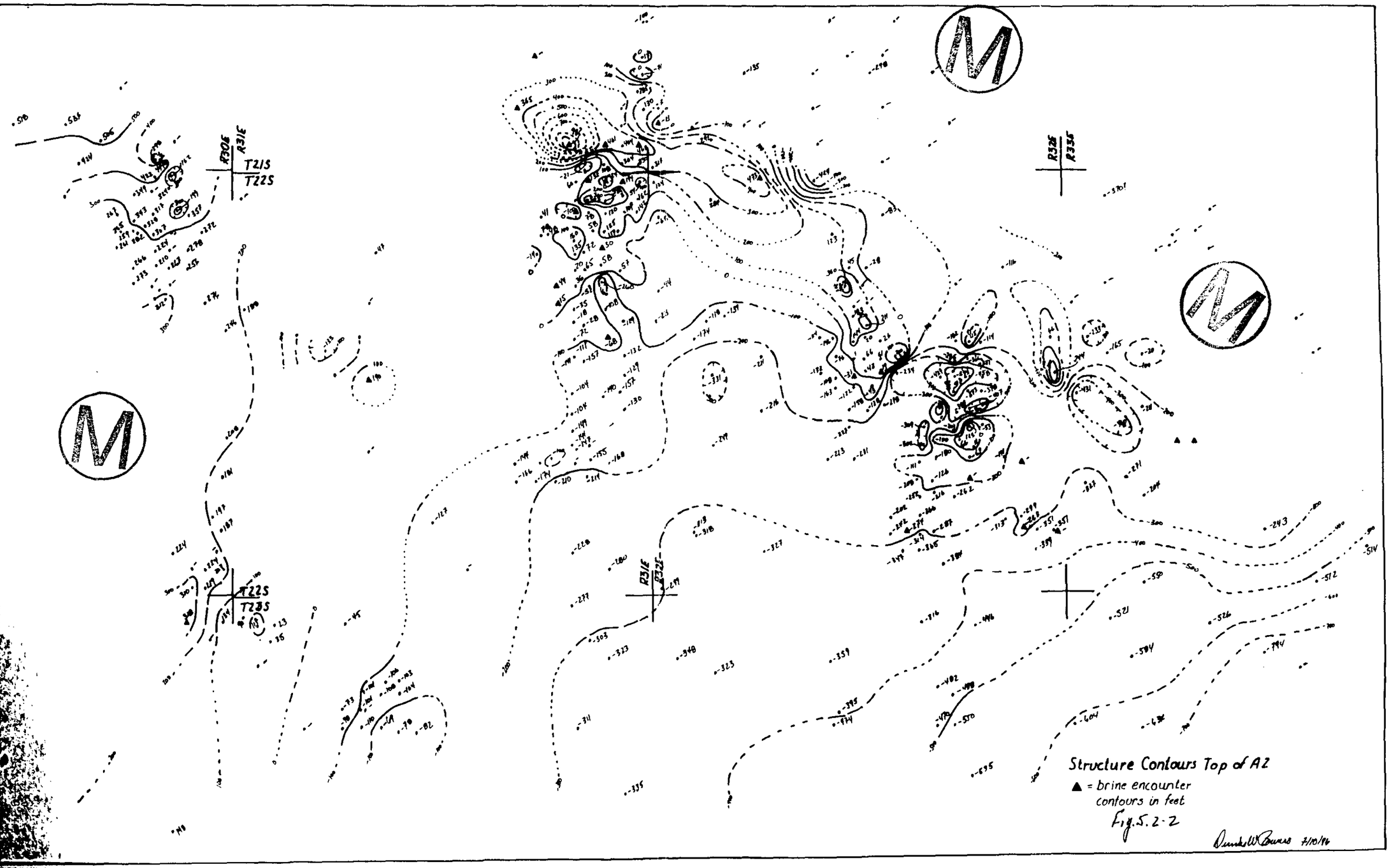

Structure Contours Top of A2

▲ = brine encounter

contours in feet

Fig. 5.2-2

Dennis W. Bowers 7/10/96

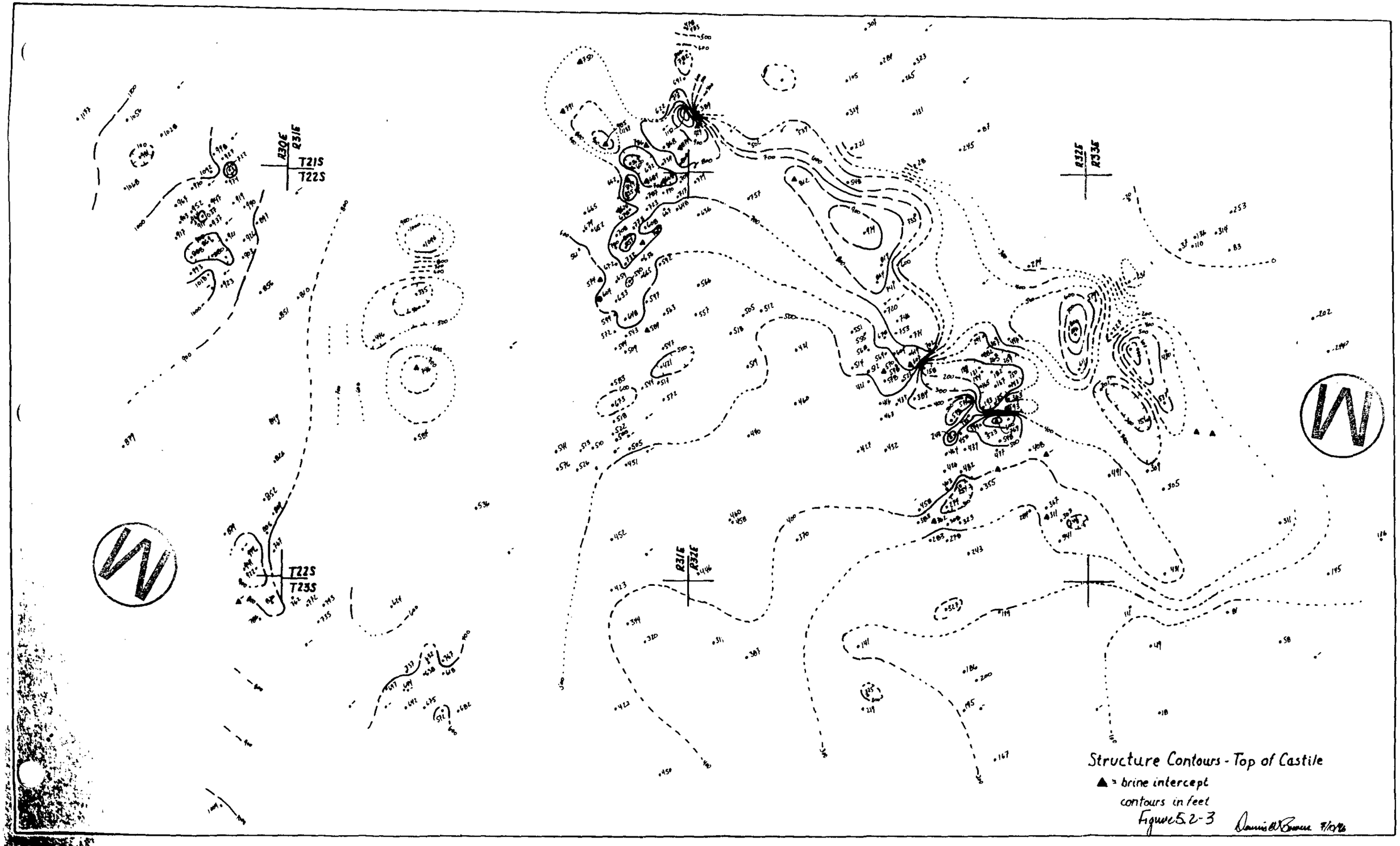
R30E
R31E
T21S
T22S
R31E
R32E
R32E
R33E
T22S
T23S
Structure Contours - Top of Castile
▲ = brine intercept
contours in feet

Figure 5.2-3

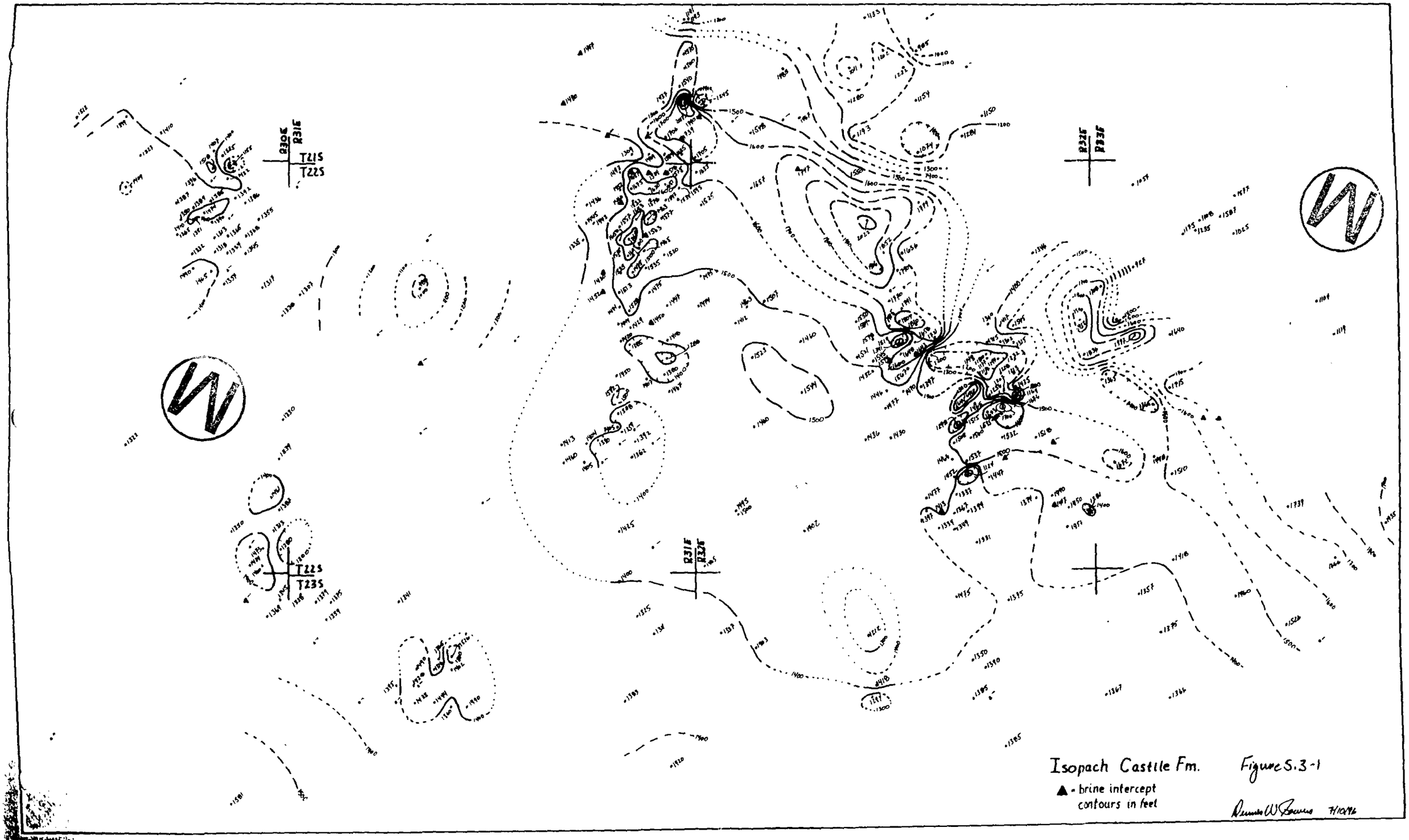

Isopach Castile Fm. Figure S.3-1

▲ - brine intercept
contours in feet

Dennis W. Powers 7/10/96

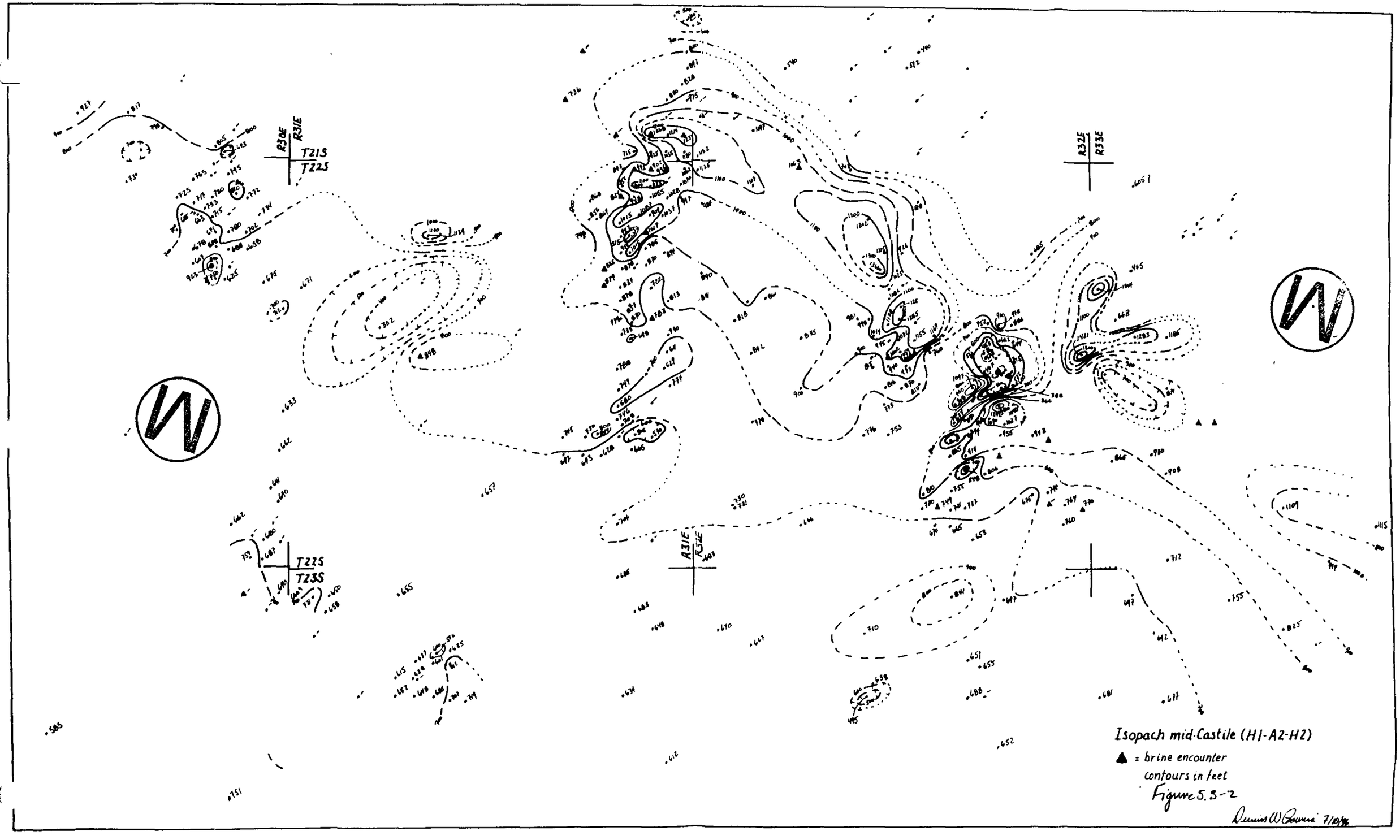

Isopach mid-Castile (H1-A2-H2)

▲ = brine encounter

contours in feet

Figure 5.5-2

Dennis W. Powers 7/18/96

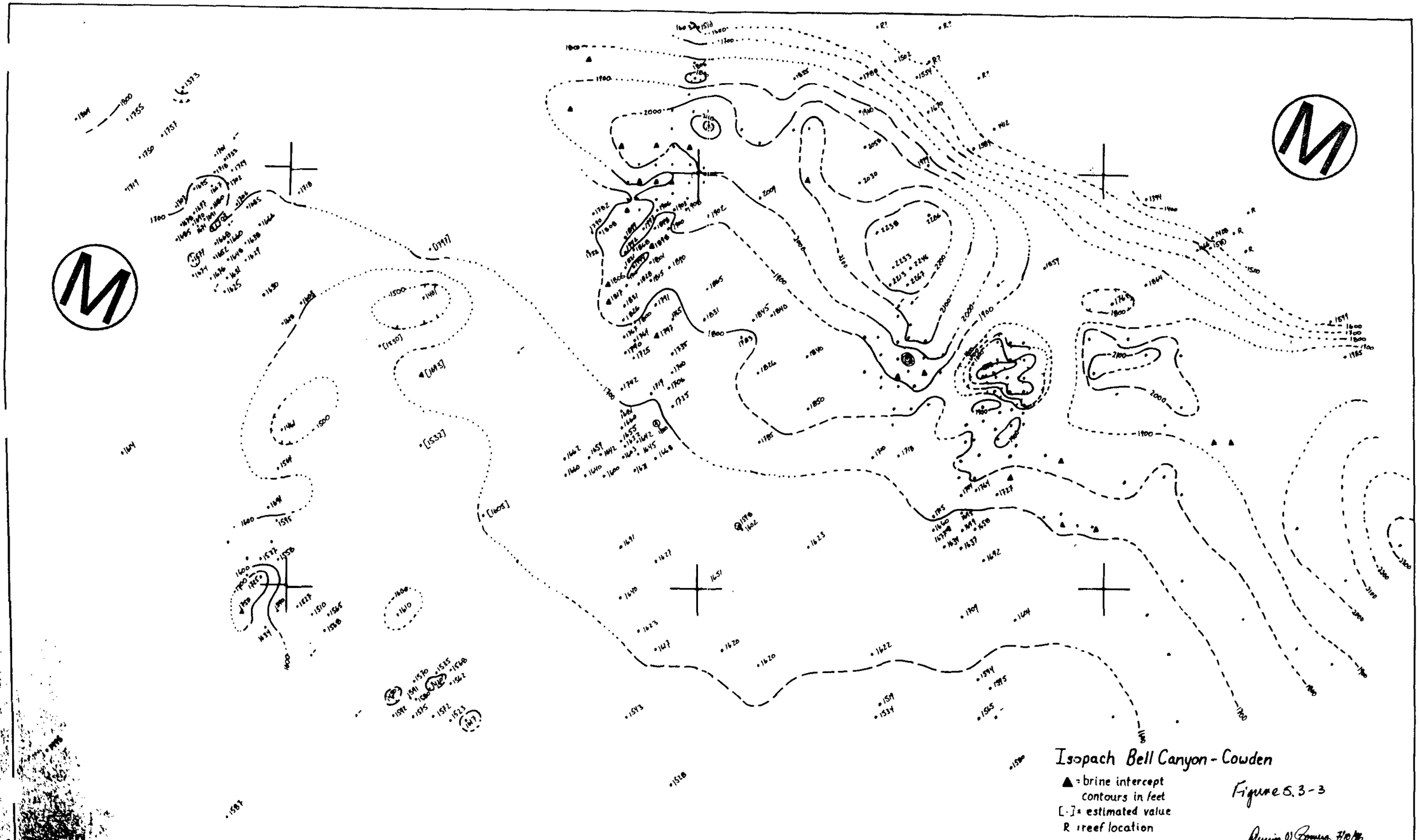
Isopach Bell Canyon - Cowden
▲ = brine intercept
contours in feet
[·] = estimated value
R = reef location
Figure 5.3-3

kriging estimates of intercepting brine under the WIPP site (see section 7.0).

6.0 GEOSTATISTICAL ANALYSIS

6.1 INTRODUCTION

We utilize a geostatistical approach to estimate the conditional probability of a brine reservoir intercept within the Castile Formation because geostatistics permits quantification of a phenomenon's spatial correlation and it provides robust estimation algorithms in kriging. The data are first examined with a suite of geostatistical tools to estimate the phenomenon's covariance function and then test the covariance estimate's robustness. This function quantifies how the phenomenon's observed values are correlated in space, in time, or in both. We can gain a better understanding of the scale of the phenomenon from the correlation scale, the distance over which the observed values appear to be correlated, of most estimated covariance functions. The data and the estimated covariance function are then input into a kriging algorithm to give a "best" unbiased, minimized least-squares error estimate of the phenomenon's value at unsampled locations while honoring the data exactly. For a binary phenomenon, such as the presence or absence of a brine reservoir intercept, kriging provides a direct estimate of the probability of the phenomenon at an unsampled location conditioned on the data locations and on the estimated covariance function (Deutsch and Journel, 1992). We can test the validity or appropriateness of the probability estimates by comparing the estimated covariance with covariance functions estimated from related phenomena, particularly those which may have created or influenced the spatial distribution of interest.

Our phenomenon of interest is whether a borehole will intercept a brine reservoir in the Castile Formation. We have observations of intercept/no-intercept from 354 wells distributed across roughly 645 km^2 (252 mi^2) of Delaware Basin. The WIPP site is roughly centered within this area. Taking on a value of either 1 or 0, binary variable observations are a type of categorical variable, which can represent phenomena such as rock types, counts of numbers of species, or whether a contaminant concentration exceeds a given threshold value. In contrast, continuous variables describe phenomena whose values vary more continuously than discretely; e.g., hydraulic conductivity, chemical concentration, temperature, etc. We seek the probability of a brine reservoir intercept at specific unsampled locations. Assuming the data set is representative and that classification errors are negligible, we can calculate a probability estimate for the unsampled locations which depends on the observed values: divide the 27 intercepts by 354, the total number of observations, to get a mean probability of 0.076. Although legitimate, this approach does not include information contributed by locations of the observed values relative to the

unsampled locations of interest. It is equivalent to deciding that there is no spatial relationship between occurrences; the mean probability can be reduced by simply enlarging the study area, which will include more drillholes without evidence of brine occurrences.

We can treat the observed values as having originated from a random function (RF), a name which is applied to a collection of random variables distributed across a domain of interest. The spatial correlation of a RF Z is described by the (auto)covariance, $C_{Z(x),Z(x+h)}$, where E is the expectation operator, **x** is the location vector for an observation, and **h** is the distance between it and another observation.

$$C_{Z(x),Z(x+h)} = E\{[Z(\boldsymbol{x}) - E\{Z(\boldsymbol{x})\}][Z(\boldsymbol{x}+\boldsymbol{h}) - E\{Z(\boldsymbol{x}+\boldsymbol{h})\}]\} \qquad (Eqn.6-1)$$

If we assume that the mean is constant and that the covariance is simply a function of the distance **h** separating the two values within the domain of interest, we can then simplify the covariance function:

$$C_z(\boldsymbol{h}) = E\{[Z(\boldsymbol{x})\,Z(\boldsymbol{x}+\boldsymbol{h})]\} - E\{Z(\boldsymbol{x})\}^2 \qquad (eqn.\ 6-2)$$

These assumptions are the result of deciding to treat the random function Z as a stationary RF. It is useful to decide an RF is stationary because we seldom can take repeated measurements of the phenomenon of interest at the same location, making it impossible to estimate the cumulative distribution function (cdf) at that point. Instead, by deciding to use a stationary random function model, we can use samples from other locations to estimate the cdf. It cannot be determined from the data whether the stationarity decision is valid . See Deutsch and Journel, 1992, p 12-13; Isaaks and Srivastava, 1989, p. 220-221; and Journel, 1986 for further discussion. This decision, however, permits us the use of a range of geostatistical tools, such as the semi-variogram, to estimate the covariance and thereby quantify the spatial variability.

The semi-variogram, g(**h**), is the variance of the difference between observations separated by a distance (or lag) **h**:

$$\gamma(\boldsymbol{h}) = \frac{Var\{Z(\boldsymbol{x}-\boldsymbol{h}) - Z(\boldsymbol{x})\}}{2} = C_z(\boldsymbol{0}) - C_z(\boldsymbol{h}) \qquad (Eqn.\ 6-3)$$

The covariance at separation distance **0** is simply the variance of Z. Equation 3 demonstrates the relationship between the variogram and the covariance function for a stationary RF. Their interrelationship is depicted in Figure 1. The

FIGURE 6-1
Interrelationship Between the Covariance and Semi-Variogram Functions

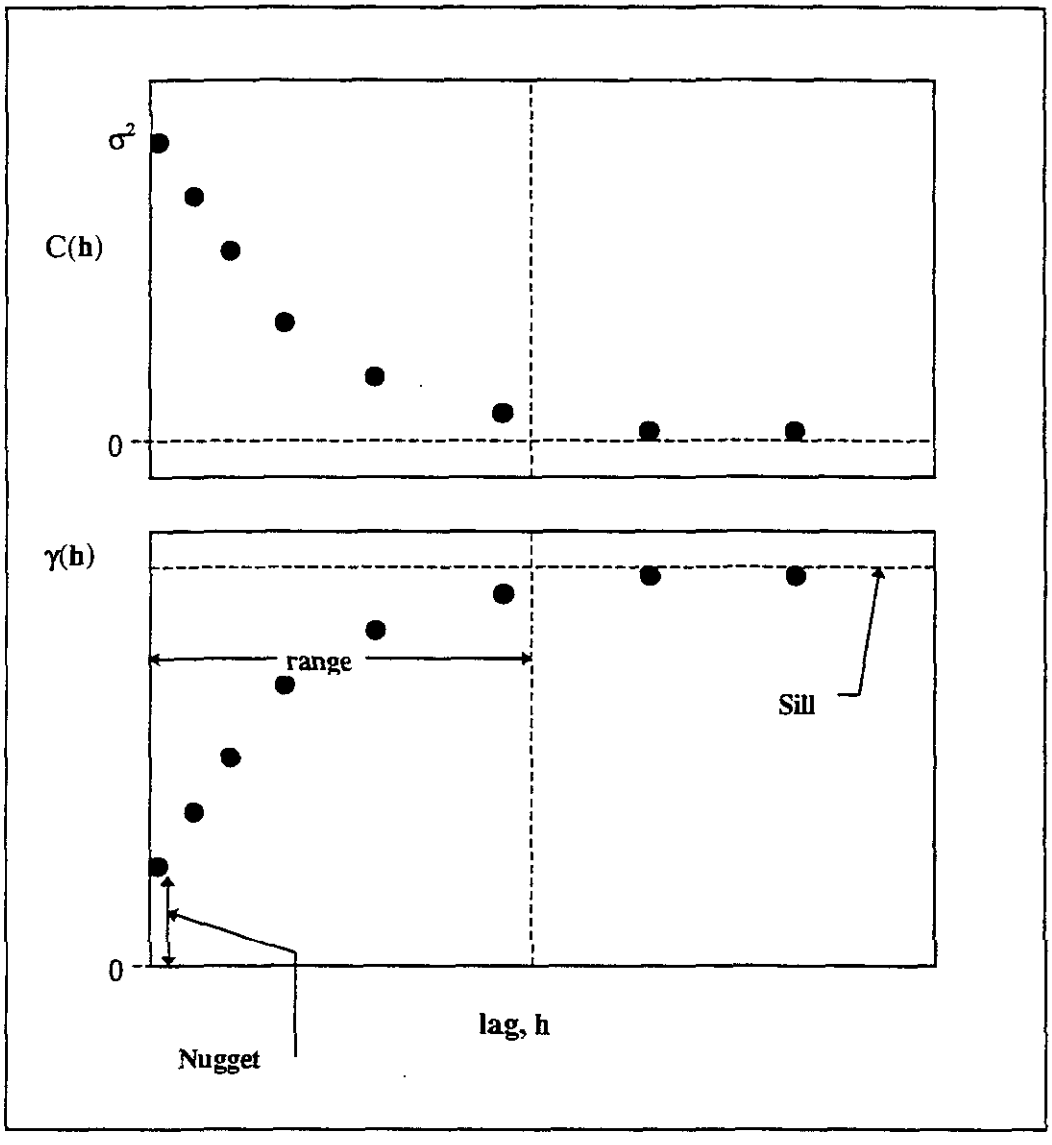

following discussion assumes a random function defined over a two-dimensional domain; generalization to a three-dimensional domain is straightforward. Most semi-variograms consist of three parameters: the range, defined as the lag at which the semi-variogram value levels out, i.e., the correlation between two observations decreases to zero; the sill, defined as the $\gamma(\mathbf{h})$ value at which the semi-variogram levels out; and the nugget, which refers to a discontinuity between the estimated semi-variogram's first point (nearest to a zero lag) and the origin. The range represents the length (or time) scale over which correlation between any two observations is still observed. The sill represents the population or sample variance of all the observations, and the nugget represents the sum of measurement errors and small-scale spatial variability not yet resolved. Each of these is depicted in Figure 6-1.

If, when calculated along a number of different directions, the sample semi-variograms show no significant changes in range, nugget, or sill values then the phenomenon is said to be isotropic; otherwise, it is anisotropic. Anisotropy in the directional semi-variograms is analogous to the major and minor axes of an ellipse (or ellipsoid in 3-D space). The directions corresponding to the major and minor axes can be thought of as the phenomenon's preferred or principal directions. Figure 6-2 demonstrates the relevant parameters for calculating a directional semi-variogram. To calculate an isotropic semi-variogram, which is also called an omni-directional semi-variogram, the search and bandwidth distances and half-angle should be set to their maxima, e.g., the length of the domain and 90 degrees, respectively.

A host of related geostatistical tools for describing spatial variability have been developed to complement the strengths and weaknesses of the semi-variogram (see Deutsch and Journel, 1992, p. 56). The correlogram and non-ergodic covariance functions can filter out trends in the variances and means for each lag group respectively. The relative semi-variograms and semi-rodogram are less susceptible to data clustering and outlier values than the semi-variogram. The semi-madogram is more robust to outliers than the semi-variogram. Prudent practice requires that one or more of these alternative measures of spatial variability be examined in addition to the traditional semi-variogram.

Estimation of the values at unsampled locations can begin once the spatial variability has been adequately characterized by a semi-variogram (or covariance) function with an estimated sill, nugget, and range. A very wide range of methods have been developed to solve the general interpolation problem (see Cressie, 1991), but only the kriging algorithms provide an unbiased, minimum error variance estimate, which exactly honors observed values, for an explicit covariance model. The kriged or predicted value is a function of the estimated covariance and of the locations, not the values, of the initial observations of the phenomenon. However, the value predicted for an unsampled location is conditional on the observed values, since they are

FIGURE 6-2
Parameters for Calculating Sample Semi-Variograms

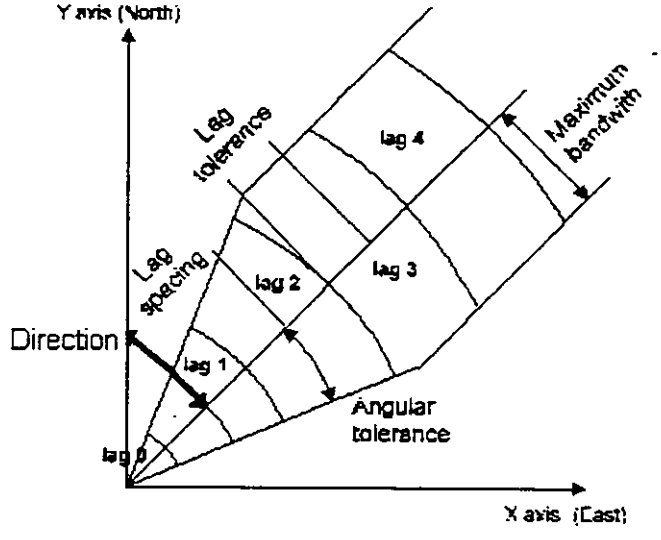

Adapted from Y. Pannatier, VARIOWIN HELP.

reproduced exactly by the algorithms. When applied to a binary variable, such as the presence or absence of a rock type or a brine reservoir intercept, the most commonly used kriging algorithm, ordinary kriging, provides a direct estimate of the conditional probability of that variable (Journel, 1984; Deutsch and Journel, 1992, p. 73). As above, this probability estimate is a function of the covariance model adopted and of the data locations and is conditioned on the observations.

6.2 METHODS

6.2.1 Variography

Variography is the process of extricating a phenomenon's spatial correlation from a set of observed values. Also known as structural analysis, the process focuses on estimating a sample semi-variogram or related functions, which are proxies for the covariance function, and then critically examining the estimate for sensitivity to individual data points, data clustering, and extreme values (outliers). Values for the range, sill, and nugget are determined from a theoretical semi-variogram model which is fitted to the sample semi-variogram.

6.2.1.1 Sample Semi-Variogram Calculation

Semi-variograms are calculated according to

$$\gamma(\boldsymbol{h}) = \frac{1}{2N(\boldsymbol{h})}\sum_{i=1}^{N(\boldsymbol{h})}(x_i - y_i)^2 \qquad (Eqn.\ 6\text{-}4)$$

where **h** is the approximate or average lag distance for each lag class, N(**h**) is the number of pairs for each lag class, x_i is the initial or tail value, and y_i is the final or head value for the pair. All variographic calculations were carried out using the VARIO module of the public domain software package UNCERT (Wingle et al, 1994), available from the Colorado School of Mines in Golden, CO. Calculations for the final semi-variograms were compared with those from two other geostatistical software packages: GSLIB (Deutsch and Journel, 1992) and VARIOWIN (Pannatier, 1994).

Since the geological structure data were not available to help constrain the choice of geometric directions prior to this study's start, we calculated sample semi-variograms for the isotropic (omni-directional) case and for a full range of anisotropic geometric directions. This ensured there was no bias in the selection of sample semi-variogram directions. We did not consider zonal anisotropy in this analysis because we have assumed the Castile Formation, from which all of the observations were collected, has a homogeneous variance

about the probability of a brine intercept. That is, the brine intercept probability variance is constant across the study area. Our results indicate the sill does not vary significantly compared to the ranges for the directional sample semi-variograms and therefore the anisotropy is better described by the geometric rather than the zonal approach.

The directional semi-variograms were estimated for azimuths 0, 20, 45, 70, 90, 110, 135, and 160 degrees measured clockwise from a 0 degree north. Lag spacings between 1000 ft and 2000 ft were examined because they bracketed the most common borehole spacings observed in the data. The maximum search distance, directional bandwidth, and horizontal half-angle were set to their maximum values of 150000 ft, 150000 ft and 90 degrees for the isotropic sample semi-variogram. The data were sufficient in number to restrict the horizontal half-angle to 15 degrees , maximum search distance to 50000 ft, and the directional bandwidth to 10000 ft and still have adequate numbers of observation pairs (>30) within each of the first 20 or more lags for all of the anisotropic sample semi-variograms.

Sample semi-variograms were judged significant if they exhibited a reasonably monotonic increasing structure within the first 25% of the lag classes with adequate numbers of pairs within each lag class. All significant sample semi-variograms were retained for fitting of theoretical semi-variogram model parameters (range, sill, and nugget variance). When an anisotropic sample semi-variogram was found significant, we calculated the sample semi-variogram along its orthogonal direction.

6.2.1.2 Sample Semi-Variogram Robustness

Clustering of the data locations can create apparent structure in sample semi-variograms (Deutsch and Journel, 1992; Isaaks and Srivastava, 1989, p. 162). Given the obvious clustering of borehole locations (see Figure 6-3), we tested the sample semi-variogram robustness to clustering using two different approaches. The first compares sample semi-variograms from the entire data set with those computed for two non-overlapping data subsets which have relatively uniform spatial distributions of boreholes and possess adequate numbers of brine reservoir intercepts. Subset 1 contains 81 boreholes, 15 of which had brine intercepts. Subset 2 holds 93 boreholes, 9 of which had evidence of brine intercepts. Figures 6-4 and 6-5 show the locations of the two data subsets. These two subsets were the only areas to possess both a relatively uniform distribution of boreholes and sufficient numbers of brine intercepts. Most of the boreholes in these two subsets were drilled to explore sand channels which underlie the Castile Formation. Correlation structures which appeared significant in each of the data subsets and in the complete data set were judged to be independent of the large scale data clustering evident in Figure 6-3.

Figure 6-

All Borehole Locations

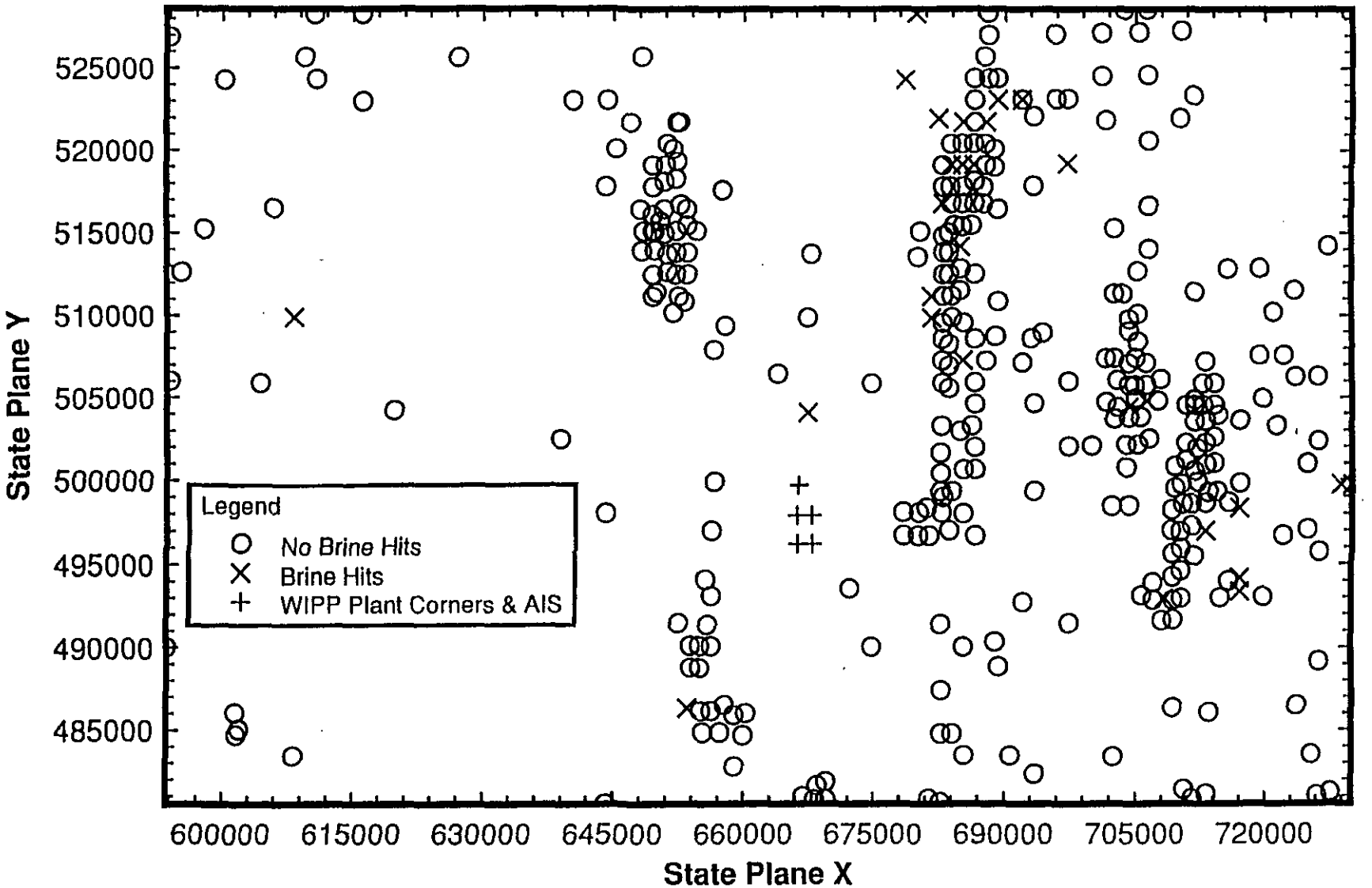

Figure 6-

Borehole Locations

First Data Cluster: BRSM1.DAT

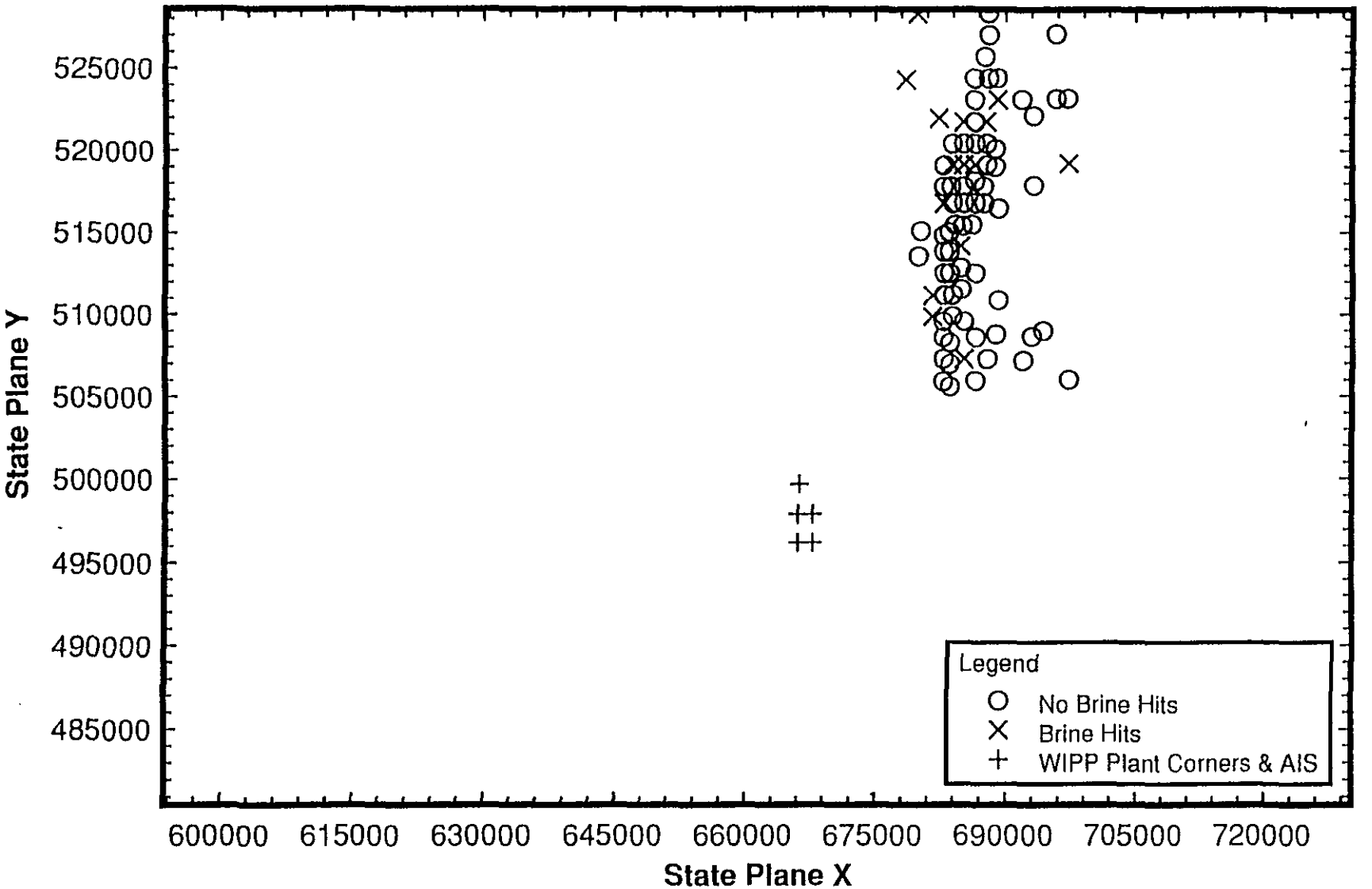

Figure 6-5

Borehole Locations

Second Data Cluster: BRSM2.DAT

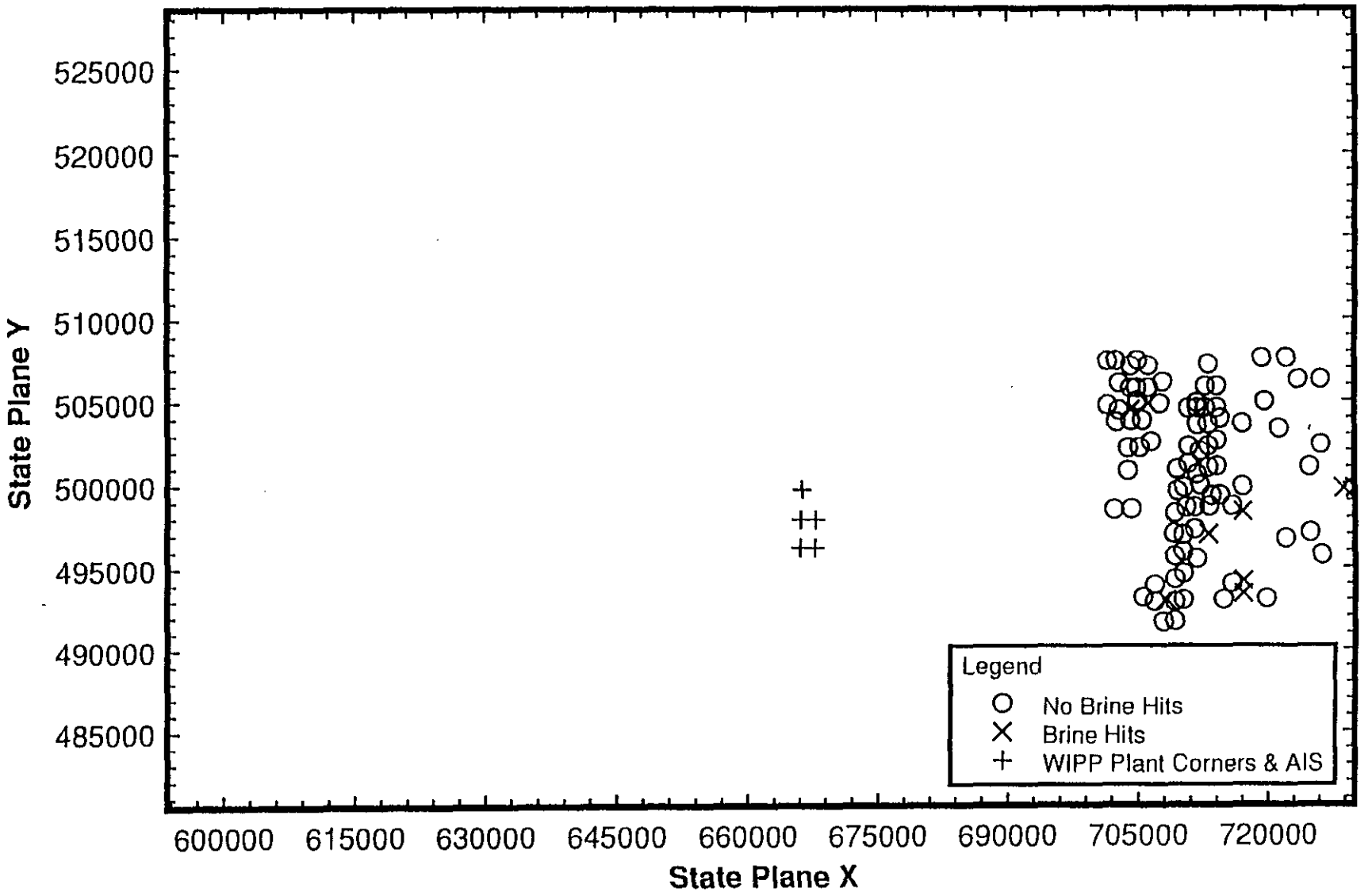

The second approach utilizes alternative measures of spatial continuity which are less sensitive to data clustering. The general and pairwise relative semi-variograms are typically less vulnerable to clustering because they normalize the semi-variogram value for each lag class by the squared mean of the data and the squared average of the paired values; however, they can only be computed for strictly positive data (Deutsch and Journel, 1992). Since our data were mainly zeros and a few ones, we added a value of one to each data point, shifting the data range from [0,1] to [1,2] and then calculated the relative semi-variograms. This shift preserves the maximum and minimum differences between any two data points, which are all that is required for calculation.

The semi-rodogram, defined as

$$\gamma_R(\boldsymbol{h}) = \frac{1}{2N(\boldsymbol{h})}\sum_{i=1}^{N(\boldsymbol{h})}\sqrt{|x_i - y_i|} \qquad (Eqn.6\text{-}5)$$

is also more resistant to clustering than the semi-variogram (Deutsch and Journel, 1992, p. 56). However, this measure (and the related semi-madogram) is numerically identical to the semi-variogram when computed for a binary variable limited to differences of 1 and 0. While this may suggest the semi-variogram for a binary variable with the same maximum and minimum differences should be relatively indifferent to data clustering, it may simply be a numerical artifact. Accordingly, the semi-rodograms were not used in the analysis.

We examined the impact of classification error on the sample semi-variogram calculations. Initial variographic calculations had been made prior to reclassifying well AEC7 from a brine intercept to a non-intercept. We recalculated sample semi-variograms for each of the data subsets and for the entire data set and then compared them to the previous results.

Undue influence of outlier data values was not considered to be significant because the range of allowable values was strictly limited to 0 and 1.

6.2.1.3 Theoretical Variogram Model Fitting

The range, sill, and nugget variance were estimated for each of the final sample semi-variograms using UNCERT's VARIOFIT module. Fits of each of the most common theoretical semi-variogram models: spherical, exponential, and Gaussian, were made both with and without non-zero nugget variances. Model fit was evaluated subjectively with the objective of preserving the apparent smaller scale range and nugget as much as possible. Automated, non-linear curve fits of theoretical models to the sample semi-variograms were also examined to check for subjective bias in the initial manual fit.

6.2.2 Kriging of a Binary Categorical Variable

We estimated the conditional probabilities of a brine intercept at regularly-spaced grid nodes using ordinary point kriging for each of the selected theoretical semi-variogram models. An areally-averaged probability was then computed from the kriged point probabilities for the waste panel area.

Ordinary point kriging was carried out using UNCERT's GRID module for each theoretical semi-variogram model. Inputs include the estimated semi-variogram parameters, the intercept/no-intercept observations, grid definition parameters, and search parameters. We selected a 1000 ft grid node spacing along both the N-S and E-W axes. The kriged domain range included all of the data points and had an E-W range of [590000, 731000] and a N-S range of [480000, 530000] in NM state plane coordinates. We compared results from the normal search mode, with minimum and maximum number of data points set to 4 and 16, to those from the octant search mode, which had minimum and maximum number of data points set to 2 and 16 and a maximum per octant of 8 points.

The CONTOUR module from UNCERT was used to create color-coded maps of the conditional brine intercept probabilities for each of the semi-variogram models. Point-kriged probabilities for each node within the waste panel, the shaft pillar, and the experimental areas were pulled from the output files and noted. We estimated an average conditional probability for the entire waste panel area through weighting each nodal conditional probability by the percentage of the total waste panel area it influenced. These calculations were made using the EXCEL spreadsheet package.

We checked the point-kriged probabilities from UNCERT's GRID module against results from GSLIB's KTB3D algorithm using the same grid, search, and variogram model parameters.

6.3 RESULTS AND DISCUSSION

6.3.1 Variography

6.3.1.1 Sample Semi-Variogram Calculations

Figures 6-6ab and 6-7ab show all the sample semi-variograms for the first and second data subsets. Figure 6-6a depicts the most significant sample semi-variograms found in Subset 1: the isotropic case and azimuths 20 and 160 degrees together with their orthogonals (110 and 70 degrees, respectively). The remaining directional sample semi-variograms, shown in Figure 6-6b, demonstrate a pure nugget effect, i.e., there is no spatial correlation. Figure 6-7a shows that only the azimuth 160 directional semi-variogram clearly demonstrates any correlation structure. The isotropic case semi-variogram also

Castile Brine Reservoirs: BRSM1.DAT

Fig 6-6a

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

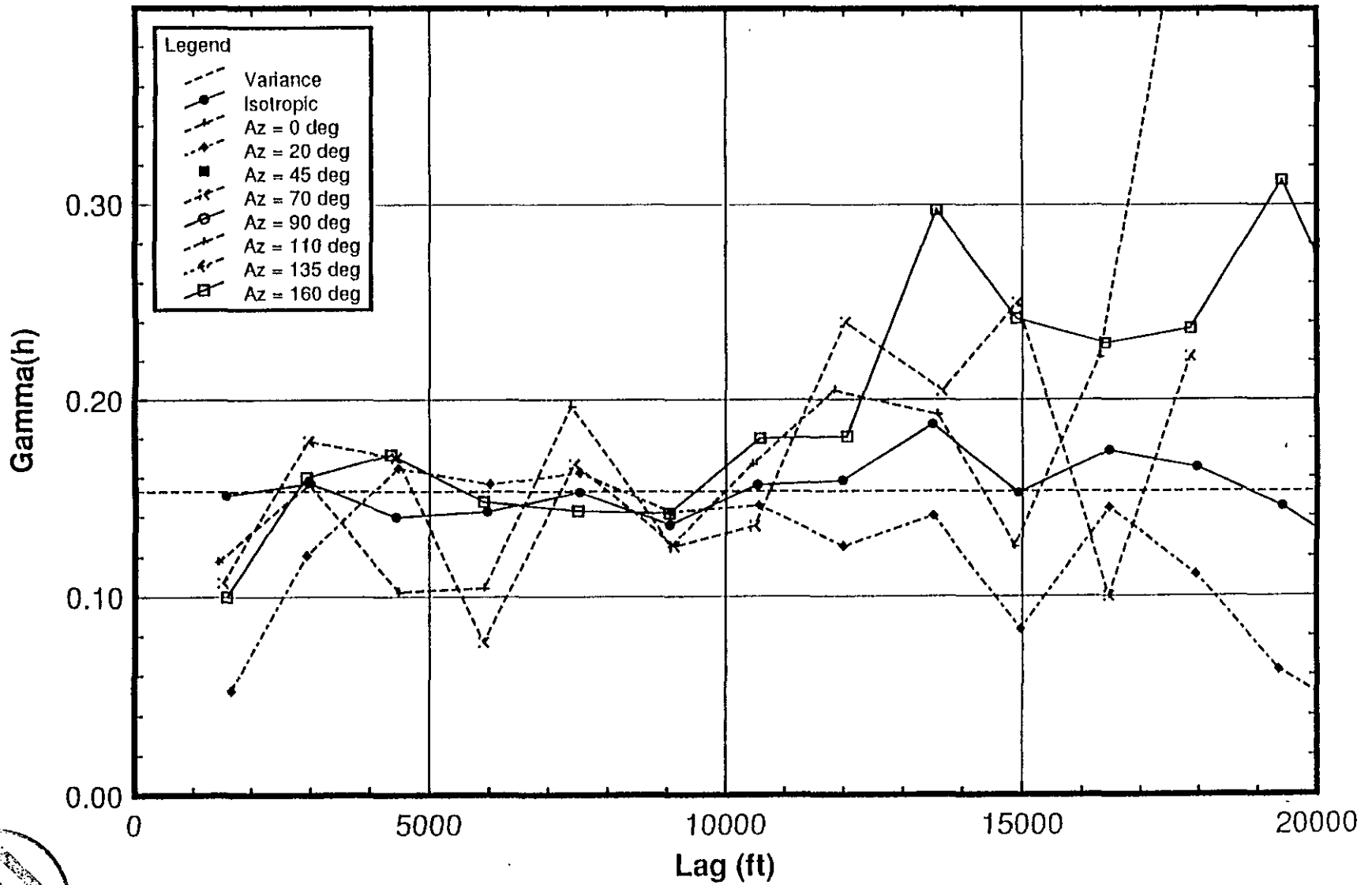

Castile Brine Reservoirs: BRSM1.DAT

Figure 6-6b

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

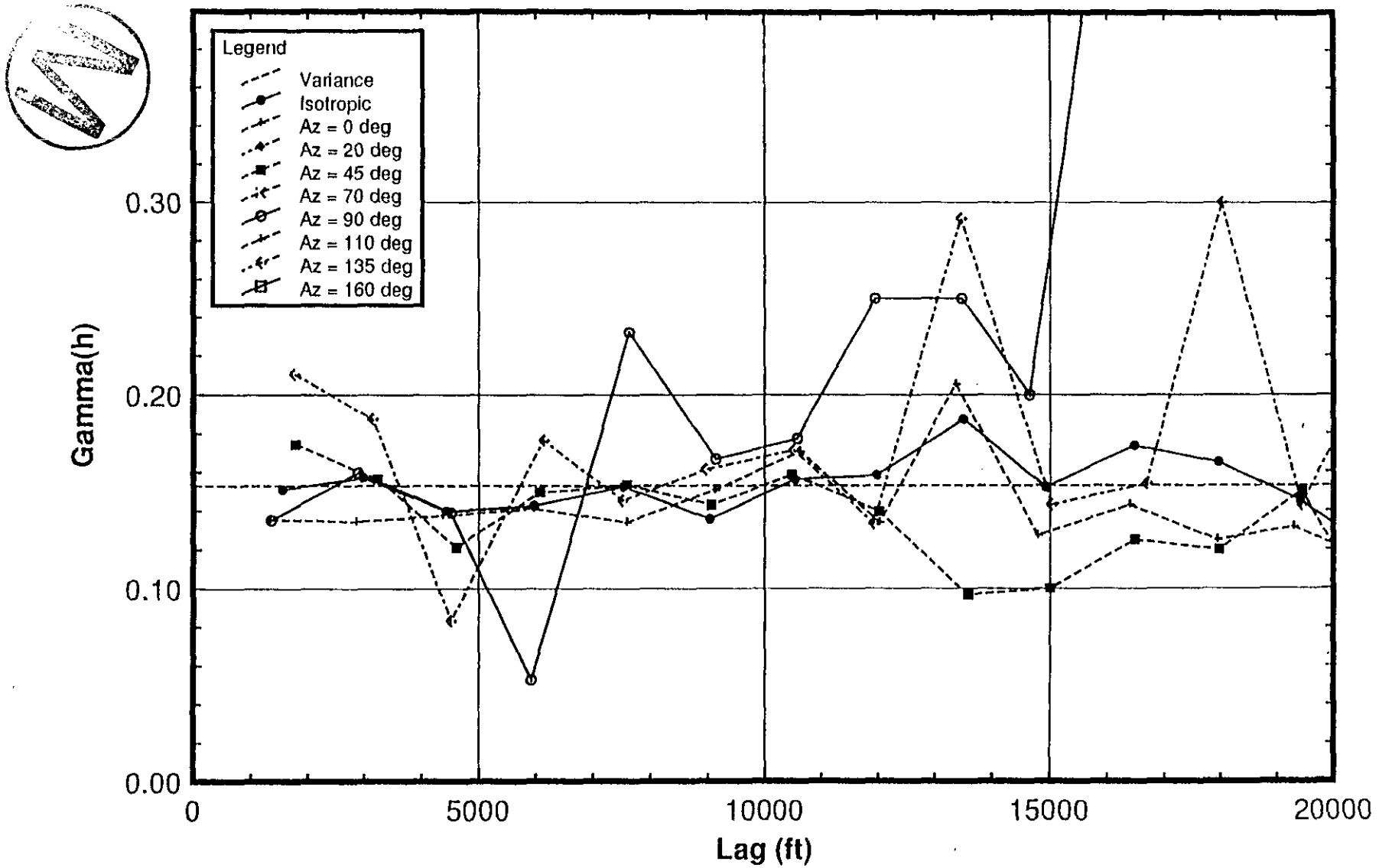

Figure 6-7a

Castile Brine Reservoirs: BRSM2.DAT

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

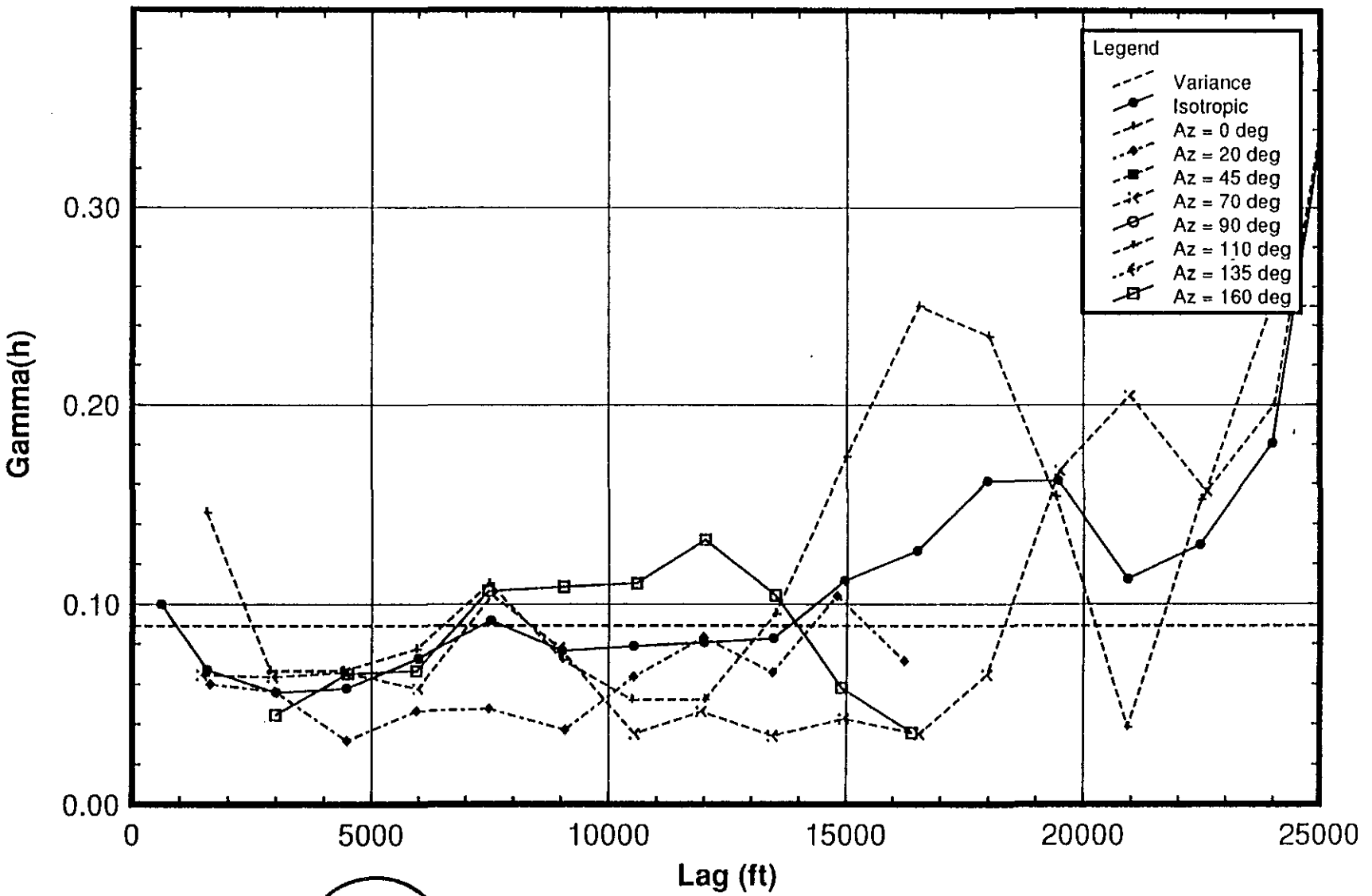

Figure 6-7b

Castile Brine Reservoirs: BRSM2.DAT

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

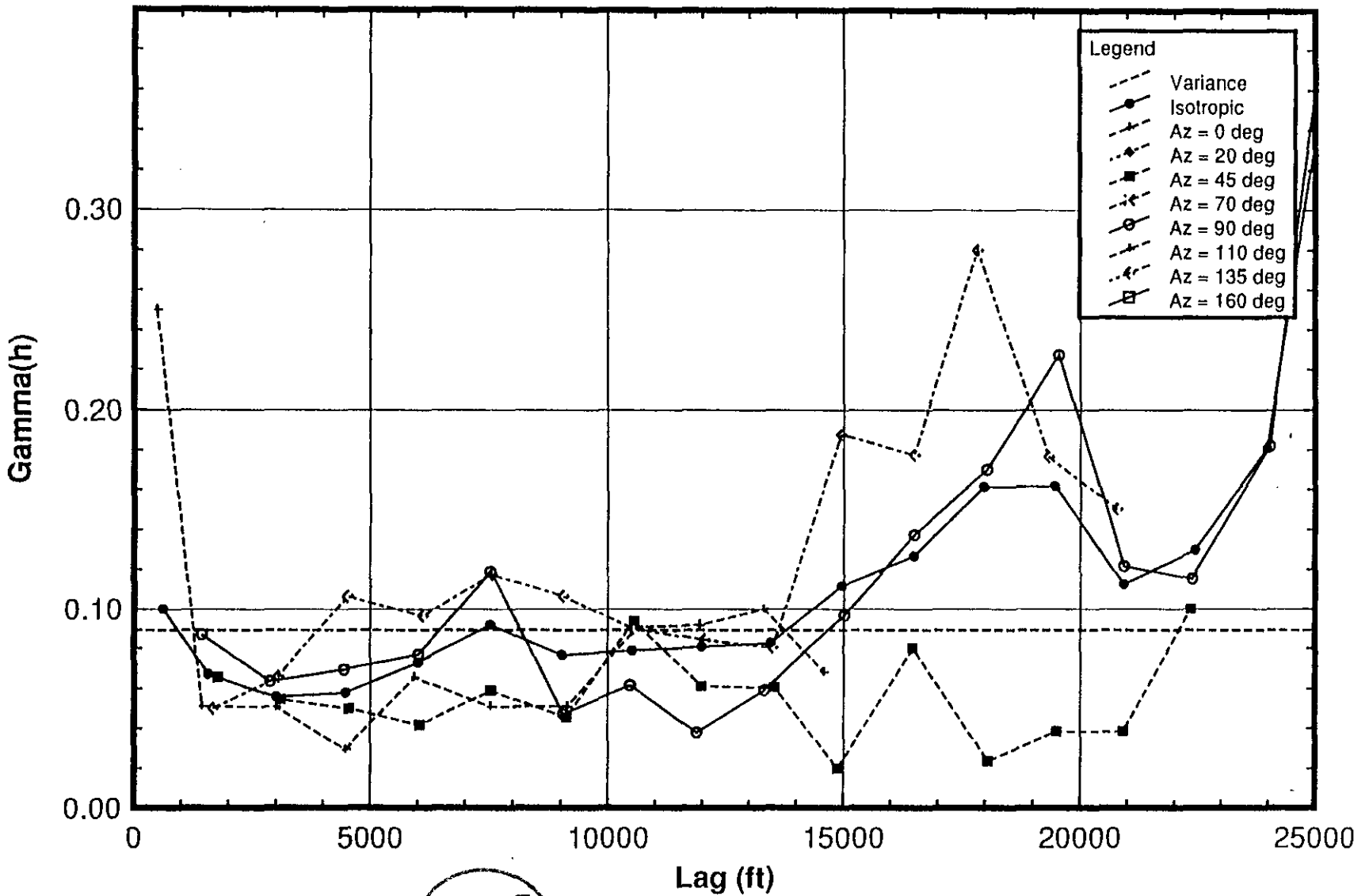

demonstrates correlation structure because its first lag spacing point has too few pairs to be considered a valid estimate. The 20 degree azimuth does not exhibit significant correlation structure. The same holds for all the remaining directions depicted in Figure 6-7b.

Figure 6-8a indicates that significant correlation structure can be found in the isotropic and 20, 70, and 160 degrees azimuth sample semi-variograms for the complete data set. Figure 6-8b shows that the remaining directions have no correlation structure and are best described by a pure nugget effect. The relatively large number of data points within the complete data set ensured that large numbers of pairs were found in all of the early lag classes, e.g., from 0 to 20000 ft lags. The semi-variogram values are typically less dependable for the later lag classes because the semi-variogram estimates become increasingly unstable as lag spacing increases beyond 25 to 40% of the maximum separation distance within the data set.

The only spatial correlation structures which appear consistently across the three data sets are the isotropic (omni-directional) and the anisotropic 160 degrees azimuth sample semi-variograms. The latter sample semi-variogram persisted across a fairly narrow range of azimuth angles: from 157 to 162 degrees azimuth. Although it exhibits some noise (or, potentially, cyclicity) at the fourth lag, the 70 degree azimuth sample semi-variogram was consistent across the three data sets. The correlation structures observed for the 160 and 70 degree azimuth and isotropic semi-variograms persisted when lag spacings were varied from the initial value of 1500 ft to 1000 and 2000 ft. This was not the case for the 20 degree azimuth semi-variogram, which was observed at 1500 and 2000 ft lags but not at the 1000 ft lag. Furthermore, its orthogonal semi-variogram (azimuth of 110 degrees) did not show any significant correlation structure in any of the data sets for any lag spacing. Consequently, the 20 degree azimuth model was not considered to be a significant sample semi-variogram.

The relative semi-variograms for the complete data set shifted from [0,1] to [1,2] (see Figures 6-9ab and 6-10ab) confirm the isotropic and 160 and 70 degree azimuth semi-variograms demonstrate significant correlation structure. Changing borehole AEC7 from an intercept to a no-intercept had a negligible impact on the estimated sample semi-variograms. We found an exact equivalence to four or more decimal places between the calculations made with UNCERT's VARIO and those made using the GSLIB and VARIOWIN variography routines. The calculation results for each package are presented in Appendix I.

6.3.1.2 Theoretical Semi-Variogram Model Fitting

Table 6-1 presents the range, sill, and nugget variance parameters fitted for the

Castile Brine Reservoirs: BRSM5.DAT

Figure 6-8a

Semi-Variogram: Range = 1500 ft; BW = 10000; HA = 15

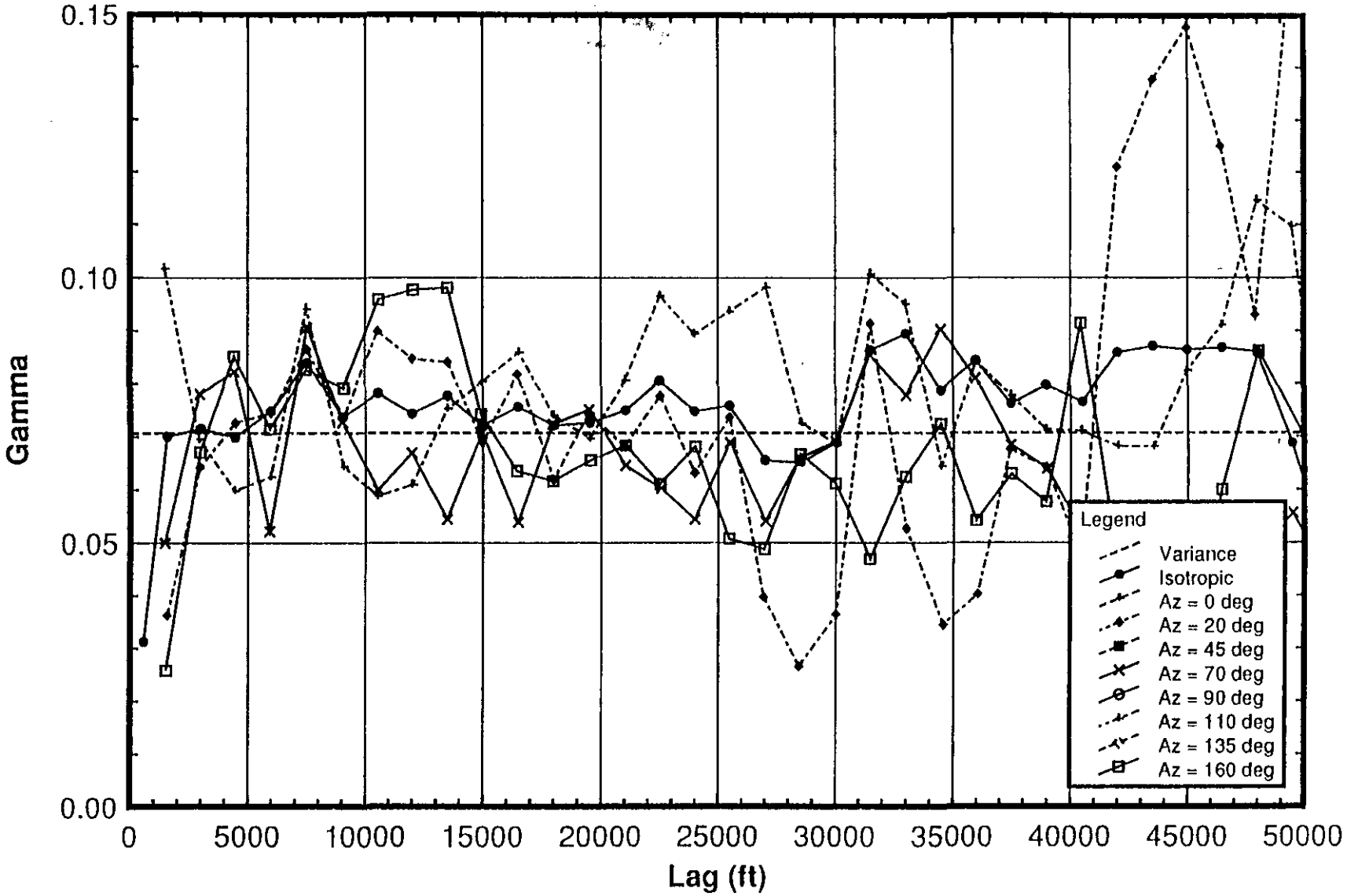

Castile Brine Reservoirs: BRSM5.DAT

Figure 6-86

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

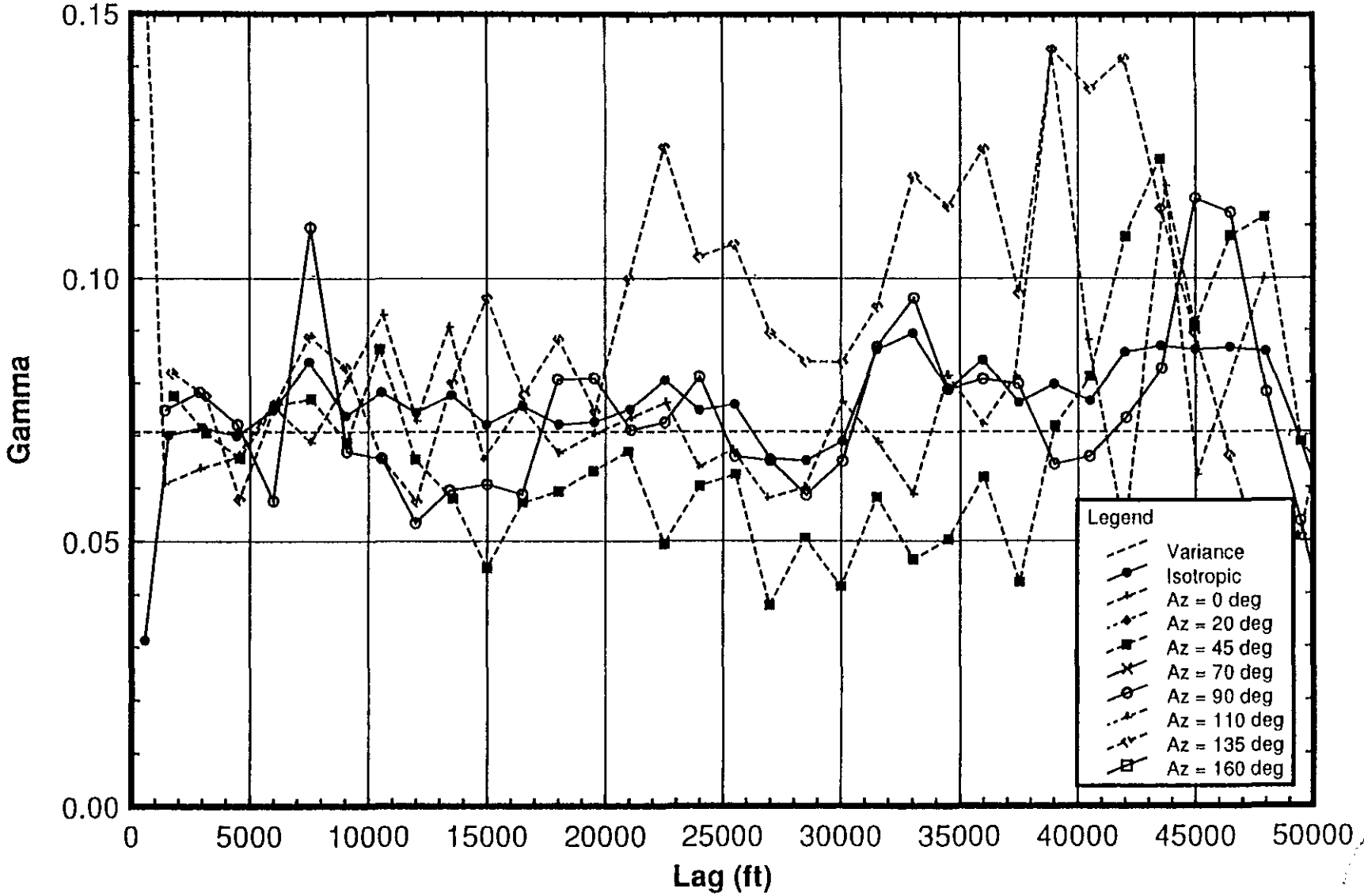

Castile Brine Reservoirs: BRSM512.DAT

Figure 6-9a

General Relative Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

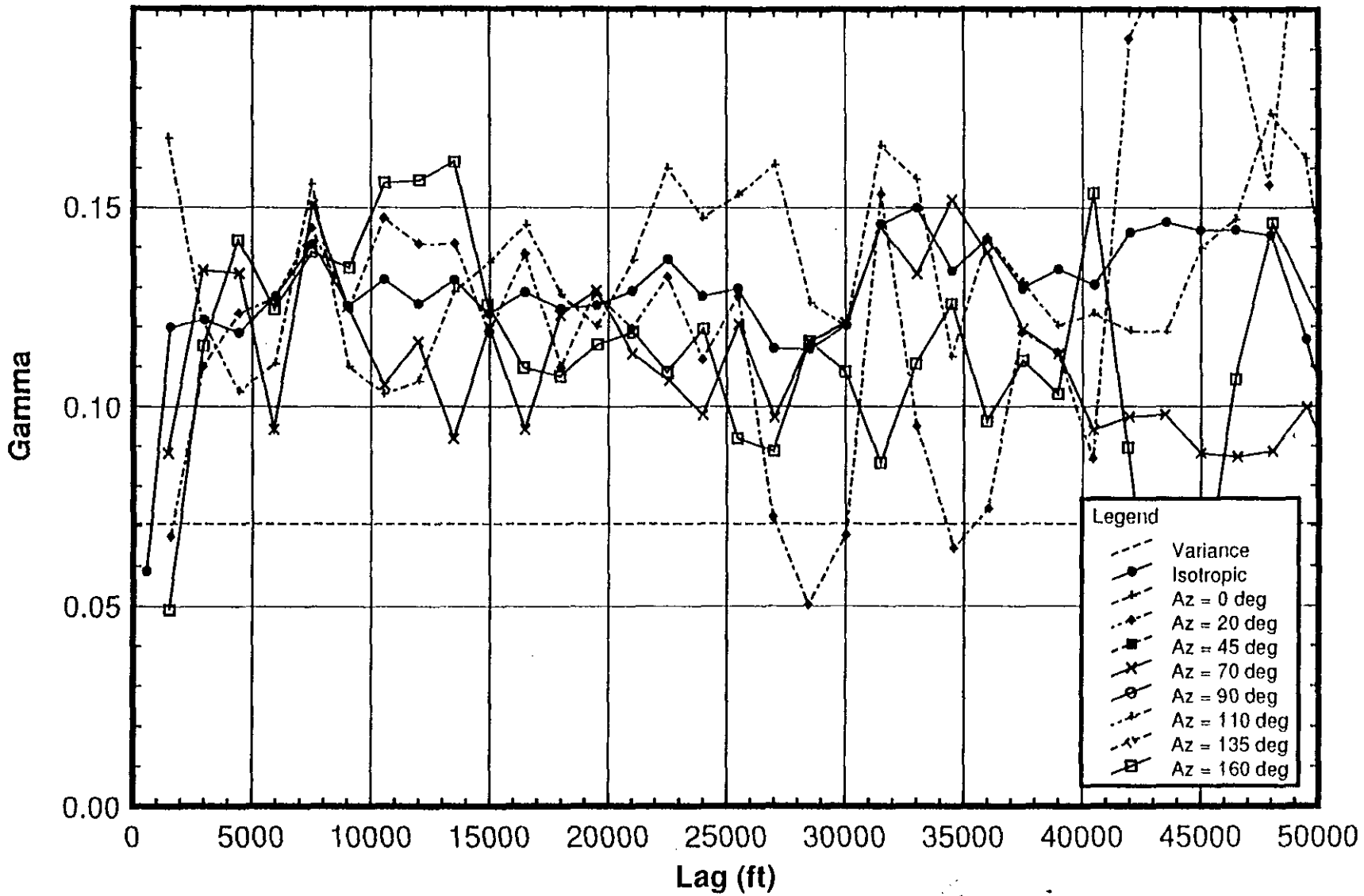

Figure 6-96

Castile Brine Reservoirs: BRSM512.DAT

General Relative Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

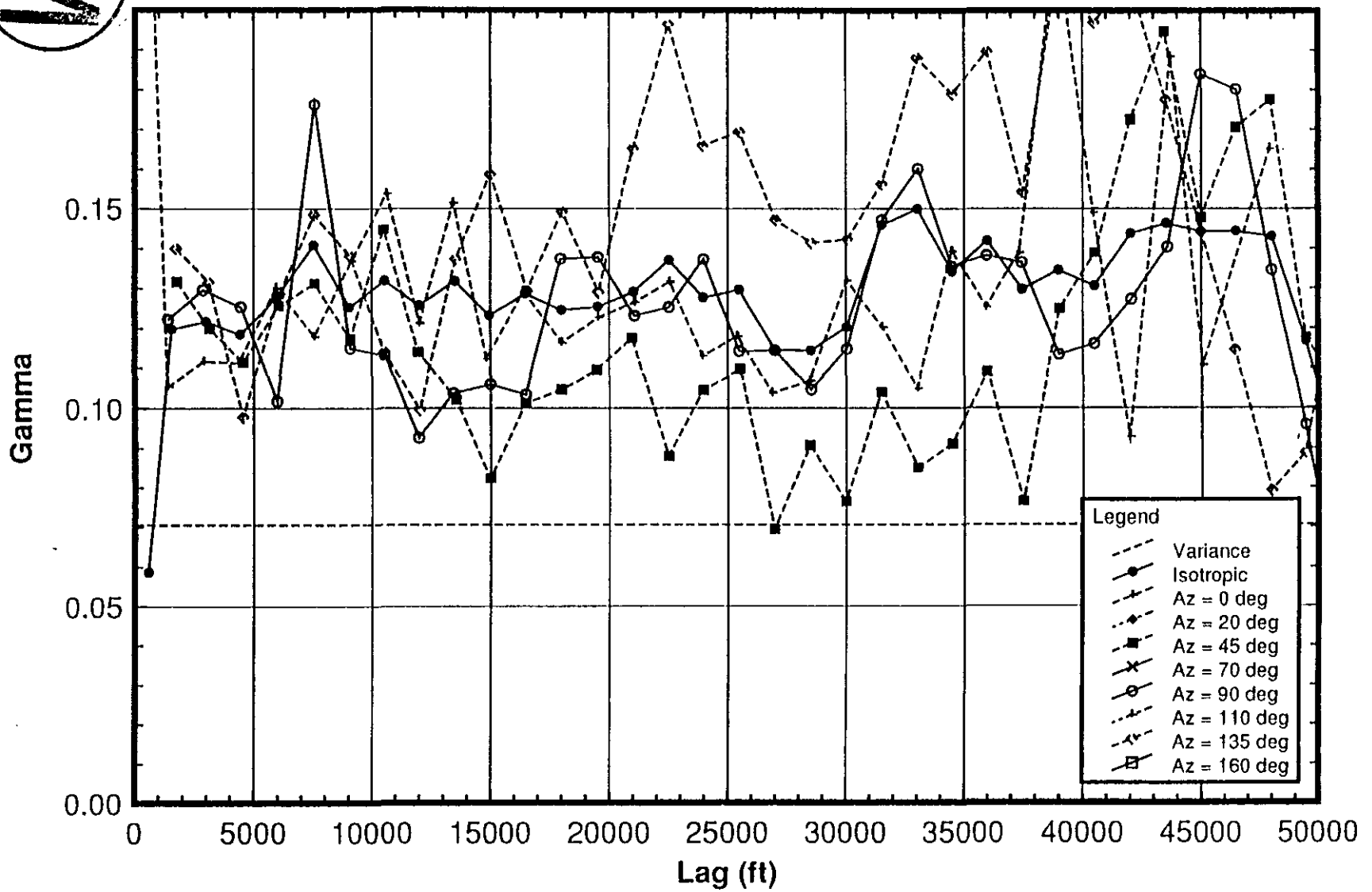

Figure 6-10a

Castile Brine Reservoirs: BRSM512.DAT

Pairwise Relative Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

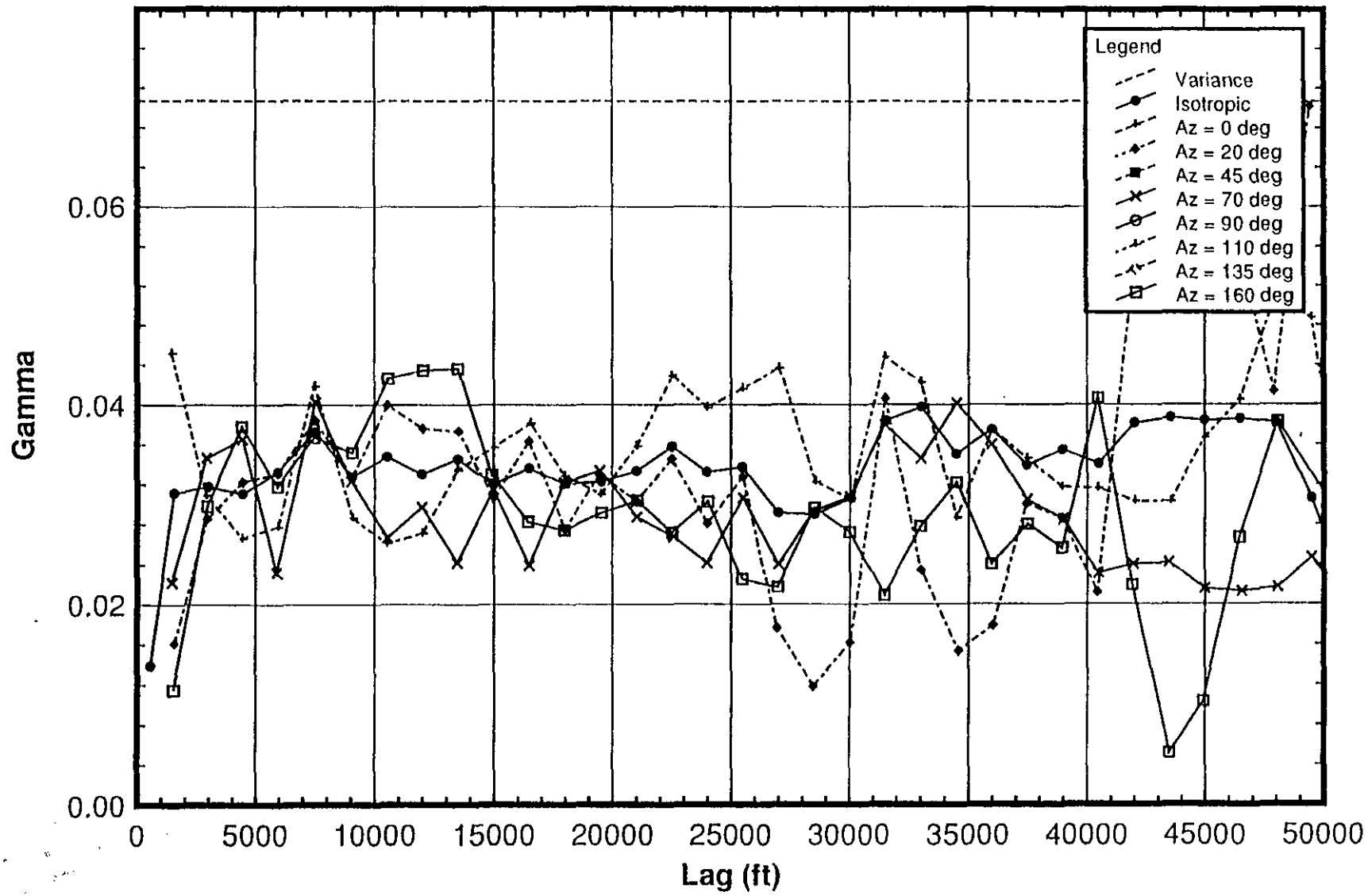

Figure 6-10b

Castile Brine Reservoirs: BRSM512.DAT

Pairwise Relative Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

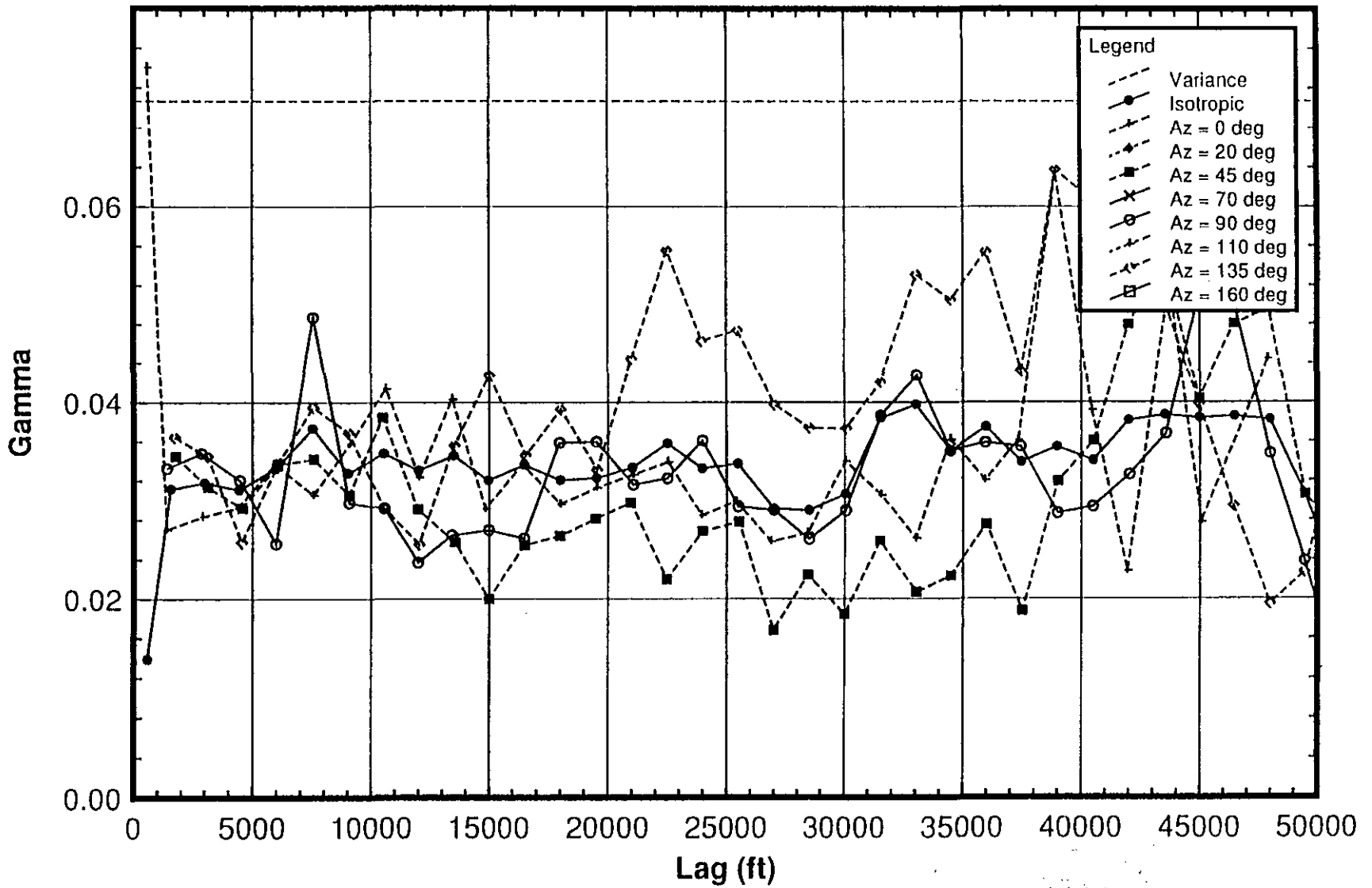

isotropic and two anisotropic sample semi-variograms. The "best" fits were made using the spherical theoretical variogram model, typically with zero nugget variance. The Gaussian theoretical variogram model allowed a non-zero nugget for the 160 degree azimuth sample semi-variogram. Figures 6-11abc show how the fitted spherical theoretical variograms match the sample semi-variograms.

It is important to note that the effective ranges of the various theoretical model types differ substantially. While the spherical model's range and effective range are equal, the effective range for the Gaussian model is √3 times its range. Similarly, multiply the exponential model's range by 3 to get its effective range. Only the effective ranges can be compared across model types.

Table 6-1
Fitted Model Variogram Parameters

Sample Semi-Variogram	Theoretical Model Type	Nugget	Range (ft)	C (= Sill - Nugget)
Azimuth 160 degrees	Spherical	0.00	5700	0.085
	Gaussian	0.01	2500	0.074
Azimuth 70 degrees	Spherical	0.00	2880	0.080
	Gaussian	0.01	1400	0.068
Isotropic	Spherical	0.01	2500	0.065
	Exponential	0.00	800	0.076

6.3.2 Kriging

Figure 6-12 shows the point-kriged conditional probability of a brine reservoir intercept for the WIPP site and the surrounding vicinity using the 160 - 70 degree azimuth model semi-variograms. The waste panel centers are indicated by four crosses located in the center left of the map at roughly state plane coordinates [667000, 499000]. It is immediately south of the isolated brine reservoir hit shown as a high probability zone in yellow and orange. Note the anisotropic orientation of the probability contours: they are aligned along an azimuth corresponding to the 160 degree sample semi-variogram orientation. The contours form an ellipse because the 70 degree azimuth range is roughly half the range for the 160 degree orientation. The were no differences observed, to three or more decimal places, in point-kriged intercept probabilities within the site area footprints when results from the normal and octant search methods were compared. Figure 6-13 shows the individual nodal kriged probabilities within the site's three areas of interest: waste panel, shafts and access, and the experimental area. The kriged probabilities show an increasing trend moving from south to north as you approach the observed brine intercept at the WIPP-12 borehole.

Within the waste panel area, however, the kriged probabilities range between

Figure 6-11a

Castile Fm. Brine Reservoir: BRSM5.DAT

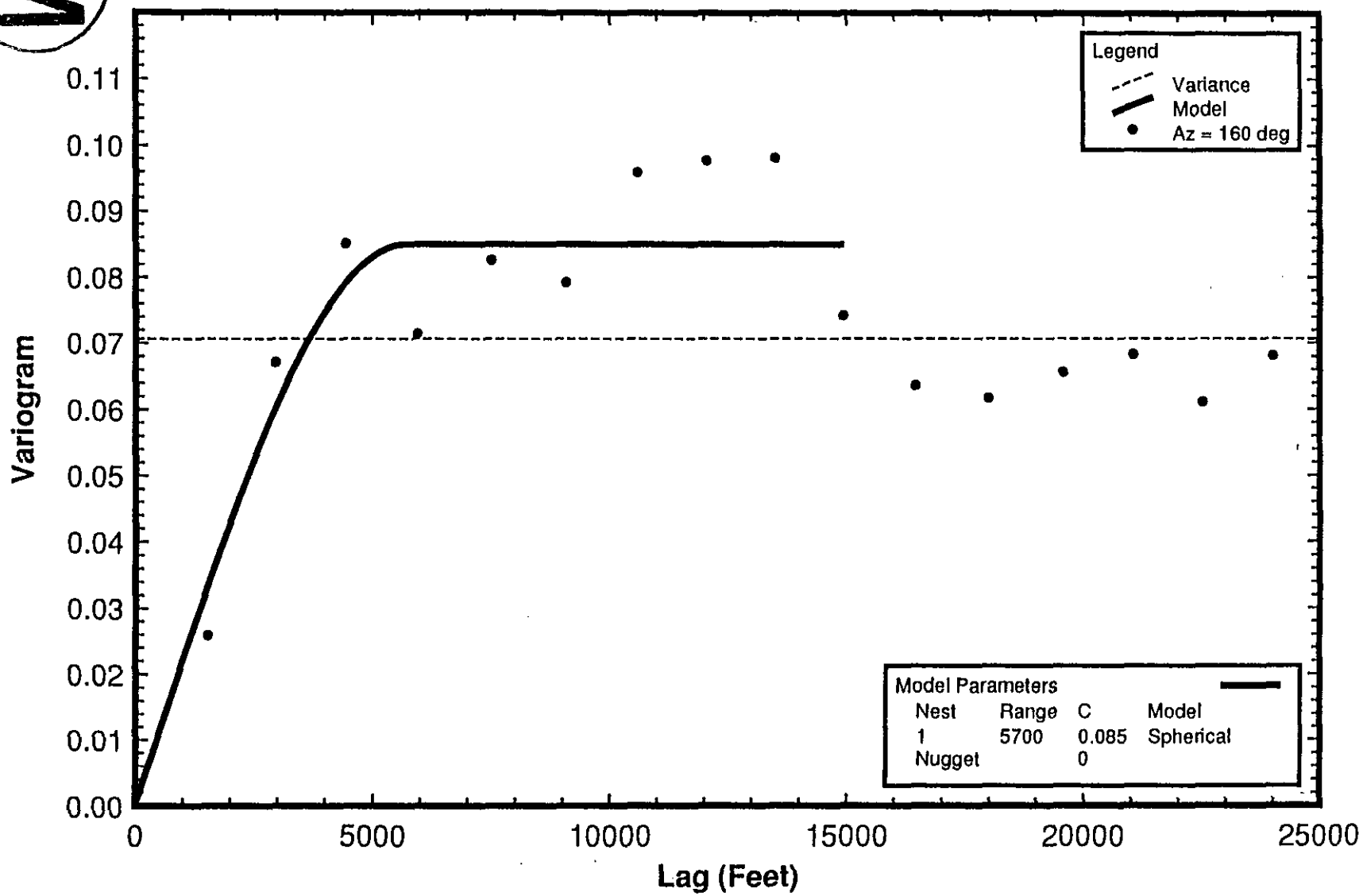

Castile Fm. Brine Reservoir: BRSM5.DAT

Figure 6-11b

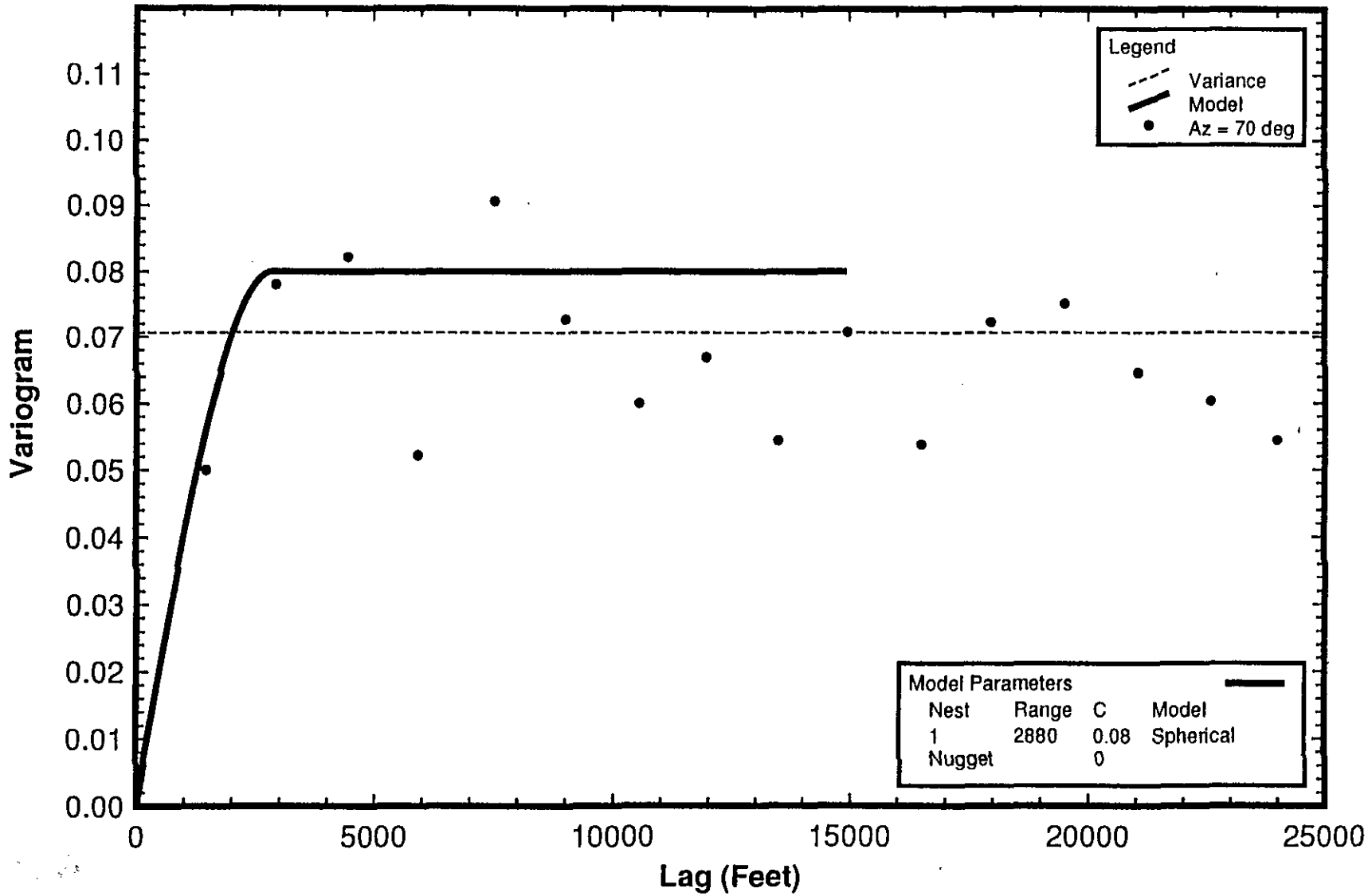

Figure 6-11c

Castile Fm. Brine Reservoir: BRSM5.DAT

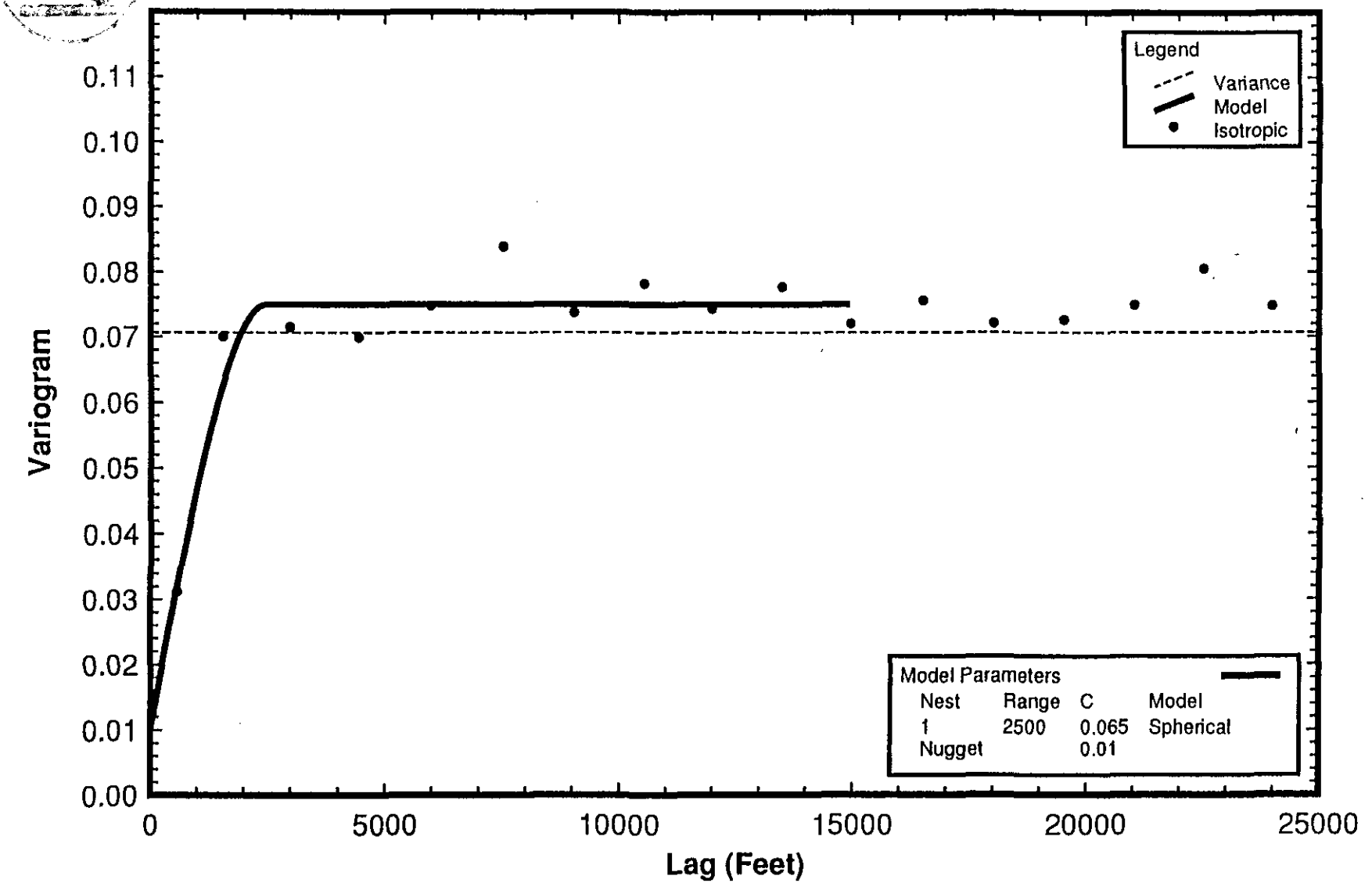

Figure 6-12

Probability of Encountering a Castile Brine Reservoir

Anisotropic Spherical Semi-Variogram: Azimuth = 160 deg; Range = 5700 ft; Nugget = 0

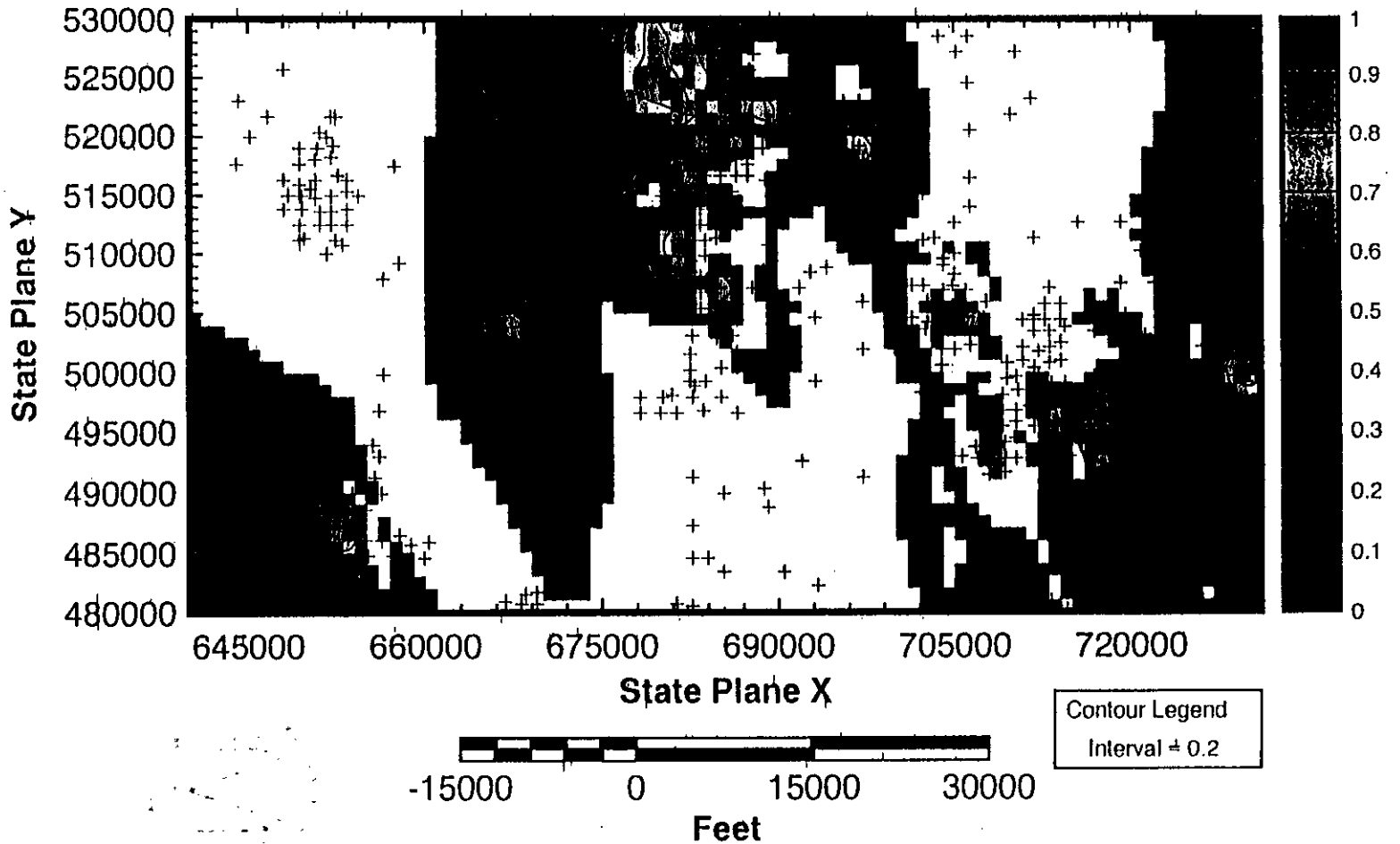

Figure 6-13

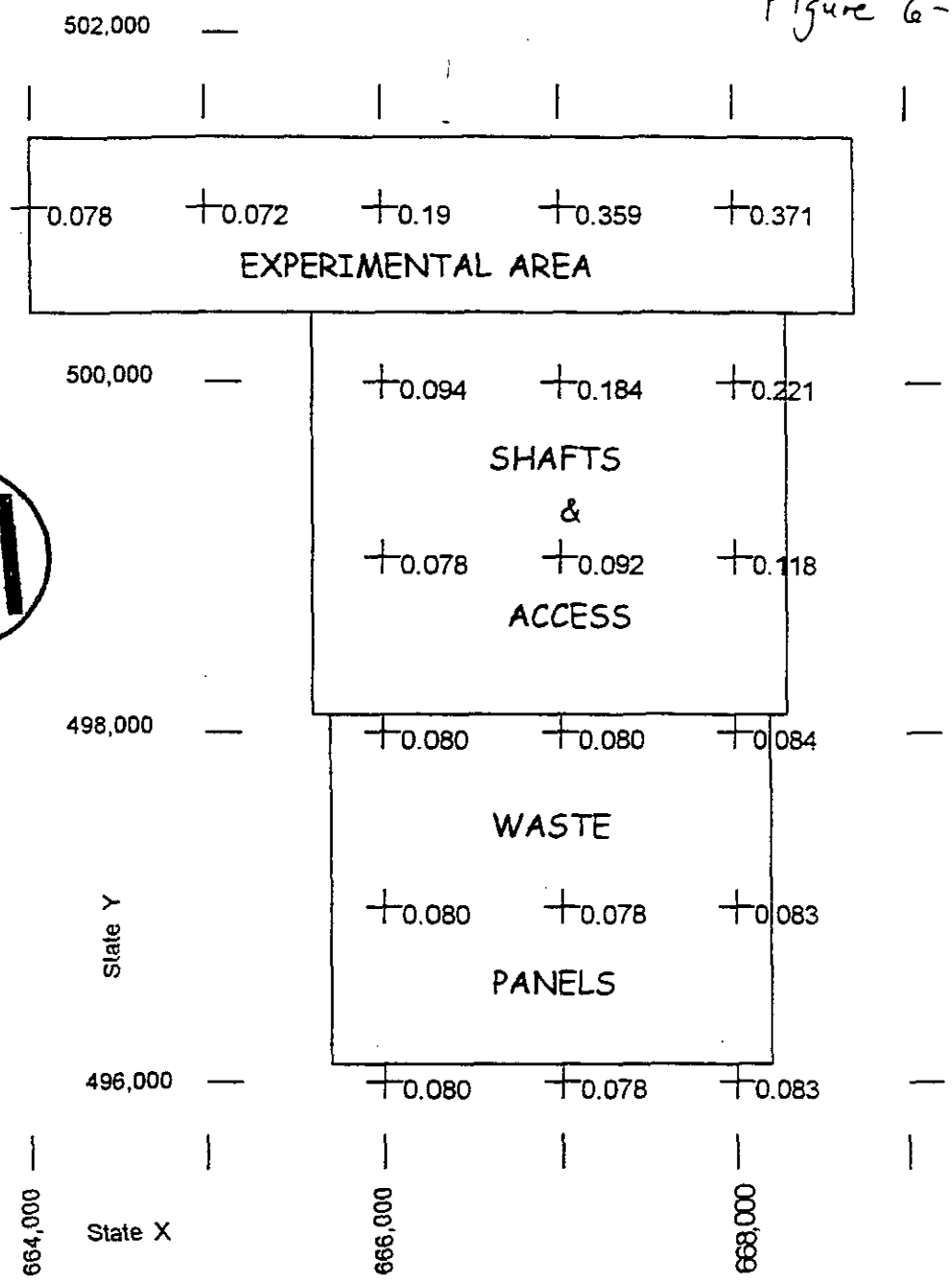

Nodal Probabilities of Intercepting Brine in Castile
(Anisotropic: az = 160; range 5700 ft, nugget = 0)

0.078 and 0.084. Each node is centered in a grid block which has dimensions of 1000 ft on each face. We calculated an areally-averaged probability of 0.080 for the entire waste panel site by weighting each point-kriged probability by the proportion of the waste panel area its grid block occupies. This weighted probability average is roughly equivalent to a 3x3 block-kriged probability if the block overlaid the waste panel area exactly.

The waste panel point-kriged probabilities calculated using the isotropic theoretical semi-variogram model were all less than 0.07. The lower probabilities were caused by the substantially shorter range (2500 vs 5700 ft). Figure 6-14 shows the point-kriged conditional probability map assuming the isotropic theoretical model semi-variogram.

6.3.3 Variations in Kriging Results

We examined partially the effects of "errors" in classification equivalent to either missing a brine intercept in a drillhole or believing pressurized brine is present when it is not. Drillholes AEC 7 was included in our first analyses because it was included in some lists as a potential brine reservoir. After further review of the basic data report (Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982), we have excluded it from the list (Table 4.1-2).

The kriging results were unchanged by the change in classification of borehole AEC 7 from an intercept to a no-intercept. The negligible impact of the classification error is attributable to the large distance (roughly 10 km), relative to the semi-variogram ranges observed, between the site and AEC 7's location. This suggests that classification errors must be considered with regard to the location of interest before their impact on the estimated probabilities can be understood. Individual misclassification errors will have continue to have a negligible impact on estimated intercept probabilities at the site unless those errors occur within one or two correlation lengths (ranges) of the site footprint and they are Type II errors. Type I errors are also known as false positives; Type II errors are known as false negatives. Thus, to create a significant change in the estimated site probabilities, one of the nearby no-intercept observations would have to reclassified as a brine intercept. It is unlikely such an error has occurred because most of the wells near the WIPP site were drilled by the Department of Energy, and conditions should have been quite favorable for detecting such Castile brine reservoirs. Our approach is robust with regard to individual misclassification errors located beyond several miles from the WIPP site.

Differences in the intercept probabilities estimated using UNCERT's GRID module and those estimated using the KT3B algorithm found in GSLIB (Deutsch and Journel, 1992) were 5% or less within the waste panel footprint. The GSLIB routine estimates for the shaft & access and experimental areas were less than

Figure 6-14

Probability of Encountering a Castile Brine Reservoir

Isotropic Spherical Semi-Variogram: Range = 2500 ft; Nugget = 0.01

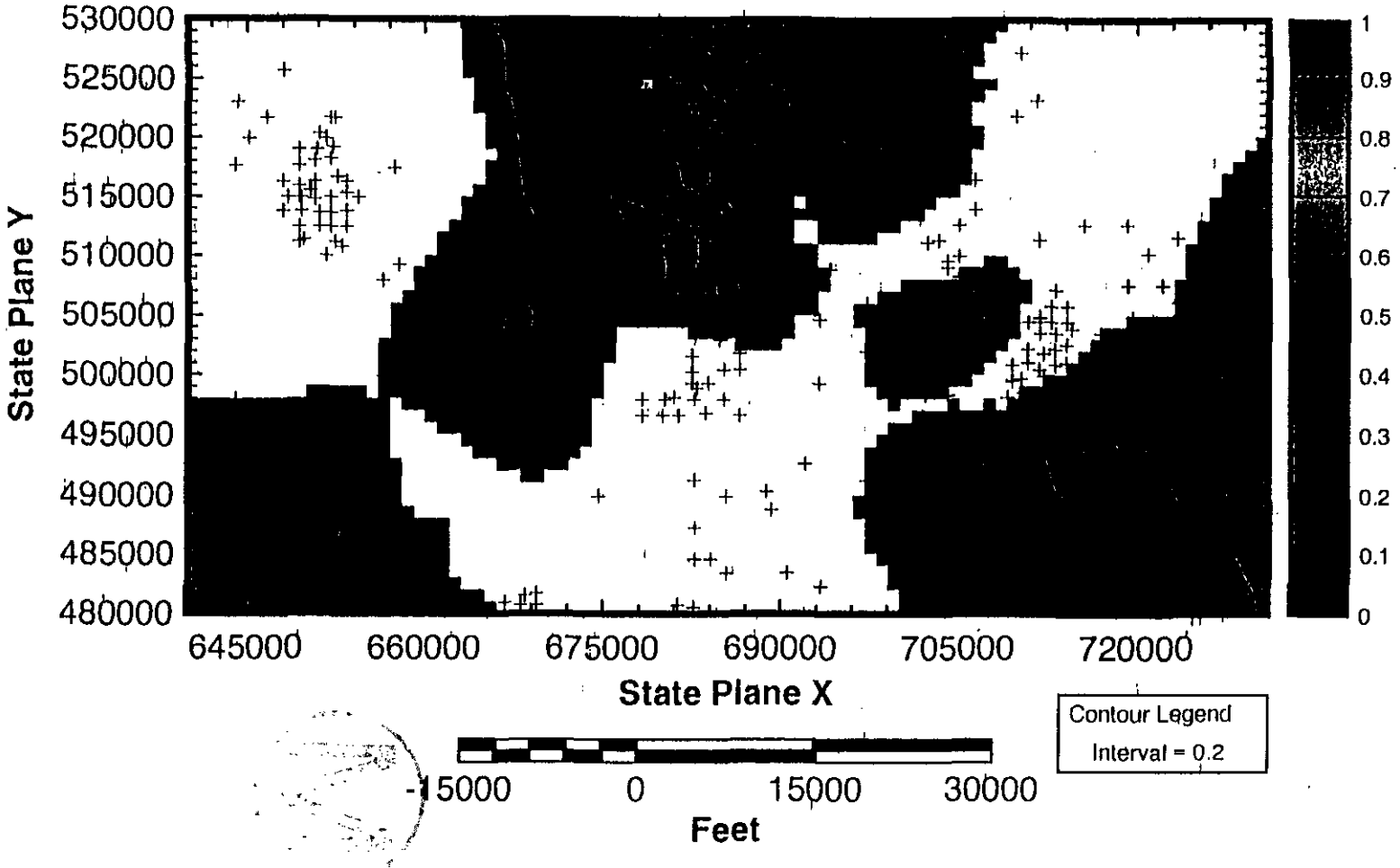

those calculated with GRID, which was based on the KT3B algorithm. This is attributed to the different search strategies utilized by the packages.

6.4 SUMMARY

- There is significant spatial correlation to the presence of brine reservoirs based on the available data. The physical cause of the correlation is, at present, unknown.
- The most significant correlation occurs along an azimuth of 160 degrees counterclockwise from north. It is anisotropic. This correlation structure does not appear to significantly influenced by data clustering. The main drilling trends are north-northeast.
- Another model of spatial correlation, along azimuth of 20 degrees, may be significant. However, it appears to be influenced by data clustering.
- The spatial correlation length scale of a brine reservoir hit, as described by the semi-variogram range, is relatively small: less than 6000 ft.
- The kriged point probability of a borehole encountering a brine reservoir in the Castile Formation within the waste panel footprint does not exceed 0.10, regardless of which spatial correlation model is chosen.
- The point-kriged probability estimates are insensitive to individual data classification errors located more than several miles from the WIPP site areas of concern.

7.0 GEOSTATISTICAL INVESTIGATION OF THE CASTILE FORMATION'S GEOLOGICAL STRUCTURE

7.1 INTRODUCTION

The objective of this investigation is to determine whether there are significant quantitative relationships between the brine reservoir intercepts and structural geologic data, particularly data that may be indicative of processes which created or influenced the observed brine intercept spatial distribution. Ideally, a geostatistical analysis will identify a random field's spatial correlation structure that is consistent with the processes which controlled the distribution of that random field. For example, the spatial variability of soil lead concentrations in fields surrounding a lead smelter should be consistent with the orientation of the prevailing winds and smelter operation patterns.

We believe brine reservoirs were caused by deformation of the uppermost units within the Castile Formation. We hypothesize that structural data, such as the thickness of these units, can provide insight into the amount and location of deformation. We began testing our hypothesis by 1) estimating the spatial variability of the structural data to compare with the brine intercept results from section 6.0 and 2) using statistics to examine potential interrelationships between geological structure and brine intercept data. Given our assumptions that structural data and brine reservoirs are functions of the amount of deformation in the upper Castile, any structural data similarities to the correlation scale and direction observed for brine intercepts adds greater weight to our conclusions about brine reservoir spatial variability. This investigation could potentially provide significant improvements in predicting the conditional probability of a brine reservoir intercept within the WIPP site.

For example, Figure 6-1 shows there are relatively few boreholes within 10000 ft of the WIPP site with information about brine intercepts/no-intercepts. There are, however, numerous boreholes across the site with information about the geologic structure of the Salado and Rustler Formations. If a strong association between brine intercepts/no-intercepts and geological structure data can be determined, then we could use the cokriging approach to get better-constrained estimates of the conditional probability of a Castile brine reservoir intercept within the site than can be estimated using brine hit/miss data alone. Cokriging extends the kriging algorithms by conditioning prediction of a random field at unsampled locations (e.g., brine hit probability) on observations of the original and a second, related, random field (e.g., brine hits/misses and amount of deformation). It also assumes knowledge of the random fields' autocovariance and cross-covariance functions, which are typically estimated from sample semi-variograms and cross-semivariograms. Cokriging can only improve on a standard kriging algorithm when observation locations of the second random field are more numerous within the area of interest than those for the first

random field. At the WIPP site, this would require a strong relationship between brine hits and structural information for units above the Castile Formation, such as Marker Bed 124, since there are many more different observation locations for these units than for units within the Castile across the WIPP site.

We have some doubts whether the cokriging approach will work for the specific case of brine intercepts/no-intercepts and structural data since the cross-covariance (or cross-semivariogram) for each lag only receives a positive contribution from pairs which include brine intercepts (see Eqns 7-1 and 7-2 below). This suggests that the estimated cross-covariance is then a function of the ratio of brine intercepts to brine no-intercepts. However, cokriging may still provide significant improvements in the conditional probability estimates from Section 6 because it, like standard kriging and unlike many other interpolation algorithms, honors the data exactly.

We focused on the thickness between the top of the Bell Canyon and the base of the Cowden, which immediately overlies the presumed location of the brine reservoirs within the Castile's uppermost anhydrite (Anhydrite III) and halite (Halite II) zones. Measurements of this thickness, called here the Cowden isopach of IsoCowden, were made using geophysical logs for 352 boreholes. The dataset differs slightly from that used for geostatistical analysis of brine reservoir intercepts (Section 6.0). We estimated the Cowden isopach for five brine intercept boreholes and several drillholes without intercepts using information from nearby boreholes (section 5.0; Appendix E). As before, the 352 wells are distributed across roughly 645 km^2 (252 mi^2) of Delaware Basin. The WIPP site is roughly centered within this area.

In addition to estimating the spatial variability of the Cowden isopach, we examined the spatial cross-correlation between the Cowden isopach and brine intercept/no-intercepts. The cross-covariance between two random fields, Y and Z, is described by $C_{Y(\mathbf{x}),Z(\mathbf{x}+\mathbf{h})}$, where E is the expectation operator, **x** is the location vector for an observation, and **h** is the distance between it and another observation:

$$C_{Y(\mathbf{x}),Z(\mathbf{x}+\mathbf{h})} = E\{[Y(\mathbf{x}) - E\{Y(\mathbf{x})\}][Z(\mathbf{x}+\mathbf{h}) - E\{Z(\mathbf{x}+\mathbf{h})\}]\} \qquad (Eqn.7-1)$$

The cross-semivariogram, $\gamma_C(\mathbf{h})$, is the variance of the difference between observations of two variables separated by a distance (or lag) **h**:

$$\gamma_C(\mathbf{h}) = \frac{Var\{Z(\mathbf{x}-\mathbf{h}) - Y(\mathbf{x})\}}{2} \qquad (Eqn.\ 7.2)$$

7.2 METHODS

7.2.1 Exploratory Data Analysis

We examined differences in Cowden isopach measurements for two categories: boreholes with brine intercepts and boreholes with brine no-intercepts. Descriptive statistics, such as sample mean, standard deviation, skewness, etc., and sample cumulative frequency distributions for the two categories were compared.

Descriptive statistics and sample cumulative frequency distributions of Cowden isopach measurements were calculated for boreholes with and without brine intercepts. Graphs and calculations were made using the Excel spreadsheet program, version 4, from Microsoft and MathSoft's MathCad 6.0+ mathematical analysis program.

7.2.2 Variography

We quantified Cowden isopach spatial correlation through calculation of sample semi-variograms. We tested our estimates for sensitivity to data clustering and extreme values (outliers) by computing sample semi-variograms for subsets of the data and by examining more robust measures such as the semi-rodogram, general relative semi-variogram, and non-ergodic covariance function (see Section 6.1). Values for the range, sill, and nugget variance are determined by fitting a theoretical semi-variogram model to the sample semi-variogram.

7.2.1.1 Sample Semi-Variogram Calculation

Sample semi-variograms are calculated according to Eqn. 6-4 for the isotropic (omni-directional) case and for a range of anisotropic geometric directions: azimuths 0, 20, 45, 70, 90, 110, 135, and 160 degrees measured clockwise from a 0 degree north. All variographic calculations were carried out using the VARIO module of the public domain software package UNCERT (Wingle et al, 1994), available from the Colorado School of Mines in Golden, CO.

Lag spacing was set at 1500 ft to match the lag spacings from the analysis of brine intercept/no-intercept spatial variability. The maximum search distance, directional bandwidth, and horizontal half-angle were set to their maximum values of 150000 ft, 150000 ft and 90 degrees for the isotropic sample semi-variogram. The data were sufficient in number to restrict the horizontal half-angle to 15 degrees, maximum search distance to 150000 ft, and the directional bandwidth to 10000 ft for all of the anisotropic sample semi-variograms.

Sample semi-variograms were judged significant if they exhibited a reasonably monotonic increasing structure within the first 25% of the lag classes with

adequate numbers of pairs within each lag class. Theoretical semi-variogram model parameters (range, sill, and nugget variance) were estimated for selected sample semi-variograms.

7.2.1.2 Sample Semi-Variogram Robustness

We tested the Cowden isopach sample semi-variogram robustness to clustering using two different approaches. The first compares sample semi-variograms from the entire data set with those computed for two non-overlapping data subsets which have relatively uniform spatial distributions of boreholes and possess adequate numbers of brine reservoir intercepts. Subset 1 contains 80 boreholes, 15 of which had brine intercepts. Subset 2 holds 93 boreholes, 9 of which had evidence of brine intercepts. These two subsets possess both a relatively uniform distribution of boreholes and sufficient numbers of brine intercepts to generate adequate numbers of observation pairs for each lag. Correlation structures which appeared significant in each of the data subsets and in the complete data set were judged to be independent of the large scale data clustering evident in Figure 6-3.

The second approach utilizes alternative measures of spatial continuity which are less sensitive to data clustering. The semi-rodogram and general and pairwise relative semi-variograms are typically less vulnerable to clustering because they normalize the semi-variogram value for each lag class by the squared mean of the data and the squared average of the paired values; Eqn. 6-5 defines the semi-rodogram and Eqn. 7-3 defines the general relative semi-variogram. We calculated sample semi-rodograms, general relative semi-variograms, and non-ergodic covariances for each data subset, their union, and the entire data set.

$$\gamma_{GR}(\boldsymbol{h}) = \frac{Var\{Z(\boldsymbol{x}-\boldsymbol{h}) - Z(\boldsymbol{x})\}}{\left[\frac{m_t m_h}{2}\right]^2} \qquad (Eqn.\ 7\text{-}3)$$

where m_t and m_h are the means of the tails and heads of each pair within a lag.

7.2.1.3 Sample Cross-Semivariogram Estimation

We estimated the sample cross-semivariograms for the brine intercept/no-intercept and Cowden isopach using

$$\gamma_C(\boldsymbol{h}) = \frac{1}{2N(\boldsymbol{h})}\sum_{i=1}^{N(\boldsymbol{h})}(z_i - y_i)^2 \qquad (Eqn.\ 7\text{-}4)$$

Sample cross-semivariograms were determined for the union of Subsets 1 and 2 for the isotropic case and along the same eight sample semi-variogram directions. Calculations were made with the GAM2V routine from the GSLIB library (Deutsch and Journel, 1992) because the Sun OS version of UNCERT's VARIO module does not yet support cross-semivariogram estimation.

7.2.1.3 Theoretical Variogram Model Fitting

We estimated range, sill, and nugget variance using UNCERT's VARIOFIT module for only a few selected sample semi-variograms because of a time limitation and because we did not need to krige Cowden isopach values. We estimated ranges by eye for the remaining sample semi-variograms, assuming a spherical theoretical semi-variogram model, to enable quick comparison with the ranges estimated for the brine intercept/no-intercept variable.

7.3 RESULTS AND DISCUSSION

7.3.1 Exploratory Data Analysis

Table 7-1 summarizes the descriptive statistics for Cowden isopach categorized by whether a brine intercept was observed (or not) in the borehole. Note that the mean, minimum, and maximum for the brine hit group are all larger than those for the brine miss group. Isopach standard deviations relatively close (coefficient of variation is 10% for each group). The brine intercept group is skewed to larger isopach values and is significantly kurtic, i.e., its probability density function (histogram) is more flat than peaked. In contrast, the brine no-intercept group shows relatively little skewness and kurtosis.

Table 7-1
Summary Statistics for Cowden Isopach by Brine Intercept/No-Intercept

Statistic	Brine Intercepts	Brine No-Intercepts
Mean	1905.77	1760.16
Standard Error	37.49	9.99
Median	1891.00	1726.00
Mode	1925.00	1660.00
Standard Deviation	191.16	180.31
Variance	36541.94	32511.90
Kurtosis	5.97	-0.02
Skewness	2.01	0.55
Range	919	944
Minimum	1677	1373
Maximum	2596	2317
Sum	49550	573812
Count	26	326

Figure 7-1 presents the sample cumulative relative frequency distributions for the two groups. Figure 7-2 depicts sample histograms for each group. Comparison of the intercept and no-intercept curves suggests there is a minimum Cowden isopach value of 1650 to 1680 ft below which brine reservoirs are not observed.

We attempted to fit a Poisson distribution to the sample relative frequency distribution for the brine intercepts. Results are shown in Figure 7-3. If we can assume the Cowden isopach for brine intercepts is governed by a Poisson process, then it is highly unlikely that brine intercepts will be observed when the Cowden isopach is less than 1670 ft. We attempted to fit several other distributions but met with no success.

7.3.2 Variography

7.3.2.1 Sample Semi-Variogram Calculations

Figures 7-4ab and 7-5ab show the sample semi-variograms for the first and second data subsets, which occupy the same locations used in Section 6.2. Appendix J contains printouts of the calculation log files. The results are less clear-cut than those presented for the brine intercept/no-intercept binary variable in Section 6.3. Locally-varying trends in Cowden isopach values keep both isotropic and anisotropic sample semi-variograms from leveling out near the sill. See, for example, the sample semi-variograms for azimuths 0, 20, 45, and 70 degrees, as well as the isotropic case, for Subset 1 (Figures 7-4ab). These thickening-thinning trends can be seen in Figure 5.3-3, which depicts the top of Bell Canyon to base of Cowden isopach contours. Note the especially strong north-south trend in isopach value across the center of the map. The sample semi-variograms for azimuths 90, 100, and 135 degrees appear to be mostly noise. While some evidence for trends in the sample semi-variograms for Subset 2 can be observed (e.g., azimuths 0 and 45 degrees), it is not as common as in the Subset 1 results. This is most likely attributable to the lack of strong trends within that data set (see Figure 5.3-3).

The sample semi-variogram for azimuth 160 degrees suggests the presence of a nested correlation structure under both data subsets. The small-scale correlation length (range) appears to fall between 4000 and 5000 ft. The azimuth 0, 20, and 135 degree sample semi-variograms for Subset 2 and the 0 degree azimuth sample semi-variogram for Subset 1 also indicate such a small-scale correlation structure. The large-scale correlation length may reach its sill somewhere near 15000 ft; however, this large-scale structure may be an artifact of the small number of pairs found within those largest lags.

Figures 7-6ab present the sample semi-variograms for the complete data set.

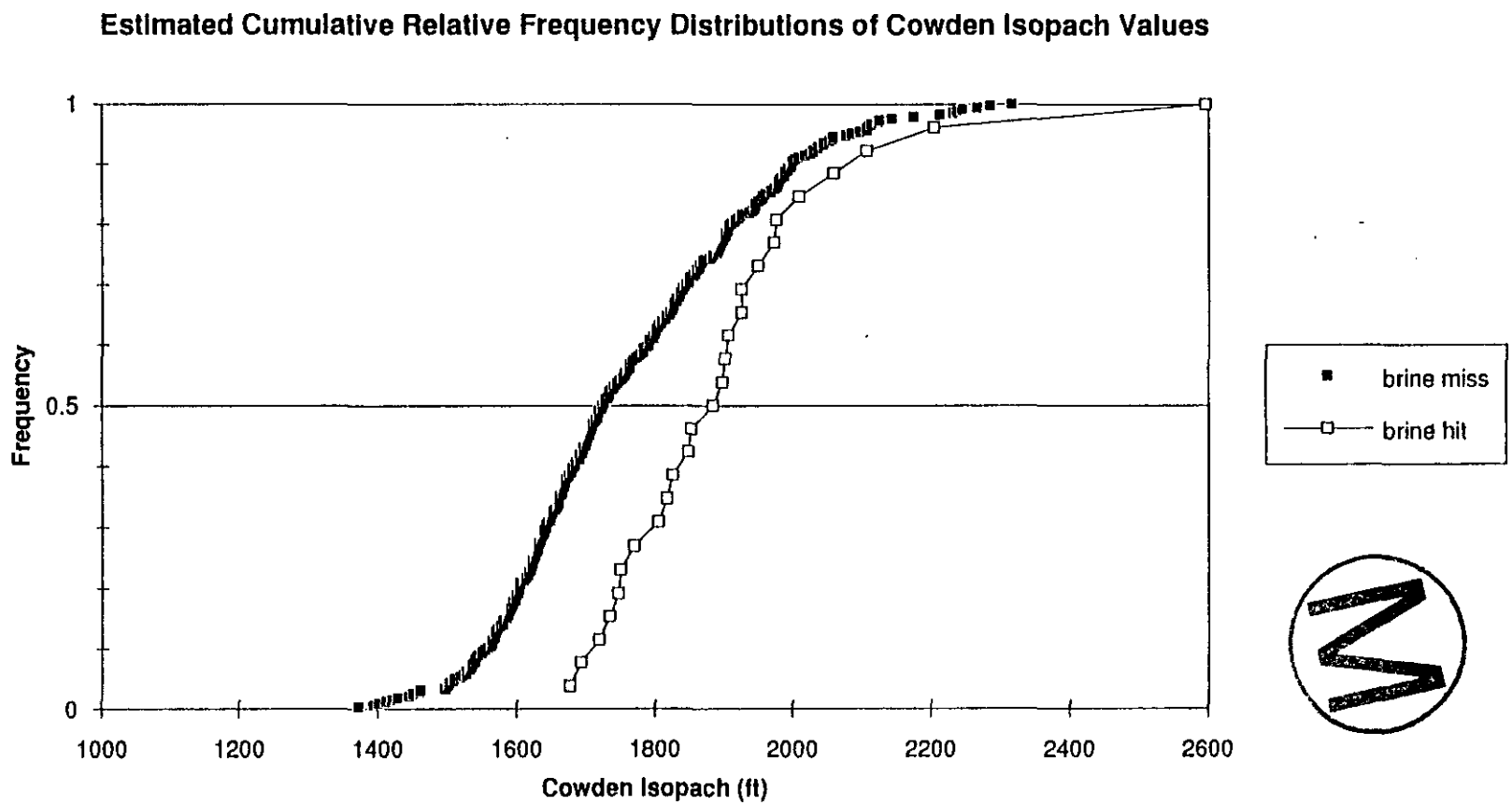
Estimated Cumulative Relative Frequency Distributions of Cowden Isopach Values
Frequency
1
0.5
0
1000
1200
1400
1600
1800
2000
2200
2400
2600
Cowden Isopach (ft)
brine miss
brine hit

Sample Relative Frequency Distributions

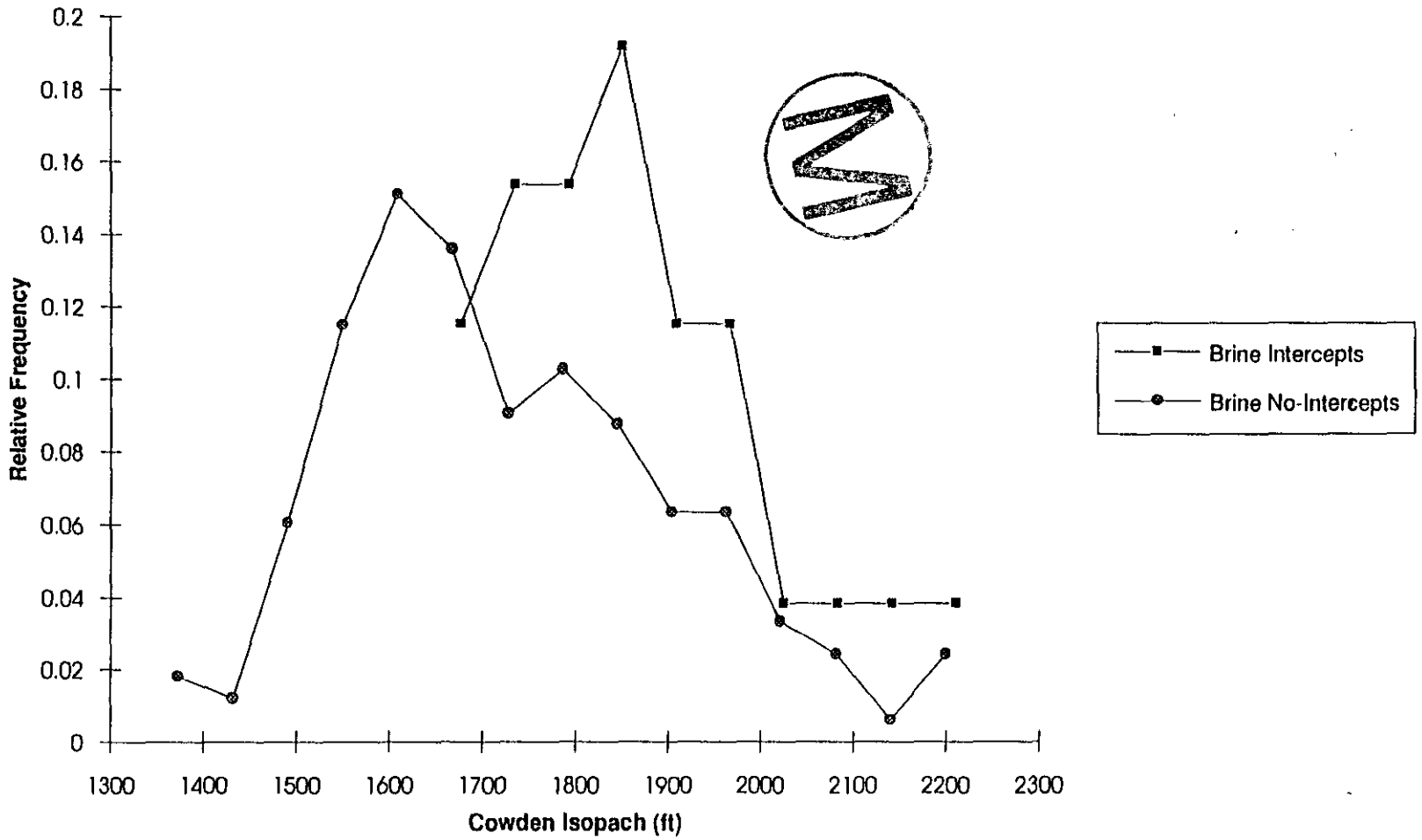

FIGURE 7-3

Estimated Cowden Isopach Probability Density Function (PDF) vs. Poisson PDF

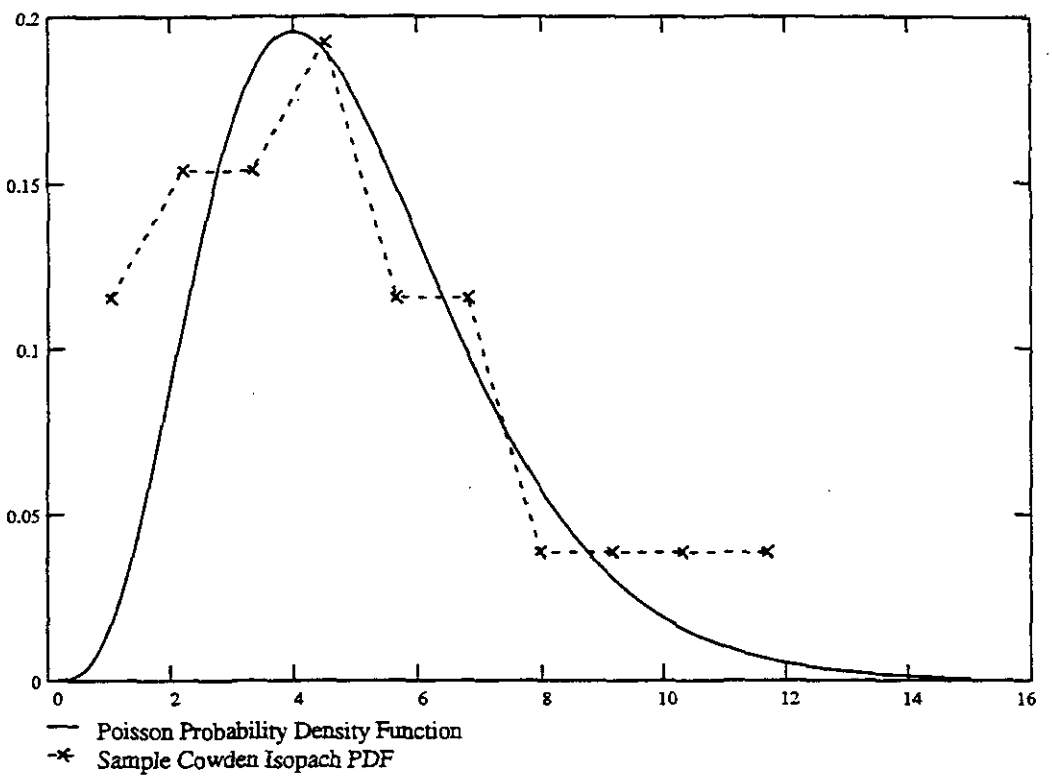

Figure 7-4a

Castile Fm. Isopach Data for Subset 1: isocow

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

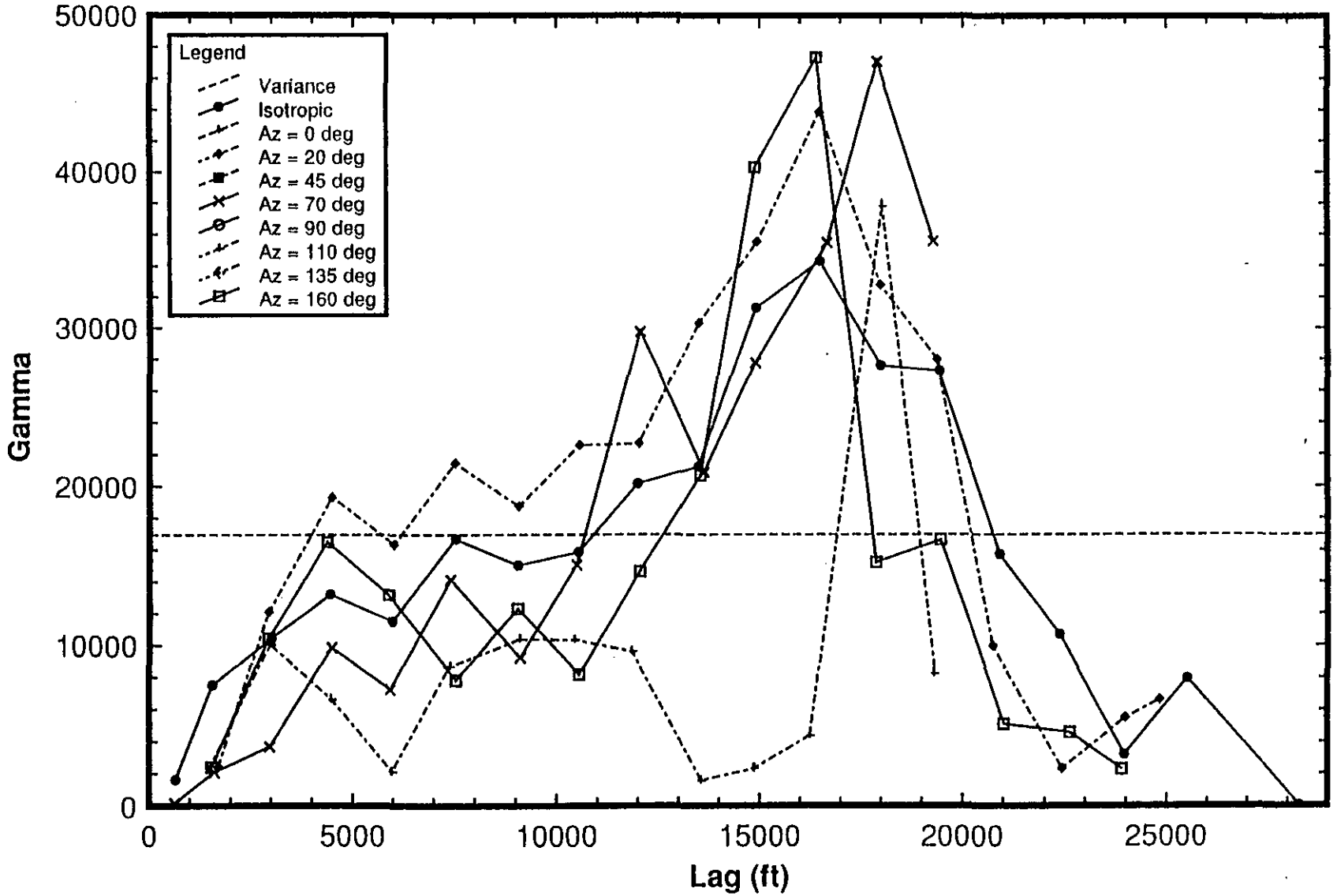

Figure 7-.5

Castile Fm. Isopach Data for Subset 1: isocow

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

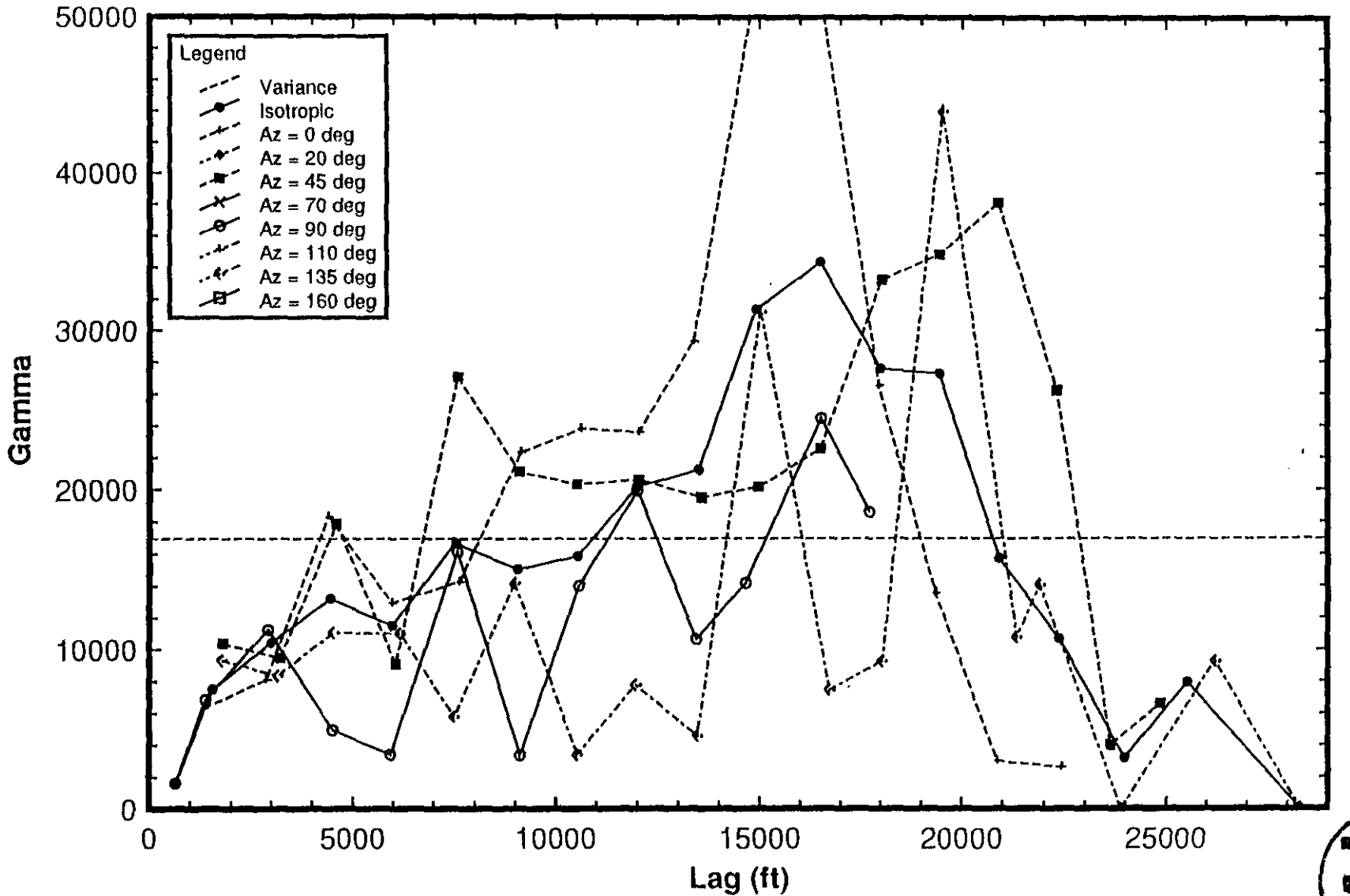

Figure 7-29

Castile Fm. Isopach Data for Subset 2: isocow

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

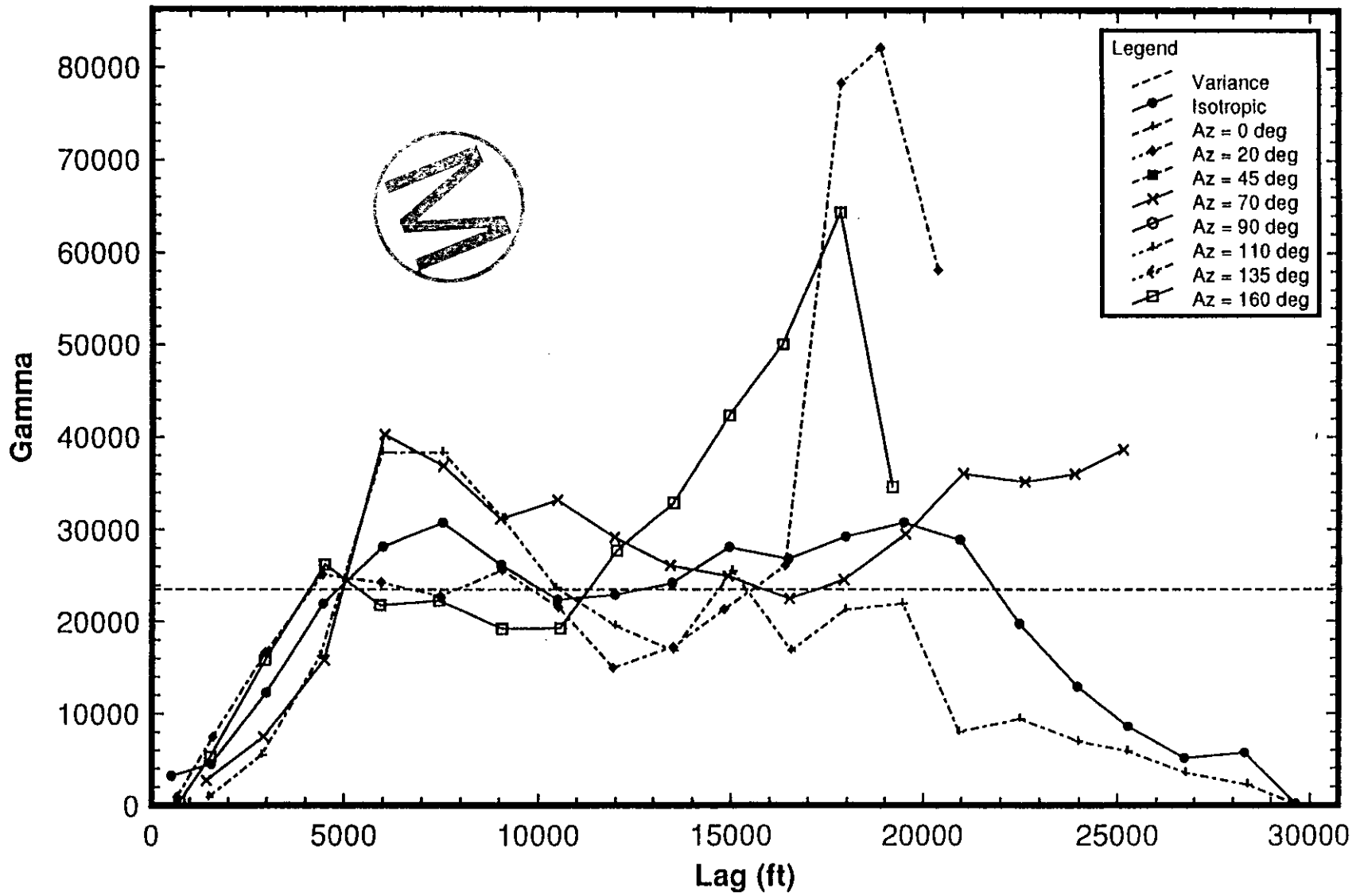

Figure 4-5b

Castile Fm. Isopach Data for Subset 2: isocow

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

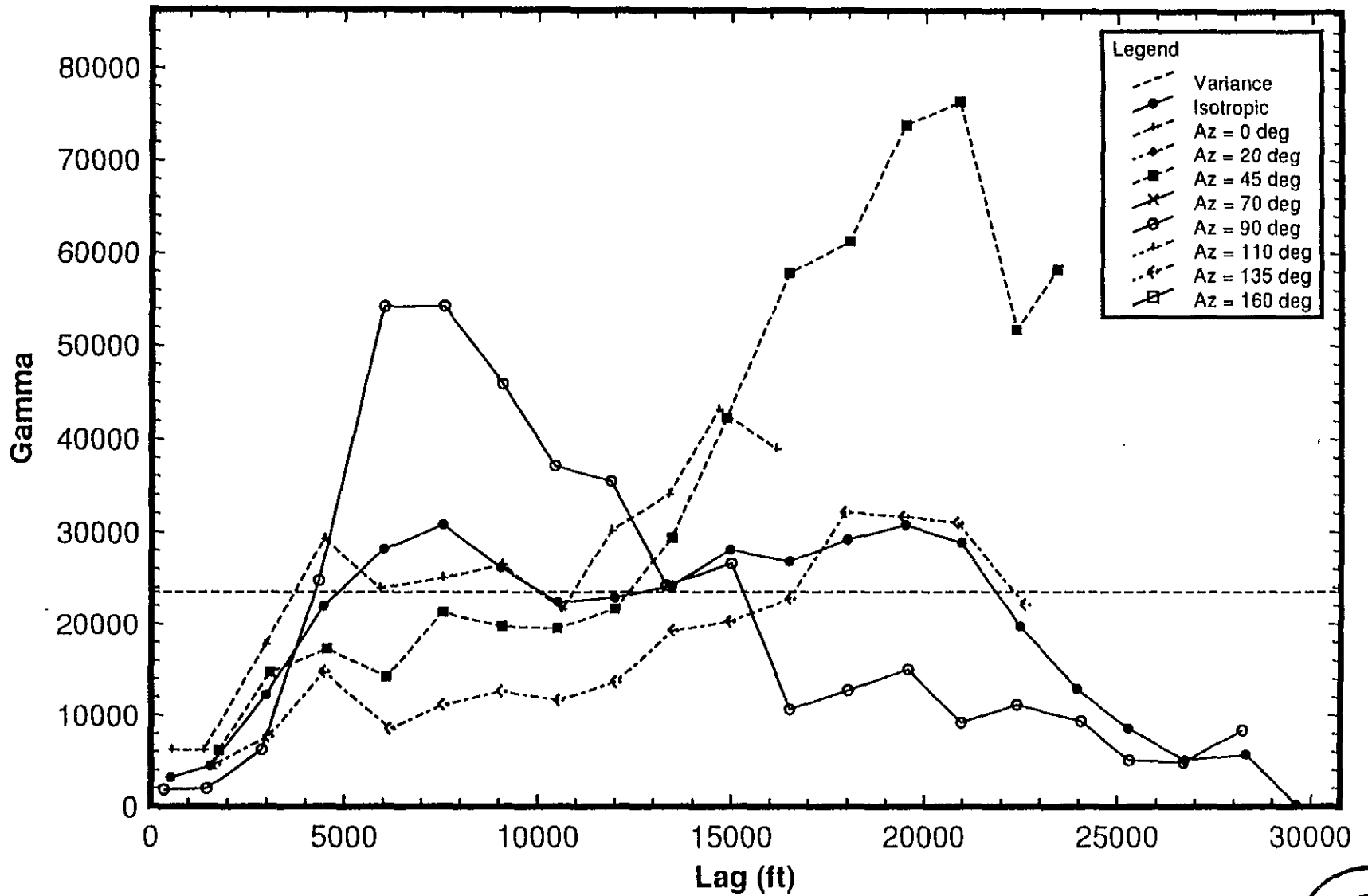

Figure 7-6

Castile Fm. Isopach Data: icowr3

Semi-Variogram: Lag =1500 ft; BW = 10000; HA = 15

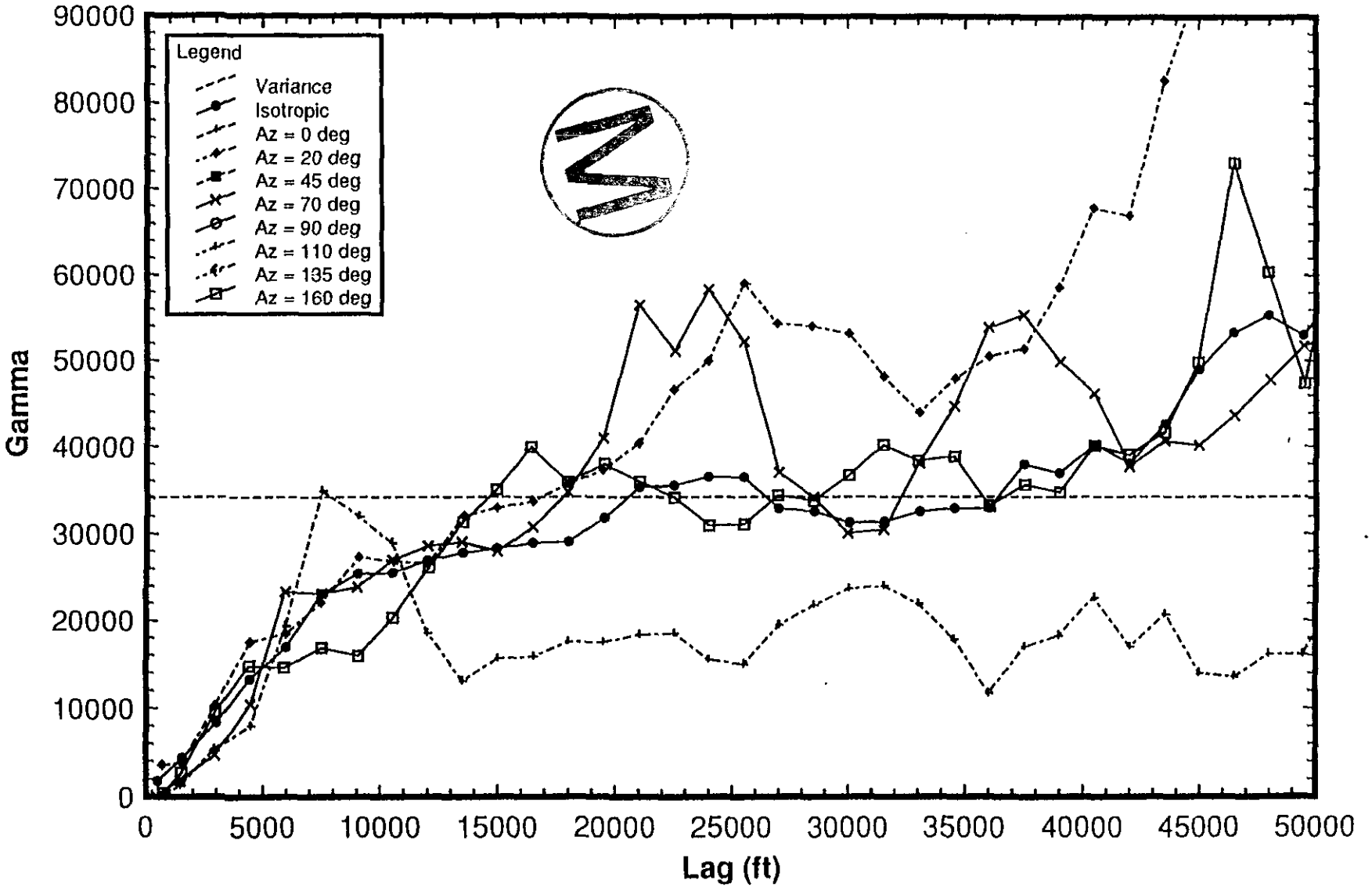

Figure 7-6b

Castile Fm. Isopach Data: icowr3

Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

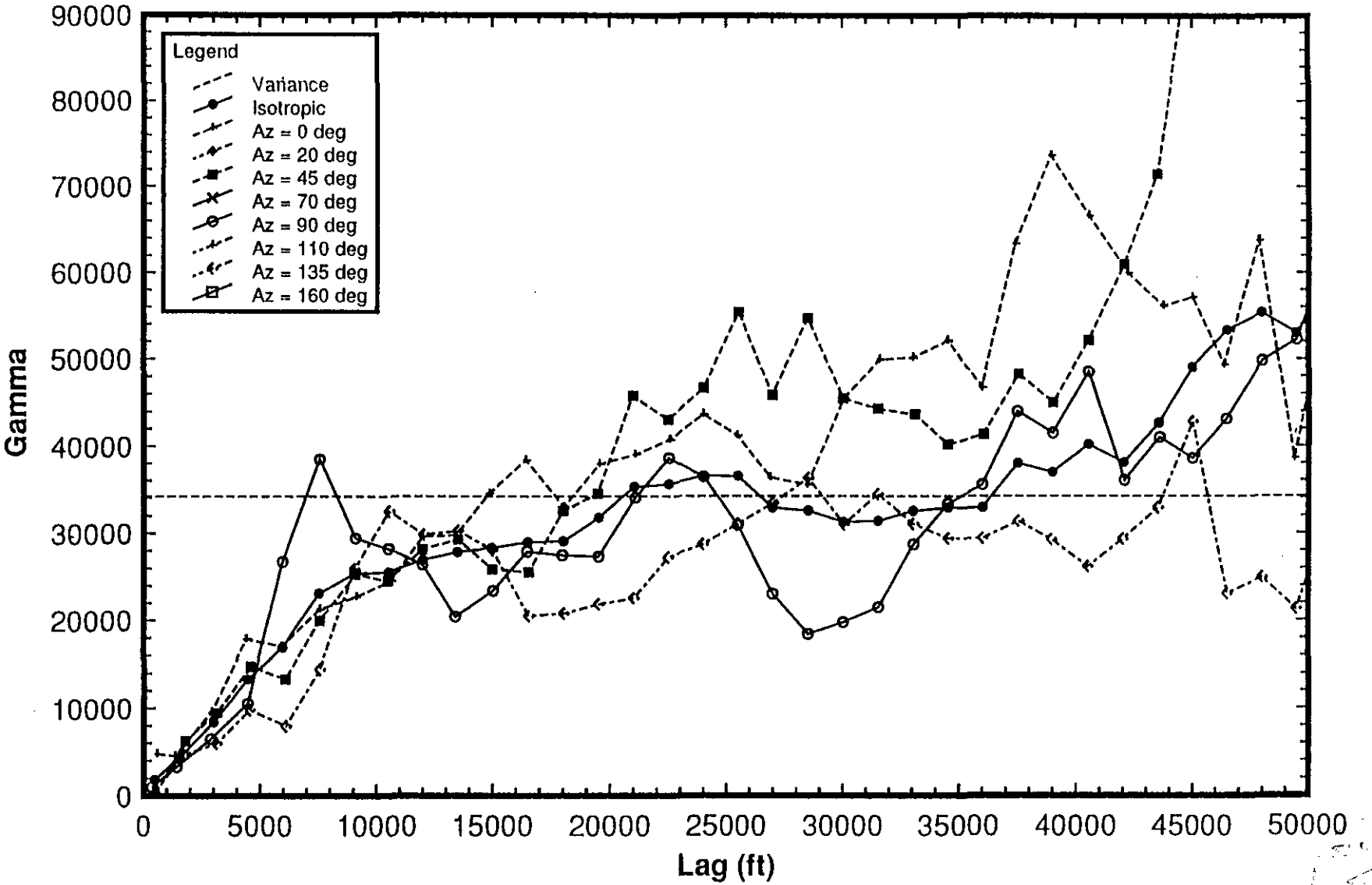

Trends in isopach values are evident in the isotropic and azimuth 0, 20, 45, and 70 degree anisotropic sample semi-variograms. Small-scale correlation structures with effective ranges varying between 5000 and 6000 ft are shown most clearly in the azimuth 160, 135, and 70 degree sample semi-variograms. The 0, 20, and 45 degree directional semi-variograms also appear to possess this small-scale structure. Additional analyses indicated that the small-scale correlation features similar to that found in the azimuth 135 and 160 degree directions were observable along azimuths 140, 145, 150, and 155 degrees for the complete data set. This observation is by the orientation of the Cowden isopach maximum shown in Figure 5.3-3, which varies between azimuths 135 and 160 degrees.

Figures 7-6ab also demonstrate a significant large-scale correlation structure which has an effective range between roughly 10000 ft (for azimuth 135 deg.) and 18000 to 20000 ft (azimuths 70 and 160 deg.). The distance separating Subset 1 from Subset 2 closely corresponds to the upper end of the range estimate, possibly indicating the sample semi-variogram values are controlled by data clustering. However, the large-scale correlation structure is observable in the sample general relative semi-variograms for the same directions (see Figures 7-7ab), suggesting that data clustering is not the cause. Plots of the non-ergodic covariance and the semi-rodograms add support to this conclusion. The remaining directional sample semi-variograms demonstrate more trend effects than large-scale spatial correlation at larger lags.

7.3.2.2 Sample Cross-Semivariogram Calculation

Figures 7-8ab show the estimated cross-semivariograms for a combination of data Subsets 1 and 2. As above, there is consistent evidence for a small-scale correlation structure with an effective range of 5000 to 9000 ft (azimuths 0, 20, 70, 135, and 160 deg.). Several of the directional sample cross-semivariograms indicate the possibility of a large-scale correlation structure with an effective range of roughly 20000 ft. Although we have doubts about the impact of computing a cross-semivariogram using a binary variable, these results are consistent with the correlation structures observed along the azimuth 160 degree sample semi-variograms.

If there is a minimum Cowden isopach thickness for brine reservoirs and if the observed minimum is close to the actual threshold, it may be possible to define an indicator variable for the threshold Cowden isopach and then cokrige the brine intercept/no-intercept binary variable with the indicator variable.

7.3.2.3 Theoretical Semi-Variogram Model Fitting

Figures 7-9ab show the fitted theoretical variograms for the small-scale correlation structures observed in the azimuth 160 deg. sample semi-variograms

Figure 7-19

Castile Fm. Isopach Data: icowr3

Gen. Relative Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

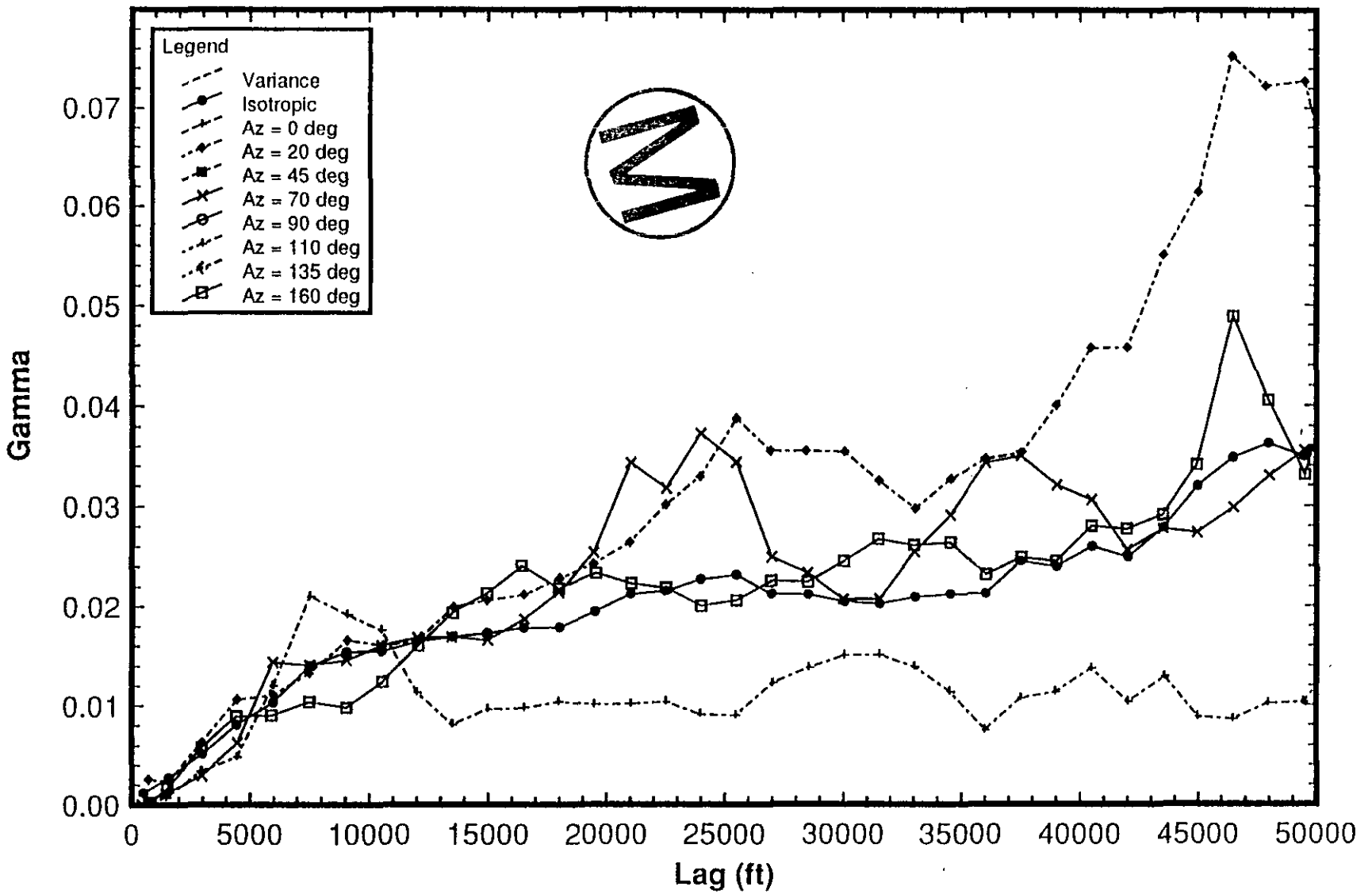

Figure 7-7b

Castile Fm. Isopach Data: icowr3

Gen. Relative Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

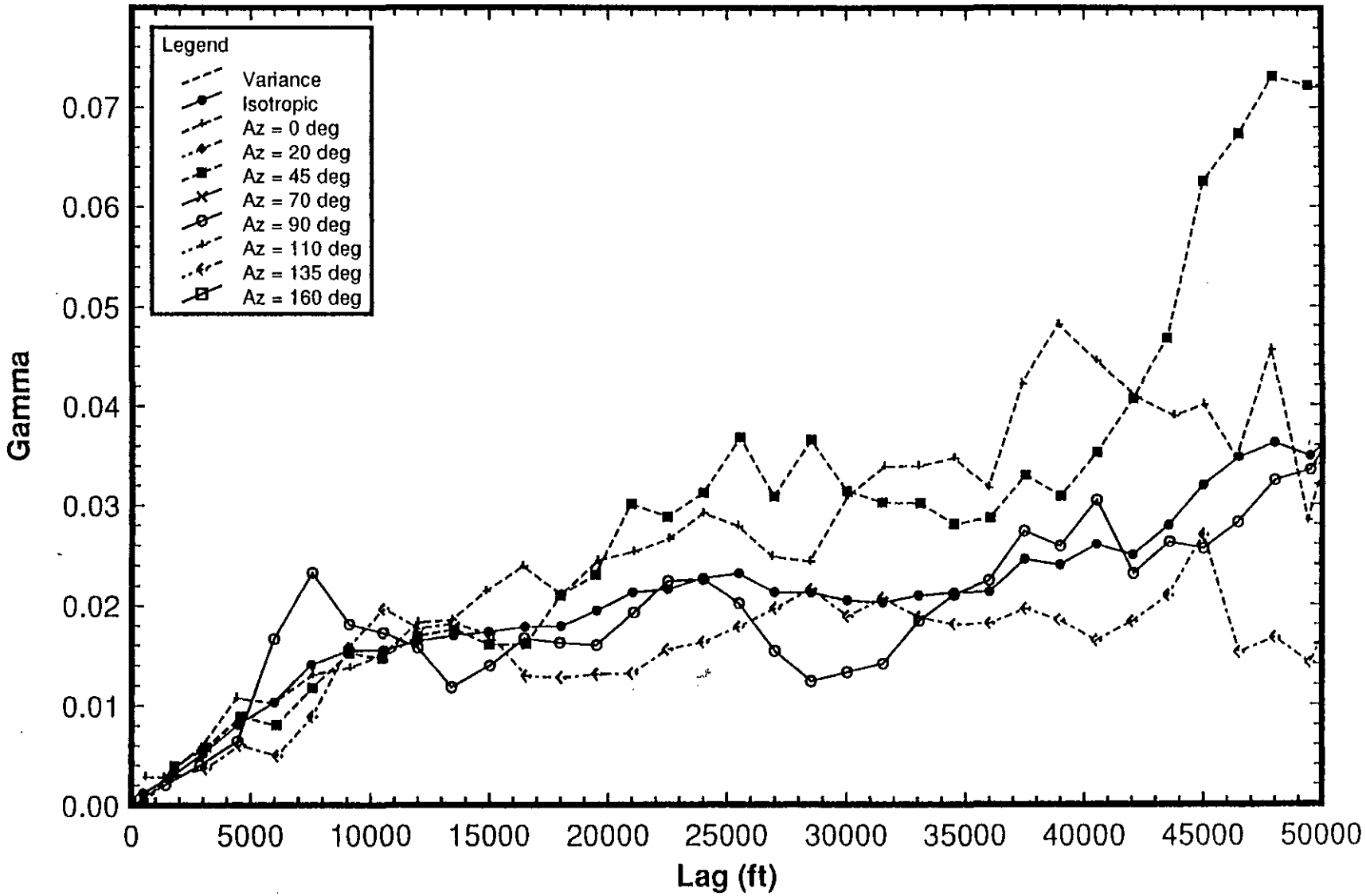

Figure 7-76

Castile Fm. Isopach Data: icowr3

Gen. Relative Semi-Variogram: Lag = 1500 ft; BW = 10000; HA = 15

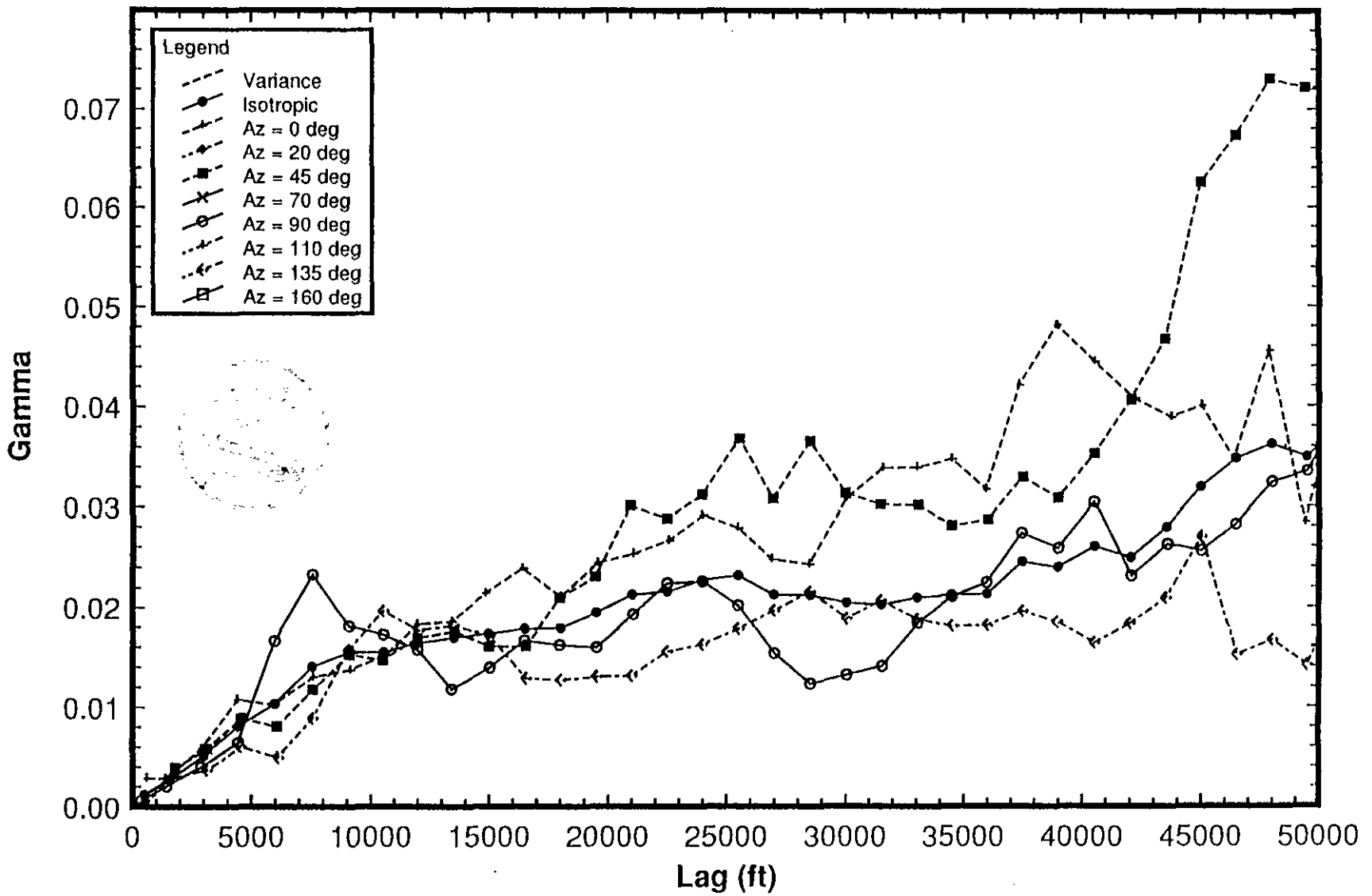

Figure 7-8a

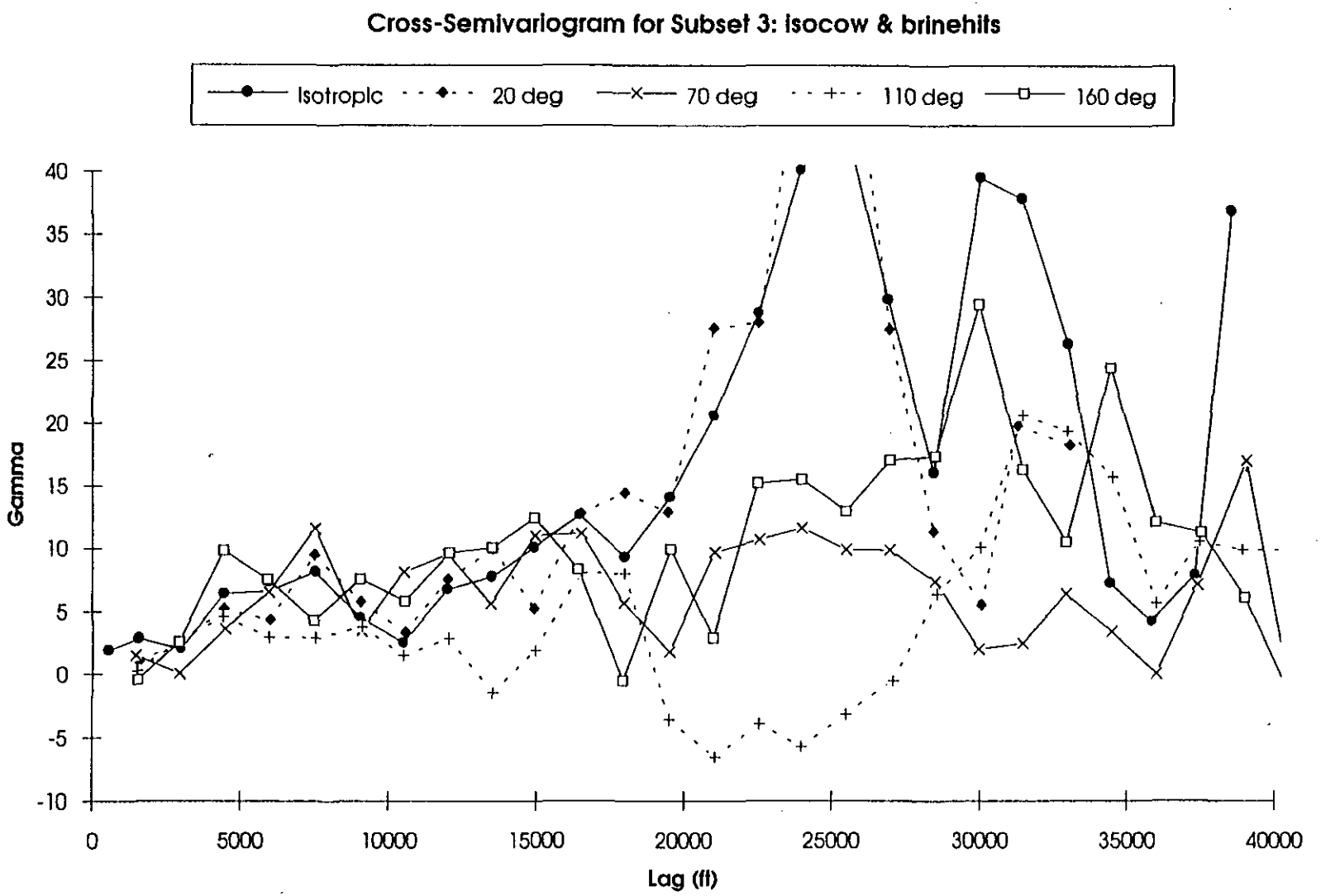
Cross-Semivariogram for Subset 3: isocow & brinehits
Isotropic
20 deg
70 deg
110 deg
160 deg
Gamma
40
35
30
25
20
15
10
5
0
-5
-10
0
5000
10000
15000
20000
25000
30000
35000
40000
Lag (ft)

7/2/96

Figure 7-8b

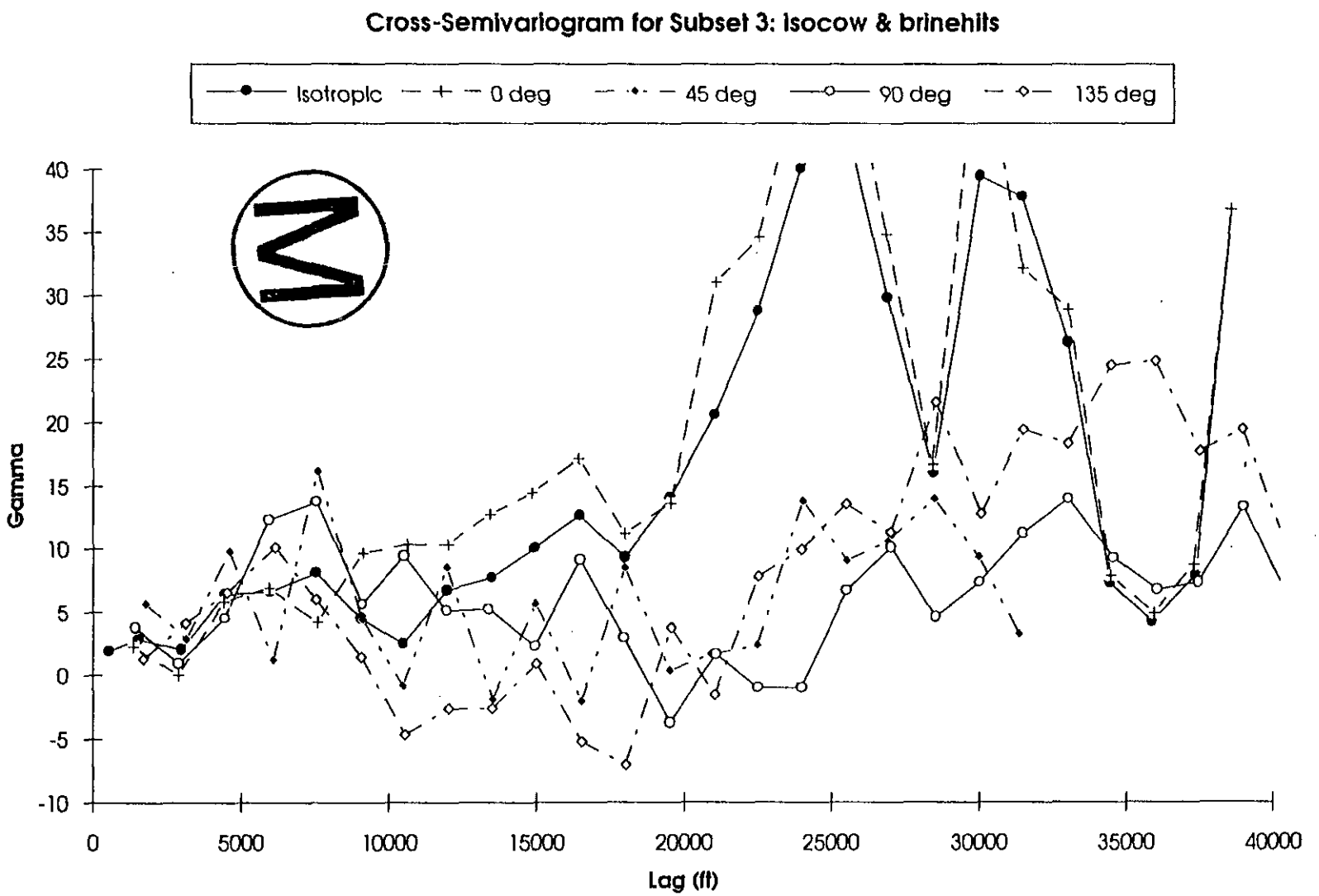

Figure 7-9a

Cowden Isopach for Subset 2

Anisotropic Azimuth 160 deg.: Small-Scale Correlation

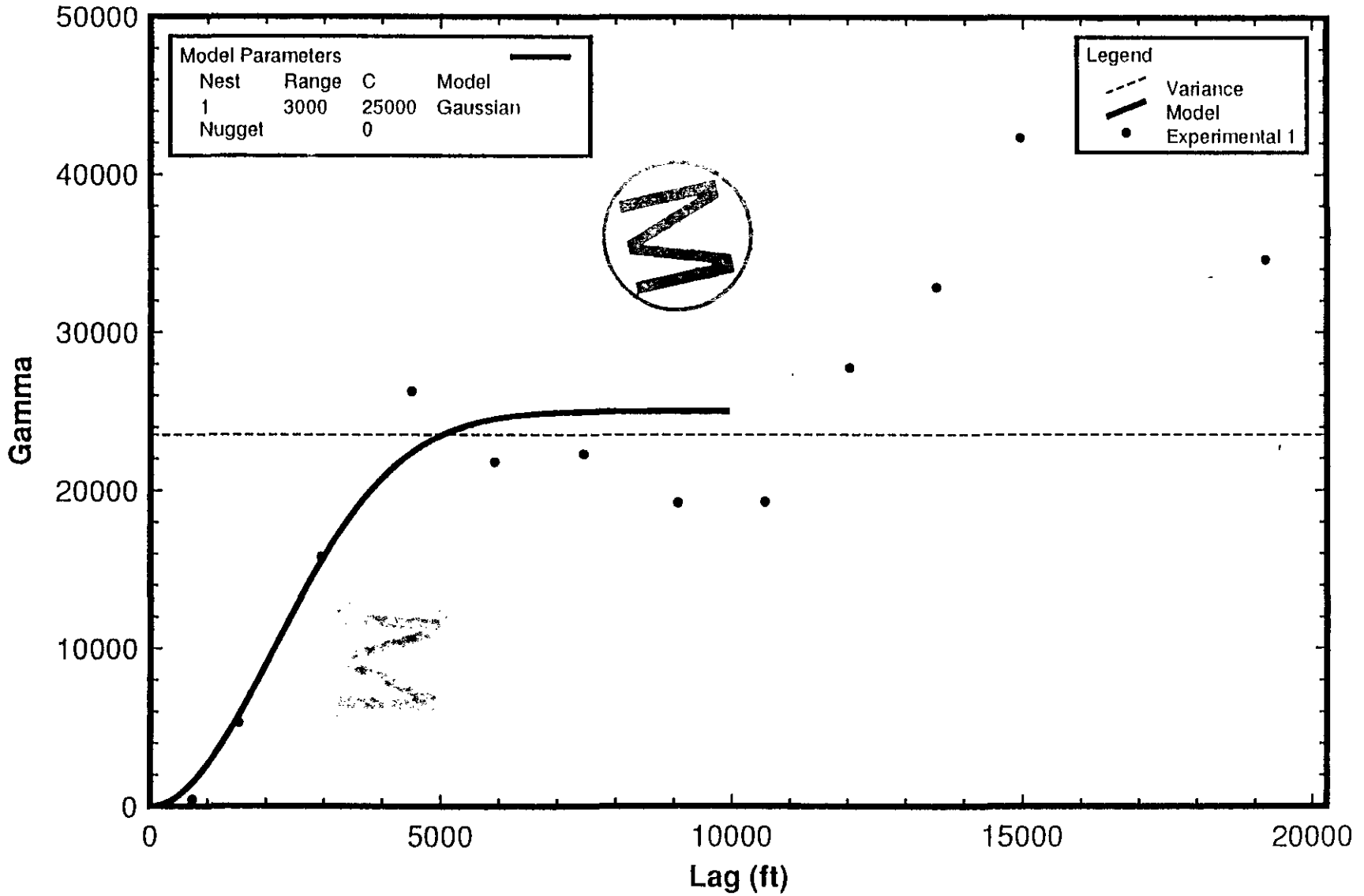

Figure 1-96

Cowden Isopach: icowr3

Anisotropic Azimuth 160 deg.: Small-Scale Correlation

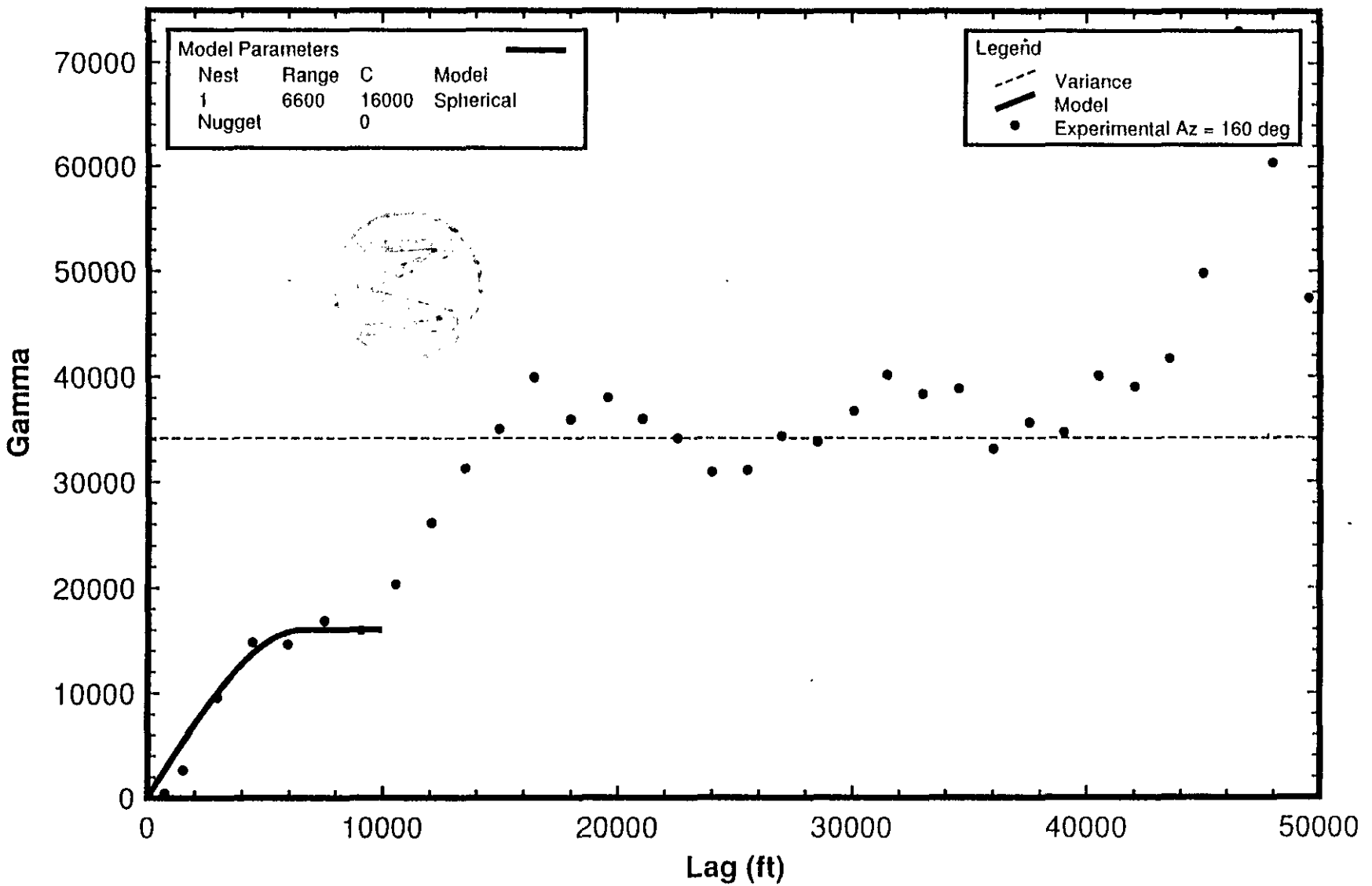

for all data and for Subset 2. We fit a Gaussian model to the latter sample semi-variogram with an effective range of $\sqrt{3} \times 3000$ ft = 5200 ft (Figure 7-9a). The small-scale feature for the complete data set was fitted with a spherical model and an effective range of 6600 ft (Figure 7-9b). These range values matched those estimated by eye for the small-scale correlation structure observed in the other sample semi-variograms. We focused solely on estimating effective ranges because we had no need of kriging the Cowden isopach variable.

7.4 SUMMARY

- The Bell Canyon to base of Cowden thickness (Cowden isopach) shows significant spatial correlation along several directions. Several directions demonstrate both small and large scale correlation structures.
- The observed large-scale spatial correlation had an effective range on the order of 10000 to 20000 ft.
- Small-scale spatial correlation, with effective ranges between 5000 and 7000 ft, was observed in the azimuth 160, 70, and 135 degree directions.
- The most consistent, significant correlation occurs in a range of azimuths from 135 to 160 degrees counterclockwise from north. These correlation structure does not appear to significantly influenced by data clustering and are consistent with the direction and correlation lengths observed for the brine intercept/no-intercept binary variable analyzed in Section 6.0
- Sample cross-semivariograms also appear to share the same small-scale correlation structure observed in the azimuth 160 degree sample semi-variograms.
- The geostatistical analysis results for the Cowden isopach are consistent with those for brine intercept/no-intercept.
- There may be a threshold Cowden isopach value, roughly 1670 ft, below which brine reservoirs do not occur.

8.0 INTEGRATION AND CONCLUSIONS

The geological information clearly outlines the area where evaporites have been greatly deformed to the northeast of the WIPP. Both structure contour and isopach data also give indications for certain horizons and intervals that areas at WIPP 12 and the Hudson Belco well differ from the surrounding areas. Drillholes east of the WIPP site differ structurally from regional trends as well, but are less deformed than the maximum for our study areas. The geological information strongly suggest that brine encounters are related to deformation of Castile evaporites.

The geostatistical analysis of brine intercepts alone demonstrates there is a directional anisotropy for brine reservoir intercepts along an azimuth of 160 degrees. This direction is in general agreement with the orientation of the major structures revealed by geological analysis. Further analysis of the spatial correlation of thickness data shows similar anisotropy, and is consistent with an association between the structural deformation of the upper anhydrite zones and the presence of brine reservoirs within the Castile Formation. Analysis of one interval shows also that known brine occurrences are in areas where the interval is thicker than estimated for the WIPP site; there may be a threshold thickness related to degree of deformation. Further analysis of this approach is warranted before concluding that this kind of information limits the probability of brine encounters under the WIPP site.

Two models of spatial correlation for brine encounters were observed: one isotropic with a range of 2500 ft and one anisotropic with a longer range of 5700 ft. We recommend conditional probabilities of encountering a brine reservoir intercept be estimated using the anisotropic model because it yields the larger estimate, though differences are small. Using the anisotropic model, the area-weighted average of estimated conditional probabilities at computational nodes located over the waste panel is 0.08.

9.0 REFERENCES

Anderson, R.Y., and Powers, D.W. 1978. Salt anticlines in the Castile-Salado evaporite sequence, northern Delaware Basin, New Mexico: Circular 159, Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas, G.S. Austin, ed., New Mexico Bureau of Mines and Mineral Resources, Socorro, NM, p. 78-83.

Bachman, G.O. 1984. Regional geology of Ochoan evaporites, northern part of Delaware Basin: Circular 184, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Borns, D.J. 1987. The geologic structures observed in drillhole DOE-2 and their possible origins: Waste Isolation Pilot Plant: SAND86-1495, Sandia National Laboratories, Albuquerque, NM.

Borns, D.J., and Shaffer, S-E. 1985. Regional well-log correlation in the New Mexico portion of the Delaware Basin: SAND83-1798, Sandia National Laboratories, Albuquerque, NM.

Borns, D.J., Barrows, L.J., Powers, D.W., and Snyder, R.P. 1983. Deformation of evaporites near the Waste Isolation Pilot Plant (WIPP) site: SAND82-1069, Sandia National laboratories, Albuquerque, NM.

Chaturvedi, L. 1984. Occurrence of gases in the Salado Formation: EEG-25, Environmental Evaluation Group, Santa Fe, NM.

Cressie, N. 1991. Statistics for Spatial Data. John Wiley and Sons, New York. 900 pages.

D'Appolonia Consulting Engineers, Inc. 1982. Data file report, ERDA-6 & WIPP-12 testing: Westinghouse Electric Corporation, Albuquerque, NM.

Deutsch, C.V., and Journel, A.G. 1992. GSLIB: Geostatistical Software Library and User's Guide. Oxford University Press, New York. 340 pages.

Gonzales, M.M. 1989. Compilation and comparison of test-hole location surveys in the vicinity of the Waste Isolation Pilot Plant site: SAND 88-1065, Sandia National Laboratories, Albuquerque, NM.

Griswold, G.B. 1977. Site selection and evaluation studies of the Waste Isolation Pilot Plant (WIPP), Los Medanos, Eddy County, NM: SAND77-0946, Sandia National Laboratories, Albuquerque, NM.

Holt, R.M., and Powers, D.W. 1988. Facies variability and post-depositional alteration within the Rustler Formation in the vicinity of the Waste Isolation Pilot Plant, southeastern New Mexico: DOE/WIPP 88-004, US Department of Energy, Carlsbad, NM.

Isaaks, E.H., and Srivastava, R.M. 1989. An Introduction to Applied Geostatistics. Oxford University Press, New York. 561 pages.

Jones, C.L. 1981. Geologic data for borehole ERDA-6, Eddy County, New Mexico:

Open-file Report 81-468, US Geological Survey, Denver, CO.

Jones, C.L., Bowles, C.G., and Bell, K.G. 1960. Experimental drill hole logging in potash deposits of the Carlsbad District, New Mexico: Open-file Report 60-84, US Geological Survey, Denver, CO.

Journel, A.G. 1984. The place of non-parametric geostatistics. In G. Verly et al, eds., Geostatistics for Natural Resources Characterization, pages 307-355, Reidel, Dordrecht, Holland.

Journel, A.G. 1986. Geostatistics: Models and tools for the earth sciences. Math. Geology, v. 18, no. 1, p. 119-140.

Kehrman, R. 1994. Recent occurrences of pressurized brine in the Castile Formation: WS:94:03255, letter to W.D. Weart, Sandia National Laboratories, dated 7/20/1994. (Included as Appendix F)

Pannatier, Y. 1994. MS-WINDOWS Programs for Exploratory Variography and Variogram Modeling in 2D. In Statistics of Spatial Processes: Theory and Applications. Bari, Italy, September 27-30, 1993. V. Capasso, G. Girone, and D. Posa, eds., pages 165-170.

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. Brine reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) project, southeastern New Mexico: WTSD-TME-3155, US Department of Energy, Albuquerque, NM.

Powers, D.W., and Holt, R.M. 1990. Sedimentology of the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) site: Field Trip #14 Guidebook, Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, D.W. Powers et al., eds., Geological Society of America (Dallas Geological Society), p. 27-32.

Powers, D.W., and Holt, R.M. 1995. Regional geological processes affecting Rustler hydrogeology: IT Corporation report to Westinghouse Electric Corporation (in review as SAND report). (Included as Appendix G)

Powers, D.W., Lambert, S.J., Shaffer, S-E., Hill, L.R., and Weart, W.D., eds. 1978. Geological characterization report, Waste Isolation Pilot Plant (WIPP) site, southeastern New Mexico: SAND 78-1596, Sandia National Laboratories, Albuquerque, NM.

Register, J.K. 1981. Brine pocket occurrences in the Castile Formation, southeastern New Mexico: TME 3080, US Department of Energy, Albuquerque, NM.

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1983. Basic data report for drillhole AEC 7 (Waste Isolation Pilot Plant - WIPP): SAND79-0268, Sandia National Laboratories, Albuquerque, NM.

Sandia National Laboratories and US Geological Survey. 1983. Basic data report for drillhole ERDA 6 (Waste Isolation Pilot Plant - WIPP): SAND79-0267, Sandia National Laboratories, Albuquerque, NM.

Silva, M. 1996. Letter to P. Swift, Sandia National Laboratories, dated 3/20/1996,

enclosing reports from petroleum companies regarding brine occurrences in selected wells. (Included as Appendix H)

Wingle, W.L., Poeter, E.P., and McKenna, S.A. 1994. UNCERT User's Guide. Colorado School of Mines, Golden, CO 80401.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix MON

United States Department of Energy
Waste Isolation Pilot Plant

M

Carlsbad Area Office
Carlsbad, New Mexico

Preclosure and Postclosure (Long-Term) Monitoring Plan

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ACRONYMS

BEAR	Backfill Engineering Analysis Report
C&C	Consultation and Cooperation
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EPA	U.S. Environmental Protection Agency
FEIS	Final Environmental Impact Statement
FSAR	Final Safety Analysis Report
NGS	National Geodetic Survey
NMED	New Mexico Environment Department
NQA	nuclear quality assurance
QA	quality assurance
RCRA	Resource Conservation and Recovery Act
SNL	Sandia National Laboratories
SPDV	Site and Preliminary Design Validation
TRU	transuranic
VOC	volatile organic compounds
WEC	Westinghouse Electric Corporation
WIPP	Waste Isolation Pilot Plant
WQSP	Water Quality Sampling Program

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APPENDIX MON

This report details the techniques and design descriptions of components and systems which will be used in implementation of the preclosure and postclosure (long-term) monitoring plan for the Waste Isolation Pilot Plant (WIPP) repository. The regulatory criteria which drive preclosure and postclosure monitoring of the facility and the rationale for the engineered systems that will be used for monitoring are discussed. This report describes both the preclosure and postclosure monitoring plans.

MON.1 Purpose

The purpose of this report is to discuss the preclosure and postclosure (long-term) monitoring programs that will be used to measure the WIPP-related significant and monitorable parameters that have been screened by summarizing the regulatory requirements (Title 40 of the Code of Federal Regulations [CFR] § 191.14(b) and the criteria at 40 CFR § 194.42). The five screening criteria that were applied to the parameters individually are

- Addresses significant disposal system parameters,
- Addresses an important disposal system concern,
- Obtains meaningful data in a short time period,
- Does not violate disposal system integrity, and
- Complements Resource Conservation and Recovery Act (RCRA) programs.

The report also identifies the use of subsidence monitoring as the focus for postclosure monitoring in addition to the screened parameters that will form the basis for preclosure monitoring. In describing the postclosure monitoring program, the report also provides an analysis of geophysical techniques that may have possible applicability to remote monitoring of repository performance subsequent to closure.

MON.2 Scope

The U.S. Department of Energy (DOE) has developed a number of separate monitoring programs to address various environmental, health, safety, and other applicable regulatory requirements. Within these programs, monitoring and measurement activities include the determination of values that are directly and indirectly related to parameters that have survived a screening process which includes the criteria described above. These ongoing programs include a geomechanical monitoring program, a groundwater monitoring program, an environmental monitoring program, a volatile organic compound (VOC) monitoring

program, and a subsidence monitoring program. This appendix identifies discrete programs that address monitoring for each of the parameters which survived the screening process, as well as subsidence monitoring.

This appendix describes in detail a postclosure monitoring program built around subsidence monitoring for evaluating long-term repository performance. The postclosure monitoring description includes defining the requirements and developing specifications for the postclosure monitoring system. This will also include the development of testing, quality assurance (QA), and quality control guidelines for the postclosure monitoring program.

Within the subsidence monitoring program description, a discussion of other geophysical techniques addresses technologies that may be used to enhance the technical interpretations resulting from subsidence data in the event that some data are not within the expected range. The known limitations of these technologies in remotely monitoring the repository performance are also described.

MON.3 Regulatory Background

The WIPP is regulated by the U.S. Environmental Protection Agency (EPA) and the state of New Mexico Environment Department (NMED). In addition, the DOE has entered into an agreement with the state of New Mexico for consultation and cooperation regarding the WIPP. Prior to initiating disposal operations, a hazardous waste permit will be granted by the NMED as required by the RCRA regulations. Also, the EPA is authorized to certify that the WIPP is in compliance with the provisions of 40 CFR Part 191. In February 1996, the EPA promulgated Title 40 CFR Part 194, entitled *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR 191 Disposal Regulations* (EPA 1996a).

As a result of the 40 CFR Part 194 standards governing certification of the WIPP, plans for monitoring the repository during waste emplacement (preclosure) and for the postclosure (long-term) are required. Other requirements imposed on postclosure monitoring are associated with the Agreement of Consultation and Cooperation (C&C) between the state of New Mexico and the DOE (DOE 1981). This agreement details specific postclosure environmental monitoring requirements.

MON.3.1 40 CFR § 191.14 EPA Regulation

The regulations found in 40 CFR Part 191 outline the requirements for the WIPP repository. 40 CFR § 191.14(b) states:

> Disposal systems shall be monitored after disposal to detect substantial and detrimental deviation from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.

The regulation states in 40 CFR § 191.14(a),

> Active institutional controls over the disposal sites should be maintained for as long a period of time as practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active controls for more than 100 years after disposal.

The regulation defines as an element of active institutional control, "monitoring parameters related to disposal system performance."

The following list summarizes 40 CFR Part 191 regulations relating to postclosure monitoring.

- The disposal site shall be monitored after disposal to detect substantial and detrimental deviations from expected performance.
- The monitoring techniques used must not jeopardize waste isolation.
- Monitoring will continue as long as practicable and/or until no significant concerns are to be addressed.

MON.3.2 40 CFR § 194.42 EPA Regulation

Title 40 CFR § 194.42 describes the EPA's monitoring criteria that the EPA will use in determining whether or not the requirements which must be addressed by the DOE (the Department in the regulation) have been achieved. These specific criteria are

> (a) The Department shall conduct an analysis of the effects of disposal system parameters on the containment of waste in the disposal system and shall include the results of such analysis in any compliance application. The results of the analysis shall be used in developing plans for preclosure and postclosure monitoring required pursuant to paragraphs (c) and (d) of this section. The disposal system parameters analyzed shall include, at a minimum:
>
> (1) Properties of backfilled material, including porosity, permeability, and degree of compaction and reconsolidation;
>
> (2) Stresses and extent of deformation of the surrounding roof, walls, and floor of the waste disposal room;
>
> (3) Initiation or displacement of major brittle deformation features in the roof or surrounding rock;
>
> (4) Ground water flow and other effects of human intrusion in the vicinity of the disposal system;
>
> (5) Brine quantity, flux, composition, and spatial distribution;

(6) Gas quantity and composition; and

(7) Temperature distribution.

(b) For all disposal system parameters analyzed pursuant to paragraph (a) of this section, any compliance application shall document and substantiate the decision not to monitor a particular disposal system parameter because that parameter is considered to be insignificant to the containment of waste in the disposal system or to the verification of predictions about the future performance of the disposal system.

(c) Preclosure monitoring. To the extent practicable, preclosure monitoring shall be conducted of significant disposal system parameter(s) as identified by the analysis conducted pursuant to paragraph (a) of this section. A disposal system parameter shall be considered significant if it affects the system's ability to contain waste or the ability to verify predictions about the future performance of the disposal system. Such monitoring shall begin as soon as practicable; however, in no case shall waste be emplaced in the disposal system prior to the implementation of preclosure monitoring. Preclosure monitoring shall end at the time at which the shafts of the disposal system are backfilled and sealed.

(d) Postclosure monitoring. The disposal system shall, to the extent practicable, be monitored as soon as practicable after the shafts of the disposal system are backfilled and sealed to detect substantial and detrimental deviations from expected performance and shall end when the Department can demonstrate to the satisfaction of the Administrator that there are no significant concerns to be addressed by further monitoring. Postclosure monitoring shall be complementary to monitoring required pursuant to applicable federal hazardous waste regulations at part 264, 265, 268, and 270 of this chapter and shall be conducted with techniques that do not jeopardize the containment of waste in the disposal system.

(e) Any compliance application shall include detailed preclosure and postclosure monitoring plans for monitoring the performance of the disposal system. At a minimum, such plans shall:

(1) Identify the parameters that will be monitored and how baseline values will be determined;

(2) Indicate how each parameter will be used to evaluate any deviations from the expected performance of the disposal system; and

(3) Discuss the length of time over which each parameter will be monitored to detect deviations from expected performance.

MON.3.3 40 CFR Part 264 Groundwater Monitoring Regulations

Previous geological exploration and testing have mapped the geologic strata above and below the repository. Two minor water bearing units are in the Rustler Formation approximately 540 to 850 feet (165 to 260 meters) below ground level. The water quality of these units is classified as poor. A small number of exploratory boreholes and hydrocarbon exploration wells in the vicinity of the WIPP site have documented encounters of isolated pressurized

brine reservoirs in the Castile Formation, which is approximately 2,825 to 4,075 feet (860 to 1,242 meters) below ground level at the WIPP.

Typically, the RCRA regulations require groundwater monitoring in the uppermost aquifer located directly below a hazardous waste management unit. The EPA allows this requirement to be waived if it can be proven that the hazardous material will not migrate past specified boundaries in excess of health-based limits and that monitoring will not be productive in determining compliance. In its RCRA permit application to the state of New Mexico, the DOE has applied for this groundwater monitoring waiver. However, the NMED has indicated that it is their policy to require the DOE to perform groundwater monitoring regardless of whether or not the WIPP is eligible for a groundwater monitoring waiver. Because of this, the DOE has prepared a postclosure groundwater monitoring plan for implementation after the completion of final facility closure.

An EPA RCRA document, *RCRA Ground-Water Monitoring Technical Enforcement Guidance Document*, (EPA 1986) provides guidance for developing RCRA permit applications. This guidance document describes hydrological well monitoring at hazardous waste management facilities. In Section 10.3 of the EPA document, two postclosure monitoring items are discussed. The EPA states, "Postclosure care must provide for a period of at least 30 years after completion of the authorized closure of the repository. If ground-water monitoring systems are utilized during the repository active life, they must also be operated and maintained throughout the postclosure care period" (EPA 1986). As stated, monitoring groundwater is not always required but when monitoring is required and performed during the operational period, the wells must be monitored for 30 years after closure.

The DOE has installed six groundwater monitoring wells in the Culebra. Three wells are located upgradient of the WIPP to provide background information against which to compare downgradient well data. The other three wells are located downgradient. One other well has been installed to sample groundwater in the Dewey Lake. The RCRA specifications are used as guidelines in installing the wells to the extent practicable.

There are no unique requirements applicable to the WIPP contained within 40 CFR Parts 265 or 270 that are outside the monitoring described in this postclosure monitoring program.

MON.3.4 40 CFR § 268.6

In 40 CFR § 268.6(a)(4), the EPA states, "A monitoring plan that detects migration at the earliest practicable time..." is required when a no-migration variance is requested.

The WIPP has petitioned for a no-migration variance which, as stated in this regulation, requires a postclosure monitoring plan. The DOE intends to operate a single postclosure monitoring plan which satisfies the requirements of both 40 CFR § 268.6 and 40 CFR Part 191.

MON.3.5 Agreement for Consultation and Cooperation

The Agreement for Consultation and Cooperation is an agreement between the state of New Mexico and the DOE (DOE 1981). This agreement defines specific legal areas of responsibility for the two parties. In the agreement, two specific areas relating to postclosure monitoring are addressed. They are

> The level of environmental radiological surveillance developed during the operational phase shall be continued during and for at least two years following complete decommissioning and decontamination of the surface facilities. This is to include both the State and the Department of Energy's programs. In addition, increased surface soil and vegetation samples will be collected and analyzed to ensure decontamination standards in effect at the time are met. (DOE 1981)
>
> The final environmental radiological surveillance phase will primarily serve to ensure the public that the re-suspension of contaminated ground surface particles, if any, is not creating a potential long-term inhalation problem. The minimum program projected at this time and to be continued for a period of not less than five (5) years following the termination of the decommissioning and decontamination phase is:
>
> (A) Intermittent operation of the state-operated high volume air sampling stations.
> (B) Four annual soil surface samples.
> (C) Four annual water samples.
> (D) Thermoluminescent dosimeters. (DOE 1981)

The radiological part of the environmental monitoring plan (Appendix EMP) for the WIPP facility fulfills the first requirement (DOE 1994a, Section 5.3, Radiological Environmental Monitoring). The total number of samples taken can be increased as necessary. The appropriate section of the environmental monitoring plan can also be used for items (A), (B), and (C). A determination was made by the DOE to discontinue the environmental thermoluminescent dosimeters efforts at and around the WIPP. The Environmental Evaluation Group concurred with the DOE determination. The DOE and Environmental Evaluation Group determined that environmental thermoluminescent dosimeters would not detect releases at the site because they are designed primarily to detect penetrating radiation. The waste to be emplaced at the WIPP contains predominantly alpha emitters (nonpenetrating). Therefore, no environmental thermoluminescent dosimeters monitoring will be performed by DOE after closure (DOE 1994a, WD 1990).

MON.4 Preclosure Monitoring

Attachment MONPAR to this appendix documents the results of the analysis conducted to determine the effects of disposal system parameters on the containment of waste in the disposal system as required by 40 CFR § 194.42(a). The analysis also documents decisions not to monitor particular parameters. This information is required by 40 CFR § 194.42(b).

Information from the monitored parameters may be used to verify the reliability of models used in the performance assessment analysis. Where applicable, modifications to the models

will be made to update the performance assessment during the five-year recertification periods. Table MON-1 describes all the preclosure parameters to be monitored.

Table MON-1. Preclosure Monitorable Parameters

Parameters	Comments
SALADO PHYSICAL PARAMETERS	
Creep closure	Direct measurement in open areas of repository
Extent of deformation	Direct measurement in open areas of repository
Initiation of brittle deformation	Analysis of monitored data
Displacement of deformation features	Direct observation and measurement in open areas of the repository
NON-SALADO HYDROLOGICAL PROPERTIES	
Culebra brine composition	Analysis of brine samples collected from water quality sampling program (WQSP) wells
Culebra well water level	Direct measurements from WIPP wells
Culebra groundwater flow direction	Analysis of well water levels
Castile brine reservoir location	Observed based upon drilling activity in the Delaware Basin
Drilling practices	Observed based upon drilling activity in the Delaware Basin
WASTE RELATED PARAMETERS	
Waste activity	Waste characterization information
SUBSIDENCE	
Subsidence	Direct measurements at benchmark locations

MON.4.1 Geomechanical Parameters

The ground-control program at the WIPP facility involves a conservative approach to ensure that the underground repository is safe from any unplanned roof or rib falls. From the moment an excavation is mined and throughout the life of the opening, care is taken to remove or restrain any loose, unsafe pieces of ground. As the openings age, areas of the roof, ribs, and floor may become unstable. To prevent this from occurring, a comprehensive ground control monitoring and support system has been implemented.

The continuation of the ground-control program and use of the associated instrumentation during the preclosure phase of WIPP operations will provide information about the physical

response of the Salado to the excavations. Specifically, the following parameters will be monitored

- creep closure,
- extent of deformation,
- initiation of brittle deformation, and
- displacement of deformation features.

These parameters are only available for monitoring during the preclosure period.

MON.4.1.1 Ground Control Description

There are two major categories for the ground-control support systems, the rock-bolt systems and the supplementary systems. The rock-bolt systems comprise both mechanically anchored bolts and resin-anchored threaded bars. The supplementary systems include cable with mesh, truss, and/or other components.

The fundamentals on which the ground-control program at the WIPP facility are based are as follows:

- ground stability is maintained as long as access is possible,
- ground-control maintenance efforts will necessarily increase with the age of the openings,
- ground-control plans are specific, yet flexible, and
- regular ground-control maintenance is necessary.

The approach used in the ground-control program at the WIPP facility uses experience gained from observation and analysis of salt behavior in the underground repository. This experience allows various projections to be made regarding future ground-support requirements.

One of the key elements incorporated into this approach is that salt moves, or creeps. Because of its plastic nature, salt tends to flow into any available opening. Ground-support systems cannot resist salt creep, so to provide long-term support, the ground-control system must be able to accommodate the continuous creep of salt and restrain broken or fractured rock in the roof areas.

As more information becomes available regarding the long-term behavior of the WIPP underground excavations, the ground-control maintenance plan will be revised accordingly.

The long-term plans are, therefore, designed to be flexible enough to accommodate any necessary future changes. The ground-control plan is, and will continue to be regularly reviewed and revised as iterative, periodic evaluations are performed and the need is identified.

Prior to waste emplacement in any specific area (room), the plans (for Panels 2 through 8) are to spot bolt with short, mechanically anchored bolts as needed. If spalls or loose ground are encountered, mesh or an equivalent restraint will be used in conjunction with these bolts to secure any loose ground encountered during normal inspection processes. These bolts will not penetrate through to the next clay and anhydrite interface and will be anchored within the beam formed by the mine roof and the clay and anhydrite interface above. This is the primary or initial support that will be used in Panels 2 through 8.

As deteriorating ground conditions require, pattern bolting will be used. However, based on experience with the Site and Preliminary Design Validation (SPDV) rooms and the rooms in Panel 1, pattern bolting will likely not be needed until two to five years after excavation. The expert panel that was convened to study Panel 1 in 1991 (DOE 1991) concluded that the then-current support technology of 10-foot- (3-meter-) long mechanical bolts used in Panel 1 was adequate to ensure stability for 7 to 11 years from the time of excavation. These bolts were installed beginning approximately two years after initial excavation on a pattern described as a 5-foot by 5-foot (1.5-meter by 1.5-meter) offset pattern (one bolt per 25 square feet [2.3 square meters]). Experience in Panel 1 confirms the conclusion of the expert panel. Plans call for bolt systems installed in future bolt patterns to be equal to or in excess of the bearing characteristics of the mechanically anchored bolts used in the primary pattern in Panel 1.

Rigid support systems are currently available that provide superior load bearing capacity and ductility when compared to mechanically anchored bolts. These include threaded bars, for example, DSI or Williams manufacture, and cable bolts, for example, Rocky Mountain Bolt or Jenmar manufacture. In addition, several yielding systems are now available that also provide superior load bearing capacities and have yielding capabilities in ranges exceeding one foot. These include yielding cable bolts, for example, Rocky Mountain Bolt or Western Support Systems manufacture, and slip nut systems, for example, DSI manufacture. The system judged best, which is available at the time a need for pattern bolting is identified, will be used in Panels 2 through 8. In all cases, bolts will be located no more than 5 feet (1.5 meters) apart (one bolt per 25 square feet [2.3 square meters]) in the center half of a room (8.25 feet [2.5 meters] each side of centerline) where the potential for a detaching wedge exists. The pattern support in the center half of the room will be anchored above the first clay and anhydrite interface. Pattern support near the ribs will be capable of supporting spalls or fractured ground typically found near ribs, but is not expected to penetrate the first clay and anhydrite interface. Mesh will be used as appropriate to control small pieces of broken rock.

The justification for selection of these systems includes their demonstrated ability to support the expected loads. In the case of yielding systems, they will be selected based on their support capabilities and the ability to accommodate expected rock deformation.

MON.4.1.2 Geomechanical Monitoring

The geomechanical monitoring program at the WIPP facility is an integral part of the ground-control program (see Figure MON-1). Waste disposal rooms, drifts, and geomechanical test rooms will be monitored to provide confirmation of structural integrity. Geomechanical data on the performance of the repository shafts and excavated areas are collected as part of the geotechnical field-monitoring program. The results of the geotechnical investigations are reported annually. The report describes monitoring programs and geomechanical data collected during the previous year.

The ground control monitoring system is a commercially available, computerized process-control and real-time data acquisition system. This system is used in industry to control such things as drive belts, fans, pumps, and alarms. The primary use of the system at the WIPP is for geotechnical data acquisition.

At the WIPP, the system is presently used to monitor rockbolt loadcells, extensometers, convergence meters, strain gauges, and joint meters at various locations in the repository.

The geomechanical monitoring system provides in situ data to support the continuous assessment of the design for underground facilities. Specifically, the geomechanical monitoring system provides for

- early detection of conditions that could affect operational safety,
- evaluation of disposal room closure that ensures safe access,
- guidance for system and component design modifications, and
- data for interpreting the behavior of underground openings using established design criteria as a benchmark.

The instrumentation components and systems in Table MON-2 are candidates for use in support of the geomechanical program. In addition to the over 100 installed extensometers, the geomechanical monitoring system includes over 400 convergence locations throughout the repository and shafts. These locations are comprised of anchor points installed in walls permitting repeatable measurements to be taken manually with a tape extensometer. The tape extensometer is capable of accuracy of 0.007 inches through the use of a dial indicator. The frequency of readings by location varies with an overall policy to read each location once per calendar quarter. Actual frequency of individual location monitoring is determined by the cognizant engineer based upon operational requirements and long-term excavation

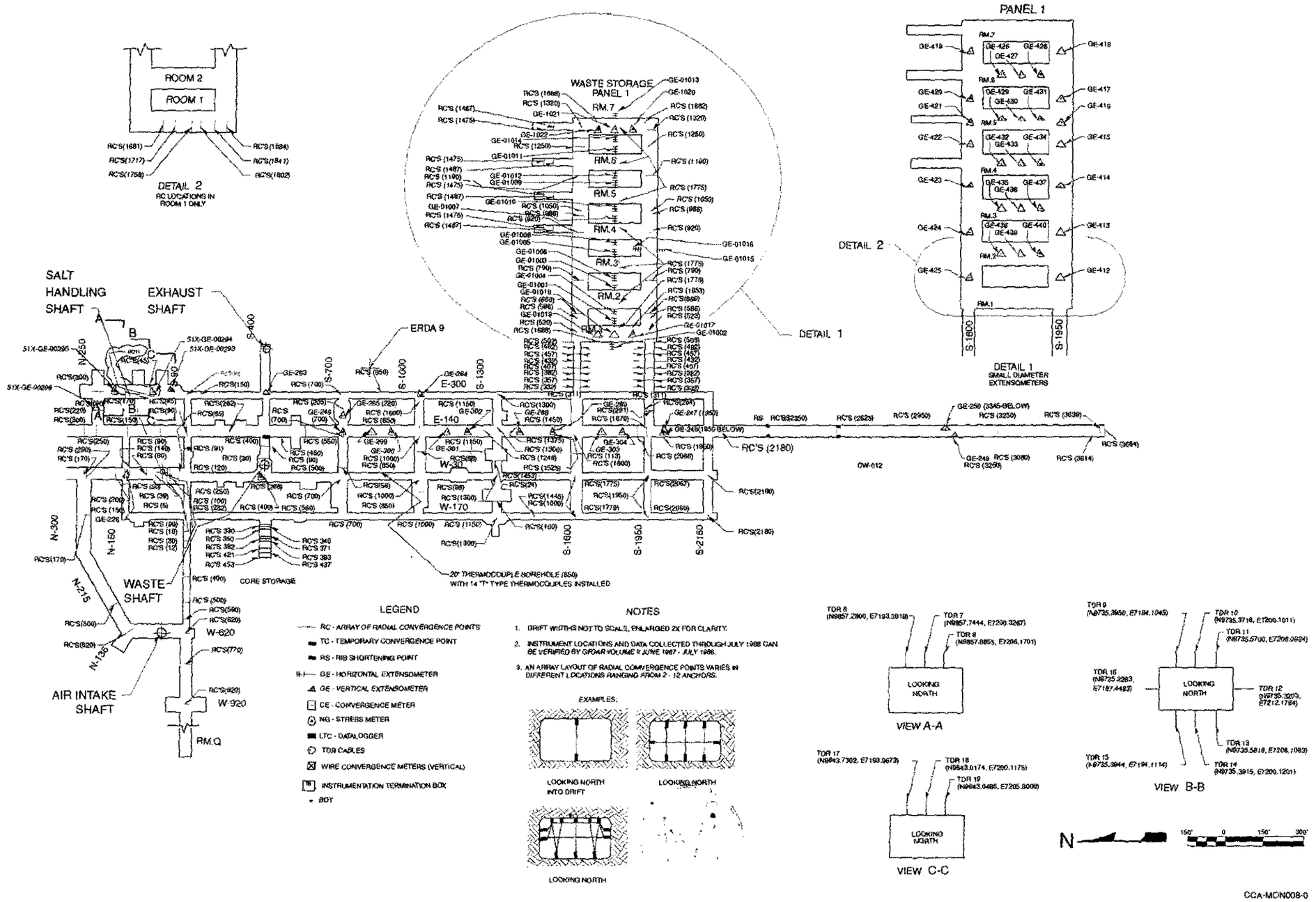

Figure MON-1. Layout and Instrumentation of Geomechanical Monitoring System - as of 1/96

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Table MON-2. Instrumentation Used in Support of the Geomechanical Monitoring System

Instrument Type	Features	Parameter Measured	Range
Borehole Extensometer	The extensometer provides for monitoring the deformation parallel to the borehole axis. Units suitable for up to five measurement anchors in addition to the reference head. Maximum borehole depths shall be 50 feet (15 meters).	Cumulative deformation	0 to 2 inches (0 to 0.05 meters)
Borehole Television Camera	Closed circuit television may be used for monitoring areas otherwise inaccessible, such as boreholes or shafts.	Video image	N/A
Convergence Points and Tape Extensometers	Mechanically anchored eyebolts to which a portable tape extensometer is attached.	Cumulative deformation	2 to 50 feet (0.6 to 15 meters)
Convergence Meters	Includes wire and sonic meters. Mounted on rigid plates anchored to the rock surface.	Cumulative deformation	2 to 50 feet (0.6 to 15 meters)
Inclinometers	Both vertical and horizontal inclinometers are used. Traversing type of system in which a probe is moved periodically through casing located in the borehole whose inclination is being measured.	Cumulative deformation	0 to 30 degrees
Rock Bolt Load Cells	Spool type units suitable for use with rock bolts. Tensile stress is inferred from stain gauges mounted on the surface of the spool.	Load	0 to 300 kips
Earth Pressure Cells	Installed between concrete keys and rock. Preferred type is a hydraulic plate connected to a vibrating wire transmitter.	Lithostatic pressure	0 to 1000 pounds per square inch
Piezometer Pressure Transducers	Located in shafts and of robust design and construction. Periodic checks on operability required.	Fluid pressure	0 to 500 pounds per square inch
Strain Gauges	Installed within the concrete shaft key. Suitably sealed for the environment. Two types used—surface mounted and embedded.	Cumulative deformation	0 to 3,000 microinches per inch (embedded) 0 to 2,500 microinches per inch (surface)

performance. Weekly schedules control the program. In addition, background observation are made in all accessible areas at least annually. Hardcopy and electronic records meeting QA documentation requirements in Appendix GTMP provide the historical records of measurements and observations.

The minimum instrumentation for Panels 2 through 8 is one borehole extensometer installed in the roof at the center of each disposal room. The roof extensometers will be used to monitor the dilation of the immediate salt roof beam and possible bed separations along clay seams. Additional instrumentation will be installed as conditions warrant.

Remote polling of the geomechanical instrumentation will be performed at least once every month. The results from the remotely read instrumentation will be evaluated after each scheduled polling. Documentation of the results will be provided annually in the geotechnical analysis report. This frequency will be increased as necessary.

Data from remotely read instrumentation are maintained as part of a geotechnical instrumentation system. The instrumentation system provides for data maintenance, retrieval, and presentation. The instrumentation system's cognizant engineer first retrieves the data from the instrumentation system and verifies their accuracy by assuring the measurements were taken in accordance with applicable instructions and that equipment calibration is known. Next, the cognizant engineer reviews the data after each polling to assess the performance of the instrument and of the excavation. Data that appear anomalous are detected during this polling and are investigated to determine the cause (instrumentation problem, error in recording, changing rock conditions). The data are then processed to calculate various parameters such as the change between successive readings and deformation rates. Unexpected deformation rates are investigated by geotechnical engineering to determine if remedial action is needed.

The stability of an open panel excavation is generally determined by the rock deformation rate. The excavation may be considered unstable when there is a continuous increase in the deformation rate that cannot be controlled. Evaluations will be conducted to assess the effectiveness of the roof support system and estimate the stand-up time of the excavation.

MON.4.1.3 Monitoring Experience

The DOE established a geotechnical baseline during the SPDV phase as documented in Appendix DVR. Ongoing measurements are reported annually. Much experience in the use of geomechanical instrumentation was gained as the result of performance monitoring of Panel 1, which began at the time of completion of the panel excavation in 1988. The monitoring system installed at that time involved simple measurements and observations, for example, vertical and horizontal convergence rates, and visual inspections. Minimal maintenance of instrumentation is required, and the instrumentation is easily replaced if it malfunctions. Conditions throughout Panel 1 are well known. The monitoring program

continues to provide data to compare the performance of Panel 1 with that established elsewhere in the underground facility. Panel 1 performance is characterized by the following:

- The development of bed separations and lateral shifts at the interfaces of the salt and the clays underlying the anhydrites a and b,
- Room closures. A closure caused only by the roof movement will be separated from the total closure,
- The behavior of the pillars,
- Fracture development in the roof and floor, and
- Distribution of load on the support system.

Roof conditions are assessed from observation boreholes and extensometer measurements. Measurements of room closure, rock displacements, and observations of fracture development in the immediate roof beam are made and used to evaluate the performance of a panel. A description of the Panel 1 monitoring program was presented to the members of the geotechnical experts panel (DOE 1991) who concurred that it was adequate to determine deterioration within the rooms and that it could provide early warning of deteriorating conditions.

The assessment and evaluation of the condition of WIPP excavations is an interactive, continuous process using the data from the monitoring programs. Criteria for corrective action are continually reevaluated based on performance to date. Actions taken are based on these analyses and planned utilization of the excavation. Because WIPP excavations are in a natural geologic medium, there is inherent variability from point to point. The principle adopted is to anticipate potential ground-control requirements and implement them in a timely manner rather than to wait until a need arises.

MON.4.2 Hydrological Parameters

The WIPP's groundwater monitoring plan is described in detail in Appendix GWMP. The continuation of this program throughout the preclosure phase will provide information about the following specific parameters:

- Culebra groundwater composition,
- Change in Culebra groundwater flow direction, and
- Culebra well water level.

MON.4.2.1 Groundwater Monitoring Description

Appendix GWMP describes the basis for the groundwater monitoring plan, the organization of the program, the QA for the groundwater monitoring plan, and the sampling program description. Water quality sampling locations are shown in Figure MON-2 (WQSP-1 through WQSP-6A) for Culebra water samples. The locations of previous water quality sampling wells are shown in Figure MON-3. Sampling frequency is defined in Table MON-3 to be annually. However, the DOE is currently collecting background samples on these wells. This will involve a minimum of four semiannual samples prior to the end of fiscal year 1997. Analytes of interest are listed in Table MON-4. Background samples will be analyzed for target analytes to allow precise analyses of samples collected from locations within the monitoring area. Analytical methodologies used will be EPA-recommended procedures as described in EPA Report SW-846 *Test Methods for Evaluating Solid Waste,* third edition, November 1986 (EPA 1988a). The prescribed practical quantitation limits are the lowest concentrations of analytes in groundwaters that can be reliably determined within specified

Table MON-3. Typical Sampling Schedule

Type of Sample	Sampling Locations[a]	Sampling Frequency
Liquid influent	1	Annually
Liquid effluent	1	Annually
Airborne effluent	3	Continuously
Meteorology	2	Continuously
Atmospheric particulate	7	Weekly
Vegetation radioanalysis	7[b]	Annually
Beef radioanalysis	2	Annually[b]
Game bird radioanalysis	1	Annually
Rabbit radioanalysis	2	Annually
Deer radioanalysis	2	Annually
Fish radioanalysis	2	Annually
Soil radioanalysis	6	Annually
Surface-water radioanalysis	12	Annually
Groundwater	7	Annually[c]
Groundwater levels	69	Monthly
Sediments radioanalysis	10	Annually
Aerial photography	1	Annually
Soil chemistry	7	Annually
Wildlife survey	4	Annually

[a] Sampling locations are shown in the Site Environmental Report (Appendix SER).
[b] If available.
[c] Semiannual sampling will be conducted on wells WQSP 1 through 6 and 6a until three samples are collected for establishing baseline conditions. Annual samples will be taken subsequently.

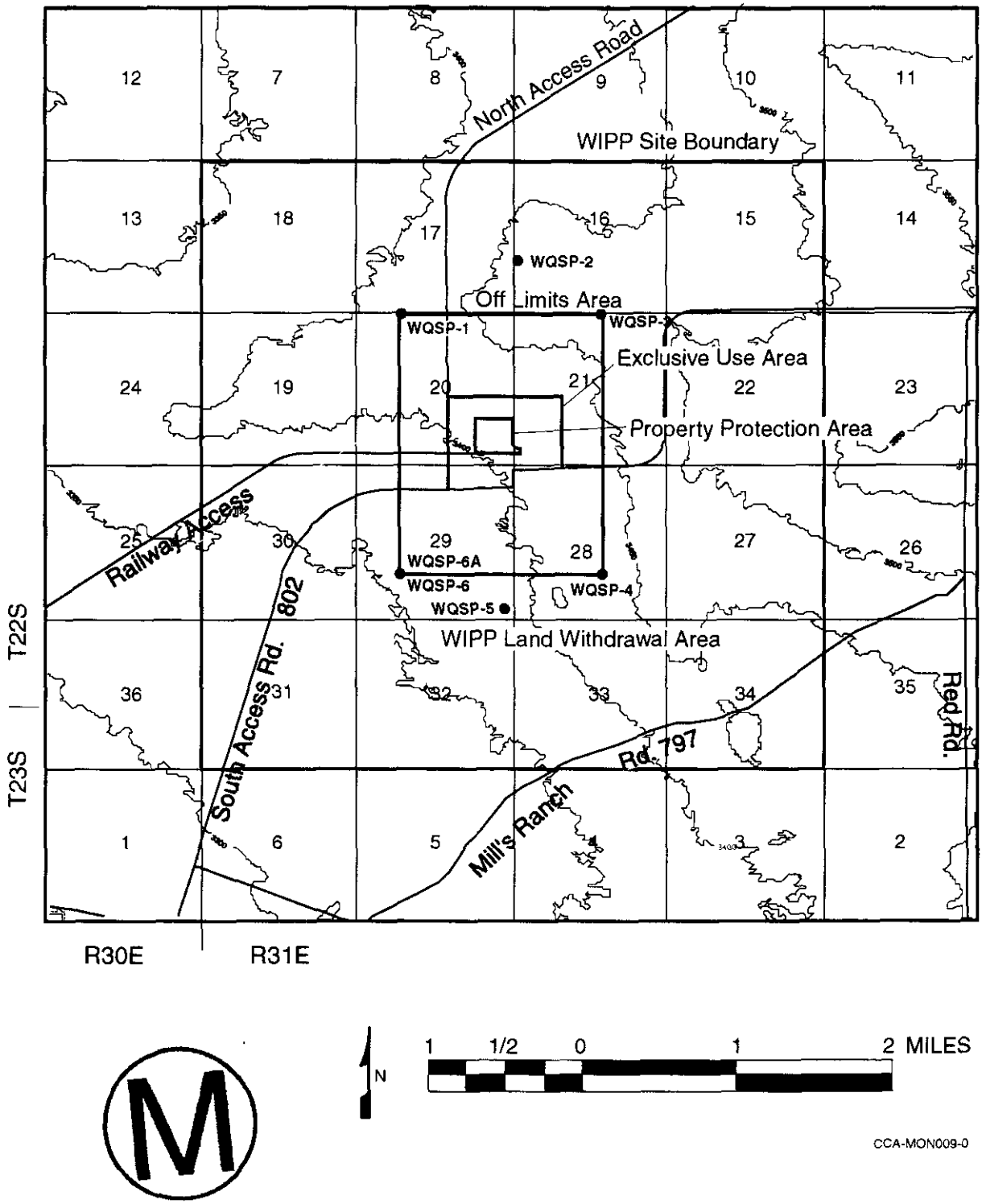

Figure MON-2. Location of the New Water Quality Sampling Wells

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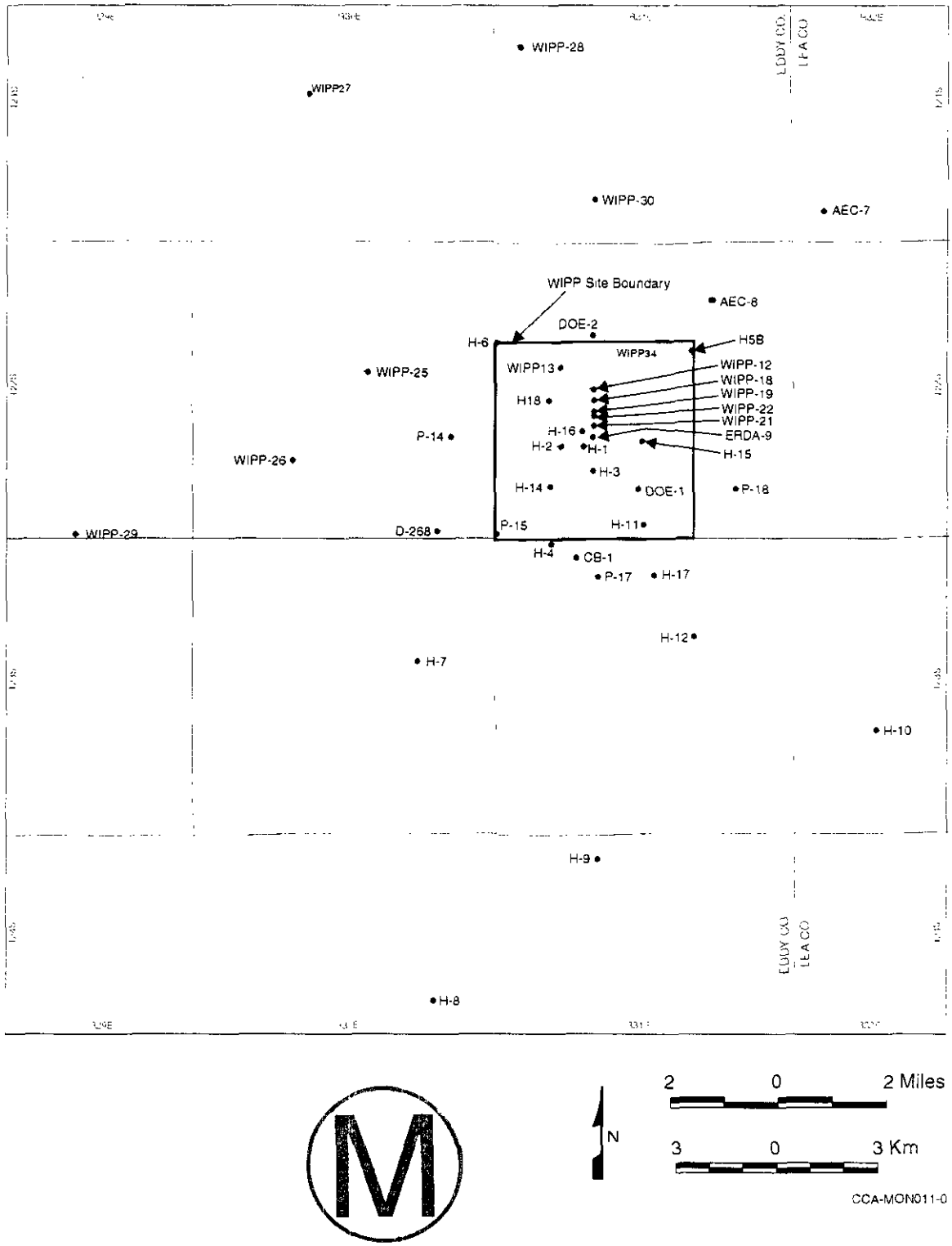

Figure MON-3. Groundwater Level Surveillance Wells

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Table MON-4. Typical Environmental Surveillance Analyses

Type of Sample	Analysis
Liquid influent	Radionuclides
Liquid effluent	Specific radionuclides, chemical constituents
Airborne effluent	Gross, β, specific radionuclides
Meteorology	Temperature, wind speed, wind direction, precipitation, dewpoint, barometric pressure
Air quality	Total suspended particulates
Vegetation radioanalysis	Specific radionuclides
Beef radioanalysis	Specific radionuclides
Game bird radioanalysis	Specific radionuclides
Rabbit radioanalysis	Specific radionuclides
Deer radioanalysis	Specific radionuclides
Fish radioanalysis	Specific radionuclides
Soil radioanalysis	Specific radionuclides
Surface-water radioanalysis	Specific radionuclides
Groundwater	Specific radionuclides, chemical constituents[a]
Sediments radioanalysis	Specific radionuclides
Aerial photography	Area of land disturbed
Wildlife survey	Bird and small mammal population densities
Salt impact study: Soil chemistry	pH, electrical conductivity, sodium, chloride, magnesium, calcium, potassium

Specific radionuclides = ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{233}U, ^{241}Am, ^{244}Cm, ^{232}Th, ^{237}Np, ^{226}Ra, ^{137}Cs, ^{90}Sr, ^{60}Co, U_{nat}, and Th_{nat}.

Chemical constituents = chloride; iron; manganese; phenols; sodium; sulfate; pH; specific conductance; total organic carbon; total organic halogen; Specified RCRA constituents; antimony; arsenic; barium; beryllium; cadmium; chromium; fluoride; lead; mercury; nickel; nitrate; selenium; silver; thallium; zinc; endrin; methoxychlor; toxaphene; 2-4-D; 2,4,5-TP silvex; radium; turbidity; coliform bacteria. Additional analytes may be specified in the WIPP facility hazardous waste permit.

[a] For the purposes of establishing baseline values in wells WQSP 1-6 and 6a, the analyses will include all 40 CFR Part 264 Appendix IX constituents.

limits of precision and accuracy by the prescribed methods under routine laboratory operating conditions. Data analysis will be conducted in such a way that it will provide an objective and reliable means for interpreting data while relating it to the objectives of the data collection program. For the groundwater monitoring plan the principal goal of data analyses is the comparison of a data point or data set to equivalent data collected at another location and at an earlier time (such as preoperational baseline data or data collected at a control location), or to a fixed standard.

The Culebra groundwater composition and flow were characterized and documented in the *Background Water Quality Characterization Report for the Waste Isolation Pilot Plant,* DOE-WIPP 92-013 (DOE 1992).

Individual grab samples are taken from each well by pumping the well. However, prior to taking the final sample, serial sampling is conducted to ensure that a representative final sample is obtained. Typically, a well is pumped for many hours prior to beginning serial sampling. The pumping rate varies from less than 1 gallon per minute to more than 10 gallons per minute depending upon the characteristics of the particular well being sampled. The final sample is taken through a dedicated nylon line to ensure no contamination from a metal line will occur.

Since many of the chemical constituents that are measured are not chemically stable and need to be preserved, samples are treated where required with either high purity hydrochloric acid, nitric acid, or sulfuric acid. This treatment information is recorded on the final sample checklist for use by field personnel when collecting samples. A uniquely numbered Chain of Custody form and Request for Analysis form are used to track the samples. The primary consideration for storage or transportation is that samples must be analyzed within the prescribed holding times. Insulated shipping containers packaged with reusable blue ice are used to keep the samples cool during transport to the contract laboratory. Procedures for sample tracking and preservation are generated, approved, and maintained in accordance with an approved Quality Assurance Plan.

Results of the Groundwater Monitoring Program are published annually in the *Site Environmental Report* (DOE 1994b).

MON.4.2.2 Groundwater Analysis

Several levels of analyses are required for each parameter before statistically valid interpretation of data can be achieved. The type of analysis used at each level varies among parameters because of the particular characteristics of parameters and the specific objectives of monitoring. Five general levels of data analyses are described here. Analyses at each of these levels is considered for each parameter. The levels are

(1) Determination of accuracy for each point measurement by quantification and control of precision and bias,

(2) Evaluation of the effects of auto-correlation on the expected value of the point measurement as a result of location and time of sampling,

(3) Identification of the appropriate model of variability, that is, a probability density distribution, for each point measurement and the calculation of descriptive statistics based on the chosen model,

(4) Treatment of data anomalies, and

(5) Interpretation of data through statistically valid comparisons (tests) and trend analysis.

Each of these levels of data analyses are described below. These descriptions also include a discussion of applicable requirements for the groundwater monitoring plan.

MON.4.2.2.1 *Accuracy*

Accuracy is a measure of the closeness of a measurement to its actual, or true, value. Because the true value cannot be determined independently, accuracy cannot be absolutely determined. However, accuracy is controlled by two basic elements: bias (consistent over- or underestimation of the true value) and precision, (concentration of repeated measurements around a central [expected] value). Accuracy is maximized when bias is minimized and precision is maximized.

To some extent, precision and bias are controlled by strict adherence to sample collection, handling, and measurement protocols. Groundwater monitoring plan procedures specify the protocols for those functions performed at the WIPP and quality control procedures establish control on precision and bias for analytical work.

MON.4.2.2.2 *Temporal and Spatial Analysis*

Environmental parameters vary with space and time. The effect of one or both of these two factors on the expected value of a point measurement is statistically evaluated through spatial analysis and time series analysis; however, these methods often require extensive sampling efforts that are in excess of the practical requirements of the WIPP groundwater monitoring plan. Applying these methods to a particular parameter is, therefore, limited by consideration of its relative significance in the final interpretation of the data.

In particular, spatial analysis has limited use in this program, although the effect of spatial auto-correlation on the interpretation of the data is considered for each parameter. Spatial variability is accounted for by selecting the optimal sampling locations. Data analysis is performed on a location-specific basis, or data from different locations are combined only when the data have been determined to be statistically homogeneous.

Time series analysis plays a more important role in data analysis for the groundwater monitoring plan. Parameters are reported as time series, either in tabular form or as time plots. For key time series parameters, these plots are in the form of control charts on which control levels will be identified based on preoperational data base, fixed standards, control location data bases, or other standards for comparison. Where significant seasonal changes in the expected value of the parameter are identified in the preoperational database or in the control locations, corrections in the control levels that reflect the seasonal change are made.

MON.4.2.2.3 Distributions and Descriptive Statistics

For data sets that include more than 10 data points that are homogeneous in space and time (including seasonal homogeneity), and have less than 10 percent missing data, a test for conformance to the normal distribution is performed. A probability plot is an accepted method for performing this test; however, more powerful tests of normality, such as the W Test, or D'Agostino's Test are more accurate. Any standard best-fit test is acceptable, provided the assumptions of the tests are met.

If normality is not observed, the data will be log-transformed and retested for normality. If the transformed data fit a normal distribution, the original data will be accepted as having log-normal distribution. If normality is still not observed, two courses of action may be taken. One option is to continue to test the fit to standard families of distributions, such as the gamma, beta, and Weibull, with proper modifications to subsequent analyses based on these results. The other possible course of action is to use nonparametric methods of data analysis.

For data sets smaller than 10, but homogeneous and complete, the log-normal distribution is assumed. Data sets with more than 10 percent missing data are analyzed using nonparametric methods. Nonhomogeneous data sets are divided into homogeneous subsets and each of these analyzed individually.

Descriptive statistics are calculated for each homogeneous data set. At a minimum, these calculations include determining a central value and a range of variation. The central value is the arithmetic mean of the untransformed data if the data are not censored at either end. If the data are censored, either a trimmed mean or the median is used as the central value (which may be within the censored range). If the data set is greater than 10 and is uncensored, the standard deviation is calculated and used as a basis for the reported range in variation. If these criteria are not met, the range between the 25th and 75th percentiles is used.

MON.4.2.2.4 Data Anomalies

Data anomalies include data points reported as being below the limit of detection or otherwise censored over a specific range of values, missing data points occurring randomly in the data set, and outliers that cannot be ascribed to a known variation source.

Whenever possible, values that are below detection limits are obtained and incorporated into the database for statistical analysis. When values are not available, alternative methods of analysis, as described in previous sections, are used. In particular, the use of nonparametric statistics is required.

Missing data points comprising less than 10 percent of the data set do not affect data analyses. Results based on data where more than 10 percent are missing are identified as such at the time of reporting. Consideration of the potential effect of missing data must be made when the majority of the data are missing from a discrete time span.

An outlier is defined as any data point occurring in either extreme upper or lower range of the data distribution for which there is less than 0.01 probability of occurrence. For normally distributed data, this is roughly 2.3 or more standard deviations above or below the mean. When no probability model is identified, outliers may only be found through visual inspection of the data.

If an outside source of variation is not identified to account for outliers in a data set, the outlier(s) is included in the data set and is considered in all subsequent analyses. If the inclusion of such outliers is found to affect the final results of the analyses significantly, results both with and without outliers are reported.

MON.4.2.2.5 Comparisons and Reporting

Comparisons between data sets are performed using standard statistical tests. The selection of the specific test is dependent upon the relative power of the test and the degree to which the underlying requirements of the test are met. In addition to tests comparing data from distinct locations and times, trend analyses are performed on time series where sufficient data exist. A 95-percent confidence level will be used for the final interpretation of results.

Citation of the source of the test method or the software used to perform the tests will be made when results are reported. Data and subsequent calculated values are reported in the annual site environmental report in accordance with standard rules for significant figures.

MON.4.3 Gaseous Parameters

VOC monitoring has been performed at the WIPP facility to establish background VOC levels at the site. During initial stages of the disposal phase, confirmatory VOC monitoring will be performed in the repository. Appendix VCMP describes the confirmatory VOC monitoring program in detail.

MON.4.3.1 Background Volatile Organic Compound Monitoring

The VOC monitoring program has focused on the air pathway since 1991. The airborne emission of VOCs is the only credible pathway for release from the WIPP during disposal

operations, and this pathway will be eliminated upon final facility closure. With more than four years of data collected, a credible basis for determining the WIPP facility's background levels of the targeted VOCs has been established.

The VOC monitoring plan conducted for the WIPP to date is described in detail in the *VOC Monitoring Plan* (WEC 1994a). The program monitored the air exhausted from the mine's ventilation shaft for VOCs that might have been released from the test wastes. To differentiate between ambient or background VOCs from aboveground and underground sources and VOCs released from transuranic (TRU) -mixed wastes, VOC concentrations have been measured at the following locations:

- near the top of the exhaust shaft (Station VOC-1),
- near the air intake shaft (Station VOC-2), and
- ventilation air intake passageways to the waste-containing rooms (Station VOC-8).

Sampling followed a regular schedule with the samples analyzed for the quantities of five target VOCs. The samples were then analyzed for other organics present in sufficient quantities to be detected. The five target compounds were carbon tetrachloride, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, and 1,1,2-trichloro-1,2,2-trifluoroethane. These compounds were selected because of their prevalence in TRU-mixed wastes and their inclusion in the conditional no-migration determination. The *VOC Monitoring Quality Assurance Project Plan* identifies the following data quality objectives as applicable to the VOCs monitoring program (WEC 1994b)

- Method detection limit of 0.5 parts per billion or one-fifth of any health-based limit for a targeted constituent, whichever is greater,
- Precision, that is, relative percent difference between field duplicate samples, of ±15 percent,
- Accuracy of ±10 percent, and
- Data completeness of 90 percent, as adjusted statistically to account for the results of data validation audits.

The EPA Compendium Method TO-14 (EPA 1988b), which specifies passivated stainless steel canisters for sample collection, was used as guidance to meet these objectives. The analytical methods consisted of cryogenic trapping and gas chromatography and mass spectrometry. Results of the VOC monitoring program have been provided annually to the EPA. QA and quality control activities conducted in accordance with the *VOC Monitoring Quality Assurance Project Plan* (WEC 1994b) included duplicate sampling, spiked samples, and annual audits of the laboratory conducting the analyses.

MON.4.3.2 Confirmatory Volatile Organic Compound Monitoring

The concentrations of VOCs at the point of compliance during disposal operations and facility closure have been estimated to be one-third to five orders of magnitude below health-based limits. Since these calculations were based on conservative assumptions, and since the DOE has collected more than four years of data to support the validity of background levels of VOCs in air, the DOE will implement confirmatory VOC monitoring activities during the disposal phase.

The DOE has prepared a VOC monitoring plan that describes the aspects of a VOC monitoring strategy. The plan has been prepared so that the DOE can show that the assumptions and predictions used to demonstrate compliance to the environmental performance standards are valid. Validity is shown when observed emissions are equal to or less than those predicted. The VOC confirmatory monitoring plan is provided in Appendix VCMP. The confirmatory monitoring plan includes monitoring design, sampling and analysis procedures, and QA objectives. The plan was submitted in compliance with 20 NMAC 4.1, Subpart V, § 264.602, § 268.6, and § 270.23(a)(2).

The VOC confirmatory monitoring plan describes a sampling and analysis program to confirm the theoretical calculations. The monitoring program is capable of quantifying VOC concentrations in the ambient mine air at the WIPP. The confirmatory monitoring plan addresses the following information requirements:

- Rationale for the design of the monitoring program, based on possible pathways, operations, engineered and natural barriers, and monitoring locations optimized for detection, and

- Descriptions of the specific elements of the monitoring program including the type of monitoring, the location of stations, the frequency of sampling, the target analytes, the schedule for implementation, the equipment used, the sampling and analytical techniques, and the data recording and reporting procedures.

The design of the confirmatory monitoring plan was based on the results of extensive background VOC monitoring activities conducted at the WIPP. These data represent the anticipated background levels of VOCs during operations at the WIPP.

The DOE's intent is to collect air samples upstream and downstream of Panel 1 beginning just prior to waste emplacement and proceeding until at least six months following completion of panel closure. The DOE will continue monitoring until the criteria for terminating monitoring are met. These criteria are established in Appendix VCMP for each target analyte.

The current VOC monitoring program uses EPA Compendium Method TO-14 (EPA 1988b). The DOE has had success with TO-14 at the WIPP when care is taken in placing samplers so as to avoid high dust and if stringent cleaning requirements are imposed for the sample

canisters. This level of rigor is necessary because of the extremely low concentrations of analytes that are being monitored. The DOE is evaluating the use of the Fourier Transform Infra-Red technique for monitoring VOCs at WIPP. This method is being used successfully at other locations and has recently been approved by the EPA for measuring the concentration of VOCs in the headspace gases of drums of transuranic waste. If the Fourier Transform Infra-Red technique becomes viable, the monitoring plan will be revised and the revisions will be submitted to the NMED for approval prior to implementation.

The confirmatory monitoring plan will be run under a QA plan that conforms to the document entitled, *EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations* (EPA 1994). QA criteria are described in Appendix VCMP. Appendix VCMP also includes a discussion of other aspects of the QA program including sample handling, calibration, analytical procedures, data reduction, validation and reporting, performance and system audits, preventive maintenance, and corrective actions.

MON.4.4 Other Parameters

A number of other parameters may be evaluated from the observation of activities included within the WIPP program and/or occurring in the WIPP vicinity. In the course of characterizing WIPP waste at other DOE facilities, waste activity is determined as part of the data needed to ensure that the waste received at WIPP meets the applicable restrictions in the Waste Acceptance Criteria.

Through continuation of monitoring the drilling activities in the nine townships centered on the township within which the WIPP is located, additional data can be developed on drilling rates for comparison to the assumed values developed from the 100-year history of Delaware Basin resource recovery. The monitoring of the drilling activities for boreholes penetrating the Castile Formation will provide additional data regarding assumptions made in performance assessment with respect to location of Castile brine reservoirs. Monitoring the well plugging and abandonment operations within the nine townships will provide information regarding the types of plugs used and their rate of use. Important deviations will be recognized and considered in performance assessment activities supporting recertification.

MON.5 Postclosure (Long-Term) Monitoring

The basis for postclosure monitoring is found in 40 CFR Part 191, 40 CFR Part 268, and 40 CFR Part 264. 40 CFR Part 194 provides the criteria for meeting the 40 CFR Part 191 requirements. In March 1996 the EPA published EPA 402-R-95-014, *Compliance Application Guidance for 40 CFR Part 194* (EPA 1996b). The compliance application guidance provides guidance in meeting the criteria specified in 40 CFR Part 194. The regulations were reviewed and the areas that apply to postclosure monitoring are discussed below. An outline of individual design requirements is also provided.

Those parameters that will be monitored upon implementation of the postclosure monitoring program are listed in Table MON-5. The parameters identified in Section MON.4 that can be monitored during the postclosure period are the following:

- Culebra groundwater, water level changes, and changes in groundwater flow direction,
- Castile brine reservoir location, and
- drilling practices (including plugging).

Table MON-5. Postclosure Monitoring Parameters

NON-SALADO HYDROLOGICAL PARAMETERS	
Culebra brine composition	Analysis of brine samples collected from WQSP wells
Culebra well water level	Direct measurements from WIPP wells
Culebra groundwater flow direction	Observation of well water level changes over time
Castile brine reservoir location	Observed based upon drilling activity in the Delaware Basin
Castile brine reservoir pressure	Observed based upon drilling activity in the Delaware Basin
Drilling intensity	Observed based upon drilling activity in the Delaware Basin
Borehole plugging	Observed based upon drilling activity in the Delaware Basin
REPOSITORY PERFORMANCE PARAMETER	
Subsidence	Can be measured and evaluated against predictions and baseline database

In addition to these parameters, continued, periodic subsidence surveys will provide data for review and analysis against predictions. This will allow the DOE to identify any data anomalies that might occur. Analysis of such anomalies, if they do occur, may provide information regarding the conceptual models used to predict long-term repository performance. Anomalous conditions would be those that are statistically different than conditions predicted by the conceptual models. Such anomalous conditions would require further investigations by the DOE to determine if the condition is detrimental to disposal system performance.

Postclosure monitoring of the repository will use subsidence monitoring as the repository's primary performance indicator. In addition, radiological environmental monitoring will be performed at the same level as was used during the operational phase for the first two years after decontamination and decommissioning, and in a limited fashion, environmental monitoring will be conducted for three years thereafter.

MON.5.1 Postclosure Monitoring Requirements

The postclosure monitoring plan will not be implemented until after final facility closure (sealing of the shafts). The repository is scheduled to open in 1998 and is projected to operate until 2023; decontamination and decommissioning will be completed within 10 years following the final receipt of TRU waste. The postclosure monitoring plan includes provisions to review the postclosure monitoring system during the operational phase. Any changes will be made only after review and approval by the appropriate regulatory authorities.

After closure, buildings and above ground facilities will be removed, and active controls will be implemented. Postclosure monitoring techniques will be designed so as to minimize associated maintenance activities and the need for support facilities. The monitoring techniques are as stand-alone as possible since power may only be available for part of the postclosure period. The postclosure monitoring systems will be located on the surface to facilitate access for maintenance and operation. Safeguards will be provided to protect the equipment from vandalism and the environment.

Monitoring techniques that obtain useful data at reasonable cost with minimal maintenance over an extended period of time are the most favorable.

In summary, institutional postclosure monitoring requirements used as assumptions to arrive at system specifications are as follows:

- The postclosure monitoring system design shall be as human independent as practicable,
- The system must endure the conditions posed by the natural environment,
- The system must be cost-effective,
- The system must not require unreasonably large support facilities,
- The system shall require minimal maintenance and power requirements, and
- All components susceptible to vandalism shall be secured from public access.

MON.5.2 Postclosure Monitoring System Specifications

The postclosure monitoring specifications are listed below.

- Those parameters identified in Attachment 1, MONPAR, to this appendix as applicable for postclosure monitoring will be included in the postclosure monitoring program.

- The postclosure monitoring system shall be designed and implemented so as to detect substantial deviations from expected repository performance after closure.

- The monitoring technique(s) used must not jeopardize the naturally protective nature of the disposal system and must therefore be nonintrusive.

- Monitoring will continue as long as practicable, and/or until the DOE can demonstrate to EPA that there are no significant concerns to be addressed by further monitoring.

- The groundwater monitoring plan and the water quality sampling wells shall be maintained for a minimum of 30 years after closure.

- The radiological aspect of the operational environmental monitoring plan shall be continued for a minimum of two years past decontamination and decommissioning in accordance with the C&C agreement.

- Four annual soil surface samples and four annual surface water samples shall be taken for five years after decontamination and decommissioning in accordance with the C&C agreement.

- The design of the postclosure monitoring program will depend in part on the results of data obtained during the operational phase.

- Postclosure monitoring system design shall require minimal support from humans.

- The system must endure the natural environment.

- The system must be cost-effective.

- The system must not require unreasonably large support facilities.

- All components susceptible to vandalism shall be secured from public access.

MON.5.3 System Description

The basic requirements listed in the Section MON.5.1 were used to define a postclosure monitoring system that would best fulfill all the applicable requirements. The system comprises four monitoring programs of varying duration: (1) groundwater surveillance; (2) radiological environmental monitoring; (3) subsidence monitoring; and (4) observation of drilling activities.

The postclosure monitoring system will also consist of any preexisting hydrological wells plus any additional wells deemed useful. The well monitoring program that was used during the operational phase will be used during the postclosure phase. The frequency of the testing will

be modified after closure to include maintenance and well casing replacement as appropriate. Testing intervals will be lengthened if previous data have been relatively constant during the operational phase. The final postclosure monitoring schedule will be determined by a closure review study.

The radiological portions of the operational environmental monitoring plan in place prior to closure will be used in postclosure monitoring for a minimum of two years after closure with limited radiological monitoring for the following three years.

Subsidence monitoring will be supported by several other systems. These systems include a subsidence network, a monitoring program, a baseline database, a closure review study, and a subsidence data study. The postclosure monitoring will be implemented until the DOE decides, and the regulators concur, that no further monitoring is required. The data collection for both the baseline database and subsidence data are verified through a QA and quality control program to assure data quality. The monitoring program will be documented through a set of operating procedures that are validated and maintained under the QA and quality control program. All actions relating to repository performance indications from the subsidence monitoring program will be resolved through the DOE office overseeing the project.

A subsidence data study will be performed during the developmental and operational (waste emplacement) phases of the WIPP. This study will provide the subsidence prediction data and gather all data for the baseline database. The findings will include the predictions and bounding conditions for repository performance and will be used to define scenarios that would characterize what measured subsidence is outside of the bounds of the predicted range. These scenarios will be used in the baseline database to provide guidance that will be used in evaluating unexpected subsidence monitoring data.

The DOE will continue to observe drilling and borehole plugging practices in the Delaware Basin, thereby gathering additional information relevant to human intrusion and the parameters in Table MON-5, as these are significant to repository performance.

A closure review study will be performed during the late operational phase that assesses the condition of the facility at closure. The study will:

- Evaluate the postclosure monitoring plan, the data generated during the operational and closure phases and regulatory requirements at the closure date,
- Update the postclosure monitoring program,
- Evaluate the necessity for continued monitoring and determine the appropriate repository parameters to be monitored, and

- Revise the postclosure monitoring schedule to account for any necessary changes based on the study findings.

The groundwater surveillance program is described in detail in Appendix GWMP. The environmental monitoring program is described in Appendix EMP. The subsidence monitoring program is described in Appendix SMP. The observation of drilling practices is described in Appendix DMP.

Technology, regulations, site management, safety requirements, and public opinions will advance and change over the period of time from now until final facility closure. A review at the time of facility closure will be performed to update the postclosure monitoring techniques and schedules. Monitoring frequencies, instrumentation, locations, and dates will be revised as appropriate.

A closure review study will be initiated to evaluate the postclosure monitoring plan and update all aspects that are not current. This plan will review the data in the baseline database and all governing regulatory issues associated with postclosure monitoring of the facility. The closure review study will determine what monitoring is required, what will be monitored, what equipment and techniques will be used, and the area and lines that will be monitored. A feasibility study will evaluate technology available at that time that can be used to accomplish the monitoring objectives.

MON.5.4 Monitoring Schedules

The schedule for postclosure monitoring is based on an approach using several basic monitoring groups to implement the four parts of the monitoring program; the initial geophysical survey group, the radiological environmental monitoring plan group, the subsidence monitoring group, and the abbreviated radiological environmental monitoring group. The initial geophysical survey group will be composed of a seismic survey, a resistivity survey, an environmental monitoring survey, a gravitational survey, and a radiological aerial survey. The radiological environmental monitoring plan group (a continuation of the operational environmental monitoring program) will be performed for the first two years only. The subsidence monitoring group will include a leveling survey in the first and third year and every 10 years thereafter. The last group, the abbreviated radiological environmental monitoring group, will include only three sample types (airborne particulate, soil, and water) taken on an annual basis for at least three years following cessation of the radiological environmental monitoring plan group. The schedule for the preclosure monitoring process is detailed in Figure MON-4 and the specific postclosure monitoring schedule is shown in Figure MON-5.

MON.6 Review of Postclosure Monitoring Technologies

Each of the technologies listed below are discussed, defining the monitoring technology and describing the past, current, and future work using this technology as related to performance

monitoring. Also defined are the advantages, disadvantages, and proposed uses of the technologies in postclosure monitoring of the repository.

- Subsidence
- Seismic reflection and refraction
- Gravitational
- Electromagnetic
- Resistivity
- Direct repository monitoring

MON.6.1 Subsidence

Subsidence is defined as vertical movement of the land surface anywhere in the subsidence basin. Subsidence monitoring is defined as the measurement of *relative vertical movement* of the land surface. This movement can be up (uplift) or down (subsidence) and is relative to a fixed reference. This reference is assumed fixed, even though it is subjected to the same factors that cause the surface movement and is moving also. Subsidence monitoring is used to determine the measurable vertical movement of a land mass. The techniques used to monitor subsidence measure the vertical height difference between two or more markers placed on the surface a known distance away from each other and is done with a leveling survey. Usually, one reference benchmark is used as the standard and the relative movement of other stations or benchmarks are measured to detect vertical movement over time. All subsidence measurements are relative because the reference is not fixed.

The error of the survey is determined by the equipment and distances between the stations. A first order survey has an error of one part in 100,000 and a second order survey has an error of one part in 20,000. With current technology, several thousandths of an inch vertical movement can be measured to the stated accuracy.

Subsidence can be caused by a variety of factors. Mining, hydrocarbon extraction, water injection and extraction, geological tilt, and dissolutioning are major subsidence causing factors all of which may be applicable to the WIPP over the long term.

MON.6.1.1 Advantages of Subsidence Monitoring

Subsidence monitoring is advantageous because it is a passive monitoring technique that is relatively simple to perform and uses well established technologies. The cost of the survey is low compared to other technologies. This technique requires little system maintenance or monitoring and has no power requirement. The benchmarks are not affected by weather and

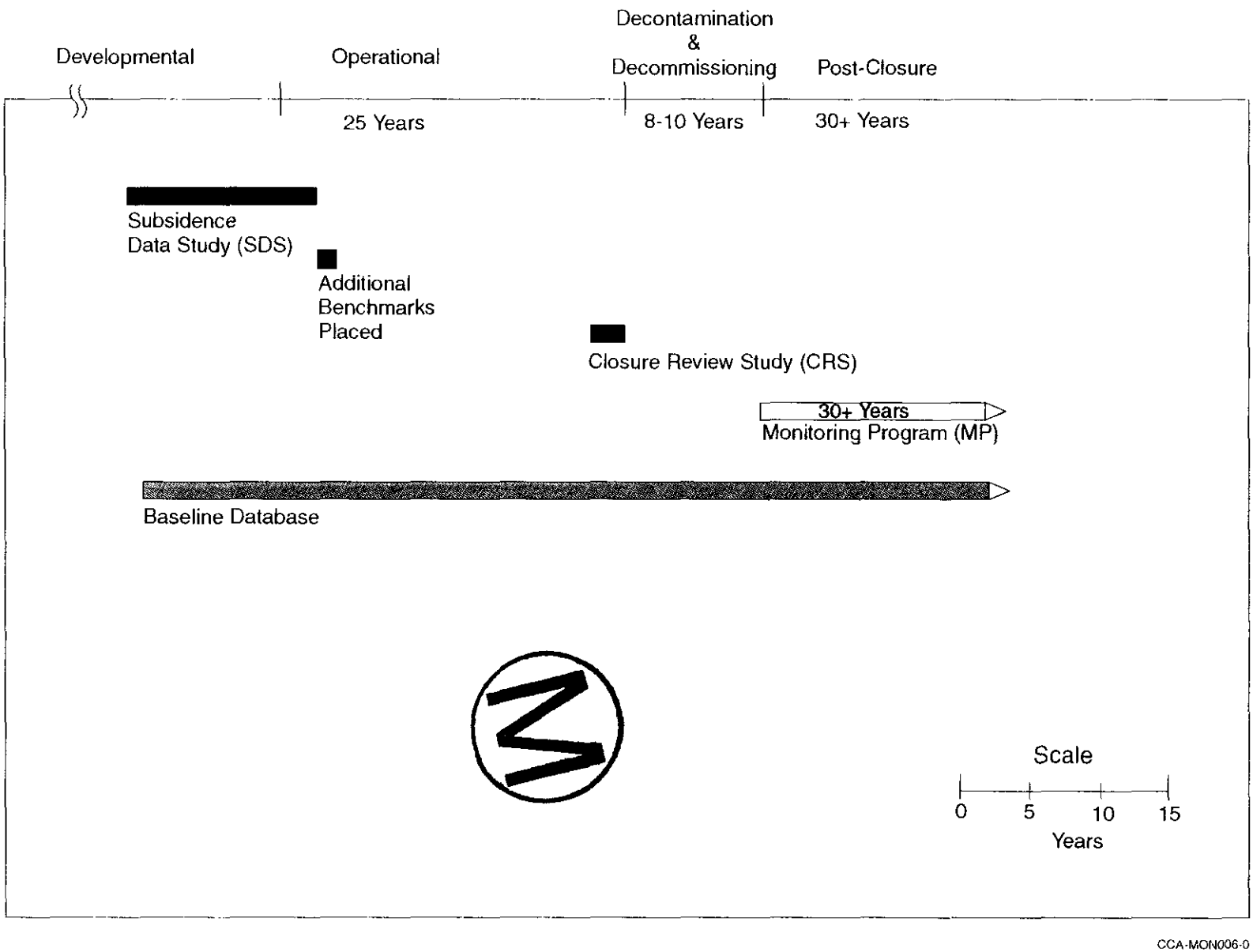

Figure MON-4. Preclosure Monitoring Program Conceptual Schedule

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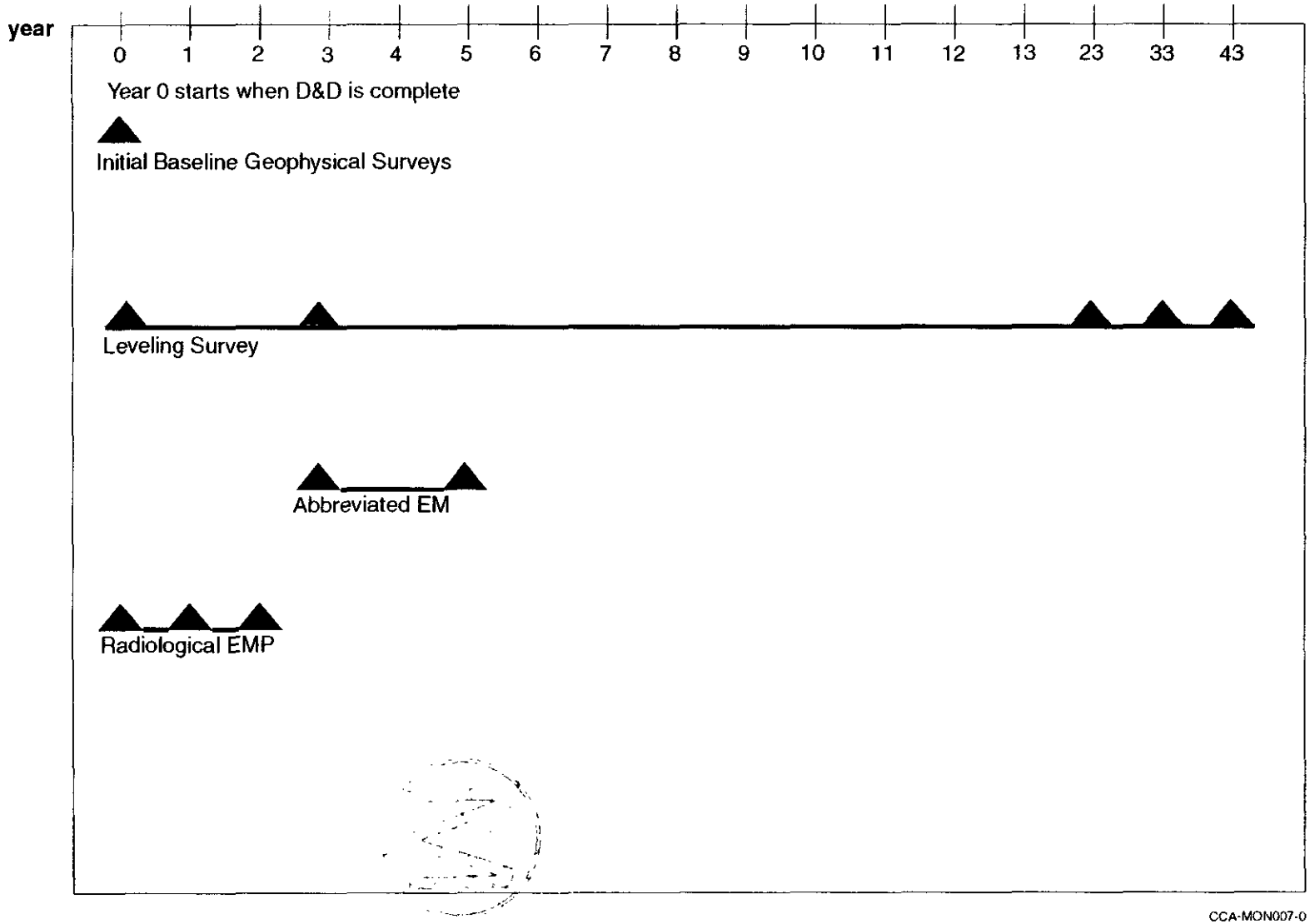

Figure MON-5. Postmonitoring Schedule

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can last for hundreds of years. Benchmarks can be replaced if required and the data can be offset to account for the change without affecting data quality.

MON.6.1.2 Disadvantages of Subsidence Monitoring

The disadvantages associated with subsidence monitoring is in the benchmark placement. The benchmark should be left undisturbed. Existing benchmarks may be destroyed or moved if new construction occurs over the benchmarks. The permanent markers design calls for large earthen berms around the facility after closure. The placement of the berm may cover some of the existing benchmarks and may preclude the necessary line-of-sight measurements between existing benchmarks. The benchmarks are also not currently protected, and could be destroyed during land use by ranchers, drillers, or developers. This necessitates replacing markers and incorporating new markers on the berm to maintain a line-of-sight reference with the benchmarks. Future advancements in global positioning systems may eliminate the need for line-of-sight placement of the benchmarks.

MON.6.1.3 Past Subsidence Work

During the initial site selection process, 195 miles (314 kilometers) of first order, Class 1 leveling survey was performed in 1977 by the National Geodetic Survey (NGS). Later, new survey lines were established that connected the previous first order benchmarks through Carlsbad to second order survey lines through Eunice and Hobbs. Benchmarks were placed over the Nash Draw from the north end to the Remuda Basin, over potash mines, the WIPP site, and the San Simon Sink (Powers 1993). Independent of the NGS benchmarks, an additional 52 benchmarks were installed over the WIPP site and surrounding area.

The NGS network was resurveyed in 1981 and the relative movement between Carlsbad and the WIPP site was measured to be about 0.8 inches (2 centimeters). The relationships between subsidence and potash mining in the WIPP vicinity are discussed in Powers (1993). From data in this report, potash mining was shown to have caused significant subsidence at mines close to the WIPP. Two benchmarks over the Mississippi Chemical Corporation mine measured relative to Carlsbad show 10- and 40-inch (25.4- and 102.7-centimeter) movement downward from 1977 to 1981. Powers (1993) also discusses mining effects on surface subsidence at other mines and correlated a relationship between mining and the surface area effects. This effect is of importance to WIPP monitoring in that estimations of area mining and WIPP mining can be calculated into the subsidence predictions.

From Powers (1993), "In May, 1982, the NGS placed and leveled 15 additional high-quality benchmarks along a north-south line across the position of WIPP 12 (1 mile [1.6 kilometers] north of WIPP surface facilities) and the underlying brine reservoirs in the Castile Formation." After testing and fluid production of approximately 27,058 barrels of brine from the brine reservoir, the NGS resurveyed these benchmarks in January, 1983. According to Powers (1993), "The major difference in elevation across these 15 benchmarks from May, 1982 to

January, 1983, is about 6 to 7 millimeters between the north end of the line and the approximate position of the WIPP."

MON.6.1.4 Subsidence Predictions

Subsidence predictions as a result of mining can also be calculated empirically. Techniques such as mass conservation, National Coal Board, and profile and influence functions can be used to calculate subsidence caused by mining. The influence function technique can estimate subsidence from room and pillar type mining, which is the type of mining used at the WIPP (Sutherland and Munson 1983). Four studies have been performed that have calculated subsidence predictions, the results are found in the *Final Environmental Impact Statement (FEIS)* (DOE 1980), the *Final Safety Analysis Report (FSAR)* (DOE 1990), Sandia National Laboratories' (SNL's) 1991 comparison with 40 CFR Part 191 (WIPP Performance Assessment Division 1991), and the *Backfill Engineering Analysis Report (BEAR)* (WEC 1994c). The following details each report's maximum subsidence predictions:

MAXIMUM SUBSIDENCE PREDICTIONS

FEIS

70-percent backfill density	1-foot (0.3-meter) subsidence
50-percent backfill density	1.6-foot (0.5-meter) subsidence
No backfill	3.28-foot (1.0-meter) subsidence

FSAR

Shaft pillar area (backfill type and amount not specified)	1- to 1.2-foot (0.3- to 0.38-meter) subsidence

SNL

35° angle	0.3-foot (0.09-meter) subsidence
25° angle	0.4-foot (0.13-meter) subsidence

BEAR

No backfill	1.3- to 2-foot (0.40- to 0.60-meter) subsidence
Highly compacted backfill	1- to 1.7-foot (0.30- to 0.52-meter) subsidence

MON.6.1.5 Current Work in Subsidence Monitoring

Current subsidence work includes annual monitoring, a proposed NGS, and a satellite positioning survey. The WIPP Subsidence Monitoring Program is performed annually allowing for a comparison of the data, development of a database, and analysis of subsidence characteristics at the WIPP site. The program includes surface subsidence monitoring involving twenty miles of leveling loops through approximately fifty monuments (S-Caps). Subsidence monitoring surveys include Global Positioning Satellite and surveys of the S-Caps. Figure SMP-1 (see Appendix SMP) identifies approximately 50 benchmarks (those

designated "S" and "PT") distributed throughout the area of influence of the repository and excavated support regions. The annual survey is completed so as to achieve closures that exceed a minimum standard of Second Order Class II for vertical control surveys. State of the art digital leveling technology is employed for all subsidence surveys. From 1996 onward, the survey is being performed to yet higher standards to allow for upgrading the precision of measurements.

Maintenance and calibration of equipment used for monitoring is addressed in Section 2.4.4 of the Westinghouse Waste Isolation Division Quality Assurance Program Description, (see Appendix QAPD). For subsidence measurements, maintenance and calibration are performed by the equipment vendor in accordance with national standards. Equipment is only procured from, maintained, and calibrated by vendors on the WIPP approved Qualified Supplier's List.

Data, plots, graphics, and reports generated as a result of the subsidence surveys are reviewed by cognizant technical engineering personnel to ensure their adequacy and accuracy in accordance with DOE and DOE/WIPP Quality Assurance Review procedures.
The WIPP currently monitors the existing benchmarks as indicated in Figure SMP-1 (see Appendix SMP) on an annual basis (drawing by John West Engineering Co., 1-11-93).

MON.6.1.6 Future Work on Subsidence Monitoring

A NGS survey was performed in 1996 however the final report has not yet been published. The current plan is to resurvey about every 10 years. The last NGS survey was performed in 1982.

MON.6.1.7 Define Use of Subsidence Surveys for Postclosure Monitoring

This report assumes that substantial work will be performed during the operational phase to gather subsidence information and data. This data will be used to relate expected subsidence over time for various scenarios of repository performance. The effects of petroleum production, mining, and geological subsidence must be accounted for in these scenarios. These estimates would be compared to actual measurements.

During the operational phase, the current benchmarks and new benchmark network will be used to gather baseline data. After the operational phase, however, decommissioning of the surface facilities and erection of active and passive controls will eliminate some of this network. For this reason, during the decommissioning, damaged or lost stations should be replaced. Additional stations may be necessary to compensate for line-of-sight losses incurred as a result of the proposed passive permanent markers. It is expected that analysis may have determined subsidence estimates at specific locations; these locations should be included in the benchmark network.

After decommissioning and adjustment of the benchmark network, a Class 1 leveling survey will be performed to determine baseline data. The network will be monitored after closure

and until monitoring is determined to be no longer necessary. The monitoring frequency is to be every third year for the first 15 years. During this time, the data will be compared to the previous trends and if no important anomalies are found, the monitoring frequencies will be adjusted to 10-year intervals.

MON.6.2 Seismic Reflection and Refraction Surveys

Seismic reflection and refraction surveys are used to determine the depth, thickness, composition, and physical properties of geologic layers. Data from the survey can locate specific horizons such as water tables, clay layers, and bedrock. This technology can be used to map the geological structures of large areas at great depths. Survey results are often used by geologists to locate specific geologies that may contain hydrocarbon reserves.

This method uses seismic wave transmissions to determine geologic structure depth and composition. Seismic waves travel at different velocities depending on the soil and rock type. Hard and dense rock have higher wave velocities than soft and less dense rock. Seismic waves can travel through, reflect, or refract off of geological structures. Some of the wave energy will travel along the layers. This phenomena is used to determine depth and composition of the strata by measuring the return time of an induced wave generated at the surface and reflected and refracted back from the underlying strata.

This technique measures wave travel times through a sensor array called geophones placed over the area of interest. A seismic wave is generated by dropping a weight (anything from a hand sledge to truck-mounted ram), or by using high explosives. A seismograph is used to amplify and record the data. By using various seismic wave input energies, sensor array spacings and numbers, specific depths can be mapped. The map corresponds to a geological profile along the line surveyed. Figure MON-6 details the basic seismic surveying technique.

MON.6.2.1 Advantages of Seismic Reflection and Refraction Surveys

One advantage of this technique is the abundance of existing data. Numerous petroleum companies have performed seismic surveys in the WIPP area and several other surveys were performed during site selection (Powers et al. 1978; included in this compliance application as Appendix GCR). This data can be used as a reference to detect changes by comparison with new data. The quality of the data is good for lower structures but is not as useful above the 3,000-foot (914-meter) level (Appendix GCR).

Seismic surveys are nonintrusive and require no permanent devices to be installed at the site. Seismic surveys are relatively inexpensive.

MON.6.2.2 Disadvantages of Seismic Reflection and Refraction Surveys

Basic disadvantages of this technique include data quality and interpretation. This technique is sensitive to noise and equipment set-up. The data must be electronically processed,

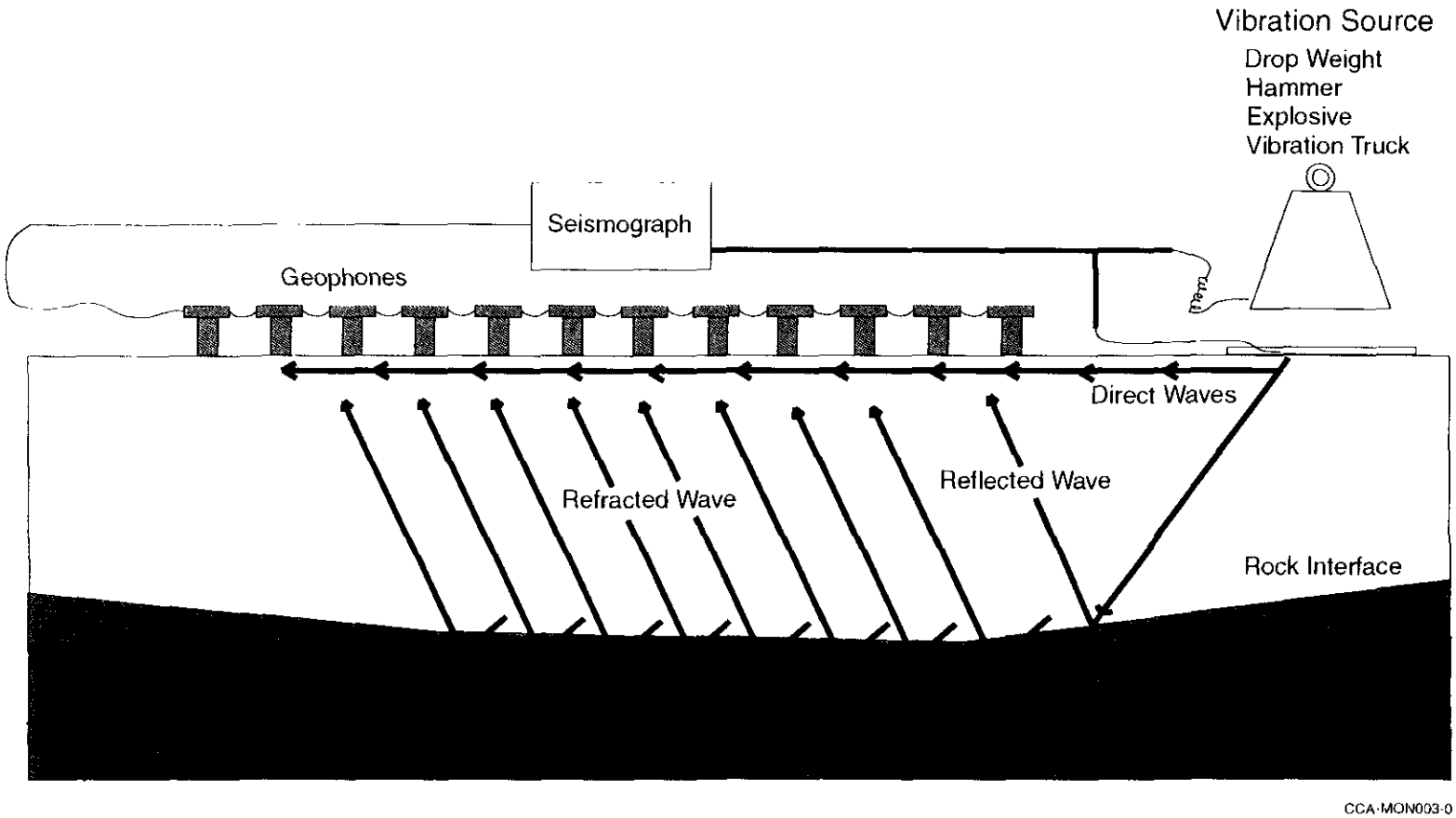

Figure MON-6. Seismic Reflection and Refraction Survey Concept

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conditioned, and interpreted by an experienced geologist. Interpretation is an art form and no two interpretations are the same (Griswold 1977). This can create repeatability errors if the surveys are repeated on the same geology. The results are usually compared to core samples to verify the interpretation and validate the results.

Seismic surveys use equipment that allows for many variations in how data are collected. For comparison reasons, surveys must be performed using similar equipment set-ups, that is, array spacings, line locations, and data conditioning. Any variations in the technique and equipment must be accounted for in the interpretation of the data to ensure that changes caused when different equipment is used for repeated surveys are not interpreted as geological changes.

Relatively thin strata and layers of similar densities cannot be distinguished. Because the technique is based on wave velocities, layers of material that may have different chemical and geological characteristics, but similar velocity components, cannot be differentiated.

MON.6.2.3 Past Seismic Reflection and Refraction Survey Work

During the siting process for the WIPP, several geophysical techniques were used to gather geological data that would identify a suitable site location.

From 1976 to 1978, SNL conducted three surveys totaling 79 line miles (127 kilometers) of data, of which 72 line miles (116 kilometers) were over or near the WIPP site (Hern et al. 1978). The first survey consisted of three lines totaling 24.98 line miles (40.47 kilometers) of conventional petroleum style data and was collected from petroleum companies. The other two surveys were conducted using short geophone spacing and high signal frequency for better shallow field resolution above 4,000 feet (1,220 meters) (Appendix GCR). One of these surveys totaled 47.04 line miles (67.65 kilometers) involving 13 lines. The third survey included 7.5 line miles (12 kilometers) of profiling run along crossing lines through the site (Griswold 1977; Hern et al. 1978).

Approximately 189 line miles (304 kilometers) of older (1950s to 1960s) seismic surveys performed by Shell Oil Co. were purchased from a brokerage firm (G.J. Long Associates 1976). Exxon allowed 196 line miles (315 kilometers) of their data to be viewed at their office, Amoco allowed 513 line miles (825 kilometers) of data to be viewed (G.J. Long Associates 1976). This data were considered proprietary and could not be distributed to other sources. All of the listed data were gathered and interpreted during 1976 (Griswold 1977). Results of the data were used to map the geological layers around the WIPP site. These maps are found in WP 02-9, FSAR Section 2.7 (DOE 1990).

In 1976, attempts were made to perform a high-resolution shallow survey using weight drop techniques. This survey produced data that was not interpretable when compared to known geological information (Hern et al. 1978).

In 1979, an extensive seismic survey was performed that profiled lines directly over the WIPP site boundaries in north-south and east-west patterns. The north-south lines were spaced at 0.25-mile (0.4-kilometer) intervals and the east-west lines were spaced 0.5-mile (0.8-kilometer) apart in Zone 2. In the areas between Zones 2 and 3, the lines were spaced farther apart. The north-south lines were separated by 0.5-miles (0.8-kilometers) and the east-west lines were spaced at one mile (1.62 kilometers). This survey used the same basic parameters as the original Sandia National Laboratories (SNL) survey with closer line spacing. The intent was to improve the accuracy of the data above the Salado.

MON.6.2.4 Current Seismic Reflection and Refraction Work

No seismic surveys are being performed.

MON.6.2.5 Define Uses for Seismic Reflection and Refraction Surveys in Postclosure Monitoring

The seismic method determines the difference in geology by measuring the velocity of a wave through the rock. Any physical change in the rock is accompanied by a corresponding change in its velocity. Seismic surveys can be used to map the repository at various times. The specific depths and densities of various formations can be mapped and compared to data generated in the future to evaluate the repository performance. Changes in the strata, such as changes in aquifer depth and strata density changes, can be determined.

After the repository is sealed and the facility is decommissioned, a seismic survey could be performed over the repository and surrounding area. This survey could be performed to provide good resolution above and below the repository. The survey results and raw data could be documented and all interpretations of the data could be documented. The results and data could be archived so baseline data can be used for comparison to future seismic data if the need arises. The baseline data will help identify changes in the geology surrounding the facility that could help determine if the repository performance is acceptable. The survey could be performed after closure and will not be resurveyed unless new data are required.

The following are requirements for seismic monitoring uses in postclosure monitoring.

- Archive data in at least two permanent formats,
- Line surveys will be referenced to benchmarks in the subsidence network,
- All data reduction programs will be included in the archive data,
- The exact location for the survey will be in accordance with the recommendation of an experienced geologist, and

- Research will be conducted to identify methods to improve repeatability in geophone placement.

MON.6.3 Gravitational Surveys

The gravity survey method maps small variations in the earth's gravitational field. These variations result from mass and density difference in the subsurface lithography of the earth's crust. Interpretation of the data from a gravity survey can detect structural displacement in the strata (Barrows et al. 1983). The survey is performed by using a gravimeter. The instrument measures the gravity intensity at a point. The data is expressed in milligal, where a gal is an acceleration of 1 centimeter per square second. Standard equipment is accurate to within a tenth of a milligal.

MON.6.3.1 Advantages of Gravitational Surveys

This technology is helpful in determining the depth and area of various geological anomalies. In itself, gravity surveys are not concise, but aid the researcher in determining areas (anomalies) that should be explored using other geophysical techniques to determine the specifics of the anomaly.

The gravity survey is nonintrusive and relatively inexpensive when compared to other geophysical monitoring techniques.

MON.6.3.2 Disadvantages of Gravitational Surveys

Gravity surveys do not provide the type of information that allows a geologist to determine the exact geological description and location of the strata surveyed.

This technique is very dependent on placement of the gravimeter. Placement errors can cause variability in results if the survey is repeated. For repeatability, exact placement of the gravimeter must be recorded and verified. This variation is not as pronounced when the results are mapped over a large area.

The data from the gravimeter is sensitive to surface structure, elevation, geographic latitude, and solar and lunar tides (Barrows et al. 1983). Corrections must be made for the terrain and usually cause an error of ± 0.3 milligal (U.S. Department of the Interior [DOI] 1981). Surveying data point position and altitude is half the effort of the gravity survey. This method is prone to human error because manual recording is used. The data is often edited by reviewing the data and deleting any suspected transcription errors.

MON.6.3.3 Past Gravitational Survey Work

During the siting phase a regional gravity control was purchased in 1976, from a geophysical company (Griswold 1977, DOE 1983). Over 3,000 miles (4,800 kilometers) of gravity data

were collected in the area as part of various hydrocarbon exploration surveys (Westinghouse Electric Corporation (WEC) 1990, Final Safety Analysis Report (FSAR) 2.7-27). Also, two gravity surveys, the main site and the reconnaissance profiles, were conducted by SNL. Three smaller areas within the main site survey were resurveyed in greater detail to provide information on suspected anomalies.

The main site survey covered approximately 8.5 square miles (13.7 square kilometers). The lines were spaced 0.6 miles (0.27 kilometers) apart and ran north-south with the stations spaced at 0.18-mile (0.09-kilometer) intervals (Barrows et al. 1983). During this survey, an anomaly was discovered and a borehole was drilled in that area. This area was surveyed in greater detail and covered an area 1,164 feet by 679 feet (355 meters by 207 meters). The stations were spaced in a grid 97 feet (30 meters) apart. Two other smaller areas were resurveyed to provide enhanced detail.

These data were used to detect anomalies in the strata and develop an interpretation of the disturbed zone. However, the disturbed zone data was inconclusive (Barrows et al. 1983). Areas surveyed detected some karst development. A gravity contour map of the WIPP site areas surveyed is found in Barrows et al. (1983).

MON.6.3.4 Current Gravitational Survey Work

No gravitational survey work is currently being performed by the DOE.

MON.6.3.5 Define Uses of Gravitational Surveys for Postclosure Monitoring

Gravity survey data could be included in the baseline database. All past surveys could be included along with extensive documentation defining the equipment, procedures, and data collection and processing techniques used. Surveys could be performed over the repository after closure and decommissioning, to provide baseline data for the repository. The original gravity survey data will not include the influence of over 6 million cubic feet (170 thousand cubic meters) of waste, so a new survey would be needed to provide a baseline after closure.

MON.6.4 Electromagnetic Conductivity Surveys

The term electromagnetic conductivity is used by many geological companies to describe various geophysical equipment. For this report, the term is defined as a method that measures subsurface conductivity by low-frequency electromagnetic induction. This method uses a coil placed on the surface that transmits electromagnetic pulses that induce eddy current loops in the layered strata below the transmitting loop. The induced loop currents are in theory directly proportional to the resistance of the strata. The induced current produces a secondary field current that can be sensed by a receiving coil placed a fixed distance from the transmitting coil. The reading is a bulk measurement of conductivity of the strata directly below the transmitting loop to the effective depth of the instrument. The instruments effective depth is related to the distance between the transmitting and receiving coils. The electromagnetic

system usually measures conductivity of the materials in millimhos per meter and is easily converted to resistivity. Conductivity is the reciprocal of resistivity.

The electromagnetic system determines the conductivity of the strata that is related to the soil and rock geophysical and geochemical properties. Properties such as porosity, permeability, concentrations of colloids and dissolved electrolytes in the pores, and conductive minerals all influence conductivity, but the most influential factor is water content. Because water is the main factor, aquifers and brine pockets can be detected. Pipes, waste containers, metallic debris, and wire lines can also be detected.

Electromagnetic systems can be used to profile and map strata. Both stationary and mobile systems are available. Mobile systems are capable of taking continuous readings. A diagram of the basic system configuration is shown in Figure MON-7.

MON.6.4.1 Advantages of Electromagnetic Conductivity Surveys

The electromagnetic method is nonintrusive and can detect brine occurrences, strata layers with differing physical properties, and aquifers. Mapping of an area can be compared to subsequently acquired data to determine changes such as brine movements. The depth and area of brine pockets can be determined which can then be used to estimate the volumes of the pockets. Electromagnetic surveys may be used to locate waste after placement.

The electromagnetic method does not require ground contact and the measurements can be taken continuously. Methods of this nature have good repeatability. Measurements can be made at ground level or from aerial surveys.

MON.6.4.2 Disadvantages of Electromagnetic Conductivity Surveys

Electromagnetic technology falls short in data interpretation when a highly resistive layer is sandwiched between two highly conductive layers. Strata can have the same relative conductivity but be entirely different geologically. This method is not concise enough to be a stand-alone method, but can be used along with other geophysical techniques to interpret the strata.

The results can vary with ground moisture content. Results after substantial rains are significantly different than those performed after prolonged droughts. Interpretation of the data must account for these variations.

MON.6.4.3 Past Electromagnetic Conductivity Survey Work

Several electromagnetic type surveys were performed by SNL. One survey was initiated to map brine occurrences in the strata above and below the repository. The survey measured 36 locations in a 0.9- by 0.6-mile (1.5- by 1.0-kilometer) grid directly over the repository. Two other measurements were made, one at the WIPP-12 borehole and the other at the DOE-1

borehole. A calibration measurement was made at ERDA-9. The final interpretation of the survey data details brine occurrences. These results correlated well with the depths of the brine occurrences found at WIPP-12 and ERDA-9 (Earth Technology Corporation 1988).

When comparing the results of electromagnetic survey data with borehole logs, the accuracy of determining the depth to brine is better than 246 feet (75 meters) at depths between 3,280 to 4,920 feet (1,000 to 1,500 meters).

Aeromagnetic survey maps are available from the U.S. Geological Survey (Map GP-861, Carlsbad/West Texas) and Aero Service Library (No. 43-6, Carlsbad/West Texas) (Elliot Geophysical Co. 1976).

MON.6.4.4 Current Electromagnetic Conductivity Survey Work

No electromagnetic work is currently being performed.

MON.6.4.5 Define Uses of Electromagnetic Conductivity Surveys for Postclosure Monitoring

Electromagnetic surveying is capable of detecting water or brine occurrences, and can differentiate layers with varying physical properties. This technique could be used to monitor the facility after closure to determine if brine has migrated into the shafts, boreholes and/or repository.

The performance of the shaft, borehole seals, and boreholes could be monitored to determine if they are maintaining the isolation between the aquifers in the Rustler Formation. The repository could be mapped directly after the repository is sealed and included in the baseline data to be used for comparison at a later date.

MON.6.5 Resistivity Surveys

The resistivity method is similar in nature to the electromagnetic method. Resistivity measures the resistance of the rock and electromagnetic measures the conductance. Resistance is the reciprocal of conductance. The resistivity of the rock and soil is influenced by the same factors listed in the previous section for conductivity. By varying the electrode spacing geometries and currents, different parameters can be measured. Two specific methods used during WIPP siting are called Schlumberger sounding and gradient array profiling.

The resistivity method uses four sets of electrodes on the surface, spaced in a specific geometry. Two electrodes are energized to create a current through the strata between the electrodes. The second pair of electrodes measures the potential produced from the first pair. The strata's resistivity can be calculated from the potential and electrode geometry and spacing.

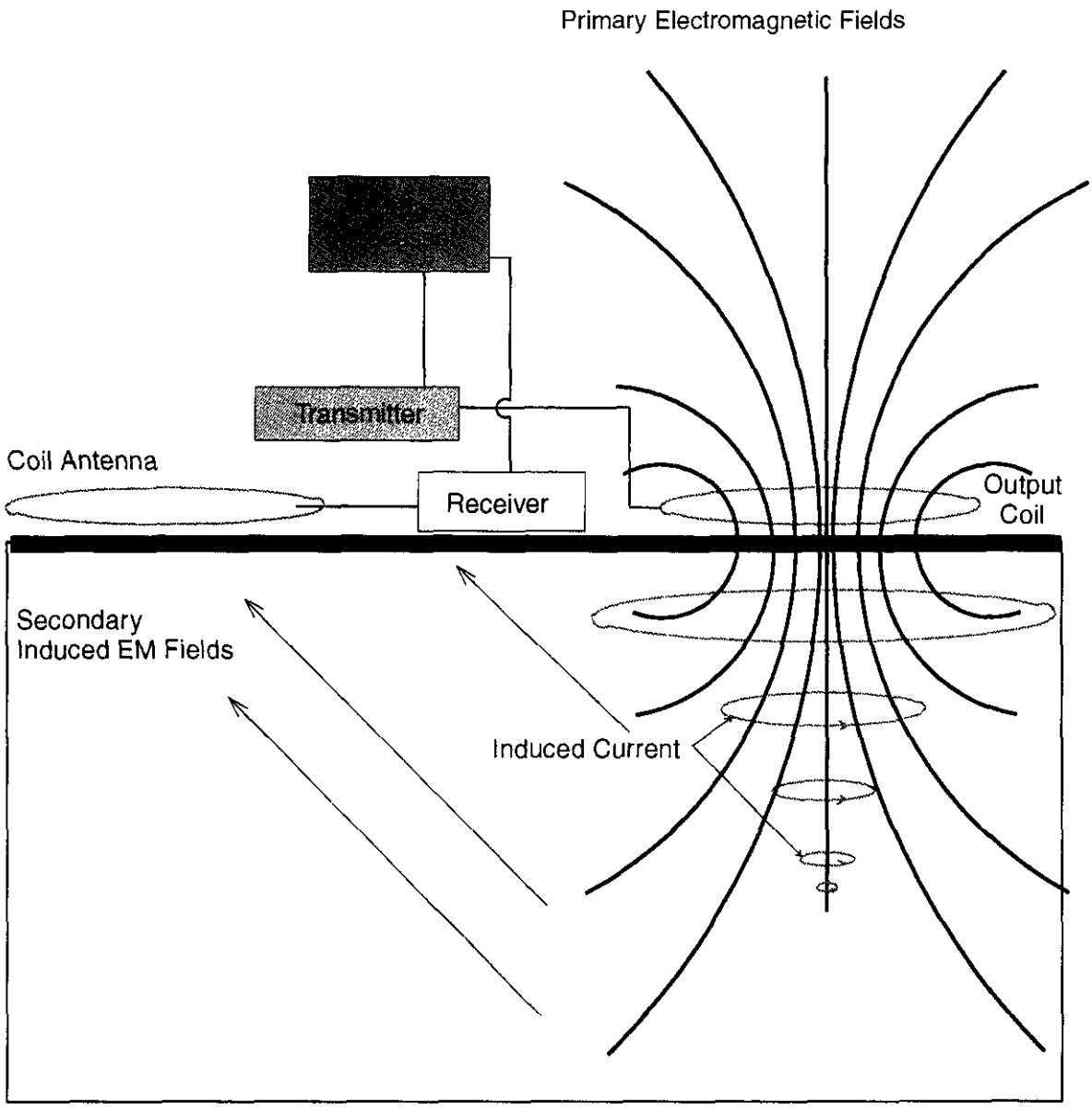

Figure MON-7. Electromagnetic Survey Technique

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As with the other types of geophysical monitoring methods, resistivity measurements can be used to perform sounding and profiling. Profiling maps the changes in the subsurface resistivity horizontally. Sounding can detect vertical changes in subsurface resistivity. The interpretation of the results can be used to determine the depth and thickness of geologic layers of different resistivity. This method can detect soil thickness and depth to aquifers or brine layers. A diagram describing the basic system configuration is shown in Figure MON-8.

MON.6.5.1 Advantages of Resistivity Surveys

The gradient array method is a relatively simple method. The electrodes are separated at large distances which enables economical mapping of large areas.

The advantages of this method are identical to the electromagnetic method.

MON.6.5.2 Disadvantages of Resistivity Surveys

Variations in placement will give differing results if the survey is repeated in the same area. The resistivity surveys require direct ground contact and cannot be performed continuously. The condition of the surface layer can affect the results because variation in the soils moisture content can be detected. Measurements performed shortly after rains will be significantly different than measurements taken after prolonged droughts. However, this can be accounted for in the interpretation of the results. Resistivity also has the same disadvantages as the electromagnetic method.

MON.6.5.3 Past Resistivity Survey Work

Extensive resistivity surveys were conducted during the siting of the WIPP from 1976 to 1978. Areas around suspected breccia pipes and sinks (off-site) were surveyed to determine if resistivity surveys could be used to detect these structures within the WIPP site. All zones of the WIPP site were surveyed. Mining Geophysical Surveys, Inc. performed 53 Schlumberger array soundings and approximately 391 line miles (629 kilometers) of gradient array profiling (9,880 measurements) (Elliot Geophysical Co. 1977).

MON.6.5.4 Current Resistivity Survey Work

No resistivity work is currently being performed.

MON.6.5.5 Define Uses of Resistivity Surveys for Postclosure Monitoring

This technology can be used along with electromagnetic techniques to gather data immediately after the repository is sealed. Both profiling and sounding would be performed to produce geological maps of the strata's resistivity. When the surveys are made, the exact locations and methods used could be carefully documented. If possible, research could be

required to develop a system for electrode placement to ensure good repeatability in the surveys. This data would be documented in the baseline database for future comparison.

MON.6.6 Environmental Monitoring

Environmental monitoring of the WIPP repository will be performed during the operational and decontamination-and-decommissioning periods. The C&C between the state of New Mexico and the DOE requires radiological environmental monitoring for at least five years after final facility closure. This agreement specifies that the environmental monitoring program in place during the operational phase must be continued after closure and decommissioning for at least two years, and that an abbreviated program with a limited number of radiological air, soil, water, and background samples be continued for the following three years.

The postclosure environmental monitoring program is required to include the following (DOE 1994a):

- Radiological Environmental Monitoring (first two years after decontamination and decommissioning)

  - Airborne particulate
    lo-vol sampling, eight stations
  - Vegetation
    four sites
  - Beef
    annual muscle samples if available
  - Game animals
    annual muscle samples of rabbits and quail.
  - Soil samples
    annual, multiple samples at multiple depths at six locations.
  - Surface and drinking water
    annual surface water samples from 12 major bodies of surface water in the vicinity of the site (drinking water will not exist after decontamination and decommissioning)
  - Groundwater
    annually, one sample from eight of the wells within the 16 sections boundary taken from the Culebra Dolomite.
  - Aquatic foodstuffs
    samples of catfish taken from the Pecos River and Brantley Lake and analysis annually.
  - Sediment sampling
    annual samples taken from the Hill and Indian tank and the Pecos River near Artesia and Malaga, New Mexico.

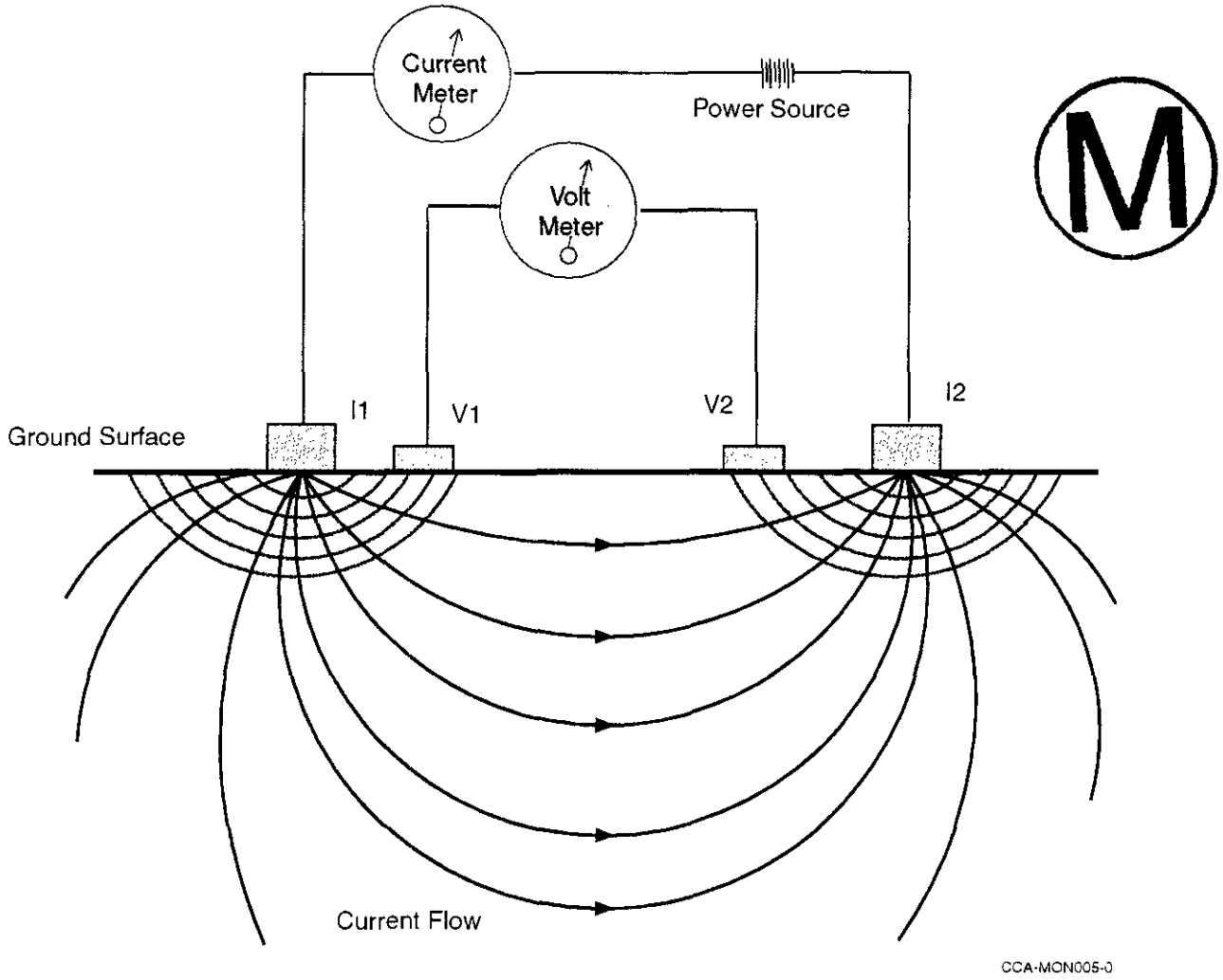

Figure MON-8. Resistivity Survey Concept

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- Abbreviated radiological environmental monitoring (three, four, and five years after decontamination and decommissioning).

  - Airborne particulate
    intermittent operation of the state-operated high-volume air sampling stations.
  - Soil
    four annual soil surface samples.
  - Water
    four annual well water samples.

Only the radiological environmental monitoring techniques that apply after final closure are included. Items such as effluent monitoring at the exhaust shaft were not included because they do not apply after final facility closure.

Environmental monitoring has been an ongoing program since the WIPP's inception. Baseline environmental data were gathered and reported in annual reports and an environmental monitoring plan was created. The current operational environmental monitoring plan is detailed in the *Waste Isolation Pilot Plant Environmental Monitoring Plan*, WIPP/DOE 94-024 (DOE 1994a) and the *Waste Isolation Pilot Plant Site Environmental Report for the Calendar Year 1993*, DOE/WIPP 94-2033 (DOE 1994b).

MON.6.7 Direct Repository Monitoring

From earlier discussions, no proposed postclosure monitoring techniques include technologies to directly monitor the repository. This is due to the inherent difficulties imposed by the noninvasive requirement. No wiring or boreholes will be used to connect monitoring equipment in the repository to the surface.

The U.S. Bureau of Mines and commercial companies throughout the world are currently researching techniques to communicate through the strata to mine working areas using very-low frequency and ultra-low frequency electromagnetic radiation. Several companies have developed mine paging systems that use very-low frequency to warn workers within the mine using a system placed on the surface. One system can transmit messages with up to 32 characters to mobile mine pagers. This technology shows promise in remote instrumentation communication that could directly monitor the repository. It has been demonstrated in other salt mines that communication from the surface to the depth of the WIPP repository is possible.

Recently, researchers have started to investigate methods to remotely monitor the sealed rooms and panels. This work uses very-low frequency technology to link sensors and equipment in sealed rooms to the data recorder without a hardwired link. Current work is focused on communication from where the link between the transmitter and receiver is only 10 to 33 feet (3 to 10 meters).

Very-low frequency could be used to transmit data from the surface to equipment located in the repository but the problem lies in communicating the sensor data to the surface. The power required to transmit between the surface and the underground using the current technology is related to the strata conductivity, the output power at the transmitter, and the antenna design. Tests performed in actual mines used large loop antennas on the surface to transmit the signal. Tests have shown that loop diameter is more important in transmission efficiency than output power. Antennas ranging from 98 feet to over 328 feet (30 meters to over 100 meters) in diameter have been used (DOI 1991).

There are many problems that must be overcome to directly monitor the repository after closure. Some of these problems are listed below.

- Future sensor and transducer calibration would not be possible,
- Sensor longevity in the repository environment is not likely,
- Data collection and transmission power requirements could be problematic, and
- Antenna locations and sizes could pose issues with regard to other surface structures and activities.

MON.6.7.1 Sensor Calibration

Over time, most sensors, such as pressure, gas analyzer, and extensometer sensor and transducer, experience some change in resolution or drift. Any type of sensor and transducer used would need to operate for 100 years without recalibration. To overcome this problem, redundant sensors, sensor drift calculations, and accessible sensors as standards could be used to limit the induced errors. However, this would not ensure accuracy over the required time frame.

MON.6.7.2 Sensor Longevity

The sensors used for postclosure monitoring would be required to operate in a salt/brine environment for over 100 years. This imposes the biggest obstacle in direct repository monitoring. Corrosion, oxidation, and various chemical reactions would easily limit the life span to less than 50 years.

MON.6.7.3 Data Collection and Transmission Power Requirements

A power source that could operate for the time required is not currently available. Battery systems have limited shelf lives and capacities. Lithium-type batteries have the longest shelf life of the common battery types. Standard shelf lives of five to 10 years at their rated capacity is standard with some manufacturer's claiming 80-percent capacity after 15 years. Because the capacity requirements are dependent on the equipment load, the highest current

requirement would occur during data transmittal. From experimental work, an estimate of at least 350 watts may be required to transmit to the surface. This can be accomplished with standard power sources for the short-term, but other currently unavailable methods of power generation would be required for the long-term.

One potential method is power transmission and retention. Power could be transmitted from the surface using ultra-low frequency energy and an antenna would intercept this energy and store it in capacitors or a special battery. Because the system could be charged for long periods of time between data transmissions, only a small amount of surface transmitted power is required. The problem with this approach is power storage.

The chemical nature of rechargeable batteries limits their life span. The effects of oxidation, outgasing, and heat damage will cause a battery to fail. The life span of most common rechargeable (lead acid, gel, and nickel cadmium) batteries is dependent on the number of recharge cycles, the rate of discharge, and charge rates. Under favorable conditions, most rechargeable batteries can last up to 10 years.

The capacitor is a device that stores energy on two plates separated by an insulator. Capacitors can be designed for this application that would last the required time frame. The problem associated with capacitors is related to power storage capability and size. In comparison, a capacitor and a battery with the same approximate volume do not have the same energy storage capacity. For example, a one-microfarad capacitor charged to 1,000 volts has 0.5 Joules of energy storage, a 500-mAh nickel cadmium (1.2 volts) of similar volume has 2,160 Joules of energy storage. A capacitor that has this energy storage potential would be extremely large (4,320 times larger).

Satellite power sources use nuclear energy to generate power. The systems are not considered off-the-shelf technology. However, work is progressing on a nuclear heat power source using (almost) off-the-shelf technology. One experimental study calls this type of power source a Powerstick (Chmielewski and Ewell 1994). This theoretical device would use a nuclear heat source and a thermopile to generate an electrical potential. The heat source is a common satellite product used to heat instrumentation. The power source is capable of producing 42 milliwatts at 15 volts initially and would degrade to 37 milliwatts at 14 volts in 10 years. These power sources could be used to slowly charge batteries and/or capacitors that would then be used for a short duration, high-demand data transmission cycle or in parallel for a higher current source.

The regulatory issues associated with nuclear power sources have not been researched. If the remotely-handled waste could supply an adequate heat source and WIPP receives remotely-handled waste, the regulatory issues may be overcome.

The nuclear and thermopile power source technology has not been proven and there is no prototype as yet. Advances in battery design and the development of this nuclear power source could eventually allow this technology to power a direct repository monitor.

MON.6.7.4 Antenna Location and Size

The size of the antenna may pose a problem in the mine setting. If the antenna is placed inside a room, diameters are limited to a maximum of approximately 328 feet (100 meters). If the antenna can be wrapped around a pillar, the antenna would have a radius of approximately 164 feet (50 meters) but diameters between 32.8 feet and 328 feet (10 meters and 100 meters) would require special provisions. Also, the effects of the metal in the room will increase the power requirement. These problems can be overcome and experimentation would be needed to verify the effectiveness of the antenna design.

From current technology, no known system is currently available that could be used to directly transmit data to the surface without a hardwired link. Extensive research and development is needed to develop such a system; however, the systems longevity will be suspect, since actual long-term testing could not be accomplished and new technologies are rarely foolproof. For this reason, direct repository monitoring is not recommended at this time for postclosure monitoring.

MON.6.8 Conclusion

There is no single geophysical technical exploratory technique that can determine the condition of the surveyed strata. Several techniques are used to gather data to assess the geological structure that is being examined because interpretation of one technique often uses data from another. For this reason, no single technique could be used to fully assess the repository's condition. One technique can be used as an identifier to alert that a condition may exist and other techniques can be used in unison to assess and validate the condition.

From the review of geophysical survey techniques, the best current monitoring technology that can be used for a postclosure monitoring identifier is subsidence. This method is the most practical because it is a simple, repeatable, low-cost, low-maintenance, low-technology approach to monitoring the repository. This method should be used as a primary monitor technique for determining that a possible repository performance problem exists. Other techniques can then be utilized to determine the cause of the problem.

A combination of seismic, electromagnetic, resistivity, and gravitational surveys can be used to assess repository performance. However, it is not practical to perform these on a regular basis. These techniques are also not needed if there is good confidence that a performance-related event will not occur. For this reason, an initial collection of surveys could be compiled and used as a standard to assess future data and perform subsidence monitoring to forewarn of changing conditions that may significantly affect repository performance.

MON.7 Postclosure Monitoring Program Summary

Physical, chemical, economical, and technical factors have been included in the conceptual approach to designing a practical, yet effective, postclosure monitoring system. The needed

information can be obtained from a monitoring system composed of a subsidence network, a monitoring program, a baseline database, a closure review study, and a subsidence data study.

The following summarizes the postclosure monitoring program.

- The DOE will create a baseline database that includes data from developmental and operational phase activities.

- The DOE will perform a subsidence data study.

- The DOE will compile subsidence predictions and include any performance assessment- developed scenarios of repository performance which fall outside the baseline subsidence predictions. The DOE will develop proper benchmark locations over the repository. The subsidence predictions will be developed from the information available in the *Backfill Engineering Analysis Report (BEAR)* (WEC 1994c) and from any additional information provided by the performance assessment.

- The DOE will create a subsidence network over and around the facility.

- The DOE will perform a closure review study.

- The DOE will perform the following surveys to establish baseline data for the baseline database.

  - Seismic survey over the waste panels after final facility closure (one time).
  - Resistivity survey over the waste panels after final facility closure (one time).
  - Electromagnetic survey over the waste panels after closure (one time).
  - Gravitational survey after final facility closure (one time).
  - Subsidence survey (throughout the program lifetime).
  - Obtain and archive core samples from previous core work (one time).

- The DOE will initiate the monitoring program after closure. The DOE will perform periodic leveling surveys of the subsidence network and develop a schedule for future surveys. The DOE will perform the radiological environmental monitoring program for two years and the abbreviated program for an additional three years.

- The DOE will compare leveling survey data to expected results.

- The DOE will perform periodic reviews at least every two years during the monitoring program to evaluate the monitoring schedule.

- The DOE will perform maintenance on RCRA wells, replacing casings as required or every 25 years until monitoring ceases. The DOE will monitor in accordance with the postclosure monitoring schedule and postclosure monitoring plan requirements.

- The DOE will perform maintenance on subsidence network as required (determined during the leveling surveys).

This monitoring concept is based on current technologies and data for monitoring repository performance. Future monitoring during the repository development and operational phases may provide data that lead to the conclusion that postclosure monitoring will not be relevant or may identify new parameters that must be monitored.

The monitoring techniques specified in this report can be used to meet the requirements in the current regulations governing the facility and to monitor performance of the facility. This concept provides for a reliable database against which future monitoring results can be compared.

MON.8 QA and Quality Control Requirements

Various QA and quality control requirements exist for the DOE and many QA and quality control programs are in place. The WIPP is a DOE facility and as such has specific DOE guidelines for QA and quality control management. These guidelines for WIPP can be referenced in the *Quality Assurance Program Document,* CA0-94-1012, 1996, Revision 1.0. The DOE has agreed to adopt QA and quality control guidance from the American Society of Mechanical Engineers Nuclear Quality Assurance (NQA)-1, NQA-2 Part 2.7, and NQA-3. The EPA also has imposed QA and quality control requirements for the data management and the postclosure monitoring plan, specifically requirements in 40 CFR § 268.6(b (4) and 40 CFR § 268.6 (c) (1 through 5). The scientific advisor also has a QA and quality control program that is used for data collection that impacts postclosure monitoring.

For this postclosure monitoring report, all the current and future programs will be conducted under the applicable QA and quality control qualifications described in Chapter 5.0.

Other QA issues are associated with 40 CFR § 268.6 requirements. This regulation requires the postclosure monitoring plan to contain detailed records of the postclosure monitoring system and data collection and recording procedures. Specifically, "All sampling, testing, and analytical data must be approved by the Administrator and must provide data that is accurate and reproducible" (40 CFR § 268.6(c)(5)(i)) and, "A quality assurance and quality control plan addressing all aspects of the monitoring program must be provided to and approved by the Administrator" (40 CFR § 268.6(c)(5)(iii)). The DOE's quality control description for the WIPP has been used in all applicable postclosure monitoring program development and shall be used for all future actions within the postclosure monitoring program.

REFERENCES

Barrows, L.J., Shaffer, S-E., Miller, W.B., and Fett, J.D. 1983. *Waste Isolation Pilot Plant (WIPP) Site Gravity Survey and Interpretation*, SAND82-2922. Sandia National Laboratories, Albuquerque, NM.

Chmielewski, B.C., and Ewell R. 1994. *The Powerstick.* Jet Propulsion Laboratory. Pasadena, CA: California Institute of Technology.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026, Vols. 1 and 2. Office of Environmental Restoration and Waste Management, Washington, D.C.

DOE (U.S. Department of Energy). 1981. State of New Mexico vs. U. S. Department of Energy, *Agreement for Consultation and Cooperation.* Civil Action No. 81-0363 JB, July 1981 and supplements, revisions, and modifications dated December 1982, March 1983, November 1984, and March 1988.

DOE (U.S. Department of Energy). 1983. *Results of Site Validation Experiments,* TME-3177, Vol. II, p. 47. U.S. Department of Energy, Albuquerque, NM.

DOE (U.S. Department of Energy). 1990. *Final Safety Analysis Report.* WP 02-9, Rev. 0, May 1990. Westinghouse Electric Corporation, Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U.S. Department of Energy). 1991. *Report of the Geotechnical Panel on the Effective Life of Rooms in Panel 1,* DOE/WIPP 91-023. Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U.S. Department of Energy). 1992. *Background Water Quality Characterization Report for the Waste Isolation Pilot Plant (WIPP).* DOE-WIPP 92-013. Department of Energy, Carlsbad, NM.

DOE (U.S. Department of Energy). 1993. *Waste Isolation Pilot Plant Repository Monitoring Program Strategic Plan*, DOE/WIPP 93-029. Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U. S. Department of Energy). 1994a. *Waste Isolation Pilot Plant Environmental Monitoring Plan,* DOE/WIPP 94-024. Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U. S. Department of Energy). 1994b. *Waste Isolation Pilot Plant Site Environmental Report for the Calendar Year 1993,* DOE/WIPP 94-2033. Waste Isolation Pilot Plant, Carlsbad, NM.

DOI (U.S. Department of the Interior) Geologic Survey. 1981. *A Preliminary Analysis of Gravity and Aeromagnetic Surveys of the Timber Mountain Area, Southern Nevada.* Open File Report.

DOI (U.S. Department of the Interior) Bureau of Mines. 1991. *Ultra Low Frequency Electromagnetic Fire Alarm System for Underground Mines*. Report of Investigations RI- 9377.

Earth Technology Corporation. 1988. *Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site*, SAND87-7144. Sandia National Laboratories, Albuquerque, NM.

Elliot Geophysical Company. 1976. *A Preliminary Geophysical Study of a Trachyte Dike in Close Proximity to the Proposed Los Medaños Nuclear Waste Disposal Site, Eddy and Lea Counties, New Mexico.*

Elliot Geophysical Company. 1977. *Evaluation of the Proposed Los Medaños Nuclear Waste Disposal Site by Means of Electrical Resistivity Surveys, Eddy and Lea Counties, New Mexico.*

EPA (U.S. Environmental Protection Agency). 1986. *RCRA Ground-Water Monitoring Technical Enforcement Guidance Document*, OSWER-9950.1. Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1988a. Test Methods for Evaluating Solid Waste. Volume 1A through 1C and Volume 2. Field Manual Physical Chemical Methods (3rd Edition). Report EPA/SW-846, September 1988, National Technical Information Service, Springfield, VA.

EPA (U.S. Environmental Protection Agency). 1988b. *Compendium Method TO-14, The Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using SUMMA® Passivated Canister Sampling and Gas Chromatographic Analysis*. Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1994. *Requirements for Quality Assurance Project Plans for Environmental Data Operations*. EPA QA/R-5. Quality Assurance Management Staff. U.S. Environmental Protection Agency (Draft Interim Final). Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1996a. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. *Federal Register*, Vol. 61, pp. 5224 – 5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1996b. Compliance Application Guide for 40 CFR Part 194. EPA 402-R-95-014, March 29, 1996. Office of Radiation and Indoor Air, Washington, D.C.

G.J. Long and Associates, Inc. 1976. *Report Interpretation of Geological Data Los Medaños and Vicinity Lea and Eddy Counties, New Mexico.*

Griswold, G.B. 1977. *Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM.* SAND77-0964. Sandia National Laboratories, Albuquerque, NM.

Hern, J.L., Powers, D.W., and Barrows, L.J. 1978. *Seismic Reflection Data Report Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico*, Vol. I & II. SAND79-0264. Sandia National Laboratories, Albuquerque, NM.

Powers, D.W., Lambert, S.J., Shaffer, S-E., Hill, L.R., and Weart, W.D., eds. 1978. *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND78-1596. Sandia National Laboratories, Albuquerque, NM.

Powers, D.W. 1993. *Background Report on Subsidence Studies for the Potash Mines and WIPP Site Area, Southeastern New Mexico.* IT Corporation.

Sutherland, H.J. and Munson. 1983. *Subsidence Predictions for High Extraction Mining Using Complementary Influence Functions.* SAND82-2949. Albuquerque: Sandia National Laboratories.

WD (WD:90:1003). 1990. R. F. Kehrman letter to J. A. Mewhinney, "Subject: Discontinuation of Environmental Dosimetry Program." July 24, 1990.

WEC (Westinghouse Electric Corporation). 1994a. *VOC Monitoring Plan.* WP 12-6, Rev. 1. January 21, 1994. Waste Isolation Division, Carlsbad, NM.

WEC (Westinghouse Electric Corporation). 1994b. *VOC Monitoring Quality Assurance Project Plan.* WP 12-7, Rev. 2. January 21, 1994. Carlsbad, NM: Waste Isolation Division.

WEC (Westinghouse Electric Corporation). 1994c. *Backfill Engineering Analysis Report.* IT Corporation for WEC.

WIPP Performance Assessment Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991.* SAND91-0893. Vols. 1-3. Sandia National Laboratories, Albuquerque, NM.

ATTACHMENT

Attachment 1: MONPAR (Monitoring Parameters)

M

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

MON Attachment 1

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ACRONYMS

CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
FEPs	features, events, and processes
LHS	Latin hypercube sampling
WIPP	Waste Isolation Pilot Plant

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MONPAR

MONPAR.1 Analysis Methodology

In accordance with 40 Code of Federal Regulations (CFR) § 194.42(a), the DOE has analyzed the effects of disposal system parameters on the containment of waste in the disposal system. The results of the analysis are to be used in developing plans for preclosure (operational) and postclosure monitoring. According to 40 CFR § 194.42(c), the objective of the analysis is to identify parameters that are significant. The analysis included the items described in 40 CFR § 194.42(a):

> (1) Properties of backfilled material, including porosity, permeability, and degree of compaction and reconsolidation;
>
> (2) Stresses and extent of deformation of the surrounding roof, walls, and floor of the waste disposal room;
>
> (3) Initiation or displacement of major brittle deformation features in the roof or surrounding rock;
>
> (4) Ground water flow and other effects of human intrusion in the vicinity of the disposal system;
>
> (5) Brine quantity, flux, composition, and spatial distribution;
>
> (6) Gas quantity and composition; and
>
> (7) Temperature distribution.

Significant parameters are defined in 40 CFR § 194.42(c) as those that "affect the system's ability to contain waste or the ability to verify predictions about the future performance of the disposal system."

In this analysis, the U.S. Department of Energy (DOE) has used an approach which is consistent with previous work regarding disposal system performance, and is also consistent with the criteria for certification, as described in this appendix.

The term parameter is used in 40 CFR Part 194 to describe properties and processes in the disposal system. While this use is somewhat inconsistent with the DOE's use of parameters in the mathematical modeling system, the DOE has considered parameters, properties, and processes in this analysis to satisfy the criteria of 40 CFR § 194.42.

40 CFR § 194.42(c) says "A disposal system parameter shall be considered significant if it affects the system's ability to contain waste or the ability to verify predictions about the future performance of the disposal system." The DOE has implemented these criteria for significance in this analysis as follows:

- A parameter's effect on "the system's ability to contain waste" has been evaluated in terms of its potential effect on compliance with the regulatory release limits.

- A parameter's effect on "the ability to verify predictions about the performance of the disposal system" has been evaluated in terms of verifying the assumptions used in modeling the system's performance.

The waste containment requirements in 40 CFR § 191.13 are defined as compliance with the release limits in 40 CFR § 191.13(a) and with the individual and groundwater protection standards in 40 CFR § 191.15 and 40 CFR § 191.24, respectively. Containment and compliance are directly related: properties and processes which are significant for waste containment are also significant for compliance with the release limits. Therefore, the DOE uses compliance with the release limits as the performance measure to determine which parameters are significant to waste containment.

The DOE may verify assumptions used in system performance in one or more of the following ways:

- Measurement of physical and chemical conditions to see if they remain consistent with expected conditions or within the range of conditions incorporated into the assumptions and models. This is useful only for those conditions that are significant to calculated system performance.

- Measurement of physical and chemical processes that are currently modeled based on professional judgement or regulatory guidance because data are not available. This may be applicable to processes that are significant to system performance and have not been considered in previous performance assessments.

As described in Section 6.4.11, the parameter database includes the parameters used in performance assessment codes. The parameters in the database fall into two broad categories: those that are assigned fixed values, and those that are uncertain and are therefore assigned a range of values.

The DOE considered the major processes and models described in Section 6.4 and the results of previous performance assessments and developed an initial list of potentially significant parameters to be subjected to this analysis. Parameters were included in this analysis because they met one or more of the following criteria:

- The parameter represents one or more important aspects of the process or model

- The parameter represents subjective uncertainty (such as spatial variability in a physical property or process used in modeling results of repository performance)

- The parameter represents stochastic uncertainty (such as drilling rate for consideration of human intrusions)

- The parameter represented subjective or stochastic uncertainty in previous preliminary performance assessment calculations (such as the diameter of the drill bit in the intrusion borehole)

- The parameter proved to be moderately to highly sensitive in previous preliminary performance assessment calculations (for example, 1991, 1992)

The DOE assigned a range of values to each of the uncertain parameters used in the performance assessment. The subjective parameters are the basis for creating the vectors (sets) of parameter values using Latin hypercube sampling (LHS) in the Monte Carlo analysis described in Section 6.1.5. The stochastic parameters that represent the probability of plausible and important events are subjected to random sampling in construction of the complementary cumulative distribution function (CCDF) used in comparisons with the release limits in 40 CFR § 191.13(a).

In the analysis of parameters discussed in this appendix, the DOE considered the parameters meeting the criteria listed above, together with the properties and processes identified in 40 CFR § 194.42(a). Each parameter is considered in the context of scenarios where it may be significant. As described in Section 6.2 and Appendix SCR, there are three categories of features, events, and processes (FEPs) that are screened for scenario construction:

- Natural FEPs

- Waste- and repository-induced FEPs

- Human-initiated events and processes

The results of the analysis of the effects of disposal system parameters on waste containment are organized into the same three categories and are presented in the following sections.

MONPAR.2 Potentially Significant Parameters for Describing Natural Properties and Processes

The parameters for describing natural properties and processes that were considered in this analysis fall into seven groups:

- Hydrologic properties of the undisturbed Salado Formation, including properties that govern brine quantity, flux, and spatial distribution.

- Composition of brine in the Salado.

- Hydrologic properties of the undisturbed Culebra Member of the Rustler Formation, including properties that govern brine quantity, flux, and spatial distribution.

- Composition of brine in the Culebra.

- Hydrologic properties of the undisturbed Castile Formation, including properties that govern brine quantity, flux, and spatial distribution.

- Composition of brine in the Castile.

- Natural temperature distribution in the disposal system.

The results of the DOE's analysis are presented in Table MONPAR-1. The parameters describing natural properties and processes are discussed in the following section.

MONPAR.2.1 Salado Hydrology

Hydrologic properties of the intact Salado Formation are incorporated into performance assessment through use of parameters which are consistent with extensive experimental observations.

Variations in these parameters have a moderate effect on system performance assessment. There is no indication that properties of the intact (far-field) Salado will change during the regulatory period; thus they will not be monitored during the operational period nor during the postclosure period.

The Salado is made up of low-permeability beds of variable composition. The low permeability provides a hydrologic barrier in all directions between the repository and the accessible environment. The structure of the Salado and its bedded hydrostratigraphic units are incorporated into the geometry of the performance assessment models as discrete regions (Section 6.4.2). The Salado in the vicinity of the repository is composed mainly of pure and impure halite and anhydrite. A large amount of information about the hydraulic properties of these materials has been collected through field and laboratory experiments.

Excavation of the repository has altered natural pressure gradients in the Salado, creating the potential for fluid flow. The properties of the rock in the zone surrounding the repository have also been altered in response to the pressure gradients. This disturbed rock zone (DRZ) and its properties are discussed in Sections MONPAR.3.1, MONPAR.3.2, and MONPAR.3.3.

In the intact Salado (outside the DRZ), hydrologic parameters for the layers are uniform and constant, with the exception of porosity, permeability, pore pressure, pore shape distribution, and residual brine saturation (minimum brine concentration at which flow will occur through

Table MONPAR-1. Potentially Significant Natural Parameters

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Salado hydrology	Hydrologic properties of undisturbed Salado. Brine quantity, flux, and spatial distribution.	Properties and conditions in the far-field (undisturbed) Salado affect radionuclide containment and transport within the halite and anhydrite interbeds beyond the disturbed rock zone.	Impure halite effective porosity	Performance assessment models and calculations	2	2	N	N
			Impure halite permeability		2	2	N	N
			Impure halite pore compressibility		3	3	N	N
			Impure halite far-field pore pressure		2	2	N	N
			Anhydrite permeability		1[c]	1[c]	N	N
			Anhydrite pore compressibility		2	2	N	N
			Anhydrite 2-phase flow model choice		2	2	N	N
			Salado pore shape		2	2	N	N
			Salado residual brine saturation		2	2	N	N
			Salado residual gas saturation		2	2	N	N

Table MONPAR-1. Potentially Signficant Natural Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containmenta	Significant Effects on Verifying Predictions a	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Salado hydrology (continued)	Hydrologic properties of undisturbed Salado. Brine quantity, flux, and spatial distribution.	Properties and conditions in the far-field (undisturbed) Salado affect radionuclide containment and transport within the halite and anhydrite interbeds beyond the disturbed rock zone.	Brine quantity (initial brine saturation)[d]	40 CFR § 194.42(a)(5)	3	3	N	N
			Brine flux (permeabilities, porosity, pore compressibilities, model choice)[d]		2	2	N	N
			Brine spatial distribution (initial brine saturation)[d]		3	3	N	N
Salado brine	Brine composition	Brine composition affects radionuclide mobilization and repository chemistry.	Brine composition (pmH, minerals)[d]	40 CFR § 194.42(a)(5)	1	1	N	N
Culebra hydrology	Hydrologic properties of undisturbed Culebra. Groundwater quantity, flux, and spatial distribution.	Properties and conditions in the undisturbed Culebra affect radionuclide transport within the Culebra in the absence of effects of human-initiated events and processes.	Transmissivity	Performance assessment models and calculations	2	2	N	N
			Advective porosity (fracture porosity)		2	2	N	N
			Half matrix block length (fracture spacing)		1	1	N	N

Table MONPAR-1. Potentially Signficant Natural Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Culebra hydrology (continued)	Hydrologic properties of undisturbed Culebra. Brine quantity, flux, and spatial distribution.	Properties and conditions in the undisturbed Culebra affect radionuclide transport within the Culebra in the absence of effects of human-initiated events and processes.	Diffusional porosity (matrix porosity)	Performance assessment models and calculations	2	2	N	N
			Longitudinal dispersivity		3	3	N	N
			Climate change index		3	3	N	N
			Groundwater quantity (initial brine saturation)[d]	40 CFR § 194.42(a)(5)	3	3	N	N
			Groundwater flux (transmissivity, fracture and matrix porosity, fracture spacing and index, dispersivity, climate index)[d]		2	2	Y	Y
			Groundwater spatial distribution (initial brine saturation)[d]		3	3	N	N
Culebra groundwater	Groundwater (brine) composition	Groundwater composition may affect radionuclide transport.	Groundwater composition (pmH, minerals)[d]	40 CFR § 194.42(a)(5)	3	3	Y	N

Table MONPAR-1. Potentially Signficant Natural Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Castile hydrology	Hydrologic properties of undisturbed Castile. Brine quantity, flux, and spatial distribution.	Properties and conditions in the undisturbed Castile may affect direct releases from human-initiated drilling events.	Brine volume in reservoir	Performance assessment models and calculations	1[e]	1[e]	N	N
			Brine reservoir volume selection index		1[e]	1[e]	N	N
			Brine reservoir pressure		1[e]	1[e]	N	N
			Brine reservoir permeability		1[e]	1[e]	N	N
			Brine reservoir rock compressibility		1[e]	1[e]	N	N
			Brine quantity (brine volume)[d]	40 CFR § 194.42(a)(5)	1[e]	1[e]	N	N
			Brine flux (permeability, pressure, porosity, compressibility)[d]		1[e]	1[e]	N	N
			Brine spatial distribution (reservoir volume, rock volume)[d]		1[e]	1[e]	N	N

Table MONPAR-1. Potentially Signficant Natural Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Castile brine	Brine composition	Brine composition may affect repository chemistry following human-initiated drilling events which penetrate the Castile.	Brine composition (pmH, minerals)[d]	40 CFR § 194.42(a)(5)	2	2	N	N
Temperature distribution	Temperature distribution in the disposal system	Natural temperature gradients may cause physical and chemical processes and conditions that enhance radionuclide transport	Natural temperature distribution (not explicitly represented through parameters)	40 CFR § 194.42(a)(7)	3	3	N	N

[a] Significance legend: 1 - high, 2 - medium, 3 - low.
[b] See Appendix MON for monitoring program.
[c] Significant only in E2 intrusion. Significance is 2 in all other cases.
[d] The parameters listed in parentheses are among those used to calculate or model this property. Potentially significant parameters are also addressed separately.
[e] Significant only in E1 or E1E2 intrusions. Significance is 3 in all other cases.

the halite). Conceptually, this assumption of constant properties is based on observations of compositional and structural regularity in layers exposed by the repository and on the inference that there is little variation in large-scale averages of rock or flow properties across the disposal system. Effective porosity, permeability, pore pressure, pore shape distribution, and residual brine saturation are varied in the performance assessment models to account for observed spatial variations. Observed pore pressures are elevated above hydrostatic. In the models, they are also below lithostatic pressures; this is consistent with data collected during Waste Isolation Pilot Plant (WIPP) site experimental observations.

In summary, variable hydrologic parameters which are used to calculate **brine flux** in the intact Salado halite are **effective porosity**, **permeability**, **pore pressure**, and **pore compressibility**. Variable parameters describing the anhydrite interbeds are **effective porosity**, **permeability**, and **pore compressibility**. The **choice of model for 2-phase flow** in the anhydrite interbeds is used to accommodate the potential applicability of either of two models in predicting flow. Variable parameters common to both materials are **residual brine saturation**, **residual gas saturation**, and **pore shape distribution**. These parameters are subjected to LHS to incorporate the effects of their variability into the performance assessment calculations. These parameters are moderately significant, as they govern brine flow between the Salado and the DRZ.

Brine quantity within the Salado is estimated at 1 to 2 percent by volume. There is some variation in **spatial distribution**: the thin clay seams have been observed by Deal et al. (1993) to contain up to 25 to 29 percent brine by volume (Section 2.2.1.3). This brine may move toward areas of low pressure, such as the repository (see discussion of hydrologic properties of the DRZ in Section MONPAR.3.3). Flow in the intact Salado occurs only in response to pressure gradients; these do not occur in the undisturbed Salado. Much of the brine appears to be completely immobilized within the salt. Additional information is available in Appendix GCR. Brine quantity and spatial distribution are incorporated into the performance assessment models through the parameters described above.

MONPAR.2.2 Salado Brine Composition

Composition of Salado brines has been well established through investigations. Brine composition is significant and is incorporated into performance assessment calculations.

Based on the extensive experimental evidence collected, there is no indication that Salado brine composition will change over the regulatory period; thus it will not be routinely monitored during the operational period nor during the postclosure period.

The composition of Salado brines has been well established through investigations over the past 15 years. Two primary brines represent the Salado: Brine A and Brine SPC (Brush, 1990). The relevant properties of both brines are incorporated into the performance assessment models through their effects on repository chemistry (MONPAR.3.7 and Appendix SOTERM). The chemical conditions in the repository, including the pmH, are

assumed to be controlled by equilibrium between minerals (that is, magnesium oxide, Salado halite, and anhydrite present in interbeds), brine present, and waste. The pmH in this system with Salado brine will be about 9.4, and the carbon dioxide fugacity will be low and will be determined by the equilibrium system. The effects of magnesium oxide on repository chemistry are discussed further in MONPAR.3.7.

Given the geologic stability of the Salado and the age of the brine, overall **brine composition** is not expected to change significantly over the time scale of repository operations or, indeed, over the time scale relevant to system performance prediction.

MONPAR.2.3 Culebra Hydrology

Hydrologic properties of the undisturbed Culebra Member of the Rustler Formation exhibit spatial variability and are incorporated into performance assessment through both fixed values and parametric ranges which are consistent with experimental observations to date. Variations in some of the parameters are significant to system performance, as noted below.

The hydrologic properties of the undisturbed Culebra are not expected to change during the regulatory period, thus they will not be monitored during the operational period nor during the postclosure period.

The Culebra is a fractured dolomite with nonuniform properties both horizontally and vertically. Hydrologic properties of the Culebra become important during consideration of pathways for radionuclide migration resulting from inadvertent human intrusion. While undisturbed release to the Culebra are possible, modeling shows that the most likely source for radionuclide release to the Culebra via an abandoned borehole that intersects the repository where plug materials have failed over time due to natural degradation processes. If radionuclides are introduced into the Culebra, they may be transported from the point of introduction by natural **groundwater (brine) flux** through the Culebra.

In performance assessment, the spatial distribution of **transmissivity** in the Culebra is moderately significant, as are assumptions about fracture or matrix flow and processes that may occur that retard radionuclide transport (Section MONPAR.3.10). As described in Section 6.4.6.2, the spatial variation in transmissivity observed in the Culebra (Section 2.2.1.4.1.2) is retained in performance assessment and incorporated into the calculation scheme through use of a set of transmissivity fields which honor an extensive set of experimental data. Use of a large number of transmissivity fields is a statistically sound method for characterizing the uncertainty associated with transmissivity in the Culebra.

There is considerable variability in the structure and size of porous features in the Culebra, including fractures (of a variety of dimensions and interconnectedness), vuggy zones, and inter- and intragranular porosity. The principal flow occurs within those features with the high permeability. Slower flow rates and diffusion are primary processes in the lower permeability features. The Culebra is conceptualized as having two types of porosity,

advective and diffusive. Spatial variation in measured properties and uncertainties in the parameters is moderately significant and is captured through the use of LHS sampling for **advective (fracture) porosity, half matrix block length (fracture spacing), diffusive (matrix) porosity**, and **longitudinal dispersivity**. Advective porosity represents the porous features in which flow occurs. Advective porosity values are low, which is representative of flow in fractures. Diffusive porosity represents those porous features in which no flow is assumed to occur and diffusion occurs. Diffusive porosities are large relative to advective porosity, representative of the vugs, interparticle, and intercrystalline porosity of the bulk rock.

Groundwater (brine) quantity and **spatial distribution** are calculated quantities that are incorporated into the groundwater basin model of the units above the Salado (Section 2.2.1.4). Climate change effects have been incorporated into the flow model through use of a **climate change index** simulating increased recharge at the water table resulting from a cooler, wetter climate. The increased recharge is modeled through the groundwater velocity field in the Culebra. Variation in the climate change index is captured through the use of LHS sampling in performance assessment and is not significant to system performance.

MONPAR.2.4 Culebra Groundwater Composition

Culebra groundwater is less saline than Salado and Castile brines. The Culebra groundwater is spatially variable, and its composition has been well established through investigations. Groundwater composition is incorporated into performance assessment calculations; however it is not significant to performance.

Based on extensive experimental evidence there is no indication that Culebra groundwater composition will change over the regulatory period; however, monitoring would provide information that is relevant to a comprehensive environmental monitoring program.

There is considerable variation in groundwater chemistry in the Culebra. Four zones, each with its characteristics, have been identified (Section 2.4.2.1). The groundwater in each of these zones has been well characterized. Note that the fluid in the Culebra is referred to as groundwater to differentiate it from the more saline brines found in the Salado and Castile.

Given the observed geologic stability of the Culebra and the age of the groundwater, overall **brine (groundwater) composition** is not expected to change significantly over the time scale of repository operations or, indeed, over the time scale important to disposal system performance.

MONPAR.2.5 Castile Hydrology

The Castile Formation underlying the WIPP may contain reservoirs of pressurized brine. This is incorporated into performance assessment through use of input parameters that address hydrologic properties and the probability that a reservoir will be encountered during

an intrusion event. The hydrologic properties are significant to disposal system performance in such an intrusion event. The Castile is not significant to system performance except for the brine reservoirs.

There is no indication that the properties of the undisturbed reservoirs will change over the regulatory period although the assumpiton is made in the modeling that intrusions into brine reservoirs leads to their eventual depletion. It is not possible to completely define the location and extent of brine reservoirs without jeopardizing the integrity of the disposal system.

The Castile underlying the WIPP is dominated by low-permeability anhydrite and halite zones, with isolated regions of higher permeability that may contain pressurized brine. Hydraulic tests indicate these brine reservoirs are limited in extent, but their location and dimensions are uncertain, as described in Section 6.4.12.6. The probability of encountering a reservoir in any intrusion event is discussed in MONPAR.4.1. The presence of the brine and the parameters describing reservoir properties are significant to repository performance only in the event of inadvertent human intrusion into the repository and underlying brine reservoir (the E1 intrusion event described in Section 6.3.2.2.1).

The properties of the brine reservoir used in performance assessment include the **pressure**, **permeability**, **rock compressibility**, and **brine volume** (quantity). As described in Section 6.4.8, five possible reservoir **brine volumes** are used in calculating the consequences of first penetration of a reservoir by an exploratory borehole. An **index** is used to randomly select the volume of the reservoir that may be encountered during an intrusion event. In the performance assessment calculations, the porosity of the brine reservoir is set such that the reservoir brine volume is contained in the constant rock volume used in the model (that is, the **spatial distribution** of the brine). A brine reservoir is assumed to exist beneath the waste panels, and it is assigned properties that include some sampled parameters.

MONPAR.2.6 Castile Brine Composition

Composition of brines from two Castile brine reservoirs is moderately significant and is incorporated into performance assessment calculations.

There is no evidence to suggest that the brine composition will change over the regulatory period. It is not possible to further investigate composition of any brine which may be present below the repository without jeopardizing the integrity of the disposal system. Therefore no further investigations or monitoring will be performed during the operational period nor during the postclosure period.

Two brines encountered in the Castile (WIPP-12 and ERDA-6) differ from each other, but both are nearly saturated with respect to halite (Brush, 1990). The relevant aspects of the ERDA-6 **brine composition** are incorporated into the performance assessment models through its effect on repository chemistry (MONPAR.3.7 and Appendix SOTERM). Under

conditions where pressurized Castile brine enters the repository, the chemical conditions in the repository, including the pmH, are assumed to be controlled by equilibrium between minerals (that is, magnesium oxide, halite, and anhydrite present in interbeds), brine present, and waste. The pmH in the system with Castile brine will be approximately 9.9. The carbon dioxide fugacity will accordingly be maintained at low levels and will be determined by the equilibrium system. This will serve to limit radionuclide solubilities. The effects of magnesium oxide on repository chemistry are discussed further in MONPAR.3.7.

MONPAR.2.7 Natural Temperature Distribution

Natural geological thermal gradients have been characterized and are not significant: they will not affect repository performance, either directly by affecting the containers and repository chemistry, or indirectly by altering fluid flow through the Salado or the Culebra. Therefore natural thermal gradients will not be monitored during the operational period nor during the postclosure period.

As described in Appendix SCR (Section SCR.1.2.2.3), the geothermal gradient in the region of the WIPP has been measured at about 50°C per mile (30°C per kilometer). Given the generally low permeability in the region, and the limited thickness of units in which groundwater flow occurs (for example, the Culebra), natural convection will not have a significant effect on groundwater flow. No natural FEPs have been identified that could significantly alter the **temperature distribution** of the disposal system or give rise to thermal effects on groundwater flow.

MONPAR.3 Potentially Significant Parameters that Describe Waste- and Repository-Induced Properties and Processes

The parameters that describe waste- and repository-induced properties and processes that were considered in the analysis fall into ten groups:

- Stresses and extent of deformation of the surrounding roof, walls, and floor of the waste disposal room; mechanical properties and behavior of the halite during creep closure.

- Initiation or displacement of major brittle deformation features in the roof or rock; mechanical properties and behavior of brittle rock (anhydrites) during creep closure.

- Altered hydrologic properties of the Salado in the DRZ surrounding the repository, including properties which govern brine quantity, flux, and spatial distribution.

- Mechanical and hydrologic properties of the disposal room (and the waste in it) in response to repository conditions (mechanical properties of backfill are considered separately).

- Properties of backfilled material, including porosity, permeability, and degree of compaction and reconsolidation.

- Gas generation processes and rates; quantity and composition of gas in the disposal room.

- Disposal room chemistry and radionuclide source term; chemical composition of the brine, and interactions between the waste, brine, gas, and backfill.

- Temperature distribution in the repository.

- Shaft seal system performance.

- Mechanisms for radionuclide transport and retardation outside the repository.

The results of the DOE's analysis are presented in Table MONPAR-2. The parameters describing the waste- and repository-induced properties and processes are discussed in the following section.

MONPAR.3.1 Creep Closure

Creep closure of the repository will occur, and is included within compliance assessment and performance assessment models as a control on waste consolidation and other time-dependent disposal room conditions. The individual creep closure related parameters are not significant to performance assessment. Sufficient data have been collected for the purposes of verifying the underlying rock mechanics models as discussed subsequently. The numerical models of the repository used in performance assessment are based upon assumptions about long-term behavior that are not applicable to behavior during the operational period.

Further monitoring of creep closure and stress would not provide information that is useful for calculating disposal system performance, nor would it lead to additional confidence in the performance assessment models. However, monitoring creep closure would provide information that is relevant to repository operations (Section 7.2.3.1).

Since the start of excavation at the WIPP, salt creep has led to deformation of the roof, walls and floor of the openings. Extensive monitoring of the resulting creep closure and **extent of deformation** has taken place over more than a decade, through measurements within the excavated rooms, and additional monitoring has been conducted in boreholes drilled from the repository. Data acquired from these measurements have been used to calculate **stresses** and to derive, calibrate and verify conceptual and numerical models of salt creep around excavations (for example, see Munson et al. 1989a,b; Munson and DeVries 1991). The models incorporate individual parameters such as **shear modulus**, **Young's modulus** and **Poisson's ratio**, and thermal properties such as **specific heat** to calculate extent of creep and dislocation.

Table MONPAR-2. Potentially Signficant Waste- and Repository-Induced Parameters

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Creep closure	Mechanical properties and behavior of the halite during creep closure. Stresses and extent of deformation of the surrounding roof, walls, and floor of the waste disposal room.	In response to the pressure gradient caused by the excavation and potential repository pressurization, the salt surrounding the repository will deform and creep. Fractures will also form in the salt, creating a disturbed rock zone (DRZ) around the repository (hydrologic properties of the DRZ are discussed separately).	Stresses (shear modulus, Young's modulus, Poisson's ratio, specific heat)[c]	40 CFR § 194.42(a)(2)	3	3	Y	N
			Extent of deformation (shear modulus, Young's modulus, Poisson's ratio, specific heat)[c]		3	3	Y	N
Major deformation features in surrounding rock	Mechanical properties and behavior of brittle rock during creep closure. Initiation or displacement of major brittle deformation features in the roof or surrounding rock.	In response to the pressure gradient caused by the excavation and potential repository pressurization, the brittle anhydrite interbeds are likely to fracture. Such fractures could potentially extend beyond the DRZ, forming large-scale fractures and causing subsidence.	Initiation of brittle deformation features (fracture initiation pressure, increment for full fracturing)[c]	40 CFR § 194.42(a)(3)	3	3	Y	N
			Displacement of major brittle deformation features (not explicitly represented through parameters)		3	3	Y	N

Table MONPAR-2. Potentially Signficant Waste- and Repository-Induced Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Salado hydrology near the repository (DRZ)	Hydrologic properties of disturbed Salado in the DRZ near the repository. Brine quantity, flux, and spatial distribution.	Altered hydrologic properties in the DRZ (halite and anhydrite) may enhance fluid transport into and out of the waste disposal area.	DRZ permeability	Performance assessment models and calculations	2	2	N	N
			DRZ effective porosity		2	2	N	N
			Brine flux (DRZ effective porosity and permeability, fracture permeability enhancement)[c]	40 CFR § 194.42(a)(5)	2	2	N	N
			Brine quantity and spatial distribution (DRZ initial brine saturation)[c]		3	3	N	N
Disposal room properties	Mechanical and hydrologic properties of the disposal room (and the waste in it) in response to repository conditions	Disposal room properties affect fluid flow in and out of the repository, and radionuclide migration out of the repository.	Waste area residual gas saturation	Performance assessment models and calculations	2[d]	2[d]	N	N
			Waste area residual brine saturation		2[d]	2[d]	N	N
			Brine wicking		2	2	N	N
			Waste area permeability		2	2	N	N

Table MONPAR-2. Potentially Signficant Waste- and Repository-Induced Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Backfill mechanical properties	Properties of backfilled material, including porosity, permeability, and degree of compaction and reconsolidation	Backfill present in the disposal room may provide sufficient mechanical strength to retard creep closure of the surrounding halite. Backfill may also alter fluid flow in the disposal room.	Backfill porosity	40 CFR § 194.42(a)(1)	3	3	N	N
			Backfill permeability		3	3	N	N
			Degree of backfill compaction		3	3	N	N
			Backfill reconsolidation		3	3	N	N
Gas generation	Gas generation processes and rates. Quantity and composition of gas in the disposal room.	Gas pressure may retard disposal room closure and enhance fluid flow and radionuclide migration out of the disposal room. Gas composition affects brine composition and disposal room chemistry.	Rate of steel corrosion under inundated conditions with carbon dioxide present	Performance assessment models and calculations	3	3	N	N
			Rate of steel corrosion under inundated conditions without carbon dioxide		2	2	N	N
			Rate of microbial degradation under inundated conditions		3	3	N	N
			Rate of microbial degradation under humid conditions		3	3	N	N

Table MONPAR-2. Potentially Signficant Waste- and Repository-Induced Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Gas generation (continued)	Gas generation processes and rates. Quantity and composition of gas in the disposal room.	Gas pressure may retard disposal room closure and enhance fluid flow and radionuclide migration out of the disposal room. Gas composition affects brine composition and disposal room chemistry.	β-factor for microbial degradation process	Performance assessment models and calculations	3	3	N	N
			Probability factor for different types of microbial degradation		3	3	N	N
			Gas quantity (rates of corrosion and microbial degradation, probability of microbial degradation)[c]	40 CFR § 194.42(a)(6)	2	2	Y	N
			Gas composition (hydrogen, carbon dioxide)[c]		3	3	Y	N
Disposal room chemistry	Chemical composition of brine in disposal room. Chemical interactions between waste, brine, gas, and backfill. Actinide source term.	Brine composition and properties affect actinide solubility and colloid formation and stability. Gas composition affects brine composition. Backfill controls composition of gas and brine.	Choice of radionuclide oxidation state distribution	Performance assessment models and calculations	1	1	N	N

Table MONPAR-2. Potentially Signficant Waste- and Repository-Induced Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Disposal room chemistry (continued)	Chemical composition of brine in disposal room. Chemical interactions between waste, brine, gas, and backfill. Actinide source term.	Brine composition and properties affect actinide solubility and colloid formation and stability. Gas composition affects brine composition. Backfill controls composition of gas and brine.	Solubility of Am(III), Cm(III), Pu(III), Pu(IV), Th(IV), U(IV), Np(IV), Np(V), and U(VI) in Salado brine[e]	Performance assessment models and calculations	I	I	N	N
			Solubility of Am(III), Cm(III), Pu(III), Pu(IV), Th(IV), U(IV), Np(IV), Np(V), and U(VI) in Castile brine[e]		I	I	N	N
			Concentration of humic colloids containing III, IV, V, and VI actinides (expressed as a fraction of concentration of dissolved III, IV, V, and VI actinides, respectively) in Salado brine		I	I	N	N

Table MONPAR-2. Potentially Signficant Waste- and Repository-Induced Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment [a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Disposal room chemistry (continued)	Chemical composition of brine in disposal room. Chemical interactions between waste, brine, gas, and backfill. Actinide source term.	Brine composition and properties affect actinide solubility and colloid formation and stability. Gas composition affects brine composition. Backfill controls composition of gas and brine.	Concentration of humic colloids containing III, IV, V, and VI actinides (expressed as a fraction of concentration of dissolved III, IV, V, and VI actinides, respectively) in Castile brine	Performance assessment models and calculations	1	1	N	N
Shaft seal system	Performance of shaft seal system.	Shaft seals help provide long-term waste containment in the repository.	Clay member permeability	Performance assessment models and calculations	2	2	N	N
			Concrete member permeability		2	2	N	N
			Asphalt member permeability		2	2	N	N
			Shaft DRZ permeability		2	2	N	N
			Index for selecting crushed salt seal component permeability to represent consolidation		1	1	N	N

Table MONPAR-2. Potentially Signficant Waste- and Repository-Induced Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment [a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Shaft seal system (continued)	Performance of shaft seal system.	Shaft seals help provide long-term waste containment in the repository.	Seal residual gas saturation	Performance assessment models and calculations	3	3	N	N
			Seal residual brine saturation		3	3	N	N
			Seal pore shape		3	3	N	N
Temperature distribution	Temperature distribution in the repository	Waste- and repository-induced temperature gradients may cause physical and chemical processes and conditions that enhance radionuclide transport	Waste- and repository-induced temperature distribution (not explicitly represented through parameters)	40 CFR § 194.42(a)(7)	3	3	N	N
Radionuclide transport	Mechanisms for transport and retardation outside the repository.	Transport is governed by the form of the radionuclide and the physical and chemical features of the formation.	Distribution coefficients for dissolved radionuclides in the Salado	Performance assessment models and calculations	3	3	N	N
			Distribution coefficients for colloidal radionuclides in the Salado		3	3	N	N

Table MONPAR-2. Potentially Signficant Waste- and Repository-Induced Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment [a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Radionuclide transport (continued)	Mechanisms for transport and retardation outside the repository.	Transport is governed by the form of the radionuclide and the physical and chemical features of the formation.	Distribution coefficients for dissolved Am(III), Pu(III), Pu(IV), Th(IV), U(IV), and U(VI) in the Culebra	Performance assessment models and calculations	1	1	N	N

[a] Significance legend: 1 - high, 2 - medium, 3 - low.
[b] See Appendix MON for monitoring program.
[c] The parameters listed in parentheses are among those used to calculate or model this property. Potentially significant parameters are also addressed separately.
[d] Significant only in E1 intrusions: E1, E2, and E1E2. Significance is 3 in all other cases.
[e] Solubility distributions are calculated for each actinide using the FMT model and code.

The detailed rock mechanics models of salt creep have been used to derive simplified models for the DRZ and repository for use in performance assessment calculations (Section 6.4.3.1, Appendix PORSURF). Although based on rock mechanics, these models of repository behavior are also based on a number of assumptions about long-term behavior that will not be applicable to modeling behavior during the preclosure period (for example, the models assume that the waste containers have little strength and do not impede closure of the disposal room).

MONPAR.3.2 Major Deformation Features

The initiation or displacement of major brittle deformation features in the roof or surrounding rock, beyond that already accounted for in performance assessment calculations, is not significant to the containment of waste. The individual parameters that are used in modeling the mechanical behavior of brittle anhydrite interbeds are not significant to performance assessment; the parameters that are used in modeling hydrological effects are discussed in MONPAR.3.3.

Monitoring mechanical behavior of the interbeds would not provide information that is useful for calculating system performance, nor would it lead to additional confidence in the performance assessment models. However, monitoring would provide information that is relevant to repository operations (Section 7.2.3.1).

Because the Salado is not composed of pure halite, and because the rate of deformation near the repository may be too great to be accommodated entirely by salt creep, other deformation mechanisms will accompany salt creep. These other mechanisms can be collectively classified as brittle deformation. Should these mechanisms occur, they will result in the extension of the DRZ around the repository. This potentially increases the instability of the DRZ could to lead to localized roof falls in the first few hundred years (Appendix SCR, Section SCR.2.3.3). In such cases, development of the DRZ may be sufficient to disrupt the anhydrite layers above the repository, which may create a zone of rock containing anhydrite extending from the interbeds toward a waste-filled room. **Brittle deformation features** (fractures) may be induced as the rock stress and strain distributions evolve because of creep, or in response to fluid pressure in the repository. Because of uncertainty in the process by which the disposal room DRZ heals, the flow model used in the performance assessment assumes that a higher-permeability zone remains for the long term. Thus, the potential effects of roof falls on flow paths are accounted for in performance assessment calculations through the parameters describing the hydrologic properties of the DRZ (MONPAR.3.3). In the long term, the effects of roof falls in the repository will not be significant because salt creep will reduce the void space and the potential for roof falls; the salt creep will also consolidate roof material that has fallen into the rooms.

Subsidence through salt creep or roof collapse associated with excavation or repository closure might affect the hydrologic properties of units above the repository and might cause large-scale rock fracturing (**displacement of major brittle deformation features**) between the repository horizon and the surface (Appendix SCR, Section SCR.2.3.4). The amount of subsidence that can occur as a result of salt creep closure in the waste-filled and sealed areas of the repository

depends on the volume of extracted rock, the initial and compressed porosities of various emplaced materials, the amount of inward creep of the repository walls, and the gas and fluid pressures within the repository. The DOE (Westinghouse 1994) has analyzed potential excavation-induced subsidence at the WIPP. For an empty repository, the DOE estimated the maximum potential subsidence at the surface to be less than 2 feet (0.62 meter). Maximum subsidence at the depth of the Culebra was estimated to be less than 1.8 feet (0.56 meter), and the maximum horizontal displacement at the depth of the Culebra was estimated to be less than 0.08 feet (0.2 meter), with a maximum horizontal strain of 0.007 percent. The induced strains will be uniformly distributed because no known faults or discontinuities occur in the vicinity of the WIPP. Strains of this magnitude would not be expected to cause cracking or extensive fracturing.

The DOE (Westinghouse 1994) also reported investigations of subsidence associated with potash mining operations located near the WIPP site to gain insight into the expected subsidence conditions at the WIPP. Subsidence over potash mines in the area will be much greater than at the WIPP because of the significant differences in stratigraphic position, depth, extraction ratio, and layout. The proposed WIPP rock extraction ratio is about 22 percent, as compared to over 65 percent for the lowest extraction ratios within local potash mines investigated by DOE. Also, the WIPP site is located stratigraphically much lower than the lowest potash mine, which is near the base of the McNutt Potash Zone (hereafter referred to as the McNutt). The base of the McNutt is about 490 feet (150 meters) above the repository horizon.

The reported maximum total subsidence at potash mines is about 5 feet (1.5 meters). This level of subsidence has been observed to have caused surface fractures. However, the DOE found no evidence that subsidence over potash mines had caused fracturing sufficient to connect the mining horizon to water-bearing units or the surface. The level of disturbance caused by subsidence above the WIPP repository will be less than that associated with potash mining and thus, by analogy, will not create fluid flow paths between the repository and the overlying units.

As a result of numerical analyses and observations of subsidence associated with potash mines, fracturing within units overlying the Salado and surface displacements caused by subsidence associated with repository closure are considered insignificant. The potential for subsidence to create fluid flow paths between the repository and units overlying the Salado is also considered insignificant, as it has low probability of occurrence over 10,000 years.

MONPAR.3.3 Hydrologic Properties in the DRZ

The presence of a DRZ surrounding the repository has been incorporated into performance assessment calculations. The properties of the DRZ have been well characterized; they include altered hydrologic properties which are expected to enhance near-field fluid flow both to and from the repository. The initial conditions and enhanced fluid flow are moderately significant to disposal system performance. In an effort to simplify the calculations, the effects

are...properties of the DRZ. This is believed to be a conservative choice with respect to the ultimate impact on predicted release.

Monitoring the DRZ hydrologic properties would not provide relevant information or verify assumptions used in performance assessment; therefore they will not be monitored during the operational period nor during the postclosure period.

Construction of the repository has caused a local change in stress field and has altered the permeability and effective porosity of the nearby rock around the repository. The increases in permeability and porosity in the interbeds are not expected to be completely reversible with creep closure of the disposal rooms. In addition, increased fluid pressure in the repository is expected to cause dilation and fracturing of the anhydrite interbeds. If they occur in performance assessments, these changes will further increase the permeability and porosity of the interbeds, providing enhanced pathways for flow of gas and brine (**brine flux**) between the waste-filled rooms and the nearby interbeds. The model of the DRZ used in performance assessment (described in Section 6.4.5.3) includes permanently increased **permeability** (to enhance fluid flow), and an increased effective **porosity** (reflecting observed changes in the DRZ and long-term conditions consistent with increased permeability). The performance assessment treatment of the DRZ creates a permanent high-permeability region that does not significantly impede flow between the repository and affected interbeds.

In the computational models, **brine quantity** and **spatial distribution** are calculated using the **initial brine saturation** and other parameters describing initial conditions for the simulation of the regulatory period. These parameters describe properties that are consistent with modeling assumptions and with observed conditions in that the DRZ is assumed to be initially fully brine-saturated near the repository. Excavation and waste emplacement operations result in partial drainage of the DRZ, subsequent evaporation of drained brine into mine air, followed by removal from the modeled system by air exchanged to the surface. The duration of the modeled operations is five years, simulating the shortest expected time between excavation and sealing of an individual panel. Thus the modeled DRZ has the highest reasonable initial brine saturation.

MONPAR.3.4 Hydrologic Properties in the Disposal Room

Mechanical and hydrologic properties of the disposal room are incorporated into performance assessment as they affect gas generation and fluid flow into and out of the repository. These properties and parameters are moderately significant to disposal system performance. Additional properties are significant in the event of intrusion into the repository; these are discussed in MONPAR.4.2. The conceptual model of disposal room behavior is based on extensive experimental data which support a number of assumptions about long-term behavior that will not be applicable during the preclosure period.

The closed disposal room will not achieve the expected long-term properties predicted in performance assessment during the operational or active control periods. Therefore,

monitoring the mechanical and hydrologic properties would not provide relevant information or verify assumptions used in performance assessment. Thus the disposal room properties will not be monitored during the operational period nor during the postclosure period.

Creep closure of waste disposal areas will cause their volume to decrease as the Salado deforms to consolidate and encapsulate the waste. This results in an associated change to the waste porosity. Resistance to creep closure is a function of both waste strength and fluid pressure. The amount of waste consolidation that occurs and the time it takes are governed by properties of the waste (waste strength, modulus, etc.), properties of the surrounding rock, the dimensions and location of the room, and the quantities of fluids present in the room. As described in Section 6.4.3.1, the closure process is modeled in terms of a porosity surface relating waste porosity to gas quantity, fluid pressure, and time under various conditions which affect gas generation.

In order to simulate long-term behavior, all waste containers are assumed to be breached at the time of final facility closure, allowing the contents to be immediately available for reactions which could generate gas. The effects of **wicking** are incorporated to account for the possibility of increased brine contact with the waste. The **permeability** of the waste is maintained in the model at a value representative of the average value of the compacted waste. Maximizing brine contact with the waste also increases radionuclide solubility and is consistent with assumptions in the conceptual models of repository chemistry (Section 6.4.3.4 and MONPAR.3.7). The **residual brine saturation** and **residual gas saturation** indicate the brine and gas saturation (respectively) at which brine or gas will flow through the waste; below these saturations the brine and gas are immobile. The variations in these parameters reflect the variety of wastes present in the repository.

These waste properties are moderately significant in the event of inadvertent human intrusion into the repository, as they will have some effect on the direct and long-term releases by affecting fluid flow through the repository. Direct and long-term releases resulting from inadvertent human intrusion are discussed in Sections MONPAR.4.2 and MONPAR.4.3, respectively.

MONPAR.3.5 Backfill Properties

The mechanical and hydrologic properties of the backfill are not significant to the performance assessment. Therefore, they will not be monitored during the operational or postclosure periods. Chemical control and chemical properties of the backfill are addressed in Section MONPAR.3.7.

The principal function of the backfill to be emplaced in the WIPP will be to control the chemical conditions in the disposal rooms resulting in a reduced potential for radionuclides to dissolve in brine. The backfill material will also have beneficial mechanical and hydrologic effects.

The amount of subsidence that can occur as a result of salt creep closure depends on the extraction ratio, the initial and compressed porosities of emplaced materials, the amount of inward creep of the repository walls, and the gas and fluid pressures within the repository. The DOE (Westinghouse 1994) has analyzed potential excavation-induced subsidence and the mechanical benefits of backfilling at the WIPP. Results of the DOE's study show that backfill emplacement would not significantly decrease subsidence in the waste emplacement area.

Similarly, because the backfill volume will be less than the waste volume, the reduction in average room permeability and effective porosity provided by the backfill will be insignificant. After waste emplacement, room permeability and effective porosity will be controlled essentially by the waste properties, the amount of salt creep, and the gas and fluid pressures. Thus, the backfill **porosity**, **permeability**, **degree of compaction**, and **reconsolidation** will have an insignificant effect on hydrologic conditions in the disposal rooms. Further, any deviations from expected performance will be beneficial to disposal system performance.

MONPAR.3.6 Gas Generation

Gas generated in the repository may retard creep closure, may fracture the anhydrite interbeds in the DRZ (enhancing fluid flow), and may enhance direct releases (MONPAR.4.2) These effects are moderately significant and are accounted for in performance assessment. Gas composition (carbon dioxide concentration) and the corrosion rate of metals are controlled chemically by the backfill and are not significant. Gas generation is moderately significant to system performance. The conceptual model of gas generation processes is based on experimental data and incorporates a number of assumptions about long-term behavior that will not be applicable during the operational period (such as anoxic conditions).

Monitoring the quantity and composition of gas generated in the closed panels would not provide information that is useful for calculating system performance, nor would it lead to additional confidence in the performance assessment models.

The major gas generation and consumption processes are incorporated into the models of the repository (Section 6.4.3.3). Gas will be produced in the repository because of a variety of chemical reactions, primarily those occurring between brine, metals, microbes, cellulosics and similar materials, plastics, and rubber materials, and by liberation of dissolved gases to the gas phase. The dominant processes are anoxic corrosion of metals in the waste containers and the waste and microbial degradation of cellulosics, plastics, and rubbers in the waste. Anoxic corrosion reactions will occur (in the presence of liquid brine) between brine and steel, aluminum, and aluminum alloys, producing hydrogen. All possible corrosion reactions are dependent on the presence of brine and decrease under alkaline conditions. The **corrosion rate** is affected by the presence of carbon dioxide produced by microbial degradation. Carbon dioxide will be controlled through reaction with the magnesium oxide (MgO) backfill (Appendix SOTERM Section SOTERM.2.2.2). Therefore, the gas in the repository will be composed primarily of hydrogen and the corrosion of steel in the absence of carbon dioxide is

the primary mechanism for gas generation in the closed repository; it is moderately significant to system performance.

Microbial degradation of cellulosics may or may not occur in the repository; this uncertainty is represented in the model by a **probability factor**. The **microbial degradation rate** differs for brine-inundated and humid conditions. The **β factor** is used to characterize the extent to which microbial-generated gases react with steel and steel corrosion products. Microbial degradation may produce a variety of gases; however, for the waste inventory and expected conditions, carbon dioxide and methane are expected to be the dominant gases generated. Radiolysis has been demonstrated by laboratory experiment and model calculations to be insignificant (Appendix SCR Section SCR.2.5.1.3.1).

The current conceptual models assign the density and viscosity of hydrogen to all generated gases. Since hydrogen is the most mobile of all the possible gas components, this assumption is both reasonable and conservative. Therefore, this assumption renders the **composition of the gas** as insignificant.

Gas quantity is a calculated quantity. It will affect repository pressure, which is a moderately significant parameter in other submodels of the disposal system, such as those calculating creep closure (Section 6.4.3.1), interbed fracturing (Section 6.4.5.2), two-phase flow (Section 6.4.3.2), and the radionuclide release associated with spallings during an inadvertent drilling intrusion (Section 6.4.7.1). Thus, gas quantity must be estimated and is significant to performance assessment. The model incorporates several assumptions designed to maximize gas generation in the years immediately following closure (for example, minimizing brine drainage from the DRZ by limiting the modeled operating period to five years and immediately breaching all containers). Thus, monitoring gas pressure or composition would not verify the assumptions made in the models.

MONPAR.3.7 Repository Chemical Conditions

Chemical conditions in the repository will affect radionuclide solubility; the solubility of dissolved radionuclides and stability of colloidal species are significant to system performance. The chemical conditions are controlled by interactions between the waste, abundant minerals in the brine, the backfill, and gas generated by microbial degradation in the repository. The conceptual model incorporates assumptions about long-term performance (for example, chemical constant conditions, thermodynamic equilibrium, and mixing the waste and brine) that are not applicable during the operational period.

The closed repository will not achieve the long-term chemical conditions (brine composition, dissolved actinide concentrations, or colloidal actinide concentrations) used in performance assessment during the operational or active control periods. Therefore, monitoring the chemical conditions will not provide relevant information or verify assumptions used in performance assessment. Chemical conditions in the repository cannot be monitored after

decommissioning without jeopardizing repository integrity. Thus these parameters will not be monitored during the operational period nor during the postclosure periods.

Brine composition in the repository can vary depending on the sequence of future human events. Brine from the Salado or brine from the Castile may be present in the repository in certain scenarios (Section 6.4.3.4). The compositions of these brines are discussed in MONPAR.2.2 and MONPAR.2.6, respectively. The chemical environment in the repository after closure is expected to favor lower oxidation states (that is, to be reducing). Based on experimental data (Appendix SOTERM Section SOTERM.3.4), the DOE has determined that alkaline conditions in the repository favor lower solubilities of the radionuclides (actinides).

Magnesium oxide will be added to the repository with the waste to ensure that alkaline conditions exist in the repository. The DOE will emplace enough magnesium oxide with sufficient surface area to ensure carbon dioxide uptake will exceed the carbon dioxide production rate. Therefore, it has been assumed that MgO emplaced with the waste will react with the carbon dioxide that forms, creating magnesium carbonate materials. Consequently, the fugacity of the carbon dioxide will be low. Because the processes that might cause time-dependent changes in important chemical conditions in the repository have been eliminated by addition of magnesium oxide and by the assumptions made regarding brine composition, performance assessment uses constant chemical conditions. The chemical conditions in the repository, including the pmH, are assumed to be controlled by equilibrium between minerals (that is, magnesium oxide, Salado halite, and anhydrite present in interbeds), brine present, and waste. In Salado brine, the pmH in this system will be about 9.4. In Castile brine, the pmH in this system will be about 9.9. (Appendix SOTERM Section SOTERM 2.2.2).

Radionuclides in the waste may be mobilized either by dissolution in brine, by bioaccumulation or sorption onto colloidal particles, or by condensation into colloidal forms as actinide-intrinsic colloids that could be carried by brine (Section 6.4.3.6). The dissolved actinide source term model calculates the dissolved concentration of each actinide in solution by applying the modeled solubility for the particular oxidation state, as determined by the oxidation state distribution for that actinide, at the repository conditions presented in Section 6.4.3.4. There are two possible oxidation state distributions for the actinides; each with a 50 percent chance of occurring. In the first distribution, the actinides exist in the more reduced oxidation states (reflecting extreme reducing conditions): U(IV), Np(IV), and Pu(III). In the second distribution, the radionuclides are present at higher oxidation states (reflecting less extreme reducing conditions): U(VI), Np(V), and Pu(IV). Both distributions also include Th(IV), Am(III), and Cm(III). The **oxidation state index** is used to randomly select which distribution is used in a given realization (Appendix SOTERM Section SOTERM.4). The **solubility** of the actinides in each oxidation state is calculated as a function of equilibrium between anhydrite, magnesium oxide, and brine. Thus the solubility is modeled in both **Salado and Castile brines**.

Colloidal particles may be formed in the repository through a variety of processes. The expected processes include waste degradation, microbial activity, rock decomposition, and

chemical condensation. These particles may also be carried into the repository by liquids moving from the Salado or through boreholes. Because of the presence of soils, nutrients, and cellulosic substrates for microbial action in WIPP waste (Appendix BIR), humic substances and microbes will be present in disposal room brines, and may form in situ. Actinide-intrinsic colloids may form in the disposal rooms from condensation of dissolved actinides. Mineral fragments, as well as humic substances and microbes, may provide surfaces on which dissolved actinides could sorb.

Actinides associated with microbes and humics are related to the concentration of dissolved actinides in the repository through proportionality constants (that is, the **proportion of actinides in the dissolved and colloidal phases**) determined from interpretation of WIPP-relevant experiments and the literature. The relationship is not based rigorously on thermodynamic equilibrium, but is simply a relationship. The concentration of actinides associated with the Pu(IV)-polymer is a constant value determined from experimental results at the pH conditions dictated by the presence of MgO backfill. Likewise, the concentration of actinides associated with mineral colloids is also a constant value, not linked to the concentration of dissolved actinides. Actinides associated with humics and microbes represent most of the colloidal actinide source term. Consequently, the colloidal actinide source term is closely related to the dissolved actinide source term. As discussed in a later section, however, the source terms are considered separately for transport in the Culebra.

The concentrations of colloidal actinides indicated in this section are assumed to be concentrations of actinides mobilized on colloidal particles. The indicated concentrations will be entrained in moving brine. For conservatism, it is assumed that no actinides sorb onto colloidal particles that are not mobile in the repository. Thus all actinides in the repository will be present in the solid phase, dissolved in the aqueous phase, or as colloidal actinides suspended in the aqueous phase.

MONPAR.3.8 Temperature Distribution

Waste-induced and repository-induced thermal gradients in the repository are not significant: they will not affect repository performance, either directly by affecting the containers and repository chemistry, or indirectly by altering fluid flow through the Salado or the Culebra. Therefore waste- and repository-induced thermal gradients will not be monitored during the operational period nor during the postclosure period.

Temperature in the repository may be influenced by radioactive decay, and exothermic reactions. As described in Appendix SCR (Section SCR.2.2.2), the maximum temperature increase due to radioactive decay will be in the vicinity of remote-handled transuranic waste containers; the increase is approximately 3 °C. The expected repository temperature increase due to radioactive decay is less than 2 °C.

The exothermic reactions anticipated in the repository are hydration of concrete material in the seals and panel closures, hydration of the magnesium oxide backfill, and temperature increases

associated with hydration of the concrete in the seals and panel closures localized in and around the seals and panel closures. The seals contain a large quantity of concrete but are not located adjacent to the waste disposal panels. Salt dissipates heat quickly; thus the effects are also expected to be minimal. Temperature increases due to hydration of backfill are expected to be insignificant and will be further limited by low brine inflow rates. The maximum temperature increase in the repository due to magnesium oxide hydration reactions will be approximately 5°C (Attachment MONPAR-1). The total temperature rise (due to radioactive decay and exothermic reactions) is estimated to be less than 7°C.

MONPAR.3.9 Shaft Seal System

Shaft seals assure waste containment in the repository. They are incorporated into performance assessment and their hydrologic properties are moderately significant to disposal system performance.

The seals will not be emplaced until the repository is decommissioned; thus their performance cannot be monitored during the operational period. The performance of the seals cannot be monitored after emplacement without jeopardizing the integrity of the disposal system. Thus the seal performance will not be monitored during the operational period or during the postclosure period.

The seal system consists of multiple components emplaced in the shaft: **clay**, **concrete**, **asphalt**, and crushed salt. A **DRZ** has formed around each shaft in response to the deviatoric stress created by excavation of the shafts; this DRZ has enhanced hydrologic properties similar to those in the DRZ surrounding the disposal rooms. The effective permeability of each seal component is a function of the **permeability** of the seal component and the permeability of the DRZ surrounding that component; the effective permeability is calculated using the equations in Appendix PAR, Parameter 12. The effective permeability will decrease over time as the seal material consolidates and the DRZ heals; the values used in the performance assessment calculations reflect this process. For the crushed salt members of the seal system, salt consolidation over time is also expressed as a series of permeabilities which are used for the time periods under consideration. An **index** is employed in selecting the permeability for each time period to ensure that the modeled consolidation of the salt increases with time (and the resulting effective permeability decreases).

Additional material properties affect brine and gas flow through the seals: **residual brine saturation** (the minimum brine saturation at which liquid will flow), **residual gas saturation** (the minimum gas saturation at which gas flow will occur), and **pore shape distribution**. These parameters are representative of all the seal materials. The variations in reported values for the materials are incorporated into the performance assessment calculations through LHS.

MONPAR.3.10 Radionuclide Transport and Retardation

Radionuclides in dissolved and colloidal form may migrate from the repository into the Salado or into the Culebra through a borehole. The transport and retardation properties depend on the oxidation state and the form (dissolved or colloidal) of the actinide under consideration. The transport and retardation processes are significant to system performance and are incorporated into performance assessment.

Transport into the Salado or the Culebra will not occur during the active control period, thus monitoring in the operational or early postclosure periods will not provide useful information. In addition, it is not possible to monitor the Salado without jeopardizing the integrity of the disposal system. Therefore, transport in the Salado and the Culebra will not be monitored during the operational period nor during the postclosure period.

Actinide transport in the Salado and the Culebra are considered to be possible mechanisms for release to the accessible environment. As in other areas of the disposal system, actinides may be transported as dissolved species or as colloidal particles. Actinide transport is affected by a variety of processes that may occur along the flow path.

Colloidal actinides are subject to retardation by chemical interaction between colloids and solid surfaces (represented by the **distribution coefficient (K_d)**) describing actinide partitioning or distribution between the solid and liquid phases) and by clogging of small pore throats (that is, filtration). However, colloidal particles, if not retarded, are transported slightly more rapidly than the average velocity of the bulk liquid flow. Because the effects are offsetting with respect to the potential for transport, residual effects of these opposing processes will be either small or beneficial. These effects are therefore not incorporated in the modeling of actinide transport in the Salado interbeds.

Radionuclides might be introduced into the Culebra by brine flowing up a borehole or by brine flowing up the DRZ around the shafts. However, modeling shows that the chief source of radionuclides in the Culebra is releases from an abandoned and unplugged borehole that intersects the repository. As noted in Section MONPAR.2.3, groundwater flow in the Culebra is described using a double-porosity model, in which a portion of the porosity is associated with high-permeability features where transport occurs by advection, and the rest of the porosity is associated with low-permeability features where flow does not occur.

Three principal processes affect the transport and retardation of dissolved actinides in the Culebra: (1) advection in the natural groundwater flow, (2) diffusion into the matrix, and (3) sorption to varying extents onto the minerals lining pore walls or fractures. Advection is the transport of contaminant with the bulk flow of liquid. Diffusion is the transport of contaminants due to molecular motion in the presence of concentration gradients. Dispersion is an additional component of transport of contaminant that occurs during liquid flow due to irregularities in the porous medium and differences in the velocity of liquid moving through pores. The sorption processes are incorporated into performance assessment models through a

linear isotherm model expressing the concentration of actinide sorbed relative to the concentration of actinide in solution. The isotherms for sorption **in the Culebra** are represented by **distribution coefficients** (K_d) describing the distribution of each **dissolved actinide** in each oxidation state between the solid and liquid phases: Am(III), Pu(III), Pu(IV), U(IV), Th(IV), and U(VI).

Colloidal particles in the Culebra are subject to many of the same processes that affect dissolved actinides, but because of their size several additional processes affect them. There are three process differences. Colloidal particles in general are preferentially carried in the center of pore throats by faster-moving fluid located there, which causes slightly increased rates of transport. Colloidal particles can be restricted (filtered) from flowing groundwater when they encounter small-aperture features in the pore network. Finally, colloidal particles may undergo different sorption processes than dissolved species.

Actinide intrinsic colloids and humic materials are small enough for diffusion to occur, so the conceptual model for these **colloidal particles in the Culebra** is analogous to the model specified for dissolved actinides. The conceptual model assumes that other retardation processes (for example, filtration) will not occur.

In contrast, colloidal particles that are larger than pore throats in the matrix will be excluded from the matrix and will remain in advective porosity. Microbes and mineral fragments are larger than the mean pore-throat diameter; therefore the conceptual model for these particles includes the processes of advection and filtration by small-aperture features that occur within the advective porosity.

MONPAR.4 Potentially Significant Parameters that Describe Human-Initiated Events and Processes

The parameters describing human-initiated events and processes that were considered in the analysis fall into five groups:

- Frequency of intrusion into the repository through drilling; this includes both the drilling rate and location of the drilling events.
- Consequences of future direct intrusion into the repository; direct releases in the form of cuttings, cavings, spallings, and direct brine flow to the surface during drilling.
- Properties of the boreholes that affect fluid flow and radionuclide transport, leading to long-term releases.
- Effects of current drilling and resource extraction activities (mining is treated separately) on groundwater flow in the vicinity of the disposal system.
- Effects of current and future mining in the McNutt potash zone in the Salado.

The results of DOE's analysis are presented in Table MONPAR-3. The parameters describing the human-initiated events and processes are discussed in the following section.

MONPAR.4.1 Drilling Intrusions

Intrusion into the repository through drilling may occur during the regulatory time period. In accordance with regulatory requirements, such intrusions are modeled to occur randomly in time and space. Drilling leads to direct releases during the drilling itself and possible long-term releases due to effects on fluid flow in the disposal system. The drilling rate (boreholes per square kilometer per 10,000 years) is significant to repository performance. The DOE uses a drilling rate in performance assessment that is based on historical rates in the Delaware Basin. The locations of the boreholes are also significant to performance assessment.

The DOE will monitor the drilling activity in the Delaware Basin during the operational and postclosure periods and will use the results in performance calculations performed in support of recertification.

In keeping with the requirements of 40 CFR § 194.33(b)(1), the DOE models consequences of inadvertent human intrusion into the repository by drilling as the most severe scenario that may affect long-term performance of the disposal system. The DOE's treatment of the probability of inadvertent human intrusion is discussed in Section 6.4.12.2. Intrusions may occur at any time between 100 years and 10,000 years after final facility closure. The assumption that random drilling over the repository begins in 100 years after final facility closure is based on 100 percent effectiveness for the active institutional controls to be implemented by the DOE (Section 7.1 and Appendix AIC). The DOE's system of passive institutional controls will reduce the likelihood of intrusions for the next 600 years, but will not eliminate intrusions (See Section 2.3 and Appendix EPIC).

Both the number and time of intrusions are determined sequentially by sampling from a cumulative distribution function derived from the Poisson model that probabilistically describes the period that elapses between an intrusion and the next intrusion for a specified rate constant. The **time between intrusions**, or the time before the first intrusion, may vary from 0 years to greater than 9,900 years, with a probability determined by the rate constant λ. The rate constant is derived from the **drilling rate** established for the WIPP vicinity and the area of the repository. As discussed in Section 6.4.12.6 and Appendix DEL (Section DEL.7.4), this rate is based on a review of past and present drilling activity in the Delaware Basin. The rate constant is also time dependent in that while active institutional controls are 100 percent effective it is equal to zero, and while passive institutional controls are effective it is less than the uncontrolled drilling rate. The area corresponds to the total plan-view area of the waste-disposal region. Both the drilling rate and the time between intrusions are significant to performance assessment (See Appendix MASS).

Table MONPAR-3. Potentially Signficant Human-Initiated Parameters

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Drilling intrusions	Intrusion into the repository	Intrusion boreholes provide pathways for fluid flow and radionuclide transport	Drilling rate	Performance assessment models and calculations	1[c]	1[c]	Y	Y
			Time between intrusions		1[c]	1[c]	N	N
			Borehole location		1[c]	1[c]	N	N
			Probability of encountering a brine reservoir in the Castile		1[c]	1[c]	N	N
Direct releases	Direct releases from intrusion into the repository through future drilling.	Waste may be released by several mechanisms during drilling: cuttings, cavings, spallings, and brine blowout	Borehole diameter	Performance assessment models and calculations	2[c]	2[c]	N	N
			Waste activity		1[c]	1[c]	Y	N
			Waste effective shear resistance to erosion		2[c]	2[c]	N	N
			Waste particle diameter		1[c]	1[c]	Y	N
			Waste tensile strength		2[c]	2[c]	N	N
			Gravity factor for spalling		2[c]	2[c]	N	N
			Strength factor for spalling		3	3	N	N
Borehole properties	Properties of boreholes change over time	Borehole properties have long-term effects on fluid flow and radionuclide transport	Borehole permeability	Performance assessment models and calculations	1[c]	1[c]	Y	N
			Index for selecting type of borehole plug		1[c]	1[c]	Y	N

Table MONPAR-3. Potentially Signficant Human-Initiated Parameters (Continued)

Topic	Property or Process	Impact on Performance	Parameter(s)	Identification as a Potentially Significant Parameter	Significant Effects on Waste Containment[a]	Significant Effects on Verifying Predictions[a]	Retained for Monitoring[b]	
							Opera-tional	Post-closure
Human activity	Effects of current drilling and resource recovery activities. Ground water flow and other effects of human intrusion in the vicinity of the disposal system.	Groundwater flow is altered by current drilling and resource recovery activities.	Changes in groundwater flow in the Culebra (transmissivity, fracture and matrix porosity, fracture spacing and index, dispersivity)[d]	40 CFR § 194.42(a)(4)	2	2	Y	N
			Changes in groundwater flow in the Salado (permeability, porosity, pore compressibility, model choice)[d]		3	3	N	N
Mining	Effects of mining in the McNutt Potash Zone in the Salado.	Groundwater flow in the Culebra is altered by subsidence associated with potash mining activities.	Probability that mining will occur within a given century	Performance assessment models and calculations	2	2	N	N
			Mining index for adjusting Culebra transmissivity		2	2	N	N

[a] Significance legend: 1 - high, 2 - medium, 3 - low
[b] See Appendix MON for monitoring program.
[c] Significant only in intrusions: E1, E2, and E1E2. Significance is 3 in all other cases.
[d] The parameters listed in parentheses are among those used to calculate or model this property. Potentially significant parameters are also addressed separately.

Drilling events are assumed to be random in time and space, and the location of each intrusion borehole within the repository is sampled randomly. This is done in the analysis by discretizing a plan view of the area under the passive institutional control berms into 144 separate locations, and requiring each intruding borehole to penetrate one, and only one, location. The probability of intersecting each location is determined based on the fraction of the total plan-view area represented by the location.

The **location of an intrusion borehole** is used to determine whether a borehole that penetrates the repository intersects waste. Those boreholes that intersect the experimental and operational regions do not intersect waste and do not contribute to the direct releases at the ground surface during drilling. Intrusions into the experimental and operational regions may, however, contribute to long-term groundwater releases through the E1E2 scenario in which multiple wells penetrate the repository. Direct releases and long-term releases are discussed further in MONPAR.4.2 and MONPAR.4.3, respectively.

The **probability** of encountering a brine reservoir in the Castile is significant to long-term disposal system performance. Boreholes that intersect pressurized brine in the Castile below the repository are E1 events (Section 6.3.2.2.2), and boreholes that do not are E2 events (Section 6.3.2.2.1). Based on geophysical methods, geological structure analysis, and geostatistical correlation, the DOE has determined that there is an 8 percent probability that a reservoir will be encountered during any intrusion event (see Section 6.4.12.6).

MONPAR.4.2 Direct Releases

The releases associated with direct intrusion into the repository are incorporated into performance assessment. These releases are significant to compliance, and are affected by conditions in the disposal area at the time of intrusion. The conceptual model includes assumptions about long-term performance (for example, waste properties after consolidation and degradation), and random events (such as drilling intrusions); these assumptions are not applicable during the preclosure period. The conceptual model also includes assumptions about long-term performance (for example, waste activity) that are applicable during the preclosure period.

The waste in the closed repository will not achieve their long-term properties (consolidation, saturation) used in performance assessment during the operational period and for the first 100 years after closure. Therefore, long-term monitoring waste properties will not provide relevant information or verify assumptions used in performance assessment and need not be monitored.

As discussed in Section 6.4.7.1, releases that may occur during and immediately following a drilling event are modeled under the assumption that future drilling practices will be the same as those of the present, consistent with the requirements of 40 CFR § 194.33(c)(1). If present day rotary drilling techniques are used to penetrate the waste, radionuclides may be brought to the surface by four means. First, some quantity of cuttings, which contain material intersected

by the drill bit, will be brought to the surface by the drilling fluids. The release in this case is governed by the **activity of intersected waste** and the **diameter of the drill bit**.

Second, cavings, which contain material eroded from the borehole wall by the circulating drill fluid, may also be brought to the surface by the circulating drilling fluids. The release is affected by the **effective shear resistance to erosion**.

Third, if the repository contains fluids at pressures significantly higher than those anticipated by the driller for that depth, spalling of waste material into the borehole may occur as high-pressure gas flows into the borehole. Spalled material may be brought to the surface by continued drilling activity. The gas itself is not radioactive and will not contribute to the radionuclide release as it is vented at the surface. The **waste particle diameter** is significant for this release scenario. The **tensile strength** and **gravity factor** have a moderately significant effect on the quantity of material brought to the surface. The quantity is not significantly affected by the **strength factor**.

Fourth, brine as well as gas may enter the borehole from the repository if the driller is unable to control the pressure within the well or if the driller chooses not to control the pressure. The brine may flow to the surface, and if it has been in contact with waste, it may contain dissolved and/or suspended radionuclides. The properties of the Castile brine reservoir (MONPAR.2.5) are significant for this release. Properties of earlier intrusion boreholes (such as plug configurations and permeabilities) may affect conditions (such as pressure and fluid content) in the repository; these conditions in turn may affect the direct release of brine during drilling (borehole properties are discussed in MONPAR.4.3).

The geometry of the waste panels is represented in the model, and mathematical methods are applied to the conditions in the borehole to obtain accurate representation of the flow into the borehole (see Appendix MASS Section MASS.16 and Attachment 16-2). Hydrologic properties in the disposal room (MONPAR.3.4) have a moderately significant effect on performance assessment.

MONPAR.4.3 Borehole Properties

The properties of a borehole change over time, and are incorporated into performance assessment. The properties are established to be "consistent with practices in the Delaware Basin at the time a compliance application is prepared" [Part 194.33(c)(1)]. These parameters are significant to compliance.

The current practices will be monitored and changes will be incorporated into the performance assessment models of borehole properties in future calculations in support of recertification.

Intrusion boreholes have long-term effects on fluid flow in the disposal system after the borehole casing and plugs installed at the time of abandonment have degraded. The presence

of the degraded borehole may provide a pathway for fluid flow between the repository and the surrounding formations, and for radionuclide migration toward the accessible environment.

The fluid flow between the repository and surrounding formations (particularly a brine reservoir in the Castile) may affect conditions (such as pressure and fluid content) within the repository; these conditions could in turn affect direct releases during drilling (MONPAR.4.2).

Borehole plug configurations used today in the Delaware Basin vary based on the local stratigraphy encountered in the hole, its total depth, and the types of fluids present. Each of these plugging configurations meets the minimum requirements of the applicable plugging regulations. All holes are plugged with some combination of solid concrete plugs isolating different fluid-bearing horizons from each other and from the ground surface. As discussed in detail in Appendix DEL Section DEL.5, six different plug configurations are identified that are potentially relevant to future borehole abandonment practice at the WIPP. As discussed in Appendix MASS Section MASS.16.3.3, these six plug configurations can be approximated for performance assessment by three conceptual plugging patterns. Probabilities of occurrence for each of these three plugging configurations are discussed in Section 6.4.12.7.

The first type of plug incorporated in the performance assessment models is the continuous concrete plug described in Section 6.4.7.2.1. Because of the small cross-sectional area and low permeability of the potential pathway, long-term releases through this plug are assumed to be zero.

In the two-plug configuration, two concrete plugs are assumed to have a significant effect on long-term flow in the borehole. These plugs initially have the properties of intact concrete. The lower plug of interest is assumed to be located somewhere between the hypothetical Castile brine reservoir and underlying formations. A second plug is located within the lower portion of the Rustler Formation, immediately above the Salado. As described in Section 6.4.7.2.2, the steel casing in the borehole and the upper concrete plug are assumed to have failed completely after 200 years, and the borehole is filled with a silty-sand-like material composed of degraded concrete, corrosion products, and material that sloughs from the borehole walls. The plug below the Castile brine reservoir is located in a less aggressive chemical environment, and its properties remain constant in performance assessment. The permeability in the borehole between the repository and the Castile is modeled assuming a decrease after 1,000 years as creep closure consolidates the material in the borehole. The borehole does not close completely in 10,000 years.

In the three-plug configuration (Section 6.4.7.2.3), three concrete plugs are assumed to have an effect on long-term flow in the borehole. Again, the plugs initially have the properties of intact concrete. Two of the plugs are identical to those modeled in the two-plug configuration. The third plug is located within the Castile above the brine reservoir and below the waste-disposal panel. This plug is assumed to behave in the same manner as the lower plug in the two-plug configuration: that is, its properties remain unchanged in performance assessment. Otherwise, all portions of the borehole in the three-plug configuration are assumed to have the same

material properties as the corresponding regions in the two-plug configuration, with adjustments to borehole-fill permeability occurring 1,000 years after failure of the overlying plug.

The DOE has chosen not to model this configuration explicitly in the performance assessment calculations, as the boreholes in which the three-plug configuration is emplaced are assumed to result in long-term releases comparable to those calculated for E2 intrusions, regardless of whether they penetrate a Castile brine reservoir.

The **permeability** of the borehole is varied to represent degradation of the two-plug and three-plug configurations after 200 years and the resulting increase in permeability. The **plug index** is used to represent the probability that the borehole under consideration has a continuous two-plug or three-plug configuration.

MONPAR.4.4 Current Drilling and Resource Recovery

Historical, current and near-future human activities in the vicinity of the repository could affect groundwater flow in the Culebra prior to closure of the repository, as well as subsequent to repository closure. The significance of these human activities depends on the extent and magnitude of the induced hydrological, geochemical and mechanical disturbance. Changes in groundwater in the Culebra are moderately significant to performance. Such changes are incorporated into performance assessment as described in MONPAR.4.5. Changes in brine flow in the Salado as a result of any current or near-future human activities in the vicinity of the repository is not anticipated and therefore are not significant to performance assessment.

The DOE will monitor water levels in the Culebra during the operational period to detect deviations from expected performance. Monitoring of groundwater flow conditions in the Salado could create additional pathways for radionuclide transport, and would potentially jeopardize long-term performance of the disposal system; thus the DOE will not perform such monitoring.

Historical, current and near-future human activities outside the controlled area could affect groundwater flow and chemistry conditions and other properties of the disposal system. A potentially significant effect of human activities will be to alter hydrological conditions in the Culebra significantly, which, in the event of radionuclide migration to the Culebra, could result in altered travel times for radionuclide transport to the accessible environment (Sandia National Laboratories 1992).

Activities that could impact the long-term performance of the disposal system that are currently taking place and expected to continue in the near future outside the controlled area are:

- Drilling associated with water, potash, oil, and gas exploration and production,
- Water, oil, and gas production, and

- Disposal of liquid by-products from oil and gas production.

The effects of historical, current, and near-future drilling, activities involving the use of a borehole (fluid extraction or injection), and flow through abandoned boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Groundwater flow conditions in the Culebra will affect containment of waste in the disposal system in the event of radionuclide migration to the Culebra. Furthermore, subsidence due to potash mining in the vicinity of the WIPP (MONPAR.4.5) may lead to **changes in groundwater flow in the Culebra**. Thus, water levels in the Culebra will be monitored in the preclosure period to build confidence in Culebra groundwater conditions (see Appendix GWMP).

Groundwater flow in the Salado is not expected to change as a result of any current or near-future human activities (other than activities associated with operation of the repository). Monitoring of groundwater flow conditions in the Salado could create additional pathways for radionuclide transport, and would potentially jeopardize long-term performance of the disposal system. Therefore, no monitoring of Salado groundwater flow will be conducted.

MONPAR.4.5 Mining

The McNutt in the Salado is present in the controlled area overlying the repository. The probability that the potash will be mined and the effects on system performance are incorporated into performance assessment in accordance with the conceptual model in Parts 194.32(b) and (c). The effects are moderately significant to long-term disposal system performance. Monitoring the effects of human activities in the vicinity of the WIPP is discussed in MONPAR.4.4.

The only natural resource being mined currently near the WIPP is potash from the McNutt zone of the Salado, and it is the only mineral considered for future mining. Mineral resources within the disposal system that are similar in quality and type to those currently being mined outside the controlled area are assumed to be mined at an uncertain time in the future. Outside the disposal system, mineral resources reasonably expected to be mined in the near future are also assumed to be mined. These effects are included in analyses of both disturbed and undisturbed performance. Inside the disposal system, **whether a mining event occurs in any given century** after the active institutional control period is determined by a probabilistic model. Outside the disposal system, what is reasonably expected to be mined is assumed to be mined by the end of WIPP disposal operations. With respect to consequence analysis, mining affects only the hydraulic conductivity of the units overlying the Salado as discussed in Section 6.4.6.2.3.

The DOE has identified areas that are assumed to be mined in a manner consistent with the conceptual model and other guidance presented by the EPA in Part 194. Appendix MASS

(Section MASS.15.4 and Attachments MASS 15.4 and MASS 15.5) includes a description of the method used to determine the extent of mining in the McNutt both inside and outside the disposal system. The changes in hydraulic conductivity due to mining inside and outside of the controlled area are modeled in performance assessment as changes in the Culebra transmissivity due to subsidence induced by the excavated potash. The transmissivity changes are executed through a **mining index** used to uniformly adjust the transmissivity of the affected areas by a factor between 1 and 1,000 that is randomly sampled in LHS.

The effects of mining all potash deposits "similar in quality and type to those resources currently extracted from the Delaware Basin" (40 CFR § 194.32[b]) outside the disposal system are included in the undisturbed performance scenario, and are therefore included in all scenarios. In other words, all calculations of transport in the Culebra include the effects of mining outside the controlled area. This is the undisturbed mining case because mining within the disposal system has not occurred.

If mining occurs within the disposal system, an area of the Culebra inside and outside the disposal system will be affected. This is the disturbed mining case. To evaluate the impact of disturbed mining, a second simulation of Culebra flow directions and rates is executed on both the regional and local domains. In this second simulation, the location-specific values in the transmissivity field are multiplied by the same mining multiplier used for the undisturbed mining case.

REFERENCES

Deal, D.E., Abitz, R.J., Myers, J., Case, J.B., Martin, M.L., Roggenthen, W.M., and Belski, D.S., 1991. *Brine Sampling and Evaluation Program, 1990 Report.* DOE-WIPP-91-036. Prepared for U.S. Department of Energy by IT Corporation and Westinghouse Electric Corporation. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026. Vols. 1 and 2. Assistant Secretary for Defense Programs. Washington, D.C. WPO 38835, WPO 38838, WPO 38839.

DOE (U.S. Department of Energy). 1990. *Final Safety Analysis Report.* WP 02-9, Rev. 0, May 1990. Westinghouse Electric Corporation, Waste Isolation Pilot Plant, Carlsbad, NM.

Brush, L.B. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for WIPP.* SAND90-0266. Sandia National Laboratories, Albuquerque, NM.

Munson, D.E. and K. L. DeVries, 1991. Development and validation of a predictive technology for creep closure of underground rooms ins salt, *Proc. 7th International Congress of Rock Mechanics*, 1, A.A. Balkema, Brookfield, VT: pp. 127-134.

Munson, D.E., A. F. Fossum, and P.E. Senseny, 1989a. *Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures.* SAND88-2948. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E., A.F. Fossum, and P.E. Senseny, 1989b. *Approach to First Principles Model Prediction of Measured WIPP In Situ Room Closure in Salt.* SAND88-2535. Albuquerque, NM: Sandia National Laboratories.

Westinghouse Electric Corporation. 1994. *Backfill Engineering Analysis Report, Waste Isolation Pilot Plant.* Westinghouse Electric Corporation, Wasete Isolation Division, Carlsbad, NM.

Sandia National Laboratories. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December, 1992.* SAND92-0700, Vol. 4. Sandia National Laboratories, Albuquerque, NM.

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MONPAR ATTACHMENT A

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

date: August 20, 1996

to: Distribution

from: David Bennett, Yifeng Wang, and Tim Hicks

subject: An Evaluation of Heat Generation Processes for the WIPP

1.0 Introduction

Nuclear criticality, exothermic reactions, and radioactive decay are possible sources of heat in the WIPP repository. Nuclear criticality has been eliminated from performance assessment calculations on the basis of low probability (see SNL Summary Memo of Record RNT-1). This memo discusses possible heat generating processes at the WIPP and the potential magnitude of the temperature increases they might induce. Heat from exothermic reactions is discussed in Section 2 and heat from radioactive decay is discussed in Section 3.

Conclusions are provided in Section 4. In summary, soon after disposal concrete hydration in the panel closures and shaft seals will give rise to temperature increases lasting a few decades. Heat from radioactive decay will generate a maximum temperature increase of less than 2°C above the ambient temperature (about 27°C) within 100 years after disposal. A number of potential exothermic reactions other than concrete hydration have been identified. These reactions are brine limited and will cause only minor perturbations to the temperature distribution within the disposal system. The maximum calculated rate of brine inflow to a waste disposal panel, and thus, the maximum exothermic reaction rates, occur for the S2 scenario involving an E1 drilling event at 350 years after disposal. By the time such a drilling event takes place heat generation from concrete seal hydration and radioactive decay will have decreased substantially, and the temperatures in the disposal rooms will have reduced to close to initial values. Note that active institutional controls are expected to prevent drilling within the controlled area for 100 years after disposal. Thus, exothermic reactions following a drilling intrusion into a waste disposal panel will be the only potentially significant heat generating processes at the time of a drilling intrusion.

The maximum temperature that could be achieved in the panel following a drilling intrusion at 350 years occurs as a result of aluminum corrosion; this reaction could result in a maximum temperature increase of about 6°C two years after the drilling event. This predicted value of temperature increase is based on several conservative assumptions. For example, it is assumed that no aluminum corrosion has occurred prior to the drilling event and that all the brine introduced to the waste panel is available for aluminum corrosion. In reality some aluminum corrosion is likely to have occurred prior to the drilling event, reducing the volume of aluminum available for the reaction, and other reactions with lower reaction enthalpies (such as backfill hydration) or lower reaction rates (such as microbial degradation) will compete with aluminum corrosion to consume brine resulting in a smaller temperature increase. Based on similar conservative assumptions, backfill hydration could result in a maximum temperature increase of less than 5°C. These maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability. Thus, the temperature rise of 6°C represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously.

2.0 Heat From Exothermic Reactions

Exothermic reactions in the repository will liberate heat resulting in elevated temperatures. The magnitude and duration of this temperature increase will depend on the amount and rate of energy release, the geometry of the heat source, the thermal conductivities of the surrounding rocks, and any influence of groundwater or brine flow on heat transport.

In the WIPP a range of different types of reactions will occur, including corrosion, microbial degradation, waste dissolution, and concrete and backfill hydration, and these will liberate different amounts of heat at different times. The amount of heat liberated by the different reactions will depend on the extent of reaction that occurs (for example, how much gas generation or concrete hydration takes place), and the enthalpy of the reactions. The former will depend on the inventory of materials emplaced in the WIPP, and the subsequent chemical evolution of the repository system. The latter can be assessed by considering typical enthalpies for the reaction types of interest.

Enthalpies of reaction, $\Delta_r H°$, for example reactions representing processes that may take place in the repository are given in Table 1 (from SNL Summary Memo of Record GG-7, SP-7). The reactions shown are based on the chemical conditions expected in the WIPP. Note that negative values for $\Delta_r H°$ indicate that the reactions liberate heat as they progress from left to right.

Table 1. Enthalpies of reaction, $\Delta_r H°$, for the WIPP

Reaction	Example Stoichiometry and Standard Enthalpies of Formation, $\Delta_f H°$ (kJ/mol)	Reaction Enthalpy $\Delta_r H°$ (kJ/mol)	Data Source
Backfill hydration	$MgO_{(s)} + H_2O_{(l)} = Mg(OH)_{2(s)}$ $\Delta_f H°$ -601.7 -285.8 -925.5	-38	Krauskopf, 1982, 561
Backfill carbonation	$Mg(OH)_2 + CO_2(g) = MgCO_3 + H_2O$ $\Delta_f H°$ -925.4 -393.1 -1110.3 -285.8	-77	Drever, 1982, 351-256
Microbial degradation	$C_6H_{10}O_5 + H_2O = 3CH_4 + 3CO_2$ $\Delta_f H°$ -805.5 -285.8 3 x (-74.4) 3x (-393.5)	-312	Lide, 1994, 5-16 to 5-37
Aluminum Corrosion	$Al + 3H_2O = Al(OH)_3 + 1.5H_2$ $\Delta_f H°$ 0 3x(-285.8) 1291.9 0	-434	Drever, 1982, 351-256
Anoxic corrosion of steel	$Fe_{(s)} + 2H_2O_{(l)} = Fe(OH)_{2(s)} + H_{2(g)}$ $\Delta_f H°$ 0 2 x (-285.8) -569.0 0	+2.7	Wagman et al., 1982, Table 41
Waste dissolution	$UO_{2(s,cr)} + 2H_2O_{(l)} = U(OH)_{4(aq)}$ $\Delta_f H°$ -1085.0 2 x (-285.8) -1655.8	+0.9	Grenthe et al., 1992, Table III-1
Concrete hydration	$CaO_{(s)} + H_2O_{(l)} = Ca(OH)_{2(s)}$ $\Delta_f H°$ -635.1 -285.8 -986.1	-65.2	Wagman et al., 1982, 2-26

Even though there is uncertainty surrounding the extent of reactions that will occur, the reaction enthalpies indicate that the thermal effects of anoxic corrosion of steel and the waste dissolution reaction will be endothermic and will be of low consequence to the performance of the disposal system. However, the other reactions shown in Table 1 have the potential to evolve significant amounts of heat. The potential effects of these processes on the temperature within the disposal system are discussed below.

2.1 Backfill Hydration

Potential temperature increases in the repository as a result of exothermic backfill hydration reactions have been evaluated by Wang (1996, attachment to this memo). In his analysis, Wang (1996) made the following assumptions:

- The reaction will proceed rapidly so that the rate of heat generation will be

controlled by brine availability.

- All brine entering a waste disposal panel will contact and react with the backfill in the panel uniformly.

- All of the emplaced backfill will undergo hydration.

The maximum calculated rate of brine inflow into a panel (about 200 m^3/year) occurs for the S2 scenario involving an E1 drilling event at 350 years after disposal. The molar density of water is 5.56×10^4 moles/m^3, and thus, the reaction rate of backfill hydration in the panel will be 1.1×10^7 moles/year. Based on the reaction enthalpy shown in Table 1, backfill hydration will generate a thermal load of about 13 kW. There will be about 2×10^8 moles MgO emplaced per panel and thus the reaction could continue for about 20 years if sufficient brine was available.

Wang (1996) estimated the maximum temperature that could be generated by backfill hydration within a panel. Assuming heat loss will occur by conduction through the salt forming the roof and floor of the panel and that heat losses through the side walls are negligible, Wang (1996) calculated that the maximum temperature rise in a panel, as a consequence of backfill hydration following a borehole intrusion and subsequent brine inflow, would be about 4.5°C.

2.2 Backfill Carbonation

Wang (1996) also estimated the potential temperature rise that could occur as a result of backfill carbonation. Wang (1996) assumed that the reaction will be limited by microbial CO_2 production; the maximum rate of CO_2 production is 2.9×10^5 moles/year. Based on the reaction enthalpy shown in Table 1, backfill carbonation will generate a thermal load of about 0.7 kW. About 3.6×10^7 moles CO_2 could be produced in a single panel (see Wang, 1996) and thus the reaction could continue for about 125 years. Wang (1996) estimated the maximum temperature that could be generated by backfill carbonation within a panel to be about 0.6°C.

2.3 Microbial Degradation

Wang (1996) estimated the maximum reaction rate for microbial degradation in a panel to be about 1×10^5 moles/year and the inventory to be about 1.2×10^7 moles $C_6H_{10}O_5$ per panel. Thus, the reaction could continue for about 120 years. Based on the reaction enthalpy shown in Table 1, microbial degradation will generate a thermal load of about 1 kW. Wang (1996) estimated the maximum temperature that could be generated by microbial degradation within a panel to be about 0.8°C.

2.4 Aluminum Corrosion

Wang (1996) determined that the rate of corrosion of aluminum will be controlled by brine availability. From Table 1, the reaction rate of aluminum corrosion in the panel will be about 0.4×10^7 moles/year, assuming a brine inflow rate of 200 m^3/year (1.1×10^7 moles/year). About 8×10^6 moles of aluminum will be emplaced in each panel and thus aluminum corrosion could continue for 2 years. Based on the reaction enthalpy shown in Table 1, aluminum corrosion will generate a thermal load of about 51 kW. Wang (1996) estimated the maximum temperature that could be generated by aluminum corrosion within a panel to be about 6°C.

2.5 Concrete Hydration

Concrete hydration reactions will occur in the seals and panel closures and in the waste.

2.5.1 Seals and panel closures

Concrete hydration reactions are known to proceed for extended periods (perhaps thousands of years). However, the rates of these reactions decrease with time and, within the WIPP, the greatest evolution of heat will occur during the short periods following emplacement of panel closures during the operational phase and following shaft seal emplacement and repository closure. A quantitative analysis of the thermal effects of emplacing large concrete seals in salt at the WIPP was made by Loken (1994), Loken and Chen (1995). Their analysis showed that the energy released by the hydration of the seal concrete could raise the temperature of the concrete to approximately 53° C and that of the surrounding salt to approximately 38° C one week after seal emplacement.

2.5.2 Waste

WIPP waste contains cement which is used to solidify liquids, particulates and sludges. Storz (1996) estimated that all the waste to be emplaced at the WIPP will contain a total of about 8.5×10^6 kg of cement. This is equivalent to about 1.5×10^7 moles of calcium oxide (CaO) per waste disposal panel, representing the cement as CaO. Although a substantial amount of hydration may occur prior to waste disposal, this process will continue at a slower rate after disposal. Disregarding the hydration that will occur prior to disposal and assuming a brine inflow rate of 200 m^3/year, the reaction rate of concrete hydration in the panel will be about 1.1×10^7 moles/year, and the reaction could continue for about 1.4 years. Based on the reaction enthalpy shown in Table 1, concrete hydration will generate a thermal load of about 23 kW. Thus, using analyses similar to that used by Wang (1996) the maximum temperature that could be generated by concrete hydration of the waste within a panel is about 2°C.

3.0 Heat From Radioactive Decay

Radioactive decay of the contact handled CH and remote handled RH TRU waste emplaced in the repository will generate heat. The importance of heat from radioactive decay depends on the effects that the induced temperature changes would have on mechanics, fluid flow, and geochemical processes. For example, temperature increases could result in thermally induced fracturing, regional uplift, or thermally driven flow of gas and brine in the vicinity of the repository.

According to the Waste Acceptance Criteria (WAC), the design basis for the WIPP requires that the thermal loading does not exceed 10 kilowatts per acre. The WAC also require that the thermal power generated by waste in an RH TRU container shall not exceed 300 watts, but the WAC do not limit the thermal power of CH TRU waste containers.

A numerical study to calculate induced temperature distributions and regional uplift is reported in DOE (1980, pp.9-149–9-150). This study involved estimation of the thermal power of CH TRU waste containers. The DOE (1980) analysis assumed:

- All CH TRU waste drums and boxes contain the maximum permissible quantity of plutonium. According to the WAC, the fissionable radionuclide content for CH TRU waste containers shall be no greater than 200 grams per 0.21 cubic meter drum and 350 grams per 1.8 cubic meter standard waste box (in Pu-239 fissile gram equivalents).

- The plutonium in CH TRU waste containers is weapons grade material producing heat at 0.0024 watts per gram. Thus, the thermal power of a drum is approximately 0.5 watts and that of a box is approximately 0.8 watts.

- Approximately 3.7×10^5 cubic meters of CH TRU waste are distributed within a repository enclosing an area of 7.3×10^5 square meters. This is a conservative assumption in terms of quantity and density of waste within the repository, because the maximum capacity of the WIPP is 1.756×10^5 cubic meters for all waste (as specified by the Land Withdrawal Act [LWA]) to be placed in an enclosed area of approximately 5.1×10^5 square meters.

- Half of the CH TRU waste volume is placed in drums and half in boxes so that the repository will contain approximately 9×10^5 drums and 10^5 boxes. Thus, a calculated thermal power of 2.8 kilowatts per acre (0.7 watts per square meter) of heat is generated by the CH TRU waste.

- Insufficient RH TRU waste is emplaced in the repository to influence the total thermal load.

Thorne and Rudeen (1980) estimated the long-term temperature response of the disposal system to waste emplacement. Calculations assumed a uniform initial power density of 2.8 kilowatts per acre (0.7 watts per square meter) which decreases over time. Thorne and Rudeen (1980) attributed this thermal load to RH TRU waste, but DOE (1980), more appropriately, attributed this thermal load to CH TRU waste based on the assumptions listed above. Thorne and Rudeen (1980) estimated the maximum rise in temperature at the center of a repository to be 1.6°C at 80 years after waste emplacement.

Sanchez and Trellue (1996) estimated the maximum thermal power of an RH TRU waste container. The Sanchez and Trellue (1996) analysis involved inverse shielding calculations to evaluate the thermal power of an RH TRU container corresponding to the maximum permissible surface dose; according to the WAC the maximum allowable surface dose equivalent for RH TRU containers is 1000 rem/hr. The following calculational steps were taken in the Sanchez and Trellue (1996) analysis:

- Calculate the absorbed dose rate for gamma-ray radiation corresponding to the maximum surface dose equivalent rate of 1000 rem/hr. Beta and alpha radiation are not included in this calculation because such particles will not penetrate the waste matrix or the container in significant quantities. Neutrons are not included in the analysis because, according to the WAC, the maximum dose rate from neutrons is 270 mrem/hr, and the corresponding neutron heating rate will be insignificant.

- Calculate the exposure rate for gamma radiation corresponding to the absorbed dose rate for gamma radiation.

- Calculate the gamma flux density at the surface of a RH TRU container corresponding to the exposure rate for gamma radiation. Assuming the gamma energy is 1.0 MeV the maximum allowable gamma flux density at the surface of a RH TRU container is about 5.8×10^8 gamma rays per square centimeter per second.

- Determine the distributed gamma source strength, or gamma activity, in an RH container from the surface gamma flux density. The source is assumed to be shielded such that the gamma flux is attenuated by the container and by absorbing material in the container. The level of shielding depends on the matrix density. Scattering of the gamma flux, with loss of energy, is also accounted for in this calculation through inclusion of a gamma buildup factor.

The distributed gamma source strength is determined assuming a uniform source in a right cylindrical container. The maximum total gamma source (gamma curies) is then calculated for a RH TRU container containing 0.89 cubic meters of waste. For the waste of greatest expected density (about 6,000 kilograms per cubic meter) the gamma source is about $2x10^4$ curies per cubic meter.

- Calculate the total curie load of a RH TRU container (including alpha and beta radiation) from the gamma load. The ratio of the total curie load to the gamma curie load was estimated through examination of the radionuclide inventory presented in the WIPP Baseline Inventory Report (BIR) (DOE, 1995). The gamma curie load and the total curie load for each radionuclide listed in the WIPP BIR were summed. Based on these summed loads the ratio of total curie load to gamma curie load of RH TRU waste was calculated to be 1.01.

- Calculate the thermal load of a RH TRU container from the total curie load. The ratio of thermal load to curie load was estimated through examination of the radionuclide inventory presented in the WIPP BIR (DOE, 1995). The thermal load and the total curie load for each radionuclide listed in the WIPP BIR were summed. Based on these summed loads the ratio of thermal load to curie load of RH TRU waste was calculated to be about 0.0037 watts/curie. For a gamma source of $2x10^4$ curies per cubic meter the maximum permissible thermal load of a RH TRU container is about 70 watts per cubic meter. Thus, the maximum thermal load of a RH TRU container is about 60 watts, and the WAC upper limit of 300 watts will not be achieved.

Note that Sanchez and Trellue (1996) calculated the average thermal load for a RH TRU container to be less than 1 watt. Also, the total RH TRU heat load is less than 10% of the total heat load in the WIPP. Thus, the total thermal load of the RH TRU waste will not significantly affect the average rise in temperature in the repository resulting from decay of CH TRU waste.

Temperature increases will be greater at locations where the thermal power of a RH TRU container is 60 watts, if any such containers are emplaced. Sanchez and Trellue (1996) estimated the temperature increase at the surface of a 60 watt RH TRU waste container. Their analysis involved solution of a steady-state thermal conduction problem with a constant heat source term of 70 watts per cubic meter. These conditions represent conservative assumptions because the thermal load will decrease with time as the radioactive waste decays. The temperature increase at the surface of the container was calculated to be about 3°C.

In summary, analysis has shown that the average temperature increase in the WIPP repository due to radioactive decay of the emplaced CH and RH TRU waste will be about 1.6°C, with a maximum rise occurring at the center of the repository at about 80 years after waste emplacement. Temperature increases of about 3°C may occur in the vicinity of RH TRU containers with the highest allowable thermal load of about 60 watts (based on the maximum allowable surface dose equivalent for RH TRU containers).

4.0 Conclusions

Heat from exothermic reactions and radioactive decay will result in minor temperature increases in the repository. The potential temperature increases caused by these processes are summarized in Table 2.

Table 2. Maximum temperature increases at the WIPP.

Heat Source	Maximum temperature increase	Time of maximum temperature increase
Backfill hydration	4.5°C	20 years after a drilling intrusion
Backfill carbonation	0.6°C	125 years after a drilling intrusion
Microbial degradation	0.8°C	120 years after a drilling intrusion
Aluminum corrosion	6.0°C	2 years after a drilling intrusion
Concrete hydration (seals)	25°C in the shaft seal 10°C in the surrounding salt	1 week after emplacement
Concrete hydration (waste)	2.0°C	1.4 years after a drilling intrusion
Radioactive decay of CH TRU waste	1.6°C	80 years after disposal
Radioactive decay of RH TRU waste	3°C near a few containers	Within 100 years after disposal

During the operational phase and soon after disposal concrete hydration in the panel closures and shaft seals will give rise to temperature increases lasting a few decades. Heat from radioactive decay will generate a maximum temperature increase of less than 2°C within 100 years after disposal. A number of potential exothermic reactions have been identified. These reactions are brine limited and will cause only minor perturbations to the temperature distribution within the disposal system. The maximum calculated rate of brine inflow to a waste disposal panel occurs for the S2 scenario involving an E1 drilling event at 350 years after disposal. The maximum temperature that could be achieved in the panel

occurs as a result of aluminum corrosion; this reaction could result in a maximum temperature increase of about 6°C two years after the drilling event. Similarly, rapid backfill hydration could result in a maximum temperature increase of less than 5°C. These predicted values of temperature increase are based on a number of conservative assumptions. For example, the calculated temperature resulting from aluminum corrosion is based on the assumption that no corrosion has occurred prior to the drilling event and that all the brine introduced to the waste panel is available for aluminum corrosion. In reality some aluminum corrosion is likely to have occurred prior to the drilling event, reducing the volume of aluminum available for the reaction, and other reactions with lower reaction enthalpies or lower reaction rates will consume brine resulting in a smaller temperature increase.

Temperature increases of the magnitude and duration shown in Table 2 will have no significant effects on the performance of the disposal system. The effects of such temperature increases on the performance of the disposal system have been discussed in the SNL Summary Memos of Record RNT-24 (thermochemical effects), S-10 and GG-4 (thermal convection), S-11, SP-6, RM-1 (thermally-induced stress).

5.0 References

DOE (U.S. Department of Energy), 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026. Vol. 1 of 2. U.S. Department of Energy, Washington, DC.

DOE (U.S. Department of Energy) 1995. Transuranic Waste Baseline Inventory Report. DOE/CAO-95-1121, Revision 2, December 1995, Carlsbad, NM.

Drever, J.I. 1982. The Geochemistry of Natural Water. Prentice-Hall.

Grenthe, I. Fuger, J., Konings, R.J.M., Lemire, R.J., Muller, A.B., Nguyen-Trung, C., and Wanner, H. 1992. *Chemical Thermodynamics of Uranium.* Eds. H. Wanner and I. Forest. Amsterdam, London, New York: North-Holland for NEA/OECD. pp: 30-50.

Krauskopf, K.B. 1982. *Introduction to Geochemistry. Second (International) Edition.* McGraw-Hill International Series in the Earth and Planetary Sciences. McGraw-Hill Book Company. p. 561.

Lide, D.R. 1994. Handbook of Chemistry and Physics. CRC Press.

Loken, M.C. 1994. "SMC Thermal Calculations", RSI Calculation No. A141-GE-05, Prepared for Parsons Brinckerhoff, San Francisco, CA. Rapid City, SD: RE/SPEC Inc.

Loken, M.C., and Chen, R. 1995. "Rock Mechanics Analysis of SMC", RSI Calculation No. A141-GE-07, Prepared for Parsons Brinckerhoff, San Francisco, CA. Rapid City, SD: RE/SPEC Inc.

Sanchez, L. C., and Trellue, H. R., 1996. "Estimation of Maximum RH-TRU Thermal Heat Load for WIPP." Memo to T. Hicks (Galson Sciences Ltd.), January 17, 1996. Sandia National Laboratories, Albuquerque, NM. SWCF-A WBS:1.1.6.2.:PA:PBWAC - WIPP ACTIVITY.

Storz, L. 1996. *Estimate of the Amount of $Ca(OH)_2$ Contained in the Portland Cement Fraction of the Waste for Disposal in the WIPP.* Memo of June 24, 1996. SWCF (Or. 6752), WBS 1.1.09.

Thorne, B. J., and Rudeen, D. K., 1980. *Regional Effects of TRU Repository Heat.* SAND-7161. Sandia National Laboratories, Albuquerque, NM.

Wagman, D.D., Evans, W.H., Parker, V.B., Schumm, R.H., Halow, I., Bailey, S.M.,

Churney, K.L, and Nuttall, R.L. 1982. The NBS Tables of Chemical Thermodynamic Properties. Selected Values for Inorganic and C_1 and C_2 Organic Substances in SI Units. *Journal of Physical and Chemical Reference Data,* Volume 11, Supplement No. 2. American Chemical Society.

Wang, Y. 1996. *Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment: A Revised Version..* Memorandum of August 19, 1996. SWCF-A (Org. 6352), WBS 1.1.09.1.1(RC). (attached)

Attachment: memorandum of August 19, 1996, by Yifeng Wang, to Distribution. "Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment: A revised version," Sandia National Laboratories.

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date: August 19, 1996

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from: Yifeng Wang (Org. 6832)

subject: Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment: A revised version

Temperature increases caused by exothermal chemical reactions in the repository have been evaluated in the memo by Wang (1996). This memo is the revised version of the previous memo. Two revisions have been made: (1) anoxic steel corrosion reaction is no longer an exothermal reaction; (2) waste panel number is adjusted from eight to ten. All revisions made here do not change the conclusion that the thermal effect of exothermal chemical reactions in the repository is negligible.

Assumptions:

The following exothermal chemical reactions are considered:

$$MgO + H_2O \rightarrow Mg(OH)_2 \quad (1)$$

$$Mg(OH)_2 + CO_2 \rightarrow MgCO_3 \quad (2)$$

$$C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2 \quad (3)$$

$$Al + 3H_2O \rightarrow Al(OH)_3 + 1.5\ H_2\ . \quad (4)$$

Anoxic steel corrosion is a major chemical reaction expected to occur in the repository:

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2. \quad (5)$$

However, this reaction is considered here, because it is not an exothermal reaction. The enthalpy change of Reaction (5) is estimated to be 0.64 Kcal/mole Fe.

Considering that the vertical dimension of the repository (~ 1 m, B. M. Butcher, personal comm.) will be much less than the horizontal extension after room closure, we assume that the heat released from the reactions will be dissipated away mainly from the ceiling and ground of the repository and the heat loss from the side walls is negligible. We also assume that all reactions will take place uniformly in a reaction region of interest. We here restrict the reaction region in a single waste panel, for the following reason: Some of the above reactions may be limited by brine inflow. BRAGFLO simulations have shown that, in the human intrusion cases, the rate of brine inflow into a borehole-penetrated waste panel will be significantly higher than that into the rest of the repository. Choosing a panel rather than the whole repository as a reaction region will make heat generation rate per unit of volume higher and the heat dissipating surface area smaller in our calculations, and

therefore it is conservative. However, this choice will not affect the calculations for the reactions that are not limited by brine inflow, as you will see below.

Theory:

Based on these assumptions, the thermal effect of an exothermal chemical reaction can be modeled by a simplified system shown in Figure 1. The temperature distribution (T) can be described by the following equations:

$$C_p \rho \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial X^2} \tag{6}$$

$$T(X,0) = T_0 \tag{7}$$

$$R\Delta H = 2Sk \left. \frac{\partial T}{\partial X} \right|_{X=0} \tag{8}$$

$$T(\infty,t) = T_0 \tag{9}$$

where C_p is the heat capacity of surrounding rocks (J/mole/K); ρ is the molar density of surrounding rocks (moles/m^3); t is time (year); X is the spatial coordinate (m); k is the thermal conductivity of surrounding rocks (J/year/m/K); T_0 is the background temperature (K); R is the reaction rate (moles/year); ΔH is the enthalpy change of the reaction (J/mole); S is the horizontal area of a waste panel (m^2).

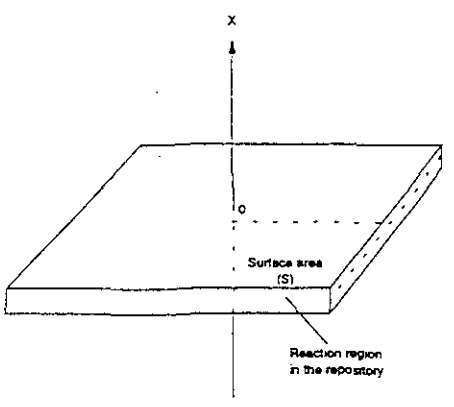

Figure 1. A modeling system for heat production and conduction.

The above equations can be solved for T with a Laplace-transformation method:

$$T - T_0 = -\frac{R\Delta H}{2S\sqrt{C_p\rho k}}\left[2\sqrt{\frac{t}{\pi}}e^{-\frac{C_p\rho X^2}{4Kt}} - \sqrt{\frac{C_p\rho}{k}}X\,erfc\left(\frac{X}{2}\sqrt{\frac{Cp\rho}{kt}}\right)\right]. \tag{10}$$

The temperature increase in the repository (ΔT) is obtained by setting X = 0 in equation (6):

$$\Delta T = T(0,t) - T_0 = -\frac{R\Delta H}{S}\sqrt{\frac{t}{\pi C_p\rho k}}. \tag{11}$$

Equation (7) shows that the repository temperature will increase with t until $t = \frac{M}{R}$, when all the reactant is consumed. Here M is the inventory of the reactant in a waste panel (moles). Therefore, the maximum temperature increase (ΔT_{max}) in the repository due to the exothermal reaction can be calculated by

$$\Delta T_{max} = T(0,t) - T_0 = -\frac{\Delta H}{S}\sqrt{\frac{RM}{\pi C_p\rho k}}. \tag{12}$$

Equation (12) shows that, for the reactions not limited by brine inflow, reducing the reaction region size does not affect ΔT_{max}, because the parameters S, R, and M will be reduced by the same factor, which is canceled out in the equation. This is not true for the brine-limited reactions, the rates of which are no longer dependent on reactant inventory.

Assuming the physical properties of the surrounding rocks can be represented by halite, we then have:

C_p = 50 J/mole/K (Lide, 1994, p. 12-158)

$\rho = 3.7\times10^4$ moles/m^3 (Lide, 1994, p. 4-149)

k = 6 W/m/K = 1.9×10^8 J/year/m/K (Lide, 1994, p. 12-165)

S = 1.2×10^4 m^2 (Sandia WIPP Project, 1992, p. 3-4).

With these parameter values, we obtain from equation (12):

$$\Delta T_{max} = 2.5x10^{-12} \Delta H \sqrt{RM} \ . \qquad (13)$$

Results:

(1) Reaction: $MgO + H_2O \rightarrow Mg(OH)_2$

We assume that this reaction is instantaneous and thus is limited by brine inflow. Based on BRAGFLO simulations for E1 scenario (Figure 2), the conservative (maximum) estimate of the rate of brine inflow into a borehole penetrated waste panel is about 200 m^3/year, equivalent to the reaction rate of $1.1x10^7$ moles/year. With $\Delta H = -3.9x10^4$ J/mole (Drever, 1982, p. 351-356) and $M = 2x10^8$ moles, we estimate ΔT_{max}, ≈ 4.5 K.

(2) Reaction: $Mg(OH)_2 + CO_2(g) = MgCO_3 + H_2O$

We assume that this reaction is limited by microbial CO_2 production. It is estimated that the maximum rate of CO_2 production (R) is $2.9x10^5$ moles/year and the total CO_2 that can be produced (M) is $3.6x10^7$ moles in a single waste panel (Wang & Brush, 1996; DOE/CAO, 1996). With $\Delta H = -0.8x10^5$ J/mole (Drever, 1982, p. 351-256), ΔT_{max}, is estimated to be 0.6 K.

(3) Microbial degradation: $C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2$

The maximum reaction rate and the inventory of $C_6H_{10}O_5$ in a single waste panel are estimated to be $1x10^5$ moles/year and $1.2x10^7$ moles (Wang & Brush, 1996; DOE/CAO, 1996). With $\Delta H = -3.1x10^5$ J/mole (Lide, 1994, p. 5-16 to 5-37), ΔT_{max}, is estimated to be 0.8 K. Because of lack of thermodynamic data for cellulose materials, we here assume that the enthalpy of $C_6H_{10}O_5$ is approximately equal to that of $C_6H_{10}O_4$.

(4) Aluminum corrosion: $Al + 3H_2O \rightarrow Al(OH)_3 + 1.5\ H_2$

The inventory of Al in a single panel is about $8x10^6$ moles (DOE/CAO, 1996). Aluminum are present as foil in the waste and its thickness is estimated to be $2.54x10^{-4}$ cm. The total surface area of Al foil is thus estimated to be ~ $2.6x10^8$ m^2. With this high surface area and the measured corrosion rate (2.9 mole H_2/m^2/year, Telander & Westerman, 1996), Al corrosion reaction is expected to be limited by brine inflow, and the maximum corrosion rate is ~ $0.4x10^7$ moles/year. With $\Delta H = -4.4x10^5$ J/mole (Drever, 1982, p. 351-356), ΔT_{max}, is estimated to be 6 K.

Figure 2. SNL WIPP PA96: BRAGFLO SIMULATIONS (CCA R1 S2)

Cumulative Brine Inflow into Waste Panel

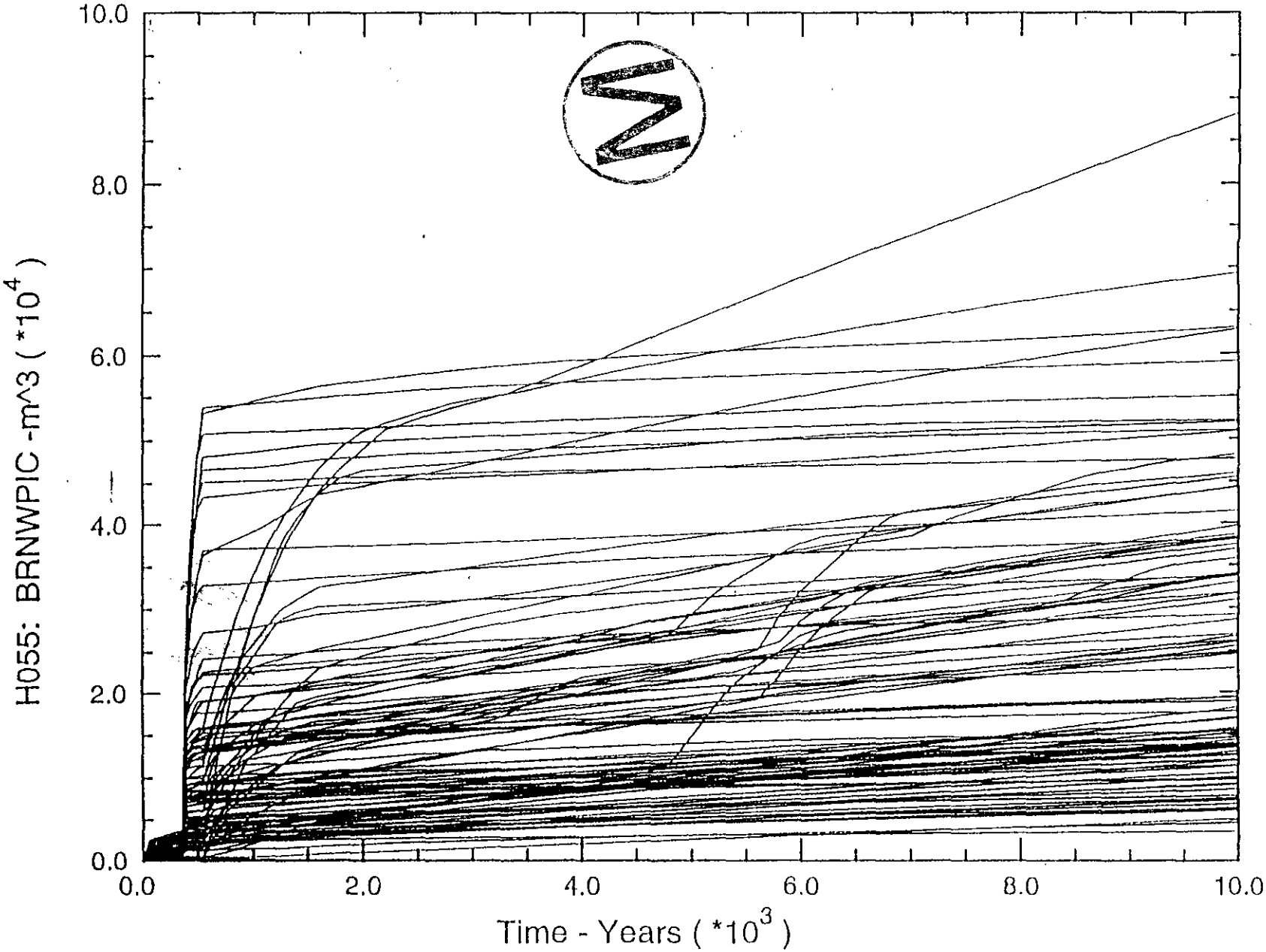

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The two brine-inflow-limited reactions - MgO hydration and Al corrosion - could possibly bring repository temperature up to 6 K. However, this temperature increase will not affect the overall repository performance, for two reasons: (1) The maximum temperature, if it is achieved, will be sustained only over a very short time period. For example, to achieve this temperature, Al has to be corroded completely within 2.5 years. After that, the accumulated heat will be dissipated away quickly. Thus, the maximum temperature, if it is attained, will last perhaps less than a year. (2) More importantly, because the two reactions are brine-limited, they will consume all free brine in the repository until all the reactants are completely consumed. Therefore, the maximum temperature will occur much earlier than enough free brine accumulates in the repository for the release of dissolved actinides. Based on the above calculations, the thermal effect of the other reactions, which are not limited by brine inflow and can last over a significant portion of 10000 year time period, are definitely negligible.

In conclusion, ignoring the thermal effect of chemical reactions (1 - 5) can not affect the overall repository performance assessment.

References:

DOE/CAO (1996) Transuranic Waste Baseline Inventory Report (Rev. 3).

Drever, J. I. (1982) The Geochemistry of Natural Water. Prentice-Hall.

Lide, D. R. (1994) Handbook of Chemistry and Physics. CRC Press.

Sandia WIPP Project (1992) Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters. SAND92-0700/3.

Telander, M. R. & Westerman R. E. (1996) Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Final Report. (Draft)

Wang, Y. & Brush, L. H. (1996) Estimate of gas-generation parameters for the long-term performance assessment. memo to M. S. Tierney, 1/26/1996, WBS 1.1.09.1.1(RC).

Wang, Y. (1996) Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment. memo to V. R. Bynum & L. H. Brush, 7/19/1996, WBS 1.1.09.1.1(RC).

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix NUTS

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

WIPP PA User's Manual for NUTS

M

WIPP PA

User's Manual

for

NUTS (Version 2.02)

Document Version 1.00

WPO #37927

MAY 29, 1996

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1.0 INTRODUCTION

This document is the User's Manual for the WIPP radioisotope-mobilization-and-decay code named NUTS (version number 2.02). It discusses the code, its execution, and its performance in the context of the 1996 Waste Isolation Pilot Project (WIPP) Compliance Certification Application (CCA) Performance Assessment (PA), and in that context only. The manual identifies the code, its authors and expert consultants (Section 1). It describes the code's WIPP-PA purposes and functions (Section 2), provides recommended user training (Section 3), outlines the code's theoretical basis and numerical methods (Section 4), its inherent capabilities and limitations (Section 5), describes user interactions (Section 6), input files (Section 7), error messages (Section 8), and output files (Section 9), and provides examples of relevant input, output, and debug files in its Appendices as well as calculations of interest (distributed throughout). Efforts have also been made to assist users in understanding how to make the required input-option decisions, to provide insights into the structure and use of the code's various input and output files, and explain the code's operation. Several examples of input files are included to help in running NUTS efficiently for cases likely to be encountered.

1.1 Software Identifier

Code Name: NUTS, a NUclide* Transport System

WIPP Prefix: NUT

Version Number: 2.02

Date: 23 May 1996 (CMS Build Date)

Platform: FORTRAN 77 for OpenVMS AXP, ver. 6.1, on a DEC Alpha VAX (see Section 2.3)

1.2 Points of Contact

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* Throughout this document, the word "Nuclide" is intended to be synonymous with "Isotope," and never to mean "an atomic nucleus with regard to energy level."

2.0 FUNCTIONAL REQUIREMENTS

R.1 First order decay of radioactive constituents in multiple member chains.

R.2 Retardation due to sorption of the chemical constituents via a linear equilibrium isotherm.

R.3 One-dimensional convection-dispersion-decay with spatially constant velocity and dispersion coefficients.

R.4 The ability to execute to completion under a data range geometry, and dimensions similar to that anticipated in the WIPP PA calculation and resulting in a qualitatively correct mass balance.

R.5 Time-varying Source Terms, with a slab source (non-point source).

R.6 Two-dimensional transport with convective, dispersion, decay, sorption, restricted to flow fields that are aligned with the grid if dispersion is not zero (i.e, no cross-terms are required in the governing equations) and restricted to dispersivities that are consistent with first-order upwind differencing.

R.7 Non-uniform, or stretched Cartesian grids.

R.8 Spatially variable material coefficients (e.g. Saturation, Porosity, Dispersitivity, Flow-Fields).

R.9 Solubility limit with linear precipitation model and colloid preferential solubility at the inventory limit.

R.10 Implementation of Neumann boundary conditions.

R.11 Implementation of Dirichlet conditions.

NUTS has a considerable number of external-interface requirements. They are listed in Section 2.4 of the code's Requirements Document.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

To exercise NUTS, users should have (1) basic knowledge of open VMS, (2) basic facility with Digital Command Language, and (3) an overall understanding of Sandia's CAMDAT database, which is used in virtually every WIPP code (Rechard, 1992; and Rechard et al., 1993). User's should also have (4) access to the WIPP cluster of Alpha-VAX microcomputers or their functional equivalents.

To manipulate and/or interpret the results of NUTS as it is exercised in WIPP PAs, users should have (1) a basic understanding of the chemistry of radioactive decay, solution chemistry, sorption chemistry, fluid flow and fluid transport in porous media, (2) a basic understanding of partial-differential equations and integral calculus, as they apply in the mathematical formulation of physical principles and especially of conservation of mass*, (3) a generalist's conceptual understanding of numerical methods as they are applied to the numerical solution of the boundary-value problems of mathematical physics and chemistry, and (4) a basic overview understanding of the WIPP PA process, including conceptual models, scenarios, inventories, release routes, uncertainty sampling, input-data vectors, and a general familiarity with the files and functions of the WIPP codes that run prior to exercising NUTS, principally BRAGFLO and ALGEBRA, and those that exercise immediately after NUTS, principally CCDFGF (WIPP PA Dept [5 Volumes], 1992). An annotated flow diagram of NUTS's 1996 CCA code sequence is shown in Figure 3.1.

* Strictly speaking, the transport system is not mass conserving. Alpha decay involves a loss of mass. Thus, NUTS actually conserves the number of molecules of radioactive material involved in the decay process.

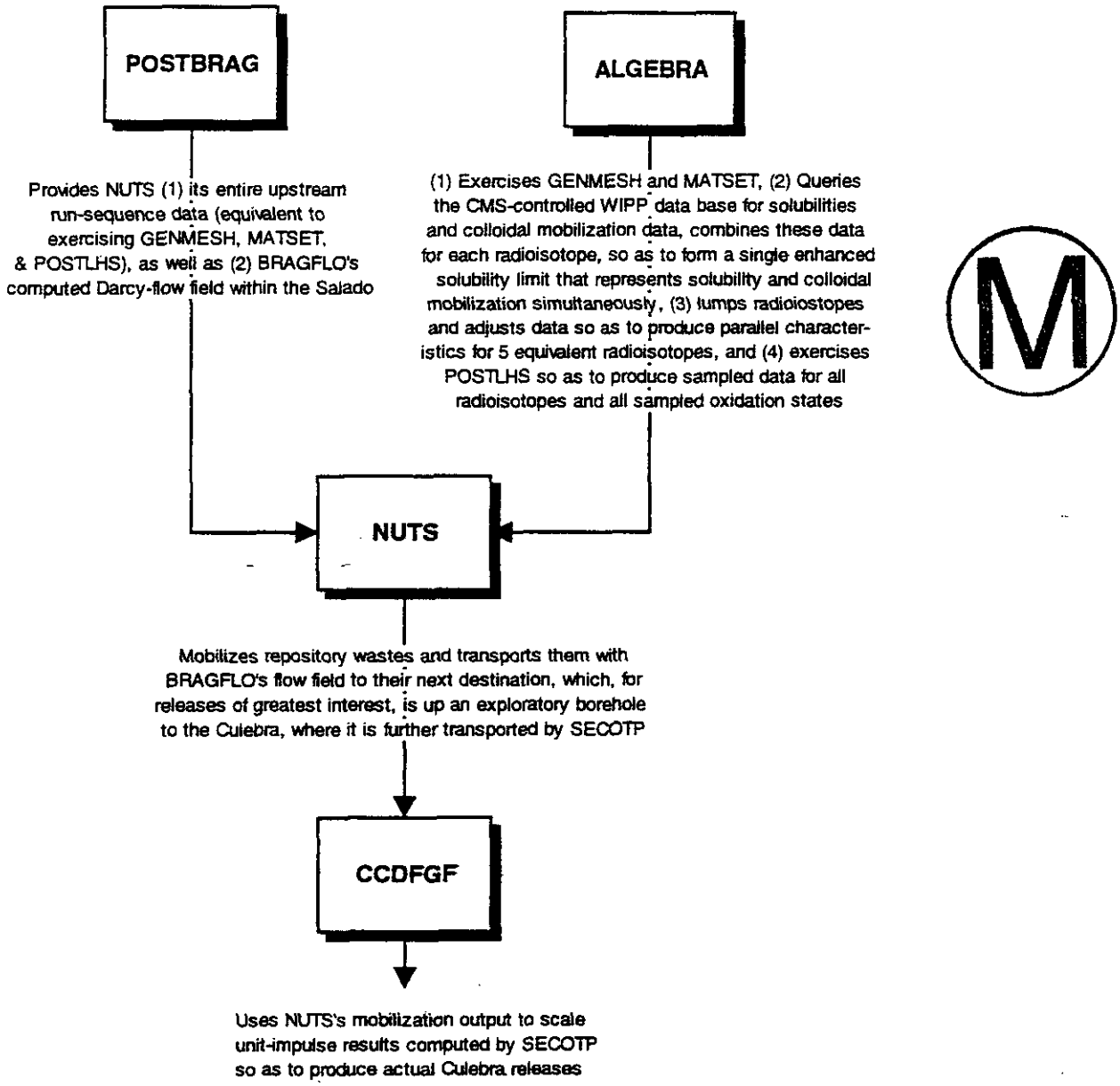

Figure 3.1: The code sequence for NUTS as it is exercised in the 1996 CCA.

4.0 DESCRIPTION of the MODEL and METHODS

4.1 Background

4.1.1 NUTS's General Role in the CCA PA

NUTS's principal CCA PA role is to estimate the radioactive contaminant load mobilized into the brine phase of the brine/gas mixture that seeps or flows through and around the WIPP repository's decommissioned waste panels. Mobilization by any process, for example dissolution or suspension on colloids, is modeled as taking place instantaneously. The contaminants introduced into the brine are the aged radioisotopes that are assumed to reside in the repository at the time of decommissioning plus any progeny of those radioisotopes that may have been produced through natural decomposition. Thus, a detailed inventory of the radioactive isotopes stored in the repository at the time of decommissioning must be provided to NUTS before it may be exercised.

NUTS plays no role in the physics of the fluid flow in or near the repository. The time history of the detailed (Darcy) volumetric flow rate throughout the repository must be provided to NUTS by an independent hydrological-flow code. In the case of the CCA, that code is BRAGFLO.

In the CCA WIPP assessment scenarios, brine is assumed to enter the repository panels in either of two very different ways, namely: (a) by natural seepage from the surrounding Salado formation, and (b) by various sorts of unnatural flows induced by exploratory boreholes. In the case of undisturbed operation, brine can seep into the repository through the disturbed rock zone from the surrounding undisturbed halite and marker beds. In the case of a repository breached by an exploratory borehole, the brine could flow into and through the repository via the pipe-like channels created by the borehole(s). The most intense flow would occur if the borehole also penetrated a deep pressurized brine pocket, and some boreholes are assumed to do so.

The natural time scales associated with deep, tight-media, groundwater flows are typically centuries, and WIPP intrusion scenarios include temporal lapses of millennia prior to the hypothesized breaching of repository waste panels by boreholes. Moreover, EPA regulations extend to 10,000 years after decommissioning. On these time scales, radioisotopes of interest exhibit significant natural decay by which they transform to other radioactive and non-radioactive isotopes and/or compounds in well-established ways. Thus, it is required to quantify the decay process and maintain a running record of the decayed contents of the repository as well as all the products of decomposition from the time of decommissioning onward to 10,000 years. NUTS does that.

In the context of the CCA, NUTS has a single principal area of application. It is this: given the defining characteristics of the flow of uncontaminated brine into the repository's waste panels, NUTS is required to model the dissolution and sorption of radioisotopes into the brine that wets the waste panels, and to calculate, given the fluid flow rates, the rate at which each isotope that was initially present in the repository, including the radioactive progeny of those isotopes, exits the repository via the now contaminated brine flow. The exit rate of contaminants depends on (i)

the outflow rate of the brine and (ii) the concentration of isotopes within the flowing brine. The first quantity is provided in advance by BRAGFLO, which analyses the 2-phase Darcy flow throughout the Castile, Salado, Rustler, and Dewey Lake Formations throughout the entire Land Withdrawal Act region. NUTS is required to calculate the second quantity (concentration of each radioisotope), and to do so by treating all the important physical processes that can affect transport via a brine carrier flowing through a porous medium.

Mobilization is assumed to take place instantaneously and to maximum capacity, i.e. to the "solubility" limit, given adequate stocks. In the CCA, the "solubility limit" is actually a maximum mobilized concentration that includes the maximum concentration of an element mobilized on four types of colloids as well as the solubility of the element. Construction of this maximum mobilized concentration is performed before the NUTS calculation using ALGEBRA.

Because of natural decay processes, it is entirely possible to find compounds in the effluent that were not present in the initial repository inventory.

4.1.2 Overview of NUTS's Capabilities

NUTS is a multidimensional, multicomponent, radioactive-contaminant transport code. It is designed to apply to single-porosity (SP), dual-porosity (DP), and/or dual-permeability (DPM) porous media. In two dimensions, the discretization employs five-point finite-difference methods. NUTS is designed to treat an enormously broad spectrum of transport problems. However, many of its options have been disabled in the CCA calculations for the sake of simplicity. CCA-disabled options are described briefly herein, and are clearly noted as disabled for CCA calculations.

The model simulates radioisotope transport through porous media and includes first-order radioactive decay processes. However, the simulator is not limited to radioactive materials. The transport of materials of all kinds, radioactive or not, may be simulated. In CCA applications, only radioisotopes are transported by NUTS.

In treating sorption between the waste and the media that surround it, NUTS allows for three types of sorption isotherms. They are: (1) linear, (2) Freundlich, and (3) Langumir equilibrium isotherms. **Only option (1) is tested for regulatory calculations, and none was used in the CCA calculations. A type of sorption onto colloids, however, was modeled in the ALGEBRA calculation run prior to NUTS. It is described in Section 4.5.1.**

NUTS normally models hydrodynamic dispersion under the assumption that the porous media through which the transport occurs are dispersively isotropic. However, for CCA calculations, both molecular and mechanical dispersion are taken to be zero. The effects of molecular dispersion are truly small (O(10m)). Mechanical dispersion is proportional to velocity and other physical and geometric factors (see Section 4.2.3). Ignoring transverse dispersion tends to keep solutes in the higher-velocity regions of the flow field. Ignoring lateral dispersion ignores streamwise elongation, which is reasonable given that EPA limits are defined in terms of time-integrated measures. For example, when and how a signal reaches the land-withdrawal boundary

are unimportant, as long as the signal reaches the boundary in 10,000 years. Numerical dispersion and statistical dispersion (due to sampling) are both present in NUTS results, and mimic physical dispersion.

"Dissolution" of waste components into the brine carrier medium is modeled, and the possibility of their precipitation during migration is included, should solutes exceed their local "solubility" limits. Precipitates are required to undergo decay and are permitted to "redissolve" in the brine if the concentration drops below the solubility limit.

Representation of multiple radioactive sites (repositories) is also possible. In that case, the contribution from each site to the component concentration and precipitation, if any, at each computational node can be found. A similar technique may be used to treat a daughter isotope generated from the decay of different parents. **However, use of this aspect of the code is not contemplated for the WIPP CCA PA, and it is therefore not tested.**

The system of governing partial-differential equations (mass conservation for each radioisotopic constituent) is discretized and solved sequentially to determine the contribution from a decaying parent to the immediate daughter. In the sequential method, the solution proceeds progressively from the top of each radioactive chain. Therefore, the contribution to any daughter from its decaying parent is available. This approach avoids the numerical problems associated with inverting a large, sparsely-populated matrix in which the bands are not well structured.

NUTS was developed specifically to assist in performance assessments of the WIPP. **It is that application, and specifically the CCA calculation, that will be described herein.** However, in its broadest sense, NUTS can be used in other applications involving contaminant transport of all kinds through porous media. Table-1 provides a summary for the features used in the CCA calculations.

4.2 Theoretical Foundations of Transport in Fractured Porous Media having Dual-Porosity and Dual-Permeability

In the textbook approach to dual-permeability, the partial differential equations (PDEs) representing transport in a fractured, porous medium are normally written as (1) the PDEs governing transport along the fractures, and (2) the PDEs governing transport through the matrix. The two PDEs are coupled by a transfer function that represents material transport between the two media (Kazemi et al, 1976; Hill and Thomas, 1985; Litvak, 1985; Coats, 1989). That is the approach taken herein.

4.2.1 Introduction to Fractured Porous Media

A fracture can be defined as a surface of discontinuity resulting from loss of cohesion of rock materials due to rupture. Most fractures in brittle rocks of low porosity occur as a result of tectonic processes. These fractures are usually large in size and extent, and are called

Table 1. NUTS Features Used in the CCA Calculations

NUTS Features	Features in the CCA Calculations	
	Used	Disabled
Single-porosity, fracture		x
Single-porosity, matrix	x	
Double-porosity		x
Double-permeability		x
Advective transport	x	
Diffusive-dispersive transport		x
Sorption		x
Colloid transport+		x
Decay	x	
Gas phase transport		x
Temperature dependency		x
Multiple sites		x
Precipitation	x	
Solubility limit	x	
Interior sources	x	

+ Colloids are lumped with dissolved inventory (see Section 4.5.1)

macrofractures. In less brittle rocks with higher intergranular porosities, the resulting fractures are usually smaller and less extensive, and are called microfractures, or fissures. Fractures generated by the state of stress in the earth's crust can be attributed to (van Golf-Racht, 1982):

1. folding and faulting;

2. rock volume shrinkage and the dehydration process;

3. volume shrinkage associated with heat loss; and

4. differential stress on the plane of weakness due to deep erosion of overburden rocks.

Thus, fractured porous media are typically conventional sedimentary materials possessing discontinuities introduced later by some sort of physical activity. Digenesis processes, such as mineral deposition (calcite), and dissolution of matrix and formation of stylolites may be associated with fracture formation. Fractures may be regular or irregular, closed and filled with cement, or open to flow. Most-fractured systems, occurring in a large variety of rock mineralogy, are described adequately (for hydrological purposes) by specifying the fracture spacing, orientation, length, and degree of cementation. These data are usually obtained from cores and outcrops coupled with rock mechanics studies, well logging, and seismic-profile distortion. Because of the inherent complexity associated with the characterization of these mineral discontinuities, porous-medium parameters such as porosity, permeability, etc., normally have a wide range of numerical uncertainty. Accordingly, the classical models of fluid flow and transport in porous media have been shown to be inadequate to represent a heterogeneous system in which the heterogeneities are due to fractures, vugs, and channels. A new and more complex model is required, the complexity deriving from the existence of two entirely different but interconnected paths for fluid flow and transport. Because natural fractures tend to be irregular in their distribution, orientation, and extension, some sort of reasonable idealization is required as a basis for a reasonable physical and mathematical description of the medium.

The basic theory of fluid flow in fractured porous media was introduced by Barenblatt and Zeltov (1960), who applied a continuum approach. Their approach is similar to the approach used in classical fluid-dynamical theories in which the physical properties of a cluster containing many molecules is allowed to persist in the limit of smallness. Barenblatt and Zeltov choose a smallest physical scale that lies between microscopic and macroscopic representations of fluid properties in regular porous media. In their approach, a representative elementary volume (REV), also called a control volume, is considered. It is much larger than pore size (i.e., it contains many pores and grains) but much smaller than the total domain considered. The REV's average porosity, permeability, pressure, saturation, concentration, and flux are ascribed to the mathematical point residing at the center of the REV (see Bear, 1972), which forms the basis of their hypothesis for a continuum. In applying a strictly continuum approach to dual-porosity or dual-permeability systems, one can assign a pair of average properties to each mathematical point; one representing fracture properties and one representing matrix properties. In other words, the medium consists of two overlapping continua that communicate one with another. In

this formulation, the REV contains many matrix blocks and fractures (see Figure 4.1). In actual double-porosity conceptualizations, the fractures, because of their high permeability relative to the matrix and high intensity (small spacing), are assumed to constitute a continuous medium. The matrix blocks between them are discontinuous and form the main storage region for the fluid. In double-permeability formulations, fracture spacings are larger, and matrix-to-matrix flow is permitted in the mathematical formulation of the problem*.

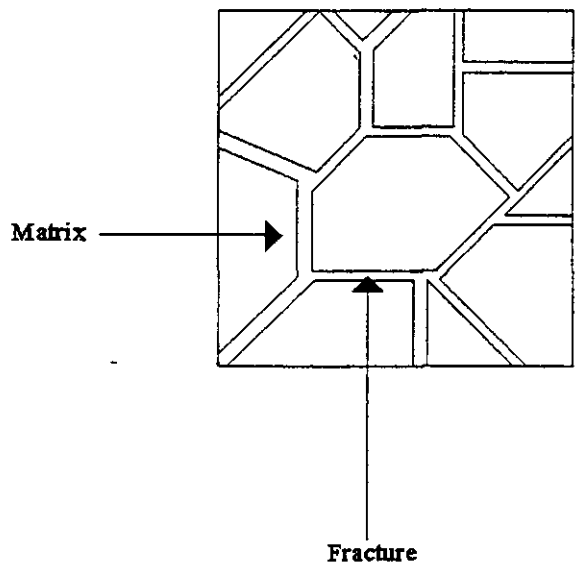

Figure 4.1 Schematic Diagram of Fractured REV.

4.2.2 Basic Dissolution Processes

When salty ground water comes into contact with repository wastes, dissolution of the soluble isotopes begins to take place and continues until equilibrium concentrations are attained, or until all undissolved supplies of radioisotopes are consumed. The capacity of WIPP brines to dissolve radioisotopes is controlled by temperature, pressure, and chemical properties of the brine and of the solutes. The main physical principal on which NUTS's transport equations are based is conservation of mass, and the principal dependant variable in which those equations are written is C, the concentration of solute (i.e., radioisotope) in the underlying fluid (i.e., brine). A pair of conservation equations arises for each radioisotope, one for the fracture domain and one for the matrix domain. The equation pairs are coupled one to another by transfer functions that

* For more information about these conceptualizations, the reader is referred to Beckner *et al.* (1991), Chen *et al.* (1987),Dean and Lo (1988), DeSwaan (1978, 1982), Duguid and Lee (1977), Dutra and Aziz (1991), Dykhuizeen (1990), Evans (1982), Gilman and Kazemi (1983, 1988), Gilman (1986), Huang-Zhang (1983), Kazemi and Merrill (1979), Kazemi *et al.* (1989), Narasimhan (1982), Pruess and Narasimhan (1985), Reiss *et al.* (1973), Rossen (1979), Saidi (1983), Shinta and Kazemi (1993), Sonier *et al.* (1986), Thomas et al (1983), Wu and Rruess (1988).

represent the flux of a given radioisotope between the matrix and fracture domains of the flow. The equation pairs are also coupled one with another by radioactive decay processes. Thus, a complex system of coupled partial differential equations is anticipated.

The concentration, C, of a given radioisotope must be non-negative everywhere in the domain. However, it also has an upper bound, equal to the maximum solubility limit for each element of the waste in whichever brine or combination of brines is present. There are two principal sources of brine, one of Salado origin and one of Castile origin (WIPP PA Dept, 1992, vol 1), and the brines are chemically different. The different brines come into play in the different scenarios. NUTS must be given the solubility limit of all soluble radioactive elements as part of its input data. It allocates the solubility limit for the isotopes according to their mole fractions. If radioisotope concentrations should exceed their solubility limits, NUTS will precipitate the excess in the grid block. NUTS subjects precipitates to decay and treats precipitation as a reversible process. If the concentration of a solute drops below the solubility limit, WIPP brines are permitted to redissolve from the precipitate a mass sufficient to restore the solubility limit of that solute, assuming sufficient precipitate is available.

4.3 Differential Equations Governing Transport in Fractured Porous Media

The mathematical formulation for the dual-continuum approach requires a mass-conservation equation for each continuum. Each such equation contains a coupling term (transfer function) that represents intercommunication (i.e., transport) between the two domains. The continuity-equation development that follows is general and therefore applies to both matrix and fracture domains, proving the coupling term is added. In porous media, the principal focus is on the transport of a solute whose intensity is measured in terms of a fluid concentration measured in Kg of solute per Kg of fluid. The mass-conservation equation (continuity equation) is derived by considering a REV shaped like a rectangular parallelepiped in the direction of the Cartesian coordinates (x, y, z), and having an infinitesimal volume of $\delta x \delta y \delta z$. The mass conservation principle can be stated in words as follows:

$$\left| \textit{Mass Flux in} - \textit{Mass Flux out} + \textit{Source / Sink} = \textit{Accumulation} \right|_{REV}$$

Boundary fluxes and internal sources derive from a myriad of physical processes, which we will describe and quantify individually in the subsections that follow.

4.3.1 Advective Transport

The mass-flux vector of the solute is represented as q^*, and its three Cartesian components as q^*_x, q^*_y, q^*_z, as shown in Figure 4.2.

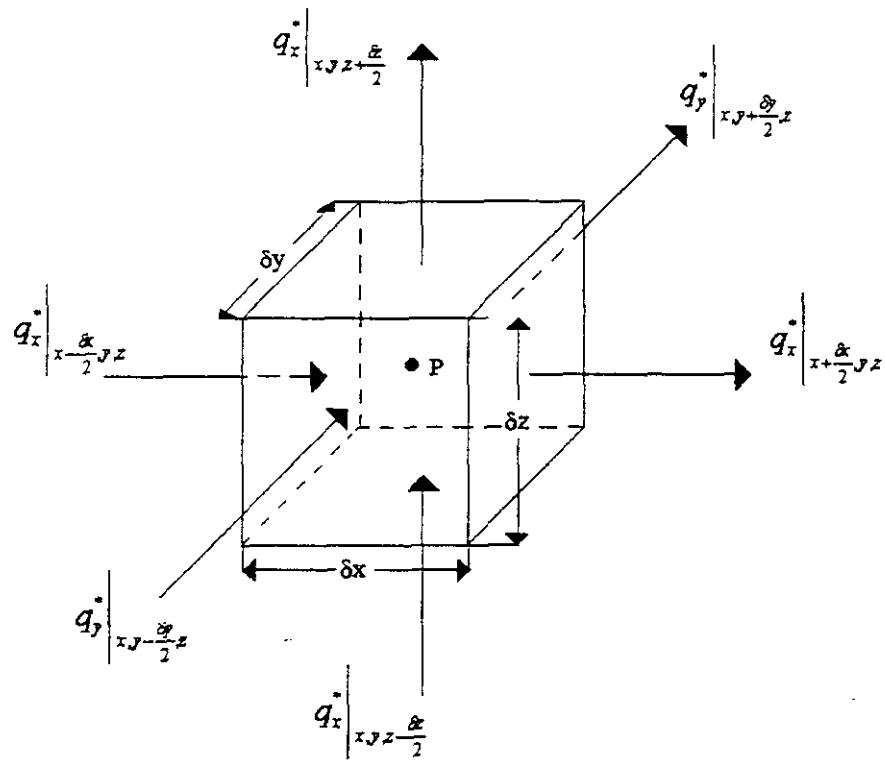

Figure 4.2 Schematic Diagram Showing the REV and the Fluxes q*.

The net mass inflow associated with flow in the x-direction during the time period δt is:

$$\left[q_x^* \Big|_{x-\frac{\delta x}{2}} - q_x^* \Big|_{x+\frac{\delta x}{2}} \right]_{y,z} \delta y \delta z \delta t . \qquad \textbf{4.1}$$

Using Taylor's series to expand around the central point P(x,y,z) of the REV, Equation 4.1 becomes:

$$\left[\left\{ q_x^* - \frac{\delta x}{2}\frac{\partial q_x^*}{\partial x} + \frac{(\delta x)^2}{8}\frac{\partial^2 q_x^*}{\partial x^2} - \ldots \right\} - \left\{ q_x^* + \frac{\delta x}{2}\frac{\partial q_x^*}{\partial x} + \frac{(\delta x)^2}{8}\frac{\partial^2 q_x^*}{\partial x^2} + \ldots \right\} \right] \delta y \delta z \delta t . \qquad \textbf{4.2}$$

Simplifying and neglecting higher order terms (which go to zero in the limit), Equation 4.2 reduces to:

$$-\frac{\partial q_x^*}{\partial x}\delta x\delta y\delta z\delta t\,.$$

Repeating the same procedure in the other two directions, the net mass of solute accumulated due to flux across the boundaries during the time period δt is:

$$-\left[\frac{\partial q_x^*}{\partial x}+\frac{\partial q_y^*}{\partial y}+\frac{\partial q_z^*}{\partial z}\right]\delta x\delta y\delta z\delta t\,. \qquad \textbf{4.3}$$

The net mass of solute accumulated in the control volume from internal sources (and lost to sinks) during the time period δt is:

$$q^*_{s/s}C'_{i/p}\delta x\delta y\delta z\delta t\,, \qquad \textbf{4.4}$$

where all symbols are defined in the summary list below. The net increase in mass of solute in the control volume during time δt may also be written as the local time rate of change of solute mass in the volume times δt, that is, as:

$$\frac{\partial(\phi S\rho C')}{\partial t}\delta x\delta y\delta z\delta t\,. \qquad \textbf{4.5}$$

Combining the terms in Equations 4.3, 4.4 and 4.5 according to the word equation stated in Section 4.3 results in:

$$-\left[\frac{\partial q_x^*}{\partial x}+\frac{\partial q_y^*}{\partial y}+\frac{\partial q_z^*}{\partial z}\right]\delta x\delta y\delta z\delta t+q^*_{s/s}C'_{i/p}\delta x\delta y\delta z\delta t=\frac{\partial(\phi S\rho C')}{\partial t}\delta x\delta y\delta z\delta t\,. \qquad \textbf{4.6}$$

Dividing Equation 4.6 by $\delta x\delta y\delta z\delta t$ and taking the limit as the control volume approaches zero leads to:

$$-\nabla.q^*+q^*_{s/s}C'_{i/p}=\frac{\partial(\phi S\rho C')}{\partial t}\,, \qquad \textbf{4.7}$$

where the nomenclature is defined as follows:

$$q^*=\rho\upsilon C' \qquad \textbf{4.8}$$

and

$q^*_{s/s}$ = solvent sink/source mass rate per unit volume (kg/s/m^3)

ρ = solvent density (kg/ m^3)

ϕ = porosity of porous medium (dimensionless fraction)

v = solvent advective velocity (m/s)

C' = solute concentration (kg/kg)

$C'_{i/p}$ = injected/produced solute concentration (kg/kg)

t = time (s)

S = saturation (dimensionless fraction)

If the entire Equation 4.7 is divided by the solvent density ρ (a constant), and q^* is replaced by its equivalent value (Equation 4.8), Equation 4.7 becomes:

$$-\nabla.\mathrm{v}C + qC_{i/p} = \frac{\partial(\phi SC)}{\partial t}, \qquad \textbf{4.9}$$

where:

C = solute concentration (kg/ m^3)

q = solvent sink/source volumetric rate per unit volume ($m^3/s/m^3$)

Equation 4.9 as written applies to the fluid domain as a whole (i.e., matrix plus fracture). However, as was said, we prefer to divide the domain into two separate flow regimes, matrix and fracture, and to allow the two to intercommunicate through a transfer function. The transfer function represents mass flux from the fracture to the matrix. Therefore, the transfer function that appears as a source in the matrix equation will appear as a sink (i.e., the same term, but with its sign reversed) in the fracture equation. The continuity equation that applies to either domain is written as follows:

$$-\nabla.\mathrm{v}_f C_f + q_f C_{fi/p} - \bar{\tau}_{m/f} C_{m/f} = \frac{\partial(\phi SC)_f}{\partial t}, \text{ for the fracture, and} \qquad \textbf{4.10a}$$

$$-\nabla.\mathrm{v}_m C_m + q_m C_{mi/p} + \bar{\tau}_{m/f} C_{m/f} = \frac{\partial(\phi SC)_m}{\partial t}, \text{ for the matrix,} \qquad \textbf{4.10b}$$

where $C_{m/f}$ is the upstream concentration of solute in kg/m^3 in either the fracture or the matrix depending on the direction of the solvent flow (see Section 4.4.1 for the computation of the upstream weighting factor), and $\bar{\tau}$ is the volumetric exchange rate, $m^3/s/m^3$ of solvent mass transfer between the fracture and the matrix. The + and - signs in the transfer terms in Equation 4.10 imply that the transfer acts as a source in one continuum and as a sink in the other. That is, what is lost from the matrix is gained by the fracture and vice versa.

4.3.2 Advective Transport Across Fracture/Matrix Interfaces

Transfers at fracture/matrix interfaces are dominated by a nearly steady-state Darcian flow represented by $\tau_{wm/f}$. The magnitude of these flow terms and their idealization are controlled and provided by the fluid flow code as volumetric rates.

The fracture /matrix transfer function τ for the brine could be evaluated in the fluid flow code by the following formula:

$$\tau_w = \sigma k_m \left(\frac{k_r}{\mu}\right)_{m/f} \left[P_f - P_m - \gamma_{m/f}(D_f - D_m)\right], \qquad \textbf{4.11}$$

where

D depth [m],
k permeability [m^2],
k_r relative permeability [dimensionless],
P pressure [Pa],
γ static pressure gradient [Pa/m],
μ viscosity [Pa/s],
σ shape factor [m^{-2}].

Subscripts

f = fracture
m = matrix
w = brine

4.3.3 Diffusive and Dispersive Transports

Advection represents the transport of solute as it is carried along by the motion of the fluid. Diffusion and dispersion represent transport of the solute due to its motion (or apparent motion) through the fluid. Molecular diffusion results from thermal motion of solute molecules. In porous media, the diffusion coefficient (sometimes called the apparent molecular diffusion coefficient) is calculated from the free-water molecular diffusion coefficient D^*_m adjusted for the tortuous path and the water content (saturation) of the transported phase of interest. Mechanical

dispersion is the mixing process resulting from the fluctuation in the ground-water velocity due to the heterogeneity of the porous media. Thus, if a sharp contaminant front is introduced into a porous-medium flow, the front will rapidly thicken as though an efficient diffusion mechanism were at work, whereas an abrupt interface would be expected to persist if only advective transport was at work. Among the processes that lead to thickening and distortion of a hypothetical front are sorption-desorption processes, molecular diffusion, and mechanical mixing (Bear, 1988). The last two are usually combined into a single effect called hydrodynamic dispersion.

In practical applications of solute-transport theory, it is customary to account for both the molecular and mechanical components of hydrodynamic dispersion. NUTS utilizes Fick's law to describe the dispersive contribution to mass transfer in both the fracture and matrix components of the flow. In vector notation, it is written:

$$F_D = \phi S K \nabla C, \qquad \textbf{4.12}$$

where F_D is the dispersion flux. Generally (but **not** in CCA calculations), NUTS treats the material dispersivity as a 2nd-rank tensor, with the additional assumption that the porous transport medium is isotropic. Bear (1988) has shown that this assumption is equivalent to representing the dispersivity tensor as a positive-definite, symmetric, 2nd-rank tensor. The most general dispersivity tensor would be the one shown in component form by the following matrix:

$$K = \begin{vmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{vmatrix}. \qquad \textbf{4.13}$$

However, because the dispersion tensor is assumed to be symmetric, six of its coefficients are related as follows: $K_{xy} = K_{yx}$, $K_{xz} = K_{zx}$, and $K_{yz} = K_{zy}$, or in indicial notation,

$$K_{ij} = \frac{D_m^*}{\tau^*}\delta_{ij} + \frac{\alpha_T}{\phi S}|v|\delta_{ij} + \frac{v_i v_j}{\phi S|v|}(\alpha_L - \alpha_T), \qquad \textbf{4.14}$$

where nomenclature is defined in the listing below. If the chosen coordinate system happens to coincide with the principal axes of dispersion, all the off-diagonal values will become zero in the tensor matrix. In that coordinate system, the dispersion coefficient in the x-direction for the fracture flow and the matrix flow become (Bear, 1993):

$$K_{fx} = \left\{ \frac{D_m^*}{\tau_f^*} + \frac{1}{\phi_f S_f |\vec{v}_f|}\left[\alpha_{Lf} v_{fx}^2 + \alpha_{Tf}\left(v_{fy}^2 + v_{fz}^2\right)\right] \right\}, \qquad \textbf{4.15}$$

and

$$K_{mx} = \left\{ \frac{D_m^*}{\tau_m^*} + \frac{1}{\phi_m S_m |\vec{v}_m|} \left[\alpha_{Lm} v_{mx}^2 + \alpha_{Tm} \left(v_{my}^2 + v_{mz}^2 \right) \right] \right\}, \qquad \textbf{4.16}$$

where the terms between braces are the x-component of the dispersivity tensor within (i) the fracture flow and (ii) the matrix flow, respectively, and where,

D^*_m = free water molecular diffusion coefficient [m^2/s],
τ^* = tortuosity+ [dimensionless],
α_L = longitudinal dispersivity [m],
α_T = transverse dispersivity [m],
δ_{ij} = kronecker delta [dimensionless],

and the velocity vector $\vec{v}$ is given by:

$$|\vec{v}| = \sqrt{v_x^2 + v_y^2 + v_z^2}\,. \qquad \textbf{4.17}$$

where v_x, v_y, v_z are the fluid flow velocities [m/s] in x, y, z directions, respectively. Similar formulations apply for the y and z components of the dispersivity tensor. The present version of NUTS applies the above formulation to diagonal components of the dispersivity tensor and ignores off-diagonal contributions.

Dispersion in the fracture and matrix is generally small and can be neglected in comparison to the advective part of the transport. Moreover, dispersion can always be a significant means of mass transfer between the fracture and matrix flow zones. Fick's law for the transport between the fracture and the matrix is written as:

$$F_{Dm/f} = \phi_m S_m K_{m/f} \left(C_f - C_m \right) \qquad \textbf{4.18}$$

Bear (1993) gives the dispersion coefficient for fracture/matrix flow as:

$$K_{wm/f} = \sigma \left\{ \frac{D_m^*}{\tau_m^*} + \alpha_m \frac{|v_{m/f}|}{\phi_m S_m} \right\}, \qquad \textbf{4.19}$$

where

+ Throughout this document, tortuosity is defined as the ratio of the square of the tortuous path length to the square of the mean path length. This definition results in tortuosities greater than or equal to unity. However, the reader should bear in mind that some formulations found in the literature use the inverse of the definition, leading to tortuosities less than or equal unity.

$v_{m/f}$ is the velocity of liquid transfer [m/s], and
σ is a shape factor.

In Equation 4.19, it is assumed that the contribution from the fracture dispersion is negligible compared with the matrix (the fracture aperture is very small compared with the matrix block dimensions).

The shape factor σ is defined, in general, as

$$\sigma = \sum_S \frac{A_m}{V_m d}, \qquad \textbf{4.20}$$

where

S is all the faces in the matrix block subjected to flow,
A_m is the surface area of the face subjected to flow [m^2],
V_m is the volume of the matrix block [m^3], and
d is the distance between the face and the center of the matrix block [m].

Sigma plays the role of Δn in $\Delta C/\Delta n$, which is the normal gradient to an interfacial surface. For a rectangular parallelepiped matrix block, the shape factor is calculated (Kazemi et al., 1976) to be,

$$\sigma = 4\left(\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}\right), \qquad \textbf{4.21}$$

where L_x, L_y, and L_z are the block dimensions in x, y, and z directions.

Collecting intermediate results, if Equations 4.12 and 4.18 are added to Equations 4.10, the resulting equations will be

$$\nabla.\phi_f S_f K_f \nabla C_f - \nabla.v_f C_f + q_f C_{fi/p} - \bar{\tau}_{m/f} C_{m/f} - \phi_m S_m K_{m/f}\left(C_f - C_m\right) = \frac{\partial(\phi S C)_f}{\partial t} \qquad \textbf{4.22}$$

for the fracture, and

$$\nabla.\phi_m S_m K_m \nabla C_m - \nabla.v_m C_m + q_m C_{mi/p} + \bar{\tau}_{m/f} C_{m/f} + \phi_m S_m K_{m/f}\left(C_f - C_m\right) = \frac{\partial(\phi S C)_m}{\partial t} \qquad \textbf{4.23}$$

for the matrix.

4.3.4 Asymmetric Dispersion

The mechanical-dispersion expression introduced in the transport equation is little more than a global expression that endeavors to compensate for our lack of detailed information regarding the microscopic nature of the heterogeneities inherent in porous media. However, examination of Equations 4.15 and 4.16 suggests the effective dispersion coefficient will always be positive. Therefore, mechanical dispersion always follow and enhance the trends established by molecular diffusion. It is reasonable to assume molecular diffusion follows Fick's law because of the random thermal motion of molecules. Therefore, molecular diffusion can expand symmetrically in all directions providing only that there exists a concentration gradient. This argument, if applied to the mechanical dispersion, will lead a well-known problem in which dispersion is directed opposite to the direction of the flow. Opposite-direction dispersion is physically incorrect and is associated with *a priori* ignorance of the flow direction (i.e., v^2 is always positive). In order to overcome this problem, NUTS has a module for Asymmetric dispersion that allows the dispersion to go only in the direction of the flow regardless of method used to discretize the transport equation. Because the method used is conservative, the only effect this treatment has on the transport, is shifting the centroid of the mass further downstream. In other words, the movement of the transport front will be little faster in the case of Asymmetric dispersion, as is depicted in Figure 4.3.

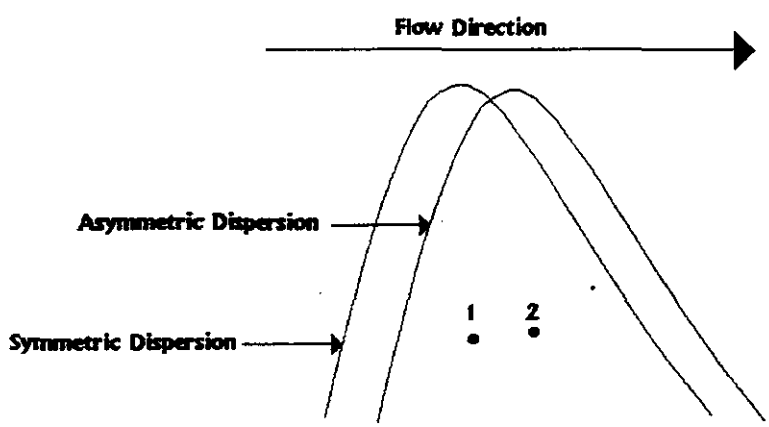

Figure 4.3 Symmetric versus Asymmetric Dispersion Fronts.

Asymmetric Dispersion is implemented numerically by computing a binary (0,1) parameter, κ as follows:

$$\kappa = \begin{vmatrix} 1 & \textit{if the concenteration gradient is in the same direction as the flow gradient} \\ 0 & \textit{otherwise} \end{vmatrix}$$

The parameter κ is then used as a multiplier only to the dispersion part of the transport equation (the molecular diffusion part is symmetric). This manipulation is performed while preparing the diagonal entries of the numerical matrix to assure mass conservation of the system.

4.3.5 Sorption-Desorption

Sorption refers to the ability of certain solids to extract substances preferentially from solution and deposit them on their surfaces. The solution can be either gaseous or liquid. Two general types of sorption are treated; physical sorption and chemical sorption. Physical sorption is a reversible process and arises on account of van der Waal intermolecular forces on the sorbing solid and the sorbed substance. In porous media, the sorbed substance may not react with the sorbing solid, but it can penetrate it via interstices, if a wettability condition is in effect. Chemical sorption is a result of chemical interaction between the sorbate and the sorbent. The chemical bond associated with this attraction is generally much greater than that found in the physical sorption. Ion exchange is sometimes classified as a kind of the chemical sorption.

Desorption is the process in which the solid phase releases some of the sorbed material back into solution. Sorption-desorption as a process depends on, pressure, temperature, and the chemical composition of the sorbate and the sorbent. It is usually described by an empirical relationship relating the concentration of the solute and the concentration of sorbate at a constant temperature, and is called an "isotherm." If a first-order kinetic model is used to describe the sorption-desorption process, one can write the following reaction-rate equation,

$$\frac{\partial R}{\partial t} = k_1 C - k_2 C_s, \qquad \textbf{4.24}$$

where R is the net rate of reaction, k_1 is the sorption reaction constant, k_2 is the desorption reaction constant, C is the concentration of sorbent in kg per kg of fluid, C_s is the concentration of sorbate in kg/kg dry porous media. In the limit of sorptive equilibrium,

$$\frac{\partial R}{\partial t} \to 0 \qquad \text{as } t \to \infty, \text{ and}$$

$$\frac{k_1}{k_2} = \chi = \frac{C_s}{C} \Rightarrow C_s = \chi C, \qquad \textbf{4.25}$$

where χ is a parameter that dependents on the shape of the equilibrium isotherm and the equilibrium conditions. For a linear isotherm $\chi = k_d$, the linear sorption equilibrium constant. The mass rate of sorption per unit volume, F_S, in kg/s/m^3 can therefore be determined from

$$F_S = \frac{\partial}{\partial t}(1-\phi)\rho_s C_s, \qquad \textbf{4.26}$$

where

ρ_s = rock grain density kg/m^3.

4.3.6 Matrix/Fracture Boundary Sorption

Many dissolved WIPP chemicals are subject to sorption onto the solid surfaces that form the boundaries in the rock matrix through which they flow. This phenomenon takes place because of the locally irregular atomic and molecular properties of the surface skins of virtually all materials. The mass transfer between a solute and the solid surface that bounds it is controlled by the chemical properties of the solid surface, the liquid transport medium, and the solute. Boundary sorption manifests itself as a retarding factor and is expressed in NUTS through the variables C_{sm} and C_{sf}, which represent the sorbed concentration of any specific radionuclide per unit mass of rock. It is conventional to relate C_{sm} and C_{sf} to the solute concentration by any of various empirical relations called "isotherms." As the name suggests, these isotherms are families of empirical graphs of sorbate concentration versus solute concentration at constant temperature. NUTS accommodates three equilibrium isotherms. They are the:

1. Linear sorption isotherm in which adsorbate concentration is related to solute concentration by:

$$C_s^{n+1} = k_d\ C_w^{n+1}, \qquad \textbf{4.27}$$

where

n+1 represents the implicitness of the concentration (current time step), and
k_d is the equilibrium partition coefficient.

2. Freundlich sorption isotherm in which sorbate concentration is related to solute concentration by:

$$C_s^{n+1} = x_1\left(C_w^{\frac{1}{x_2}}\right)^{n+1} = x_1\left(C_w^{\frac{1-x_2}{x_2}}\right)^{n} C_w^{n+1} = \chi\, C_w^{n+1} \qquad \textbf{4.28}$$

where n refers to the former time step, $\chi = x_1\left(C_w^{\frac{1-x_2}{x_2}}\right)^n$, and x_1 and x_2 are the Freundlich distribution coefficient and the Freundlich coefficient, respectively.

3. Langumir sorption isotherm, which, together with the linear isotherm, is one of the most common isotherms used in the literature today, and is defined by:

$$C_s^{n+1} = \chi_1 C_w^{n+1} \quad where\ \chi_1 = x_1\left(1 - \frac{x_2 C_w^n}{1 + x_2 C_w^n}\right) \qquad \textbf{4.29}$$

where the empirical parameters x_1 and x_2 are the Langumir distribution coefficient and the Langumir coefficient, respectively.

NUTS permits sorption in the fractures and the matrix, but it has the user-controlled ability to bypass sorption in either flow field. Moreover, it is possible to assign any specified isotope as sorbable or nonsorbable, regardless of the flow regime.

Matrix/fracture boundary sorption and desorption are **not** included in the CCA calculation. However, sorption onto colloidal materials suspended within the flow is included, and is treated exactly as dissolution is treated, i.e., the effective maximum solubility coefficients are increased so as to represent the sum of all maximum allowable concentrations associated with (i) dissolution and (ii) all allowable forms of colloidal mobilization. See Section 4.5.1.

4.3.7 Decay

Radioisotopes are naturally unstable and spontaneously emit clusters of particles equivalent to helium atoms until, eventually, they arrive at stable configurations. Thus, the mass of daughter products is always lower than that of the parent radioisotope. Rates of disintegration vary over a wide range. Some are so slow that the parent radioisotopes are regarded as stable for all practical purposes. The mode of the observed disintegration can be classified into two categories: 1) disintegration associated with a change in atomic mass, such as alpha particle emission and spontaneous fission, and 2) disintegration without a change in atomic mass, such as the emission of positive or negative beta particles and the capture by the nucleus of an electron in the n=1 shell. Regardless of the mode of disintegration, the rate of the process is governed by a first-order rate law. Thus, the differential equation governing the mass of radioisotope residing at the top of a decay chain is of the form

$$\frac{\partial N}{\partial t} = -\lambda N, \qquad \textbf{4.30}$$

where λ, the proportionality constant, is called the decay constant, and N is the number of atoms present at a given time, t . The integration of Equations like 4.30 leads to solutions of the form

$$N = N_0 e^{-\lambda t}, \qquad \textbf{4.31}$$

where N is the number of the atoms at any time, t , and N_0 is the number of the atoms at zero time. The decay constant is related to the half life by the following relationship:

$$\lambda = \frac{\ln 2}{t_{1/2}}, \qquad \textbf{4.32}$$

where $t_{1/2}$ is the half life. The decay constant and, therefore, the half life are fixed physical characteristics of each unstable radioisotope and are independent of its state of chemical combination, the presence of electric and magnetic fields, the temperature, and the pressure. Because there are Avogadro's number of atoms in each mole of a substance and a mass equivalent to the molecular weight in each mole, Equations 4.30 and 4.31 can be written in terms of mass M as:

$$\frac{\partial M}{\partial t} = -\lambda M, \qquad \textbf{4.33}$$

and

$$M = M_0 e^{-\lambda t}, \qquad \textbf{4.34}$$

where

M = mass of the solute at any time t (kg) , and

M_0 = mass of the solute at the initial time t_0 (kg) .

In porous media, the total mass of a radioisotope is distributed between the dissolved mass and the adsorbed mass. Therefore, from Equation 4.33, the rate at which mass is transported by decay, F_{decay}, in kg/s/m^3, can be written in terms of concentration as

$$F_{Decay} = -\lambda\left(\phi SC + (1-\phi)\rho_s C_s\right). \qquad \textbf{4.35}$$

Equation 4.35 represents a sink (i.e., loss of mass). If there is a parent(s) for the substance in question, the decay of the parent(s) will act as a source in the transport equation and have a value equal to the rate of growth of the daughter. The rate of growth due to parent(s) decay, F_g in kg/s/m^3 is

$$F_g = \sum_J \left(\phi SC + (1-\phi)\rho_s C_s\right)_{pj} \lambda_{pj}, \qquad \textbf{4.36}$$

where J is the total number of parent substances and pj is a parent index.

4.3.8 The Overall Mass-Transport Equation

Amassing all the source/sink effects associated with sorption and radioactive decay (Equations 4.26, 4.35, and 4.36) within the continuity equation thus far derived (Equations 4.22 and 4.23), the overall mass-transport equation applicable to either hydrological regime is:

$$\begin{aligned} &\nabla.\phi SK\nabla C - \nabla.\nu C + C^* q \pm \bar{\tau} C_{m/f} \pm \phi_m S_m K_{m/f}\left(C_f - C_m\right) = \\ &\frac{\partial}{\partial t}\left(\phi SC + (1-\phi)\rho_s C_s\right) + \left(\phi SC + (1-\phi)\rho_s C_s\right)\lambda - \\ &\sum_{j=1}^{J}\left(\phi SC + (1-\phi)\rho_s C_s\right)_{pj} \lambda_{pj} C_{pj} \end{aligned} \qquad \textbf{4.37}$$

In fractured porous media, if the total porosity, ϕ_t is defined as $\phi_t = \phi_m + \phi_f$, where ϕ_m is the matrix porosity and ϕ_f is the fracture porosity, then the partial differential equations representing the transport in the two geophysical domains (fractured, and porous media) can be written as follows:

Fracture Equation:

$$\begin{aligned} &\nabla.\phi_{wf} S_{wf} K_{wf} \nabla C_{wf} - \nabla.\nu_{wf} C_{wf} + C^*_{wf} q_{wf} - \bar{\tau} C_{wm/f} - \phi_{wm} S_{wm} K_{wm/f}\left(C_{wf} - C_{wm}\right) = \\ &\frac{\partial}{\partial t}\left(\phi_{wf} S_{wf} C_{wf} + (1-\phi_t)\rho_s C_{sf}\right) + \left(\phi_{wf} S_{wf} C_{wf} + (1-\phi_t)\rho_s C_{sf}\right)\lambda - \\ &\sum_{j=1}^{J}\left(\phi_{wf} S_{wf} C_{wf} + (1-\phi_t)\rho_s C_{sf}\right)_{pj} \lambda_{pj} C_{wfpj} \end{aligned} \qquad \textbf{4.38}$$

Matrix Equation:

$$\begin{aligned} &\nabla.\phi_{wm} S_{wm} K_{wm} \nabla C_{wm} - \nabla.\nu_{wm} C_{wm} + C^*_{wm} q_{wm} + \bar{\tau} C_{wm/f} + \phi_{wm} S_{wm} K_{wm/f}\left(C_{wf} - C_{wm}\right) = \\ &\frac{\partial}{\partial t}\left(\phi_{wm} S_{wm} C_{wm} + (1-\phi_t)\rho_s C_{sm}\right) + \left(\phi_{wm} S_{wm} C_{wm} + (1-\phi_t)\rho_s C_{sm}\right)\lambda - \\ &\sum_{j=1}^{J}\left(\phi_{wm} S_{wm} C_{wm} + (1-\phi_t)\rho_s C_{sm}\right)_{pj} \lambda_{pj} C_{wmpj} \end{aligned} \qquad \textbf{4.39}$$

where *f* =fracture, *m*=matrix, *w* = brine, *s*=solid, *t*=total, *m/f* = fracture/matrix, and $C^*=C_{i,p}$

4.3.9 Initial and Boundary Conditions

The system of transport equations (fracture and matrix) given above is part of a boundary-value problem. Therefore, some sort of (i) initialization condition is required throughout the domain, and (ii) boundary conditions for all time are required for the dependent variable $C(x,y,z,t)$. The initial condition of the matrix equation in the three-dimensional domain (0,X; 0,Y; and 0,Z) is

$$C_{wm}(x,y,z,0) = f_m(x,y,z) \qquad 0 \le x \le X,\ 0 \le y \le Y,\ 0 \le z \le Z. \qquad \textbf{4.40}$$

Similarly, the fracture is initialized by

$$C_{wf}(x,y,z,0) = f_f(x,y,z) \qquad 0 \le x \le X,\ 0 \le y \le Y,\ 0 \le z \le Z. \qquad \textbf{4.41}$$

To assure that the system is in initial equilibrium, there must be no pressure or concentration gradients between the two continua, which leads to:

$$f_f(x,y,z) = f_m(x,y,z) \qquad \textbf{4.42}$$

which must hold along their common boundary. The boundary conditions in the fracture and/or the matrix may be either Dirichlet or Neumann boundary conditions of the first kind. If they are Dirichlet conditions, the dependent variable itself is specified at the boundaries, as follows:

$$\begin{aligned}
C(0,y,z,t) &= g_{1x}(t) && t \ge 0,\\
C(X,y,z,t) &= g_{1X}(t) && t \ge 0,\\
C(x,0,z,t) &= g_{1y}(t) && t \ge 0,\\
C(x,Y,z,t) &= g_{1Y}(t) && t \ge 0,\\
C(x,y,0,t) &= g_{1z}(t) && t \ge 0,\\
C(x,y,Z,t) &= g_{1Z}(t) && t \ge 0.
\end{aligned} \qquad \textbf{4.43}$$

If they are Neumann boundary conditions, the normal derivatives of the dependent variable are specified at the boundaries, as follows

$$\frac{\partial}{\partial x}\left[C(0,y,z,t)\right] = g_{2x}(t) \qquad t \geq 0,$$

$$\frac{\partial}{\partial x}\left[C(X,y,z,t)\right] = g_{2X}(t) \qquad t \geq 0,$$

$$\frac{\partial}{\partial y}\left[C(x,0,z,t)\right] = g_{2y}(t) \qquad t \geq 0,$$

$$\frac{\partial}{\partial y}\left[C(x,Y,z,t)\right] = g_{2Y}(t) \qquad t \geq 0, \qquad \textbf{4.44}$$

$$\frac{\partial}{\partial z}\left[C(x,y,0,t)\right] = g_{2z}(t) \qquad t \geq 0,$$

$$\frac{\partial}{\partial z}\left[C(x,y,Z,t)\right] = g_{2Z}(t) \qquad t \geq 0.$$

These conditions are sometimes specified internally in the domain and called point source/sink.

In NUTS applications, Dirichlet boundary conditions can be used at both the outer boundaries or internally at sources. Neumann boundary conditions, on the other hand are used to specify no-transport at the outer boundaries of the simulation domain, i.e., $\frac{\partial C}{\partial x} = 0$, $\frac{\partial C}{\partial y} = 0$, and $\frac{\partial C}{\partial z} = 0$

4.4 Discretization Methods

The partial differential equations and boundary/initial conditions derived in Section 4.3 and representing transport in a dual-porosity, dual-permeability medium can be solved analytically for only the very simplest of problems, problems that bear virtually no relationship to real-world ground-water flows like those of the WIPP. To treat real-world problems, it is necessary to turn to numerical integration techniques, of which several are available.

The most common numerical methods used in modern hydrology are the finite-difference and finite-element (variational) methods, and particularly the Galerkin method. NUTS uses the finite-difference method to transform the time-space continuum problem into a solvable discrete mathematical model. An *algebraic* equation approximating the partial differential equation at each point of the domain of interest is derived. The derivational methods are described in this Section.

The first important step of the derivation is to define a convenient mesh (grid) over the entire spatial domain of interest.

For simplicity, consider the discrete representation of a continuous independent variable, x, between 0 and 1, as shown in Figure 4.4.

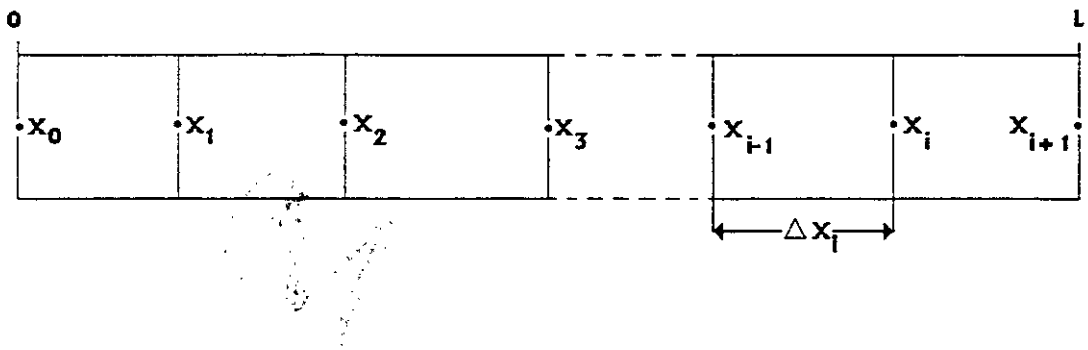

Figure 4.4 Point-Center Grid in Finite-Difference Approximation.

As is shown, the continuous domain is replaced by a set of discrete points whose spacing may be equal or unequal, and the discrete variable x is defined at those points. Clearly, the smaller the spacing the greater the resolution, but the more complex the resulting algebraic problem. Optimum spacings normally depend on the type of problem, the solution requirements, and the available resources. In Figure 4.4, the discrete values of x are denoted by x_i, $i = 0, 1, 2, ...$ The algebra is a little easier if the intervals are of equal width Δx, where Δx is called the finite difference.

$$x_i = i\Delta x . \qquad \textbf{4.45}$$

In that case, neighboring points are related to one another by

$$x_{i+1} = x_i + \Delta x , \qquad \textbf{4.46}$$

and Δx is the distance between successive grid points.

$$x_{i-1} = x_i - \Delta x . \qquad \textbf{4.47}$$

The function $C(x)$, which we think of as one of the unknown dependent variables of our problem, is normally defined on the continuous interval 0,1 . We will replace it by its finite-difference approximation C_i, which is defined only at the points $x = x_i$, $i = 0, 1, ..., I+1$, and is represented by

$$C(x_i) = C_i . \qquad \textbf{4.48}$$

Since our governing equations are partial differential equations, it is essential to have finite-difference expressions for the derivatives of an unknown function, as well as the function itself.

The derivative of the function C_i can be determined by Taylor's expansion C_i in the neighborhood of the point x. Thus for the function $C(x+\Delta x)$,

$$C(x+\Delta x)=C(x)+\frac{\partial C}{\partial x}\Delta x+\frac{\partial^2 C}{\partial x^2}\frac{\Delta x^2}{2!}+\frac{\partial^3 C}{\partial x^3}\frac{\Delta x^3}{3!}+\cdots+R_n, \qquad \textbf{4.49}$$

where the derivatives are evaluated at x and the remainder term R_n is given by

$$R_n=\frac{1}{n!}\left(\Delta x\frac{\partial}{\partial x}\right)^n C(x+\zeta\Delta x), \qquad \textbf{4.50}$$

and ζ lies between 0 and 1, so the argument of C lies between x and $x+\Delta x$. Equation 4.50 is sometimes written in the form

$$R_n=O\left[|\Delta x|^n\right], \qquad \textbf{4.51}$$

in which $|\Delta x|^n$ refers to the order of the truncation error in the Taylor series, and means there exists a positive constant M such that

$$|R_n|\le M\left(|\Delta x|^n\right) \text{ as } \Delta x\to 0. \qquad \textbf{4.52}$$

If we use a more compact notation, Equation 4.49 may be written as

$$C_{i+1}=C_i+\Delta x C_{ix}+\frac{(\Delta x)^2}{2!}C_{ixx}+\frac{(\Delta x)^3}{3!}C_{ixxx}+\cdots+R_n \qquad \textbf{4.53}$$

Similarly, the function $C(x-\Delta x)$ can be written as

$$C_{i-1}=C_i-\Delta x C_{ix}+\frac{(\Delta x)^2}{2!}C_{ixx}-\frac{(\Delta x)^3}{3!}C_{ixxx}+\cdots+R_n \qquad \textbf{4.54}$$

where $C_x=\frac{\partial C}{\partial x}, C_{xx}=\frac{\partial^2 C}{\partial x^2}$, etc., and all derivatives are evaluated at the point *i*. By adding and then subtracting Equations 4.53 and 4.54, one can arrive at finite-difference approximations for the first two derivatives of C_i, as follows:

$$C_{ix}=\frac{C_{i+1}-C_i}{\Delta x}+O(\Delta x), \qquad \textbf{4.55}$$

$$C_{ix} = \frac{C_i - C_{i-1}}{\Delta x} + O(\Delta x), \qquad \textbf{4.56}$$

$$C_{ix} = \frac{C_{i+1} - C_{i-1}}{2\Delta x} + O\left[(\Delta x)^2\right], \qquad \textbf{4.57}$$

$$C_{ixx} = \frac{C_{i+1} - 2C_i + C_{i-1}}{(\Delta x)^2} + O\left[(\Delta x)^2\right] \qquad \textbf{4.58}$$

Equations 4.55, 4.56, 4.57 are known, respectively, as forward-, backward-, and central-difference formulae for the first derivative of C_i . Equation 4.58 gives a finite-difference approximation for the second derivative of C_i . All these formulae arise from truncated infinite series. Thus, truncation errors are involved. Truncation errors vary in these formulations, being first-order in the forward and backward difference formulae, and second-order in the central-difference and the second derivative.

In NUTS's discretization of the transport equation, a block-centered grid is used, which is consistent with BRAGFLO's discretization. With a block-centered grid, the location of the advective component of the transport is evaluated not at grid points, but at the interior points mid way between grid points. This formulation leads to introduction of new points at which the discretized variable is defined, namely, at $C_{i+1/2}$ and $C_{i-1/2}$, which is in addition to the discrete points i where the concentration C_i was defined earlier (see Figure 4.5)

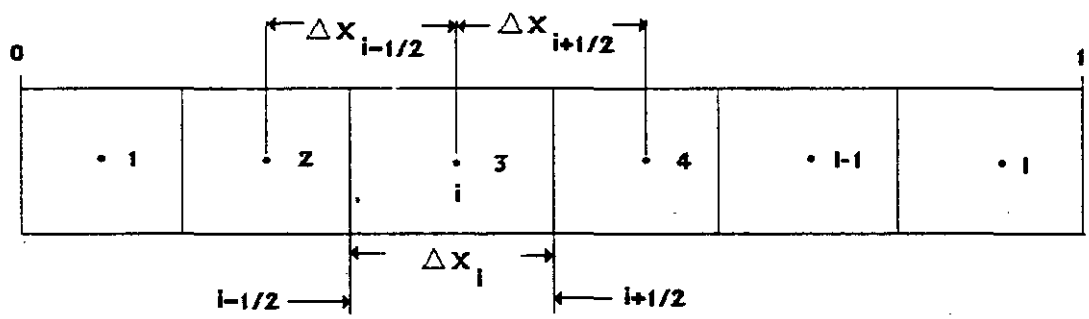

Figure 4.5 Block-Center Grid in Finite-Difference Approximation.

where $\Delta x_{i+\frac{1}{2}} = \frac{\Delta x_i + \Delta x_{i+1}}{2}$ is the distance between the neighboring points i and $i+1$. Various methods are used to approximate the value of the function at these interfacial points, each method having a characteristic accuracy. Among the most common methods are:

1. Mid-point weighting approximation. In this second-order accurate method, the concentration at the interface is approximated as follows:

$$C_{i-\frac{1}{2}} = (0.5+\mu_1)C_i + (0.5-\mu_1)C_{i-1}, \qquad \textbf{4.59}$$

and

$$C_{i+\frac{1}{2}} = (0.5+\mu_2)C_{i+1} + (0.5-\mu_2)C_i, \qquad \textbf{4.60}$$

where

$$\mu_1 = \frac{1}{4}\frac{\Delta x_{i-1} - \Delta x_i}{\Delta x_{i-1} + \Delta x_i}, \text{ and } \mu_2 = \frac{1}{4}\frac{\Delta x_i - \Delta x_{i+1}}{\Delta x_i + \Delta x_{i+1}}. \qquad \textbf{4.61}$$

From Equation 4.61, it is obvious that μ_1 and μ_2 are both zero for a uniform grid, wherein $C_{i+½}$ and $C_{i-½}$ become simple averages of neighboring values.

2. One-point upstream weighting. The interfacial concentration in this first-order accurate method is approximated by the concentration of the upstream block as follows:

$$C_{i-\frac{1}{2}} = \begin{Bmatrix} C_i & \textit{if the flow from } i \textit{ to } i-1 \\ C_{i-1} & \textit{if the flow from } i-1 \textit{ to } i \end{Bmatrix}. \qquad \textbf{4.62}$$

Similarly

$$C_{i+\frac{1}{2}} = \begin{Bmatrix} C_i & \textit{if the flow from } i \textit{ to } i+1 \\ C_{i+1} & \textit{if the flow from } i+1 \textit{ to } i \end{Bmatrix}. \qquad \textbf{4.63}$$

3. Two-point upstream weighting. This method is second-order accurate. The interfacial concentration in the two-point upstream weighting is approximated by the concentration of the two grid blocks upstream of the interface as follows:

$$C_{i-\frac{1}{2}} = \begin{Bmatrix} (1+\mu_1)C_i - \mu_1 C_{i+1} & \textit{if the flow from } i \textit{ to } i-1 \\ (1+\mu_2)C_{i-1} - \mu_2 C_{i-2} & \textit{if the flow from } i-1 \textit{ to } i \\ \textit{where } \mu_1 = \dfrac{\Delta x_i}{\Delta x_i + \Delta x_{i+1}} \textit{ and } \mu_2 = \dfrac{\Delta x_{i-1}}{\Delta x_{i-1} + \Delta x_{i-2}} & \end{Bmatrix}, \qquad \textbf{4.64}$$

and

$$C_{i+\frac{1}{2}} = \begin{cases} (1+\mu_1)C_i - \mu_1 C_{i-1} & \text{if the flow from } i \text{ to } i+1 \\ (1+\mu_2)C_{i+1} - \mu_2 C_{i+2} & \text{if the flow from } i+1 \text{ to } i \\ \text{where } \mu_1 = \dfrac{\Delta x_i}{\Delta x_i + \Delta x_{i-1}} \text{ and } \mu_2 = \dfrac{\Delta x_{i+1}}{\Delta x_{i+1} + \Delta x_{i+2}} & \end{cases}. \qquad \textbf{4.65}$$

4. Leonard method. This third-order accurate method uses two grid blocks upstream and one grid block downstream. In this method and for a uniform grid, if the flow in Figure 4.5 is from the left to the right, then

$$C_{i-\frac{1}{2}} = \frac{2C_i + 5C_{i-1} - C_{i-2}}{6}, \qquad \textbf{4.66}$$

and

$$C_{i+\frac{1}{2}} = \frac{2C_{i+1} + 5C_i - C_{i-1}}{6}. \qquad \textbf{4.67}$$

5. Total-variation-diminishing (TVD) flux-limiter methods. In this class of methods, the flux, $F = vC$, and not the concentration is used as the independent variable. It starts with the average of F,

$$F_{i+\frac{1}{2}} = f_i + \frac{\Delta x}{2}\frac{f_{i+1} - f_i}{\Delta x} \qquad \textbf{4.68}$$

which is written as the first two terms of a Taylor expansion. Then, the slope-term contribution is multiplied by a flux-limiter function, φ, so that

$$F_{i+\frac{1}{2}} = f_i + \varphi(r_i)A_{i+\frac{1}{2}} \qquad \textbf{4.69}$$

where $A_{i+\frac{1}{2}}$ is the slope-term contribution and $\varphi(r)$, the flux-limiter term, is chosen in a way that gives a value of approximately 1.0 in smooth regions of the concentration profile. In regions where oscillations could occur due to the unrestrained slope-term contributions, $\varphi(r)$ is allowed to vary so as to eliminate spurious solutions. The variable r is defined as the ratio of successive slope terms, namely:

$$r_i = \frac{A_{i-\frac{1}{2}}}{A_{i+\frac{1}{2}}} \qquad \textbf{4.70}$$

Many satisfactory flux-limiter functions are available in the literature. A widely used example is the van Leer limiter, which is defined as:

$$\varphi(r_i) = \frac{|r_i| + r_i}{1 + |r_i|} \qquad \textbf{4.71}$$

The flux limiter should be calculated to be TVD, which means the total variation in the concentration is non increasing. If the total variation in the concentration at a certain time is defined by:

$$TV(C^n) = \sum (C^n_{i+1} - C^n_i) \qquad \textbf{4.72}$$

then in the TVD,

$$TV(C^{n+1}) \le TV(C^n) \qquad \textbf{4.73}$$

where $n+1$ refers to the next time step. The formulation for $F_{i-\frac{1}{2}}$ is parallel. Using Equation 4.69, it is clear that TVD is a mid-point scheme, when $\varphi(r)=1$; a one-point upstream weighting scheme, when $\varphi(r)=0$; and a two-point upstream weighting scheme, when $\varphi(r)=r$. Other constraints apply to the flux-limiter function, depending on the degree of implicitness in the solution, but they are beyond the scope of this manual.

Thus far, the discretized values of the function and its spatial derivatives have been introduced. For time dependent problems, which arise in WIPP PAs, the dependent variables, generically denoted C_i are also functions of time $C_i = C_i(t)$. Therefore, at each grid point x_i, (i) a continuous or (ii) a discrete solution in time must also be calculated. If the time derivative is not discretized, the system of governing equations can, in principle, be solved by any of the methods traditionally used to solve ordinary differential equations. Euler's method, and the Runge-Kutta method are popular choices. However, the more common approach is to discretize temporal derivatives as well as spatial derivatives. In finite-difference formulations, the time derivative is approximated by one of the equations given above (Equation 4.55 to 4.58). A straightforward solution can be achieved by approximating the time derivative using the forward-difference method, as shown below:

$$\left(\frac{\partial C_i}{\partial t}\right)^n = \frac{C_i^{n+1} - C_i^n}{\Delta t}, \qquad \textbf{4.74}$$

where Δt refers to the time-step size, $n+1$ signifies the next time in the discrete sequence, and n is the present time. When the spatial distribution of the dependent variable C_i is known at the time step n, the system of equations can be solved explicitly. On the other hand, if the time derivative in Equation 4.74 is approximated using the backward-difference method and the spatial distribution of the dependent variable C_i is known at the time step $n+1$, a system of I equations must be solved. This method is called the implicit method. The implicit and explicit methods can also be combined so as to form a third integration method. Which method of solution to choose is not wholly arbitrary. Questions of stability, convergence, consistency, and the order of the method must be considered. Consequently, a versatile code must provide for several alternatives.

NUTS accommodates the first three weighting methods mentioned above, namely: one-point upstream, two-point upstream, and mid-point weighting. For temporal variabilities, NUTS's solution method can, in principle, vary from fully explicit to fully implicit. This spectrum of methods is cumbersome to describe. Therefore, for illustration purposes, an exemplary case will be shown in detail, but then details will be omitted from the discretized equations that follow. For the example, consider the hyperbolic, one-dimensional, purely-advective, partial differential equation given as Equation 4.75, in which the time derivative is discretized according to Equation 4.74:

$$(1-\theta)\left(-u\frac{\partial C}{\partial x}\right)^{n+1} + \theta\left(-u\frac{\partial C}{\partial x}\right)^{n} = \frac{C_i^{n+1} - C_i^n}{\Delta t}. \qquad \textbf{4.75}$$

In Equation 4.75: if $\theta = 1$, the temporal scheme is explicit; if $\theta = 0$, the temporal scheme is implicit; and if $\theta = 1/2$, the scheme is mixed, and this particular scheme is known as the Crank-Nicolson method.

4.4.1 Discrete Analogues of the Conservation of Mass Equations

Let us now consider the partial differential equations that govern transport in the fracture and the matrix of interest. We will discretize them in general and then develop the linear system for different numerical implementations. For the fracture, the discretized mass-transport equation in the brine is:

$$
\begin{aligned}
&\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{i+\frac{1}{2}}\left(C_{wfi+1}^{n+1} - C_{wfi}^{n+1}\right) - \left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{i-\frac{1}{2}}\left(C_{wfi}^{n+1} - C_{wfi-1}^{n+1}\right) + \\
&\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{j+\frac{1}{2}}\left(C_{wfj+1}^{n+1} - C_{wfj}^{n+1}\right) - \left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{j-\frac{1}{2}}\left(C_{wfj}^{n+1} - C_{wfj-1}^{n+1}\right) + \\
&\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{k+\frac{1}{2}}\left(C_{wfk+1}^{n+1} - C_{wfk}^{n+1}\right) - \left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{k-\frac{1}{2}}\left(C_{wfk}^{n+1} - C_{wfk-1}^{n+1}\right) + \\
&q_{wfi+\frac{1}{2}}^{n+1} C_{wfi+\frac{1}{2}}^{n+1} - q_{wfi-\frac{1}{2}}^{n+1} C_{wfi-\frac{1}{2}}^{n+1} + q_{wfj+\frac{1}{2}}^{n+1} C_{wfj+\frac{1}{2}}^{n+1} - q_{wfj-\frac{1}{2}}^{n+1} C_{wfj-\frac{1}{2}}^{n+1} + q_{wfk+\frac{1}{2}}^{n+1} C_{wfk+\frac{1}{2}}^{n+1} - q_{wfk-\frac{1}{2}}^{n+1} C_{wfk-\frac{1}{2}}^{n+1} \\
&+ C_{wfi}^{*n+1} Q_{wfi}^{n+1} - \tau_{wm/fi}^{n+1}\left(\omega_{m/fi} C_{wfi}^{n+1} + \left(1-\omega_{m/fi}\right) C_{wmi}^{n+1}\right) - \\
&\left(\phi_{mi}^{n+1} S_{wmi}^{n+1} K_{wm/fi}^{n+1}\right)\left(C_{wfi}^{n+1} - C_{wmi}^{n+1}\right) = \\
&\frac{V_{Ri}}{\Delta t}\left[\left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n+1} - \left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n}\right] + \\
&V_{Ri}\left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n+1}\lambda - V_{Ri}\sum_{l=1}^{L}\left[\left\{\phi_{fi} S_{wfi} C_{wfli} + \left(1-\phi_t\right)\rho_s C_{sfli}\right\}\lambda_l\right]^{n+1}.
\end{aligned}
\tag{4.76}
$$

Similarly, for the matrix continuum, the discretized mass-transport equation in the brine is:

$$
\begin{aligned}
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{i+\frac{1}{2}}\left(C_{wmi+1}^{n+1} - C_{wmi}^{n+1}\right) - \left(\phi_m^{n+1} S_{wf}^{n+1} K_{wm}^{n+1}\right)_{i-\frac{1}{2}}\left(C_{wmi}^{n+1} - C_{wmi-1}^{n+1}\right) + \\
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{j+\frac{1}{2}}\left(C_{wmj+1}^{n+1} - C_{wmj}^{n+1}\right) - \left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{j-\frac{1}{2}}\left(C_{wmj}^{n+1} - C_{wmj-1}^{n+1}\right) + \\
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{k+\frac{1}{2}}\left(C_{wmk+1}^{n+1} - C_{wmk}^{n+1}\right) - \left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{k-\frac{1}{2}}\left(C_{wmk}^{n+1} - C_{wmk-1}^{n+1}\right) + \\
&q_{wmi+\frac{1}{2}}^{n+1} C_{wmi+\frac{1}{2}}^{n+1} - q_{wmi-\frac{1}{2}}^{n+1} C_{wmi-\frac{1}{2}}^{n+1} + q_{wmj+\frac{1}{2}}^{n+1} C_{wmj+\frac{1}{2}}^{n+1} - q_{wmj-\frac{1}{2}}^{n+1} C_{wmj-\frac{1}{2}}^{n+1} + q_{wmk+\frac{1}{2}}^{n+1} C_{wmk+\frac{1}{2}}^{n+1} - q_{wmk-\frac{1}{2}}^{n+1} C_{wmk-\frac{1}{2}}^{n+1} \\
&+ C_{wmi}^{*n+1} Q_{wmi}^{n+1} + \tau_{wm/fi}^{n+1}\left(\omega_{m/fi} C_{wfi}^{n+1} + \left(1-\omega_{m/fi}\right) C_{wmi}^{n+1}\right) + \left(\phi_{mi}^{n+1} S_{wmi}^{n+1} K_{wm/fi}^{n+1}\right)\left(C_{wfi}^{n+1} - C_{wmi}^{n+1}\right) = \\
&\frac{V_{Ri}}{\Delta t}\left[\left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n+1} - \left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n}\right] + \\
&V_{Ri}\left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n+1}\lambda - V_{Ri}\sum_{l=1}^{L}\left[\left\{\phi_{mi} S_{wmi} C_{wmli} + \left(1-\phi_t\right)\rho_s C_{smli}\right\}\lambda_l\right]^{n+1}
\end{aligned}
\tag{4.77}
$$

4.4.2 One-Point Upstream-Winding Discretization of Transport Equations

Fracture Equation

$$
\begin{aligned}
&\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{i+\frac{1}{2}}\left(C_{wfi+1}^{n+1} - C_{wfi}^{n+1}\right) - \left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{i-\frac{1}{2}}\left(C_{wfi}^{n+1} - C_{wfi-1}^{n+1}\right) + \\
&\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{j+\frac{1}{2}}\left(C_{wfj+1}^{n+1} - C_{wfj}^{n+1}\right) - \left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{j-\frac{1}{2}}\left(C_{wfj}^{n+1} - C_{wfj-1}^{n+1}\right) +
\end{aligned}
$$

$$
\begin{aligned}
&\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{k+\frac{1}{2}}\left(C_{wfk+1}^{n+1} - C_{wfk}^{n+1}\right) - \left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{k-\frac{1}{2}}\left(C_{wfk}^{n+1} - C_{wfk-1}^{n+1}\right) + \\
&q_{wfi+\frac{1}{2}}^{n+1}\left(\omega_{fi+1} C_{wfi}^{n+1} + \left(1-\omega_{fi+1}\right) C_{wfi+1}^{n+1}\right) - q_{wfi-\frac{1}{2}}^{n+1}\left(\omega_{fi} C_{wfi-1}^{n+1} + \left(1-\omega_{fi}\right) C_{wfi}^{n+1}\right) + \\
&q_{wfj+\frac{1}{2}}^{n+1}\left(\omega_{fj+1} C_{wfj}^{n+1} + \left(1-\omega_{fj+1}\right) C_{wfj+1}^{n+1}\right) - q_{wfj-\frac{1}{2}}^{n+1}\left(\omega_{fj} C_{wfj-1}^{n+1} + \left(1-\omega_{fj}\right) C_{wfj}^{n+1}\right) + \\
&q_{wfk+\frac{1}{2}}^{n+1}\left(\omega_{fk+1} C_{wfk}^{n+1} + \left(1-\omega_{fk+1}\right) C_{wfk+1}^{n+1}\right) - q_{wfk-\frac{1}{2}}^{n+1}\left(\omega_{fk} C_{wfk-1}^{n+1} + \left(1-\omega_{fk}\right) C_{wfk}^{n+1}\right) + \\
&C_{wfi}^{n+1} Q_{wfi}^{n+1} - \tau_{wm/fi}^{n+1}\left(\omega_{m/fi} C_{wfi}^{n+1} + \left(1-\omega_{m/fi}\right) C_{wmi}^{n+1}\right) - \left(\phi_{mi}^{n+1} S_{wmi}^{n+1} K_{wm/fi}^{n+1}\right)\left(C_{wfi}^{n+1} - C_{wmi}^{n+1}\right) = \\
&\frac{V_{Ri}}{\Delta t}\left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n+1} - \frac{V_{Ri}}{\Delta t}\left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n} + \\
&V_{Ri}\left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n+1}\lambda - V_{Ri}\sum_{l=1}^{L}\left\{\left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfli}\right\}\lambda_l\right\}^{n+1}.
\end{aligned}
\tag{4.78}
$$

By collecting similar terms, the above equation can be represented by the following linear system,

$$
\begin{aligned}
&A_f C_{wfk-1}^{n+1} + B_f C_{wfj-1}^{n+1} + C_f C_{wfi-1}^{n+1} + D_{1f} C_{wfijk}^{n+1} + D_{2f} C_{wmijk}^{n+1} + \\
&E_f C_{wfi+1}^{n+1} + F_f C_{wfj+1}^{n+1} + G_f C_{wk+1}^{n+1} = R_f^{n+1}
\end{aligned}
\tag{4.79}
$$

where

$$
\begin{aligned}
A_f &= HD_{wfk-\frac{1}{2}}^{n+1} - \omega_{fk} q_{wfk-\frac{1}{2}}^{n+1}, \\
B_f &= HD_{wfj-\frac{1}{2}}^{n+1} - \omega_{fj} q_{wfj-\frac{1}{2}}^{n+1}, \\
C_f &= HD_{wfi-\frac{1}{2}}^{n+1} - \omega_{fi} q_{wfi-\frac{1}{2}}^{n+1}, \\
E_f &= HD_{wfi+\frac{1}{2}}^{n+1} - \left(1-\omega_{fi+1}\right) q_{wfi+\frac{1}{2}}^{n+1}, \\
F_f &= HD_{wfj+\frac{1}{2}}^{n+1} - \left(1-\omega_{fj+1}\right) q_{wfj+\frac{1}{2}}^{n+1}, \\
G_f &= HD_{wfk+\frac{1}{2}}^{n+1} - \left(1-\omega_{fk+1}\right) q_{wfk+\frac{1}{2}}^{n+1}, \\
D_{1f} &= -HD_{wfk-\frac{1}{2}}^{n+1} - HD_{wfj-\frac{1}{2}}^{n+1} - HD_{wfi-\frac{1}{2}}^{n+1} - HD_{wfk+\frac{1}{2}}^{n+1} - HD_{wfj+\frac{1}{2}}^{n+1} - HD_{wfi+\frac{1}{2}}^{n+1} - \\
&\left(1-\omega_{fk}\right) q_{wfk-\frac{1}{2}}^{n+1} - \left(1-\omega_{fj}\right) q_{wfj-\frac{1}{2}}^{n+1} - \left(1-\omega_{fi}\right) q_{wfi-\frac{1}{2}}^{n+1} + \omega_{fk+1} q_{wfk+\frac{1}{2}}^{n+1} + \omega_{fj+1} q_{wfj+\frac{1}{2}}^{n+1} + \omega_{fi+1} q_{wfi+\frac{1}{2}}^{n+1} - \\
&\frac{V_{Ri}}{\Delta t}\left\{\phi_{fi} S_{wfi} + \left(1-\phi_t\right)\rho_s \xi_{fi}\right\}^{n+1} + V_{Ri}\left\{\phi_{fi} S_{wfi} + \left(1-\phi_t\right)\rho_s \xi_{fi}\right\}^{n+1}\lambda - \tau_{wm/fi}^{n+1}\omega_{m/fi} - \phi_m^{n+1} S_{wm}^{n+1} K_{wm/fi}^{n+1},
\end{aligned}
$$

$$D_{2f}^{n+1} = -\tau_{wm/fi}^{n+1}\left(1 - \omega_{m/fi}\right) + \phi_m^{n+1} S_{wm}^{n+1} K_{wm/fi}^{n+1},$$

and

$$R_f^{n+1} = \frac{V_{Ri}}{\Delta t}\left\{\phi_{fi} S_{wfi} C_{wfi} + (1-\phi_t)\rho_s \xi_{fi} C_{wfi}\right\}^n - C_{wfi}^* Q_{wfi}^{n+1} - V_{Ri}\sum_{i=1}^{L}\left\{\left\{\phi_{fi} S_{wfi} C_{wfli} + (1-\phi_t)\rho_s \xi_{fli} C_{wfli}\right\}\lambda_l\right\}^{n+1}.$$

In the above formulations HD is the hydrodynamic dispersion and is defined at every fluid-solid interface. The convention adopted in NUTS for calculating the HD is that the values of the porosity, saturation, dispersivities, and tortousity are weighted upstream. Therefore, $HD_{wfi-1/2}$ is defined as follows:

$$HD_{wfi-\frac{1}{2}}^{n+1} = \omega_{fi}\phi_{fi} S_{wfi} + \left(1-\omega_{fi}\right)\phi_{fi-1} S_{wfi-1} \frac{\Delta y_i \Delta z_i}{\frac{\Delta x_i + \Delta x_{i-1}}{2}} \left\{\frac{D_m^*}{\tau_f^*} + \frac{1}{\omega_{fi}\phi_{fi} S_{wfi} + \left(1-\omega_{fi}\right)\phi_{fi-1} S_{wfi-1}} \frac{1}{\sqrt{v_{xf}^2 + v_{yf}^2 + v_{xf}^2}}\left(\alpha_{Lf} v_{xf}^2 + \alpha_{Tf}\left(v_{yf}^2 + v_{zf}^2\right)\right)\right\}$$

Similar equations can be written for the HD of the other interfaces. The values of ζ used in R_f and D_{1f} are sorption coefficients and depend mainly on the isotherm selected for use. For example, in the linear adsorption isotherm ζ is equivalent to k_d. In the above formulations, ω refers to the upstream weighting and has values of 0 and 1. The value of ω is calculated depending on the sign of the velocity. For two adjacent blocks i-1, and i the value of ω_i is:

$$\omega_i = \begin{cases} 1 & \textit{if the flow from } i-1, j, k \textit{ to } i, j, k \\ 0 & \textit{otherwise} \end{cases}$$

similarly, the weighting parameters in the other direction are

$$\omega_j = \begin{cases} 1 & \textit{if the flow from } i, j-1, k \textit{ to } i, j, k \\ 0 & \textit{otherwise} \end{cases}$$

and

$$\omega_k = \begin{cases} 1 & \textit{if the flow from } i, j, k-1 \textit{ to } i, j, k \\ 0 & \textit{otherwise} \end{cases}$$

Similar convention is used in calculating the matrix/fracture weighting factor which is:

$$\omega_{m/f} = \begin{Bmatrix} 1 & \textit{if flow from the fracture to the matrix} \\ 0 & \textit{otherwise} \end{Bmatrix}$$

Matrix Equation:

$$\begin{aligned}
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{i+\frac{1}{2}} \left(C_{wmi+1}^{n+1} - C_{wmi}^{n+1}\right) - \left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{i-\frac{1}{2}} \left(C_{wmi}^{n+1} - C_{wmi-1}^{n+1}\right) + \\
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{j+\frac{1}{2}} \left(C_{wmj+1}^{n+1} - C_{wmj}^{n+1}\right) - \left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{j-\frac{1}{2}} \left(C_{wmj}^{n+1} - C_{wmj-1}^{n+1}\right) + \\
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{k+\frac{1}{2}} \left(C_{wmk+1}^{n+1} - C_{wmk}^{n+1}\right) - \left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{k-\frac{1}{2}} \left(C_{wmk}^{n+1} - C_{wmk-1}^{n+1}\right) + \\
&q_{wmi+\frac{1}{2}}^{n+1} \left(\omega_{mi+1} C_{wmi}^{n+1} + \left(1-\omega_{mi+1}\right) C_{wmi+1}^{n+1}\right) - q_{wmi-\frac{1}{2}}^{n+1} \left(\omega_{mi} C_{wmi-1}^{n+1} + \left(1-\omega_{mi}\right) C_{wmi}^{n+1}\right) + \\
&q_{wmj+\frac{1}{2}}^{n+1} \left(\omega_{mj+1} C_{wmj}^{n+1} + \left(1-\omega_{mj+1}\right) C_{wmj+1}^{n+1}\right) - q_{wmj-\frac{1}{2}}^{n+1} \left(\omega_{mj} C_{wmj-1}^{n+1} + \left(1-\omega_{mj}\right) C_{wmj}^{n+1}\right) + \\
&q_{wmk+\frac{1}{2}}^{n+1} \left(\omega_{mk+1} C_{wmk}^{n+1} + \left(1-\omega_{mk+1}\right) C_{wmk+1}^{n+1}\right) - q_{wmk-\frac{1}{2}}^{n+1} \left(\omega_{mk} C_{wmk-1}^{n+1} + \left(1-\omega_{mk}\right) C_{wmk}^{n+1}\right) + \\
&C_{wmi}^{*n+1} Q_{wmi}^{n+1} + \tau_{wm/fi}^{n+1} \left(\omega_{m/fi} C_{wfi}^{n+1} + \left(1-\omega_{m/fi}\right) C_{wmi}^{n+1}\right) + \left(\phi_{mi}^{n+1} S_{wmi}^{n+1} K_{wm/fi}^{n+1}\right)\left(C_{wfi}^{n+1} - C_{wmi}^{n+1}\right) = \\
&\frac{V_{Ri}}{\Delta t}\left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n+1} - \frac{V_{Ri}}{\Delta t}\left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n} + \\
&V_{Ri}\left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n+1}\lambda - V_{Ri}\sum_{l=1}^{L}\left\{\left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smli}\right\}\lambda_l\right\}^{n+1}.
\end{aligned} \tag{4.80}$$

Corresponding to the fracture-flow equation, the linear system is:

$$\begin{aligned}
&A_m C_{wmk-1}^{n+1} + B_m C_{wmj-1}^{n+1} + C_m C_{wmi-1}^{n+1} + D_{1m} C_{wmijk}^{n+1} + D_{2m} C_{wfijk}^{n+1} + \\
&E_m C_{wmi+1}^{n+1} + F_m C_{wmj+1}^{n+1} + G_m C_{wmk+1}^{n+1} = R_m^{n+1}
\end{aligned} \tag{4.81}$$

where

$$A_m = HD_{wmk-\frac{1}{2}}^{n+1} - \omega_{mk} q_{wmk-\frac{1}{2}}^{n+1},$$

$$B_m = HD_{wmj-\frac{1}{2}}^{n+1} - \omega_{mj} q_{wmj-\frac{1}{2}}^{n+1},$$

$$C_m = HD_{wmi-\frac{1}{2}}^{n+1} - \omega_{wi} q_{wmi-\frac{1}{2}}^{n+1},$$

$$E_m = HD_{wmi+\frac{1}{2}}^{n+1} + \left(1-\omega_{mi+1}\right) q_{wmi+\frac{1}{2}}^{n+1},$$

$$F_m = HD^{n+1}_{wmj+\frac{1}{2}} + \left(1-\omega_{mj+1}\right)q^{n+1}_{wmj+\frac{1}{2}}$$

$$G_m = HD^{n+1}_{wmk+\frac{1}{2}} + \left(1-\omega_{mk+1}\right)q^{n+1}_{wmk+\frac{1}{2}},$$

$$D^{n+1}_{1m} = -HD^{n+1}_{wmk-\frac{1}{2}} - HD^{n+1}_{wmj-\frac{1}{2}} - HD^{n+1}_{wmi-\frac{1}{2}} - HD^{n+1}_{wmk+\frac{1}{2}} - HD^{n+1}_{wmj+\frac{1}{2}} - HD^{n+1}_{wmi+\frac{1}{2}}$$

$$\left(1-\omega_{mk}\right)q^{n+1}_{wmk-\frac{1}{2}} - \left(1-\omega_{mj}\right)q^{n+1}_{wmj-\frac{1}{2}} - \left(1-\omega_{mi}\right)q^{n+1}_{wmi-\frac{1}{2}} + \omega_{mk+1}q^{n+1}_{wmk+\frac{1}{2}} + \omega_{mj+1}q^{n+1}_{wmj+\frac{1}{2}} + \omega_{mi+1}q^{n+1}_{wmi+\frac{1}{2}} -$$

$$\frac{V_{Ri}}{\Delta t}\left\{\phi_{mi}S_{wmi} + \left(1-\phi_t\right)\rho_s\xi_{mi}\right\}^{n+1} + V_{Ri}\left\{\phi_{mi}S_{wmi} + \left(1-\phi_t\right)\rho_s\xi_{mi}\right\}^{n+1}\lambda + \tau^{n+1}_{wm/fi}\left(1-\omega_{m/fi}\right) - \phi^{n+1}_m S^{n+1}_{wm}K^{n+1}_{wm/fi},$$

$$D^{n+1}_{2m} = \tau^{n+1}_{wm/fi}\omega_{m/fi} + \phi^{n+1}_m S^{n+1}_{wm}K^{n+1}_{wm/fi},$$

and

$$R^{n+1}_m = \frac{V_{Ri}}{\Delta t}\left\{\phi_{mi}S_{wmi}C_{wmi} + \left(1-\phi_t\right)\rho_s\xi_{mi}C_{wmi}\right\}^n - C^*_{wmi}Q^{n+1}_{wmi} -$$

$$V_{Ri}\sum_{i=1}^{L}\left\{\left\{\phi_{mi}S_{wmi}C_{wmli} + \left(1-\phi_t\right)\rho_s\xi_{mli}C_{wmli}\right\}\lambda_l\right\}^{n+1}.$$

In a similar fashion, the HD in the matrix at I-1/2 interface is defined as follows:

$$HD^{n+1}_{wmi-\frac{1}{2}} = \omega_{mi}\phi_{mi}S_{wmi} + \left(1-\omega_{mi}\right)\phi_{mi-1}S_{wmi-1}\frac{\Delta y_i\Delta z_i}{\frac{\Delta x_i + \Delta x_{i-1}}{2}}\left\{\frac{D^*_m}{\tau^*_m} + \right.$$

$$\left.\frac{1}{\omega_{mi}\phi_{mi}S_{wmi} + \left(1-\omega_{mi}\right)\phi_{mi-1}S_{wmi-1}}\frac{1}{\sqrt{v^2_{xm} + v^2_{ym} + v^2_{zm}}}\left(\alpha_{Lm}v^2_{xm} + \alpha_{Tm}\left(v^2_{ym} + {}^2_{zm}\right)\right)\right\}$$

Similar definitions for ξ and ω's will be extended to the matrix discretization.

4.4.3 Two-Point Upstream-Winding Discretization of Transport Equations

In this method, two approaches for discretization are used. In the first approach, the equation is discretized fully implicitly as follows:

Fracture Equation

$$\left(\phi^{n+1}_f S^{n+1}_{wf}K^{n+1}_{wf}\right)_{i+\frac{1}{2}}\left(C^{n+1}_{wfi+1} - C^{n+1}_{wfi}\right) - \left(\phi^{n+1}_f S^{n+1}_{wf}K^{n+1}_{wf}\right)_{i-\frac{1}{2}}\left(C^{n+1}_{wfi} - C^{n+1}_{wfi-1}\right) +$$

$$
\begin{aligned}
&\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{j+\frac{1}{2}}\left(C_{wfj+1}^{n+1}-C_{wfj}^{n+1}\right)-\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{j-\frac{1}{2}}\left(C_{wfj}^{n+1}-C_{wfj-1}^{n+1}\right)+\\
&\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{k+\frac{1}{2}}\left(C_{wfk+1}^{n+1}-C_{wfk}^{n+1}\right)-\left(\phi_f^{n+1} S_{wf}^{n+1} K_{wf}^{n+1}\right)_{k-\frac{1}{2}}\left(C_{wfk}^{n+1}-C_{wfk-1}^{n+1}\right)+\\
&q_{wfi+\frac{1}{2}}^{n+1}\left[\omega_{fi+1}\left\{(1+\mu_{i1})C_{wfi}^{n+1}-\mu_{i1}C_{wfi-1}^{n+1}\right\}+(1-\omega_{fi+1})\left\{(1+\mu_{i2})C_{wfi+1}^{n+1}-\mu_{i2}C_{wfi+2}^{n+1}\right\}\right]-\\
&q_{wfi-\frac{1}{2}}^{n+1}\left[\omega_{i}\left\{(1+\mu_{i3})C_{wfi-1}^{n+1}-\mu_{i3}C_{wfi-2}^{n+1}\right\}+(1-\omega_{i})\left\{(1+\mu_{i4})C_{wfi}^{n+1}-\mu_{i4}C_{wfi+1}^{n+1}\right\}\right]+\\
&q_{wfj+\frac{1}{2}}^{n+1}\left[\omega_{fj+1}\left\{(1+\mu_{j1})C_{wfj}^{n+1}-\mu_{j1}C_{wfj-1}^{n+1}\right\}+(1-\omega_{fj+1})\left\{(1+\mu_{j2})C_{wfj+1}^{n+1}-\mu_{j2}C_{wfj+2}^{n+1}\right\}\right]-\\
&q_{wfj-\frac{1}{2}}^{n+1}\left[\omega_{fj}\left\{(1+\mu_{j3})C_{wfj-1}^{n+1}-\mu_{j3}C_{wfj-2}^{n+1}\right\}+(1-\omega_{fj})\left\{(1+\mu_{j4})C_{wfj}^{n+1}-\mu_{j4}C_{wfj+1}^{n+1}\right\}\right]+\\
&q_{wfk+\frac{1}{2}}^{n+1}\left[\omega_{fk+1}\left\{(1+\mu_{k1})C_{wfk}^{n+1}-\mu_{k1}C_{wfk-1}^{n+1}\right\}+(1-\omega_{fk+1})\left\{(1+\mu_{k2})C_{wfk+1}^{n+1}-\mu_{k2}C_{wfk+2}^{n+1}\right\}\right]-\\
&q_{wfk-\frac{1}{2}}^{n+1}\left[\omega_{fk}\left\{(1+\mu_{k3})C_{wfk-1}^{n+1}-\mu_{k3}C_{wfk-2}^{n+1}\right\}+(1-\omega_{fk})\left\{(1+\mu_{k4})C_{wfk}^{n+1}-\mu_{k4}C_{wfk+1}^{n+1}\right\}\right]+\\
&C_{wfi}^{*n+1} Q_{wfi}^{n+1}-\tau_{wm/fi}^{n+1}\left(\omega_{m/fi}C_{wfi}^{n+1}+(1-\omega_{m/fi})C_{wmi}^{n+1}\right)-\left(\phi_{mi}^{n+1} S_{wmi}^{n+1} K_{wm/fi}^{n+1}\right)\left(C_{wfi}^{n+1}-C_{wmi}^{n+1}\right)=\\
&\frac{V_{Ri}}{\Delta t}\left[\left\{\phi_{fi}S_{wfi}C_{wfi}+(1-\phi_t)\rho_s C_{sfi}\right\}^{n+1}-\left\{\phi_{fi}S_{wfi}C_{wfi}+(1-\phi_t)\rho_s C_{sfi}\right\}^{n}\right]+\\
&V_{Ri}\left\{\phi_{fi}S_{wfi}C_{wfi}+(1-\phi_t)\rho_s C_{sfi}\right\}^{n+1}\lambda-V_{Ri}\sum_{l=1}^{L}\left[\left\{\phi_{fi}S_{wfi}C_{wfli}+(1-\phi_t)\rho_s C_{sfli}\right\}\lambda_l\right]^{n+1}.
\end{aligned}
\tag{4.82}
$$

Matrix Equation:

$$
\begin{aligned}
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{i+\frac{1}{2}}\left(C_{wmi+1}^{n+1}-C_{wmi}^{n+1}\right)-\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{i-\frac{1}{2}}\left(C_{wmi}^{n+1}-C_{wmi-1}^{n+1}\right)+\\
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{j+\frac{1}{2}}\left(C_{wmj+1}^{n+1}-C_{wmj}^{n+1}\right)-\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{j-\frac{1}{2}}\left(C_{wmj}^{n+1}-C_{wmj-1}^{n+1}\right)+\\
&\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{k+\frac{1}{2}}\left(C_{wmk+1}^{n+1}-C_{wmk}^{n+1}\right)-\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{k-\frac{1}{2}}\left(C_{wmk}^{n+1}-C_{wmk-1}^{n+1}\right)+
\end{aligned}
$$

$$
\begin{aligned}
& q^{n+1}_{wmi+\frac{1}{2}}\left[\omega_{mi+1}\left\{(1+\mu_{i1})C^{n+1}_{wmi}-\mu_{i1}C^{n+1}_{wmi-1}\right\}+(1-\omega_{mi+1})\left\{(1+\mu_{i2})C^{n+1}_{wmi+1}-\mu_{i2}C^{n+1}_{wmi+2}\right\}\right]- \\
& q^{n+1}_{wmi-\frac{1}{2}}\left[\omega_{mi}\left\{(1+\mu_{i3})C^{n+1}_{wmi-1}-\mu_{i3}C^{n+1}_{wmi-2}\right\}+(1-\omega_{mi})\left\{(1+\mu_{i4})C^{n+1}_{wmi}-\mu_{i4}C^{n+1}_{wmi+1}\right\}\right]+ \\
& q^{n+1}_{wmj+\frac{1}{2}}\left[\omega_{mj+1}\left\{(1+\mu_{j1})C^{n+1}_{wmj}-\mu_{j1}C^{n+1}_{wmj-1}\right\}+(1-\omega_{mj+1})\left\{(1+\mu_{j2})C^{n+1}_{wmj+1}-\mu_{j2}C^{n+1}_{wmj+2}\right\}\right]- \\
& q^{n+1}_{wmj-\frac{1}{2}}\left[\omega_{mj}\left\{(1+\mu_{j3})C^{n+1}_{wmj-1}-\mu_{j3}C^{n+1}_{wmj-2}\right\}+(1-\omega_{mj})\left\{(1+\mu_{j4})C^{n+1}_{wmj}-\mu_{j4}C^{n+1}_{wmj+1}\right\}\right]+ \\
& q^{n+1}_{wmk+\frac{1}{2}}\left[\omega_{mk+1}\left\{(1+\mu_{k1})C^{n+1}_{wmk}-\mu_{k1}C^{n+1}_{wmk-1}\right\}+(1-\omega_{mk+1})\left\{(1+\mu_{k2})C^{n+1}_{wmk+1}-\mu_{k2}C^{n+1}_{wmk+2}\right\}\right]- \\
& q^{n+1}_{wmk-\frac{1}{2}}\left[\omega_{mk}\left\{(1+\mu_{k3})C^{n+1}_{wmk-1}-\mu_{k3}C^{n+1}_{wmk-2}\right\}+(1-\omega_{mk})\left\{(1+\mu_{k4})C^{n+1}_{wmk}-\mu_{k4}C^{n+1}_{wmk+1}\right\}\right]+ \\
& C^{*n+1}_{wmi}Q^{n+1}_{wmi}+\tau^{n+1}_{wm/fi}\left(\omega_{m/fi}C^{n+1}_{wfi}+(1-\omega_{m/fi})C^{n+1}_{wmi}\right)+\left(\phi^{n+1}_{mi}S^{n+1}_{wmi}K^{n+1}_{wm/fi}\right)\left(C^{n+1}_{wfi}-C^{n+1}_{wmi}\right)= \\
& \frac{V_{Ri}}{\Delta t}\left[\left\{\phi_{mi}S_{wmi}C_{wmi}+(1-\phi_t)\rho_s C_{smi}\right\}^{n+1}-\left\{\phi_{mi}S_{wmi}C_{wmi}+(1-\phi_t)\rho_s C_{smi}\right\}^{n}\right]+ \\
& V_{Ri}\left\{\phi_{mi}S_{wmi}C_{wmi}+(1-\phi_t)\rho_s C_{smi}\right\}^{n+1}\lambda-V_{Ri}\sum_{l=1}^{L}\left[\left\{\phi_{mi}S_{wmi}C_{wmli}+(1-\phi_t)\rho_s C_{smli}\right\}\lambda_l\right]^{n+1},
\end{aligned}
\tag{4.83}
$$

where

$$\mu_{i1}=\frac{\Delta x_i}{\Delta x_i+\Delta x_{i-1}},\ \mu_{i2}=\frac{\Delta x_{i+1}}{\Delta x_{i+1}+\Delta x_{i+2}},\ \mu_{i3}=\frac{\Delta x_i}{\Delta x_i+\Delta x_{i+1}},\ \mu_{i4}=\frac{\Delta x_{i-1}}{\Delta x_{i-1}+\Delta x_{i-2}},$$

$$\mu_{j1}=\frac{\Delta y_j}{\Delta y_j+\Delta y_{j-1}},\ \mu_{j2}=\frac{\Delta y_{j+1}}{\Delta y_{j+1}+\Delta y_{j+2}},\ \mu_{j3}=\frac{\Delta y_j}{\Delta y_j+\Delta y_{j+1}},\ \mu_{j4}=\frac{\Delta y_{j-1}}{\Delta y_{j-1}+\Delta y_{j-2}},$$

$$\mu_{k1} = \frac{\Delta z_k}{\Delta z_k + \Delta z_{k-1}},\ \mu_{k2} = \frac{\Delta z_{k+1}}{\Delta z_{k+1} + \Delta z_{k+2}},\ \mu_{k3} = \frac{\Delta z_k}{\Delta z_k + \Delta z_{k+1}},\ and\ \mu_{k4} = \frac{\Delta z_{k-1}}{\Delta z_{k-1} + \Delta z_{k-2}}$$

the corresponding linear system of the fracture-flow equation is:

$$A_{2f} C^{n+1}_{wfk-2} + A_{1f} C^{n+1}_{wfk-1} + B_{2f} C^{n+1}_{wfj-2} + B_{1f} C^{n+1}_{wfj-1} + C_{2f} C^{n+1}_{wfi-2} + C_{1f} C^{n+1}_{wfi-1} + D_{1f} C^{n+1}_{wfijk} + D_{2f} C^{n+1}_{wmijk} +$$
$$E_{1f} C^{n+1}_{wfi+1} + E_{2f} C^{n+1}_{wfi+2} + F_{1f} C^{n+1}_{wfj+1} + F_{2f} C^{n+1}_{wfj+2} + G_{1f} C^{n+1}_{wfk+1} + G_{2f} C^{n+1}_{wfk+2} = R^{n+1}_f, \qquad \textbf{4.84}$$

where

$$A_{1f} = HD^{n+1}_{wfk-\frac{1}{2}} - \omega_{fk}(1+\mu_{k3}) q^{n+1}_{wfk-\frac{1}{2}} - \omega_{fk+1}\mu_{k1} q^{n+1}_{wfk+\frac{1}{2}},$$

$$A_{2f} = -\omega_{fk}\mu_{k3} q^{n+1}_{wfk-\frac{1}{2}},$$

$$B_{1f} = HD^{n+1}_{wfj-\frac{1}{2}} - \omega_{fj}(1+\mu_{j3}) q^{n+1}_{wfj-\frac{1}{2}} - \omega_{fj+1}\mu_{j1} q^{n+1}_{wfj+\frac{1}{2}},$$

$$B_{2f} = -\omega_{fj}\mu_{j3} q^{n+1}_{wfj-\frac{1}{2}},$$

$$C_{1f} = HD^{n+1}_{wfi-\frac{1}{2}} - \omega_{fi}(1+\mu_{i3}) q^{n+1}_{wfi-\frac{1}{2}} - \omega_{fi+1}\mu_{i1} q^{n+1}_{wfi+\frac{1}{2}},$$

$$C_{2f} = -\omega_{fi}\mu_{i3} q^{n+1}_{wfi-\frac{1}{2}},$$

$$E_{1f} = HD^{n+1}_{wfi+\frac{1}{2}} + (1-\omega_{fi+1})(1+\mu_{i2}) q^{n+1}_{wfi+\frac{1}{2}} + (1-\omega_{fi})\mu_{i4} q^{n+1}_{wfi-\frac{1}{2}},$$

$$E_{2f} = -(1-\omega_{fi+1})\mu_{i2} q^{n+1}_{wfi+\frac{1}{2}},$$

$$F_{1f} = HD^{n+1}_{wfj+\frac{1}{2}} + (1-\omega_{fj+1})(1+\mu_{j2}) q^{n+1}_{wfj+\frac{1}{2}} + (1-\omega_{fj})\mu_{j4} q^{n+1}_{wfj-\frac{1}{2}},$$

$$F_{2f} = -(1-\omega_{fj+1})\mu_{j2} q^{n+1}_{wfj+\frac{1}{2}},$$

$$G_{1f} = HD^{n+1}_{wfk+\frac{1}{2}} + \left(1-\omega_{fk+1}\right)\left(1+\mu_{k2}\right)q^{n+1}_{wfk+\frac{1}{2}} + \left(1-\omega_{fk}\right)\mu_{k4}q^{n+1}_{wfk-\frac{1}{2}},$$

$$G_{2f} = -\left(1-\omega_{fk+1}\right)\mu_{k2}q^{n+1}_{wfk+\frac{1}{2}},$$

$$D^{n+1}_{1f} = -HD^{n+1}_{wfk-\frac{1}{2}} - HD^{n+1}_{wfj-\frac{1}{2}} - HD^{n+1}_{wfi-\frac{1}{2}} - HD^{n+1}_{wfk+\frac{1}{2}} - HD^{n+1}_{wfj+\frac{1}{2}} - HD^{n+1}_{wfi+\frac{1}{2}} -$$
$$q^{n+1}_{wfk-\frac{1}{2}}\left(1-\omega_{fk}\right)\left(1+\mu_{k4}\right) - q^{n+1}_{wfj-\frac{1}{2}}\left(1-\omega_{fj}\right)\left(1+\mu_{j4}\right) - q^{n+1}_{wfi-\frac{1}{2}}\left(1-\omega_{fi}\right)\left(1+\mu_{i4}\right) +$$
$$q^{n+1}_{wfk+\frac{1}{2}}\omega_{fk+1}\left(1+\mu_{k1}\right) + q^{n+1}_{wfj+\frac{1}{2}}\omega_{fj+1}\left(1+\mu_{j1}\right) + q^{n+1}_{wfi+\frac{1}{2}}\omega_{fi+1}\left(1+\mu_{i1}\right) -$$
$$\frac{V_{Ri}}{\Delta t}\left\{\phi_{fi}S_{wfi} + \left(1-\phi_t\right)\rho_s\xi_{fi}\right\}^{n+1} + V_{Ri}\left\{\phi_{fi}S_{wfi} + \left(1-\phi_t\right)\rho_s\xi_{fi}\right\}^{n+1}\lambda - \tau^{n+1}_{wlmfi}\omega_{mlfi} - \phi^{n+1}_m S^{n+1}_{wm}K^{n+1}_{wmlfi},$$

$$D^{n+1}_{2f} = -\tau^{n+1}_{wmlfi}\left(1-\omega_{mlfi}\right) + \phi^{n+1}_m S^{n+1}_{wm}K^{n+1}_{wmlfi},$$

and

$$R^{n+1}_f = \frac{V_{Ri}}{\Delta t}\left\{\phi_{fi}S_{wfi} + \left(1-\phi_t\right)\rho_s\xi_{fi}\right\}^{n} C^{n}_{wfi} - V_{Ri}\sum_{l=1}^{L}\left\{\left\{\phi_{fi}S_{wfi} + \left(1-\phi_t\right)\rho_s\xi_{fli}\right\}^{n+1}\lambda_l C^{n+1}_{wfli}\right\} - C^{*n+1}_{wfi}Q^{n+1}_{wfi},$$

and the linear system of the matrix equation is:

$$A_{2m}C^{n+1}_{wmk-2} + A_{1m}C^{n+1}_{wmk-1} + B_{2m}C^{n+1}_{wmj-2} + B_{1m}C^{n+1}_{wmj-1} + C_{2m}C^{n+1}_{wmi-2} + C_{1m}C^{n+1}_{wmi-1} + D_{1m}C^{n+1}_{wmijk} + D_{2m}C^{n+1}_{wfijk} +$$
$$E_{1m}C^{n+1}_{wmi+1} + E_{2m}C^{n+1}_{wmi+2} + F_{1m}C^{n+1}_{wmj+1} + F_{2m}C^{n+1}_{wmj+2} + G_{1m}C^{n+1}_{wmk+1} + G_{2m}C^{n+1}_{wmk+2} = R^{n+1}_m, \qquad \textbf{4.85}$$

where

$$A_{1m} = HD^{n+1}_{wmk-\frac{1}{2}} - \omega_{mk}\left(1+\mu_{k3}\right)q^{n+1}_{wmk-\frac{1}{2}} - \omega_{mk+1}\mu_{k1}q^{n+1}_{wmk+\frac{1}{2}},$$

$$A_{2m} = -\omega_{mk}\mu_{k3}q^{n+1}_{wmk-\frac{1}{2}},$$

$$B_{1m} = HD^{n+1}_{wmj-\frac{1}{2}} - \omega_{mj}\left(1+\mu_{j3}\right)q^{n+1}_{wmj-\frac{1}{2}} - \omega_{mj+1}\mu_{j1}q^{n+1}_{wmj+\frac{1}{2}},$$

$$B_{2m} = -\omega_{mj}\mu_{j3}q^{n+1}_{wmj-\frac{1}{2}},$$

$$C_{1m} = HD^{n+1}_{wmi-\frac{1}{2}} - \omega_{mi}(1+\mu_{i3})q^{n+1}_{wmi-\frac{1}{2}} - \omega_{mi+1}\mu_{i1}q^{n+1}_{wmi+\frac{1}{2}},$$

$$C_{2m} = -\omega_{mi}\mu_{i3}q^{n+1}_{wmi-\frac{1}{2}},$$

$$E_{1m} = HD^{n+1}_{wmi+\frac{1}{2}} + (1-\omega_{mi+1})(1+\mu_{i2})q^{n+1}_{wmi+\frac{1}{2}} + (1-\omega_{mi})\mu_{i4}q^{n+1}_{wmi-\frac{1}{2}},$$

$$E_{2m} = -(1-\omega_{mi+1})\mu_{i2}q^{n+1}_{wmi+\frac{1}{2}},$$

$$F_{1m} = HD^{n+1}_{wmj+\frac{1}{2}} + (1-\omega_{mj+1})(1+\mu_{j2})q^{n+1}_{wmj+\frac{1}{2}} + (1-\omega_{mj})\mu_{j4}q^{n+1}_{wmj-\frac{1}{2}},$$

$$F_{2m} = -(1-\omega_{mj+1})\mu_{j2}q^{n+1}_{wmj+\frac{1}{2}},$$

$$G_{1m} = HD^{n+1}_{wmk+\frac{1}{2}} + (1-\omega_{mk+1})(1+\mu_{k2})q^{n+1}_{wmk+\frac{1}{2}} + (1-\omega_{mk})\mu_{k4}q^{n+1}_{wmk-\frac{1}{2}},$$

$$G_{2m} = -(1-\omega_{mk+1})\mu_{k2}q^{n+1}_{wmk+\frac{1}{2}},$$

$$D^{n+1}_{1m} = -HD^{n+1}_{wmk-\frac{1}{2}} - HD^{n+1}_{wmj-\frac{1}{2}} - HD^{n+1}_{wmi-\frac{1}{2}} - HD^{n+1}_{wmk+\frac{1}{2}} - HD^{n+1}_{wmj+\frac{1}{2}} - HD^{n+1}_{wmi+\frac{1}{2}} -$$

$$q^{n+1}_{wmk-\frac{1}{2}}(1-\omega_{mk})(1+\mu_{k4}) - q^{n+1}_{wmj-\frac{1}{2}}(1-\omega_{mj})(1+\mu_{j4}) - q^{n+1}_{wmi-\frac{1}{2}}(1-\omega_{mi})(1+\mu_{i4}) +$$
$$q^{n+1}_{wmk+\frac{1}{2}}\omega_{mk+1}(1+\mu_{k1}) + q^{n+1}_{wmj+\frac{1}{2}}\omega_{mj+1}(1+\mu_{j1}) + q^{n+1}_{wmi+\frac{1}{2}}\omega_{mi+1}(1+\mu_{i1}) -$$
$$\frac{V_{Ri}}{\Delta t}\left\{\phi_{mi}S_{wmi} + (1-\phi_t)\rho_s\xi_{mi}\right\}^{n+1} + V_{Ri}\left\{\phi_{mi}S_{wmi} + (1-\phi_t)\rho_s\xi_{mi}\right\}^{n+1}\lambda + \tau^{n+1}_{w/mfi}(1-\omega_{m/fi}) - \phi^{n+1}_m S^{n+1}_{wm}K^{n+1}_{wm/fi},$$
$$D^{n+1}_{2m} = \tau^{n+1}_{wm/fi}\omega_{m/fi} + \phi^{n+1}_m S^{n+1}_{wm}K^{n+1}_{wm/fi},$$

and

$$R^{n+1}_m = \frac{V_{Ri}}{\Delta t}\left\{\phi_{mi}S_{wmi} + (1-\phi_t)\rho_s\xi_{mi}\right\}^n C^n_{wmi} - V_{Ri}\sum_{l=1}^{L}\left\{\left\{\phi_{mi}S_{wmi} + (1-\phi_t)\rho_s\xi_{mli}\right\}^{n+1}\lambda_l C^{n+1}_{wmli}\right\} - C^{*n+1}_{wmi}Q^{n+1}_{wmi}.$$

The second approach in the discretization of the two-point upstream winding is the split-operator method. In the split-operator method, the equation is discretized similarly but the time level for the concentration that appears in the second diagonal of the numerical matrix in each dimension (i.e., *i-2,i+2, j-2, j+2, k+2, and k-2* diagonals) is treated explicitly. This, in turn, will lead to a linear system similar to Equations 4.84 and 4.85 except that the right-hand side of the equation will be equivalent to

$$R_f^{n+1} = R_f^{n+1}\ (Equation\ 4.84) + A_{2f}C_{wfk-2}^n + B_{2f}C_{wfj-2}^n + C_{2f}C_{wfi-2}^n + E_{2f}C_{wfi+2}^n + F_{2f}C_{wfj+2}^n + G_{2f}C_{wfk+2}^n \qquad \textbf{4.86}$$

for the fracture, and

$$R_m^{n+1} = R_m^{n+1}\ (Equation\ 4.85) + A_{2m}C_{wmk-2}^n + B_{2m}C_{wmj-2}^n + C_{2m}C_{wmi-2}^n + E_{2m}C_{wmi+2}^n + F_{2m}C_{wmj+2}^n + G_{2m}C_{wmk+2}^n \qquad \textbf{4.87}$$

for the matrix. The accuracy of the split operator depends on the size of the time step, which resides somewhere between that of the one-point upwinding and that of the two-point upwinding. However, the saving in computation time is substantial.

4.4.4 Mid-Point Weighting Discretization of Transport Equations

Fracture Equation

$$\begin{aligned}
&\left(\phi_f^{n+1}S_{wf}^{n+1}K_{wf}^{n+1}\right)_{i+\frac{1}{2}}\left(C_{wfi+1}^{n+1}-C_{wfi}^{n+1}\right)-\left(\phi_f^{n+1}S_{wf}^{n+1}K_{wf}^{n+1}\right)_{i-\frac{1}{2}}\left(C_{wfi}^{n+1}-C_{wfi-1}^{n+1}\right)+\\
&\left(\phi_f^{n+1}S_{wf}^{n+1}K_{wf}^{n+1}\right)_{j+\frac{1}{2}}\left(C_{wfj+1}^{n+1}-C_{wfj}^{n+1}\right)-\left(\phi_f^{n+1}S_{wf}^{n+1}K_{wf}^{n+1}\right)_{j-\frac{1}{2}}\left(C_{wfj}^{n+1}-C_{wfj-1}^{n+1}\right)+\\
&\left(\phi_f^{n+1}S_{wf}^{n+1}K_{wf}^{n+1}\right)_{k+\frac{1}{2}}\left(C_{wfk+1}^{n+1}-C_{wfk}^{n+1}\right)-\left(\phi_f^{n+1}S_{wf}^{n+1}K_{wf}^{n+1}\right)_{k-\frac{1}{2}}\left(C_{wfk}^{n+1}-C_{wfk-1}^{n+1}\right)+\\
&q_{wfi+\frac{1}{2}}^{n+1}\left[(0.5+\mu_{i2})C_{wfi+1}^{n+1}+(0.5-\mu_{i2})C_{wfi}^{n+1}\right]-q_{wfi-\frac{1}{2}}^{n+1}\left[(0.5+\mu_{i1})C_{wfi}^{n+1}+(0.5-\mu_{i1})C_{wfi-1}^{n+1}\right]+\\
&q_{wfj+\frac{1}{2}}^{n+1}\left[(0.5+\mu_{j2})C_{wfj+1}^{n+1}+(0.5-\mu_{j2})C_{wfj}^{n+1}\right]-q_{wfj-\frac{1}{2}}^{n+1}\left[(0.5+\mu_{j1})C_{wfj}^{n+1}+(0.5-\mu_{j1})C_{wfj-1}^{n+1}\right]+\\
&q_{wfk+\frac{1}{2}}^{n+1}\left[(0.5+\mu_{k2})C_{wfk+1}^{n+1}+(0.5-\mu_{k2})C_{wfk}^{n+1}\right]-q_{wfk-\frac{1}{2}}^{n+1}\left[(0.5+\mu_{k1})C_{wfk}^{n+1}+(0.5-\mu_{k1})C_{wfk-1}^{n+1}\right]+
\end{aligned} \qquad \textbf{4.88}$$

$$C_{wfi}^{*n+1} Q_{wfi}^{n+1} - \tau_{wm/fi}^{n+1}\left(\omega_{m/fi} C_{wfi}^{n+1} + \left(1-\omega_{m/fi}\right) C_{wmi}^{n+1}\right) - \left(\phi_{mi}^{n+1} S_{wmi}^{n+1} K_{wm/fi}^{n+1}\right)\left(C_{wfi}^{n+1} - C_{wmi}^{n+1}\right) =$$

$$\frac{V_{Ri}}{\Delta t}\left[\left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n+1} - \left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n}\right] +$$

$$V_{Ri}\left\{\phi_{fi} S_{wfi} C_{wfi} + \left(1-\phi_t\right)\rho_s C_{sfi}\right\}^{n+1}\lambda - V_{Ri}\sum_{l=1}^{L}\left[\left\{\phi_{fi} S_{wfi} C_{wfli} + \left(1-\phi_t\right)\rho_s C_{sfli}\right\}\lambda_l\right]^{n+1}$$

Matrix Equation

$$\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{i+\frac{1}{2}}\left(C_{wmi+1}^{n+1} - C_{wmi}^{n+1}\right) - \left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{i-\frac{1}{2}}\left(C_{wmi}^{n+1} - C_{wmi-1}^{n+1}\right) +$$
$$\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{j+\frac{1}{2}}\left(C_{wmj+1}^{n+1} - C_{wmj}^{n+1}\right) - \left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{j-\frac{1}{2}}\left(C_{wmj}^{n+1} - C_{wmj-1}^{n+1}\right) +$$
$$\left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{k+\frac{1}{2}}\left(C_{wmk+1}^{n+1} - C_{wmk}^{n+1}\right) - \left(\phi_m^{n+1} S_{wm}^{n+1} K_{wm}^{n+1}\right)_{k-\frac{1}{2}}\left(C_{wmk}^{n+1} - C_{wmk-1}^{n+1}\right) +$$

$$q_{wmi+\frac{1}{2}}^{n+1}\left[\left(0.5+\mu_{i2}\right)C_{wmi+1}^{n+1} + \left(0.5-\mu_{i2}\right)C_{wmi}^{n+1}\right] - q_{wmi-\frac{1}{2}}^{n+1}\left[\left(0.5+\mu_{i1}\right)C_{wmi}^{n+1} + \left(0.5-\mu_{i1}\right)C_{wmi-1}^{n+1}\right] +$$

$$q_{wmj+\frac{1}{2}}^{n+1}\left[\left(0.5+\mu_{j2}\right)C_{wmj+1}^{n+1} + \left(0.5-\mu_{j2}\right)C_{wmj}^{n+1}\right] - q_{wmj-\frac{1}{2}}^{n+1}\left[\left(0.5+\mu_{j1}\right)C_{wmj}^{n+1} + \left(0.5-\mu_{j1}\right)C_{wmj-1}^{n+1}\right] + \qquad \mathbf{4.89}$$

$$q_{wmk+\frac{1}{2}}^{n+1}\left[\left(0.5+\mu_{k2}\right)C_{wmk+1}^{n+1} + \left(0.5-\mu_{k2}\right)C_{wmk}^{n+1}\right] - q_{wmk-\frac{1}{2}}^{n+1}\left[\left(0.5+\mu_{k1}\right)C_{wmk}^{n+1} + \left(0.5-\mu_{k1}\right)C_{wmk-1}^{n+1}\right] +$$

$$C_{wmi}^{*n+1} Q_{wmi}^{n+1} + \tau_{wm/fi}^{n+1}\left(\omega_{m/fi} C_{wfi}^{n+1} + \left(1-\omega_{m/fi}\right) C_{wmi}^{n+1}\right) + \left(\phi_{mi}^{n+1} S_{wmi}^{n+1} K_{wm/fi}^{n+1}\right)\left(C_{wfi}^{n+1} - C_{wmi}^{n+1}\right) =$$

$$\frac{V_{Ri}}{\Delta t}\left[\left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n+1} - \left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n}\right] +$$

$$V_{Ri}\left\{\phi_{mi} S_{wmi} C_{wmi} + \left(1-\phi_t\right)\rho_s C_{smi}\right\}^{n+1}\lambda - V_{Ri}\sum_{l=1}^{L}\left[\left\{\phi_{mi} S_{wmi} C_{wmli} + \left(1-\phi_t\right)\rho_s C_{smli}\right\}\lambda_l\right]^{n+1}$$

where

$$\mu_{i1} = \frac{1}{4}\frac{\Delta x_{i-1} - \Delta x_i}{\Delta x_{i-1} + \Delta x_i},\ \mu_{i2} = \frac{1}{4}\frac{\Delta x_i - \Delta x_{i+1}}{\Delta x_i + \Delta x_{i+1}},\ \mu_{j1} = \frac{1}{4}\frac{\Delta y_{j-1} - \Delta y_j}{\Delta y_{j-1} + \Delta y_j},\ \mu_{j2} = \frac{1}{4}\frac{\Delta y_j - \Delta y_{j+1}}{\Delta y_j + \Delta y_{j+1}},$$

$$\mu_{k1} = \frac{1}{4}\frac{\Delta z_{k-1} - \Delta z_k}{\Delta z_{k-1} + \Delta z_k},\ and\ \mu_{k2} = \frac{1}{4}\frac{\Delta z_k - \Delta z_{k+1}}{\Delta z_k + \Delta z_{k+1}}$$

A similar linear system as in Equations 4.79 and 4.81 is formed, in which

$$A_f = HD^{n+1}_{wfk-\frac{1}{2}} - (0.5 + \mu_{k1}) q^{n+1}_{wfk-\frac{1}{2}}$$

$$A_m = HD^{n+1}_{wmk-\frac{1}{2}} - (0.5 + \mu_{k1}) q^{n+1}_{wmk-\frac{1}{2}}$$

$$B_f = HD^{n+1}_{wfj-\frac{1}{2}} - (0.5 + \mu_{j1}) q^{n+1}_{wfj-\frac{1}{2}}$$

$$B_m = HD^{n+1}_{wmj-\frac{1}{2}} - (0.5 + \mu_{j1}) q^{n+1}_{wmj-\frac{1}{2}}$$

$$C_f = HD^{n+1}_{wfi-\frac{1}{2}} - (0.5 + \mu_{i1}) q^{n+1}_{wfi-\frac{1}{2}}$$

$$C_m = HD^{n+1}_{wmi-\frac{1}{2}} - (0.5 + \mu_{i1}) q^{n+1}_{wmi-\frac{1}{2}}$$

$$E_f = HD^{n+1}_{wfi+\frac{1}{2}} + (0.5 + \mu_{i2}) q^{n+1}_{wfi+\frac{1}{2}}$$

$$E_m = HD^{n+1}_{wmi+\frac{1}{2}} + (0.5 + \mu_{i2}) q^{n+1}_{wmi+\frac{1}{2}}$$

$$F_f = HD^{n+1}_{wfj+\frac{1}{2}} + (0.5 + \mu_{j2}) q^{n+1}_{wfj+\frac{1}{2}}$$

$$F_m = HD^{n+1}_{wmj+\frac{1}{2}} + (0.5 + \mu_{j2}) q^{n+1}_{wmj+\frac{1}{2}}$$

$$G_f = HD^{n+1}_{wfk+\frac{1}{2}} + (0.5 + \mu_{k2}) q^{n+1}_{wfk+\frac{1}{2}}$$

$$G_m = HD^{n+1}_{wmk+\frac{1}{2}} + (0.5 + \mu_{k2}) q^{n+1}_{wmk+\frac{1}{2}}$$

and

$$D_{1f}^{n+1} = -HD^{n+1}_{wfk-\frac{1}{2}} - HD^{n+1}_{wfj-\frac{1}{2}} - HD^{n+1}_{wfi-\frac{1}{2}} - HD^{n+1}_{wfk+\frac{1}{2}} - HD^{n+1}_{wfj+\frac{1}{2}} - HD^{n+1}_{wfi+\frac{1}{2}} - q^{n+1}_{wfk-\frac{1}{2}}(0.5+\mu_{ki}) -$$

$$q^{n+1}_{wfj-\frac{1}{2}}(0.5+\mu_{j1}) - q^{n+1}_{wfi-\frac{1}{2}}(0.5+\mu_{i1}) + q^{n+1}_{wfk+\frac{1}{2}}(0.5-\mu_{k2}) + q^{n+1}_{wfj+\frac{1}{2}}(0.5-\mu_{j2}) + q^{n+1}_{wfi+\frac{1}{2}}(0.5-\mu_{i2}) -$$

$$\frac{V_{Ri}}{\Delta t}\left\{\phi_{fi}S_{wfi} + (1-\phi_t)\rho_s\xi_{fi}\right\}^{n+1} + V_{Ri}\left\{\phi_{fi}S_{wfi} + (1-\phi_t)\rho_s\xi_{fi}\right\}^{n+1}\lambda - \tau^{n+1}_{w/mfi}\omega_{m/fi} - \phi^{n+1}_m S^{n+1}_{wm} K^{n+1}_{wm/fi}$$

$$D_{1m}^{n+1} = -HD^{n+1}_{wmk-\frac{1}{2}} - HD^{n+1}_{wmj-\frac{1}{2}} - HD^{n+1}_{wmi-\frac{1}{2}} - HD^{n+1}_{wmk+\frac{1}{2}} - HD^{n+1}_{wmj+\frac{1}{2}} - HD^{n+1}_{wmi+\frac{1}{2}} - q^{n+1}_{wmk-\frac{1}{2}}(0.5+\mu_{k1}) -$$

$$q^{n+1}_{wmj-\frac{1}{2}}(0.5+\mu_{j1}) - q^{n+1}_{wmi-\frac{1}{2}}(0.5+\mu_{i1}) + q^{n+1}_{wmk+\frac{1}{2}}(0.5-\mu_{k2}) + q^{n+1}_{wmj+\frac{1}{2}}(0.5-\mu_{j2}) + q^{n+1}_{wmi+\frac{1}{2}}(0.5-\mu_{i2}) -$$

$$\frac{V_{Ri}}{\Delta t}\left\{\phi_{mi}S_{wmi} + (1-\phi_t)\rho_s\xi_{mi}\right\}^{n+1} + V_{Ri}\left\{\phi_{mi}S_{wmi} + (1-\phi_t)\rho_s\xi_{mi}\right\}^{n+1}\lambda + \tau^{n+1}_{w/mfi}(1-\omega_{m/fi}) - \phi^{n+1}_m S^{n+1}_{wm} K^{n+1}_{wm/fi}$$

$$D_{2f}^{n+1} = -\tau^{n+1}_{wm/fi}(1-\omega_{m/fi}) + \phi^{n+1}_m S^{n+1}_{wm} K^{n+1}_{wm/fi}$$

$$D_{2m}^{n+1} = \tau^{n+1}_{wm/fi}\omega_{m/fi} + \phi^{n+1}_m S^{n+1}_{wm} K^{n+1}_{wm/fi}$$

$$R_f^{n+1} = \frac{V_{Ri}}{\Delta t}\left\{\phi_{fi}S_{wfi} + (1-\phi_t)\rho_s\xi_{fi}\right\}^n C^n_{wfi} - V_{Ri}\sum_{l=1}^{L}\left\{\left\{\phi_{fi}S_{wfi} + (1-\phi_t)\rho_s\xi_{fli}\right\}^{n+1}\lambda_l C^{n+1}_{wfli}\right\} - C^{*n+1}_{wfi} Q^{n+1}_{wfi}$$

$$R_m^{n+1} = \frac{V_{Ri}}{\Delta t}\left\{\phi_{mi}S_{wmi} + (1-\phi_t)\rho_s\xi_{mi}\right\}^n C^n_{wmi} - V_{Ri}\sum_{l=1}^{L}\left\{\left\{\phi_{mi}S_{wmi} + (1-\phi_t)\rho_s\xi_{mli}\right\}^{n+1}\lambda_l C^{n+1}_{wmli}\right\} - C^{*n+1}_{wmi} Q^{n+1}_{wmi}.$$

It is worth mentioning that in all the above methods no fictitious or interior grid points are used in the discretization of the boundary conditions. In two-point upwinding, there might be, depending on the direction of the flow, a need for such points. However, one-point upstream is used instead. This has been done in the problem at hand because the source is located in the middle of the domain with negligible or no transport near boundaries. In the cases when there is an active flow field near the boundaries, such treatment (one-point upstream) may lead to a first-order method even if two-point upstream weighting is used in the interior.

The transport equations (Equations 4.38 and 4.39) have N *G unknowns for single porosity and 2N*G unknowns for dual-porosity and dual-permeability formulations, where N is the number of equations in each grid block and G is the number of grid blocks in the simulated spatial domain.

The system of governing partial differential equations (two for each transported constituent) is strongly coupled one to the other because of the strong contribution from parental decay to the concentration of the immediate daughter. Consequently, the sequential method is used to solve the system implicitly (if the implicit method is used). In the sequential method, the solution proceeds progressively from the top to the bottom of each radioactive chain. Therefore, the contribution to any daughter from parental decay will be immediately calculable.

The matrix resulting from one-point upstream winding and the mid-point weighting resembles the following for a two-dimensional system of 3x3 grid blocks

$$\begin{bmatrix}
f & m & f & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
f & m & 0 & m & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
f & 0 & f & m & f & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & m & f & m & 0 & m & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & f & 0 & f & m & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & m & f & m & 0 & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & 0 & 0 \\
f & 0 & 0 & 0 & 0 & f & m & f & 0 & 0 & f & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & m & 0 & 0 & 0 & 0 & f & m & 0 & m & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 \\
0 & 0 & f & 0 & 0 & 0 & f & 0 & f & m & f & 0 & 0 & 0 & f & 0 & 0 & 0 \\
0 & 0 & 0 & m & 0 & 0 & 0 & m & f & m & 0 & m & 0 & 0 & 0 & m & 0 & 0 \\
0 & 0 & 0 & 0 & f & 0 & 0 & 0 & f & 0 & f & m & 0 & 0 & 0 & 0 & f & 0 \\
0 & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & m & f & m & 0 & 0 & 0 & 0 & 0 & m \\
0 & 0 & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & f & m & f & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & m & 0 & m & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & f & m & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & f & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & m & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & f \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & m
\end{bmatrix}$$

Since two-point upstream winding uses information from the grid block further in the upstream direction, the band width of the matrix will be doubled compared with the previous one. Also the matrix will be less sparse. For the same system of 3x3, the numerical matrix is:

$$\begin{bmatrix}
f & m & f & 0 & f & 0 & f & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & 0 & 0 \\
f & m & 0 & m & 0 & m & 0 & m & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & 0 \\
f & 0 & f & m & f & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 \\
0 & m & f & m & 0 & m & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 \\
f & 0 & f & 0 & f & m & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & 0 & f & 0 \\
0 & m & 0 & m & f & m & 0 & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & 0 & m \\
f & 0 & 0 & 0 & 0 & f & m & f & 0 & f & 0 & f & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & m & 0 & 0 & 0 & 0 & f & m & 0 & m & 0 & m & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & f & 0 & 0 & 0 & f & 0 & f & m & f & 0 & 0 & 0 & f & 0 & 0 & 0 \\
0 & 0 & 0 & m & 0 & 0 & 0 & m & f & m & 0 & m & 0 & 0 & 0 & m & 0 & 0 \\
0 & 0 & 0 & 0 & f & 0 & f & 0 & f & 0 & f & m & 0 & 0 & 0 & 0 & f & 0 \\
0 & 0 & 0 & 0 & 0 & m & 0 & m & 0 & m & f & m & 0 & 0 & 0 & 0 & 0 & m \\
f & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & 0 & f & m & f & 0 & f & 0 & 0 \\
0 & m & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & f & m & 0 & m & 0 & m & 0 \\
0 & 0 & f & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & f & 0 & f & m & f & 0 \\
0 & 0 & 0 & m & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & m & f & m & 0 & m \\
0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & f & 0 & 0 & 0 & 0 & f & 0 & f & m \\
0 & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & m & 0 & 0 & 0 & 0 & m & f & m
\end{bmatrix}$$

where *f* refers to fracture entry, *m* refers to matrix entries, and *0* refers to zero entry.

Standard Gaussian elimination is used to invert the numerical matrix. Two techniques are applied to reduce the size of the numerical matrix to more manageable dimensions. In the first technique, an optimum dimension (in standard ordering) is chosen to define the connectivity of the grid blocks. The guideline for this choice is the minimum number of grid blocks. Hence, for a two dimensional problem in x and y, the numbering will start from min(x,y) and proceed to the

next dimension. The second technique is used to straighten the numerical matrix diagonals and limit the calculation to the entries between the uppermost and the lowermost diagonals. Therefore, for a single-porosity system in two dimensions, a pentagonal matrix of IBW*G is inverted instead of G*G matrix, where IBW is the band width.

4.5 Other Important Physical and Chemical Aspects of the Modeling

4.5.1 Treatment of Mobilization Involving Colloidal Materials

In order to minimize unnecessary computations, dissolved and colloidal mobilized species have been combined for transport within NUTS. This is justified because molecular diffusion and sorption are the only physical processes that could cause differences in the modeled transport of dissolved versus colloidal species, and since they have been set to zero, the species will transport identically. The combination of dissolved and colloidal species is performed prior to NUTS in an ALGEBRA calculation. In this calculation, four types of colloid-related mobilization are considered, as follows: (i) condensation of hydrolized actinide ions into intrinsic colloids, and sorption onto already existent colloidal materials of (ii) humic, (iii) microbial, and (iv) mineral origen. Maximum concentrations for these four different types of colloidal particulates are *added* to the maximum concentration for dissolution for each of the radioisotopes and (sampled) oxidation states. The sum of the five maximum concentrations is then used in a single dissolution-like computation that estimates the net mobilization due to colloids and dissolution combined.

4.5.2 Lumped Radioisotopes

To keep computational resources at a reasonable level, and because several of the radioisotopes in the inventory have been shown to be unimportant in terms of release calculations, inventory radioisotopes have been (i) combined, where possible, or (ii) omitted, where justifiable, so as to reduce the list of 29 actual radioisotopes to be monitored to 5 "equivalent" radioisotopes. The rules were to combine the effects of some radioisotopes (by adding their inventories), providing they have similar half lives, and to omit 10 others whose effects on release values have been shown to be negligible (less than 0.01 normalized EPA units). For example, ^{233}U and ^{234}U are 30 to 100 times more important than other uranium isotopes in terms of normalized EPA releases. Thus, ^{235}U, ^{236}U, and ^{238}U can be ignored without a significant impact on release calculations. ^{233}U and ^{234}U comprise less than 1% of the total uranium inventory mass. To account for that, the solubility of uranium is decreased by a factor of 100. Lastly, since the half lives are similar, ^{233}U and ^{234}U are combined into a single equivalent radioisotope. Thus, 5 radioisotopes have thereby been reduced to one equivalent radioisotope. Similarly, ^{229}Th is absorbed into ^{230}Th, their solubility reduced by 1000 to account for their representation in the inventory, and ^{232}Th is ignored altogether on account of its negligible effect on release values. In every case, revisions favored overestimating released materials.

In CCA calculations, NUTS is exercised first using the five equivalent radioisotopes. If releases do not approach EPA limits, results are permitted to stand. If releases approach EPA limits, NUTS will be reexercised with actual inventories. The physical properties of the 5 "equivalent"

radioisotopes are computed by the same ALGEBRA run that combines maximum concentrations due to dissolution and colloidal mobilization (see Section 4.5.1)

4.5.3 Temperature Dependency

At the user's option, NUTS can implement a temperature+ dependency for selected parameters. For example, solubility limit is considered either as (1) a constant or (2) it can be evaluated from data correlations that account for its thermal dependency in non-isothermal processes.

Additionally, molecular diffusivity varies with temperature, and the following derived formula is used to account for that dependency:

$$D_m^*(T) = D_{mref}^* \frac{T}{T_{ref}} \frac{\mu_{ref}}{\mu(T)}, \qquad \textbf{4.90}$$

where

D^*_{mref} is the molecular diffusion evaluated at the temperature T_{ref},
$D^*_m(T)$ is the molecular diffusion at temperature T,
μ_{ref} is the reference viscosity at T_{ref},
$\mu(T)$ solvent viscosity at temperature T, and
T_{ref} is the reference temperature.

Sorption is also a temperature-dependent process. The following is a zeroth-order formulation derived to account preliminarily for the temperature dependency of k_d. It can also be applied to the Freundlich and Langumir coefficients with fair accuracy.

$$k_{d2} = k_{d1} \; exp\left[\frac{\xi(T_2 - T_1)}{T_2 T_1}\right], \quad where\, \xi = \frac{\Delta H^o}{R}. \qquad \textbf{4.91}$$

In the above formulation, k_{d1}, and k_{d2} are equilibrium partition constants at temperatures T_1 and T_2, respectively. H^o is the enthalpy of sorption at reference temperature T^o, and R is the universal gas constant.

4.5.4 Theoretical Foundations for the Gas-Transport Model Phase

In gas transport problems, it is essential to consider the chemical interaction between the flowing gas and the constituents of the porous medium through which the gas flows. That interaction or phase equilibrium can be classified as (1) gas/solid-phase equilibrium described by sorption-desorption processes, and (2) gas/liquid-phase equilibrium.

+ Temperatures should be provided to NUTS as an input by suitable thermal simulator.

The description of multiphase equilibrium in porous media is complex and requires a compositional simulator that strongly couples the transport with the flow equations. This kind of treatment arises because some mixtures like, for example VOCs + H2O, are observed under certain conditions of pressure, temperature and composition, as a single phase (liquid or vapor), a double-phase (vapor-liquid or liquid-liquid), or a triple-phase (vapor-liquid-liquid) fluid. To (a) describe such a system appropriately and (b) to predict the number and form of the phases in equilibrium, the transport by the liquid and gas phases should be calculated simultaneously. In that event, the solute would be partitioned according to its equilibrium constant between the phases in equilibrium.

Such a compositionally equilibrated system requires not only a detailed description of the pressure, temperature and initial composition fields in the computational domain, but also is very demanding in regard to computation time and resources. Because of data limitations, NUTS considers the porous medium and its liquid contents as a retardation factor for the constituents transported by the gas phase (Doctor et al., 1992). The phenomena described below are included in NUTS.

1. Solid-/gas-phase equilibrium is treated using the same linear, equilibrium, sorption isotherm described above for liquid-phase flows.

2. Liquid-/gas-phase equilibrium is modeled through gas solubility in the brine as a function of temperature. The equation that describes such equilibria is

$$K_{LG} = \frac{C_L}{C_G}, \qquad \textbf{4.92}$$

where C_L and C_G are the concentration of the solute in the liquid and gas phases, respectively. The value of the ratio on the right-hand side is represented as a linear function of temperature, namely:

$$\frac{C_L}{C_G} = A - BT, \qquad \textbf{4.93}$$

where A and B are the intercept and slope, respectively, of the empirical data. This linear representation is valid only for a limited range of temperatures and only at low pressures, where compositional dependency is usually weak.

Because migration in the liquid phase is much slower than in the gas phase, and because the gas- and the liquid-phase transports are decoupled in NUTS, liquid transport of a constituent transported abundantly by the gas phase will not be tracked. With the above mentioned assumptions, the transport in the gas phase of a dual-permeability system can be described by the following finite-difference equations:

Equation for Material Transport in the Fracture Component of the Gaseous Flow:

$$\begin{aligned}
&\Delta_x\left[\phi_f S_{Gf} K_{Gf} \Delta_x C_{nGf}\right] + \Delta_y\left[\phi_f S_{Gf} K_{Gf} \Delta_y C_{nGf}\right] + \Delta_z\left[\phi_f S_{Gf} K_{Gf} \Delta_z C_{nGf}\right] + \\
&\Delta_x q_{Gf} C_{nGf} + \Delta_y q_{Gf} C_{nGf} + \Delta_z q_{Gf} C_{nGf} + C^*_{nGf} Q_{Gf} - \tau_{Gm/f} C_{nGm/f} - \phi_m S_{Gm} K_{Gm/f}\left(C_{nGf} - C_{nGm}\right) = \\
&\frac{V_R}{\Delta t}\Delta_t\left[\phi_f S_{Gf} C_{nGf} + (1-\phi_t)\rho_s C_{nsf} + \phi_f\left(1 - S_{Gf}\right) K_{LG} C_{nGf}\right] + \\
&V_R\left[\phi_f S_{Gf} C_{nGf} + (1-\phi_t)\rho_s C_{nsf} + \phi_f\left(1 - S_{Gf}\right) K_{LG} C_{nGf}\right]\lambda_n - \\
&V_R \sum_{j=1}^{J}\left\{\left\{\phi_f S_{Gf} C_{nGfpj} + (1-\phi_t)\rho_s C_{nsfpj} + \phi_f\left(1 - S_{Gf}\right) K_{LG} C_{nGfpj}\right\}\lambda_{npj}\right\} \quad n = 1,2,\ldots,N
\end{aligned} \tag{4.94}$$

Equation for Material Transport in the Matrix Component of the Gaseous Flow:

$$\begin{aligned}
&\Delta_x\left[\phi_m S_{Gm} K_{Gm} \Delta_x C_{nGm}\right] + \Delta_y\left[\phi_m S_{Gm} K_{Gm} \Delta_y C_{nGm}\right] + \Delta_z\left[\phi_m S_{Gm} K_{Gm} \Delta_z C_{nGm}\right] + \\
&\Delta_x q_{Gm} C_{nGm} + \Delta_y q_{Gm} C_{nGm} + \Delta_z q_{Gm} C_{nGm} + C^*_{nGm} Q_{Gm} + \tau_{Gm/f} C_{nGm/f} + \phi_m S_{Gm} K_{Gm/f}\left(C_{nGf} - C_{nGm}\right) = \\
&\frac{V_R}{\Delta t}\Delta_t\left[\phi_m S_{Gm} C_{nGm} + (1-\phi_t)\rho_s C_{nsm} + \phi_m\left(1 - S_{Gm}\right) K_{LG} C_{nGm}\right] + \\
&V_R\left[\phi_m S_{Gm} C_{nGm} + (1-\phi_t)\rho_s C_{nsm} + \phi_m\left(1 - S_{Gm}\right) K_{LG} C_{nGm}\right]\lambda_n - \\
&V_R \sum_{j=1}^{J}\left\{\left\{\phi_m S_{Gm} C_{nGmpj} + (1-\phi_t)\rho_s C_{nsmpj} + \phi_m\left(1 - S_{Gm}\right) K_{LG} C_{nGmpj}\right\}\lambda_{npj}\right\} \quad n = 1,2,\ldots,N
\end{aligned} \tag{4.95}$$

where

C_{nG} = solute concentration of component n in the gas phase[kg/m^3],

C^*_{nG} = injected or produced solute concentration of component n [kg/m^3],
C_{ns} = sorbate concentration of component n [kg/kg],
K = dispersion coefficient [m^3/s],
K_{LG} = gas-liquid equilibrium constant [dimensionless],
N = total number of nuclides,
Q = gas injection/production rate [m^3/s],
q = gas interfacial volumetric rate [m^3/s],
S = gas saturation, fraction,
t = time [s],
V_R = grid block volume [m^3],
Δ_t = value at time n+1 - value at time n,
Δ_x = centeral finite difference operator in x-direction,
Δ_y = centeral finite difference operator in y-direction,
Δ_z = centeral finite difference operator in z-direction,
λ = decay constant [s^{-1}],

ϕ = porosity [dimensionless],
ρ = density [kg/m^3],
τ = matrix /fracture transfer function [m^3/s],

Subscripts:
f = fracture
m = matrix
m/f = matrix/fracture
n = component number
pj = parent number
s = solid phase (rock)
t = total (fracture + matrix)
G = gas phase

5.0 INHERENT CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

NUTS's inherent capabilities and limitations are listed below.

1. The flow and transport equations are decoupled, which is permitted only if solute concentrations are dilute. Decoupling does not affect fluid density, viscosity, or other related physical properties.

2. Local equilibrium is assumed to exist between interactive phases.

3. The radioisotopes transported by NUTS are assumed to be thermodynamically stable within their solubility limits. No gas phases or radioisotope-rich liquid phases are allowed. However, precipitation is possible and is calculated when and if solute concentrations exceed their solubility limits.

4. Dissolved radioisotopes are assumed to be in equilibrium with their precipitates. Precipitation is treated as a reversible process and is controlled by the value of solute concentration compared to the solubility limit, which defines the upper bound for dissolution.

5. Sorption is assumed to be controlled entirely by one of three equilibrium isotherms.

6. Dispersion is assumed to obey Fick's second law with dispersivities appropriate to an isotropic porous medium. Thus, the dispersivity tensor reduces to two numerical constants for the two principal flow directions.

7. The solubility of each isotope is evaluated as follows:

   Isotopic Solubility = Mole Fraction of that particular isotope x the elemental solubility

8. Gas-liquid equilibrium is assumed to obey the linear relationship represented by Equation 4.92, with temperature dependence given by Equation 4.93.

9. Because gases travel much faster than liquids, the liquid phase is regarded as a retarding agent to the constituents transported by the gas phase.

These and other inherent capabilities and limitations of the model are discussed item for item in Sections 4.0 and 6.0, and in the examples.

6.0 USER INTERACTIONS WITH THE SOFTWARE

6.1 Exercising NUTS Interactively

NUTS may be exercised either interactively or through command files. To exercise NUTS interactively, type "NUTS" at the VMS $ prompt and strike the carriage return. The title page and disclaimer will scroll by on screen. The program will then prompt the user with a series of questions including the names of a sequence of required input and output files. The sequence of queries is addressed in order in Section 6.2. The files themselves are discussed in detail in the remainder of this chapter, and illustrative examples are given in the appendices. If all NUTS's prompts are answered satisfactorily, the final "carriage return" will cause NUTS to exercise. If the run is successful, a "normal completion" notice will appear on screen. If not, an error message will result.

NUTS may be compiled on PC, VAX, and UNIX systems with minimal effort. However, for the WIPP CCA PA, NUTS will operate exclusively in a cluster of Alpha-VAX microcomputers. Consequently, the other applications will not be discussed explicitly in this manual. However, to gain the flexibility to run on different platforms, NUTS was intentionally designed to run in two slightly different configurations. The first is called the "stand-alone" configuration and is written NUTS-SA. The second, designed specifically for the WIPP's Compliance Assessment Methodology Controller (CAMCON), is called CAMCON configuration and is written NUTS-CC. The main differences between the two are (1) the types of libraries with which each compiles, (2) the flexibilities associated with the two sets of input/output capabilities, and (3) that NUTS-SA and NUTS-CC have two *different* executables. NUTS-CC will be used exclusively for the WIPP CCA PA. However, because NUTS-CC's operational procedures are a subset of NUTS-SA, we will begin with a discussion of the Stand-Alone input/output features. That discussion will be followed with the requirements for and limitations of NUTS-CC.

6.2 User-Interactive Options Afforded by NUTS-SA

NUTS requires the following three types of Input/Output:

1. A User-Interactive Input Sequence
2. A Parameter Statement
3. Input/Output Files

These three types of input/output* are reviewed in the three subsections that follow.

6.3 User-Interactive Input Sequence

A limited number of control flags are available for user specification during the course of executing the program. These controls are part of the input and mainly specify the following information:

* The units adopted in NUTS are SI units unless specified otherwise.

a) Names, sources, and types of the I/O files (ASCII, binary, etc.).
b) The type of porous media to be modeled (single-, or dual-porosity and/or permeability).
c) The number of phases in the transporting medium (usually 1), and the type of phase (gas or liquid).
d) The type of the compiler and terminal (for QA purposes).

The following is a description of user-interactive input*:

6.3.1 Is This a DEBUG Run? (Y/N) {N}

Accepts Y, N, y, or n. Press the carriage-return key to select the default option.

6.3.2 The Default Input-File Name is NUTS.IN

Do You Want To Use This Name (Y/N)--> {NUTS.IN}

Accepts Y, N, y, & n. Press the carriage-return key to select the default option.

a. If the answer is "Y" or "y" the program will proceed to the next question.

b. If the answer is "N" or "n" , the program will prompt the following:

Enter NUTS Input File Name

The user may specify an input-file name up to 80 characters in length and strike the carriage-return key, wherein the sequence of questions will proceed.

If instead, the user strikes the "Return key" the following will appear on screen:

The Default Input File Name NUTS.IN
Is Assigned To The Input File
Do You Like To Change It (Y/N)

Accepts Y, N, y, or n. Press the carriage-return key to select the default option.

If the answer is "Y" , the program will start again from "b". Otherwise it will proceed.

If an invalid input filename is entered, the program will deliver an error message and terminate.

6.3.3 The Default Output File Name is NUTS.OUT

Do You Want To Use This Name (Y/N)--> {NUTS.OUT}

Accepts Y, N, y, or n. Press the carriage-return key to select the default option.

Depending on the answer, the program will proceed exactly as in (6.3.2). If an original filename is assigned, be sure to use a character*80 name.

* Quantities listed within braces are the default-option replies to program queries. They are selected by pressing the carriage return.

6.3.4 Read the material map from BRAGFLO input file (Y/N)? {Y}

Accepts Y, N, y, or n. Press the carriage-return key to select the default option.

a. If the answer is "Y" or "y", NUTS will read the material map from BRAGFLO's input file**.

b. If the answer is "N" or "n", NUTS will expect to read the material map from its own ASCII input file.

6.3.5 Is This a Test Run? (Y/N) {N}

Accepts Y, N, y, or n. Press the carriage-return key to select the default option.

a. If the answer is "Y" or "y", NUTS will ask the following:
Enter name of TEST file
The user may specify an original filename up to 80 characters in length.

b. If the answer is "N" or "n", the program will prompt the following:
Enter BRAGFLO input binary/CDB file name.
The user may specify an original filename up to 80 characters in length.
NUTS will then inquire:
Will BRAGFLO data be read from CDB or binary+ ?
Enter BIN for binary or CDB for CDB {BIN}
Accepts BIN, bin, Bin, CDB, cdb, or Cdb. Press the carriage-return key to select the default option.

If an invalid filename is entered (whether a test-file or BRAGFLO-file name), the program will issue an error message and abort.

6.3.6 Enter Type of Output File {ASC}

The following output files are allowed:

1. **ASC for ASCII file**
2. **BIN for binary file**
3. **CDB for CAMCON database**
4. **ASC-BIN for ASCII and binary files**
5. **ASC-CDB for ASCII and CDB files**
6. **BIN-CDB for binary and CDB files**
7. **ASC-BIN-CDB for ASCII, binary, and CDB files**

Accept ASC, BIN, CDB, ASC-BIN, ASC-CDB, BIN-CDB, or ASC-BIN-CDB†.

The case of the characters (either upper or lower case) and the sequence of the combination of the file types is not restricted; i.e., ASC-BIN, BIN-ASC, asc-bin, or bin-

---

**NUTS expects to open a BRAGFLO ASCII input file that has the same name as BRAGFLO's binary file, but has an INP extension

+ NUTS has the ability to read BRAGFLO binary outputs before and after post-processing into CDB

† Because of some technical limitation in CAMCON system, we recommend using CDB option in NUTS_CC version of the code.

asc will all be allowed. However, the combination between upper and lower cases is not allowed (Example: ASC-bin is not allowed).

If "BIN" is among the options required by the user, NUTS will prompt:

Enter Binary Output Format

The following types are allowed

1. Enter BRAG OR brag FOR BRAGFLO Output Format

2. Enter NUTS OR nuts FOR NUTS Output Format

Accepts BRAG, brag, NUTS, or nuts

6.3.7 Enter Type of Porous Medium {MATRIX}

The following types are allowed:

1. "FRACTURE, Fracture, fracture, FRACT, fract, Fract, F, or f " for fracture calculations.

2. "MATRIX, Matrix, matrix, mat, MAT, Mat, M, or m" for matrix calculations.

3. "DUAL-POROSITY, dual-porosity, Dual-porosity, DP, Dp, dp, D-P, d-p, or D-p" for dual-porosity.

4. " DUAL-PERMEABILITY, dual-permeability, DPM, dpm, D-PM, d-pm, Dpm, or D-pm" for dual-permeability.

Accepts FRACTURE, Fracture, fracture, FRACT, fract, Fract, F, f; MATRIX, Matrix, matrix, mat, MAT, Mat, M, m; DUAL-POROSITY, dual-porosity, Dual-porosity, DP, Dp, dp, D-P, d-p, or D-p; DUAL-PERMEABILITY, dual-permeability, DPM, dpm, D-PM, d-pm, Dpm, or D-pm. Press the carriage-return key to select the default option.

6.3.8 Enter Number of Phases {1}

Accepts an integer ≥ 1

6.3.9 Enter the Type of Phase (Liquid/Gas) {L}

The following types are allowed:

1. LIQUID, liquid, Liquid, L, l, LIQ, liq for liquid phase

2. GAS, gas, Gas, G, g, GS, gs for gas phase

Accepts LIQUID, liquid, Liquid, L, l, LIQ, liq; GAS, gas, Gas, G, g, GS, or gs. Press the carriage-return key to select the default option.

6.3.10 Enter the Type of Compiler *(character*32)*

The following are allowed:

1. Enter VAX for VAX SYSTEM

2. Enter UNIX for UNIX SYSTEM

3. Enter PC for PC LAHEY SYSTEM

Accepts VAX, vax, UNIX, unix, PC, or pc.

6.3.11 Enter the name of the computer system
Ex: CRAY, GATEWAY2000, ALPHA, etc.

6.4 NUTS's Parameter Statement

NUTS uses an INCLUDE file (NUT_PARAM.INC) that contains a single **PARAMETER** statement to set the dimensions of different kinds of arrays used in the computations. Each parameter value is allotted space based on the needs of the WIPP's PA calculations. For larger problems, the parameters of NUT_PARAM.INC can be easily adjusted. As in any parameter statement, the size of the array may be greater (but not less) than that required by the problem. An example of a parameter statement used for Compliance Certification Application (CCA) calculations is as follows:

```
C
C       Note+ :
C       SET MBW >= {[(MAX(MX,MY)+1)* # OF PHASES* # OF                    CONTINUUM - #
OF CONTINUUM]*2 + 1} * 2

        INTEGER
     +     MX, MY, MZ, NB, NS,
     +     NC, NP, NDR, MBW, NFVARA, NMVARA,
     +     NFVARB, NMVARB, NFVARC, NMVARC,
     +     NVARTIT, NVPR, MXHIV, MVHIV,
     +     MGVAR, NMATM, MMATTIME, MWASTE,
     +     IHNTVARB, IHGNTVARB,
     +     MXPOINT, MYPOINT
        PARAMETER
     +     (
     +     MX          = 200,
     +     MY          = 40,
     +     MZ          = 1,
     +     NB          = 8000,
     +     NS          = 2,
     +     NC          = 9,
     +     NP          = NC,
     +     NDR         = 2,
     +     MBW         = 410,
     +     NFVARA      = 14,
     +     NMVARA      = 14,
     +     NFVARB      = 14,
     +     NMVARB      = 14,
     +     NFVARC      = 14,
     +     NMVARC      = 14,
     +     NVARTIT     = 28,
     +     NVPR              = 300,
     +     MXHIV       = 540,
     +     MVHIV       = MXHIV,
     +     MGVAR       = 10,
     +     NMATM       = 80,
     +     MMATTIME    = 50,
     +     MWASTE      = 50,
     +     IHNTVARB    = 28*NC,
     +     IHGNTVARB   = 10*NC,
     +
     +     MXPOINT     = 30,
     +     MYPOINT     = 30
```

+ This statement calculates a size of numerical matrix suitable for two-point upstream weighting option. For other options use half this size

+)

The above parameter statement variables are declared to satisfy the maximum memory requirement anticipated in the CCA calculations. In general, numbers smaller than 1 are not allowed in these declarations. The definition of the above-mentioned parameters is given in Table 2 for the variables and Table 3 for the constants+.

+ These parameters are used in the parameter statement and should not be changed.

Table 2. Variables used in NUT_PARAM.INC

Parameter	Description
MX	Maximum number of grid blocks in x-direction.
MY	Maximum number of grid blocks in y-direction.
MZ	Maximum number of grid blocks in z-direction.
NB	Maximum total number of the grid blocks (MX*MY*MZ)
NS	Maximum number of radioactive sites.
NC	Maximum number of isotopes or constituents.
NP	Maximum number of parents for each isotopes.
NDR	Maximum number of rock density ranges.
MBW	Maximum numerical matrix band width.
NVPR*	Number of element array maps from BRAGFLO.
MXHIV*	Maximum total number of history variables allowed in BRAGFLO.
MVHIV*	Maximum number of history variables per output distribution in BRAGFLO.
MGVAR*	Number of global variables printed out in an ASCII or binary BRAGFLO output file.
NMATM	Maximum number of materials specified in BRAGFLO
MMATTIME	Maximum number of times material map is specified in BRAGFLO
MWASTE	Maximum number of waste regions.
IHNTVARB**	Maximum total number of history variables to be printed in BRAGFLO style binary file.
IHGNTVARB**	Maximum total number of global variables to be printed in BRAGFLO style binary file.
MXPOINT	Maximum number of rows allowed in an interpolation table
MYPOINT	Maximum number of columns allowed in an interpolation table

* These parameters are related to BRAGFLO output and relevant only when BRAGFLO binary output is dealt with directly by NUTS (not through the CAMCON).

** These parameters are relevant only when NUTS binary output is to be post-processed with BRAGFLO binary output

Table 3. Constants used in NUT_PARAM.INC

Parameter	Description
NFVARA	Number of fracture arrays to be output in an ASCII file = 14.
NMVARA	Number of matrix arrays to be output in an ASCII file = 14.
NFVARB	Number of fracture arrays to be output in a binary file = 14.
NMVARB	Number of matrix arrays to be output in a binary file = 14.
NFVARC	Number of fracture arrays to be output in a CDB file = 14.
NMVARC	Number of matrix arrays to be output in a CDB file = 14.
NVARTIT	Number of descriptive variables = 28.

6.5 Input/Output Files Used by NUTS-SA

NUTS is capable of accommodating different combinations of input/output files in each run, depending upon the user's specifications and requirements. We will classify these files as input, output, and debug* files. The convention generally used in naming NUTS's input/output files is to form a root name by concatenating the names of the flux-field input file and the radioisotope input file, and then adding any of ASC, BIN, or DBG as extensions. A subset or the entire list of these files may be opened in a single application. The files are briefly listed below, and then described in considerable detail in the subsections that follow.

1. An ASCII radioisotope input file

2. An ASCII flux-field input file

3. A binary flux-field input file (output from BRAGFLO) if not provided as an ASCII

4. Binary output files
   a. BRAGFLO-type binary output file (to be post-processed by BRAGFLO's post-processor)
   b. NUTS-type binary output file

* Strictly speaking, debug files are text output files. However, we prefer to classify them separately.

5. ASCII output file
   a. Extensive output file
   b. Specific ranges output file

6. Debug ASCII output files

An expanded description of NUTS's input and output files follows.

6.5.1 ASCII Radioisotope Input File

This file consists of pieces of information provided by different procedures and controlled by the flags listed during NUTS's initial interrogation (and also in the user interactive input). The input can be categorized as:

1) General input the user will encounter in all NUTS input files (isotope-related input).
2) Input related to the type of the porous media encountered (Continuum-related input).
3) Material-properties-map input.

The subsections that follow, numbered **6.5.1.n** , where **n** is various combinations of letters and numbers, are a sequential description of the ASCII radioisotope input file. A sample ASCII input file is given in Appendix A.

6.5.1.A Program Controls and Flags

The very first part of the ASCII-radioisotope (A/R) input file is mainly flags that control both subsequent inputs and the computation itself. These flags and most of the description that follows will be presented in a form resembling computer language, to simplify the readability of the manual.

6.5.1.A1 Site Description and Flags

Line 1. Descriptor: NUTS title of the run. *Accepts a character string up to 100 characters as a descriptive line.*

Line 2. NUTS_TITLE.

NUTS_TITLE: This is a descriptive line for the run. The title is saved and concatenated with BRAGFLO's titles when they are printed out, which are simple clues for the user as to which NUTS and BRAGFLO runs were considered. *Accepts a character string up to 100 characters in length.*

Line 3. Descriptor: Number of sites and materials. *Accepts a character string up to 100 characters in length as a descriptive line.*

Line 4. NSITES, NMAT_INPUT

NSITES: is the number of contamination sites used in the run. Any grid block or combination of grid blocks can be a site. Thus, this is a useful representation if similar constituents from different grid blocks are to be tracked or the overlap of contamination from different places is to be assessed. *Accepts an integer > 0 , but < the total number of the grid blocks.*

NMAT_INPUT: is the number of porous materials encountered in the domain. It describes the number of materials having different properties such as porosity, permeability, density, etc. This number is compared in NUTS with the number read from BRAGFLO ASCII input file while reading the material map. If the two numbers are different, NUTS will output an aborting message and stop. *Accepts an integer > 0 , but < the total number of the grid blocks.*

DO I = 1, NSITES

Line 5. SITE_NAME(I), NCOMPONENT(I)

SITE_NAME: represents the name of the site to be modeled. *Accepts a 20 character string.*

NCOMPONENT: is the number of radioactive components to be modeled in each site. Similar components from different sites or parents are considered to be distinct, i.e., if ^{238}U exists at two sites, it will be counted as a separate constituent at each site. NCOMPONENT is the total number of all components that pre-exist, plus any that are anticipated to appear as a result of the decay process. *Accepts an integer > 0.*

END DO

Line 6. Descriptor: 1. Site name, 2. Component, Daughter, Parent, and Group names. *Accepts a character string up to 100 characters in length as a descriptive line.*

M = 0

DO I = 1, NSITES

Line 7. SNAME(I)

SNAME: a dummy variable for the SITE_NAME. SITE_NAME is renamed as a precaution in case of an input error, which, if it occurs, will not affect the stored name. *Accepts a 20-character string.*

DO J = 1, NCOMPONENT(I)

M = M + 1

Line 8. COMPONENT_NAME(I,M), DAUGHTER_NAME(M), PARENT_NAME(M), GROUP_NAME(M)

COMPONENT_NAME: the name of the radioactive isotope+ . *Accepts a 20-character string.*

DAUGHTER_NAME : for isotopes that decay into a daughter, this variable refers to the name of the next isotope in the decay chain. For constituents that do not undergo decay or whose half-lives are greater than the simulation time, the character string 'NONE' in upper case should be used. *Accepts a 20-character string.*

PARENT_NAME: the name of the preceding isotope in the decay chain. If the component has no parent, the character string 'NONE' in upper case should be used. *Accepts a 20-character string.*

GROUP_NAME: Refers to the element name of the isotope. *Accepts a 20-character string.*

END DO
END DO

Note: In the Do Loop of Line 8, it is very important to strictly follow the chain from the top down to the last member. The branches in diverging or converging chains should be treated as a separate chain. This may require an adjustment in the decay constant, inventory, and/or the name of the component at which the convergence or the divergence occurs. It is also necessary in the above entries to be consistent in the spelling and the letter case of the component, daughter, parent and group names throughout the rest of the input, except "NONE" that should be used in upper case.

Line 9. Descriptor: 1. Number of element, 2. element name, temperature dependency of solubility and table look-up solubility. *Accepts a character string up to 100 characters as a descriptive line.*

Line 10. NOELEMENT

NOELEMENT: Number of elements. *Accepts an integer >0 , but < the total number of isotopes.*

DO I = 1, NOELEMENT

Line 11. ELEMENT_NAME(I), ELTEMP_SOLB(I), SOLB_TABLE(I)

ELEMENT_NAME: the element's name. It should be identical to GROUP_NAME. *Accepts a 20-character string.*

ELTEMP_SOLB: a logical flag that indicates the temperature dependency of the solubility of the element. *Accepts T or F.*

SOLB_TABLE: a logical flag to indicate whether or not the solubility of the element will be provided by a table. *Accepts T or F.*

+ Throughout this manual, isotope, radioactive isotope, component, and constituent are used interchangeably. They all refer to the chemical species to be modeled and only their properties will define whether that species is radioactive or not.

END DO

Note: A classical definition of the element is a substance that can not be decomposed by chemical means into simpler substances. However, in this manual, element is used to refer to the ionic state of all compounds of an element in more than one oxidation state that compete on the same solubility.

Line 12. Descriptor: Colloidal transport (T/F). *Accepts a character string up to 100 characters as a descriptive line.*

Line 13. COLLOID

COLLOID: a logical flag to indicate whether colloidal transport is intended. *Accepts a T or F.*

If the answer above is T, then enter Line 14 to Line 18.

Line 14. Descriptor:
1. Number of colloids
2. location of the colloid in Line 8.
3. location of the dissolved species of the same kind.
4. preferential solubility.

Accepts a character string up to 100 characters as a descriptive line.

Line 15. NCOLLOID

NCOLLOID: Number of colloids to be transported. *Accepts an integer >0 , but < the total number of isotopes.*

Line 16. (LOC_COLLOID(I), I = 1, NCOLLOID)

LOC_COLLOID: Location of the colloid in the input sequence of line 8 of Section 6.5.1.A1. *Accepts an integer >0 , but < the total number of isotopes.*

Line 17. (IDIS(LOC_COLLOID(I)), I = 1, NCOLLOID)

IDIS: Location of the dissolved species competing with the colloid, in going to solution, in the input sequence of line 8 of Section 6.5.1.A1. *Accepts an integer* >0 , but < the total number *of isotopes.*

Line 18. (PREF_SOLB(LOC_COLLOID(I)), I = 1, NCOLLOID)

PREF_SOLB: Logical flag that identifies whether the colloid has preference to go to solution. Accepts a T or F.

Note: Colloid transport in NUTS is used in a simple form. Even though the colloids are treated like the none-colloid species in having a distinguished name and properties, transport with colloid has two different treatments. The first treatment is the ability to scale the velocity of the brine by a scaling factor. This will adjust the velocity field for the whole transport process. The second treatment is the preferential solubility for the colloids. The preferential solubility is given to the colloid only at the inventory limit. Therefore, if a

dissolved and a colloid ^{238}U starts with some part in solution and some precipitate, at the inventory limit, the colloid will use up its own precipitate first, then the precipitate of the dissolved part of ^{238}U followed by the non-colloid dissolved ^{238}U and up to the solubility limit of the colloid each time.

Line 19. Descriptor: pH required (Y/N). *Accepts a character string up to 100 characters as a descriptive line.*

Line 20. PHREQ

PHREQ: Flag related to brine-pH information. It is associated with the solubility calculation. pH will be required if correlations are to be used to determine the solubility of an element. *Accepts Y, y, N, or n.*

Line 21. Descriptor: Order of the numerical method

Line 22. MORDER:

MORDER: Order of the method. The following options are allowed:
MORDER =1, for one-point upstream winding.
MORDER =2, for two-point upstream winding.
MORDER =3, for split-operator two-point upstream winding.
MORDER =4, for mid-point weighting.
Accepts an integer >0 , but ≤ 4.

Line 23. Descriptor: Degree of implicitness.

Line 24. BETA2:

BETA2: A multiplier used in the differential equation to weight the contribution from the explicit and implicit parts of the transport equation. The following values of BETA2 are of special interest:
BETA = 1 , for fully implicit.
BETA = 0 , for fully explicit.
BETA = 1/2 , for Cranck-Niclson.
Accepts a real number ≥ 0, but ≤ 1.

6.5.1.A2 Single-Porosity Fracture Controls and Flags

These controls are applied if a single-porosity, fracture medium is to be modeled:

Fracture Sorption Controls

Line 1. Descriptor: Is fracture sorption required (Y/N)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 2. ADSTYPEF

ADSTYPEF: This character identifies whether or not sorption is required. *Accepts Y, y, N, or n.*
If the above answer is 'Y' or 'y', then input lines 3 and 4.

Line 3. FRAC_ISOTHERM

FRAC_ISOTHERM: Type of sorption isotherm. The following are considered by NUTS:
Linear isotherm. *Accepts L or l.*
Freundlich isotherm. *Accepts F, or f.*
Langumir isotherm. *Accepts LA, la, or La.*

DO I = 1, NUCLIDE ' NUCLIDE = Total number of constituents'

Line 4.NAME(I), FSORPTION(I), FADSTEMPDEP(I)

NAME: Dummy variable for the name of the component. *Accepts a 20-character string.*

FSORPTION: Character to identify whether the component is sorbable. *Accepts ADSORP for sorbable constituents, or NON_ADSORP for non-sorbable constituents.*

FADSTEMPDEP: Logical flag for temperature dependency of the fracture sorption isotherm. *Accepts T, or F.*

END DO

Fracture Dispersion Controls

Line 5.Descriptor: Does dispersion take place within the fracture (Y/N) *Accepts a character string up to 100 characters in length as a descriptive line*

Line 6.FDISPREQ

FDISPREQ: Fracture-dispersion flag. *Accepts Y, y, N, or n.*

Line 7. Descriptor: Do you have symmetrical dispersion in the fracture (F/T) and will data be read from NUTS ASCII (F/T). *Accepts a character string up to 100 characters in length as a descriptive line. The input on Line 8 is required only when the answer to line 6 is Y or y.*

Line 8.FSYMDISP, FDSPNUT INPUT

FSYMDISP: Logical flag to specify whether mechanical dispersion is symmetrical or only downstream (default = downstream). *Accepts T or F.*

FDSPNUTINPUT: Logical flag to specify whether the following dispersion data will be read from NUTS ASCII input (if the flag is true) and from the CDB (if the flag is false) (default = NUTS input).

Accepts T or F.

Fracture Source Controls

Line 9. Descriptor: Does injection/production occur in the fracture (Y/N)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 10. FSTATUSINJ
FSTATUSINJ: Character to inform NUTS injection/production is to be activated in the fracture. *Accepts Y, y, N, or n.*

Line 11. Descriptor: Do Dirichlet boundary conditions apply in the fracture (T/F)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 12. FDIRICHLET
FDIRICHLET: Logical flag to inform NUTS that Dirichlet boundary condition will be considered in some computational nodes.
Accepts T or F

Note: Dirichlet boundary conditions in NUTS are implemented by using the penalty method[+]. In this method, the main diagonal of the linear equation of the grid block is multiplied by a large number, β and the right-hand side of the same equation is replaced by $\beta * C_{dir}$, where Cdir is Dirichlet boundary condition concentration. As long as the multiplier is a very large number, the concentration of the grid block will be maintained at Dirichlet condition.

Fracture Initial Concentration Controls

Line 13. Descriptor: Is manual initialization required in the fracture (T/F)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 14. FMAN_CONC_INIT
FMAN_CONC_INIT: Logical flag to inform NUTS that the concentration in the fracture is initialized manually.
Accepts T or F.

Fracture Printed Element Variables Controls

This module specifies the format (ASCII, BINARY or CAMCON DATA BASE [CDB]) in which fracture concentration, precipitation, etc. to be represented in the output files.

[+] Becker, E.B., Cary, G.F., and J.T. Oden (1981): *Finite Elements: An Introduction*, Volume 1, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

If an ASCII file is to be output, then:

Line 15. Descriptor: Variables to be printed as an ASCII file
Accepts a character string up to 100 characters in length as a descriptive line.

Line 16. (IPRNTFA(I), I = 1, NFVARA)

IPRNTFA: This integer array has fourteen flags for the fracture-element variables to be printed as an ASCII file.
Choose 1 to print the variable and 0 to omit the variable from printing.
This flag will activate or deactivate printing of the following variables:

IPRNTFA(1):	Fracture total mass of dissolved constituents in the brine in each grid block, kg
IPRNTFA(2):	Fracture total mass of precipitated constituents in each grid block, kg
IPRNTFA(3):	Fracture total mass of dissolved, precipitated and sorbed constituents in each grid block, kg
IPRNTFA(4):	Fracture total dissolved curies of all constituents in each grid block, curies
IPRNTFA(5):	Fracture total precipitated curies of all constituents in each grid block, curies
IPRNTFA(6):	Fracture total dissolved, precipitated, and sorbed curies of all constituents in each grid block, curies
IPRNTFA(7):	Fracture volumetric concentration of the dissolved isotope, kg/(m^3 brine).
IPRNTFA(8):	Fracture dissolved mass in the brine of a certain constituent , kg.
IPRNTFA(9):	Fracture precipitated mass of a certain constituent, kg.
IPRNTFA(10):	Fracture soil base concentration of the isotope, mg/(kg soil).
IPRNTFA(11):	Fracture curies of volumetric concentration of a certain constituent, curies/(m^3 brine).
IPRNTFA(12):	Fracture curies of dissolved mass in the brine of a certain constituent, curies.
IPRNTFA(13):	Fracture curies of precipitated mass of a certain constituent, curies.
IPRNTFA(14):	Fracture curies of dissolved, precipitated and sorbed mass of a certain constituent, curies.

Line 17. Descriptor: Spatial range (s) of data to be printed in an ASCII file for specific variable

Accepts a character string up to 100 characters in length as a descriptive line

Line 18. ASC_FPRINT_RANGE

ASC_FPRINT_RANGE: Allows a range(s) of data to be output in an ASCII file.
Accepts Y, y, N, or n.

If a BINARY* file is to be output, then:

Line 19. Descriptor: Variables to be printed to a BINARY file
Accepts a character string up to 100 character in length as a descriptive line.

Line 20. (IPRNTFB(I), I = 1, NFVARB)

IPRNTFB: integer array similar to IPRNTFA(I) has fourteen flags for the element fracture variables to be printed in a binary file.
Choose 1 to print the variable, and 0 to omit printing.

If a spatial range(s) is to be printed (line 18 is "Y" or 'y'), then:

Line 21. Descriptor: Ranges to be printed in an ASCII file
Accepts a character string up to 100 characters in length as a descriptive line.

Line 22. NO_ASC_FRAC_RANGES:

NO_ASC_FRAC_RANGES: Number of ranges to be printed
Accepts an integer > 0 , but < the total number of grid blocks.

DO I = 1, NO_ASC_FRAC_RANGES

Line 23 IARANGE(I), MFASTRTI(I), MFASTRTJ(I), MFASTRTK(I), MFAENDI(I), MFAENDJ(I), and MFAENDK(I)

IARANGE: Range number
Accepts an integer > 0, but < NO_ASC_FRAC_RANGES

MFASTRTI,J,K I,J,K indices of the grid block starting the range
Accepts an integer > 0 and I < NX, J < NY, K < NZ.

MFAENDI,J,K I,J,K indices of the grid block ending the range
Accepts an integer > 0 and I < NX, J < NY, K < NZ.

Line 24. (IPRNSFA(I,J), J = 1, NFVARA)

IPRNSFA: integer array similar to IPRNTFA

END DO

* Lines 19 and 20 are required for the CDB output in the NUT-CC version of the code.

6.5.1.A3 Single-Porosity Matrix Controls and Flags

These controls are applied if a single-porosity matrix is to be modeled.

Matrix Sorption

Line 1. Descriptor: Is matrix sorption required (Y/N)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 2.ADSTYPEM
ADSTYPEM: This character activates or deactivates sorption in the matrix.
Accepts Y, y, N, or n. If the answer is 'Y' or 'y' then:

Line 3.MAT_ISOTHERM
MAT_ISOTHERM: one of three types of matrix sorption isotherm, namely:
Linear isotherm. *Accepts L or l.*
Freundlich isotherm. *Accepts F, or f.*
Langumir isotherm. *Accepts LA, la, or La.*

DO I = 1, NUCLIDE

Line 4.NAME(I), MSORPTION(I), MADSTEMPDEP(I)
NAME: Dummy variable for the name of the component.
Accepts a 20-character string.
MSORPTION: Character to identify whether the component is sorbable.
Accepts ADSORP for sorbable or NON_ADSORP for non-sorbable constituents.
MADSTEMPDEP: logical flag for temperature dependency of the matrix sorption isotherm.
Accepts T or F.

END DO

Matrix Dispersion Controls

Line 5.Descriptor: Do you have dispersion in the matrix (Y/N)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 6.MDISPREQ
MDISPREQ: Matrix-dispersion flag.
Accepts 'Y' or 'y' to consider, and 'N' or 'n' to omit dispersion in the matrix.

Line 7. Descriptor: Do you have symmetric dispersion in the matrix (F/T), and will data be read from NUTS ASCII (F/T).
Accepts a character string up to 100 characters in length as a descriptive line. The input on line 8 is required only when the answer to line 6 is Y or y.

Line 8. MSYMDISP, MDSPNUTINPUT

MSYMDISP: Logical flag to specify whether mechanical dispersion is symmetric or only downstream (default = downstream). *Accepts T or F.*

MDSPNUTINPUT: Logical flag to specify whether the following dispersion data will be read from NUTS ASCII input (if the flag is true) and from the CDB (if the flag is false) (default = NUTS input). *Accepts T or F.*

Matrix Source Controls

Line 9. Descriptor: Is injection/production present in the matrix (Y/N) *Accepts a character string up to 100 characters in length as a descriptive line.*

Line 10. MSTATUSINJ

MSTATUSINJ: Informs NUTS whether or not injection/production is present in the matrix. *Accepts Y, y, N, or n.*

Line 11. Descriptor: Are Dirichlet boundary conditions present in the matrix (T/F) *Accepts a character string up to 100 characters in length as a descriptive line.*

Line 12. MDIRICHLET

MDIRICHLET: Logical flag to inform NUTS that Dirichlet boundary condition will be considered at some computational nodes. *Accepts T or F.*

Matrix Initial Concentration Controls

Line 13. Descriptor: Is manual initialization present in the matrix (T/F) *Accepts a character string up to 100 characters in length as a descriptive line.*

Line 14. MMAN_CONC_INIT

MMAN_CONC_INIT: Logical flag informing NUTS that the concentration in the matrix is initialized manually. *Accepts T or F.*

Matrix Initial Concentration from NUTS Undisturbed CDB

In the CCA calculations, two intrusion times are considered in BRAGFLO: 350 and 1000 years. In probabilistic evaluation of the intrusion times, times other than 350 and 1000 years need to be considered for the transport purposes. This step has been done by interpolating the flow fields results from BRAGFLO for 350 years to perform the transport with an intrusion that occurs at 100 years. Similarly, the flow fields of the 1000 years intrusion are extrapolated to intrusions that

take place at 3000, 5000, 7000, and 9000 years. To account for the fact that the period before the intrusion is undisturbed, the output CDB from undisturbed NUTS transport calculations is used to initialize the calculation at that specific time of intrusion.

Line 15. Descriptor: Concentration is initialized from NUTS undisturbed CDB (T/F)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 16. CONC_CDB_INITIALIZATION

CONC_CDB_INITIALIZATION: Logical flag informing NUTS that the concentration in the matrix is initialized from the undisturbed CDB.
Accepts T or F.

Matrix Printed Element Variable Controls

This module specifies the output-file format (ASCII, BINARY or CAMCON DATA BASE [CDB]) of results for matrix concentration, precipitation, etc.

If an ASCII file is to be output, then:

Line 17. Descriptor: Variables to be printed in an ASCII file
Accepts a character string up to 100 characters in length as a descriptive line.

Line 18. (IPRNTMA(I), I = 1, NMVARA)

IPRNTMA: An integer array containing fourteen flags for the matrix-element variables to be printed in an ASCII file.
Choose 1 to print and 0 not to print the variable in question.
IPRNTMA(I) refers to following variables:

IPRNTMA(1): Matrix total mass of dissolved constituents in the brine in each grid block, kg
IPRNTMA(2): Matrix total mass of precipitated constituents in each grid block, kg
IPRNTMA(3): Matrix total mass of dissolved, precipitated and sorbed constituents in each grid block, kg
IPRNTMA(4): Matrix total dissolved curies of all constituents in each grid block, curies
IPRNTMA(5): Matrix total precipitated curies of all constituents in each grid block, curies
IPRNTMA(6): Matrix total dissolved, precipitated, and sorbed curies of all constituents in each grid block, curies
IPRNTMA(7): Matrix volumetric concentration of the dissolved isotope, kg/(m^3 brine).
IPRNTMA(8): Matrix dissolved mass in the brine of a certain constituent, kg.

IPRNTMA(9): Matrix precipitated mass of a certain constituent, kg.
IPRNTMA(10): Matrix soil base concentration of the isotope, mg/(kg soil).
IPRNTMA(11): Matrix curies of volumetric concentration of a certain constituent, curies/(m^3 brine).
IPRNTMA(12): Matrix curies of dissolved mass in the brine of a certain constituent, curies.
IPRNTMA(13): Matrix curies of precipitated mass of a certain constituent, curies.
IPRNTMA(14): Matrix curies of dissolved, precipitated and sorbed mass of a certain constituent, curies.

Line 19. Descriptor: Spatial range (s) of data to be printed in an ASCII file for specific variables
Accepts a character string up to 100 characters in length as a descriptive line.

Line 20. ASC_MPRINT_RANGE
ASC_MPRINT_RANGE: This character *accepts Y, y, N, or n* answers for the range(s) of data to be output in an ASCII file.

If a BINARY* file is to be output, then:

Line 21. Descriptor: Matrix variables to be printed in a BINARY file
Accepts a character string up to 100 characters in length as a descriptive line.

Line 22. (IPRNTMB(I), I = 1, NMVARB)
IPRNTMB: A fourteen-flag integer array similar to IPRNTMA(I)
Choose 1 to print, or 0 to omit the element matrix variables in a binary file.

If spatial range(s) is to be printed (Line 20 is "Y" or "y"), then:

Line 23. Descriptor: Ranges to be printed in an ASCII file
Accepts a character string up to 100 characters in length as a descriptive line.

Line 24. NO_ASC_MATRIX_RANGES
NO_ASC_MATRIX_RANGES: Number of ranges to be printed
Accepts an integer > 0 , but < the total number of grid blocks.

* Lines 21 and 22 are required for the CDB output in the NUT-CC version of the code.

DO I = 1, NO_ASC_MATRIX_RANGES

Line 25. IARANGE(I) ,MASTRTI(I) ,MASTRTJ(I) ,MASTRTK(I), MAENDI(I), MAENDJ(I), MAENDK(I)

IARANGE: Range number
Accepts an integer > 0, but < NO_ASC_MATRIX_RANGES

MASTRTI,J,KI,J,K: Indices of the grid block starting the range
Accepts an integer > 0 and I < NX, J < NY, K < NZ

MAENDI,J,K: I,J,K indices of the grid block ending the range
Accepts an integer > 0 and I > NX, J > NY, K > NZ

Line 26. (IPRNSMA(I,J), J = 1, NMVARA)

IPRNSMA: an integer array similar to IPRNTMA

END DO

6.5.1.A4 Dual-Porosity/Dual-Permeability Controls and Flags

If a dual-porosity or a dual-permeability medium is to be modeled, the flag sequence will be as follows:

a. Enter the flags described in Section 6.5.1.A2, Line 1 to Line 24
b. Enter the flags described in Section 6.5.1.A3, Line 1 to Line 8
c. Enter the following flags for

Fracture/Matrix Dispersion

Line 8a. Descriptor: Is fracture/matrix dispersion present (Y/N)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 8b. MFDISPREQ

MFDISPREQ: Fracture/matrix dispersion flag.
Accepts 'Y' or 'y' if dispersion from matrix to fracture is present and 'N' or 'n' if it is not.

d. Enter the flags described in Section 6.5.1.A3, Line 9 to Line 26.

6.5.1.A5 k_d Temperature-Dependency Information

This module provides NUTS with information about the constituents in which k_d is temperature dependent.

Line 1. Descriptor: Component name, reference temperature, and sorption exponential coefficient.
Accepts a character string up to 100 characters in length as a descriptive line.

IF either ADSTYPEF or ADSTYPEM (above) was selected as 'Y' or 'y', then:
DO I = 1, NUCLIDE
IF either FADSTEMPDEP(I) or MADSTEMPDEP(I) (above) was selected as "TRUE," then:

Line 2.NAME(I), REFTEMPKD(I), ADSEXPCOEFF(I)

NAME: Dummy variable for the name of the constituent.
Accepts a 20-character string.

REFTEMPKD: The reference temperature at which k_d is evaluated.
Upper and lower bounds are not provided.

ADSEXPCOEFF: Sorption exponential coefficient.
Upper and lower bounds are not provided.

END DO

6.5.1.A6 Molecular-Diffusion Temperature-Dependency Flags

These flags inform NUTS whether the molecular diffusion of a given constituent is temperature dependent in cases where **FDISPREQ** or **MDISPREQ** or **MFDISPREQ** is required ('Y' or 'y'). If none is required, no information will be provided by this item.

If FDISPREQ or MDISPREQ or MFDISPREQ is 'Y' or 'y', then:

Line 1. Descriptor: Component, name, and molecular-diffusion temperature dependency flag
Accepts a character string up to 100 characters in length as a descriptive line.

DO I = 1, NUCLIDE

Line 2.NAME(I), DMOLTEMDEP(I)

NAME: Dummy variable for the name of the constituent.
Accepts a 20-character string.

DMOLTEMDEP: Logical flag for temperature dependency of the molecular diffusion.
Accepts T or F.

END DO

6.5.1.A7 Printing-Frequency Information

This module specifies the frequency at which results will be printed to ASCII, BINARY, or CAMCON DATA BASE (CDB) output files.

If an ASCII file is to be output, then:

Line 1.Descriptor: Printing frequency in an ASCII file

Accepts a character string up to 100 characters in length as a descriptive line.

Line 2.IPRFRQA, TIMEASCMAX

IPRFRQA: Frequency of printing to an ASCII file, e.g.: 1 if every time step is to be printed, 2 for every other time step and so on.
Accepts an integer > 0.

TIMEASCMAX: Maximum time between printings. If this time is exceeded, NUTS will print the results regardless of the frequency specified above.
Accepts a real number >0 , but < the total simulation time.

If a BINARY file is to be output, then:

Line 3.Descriptor: Printing frequency to a BINARY file
Accepts a character string up to 100 characters in length as a descriptive line.

Line 4.IPRFRQB, TIMEBINMAX

IPRFRQB: Frequency of printing to a BINARY file.
Accepts an integer > 0; n means every nth timestep will be printed.

TIMEBINMAX: Maximum time allowed between printing interval.
Accept real number >0 , but < the total simulation time.

If a CDB file is to be output, then:

Line 5.Descriptor: Printing frequency to a CDB file
Accepts a character string up to 100 characters in length as a descriptive line.

Line 6.IPRFRQC, TIMECDBMAX

IPRFRQC:Frequency of printing to a CDB file.
Accepts an integer > 0; n means every nth timestep will be printed.
TIMECDBMAX: Maximum duration allowed between printings.
Accepts real numbers >0 , but < the total simulation time.

6.5.1.A8 External Source Flag

This flag identifies whether there is a dynamic source interfacing with NUTS. Two kinds of dynamic sources are used in NUTS. The first kind is an Actinide Source Submodel that has the ability to look at the distribution of the waste canisters, their corrosion and breach of the radioactive material, the chemical reaction of the waste with the brine, and the transport of the waste (by diffusion) from the breached canister to the porous media. This repository-scale calculation can be conducted through an interface between NUTS and the Actinide Source Submodel and is not used in the CCA calculations. Another dynamic source model is used in

NUTS for testing purposes. This source is a sort of interpolating function that has the ability to change the form (spike, slab, triangle, double hump, etc.) and the amount of the release. This function is built in NUTS and used to generate the sources in many of the test cases for code evaluation (see the QA documentation package NUTS).

Line 1. Descriptor: Is external source interfacing present (T/F)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 2.STOCKMAN
STOCKMAN: Logical flag to inform NUTS about the external source model.
Accepts T or F.

6.5.1.A9 Time-Minimum Limit

When a high degree of non-linearity is encountered in BRAGFLO calculations, the automatic time stepping module in BRAGFLO will reduce the time step to whatever value leads to the solution convergence. This value in some occasions could be as low as a fraction of a second. Because NUTS reads the time step information from the CDB, which is stored in single precision, and because of the precision (time is read and written in seconds), the difference between two successive times (time step size) for such a highly nonlinear step, can be zero. This inaccuracy in the time information is limited to a few time steps and irrelevant for the transport calculations. However, in the mathematical formulation of the transport equation, the time step appears as a divisor; in these instances, a division by zero problem will halt the calculation. To avoid this problem a time step minimum limit in the order of 10^{-16} or less is used whenever zero time step is encountered.

Line 1.Descriptor: Input timestep lower limits.
Accepts a character string up to 100 characters in length as a descriptive line.

Line 2. TIMELIMIT
TIMELIMIT: Time lower limit.
The value should not exceed 1.E-16 s

6.5.1.A10 Intrusion Time Interpolation and Extrapolation

Line 1. Descriptor: Actual time of intrusion, Interpolated/Extrapolated time, Tolerance. *Accepts a character string up to 100 characters in length as a descriptive line.*

If concentration initialization is to be done from the CDB (CONC_CDB_INITIALIZATION is true) then:

Line 2. TIME_INTRUSION, RESET_TIME_INTRUSION, TIMETOL

TIME_INTRUSION: The actual intrusion time specified in BRAGFLO run (350 and 1000 yrs for the CCA calculations).
RESET_TIME_INTRUSION: Interpolated/Extrapolated intrusion time.
TIMETOL:* Accepted tolerance to initialize at closest time to the RESET_TIME_INTRUSION.

6.5.1.B Material Map Input

NUTS's interactive input will determine the location from which NUTS will read the material map. If the user specified **BRAGFLO** input as the source for the material map, NUTS will open BRAGFLO's input file and read the material map and various reference condition parameters. NUTS assumes BRAGFLO's input and output files have the same name with an extension **.INP** for input and **.BIN or .CDB** for the output. If the user specified NUTS as a source for the material map, NUTS will proceed reading the input file in the following sequence:

Line 1.Descriptor: Number of times for specifying material map
*Accepts a character string up to *17 characters as a descriptive line.*

Note: NUTS will key on this label to start reading the material map, regardless of whether BRAGFLO or NUTS input is specified. Because of the format of BRAGFLO input, **this label should be used exactly preceded by two or three empty spaces (see the example in Appendix B).**

Line 2. NMATTIMES
NMATTIMES: Number of times the material map will change during simulation time.
Accepts an integer > 0.

DO I = 1, NMATTIMES

Line 3. Descriptor(I): Start time for material map
Accepts a character string up to 17 characters in length as a descriptive line.

Line 4.TIMEMAST(I)
TIMEMAST: Starting time for material map (s).
Accepts a real number > 0.

Line 5.Descriptor(I): Material-type grid map
Accepts a character string up to 17 characters in length as a descriptive line.

Line 6.(((IMAT(I,J,K), I = 1, NX), J = 1, NY), K = 1, NZ)
IMAT(I,J,K): An array that holds the material map of the grid blocks for the entire spatial domain.

* NUTS will read the time in the CDB file and add the tolerance. If the total of time + TIMETOL ≥ RESET_TIME_INTRUSION, this time will be picked up for initialization.

Accepts an integer > 0.

END DO

Line 7. Descriptor: Material name
Accepts a character string up to 17 characters in length as a descriptive line.

DO I = 1, NMAT

Line 8. J,MAT_NAME(I)

J: Material number in the material map. *Accepts an integer.*

MAT_NAME: Material name .
Accepts a 50-character string.
Note: NMAT is the number of the material specified in the material map. NMAT is compared with the input material number (**NMAT_INPUT**). If the two numbers do not agree, *NUTS will print a warning message and abort.*

END DO

Line 9.Descriptor: Number of waste regions.
Accepts a character string up to 17 characters in length as a descriptive line.

Line 10. NWST

NWST: Number of waste regions. If the NWST>NSITES=1, NUTS will combine the waste regions into one site. In the cases when NWST>NSITES>1, NUTS will print a warning message on screen and it will terminate.
Accepts an integer > 0 and = NSITES.

Line 11. Descriptor: Names of waste regions.
Accepts a character string up to 17 characters in length as a descriptive line.

Line 12. (MAT_WASTE(I), I = 1,NWST)

Line 13. (MAT_WASTE(I), I = 1,NWST)

MAT_WASTE: Waste region material index.
Accepts any integer.

If the material map input is from BRAGFLO, NUTS will key on ' REFERENCE TEMPE' to read the following:

Line 13. RTEMP_BRAG, RPRES_BRAG

RTEMP_BRAG: Reference temperature.
Accepts 273.15<any real number < 473.15

RPRES_BRAG: Reference pressure.
Accepts 0 < any real, positive number < 1.E10

If the material map input is from BRAGFLO, NUTS will also key on" SALT% DEN" to read:

Line 14. A1, A2, A3, A4, A5

A1: Reference brine density.

A2, A3, and A4: BRAGFLO parameters irrelevant to NUTS applications.

A5: Brine compressibility.

Note: A1 and A2 are not checked directly, however they are used to calculate density under reservoir conditions. Since the density bounds are checked, A1 and A2 are implicitly checked.

If the material map input is from BRAGFLO, NUTS will also key on " # LAMBDA "to read:

DO I=1, NMAT
Line 15, IA1, A2, BRESD_MAT(I)

IA1, A2: BRAGFLO parameters irrelevant to NUTS applications.

BRESD_MAT: Brine residual saturation of the material.

END DO

An example of the material map with a 9-grid-block spatial domain for one time is given in Appendix B.

6.5.1.C Properties Input

6.5.1.C1 Physical Properties

Line 1. Descriptor: End of material map and start of physical properties input
Accepts a character string up to 100 characters in length as a descriptive line.

Line 2. Descriptor: Element solubility input
Accepts a character string up to 100 characters in length as a descriptive line.

If the data are to be read from NUTS's input file and not the CDB, then:

DO I = 1, NOELEMENT
If the solubility is not temperature dependent and not table look-up (ELTEMP_SOLB(I) .and. SOLB_TABLE(I) = .FALSE.) then:

Line 3. NAME(I), ALOG_ELEMNT_SOLB_LIMIT(I)

NAME: Dummy variable for the element name.
Accepts a 20-character string.

ALOG_ELEMNT_SOLB_LIMIT: Log_{10} of the element solubility limit (mol/liter).

Accepts any real number for which Log_{10} inverse exists.

END DO

DO I = 1, NOELEMENT
If the solubility is table look-up (SOLB_TABLE(I) = .TRUE.) then:

Line 4. NAME(I),EQSPACED(I),ID_INT
NAME: Dummy variable for the element name.
Accepts a 20-character string.
EQSPACED: Logical flag for equally spaced entries.
Accepts T or F.
ID_INT: Interpolation table dimensions identifier.
Accepts two values: ID_INT = 1 for 1D interpolation, and ID_INT = 2 for 2D interpolation tables

If 1D table then:
Line 5. NROW1D
NROW1D: Number of rows in the table.
Accepts an integer > 0.

DO K = 1, NROW1D
Line 6. ROW1D, FX
ROW1D: Row entry in the table.
Accepts any real number.
FX: Table entries.
Accepts any real number.

END DO
If 2D table then:
Line 7. NROW(I), NCOLUMN(I)
NROW: Number of rows in the table.
Accepts an integer > 0.
NCOLUMN: Number of columns in the table.
Accepts an integer > 0.
Line 8. (COLUMN(J,I), J = 1,NCOLUMN(I)
COLUMN: Column entry in two-dimensional table.
Accepts any real number.

DO K = 1, NROW(I)
Line 9. ROW(K,I),(FXY(K,NNC,I), NNC = 1, NCOLUMN(I))
ROW: Row entry in two-dimensional table.
Accepts any real number.
FXY: Table entries.
Accepts any real number.

END DO

END DO

Note: In the above table the units *must* be consistent.

DO I = 1, NOELEMENT
If the solubility is temperature dependent (ELTEMP_SOLB(I) = .TRUE.) then:
Line 10. NAME(I), C0(I),C1(I),C2(I),C3(I),C4(I),C5(I)
NAME: Dummy variable for the element name.
Accepts a 20-character string.
C0-5: Coefficients of the correlation polynomial.
Accepts any real number.
END DO

Line 11. Descriptor: Name, molecular (or atomic) weight, inventory, half-life
Accepts a character string up to 100 characters in length as a descriptive line.
If the data are to be read from NUTS's input file and not the CDB, then:
DO I = 1, NUCLIDE
Line 12. NAME(I),XMOLWT(I),CUINVCHD(I),CUINVRHD(I),HALF-LIFE(I)
NAME: Dummy variable for component name.
Accepts a 20-character string.
XMOLWT: Molecular or atomic weight of the component (kg-mol).
Accepts any real number > 0 and < 1 .
CUINVCHD: Curies of contact handled inventory (Ci).
Accepts any real number > 0.
CUINVRHD: Curies of remote handled inventory (Ci).
Accepts any real number > 0.
HALF-LIFE: Component half-life (s).
Accepts any real number >= 0.
Note: 0 is used for HALF-LIFE as a flag to identify stable components.
END DO

If phase type is gas, then:

Line 13. Descriptor: Component name, intercept and slope of equilibrium line
Accepts a character string up to 100 characters in length as a descriptive line.
DO I = 1, NUCLIDE
Line 14. NAME(I), EQCI(I), EQCS(I)
NAME: Dummy variable for component name.
Accepts a 20-character string.
EQCI: Intercept of gas-liquid equilibrium line.
Accepts any meaningful real number.
EQCS: Slope of gas-liquid equilibrium line.
Accepts any meaningful real number.
END DO

Line 15. Descriptor: Ground-water pH Input
Accepts a character string up to 100 characters in length as a descriptive line.

If PHREQ is 'Y' or 'y', then:

If the data are to be read from NUTS's input file and not the CDB, then:

Line 16. (RPH(I), I = 1, NMAT)
RPH: pH of ground water for the range specified by the material map index.
Accepts 0 < RPH < 14.

Line 17. Descriptor: Standard conditions brine density if a test run.
Accepts a character string up to 100 characters in length as a descriptive line.

If the run is a test run (densities can not be read from BRAGFLO), then:

Line 18. RBR_DEN
RBR_DEN: Standard condition brine density.
Accepts 0 < real number < 2000.

6.5.1.C2 Component Molecular-Diffusion Input

Line 1. Descriptor: Molecular diffusion input
Accepts a character string up to 100 characters in length as a descriptive line.

If MDISPREQ or FDISPREQ or MFDISPREQ is 'Y' or 'y', then:
If the data are to be read from NUTS input file and not the CDB, then:

DO I = 1, NUCLIDE

Line 2. NAME(I), DMOL(I)
NAME: Dummy variable for component name.
Accepts a 20-character string.
DMOL: Molecular diffusion of the component (m^2/s).
Accepts a real number > 0 and < a number that gives a molecular diffusional velocity+ of 0.6 m/s

END DO

Line 3. Descriptor: Reference viscosity and temperature
Accepts a character string up to 100 characters in length as a descriptive line.

DO I = 1, NUCLIDE
If DMOLTEMDEP(I) is .TRUE. then:
C2.1.3 VISREF(I), TREF(I)

+ diffusional velocity is calculated as = DMOL * distance (in the direction of the flow)/area (perpendicular to the direction of the flow). The value of 0.6 m/s is based on a Reynolds number = 1 in the porous medium, which assures a linear velocity dependence (i.e., satisfies Darcy's Law).

VISREF: Reference viscosity at which molecular diffusion is measured (Pa/s).
Accepts a real number > 0.

TREF: Reference temperature at which molecular diffusion is measured (K).
Accepts a real number > 0.

END DO

6.5.1.C3 Rock-Density Input

This module reads the density of each material mentioned in the material map.

Line 1. Descriptor: Rock density
Accepts a character string up to 100 characters in length as a descriptive line.

If soil base concentration is required to be output (option IPRNTFA(10) or IPRNTFB(10) or IPRNTFC(10) or IPRNTMA(10) or IPRNTMB(10) or IPRNTMC(10)) is 1 or sorption is to be calculated (ADSTYPEM or ADSTYPEF is "Y" or "y") and if the data are to be read from NUTS input file and not the CDB, then,

Line 2. (RROCK_DENS(I), I = 1, NMAT)

RROCK_DENS: Rock grain density for the range specified by the material map index (kg/m^3). *Accepts a real number > 0 and < 5000.*

6.5.1.C4 Waste-Matrix Input

In the cases where the waste is placed in a certain grid block belonging to a certain site, this input specifies the number of constituents, which constituents they are, and where in the grid-block map these constituents are located. It is this matrix that defines where to initialize the concentrations of the waste material.

Line 1. Descriptor: Waste matrix input
Accepts a character string up to 100 characters in length as a descriptive line.

Line 2. NWSTCOMP_TOTAL

NWSTCOMP_TOTAL: Number of Component placed in the waste.
Accepts an integer > 0 and < the total number of components.

If NWSTCOMP_TOTAL is zero, then stop waste matrix input here. Otherwise,

DO I = 1, NWSTCOMP_TOTAL

Line 3. NAME(I),LOCWASTINP(I),NWASTREGION(I)

NAME: Dummy variable for component name.
Accepts a 20-character string.

LOCWASTINP: Location of the component in the input (COMPONENT_NAME list).
Accepts an integer > 0 and < the total number of components.

NWASTREGION: Waste site number.
Accepts an integer > 0 and < NSITES.

END DO

Line 4. Descriptor: (1. site name, number of grid; 2. indices of waste matrix)
Accepts a character string up to 100 characters in length as a descriptive line.

DO I = 1, NSITES

Line 5. SNAME(I),NGRIDSITE(I)

SNAME: A dummy character for the site name.
Accepts a 20-character string.
NGRIDSITE: Number of grid block of waste in that particular site.
Accepts an integer > 0 and < the total number of grid blocks.

Line 6. (IS(I,J),JS(I,J),KS(I,J), J=1, NGRIDSITE(I))

IS,JS,KS: i,j, and k indices of the grid blocks in the waste site.
Accepts an integer > 0 and IS ≤ NX, JS ≤ NY, and KS ≤ NZ.

6.5.1.C5 Single-Porosity Fracture Input

If a single-porosity fracture medium is to be modeled, then:

Fracture Sorption Input

This module inputs the constituent sorption properties of the fracture. Three equilibrium isotherms are considered depending on the value of FRAC_ISOTHERM.

Line 1. Descriptor: Fracture sorption
Accepts a character string up to 100 characters in length as a descriptive line.

If the data are to be read from NUTS's input file and not the CDB, then:

If ADSTYPEF is 'N' or 'n', then stop the input for this module here. Otherwise,

If FRAC_ISOTHERM IS 'L' or 'l' then:

DO I = 1, NUCLIDE

Line 2. NAME(I)
NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 3. (RXLF(J), J = 1, NMAT)

RXLF: Linear sorption coefficient (k_d) of the fracture for the range specified by the material map index (m^3/kg).
Accepts a number > 1.

END DO

If FRAC_ISOTHERM is 'F' or 'f' then:

DO I = 1, NUCLIDE

Line 4. NAME(I)

NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 5.(RXFDCF(J), J = 1, NMAT)

Line 6.(RXFCF(J), J = 1, NMAT)

RXFDCF: Freundlich distribution coefficient of the fracture for the range specified by the material map index (m^3fluid/kg solid).
Upper and lower bounds are not specified.

RXFCF: Freundlich coefficient of the fracture for the range specified by the material map index (dimensionless).
Upper and lower bounds are not specified

END DO

If FRAC_ISOTHERM is 'LA' or 'la' or 'La', then:

DO I = 1, NUCLIDE

Line 7. NAME(I)

NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 8. (RXLDCF(J), J = 1, NMAT)

Line 9. (RXLCF(J), J = 1, NMAT)

RXLDCF: Langumir distribution coefficient of the fracture for the range specified by the material map index (m^3fluid/kg solid).
Upper and lower bounds are not specified.

RXLCF: Langumir coefficient of the fracture for the range specified by the material map index (dimensionless).
Upper and lower bounds are not specified.

END DO

Fracture Dispersion Input

This module inputs dispersion parameters for the fracture.

Line 10. Descriptor: Fracture dispersion

Accepts a character string up to 100 characters in length as a descriptive line.

If the data are to be read from NUTS's input file and not the CDB, then:
If FDISPREQ is 'N' or 'n' stop the input for this module here. Otherwise,

Line 11. Descriptor: Longitudinal dispersivity in the fracture
Accepts a character string up to 100 characters in length as a descriptive line.

Line 12. (RALPHALF(I), I = 1, NMAT)
RALPHALF: Longitudinal dispersivity of the fracture for the range specified by the material map index (m).
Accepts a real number > 0 and < the smallest hydrological dimension of the spatial domain.

Line 13. Descriptor: Transverse dispersivity in the fracture
Accepts a character string up to 100 characters in length as a descriptive line.

Line 14. (RALPHATF(I), I = 1, NMAT)
RALPHATF: Transverse dispersivity of the fracture for the range specified by the material map index (m).
Accepts a real number > 0 and < longitudinal dispersivity.

Line 15. Descriptor: Tortuosity in the fracture
Accepts a character string up to 100 characters in length as a descriptive line.

Line 16. (RTORF(I), I = 1, NMAT)
RTORF: Fracture tortuosity for the range specified by the material map index (dimensionless).
Accepts a real number > 1.

Fracture Source Input

Line 17. Descriptor: Start fracture source input for injection/production
Accepts a character string up to 100 characters in length as a descriptive line.

If FSTATUSINJ is 'N' or 'n', then skip the next Lines 18 to 25, otherwise,

Line 18. NTMNINJCOMP
NTMNINJCOMP: Total number of injected components.
Accepts an integer 0<NTMNINJCOMP < total number of component

DO J = 1, NTMNINJCOMP

Line 19. NAME(J), LOCINPM(J), NMTBLOKINJ(J)
NAME: Dummy variable for component name.

Accepts a 20-character string.

LOCINPM: Location of the injected component in the component input sequence.

Accepts an integer 0<LOCINPM < total number of component

NMTBLOKINJ: Total number of grid blocks at which this component is injected.

Accepts an integer 0 < NMTBLOKINJ *< total number of grid blocks*

Line 20. (INJBIM(I,J), INJBJM(I,J), INJBKM(I,J), I = 1, NMTBLOKINJ(J))

INJBIM: I index of the injection block.

*Accepts an integer 0<*INJBIM *< total number of grid blocks in x direction.*

INJBJM: J index of the injection block.

*Accepts an integer 0<*INJBJM *< total number of grid blocks in y direction.*

INJBKM: K index of the injection block.

*Accepts an integer 0<*INJBKM *< total number of grid blocks in z direction*

END DO

DO I = 1, NTMNINJCOMP

Line 21. NAME(I)

NAME: Dummy variable for component name.

Accepts a 20-character string.

Line 22. (CONCMIJKINJ(INJBIM(J,I), INJBJM(J,I), INJBKM(J,I)), J = 1, NMTBLOKINJ(I))

CONCMIJKINJ: Concentration of the injected component (kg/m^3).

Accepts a real number > 0.

END DO

Line 23. Descriptor: Injection production rates

Accepts a character string up to 100 characters in length as a descriptive line.

Line 24. NMBLOCKSOURCE, TIMEFSTRT, TIMEFEND

NMBLOCKSOURCE: Number of grid blocks having the source.

Accepts an integer 0 < NMBLOCKSOURCE *< total number of grid blocks.*

TIMEFSTRT: Starting time of injection/production in fracture (s).

Accepts a real number 0 < TIMEFSTRT < TIMEFEND

TIMEFEND: Ending time of injection/production in fracture (s).

Accepts a real number 0 < TIMEFEND

DO I = 1, NMBLOCKSOURCE

Line 25. IQIM(I), IQJM(I), IQKM(I), RATE(I)

IQIM, IQJM, IQKM: I,J,K indices of the injection/production block.

Accepts an integer 0 < IQIM, IQJM, IQKM *< total number of grid blocks in x, y, z direction.*

RATE: Injection/production rate (m^3/s).
Accepts a real number > 0.

END DO

Line 26. Descriptor: Dirichlet boundary condition in the fracture
Accepts a character string up to 100 characters in length as a descriptive line.

If FDIRICHLET then:

Line 27. NTMDIRCOMP,TYPEDIR

NTMDIRCOMP: Number of components with Dirichlet boundary condition (DBC)
Accepts a real number 0 < NTMDIRCOMP *< total number of component.*

TYPEDIR: Character to identify whether DBCs are specified in the repository only or may occur elsewhere in the domain.
Accepts two values; (1) GENERAL : DBCs occur only in the repository, or (2) NOT-GENERAL: DBCs may occur anywhere.

DO J = 1, NTMDIRCOMP
If TYPEDIR is GENERAL or general, then:

Line 28. NAME(J),LOCMDIRINP(J),GCONDIR(J)

NAME: Dummy variable for component name.
Accepts a 20-character string.

LOCMDIRINP: Location of the component in the input sequence.
Accepts an integer 0 < LOCMDIRINP *< total number of component.*

GCONDIR: Dirichlet B.C.s on Concentration (kg/m^3).
Accepts a real number > 0.

If TYPEDIR is NOT-GENERAL, then:

Line 29. NAME(J), LOCMDIRINP(J), NMTDIRBLOK(J)

NAME: Dummy variable for component name.
Accepts a 20-character string.

LOCMDIRINP: Location of the component in the input sequence.
Accepts an integer 0 < LOCMDIRINP *< total number of components.*

NMTDIRBLOK: Total number of grid blocks with D.B.C.
Accepts an integer 0 < NMTDIRBLOK *< total number of grid blocks.*

Line 30. (IDRBIM(I,J), IDRBJM(I,J), IDRBKM(I,J), I = 1, NMTDIRBLOK(J))

IDRBIM, IDRBJM, IDRBKM: I,J,K indices of the D.B.C grid blocks.

*Accepts an integer 0 <*IDRBIM, IDRBJM, IDRBKM *< total number of grid blocks in x, y, z direction, respectively.*

END DO

DO I = 1, NTMDIRCOMP

Line 31. NAME(I)

NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 32. (DIRCONCMIJK(IDRBIM(J,I), IDRBJM(J,I), IDRBKM(J,I)), J = 1, NMTDIRBLOK(I))

DIRCONCMIJK DBC on concentration of the ijk th component (kg/m^3).
Accepts a real number > 0.

END DO

Fracture Dynamic Source Function Input

This module is created to generate a dynamic source function in the fracture. The shape of the source here can vary by changing the correlation parameters that specify the time range and the normalization factor. The function is activated by the same flag used for the Actinide Source submodel. This source is usually needed in the testing processes outside the CAMCON environment.

Line 33. Descriptor: Testing dynamic source input.

If (.NOT. STOCKMAN) skip Line 34 to Line 40.

Line 34. NTMDEPSRC

NTMDEPSRC: Total number of the radioactive istopes that have time dependent source. *Accepts a real number 0 <* NTMDEPSRC *< total number of component.*

If NTMDEPSRC is zero skip line 35 to Line 40.

DO J = 1, NTMDEPSRC

Line 35. NAME(J), LOCSRCINP(J), NMTBLOKSRC(J)

NAME: Dummy variable for component name.
Accepts a 20-character string.

LOCMDIRINP: Location of the component in the input sequence.
Accepts an integer 0 < LOCMDIRINP *< total number of components.*

NMTBLOKSRC: Total number of grid blocks with dynamic source.

Accepts an integer 0 < NMTBLOKSRC < *total number of grid blocks.*

Line 36. (ISRCI(I,J), ISRCJ(I,J), ISRCK(I,J), I = 1, NMTBLOKSRC(J))

ISRCI: I index of the grid block that has the source.
ISRCJ: J index of the grid block that has the source.
ISRCK: K index of the grid block that has the source.
Accepts an integer 0 <ISRCI, ISRCJ, ISRCK < *total number of grid blocks in x, ,y, z direction, respectively.*

END DO

DO J = 1, NTMDEPSRC

Line 37. NAME(J)

NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 38. (QC0IJK(ISRCI(I,J), ISRCJ(I,J), ISRCK(I,J), I = 1, NMTBLOKSRC(J))

QC0IJK: The source strength of the grid block in kg/s.
Accepts any real number.

Line 39.

((TBIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
TCIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
TDIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
TEIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
TFIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J))),
I = 1, NMTBLOKSRC(J))

TBIJK: Start of time range 1.
TCIJK: Start of time range 2.
TDIJK: Start of time range 3.
TEIJK: Start of time range 4.
TFIJK: Start of time range 5.

Line 40.

((GBIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
GCIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
GDIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
GEIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
GFIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J))),
I = 1, NMTBLOKSRC(J))

GBIJK: Start of normalization factor range 1.

GCIJK: Start of normalization factor range 2.
GDIJK: Start of normalization factor range 3.
GEIJK: Start of normalization factor range 4.
GFIJK: Start of normalization factor range 5.

END DO

Fracture Concentration Initialization Input

Line 41. Descriptor: Initial concentration in the fracture if any.
Accepts character string up to 100 characters in length as a descriptive line.

If FMAN_CONC_INIT is true, then:

Line 42. NINITCOMP
NINITCOMP: Number of components to be initialized.
Accepts 0 < integer < total number of components.

DO J = 1, NINITCOMP

Line 43. NAME(J),LOCINP(J)NBLOKINI(J)
NAME: Dummy variable for component name.
Accepts a 20-character string.
LOCINP: Location of the component in the input sequence.
Accepts an integer 0 <LOCINP < *total number of components.*
NBLOKINI: Total number of grid blocks initialized.
Accepts an integer 0 < NBLOKINI < *total number of grid blocks.*

Line 44. (INII(I,J), IINIJ(I,J), INIK(I,J), I = 1, NBLOKINI(J))
INII, INIJ, INIK: I,J,K indices of the initialized grid blocks.
Accepts an integer 0<INII, INIJ, INIK < *total number of grid blocks in x, y, z direction, respectively.*

END DO

DO J = 1, NINITCOMP

Line 45. NAME(J)
NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 46. CONCIJKINI(INII(I,J), IINIJ(I,J), INIK(I,J), I = 1, NBLOKINI(J))
CONCIJKINI: Initialized concentration of the grid.
Accepts a real number.

END DO

Fracture Colloid Transport Scaling Factors Input

Line 47. Descriptor: Colloidal transport scaling factors

Accepts a character string up to 100 characters in length as a descriptive line.

If colloidal transport is required, then:

Line 48. Descriptor: Scaling factor for velocities in x-direction.
Accepts a character string up to 100 characters in length as a descriptive line.

Line 49. (SCALEX(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
SCALEX: Scaling factors of x-direction velocities.
Accepts an integer ≥ 1.

Line 50. Descriptor: Scaling factor for velocities in y-direction.
Accepts a character string up to 100 characters in length as a descriptive line.

Line 51. (SCALEY(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
SCALEY: Scaling factors of y-direction velocities.
Accepts an integer ≥ 1.

Line 52. Descriptor: Scaling factor for velocities in z-direction.
Accepts a character string up to 100 characters in length as a descriptive line.

Line 53. (SCALEZ(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
SCALEZ: Scaling factors of z-direction velocities.
Accepts an integer ≥ 1.

6.5.1.C6 Single-Porosity Matrix Input

If a single-porosity matrix is to be modeled, then:

Matrix Sorption Input

This module inputs the constituent sorption properties of the matrix. Three equilibrium isotherms are considered, depending on the value of MAT_ISOTHERM.

Line 1. Descriptor: Matrix sorption
Accepts a character string up to 100 characters in length as a descriptive line.

If the data are to be read from NUTS's input file and not the CDB, then:
If ADSTYPEM is 'N' or 'n', terminate inputs for this module here. Otherwise,

If MAT_ISOTHERM IS 'L' or 'l', then:

DO I = 1, NUCLIDE

Line 2. NAME(I)
NAME: Dummy variable for component name.

Accepts a 20-character string.

Line 3. (RXLM(J), J = 1, NMAT)

RXLM: Linear sorption coefficient (k_d) of the matrix for the range specified by the material map index (m^3/kg).
Accepts a number > 0

END DO

If MAT_ISOTHERM is 'F' or 'f' then:

DO I = 1, NUCLIDE

Line 4. NAME(I)

NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 5. (RXFDCM(J), J = 1, NMAT)

Line 6. (RXFCM(J), J = 1, NMAT)

RXFDCM: Freundlich distribution coefficient of the matrix for the range specified by the material map index (m^3/kg).
Upper and lower bounds are not specified.

RXFCM: Freundlich coefficient of the matrix for the range specified by the material map index (dimensionless).
Upper and lower bounds are not specified.

END DO

If MAT_ISOTHERM is 'LA' or 'la' or 'La', then:

DO I = 1, NUCLIDE

Line 7. NAME(I)

NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 8. (RXLDCM(J), J = 1, NMAT)

Line 9. (RXLCM(J), J = 1, NMAT)

RXLDCM: Langumir distribution coefficient of the Matrix for the range specified by the material map index (m^3/kg).
Upper and lower bounds are not specified.

RXLCM: Langumir coefficient of the matrix for the range specified by the material map index (dimensionless).
Upper and lower bounds are not specified.

END DO

Matrix Dispersion Input

This module inputs dispersion parameters for the Matrix.

Line 10. Descriptor: Matrix dispersion
Accepts a character string up to 100 characters in length as a descriptive line.

If the data are to be read from NUTS input file and not the CDB, then:
If MDISPREQ is 'N' or 'n' stop the input for this module here, otherwise,

Line 11. Descriptor: Longitudinal dispersivity in the matrix
Accepts a character string up to 100 characters in length as a descriptive line.

Line 12. (RALPHALM(I), I = 1, NMAT)
RALPHALM: Longitudinal dispersivity of the matrix for the range specified by the material map index (m).
Accepts 0 < any real number < the smallest hydrological dimension of the spatial domain.

Line 13. Descriptor: Transverse dispersivity in the matrix
Accepts a character string up to 100 characters in length as a descriptive line.

Line 14. (RALPHATM(I), I = 1, NMAT)
RALPHATM: Transverse dispersivity of the matrix for the range specified by the material map index (m).
Accepts a real number > 0 and < longitudinal dispersivity.

Line 15. Descriptor: Tortuosity in the matrix
Accepts a character string up to 100 characters in length as a descriptive line.

Line 16. (RTORM(I), I = 1, NMAT)
RTORM Matrix tortuosity for the range specified by the material map index (dimensionless). *Accepts a real number > 1.*

Matrix Source Input

Line 17. Descriptor: Start matrix source input for injection/production
Accepts a character string up to 100 characters in length as a descriptive line.

If MSTATUSINJ is 'N' or 'n', then skip Lines 18 to 25. Otherwise,

Line 18. NTMNINJCOMP
NTMNINJCOMP: Total number of injected components.
Accepts 0 < NTMNINJCOMP < total number of components.

DO J = 1, NTMNINJCOMP

Line 19. NAME(J), LOCINPM(J), NMTBLOKINJ(J)
NAME: Dummy variable for component name.
Accepts a 20-character string.
LOCINPM: Location of the injected component in the component input sequence.

Accepts an integer 0 < LOCINPM < total number of components.

NMTBLOKINJ: Total number of grid blocks at which this component is injected.
Accepts an integer 0 < NMTBLOKINJ *< total number of grid blocks.*

Line 20. (INJBIM(I,J), INJBJM(I,J), INJBKM(I,J), I = 1, NMTBLOKINJ(J))

INJBIM: I index of the injection block.
Accepts an integer 0 < INJBIM *< total number of grid blocks in x direction.*

INJBJM: J index of the injection block.
Accepts an integer 0 < INJBJM *< total number of grid blocks in y direction.*

INJBKM: K index of the injection block.
Accepts an integer 0 < INJBKM *< total number of grid blocks in z direction.*

END DO

DO I = 1, NTMNINJCOMP

Line 21. NAME(I)

NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 22. (CONCMIJKINJ(INJBIM(J,I), INJBJM(J,I), INJBKM(J,I)), J = 1, NMTBLOKINJ(I))

CONCMIJKINJ: Concentration of the injected component (kg/m^3).
Accepts a real number > 0.

END DO

Line 23. Descriptor: Injection production rates
Accepts a character string up to 100 characters in length as a descriptive line.

Line 24. NMBLOCKSOURCE, TIMEMSTRT, TIMEMEND

NMBLOCKSOURCE: Number of grid blocks having the source.
Accepts an integer 0 < NMBLOCKSOURCE *< total number of grid blocks.*

TIMEFSTRT: Starting time of injection/production ithe matrix (s).
Accepts a real number 0 < TIMEFSTRT < TIMEFEND.

TIMEFEND: Ending time of injection/production in the matrix (s).
Accepts a real number 0 < TIMEFEND.

DO I = 1, NMBLOCKSOURCE

Line 25. IQIM(I), IQJM(I), IQKM(I), RATE(I)

IQIM, IQJM, IQKM: I,J,K indices of the injection/production block.
*Accepts an integer 0<*IQIM, IQJM, IQKM *< total number of grid blocks in x ,y, z direction, respectively.*

RATE: Injection/production rate (m^3/s).
Accepts a real number > 0.

END DO

Line 26: Descriptor: Dirichet boundary condition in the matrix
Accepts a character string up to 100 characters in length as a descriptive line.

If MDIRICHLET, then:

Line 27. NTMDIRCOMP,TYPEDIR

NTMDIRCOMP: Number of components with Dirchlet boundary condition (DBC).
Accepts 0 < NTMDIRCOMP *< total number of components.*

TYPEDIR: Character to identify whether DBCs are specified in the repository only or elsewhere in the domain.
Accepts two values (1) GENERAL; for the whole repository DBC, or (2) NOT-GENERAL; for DBC specified in specific places.

DO J = 1, NTMDIRCOMP

If TYPEDIR is GENERAL or general then:

Line 28. NAME(J),LOCMDIRINP(J),GCONDIR(J)

NAME: Dummy variable for component name.
Accepts a 20-character string.

LOCMDIRINP: Location of the component in the input sequence.
Accepts an integer 0 < LOCMDIRINP *< total number of components.*

GCONDIR: Dirchlet boundary condition on concentration (kg/m^3).
Accepts a real number > 0.

If TYPEDIR is NOT-GENERAL or not-general, then:

Line 29. NAME(J), LOCMDIRINP(J), NMTDIRBLOK(J)

NAME: Dummy variable for component name.
Accepts a 20-character string.

LOCMDIRINP: Location of the component in the input sequence.
Accepts an integer 0 < LOCMDIRINP *< total number of components.*

NMTDIRBLOK: Total number of grid blocks with D.B.C.
Accepts an integer 0 < NMTDIRBLOK *< total number of grid blocks.*

Line 30. (IDRBIM(I,J), IDRBJM(I,J), IDRBKM(I,J), I = 1, NMTDIRBLOK(J))

IDRBIM, IDRBJM, IDRBKM: I,J,K indices of the D.B.C grid blocks.
Accepts an integer 0 < IDRBIM, IDRBJM, IDRBKM *< total number of grid blocks in x ,y, z direction, respectively.*

Endif
END DO

DO I = 1, NTMDIRCOMP

Line 31. NAME(I)

NAME: Dummy variable for component name.
Accepts a 20-character string.

Line 32. (DIRCONCMIJK(IDRBIM(J,I), IDRBJM(J,I), IDRBKM(J,I)),J = 1, NMTDIRBLOK(I))

DIRCONCMIJK: Concentration of the component having DBC (kg/m^3).
Accepts a real number > 0.

END DO

Matrix Dynamic Source Function Input

This module is created to generate a dynamic source function in the matrix. The shape of the source here can vary by changing the correlation parameters that specify the time range and the normalization factor. The function is activitated by the same flag used for the Actinide Source submodel. This source is usually needed in the testing processes outside the CAMCON environment.

Line 33. Descriptor: Testing Dynamic source input.

If (.NOT. STOCKMAN) skip Line 34 to Line 40.

Line 34. NTMDEPSRC

NTMDEPSRC Total number of the radioactive istopes that have time dependent source. *Accepts a real number 0 < NTMDEPSRC < total number of component.*

If NTMDEPSRC is zero skip line 35 to Line 40.

DO J = 1, NTMDEPSRC

Line 35. NAME(J), LOCSRCINP(J), NMTBLOKSRC(J)

NAME: Dummy variable for component name.
Accepts a 20-character string.

LOCMDIRINP: Location of the component in the input sequence.
Accepts an integer 0 < LOCMDIRINP < total number of components.

NMTBLOKSRC: Total number of grid blocks with dynamic source.
Accepts an integer 0 < NMTBLOKSRC < total number of grid blocks.

Line 36. (ISRCI(I,J), ISRCJ(I,J), ISRCK(I,J), I = 1, NMTBLOKSRC(J))

ISRCI: I index of the grid block that has the source.
ISRCJ: J index of the grid block that has the source.
ISRCK: K index of the grid block that has the source.

Accepts an integer 0 <ISRCI, ISRCJ, ISRCK < total number of grid blocks in x, ,y, z direction, respectively.

END DO

DO J = 1, NTMDEPSRC

Line 37. NAME(J)

NAME: Dummy variable for component name.

Accepts a 20-character string.

Line 38. (QC0IJK(ISRCI(I,J), ISRCJ(I,J), ISRCK(I,J), I = 1, NMTBLOKSRC(J))

QC0IJK: The source strength of the grid block in kg/s.

Accepts any real number.

Line 39.

((TBIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
TCIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
TDIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
TEIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
TFIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J))),
I = 1, NMTBLOKSRC(J))

TBIJK: Start of time range 1.
TCIJK: Start of time range 2.
TDIJK: Start of time range 3.
TEIJK: Start of time range 4.
TFIJK: Start of time range 5.

Line 40.

((GBIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
GCIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
GDIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
GEIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J)),
GFIJK(ISRCI(I,J),ISRCJ(I,J),ISRCK(I,J))),
I = 1, NMTBLOKSRC(J))

GBIJK: Start of normalization factor range 1.
GCIJK: Start of normalization factor range 2.
GDIJK: Start of normalization factor range 3.
GEIJK: Start of normalization factor range 4.
GFIJK: Start of normalization factor range 5.

END DO

Matrix Concentration Initialization Input

Line 41. Descriptor: Initial concentration in the matrix if any.
Accepts a character string up to 100 characters in length as a descriptive line.

If MMAN_CONC_INIT is true, then:

Line 42. NINITCOMP

NINITCOMP: Number of components to be initialized.
Accepts 0 < integer < total number of components.

DO J = 1, NINITCOMP

Line 43. NAME(J),LOCINP(J)NBLOKINI(J)

NAME: Dummy variable for component name.
Accepts a 20-character string.

LOCINP: Location of the component in the input sequence.
Accepts an integer 0 < LOCINP *< total number of components.*

NBLOKINI: Total number of grid blocks initialized.
Accepts an integer 0 < NBLOKINI *< total number of grid blocks.*

Line 44. (INII(I,J), IINIJ(I,J), INIK(I,J), I = 1, NBLOKINI(J))

INII, INIJ, INIK: I,J,K indices of the initialized grid blocks.
Accepts an integer 0 < INII, INIJ, INIK *< total number of grid blocks in x ,y, z direction, respectively.*

END DO

DO J = 1, NINITCOMP

Line 45. NAME(J)

NAME: Dummy variable for component name.
Accepts a 20-character sting.

Line 46. CONCIJKINI(INII(I,J), IINIJ(I,J), INIK(I,J), I = 1, NBLOKINI(J))

CONCIJKINI: Initialized concentration, kg/s

Matrix Colloid Transport Scaling Factors Input

Line 47. Descriptor: Colloidal transport scaling factors
Accepts a character string up to 100 characters in length as a descriptive line.

If colloidal transport required, then:

Line 48. Descriptor: Scaling factor for velocities in x-direction.
Accepts a character string up to 100 characters in length as a descriptive line.

Line 49. (SCALEX(I,J,K),I=1,NX),J=1,NY),K=1,NZ)

SCALEX: Scaling factors of x-direction velocities.
Accepts an integer ≥ 1.

Line 50. Descriptor: Scaling factor for velocities in y-direction.
Accepts a character string up to 100 characters in length as a descriptive line.

Line 51. (SCALEY(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
SCALEY: Scaling factors of y-direction velocities.
Accepts an integer ≥ 1.

Line 52. Descriptor: Scaling factor for velocities in z-direction.
Accepts a character string up to 100 characters in length as a descriptive line.

Line 53. (SCALEZ(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
SCALEZ: Scaling factors of z-direction velocities.
Accepts an integer ≥ 1.

6.5.1.C7 Dual-Porosity or Dual-Permeability Input

If the medium is dual-porosity or dual-permeability, then:

Input Section 6.5.1C5, lines 1 to 53 and Section 6.5.1C6, lines 1 to 53 following the same order and conditions mentioned above.

6.5.2 ASCII Flux-Field Input File (homogeneous)

An example of NUTS's ASCII flux-field input file for homogeneous properties is given in Appendix C.

Line 1. Descriptor Is the input homogeneous (T/F)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 2. DUMP
DUMP: Logical flag to specify whether the following input is homogeneous. The value of this parameter is important only for CDB runs.
Accepts T or F.

6.5.2A Title Information

Line 3.Descriptor: Test run title
Accepts a character string up to 100 characters in length as a descriptive line.

Line 4.TEST_TITLE
TEST_TITLE: This is a descriptive line of the test run. The line is saved and concatenated with NUTS's title when printed out to give an idea about both NUTS and test runs considered.
Accepts up to a 100-character string.

6.5.2B Time Information

Line 5.Descriptor: Time step size and number of time steps
Accepts a character string up to 100 characters in length as a descriptive line.

Line 6.DT, NTIMESTEP

DT: Time step size (s).
Accepts a real number > 0.

NTIMESTEP: Number of time steps required to run NUTS.
Accepts an integer > 0.

6.5.2C Dimension Information

Line 7. Descriptor: Number of grid blocks in x, y, z
Accepts a character string up to 100 characters in length as a descriptive line.

Line 8.NX, NY, NZ

NX: Number of grid blocks in x-direction.
Accepts an integer > 1.

NY: Number of grid blocks in y-direction.
Accepts an integer > 1.

NZ: Number of grid blocks in z-direction.
Accepts an integer > 1.

Line 9.Descriptor: Dimension of grid blocks in x, y, z
Accepts a character string up to 100 characters in length as a descriptive line.

Line 10. DXTEST, DYTEST, DZTEST

DXTEST: Dimension of the grid block in x-direction (m).
Accepts a real number > 0.

DYTEST: Dimension of the grid block in y-direction (m).
Accepts a real number > 0.

DZTEST: Dimension of the grid block in z-direction (m).
Accepts a real number > 0.

6.5.2D Fracture Information

If the medium to be modeled is fractured, then:

Line 11. Descriptor: Fracture porosity and saturation
Accepts a character string up to 100 characters in length as a descriptive line.

Line 12. PHIFINT, SWFINT

PHIFINT: Initial porosity of the fracture (fraction).
Accepts a real number $0 \leq PHIFINT \leq 1$.

SWFINT: Initial saturation of the fracture (fraction).
Accepts a real number $0 \leq SWFINT \leq 1$.

Line 13. Descriptor: Fracture Constant velocity field
Accepts a character string up to 100 characters in length as a descriptive line.

Line 14. TVELXF, TVELYF, TVELZF

TVELXF: Fracture velocity of the phase in x-direction (m/s).
Accepts a real number TVELXF < 0.6

TVELYF: Fracture velocity of the phase in y-direction (m/s).
Accepts a real number TVELYF < 0.6

TVELZF: Fracture velocity of the phase in z-direction (m/s).
Accepts a real number TVELZF < 0.6

Line 15. Descriptor: Block temperature and brine viscosity
Accepts a character string up to 100 characters in length as a descriptive line.

Line 16. TTEMP_FRAC, TVISW_FRAC

TTEMP_FRAC: Temperature of the grid block (K).
Accepts a real number > 273.15

TVISW_FRAC: Fracture brine viscosity (Pa/s).
Accept a real number > 0

6.5.2E Matrix Information

If the matrix to be modeled is a continuum, then:

Line 17. Descriptor: Matrix porosity and saturation
Accept character string up to 100 chars as a descriptive line

Line 18. PHIMINT, SWMINT

PHIMINT: Initial porosity of the matrix (fraction).
Accepts a real number $0 \leq PHIMINT \leq 1$

SWMINT: Initial saturation of the matrix (fraction).
Accepts a real number $0 \leq SWMINT \leq 1$

Line 19. Descriptor: Matrix constant velocity field
Accept character string up to 100 chars as a descriptive line

Line 20. TVELXM, TVELYM, TVELZM

TVELXM: Matrix velocity of the phase in x-direction (m/s).
Accepts a real number TVELXM < 0.6

TVELYM: Matrix velocity of the phase in y-direction (m/s).
Accepts a real number TVELYM < 0.6

TVELZM: Matrix velocity of the phase in z-direction (m/s).
Accepts a real number TVELZM < 0.6

Line 21. Descriptor: Block temperature and brine viscosity
Accepts a character string up to 100 characters in length as a descriptive line.

Line 22. TTEMP_MAT, TVISW_MAT

TTEMP_MAT: Temperature of the grid block (K).
Accepts a real number > 273.15.

TVISW_MAT: Matrix brine viscosity (Pa/s).
Accepts a real number > 0.

6.5.2F Dual-Porosity/Dual-Permeability Information

If a dual-porosity or dual-permeability medium is to be modeled, then:

Line 23. Descriptor: Shape factor and the transfer function
Accepts a character string up to 100 characters in length as a descriptive line.

Line 24. TSIGMA, TTAUW

TSIGMA: Shape factor (m^2).
Accepts a real number > 0.

TTAUW: Fracture/matrix transfer function (m^3/s)
Accepts a real number > 0.

6.5.3 ASCII Flux-Field Input File (heterogeneous)

An example of NUTS's ASCII flux-field input file for heterogeneous properties is given in Appendix D.

Line 1. Descriptor: Is the input homogeneous (T/F)
Accepts a character string up to 100 characters in length as a descriptive line.

Line 2. DUMP

DUMP: Logical flag to specify whether the following input is homogeneous. The value of this parameter is important only for CDB runs.
Accepts T or F.

6.5.3A Title Information

Line 3. Descriptor: Test run title
Accepts a character string up to 100 characters in length as a descriptive line.

Line 4. TEST_TITLE

TEST_TITLE: This is a descriptive line of the test run. The line is saved and concatenated with NUTS title when printed out to give an idea about both NUTS and test runs considered.
Accepts up to a 100-character string.

6.5.3B Time Information

Line 5. Descriptor: Time step size and number of time steps
Accepts a character string up to 100 characters in length as a descriptive line.

Line 6. DT, NTIMESTEP

DT: Time step size (s).
Accepts a real number > 0.

NTIMESTEP: Number of time steps required to run NUTS.
Accepts an integer > 0.

6.5.3C Dimension Information

Line 7. Descriptor: Number of grid blocks in x, y, z
Accepts a character string up to 100 characters in length as a descriptive line.

Line 8. NX, NY, NZ

NX: Number of grid blocks in x-direction.
Accepts an integer ≥ 1.

NY: Number of grid blocks in y-direction.
Accepts an integer ≥ 1.

NZ: Number of grid blocks in z-direction.
Accepts an integer ≥ 1.

Line 9. Descriptor: Dimension of grid blocks in x-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 10. ((DX3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)

DX3D: Dimension of the grid block in x-direction (m).
Accepts a real number > 0

Line 11. Descriptor: Dimension of grid blocks in y-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 12. ((DY3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)

DY3D: Dimension of the grid block in y-direction (m).
Accept a real number > 0

Line 13. Descriptor: Dimension of grid blocks in z-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 14. ((DZ3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)

DZ3D: Dimension of the grid block in z-direction (m).
Accepts a real number > 0.

6.5.3D Fracture Information

If the continuum to be modeled is fractured, then:

Line 15. Descriptor: Fracture porosities
Accepts a character string up to 100 characters in length as a descriptive line.

Line 16. ((PHIFINT3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
PHIFINT3D: Porosity of the fracture (fraction).
Accepts a real number $0 \leq PHIFINT \leq 1$.

Line 17. Descriptor: Fracture saturations
Accepts a character string up to 100 characters in length as a descriptive line.

Line 18. ((SWFINT3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
SWFINT3D: Saturation of the fracture (fraction).
Accepts a real number $0 \leq SWFINT \leq 1$.

Line 19. Descriptor: Fracture velocity field in x-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 20. ((VELWXF3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
VELWXF3D: Fracture velocity of the phase in x-direction (m/s).
Accepts a real number $VELWXF3D < 0.6$.

Line 21. Descriptor: Fracture velocity field in y-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 22. ((VELWYF3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
VELWYF3D: Fracture velocity of the phase in y-direction (m/s).
Accepts a real number $VELWYF3D < 0.6$.

Line 23. Descriptor: Fracture velocity field in z-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 24. ((VELWZF3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
VELWZF3D: Fracture velocity of the phase in z-direction (m/s).
Accepts a real number $VELWZF3D < 0.6$.

Line 25. Descriptor: Fracture grid block brine temperature
Accepts a character string up to 100 characters in length as a descriptive line.

Line 26. ((FTEMP3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
FTEMP3D: Temperature of the brine in the grid block (K).
Accepts a real number > 273.15.

Line 27. Descriptor: Fracture grid block brine viscosity.
Accepts a character string up to 100 characters in length as a descriptive line.

Line 28. ((FVIS3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)

FVIS3D: Fracture brine viscosity (Pa/s).
Accepts a real number > 0.

6.5.3E Matrix Information:

If the matrix to be modeled is a continuum, then:

Line 29. Descriptor: Matrix porosities
Accepts a character string up to 100 characters in length as a descriptive line.

Line 30. ((PHIMINT3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
PHIMINT3D: Porosity of the matrix (fraction).
Accepts a real number 0 < PHIMINT < 1

Line 31. Descriptor: Matrix saturations
Accepts a character string up to 100 characters in length as a descriptive line.

Line 32. ((SWMINT3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
SWMINT3D: Saturation of the matrix (fraction).
Accepts a real number 0 < SWMINT < 1.

Line 33. Descriptor: Matrix velocity field in x-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 34. ((VELWXM3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
VELWXM3D: Matrix velocity of the phase in x-direction (m/s).
Accepts a real number TVELXM3D < 0.6.

Line 35. Descriptor: Matrix velocity field in y-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 36. ((VELWYM3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
VELWYM3D: Matrix velocity of the phase in y-direction (m/s).
Accepts a real number TVELYM3D < 0.6.

Line 37. Descriptor: Matrix velocity field in z-direction
Accepts a character string up to 100 characters in length as a descriptive line.

Line 38. ((VELWZM3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
VELWZM3D: Matrix velocity of the phase in z-direction (m/s).
Accepts a real number TVELZM3D < 0.6

Line 39. Descriptor: Matrix Block temperature
Accepts a character string up to 100 characters in length as a descriptive line.

Line 40. ((XMTEMP3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)
XMTEMP3D: Matrix Block brine temperature (K).
Accepts a real number > 273.15

Line 41. Descriptor: Matrix Block brine viscosity

Accepts a character string up to 100 characters in length as a descriptive line.

Line 42. ((XMVIS3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)

XMVIS3D: Matrix brine viscosity (Pa/s).
Accepts a real number > 0.

6.5.3F Dual-Porosity/Dual-Permeability Information

If medium to be modeled has dual-porosity or dual-permeability, then:

Line 43. Descriptor: Shape factor
Accepts a character string up to 100 characters in length as a descriptive line.

Line 44. ((SIGMA3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)

SIGMA3D: Shape factor (m^2).
Accepts a real number > 0.

Line 45. Descriptor: Transfer function
Accepts a character string up to 100 characters in length as a descriptive line.

Line 46. ((TAUW3D(I,J,K),I=1,NX),J=1,NY),Z=1,NZ)

TAUW3D: Fracture/matrix transfer function (m^3/s)
Accepts a real number > 0.

6.5.4 Binary Flux-Field Input File

This file is the binary BRAGFLO output. It is read only for the single porosity matrix. It provides NUTS with the following variables:

a. QA information
b. Time information
c. Grid blocks dimension and volumetric information
d. Grid block saturation, pressure, velocity or fluxes field, and fluid densities

A full description of this file and the variables printed is available in BRAGFLO User's Manual.

6.5.5 Binary Output Files

6.5.5A Binary Output Files (BRAGFLO Style)

This NUTS binary output is meant to be post-processed with the results of BRAGFLO. Therefore, the sequence and type of information in this file are in harmony with BRAGFLO's binary output (for a detailed description, the reader is referred to BRAGFLO User's Manual). The post-processor used for this objective is BINCOMBO_NV.

6.5.5B Binary Output Files (NUTS Style)

To illustrate the structure of NUTS's output and to enable the reader to post-process its results, a FORTRAN program that reads NUTS's binary output file is given in Appendix K. The first part of the output, nested by an IF(IFLAGTIME .EQ. 0) statement, contains QA information, input echoes, and variable initializations. This information is output to the binary file once, at time zero. Temporally-varying quantities are an exception to the once-at-time-zero rule. They may be reported additionally at subsequent time steps, but only variables specified in the input controls will be written out at subsequent times.

6.5.6 ASCII Output Files

6.5.6A Extensive ASCII Output File

This file contains information similar to that in the NUTS-style binary output file. An illustrative example of NUTS's extensive ASCII output file is given in Appendix E.

6.5.6B Specific-Ranges ASCII Output File

The purpose of this file is to produce an ASCII output file for output variables of interest to the user, and in specified spatial ranges. Its feature can be activated from the input file together with the ASCII file option.

6.5.7 Debug (Scratch) ASCII Output File

This feature produces a scratch or debug file in ASCII format that identifies the beginning and the end of the major procedures in NUTS, and writes the main variables associated with those procedures. The file stays open for only one time step. Therefore, it will echo some of the input data and the time-dependent variables at the first time step. The purposes of this output are (1) to facilitate debugging, and (2) to enable verification of numerical calculations.

6.6 Generating an Executable for NUTS-SA:

A command file to build NUTS-SA's executable is provided in Appendix F. This command file can build either a debug executable or a normal executable. In the building process, the main program NUT_MAIN.FOR will be compiled and will be linked to the NUT_LIB_STANDALONE.FOR.

6.7 Input/Output (I/O) and Other Files Used by NUTS-CC

Being a subset of NUTS-SA, NUTS-CC uses the following I/O files:

1. User Interactive Input

2. Parameter Statements
3. Input/Output Files

6.7.1 User-Interactive Input

A limited number of control flags are provided by the user while executing the program. These controls are part of the input and mainly specify the following:

a) Name of the flux fields filename. *Accepts an 80-character string.*
b) Type of the run, whether it is a test. *Accepts Y or N.*
c) Type of the output file (ASCII/Binary). *Accepts ASC, BIN or ASC-BIN.*
d) NUTS input filename. *Accepts an 80-character string.*
e) NUTS output filename. *Accepts an 80-character string.*
f) NUTS output debug filename. *Accepts an 80-character string.*
g) Type of fluid. *Accepts L or G.*
h) BRAGFLO ASCII input filename (*.INP) if the answer in b) is Yand CANCEL if the answer in b) is N. *Accepts an 80 character string.*
i) Will NUTS input or the data base be used to provide chemical constituent properties and rock properties. *Accepts N for NUTS or CDB for the data base.*
j) Properties CDB when the answer in i) is CDB and CANCEL otherwise. *Accepts an 80 character string.*
k) NUTS udisturbed scenario CDB output file name used to initialized certain kind of computation. This kind of initialization is required only for intrusion time other than that used in BRAGFLO. *Accepts NUTS undisturbed scenario CDB output file name for intrusion calculation and up to 80 character or CANCEL otherwise.*

An example of such an interactive input included in a command file is as follows:

```
$ NUTS -                          ! The Executable
   TEST_CON_DISP_DEC.IN -         !Test Flux Field Input File
   Y -                            !Test Run? (y)
   ASC -                          !ASC/BIN Output
   NUT_CON_DISP_DEC.IN -          !Nuts Input File
   NUT_CON_DISP_DEC.OUT -         !NUTS Output ASCII File
   NUT_CON_DISP_DEC.DBG -         !DEBUG File
   L -                            !Liquid/Gas
   CANCEL -                       !(Would have been BRAGFLO.INP)
   N -                            !Read Nuclide Data from NUTS Input
   CANCEL -                       ! Properties CDB input file
   CANCEL                         ! NUTS undisturbed scenario output file
$ EXIT
```

6.7.2 NUTS-CC Parameter Statement

NUTS-CC uses the same parameter statement (NUT_PARAM.INC) used by NUTS-SA. In addition, the CAMCON SYSTEM requires additional parameters. These parameters are included in NUT_CDBXFER.INC.

6.7.3 Other Files Used by NUTS-CC

NUTS_CC accesses different combinations of files in each run depending on user specifications. These files can be classified as input, output, or debug files. The names of these files are provided in the interactive input given earlier in this chapter. A specific combination or all of the following files can be opened simultaneously:

1. ASCII radioisotope input file

2. Either (A) ASCII flux fields input files
   a. Homogenous properties file
   b. Heterogeneous properties file

3. Or (B) Binary flux-field input files (CDB files from BRAGFLO's output), and BRAGFLO ASCII input file associated with this case.

4. Binary (CDB) output files

5. Extensive ASCII output file.

6. Properties CDB input file.

7. NUTS undisturbed scenario output file for initialization of well bore intrusion calculations (the same output of item 4 above).

8. Debug (scratch) ASCII output file.

The files in items 1, 2, 5 and 8 are similar to those used in NUTS-SA. The only difference between the two is in the way the binary files are treated. In NUTS-SA, if two ASCII files are used as inputs (one for the nuclides and rock properties, and the other for the flux fields), then a binary output file can be generated. However, in NUTS-CC, a binary CDB is generated only if the flux fields are read from a binary CDB.

6.7.4 Binary (CDB) Flux-Field and the Associated ASCII Input Files

NUTS-CC uses this file to read the output from BRAGFLO. Time = zero information will be read first. It includes some QA information, the geometrical description of the problem, and initial saturation and porosity data. At each timestep thereafter, brine pressure (PRESBRIN), porosity (POROS), gas saturation (SATGAS), interface volumetric fluxes (FLOWBRX, FLOWBRY), and well fluxes (WELLBRIN) will be read. BRAGFLO ASCII input file is used here to provide NUTS with the material maps information, brine reference density and compressibility, and brine residual saturation.

6.7.5 NUTS's Binary (CDB) Output File

In the binary (CDB) output file, the following variables will be added to the input CDB data:

CNCNJM#: Concentration of the injected component.
FLUXIM#: Mass flux at the interface I (the convention is to put the flux at the left interface (i-1) of each grid block (i,j,k) and the sign is positive to the right).
FLUXJM#: Mass flux at the interface J (the convention is to put the flux at the lower interface (j-1) of each grid block (i,j,k) and the sign is positive in upward direction).
CNDMMS#: Mass of the condensed component # (has a non-zero value only in gas transport).

Depending on user specifications, concentration or mass of the component(s) will be output to the CDB file and in any form specified by the output array control flags (IPRNTMB (1-14)) as shown in Table 4.

Table 4. CDB Output Variables and Their Description

Printing Flag	Description of the Matrix Variable	NUTS CDB output variable name
IPRNTMB(1)	Total mass of dissolved constituents in the brine in each grid block, kg.	SM_DIS
IPRNTMB(2)	Total mass of precipitated constituents in each grid block, kg.	SM_PREC
IPRNTMB(3)	Total mass of dissolved, precipitated and adsorbed constituents in each grid block, kg.	SM_TOT
IPRNTMB(4)	Total dissolved curies of all constituents in each grid block, Ci.	CSM_DIS
IPRNTMB(5)	Total precipitated curies of all constituents in each grid block, Ci.	CSM_PREC
IPRNTMB(6)	Total dissolved, precipitated, and adsorbed curies of all constituents in each grid block, Ci.	CSM_TOT
IPRNTMB(7)	Volumetric concentration of the dissolved isotope, kg/(m^3 brine).	CM#
IPRNTMB(8)	Dissolved mass in the brine of a certain constituent, kg.	BMDISM#
IPRNTMB(9)	Precipitated mass of a certain constituent, kg.	BMPRCM#
IPRNTMB(10)	Soil base concentration of the isotope, mg/(kg soil).	ADPRCNM#
IPRNTMB(11)	Curies of volumetric concentration of a certain constituent, Ci/(m^3 brine).	VOLMCC#
IPRNTMB(12)	Curies of dissolved mass in the brine of a certain constituent, Ci.	DISMMC#
IPRNTMB(13)	Curies of precipitated mass of a certain constituent, Ci.	PRCPMMC#
IPRNTMB(14)	Curies of dissolved, precipitated and adsorbed mass of a certain constituent, Ci.	TOTMMC#

In the above notations, # refers to the location of the component in the input sequence, and M refers to the matrix continuum. Similar notation is also available for the fracture continuum.

6.7.6 NUTS's Properties Binary (CDB) Input File

When the answer to item (j) in the user interactive input (Section 6.7.1) is CDB, NUTS-CC expects to read the isotopes' property from a CDB file instead of NUTS's ASCII file. These

properties include but are not limited to the inventories, atomic weight, solubility limit, and half-life of the isotope. Other properties that are not used in the CCA calculations, such as pH of the brine, sorption coefficients, grain densities, molecular diffusion, dispersivities, and tortousities, can also be read from the same file provided that the flag related to the respective module is activated in NUTS's ASCII input (through certain flags, one can activate sorption, dispersion, etc.).

6.8 Generating an Executable for NUTS-CC

A command file that builds NUTS-CC's executable is provided in Appendix G. This command file builds either (i) a debug file or (ii) a normal executable. In the building process, the main program NUT_MAIN.FOR will be compiled and linked with NUT_CDBLIB.FOR, NUT_LIB.FOR, CAMDAT_LIB.FOR, CAMCON_LIB.FOR, and CAMSUPES_LIB.FOR.

6.9 Exercising NUTS from a Command Line

Appendix H provides several examples of command files (*.com) to run NUTS from WIPP's Alpha-VAX cluster.

7.0 DESCRIPTION OF NUTS'S INPUT FILES

NUTS's input files are discussed in detail in Sections 6.3.1 (ASCII radioisotope file) and 6.3.2 (ASCII flux-field input file). Appendices A, B, C, and D provide examples of NUTS's ASCII Radioisotope input files, its flux-field input files (homogenous and heterogeneous cases), and a sample material map, all designed to run on the WIPP Alpha-VAX microcomputer cluster.

8.0 ERROR MESSAGES

Selected error messages and steps toward their correction are listed in Section 6.0, at the places where they may arise.

A complete listing of NUTS's error and warning messages is given in Appendix I. Error messages will be written on the screen and in the debug file and will cause NUTS to stop. Warning messages will be written only in the debug file and will generally not result in an abort. General warning messages will appear on the screen if NUTS detects undesirable value(s) in the input data.

9.0 DESCRIPTION OF NUTS'S OUTPUT FILES

NUTS's output is capable of appearing in various user-readable and user non-readable formats, depending on user inputs. To assist the user, examples in both formats are included. The first, which is user readable, is NUTS's normal debug file. An annotated version of that file appears in Appendix J.

The second example is of a user-readable output file, namely, NUTS's Extensive ASCII Output File. It is by far the most complete, user-readable, NUTS output file.

Several of NUTS's important input and output files may, at the user's option, be written in binary format. As a service to users, we have provided a translation program that renders NUTS's binary files readable. That program has not been QAed and consequently it should not be regarded as an official part of NUTS's QA documentation. However, to assist the user, the translation program is included herein as Appendix K.

10.0 REFERENCES

Asfari, A., and P.A. witherspoon (1973). "Numerical Simulation of Naturally Fractured Reservoirs", Paper SPE 4290, presented at the 3rd Numerical Simulation of Reservoir Performance Symposium, Houston, TX, 10-12 Jan.

Bear, J. (1988). "Dynamic of Fluids in Porous Media", Dover Publications, Inc., NY.

Bear, J. (1993) " Flow and Contaminant Transport in Fractured Rock", Academic Press, Inc.

Beckner, B.L., Firoozabadi, A., and K. Aziz (1988). "Modeling Transverse Imbibition in Double-Porosity Simulators", Paper SPE 17414 presented at the SPE California Regional Meeting, Long Beach, CA 23-25 March.

Beckner, B.L., Chan, H.M., McDonald, A.E., Wooten, S.O., and T.A. Jones (1991). "Simulating naturally fractured Reservoirs Using Subdomain Method", paper SPE 21241, presented at the 11th SPE Symposium on reservoir Simulation, Anaheim, CA, 17-20 Feb.

Chen, W.H., Wasserman, M.L., and R.E. Fitzmorris (1987). "A Thermal Simulator for Naturally Fractured Reservoirs", paper SPE 16008 presented at the 9th SPE Symposium on Reservoir Simulation, San Antonio, TX, 1-4, Feb.

Coats, K.H. (1989). " Implicit Compositional Simulation of Single-Porosity and Dual-Porosity Reservoirs", Paper SPE 18427 presented at the 10th SPE Symposium on Reservoir Simulation, Houston, TX, Feb. 6-8, 1989.

Dean, R.H., and L.L. Lo (1988) " Simulations of Naturally Fractured Reservoirs", SPE Reservoir Engineering, 638-648.

DeSwaan, A. (1978). "Theory of Waterflooding in Fractured Reservoirs", SPEJ(117-122.

DeSwaan A.D. (1982). "A Three-Phase Model for Fractured Reservoirs Presenting Fluid Segregation", paper SPE 10510, presented at the 6th SPE Symposium on Reservoir Simulation, New Orleans, LA Jan. 31- Feb. 3.

Doctor, P.G. et al. (1992). "An Example Postclosure Risk Assessment Using the Potential Yucca Mountain Site", Pacific Northwest Laboratory, Washington.

Duguid, J.O., and P.C.Y. Lee (1977). "Flow in Fractured Porous Media", Water Resources Research, 558-566.

+ SPEJ refers to the Society of Petroleum Engineers Journal

Dutra, T.V., and K. Aziz (1991). " A New Double-Porosity Reservoir Model for Oil/Water Flow Problems", paper SPE 21248, presented at the 11th SPE Symposium on reservoir Simulation, Anaheim, CA, 17-20 Feb.

Dykhuizen, R.C. (1990). " A new Coupling Term for Dual-Porosity Models", Water Resources Research, Vol. 26, No. 2, 351-356.

Evans, R.D. (1982) " A Proposed Model for Multi-Phase Flow Through naturally Fractured Reservoir", SPEJ, 669-680.

Gilman, J.R. and H. Kazemi (1983). " Improvement in Simulation of naturally Fractured Reservoirs", SPEJ 695-707.

Gilman, J.R. (1986). " An Efficient Finite-Difference Method for Simulating Phase Segregation in the Matrix Blocks in Double-Porosity Reservoirs", SPE Reservoir Engineering, 403-413.

Gilman, J.R. and H. Kazemi (1988). " Improved Calculations for Viscous and gravity Displacement in Matrix Blocks in Dual-Porosity Simulators", JPT, 60-70.

Hill, A.C. and G.W. Thomas. (1985). "A New Approach for Simulating Complex Fractured Reservoirs", Paper SPE 13537 presented at the 1985 Res. Sim. Sym., Dallas, TX, 10-13 Feb.

Huang_Zhang C. (1983). "Numerical Simulation of Conning Behavior in a Naturally Fractured reservoir", SPEJ, 879-884.

Kazemi, H., L.S. Merrill, K.L. Porterfield and P.R. Zeman. (1976). "Numerical Simulation of Water-Oil Flow in Naturally Fractured Reservoirs", SPEJ 317-326.

Kazemi, H., and L.S. Merrill (1979). "Numerical Simulation of Water Imbibition in Fractured Cores", SPEJ 175-182.

Kazemi, H., Gilman, J.R., and A.M. El-Sharkawy (1989). "Analytical and Numerical Solution of Oil Recovery From Fractured Reservoirs Using Empirical Transfer Functions", paper SPE 19849 presented at the 64th SPE Annual Meeting, San Antonio, TX, 8-11 Oct.

Litvak, B.L. (1985). "Simulation and Characterization of Naturally Fractured Reservoirs", Proc. Res. Characterization Technical Conf., Dallas Academic Press, NY.

Narasimhan, T.N. (1982). "Multi-Dimensional Numerical Simulation of Fluid Flow in Fractured porous Media", Water Resources Research, Vol. 18, No. 4, 1235-1247.

Pruess, K. and T.N. Narasimhan (1985). "A Practical Method for Modeling Fluid and Heat Flow in fractured Porous Media", SPEJ, 15-26.

Rechard, R. P. , A. P. Gilkey, H. J. Iuzzolino, D. K. Rudeen, and K. A. Byle. (1993). Programmer's Manual for CAMCON: Compliance Assessment Methodology Controller. SAND90 - 1984. Sandia National Laboratories, Albuquerque NM.

Rechard, R. P., ed. (1992). User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller; Version 3.0. SAND90 - 1983. Sandia National Laboratories, Albuquerque NM.

Reiss, L.H., Bossie-Codreanu, D.N., and L. DuPrey (1973). "Flow in Fissured Reservoirs", Paper SPE 4343, presented at the 2nd Annual European Meeting of SPE-AIME, London, England, 2-3 April.

Rossen, R.H. (1977). " Simulation of Naturally Fractured Reservoirs with Semi-Implicit Source Terms", SPEJ 201-210.

Saidi, A. (1983). " Simulation of Naturally Fractured Reservoirs", Paper SPE 12270 presented at the SPE Symposium on Reservoir Simulation, San Francisco, 16-18 Nov.

Shinta, A.A. and H. Kazemi. (1993). "Tracer Transport in Characterization of Dual-Porosity Reservoirs", Paper SPE 26636 presented at the 1993 SPE Annual Tech. Conf and Exh., Houston, TX, 3-6 Oct.

Sonier, F., Souillard, P., and F.T. Blaskovich (1986). "Numerical Simulation of Naturally Fractured Reservoirs", SPE Reservoir Engineering, 1114-1122.

Thomas, L.K., Dixon, T.N., and R.G. Pierson (1983). " Fractured Reservoir Simulation", SPEJ, 42-54.

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 1: Third Comparison with 40 CFR 191, Subpart B. SAND92 - 0700/1. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 2: Technical Basis. SAND92 - 0700/2. Sandia National Laboratories, Albuquerque NM

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters. SAND92 - 0700/3. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B. SAND92 - 0700/4. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance. SAND92 - 0700/5. Sandia National Laboratories, Albuquerque NM.

Wu, Y.S., and K. Pruess (1988). " A Multiple-Porosity Method for Simulation of Naturally Fractured Petroleum Reservoirs", SPE Reservoir Engineering, 327-336.

11.0 APPENDICES

Appendix A: Examples of ASCII Radioisotope Input Files

Example 1:

```
** NUTS TITLE **
'CONVECTION-DISPERSION-DECAY IN ONE DIMENSION PROBLEM TEST'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# COMP. TO BE MODELED)1,..,NSITES **
1,2
'TEST4_SITE'   1
**(1. SITE, 2.COMP., DAUGHTER, PARENT, GROUP NAMES)1,..,NSITES **
'TEST4_SITE'
'COMP1'    'DAUGHT1'    'NONE'     'ELM1'
** 1.# OF ELEMENT,(2.ELEM. NAME, TEMP. DEPEND., TABLE LOOK-UP)1,..,NELEMENT **
1
'ELM1'     .FALSE.    .FALSE.
** COLLOIDAL TRANSPORT FLAG (T/F) **
.FALSE.
** PH DEPENDENT SOLUBILITY( IS PH REQUIRED (Y/N)) **
'N'
** METHOD ORDER,ONE-POINT=1,TWO-POINT=2,SPLIT-OPERATOR=3,MID-POINT=4 **
1
** DEGREE OF IMPLICITNESS **
1.
** IS MATRIX SORPTION REQUIRED (Y/N) **
'N'
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'Y'
** MATRIX SYMMETRIC DISPERSION AND DATA PROVIDED BY NUTS(T/F): ANSWER IF DISP.=Y **
.TRUE.   .TRUE.
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'N'
** DO YOU HAVE DIRICHLET B.CS. IN THE MATRIX (F/T) **
.TRUE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (F/T) **
.TRUE.
** MATRIX INITIAL.IN THE CDB FOR INTERPOLATED INTRUSION TIME IN E1 SCENARIO **
.FALSE.
** PRINT FLAGS OF MATRIX VARIABLES IN AN ASCII FILE**
0,0,0,0,0,0,1,0,0,0,0,0,0,0
** SPECIFIC RANGE OF DATA TO BE PRITED IN AN ASCII FILE **
'N'
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEND.) **
** TEMP. DEPEND.OF MOLECULAR DIFFUSION (ENTER DATA IF DISPER. IS (Y)) **
'COMP1'    .FALSE.
** PRINTING FREQUENCY IN AN ASCII FILE **
1,1.E10
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.FALSE.
** MINIMUM LIMIT OF TIME TO BE SET IF ZERO ENCOUNTERED **
1.D-18
** IF CDB INITIAL., INTRUSION TIME, INTERPOLATED TIME, TOLERANCE IN SECONDS **
  NUMBER OF TIMES FOR SPECIFING MATERIAL MAP
  1
  START TIME FOR MAP 1
  0.D0
  MATERIAL TYPE GRID MAP
  1  2  2  2  2  2  2  2  2  2
  2  2  2  2  2  2  2  2  2  2
  2  2  2  2  2  2  2  2  2  2
  2  2  2  2  2  2  2  2  2  2
  2  2  2  2  2  2  2  2  2  2
  2  2  2  2  2  2  2  2  2  2
  #   NAME
  1   REGION1
  2   REGION2
  NUMBER OF WASTE REGIONS
```

```
  1
  MAT_WASTEI
  1
  1
*** END MATERIAL MAP AND START NUCLIDES PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME, SOLUBILITY LIMIT) 1,..,NELEMENT **
'ELM1'     7
** (COMP. NAME, MOL. (ATOMIC) WT., INITIAL INVENTS., HALF LIFE)1,..,NUCLIDE **
'COMP1'    0.238    0.0     0.0    7.7016E12
** GROUND WATER PH INPUT **
** STANDARD BR. DENS. IF NOT BRAGFLO RUN ( ASCII FILE FOR FLUX FIELD) **
1000.
** MOLECULAR DIFFUSION OF EACH COMPONENT **
'COMP1'    1.E-9
** REFERENCE VISCOSITY AND TEMPERATURE **
** ROCK DENSITY INPUT **
** WASTE MATRIX INPUT **
1
'COMP1'  1   1
** (1.SITE NAME, # OF GRID IN THE SITE 2. INDECES), 1....NSITES **
'TEST4_SITE'   1
1,1,1
** MATRIX SORPTION INPUT **
** MATRIX DISPERSION INPUT **
** MATRIX LONGITUDINAL MATERIAL DISPERSIVITIES **
10.0       10.0
** MATRIX TRANSVERSE MATERIAL DISPERSIVITIES **
0.0   0.0
** MATRIX MATERIAL TORTUOSITY **
10.0  10.0
** MATRIX SOURCE (INJECTION/PRODUCTION) INPUT IF ANY **
** MATRIX DIR. B.CS. (REP.='GENERAL, ANYWHERE='NOT_GENERAL') **
1   'GENERAL'
'COMP1'    1      1.0
** TIME DEPENDENT SOURCE IN THE MATRIX **
** MATRIX CONCENTRATION INITIALIZATION **
1
'COMP1'    1      1
1          1      1
'COMP1'
1.0
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
```

Example 2:

```
** NUTS RUN TITLE **
'2D TEST, ADVECTIVE IN X, DISPERSIVE IN X & Y, DECAY AND SORPTION, DT=5 Y'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# COMP. TO BE MODELED)1,..,NSITES **
1,2
'NMVP_SITE'   1
**(1. SITE, 2. COMP., DAUGHTER, PARENT, GROUP NAMES)1,..,NSITES **
'NMVP_SITE'
'U234'    'DAUGHT1'    'NONE'     'U'
** 1.# OF ELEMENT,(2.ELEM. NAME, TEMP. DEPEND., TABLE LOOK-UP)1,..,NELEMENT **
1
'U'     .FALSE.    .FALSE.
** COLLOIDAL TRANSPORT FLAG (T/F) **
.FALSE.
** PH DEPENDENT SOLUBILITY( IS PH REQUIRED (Y/N)) **
'N'
** ORDER OF THE METHOD **
1
** DEGREE OF IMPLICITNESS  **
1.
** IS MATRIX SORPTION REQUIRED (Y/N) **
'Y'
'L'
'U234'  'ADSORP'      .FALSE.
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'Y'
** DOES MATRIX HAVE SYMMETRIC DISPERSION (T/F): ANSWER IF DISPERSION IS Y **
.TRUE.   .TRUE.
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'N'
** DO YOU HAVE DIRICHLET B.CS. IN THE MATRIX (F/T) **
.TRUE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (F/T) **
.FALSE.
** MATRIX INITIAL. IN THE CDB FOR INTERPOLATED INTRUSION TIME IN E1 SCENARIO **
.FALSE.
** PRINT FLAGS OF MATRIX VARIABLES IN AN ASCII FILE**
0,0,0,0,0,0,1,0,0,0,0,0,0,0
** SPECIFIC RANGE OF DATA TO BE PRITED IN AN ASCII FILE **
'N'
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEND.) **
** TEMP. DEPEND. OF MOLECULAR DIFFUSION (ENTER DATA IF DISP. IS (Y)) **
'U234'     .FALSE.
** PRINTING FREQUENCY IN AN ASCII FILE **
200,1.E12
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.TRUE.
** MINIMUM LIMIT OF TIME TO BE SET IF ZERO ENCOUNTERED **
  1.D-18
** IF CDB INITIAL., INTRUSION TIME, INTERPOLATED TIME, TOLERANCE IN SECONDS **
  NUMBER OF TIMES FOR SPECIFING MATERIAL MAP
  1
  START TIME FOR MAP 1
  0.D0
  MATERIAL TYPE GRID MAP
  239*2  11*1  14*2  8*2  11*1 14*2  8*2 11*1 14*2  693*2
  #   NAME
  1   REGION1
  2   REGION2
  NUMBER OF WASTE REGIONS
  1
  MAT_WASTEI
  1
  1
*** END MATERIAL MAP AND START NUCLIDES PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME, SOLUBILITY LIMIT) 1,..,NELEMENT **
'U'     7
** (COMP. NAME, MOL. (ATOMIC) WT., INITIAL INVENTS., HALF LIFE)1,..,NUCLIDE **
'U234'    0.234    0.0     0.0    7.7156621D12
```

```
** GROUND WATER PH INPUT **
** STANDARD BR. DENS. IF NOT BRAGFLO RUN ( ASCII FILE FOR FLUX FIELD) **
1000.
** MOLECULAR DIFFUSION OF EACH COMPONENT **
'U234'    2.7D-10
** REFERENCE VISCOSITY AND TEMPERATURE **
** ROCK DENSITY INPUT **
2500.0     2500.0
** WASTE MATRIX INPUT **
1
'U234'    1     1
** (1. SITE NAME, # OF GRID IN THE SITE, 2. INDECES), 1....NSITES **
'NMVP_SITE'   33
9,8,1  10,8,1  11,8,1  12,8,1  13,8,1
14,8,1 15,8,1  16,8,1  17,8,1  18,8,1
19,8,1
9,9,1  10,9,1  11,9,1  12,9,1  13,9,1
14,9,1 15,9,1  16,9,1  17,9,1  18,9,1
19,9,1
9,10,1  10,10,1  11,10,1  12,10,1  13,10,1
14,10,1 15,10,1  16,10,1  17,10,1  18,10,1
19,10,1
** MATRIX SORPTION INPUT **
'U234'
2.222222222D-5   2.222222222D-5
** MATRIX DISPERSION INPUT **
** MATRIX LONGITUDINAL MATERIAL DISPERSIVITIES **
100.0   100.0
** MATRIX TRANSVERSE MATERIAL DISPERSIVITIES **
5.0   5.0
** MATRIX MATERIAL TORTOUSITY **
10.0   10.0
** MATRIX SOURCE (INJECTION/PRODUCTION) INPUT IF ANY **
** MATRIX DIR. B.CS. (REP.='GENERAL, ANYWHERE='NOT_GENERAL') **
1  'NOT_GENERAL'
'U234'  1   128
  33,1,1   33,2,1   33,3,1   33,4,1    33,5,1
  33,6,1   33,7,1   33,8,1   33,9,1   33,10,1
 33,11,1  33,12,1  33,13,1  33,14,1   33,15,1
 33,16,1  33,17,1  33,18,1  33,19,1   33,20,1
 33,21,1  33,22,1  33,23,1  33,24,1   33,25,1
 33,26,1  33,27,1  33,28,1  33,29,1   33,30,1
 33,31,1
 1,31,1  2,31,1  3,31,1  4,31,1  5,31,1
 6,31,1  7,31,1  8,31,1  9,31,1 10,31,1
11,31,1 12,31,1 13,31,1 14,31,1 15,31,1
16,31,1 17,31,1 18,31,1 19,31,1 20,31,1
21,31,1 22,31,1 23,31,1 24,31,1 25,31,1
26,31,1 27,31,1 28,31,1 29,31,1 30,31,1
31,31,1 32,31,1 33,31,1
  1,1,1   1,2,1   1,3,1   1,4,1    1,5,1
  1,6,1   1,7,1   1,8,1   1,9,1   1,10,1
 1,11,1  1,12,1  1,13,1  1,14,1   1,15,1
 1,16,1  1,17,1  1,18,1  1,19,1   1,20,1
 1,21,1  1,22,1  1,23,1  1,24,1   1,25,1
 1,26,1  1,27,1  1,28,1  1,29,1   1,30,1
 1,31,1
 1,1,1  2,1,1  3,1,1  4,1,1  5,1,1
 6,1,1  7,1,1  8,1,1  9,1,1 10,1,1
11,1,1 12,1,1 13,1,1 14,1,1 15,1,1
16,1,1 17,1,1 18,1,1 19,1,1 20,1,1
21,1,1 22,1,1 23,1,1 24,1,1 25,1,1
26,1,1 27,1,1 28,1,1 29,1,1 30,1,1
31,1,1 32,1,1 33,1,1
'U234'
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
```

```
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
0.  0.  0.  0.  0.  0.  0.  0.
** TIME DEPENDENT SOURCE IN THE MATRIX ****
1
'U234'  1   33
9,8,1  10,8,1  11,8,1  12,8,1  13,8,1
14,8,1 15,8,1  16,8,1  17,8,1  18,8,1
19,8,1
9,9,1  10,9,1  11,9,1  12,9,1  13,9,1
14,9,1 15,9,1  16,9,1  17,9,1  18,9,1
19,9,1
9,10,1  10,10,1  11,10,1  12,10,1  13,10,1
14,10,1 15,10,1  16,10,1  17,10,1  18,10,1
19,10,1
'U234'
  0.27579693E-10  0.62967336E-11  0.12593467E-11  0.25186934E-12
  0.12593467E-11  0.62967336E-11  0.27579693E-10  0.25186934E-10
  0.62967336E-10  0.31168831E-09  0.62967336E-10  0.27579693E-10
  0.62967336E-11  0.12593467E-11  0.25186934E-12  0.12593467E-11
  0.62967336E-11  0.27579693E-10  0.25186934E-10  0.62967336E-10
  0.31168831E-09  0.62967336E-10  0.27579693E-10  0.62967336E-11
  0.12593467E-11  0.25186934E-12  0.12593467E-11  0.62967336E-11
  0.27579693E-10  0.25186934E-10  0.62967336E-10  0.31168831E-09
  0.62967336E-10
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0  0.3156D10 0.3156D10 1.D38  1.D38
0.D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
```

```
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
0.0D0,1.D0,0.D0,0.D0,0.0D0
** MATRIX CONCENTRATION INITIALIZATION **
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
```

Example 3:

```
** NUTS TITLE **
'NUTS TRACER TEST FOR E01_DOWN SENARIO'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# COMP. TO BE MODELED)1,..,NSITES **
1,38
'WIPP_SITE'    2
**(1. SITE, 2.COMP., DAUGHTER, PARENT, GROUP NAMES)1,...,NSITES **
'WIPP_SITE'
'WASTE#1'   'NONE'   'NONE'   'WASTE'
'CASTL#1'   'NONE'   'NONE'   'CASTL'
** 1.# OF ELEMENT,(2.ELEM. NAME, TEMP. DEPEND., TABLE LOOK-UP)1,..,NELEMENT **
2
'WASTE'    .FALSE.   .FALSE.
'CASTL'    .FALSE.   .FALSE.
** COLLOIDAL TRANSPORT FLAG (T/F) **
.FALSE.
** PH DEPENDENT SOLUBILITY(IS PH REQUIRED (Y/N)) **
'N'
** ORDER OF THE METHOD ***
1
** DEGREE OF IMPLICITNESS **
1.
** IS MATRIX SORPTION REQUIRED (Y/N) **
'N'
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'N'
** DOES MATRIX HAVE SYMMETRIC DISPERSION (T/F): ANSWER IF DISPERSION IS Y **
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'N'
** DO YOU HAVE DIRICHLET B.CS. IN THE MATRIX (F/T) **
.TRUE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (F/T) **
.FALSE.
** MATRIX INITIAL.IN THE CDB FOR INTERPOLATED INTRUSION TIME IN E1 SCENARIO **
.FALSE.
** PRINT FLAGS OF MATRIX VARIABLES IN A BINARY FILE **
0,0,0,0,0,0,1,0,0,0,0,0,0,0
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEND.) **
** PRINTING FREQUENCY IN A BINARY FILE **
1,12
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.FALSE.
** MINIMUM LIMIT OF TIME TO BE SET IF ZERO ENCOUNTERED **
1.D-18
** IF CDB INITIAL., INTRUSION TIME, INTERPOLATED TIME, TOLERANCE IN SECONDS **
*** END MATERIAL MAP AND START NUCLIDES PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME, SOLUBILITY LIMIT) 1,..,NELEMENT **
'WASTE'      1.
'CASTL'      1.
** (COMP. NAME, MOL.(ATOMIC) WT., INITIAL INVENTS., HALF LIFE)1,..,NUCLIDE **
'WASTE#1'   .1    0.   0.   0.
'CASTL#1'   .1    0.   0.   0.
** GROUND WATER PH INPUT **
** STANDARD BR. DENS. IF NOT BRAGFLO RUN (READ ASCII FILE FOR FLUX FIELD) **
** MOLECULAR DIFFUSION OF EACH COMPONENT **
** ROCK DENSITY INPUT **
** WASTE MATRIX INPUT (LOCATION OF THE WASTE) **
1
'WASTE#1'   1    1
** (1. SITE_NAME, # OF THE GRID IN THE SITE, 2. INDECES ),1...NSITES **
'WIPP_SITE'     30
  8,8,1     9,8,1    10,8,1  12,8,1     13,8,1    14,8,1    15,8,1    16,8,1
 17,8,1    18,8,1     8,9,1   9,9,1     10,9,1    12,9,1    13,9,1    14,9,1
 15,9,1    16,9,1    17,9,1  18,9,1     8,10,1    9,10,1   10,10,1   12,10,1
13,10,1   14,10,1   15,10,1 16,10,1    17,10,1   18,10,1
** MATRIX SORPTION INPUT **
** MATRIX DISPERSION INPUT **
** MATRIX SOURCE INPUT (INJECTED NUCLIDES IF ANY) **
** MATRIX DIR. B.CS. INPUT (REP.='GENERAL',ANYWHERE= 'NOT_GENERAL') **
```

```
2  'NOT_GENERAL'
'WASTE#1'     1      30
  8,8,1     9,8,1    10,8,1  12,8,1     13,8,1    14,8,1    15,8,1    16,8,1
 17,8,1    18,8,1     8,9,1   9,9,1     10,9,1    12,9,1    13,9,1    14,9,1
 15,9,1    16,9,1    17,9,1  18,9,1      8,10,1   9,10,1   10,10,1   12,10,1
13,10,1   14,10,1   15,10,1 16,10,1    17,10,1   18,10,1
'CASTL#1'       2       27
 3,1,1    4,1,1    5,1,1   6,1,1    7,1,1    8,1,1    9,1,1
10,1,1   11,1,1   12,1,1  13,1,1   14,1,1   15,1,1   16,1,1
17,1,1   18,1,1   19,1,1  20,1,1   21,1,1   22,1,1   23,1,1
24,1,1   25,1,1   26,1,1  27,1,1   28,1,1   29,1,1
'WASTE#1'
 1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
 1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
 1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
'CASL#1'
 1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
 1.  1.  1.  1.  1.  1.  1.  1.  1.  1.
 1.  1.  1.  1.  1.  1.  1.
** TIME DEPENDENT SOURCE IN THE MATRIX **
** MATRIX CONCENTRATION INITIALIZATION **
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
```

Example 4:

```
** NUTS TITLE **
'1D TEST, ADVEC. AND DISP. IN X, 3 MEMBER DECAY AND SORPTION'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# COMP. TO BE MODELED)1,..,NSITES **
1,2
'CHAIN_SITE'   3
**(1. SITE, 2.COMP., DAUGHTER, PARENT, GROUP NAMES)1,..,NSITES **
'CHAIN_SITE'
'ISO1'     'DAUGHT1'    'NONE'        'EL1'
'DAUGHT1'  'DAUGHT2'    'ISO1'        'EL1'
'DAUGHT2'  'DAUGHT3'    'DAUGHT1'     'EL1'
** 1.# OF ELEMENT,(2.ELEM. NAME, TEMP. DEPEND., TABLE LOOK-UP)1,..,NELEMENT **
1
'EL1'      .FALSE.    .FALSE.
** COLLOIDAL TRANSPORT FLAG (T/F) **
.FALSE.
** PH DEPENDENT SOLUBILITY( IS PH REQUIRED (Y/N)) **
'N'
********* ORDER OF THE METHOD  ********
1
********* DEGREE OF IMPLICITNESS  ********
1.D0
** IS MATRIX SORPTION REQUIRED (Y/N) **
'Y'
'L'
'ISO1'      'ADSORP'       .FALSE.
'DAUGHT1'   'ADSORP'       .FALSE.
'DAUGHT2'   'ADSORP'       .FALSE.
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'Y'
** DOES MATRIX HAVE SYMMETRIC & NUTS DISPER.(T/F): ANSWER IF DISPER.IS Y **
.TRUE.  .TRUE.
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'N'
** DO YOU HAVE DIRICHLET B.CS. IN THE MATRIX (F/T) **
.TRUE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (F/T) **
.TRUE.
** MATRIX INITIAL. IN THE CDB FOR INTERPOLATED INTRUSION TIME IN E1 SCENARIO **
.FALSE.
** PRINT FLAGS OF MATRIX VARIABLES IN AN ASCII FILE**
0,0,0,0,0,0,1,0,0,0,0,0,0,0
** SPECIFIC RANGE OF DATA TO BE PRITED IN AN ASCII FILE **
'N'
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEND.) **
** TEMP. DEPEND. OF MOLECULAR DIFFUSION (ENTER DATA IF DISP. IS (Y)) **
'ISO1'      .FALSE.
'DAUGHT1'   .FALSE.
'DAUGHT2'   .FALSE.
** PRINTING FREQUENCY IN AN ASCII FILE **
25,1.D12
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.FALSE.
** MINIMUM LIMIT OF TIME TO BE SET IF ZERO ENCOUNTERED **
  1.D-18
** IF CDB INITIAL., INTRUSION TIME, INTERPOLATED TIME, TOLERANCE IN SECONDS **
  NUMBER OF TIMES FOR SPECIFING MATERIAL MAP
  1
  START TIME FOR MAP 1
  0.D0
  MATERIAL TYPE GRID MAP
  1*1 76*2
  #   NAME
  1   FORM1
  2   FORM2
  NUMBER OF WASTE REGIONS
  1
  MAT_WASTEI
```

```
  1
  1
*** END MATERIAL MAP AND START NUCLIDES PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME, SOLUBILITY LIMIT) 1,..,NELEMENT **
'EL1'      7.D0
** (COMP. NAME, MOL. (ATOMIC) WT., INITIAL INVENTS., HALF LIFE)1,..,NUCLIDE **
'ISO1'      0.1D0     0.D0     0.D0     1.366548D10
'DAUGHT1'   0.1D0     0.D0     0.D0     4.734000D8
'DAUGHT2'   0.1D0     0.D0     0.D0     2.064024D11
** GROUND WATER PH INPUT **
** STANDARD BR. DENS. IF NOT BRAGFLO RUN ( ASCII FILE FOR FLUX FIELD) **
1000.D0
** MOLECULAR DIFFUSION OF EACH COMPONENT **
'ISO1'      0.D0
'DAUGHT1'   0.D0
'DAUGHT2'   0.D0
** REFERENCE VISCOSITY AND TEMPERATURE **
** ROCK DENSITY INPUT **
1.111111111D0     1.111111111D0
** WASTE MATRIX INPUT **
3
'ISO'        1     1
'DAUGHT1'    2     1
'DAUGHT1'    3     1
**(1.SITE NAME, # OF GRID IN THE SITE 2. INDECES OF THE BLOCKS)1...NSITES **
'CHAIN_SITE'    1
1,1,1
** MATRIX SORPTION INPUT **
'ISO1'
935.1D0        935.1D0
'DAUGHT1'
7793.233D0     7793.233D0
'DAUGHT2'
311.633D0      311.633D0
** MATRIX DISPERSION INPUT **
** MATRIX LONGITUDINAL MATERIAL DISPERSIVITIES **
2.5908D0     2.5908D0
** MATRIX TRANSVERSE MATERIAL DISPERSIVITIES **
0.0D0    0.0D0
** MATRIX MATERIAL TORTOUSITY **
10.0D0    10.0D0
** MATRIX SOURCE (INJECTION/PRODUCTION) INPUT IF ANY **
** MATRIX DIR. B.CS. (REP.='GENERAL, ANYWHERE='NOT_GENERAL') **
3     'NOT_GENERAL'
'ISO1'       1        2
1,1,1  77,1,1
'DAUGHT1'    2        2
1,1,1  77,1,1
'DAUGHT2'    3        2
1,1,1  77,1,1
'ISO1'
1.D0       0.D0
'DAUGHT1'
0.01D0     0.D0
'DAUGHT2'
0.004D0    0.D0
** TIME DEPENDENT SOURCE IN THE MATRIX ****
** MATRIX CONCENTRATION INITIALIZATION **
3
'ISO1'       1       1
1,1,1
'DAUGHT1'    1       1
1,1,1
'DAUGHT2'    1       1
1,1,1
'ISO1'
1.D0
'DAUGHT1'
0.01D0
'DAUGHT2'
```

```
0.004D0
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
```

Example 5:

```
** NUTS TITLE **
'1D TEST, FOR PRECIPITATION AND PREFERENTIAL COLLOID SOLUBILITY'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# COMP. TO BE MODELED)1,..,NSITES **
1,2
'SRC_SITE'   2
**(1. SITE, 2.COMP., DAUGHTER, PARENT, GROUP NAMES)1,..,NSITES **
'SRC_SITE'
'SOLUBLE1'     'NONE'     'NONE'     'ELSOL1'
'COLLOID1'     'NONE'     'NONE'     'ELCOL1'
** 1.# OF ELEMENT,(2.ELEM. NAME, TEMP. DEPEND., TABLE LOOK-UP)1,..,NELEMENT **
2
'ELSOL1'    .FALSE.    .FALSE.
'ELCOL1'    .FALSE.    .FALSE.
** COLLOIDAL TRANSPORT FLAG (T/F) **
.TRUE.
**1. # OF COLLOIDS,(2. LOC. COLLOID,3. LOC OF THE RELATED DISS)1...NCOLLOID **
1
2
1
.TRUE.
** PH DEPENDENT SOLUBILITY( IS PH REQUIRED (Y/N)) **
'N'
********* ORDER OF THE METHOD  ********
1
********* DEGREE OF IMPLICITNESS  ********
1.
** IS MATRIX SORPTION REQUIRED (Y/N) **
'N'
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'N'
** DISPERSION IS SYMMETRIC (T/F), INPUT FROM NUTS (T/F) ***
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'N'
** DO YOU HAVE DIRICHLET B.CS. IN THE MATRIX (F/T) **
.TRUE.
** MATIRX INITIAL. IN THE CDB FOR INTERPOLATED INTURSION TIME IN E1 SCENARIO **
.FALSE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (F/T) **
.FALSE.
** PRINT FLAGS OF MATRIX VARIABLES IN AN ASCII FILE**
0,0,0,0,0,0,0,1,1,0,0,0,0,0
** SPECIFIC RANGE OF DATA TO BE PRITED IN AN ASCII FILE **
'N'
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEND.) **
** PRINTING FREQUENCY IN AN ASCII FILE **
1,1.E12
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.FALSE.
** MINIMUM LIMIT OF TIME TO BE SET IF ZERO ENCOUNTERED **
  1.D-18
** IF CDB INITIAL., INTRUSION TIME, INTERPOLATED TIME, TOLERANCE IN SECONDS **
  NUMBER OF TIMES FOR SPECIFING MATERIAL MAP
  1
  START TIME FOR MAP 1
  0.D0
  MATERIAL TYPE GRID MAP
  1*2 1*1  1*2
  #   NAME
  1   REPOS
  2   LEFTRIGHT
  NUMBER OF WASTE REGIONS
  1
  MAT_WASTEI
  1
  1
*** END MATERIAL MAP AND START NUCLIDES PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME, SOLUBILITY LIMIT) 1,..,NELEMENT **
'ELSOL1'    1.D0
```

```
'ELCOL1'     0.9542425D0
** (COMP. NAME, MOL. (ATOMIC) WT., INITIAL INVENTS., HALF LIFE)1,..,NUCLIDE **
'SOLUBLE1'     0.1   1.1578947  0.   0.
'COLLOID1'     0.1   1.0421053  0.   0.
** GROUND WATER PH INPUT **
** STANDARD BR. DENS. IF NOT BRAGFLO RUN ( ASCII FILE FOR FLUX FIELD) **
1000.
** MOLECULAR DIFFUSION OF EACH COMPONENT **
** ROCK DENSITY INPUT **
** WASTE MATRIX INPUT **
2
'SOLUBLE1'     1      1
'COLLOID1'     2      1
** (1. SITE NAME, # OF GRID 2. INDECES OF WASTE MATRIX)1....NSITE **
'NMVP_SITE'  1
2,1,1
** MATRIX SORPTION INPUT **
** MATRIX DISPERSION INPUT **
** MATRIX SOURCE (INJECTION/PRODUCTION) INPUT IF ANY **
** MATRIX DIR. B.CS. (REP.='GENERAL, ANYWHERE='NOT_GENERAL') **
2  'NOT_GENERAL'
'SOLUBLE1'  1   1
3,1,1
'COLLOID1'  2   1
3,1,1
'SOLUBLE1'
0.
'COLLOID1'
0.
** TIME DEPENDENT SOURCE IN THE MATRIX ****
** MATRIX CONCENTRATION INITIALIZATION **
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
** SCALING FACTORS IN X-DIRECTION **
1.  1.  1.
** SCALING FACTORS IN Y-DIRECTION **
1.  1.  1.
** SCALING FACTORS IN Z-DIRECTION **
1.  1.  1.
```

Appendix B: Example of a Nine-Grid-Block, One-Time Material Map

This example shows the exact input sequence for a one-time material map.

```
{Two spaces} Number of times for specifying material map
1
Start time for map 1
0.E0
Material type grid map
1  2  3
4  5  6
7  8  9
#   Name
1   S_halite
2   Drz_0
3   Trans_zn
4   S_mb139
5   Waste
6   S_mb138
7   Cavity 1
8   Cavity 2
9   Imperm_z
Number of Waste Regions
1
MAT_WASTEI
5
```

Appendix C: Example of an ASCII Flux-Field Input File (Homogeneous)

```
** DO YOU HAVE HOMOGENEOUS PROPERTIES? (T/F) **
T
** TITLE OF THE TEST RUN  **
'STAND ALONE FLUX FIELD TEST'
** TIME STEP SIZE AND NUMBER  **
3.1536E4  100
** # OF BLOCKS IN X,Y,Z **
4         3         1
** DIMENSION OF BLOCKS IN X,Y,Z **
100.      100.      100.
** POROSITY AND SATURATION OF THE MATRIX **
0.3       .6
** VELOCITIES IN X,Y,Z IN THE MATRIX **
4.E-8     4.E-8     0.
** MATRIX FLUID TEMPERATURE AND VISCOSITY **
300.      1.E-2
```

Appendix D: Example of an ASCII Flux-Field Input File (Heterogeneous)

```
** DO YOU HAVE HOMOGENEOUS GEOMETRICAL PROPERTIES? (T/F) **
F
** TITLE OF THE TEST RUN **
'CONSTANT FIELD FOR CONVECTION-DISPERSION-DECAY IN 1D TEST'
** TIME STEP SIZE (Sec.) AND NUMBER **
8.64E5      40
** # OF GRID BLOCKS IN X,Y,Z **
60    1     1
** DIMENSION (M) OF GRID BLOCKS IN X **
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
** DIMENSION (M) OF GRID BLOCKS IN Y **
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
** DIMENSION (M) OF GRID BLOCKS IN Z **
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0  20.0
** POROSITY OF THE MATRIX GRID BLOCKS **
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2

** SATURATION OF THE MATRIX GRID BLOCKS **
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
** MATRIX VELOCITY (M/s) FIELD IN X-DIRECTION **
0.0    1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6
1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6
1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6
1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6
1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6
1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6  1.E-6
** MATRIX VELOCITY (M/s) FIELD IN Y-DIRECTION **
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
** MATRIX VELOCITY (M/s) FIELD IN Z-DIRECTION **
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
** MATRIX GRID BLOCKS FLUID TEMPERATURE (K) **
300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0
```

```
300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0
300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0
300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0
300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0
300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0  300.0
** MATRIX GRID BLOCKS FLUID VISCOSITY (Pa.Sec)  **
1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2
1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2
1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2
1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2
1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2
1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2  1.E-2
```

Appendix E: Example of NUTS's Extensive ASCII Output File

```
IFLAGTIME    =      0
TIME STEP # =      0
TIME (Sec.)     =     0.0000E+00
DATE OF THE RUN      = 17-SEP-95
TIME OF THE RUN      = 03:00:50
PROGRAM NAME  = NUTS
VERSION NUMBER       = 1.02ZO
REVISION DATE = 15-06-95
COMPUTER SYSTEM      = ALPHA
IS IT A TEST FILE? Y
OUTPUT FILE TYPE     = ASC
RUN TITLE = CONVECTION-DISPERSION-DECAY IN ONE DIMENSION PROBLEM TEST _CONSTANT
FIELD FOR INPUT FILE NAME = U1:[AASHINT.CMS_NUTS.TEST.TEST4]NUCONVECTION-DISPERSION
BRAGFLO/TEST-RUN TITLE = CONSTANT FIELD FOR CONVECTION-DISPERSION-DECAY IN 1D TEST
NUTS-RUN TITLE = CONVECTION-DISPERSION-DECAY IN ONE DIMENSION PROBLEM TEST
NUTS T_CON_DISP_DEC.IN;1
BRAGFLO/TEST-RUN INPUT FILE NAME =
U1:[AASHINT.CMS_NUTS.TEST.TEST4]TEST_CON_DISP_DEC.IN;1
NUTS OUTPUT PREFIX    = NUT
ASCII FILE OUTPUT FILE NAME =U1:[AASHINT.CMS_NUTS.TEST.TEST4]NUT_CON_DISP_DEC.OUT
DEBUG FILE OUTPUT FILE NAME = U1:[AASHINT.CMS_NUTS.TEST.TEST4]NUT_CON_DISP_DEC.DBG
*******************************************************************************
   Type of the porous media        = M
   Fracture is a continuum?        = F
   Matrix is a continuum?          = T
   Single-porosity calculation?    = T
   Dual-porosity calculation?      = F
   Dual-permeability calculation?= F

*******************************************************************************

              D I M E N S I O N A L    I N F O R M A T I O N
              ----------------------------------------------

  No. of Dimensions                =   1
  No. of Blocks in x-direction     =  60
  No. of Blocks in y-direction     =   1
  No. of Blocks in z-direction     =   1
  Calculation Will be Conducted in X Direction
*******************************************************************************
  No. of Continum =   1
  No. of Phases   =   1

*******************************************************************************

              ---- Grid Block Length (x-direction)----

     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02

              ---- Grid Block Width (y-direction)----

     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
     0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
```

```
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02

              ---- Grid Block Thickness (z-direction)----

    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
    0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02   0.2000E+02
*******************************************************************************

 *** GRID BLOCK X COORDINATES ****

    0.1000E+02   0.3000E+02   0.5000E+02   0.7000E+02   0.9000E+02
    0.1100E+03   0.1300E+03   0.1500E+03   0.1700E+03   0.1900E+03
    0.2100E+03   0.2300E+03   0.2500E+03   0.2700E+03   0.2900E+03
    0.3100E+03   0.3300E+03   0.3500E+03   0.3700E+03   0.3900E+03
    0.4100E+03   0.4300E+03   0.4500E+03   0.4700E+03   0.4900E+03
    0.5100E+03   0.5300E+03   0.5500E+03   0.5700E+03   0.5900E+03
    0.6100E+03   0.6300E+03   0.6500E+03   0.6700E+03   0.6900E+03
    0.7100E+03   0.7300E+03   0.7500E+03   0.7700E+03   0.7900E+03
    0.8100E+03   0.8300E+03   0.8500E+03   0.8700E+03   0.8900E+03
    0.9100E+03   0.9300E+03   0.9500E+03   0.9700E+03   0.9900E+03
    0.1010E+04   0.1030E+04   0.1050E+04   0.1070E+04   0.1090E+04
    0.1110E+04   0.1130E+04   0.1150E+04   0.1170E+04   0.1190E+04

 *** GRID BLOCK Y COORDINATES ****

    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02

 *** GRID BLOCK Z COORDINATES ****

    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
```

```
     0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
*******************************************************************************

                ---- Grid Block Volume ----

     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
     0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04   0.8000E+04
*******************************************************************************

                ---- Interface Area in x-direction ----

     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03

                ---- Interface Area in y-direction ----

     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03

                ---- Interface Area in z-direction ----

     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
     0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03   0.4000E+03
*******************************************************************************
  !!!! No PH Evaluation Is Considered!!!!
  !!!! in the Matrix or the Fracture !!!!
```

```
*****************************************************************************
                W A S T E   I F O R M A T I O N
                -------------------------------

  No. OF Radioactive Nuclides     =   1
  No. OF Radioactive Sites        =   1

*****************************************************************************

  SITE NAME                       No. of Component
  -----------                     ----------------

  TEST4_SITE                            1


  Component            Daughter              Parent              Group
------------         -------------         --------            --------

                For The Site TEST4_SITE

  COMP1                 DAUGHT1               NONE                ELM1

  COMPONENT         NO OF SIM. COMP.        LOCATION
  ---------         ----------------       -----------

  COMP1                   1                     1

  COMPONENT             STATUS               DECAY CONSTANT
  ---------           --------              -----------------

  COMP1               RADIOACTIVE              0.9000E-13

                -Initial Inventory of radionuclide (Kg/m3)-

  COMP1                      0.0000E+00
*****************************************************************************
*****************************************************************************

                - Waste Matrix (1 = Waste, 0 = No Waste) -

   1 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
   0 0 0 0 0
*****************************************************************************

                -Solubility Limit of Radionuclide (Kg/m3)-

  Number of Elements =      1

  Elmnt Name, Temp. Dep.,Sol. Limit or Parameters

  ELM1                           F              0.2380E+10

  COMPONENT         NO OF SIM. ELEM.         LOCATION
  ---------        -----------------       ----------------
```

```
  COMP1                    1                        1
*******************************************************************************

  Total Waste Volume (m3) of TEST4_SITE            =    0.80000E+04

*******************************************************************************

  COMPONENT            MoL. Wt.
  ---------           ----------

  COMP1               0.2380E+00
*******************************************************************************

              A D S O R P T I O N   I N F O R M A T I O N
              --------------------------------------------

  N
  !!!! No Sorption Calculation Is Considered!!!!
  !!!!!!!!!!!!!!!!! in the Matrix !!!!!!!!!!!!!!!!

*******************************************************************************

              R O C K  D E N S I T Y  I N F O R M A T I O N
              ----------------------------------------------

    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
    0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04   0.3000E+04
*******************************************************************************

              L O N G.  D I S P.  I N F O R M A T I O N
              -----------------------------------------

  !!!!!!! R O C K  M A T R I X !!!!!!!

    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02

              T R A N S.  D I S P.  I N F O R M A T I O N
              -------------------------------------------

  !!!!!!! R O C K  M A T R I X !!!!!!!

    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
```

```
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00

              R O C K   T O R .   I N F O R M A T I O N
              -----------------------------------------
!!!!!!! R O C K   M A T R I X !!!!!!!

    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
    0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02   0.1000E+02
*******************************************************************************

                  ----  Matrix Injection History----

  NO MATRIX INJECTION HISTORY AVAILABLE????????

*******************************************************************************
  MATRIX DIRICHLET B.CS. ARE AVAILABLE   =       T
  FRACTURE DIRICHLET B.CS. ARE AVAILABLE =       F

              Matrix Drichlet B.CS. Concentration of COMP1

   0.10000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
*******************************************************************************
              **** TITLE OF PRINTED MATRIX VARIABLES ****

   MVCPG OF THE D-N IN THE BRINE

  **** MATRIX PRINT FLAG IN THE ASCII FILE ****

   0 0 0 0 0 0 1 0 0 0 0 0 0 0
*******************************************************************************

               MATRIX INITIALIZATION

       ---- Matrix Porosity Initialization----

    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00
```

```
    0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00   0.2000E+00

      ---- Matrix Saturation Initialization----

    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01
    0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01   0.1000E+01

      ---- Matrix Initial Brine Volume----

    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
    0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04

COMP1
   MVCPG OF THE D-N IN THE BRINE
    0.10000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  IFLAGTIME    =      1
  TIME STEP # =       1
  TIME (Sec.) =     0.8640E+06
*******************************************************************************
  MATRIX  FLUXES CROSSING J-1 AND I-1 BOUNDARIES
  OF COMPONENT COMP1

    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
*******************************************************************************
    0.00000E+00  0.55395E-03  0.12755E-03  0.29369E-04  0.67624E-05
    0.15571E-05  0.35853E-06  0.82553E-07  0.19008E-07  0.43767E-08
```

0.10078E-08	0.23204E-09	0.53430E-10	0.12302E-10	0.28327E-11
0.65225E-12	0.15018E-12	0.34581E-13	0.79624E-14	0.18334E-14
0.42215E-15	0.97202E-16	0.22381E-16	0.51534E-17	0.11866E-17
0.27322E-18	0.62911E-19	0.14486E-19	0.33354E-20	0.76799E-21
0.17683E-21	0.40717E-22	0.93753E-23	0.21587E-23	0.49706E-24
0.11445E-24	0.26353E-25	0.60679E-26	0.13972E-26	0.32170E-27
0.74074E-28	0.17056E-28	0.39272E-29	0.90427E-30	0.20821E-30
0.47942E-31	0.11039E-31	0.25418E-32	0.58526E-33	0.13476E-33
0.31029E-34	0.71446E-35	0.16451E-35	0.37879E-36	0.87219E-37
0.20083E-37	0.46241E-38	0.00000E+00	0.00000E+00	0.00000E+00

****

MATRIX FLOW RATE AT INTERFACE I

0.0000E+00	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03

****

MATRIX FLOW RATE AT INTERFACE J

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

****

MATRIX TIME DEPENDENT VARIABLES

MATRIX PRODUCTION RATE FROM EACH GRID BLOCK

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

****

MATRIX INJECTION RATE INTO EACH GRID BLOCK

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

```
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
*******************************************************************************
  BRINE VOLUME IN EACH BLOCK

     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
*******************************************************************************
  COMP1
   MVCPG OF THE D-N IN THE BRINE
    0.10000E+01  0.23026E+00  0.53018E-01  0.12208E-01  0.28109E-02
    0.64722E-03  0.14903E-03  0.34314E-04  0.79010E-05  0.18192E-05
    0.41889E-06  0.96452E-07  0.22209E-07  0.51137E-08  0.11775E-08
    0.27111E-09  0.62426E-10  0.14374E-10  0.33097E-11  0.76207E-12
    0.17547E-12  0.40403E-13  0.93030E-14  0.21421E-14  0.49322E-15
    0.11357E-15  0.26150E-16  0.60211E-17  0.13864E-17  0.31922E-18
    0.73503E-19  0.16925E-19  0.38970E-20  0.89730E-21  0.20661E-21
    0.47573E-22  0.10954E-22  0.25222E-23  0.58075E-24  0.13372E-24
    0.30790E-25  0.70895E-26  0.16324E-26  0.37587E-27  0.86546E-28
    0.19928E-28  0.45885E-29  0.10565E-29  0.24327E-30  0.56014E-31
    0.12898E-31  0.29697E-32  0.68380E-33  0.15745E-33  0.36254E-34
    0.83476E-35  0.19221E-35  0.44261E-36  0.10240E-36  0.29944E-37
*******************************************************************************
            MATRIX MATERIAL BALANCE FOR NUCLIDE COMP1
  MATRIX MAXBLOCMBE%    =    0.2118E-21
  MATRIX MBE%           =    0.1010E-04
  MATRIX CMBE%          =    0.1010E-04
  MATRIX CRES           =   -0.2517E-21
  MATRIX CSRC           =    0.4786E+03

*******************************************************************************
  IFLAGTIME    =     1
  TIME STEP # =      2
  TIME (Sec.) =    0.1728E+07
*******************************************************************************
  MATRIX  FLUXES CROSSING J-1 AND I-1 BOUNDARIES
  OF COMPONENT COMP1

    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
*******************************************************************************
    0.00000E+00  0.52063E-03  0.21215E-03  0.70097E-04  0.21032E-04
    0.59693E-05  0.16338E-05  0.43592E-06  0.11413E-06  0.29444E-07
    0.75088E-08  0.18968E-08  0.47541E-09  0.11837E-09  0.29304E-10
    0.72192E-11  0.17709E-11  0.43278E-12  0.10541E-12  0.25598E-13
    0.61994E-14  0.14978E-14  0.36106E-15  0.86865E-16  0.20859E-16
    0.50007E-17  0.11969E-17  0.28608E-18  0.68285E-19  0.16279E-19
```

0.38762E-20	0.92197E-21	0.21907E-21	0.52004E-22	0.12334E-22
0.29227E-23	0.69204E-24	0.16374E-24	0.38712E-25	0.91464E-26
0.21596E-26	0.50960E-27	0.12018E-27	0.28326E-28	0.66729E-29
0.15711E-29	0.36975E-30	0.86976E-31	0.20450E-31	0.48063E-32
0.11291E-32	0.26515E-33	0.62243E-34	0.14606E-34	0.34262E-35
0.80343E-36	0.18834E-36	0.44136E-37	0.10337E-37	0.00000E+00

****

MATRIX FLOW RATE AT INTERFACE I

0.0000E+00	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03
0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03	0.4000E-03

****

MATRIX FLOW RATE AT INTERFACE J

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

****

MATRIX TIME DEPENDENT VARIABLES

MATRIX PRODUCTION RATE FROM EACH GRID BLOCK

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

****

MATRIX INJECTION RATE INTO EACH GRID BLOCK

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

```
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
*******************************************************************************
  BRINE VOLUME IN EACH BLOCK

     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
*******************************************************************************
  COMP1
   MVCPG OF THE D-N IN THE BRINE
    0.10000E+01  0.39683E+00  0.12973E+00  0.38702E-01  0.10945E-01
    0.29884E-02  0.79590E-03  0.20809E-03  0.53629E-04  0.13664E-04
    0.34494E-05  0.86401E-06  0.21501E-06  0.53207E-07  0.13103E-07
    0.32132E-08  0.78502E-09  0.19115E-09  0.46408E-10  0.11237E-10
    0.27144E-11  0.65422E-12  0.15737E-12  0.37785E-13  0.90570E-14
    0.21676E-14  0.51802E-15  0.12363E-15  0.29470E-16  0.70166E-17
    0.16688E-17  0.39649E-18  0.94113E-19  0.22319E-19  0.52886E-20
    0.12521E-20  0.29624E-21  0.70035E-22  0.16546E-22  0.39066E-23
    0.92179E-24  0.21738E-24  0.51233E-25  0.12069E-25  0.28415E-26
    0.66868E-27  0.15729E-27  0.36981E-28  0.86910E-29  0.20417E-29
    0.47944E-30  0.11254E-30  0.26408E-31  0.61945E-32  0.14525E-32
    0.34050E-33  0.79792E-34  0.18694E-34  0.44003E-35  0.13138E-35
*******************************************************************************
            MATRIX MATERIAL BALANCE FOR NUCLIDE COMP1
  MATRIX MAXBLOCMBE%    =    0.1626E-18
  MATRIX MBE%           =    0.9459E-05
  MATRIX CMBE%          =    0.1956E-04
  MATRIX CRES           =    0.7458E-19
  MATRIX CSRC           =    0.9284E+03
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.
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*******************************************************************************
  IFLAGTIME    =     1
  TIME STEP # =    40
  TIME (Sec.) =    0.3456E+08
*******************************************************************************
  MATRIX  FLUXES CROSSING J-1 AND I-1 BOUNDARIES
  OF COMPONENT COMP1

    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
    0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
```

```
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
*******************************************************************************
   0.00000E+00  0.40115E-03  0.40019E-03  0.39721E-03  0.39085E-03
   0.37959E-03  0.36221E-03  0.33812E-03  0.30764E-03  0.27204E-03
   0.23335E-03  0.19393E-03  0.15607E-03  0.12163E-03  0.91824E-04
   0.67202E-04  0.47718E-04  0.32906E-04  0.22061E-04  0.14394E-04
   0.91505E-05  0.56733E-05  0.34342E-05  0.20316E-05  0.11757E-05
   0.66620E-06  0.36994E-06  0.20149E-06  0.10772E-06  0.56575E-07
   0.29208E-07  0.14834E-07  0.74152E-08  0.36509E-08  0.17714E-08
   0.84749E-09  0.39999E-09  0.18633E-09  0.85714E-10  0.38951E-10
   0.17494E-10  0.77683E-11  0.34119E-11  0.14827E-11  0.63773E-12
   0.27159E-12  0.11455E-12  0.47865E-13  0.19821E-13  0.81357E-14
   0.33111E-14  0.13365E-14  0.53512E-15  0.21259E-15  0.83821E-16
   0.32806E-16  0.12747E-16  0.49183E-17  0.18809E-17  0.68370E-18
*******************************************************************************

 MATRIX FLOW RATE AT INTERFACE I

    0.0000E+00   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
    0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03   0.4000E-03
*******************************************************************************

 MATRIX FLOW RATE AT INTERFACE J

    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
*******************************************************************************

                 MATRIX TIME DEPENDENT VARIABLES

 MATRIX PRODUCTION RATE FROM EACH GRID BLOCK

    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
*******************************************************************************
 MATRIX INJECTION RATE INTO EACH GRID BLOCK

    0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
```

```
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
     0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
*******************************************************************************
  BRINE VOLUME IN EACH BLOCK

     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
     0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04   0.1600E+04
*******************************************************************************
  COMP1
   MVCPG OF THE D-N IN THE BRINE
    0.10000E+01  0.99423E+00  0.98175E+00  0.95918E+00  0.92329E+00
    0.87191E+00  0.80466E+00  0.72337E+00  0.63193E+00  0.53556E+00
    0.43992E+00  0.35011E+00  0.26998E+00  0.20182E+00  0.14634E+00
    0.10302E+00  0.70477E-01  0.46898E-01  0.30389E-01  0.19194E-01
    0.11829E-01  0.71204E-02  0.41904E-02  0.24132E-02  0.13612E-02
    0.75268E-03  0.40831E-03  0.21748E-03  0.11381E-03  0.58563E-04
    0.29648E-04  0.14777E-04  0.72551E-05  0.35109E-05  0.16754E-05
    0.78887E-06  0.36665E-06  0.16830E-06  0.76323E-07  0.34211E-07
    0.15163E-07  0.66478E-08  0.28839E-08  0.12384E-08  0.52656E-09
    0.22176E-09  0.92530E-10  0.38263E-10  0.15685E-10  0.63752E-11
    0.25701E-11  0.10278E-11  0.40787E-12  0.16064E-12  0.62802E-13
    0.24378E-13  0.93980E-14  0.36023E-14  0.14022E-14  0.78821E-15
*******************************************************************************
            MATRIX MATERIAL BALANCE FOR NUCLIDE COMP1
  MATRIX MAXBLOCMBE%    =    0.4337E-18
  MATRIX MBE%           =    0.7946E-05
  MATRIX CMBE%          =    0.3300E-03
  MATRIX CRES           =   -0.2574E-16
  MATRIX CSRC           =    0.1461E+05

*******************************************************************************
```

Appendix F: Command File to Build NUTS-SA's Executable

Stand -alone build file:

```
$ nuts_main = "NUT_MAIN"
$
$ if p1 .eqs. ""
$   then
$   inquire/nopunct/local inp "Debug? Y/N (n) "
$   if inp .eqs. "Y"
$     then
$     p1="DEBUG"
$    else
$     p1= ""
$   endif
$ endif
$
$ if p1 .eqs. "DEBUG"
$   then
$   fortran_switches = "/separate/noopt/debug"
$   link_switches = "/debug/exe=nuts_debug_standalone"
$   appended_info = "a DEBUG version of NUTS"
$   nuts == "$" + f$environment("DEFAULT") + "nuts_debug"
$  else
$   fortran_switches = "/separate/assume=dummy"
$   link_switches = "/exe=nuts_standalone"
$   appended_info = "NUTS"
$   nuts == "$" + f$environment("DEFAULT") + "nuts"
$ endif
$
$ write sys$output "Compiling and Linking " + appended_info
$
$ write sys$output "  Compiling " + nuts_main
$ fortran 'fortran_switches' 'nuts_main'
$
$ write sys$output "  Compiling NUT_LIB_STANDALONE "
$ lib/cre nut_lib_standalone
$ fortran 'fortran_switches' nut_lib_standalone
$ lib/repl nut_lib_standalone nut_lib_standalone
$
$ write sys$output "  Linking..."
$ link 'link_switches 'nuts_main',nut_lib_standalone/l
$
$ exit
```

Appendix G: Command File to Build NUTS-CC's Executable

```
$ nuts_main = "NUT_MAIN"
$
$ if p1 .eqs. ""
$   then
$   inquire/nopunct/local inp "Debug? Y/N (n) "
$   if inp .eqs. "Y"
$     then
$     p1="DEBUG"
$    else
$     p1= ""
$   endif
$ endif
$
$ if p1 .eqs. "DEBUG"
$   then
$   fortran_switches = "/separate/noopt/debug"
$   link_switches = "/debug/exe=nuts_debug"
$   appended_info = "a DEBUG version of NUTS"
$   nuts == "$" + f$environment("DEFAULT") + "nuts_debug"
$  else
$   fortran_switches = "/separate/assume=dummy"
$   link_switches = "/exe=nuts"
$   appended_info = "NUTS"
$   nuts == "$" + f$environment("DEFAULT") + "nuts"
$ endif
$
$ write sys$output "Compiling and Linking " + appended_info
$
$ write sys$output "  Compiling " + nuts_main
$ fortran 'fortran_switches' 'nuts_main'
$
$ write sys$output "  Compiling NUT_LIB"
$ lib/cre nut_lib
$ fortran 'fortran_switches' nut_lib!.for_standalone
$ lib/cre nut_lib nut_lib
$
$ write sys$output "  Compiling NUTS_CDBLIB"
$ lib/cre nut_cdblib
$ fortran 'fortran_switches' nut_cdblib
$ lib/cre nut_cdblib nut_cdblib
$
$ write sys$output "  Linking..."
$ link 'link_switches 'nuts_main',nut_lib/l,nut_cdblib/l, -
        camdat_lib/l, camcon_lib/l, camsupes_lib/l
$
$ exit
```

Appendix H: Command Files and ASCII Files that Execute NUTS on the WIPP Alpha-VAX Cluster

This Appendix includes examples of three general cases encountered in the CCA calculation using the NUTS_CC executable and one general case of NUTS_SA executable. For further details, see explanations of inputs in Chapter 6.

Example (1): Single-porosity, matrix, tracer test conducted by implementing Dirichlet boundary conditions in the waste region with concentration equal 1 and infinite solubility. There are two input files: Binary input for the flux field from BRAGFLO (BF3_CCA_R1_S1_V23.CDB) and an ASCII file provided by the user (NUT_CCA_SCN_R1_S1.INP). The material map is read from BRAGFLO ASCII input (BF2_CCA_R1_S1_V23.INP). In this example two output files are required, they are: ASCII debug file (NUT_CCA_SCN_R1_S1_V023.OUT) and NUTS' CDB binary file (NUT_CCA_SCN_R1_S1_V023.CDB). The constituent properties are provided by NUTS and Liquid phase transport is conducted.

Interactive Input Command File (TRACER.COM)

```
$ SET DEFAULT DISK$TINA_CCA3:[BF.AASHINT.CCA3.INPUT]
$ NUTS:==$N1:[NOBACK.AASHINT.NMVP.NMVP96.CCASRC.TEMP]NUTS.EXE        ! NUTS EXECUTABLE
PATH.
$ NUTS -
  DISK$TINA_CCA3:[BF.DATA.R1S1]BF3_CCA_R1_S1_V23.CDB -               ! BRAGFLO CDB
INPUT.
  N -
        ! TEST (Y/N)?.
  BIN -
        ! ASC/BIN (CDB) OUTPUT.
  NUT_CCA_SCN_R1_S1.INP -
! NUTS ASCII INPUT.
  NUT_CCA_SCN_R1_S1_V023.CDB -
NUTS CDB OUTPUT.
  NUT_CCA_SCN_R1_S1_V023.OUT -
NUTS DEBUG FILE.
  L -
        ! LIQUID/GAS TRANSPORT.
  DISK$TINA_CCA3:[BF.AASHINT.CCA3.INPUT]BF2_CCA_R1_S1_V23.INP -      ! BRAGFLO ASC
INPUT.
  N -                                   ! NUCLIDE INPUT DATA (CDB (C)/NUTS (N)) .
  CANCEL -                                          ! PROPERTY CDB (SOLUBILITY DATA).
  CANCEL                                        ! NUTS UNDISTRUBED CDB OF THE SAME
VECTOR.
$ EXIT
```

NUTS' ASCII Input (NUT_CCA_SCN_R1_S1.INP)

```
** NUTS TITLE **
'NUTS TRACER SCREENING TEST FOR CCA R1S1 (UNDISTURBED SCENARIO)'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# COMP. TO BE MODELED)1,..,NSITES **
1,46
'WIPP_SITE'   1
**(1. SITE, 2.COMP., DAUGHTER, PARENT, GROUP NAMES)1,..,NSITES **
'WIPP_SITE'
'TWASTE'  'NONE'  'NONE'  'WASTE'
** 1.# OF ELEMENT,(2.ELEM. NAME, TEMP. DEPEND., TABLE LOOK-UP)1,..,NELEMENT **
1
'WASTE'   .FALSE.  .FALSE.
```

```
** COLLOIDAL TRANSPORT FLAG (T/F) **
.FALSE.
** PH DEPENDENT SOLUBILITY(IS PH REQUIRED (Y/N)) **
'N'
** ORDER OF THE METHOD **
1
** DEGREE OF IMPLICITNESS **
1.D0
** IS MATRIX SORPTION REQUIRED (Y/N) **
'N'
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'N'
** DOES MATRIX HAVE SYMMETRIC DISPERSION (T/F): ANSWER IF DISPERSION IS Y **
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'N'
** DO YOU HAVE DIRICHLET B.CS. IN THE MATRIX (F/T) **
.TRUE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (F/T) **
.FALSE.
** OPEN NUTS UNDISTURBED CDB FOR INTRUSION TIME OTHER THAN 350,1000 YRS **
.FALSE.
** PRINT FLAGS OF MATRIX VARIABLES IN A BINARY FILE **
0,0,0,0,0,0,1,0,0,0,0,0,0,0
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEND.) **
** PRINTING FREQUENCY IN A BINARY FILE **
1,1.D14
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.FALSE.
** MINIMUM LIMIT OF TIME TO BE SET IF ZERO ENCOUNTERED **
1.D-18
** INTRUSION TIME, ITERPOLATED INTRUSION TIME, TOLERANCE **
*** END MATERIAL MAP AND START NUCLIDES PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME, SOLUBILITY LIMIT) 1,...,NELEMENT **
'WASTE'     -2.D0
** (COMP. NAME, MOL.(ATOMIC) WT., INITIAL INVENTS., HALF LIFE)1,..,NUCLIDE **
'TWASTE'    .1D0   0.D0   0.D0   0.D0
** GROUND WATER PH INPUT **
** STANDARD BR. DENS. IF NOT BRAGFLO RUN (READ ASCII FILE FOR FLUX FIELD) **
** MOLECULAR DIFFUSION OF EACH COMPONENT **
** ROCK GRAIN DENSITY INPUT (REQUIRED ONLY IF SORPTION OR SOIL BASE CONC.) **
** WASTE MATRIX INPUT (1.# OF ISO,2.NAME, LOC. IN THE INPUT, WASTE SITE #) **
1
'TWASTE'  1   1
*** (1.SITE NAME, NUMBER OF GRIDS IN THE SITE 2.INDECES)1...NSITES ***
'WIPP_SITE' 30
  9,8,1   10,8,1   11,8,1   12,8,1   13,8,1   14,8,1   15,8,1
 17,8,1   18,8,1   19,8,1
  9,9,1   10,9,1   11,9,1   12,9,1   13,9,1   14,9,1   15,9,1
 17,9,1   18,9,1   19,9,1
 9,10,1  10,10,1  11,10,1  12,10,1  13,10,1  14,10,1  15,10,1
17,10,1  18,10,1  19,10,1
** MATRIX SORPTION INPUT **
** MATRIX DISPERSION INPUT **
** MATRIX SOURCE INPUT (INJECTED NUCLIDES IF ANY) **
** MATRIX DIR. B.CS. INPUT (REP.='GENERAL',ANYWHERE= 'NOT_GENERAL') **
1  'NOT_GENERAL'
'TWASTE'    1     30
  9,8,1   10,8,1   11,8,1   12,8,1   13,8,1   14,8,1   15,8,1
 17,8,1   18,8,1   19,8,1
  9,9,1   10,9,1   11,9,1   12,9,1   13,9,1   14,9,1   15,9,1
 17,9,1   18,9,1   19,9,1
 9,10,1  10,10,1  11,10,1  12,10,1  13,10,1  14,10,1  15,10,1
17,10,1  18,10,1  19,10,1
'TWASTE'
 1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0
 1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0
 1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0  1.D0
** TIME DEPENDENT SOURCE IN THE MATRIX **
** MATRIX CONCENTRATION INITIALIZATION **
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
```

Example (2): Single-porosity, matrix, radiological transport with five isotopes. Three single isotopes and one chain of two members are used. The repository location is described by the waste matrix input. The inventories, atomic weights, half-life, and solubilities are provided by the properties CDB. There are three input files: CDB Binary input file for the flux field from BRAGFLO (BF3_CCA_R1_S4_V23.CDB) and an ASCII file provided by the user (NUT_CCA_ISO_R1_S4.INP). The material map is read from BRAGFLO ASCII input (BF2_CCA_R1_S4_V23.INP), whereas the radioactive material properties are read from the CDB binary input file NUT_CCA_PROP_R1_S4_V023.INP.

In this example, liquid transport is conducted and two output files are required, they are: ASCII debug file (NUT_CCA_ISO_R1_S4_V023.OUT) and NUTS' CDB binary file (NUT_CCA_ISO_R1_S4_V023.CDB).

Interactive Input Command File (ISO.COM)

```
$ SET DEFAULT DISK$TINA_CCA3:[BF.AASHINT.CCA3.INPUT]
$ NUTS:==$N1:[NOBACK.AASHINT.NMVP.NMVP96.CCASRC.TEMP]NUTS.EXE        ! NUTS EXECUTABLE
PATH.
$ NUTS -
  DISK$TINA_CCA3:[BF.DATA.R1S4]BF3_CCA_R1_S4_V23.CDB -               ! BRAGFLO CDB
INPUT.
  N -
        ! TEST (Y/N)?.
  BIN -
        ! ASC/BIN (CDB) OUTPUT.
  NUT_CCA_ISO_R1_S4.INP -
! NUTS ASCII INPUT.
  NUT_CCA_ISO_R1_S4_V023.CDB -
NUTS CDB OUTPUT.
  NUT_CCA_ISO_R1_S4_V023.OUT -
NUTS DEBUG FILE.
  L -
        ! LIQUID/GAS TRANSPORT.
  DISK$TINA_CCA3:[BF.AASHINT.CCA3.INPUT]BF2_CCA_R1_S4_V23.INP -      ! BRAGFLO ASC
INPUT.
  CDB -                                          ! NUCLIDE INPUT DATA (CDB (C)/NUTS (N))
.
  NUT_CCA_PROP_R1_S4_V023.INP -                        ! PROPERTY CDB (SOLUBILITY DATA).
  CANCEL                                                ! NUTS UNDISTRUBED CDB OF THE
SAMEVECTOR.
$ EXIT
```

NUTS' ASCII Input (NUT_CCA_ISO_R1_S4.INP)

```
** NUTS TITLE **
'NUTS RADIOLOGICAL TRANSPORT FOR CCA R1S4 (E2 SCENARIO, 350 YRS INTRUSION)'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# COMP. TO BE MODELED)1,..,NSITES **
1,49
'WIPP_SITE'    5
**(1. SITE, 2.COMP., DAUGHTER, PARENT, GROUP NAMES)1,..,NSITES **
'WIPP_SITE'
'AM241L'   'NONE'     'NONE'   'AML'
'PU239L'   'NONE'     'NONE'   'PUL'
'PU238L'   'NONE'     'NONE'   'PUL'
'U234L'    'TH230L'   'NONE'   'UL'
'TH230L'   'TH230D'   'NONE'   'THL'
** 1.# OF ELEMENT,(2.ELEM. NAME, TEMP. DEPEND., TABLE LOOK-UP)1,..,NELEMENT **
4
'AML'    .FALSE.   .FALSE.
```

```
'PUL'    .FALSE.   .FALSE.
'UL'     .FALSE.   .FALSE.
'THL'    .FALSE.   .FALSE.
** COLLOIDAL TRANSPORT FLAG (T/F) **
.FALSE.
** PH DEPENDENT SOLUBILITY(IS PH REQUIRED (Y/N)) **
'N'
** ORDER OF THE METHOD **
1
** DEGREE OF IMPLICITNESS **
1.D0
** IS MATRIX SORPTION REQUIRED (Y/N) **
'N'
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'N'
** DOES MATRIX HAVE SYMMETRIC DISPERSION (T/F): ANSWER IF DISPERSION IS Y **
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'N'
** DO YOU HAVE DIRICHLET B.CS. IN THE MATRIX (F/T) **
.FALSE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (F/T) **
.FALSE.
** OPEN NUTS UNDISTURBED CDB FOR INTRUSION TIME OTHER THAN 350,1000 YRS **
.FALSE.
** PRINT FLAGS OF MATRIX VARIABLES IN A BINARY FILE **
0,0,0,0,0,0,1,1,1,0,0,0,0,1
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEND.) **
** PRINTING FREQUENCY IN A BINARY FILE **
1,1.D12
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.FALSE.
** MINIMUM LIMITS OF TIME TO BE SET IF ZERO ENCOUNTERED **
1.D-18
** INTRUSION TIME, ITERPOLATED INTRUSION TIME, TOLERANCE **
*** END MATERIAL MAP AND START NUCLIDES PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME, SOLUBILITY LIMIT) 1,..,NELEMENT **
** (COMP. NAME, MOL.(ATOMIC) WT., INITIAL INVENTS., HALF LIFE)1,..,NUCLIDE **
** GROUND WATER PH INPUT **
** STANDARD BR. DENS. IF NOT BRAGFLO RUN (READ ASCII FILE FOR FLUX FIELD) **
** MOLECULAR DIFFUSION INPUT **
** ROCK DENSITY INPUT **
** WASTE MATRIX INPUT (LOCATION OF THE WASTE) **
5
'AM241L'   1    1
'PU239L'   2    1
'PU238L'   3    1
'U234L'    4    1
'TH230L'   5    1
*** (1.SITE NAME, NUMBER OF GRIDS IN THE SITE 2.INDECES)1...NSITES ***
'WIPP_SITE' 30
  9,8,1   10,8,1    11,8,1    12,8,1    13,8,1   14,8,1   15,8,1
 17,8,1   18,8,1    19,8,1
  9,9,1   10,9,1    11,9,1    12,9,1    13,9,1   14,9,1   15,9,1
 17,9,1   18,9,1    19,9,1
 9,10,1  10,10,1   11,10,1   12,10,1   13,10,1  14,10,1  15,10,1
17,10,1  18,10,1   19,10,1
** MATRIX SORPTION INPUT **
** MATRIX DISPERSION INPUT **
** MATRIX SOURCE INPUT (INJECTED NUCLIDES IF ANY) **
** MATRIX DIR. B.CS. INPUT (REP.='GENERAL',ANYWHERE= 'NOT_GENERAL') **
** TIME DEPENDENT SOURCE IN THE MATRIX **
** MATRIX CONCENTRATION INITIALIZATION **
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
```

Example (3): Single-porosity, matrix, radiological transport with five isotopes. Three single isotopes and one chain of two members are used. The repository location is described by the waste matrix input. The inventories, atomic weights, half-life, and solubilities are provided by the properties CDB. There are four input files: CDB Binary input file for the flux field from BRAGFLO (BF3_CCA_R1_S5_V23.CDB) and an ASCII file provided by the user (NUT_CCA_INT3_R1_S5_V023.INP). The material map is read from BRAGFLO ASCII input (BF2_CCA_R1_S5_V23.INP), whereas the radioactive material properties are read from the CDB binary input file NUT_CCA_PROP_R1_S5_V023.INP. There is an additional CDB input file required to initialization the intrusion time calaculation at 3000 years. This file is the output of NUTS for the undisturbed scenario of vector 23 (NUT_CCA_ISO_R1_S1_V023.INP).

In this example, liquid transport is conducted and two output files are required, they are: ASCII debug file (NUT_CCA_INT3_R1_S5_V023.OUT) and NUTS' CDB binary file (NUT_CCA_INT3_R1_S5_V023.CDB).

Interactive Input Command File (INT3.COM)

```
$ SET DEFAULT DISK$TINA_CCA3:[BF.AASHINT.CCA3.INPUT]
$ NUTS:==$N1:[NOBACK.AASHINT.NMVP.NMVP96.CCASRC.TEMP]NUTS.EXE        ! NUTS EXECUTABLE
PATH.
$ NUTS -
  DISK$TINA_CCA3:[BF.DATA.R1S5]BF3_CCA_R1_S5_V23.CDB -               ! BRAGFLO CDB
INPUT.
  N -
        ! TEST (Y/N)?.
  BIN -
        ! ASC/BIN (CDB) OUTPUT.
  NUT_CCA_INT3_R1_S5_V023.INP -
! NUTS ASCII INPUT.
  NUT_CCA_INT3_R1_S5_V023.CDB -
! NUTS CDB OUTPUT.
  NUT_CCA_INT3_R1_S5_V023.OUT -
! NUTS DEBUG FILE.
  L -
        ! LIQUID/GAS TRANSPORT.
  DISK$TINA_CCA3:[BF.AASHINT.CCA3.INPUT]BF2_CCA_R1_S5_V23.INP -      ! BRAGFLO ASC
INPUT.
  CDB -                                          ! NUCLIDE INPUT DATA (CDB (C)/NUTS (N))
.
  NUT_CCA_PROP_R1_S5_V023.INP -                        ! PROPERTY CDB (SOLUBILITY DATA).
 NUT_CCA_ISO_R1_S5_V023.CDB                      ! NUTS UNDISTRUBED CDB OF THE SAME
VECTOR.
$ EXIT
```

NUTS' ASCII Input (NUT_CCA_INT3_R1_S5_V023.INP)

```
** NUTS TITLE **
'NUTS RADIOLOGICAL TRANSPORT FOR CCA R1S5V023 (E2 SCENARIO, 3000 YRS INTRUSION)'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# COMP. TO BE MODELED)1,..,NSITES **
1,49
'WIPP_SITE'   5
**(1. SITE, 2.COMP., DAUGHTER, PARENT, GROUP NAMES)1,..,NSITES **
'WIPP_SITE'
'AM241L'   'NONE'     'NONE'   'AML'
'PU239L'   'NONE'     'NONE'   'PUL'
'PU238L'   'NONE'     'NONE'   'PUL'
'U234L'    'TH230L'   'NONE'   'UL'
'TH230L'   'TH230D'   'NONE'   'THL'
** 1.# OF ELEMENT,(2.ELEM. NAME, TEMP. DEPEND., TABLE LOOK-UP)1,..,NELEMENT **
```

```
4
'AML'    .FALSE.   .FALSE.
'PUL'    .FALSE.   .FALSE.
'UL'     .FALSE.   .FALSE.
'THL'    .FALSE.   .FALSE.
** COLLOIDAL TRANSPORT FLAG (T/F) **
.FALSE.
** PH DEPENDENT SOLUBILITY(IS PH REQUIRED (Y/N)) **
'N'
** ORDER OF THE METHOD **
1
** DEGREE OF IMPLICITNESS **
1.D0
** IS MATRIX SORPTION REQUIRED (Y/N) **
'N'
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'N'
** DOES MATRIX HAVE SYMMETRIC DISPERSION (T/F): ANSWER IF DISPERSION IS Y **
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'N'
** DO YOU HAVE DIRICHLET B.CS. IN THE MATRIX (F/T) **
.FALSE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (F/T) **
.FALSE.
** OPEN NUTS UNDISTURBED CDB FOR INTRUSION TIME OTHER THAN 350,1000 YRS **
.TRUE.
** PRINT FLAGS OF MATRIX VARIABLES IN A BINARY FILE **
0,0,0,0,0,0,1,1,1,0,0,0,0,1
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEND.) **
** PRINTING FREQUENCY IN A BINARY FILE **
1,1.D12
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.FALSE.
** MINIMUM LIMITS OF TIME TO BE SET IF ZERO ENCOUNTERED **
1.D-18
** INTRUSION TIME, ITERPOLATED INTRUSION TIME, TOLERANCE **
0.3155693D11    0.946708D11    0.D0
*** END MATERIAL MAP AND START NUCLIDES PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME, SOLUBILITY LIMIT) 1,...,NELEMENT **
** (COMP. NAME, MOL.(ATOMIC) WT., INITIAL INVENTS., HALF LIFE)1,..,NUCLIDE **
** GROUND WATER PH INPUT **
** STANDARD BR. DENS. IF NOT BRAGFLO RUN (READ ASCII FILE FOR FLUX FIELD) **
** MOLECULAR DIFFUSION INPUT **
** ROCK DENSITY INPUT **
** WASTE MATRIX INPUT (LOCATION OF THE WASTE) **
5
'AM241L'   1    1
'PU239L'   2    1
'PU238L'   3    1
'U234L'    4    1
'TH230L'   5    1
*** (1.SITE NAME, NUMBER OF GRIDS IN THE SITE 2.INDECES)1...NSITES ***
'WIPP_SITE' 30
  9,8,1   10,8,1    11,8,1    12,8,1    13,8,1   14,8,1   15,8,1
 17,8,1   18,8,1    19,8,1
  9,9,1   10,9,1    11,9,1    12,9,1    13,9,1   14,9,1   15,9,1
 17,9,1   18,9,1    19,9,1
 9,10,1  10,10,1   11,10,1   12,10,1   13,10,1  14,10,1  15,10,1
17,10,1  18,10,1   19,10,1
** MATRIX SORPTION INPUT **
** MATRIX DISPERSION INPUT **
** MATRIX SOURCE INPUT (INJECTED NUCLIDES IF ANY) **
** MATRIX DIR. B.CS. INPUT (REP.='GENERAL',ANYWHERE= 'NOT_GENERAL') **
** TIME DEPENDENT SOURCE IN THE MATRIX **
** MATRIX CONCENTRATION INITIALIZATION **
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
```

Example (4): Dual-permeability, One Site, Eleven Component, No Temperature Dependency, No waste emplacement, Injection in the Matrix only, No Dirichlet B.Cs., No External Dynamic Source, Material-map from Input, and writing in an ASCII output.

Interactive Input Command File (DUAL.COM)

```
$ RUN N1:[NOBACK.AASHINT.NMVP.NMVP96.CCASRC.TEMP]NUTS_STANDALONE
N
N
DUALNUTS.IN
Y
N
Y
DUALTEST.IN
ASC
DPM
1
L
VAX
ALPHA
```

DUALNUTS.IN

```
** NUTS TITLE **
'NUTS TEST RUN EXAMPLE'
** 1.# OF SITES,# OF MATERIAL,(2.SITE NAME,# OF COMP. TO BE MODELED)1,..,NSITES **
1   7
'TEST_SITE'      11
**(1.SITE NAME,2.COMP.,DAUGHTER,PARENT,GROUP NAMES)1,..,NSITES **
'TEST_SITE'
'PU239'        'U235'         'NONE'         'PU'
'U235'         'PA231'        'PU239'        'U '
'PA231'        'NONE'         'U235'         'PA'
'NP237'        'U233'         'NONE'         'NP'
'U233'         'NONE'         'NP237'        'U '
'U238'         'U234'         'NONE'         'U '
'U234'         'NONE'         'U238'         'U '
'I129'         'NONE'         'NONE'         'I '
'TC99'         'NONE'         'NONE'         'TC'
'SE79'         'NONE'         'NONE'         'SE'
'U235'         'NONE'         'NONE'         'U '
** 1.# OF ELEMENT,(2.ELEMENT NAME, TEMP. DEPENDENCY, TABLE LOOK-UP)1,..,NELEMENT **
7
'U     .FALSE.       .FALSE.
'PU'   .FALSE.       .FALSE.
'PA'   .FALSE.       .FALSE.
'NP'   .FALSE.       .FALSE.
'I     .FALSE.       .FALSE.
'TC'   .FALSE.       .FALSE.
'SE'   .FALSE.       .FALSE.
** COLLOIDAL TRANSPORT FLAG (T/F) **
.FALSE.
** pH DEPENDENT SOLUBILITY(IS pH REQUIRED (Y/N)) **
'N'
** ORDER OF THE METHOD **
1
** DEGREE OF IMPLICITNESS **
1.
** IS FRACTURE SORPTION REQUIRED (Y/N) **
'N'
** DO YOU HAVE DISPERSION IN THE FRACTURE (Y/N) **
'Y'
*FRACTURE DISPERSION IS SYMMETRIC AND DATA PROVIDED BY NUTS(T/F):ANSWER IF DISP IS Y*
.TRUE.       .TRUE.
```

```
** DO YOU HAVE INJECTION/PRODUCTION IN THE FRACTURE (Y/N) **
'N'
** DO YOU HAVE DIRICLET B.CS. IN THE FRACTURE (F/T) **
.FALSE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE FRACTURE (T/F) **
.FALSE.
** PRINT FLAGS OF FRACTURE VARIABLES IN ASCII FILE **
0,0,0,0,0,0,1,0,0,0,0,0,0,0
** DO YOU HAVE DATA TO BE PRINTED IN FRACTURE SPECIFIED GRID BLOCK RANGE **
'N'
** IS MATRIX SORPTION REQUIRED (Y/N) **
'Y'
'L'
'PU239'                'ADSORP'      .FALSE.
'U235 '                'ADSORP'      .FALSE.
'PA231'                'ADSORP'      .FALSE.
'NP237'                'ADSORP'      .FALSE.
'U233 '                'ADSORP'      .FALSE.
'U238 '                'ADSORP'      .FALSE.
'U234 '                'ADSORP'      .FALSE.
'I129 '                'ADSORP'      .FALSE.
'TC99 '                'ADSORP'      .FALSE.
'SE79 '                'ADSORP'      .FALSE..
'U236 '                'ADSORP'      .FALSE.
** DO YOU HAVE DISPERSION IN THE MATRIX (Y/N) **
'Y'
*MATRIX DISPERSION IS SYMMETRIC AND DATA PROVIDED BY NUTS(T/F):ANSWER IF DISP IS Y*
.TRUE.        .TRUE.
** DO YOU HAVE MATRIX/FRACTURE DISPERSION (Y/N) **
'Y'
** DO YOU HAVE INJECTION/PRODUCTION IN THE MATRIX (Y/N) **
'Y'
** DO YOU HAVE DIRICLET B.CS. IN THE MATRIX (F/T) **
.FALSE.
** IS CONCENTRATION INITIALIZED MANUALLY IN THE MATRIX (T/F) **
.FALSE.
** MATRIX INITIAL. IN THE CDB FOR INTERPOLATED INTRUSION TIME IN E1 SCENARIO(T/F) **
.FALSE.
** PRINT FLAGS OF MATRIX VARIABLES IN ASCII FILE**
0,0,0,0,0,0,1,0,0,0,0,0,0,0
** DO YOU HAVE DATA TO BE PRINTED IN MATRIX SPECIFIED GRID BLOCK RANGE **
'N'
** TEMP. DEPEND. OF Kd (ENTER DATA IF ADSORP. IS (Y) AND TEMP. DEPEN.) **
** TEMP. DEPEND.OF MOLECULAR DIFFUSION (ENTER DATA IF DISPER. IS (Y)) **
'PU239'                .FALSE.
'U235 '                .FALSE.
'PA231'                .FALSE.
'NP237'                .FALSE.
'U233 '                .FALSE.
'U238 '                .FALSE.
'U234 '                .FALSE.
'I129 '                .FALSE.
'TC99 '                .FALSE.
'SE79 '                .FALSE.
'U236 '                .FALSE.
** PRINTING FREQUENCY IN ASCII FILE **
1,1.E10
** DO YOU HAVE EXTERNAL NUCLIDE SOURCE? (T/F) **
.FALSE.
** MINIMUM LIMIT OF TIME TO BE SET IF ZERO ENCOUNTERED **
1.E-18
** IF CDB, INTRUSION TIME, INTERPOLATED TIME, TOLERANCE IN SECONDS **
  NUMBER OF TIMES FOR SPECIFING MATERIAL MAP
1
START TIME FOR MAP 1
0.E0
MATERIAL TYPE GRID MAP
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

```
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7
#    NAME
1    FMN#1
2    FMN#2
3    FMN#3
4    FMN#4
5    FMN#5
6    FMN#6
7    FMN#7
NUMBER OF WASTE REGIONS
1
MAT_WASTEI
5
5
*** END OF MAT_MAP AND START NUCLIDE PROPERTIES ***
** IF NOT TEMP. DEPEND. (ELEMENT NAME,LOG SOLUBILITY LIMIT) 1,..,NELEMENT **
'U '   7
'PU'   7
'PA'   7
'NP'   7
'I '   7
'TC'   7
'SE'   7
** (COMP. NAME, MOL. WT., INITIAL INVENTORIES, HALF LIFE)1,..,NUCLIDE **
'PU239'      0.239        392.   0.     7.59E11
'U235 '      0.235        0.     0.     2.22E16
'PA231'      0.231        0.     0.     1.03E12
'NP237'      0.237        0.     0.     6.75E13
'U233 '      0.233        0.     0.     5.00E12
'U238 '      0.238        0.     0.     1.41E17
```

```
'U234 '       0.234        0.     0.     7.72E12
'I129 '       0.129        110.   0.     4.95E14
'TC99 '       0.99         0.     0.     6.72E12
'SE79 '       0.79         0.     0.     2.05E12
'U236 '       0.236        1.45E4 0.     7.39E14
** GROUND WATER pH INPUT **
** STANDARD BRINE DENSITY IF NOT BRAGFLO RUN (ASCII FILE FOR FLUX FIELD) **
1000.
** MOLECULAR DIFFUSION OF EACH COMPONENT **
'PU239'              1.00E-9
'U235 '              1.00E-9
'PA231'              1.00E-9
'NP237'              1.00E-9
'U233 '              1.00E-9
'U238 '              1.00E-9
'U234 '              1.00E-9
'I129 '              1.00E-9
'TC99 '              1.00E-9
'SE79 '              1.00E-9
'U236 '              1.00E-9
** REFERENCE VISCOSITY AND TEMPERATURE **
** ROCK DENSITY INPUT **
1993    1746    1838    2021    2283    1714    2366
** WASTE MATRIX INPUT **
3
'PU239'              1      1
'I129 '              8      1
'U236 '              11     1
** (SITE NAME, NO. OF GRID IN THE SITE, 2. INDICES), 1,..., NSITES **
'TEST_SITE'    1
28  15  1
** FRACTURE SORPTION INPUT **
** FRACTURE DISPERSION INPUT **
** FRACTURE LONGITUDINAL MATERIAL DISPERSIVITIES **
7*1.D0
** FRACTURE TRANSVERSE MATERIAL DISPERSIVITIES **
7*1.D0
** FRACTURE MATERIAL TORTUOSITY **
7*1.D0
** FRACTURE SOURCE INPUT (INJECTION PRODUCTION) IF ANY **
** FRACTURE DIRICHLET BOUNDARY CONDITIONS, IF ANY **
** TIME DEPENDENT SOURCE IN THE FRACTURE **
** FRACTURE MANUAL CONCENTRATION INITIALIZATION **
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE FRACTURE **
** MATRIX SORPTION **
'PU239'
1.00E-1  4.00E-2  1.00E-1  4.00E-2  1.00E-1  4.00E-2  1.00E-1
'U235 '
2.50E-3  1.00E-2  2.00E-3  1.00E-2  2.25E-3  1.00E-2  2.50E-3
'PA231'
2.00E-3  4.00E-3  5.00E-4  4.00E-3  1.25E-3  4.00E-3  2.00E-3
'NP237'
2.00E-3  4.00E-3  5.00E-4  4.00E-3  1.25E-3  4.00E-3  2.00E-3
'U233 '
2.50E-3  1.00E-2  2.00E-3  1.00E-2  2.25E-3  1.00E-2  2.50E-3
'U238 '
2.50E-3  1.00E-2  2.00E-3  1.00E-2  2.25E-3  1.00E-2  2.50E-3
'U234 '
2.50E-3  1.00E-2  2.00E-3  1.00E-2  2.25E-3  1.00E-2  2.50E-3
'I129 '
0.00E0  0.00E0  0.00E0   0.00E0  0.00E0  0.00E0   0.00E0
'TC99 '
0.00E0  0.00E0  0.00E0   0.00E0  0.00E0  0.00E0   0.00E0
'SE79 '
2.50E-3  1.00E-2  2.00E-3  1.00E-2  2.25E-3  1.00E-2   2.50E-3
'U236 '
2.50E-3  1.00E-2  2.00E-3  1.00E-2  2.25E-3  1.00E-2  2.50E-3
** MATRIX DISPERSION INPUT **
** MATRIX LONGITUDINAL MATERIAL DISPERSIVITIES **
1.30E02  1.70E02  1.10E02
```

```
1.70E02  1.20E02  1.70E02
1.30E02
** MATRIX TRANSVERSE MATERIAL DISPERSIVITIES **
1.30E01  1.70E01  1.10E01
1.70E01  1.20E01  1.70E01
1.30E01
** MATRIX MATERIAL TORTUOSITY **
10.  10.  10.
10.  10.  10.
10.
** MATRIX SOURCE INPUT (INJECTED NUCLIDES IF ANY) **
11
'PU239'              1      1
28           15      1
'U235 '              2      1
28           15      1
'PA231'              3      1
28           15      1
'NP237'              4      1
28           15      1
'U233 '              5      1
28           15      1
'U238 '              6      1
28           15      1
'U234 '              7      1
28           15      1
'I129 '              8      1
28           15      1
'TC99 '              9      1
28           15      1
'SE79 '              10     1
28           15      1
'U236 '              11     1
28           15      1
'PU239'
1.E-7
'U235 '
1.E-7
'PA231'
1.E-7
'NP237'
1.E-7
'U233 '
1.E-7
'U238 '
1.E-7
'U234 '
1.E-7
'I129 '
1.E-7
'TC99 '
1.E-7
'SE79 '
1.E-7
'U236 '
1.E-7
** INJECTION RATE IN THE MATRIX **
1      0.     1.E30
28     15     1      1.E0
** MATRIX DIRICHLET B.CS. INPUT, IF ANY **
** TIME DEPENDENT SOURCE IN THE MATRIX **
** MATRIX MANUAL CONCENTRATION INITIALIZATION **
** COLLOID TRANSPORT VELOCITY SCALING FACTORS IN THE MATRIX **
```

DUALTEST.IN

```
** DO YOU HAVE HOMOGENEOUS PROPERTIES? (T/F) **
T
** TITLE OF THE TEST RUN  **
'FLUX FIELD TEST'
** TIME STEP SIZE AND NUMBER  **
3.1536E4       100
** # OF GRID BLOCKS IN X,Y,Z **
58    22    1
** DIMENSION OF GRID BLOCKS IN X,Y,Z **
100.   100.    100.
** POROSITY AND SATURATION OF THE FRACTURE **
0.01          0.6
** VELOCITIES IN X,Y,Z IN THE FRACTURE **
8.E-6       8.E-6       0.
** FRACTURE TEMPERATURE AND FLUID VISCOSITY **
298.15       1.E-3
** POROSITY AND SATURATION OF THE MATRIX **
0.3       .6
** VELOCITIES IN X,Y,Z IN THE MATRIX **
4.E-8        4.E-8      0.
** MATRIX TEMPERATURE AND FLUID VISCOSITY **
298.15       1.E-3
** SHAPE FACTOR, AND TRNSFER FUNCTION **
0.08      4.E-10
```

Appendix I: Listing of NUTS's Error Messages

Error Messages are categorized according to the files in which they arise.

BRAGFLO INPUT

Aborting Messages:

1. Number of grid blocks in x can not be #. Use at least "1" grid block. NUTS will be aborted.
2. Number of grid blocks in y can not be #. Use at least "1" grid block. NUTS will be aborted.
3. Number of grid blocks in z can not be #. Use at least "1" grid block. NUTS will be aborted.
4. Grid block length in x can not be # for block number. Use positive number > 0 NUTS will be aborted.
5. Grid block length in y can not be # for block number. Use positive number > 0 NUTS will be aborted
6. Grid block length in z can not be # for block number. Use positive number > 0 NUTS will be aborted.
7. Viscosity of the brine can not be # for block number i,j,k. Use positive number. NUTS will be aborted.
8. Grid block porosity can not be # for block number i,j,k. Use positive number. NUTS will be aborted.
9. Grid block saturation can not be # for block number i,j,k. Use positive number. NUTS will be aborted.
10. Darcian Velocity in x can not be # for block number i,j,k. Numbers <= 0.6 are appropriate. NUTS will be aborted.
11. Darcian Velocity in y can not be # for block number i,j,k. Numbers <= 0.6 are appropriate. NUTS will be aborted.
12. Darcian Velocity in z can not be # for block number i,j,k. Numbers <= 0.6 are appropriate. NUTS will be aborted.
13. Grid block brine pH can not be # for block number. Use positive number. NUTS will be aborted.
14. Flux in x can not be # for block number i,j,k. Numbers based on v <= 0.6 m/s are appropriate. NUTS will be aborted.
15. Flux in y can not be # for block number i,j,k. Numbers based on v <= 0.6 m/s are appropriate. NUTS will be aborted.
16. Flux in z can not be # for block number i,j,k. Numbers based on v <= 0.6 m/s are appropriate. NUTS will be aborted.
17. Density of brine can not be # for block number i,j,k. Use a positive number. NUTS will be aborted.
18. Grid block brine viscosity as # is high. This value is not for a liquid. NUTS will be aborted.
19. Grid block saturation can not be # for block number i,j,k. Use numbers <= 1. NUTS will be aborted.
20. Grid block porosity can not be # for block number i,j,k. Use numbers <= 1. NUTS will be aborted.

21. This message will appear in the debug file:
    SERIOUS ERROR IS DETECTED IN BRAGFLO BINARY FILE (BRAGFLO file name) NUTS RUN IS TERMINATED, PLEASE SEE THE ABOVE WRITTEN MESSAGES
22. This message will appear on the screen:
    SERIOUS ERROR IS DETECTED IN BRAGFLO BINARY FILE(BINARY FILE NAME) NUTS RUN IS TERMINATED. PLEASE CONSULT WITH (NUTS debug file) TO IDENTIFY THE PROBLEM.

Warning Messages:

1. Grid block PCO2 # is too high for block number i,j,k.
2. Grid block Brine Pressure # is too high for block number i,j,k.
3. Reference temperature as # is low. Use > 273.15 K.
4. Reference temperature as # is high. This may need thermal simulator.
5. Reference brine pressure as # is too high.
6. Temperature of the grid block is # for block number i,j,k. Use > 273.15 K.
7. Grid block dimension in x as # is high for grid block i,j,k. This may lead to high numerical dispersion.
8. Grid block dimension in y as # is high for grid block i,j,k. This may lead to high numerical dispersion.

9. Grid block dimension in z as # is high for grid block i,j,k. This may lead to high numerical dispersion.
10. Grid block temperature as # is high for grid block i,j,k. This may need thermal simulator.
11. Grid block brine pH as # is high for grid block i,j,k. Use practical value.
12. Grid block brine density as # is high for grid block i,j,k. Use practical value
13. This message will appear on the screen:
    Undesirable value(s) is detected in the input file (BRAGFLO binary file name)
    For further information, please check (NUTS debug file name).
14. This message will appear in NUTS debug file:
    Undesirable value(s) is detected in the input file (BRAGFLO binary file name)
    For more information, please check above written messages.

Normal Completion Message:

Upon completion of reading the binary input file successfully, this ,message will appear both on the screen and in the NUTS debug file.

NORMAL COMPLETION READING THE INPUT FILE FROM BRAGFLO
(BRAGFLO binary file name)

FLUX FIELD ASCII INPUT:

Aborting Messages

1. Number of grid blocks in x can not be #. Use at least "1" grid block. NUTS will be aborted.
2. Number of grid blocks in y can not be #. Use at least "1" grid block. NUTS will be aborted.
3. Number of grid blocks in z can not be #. Use at least "1" grid block. NUTS will be aborted.
4. Grid block length in x can not be # for block number. Use positive number > 0 NUTS will be aborted.
5. Grid block length in y can not be # for block number. Use positive number > 0 NUTS will be aborted
6. Grid block length in z can not be # for block number. Use positive number > 0 NUTS will be aborted.
7. Viscosity of the brine can not be # for block number i,j,k. Use positive number. NUTS will be aborted.
8. Grid block porosity can not be # for block number i,j,k. Use positive number. NUTS will be aborted.
9. Grid block saturation can not be # for block number i,j,k. Use positive number. NUTS will be aborted.
10. Darcian Velocity in x can not be # for block number i,j,k. Numbers <= 0.6 are appropriate. NUTS will be aborted.
11. Darcian Velocity in y can not be # for block number i,j,k. Numbers <= 0.6 are appropriate. NUTS will be aborted.
12. Darcian Velocity in z can not be # for block number i,j,k. Numbers <= 0.6 are appropriate. NUTS will be aborted.
13. Density of brine can not be # for block number i,j,k. Use a positive number. NUTS will be aborted.
14. Grid block brine viscosity as # is high. This value is not for a liquid. NUTS will be aborted.
15. Grid block saturation can not be # for block number i,j,k. Use numbers <= 1. NUTS will be aborted.
16. Grid block porosity can not be # for block number i,j,k. Use numbers <= 1. NUTS will be aborted.
17. Time step size can not be #. Use positive number. NUTS will be aborted.
18. Number of time steps can not be #. Use positive number. will be aborted.
19. This message will appear in the debug file:
    SERIOUS ERROR IS DETECTED IN THE TEST FILE (file name) NUTS RUN IS TERMINATED, PLEASE SEE THE ABOVE WRITTEN MESSAGES
20. This message will appear on the screen:
    SERIOUS ERROR IS DETECTED IN THE TEST FILE (file name) NUTS RUN IS TERMINATED. PLEASE CONSULT WITH (NUTS debug file) TO IDENTIFY THE PROBLEM.

Warning Messages:

1. Temperature of the grid block is # for block number i,j,k. Use > 273.15.
2. Grid block dimension in x as # is high for grid block i,j,k. This may lead to high numerical dispersion.
3. Grid block dimension in y as # is high for grid block i,j,k. This may lead to high numerical dispersion.
4. Grid block dimension in z as # is high for grid block i,j,k. This may lead to high numerical dispersion.
5. Grid block temperature as # is high for grid block i,j,k. This may need thermal simulator.
6. Grid block brine density as # is high for grid block i,j,k use practical value.
7. You have # character title. Title should not exceed 100 character.
8. This message will appear on the screen.
   Undesirable value(s) is detected in the input file (input file name). For further information. Please check (debug file name).
9. This message will appear in the debug file.
   Undesirable value(s) is detected in the input file (input file name). For more information, please check above written messages.

Normal Completion Message

Upon completion of reading the test input file successfully, this message will appear both on the screen and in the NUTS debug file.

NORMAL COMPLETION READING THE INPUT FILE (INPUT FILE NAME)

NUTS ASCII Input

Aborting messages

1. Number of disposal sites can not be #. Use at least "1" site. NUTS will be aborted.
2. Number of sites # can not be>number of grid blocks # . They can be equal. NUTS will be aborted.
3. Number of material can not be #. Use at least "1" material. NUTS will be aborted.
4. # of material # can not be> # of grid blocks. They can be equal. NUTS will be aborted.
5. Number of the component in site # in the input can not be #. Use a number >=1. NUTS will be aborted.
6. Number of elements can not be #. Use at least "1" element. NUTS will be aborted.
7. Number of element # can not be>number of nuclides #. They can be equal. NUTS will be aborted.
8. Number of NUCLIDE can not be #. Use at least "1" nuclide. NUTS will be aborted.
9. Solubility of element number # in the input can not be #. Use a positive number. NUTS will be aborted.
10. Molecular weight of component number in the input can not be #. Use a positive number. NUTS will be aborted.
11. Molecular weight of component number in the input can not be >1. The conversion factors are based on Kg Mol and not gm Mol. NUTS will be aborted.
12. Contact handled inventory of component number # in the input can not be #. Use a positive number. NUTS will be aborted.
13. Remote handled inventory of component number # in the input can not be #. Use a positive number. NUTS will be aborted.
14. Half-life of component number # in the input can not be #. Use a positive number. NUTS will be aborted.
15. Brine pH can not be # for material number #. Use positive number. NUTS will be aborted.
16. Molecular diffusion of component number # in the input can not be #. Use a positive number. NUTS will be aborted.
17. Diffusion Velocity in x can not be # for block number i,j,k. Numbers <= 0.6 m/s are appropriate. NUTS will be aborted.
18. Diffusion Velocity in y can not be # for block number i,j,k. Numbers <= 0.6 m/s are appropriate. NUTS will be aborted.
19. Diffusion Velocity in z can not be for block number i,j,k. Numbers <= 0.6 m/s are appropriate. NUTS will be aborted.
20. Rock density can not be # for material number #. Use a positive number. NUTS will be aborted.
21. Number of waste component can not be #. Use a positive number. NUTS will be aborted.
22. Number of waste component can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.
23. Location of waste component in the input can not be #. Use a positive number. NUTS will be aborted.
24. Location of waste component can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.
25. The # of the waste region in the input can not be #. Use a positive number. NUTS will be aborted.
26. The # of the waste region in the input can not be #. Use a number < # which is total # of sites. NUTS will be aborted.
27. the # of grid block in each site can not be #. Use a number < # which is total number of grid blocks. NUTS will be aborted.
28. the # of grid block in each site can not be #. Use a number >= #. NUTS will be aborted.
29. This message will appear in NUTS debug file
    SERIOUS ERROR IS DETECTED IN THE INPUT FILE (NUTS INPUT FILE NAME). NUTS RUN IS TERMINATED. PLEASE SEE ABOVE WRITTEN MESSAGES.
30. This message will appear on the screen
    SERIOUS ERROR IS DETECTED IN THE INPUT FILE (NUTS INPUT FILE NAME). NUTS RUN IS TERMINATED. PLEASE CONSULT WITH (NUTS DEBUG FILE NAME) TO IDENTIFY THE PROBLEM.
31. Linear sorption coefficient of component number # in the material number # can not be #. Use a positive number. NUTS will be aborted.

32. Rock longitudinal dispersivity can not be # for material number #. Use a positive number. NUTS will be aborted.

33. Rock transverse dispersivity can not be # for material number #. Use a positive number. NUTS will be aborted.

34. Number of injected nuclide can not be #. Use a positive number. NUTS will be aborted.

35. Number of injected nuclide can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.

36. Location of injected nuclide in the input can not be #. Use a positive number. NUTS will be aborted.

37. Location of injected nuclide can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.

38. Total # of injection grids in the input can not be #. Use a positive number. NUTS will be aborted.

39. Total # of injection grids in the input can not be #. Use a number < # which is total # of grids. NUTS will be aborted.

40. Injection grid I-index in the input can not be #. Use a positive number. NUTS will be aborted.

41. Injection grid I-index in the input can not be #. Use a number < # which is total # of grids in I-dir. NUTS will be aborted.

42. Injection grid J-index in the input can not be #. Use a positive number. NUTS will be aborted.

43. Injection grid J-index in the input can not be #. Use a number < # which is total # of grids in J-dir. NUTS will be aborted.

44. Injection grid K-index in the input can not be #. Use a positive number. NUTS will be aborted.

45. Injection grid K-index in the input can not be #. Use a number < # which is total # of grids in K-dir. NUTS will be aborted.

46. Number of the grids with a source can not be #. Use a positive number. NUTS will be aborted.

47. Number of the grids with a source can not be #. Use a number < # which is total # of grids. NUTS will be aborted.

48. Source grid I-index in the input can not be #. Use a positive number. NUTS will be aborted.

49. Source grid I-index in the input can not be #. Use a number < # which is total # of grids in I-dir. NUTS will be aborted.

50. Source grid J-index in the input can not be #. Use a positive number. NUTS will be aborted.

51. Source grid J-index in the input can not be #. Use a number < # which is total # of grids in J-dir. NUTS will be aborted.

52. Source grid K-index in the input can not be #. Use a positive number. NUTS will be aborted.

53. Source grid K-index in the input can not be #. Use a number < # which is total # of grids in K-dir. NUTS will be aborted.

54. Source rate is zero in source block #. If you have a source, you should have a rate. NUTS will be aborted.

55. Source starting time can not be #. Use a positive number or 0. NUTS will be aborted.

56. Source starting time can not be # Which is > ending time #. NUTS will be aborted.

57. Source ending time can not be #. Use a positive number or 0. NUTS will be aborted.

58. Number nuclides having Dirichlet B.Cs can not be #. Use a positive number. NUTS will be aborted.

59. Number nuclides having Dirichlet B.Cs can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.

60. Location of nuclides having Dirichlet B.Cs in the input can not be #. Use a positive number. NUTS will be aborted.

61. Location of nuclide having Dirich. B.Cs can not be #. 'Use a number < # which is total # of the nuclides. NUTS will be aborted.

62. Total # of grids having Dirich. B.Cs can not be #. Use a positive number. NUTS will be aborted.

63. Total # of grids having Dirich. B.Cs can not be #. Use a number < # which is total # of grids. NUTS will be aborted.

64. Dirichlet grid I-index in the input can not be #. Use a positive number. NUTS will be aborted.

65. Dirichlet grid I-index in the input can not be #. Use a number < # which is total # of grids in I-dir. NUTS will be aborted.

66. Dirichlet grid J-index in the input can not be #. Use a positive number. NUTS will be aborted.

67. Dirichlet grid J-index in the input can not be #. Use a number < # which is total # of grids in J-dir. NUTS will be aborted.

68. Dirichlet grid K-index in the input can not be #. Use a positive number. NUTS will be aborted.

69. Dirichlet grid K-index in the input can not be #. Use a number < # which is total # of grids in K-dir. NUTS will be aborted.

70. Injected conc. of component # in grid i,j,k can not be #. Please use a positive number. NUTS will be aborted.

71. Dirichlet B.C. conc. of component # in grid i,j,k can not be #. Please use a positive number. NUTS will be aborted.

72. Number nuclides initialized can not be #. Use a positive number. NUTS will be aborted.

73. Number of initialized nuclide can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.

74. Location of initialized nuclides in the input can not be #. Use a positive number. NUTS will be aborted.

75. Location of initialized nuclide can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.

76. Total # of initialized grids in the input can not be #. Use a positive number. NUTS will be aborted.

77. Total # of initialized grids can not be #. Use a number < # which is total # of grids. NUTS will be aborted.

78. Initialized grid I-index in the input can not be #. Use a positive number. NUTS will be aborted.

79. Initialized grid I-index in the input can not be #. Use a number < # which is total # of grids in I-dir. NUTS will be aborted.

80. Initialized grid J-index in the input can not be #. Use a positive number. NUTS will be aborted.

81. Initialized grid J-index in the input can not be #. Use a number < # which is total # of grids in J-dir. NUTS will be aborted.

82. Initialized grid K-index in the input can not be #. Use a positive number. NUTS will be aborted.

83. Initialized grid K-index in the input can not be #. Use a number < # which is total # of grids in K-dir. NUTS will be aborted.

84. Initialized conc. of component # in grid i,j,k can not be #. Please use a positive number. NUTS will be aborted.

85. Scaling factor for colloid transport in x-direction for grid block i,j,k can not be #. Use a number >= 1. NUTS will be aborted.

86. Scaling factor for colloid transport in y-direction for grid block i,j,k can not be #. Use a number >= 1. NUTS will be aborted.

87. Scaling factor for colloid transport in z-direction for grid block i,j,k can not be #. Use a number >= 1. NUTS will be aborted.

88. This message will appear in the debug file:

    SERIOUS ERROR IS DETECTED IN THE INPUT FILE (NUTS INPUT FILE NAME) NUTS RUN IS TERMINATED. PLEASE SEE ABOVE WRITTEN MESSAGES

89. This message will appear on the screen:

    SERIOUS ERROR IS DETECTED IN THE INPUT FILE (NUTS INPUT FILE NAME) NUTS RUN IS TERMINATED. PLEASE CONSULT WITH (NUTS DEBUG FILE NAME) TO IDENTIFY THE PROBLEM.

90. Number of time dependent source nuclides can not be #. Use a positive number. NUTS will be aborted.

91. Number of time dependent source nuclides can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.

92. Location of time dependent source nuclides can not be #. Use a positive number. NUTS will be aborted.

93. Location of time dependent source nuclides can not be #. Use a number < # which is total # of the nuclides. NUTS will be aborted.

94. Total # of time dependent source grids in the input can not be #. Use a positive number. NUTS will be aborted.

95. Total # of time dependent source grids can not be #. Use a number < # which is total # of grids. NUTS will be aborted.

96. Time dependent source grid I-index can not be #. Use a positive number. NUTS will be aborted.

97. Time dependent source grid I-index can not be #. Use a number < # which is total # of grids in I-dir. NUTS will be aborted.

98. Time dependent source grid J-index can not be #. Use a positive number. NUTS will be aborted.

99. Time dependent source grid J-index can not be #. Use a number < # which is total # of grids in J-dir. NUTS will be aborted.

100. Time dependent source grid K-index can not be #. Use a positive number. NUTS will be aborted.

101. Time dependent source grid K-index can not be #. Use a number < # which is total # of grids in K-dir. NUTS will be aborted.
102. Number of colloids used as # is > the total number of isotopes #. Please set NCOLLOID <= #. NUTS will be terminated.
103. Number of colloids used as # can not be 0 or negative, please use a number <= #. NUTS will be terminated.
104. Location of the colloid used as # is > the total number of isotopes #. Please set the location <= #. NUTS will be terminated.

105. Location of the colloid used as # can not be negative, please use a positive number <= #. NUTS will be terminated.

Warning Messages

1. Brine pH as # for material number # is high!! check it please.
2. Rock density as # for material number # is high. Please check.
3. This message will appear on the screen

4. This message will appear on the screen
Undesirable value(s) is detected in the input file (NUTS Input File Name). For further information. Please check (NUTS Debug File Name).
5. This message will appear in NUTS debug file
Undesirable value(s) is detected in the input file (NUTS Input File Name). For more information, please check above written messages.
6. Rock longitudinal dispersivity input as # for material number # is larger than the maximum hydrological distance #. Please check the value.

7. Rock transverse dispersivity input as # for material number # is larger than longitudinal dispersivity #. Please check the value.
8. Linear sorption coefficient of component number # in the material number # is very high as #. Use a positive number <=1.

9. Undesirable value(s) is detected in the input file (NUTS Input File Name) For further information. Please check (NUTS Debug File Name).

10. Undesirable value(s) is detected in the input file (NUTS Input File Name) For more information, please check above written messages

11. Only 1 for 1.st order or 2 for 2.nd order, 3 for 2.nd order with split operator, and 4 for central difference are allowed. The order of the method requested as # is not available in NUTS.

12. Only BETA2 of [0,1] interval is accepted, 0 is explicit solution, 1/2 is Crank Niclson, 1 is fully implicit. The value requested as # is not available in NUTS (if BETA2 > 1, NUTS will set the solution to fully implicit and if BETA2 < 1, NUTS will set the solution to fully explicit.

13. For component #, grid block # has row entry = # < #, the minimum value in the table of that component. The value is reset to the minimum value.
14. For component #, grid block # has row entry = # > #, the maximum value in the table of that component. The value is reset to the maximum value.
15. For component #, grid block # has column entry = # < #, the minimum value in the table of that component. The value is reset to the minimum value.
16. For component #, grid block # has column entry = # > #, the maximum value in the table of that component. The value is reset to the maximum value.

Normal Completion Message:
Upon completion of reading NUTS ASCII input file successfully, these messages will appear both on the screen and in the NUTS debug file.

1. NORMAL COMPLETION READING NUCLIDES PROPERTIES FROM (NUTS INPUT FILE NAME).
2. NORMAL COMPLETION READING THE MATRIX PROPERTIES FROM (NUTS INPUT FILE NAME) (If the matrix is a continuum).

3. NORMAL COMPLETION READING THE FRACTURE PROPERTIES FROM (NUTS INPUT FILE NAME) (If the fracture is a continuum).

Operational Messages:

Aborting Messages

1. There is inconsistency in DT due to injection/production. The program is terminated.

2. Check your input for Langumir coefficient. It may mistakeningly input as negative, or negative concentration has been detected. Check and rerun the program.
3. The matrix is singular.
4. Not enough memory allocated for band width. Parameter declaration of MBW is #, while the number required is #. Please set MBW >= # in NUT_PARAM.INC. and rerun
5. Subroutine Bin_read is only capable of reading single-porosity matrix porous media output in this time. Execution is terminated in Sub. CONVERT.
6. End of file is encountered, "execution terminated:" for further calculation, check BIN_READ and rerun (Time is written).
7. Zero tortuousity value is encountered. Division by zero will follow. The program is terminated in DSPRSN2.FOR. Check tortuousity and rerun.
8. %WARNING - ARRAY OUT OF BOUND
   Not enough memory allocated for x dimension. Parameter declaration of MX is #, While the number of grid blocks is #. Please set MX>= # in NUT_PARAM.INC and rerun
9. %WARNING - ARRAY OUT OF BOUND
   Not enough memory allocated for y dimension. Parameter declaration of MY is #, While the number of grid blocks is #. Please set MY>= # in NUT_PARAM.INC and rerun
10. %WARNING - ARRAY OUT OF BOUND
    Not enough memory allocated for z dimension. Parameter declaration of MZ is #, While the number of grid blocks is #. Please set MZ>= # in NUT_PARAM.INC

11. %WARNING - ARRAY OUT OF BOUND
    Not enough memory allocated for total number of grid blocks. Parameter declaration of NB is #, While the number of grid blocks is #. Please set NB>= # in NUT_PARAM.INC and rerun
12. End of file encountered, "execution terminated", check the time! if >= 10000 yrs, normal completion (print the time in second and years).
13. Material Map of time zero is not in BRAGFLO input. Execution is terminated in subroutine MAT_MAP.
14. Material Map of time zero is not in NUTS input. Execution is terminated in subroutine MAT_MAP.
15. Inconsistency in the # of materials. Execution is terminated in MAT_MAP.
16. Unable to read parameter from BRAGFLO input
    Execution is stopped
    ------ Diagnosis -------

17. End of file is encountered in CDB_INITM_CONC_FLAG. Program is terminated
18. End of file is encountered in PHYSPROP. Program is terminated
19. End of file is encountered in ADS_INPUT. Program is terminated
20. End of file is encountered in MATDSP_INPUT. Program is terminated
21. End of file is encountered in FRCDSP_INPUT. Program is terminated
22. End of file is encountered in COMPMOL_DIFFUSION. Program is terminated
23. End of file is encountered in ROCK_DENSITY_INPUT. Program is terminated
24. End of file is encountered in WASTE_MATRIX_INPUT. Program is terminated
25. End of file is encountered in SITE_FLAG. Program is terminated
26. End of file is encountered in MATADS_FLAG. Program is terminated
27. End of file is encountered in FRCADS_FLAG. Program is terminated
28. End of file is encountered in KDTEMPDEP_FLAG. Program is terminated
29. End of file is encountered in MATDSP_FLAG. Program is terminated
30. End of file is encountered in FRCDSP_FLAG. Program is terminated
31. End of file is encountered in MATFRCDSP_FLAG. Program is terminated
32. End of file is encountered in MOLDIFTEMDEP_FLAG. Program is terminated
33. End of file is encountered in MATSRC_FLAG. Program is terminated

34. End of file is encountered in FRCPRINT_FLAG. Program is terminated
35. End of file is encountered in FRCSRC_FLAG. Program is terminated
36. End of file is encountered in MATPRINT_FLAG. Program is terminated
37. End of file is encountered in PRNTFREQ_FLAG. Program is terminated
38. End of file is encountered in EXTSRC_FLAG. Program is terminated
39. End of file is encountered in INTRUSION_TIME_SUB. Program is terminated
40. End of file is encountered in ZEROLIMIT. Program is terminated
41. End of file is encountered in INITF_CONC_MAN. Program is terminated
42. End of file is encountered in INITM_CONC_MAN. Program is terminated

43. End of file is encountered in CONC_INIT_INPUT. Program is terminated
44. End of file is encountered in SCALE_FACT_COLLOID_INPUT. Program is terminated
45. End of file is encountered in SOURCE_INPUT. Program is terminated
46. %%% WARNING %%%
    Zero value index is detected. Execution is terminated in IND_INTERPOLATE SUB.
47. %%% WARNING %%%
    Zero value index is detected. Execution is terminated in IND1D_INTERPOLATE SUB.
48. Division by zero. Element (element name)
49. Not enough memory allocated for the nuclides. Parameter declaration of NC is #, While the number of radionuclides is #. Please set NC>= # in NUT_PARAM.INC and rerun
50. No data available to read after # time steps of BRAGFLO. The program is terminated.
51. WARNING !!! WARNING !!!WARNING !!! WARNING !!!
    Number of sites specified by NUTS input is different from the number given in BRAGFLO. Execution will be terminated.

Warning Messages

1. WARNING !!! WARNING !!!
   DT<=0 is detected DT will be set To #
2. WARNING !!! WARNING !!!WARNING !!! WARNING !!!
   Number of sites specified by NUTS input is "1", different from number of waste regions "(>1)" specified by BRAGFLO. Number of waste regions will be collapsed to number of sites specified by NUTS input.
3. !!! WARNING !!!
   For component # grid block # has row entry = # < #, the minimum value in the table of that component. The value is reset to the minimum value.
4. !!! WARNING !!!
   For component # grid block # has row entry = # > #, the maximum value in the table of that component. The value is reset to the maximum value.
5. !!! WARNING !!!
   For component # grid block # has column entry = # < #, the minimum value in the table of that component. The value is reset to the minimum value.
6. !!! WARNING !!!
   For component # grid block # has column entry = # > #, the maximum value in the table of that component. The value is reset to the maximum value.
7. No sorption isotherm has been specified. No sorption will be considered.

Appendix J: An Example of NUTS's Debug Output File

```
NUTS_PA96 2.02 PROD PA96 05/23/96                                    05/24/96 11:45:54

N     NN  UU    UU  TTTTTT    SSSSSS            PPPPPP    AAAAA      9999     6666
NN    NN  UU    UU    TT     SS                 PP    PP  AA   AA   9    9   6
NNN   NN  UU    UU    TT     SS                 PP    PP  AA   AA   9    9   6
NN N  NN  UU    UU    TT      SSSSS             PPPPPP    AAAAAAA    99999   66666
NN   NNN  UU    UU    TT          SS            PP        AA   AA        9   6    6
NN    NN  UU    UU    TT          SS            PP        AA   AA        9   6    6
NN     N   UUUUU     TT     SSSSSS   _______    PP        AA   AA     9999     6666

                    NUTS - Nuclide Transport System Model

                         NUTS_PA96 Version 2.02
                        PROD PA96 Built 05/23/96
                         Written by Ali Shinta
                        Sponsored by Ali Shinta

                      Run on 05/24/96 at 11:45:54
                   Run on ALPHA AXP BEATLE OpenVMS V6.1

          ************************************************************

          Prepared for
          Sandia National Laboratories
          Albuquerque, New Mexico 87185-5800
          for the United States Department of Energy
          under Contract DE-AC04-76DP00789

          ************************************************************

                                Disclaimer
                                ----------

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          United States Government, any agency thereof or any of their
          contractors or subcontractors. The views and opinions
          expressed herein do not necessarily state or reflect those
          of the United States Government, any agency thereof or any
          of their contractors or subcontractors.

          ************************************************************

*******************************************************************************

FILE ASSIGNMENTS:
-----------------
POSTBRAG_T CDB file:
   WP$TESTROOT:[NUT.TEST.TEST4]NUT_TEST_CDPDC.IN;1
      Written on 01/24/96 12:00:08
Is this a TEST RUN? (Y/N):
   Y
I/O: (ASC, BIN, ASC-BIN):
   ASC
```

```
NUTS Input data file:
   WP$TESTROOT:[NUT.TEST.TEST4]NUT_CDPDC.IN;8
      Written on 05/24/96 11:39:43
NUTS Output CDB file:
   WP$TESTROOT:[NUT.TEST.TEST4]NUT_CDPDC.OUT
NUTS Diagnostic/Debug data file:
   WP$TESTROOT:[NUT.TEST.TEST4]NUT_CDPDC.DBG
Calculate for LIQUID or GAS? (L/G):
   L
BRAGFLO input file:

Read NUCLIDE related Material Properties from CDB or from NUTS input file (CDB/N:
   N
SOLUBILITY AND INVENTORY CDB:

UNDISTRUBED SCENARIO CDB:

                    !!!!!!!!!!!! DIGNOSTIC MESSAGES !!!!!!!!!!!!
                    !!!!!!!!!!!!!! TEST FILE INPUT !!!!!!!!!!!!!!!


*****************************************************************************
*****************************************************************************
                    NORMAL COMPLETION READING THE INPUT FILE
                    WP$TESTROOT:[NUT.TEST.TEST4]NUT_TEST_CDPDC.IN;1
*****************************************************************************
*****************************************************************************
               ******** START SUBROUTINE ONED3DINDEX ********

               ******** END SUBROUTINE ONED3DINDEX ********

               <><> START READING FROM READ_RAD SUB. <><>

                    !!!!!!!!!!!! DIGNOSTIC MESSAGES !!!!!!!!!!!!
                    !!!!!!!!!!!!!! NUTS INPUT !!!!!!!!!!!!!!
                    !!!!!!!!! GENERAL PROPERTIES !!!!!!!!!


*****************************************************************************
*****************************************************************************
                    NORMAL COMPLETION READING NUCLIDES PROPERTIES FROM
                    WP$TESTROOT:[NUT.TEST.TEST4]NUT_CDPDC.IN;8
*****************************************************************************
*****************************************************************************


*****************************************************************************
*****************************************************************************
                    NORMAL COMPLETION READING THE MATRIX PROPERTIES FROM
                    WP$TESTROOT:[NUT.TEST.TEST4]NUT_CDPDC.IN;8
*****************************************************************************
*****************************************************************************
               <><> FINISH READING FROM READ_RAD. <><>

               <><> START INITIALIZATION IN INITIALIZATION SUB. <><>

               <><> END INITIALIZATION IN INITIALIZATION SUB. <><>

               ******** START SUBROUTINE STOTALMAS ********

               ******** END SUBROUTINE STOTALMAS ********

               ******** START SUBROUTINE NTOTALMAS ********

               ******** END SUBROUTINE NTOTALMAS ********

               ******* START SUBROUTINE CURIES_VALUES *******
```

```
******* END SUBROUTINE CURIES_VALUES *******

******* START SUBROUTINE CNTOTALMAS *******

******* END SUBROUTINE CNTOTALMAS *******

++++++ START WRITING IN ASC_WRITE SUB. +++++++
 FIRST CALL, THE VARIABLES ARE INITIALIZED ABOVE

THE FOLLOWING INFORMATION IS BASICALLY AN ECHO
FOR THE INPUT DATA AND INITIALIZATION OF THE
CONCENTRATION AND PRECIPITATION

++++++++++++++ START TIMELOOP ++++++++++++++
\/\/\/
```

```
0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
```

```
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
            +*! CALCULATION STARTED AT DSPRSN1 SUB +*!
            {{{{
```

```
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

---- Dispersion in Z-Direction ----


Dispersion of COMP1

  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
            $$$ CALCULATION STARTED AT ADSORP SUB $$$
            [][][][][][][][][][][][][][][][][][][][][][][][][][]
%%% NO MATRIX SORPTION CALCULATION IS REQUIRED %%%

            $$$ CALCULATION ENDED IN ADSORP $$$!
---- sorption in all Blocks ----


Sorption of COMP1

  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
            ::::::::: START IN MATRIX PRDECAY SUB. :::::::::

            :::::: CALCULATION ENDED IN PRDECAY :::::::
---- Precipitate Decay in all Blocks ----


Precipitate Decay of COMP1

  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
```

```
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
            {{{{{{{{{ START IN MATRIX DECAYSOURCE SUB. }}}}}}}}}

            {{{{{{ CALCULATION ENDED IN DECAYSOURCE }}}}}}
---- Decay Coefficient in all Blocks ----


Decay Coefficient of COMP1

  0.14400E-09  0.14400E-09  0.14400E-09  0.14400E-09  0.14400E-09
```

```
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
  0.0000E+00   0.4000E-03   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
      ///// START IN MATRIX DECAY_SUM COMPONENT COMP1                  /////

            ///// END DECAY_SUM FOR COMPONENT COMP1                  /////
---- The Parent Contribution Is ----

  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
            ->->->-> START IN CONC_MATRIX SUB.->->->->

            ->->->-> CALCULATION ENDED IN CONC_MATRIX ->->->->
---- The Concentration Matrix Is ----

REFERENCE HALF BAND WIDTH =     1

  0.0000E+00   0.0000E+00   0.1000E+39   0.2000E-03   0.0000E+00   0.1000E+39
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
  0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
```

```
 0.0000E+00   0.6000E-03  -0.2652E-02   0.2000E-03   0.0000E+00   0.0000E+00
```

0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2652E-02	0.2000E-03
0.6000E-03	-0.2052E-02	0.0000E+00

XXXXX FRACTURE CONCENTRATION OF COMP1 XXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

XXXXX MATRIX CONCENTRATION OF COMP1 XXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

0.10000E+01	0.23026E+00	0.53018E-01	0.12208E-01	0.28109E-02
0.64722E-03	0.14903E-03	0.34314E-04	0.79010E-05	0.18192E-05
0.41889E-06	0.96452E-07	0.22209E-07	0.51137E-08	0.11775E-08
0.27111E-09	0.62426E-10	0.14374E-10	0.33097E-11	0.76207E-12
0.17547E-12	0.40403E-13	0.93030E-14	0.21421E-14	0.49322E-15
0.11357E-15	0.26150E-16	0.60211E-17	0.13864E-17	0.31922E-18
0.73503E-19	0.16925E-19	0.38970E-20	0.89730E-21	0.20661E-21
0.47573E-22	0.10954E-22	0.25222E-23	0.58075E-24	0.13372E-24
0.30790E-25	0.70895E-26	0.16324E-26	0.37587E-27	0.86546E-28
0.19928E-28	0.45885E-29	0.10565E-29	0.24327E-30	0.56014E-31
0.12898E-31	0.29697E-32	0.68380E-33	0.15745E-33	0.36254E-34
0.83476E-35	0.19221E-35	0.44261E-36	0.10240E-36	0.29944E-37

&&&&&&&& START IN MATRIX PRECIPITATE SUB. &&&&&&&&

&&&&& CALCULATION ENDED IN PRECIPITATE SUB. &&&&&

---------- Precipitate ----------

Precipitate of COMP1

```
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
END END END END END END END END END END
BYE BYE BYE BYE BYE BYE BYE BYE BYE BYE
||||||||||||||||||||||||||||||||||||||||
****************************************

******** START SUBROUTINE STOTALMAS ********

******** END SUBROUTINE STOTALMAS ********

******** START SUBROUTINE NTOTALMAS ********

******** END SUBROUTINE NTOTALMAS ********

******* START SUBROUTINE CURIES_VALUES *******

******* END SUBROUTINE CURIES_VALUES *******

******* START SUBROUTINE CNTOTALMAS *******

******* END SUBROUTINE CNTOTALMAS *******
```

Appendix K: FORTRAN Program to Convert NUTS's Binary Output to a Readable Format

NUTS_BIN_READ Procedure:

A FORTRAN listing for the procedures that can be used to read the binary files from NUclide Transport System (NUTS) is provided in this appendix. A discription of the variables and a descriptive line before the main functions of the procedure are also included to increase the readability of the subroutines.

```
C
C***************** START SUBROUTINE NUTS_BIN_READ *****************
C
                    SUBROUTINE NUTS_BIN_READ
C
C-----------------------------------------------------------------
C
C                         NUTS_BIN_READ
C
C       Purpose:
C       --------
C       This subroutine reads NUTS output binary file
C
C       Author:         Ali A. Shinta
C       -------
C
C       Call:  BRE33D, BRE23D
C
C       Arguments:
C       ----------
C DXGRID              Grid block length in x-direction
C DYGRID              Grid block length in y-direction
C DZGRID              Grid block length in z-direction
C ZTIME              Total time
C IFLAGTIME          Flag = 0 for time = 0 and 1 otherwise
C NO_TIMESTEP Time step no.
C SDATE              Date of the run
C STIME              Time of the run
C NPNAME             Program name
C NVRSION            Program version no.
C NREVDATE           Revision date
C NCPUNAME           Name of the machine on which the run is conducted
C ANSWERTEST Flag to tell if the input is from BRAGFLO or stand alone file
C FINFILETYPE Output files type
C COMBTITLE          A combination of NUTS title and BRAGFLO or TEST run title
C INTITLE            BRAGFLO or TEST run title
C NUTS_TITLE         NUTS title
C IDIMENSION         No. of dimensions
C RADINPUT           Nuts input file name
C FILE_NAME          BRAGFLO or test run input file name
C RADOUTDBG   NUTS ASCII debug output file name
C RADOUTPUT   NUTS output file name
C RADOUTBIN   Output Binary name
C RADOUTASC   Output ASCII file name
C MEDIUM             Type of the porous medium (fracture, matrix, etc..)
C FRACTUR             Logical flag to identify fracture continuum
C MATRIX             Logical flag to identify matrix continuum
C SINGLE_POROSITY     Logical flag to identify single-porosity system
C DUAL_POROSITY        Logical flag to identify dual-porosity
C DUAL_PERMEABILITY Logical flag to identify dual-permeability system
C NBLOCK             Total number of grid blocks
C NX OR IMAX         No. of grid blocks in x-direction
C NY OR JMAX         No. of grid blocks in y-direction
C NZ OR KMAX  No. of grid blocks in z-direction
```

```
C NOCONTINUM  No. of continum
C NO_PHASES          Number of phases
C X                  Grid block x-coordinate
C Y                  Grid block x-coordinate
C Z                  Grid block x-coordinate
C AXGRID             Interblock area in x-direction (I,I-1)
C AYGRID             Interblock area in y-direction (J,J-1)
C AZGRID             Interblock area in z-direction (K,K-1)
C VRGRID             Grid volume
C PHREQ              Flag to identify pH dependency (Y/N)
C PHGRID             Grid block ground water pH
C NSITES             No. of radioactive sites
C NUCLIDE            Total number of radionuclide
C SITE_NAME          Name of the disposal site
C COMPONENT_NAME Component name
C NAME        Component name
C Daughter_NAME      Component daughter name
C ELEMENT_NAME       Element name
C GROUP_NAME  Group under which the isotope is classified, i.e: U for
U235,238,......etc.
C PARENT_NAME Component parent name
C NCOMPONENT  No. of the components in each site
C WASTEVOL           Site's waste vol in M3.
C COMPINT            Initial inventory of the component in Kg.
C XMOLWT             Molecular weight
C XLAMDA             Decay constant of the component in 1/s.
C RAD                Character to identify the component radioactivity (radioactive and
not_radioactive)
C NOELEMENT   No. of the input elements
C ELSOLB_LIMIT_COR Element solubility limit (Kg/M3) of block I
C ELTEMP_SOLB Logical variable to identify if the element solubility is temperature
dependent
C ELEMNT_SOLB_LIMIT  Element solubility limit
C C0-5               Solubility parameters for temperature dependency correlation
C PHASETYPE          Phase type to be transported (liquid or gas)
C EQCI               Intercept of the equilibrium line for gas solubility in the ground
water
C EQCS        Slope of the equilibrium line for gas solubility in the ground water
C IWASTE             Waste matrix, 1=waste node, 0=no-waste node.
C ADSTYPEM or F      Flag to identify whether sorption is considered (Y/N)
C MAT_ISOTHERM       Type of the adsorp. isotherm in the matrix
C                    L/l=Linear,F/f=Freundlich,LA/La/la=Langumir
C FRAC_ISOTHERM      Type of the adsorp. isotherm in the fracture
C                    L/l=Linear,F/f=Freundlich,LA/La/la=Langumir
C MSORPTION          Flag to identify whether the component is
C                    sorbable in the matrix (ADSORP/NON_ADSORP)
C MADSTEMPDEP Logical flag to identify whether the component sorption is temp.
dependent
C FSORPTION          Flag to identify whether the component is
C                    sorbable in the matrix (ADSORP/NON_ADSORP)
C FADSTEMPDEP Logical flag to identify whether the component sorption is temp.
dependent


C XLMGRID            Linear sorption coefficient in the matrix ({M3 fluid}/{Kg solid})
C XLFGRID            Linear sorption coefficient in the fracture ({M3 fluid}/{Kg
solid})
C XFCMGRID           Freundlich coefficient in the matrix (dimensionless).
C XFDCMGRID          Freundlich distribution coefficient in the matrix ({M3 fluid}/{Kg
solid}).
C XLCMGRID           Langumir coefficient in the matrix (dimensionless).
C XLDCMGRID          Langumir distribution coefficient in the matrix
C XFCFGRID           Freundlich coefficient in the fracture (dimensionless).
C XFDCFGRID          Freundlich distribution coefficient in the fracture ({M3
fluid}/{Kg solid}).
C XLCFGRID           Langumir coefficient in the fracture (dimensionless).
C XLDCFGRID          Langumir distribution coefficient in the fracture
C REFTEMPKD          Reference temperature of Kd measurment
C ADSEXPCOEFF Coefficient to adjust sorption at new temperature
```

```
C RHOGRID            Grid block rock density (kg/m3)
C MDISPREQ           Flag to identify whether there is dispersion in the matrix (Y/N)
C FDISPREQ           Flag to identify whether there is dispersion in the matrix (Y/N)
C MFDISPREQ          Flag to identify whether there is dispersion between matrix and
fracture (Y/N)
C ALLMGRID           Longitudinal matrix dispersivity
C ALLFGRID           Longitudinal fracture dispersivity
C ALTMGRID           Transverse matrix dispersivity
C ALTFGRID           Transverse fracture dispersivity
C TORMGRID           Matrix tortousity
C TORFGRID           Matrix tortousity
C DMOL         Molecular diffusion at reference temperature (M2/s.)
C DMOLTEMDEP Logical flag to identify whether the molecular diffusion
C                    is temperature dependent (.T./.F.)
C TREF         Reference temperature (K)
C VISREF             Viscocity at reference temperature TREF (Pa/s)
C FSTATUSINJ         Flag to identify whether there is injection in the fracture (Y/N)
C MSTATUSINJ Flag to identify whether there is injection in the matrix (Y/N)
C STOCKMAN           Logical flag to identify whether NUTS interfaces with actinide
source submodel
C TIMEMSTRT          Starting time of injection/production in the matrix (s)
C TIMEMEND           Ending time of injection/production in the matrix (s)
C TIMEFSTRT          Starting time of injection/production in the fracture (s)
C TIMEFEND           Ending time of injection/production in the fracture (s)
C CONCINJMGRID       Concentration of the injected component j in grid i of the matrix
(kg/m3)
C CONCINJFGRID       Concentration of the injected component j in grid i of the
fracture (kg/m3)
C FDIRICHLET         Flag to identify whether dirichlet B.C. is available in the
fracture (T/F)
C MDIRICHLET Flag to identify whether dirichlet B.C. is available in the matrix (T/F)
C CONCDIRMGRID       Specified concentration for D.B.C. in the matrix block (kg/m3)
C CONCDIRFGRID       Specified concentration for D.B.C. in the matrix block (kg/m3)
C IPRFRQA            Frequency of print in ASCII file (ex:5=each 5 timesteps)
C IPRFRQB            Frequency of print in BINARY file
C IPRNTFA            Flag to print the fracture variable in ASCII file
C IPRNTFB            Flag to print the fracture variable in BINARY file
C IPRNTMA            Flag to print the matrix variable in ASCII file
C IPRNTMB            Flag to print the matrix variable in BINARY file
C IPRNTMc            Flag to print the matrix variable in CDB file
C VAR                Printed variable name
C DEBUG              Logical flag to generate debug file and variables
C SWMOLDGRID Matrix saturation at time level n
C PORMOLDGRID Matrix porosity at time level n
C SWFOLDGRID Fracture saturation at time level n
C PORFOLDGRID Fracture porosity  at time level n
C BRVOLGRID          Brine volume in each matrix grid (m3)
C SUMM_DISGRID       Matrix total mass per grid block of the dissolved isotopes
C SUMF_DISGRID       Fracture total mass per grid block of the dissolved isotopes
C SUMM_PRECIPGRID  Matrix total mass per grid block of the precipitated isotopes
C SUMF_PRECIPGRID   Fracture total mass per grid block of th eprecipitated isotopes
C SUMM_TOTALGRID  Matrix total mass per grid block of the dissolved,
C                    precipitated, and sorbed isotopes
C SUMF_TOTALGRID     Fracture total mass per grid block of the dissolved,
C                    precipitated, and sorbed isotopes
C CSUMM_DISGRID      Matrix total curies per grid block of the dissolved isotopes
C CSUMF_DISGRID      Fracture total curies per grid block of the dissolved isotopes
C CSUMM_PRECIPGRID  Matrix total curies per grid block of the precipitated isotopes
C CSUMF_PRECIPGRID   Fracture total curies per grid block of th eprecipitated isotopes
C CSUMM_TOTALGRID  Matrix total curies per grid block of the dissolved,
C                      precipitated, and sorbed isotopes
C CSUMF_TOTALGRID    Fracture total curies per grid block of the dissolved,
C                        precipitated, and sorbed isotopes
C CM                 Concentration of the isotope in the matrix at time level n+1
C CMOLD              Concentration of the isotope in the matrix at time level n
C CF                 Concentration of the isotope in the fracture  at time level n+1
C CFOLD              Concentration of the isotope in the fracture  at time level n
C BLOCF_DIS_MASSGRID       Fracture mass of dissolved isotope per grid volume Kg/(M3
rock).
```

```
C BLOCM_DIS_MASSGRID        Matrix mass of dissolved isotope per grid volume in Kg/(M3
rock).
C BLOCF_PRC_MASSGRID        Fracture mass of precipitated isotope per grid volume Kg/(M3
rock).
C BLOCM_PRC_MASSGRID  Matrix mass of precipitated isotope per grid volume Kg/(M3
rock).
C ADPRCONM_TOTAL_MASSGRID Total mass resulted from dissolved, precipitated and
C                               sorbed isotopes in the matrix
C ADPRCONF_TOTAL_MASSGRID Total mass resulted from dissolved, precipitated and
C                               sorbed isotopes in the fracture
C VOLM_CONC_CURIESGRID      Equivalent curies of the volumetric concentration in the
matrix
C VOLF_CONC_CURIESGRID      Equivalent curies of the volumetric concentration in
thefracture
C DISM_MASS_CURIESGRID      Curies of the dissolved mass per grid block in the matrix
C DISF_MASS_CURIESGRID      Curies of the dissolved mass per grid block in the fracture
C PRCIPM_MASS_CURIESGRID    Curies of the precipitated mass per grid block in the matrix
C PRCIPF_MASS_CURIESGRID          Curies of the precipitated mass per grid block in the
matrix
C TOTALM_MASS_CURIESGRID    Curies of the total mass (dissolved + sorbed + Precipitate)
                                per grid block in the matrix
C TOTALF_MASS_CURIESGRID    Curies of the total mass (dissolved + sorbed + Precipitate)
                                per grid block in the fracture
C FLUXJM1MGRID              Fluxes crossing grid block lower interface in y-direction in
the matrix (kg/s)
C FLUXJF1MGRID              Fluxes crossing grid block lower interface in y-direction in
the fracture (kg/s)
C FLUXIM1MGRID              Fluxes crossing grid block left interface in x-direction in
the matrix (kg/s)
C FLUXIF1MGRID              Fluxes crossing grid block left interface in x-direction in
the fracture (kg/s)
C CONDMMASSGRID             Gas mass that dissolve in the grid block brine of the matrix
(kg)
C CONDFMASSGRID             Gas mass that dissolve in the grid block brine of the matrix
(kg)
C QWXF_GRID                 Water interblock rate in x-direction in the fracture (m3/s)
C QWYF_GRID                 Water interblock rate in y-direction in the fracture (m3/s)
C QWZF_GRID                 Water interblock rate in z-direction in the fracture (m3/s)
C QWXM_GRID          Water interblock rate in x-direction in the matrix (m3/s)
C QWYM_GRID          Water interblock rate in y-direction in the matrix (m3/s)
C QWZM_GRID          Water interblock rate in z-direction in the matrix (m3/s)
C QPRMGRID                  Matrix production rate (M3 /s)
C QINMGRID                  Matrix injection rate (M3 /s)
C BLOCKMBMMAX        Maximum residual among matrix blocks
C CMBIM                     Isotope material balance error for the time step in the
matrix
C CMBTM                     Cumulative isotope material balance error in the matrix
C SUMRTM                    Cumulative residuals in the matrix
C SUMQTM                    Cumulative sources in the matrix
C BLOCKMBFMAX        Maximum residual among fracture blocks
C CMBIF                     Isotope material balance error for the time step in the
fracture
C CMBTF                     Cumulative isotope material balance error in the fracture
C SUMRTF                    Cumulative residuals in the fracture
C SUMQTF                    Cumulative sources in the fracture
C JBIN                      NUTS binary output file unit number
C
C*****************************************************************************
C*****************************************************************************


C-----------------------------------------------------------------
C
      INCLUDE 'PARAMBR.INC'
      INCLUDE 'BINRHEAD.INC'
      COMMON/D3SIZE/NX,NY,NZ
      INTEGER NX,NY,NZ,I,J,KK
C
C------------------------ READ TIME INFORMATION ------------------------
C
```

```
      READ(JBIN)ZTIME,IFLAGTIME,NO_TIMESTEP
C
C!!!!!!!!!!!!!!!!!!!!!! START READING INITIAL VARIABLES !!!!!!!!!!!!!!!!!!!!!
C
      IF(IFLAGTIME .EQ. 0) THEN
C
C------------------------ READ PROGRAM HEADINGS (QA INFORMATION)
------------------------
C
      READ (JBIN) SDATE
      READ (JBIN) STIME
      READ (JBIN) NPNAME
      READ (JBIN) NVRSION
      READ (JBIN) NREVDATE
      READ (JBIN) NCPUNAME
C
C------------------------ READ THE RUN TITLES AND FILES' TYPE ------------------------
-----------
C
      READ(JBIN) ANSWERTEST,FINFILETYPE
      READ(JBIN) COMBTITLE,INTITLE,NUTS_TITLE
C
C--------------------- READ THE FILES' NAMES ----------------------
C
      READ(JBIN) RADINPUT,FILE_NAME,RADOUTPUT
      IF(FINFILETYPE .EQ. 'ASC' .OR. FINFILETYPE .EQ. 'ASC-BIN'
     1 .OR. FINFILETYPE .EQ. 'ASC-CDB' .OR. FINFILETYPE .EQ.
     2 'ASC-BIN-CDB' .OR. DEBUG)
     3 READ(JBIN) RADOUTASC
      IF(FINFILETYPE .EQ. 'BIN' .OR. FINFILETYPE .EQ. 'ASC-BIN'
     1 .OR. FINFILETYPE .EQ. 'BIN-CDB' .OR. FINFILETYPE .EQ.
     2 'ASC-BIN-CDB')
     3 READ(JBIN) RADOUTBIN
      IF(FINFILETYPE .EQ. 'CDB' .OR. FINFILETYPE .EQ. 'ASC-CDB'
     1 .OR. FINFILETYPE .EQ. 'BIN-CDB' .OR. FINFILETYPE .EQ.
     2 'ASC-BIN-CDB')
     3 READ(JBIN) RADOUTCDB

C
C--------------- READ MEDIA TYPE AND LOGICAL CONTROLS ----------------
C
      READ(JBIN) MEDIUM,FRACTURE,MATRIX,SINGLE_POROSITY,
     & DUAL_POROSITY,DUAL_PERMEABILITY
C
C---------------- READ THE TOTAL NUMBER OF GRID BLOCKS --------------
C
      READ(JBIN) NBLOCK
C
C-------------------- READ DIMENSIONS OUTPUT -----------------------
C
      READ(JBIN) IDIMENSION,NX,NY,NZ,DIRECTION
      READ(JBIN) NOCONTINUM,NO_PHASES
C
C---------------- Grid Grid Block Length (x-direction)
C
      CALL BRE33D(DXGRID,JBIN)
C
C---------------- Grid Grid Block Width (y-direction)
C
      CALL BRE33D(DYGRID,JBIN)
C
C---------------- Grid Grid Block Hight (z-direction)
C
      CALL BRE33D(DZGRID,JBIN)
C
C--------------- READ Grid Block X,Y,Z COORDINATE
C
      CALL BRE33D(X,JBIN)
      CALL BRE33D(Y,JBIN)
      CALL BRE33D(Z,JBIN)
```

```
C
C------------------------ Read Grid Block Volume ---------------------
C
      CALL BRE33D(VRGRID,JBIN)
C
C------------------- Read Interface Area in x-direction ----------------
C
      CALL BRE33D(AXGRID,JBIN)
C
C------------------- Read Interface Area in y-direction ----------------
C
      CALL BRE33D(AYGRID,JBIN)
C
C------------------- Read Interface Area in z-direction ----------------
C
      CALL BRE33D(AZGRID,JBIN)
C
C------------------------ Read Ground Water pH -------------------------
C
      READ(JBIN) PHREQ
      IF(PHREQ .EQ. 'Y' .OR. PHREQ .EQ. 'y') CALL BRE33D(PHGRID,JBIN)
C
C------------------------ WASTE INFORMATION ----------------------
C
      READ(JBIN) NUCLIDE, NSITES
C
C----------------------- SITE INFORMATION
C
      READ(JBIN) (SITE_NAME(I), NCOMPONENT(I),WASTEVOL(I),
     & I=1,NSITES)
      READ(JBIN) (NAME(I),DAUGHTER_NAME(I),PARENT_NAME(I),
     & GROUP_NAME(I), I=1,NUCLIDE)
C
      READ(JBIN)(XMOLWT(I),RAD(I),XLAMDA(I),COMPINT(I),I=1,NUCLIDE)
C
C---------------SOLUBILITY DATA
C
      READ(JBIN) NOELEMENT
      READ(JBIN) (ELTEMP_SOLB(I), I = 1,NOELEMENT)
      DO I = 1, NOELEMENT
          IF(.NOT. ELTEMP_SOLB(I)) THEN
C
C<><><><><><> ELEMENT NAME,TEMP. DEPENDENCY,SOLUBILITY LIMIT
C
      READ(JBIN) ELEMENT_NAME(I),ELEMNT_SOLB_LIMIT(I)
          ELSE
C
C<><><><><><> ELEMENT NAME,TEMP. DEPENDENCY,CORRELATION PARAMETERS
C
      READ(JBIN) ELEMENT_NAME(I),C0(I),C1(I),C2(I),
     & C3(I),C4(I),C5(I)
      ENDIF
      END DO
C
C------------------ GAS EQUILIBRIUM LINE CONSTANTS ---------------------
C
      IF(PHASETYPE .EQ. 'G')
     & READ(JBIN) (EQCI(I),EQCS(I), I = 1,NUCLIDE)
C
C------------------- WASTE MATRIX
C
      READ(JBIN)((IWASTE(I,J),I=1,NBLOCK),J=1,NUCLIDE)
C
C------------------------- SORPTION INPUT INFORMATION -------------
C
C************* MATRIX SORPTION
C
                    IF(MATRIX) THEN
      READ(JBIN) ADSTYPEM
      IF(ADSTYPEM .EQ. 'N' .OR. ADSTYPEM .EQ. 'n') GO TO 100
```

```
      READ(JBIN) MAT_ISOTHERM
      READ(JBIN)(NAME(J),MSORPTION(J),MADSTEMPDEP(J),J=1,NUCLIDE)
C
C-------------- LINEAR DISTRIBUTION COEFFICIENTS ------------
C
      IF(MAT_ISOTHERM .EQ. 'L' .OR. MAT_ISOTHERM .EQ. 'l') THEN
      DO 10 J = 1, NUCLIDE
      CALL BRE23D(XLMGRID,JBIN,J)
 10   CONTINUE
      ENDIF
C
C------------- FREUNDLICH DISTRIBUTION COEFFICIENTS --------------
C
      IF(MAT_ISOTHERM .EQ. 'F' .OR. MAT_ISOTHERM .EQ. 'f') THEN
      DO 20 J = 1, NUCLIDE
      CALL BRE23D(XFDCMGRID,JBIN,J)
 20   CONTINUE
      DO 30 J = 1, NUCLIDE
      CALL BRE23D(XFCMGRID,JBIN,J)
 30    CONTINUE
      ENDIF
C
C-------------- LANGUMIR DISTRIBUTION COEFFICIENTS -------------
C
      IF(MAT_ISOTHERM .EQ. 'LA' .OR. MAT_ISOTHERM .EQ. 'La'
     &     .OR. MAT_ISOTHERM .EQ. 'la') THEN
      DO 40 J = 1, NUCLIDE
      CALL BRE23D(XLDCMGRID,JBIN,J)
 40   CONTINUE
      DO 50 J = 1, NUCLIDE
      CALL BRE23D(XLCMGRID,JBIN,J)
 50   CONTINUE
      ENDIF
 100   CONTINUE
                    ENDIF
C
C*************** FRACTURE SORPTION
C
                    IF(FRACTURE) THEN
      READ(JBIN) ADSTYPEF
      IF(ADSTYPEF .EQ. 'N' .OR. ADSTYPEF .EQ. 'n') GO TO 200
      READ(JBIN) FRAC_ISOTHERM
      READ(JBIN)(NAME(J),FSORPTION(J),FADSTEMPDEP(J),J=1,NUCLIDE)
C
C-------------- LINEAR DISTRIBUTION COEFFICIENTS ------------
C
      IF(FRAC_ISOTHERM .EQ. 'L' .OR. FRAC_ISOTHERM .EQ. 'l') THEN
      DO 110 J = 1, NUCLIDE
      CALL BRE23D(XLFGRID,JBIN,J)
 110  CONTINUE
      ENDIF
C
C------------- FREUNDLICH DISTRIBUTION COEFFICIENTS -------------
C
      IF(FRAC_ISOTHERM .EQ. 'F' .OR. FRAC_ISOTHERM .EQ. 'f') THEN
      DO 120 J = 1, NUCLIDE
      CALL BRE23D(XFDCFGRID,JBIN,J)
 120  CONTINUE
      DO 130 J = 1, NUCLIDE
      CALL BRE23D(XFCFGRID,JBIN,J)
 130  CONTINUE
      ENDIF
C
C-------------- LANGUMIR DISTRIBUTION COEFFICIENTS -------------
C
      IF(FRAC_ISOTHERM .EQ. 'LA' .OR. FRAC_ISOTHERM .EQ. 'La'
     &     .OR. FRAC_ISOTHERM .EQ. 'la') THEN
      DO 140 J = 1, NUCLIDE
      CALL BRE23D(XLDCFGRID,JBIN,J)
 140  CONTINUE
```

```
      DO 150 J = 1, NUCLIDE
      CALL BRE23D(XLCFGRID,JBIN,J)
 150  CONTINUE
      ENDIF
 200   CONTINUE
                    ENDIF
C
C-------------- REFERENCE TEMP. AND SORPTION EXPONENT -------------
C
      IF((ADSTYPEF .EQ. 'Y' .OR. ADSTYPEF .EQ. 'y') .OR.
     & (ADSTYPEM .EQ. 'Y' .OR. ADSTYPEM .EQ. 'Y')) THEN
       DO I = 1, NUCLIDE
      IF(FADSTEMPDEP(I) .OR. MADSTEMPDEP(I))
     & READ(JBIN)NAME(J),REFTEMPKD(J),ADSEXPCOEFF(J)
       END DO
       ENDIF
C
C--------------------- ROCK DENSITY OUTPUT ----------------------
C
      IF(ADSTYPEM .EQ. 'N' .OR. ADSTYPEM .EQ. 'n' .AND.
     &  ADSTYPEF .EQ. 'N' .OR. ADSTYPEF .EQ. 'n') GO TO 300
      CALL BRE33D(RHOGRID,JBIN)
C
 300   CONTINUE
C
C---------------------------- DISPERSION ---------------------------
C
      IF(SINGLE_POROSITY .AND. FRACTURE) READ(JBIN) FDISPREQ
      IF(SINGLE_POROSITY .AND. MATRIX) READ(JBIN) MDISPREQ
      IF(DUAL_POROSITY .OR. DUAL_PERMEABILITY)
     & READ(JBIN) MDISPREQ,MFDISPREQ,FDISPREQ
C
C************************ MATRIX
C
                    IF(MATRIX) THEN
      IF(MDISPREQ .EQ. 'N' .OR. MDISPREQ .EQ. 'n') GO TO 400
C
C--------------------- MATRIX LONGITUDINAL DISPERSIVITY -------------
C

      CALL BRE33D(ALLMGRID,JBIN)
C
C--------------------- ROCK TRANSVERSE DISPERSIVITY -------------
C
      CALL BRE33D(ALTMGRID,JBIN)
C
C--------------------- ROCK TORTOUSITY DATA -------------
C
      CALL BRE33D(TORMGRID,JBIN)
C
 400   CONTINUE
                    ENDIF
C
C************************ FRACTURE
C
                    IF(FRACTURE) THEN
      IF(FDISPREQ .EQ. 'N' .OR. FDISPREQ .EQ. 'n') GO TO 500
C
C------------------ FRACTURE LONGITUDINAL DISPERSIVITY -------------
C
      CALL BRE33D(ALLFGRID,JBIN)
C
C--------------------- FRACTURE TRANSVERSE DISPERSIVITY -------------
C
      CALL BRE33D(ALTFGRID,JBIN)
C
C--------------------- FRACTURE TORTOUSITY DATA -------------
C
      CALL BRE33D(TORFGRID,JBIN)
 500   CONTINUE
```

```
                    ENDIF
C
C---------------------MOLECULAR DIFFUSION DATA -------------
C
      IF((MDISPREQ .EQ. 'Y' .OR. MDISPREQ .EQ. 'y') .OR.
     & (FDISPREQ .EQ. 'Y' .OR. MDISPREQ .EQ. 'y')) THEN
      READ(JBIN) (DMOLTEMDEP(I), I = 1, NUCLIDE)
      DO I = 1, NUCLIDE
      IF(.NOT. DMOLTEMDEP(I)) THEN
C
C<><><><><> MOLECULAR DIFFUSION,TEMP. DEPENDENCY
C
      READ(JBIN) DMOL(I)
      ENDIF
      IF(DMOLTEMDEP(I)) THEN
C
C<><><><> MOLECULAR DIFFUSION,TEMP. DEPENDENCY,REF. TEMP & VISCOSITY
C
      READ(JBIN) DMOL(I),TREF(I),VISREF(I)
      ENDIF
      END DO
      ENDIF
C
C-------------------- INJECTION HISTORY ---------------------
C
      IF(SINGLE_POROSITY .AND. FRACTURE)
     & READ(JBIN) FSTATUSINJ,STOCKMAN
C
      IF(SINGLE_POROSITY .AND. MATRIX)
     & READ(JBIN) MSTATUSINJ,STOCKMAN
C
      IF(DUAL_POROSITY .OR. DUAL_PERMEABILITY)
     & READ(JBIN) MSTATUSINJ,FSTATUSINJ,STOCKMAN
C
      IF(STOCKMAN) GO TO 901
C
C***************** MATRIX
C
                    IF(MATRIX) THEN
      IF(MSTATUSINJ .EQ. 'N' .OR. MSTATUSINJ .EQ. 'n') GO TO 700
      READ(JBIN) TIMEMSTRT, TIMEMEND
      DO 600 J = 1,NUCLIDE
      CALL BRE23D(CONCINJMGRID,JBIN,J)
 600    CONTINUE
 700    CONTINUE
                    ENDIF
C
C******************* FRACTURE
C
                    IF(FRACTURE) THEN
      IF(FSTATUSINJ .EQ. 'N' .OR. FSTATUSINJ .EQ. 'n') GO TO 900
      READ(JBIN) TIMEFSTRT, TIMEFEND
      DO 800 J = 1,NUCLIDE
      CALL BRE23D(CONCINJFGRID,JBIN,J)
 800    CONTINUE
 900    CONTINUE
                    ENDIF
 901  CONTINUE
C
C-------------- SPECIFY DIRICHLET B.C. IF ANY ----------------------
C
      IF(SINGLE_POROSITY .AND. FRACTURE) READ(JBIN) FDIRICHLET
      IF(SINGLE_POROSITY .AND. MATRIX) READ(JBIN) MDIRICHLET
      IF(DUAL_POROSITY .OR. DUAL_PERMEABILITY)
     & READ(JBIN) MDIRICHLET,FDIRICHLET
C
C******************* MATRIX
C
              IF(MATRIX) THEN
      IF(MDIRICHLET) THEN
```

```
      DO 902 J = 1,NUCLIDE
      CALL BRE23D(CONCDIRMGRID,JBIN,J)
 902    CONTINUE
      ENDIF
            ENDIF
C
C******************* FRACTURE
C
                    IF(FRACTURE) THEN
      IF(FDIRICHLET) THEN
      DO 904 J = 1,NUCLIDE
      CALL BRE23D(CONCDIRFGRID,JBIN,J)
 904    CONTINUE
      ENDIF
                    ENDIF
C----------------- READ PRINT FLAGS OF THE BINARY FILE -----------------
C----------- SPECIFY NUMBER OF OUTPUT ARRAYS AND THEIR TITLES --------
C
      IF(FINFILETYPE .EQ. 'BIN' .OR. FINFILETYPE .EQ. 'ASC-BIN'
     1 .OR. FINFILETYPE .EQ. 'BIN-CDB' .OR. FINFILETYPE .EQ.
     2 'ASC-BIN-CDB'.OR. DEBUG) THEN
C
C*********** MATRIX
C
            IF(MATRIX) THEN
      READ(JBIN) (IPRNTMB(I), I = 1, NMVARB)
      DO 910 I = 1, NVARTIT/2
      IF(IPRNTMB(I) .GT. 0) READ(JBIN) VAR(I)
 910  CONTINUE
            ENDIF
C
C*********** FRACTURE
C
            IF (FRACTURE) THEN
      READ(JBIN) (IPRNTFB(I), I = 1, NFVARB)
      KK = 0
      DO 920 I = NVARTIT/2+1, NVARTIT
      KK = KK + 1
      IF(IPRNTFB(KK) .GT. 0) READ(JBIN) VAR(I)
 920  CONTINUE
            ENDIF
                    ENDIF
C
C******************** READ PRINT FLAGS OF ASCII FILES
C
      IF(FINFILETYPE .EQ. 'ASC' .OR. FINFILETYPE .EQ. 'ASC-BIN'
     1 .OR. FINFILETYPE .EQ. 'ASC-CDB' .OR. FINFILETYPE .EQ.
     2 'ASC-BIN-CDB'.OR. DEBUG) THEN
C
C+++++++++++++++++ FRACTURE OUTPUT FLAGS
C
      IF(FRACTURE) READ(JBIN) (IPRNTFA(I), I = 1, NFVARA)
C
C+++++++++++++++++ MATRIX OUTPUT FLAGS
C
      IF(MATRIX) READ(JBIN) (IPRNTMA(I), I = 1, NMVARA)
                    ENDIF
C
C******************** READ PRINT FLAGS OF CDB FILES
C
      IF(FINFILETYPE .EQ. 'CDB' .OR. FINFILETYPE .EQ. 'ASC-CDB'
     1 .OR. FINFILETYPE .EQ. 'BIN-CDB' .OR. FINFILETYPE .EQ.
     2 'ASC-BIN-CDB'.OR. DEBUG) THEN
C
C+++++++++++++++++ FRACTURE OUTPUT FLAGS
C
      IF(FRACTURE) READ(JBIN) (IPRNTFC(I), I = 1, NFVARC)
C
C+++++++++++++++++ MATRIX OUTPUT FLAGS
C
```

```
      IF(MATRIX) READ(JBIN) (IPRNTMC(I), I = 1, NMVARC)
                 ENDIF
C
C==================== START MATRIX INITIALIZATION ====================
C
C------------------- Matrix Porosity Initialization -----------------
C
                 IF(MATRIX) THEN
      CALL BRE33D(PORMOLDGRID,JBIN)
C
C------------------- Matrix Saturation Initialization ---------------
C
      CALL BRE33D(SWMOLDGRID,JBIN)
C
C------------------- BRINE VOLUME Initialization --------------------
C
      CALL BRE33D(BRVOLGRID,JBIN)
C
C------------------- TOTAL DISSOLVED MASS PER GRID BLOCK ------------
C
      IF(IPRNTMB(1) .GT. 0) CALL BRE33D (SUMM_DISGRID,JBIN)
C
C----------------TOTAL PRECIPITATED MASS PER GRID BLOCK ---------------
C
      IF(IPRNTMB(2) .GT. 0) CALL BRE33D (SUMM_PRECIPGRID,JBIN)
C
C----------------- THE TOTAL OF DISSOLVED, PRECIPITATED, ---------------
C--------------------- AND SORBED MASS PER GRID BLOCK -----------------
C
      IF(IPRNTMB(3) .GT. 0) CALL BRE33D (SUMM_TOTALGRID,JBIN)
C
C---------------- TOTAL DISSOLVED CURIES PER GRID BLOCK ----------------
C
      IF(IPRNTMB(4) .GT. 0) CALL BRE33D (CSUMM_DISGRID,JBIN)
C
C--------------- TOTAL PRECIPITATED CURIES PER GRID BLOCK --------------
C
      IF(IPRNTMB(5) .GT. 0) CALL BRE33D (CSUMM_PRECIPGRID,JBIN)
C
C----------------- THE TOTAL OF DISSOLVED, PRECIPITATED, ---------------
C------------------- AND SORBED CURIES PER GRID BLOCK -----------------
C
      IF(IPRNTMB(6) .GT. 0) CALL BRE33D (CSUMM_TOTALGRID,JBIN)
C
      DO 1000 J = 1, NUCLIDE
      READ(JBIN) NAME(J)
C
C------------------- INITIAL VOLUMETRIC CONCENTRATION ---------------
C
      IF(IPRNTMB(7) .GT. 0) CALL BRE23D(CMOLDGRID,JBIN,J)
C
C----------------------- INITIAL DISSOLVED MASS --------------------
C
      IF(IPRNTMB(8) .GT. 0) CALL BRE23D(BLOCM_DIS_MASSGRID,JBIN,J)
C
C----------------- INITIAL MASS OF THE PRECIPITATE ------------------
C
      IF(IPRNTMB(9) .GT. 0) CALL BRE23D(BLOCM_PRC_MASSGRID,JBIN,J)
C
C----------------- INITIAL TOTAL MASS ON SOIL BASIS -----------------
C
      IF(IPRNTMB(10) .GT. 0)
     & CALL BRE23D(ADPRCONM_TOTAL_MASSGRID,JBIN,J)
C
C----------------- INITIAL CURIES OF VOLUMETRIC CONCENTRATION ---------
C
      IF(IPRNTMB(11) .GT. 0)
     & CALL BRE23D(VOLM_CONC_CURIESGRID,JBIN,J)
C
C----------------- INITIAL CURIES OF DISSOLVED NUCLIDES -------------
```

```
C
      IF(IPRNTMB(12) .GT. 0)
     & CALL BRE23D(DISM_MASS_CURIESGRID,JBIN,J)
C
C----------------- INITIAL CURIES OF THE PRECIPITATE -------------
C
      IF(IPRNTMB(13) .GT. 0)
     & CALL BRE23D(PRCIPM_MASS_CURIESGRID,JBIN,J)
C
C-------------------- INITIAL CURIES OF TOTAL MASS -----------------
C
      IF(IPRNTMB(14) .GT. 0)
     & CALL BRE23D(TOTALM_MASS_CURIESGRID,JBIN,J)
 1000 CONTINUE
                    ENDIF
C
C==================== START FRACTURE INITIALIZATION ====================
C
C--------------------- Fracture Porosity Initialization --------------
C
              IF(FRACTURE) THEN
      CALL BRE33D(PORFOLDGRID,JBIN)
C
C-------------------- Fracture Saturation Initialization --------------
C
      CALL BRE33D(SWFOLDGRID,JBIN)
C
C------------------ TOTAL DISSOLVED MASS PER GRID BLOCK -----------------
C
      IF(IPRNTFB(1) .GT. 0) CALL BRE33D (SUMF_DISGRID,JBIN)
C
C----------------TOTAL PRECIPITATED MASS PER GRID BLOCK ----------------
C
      IF(IPRNTFB(2) .GT. 0) CALL BRE33D (SUMF_PRECIPGRID,JBIN)
C
C----------------- THE TOTAL OF DISSOLVED, PRECIPITATED, ----------------
C---------------------- AND SORBED MASS PER GRID BLOCK -----------------
C
      IF(IPRNTFB(3) .GT. 0) CALL BRE33D (SUMF_TOTALGRID,JBIN)
C
C---------------- TOTAL DISSOLVED CURIES PER GRID BLOCK -----------------
C
      IF(IPRNTFB(4) .GT. 0) CALL BRE33D (CSUMF_DISGRID,JBIN)
C
C--------------- TOTAL PRECIPITATED CURIES PER GRID BLOCK ---------------
C
      IF(IPRNTFB(5) .GT. 0)CALL BRE33D (CSUMF_PRECIPGRID,JBIN)
C
C----------------- THE TOTAL OF DISSOLVED, PRECIPITATED, ----------------
C-------------------- AND SORBED CURIES PER GRID BLOCK -----------------
C
      IF(IPRNTFB(6) .GT. 0)CALL BRE33D (CSUMF_TOTALGRID,JBIN)
C
      DO 2000 J = 1, NUCLIDE
      READ(JBIN) NAME(J)
C
C------------------ INITIAL VOLUMETRIC CONCENTRATION -----------------
C
      IF(IPRNTFB(7) .GT. 0)CALL BRE23D(CFOLDGRID,JBIN,J)
C
C----------------------- INITIAL DISSOLVED MASS --------------------
C
      IF(IPRNTFB(8) .GT. 0)CALL BRE23D(BLOCF_DIS_MASSGRID,JBIN,J)
C
C----------------- INITIAL MASS OF THE PRECIPITATE -----------------
C
      IF(IPRNTFB(9) .GT. 0)CALL BRE23D(BLOCF_PRC_MASSGRID,JBIN,J)
C
C-------------------- TOTAL MASS ON SOIL BASIS --------------------
C
```

```
      IF(IPRNTFB(10) .GT. 0)
     & CALL BRE23D(ADPRCONF_TOTAL_MASSGRID,JBIN,J)
C
C----------------- INITIAL CURIES OF VOLUMETRIC CONCENTRATION ----------
C
      IF(IPRNTFB(11) .GT. 0)
     & CALL BRE23D(VOLF_CONC_CURIESGRID,JBIN,J)
C
C----------------- INITIAL CURIES OF DISSOLVED NUCLIDES -------------
C
      IF(IPRNTFB(12) .GT. 0)
     & CALL BRE23D(DISF_MASS_CURIESGRID,JBIN,J)
C
C----------------- INITIAL CURIES OF THE PRECIPITATE -------------
C
      IF(IPRNTFB(13) .GT. 0)
     & CALL BRE23D(PRCIPF_MASS_CURIESGRID,JBIN,J)
C
C------------------- INITIAL CURIES OF TOTAL MASS -----------------
C
      IF(IPRNTFB(14) .GT. 0)
     & CALL BRE23D(TOTALF_MASS_CURIESGRID,JBIN,J)
 2000 CONTINUE
C
                          ENDIF
                                RETURN
                                      ENDIF
C
C!!!!!!!!!!!!!!!!!!!!!!!!!!! END OF INTIALIZATION AND INPUT ECHO
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
C
C
C!!!!!!!!!!!!!!!!!! OUTPUT TIME DEPENDENT VARIABLES !!!!!!!!!!!!!!!!!!
C
C%%%%%%%%%%  SPECIAL INTEREST VARIABLES OUTPUT %%%%%%%%%%%
C
C------------------ MASS FLUXES CROSSING J-1 AND I-1 BOUNDARIES ----------------
C************* MATRIX
C
      IF(SINGLE_POROSITY .AND. MATRIX) THEN
      DO 2500 J = 1, NUCLIDE
      READ(JBIN) NAME(J)
      CALL BRE23D(FLUXJM1MGRID,JBIN,J)
      CALL BRE23D(FLUXIM1MGRID,JBIN,J)
 2500 CONTINUE
      ENDIF
C
C*************** FRACTURE
C
      IF(SINGLE_POROSITY .AND. FRACTURE) THEN
      DO 2600 J = 1, NUCLIDE
      READ(JBIN) NAME(J)
      CALL BRE23D(FLUXJM1FGRID,JBIN,J)
       CALL BRE23D(FLUXIM1FGRID,JBIN,J)
 2600 CONTINUE
      ENDIF
C
C*************** DUAL-POROSITY OR DUAL-PERMEABILITY
C
      IF(DUAL_POROSITY .OR. DUAL_PERMEABILITY) THEN
      DO 2700 J = 1, NUCLIDE
      READ(JBIN) NAME(J)
      CALL BRE23D(FLUXJM1TGRID,JBIN,J)
      CALL BRE23D(FLUXIM1TGRID,JBIN,J)
 2700 CONTINUE
      ENDIF
C
C---------------------- MASS DISSOLVED IN THE BRINE  FROM GAS PHASE -----------------
C
                    IF(PHASETYPE .EQ. 'G') THEN
```

```
C
C******************** MATRIX
C
        IF(SINGLE_POROSITY .AND. MATRIX) THEN
        DO 2710 J = 1, NUCLIDE
        READ(JBIN) NAME(J)
        CALL BRE23D(CONDMMASSGRID,JBIN,J)
 2710   CONTINUE
        ENDIF
C
C******************** FARCTURE
C
      IF(SINGLE_POROSITY .AND. FRACTURE) THEN
        DO 2720 J = 1, NUCLIDE
        READ(JBIN) NAME(J)
        CALL BRE23D(CONDFMASSGRID,JBIN,J)
 2720   CONTINUE
        ENDIF
C
C************ DUAL POROSITY OR DUAL PERMEABILITY
C
      IF(DUAL_POROSITY .OR. DUAL_PERMEABILITY) THEN
      DO 2730 J = 1, NUCLIDE
      READ(JBIN) NUCLIDE
        CALL BRE23D(CONDMMASSGRID,JBIN,J)
        CALL BRE23D(CONDFMASSGRID,JBIN,J)
 2730 CONTINUE
            ENDIF
                        ENDIF
C
C----------------- SOURCE FROM THE ACTINIDE SOURCE SUBMODEL ---------------
C Note that the source is in kg/s and injected only in the fracture
C
            IF(STOCKMAN) THEN
      DO 2740 J = 1,NUCLIDE
      READ(JBIN) NUCLIDE
      CALL BRE23D(CONCINJFGRID,JBIN,J)
 2740   CONTINUE
            ENDIF
C
C------------------- BRINE INTERFACES VOLUMETRIC FLUXES (M3/S) ----------------------
C************** FRACURE
C
        IF(SINGLE_POROSITY .AND. FRACTURE) THEN
      CALL BRE33D (QWXF_GRID,JBIN)
      CALL BRE33D (QWYF_GRID,JBIN)
      ENDIF
C
C************** MATRIX
C
        IF(SINGLE_POROSITY .AND. MATRIX) THEN
      CALL BRE33D (QWXM_GRID,JBIN)
      CALL BRE33D (QWYM_GRID,JBIN)
      ENDIF
C
C**************** DUAL-PERMEABILITY OR POROSITY
C
        IF(DUAL_POROSITY .OR. DUAL_PERMEABILITY) THEN
      CALL BRE33D (QWXF_GRID,JTEMP)
      CALL BRE33D (QWYF_GRID,JTEMP)
      CALL BRE33D (QWXM_GRID,JTEMP)
      CALL BRE33D (QWYM_GRID,JTEMP)
      ENDIF
CI
CI=====================================================================I
CI                              MATRIX                                I
CI=====================================================================I
C
            IF(MATRIX) THEN
C
```

```
C--------------------- PRODUCTION RATE OF EACH BLOCK --------------------
C
      CALL BRE33D (QPRMGRID,JBIN)
C
C---------------------- INJECTION RATE OF EACH BLOCK --------------------
C
      CALL BRE33D (QINMGRID,JBIN)
C
C------------------- BRINE VOLUME IN EACH GRID BLOCK---------------
C
      CALL BRE33D(BRVOLGRID,JBIN)
C
C%%%%%%%%%%%  USER SPECIFIED VARIABLES OUTPUT %%%%%%%%%%%%
C
C
C------------------ TOTAL DISSOLVED MASS PER GRID BLOCK -----------------
C
      IF(IPRNTMB(1) .GT. 0) CALL BRE33D (SUMM_DISGRID,JBIN)
C
C----------------TOTAL PRECIPITATED MASS PER GRID BLOCK ----------------
C
      IF(IPRNTMB(2) .GT. 0) CALL BRE33D (SUMM_PRECIPGRID,JBIN)
C
C----------------- THE TOTAL OF DISSOLVED, PRECIPITATED, ----------------
C--------------------- AND SORBED MASS PER GRID BLOCK -----------------
C
      IF(IPRNTMB(3) .GT. 0) CALL BRE33D (SUMM_TOTALGRID,JBIN)
C
C---------------- TOTAL DISSOLVED CURIES PER GRID BLOCK -----------------
C
      IF(IPRNTMB(4) .GT. 0) CALL BRE33D (CSUMM_DISGRID,JBIN)
C
C--------------- TOTAL PRECIPITATED CURIES PER GRID BLOCK ---------------
C
      IF(IPRNTMB(5) .GT. 0) CALL BRE33D (CSUMM_PRECIPGRID,JBIN)
C
C----------------- THE TOTAL OF DISSOLVED, PRECIPITATED, ----------------
C------------------- AND SORBED CURIES PER GRID BLOCK -----------------
C
      IF(IPRNTMB(6) .GT. 0) CALL BRE33D (CSUMM_TOTALGRID,JBIN)
C
      DO 3000 J = 1, NUCLIDE
      READ(JBIN) NAME(J)
C
C======================= VOLUMETRIC CONCENTRATION =======================
C
      IF(IPRNTMB(7) .GT. 0) CALL BRE23D(CMGRID,JBIN,J)
C
C============================ DISSOLVED MASS ============================
C
      IF(IPRNTMB(8) .GT. 0) CALL BRE23D(BLOCM_DIS_MASSGRID,JBIN,J)
C
C======================= MASS OF THE PRECIPITATE ========================
C
      IF(IPRNTMB(9) .GT. 0) CALL BRE23D(BLOCM_PRC_MASSGRID,JBIN,J)
C
C======================= TOTAL MASS ON SOIL BASIS =======================
C
      IF(IPRNTMB(10) .GT. 0)
     & CALL BRE23D(ADPRCONM_TOTAL_MASSGRID,JBIN,J)
C
C================== CURIES OF VOLUMETRIC CONCENTRATION ==================
C
      IF(IPRNTMB(11) .GT. 0)
     & CALL BRE23D(VOLM_CONC_CURIESGRID,JBIN,J)
C
C===================== CURIES OF DISSOLVED NUCLIDES =====================
C
      IF(IPRNTMB(12) .GT. 0)
     & CALL BRE23D(DISM_MASS_CURIESGRID,JBIN,J)
```

```
C
C====================== CURIES OF THE PRECIPITATE =======================
C
      IF(IPRNTMB(13) .GT. 0)
     & CALL BRE23D(PRCIPM_MASS_CURIESGRID,JBIN,J)
C
C========================= CURIES OF TOTAL MASS =========================
C
      IF(IPRNTMB(14) .GT. 0)
     & CALL BRE23D(TOTALM_MASS_CURIESGRID,JBIN,J)
C
C------------------- MATRIX MATERIAL BALANCE ERROR --------------------
C
      READ(JBIN)NAME(J),BLOCKMBMMAX(J),CMBIM(J),CMBTM(J),
     & SUMRTM(J),SUMQTM(J)
 3000 CONTINUE
                          ENDIF
C
CI=====================================================================I
CI                              FRACTURE                              I
CI=====================================================================I
C
            IF(FRACTURE) THEN
C
C--------------------- PRODUCTION RATE OF EACH BLOCK --------------------
C
      CALL BRE33D (QPRFGRID,JBIN)
C
C---------------------- INJECTION RATE OF EACH BLOCK --------------------
C
      CALL BRE33D (QINFGRID,JBIN)
C
C%%%%%%%%%%  USER SPECIFIED VARIABLES OUTPUT %%%%%%%%%%%
C
C
C------------------ TOTAL DISSOLVED MASS PER GRID BLOCK -----------------
C
      IF(IPRNTFB(1) .GT. 0) CALL BRE33D (SUMF_DISGRID,JBIN)
C
C----------------TOTAL PRECIPITATED MASS PER GRID BLOCK ----------------
C
      IF(IPRNTFB(2) .GT. 0) CALL BRE33D (SUMF_PRECIPGRID,JBIN)
C
C----------------- THE TOTAL OF DISSOLVED, PRECIPITATED, ----------------
C--------------------- AND SORBED MASS PER GRID BLOCK -----------------
C
      IF(IPRNTFB(3) .GT. 0) CALL BRE33D (SUMF_TOTALGRID,JBIN)
C
C---------------- TOTAL DISSOLVED CURIES PER GRID BLOCK -----------------
C
      IF(IPRNTFB(4) .GT. 0) CALL BRE33D (CSUMF_DISGRID,JBIN)
C
C--------------- TOTAL PRECIPITATED CURIES PER GRID BLOCK ---------------
C
      IF(IPRNTFB(5) .GT. 0) CALL BRE33D (CSUMF_PRECIPGRID,JBIN)
C
C----------------- THE TOTAL OF DISSOLVED, PRECIPITATED, ----------------
C------------------- AND SORBED CURIES PER GRID BLOCK -----------------
C
      IF(IPRNTFB(6) .GT. 0) CALL BRE33D (CSUMF_TOTALGRID,JBIN)
      DO 4000 J = 1, NUCLIDE
      READ(JBIN) NAME(J)
C
C======================= VOLUMETRIC CONCENTRATION =======================
C
      IF(IPRNTFB(7) .GT. 0) CALL BRE23D(CFGRID,JBIN,J)
C
C============================ DISSOLVED MASS ============================
C
      IF(IPRNTFB(8) .GT. 0) CALL BRE23D(BLOCF_DIS_MASSGRID,JBIN,J)
```

```
C
C======================= MASS OF THE PRECIPITATE =======================
C
      IF(IPRNTFB(9) .GT. 0) CALL BRE23D(BLOCF_PRC_MASSGRID,JBIN,J)
C
C======================= TOTAL MASS ON SOIL BASIS =======================
C
      IF(IPRNTFB(10) .GT. 0)
     & CALL BRE23D(ADPRCONF_TOTAL_MASSGRID,JBIN,J)
C
C=================== CURIES OF VOLUMETRIC CONCENTRATION =================
C
      IF(IPRNTFB(11) .GT. 0)
     & CALL BRE23D(VOLF_CONC_CURIESGRID,JBIN,J)
C
C==================== CURIES OF DISSOLVED NUCLIDES ======================
C
      IF(IPRNTFB(12) .GT. 0)
     & CALL BRE23D(DISF_MASS_CURIESGRID,JBIN,J)
C
C======================= CURIES OF THE PRECIPITATE ======================
C
      IF(IPRNTFB(13) .GT. 0)
     & CALL BRE23D(PRCIPF_MASS_CURIESGRID,JBIN,J)
C
C========================= CURIES OF TOTAL MASS =========================
C
      IF(IPRNTFB(14) .GT. 0)
     & CALL BRE23D(TOTALF_MASS_CURIESGRID,JBIN,J)
C
C------------------- FRACTURE MATERIAL BALANCE ERROR --------------------
C
      READ(JBIN)NAME(J),BLOCKMBFMAX(J),CMBIF(J),CMBTF(J),
     & SUMRTF(J),SUMQTF(J)
 4000 CONTINUE
                          ENDIF

C
C*********************************************************************
C
      RETURN
C
C%%%%%%%%%%%%% END OF SUBROUTINE NUTS_BIN_READ %%%%%%%%%%%%%%%%%%
C
      END
C
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C
C******************* START SUBROUTINE BRE33D ********************
C
      SUBROUTINE BRE33D(ARRAY,JTEMP)
C
C-------------------------------------------------------------------
C
C                              BRE33D
C
C       Purpose:
C       --------
C      This subroutine read 3D variable from a binary file in a single
C      precision format
C
C       Author:         Ali A. Shinta
C       -------
C
C      Call:  NONE
C      Called by: NUTS_BIN_READ
C       Arguments:
C       ----------
C      ARRAY  Single precision 3D variable
C      JTEMP  Input file unit number
```

```
C
C-----------------------------------------------------------------
C
      INCLUDE 'PARAMBR.INC'
      IMPLICIT NONE
      COMMON/D3SIZE/NX,NY,NZ
      INTEGER NX,NY,NZ,I,J,K,JTEMP
      DIMENSION ARRAY(MX,MY,MZ)
      REAL ARRAY
      DO 10 K = 1, NZ
      DO 10 J = 1, NY
      DO 10 I = 1, NX
      ARRAY(I,J,K) = 0.0
 10   CONTINUE
C
      READ(JTEMP)(((ARRAY(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
C
      RETURN
C
C%%%%%%%%%%%%%%%%%%%% END OF SUBROUTINE BRE33D %%%%%%%%%%%%%%%
C
      END
C
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C
C******************** START SUBROUTINE BRE23D ********************
C
      SUBROUTINE BRE23D(VAROUTPUT,JTEMP,ICOUNT)
C
C-----------------------------------------------------------------
C
C                              BRE23D
C
C       Purpose:
C       --------
C      This subroutine read a single precision 3D variable from BINARY
C      file an return it as 4D.
C
C       Author:          Ali A. Shinta
C       -------
C
C      Call:  None
C      Called by: NUTS_BIN_READ
C       Arguments:
C       ----------
C      VAROUTPUT            4D single precision variable
C      ARRAY          Single precision 3D variable
C
C-----------------------------------------------------------------
C
      INCLUDE 'PARAMBR.INC'
      IMPLICIT NONE
      COMMON/D3SIZE/NX,NY,NZ
      INTEGER NX,NY,NZ,I,J,K,JTEMP,ICOUNT
      DIMENSION ARRAY(MX,MY,MZ),VAROUTPUT(MX,MY,MZ,NC)
      REAL ARRAY,VAROUTPUT
C
      DO 10 K = 1, NZ
      DO 10 J = 1, NY
      DO 10 I = 1, NX
      ARRAY(I,J,K) = 0.0
 10   CONTINUE
C
      READ(JTEMP)(((ARRAY(I,J,K),I=1,NX),J=1,NY),K=1,NZ)
C
      DO 20 K = 1, NZ
      DO 20 J = 1, NY
      DO 20 I = 1, NX
```

```
      VAROUTPUT(I,J,K,ICOUNT) = 0.0
      VAROUTPUT(I,J,K,ICOUNT) = ARRAY(I,J,K)
 20   CONTINUE
C
      RETURN
C
C%%%%%%%%%%%% END OF SUBROUTINE  BRE23D %%%%%%%%%%%%%%%%
C
      END
C%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
C
C*********************************************************************
C---------------------------- BINRHEAD.INC ---------------------------
C*********************************************************************
C
C-------------------------------------------------------------------
C
C                          BINRHEAD.INC
C
C       Purpose:
C       --------
C      This include file has the common blocks and the declarations
C      required for NUTS_BIN_READ.
C
C       Author:          Ali A. Shinta
C       -------
C
C       Call: NONE
C      Called By: NUTS_BIN_READ
C
C       Arguments:
C       ----------
C       AS DEFINED PREVIOUSLY
C-------------------------------------------------------------------
C
        IMPLICIT NONE
C
C-------------------------------------------------------------------
      COMMON/DIMENSION/DXGRID(MX,MY,MZ),DYGRID(MX,MY,MZ),
     & DZGRID(MX,MY,MZ),VRGRID(MX,MY,MZ),AXGRID(MX,MY,MZ),
     & AYGRID(MX,MY,MZ),AZGRID(MX,MY,MZ),X(MX,MY,MZ),
     & Y(MX,MY,MZ),Z(MX,MY,MZ),NBLOCK,IDIMENSION,
     & DIRECTION
C
      REAL DXGRID,DYGRID,DZGRID,VRGRID,AXGRID,AYGRID,AZGRID,X,Y,Z
C
      INTEGER NBLOCK,IDIMENSION
C
      CHARACTER*10 DIRECTION
C-------------------------------------------------------------------
      COMMON/PROPERTIES/RHOGRID(MX,MY,MZ),QPRMGRID(MX,MY,MZ),
     & QPRFGRID(MX,MY,MZ),QINMGRID(MX,MY,MZ),QINFGRID(MX,MY,MZ),
     & PHGRID(MX,MY,MZ),PORFOLDGRID(MX,MY,MZ),PORMOLDGRID(MX,MY,MZ),
     & SWFOLDGRID(MX,MY,MZ),SWMOLDGRID(MX,MY,MZ),PHREQ
C
      REAL RHOGRID,QPRMGRID,QPRFGRID,QINMGRID,QINFGRID,PHGRID,
     & PORFOLDGRID,PORMOLDGRID,SWFOLDGRID,SWMOLDGRID
C
      CHARACTER*20 PHREQ
C-------------------------------------------------------------------
      COMMON/MISCELL/ZTIME,IFLAGTIME,NUCLIDE,NO_PHASES,NOCONTINUM,
     &  NO_TIMESTEP
C
      REAL ZTIME
C
      INTEGER IFLAGTIME,NUCLIDE,NO_PHASES,NOCONTINUM,NO_TIMESTEP
```

```
C-----------------------------------------------------------------------
      COMMON/UFNAMETITLES/JBIN,FINFILETYPE,ANSWERTEST,RADINPUT,
     & RADOUTPUT,RADOUTBIN,RADOUTASC,RADOUTCDB,VAR(NVARTIT),
     & NUTS_TITLE,INTITLE,COMBTITLE,FILE_NAME,DEBUG
C
      INTEGER JBIN
C
      CHARACTER*20 FINFILETYPE,ANSWERTEST
      CHARACTER*35 VAR
      CHARACTER*80 RADINPUT,RADOUTPUT,RADOUTBIN,RADOUTASC,
     & FILE_NAME,RADOUTCDB
      CHARACTER*100 NUTS_TITLE,INTITLE
      CHARACTER*132 COMBTITLE
C
      LOGICAL DEBUG
C-----------------------------------------------------------------------
      COMMON/FMMASSES/ADPRCONF_TOTAL_MASSGRID(MX,MY,MZ,NC),
     & ADPRCONM_TOTAL_MASSGRID(MX,MY,MZ,NC),
     & BLOCF_DIS_MASSGRID(MX,MY,MZ,NC),
     & BLOCM_DIS_MASSGRID(MX,MY,MZ,NC),
     & BLOCF_PRC_MASSGRID(MX,MY,MZ,NC),
     & BLOCM_PRC_MASSGRID(MX,MY,MZ,NC),
     & SUMF_DISGRID(MX,MY,MZ),
     & SUMF_PRECIPGRID(MX,MY,MZ),
     & SUMF_TOTALGRID(MX,MY,MZ),
     & SUMM_DISGRID(MX,MY,MZ),
     & SUMM_PRECIPGRID(MX,MY,MZ),
     & SUMM_TOTALGRID(MX,MY,MZ)
C
      REAL ADPRCONF_TOTAL_MASSGRID,ADPRCONM_TOTAL_MASSGRID,
     & BLOCF_DIS_MASSGRID,BLOCM_DIS_MASSGRID,BLOCF_PRC_MASSGRID,
     & BLOCM_PRC_MASSGRID,SUMF_DISGRID,SUMF_PRECIPGRID,
     & SUMF_TOTALGRID,SUMM_DISGRID,SUMM_PRECIPGRID,
     & SUMM_TOTALGRID
C-----------------------------------------------------------------------
      COMMON/FMCURIES/VOLM_CONC_CURIESGRID(MX,MY,MZ,NC),
     & DISM_MASS_CURIESGRID(MX,MY,MZ,NC),
     & PRCIPM_MASS_CURIESGRID(MX,MY,MZ,NC),
     & TOTALM_MASS_CURIESGRID(MX,MY,MZ,NC),
     & VOLF_CONC_CURIESGRID(MX,MY,MZ,NC),
     & DISF_MASS_CURIESGRID(MX,MY,MZ,NC),
     & PRCIPF_MASS_CURIESGRID(MX,MY,MZ,NC),
     & TOTALF_MASS_CURIESGRID(MX,MY,MZ,NC),
     & CSUMF_DISGRID(MX,MY,MZ),CSUMF_PRECIPGRID(MX,MY,MZ),
     & CSUMF_TOTALGRID(MX,MY,MZ),CSUMM_DISGRID(MX,MY,MZ),
     & CSUMM_PRECIPGRID(MX,MY,MZ),CSUMM_TOTALGRID(MX,MY,MZ)
C
      REAL VOLM_CONC_CURIESGRID,DISM_MASS_CURIESGRID,
     & PRCIPM_MASS_CURIESGRID,TOTALM_MASS_CURIESGRID,
     & VOLF_CONC_CURIESGRID,DISF_MASS_CURIESGRID,
     & PRCIPF_MASS_CURIESGRID,TOTALF_MASS_CURIESGRID,
     & CSUMF_DISGRID,CSUMF_PRECIPGRID,
     & CSUMF_TOTALGRID,CSUMM_DISGRID,
     & CSUMM_PRECIPGRID,CSUMM_TOTALGRID
C-----------------------------------------------------------------------
      COMMON/BACPRINTFLAGS/IPRNTFB(NFVARB),IPRNTMB(NMVARB),
     & IPRNTFA(NFVARA),IPRNTMA(NMVARA),
     & IPRNTFC(NFVARC),IPRNTMC(NMVARC)
C
      INTEGER IPRNTFB,IPRNTMB,IPRNTFA,IPRNTMA,IPRNTFC,IPRNTMC
C-----------------------------------------------------------------------
      COMMON/FMCONCMATBERR/CMBIF(NC),CMBTF(NC),SUMRTF(NC),
     & SUMQTF(NC),BLOCKMBFMAX(NC),CMBIM(NC),CMBTM(NC),
     & SUMRTM(NC),SUMQTM(NC),BLOCKMBMMAX(NC)
C
      REAL CMBIF,CMBTF,SUMRTF,SUMQTF,BLOCKMBFMAX,CMBIM,CMBTM,
     & SUMRTM,SUMQTM,BLOCKMBMMAX

C-----------------------------------------------------------------------
      COMMON/RADSITE/ELEMNT_SOLB_LIMIT(NC),C0(NC),C1(NC),C2(NC),
```

```
     & C3(NC),C4(NC),C5(NC),XMOLWT(NC),COMPINT(NC),WASTEVOL(NS),
     & XLAMDA(NC),IWASTE(NB,NC),NCOMPONENT(NS),NSITES,NOELEMENT,
     &   RAD(NC),ELTEMP_SOLB(NC)
C
      REAL ELEMNT_SOLB_LIMIT,C0,C1,C2,C3,C4,C5,XMOLWT,COMPINT,
     & WASTEVOL,XLAMDA
C
      INTEGER IWASTE,NCOMPONENT,NSITES,NOELEMENT
C
      CHARACTER*20 RAD
C
      LOGICAL ELTEMP_SOLB
C-----------------------------------------------------------------------
      COMMON/NAMES/PARENT_NAME(NC),NAME(NC),
     & DAUGHTER_NAME(NC),ELEMENT_NAME(NC),
     & GROUP_NAME(NC),SITE_NAME(NS)
C
      CHARACTER*20 PARENT_NAME,NAME,DAUGHTER_NAME,ELEMENT_NAME,
     & GROUP_NAME,SITE_NAME
C-----------------------------------------------------------------------
      COMMON/ADSORPPROP/XLFGRID(MX,MY,MZ,NC),XLMGRID(MX,MY,MZ,NC),
     & XFDCFGRID(MX,MY,MZ,NC),XFDCMGRID(MX,MY,MZ,NC),
     & XFCFGRID(MX,MY,MZ,NC),XFCMGRID(MX,MY,MZ,NC),
     & XLDCMGRID(MX,MY,MZ,NC),XLDCFGRID(MX,MY,MZ,NC),
     & XLCMGRID(MX,MY,MZ,NC),XLCFGRID(MX,MY,MZ,NC),
     & REFTEMPKD(NC),ADSEXPCOEFF(NC),
     & FSORPTION(NC),MSORPTION(NC),ADSTYPEF,
     & ADSTYPEM,MAT_ISOTHERM,FRAC_ISOTHERM,
     & MADSTEMPDEP(NC),FADSTEMPDEP(NC)
C
      REAL XLFGRID,XLMGRID,XFDCFGRID,XFDCMGRID,XFCFGRID,XFCMGRID,
     & XLDCMGRID,XLDCFGRID,XLCMGRID,XLCFGRID,REFTEMPKD,ADSEXPCOEFF
C
      CHARACTER*20 FSORPTION,MSORPTION,ADSTYPEF,ADSTYPEM,
     & MAT_ISOTHERM,FRAC_ISOTHERM
C
      LOGICAL MADSTEMPDEP,FADSTEMPDEP
C-----------------------------------------------------------------------
      COMMON/DISPPROP/ALLFGRID(MX,MY,MZ),ALTFGRID(MX,MY,MZ),
     & TORFGRID(MX,MY,MZ),ALLMGRID(MX,MY,MZ),ALTMGRID(MX,MY,MZ),
     & TORMGRID(MX,MY,MZ),DMOL(NC),VISREF(NC),TREF(NC),MDISPREQ,
     & FDISPREQ,MFDISPREQ,DMOLTEMDEP(NC)
C
      REAL ALLFGRID,ALTFGRID,TORFGRID,ALLMGRID,ALTMGRID,
     & TORMGRID,DMOL,VISREF,TREF
C
      CHARACTER*20 MDISPREQ,FDISPREQ,MFDISPREQ
C
      LOGICAL DMOLTEMDEP
C-----------------------------------------------------------------------
      COMMON/CONCFM/CFGRID(MX,MY,MZ,NC),CMGRID(MX,MY,MZ,NC),
     & CFOLDGRID(MX,MY,MZ,NC),CMOLDGRID(MX,MY,MZ,NC)
C
      REAL CFGRID,CMGRID,CFOLDGRID,CMOLDGRID
C-----------------------------------------------------------------------
      COMMON/CONCSOURCE/CONCINJFGRID(MX,MY,MZ,NC),
     & CONCDIRMGRID(MX,MY,MZ,NC),CONCDIRFGRID(MX,MY,MZ,NC),
     & CONCINJMGRID(MX,MY,MZ,NC),TIMEMSTRT,TIMEMEND,TIMEFSTRT,
     & TIMEFEND,MDIRICHLET,FDIRICHLET,MSTATUSINJ,FSTATUSINJ,STOCKMAN
C
      REAL CONCINJFGRID,CONCDIRMGRID,CONCDIRFGRID,CONCINJMGRID,
     & TIMEMSTRT,TIMEMEND,TIMEFSTRT,TIMEFEND
C
      CHARACTER*20 MSTATUSINJ,FSTATUSINJ
C
      LOGICAL MDIRICHLET,FDIRICHLET,STOCKMAN
C-----------------------------------------------------------------------
      COMMON/PORMEDIA/MEDIUM,FRACTURE,MATRIX,SINGLE_POROSITY,
     & DUAL_POROSITY,DUAL_PERMEABILITY
C
```

```
      CHARACTER*24 MEDIUM
C
      LOGICAL FRACTURE,MATRIX,SINGLE_POROSITY,DUAL_POROSITY,
     & DUAL_PERMEABILITY
C-----------------------------------------------------------------
      COMMON/HEADINGS/NPNAME,NVRSION,NREVDATE,NCPUNAME,SDATE,STIME
C
       CHARACTER SDATE*9,STIME*8,NCPUNAME*32
      CHARACTER*8 NPNAME, NVRSION,NREVDATE
C-----------------------------------------------------------------
      COMMON/INTERFLUXES/FLUXJM1MGRID(MX,MY,MZ,NC),
     & FLUXJM1FGRID(MX,MY,MZ,NC),FLUXJM1TGRID(MX,MY,MZ,NC),
     & FLUXIM1MGRID(MX,MY,MZ,NC),FLUXIM1FGRID(MX,MY,MZ,NC),
     & FLUXIM1TGRID(MX,MY,MZ,NC)
C
      REAL FLUXJM1MGRID,FLUXJM1FGRID,FLUXJM1TGRID,
     & FLUXIM1MGRID,FLUXIM1FGRID,FLUXIM1TGRID
C-----------------------------------------------------------------
       COMMON/BCONDMAS/CONDMMASSGRID(MX,MY,MZ,NC),
     & CONDFMASSGRID(MX,MY,MZ,NC),EQCI(NC),EQCS(NC),
     & PHASETYPE
C
      REAL CONDMMASSGRID,CONDFMASSGRID,EQCI,EQCS
C
      CHARACTER PHASETYPE*10
C-----------------------------------------------------------------
      COMMON/BRVOLGRID/BRVOLGRID(MX,MY,MZ)
      REAL*4 BRVOLGRID
C-----------------------------------------------------------------
      COMMON/BRINERATES/QWXF_GRID(MX,MY,MZ),QWYF_GRID(MX,MY,MZ),
     & QWXM_GRID(MX,MY,MZ),QWYM_GRID(MX,MY,MZ)
      REAL*4 QWXF_GRID,QWYF_GRID,QWXM_GRID,QWYM_GRID
C
C%%%%%%%%%%%%%%%%%% END OF BINRHEAD.INC   %%%%%%%%%%%%%%%%%%
C
```

Appendix L: Review Forms

As a convenience to users, this section contains a complete history of all the Quality-Assurance Review Forms issued during the review of this User's Manual. Review forms are issued after the User's Manual has been completed and reviewed. Thus, they will be appended to the manual after it has been paginated and therefore they may not, themselves, be paginated.

NOTE: Copies of the User's Manual Reviewer's Forms are available in the Sandia WIPP Central Files.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix PANEL

M

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

WIPP PA User's Manual for PANEL

WIPP PA

User's Manual

for

PANEL (Version 3.60)

Document Version 1.00

WPO #37361

MAY 10, 1996

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1.0 INTRODUCTION

This document is the User's Manual for the WIPP radioisotope-mobilization-and-decay code named PANEL (version number 3.60). It discusses the code, its execution, and its performance in the context of the 1996 Waste Isolation Pilot Project (WIPP) Compliance Certification Application (CCA) Performance Assessment (PA), and in that context only. The manual identifies the code, its authors and expert consultants (Section 1). It describes the code's WIPP-PA purposes and functions (Section 2), provides recommended user training (Section 3), outlines the code's theoretical basis and numerical methods (Section 4), its capabilities and limitations (Section 5), describes user interactions (Section 6), input files (Section 7), error messages (Section 8), and output files (Section 9), and provides examples of relevant input, output, and debug files in its Appendices as well as calculations of interest (distributed throughout).

1.1 Software Identifier:

Code Name: PANEL, a radioisotope-mobilization and decay code

WIPP Prefix: ~~PNL~~ PANEL JWB 9-4-96

Version Number: 3.60

Date: 10/May/96 (which is the code's build date in the CMS system)

Platform: FORTRAN 77 for Open VMS AXP, ver. 6.1, on a DEC Alpha

1.2 Points of Contact:

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2.0 FUNCTIONAL REQUIREMENTS

2.1 Functional Requirements

Given input data that (1) define the radioactive contents of the WIPP repository at time of decommissioning, (2) define the solubilities of all the elements within the repository that are to be mobilized for removal, and (3) describe (a) the volume of brine in the panel of interest, and (b) the rate at which brine is removed from that panel, PANEL computes the following at all future times up to 10,000 years:

R.1 The mass of each radioisotope present in the repository by accounting for radioactive decay.

R.2 The amount of each radioisotope that transforms into a mobile phase.

R.3 The amount of each mobilized radioisotope that is transported by the brine flow and removed from the waste area.

PANEL has several external-interface requirements, including the ability (A) to read data from standard binary CAMDAT database files, (B) to produce a standard binary CAMDAT database file as output, and (C) to link to the following WIPP libraries: CAMDAT_LIB, CAMCON_LIB, and CAMSUPES_LIB.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

To exercise PANEL, users should have (1) basic knowledge of open VMS, (2) basic facility with Digital Command Language, (3) basic facility of Sandia's CAMDAT database, which is used in virtually every WIPP code (Rechard, 1992), and (4) operational familiarity with all of the support codes that must be exercised before and after PANEL is exercised. User's should also have (5) access to the WIPP cluster of DEC Alpha microcomputers with an open VMS AXP (ver. 6.1) operating system or their functional equivalents.

To manipulate and/or interpret the results of PANEL as it is exercised in WIPP PAs, user's should have (1) a basic understanding of the chemistry of radioactive decay, solution chemistry, colloid chemistry, and fluid flow in confined conduits, (2) a basic understanding of ordinary differential equations and integral calculus, as they apply in the mathematical formulation of physical principles and especially of conservation of mass*, and (3) a basic overview understanding of the WIPP PA process, including conceptual models, scenarios, inventories, release routes, uncertainty sampling, input-data vectors, and a general familiarity with the files and functions of the WIPP support codes that run prior to exercising PANEL, namely, GENMESH, MATSET, POSTLHS, and ALGEBRA (WIPP PA Dept [5 Volumes], 1992). It is also useful to have basic familiarity with two upstream WIPP process codes, namely BRAGFLO and DBR_BRAGFLO** . An annotated sketch of the PANEL code sequence involving the above codes is shown in Figure 1.

* Strictly speaking, the system is not mass conserving. Radioactive decay involves the loss of mass, although it is insignificant for assessment puposes. Still, PANEL conserves the number of atoms of radioactive material during the decay process. Accordingly, PANEL's principal computational units are moles. Upon completing its work, PANEL converts its release units from moles back to kilograms for its Culebra applications. For DBR_BRAGFLO applications, a final ALGEBRA step converts output units to Normalized EPA units per cubic meter of outflow. Note also that PANEL treats both alpha and beta decay.

** In other CCA code documentation, these two codes are sometimes referred to by their CMS version numbers, which are BRAGFLO 4.00 and BRAGFLO 4.01, respectively. The two BRAGFLO codes are quite similar in their internal structure, but quite different in their purposes, applications, and run sequences.

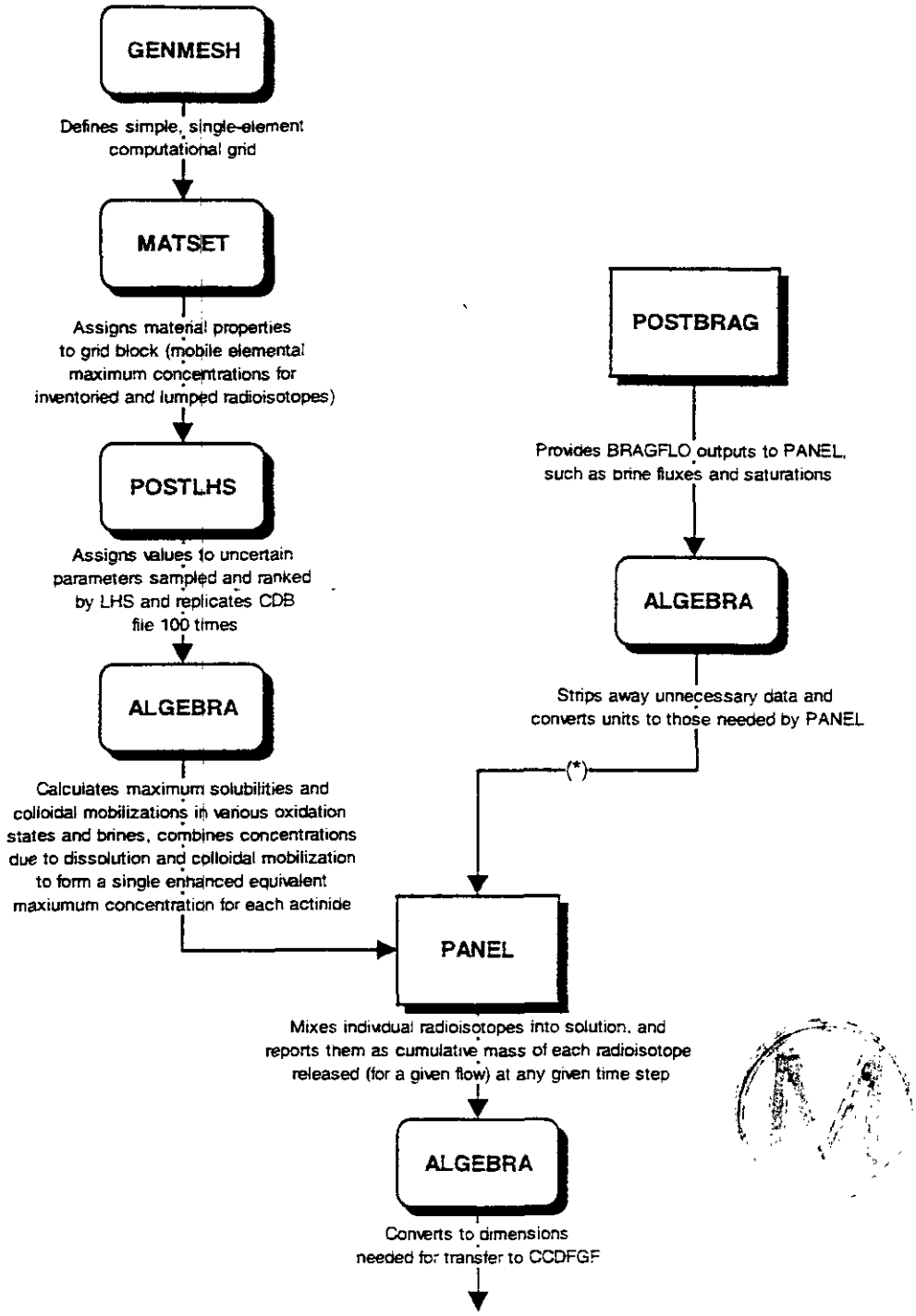

Figure 1: The run sequence for PANEL in a 1996 CCA BRAGFLO run. Process codes are square and support codes are rounded. The asterisk represents the location of an additional ALGEBRA application that is required in DBR_BRAGFLO runs to replace POSTBRAGFLO's data with hypothetical flow-rate and brine-volume data.

4.0 DESCRIPTION OF THE MODEL AND METHODS

4.1 A Broad Description of the CCA Model

PANEL's CCA PA role is to estimate the mobilized radioactive contaminant load in the brine phase of the brine/gas mixture that seeps or flows through the repository's decommissioned waste panels. Mobilization by any process, for example dissolution or suspension on colloids, is modeled as taking place instantaneously. The contaminants introduced into the brine are the aged radioisotopes that are assumed to reside in the repository at the time of decommissioning plus any progeny of those radioisotopes that may have been produced through natural decomposition. Thus, a detailed inventory of the radioactive isotopes stored in the repository at the time of decommissioning must be provided to PANEL before it may be exercised.

PANEL plays no role in the physics of the fluid flow in or near the repository. The volume of brine within the repository and the volumetric flow rate out of the repository must be provided to PANEL by an independent physical-process code such as BRAGFLO. In DBR_BRAGFLO direct-release applications, both data are provided by hypothesis. In both applications, values are retrieved from the controlled WIPP data base.

In CCA WIPP assessment scenarios, brine is assumed to enter the repository panels in either of two very different ways, namely: (a) by natural seepage from the surrounding Salado formation, and (b) by various locally-enhanced flows induced by hypothetical exploratory boreholes. In the case of undisturbed operation, Salado brine can seep through the disturbed rock zone from the surrounding undisturbed halite and marker beds. In the case of a repository breached by an exploratory borehole, Castile and/or Culebra brine could flow into and through the repository via the pipe-like channels created by the borehole(s). The most intense flow (of Castile brine) would occur if a borehole that penetrates a waste panel also penetrates a deep pressurized brine pocket, and some boreholes are assumed to do so.

The natural time scales associated with deep, tight-media, groundwater flows are typically centuries, and WIPP intrusion scenarios include temporal lapses of millennia prior to the hypothesized breaching of repository waste panels by boreholes. Moreover, EPA regulations extend to 10,000 years after decommissioning. On these time scales, radioisotopes of interest exhibit significant natural decay by which they transform to other radioactive and non-radioactive isotopes and/or compounds in a well-established way (Kaplan, 1964). Thus, it is required to quantify the decay process and maintain a running record of the decayed contents of the repository as well as all the products of decomposition from the time of decommissioning onward to 10,000 years. PANEL does that.

In the context of the CCA, PANEL has two principal areas of application. In the first, given the defining characteristics of the flow of uncontaminated brine into the repository's waste panels, PANEL is required to account for mobilization due to dissolution and colloidal suspension of radioisotopes into the brine that wets the waste panels, and to calculate, given the fluid outflow rate, the exit rate (via the now contaminated brine flow) of each tracked isotope that was initially present in the repository, including the radioactive progeny and parents of those isotopes. The

exit rate of contaminants depends on (i) the outflow rate of brine from the panel under consideration and (ii) the concentration of radioisotopes within the flowing brine, which depends on (iii) the volume of brine present in the repository at any given time and (iv) the inventory in the panel under consideration at the time. The first and third quantities must be provided in advance by, for example, BRAGFLO, which analyses the 2-phase Darcy flow throughout the Castile, Salado, Rustler, and Dewey Lake Formations throughout the entire Land Withdrawal Act region. PANEL is required to calculate the second and fourth quantities at each of its timesteps, which are 50 years. The WIPP code NUTS is charged to perform that very calculation for most CCA PA scenarios. However, for S6 scenarios in which 2 boreholes penetrate the same waste panel and the second one of them also penetrates a pressurized Castile brine pocket, PANEL is directed to perform the calculation. PANEL's treatment of the flow field within the repository is much simpler than NUTS's treatment of it, but their treatment of chemical processes is identical except that PANEL considers 30* of the release-relevant radioisotopes, whereas NUTS treats only the 5 lumped equivalent isotopes. PANEL is afforded that versatility because it exercises quickly, run time being a factor on account of the large number of cases that are required. PANEL can also serve as an internal consistency check for NUTS by providing reasonable upper-bound limits.

In the second type of application, PANEL calculates the contaminant load contained in the volume of brine (if any) that would be released directly to the surface in the form of a mixture with the liquid slurry drillers use to cool and lubricate drill bits, and to remove borehole debris. Such releases would occur at the time of drilling as a result of pressure relief and are possible only if repository pore pressures exceed 8MPa. In this application, PANEL uses ALGEBRA to retrieve (1) a fixed assumed repository brine volume and (2) an assumed repository outflow rate that is very small but non zero. PANEL's release rates are divided by the assumed flow rate to compute mobilized mass per unit volume of brine for each radioisotope considered. Thus, PANEL's final result of radioisotope released per volume of brine released is actually independent of the assumed flow rate. The volume of brine that is released (if any) must be provided by another code, which was DBR_BRAGFLO in the 1996 CCA.

In both of the above applications, the outflow rate of the brine and the volume of brine present in the repository at any given time are required by PANEL to calculate and report its principal results, namely, the total transport, up to the present timestep, of each of 21** selected (decayed) radioisotopes that exist within the repository.

Because of natural decay processes, it is entirely possible to find compounds in the effluent that were not present in the initial repository inventory.

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* PANEL treats 30 of the 33 radioisotopes singled out as potentially important in the 1996 CCA, the other 3 being insignificant. One of the 30, SM147, is absent from the initial inventory. It appears only as a decay product, which explains why the initial conditions in Appendix F are 29-rows long. SM147 ingrowth is calculated and reported, but, like 8 other isotopes, SM147 is neither mobilized nor released. Thus, PANEL mobilizes and releases 21 radioisotopes.

** In 1996 CCA runs, PANEL transported the 21 isotopes of 6 elements (Am, Cm, Np, Pu, Th, & U), the choice being based on their significance in earlier assessments. PANEL is able to mobilize any number of radioisotopes if it undergoes minor revisions, recompiling, and reQAing.

To compute the initial inventory, PANEL assumes the repository comprises (i) 8 storage panels, each having a plan-view area of 11,640 m^2, (ii) a southern equivalent panel having an area of 8,820 m^2 and (iii) a northern equivalent panel having an area of 9,564 m^2 (WIPP PA Div., 1991, pages 3-5). These areas are used to scale the inventory linearly to the appropriate panel size. In past PAs, PANEL's runs assumed the contents of the *entire* repository inventory were available for release into whatever brine was present. In no PA is the fraction of the repository that is available to brine flow adjustable as an input parameter. It is hard-wired into the code and is not, therefore, readily adjustable by the user. For 1996 CCA regulatory runs, the fraction has been set to represent one standard panel, that is, 11,640 m^2 divided by the net area of the repository (which is 111, 504 m^2), or 0.1044.

4.2 Description of PANEL's Methods

PANEL is triple-purpose model. First, it is a radioisotope waste-mobilization model designed specifically to model waste mobilization in the WIPP's wetted repository waste panels. Secondly, PANEL is a radioactive-decay model and has the capability of tracking the repository's inventory as a function of time so as to account for (i) the decrease in mass of the isotopes initially placed there, and (ii) the corresponding increase in mass of their associated daughter, granddaughter, and subsequent decay products, which arise due to normal radioactive decay processes. Lastly, in the presence of the radiated products of radioactive decay, chemical compounds may disassociate through a process called radiolysis. PANEL is capable of calculating the amount of hydrogen gas produced in the repository as a function of time due to radiolysis by each isotope present in the repository. In PANEL, these three kinds of computations are called runs of type 1, 2, and 3, respectively. **The radiolysis capability of PANEL, called a type-3 run, is not used in CCA regulatory calculations. It is unavailable to CCA users and will not be discussed further herein.**

In WIPP type-1 applications, PANEL estimates the total radioisotope discharge from the repository* that would result from various scenarios including one or more boreholes penetrating the Culebra, the Salado, the repository itself, and possibly a pressurized brine pocket in the Castile Formation beneath the Salado. Radioisotope mobilization and discharge from the repository depend in part on (i) the brine volume within the repository, and (ii) the outflow rate of brine from the repository. These are vital inputs for PANEL's isotope-transport calculation and are normally provided to PANEL by (a) an independent WIPP flow code such as BRAGFLO in groundwater applications, and (b) by hypothesis in DBR_BRAGFLO direct-release applications.

* PANEL's releases are from the interior of the WIPP repository (i.e., from within its waste panels) to the exterior of the waste panels, but no further. PANEL does not profess to describe the transport of radioisotopes or brine through the porous media surrounding the waste panels. That task is performed by other WIPP codes such as NUTS or the SECO suite of codes. However, because the flow associated with DBR_BRAGFLO direct-release applications is relatively rapid (time scale of days) PANEL's results apply directly in that case.

In the sections that follow, mobilization of isotopes will be discussed in detail. Efforts have been made to provide a unified approach to these two subjects. The general framework used is as follows:

In general, the "inventory" of the ith element at the nth timestep, $I_i(t_n)$, will mean the total amount of the ith element in the repository at the time t_n, regardless of its form. Thus, elements in their original form, daughter elements arising from radioactive decay, dissolved elements, elements attached to colloids, and intrinsic colloids are all regarded as part of the inventory, provided they reside within the repository. They are removed from the "inventory" of a given element only if (i) they decay or (ii) they are mobilized and transported by means of a brine outflow to the exterior of the repository. In the latter case, they are assumed, in borehole scenarios, either (a) to flow up the borehole toward the Culebra** and higher level Formations, or (b) to flow up the borehole and directly to the surface at time of drilling in DBR_BRAGFLO direct-release applications. In either case, they may disperse through the various porous media found in the vicinity of the repository, such as the disturbed rock zone and/or the anhydrite layers, but PANEL does not model the post-repository behavior of such transports.

If $C^g_{max,i}$ is a generic maximum concentration (in moles/*l*) in brine of the ith element due to some generic physical process (dissolution or mobilization associated with colloids), then, at each timestep, PANEL will mobilize m^g_i moles of the ith element into $V(t_n)$ liters of brine, the volume of brine residing in the repository at the nth timestep. If PANEL is being used to support Culebra transport, $V(t_n)$ would be one of the input data provided by BRAGFLO***. If PANEL is being used to support direct-release calculations, $V(t_n)$ is taken to be a constant (4000 cubic meters in the 1996 CCA). If sufficient amounts of the ith element are available in the inventory, m_i will take on its maximum value, namely

$$m^g_{max,i} = C^g_{max,i}\ V(t_n).$$

If $m^g_{max,i}$ moles of the ith element are not available in the inventory at the timestep in question, PANEL will mobilize a smaller amount, namely m^g_i, into the brine, where m^g_i is whatever amount is available at that timestep. That is,

$$m^g_i = I_i(t_n).$$

** Within the Culebra, their further transport is modeled by the SECO suite of WIPP codes.

*** Because the repository contains both brine and gas, the volume of liquid within the waste panels may vary. That is, the repository brine may have a free surface, and that free surface may rise or fall. Thus, the flow rate out of the repository need not equal the flow rate into the repository. It is (i) the brine outflow from the waste panels and (ii) the concentration of a radioisotope within that brine outflow that govern the amount of that isotope that will be delivered to the Culebra, to other fluid-bearing strata, or to the surface via a borehole at time of drilling. Strictly speaking, the timesteps used by BRAGFLO may be smaller than the 50-year timesteps used by PANEL. Consequently, BRAGFLO's V(t) could vary over one of PANEL's timesteps. In that case, PANEL uses the BRAGFLO value of V(t) that occurs at the end of its 50-year timestep.

The resulting concentration of the ith element in the brine (in moles/*l*) would be $C^g_i = I_i / V$. To summarize, if, at the end of the nth timestep, $I_i \geq (C^g_{max,i} V)$, PANEL will have $(C^g_{max,i} V)$ moles of the ith element in the brine. If $I_i < (C^g_{max,i} V)$, PANEL will have I_i moles of the ith element in the brine.

The two principal mobilization mechanisms (associated with colloids and dissolution) are described in detail in terms of the above formulation in Sections 4.3, 4.4, and 4.5. The decay model is described in Section 4.6 and the actual release calculation is described in Section 4.7. The sequence of codes that is run in support of PANEL, including PANEL itself, is described in Section 4.8 and shown in Figure 1 (see Chapter 3).

4.3 Description of PANEL's Colloidal-Suspension Model

In CCA applications, mobilization associated with suspended colloids has been combined with mobilization due to dissolution. That approach is justified because dispersion and sorption are the only physical processes that could cause significant differences in the transport models used for dissolved versus colloidal species, and since dispersion and adsorption are not modeled by PANEL, the transport models that apply to the two species will be identical. The merging of the treatment of mobilization of dissolved and colloidal species is performed prior to PANEL in an ALGEBRA calculation known as "SOTERM" for "solubility term." In that application, four types of colloid-related mobilization are considered, as follows: (i) condensation of hydrolyzed actinide ions into intrinsic colloids, and sorption onto already existent colloidal materials of (ii) humic, (iii) microbial, and (iv) mineral origin. Maximum concentrations for the four different types of colloidal particulates are combined with the maximum concentration for dissolution for each of the radioisotopes. A maximum concentration associated with the five processes together is then used in a single dissolution-like computation that estimates the net mobilization due to colloid mobilization and dissolution. That calculation is described in the next section.

PANEL contains another different colloid-transport model that is based on the assumptions of (1) rapid sorption onto mobile colloids, (2) the same sorption concentrations for all radioisotopes, and (3) consideration of two sizes of colloidal particulates, namely small and large, with different sorption capacities for each. **However, that model is not included with PANEL for CCA applications and is therefore not included in PANEL's QAed software documentation.** For information and completeness, that model is described in Appendix G, at the end of this User's Manual. Note that several of the defunct data columns reported in PANEL's DBG file (Appendix F) relate to this model.

4.4 Description of PANEL's Dissolution Model

PANEL's "dissolution" model is designed to estimate the net effects of dissolution but can be used for any type of mobilization that behaves mathematically like dissolution. In the CCA calculations, colloid mobilization has been combined with dissolution by adding the maximum concentration from colloidal forms to the maximum concentrations due to dissolution. The modified maximum solubilities or modified maximum concentrations are referred to herein as

"enhanced" modified maximum solubilities or concentrations, since the effect of mobilized colloids is always to increase net effective solubility limits.

The dissolution part of PANEL's waste-mobilization-and-transport model is based on the following assumptions: (1) The concentration of each brine-dissolved element is uniform (i.e., constant) throughout a waste panel. (2) Mobilization, is assumed to take place instantaneously and to maximum capacity, i.e., to saturation if inventory permits. (3) Supersaturation is disallowed. (4) When an element has several isotopes, the molar proportions of those isotopes dissolved in the brine are taken to be the same as the molar proportions in the total inventory contained in the waste panel.

The total enhanced concentration of the *i*th element in the repository brine during the nth timestep is given by $C^d_{i,}(t_n)$, where

$$C^d_i(t_n) = \begin{cases} C^d_{max,i} & , \text{ if } I_i(t_n)/V(t_n) \geq C^d_{max,i} \\ I_i(t_n)/V(t_n) & , \text{ if } I_i(t_n)/V(t_n) < C^d_{max,i} \end{cases} ,$$

and where

$C^d_{max,i}$	=	enhanced maximum concentration of all elements *i*,
$I_i(t_n)$	=	the inventory (mol) of the ith element at the nth timestep, and
$V(t_n)$	=	volume (*l*) of brine contained in the repository during the nth timestep.

If PANEL is exercised in support of Culebra transport, the repository brine volume $V(t_n)$ is provided by BRAGFLO. Because BRAGFLO's timesteps are often smaller than PANEL's. PANEL uses the value of $V(t_n)$ reported at the end of its 50-year timestep. PANEL then converts $V(t_n)$ from units of m^3 to *l* and uses it in the equations above. The enhanced dissolution calculation is carried out element for element without regard to isotope. However, PANEL's results are reported on an isotope-for-isotope basis. The division of dissolved elements to their isotopes is according to the isotopic ratios in the inventory. Hence,

$$C^d_{i,j}(t_n) = C^d_i(t_n)\,[I_{i,j}(t_n)/\,I_i(t_n)] \quad ,$$

where all symbols are as previously defined, but with subscript j for isotopes . The inventory, $I_{i,j}$, continues to be time-dependent due to (i) removal from the repository by outflow of contaminated brine, and (ii) radioactive decay. The former effect is calculated by PANEL by correcting the inventory for the amount of isotope mobilized and removed by outflow. The latter effect is explained in Section 4.6 and requires application of Bateman's equations, which quantify both the decay of radioisotopes and the growth of daughter products.

4.5 Accounting for Valence State During Dissolution

PANEL includes a random sampling scheme that apportions the amount of each element present in a repository into its various possible oxidation states. **This option is not used in the CCA calculations, will not be available to CCA users, and is *not* intended to be part of PANEL's QAed software documentation.** However, a description of the oxidation-state sampling option is included in Appendix H of this User's Manual. It is included for completeness and information.

4.6 Description of PANEL's Decay Model

Despite whatever else may be happening, every radioisotope in every decay chain is continually decaying to form its daughter product and, simultaneously, it may be continually growing through the decay of its parent isotope. The rates of decay and growth are different for different isotopes, often quite different. The equations that quantify the decay-and-growth cycle of radioisotopes were first described by Bateman (1910) and traditionally bear his name.

Bateman's equations state that the rate at which the mass of a radioisotope decreases by natural radioactive decay is proportional to the present available mass of that radioisotope. In single decays, the constant of proportionality is the natural logarithm of 2 divided by the half-life of the radioisotope in question. If the isotope in question is other than the first isotope in the chain, its mass will also increase at a rate proportional to the present mass of its parent isotope. In simple decay chains, the constant of proportionality is the natural logarithm of 2 divided by the half-life of the parent. In multiple (i.e., bifurcated) chains, the decay algebra is slightly more complicated. However, the simple decay chains used in WIPP PAs have no bifurcations. PANEL's decay chains are listed in the block data GE_CHART given in PANEL's Implementation Document, and a printout of the products of decay appears in Appendix F.

In equation form, if M_i* (i = 1, 2, 3, ...) represents the present mass of the ith isotope in the repository in a 2-member chain, then

$$dM_i/dt = -\lambda_i M_i + \lambda_{i-1} M_{i-1},$$

where λ_i is $\ln(2)/T_i$, and T_i is the half-life of the ith isotope. For example, in a simple, direct, three-member chain, Bateman's equations would be written:

$$dM_1/dt = -\lambda_1 M_1$$

$$dM_2/dt = -\lambda_2 M_2 + \lambda_1 M_1$$

$$dM_3/dt = -\lambda_3 M_3 + \lambda_2 M_2.$$

* M includes the amount m of the inventory that was mobilized as well as the remainder that has not been mobilized. That is, M includes *all* forms of all isotopes in the repository.

These are linear ordinary differential equations with constant coefficients and well-posed initial conditions. Therefore, they have a unique, simple, well-known, closed-form solution. It involves (i) exponential functions, which are library functions on the WIPP DEC Alphas, and (ii) the various physical parameters of the problem. It is that solution that PANEL uses to age the inventory for decay. For the above three-element example, the closed-form solution is:

$$M_1(t) = [M_1(t=0)]\,[e^{-\lambda_1 t}]$$

$$M_2(t) = [M_2(t=0)]\,[e^{-\lambda_2 t}] + [\lambda_1 M_1(t=0)]\,[e^{-\lambda_1 t} - e^{-\lambda_2 t}] / [\lambda_2 - \lambda_1]$$

$$M_3(t) = [M_3(t=0)]\,[e^{-\lambda_3 t}] + [\lambda_2 M_2(t=0)]\,[e^{-\lambda_2 t} - e^{-\lambda_3 t}] / [\lambda_3 - \lambda_2]$$

$$+ \lambda_1\lambda_2 M_1(t=0)\,\{e^{-\lambda_1 t}/[\lambda_2-\lambda_1][\lambda_3-\lambda_1] + e^{-\lambda_2 t}/[\lambda_3-\lambda_2][\lambda_1-\lambda_2] + e^{-\lambda_3 t}/[\lambda_1-\lambda_3][\lambda_2-\lambda_3]\}$$

The closed-form solutions of Bateman's equations become algebraically more complex as the decay chain they treat becomes longer. However, they continue to involve only (1) physical parameters of the problem and (2) exponential functions of time (Kaplan [Chapter 10], 1964).

PANEL uses the more complex analogue of the above results to age the inventory for decay before proceeding to the next timestep. In the equations above, the values of $M_i(t=0)$ are assigned according to the contents of the inventory at the beginning of the PANEL timestep t_n. The right-hand sides of Bateman's equations are then evaluated using $t = 50$ years and the physical constants of the problem. The results, $M_i(t)$, for $t = 50$ years, are the decay-corrected masses of each isotope at the end** of PANEL's timestep t_n. The inventory at each timestep t_n is corrected twice, (i) once for decay, and (ii) once for removal due to mobilization. It is then forwarded as the initial inventory for PANEL's next timestep, which starts at time t_{n+1}.

The above sections outline the methods by which isotopes are mobilized and decayed. However, PANEL's ultimate goal is to calculate, as a function of time, the net *releases* from the repository. The release calculation requires the net concentrations of isotopes within the repository as a function of time, which have been calculated above. It also requires repository brine-outflow data. The calculation that combines the two to form *releases* is described in the next section.

4.7 PANEL's Release Calculation

Following WIPP PA performance scenarios (WIPP PA Dept., 1992), pressurized brine either flows upward from a deep brine pocket via an intrusion borehole or it seeps slowly through the Salado halite. A fraction of it enters a waste panel, flows through the waste, mobilizing

** Actually, PANEL's decay calculations are centered within each 50-year timestep, the working value being taken as the average of the Bateman-decayed inventory at the beginning and end of the timestep. Thus, they are actually referred to 25, 75, 125, etc years after decommissioning, rather than 50, 100, 150, as described herein. The difference is unimportant in principle and inconsequential in fact.

radioisotopes as it does, and then flows either (1) upward to the Culebra via the same or a second intrusion borehole, (2) directly to the surface at the time of drilling via the intrusion borehole itself, or (3) along some other path. PANEL's job is to calculate the cumulative mass of radioisotopes mobilized at repository level and thereafter transported by the brine. The volume of brine removed from the repository during PANEL's nth timestep and transported to the Culebra is v_n (in *l*), a quantity that is provided in the output CDB of a WIPP flow code such as BRAGFLO, or by hypothesis, depending on the application at hand. The total amount of jth isotope of the ith element (in moles) transported with the brine is $C_{i,j}(t_n)\, v_n$, where $C_{i,j}(t_n)$ is the enhanced concentration (in moles/*l*) of the jth isotope of the ith element in the repository during the nth timestep due to *all* mobilization processes. It is useful to bear in mind that PANEL reports release results subdivided according to isotope but not mobilization process. However, the information needed to apportion the PANEL releases between the mobilization processes is contained in the computational database produced by the SOTERM ALGEBRA run. Before forwarding its release data, PANEL first converts release units from moles back to kilograms. It does so by multiplying each release by $W_{i,j}/1000$, where $W_{i,j}$ is the molecular weight of the jth isotope of the ith element in grams/mole, and 1000 is the number of grams in a kilogram. In support of direct-release calculations, the cumulative kg release of each isotope from PANEL is converted by a post-PANEL ALGEBRA run to concentration data by forming the difference of the time integral of the calculated release divided by the difference of the time integral of the assumed outflow rate, these calculations being based on the minuscule assumed flow rate of roughly 10^{-5} cubic meters per year. ALGEBRA then converts the units to Normalized EPA release units per cubic meter and sums the isotopes in preparation for multiplication by DBR_BRAGFLO's direct-release volumetric-brine-output estimates, which are reported in cubic meters. The resultant product is, of course, in normalized EPA release units.

In general, BRAGFLO does not provide v_n . Rather, it provides the brine outflow rate $q(t_n)$ (in m^3/s), and quite often it reports q at timesteps t_n to t_{n+1} that may be a good deal smaller than PANEL's timesteps t_n to t_{n+1}. To rectify the mismatch, PANEL (i) converts BRAGFLO's brine outflow rates to *l*/s, and then (ii) computes v_n by integrating q over one of PANEL's timesteps. The computation is by right-hand integration, and looks like

$$v_n(t_n) = \sum_{m:\, t_m = t_n}^{t_m = t_{n+1}} [\, q(t_{m+1})][t_{m+1} - t_m] \quad .$$

The amounts (in moles) of the jth isotope of the ith element mobilized and transported out of the repository during the nth timestep due to dissolution and colloidal mobilization is $[v_n\, C_{i,j}(t_n)]$, where $C_{i,j}$ was defined earlier. Once these materials have exited the repository, the inventory must be revised to account for their removal before PANEL can proceed to the next timestep. PANEL must also age the revised inventory. Thus, PANEL calculates the inventory at the next timestep as:

$$I_{i,j}(t_{n+1}) = I_{i,j}(t_n) - [v_n\, C_{i,j}(t_n)] - D_{i,j}(t_n) + G_{i,j}(t_n) \quad ,$$

where $D_{i,j}(t_n)$ represents the total loss of the jth isotope of the ith element due to radioactive decay and $G_{i,j}(t_n)$ represents the gain from the parent.

The above discussion focused on PANEL's work *during* each timestep. However, PANEL does not report timestep-for-timestep results. Rather, it adds the release results of the present timestep to the sum of the release results for all prior timesteps and reports the sum. That is, it reports, at each timestep, the *cumulative* release $R_{i,j}(t_n)$ of the jth radioisotope of element *i* from the repository. In mathematical terms, the cumulative release due to a generic process is written as follows:

$$R_{i,j}(t_n) = \int_0^{t_n} C_{i,j}(t)q(t)dt = \sum_{k=1}^{n} C_{i,j}(t_k)v_k(t_k)$$

where

- $C_{i,j}(t_k)$ is the individual concentration (in moles/*l*) of the jth isotope of the ith element in the repository brine, due to the net effective mobilization processes,
- $q(t)$ is the rate (in *l*/s) at which brine *flows out* from the waste repository at time *t*. It is determined by BRAGFLO and forwarded to PANEL as an input on runs supporting Culebra transport, or assumed to be a minuscule amount (10^{-5} m^3/yr) in runs supporting DBR_BRAGFLO calculations of direct release.
- $v_n(t_n)$ is the volume (in *l*) of brine ejected from the repository during PANEL's nth timestep and is calculated by PANEL using either (1) outflow data from BRAGFLO, or (2) the assumed rate.

4.8 PANEL's Run Sequence

To exercise PANEL as it was exercised in the 1996 CCA, it is necessary to exercise a sequence of WIPP codes that support PANEL in various ways. Figure 1 (see Chapter 3.0) is an annotated depiction of that sequence for a run in support of a groundwater release through the Culebra (SECOTP and CCDF_GF). The caption of Figure 1 explains the run-sequence differences required for DBR_BRAGFLO applications. Sample input files for the five support codes of the sequence are provided in Appendices A through E of this User's Manual. The codes themselves are discussed in other documents supporting WIPP CCA software QA.

5.0 INHERENT CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

PANEL is capable of mobilizing and decaying all significant radioactive elements that are presently given in the repository's inventory, as it is specified on the controlled WIPP data base. For the decay calculation, PANEL contains, internally, all the data necessary to age 30 WIPP isotopes, including the relevant system of Bateman solution equations, the decay chains, the half-lives, etc. To keep the mobilization calculation efficient, PANEL reads the mobilization parameters associated with six selected elements (Am, Cm, Np, Pu, Th, and U) that occur in various isotopic forms, which leads to mobilizations for 21 distinct chemical species. What PANEL does during each timestep is extremely simple, both physically and mathematically. The only differential equations it solves (Bateman's) are solved analytically and evaluated using library functions. Its mixing model is essentially algebraic within each timestep. It is straightforward and step like, exactly as was described in Section 4, above. PANEL's most advanced step is integrating its release results, which it accomplishes straightforwardly using right-hand numerical integration. Its limitations are only the validity of its assumptions, which are principally:

1. The mechanical mixing time and chemical reaction-rate times within the repository are small compared to characteristic flow times. Time scales (1) for hydrological flows and (2) for quiescent periods between exploratory borehole penetrations are so large that this assumption is not threatened. PANEL assumes all of the waste (i.e., the maximum possible amount) contained in a single waste panel is available for mobilization. It is a conservative estimate and actually represents an upper bound.

2. (A) The concentration of each brine-dissolved element is uniform (i.e., constant) throughout a waste panel. (B) The enhanced maximum concentration of each brine-dissolved-and-colloidally-mobilized element is dependent on (a) the valence state with which that element occurs in the repository and (b) the source of the brine, there being three principal sources, namely: brine from the Salado, brine from the Castile, and brine from the Culebra. Item 2B pertains more to ALGEBRA's pre-PANEL analysis than it does to PANEL itself. It is included here for completeness. (C) The fraction of each element that is permitted to dissolve into incoming brine is set *a priori* to the enhanced equivalent solubility limit for that element (that is, to the maximum possible value). Enhanced equivalent solubility data must be determined on the basis of reasonable chemical hypotheses and provided to PANEL. {In the 1996 CCA, these data were provided by ALGEBRA (see Figure 1 in Chapter 3). The chemical basis for ALGEBRA's calculations are described in Section 7 of the SOTERM Appendix of the WIPP's 1996 Compliance Certification Application}. If insufficient material is available in the repository to reach the enhanced equivalent solubility limit, PANEL will mobilize whatever amount is available. The amounts of material available within the repository are estimated from inventory data. (D) Supersaturation is disallowed. (E) When an element has several isotopes, the molar proportions of those isotopes dissolved in the brine are taken to be the same as the molar proportions in the total inventory contained in the waste panel.

3. Mobilization by colloidally suspended particulate matter is treated in exactly the same way that dissolution is treated. Maximum concentrations for four different types of colloidal particulates are added to the maximum concentration for dissolution for each of the radioisotopes and oxidation states. The sum of the five maximum concentrations is then used in a single dissolution-like computation that estimates the net mobilization due to colloids and dissolution. {The chemical basis for these calculations is provided in Sections 6 and 7 of the SOTERM Appendix of the WIPP's 1996 Compliance Certification Application}. PANEL assumes (a) all isotopes present in the repository either form or sorb rapidly onto colloidal particulates, and all rapidly reach their assigned maximum capacities, so that (b) time dependency in colloidal formation and sorptive processes can be ignored. Item 3 pertains more to ALGEBRA's pre-PANEL analysis than it does to PANEL itself. It is included here for completeness.

4. In the past, PANEL has assumed the brine has access to the entire inventory, that is, to the entire contents of the repository. That is equivalent to assuming all the lower-level internal seals in the repository have failed well prior to the time of intrusion. In present applications, mobilization is limited to the particular waste panel that was penetrated. That is, internal seals are assumed to hold.

5. PANEL models the inventory as though it were distributed uniformly with regard to intensity and species throughout the entire repository. Thus, the full inventory is scaled linearly to a single panel's size. The possibility of inventory variability from one panel to another is not modeled.

6.0 USER INTERACTIONS WITH THE SOFTWARE

In order to be executed, PANEL must have access, through CAMCON, to two previously created input data files. In WIPP PAs, these files take the form of CDB files (CAMCON Data Base) that were written as output files by the other WIPP PA codes that were exercised before PANEL in the PA code sequence.

LHS, for Latin Hypercube Sampling, is such a code and leads to the production of numerous CDB files, one for each of the collections of sampled input data called input vectors. The number of samples is normally determined by an optimization scheme that balances the need for statistical confidence (which favors larger samples) against resource costs (which favor smaller samples). The exact number of samples required for the 1996 CCA is fixed at 100. PANEL's calculations will therefore be executed in sets having 100 runs each, and many more if one includes replication runs. This multiplicity of runs is intended to assure (a) representative and (b) adequate sampling. Because of it, reasonable measures were applied to make PANEL as efficient as possible in terms of run time. In the 1996 CCA runs, PANEL did not receive its sampled data directly from LHS. Rather, as shown in Figure 1, LHS's sampled data were passed through an ALGEBRA step, which modifies some of the chemical data so as to generate enhanced equivalent solubility limits (see Chapter 4 herein, and Section 7 of the SOTERM Appendix of the WIPP's 1996 Compliance Certification Application).

As was said above, PANEL executes in three different ways, called run types, and performs three very different kinds of computations. Type-1 runs mobilize wastes (by dissolution and colloidal mobilization) and require externally-specified brine flows. Type-2 runs account for radioactive decay through Bateman's equations and require that the inventory be specified. **Type-3 runs account for radiolysis, and will not be used in regulatory calculations.** CMS regulatory runs are directed from a command file. To assist the user to understand the individual steps carried out by the command file, the two principal WIPP-type runs will be discussed below in detail from the user-interactive point of view, but first some general remarks that apply to all three run types.

6.1 Exercising Panel in General

To exercise PANEL in general, the user types the command line below at the VMS "$" prompt, and follows it with a carriage return:

```
$ PANEL (arg1) (arg2) (arg3) (arg4) (arg5)
```

The five required command-line arguments are defined as follows:

- The value of arg1 depends on the type of run PANEL is making. For type-1 runs, arg1 is an "S" for "standard". For type-2 runs, arg1 is a "D" for "decay only". For type-3 runs, arg1 is an "R" for "radiolysis".

• arg2 is any one of PANEL's sampled input CDB files. Typically, they are named* LHS_S1_S_Vyyy, where yyy is a variable index that identifies the realization. In CCA calculations, yyy would vary from 001 to 100. The file actually employed in 1996 CCA runs was named ALG_ST_CCA_Rz_Sx_Vyyy.CDB, where z (= 1, 2, or 3) is the replicate number and x (= 1,2, ..., 6) is the scenario number.

• arg3 is any one of PANEL's sampled output CDB files. It is not recommended, but users have limited freedom in naming these files, providing care is exercised to use proper format and compatible scenario and realization identification numbers. For example, this filename might use the format PANEL_Sx_S_Vyyy.CDB. The indices x take on the values 1, 2, ..., 6, and *must* correspond to the scenario being analyzed. The yyy are as before.

• arg4 is the sampled input CDB file that specifies the repository brine volume and rate of brine outflow from the repository and must correspond to the scenario and realization numbers specified in the other input files. These files contain essential brine-flux data, and the user must know their BRAGFLO filenames. Examples are given in the subsections that follow. In 1996 CCA runs, BRAGFLO's output files were passed through a preliminary ALGEBRA step that simplified them so as to enhance run speed (see Figure 1).

• arg5 is PANEL's output debug file. The user is free to choose its name. An example is given in Appendix F.

Notice that PANEL does not have an input file *per se*. That is because there is nothing for the user to specify beyond the run type, which is chosen in arg1, above. All PANEL's input data derive from upstream codes and from the data distributions written on the controlled WIPP data base. In that sense, arg2 serves as PANEL's input file in that it contains all the data previously written to the CDB file for the run in question. However, it isn't a control file in the usual sense, since control files are normally text files and (arg2) is in CDB format. GENMESH, MATSET, POSTLHS, and ALGEBRA are the four codes immediately upstream from PANEL. Examples of their input control files for PANEL runs are reproduced in APPENDICES A, B, C, and D. Appendix D applies to the source-term ALGEBRA run, which is quite different from the ALGEBRA run described in the following section.

6.2 Exercising ALGEBRA to Prepare PANEL's Input Flow Data CDB File

It is possible to streamline PANEL somewhat by exercising ALGEBRA in a mode that strips the arg4 BRAGFLO CDB file of unnecessary information and, thereby, decreases run time. The change in run time is small, but it accumulates during multiple runs. This step is a housekeeping chore and does not affect PANEL's operations or foundations in any way. However, as it is included in 1996 CCA regulatory calculations, it is described in this User's Manual. The entire input file required by this application of ALGEBRA is included in Appendix E.

* The filenames used in this section will work, however, they differ from the filenames employed by the CMS that controls CCA runs. CMS filenames appear in the examples in the appendices of this manual. Also, the letter R, which in past PAs signified "realization," has been replaced by V for "vector." R now signifies "replicate."

The Appendix-E ALGEBRA input file is actually more complex than is absolutely required by PANEL, which uses only two of the many POSTBRAG output variables the input file calls, namely: variable #30, BRNVOL_W, and variable #78, BNBHUDRZ. However, it is the ALGEBRA file that was used in the 1996 CCA calculations and it is therefore listed in Appendix E. Variable #30 is volume of brine in the repository during the present timestep. Variable #78 is the cumulative brine outflow up the borehole.

In the paragraph that follows, the command line that exercises the necessary ALGEBRA application is given.

If the file named BRAGFLO_FLOW_S6_V064.CDB is POSTBRAGFLO's output CDB, and if its ALGEBRA-revised version is named BRAGFLO_ALG_FLOW_S6_V064.CDB, then the command line to exercise ALGEBRA on BRAGFLO's output in preparation for exercising PANEL is as follows:

```
$ ALGEBRA -<CR>
_ $ BRAGFLO_FLOW_S6_V064.CDB -<CR>
_ $ BRAGFLO_ALG_FLOW_S6_V064.CDB -<CR>
_ $ POSTALG_CCA_186.INP -<CR>
_ $ CANCEL <CR>
```

where <CR> means strike the "carriage return", and where the debug file has been canceled. The third file in the sequence, POSTALG_CCA_186.INP , is the ALGEBRA input control file that was actually used in 1996 CCA runs. It resides on the WIPP Alphas in the file U1:[JDMILLE.CCA.POSTALG] and is listed in full in Appendix E.

6.3 Exercising PANEL in an Undisturbed Type-1 Run

To exercise PANEL in a standard brine-flux type-1 run, enter the following command-line format at the VMS "$" prompt:

```
$ PANEL S ALG_ST_CCA_R1_S1_Vyyy.CDB PANEL_S1_S_Vyyy.CDB -
_ $ BRAGFLO_ALG_FLOW_S1_Vyyy.CDB PANEL_S1_S_Vyyy.DBG
```

This command will exercise PANEL in the standard (type-1) manner for events associated with scenario number 1, which is the identification number for the undisturbed state. The brine-flux input-data CDB file is recognized as BRAGFLO's output file for an "undisturbed" scenario number and unspecified realization number. The hyphen at the end of the command line is the digital-command-language symbol for "continued on the next line". In CCA runs, PANEL will not be applied to undisturbed runs.

6.4 Exercising PANEL in an E2E1 type-1 Run

In CCA parlance, scenario number 6 corresponds to the E2E1 case in which a double intrusion occurs and floods at least one of the waste panels with pressurized brine. PANEL will be used to mobilize radioisotopes for all 1996 CCA S6 runs. To exercise PANEL for that scenario and an unspecified realization number (i.e., input-vector number) yyy, enter the following command-line format at the VMS "$" prompt:

```
$ PANEL S ALG_ST_CCA_R1_S6_Vyyy.CDB PANEL_S6_S_Vyyy.CDB -
_ $ BRAGFLO_ALG_FLOW_S6_Vyyy.CDB PANEL_S6_S_Vyyy.DBG
```

That command line will exercise PANEL as a standard type-1 run for a scenario 6, which is an E2E1 double intrusion in which the first (E2) intrusion occurs at 1000 years and the second (E1) intrusion occurs at 2000 years after decommissioning. The brine-flux input-data CDB files PANEL requires are again recognized as BRAGFLO's output CDB files as modified by ALGEBRA.

6.5 Exercising PANEL in a Decay-Only Run

To calculate the time history of a repository inventory when the inventory is influenced only by the effects of radioactive decomposition, which includes decreases in the masses of the given isotopes and increases in the masses of their daughter, granddaughter and succeeding products, enter the following command-line format at the VMS "$" prompt.

```
$ PANEL D LHS_S1_S_Vyyy.CDB DECAY_S6_S_Vyyy.CDB CANCEL -
_ $ DECAY_S6_S_Vyyy.DBG
```

The above command line will exercise PANEL in the decay mode (a type-2 run). Note that the scenario identification number is set at 06, as though this were an E2E1 run. That is a nomenclature formality. Any scenario number could have been used, since the decay process is wholly independent of scenario. The brine-flux input-data CDB file is canceled, which means PANEL defaults to internal values that specify no flow.

6.6 Exercising PANEL in a Radiolysis Run

Type-3 radiolysis runs will not be exercised in the CCA PA. Consequently, this topic will not be discussed herein.

7.0 DESCRIPTION OF PANEL'S INPUT FILES

All PANEL's input data, except for run type, are read directly from CDB input files. Consequently, the user may not readily interact with or control these data. In essence, the input file for PANEL is the output CDB file from the post-POSTLHS ALGEBRA run. Examples of the input files for the five codes immediately upstream of PANEL are given in Appendices A, B, C, D, and E.

PANEL's input data include the quantities listed below. They are all read or derived from the controlled WIPP data base and are, therefore, not available for user interaction.

Variable name	Description	Database Name	
SECPY	The number of seconds in a year	GLOBAL	YRSEC
SOL(3,IELE)	Base-10 log of actinide's solubility in m/l	**	LOGSOLM
XLOAD(IDION)	The initial inventory of the WIPP	*****	INVCHD
		*****	INVRHD ,

where ** = AM, CM, NP, PU, TH, & U , and
***** = PU242, etc.

The ranges of validity of these parameters are not a user-relevant issue. The parameters are internally controlled and unavailable for user specification. Those parameters that are uncertain vary over ranges that are specified by a scrupulously controlled scientific procedure (WIPP PA Div., 1991; and WIPP PA Dept, Vol. 3, 1992). Parameter values that were used in a particular run are echoed in PANEL's DBG file for that run. A sample PANEL DBG file is included in Appendix F.

8.0 ERROR MESSAGES

Because there is relatively little user interaction in PANEL's operation, there are relatively few places for errors to occur. Errors are, however, possible and lead directly to the generation of error messages. Most error messages inform the user of the general area in which the error occurred. The user is then expected to explore that area and make corrections accordingly. A brief list of possible error messages follows and includes comments on appropriate corrective actions.

• INCORRECT FILE ASSIGNMENTS • PANEL couldn't find and/or open the files specified in the command line. Troubleshoot.

• PROBLEM WITH INPUT CDB • PANEL doubts the POSTLHS output. Troubleshoot.

• PROBLEM WITH OUTPUT CDB • These are normally space problems. Troubleshoot.

• SCENARIO NUMBER NOT FOUND IN FILE NAME • Troubleshoot.

• RUN NUMBER NOT FOUND IN FILE NAME • Troubleshoot.

• PROBLEM WITH FLUX CDB • This problem could refer to the BRAGFLO output, the NUTS output, or, if ALGEBRA is used to preprocess flux input, to ALGEBRA output. Troubleshoot.

• PROBLEM WITH DBOQAREC • Problem with the output CDB QA records.

• PROBLEM WITH DBOHEAD • Problem starting the Output CDB.

• PROBLEM WITH DBOCLOSE • Problem ending the Output CDB.

• DT PROBLEM • Indicates a problem with PANEL's timestep. PANEL's usual timestep is 50 yr. However, if more than 10% of the brine volume exits during a single timestep, PANEL will reduce its next timestep by 50%. If the auto-reduction option operates several times in succession, PANEL will abort. In most cases, that would suggest a problem with the BRAGFLO input file.

• DBOVAR ERROR N, where N=0, 1, 2, 3, etc • Indicates a database output variable error. These are usually not run errors, but may occur, for example, if a variable is written to output but is not named.

• PROBLEM N WITH FLUXIN.CDB, where N=1, 2, 3 • Problems reading the brine flux inflow file.

• BRINEV=0, TFLUXOUT>0 • Problems reading the brine flux outflow file.

• PROBLEM 1A WITH FLUXIN.CDB • Problem reading the brine flux inflow file.

• INBHFLO, TIME PROBLEM • Indicates a problem in the borehole outflow. Normally, the BRAGFLO run would abort before 10,000 years.

• INDBIELBK • Indicates input element blocks exceed 100 in number. Normally there are 28 blocks in a WIPP run, so this error never arises.

9.0 DESCRIPTION OF PANEL'S OUTPUT FILES

PANEL's only user-readable output file is its debug file, which echoes input data and repeats, in summary format, many of the data reported on PANEL's output CDB file. An example of a PANEL debug file is included in Appendix F. The quantities reported there are described below.

PANEL writes 92 history variables to the data base at each timestep. Those variables are listed below in tabular format and are defined in the paragraphs immediately below the list.

History Variables:

BRNVOL00	SMFLOW00	SD0SR90	SL0SR90	SS0SR90
SD0CS137	SL0CS137	SS0CS137	SD0PB210	SL0PB210
SS0PB210	SD0RA226	SL0RA226	SS0RA226	SD0RA228
SL0RA228	SS0RA228	SD0TH229	SL0TH229	SS0TH229
SD0TH230	SL0TH230	SS0TH230	SD0TH232	SL0TH232
SS0TH232	SD0PA231	SL0PA231	SS0PA231	SD0U233
SL0U233	SS0U233	SD0U234	SL0U234	SS0U23
SD0U235	SL0U235	SS0U235	SD0U236	SL0U236
SS0U236	SD0U238	SL0U238	SS0U238	SD0NP237
SL0NP237	SS0NP237	SD0PU238	SL0PU238	SS0PU238
SD0PU239	SL0PU239	SS0PU239	SD0PU240	SL0PU240
SS0PU240	SD0PU241	SL0PU241	SS0PU241	SD0PU242
SL0PU242	SS0PU242	SD0PU244	SL0PU244	SS0PU244
SD0AM241	SL0AM241	SS0AM241	SD0CM244	SL0CM244
SS0CM244	SD0CM248	SL0CM248	SS0CM248	SD0CF252
SL0CF252	SS0CF252	SD0PM147	SL0PM147	SS0PM147
SD0SM147	SL0SM147	SS0SM147	SD0AM243	SL0AM243
SS0AM243	SD0CM243	SL0CM243	SS0CM243	SD0CM245
SL0CM245	SS0CM245			

In the above listing, the 00 in the BRNVOL00 and the SMFLOW00 variables, and the 0 used as the third character in all the other history variables are indices intended to identify the waste panel that was assumed to be breached. Since 1991, all PA calculations have been full-repository runs. That is, the entire contents of the repository were assumed to be wetted by the inflowing brine, which, in previous PANEL runs, meant using the panel index numbers 0, and 00. In CCA runs, the panel index numbers will continue to be set at 0 and 00, however, in CCA runs, 0 will mean any *one* of the standard-sized waste panels (area = 11,640 m^2, or roughly one-tenth of the repository's total volume).

BRNVOL00 is the Brine Volume in the repository for the present run in cubic meters.

SMFLOW00 in the time-integrated rate of outflow of brine from the repository up the intrusion borehole in cubic meters.

For type-1 runs:
SD0***** is the time-integrated mass in kilograms of isotope ***** discharged in solution from the panel.
SL0***** is the time-integrated mass in kilograms of isotope ***** discharged on large colloids[+].
SS0***** is the time-integrated mass in kilograms of isotope ***** discharged on small colloids[+].
For type-2 runs:
SD0***** is the current inventory of isotope ***** in Curies.

Type-3 runs are not included in the CCA PA and therefore are not discussed herein.

9.1 Tips for Using type-1 Outputs

PANEL routinely outputs release data for 21 radioisotopes. However, the transport codes that read these data as input data may accommodate an even smaller number of radioisotopes. If the transport code that follows PANEL is not transporting a certain radioisotope, say R, it is *not* sufficient simply to delete PANEL's R releases from the computation. That is because the transport code may be considering R's daughter, D, or R's granddaughter, GD. If so, the mass flux and the integrated mass of R should be accounted for and added to PANEL's calculated mass fluxes and integrated masses of D and/or GD. That can be accomplished exactly if the downstream code has complete Bateman-decay capability (in which case, R would act as a source term in D's or GD's transport equation). If it does not, the effect can be approximated as outlined below.

For example, suppose the transport code is not considering radioisotope PU242, but is considering U238. To account for the U238 produced by decomposition of PU242, one might add SD0PU242 to SD0U238, add SL0PU242 to SL0U238, and add SS0PU242 to SS0U238. This correction is crude but conservative.

Alternatively, one might add the integrated release of R in kilograms to the release of D or GD (also in kilograms) in such a way that the total amount of radioactivity (in Curies) is maintained. For example: one might add SD0PU242*HLPU239/HLPU242 to SD0PU239, where HL***** represents the half-life of a radioisotope named *****. The same correction would be applied to the releases associated with PANEL's colloidal mobilization module when it is enabled (it was disenabled in the 1996 CCA).

[+] In the 1996 CCA, SLO and SSO are both zero because colloidal mobilization was combined with mobilization due to dissolution (see Chapter 4). That is, PANEL's internal colloidal-mobilization code was disenabled.

10.0 REFERENCES

Bateman, H. (1910) The Solution of a System of Differential Equations Occurring in the Theory of Radio-active Transformations, *Proc. Cambridge Phil. Soc.* **16**, 423.

Kaplan, Irving (1964) *Nuclear Physics,* 2nd Ed. (Chapter 10), Addison-Wesley Publishing Co, Reading, Mass.

Rechard, R. P., ed. (1992). *User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller; Version 3.0.* SAND90 - 1983. Sandia National Laboratories, Albuquerque NM.

Rechard, R. P. , A. P. Gilkey, H. J. Iuzzolino, D. K. Rudeen, and K. A. Byle. (1993). *Programmer's Manual for CAMCON: Compliance Assessment Methodology Controller.* SAND90 - 1984. Sandia National Laboratories, Albuquerque NM.

WIPP PA Division (1991) *Preliminary Comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant, December 1991.* Volume 3. Eds, R. P. Richard, A. C. Peterson, J. D. Schreibner, H. J. Iuzzolino, M. S. Tierney, and J. S. Sandha. SAND91 - 0893/3. Sandia National Laboratories, Albuquerque, NM.

WIPP PA Department (1992). *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 1: Third Comparison with 40 CFR 191, Subpart B.* SAND92 - 0700/1. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 2: Technical Basis.* SAND92 - 0700/2. Sandia National Laboratories, Albuquerque NM

WIPP PA Department (1992). *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters.* SAND92 - 0700/3. Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B. SAND92 - 0700/4.* Sandia National Laboratories, Albuquerque NM.

WIPP PA Department (1992). *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance.* SAND92 - 0700/5. Sandia National Laboratories, Albuquerque NM.

APPENDIX A: EXAMPLE OF A GENMESH INPUT FILE FOR A PANEL RUN.

GENMESH INPUT FILE

```
!=====================================================================
!   FILETYPE: GENMESH input text file
!   TITLE: Simple GENMESH to set up Source Term CDB
!   ANALYSTS: Christine Stockman
!   DATE: May 31, 1996
!=====================================================================
!
  *SETUP
    DIM=      3
    ORIGIN= 0.0, 0.0, 0.0
    IJKMAX= 2, 2, 2
  *GRID
!   ==================== X direction =====================
    DEL, COORD=X, DEL=   1.00, INRANGE=  1,  2, FACTOR= 1.0
!   ==================== Y direction =====================
    DEL, COORD=Y, DEL=   1.00, INRANGE=  1,  2, FACTOR= 1.0
!   ==================== Z direction =====================
    DEL, COORD=Z, DEL=   1.00, INRANGE=  1,  2, FACTOR= 1.0
!
  *REGIONS
   REGION= 1, IRANGE= 1,2, JRANGE= 1,2 KRANGE= 1, 2
 !=================================================================
  *END
```

END OF APPENDIX A

APPENDIX B: EXAMPLE OF A MATSET INPUT FILE FOR A PANEL RUN

MATSET INPUT FILE

```
!=========================================================================
! TITLE:     SOURCE TERM 1996: The WIPP PA CCA Calculation
! ANALYSTS: C. T. STOCKMAN, J. W. GARNER
! CREATED:  MAY 31, 1996
! MODIFIED:
! PURPOSE:  PREPARE SOURCE TERM CDB FOR NUTS, PANEL
!=========================================================================
!
*HEADING
 RUN=0
 SCALE=SOURCE
 SCENARIO=00
 TITLE=SOURCE TERM
!
*PRINT_ASSIGNED_VALUES
!
*UNITS=SI
!
*CREATE_BLOCK
  BLOCKID=      2,  3,  4,  5,  6,  7,  8,  9, 10, 11, 12, 13, 14, 15, &
           16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, &
         31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, &
         46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, &
         61, 62, 63, 64, 65, 66, 67
*RETRIEVE*NAME
 COORDINATE, DIM=3, NAMES=X, Y, Z
 MATERIAL,    1=GLOBAL, 2=REFCON, &
    3=AM241,  4=AM243,  5=CF252,  6=CM243,  7=CM244,  8=CM245, &
    9=CM248, 10=CS137, 11=NP237, 12=PA231, 13=PB210, 14=PM147, &
   15=PU238, 16=PU239, 17=PU240, 18=PU241, 19=PU242, 20=PU244, &
   21=RA226, 22=RA228, 23=SR90,  24=TH229, 25=TH230, &
   26=TH232, 27=U233,  28=U234,  29=U235,  30=U236,  31=U238,  &
   32=AM, 33=CF, 34=CM, 35=CS, 36=NP, 37=PA, 38=PB, 39=PM, 40=PU, &
   41=RA, 42=SR, 43=TH, 44=U,  &
   45=SOLMOD3, 46=SOLMOD4, 47=SOLMOD5, 48=SOLMOD6, &
   49=PHUMOX3, 50=PHUMOX4, 51=PHUMOX5, 52=PHUMOX6, &
   53=SOLAM3,  54=SOLPU3,  55=SOLPU4,  56=SOLTH4,  57=SOLU4,  58=SOLU6,    &
   59=AM241L:AM241, 60=PU238L:PU238, 61=PU239L:PU239,  &
   62=TH230L:TH230, 63=U234L:U234,&
   64=AML, 65=PUL, 66=THL, 67=UL
!MATERIALS 61-69 ARE LUMPED PARAMETERS FOR NUTS
!
 PROPERTY,  MATERIAL=Global,    NAMES =OXSTAT
 PROPERTY,  MATERIAL=REFCON,    NAMES =YRSEC
!ISOTOPES
 PROPERTY   MATERIAL=Am241,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Am243,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Cf252,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Cm243,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Cm244,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Cm245,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Cm248,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Cs137,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Np237,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY   MATERIAL=Pa231,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
```

```
 PROPERTY    MATERIAL=Pb210,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Pm147,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Pu238,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Pu239,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Pu240,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Pu241,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Pu242,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Pu244,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Ra226,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Ra228,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Sr90 ,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Th229,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Th230,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=Th232,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=U233,       NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=U234,       NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=U235,       NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=U236,       NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=U238,       NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
!
 PROPERTY    MATERIAL=AM241L,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=PU238L,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=PU239L,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=TH230L,     NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
 PROPERTY    MATERIAL=U234L,      NAMES =InvCHD,InvRHD,ATWEIGHT,HALFLIFE
!ELEMENTS
 PROPERTY    MATERIAL=AM,         NAMES =CONCMIN,CONCINT,CAPHUM,CAPMIC,PROPMIC
 PROPERTY    MATERIAL=CF,         NAMES =LOGSOLM
 PROPERTY    MATERIAL=CM,       NAMES =LOGSOLM
 PROPERTY    MATERIAL=SR,         NAMES =LOGSOLM
 PROPERTY    MATERIAL=CS,         NAMES =LOGSOLM
 PROPERTY    MATERIAL=NP,         NAMES =CONCMIN,CONCINT,CAPHUM,CAPMIC,PROPMIC
 PROPERTY    MATERIAL=PA,         NAMES =LOGSOLM
 PROPERTY    MATERIAL=PB,         NAMES =LOGSOLM
 PROPERTY    MATERIAL=PM,         NAMES =LOGSOLM
 PROPERTY    MATERIAL=PU,         NAMES =CONCMIN,CONCINT,CAPHUM,CAPMIC,PROPMIC
 PROPERTY    MATERIAL=RA,         NAMES =LOGSOLM
 PROPERTY    MATERIAL=TH,         NAMES =CONCMIN,CONCINT,CAPHUM,CAPMIC,PROPMIC
 PROPERTY    MATERIAL=U,          NAMES =CONCMIN,CONCINT,CAPHUM,CAPMIC,PROPMIC
!
 PROPERTY    MATERIAL=PUL,        NAMES =LOGSOLM
 PROPERTY    MATERIAL=AML,        NAMES =LOGSOLM
 PROPERTY    MATERIAL=UL,         NAMES =LOGSOLM
 PROPERTY    MATERIAL=THL,        NAMES =LOGSOLM
!OXIDATION STATES
 PROPERTY    MATERIAL=SOLMOD3,    NAMES =SOLSIM,SOLCIM,SOLSOM,SOLCOM
 PROPERTY    MATERIAL=SOLMOD4,    NAMES =SOLSIM,SOLCIM,SOLSOM,SOLCOM
 PROPERTY    MATERIAL=SOLMOD5,    NAMES =SOLSIM,SOLCIM,SOLSOM,SOLCOM
 PROPERTY    MATERIAL=SOLMOD6,    NAMES =SOLSIM,SOLCIM,SOLSOM,SOLCOM
 PROPERTY    MATERIAL=PHUMOX3,    NAMES =PHUMSIM,PHUMCIM
 PROPERTY    MATERIAL=PHUMOX4,    NAMES =PHUMSIM,PHUMCIM
 PROPERTY    MATERIAL=PHUMOX5,    NAMES =PHUMSIM,PHUMCIM
 PROPERTY    MATERIAL=PHUMOX6,    NAMES =PHUMSIM,PHUMCIM
!
 PROPERTY    MATERIAL=SOLAM3,     NAMES =SOLSIM,SOLCIM
 PROPERTY    MATERIAL=SOLPU3,     NAMES =SOLSIM,SOLCIM
 PROPERTY    MATERIAL=SOLPU4,     NAMES =SOLSIM,SOLCIM
 PROPERTY    MATERIAL=SOLTH4,     NAMES =SOLSIM
 PROPERTY    MATERIAL=SOLU4,      NAMES =SOLSIM
 PROPERTY    MATERIAL=SOLU6,      NAMES =SOLSIM,SOLCIM
```

```
!=========================================================================
*SET*VALUES
!LOGSOLM=0 ARE NEEDED AS PLACE HOLDERS FOR ELEMENTS THAT WILL HAVE THEIR
!SOLUBILITIES CONSTRUCTED
 PROPERTY   MATERIAL=CF,        NAMES*VALUE: LOGSOLM=0.
 PROPERTY   MATERIAL=CM,      NAMES*VALUE: LOGSOLM=0.
 PROPERTY   MATERIAL=PA,        NAMES*VALUE: LOGSOLM=0.
 PROPERTY   MATERIAL=PM,      NAMES*VALUE: LOGSOLM=0.
!
 PROPERTY   MATERIAL=AML,     NAMES*VALUE: LOGSOLM=0.
 PROPERTY   MATERIAL=THL,     NAMES*VALUE: LOGSOLM=0.
 PROPERTY   MATERIAL=PUL,     NAMES*VALUE: LOGSOLM=0.
 PROPERTY   MATERIAL=UL,      NAMES*VALUE: LOGSOLM=0.
!
*END
!-------------------------------------------------------------------------
```

END OF APPENDIX B

APPENDIX C: EXAMPLE OF A POSTLHS INPUT FILE FOR A PANEL RUN

POSTLHS INPUT FILE

```
!=================================================================
! TITLE:   POSTLHS input file == POSTLHS_S00.INP
! ANALYST: J.W.GARNER  --  5/29/92
!=================================================================
!
! DESCRIPTION: NAS FALL,1992 SCENARIO
!
!=================================================================
!
!=================================================================
*END
```

END OF APPENDIX C

APPENDIX D: EXAMPLE OF ALGEBRA'S POST-POSTLHS SOURCE-TERM INPUT FILE

A detailed explanation of the chemical basis for this input file may be found in Section 7 of the SOTERM Appendix of the WIPP's 1996 Compliance Certification Application.

SOURCE TERM ALGEBRA INPUT FILE

```
!=================================================================
!TITLE: SOURCE TERM CALCULATIONS, SALADO BRINE
!ANALYSTS: CHRISTINE STOCKMAN SNL Org 6749
!CREATED:  MAY 29, 1996
!MODIFIED: JULY 29, 1996
!MODIFIED for: additional "lumping" of inventory
!=================================================================
!OX IS NEG AND 0 FOR LOW OX STATE AND POSITIVE FOR HIGH OX STATE
OX=OXSTAT[B:1]-0.5
!AM
!AM=32,SOLMOD3=45,SOLAM3=53,PHUMOX3=49
LIMIT BLOCKS 32
DIS=MAKEPROP(10**SOLSIM[B:53]*SOLSIM[B:45])
HUM=MAKEPROP(MIN(CAPHUM,10**SOLSIM[B:53]*SOLSIM[B:45]*PHUMSIM[B:49]))
MIC1=MAKEPROP(10**SOLSIM[B:53]*SOLSIM[B:45]*PROPMIC)
TOT=MAKEPROP(DIS+HUM+MIC1+CONCINT+CONCMIN)
TOTNM=MAKEPROP(DIS+HUM+CONCINT+CONCMIN)
TOTSOL = MAKEPROP(IFLT0(CAPMIC-TOT,MIN(TOTNM+CAPMIC,TOT),TOT))
MIC= MAKEPROP(IFLT0(CAPMIC-TOT,TOTSOL-TOTNM,MIC1))
LOGSOLM=MAKEPROP(LOG10(TOTSOL))
FRCDIS=MAKEPROP(DIS/TOTSOL)
FRCHUM=MAKEPROP(HUM/TOTSOL)
FRCMIC=MAKEPROP(MIC/TOTSOL)
FRCINT=MAKEPROP(CONCINT/TOTSOL)
FRCMIN=MAKEPROP(CONCMIN/TOTSOL)
!TH
!TH=43,SOLMOD4=46,PHUMOX4=50, SOLTH4=56
LIMIT BLOCKS 43
DIS=MAKEPROP(10**SOLSIM[B:56]*SOLSIM[B:46])
HUM=MAKEPROP(MIN(CAPHUM,10**SOLSIM[B:56]*SOLSIM[B:46]*PHUMSIM[B:50]))
MIC1=MAKEPROP(10**SOLSIM[B:56]*SOLSIM[B:46]*PROPMIC)
TOT=MAKEPROP(DIS+HUM+MIC1+CONCINT+CONCMIN)
TOTNM=MAKEPROP(DIS+HUM+CONCINT+CONCMIN)
TOTSOL = MAKEPROP(IFLT0(CAPMIC-TOT,MIN(TOTNM+CAPMIC,TOT),TOT))
MIC= MAKEPROP(IFLT0(CAPMIC-TOT,TOTSOL-TOTNM,MIC1))
LOGSOLM=MAKEPROP(LOG10(TOTSOL))
FRCDIS=MAKEPROP(DIS/TOTSOL)
FRCHUM=MAKEPROP(HUM/TOTSOL)
FRCMIC=MAKEPROP(MIC/TOTSOL)
FRCINT=MAKEPROP(CONCINT/TOTSOL)
FRCMIN=MAKEPROP(CONCMIN/TOTSOL)
!PU3
!PUT LOGSOLM ETC INTO SOLPU3 UNTIL CHECK OXIDATION STATE, THEN PUT INTO PU
!PU=40,SOLMOD3=45,SOLPU3=54,PHUMOX3=49
LIMIT BLOCKS 54
DIS=MAKEPROP(10**SOLSIM[B:54]*SOLSIM[B:45])
HUM=MAKEPROP(MIN(CAPHUM[B:40],10**SOLSIM[B:54]*SOLSIM[B:45]*PHUMSIM[B:49]))
MIC1=MAKEPROP(10**SOLSIM[B:54]*SOLSIM[B:45]*PROPMIC[B:40])
TOTNM=MAKEPROP(DIS+HUM+CONCINT[B:40]+CONCMIN[B:40])
```

```
TOT=MAKEPROP(TOTNM+MIC1)
TOTSOL = MAKEPROP(IFLT0(CAPMIC[B:40]-TOT,MIN(TOTNM+CAPMIC[B:40],TOT),TOT))
MIC= MAKEPROP(IFLT0(CAPMIC[B:40]-TOT,TOTSOL-TOTNM,MIC1))
LOGSOLM=MAKEPROP(LOG10(TOTSOL))
FRCDIS=MAKEPROP(DIS/TOTSOL)
FRCHUM=MAKEPROP(HUM/TOTSOL)
FRCMIC=MAKEPROP(MIC/TOTSOL)
FRCINT=MAKEPROP(CONCINT[B:40]/TOTSOL)
FRCMIN=MAKEPROP(CONCMIN[B:40]/TOTSOL)
!PU4
!PUT LOGSOLM ETC INTO SOLPU4 UNTIL CHECK OXIDATION STATE, THEN PUT INTO PU
!PU=40,SOLMOD4=46,SOLPU4=55,PHUMOX4=50
LIMIT BLOCKS 55
DIS=MAKEPROP(10**SOLSIM[B:55]*SOLSIM[B:46])
HUM=MAKEPROP(MIN(CAPHUM[B:40],10**SOLSIM[B:55]*SOLSIM[B:46]*PHUMSIM[B:50]))
MIC1=MAKEPROP(10**SOLSIM[B:55]*SOLSIM[B:46]*PROPMIC[B:40])
TOTNM=MAKEPROP(DIS+HUM+CONCINT[B:40]+CONCMIN[B:40])
TOT=MAKEPROP(TOTNM+MIC1)
TOTSOL = MAKEPROP(IFLT0(CAPMIC[B:40]-TOT,MIN(TOTNM+CAPMIC[B:40],TOT),TOT))
MIC= MAKEPROP(IFLT0(CAPMIC[B:40]-TOT,TOTSOL-TOTNM,MIC1))
LOGSOLM=MAKEPROP(LOG10(TOTSOL))
FRCDIS=MAKEPROP(DIS/TOTSOL)
FRCHUM=MAKEPROP(HUM/TOTSOL)
FRCMIC=MAKEPROP(MIC/TOTSOL)
FRCINT=MAKEPROP(CONCINT[B:40]/TOTSOL)
FRCMIN=MAKEPROP(CONCMIN[B:40]/TOTSOL)
!NOW CHECK OX
LIMIT BLOCK 40
LOGSOLM=MAKEPROP(IFGT0(OX,LOGSOLM[B:55],LOGSOLM[B:54]))
FRCDIS =MAKEPROP(IFGT0(OX,FRCDIS[B:55],FRCDIS[B:54]))
FRCHUM =MAKEPROP(IFGT0(OX,FRCHUM[B:55],FRCHUM[B:54]))
FRCINT =MAKEPROP(IFGT0(OX,FRCINT[B:55],FRCINT[B:54]))
FRCMIN =MAKEPROP(IFGT0(OX,FRCMIN[B:55],FRCMIN[B:54]))
FRCMIC =MAKEPROP(IFGT0(OX,FRCMIC[B:55],FRCMIC[B:54]))
!U4
!PUT LOGSOLM ETC INTO SOLU4 UNTIL CHECK OXIDATION STATE, THEN PUT INTO U
!U=44,SOLMOD4=46,SOLU4=57,PHUMOX4=50
LIMIT BLOCKS 57
DIS=MAKEPROP(10**SOLSIM[B:57]*SOLSIM[B:46])
HUM=MAKEPROP(MIN(CAPHUM[B:44],10**SOLSIM[B:57]*SOLSIM[B:46]*PHUMSIM[B:50]))
MIC1=MAKEPROP(10**SOLSIM[B:57]*SOLSIM[B:46]*PROPMIC[B:44])
TOTNM=MAKEPROP(DIS+HUM+CONCINT[B:44]+CONCMIN[B:44])
TOT=MAKEPROP(TOTNM+MIC1)
TOTSOL = MAKEPROP(IFLT0(CAPMIC[B:44]-TOT,MIN(TOTNM+CAPMIC[B:44],TOT),TOT))
MIC= MAKEPROP(IFLT0(CAPMIC[B:44]-TOT,TOTSOL-TOTNM,MIC1))
LOGSOLM=MAKEPROP(LOG10(TOTSOL))
FRCDIS=MAKEPROP(DIS/TOTSOL)
FRCHUM=MAKEPROP(HUM/TOTSOL)
FRCMIC=MAKEPROP(MIC/TOTSOL)
FRCINT=MAKEPROP(CONCINT[B:44]/TOTSOL)
FRCMIN=MAKEPROP(CONCMIN[B:44]/TOTSOL)
!U6
!PUT LOGSOLM ETC INTO SOLU6 UNTIL CHECK OXIDATION STATE, THEN PUT INTO U
!U=44,SOLMOD6=48,SOLU6=58,PHUMOX6=52
LIMIT BLOCKS 58
DIS=MAKEPROP(10**SOLSIM[B:58]*SOLSIM[B:48])
HUM=MAKEPROP(MIN(CAPHUM[B:44],10**SOLSIM[B:58]*SOLSIM[B:48]*PHUMSIM[B:52]))
MIC1=MAKEPROP(10**SOLSIM[B:58]*SOLSIM[B:48]*PROPMIC[B:44])
TOTNM=MAKEPROP(DIS+HUM+CONCINT[B:44]+CONCMIN[B:44])
TOT=MAKEPROP(TOTNM + MIC1)
```

```
TOTSOL = MAKEPROP(IFLT0(CAPMIC[B:44]-TOT,MIN(TOTNM+CAPMIC[B:44],TOT),TOT))
MIC= MAKEPROP(IFLT0(CAPMIC[B:44]-TOT,TOTSOL-TOTNM,MIC1))
LOGSOLM=MAKEPROP(LOG10(TOTSOL))
FRCDIS=MAKEPROP(DIS/TOTSOL)
FRCHUM=MAKEPROP(HUM/TOTSOL)
FRCMIC=MAKEPROP(MIC/TOTSOL)
FRCINT=MAKEPROP(CONCINT[B:44]/TOTSOL)
FRCMIN=MAKEPROP(CONCMIN[B:44]/TOTSOL)
!NOW CHECK OX
LIMIT BLOCK 44
LOGSOLM=MAKEPROP(IFGT0(OX,LOGSOLM[B:58],LOGSOLM[B:57]))
FRCDIS =MAKEPROP(IFGT0(OX,FRCDIS[B:58],FRCDIS[B:57]))
FRCHUM =MAKEPROP(IFGT0(OX,FRCHUM[B:58],FRCHUM[B:57]))
FRCINT =MAKEPROP(IFGT0(OX,FRCINT[B:58],FRCINT[B:57]))
FRCMIN =MAKEPROP(IFGT0(OX,FRCMIN[B:58],FRCMIN[B:57]))
FRCMIC =MAKEPROP(IFGT0(OX,FRCMIC[B:58],FRCMIC[B:57]))
!
!NP
!PUT LOGSOLM ETC INTO SOLNP UNTIL CHECK OXIDATION STATE, THEN PUT INTO NP
!NP=36,SOLMOD4=46,PHUMOX4=50,SOLMOD5=47,PHIMOX5=51
LIMIT BLOCKS 36
DISNP4=MAKEPROP(SOLSIM[B:46])
HUMNP4=MAKEPROP(MIN(CAPHUM[B:36],SOLSIM[B:46]*PHUMSIM[B:50]))
MNP4=MAKEPROP(SOLSIM[B:46]*PROPMIC[B:36])
TNMNP4=MAKEPROP(DISNP4+HUMNP4+CONCINT[B:36]+CONCMIN[B:36])
TOT4=MAKEPROP(TNMNP4+MNP4)
TOTNP4 = MAKEPROP(IFLT0(CAPMIC-TOT4,MIN(TNMNP4+CAPMIC,TOT4),TOT4))
MICNP4=MAKEPROP(IFLT0(CAPMIC-TOT4,TOTNP4-TNMNP4,MNP4))
!
DISNP5=MAKEPROP(SOLSIM[B:47])
HUMNP5=MAKEPROP(MIN(CAPHUM[B:36],SOLSIM[B:47]*PHUMSIM[B:51]))
MNP5=MAKEPROP(SOLSIM[B:47]*PROPMIC[B:36])
TNMNP5=MAKEPROP(DISNP5+HUMNP5+CONCINT[B:36]+CONCMIN[B:36])
TOT5=MAKEPROP(TNMNP5+MNP5)
TOTNP5 = MAKEPROP(IFLT0(CAPMIC-TOT5,MIN(TNMNP5+CAPMIC,TOT5),TOT5))
MICNP5=MAKEPROP(IFLT0(CAPMIC-TOT5,TOTNP5-TNMNP5,MNP5))
LOGSOLM=MAKEPROP(IFGT0(OX,LOG10(TOTNP5),LOG10(TOTNP4)))
FRCDIS =MAKEPROP(IFGT0(OX,DISNP5/TOTNP5,DISNP4/TOTNP4))
FRCHUM =MAKEPROP(IFGT0(OX,HUMNP5/TOTNP5,HUMNP4/TOTNP4))
FRCMIC =MAKEPROP(IFGT0(OX,MICNP5/TOTNP5,MICNP4/TOTNP4))
FRCINT =MAKEPROP(IFGT0(OX,CONCINT[B:36]/TOTNP5,CONCINT[B:36]/TOTNP4))
FRCMIN =MAKEPROP(IFGT0(OX,CONCMIN[B:36]/TOTNP5,CONCMIN[B:36]/TOTNP4))
!
!PA
!PA=37, NP=36
LIMIT BLOCKS 37
LOGSOLM=MAKEPROP(LOGSOLM[B:36])
!
!CF,CM,PM SET TO AM=32
LIMIT BLOCKS 33, 34, 39
LOGSOLM=MAKEPROP(LOGSOLM[B:32])
!
!NOW TO LUMP FOR NUTS
!NOW INVENTORY ARE FOR SINGLE SPEICES, NEED TO ADD IN TH229, U233,
!Pu241, Pu240, Pu242
!
!use most conservative method: if added species is shorter-lived, add curies
!if added species is longer-lived, add curies scaled by halflives (add grams)
!
!U234L=63, U234=28, U233=27
```

```
LIMIT BLOCK 63
INVCHD=MAKEPROP(INVCHD[B:28]+INVCHD[B:27])
INVRHD=MAKEPROP(INVRHD[B:28]+INVRHD[B:27])
!
!TH230L=62, TH229=24, TH230=25
LIMIT BLOCK 62
INVCHD=MAKEPROP(INVCHD[B:25]+INVCHD[B:24])
INVRHD=MAKEPROP(INVRHD[B:25]+INVRHD[B:24])
!
!AM241L=59, AM241=3, PU241=18
!DECAY ALL PU241 TO AM241 AND ADD THIS IN TO AM241
!SO CONVERT CI PU241 TO KG PU241, CONVERT TO KG AM241, CONVERT BACK TO CI
AM241
!THIS IS DONE USING RATIO OF HALFLIFES
LIMIT BLOCK 59
INVCHD=MAKEPROP(INVCHD[B:3]+INVCHD[B:18]*HALFLIFE[B:18]/HALFLIFE[B:3])
INVRHD=MAKEPROP(INVRHD[B:3]+INVRHD[B:18]*HALFLIFE[B:18]/HALFLIFE[B:3])
!
!PU239L=61, PU239=16, PU240=17, PU242=19
LIMIT BLOCK 61
LIFERATO = HALFLIFE[B:19]/HALFLIFE[B:16]
INVCHD=MAKEPROP(INVCHD[B:16]+INVCHD[B:17]+INVCHD[B:19]*LIFERATO)
INVRHD=MAKEPROP(INVRHD[B:16]+INVRHD[B:17]+INVCHD[B:19]*LIFERATO)
!
!REDUCE SOLUBILITIES BY RATIO'S WITH OTHER ISOTOPES
!AML=64,PUL=65,THL=66,UL=67: AM=32,PU=40,TH=43,U=44
LIMIT BLOCK 64
LOGSOLM=MAKEPROP(LOGSOLM[B:32])
FRCDIS=MAKEPROP(FRCDIS[B:32])
FRCHUM=MAKEPROP(FRCHUM[B:32])
FRCMIC=MAKEPROP(FRCMIC[B:32])
FRCINT=MAKEPROP(FRCINT[B:32])
FRCMIC=MAKEPROP(FRCMIC[B:32])
LIMIT BLOCK 65
LOGSOLM=MAKEPROP(LOGSOLM[B:40])
FRCDIS=MAKEPROP(FRCDIS[B:40])
FRCHUM=MAKEPROP(FRCHUM[B:40])
FRCMIC=MAKEPROP(FRCMIC[B:40])
FRCINT=MAKEPROP(FRCINT[B:40])
FRCMIC=MAKEPROP(FRCMIC[B:40])
LIMIT BLOCK 66
LOGSOLM=MAKEPROP(LOGSOLM[B:43]-3)
FRCDIS=MAKEPROP(FRCDIS[B:43])
FRCHUM=MAKEPROP(FRCHUM[B:43])
FRCMIC=MAKEPROP(FRCMIC[B:43])
FRCINT=MAKEPROP(FRCINT[B:43])
FRCMIC=MAKEPROP(FRCMIC[B:43])
LIMIT BLOCK 67
LOGSOLM=MAKEPROP(LOGSOLM[B:44]-2)
FRCDIS=MAKEPROP(FRCDIS[B:44])
FRCHUM=MAKEPROP(FRCHUM[B:44])
FRCMIC=MAKEPROP(FRCMIC[B:44])
FRCINT=MAKEPROP(FRCINT[B:44])
FRCMIC=MAKEPROP(FRCMIC[B:44])
!
END
```

END OF APPENDIX D

APPENDIX E: EXAMPLE OF ALGEBRA'S POST-POSTBRAGFLO INPUT FILES: USED TO PREPARE BRINE INPUT DATA FOR PANEL.

This file is more complex than is required for PANEL's needs. PANEL reads only variables #30 and # 78, which are explained on the file.

```
!==========================================================================
!
! ALGEBRA file for calculating BRAGFLO sensitivity analysis parameters
!
! Based on file: POSTALG_CCA_180.INP   (Parameters 1-180) plus 6 additional
!
! 07 June 1996 - 186 variables
!
! Authors:  Joel D. Miller, SNL Org. 9363
!           David A. Mc Arthur, Org. 9363
!
!==========================================================================
!
! Eliminate excess output
!
DELETE ALL
!
! Calculate general parameters
!
GRIDVOL = DEL_X * DEL_Y * THICK
!
!**************************************************************************
!**************************************************************************
!
! Remaining inventories of steel and cellulose (kg)
!
!   Param 001: Remaining mass of steel ----------> FE_KG
!   Param 002: Remaining mass of cellulose ------> CELL_KG
!
! Remaining inventories of steel and cellulose (%/100)
!
!   Param 003: Remaining fraction of steel  -----> FE_REM
!   Param 004: Remaining fraction of cellulose --> CELL_REM
!
! Cumulative gas generation in waste disposal regions (moles)
!
!   Param 005: by corrosion ------------> FE_MOLE
!   Param 006: by humid microbial ------> CELL_M_H
!   Param 007: by inundated microbial --> CELL_M_I
!   Param 008: by total microbial ------> CELL_MOL, C_M_HI_T
!   Param 010: Total gas generation ----> GAS_MOLE
!
! Cumulative gas generation in waste disposal regions (moles/drum)
!
!   Param 011: by corrosion ------------> FE_MOL_D
!   Param 012: by humid microbial ------> CEL_MH_D
!   Param 013: by inundated microbial --> CEL_MI_D
!   Param 014: by total microbial ------> CELMOL_D, C_MHIT_D
!   Param 016: Total gas generation ----> GASMOL_D
!
! Cumulative gas generation in waste disposal regions (m**3)
!
!   Param 017: by corrosion ------------> GAS_FE_V
!   Param 018: by humid microbial ------> GAS_CMH
```

```
!   Param 019: by inundated microbial --> GAS_CMI
!   Param 020: by total microbial ------> GAS_C_V, C_MHIT_V
!   Param 022: Total gas generation ----> GAS_VOL
!
!****************************************
!
! Limit calculation to areas with waste (WAS_AREA + REPOSIT)
!
LIMIT ELEMENT 596 TO 625
!
! Define molecular weights of iron, cellulosics, water and brine (kg/mol)
!
MW_FE    = 0.055847
MW_CELL  = 0.03002628
MW_H2O   = 0.01801534
MW_BRINE = 0.022653859
!
! Calculate mass inventories (kg) remaining
!
FE_KG    = SUM(GRIDVOL*FECONC)
CELL_KG  = SUM(GRIDVOL*CELLCONC)
!
! Maximum Fe and bio is at time = 0.0
!
MXFE     = ENVMAX(FE_KG)
MXCELL   = ENVMAX(CELL_KG)
!
! Calculate masses consumed and divide by initial amount to get fractions gone
! Subtract fraction gone from one to get fractions remaining
!
FE_REM   = 1.0 - ((MXFE - FE_KG)/MXFE)
CELL_REM = 1.0 - ((MXCELL - CELL_KG)/MXCELL)
!
! Calculate total moles of gas (H2) generated from corrosion of Fe
!
FE_MOLE  = (MXFE - FE_KG)/MW_FE*(4.0-STOICOR[B:12])/3.0
!
! Calculate total moles of gas (H2) generated from biodegradation of cellulosics
!
CELL_MOL = (MXCELL - CELL_KG)/MW_CELL*STOIMIC[B:12]
!
! Total moles of gas generated
!
GAS_MOLE = FE_MOLE + CELL_MOL
!
! Determine humid and inundated biodegradation components
!
!   Inundated rate GRATI (moles/s)
!
SATBR    = 1.0 - SATGAS
SATFAC   = 1.0 - EXP(-1000*SATBR)
LSAT     = SATBR + SAT_WICK[B:12]*(SATFAC)
LSAT     = IFGT0(LSAT-1,1,LSAT)
GRATI    = KBGSI[B:12]*(LSAT)*STOIMIC[B:12]*GRIDVOL
!
!   Humid rate GRATH (moles/s)
!
GSAT     = SATGAS - SAT_WICK[B:12]*SATFAC
GSAT     = IFLT0(GSAT,0.0,GSAT)
GRATH    = KBGSH[B:12]*(GSAT)*STOIMIC[B:12]*GRIDVOL
!
!   Determine the time interval DT by integrating a non-zero function
!
!     This is necessary because the input .cdb file has history variables and
!     associated history time steps, which prevents using DT = TIME-TIME[T:-1]
!
```

```
!     VAL(I) = (VAL(I-1) + D(VAL)/DT)*DT where VAL is the integral of DENGAS
!     DENGAS is the gas density and is always greater than zero
!
DENGASC  = INTRIGHT(DENGAS)
DT       = (DENGASC - DENGASC[T:-1])/DENGAS
!
!   Calculate kg/m**3 of cellulose consumed as if rate is valid for entire
!     time interval (DT)
!
KGCI     = KBGSI[B:12]*LSAT*MW_CELL*DT
KGCH     = KBGSH[B:12]*GSAT*MW_CELL*DT
KGTOT    = KGCI + KGCH
!
!   Adjust GRATI and GRATH for step when CELLCONC goes to zero
!   Note:  KGTOT may be equal to zero if KBGSI and KBGSH are both zero
!          so to avoid dividing by zero set DENOM equal to 1, which is
!          acceptable since the coding below will use the true branch
!          for calculating GRATI and GRATIH
!
DENOM    = IFEQ0(KGTOT,1,KGTOT)
SLOPE    = CELLCONC[T:-1]/DENOM
GRATI    = IFGT0(CELLCONC,GRATI,GRATI*SLOPE)
GRATH    = IFGT0(CELLCONC,GRATH,GRATH*SLOPE)
!
!   Sum up humid and inundated over panel elements, add together for total
!
GRATHT   = SUM(GRATH)
GRATIT   = SUM(GRATI)
GRATIH   = GRATIT + GRATHT
!
!   Integrate humid, inundated, and total (note C_M_HI_T should equal CELL_MOL)
!
CELL_M_H = INTRIGHT(GRATHT)
CELL_M_I = INTRIGHT(GRATIT)
C_M_HI_T = INTRIGHT(GRATIH)
!
! Clean up output--limit to requested quantities, delete temporary variables
!                  that are not used in another calculation later
!
DELETE MW_FE, MW_CELL, MW_H2O, MW_BRINE, MXFE, MXCELL
DELETE GRATHT, GRATIT, GRATIH, GRATI, GRATH, SATBR, DT, SATFAC
DELETE LSAT, GSAT, DENGASC, KGCI, KGCH, KGTOT, DENOM, SLOPE
!
!****************************************
!
! Convert to units of moles per drum by dividing by total number of drums
!
FE_MOL_D = FE_MOLE  / DRUMTOT[B:12]
CEL_MH_D = CELL_M_H / DRUMTOT[B:12]
CEL_MI_D = CELL_M_I / DRUMTOT[B:12]
CELMOL_D = CELL_MOL / DRUMTOT[B:12]
C_MHIT_D = C_M_HI_T / DRUMTOT[B:12]
GASMOL_D = GAS_MOLE / DRUMTOT[B:12]
!
!****************************************
!
! Convert to volumetric units (m**3) using PV=nRT at reference P & T
!
!   T =     300.15 K
!   P = 101325.00 Pa        = 101325 N/(m**2)
!   R = 8.3145    J/(mol*K) = 8.3145 (N*m)/(mol*K)
!   V = n*(R*T/P) m**3      = n moles * 0.024630 (m**3)/mole
!
GAS_FE_V = 0.02463 * FE_MOLE
GAS_CMH  = 0.02463 *•CELL_M_H
GAS_CMI  = 0.02463 * CELL_M_I
```

```
GAS_C_V  = 0.02463 * CELL_MOL
C_MHIT_V = 0.02463 * C_M_HI_T
GAS_VOL  = 0.02463 * GAS_MOLE
!
!****************************************
!
!*****************************************************************************
!*****************************************************************************
!
! Volume-averaged pressure (Pa)
!
!   Param 023: for region 23 (waste panel,          block 12) --> WAS_PRES
!   Param 024: for region 24 (rest of repository,   block 13) --> REP_PRES
!   Param 025: for region 26 (operation region,     block 21) --> OPS_PRES
!   Param 026: for region 27 (experimental region, block 22) --> EXP_PRES
!   Param 027: for regions 23+24 ------------------------------> W_R_PRES
!   Param 028: for region 30 (brine pocket,         block 11) --> B_P_PRES
!
!****************************************
!
! WAS_AREA
!
LIMIT ELEMENT 596 TO 616
!
! Total volume of waste area
!
R12VOL = SUM(GRIDVOL)
!
! Add up brine pressures weighted by element volume
!
R12PRES = SUM(GRIDVOL*PRESBRIN)
!
! Determine average pressure in waste area
!
WAS_PRES = R12PRES/R12VOL
!
!****************************************
!
! REPOSIT
!
LIMIT ELEMENT 617 TO 625
R13VOL   = SUM(GRIDVOL)
R13PRES  = SUM(GRIDVOL*PRESBRIN)
REP_PRES = R13PRES/R13VOL
!
!****************************************
!
! OPS_AREA
!
LIMIT ELEMENT 626 TO 631
R21VOL   = SUM(GRIDVOL)
R21PRES  = SUM(GRIDVOL*PRESBRIN)
OPS_PRES = R21PRES/R21VOL
!
!****************************************
!
! EXP_AREA
!
LIMIT ELEMENT 632 TO 637
R22VOL   = SUM(GRIDVOL)
R22PRES  = SUM(GRIDVOL*PRESBRIN)
EXP_PRES = R22PRES/R22VOL
!
!****************************************
!
! Average brine pressure in waste area and rest of repository
```

```
!
W_R_PRES = (R12PRES + R13PRES)/(R12VOL + R13VOL)
!
!****************************************
!
! Brine pocket
!
LIMIT ELEMENT 1007 TO 1023
R30VOL   = SUM(GRIDVOL)
R30PRES  = SUM(GRIDVOL*PRESBRIN)
B_P_PRES = R30PRES/R30VOL
!
!****************************************
!
! Clean up output--limit to requested quantities (regional volumes used below)
!
DELETE R12PRES, R13PRES, R21PRES, R22PRES, R30PRES
!
!*****************************************************************************
!*****************************************************************************
!
! Param 029: Total pore volume in repository (m**3) --> PORVOL_T
!
!****************************************
!
! WAS_AREA + REPOSIT -
!
LIMIT ELEMENT 596 TO 625
!
! Pore volume = porosity (m**3 void/m**3 rock) * volume
!
PORVOL_T = SUM(POROS*GRIDVOL)
!
!*****************************************************************************
!*****************************************************************************
!
! Brine volume in repository (m**3)
!
!   Param 030: for region 23 (waste panel,         block 12) --> BRNVOL_W
!   Param 031: for region 24 (rest of repository,  block 13) --> BRNVOL_R
!   Param 032: for regions 23+24 ------------------------------> BRNVOL_T
!   Param 033: for region 26 (operations,          block 21) --> BRNVOL_O
!   Param 034: for region 27 (experimental region, block 22) --> BRNVOL_E
!   Param 035: for regions 23+24+26+27 ------------------------> BRNVOL_A
!
!****************************************
!
! WAS_AREA
!
LIMIT ELEMENT 596 TO 616
!
! Brine volume     = porosity * volume * brine saturation
! Brine saturation = 1.0 - SATGAS
!
BRNVOL_W = SUM(POROS*GRIDVOL*(1.0-SATGAS))
!
!****************************************
!
! REPOSIT
!
LIMIT ELEMENT 617 TO 625
!
BRNVOL_R = SUM(POROS*GRIDVOL*(1.0-SATGAS))
!
!****************************************
!
```

```
! WAS_AREA + REPOSIT
!
BRNVOL_T = BRNVOL_W + BRNVOL_R
!
!*************************************
!
! OPS_AREA
!
LIMIT ELEMENT 626 TO 631
!
BRNVOL_O = SUM(POROS*GRIDVOL*(1.0-SATGAS))
!
!*************************************
!
! EXP_AREA
!
LIMIT ELEMENT 632 TO 637
!
BRNVOL_E = SUM(POROS*GRIDVOL*(1.0-SATGAS))
!
!*************************************
!
! All repository regions
!
BRNVOL_A = BRNVOL_T + BRNVOL_O + BRNVOL_E
!
!*************************************************************************
!*************************************************************************
!
! Volume-averaged gas saturation (dimensionless)
!
!   Param 036: for region 23 (waste panel,         block 12) --> WAS_SATG
!   Param 037: for region 24 (rest of repository,  block 13) --> REP_SATG
!   Param 038: for region 26 (operation region,    block 21) --> OPS_SATG
!   Param 039: for region 27 (experimental region, block 22) --> EXP_SATG
!   Param 040: for regions 23+24 ----------------------------> W_R_SATG
!   Param 041: for region 30 (brine pocket,        block 11) --> B_P_SATG
!
!*************************************
!
! WAS_AREA
!
LIMIT ELEMENT 596 TO 616
!
! Add up gas saturation weighted by element volume
!
R12SATG = SUM(GRIDVOL*SATGAS)
!
! Determine average gas saturation in waste area
!
WAS_SATG = R12SATG/R12VOL
!
!*************************************
!
! REPOSIT
!
LIMIT ELEMENT 617 TO 625
R13SATG  = SUM(GRIDVOL*SATGAS)
REP_SATG = R13SATG/R13VOL
!
!*************************************
!
! OPS_AREA
!
LIMIT ELEMENT 626 TO 631
R21SATG  = SUM(GRIDVOL*SATGAS)
```

```
OPS_SATG = R21SATG/R21VOL
!
!****************************************
!
! EXP_AREA
!
LIMIT ELEMENT 632 TO 637
R22SATG  = SUM(GRIDVOL*SATGAS)
EXP_SATG = R22SATG/R22VOL
!
!****************************************
!
! Average gas saturation in waste area and rest of repository
!
W_R_SATG = (R12SATG + R13SATG)/(R12VOL + R13VOL)
!
!****************************************
!
! Brine pocket
!
LIMIT ELEMENT 1007 TO 1023
R30SATG  = SUM(GRIDVOL*SATGAS)
B_P_SATG = R30SATG/R30VOL
!
!****************************************
!
! Clean up output--limit to requested quantities
!
DELETE R12SATG, R13SATG, R21SATG, R22SATG, R30SATG
DELETE R12VOL,  R13VOL,  R21VOL,  R22VOL,  R30VOL
!
!*****************************************************************************
!*****************************************************************************
!
! Volume-averaged brine saturation (dimensionless)
!
!   Param 042: for region 23 (waste panel,         block 12) --> WAS_SATB
!   Param 043: for region 24 (rest of repository,  block 13) --> REP_SATB
!   Param 044: for region 26 (operation region,    block 21) --> OPS_SATB
!   Param 045: for region 27 (experimental region, block 22) --> EXP_SATB
!   Param 046: for regions 23+24 ----------------------------> W_R_SATB
!   Param 047: for region 30 (brine pocket,        block 11) --> B_P_SATB
!
!****************************************
!
! WAS_AREA
!
WAS_SATB = 1.0 - WAS_SATG
!
!****************************************
!
! REPOSIT
!
REP_SATB = 1.0 - REP_SATG
!
!****************************************
!
! OPS_AREA
!
OPS_SATB = 1.0 - OPS_SATG
!
!****************************************
!
! EXP_AREA
!
EXP_SATB = 1.0 - EXP_SATG
```

```
!
!****************************************
!
! Average brine saturation in waste area and rest of repository
!
W_R_SATB = 1.0 - W_R_SATG
!
!****************************************
!
! Brine pocket
!
B_P_SATB = 1.0 - B_P_SATG
!
!****************************************
!
!*****************************************************************************
!*****************************************************************************
!
! Volume-averaged porosity (m**3 void/m**3 rock)
!
!   Param 048: for region 23 (waste panel,         block 12) --> WAS_POR
!   Param 049: for region 24 (rest of repository,  block 13) --> REP_POR
!   Param 050: for region 26 (operation region,    block 21) --> OPS_POR
!   Param 051: for region 27 (experimental region, block 22) --> EXP_POR
!   Param 052: for regions 23+24 ----------------------------> W_R_POR
!
!****************************************
!
! WAS_AREA
!
LIMIT ELEMENT 596 TO 616
!
WAS_POR = SUM(GRIDVOL*POROS)/SUM(GRIDVOL)
!
!****************************************
!
! REPOSIT
!
LIMIT ELEMENT 617 TO 625
!
REP_POR = SUM(GRIDVOL*POROS)/SUM(GRIDVOL)
!
!****************************************
!
! OPS_AREA
!
LIMIT ELEMENT 626 TO 631
!
OPS_POR = SUM(GRIDVOL*POROS)/SUM(GRIDVOL)
!
!****************************************
!
! EXP_AREA
!
LIMIT ELEMENT 632 TO 637
!
EXP_POR = SUM(GRIDVOL*POROS)/SUM(GRIDVOL)
!
!****************************************
!
! Average porosity in waste area and rest of repository
!
LIMIT ELEMENT 596 TO 625
!
W_R_POR = SUM(GRIDVOL*POROS)/SUM(GRIDVOL)
!
```

```
!*************************************
!
!*****************************************************************************
!*****************************************************************************
!
! Param 053: Brine consumed (m**3) --> BRN_RMV
!
LIMIT ELEMENT OFF
!
!   Add up consumption rates (resulting units are kg/s)
!
BRN_CR = SUM(BRINRATE*GRIDVOL)
!
!   Integrate result to get kg of brine consumed
!
BRN_CON = INTRIGHT(BRN_CR)
!
!   Convert to volumetric amount (m**3) by
!      dividing by brine density (kg/m**3) at reference conditions
!
BRN_RMV = -1.0*BRN_CON/1220.0
!
!   Delete temporary variables
!
DELETE BRN_CR, BRN_CON
!
!**********************************************
!
!*****************************************************************************
!*****************************************************************************
!
! Cumulative brineflow (m**3)
!
!   Param 054: Total brineflow into repository ----------> BRNREPTC
!   Param 055: Total brineflow into waste panel ---------> BRNWPIC
!   Param 056: Total brineflow into rest of repository --> BRNRRIC
!   Param 057: Total brineflow into operations region ---> BRNORIC
!   Param 058: Total brineflow into experimental area ---> BRNEAIC
!   Param 059: Net brineflow out of repository ----------> BRNREPOC
!   Param 060: Net brineflow out of waste panel ---------> BRNWPOC
!   Param 061: Net brineflow out of rest of repository --> BRNRROC
!   Param 062: Net brineflow out of operations region ---> BRNOROC
!   Param 063: Net brineflow out of experimental area ---> BRNEAOC
!   Param 064: Net brineflow into repository ------------> BRNREPNC
!   Param 065: Net brineflow into waste panel -----------> BRNWPNC
!   Param 066: Net brineflow into rest of repository ----> BRNRRNC
!   Param 067: Net brineflow into operations regions ----> BRNORNC
!   Param 068: Net brineflow into experimental area -----> BRNEANC
!   Param 069: Brineflow up shaft (@element 661) --------> BRNSHUPC
!   Param 070: Brineflow up shaft (@element 666) --------> BRNSHUPR
!   Param 071: Brineflow up shaft (@element 669) --------> BRNSHUPS
!   Param 072: Brineflow up borehole (@element 599) -----> BRNBHUPP
!   Param 073: Brineflow up borehole (@element 471) -----> BRNBHUPC
!   Param 074: Brineflow up borehole (@element 713) -----> BRNBHRCC
!   Param 075: Brineflow up borehole (@element 841) -----> BRNBHRUC
!   Param 076: Brineflow up borehole (@element 937) -----> BRNBHRSC
!   Param 077: Brineflow up borehole (@element 439) -----> BNBHLDRZ
!   Param 078: Brineflow up borehole (@element 575) -----> BNBHUDRZ
!
!**************************************
!
! Total cumulative brineflow into repository
!
!   Accumulate x-direction inward flows from left side of repository
!
BRNREPIX =            IFGT0(FLOWBRX[E:596],FLOWBRX[E:596],0.0)
```

```
BRNREPIX = BRNREPIX + IFGT0(FLOWBRX[E:603],FLOWBRX[E:603],0.0)
BRNREPIX = BRNREPIX + IFGT0(FLOWBRX[E:610],FLOWBRX[E:610],0.0)
!
!   Add x-direction inward flow contributions from right side
!
BRNREPIX = BRNREPIX + IFLT0(FLOWBRX[E:641],-1.0*FLOWBRX[E:641],0.0)
BRNREPIX = BRNREPIX + IFLT0(FLOWBRX[E:642],-1.0*FLOWBRX[E:642],0.0)
BRNREPIX = BRNREPIX + IFLT0(FLOWBRX[E:643],-1.0*FLOWBRX[E:643],0.0)
!
!   Accumulate y-direction inward flows from bottom of repository
!
BRNREPIY =            IFGT0(FLOWBRY[E:596],FLOWBRY[E:596],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:597],FLOWBRY[E:597],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:598],FLOWBRY[E:598],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:599],FLOWBRY[E:599],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:600],FLOWBRY[E:600],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:601],FLOWBRY[E:601],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:602],FLOWBRY[E:602],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:638],FLOWBRY[E:638],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:617],FLOWBRY[E:617],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:618],FLOWBRY[E:618],0.0)
BRNREPIY = BRNREPIY + IFGT0(FLOWBRY[E:619],FLOWBRY[E:619],0.0)
!
!   Add Y-direction inward flow contributions from top side
!
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:468],-1.0*FLOWBRY[E:468],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:469],-1.0*FLOWBRY[E:469],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:470],-1.0*FLOWBRY[E:470],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:471],-1.0*FLOWBRY[E:471],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:472],-1.0*FLOWBRY[E:472],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:473],-1.0*FLOWBRY[E:473],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:474],-1.0*FLOWBRY[E:474],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:475],-1.0*FLOWBRY[E:475],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:476],-1.0*FLOWBRY[E:476],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:477],-1.0*FLOWBRY[E:477],0.0)
BRNREPIY = BRNREPIY + IFLT0(FLOWBRY[E:478],-1.0*FLOWBRY[E:478],0.0)
!
!   Sum x- and y-direction inward flows, then integrate over time
!
BRNREPT  = BRNREPIX + BRNREPIY
BRNREPTC = INTRIGHT(BRNREPT)
!
!   Delete flow rate temporary variables
!
DELETE BRNREPT, BRNREPIX, BRNREPIY
!
!****************************************
!
! Total cumulative brine flow into waste panel
!
!   Left side
!
BRNWPI   =          IFGT0(FLOWBRX[E:596],FLOWBRX[E:596],0.0)
BRNWPI   = BRNWPI + IFGT0(FLOWBRX[E:603],FLOWBRX[E:603],0.0)
BRNWPI   = BRNWPI + IFGT0(FLOWBRX[E:610],FLOWBRX[E:610],0.0)
!
!   Right side
!
BRNWPI   = BRNWPI + IFLT0(FLOWBRX[E:638],-1.0*FLOWBRX[E:638],0.0)
BRNWPI   = BRNWPI + IFLT0(FLOWBRX[E:639],-1.0*FLOWBRX[E:639],0.0)
BRNWPI   = BRNWPI + IFLT0(FLOWBRX[E:640],-1.0*FLOWBRX[E:640],0.0)
!
!   Bottom
!
BRNWPI   = BRNWPI + IFGT0(FLOWBRY[E:596],FLOWBRY[E:596],0.0)
BRNWPI   = BRNWPI + IFGT0(FLOWBRY[E:597],FLOWBRY[E:597],0.0)
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BRNWPI    = BRNWPI + IFGT0(FLOWBRY[E:598],FLOWBRY[E:598],0.0)
BRNWPI    = BRNWPI + IFGT0(FLOWBRY[E:599],FLOWBRY[E:599],0.0)
BRNWPI    = BRNWPI + IFGT0(FLOWBRY[E:600],FLOWBRY[E:600],0.0)
BRNWPI    = BRNWPI + IFGT0(FLOWBRY[E:601],FLOWBRY[E:601],0.0)
BRNWPI    = BRNWPI + IFGT0(FLOWBRY[E:602],FLOWBRY[E:602],0.0)
!
!   Top
!
BRNWPI    = BRNWPI + IFLT0(FLOWBRY[E:468],-1.0*FLOWBRY[E:468],0.0)
BRNWPI    = BRNWPI + IFLT0(FLOWBRY[E:469],-1.0*FLOWBRY[E:469],0.0)
BRNWPI    = BRNWPI + IFLT0(FLOWBRY[E:470],-1.0*FLOWBRY[E:470],0.0)
BRNWPI    = BRNWPI + IFLT0(FLOWBRY[E:471],-1.0*FLOWBRY[E:471],0.0)
BRNWPI    = BRNWPI + IFLT0(FLOWBRY[E:472],-1.0*FLOWBRY[E:472],0.0)
BRNWPI    = BRNWPI + IFLT0(FLOWBRY[E:473],-1.0*FLOWBRY[E:473],0.0)
BRNWPI    = BRNWPI + IFLT0(FLOWBRY[E:474],-1.0*FLOWBRY[E:474],0.0)
!
!   Integrate for cumulative, delete flow rate
!
BRNWPIC   = INTRIGHT(BRNWPI)
DELETE BRNWPI
!
!****************************************
!
! Total cumulative brine flow into rest of repository
!
!   Left side
!
BRNRRI    =          IFGT0(FLOWBRX[E:617],FLOWBRX[E:617],0.0)
BRNRRI    = BRNRRI + IFGT0(FLOWBRX[E:620],FLOWBRX[E:620],0.0)
BRNRRI    = BRNRRI + IFGT0(FLOWBRX[E:623],FLOWBRX[E:623],0.0)
!
!   Right side
!
BRNRRI    = BRNRRI + IFLT0(FLOWBRX[E:641],-1.0*FLOWBRX[E:641],0.0)
BRNRRI    = BRNRRI + IFLT0(FLOWBRX[E:642],-1.0*FLOWBRX[E:642],0.0)
BRNRRI    = BRNRRI + IFLT0(FLOWBRX[E:643],-1.0*FLOWBRX[E:643],0.0)
!
!   Bottom
!
BRNRRI    = BRNRRI + IFGT0(FLOWBRY[E:617],FLOWBRY[E:617],0.0)
BRNRRI    = BRNRRI + IFGT0(FLOWBRY[E:618],FLOWBRY[E:618],0.0)
BRNRRI    = BRNRRI + IFGT0(FLOWBRY[E:619],FLOWBRY[E:619],0.0)
!
!   Top
!
BRNRRI    = BRNRRI + IFLT0(FLOWBRY[E:476],-1.0*FLOWBRY[E:476],0.0)
BRNRRI    = BRNRRI + IFLT0(FLOWBRY[E:477],-1.0*FLOWBRY[E:477],0.0)
BRNRRI    = BRNRRI + IFLT0(FLOWBRY[E:478],-1.0*FLOWBRY[E:478],0.0)
!
!   Integrate for cumulative, delete flow rate
!
BRNRRIC   = INTRIGHT(BRNRRI)
DELETE BRNRRI
!
!****************************************
!
! Total cumulative brine flow into operations region
!
!   Left side
!
BRNORI    =          IFGT0(FLOWBRX[E:626],FLOWBRX[E:626],0.0)
BRNORI    = BRNORI + IFGT0(FLOWBRX[E:628],FLOWBRX[E:628],0.0)
BRNORI    = BRNORI + IFGT0(FLOWBRX[E:630],FLOWBRX[E:630],0.0)
!
!   Right side
!
```

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BRNORI    = BRNORI + IFLT0(FLOWBRX[E:646],-1.0*FLOWBRX[E:646],0.0)
BRNORI    = BRNORI + IFLT0(FLOWBRX[E:647],-1.0*FLOWBRX[E:647],0.0)
BRNORI    = BRNORI + IFLT0(FLOWBRX[E:648],-1.0*FLOWBRX[E:648],0.0)
!
!   Bottom
!
BRNORI    = BRNORI + IFGT0(FLOWBRY[E:626],FLOWBRY[E:626],0.0)
BRNORI    = BRNORI + IFGT0(FLOWBRY[E:627],FLOWBRY[E:627],0.0)
!
!   Top
!
BRNORI    = BRNORI + IFLT0(FLOWBRY[E:480],-1.0*FLOWBRY[E:480],0.0)
BRNORI    = BRNORI + IFLT0(FLOWBRY[E:481],-1.0*FLOWBRY[E:481],0.0)
!
!   Integrate for cumulative, delete flow rate
!
BRNORIC   = INTRIGHT(BRNORI)
DELETE BRNORI
!
!****************************************
!
! Total cumulative brine flow into experimental area
!
!   Left side
!
BRNEAI    =          IFGT0(FLOWBRX[E:632],FLOWBRX[E:632],0.0)
BRNEAI    = BRNEAI + IFGT0(FLOWBRX[E:634],FLOWBRX[E:634],0.0)
BRNEAI    = BRNEAI + IFGT0(FLOWBRX[E:636],FLOWBRX[E:636],0.0)
!
!   Right side
!
BRNEAI    = BRNEAI + IFLT0(FLOWBRX[E:148],-1.0*FLOWBRX[E:148],0.0)
BRNEAI    = BRNEAI + IFLT0(FLOWBRX[E:156],-1.0*FLOWBRX[E:156],0.0)
BRNEAI    = BRNEAI + IFLT0(FLOWBRX[E:164],-1.0*FLOWBRX[E:164],0.0)
!
!   Bottom
!
BRNEAI    = BRNEAI + IFGT0(FLOWBRY[E:632],FLOWBRY[E:632],0.0)
BRNEAI    = BRNEAI + IFGT0(FLOWBRY[E:633],FLOWBRY[E:633],0.0)
!
!   Top
!
BRNEAI    = BRNEAI + IFLT0(FLOWBRY[E:524],-1.0*FLOWBRY[E:524],0.0)
BRNEAI    = BRNEAI + IFLT0(FLOWBRY[E:525],-1.0*FLOWBRY[E:525],0.0)
!
!   Integrate for cumulative, delete flow rate
!
BRNEAIC   = INTRIGHT(BRNEAI)
DELETE BRNEAI
!
!****************************************
!
! Net cumulative brineflow into repository = flow in minus flow out
!   (brine consumed by waste corrosion neglected since brine consumption
!    rate not available as history variable in bragflow output database)
!
!   Accumulate x-direction outward flows from left side of repository
!
BRNREPOX =            IFLT0(FLOWBRX[E:596],-1.0*FLOWBRX[E:596],0.0)
BRNREPOX = BRNREPOX + IFLT0(FLOWBRX[E:603],-1.0*FLOWBRX[E:603],0.0)
BRNREPOX = BRNREPOX + IFLT0(FLOWBRX[E:610],-1.0*FLOWBRX[E:610],0.0)
!
!   Add x-direction outward flow contributions from right side
!
BRNREPOX = BRNREPOX + IFGT0(FLOWBRX[E:641],FLOWBRX[E:641],0.0)
BRNREPOX = BRNREPOX + IFGT0(FLOWBRX[E:642],FLOWBRX[E:642],0.0)
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```
BRNREPOX = BRNREPOX + IFGT0(FLOWBRX[E:643],FLOWBRX[E:643],0.0)
!
!   Accumulate y-direction outward flows from bottom of repository
!
BRNREPOY =             IFLT0(FLOWBRY[E:596],-1.0*FLOWBRY[E:596],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:597],-1.0*FLOWBRY[E:597],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:598],-1.0*FLOWBRY[E:598],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:599],-1.0*FLOWBRY[E:599],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:600],-1.0*FLOWBRY[E:600],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:601],-1.0*FLOWBRY[E:601],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:602],-1.0*FLOWBRY[E:602],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:638],-1.0*FLOWBRY[E:638],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:617],-1.0*FLOWBRY[E:617],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:618],-1.0*FLOWBRY[E:618],0.0)
BRNREPOY = BRNREPOY + IFLT0(FLOWBRY[E:619],-1.0*FLOWBRY[E:619],0.0)
!
!   Add Y-direction outward flow contributions from top side
!
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:468],FLOWBRY[E:468],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:469],FLOWBRY[E:469],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:470],FLOWBRY[E:470],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:471],FLOWBRY[E:471],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:472],FLOWBRY[E:472],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:473],FLOWBRY[E:473],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:474],FLOWBRY[E:474],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:475],FLOWBRY[E:475],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:476],FLOWBRY[E:476],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:477],FLOWBRY[E:477],0.0)
BRNREPOY = BRNREPOY + IFGT0(FLOWBRY[E:478],FLOWBRY[E:478],0.0)
!
!   Sum x- and y-direction outward flows, then integrate over time
!
BRNREPO  = BRNREPOX + BRNREPOY
BRNREPOC = INTRIGHT(BRNREPO)
!
!   Subtract outflow from inflow to obtain net inflow
!
BRNREPNC = BRNREPTC - BRNREPOC
!
!   Delete flow rate temporary variables
!
DELETE BRNREPO, BRNREPOX, BRNREPOY
!
!****************************************
!
! Net cumulative brine flow into waste panel = flow in minus flow out
!
!   Left side outward flows
!
BRNWPO   =           IFLT0(FLOWBRX[E:596],-1.0*FLOWBRX[E:596],0.0)
BRNWPO   = BRNWPO + IFLT0(FLOWBRX[E:603],-1.0*FLOWBRX[E:603],0.0)
BRNWPO   = BRNWPO + IFLT0(FLOWBRX[E:610],-1.0*FLOWBRX[E:610],0.0)
!
!   Right side
!
BRNWPO   = BRNWPO + IFGT0(FLOWBRX[E:638],FLOWBRX[E:638],0.0)
BRNWPO   = BRNWPO + IFGT0(FLOWBRX[E:639],FLOWBRX[E:639],0.0)
BRNWPO   = BRNWPO + IFGT0(FLOWBRX[E:640],FLOWBRX[E:640],0.0)
!
!   Bottom
!
BRNWPO   = BRNWPO + IFLT0(FLOWBRY[E:596],-1.0*FLOWBRY[E:596],0.0)
BRNWPO   = BRNWPO + IFLT0(FLOWBRY[E:597],-1.0*FLOWBRY[E:597],0.0)
BRNWPO   = BRNWPO + IFLT0(FLOWBRY[E:598],-1.0*FLOWBRY[E:598],0.0)
BRNWPO   = BRNWPO + IFLT0(FLOWBRY[E:599],-1.0*FLOWBRY[E:599],0.0)
BRNWPO   = BRNWPO + IFLT0(FLOWBRY[E:600],-1.0*FLOWBRY[E:600],0.0)
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BRNWPO    = BRNWPO + IFLT0(FLOWBRY[E:601],-1.0*FLOWBRY[E:601],0.0)
BRNWPO    = BRNWPO + IFLT0(FLOWBRY[E:602],-1.0*FLOWBRY[E:602],0.0)
!
!   Top
!
BRNWPO    = BRNWPO + IFGT0(FLOWBRY[E:468],FLOWBRY[E:468],0.0)
BRNWPO    = BRNWPO + IFGT0(FLOWBRY[E:469],FLOWBRY[E:469],0.0)
BRNWPO    = BRNWPO + IFGT0(FLOWBRY[E:470],FLOWBRY[E:470],0.0)
BRNWPO    = BRNWPO + IFGT0(FLOWBRY[E:471],FLOWBRY[E:471],0.0)
BRNWPO    = BRNWPO + IFGT0(FLOWBRY[E:472],FLOWBRY[E:472],0.0)
BRNWPO    = BRNWPO + IFGT0(FLOWBRY[E:473],FLOWBRY[E:473],0.0)
BRNWPO    = BRNWPO + IFGT0(FLOWBRY[E:474],FLOWBRY[E:474],0.0)
!
!   Integrate for cumulative outward flow, delete flow rate
!
BRNWPOC  = INTRIGHT(BRNWPO)
DELETE BRNWPO
!
!   Subtract outflow from inflow to obtain net inflow
!
BRNWPNC = BRNWPIC - BRNWPOC
!
!****************************************
!
! Total cumulative brine flow out of rest of repository
!
!   Left side outward flows
!
BRNRRO    =           IFLT0(FLOWBRX[E:617],-1.0*FLOWBRX[E:617],0.0)
BRNRRO    = BRNRRO + IFLT0(FLOWBRX[E:620],-1.0*FLOWBRX[E:620],0.0)
BRNRRO    = BRNRRO + IFLT0(FLOWBRX[E:623],-1.0*FLOWBRX[E:623],0.0)
!
!   Right side
!
BRNRRO    = BRNRRO + IFGT0(FLOWBRX[E:641],FLOWBRX[E:641],0.0)
BRNRRO    = BRNRRO + IFGT0(FLOWBRX[E:642],FLOWBRX[E:642],0.0)
BRNRRO    = BRNRRO + IFGT0(FLOWBRX[E:643],FLOWBRX[E:643],0.0)
!
!   Bottom
!
BRNRRO    = BRNRRO + IFLT0(FLOWBRY[E:617],-1.0*FLOWBRY[E:617],0.0)
BRNRRO    = BRNRRO + IFLT0(FLOWBRY[E:618],-1.0*FLOWBRY[E:618],0.0)
BRNRRO    = BRNRRO + IFLT0(FLOWBRY[E:619],-1.0*FLOWBRY[E:619],0.0)
!
!   Top
!
BRNRRO    = BRNRRO + IFGT0(FLOWBRY[E:476],FLOWBRY[E:476],0.0)
BRNRRO    = BRNRRO + IFGT0(FLOWBRY[E:477],FLOWBRY[E:477],0.0)
BRNRRO    = BRNRRO + IFGT0(FLOWBRY[E:478],FLOWBRY[E:478],0.0)
!
!   Integrate for cumulative outward flow, delete flow rate
!
BRNRROC  = INTRIGHT(BRNRRO)
DELETE BRNRRO
!
!   Subtract outflow from inflow to obtain net inflow
!
BRNRRNC = BRNRRIC - BRNRROC
!
!****************************************
!
! Total cumulative brine flow out of operations region
!
!   Left side outward flows
!
BRNORO    =           IFLT0(FLOWBRX[E:626],-1.0*FLOWBRX[E:626],0.0)
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BRNORO    = BRNORO + IFLT0(FLOWBRX[E:628],-1.0*FLOWBRX[E:628],0.0)
BRNORO    = BRNORO + IFLT0(FLOWBRX[E:630],-1.0*FLOWBRX[E:630],0.0)
!
!   Right side
!
BRNORO    = BRNORO + IFGT0(FLOWBRX[E:646],FLOWBRX[E:646],0.0)
BRNORO    = BRNORO + IFGT0(FLOWBRX[E:647],FLOWBRX[E:647],0.0)
BRNORO    = BRNORO + IFGT0(FLOWBRX[E:648],FLOWBRX[E:648],0.0)
!
!   Bottom
!
BRNORO    = BRNORO + IFLT0(FLOWBRY[E:626],-1.0*FLOWBRY[E:626],0.0)
BRNORO    = BRNORO + IFLT0(FLOWBRY[E:627],-1.0*FLOWBRY[E:627],0.0)
!
!   Top
!
BRNORO    = BRNORO + IFGT0(FLOWBRY[E:480],FLOWBRY[E:480],0.0)
BRNORO    = BRNORO + IFGT0(FLOWBRY[E:481],FLOWBRY[E:481],0.0)
!
!   Integrate for cumulative outward flow, delete flow rate
!
BRNOROC   = INTRIGHT(BRNORO)
DELETE BRNORO
!
!   Subtract outflow from inflow to obtain net inflow
!
BRNORNC = BRNORIC - BRNOROC
!
!****************************************
!
! Total cumulative brine flow out of experimental area:
!
!   Left side outward flows
!
BRNEAO    =           IFLT0(FLOWBRX[E:632],-1.0*FLOWBRX[E:632],0.0)
BRNEAO    = BRNEAO + IFLT0(FLOWBRX[E:634],-1.0*FLOWBRX[E:634],0.0)
BRNEAO    = BRNEAO + IFLT0(FLOWBRX[E:636],-1.0*FLOWBRX[E:636],0.0)
!
!   Right side
!
BRNEAO    = BRNEAO + IFGT0(FLOWBRX[E:148],FLOWBRX[E:148],0.0)
BRNEAO    = BRNEAO + IFGT0(FLOWBRX[E:156],FLOWBRX[E:156],0.0)
BRNEAO    = BRNEAO + IFGT0(FLOWBRX[E:164],FLOWBRX[E:164],0.0)
!
!   Bottom
!
BRNEAO    = BRNEAO + IFLT0(FLOWBRY[E:632],-1.0*FLOWBRY[E:632],0.0)
BRNEAO    = BRNEAO + IFLT0(FLOWBRY[E:633],-1.0*FLOWBRY[E:633],0.0)
!
!   Top
!
BRNEAO    = BRNEAO + IFGT0(FLOWBRY[E:524],FLOWBRY[E:524],0.0)
BRNEAO    = BRNEAO + IFGT0(FLOWBRY[E:525],FLOWBRY[E:525],0.0)
!
!   Integrate for cumulative outward flow, delete flow rate
!
BRNEAOC   = INTRIGHT(BRNEAO)
DELETE BRNEAO
!
!   Subtract outflow from inflow to obtain net inflow
!
BRNEANC = BRNEAIC - BRNEAOC
!
!****************************************
!
! Cumulative brineflow up through shaft (past Salado/Rustler Interface)
```

```
!
BRNSHUP  = IFGT0(FLOWBRY[E:661],FLOWBRY[E:661],0.0)
BRNSHUPC = INTRIGHT(BRNSHUP)
!
!****************************************
!
! Cumulative brineflow up through shaft (past Rustler)
!
BRNSUPR  = IFGT0(FLOWBRY[E:666],FLOWBRY[E:666],0.0)
BRNSHUPR = INTRIGHT(BRNSUPR)
!
!****************************************
!
! Cumulative brineflow up through shaft (to surface)
!
BRNSUPS  = IFGT0(FLOWBRY[E:669],FLOWBRY[E:669],0.0)
BRNSHUPS = INTRIGHT(BRNSUPS)
!
!****************************************
!
! Cumulative brineflow up borehole (into panel)
!
BRNBBUP  = IFGT0(FLOWBRY[E:599],FLOWBRY[E:599],0.0)
BRNBHUPP = INTRIGHT(BRNBBUP)
!
!****************************************
!
! Cumulative brineflow up borehole (measured at repository top boundary)
!
BRNBHUP  = IFGT0(FLOWBRY[E:471],FLOWBRY[E:471],0.0)
BRNBHUPC = INTRIGHT(BRNBHUP)
!
!****************************************
!
! Cumulative brineflow up borehole (measured at Rustler/Culebra interface)
!
BRNBHRC  = IFGT0(FLOWBRY[E:713],FLOWBRY[E:713],0.0)
BRNBHRCC = INTRIGHT(BRNBHRC)
!
!****************************************
!
! Cumulative brineflow up borehole (past Rustler)
!
BRNBHRU  = IFGT0(FLOWBRY[E:841],FLOWBRY[E:841],0.0)
BRNBHRUC = INTRIGHT(BRNBHRU)
!
!****************************************
!
! Cumulative brineflow up borehole (to surface)
!
BRNBHRS  = IFGT0(FLOWBRY[E:937],FLOWBRY[E:937],0.0)
BRNBHRSC = INTRIGHT(BRNBHRS)
!
!****************************************
!
! Cumulative brineflow up borehole (into lower DRZ below waste panel)
!
BNBHLDR  = IFGT0(FLOWBRY[E:439],FLOWBRY[E:439],0.0)
BNBHLDRZ = INTRIGHT(BNBHLDR)
!
!****************************************
!
! Cumulative brineflow up borehole (at top of DRZ region)
!
BNBHUDR  = IFGT0(FLOWBRY[E:575],FLOWBRY[E:575],0.0)
BNBHUDRZ = INTRIGHT(BNBHUDR)
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!
!****************************************
!
! Clean up output--limit to requested quantities
!
DELETE BRNSHUP, BRNSUPR, BRNSUPS, BNBHLDR, BNBHUDR
DELETE BRNBBUP, BRNBHUP, BRNBHRC, BRNBHRU, BRNBHRS
!
!*****************************************************************************
!*****************************************************************************
!
! Total brineflow out of marker beds toward repository (m**3)
!
!   Param 079: MB 138,        North --> BRM38NIC
!   Param 080: Anhydrite A&B, North --> BRAABNIC
!   Param 081: MB 139,        North --> BRM39NIC
!   Param 082: MB 138,        South --> BRM38SIC
!   Param 083: Anhydrite A&B, South --> BRAABSIC
!   Param 084: MB 139,        South --> BRM39SIC
!   Param 085: all marker beds -------> BRAALIC
!
!****************************************
!
! Total inward brineflow from MB 138, north (right) side
!
BRNM38NI = IFLT0(FLOWBRX[E:588],-1.0*FLOWBRX[E:588],0.0)
BRM38NIC = INTRIGHT(BRNM38NI)
!
!****************************************
!
! Total inward brineflow from Anhydrite A&B, north (right) side
!
BRNAABNI = IFLT0(FLOWBRX[E:556],-1.0*FLOWBRX[E:556],0.0)
BRAABNIC = INTRIGHT(BRNAABNI)
!
!****************************************
!
! Total inward brineflow from  MB 139, north (right) side
!
BRNM39NI = IFLT0(FLOWBRX[E:540],-1.0*FLOWBRX[E:540],0.0)
BRM39NIC = INTRIGHT(BRNM39NI)
!
!****************************************
!****************************************
!
! Total inward brineflow from MB 138, south (left) side
!
BRNM38SI = IFGT0(FLOWBRX[E:572],FLOWBRX[E:572],0.0)
BRM38SIC = INTRIGHT(BRNM38SI)
!
!****************************************
!
! Total inward brineflow from Anhydrite A&B, south (left) side
!
BRNAABSI = IFGT0(FLOWBRX[E:482],FLOWBRX[E:482],0.0)
BRAABSIC = INTRIGHT(BRNAABSI)
!
!****************************************
!
! Total inward brineflow from MB 139, south (left) side
!
BRNM39SI = IFGT0(FLOWBRX[E:436],FLOWBRX[E:436],0.0)
BRM39SIC = INTRIGHT(BRNM39SI)
!
!****************************************
!
```

```
! Total inward brineflow from all anhydrite layers
!
BRAALIC  = BRM38NIC + BRAABNIC + BRM39NIC + BRM38SIC + BRAABSIC + BRM39SIC
!
!****************************************
!
! Clean up output--limit to requested quantities
!
DELETE BRNM38NI, BRNAABNI, BRNM39NI, BRNM38SI, BRNAABSI, BRNM39SI
!
!*****************************************************************************
!*****************************************************************************
!
! Total brineflow into marker beds away from repository (m**3)
!
!   Param 086: MB 138,        North --> BRM38NOC
!   Param 087: Anhydrite A&B, North --> BRAABNOC
!   Param 088: MB 139,        North --> BRM39NOC
!   Param 089: MB 138,        South --> BRM38SOC
!   Param 090: Anhydrite A&B, South --> BRAABSOC
!   Param 091: MB 139,        South --> BRM39SOC
!   Param 092: all marker beds -------> BRAALOC
!
!****************************************
!
! Total brineflow into MB 138 away from repository, north (right) side
!
BRNM38NO = IFGT0(FLOWBRX[E:588],FLOWBRX[E:588],0.0)
BRM38NOC = INTRIGHT(BRNM38NO)
!
!****************************************
!
! Total brineflow into Anhydrite A&B away from repository, north side
!
BRNAABNO = IFGT0(FLOWBRX[E:556],FLOWBRX[E:556],0.0)
BRAABNOC = INTRIGHT(BRNAABNO)
!
!****************************************
!
! Total brineflow into MB 139 away from repository, north (right) side
!
BRNM39NO = IFGT0(FLOWBRX[E:540],FLOWBRX[E:540],0.0)
BRM39NOC = INTRIGHT(BRNM39NO)
!
!****************************************
!****************************************
!
! Total brineflow into MB 138 away from repository, south (left) side
!
BRNM38SO = IFLT0(FLOWBRX[E:572],-1.0*FLOWBRX[E:572],0.0)
BRM38SOC = INTRIGHT(BRNM38SO)
!
!****************************************
!
! Total brineflow into Anhydrite A&B away from repository, south side
!
BRNAABSO = IFLT0(FLOWBRX[E:482],-1.0*FLOWBRX[E:482],0.0)
BRAABSOC = INTRIGHT(BRNAABSO)
!
!****************************************
!
! Total brineflow into MB 139 away from repository, south (left) side
!
BRNM39SO = IFLT0(FLOWBRX[E:436],-1.0*FLOWBRX[E:436],0.0)
BRM39SOC = INTRIGHT(BRNM39SO)
!
```

```
!****************************************
!
! Total outward brineflow into all anhydrite layers
!
BRAALOC  = BRM38NOC + BRAABNOC + BRM39NOC + BRM38SOC + BRAABSOC + BRM39SOC
!
!****************************************
!
! Clean up output--limit to requested quantities
!
DELETE BRNM38NO, BRNAABNO, BRNM39NO, BRNM38SO, BRNAABSO, BRNM39SO
!
!*****************************************************************************
!*****************************************************************************
!
! Net brineflow through marker beds (m**3)
!
!   Param 093: MB 138,        North --> BRM38NNC
!   Param 094: Anhydrite A&B, North --> BRAABNNC
!   Param 095: MB 139,        North --> BRM39NNC
!   Param 096: MB 138,        South --> BRM38SNC
!   Param 097: Anhydrite A&B, South --> BRAABSNC
!   Param 098: MB 139,        South --> BRM39SNC
!   Param 099: all marker beds -------> BRAALNC
!
!****************************************
!
! Net brineflow through MB 138, north (right) side
!
BRNM38NN = FLOWBRX[E:588]
BRM38NNC = INTRIGHT(BRNM38NN)
!
!****************************************
!
! Net brineflow through Anhydrite A&B, north (right) side
!
BRNAABNN = FLOWBRX[E:556]
BRAABNNC = INTRIGHT(BRNAABNN)
!
!****************************************
!
! Net brineflow through MB 139, north (right) side
!
BRNM39NN = FLOWBRX[E:540]
BRM39NNC = INTRIGHT(BRNM39NN)
!
!****************************************
!****************************************
!
! Net brineflow through MB 138, south (left) side
!
BRNM38SN = FLOWBRX[E:572]
BRM38SNC = INTRIGHT(BRNM38SN)
!
!****************************************
!
! Net brineflow through Anhydrite A&B, south (left) side
!
BRNAABSN = FLOWBRX[E:482]
BRAABSNC = INTRIGHT(BRNAABSN)
!
!****************************************
!
! Net brineflow through MB 139, south (left) side
!
BRNM39SN = FLOWBRX[E:436]
```

```
BRM39SNC = INTRIGHT(BRNM39SN)
!
!****************************************
!
! Net brineflow through all anhydrite layers
!
BRAALNC  = BRM38NNC + BRAABNNC + BRM39NNC + BRM38SNC + BRAABSNC + BRM39SNC
!
!****************************************
!
! Clean up output--limit to requested quantities
!
DELETE BRNM38NN, BRNAABNN, BRNM39NN, BRNM38SN, BRNAABSN, BRNM39SN
!
!*****************************************************************************
!*****************************************************************************
!
! Cumulative gas flow (m**3)
!
!   Param 100: up shaft (@element 661) ---------------> GASSHUPC
!   Param 101: up borehole (@element 471) -------------> GASBHUPC
!   Param 102: up borehole (@element 575) -------------> GASBHUDZ
!   Param 103: into brine pocket (@element 985) ------> GASBPDNC
!   Param 104: out of brine pocket (@element 985) ----> GASBPUPC
!   Param 105: net into brine pocket (@element 985) --> GASBPNTC
!
!****************************************
!
! Cumulative gas flow up through shaft (past Salado/Rustler Interface)
!
GASSHUP  = IFGT0(FLOWGASY[E:661],FLOWGASY[E:661],0.0)
GASSHUPC = INTRIGHT(GASSHUP)
!
!****************************************
!
! Cumulative gas flow up borehole (measured at repository top boundary)
!
GASBHUP  = IFGT0(FLOWGASY[E:471],FLOWGASY[E:471],0.0)
GASBHUPC = INTRIGHT(GASBHUP)
!
!****************************************
!
! Cumulative gas flow up borehole (measured at top of DRZ)
!
GASBHUD  = IFGT0(FLOWGASY[E:575],FLOWGASY[E:575],0.0)
GASBHUDZ = INTRIGHT(GASBHUD)
!
!****************************************
!
! Cumulative gas flow into brine pocket (at top of brine pocket)
!
GASBPDN  = IFLT0(FLOWGASY[E:985],-1.0*FLOWGASY[E:985],0.0)
GASBPDNC = INTRIGHT(GASBPDN)
!
!****************************************
!
! Cumulative gas flow out of brine pocket (at top of brine pocket)
!
GASBPUP  = IFGT0(FLOWGASY[E:985],FLOWGASY[E:985],0.0)
GASBPUPC = INTRIGHT(GASBPUP)
!
!****************************************
!
! Cumulative net gas flow into brine pocket (at top of brine pocket)
!
GASBPNT  = -1.0*FLOWGASY[E:985]
```

```
GASBPNTC = INTRIGHT(GASBPNT)
!
!****************************************
!
! Clean up output--limit to requested quantities
!
DELETE GASSHUP, GASBHUP, GASBHUD, GASBPDN, GASBPUP, GASBPNT
!
!*****************************************************************************
!*****************************************************************************
!
! Total gas flow through marker beds away from repository (m**3)
!
!   Param 106: MB 138,        North --> GSM38NOC
!   Param 107: Anhydrite A&B, North --> GSAABNOC
!   Param 108: MB 139,        North --> GSM39NOC
!   Param 109: MB 138,        South --> GSM38SOC
!   Param 110: Anhydrite A&B, South --> GSAABSOC
!   Param 111: MB 139,        South --> GSM39SOC
!   Param 112: all marker beds -------> GSAALOC
!
!****************************************
!
! Total gas flow in MB 138 away from repository, north (right) side
!
GASM38NO = IFGT0(FLOWGASX[E:588],FLOWGASX[E:588],0.0)
GSM38NOC = INTRIGHT(GASM38NO)
!
!****************************************
!
! Total gas flow in Anhydrite A&B away from repository, north side
!
GASAABNO = IFGT0(FLOWGASX[E:556],FLOWGASX[E:556],0.0)
GSAABNOC = INTRIGHT(GASAABNO)
!
!****************************************
!
! Total gas flow in MB 139 away from repository, north (right) side
!
GASM39NO = IFGT0(FLOWGASX[E:540],FLOWGASX[E:540],0.0)
GSM39NOC = INTRIGHT(GASM39NO)
!
!****************************************
!****************************************
!
! Total gas flow in MB 138 away from repository, south (left) side
!
GASM38SO = IFLT0(FLOWGASX[E:572],-1.0*FLOWGASX[E:572],0.0)
GSM38SOC = INTRIGHT(GASM38SO)
!
!****************************************
!
! Total gas flow in Anhydrite A&B away from repository, south side
!
GASAABSO = IFLT0(FLOWGASX[E:482],-1.0*FLOWGASX[E:482],0.0)
GSAABSOC = INTRIGHT(GASAABSO)
!
!****************************************
!
! Total gas flow in MB 139 away from repository, south (left) side
!
GASM39SO = IFLT0(FLOWGASX[E:436],-1.0*FLOWGASX[E:436],0.0)
GSM39SOC = INTRIGHT(GASM39SO)
!
!****************************************
!
```

```
! Total gas flow into all anhydrite layers
!
GSAALOC  = GSM38NOC + GSAABNOC + GSM39NOC + GSM38SOC + GSAABSOC + GSM39SOC
!
!*************************************
!
! Clean up output--limit to requested quantities
!
DELETE GASM38NO, GASAABNO, GASM39NO, GASM38SO, GASAABSO, GASM39SO
!
!*****************************************************************************
!*****************************************************************************
!
! Interbed fracturing: Length of fracturing zone (m)
!
!   Param 113: MB 138,         North --> FRACX38N
!   Param 114: Anhydrite A&B,  North --> FRACXABN
!   Param 115: MB 139,         North --> FRACX39N
!   Param 116: MB 138,         South --> FRACX38S
!   Param 117: Anhydrite A&B,  South --> FRACXABS
!   Param 118: MB 139,         South --> FRACX39S
!
!*************************************
!
! Fracturing in MB 138 away from repository, north (right) side
!
LIMIT ELEMENT 588 TO 595
!
!   Define meaningful fracturing as doubling of initial permeability
!
FR_TOL38 = 2.0*PERM_X[B:5]
!
!   Set reference point for fracturing length at the north repository border
!
XREF38N = X[N:1590]
!
!   Determine average x-coordinate of element centroid as element variable
!
XECENT = NOD2ELE(X)
!
!   Compare any change in permeability against fracture criterion
!     If criterion met (i.e., permeability of an element has at least doubled)
!     then calculate length of fracture as distance from reference point
!     to centroid of element, otherwise set fracture length to zero
!
XDIST = IFGT0(PERMBRX-FR_TOL38,XECENT-XREF38N,0.0)
!
!   Extract maximum value of fracture length at each time
!
FRACX38N = SMAX(XDIST)
!
!   Delete temporary variables (tolerance used repeated below, then deleted)
!
DELETE XREF38N, XECENT, XDIST
!
!*************************************
!
! Fracturing in Anhydrite A&B away from repository, north (right) side
!
LIMIT ELEMENT 556 TO 563
!
FR_TOLAB = 2.0*PERM_X[B:4]
XREFABN  = X[N:1488]
XECENT   = NOD2ELE(X)
XDIST    = IFGT0(PERMBRX-FR_TOLAB,XECENT-XREFABN,0.0)
FRACXABN = SMAX(XDIST)
```

```
!
DELETE XREFABN, XECENT, XDIST
!
!****************************************
!
! Fracturing in MB 139 away from repository, north (right) side
!
LIMIT ELEMENT 540 TO 547
!
FR_TOL39 = 2.0*PERM_X[B:3]
XREF39N  = X[N:1284]
XECENT   = NOD2ELE(X)
XDIST    = IFGT0(PERMBRX-FR_TOL39,XECENT-XREF39N,0.0)
FRACX39N = SMAX(XDIST)
!
DELETE XREF39N, XECENT, XDIST
!
!****************************************
!****************************************
!
! Fracturing in MB 138 away from repository, south (left) side
!
LIMIT ELEMENT 564 TO 571
!
XREF38S  = X[N:1573]
XECENT   = NOD2ELE(X)
XDIST    = IFGT0(PERMBRX-FR_TOL38,XREF38S-XECENT,0.0)
FRACX38S = SMAX(XDIST)
!
DELETE XREF38S, XECENT, XDIST
!
!****************************************
!
! Fracturing in Anhydrite A&B away from repository, south (left) side
!
LIMIT ELEMENT 548 TO 555
!
XREFABS  = X[N:1471]
XECENT   = NOD2ELE(X)
XDIST    = IFGT0(PERMBRX-FR_TOLAB,XREFABS-XECENT,0.0)
FRACXABS = SMAX(XDIST)
!
DELETE XREFABS, XECENT, XDIST
!
!****************************************
!
! Fracturing in MB 139 away from repository, south (left) side
!
LIMIT ELEMENT 532 to 539
!
XREF39S  = X[N:1267]
XECENT   = NOD2ELE(X)
XDIST    = IFGT0(PERMBRX-FR_TOL39,XREF39S-XECENT,0.0)
FRACX39S = SMAX(XDIST)
!
DELETE XREF39S, XECENT, XDIST
!
!****************************************
!
!*******************************************************************************
!*******************************************************************************
!
! Interbed fracturing: Volume of fracturing zone (m**3)
!
!   Param 119: MB 138,         North --------------> VFRAC38N
!   Param 120: Anhydrite A&B, North --------------> VFRACABN
```

```
!   Param 121: MB 139,         North ---------------> VFRAC39N
!   Param 122: MB 138,         South ---------------> VFRAC38S
!   Param 123: Anhydrite A&B, South ---------------> VFRACABS
!   Param 124: MB 139,         South ---------------> VFRAC39S
!   Param 125: Total marker bed fracture volume --> VFRACTMB
!
!****************************************
!
! Volume of fracture zone in MB 138 away from repository, north (right) side
!
LIMIT ELEMENT 588 TO 595
!
!   Extract z-direction thickness of fractured elements, set result to zero
!     for intact elements
!
EL_Z_38N = IFGT0(PERMBRX-FR_TOL38,THICK,0.0)
!
!   Set flag for each fractured element to determine number of affected elements
!
FLAG_38N = IFGT0(EL_Z_38N,1.0,0.0)
TOTF_38N = SUM(FLAG_38N)
!
!   Check whether any number of elements has fractured, if none then
!     set to dummy number for division step to avoid divide by zero
!
TOTF_38N = IFGT0(TOTF_38N,TOTF_38N,999.0)
!
!   Obtain average fractured y-z area--note that contributions to area sum
!     from intact elements will be zero and that sum will be zero if no
!     elements have fractured
!
A_AVG38N = SUM(EL_Z_38N*DEL_Y)/TOTF_38N
!
!   Multiply average fractured element y-z area times the total fracture length
!     to obtain fracture zone volume
!
VFRAC38N = FRACX38N * A_AVG38N
!
!   Delete temporary variables except for tolerance and z-direction thickness
!
DELETE FLAG_38N, TOTF_38N, A_AVG38N
!
!****************************************
!
! Volume of fracture zone in Anhydrite A&B away from repository, north side
!
LIMIT ELEMENT 556 TO 563
!
EL_Z_ABN = IFGT0(PERMBRX-FR_TOLAB,THICK,0.0)
FLAG_ABN = IFGT0(EL_Z_ABN,1.0,0.0)
TOTF_ABN = SUM(FLAG_ABN)
TOTF_ABN = IFGT0(TOTF_ABN,TOTF_ABN,999.0)
A_AVGABN = SUM(EL_Z_ABN*DEL_Y)/TOTF_ABN
VFRACABN = FRACX39N * A_AVGABN
!
DELETE FLAG_ABN, TOTF_ABN, A_AVGABN
!
!****************************************
!
! Volume of fracture zone in MB 139 away from repository, north (right) side
!
LIMIT ELEMENT 540 TO 547
!
EL_Z_39N = IFGT0(PERMBRX-FR_TOL39,THICK,0.0)
FLAG_39N = IFGT0(EL_Z_39N,1.0,0.0)
TOTF_39N = SUM(FLAG_39N)
```

```
TOTF_39N = IFGT0(TOTF_39N,TOTF_39N,999.0)
A_AVG39N = SUM(EL_Z_39N*DEL_Y)/TOTF_39N
VFRAC39N = FRACX39N * A_AVG39N
!
DELETE FLAG_39N, TOTF_39N, A_AVG39N
!
!****************************************
!****************************************
!
! Volume of fracture zone in MB 138 away from repository, south (left) side
!
LIMIT ELEMENT 564 TO 571
!
EL_Z_38S = IFGT0(PERMBRX-FR_TOL38,THICK,0.0)
FLAG_38S = IFGT0(EL_Z_38S,1.0,0.0)
TOTF_38S = SUM(FLAG_38S)
TOTF_38S = IFGT0(TOTF_38S,TOTF_38S,999.0)
A_AVG38S = SUM(EL_Z_38S*DEL_Y)/TOTF_38S
VFRAC38S = FRACX38S * A_AVG38S
!
DELETE FLAG_38S, TOTF_38S, A_AVG38S, FR_TOL38
!
!****************************************
!
! Volume of fracture zone in Anhydrite A&B away from repository, south side
!
LIMIT ELEMENT 548 TO 555
!
EL_Z_ABS = IFGT0(PERMBRX-FR_TOLAB,THICK,0.0)
FLAG_ABS = IFGT0(EL_Z_ABS,1.0,0.0)
TOTF_ABS = SUM(FLAG_ABS)
TOTF_ABS = IFGT0(TOTF_ABS,TOTF_ABS,999.0)
A_AVGABS = SUM(EL_Z_ABS*DEL_Y)/TOTF_ABS
VFRACABS = FRACX39S * A_AVGABS
!
DELETE FLAG_ABS, TOTF_ABS, A_AVGABS, FR_TOLAB
!
!****************************************
!
! Volume of fracture zone in MB 139 away from repository, south (left) side
!
LIMIT ELEMENT 532 TO 539
!
EL_Z_39S = IFGT0(PERMBRX-FR_TOL39,THICK,0.0)
FLAG_39S = IFGT0(EL_Z_39S,1.0,0.0)
TOTF_39S = SUM(FLAG_39S)
TOTF_39S = IFGT0(TOTF_39S,TOTF_39S,999.0)
A_AVG39S = SUM(EL_Z_39S*DEL_Y)/TOTF_39S
VFRAC39S = FRACX39S * A_AVG39S
!
DELETE FLAG_39S, TOTF_39S, A_AVG39S, FR_TOL39
!
!****************************************
!
! Total volume of all fracture zones in marker beds away from repository
!
VFRACTMB = VFRAC38N + VFRACABN + VFRAC39N + VFRAC38S + VFRACABS + VFRAC39S
!
!****************************************
!
!*****************************************************************************
!*****************************************************************************
!
! Interbed fracturing: Volume-averaged permeability in fracturing zone (m**2)
!
!   Param 126: MB 138,        North --> APERM38N
```

```
!   Param 127: Anhydrite A&B, North --> APERMABN
!   Param 128: MB 139,        North --> APERM39N
!   Param 129: MB 138,        South --> APERM38S
!   Param 130: Anhydrite A&B, South --> APERMABS
!   Param 131: MB 139,        South --> APERM39S
!
!****************************************
!
! Volume-averaged permeability in MB 138 away from repository, north side
!
LIMIT ELEMENT 588 TO 595
!
!   Calculate individual element volume using previously extracted z-direction
!     thickness, with thickness set to zero for non-fractured elements
!
VOL_E38N = DEL_X * DEL_Y * EL_Z_38N
!
!   Multiply individual element permeabilites times individual element volume,
!     note that result will be zero for intact elements
!
VPERM38N = PERMBRX * VOL_E38N
!
!   Add up total element volume of fractured elements, note that this could
!     be zero if no element has fractured--if it is zero then set it to a
!     dummy value to avoid divide by zero in next step
!
TVOLE38N = SUM(VOL_E38N)
TVOLE38N = IFGT0(TVOLE38N,TVOLE38N,-999.0)
!
!   Calculate volume-averaged permeabilities for fractured elements only,
!     for timesteps with no fracturing set average permeability to initial value
!
APERM38N = IFGT0(TVOLE38N,SUM(VPERM38N)/TVOLE38N,PERM_X[B:5])
!
!   Delete temporary variables which aren't used later
!
DELETE EL_Z_38N, TVOLE38N, VPERM38N
!
!****************************************
!
! Volume-averaged permeability in Anhydrite A&B away from repository, north side
!
LIMIT ELEMENT 556 TO 563
!
VOL_EABN = DEL_X * DEL_Y * EL_Z_ABN
VPERMABN = PERMBRX * VOL_EABN
TVOLEABN = SUM(VOL_EABN)
TVOLEABN = IFGT0(TVOLEABN,TVOLEABN,-999.0)
APERMABN = IFGT0(TVOLEABN,SUM(VPERMABN)/TVOLEABN,PERM_X[B:4])
!
DELETE EL_Z_ABN, TVOLEABN, VPERMABN
!
!****************************************
!
! Volume-averaged permeability in MB 139 away from repository, north side
!
LIMIT ELEMENT 540 TO 547
!
VOL_E39N = DEL_X * DEL_Y * EL_Z_39N
VPERM39N = PERMBRX * VOL_E39N
TVOLE39N = SUM(VOL_E39N)
TVOLE39N = IFGT0(TVOLE39N,TVOLE39N,-999.0)
APERM39N = IFGT0(TVOLE39N,SUM(VPERM39N)/TVOLE39N,PERM_X[B:3])
!
DELETE EL_Z_39N, TVOLE39N, VPERM39N
!
```

```
!****************************************
!****************************************
!
! Volume-averaged permeability in MB 138 away from repository, south side
!
LIMIT ELEMENT 564 TO 571
!
VOL_E38S = DEL_X * DEL_Y * EL_Z_38S
VPERM38S = PERMBRX * VOL_E38S
TVOLE38S = SUM(VOL_E38S)
TVOLE38S = IFGT0(TVOLE38S,TVOLE38S,-999.0)
APERM38S = IFGT0(TVOLE38S,SUM(VPERM38S)/TVOLE38S,PERM_X[B:5])
!
DELETE EL_Z_38S, TVOLE38S, VPERM38S
!
!****************************************
!
! Volume-averaged permeability in Anhydrite A&B away from repository, south side
!
LIMIT ELEMENT 548 TO 555
!
VOL_EABS = DEL_X * DEL_Y * EL_Z_ABS
VPERMABS = PERMBRX * VOL_EABS
TVOLEABS = SUM(VOL_EABS)
TVOLEABS = IFGT0(TVOLEABS,TVOLEABS,-999.0)
APERMABS = IFGT0(TVOLEABS,SUM(VPERMABS)/TVOLEABS,PERM_X[B:4])
!
DELETE EL_Z_ABS, TVOLEABS, VPERMABS
!
!****************************************
!
! Volume-averaged permeability in MB 139 away from repository, south side
!
LIMIT ELEMENT 532 TO 539
!
VOL_E39S = DEL_X * DEL_Y * EL_Z_39S
VPERM39S = PERMBRX * VOL_E39S
TVOLE39S = SUM(VOL_E39S)
TVOLE39S = IFGT0(TVOLE39S,TVOLE39S,-999.0)
APERM39S = IFGT0(TVOLE39S,SUM(VPERM39S)/TVOLE39S,PERM_X[B:3])
!
DELETE EL_Z_39S, TVOLE39S, VPERM39S
!
!****************************************
!
!*****************************************************************************
!*****************************************************************************
!
! Interbed fracturing: Increase in pore volume in fracturing zone (m**3)
!
!   Param 132: MB 138,        North ------------------> PVOLI38N
!   Param 133: Anhydrite A&B, North ------------------> PVOLIABN
!   Param 134: MB 139,        North ------------------> PVOLI39N
!   Param 135: MB 138,        South ------------------> PVOLI38S
!   Param 136: Anhydrite A&B, South ------------------> PVOLIABS
!   Param 137: MB 139,        South ------------------> PVOLI39S
!   Param 138: Total frac zone pore volume increase --> PVOLI_T
!
!****************************************
!
! Increase in pore volume in MB 138, north side
!
LIMIT ELEMENT 588 TO 595
!
!   Calculate total current pore volumes for fractured elements, note that
!     contribution from intact elements will be zero since this measure of
```

```
!     their volume was set to zero
!
PVC38N = SUM(POROS*VOL_E38N)
!
!   Extract minimum porosity values (are these always initial values?)
!
PORMIN = ENVMIN(POROS)
!
!   Sum minimum pore volume in fractured zone
!
PVM38N = SUM(PORMIN*VOL_E38N)
!
!   Increase in pore volume is the current sum minus the minimum
!
PVOLI38N = PVC38N - PVM38N
!
!   Delete temporary variables
!
DELETE VOL_E38N, PVC38N, PVM38N, PORMIN
!
!****************************************
!
! Increase in pore volume in Anhydrite A&B, north side
!
LIMIT ELEMENT 556 TO 563
!
PVCABN   = SUM(POROS*VOL_EABN)
PORMIN   = ENVMIN(POROS)
PVMABN   = SUM(PORMIN*VOL_EABN)
PVOLIABN = PVCABN - PVMABN
!
DELETE VOL_EABN, PVCABN, PVMABN, PORMIN
!
!****************************************
!
! Increase in pore volume in MB 139, north side
!
LIMIT ELEMENT 540 TO 547
!
PVC39N = SUM(POROS*VOL_E39N)
PORMIN = ENVMIN(POROS)
PVM39N = SUM(PORMIN*VOL_E39N)
PVOLI39N = PVC39N - PVM39N
!
DELETE VOL_E39N, PVC39N, PVM39N, PORMIN
!
!****************************************
!****************************************
!
! Increase in pore volume in MB 138, south side
!
LIMIT ELEMENT 564 TO 571
!
PVC38S   = SUM(POROS*VOL_E38S)
PORMIN   = ENVMIN(POROS)
PVM38S   = SUM(PORMIN*VOL_E38S)
PVOLI38S = PVC38S - PVM38S
!
DELETE VOL_E38S, PVC38S, PVM38S, PORMIN
!
!****************************************
!
! Increase in pore volume in Anhydrite A&B, south side
!
LIMIT ELEMENT 548 TO 555
!
```

```
PVCABS   = SUM(POROS*VOL_EABS)
PORMIN   = ENVMIN(POROS)
PVMABS   = SUM(PORMIN*VOL_EABS)
PVOLIABS = PVCABS - PVMABS
!
DELETE VOL_EABS, PVCABS, PVMABS, PORMIN
!
!****************************************
!
! Increase in pore volume in MB 139, south side
!
LIMIT ELEMENT 532 TO 539
!
PVC39S   = SUM(POROS*VOL_E39S)
PORMIN   = ENVMIN(POROS)
PVM39S   = SUM(PORMIN*VOL_E39S)
PVOLI39S = PVC39S - PVM39S
!
DELETE VOL_E39S, PVC39S, PVM39S, PORMIN
!
!****************************************
!****************************************
!
! Total increase in pore volume in fractured zones
!
PVOLI_T = PVOLI38N + PVOLIABN + PVOLI39N + PVOLI38S + PVOLIABS + PVOLI39S
!
!****************************************
!
!*******************************************************************************
!*******************************************************************************
!
!   Param 139: Brine volume in brine pocket ---------------> BRNVOL_B
!   Param 140: Downward brine flow at E:223 ---------------> BNBHDNUZ
!   Param 141: Downward brine flow at E:471 ---------------> BRNBHDNC
!   Param 142: Steel mass remaining in waste panel --------> FEKG_W
!   Param 143: Cellulose mass remaining in waste panel ----> CELLKG_W
!   Param 144: Fraction steel remaining in waste panel ----> FEREM_W
!   Param 145: Fraction cellulose remain in waste panel ---> CELREM_W
!   Param 146: Total gas volume generated in waste panel --> GASVOL_W
!   Param 147: Total pore volume in waste panel -----------> PORVOL_W
!
!****************************************
!
! Brine volume (m**3) in brine pocket
!
LIMIT ELEMENT 1007 TO 1023
!
! Brine volume     = porosity * volume * brine saturation
! Brine saturation = 1.0 - SATGAS
!
BRNVOL_B = SUM(POROS*GRIDVOL*(1.0-SATGAS))
!
!****************************************
!
! Cumulative brineflow down borehole at upper DRZ
!
BNBHDNU  = IFLT0(FLOWBRY[E:223],-1.0*FLOWBRY[E:223],0.0)
BNBHDNUZ = INTRIGHT(BNBHDNU)
!
DELETE BNBHDNU
!
!****************************************
!
! Cumulative brineflow down borehole (measured at repository top boundary)
!
```

```
BRNBHDN  = IFLT0(FLOWBRY[E:471],-1.0*FLOWBRY[E:471],0.0)
BRNBHDNC = INTRIGHT(BRNBHDN)
!
DELETE BRNBHDN
!
!****************************************
!
! Total gas volume (m**3) generated in waste panel
!
LIMIT ELEMENT 596 TO 616
!
! Define molecular weights of iron and cellulosics (kg/mol)
!
MW_FE    = 0.055847
MW_CELL  = 0.03002628
!
! Calculate mass inventories (kg) remaining
!
FEKG_W   = SUM(GRIDVOL*FECONC)
CELLKG_W = SUM(GRIDVOL*CELLCONC)
!
! Maximum Fe and bio is at time = 0.0
!
MXFE_W   = ENVMAX(FEKG_W)
MXCELL_W = ENVMAX(CELLKG_W)
!
! Calculate masses consumed and divide by initial amount to get fractions gone
! Subtract fraction gone from one to get fractions remaining
!
FEREM_W  = 1.0 - ((MXFE_W - FEKG_W)/MXFE_W)
CELREM_W = 1.0 - ((MXCELL_W - CELLKG_W)/MXCELL_W)
!
! Calculate total moles of gas (H2) generated from corrosion of Fe
!
FEMOL_W  = (MXFE_W - FEKG_W)/MW_FE*(4.0-STOICOR[B:12])/3.0
!
! Calculate total moles of gas (H2) generated from biodegradation of cellulosics
!
CELMOL_W = (MXCELL_W - CELLKG_W)/MW_CELL*STOIMIC[B:12]
!
! Total moles of gas generated
!
GASMOL_W = FEMOL_W + CELMOL_W
!
! Convert to volumetric units (m**3) using PV=nRT at reference P & T
!
!   T =    300.15 K
!   P = 101325.00 Pa        = 101325 N/(m**2)
!   R = 8.3145    J/(mol*K) = 8.3145 (N*m)/(mol*K)
!   V = n*(R*T/P) m**3      = n moles * 0.024630 (m**3)/mole
!
GASVOL_W  = 0.02463 * GASMOL_W
!
DELETE GASMOL_W
DELETE MW_FE,   MXFE_W,   FEMOL_W
DELETE MW_CELL, MXCELL_W, CELMOL_W
!
!****************************************
!
! Total pore volume (m**3) in waste panel
!
LIMIT ELEMENT 596 TO 616
!
! Pore volume = porosity (m**3 void/m**3 rock) * volume
!
PORVOL_W = SUM(POROS*GRIDVOL)
```

```
!
!****************************************
!
!*****************************************************************************
!*****************************************************************************
!
!   Param 148: Volume avgd "brine porosity" in waste panel ---------> BRNPOR_W
!   Param 149: Volume avgd "brine porosity" in rest of repository --> BRNPOR_R
!   Param 150: Volume avgd "brine porosity" in waste regions -------> BRNPOR_T
!
!****************************************
!
! "Brine porosity" (dimensionless) averaged over Waste Panel
!
LIMIT ELEMENT 596 TO 616
!
! Brine saturation = 1.0 - SATGAS
!
WPVOL    = SUM(GRIDVOL)
BRNPORW  = SUM(GRIDVOL*POROS*(1.0-SATGAS))
BRNPOR_W = BRNPORW/WPVOL
!
DELETE WPVOL, BRNPORW
!
!****************************************
!
! "Brine porosity" (dimensionless) averaged over Rest of Repository
!
LIMIT ELEMENT 617 TO 625
!
! Brine saturation = 1.0 - SATGAS
!
RRVOL    = SUM(GRIDVOL)
BRNPORR  = SUM(GRIDVOL*POROS*(1.0-SATGAS))
BRNPOR_R = BRNPORR/RRVOL
!
DELETE RRVOL, BRNPORR
!
!****************************************
!
! "Brine porosity" (dimensionless) averaged over Waste Panel and Rest of
!                   Repository
!
LIMIT ELEMENT 596 TO 625
!
! Brine saturation = 1.0 - SATGAS
!
WRVOL    = SUM(GRIDVOL)
BRNPORT  = SUM(GRIDVOL*POROS*(1.0-SATGAS))
BRNPOR_T = BRNPORT/WRVOL
!
DELETE WRVOL, BRNPORT
!
!****************************************
!
!*****************************************************************************
!*****************************************************************************
!
!   Param 151: Total brineflow out of MB 138 towards repository --> BRNM38I
!   Param 152: Total brineflow out of A. A&B towards repository --> BRNAABI
!   Param 153: Total brineflow out of MB 139 towards repository --> BRNM39I
!   Param 154: Total brineflow into MB 138 away from repository --> BRNM38O
!   Param 155: Total brineflow into A. A&B away from repository --> BRNAABO
!   Param 156: Total brineflow into MB 139 away from repository --> BRNM39O
!
!****************************************
```

```
!
! Total brineflow out of Marker Bed 138 toward repository (m**3)
!
BRNM38I  = BRM38NIC + BRM38SIC
!
!****************************************
!
! Total brineflow out of Anhydrite A&B toward repository (m**3)
!
BRNAABI  = BRAABNIC + BRAABSIC
!
!****************************************
!
! Total brineflow out of Anhydrite A&B toward repository (m**3)
!
BRNM39I  = BRM39NIC + BRM39SIC
!
!****************************************
!
! Total brineflow into Marker Bed 138 away from repository (m**3)
!
BRNM38O  = BRM38NOC + BRM38SOC
!
!****************************************
!
! Total brineflow into Anhydrite A&B away from repository (m**3)
!
BRNAABO  = BRAABNOC + BRAABSOC
!
!****************************************
!
! Total brineflow into Marker Bed 139 away from repository (m**3)
!
BRNM39O  = BRM39NOC + BRM39SOC
!
!****************************************
!
!*****************************************************************************
!*****************************************************************************
!
! Param 157: Brine consumed in Waste Panel (m**3) --> BRN_RMVW
!
LIMIT ELEMENT 596 TO 616
!
!   Add up consumption rates (resulting units are kg/s)
!
BRN_CRW  = SUM(BRINRATE*GRIDVOL)
!
!   Integrate result to get kg of brine consumed
!
BRN_CONW = INTRIGHT(BRN_CRW)
!
!   Convert to volumetric amount (m**3) by
!      dividing by brine density (kg/m**3) at reference conditions
!
BRN_RMVW = -1.0*BRN_CONW/1220.0
!
!   Delete temporary variables
!
DELETE BRN_CRW, BRN_CONW
!
!*************************************************
!
! Param 158: Brine consumed in Rest of Repository (m**3) --> BRN_RMVR
!
LIMIT ELEMENT 617 TO 625
```

```
!
!   Add up consumption rates (resulting units are kg/s)
!
BRN_CRR = SUM(BRINRATE*GRIDVOL)
!
!   Integrate result to get kg of brine consumed
!
BRN_CONR  = INTRIGHT(BRN_CRR)
!
!   Convert to volumetric amount (m**3) by
!      dividing by brine density (kg/m**3) at reference conditions
!
BRN_RMVR = -1.0*BRN_CONR/1220.0
!
!   Delete temporary variables
!
DELETE BRN_CRR, BRN_CONR
!
!*****************************************************************************
!*****************************************************************************
!
!   Param 159: Remaining fraction of steel in Rest of Repository --> FEREM_R
!   Param 160: Remaining fraction of cellulose in Rest of Repos. --> CELREM_R
!
!*******************************************
!
LIMIT ELEMENT 617 TO 625
!
! Calculate mass inventories (kg) remaining
!
FE_KGR     = SUM(GRIDVOL*FECONC)
CELL_KGR   = SUM(GRIDVOL*CELLCONC)
!
! Maximum Fe and bio is at time = 0.0
!
MXFER      = ENVMAX(FE_KGR)
MXCELLR    = ENVMAX(CELL_KGR)
!
! Calculate masses consumed and divide by initial amount to get fractions gone
! Subtract fraction gone from one to get fractions remaining
!
FEREM_R    = 1.0 - ((MXFER - FE_KGR)/MXFER)
CELREM_R   = 1.0 - ((MXCELLR - CELL_KGR)/MXCELLR)
!
! Delete intermediate variables:
!
DELETE FE_KGR, CELL_KGR, MXFER, MXCELLR
!
!*****************************************************************************
!*****************************************************************************
!
!  Param 161: Cumulative Brineflow into Waste Panel excl. Borehole --> BRWI_XBH
!  Param 162: (Salado brine inflow)/(total brine inflow) at DRZ -----> SAL_BR_T
!  Param 163: (Salado br. inflow)/(unconsumed br. inflow) at DRZ ----> SAL_BR_U
!  Param 164: (Salado br. inflow)/(total br. in.) at Waste Panel ----> SB_TB_WP
!  Param 165: (Salado br. in.)/(unconsumed br. in.) at Waste Panel --> SB_UB_WP
!
!*******************************************
!
! Cumulative brine inflow into Waste Panel, excluding Borehole
!
!   Bottom except for Borehole
!
BRWI_X    =           IFGT0(FLOWBRY[E:596],FLOWBRY[E:596],0.0)
BRWI_X    = BRWI_X + IFGT0(FLOWBRY[E:597],FLOWBRY[E:597],0.0)
BRWI_X    = BRWI_X + IFGT0(FLOWBRY[E:598],FLOWBRY[E:598],0.0)
```

```
BRWI_X    = BRWI_X + IFGT0(FLOWBRY[E:600],FLOWBRY[E:600],0.0)
BRWI_X    = BRWI_X + IFGT0(FLOWBRY[E:601],FLOWBRY[E:601],0.0)
BRWI_X    = BRWI_X + IFGT0(FLOWBRY[E:602],FLOWBRY[E:602],0.0)
!
!   Top except for Borehole
!
BRWI_X    = BRWI_X + IFLT0(FLOWBRY[E:468],-1.0*FLOWBRY[E:468],0.0)
BRWI_X    = BRWI_X + IFLT0(FLOWBRY[E:469],-1.0*FLOWBRY[E:469],0.0)
BRWI_X    = BRWI_X + IFLT0(FLOWBRY[E:470],-1.0*FLOWBRY[E:470],0.0)
BRWI_X    = BRWI_X + IFLT0(FLOWBRY[E:472],-1.0*FLOWBRY[E:472],0.0)
BRWI_X    = BRWI_X + IFLT0(FLOWBRY[E:473],-1.0*FLOWBRY[E:473],0.0)
BRWI_X    = BRWI_X + IFLT0(FLOWBRY[E:474],-1.0*FLOWBRY[E:474],0.0)
!
!   Left side
!
BRWI_X    = BRWI_X + IFGT0(FLOWBRX[E:596],FLOWBRX[E:596],0.0)
BRWI_X    = BRWI_X + IFGT0(FLOWBRX[E:603],FLOWBRX[E:603],0.0)
BRWI_X    = BRWI_X + IFGT0(FLOWBRX[E:610],FLOWBRX[E:610],0.0)
!
!   Right side
!
BRWI_X    = BRWI_X + IFLT0(FLOWBRX[E:602],-1.0*FLOWBRX[E:602],0.0)
BRWI_X    = BRWI_X + IFLT0(FLOWBRX[E:609],-1.0*FLOWBRX[E:609],0.0)
BRWI_X    = BRWI_X + IFLT0(FLOWBRX[E:616],-1.0*FLOWBRX[E:616],0.0)
!
!   Accumulate over time
!
BRWI_XBH = INTRIGHT(BRWI_X)
!
DELETE BRWI_X
!
!*******************************************
!
! (Salado brine inflow)/(total brine inflow) at DRZ
!
!   Define a dummy denominator to avoid dividing by zero
!
DENDUM05 = BRAALIC + BNBHLDRZ + BNBHDNUZ
DENDUM06 = IFEQ0(DENDUM05,1.0,DENDUM05)
!
SAL_BR_T = BRAALIC/DENDUM06
!
DELETE DENDUM05, DENDUM06
!
!*******************************************
!
! (Salado brine inflow)/(unconsumed brine inflow) at DRZ
!
!   Define a dummy denominator to avoid dividing by zero
!
DENDUM07 = BRAALIC + BNBHLDRZ + BNBHDNUZ - BRN_RMV
DENDUM08 = IFEQ0(DENDUM07,1.0,DENDUM07)
!
SAL_BR_U = BRAALIC/DENDUM08
!
DELETE DENDUM07, DENDUM08
!
!*******************************************
!
! (Salado brine inflow)/(total brine inflow) at Waste Panel
!
!   Define a dummy denominator to avoid dividing by zero
!
DENDUM09  = BRWI_XBH + BRNBHDNC + BRNBHUPP
DENDUM10  = IFEQ0(DENDUM09,1.0,DENDUM09)
!
```

```
SB_TB_WP = BRWI_XBH/DENDUM10
!
DELETE DENDUM09, DENDUM10
!
!*****************************************
!
! (Salado brine inflow)/(unconsumed brine inflow) at Waste Panel
!
!   Define a dummy denominator to avoid dividing by zero
!
DENDUM11  = BRWI_XBH + BRNBHDNC + BRNBHUPP - BRN_RMVW
DENDUM12  = IFEQ0(DENDUM11,1.0,DENDUM11)
!
SB_UB_WP = BRWI_XBH/DENDUM12
!
DELETE DENDUM11, DENDUM12
!
!*****************************************************************************
!*****************************************************************************
!
! Cumulative brineflow (m**3) vertically at Magenta Dolomite Member
!
!   Param 166: Brineflow up shaft (@element 664) --------> BRNSHUMC
!   Param 167: Brineflow up borehole (@element 777) -----> BRNBHUMC
!
!****************************************
!
! Cumulative brineflow up through shaft (at Magnenta Member)
!
BRNSHUM  = IFGT0(FLOWBRY[E:664],FLOWBRY[E:664],0.0)
BRNSHUMC = INTRIGHT(BRNSHUM)
!
!****************************************
!
! Cumulative brineflow up borehole (at Magenta Member)
!
BRNBHUM  = IFGT0(FLOWBRY[E:777],FLOWBRY[E:777],0.0)
BRNBHUMC = INTRIGHT(BRNBHUM)
!
!****************************************
!
! Clean up output--limit to requested quantities
!
DELETE BRNSHUM, BRNBHUM
!
!*****************************************************************************
!*****************************************************************************
!
! Total outward brineflow in marker beds across land-withdrawal boundary (m**3)
!
!   Param 168: MB 138,        North --> BRM38NLW
!   Param 169: Anhydrite A&B, North --> BRAABNLW
!   Param 170: MB 139,        North --> BRM39NLW
!   Param 171: MB 138,        South --> BRM38SLW
!   Param 172: Anhydrite A&B, South --> BRAABSLW
!   Param 173: MB 139,        South --> BRM39SLW
!   Param 174: all marker beds -------> BRAALLWC
!
!****************************************
!
! Total outward brineflow in MB 138 across l-w boundary, north (right) side
!
BRNM38N0 = IFGT0(FLOWBRX[E:594],FLOWBRX[E:594],0.0)
BRM38NLW = INTRIGHT(BRNM38N0)
!
!****************************************
```

```
!
! Total outward brineflow in Anhydrite A&B across 1-w boundary, north side
!
BRNAABN0 = IFGT0(FLOWBRX[E:562],FLOWBRX[E:562],0.0)
BRAABNLW = INTRIGHT(BRNAABN0)
!
!****************************************
!
! Total outward brineflow in MB 139 across 1-w boundary, north (right) side
!
BRNM39N0 = IFGT0(FLOWBRX[E:546],FLOWBRX[E:546],0.0)
BRM39NLW = INTRIGHT(BRNM39N0)
!
!****************************************
!****************************************
!
! Total outward brineflow in MB 138 across 1-w boundary, south (left) side
!
BRNM38S0 = IFLT0(FLOWBRX[E:566],-1.0*FLOWBRX[E:566],0.0)
BRM38SLW = INTRIGHT(BRNM38S0)
!
!****************************************
!
! Total outward brineflow in Anhydrite A&B across 1-w boundary, south side
!
BRNAABS0 = IFLT0(FLOWBRX[E:550],-1.0*FLOWBRX[E:550],0.0)
BRAABSLW = INTRIGHT(BRNAABS0)
!
!****************************************
!
! Total outward brineflow in MB 139 across 1-w boundary, south (left) side
!
BRNM39S0 = IFLT0(FLOWBRX[E:534],-1.0*FLOWBRX[E:534],0.0)
BRM39SLW = INTRIGHT(BRNM39S0)
!
!****************************************
!
! Total outward brineflow in all anhydrite layers across 1-w boundary
!
BRAALLWC = BRM38NLW + BRAABNLW + BRM39NLW + BRM38SLW + BRAABSLW + BRM39SLW
!
!****************************************
!
! Clean up output--limit to requested quantities
!
DELETE BRNM38N0, BRNAABN0, BRNM39N0, BRNM38S0, BRNAABS0, BRNM39S0
!
!*****************************************************************************
!*****************************************************************************
!
! Contributions of gas generated from each source (%/100)
!
!   Param 175: Fraction of total gas due to steel corrosion ----------> FR_TG_C
!   Param 176: Fraction of total gas due to total microbial ----------> FR_TG_M
!   Param 177: Fraction of total gas due to humid microbial ----------> FR_TG_H
!   Param 178: Fraction of total gas due to inundated microbial ------> FR_TG_I
!   Param 179: Fraction of microbial gas from humid conditions -------> FR_MG_H
!   Param 180: Fraction of microbial gas from inundated conditions ---> FR_MG_I
!
!****************************************
!
! Fraction of total gas due to steel corrosion
!
!   Check total amount of gas to avoid subsequent divide by zero (if total gas
!   is equal to zero, then divide by one since fraction will be zero)
!
```

```
GAS_SUM  = IFEQ0(GAS_MOLE,1.0,GAS_MOLE)
!
!   Check total amount of microbial-generated gas to avoid divide by zero
!
GM_SUM   = IFEQ0(C_M_HI_T,1.0,C_M_HI_T)
!
FR_TG_C  = FE_MOLE/GAS_SUM
!
!****************************************
!
! Fraction of total gas due to total microbial degradation
!
FR_TG_M  = 1.0 - FR_TG_C
!
!****************************************
!
! Fraction of total gas due to humid microbial degradation
!
FR_TG_H  = FR_TG_M*(CELL_M_H/GM_SUM)
!
!****************************************
!
! Fraction of total gas due to inundated microbial degradation
!
FR_TG_I  = FR_TG_M*(1.0 - (CELL_M_H/GM_SUM))
!
!****************************************
!
! Fraction of microbial gas due to humid conditions
!
FR_MG_H  = CELL_M_H/GM_SUM
!
!****************************************
!
! Fraction of microbial gas due to inundated conditions
!
FR_MG_I  = 1.0 - (CELL_M_H/GM_SUM)
!
!****************************************
!
! Delete temporary variables
!
DELETE GAS_SUM, GM_SUM
!
!*****************************************************************************
!*****************************************************************************
!
! Cumulative brineflow (m**3) across panel seal
!
!   Param 181: Total brineflow into waste panel ---------> BRNPSIWC
!   Param 182: Total brineflow into rest of repository --> BRNPSIRC
!   Param 183: Net brineflow out of waste panel ---------> BRNPSOWC
!   Param 184: Net brineflow out of rest of repository --> BRNPSORC
!   Param 185: Net brineflow into waste panel -----------> BRNPSNWC
!   Param 186: Net brineflow into rest of repository ----> BRNPSNRC
!
!****************************************
!
! Total cumulative brineflow across panel seal into waste panel
!
BRNPSIW  =            IFLT0(FLOWBRX[E:638],-1.0*FLOWBRX[E:638],0.0)
BRNPSIW  = BRNPSIW + IFLT0(FLOWBRX[E:639],-1.0*FLOWBRX[E:639],0.0)
BRNPSIW  = BRNPSIW + IFLT0(FLOWBRX[E:640],-1.0*FLOWBRX[E:640],0.0)
!
BRNPSIWC = INTRIGHT(BRNPSIW)
!
```

```
DELETE BRNPSIW
!
!*************************************
!
! Total cumulative brineflow across panel seal into rest of repository
!
BRNPSIR  =           IFGT0(FLOWBRX[E:617],FLOWBRX[E:617],0.0)
BRNPSIR  = BRNPSIR + IFGT0(FLOWBRX[E:620],FLOWBRX[E:620],0.0)
BRNPSIR  = BRNPSIR + IFGT0(FLOWBRX[E:623],FLOWBRX[E:623],0.0)
!
BRNPSIRC = INTRIGHT(BRNPSIR)
!
DELETE BRNPSIR
!
!*************************************
!
! Total cumulative brineflow across panel seal out of waste panel
!
BRNPSOW  =           IFGT0(FLOWBRX[E:638],FLOWBRX[E:638],0.0)
BRNPSOW  = BRNPSOW + IFGT0(FLOWBRX[E:639],FLOWBRX[E:639],0.0)
BRNPSOW  = BRNPSOW + IFGT0(FLOWBRX[E:640],FLOWBRX[E:640],0.0)
!
BRNPSOWC = INTRIGHT(BRNPSOW)
!
DELETE BRNPSOW
!
!*************************************
!
! Total cumulative brineflow across panel seal out of rest of repository
!
BRNPSOR  =           IFLT0(FLOWBRX[E:617],-1.0*FLOWBRX[E:617],0.0)
BRNPSOR  = BRNPSOR + IFLT0(FLOWBRX[E:620],-1.0*FLOWBRX[E:620],0.0)
BRNPSOR  = BRNPSOR + IFLT0(FLOWBRX[E:623],-1.0*FLOWBRX[E:623],0.0)
!
BRNPSORC = INTRIGHT(BRNPSOR)
!
DELETE BRNPSOR
!
!*************************************
!
! Net inflow of brine across panel seal into waste panel
!
BRNPSNWC = BRNPSIWC - BRNPSOWC
!
!*************************************
!
! Net inflow of brine across panel seal into waste panel
!
BRNPSNRC = BRNPSIRC - BRNPSORC
!
!*************************************************************************
!*************************************************************************
!
LIMIT ELEMENT OFF
!
DELETE GRIDVOL
!
!*************************************************************************
!*************************************************************************
END
```

END OF APPENDIX E

APPENDIX F: EXAMPLE OF PANEL'S OUTPUT DBG FILE

Explanatory comments, which do not ordinarily appear on PANEL's DBG files, are inserted on the DBG file that follows. The are intended to assist the reader and are printed in italics so as to set them off.

```
PANEL_PA96 3.60 PROD PA96 05/17/96                                  06/14/96 13:58:20

PPPPPP   AAAAA  N    NN EEEEEEE LL              PPPPPP   AAAAA    9999   6666
PP   PP AA   AA NN   NN EE      LL              PP   PP AA   AA  9    9 6
PP   PP AA   AA NNN  NN EE      LL              PP   PP AA   AA  9    9 6
PPPPPP  AAAAAAA NN N NN EEEEE   LL              PPPPPP  AAAAAAA   99999 66666
PP      AA   AA NN  NNN EE      LL              PP      AA   AA       9 6    6
PP      AA   AA NN   NN EE      LL              PP      AA   AA       9 6    6
PP      AA   AA NN    N EEEEEEE LLLLLLL _______ PP      AA   AA   9999   6666

                    PANEL_PA96 Version 3.60
                    PROD PA96 Built 05/17/96
                     Written by JIM GARNER
                     Sponsored by JIM GARNER

                  Run on 06/14/96 at 13:58:20
               Run on ALPHA AXP BONNIE OpenVMS V6.1

        ************************************************************

        Prepared for
        Sandia National Laboratories
        Albuquerque, New Mexico 87185-5800
        for the United States Department of Energy
        under Contract DE-AC04-76DP00789

        ************************************************************

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                              ----------

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        ************************************************************

*****************************************************************************
```

Explanatory Comment: The section that follows this comment echoes PANEL's input data and includes: (i) the values of arg1 through arg5 (see Chapter 6), namely: the run type plus four file specifications. It is arranged in twelve rows and includes file names, plus dates of origin of the two external files. (ii) The next row gives the number of seconds per year. (iii) The next six rows give the log to the base 10 of the solubilities (in moles/l), which are called LOGSOLM on the CAMDAT data base and are provided by ALGEBRA. (iv) In the next several dozen rows are given the initial inventories (in Curies) of contact-handled (INVCHD) and remote-handled (INVRHD) radioisotopes (note that unfound isotopes are set to zero inventory by default); (v) a three-column, 73-row listing of (1) time (in seconds) from zero to 10,000 years, (2) cumulative brine outflow from the repository (in m^3) from BRAGFLO, and (3) volume of brine in the repository (in m^3) from BRAGFLO (modified as required to conform to a 1000-m^3 minimum); (vi) a one-row listing of (a) the panel index, which has no meaning or purpose in CCA runs and is set to unity, and (b) an initial time index, which is set to zero at the time of decommissioning; (vii) a 6-row, three-column listing of the elements PANEL will mobilize giving (1) the solubility for sorption onto large colloids (set to zero in CCA runs), (2) the solubility for sorption onto small colloids (set to zero in CCA runs), and (3) the solubilities by enhanced equivalent dissolution, in moles/l; (viii) a two-row listing of data that are unused in CCA runs, (ix) a 30-row (one row for each PANEL isotope), 7-column listing of (1) the numerical index from 1 to 30, (2) isotope identification, (3) half-life in years, (4) identification of daughter decay product, (5) the radioactivity of that isotope in Curies/mole, (6) the radioactivity of that isotope in Curies per kilogram, (7) the total WIPP inventory of that isotope in Curies, and (8) the total WIPP inventory of that isotope in kilograms; and (x) a final row stating the total initial inventory of the WIPP repository based on all transuranic alpha emitters having half lives greater than 20 years. End of Comment.

```
FILE ASSIGNMENTS:
-----------------
TYPE OF RUN,S=standard,R=radialysis,D=decay only:
   S
CAMDAT data base:
   BONNIE$CCA1_WORKROOT:[PANEL.DATA.R1S6V23]ALG_ST_CCA_R1_S6_V023.CDB;1
      Written on 06/02/96 19:59:16
output CAMDAT data base:
   BONNIE$CCA1_WORKROOT:[PANEL.DATA.R1S6V23]PANEL_CCA_R1_S6_V023.CDB
FLUX FILES FROM BRAGFLO:
   BONNIE$CCA1_WORKROOT:[PANEL.DATA.R1S6V23]BF_POSTALG_CCA_R1_S6_V023.CDB;1
      Written on 06/10/96 20:21:36
diagnostics file:
   BONNIE$CCA1_WORKROOT:[PANEL.DATA.R1S6V23]PANEL_CCA_R1_S6_V023.DBG
FROM CDB, REFCON   YRSEC      3.1557E+07
FROM CDB, TH       LOGSOLM   -7.0535E+00
FROM CDB, U        LOGSOLM   -5.0733E+00
FROM CDB, NP       LOGSOLM   -4.5430E+00
FROM CDB, PU       LOGSOLM   -7.0651E+00
FROM CDB, AM       LOGSOLM   -6.4662E+00
FROM CDB, CM       LOGSOLM   -6.4662E+00
FROM CDB, SR90     INVCHD     6.8500E+03
FROM CDB, SR90     INVRHD     2.0900E+05
FROM CDB, CS137    INVCHD     8.0600E+03
FROM CDB, CS137    INVRHD     2.1600E+05
FROM CDB, PB210    INVCHD     2.5500E+00
FROM CDB, PB210    INVRHD     7.1600E-06
FROM CDB, RA226    INVCHD     1.1600E+01
FROM CDB, RA226    INVRHD     3.5800E-05
FROM CDB, RA228    INVCHD     7.4700E-01
FROM CDB, RA228    INVRHD     7.7700E-02
FROM CDB, TH229    INVCHD     2.8800E+00
FROM CDB, TH229    INVRHD     1.1700E-01
FROM CDB, TH230    INVCHD     8.0600E-02
FROM CDB, TH230    INVRHD     7.5600E-03
FROM CDB, TH232    INVCHD     9.1300E-01
FROM CDB, TH232    INVRHD     9.2500E-02
FROM CDB, PA231    INVCHD     4.5100E-01
FROM CDB, PA231    INVRHD     1.9100E-03
```

```
FROM CDB, U233      INVCHD     1.7900E+03
FROM CDB, U233      INVRHD     1.5800E+02
FROM CDB, U234      INVCHD     4.6500E+02
FROM CDB, U234      INVRHD     4.2700E+01
FROM CDB, U235      INVCHD     1.2800E+01
FROM CDB, U235      INVRHD     4.6300E+00
FROM CDB, U236      INVCHD     3.3300E-01
FROM CDB, U236      INVRHD     9.6800E-02
FROM CDB, U238      INVCHD     3.9600E+01
FROM CDB, U238      INVRHD     1.0500E+01
FROM CDB, NP237     INVCHD     5.6100E+01
FROM CDB, NP237     INVRHD     2.8500E+00
FROM CDB, PU238     INVCHD     2.6100E+06
FROM CDB, PU238     INVRHD     1.4500E+03
FROM CDB, PU239     INVCHD     7.8500E+05
FROM CDB, PU239     INVRHD     1.0300E+04
FROM CDB, PU240     INVCHD     2.1000E+05
FROM CDB, PU240     INVRHD     5.0700E+03
FROM CDB, PU241     INVCHD     2.3100E+06
FROM CDB, PU241     INVRHD     1.4200E+05
FROM CDB, PU242     INVCHD     1.1700E+03
FROM CDB, PU242     INVRHD     1.5000E-01
FROM CDB, PU244     INVCHD     1.5000E-06
FROM CDB, PU244     INVRHD     2.2100E-11
FROM CDB, AM241     INVCHD     4.4200E+05
FROM CDB, AM241     INVRHD     5.9600E+03
FROM CDB, CM244     INVCHD     3.1500E+04
FROM CDB, CM244     INVRHD     3.1500E+02
FROM CDB, CM248     INVCHD     8.9500E-02
FROM CDB, CM248     INVRHD     2.0500E-04
FROM CDB, CF252     INVCHD     2.3900E+02
FROM CDB, CF252     INVRHD     1.2900E+00
FROM CDB, PM147     INVCHD     7.8700E+00
FROM CDB, PM147     INVRHD     1.0700E+01
ELBNAM SM147    AND PROPNAM INVCHD   NOT FOUND!! SET TO   0.000E+00
ELBNAM SM147    AND PROPNAM INVRHD   NOT FOUND!! SET TO   0.000E+00
FROM CDB, AM243     INVCHD     3.2600E+01
FROM CDB, AM243     INVRHD     2.2800E-04
FROM CDB, CM243     INVCHD     2.7200E+00
FROM CDB, CM243     INVRHD     4.9500E+01
FROM CDB, CM245     INVCHD     1.1500E+02
FROM CDB, CM245     INVRHD     1.4600E-06
   1  0.0000E+00  0.0000E+00  1.0000E+03
   2  7.0909E+03  1.3455E-10  1.0000E+03
   3  6.9351E+05  1.1810E-08  1.0000E+03
   4  3.0444E+07  2.3075E-07  1.0000E+03
   5  2.2386E+08  9.2151E-07  1.1838E+03
   6  3.1569E+08  1.1035E-06  1.2347E+03
   7  3.2622E+08  1.1226E-06  1.2401E+03
   8  7.8892E+08  1.7046E-06  1.4220E+03
   9  7.8938E+08  1.7051E-06  1.4222E+03
  10  8.2954E+08  1.7438E-06  1.4357E+03
  11  1.5778E+09  2.2735E-06  1.6603E+03
  12  1.5789E+09  2.2741E-06  1.6606E+03
  13  1.6770E+09  2.3283E-06  1.6881E+03
  14  3.1557E+09  2.8999E-06  2.0817E+03
  15  3.1571E+09  2.9003E-06  2.0820E+03
  16  3.2797E+09  2.9364E-06  2.1138E+03
  17  4.4737E+09  3.2248E-06  2.4182E+03
  18  4.5101E+09  3.2325E-06  2.4274E+03
  19  6.3114E+09  3.5390E-06  2.8754E+03
  20  6.3119E+09  3.5390E-06  2.8755E+03
  21  6.3520E+09  3.5449E-06  2.8854E+03
  22  6.7391E+09  3.5987E-06  2.9805E+03
  23  7.2882E+09  3.6694E-06  3.1148E+03
  24  8.5446E+09  3.8106E-06  3.4172E+03
```

```
   25  1.0732E+10  4.0056E-06  3.9304E+03
   26  1.1244E+10  4.0457E-06  4.0395E+03
   27  1.2486E+10  4.1342E-06  4.2385E+03
   28  1.2623E+10  4.1434E-06  4.2147E+03
   29  1.2632E+10  4.1439E-06  4.2139E+03
   30  1.2680E+10  4.1472E-06  4.2190E+03
   31  1.3110E+10  4.1743E-06  4.1700E+03
   32  1.3574E+10  4.2030E-06  4.1125E+03
   33  1.4459E+10  5.1364E-06  4.0265E+03
   34  1.7279E+10  6.1555E-06  3.8144E+03
   35  2.8169E+10  1.2136E-05  3.3158E+03
   36  3.1557E+10  1.2136E-05  3.2414E+03
   37  3.1557E+10  1.2136E-05  3.2414E+03
   38  3.1557E+10  1.2136E-05  3.2414E+03
   39  3.1557E+10  1.2136E-05  3.2414E+03
   40  3.1557E+10  1.2136E-05  3.2420E+03
   41  3.1596E+10  1.2136E-05  3.2927E+03
   42  3.2488E+10  1.2136E-05  3.6356E+03
   43  3.4302E+10  1.2136E-05  3.6149E+03
   44  3.7428E+10  1.2136E-05  3.6104E+03
   45  3.9652E+10  1.2136E-05  3.6314E+03
   46  4.3479E+10  1.2136E-05  3.7210E+03
   47  4.3933E+10  1.2136E-05  3.7426E+03
   48  4.6069E+10  1.2136E-05  3.8196E+03
   49  4.9520E+10  1.2136E-05  3.9900E+03
   50  5.3592E+10  1.2136E-05  4.1723E+03
   51  5.6446E+10  1.2136E-05  4.2664E+03
   52  6.3114E+10  1.2136E-05  4.4583E+03
   53  6.3114E+10  1.2136E-05  4.4713E+03
   54  6.3118E+10  1.2136E-05  5.1120E+03
   55  6.3372E+10  1.2136E-05  5.2406E+03
   56  6.9425E+10  1.2136E-05  4.7056E+03
   57  6.9426E+10  1.2136E-05  4.7056E+03
   58  6.9476E+10  1.2136E-05  4.7080E+03
   59  7.3830E+10  1.2136E-05  4.8012E+03
   60  8.8820E+10  1.2136E-05  5.0775E+03
   61  1.0098E+11  1.3066E+02  5.2020E+03
   62  1.0098E+11  1.3083E+02  5.2021E+03
   63  1.0128E+11  1.4678E+02  5.2072E+03
   64  1.0979E+11  8.6931E+02  5.2682E+03
   65  1.2583E+11  3.1457E+03  5.3303E+03
   66  1.4125E+11  5.9569E+03  5.3494E+03
   67  1.6228E+11  9.9205E+03  5.3267E+03
   68  1.9684E+11  1.6271E+04  5.2509E+03
   69  2.3140E+11  2.2559E+04  5.1746E+03
   70  2.6596E+11  2.8795E+04  5.0981E+03
   71  3.0052E+11  3.4789E+04  5.0619E+03
   72  3.1557E+11  3.7294E+04  5.0531E+03
   73  3.2557E+11  3.7294E+04  5.0531E+03
 IPANEL,TZERO=  1        0.0
  SOLS      TH  0.0000E+00  0.0000E+00  8.8400E-08
  SOLS      U   0.0000E+00  0.0000E+00  8.4470E-06
  SOLS      NP  0.0000E+00  0.0000E+00  2.8642E-05
  SOLS      PU  0.0000E+00  0.0000E+00  8.6083E-08
  SOLS      AM  0.0000E+00  0.0000E+00  3.4184E-07
  SOLS      CM  0.0000E+00  0.0000E+00  3.4184E-07
 SOL3,SOL4,SOL5,SOL6 =   0.000E+00   0.000E+00   0.000E+00   0.000E+00
 RAN1,RAN2,RAN3,RAN4 =   1.000E-01   5.000E-01   5.000E-01   5.000E-01
1   IDION       RHL       IDAUG     CUPMO       CUPKG      WIPP CURIES    WIPP KG
  1 SR-90   2.9120E+01           1.2277E+04  1.3641E+05 0  2.1585E+05  1.5824E+00
  2 CS-137  3.0000E+01           1.1917E+04  8.6982E+04 0  2.2406E+05  2.5759E+00
  3 PB-210  2.2300E+01           1.6031E+04  7.6339E+04 0  2.5500E+00  3.3404E-05
  4 RA-226  1.6000E+03  PB-210   2.2344E+02  9.8865E+02 1  1.1600E+01  1.1733E-02
  5 RA-228  5.7500E+00           6.2173E+04  2.7269E+05 0  8.2470E-01  3.0243E-06
  6 TH-229  7.3400E+03           4.8705E+01  2.1269E+02 1  2.9970E+00  1.4091E-02
  7 TH-230  7.7000E+04  RA-226   4.6428E+00  2.0186E+01 1  8.8160E-02  4.3673E-03
```

8	TH-232	1.4050E+10	RA-228	2.5445E-05	1.0968E-04	1	1.0055E+00	9.1680E+03
9	PA-231	3.2760E+04		1.0913E+01	4.7241E+01	1	4.5291E-01	9.5873E-03
10	U -233	1.5850E+05	TH-229	2.2555E+00	9.6803E+00	1	1.9480E+03	2.0123E+02
11	U -234	2.4450E+05	TH-230	1.4622E+00	6.2485E+00	1	5.0770E+02	8.1251E+01
12	U -235	7.0380E+08	PA-231	5.0795E-04	2.1615E-03	1	1.7430E+01	8.0638E+03
13	U -236	2.3420E+07	TH-232	1.5265E-02	6.4681E-02	1	4.2980E-01	6.6450E+00
14	U -238	4.4680E+09	U -234	8.0013E-05	3.3619E-04	1	5.0100E+01	1.4902E+05
15	NP-237	2.1400E+06	U -233	1.6705E-01	7.0487E-01	1	5.8950E+01	8.3632E+01
16	PU-238	8.7740E+01	U -234	4.0745E+03	1.7120E+04	1	2.6115E+06	1.5254E+02
17	PU-239	2.4070E+04	U -235	1.4852E+01	6.2144E+01	1	7.9530E+05	1.2798E+04
18	PU-240	6.5370E+03	U -236	5.4688E+01	2.2787E+02	1	2.1507E+05	9.4384E+02
19	PU-241	1.4400E+01	AM-241	2.4826E+04	1.0301E+05	0	2.4520E+06	2.3803E+01
20	PU-242	3.7630E+05	U -238	9.5003E-01	3.9258E+00	1	1.1702E+03	2.9807E+02
21	PU-244	8.2600E+07	PU-240	4.3281E-03	1.7738E-02	1	1.5000E-06	8.4566E-05
22	AM-241	4.3220E+02	NP-237	8.2716E+02	3.4322E+03	1	4.4796E+05	1.3052E+02
23	CM-244	1.8110E+01	PU-240	1.9740E+04	8.0903E+04	0	3.1815E+04	3.9325E-01
24	CM-248	3.3900E+05	PU-244	1.0546E+00	4.2523E+00	1	8.9705E-02	2.1096E-02
25	CF-252	2.6380E+00	CM-248	1.3552E+05	5.3777E+05	0	2.4029E+02	4.4683E-04
26	PM-147	2.6234E+00	SM-147	1.3627E+05	9.2702E+05	0	1.8570E+01	2.0032E-05
27	SM-147	1.0600E+11		3.3726E-06	2.2943E-05	1	0.0000E+00	0.0000E+00
28	AM-243	7.3700E+03	PU-239	4.8507E+01	1.9962E+02	1	3.2600E+01	1.6331E-01
29	CM-243	2.9100E+01	PU-239	1.2285E+04	5.0556E+04	1	5.2220E+01	1.0329E-03
30	CM-245	8.5300E+03	PU-241	4.1911E+01	1.7106E+02	1	1.1500E+02	6.7226E-01

0 TOTAL CURIES OF ALPHA EMITTERS WITH HALF-LIFE > 20 YEARS = 4.0737E+06

Explanatory Comment: The data that follow are the scenario-revised initial inventory for PANEL. This step is designed to reduce PANEL's working inventory to accommodate scenarios in which only a fraction of the repository's contents are wetted. Only one standard panel is wetted by brine. Consequently, the scale of the run is set at 0.1044, which represents the area of one standard panel divided by the area of the entire repository. The initial inventory is a one-for-one echo of the entire inventory reported above, with the exception that PANEL has deleted SM-147 from the list. That is because its net individual inventory on the given inventory list is zero and it is not generated as a result of decay. The initial-inventory data are listed as a 6-column, 29-row matrix. The first column identifies the isotope. The 2nd column states its half-life. The third column gives the total initial inventory in Curies and matches identically the 6th column in the preceding data matrix. The fourth column lists the same data in kilograms and matches identically the 7th column in the matrix above. The fifth and sixth columns match the third and fourth columns, but are smaller by a factor of 0.1044, which is the scaling factor listed on the second line below and represents the fact that the contents of only one panel of the repository are accessible. End of comment.

1
0 INITIAL CONDITIONS FOR PANEL # 1
SCALE OF THIS RUN= 0.1044

		WIPP INVENTORY		SCALED INVENTORY	
ISOTOPE	HL	CURIES	KG	CURIES	KG
SR-90	2.912E+01	2.159E+05	1.582E+00	2.253E+04	1.652E-01
CS-137	3.000E+01	2.241E+05	2.576E+00	2.339E+04	2.689E-01
PB-210	2.230E+01	2.550E+00	3.340E-05	2.662E-01	3.487E-06
RA-226	1.600E+03	1.160E+01	1.173E-02	1.211E+00	1.225E-03
RA-228	5.750E+00	8.247E-01	3.024E-06	8.609E-02	3.157E-07
TH-229	7.340E+03	2.997E+00	1.409E-02	3.129E-01	1.471E-03
TH-230	7.700E+04	8.816E-02	4.367E-03	9.203E-03	4.559E-04
TH-232	1.405E+10	1.005E+00	9.168E+03	1.050E-01	9.571E+02
PA-231	3.276E+04	4.529E-01	9.587E-03	4.728E-02	1.001E-03
U -233	1.585E+05	1.948E+03	2.012E+02	2.034E+02	2.101E+01
U -234	2.445E+05	5.077E+02	8.125E+01	5.300E+01	8.482E+00
U -235	7.038E+08	1.743E+01	8.064E+03	1.820E+00	8.418E+02
U -236	2.342E+07	4.298E-01	6.645E+00	4.487E-02	6.937E-01
U -238	4.468E+09	5.010E+01	1.490E+05	5.230E+00	1.556E+04
NP-237	2.140E+06	5.895E+01	8.363E+01	6.154E+00	8.730E+00
PU-238	8.774E+01	2.611E+06	1.525E+02	2.726E+05	1.592E+01
PU-239	2.407E+04	7.953E+05	1.280E+04	8.302E+04	1.336E+03
PU-240	6.537E+03	2.151E+05	9.438E+02	2.245E+04	9.853E+01
PU-241	1.440E+01	2.452E+06	2.380E+01	2.560E+05	2.485E+00
PU-242	3.763E+05	1.170E+03	2.981E+02	1.222E+02	3.112E+01
PU-244	8.260E+07	1.500E-06	8.457E-05	1.566E-07	8.828E-06
AM-241	4.322E+02	4.480E+05	1.305E+02	4.676E+04	1.362E+01
CM-244	1.811E+01	3.181E+04	3.932E-01	3.321E+03	4.105E-02
CM-248	3.390E+05	8.971E-02	2.110E-02	9.364E-03	2.202E-03
CF-252	2.638E+00	2.403E+02	4.468E-04	2.508E+01	4.664E-05
PM-147	2.623E+00	1.857E+01	2.003E-05	1.939E+00	2.091E-06
AM-243	7.370E+03	3.260E+01	1.633E-01	3.403E+00	1.705E-02
CM-243	2.910E+01	5.222E+01	1.033E-03	5.451E+00	1.078E-04
CM-245	8.530E+03	1.150E+02	6.723E-01	1.200E+01	7.018E-02

Explanatory Comment: The remaining data represent a summary overview synopsis of the results of PANEL's calculations. The data are presented in eleven similarly-structured clusters herein printed as three-clusters-per-two-pages after this first page. Each cluster conforms to the following format: The first row identifies the timestep in years and the volume (in m³) of brine in the repository. The next six rows are a five-column summary of the mobilization. The first column represents an effective dissolution solubility (in moles/l) for all isotopes of the element combined in that it, multiplied by the brine volume (converted from m³ to l, and assuming mobilization is NOT inventory limited) gives the amount in the third column, which is the overall amount (in moles) of all isotopes of that element in solution during that timestep. If mobilization is inventory limited, the limit will appear in the third column. The second column represents the inventory available for mobilization (in moles). The next column is the amounts of that element dissolved on the basis of the enhanced equivalent solubility during that time step. The last two columns are not used in CCA runs and list zeros. The final column is a flag that signals (if it is one) that the entire available inventory of that element has been mobilized during that timestep (as is the case for NP and CM during the second timestep [i.e., time = 100years]), or (if it is zero) that stocks of unmobilized inventory remain at the end of that timestep. The next grouping is a 30-row, eight-column matrix that lists the symbol for the isotope followed by the results of the release during that timestep. The 2nd and 3rd columns are not used in CCA runs. The fourth column gives the amount of that isotope released via enhanced equivalent dissolution (in Kg) during that timestep. The next two columns give the remaining inventory in Curies and kilograms. The last two columns give the sum of the first three columns first in Curies and then in kilograms. The final row of the data cluster gives the integrated (from t = 0) brine outflow from the repository in m³. End of Comment.

1 TIME= 0. YEARS, BRINE VOLUME= 1000. M**3

0 ELEMENT	SOLUBILITY	LOADING	DISOLVED	LARGE COL	SMALL COL	
TH	8.840E-08	4.125E+03	8.840E-02	0.000E+00	0.000E+00	0
U	8.447E-06	6.909E+04	8.447E+00	0.000E+00	0.000E+00	0
NP	2.864E-05	3.926E+01	2.864E+01	0.000E+00	0.000E+00	0
PU	8.608E-08	6.185E+03	8.608E-02	0.000E+00	0.000E+00	0
AM	3.418E-07	5.887E+01	3.418E-01	0.000E+00	0.000E+00	0
CM	3.418E-07	3.917E-01	3.418E-01	0.000E+00	0.000E+00	0

0ISOTOPE	AMOUNT RELEASED (KG)			INVENTORY REMAINING		TOTAL RELEASED	
	LARGE COL	SMALL COL	DISOLVED	CURIES	KG	CURIES	KG
SR-90	0.000E+00	0.000E+00	0.000E+00	2.253E+04	1.652E-01	0.000E+00	0.000E+00
CS-137	0.000E+00	0.000E+00	0.000E+00	2.339E+04	2.689E-01	0.000E+00	0.000E+00
PB-210	0.000E+00	0.000E+00	0.000E+00	2.662E-01	3.487E-06	0.000E+00	0.000E+00
RA-226	0.000E+00	0.000E+00	0.000E+00	1.211E+00	1.225E-03	0.000E+00	0.000E+00
RA-228	0.000E+00	0.000E+00	0.000E+00	8.609E-02	3.157E-07	0.000E+00	0.000E+00
TH-229	0.000E+00	0.000E+00	0.000E+00	3.129E-01	1.471E-03	0.000E+00	0.000E+00
TH-230	0.000E+00	0.000E+00	0.000E+00	9.203E-03	4.559E-04	0.000E+00	0.000E+00
TH-232	0.000E+00	0.000E+00	0.000E+00	1.050E-01	9.571E+02	0.000E+00	0.000E+00
PA-231	0.000E+00	0.000E+00	0.000E+00	4.728E-02	1.001E-03	0.000E+00	0.000E+00
U -233	0.000E+00	0.000E+00	0.000E+00	2.034E+02	2.101E+01	0.000E+00	0.000E+00
U -234	0.000E+00	0.000E+00	0.000E+00	5.300E+01	8.482E+00	0.000E+00	0.000E+00
U -235	0.000E+00	0.000E+00	0.000E+00	1.820E+00	8.418E+02	0.000E+00	0.000E+00
U -236	0.000E+00	0.000E+00	0.000E+00	4.487E-02	6.937E-01	0.000E+00	0.000E+00
U -238	0.000E+00	0.000E+00	0.000E+00	5.230E+00	1.556E+04	0.000E+00	0.000E+00
NP-237	0.000E+00	0.000E+00	0.000E+00	6.154E+00	8.730E+00	0.000E+00	0.000E+00
PU-238	0.000E+00	0.000E+00	0.000E+00	2.726E+05	1.592E+01	0.000E+00	0.000E+00
PU-239	0.000E+00	0.000E+00	0.000E+00	8.302E+04	1.336E+03	0.000E+00	0.000E+00
PU-240	0.000E+00	0.000E+00	0.000E+00	2.245E+04	9.853E+01	0.000E+00	0.000E+00
PU-241	0.000E+00	0.000E+00	0.000E+00	2.560E+05	2.485E+00	0.000E+00	0.000E+00
PU-242	0.000E+00	0.000E+00	0.000E+00	1.222E+02	3.112E+01	0.000E+00	0.000E+00
PU-244	0.000E+00	0.000E+00	0.000E+00	1.566E-07	8.828E-06	0.000E+00	0.000E+00
AM-241	0.000E+00	0.000E+00	0.000E+00	4.676E+04	1.362E+01	0.000E+00	0.000E+00
CM-244	0.000E+00	0.000E+00	0.000E+00	3.321E+03	4.105E-02	0.000E+00	0.000E+00
CM-248	0.000E+00	0.000E+00	0.000E+00	9.364E-03	2.202E-03	0.000E+00	0.000E+00
CF-252	0.000E+00	0.000E+00	0.000E+00	2.508E+01	4.664E-05	0.000E+00	0.000E+00
PM-147	0.000E+00	0.000E+00	0.000E+00	1.939E+00	2.091E-06	0.000E+00	0.000E+00
SM-147	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
AM-243	0.000E+00	0.000E+00	0.000E+00	3.403E+00	1.705E-02	0.000E+00	0.000E+00
CM-243	0.000E+00	0.000E+00	0.000E+00	5.451E+00	1.078E-04	0.000E+00	0.000E+00
CM-245	0.000E+00	0.000E+00	0.000E+00	1.200E+01	7.018E-02	0.000E+00	0.000E+00

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 SMFLOW0 0.000E+00
1          TIME=   100. YEARS,  BRINE VOLUME=  2082. M**3
0  ELEMENT       SOLUBILITY  LOADING   DISOLVED   LARGE COL  SMALL COL
      TH         8.840E-08  4.125E+03  1.840E-01  0.000E+00  0.000E+00  0
      U          8.447E-06  6.914E+04  1.758E+01  0.000E+00  0.000E+00  0
      NP         2.864E-05  4.864E+01  4.864E+01  0.000E+00  0.000E+00  1
      PU         8.608E-08  6.129E+03  1.792E-01  0.000E+00  0.000E+00  0
      AM         3.418E-07  5.506E+01  7.116E-01  0.000E+00  0.000E+00  0
      CM         3.418E-07  2.947E-01  2.947E-01  0.000E+00  0.000E+00  1
0ISOTOPE     AMOUNT RELEASED (KG)        INVENTORY REMAINING     TOTAL RELEASED
          LARGE COL SMALL COL DISOLVED   CURIES      KG        CURIES      KG
 SR-90   0.000E+00 0.000E+00 0.000E+00  2.085E+03 1.528E-02  0.000E+00 0.000E+00
 CS-137  0.000E+00 0.000E+00 0.000E+00  2.321E+03 2.668E-02  0.000E+00 0.000E+00
 PB-210  0.000E+00 0.000E+00 0.000E+00  1.134E+00 1.486E-05  0.000E+00 0.000E+00
 RA-226  0.000E+00 0.000E+00 0.000E+00  1.161E+00 1.175E-03  0.000E+00 0.000E+00
 RA-228  0.000E+00 0.000E+00 0.000E+00  1.050E-01 3.849E-07  0.000E+00 0.000E+00
 TH-229  0.000E+00 0.000E+00 2.913E-16  2.221E+00 1.044E-02  6.196E-14 2.913E-16
 TH-230  0.000E+00 0.000E+00 1.017E-16  8.405E-02 4.164E-03  2.053E-15 1.017E-16
 TH-232  0.000E+00 0.000E+00 5.947E-11  1.050E-01 9.571E+02  6.523E-15 5.947E-11
 PA-231  0.000E+00 0.000E+00 0.000E+00  5.103E-02 1.080E-03  0.000E+00 0.000E+00
 U -233  0.000E+00 0.000E+00 7.446E-12  2.033E+02 2.100E+01  7.208E-11 7.446E-12
 U -234  0.000E+00 0.000E+00 4.239E-12  1.064E+02 1.703E+01  2.649E-11 4.239E-12
 U -235  0.000E+00 0.000E+00 2.989E-10  1.828E+00 8.456E+02  6.461E-13 2.989E-10
 U -236  0.000E+00 0.000E+00 3.759E-13  1.110E-01 1.716E+00  2.431E-14 3.759E-13
 U -238  0.000E+00 0.000E+00 5.515E-09  5.230E+00 1.556E+04  1.854E-12 5.515E-09
 NP-237  0.000E+00 0.000E+00 1.937E-08  7.758E+00 1.101E+01  1.366E-08 1.937E-08
 PU-238  0.000E+00 0.000E+00 5.003E-13  1.237E+05 7.227E+00  8.565E-09 5.003E-13
 PU-239  0.000E+00 0.000E+00 5.392E-11  8.278E+04 1.332E+03  3.351E-09 5.392E-11
 PU-240  0.000E+00 0.000E+00 3.967E-12  2.222E+04 9.753E+01  9.039E-10 3.967E-12
 PU-241  0.000E+00 0.000E+00 4.392E-14  2.090E+03 2.029E-02  4.525E-09 4.392E-14
 PU-242  0.000E+00 0.000E+00 1.257E-12  1.221E+02 3.111E+01  4.935E-12 1.257E-12
 PU-244  0.000E+00 0.000E+00 3.632E-19  1.646E-07 9.280E-06  6.443E-21 3.632E-19
 AM-241  0.000E+00 0.000E+00 2.386E-10  4.728E+04 1.378E+01  8.190E-07 2.386E-10
 CM-244  0.000E+00 0.000E+00 4.805E-11  7.229E+01 8.935E-04  3.887E-06 4.805E-11
 CM-248  0.000E+00 0.000E+00 5.263E-12  9.558E-03 2.248E-03  2.238E-11 5.263E-12
 CF-252  0.000E+00 0.000E+00 0.000E+00  9.730E-11 1.809E-16  0.000E+00 0.000E+00
 PM-147  0.000E+00 0.000E+00 0.000E+00  6.496E-12 7.008E-18  0.000E+00 0.000E+00
 SM-147  0.000E+00 0.000E+00 0.000E+00  4.798E-11 2.091E-06  0.000E+00 0.000E+00
 AM-243  0.000E+00 0.000E+00 2.858E-13  3.371E+00 1.689E-02  5.705E-11 2.858E-13
 CM-243  0.000E+00 0.000E+00 1.476E-13  5.035E-01 9.960E-06  7.460E-09 1.476E-13
 CM-245  0.000E+00 0.000E+00 1.653E-10  1.191E+01 6.961E-02  2.828E-08 1.653E-10
 SMFLOW0 2.900E-06


1          TIME=   200. YEARS,  BRINE VOLUME=  2875. M**3
0  ELEMENT       SOLUBILITY  LOADING   DISOLVED   LARGE COL  SMALL COL
      TH         8.840E-08  4.125E+03  2.542E-01  0.000E+00  0.000E+00  0
      U          8.447E-06  6.918E+04  2.429E+01  0.000E+00  0.000E+00  0
      NP         2.864E-05  5.680E+01  5.680E+01  0.000E+00  0.000E+00  1
      PU         8.608E-08  6.095E+03  2.475E-01  0.000E+00  0.000E+00  0
      AM         3.418E-07  4.695E+01  9.829E-01  0.000E+00  0.000E+00  0
      CM         3.418E-07  2.904E-01  2.904E-01  0.000E+00  0.000E+00  1
0ISOTOPE     AMOUNT RELEASED (KG)        INVENTORY REMAINING     TOTAL RELEASED
          LARGE COL SMALL COL DISOLVED   CURIES      KG        CURIES      KG
 SR-90   0.000E+00 0.000E+00 0.000E+00  1.929E+02 1.414E-03  0.000E+00 0.000E+00
 CS-137  0.000E+00 0.000E+00 0.000E+00  2.302E+02 2.647E-03  0.000E+00 0.000E+00
 PB-210  0.000E+00 0.000E+00 0.000E+00  1.130E+00 1.480E-05  0.000E+00 0.000E+00
 RA-226  0.000E+00 0.000E+00 0.000E+00  1.118E+00 1.131E-03  0.000E+00 0.000E+00
 RA-228  0.000E+00 0.000E+00 0.000E+00  1.050E-01 3.849E-07  0.000E+00 0.000E+00
 TH-229  0.000E+00 0.000E+00 4.904E-16  4.110E+00 1.932E-02  1.043E-13 4.904E-16
 TH-230  0.000E+00 0.000E+00 1.915E-16  1.920E-01 9.513E-03  3.866E-15 1.915E-16
 TH-232  0.000E+00 0.000E+00 7.258E-11  1.050E-01 9.571E+02  7.960E-15 7.258E-11
 PA-231  0.000E+00 0.000E+00 0.000E+00  5.480E-02 1.160E-03  0.000E+00 0.000E+00
 U -233  0.000E+00 0.000E+00 9.085E-12  2.032E+02 2.099E+01  8.794E-11 9.085E-12
 U -234  0.000E+00 0.000E+00 5.723E-12  1.306E+02 2.090E+01  3.576E-11 5.723E-12
 U -235  0.000E+00 0.000E+00 3.650E-10  1.836E+00 8.493E+02  7.890E-13 3.650E-10
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U -236	0.000E+00	0.000E+00	5.462E-13	1.764E-01	2.727E+00	3.533E-14	5.462E-13
U -238	0.000E+00	0.000E+00	6.729E-09	5.230E+00	1.556E+04	2.262E-12	6.729E-09
NP-237	0.000E+00	0.000E+00	2.278E-08	9.174E+00	1.302E+01	1.606E-08	2.278E-08
PU-238	0.000E+00	0.000E+00	5.472E-13	5.615E+04	3.280E+00	9.368E-09	5.472E-13
PU-239	0.000E+00	0.000E+00	6.588E-11	8.255E+04	1.328E+03	4.094E-09	6.588E-11
PU-240	0.000E+00	0.000E+00	4.839E-12	2.199E+04	9.650E+01	1.103E-09	4.839E-12
PU-241	0.000E+00	0.000E+00	4.399E-14	2.870E+01	2.786E-04	4.531E-09	4.399E-14
PU-242	0.000E+00	0.000E+00	1.537E-12	1.221E+02	3.110E+01	6.033E-12	1.537E-12
PU-244	0.000E+00	0.000E+00	4.485E-19	1.726E-07	9.732E-06	7.956E-21	4.485E-19
AM-241	0.000E+00	0.000E+00	2.912E-10	4.034E+04	1.175E+01	9.995E-07	2.912E-10
CM-244	0.000E+00	0.000E+00	4.815E-11	1.573E+00	1.945E-05	3.895E-06	4.815E-11
CM-248	0.000E+00	0.000E+00	5.906E-12	9.556E-03	2.247E-03	2.512E-11	5.906E-12
CF-252	0.000E+00	0.000E+00	0.000E+00	3.774E-22	7.018E-28	0.000E+00	0.000E+00
PM-147	0.000E+00	0.000E+00	0.000E+00	2.177E-23	2.348E-29	0.000E+00	0.000E+00
SM-147	0.000E+00	0.000E+00	0.000E+00	4.798E-11	2.091E-06	0.000E+00	0.000E+00
AM-243	0.000E+00	0.000E+00	3.548E-13	3.340E+00	1.673E-02	7.083E-11	3.548E-13
CM-243	0.000E+00	0.000E+00	1.489E-13	4.651E-02	9.200E-07	7.529E-09	1.489E-13
CM-245	0.000E+00	0.000E+00	1.851E-10	1.181E+01	6.905E-02	3.167E-08	1.851E-10
SMFLOW0	3.539E-06						

1 TIME= 300. YEARS, BRINE VOLUME= 3634. M**3

0 ELEMENT	SOLUBILITY	LOADING	DISOLVED	LARGE COL	SMALL COL	
TH	8.840E-08	4.125E+03	3.212E-01	0.000E+00	0.000E+00	0
U	8.447E-06	6.920E+04	3.069E+01	0.000E+00	0.000E+00	0
NP	2.864E-05	6.374E+01	6.374E+01	0.000E+00	0.000E+00	1
PU	8.608E-08	6.068E+03	3.128E-01	0.000E+00	0.000E+00	0
AM	3.418E-07	4.001E+01	1.242E+00	0.000E+00	0.000E+00	0
CM	3.418E-07	2.880E-01	2.880E-01	0.000E+00	0.000E+00	1

0ISOTOPE	AMOUNT RELEASED (KG)			INVENTORY REMAINING		TOTAL RELEASED	
	LARGE COL	SMALL COL	DISOLVED	CURIES	KG	CURIES	KG
SR-90	0.000E+00	0.000E+00	0.000E+00	1.785E+01	1.308E-04	0.000E+00	0.000E+00
CS-137	0.000E+00	0.000E+00	0.000E+00	2.284E+01	2.626E-04	0.000E+00	0.000E+00
PB-210	0.000E+00	0.000E+00	0.000E+00	1.093E+00	1.431E-05	0.000E+00	0.000E+00
RA-226	0.000E+00	0.000E+00	0.000E+00	1.081E+00	1.094E-03	0.000E+00	0.000E+00
RA-228	0.000E+00	0.000E+00	0.000E+00	1.050E-01	3.849E-07	0.000E+00	0.000E+00
TH-229	0.000E+00	0.000E+00	6.683E-16	5.981E+00	2.812E-02	1.421E-13	6.683E-16
TH-230	0.000E+00	0.000E+00	2.851E-16	3.150E-01	1.560E-02	5.756E-15	2.851E-16
TH-232	0.000E+00	0.000E+00	7.984E-11	1.050E-01	9.571E+02	8.756E-15	7.984E-11
PA-231	0.000E+00	0.000E+00	0.000E+00	5.857E-02	1.240E-03	0.000E+00	0.000E+00
U -233	0.000E+00	0.000E+00	9.991E-12	2.031E+02	2.098E+01	9.672E-11	9.991E-12
U -234	0.000E+00	0.000E+00	6.665E-12	1.416E+02	2.266E+01	4.165E-11	6.665E-12
U -235	0.000E+00	0.000E+00	4.018E-10	1.844E+00	8.531E+02	8.685E-13	4.018E-10
U -236	0.000E+00	0.000E+00	6.844E-13	2.411E-01	3.728E+00	4.427E-14	6.844E-13
U -238	0.000E+00	0.000E+00	7.401E-09	5.230E+00	1.556E+04	2.488E-12	7.401E-09
NP-237	0.000E+00	0.000E+00	2.439E-08	1.038E+01	1.473E+01	1.719E-08	2.439E-08
PU-238	0.000E+00	0.000E+00	5.590E-13	2.548E+04	1.489E+00	9.569E-09	5.590E-13
PU-239	0.000E+00	0.000E+00	7.252E-11	8.231E+04	1.324E+03	4.507E-09	7.252E-11
PU-240	0.000E+00	0.000E+00	5.319E-12	2.176E+04	9.548E+01	1.212E-09	5.319E-12
PU-241	0.000E+00	0.000E+00	4.399E-14	1.187E+01	1.153E-04	4.531E-09	4.399E-14
PU-242	0.000E+00	0.000E+00	1.692E-12	1.221E+02	3.110E+01	6.644E-12	1.692E-12
PU-244	0.000E+00	0.000E+00	4.983E-19	1.806E-07	1.018E-05	8.838E-21	4.983E-19
AM-241	0.000E+00	0.000E+00	3.203E-10	3.436E+04	1.001E+01	1.099E-06	3.203E-10
CM-244	0.000E+00	0.000E+00	4.815E-11	3.425E-02	4.233E-07	3.896E-06	4.815E-11
CM-248	0.000E+00	0.000E+00	6.169E-12	9.554E-03	2.247E-03	2.623E-11	6.169E-12
CF-252	0.000E+00	0.000E+00	0.000E+00	1.464E-33	0.000E+00	0.000E+00	0.000E+00
PM-147	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SM-147	0.000E+00	0.000E+00	0.000E+00	4.798E-11	2.091E-06	0.000E+00	0.000E+00
AM-243	0.000E+00	0.000E+00	3.993E-13	3.308E+00	1.657E-02	7.971E-11	3.993E-13
CM-243	0.000E+00	0.000E+00	1.490E-13	4.296E-03	8.498E-08	7.532E-09	1.490E-13
CM-245	0.000E+00	0.000E+00	1.932E-10	1.172E+01	6.849E-02	3.304E-08	1.932E-10
SMFLOW0	3.893E-06						

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1          TIME=   400. YEARS,  BRINE VOLUME=  4215. M**3
0  ELEMENT       SOLUBILITY  LOADING    DISOLVED   LARGE COL  SMALL COL
      TH         8.840E-08  4.126E+03  3.726E-01  0.000E+00  0.000E+00  0
      U          8.447E-06  6.923E+04  3.560E+01  0.000E+00  0.000E+00  0
      NP         2.864E-05  6.966E+01  6.966E+01  0.000E+00  0.000E+00  1
      PU         8.608E-08  6.045E+03  3.628E-01  0.000E+00  0.000E+00  0
      AM         3.418E-07  3.409E+01  1.441E+00  0.000E+00  0.000E+00  0
      CM         3.418E-07  2.858E-01  2.858E-01  0.000E+00  0.000E+00  1
0ISOTOPE     AMOUNT RELEASED (KG)          INVENTORY REMAINING      TOTAL RELEASED
          LARGE COL SMALL COL DISOLVED    CURIES       KG          CURIES       KG
 SR-90   0.000E+00 0.000E+00 0.000E+00  1.651E+00 1.210E-05  0.000E+00 0.000E+00
 CS-137  0.000E+00 0.000E+00 0.000E+00  2.266E+00 2.605E-05  0.000E+00 0.000E+00
 PB-210  0.000E+00 0.000E+00 0.000E+00  1.061E+00 1.389E-05  0.000E+00 0.000E+00
 RA-226  0.000E+00 0.000E+00 0.000E+00  1.052E+00 1.064E-03  0.000E+00 0.000E+00
 RA-228  0.000E+00 0.000E+00 0.000E+00  1.050E-01 3.849E-07  0.000E+00 0.000E+00
 TH-229  0.000E+00 0.000E+00 8.415E-16  7.833E+00 3.683E-02  1.790E-13 8.415E-16
 TH-230  0.000E+00 0.000E+00 3.852E-16  4.446E-01 2.203E-02  7.777E-15 3.852E-16
 TH-232  0.000E+00 0.000E+00 8.497E-11  1.050E-01 9.571E+02  9.320E-15 8.497E-11
 PA-231  0.000E+00 0.000E+00 0.000E+00  6.235E-02 1.320E-03  0.000E+00 0.000E+00
 U -233  0.000E+00 0.000E+00 1.063E-11  2.030E+02 2.097E+01  1.029E-10 1.063E-11
 U -234  0.000E+00 0.000E+00 7.371E-12  1.465E+02 2.345E+01  4.606E-11 7.371E-12
 U -235  0.000E+00 0.000E+00 4.280E-10  1.852E+00 8.568E+02  9.250E-13 4.280E-10
 U -236  0.000E+00 0.000E+00 8.128E-13  3.052E-01 4.719E+00  5.257E-14 8.128E-13
 U -238  0.000E+00 0.000E+00 7.877E-09  5.230E+00 1.556E+04  2.648E-12 7.877E-09
 NP-237  0.000E+00 0.000E+00 2.541E-08  1.141E+01 1.619E+01  1.791E-08 2.541E-08
 PU-238  0.000E+00 0.000E+00 5.627E-13  1.157E+04 6.756E-01  9.634E-09 5.627E-13
 PU-239  0.000E+00 0.000E+00 7.722E-11  8.207E+04 1.321E+03  4.799E-09 7.722E-11
 PU-240  0.000E+00 0.000E+00 5.657E-12  2.153E+04 9.448E+01  1.289E-09 5.657E-12
 PU-241  0.000E+00 0.000E+00 4.399E-14  1.164E+01 1.130E-04  4.531E-09 4.399E-14
 PU-242  0.000E+00 0.000E+00 1.803E-12  1.221E+02 3.109E+01  7.078E-12 1.803E-12
 PU-244  0.000E+00 0.000E+00 5.352E-19  1.887E-07 1.064E-05  9.494E-21 5.352E-19
 AM-241  0.000E+00 0.000E+00 3.409E-10  2.927E+04 8.528E+00  1.170E-06 3.409E-10
 CM-244  0.000E+00 0.000E+00 4.815E-11  7.454E-04 9.213E-09  3.896E-06 4.815E-11
 CM-248  0.000E+00 0.000E+00 6.317E-12  9.552E-03 2.246E-03  2.686E-11 6.317E-12
 CF-252  0.000E+00 0.000E+00 0.000E+00  0.000E+00 0.000E+00  0.000E+00 0.000E+00
 PM-147  0.000E+00 0.000E+00 0.000E+00  0.000E+00 0.000E+00  0.000E+00 0.000E+00
 SM-147  0.000E+00 0.000E+00 0.000E+00  4.798E-11 2.091E-06  0.000E+00 0.000E+00
 AM-243  0.000E+00 0.000E+00 4.360E-13  3.278E+00 1.642E-02  8.702E-11 4.360E-13
 CM-243  0.000E+00 0.000E+00 1.490E-13  3.969E-04 7.850E-09  7.532E-09 1.490E-13
 CM-245  0.000E+00 0.000E+00 1.977E-10  1.162E+01 6.793E-02  3.382E-08 1.977E-10
 SMFLOW0 4.143E-06

1          TIME=   500. YEARS,  BRINE VOLUME=  3927. M**3
0  ELEMENT       SOLUBILITY  LOADING    DISOLVED   LARGE COL  SMALL COL
      TH         8.840E-08  4.126E+03  3.472E-01  0.000E+00  0.000E+00  0
      U          8.447E-06  6.925E+04  3.317E+01  0.000E+00  0.000E+00  0
      NP         2.864E-05  7.470E+01  7.470E+01  0.000E+00  0.000E+00  1
      PU         8.608E-08  6.024E+03  3.381E-01  0.000E+00  0.000E+00  0
      AM         3.418E-07  2.905E+01  1.343E+00  0.000E+00  0.000E+00  0
      CM         3.418E-07  2.835E-01  2.835E-01  0.000E+00  0.000E+00  1
0ISOTOPE     AMOUNT RELEASED (KG)          INVENTORY REMAINING      TOTAL RELEASED
          LARGE COL SMALL COL DISOLVED    CURIES       KG          CURIES       KG
 SR-90   0.000E+00 0.000E+00 0.000E+00  1.528E-01 1.120E-06  0.000E+00 0.000E+00
 CS-137  0.000E+00 0.000E+00 0.000E+00  2.248E-01 2.585E-06  0.000E+00 0.000E+00
 PB-210  0.000E+00 0.000E+00 0.000E+00  1.036E+00 1.357E-05  0.000E+00 0.000E+00
 RA-226  0.000E+00 0.000E+00 0.000E+00  1.029E+00 1.040E-03  0.000E+00 0.000E+00
 RA-228  0.000E+00 0.000E+00 0.000E+00  1.050E-01 3.849E-07  0.000E+00 0.000E+00
 TH-229  0.000E+00 0.000E+00 2.139E-15  9.667E+00 4.545E-02  4.549E-13 2.139E-15
 TH-230  0.000E+00 0.000E+00 1.183E-15  5.772E-01 2.859E-02  2.388E-14 1.183E-15
 TH-232  0.000E+00 0.000E+00 1.151E-10  1.050E-01 9.571E+02  1.263E-14 1.151E-10
 PA-231  0.000E+00 0.000E+00 0.000E+00  6.614E-02 1.400E-03  0.000E+00 0.000E+00
 U -233  0.000E+00 0.000E+00 1.439E-11  2.029E+02 2.096E+01  1.393E-10 1.439E-11
 U -234  0.000E+00 0.000E+00 1.161E-11  1.488E+02 2.381E+01  7.256E-11 1.161E-11
 U -235  0.000E+00 0.000E+00 5.820E-10  1.860E+00 8.606E+02  1.258E-12 5.820E-10
 U -236  0.000E+00 0.000E+00 1.748E-12  3.686E-01 5.698E+00  1.131E-13 1.748E-12
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U -238	0.000E+00	0.000E+00	1.067E-08	5.230E+00	1.556E+04	3.586E-12	1.067E-08
NP-237	0.000E+00	0.000E+00	3.140E-08	1.228E+01	1.743E+01	2.213E-08	3.140E-08
PU-238	0.000E+00	0.000E+00	5.726E-13	5.249E+03	3.066E-01	9.803E-09	5.726E-13
PU-239	0.000E+00	0.000E+00	1.048E-10	8.184E+04	1.317E+03	6.516E-09	1.048E-10
PU-240	0.000E+00	0.000E+00	7.626E-12	2.130E+04	9.348E+01	1.738E-09	7.626E-12
PU-241	0.000E+00	0.000E+00	4.399E-14	1.155E+01	1.121E-04	4.532E-09	4.399E-14
PU-242	0.000E+00	0.000E+00	2.454E-12	1.220E+02	3.109E+01	9.635E-12	2.454E-12
PU-244	0.000E+00	0.000E+00	7.628E-19	1.967E-07	1.109E-05	1.353E-20	7.628E-19
AM-241	0.000E+00	0.000E+00	4.618E-10	2.494E+04	7.265E+00	1.585E-06	4.618E-10
CM-244	0.000E+00	0.000E+00	4.815E-11	1.622E-05	2.005E-10	3.896E-06	4.815E-11
CM-248	0.000E+00	0.000E+00	7.116E-12	9.550E-03	2.246E-03	3.026E-11	7.116E-12
CF-252	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
PM-147	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SM-147	0.000E+00	0.000E+00	0.000E+00	4.798E-11	2.091E-06	0.000E+00	0.000E+00
AM-243	0.000E+00	0.000E+00	6.870E-13	3.247E+00	1.627E-02	1.371E-10	6.870E-13
CM-243	0.000E+00	0.000E+00	1.490E-13	3.666E-05	7.251E-10	7.532E-09	1.490E-13
CM-245	0.000E+00	0.000E+00	2.218E-10	1.153E+01	6.738E-02	3.793E-08	2.218E-10
SMFLOW0	5.613E-06						

1 TIME= 1000. YEARS, BRINE VOLUME= 3241. M**3

0 ELEMENT	SOLUBILITY	LOADING	DISOLVED	LARGE COL	SMALL COL	
TH	8.840E-08	4.126E+03	2.865E-01	0.000E+00	0.000E+00	0
U	8.447E-06	6.935E+04	2.738E+01	0.000E+00	0.000E+00	0
NP	2.864E-05	9.067E+01	9.067E+01	0.000E+00	0.000E+00	1
PU	8.608E-08	5.924E+03	2.790E-01	0.000E+00	0.000E+00	0
AM	3.418E-07	1.307E+01	1.108E+00	0.000E+00	0.000E+00	0
CM	3.418E-07	2.726E-01	2.726E-01	0.000E+00	0.000E+00	1

0ISOTOPE	AMOUNT RELEASED (KG)			INVENTORY REMAINING		TOTAL RELEASED	
	LARGE COL	SMALL COL	DISOLVED	CURIES	KG	CURIES	KG
SR-90	0.000E+00	0.000E+00	0.000E+00	1.036E-06	7.593E-12	0.000E+00	0.000E+00
CS-137	0.000E+00	0.000E+00	0.000E+00	2.161E-06	2.485E-11	0.000E+00	0.000E+00
PB-210	0.000E+00	0.000E+00	0.000E+00	1.006E+00	1.317E-05	0.000E+00	0.000E+00
RA-226	0.000E+00	0.000E+00	0.000E+00	1.008E+00	1.020E-03	0.000E+00	0.000E+00
RA-228	0.000E+00	0.000E+00	0.000E+00	1.050E-01	3.849E-07	0.000E+00	0.000E+00
TH-229	0.000E+00	0.000E+00	1.091E-14	1.857E+01	8.731E-02	2.320E-12	1.091E-14
TH-230	0.000E+00	0.000E+00	7.075E-15	1.249E+00	6.186E-02	1.428E-13	7.075E-15
TH-232	0.000E+00	0.000E+00	2.489E-10	1.050E-01	9.571E+02	2.730E-14	2.489E-10
PA-231	0.000E+00	0.000E+00	0.000E+00	8.523E-02	1.804E-03	0.000E+00	0.000E+00
U -233	0.000E+00	0.000E+00	3.105E-11	2.025E+02	2.092E+01	3.006E-10	3.105E-11
U -234	0.000E+00	0.000E+00	3.071E-11	1.504E+02	2.407E+01	1.919E-10	3.071E-11
U -235	0.000E+00	0.000E+00	1.272E-09	1.900E+00	8.791E+02	2.750E-12	1.272E-09
U -236	0.000E+00	0.000E+00	7.839E-12	6.756E-01	1.044E+01	5.070E-13	7.839E-12
U -238	0.000E+00	0.000E+00	2.304E-08	5.230E+00	1.556E+04	7.745E-12	2.304E-08
NP-237	0.000E+00	0.000E+00	6.631E-08	1.506E+01	2.137E+01	4.674E-08	6.631E-08
PU-238	0.000E+00	0.000E+00	5.809E-13	1.011E+02	5.904E-03	9.945E-09	5.809E-13
PU-239	0.000E+00	0.000E+00	2.276E-10	8.067E+04	1.298E+03	1.414E-08	2.276E-10
PU-240	0.000E+00	0.000E+00	1.620E-11	2.020E+04	8.865E+01	3.693E-09	1.620E-11
PU-241	0.000E+00	0.000E+00	4.400E-14	1.109E+01	1.076E-04	4.533E-09	4.400E-14
PU-242	0.000E+00	0.000E+00	5.368E-12	1.219E+02	3.106E+01	2.107E-11	5.368E-12
PU-244	0.000E+00	0.000E+00	1.889E-18	2.367E-07	1.335E-05	3.351E-20	1.889E-18
AM-241	0.000E+00	0.000E+00	9.975E-10	1.119E+04	3.260E+00	3.423E-06	9.975E-10
CM-244	0.000E+00	0.000E+00	4.815E-11	7.925E-14	9.795E-19	3.896E-06	4.815E-11
CM-248	0.000E+00	0.000E+00	1.116E-11	9.540E-03	2.244E-03	4.746E-11	1.116E-11
CF-252	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
PM-147	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SM-147	0.000E+00	0.000E+00	0.000E+00	4.798E-11	2.091E-06	0.000E+00	0.000E+00
AM-243	0.000E+00	0.000E+00	2.340E-12	3.098E+00	1.552E-02	4.671E-10	2.340E-12
CM-243	0.000E+00	0.000E+00	1.490E-13	2.465E-10	4.876E-15	7.532E-09	1.490E-13
CM-245	0.000E+00	0.000E+00	3.411E-10	1.107E+01	6.470E-02	5.835E-08	3.411E-10
SMFLOW0	1.214E-05						

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1          TIME=  1500. YEARS,  BRINE VOLUME=  3882. M**3
0  ELEMENT       SOLUBILITY  LOADING   DISOLVED   LARGE COL  SMALL COL
      TH         8.840E-08  4.126E+03  3.432E-01  0.000E+00  0.000E+00  0
      U          8.447E-06  6.944E+04  3.279E+01  0.000E+00  0.000E+00  0
      NP         2.864E-05  9.784E+01  9.784E+01  0.000E+00  0.000E+00  1
      PU         8.608E-08  5.827E+03  3.342E-01  0.000E+00  0.000E+00  0
      AM         3.418E-07  5.901E+00  1.327E+00  0.000E+00  0.000E+00  0
      CM         3.418E-07  2.621E-01  2.621E-01  0.000E+00  0.000E+00  1
0ISOTOPE     AMOUNT RELEASED (KG)        INVENTORY REMAINING     TOTAL RELEASED
          LARGE COL SMALL COL DISOLVED   CURIES      KG        CURIES      KG
 SR-90   0.000E+00 0.000E+00 0.000E+00  7.022E-12 5.148E-17  0.000E+00 0.000E+00
 CS-137  0.000E+00 0.000E+00 0.000E+00  2.077E-11 2.388E-16  0.000E+00 0.000E+00
 PB-210  0.000E+00 0.000E+00 0.000E+00  1.112E+00 1.457E-05  0.000E+00 0.000E+00
 RA-226  0.000E+00 0.000E+00 0.000E+00  1.123E+00 1.136E-03  0.000E+00 0.000E+00
 RA-228  0.000E+00 0.000E+00 0.000E+00  1.050E-01 3.849E-07  0.000E+00 0.000E+00
 TH-229  0.000E+00 0.000E+00 1.091E-14  2.704E+01 1.272E-01  2.320E-12 1.091E-14
 TH-230  0.000E+00 0.000E+00 7.075E-15  1.918E+00 9.502E-02  1.428E-13 7.075E-15
 TH-232  0.000E+00 0.000E+00 2.489E-10  1.050E-01 9.571E+02  2.730E-14 2.489E-10
 PA-231  0.000E+00 0.000E+00 0.000E+00  1.045E-01 2.213E-03  0.000E+00 0.000E+00
 U -233  0.000E+00 0.000E+00 3.105E-11  2.021E+02 2.088E+01  3.006E-10 3.105E-11
 U -234  0.000E+00 0.000E+00 3.071E-11  1.502E+02 2.404E+01  1.919E-10 3.071E-11
 U -235  0.000E+00 0.000E+00 1.272E-09  1.940E+00 8.973E+02  2.750E-12 1.272E-09
 U -236  0.000E+00 0.000E+00 7.839E-12  9.667E-01 1.495E+01  5.070E-13 7.839E-12
 U -238  0.000E+00 0.000E+00 2.304E-08  5.230E+00 1.556E+04  7.745E-12 2.304E-08
 NP-237  0.000E+00 0.000E+00 6.631E-08  1.630E+01 2.313E+01  4.674E-08 6.631E-08
 PU-238  0.000E+00 0.000E+00 5.809E-13  1.946E+00 1.137E-04  9.945E-09 5.809E-13
 PU-239  0.000E+00 0.000E+00 2.276E-10  7.951E+04 1.279E+03  1.414E-08 2.276E-10
 PU-240  0.000E+00 0.000E+00 1.620E-11  1.916E+04 8.407E+01  3.693E-09 1.620E-11
 PU-241  0.000E+00 0.000E+00 4.400E-14  1.065E+01 1.033E-04  4.533E-09 4.400E-14
 PU-242  0.000E+00 0.000E+00 5.368E-12  1.218E+02 3.103E+01  2.107E-11 5.368E-12
 PU-244  0.000E+00 0.000E+00 1.889E-18  2.767E-07 1.560E-05  3.351E-20 1.889E-18
 AM-241  0.000E+00 0.000E+00 9.975E-10  5.024E+03 1.464E+00  3.423E-06 9.975E-10
 CM-244  0.000E+00 0.000E+00 4.815E-11  3.871E-22 4.785E-27  3.896E-06 4.815E-11
 CM-248  0.000E+00 0.000E+00 1.116E-11  9.530E-03 2.241E-03  4.746E-11 1.116E-11
 CF-252  0.000E+00 0.000E+00 0.000E+00  0.000E+00 0.000E+00  0.000E+00 0.000E+00
 PM-147  0.000E+00 0.000E+00 0.000E+00  0.000E+00 0.000E+00  0.000E+00 0.000E+00
 SM-147  0.000E+00 0.000E+00 0.000E+00  4.798E-11 2.091E-06  0.000E+00 0.000E+00
 AM-243  0.000E+00 0.000E+00 2.340E-12  2.955E+00 1.481E-02  4.671E-10 2.340E-12
 CM-243  0.000E+00 0.000E+00 1.490E-13  1.658E-15 3.279E-20  7.532E-09 1.490E-13
 CM-245  0.000E+00 0.000E+00 3.411E-10  1.063E+01 6.213E-02  5.835E-08 3.411E-10
 SMFLOW0 1.214E-05

1          TIME=  2000. YEARS,  BRINE VOLUME=  4458. M**3
0  ELEMENT       SOLUBILITY  LOADING   DISOLVED   LARGE COL  SMALL COL
      TH         8.840E-08  4.127E+03  3.941E-01  0.000E+00  0.000E+00  0
      U          8.447E-06  6.954E+04  3.766E+01  0.000E+00  0.000E+00  0
      NP         2.864E-05  1.010E+02  1.010E+02  0.000E+00  0.000E+00  1
      PU         8.608E-08  5.733E+03  3.838E-01  0.000E+00  0.000E+00  0
      AM         3.418E-07  2.684E+00  1.524E+00  0.000E+00  0.000E+00  0
      CM         3.418E-07  2.520E-01  2.520E-01  0.000E+00  0.000E+00  1
0ISOTOPE     AMOUNT RELEASED (KG)        INVENTORY REMAINING     TOTAL RELEASED
          LARGE COL SMALL COL DISOLVED   CURIES      KG        CURIES      KG
 SR-90   0.000E+00 0.000E+00 0.000E+00  4.761E-17 3.490E-22  0.000E+00 0.000E+00
 CS-137  0.000E+00 0.000E+00 0.000E+00  1.997E-16 2.296E-21  0.000E+00 0.000E+00
 PB-210  0.000E+00 0.000E+00 0.000E+00  1.328E+00 1.740E-05  0.000E+00 0.000E+00
 RA-226  0.000E+00 0.000E+00 0.000E+00  1.345E+00 1.360E-03  0.000E+00 0.000E+00
 RA-228  0.000E+00 0.000E+00 0.000E+00  1.050E-01 3.849E-07  0.000E+00 0.000E+00
 TH-229  0.000E+00 0.000E+00 1.091E-14  3.511E+01 1.651E-01  2.320E-12 1.091E-14
 TH-230  0.000E+00 0.000E+00 7.075E-15  2.584E+00 1.280E-01  1.428E-13 7.075E-15
 TH-232  0.000E+00 0.000E+00 2.489E-10  1.050E-01 9.571E+02  2.730E-14 2.489E-10
 PA-231  0.000E+00 0.000E+00 0.000E+00  1.241E-01 2.626E-03  0.000E+00 0.000E+00
 U -233  0.000E+00 0.000E+00 3.105E-11  2.017E+02 2.084E+01  3.006E-10 3.105E-11
 U -234  0.000E+00 0.000E+00 3.071E-11  1.500E+02 2.401E+01  1.919E-10 3.071E-11
 U -235  0.000E+00 0.000E+00 1.272E-09  1.978E+00 9.153E+02  2.750E-12 1.272E-09
 U -236  0.000E+00 0.000E+00 7.839E-12  1.243E+00 1.921E+01  5.070E-13 7.839E-12
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U -238	0.000E+00	0.000E+00	2.304E-08	5.230E+00	1.556E+04	7.745E-12	2.304E-08
NP-237	0.000E+00	0.000E+00	6.631E-08	1.686E+01	2.392E+01	4.674E-08	6.631E-08
PU-238	0.000E+00	0.000E+00	5.809E-13	3.747E-02	2.189E-06	9.945E-09	5.809E-13
PU-239	0.000E+00	0.000E+00	2.276E-10	7.838E+04	1.261E+03	1.414E-08	2.276E-10
PU-240	0.000E+00	0.000E+00	1.620E-11	1.817E+04	7.973E+01	3.693E-09	1.620E-11
PU-241	0.000E+00	0.000E+00	4.400E-14	1.022E+01	9.922E-05	4.533E-09	4.400E-14
PU-242	0.000E+00	0.000E+00	5.368E-12	1.217E+02	3.100E+01	2.107E-11	5.368E-12
PU-244	0.000E+00	0.000E+00	1.889E-18	3.167E-07	1.785E-05	3.351E-20	1.889E-18
AM-241	0.000E+00	0.000E+00	9.975E-10	2.259E+03	6.582E-01	3.423E-06	9.975E-10
CM-244	0.000E+00	0.000E+00	4.815E-11	1.891E-30	2.337E-35	3.896E-06	4.815E-11
CM-248	0.000E+00	0.000E+00	1.116E-11	9.521E-03	2.239E-03	4.746E-11	1.116E-11
CF-252	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
PM-147	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SM-147	0.000E+00	0.000E+00	0.000E+00	4.798E-11	2.091E-06	0.000E+00	0.000E+00
AM-243	0.000E+00	0.000E+00	2.340E-12	2.820E+00	1.413E-02	4.671E-10	2.340E-12
CM-243	0.000E+00	0.000E+00	1.490E-13	1.115E-20	2.205E-25	7.532E-09	1.490E-13
CM-245	0.000E+00	0.000E+00	3.411E-10	1.020E+01	5.965E-02	5.835E-08	3.411E-10
SMFLOW0	1.214E-05						

1 TIME= 5000. YEARS, BRINE VOLUME= 5332. M**3

0 ELEMENT	SOLUBILITY	LOADING	DISOLVED	LARGE COL	SMALL COL	
TH	8.840E-08	4.127E+03	4.713E-01	0.000E+00	0.000E+00	0
U	8.447E-06	6.999E+04	4.504E+01	0.000E+00	0.000E+00	0
NP	2.864E-05	1.801E+01	1.801E+01	0.000E+00	0.000E+00	1
PU	8.608E-08	5.204E+03	4.590E-01	0.000E+00	0.000E+00	0
AM	3.418E-07	1.280E-02	1.280E-02	0.000E+00	0.000E+00	1
CM	3.418E-07	3.455E-02	3.455E-02	0.000E+00	0.000E+00	1

0ISOTOPE	AMOUNT RELEASED (KG)			INVENTORY REMAINING		TOTAL RELEASED	
	LARGE COL	SMALL COL	DISOLVED	CURIES	KG	CURIES	KG
SR-90	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
CS-137	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
PB-210	0.000E+00	0.000E+00	0.000E+00	3.941E+00	5.163E-05	0.000E+00	0.000E+00
RA-226	0.000E+00	0.000E+00	0.000E+00	3.976E+00	4.022E-03	0.000E+00	0.000E+00
RA-228	0.000E+00	0.000E+00	0.000E+00	1.049E-01	3.849E-07	0.000E+00	0.000E+00
TH-229	0.000E+00	0.000E+00	6.021E-05	7.587E+01	3.567E-01	1.281E-02	6.021E-05
TH-230	0.000E+00	0.000E+00	5.248E-05	6.494E+00	3.217E-01	1.059E-03	5.248E-05
TH-232	0.000E+00	0.000E+00	1.860E-01	1.049E-01	9.569E+02	2.040E-05	1.860E-01
PA-231	0.000E+00	0.000E+00	0.000E+00	2.451E-01	5.187E-03	0.000E+00	0.000E+00
U -233	0.000E+00	0.000E+00	2.264E-02	1.990E+02	2.056E+01	2.191E-01	2.264E-02
U -234	0.000E+00	0.000E+00	2.616E-02	1.486E+02	2.379E+01	1.635E-01	2.616E-02
U -235	0.000E+00	0.000E+00	1.086E+00	2.198E+00	1.017E+03	2.348E-03	1.086E+00
U -236	0.000E+00	0.000E+00	3.877E-02	2.622E+00	4.054E+01	2.508E-03	3.877E-02
U -238	0.000E+00	0.000E+00	1.705E+01	5.224E+00	1.554E+04	5.733E-03	1.705E+01
NP-237	0.000E+00	0.000E+00	2.026E+01	3.009E+00	4.269E+00	1.428E+01	2.026E+01
PU-238	0.000E+00	0.000E+00	5.841E-13	1.909E-12	1.115E-16	1.000E-08	5.841E-13
PU-239	0.000E+00	0.000E+00	1.730E-01	7.188E+04	1.157E+03	1.075E+01	1.730E-01
PU-240	0.000E+00	0.000E+00	9.243E-03	1.322E+04	5.800E+01	2.106E+00	9.243E-03
PU-241	0.000E+00	0.000E+00	6.077E-09	1.479E+00	1.435E-05	6.260E-04	6.077E-09
PU-242	0.000E+00	0.000E+00	4.512E-03	1.210E+02	3.083E+01	1.771E-02	4.512E-03
PU-244	0.000E+00	0.000E+00	3.826E-09	4.877E-07	2.750E-05	6.786E-11	3.826E-09
AM-241	0.000E+00	0.000E+00	3.381E-02	4.444E+00	1.295E-03	1.161E+02	3.381E-02
CM-244	0.000E+00	0.000E+00	4.815E-11	0.000E+00	0.000E+00	3.896E-06	4.815E-11
CM-248	0.000E+00	0.000E+00	1.842E-03	1.645E-03	3.869E-04	7.834E-03	1.842E-03
CF-252	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
PM-147	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
SM-147	0.000E+00	0.000E+00	0.000E+00	4.798E-11	2.091E-06	0.000E+00	0.000E+00
AM-243	0.000E+00	0.000E+00	9.717E-03	3.682E-01	1.844E-03	1.940E+00	9.717E-03
CM-243	0.000E+00	0.000E+00	1.490E-13	0.000E+00	0.000E+00	7.532E-09	1.490E-13
CM-245	0.000E+00	0.000E+00	4.207E-02	1.385E+00	8.099E-03	7.196E+00	4.207E-02
SMFLOW0	9.074E+03						

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1          TIME= 10000. YEARS,  BRINE VOLUME=  5053. M**3
0  ELEMENT       SOLUBILITY  LOADING   DISOLVED   LARGE COL  SMALL COL
      TH         8.840E-08  4.127E+03  4.467E-01  0.000E+00  0.000E+00  0
      U          8.447E-06  7.049E+04  4.268E+01  0.000E+00  0.000E+00  0
      NP         2.864E-05  6.601E-02  6.601E-02  0.000E+00  0.000E+00  1
      PU         8.608E-08  4.453E+03  4.350E-01  0.000E+00  0.000E+00  0
      AM         3.418E-07  2.148E-05  2.148E-05  0.000E+00  0.000E+00  1
      CM         3.418E-07  8.532E-05  8.532E-05  0.000E+00  0.000E+00  1
0ISOTOPE     AMOUNT RELEASED (KG)          INVENTORY REMAINING      TOTAL RELEASED
          LARGE COL SMALL COL DISOLVED   CURIES       KG          CURIES       KG
 SR-90   0.000E+00 0.000E+00 0.000E+00  0.000E+00 0.000E+00  0.000E+00 0.000E+00
 CS-137  0.000E+00 0.000E+00 0.000E+00  0.000E+00 0.000E+00  0.000E+00 0.000E+00
 PB-210  0.000E+00 0.000E+00 0.000E+00  9.856E+00 1.291E-04  0.000E+00 0.000E+00
 RA-226  0.000E+00 0.000E+00 0.000E+00  9.895E+00 1.001E-02  0.000E+00 0.000E+00
 RA-228  0.000E+00 0.000E+00 0.000E+00  1.049E-01 3.846E-07  0.000E+00 0.000E+00
 TH-229  0.000E+00 0.000E+00 3.447E-04  1.212E+02 5.697E-01  7.332E-02 3.447E-04
 TH-230  0.000E+00 0.000E+00 3.391E-04  1.269E+01 6.286E-01  6.846E-03 3.391E-04
 TH-232  0.000E+00 0.000E+00 7.642E-01  1.049E-01 9.563E+02  8.381E-05 7.642E-01
 PA-231  0.000E+00 0.000E+00 0.000E+00  4.579E-01 9.694E-03  0.000E+00 0.000E+00
 U -233  0.000E+00 0.000E+00 9.155E-02  1.941E+02 2.005E+01  8.862E-01 9.155E-02
 U -234  0.000E+00 0.000E+00 1.062E-01  1.461E+02 2.339E+01  6.637E-01 1.062E-01
 U -235  0.000E+00 0.000E+00 4.791E+00  2.519E+00 1.166E+03  1.036E-02 4.791E+00
 U -236  0.000E+00 0.000E+00 2.187E-01  4.127E+00 6.381E+01  1.414E-02 2.187E-01
 U -238  0.000E+00 0.000E+00 6.970E+01  5.207E+00 1.549E+04  2.343E-02 6.970E+01
 NP-237  0.000E+00 0.000E+00 2.451E+01  1.103E-02 1.565E-02  1.728E+01 2.451E+01
 PU-238  0.000E+00 0.000E+00 5.841E-13  1.336E-29 7.806E-34  1.000E-08 5.841E-13
 PU-239  0.000E+00 0.000E+00 7.158E-01  6.221E+04 1.001E+03  4.448E+01 7.158E-01
 PU-240  0.000E+00 0.000E+00 3.188E-02  7.774E+03 3.412E+01  7.265E+00 3.188E-02
 PU-241  0.000E+00 0.000E+00 7.237E-09  3.554E-03 3.450E-08  7.455E-04 7.237E-09
 PU-242  0.000E+00 0.000E+00 1.998E-02  1.198E+02 3.053E+01  7.845E-02 1.998E-02
 PU-244  0.000E+00 0.000E+00 1.798E-08  5.000E-07 2.819E-05  3.190E-10 1.798E-08
 AM-241  0.000E+00 0.000E+00 3.457E-02  3.614E-03 1.053E-06  1.186E+02 3.457E-02
 CM-244  0.000E+00 0.000E+00 4.815E-11  0.000E+00 0.000E+00  3.896E-06 4.815E-11
 CM-248  0.000E+00 0.000E+00 2.227E-03  5.971E-06 1.404E-06  9.470E-03 2.227E-03
 CF-252  0.000E+00 0.000E+00 0.000E+00  0.000E+00 0.000E+00  0.000E+00 0.000E+00
 PM-147  0.000E+00 0.000E+00 0.000E+00  0.000E+00 0.000E+00  0.000E+00 0.000E+00
 SM-147  0.000E+00 0.000E+00 0.000E+00  4.798E-11 2.091E-06  0.000E+00 0.000E+00
 AM-243  0.000E+00 0.000E+00 1.141E-02  8.324E-04 4.170E-06  2.278E+00 1.141E-02
 CM-243  0.000E+00 0.000E+00 1.490E-13  0.000E+00 0.000E+00  7.532E-09 1.490E-13
 CM-245  0.000E+00 0.000E+00 4.959E-02  3.345E-03 1.955E-05  8.483E+00 4.959E-02
 SMFLOW0 3.729E+04
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END OF APPENDIX F

APPENDIX G: PANEL'S COLLOIDAL-SUSPENSION MODEL (NOT AVAILABLE FOR THE CCA PA)

This section describes, as a matter of record, a colloidal suspension model that is included within PANEL, but is hard-wired in the off position for CCA calculations. It is included for information and completeness, and is ***not*** part of PANEL's QAed software documentation.

PANEL's sorption model is based on the assumption that all isotopes present in the repository sorb rapidly onto colloidal particulates, and all rapidly reach the same maximum capacity C^l_{max} or C^s_{max} in moles/*l* of brine for large and small colloids, respectively. Clearly, this application of sorption mechanics is both primitive and inconsistent. Sorption is normally a time-dependent process. Moreover, different elements have different affinities for sorption onto colloids, and sorptive concentration of an element onto colloidal materials depends (i) on the concentration of that element in solution, (ii) the concentration of mobile colloids, and (iii) the reversible or irreversible exchange characteristics between dissolved and sorbed materials. These more advanced issues are being addressed. The inconsistency arises from the fact that repository wastes are permitted to sorb onto mobile colloids and thereby readily exit the repository in its brine outflows, however, they are not permitted to sorb onto immobile repository materials, where they would be help captive and thereby prevented from exiting the repository. That approach to sorption is clearly conservative, but it is also inconsistent.

F.1 LARGE COLLOIDS

At each timestep, PANEL combines, by element, the amounts (in moles) of all the isotopes of each element present in the repository. Then, to each $V(t_n)$ liters of brine in the repository, PANEL assigns exactly $V(t_n)\, C^l_{max,i}$ moles of each inventoried element to be sorbed onto large colloidal particles, assuming that amount is available in the repository. The parameters $C^l_{max,i}$ are assumed to be given for each of the i elements. If the required amount of the ith inventoried element is not available at that timestep, PANEL assigns whatever amount remains in the inventory, namely, $I_i(t_n)$. Thus, at the nth timestep, the amount (in moles) of ith element in the repository sorbed onto large colloids is

$$m^l_i(t_n) = \begin{cases} C^l_{max,i}\, V(t_n) \;, & \text{if } C^l_{max,i}\, V(t_n) \le I_i(t_n) \\ I_i(t_n) \;, & \text{if } C^l_{max,i}\, V(t_n) \ge I_i(t_n) \end{cases} ,$$

where $V(t_n)$ is the total volume of brine in the repository at the nth timestep. PANEL assumes the jth isotope of the ith element sorbs onto large colloids in the same proportion that the jth isotope occurs in the inventory itself. Thus, the resultant concentration of the jth isotope of the ith element due to sorption onto large colloids is

$$C^l_{i,j}(t_n) = [\, I_{i,j}(t_n) / I_i(t_n) \,]\, m^l_i(t_n) / V(t_n) ,$$

where $I_{i,j}(t_n)$ is the number of moles of the jth isotope of the ith element in the repository.

PANEL then corrects the inventory to account for sorption onto large colloids during that timestep. The corrected inventory is given by $I'(t_n)$, where

$$I'_i(t_n) = I_i(t_n) - m^l_i(t_n)$$

At present, numerical values of $C^l_{max,i}$ are not available in the controlled WIPP database. Consequently, its values are specified within PANEL and are presently set at 10^{-7} moles/l for all inventoried elements within the repository that are to be mobilized for removal.

F.2 SMALL COLLOIDS

At each timestep, PANEL combines the masses (in moles) of all the isotopes of every element present in the repository. Then, to each $V(t_n)$ liters of brine in the repository, PANEL assigns exactly $V(t_n)\, C^s_{max,i}$ moles of each radioactive element to be sorbed onto small colloidal particles, assuming that amount is available in the repository. If that amount is not available, PANEL assigns whatever amount remains in the inventory, namely, $I'_i(t_n)$. Thus, at the nth timestep, the amount (in moles) of ith element in the repository sorbed onto small colloids is

$$m^s_i(t_n) = \begin{cases} C^s_{max,i}\, V(t_n) & , \text{ if } C^s_{max,i}\, V(t_n) \le I'_i(t_n) \\ I'_i(t_n) & , \text{ if } C^s_{max,i}\, V(t_n) \ge I'_i(t_n) \end{cases} ,$$

where $V(t_n)$ is the volume of brine in the repository at the nth timestep, and I'_i is the inventory of the ith element adjusted for sorption onto large colloids. PANEL assumes the jth isotope of the ith element sorbs onto small colloids in the same proportion that it occurs in the inventory itself. Thus, the resultant concentration of the jth isotope of the ith element due to sorption onto small colloids is

$$C^s_{i,j}(t_n) = [\, I_{i,j}(t_n) / I_i(t_n) \,]\, m^s_i(t_n) / V(t_n) .$$

In the above equation, note that although the inventory $I_i(t_n)$ changes due to sorption onto large colloids, the ratio $I_{i,j}(t_n) / I_i(t_n)$ does not change.

PANEL then recorrects the inventory to account, in addition, for sorption onto small colloids. The recorrected inventory becomes $I''(t_n)$, where

$$I''_i(t_n) = I'_i(t_n) - m^s_i(t_n)$$

At present, numerical values of $C^s_{max,i}$ are not available in the controlled WIPP database. Consequently, its values are specified within PANEL and are presently set at 2×10^{-6} moles/*l* for all inventoried elements in the repository that are to be mobilized for removal.

Overviewing the behavior of colloidal sorption from $t = 0$, the colloidal load for a given isotope will quickly rise from its initial value to a maximum (saturation) and remain there until the stores of that isotope can no longer maintain maximum saturation. If that event occurs before 10,000 years, it will affect the PA release response for that isotope. Specifically, uncontaminated brine will continue to enter the repository, but, because excess inventory stores have been depleted, except for production of that element as a daughter, the incoming nuclide-free brine will mix as is with the near-maximally loaded contents of the wetted repository. As a result, the concentration of that element will slowly decrease in the repository.

In the actual sorption calculation as it is written in the code, a multiplicative factor of 1000 appears in the colloidal mobilization equation. It represents the number of liters in a cubic meter and accounts for the fact that brine volume (from BRAGFLO via NUTS) is reported in cubic meters, but is required in liters for PANEL's adsorption calculation.

PANEL calculates the mobilized mass of each isotope in moles. However, the next code in the sequence (SECOFL2D) prefers to receive the mobilized mass to date in kilograms. That conversion involves multiplication by a constant, namely $W_i/1000$, where W_i is the atomic weight of the ith isotope (in grams per mole) and 1000 is the number of grams in a kilogram. The conversion is performed by PANEL.

END OF APPENDIX G

APPENDIX H: PANEL'S OXIDATION-STATE SAMPLING SCHEME (NOT AVAILABLE FOR THE CCA PA)

PANEL includes a random sampling scheme that apportions each element into its possible oxidation states. The scheme is unavailable for CCA calculations and so is ***not*** to be regarded as part of PANEL's QAed software documentation. However, for information and completeness, the scheme is described in this appendix.

Chemical solubility depends on the oxidation state of the compound to be dissolved. Because the oxidation states of the radioisotopes in the repository inventory are not known, nor are they readily knowable, a sampling method was devised to estimate the breadth of possibilities. It subdivides the amount of a radioactive element present in the repository into its various possible valence states using four randomly-generated numbers whose values vary between zero and unity. They are called RAN1, RAN2, RAN3, and RAN4, and are related to the 6th, 3rd, 4th, and 5th valence states, respectively. Once the four random numbers have been generated for a given realization, the sampling method is as follows:

- The mass of valence-state-6 uranium is taken to be the entire inventory mass of uranium corrected for suspended uranium times 0.2×RAN1. The remainder is taken to be the mass of valence-state-4 uranium.

- The mass of valence-state-6 plutonium is taken to be the entire inventory mass corrected for suspended plutonium times 0.2×RAN1. The remaining plutonium is taken to be distributed over the three remaining valence states 3, 4, and 5 in the following proportions: RAN2/SUM1, RAN3/SUM1, and RAN4/SUM1, respectively, where SUM1 = RAN2 + RAN3 + RAN4.

- Thorium is assumed to exist entirely in valence state 4.

- The inventory mass of neptunium corrected for the amount sorbed onto colloidal particles is apportioned between valence states 4 and 5 in the proportions RAN3/SUM2 and RAN4/SUM2, respectively, where SUM2 is RAN3 + RAN4.

- The entire inventory mass of americium, corrected for sorption, is assumed to occur in valence state 3.

For example: Suppose the four randomly-generated numbers for the present realization are RAN1 = 0.5, RAN2 = 0.4, RAN3 = 0.6, and RAN4 = 0.2. Suppose further, the amount of plutonium available for dissolution at the nth timestep is $\Gamma''_n(Pu)$. Then the amounts of plutonium assigned to the four possible valence states are as follows:

Valence State	Amount
6	$[\Gamma''_n(Pu)][0.2][0.5] = 0.1\ \Gamma''_n(Pu)$
3	$[\Gamma''_n(Pu)][1-0.1][0.4/(0.4 + 0.6 + 0.2)] = 0.30\ \Gamma''_n(Pu)$

4 $[\Gamma'_n(Pu)][1-0.1][0.6/(0.4 + 0.6 + 0.2)] = 0.45\ \Gamma'_n((Pu)$

5 $[\Gamma'_n(Pu)][1-0.1][0.2/(0.4 + 0.6 + 0.2)] = 0.15\ \Gamma'_n(Pu)$

Thus, the entire available mass of plutonium is apportioned 10% to valence state 6, 30% to valence state 3, 45% to valence state 4, and 15% to valence state 5. In the same realization (i.e., using the same numerical values for the four random numbers), the entire available mass of neptunium would be apportioned 75% in valence state 4 and 25% in valence state 5, that is, 0.6/(0.6+0.2) and 0.2/(0.6+0.2). The random numbers would, of course, change for each realization.

Each valence state has a different solubility. Using these different solubilities and the amounts of each element apportioned into the various possible valence states, the dissolved concentration of each valence state of each element is calculated using the formulation given above. The fractional concentrations (in moles/*l*) for all the possible valence states of an element are then added. The sum, multiplied by the volume of repository brine removed during that timestep, represents the mass transport (in moles) of that element due to dissolution during that timestep. As was the case for transport due to sorption, the final results are apportioned to the various isotopes of each element present in the repository according to the present fractional distribution of isotopes in the repository. These amounts are added timestep for timestep to form a running total release. Finally, the final results are converted to kilograms (i.e., multiplied by molecular weight [in grams per mole] divided by 1000) in preparation for input to the next code in the PA sequence.

It remains (i) to discuss PANEL's decay model, (ii) to review, in summary form, the calculation by which radioisotopes are removed from the repository, and (iii) to discuss adjustments of the inventory to account for removal from the repository. Those topics are discussed sequentially in the sections that follow. However, we state here that once all of those things have taken place, that is, once a timestep's worth of radionuclides have been removed from the repository and the inventory has been decayed, PANEL allows the fractional distribution of elements to the various valence states to readjust themselves to their initial (i.e., prior to dissolution) ratios as determined by the random sampling scheme. That readjustment takes place before the n+1st timestep's calculation is begun . Thus, if, say, the 6th valence state suffers a large removal in one timestep, compared to other valence states, PANEL will assume chemical reactions take place that resupply valence state 6 at the expense of the other valence states, until the overall ratio of valence states is returned to its original distribution in time for the next 50-year timestep.

END OF APPENDIX H

APPENDIX I: QA REVIEW FORMS

As a convenience to users, this section contains a complete history of all the Quality-Assurance Review Forms issued during the review of this User's Manual. Review forms are issued after the User's Manual has been completed and reviewed. Thus, they will be appended to the manual after it has been paginated and therefore they may not, themselves, be paginated.

END OF APPENDIX I

END OF THE USER'S MANUAL

NOTE: Copies of the User's Manual Reviewer's Forms are available in the Sandia WIPP Central Files.

M

APPENDIX A
DERIVATION OF RELATIONSHIPS FOR THE AIR-FLOW MODELS

APPENDIX A
DERIVATION OF RELATIONSHIPS FOR THE AIR-FLOW MODELS

A1.0 Introduction

This appendix shows the unrestricted and restricted air-flow models used to determine the performance of the panel closure system alternatives. These analyses are order-of-magnitude estimates of the volume of gas that might flow through the panel seal systems at the Waste Isolation Pilot Plant (WIPP).

A2.0 Model for Unrestricted Flow of VOCs

A model for the unrestricted flow of volatile organic compounds (VOC) was developed to predict the mass flow rates of VOCs and to compare this mass flow rate to the design migration limit for VOCs. As gas generation and panel volumetric creep closure proceed, a mixture of gases containing the VOC concentrations flows from each waste container. It is assumed for the unrestricted flow model that the headspace concentrations serve as a constant source of VOCs. This assumption is highly conservative, because most containers only have trace quantities of VOCs either trapped in the headspace or adsorbed on the surfaces of the various waste forms. It is believed that only a small number of waste containers have significantly greater sources of VOCs, such as a solvent-soaked rag or a can containing residual partially dried paint. Only these waste containers have a likelihood of maintaining a constant headspace VOC concentration as gas generation proceeds. However, the exact proportion of waste containers with higher VOC concentrations versus those with trace quantities is currently unknown. These data are based on results of the characterization of approximately 500 transuranic (TRU) mixed waste drums at the Idaho National Engineering Laboratory (INEL) and Rocky Flats.

The VOCs migrate due to advection from volumetric closure of the panel void space at a rate of about 28,250 ft^3 (800 m^3) per year. Gas generation for the waste inventory at a rate of 0.1 mole per drum per year (8,200 moles per panel per year) results in a volumetric flow rate of 7,060 ft^3 (200 m^3) per year. Because flow is unrestricted, the VOCs migrate under a pressure of one atmosphere. Other assumptions in the unrestricted model are as follows:

- Any gases released into the mine atmosphere would be reduced in concentration by 460,000[1] cfm of uncontaminated air. The mass flow rate of individual VOCs from individual panels following their closure is summed to determine the mass flow rate of VOCs through the exhaust shaft.

- This calculation considers the schedule for closure of individual panels as illustrated in Figure A-1 during the operational life of the WIPP. The VOC mass flow rate changes with time, with the maximum mass flow release occurring after 10 panel equivalents have been closed, about 25 years.

- Each VOC is analyzed in the calculations. Carbon tetrachloride is the most restrictive VOC in terms of satisfying the health-based levels for individual VOCs.

- Open panels of waste will not be considered as a source contributing to the emissions for a no-migration demonstration.

Considering only advection to result in the migration of VOCs, the mass-balance relationship is:

$$C_p * Q_p = C_{es} * Q_{es}$$

where

C_p = Head space concentration for an individual VOC
Q_p = Flow rate of VOCs from the panel that may vary with time
C_{es} = Concentration of VOCs at the exhaust shaft.
Q_{es} = Underground ventilation flow rate for the exhaust shaft

Air dispersion modeling is used for evaluating the receptor concentrations at the WIPP site boundary based upon the exhaust shaft source term. The air dispersion modeling considers such factors as meteorological data, release velocity, release temperature, and proximity of the WIPP site boundary to the exhaust shaft. The results of the modeling are expressed as a ratio R of the concentration at the exhaust shaft to the concentration at at the WIPP site boundary:

$$C_{es} \leq RC_{hbl}$$

This inequality can be expressed in terms of mass flow rate:

[1]The design ventilation rate for the WIPP underground is 425,000 standard cfm (12,000 standard m^3 per minute) under standard temperature and pressure conditions of 25 degrees Celsius and 1 atmosphere. The ventilation flow rate of 460,000 cfm (13,025 m^3 per minute) is the observed ventilation rate at the repository horizon under actual temperature and pressure conditions.

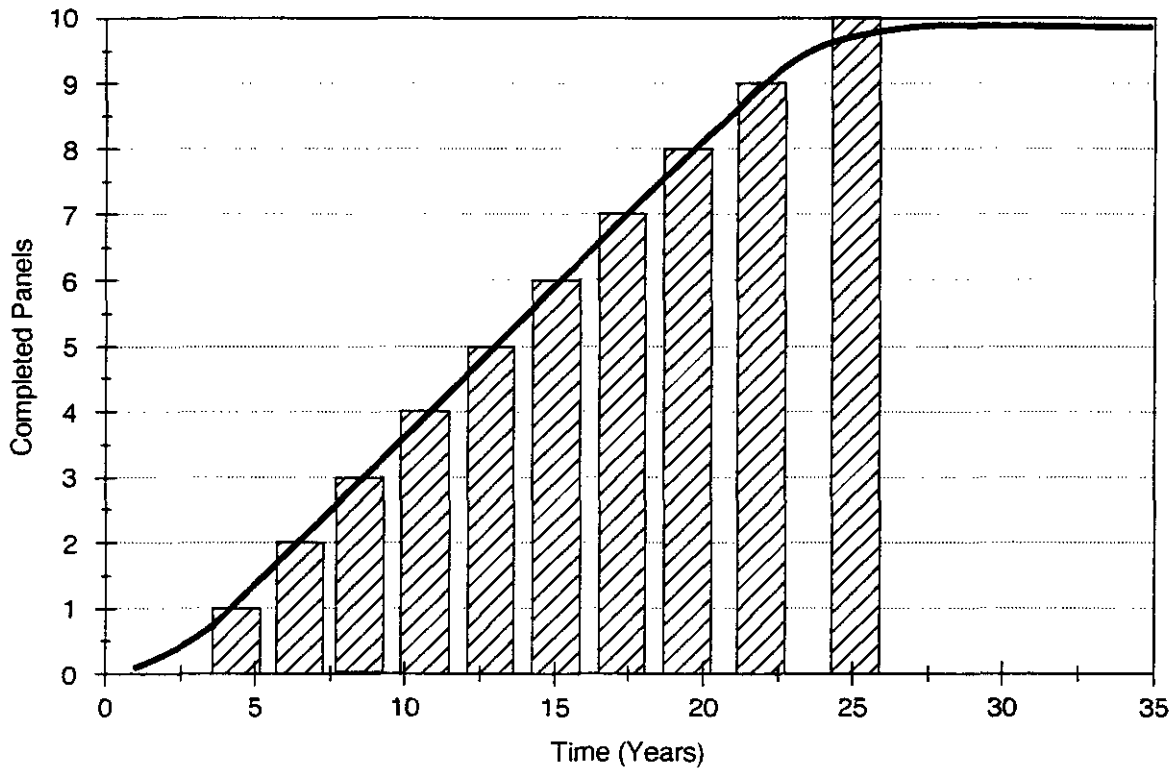

Figure A-1
Schedule for Panel Completion

$$\frac{C_p * Q_p}{Q_{es}} * \frac{1}{R} \leq C_{hbl}$$

where

R = Ratio of the concentrations at the exhaust shaft to the concentrations at the WIPP site boundary

C_{hbl} = Concentration to satisfy the health-based level for the individual VOC.

The ratio of the concentrations at the WIPP site boundary, R equals 10,753, reflecting the substantial atmospheric dispersion in reducing the concentration of VOCs.

The flow rates of VOCs from the panels are calculated for two mechanisms, gas generation and volumetric closure, using the following:

$$Q_p = Q_{gr} + Q_c$$

where

Q_{gr} = Volumetric flow rate due to gas generation[2] (200 m^3 per year per panel)

Q_c = Volumetric flow rate due to panel volumetric closure (800 m^3 per year per panel).

Table A-1 presents the closed panel release limits (migration limits) for VOCs based upon the health-based concentrations of individual VOCs. This inequality can be rewritten as:

$$C_p \cdot Q_p \leq C_{hbl} \cdot Q_{es} \cdot R$$

Table A-2 presents for a single closed panel and ten equivalent closed panels, the release rate for individual VOCs at the end of the 35-year operating period.

For the WIPP site boundary, the VOC concentrations are reduced substantially in the atmosphere. The above analysis shows that the concentration at the WIPP site boundary would be approximately 4 orders of magnitude lower than the concentration at the exhaust shaft. The predicted VOC mass flow rates due to unrestricted flow suffice to comply with the

[2]The volumetric flow due to gas generation is calculated as the gas generation rate (0.1 moles per drum per year) times the number of drums within a panel times the specific volume under atmospheric pressure.

Table A-1
Closed Panel Release Limits for VOCs

Compound	WIPP Site Boundary Health-Based Exposure Level[a] (micrograms per cubic meter)	Exhaust Shaft Concentration Migration Limit (micrograms per cubic meter)	Closed Ten Panel Migration Limit (grams per minute)
Carbon disulfide	10.00	107,530	1,400
Carbon tetrachloride	0.13	1,398	18
Chlorobenzene	20.00	215,060	2,801
Chloroform	0.09	968	13
1,1-dichloroethylene	0.40	4,301	56
Methyl ethyl ketone	1000.00	10,753,000	140,045
Methylene chloride	4.26	45,808	597
1,1,2,2-tetrachoroethane	0.35	3,764	49
Toluene	400.00	4,301,200	56,018

Table A-2
Closed Panel Release Rates for VOCs

Compound	Average Headspace Concentration (milligrams per cubic meter)[a]	Single-Panel Volumetric-Release Rate (cubic meters per minute)	Ten-Panel Volumetric-Release Rate (cubic meters per minute)	Single-Panel Mass-Release Rate (grams per minute)	Ten-Panel Mass-Release Rate (grams per minute)
Carbon disulfide	0.41	0.0019	0.019	7.80×10^{-7}	7.80×10^{-6}
Carbon tetrachloride	3625.77	0.0019	0.019	6.90×10^{-3}	6.90×10^{-2}
Chlorobenzene	63.99	0.0019	0.019	1.22×10^{-4}	1.22×10^{-3}
Chloroform	76.79	0.0019	0.019	1.46×10^{-4}	1.46×10^{-3}
1,1-dichloroethylene	48.68	0.0019	0.019	9.26×10^{-5}	9.26×10^{-4}
Methyl ethyl ketone	241.73	0.0019	0.019	4.60×10^{-4}	4.60×10^{-3}
Methylene chloride	3387.03	0.0019	0.019	6.45×10^{-3}	6.45×10^{-2}
1,1,2,2-tetrachloroethane	69.65	0.0019	0.019	1.33×10^{-4}	1.33×10^{-3}
Toluene	105.51	0.0019	0.019	2.01×10^{-4}	2.01×10^{-3}

[a]Westinghouse Electric Corporation, 1995, "Underground Hazardous Waste Management Unit Closure Criteria for the Waste Isolation Pilot Plant Operational Phase," *WID/WIPP-2038*, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

closed ten-panel migration limit based upon the health-based levels at the WIPP site boundary over the operational life of the repository.

A3.0 Air Model

The modeling assumptions for the restricted air-flow model are as follows:

- The gases are generated at a specified rate (0.10 moles per drum per year).
- The gases flow out of the panel entries according to Darcy's law under quasi-steady state conditions.
- The gases within the pore space obey the ideal gas law
- The rates of gas generation, gas outflow, and change in compressive storage must balance.
- Hydrodynamic dispersion is neglected in the analysis.

After panel closure, the volume, moles of gas, and pressure are changing as functions of time. The ideal gas law (Hiller and Herber, 1960) is written as:

$$p = \frac{n * R * T}{V}$$

where

p = Pressure
n = Moles of gas in the panel
R = Universal gas constant
T = Absolute temperature
V = Volume

Differentiating with respect to t and using the chain rule, we obtain the following relationship:

$$\frac{dp}{dt} = R * T * \frac{\frac{dn}{dt} * V - n * \frac{dV}{dt}}{V^2}$$

The volumetric closure rate is negative and constant as discussed below. The rate at which gas enters the panel minus the rate that gas leaves the panel must equal the change in moles stored. We obtain the mass-balance relationship:

$$\frac{dn}{dt} = g_r - \frac{p}{R*T} * K_s * \frac{A}{L} * \frac{p - p_{atm}}{\gamma}$$

where

g_r	=	Panel gas generation rate
p_{atm}	=	Atmospheric pressure
γ	=	Air density
K_s	=	Effective panel closure system conductivity
A	=	Cross-sectional area
L	=	Length of flow path

We define the conductance (C) as:

$$C = K_s * \frac{A}{L}$$

and substituting into the ordinary differential equations (ODE), we obtain

$$\frac{dp}{dt} = R*T*\frac{g_r - \frac{p}{R*T} * C * \frac{p - p_{atm}}{\gamma} * V - n * \frac{dV}{dt}}{V^2}$$

$$\frac{dn}{dt} = g_r - \frac{p}{R*T} * C * \frac{p - p_{atm}}{\gamma}$$

These two first-order coupled ODEs can be solved by a simple explicit finite difference technique:

$$p_j = p_{j-1} + R * T * \frac{g_r - \frac{p_{j-1}}{R*T} * C * \frac{p_{j-1} - p_{atm}}{\gamma} * V - n_{j-1} * \frac{dV}{dt}}{V^2} * \Delta t$$

$$n_j = n_{j-1} + g_r - \frac{p_{j-1}}{R*T} * C*\frac{p_{j-1} - p_{atm}}{\gamma}\Delta t$$

where

p_j, n_j	= the pressure and moles of gas at the current time step
P_{j-1}, n_{j-1}	= the pressure and moles of gas at the previous time step

subject to the boundary condition that the initial pressure equals atmospheric pressure, and the initial moles of gas can be determined by the ideal gas law at initial volume and pressure. Further note that the volume can be expressed as the linear function:

$$V(t) = \alpha * t + \beta$$

where

α	= slope of the volume-time relationship
β	= intercept of volume-time relationship
t	= time

These expressions can be substituted into the above explicit finite difference relationships, and the pressure and molar air flow rates determined as functions of time.

$$\frac{dV}{dt} = \alpha$$

APPENDIX B

CALCULATIONS IN SUPPORT OF PANEL GAS PRESSURIZATION DUE TO CREEP CLOSURE

APPENDIX B
CALCULATIONS IN SUPPORT OF PANEL GAS PRESSURIZATION DUE TO CREEP CLOSURE

B.1.0 Introduction

This appendix presents the closure mechanisms and supporting calculations for panel volumetric closure for the analysis of gas pressurization within a closed panel at the Waste Isolation Pilot Plant (WIPP). The volume reduction is due to the panel volume change from viscoplastic creep closure of the walls, roof, and floor. As the walls, roof, and floor of the excavations converge, the total volume of the panel decreases. The volumetric closure of a panel is the result of several different mechanisms working in tandem. These mechanisms include:

- Viscoplastic creep of the salt toward the excavation
- Fracturing in the roof and floor caused by the deviatoric stresses around the excavation
- Bed separation at the clay seams in the roof and the floor.

The combination of these three mechanisms causes the observed convergence rates in Panel 1. Of these mechanisms, only creep of the salt reduces the total volume of the panel and pore space in the surrounding disturbed rock zone (DRZ). Fracturing in the roof and floor and bed separation transfer the void volume within the excavation to the DRZ. This void volume within the DRZ is assumed to be interconnected with the open excavation. Therefore the total reduction in volume within the panel, based simply on room closure, overestimates the effective reduction in void volume. However, quantifying the amount of interconnected void space within the DRZ would require a much more detailed analysis. The total volume change calculated from the room closure measurements is therefore considered conservative.

Other assumptions made in this calculation are:

- The volumetric closure rates are constant after panel closure.
- The waste in the panel provides no significant resistance to creep closure during the initial 35 years.

- The air volume is the total volume of the excavations minus the solid volume of the waste in drums or other waste packages. This is estimated to equal 138,000 ft^3 (3,908 m^3).

- The closure rate of each room in the panel equals the closure rate at the midpoint of the room.

- The length of each room or drift is constant; to simplify the calculations, only the width and height change with creep closure.

- The panel is comprised of seven rooms and two panel access drifts.

B.2.0 Panel Volume Change Calculation

The panel volume change calculation is performed by first calculating the initial panel volume, then calculating the room and drift closure rates, and finally calculating the panel volumetric closure rate. Following is a detailed description of each part of the calculation.

B.2.1 Initial Panel Volume

The initial panel volume is determined immediately after completion of excavation. The total volume is calculated by summing the individual room and drift volumes within the panel. These volumes are based on the as-built dimensions of the excavated rooms and drifts in Panel 1 (DOE, 1993). Table B-1 presents the room and drift dimensions and the calculated volume of each room and drift. The volume of the air-intake and air-exhaust drifts is not included. The total initial volume of Panel 1 is 1,669,434 ft^3 (47,273 m^3).

The total solid volume of the waste in a filled panel is 138,000 ft^3 (3,908 m^3) (DOE, 1994; Butcher, et al., 1991). Subtracting the waste volume from the total panel volume gives the total initial air volume (1,531,434 ft^3 [43,365 m^3]) in the panel.

B.2.2 Closure Rates

Using convergence data from Panel 1 the average closure rates of the rooms and drifts are determined (DOE, 1993). Closure rates within the rooms and drifts are higher in the first five years after excavation. The roof-to-floor and wall-to-wall closure rates for each of the rooms and drifts are presented in Table B-2.

Because all of the excavations in Panel 1 are approximately 13 x 33 ft (4 x 10 m), the closure rates for each room or drift are the same.

Table B-1
Initial Room and Drift Dimensions and Volume of Panel 1

Room or Drift	Initial Width (ft)	Initial Height (ft)	Initial Length (ft)	Initial Volume (ft^3)
Room 1	33	13	300	128,700
Room 2	33	13	300	128,700
Room 3	33	13	300	128,700
Room 4	33	13	300	128,700
Room 5	33	13	300	128,700
Room 6	33	13	300	128,700
Room 7	33	14	300	138,600
South 1950 panel access drift	33	14	848	391,776
South 1600 from Room 1 to Room 5	33	13	573	245,817
South 1600 from Room 5 to Room 7	33	14	262	121,044
Total Initial Panel Volume				1,669,437

B.2.3 Volumetric Panel Closure Rate

Using the closure rates from Table B-2, the dimensions of the rooms and drifts in Panel 1 can be calculated at the end of each progressive year or for subsequent years using the following equations.

For 0 to 5 years after excavation:

$$V_t = (w_i - R_H t) \times (h_i - R_{VO} t) \times l_i$$

Table B-2
Room and Drift Closure Rates
(DOE, 1993)

Room or Drift	Vertical Closure Rate		Horizontal Closure Rate	
	0 to 5 Years (ft/yr)	> 5 Years (ft/yr)	0 to 5 Years (ft/yr)	> 5 Years (ft/yr)
Room 1	0.3194	0.2109	0.2234	0.1160
Room 2	0.3194	0.2109	0.2234	0.1160
Room 3	0.3194	0.2109	0.2234	0.1160
Room 4	0.3194	0.2109	0.2234	0.1160
Room 5	0.3194	0.2109	0.2234	0.1160
Room 6	0.3194	0.2109	0.2234	0.1160
Room 7	0.3194	0.2109	0.2234	0.1160
South 1950 panel access drift	0.3194	0.2109	0.2234	0.1160
South 1600 from Room 1 to Room 5	0.3194	0.2109	0.2234	0.1160
South 1600 from Room 5 to Room 7	0.3194	0.2109	0.2234	0.1160

For greater than 5 years after excavation:

$$V_t = (w_i - R_H t) \times (h_i - R_{V5}(t-5) - R_{V0}5) \times l_i$$

where

V_t = Volume of the room at time t
t = Time (in years)
w_i = Initial room width
h_i = Initial room height
l_i = Initial room length
R_H = Horizontal closure rate (ft/year)
R_{V0} = Vertical closure rate for first 5 years (ft/year)
R_{V5} = Vertical closure rate after 5 years (ft/year).

We obtain the incremental change in volume:

$$\Delta V = V_1 - V_2$$

where

V_1 = Volume of room at time t_1 (ft^3)
V_2 = Volume of room at time t_2 (ft^3)
ΔV = Change in volume of room between time t_1 and t_2 (ft^3)
t_1, t_2 = Years after excavation

The volume of all the rooms within the panel is calculated at the time of four years after excavation, when the waste is assumed to have been emplaced the amount of time required for waste emplacement (Table B-3). The total volume of the panel after four years is 1,469,112 ft^3 (41,601 m^3). The volume of the panel is then calculated at five years after excavation or one year after panel closure (Table B-3). This volume is 1,420,312 ft^3 (40,219 m^3), and the volume reduction in that year is 48,800 ft^3 (1,382 m^3).

The initial volume in a closed panel after approximately four years is obtained from the total volume at four years (1,469,112 ft^3 [41,601 m^3]) minus the solids volume (138,000 ft^3 [3,908 m^3]), or 1,331,112 ft^3 (37,693 m^3). This volume is used as the initial volume for the restricted air-flow model calculations.

The rate of change for panel volume is assumed to be constant for the first five years after excavation, because the vertical and horizontal closure rates are constant during this period. (Actually, rate of volume change over time decreases slightly with each year due to "corner effects," but this error is less than 2 percent and is considered insignificant.) Table B-3 also shows the panel volumes at 15 and 16 years after excavation and the change in volume between those years. The volumetric panel closure rate is 28,673 ft^3 per year (812 m^3 per year). This is the rate in volume change per year in the panel from five to approximately 35 years after excavation.

At approximately 16 years after excavation, the roof comes in contact with the waste stack. Only 35 years after excavation does the waste stack begin to provide significant resistance to creep (approximately 2 MPa). This resistance is expected to slow the vertical convergence rate by some amount.

Table B-3
Panel Volume at Various Times

Room or Drift	Volume of Room (ft^3)			
	At 4 Years	At 5 Years	At 15 Years	At 16 Years
Room 1	112,914	109,069	85,662	83,401
Room 2	112,914	109,069	85,662	83,401
Room 3	112,914	109,069	85,662	83,401
Room 4	112,914	109,069	85,662	83,401
Room 5	112,914	109,069	85,662	83,401
Room 6	112,914	109,069	85,662	83,401
Room 7	122,545	118,633	94,879	92,583
South 1950 panel access drift	346,395	335,337	268,191	261,702
South 1600 from Room 1 to Room 5	215,665	208,321	163,614	159,296
South 1600 from Room 5 to Room 7	107,023	103,607	82,861	80,856
Total Volume of Panel 1	1,469,112	1,420,312	1,123,529	1,094,856
Change in Volume		48,800		28,673

B.3.0 References

Butcher, B. M., T. W. Thompson, R. G. VanBuskirk, N. C. Patti, 1991, "Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste," *SAND90-1206*, Sandia National Laboratories, New Mexico.

U.S. Department of Energy (DOE), 1993, "Geotechnical Analysis Report, July 1991 through June 1992," *DOE-WIPP 93-019*, U.S. Department of Energy, Washington D.C.

U.S. Department of Energy (DOE), 1994, "Panel One Utilization Plan," *WIPP/WID-94-2027*, Westinghouse Electric Corporation, Carlsbad, New Mexico.

APPENDIX C
FLAC MODELING OF THE PANEL CLOSURE SYSTEM

APPENDIX C
FLAC MODELING OF THE PANEL CLOSURE SYSTEM

Numerical modeling is considered one of the better methods available for quantifying the interaction of concrete barriers with the surrounding media. Therefore, a series of models have been developed for this report to evaluate the interaction of the main concrete barrier of the panel closure system with the surrounding salt for different alternatives and concrete barrier geometries. This appendix discusses the code used and describes the material constitutive models used in the stress analysis.

C.1.0 The FLAC Code

FLAC software has been used for numerical modeling of the underground excavations at the WIPP since 1991. FLAC is a two-dimensional explicit finite difference code that simulates the behavior of rock and soil-like structures. The WIPP Reference Creep Law is built into FLAC and has been verified to Nuclear Regulatory Commission standards (Itasca, 1995). In addition, all versions of FLAC used by the Westinghouse Waste Isolation Division have been verified against the WIPP Second Benchmark Problem (Krieg, 1984).

C.2.0 Material Constitutive Models

The material properties associated with the material constitutive models are given in Tables C-1 through C-3. These properties are the standard properties which have been used in previous WIPP geotechnical FLAC modeling such as the Backfill Engineering Analysis Report (BEAR) (IT, 1994). Note that the stress analysis of the concrete barrier also uses the same stress-strain relationship for the uncompacted crushed salt as was used in the BEAR. The stress analysis in Figure 4-4 used uncompacted crushed salt on one side of the enlarged concrete barrier and open void space on the other side. The crushed salt has subsequently been eliminated from the panel closure system final design. The symmetry in the principal stress plots for the enlarged concrete barrier analysis indicated that the presence or absence of the crushed salt does not significantly affect the stresses within the enlarged concrete barrier. Therefore, the FLAC analysis results presented in Figure 4-4 apply to the panel closure system final design.

Table C-1[a]
FLAC[b] Model Time-Dependent Material Properties

Property	Halite	Argillaceous Halite	Halite, 10% Polyhalite
Bulk modulus (GPa)	20.7	20.7	22.1
Shear modulus (GPa)	12.4	12.4	13.2
Density (kg/m^3)	2,300	2,300	2,300
Activation energy (cal/mol)	12,000	12,000	12,000
A	4.56	4.56	4.56
B	127	127	127
D (Pa$^{-4.9}$/s)	5.79×10^{-36}	1.74×10^{-35}	5.21×10^{-36}
n	4.9	4.9	4.9
Gas constant (cal/mol K)	1.987	1.987	1.987
Critical strain rate	5.39×10^{-8}	5.39×10^{-8}	5.39×10^{-8}

Table C-2[a]
FLAC[b] Elastic Material Properties

Property	Anhydrite	Polyhalite	Concrete
Bulk modulus (GPa)	83.4	65.8	11.6
Shear modulus (GPa)	27.8	20.3	9.0
Density (kg/m^3)	2,300	2,300	2320
Cohesion (MPa)	27	17.2	–
Friction (degrees)	29	46.5	–

Table C-3[a]
FLAC[b] Clay Seam Material Properties

Property	Value
Normal stiffness (Pa/m)	1.0×10^{12}
Shear stiffness (Pa/m)	5.0×10^{10}
Cohesion (Pa)	0.0
Friction (degrees)	5

[a]IT, 1994

[b]FLAC = Fast Lagrangian Analysis of Continua
GPa = Gigapascal(s)
kg/m^3 = Kilogram(s) per cubic meter
cal/mol = Calorie(s) per mole
Pa$^{-4.9}$/s = Pascal(s) to the negative 4.9 per second
cal/mol K = Calorie(s) per mole Kelvin
A,B,n = unitless model factors
D = model factor
Pa/m = Pascal(s) per meter
MPa = Megapascal(s)

C.3.0 References

IT Corporation (IT), 1994, "Backfill Engineering Analysis Report," report prepared for Westinghouse Electric Corporation, Carlsbad, New Mexico.

Itasca Consulting Group, Inc. (Itasca), 1995, "FLAC User's Manual," Itasca Consulting Group, Inc., Minneapolis, Minnesota.

Krieg, R. D., 1984, "Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant," *SAND83-1908*, Sandia National Laboratories, Albuquerque, New Mexico.

APPENDIX D
BRINE/CEMENT INTERACTIONS

APPENDIX D
BRINE/CEMENT INTERACTIONS

Concern about potentially deleterious constituents in the Waste Isolation Pilot Plant (WIPP) brines were initially raised when evidence of some minor concrete deterioration in the waste shaft key was noted. The cause is geochemical alteration of the concrete shaft liner and shaft grout by the brine present at the Rustler-Salado contact. Chemical constituents detected in brine samples included both organic and inorganic compounds that probably originated from dissolution of the concrete liner and grout materials used in the shaft construction. The presence of large amounts of organics that likely originated from the chemical grout appeared to have complexed the calcium present in the brine, interfering with the inorganic chemistry of the naturally occurring brine. The brines in contact with the waste shaft key were also found to be significantly higher in both chlorides and magnesium than the Salado Formation brine. These factors probably resulted in a Rustler/Salado brine chemistry more aggressive than that of the naturally occurring Salado brines that may contact the panel barrier.

Lankard Materials Laboratory (LML) (1992) concluded that there has been both a "physical attack" component and a "chemical attack" component acting upon the waste shaft key by brines. A "worst-case" scenario proposed by LML indicated that deterioration from both chemical and physical factors could result in a loss of material on the shaft side of the concrete liner at a rate of approximately 12 centimeters (5 inches) over a 50-year period.

The very local deterioration of the waste shaft key concrete resulted in some reduction in its load-bearing capacity and some increase in its permeability to brine infiltration. In addition, exposure of chemical residue deposits to the air within the shaft may have created a spalling effect that also facilitated local concrete deterioration on the interior (shaft opening) side of the liner.

Sandia National Laboratories/New Mexico (SNL/NM) studied the effect of high-magnesium brine interactions on various candidate barrier materials (SNL/NM, 1994). High-magnesium brines are characteristic of the Rustler-Salado contact, which is the location of the waste shaft key. The study was intended to evaluate chemical impacts to mass-concrete barriers in the WIPP panels and to the Salado Formation. However, the results of the study were also used to evaluate the cause of the deterioration of the waste shaft key. IT Corporation (IT) (1994),

in a separate study, also evaluated the geochemistry of brines associated with the waste shaft key near the Rustler-Salado Formation contact.

Both studies concluded that the brines have chemically reacted with the constituents in the concrete and grouts used in the waste shaft key liner. The SNL/NM (SNL/NM, 1994) study theorized that the loss of the liner's strength was facilitated by the loss of calcium from the concrete liner. SNL/NM noted that the magnesium present in the brine replaced calcium in the concrete, but the replacement process occurred as a delayed reaction. Magnesium replacement did not occur until after the structural integrity of the waste shaft key liner was already impacted negatively by the loss of calcium, which increased the porosity of the liner. This resulted in a more open and permeable microstructure not attributable solely to a weakening effect from magnesium replacement. Both the IT and SNL/NM studies supported the conclusion that the waste shaft key liner deterioration occurred only locally and in the outermost reaction zone of the liner, so that the structural integrity of the liner as a whole was not significantly impacted. SNL/NM proposed that further deterioration of the liner may be limited only to areas of the concrete liner that develop stress fractures.

Wakeley et al. (1993) studied salt-saturated concrete and grout emplaced in the floor of the WIPP repository six years before its retrieval. The concrete and grout used in the study were cementitious, rather than organic. In retrieving the concrete and grout plugs, the plugs were overcored to also retrieve some host rock.

The study concluded that little to no deterioration occurred to the concrete or grout and that general compressive strengths of the concrete and grout increased over time. The lowest compressive strength values were observed in samples taken from the disturbed rock zone. Reaction rims with increased permeability were noted on anhydrite surrounding the plugs, suggesting interaction between the grout or concrete and host rock. However, comparable evidence of a reaction with the concrete or grout was not seen. There was also evidence of dissolution of halite in the anhydrite zone near the plugs; however, the evidence also indicates that the presence of the halite facilitated better bonding between the grout or concrete and the host rock. Crystallization of new phases was also noted on free surfaces, indicating that strongly ionic magnesium-bearing fluids were present and moving. The fluid movement appeared to have no effect on the host rock other than to improve bonding.

The differences in the appearances, strengths, and phase assemblages between the grout/concrete plugs in the study discussed above and the waste shaft key liner concrete are

different enough that two extremely different service environments can be inferred. The magnesium level and fluid transport are apparently much greater in the waste shaft key location, facilitating a greater degree of deterioration of the waste shaft key concrete than was noted in the plugs studied by Wakeley et al. (1993). The waste shaft key concrete liner was also composed of organic constituents, which appeared to be more reactive with the brine chemistry. The main concrete barrier will be located in a service environment similar to that studied by Wakeley et al. (1993), where very minor amounts of brine would contact the main concrete barrier.

References

IT Corporation (IT), 1994, "Geochemistry of Brines Recovered from the WIPP Waste Shaft in the Vicinity of the Rustler/Salado Contact," report prepared for Westinghouse Electric Corporation, Carlsbad, New Mexico.

Lankard Materials Laboratory (LML), 1992, "Laboratory Investigation of Factors Influencing the Deterioration of the Concrete Waste Handling Shaft Liner at the WIPP," *I-2480-5*, (July 1992) in "Waste Handling Shaft Concrete Liner Degradation Conclusions and Recommendations, Appendix A, *DOE/WIPP 92-050*, Waste Isolation Division, Westinghouse Electric Corporation, Carlsbad, New Mexico.

Sandia National Laboratories/New Mexico (SNL/NM), 1994, "Durability of Concrete Materials in High-Magnesium Brine," *SAND93-7073*, Sandia National Laboratories, Albuquerque, New Mexico.

Wakeley, L. D., P. T. Harrington, and C. A. Weiss, Jr., 1993, "Properties of Salt-Saturated Concrete and Grout After Six Years In Situ at the Waste Isolation Pilot Plant," *SAND93-7019*, Sandia National Laboratories, Albuquerque, New Mexico.

APPENDIX E

PREVIOUS STUDIES OF PANEL-CLOSURE SYSTEM MATERIALS

APPENDIX E
PREVIOUS STUDIES OF PANEL-CLOSURE SYSTEM MATERIALS

In researching the available literature relating to panel-closure system designs and materials, studies on both long-term and short-term barrier performance were evaluated. The intended function of the main concrete barrier described in this report is to provide short-term (35 years) barrier capability until the repository host rock reconsolidates around the barrier. However, studies on long-term barrier performance were found useful for the panel-closure system material compatibility evaluation performed for this document. The results of these studies provided insight into the complex issues to be considered for selecting an appropriate concrete and grout for the panel-closure system.

Stormont (1987) studied small-scale seal performance tests (SSSPT). The SSSPTs were designed as in situ experiments to evaluate the performance of candidate seal materials. Barrier systems consisted of the barrier itself, the barrier-rock interface, and the surrounding rock. The system performance was evaluated using thermal/mechanical and fluid flow (both gas and brine) data generated by testing under expected repository conditions. Thermal, mechanical, and hydrologic performance of the barriers was evaluated. Test Series A consisted of a bulkhead constructed of salt-based concrete. Regarding hydration of the concrete, stresses and strains induced in the rock and the barrier were a result of hydration. Stresses and strains also resulted from the salt creep and from the panel-closure system material. Evaluation of these stresses and strains yielded information about the stability of the barrier system and the structural/fluid flow relationship. The permeabilities of the barrier material with respect to gas and brine were important for evaluating the potential for a repository breach scenario. Test Series A was conducted in geologic horizons that included bedded halite and interbeds of clay and anhydrite.

Three types of concrete were evaluated for the Test Series A study: salt-free concrete, salt concrete, and expansive salt-based concrete. The latter proved to yield the most favorable results due to its significant expansive properties, which create a tight interface; its workability (about 4 hours); and for its ability to inhibit dissolution of surrounding salt during cement hydration.

Stormont (1988) also studied the performance of grout and concretes as constituents of main concrete barriers for the panel-closure system. The use of cementitious grouts within the disturbed rock zone adjacent to the main barrier was determined to be detrimental at times, as it could facilitate fracture propagation. To prevent the load reaction causing the fracture propagation, Stormont proposed the emplacement of rigid concrete at the main barrier location. Stormont's investigations of concrete to form the actual main barrier indicated that concrete is impermeable, and any associated leakage across the barrier would occur at the concrete/rock interface zone. Leakage could be attributed to concrete shrinkage and the integrity of the rock itself. However, Stormont noted that the presence of halite in the host rock would result in compressional forces exerted on the concrete barrier over time, with little or no leakage occurring.

SSSPT performed by Stormont (1988) and Finley and Tillerson (1992) evaluated salt-based concrete, bentonite, and salt blocks for barrier performance. In the salt-based concrete barriers, both brine and gas migration across the barrier-rock interface were retarded by salt creep adjacent to the barrier and the expansive properties of the salt-based concrete. The salt-based concrete barriers also withstood significant back-pressure forces. Bentonite and salt blocks did not perform as satisfactorily with respect to their load-bearing capacities or fluid permeabilities.

Hansen et al. (1994) discussed barrier materials for vertical shaft environments in terms of the barriers' long- and short-term components. The single long-term component envisaged in their studies was reconsolidated salt, especially engineered to achieve a barrier function in approximately 100 years. However, short-term materials included concrete, bentonite, grout, chemical seal rings, and potential alternatives, although the alternatives were not included in a reference barrier design. Each barrier component had a functional requirement to prevent the passageways from becoming the preferred passageways for transport of brines or gases to or from the repository. Short-term components provided barriers to brine and groundwater inflow to the consolidating and long-term members and to the repository. The composition of each selected barrier was based on experience in the mining industry, assurance of function through test results, and compatibility with the stratigraphy in which the barrier was placed. The authors looked at specific geologic horizons with respect to their ability to prevent brine and gas flow.

Test Series B (Peterson et al., 1987) more likely approximated the configuration of the proposed panel barrier, which will be emplaced in a horizontal drift leading to the waste-

emplacement panels. The type of material used in the testing was a salt-saturated expansive concrete, as was used in Test Series A.

In both the A and B test series, the parameter of primary interest was the barrier permeability. For calculational purposes, it was assumed that all flow goes through the barrier. However, some flow may enter the surrounding formation as well, although it is difficult to determine and quantify. Factors affecting measured flow rates through the barrier would include the pressure under which the brine was flowing. If a brine was saturated with respect to its liquid phase at ambient conditions, added pressures may decrease its saturation and encourage dissolution of the surrounding halite.

In one test, barrier brine flow rate decreased slowly with time; this is an important consideration when modeling long-term response. Possible mechanisms causing this decrease include precipitation, healing, or creep closure of open pore spaces. Estimates of brine and gas permeabilities depend strongly on the degree of pore saturation.

Only gas-flow tests were performed in the B Series. All of the barriers leaked (though at slow rates) in the B Series tests. No leakage occurred at the barrier/formation interface. Leaks were associated with a small formation fracture and with an instrumentation bundle. Gas-flow tests performed approximately one year later indicated no leakage associated with the barriers.

Test Series C (Stormont et al., 1987) consisted of salt and salt-bentonite block barrier material emplaced in a horizontal drift within almost pure halite. Four barriers were composed of salt blocks, and four barriers consisted of salt-bentonite blocks. Four of the barriers, two representing each type of material described above, were evaluated without instrumentation, for fluid flow and permeability testing. Instrumentation and cabling are often leak paths for such testing. The instrumentation used in the other barriers measured deformations and pressures and provided other important data. The data suggest that crushed salt provides very little resistance to closure until the crushed salt is very dense. Deformation experiments were designed to verify or refute this evidence.

Principal advantages to salt-block emplacements as opposed to mechanical or pneumatic backfilling were that initial porosity of the crushed or granular salt was minimized, reducing the time required for effective or complete salt consolidation. This in turn reduced the likelihood of brine influx from the surrounding strata that could impede the consolidation

process. Block emplacements also allowed considerable control over production and emplacement. Blocks could be tailored to achieve certain properties, such as addition of bentonite or moisture.

Experiments with different types of blocks indicated that the relative density of the blocks increased with the maximum particle size used. Further, blocks cured in humid environments became extremely friable and unviable. Within the Waste Isolation Pilot Plant (WIPP) facility, the humidity of the ventilation air is below the critical humidity of 75 percent (the air will take moisture from the salt).

Blocks cured at ambient conditions were the most resilient in that they resisted chipping and shattering. Their "toughness" was a result of the development of an indurated "skin" from particle caking. Caking occurs when moisture at particle contacts is evaporated, resulting in bridging and microcrystalline growth that essentially cements the particles together. However, an indurated skin may also hinder consolidation at the interfaces between blocks from a lack of available water believed necessary for rapid consolidation.

The purpose of adding bentonite to salt blocks was to reduce the permeability without requiring extensive consolidation. Data collected indicated that permeabilities to brines and water fell off to microdarcy values somewhere between 25 and 50 percent bentonite by weight. For this experiment, a 1:1 ratio of salt to bentonite was used. Over 90 percent of the bentonite was composed of the clay mineral montmorillonite. Water was also introduced into the mixture.

Salt/bentonite blocks cured in the humid environment took sufficient moisture from the air to become extremely friable, and therefore, unviable. Under covered conditions, less moisture was lost. Salt/bentonite blocks were also tougher than salt-only blocks. Also, greater amounts of moisture contributed to a tougher block than the addition of less moisture.

The use of mortars was necessary to fill the voids between the blocks and the borehole wall. Mortar was generally only emplaced into the interface and not between blocks. The mortars were composed of the same materials as the blocks.

In summary, both types of blocks were found to lose excessive moisture to the dry mine atmosphere unless they were covered between the time of production and the time of emplacement. Initial fluid flow testing of the salt/bentonite barriers revealed that erosion

along the block/rock interface occurred when the brine was introduced too rapidly to allow the bentonite to take up the water and swell to shut down flow paths. Subsequent testing with slower introduction of brine confirmed this result, that is, salt/bentonite blocks could be effective barriers to brine flow. Structural measurements provided data to test laboratory models of salt consolidation. To date, the measurements do not contradict model predictions of the barriers providing little resistance to hole closure until they become very dense.

The concrete and grout used in the above-referenced study were developed by Gulick and Wakeley (1989). They proposed expansive salt-saturated concrete (ESC) and grout mixtures that yielded favorable results for suitability as panel barrier and grout materials during the in-place testing at the WIPP repository. The grout composition was summarized in the text of this report in Section 2.2.1. The formulation for the ESC is shown in Table E-1.

Table E-1
Expansive Salt-Saturated Concrete

Component	Percent of Total Mass
Class H cement	9.03
Chem comp III	6.03
Cal seal (plaster)	1.80
Class C fly ash	5.10
Fine aggregate	34.11
Coarse aggregate	34.58
Sodium chloride	2.50
Defoaming agent	0.21
Sodium citrate	0.11
Water (iced)	6.60

Class H cement is a standard oil-well cement. It has been used extensively in grouts and concretes in underground applications. Class C fly ash contributes expansive properties to the concrete. Cal Seal (a plaster of paris manufactured by Haliburton) also develops expansive properties in mixtures containing Class H cement. Expansive components that are added to the concrete or grout mixtures enhance bonding between the concrete or grout and the host rock. The addition of sodium chloride to the mixture is necessary to assure that the water

content of the concrete or grout is in equilibrium with the host rock. This prevents dissolutioning, and also inhibits or reduces deterioration of the concrete or grout. Defoaming agents inhibit air entrainment in the concrete or grout mixture.

References

Finley, R. E., and J. R. Tillerson, 1992, "WIPP Small Scale Performance Test—Status and Impacts," *SAND91-2247*, Sandia National Laboratories, Albuquerque, New Mexico.

Gulick, C. W., and L. D. Wakeley, 1989, "Reference Properties of Cement-Based Plugging and Sealing Materials for the Waste Isolation Pilot Plant (WIPP)," *Technical Report SL-89-17*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
IT Corporation (IT), 1994, "Backfill Engineering Analysis Report," report prepared for Westinghouse Electric Corporation, Carlsbad, New Mexico.

Hansen, F. D., M. S. Lin, and L. L. Van Sambeek, 1993, "Concepts for Operational Period Panel Seal Design at the WIPP," *SAND93-0729*, Sandia National Laboratories, Albuquerque, New Mexico.

Peterson, E. W., P. L. Lagus, and K. Lie, 1987, "Fluid Flow Measurements of Test Series A and B for the Small Scale Seal Performance Tests," *SAND87-7041*, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., 1988, "Preliminary Seal Design Evaluation for the Waste Isolation Pilot Plant," *SAND87-3083*, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., 1987, "Small-Scale Seal Performance Test Series 'A' Thermal/Structural Data Through the 180th Day," *SAND87-0178*, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J. C., E. W. Peterson, and P. L. Lagus, 1987, "Summary of the Observations About WIPP Facility Horizon Flow Measurements Through 1986," *SAND87-0176*, Sandia National Laboratories, Albuquerque, New Mexico.

APPENDIX F

HEAT TRANSFER MODEL DERIVATION
METHANE EXPLOSION

APPENDIX F
HEAT TRANSFER MODEL DERIVATION
METHANE EXPLOSION

Under the conditions of a postulated methane explosion within the panel, the temperature of the gas is raised by the combustion process to an initial value $T_{g\ init}$ with time t = 0 corresponding to initial conditions in the panel. Subsequently, the gas temperature in the panel decreases as heat is transferred to the surrounding salt and to the two explosion-isolation walls in the air-intake and air-exhaust drifts of each panel.

At time t = 0 the pressure in the panel is P_{init} based on panel closure due to creep and the elevation in pressure resulting from the explosion. Thus, the rise time of the temperature is not considered in the model.

At time t = 0, the volume of the panel is V_{init} and is assumed to remain constant throughout the cooling of the gas in the panel because of the short duration of the explosion. This means that the effect of creep on the panel volume is assumed negligible during the postulated explosion. The initial volume is given by:

$$V_{init} = V_{panel} - V_{waste} - V_{creep}$$

where

V_{init} = Initial volume
V_{panel} = Volume of the panel
V_{waste} = Volume of the waste
V_{creep} = Volume reduction due to creep

and is taken as given at the start of the heat transfer analysis and assumed to remain constant during the transfer of heat to the panel walls, roof, and floor.

F.1.0 Heat Balance

Assuming a constant volume is equivalent to stating that any creep closure of the panel volume during the explosion and subsequent cooling can be neglected.

$$\frac{dQ_{volume\ of\ gas}}{dt} = qA_{walls,\ floor,\ roof}$$

where $Q_{volume\ of\ gas}$ represents the heat contained in the hot gases subsequent to an explosion, q is the heat flux rate at the boundaries of the panel volume, and $A_{walls,\ floor,\ roof}$ is the surface area of the panel volume.

Following D'Appolonia (1978) it is conservatively assumed that the heat transfer to the surrounding walls, floor, roof, is related to the rate of change of enthalpy of the reaction products gas. Thus, the heat content of the room is given by:

$$\frac{dQ_{volume\ of\ gas}}{dt} = nC_p\frac{dT_g}{dt}$$

where n is the number of moles of gas in the room subsequent to the explosion, T_g is the gas temperature, and C_p is the heat content of the gas at constant pressure.[1] Thus,

$$nC_p\ \frac{dT_g}{dt} = qA_{walls,\ floor,\ roof} \qquad (1)$$

F.2.0 Moles of Gas

The gas in the panel subsequent to the explosion is a mixture of the combustion products of the explosive gas which is taken to be a mixture of methane, CH_4 and air. Because methane can explode with other than a stoichiometric air/methane mixture (i.e., the methane concentration in air for an explosion to occur is a range as opposed to a single value), it is impossible to determine the number of moles of combustion product gas precisely. Thus, it is assumed that the explosion occurs with a stoichiometric air/methane mixture.

[1]The specific heat at constant volume is used even though the explosion or rapid combustion of the methane-air mixture occurs at constant volume because the rate of change of enthalpy as opposed to internal energy has been used.

F.2.1 Mixture

The stoichiometric reaction for methane is (Bodartha, 1980):

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

with the moles of air given by:

$$n_{air} = 4.77(2) = 9.54 \textit{ mole air/mole methane}$$

or 9.54 moles of air are required to provide 2 moles of oxygen. Using a ratio of 9.54 moles of air per mole of methane, the total moles of gas at the time of the explosion would be:

$$n = (9.54 + 1)n_{CH4}$$

The number of moles of nitrogen in the air and in the combustion products gas is 3.77(2) = 7.54 moles/mole of methane (Bodartha, 1980). Thus,

$$7.54 \text{ moles } N_2 + 2 \text{ moles } O_2 + 1 \text{ mole } CH_4 =$$
$$7.54 \text{ moles } N_2 + 1 \text{ mole } CO_2 + 2 \text{ moles } H_2O$$

On a molar basis the reaction products are 71.5% nitrogen, 9.5% carbon dioxide, and 19% water vapor. This compares with a reaction product that is 72.9% nitrogen, 11.6% carbon dioxide and 15.5% water vapor when propane is burned at a stoichiometric ratio (D'Appolonia, 1978). Also, 10.54 moles of the methane-air mixture produces 10.54 moles of reaction products. Thus, the number of moles of air/methane prior to the explosion is the same as the number of moles of the product gas and the above relation for n will be used to compute the heat content in a panel prior to cooling.

$$n_{gas} = 10.54\ n_{CH4} \tag{2}$$

Substituting (2) into (1),

$$10.54\ n_{CH4}\ C_p \frac{dT_g}{dt} = qA_{walls,\ floor,\ roof}$$

or

$$\frac{dT_g}{dt} = \frac{qA_{walls,\ floor,\ roof}}{10.54\ n_{CH4}\ C_p} \tag{3}$$

is the differential equation for the time rate of change of the gas temperature in the panel following an explosion.

F.2.2 Specific Heat

The specific heat, Cp, of the combustion products of the explosion is required by equation (3). In general, the specific heat is a function of temperature over large temperature ranges. Figure C-1 shows plots of specific heats of the combustion products of stoichiometric propane-air mixtures and methane-air mixtures based on data from D'Appolonia (1978) and Reid, et al., (1977). The curves for propane-air mixtures are shown for comparison between the Reid, et al. data and the D'Appolonia data.

For an explosion temperature on the order of 2400 degrees kelvin (°K), and using an average of the wall temperature and gas temperature to evaluate the specific heat, the temperature dependence curve will be evaluated in the region of 1400 °K which is about the maximum useful temperature for the Reid, et al. data.

As shown on Figure F-1, the Reid et al. (1977) and D'Appolonia (1978) data agree well up to a temperature of approximately 1400 °K. At the greater temperatures Reid et al. (1977), and other data indicate a decrease in specific heat with greater temperatures which is not consistent with expectation.

Figure F-2 shows a comparison of Reid et al. (1977) and the D'Appolonia (1978) data multiplied by 0.961, the ratio of specific heats for a methane-air mixture to a propane-air mixture at 300 °K. Below 1400 °K the agreement is very good. Above 1400 °K the curve based on the D'Appolonia data remains valid. Therefore, the specific heat of the combustion products formed from a stoichiometric methane air mixture as a function of temperature is[2]

$$C_p = 1.29\ x\ 10^{-3}\ T + 7.3353 - \frac{32682}{T^2} \tag{4}$$

[2]Equation (4) was obtained by multiplying Equation (9) of Appendix B of D'Appolonia [1978] by 0.961.

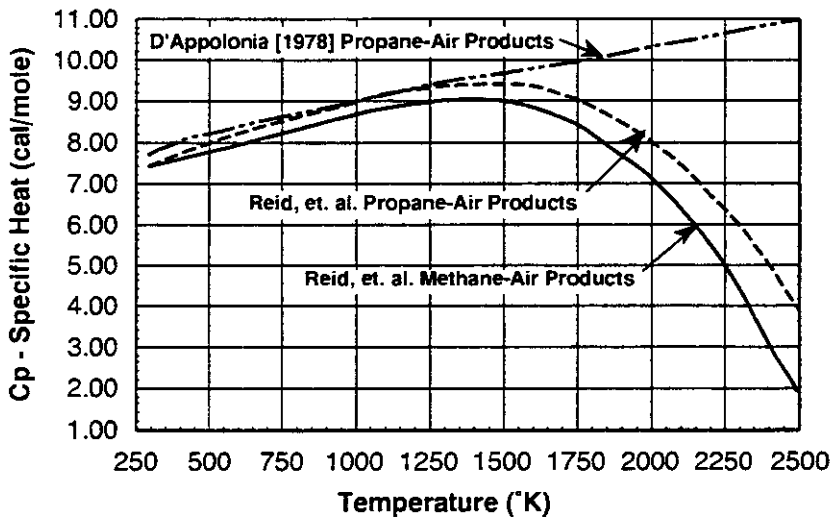

Figure F-1
Specific Heat as a Function of Temperature

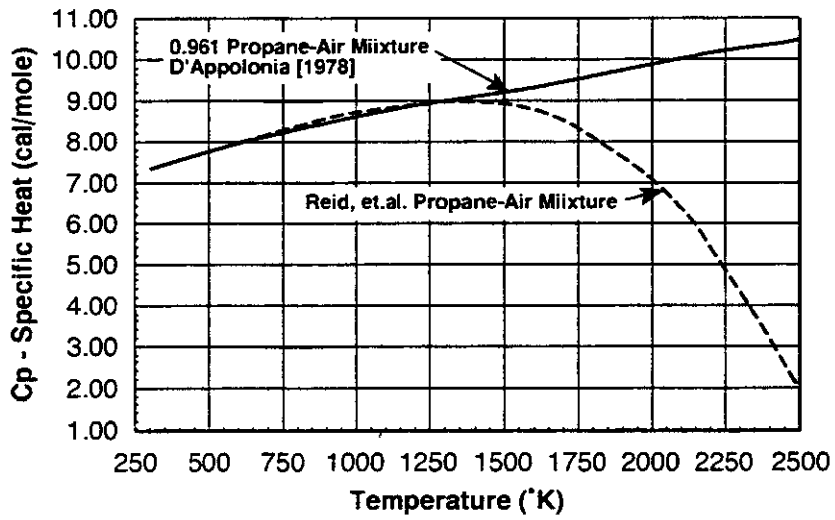

Figure F-2
Specific Heat for Methane-Air Stochiometric Mixture

F.3.0 Heat Transfer to the Walls, Floor, Etc.

Heat is transferred from the gas to the surrounding walls, floor and roof of the panel rooms by both convection and radiation. Heat is then transferred into the walls, floor, roof, via conduction. Thus, the rate of heat conduction into the salt or the wall is governed by the rate at which heat can be conducted into the solids.

F.3.1 Radiation Heat Transfer

Heat transferred from the gas to the walls, floor, roof, is given by:

$$q_{rs} = \sigma\left(T_g^4 - T_w^4\right)$$

where q_{rs} is the heat flux to the walls, floor, roof, σ is the Stefan-Boltzmann constant (1.35×10^{-12} cal/cm^2-sec-°K), and T_w is the temperature of the walls, floor, and roof.

The majority of the surface area of the panel available for heat transfer via both radiation and convection is salt. However, a small portion of the total area will be the inner face of the explosion-isolation wall (or construction-isolation well). Because the wall, floor, roof temperature is controlled by the time dependent conduction of heat into either the walls, floor, roof or the wall faces, and the diffusivities and conductivities of the salt and wall, floor, roof material may be different, the radiation heat transfer is divided into two components.

The radiative heat transfer to the salt (T_{ws}) is:

$$q_{rs} = \sigma\left(T_g^4 - T_{ws}^4\right)$$

and the radiative heat transfer to the explosion-isolation wall (T_{wb}) is:

$$q_{rb} = \sigma\left(T_g^4 - T_{wb}^4\right)$$

The combined radiative heat transfer to the walls, floors, roof is:

$$Q_r = q_{rs}A_s + q_{rb}A_b$$

or

$$Q_r = \sigma\left(A_s\left[T_g^4 - T_{ws}^4\right] + A_b\left[T_g^4 - T_{wb}^4\right]\right) \tag{5}$$

where A_b = Area of the walls, and A_s = area of the salt.

Equation (5) comprises the radiation portion of the right hand side of the differential equation, (3), for the rate of gas temperature in the panel.

F.3.2 Convection Heat Transfer

In addition to radiation, heat is transferred to the walls, floor, roof, and explosion-isolation walls by natural convection. In subsequent discussion, walls denote all exposed surface area of salt within a panel. Explosion-isolation walls denote the surface area of the expendable walls placed in the sealed air-intake and air-exhaust drifts of the panel.

F.3.2.1 Heat Transfer from Gas to the Walls

In addition to radiation, heat is transferred to the walls, floor, roof, and explosion-isolation walls via natural convection. The heat flux due to convection (q_c) is given by:

$$q_c = h\left(T_b - T_w\right)$$

where h = Film coefficient.

As for the case of radiation, the majority of heat transfer by convection will occur to the surrounding salt. However, a portion will be transferred to the explosion-isolation wall. Because the temperature of the explosion-isolation wall may be different from the temperature of the salt, the convective heat transfer is divided into the two components analogous to the radiation heat transfer. For the salt, the convection heat transfer is:

$$q_{cs} = h\left(T_g - T_{ws}\right)$$

and for the explosion-isolation walls:

$$q_{cb} = h\left(T_g - T_{wb}\right)$$

The combined radiative heat transfer (Q_c) to the walls, floors, roof, and explosion-isolation walls is:

$$q_{cb} = h\left(T_g - T_{wb}\right)$$

The combined radiative heat transfer (Q_c) to the walls, floors, roof, and explosion-isolation walls is:

assuming that the heat transfer coefficient does not change with location or material.

$$Q_c = q_{c\ NaCl}\ A_s + q_{cb} A_b$$

Theoretically the convective heat transfer coefficient is different for the face of the explosion-isolation walls, which are vertical compared with the heat transfer coefficient for the roof and floor faces of the panel which are horizontal. Neglecting the difference in heat transfer coefficient due to geometric differences, the above two equations for the heat flow to the walls, floor, roof, and explosion-isolation walls can be combined to give

$$Q_c = h\left(A_s\left[T_g - T_{ws}\right] + A_b\left[T_g - T_{wb}\right]\right) \tag{6}$$

Equation (6) gives the convective heat transfer portion of the right hand side of Equation (3). Combining (3), (5) and (6),

$$\frac{dT_g}{dt} = -\frac{Q_c + Q_r}{10.54\ n_{CH4}\ C_p} \tag{7}$$

where the negative sign indicates that Q_c and Q_r represent heat transferred out of the system consisting of the gas in the room. These same quantities then represent heat transferred into the surrounding salt and explosion-isolation wall.

F.3.2.2 Convection Coefficient

Assuming the convection coefficient is the same at all surfaces and following the methods developed in D'Appolonia (1978), with all units in the centimeter-gram-second (cm-g-sec) system of units,

$$N_u = 0.13[P_r G_r]^{1/3}$$

where P_r is the Prandtl number and G_r is the Grashof number. The Prandtl number is essentially constant and is taken as 0.71 regardless of pressure and temperature. The Grashof number is given by

$$G_r = \frac{g\beta L^3(T_g - T_w)}{\nu^2}$$

where g is the acceleration of gravity, β is the volume coefficient of thermal expansion and ν is the kinematic viscosity of the gas. For ideal gases,

$$\beta = \frac{1}{T_g}$$

and the kinematic viscosity is given by

$$\nu = \frac{\mu}{\rho}$$

where μ is the absolute viscosity ρ = mass density. Substituting for n and β in the expression for the Grashof number,

$$G_r = \frac{g\rho^2 L^3(T_g - T_w)}{T_m \mu^2}$$

where

$$T_m = \frac{T_g + T_w}{2}$$

is the average of the gas and surface temperature.

Substituting for the Grashof number and Prandtl number in the expression for the Nusselt number,

$$N_u = 0.13\left(0.71\frac{g\rho^2 L^3[Tg-T_w]}{T_m\mu^2}\right)^{1/3}$$

$$N_u = 0.146L\left(\frac{g\rho^2}{\mu^2}\left[\frac{T_g-T_w}{T_g+T_w}\right]\right)^{1/3}$$

and substituting for the Nusselt number in the expression for the convection coefficient,

$$h = 0.146k_g\left(\frac{g\rho^2}{\mu^2}\left[\frac{T_g-T_w}{T_g+T_w}\right]\right)^{1/3}$$

Since the thermal conductivity of the gas is given by[3]

$$k_g = 6.4 \ x \ 10^{-5}\left(\frac{T_m}{300}\right)^{.75}$$

$$h = 9.34 \ x \ 10^{-6}\left(\frac{T_g+T_w}{600}\right)^{.75}\left(\frac{g\rho^2}{\mu^2}\left[\frac{T_g-T_w}{T_g+T_w}\right]\right)^{1/3} \qquad (8)$$

Figure F-3 shows h as a function of surface temperature based on a gas temperature of 2400°K and density and viscosity consistent with conditions at the time of an explosion.

Assuming that no additional gas is generated subsequent to the explosion, the density of the gas after the explosion is the same as before the explosion since mass is conserved. Thus, the gas density after the explosion is the molecular weight of n moles of methane plus 9.54n moles of air divided by the initial volume,

[3]D'Appolonia [1978].

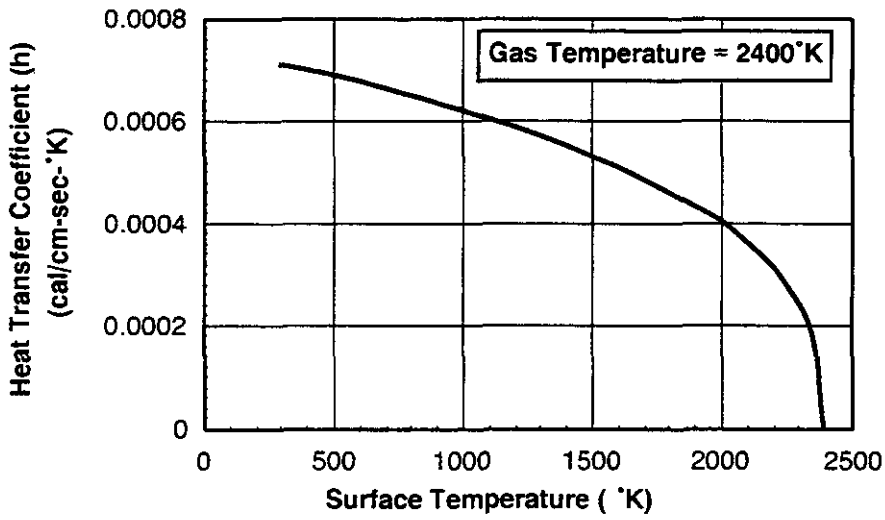

Figure F-3
Convection Heat Transfer Coefficient Versus Temperature

$$\rho = n\left(\frac{M_{w\ CH4} + 9.54M_{w\ air}}{V_{init}}\right)$$

$$\rho = n\left(\frac{16 + 9.54(29)}{V_{init}}\right)$$

$$\rho = \frac{292.66n}{V_{init}} \tag{9}$$

$$\mu = 1.85\ x\ 10^{-4}\left(\frac{T_m}{300}\right)^{0.67} \tag{10}$$

and the viscosity is given by (D'Appolonia, 1978), where the viscosity is evaluated at the average of the surface and gas temperatures.

Because there will be two different surface temperatures, one corresponding to the salt, and one for the explosion-isolation wall, there will be different convective heat transfer coefficients as well.

F.3.3 Conduction Into the Walls, Floor, Roof, and Explosion-Isolation Walls

The temperature which controls the heat transfer from the gas via radiation and convection is controlled by the rate at which heat is conducted into the walls, roof, floor, and explosion-isolation walls. The diffusion of heat into the walls, floor, roof, and explosion-isolation walls is assumed to be governed by a one-dimensional, semi-infinite thermal diffusion model. If the temperature penetrates the explosion-isolation walls, the model is changed to be thermal diffusion across a slab of finite thickness with an ambient gas temperature on the side in the isolation zone.

Thermal diffusion into the walls, floor, roof, and explosion-isolation walls is governed by the partial differential equation,

$$\alpha \frac{\partial^2 T}{\partial x^2} = \frac{\partial T}{\partial t}$$

where α is the thermal diffusivity, T is the temperature, x is the distance into the wall, floors, roof, or explosion-isolation walls, and t is time. At x = 0 the flow of heat into the walls, floor, roof, or explosion-isolation walls is governed by the boundary condition,

$$-k \frac{\partial T}{\partial x} = q_{in}$$

where q_{in} is the heat flux into the walls, etc. from the gas via convection and radiation and k is the thermal conductivity. Because the thermal diffusivity and conductivity for salt is different from that of the explosion-isolation wall, two conduction models are required.

F.3.3.1 Heat Conduction to the Salt

The first involves the heat transferred from the gas to the salt and is governed by the partial differential equation,

$$\alpha_s \frac{\partial^2 T_s}{\partial x^2} = \frac{\partial T_s}{\partial t} \qquad (11i)$$

where α_s is the thermal diffusivity of salt which is a function of temperature. Figure F-3 shows plots of thermal diffusivity for halite, anhydrite, argillaceous halite and polyhalite (Krieg, 1983). Figure F-4 also shows data from D'Appolonia (1978) that used the relation

$$\alpha_s = \frac{10}{T_s}$$

for salt. The D'Appolonia temperature dependence yields slightly higher values compared with the Waste Isolation Pilot Plant (WIPP) data, but indicates a consistency in the data. For purposes of the post-explosion heat transfer analysis the temperature dependent data for salt has been used.

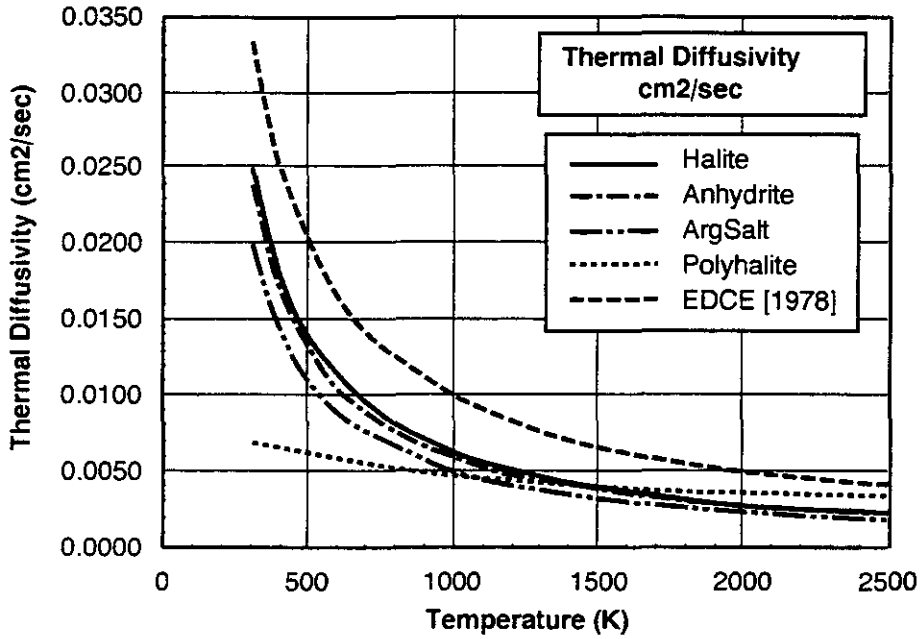

Figure F-4
Thermal Diffusivity of WIPP Geologic Materials

$$\alpha_s = 0.025\left[\frac{300}{T_s}\right]^{1.14} \tag{12i}$$

The boundary condition at the surface of the salt is:

$$-k_s\frac{\partial T_s}{\partial x} = q_{sr}+q_{sc} \tag{13i}$$

where k_s is the thermal conductivity of the salt. Figure F-4 shows plots of thermal conductivities for the same materials as a function of temperature. Again, the thermal conductivity from D'Appolonia (1978):

$$k_s = \frac{4.5}{T_s}$$

is also shown on Figure F-5 to check the consistency of the WIPP data. Again, the thermal conductivity for halite was used for the post-explosion heat transfer analysis.

$$k_s = 0.012\left[\frac{300}{T_s}\right]^{1.14} \tag{14i}$$

The terms q_{sr} and q_{sc} in (13i) couple the heat conduction into the salt with the rate of cooling of the gas via equations (7) through (10). In addition to the boundary conditions given by (12i), initial conditions at time t = 0 are required. It is assumed that at t = 0 the salt is at the ambient temperature in the panel, T_{amb}. Equations (11i) through (14i) with the initial conditions form the complete problem for the temperature in the salt as a function of time as the gas cools following the explosion.

F.3.3.2 Heat Conduction to the Explosion-Isolation Walls

The second model involves the heat transferred from the gas to the explosion-isolation walls and is governed by the partial differential equation,

$$\alpha_b\frac{\partial^2 T_b}{\partial x^2} = \frac{\partial T_b}{\partial t} \tag{11ii}$$

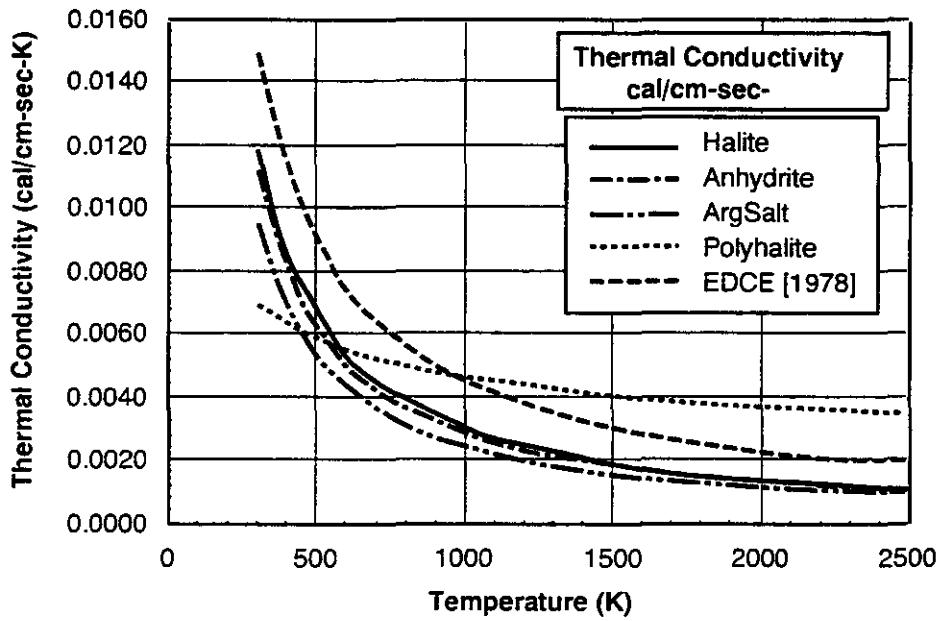

Figure F-5
Thermal Conductivity of WIPP Geologic Materials

where α_b is the thermal diffusivity of explosion-isolation walls. If the explosion-isolation walls are concrete, the thermal diffusivity does not vary with temperature (D'Appolonia, 1978),

$$\alpha_s = 0.005 \tag{12ii}$$

The boundary condition is:

$$-k_b \frac{\partial T_b}{\partial x} = q_{br} + q_{bc} \tag{13ii}$$

where q_{br} = heat flux for the salt, q_{bc} = heat flux for explosion-isolation walls, and k_b is the thermal conductivity of the walls. Again, if the explosion-isolation walls are concrete, the thermal conductivity is constant (D'appolonia, 1978).

$$k_b = 0.002 \tag{14ii}$$

Analogous to the case for salt, the terms q_{br} and q_{bc} in (13ii) couple the heat conduction into the salt with the rate of cooling of the gas via equations (7) through (10). At t = 0 the explosion-isolation walls are at the ambient temperature at the panel level, T_{amb}.

F.4.0 Numerical Model

Equations (1) through (14) were solved using a computer program based on an explicit finite difference representation of the equations. In subsequent discussion the following symbols are used,

τ	=	time step Δt
ε	=	distance between mesh points, Δx, in finite difference representation of semi-infinite solid used to model the explosion-isolation walls.
n	=	subscript denoting the value of a variable at time t.
n+1	=	subscript denoting the value of a variable at time $t+\tau$.
m	=	subscript denoting the value of a variable at mesh point m in a finite difference representation of a semi-infinite solid. m = 0 corresponds to the boundary x = 0.
T_{gn}	=	gas temperature at time t.
T_{s0}	=	temperature at x = 0 in salt.
T_{b0}	=	temperature at x = 0 in an explosion-isolation wall.
T_{smn}	=	temperature in salt at mesh point m and time n.
T_{bmn}	=	temperature in explosion-isolation walls at mesh point m and time n.
α_{sm}	=	thermal diffusivity in salt at mesh point m (function of temperature).

α_{bm} = thermal diffusivity of explosion-isolation wall material at mesh point m (may be constant or a function of temperature).
q_{rsn} = heat flux to wall (salt) via radiation at time point n.
q_{rbn} = heat flux to explosion-isolation wall via radiation at time point n.
q_{csn} = heat flux to wall (salt) via convection at time point n.
q_{cbn} = heat flux to explosion-isolation wall via convection at time point n.

Where symbols are used for parameters that are a function of temperature and consequently also a function of time, the subscripts n and n+1 refer to whether the parameter is evaluated at t or t + Δt.

F.4.1 Overview of Computer Program

Figure F-6 provides a simplified flow chart of the computer program used to solve the equations in the model in explicit finite difference form.

F.4.2 Finite Difference Formulation

For the first past through the calculational loop n = 0 and the gas temperature is set to T_{g0}, the initial temperature. Based on the assumption of constant volume during the explosion, the temperature is related to the pressure by,

$$T_{g0} = T_{gamb}\left(\frac{P_0}{P_{amb}}\right) = 8T_{gamb} \tag{15}$$

where

T_{gamb} = the gas temperature prior to the explosion
P^{amb} = the gas pressure prior to the explosion (taken as 2 atm)
P_0 = the gas pressure caused by the explosion (taken as 16 atm)
T_{g0} = the gas temperature caused by the explosion which is the initial gas temperature for the cooling analysis.

The initial temperature of the salt (T_{smo}) and explosion-isolation walls (T_{bmo}) for the heat conduction calculations are set to the ambient temperature at all mesh points.

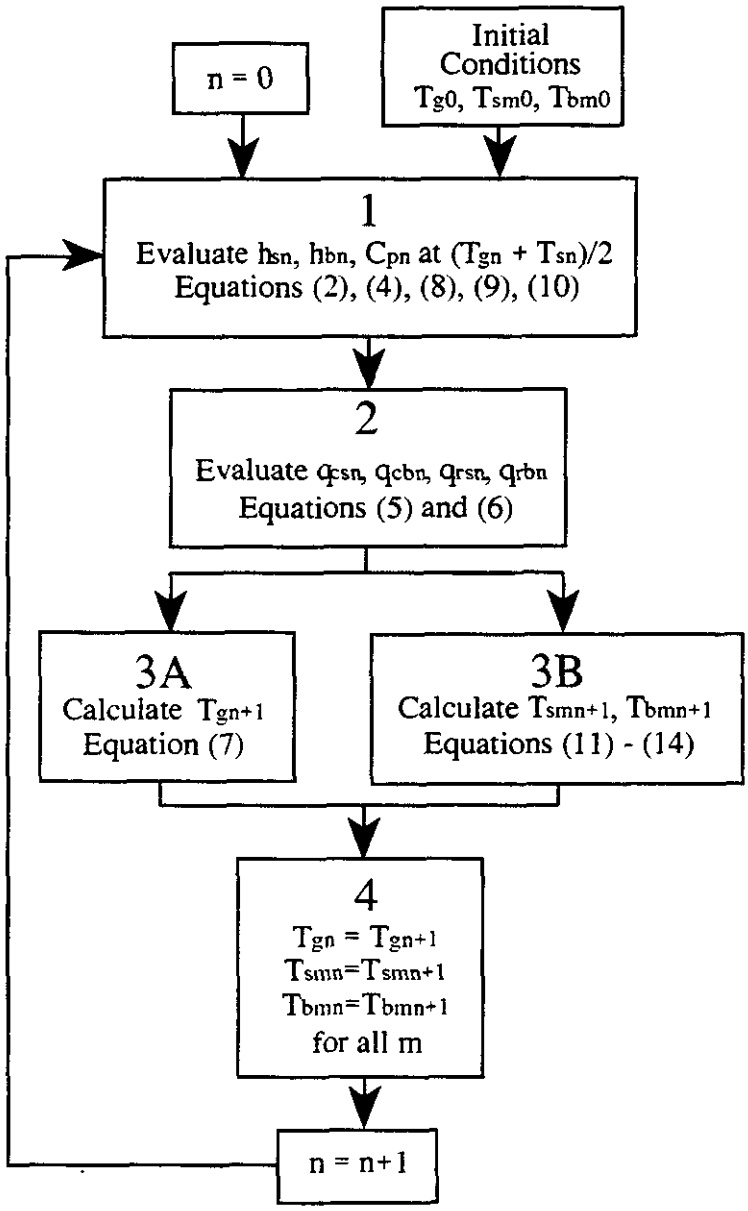

Figure F-6
Program Flow Chart

$$T_{sm0} = T_{amb} \quad m = 1 \ldots M$$
$$T_{bm0} = T_{amb} \quad m = 1 \ldots M \tag{16}$$

where M is the maximum mesh point number used in the finite difference representation of the semi-infinite solid. T_{amb} is the ambient temperature of the salt and explosion-isolation wall at the time of the explosion.

F.4.2.1 Program Section 1

Section 1 of the program (Figure F-3) calculated the parameters required for the determination of the heat fluxes from the hot gas to the cooler walls. These calculations are performed initially based on values for n = 0, initial conditions. Subsequently, they are evaluated based on the temperature values at time point n.

Thus,

$$\mu_{sn} = 1.85 \times 10^{-4} \left(\frac{T_{gn} + T_{s0n}}{600} \right)^{0.67}$$
$$\mu_{bn} = 1.85 \times 10^{-4} \left(\frac{T_{gn} + T_{b0n}}{600} \right)^{0.67} \tag{17}$$

where

μ_{sn} = viscosity of the salt

μ_{bn} = viscosity of the explosion-isolation wall

T_{gn} = gas temperature at time point n

T_{s0n} = wall temperature of the salt at time point n, which is the m = 0 mesh point of the finite difference representation of the semi-infinite solid used to model heat conduction into the salt

T_{b0n} = surface temperature of the explosion-isolation wall.

Since the initial surface temperatures of the salt and the walls are the same, the initial value of μ will be the same at both the salt and the walls. However, with time as the surface temperature of the explosion-isolation walls varies from the surface temperature of the salt, the values of μ will be different for the salt compared with the walls. This plays a role in

having different convection heat transfer coefficients at the salt compared with the explosion-isolation walls.

The convection heat transfer coefficients are given by (8) below.

$$h_{sn} = 9.34 \; x \; 10^{-6} \left(\frac{T_{gn} + T_{s0n}}{600} \right)^{.75} \left(\frac{g\rho^2}{\mu_{sn}^2} \left[\frac{T_{gn} - T_{s0n}}{T_{gn} + T_{s0n}} \right] \right)^{1/3}$$

$$h_{bn} = 9.34 \; x \; 10^{-6} \left(\frac{T_{gn} + T_{b0n}}{600} \right)^{.75} \left(\frac{g\rho^2}{\mu_{bn}^2} \left[\frac{T_{gn} - T_{b0n}}{T_{gn} + T_{b0n}} \right] \right)^{1/3} \qquad (18)$$

The density, ρ, remains constant by virtue of the constant volume and constant number of moles. The acceleration of gravity, g, also remains constant for all time points.

The specific heat of the gas which is required for Section 3A of the program is given by (4) below.

$$C_{pn} = 6.45 \; x \; 10^{-4} \left(T_{gn} + T_{s0n} \right) + 7.3353 - \frac{130728}{\left(T_{gn} + T_{s0n} \right)^2} \qquad (19)$$

Because the specific heat is a bulk property of all of the gas in the panel, it is affected by all of the surface area in the panel. Because the surface area of the salt is orders of magniture larger than the surface area of the explosion-isolation walls, the specific heat at each time is based solely on the surface temperature of the salt.

F.4.2.2 Program Section 2

The heat flux rates to the walls as well as the total heat transfer rates to the walls via convection and radiation are calculated in Section 2 of the program. Flux is required for the boundary condition for the heat conduction analysis of Section 3B and total heat flow is required for the change in gas temperature calculation in Section 3A.

The total heat flow values are given by (5) and (6) which for time step n become where h_{sn} and h_{bn} are given by (18). The total heat flows are used in Section 3A of the program evaluates the time rate of change of the gas temperature using equation (7).

$$Q_{rn} + \sigma\left(A_s\left[T_{gn}^4 - T_{s0n}^4\right] + A_b\left[T_{bn}^4 - T_{b0n}^4\right]\right)$$
$$Q_{cn} = A_s h_{sn}\left(T_{gn} - T_{s0n}\right) + A_b h_{bn}\left(T_{gn} - T_{bn}\right) \tag{20}$$

The total heat flows at time step n given by (20) are heat flow out of the gas occupying the panel volume and into the explosion-isolation walls. For the heat flow into the explosion-isolation walls, the areas, A_s and A_b cancel from the equations representing the boundary conditions at x = 0 for the transient heat conduction problems solved in Section 3B of the program. Thus, for Section 3B, the heat flux values are required. These are the same as (20) without the areas.

$$q_{rn} = \sigma\left(\left[T_{gn}^4 - T_{s0n}^4\right] + \left[T_{gn}^4 - T_{b0n}^4\right]\right)$$
$$q_{cn} = h_{sn}\left(T_{gn} - T_{s0n}\right) + h_{bn}\left(T_{bn} - T_{bn}\right) \tag{21}$$

where q_{rn} and q_{cn} are the heat fluxes due to radiation and convection.

For the total heat flow and heat flux due to radiation, the Stefan-Boltzmann constant is taken to be constand for all values of temperature and hence time.

$$\sigma = 1.355 \; x \; 10^{-12} \tag{22}$$

F.4.2.3 Program Section 3

Section 3 comprises the main body of the program.

F.4.2.3.1 Program Section 3A

Equation (7) governs the rate of change of gas temperature in the panel volume. Using the explicit finite difference approximation,

$$\frac{dT_g}{dt} = \frac{1}{\tau}\left(T_{gn+1} - T_{bn}\right)$$

where $\tau = \Delta t$ is the time increment, Equation (7) becomes

$$T_{gn+1} = T_{gn} - \tau \left(\frac{Q_{cn} + Q_{rn}}{10.54\ n_{CH4}\ C_{pn}} \right) \tag{23}$$

where Q_{cn}, Q_{rn}, and C_{pn} are given by (20) and (19) and n_{CH4} is an input representing the moles of methane in the panel volume at the time of the explosion. Equation (23) gives the gas temperature in the panel at time $t + \Delta t$ in terms of the gas temperature at time t and the total heat flow values at time t.

F.4.2.3.2 Program Section 3B

Section 3B of the program is the most complex. It solves two transient heat conduction problems assuming that the walls, floor, roof, and explosion-isolation walls are semi-infinite solids having thermal conductivities and diffusivities that may or may not be temperature dependent. In the case of the walls, floor and roof, the panel volume the conductivity and diffusivity of salt is dependent on temperature. Assuming that the explosion-isolation wall material is concrete, the conductivity and diffusivity of the explosion-isolation wall are independent of temperature.

Because of the temperature dependence of the conductivity and diffusivity of the salt, and the time-dependent spatial temperature distribution into the walls, floor and roof, the conductivity that is required for the boundary condition at $x = 0$ varies with time and the thermal diffusivity varies in both time and space. The partial differential equation for transient heat conduction when the diffusivity varies spatially is given by:

$$\frac{\partial}{\partial x}\left(\alpha \frac{\partial T}{\partial x} \right) = \frac{\partial T}{\partial t} \tag{a}$$

which can be expanded as:

$$\left(\frac{\partial \alpha}{\partial x} \right)\left(\frac{\partial T}{\partial x} \right) + \alpha \frac{\partial^2 T}{\partial x^2} = \frac{\partial T}{\partial t} \tag{b}$$

Using the finite difference approximations,

$$\frac{\partial \alpha}{\partial x} = \frac{1}{2\varepsilon}\left(\alpha_{m+1} - \alpha_{m-1}\right) \tag{ci}$$

$$\alpha\frac{\partial^2 T}{\partial x^2} = \frac{\alpha_m}{\varepsilon^2}\left(T_{m-1} - 2T_m + T_{m+1}\right) \tag{cii}$$

$$\frac{\partial T}{\partial x} = \frac{1}{2\varepsilon}\left(T_{m+1} - T_{m-1}\right) \tag{cii}$$

where e = Δx, the left hand side of equation (b) becomes

$$\left(\frac{\partial T}{\partial x}\right)\left(\frac{\partial T}{\partial x}\right) + \alpha\frac{\partial^2 T}{\partial x^2} = \frac{1}{4\varepsilon^2}\left(\left[\alpha_{m+1}-\alpha_{m-1}\right]\left[T_{m+1}-T_{m-1}\right]+4\alpha_m T_{m-1}-8\alpha_m T_m+4\alpha_m T_{m+1}\right) \tag{d}$$

or

$$= \frac{1}{4\varepsilon^2}\left(\alpha_{m+1}T_{m+1}-\alpha_{m+1}T_{m-1}-\alpha_{m-1}T_{m+1}+\alpha_{m-1}T_{m-1}\right)+ \frac{1}{4\varepsilon^2}\left(4\alpha_m T_{m-1}-8\alpha_m T_m+4\alpha_m T_{m+1}\right) \tag{e}$$

$$4\varepsilon^2\left(\left[\frac{\partial \alpha}{\partial x}\right]\left[\frac{\partial T}{\partial x}\right]+\alpha\frac{\partial^2 T}{\partial x^2}\right) = v_{m-1}\left(\alpha_{m-1}+4\alpha_m-\alpha_{m+1}\right)-8\alpha_m T_m+T_{m+1}\left(\alpha_{m+1}+4\alpha_m-\alpha_{m-1}\right) \tag{f}$$

Using an explicit finite difference representation of the time derivative as used in Section 3A.

$$\frac{\partial T_m}{\partial t} = \frac{1}{\Delta t}\left(T_{m\,n+1}-T_{m\,n}\right) \tag{g}$$

Substituting (f) and (g) into the partial differential equation (a),

$$T_{m-1\ n}\left(\alpha_{m-1}+4\alpha_m-\alpha_{m+1}\right)-8\alpha_m T_{m\ n}+T_{m+1\ n}\left(\alpha_{m+1}+4\alpha_m-\alpha_{m-1}\right) = \frac{1}{N}\left(T_{m\ n+1}-T_{m\ n}\right) \tag{h}$$

where

$$N = \frac{\Delta t}{4\varepsilon^2} \tag{i}$$

is analogous to the modulus for the case of constant diffusion. Solving (h) for $T_{m\ n+1}$

$$T_{m\ n+1} = T_{m-1\ n}N\left(\alpha_{m-1} + 4\alpha_m-\alpha_{m+1}\right)-\left(8N-1\right)\alpha_m T_{m\ n}+T_{m+1\ n}N\left(\alpha_{m+1}+4\alpha_m-\alpha_{m-1}\right) \tag{j}$$

For the case of constant diffusivity,

$$\alpha_{m-1} = \alpha_m = \alpha_{m+1} = \alpha$$

with

$$M = \frac{\alpha\Delta t}{\varepsilon^2} = 4\alpha N \tag{k}$$

equation (j) becomes

$$T_{m\ n+1} = M\left(T_{m+1\ n} + T_{m-1\ n}\right) - \left(2M-1\right)T_{m\ n} \tag{l}$$

which is the finite difference equation for the case of constant diffusivity (Carslaw and Jaeger, 1959). Thus, equation (j) reduces to the correct equation when the diffusivity is constant and is the finite difference equation for the case of variable diffusivity.

For a numerical stability criteria,

$$M<0.5 \tag{m}$$

the corresponding relation for the case of variable diffusivity becomes equation (n) for all m.

$$MAX(\alpha_m N) < 0.125 \tag{n}$$

The thermal conductivity and thermal diffusivity at each time point are evaluated from the temperature at that time and space as given previously for the temperature variation of the conductivity and diffusivity.

The boundary condition at x = 0, is the same as for the case of constant diffusivity,

$$-k_n \frac{\partial T_n}{\partial x} = q_{rn} + q_{cn} \tag{o}$$

where q_{rn} and q_{rn} are determined in Section 2. Using the finite difference relationship (Carslaw and Jaeger, 1959),

$$\frac{\partial T_n}{\partial x} = \frac{1}{2e}\left(-3T_{0\,n} + 4T_{1\,n} - T_{2\,n}\right) \tag{p}$$

equation (o) becomes:

$$-\frac{k_n}{2\varepsilon}\left(-3T_{0\,n} + 4T_{1\,n} - T_{2\,n}\right) = q_{rn} + q_{cn}$$

$$3T_{0\,n} - 4T_{1\,n} + T_{2\,n} = \frac{2\varepsilon}{k_n}\left(q_{rn} + q_{cn}\right) \tag{q}$$

Substituting for q_{rn} and q_{cn}:

$$3T_{0\,n} - 4T_{1\,n} + T_{2\,n} = \eta_n\left(T_{gn} - T_{0n}\right) + \gamma_n\left(T_{gn}^4 - T_{0n}^4\right)$$

where

$$\eta_n = \frac{2\varepsilon h_n}{-k_n} \tag{r}$$

and

Using the identity

and defining

$$\gamma_n = \frac{2\varepsilon\sigma}{k_n} \tag{s}$$

$$T_{gn}^4 - T_{0n}^4 = (T_{gn} - T_{0n})(T_{gn} + T_{0n})\left(T_{gn}^2 + T_{0n}^2\right)$$

$$f_n = (T_{gn} + T_{0n})\left(T_{gn}^2 + T_{0n}^2\right) \tag{t}$$

$$3T_{0n} - 4T_{1n} + T_{2n} = \left(\eta_n + \gamma_n f_n\right)(T_{gn} - T_{0n}) \tag{u}$$

For the case of both convection and radiation equation (u) is a fourth order equation in T_{0n} and has to be solved using a numerical technique such as Newton-Raphson iteration. Since the effect of radiation heating of the walls, floor, roof, and explosion-isolation walls leads to a more rapid cooling of the combustion gas following the explosion, and temperatures effects on the salt or explosion-isolation material is worse for longer durations, it is conservative to neglect radiation heat transfer. In this case, equation (u) becomes linear:

$$3T_{0n} - 4T_{1n} + T_{2n} = \eta_n\,(T_{gn} - T_{0n}) \tag{v}$$

which can be solved directly for T_{0n}:

$$T_{0n} = \frac{4T_{1n} - T_{2n} + \eta_n\,T_{gn}}{3 + \eta_n} \tag{w}$$

At each time the field equations are solved based on the previous time. The boundary condition (w) is then applied.

Equations (j) and (u) are formulated for both the salt comprising the walls, floor, and roof and for the explosion-isolation walls. As noted, the field equations for variable diffusivity reduce appropriately to the special case of a constant diffusivity so the above equations are sufficiently general to handle both the material of the explosion-isolation wall and the salt.

F.4.2.4 Program Section 4

In Section 4 of the program, the temperature values at time t+Δt (n+1) become the new values at time t (n). The time counter, n, is incremented by 1 and the program returns to Section 1 to compute the solution at the subsequent time step.

F.4.3 Initial Volume, Surface Area and Number of Moles

The volume of gas to be cooled via heat transfer to the walls, roof, floor, and explosion-isolation walls following an explosion is taken to correspond to the effective panel volume at the time when the air-methane mixture in the panel enters the explosive range. The effective volume is defined as:

$$V_{eff} = \phi V$$

where V is the panel volume considering closure of the panel and Φ is the porosity which accounts for the waste emplaced in the panel. Figure F-7 shows a plot of the effective volume as a function of time.

Based on Figure 4.2 of the Conceptual Design Report (DOE, 1995), the methane-air mixture in the panel volume enters the explosive range at 25 years. From Figure F-7 this corresponds to a panel volume of 1.6×10^{10} cm^3 at the time the postulated explosion occurs.

The surface area at the time of the postulated explosion was obtained from the volume at the time the methane air mixture enters the explosive range at 25 years and the initial ratio of surface area to volume.

$$A_s = \left(\frac{A_{sinit}}{V_{init}}\right) V$$

Figure F-8 shows a plot of panel surface area as a function of time.

Based on the air-methane mixture entering the explosive range at 25 years, the surface area at the time of the explosion is 1.6×10^8 cm^2. The area of two 14 foot x 14 foot explosion-isolation walls is 1.82×10^5 cm^2. Thus the area of the explosion-isolation walls is

$$\frac{1.82 \; x \; 10^5}{1.6 \; x \; 10^8} = 0.0014 = 0.14\%$$

of the total surface area.

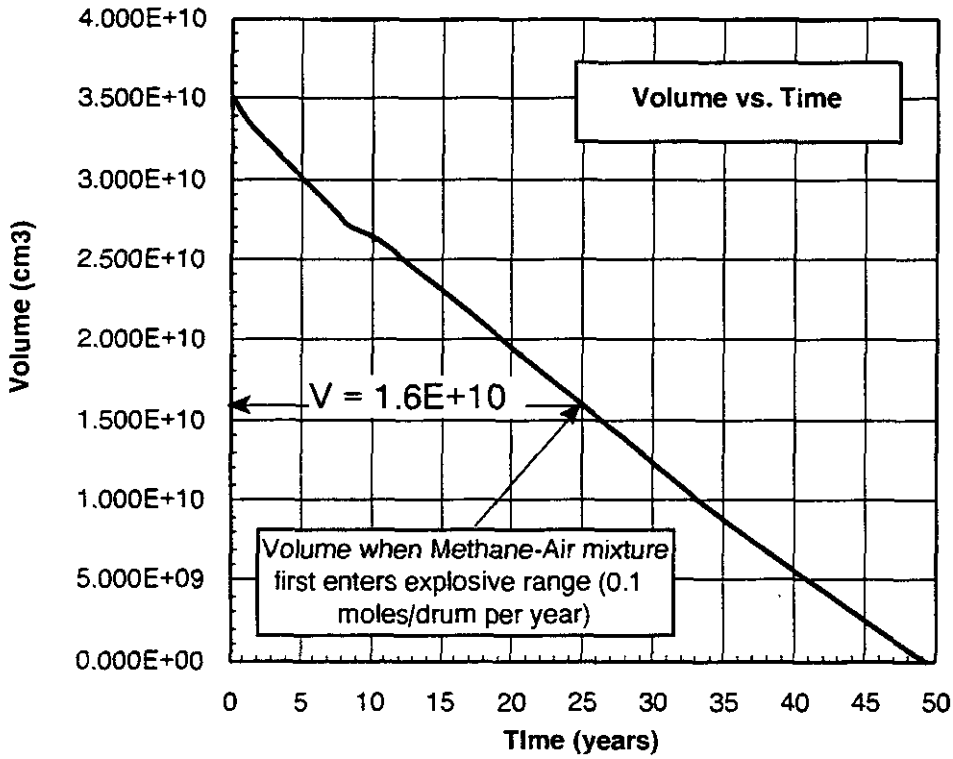

Figure F-7
Effective Panel Volume vs Time

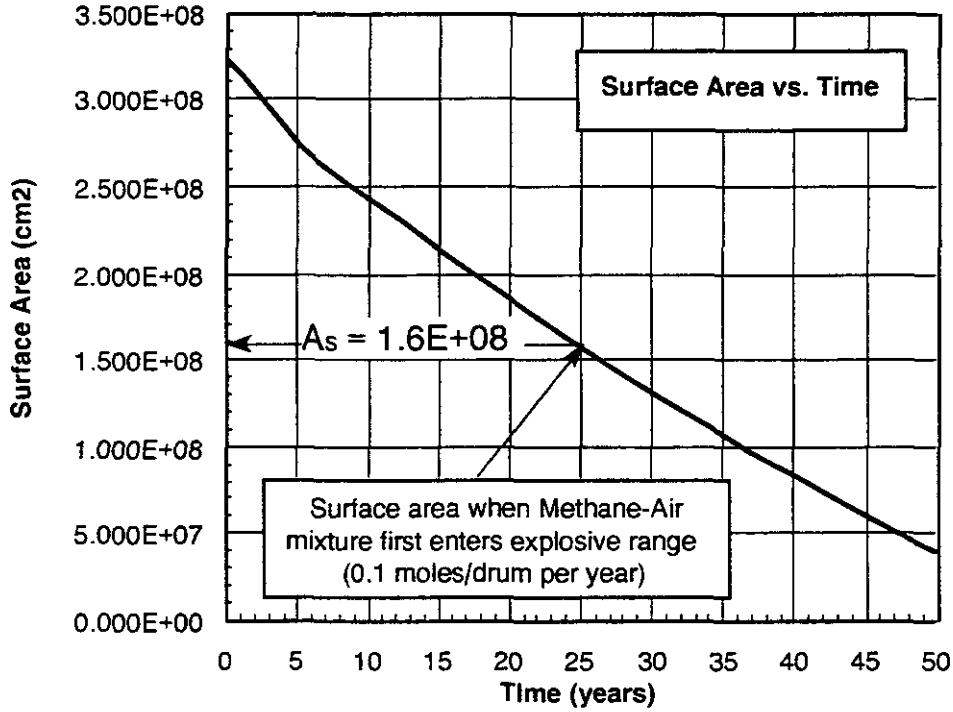

Figure F-8
Surface Area Rooms, Floor and Roof vs Time

The number of moles of combustion gas is found using the ideal gas law based on an initial pressure of 16 atmospheres (atm) and an initial temperature of 2,400 °K.

$$n = \frac{pV}{RT} \tag{24}$$

with

R = 82.06 cm^3-atm/mol-°K (ideal gas law constant)
p = 16 atm
V = 1.6×10^{10}
T = 2400 °K

$$n = \frac{16 \; x \; (1.6 \; x \; 10^{10})}{82.06 \; x \; 2400}$$

$$n = 1.3 \; x \; 10^6 \; moles$$

The program uses the number of moles of methane and air independently to calculate the density. Thus,

$$10.54 \; n_{CH4} = 1.3 \; x \; 10^6 \tag{25}$$

$$n_{CH4} = 1.233 \; x \; 10^5$$

$$n_{air} = 9.54 \; x \; n_{CH4} = 1.176 \; x \; 10^6$$

The density is given by

$$\frac{(1.233 \; x \; 10^5)(16) + (1.176 \; x \; 10^6)(29)}{1.6 \; x \; 10^{10}} = 0.002255$$

F.5.0 Results

The numerical formulation discussed in Section 4.0 was executed using a spatial grid size, ε - 1 cm and a time increment, τ = 10 seconds. No problems with numerical stability were encountered using these values.

At time t = 0, the initial heat transfer from the combustion gas to the salt and explosion-isolation walls results is a large temperature gradient at the surface. To represent this gradient accurately using a finite difference formulation would require an extremely small grid spacing as the initial temperature gradient extends only an infinitesimal distance into the surface. Using a grid spacing sufficiently small to accurately characterize the initial gradient would be prohibitive, relative to the number of mesh points and time steps required.

The initial conditions for the finite difference calculations were determined by using an exact solution for the case of constant convective heat transfer coefficient and constant gas temperature. The use of the closed form solution to determine the initial conditions assumes that the change in gas temperature over small initial times is small and that the heat transfer coefficient is weakly dependent on the temperature difference between the gas and the surfaces of the salt and explosion-isolation walls. Based on the closed form solution, the initial conditions for the finite difference model were taken at a time of 12.7 seconds following the explosion. For shorter initial times, the gradient had not propagated sufficiently far into the surfaces to be represented with a 1 cm. grid spacing. Thus, the initial time for the finite difference calculations was 12.7 seconds with initial temperatures based on the closed form solution.

Figure F-9 shows the gas temperature, salt temperature (walls, floor, and roof) and explosion-isolation wall temperature as a function of time following the explosion. Figure F-10 shows the temperature distribution into the explosion-isolation walls at various times following the explosion. Figure F-11 shows the temperature distribution into the salt at various times following the explosion.

Figure F-9 shows that the temperature of the gas has nearly reached the initial ambient conditions after about 2 hours. Over that span of time, elevated temperature in the explosion-isolation wall has a maximum extent of 15 cm (about 6 inches) into the explosion-isolation wall. Since the explosion-isolation wall is at least 36 inches (91.4 cm) thick, the elevated temperature will not reach the opposite side of the wall. Thus, the assumption of a semi-infinite body in the numerical model is not violated.

A comparison of the results shown on Figure F-9 with the results given in D'Appolonia (1978) is favorable. The ratios of surface area and volume used in D'Appolonia (1978) as well as the initial pressures are not the same as used for this analysis. The temperatures shown on Figure F-9 are slightly higher than those predicted for a pressure of 9 atm as shown

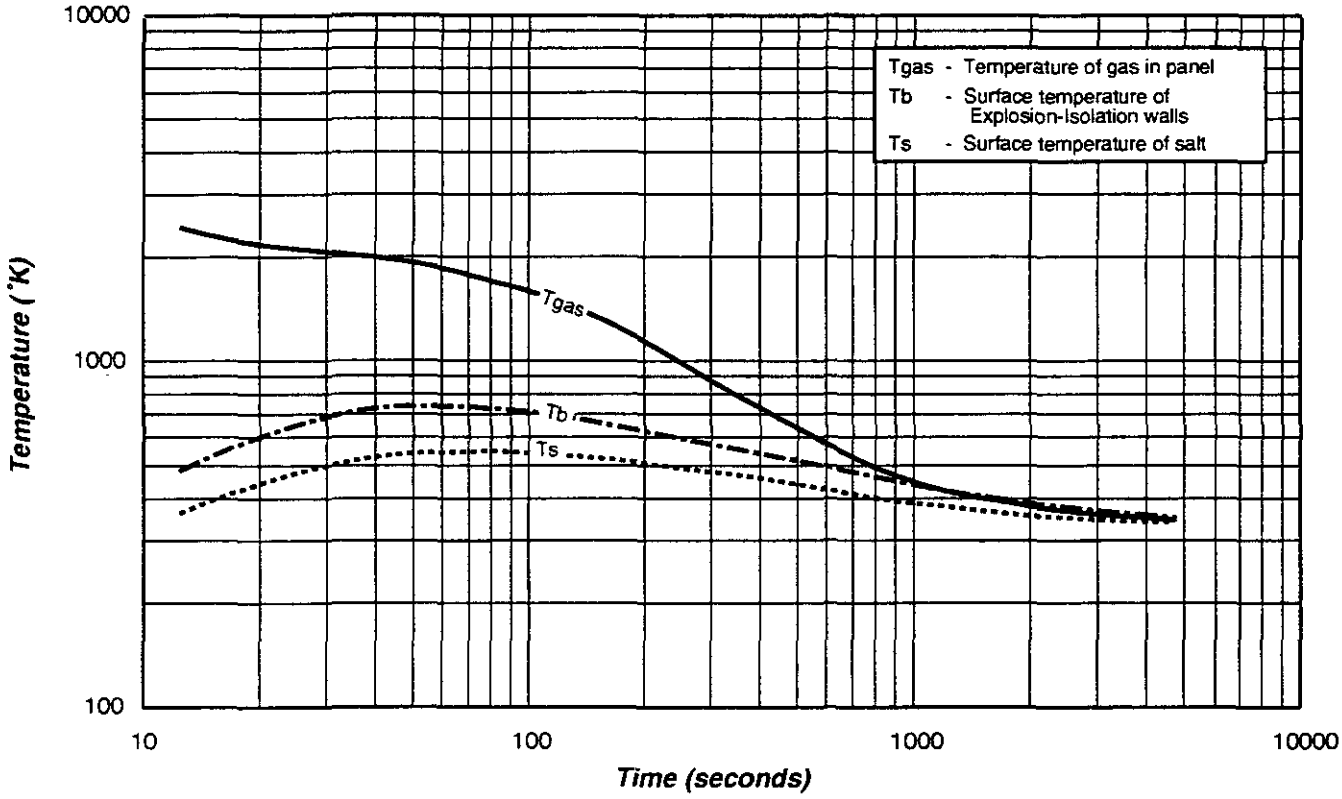

Figure F-9

Temperature Variation with Time for Gas, Salt, and Explosion-Isolation Walls

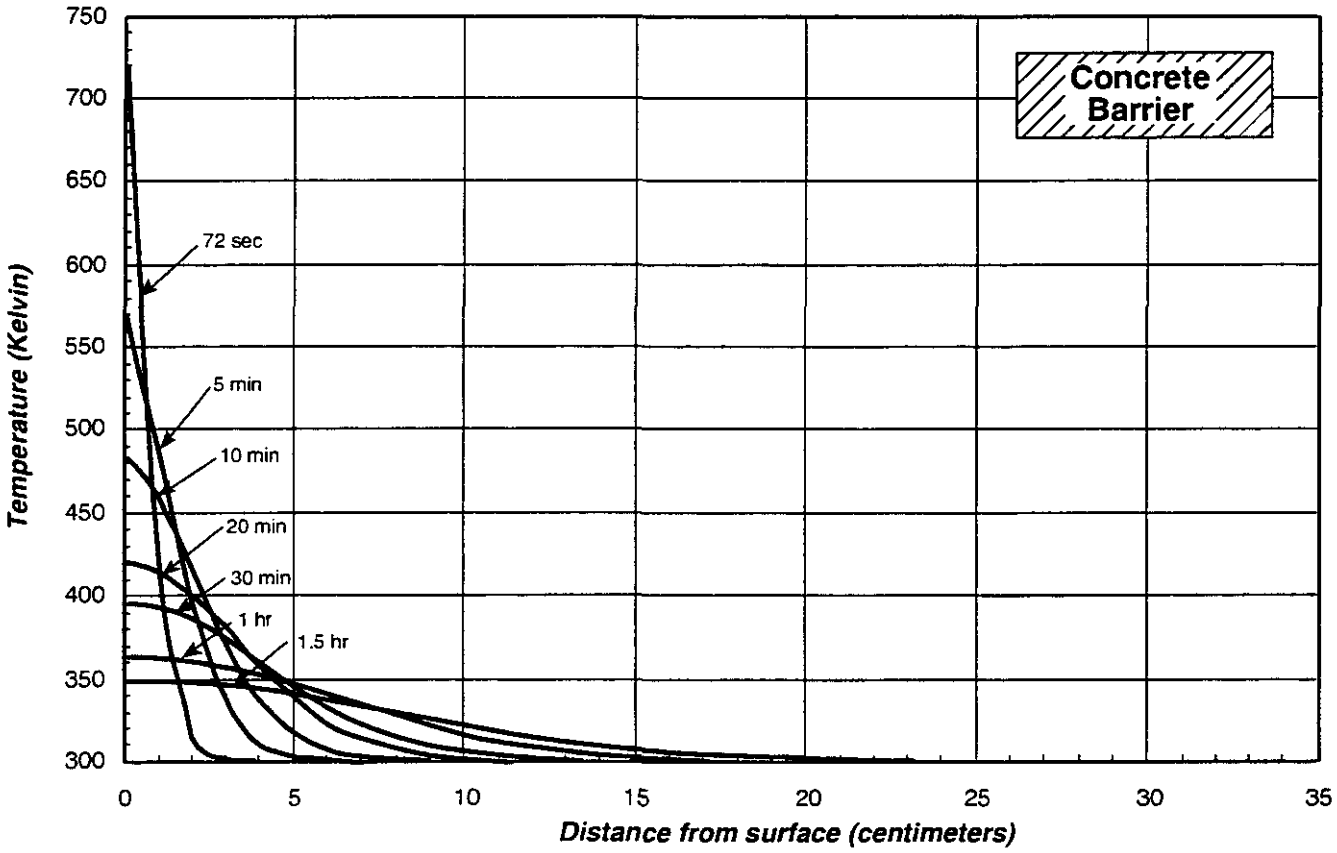

Figure F-10
Temperature Distribution with Time for Concrete Barrier

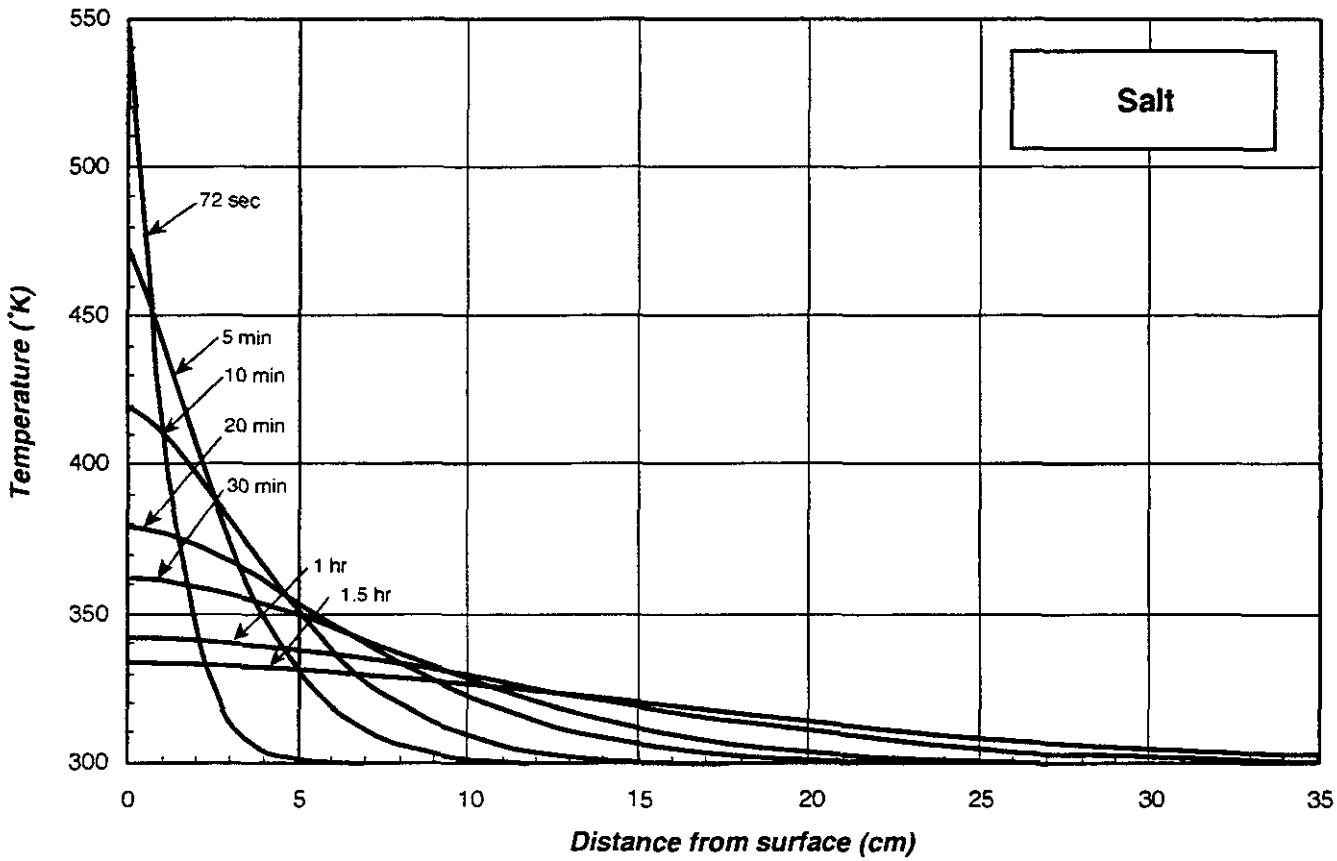

Figure F-11
Temperature Distribution with Time for Salt

in D'Appolonia [1978]. This is as expected since the initial pressure affects the number of moles which determines the rate of temperature decay in the gas. This is illustrated by comparison of the results for 9 atm with those for 27 atm shown in D'Appolonia (1978). The favorable comparison of the results shown on Figure F-9 with those of D'Appolonia (1978) provides verification of the numerical model used in these analyses.

F.6.0 References

Bodurtha, F. T., 1980, *Industrial Explosion Prevention and Control*, McGraw-Hill Book Company, New York, New York.

Carslaw, H. S., and J. C. Jaeger, 1959, *Conduction of Heat in Solids*, 2nd ed., Oxford at the Clarendon Press, Oxford, England.

D'Appolonia Consulting Engineers, 1978, "Potential for Hydrocarbon Explosions and Probable Related Impacts in Mechanically Mined Underground Crude Oil Storage Facilities," D'Appolonia Consulting Engineers, Pittsburg, Pennsylvania.

Krieg, R. D., 1983, "Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project," *SAND83-1908*, Sandia National Laboratories, Albuquerque, New Mexico.

Reid, R. C., J. M. Prausnitz, and T. K. Sherwood, 1977, *The Properties of Gases and Liquids*, 3rd ed., McGraw-Hill Book Company, New York, New York.

U.S. Department of Energy (DOE), 1995, "Conceptual Design for Operational Phase Panel Closure Systems," *DOE-WIPP-95-2957*, U.S. Department of Energy, WIPP Project Office, Carlsbad, New Mexico.

M

APPENDIX G
TECHNICAL SPECIFICATIONS

SECTION 01010

SUMMARY OF WORK

SECTION 01010

SUMMARY OF WORK

PART 1 - GENERAL

1.1 Scope
This section includes:

- Scope of Work
- Definitions and Abbreviations
- Drawings
- Work by Others
- Contractors Use of Site
- Contractors Use of Facilities
- Work Sequence
- Work Plan
- Submittals

1.2 Scope of Work
The Contractor shall furnish all labor, materials, equipment and tools to perform operations in connection with the construction of two (2) panel closure systems for each panel, one of each to be installed in the air intake drift and the air exhaust drift of a waste-emplacement panel, as shown on the drawings and called for in these specifications.

Four (4) possible arrangements of the concrete barrier and isolation walls are shown on the attached Figure 1 "Plan Variations." The specific requirements for the panel closure system will be determined by the Westinghouse WID prior to the time of installation and will be defined in the contract documents.

- Concrete barrier with disturbed rock zone (DRZ) removal up through clay seam G and down through marker bed 139 (MB 139) in combination with a construction isolation wall (Sketch A).

- Concrete barrier with DRZ removal in combination with an explosion isolation wall (Sketch B.)

- Concrete barrier without DRZ removal in combination with construction isolation wall (Sketch C).

- Concrete barrier without DRZ removal in combination with an explosion isolation wall (Sketch D).

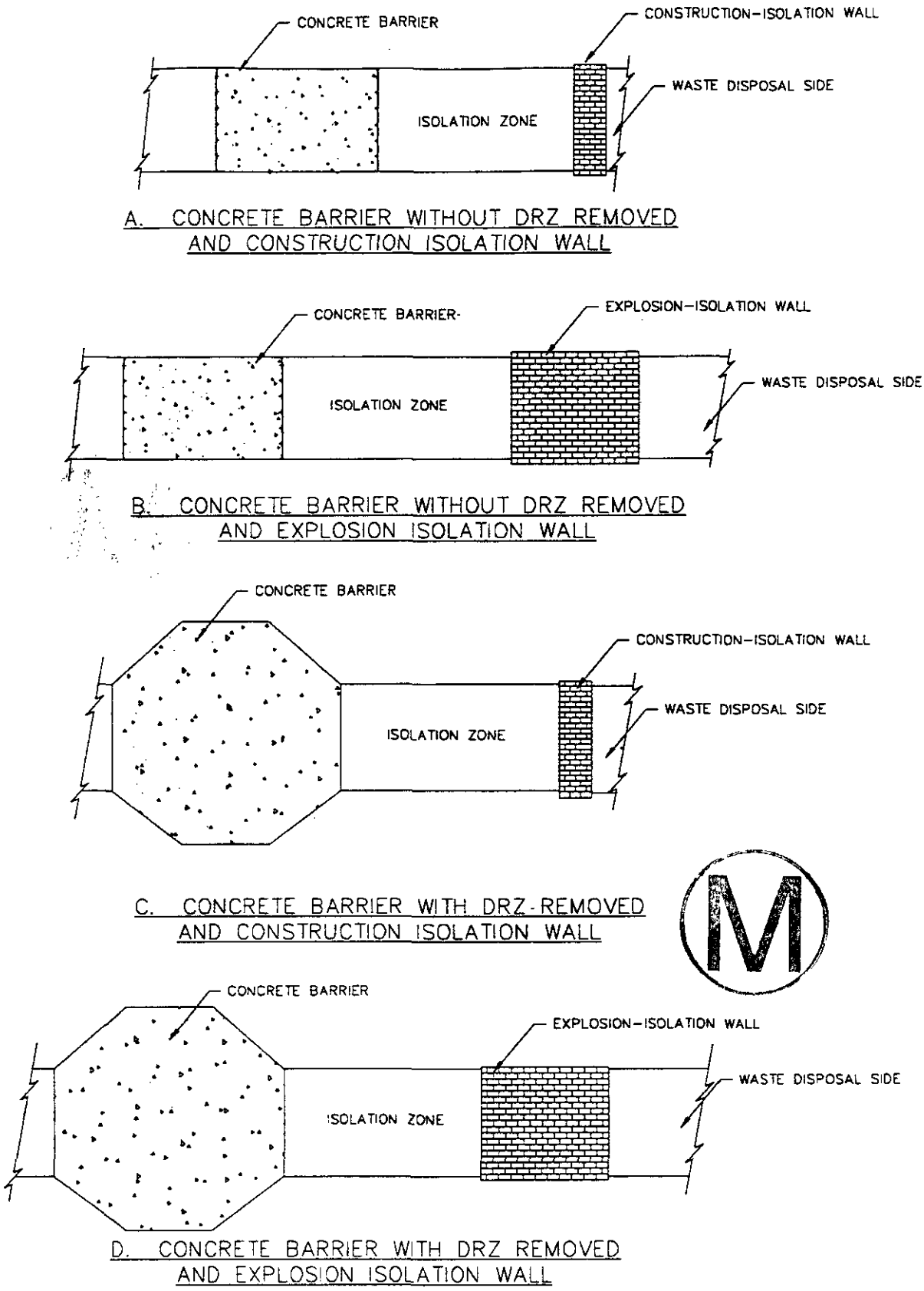

Figure 1
Plan Variations

The scope of work shall include but not be limited to the following units of work:

- Develop work plan, health and safety plan (HASP) and contractors quality control plan (CQCP)

- Prepare and submit all plans requiring approval

- Mobilize to site

- Coordinate construction with operations

- Perform the following for the air intake entry and the air exhaust entry.
  - Excavate the surface preparation for the explosion (or construction) isolation wall
  - Construct the explosion (or construction) isolation wall
  - Excavate the DRZ if required by contract
  - Install the form work for the concrete barrier
  - Place concrete for the concrete barrier
  - Grout the interface of concrete barrier/back wall
  - Provide contact grouting along the contact surface (if required by the engineer)

- Clean up construction areas in underground and above ground

- Submit all required record documents

- Demobilize from site

1.3 Definitions and Abbreviations

Definitions

Contact-handled waste—Contact-handled defense transuranic (TRU) waste with a surface dose rate not to exceed 200 millirem per hour.

Concrete barrier—A barrier placed in the access drifts of a panel to restrict the mass flow rate of volatile organic compounds (VOC).

Concrete block—Concrete used for construction of either an explosion-isolation wall or a construction-isolation wall.

Construction-isolation wall—A wall immediately adjacent to the panel waste-emplacement area that is made of concrete block, with mortar or of steel to isolate construction personnel from coming into contact with the waste.

Creep—Plastic deformation of salt under deviatoric stress.

Design migration limit—A mass flow rate that results in an exposure of the affected individual that is at least 1 order of magnitude below the health-based exposure levels for VOCs during the Waste Isolation Pilot Plant (WIPP) operational period.

Disturbed rock zone (DRZ)—A zone surrounding underground excavations where stress redistribution occurs with attendant dilation and fracturing.

Explosion-isolation wall—A concrete-block wall adjacent to the panel waste-emplacement area with mortar that can sustain the pressure and temperature transients of a methane explosion.

Health-based concentration level—The annual average concentration level for a VOC in air that must not be exceeded at the point of compliance.

Health-based migration limit—The mass flow rate of a VOC from all closed panels that results in the health-based concentration level at the point of compliance.

Hydration temperature—The transient temperature developed by a cementitious material due to the hydration of the cement.

Interface grouting—Grouting performed through grout boxes and pipe lines to fill the void at the concrete barrier/back-wall interface.

Methane explosion—A postulated deflagration caused by the buildup of methane gas to explosive levels.

Partial closure—The process of rendering a part of the hazardous waste management unit in the underground repository inactive and closed according to approved facility closure plans. The partial-closure process is considered complete after partial-closure activities are performed in accordance with approved Resource Conservation and Recovery Act (RCRA) partial closure plans.

Point of compliance—The operating point of compliance for VOC health-based exposure levels at the WIPP, which is the WIPP site boundary.

Remote-handled waste—Any of the various forms of high beta-gamma defense TRU waste requiring remote-handling due to a surface dose rate exceeding 200 millirem per hour.

Standard barrier—A concrete barrier emplaced into the panel-access drifts without major excavation of the surrounding rock.

Volatile Organic Compound (VOC)—Any VOC comprising the land-disposal-restricted indicator VOC constituents in the WIPP waste inventory.

Westinghouse—Westinghouse Electric Corporation, Waste Isolation Division (WID) as the construction management authority.

Abbreviations/Acronyms

ACI	American Concrete Institute
AISC	American Institute for Steel Construction
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
AWS	American Welding Society
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
EPA	U.S. Environmental Protection Agency
MB 139	Marker Bed 139
MSHA	U.S. Mining Safety and Health Administration
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
RCRA	Resource Conservation and Recovery Act
SMC	Salado Mass Concrete
USACE	U.S. Army Corps of Engineers
WID	Waste Isolation Division
WIPP	Waste Isolation Pilot Plant

1.4 List of Drawings

The following drawings are made apart of this specification:

762447-E1	Panel closure system, air intake and exhaust drifts, title sheet
762447-E2	Panel closure system, underground waste-emplacement panel plan
762447-E3	Panel closure system, air intake drift, construction details
762447-E4	Panel closure system, air exhaust drift, construction details
762447-E5	Panel closure system, construction and explosion walls, construction details
762447-E6	Panel closure system, air intake and exhaust drifts, grouting and miscellaneous details

1.5 Work by Others

Survey

All survey work to locate the barriers and walls, control and confirm excavation, and complete the work will be supplied by Westinghouse. All survey measurements for record purposes will also be performed by Westinghouse. The Contractor shall be responsible for verifying the excavation dimensions to develop the form work to fit the excavation.

Excavation

The Westinghouse WID may elect to perform certain portions of the work, notably the excavation. The work performed by the Westinghouse will be defined prior to the contract.

1.6 Contractor's Use of Site

Site Conditions

The site is located near Carlsbad, New Mexico, as shown on the site location maps and the title sheet drawing. The underground arrangements and location of the WIPP waste-emplacement panels are shown on the plan view drawing. The work described above is to construct the concrete barriers in the air intake and exhaust drifts of one of the panels upon completion of the disposal phase of that panel. The waste-emplacement panels are located approximately 2,150 feet below the ground surface. The Contractor shall visit the site and become familiar with the site and site conditions prior to preparing his bid proposal.

Contractor's Use of Site

Areas at the ground surface will be designated for the Contractor's use in assembling and storing his equipment and materials. The Contractor shall utilize only those areas designated.

Limited space within the underground area will be designated for the Contractor's use for storage of material and setup of equipment.

Coordination of Contractor's Work

The Contractor is advised that on-going waste emplacement and excavation operations are being conducted throughout the period of construction of the panel barrier system. The Contractor shall coordinate his construction operations with that of the waste emplacement and mining operations. All coordination shall be through Westinghouse WID.

1.7 Contractor's Use of Facilities

Existing facilities at the site which are available for use by the Contractor are:

- WIPP roadheader
- Waste shaft conveyance
- Salt skip hoist
- (1) 20 ton forklift

- (1) 40 ton forklift
- 460 volt AC, 3 phase power
- Water (underground, at waste shaft only) (above ground, at location designated by Engineer)

Additional information on these facilities is presented in Section 02010.

1.8 Work Sequence
Work Sequence shall be as shown on the drawings and directed by Westinghouse WID .

1.9 Work Plan
The Contractor shall prepare and submit for approval by Westinghouse WID a Work Plan fully describing his proposed construction operation. The work plan shall define all proposed equipment. The work plan shall also include the method of excavation, grouting, and pumping concrete. The work plan shall also contain such items as control of surface dust emissions. No work shall be performed prior to approval of the Work Plan.

1.10 Health and Safety Plan (HASP)
The Contractor shall obtain, review, and agree to applicable portions of the existing WIPP Safety Manual, WP 12-1. The Contractor shall prepare and submit for approval to Westinghouse, a project-specific HASP taking into account all applicable sections of the WIPP Safety Manual. The Contractor shall also perform a Job Hazard Analysis in accordance with WP 12-111.

1.11 Contractor Quality Control Plan (CQCP)
The Contractor shall prepare and submit for approval to Westinghouse a CQCP identifying all personnel and procedures to produce an end product which complies with the contract requirements. The CQCP shall comply with all Westinghouse WID requirements and Section 01400, Contractor Quality Control, of this specification.

1.12 Submittals
Submittals shall be in accordance with Westinghouse WID Submittal Procedures and as required by the individual specifications.

PART 2 - PRODUCTS

(Not used)

PART 3 - EXECUTION

(Not Used)

SECTION 01090

REFERENCE STANDARDS

SECTION 01090

REFERENCE STANDARDS

PART 1 - GENERAL

1.1 Scope
This section includes:

- Provision of Reference Standards at Site.
- Acronyms used in Contract Documents for Reference Standards. Source of Reference Standards.

1.2 Quality Assurance

For products or workmanship specified by association, trade, or Federal Standards, comply with requirements of the standard, except when more rigid requirements are specified or are required by applicable codes.

Conform to reference by date of issue current on the date of the owner-contractor agreement.

The Contractor shall obtain copy of the standards referenced in the individual specification sections. Maintain a copy at jobsite during submittals, planning, and progress of the specific work, until completion of work.

Should specified reference standards conflict with the contract documents, request clarification from the Engineer before proceeding.

1.3 Schedule of References
Various publications are referenced in other sections of the specifications to establish requirements for the work. These referenced are identified by documents number and title. The addresses of the organizations whose publications are referenced are listed below.

ACI	ACI International P.O. Box 19150 Detroit,MI 48219-0150 Ph: 313-532-2600 Fax: 313-533-4747

AITC	American Institute of Timber Construction 7012 So. Revere Parkway, Suite 140 Englewood, CO 80112 Ph: 303-792-9559 Fax: 303-792-0669
AISC	American Institute of Steel Construction One E. Wacker Dr., Suite 3100 Chicago, IL 60601-2001 Ph: 312-670-2400 Fax: 312-670-5403
ANSI	American National Standards Institute 11 West 42nd St. New York NY 10036 pH: 212-642-4900 Fax: 212-302-1286
API	American Petroleum Institute 1220 L. St., NW Washington, DC 20005 Ph: 202-682-8375 Fax: 202-962-4776
ASTM	American Society for Testing and Materials 1916 Race St. Philadelphia, PA 19103 Ph: 610-832-9585 Fax: 215-977-9679
AWS	American Welding Society 550 LeJeune Road Miami, FL 33135 Ph: 800-443-9353 Fax: 305-443-7559
CFR	Code of Federal Regulations Government Printing Office Washington, DC 20402 Ph: 202-783-3238 Fax: 202-223-7703

EPA	Environmental Protection Agency Public Information Center 401 M St., SW Washington, DC 20460 Ph: 202-260-2080
FTM-STO	Federal Test Method Standards Standardization Documents Order Desk Bldg. 4D 700 Robbins Ave. Philadelphia, PA 19111-5094 Ph: 215-697-2179 Fax: 215-697-2978
NRMCA	National Ready-Mixed Concrete Association 900 Spring St. Silver Spring, MD 20910 Ph: 301-587-1400 Fax: 301-585-4219
NTIS	National Technical Information Service U.S. Department of Commerce Springfield, VA 22161 (703) 487-4650
PCA	Portland Cement Association 5420 Old Orchard Road Skokie, IL 60077
USACE	U.S. Army Corps of Engineers U.S. Army Engineer Waterway Experiment Station ATTN: Technical Report Distribution Section, Services Branch, TIC 3909 Halls Ferry Rd. Vicksburg, MS 39180-6199 Ph: 601-634-2355 Fax: 601-634-2506
WID	Westinghouse Electric Corporation Waste Isolation Division Carlsbad, New Mexico 88221

End of Section

SECTION 01400
CONTRACTOR QUALITY CONTROL

SECTION 01400

CONTRACTOR QUALITY CONTROL

PART 1 - GENERAL

1.1 Scope
This section includes:

- Contractor Quality Control Plan (CQCP)
- Reference Standards
- Quality Assurance
- Tolerances
- Testing Services
- Inspection Services
- Submittals

1.2 Related Sections

- 01090 - Reference Standards
- 01600 - Material and Equipment
- 02222 - Excavation
- 02722 - Grouting
- 03100 - Concrete Formwork
- 03300 - Cast-in-Place Concrete
- 04100 - Mortar
- 04300 - Unit Masonry System

1.3 Contractor Quality Control Plan
The Contractor shall prepare and submit for approval by Westinghouse WID, a Quality Control Plan, as described in Section 3.2. No work shall be performed prior to approval of the Contractor's Quality Control Plan.

1.4 References and Standards
Refer to individual specification sections for standards referenced therein, and to Section 01090 - Reference Standards for general listing.

Standards referenced in this section are as follows:

ASTM C1077-95a	Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation

ASTM C1093-88	Practice for Accreditation of Testing Agencies for Unit Masonry
ASTM E329-95	Practice for Use in the Evaluation of Inspection and Testing Agencies as Used in Construction
ASTM E543-95	Practice for Determining the Qualification of Nondestructive Testing Agencies
ASTM E548-94	Practice for Preparation of Criteria for Use in the Evaluation of Testing Laboratories and Inspection Bodies

1.5 Quality Assurance

- Monitor quality control over suppliers, manufacturers, products, services, site conditions, and workmanship, to produce work of specified quality
- Comply with specified standards as minimum quality for the work except where more stringent tolerances, codes, or specified requirements indicate higher standards or more precise workmanship
- Perform work by persons qualified to produce required and specified quality
- Verify that field measurements are as indicated on shop drawings
- Secure products in place with positive anchorage devices designed and sized to withstand stresses, vibration, physical distortion, or disfigurement.

1.6 Tolerances

Monitor excavation fabrication and installation tolerance control of work and products to produce acceptable work. Do not permit tolerances to accumulate.

Adjust products to appropriate dimensions; position before securing products in place.

1.7 Testing Services

Unless otherwise indicated by Westinghouse WID, the Contractor shall employ an independent firm to perform the testing services and other services specified in the individual specification sections, and as required by Westinghouse WID. Testing and source quality control may occur on or off the project site.

The testing laboratory shall comply with applicable sections of the reference standards and shall be authorized to operate in the state in which the project is located.

Testing equipment shall be calibrated at reasonable intervals with devices of an accuracy traceable to either the National Bureau of Standards or accepted values of natural physical constants.

1.8 Inspection Services

The Contractor shall employ an independent firm to perform inspection services as a supplement to the Contractor's quality control as specified in the individual specification sections, and as required by Westinghouse WID. Inspection may occur on or off the project site.

The inspection firm shall comply with applicable sections of the reference standards.

1.9 Submittals

The Contractor shall submit a Contractors' Quality Control Plan as described herein.

Prior to start of work, the Contractor shall submit for approval, the testing laboratory name, address, telephone number and name of responsible officer of the firm. He shall also submit a copy of the testing laboratory compliance with the reference ASTM standards, and a copy of report of laboratory facilities inspection made by Materials Reference Laboratory of National Bureau of Standards with memorandum of remedies of any deficiencies reported by the inspection.

Prior to start of work, the Contractor shall submit for approval the inspection firm name, address, telephone number and name of responsible officer of the firm. He shall also submit the personnel proposed to perform the required inspection, along with their individual qualifications and certifications (Example: Certified AWS Welding Inspector.)

PART 2 - PRODUCTS

Not used.

PART 3 - EXECUTION

3.1 General

The Contractor is responsible for quality control and shall establish and maintain an effective quality control system. The quality control system shall consist of plans, procedures, and organization necessary to produce an end product which complies with the contract requirements. The system shall cover all construction operations, both on site and off site, and shall be keyed to the proposed construction sequence. The project superintendent will be held responsible for the quality of work on the job. The project superintendent in this context shall mean the individual with the responsibility for the overall management of the project including quality and production.

3.2 Quality Control Plan

3.2.1 General

The Contractor shall furnish for review and approval by Westinghouse WID, not later than 30 days after receipt of notice to proceed, the Contractor Quality Control (CQC) Plan proposed to implement the requirements of the Contract. The plan shall identify personnel, procedures, control, instructions, test, records, and forms to be used. Construction will be permitted to begin only after acceptance of the CQC Plan.

3.2.2 Content of the CQC Plan

The CQC Plan shall include, as a minimum, the following to cover all construction operations, both on site and off site, including work by subcontractors, fabricators, suppliers, and purchasing agents:

- A description of the quality control organization, including a chart showing lines of authority and acknowledgment that the CQC staff shall implement the control system for all aspects of the work specified. The staff shall include a CQC System Manager who shall report to the project superintendent.

- The name, qualifications (in resume format), duties, responsibilities, and authorities of each person assigned a CQC function.

- Description of the CQC System Manager's responsibilities and delegation of authority to adequately perform the functions of the CQC System Manager, including authority to stop work which is not in compliance with the contract. The CQC System Manager shall issue letters of direction to all other various quality control representatives outlining duties, authorities, and responsibilities.

- Procedures for scheduling, reviewing, certifying, and managing submittals, including those of subcontractors, off site fabricators, suppliers, and purchasing agents. These procedures shall be in accordance with Westinghouse WID Submittal Procedures.

- Control, verification, and acceptance testing procedures for each specific test to include the test name, specification paragraph requiring test, feature of work to be tested, test frequency, and person responsible for each test. (Laboratory facilities will be subject to approval by Westinghouse WID.)

- Procedures for tracking construction deficiencies from identification through acceptable corrective action. These procedures will establish verification that identified deficiencies have been corrected.

- Reporting procedures, including proposed reporting formats.

- A list of the definable features of work. A definable feature of work is a task which is separate and distinct from other tasks and has separate control requirements. It could be identified by different trades or disciplines, or it could be work by the same trade in a different environment. Although each section of the specifications may generally be considered as a definable feature of work, there are frequently more than one definable feature under a particular section. This list will be submitted to Westinghouse WID for approval.

3.2.3 Acceptance of Plan

Acceptance of the Contractor's plan is required prior to the start of construction. Acceptance is conditional and will be predicated on satisfactory performance during the construction. The Owner reserves the right to require the Contractor to make changes in his CQC Plan and operations including removal of personnel, as necessary, to obtain the quality specified.

3.2.4 Notification of Changes

After acceptance of the CQC Plan, the Contractor shall notify Westinghouse WID in writing of any proposed change. Proposed changes are subject to acceptance by Westinghouse WID.

3.3 Quality Control Organization

3.3.1 General

The requirements for the CQC organization are a CQC System Manager and sufficient number of additional qualified personnel supplemented by independent testing and inspection firms as required by the specifications, to ensure contract compliance. The Contractor shall provide a CQC organization which shall be at the site at all times during progress of the work and with complete authority to take any action necessary to ensure compliance with the contract. All CQC staff members shall be subject to acceptance by Westinghouse WID.

3.3.2 CQC System Manager

The Contractor shall identify as CQC System Manager an individual within his organization at the site of the work who shall be responsible for overall management of CQC and have the authority to act in all CQC matters for the Contractor. The CQC System Manager shall be a graduate engineer, with a minimum of five years construction experience on construction similar to this contract. This CQC System Manager will be employed by the prime Contractor. The CQC System Manager shall be assigned no other duties. An alternate for the CQC System Manager will be identified in the plan to serve in the event of the System Manager's absence. The requirements for the alternate will be the same as for the designated CQC System Manager.

3.3.3 CQC Personnel

In addition to CQC personnel specified elsewhere in the contract, the Contractor shall provide as part of the CQC organization specialized personnel or third party inspectors to assist the CQC System Manager. These individuals shall be employed by the prime Contractor; be

responsible to the CQC System Manager; have the necessary education and/or experience. These individuals shall have no other duties other than quality control.

3.3.4 Organizational Changes

The Contractor shall maintain his CQC staff at full strength at all times. When it is necessary to make changes to the CQC staff the Contractor shall revise the CQC Plan to reflect the changes and submit the changes to Westinghouse WID for acceptance at the Contractors' expense.

3.4 Tests

3.4.1 Testing Procedure

The Contractor shall perform specified or required tests to verify that control measures are adequate to provide a product which conforms to contract requirements. Upon request, the Contractor shall furnish to Westinghouse WID duplicate samples of test specimens for possible testing by Westinghouse WID. Testing includes operation and/or acceptance tests when specified. The Contractor shall procure the services of an approved testing laboratory. The Contractor shall perform the following activities and record and provide the following data:

- Verify that testing procedures comply with contract requirements.
- Verify that facilities and testing equipment are available and comply with testing standards.
- Check test instrument calibration data against certified standards.
- Verify that recording forms and test identification control number system, including all of the test documentation requirements, have been prepared.
- Results of all tests taken, both passing and failing tests, will be recorded on the CQC report for the date taken. Specification paragraph reference, location where tests were taken, and the sequential control number identifying the test will be given. If approved by Westinghouse WID, actual test reports may be submitted later with a reference to the test number and date taken. An information copy of tests performed by an off site or commercial test facility will be provided directly to Westinghouse WID. Failure to submit timely test reports as stated may result in nonpayment for related work performed and disapproval of the test facility for this contract.

3.5 Testing Laboratory

The testing laboratory shall provide qualified personnel to perform specified sampling and testing of products in accordance with specified standards, and ascertain compliance of materials and mixes with requirements of Contract Documents. The testing laboratory shall promptly notify Westinghouse WID and Contractor of any observed irregularities or non-conformance of Work or Products.

Reports indicating results of tests, and compliance (or noncompliance) with the contract documents will be submitted in accordance with Westinghouse WID submittal procedures.

The Contractor shall cooperate with the independent testing firm, furnish samples, storage, safe access, and assistance by incidental labor as required. Testing by the independent firm does not relieve the contractor of the responsibility to perform the work to the contract requirements.

The laboratory may not:

- Release, revoke, alter, or enlarge on requirements of the contract
- Approve or accept any portion of the work
- Assume any duties of the Contractor.

The laboratory has no authority to stop the work.

3.6 Inspection Services

The inspection firm shall provide qualified personnel at site to supplement the Contractor's Quality Control Program to perform specified inspection of Products in accordance with specified standards. He shall ascertain compliance of materials and mixes with requirements of Contract Documents, and promptly notify the CQC System Manager, Westinghouse WID and the Contractor of observed irregularities or non-conformance of Work or Products. The inspector does not have the authority to stop the work. The inspector shall refer such cases to the CQC System Manager who has the authority to stop work (see Section 3.2.2).

Reports indicating results of the inspection and compliance (or noncompliance) with the contract documents will be submitted in accordance with Westinghouse WID submittal procedures.

The Contractor shall cooperate with the independent inspection firm, furnish samples, storage, safe access and assistance by incidental labor, as requested.

Inspection by the independent firm does not relieve the Contractor of the responsibility to perform the work to the contract requirements.

3.7 Completion Inspection

3.7.1 Pre-Final Inspection

At the completion of all work the CQC System Manager shall conduct an inspection of the work and develop a "punch list" of items which do not conform to the approved drawings and specifications. Once this is accomplished the Contractor shall notify Westinghouse WID that the facility is complete and is ready for the "Prefinal" inspection. Westinghouse WID will perform this inspection to verify that the facility is complete. A "Final Punch List" will be developed as a result of this inspection. The Contractor's CQC System Manager shall ensure

that all items on this list have been corrected and notify Westinghouse WID so that a "Final" inspection can be scheduled. Any items noted on the "Final" inspection shall be corrected in a timely manner. These inspections and any deficiency corrections required by this paragraph will be accomplished within the time slated for completion of the entire work.

3.7.2 Final Acceptance Inspection

The final acceptance inspection will be formally scheduled by Westinghouse WID based upon notice from the Contractor. This notice will be given to Westinghouse WID at least 14 days prior to the final acceptance inspection and must include the Contractor's assurance that all specific items previously identified to the Contractor as being unacceptable, along with all remaining work performed under the contract, will be complete and acceptable by the date scheduled for the final acceptance inspection.

3.8 Documentation

The Contractor shall maintain current records providing factual evidence that required quality control activities and/or tests have been performed. These records shall include the work of subcontractors and suppliers and shall be on an acceptable form that includes, as a minimum, the following information:

- Contractor/subcontractor and their area of responsibility.
- Operating plant/equipment with hours worked, idle, or down for repair.
- Work performed each day, giving location, description, and by whom.
- Test and/or quality control activities performed with results and references to specifications/drawings requirements. List deficiencies noted along with corrective action.
- Quantity of materials received at the site with statement as to acceptability, storage, and reference to specifications/drawings requirements.
- Submittals reviewed, with contract reference, by whom, and action taken.
- Off-site surveillance activities, including actions taken.
- Instructions given/received and conflicts in plans and/or specifications.
- Contractor's verification statement.

These records shall indicate a description of trades working on the project; the number of personnel working; weather conditions encountered; and any delays encountered. These records shall cover both conforming and deficient features and shall include a statement that equipment and materials incorporated in the work and workmanship comply with the contract. The original and one copy of these records in report form shall be furnished to Westinghouse

WID daily. Reports shall be signed and dated by the CQC System Manager. The report from the CQC System Manager shall include copies of test reports and copies of reports prepared by all subordinate quality control personnel.

3.9 Notification of Noncompliance

Westinghouse WID will notify the Contractor of any detected noncompliance with the foregoing requirements. The Contractor shall take immediate corrective action after receipt of such notice. Such notice, when delivered to the Contractor at the worksite, shall be deemed sufficient for the purpose of notification. If the Contractor fails or refuses to comply promptly, Westinghouse WID may issue an order stopping all or part of the work until satisfactory corrective action has been taken. No part of the time lost due to such stop orders shall be made the subject of claim for extension of time or for excess costs or damages by the Contractor.

End of section.

M

SECTION 01600
MATERIAL AND EQUIPMENT

SECTION 01600

MATERIAL AND EQUIPMENT

PART 1 - GENERAL

1.1 Scope
This section includes:

- Equipment
- Products
- Transportation and handling
- Storage and protection
- Substitutions

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 02010 - Mobilization and Demobilization
- 02222 - Excavation
- 02722 - Grouting
- 03100 - Concrete Formwork
- 03300 - Cast-in-Place Concrete
- 04100 - Mortar
- 04300 - Unit Masonry System

1.3 Equipment
The Contractor shall specify his proposed equipment in the Work Plan. Power equipment for use underground shall be either electrical or diesel engine driven. All diesel engine equipment shall be certified for use underground.

1.4 Products
The Contractor shall specify in the Work Plan, or in subsequently required submittals the proposed products including, but not limited to the grout mix and its components, concrete mix and its components, mortar mix and its components, formwork, and masonry. The proposed products shall be supported by laboratory test results as required by the specifications. All products shall be subject to approval by Westinghouse WID.

1.5 Transportation and Handling

- Transport and handle products in accordance with manufacturer's instructions.
- Promptly inspect shipments to ensure that products comply with requirements, quantities are correct, and products are undamaged.
- Provide equipment and personnel to handle products by methods to prevent soiling, disfigurement, or damage.

1.6 Storage and Protection

- Store and protect products in accordance with manufacturers' instructions.
- Store with seals and labels intact and legible.
- Store sensitive products in weather tight, climate controlled, enclosures in an environment favorable to product.
- For exterior storage of fabricated products, place on sloped supports above ground.
- Cover products subject to deterioration with impervious sheet covering. Provide ventilation to prevent condensation and degradation of products.
- Store loose granular materials on solid flat surfaces in a well-drained area. Prevent mixing with foreign matter.
- Provide equipment and personnel to store products by methods to prevent soiling, disfigurement, or damage.
- Arrange storage of products to permit access for inspection. Periodically inspect to verify products are undamaged and are maintained in acceptable condition.

1.7 Substitutions

1.7.1 Equipment Substitutions

The Contractor may substitute equipment for that proposed in the Work Plan subject to Westinghouse WID's approval. The Contractor shall demonstrate the need for the substitution, and the applicability of the proposed substitute equipment.

1.7.2 Product Substitutions

The Contractor may not substitute products after the proposed products have been approved by Westinghouse WID unless he can demonstrate that the supplier/source of that product no longer exists in which case he shall submit alternate products with lab test results to

Westinghouse WID for approval. In the case that product is a component in a mix, the Contractor shall perform mix testing using that component and submit laboratory test results.

PART 2 - PRODUCTS

Not used.

PART 3 - EXECUTION

Not used.

End of section.

M

SECTION 02010
MOBILIZATION AND DEMOBILIZATION

SECTION 02010

MOBILIZATION AND DEMOBILIZATION

PART 1 - GENERAL

1.1 Scope
This section includes:

- Mobilization of equipment and facilities to site
- Contractor use of site
- Use of existing facilities
- Demobilization of equipment and facilities
- Site cleanup

1.2 Related Sections

- 01010 - Summary of Work
- 01600 - Material and Equipment

PART 2 - PRODUCTS

Not used.

PART 3 - EXECUTION

3.1 Mobilization of Equipment and Facilities to Site
Upon authorization to proceed, the Contractor shall mobilize his equipment and facilities to the jobsite. Equipment and facilities shall be as specified, and as defined in the Contractor's Work Plan. The Contractor shall erect the batch plant and assemble his equipment and materials in the areas designated by Westinghouse WID. Facilities shall be located as near as practical to the existing utilities.

Westinghouse WID will provide utilities (460 volt AC, 3 phase, and water) at designated locations. The Contractor shall be responsible for all hookups and tie-ins required for his operations.

The Contractor shall be responsible for providing his own office, storage, and sanitary facilities.

Areas will be designated for the Contractor's use in the underground area in the vicinity of the panel closure system installation. These areas are limited.

3.2 Use of Site

The Contractor shall use only those areas specifically designated for his use by Westinghouse WID. The Contractor shall limit his on-site travel to the specific routes required for performance of his work, and designated by Westinghouse WID.

3.3 Use of Existing Facilities

Existing facilities at the site which are available for use by the Contractor are:

- WIPP roadheader
- Waste shaft conveyance
- Salt skip hoist
- (1) 20 ton forklift
- (1) 40-ton forklift
- 460 Volt AC, 3 phase power
- Water (in mine, at waste shaft only-above ground at location designated by Westinghouse WID).

The Contractor shall arrange for use of the facilities with Westinghouse WID and coordinate his actions/requirements with that of the ongoing operations.

Use of water in the underground will be restricted. No washout or cleanup will be permitted in the underground. Above ground washout/cleanup or equipment will be allowed in the areas designated by Westinghouse WID.

The Contractor is cautioned to be aware of the physical dimensions of the waste conveyance and the air lock (see Figures 2 and 3, attached).

The Contractor shall be responsible for any damage incurred by the existing site facilities as a result of his operations. Any damage shall be reported immediately to Westinghouse WID and repaired at the Contractor's cost.

3.4 Demobilization of Equipment and Facilities

At completion of this work, the Contractor shall demobilize his equipment and facilities from the job site. The batch plant shall be disassembled and removed along with any unused material. All Contractor's equipment and materials shall be removed from the mine and all disturbed areas restored. Utilities shall be removed to their connection points unless otherwise directed by Westinghouse WID.

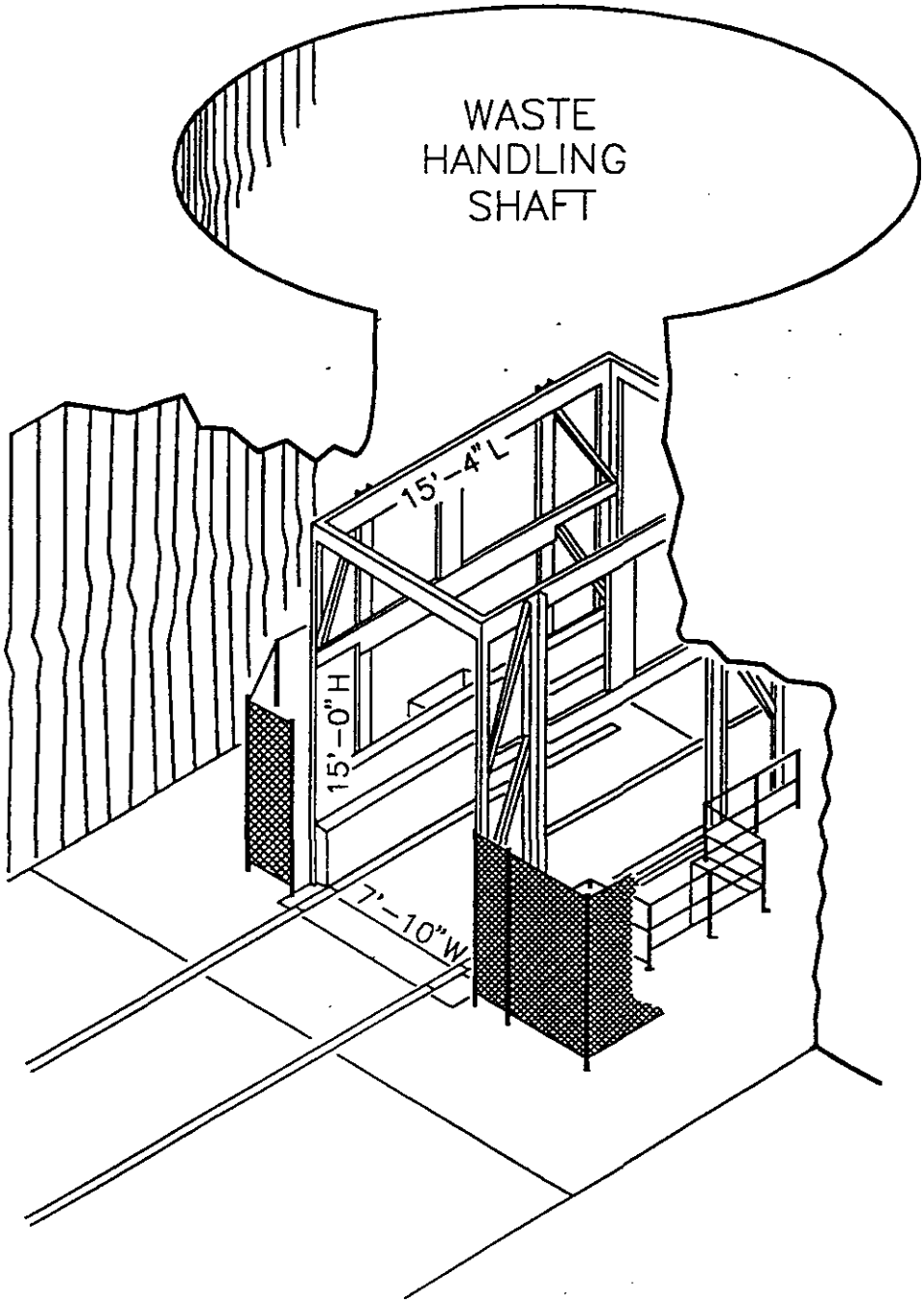

M

NOTES

(1) CAGE DIMENSIONS SHOWN ARE INSIDE.

(2) WASTE HOIST DESIGN CAPACITY IS 80,000 LBS.

Figure 2

Waste Handling Shaft Cage Dimensions

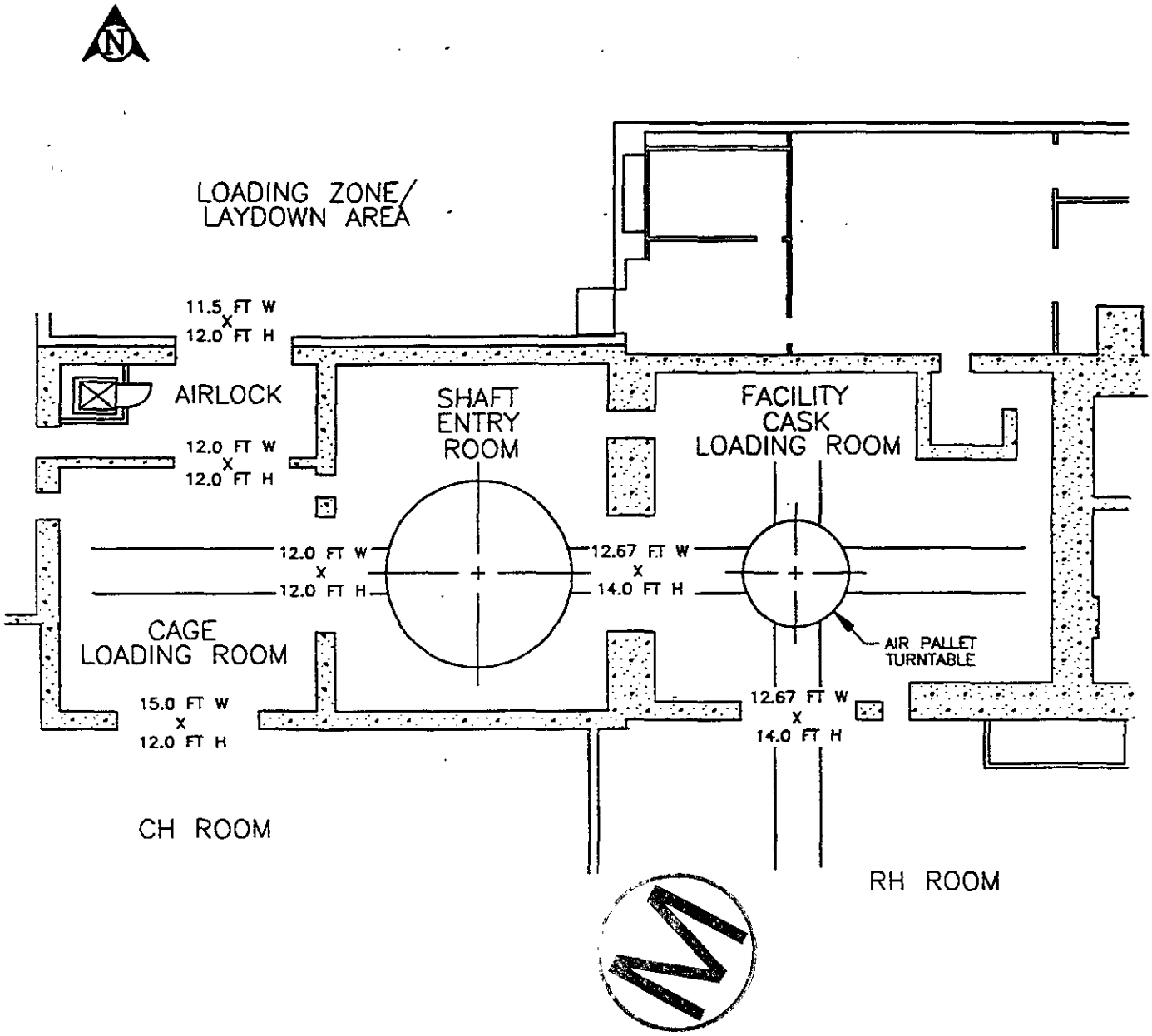

Figure 3

Waste Shaft Collar and Airlock Arrangement

3.5 Site Cleanup

At conclusion of the work, the Contractor shall remove all trash, waste, debris, excess construction materials, and restore the affected areas to its prior condition, to the satisfaction of Westinghouse WID. A final inspection of the areas will be conducted by Westinghouse WID and the Contractor before final payment is approved.

End of section.

M

SECTION 02222
EXCAVATION

SECTION 02222

EXCAVATION

PART 1 - GENERAL

1.1 Scope
This section includes:

- Excavation for main concrete barrier
- Excavation for surface preparation and levelling of base areas for isolation walls
- Disposition of excavated materials.

1.2 Related Sections

- 01010 - Summary of Work
- 01600 - Material and Equipment
- 03100 - Concrete Form Work
- 04300 - Unit Masonry System.

1.3 Reference Documents
"Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project" by R.D. Krieg-Sandia National Laboratory Document Sand 83-1908. [Available through National Technical Information Service (NTIS).]

1.4 Field Measurements and Survey
All survey required for performance of the work will be provided by Westinghouse WID. To develop the concrete formwork to fit the excavation, the Contractor shall be responsible for verifying the excavation dimensions.

PART 2 - PRODUCTS

Not used.

PART 3 - EXECUTION

3.1 Excavating for Concrete Barrier
Excavation for the main concrete barrier shall be performed to the lines and grades shown on the drawings. Excavate the back a minimum of 1 inch to 3 inches beyond clay seam G, and the floor a minimum of 1 inch to 3 inches below the anhydride marker bed 139 (MB-139) to

assure removal of the disturbed rock zone (DRZ). Excavation shall be performed utilizing mechanical means such as a cutting head on a suitable boom, by drilling boreholes and using an expansive agent to fragment the rock or other competent equipment or methods submitted to Westinghouse WID for review and approval. The use of explosives is prohibited. The existing WIPP roadheader mining machine may also be available for use. The Contractor is to determine availability and coordinate proposed use of the roadheader with Westinghouse WID. The existing roadheader is capable of excavating the back and the portions of the ribs above the floor level. However, it is not capable of excavating the portion below floor level.

The tolerances for the concrete barrier excavation shall be +6 inches, to 0 inch. In addition, the Contractor is to remove all loose or spalling rock from the excavation surface to provide a sound surface abutting the concrete barrier. The Contractor shall provide and install roof bolts for support as required for personnel protection and approved ground control plans.

3.2 Excavating for Surface Preparation and leveling of Base Areas for Isolation Walls

The Contractor shall excavate a 6-inch surface preparation around the entire perimeter of the isolation walls. The surface preparation in the floor shall be made level to produce a surface for placing the first course of block in the isolation walls. Tolerances for the leveled portion of the surface preparation are ±1 inch. Excavation may be performed by either mechanical or manual means. Use of explosives is prohibited.

3.3 Disposition of Excavated Materials

The Contractor shall remove all excavated materials from the panel-access drift where they are excavated. Excavated materials shall be removed from the mine via the salt skip to the surface, where they will be disposed on site at a location as directed by Westinghouse WID.

3.4 Field Measurements and Survey

All survey required for performance of the work will be provided by Westinghouse WID. The Contractor shall protect all survey control points, bench marks, etc., from damage by his operations. WID will verify by survey that the Contractor has excavated to the required lines and grades. The Contractor shall be responsible for verifying the excavation dimensions to develop concrete formwork to fit the excavation. No form work or block work is to be erected until this survey is completed. The Contractor is to coordinate the survey work with his operations to assure against lost time. The Contractor shall notify Westinghouse WID at least 24 hours prior to the time surveying is required

End of section.

SECTION 02722
GROUTING

SECTION 02722

GROUTING

PART 1 - GENERAL

1.1 Scope

This section includes:

- Grouting of concrete barrier.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 03100 - Concrete Form Work
- 03300 - Cast-in-Place Concrete

1.3 References

ASTM C1107-91a Standard Specification for Dry, Hydraulic Cement Grout (Nonshrink)

ASTM C109/ C109M-95 Test Method for Compressive Strength of Hydraulic Cement Mortars

1.4 Submittals for Review and Approval

Thirty days prior to the initiation of grouting, the Contractor shall submit to Westinghouse WID for review and approval, the following:

- Type of grout proposed

- Product data:

  - Manufacturer's specification and certified laboratory tests for the manufactured grout, if proposed

  - Certified laboratory tests for the salt-saturated grout, if proposed, using project-specific materials

- Proposed grouting method, including equipment and materials and construction sequence in Work Plan.

1.5 Submittals for Construction

Daily grouting report indicating the day, date, time of mixing and delivery, quantity of grout placed, water used, pressure required, problems encountered, action taken, quality control data, testing results, etc., no later than 24 hours following construction.

PART 2 - PRODUCTS

2.1 Grout Materials

Grout used for grouting in connection with fresh water/plain cement concrete shall be nonshrink, cement-based grout, Five Star 110 as manufactured by Five Star Products Inc., 425 Stillson Road, Fairfield, Connecticut 06430 or approved equal. Mixing and installation shall be in accordance with the manufacturer's recommendations.

As an alternate to the above grout, in connection with the Salado Mass concrete mix, the Contractor shall use, subject to the approval of Westinghouse WID, a salt saturated grout. The following formulation is suggested to the Contractor as an initiation point for selection of the grout mix. Salt saturated grout strength shall be 4500 psi at 28 days.

Salt-Saturated Grout (BCT-1F)

Component	Percent of total Mass (wt.)
Class H cement	48.3
Class C fly ash	16.2
Cal Seal (plaster - from Halliburton)	5.7
Sodium chloride	7.9
Dispersant	0.78
Defoamer	0.02
Water	21.1

Water for mixing shall be of potable quality, free from injurious amounts of oil, acid, alkali, salt, or organic matter, sediments, or other deleterious substances, as specified for concrete, Section 03300-2.3.

2.2 Product Data

If the Contractor proposes to utilize a manufactured nonshrink cement-based grout, he shall submit complete manufacturer's specifications for the product, along with certified laboratory test results of the material.

If the Contractor proposes to utilize the salt-saturated grout in connection with the Salado Mass concrete mix, he shall submit manufacturer's/supplier's specifications for the component materials, and certified laboratory test results for the resultant mix.

PART 3 - EXECUTION

3.1 General

The Contractor shall furnish all labor material, equipment, and tools to perform all operations in connection with the grouting.

Grout delivery and return lines for interface grouting shall be installed in the form work or in the area to be grouted to provide uniform distribution of the grout as shown on the drawings. The exact location of the boxes and lines shall be determined in the field. Additional grout delivery and return lines and boxes may be required by Westinghouse WID.

Pumps shall be positive displacement piston type pump designed for grouting service capable of operating at a discharge pressure of 100 psi. The Contractor shall supply a standby pump to be utilized in the event of a breakdown of the primary unit.

Mixers shall be high velocity "colloidal" type with a rotary speed of 1,200 to 1,500 rpm. Grout shall be mixed to a pumpable mix as per the manufacturer's recommendations.

Mixing water shall be accurately metered to control the consistency of the grout.

The Contractor shall provide all necessary valves, gages, and pressure hoses.

Water for mixing is available at the waste shaft. The Contractor is cautioned that no free water discharges or spills are permitted in the mine. All cleanup and washout operations shall be performed at the ground surface.

Potential spill areas in the underground shall be identified by the Contractor in the work plan. The Contractor shall provide measures to contain suitable containment. Isolation measures shall include, but are not limited to, lining with a membrane material (PVC, hypalon, HDPE), draped curtains (polyethylene,PVC, etc.), corrugated sheet metal protective walls or a combination of these and other measures.

If salt-saturated grout is selected for use, the Contractor shall make provisions to accurately proportion the components. Proportioning shall be by weighing. Sufficient quantities of dry

components shall be developed prior to initiation of the grouting to perform the work so as not to incur delays during the mixing/placing sequence.

3.2 Interface Grouting of Concrete Barrier

After each cell of the concrete barrier has been allowed to cure for a period of seven days, or as directed by Westinghouse WID, the Contractor shall interface grout the remaining space between the back wall and the top surface of the concrete barrier.

Each cell of the concrete barrier shall be grouted before the next adjacent cell is formed and concrete placed. Grout delivery and return lines shall be installed with the form work as shown and called for on the drawings, or as directed by Westinghouse WID.

The placing of grout, unless otherwise directed by Westinghouse WID shall be continuous until completed. Grouting shall progress from lower to higher grout pipes. Grouting shall proceed through a single delivery line until grout escapes from the adjacent return line. The Contractor shall then secure these lines and move to the next adjacent set of delivery and return lines. Pressure shall be adjusted to adequately deliver the grout to the forms, as witnessed by grout in the return line.

The grouting operation shall be conducted in a manner such that it does not affect the stability of the concrete barrier structure.

3.3 Contact Grouting

After completion of interface grouting if directed by Westinghouse WID, the Contractor shall contact grout to fill any remaining voids at the concrete barrier/back wall interface. Contact grouting includes all operations to drill, clean, and grout holes installed in the concrete barrier.

The Contractor shall drill and grout the interface zone to the main concrete barrier as directed by Westinghouse WID.

The location, direction, and depth of each grout hole shall be as directed by Westinghouse WID. The order in which the holes are drilled and the manner in which each hole is drilled and grouted, the proportions of the water used in the grout, the time of grouting, the pressures used in grouting, and all other details of the grouting operations shall be as directed by Westinghouse WID.

Wherever required, contact grouting will entail drilling the hole to a limited depth, installing a packer, and performing grouting.

3.3.1 Drilling

The holes shall be drilled with rotary-type drills. Drilling grout holes with percussion-type drills will not be permitted except as approved by Westinghouse WID.

The requirements as to location, depth, spacing, and direction of the holes shall be as directed by Westinghouse WID.

The minimum diameter shall be approximately 11/2 inches.

When the drilling of each hole or stage of has been completed, compressed air will be used to flush out drill cuttings. The hole shall then be temporarily capped or otherwise suitably protected to prevent the hole from becoming clogged or obstructed until it is grouted.

3.3.2 Materials for Contact Grouting

Standard weight black steel pipe conforming to ASTM A-53 shall be set in the concrete in the locations as directed by Westinghouse WID. All pipe and fittings shall be furnished by the Contractor.

The size of the grout pipe for each hole and the depth of the holes for setting pipe for grouting shall be as directed by Westinghouse WID. Care shall be taken to avoid clogging or obstructing the pipes before being grouted, and any pipe that becomes clogged or obstructed from any cause shall be cleaned satisfactorily or replaced.

The packers shall be furnished by the Contractor and shall consist of expansible tubes or rings of rubber, leather, or other suitable material attached to the end of the grout supply pipe. The packers shall be designed so that they can be expanded to seal the drill hole at the specified locations and when expanded shall be capable of withstanding without leakage, for a period of 5 minutes, air pressure equal to the maximum grout pressures to be used.

3.3.3 Grouting Procedures

Different grouting pressures will be required for grouting different sections of the grout holes. Pressures as high as necessary to deliver the grout but which, as determined by trial, are safe against concrete displacement shall be used in the grouting.

If, during the grouting of any hole, grout is found to flow from adjacent grout holes or connections in sufficient quantity to interfere seriously with the grouting operation or to cause appreciable loss of grout, such grout holes and connections shall be capped temporarily. Where such capping is not essential, holes shall be left open to facilitate the escape of air as the grout is forced into other holes. Before the grout has set, the grout pump shall be connected to adjacent capped holes and to other holes from which grout flow was observed, and grouting of all holes shall be completed. If during the grouting of any hole, grout is found to flow from points in the barrier, any parts of the concrete structure, or other locations, such flows or leaks shall be plugged or caulked by the Contractor as directed by Westinghouse WID.

As a safeguard against concrete displacement, excessive grout travel, or while grout leaks are being caulked, Westinghouse WID may require the reduction of the pumping pressure, intermittent pumping, or the discontinuance of pumping.

The consistency of the grout mix shall be varied, as directed by Westinghouse WID, depending on the conditions encountered. Where the grout hole or connection continues to take a large amount of grout after the mix has been thickened, Westinghouse WID may require that pumping be done intermittently, waiting up to 8 hours between pumping periods to allow grout in the barrier to set. After the grouting is complete, the pressure shall be maintained by means of stopcocks, or other suitable valve that it will be retained in the holes or connections being grouted.

3.4 Cleanup

No clean-up or washing of equipment with water is allowed in the underground. No free water spills are permitted. All clean out or wash out requiring water will be performed above ground at the location approved by Westinghouse WID. See note above regarding potential spill areas in Section 3.1 - General.

3.5 Quality Control

The Contractor shall provide a third-party quality control inspector at the site throughout the grout placement operations. The inspector shall determine that the grout mix is properly proportioned and properly mixed to the approved consistency. The inspector shall sample and make one set of grout cubes for compression testing for every 50 cubic feet of grout placed, or fraction thereof, for each day of grout placement.

End of section.

M

SECTION 03100
CONCRETE FORMWORK

SECTION 03100

CONCRETE FORMWORK

PART 1 - GENERAL

1.1 Scope

This section includes:

- Formwork for cast-in-place concrete with shoring, bracing, and anchorage
- Accessory items, grout pipes, concrete delivery pipes.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 02722 - Grouting
- 03300 - Cast-in-Place Concrete
- 04300 - Unit Masonry System

1.3 References

ACI 301-89	Specifications for Structural Concrete for Buildings
ACI 318-89(92)	Building Code Requirements for Reinforced Concrete
ACI 347-94	Recommended Practice for Concrete Formwork
ASTM A-36/ A36M-91	Standard Specification for Structural Steel
ASTM A-53-90b	Standard Specification for Pipe, Steel, Black, and Hot-Dipped Zinc Coated Welded and Seamless
ASTM A-325-91c	Standard Specification for Structural Bolts, Steel, Heat-Treated 120/105 ksi Minimum Tensile Strength
ASTM A-615-95b	Standard Specifications for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
AWS A3.0-94	Welding Terms and Definitions

AWS A5.1-91	Specification for Mild Steel Covered Arc Welding Electrodes
AWS D1.1-94	Structural Welding Code-Steel
AISC	Manual of Steel Construction Latest Edition

1.4 Submittals

The Contractor shall submit the following supporting documentation for the adequacy of the formwork 30 days prior to initiation of work at site:

- Shop detail drawings with appropriate calculations to support the adequacy of the formwork.
- Mill test certification of materials utilized in construction of the forms.
- Details of installation contained in the Contractor's Work Plan.

1.5 Quality Assurance

The design and detail of the formwork shall be conducted under direct supervision of a professional structural Engineer experienced in design of this work. Responsibilities include:

- Fabricating formwork in accordance with AISC manual of steel construction.
- Performing all welding in accordance with AWS D1.1 structural welding code.
- Performing all bolting in accordance with AISC specification for structural joints using ASTM A325 or A490 bolts.
- Performing work in accordance with ACI 301, 318, and 347, AISC and AWS standards. Maintain one copy of all standards at site.

PART 2 - PRODUCTS

2.1 Form Materials

Forms for the concrete barrier shall be constructed of ASTM A-36 steel.

Pipe inserts shall be ASTM A-53 black standard weight pipe.

Form spacers shall be ASTM A-36 round stock.

Bolts shall be ASTM A325 high strength structural bolts.

Grout pipes shall be ASTM A-53 standard weight pipe or flex conduit as shown on the drawings.

Rock anchors shall develop strength equal to or greater than ASTM A-36 round stock.

Welding electrodes shall conform to AWS A5.1.

PART 3 - EXECUTION

3.1 General

The Contractor shall furnish all labor material equipment and tools to perform all operations in connection with the design, detail, fabrication and erection of the formwork and the fabrication and installation of grout pipes for the main concrete barrier. All work shall be performed according to standards referred to in Paragraph 1.3.

The Contractor may, at his option submit an alternate design or modify the design shown on the drawings, subject to the approval of Westinghouse WID. All designs must be supported by design calculations stamped and sealed by a registered professional engineer.

The Contractor shall furnish, fabricate and install all grout pipes and grout boxes for both the concrete barrier and the isolation walls.

3.2 Shop Drawings

The Contractor shall design and detail all formwork for the concrete barrier, complete with any required bracing and shoring for the concrete barrier as shown on the drawings, in accordance with ACI 318 and 347 and the AISC manual of steel construction.

The details shall incorporate provision for adjusting and modifying the formwork to suit the excavation. Excavation tolerances are given in Section 02222 Excavation.

The Contractor shall be responsible for verifying the excavation dimensions to develop the concrete formwork to fit the excavation.

Prior to fabrication, the Contractor shall submit shop drawings complete with supporting calculations for review/approval by Westinghouse WID 30 days prior to initiating work. The contractor shall incorporate all Westinghouse WID's comments, revisions, resolve all questions and resubmit drawings for final approval prior to proceeding with fabrication.

3.3 Fabrication

The Contractor shall fabricate all formwork and ancillary items in accordance with the latest edition of the AISC Manual of Steel Construction and the approved detail drawings.

Formwork shall contain all inserts for grouting and pumping concrete. Sufficient valving shall be provided on inserts to allow shut off of concrete and grout to prevent back flow through the form work.

All welding shall be in accordance with AWS D1.1 structural welding code including operator and procedure certifications. Elements shall be welded using E-7018 low hydrogen electrodes. Panels shall be piece marked to correspond to the erection drawing(s) and sequence at fabrication.

3.4 Installation

3.4.1 Grout Pipes

The Contractor shall furnish, fabricate, and install all grout pipes and boxes as approved by Westinghouse WID. Grout pipes and boxes shall be attached to the back surface using masonry anchors as shown on the drawings or other approved methods. Grout pipes shall be connected to the inserts installed in the permanent forms and securely fastened to the formwork. All grout pipes will be blown out with compressed air after installation and prior to closure of the formwork to assure they are clean and free from debris or obstructions. Grout pipes shall then be temporarily capped to prevent entry of foreign matter until ready for grouting. The Contractor shall apply masking tape to the grout box openings to prevent concrete infiltration during concrete placement.

3.4.2 Formwork

The steel formwork for the concrete barrier is to remain in place at completion of each segment of the barrier, therefore all formwork shall be free from oil, grease, rust, dirt, mud or other material that would prevent bonding by the concrete. Forms will not be oiled or receive application of release agent.

The Contractor shall install formwork at the locations shown on the drawings to the lines and grades shown. Forms are to be mortar tight. The Contractor shall adjust the formwork to suit the contour of the excavation. Rock may be trimmed or chipped to suit where interferences are encountered. Where overexcavation has occurred in excess of the designed-in adjustability of the formwork, modifications shall be proposed to Westinghouse WID for his approval prior to installation. Installation of the formwork shall be reviewed and approved by Westinghouse WID prior to proceeding with concrete installation.

The Contractor shall provide a sealant or gasket material subject to the approval of Westinghouse WID.

3.5 Quality Control

The Contractor shall arrange for and contract with an approved third party inspector to provide inspection/testing services for the fabrication and installation of the formwork and ancillary items, as required by the QA/QC plan.

The Contractor shall furnish certified mill test reports for all materials utilized in the fabrication.

All welding shall be in accordance with AWS D1.1 structural welding code. The Contractor shall furnish welding operator and procedure certifications for all operators and procedures utilized.

Fabricated components shall be inspected for dimension and overall quality. Welds shall be inspected by an AWS certified welding inspector.

The inspector shall visually inspect the installation for fit-up and dimensionally for location.

3.6 Handling, Shipping, Storage

The Contractor shall handle, ship, and store fabricated components with care to avoid damage. Stored components shall be placed on timbers or pallets off the ground to keep the units clean. Components shall be tarped while in outdoor storage. Components that become spattered or contaminated with mud will be thoroughly cleaned during erection, and prior to concrete emplacement. Damaged components will be rejected by the inspector and replaced by the contractor at his cost.

End of section.

SECTION 03300
CAST-IN-PLACE CONCRETE

SECTION 03300

CAST-IN-PLACE CONCRETE

PART 1 - GENERAL

1.1 Scope

This section includes:

- Cast-in-place concrete for concrete barrier
- Concrete mix design.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 02222 - Excavation
- 02722 - Grouting
- 03100 - Concrete Formwork

1.3 References

ACI 211.1-91	Standard Practice for Selecting Proportions for Normal, Heavy Weight, and Mass Concrete
ACI 318.1-89(92)	Building Code Requirements for Structural Plain Concrete
ACI 304R-89	Guide for Measuring, Mixing, Transporting, and Placing Concrete
ASTM C 33-93	Standard Specification for Concrete Aggregates
ASTM C 39-94	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C 94-94	Standard Specification for Ready-Mixed Concrete
ASTM C 136-95a	Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
ASTM C 143-90a	Standard Specification for Slump of Hydraulic Cement Concrete

ASTM C 150-95	Standard Specification for Portland Cement
ASTM C 186-94	Standard Test Method for Heat of Hydration of Hydraulic Cement
ASTM C 403/ C 403M-95	Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
ASTM C 494-95	Standard Specification for Chemical Admixtures for Concrete
ASTM C 618-94a	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolam for Use as an Admixutre in Portland Cement Concrete
ASTM C 845-90	Standard Specification for Expansivce Hydraulic Cement
ASTM D 2216-92	Standard Test Method for Laboratory Determination of Water (moisture) Content of Soil and Rock
USACE CRD-C 36	Method of Test for Thermal Diffusivity of Concrete
USACE CRD-C 48	Standard Test Method for Water Permeability of Concrete
API 10	Cements
NRMCA	Check List for Certification of Ready Mixed Concrete Production Facilities
NRMCA	Concrete Plant Standards

Westinghouse WID Standards

WIPP-DOE-71	Design Criteria Waste Isolation Pilot Plant, Revised Mission Concept -- IIA (DOE, 1984)
WP 03-1	WIPP Startup and Acceptance Test Program (Westinghouse, 1993b)
WP 09-010	Design Development Testing (Westinghouse, 1991)
WP 09-CN3021	Component Numbering (Westinghouse, 1994a)
WP 09-024	Configuration Management Board/Engineering Change Proposal (ECP) (Westinghouse, 1994b)

1.4 Submittals for Review/Approval

The Contractor shall submit the following for approval 30 days prior to initiating any work at the site:

Type of concrete proposed

Product Data - Laboratory test data and trial mix data for the proposed concrete to be utilized for the concrete barrier.

Proposed method of installation, including equipment and materials in work plan.

1.5 Submittals at Completion

Laboratory test data developed during the installation of the concrete barrier.

1.6 Quality Assurance

Perform work in accordance with the Contractor's Quality Control Plan and referenced ACI and ASTM standards.

Acquire cement, aggregate and component materials from the same source throughout the work.

PART 2 - PRODUCTS

2.1 Cement

Portland cement shall conform to ASTM C150 Type II modified with Pozzolan ~~or IV for~~ plain cement concrete or API 10 Class H oil well cements. Cement utilized in the mix shall be Portland cement, Type II modified with pozzolan or type IV, to limit the heat of hydration of the resultant mix. The source of the cement to be used shall be indicated and manufacturer's certification that the cement complies to the applicable standard shall be provided with each shipment.

2.2 Aggregates

Aggregates shall be quartz aggregates conforming to the requirements of ASTM C33.

Fine aggregate shall meet the requirements of ASTM C33 having a fineness modulus in the range of 2.80 to 3.00.

Coarse aggregate maximum size shall be 1 1/2 inches and shall be clean, cubical, angular, 100 percent crushed aggregate without flat or elongated particles.

The source of the aggregate is to be indicated and test reports certifying that the aggregate complies with the applicable standard are to be submitted for approval with the trial mix data.

2.3 Water

Water used in mixing concrete shall be of potable quality, free of injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances.

Water shall conform to the provisions in ASTM C94, and in addition, shall conform to the following:

- pH not less 6.0 or greater than 8.0
- Carbonates and/or bicarbonates of sodium and potassium: 1000 ppm maximum
- Chloride ions (Cl): 250 ppm maximum
- Sulfate ions (SO_4): 1000 ppm maximum
- Iron content: 0.3 ppm maximum
- Total solids: 2000 ppm maximum

When ice is used in concrete mix, the water used for making ice shall meet all of the above requirements.

The source of water is to be indicated and certified copies of test data from an approved laboratory confirming that the water to be used meets the above requirements shall be submitted for approval with the trial mix data.

2.4 Admixtures

Pozzolan shall conform to ASTM C618. Sampling and testing of pozzolans shall conform to ASTM C311. Approximately 5 percent by weight of pozzolan may be used to replace cement in the mixes when approved.

All admixtures shall conform to ASTM C-494. The source of any admixtures proposed are to be indicated and certified copies of test data from an approved laboratory shall be submitted for approval with the trial mix.

2.5 Target Properties of the Concrete Mix

The Contractor shall develop and proportion a plain cement concrete mix for use in constructing the concrete barrier. The Contractor shall demonstrate by trial mix that the proposed concrete meets the following properties:

Target properties for Barrier Concrete

Property	Comment
4-hr working time	Indicated by 8-inch slump (ASTM C 142) after 3-hr intermittent mixing. Max 10-inch slump at mixing.
Less than 25 °F heat rise prior to placement	Difference between initial condition and temperature after 4 hr.
4,000 psi compressive strength (f'_c)	At 28 days after casting (ASTM C 39)
Volume stability	Length change between +0.05 percent and -0.02 percent (ASTM C 490)
Minimal entrained air	2 percent to 3 percent air

The Contractor shall use water reducing agents, plasticizers and other admixtures to achieve the slump and workability of the mix without adding excessive mixing water or excessive water-cement ratio. All admixtures shall conform to ASTM C-294.

The Contractor shall provide certified copies of test data from an approved laboratory demonstrating compliance with the above target properties.

In addition to the target properties the Contractor shall provide certified test data for the trial mix for the following properties:

- Heat of hydration ASTM C-186
- Concrete Set ASTM C-403
- Thermal Diffusivity USACE CRD-C36
- Water Permeability USACE CRD-C43

2.6 Salado Mass Concrete

The Contractor may elect to utilize the Salado Mass concrete in preference to developing a plain cement concrete. If Salado Mass concrete is selected, the Contractor shall demonstrate that the Salado Mass concrete meets the target properties shown above. Recommended initial proportioning of the Salado Mass concrete is as follows:

Component	Percent of Total Mass
Class H cement (API 10)	4.93
Chem Comp III (ASTM C-845 Type K)	2.85
Class F fly ash (ASTM C-618)	6.82
Fine aggregate	33.58
Coarse aggregate	43.02
Sodium chloride	2.18
Defoaming agent	0.15
Sodium citrate	0.09
Water	6.38

The Contractor shall prepare a trial mix and provide certified test data from an approved testing laboratory for slump, compressive strength, heat rise, heat of hydration, concrete set time, thermal diffusivity, and water permeability as indicated above for the plain concrete mix.

PART 3 - EXECUTION

3.1 General

The Contractor shall provide all labor material, equipment and tools necessary to develop, supply, mix, transport and place mass concrete in the forms as shown on the drawings and called for in these specifications. All work shall be according to the standard references in paragraph 1.3.

The Contractor will be required to provide and erect on the site a batch plant, suitable to store, handle, weight and deliver the proposed concrete mix. The batch plant shall be certified to NRMCA standards. The batch plant shall be erected on site in the location as directed by Westinghouse WID.

The Contractor shall batch, mix, and deliver to the underground, sufficient quantity of concrete to complete placement of concrete within one form section, as shown on the drawings. Once begun, placement of concrete in a section shall be continuous until completed. Target time for concreting one section is eight to ten hours allowing an additional two hours for clean up of equipment, for a total 10- to 12-hour shift.

It is expected that addition of water to the dry materials and mixing of the concrete will occur at the ground surface with transport of wet concrete to a pump at the underground level where it will be pumped into the forms.

The Contractor is to provide all transport vehicles or means to transfer the wet concrete from the mixer truck to the pump. It is expected that the Contractor will use the waste conveyance hoist to transfer from the ground surface to the mine level. The Contractor is to familiarize himself with the dimensions of the waste conveyance and the airlock in order to provide suitable transport vehicles. The Contractor is also to familiarize himself with the capacity and speed of the conveyance to allow transfer of sufficient concrete to sustain the continuing placement of concrete. (See Figures 2 and 3 attached to Section 02010 - Mobilization and Demobilization).

The Contractor shall determine the horizontal distance to the entry where placement of the concrete barrier is to occur, and develop a route, with the approval of Westinghouse WID for traffic flow within the underground.

Details of the logistics for handling the concrete shall be included in the Contractors' Work Plan, and submitted to Westinghouse WID for approval prior to start of work at the site.

Potential spill areas in the underground shall be identified by the Contractor in the Work Plan. The Contractor shall provide measures to contain and isolate any water from contact with the halite in these areas. Suitable containment isolation measures shall include but are not limited to, lining with a membrane material (PVC, hypalon, HDPE), draped curtains (polyethylene, PVC, etc.), corrugated sheet metal protective walls or a combination of these and other measures.

3.2 Pumping Concrete

The Contractor shall provide pumping equipment suitable for placing the concrete into the forms. The Contractor at a minimum, shall provide an operating and a spare pump, to be used in the event of breakdown of the primary unit. After transporting and prior to pumping the concrete shall be remixed to compensate for segregation of aggregate during transport. The Contractor shall indicate the equipment proposed for pumping (manufacturer, model, type, capacity, pressure and remixing at the point of delivery in the Work Plan).

Each batch of concrete shall be checked at the surface at the time of mixing and again at the point of transfer to the pump for slump and temperature, and shall conform to the following:

- Max. slump at mixing - 10 inches
- Max. slump at delivery to pump - 8 inches
- Max. temperature at placement = 70°F

Note: No water is to be added to the mix after the initial mixing and slump are determined.

The Contractor shall connect to the pipe ports fabricated into the forms for delivery of the concrete, beginning with the lowest ports first. Pumping shall continue until concrete is seen in the adjacent port at which time the delivery hose will be transferred to that port and the first port capped.

Pumping shall continue moving laterally then upward until the entire form is filled and the pour is completed.

3.4 Coordination of Work

The Contractor is to coordinate his work mixing, transporting, and placing the mass concrete with the on-going operations in the underground. Coordination of use of the facilities and existing equipment shall be through Westinghouse WID.

3.5 Clean-Up

No clean up or washing of equipment with water will be allowed in the underground. No free water spills are permitted in the underground. All clean-out or wash-out requiring water will be performed above ground at the location approved by Westinghouse WID.

3.6 Quality Control

The Contractor shall provide a third-party quality control inspector at the site throughout the concrete placement. The inspector shall be responsible for determining that the batch plant is proportioning the mix according to the approved proportions. The batch plant shall provide a print out of batch quantities for each truck delivered to the mine. The inspector shall also determine the slump for each batch as it is mixed and allow additional water to be added until the initial slump is achieved. No additional water is to be added after this time. Temperature will also be recorded at this time.

The inspector shall also determine the slump and temperature following the remixing when concrete is transferred to the pump. Concrete not meeting or exceeding the specification is to be rejected and removed from the underground.

Concrete test cylinders to determine unconfined compression strength shall be taken by the inspection at the delivery from remixer to the pump in the underground. Four (4) cylinders shall be made for each 50 cubic yards of concrete placed. Cylinders shall be sealed with polyethylene and taped and field cured at ambient temperatures in the mine adjacent to the concrete barrier area. Two (2) samples shall be tested at 7 days and the remaining two (2) at 28 days.

End of section.

SECTION 04100
MORTAR

SECTION 04100

MORTAR

PART 1 - GENERAL

1.1 Scope
This section includes:

- Mortar for Isolation Wall Construction.

1.2 Related Sections

- 01010 - Summary of Work
- 01400 - Contractor Quality Control
- 01600 - Material and Equipment
- 04300 - Unit Masonry System

1.3 References

ASTM C91-95	Standard Specification for Masonry Cement
ASTM C144-93	Standard Specification for Aggregate for Masonry Mortar
ASTM C150-95	Standard Specification for Portland Cement
ASTM C207-91	Standard Specification for Hydrated Lime for Masonry Purposes
ASTM C270-94	Standard Specification for Mortar for Unit Masonry
ASTM C780-94	Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry
ASTM C1142-94	Ready-Mixed Mortar for Unit Masonry
ASTM E447-92	Test Methods for Compressive Strength of Masonry Prisms

1.4 Submittals for Review and Approval
The Contractor shall submit for approval the following 30 days prior to the initiation of work at the site.

Design mix.

Certified laboratory tests for the proposed design mix, indicating conformance of mortar to property requirements of ASTM C270, and test and evaluation reports to ASTM C780.

1.5 Submittals at Completion

Certified laboratory test results for the construction testing of mortar mix.

1.6 *Quality Assurance*

Perform work in accordance with the Contractor's Quality Control Plan and referenced ASTM standards. Acquire cement, aggregate, and component materials from the same source throughout the work.

1.7 Delivery Storage Handling

Maintain packaged materials clean, dry and protected against dampness, freezing and foreign matter.

PART 2 - PRODUCTS

2.1 Mortar Mix

The Contractor shall provide mortar for Isolation Walls, which shall be in conformance with ASTM C270 type M, using the property specification (3,000 psi at 28 days).

Sand for mortar shall conform to ASTM C144.

Water used for mixing mortar shall be of potable quality, free of injurious amounts of oil, acid alkali, organic matter, sediments, or other deleterious substances, as specified for Concrete, Section 03300 2.3.

The supply of materials as defined in the design mix shall remain the same throughout the job.

PART 3 - EXECUTION

3.1 General

The Contractor shall furnish all labor material equipment and tools to perform all operations in connection with supplying and mixing mortar for constructing the isolation walls.

The Contractor shall fully describe his proposed mortar mixing operation, including proposed equipment and materials in the Work Plan.

3.2 Mortar Mixing

Mortar shall be machine-mixed with sufficient water to achieve satisfactory workability. Maintain sand uniformly damp immediately before the mixing process. If water is lost by evaporation, retemper only within one and one half hours of mixing. Use mortar within two hours of mixing at ambient temperature of 85° in the mine.

3.3 Installation

The Contractor shall install mortar to the requirements of Section 04300 Unit Masonry System.

3.4 Field Quality Control

The Contractor shall provide a third party Quality Control Inspector to perform all sampling and testing to confirm that the mortar mix conforms to the proposed mix properties developed in the design mix.

Construction testing of mortar mix shall be in accordance with ASTM C780 for compression strength. Four (4) prism specimens shall be taken for each 50 cu. ft. of mortar or fraction thereof placed each day.

End of Section.

SECTION 04300
UNIT MASONRY SYSTEM

SECTION 04300

UNIT MASONRY SYSTEM

PART 1 - GENERAL

1.1 Scope
This section includes:

- Concrete Masonry Units

1.2 Related Sections

- 01010 Summary of Work
- 01400 Contractor Quality Control
- 01600 Material and Equipment
- 02722 Grouting
- 03100 Concrete Formwork
- 04100 Mortar

1.3 References

ASTM C55-94a Standard Specification for Concrete Building Brick

ASTM C140-94a Standard Method of Sampling and Testing Concrete Masonry Units

1.4 Submittals for Revision and Approval
The Contractor shall submit for approval the following 30 days prior to initiation of the work at the site.

Certified laboratory test results for the proposed solid masonry units.

1.5 Quality Assurance
Perform the work in accordance with the Contractor's Quality Control Plan.

PART 2 - PRODUCTS

2.1 Concrete Masonry Units
Concrete masonry units shall be solid (no cavities or cores), load bearing high-strength units having a minimum compressive strength of 3500 psi. Concrete masonry units shall be tested

in accordance with ASTM C140. All other aspects of the concrete masonry units shall comply with ASTM C55, Type I Moisture Controlled.

Nominal modular size shall be 8 x 8 x 16 inches, or as otherwise approved by Westinghouse WID.

Concrete brick shall comply with ASTM C55, Grade N, Type I (moisture controlled) having a minimum compressive strength of 3500 psi (Avg. 3 units) or 3000 psi for individual unit.

2.2 Mortar

Mortar shall be as specified in Section 04100 Mortar.

PART 3 - EXECUTION

3.1 General

The Contractor shall furnish all labor, material, equipment and tools to perform all operations of installing Unit Masonry Isolation Walls to the lines and grades shown on the drawings.

The Contractor shall examine the excavation of the entry to affirm that the keys have been properly leveled and cut to the appropriate depths, at the proper locations prior to any to any work.

3.2 Installation

The Contractor shall install the isolation walls using concrete masonry units as specified above. Masonry units shall be installed with 3/8-inch mortar joints with full mortar bedding and full head joints. Masonry units shall be installed in running bond with headers every third course. Masonry units shall be mortared tight to the ribs and the back wall to provide a seal all around the isolation wall.

Concrete brick may be used as required for fit-up around grout pipes, or minimizing the dimensional fit-up at the top or sides of the isolation walls as approved by Westinghouse WID. The interface between the top of the isolation wall and the back wall shall be completely mortared to provide full contact between the back and the block wall.

3.3 Field Quality Control

The Contractor shall provide a third-party Quality Control Inspector to inspect the installation of the Concrete Masonry Unit Isolation Walls. Inspection and testing of the mortar shall be in accordance with Section 04100 Mortar.

End of Section

APPENDIX H
DESIGN DRAWINGS

6 Large 3 X 4 foot drawings
Not available for electronic version
See hard copy

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix PEER

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

FOREWORD

Appendix PEER is divided by 25 major tabs. These 25 tabs break the appendix into the major topical areas. Within each tab there may be several documents of interest. For example, each tab under Current Peer Reviews contains the Peer Review Plan, the Peer Review Report and the verification of independence for the Peer Panel. These documents are separated by paper inserts only.

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PEER 19.4 EEG-10: Radiological Health Review of the Final Environmental Impact Statement, Waste Isolation Pilot Plant, U.S. Department of Energy

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PEER 1 - Conceptual Models Peer Review

Title: CONCEPTUAL MODELS PEER REVIEW PLAN

(Assistant Manager, Office of Regulatory Compliance, Carlsbad Area Office) Date: 3/28/96

1. INTRODUCTION

This Conceptual Model Peer Review (CMPR) Plan describes the peer review and documentation the WIPP Project will use to ensure that the conceptual models used in performance assessment (PA) reasonably represent possible future states of the disposal system.

1.1 BACKGROUND

In accordance with the regulatory requirements, as specified in 40 CFR Part 191, and the criteria for the implementation of those requirements, as specified in 40 CFR Part 194, the Department of Energy (DOE) will conduct a peer review (PR) of the conceptual models used in the compliance certification application for the WIPP Project. Specifically, a PR will be conducted to determine whether the conceptual models developed and selected by DOE reasonably represent future states of the disposal system. Sandia National Laboratories (SNL) is responsible for the WIPP PA. SNL has determined which processes are significant and have developed conceptual models which represent possible future states of the disposal system and subsystems. To facilitate review of the conceptual models, they have been divided into the following three associated subsystems:

- Natural barriers (Salado and non-Salado flow and transport);
- Engineered barriers (rock mechanics and shaft/borehole seals); and
- Waste form and the disposal room.

SNL has developed a description of the conceptual models, the associated parameters, and parameter values, and is developing and implementing a process for the selection and assembly of data and other information which will be utilized to support PR of the conceptual models.

1.2 PURPOSE

The purpose of the WIPP PR process for conceptual models is to ensure that the conceptual models used in PA reasonably represent possible future states of the disposal system.

The requirement for conducting peer reviews is specified in sections 27 (a)(1) and 22 (b) of 40 CFR Part 194. Specifically, a PR is a documented, critical review performed by peers who possess qualifications at least equal to those of the individuals who conducted the original work. The PR shall be independent of the work being reviewed; independence from the work being reviewed means that the peer: a) was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed.

1.3 SCOPE

This CMPR Plan describes the peer review process that the DOE Carlsbad Area Office (CAO) will use for review of conceptual models. A PR is an in-depth critique of assumptions, calculations, extrapolations, alternate interpretations, methodology, and acceptance criteria employed, and of the conclusions drawn in the original work. This Plan defines the management approach, resources, schedule, and technical requirements for using peer reviews to confirm the adequacy of the conceptual models.

2. PEER REVIEW PLANNING AND IMPLEMENTATION

2.1 APPROACH

The DOE-CAO has prepared this Conceptual Model Peer Review (CMPR) Plan to document the approach to conducting the PR process. The CMPR will be conducted using a rigorous proceduralized approach in accordance with NUREG-1297. The DOE-CAO has prepared a procedure for conducting peer reviews in accordance with sections 27 (a)(1) and 22 (b) of 40 CFR Part 194. The DOE-CAO procedure ensures that each PR will be a documented, critical review performed by qualified peers who are independent of the work being reviewed. SNL has prepared a procedure to provide the information necessary to support peer review of the conceptual models.

2.1.1 DESCRIPTION OF CONCEPTUAL MODELS TO BE REVIEWED

Section 23(a)(3)(v) of 40 CFR Part 194 requires that any compliance certification application shall include documentation that the conceptual models have undergone PR according to 40 CFR Part 194 section 27. SNL will provide a description of the conceptual models and other supporting information to the PR Manager for peer review. The following listed conceptual models have been identified to be reviewed:

CONTAINMENT SUB-SYSTEM	CONCEPTUAL MODELS
Natural Barriers (Flow & Transport)	Disposal System Geometry Culebra Repository Fluid Flow Salado Impure Halite Salado Interbeds Disturbed Rock Zone Actinide Transport (Salado) Units Above the Salado Dissolved Actinides (Culebra) Colloidal Actinides (Culebra) Exploration Boreholes Cutting/Cavings Spallings Blowout Castile & Brine Reservoir Multiple Intrusions Climate Change
Engineered Systems (Shaft Seals & Rock Mechanics)	Disposal Room Geometry Creep Closure Repository Fluid Flow Shafts & Shaft Seals Disturbed Rock Zone
Waste Form & Disposal Room (Disposal Room Closure & Chemistry)	Gas Generation Chemical Conditions Dissolved Actinide Source Term Colloidal Actinides Source Term

2.1.2 COMPOSITION OF PEER REVIEW PANEL

The CMPR Panel will be composed of a minimum of three individuals who possess the subject matter technical expertise to a degree at least equivalent to that needed for the original work. It is currently planned to have panel members who are experts in Natural Barrier System (flow and transport), Engineered Barriers (shaft seals and rock mechanics) and Waste Form and Disposal Room Chemistry.

Through a formal orientation process, each panel member will be made familiar with the WIPP containment system and the basis of the conceptual models which describe the containment system. In addition they will be provided a basic description of how

the conceptual models are represented in numerical models, algorithms, and codes. The peer reviewers will be made familiar with the parameter inputs to the PA codes and the results of prior PAs, sensitivity analyses, and critical comments from previous reviews. Each peer reviewer will be selected, oriented, and trained in accordance with approved procedures.

2.1.3 LOGISTICS AND MANAGEMENT

Not all information necessary to support peer review of conceptual models is currently available. Therefore, it is necessary to conduct the CMPR in a phased manner. The phasing dependens on information availability. The PR Manager, working closely with SNL, has developed a preliminary schedule that provides the necessary information on an "as available" basis. Flexibility is required by all supporting organizations (i.e., DOE-CAO, SNL, and the PR manager, staff and panel members) to accommodate schedule changes due to uncertainty in the timing of information availability.

2.2 SUGGESTED METHODS

The method to be used by the CMPR Panel for the adequacy and reasonableness of the conceptual models will be developed based on SNL requirements for the process of conducting PR. The methods the PR Panel uses to evaluate the subject matter shall include, as applicable, the adequacy criteria identified in section 2.3 below.

2.3 ADEQUACY CRITERIA

Conceptual models which have been selected and developed by the DOE must meet commonly accepted technical and scientific standards based on in-depth evaluation. The peer review panel will evaluate and report on, as applicable:

- Adequacy of requirements and criteria;
- Validity of assumptions;
- Alternate interpretations as appropriate;
- Uncertainty of results and consequences if wrong;
- Appropriateness and limitations of methodology and procedures;
- Adequacy of application;
- Accuracy of calculations; and
- Validity of conclusions.

Adequacy of the conceptual models will be determined based on whether or not they reasonably represent possible future states of the disposal system.

2.4 SCHEDULE

Based on the concept described in section 2.1.3, Attachment A presents a schedule of CMPR activities and milestones. This schedule will serve as the baseline schedule from which requested schedule deviations will be evaluated and approved if appropriate. Revisions to the baseline schedule will not require revision to this Plan, but will be attached to the plan by reference.

2.5 DELIVERABLES

Monthly status reports addressing CMPR progress against schedule and expenditures against budget will be submitted by the CTAC Project Manager and will be incorporated in the CTAC monthly report to the DOE-CAO. Significant variances in progress or spend rates will be explained and will include the cause of the variance, impact to the overall CMPR schedule and recommended corrective actions. A draft and final report of this PR will be submitted to DOE-CAO.

2.6 RESOURCE REQUIREMENTS

To meet the CMPR schedule as outlined in section 2.4 an estimate of the resources which may be required and the allowed manpower support levels are specified in Attachment C.

3. QUALITY ASSURANCE

The CMPR process will be conducted in a controlled manner and in compliance with the CAO Quality Assurance Program Description, CAO-94-1012, and other applicable QA procedures.

4. RECORDS MANAGEMENT

Records generated as a result of PR activities defined in this peer review plan and designated as QA records will be identified in the PR Procedure. Conceptual Models PR records will be assembled and maintained in accordance with the PR Management Procedure and the PR Desk Instruction(s). Ultimately, PR records will be dispositioned in accordance with DOE-CAO records management requirements. SNL records will be managed in accordance with SNL Records Management Procedure, SNL QAP 17-1.

5. DOCUMENT CONTROL

All plans, procedures, and other Documents which require document control will be handled in accordance with applicable DOE-CAO controlled document procedures.

ATTACHMENT A

CONCEPTUAL MODEL PEER REVIEW (CMPR) SCHEDULE

ACTIVITY	DRAFT	FINAL
CMPR Plan	3/8	3/29
PR Panel Assigned	NA	3/29
Information Package to PR Manager	3/15	4/2
Initiate CMPR	NA	4/2
Complete CMPR	NA	6/28
Submit CMPR Report	6/21	7/1

ATTACHMENT B

ESTIMATED PEER REVIEW RESOURCE REQUIREMENTS

Support	Hours
Subject matter experts	1800
Technical Coordinator	300
Clerical Support	300

CONCEPTUAL MODELS

PEER REVIEW REPORT

Final

Waste Isolation Pilot Plant

Conceptual Models Peer Review Report

A Peer Review Conducted By

Charles Wilson
Darrell Porter
John Gibbons
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for

U.S. Department of Energy
Carlsbad Area Office
Office of Regulatory Compliance

July 1996

FOREWORD

The U.S. Environmental Protection Agency promulgated "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule" in Code of Federal Regulations, Title 40, Part 194 (40 CFR Part 194) on February 9, 1996. The 40 CFR Part 194 regulation prescribes three specific peer reviews and also provides the opportunity for the Department of Energy to use peer reviews, conducted in accordance with NUREG 1297, as a means of qualifying data and information for use in the demonstration of compliance.

This report contains the results of a peer review of specific conceptual models to be used in the demonstration of WIPP compliance with 40 CFR Part 194. To ensure the independence of this review, the Department of Energy has directed the assignment of an independent contractor to administratively manage the peer review panel activities. Peer reviewers were selected based on their demonstrated independence from the work being reviewed and their technical expertise in the subject matter to be reviewed. The peer review panel members collectively possess an appropriate spectrum of knowledge and experience in the subject matter reviewed.

This peer review was conducted in full compliance with the quality assurance requirements as defined in 40 CFR Part 194.

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ACRONYMS

WIPP	Waste Isolation Pilot Plant
DOE	U.S. Department of Energy
SNL	Sandia National Laboratories
WID	Waste Isolation Division (Westinghouse)
EPA	U.S. Environmental Protection Agency
EEG	Environmental Evaluation Group
CCA	Compliance Certification Application
CFR	Code of Federal Regulations
TRU	transuranic (waste)
LWA	Land Withdrawal Act
CAO	Carlsbad Area Office
CTAC	Carlsbad Technical Assistance Contractor
ET	evapotranspiration
FEP	features, events, and processes
DRZ	disturbed rock zone
MB	marker bed
MDCF	multimechanism deformation coupled fracture
RM	reduced modules
FMT	fracture-matrix-transport
SIT	specific ion interaction

EXECUTIVE SUMMARY

This report presents the results of an independent technical peer review of the adequacy of 24 conceptual models representing features, processes, and events involved in assessing the long-term performance of the Waste Isolation Pilot Plant (WIPP). These models were identified by the U.S. Department of Energy (DOE) through its scientific advisor, Sandia National Laboratories (SNL). WIPP has been developed at a site near Carlsbad, New Mexico, by the DOE to become the nation's repository for geologic isolation of transuranic radioactive waste resulting from nuclear weapons programs. Westinghouse Electric Corporation, Waste Isolation Division (WID) is the operations contractor for the WIPP. SNL and WID have provided most of the information used in this review. This independent peer review is required by 40 Code of Federal Regulations (CFR) 194.27 as part of the compliance application prepared by the DOE. The U.S. Environmental Protection Agency (EPA) will use the peer review documentation to help ensure that an adequate scientific foundation exists for a national decision on whether to dispose of this waste at WIPP.

The independent review was conducted by a six-member interdisciplinary Review Panel (Panel) having the requisite broad experience and expertise to address the range of issues associated with the ability of WIPP to successfully isolate waste for the 10,000-year regulatory time frame. The peer review was conducted at SNL in Albuquerque, New Mexico, from April through June 1996. The Panel was given access to conceptual model descriptions, scientific reports, briefings, and SNL scientists, and to the SNL Nuclear Waste Management Program Library. During meetings of the Panel, representatives of the EPA, DOE, and New Mexico Environmental Evaluation Group (EEG) observed the Panel's deliberations. The Panel also had access to reports of prior peer reviews and had the full cooperation of the DOE, SNL, and WID throughout the review.

A conceptual model is a statement of how important features, events, and processes such as fluid flow, chemical processes, or intrusion scenarios, are to be represented in performance assessment. To be used in performance assessment, the conceptual model must be successfully translated into analytical statements and mathematical analogs. The Panel reviewed in detail the 24 conceptual models against criteria of the EPA, including the scientific information used to develop the model, the assumptions, alternative models considered, uncertainties, adequacy, accuracy, and validity of conclusions. The Panel also made an assessment of the information used and whether the conceptual model is adequate for implementation in an overall performance assessment model. The review process and review criteria are discussed in Section 2.

The Panel has applied the stringent assessment criteria provided in NUREG 1297 and has concluded that thirteen of the models are adequate for implementation. The remaining eleven models were not found to be adequate for use in performance assessment of the WIPP. Models were judged to be inadequate if they failed to convince the Panel of their adequacy in terms of nine criteria. These criteria addressed: adequacy of information; validity of assumptions; alternatives evaluated; uncertainties; adequacy of the model and its application, accuracy, results, and conclusions; and whether the model was ready for implementation in the performance assessment process. Following is a list of the 24 models and a statement of the Panel's conclusion.

Disposal System Geometry	Adequate
Culebra Hydrogeology	Not Adequate (no consequence)*
Repository Fluid Flow	Not Adequate
Salado	Adequate
Impure Halite	Adequate
Salado Interbeds	Not Adequate
Disturbed Rock Zone	Adequate
Actinide Transport in the Salado	Adequate
Units Above the Salado	Not Adequate (no consequence)*
Transport of Dissolved Actinides in the Culebra	Adequate
Transport of Colloidal Actinides in the Culebra	Not Adequate
Exploration Boreholes	Not Adequate
Cuttings/Cavings	Adequate
Spallings	Not Adequate
Direct Brine Release	Not Adequate
Castile and Brine Reservoir	Not Adequate
Multiple Intrusions	Adequate
Climate Change	Adequate
Creep Closure	Adequate
Shafts and Shaft Seals	Adequate
Gas Generation	Not Adequate
Chemical Conditions	Not Adequate
Dissolved Actinide Source Term	Adequate
Colloidal Actinide Source Term	Adequate

*Although the conceptual model was found to be inadequate, no consequence to performance assessment is anticipated.

Several of the issues raised by the Panel could have significant effects on performance assessment. The details of evaluations and issues raised for each model are contained in Section 3 of this report. The relationships among the models are described in Section 4, and a summary of the evaluations is contained in Section 5.

The Panel believes that careful resolution of the issues discussed in Section 3, and any resulting changes to the models, will help to improve the overall quality of the performance assessment and provide a firmer basis for a national decision on whether to emplace waste at WIPP.

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) Conceptual Models Peer Review is one of several peer reviews being conducted by the U.S. Department of Energy (DOE). The Conceptual Models Peer Review focused on the conceptual models developed and selected by DOE through its scientific advisor, Sandia National Laboratories (SNL), to determine if they adequately and reasonably represent future states of the WIPP disposal system for use in performance assessment. This review was conducted in support of and meets the regulatory requirements of 40 Code of Federal Regulations (CFR) 191 and the implementation of those requirements by 40 CFR 194. In these regulations, this peer review of conceptual models is specifically identified by the U.S. Environmental Protection Agency (EPA) as an activity required to supplement the DOE's Compliance Certification Application (CCA) for the WIPP.

According to 40 CFR 194.27, the peer review is to be conducted in accordance with the Nuclear Regulatory Commission's document NUREG 1297, stipulating requirements for conducting peer reviews. The adequacy criteria set forth in NUREG 1297 were used by the Review Panel (Panel) as a baseline for reviewing DOE's conceptual models. To implement 40 CFR 194, DOE-Carlsbad Area Office (CAO) developed Team Procedure TP-10.5, which stipulates that a peer review is an in-depth critique of assumptions, calculations, extrapolations, alternate interpretations, methodology, and acceptance criteria employed, and of conclusions drawn in the original work.

This report documents the results of the Conceptual Models Peer Review, as determined in accordance with the aforementioned requirements. Section 2 of this report presents background information relating to the WIPP facility and review methodology. This includes a description of the repository, its geologic and hydrogeologic settings, the scenarios used, review methodology, and evaluation criteria. Section 3 presents the evaluation of each of the 24 models as assessed against a predetermined list of nine evaluation criteria. Section 4 discusses the integration of the 24 models into an overall conceptual model for the waste disposal system. Section 5 provides a summary of the evaluations. These sections are followed by appendices which include administrative information and professional biographies for each of the Panel members.

2.0 BACKGROUND

The DOE was authorized in 1979 (by Public Law 96-164) and funded by the Congress to develop a facility for demonstrating the safe disposal of transuranic (TRU) radioactive wastes generated in national defense activities. The Land Withdrawal Act (LWA) of 1992 (Public Law 102-579) provided additional authorization to continue the project under a stipulated statutory process. This facility, the WIPP, is located in southeastern New Mexico. The WIPP is operationally ready to receive waste and is being proposed by DOE for EPA approval as an operating radioactive waste disposal facility through the CCA process. The purpose of the (Compliance Certification Application (CCA) is to demonstrate through performance assessments the ability of the WIPP to successfully isolate radioactive waste from the accessible environment for the 10,000-year regulatory time frame. If regulatory compliance is demonstrated and a decision to start disposal of waste at the WIPP is made, following the provisions of the LWA, the WIPP will be used for the permanent disposal of TRU wastes, including TRU wastes containing hazardous constituents (TRU mixed waste).

2.1. WIPP Overview

The WIPP facility has been constructed in southeastern New Mexico (Figure 2-1), 26 miles east of Carlsbad, on Federal land. Prior to October 1992, this land was administered by the U.S. Department of the Interior, Bureau of Land Management. In October 1992, Congress transferred jurisdiction of the land through the LWA to the Secretary of Energy. The site encompasses 10,240 acres in a sparsely populated area, with fewer than 30 people living within 10 miles of the WIPP. The immediate surrounding land is used for livestock grazing, potash mining, and oil and gas production.

Surface structures, the planned and partially developed underground repository, and four connecting shafts make up the WIPP facility. The purpose of the surface structures is to provide security and safeguards and to accommodate routine operations, administrative activities, and further scientific studies.

The underground excavation is 655 meters (2150 feet) below the surface in the bedded salt of the Salado Formation. It includes a 12-acre area used for conducting scientific investigations and experiments in which no waste will be placed, an operations area with equipment and maintenance facilities, an area in which the waste will be emplaced for permanent disposal if the disposal site approval decision is made, and four major interconnecting tunnels used for ventilation and traffic. The subsurface waste-disposal area is to cover 100 acres and will contain eight separately excavated panels, each containing

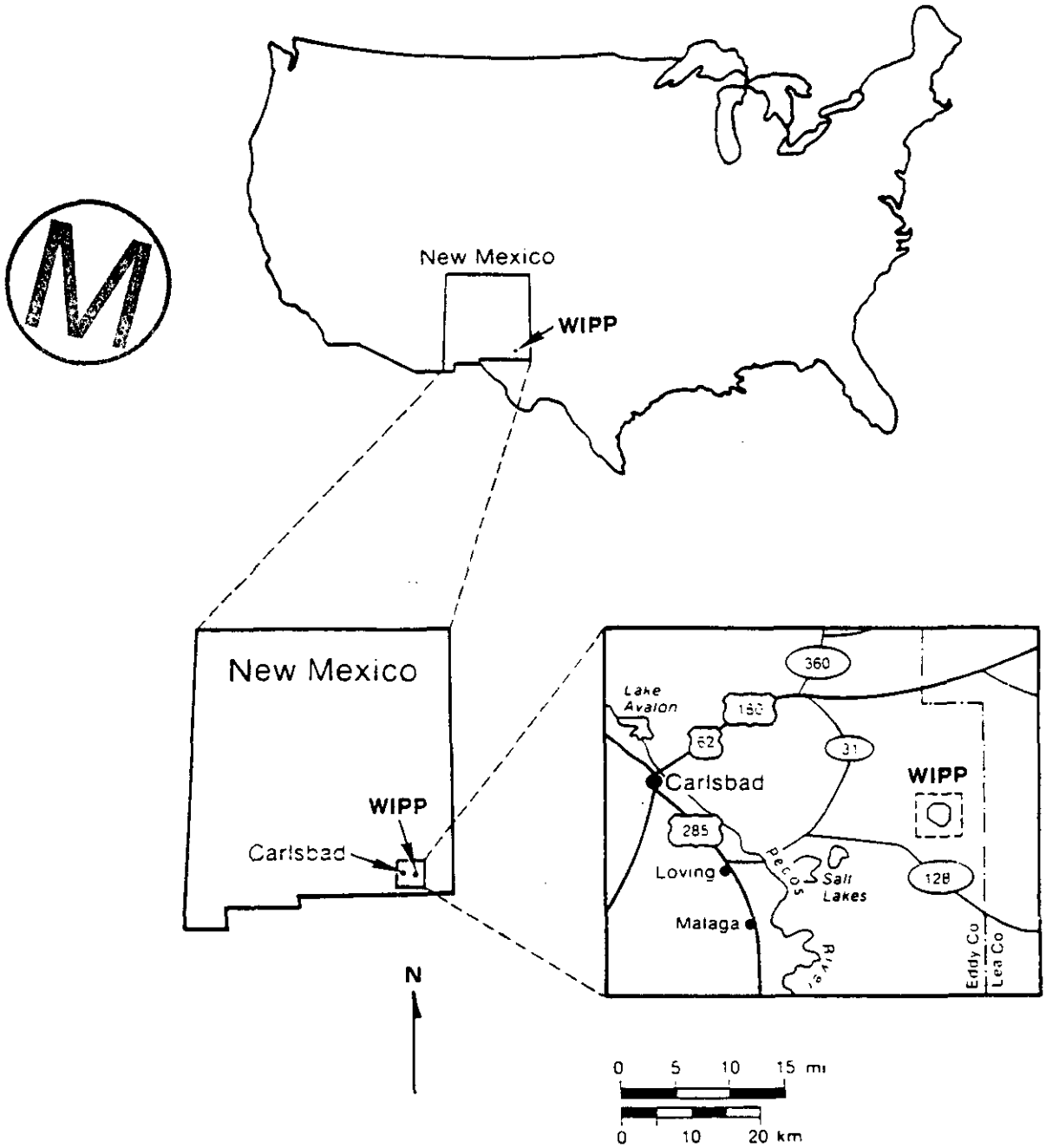

Figure 2-1. WIPP Facility Location

seven disposal rooms, and two additional panels in the area currently containing the drifts accessing the waste disposal area.

2.2. Peer Review Management

The Conceptual Models Peer Review was an independent review supported by the Office of Regulatory Compliance, DOE-CAO and delegated to its technical assistance contractor, known as the Carlsbad Technical Assistance Contractor (CTAC). CTAC commissioned Informatics Corporation, an independent firm, with the task of managing the peer reviews. The Conceptual Models Peer Review is the first of six peer reviews conducted between April 1 and August 15, 1996. The other peer reviews include: Engineered Systems Data Qualification Peer Review; Natural Barriers Data Qualification Peer Review; Waste Form and Disposal Room Data Qualification Peer Review; Passive Institutional Controls Peer Review; and Waste Characterization and Sensitivity Analyses Peer Review. Similar reviews are being conducted on engineered barrier evaluations by the WIPP operations contractor.

Each peer review was administered separately, with its own administrative coordinator and administrative assistant. Early in the review, a technical panel leader was selected from among the peer review members to serve as the focal point for the technical aspects of the review, analysis, and development of a report. The six panels shared access to an administrative document-gathering, recordkeeping, and document processing center comprised of several support staff.

The selection of panel members, training of coordinators and reviewers, and operation of the review process were governed by DOE-CAO's Team Procedure TP-10.5, the Conceptual Model Peer Review Plan, and Informatics' Desk Instruction IDI-1.0. Detailed information regarding the review process is further delineated in these documents and in the records of the Panel's review, both found in the SNL Records Center.

The Panel was requested to review the adequacy of the following 24 conceptual models that are being used by the DOE in assessing the future states of the geologic repository system.

1. Disposal System Geometry
2. Culebra Hydrogeology
3. Repository Fluid Flow
4. Salado
5. Impure Halite

6. Salado Interbeds
7. Disturbed Rock Zone
8. Actinide Transport in the Salado
9. Units Above the Salado
10. Transport of Dissolved Actinides in the Culebra
11. Transport Colloidal Actinides in the Culebra
12. Exploration Boreholes
13. Cuttings/Cavings
14. Spallings
15. Direct Brine Release
16. Castile and Brine Reservoir
17. Multiple Intrusions
18. Climate Change
19. Creep Closure
20. Shafts and Shaft Seals
21. Gas Generation
22. Chemical Conditions
23. Dissolved Actinide Source Term
24. The WIPP Colloidal Actinide Source Term

2.3. System Overview

The WIPP disposal system includes the underground repository and shaft system, the geologic host rocks, and the local and regional hydrologic system. Figure 2-2 shows the WIPP controlled area, the accessible environment, and the disposal unit boundary.

2.3.1. Repository

The WIPP surface facilities, shafts, and underground workings are shown in Figure 2-3. The WIPP repository includes four shafts (exhaust shaft, waste shaft, salt handling shaft, and air intake shaft), an experimental area, an operations area, and a waste disposal area.

Present plans call for mining eight panels of seven rooms each and two equivalent panels in the central drifts. As each panel is filled with waste, the next panel will be mined. Before the repository is closed

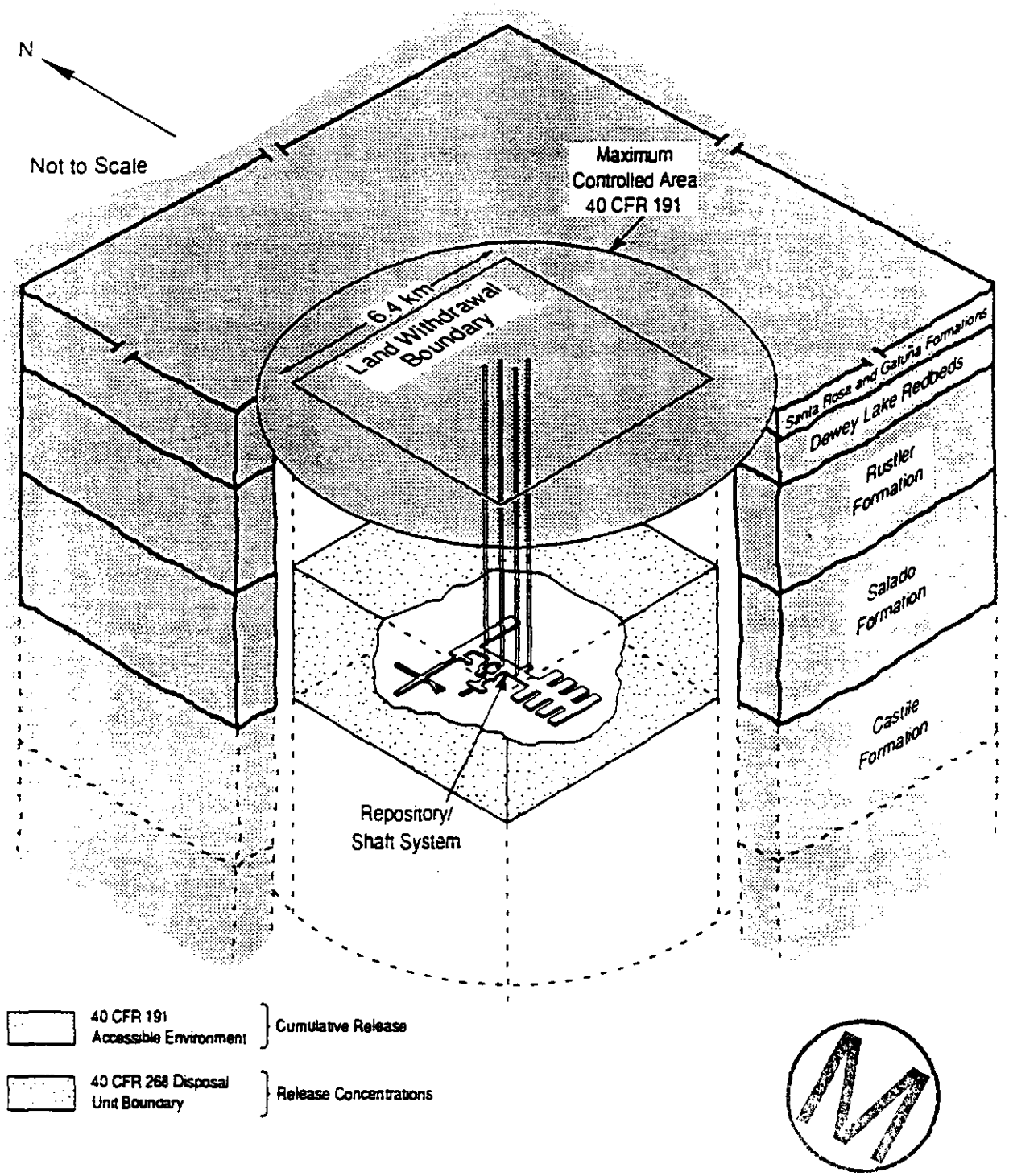

Figure 2-2. WIPP Controlled Area

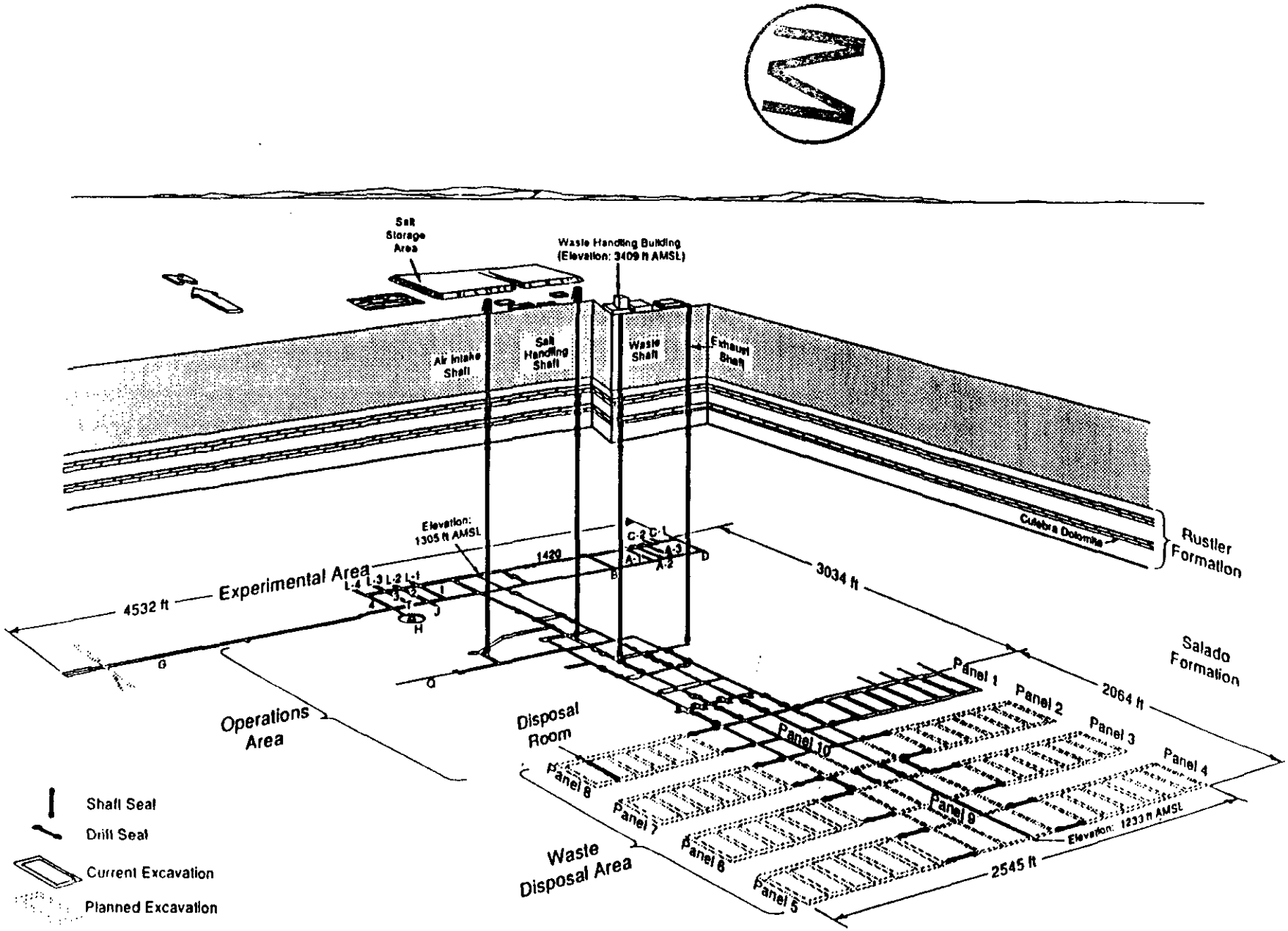

Figure 2-3. WIPP Facilities

permanently, each panel will be sealed, waste will be placed in the drifts between the panels, creating two additional panel volumes, and access ways will be sealed off from the shafts. The shafts will then be sealed to isolate the repository from the ground surface. Final closure of the facility will be facilitated by the creep closure of the salt.

2.3.2. Geologic Setting

The geologic history of southeastern New Mexico and the data collected regarding the subsurface stratigraphy at the WIPP site are important and are discussed extensively in Section 2 of the CCA (DOE 1996) and documents referenced in the CCA. The general stratigraphy at the WIPP site is presented in Figure 2-4. The relevant geologic background setting for the peer review, however, includes specific formations and their lithologies. The Bell Canyon, Castile, Salado, Rustler, Dewey Lakes, Gatuna, and Santa Rosa Formations are the lithologic units within which the conceptual models represent processes and predictions of future states of the proposed disposal system.

The sandstones, siltstones, limestones and shales of the Bell Canyon Formation define the first extensive, continuous, transmissive unit below the WIPP repository and provide a source of groundwater that could migrate vertically into the repository. The halite and anhydrite beds of the Castile Formation separate the Bell Canyon from the Salado and contain pressurized brine reservoirs. Brine reservoirs are a repository performance concern expressed in human intrusion scenarios. The halite-dominated Salado Formation contains the proposed repository and provides the primary natural barrier for containing radionuclides. The laterally extensive Culebra Dolomite Member of the Rustler Formation is the closest stratigraphic unit above the Salado with the potential to transport a radionuclide release to the accessible environment. Studies conclude that transmissivities in the Culebra vary by six orders of magnitude across the WIPP site area. Fracturing and vuggy zones account for much of the variability in the physical/hydraulic properties of the Culebra.

While other stratigraphic members of the Rustler Formation, beds of anhydrite and polyhalite, clays, and other inclusions may be important as each of the conceptual models is reviewed, the four formations and units described above define the most important components of the geologic setting for the WIPP conceptual models review.

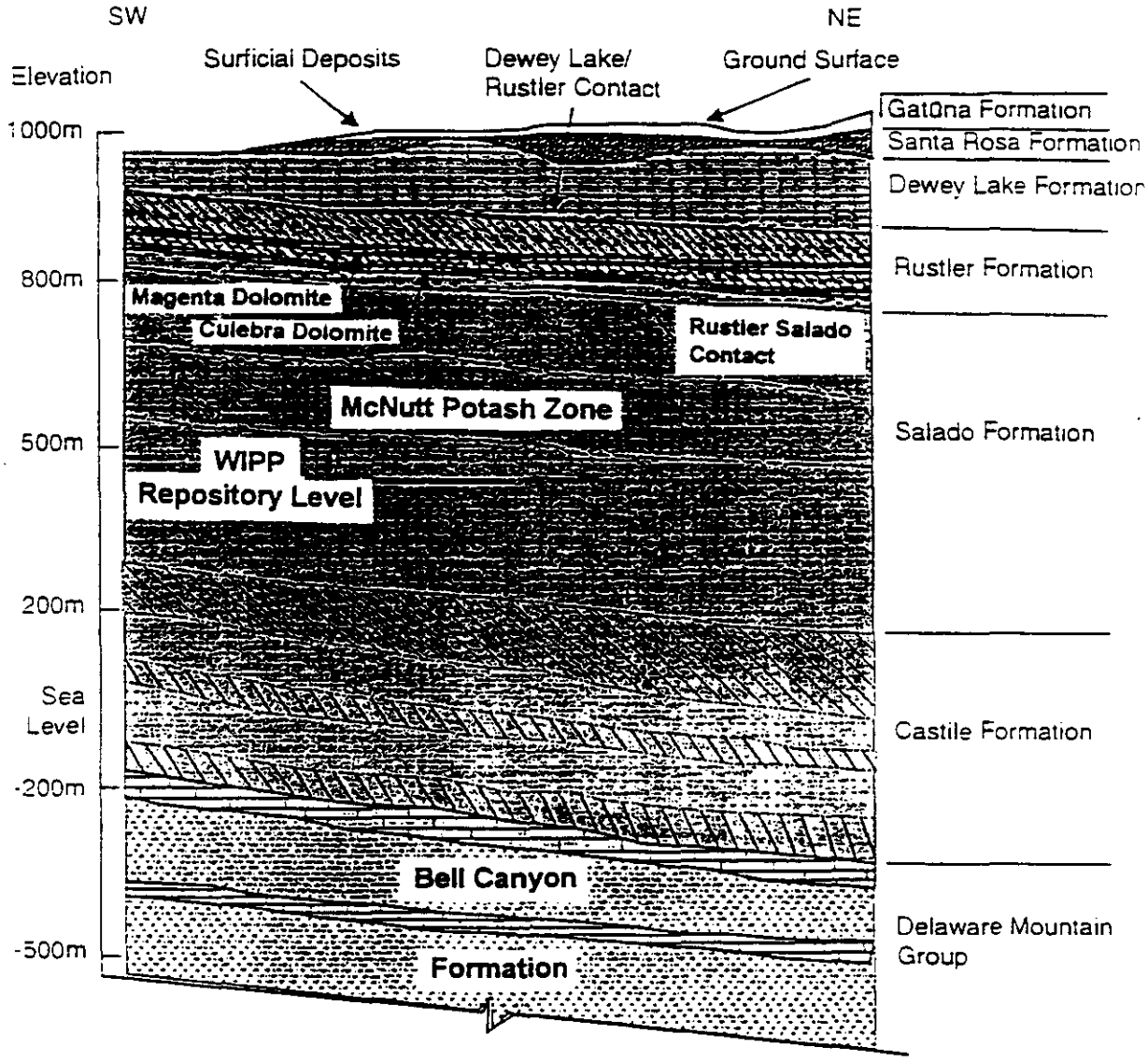

Figure 2-4. General Stratigraphy at the WIPP Site

2.3.3. Hydrologic Setting

2.3.3.1. Surface Water

The WIPP site is located within the Pecos River Basin. At its nearest point, the Pecos River flows approximately 12 miles southwest of the WIPP site boundary. There are no perennial streams at the WIPP site and in this semi-arid region, approximately 75% of annual precipitation results from intense, short-duration events between April and September. More than 90% of the mean annual precipitation is lost through evapotranspiration (ET) and on a mean annual basis, ET potential exceeds expected rainfall. EPA concluded in 1989 (EPA 1990a) that there were "no surface water features near the WIPP that could potentially affect repository performance in such a way as to influence the no-migration demonstration."

2.3.3.2. Groundwater

Extensive coring, logging and testing of boreholes in the vicinity of the WIPP site has provided data for the characterization of the hydrostratigraphy and hydrogeology important to the WIPP site region. While the deep Capitan Limestone, the Rustler-Salado contact zone near Nash Draw, and the shallower Dewey Lakes and Santa Rosa Formations are important in characterizing the WIPP region, the Bell Canyon, Castile, Salado, and Rustler Formations are the units critical to the evaluation of WIPP groundwater issues.

As presented in the geologic setting, the Bell Canyon Formation is the first continuous, transmissive, water-bearing unit beneath the WIPP. This formation provides a source of groundwater below the WIPP repository that could migrate into the repository if a pathway were available. The Bell Canyon Formation exhibits hydraulic conductivities in the range of 10^{-7} to 10^{-12} meters per second and pressures were measured in the range of 12.6 to 13.3 megapascals.

The Castile Formation is of interest to site characterization as a hydrologic barrier between the Salado and Bell Canyon Formations and because it contains isolated pressurized brine reservoirs. The Castile is predominantly low-permeability halite and anhydrite with greater permeabilities in zones of fracture and structural deformation. In the areas of higher permeability, brine pressures exist that are sufficiently above nominal hydrostatic pressure for brine to flow upward through a borehole to the surface.

The halite and anhydrite rocks of the Salado Formation are relatively impermeable and tests have shown that flows range from extremely low to no flow when appreciable pressures are applied. The Salado contains the proposed repository and provides the primary natural barrier for containing radionuclides.

The Magenta and Culebra Dolomite Members of the Rustler Formation are laterally extensive, transmissive, and display hydraulic characteristics sufficient for the lateral transport of radionuclides. Hydraulic conductivities in both members range over five to six orders of magnitude in the WIPP area, but the Magenta is generally less transmissive than the Culebra. The Culebra is the first, most extensive, and most transmissive unit above the Salado at the WIPP site. As such, the Culebra provides the most direct pathway from the WIPP repository to the accessible environment and is the most important component of the hydrogeologic setting for the conceptual models peer review.

2.4. Peer Review Panel Methodology

The review of the conceptual models commenced after a training/orientation period and was conducted in accordance with management plans, the conceptual model peer review plan, desk instructions, and other relevant protocols. Panel member qualifications are detailed in Appendix A of this report.

The work of the Panel began following training/orientation on April 5, 1996 and was scheduled to terminate on June 28, 1996 with the submittal of this final report. The Conceptual Model Peer Review Panel employed six basic approaches in their overall method of conducting and accumulating information for the reviews: 1) extensive review of available, referenced, and "roadmapped" literature relevant to the Panel; 2) attendance at briefings on conceptual models and relevant aspects of the performance assessment process; 3) conduct conceptual model or issue-focused presentations/question-and-answer sessions with DOE scientists and engineers; 4) intensive review of literature/documents discovered through continued research and focused question-and-answer sessions; 5) conduct formal and informal discussions among Panel members; and 6) participate in a tour of WIPP facilities and the local area outside the WIPP site, and in presentations/discussions associated with the tour.

The Panel was provided a list of 24 conceptual models to be independently reviewed with respect to whether or not they represent a reasonable view of future states of the proposed disposal system for the WIPP. For the review, conceptual models are defined as a set of qualitative assumptions used to describe a system or subsystem for a specific purpose. Although such a definition could limit the scope of a review, the Panel evaluated the models in accordance with NUREG 1297 criteria, from conception to their integration with mathematical representations, and paid careful attention to alternative models and approaches. In addition, the Panel recognized that individual models may warrant varying levels of reviews of their mathematical representations, computerized representations, and results.

Individual Panel members were assigned lead responsibility for specific conceptual model reviews and preparation of subsequent sections for the report. The Panel members collectively assumed writing responsibilities for introductory and conclusionary sections in the report.

Early in the review process five Panel members visited the WIPP site to tour surface and subsurface facilities and to view nearby geological features. The purpose of the visit was to view first hand the site-specific features that have potential impact on the long-term behavior of the WIPP. When touring the underground facilities, the Panel members observed the Q Room experiment site, the horizons of the Salado halite visible within the repository, fractures within the repository disturbed rock zone, and collapse features in a room where a roof had fallen. Panel members also visited the WIPP core library and observed selected core samples representative of the geological formations that could not be seen underground. Geological features viewed by the Panel near the WIPP included outcrops of the Culebra and Magenta Dolomites, Dewey Lakes Redbeds, and the Gatuna Formation. Two Panel members visited the Western AG potash mine northwest of the WIPP, where ore zones and anhydrite marker beds not visible at WIPP were seen.

Due to the large volume of project literature required for review, the Panel adopted a process in which each member would work independently in getting pertinent information on a given topic. Group briefings were reserved for the broader topics. All information was freely disseminated for consensus-building among Panel members in the completed analysis. On learning that complete information was not available to complete the Panel's scope of work on time, the Panel requested DOE to provide specific information on an accelerated interim basis. This proved to be highly beneficial to the timeliness of model reviews. It was recognized that much of this input had not been reviewed in accordance with SNL procedures and that some of the information reflected the current status of an ongoing decision process. The Panel members are aware that errors can be made in understanding and accuracy when using information of this type, and used the full access provided by DOE to those personnel necessary to provide guidance and clarification to the answers sought.

In organizing its work, the Panel established limitations on its review and the content of this report. Panel members did not review or offer comments on regulations. The Panel confined its review to the suite of conceptual models identified by DOE (Section 2.2). Finally, to maintain independence, the Panel will not offer recommendations for specific methods and approaches to address its concerns. A cutoff date of June 7, 1996 was established for receiving new information for inclusion in the review. It was

decided that if the Panel could not reach a conclusion due to a lack of information on a particular model, it would be so stated in the Panel's report.

Two additional activities were identified by DOE for the Panel. First, an overview of the Panel's finding would be presented to DOE, SNL, and observers, and the Panel would respond to questions raised to clarify the concerns identified in this report. The presentation is scheduled for July 1 and 2, 1996. Second, the Panel was requested to reconvene in August to review DOE's written responses to the Panel's findings, and prepare an addendum to this report, if necessary, indicating the adequacy with which the Panel's findings and concerns were resolved by SNL.

2.5. Criteria for Conceptual Model Review

The nine criteria used to review each of the 24 conceptual models are listed below along with a brief description of the way in which each was used by the Panel. Examples are provided where appropriate, to provide clarification. The nine criteria are based on the EPA regulation 40 CFR 194.27, NUREG 1297 Section IV.5, the EPA Compliance Application Guidance, and Panel discussions.

Information Used to Develop the Conceptual Model. This is an evaluation of data and information used to develop conceptual models and submodels. It includes attributes of the disposal system learned by DOE during site characterization activities, such as refinements to the room creep closure model or an improved understanding of disturbed rock zone characteristics.

Validity of Model Assumptions. The validity of key assumptions in the model and its application are assessed in terms of how they could affect the usefulness of the conceptual model. The review addresses the comprehensive inclusion of important features, events, processes, and other key assumptions. Examples are the assumption of Darcy flow in the various media, use of the ideal gas law at high pressures, or the method chosen to represent time-dependence of strain.

Evaluation of Alternatives. This section briefly identifies and assesses plausible alternative conceptual models or submodels seriously considered by DOE but not used, and the rationale why such alternative models were not used. Again, important features, events, and processes must be considered. The Panel does not expect the descriptions of alternative models to be as extensive as for the models chosen, but they should adequately document why the alternative models were not used. For example, the choice among matrix, dual porosity, or flow channeling in stratigraphic units, or the use of transmissivity fields versus uniform transmissivity, should be explained.

Uncertainties. This includes an evaluation of the key uncertainties in the selected conceptual models and a discussion of the consequences if aspects of the conceptual model chosen were inappropriate or incompletely constrained for the site or process. For example, if elements of the particular models used to estimate the effect of pH on actinide solubility or the permeability of the disturbed rock zone around the shaft were flawed or incorrect, how significantly would this affect performance? This is not expected to be an exhaustive evaluation, but it should raise the reasonable question, "What if the model were wrong?"

Adequacy of the Conceptual Model. Based primarily on the previous four criteria, this is a simple statement of whether the individual conceptual models and submodels represent a reasonable approximation of the actual disposal system elements.

Adequacy of Application. This is an assessment of whether it appears that the individual conceptual model is being adequately applied into an acceptable overall performance modeling system. This particular assessment does not cover the relationships among conceptual models, but whether the significant components of the individual conceptual models are appropriately implemented in support of performance assessment. For example, are the various geometrical systems and representations of the conceptual models adequately applied within the performance modeling system, or do there appear to be discontinuities between the conceptual model and its application? Also, are there apparently important alterations of key assumptions between the conceptual model and its implementation in performance modeling?

Accuracy of Results. This is a statement of whether the results of performance modeling using the conceptual model within the performance system are sufficiently accurate to adequately simulate the physical and chemical processes represented. This could either be a subjective judgment (if analytical results were not available with any necessary caveats) or a more robust and useful judgment (if results of analyses were available). Review of key results could also improve the basis for the Panel's statements about adequacy of application, overall validity of outcome of analyses, and adequacy for implementation.

Typical results that could be useful in providing a basis for these improved judgments include reports of sensitivity studies among key intermediate parameters, such as: 1) mean and extreme values of expected brine inflows, 2) gas pressurizations, 3) likelihoods of marker bed fracture, 4) directions of brine flow in the undisturbed condition, 5) the effect of mining in the vicinity of waste panels, 6) relative amounts of waste released from intrusion scenario components (direct brine releases, cuttings, cavings and spallings), and 7) initial typical complementary cumulative distribution functions. Similar results from

past performance assessments have provided a basis for improved judgments of models and modeling systems, and numerous improvements have been made in models since the 1992 performance assessment. A review of results is also desirable to facilitate making useful conclusions.

Validity of Conclusions. This is a judgment of the validity of any key conclusions that have been drawn based on results of the implementation of conceptual models in the modeling framework. The key question is whether or not conclusions from model implementations appropriately relate to the expected goal of assessing the long-term performance of the disposal system. Again, a judgment in the absence of some key output information would need to be accompanied by appropriate explanations.

Adequacy for Implementation. This is an overall, bottom-line assessment of whether the conceptual models, as intended for use in the compliance application, represent a reasonable approximation of the actual disposal system based on the eight previous criteria.

3.0 MODEL EVALUATIONS

This section presents the results of the Panel's evaluations of the 24 individual conceptual models that the DOE requested the Panel to review. Each of these models is first described and then evaluated for adequacy in accordance with the nine criteria summarized in Section 2.5. Following each evaluation, space has been provided for dissenting views; however, no dissenting views were forwarded by any Panel member. An evaluation of the integration of these conceptual models into the WIPP performance assessment is provided in Section 4.

3.1. Disposal System Geometry

3.1.1. Model Description

The Disposal System Geometry conceptual model expresses the dimensionality of the engineered system and surrounding geologic/hydrogeologic formations. The parameters of dimensionality are length, width, and height, which are expressed in individual grid blocks and remain constant for all scenarios and realizations. The processes that rely on the geometric assumptions and parameters of dimensionality are represented across the overall performance assessment system through a finite difference mathematical model called BRAGFLO. The principal processes that depend on the conceptual model for disposal system geometry are fluid flow and actinide transport. The flow fields generated by BRAGFLO are based on the geometric representation of the repository and adjacent formations and the finite difference method, and are communicated to the NUTS code that determines the transport of actinides to the accessible environment.

3.1.2. Review of Criteria

3.1.2.1. Information Used To Develop the Conceptual Model

Numerous references accompany the various background, descriptive, and features, events, and processes (FEP) screening write-ups for the repository and disposal system geometries. Except for regulatory and guidance documents, all references are to internal (SNL) reports that characterize various aspects of and inputs to the modeling of the disposal system geometry. The reports present data and information used to develop the conceptual model and background references for specific applications, but no extensive reference list on "conceptual modeling" of disposal system geometry has been compiled by DOE.

Information concerning the effects of detailed stratigraphy and stratigraphic dip on brine and gas flow, and uncertainty and parameter sensitivity analyses for gas and brine migration, is presented in WIPP

(1992a and 1992b) and Christian-Frear and Webb (1996). Other reports (WIPP 1993, Rechard et al. 1990, and Marietta et al. 1989) explain the WIPP performance assessment aspects of characterizing the disposal system geometry, and FEP screening documents present modeling alternatives. Various sections of the Compliance Certification Application (DOE 1996) summarize disposal system, repository, and intrusion event geometries. The Disposal System Geometry conceptual model is the result of integrating other models that describe the physical and chemical conditions and processes expected in the repository into a characterization of the material properties of the repository and surrounding strata. As such, the conceptual model and its application are described in terms of a process that has evolved to its current structure, and has generally been developed after the mathematical models have been defined.

3.1.2.2. Validity of Model Assumptions

The Disposal Systems Geometry conceptual model must have assumptions that are internally consistent and consistent with the assumptions of other models that represent repository processes. Since the geometry by which processes are simulated is so closely tied to the processes themselves, it is difficult to review the conceptual model for disposal system geometry totally separate from other models.

As stated in Part 2.5, the validity of key conceptual modeling assumptions will be assessed in terms of how the assumptions could affect the usefulness of the conceptual model. While the assumptions that describe the repository-process conceptual models that are closely tied to the geometry (Creep Closure, Repository Fluid Flow, Gas Generation, Chemical Conditions, Dissolved and Colloidal Actinide Source Terms) are not reviewed in this section, they are reviewed individually in Section 3, and collectively in Section 4.

Assumptions key to the disposal system geometry conceptual model for undisturbed and disturbed conditions (disposal system, disposal room, adjacent disturbed rock zone (DRZ), and geologic systems) include: 1) the three-dimensional systems can be represented by two-dimensional simplifications; 2) the associations between and relationships across regions with varying material properties can be represented by the discretized grid blocks and by the finite difference method used in the computational model; 3) the four shafts can be represented by one shaft; 4) the entire repository can be represented by the simplified floor plan used in the computation model; 5) the intrusion borehole represents the concerns of the intrusion scenarios; and 6) effects of flow in the DRZ and intact rocks outside of the repository are represented by the divergent grid to the north and south away from the repository.

The representation of relevant systems by two-dimensional simplifications not only affects the usefulness of the conceptual model, it is intended to make the model useful. As stated in Section 3.1.2.1, the geometry followed the definition of the mathematical models. Early three-dimensional mathematical models were unwieldy and computationally inefficient with respect to time, cost, and overall management. The two-dimensional representation is efficient in terms of time, cost, and managing a large number of vectors. The BRAGFLO code, as simplified (BRAGFLO is a three-dimensional code), compared favorably with a three-dimensional alternative (TOUGH 28W) used for verification with respect to the relevant outputs. Two-dimensional simplifications appear to adequately represent the structural system through which fluid flow can be simulated to the shafts or intrusion boreholes. The two-dimensional representation may not be adequate, however, for simulating fluid movement across the repository and waste panel area to the anhydrite interbeds because such flow may be unrealistically impeded by the small depths and potentially low permeabilities assigned to the cells representing the shafts and boreholes in the model. This issue is further discussed in the Repository Fluid Flow conceptual model in Section 3.3.

The conceptual approach of characterizing varying material properties by discretized grid blocks, and using finite differences and partial differential equations to compute a flow field for a series of grid points, is useful and a standard method for hydraulic routing. It is beyond the scope of the conceptual model review to conduct a detailed analysis of the BRAGFLO code, and the finite difference method will be assumed to be of standard computational design. The usefulness of this method is well established in hydrogeology, considered valid for routing liquids, and is a valuable tool for sensitivity analysis.

It appears that the one-degree dip in the Salado, the important cross sectional areas (vertical and horizontal), and distances between key system features and pathways have been retained within modeling simplifications. As these characteristics are retained, the overall geometry conceptual model remains valid. Beyond the conceptual method, the panel makes no comment on the validity of the grid block densities or volumetric variation and whether or not they adequately represent material property maps and changes in properties and their distribution.

The representation of the four shafts by a single shaft of cross sectional area and volume equal to the sum of the four shafts, is a conservative representation and simplifies the mathematical representation of brine and gas flow to and in the shaft. The single shaft is located, geometrically, in the position of the waste handling shaft, which is the closest of all four shafts to the waste disposal regions. The Panel foresees no

reasonable situation where such an assumption could compromise model usefulness and render the assumption invalid, but the presence of four sealed shafts presents four times the risk of failure of one shaft, and this may not have been taken into account. The four-shaft simplification assumption stimulates questions of reality, accuracy, and scientific credibility. While apparent conservatism, at least in the context of the scope of this review, answers most operational and performance questions, it would have been more credible, from a modeling perspective, to model the actual system.

The simplified repository floor plan represents a conservative view, and clearly provides fewer obstacles to flow in the repository than would actually be encountered by fluids. The simplifications and assigned high permeabilities answer operational and performance questions, since the conservatism and validity of the assumption was not refutable within the scope of this review. While the Panel is not satisfied that the simplifications for the sake of conservatism replace credible models of the actual systems, the assumptions remain valid.

The intrusion scenarios require assumptions about the intrusion borehole in terms of location, size, and how the brine and gas are conveyed to the borehole. The intrusion borehole is assumed to penetrate the repository and brine reservoir as appropriate to the scenario. During the intrusion scenario the represented waste panel is discretized to simulate radial flow of waste fluids to the borehole.

3.1.2.3. Evaluation of Alternatives

During the conceptual models review, information that indicated or described alternative conceptual models that were considered but not used was limited to FEP S-1 documents and unpublished informative write-ups provided by DOE (Larson 1996). Many grid configurations were experimented with in previous performance assessments, and sensitivity and uncertainty analyses (WIPP 1992a, 1992b) were conducted relative to the geometry model. Analyses that examined how detailed stratigraphy and stratigraphic dip affected brine and gas migration were reported in Christian-Frear and Webb (1996) and Webb and Larson (1996). Through all of the analyses and experiments the basic concept of the grid as the geometric framework has not changed. The specific geometric framework suitable for modeling disposal system processes and interactions was developed after the mathematical/computational system was defined. Three-dimensional and two-dimensional models were evaluated, with the three-dimensional model described as computationally inefficient for the large number of vectors required for the WIPP performance assessment, and was considered costly in terms of time and resources.

With the selection of the two-dimensional approach and the simplified BRAGFLO code, FEP S-1 screening verified (justified) the two-dimensional WIPP grid with a three-dimensional model (TOUGH 28 W). Based on the favorable comparison of outputs from the models, the DOE selected the two-dimensional model for use in the WIPP performance assessment.

Intrusion scenarios are limited to those that penetrate the repository waste panels or repository and brine reservoir. No alternative borehole intrusion scenarios are considered that miss the repository but penetrate the adjacent DRZ or strata and impact the physical properties of the DRZ or strata.

3.1.2.4. Uncertainties

The key uncertainties associated with the disposal system geometry conceptual model are associated with the simplifications made for the sake of conservatism (as opposed to, for example, operational efficiency, cost, and resource constraints) and with the question of whether the computational mesh is representative of the geometry of the system. While the two-dimensional simplifications embody assumptions key to the conceptual model, verification screening illustrates that these simplifications result in outputs of sufficient quality for use in the WIPP performance assessment (FEP S-1 1992 and 1993).

As stated in Section 3.1.2.2, the Panel concludes that there is little uncertainty or confusion with the fundamental geometric framework of discretized grid blocks or the use of the finite difference method to compute flow fields over a series of grid points. The uncertainty that exists relates to the definition of the processes by the mathematical representations and the representativeness of the computational mesh.

3.1.2.5. Adequacy of the Conceptual Model

The conceptual/geometric framework and computational method selected to characterize the material properties of the disposal system and relevant physical and chemical processes is adequate. As stated in previous sections, the implementation of the conceptual model has not been evaluated within the scope of this review and cannot be commented on.

The two-dimensional simplifications, considered part of the conceptualization of the disposal system geometry, have been subjected to verification and are considered adequate for use in characterizing releases for the WIPP performance assessment.

3.1.2.6. Adequacy of Application

The Disposal System Geometry conceptual model provides an adequate framework, method, and set of assumptions, and appears to be applied as an acceptable performance element. There are no apparent compatibility problems between the geometry and process-related conceptual models in terms of assumptions or application method that would create misrepresentations. The overall adequacy of the application should be measured by how well material properties are represented and physical and chemical processes are simulated. These measures, in turn, depend on the relevant conceptual models and data relevant to those processes being modeled. Therefore, a more definitive assessment of the adequacy of application of the Disposal System Geometry conceptual model could be determined from analyses, outputs, and results generated by the relevant process-related conceptual models, which were not available to the Panel at the time of review.

3.1.2.7. Accuracy of Results

For evaluating the accuracy of the results of the Disposal System Geometry conceptual modeling activity, model formulation results, as well as model evaluation/application results, must be reviewed. Model formulation results are the description or descriptive write-up that presents the conceptual model. Model evaluation/application results are those that indicate the performance of the conceptual model through sensitivity analyses, verification studies, or results of performance modeling of all or intermediate parameters.

The conceptual model, as defined by the geometric framework, the proposed use of a finite difference method, two-dimensional computational simplifications, and disposal system simplifications, is accurately presented as formulated. The Panel was required to consult numerous documents to acquire a comprehensive view of the conceptual model and the formulation process, but the description of the conceptual model is complete and accurate.

As presented in Section 3.1.2.6, the Disposal System Geometry model evaluation results, or results of model applications, should be measured for accuracy within the models that have conceptualized the physical and chemical processes. While the simplifications of this conceptual model have been verified as to comparability of outputs with other models (FEP S-1 1992 and 1993), the Disposal System Geometry model itself only produces results, as it represents material properties and processes conceptualized in other models. Therefore, the Panel cannot attest to the overall accuracy of the model.

3.1.2.8. Validity of Conclusions

The Panel is not aware of any results of the implementation of the Disposal System Geometry conceptual model (see Section 3.1.2.7) and therefore, there are no conclusions to validate.

3.1.2.9. Adequacy for Implementation

The conceptual model for the Disposal System Geometry provides a suitable framework for modeling the important processes and their interactions in the disposal system. The mathematical representation of the conceptual model within the BRAGFLO code has not been reviewed and, as a result, the panel offers no conclusions on the representativeness of applications using the code. The concept that the spatial effects of processes and interactions can be represented in two dimensions is defensible. The simplification in the system representation and computational method to simulate the two dimensions are defensible and adequate for implementation. The basic grid framework for representing the material properties of the disposal system, adjacent DRZ, geologic formations, and intrusion scenarios is adequate, and the proposed use of a finite difference method to connect the nodes and generate flow fields is also defensible and adequate for implementation.

3.1.2.10. Dissenting Views

There were no dissenting views for this model.

3.2. Culebra Hydrogeology

3.2.1. Model Description

The Culebra is identified as a principal potential pathway for radionuclide release to the environment. The conceptual model should support the results of hydrologic testing and provide bases for population of the model in regions lacking data. The conceptual model should correlate the regional and site scale hydrogeology with the model boundaries and help shape hydrologic gradients and local field boundaries.

The Culebra hydrogeologic characterization framework has evolved from two fundamentally different regional flow models, several formulations explaining local flow conditions represented by hydrologic testing, and several hypotheses explaining the distribution of permeability regions in the Culebra. The regional flow models include the "confinement" model and the "groundwater basin" model. The confinement model depicts the Rustler Formation (of which the Culebra is a member) as a series of perfectly isolated layers which are hydrogeologically independent. The groundwater basin model depicts

the Culebra as a layer within a series of interacting hydrologic units of varying properties which include all the hydrologic units between the ground surface and the Salado Formation. In the groundwater basin model, hydrologic gradients are thought to be vertical in the low permeability layers (Tamarisk, Forty-Niner, Unnamed Lower Member) and horizontal in the Culebra and Magenta Dolomites.

Observations in the field and shaft openings indicate that the Culebra is a dolomite averaging approximately 7 meters in thickness. Generally fine-grained, red brown in color, occasionally vuggy and fractured, the crudely layered dolomite appears to be typical of evaporite dolomites. The fractures tend to be disorderly in orientation and in some places polygonal, and the vugs are occasionally open. The MgO content of the dolomite varies greatly vertically and areally within the Culebra member. These lithologic characteristics and the sedimentological setting imply that the Culebra is a reflux dolomite, deposited originally as a calcite sediment and subsequently altered by infiltration of MgO-rich evaporite brine. The variability of MgO content, texture, and fracture distribution are most probably due to variability in volume changes due to timing, rate, and degree of dolomitization of the original calcite sediment.

Hydrologic testing of the Culebra has indicated that the hydrologic properties of the unit (principally permeability and porosity) vary strongly both vertically and areally. At some localities, the test flow rates and interactions between wells have led to hypotheses that relatively low permeabilities resulting from flow through the rock matrix dominates the hydrogeology of the Culebra over regions many tens of meters in extent. Similar tests in other localities have implied high permeabilities over distances of several kilometers, which are hypothesized to be the result of the dominance of fracture permeability along interconnected fracture zones. Other localities show intermediate flow characteristics, which may be the result of combined effects of flow-through fractures and matrix. Multiple models that hypothesize the combined and singular effects of hydrologic sample intervals across regions of vertically varying modes and rates of flow have been proposed to explain some of the variability of test results. These models have been tested by varying sample intervals and pumping rates several times in the same stratigraphic interval. It appears that sample interval does not entirely explain the composite flows observed and that dual porosity flow models are appropriate. There are regional variations in hydrologic properties in the Culebra that are too large in magnitude to be explained by variation in sample interval or proportionality of flow mechanism, and that appear to be areally distributed within and around the repository area. These areal variations in the hydrogeologic nature of the Culebra have not been clearly associated with a conceptual model of the geology of the dolomite or of the Rustler Formation as a whole. The Culebra is the most extensively tested hydrogeologic unit in the WIPP region.

Jones (1974, 1975, 1978) and Snyder and Gard (1982) postulated that the hydrology of the Culebra was primarily related to the dissolution of halite within the Rustler Formation. Jones postulated the existence of dissolution "fronts," partly the consequence of Pleistocene climatological history, which are presently active at reduced rates based on halite distribution within the Rustler and at the Rustler-Salado contact. Subsidence of the Rustler related to dissolution was the postulated mechanism for locally increased aperture of preexisting fractures. Although dissolution is certainly a strong influence on the geology of the Rustler Formation in Nash Draw and isopac maps of the Rustler Formation members show erratic thickness changes in the soluble members (Brinster 1991), workers in the region remain divided about the role of dissolution in the hydrogeology of the Rustler Formation and of the included Culebra Member. Holt and Powers (1988) argue that variations in stratigraphic thickness within the Rustler are the result of depositional processes and that changes in overburden pressure due to erosion explain the variability of hydrologic properties. Bachman (1987) and Lambert (1987) argue that solution has been inactive since mid to late Pleistocene time. Chapman (1986) contends that Culebra waters contain significant amounts of meteoric water, while Lambert argues against the presence of any meteoric water. Corbet and Wallace (1993) argues that the filling of fractures and the removal of fracture fillings by dissolution explains gross regional variations in transmissivity.

Hydrologic testing has not resolved the questions raised by arguments about the origin of variability of hydraulic properties by simple correlation with geologic features. Some fundamental geologic variables, such as fracture distribution, aperture, and orientation, as well as patterns of variation in matrix permeability and porosity, have not been sufficiently characterized to make such correlations possible. Such characterization would require a large investment in angle hole nests and extensive three-dimensional modeling. The uncertainties in the hydrogeologic character of the Culebra has led to the abandonment of attempts to formulate a detailed hydrogeologic conceptual model and there have been several attempts to generate an acceptably predictive numerical hydrologic model exclusively from testing data. These attempts are summarized in Figure 3-1 and in Table 3.1. Recent multiwell tracer tests are presently being evaluated to more fully support transport modeling.

Chapman (1986), LaVenue (1990), Siegel (1991), and Beauheim (1989) have not been able to relate detailed hydrogeologic features, hydrogeochemical facies, radiogenic ages, flow constraints, or hydrologic testing results to a consistent, detailed hydrogeological conceptual model. Neither have they been able to uniquely explain water level changes observed in monitoring of the WIPP region over the last several decades. Groundwater flow directions in the Culebra member over the Los Medanos region,

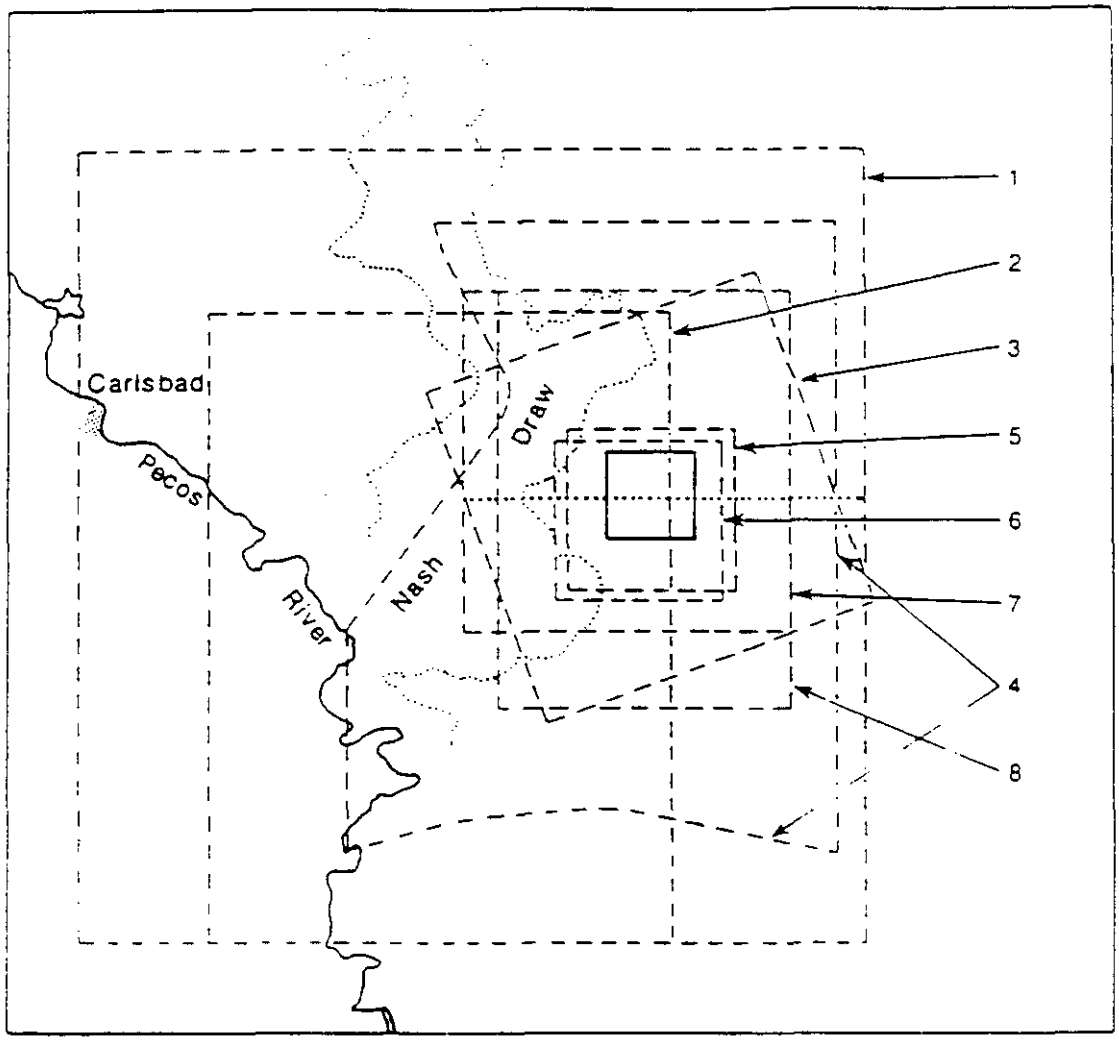

0 5 10 15 Kilometers

1 5 10 Miles

1 U.S. Department of Energy (1980a,1980b); Cole and Bond (1980)
2 D'Appolonia Consulting Engineers (1981)
3 Barr et al. (1983)
4 Davies (1989)
5 Niou and Pietz (1987)
6 Haug et al. (1987)
7 LaVenue et al. (1988)
8 Present Study

INTERA Technologies

Figure 3.1. Approximate Boundaries of Groundwater Flow Models in the WIPP (after Lappin and Hunter 1989)

Table 3.1. Summary of Modeling Investigations of the Rustler Formation or Culebra Dolomite Member in the WIPP Site Region

Investigation	Hydrogeologic Unit Modeled	Head Calibration
DOE 1980	Rustler	Steady State
D'Appolonia 1981	Rustler	Steady State
Cole and Bond 1980	Rustler	Steady State
Barr et al. 1983	Culebra	Steady State
Davies 1989	Culebra	Steady State
Niou and Pietz 1987	Culebra	Transient
Haug et al. 1988	Culebra	Steady State
LaVenue et al. 1988	Culebra	Steady State
Present Study	Culebra	Combined Steady State/Transient

as well as in other members of the Rustler Formation, are reasonably well defined. The work synthesized by LaVenue (1990) and Brinster (1991) and the intervening single and multiwell and tracer testing in the Culebra, are an attempt to characterize the hydrology of the Culebra in a well-constrained area around the WIPP on the basis of a relatively large body of hydrologic test data by numerical modeling alone. If this effort is ultimately successful, perhaps a comparison of model results with the existing hydrogeologic characterization of the Culebra will allow the formulation of a hydrogeologic conceptual model that explains transmissivity variation at the site scale. None exists at this time. The large number of hydrologic tests within the repository area and in the Los Medanos region around the repository, the variety of types of testing, and the long period of monitoring suggest that a numerical flow model may be sufficient to answer most of the performance-related questions about the Culebra at the repository.

3.2.2. Review of Criteria

3.2.2.1. Information Used to Develop the Conceptual Model

Information used to develop the conceptual model included field geologic observations, logging of cores from borings, observations from shaft mapping, petrographic and mineralogic study, subsurface mapping, groundwater geochemistry and geochronology, and hydrologic testing and monitoring including multiwell pumping and tracer tests. Several hypotheses correlating detailed variations in the hydrologic properties and results of monitoring of the Culebra with groundwater geochemistry and geohydrological aspects of the formation were proposed and tested against existing information or information acquired

specifically to test the hypotheses. All hypotheses failed to correlate the detailed hydrogeology of the Culebra with its tested hydrologic character. The information used to develop the conceptual model was insufficient to permit the formulation of the model at a sufficient scale.

The Culebra is a red-brown, fine grained dolomite, continuous over the WIPP area, which displays vugs and fractures that may be the primary sources of permeability and porosity. The lithologic aspect of the Culebra and the variability of its magnesium content suggest that it is a reflux dolomite formed by the gravity-driven infiltration of a calcite sediment by magnesium rich fluids, shortly after deposition in an evaporite sedimentological setting. The Culebra is bounded by two very low permeability anhydrite units. The hydrologic gradient in the Culebra is horizontal and generally southward over the repository area and the gradients in the adjacent beds are vertical. Some water-pressure measurements imply that the Culebra is underpressured. The transmissivity and gradient of the Culebra are capable of discharging more water than the formation is receiving in recharge, at least locally. There is more hydrologic test data for the Culebra than for any other hydrogeologic unit in the repository region. The model boundaries are defined by regional hydrogeologic features mapped and modeled by Corbett (1993). The information is inadequate to develop a conceptual model that explains hydraulic process and property variation at the site scale.

3.2.2.2. Validity of Model Assumptions

Since all detailed conceptual hydrogeologic hypotheses correlating the Culebra hydrogeology and geochemistry to the described hydrologic properties and the results of hydrogeologic testing and monitoring failed, no conceptual model was formed that could be linked to the computational flow model. No model assumptions, which have their origin in the conceptual model and impact performance assessment, exist for testing.

3.2.2.3. Evaluation of Alternatives

Alternative hydrogeologic models, which relied on apportioning fracture and matrix porosity and permeability within the Culebra as a result of: 1) solution of halite within the Rustler Formation; 2) solution of halite at the Rustler Salado interface; 3) variability of superincumbent load due to topography; and 4) dissolution due to gravity driven flow of brines of different density, were considered and discarded.

3.2.2.4. Uncertainties

Model uncertainties as a result of the conceptual model do not exist in this instance because of the absence of an accepted conceptual model at the appropriate level of detail. An alternative approach has been adopted which depends on the modeling of the hydrology of the Culebra entirely on the basis of the results of hydrologic testing. A detailed assessment of this numerical modeling effort is beyond the scope of this review.

Two sources of uncertainty are related to the absence of a conceptual model in this case. A conceptual model helps to explain the sources of variability observed in a data base derived from hydrologic testing and provides rational bases for populating the data-less areas in the model grid. Values are smoothed and gradients between varying clusters of data are shaped on the basis of hydrogeologic character. Absence of this influence on grid population reduces confidence in numerical model representativeness.

The second uncertainty is the absence of hydrogeologic bases for ruling out significant patterns of variance in the flow patterns and hydrologic properties in the Culebra hidden within data-less areas or areas of apparently incoherent variation in the testing area. The Culebra test results have exhibited relatively large, spatially dependent variations in hydraulic conductivity. The relatively dense testing data base and the ongoing multiwell and tracer testing are attempts to resolve this issue. Zones of relatively rapid fracture flow, without significant retardation of radionuclides by physical or geochemical processes, could cause accelerated transport in the Culebra. The existing transmissivity field models seem to cover the regions of greatest concern to site performance with what appears to be an adequate testing data distribution to rule out local variations in flow significant to performance of the site. The density of field testing data seems to be adequate.

The impact of ground subsidence due to repository closure on the hydrogeology of the Culebra is a source of uncertainty. Subsidence of nearby potash mines and an analysis by Westinghouse suggest a lowering of the ground surface of about .5 m and a small horizontal extensional strain in the Culebra (.007%). It has been asserted that the transmissivities represented by the two-dimensional flow model proposed for performance assessment are conservative enough to contain any enhancement of flow caused by subsidence of this scale. No conceptual arguments specific to Culebra hydrogeology or numerical analysis supporting the probable magnitude of enhancement of transmissivity or the sensitivity of the proposed model to that change have been presented.

3.2.2.5. Adequacy of the Conceptual Model

The conceptual model is not adequate to define variations in the transmissivity of the Culebra at the site scale. Its function has been replaced by an extensive hydrologic testing and modeling effort.

3.2.2.6. Adequacy of Application

See Section 3.2.2.5.

3.2.2.7. Accuracy of Results

No conceptual model is employed in performance assessment-related modeling. Assessment of the accuracy of the numerical flow modeling used in performance assessment is beyond the scope of this review.

3.2.2.8. Validity of Conclusions

The validity of the conclusions of numerical flow modeling is not impacted by the conceptual model in this case. Data distribution and density and geostatistical methods used to populate the model appear to be valid. The results make sense in a qualitative way.

3.2.2.9. Adequacy for Implementation

The conceptual model was not adequate for implementation. A numerical model based on an extensive hydrologic testing data base was substituted. The numerical model appears to meet the needs of the performance assessment, although the computational validity and accuracy of that model were not reviewed.

3.2.2.10. Dissenting Views

There were no dissenting views for this model.

3.3. Repository Fluid Flow

3.3.1. Model Description

The Repository Fluid Flow conceptual model addresses (1) fluid distribution in the waste, (2) long-term fluid flow to and from the Salado Formation and shafts, and (3) long-term fluid flow between the repository and intrusion boreholes. Related conceptual models include Disposal System Geometry, Disturbed Rock Zone, Creep Closure, Shafts and Shaft Seals, Gas Generation, Impure Halite, Salado, and Salado Interbeds, Castile and Brine Reservoirs, Exploration Boreholes, and Multiple Intrusions.

The Repository Fluid Flow conceptual model is a complex description of simultaneous, interacting hydrologic, chemical, geomechanical, engineering design, and human intrusion scenarios whose effects can be described separately, but require numerical modeling to identify the combined, integrated outcome. The conditions controlling repository fluid flow include brine inflow rates, halite creep rates, and gas generation from waste corrosion and degradation, which are themselves the objects of related but separately described conceptual models. The Repository Fluid Flow model accepts inputs from these related models and provides descriptions of pressures, flow rates, and flow directions for brine and gas within the excavated areas of the repository. A detailed description of the coupled processes in the conceptual model is presented in Freeze et al. (1995).

The layout of the waste repository is described in Section 2.3.1. The key elements of this layout pertaining to the Repository Fluid Flow conceptual model are the waste disposal area (the waste panels and access drifts), the panel seals, the operational area, the experimental area, the shafts, the WIPP site characterization boreholes in the vicinity of the repository, and any future exploration boreholes that are randomly determined to penetrate the repository. The waste panels in the disposal area will be sequentially filled to capacity with waste and isolated from the rest of the repository by 40-m long closure seals consisting of concrete plugs and crushed salt. The operations area is north of the disposal area and consists of four shafts and a network of interconnecting access drifts. Two additional sets of 40-m seals will be placed in the operations area between the waste and the shafts. The experimental area is north of the operations area and consists of a series of experimental rooms and access drifts.

In the current plan, waste will be placed in steel drums and waste boxes stacked to achieve efficient use of space. Magnesium oxide will be placed around the containers to absorb carbon dioxide gas generated during microbial decay of cellulosics in the waste. No structural backfill is planned for the repository. Analyses have indicated that decay and degradation of the waste are expected to generate little heat and the maximum repository-wide temperature excursion is expected to be about 5°C. The changes in density and viscosity for brine and gas at this temperature rise are small, and are not considered to be significant in performance assessment. Plans for shaft and borehole sealing are discussed in Sections 3.12 and 3.20. On repository closure, the Salado halite is expected to creep into the excavated rooms and crush the waste; however, some porosity will remain, resulting from the strength of the waste materials and from pressurized brine and gas in the waste. A discussion of the Creep Closure model is presented in Section 3.19.

In undisturbed scenarios, brine is expected to flow into the excavated entries of the repository at a slow rate both during and after closure. Brine will flow directly from the Salado halite, from higher conductivity anhydrite interbeds intersected by the excavations, from formations above the Salado by seepage through a DRZ around the shaft, and from brine squeezed from storage in clays in the impure halite. Flow into the repository through the halite is expected to be enhanced by a disturbed rock zone of higher permeability in the walls, floor, and back of the underground entries (see Section 3.7), from a series of 50-foot long site characterization boreholes drilled vertically upward and downward from the repository, and from rock bolt holes penetrating the back and walls of most entries. During the operational period, this inflow is expected to be removed by evaporation into the repository ventilation air. Under undisturbed conditions following closure, inflow is expected to continue at a low rate from the first three of these sources but not from the clay, which is expected to have been fully consolidated. The brine is expected to pool in low spots on the repository floor and to be wicked into the waste and magnesium oxide by capillary forces. Under disturbed conditions, additional inflows of brine may rapidly occur following closure if a borehole penetrating the repository also encounters pressurized brine in the underlying Castile Formation.

Both gas and brine will behave as fluids, filling pore volume in the repository. Gas and brine will be generated at the same time that the repository void spaces are being closed by halite creep, eventually reaching a state of equilibrium where the pressure of the gas and brine is balanced by the pressure of the halite on the remaining void spaces. Brine inflow into the remaining voids is expected to stop when the pressure of brine in the repository is the same as the pressure of brine in the halite. If gas production continues, the pressure of the gas will continue to rise, driving the brine back into the halite.

If the gas pressure exceeds the threshold pressure for its entry into the surrounding geologic media, the gas will enter the geologic media, increasing the available void volume. As the gas pressure approaches the lithostatic pressure, gas is expected to enter the anhydrite interbeds in the vicinity of the repository, increase the porosity in those interbeds by enlarging existing fractures along planes of weakness, and migrate laterally in the interbed away from the repository, until the increased pore volume sufficiently reduces gas pressure that the phenomenon stops (see Section 3.6). The lateral extent of such fracturing will depend on the rate of gas generation and the pressure and volume of gas present in the repository. Microfracturing of the intact halite from gas pressure buildup is expected to occur around the repository, but at a rate that is sufficiently slow that stress redistribution from halite creep will keep these fractures

from developing into a size that would be of concern to performance assessment. More extensive fracturing is expected in anhydrite, which is more brittle and does not have the creep characteristics of halite.

The volume of gas produced will be limited primarily by the volume of source material (primarily steel and cellulosics) in the repository, and the rate of gas production will be limited primarily by the volume of brine present and in contact with the waste. Gas pressure can be relieved if the repository is penetrated by an exploration borehole, in which case releases of gas, contaminated brine, and repository waste materials could occur at the ground surface (see Sections 3.12 and 3.17). The void volume in the repository can also increase when the gas pressure exceeds the lithostatic pressure by reversing the creep process.

The conceptual model for repository fluid flow is implemented for performance assessment using two separate models developed from the BRAGFLO code. The first model, which for purposes of this review will be called BRAGFLO, is used for analyzing long-term flow through the repository under both disturbed and undisturbed conditions. The second model is used for calculating short-term, direct brine releases when the repository is penetrated by one or more boreholes, and will be called BRAGFLO-DBR. This second model is discussed under the Direct Brine Release conceptual model in Section 3.15.

The repository is represented in BRAGFLO in two-dimensional vertical section as a series of volumes, each with homogeneous, isotropic material properties and behaviors, and each representing a major repository feature. The slight 1° southerly dip of the bedding is incorporated into the model. The effective depth of each modeled feature (the third dimension normal to the plane of the model) is addressed through adjusting the cross section areas of the cells representing the feature. The model material numbers and the dimensions of each feature are summarized in Table 3.2. Ranges of depths are given for features with variable depths that are represented by multiple columns of model cells. The heights of the intrusion borehole and shaft are not given because they extend to the ground surface, have varying material properties and behaviors, and heights that are greater than the height of the repository excavations.

The effective depths of the model cells were varied to simulate the increasing hydraulic gradients that would occur into the repository, intrusion borehole, and shaft under radial flow conditions. The model depths used for the borehole and shaft approximate the effective diameters of these features. The model depth for the borehole is held constant whether or not an intrusion borehole is assumed to have been

Table 3.2. Model Material Numbers and Feature Dimensions

Feature	Material Number	Length (m)	Height (m)	Depth (m)
Single waste panel	23	112	4	4.8 to 126.2
Intrusion borehole	1	0.27	- -	0.27
Single panel closure	25	40	4	10
Rest of repository	24	695	4	141.6
Multiple panel closure	25	80	4	18.9
Operations area	26	333	4	18.9
Shaft	2 to 11	10	- -	9.5
Experimental area	27	560	4	20.5 to 53.1

drilled. BRAGFLO is configured assuming a single shaft with a vertical permeability of the four shafts (and their disturbed rock zones) combined, and assuming a single exploratory borehole that penetrates the center of one of the downdip waste panels. The borehole cells are assigned the properties of the undisturbed media until a borehole is randomly assumed to have been drilled. The borehole can be either an E1 type (penetrates a waste panel in the repository and encounters pressurized brine in the underlying Castile Formation) or an E2 type (penetrates a waste panel but does not encounter pressurized brine). Penetration of a waste panel by more than one borehole is also addressed by this version of BRAGFLO and is discussed in Section 3.17. The presence of existing site characterization borehole ERDA-9, very near the repository, is not addressed by BRAGFLO.

The waste is simulated in BRAGFLO in two areas: Material 23, which represents a single waste panel, and Material 24, which represents the rest of the repository. The waste itself is assumed to be distributed uniformly throughout the two areas. Between the waste materials, BRAGFLO simulates a 40-m long panel closure seal (Material 25) representing the seals in the two panel access drifts. In addition, an 80-m long panel closure seal (also Material 25) separates the rest of the repository from the operations area and represents the two groups of 40-m long seals that will be placed in the operations area. The remaining cells (Materials 26 and 27) represent the operations and experimental areas, respectively, and are located on either side of the shaft. Each of these material areas is three cells high in vertical dimension, allowing vertical variations in brine and gas saturations and the resulting varying rates of corrosion and waste decomposition to be simulated.

Gas production rates are estimated as a function of brine availability. Wicking of brine into the waste will increase gas production rates and is modeled by arbitrarily adding a randomly selected value,

varying from zero to 1.0, to the brine saturation value in disposal area model cells containing brine (not to exceed a total brine saturation of 1.0). This value is called the wicking saturation. The additional brine is only used for chemical reaction purposes. The approach increases the volume of brine available for chemical reactions and increases the rate of corrosion and gas production. To simplify analysis of the mechanical effects of gas production and pressure buildup, all gases produced are assumed to have the properties of hydrogen and behave as ideal gases. Although this assumption would lead to underestimating the viscosity and overestimating the compressibility of the hydrogen-carbon dioxide mixture actually expected to be present, the error would be of no significance in view of the considerably larger uncertainties in other parameters in the model and the expected efficiency of the magnesium oxide in removing carbon dioxide from the system.

Repository closure through halite creep is modeled using the porosity surface approach discussed in Section 3.19. The waste disposal rooms are assumed to maintain a relatively high constant permeability, but a varying porosity during the creep closure process. The panel closure seals and the operations and experimental areas of the repository are assumed to have a constant permeability and porosity. BRAGFLO models the repository assuming two-phase Darcy porous medium flow throughout the closure process.

Material 22, representing disturbed halite, lies above and below the repository excavations and interconnects the repository with Marker Beds 138 and 139, and with Anhydrite Layers A and B. No disturbed halite is modeled in the walls of the excavations. The lateral outer boundaries of the model are over 2,000 m from the repository. All outer boundaries below the Rustler are assigned no-flow conditions.

3.3.2. Review of Criteria

3.3.2.1. Information Used to Develop the Conceptual Model

The conceptual model has relied greatly on the general Darcy model for flow in porous media, as amended for gas by considering the Klinkenberg effect, and for two-phase flow using a modified Brooks-Corey model that includes threshold pressures for gas entry into a brine-saturated medium. Brine salinity, density, compressibility, and viscosity are addressed in the model. Gas properties are given by the Redlich-Kwong-Soave equation of state, assuming behavior to be that of pure hydrogen. The principal basis for the conceptual model is not specific to WIPP, but was developed from the general state of knowledge of two-phase, isothermal flow of liquids and gases in porous media. This general

behavioral information was supplemented by site-specific studies that included measurements of the coupled hydromechanical properties of brine, intact salt, crushed salt, gas, and sealing materials. Although site-specific parameters for two-phase flow in the waste are lacking in the data base, representative values for these parameters would be difficult to obtain because of the expected heterogeneity of the waste. Surrogate parameters from other media are instead used for two-phase flow, and the uncertainties are compensated for by random sampling over ranges of values. Detailed modeling sensitivity studies of repository fluid flow and other coupled phenomena are summarized in Freeze et al. (1995) and Christian-Frear and Webb (1996). The information and concepts used were appropriate for developing the conceptual model.

3.3.2.2. Validity of Model Assumptions

The principal assumptions used to develop the model are identified in Section 3.3.1 and are critically reviewed here. Most assumptions are reasonable and appropriate and include the assumption of isothermal conditions for fluid flow calculations, the assumption of Darcy flow, the incorporation of two-phase flow, the treatment of wicking, and the phase stratification from gravity effects. The assumed lack of a DRZ in the walls of the modeled repository rooms is not expected to significantly affect the Repository Fluid Flow model, but would change the frequency of borehole penetration by increasing the target area. This issue is further addressed in Section 3.15. Certain aspects of the principal model assumptions were reviewed more closely and are addressed in the following paragraphs.

The two-dimensional representation of the repository in BRAGFLO is necessary to feasibly perform the many repeated model runs needed for probabilistic analysis. The effect of more explicitly representing the detailed stratigraphy was evaluated in Christian-Frear and Webb (1996), and the sensitivity of a more rigorous evaluation of coupled repository processes was reviewed in Freeze et al. (1995). The results of these studies identified key parameters and processes and support the two-dimensional approach used in BRAGFLO.

BRAGFLO uses the Brooks-Corey relative permeability model for two-phase flow within all media except the anhydrite interbeds. Although site-specific parameters are not available to support this model, the use of surrogate media and the practice of incorporating uncertainty through random sampling from a range of values is considered appropriate. The sensitivity of pressure buildup to the alternative van Genuchten-Parker two-phase model was documented in Christian-Frear and Webb (1996) and found to be relatively low. Although the Brooks-Corey model calculates slightly higher repository fluid pressures

than the van Genuchten-Parker model because of the reduced fluid mobility, the impact of this assumption was found to be small in the repository, where the porosities are high and the threshold pressures are low.

The depth of the model cells increases in a stepwise manner away from the repository to simulate radial flow into the repository, shaft, and borehole. While this is appropriate for flow to or from the shaft or borehole, it creates narrow constrictions in the two-dimensional flow field when considering flow across the shaft or borehole within the repository. The significant decrease in model depth in the vicinity of the borehole and shaft creates artificial constrictions for horizontal flow across the model. Model results were reviewed and have shown that the pressure drop across these constrictions is negligible under an undisturbed flow condition and that fluid movement is not unduly restricted. The lack of a significant pressure drop is expected to be related to the very low rates of flow and the relative mobility of the gas phase. However, this model configuration may restrict the rate of equilibration of brine saturation within the repository following an E1 borehole intrusion and the movement of brine from the "rest of the repository" to the anhydrite beds to the south.

Site characterization boreholes drilled by WIPP in the vicinity of the site are not addressed in BRAGFLO. ERDA-9, for example, penetrates the repository horizon within several meters of a drift wall in the operations area, but does not penetrate the repository excavation. The disposition of these boreholes is not addressed by DOE in the documents provided to the Panel. Unless properly sealed with a low permeability material such as a continuous concrete plug, such boreholes represent potential release pathways.

The permeabilities used in BRAGFLO for the waste materials and the panel closure seals are constants, but in reality are expected to change over time due to repository room closure. These parameters are important to repository fluid flow. The values chosen for permeability are in the high end of the range, and while they are conservative for late times, they underestimate permeabilities for early times. Both the closure seals and the waste may be highly permeable at early times, when the ability of the closure seals to effectively isolate waste panels may be in question. While the operations and experimental areas also are assigned constant permeabilities, the assigned value of 1×10^{-11} m^2 is considered conservatively high and therefore adequate for performance assessment purposes.

The permeability used in BRAGFLO for the DRZ is constant, but in reality is expected to change over time due to repository creep closure and to ultimately approach that of undisturbed halite as the fractures

in that zone heal. The actual permeability will be determined not only by the stress-induced fracturing, but also by the roof falls expected after closure and by the numerous test, characterization, and rock bolt boreholes that penetrate the zone from inside the repository and may not be sealed before closure. The permeability of 1×10^{-15} m^2 assigned to the DRZ has apparently been selected to not impede fluid flow from the repository to the anhydrite interbeds, but has not been based on an analysis to determine what the actual permeability would be. The value chosen for permeability is expected to be in the high end of the range, and while it would be conservative for late times, it may underestimate the permeability at early times.

The evaluation of the panel closure seals in restricting the effects of borehole intrusions to the penetrated waste panels suggests that the design, placement, and performance of these seals is important. The assigned constant permeability of 1×10^{-15} m^2 is equal to that of the disturbed rock zone, yet the crushed salt and concrete to be used in the seal will have considerably different and time-variant properties, depending on the seal design, methods of emplacement, and creep closure rates and pressures. The permeability of the concrete will increase over time due to degradation, while that of the crushed salt will decrease due to consolidation. The panel closures do not appear to have been formally designed and an engineering evaluation of their performance over time does not appear to have been performed.

3.3.2.3. Evaluation of Alternatives

The overall conceptual model for repository fluid flow has evolved over time and has been the subject of detailed review in which alternatives were evaluated and led to refinements in the numerical representation of the model in BRAGFLO (see, for example, Christian-Frear and Webb [1996] and Freeze et al. [1995]). The alternatives evaluated included three-dimensional versus two-dimensional representation, including and excluding gravity effects, and varying configurations of the two-dimensional representation. Based on these studies, the overall conceptual model, as configured for use in performance assessment, has been shown to be adequate; however, the validity of certain assumptions regarding components of this model has been questioned, as described in Section 3.3.2.2. These assumptions include alternative depths for model cells in BRAGFLO, committing to sealing the ERDA-9 borehole prior to repository closure, providing variable permeabilities for the waste, panel closure materials, and the DRZ, and providing an engineering design and performance evaluation of the panel closures.

3.3.2.4. Uncertainties

The principal uncertainties in the model results are expected to stem from uncertainties in the modeling theory and in the parametric data base. Emphasis in this review has been on identifying uncertainties that would lead to underestimating radionuclide releases. While the theoretical basis for the model may contain inaccuracies, it closely represents the state-of-the-art and with the exceptions noted above, does not appear to bias the results toward underestimating releases. The principal uncertainties in the parametric data base are associated with the hydrologic properties of the repository materials and are addressed in the aforementioned reports Freeze et al. (1995) and Christian-Frear and Webb (1996). Material properties with high degrees of uncertainty are generally treated as distributed variables. The properties of the panel seals, however, are not distributed variables and in the absence of a more thorough analysis of the seal design and its long-term performance, the ability of these seals to successfully isolate waste panels must be considered uncertain. Another uncertainty stems from the lack of a DRZ in the repository walls and the potential for waste releases through exploratory boreholes that penetrate the walls rather than the waste itself. The consequence of uncertainties in the models or data base is ultimately to overestimate or underestimate radionuclide releases; however, many of these parameter values reflect best estimates of future conditions and are considered adequate for performance assessment.

3.3.2.5. Adequacy of the Conceptual Model

The conceptual model for repository fluid flow is fundamentally sound and represents an appropriate effort to simulate the complex, strongly coupled fluid flow processes occurring within the repository during periods of simultaneous gas generation and creep closure. The appropriateness of the model was supported by the results of more detailed modeling reported in Freeze et al. (1995) and Christian-Frear and Webb (1996). The issues raised regarding the validity of the model assumptions (Section 3.3.2.2) are associated with specific, but potentially significant, details of the model. With appropriate resolution of the issues raised in this report, the adequacy of the current model would be acceptable.

3.3.2.6. Adequacy of Application

With the exception of the issues raised in Section 3.3.2.2 regarding model assumptions, the application of the conceptual model in the numerical model is adequate. Principal concerns are related to the model cell depths, the treatment of material properties that vary over time, the disposition of the ERDA-9 borehole, and a more thorough evaluation of the long-term performance of panel closures as repository seals.

3.3.2.7. Accuracy of Results

Individual parameter values supporting the conceptual model were checked and found to be reasonable. Although many simplifying assumptions are made, they are generally demonstrably conservative and are appropriate in view of the need to make the probabilistic modeling effort tractable, and in view of the relatively high degrees of uncertainty in both input parameters and the occurrence of future events. Selected modeling results were reviewed (specifically, repository pressure differences across borehole and shaft cells and at model boundaries) and were found to be reasonable. Although the accuracy of the BRAGFLO results is expected to be adequate and appropriate for performance assessment modeling, provided that the issues raised in Section 3.3.2.3 are appropriately addressed, a final determination of model accuracy cannot be made in the absence of modeling results.

3.3.2.8. Validity of Conclusions

The validity of the conceptual model is uncertain pending resolution of the issues raised in Section 3.3.2.3. In summary, the following concerns remain.

- The sensitivity of modeling results to the depths of the cells in BRAGFLO representing the borehole and shaft does not appear to have been evaluated for a variety of flow conditions to determine if the model configuration unrealistically restricts brine movement within the waste panel area or to the anhydrite beds at the southern end of the repository. If modeling results are found to be sensitive to this model configuration, alternative configurations might be considered.

- A commitment to effectively seal the ERDA-9 borehole with a continuous concrete plug does not appear to have been made by DOE. Such a commitment is expected to be provided in Chapter 3 of the CCA; however, this chapter was not available to the Panel for review.

- The sensitivity of model results to the constant permeabilities assigned to the waste materials and panel seals does not appear to have been evaluated. Higher permeabilities at early times could lead to underestimating radionuclide releases.

- The basis for the permeability value assigned to the repository DRZ has not been adequately supported, and the sensitivity of model results to the selection of a constant value for this parameter does not appear to have been evaluated for the current performance assessment model. The presence of open, unsealed boreholes within this DRZ and the likelihood of massive fracturing during roof failure suggest that the permeability of this zone may approach that of the waste.

- The waste panel closures do not appear to have been formally designed and their long-term performance does not appear to have been evaluated in the same rigorous manner as shaft and borehole seals.

3.3.2.9. Adequacy for Implementation

The Repository Fluid Flow conceptual model is not currently adequate for implementation because of the validity issues raised in Section 3.3.2.8. The conceptual model would be considered adequate for implementation if the validity issues were successfully resolved.

3.3.2.10. Dissenting Views

There were no dissenting views for this model.

3.4. Salado

3.4.1. Model Description

The Salado Formation is the principle barrier between the waste and the environment and is the primary source of brine flowing into the repository. The conceptual model supports estimates of hydrologic processes and properties, as well as mechanical behavior of the halite-rich rocks of the Salado Formation. A simplified stratigraphy for hydrologic modeling is proposed and supported. The modeling of the anhydrite interbeds is discussed elsewhere.

The Salado Formation was deposited by cyclical evaporation of marine water in an imperfectly closed sub-basin of the Permian Basin. The sub-basin, called the Delaware Basin, contains the Los Medanos region in which the WIPP site is located. The cyclical nature of deposition is represented by variations in the details of the mineralogy and geochemistry of the halite, by the presence of interbeds composed mostly of anhydrite, and by the presence of clay seams. Individual depositional cycles are a few meters thick. Relatively pure and impure (argillaceous) halite layers are present. Anhydrite interbeds, generally less than a meter or two thick, represent relatively fresh water inflow at the beginning of evaporative cycles. All of these variations represent fluctuations in water chemistry and the influx of windblown and water-borne fine clastic sediments.

The layering and composition of the Salado impact the mechanical processes of room closure and the hydrologic processes (both gas and brine) that accompany room closure. A detailed stratigraphy, which defines the distribution of mechanical properties and processes, has been developed for use with the MD model (Munson et al. 1989). Christian-Frear and Webb (1996) asserts that a simplified model containing only impure halite and interbeds is sufficient for hydrologic considerations.

The presence of a significant fraction of clay (≈5%), primarily as interstitial inclusions, significantly impacts the mechanical behavior of halite rocks. The clay promotes fracture and reduces intergranular cohesion and friction, increasing the rate of creep. Impure halite is also more permeable than its purer analogue. This may be due to the interference of clay particles in intergranular spaces with the processes of pore closure related to creep under natural loads.

The pre-excavation hydrologic environment in the halite rocks of the Salado is one which may be characterized as having very low permeability and porosity due to void-filling by diagenetic processes and creep resulting from the superincumbent load. Although both display very low porosity and permeability, the pure halite rocks display lower (almost impossible to measure) permeability than the impure halite. No significant natural flow occurs in the pre-excavation Salado environment. The anhydrite interbeds are more permeable than the halite rocks and have natural fractures. This is presumed to result from the physical properties of anhydrite, which is stronger and more brittle than halite and resists creep at the repository lithostatic pressure. Beauheim (1987) documented that permeability is greater near the excavations (beyond the secondary DRZ) at distances of several meters and that pore pressures decrease near the excavations, implying that flow resulting from stress imbalance around the excavations is occurring. Brine seeps on excavation walls, collection of brine in boreholes in the repository floor, and the measured contribution of inflowing brine to humidity in the repository, are clear indications that brine inflow is occurring.

Three flow mechanisms have been proposed based on the varied, mostly qualitative data about flow into the repository (Howarth et al. 1995). These are: 1) far-field flow in response to potentiometric gradients resulting from excavation through naturally interconnected pore spaces; 2) redistribution of pore fluids (pores not necessarily originally interconnected) due to fracture and creep around the excavations; and 3) flow due to consolidation of water-bearing clay layers. None of these mechanisms can be eliminated on the basis of the existing evidence, so an inflow model combining the estimated volumes of brine from each mechanism is proposed. No consideration of the role of brine included in halite crystals is mentioned, although fracturing and some intracrystalline creep mechanisms may liberate brine from this source.

Estimates of quantities of brine inflow from each proposed flow mechanism over the repository history (to final closure) were made on the basis of best-estimate values. Although the volume of brine inflow from the far-field mechanism is theoretically unlimited, low permeability and the relatively short time

available limit the probable actual volumes of brine that could reach the repository. The far-field mechanism may deliver between 25 to 110 m^3 of brine to a single disposal room over the life of the repository. Brine from the redistribution mechanism may range from 28 to 150 m^3. The clay compaction mechanism is assumed to have mostly ceased by the end of the disposal phase of work. These estimates depend on the repository gas pressures countervening the fluid potential gradient at a reasonably early time in the repository history. In any case, these mechanisms can supply enough brine to fully corrode the waste, between 100 and 150 m^3 per disposal room (Howarth et al. 1995). Flow out of the repository, due to elevated gas pressure by matrix flow or in fractures, is likely to be multiphase and will be less efficient than brine inflow. Specific data on Salado capillary pressures are not available.

Brine inflow and outflow have been simulated using the BRAGFLO model, and some specific enhancements to tie in specific conceptual model components have been proposed. These are: (1) Stratigraphy, (2) Salt Creep, (3) Fluid Flow, (4) Transport, (5) Thermally Driven Fluid Flow (insignificant), (6) Model Initial Conditions, (7) Disturbed Rock Zone, and (8) Interbed Fracturing. The model results were compared with the small scale brine inflow and Room Q experiments. McTigue (1993) evaluated the experimental results, using an exact analytical solution based on simple Darcy flow, for three flow histories for two flow mechanisms. This analysis provided an acceptable comparison between model and experimental results.

The INTERVAL program (Howarth et al. 1995) provided partial review of the model/experimental comparison and concluded that the Darcy-based version of BRAGFLO could replicate the Room Q results consistently with refinements of the inflow models to better simulate the pore pressure field around the excavations.

Electrogeophysical experiments were performed to evaluate the extent of the interconnected pore-space field around the repository and were found to support the far-field flow model (Borns et al. 1990). That is, the extent of saturated and interconnected pore spaces was seen to be infinite in the horizontal direction in the Salado.

3.4.2. Review of Criteria

The Salado is the primary barrier to radionuclide transport out of the repository. Its mechanical properties dictate the most important aspects of room closure and its hydrologic properties control brine inflow and gas and brine outflow. The objective of the Salado model is to provide a set of process and

property descriptions unified to define the original state of Salado equilibrium with its natural environment and its responses to excavation of the WIPP facility. The mechanical aspects of the Salado model support the Creep Closure model. The hydrologic aspects of the Salado model define the framework for consideration of brine inflow and brine and gas outflow from the repository. Detailed consideration of the anhydrite interbed and impure halite behavior are presented in other conceptual model reviews. The Salado conceptual model is central to the performance assessment because of the general absence of important quantitative measurements of principal parameters describing flow in the very low permeability halite rocks.

3.4.2.1. Information Used to Develop the Conceptual Model

Surface-based hydrologic testing of the Salado was abandoned because of the extremely long times required for testing in the extremely low permeability environment. *In situ* testing in the facility excavations included testing in short boreholes in Room Q, laboratory testing on samples from the excavation, electrogeophysical surveys, and collection of water from wall seeps and openings such as unlined boreholes. Packer tests were performed to specifically examine questions about interbed permeability and critical pressures to activate interbed fractures. Mechanical property measurements include closure rate measurements and laboratory tests. Mechanical models are discussed in the Creep Closure and DRZ model reviews.

Inflow and outflow models are based on best estimates, since only indirect measurements of flow and pore pressures in the low permeability Salado in disturbed areas near the repository are available, and no actual data are available for the hydrologic properties of the undisturbed or far-field natural state of the halite rocks. Only one, yet to be qualified, hydrofract experiment far enough from the repository to imply undisturbed stress conditions, has been done. Models of flow are essentially limiting calculations based on estimated and projected process parameters. Hydrofracture of the repository is not considered in the model since such an event is considered a "conservative" result lowering gas pressure. It is also possible that interbed critical pressures are low enough that halite hydrofract pressures may never be reached. Interbed critical pressures are estimated at a maximum of 5 MPa and Salado critical pressures appear to be between 15 and 20 MPa.

3.4.2.2. Validity of Model Assumptions

The hydrologic model of the Salado assumes that the three proposed flow mechanisms (Section 3.4.1), exclusive of flow in the interbeds, are the only credible flow mechanisms and that the estimated volumes

of brine inflow are credible. The estimated volumes of brine inflow are sufficient to corrode all of the corrodable materials in the projected waste. The key assumptions appear to be valid with respect to inflow processes. The inflow volumes depend on the interaction of inflow with repository gas pressures and on the estimates of the far-field flow response to repository excavation. The assumption of Darcy flow seems valid in the far field, but is difficult to demonstrate in the region near the repository. Inflow volume estimates are difficult to validate. Outflow hydrodynamics depend on two-phase flow models, which depend on capillary pressures in the Salado. No capillary pressure measurements are available. Larger outflow into the Salado beyond the DRZ by matrix flow is a conservative influence since the process would amount to interstitial storage of contaminants. Although likely to some extent, no credit is taken in final performance assessment calculations for this phenomenon. The assumption of cessation of flow from clay compaction before the end of the repository phase is acceptable because of the small brine volumes predicted.

3.4.2.3. Evaluation of Alternatives

No alternative models were evaluated by DOE (see Section 3.4.2.2).

3.4.2.4. Uncertainties

Although somewhat uncertain, the brine inflow model predicts sufficient volumes of brine to corrode all of the corrodable waste. There are, therefore, no consequences of reasonable additional uncertainty in terms of corrosion and gas generation. Brine volumes very much greater than those predicted would have to occur before brine mechanically interferes with room closure, and is unlikely. Brine availability for biogenic waste degradation is assumed. The Room Q and other observations appear to support the general validity of brine inflow estimates and the unlikelihood of very large uncertainties. Only very large underestimations of brine inflow would have significant impact, unless the sudden dissolution of dissolved gases during human intrusion might cause direct discharge of brine in the repository to the surface. The timing of the occurrence of gas pressures sufficient to retard brine inflow is the principle control of brine volume. This timing is addressed in the Gas Generation conceptual model and the porosity surface calculations.

3.4.2.5. Adequacy of the Conceptual Model

Given that the conceptual model predicts that there will be enough brine to corrode the waste and that other assumptions appear conservative, making other impacts unlikely, the model is adequate for its intended use.

3.4.2.6. Adequacy of Application

Assuming that the interaction of the inflow model with the gas generation model and the porosity surface calculation are adequate, the application of this model is adequate.

3.4.2.7. Accuracy of Results

It is unlikely that the results of the application of this model are highly accurate, but in view of the conservative assumptions and the large margin between the assumed impact on waste degradation and other significant impacts, the results appear to be accurate enough for the intended purposes of performance assessment.

3.4.2.8. Validity of Conclusions

The conclusions appear to be valid. Estimates of inflow volumes from the mechanisms proposed in the model appear to be reasonable.

3.4.2.9. Adequacy for Implementation

The model is adequate for implementation.

3.4.2.10. Dissenting Views

There were no dissenting views for this model.

3.5. Impure Halite

3.5.1. Model Description

The Impure Halite conceptual model explains the role of impurities in influencing the mechanical and hydraulic properties of the halite-rich rocks in the Salado. The model supports the treatment of the distribution and stratigraphy of impurities in the Creep Closure and Salado conceptual models.

There are two general classes of halite rocks in the Salado Formation. These are called pure and impure halite, based on the occurrence of significant proportions of mineral phases other than halite in the impure type. Impurities include evaporite minerals such as polyhalite and anhydrite, as well as iron oxide coatings and clay. The most abundant (as much as 5%) and important impurity is clay, with the exception of the anhydrite interbeds, which are discussed elsewhere. Clay occurs as clay seams, which

are treated as mechanical discontinuities in the Creep Closure model and as sources of inflowing brine in the Salado hydrologic model. It is as dispersed, interstitial clay that impurities have the most impact on the behavior of halite-rich rock.

Pure halite is more impermeable (Howarth et al. 1995), more ductile, and stronger (lower creep rate by a factor of four) than impure halite (Munson et al. 1989). Mechanically, the elastic interstitial clay platelets probably act as flaws, concentrating stress and modifying plastic micro-mechanical strain mechanisms. Pure halite is thought to be almost perfectly impermeable because creep under natural lithostatic stress has caused adjacent crystals to conform to each other's shape along their interfaces so completely that there is almost no space for interstitial brine. Such close-fit crystal mosaics, even in the presence of thin brine films on their interfaces, have minimal interconnection between pore spaces and any movement through the interstices would be inhibited by adsorptive and film-strength forces.

Clay particles between halite crystals interfere with the closeness of fit of adjacent crystal faces, concentrate stress, and may promote solubility of pore walls. Clays are phylosillicates, which in many cases are capable of chemically driven adsorption and desorption of water, promoting flow and water storage in pore spaces. The mechanical influence of clay promotes microfracture, which may enhance flow in response to stress imbalance around the repository.

Christian-Frear and Webb (1996) has asserted that a hydrologic model of the Salado that ignores the stratigraphic variation within the halite rich rocks of the Salado leads to an acceptable and conservative flow model result if all the halite-rich rocks are modeled as impure halite. This model conservatively overestimates flow in the halite rocks to an acceptable degree and eliminates the need to consider variation in the degrees of impurity and stratigraphic complexities among pure and impure halite rocks. Conservatively chosen values for impure halite permeability make this an adequate approach to modeling of halite-rich parts of the Salado.

The geometry of flow in the impure halite is convergent/divergent as discussed under the Repository Fluid Flow conceptual model review. The probability of hydrofracture of impure halite is probably larger than for pure halite because of the loss of cohesive strength due to clay in the interstitial spaces. Hydrofracture is not considered because it would lower gas pressures (a conservative influence), and because critical pressures for fracture of impure halite are much higher than for interbed flow. Interbed threshold pressures vary from one to five MPa, while halite critical pressures approach 20 MPa. Also, outflow estimates are based on two-phase flow and are not based on measured capillary pressures.

3.5.2. Review of Criteria

The impure halite conceptual model provides a basis for the evaluation of brine inflow and outflow from the repository within the simplified stratigraphic framework based on work by Christian-Frear and Webb (1996). Although differences in the behavior of pure and impure halite, variable degrees of impurity, and complexities of stratigraphic distribution of zones of impurity exist, the modeling of all halite rocks in the Salado as impure halite is an acceptable model simplification (Christian-Frear and Webb 1996).

3.5.2.1. Information Used to Develop the Model

Measurements of impure halite hydrologic properties (see natural barriers panel review) and assumed flow geometry and mechanisms (see the Salado model review) provide the additional bases for brine inflow estimates. Christian-Frear and Webb (1996) evaluated the acceptability of the simplified stratigraphy using impure halite only for halite-rich rocks for the Salado model. The Impure Halite model lacks precise flow rates and capillary pressures from hydrologic measurements and the flow mechanism process models are based on assumptions which have only theoretical bases, but provide results that acceptably match experimental and observational data.

3.5.2.2. Validity of Model Assumptions

The model assumptions are the process models for flow mechanisms, the Darcy nature of far-field flow, and the conservatism of the simplification of stratigraphy proposed by Christian-Frear and Webb (1996). These assumptions are reasonable and are supported by arguments presented by Howarth et al. (1995), by the comparison of model elements and inflow observations by McTigue (1993), and by review of similar results by INTERVAL (Howarth et al. 1995).

3.5.2.3. Evaluation of Alternatives

Early WIPP models considered all halite-rich rocks to be unsaturated and impermeable. Observation of inflow after excavation forced the development of flow models for halite-rich rocks. All observational and most experimental data are from impure halite. No alternative flow mechanism models have been considered (Howarth et al. 1995).

3.5.2.4. Uncertainties

The impure halite model is almost entirely theoretical and no evaluation of uncertainties is considered. Results match *in situ* brine flow observations fairly well. The result of uncertainty in the case of the simplifying assumptions with regard to stratigraphy are conservative.

3.5.2.5. Adequacy of the Conceptual Model

The model appears to be adequate for the same reasons that the overall Salado model is adequate. Brine inflow sufficient to corrode the waste and to drive biogenic degradation is assumed. For error to be significant, brine inflow would have to be very large, which is unlikely.

3.5.2.6. Adequacy of Application

The impure halite submodel is applied adequately, with the assumption that its application in the Salado model and related other models is conservative.

3.5.2.7. Accuracy of Results

The results of the model are probably not highly accurate, but appear to be adequate in their application.

3.5.2.8. Validity of Conclusions

The conclusions drawn on the basis of the impure halite model are valid for performance assessment purposes.

3.5.2.9. Adequacy For Implementation

The model is adequate for implementation for performance assessment purposes.

3.5.2.10. Dissenting Views

There were no dissenting views for this model.

3.6. Salado Interbeds

3.6.1. Model Description

The three Salado interbeds are modeled in BRAGFLO and are represented by region 20 (Marker Bed [MB] 138), region 21 (anhydrite layers a and b), and region 28 (MB 139). All three interbeds have the same model parameters (see Tables 6-12 and 6-13 in Section 6.4) and initially, the parameters are spatially constant. The only initial model difference concerns bed location and thickness.

Three primary interbeds are identified in the region of the Salado Formation nearest the waste panel: MB 138, anhydrite layers a and b, and MB 139. All three interbeds are primarily composed of anhydrite, with clay seams bounding the lower contacts of MB 138 and MB 139. As discussed below, the interbeds

have differing physical and chemical properties from the halite of the Salado Formation. Anhydrite is much less soluble than halite. The interbeds appear to be one or more orders of magnitude more permeable than the surrounding halite, primarily because of subhorizontal bedding-plane fractures (both healed and open) present in the anhydrites. Under differential stress, the interbeds may fracture while, under the same stress, halite would flow by plastic deformation. Fracturing of the relatively brittle interbeds would enhance the local permeability, allowing this otherwise low-permeability rock to carry groundwater. Furthermore, since the interbeds have a large contact area with the adjacent halites, even very small fluxes from the halite into the interbeds or to the halites from the interbeds can accumulate into a significant brine inventory. In this sense, the interbeds may cause the halite to act as a source or sink for brine in the repository. The three interbeds are explicitly represented in the conceptual model because of their physical properties and their existence in the disturbed rock zone around the repository, within which fluids are able to flow with relative ease compared to surrounding rock types.

Two major conceptual features of the interbed model are represented by, 1) transmission of brines from the impure halite to the repository via the interbeds and, 2) incorporation of fracturing and dilation of the anhydrite to allow porosity and permeability variations.

Feature one allows brine flow laterally along the higher permeability interbeds toward or away from the repository, and vertically between the interbeds and low-permeability halite. Horizontal fractures, dilation, and propping are due to gas pressures exceeding the threshold pressure. Induced vertical fractures in the interbeds are caused by interconnection of branching horizontal fractures over time, or high exceedence of the threshold gas pressure (i.e., greater than lithostatic). Pre-existing vertical fractures were caused by tectonic forces or the alteration from gypsum to anhydrite and subsequent volume reduction.

Feature two, alteration of porosity and permeability, is caused by the creation of new fractures or dilation of pre-existing, partially healed fractures due to high gas pressures. *In situ* hydrofracture tests have created sustained fracture apertures to 0.2 mm. Such pressure-dependent variables have created marked permeability changes. In the BRAGFLO model, a porous medium model simulating interbed fracturing and dilation causes porosity and permeability of a computational cell to increase as the pore pressure exceeds the threshold value. In addition, interbed transmissivity increases with increased anhydrite fracturing or dilation. Fluid is able to easily flow radially outward if adequate threshold pressure is available (1 to 5 MPa) to dilate the anhydrite. The model assigns a fracture initiation pressure at which

local fracturing occurs and changes in permeability and porosity subsequently occur. Above the threshold pressure, the local compressibility of the interbed increases linearly with pressure. This greatly increases the porosity with respect to increasing pore pressure. Additionally, permeability increases as a power function of the ratio of altered porosity to initial porosity.

3.6.2. Review of Criteria

3.6.2.1. Information Used to Develop the Conceptual Model

Three primary sources of information were used to generate the conceptual model for the Salado interbeds. These included FEP documentation, position papers, and *in situ* hydraulic tests. Four FEPs were associated with the Salado Interbed conceptual model: DR-9 (anhydrite threshold displacement pressure); S-1 (verification of 2D radial flaring); S-4 (mechanical effects of gas generation); and S-5 (brine storage in anhydrite and halite). A second source of information was the Salado position paper. The third major source of information for developing the conceptual model was obtained from *in situ* field tests of the anhydrite interbeds. Location of these tests was in the vicinity of Rooms Q and L. These information sources are believed to be adequate for model development.

3.6.2.2. Validity of Model Assumptions

The main assumptions of this conceptual model are considered valid. The chemical assumption, that anhydrite is less soluble than halite in the WIPP environment, is proven by both experimental and crystal chemical factors. The Darcy flow model is also deemed reasonable. The type of fracture propagation and dilation used in the conceptual model has been substantiated by *in situ* tests. Assumptions of increased porosity and permeability due to fracturing (caused by gas generation exceeding threshold pressures) is reasonable. Therefore, the assumptions of this conceptual model that have the largest potential impact are believed to be appropriate.

Three other assumptions of the interbed model have not been well documented. The first of these is the description of the mechanism of vertical crack propagation. This potential effect of gas overpressurization needs to either be fully described or discounted from occurring in the interbeds. Second, there does not seem to be any incorporation of the fact that there are continuous clay seams at the base of MB 138 and MB 139. The physical properties of clay seams (water content, low cohesive structure, aniostropic characteristics) may have a substantial effect on the model of the interbeds. Third, the fluid storage capacity of the interbeds is not well documented.

3.6.2.3. Evaluation of Alternatives

Earlier models of the Salado Formation in the 1980 final environmental impact statement did not differentiate the anhydrite interbeds as a separate model. When the 1989 draft environmental impact statement was produced, anhydrite interbeds were included as a model. This was based on *in situ* tests that determined the interbeds had higher permeability than the remaining Salado Formation. The 1992 performance assessment concluded that the interbeds would then be the dominant fluid pathway. It was not until this factor was recognized and gas pressures were calculated to possibly reach 20 to 25 MPa (in the 1992 performance assessment) that an attempt was made to model fracturing in the anhydrite interbeds.

At the level of a conceptual model, the primary factors of the Salado Interbeds have been addressed properly. This has been accomplished by either using well-established models (Darcy flow) or *in situ* experiments, or by adopting reasonable, conservative assumptions.

The following items do not appear to have been addressed by DOE: (1) Is storage capacity of the anhydrite layers so small that brines would be forced to travel to the Land Withdrawal Act boundary? (2) What would the consequence be if the gas threshold pressure of the clay seams was very low (for example, 0.01 MPa)?

3.6.2.4. Uncertainties

The levels of uncertainty associated with the Salado Interbeds performance at the conceptual model stage appear to be quite small. The following uncertainties may affect the model but the consequences are unknown at present. The determination of consequences would hinge on a sensitivity analysis, which is presently unavailable.

The model assumes that fracture propagation would continue uniformly in a horizontal direction. In Domski et al. (1996), test results for interbeds indicate anisotropy. Assuming that the interbeds act in an isotropic manner would be conservative, especially since *in situ* values were determined for the weakest direction (laterally).

Another assumption is that enhanced porosity and permeability in the interbeds would mitigate each other in terms of gas migration responses. This does not seem plausible since permeability increases as a power function to an increase in porosity. It would seem that permeability factors would dominate and therefore allow longer gas migration distances.

The perturbation to the model that is completely unaccounted for (threshold pressure of bounding clay seams) is included as a secondary factor in Section 3.6.2.3 above.

3.6.2.5. Adequacy of the Conceptual Model

The Salado Interbed conceptual model describes fluid flow through three discrete anhydrite layers in the vicinity of the repository. CCA Section 6.4.5.2 reports flow model objectives in dealing with the anhydrite interbeds: (1) fluid flow through the interbeds, (2) fracture formation and/or dilation of the interbeds, (3) variations in porosity of the interbeds, and (4) variations in permeability of the interbeds within the constraints of the conceptual models. These requirements are thought to be adequate. The uncertainties associated with the model can not be constrained since a sensitivity analysis is not presently available.

3.6.2.6. Adequacy of Application

A much greater uncertainty is perceived when it comes to converting the field results into the mathematical model. In all but the simplest of field observations, one must make assumptions in applying a mathematical model. However, the ability to monitor the assumptions made in developing a numerical code to simulate the physical properties acting within the anhydrite interbeds is extremely difficult. SNL states at one point that parameters in the model are treated as fitting parameters and have little relation to physical behavior, except that they affect the porosity change. At no time was the logic clearly presented whereby one could track the implementation of this conceptual model into the numerical code developed for this portion of BRAGFLO. Therefore, one must state that the discussion of how the anhydrite interbed conceptual model is applied into an overall performance modeling element was not adequate.

3.6.2.7. Accuracy of Results

The results obtained for this conceptual model fall into two categories. The first set of results are those determined from physical tests. Hydraulic tests performed *in situ* near Rooms Q and L, and laboratory tests on core samples have provided results that are deemed adequate. These tests are based on standard procedures and have been qualified as to their accuracy. There is no further question as to the validity of these physical parameter results.

The second category is based on whether the results of performance modeling using the conceptual model within the performance system are sufficiently accurate to adequately represent the physical and

chemical processes modeled. It is not possible to make a judgment on this category of results since no values have been presented to indicate the outcome of this model. The 1992 performance assessment did not incorporate a fracture propagation submodel in the Salado Interbeds model, so results and sensitivity analyses from that performance assessment are not applicable to this review. Results for this section are not meant to be the final performance assessment results, but rather are the results of BRAGFLO during various permutations.

For example, hydrofracture experiments in the anhydrite beds have created sustained fracture apertures to 0.2 mm. If BRAGFLO produced fracture aperture dimensions of 5.0 mm during gas pressurization runs, one would conclude that the results are not accurate. This sort of comparison has not been possible because model runs have not been presented.

The implementation of the fracture modeling was not explained in sufficient detail in any document. The method of how the code represents the physical property is unknown and its accuracy cannot be judged. Results of the calculation could vary significantly, depending on whether the fractures propagate gradually or in a stepwise fashion.

3.6.2.8. Validity of Conclusions

This section judges whether the key conclusions that have been drawn on the results of the Salado Interbed model in the modeling framework are valid. Since the accuracy of results is inconclusive (see Section 3.6.2.7), it is difficult to assess the validity of the conclusions. The results of parameters listed in Table 6-12 of the CCA may be considered valid for the purpose of implementation in the overall performance assessment. The results listed in Table 6-13 of the CCA may not be valid at this point. Questions of validity are addressed below.

Fracture initiation pressure for MB 139 at 0.2 MPa above hydrostatic pressure is concluded to be valid. The percent increment to allow full fracture porosity for MB 138 and 139 (3.9%) is also considered valid. The same parameter for anhydrite beds a and b is 23.9%, and no discussion is presented for the large difference in the value. The increase needed to allow full fracture porosity in these two interbeds would not be expected to differ from MB 138 and 139. Such a difference should have been thoroughly explained. The conclusion of maximum permeability (10^{-9} square meters) is extremely suspect since the storativity of the beds was not calculated. These two factors are closely linked and it is hard to envision that the permeability can increase ten orders of magnitude without a dramatically substantial change in

storativity of the interbeds. Finally, the parameter "increment above fracture initiation pressure to obtain maximum fracture pressure," does not account for the effect of bounding clay seams associated with the interbeds. To assume that an increase of approximately 1.5 MPa above lithostatic pressure is needed for maximum fracturing is probably not valid when clay seams are in close proximity

3.6.2.9. Adequacy of Implementation

The conceptual model for the Salado Interbeds is well thought out and substantiated by *in situ* experiments. However, certain items were not clearly explained or documented in Chapter 6 of the CCA. It would be helpful if the following questions were clarified:

- What is the mechanism for vertical crack propagation?
- What is fluid storage capacity of the interbeds after dilation?
- Enhanced porosity and permeability are presumed to mitigate each other in terms of gas migration responses. How can this happen when permeability is a power function (not linear) of porosity?
- What assumptions and limitations are made to represent the conceptual model by the mathematical code?
- Why is the full fracture porosity increment of 23.9% for anhydrite beds a and b so different from the 3.9% for MB 138 and 139?
- What are the calculations that show that permeability increases by 10 orders of magnitude?

It is believed that this model would be adequate for implementation in the compliance application after the question raised below is fully addressed.

- How do the physical properties of clay seams at the contact of the interbeds affect the fracture propagation and permeability of the model?

3.6.2.10. Dissenting Views

There were no dissenting views for this model.

3.7. Disturbed Rock Zone

3.7.1. Model Description

The Disturbed Rock Zone model consists of a description of a fracture zone surrounding excavations that is created by induced stresses. At the WIPP, the primary DRZ exists in all rocks; the secondary DRZ is

applicable only in viscoelastic rocks such as halite. The DRZ varies in depth away from the excavation and has been reported to be up to 50 m deep for large excavations. It exists in the repository roof, floor, and walls, and around shaft and borehole walls. Because of the distinctly different stress fields in each of these locations, the DRZ can have different properties at each location. For example, it is considered to disappear under appropriate conditions and with time in the borehole seals program, and is variously applied as it relates to the repository rooms and panels. Related models include Creep Closure, Shafts and Shaft Seals, Disposal Room Geometry, Repository Fluid Flow, Salado, and Salado Interbeds.

Induced changes to the stress field occur immediately on the passage of mining equipment during excavation. In halite, as the salt adjusts to these changes through the creep process, further micro- and macro-fracturing progressively occur in the intact rock, adding to a fracture region known as the DRZ. This DRZ was first technically addressed and demonstrated by Borns et al. (1987, 1988, 1989, 1990). Van Sambeek et al. (1993) have referred to the mining-induced fractures as the initial DRZ and the progressive fracturing as the secondary DRZ. In this analysis, the Panel will not distinguish between these except for their applications. The characteristics of the DRZ include increased rock volume and permeability and decreased brine saturation due to drainage and drying, load bearing capacity, and lithostatic pressure. Clearly these properties could lead to the DRZ providing flow paths for fluids and gases from the repository to those zones that might carry them to the accessible environment. Studies by Munson et al. (1994) have characterized the DRZ and found it to be irregular in thickness and fracturing and able to heal with time under an applied confinement. Two versions of a creep model, applicable to room closure and DRZ development, have been formulated during this period. These are a model that includes both transient primary creep and steady state creep (MD model), which has been used in the porosity surface lookup table calculation of repository void space, and the MD model, with added tertiary creep fracture (MDCF), used to confirm DRZ thickness, fracture porosity, and healing characteristics. The MD model is central to the porosity surface calculation (SANTOS), which relates creep, waste compaction, and gas pressure to overall room closure rate. The DRZ is not considered in room closure calculations since all DRZ fracture porosity is assumed to be recovered by healing at final closure. For the waste room, the DRZ model is incorporated by assuming a high permeability and low porosity, with the result that the DRZ is unable to act as a constraint to brine or gas flow from the repository rooms and is unable to store brine. A primary reason for this approach is the uncertain behavior of the rock zone, which is dependent on many uncontrollable factors.

3.7.2. Review of Criteria

3.7.2.1. Information Used to Develop the Conceptual Model

The treatment of the DRZ in both the shafts and the repository rooms is the result of development of an equivalent permeability and porosity for addition to the main room and shaft seal model elements rather than by a specific DRZ input. Analyses were conducted evaluating the reasonableness of this approach, but parameters representing the DRZ over the history of WIPP were not developed. Therefore, the information supporting evaluation criteria for review of this conceptual model is essentially the completeness of the considerations and the reasonableness of the DRZ concepts.

The DRZ has several significant impacts on the performance assessment calculations. These include a) room performance, b) gas pressure calculations, especially near term, and c) permeability of the shaft regions. The DRZ in the salt around the rooms appears to be the toughest to model because of the sizes and shapes of the openings. The shaft DRZs appear to be less difficult to model because of their simpler shape. First, the shafts are smaller than the rooms, second they are stable cylindrical forms, and third, studies show that, given a stiff support against creep, the DRZ fractures will heal in a relatively short time. For example, from analysis of WIPP data, Chan et al. (1995) projects full healing within 25 years after the shaft seals have been placed. Within the healed zone, the induced high permeability drops to a level below that of the placed seals, reducing the concern of a large flow path surrounding the sealed shaft. Contrary to this favorable healing in the shafts, DRZ healing in the waste room will not be as responsive in time or extent. Because of the relatively large room, the necessary rigid backing to support the healing process is delayed, and the DRZ functions as a more open fractured rock mass. Furthermore, only the DRZ in the roof and floor of the repository are modeled; the walls of the room are not included in the Repository Fluid Flow model. Neither the roof nor the floor will receive the support needed to close the open cracks and open boreholes that are assumed to be a part of the roof DRZ. Early healing of the floor would be optimal in order to restrain fluid flow downward, and the roof will continue to develop an open fracture DRZ upward, due to roof spalling, as the room seeks its most stable shape within the stress field. The most notable impact of the open fractures to performance assessment in the near term will be in deterring brine flow to the repository because of brine storage in the fracture zone. This could have significant uncertainty effects on the gas pressure calculations.

It should be noted that no information was found concerning studies of how soon after excavation the DRZ is fully formed. It is reasonable to consider that its formation begins concomitant with excavation

and progresses until the salt creep and the stress field have stabilized. The MDCF model appears to be an excellent tool for conceptualizing the phenomenology of salt creep and its mechanisms resulting in fracture closure and healing. Excellent progress in understanding salt's viscoelastic behavior and adding this capability to the creep flow behavior has made the modeling capability a highly supportive tool critical to understanding the DRZ. Testing of these concepts has produced favorable responses that have specifically aided the shaft seals program in mitigating concerns over seals integrity. Significant among these tests are the Room Q experiments, where identification of the reduced brine flow and increased permeability in the DRZ were measured. Data from the air-intake shaft tests showed the change of permeability as a function of distance from the shaft wall and the changes in permeability with time. Knowles et al. (1996) conducted rigid inclusion tests that confirm the ability to heal the DRZ, restoring it to ambient conditions. The many parameters associated with the DRZ have been well defined to support the BRAGFLO models. The permeability and porosities appear to be the most critical parameters for use in performance assessment. Information examined for the DRZ characterization, including its extent, ability to be restored by salt creep and restraint, and ability to be represented by modeling, was found to be acceptable.

3.7.2.2. Validity of Model Assumptions

The following assumptions are basic to the DRZ model:

- A DRZ surrounds the surfaces of any mined opening.
- A permeability value is selected that assures the DRZ is not the limiting zone for fluid transport between the waste rooms and the marker beds.
- A fixed high-level permeability value should be assigned to the DRZ everywhere.
- Roof bolts or other roof support system penetrations of the halite and boreholes through the halite into the marker beds are included as part of the DRZ, and these penetrating boreholes may not close completely.
- Various other processes may contribute to fracturing in the future.
- The DRZ surrounding the shafts will progressively heal toward near complete restoration following placement of the seals.
- The porosity and permeability are increased by the DRZ, except where a rigid backing is present to support the DRZ against creep; however, a low porosity is assumed in the room DRZ to reduce the storage capacity of that zone for performance assessment.

The basic assumption that a DRZ exists at the surface of any mined opening in the Salado is fundamental to the definition of a DRZ. That the leading boundary of the DRZ will heal, provided support exists to resist the creep, has been substantiated through the WIPP research program. Basically, the outer reaches of the DRZ (microfractures) will heal in the near term, and the DRZ primary fractures will close and heal once seal material is placed in the openings to support the process. This might reliably be achieved via the vertical cylindrical openings, but the healing problem is more complex around the waste room. There it is recognized that a variety of effects may work against the reconsolidation of the DRZ. These effects range from uneven placement and non-characterized waste support against room closure to other processes, such as roof falls, that might contribute to further development of the DRZ. These assumptions concerning the DRZ existence and its behavior appear to be adequate.

Given the shaft seals design, it is assumed that the shaft DRZ heals to the point that its permeability is below the level of seal permeability, thereby reducing its importance. Therefore, flow through the sealed shafts is attributed to the permeability of the shaft seal materials, with an adjustment to account for any DRZ component to the permeability (see Section 3.20). At the waste room, the situation is far more complex and the technology less well defined. Therefore, at the room boundary, it appears that the above assumptions support the assignment of a high permeability that essentially removes the DRZ from a limiting position of flow to and from the room, and a low porosity that will not perturb storage of the brine.

3.7.2.3. Evaluation of Alternatives

Fracture zones in the walls of excavations have always been of concern to the mining and construction industries. In most cases, however, fracturing occurs in brittle materials with elastic behavior, which is largely not the case in the viscoelastic host rock of the WIPP repository. Restoration of the DRZ to the original halite properties, as described in this report, would be applicable within most salt formations. However, at locations other than in the Salado Formation at the WIPP site (such as in the Culebra, Magenta and other members of the Rustler Formation), the DRZ will not obey the concepts forwarded. Because the DRZ in MB 138 and 139, and perhaps the anhydrite interbeds a and b, are different from the DRZ discussed here, they pose a concern for the open fractured DRZ concept and its ability to heal. This concern is discussed and analyzed within the seals design (WIPP 1996). It appears from the information available that numerous alternatives have been processed in the analysis and testing programs leading to present concepts and understandings of the DRZ. The assumptions adopted for the DRZ model are alternatives that appear to appropriately represent the existence and effects of the DRZ.

3.7.2.4. Uncertainties

A DRZ thickness of 0.8 shaft radius appears to be conservative. Munson et al. (1994) state that from the air intake shaft data (Dale and Hurtado 1996), the extent of the DRZ at 6 years is certainly less than 1.0 shaft radius, and probably only 0.7 radius. Using these same data, Chan et al. (1994) show a reasonable correlation between the test data and calculations from the multimechanism deformation coupled fracture (MDCF) model. No data were found to evaluate the effects of time on the relationship between excavation and closure. Relative to the room DRZ, the behavior of the roof DRZ might be the source of additional uncertainties in other models. Except for the shaft seals, no data were found to characterize applications of the DRZ in unique locations, such as the unsupported roof and the floor buckling from unrestrained creep.

3.7.2.5. Adequacy of the Conceptual Model

Recognition of the deleterious conditions produced by the DRZ appears to be positively addressed in studies showing the effects on brine flow in the repository and on the ability to heal under conditions of support in the shaft that makes the shaft seals issue more tangible to resolve. Because the uncertainties of possible unknown future effects of the room DRZ might go beyond the recognized problems caused by the DRZ, the room DRZ is dealt with from a conservative viewpoint. It appears that the model adequately addresses the genesis and existence of the damage zone. The MDCF model provides a realistic tool by which to examine the effects and project possible DRZ performance. Research, including that in the Room Q, the air intake shaft tests, and the rigid inclusion in salt tests (Knowles et al. 1996), has been supportive in calibrating and confirming model results (see Section 3.19). Because the roof DRZ is uniquely different from the other DRZs, the model does not adequately represent flow to the overhead marker beds. This issue is discussed in Section 3.3, Repository Fluid Flow, and in the following section. Except for this caveat, this model has the appropriate elements to support its use in the WIPP performance assessment.

3.7.2.6. Adequacy of Application

Recognition of the DRZ phenomenon around the shafts and measurements of its effects are important contributions to waste containment; in some cases these effects are among the few WIPP conditions that can be dealt with in engineering terms. It was important to find that the DRZ nearly completely heals once there is adequate backing within the shaft or borehole against which the creeping salt will reestablish its original state of stress. Because of the healed state and because tests show conservatively

that the DRZ areas of influence are within 1.0 shaft radius, it is possible to demonstrate that the DRZ permeability will become lower than that of the seals. This appropriately allows the performance assessment calculations to treat the DRZ permeability as an integral part of the seal. It is important to recognize that this healing factor is a function of the shaft seals' mechanical properties and time of placement. It is also important to recognize that because of the overwhelming uncertainties of DRZ performance in the waste rooms, it be dealt with conservatively by assumption, as stated in the model description. The waste room DRZ uncertainties basically apply to specific locations such as the roof, floor, or walls, and its extent in each.

Because of the variability of the geometry and the timing of the healing of the DRZ in the different environments in which it occurs, the DOE has substituted conservative permeabilities to represent the effect of the DRZ on repository rooms and shaft seal flows. These permeabilities are carried through the processes of repository closure and the evolution of shaft seal design, taking into consideration the marked differences in characteristics of these zones. While the shaft DRZ has been carefully studied, the repository room roof and floor DRZs have not had equal attention because of their complexity. To compensate for this, the DOE chose to use a constant, conservative value for the permeability of the repository DRZ that would not be the limiting condition for flow to and from the interbeds. This approach has not been adequately supported, particularly for the roof DRZ, where the fractures may be open, large, and progress to roof collapse. Furthermore, this zone is host to drill holes that may not be plugged and can penetrate beyond the overlying marker beds. This issue has been identified as a concern for the Repository Fluid Flow model in Section 3.3. The DRZ in the room walls is not modeled, and is thought to be of little structural impact because by conservation of pore space, the initial fracture volume of this DRZ is recovered during room closure and healing.

This evaluation recognizes that the disrupted zones near the shafts have been characterized. Also, this evaluation has shown that DOE used this information in several ways, leading the Panel to conclude that the DRZ needs to be separately considered for each of its applicable areas. These areas include the roof, floor, and walls of the waste room, and the walls of the long annular openings such as shafts and boreholes. Except for modeling the roof DRZs, the Panel believes that the work to date adequately addresses the DRZ characterization for application to the performance assessment process.

3.7.2.7. Accuracy of Results

While the Room Q tests produce data that contribute to the understanding of the waste room DRZ, it appears that the value of these results is to provide background concepts and guidance for addressing the DRZ issues. After looking at the numerous unknowns or uncontrolled processes in the waste room, it seems prudent to defer analysis of the DRZ issue in the waste room until further understanding of the waste characterization becomes available, in order to more fully consider the effective resistance the waste provides to room closure by creep.

For the shafts and boreholes, the air intake shaft permeability data (Dale and Hurtado 1996), which show the extent of damage resulting from the shaft excavation to be approximately one shaft radius, has provided good basic information on this issue. Other analyses of related data and observations from the air intake shaft tests (Munson et al. 1995; Chan et al. 1995) show that the extent of the DRZ is related to shaft size, and make phenomenon amenable to incorporation in a mechanistic model. The collaboration of Munson et al. (1989) and Chan et al. (1995) has proposed one such model through coupling the DRZ fracture to the creep model (the MDCF Model). Other calculations include the determination of fracture healing time and projections of the effects of shaft seal mechanical properties on fracture healing. It should be recognized that the MDCF modeling results largely represent an early stage in this technological development and are subject to projected corrections as more time-dependent follow-up data become available. Because of the predicted low impact of the DRZ on sealed shaft permeability a few years after seal placement, it appears totally appropriate to adjust the permeability of the shaft seal components for the small contribution that the DRZ will make to the performance assessment calculations.

The same closing comments for Section 3.7.2.6 apply to this section; therefore, the results obtained are sufficiently accurate for application of the DRZ in the performance assessment process.

3.7.2.8. Validity of Conclusions

All observed considerations of analysis, study, and proposed engineered applications regarding the DRZ and its impacts on effective shaft sealing appear to be valid. The understanding developed of DRZ phenomena and data reveal that it is critical to engineering waste containment overall because of its potential for negative impact on shaft seal permeability and integrity, and fluid flow in the rooms and room seals. It appears that all considerations of this impact and the conclusions discussed here are sound and valid.

Relative to DRZs in the waste room roof and floor, the fractured zones have a high probability to exist and not much can be done to mitigate their effects, such as providing the stiff support needed to foster healing of the DRZ as shown by the Knowles (1996b) report test results. Credits taken for room closure due to creep will be beneficial, but this may not be significant help in later years, when the potential higher gas pressures may reverse the creep. At high gas pressure this problem is exacerbated by an expanding room scenario which could extend the DRZ even further. It appears the concepts of characterization of the DRZ, particularly in the floor, have not been well researched; perhaps an elicitation panel would be constructive on this. The roof DRZ should have less significance than the floor DRZ because brine is more likely to flow through the floor than the roof; however, the roof DRZ does facilitate the access of gas to the release pathways. The Panel concludes that while the conservativeness of the assigned DRZ permeability might overcome the lack of detailed information for the roof DRZ, further analysis of the roof behavior would enhance defendability of the otherwise valid model.

3.7.2.9. Adequacy for Implementation

Given the lack of tangible controls over remedying the room DRZ, but the encouraging test results for mitigating the shaft DRZs, it appears that appropriate considerations are being made for the DRZ conditions in all applications. It is clear that continued studies of the room DRZ would provide a better background to more explicitly model the waste room and to ascertain the variation of DRZ characterization for each of its location sites, such as in the roof, floor, or walls of a room. The Panel concludes that the present DRZ model is adequate to be implemented in performance calculations. However, since the roof is different, some other approach may be appropriate for this area.

3.7.2.10. Dissenting Views.

There were no dissenting views for this model.

3.8. Actinide Transport in the Salado

3.8.1. Model Description

The only transport mechanism that will be used in this conceptual model is advection. The Actinide Transport in the Salado conceptual model previously addressed three mechanisms: 1) advection (transport with bulk flow of liquid); 2 dispersion (liquid velocity differences while moving through pores

or surface irregularities); and 3 diffusion (molecular motion in presence of concentration gradients). These mechanisms are all standard contaminant transport phenomena. DOE assumed that these three transport mechanisms of actinides in brine represented the most important processes of actinide movement in the Salado Formation. All three mechanisms look at the transport of dissolved or colloidal actinides through the anhydrite interbeds (MB 138, MB 139, and anhydrite interbeds a and b).

The advection transport mechanism is implemented by the NUTS computer code in conjunction with the Salado fluid flow portion of BRAGFLO. The NUTS code is described in Section 6.4.11 of the CCA and Appendix NUTS (which were not available for Panel review). The actual inventories of actinides come from the Dissolved and Colloidal Actinide Source Term conceptual models. The actinide source terms incorporate the assumed oxidation states and solubility factors for various actinides and a proportion of all colloids permissible.

Three physical influences that may affect actinide transport in the interbeds have been left out of the conceptual model by DOE to promote a conservative philosophy. These influences are sorption of dissolved actinides on clays, retardation of colloidal actinides by surface features, and mineral precipitation containing trace actinides from brine. Sorption of actinides onto clay surfaces is a known reaction, and DOE is highly confident that it will occur; however, the model conservatively neglects the effect. With regard to retardation of colloidal actinides by surface features, it is assumed that offsetting interactions will occur. The philosophy is that colloids can be retarded by surficial features, but will travel faster than the average velocity of the bulk liquid. Precipitation of minerals as brines move into the interbeds due to chemical gradients is a possibility. Given the concept that the amount of precipitation will be minor, and that actinides will only occur in trace amounts in the crystal structures, DOE has decided to neglect this effect in the performance assessment.

Three other mechanical processes may have a lesser impact on actinide transport in the Salado. These are fracture flow, channeling, and viscous fingering. Fracture flow is accounted for in the Salado Interbed model and takes into account increased porosity and permeability through fracture propagation and dilation. DOE expects that other fracture processes and effects not taken into account in the fracture model will be negligible. One process not incorporated, channeling, has offsetting effects. Channeling is the fluid movement through large apertures of a fracture network (i.e., locally high permeability). DOE believes this mechanism will be negated for two reasons. First, if gas is present in the undisturbed state, it will preferentially occupy areas of high permeability over brine. This will preclude these regions of

fast transport from brines. Second, the incoming brine will be miscible with the interbed brine. Such miscibility will allow diffusion and mixing phenomena to broaden finger fronts (i.e., reduce concentration gradients) until they are indistinguishable from the advancing brine front.

Gases may also penetrate interbed brines as a fingered front. However, such a mechanism will not affect actinide transport because the actinides of interest are only incorporated in the liquid phase. DOE also assumes that a liquid will not displace gases in the high-permeability regions (channels) due to capillary effects.

3.8.2. Review of Criteria

3.8.2.1. Information Used to Develop the Conceptual Model

The Actinide Transport in the Salado Formation model is based primarily on the computer code NUTS, with input from BRAGFLO. Since NUTS relies on BRAGFLO input parameters, all BRAGFLO FEPs became information used in the model development. In a sort of circular logic, NUTS was used to evaluate BRAGFLO FEPs by converting flow measurements to normalized release values. The original NUTS program was extremely intricate and robust, with its basis in classical fluid transport. However, FEP studies and system prioritization events have simplified the code. NUTS now only uses advection as a transport mechanism, tracks only the wastes encountered along the flow paths, and treats downstream fluid and the fraction that came into contact with waste. The transport mechanisms of diffusion and dispersion have been excluded from the code, based on policy decisions associated with the system prioritization analysis. The exclusion of these two transport mechanisms is believed to make this conceptual model more conservative. As stated in the model description (Section 3.8.1) the exclusion of six other processes (clay sorption, surface feature retardation, mineral precipitation, fracture flow, channeling, and viscous fingering) is deemed to allow the conceptual model to be more conservative.

A second source of information critical to the NUTS code is the field of radiochemistry. Concepts dealing with radioactive decay, half-lives, and solubilities allow major assumptions to be implemented in the NUTS program.

The third major source of information folded into the actinide transport of the Salado Formation is physical properties of the anhydrite interbeds. These interbeds are the major pathways for fluid transport in the Salado. Data concerning the physical properties of anhydrite were obtained by *in situ* hydrologic tests. The fracturing properties of the beds were deduced from both field and laboratory experiments. It is deemed that the information used is adequate to develop the model.

3.8.2.2. Validity of Model Assumptions

The following assumptions are critical to the conceptual model being evaluated here. Diffusion, hydrodynamic dispersion, and channeling in discrete fractures, are not included in the model. DOE has taken the stance that by not including these factors, the actinides are not further dispersed and therefore the model is made more conservative. These assumptions are considered valid.

The assumption of lumping radionuclides by similar half lives and solubilities is based on the basic tenets of radiochemistry. If any computer run later indicates a potential to exceed EPA's criteria, such lumping factors can be recalculated using specific data for each radioisotope. Evaluations have not been performed to see if the lumping assumption could, in effect, mask runs from approaching the EPA limits. With this caveat in mind, the assumptions made about lumping can be considered valid.

Actinide source terms (dissolved and colloidal) in the repository are used as the input for NUTS. The assumption that these source terms are the limiting cases may not be valid, however that determination is not within the scope of this model (see Sections 3.23 and 3.24).

Once the total concentrations are calculated for the dissolved and colloidal sources for each run, the final value is then transported as one package at the average flow value. The assumption made is that colloids can be transported at this slower rate and still be adequate since sorption and filtration of colloids are not accounted for. This assumption has not been proven to the Panel's satisfaction.

The final major assumptions of this model are that the grid blocks and time steps from BRAGFLO are proper to use in NUTS. Although this final set of assumptions may be reasonable, numerical results must be examined to determine if this concept (and inherent coarseness) is valid. At present, such results are not available.

3.8.2.3. Evaluation of Alternatives

Earlier versions of the NUTS code were much more comprehensive than the present version. Previous compilations had the capacity to treat virtually all special effects of radionuclide migration. However, system prioritization exercises and FEPs studies indicated that a much more simplified version of NUTS was desirable, in that results were still representative and computer run time was compressed. Hence, the present version of NUTS is streamlined. Factors that have been removed (or zeroed) include diffusion,

dispersion, channeling, chemical sorption for dissolved actinides, physical retardation for colloidal actinides, fracture flow, and viscous fingering. The present version of NUTS is reasonable for its intended use.

3.8.2.4. Uncertainties

There are a multitude of uncertainties associated with this conceptual model and the NUTS code. First, there are all the uncertainties associated with the BRAGFLO conceptual model and its parameterizations (see Section 3.3). Values plugged into NUTS from BRAGFLO contain the inherent uncertainties from BRAGFLO since the input parameters are not screened for rationale values. These uncertainties will then be propagated through the NUTS code to the next step (SECOTP2D). The second group of uncertainties centers around the coarseness of the grid blocks and time steps used in NUTS. Although these parameters may be reasonable for BRAGFLO, it has not been justified that the same applies for the NUTS code.

Since Section 6.4.11 of the CCA and the Appendix NUTS are not presently available for review, many questions are unresolved and remain as potential uncertainties. These issues involve long-term transport of radionuclides in the repository rooms, repository panel seals, DRZ, and undisturbed and fractured interbeds, and input to sealed boreholes and shafts to the Culebra Formation. Advection should allow actinides to be transported directly to the Culebra Formation; however, it is not possible at the present time to evaluate how DOE handles these unknown factors.

There are also uncertainties associated with all the assumptions listed in Section 3.8.2.2. In the cases of all valid assumptions, the associated uncertainties are negligible. Since the soluble actinide source term input parameters are directly fed to NUTS, if the values are incorrect, the consequences could be significant in that the code would transmit such errors directly to the Culebra Member.

3.8.2.5. Adequacy of the Conceptual Model

The Actinide Transport in the Salado conceptual model describes the movement of the actinide source terms by advection, using hydrologic phenomena from the BRAGFLO computer code. The concepts of advection and Darcy flow are well characterized in the geosciences and are the mainstays of this conceptual model. However, the specifics of long-term transport through the components of the repository are poorly defined. Documentation that is not present includes Table 6-15, Section 6.4.11, and Appendix NUTS of the CCA. The section describing this conceptual model (Section 6.4.5.4) does not

document in any way how the "lumped" actinide source terms are transported from the rooms through the panel seals and the DRZ, how transport is performed through undisturbed and/or fractured anhydrite interbeds, and up sealed boreholes and shafts to the Culebra. Since this conceptual model is not yet fully described, the Panel can not determine if the model is adequate.

3.8.2.6. Adequacy of Implementation

The description of how this conceptual model is integrated from one computer code to the next (BRAGFLO to NUTS) is supposedly seamless. It is stated in the ten questions document that "NUTS interface with BRAGFLO is essentially perfect in completeness and validity in that NUTS takes virtually all its flow and flow-related attribute and property data from BRAGFLO and treats them as incontestable. Thus the .. interface is perfectly smooth." Hence, in the sense of transferring flow data into the NUTS code, one would conclude that the implementation is adequate.

Two other aspects of implementation are considered. One aspect involves how dissolved actinide solubility is handled in the "lumping" sense. The second aspect of implementation deals with how colloidal actinides are dealt with in the NUTS code. It seems DOE has provided a very rational way to "lump" all the various solubilities of dissolved actinides and to describe how the four main types of colloids will be "lumped" for transport. Both of these source terms have complex properties that could have been negated by the "lumping" factor. As an example, each actinide in its various oxidation states would have specific solubilities. Therefore the dissolved actinide source term is calculated for Salado and Castile brine compositions in both the low and high oxidation states. These four main permutations would then cover the possibilities for total inventories for dissolved actinides. Colloidal actinide sources are handled in a slightly different manner. Mineral fragment and intrinsic colloid values are held constant through all the runs. Humic and microbe actinide inventories are based on mass balance calculations using inventories from waste materials. These two philosophies of solubility "lumping" have been clearly explained for dissolved and colloidal actinide transport in the NUTS computer code by the Principal Investigator and, by this means, the implementation was determined to be adequate.

3.8.2.7. Accuracy of Results

Conclusions for this section are based on preliminary results provided by the Principal Investigator. The results proved to be accurate. However, without the final parameter listings of Table 6.15 of the CCA, one cannot make a final judgment of actinide transport in the Salado Formation. It would be useful to have the following information for comparison: first, actinide values after transport through the Salado

Formation to a borehole or shaft; second, what are the final values that NUTS would produce at the interface with the Culebra; third, an example of a NUTS transport run ("lumped") that approaches the EPA standard, and then a recalculated run using the individual radionuclides. This information would be very useful in determining whether the finalized results of this conceptual model are accurate. Finally, a complete model run has not been performed that transports dissolved actinides at the median velocity and colloidal actinides at maximum velocity. These results could be critical in deciding the accuracy of the model.

3.8.2.8. Validity of Conclusions

This section presents a judgment on whether the key conclusions that have been drawn based on the results of actinide transport in the Salado Formation in the modeling framework are valid. Although the concept of lumping is shown to be rational, the explanation of transporting colloids at a median velocity may be deficient. The parameter values (Table 6-15) were not available for the Panel to review and may bear on the judgment of validity for this model. Until these two final issues are resolved, it is premature to evaluate the validity of the model conclusions.

3.8.2.9. Adequacy for Implementation

This section is an overall assessment of whether this conceptual model represents a reasonable approximation of the actual phenomena and is adequate for implementation in the compliance application. Due to the lack of information provided (Table 6-15, Section 6.4.11, and the Appendix NUTS of the CCA), and the insufficient documentation of how colloid transport at a median velocity is rationalized, it is premature to say that the full conceptual model is completely adequate for implementation. However, if one assumes that BRAGFLO is a competent model for fluid flow in the repository setting, the next step of inputting hydrologic data into NUTS for actinide transport should be straightforward. Because of this, the model is wholly adequate and reasonable for implementation.

3.8.2.10. Dissenting Views

There were no dissenting views for this method.

3.9. Units Above the Salado

3.9.1. Model Description

The conceptual model of the Units Above the Salado has much in common with the conceptual model of the Culebra. The Culebra Dolomite is a member of the Rustler Formation, which is a prominent part of the supra-Salado stratigraphy. The Culebra is modeled separately (Section 3.2) because of its importance as a potential contaminant flowpath. The model of the Units Above the Salado results from a complex of several approaches to the hydrology and hydrogeology of the region and the WIPP site area. The conceptual model would ideally serve as an integrating set of hydrogeologic processes, properties, and principals that could be used to support assumptions about the potential performance of the site, to interpret regions of low data; and to place in context the results of hydrologic testing. The Units Above the Salado conceptual model provides a geometric characterization of the hydrologic system and a general description of the geometry and processes of flow. As with the Culebra, however, no correlation is provided of variation of hydrologic properties at the site scale with hydrogeologic character. The most important assumption in the model is that the Culebra Member of the Rustler Formation is the only potential pathway for radionuclide release to the environment.

The performance assessment of the Culebra is based on a considerable hydrologic testing data base, which addresses many of the potentially significant questions and issues concerning flow along the Culebra flowpath at and around the site. The significance of the hydrology and hydrogeology of the other members of the Rustler Formation and overlying formations lies partly in their interaction with Culebra hydrology and their influence on the interpretation of flow through that unit. The Culebra is treated as a confined aquifer with a much higher transmissivity than the overlying and underlying stratigraphic units and a horizontal flow gradient generally to the south. Flow in both the enclosing units (Unnamed Lower Member and Tamarisk) is believed to be predominantly vertical and into the Culebra. Water pressure in the Culebra is characterized as low because its transmissivity and gradient are capable of discharging more water than is presently being recharged.

The interpretation of the hydrologic processes for performance assessment purposes in the units above the Salado is based mostly on the results of hydrologic testing. A regional hybrid hydrogeologic/hydrologic process model (Corbet and Wallace 1993) sets model boundaries and

speculates about regional processes contributing to the transmissivity contrasts, but offers no site-scale correlation with the testing data. This model does not address mesoscale hydrogeologic variables such as fracture orientation and distribution and the distribution of matrix permeability.

The performance assessment activity associated with the units above the Salado is the two-dimensional Culebra flow model, based solely on the hydrologic testing results. The variability of transmissivity represented in that model within and around the site area is attributed to the relative proportions of flow through fractures and variably permeable matrix, and to fracture distribution and hydraulic activity. The model does not address those variations of hydrogeologic process and properties relative to petrologic, sedimentologic, or structural features, which are the primary sources of variability. The conceptual model is disconnected from the numerical hydrologic model at the scale at which hydrogeologic information could most usefully condition the numerical model.

The assumption that the Culebra is the only potential pathway for release to the environment is related to the movement of radionuclides up a borehole or up the sealed shaft region. The assumption that radionuclides reaching the Magenta Dolomite member of the Rustler Formation or the Dewey Lakes Redbeds, which overlie the Rustler Formation, are not transported to the accessible environment is based partly on the results of very limited hydrologic testing and assumed retardation in the Dewey Lakes.

Hydrogeologically, the Culebra and Magenta Dolomites bear many similarities. Both are dolomites deposited in the same sedimentary environment. They are comparable in thickness and differ in stratigraphic position by a few tens of meters. Their post-depositional histories are identical from location to location. Their porosities are nearly identical and their ranges of permeabilities overlap. The definition of the hydrologic character of the Magenta is based on modeling of approximately 15 data points constrained to a very small geographic area.

The principle hydrogeologic difference between the Culebra and Magenta is purported to be the absence of hydrologically active fractures in the Magenta. This assertion is based on two slug tests and very limited field observation in shaft excavations. The transmissivity of the Magenta is very low in all of the limited number of tests and its low transmissivity is supported by drawdown during the sinking of the air shaft. The characterization of Magenta hydrology as unfractured is based on a very limited observational and testing data base, and the conclusions that there are no regions of high transmissivity due to fractures and that all flow in the Magenta is matrix flow are weak.

The position of the groundwater table at the level of the Dewey Lakes Redbeds is very unclear. Hydrologic testing has not been done to differentiate between purported perched water zones, to characterize saturated zones with continuity to underlying units, and to identify the general hydrologic character of the Dewey Lakes Redbeds. It is presumed that most of the materials above the Dewey Lakes are unsaturated (Gatuna and Pleistocene alluvium) and that recharge through those materials is minimal.

3.9.2. Review of Criteria

The units above the Salado contain the Culebra Dolomite, which is identified as the principal potential pathway for release of radionuclides to the environment. The conceptual model for these units provides the framework for consideration of the hydrology of the Culebra and contains other hydrostratigraphic units (Magenta and Dewey Lakes) whose potential as pathways must also be evaluated.

3.9.2.1. Information Used to Develop the Conceptual Model

The conceptual model is based on stratigraphic information from site borings and shaft excavations and on the position and nature of regional hydrogeologic features. Corbet (1993) has synthesized those features well and uses them as the basis for suggesting model boundaries and to support general flow gradient direction predictions. The model used for performance assessment purposes is a two-dimensional computational flow model based entirely on hydrologic testing in the Culebra. The conceptual model generally supports the descriptions of the hydrologic roles of the units above the Salado, with reservations about the characterization of flow in the Magenta Dolomite and the universal presence of retardation in the Dewey Lakes Redbeds. Hydrologic test data are sparse or nonexistent in all units above the Salado, except the Culebra.

3.9.2.2. Validity of Model Assumptions

The assumption that the Culebra Dolomite is the only hydrostratigraphic unit within the stratigraphic sequence above the Salado, which has the potential to act as a flowpath to the accessible environment, is the principal assumption affecting this conceptual model. That assumption implies that the Magenta Dolomite and the Dewey Lakes Redbeds are not potential pathways and that flow and transport assessments of those units are unnecessary. Estimates of contaminated brine flow up an intruding borehole in the long term imply very small (0.5 m^3) volumes of brine reaching the interval above the Culebra (personal communication, P. Vaughn). This is the consequence of underpressure hydrologic conditions purported to exist in the Culebra throughout the repository area, which lead to injection of

most of the brine rising up the borehole into the Culebra. The magnitude and distribution of underpressure in the Culebra are based on averages of several measurements and an assumed process model, which explains the underpressure condition. The assumption that the Dewey Lakes and Magenta are not flowpaths is not well supported. The assumption of availability of only small amounts of brine to those units appears to be well supported.

3.9.2.3. Evaluation of Alternatives

The conceptual model has evolved over the entire period of site characterization and performance assessment. Some alternative submodels were considered and rejected (e.g., local halite dissolution and anhydrite hydration, gravitational loading). All of these submodels failed to conclusively account for the variations in transmissivity at a useful scale. The final performance assessment model is almost entirely based on numerical assessment of hydrologic test data, which are very sparse except in the Culebra Dolomite, the most thoroughly tested stratigraphic unit at the site.

3.9.2.4. Uncertainties

The principal uncertainty in the conceptual model of the units above the Salado (excluding the details of Culebra flow, treated elsewhere) is the assumption that the Magenta and Dewey Lakes units do not constitute potential release pathways. The effect of underpressure in the Culebra appears to limit flow up an intruding borehole to the upper units in such a way that there is little consequence associated with the Dewey Lakes and Magenta flowpaths.

3.9.2.5. Adequacy of the Conceptual Model

The conceptual model adequately defines the regional and general stratigraphic geometry of the units above the Salado. It does not provide supporting explanations for the variability of hydrologic parameters and processes at the site scale. If the need to assess transport in the Magenta and Dewey Lakes were shown to exist, the small hydrologic testing data base and the existing conceptual model would not be adequate to such an assessment.

3.9.2.6. Adequacy of Application

There is no application of the conceptual model to the computational flow modeling at the site scale except for the definition of stratigraphic geometry. A thorough demonstration of the potential of the Magenta and Dewey Lakes as flowpaths is absent, and the conceptual model is inadequate to support

such a demonstration. The conceptual model adequately provides geometric and process elements to support the Culebra model.

3.9.2.7. Accuracy of Results

The accuracy of results depends on the adequacy of the testing data base and the computational flow models and are beyond the scope of this review.

3.9.2.8. Validity of Conclusions

See Sections 3.9.2.6 and 3.9.2.7. Conclusions are based on the Culebra numerical flow model and are beyond the scope of this review.

3.9.2.9. Adequacy for Implementation

The conceptual model is not significantly implemented in the computational flow model used for performance assessment (the Culebra two-dimensional flow model). The conceptual model provides adequate peripheral support to the implementation of the Culebra flow model by defining geometry and a general description of flow conditions in adjoining beds. The conceptual model is not adequate to support an assessment of the Magenta and Dewey Lakes hydrostratigraphic units as flowpaths. Assumptions supported by analysis imply that the consequences of transport in the Magenta and Dewey Lakes are low because of insignificant input of contaminants as a result of human intrusion.

3.9.2.10. Dissenting Views

There were no dissenting views for this model.

3.10. Transport of Dissolved Actinides in the Culebra

3.10.1. Model Description

The transport of actinides in the Culebra Dolomite Member of the five-member Rustler Formation was determined by DOE to be a significant pathway for potential releases to the accessible environment. This model describes the transport of soluble actinides once the material has moved into the Culebra, which could occur either under undisturbed conditions by movement up the shafts, or under disturbed conditions through intrusion boreholes, which provide a path by which gas or brine can be released up to and above the Culebra. These processes are described in other models. The quantities of actinides transported into the Culebra, as well as their chemical form, are described in the source term models.

The characteristics of the Culebra that relate to flow and transport are described in Section 3.9, and the model for spatial distribution of flow rates in the region and site area is described in Section 3.2. Therefore, this model is related to output from Shaft Seals, Chemical Conditions, and Dissolved Actinide Source Term, as well as Culebra Geometry and Flow, Gas Generation, Fluid Flow in the Salado, Disturbed Rock Zone, and the models related to intrusion, Exploration Borehole, Castile Formation and Brine Reservoir, and Multiple Intrusions.

The model, Transport of Dissolved Actinides in the Culebra, is also related to a parallel model, Transport of Colloidal Actinides in the Culebra, which depends on many of the same processes. Fundamentally, the model describes the horizontal transport of dissolved actinides by water flowing through the porosity of the dolomite, and retardation that may occur along the way. The flows are confined to the lower 4 meters of relatively permeable dolomite of the 7-meter thick Culebra. The model describes advective transport, as well as holdup due to matrix diffusion and chemical retardation. The model assumes that the overall rock porosity is composed of interconnected porosity, which forms the principle paths for advective water flow, and relatively unconnected diffusive porosity, into which species may diffuse under concentration gradients. This model is therefore referred to as a double porosity model.

The advective porosity is envisioned as a web of interconnected horizontal and vertical fractures in the dolomite, with some contribution from flow through interconnected vugs, and comprising less than 1% of the overall rock volume. The diffusive porosity is described as being accessible from advective porosity through small intercrystalline pores of the Culebra rock matrix, and comprising about 15% of the overall rock volume. Physical holdup and chemical retardation are therefore described as predominantly related to the diffusive porosity, with the surface area for chemical adsorption located within the diffusive porosity. This surface area has been measured at about 1 m^2/gm of dolomite.

Diffusion into the rock is described as related to the chemical diffusive properties of dissolved species, the tortuosity of the diffusion paths within the rock, and the surface area for diffusion between advective and diffusive porosity per unit volume of diffusive rock. Chemical retardation is described as chemical adsorption onto the dolomite grains exposed in the diffusive porosity. Although clay is believed to be present in the Culebra dolomite, particularly between horizontal bedding planes, adsorption onto this clay is not specifically assumed because its distribution and quantitative effect have not been demonstrated. Chemical adsorption is further described as a linear isotherm model, with single constants, K_ds, to

describe the equilibrium relationship of the ratio of adsorbed concentrations and dissolved actinide species.

Fifteen years of development of information and models to describe actinide transport in the Culebra has considered two controversial issues. The first is whether a single matrix porosity or a double porosity model is appropriate to describe flow and retardation. The second is whether and how chemical retardation, particularly on corrensite clay, is to be modeled. The project has used a single porosity model and adsorption on clay in the past, but currently uses a dual porosity model with adsorption onto dolomite but not onto clays. This is discussed in more detail later.

3.10.2. Review of Criteria

3.10.2.1. Information Used to Develop the Conceptual Model

The site-related information used to develop the Culebra actinide transport model has included direct observation of the formation in outcrop, borehole cores and wells, and laboratory testing. These site observations have included chemistry measurements, studies of mineralogy, and field hydraulic and tracer testing. The laboratory testing has developed the quantities of actinides in solution in brine, their oxidation states and solubilities in brine, and measured adsorption properties.

Laboratory studies conducted to understand the adsorption process included column tests and the use of intact Culebra cores. Studies of adsorption on dolomite and corrensite clay were conducted, but information on the amount and distribution of clay in advective porosity pathways was judged insufficient to justify assuming adsorption onto clay. Laboratory studies have used four synthetic brine compositions representing the range of actual brines in the Salado, Castile, and Culebra. Information was developed on effects of carbon dioxide on adsorption at partial pressures expected in the Culebra. Adsorption information for plutonium, americium, uranium, thorium, and neptunium at expected oxidation states was developed using laboratory measurements and the oxidation state analogy.

Recently, the H-11 and H-19 tracer testing was completed and the results analyzed and summarized, although no reports of this key work were available to the Panel for review. This additional tracer testing was conducted because the results of earlier tracer testing with soluble dyes did not provide adequate information to convincingly show that the dual porosity model was appropriate for actinide transport purposes. The evaluation of the current work and reevaluation of earlier work has improved the information base. However, much of the work in support of this model is recent and has not yet been

published. Improved correlation with modeling analyses has been achieved for increased ranges of flow rates and other improvements in test conditions. The information base appears generally adequate, although the parameters that relate to this model will need to be carefully chosen. These parameters are the advective and diffusive porosity, the range of block sizes, the soluble species diffusion coefficients, tortuosity, and retardation coefficients.

3.10.2.2. Validity of Model Assumptions

Some of the principal assumptions are that the transport can be described in the dual porosity model, that the oxidation states of actinides in brine transferred into the Culebra do not change during subsequent flow and transport in the Culebra, that dissolved actinides will diffuse into the matrix and be physically retarded, and that dissolved actinides can adsorb on diffusive porosity surfaces.

The basis for the assumption that the transport model should assume both advective transport in principal flow paths and diffusive transport into the rock, is that results of tracer tests along principal flow paths at the WIPP site are only explained using the dual porosity model. This is believed valid in the areas of the site where transmissivity is greater than 1×10^{-6} m^2/sec. In areas of low transmissivity, which have little advective porosity and flow, a matrix diffusion model best explains results, but is not used for the performance assessment because these low transmissivity areas do not contribute significantly to the flows away from the repository. In high transmissivity areas, a single porosity assumption is not consistent with the tracer test results. Therefore, for purposes of transport, the dual porosity assumption appears appropriate.

For purposes of determining appropriate values of adsorption coefficients and solubilities, the project assumes that the oxidation states of actinides generated in the repository do not change when the deep brines are injected into the Culebra brine. Adsorption behavior would be different if oxidation states were different, while concentrations would not be different since precipitation is assumed not to occur in Culebra brine. The assumption of constant oxidation states is based on the repository brines being strongly reducing, the Culebra brine being reducing (though perhaps less so), and the rate of any changes in oxidation state that might occur at low ambient temperatures being slow. This assumption is supported by retardation research program studies involving four different brines, including Castile and Salado brine and two brines representing the Culebra, four different chemical constituents affecting conditions, including sulfides, cellulosics, iron and nitrates, and two different chemical equilibrium data bases. It was stated that 30 of the 32 possible combinations of information indicated reducing conditions,

with only some combinations of nitrates producing slightly oxidizing conditions. Measurements of the redox states of groundwater sampled from over 20 wells around the WIPP site indicated reducing conditions everywhere on and around the site, except for areas a few miles south where recharge was thought to affect redox conditions. Thus, this assumption appears fairly well supported.

The model assumes that the properties of actinides of the same oxidation state generally are similar. This issue is discussed in Section 3.23 and will not be covered here. The most recently conducted tests of adsorption parameters included column tests with crushed dolomite at Lawrence Livermore National Laboratory, and flow-through tests using dolomite cores from the WIPP air intake shaft.

The assumption that batch tests using small particles and flow-through retardation experiments can give valid results for the adsorption parameter needs consideration. In the column tests, not yet published, K_ds were measured using dolomite, with no detectable (<1%) clay, that was crushed and sieved to give particles of about 100 mm diameter. The issue was raised that this might make the internal surface area and the clay that might be present more accessible in the experiment than it is in the intact Culebra. It was noted that measured grains in dolomite are on the order of 2 mm and pore openings are approximately 0.6 mm, and therefore a dolomite particle of 100 mm would have roughly the same surface-to-volume relationships as the rock. Also, the contact times were long enough in the experiment for diffusion transport to reach equilibrium. The issue of diffusion rates into the matrix is determined by other parameters, including porosity and tortuosity, which have been measured in other testing programs.

The flow-through tests used intact horizontal Culebra cores with pressure-induced flow of non-absorbing tracers, as well as five actinides, Pu, Am, Th, Np, and U, in solution. In this case, K_ds were inferred from the overall retardation of the core. The results of these tests are being evaluated and K_ds were determined using the values for the likely oxidation state and the brine type with the lowest values. Without commenting on the specific numerical values, which have not been finalized, this appears to be a reasonable approach. Interpretation of the results of such experiments needs to be made carefully, so that values of K_ds, tortuosity, and porosity can be reliably applied into numerical models. It would also be useful to compare the values thus obtained with other data from past determinations.

One uncertainty in the column tests is that associated with the amount of clay in the tested dolomite. X-ray diffraction studies did not detect clay, with an apparent minimum detectable value of about 1%. There is also clay in the Culebra dolomite, reportedly in the range of 1 to 5%. The intent was to use clay-

free dolomite in the column tests, but it appears this experiment may inherently include the adsorption effects from whatever amount (<1%) of clay was in the dolomite matrix. While it was not shown that this was representative of truly pure dolomite, this appears to be conservative, because the clay was likely at the low end of the range. This is a tentative conclusion however, because the results of this work were not available in published form for review.

3.10.2.3. Evaluation of Alternatives

The principal alternatives considered relate to whether transport is best described by a single porosity fracture only, a single porosity matrix only, or a dual porosity model. Neither of the single porosity models explain the data from tracer tests everywhere on the site, whereas the dual porosity model best explains the data, particularly in the regions on the site where transmissivities are high.

3.10.2.4. Uncertainties

Uncertainties related to oxidation state in the repository source term translate directly into transport-related uncertainties (see Sections 3.23 and 3.24). These uncertainties could have a large effect on the result of performance assessment. However, as discussed in Section 3.10.2.3, there appears to be a reasonable basis to conclude that the oxidation states would not change significantly on entry into the Culebra from the repository. Uncertainties on the extent of adsorption could have a significant effect as well. However, at the conceptual level, the model attempts to proceed in a reasonably conservative manner in light of these uncertainties. This does not mean that particular values of K_ds to be chosen from the conceptual model are all conservative, since numerical values for these parameters have not been evaluated.

3.10.2.5. Adequacy of the Conceptual Model

It is concluded that a dual porosity model is adequate for dissolved actinide transport analyses if ranges of model parameters are chosen properly in light of uncertainties. In that the model is supported largely by evaluation of recently completed but undocumented field and laboratory experiments, this conclusion is necessarily tentative.

3.10.2.6. Adequacy of Application

This model utilizes direct input from only a few other conceptual models: the Actinide Source Term models, and the Culebra Hydrogeology model, as well as output from the flow models under undisturbed

and disturbed conditions. At the conceptual level, these model outputs appear compatible as input to the Culebra Transport model. This does not mean there could not be problems in application through the equations and mathematical formulations in the NUTS code. A more informed judgment could be made from a review of sensitivity among key parameters, such as the relationship of the sensitivity of repository releases on source term concentrations of dissolved actinides, on K_ds, on volumes of brine injected, on effects of climate change, and mine subsidence effects on Culebra transmissivities.

3.10.2.7. Accuracy of Results

A judgment on whether the conceptual model affords sufficiently accurate results for performance assessment depends on the overall importance of various model assumptions. It is judged that the dual porosity model itself is a sufficiently accurate conceptual representation for performance assessment, based primarily on verbal briefings of the results of the latest tracer testing in the Culebra and on visual observations. However, since the results of the latest tracer tests have not been documented, this judgment is tentative. Furthermore, the method of developing parameters of importance to numerical results also have not been supported by written reports of the related recent work. Therefore, these parameters have not been reviewed, although some important uncertainties were identified above. Accuracy of results imply review of results, and none using the current model and parameters were available for review. It would be useful to review results of sensitivity analyses to understand which are the key variables, and then focus on the accuracy of those key variables. Until such information is reviewed, a firm conclusion on their accuracy cannot be properly drawn.

3.10.2.8. Validity of Conclusions

The conclusion that the actinide transport in the Culebra can be adequately modeled in a dual porosity model, with advective transport in the main flow porosity, diffusion into and physical and chemical retardation in the rock matrix porosity, is valid. Other conclusions have not been presented since the model, using the chosen parameters, has not yet been used in the performance assessment.

3.10.2.9. Adequacy for Implementation

The conceptual model appears compatible with other models it intersects with directly. The implementation of the conceptual model is through mathematical formula and computer codes which have not been evaluated. It is concluded that the conceptual model is adequate for implementation. However, the selection of model parameters needs to be critically reviewed when the reports of the laboratory and field tracer tests are available.

3.10.2.10. Dissenting Views

There were no dissenting views for this model.

3.11. Transport of Colloidal Actinides in the Culebra

3.11.1. Model Description

This model is closely related to Transport of Dissolved Actinides in the Culebra (Section 3.10), and shares many aspects and assumptions of that model. This model differs from the Dissolved Actinides model in its application of colloidal properties as opposed to dissolved properties to the transport process. The issue of whether, for transport purposes, a dual porosity approach is appropriate, is not repeated since that issue was covered in Section 3.10. However, differences in how the colloids are transported in this model are covered.

Model adjustments for colloidal transport include the different properties and processes that occur for colloids. For example, colloidal particles travel slightly faster in advective transport than dissolved species due to velocity gradients in flow apertures. Colloids can be trapped along the way, and they can diffuse into the diffusive porosity in the dolomite if they are smaller than the pore throat diameter of the dolomite. Four types of colloids are considered: mineral fragments, microbes, humic and fulvic acids, and actinide intrinsic colloids. These four types are different in size and properties; for example, some are hydrophilic, some are kinetically stable, and others are less so. Colloidal particles that are small enough to enter the dolomite matrix may chemically adsorb on surfaces once inside the diffusive porosity.

The model assumes that the colloidal particles containing actinides originate in the repository and are transferred into the Culebra in the same way as dissolved actinides, as represented in the NUTS code. In this model, it is assumed that soluble actinides do not attach to colloids that may already exist in the Culebra brine when brine containing dissolved actinides is injected into the Culebra and mixes with Culebra brine.

Colloidal transport has not been considered in the earlier assessments of repository performance; therefore the only other model implicitly considered was the null hypothesis. However, experience in other environmental situations at other DOE sites has lead to consideration of colloidal transport to explain greater transport of actinides than had been expected in these other situations, based on models that considered only soluble transport.

3.11.2. *Review of Criteria*

3.11.2.1. Information Used To Develop the Conceptual Model

Information used to develop the colloidal actinide transport model included the amounts and types of colloids thought possible in the source term model, the chemical properties and physical sizes of the particles, and how these would be transported in advective flow. In addition, information was developed on diffusion coefficients, measured pore throat diameter distribution in WIPP dolomite samples, and results of experiments to quantify whether and the extent to which colloids can adsorb onto dolomite matrix surfaces. A growing body of scientific literature and various computerized numerical models have been consulted to develop the conceptual model, and to help guide implementation.

The available information and experience with colloidal actinides is not as robust as for transport of dissolved actinides and, therefore, is likely to be less able to support a completely robust model. This model was conceived to fill a weakness in models considering soluble transport only. The available information appears adequate to formulate a useful conceptual model, but this does not mean that adequate information is yet available to fully implement a conceptional colloid transport model.

3.11.2.2. Validity of Model Assumptions

Some of the key assumptions are that 1) actinide oxidation states do not change when deep brines containing these colloids are mixed in Culebra brines; 2) soluble actinides in brine from the repository do not interact with and become attached to colloidal particles that exist in the Culebra; 3) colloids can be filtered in the advective porosity but not chemically adsorbed there; and 4) colloids which are smaller than a 0.63μm can diffuse into pore throat openings in dolomite and be chemically adsorbed onto surfaces there.

The assumption of oxidation state stability is discussed in Section 3.10.2.2, and no basis has been provided to assume colloid actinides would behave differently from soluble actinides.

The assumption that dissolved actinides do not attach to preexisting Culebra colloids is difficult to justify in principle. This assumption has been made to avoid the complication of the computer code having to simultaneously solve the dissolved species problem and the colloid transport problem. If there were significant transfer of soluble actinides to large colloidal particles in the Culebra flow, the transport of this actinide material could be significantly faster than the current model, due to reduced physical and chemical retardation. If the transfer of soluble actinides to small colloids occurred, it would not increase

the transport as much, since advective transport would be slower and, more importantly, small colloids could diffuse into diffusive porosity in the dolomite matrix and be significantly retarded and perhaps chemically adsorbed. The arguments made to simplify the test plan and model do not consider this effect. Models to predict transport by adsorption onto colloidal particles along the transport path have been developed precisely because models of soluble only transport were inadequate. It is therefore judged that this assumption is unjustified based on the literature and information developed specifically for the WIPP project.

The assumption that colloidal particles can be filtered by entrapment in narrow passages in advective porosity appears viable at the conceptual level, but no information has been presented to demonstrate this occurs significantly in the Culebra, and no information has been presented to confidently quantify the effect. The assumption is implemented as a simple "decay" term for those colloids that are too large to enter diffusive porosity. On the other hand, particles in flowing systems do indeed tend to collect in areas of low flow velocity, so such a filtering process is likely to be useful if parameters are selected carefully to avoid trivializing the overall colloidal transport.

The assumption that colloidal particles smaller than the mean pore throat diameter of 0.63μm can diffuse into the dolomite matrix and be adsorbed onto the interior surface area in the dolomite matrix needs some discussion. Of the four types of colloids being considered, the humic/fulvic acid colloids and the plutonium intrinsic polymer are believed to be smaller than 0.63 μm. Measurements of many different properties of WIPP dolomite were made to develop their ranges and statistically average values, including porosity matrix interior surface area, permeability, grain density, tortuosity and pore throat sizes. Pore size distribution measurements were made on 24 samples using the mercury injection porosimetry technique. These data were interpreted to provide a mean pore throat diameter of 0.63μm. Analysis of the data showed that the accessible internal surface area was a function of pore throat size. For a typical sample with a porosity of 14.8% overall, the data indicated that no internal surface area was accessed for pore throat diameter greater than about 1μm; that about 35% of internal area was accessible at a pore throat diameter of about 0.37μm; and 50% of the internal surface area was accessible at a pore throat diameter of about 0.2μm. Total internal surface area is about 1 m^2/gm of dolomite. Humic acid colloids and the plutonium polymer are thought to be small enough to enter the dolomite. Humic acid colloids are reported to be about 0.1μm or less and single unagglomerated plutonium polymer colloids are on the order of 0.003μm. Intrinsic colloid agglomerates could be as large as 0.04μm. Microbial

colloids are 1 or 2 μm and mineral fragments are on the order of 1μm as well. Based on this information, it appears feasible that the humic/fulvic acid colloids and plutonium intrinsic polymer colloids could diffuse into the matrix, unless surface charge forces prevented this from occurring.

The assumption that colloidal particles could be adsorbed onto the surfaces in matrix porosity is a more complex process to understand because colloidal interactions are less well understood. For example, if the colloids have the same surface charge as the rock, adsorption would be prevented, and if the charges were opposite, adsorption would be relatively strong. To explore this assumption, the project attempted to measure K_ds for actinide colloidal particles of the various types in the same laboratory column tests, and core flow through tests as for soluble actinide measurements. The results showed apparent adsorption in both situations. However, for some of the flow-through experiments, soluble actinides and colloids were mixed and the resulting K_ds were found to be the same as for soluble actinides. Therefore, this experiment did not demonstrate colloidal adsorption so much as perhaps soluble adsorption or filtration, since the experiment did not obviously assure that the actinides were on colloidal particles before being contacted through the dolomite. For microbe colloid experiments, no nitrates were added to keep the microbes growing, so as to prevent changing the oxidation state of the actinides. This may have prevented bioassimilation of actinides in microbe colloids, and again lead to the measurement of K_ds with the same values as for soluble species. Resolution of these and perhaps other uncertainties would add confidence to the assumption that actinide colloids adsorb onto surfaces and the extent to which they adsorb. In the absence of a satisfying resolution, colloidal adsorption onto dolomite matrix porosity may not be a justifiable assumption in the model.

3.11.2.3. Evaluation of Alternatives

Since consideration of transport of colloidal actinide transport has only recently been included in performance assessment, no alternatives were considered.

3.11.2.4. Uncertainties

Uncertainties in the model are associated with the key assumptions discussed in Section 3.11.2.2. The Panel concludes that very large uncertainties exist with the lack of interaction of soluble actinides and Culebra colloids in the model, and with the diffusion into dolomite porosity followed by chemical adsorption. Because of the lack of availability of published reports on the recent testing, a more definite conclusion cannot be drawn.

3.11.2.5. Adequacy of the Conceptual Model

The uncertainties in the validity in some of the key assumptions cast some doubt on the adequacy of this model. Even though the overall performance assessment model is greatly improved by the addition of colloidal actinide consideration, it appears that model predictions will result in negligible transport based on the model and parameters presented to date. If this were the outcome of the fully developed and qualified model, one could have more confidence. However, since significant uncertainties exist in major features of this model, its results could not be trusted, based on the available information. It may be that the issues raised here are readily resolved, but application of colloid science in environmental transport is a new and difficult application, and a cautious approach is believed most appropriate.

3.11.2.6. Adequacy of Application

Soluble actinide interaction with colloidal particles in the Culebra has been assumed not to occur without justification. This represents an issue of integration of this model with the Dissolved Actinide Transport in the Culebra model. Other than this, other system-wide integration issues have not been identified.

3.11.2.7. Accuracy of Results

No actual results have been provided. However, on the basis of the information reviewed, it appears this model, as currently envisioned, would not provide sufficiently accurate results.

3.11.2.8. Validity of Conclusions

Since there is doubt about other criteria, this criterion is also in doubt.

3.11.2.9. Adequacy for Implementation

It does not appear that the information available demonstrates that this model provides a sufficient basis to give confidence in the adequacy of treating colloid transport in performance assessment. It should be noted that, because of the recent undertaking of this work, none of the laboratory test reports or flow-through test reports, on which significant aspects of this model are based, are completed. Further review of the information, when published, could provide a basis to resolve some of the issues raised, after adjustment of some of the assumptions and judicious choice of parameters for a numerical solution. This could lead to an adequate model for implementation.

3.11.2.10. Dissenting Views

There were no dissenting views for this model.

3.12. Exploration Boreholes

3.12.1. Model Description

The Exploration Borehole conceptual model addresses drilling locations, methods, and frequencies within the WIPP controlled area, borehole sealing, and long-term fluid flow through the sealed borehole. Short-term flow through the unsealed borehole is addressed in the Direct Brine Release conceptual model. Associated conceptual models that describe movement of contaminated materials to, within, and from the borehole include Repository Fluid Flow, Castile and Brine Reservoir, Cutting/Cavings, Spallings, Culebra Hydrogeology, and Dissolved and Colloidal Actinide Source Terms. Actinide transport accompanying long-term brine migration is addressed by the Actinide Transport in the Salado conceptual model. The Exploration Borehole conceptual model is limited to a single borehole penetrating the repository. The Multiple Intrusion conceptual model describes conditions when more than one borehole is assumed to penetrate a waste panel. The details of this model were still under development at the time of the peer review, and information describing the model was obtained from a variety of final and draft reports and memoranda, and from verbal descriptions provided by DOE. The following model description was prepared from information presented in the 22 May 1996 Draft CCA, Section 6.4.7, The Intrusion Borehole (DOE 1996, pp. 6-64 to 6-75), from verbal descriptions, and from the cited references.

An exploration borehole may be drilled on the WIPP site for natural resources investigation and may by chance penetrate a waste panel in the repository. Such boreholes are assumed to be drilled by individuals who have no knowledge of the buried waste, after active institutional control of the site has ceased. The conceptual model for exploration boreholes is based in large part on proscriptive requirements of EPA 40 CFR 194. The EPA requirements are paraphrased as follows:

- The regulatory time frame is the time period beginning at disposal and ending 10,000 years after disposal [40 CFR 194.2].
- Both deep drilling (to or below a depth of 2,150 feet) and shallow drilling (less than a depth of 2,150 feet) that may potentially affect the disposal system during the regulatory time frame are assessed [40 CFR 194.33(a)]. The approximate depth of the repository is 2,150 feet.
- Exploratory drilling is assumed to be inadvertent and intermittent [40 CFR 194.33(b)(1)].

- Exploratory drilling for those resources provided by the waste in the disposal system or the engineered barriers designed to isolate such waste need not be considered [40 CFR 194.33(b)(1)].

- Drilling events in the Delaware Basin are assumed to occur at random intervals in time and space during the regulatory time frame [40 CFR 194.33(b)(2)].

- The frequency of deep drilling within the WIPP controlled area is assumed to be the sum of the rates of deep drilling for each resource in the Delaware Basin over the past 100 years [40 CFR 194.33(b)(3)].

- The total rate of shallow drilling at WIPP is assumed to be the sum of the rates of shallow drilling for each resource in the Delaware Basin over the past 100 years; however, in considering the historical rate of all shallow drilling, the DOE may, if justified, consider only the historical rate of shallow drilling for resources of similar type and quality to those in the controlled area [40 CFR 194.33(b)(4)].

- Future drilling practices and technology are assumed to remain consistent with practices in the Delaware Basin at the time the CCA is prepared, including the types and amounts of drilling fluids; borehole depths, diameters, and seals; and the fraction of boreholes that are sealed [40 CFR 194.33(c)(1)].

- Natural processes are assumed to degrade or otherwise affect the capability of boreholes to transmit fluids over the regulatory time frame [40 CFR 194.33(c)(2)].

- The effects of techniques used for resource recovery following drilling need not be considered [40 CFR 194.33(d)].

In developing a conceptual model that incorporates these assumptions, DOE has considered the following:

- Shallow boreholes will not intercept or affect the integrity of the repository and therefore need not be considered.

- Present drilling practices include the relative economic value of the target resource; on this basis, the objectives of exploration drilling at the WIPP site are assumed to be oil and gas because these are the only commercially viable resources for which exploration drilling would occur to or below the depth of the repository horizon.

- Although commercially viable reserves of potash are known to be within the WIPP controlled area, inadvertent penetration of the repository during exploratory drilling for this resource was not considered because such reserves lie above the repository depth.

- The frequency of deep borehole drilling is estimated based only on historical frequencies of drilling for resources of similar type and quality to those found at the WIPP site.

Exploratory drilling for hydrocarbon resources within the Delaware Basin is assumed by DOE to occur at a rate of 47 holes per square kilometer over the 10,000-year regulatory time frame. Although the timing of intrusions into the waste panels is randomly sampled, based on the 0.125 square kilometer area of the waste panels, the expected average rate of penetration is about 6 boreholes per 10,000 years. Boreholes penetrating the waste panel area but passing through a pillar or wall rather than through the waste are assumed to have no effect on waste releases, but may penetrate and partially deplete brine reservoirs in the Castile. The concept of partial reservoir depletion is discussed further in Section 3.16. Penetration of the operations or experimental areas of the repository by a borehole is assumed to have no significant consequence. All exploratory boreholes are assumed to be drilled in search of hydrocarbon resources and all are therefore assumed to penetrate entirely through the Salado and Castile Formations. Approximately 10% of these are tentatively assumed to encounter pressurized brine in the Castile (E1 scenarios), and the other 90% are assumed to not encounter pressurized brine (E2 scenarios) (see 23 May 1996 Draft CCA, Section 6.4.13.6 (DOE 1996, p. 6-119)).

Drilling is assumed to be conducted by standard rotary methods. At the time of repository penetration, the borehole is assumed to have been cased to the bottom of the Rustler Formation, following current standard practices. After drilling has progressed through the salt section, an intermediate casing is installed to the bottom of the Castile. Below that depth a third, final production casing is installed, which typically extends to the ground surface during production, but is only cemented near the production zones. On abandonment, the production casing is commonly cut above the cemented zone and reclaimed (Thompson et al. 1996, p. 6). Fluid and solids that flow through the open borehole immediately on repository penetration are described in the aforementioned Direct Brine Release, Cuttings/Cavings, and Spallings conceptual models. Long-term fluid flow through the sealed borehole is described in the following paragraphs.

On abandonment, three different scenarios have been adopted by DOE to describe the range of current borehole plugging practices. These are (1) a single, continuous cement plug extending from the top of the Salado to the bottom of the Castile; (2) two 40-m cement plugs, one at the bottom of the Castile (top of the Bell Canyon) and one at the bottom of the Rustler; and (3) three 40-m cement plugs, consisting of the two plugs described above plus an additional plug near the Salado/Castile contact below the repository. In addition, all boreholes have approximately 15-m long concrete surface plugs (Thompson et al. 1996, p. 3).

Degradation of the plugs generally follows the scenarios and rationale presented by Thompson et al. (1996). The continuous plug is not considered to degrade over time because of its structural integrity and the very low brine flow through it. The surface plug is also not considered to degrade over time because of the lack of physical or chemical stresses in the near-surface environment. In the two- and three-plug scenarios the steel casing in the Salado and Castile is expected to be locally pitted and leak within a few decades after abandonment. In these scenarios, within 200 years after abandonment the 40-m concrete plug and remaining casing above the repository and the open casing below the repository are assumed to fail completely from both mechanical and chemical stresses. Simultaneously, with the exception of the concrete plugs below the repository, the entire borehole is assumed to be filled with degraded concrete, corrosion products, and sloughed native materials that are assigned the hydraulic properties of silty sand in accordance with regulatory guidance. Because of increased stresses and halite creep rates below the repository, the borehole filling below the repository is subsequently assumed to be compacted, with a concurrent decrease in permeability. The cement plugs below the repository, however, are assumed to maintain their integrity for the duration of the 10,000-year regulatory time frame because degradation rates will be significantly reduced due to a less aggressive chemical environment (see 23 May 1996 Draft CCA, Section 6.4.7.2.2 (DOE 1996, p. 6-74). Long-term brine flow is expected to occur to or from the repository through the degrading upper borehole plugs as a function of brine availability and repository pressure.

The same version of the BRAGFLO code used to model repository fluid flow is used to implement the Exploration Borehole conceptual model. This model, which portrays a two-dimensional vertical section, is discussed in Section 3.3 of this report and in Section 6.4.2 of the 1 April 1996 Draft CCA (DOE 1996, p. 6-2). The exploration borehole is assumed to penetrate the center of one of the waste disposal panels in the repository. Boreholes penetrating into a waste panel were found in modeling results to not significantly affect brine saturations in neighboring panels, even over the regulatory time frame, because of low hydraulic gradients across the panel closure seals. The borehole is modeled by modifying the material properties of the cells representing the borehole as a function of the type of intrusion (E1 or E2) and the time after intrusion. Short-term brine flow in the open borehole is separately modeled (see Section 3.15).

For long-term flow, the borehole is assumed to be plugged immediately after repository penetration by randomly selecting one of the three plugging scenarios in accordance with its probability of occurrence. The basis for the random selection is discussed in CCA Section 6.4.12, which was not available to the

Panel for review. In an E2 scenario, where the borehole through the Castile is assumed to not encounter pressurized brine, the lower part of the borehole below the repository is given the properties of the surrounding media. In an E1 scenario, where pressurized brine is encountered below the repository, the lower borehole cells are specifically addressed in the model as described in the following paragraph.

The borehole plugs are degraded according to the following assumptions. The continuous plug, the surface plug, and the 40-m plugs below the repository will maintain their initial permeability of 5×10^{-17} m^2 throughout the 10,000-year regulatory time frame. The 40-m plug above the repository maintains its initial permeability of 5×10^{-17} m^2 for 200 years. The borehole between the plugs is assumed to remain open during this period and is assigned a permeability of 1×10^{-9} m^2. The casing is not specifically addressed in the long-term flow model and is assumed to not be present. After 200 years, the upper 40-m plug is assumed to fail and the entire borehole between plugs is assumed to have filled with a material with the properties of silty sand, whose permeability is sampled within the range of 1×10^{-11} m^2 to 1×10^{-14} m^2. Beginning 1,200 years after waste panel penetration, the permeability range of the filling material in the lower borehole below the repository is reduced by one order of magnitude to 1×10^{-12} m^2 to 1×10^{-15} m^2. The porosity of all borehole materials is held at a constant, conservatively high value of 0.32. Pore compressibility is assumed to be zero, giving the medium the approximate compressibility of brine. Two-phase brine and gas flow is modeled using a zero threshold pressure and zero residual brine and gas saturations.

The BRAGFLO model does not explicitly address the continuous plug configuration because the plug permeability is so low that flow is negligible. Under this configuration the borehole cells are given the material properties of the surrounding native materials. BRAGFLO also does not explicitly model the plugs beneath the repository. The plug at the base of the Castile is not modeled because it is considered as part of the impermeable lower boundary. The plug in the upper Castile/lower Salado, which is part of the three plug scenario, is not modeled because it results in conditions essentially equivalent to an E2 scenario in which pressurized brine is assumed to not be encountered in the Castile. If pressurized brine is not encountered in the Castile, the middle plug has negligible function regarding fluid flow in the repository. If pressurized brine is encountered, DOE assumes that the middle plug remains intact and provides an effective seal to brine flow from the Castile reservoir to the repository for the duration of the regulatory time frame. Thus, under either circumstance, the long-term repository fluid flow for the three-plug configuration would be essentially the same as the E2 scenario. Only the two-plug configuration is assumed by DOE to allow long-term releases from a Castile brine reservoir.

BRAGFLO input to performance assessment is accomplished through the use of reference conditions, eliminating the need to run BRAGFLO for each separate set of randomly occurring future intrusion events. Different sets of reference conditions are prepared from BRAGFLO results for each interface with other performance assessment models. For analysis of single exploration borehole penetrations, BRAGFLO is used to calculate cumulative releases over the 10,000-year regulatory time frame for four scenarios: an E1 intrusion at 350 years, an E1 intrusion at 1,000 years, an E2 intrusion at 350 years, and an E2 intrusion at 1,000 years. These calculations are accomplished by running the undisturbed case until the year of the intrusion, and subsequently modifying the properties of the borehole cells in the model over time, according to the degradation rate assumptions described above. The cumulative releases calculated in these runs are used as the reference conditions for analysis of long-term releases.

The reference conditions for long-term releases through exploration boreholes, thus, essentially consist of flow rates over time to the Culebra resulting from borehole intrusions at two specific times (350 and 1,000 years) for each type of intrusion (E1 or E2), and for each set of BRAGFLO parameter input values (that is, for each CCDF). These flow rates are used as input to the NUTS code to calculate cumulative releases to the Culebra. Flow rates (or cumulative releases) resulting from intrusions occurring at other times are determined from the releases computed for these two times by either correlation or interpolation. For intrusions occurring prior to 350 years, the release is assumed to be the same as at 350 years. For intrusions occurring between 350 and 1,000 years, the release is interpolated between the values for 350 and 1,000 years, and for intrusions occurring after 1,000 years, the release is assumed to be the same as at 1,000 years. For long-term release calculations, repository conditions are assumed to not change as a result of short-term releases, thus, repository fluid pressures and volumes are not reduced by the short-term losses.

3.12.2. Review of Criteria

3.12.2.1. Information Used to Develop the Conceptual Model

The principal elements of the conceptual model were developed by DOE in compliance with EPA requirements as summarized in Section 3.12.1 (40 CFR 194.33, Consideration of Drilling Events in Performance Assessments). Pursuant to this regulatory guidance, current borehole drilling, casing, and plugging practices were reviewed by DOE for hydrocarbon exploration boreholes in the Delaware Basin and this information was used as the basis for determining drilling frequencies and methods during the

regulatory time frame. Although documentation of these studies was not reviewed by the Panel, the approach taken appears to have provided a reasonable and appropriate response to the regulatory requirements.

3.12.2.2. Validity of Model Assumptions

The principal assumptions used to develop the model are identified in Section 3.12.1, and are critically reviewed here. Most assumptions are reasonable and appropriate and include the limitation of intrusion to hydrocarbon exploration drilling, use of the BRAGFLO code to simulate release, degradation of the continuous and upper cement plugs, degradation of the casing, permeability reduction in the borehole below the repository due to creep closure, and the assumptions used in modeling the continuous plug configuration. DOE's analysis of current drilling practices in the Delaware Basin, and the drilling frequency and plugging practice information developed from that analysis, are not considered to be conceptual models and were not reviewed by the Panel. An adequate technical basis for estimating the probability of encountering a pressurized brine reservoir in the Castile was not provided to the Panel and is addressed as an issue in Section 3.16 of this report. The method selected by DOE for randomly sampling borehole plugging configurations was also not available for review by the Panel and is not addressed here.

Several simplifying assumptions have been made by DOE that appear to be conservative and therefore acceptable for use in performance assessment. These include neglecting the effects of drilling mud loss into the repository at the time of penetration by an exploration borehole. The drilling mud would likely be a dense, low permeability, water-based brine weighted with bentonite or other additives that may partially fill available repository pore volume, reduce repository permeability, inhibit chemical degradation of the waste by limiting brine availability, and provide additional sorptive capacity for radionuclides. Although the mud could result in other, unforseen chemical reactions with the waste, the overall effect of drilling mud loss into the repository is expected to be beneficial.

The annular space between the borehole plugs is assumed in modeling to be open hole, but according to Thompson et al. (1996, p. C-3), standard practice in the Delaware Basin is to fill this space with a dense plugging mud that provides a platform for setting internal concrete plugs and remains as part of the plugging system. This mud is expected to have a low permeability and may be sufficiently dense to reduce long-term fluid movement through the sealed boreholes between the repository and a partially depressurized Castile brine reservoir. Ignoring this plug in the model may be overly conservative.

The range of permeabilities representative of a silty sand was checked against ranges given in three standard texts, and the results are tabulated below. As can be seen in Table 3.12.1, the values used in performance assessment are neither the highest nor the lowest and are appropriate.

Table 3.12.1. Range of Permeabilities

Source	Medium	High End Value (m^2)	Low End Value (m^2)
Freeze and Cherry 1979, p. 29	Silty Sand	1×10^{-10}	1×10^{-14}
USBR 1987, p. 98	Silty Sand	1×10^{-12}	1×10^{-17}
de Marsily 1986, p. 78	Fine Sand, Silt, Loess	1×10^{-12}	1×10^{-16}
WIPP Performance Assessment 1996	Silty Sand	1×10^{-11}	1×10^{-14}

The frequency of waste panel penetration by exploration boreholes is expected, on the average, to be about 6 penetrations per 10,000 years. This value is based on a waste panel target area of 0.125 square kilometers, which is the approximate area of the disposal rooms themselves and does not include the disturbed rock zone in the walls of the waste panel excavations. This disturbed zone will be fractured by spalling and halite creep and may have sufficient permeability to permit long-term hydraulic communication with the repository. Ignoring this zone in performance assessment reduces the effective area of the waste panels and decreases the frequency of penetration. This issue is discussed further in Section 3.15.

The exploration borehole is assumed by DOE to penetrate the repository within a waste panel. Although such a penetration would be expected to result in the greatest release potential, penetrations could also occur within the operations and experimental areas of the repository, where the greater area of excavations would lead to an increased frequency of penetration. Under long-term flow conditions, pressure is expected to equilibrate quickly throughout a sealed repository by relatively rapid gas movement, and advective brine movement may be small because of the low hydraulic gradients. Penetration of the operations and experimental areas could lower gas pressures throughout the repository, which is expected to be a beneficial result. Diffusive movement of dissolved radionuclides, however, could occur through the panel seals, allowing radionuclides to migrate into the other parts of the repository and be available for release through an exploration borehole. Also, an exploration borehole penetrating the operational area and pressurized brine in the Castile could release Castile brine into the operational, experimental, and waste panel areas and pressurize the entire repository.

Borehole plugs below the Salado are assumed by DOE to not degrade within the 10,000-year regulatory time frame. This lack of degradation is related to suppression of anoxic corrosion reactions, primarily by high hydrostatic pressures in the borehole, and preservation of the concrete plug by the longer term confinement offered by the casing (Thompson et al. 1996, Chapter 3). This approach is based on thermodynamic data and assumes that carbon dioxide and hydrogen disulfide will passivate and reduce the corrosion rate of steel surfaces, and that the buildup of hydrogen fugacity from the corrosion reaction will cause the conversion of iron to $Fe(OH)_2$, to cease at a pressure of about 45 atmospheres (4.5 MPa). Such a pressure is believed to prevent hydrogen bubble nucleation and loss of hydrogen from the chemical system and could be provided by brine inside the casing (Thompson et al. 1996, p. B-21). In the analysis of steel corrosion in the gas generation conceptual model, the DOE indicated that the hydrogen fugacity that would stop corrosion to $Fe(OH)_2$ was 70 atmospheres (7.0 MPa) based on another set of thermodynamic data, but that the corrosion reaction could not be counted on to stop at that pressure because the reaction could convert to Fe_3O_4 and continue until a pressure of perhaps 500 atmospheres (50 MPa) was reached. At these higher pressures, hydrogen bubble formation and loss from the system could occur down to the depths of the plugs below the repository, potentially resulting in their failure during the 10,000-year regulatory time frame. The potential for such failure is also indicated by Thompson et al. (1996, p. 17), where the two lower plugs are given median lives of about 5,000 years and a range of 500 to 50,000 years. The validity of DOE's assumed plug life in excess of 10,000 years is questioned in light of these alternative observations.

If the borehole plugs beneath the repository fail during the 10,000-year regulatory time frame, the role of Bell Canyon groundwater may become important. As previously noted, all exploratory boreholes are assumed to be drilled in search of hydrocarbon resources and all are therefore assumed to penetrate entirely through the Salado and Castile Formations into the Bell Canyon Formation. Although only about 10% of the holes drilled through the waste panels are assumed by DOE to encounter pressurized brine, 100% of the holes will penetrate the Bell Canyon and the plugs below the repository may be significant in isolating the repository from the Bell Canyon. Water pressure in the Bell Canyon is reported in Lappin and Hunter (1989, p. 3-151) to be insufficient to cause water to flow from the Bell Canyon to the Culebra in an uncased or leaky casing borehole if the increase in water density from salt dissolution in the Castile or Salado were considered. However, the potential for water movement to or from the repository horizon was not discussed. If borehole plugs below the Salado cannot be assumed to

have functional lives exceeding 10,000 years with a high degree of certainty, the validity of the assumption that Bell Canyon groundwater can be ignored in the performance assessment analysis may be erroneous.

The assumption in BRAGFLO that the lower plugs need not be explicitly modeled in performance assessment may be valid only if the assumption that they will remain viable during the 10,000-year regulatory time frame is valid. Failure of the lower plugs would provide a low-permeability pathway among the repository, the Bell Canyon, and any pressurized brine that may be encountered in the Castile. If a lifetime in excess of 10,000 years cannot be adequately supported, flow through the lower plugs may have to be explicitly modeled in BRAGFLO.

The three-plug configuration is assumed by DOE to cause an E1 scenario to be equivalent to an E2 scenario by eliminating effects on the repository of encountering pressurized brine in the Castile. The rationale for this assumption, as summarized in Section 3.12.1, does not appear to consider the potential for Castile brine to enter the repository during drilling before the hole is cased through the Salado and Castile. Such an event could increase the brine saturation in the penetrated waste panel, and affect subsequent waste corrosion and gas generation rates. Such a scenario would occur before the plugs were emplaced and thus would be independent of plug degradation rates.

The use of reference conditions, rather than direct model results, as the final input for performance assessment calculations is acknowledged to be a necessary simplification given the thousands of model runs that are necessary to produce stable CCDFs; however, the sensitivity of the current performance assessment inputs to the assumptions inherent in this approach have not been presented to the Panel. The validity of this approach is of concern, particularly when only two release values (those at 350 and 1,000 years) are used to determine releases over a 10,000-year period. Sensitivity studies performed during earlier performance assessments showed this approach to be valid (see, for example, Helton et al. 1992); however, similar studies have not been performed to help assure the validity of this approach for the current performance assessment model.

3.12.2.3. Evaluation of Alternatives

The overall Exploration Borehole conceptual model has evolved over time along with the Repository Fluid Flow model, and has been the subject of extensive sensitivity studies in previous draft performance assessments as noted above. Based on these studies, the overall conceptual model has been shown to be

adequate; however, the validity of certain assumptions regarding components of this model has been questioned as described in Section 3.12.3.2. These include: alternative borehole penetration locations in the repository; allowing for a more rapid degradation of borehole plugs below the repository horizon (including the effects of Bell Canyon groundwater and explicitly including borehole plugs below the repository horizon if adequate longevity of the lower borehole plugs cannot be reasonably assured); reevaluating effects on the repository from an E1 borehole and a three-plug configuration; and assessing the adequacy of the selected reference conditions.

3.12.2.4. Uncertainties

The principal uncertainties in model results are expected to stem from uncertainties in the parametric data base, in the performance of the borehole plugs, and in the accuracy of the reference condition approach to final performance assessment modeling. The principal uncertainties in the parametric data base are associated with the hydrologic properties of the repository materials and are addressed in Section 3.3, Repository Fluid Flow. The hydrologic properties of the seal materials are generally better known and have less uncertainty. Those parameters with the greatest uncertainty, such as the permeability of the silty-sand-like material derived from corrosion products that fill the borehole, are generally sampled from a range of values and their uncertainty is thereby reflected in the overall modeling results. The consequence of uncertainties in these parameters is ultimately to overestimate or underestimate radionuclide releases; however, many of these parameter values reflect best estimates of future conditions and are appropriate for use in performance assessment despite their high degree of uncertainty.

Uncertainty in the performance of the borehole plugs below the repository horizon is discussed in the preceding sections. Plug failure within the regulatory time frame could result in the need to explicitly model the plugs in BRAGFLO, and to consider the effects of a low-permeability pathway to the Bell Canyon Formation on flow into and releases from the repository.

The accuracy of the reference condition approach to final performance assessment modeling has not been demonstrated to the Panel. If sensitivity studies indicate that the present method is inadequate, a denser lookup table may be needed, consequently requiring more computer time to prepare the performance assessment.

3.12.2.5. Adequacy of the Conceptual Model

The conceptual model for exploration boreholes is fundamentally sound, and the issues raised in the validity of model assumptions (Section 3.12.2.2) are associated with specific, but potentially significant, details of the model. The adequacy of the current model is not known because of the unresolved issues identified in Section 3.12.3.3. Further information is required to determine, for example, whether modeling results are sensitive to exploration boreholes that penetrate the operations and experimental areas of the repository, or to the presence of a low permeability pathway to the Bell Canyon Formation. Such changes would affect both the conceptual and numerical models. With appropriate resolution of the issues raised in this report, the adequacy of the current model would be acceptable.

3.12.2.6. Adequacy of Application

With the exception of the issues raised in Section 3.12.2.2 regarding model assumptions, the application of the conceptual model in the numerical models is adequate. Principal concerns are related to limiting borehole penetrations to the waste panel rooms, assuming no degradation of the lower borehole seals and, therefore, not explicitly modeling them or the Bell Canyon groundwater, and demonstrating the adequacy of the limited reference conditions used to provide input to the performance assessment.

3.12.2.7. Accuracy of Results

Individual parameter values supporting the conceptual model were checked and found to be reasonable. The modeling results were not available for review and could not be checked; however, those areas where the modeling approach is questioned and could lead to inaccurate results have been identified as issues in this report.

3.12.2.8. Validity of Conclusions

The validity of the conceptual model is uncertain pending resolution of the issues raised in Section 3.12.2.3. In summary, the following concerns remain.

- *The potential for releases or changes in repository conditions from borehole penetrations in* the operations and experimental areas of the repository does not appear to have been evaluated. Radionuclides that may have migrated into those areas through the panel closures, by diffusion or other transport mechanisms, could be released to the ground surface, gas pressures could be relieved, and brine could migrate into those areas and then into the waste panels from a borehole penetrating a Castile reservoir or through degraded plugs from the Bell Canyon.

- The assumption that shorter (40-m) borehole plugs beneath the repository horizon will not significantly degrade during the 10,000-year regulatory time frame has not been adequately supported. For the two- and three-plug configurations, degradation of these plugs could result in creation of a low-permeability pathway for fluid migration between the Bell Canyon and the repository. For the three-plug configuration, degradation could result in increased fluid migration from a Castile brine reservoir to the repository.

- The possibility that an effect on the repository could result from Castile brine encountered in an E1 borehole that is assigned a three-plug configuration does not appear to have been considered in the conceptual model. Castile brine could enter the repository during drilling before the borehole is cased and result in increased rates of corrosion, waste degradation, and gas production.

- The sensitivity of the performance assessment to the simplified approach taken to determine reference conditions for BRAGFLO output does not appear to have been evaluated for the current model configuration. If reference conditions are not provided at sufficiently frequent time intervals, the modeling results may be erroneous.

3.12.2.9. Adequacy for Implementation

The Exploration Boreholes conceptual model is not currently adequate for implementation because of the validity issues raised in Section 3.12.2.8. The conceptual model would be considered adequate for implementation if the validity issues were successfully resolved.

3.12.2.10. Dissenting Views

There were no dissenting views for this model.

3.13. Cuttings/Cavings

3.13.1. Model Description

The Cuttings/Cavings conceptual model describes releases during drilling of exploration boreholes. It is one of several models that address the calculation of direct waste release to the ground surface if an exploration borehole inadvertently penetrates a waste panel, creating a possible pathway for transport of waste to the surface. Other associated models include those describing Exploration Boreholes, Repository Fluid Flow, Multiple Intrusions, and Spalling.

Of the possible pathways for release during the regulatory time frame, one of the most important is that caused by the inadvertent penetration of a waste storage room by an exploratory borehole. Normal oil and gas drilling practices can provide a means for waste to be released to the ground surface in the circulating drilling fluid (mud). From this intrusion, three mechanisms used by WIPP for waste

movement are cuttings, cavings and spallings. Cuttings are waste particles released into the mud from the cutting action of the drill bit itself and from mechanical friction. Cavings are waste particles released by erosion of the borehole walls due to circulating drilling fluids. Spallings are those particulate materials removed and transported by the movement of gases.

The cuttings mechanism is the easiest to address because the volume of waste cuttings is a simple product of the borehole cross sectional area times the room height, and is equal to the waste volume produced by the drill bit moving through the waste. Cavings is somewhat more complicated as it must incorporate the erosional effects of the shearing action of the drilling mud as it moves up the borehole annulus. This shearing may be caused by either turbulent or laminar flow. Repository pressure can have effects on cavings, which is covered by the spalling process. Spallings will be discussed further as a separate model in Section 3.14.

Details of the Cuttings/Cavings model were in a state of flux at the time of this peer review and information describing the model was obtained from various sources, but mainly from the CUTTINGS_S User's Manual, several draft reports, and from numerous contacts, presentations, and discussions.

Releases of cuttings and cavings are calculated using analytical equations governing erosion by flow up through the hole bored in the waste room, based on laminar and turbulent flow (Bergland 1992) as implemented by the CUTTING_S code. This code calculates the final caved diameter of the borehole that passes through the waste by using appropriate input based on assumed physical properties of the waste and drilling parameters. Although DOE is continuing to question whether the flow of the drill mud is laminar or turbulent, and what the parameters should be, the basic model has been generally accepted. However, the amount of material predicted to be released by cavings can be small per penetration and, therefore, its contribution to surface release has not been considered critical relative to other contributions.

The WIPP repository will consist of a number of waste disposal rooms excavated in bedded halite (salt) approximately 650 m below the ground surface. Transuranic waste packed in 55-gallon drums or standard waste boxes will be placed in each room. The waste is expected to be slowly compacted vertically by salt creep, from an original waste room height of 4 m to a compacted height of 0.5 to 2 m in approximately 100 years. In unmodified form, the waste consists of a mixture of, for example, contaminated cloth, wood, rubber, plastics, metals, glass. After placement in the repository, the waste

may become exposed to brine, which is expected to corrode the metals and generate hydrogen gas. Additional gas may be generated by the biodegradation of the organic materials. The gas volumes generated by corrosion and biodegradation are expected to increase continuously for hundreds of years and the pore pressure may become very high, possibly exceeding the lithostatic overburden stress. At some time within the 10,000-year regulatory period, it is probable that one or more exploration boreholes will be drilled into and through the vertically compacted waste and some of the waste will be carried to the surface. The volume of waste removed to the ground surface will depend on the physical properties of the compacted, decomposed wastes, the drilling procedures used, and the pressures encountered. The radioactivity of this waste is determined probabilistically, based on the distribution of waste radioactivity expected in the WIPP repository.

3.13.2. Review of Criteria

3.13.2.1. Information Used to Develop the Conceptual Model

Because the Cuttings/Cavings model is highly dependent on the borehole drilling process, it is important to understand the procedures used in drilling a gas or oil well. The current performance assessment model relies on the regulatory imposed assumption that future drilling techniques will be similar to those used today. When drilling commences, a conductor pipe is set in cement to prevent surface materials from sloughing into the wellbore during later drilling. Drilling is continued to the top of the salt section, using a large-diameter drill bit, where another steel casing is set. This "surface" casing is grouted into the hole and a blowout prevention tree is attached to the casing at the surface level. Drilling in the salt section uses drilling mud mixed in saturated brine to prevent dissolution of the salt.

Drilling mud is pumped from the reserve pit down through the drillpipe and drill bit, and up the annulus formed by the drill string and drilled hole. While drilling in the salt section, no formal attempt is made to monitor the character of the cuttings or the fluid volume of the reserve pit. (In the WIPP intrusion case, this can be an important input.) The drill string generally consists of a drill bit attached to long drill collars (heavy pipe) with a smaller outside diameter than the bit but a larger diameter than the following multiple sections of 4-1/2" diameter drillpipe. Once the drill has passed the salt section (1,375 m), the hole is again cased with cemented pipe. At this point, if the repository had been penetrated, no further contact would occur between the drilling mud and exposed WIPP waste.

Cuttings are a component of the direct brine release model, and cuttings releases are assumed to be the only drilling release to occur for repository pressures less than the hydrostatic pressure of the drilling mud (approximately 8 MPa). Because the volume of cuttings removed and transported to the surface is equal to the product of the drill bit cross sectional area, drill depth and waste porosity, it is only necessary to know these three parameters. The cuttings volume calculated becomes the lower bound to the total quantity of waste removed by drilling. The computation of cuttings release in the CUTTINGS_S code is performed within a module specific to cavings.

For the cavings part of the Cuttings/Cavings model, the erosion process is assumed to be driven solely by the shearing action of the drilling fluid (mud) on the waste as it moves up the borehole annulus between the drill pipe and the waste. For the purpose of the cavings calculations, it is further assumed that the repository is not excessively pressurized by either brine or gas (i.e., the repository pressure is less than the hydrostatic pressure of a brine column to the surface). In the annulus formed by the collars or drill pipe and the borehole wall, the flow of the drilling fluid has both a vertical and rotational component. This helical flow pattern generates shear stresses by the relative motion of adjacent fluid regions and by the action of the fluid on the borehole wall. It is assumed that if the fluid shear stress at the wall exceeds the effective shear resistance to erosion of the wall material (compacted repository wastes), erosion of the wall material will occur, increasing the diameter of the bored hole. The eroded material then will be carried onto the surface, entrained in the flowing drilling fluid. The code probabilistically determines the amount of material removed by the several release mechanisms, and decays the radionuclides release to simulate the source term at the time of intrusion.

3.13.2.2. Validity of Model Assumptions

Many of the principal assumptions used in developing the model are identified in Section 3.13.1. Overall, the assumptions are found to be reasonable and appropriate. Identification of and expansion on the key assumptions are discussed below.

The concept of release due to borehole drilling relies heavily on the assumption that future drilling techniques will be similar to those in use today. The basics of the drilling process are as outlined in Section 3.13.2.1, which comes from a large, well-tested body of experience that can be expected to be reliable.

It is implicitly assumed that the drillhole will encounter waste only as it penetrates the room. This is a simplifying assumption that is realistic but does not have to be absolute. For example, there can be a DRZ over the repository that could contain contaminated brines.

For this model it is assumed that the waste volume is probabilistically determined for each penetration. The Curie calculations are a direct computation from the amount of waste removed.

The cuttings portion of the waste material removed is assumed to be strictly the result of the neat volume of material cut away by action of the drill bit. The cavings portion accounts for the other mechanisms that complement the drilling action, such as frictional drill fluid erosion. These definitions of waste source from this model are inclusive and adequate.

It is assumed by the cavings portion of this model that the fluid shear stress at the waste surface must exceed the effective shear resistance of the waste wall for any release. This is valid since erosion occurs, increasing the diameter of the borehole with the eroded material being carried away by the circulating drilling fluid.

The equations governing waste erosion are based on laminar and turbulent flow, both of which are assumed to occur, depending on the velocity.

Among the basic assumptions made for the fluid flow calculations is that, in the absence of experimental data, the effective shear resistance to erosion of the repository waste is similar to ocean bay mud or montmorillonite clay. In the absence of accurate waste characterization or knowledge of the form this waste is in as the time of intrusion, this assumption appears appropriate because of the low shear strengths of these substances.

3.13.2.3. Evaluation of Alternatives

Only one issue is identified for which an alternative might be considered. It is a possibility that the environment for cuttings and cavings will be saturated with brine. If this becomes the case, this brine might be removed by the drilling action without the benefits of erosion or cuttings. This scenario does not appear to have been incorporated in the Cuttings/Cavings model and its significance is not known.

There are no meaningful alternatives for the cuttings and cavings model, except perhaps to consider using a finite fixed assumed input value, which would be more arbitrary.

3.13.2.4. Uncertainties

Several factors contribute to model uncertainty, principally the undefined nature and complexity of the waste, both in its initial and altered states. Information as basic as granular state, chemical form, decomposed form, density, and waste strength, is unconstrained. To conservatively treat these unknowns, property values of surrogate materials are selected to represent the worse case. As such, the accuracy of the model should be realistic, but on the conservative side. Uncertainty also may arise from inappropriate applications of turbidity resulting from assumptions in turbulent flow, which is a function of the Reynolds Number data on the transition from laminar to turbulence of the fluids. Within the full scope of exposure, however, any reasonable variation from probable waste volume removed would be confined to a restricted, relatively small volume and would not appear to lead to any significant consequences per penetration.

3.13.2.5. Adequacy of the Conceptual Model

This model is fundamentally appropriate. It is based on straightforward analysis, concepts, and technology that is well developed and believed to be adequate for depicting that part of the consequences of a waste room penetration by a borehole drill that is covered by this model.

3.13.2.6. Adequacy of Application

The CUTTINGS_S model contains well thought out and evaluated mathematics, based on researched and established fluid flow technology and science. The FORTRAN computer codes used to simulate the laminar helical flow in an annulus are documented and verified against published results. For turbulent flow, the results are highly dependent on the parameter values. The values given in the CUTTINGS_S User's Manual have resulted from significant research and are believed to provide adequate solutions. The turbulent flow is found to be dependent on absolute surface roughness and the value chosen for the calculation exceeds that of very rough concrete or riveted steel piping. As a result of these considerations, the Panel believes this model is adequate for application.

3.13.2.7. Accuracy of Results

The parameters for calculations were checked as presented in the CUTTINGS_S User's Manual and found to be appropriate. The drilling parameter values were obtained from surveying industry practices and as reported, the values are appropriate for a range of customary industrial size dimensions.

3.13.2.8. Validity of Conclusions

Physically, the conceptual process of this model is simple and valid. Some subjectiveness of validity exists in the questions of turbulent or laminar flow and the state of the waste for determining its resistance to removal by the caving process. The conservative values used in the calculations appear to alleviate these concerns, however. Therefore, the validity of this conceptual model appears to be acceptable within the uncertainties discussed in Section 3.13.2.4.

3.13.2.9. Adequacy for Implementation

This model is sufficiently developed and uncomplicated that no serious concerns were raised. The model appears to be capable of accurately representing the waste that might be removed during a drilling intrusion and is fully adequate for implementation in support of the WIPP performance assessment.

3.13.2.10. Dissenting Views

There were no dissenting views for this model.

3.14. Spallings

3.14.1. Model Description

The Spallings conceptual model is one of several that address the calculation of direct waste release to the ground surface if an exploration borehole penetrates a waste panel. Other associated models include Cuttings and Cavings, Exploration Boreholes, Repository Fluid Flow, and Multiple Intrusions.

Spallings are the particulate materials introduced into drilling mud by the movement of gas from the waste into the borehole annulus. At one time, spallings were conceived to involve three mechanisms: blowout, stuck pipe, and gas-induced spall. Because the latter two were perceived to produce insignificant releases, DOE determined that this model would concentrate on blowout. The repository pressure domain, where spallings are applicable, is above the borehole fluid hydrostatic pressure because it can occur only when the repository gas pressure is capable of countering and reversing the mud-laden drilling fluid during the drilling process. When the drillhole annulus around the drill pipe is cleared of drilling fluid, it becomes a conduit for free release of repository gases.

The principal parameters in the Spallings model are the gas pressure, the volume of gas in the repository when it is penetrated, and properties of the waste such as particle diameters and resistance to erosion.

Because the release associated with spallings is sensitive to gas pressure in the repository, it is strongly coupled to the BRAGFLO-calculated conditions in the repository at the time of penetration. In particular, the spall release may be sensitive to whether the repository has been penetrated previously by another borehole.

3.14.2. Review of Criteria

3.14.2.1. Information Used to Develop the Conceptual Model

This model was based on information on drilling practices, dimensions, and characteristics of drilling equipment parameters, and standard models for gas flow, as well as results of a simple laboratory test to examine some aspects of the conceptual model. Details of the Spallings model were in a state of flux at the time of this peer review. Information describing the model was obtained from various sources, mainly from the CUTTINGS_S Users Manual, several draft reports, presentations, and numerous personal contacts and discussions.

Because this source of release is somewhat dependent on the borehole drilling process, it will be instructive to understand the procedures utilized in drilling an oil or gas well, which the EPA has directed to be the standard for WIPP characterization studies. As described in Section 3.13.2.1, drilling produces a borehole into the repository room by a bit-cutting process that produces rock fragments. The fragments are removed by circulating a mud-laden fluid down through the drill pipe and returning it up the annular space between the pipe and the hole wall. The hydrostatic pressure of this mud column must be kept in balance with the pressure at the drill bit location. When an imbalance from overpressure in the repository occurs unchecked, the mud flow on the return side will be accelerated and ejected from the hole, creating a gas vent to the repository. Until this sudden uncontrolled venting is brought under control, violent escape of gas from the repository is expected to carry with it some of the stored waste, discharging it at the well head on the ground surface. Once gases begin to vent up the drill hole, repository room pressure gradients generated by the penetration of the repository cause a flow of gas toward the borehole that fractures the waste material, permitting the escaping gas to flow within fractures rather than through a porous waste matrix. Consequently, the intrinsic permeability of the matrix does not restrict the gas flow. Gas flow velocity up the borehole is governed by the isothermal flow of gas in a long annular tube of a given cross sectional area, tube roughness, and gas pressure at the borehole entrance. The gas pressure at the borehole entrance to the repository can be assumed to be the initial gas pressure in the repository. The mass-flow rate of gas in the fractured waste at any radial cross section is

equal to the mass-flow rate up the borehole. Radial flow of gas within the fractures in the waste matrix erodes and widens the fractures. Erosion of the waste is assumed to occur if the fracture gas velocity exceeds a threshold velocity related to the terminal velocity of a waste particle at the fracture surface and to the cohesive strength afforded by moisture in the matrix.

A key part of the Spallings model is to determine how much of the waste will be lofted into the gas stream. With the uncertainty of the waste characterization (e.g., its state and chemical form), the premise that the spalling process is self-limiting is based on the assumption that particle movement will cease when the gas velocity, measured radially from the borehole axis, equals the critical entrainment velocity. All material close to the borehole is assumed to be eroded away and removed. A laboratory experiment was modeled to demonstrate a critical lofting velocity for sample materials as a function of particle size distribution. Different terminal velocities were associated with different particle diameters. Confirmative testing of the model was conducted with the standard that if the measured amount of lofted material was less than the predicted amount of erosion, the model was considered confirmed. Confirmation was not obtained because the tests showed the expected uniform gas flow through the waste was not occurring. Instead of a cavity forming around the borehole, flow channels formed that increased in width and length as erosion proceeded in the material. These results forced the latest iteration in the blowout model. The new model (WIPP PA User's Manual for CUTTINGS_S, Appendix A, Section 2.3.1.3), called the channel flow model, is the one used for CCA calculations, although it is the understanding of the Panel that the mechanisms of this model are yet to be confirmed.

A channel-flow mechanism in the model requires either precise definition of the number, geometric configuration, and location of all the channels before they form (which is not technically feasible), or scaling the model results in some manner to reflect the channeling process. The scaling method was adopted, adjusting the predicted releases to agree with experimental release observations in the laboratory test. This laboratory test was a simple, small-scale experiment that yielded useful insights, but it could hardly be an adequate representation of actual degraded waste materials. Although the uniform-flow model was independent of experiments, in the sense that release predictions did not require direct data from the tests, a coupling between experimental results and the model was necessary for scaling. This was accomplished by introducing certain experimentally determined scaling constants into the model (Lenke et al. 1996). Notwithstanding the use of these scaling factors, the model is based on well-defined first order physical principles and is applied to different gases and solid materials by prescribing well-defined material properties, such as particle size and density, viscosity, and cementation tensile

strength. The scaling factors are the only parameters of the model not directly related to geometry or material properties, but they are necessary to represent the way channels for gas flow are likely to develop.

3.14.2.2. Validity of Model Assumptions

It is assumed that the repository pressure domain is above the hydrostatic head of the drill fluid column. This is reasonable because technically, a blowout should not occur at a lower pressure.

A simplifying assumption is that the driller does not have signs of the impending penetration and is unprepared to react. Therefore, the blowout is likely to occur and may be difficult to contain. Because of this, it is assumed that the release will be process-limited rather than operator-dependent.

An implied assumption is that the surface of the cavity will be cylindrical in nature.

The model's limiting characteristic is achieved by the derived equation's function of gas velocity and waste strength. As the velocity declines, the limiting parameter becomes the property of waste strength. The use of this property is valid, but its value is subjective because of the unknowns and uncertainties of the waste itself. In fact, this property is a function of the source of waste strength, such as cohesion, adhesion, or cementation. Cementation from a salt crystallization process in the stored waste is currently being considered as a mechanism that provides a strength value for waste that might be easily validated.

At this writing, it is assumed that the latest CUTTINGS_S model assures that the model relies on channel flow instead of a uniform low porosity flow toward the borehole. It is of concern to the Panel that the *mechanisms of this assumption are yet to be confirmed.*

3.14.2.3. Evaluation of Alternatives

The Spallings conceptual model has changed several times during its development. Early model development focused on transient, unrestrained outgasing leading to the spall (dynamic fracture) of porous cohesive granular media (Berglund 1992, Section 3.3). An experimental program related to model development focused on almost instantaneous depressurization and was limited to a one-dimensional linear sample configuration. The pore pressures required to cause spall or dynamic fracture could be closely approximated using the tensile strength of the porous soil medium (Berglund and Lenke 1995), but the model was complex and could not be directly related to an intrusion event. In addition, although the experimental observations showed fracturing under instantaneous release of gas pressure,

sample-preparation factors were largely responsible for the locations of the fractures. The fracture patterns also depended on the one-dimensional nature of the experiments, and the model did not adequately explain how the fractured material was removed.

After extensive discussion, the dynamic fracture model was replaced with a more general three-part model based on the premise that the waste could be removed by any one of three mechanisms: blowout, stuck pipe, and gas-flow assisted erosion (as the result of gas-induced spall) (Butcher et al. 1994). Which mechanism will dominate depends on the permeability and pressure drop at the borehole. Well blowout, an uncontrolled gas release from the borehole, was considered the dominant mechanism. The remaining two mechanisms, stuck pipe (waste loosened and moved while attempting to dislodge a stuck drill pipe), and gas-flow assisted erosion, were not thought to be important because they would only occur at waste permeabilities of less than 1×10^{-16} m^2. The gas-flow assisted erosion is now the basis for the channel flow modeling in the Spallings model.

3.14.2.4. Uncertainties

Development of this model is not sufficiently complete to determine uncertainties specific to the channel flow movement of waste to the existing borehole. The lack of adequate waste characterization may also provide a set of uncertainties. Other uncertainties concern the state the waste is in at the time of intrusion, which may not be feasible to ascertain.

3.14.2.5. Adequacy of the Conceptual Model

The Spallings model gives a good conceptual view of how solid waste can be removed by gases that are being rapidly vented. The latest model is most realistic mechanistically because it is predicated on the concepts of moving particles via gas movement. The original model, which relied on instantaneous decrease in gas pressure, was judged by DOE to be unrealistic because of waste permeability and gas flow considerations. The latest model appears to be the most applicable of those that have been considered to date. Notwithstanding the need for establishing two scaling parameters and a waste strength factor, this model is conceptually appropriate, but the Panel could not find sufficient information to determine its adequacy.

3.14.2.6. Adequacy of Application

Integration of the Spallings model into the CUTTINGS_S code is a relatively simple exercise, although the equations governing the waste availability for removal do not appear to be fully developed at this

time. While the concept of scaling parameters, which are intended to address waste strength by providing factors of resistance to erosion or lofting, is appropriate, the proposed parameter value has yet to be validated. Therefore, until these details are resolved, it will not be possible to assess the adequacy of application for this model.

3.14.2.7. Accuracy of Results

On testing the latest modeling efforts for confirmation of principle, additional information was gained that should be pursued before further confirmation is sought. It seems plausible that the performance assessment exercise might use an assumed entrained waste content for a given time period and sample several scenarios for concentration and time domain. Another simplistic approach might be to assume a certain waste volume around the borehole that would be removed. Given the importance to overall performance assessment of results from this model, any laboratory tests could be supplemented by a scaled-up testing demonstration that will more convincingly verify the model. At this time there is not enough information to determine the accuracy of results from the Spallings model.

3.14.2.8. Validity of Conclusions

In the opinion of the Panel, the model development is now on an appropriate path to produce a valid outcome. However, the available information was not sufficient to present a compelling argument that adequate work has been done to confirm that the conclusions would be valid. Additional testing is required to firm up the conceptualization of the channel flow scenario.

3.14.2.9. Adequacy for Implementation

Because of perceived inability to defend a time limit for release, it became necessary to implement a model that provides a self-limiting process for waste removal. It is not reasonable to expect that the entire room would be excavated by the blowout process. If this were possible, a model would not be necessary. Because of its unconfirmed state of development, this model is not adequate for implementation at this time.

3.14.2.10. Dissenting Views

There were no dissenting views for this model.

3.15. Direct Brine Release

3.15.1. Model Description

The Direct Brine Release conceptual model describes short-term releases of brine from exploratory boreholes that penetrate waste panels in the repository. The model addresses releases from both single and multiple intrusions. Long-term flow from single intrusions and the assumptions regarding the physical aspects of the boreholes are addressed in the Exploration Borehole conceptual model, and long-term flow from multiple intrusions is addressed in the Multiple Intrusions conceptual model. Other related models include Repository Fluid Flow, Castile and Brine Reservoirs, and Actinide Transport in the Salado. The related Cuttings/Cavings and Spallings models address releases of solid waste materials following borehole intrusions, but do not address brine releases. The details of the Direct Brine Release model were still under development at the time of this peer review, and information describing the model was obtained from a variety of final and draft reports and memoranda, and from verbal descriptions provided by DOE. The following model description was prepared from information presented in the 22 May 1996 Draft CCA, Sections 6.4.7.1, Releases During Drilling (DOE 1996, pp. 6-65 to 6-70), from verbal descriptions, and from the cited references.

Releases that may occur during and immediately following drilling are modeled in accordance with regulatory guidance, assuming that present standard rotary drilling practices will be used. This assumption was used by DOE to establish borehole geometry during drilling, as well as the drilling, casing, and sealing practices (Thompson et al. 1996). To help prevent blowout, the density of the drilling mud is controlled by drillers based on the fluid pressures expected at the drilling depths. Gas, as well as brine, may enter the borehole from the waste panel if the driller is unable to control the pressure in the borehole. If fluid pressures in the waste panel are sufficiently high, brine or a brine-gas mixture may flow to the ground surface. The boreholes are assumed to be cased from the ground surface to the lower Rustler before entering the Salado; thus, brine flowing up the borehole during drilling would reach the surface, but not enter the Culebra or the other permeable horizons above the Salado. The frequency with which exploration boreholes will penetrate the waste panel area is estimated based on a long-term average of 47 boreholes per square kilometer per 10,000 years, and the size of the waste panel area. This is further discussed in Section 3.12.

Before brine can flow from a waste panel to the ground surface, mobile brine must be present in the waste panel and the pressure of the brine must be greater than the pressure of the drilling mud at the repository depth. Brine is expected to enter the waste panel as seepage from the surrounding halites, anhydrite beds, and through the shaft seals, and will also enter if pressurized brine is encountered in the Castile. Mobile brine will be present in the waste panel if it has not been previously consumed by the corrosion reaction and if there is enough remaining to exceed the residual brine saturation of the waste. The residual brine saturation is the percent saturation below which the brine occurs discontinuously in the porous waste and will no longer move. The residual brine saturation in the waste panel is uncertain and is randomly sampled in performance assessment from the range of zero to 0.552 (DOE 1996, Table 6-6). The drilling mud is assumed to exert a pressure of about 8 MPa at the repository horizon; thus, for brine to be released to the ground surface its pressure in the repository must exceed this value.

In accordance with regulatory guidance, DOE does not assume that a direct brine release would be noticed by the driller, or that the driller is aware of the presence of the repository. The driller is assumed to be exploring for hydrocarbon resources, and after taking normal steps to deal with any brine releases or drilling fluid losses at the repository horizon, would continue drilling to customary depths below the Bell Canyon. Based on a review of current practices in the Delaware Basin, DOE has assumed that direct brine releases to the surface will be stopped by the driller 44 hours after penetrating the repository. Borehole plugs are assumed to be installed in three alternative configurations, and to degrade as discussed in Section 3.12. Because of the assumed degradation rates of the various plugs, only the two-plug and three-plug configurations are of consequence to direct brine releases.

Encountering pressurized brine in the Castile in a borehole is not considered by DOE to result in a direct release of repository waste. The Castile brine will be uncontaminated and, to result in a direct release, would have to be of sufficient pressure to eject the drilling mud from the borehole. Because the repository is likely to have been depressurized a short time before when it was penetrated by the same borehole, the repository pressure is expected to be lower than the Castile brine pressure and initial hydraulic gradients would be from the borehole into the repository. The longer term migration of Castile brines into the repository are addressed in the long-term BRAGFLO calculations and would affect both the long-term releases and the initial conditions (such as waste panel brine saturations and gas pressures) for the next short-term release. Direct release of waste solids by borehole wall erosion from Castile brine moving up the borehole is assumed by DOE to be negligible.

Short-term releases of dissolved or suspended radionuclides contained in brine are modeled using a two-dimensional, two-phase, transient horizontal plane model of the waste panel area, developed using the BRAGFLO code specifically for estimating short-term, direct brine flow. This model has not been specifically named, and for purposes of this report will be called the BRAGFLO-DBR model. Radionuclide transport is calculated using the PANEL code. This code conservatively assumes complete mixing in the waste panels and is further discussed in Section 3.8. BRAGFLO-DBR explicitly models all disposal rooms, pillars, panel closures, and the associated disturbed rock zone within the waste disposal area of the repository.

A one-degree dip in the repository corresponding to the average one-degree dip to the south in Salado bedding is included in the model. Including this dip has been found to be important in modeling results because of the effects of gravity. Gas movement in the anhydrite beds tends to be to the north toward areas of lower pressure, while brine tends to accumulate in the southern or lower end of the waste disposal area. Material properties in BRAGFLO-DBR are generally consistent with those in the standard version of the BRAGFLO model (called BRAGFLO in this report) used to model repository fluid flow (Section 3.3), with the exception that the intact Salado halite is assumed to be impermeable and forms an outer no-flow boundary for the model.

BRAGFLO-DBR takes its initial and boundary conditions from BRAGFLO, CUTTINGS_S, the WIPP data base, and an analytical correlation to simulate flow up the open borehole. Fluid pressures, saturations, permeabilities, porosities, two-phase flow properties, and other repository properties are determined at the time of penetration by the standard version of the BRAGFLO code. The borehole flow model has been developed from a multi-phase vertical pipe flow analysis used in the petroleum industry. Total flux and transport are determined based on a flow duration of 44 hours.

For calculating short-term releases, borehole penetrations are assumed in BRAGFLO-DBR to occur in two reference locations, at an updip location in the center of the waste panel area, and at a downdip location in the southwestern waste panel. Multiple borehole penetrations of the same waste panel are always assumed to occur at the southwestern end of the repository because the reference conditions for multiple intrusions are developed from the standard BRAGFLO model, which conservatively places the single waste panel and intrusion borehole at the downdip end of the waste panel area. Actual intrusion locations are selected randomly, but the boreholes are then assigned standardized reference locations depending on whether they penetrate the waste or a salt column, whether they are updip or downdip,

whether they are E1 or E2, and whether they are the first intrusion or a subsequent intrusion of the same waste panel. Modeling results have indicated that the effects of borehole intrusions on the repository are not significant beyond the waste panel that was penetrated; thus, second and subsequent intrusions into the same waste panel are treated separately in the model.

For the first borehole penetration in a particular waste panel, the initial and boundary conditions are determined by interpolation from reference conditions determined from undisturbed BRAGFLO results at approximately six reference times ranging from 100 to 10,000 years. BRAGFLO-DBR is run for each of these sets of reference conditions to establish a data base for interpolating short-term releases from first penetrations occurring during the regulatory time frame. Conditions for first penetrations are assumed to be the same for E1 or E2 boreholes, because at the time of penetration neither would have been drilled past the repository. Initial conditions for downdip borehole locations are taken from conditions in the single waste panel in BRAGFLO, which is at the downdip end of that model. Initial conditions for updip borehole locations are taken from the "rest of the repository" in BRAGFLO, which is at the updip end of that model.

Conditions for second penetrations are determined based on the date, type, and location of the first penetration, as well as the date, type, and location of the second penetration. Different sets of reference conditions are established for second penetrations depending on whether the first penetration was an E1 or E2, whether the second penetration occurs in the same panel or a different panel, and the lag time between the first and second penetrations. Subsequent penetrations are addressed following similar logic. Reference conditions for second and subsequent penetrations are determined from BRAGFLO calculations for E1 and E2 intrusions occurring at 350 and 1,000 years, as described in Section 3.12.

Changes in repository pressure, fluid saturation, and other repository conditions resulting from the short-term releases are not considered in the long-term flow calculations. Such effects are considered negligible by DOE over the long term because of their transient and local nature.

3.15.2. Review of Criteria

3.15.2.1. *Information Used to Develop the Conceptual Model*

The Direct Brine Release conceptual model was developed based on a combination of conceptual models for repository design and two-phase fluid flow, the physical and hydrologic properties of Castile brine reservoirs, current drilling and borehole sealing practices in the Delaware Basin, fluid flow in open

boreholes, and borehole plug degradation rates. Current practice has provided elements of this model, in accordance with regulatory requirements. This information base is considered reasonable and appropriate.

3.15.2.2. Validity of Model Assumptions

The principal assumptions used to develop the model are identified in Section 3.15.1, and are critically reviewed here. Most assumptions are reasonable and appropriate and include the general approach taken to modeling fluid flow within the boreholes and repository, treatment of borehole sealing practices, and use of reference conditions to address alternative intrusion scenarios. The frequency of drilling and the time required for a driller to control a direct brine release are based on DOE analysis of current practice and are not reviewed here. Reference conditions for direct brine releases are determined at a greater frequency than for the exploration boreholes or multiple intrusions models, and are expected to be adequate for performance assessment. The assumptions related to repository fluid flow, the physical aspects of the boreholes and borehole seals, and the characteristics of Castile brine reservoirs are discussed in Sections 3.3, 3.12, and 3.16, respectively. Changes in these assumptions would affect the approach taken to model direct brine releases. Several assumptions in the Direct Brine Release model that are potentially important to radionuclide containment and are not adequately supported are discussed in the following paragraphs.

No radionuclide release is assumed to occur from direct discharge of Castile reservoir brine in a borehole penetrating a waste panel. The rationale for this assumption does not appear to be supported by an analysis of the potential for brine mixing and borehole wall erosion. This could be more significant for penetrations occurring before complete water panel closure, when waste has not yet been fully compacted. Because the Castile brine would pass directly through a waste panel, the potential consequences of an error in this assumption could be significant.

The potential for entraining waste room brine in rapid gas flow from the waste panel is not considered in the conceptual models for either spallings or direct brine release. The Spallings model considers only the entrainment of solid particles in single-phase gas flow, and the Direct Brine Release model considers only dissolved and colloidal radionuclide transport in brine released to the surface. Brine entrainment in the gas can occur by transport of droplets or, more importantly, by air-lifting brine and waste particulates in a closed-wall pipe (the coffee percolator effect). The air-lift is in fact a method of well completion

where the violent surges from air pumped down a well are used to scour the borehole production zone and remove fine-grained sediments to enhance well production. Depending on the flow velocity in this two-phase brine/gas system, the erosional forces could be greater than for either gas or brine flow alone.

Boreholes penetrating areas of disturbed rock in the walls of the repository excavations do not appear to have been considered in performance assessment modeling. The walls will have a tendency to bow inward under the lithostatic stress, resulting in both micro- and macro-fracturing in the halite. Hydrologic tests in repository walls have shown pore pressure depressurization and reduced permeabilities within 10 m of the workings, most likely in response to halite deformation. Within this zone, pore pressures appear to have dropped to near zero at some locations, and permeabilities nearly three orders of magnitude higher than the high end of the undisturbed halite range have been measured (Lappin and Beauheim 1996). Hydrofracture measurements in horizontal boreholes within the repository have indicated that stress effects from repository excavations may extend on the order of 50 m from the end of a drift (Wawerski and Stone 1986). Boreholes very near the excavation wall could, therefore, encounter open fractures and permeabilities equivalent to those of the waste, while boreholes 10 m or more from the excavation may encounter essentially undisturbed halite. The higher permeabilities encountered in boreholes penetrating the disturbed rock zone in the excavation walls could lead to increased short- and long-term releases.

3.15.2.3. Evaluation of Alternatives

The overall conceptual model for direct brine releases is based on standard hydrogeologic and petroleum industry practices and is appropriate for use in performance assessment. Alternatives to this model may be considered, however, in the details of its application. Three fundamental issues have been identified: waste transport during the direct release of Castile brine, the entrainment of brine and waste solids in two-phase gas/brine flow from the repository, and boreholes penetrating disturbed rock in the excavation walls.

3.15.2.4. Uncertainties

Uncertainty in model results stems from uncertainties in the validity of the underlying fluid flow theory and analysis methods, from uncertainties in the input data, and from the validity of assumptions regarding the conceptual models. The underlying theory is widely used in the petroleum industry for evaluating oil reservoirs and provides a reasonable and appropriate approach to studying direct brine releases. Although the uncertainty in the input data are occasionally high, the parameter values have

generally been appropriately selected for performance assessment. The three additional processes discussed in Section 3.15.2.2 are similar in that they each address processes that were not considered by DOE. The consequence of neglecting these processes is to potentially underestimate radionuclide releases.

3.15.2.5. Adequacy of Conceptual Model

The conceptual model for direct brine releases is fundamentally sound, with the possible exception of the three processes identified in Section 3.15.2.2. These processes were not included in the conceptual model for performance assessment, and if valid, could be important to cumulative radionuclide release. With appropriate resolution of the issues raised in this report, the adequacy of the current model would be acceptable.

3.15.2.6. Adequacy of Application

With the exception of the issues raised in Section 3.15.2.2 regarding model assumptions, the internal consistency of the conceptual model and its application in BRAGFLO-DBR is logical and is adequate for performance assessment. The simplifications required to model a complex set of conditions in an efficient manner appear to be appropriate.

3.15.2.7. Accuracy of Results

Individual parameter values supporting the conceptual model were checked and found to be reasonable. Although the modeling results were not available for review and could not be checked, the density of reference conditions is expected to provide performance assessment inputs of suitable accuracy.

3.15.2.8. Validity of Conclusions

The validity of the conceptual model is uncertain, pending resolution of the issues raised in Section 3.3.2.3. In summary, the following concerns remain.

- The basis for the assumption that radionuclides do not accompany the direct discharge of Castile brine has not been adequately supported. This assumption could lead to underestimating radionuclide releases if releases do, in fact, occur through this mechanism.
- Radionuclide transport through entrainment of brine and waste solids in rapid gas releases during inadvertent borehole intrusions does not appear to have been evaluated. This transport mechanism may be an important component of the conceptual model.

- Releases resulting from flow into an exploration borehole intersecting a disturbed rock zone in the wall of a waste panel do not appear to have been evaluated. Large, open fractures in the walls could significantly increase the local halite permeability, allowing gas and brine to migrate through the borehole to the ground surface.

3.15.2.9. Adequacy for Implementation

The Direct Brine Release conceptual model is not currently adequate for implementation because of the validity issues raised in Section 3.15.8. The conceptual model would be considered adequate for implementation if the validity issues were successfully resolved.

3.15.2.10. Dissenting Views

There were no dissenting views for this model.

3.16. Castile Formation and Brine Reservoir

3.16.1. Model Description

The Castile Formation and Brine Reservoir conceptual model addresses the hydrologic characteristics of the Castile Formation and the occurrence, size, hydrologic, and chemical characteristics of brine reservoirs that may underlie the repository within the Castile Formation. Associated models include Exploration Boreholes, Multiple Intrusions, and Repository Fluid Flow. The details of this model were still under development at the time of the peer review, and information describing the model was obtained from a variety of final and draft reports and memoranda, and from verbal descriptions provided by DOE. The following model description was prepared from information presented in the 23 May 1996 Draft CCA, Section 6.4.8, Castile Formation and Brine Reservoir (DOE 1996, pp. 6-75 to 6-79), from verbal descriptions, and from the cited references.

The Castile Formation consists of a 360-m thick series of halite and anhydrite beds underlying the Salado Formation. Although few tests have been performed, by analogy to the Salado, the Castile is conceptualized as a very low permeability formation whose primary importance to WIPP performance assessment stems from the hydrologic isolation it provides the repository and from the pressurized brine reservoirs that have been encountered during deep drilling.

Deep exploratory boreholes that penetrate both the repository and the underlying Castile Formation may encounter a pressurized, higher-permeability, brine-filled region called a brine reservoir. If encountered, the fluid pressure in such a reservoir would be sufficient to cause brine to flow at potentially high rates

and high pressures through the repository and from the wellbore at the ground surface. The consequences of such flow are addressed in the Exploration Borehole and Multiple Intrusion conceptual models.

The brine reservoir is conceptualized by DOE as a heterogeneous, discontinuously fractured zone of limited extent within the Castile anhydrites. Transmissive pathways for brine and gas movement are provided by interconnected, primarily vertical fractures whose origin may be related to structural deformation. Fluid in the reservoirs is pressurized by the weight of the overlying geologic media and averages about 67% of the lithostatic pressure within the Delaware Basin (Freeze and Larson 1996).

Brine reservoirs are occasionally encountered during deep drilling in the Delaware Basin and, when allowed to flow, may discharge at rates estimated at 1,000 to 2,000 barrels (150 to 300 m^3) per day and last up to 4 to 5 days (Silva 1994). The observation that flows stop by themselves supports the concept that the size of individual brine reservoirs is limited. Brine reservoirs were penetrated by two boreholes (ERDA-6 and WIPP-12) drilled for WIPP site characterization purposes. The pore volumes of these reservoirs were estimated to be about 96,000 m^3 and 2,700,000 m^3, respectively, although the uncertainty in these estimates is large (Popielak et al. 1983). A geophysical survey, using time domain electromagnetic methods, completed over the WIPP-12 brine reservoir and the waste disposal panels, detected a conductor interpreted to be the WIPP-12 brine reservoir, and also indicated that similar brine occurrences may be present within the Castile under a portion of the waste disposal panels (Earth Technology Corporation 1988).

The chemistries of the brines from the ERDA-6 and WIPP-12 reservoirs were studied by Popielak et al. (1983) and found to be distinctly different from each other and from local groundwaters, supporting the concept that the reservoirs are isolated from each other and from local groundwaters. The major and minor element concentration ratios were interpreted by Popielak et al. to indicate that the brines originated from ancient seawater. Based on the geochemical and hydrological information, DOE believes the brine in the Castile reservoirs has not mixed to any significant extent with other waters and has not circulated within the Castile. Further, the brines are nearly saturated with halite and have little potential to dissolve additional halite.

The WIPP performance assessment requires information on the hydrologic characteristics and likelihood of encounter for a brine reservoir beneath the waste disposal area. Many of the characteristics of the reservoir penetrated by WIPP-12 have been used as a basis for modeling the hypothetical reservoir

underlying the waste. The WIPP-12 reservoir is the best characterized, it is relatively large and permeable, and it is the closest identified reservoir to the site. Relatively little gas has been found in the Castile reservoirs and the analyses of WIPP-12 have only considered single-phase brine flow.

The parameters needed to determine the hydrologic characteristics of the hypothetical reservoir beneath WIPP are described in several supporting documents. Reservoir pressure is described in Freeze and Larson (1996) as a distributed parameter with an expected value (12.7 MPa) equal to the estimated pressure of the WIPP-12 reservoir, and a range (11.1 to 17.0 MPa) based on pressures in other reservoirs encountered in the Delaware Basin. Reservoir porosity is described in Freeze (1996a) as a distributed parameter with a mean value (0.009) determined from laboratory measurements of intact anhydrite core from ERDA-6 and WIPP-12. Although the porosity values have not been finalized, they are currently proposed to be treated as a distributed parameter with a range of 0.001 to 0.02. Average fracture porosity in the WIPP-12 reservoir is estimated by Popielak et al. (1983, pp. G-44 to G-48) to range from 0.004 to 0.011, and is similar in magnitude to the intact rock porosity. A fracture porosity of 0.008 was used by DOE in estimating reservoir pore volume.

Bulk rock compressibility is described in Freeze (1996c) as a distributed parameter with a mean of 1×10^{-10} Pa^{-1} and a range of 5×10^{-12} Pa^{-1} to 1×10^{-8} Pa^{-1}. These values were determined as a best estimate considering compressibilities for intact anhydrite computed from elastic theory, compressibilities determined from the results of borehole hydrologic tests in disturbed Salado halites, and literature values for the compressibility range typically associated with fractured rock.

Reservoir permeability is described in Freeze (1996b) as a distributed parameter with an expected value of 1.6×10^{-12} m^2 and a range of 2.0×10^{-15} m^2 to 1.6×10^{-10} m^2. The expected value was derived from a GTFM analysis of Flow Test 3 in WIPP-12 (Reeves et al. 1991, Appendix A). This was a long-term test and the results best represent the average permeability across the volume of the reservoir. Permeability and rock compressibility are strongly coupled in hydrologic test analysis. In a low-porosity medium, their product should be maintained approximately constant for accurately simulating flow from a specific source; however, their ratio should be maintained approximately constant for accurately simulating pressure fluctuations. The most accurate characterization of these parameters is considered to be that which best matches both pressure and flow fluctuations. Because the expected value of rock compressibility used in the GTFM analysis of 1×10^{-9} Pa^{-1} was decreased in the performance assessment to 1×10^{-10} Pa^{-1}, the expected value of permeability used in performance assessment was increased from

1.6×10^{-13} m^2, determined in the GTFM analysis, to 1.6×10^{-12} m^2 to maintain good estimates of fluid flow. The low end of the range of permeabilities was based on the lowest value obtained in flow tests in ERDA-6, and the high end was based on the near-field high permeability zone encountered in WIPP-12.

The pore volume of the WIPP-12 reservoir was estimated using rock compressibility and porosity data and pressure changes measured in response to reservoir flow. The uncertainty in the volume estimate is largely derived from the uncertainty in rock compressibility. Estimates of the WIPP-12 reservoir pore volume are presented by Larson and Freeze (1996) as ranging from 32,000 m^3 to 64,000,000 m^3. This estimate is based on the nearly four order of magnitude range in compressibility used in performance assessment, and an estimated anhydrite reservoir fracture porosity of 0.008. A WIPP-12 reservoir pore volume of 3,200,000 m^3 was estimated for the expected compressibility of 1×10^{-10} Pa^{-1}.

The pore volume of a potential brine reservoir beneath the WIPP disposal panels was estimated by Larson and Freeze (1996) to range from 32,000 m^3 to 160,000 m^3. The lower end of this range was based on the minimum pore volume estimated for the WIPP-12 reservoir. The upper end of this range was based on the size of a reservoir that would extend beyond the perimeter of the WIPP disposal area. Assuming that the anhydrite layer containing the WIPP-12 reservoir is from 7 m to 24 m thick (Reeves et al. 1991, p. 2-10) and is analogous to the hypothetical reservoir beneath the site, the radius of a circular reservoir with a pore volume of 160,000 m^3 would range from about 510 m to 950 m. Larger reservoirs would likely extend beyond the limits of the waste panels, which have a perimeter of about 600 m by 800 m. Based on regulatory guidance, DOE assumes that the waste panels are partially protected from drilling by active and passive institutional controls for 700 years after repository closure. The larger reservoirs would underlie areas that are not protected by such controls and are assumed to be partially depleted by exploratory drilling penetrations before drilling over the waste would occur. In view of this depletion, the larger reservoirs are not considered in performance assessment because a smaller, undepleted reservoir is considered by DOE to be more significant to performance assessment than a larger, partially depleted reservoir.

Exploration boreholes are assumed to occur both in the waste itself and in the surrounding waste panel walls and room pillars. The probability that a borehole will encounter pressurized Castile brine beneath the WIPP disposal area is tentatively assumed in the WIPP performance assessment to be 10%. This probability is primarily based on a geostatistical analysis of the spatial distribution of known Castile brine reservoirs in the Delaware Basin and on the assumption that because of the primarily vertical

orientation of known fractures in the Castile anhydrites, the potential exists that a vertical borehole could penetrate the area of a reservoir without intersecting conductive fractures and, therefore, without encountering significant brine flow. A discussion of the development of this probability is presented in the 23 May 1996 Draft CCA, Section 6.4.12.6, Probability of Intersecting a Brine Reservoir (DOE 1996, pp. 6-109 to 6-110).

Boreholes randomly selected to penetrate the waste panel area and encounter pressurized brine in the Castile are assumed to contribute to the depressurization of that reservoir. Depressurization is currently assumed by DOE to occur to the extent that the reservoir no longer affects the repository after two penetrations for the smallest reservoir size (32,000 m^3), ranging up to ten penetrations for the largest reservoir size (160,000 m^3). Boreholes penetrating the walls and pillars of the waste panel area are assumed to result in no waste release, but will contribute to reservoir depressurization if they are randomly determined to encounter pressurized brine.

Numerical simulations of short-term and long-term flow from a Castile brine reservoir into the repository, to units overlying the Salado, and to the ground surface are handled by the BRAGFLO-DBR and BRAGFLO codes for single or multiple intrusion scenarios. These codes have the capability to model two-phase brine and gas flow, and it is anticipated that this capability will be applied to Castile brine reservoirs. Short-term flow is addressed in the Direct Brine Release conceptual model, and long-term flow is addressed in the Exploration Borehole and Multiple Intrusions models.

3.16.2. Review of Criteria

3.16.2.1. Information Used to Develop the Conceptual Model

The Castile Formation and Brine Reservoir conceptual model draws heavily on the properties of the WIPP-12 brine reservoir in developing characteristics for the hypothetical reservoir that could be encountered beneath the WIPP waste panels. Information is also taken from other brine reservoirs within the Delaware Basin, with emphasis on the ERDA-6 reservoir. Details on the sources and use of this information are presented in Section 3.16.1. Use of Delaware Basin reservoir information and emphasis on the WIPP-12 and ERDA-6 reservoirs are appropriate because of the increased relevance of local information and the relative wealth and accuracy of data from the two specific sources.

3.16.2.2. Validity of Model Assumptions

The principal assumptions used to develop the model are identified in Section 3.16.1 and critically reviewed here. Most assumptions are reasonable and appropriate and include the conceptual hydrologic role of the Castile Formation (exclusive of the brine reservoirs), consideration of the WIPP-12 reservoir as analogous to the hypothetical reservoir beneath the WIPP disposal area, the concept of a brine reservoir as a heterogeneous, discontinuously fractured zone of limited extent within Castile anhydrites, two-phase treatment of reservoir flow, and the selected values for reservoir pressure and porosity.

Bulk rock compressibility data were developed from a variety of sources including elastic modulus values, disturbed Salado surrogates, and literature values. Although the high end of the range (1×10^{-8} Pa^{-1}) is considered appropriate, the low end of the range (5×10^{-12} Pa^{-1}) and the mean value (1×10^{-10} Pa^{-1}) may be unrealistically low. The mean and maximum permeability values used in the performance assessment were adjusted upward by an order of magnitude from the original GTFM analysis of WIPP-12 to compensate for an order of magnitude downward adjustment in the original value of rock compressibility. The result of these adjustments is to decrease the storage capacity, increase the permeability, and increase the maximum size of the potential reservoir underlying the site. The estimated minimum size of the WIPP-12 reservoir directly supports the performance assessment and remains unaffected by the decrease in the mean compressibility. Although the assumption of a lower mean compressibility for the brine reservoir is not fully supported, the effects of this assumption appear to be conservative and therefore acceptable.

The assumption that reservoirs with pore volumes greater than 160,000 m^3 can be ignored is not adequately supported. Although sufficiently large reservoirs would extend beyond the area assumed to be protected by institutional controls for 700 years after closure, and could be intersected and partially depressurized by exploratory boreholes before boreholes are drilled over the waste panels, no supporting studies of the effects of this scenario have been presented to the Panel.

The assumption that reservoirs will be depleted by two to ten penetrations by exploration boreholes is also not adequately supported. Although the concept of depletion is rational, no supporting studies of the effects of this scenario have been presented to the Panel.

The assumed 10% probability of encountering pressurized Castile brine in an exploratory borehole is based on a geostatistical analysis of reported brine encounters, consideration of the relationship of brine

reservoirs to geological features or processes, and on the assumption that not all boreholes penetrating through the area of a reservoir will necessarily encounter brine. The adequacy of the assumption that significant brine releases are routinely documented was checked with Paul Knautz, a geologist with the New Mexico Oil Conservation Division in Hobbs (telephone 505-393-6161). Mr. Knautz indicated his confidence that the reporting requirements for significant releases were met by the operators. He stated that when encountered with a brine reservoir, the operator must report brine volume and pressure by telephone, and must truck the brine to a proper disposal facility.

Although no documentation of the geostatistical analysis was available for Panel review, preliminary results were verbally presented by DOE. The value of the results of this analysis was seriously weakened by a lack of data in the vicinity of the WIPP. The validity of the spatial correlations relied on the assumption that the geologic conditions supporting reservoir development at the WIPP site were similar to those in areas where hydrocarbon exploration boreholes were numerous and where a number of brine reservoirs were encountered. Unfortunately, there is little direct evidence to support or refute this assumption, but regional trends support the hypothesis that the probability of encountering brine decreases to the west. The kriging results on which the estimate of probability of encounter would be based were sensitive to historic brine encounters. The single encounter near WIPP (at WIPP-12) changed the probability over the waste panels from near zero to about 8%. A second encounter could have an equally dramatic effect. Due to the lack of data and the consequent sensitivity of the estimated probability, little credibility can be assigned to either value.

The assumption that not all boreholes penetrating through the area of a reservoir will necessarily encounter brine is reasonable, given that fractures in the anhydrite reservoir rock appear to be predominantly sub-vertical. However, this assumption must be quantified to be of more than conceptual value to performance assessment, and no basis for such quantification, nor of the way in which this concept has been used in developing the final probability value, has been presented to the Panel.

The approach for estimating the probability of a brine encounter apparently does not quantitatively consider the TDEM geophysical results reported in Earth Technology Corporation 1988, which suggest the presence of brine pockets beneath the waste panels and provide an alternative, site-specific approach for estimating the probability of encounter. In considering the reported uncertainty of ±75 m in estimated depth from the geophysical results (Earth Technology Corporation 1988), Borns (1996) estimated the proportion of waste panel area underlain by a potential brine reservoir to range from 10% to 55%, with

an expected value of 25%. A similar study performed on an alternative contouring of the original TDEM data for the 1992 WIPP preliminary performance assessment (WIPP Performance Assessment Department 1992b) identified a maximum proportion of 40%. Although these values may be reduced by evidence that a borehole penetrating the area of a reservoir may not actually encounter pressurized brine, or discarded based on evidence that the geophysical results are quantitatively unreliable, such evidence has not been presented to the Panel.

3.16.2.3. Evaluation of Alternatives

Although the fundamental hydrological behavior of the Castile Formation and its brine reservoirs is conceptually sound, concerns have been identified in Section 3.16.2.2 regarding the manner in which the encounter of pressurized brine is handled in performance assessment. Three fundamental issues are identified for which alternatives may be considered. These are alternative limits on the maximum reservoir volume, alternative concepts for reservoir depletion, and alternative probabilities of encountering pressurized brine.

3.16.2.4. Uncertainties

Uncertainty in model results stems from uncertainties in the validity of the underlying theory and from uncertainties in the input data. Although the underlying theory is widely used in the petroleum industry for evaluating oil and gas reservoirs and provides the best currently available approach, the results must be considered approximate, as illustrated by the high degree of uncertainty in the results presented, for example, by Popielak et al. (1983) and Spiegler (1982). Uncertainties associated with specific input parameters and assumptions are more tractable to address, and the key uncertainties are associated with the three principle issues identified in Section 3.16.2.3. Uncertainty in the two-phase flow parameters used in the analysis cannot be addressed because the values of these parameters had not been selected at the time of this review (see CCA Table 6-yz, draft of 5/23/96).

The uncertainty associated with rock compressibility is approximately one order of magnitude. Although this parameter is coupled with permeability, as previously discussed, the uncertainty in permeability is approximately two orders of magnitude. Uncertainties in compressibility propagate through the calculations and affect the estimates of both the permeability of the hypothetical reservoir at the site and the volume of the WIPP-12 reservoir. Because the uncertainty in permeability is even greater than the uncertainty in compressibility, the consequences of the uncertainty in compressibility may not be significant to the overall performance assessment. Uncertainty in permeability may have a greater

consequence in overestimating or underestimating flow rates from the reservoir if flow rates are controlled by the reservoir rather than by the borehole dimensions or plugging materials. High degrees of uncertainty in the related parameters of compressibility, permeability, and reservoir volume are not readily avoidable and stem from the wide range of values these parameters can have and from limitations in the state-of-the-art in measuring them.

The consequences of assuming a relatively small maximum size for a hypothetical brine reservoir beneath the site are not known because modeling results are not available, but could result in underestimating the volume of brine that could potentially be released. Alternatively, the modeling results may show that the volume of brine released during the 44-hour flow period assumed by DOE is relatively insensitive to reservoir volume if the reservoir volume is significantly greater than the volume of brine released from the reservoir. In this event, larger reservoir sizes may have little effect on performance assessment.

An unrealistically low probability of encountering pressurized brine could lead to underestimating radionuclide releases resulting from flow from Castile brine reservoirs. The consequences of underestimating this probability would be identified in modeling results, which were not available for review by the Panel.

The consequences of overestimating reservoir depletions by boreholes that do not penetrate a waste panel would be to underestimate reservoir and repository releases by boreholes that do penetrate a waste panel. The issue of reservoir depletions is tied to reservoir volumes, compressibility values, reservoir sizes, and the probability of encounter. Changes in any of these parameters would require modifications throughout the conceptual model.

3.16.2.5. Adequacy of the Conceptual Model

The hydrologic aspects of the conceptual model for the Castile Formation and Brine Reservoirs are fundamentally sound, and the issues raised in the validity of model assumptions (Section 3.16.2.2) are associated with the details of its application. With appropriate resolution of the issues raised in this report, the adequacy of the current model would be acceptable.

3.16.2.6. Adequacy of Application

The internal consistency of the conceptual model is adequate, based on the interdependence of expected or mean values of the parameters as described in Section 3.16.2.1. Although consideration could be given to correlating values during statistical sampling, such as permeability with compressibility, the uncertainties in these values is such that it would be difficult to judge whether any combination were totally unreasonable. The correlation of porosity and reservoir volume in BRAGFLO is considered to be an artifact of the fixed model cell volume and not a true parametric correlation based on conceptual model principles. The integration of the conceptual model with the BRAGFLO and BRAGFLO-DBR codes is addressed under the Exploration Borehole (Section 3.12), Multiple Intrusion (Section 3.17), and Direct Brine Release (Section 3.15) conceptual models.

3.16.2.7. Accuracy of Results

The data base calculations were spot-checked and found to be accurate. The parameter values were also checked against values estimated by other investigators (Popielak et al. 1983; Spiegler 1982; Reeves et al. 1991) and found to be acceptable, given the ranges of uncertainties in the input parameters. The accuracy of integration with the BRAGFLO and BRAGFLO-DBR codes is discussed in Sections 3.12, 3.17, and 3.15.

3.16.2.8. Validity of Conclusions

The validity of the conceptual model is uncertain, pending resolution of the issues raised in Section 3.16.2.3. In summary, the following key assumptions have not been adequately supported in information provided to the Panel, nor do sensitivity studies appear to have been made.

- The basis for excluding larger, potentially depressurized brine reservoirs from performance assessment has not been adequately supported. Larger reservoirs may have greater brine flow volumes and may result in greater radionuclide releases.
- The basis for the concept of reservoir depletion through previous borehole penetrations has not been adequately supported. Non-depleted reservoirs may have greater brine flow volumes and may result in greater radionuclide releases.
- The expected probability of encountering pressurized brine beneath the waste panels has not been adequately supported, nor has the basis for apparently ignoring the quantitative value of site-specific geophysical data been presented. Unrealistically low probabilities of encountering brine may result in underestimating radionuclide releases.

3.16.2.9. Adequacy for Implementation

The Castile Formation and Brine Reservoir conceptual model is not currently adequate for implementation because of the validity issues raised in Section 3.16.2.8. The conceptual model would be considered adequate for implementation if the validity issues were successfully resolved.

3.16.2.10. Dissenting Views

There were no dissenting views for this model.

3.17. Multiple Intrusions

3.17.1. Model Description

The Multiple Intrusion conceptual model is an extension of the Exploration Borehole model that describes fluid flow between the repository and multiple exploratory boreholes penetrating a single waste panel. The borehole drilling methods and frequencies, borehole plugging, and plug degradation discussed in the Exploration Borehole model in Section 3.12 are the same for multiple intrusion boreholes. Short-term flow through unsealed boreholes is addressed in the Direct Brine Release conceptual model in Section 3.15. Other related conceptual models include Repository Fluid Flow, Castile Formation and Brine Reservoirs, Cuttings/Cavings, Spallings, and Actinide Transport in the Salado. The details of this model were still under development at the time of the peer review, and information describing the model was obtained from a variety of final and draft reports and memoranda, and from verbal descriptions provided by DOE. The following model description was prepared from information presented in the 23 May 1996 Draft CCA, Sections 6.4.13.6 and 6.4.13.7 (DOE 1996, pp. 6-119 to 6-121), from verbal descriptions, and from the cited references.

The proscriptive requirements of 40 CFR 194 for exploration boreholes also apply to multiple intrusion boreholes. The focal point of the Multiple Intrusion model is the E1-E2 scenario (worst case), wherein more than one exploration borehole penetrates a waste panel and at least one of those boreholes also encounters pressurized brine in the underlying Castile Formation. However, the Multiple Intrusion model also addresses multiple intrusions by other combinations of boreholes.

Multiple intrusions are modeled by the same two-dimensional version of the BRAGFLO code used to model repository fluid flow and single borehole intrusions. Use of this model is supported by preliminary analysis of modeling results, indicating that liquid flow through the panel closure seal

between the isolated, single waste panel in the model and the "rest of the repository" is slow enough that each waste panel is effectively independent from the rest of the repository. Thus, for a multiple intrusion to occur, two or more boreholes must penetrate the same waste panel. Gas flow does occur between panels, and for this reason short-term releases are calculated separately. However, for long-term brine flow from a single waste panel, the BRAGFLO model is considered adequate. Because the panels behave independently, different configurations of boreholes may occur in different panels. The model computes releases from these configurations separately and adds them to estimate a total cumulative release.

To accommodate the limitation in the BRAGFLO model of being configured to represent only one borehole column, the boreholes are assumed to be drilled in a series of specific sequences, with shifts in material properties in the upper and lower parts of the single modeled borehole at specific times. Background information on the development and use of reference conditions and on borehole plug degradation assumptions is presented in Section 3.12. Because 90% of all deep boreholes are assumed by DOE to be of the E2 type (DOE 1996, p. 6-119), it is most probable that the first borehole to penetrate a waste panel will be of this type. The approach taken by DOE in analyzing multiple intrusions has therefore been built around this E2-E1 scenario, which occurs under the following assumptions.

The first borehole is assumed to be an E2 type that penetrates the waste panel 800 years after closure. At 1,000 years after closure the upper seal in this borehole fails and the borehole is filled with a material that has the properties of silty sand. At 2,000 years an E1 borehole penetrates a waste panel and encounters pressurized brine in the Castile. This borehole is assumed to be sealed with the two-plug configuration, the only configuration considered in performance assessment that allows flow to occur between a Castile brine reservoir and the waste panel (Section 3.12). At 2,000 years the properties of the modeled borehole column below the repository are changed to represent an open borehole, while the properties of the borehole column above the repository are unchanged and continue to represent the long-term properties of the earlier E2 borehole for the duration of the modeling. At 2,200 years the upper plug in the E1 borehole fails and the properties of the borehole below the repository are changed to those of silty sand. At 3,200 years the permeability of the borehole below the repository is reduced by one order of magnitude to represent the effects of pore volume reduction due to creep closure. No further changes in material properties occur for the duration of the modeling.

The aforementioned series of assumptions is valid given DOE's plug degradation assumptions, with the exception that after 2,200 years the upper plugs in both the E2 and E1 boreholes have failed and two pathways, rather than one, are available for brine migration to the Culebra. The assumption that only one of these two pathways conducts flow in this scenario is considered by DOE to be consistent with the assumption of complete mixing of brines within the waste panel, which requires that flow from the brine reservoir in the E1 borehole pass through the waste panel and exit through the E2 borehole, rather than through the upper part of the E1 borehole. However, multiple borehole pathways to the Culebra are included in scenarios involving multiple E1 boreholes because flow through the repository and consequent mixing can then occur among multiple boreholes.

The foregoing scenario of an E2, followed by an E1, establishes the basis for determining a standard reference cumulative radionuclide release to the Culebra, assuming an E2 borehole drilled at 800 years is followed by an E1 borehole drilled at 2,000 years. In this drilling sequence the rate of release jumps dramatically at 2,000 years because of pressurized brine flowing from the Castile reservoir. In an actual scenario the randomly selected drilling dates for these two boreholes are likely to be different. In that event, the cumulative release is calculated using the release rate from a single E2 borehole (Section 3.12) up to the date of the E1 penetration, and then applying the reference release rate starting at the time of E1 penetration in the standard E2-E1 scenario to approximate the jump in release rate that would occur at the actual date that the E1 borehole is drilled. In this approach, the brine fluxes after penetration by an E1 borehole are those occurring at the 2,000 year date of penetration assumed in the standard E2-E1 scenario, rather than the fluxes that would have been modeled at the actual date of penetration; however, the radionuclide releases associated with those fluxes are corrected for radionuclide decay and progeny production.

If the first two boreholes are randomly selected to penetrate the waste panel in a different sequence, the following rules for determining reference conditions for long-term flow are applied.

Radionuclide transport is modeled by the NUTS code for single borehole intrusions and by the PANEL code for multiple intrusions (Section 3.8). While the NUTS code is directly coupled to BRAGFLO and uses BRAGFLO's computed velocity field vectors, PANEL is a separate model that conservatively assumes complete mixing in the waste panel. PANEL is used when two or more boreholes penetrate a panel and at least one of those boreholes is an E1 type. In applying the PANEL code, the multiple

intrusions are implicitly assumed to occur in different parts of the waste panel so that cross borehole flow and mixing will occur. The PANEL code is used for transport calculations in the standard E2-E1 scenario, and use of that scenario for multiple borehole intrusions is conservative.

Table 3.17.1. Rules for Determining Reference Conditions for Long-Term Flow

Sequence of First Two Boreholes	Basis for Brine Flux	Basis for Radionuclide Transport
E2 followed by E1	Single E2 flux followed by E2-E1 flux at time of E1 penetration	Single E2 transport followed by E2-E1 transport at time of E1 penetration
E1 followed by E2	Single E1 flux followed by E2-E1 flux at time of E2 penetration	Single E1 transport followed by E2-E1 transport at time of E2 penetration
E1 followed by E1	Single E1 flux plus E2-E1 flux at time of second E1 penetration	Single E1 transport plus E2-E1 transport at time of second E1 penetration
E2 followed by E2	Single E2 flux	Single E2 transport

The first two borehole sequences in the foregoing tabulation (E2 followed by E1 and E1 followed by E2) both assume sequential calculation of flux and transport by jumping from single borehole behavior to E2-E1 behavior at the time of the second penetration. The sequence of two E1s, however, is treated by adding the E2-E1 flux and transport to the single E1 flux and transport, beginning at the time of the second E1 penetration, because flow from two brine reservoir penetrations can circulate and mix within the repository and leave through two boreholes to the Culebra. As previously mentioned, in cases where there is only a single E1 penetration, the brine is considered by DOE to be more likely to circulate within the repository, adequately mix, and then leave only through the E2 borehole to the Culebra. In cases of two E2 penetrations, long-term brine release volume is assumed to be the same as for a single E2 penetration because flow will be controlled by the rate at which brine can be supplied by the Salado halites, rather than the rate at which brine can flow in the borehole. In cases where at least one of the boreholes previously penetrating the panel is an E1 and an additional E1 is added, additional E2-E1 flux and transport values are added to the cumulative release. In cases where none of the boreholes previously penetrating the panel is an E1 and an additional E1 is added, the flux and transport sequentially shift to the E2-E1 values. However, if only E2 boreholes are present, additional E2 boreholes do not increase the flux and transport rates. In all cases, adjustments are made for radioactive decay and progeny generation to account for the times of waste panel penetration in the cumulative releases.

3.17.2. Review of Criteria

3.17.2.1. Information Used to Develop the Conceptual Model

The information used to develop the Multiple Intrusion model is essentially the same as that used to develop the Exploration Borehole and Repository Fluid Flow models. The Multiple Intrusion conceptual model becomes active at the time that two or more boreholes are randomly selected to penetrate a single waste panel. Alternative reference conditions, repository mixing, and transport models are employed for the Multiple Intrusion model, as described in Section 3.17.1. The information used to develop the conceptual model is reasonable and appropriate.

3.17.2.2. Validity of Model Assumptions

The principal assumptions used to develop the Multiple Intrusion model are identified in Section 3.17.1 and are critically reviewed here. Assumptions related to borehole drilling methods and frequencies, borehole plugging, and plug degradation are the same as those reviewed for the Exploration Borehole model in Section 3.12. The principal assumptions specific to the Multiple Intrusion model are reasonable and appropriate for performance assessment applications and include use of the two-dimensional BRAGFLO model for this application, the somewhat gymnastic but conservative assumptions made to accommodate the single borehole column in the model, and the mixing assumptions in the model.

The assumption that only a single borehole conducts brine to the Culebra in an E2-E1 scenario is troublesome; however, the potentially nonconservative nature of this assumption is compensated by the highly conservative assumption of complete mixing of Castile brine with waste panel brine. In reality, the Castile brine would flow through the waste panel to the exit borehole by preferentially following high conductivity flowpaths with relatively little volume compared with the waste panel pore volume, and consequently with relatively little mixing. Even less mixing would occur in brine flowing from the E1 in the bottom of the waste panel and out the same E1 through the top of the waste panel.

The use of reference conditions, rather than direct model results, as the final input has been handled in a relatively conservative manner. The appropriateness of assuming that the flux associated with the E1 penetration at 2,000 years in the standard E2-E1 reference case is representative of the flux into an E1 penetration at other times has not yet been directly supported by sensitivity studies using current performance assessment calculations, but by analogy to the results of such studies performed for the

1991 draft performance assessment, such an assumption is expected to be appropriately conservative (Helton et al. 1992, Chapter 4).

3.17.2.3. Evaluation of Alternatives

The approach taken to address multiple intrusions in performance assessment is reasonable and appropriate considering the complexity of addressing the many possible scenarios in an efficient manner. Further investigation into the approaches taken have indicated that they are adequate and that no alternative approaches are required. However, the validity of the current approach is based on acceptance of DOE's assumptions regarding borehole plug degradation rates. These assumptions were questioned in Section 3.12, and if those assumptions are changed, many of the basic assumptions used in the Multiple Intrusions model should also be changed. For example, if plug degradation allows fluid to flow into the waste panel from the Bell Canyon Formation through an E2 borehole, the significance of the E2 borehole in performance assessment will become more like that of an E1.

3.17.2.4. Uncertainties

The principal uncertainties in model results stem from the same types of issues that were raised for the Exploration Borehole model and are addressed in Section 3.12.2.4. No additional significant uncertainties have been identified that are specific to the Multiple Intrusions model.

3.17.2.5. Adequacy of the Conceptual Model

The conceptual model for multiple intrusions is fundamentally sound and appropriately conservative, given the simplifications that are required to model a complex set of conditions in an efficient manner.

3.17.2.6. Adequacy of Application

The application of the conceptual model to the numerical model is adequate, again given the simplifications that are required to model a complex set of conditions in an efficient manner.

3.17.2.7. Accuracy of Results

Individual parameter values supporting the conceptual model were checked and found to be reasonable. The modeling results were not available for review and could not be checked.

3.17.2.8. Validity of Conclusions

The validity of the conceptual model is expected to be adequate for performance assessment; however, modeling results have not been observed by the Panel and have not been checked through sensitivity studies similar to those used in previous performance assessments. Many of the modeling assumptions were based on borehole plug degradation assumptions whose validity was questioned in Section 3.12. If those assumptions are changed, many of the basic assumptions used in the Multiple Intrusion model would be questioned.

3.17.2.9. Adequacy for Implementation

The Multiple Intrusion conceptual model is adequate for implementation in performance assessment. However, the results of the model have not been checked by the Panel because sensitivity studies similar to those used in previous performance assessments have not yet been performed.

3.17.2.10. Dissenting Views

There were no dissenting views for this model.

3.18. Climate Change

3.18.1. Model Description

The long periods of time over which the isolation of radioactive waste must be considered stimulates concern over climatic cycles and occurrences that may impact the long-term performance of the disposal system. The Climate Change conceptual model provides quantitative consideration about the degree to which future climates may contribute to the uncertainty of estimates of potential radionuclide releases from the WIPP repository. The model does not attempt to predict or simulate a future climate, but intends to implement climate change effects into the performance assessment through a parameter named the Climate Index.

The formulation of the conceptual model for climate change (Climate Index) began with the screening out of the direct effects of climate change that do not involve groundwater. Factors such as wind patterns and thermal effects do not impact the WIPP due to its depth below the ground surface. Additional aspects of climate change were eliminated through the FEP screening process and the conceptualization

of climate change impacts focused on reasonably foreseeable events and the effects of these events on groundwater flow.

A three-dimensional regional groundwater basin model (Corbet and Wallace 1993) was employed to assist in characterizing the natural hydrogeologic processes as they could occur over geologically significant periods of time in the Delaware Basin. The model was bounded on the bottom by "impermeable" rock, on the top by the ground surface, and on the sides by groundwater divides. The upper boundary of the flow domain is the water table and differences in the elevation of the water table across the basin are assumed to be the driving force for groundwater flow. Other notable but standard assumptions are stratigraphic homogeneity and ignoring the unsaturated zone with respect to timing of infiltration (dry to wet periods). The results suggest that flow in the Culebra Dolomite Member of the Rustler Formation is strongly influenced by the water table elevation and the infiltration (recharge) rates associated with that elevation. Infiltration was varied as a step-function of average amounts of moisture reaching the water table. The model results indicated that changes in infiltration rates of tenths of a millimeter per year had significant impacts on flows in the Culebra. The basin modeling and later analyses (Corbet 1996b) approximated recharge rates that maintained the water table at or near the ground surface (maximum recharge situation) and the relationships between the various recharge rates and lateral-flow ratios. The assigned distributions of lateral-flow ratios became the Climate Index. The Climate Index is therefore a factor by which the lateral flow rate in the Culebra is uniformly increased to account for increases in recharge rates.

Two future climate or recharge patterns were evaluated: the step recharge function, with a 0.25 probability of representing the future, and the Holocene recharge function, with a 0.75 probability of occurring. The step recharge function (similar concept to Corbet and Wallace 1993), which represents a steady increase in heads and recharge rates into the future with the lateral-flow ratio reaching its maximum in 10,000 years, is assigned Climate Index values of 1.5 to 2.25. The Holocene pattern of future recharge results in periodic increases and decreases in heads and recharge rates that are assigned Climate Index values of 1.0 to 1.25. These two Climate Index ranges are sampled during each realization of disposal system performance, with each realization representing a different approximation of future climate.

3.18.2. Review of Criteria

3.18.2.1. Information Used to Develop the Conceptual Model

An extensive reference list supports the process of formulating the conceptual model for climate change. Wood (1994) and Campbell (1995) include isotopic quantification of recharge flux, and Corbet and Wallace (1993), Knupp (1995), and Wallace (1994) address groundwater modeling and hydraulic test interpretation. Swift (1992) and Powers (1990) discuss and include additional references on sedimentology, regional geology and geologic history, long-term climate variability, and climatic records. In addition to references used in conceptualizing climatic change at the WIPP, EPA criteria and guidance (EPA 1996), FEP screening references, performance assessment documentation, and evaluation of groundwater flow models developed in support of climate change conceptual model formulation document in detail the data and information used. Documents and reports produced internally to summarize studies and present results of studies relevant to the WIPP performance assessment (e.g., SAND Reports, professional society papers, DOE-WIPP, FEP, memos) were extremely valuable as they summarized data used and explained concepts applied. The information used to develop the conceptual model for climate change is extensive, referenced, available for review, and adequate.

3.18.2.2. Validity of Model Assumptions

The conceptual model for evaluating the effects of future climate change on the long-term performance of the WIPP began with a detailed examination of a great deal of literature, evolved through an understanding of past changes and situations/conditions of future change, and is now implemented through a dimensionless index that is used to change groundwater flow velocity in the Culebra Dolomite. The relationships between climatic extremes and such parameters as temperature, wind, precipitation, evapotranspiration, and vegetation cover have been researched, and the impacts of such factors on recharge have been evaluated. Since recharge impacts groundwater flow and flow characteristics are required by EPA for a compliance application, the Climate Change conceptual model formulation focused on evaluating the effects of climate change on flow characteristics of the Culebra Dolomite and Dewey Lakes Redbeds. After screening was completed (Corbet 1995a), effects evaluations were limited to the Culebra Dolomite. An extensive list of assumptions would be required to cover all of the modeling and evaluations conducted to represent real events and related climatic factors. The conceptual model for climate change assumes to represent ranges of conditions that are not related to specific events or the interactions between climatic factors, but represent reasonable extremes of potential future climates.

In addition to assuming that the climate will change over the next 10,000 years, the conceptual model of climate change assumes that periods of maximum precipitation are also periods of maximum recharge and that during such maximum situations, recharge is sufficient to maintain the water table at the land surface. A supporting (or bounding) assumption is that recharge in the late Pleistocene was sufficient to maintain the water table at the land surface. The conceptual model assumes that the range of recharge rates (0.1 to 5.0 mm/yr) represents the appropriate range of hydrologic conditions and the Climate Index factor distributions represent these conditions appropriately. A key assumption that is not clearly within the conceptual model or its implementation concerns representing three-dimensional flow in the Rustler Formation with a two-dimensional model of the Culebra Dolomite.

To invalidate the assumption that climate change will occur would require an assumption that the climate will remain constant for 10,000 years. This invalidating assumption would be inconsistent with the scientific view of climate. The assumptions of maximum precipitation/maximum recharge and that recharge could be sufficient to maintain the water table at the land surface are defensible, but not unconditionally validated as representative of a future extreme climate. These assumptions are supported by interpretations of sedimentary records (Swift 1992), isotopic analyses (Campbell 1995 and Wood 1994), paleo-environmental records, and other evaluations that estimate the characteristics of groundwater during varying climates. The assumed range of recharge rates is supported by isotopic recharge dating and rate estimation. The support documentation for the two-dimensional assumption is FEP NS-9 (Corbet 1995b).

The Panel members conclude that the main objectives of the conceptual model for climate change at this time are to incorporate uncertainty about the effects of future climates into the performance assessment and meet EPA expectations with regard to the effects of climate change on hydrological conditions and future state assumptions. Since the range of recharge rates represents the reasonable extremes of potential future climates and the climate index carries the representation into the implementation, the assumptions are valid in terms of the usefulness of the conceptual model, as is the Climate Index.

3.18.2.3. Evaluation of Alternatives

The conceptual model for representing the effects of climate change on the WIPP is a result of an evolution of thought requiring the characterization of climatic factors and simulating their effects. While interest in the possible effects of climate change has, historically, been in terms of recharge and groundwater, early interest considered increased rates of salt dissolution, fracture filling in the Culebra

and changes in groundwater flow direction. Early assessments of system performance did not consider that climate change could alter the transport of radionuclides in groundwater. Later performance assessments considered transport effects but as a function of head change. Sensitivity analyses conducted for the 1991 and 1992 preliminary performance assessments determined that cumulative radionuclide releases were not sensitive to head variation as applied, and the boundary-head approach was abandoned.

Alternative approaches to the characterization of climatic effects on groundwater and modeling groundwater flow have been considered and ruled out for conceptual and technical reasons. Alternatives to representing the factors of climate change have also been considered, ruled out during analyses, and screened out through the FEP screening process. In many cases, alternative approaches that attempted to closely relate climatic factors to hydrogeologic effects introduced additional uncertainty, and could have made the overall conceptual approach less defensible. The 1996 EPA guidance presented recommendations for the consideration of future climates in a compliance application. The guidance focuses considerations on natural processes, potential impacts to recharge, and groundwater flow, and indicates that effects on hydrogeologic conditions are expected to be analyzed and demonstrated in compliance and performance assessments. The selection of the Climate Index to implement the effects of climate change through direct scaling of groundwater velocity in the Culebra allows for the uncertainty of effects of future climates to be incorporated into the performance assessment. Multiple realizations provide for a representative range of future climate effects to be included in disposal system performance.

3.18.2.4. Uncertainties

Many obvious uncertainties accompany the interpretation of the magnitude and temporal aspects of historical climatic factors and the representation of such factors at the WIPP site 10,000 years into the future. The uncertainties are less overwhelming when climates are limited to those reasonably foreseeable, and the absolute timing of alternative climates is of less importance than the range of magnitude of the relevant climatic or climate-induced factors.

A primary objective of the Climate Change conceptual model is to incorporate uncertainty about future climates and their potential impacts on radionuclide releases from the disposal system. The conceptual model for climate change is implemented through a single parameter index that scales groundwater flow

in the Culebra Dolomite. Key uncertainties concern whether or not climate will change, if index values represent the appropriate range of changes, and whether or not implementation realizations sample the index in a manner representative of the range of climate change.

The uncertainties related to whether or not climate will change and the representativeness of index values are a result of predictions, analyses that are imprecise, and conclusions about the future based only on the past. While these uncertainties remain, the conservative assumption for performance assessment is that the climate will change, including periods of both drier and wetter conditions. The only relevant uncertainty with respect to the index is whether or not reasonably foreseeable climates are represented by the range of index values. It is the intent of the index to be bounded by the wet extreme of the Pleistocene glaciation and by another climate where there is little or no climatic effect on groundwater flow. Panel members conclude that significant scientific effort has been expended to characterize the periods bounding the index value and relate relevant climatic factors to the index, and that the index is appropriately conceptualized. Uncertainty with respect to implementation of the climate change model cannot be completely addressed by panel members since a detailed analysis of the implementation models and computational scheme is not within the scope of this review. However, even though climate change preliminary calculations resulted in relatively small increases in flow rates, decreased travel times had a large impact on normalized radionuclide releases under certain conditions (calculations performed for the 1992 performance assessment) (Corbet 1995a). Based on the potentially large consequence demonstrated, climate change has been tentatively retained for inclusion in performance assessment calculations.

3.18.2.5. Adequacy of the Conceptual Model

The climate change conceptual model represents a reasonable and defensible range of potential future climate extremes for incorporation into the performance assessment. The conceptual model includes a range of conditions, bounded by reasonably foreseeable future climates and their effects, that are adequate to represent impacts to groundwater flows in the Culebra Dolomite Member of the Rustler Formation. In addition to providing adequate representation of conditions for implementation, the background research and analysis supporting the formulation of the conceptual model for climate change provides adequate information for satisfying EPA guidance.

3.18.2.6. Adequacy of Application

The conceptual model for climate change is implemented through the Climate Index. This index is a dimensionless factor through which direct scaling of specific discharge for the Culebra Dolomite is accomplished in the SECOFL2D code (Section 4.1). The range of sampled index values available for realization of disposal system performance has been verified through modeling to represent the range of recharge impacts that reasonably foreseeable future climates would create. As such, the conceptual model is implemented through an acceptable and adequate performance modeling element.

The conceptual model for climate change is compatible with the closely related model of the steady-state groundwater velocity field for the Culebra, which it directly scales through the index. The relationship is simple and should be adequate for its intended use, assuming that the implementing computational scheme operates as designed.

3.18.2.7. Accuracy of Results

Model formulation results, as well as model application/implementation results, must be reviewed in assessing the overall accuracy of results for the conceptual model for climate change. The accuracy of model formulation results is judged on how well descriptions and descriptive write-ups present the conceptual model. In the case of the climate change model, background research and analysis, history of model development, screening and verification, descriptions of model parameters, assumptions, and an implementation scheme were available. Panel members were required to consult numerous sources for a comprehensive description of the conceptual model but, overall, the model formulation results were judged accurate.

As discussed in Section 3.18.2.6, the application or implementation of the conceptual model for climate change is conducted with the Climate Index. This dimensionless factor is sampled over its distribution and represented by direct scaling of the steady-state groundwater velocity field in SECOFL2D for the Culebra Dolomite. For performance assessment realizations of disposal system performance, each realization represents the effect of a different climate. The model is judged as capable of producing accurate results through implementation if realizations of disposal system performance adequately represent the range of future climates available within the distribution of the index.

While the scope of this conceptual model review did not include verification of realization computations, a single CCDF calculated to address FEP NS-8b had interesting results. The FEP NS-8b, summary

memo of record (SMOR) of 21 September 1995, stated that on the basis of relatively small increases in flow rates expected from including climate change in the performance assessment modeling system, and the associated low consequence of omitting the factor, climate change could be screened out. The SMOR also presented that a single CCDF calculated to address the FEP illustrated that screening out climate change would not be of low consequence. The CCDF illustrated that velocity fields that decreased travel times (increased flow rates) by a factor of 2 resulted in three orders of magnitude increases in releases for release probabilities less than 0.1. The reason for the large impact was not clear, but this quantitative evaluation of the climate change subsystem resulted in the retention of climate change for inclusion in future performance assessment calculations. While the quantitative subsystem evaluation did not prove the accuracy of implementation of the conceptual model, it is indicative and supportive of performance assessment sensitivity.

3.18.2.8. Validity of Conclusions

The results of the implementation of the conceptual model for climate change are the representation of the effects of a reasonably foreseeable range of future climates within realizations of disposal system performance. While Panel members found no documentation of the results of the application of the Climate Index in disposal system-scale performance assessment calculations or conclusions drawn, the FEP screening process (Corbet 1995a) SMOR addressed a quantitative analysis. The SMOR, discussed in Section 3.18.2.7, presents that the results of the quantitative evaluation stimulated the conclusion to retain climate change for inclusion in future performance assessment calculations.

The evaluation presented in the SMOR could not support conclusions to the degree possible from results of disposal system-scale performance assessment calculations and sensitivity analyses. In the absence of results from repository/disposal system-scale realizations and sensitivity analyses, no definitive, valid conclusions can be made. However, the evaluation at the subsystem level did support conceptual model sensitivity and uncertainty assessment and a valid conclusion was drawn on the basis of results of the evaluation.

3.18.2.9. Adequacy for Implementation

The conceptual model for climate change, as discussed in Sections 3.18.2.1 through 3.18.2.8 and defined for implementation by the Climate Index, is adequate for implementation. The Climate Index is capable of representing uncertainty about future climates and their potential impacts on disposal system

performance. While the conceptual model has been judged adequate for implementation, the mathematical representations in the computer code have not been reviewed and no conclusions can be made as to the overall adequacy of the applications/implementations.

3.18.2.10. Dissenting Views

There are no dissenting views for this model.

3.19. Creep Closure

3.19.1. Model Description

The Creep Closure model is part of a complex of submodels that are combined to effect the porosity surface lookup table. This table combines gas pressure, room closure, and waste compaction to pre-calculate repository void space for inclusion in several other performance assessment models. The Creep Closure model is reviewed here and other aspects of the porosity surface are discussed in support of that review. The Creep Closure model has a complex history of development, which extends into the period of review. The generic creep model impacts both the room closure and the development of the DRZ surrounding the repository openings. The DRZ models are discussed elsewhere.

Closure of the repository occurs naturally in the Salado halite as a response to the imbalance of forces created by excavation of the repository rooms and passages. Weak and plastic rock salt begins immediately to flow into the excavated spaces by processes dominated by creep. The rate of closure is the combined result of creep rates inherent to salt, repository temperatures and pressures, and resistance provided by repository contents. The creep rate proceeds to the limits determined by resistance from gas, brine, waste, backfill, or other contents in the repository until the void space is closed to the final porosity dictated by waste and seal material properties, contained fluid pressure, and lithostatic pressure. Roof fall in the disposal rooms, which may have significant impact on flow at least in the short term, is not included in the model.

Both brine and gas content of the repository vary with time. Brine inflow/outflow is partly controlled by gas pressures. The relationship between gas outflow rates and gas generation rates influences pressures within the repository. Gas pressure results from the alteration of waste by biogenic and corrosion-based processes. The rate of the corrosion process is dependent on brine availability. Repository gas and brine pressures are limited by the minimum pressures at which gas or brine would be forced out of the

repository via identified flowpaths through fractured interbeds within the Salado. The threshold pressures for initiation of outflow through these fractured anhydrite interbeds are therefore a key consideration in limiting resistance to closure due to gas and brine pressures. The fractures in the interbeds are essentially horizontal, so the pressures necessary to open the fractures or to initiate new fractures must be greater than the lithostatic load. Further, some resistance to gas release may result from travel through the fractured, rock-bolted halite between the repository and the interbeds. Resistance to gas outflow due to stress cage effects at the repository boundary and gas pressures necessary to maintain very extensive fractures may result in repository pressures larger than interbed threshold pressures. Gas pressures, which are some amount greater than the lithostatic pressure, are therefore possible at some times during the repository gas generation history. Internal gas pressures greater than the stress imbalance that drives creep inflow are conceivable. Internal pressures may contravene stresses in the salt and repository closure may cease, or repository inflation may occur in some scenarios. The stoichiometric treatment of time histories of gas generation and the volumetric model based on creep closure rates and waste compaction are combined in the SANTOS computer code to provide repository void volume estimates through time as part of lookup tables called the "porosity surface."

In the present WIPP performance assessment calculations (using BRAGFLO), the details of the mechanics of disposal room closure and/or eventual expansion are not explicitly calculated. Instead, the room-rock system behavior is obtained from the porosity surface. In this table, the three dimensions are time, total room porosity, and mass of gas in the room. The porosity surface is itself calculated prior to the BRAGFLO runs using the SANTOS code. This procedure is followed to avoid the massive computational effort that would be required to fully calculate (in an iterative sense) the mechanics of room closure for each performance assessment realization. At first, this may seem to be an invalid decoupling of the external environment and the disposal room. However, if the room porosity can be shown to be described with sufficient accuracy as a variable dependent only on time and gas mass (which is itself dependent only on time in the current model), then this approach is quite justified in view of its simplicity and efficiency. Note that brine content of the room is not mentioned at this point, nor are there any brine parameters on the porosity surface parameter list. This is a consequence of the calculation method and interaction with BRAGFLO, and is discussed below.

The porosity surface calculations using SANTOS are described by Stone (1996). The main features of these plane-strain calculations are a simplified stratigraphic model with boundaries at 50 m from the disposal room, the inclusion of the main clean halite and argillaceous halite layers, and the inclusion of

the two anhydrite layers of influence (MB 139 below and anhydrite a above), but no clay seams. The waste drums are lumped into a single rectangular mass, bounded by slip surfaces, that correctly reproduces the initial porosity and density. The simplified geometry used (as compared to the reference stratigraphy) is justified in Stone (1996), with supporting calculations given by Osnes and Lebreche (1995). In justifying the simplification, it is shown that including two types of salt and the anhydrite beds are necessary to provide the model sensitivity needed to support observations, but that the clay seams and additional complexities do not contribute. Thus, only halite and anhydrite properties are included as material properties in the parameters listed for the porosity surface. No roof failure of the room is considered in the porosity surface calculations. The porosity surface and its parameters have also been discussed in Butcher (1996), and Butcher et al. (1995).

The first full explanation of the porosity surface and its justification of use appears in Butcher and Mendenhall (1993). Since the pressure in the room depends on the amount of gas and the room pore volume, and this pressure creates the "back stress" resisting closure, the porosity surface can uniquely represent the room behavior if the relationship between gas volume and time is known. Since that relationship is specified (by corrosion rates and/or intrusion scenarios) the porosity surface can be used as prescribed.

A complication occurs, however, when brine is allowed to flow into or out of the room. Then, the porosity evaluated from the porosity surface must be treated as the gas-filled porosity and added to the brine-filled porosity to become the total porosity required in the performance assessment calculations using BRAGFLO. Furthermore, BRAGFLO, which is a fluid flow code, must be used to provide the brine content of the room for this iterative calculation. This coupling is only valid if the fluid flow is slow, which is a good assumption in the case of WIPP. Also, it must be assumed that the brine pressure is the same as the gas pressure within the room, which is true for high waste permeability.

The resistance to closure resulting from the compaction and consolidation of backfill and waste is based on empirical relationships derived from experimental studies. Some experimental laboratory and *in situ* experiments on crushed salt compaction for shaft sealing studies may provide definitive property assessments for backfill, although the final makeup or certainty of use of backfill materials is not known at this time. Limited experiments involving the compaction of waste-filled drums and simulated waste provide the basis for empirical estimates of waste behavior. The variable nature of waste form and

inventory lends a large uncertainty to the definition of waste physical behavior. The models of waste properties and mechanical behavior are reviewed elsewhere in this document.

The volumetric plasticity model has evolved significantly since it was proposed in its initial form by Kreig (1984). This formulation consisted of a synthesis of published empirical creep constitutive models, the geometry of material distribution, a calculated initial stress condition, and a set of creep constitutive properties derived from laboratory creep tests at SNL. Morgan et al. (1985) applied this initial formulation of the model to closure records from the south drift and found that it significantly under-predicted closure rates. Sjaardema and Kreig (1987) proposed that the characterization of Young's Modulus was the source of error in the initial model. They suggested an empirically derived reduction (division) of Young's Modulus by 12.5, which improved the performance of predictive calculations based on the model to satisfactory levels for use in crushed salt compaction tests for seals and subsequent closure observations. This model has been called the Reduced Modulus (RM) model in subsequent work.

Munson et al. (1989, 1991) undertook to resolve the empirically altered model with a "first principles" model derived from a set of more process-based rock mechanics theories. He demonstrated that a reliance on Von Mise's flow rule was less appropriate than that of Tresca, revised salt property estimates based on elimination of excavation strain from laboratory results, reevaluated creep parameters for argillaceous salt, added a term for primary creep, and improved the micro-mechanical creep models. These modifications enabled the steady-state creep response model (the MD model) to match observed closure rates at WIPP within 10%.

As it is presently formulated, the MD model does not include a treatment of the tertiary creep domain. Tertiary creep may be characterized as an acceleration in creep strain rate, accompanied by extensive microfracture, leading to macrofracture and failure. Chan (1996) has developed an amended version of the model (MDCF model), which includes tertiary creep for prediction of the formation of a DRZ around repository openings. The room closure model does not include tertiary creep on the grounds that all of the acceleration of strain (above the steady state rate) is due to microfracture and is recovered during the final stages of room closure due to DRZ healing. This concept is part of a larger concept called the conservation of void space. Because of void space conservation, no increase of gas pressure in the repository is attributed to this increase of strain rate.

The conservation of void space is only partly proven (experimentally or observationally) and is largely based on theoretical assumptions. In the case of tertiary creep of salt, the primary assumption is that all of the acceleration in strain rate during tertiary creep results from the onset of microfracture generation caused by the accumulation of intracrystalline lattice damage. The accumulation of lattice damage within individual crystals often results in work hardening and the elevated local stress levels may result in the initiation of strain by a "new" mechanism or mechanisms. However, no clear evidence exists that fracture is not accompanied by an undefined intracrystalline micromechanism, which may account for part of the change in the tertiary creep rate. The concept of continuation of unchanged steady state creep by micromechanisms that are unaffected by the damage accumulation to which the onset of fracture is attributed, seems incompatible. A more complex micromechanical model, which might include some acceleration due to non-fracture (plastic) processes, is not ruled out by any of the evidence. None of the closure observations at the WIPP occur over periods of time long enough to encompass the complete creep cycle observed in other salt mines.

Munson et al. (1995) estimates that only about 3% of the total creep strain is attributable to tertiary creep. The MD model matches short-term steady-state creep rates to within approximately 10%. If all or some part of the tertiary creep is not attributable to recoverable microfracture, the MD model may only be able to predict long-term closure rates to about 13% at best. Associated gas pressure changes through the porosity surface calculation are impacted by the inherent uncertainty in closure rates represented by the creep closure model predictions.

3.19.2. Review of Criteria

The room closure model includes the creep closure model (MD), the porosity surface lookup table, and interaction with BRAGFLO to iteratively specify brine inflow volumes. The porosity surface is constructed within the SANTOS model and consists primarily of creep closure, waste compaction, and gas pressure to estimate repository void space versus time. This review concentrates on the adequacy of the creep model (MD) with reference to the other associated models (e.g., BRAGFLO, SANTOS, porosity surface, gas generation) only as necessary to evaluate uncertainties.

3.19.2.1. Information Used to Develop the Conceptual Model

The initial version of the creep closure model was developed from published creep constitutive relationships and rock salt properties from intact rock salt deformation experiments at the SNL Rock

Mechanics Laboratory. The model was revised on the basis of short-term measurement of closure rates when the WIPP experimental rooms were opened. Both empirical revisions of elastic constants, based on closure rates, and revisions to the constitutive model, based on refinement of the understanding of deformation processes and flow rules, contributed to the development of later versions of the model.

Resistance to room closure (backstress) is the result of brine and gas pressure in the repository and of the strength of waste and backfill. Gas pressures used in the model are the result of the interplay between the time history of gas generation, the time history of void volume due to salt creep, and the threshold pressures governing gas outflow along the fractured anhydrite interbeds. Brine inflow is partially controlled by gas pressures. Repository pressure is modeled by an interplay between BRAGFLO and SANTOS, and interactions between gas pressure and creep are presented in the lookup table called porosity surface. Gas generation and brine inflow information are the product of other models. Threshold pressures for gas outflow in the interbeds are taken from packer tests of those horizons (Salado model). Strength of salt backfill is available from extensive experimental work done for the shafts and seals model. Waste strength may be the most uncertain type of information used in modeling room closure. Some experimental waste compaction has been done, but variation in waste form and inventory may make the characterization of waste physical properties highly variable. The creep closure model depends on the waste to resist closure and suppress rockfall and also contributes to the generation of an estimate of final waste porosity for waste dissolution estimates.

3.19.2.2. Validity of Model Assumptions

With the exceptions of the creep model, most of the assumptions in the global room closure conceptual model, as represented by the porosity surface calculation, are discussed in the consideration of other models (e.g., Gas Generation, Repository Fluid Flow). Many of the assumptions in the creep model were modified and tested during the development of the second iteration of the constitutive (MD) model. This redevelopment of the model was driven by the failure of the preliminary model to acceptably predict the short-term rates of closure of WIPP rooms. The redeveloped model contains a new flow rule and refinements of other model elements. The new model predicts short-term, steady-state salt creep rates (room closure rates in the WIPP excavations) acceptably (within 10%) implying that the principal assumptions are correct. No such correlations have been made for the transient (tertiary) creep behavior of the repository because of the limited observation times of room closure behavior. Tertiary creep is neglected in the MD creep closure model because of the assumption that all strain rate acceleration

(above the steady state rate) is due to microfracture and that the porosity caused by microfracture is recoverable during DRZ healing. This assumption is referred to as "the conservation of void space" and is largely unproven.

Because of the complexity of the natural environment and number of parameters evaluated, several assumptions are required to make the process of modeling and mechanical parameter evaluation possible. The most important of these appear to be:

- Thermal effects can be ignored since little waste heat generation is expected. This assumption is reasonable.

- Halite and anhydrite layers can be treated as continuous. This assumption is probably necessary in view of current computer modeling methods. It is also reasonable, in view of program requirements and data accuracy. However, discontinuous surfaces certainly exist within the assumed continuous layers. A good example is given by the few "anomalous" creep results reported by Senseny (1986), which were not included in the final creep parameter determination. Some of these occurred in samples that contained distinct linear clay seams. The effect of ignoring such data and other similar effects by assumption is not severe with regard to the final results, but should not be forgotten.

- Size scale effects can be ignored. Most geologic media exhibit a size scale effect. More often than not, this takes the form (in mechanical properties) of module reduction with size. In the case of WIPP, one might also expect an increase of creep rate with size. A hint of size effect is noted by Munson et al. (1989) but no model changes are proposed. Such effects are frequently attributed to discontinuities, which have differing properties as functions of scale. The assumption of no size scale effects therefore ties in with the continuum assumption discussed previously. Despite these cautions, ignoring scale effects seems reasonable within the realm of available data and accuracy of prediction required for these massive formations.

- The "unknown" long-term creep mechanism can be described by a standard equation and its parameters determined by relatively short-term tests. Virtually all of the halite creep during the lifetime of the repository will occur in response to a mechanism labeled as unknown. Therefore, the equation used for this mechanism, although a standard and acceptable activation equation, must also be labeled as unknown. This may have consequences with respect to long-term predictions. From the viewpoint of repository performance, the consequences are probably not severe since the parameters of the unknown mechanism have been empirically determined with some confidence.

- The presence of water can be ignored as an explicit mechanical properties material parameter. In most geologic media, saturation state strongly affects material properties. Here, with small amounts of water, one can argue that the explicit effects can be ignored. It does not appear that the WIPP project has investigated this, but the results are probably not severe. One area of caution is the possible conversion of anhydrite to gypsum on water absorption. This event,

if it occurs, will make the affected anhydrite zone softer and more plastic than now calculated. However, since the anhydrite beds tend to be zones of weakness to begin with, a severe adverse effect on subsequent modeling is not anticipated.

3.19.2.3. Evaluation of Alternatives

Alternative forms of the creep model were evaluated and compared to repository behavior during the redevelopment of the preliminary (Sjaardema and Kreig 1987) model. The empirical model, which was a version of the preliminary model with elastic modulus modified (RM model) on the basis of observed repository behavior, was used as a stop-gap model to allow the seals and backfill evaluation experiments to move forward. A more process-based model was ultimately developed which utilized a different flow rule and other refinements. This model (MD model) permitted a better understanding of the interaction of individual flow processes and could be more confidently extrapolated to differing initial and environmental conditions than the empirical version. The two models, one empirical (RM) and the other a process-based model (the MD model), agree well and are mutually supportive.

3.19.2.4. Uncertainties

The Creep Closure model contains two of the most important and sensitive variables involved in the potential release of radionuclides. Gas pressure resulting from the compression of gases in the repository from reduction of void volume and gas generation are the principal driving forces capable of pushing brine and dissolved and particulate waste out of the repository toward the accessible environment. Waste consolidation controls the pore space in the waste, which regulates the available surface area across which brine can dissolve radionuclides. Gas pressure is regulated by a complex set of model interactions. Permeability regulates gas outflow via fractured interbeds, and gas generation rates and rate of closure are the primary controls of gas pressure maxima. Gas pressures that exceed lithostatic pressures, sufficient to slow, stop, or reverse repository closure, are credible.

Timing of release relative to a complex interplay of variables controlling gas pressure, void volume, brine volume, residence time, and the reactivity of waste and brine as controlled by brine availability, waste permeability, and porosity are important in determining released brine radionuclide concentration and volume. The assessment of the interplay of timing of multiple processes is controlled by the stochastic manipulation of the processes by SANTOS and is preserved in the porosity surface lookup table. If the latin hypercube sampling strategy adequately addresses the timing issues, as claimed by DOE, consequences of uncertainty in the conceptual models are minimized if the assumed limits of variability in processes are conservative. Only in the case of waste compaction and its influence on the

degree of radionuclide entrainment and solution in brine is the conservatism of assumptions not verifiable. This is because the physical and, to a lesser degree, the chemical character of the waste is essentially unknowable within wide bounds. The consequence of this uncertainty is significant only if release impact is dominated by concentration of released radionuclides rather than by volume of released brine. Those aspects of the consequences of release are considered in other conceptual model reviews. Uncertainty associated with the room closure model (minimum of about 13%) must be evaluated through its sensitivity in the porosity surface calculation, and primarily impacts gas pressures.

3.19.2.5. Adequacy of the Conceptual Model

The adequacy of the Creep Closure conceptual model is demonstrated by its predictiveness of room closure in existing WIPP excavations. The uncertainties inherent in the model must be assessed through the sensitivity of the porosity surface calculation. The model appears to be adequately predictive.

3.19.2.6. Adequacy of Application

Integration of the Creep Closure model with the other component models and submodels to represent repository room closure is contained in the SANTOS code generation of the porosity surface lookup table for a large number of stochastically defined combinations of conditions, and appears to be adequate for performance assessment use.

3.19.2.7. Accuracy of Results

Accuracy of results for the salt creep conceptual model has been demonstrated to be adequate within the sensitivity of the overall room closure model by its ability to predict short-term closure rates in empty WIPP rooms and drifts (10%). The accuracy of the combined model of room closure with, for example, waste, backfill, and gas pressures, cannot be demonstrated at this time. Butcher (1996) claims that the sensitivities to undemonstrated variables in the combined model are low.

3.19.2.8. Validity of Results

The validity of the global room closure model cannot be assessed at this time in the absence of long-term room closure observations of filled and closed rooms, or of analogues or observations of releases from similar structural systems, particularly in the undisturbed scenario. This is ameliorated by the approach adopted in the generation of the porosity surface lookup table, which addresses the complexities of room closure processes and timing among the principal dynamic processes. The Room Closure model appears to be valid as part of the porosity surface calculation for performance assessment purposes.

3.19.2.9. Adequacy For Implementation

Implementation appears to be adequate. The porosity surface calculation appears to address the complex issues of timing among processes and provides a means of choosing representative parameters for individual processes with respect to uncertainty about process results and timing during dynamic process evolution. The creep closure model (MD) appears to be acceptably adequate to the approximation of timing among room closure, gas generation, waste compaction, and brine inflow for performance assessment purposes.

3.19.2.10. Dissenting Views

There were no dissenting views for this model.

3.20. Shafts and Shaft Seals

3.20.1. Model Description

Four existing shafts connecting the repository to the surface, which will be used in the operational phase, are represented in performance assessment by a single shaft with a cross section and volume equal to the total cross section and volume of the four real shafts. This composite shaft is modeled as separated from the waste regions in the model by the distance from the waste to the present waste handling shaft. On closure of the repository, the shafts will be sealed as described below and as represented in performance assessment by nine materials occupying 11 model regions in the shaft, as shown in Figure 3.2. The materials are earthen fill from the surface to the Rustler Formation; a clay region in the Rustler; asphalt at the top of the Salado; three concrete sections within the Salado; an upper clay region within the Salado; a thick section of compacted crushed salt; a lower clay section separated into upper and lower segments; and a concrete monolith at the repository horizon.

Conceptually, the shafts are assumed to be surrounded within the Salado by a DRZ with properties that vary with depth, time, and type of adjacent seal material. The performance assessment calculation grid represents only the cross sectional area of the shafts, and the permeability values for the various seal components at different times have been adjusted to account for the presence of the DRZ. Therefore, the DRZ is not represented explicitly in the BRAGFLO calculation. Thus, the flux that would occur through a shaft and its surrounding DRZ can be modeled equivalently using the shaft cross-sectional area with a higher permeability.

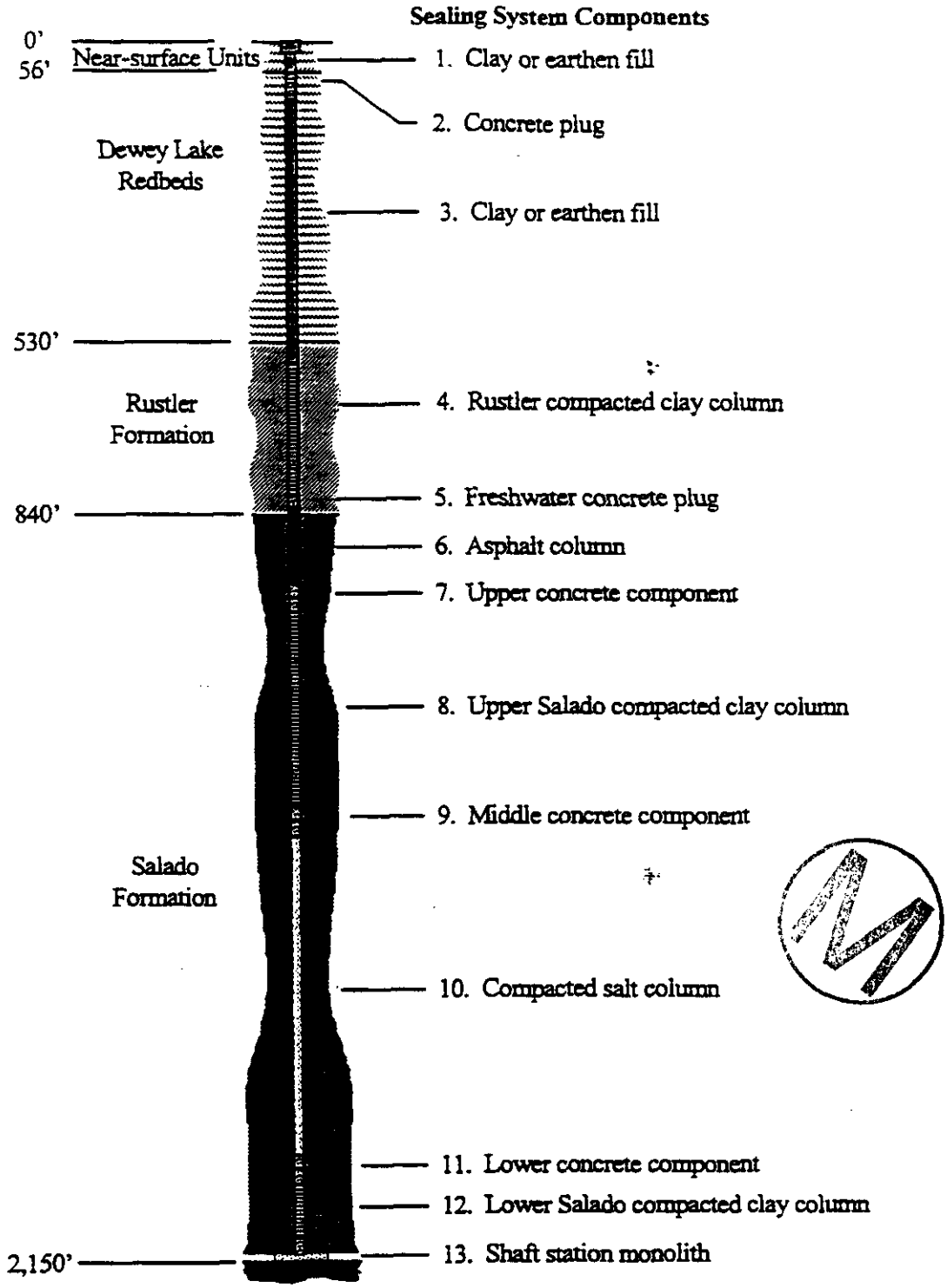

Figure 3.2. Arrangement of the Air Intake Shaft Sealing System

As described by Knowles (1996b), the shaft DRZ permeability is incorporated into the shaft permeabilities by a sampling and calculation process. DOE studies showed that the permeability can vary over an order of magnitude across the DRZ. Test data showed it is greatest near the excavation surface and decreases outward into the rock. To determine the effective permeability of the shaft DRZ, an equation was derived using the assumption that the permeability change is log linear. This equation has as variables a sampled inner DRZ permeability, intact salt permeability, shaft radius, and outer extent DRZ radius. A permeability value is computed for each shaft DRZ. A composite shaft DRZ permeability is then calculated by summing the individual products of the permeabilities and respective areas and dividing by the summed areas. Finally, the adjustment to the shaft zone permeability to account for the DRZ is computed similar to the previous step. The final shaft zone permeability is the sum of the composite permeability times the area of the combined shaft DRZs and the permeability times areas of the summed shaft area divided by the modeled shaft area. The modeled shaft area is assumed to be 95 m^2, which is the computed sum of the areas defined by the shafts' radii. The shaft seal permeability (including the DRZ) is sampled and is temporal in the BRAGFLO calculations.

3.20.2. Review of Criteria

3.20.2.1. Information Used to Develop the Conceptual Model

The conceptual model for the shafts and shaft seals used in the performance assessment has been chosen to provide a reasonable and realistic basis for simulating long-term fluid flow in either direction through the shaft seal system between the repository and brine bearing units and the surface, and to allow evaluation of the effect that uncertainty about the long-term properties of the shaft seal system may have on cumulative radionuclide releases from the disposal system.

Parameters used to characterize the shaft seal system are described in Section 6.4.4 of the CCA and in Appendix PAR. The principal parameters of interest are the permeabilities and porosities of each seal component. For salt, concrete, and clay components, permeabilities are assumed to change with time. Permeabilities are constant for asphalt and earthen fill components. These parameters include the time-dependent properties of the DRZ around the shafts to determine the hydraulic properties of the shaft seal system through time. Other parameters specified for the BRAGFLO model include pore-volume compressibility, two-phase flow parameters, and initial conditions.

The FEPs associated with model development include:

SP-1, Mechanical Effect of Gas Generation.

SP-2, WIPP Shaft Seal Degradation.

SP-4, Other Physical Degradation Mechanisms (Cracking Concrete, Erosion of Seals).

SP-5, Chemical Degradation of Seals (Alkali-Aggregate, Cement Sulfate, Cement Pore Water).

SP-6, Differing Thermal Expansion.

SP-7, Concrete Hydration.

SP-8, Effects of Microbial Growth on Concrete.

SP-9, Effect on Groundwater Chemistry.

SP-10, WIPP Investigation Boreholes.

SP-11, Evaluation of Full Shaft Conceptual Model Seal System.

This information base appears to be adequate for the intended use.

3.20.2.2. Validity of Assumptions

The basic assumptions pertinent to this model concern the applicability of the findings from the test program. Key among these are healing of the DRZ, recompaction of salt (which has application in the shaft sections filled by this material), adequately qualified parametric values for each seal component, a short-term seal to assume appropriate permeability until the salt column is reconsolidated, and implementability of the seal components.

The healing mechanism is discussed in more detail in Section 3.7 of this report. Tests are quite positive in supporting this conclusion, with the most significant of these being the results of testing the zone around a rigid inclusion in salt (Knowles et al. 1996). Recompaction of salt has been demonstrated and concerns are detailed below. Parametric values of components have been scrutinized by a qualification process for adequacy. Implementability of the seal components, as most recently described in the Draft WIPP Shaft Seal System Compliance Submittal Design Report, Appendix B, appears to be readily achievable. All of these assumptions are sufficiently supported to be acceptably valid.

3.20.2.3. Alternatives

The shaft seal system design has evolved over time (Borns and Stormont 1988; Nowak et al. 1992). The Initial Reference Seal System Design proposed a two-phase sealing strategy: short-term concrete and clay

seals and a long-term crushed salt seal. The use of native rock (i.e., crushed salt) as a permanent sealing material is considered the most effective means to eliminate the shafts as a preferred pathway for migration of hazardous constituents. Due to the time necessary for the crushed salt to reconsolidate to sufficiently low permeabilities, short-term seals were incorporated as a means to prevent fluid migration during the interim. Estimates of this interim period ranged from 100 to 200 years.

Results of the scoping calculations (CSDR 1996, Appendix D) showed that low-permeability materials were required for the shaft seals. However, the simplicity of the conceptual model limited the applicability of results to the current detailed seal system design. A comparison of the scoping calculations to the seal system design proposed for the last CCA was found in a memorandum to performance assessment (Knowles 1995a).

The current conceptual model of the WIPP shaft seals is documented in a memorandum to performance assessment (Knowles 1995b). The conceptual model is directly related to the detailed seal design both visually and technically, with all materials and components of the engineered seals being included. Parameters for the materials were developed from field and laboratory testing, literature searches, and numerical modeling. Documentation of the parameter development process is to be published.

3.20.2.4. Uncertainties

The conceptual model of the seals is based on results of detailed numerical models of the shaft seal system design that were developed to evaluate the performance of the shaft system under a range of conditions. Both fluid flow and structural response of the system were evaluated. Principal uncertainties evaluated and incorporated in the model include: 1) reconsolidation of the crushed salt component; 2) construction, permeability, and gas threshold pressure of the clay components; and 3) damage, permeability, healing, and character of the Salado and Rustler disturbed rock zones.

The consequences of uncertainty in seal component performance were a primary motivation in the development of the proposed seal system design. Although there is uncertainty in many of the materials and models, the shaft will be completely filled with high-density, low-permeability materials. The use of multiple materials and components for each sealing function resulted in a robust system. The shaft seal system being evaluated makes no distinction between "short-term" and "long-term" seal components. Instead, time dependency is incorporated directly into the model through temporal variation in seal

properties. On general overview, the uncertainties that emerged in the shaft seals program appear to have been dealt with adequately.

3.20.2.5. Adequacy of the Conceptual Model

Details concerning a description of the sealing materials and why they are expected to function as expected are to be presented in the WIPP Shaft Seal System Compliance Submittal Design Report, currently in draft. The materials include compacted earthen fill, concrete, compacted clay, asphalt, and compacted salt. These different materials are used to reduce uncertainties in performance. All materials are expected to maintain their integrity for very long periods, although for design purposes longevity only is assumed for those materials with strong scientific justification. Concrete plugs with impermeable water stops located in the Salado provide early low permeability, and the rigid support to promote healing of the DRZ. In approximately 100 years (design provides for 100 to 200 years), the compacted salt column will be sufficiently compressed to have a low permeability, thus replacing reliance on the concrete plug. The asphalt is functional as a nonpermeable plug to prevent water flow, and as a water stop within the seals in the Salado Formation. These water stops, backfilled in a one-radius kerf cut surrounding the shaft in the salt, are expected to be highly effective in deterring water flow in the DRZ surrounding the shaft. The Compliance Submittal Design report will describe the processes showing feasibility of achieving adequate placement of these seals (initial drafts appear convincing). Except for confirmation of the compactability performance of salt, this model appears to be fully adequate for implementation.

3.20.2.6. Adequacy of Application

The properties of the designed seals are realistic, achievable, and allow for controllable application. The only relatable issues for application concern the performance of recompacted salt (as discussed in Section 3.20.2.8), and performance of the DRZ. The latter issue regards the accuracy of the assumption that the DRZ will heal and accordingly can be disregarded as an explicit component of performance assessment calculations. This assumption stems from tests showing that with time, the permeability of a DRZ decreases as confirmed by tests when a stiff support is placed in an opening. The property of salt creep forces the fractures to close and original conditions to be re-established (Knowles et al. 1996). As a result of these findings, it can be assumed that following the placement of seals, the DRZ will quickly heal to create a permeability that is lower than the shaft seals provide (Chiesler 1996). Hence, it is argued that by adjusting the permeability of the seal components upward in the model, it will compensate

for the additional low flow in the DRZ, and the DRZ can be removed as an explicit input to the performance assessment calculations. Because of the relatively large extent of the DRZ and its capability of being a potential pathway for releases, this concern bears its rightful recognition in the accuracy of results.

3.20.2.7. Accuracy of Results

The results from development of the shaft sealing system pose questions of achievability, which obviously are subject to incorporating ensured quality in the design and implementation processes. On one hand, a concern may exist that the quality of materials placement might cause performance problems, and on the other hand the system is sufficiently tangible that problems can be resolved provided there is an assurance program that identifies problems in time to be addressed. Only two concerns appear to impact the concepts as discussed relative to accuracy. The first is discussed in Section 3.20.2.8, concerning establishment of a consistent and appropriate permeability value for compacted salt. The second consideration is the reliability of the expected DRZ healing process, which is an assumption of significant proportion, as discussed in Section 3.20.2.6. The results of studies, calculations, test programs, and engineering principles all appear to produce results favorable to achieving the construction of competent seals in the WIPP shafts.

3.20.2.8. Validity of Outcome

A principal conclusion from the studies and design of the WIPP shaft sealing system is that an effective and implementable design has been documented. Existing technology and use of common materials make this engineered barrier system tangible and realistic. This Panel's evaluation confirms that these attributes are fulfilled and the concepts forwarded are believed to be valid.

Two caveats were identified; however, neither threaten the validity of this model but they warrant further investigation to assure the integrity of the system. First, while the tests showing compactability of the halite adequately demonstrate the principle, to date it has not been possible to qualify an established permeability value in this medium. The principle reason lies with problems in interpretation of the test data, believed due to experimental conditions. Furthermore, having recognized that the halite is capable of being recompacted, it appears that the method of compaction by repetitive dropping of a heavy weight could cause an inhomogeneous, nonuniform packed bed. No evidence could be found that addresses this question as a requirement, as a phenomenological process, or experimentally.

The second caveat concerns the shaft monolith placed in the drift at the base of the sealing column. No evidence could be found that any analysis was made concerning whether this monolith could cause a stress condition at the shaft perimeter interface, which might create a shear zone there. The basis for this concern lies with the reality that the dimension of the monolith is sufficiently large that it creates a base platform supporting what appears to be a rigid column in a viscoelastic medium. Its effect will be that the base will be fixed at the floor datum, which might be upward moving, while the salt above in the far field is flowing downward. It appears that an analyses is warranted to assure that this is not a problem.

3.20.2.9. Adequacy for Implementation

Comments concerning two issues from the preceding section are also applicable to the model's adequacy for implementation: 1) further analysis of the salt compaction data base, firmed up with additional data, is important to support parameter permeability values, and 2) an analysis has not been found to assure the shaft monolith does not create a shear zone at the shaft perimeter interface. Aside from these, the foregoing discussions outline an insightful piece of scientific and engineering work. The shafts and seals program is well thought through and the areas of perceived concern have been addressed to various degrees of detail, each believed sufficiently adequate to support qualifying this model as adequate to proceed in supporting performance assessment.

3.20.2.10. Dissenting Views

There were no dissenting views for this model.

3.21. Gas Generation

3.21.1. Model Description

Gas generation within the disposal rooms after closure was identified as an important process to be considered in analyzing both the undisturbed and disturbed performance at WIPP. The principal features of the model are the production of hydrogen from the corrosion of iron in the waste and containers and production of carbon dioxide, methane, nitrogen and hydrogen sulfide from possible microbial degradation of cellulose, rubber, and plastics in the waste. These reactions are assumed to occur under anoxic conditions after the repository is closed and brine enters the disposal rooms and contacts the waste materials. The model also covers the removal of carbon dioxide from the gas phase by absorption and reaction with a chemical getter, magnesium oxide.

Ten to fifteen years ago it was thought that little water would be available in the dry salt to support either significant corrosion or microbial degradation of cellulose in the waste and that any gas that might be produced would be absorbed into the surrounding salt rock. However, observation of water in the underground workings, seeping from clay seams and in drilled holes, and the results of analyses and hydrologic experiments showed that interstitial water can flow into the repository. This lead to the serious consideration of corrosion and microbial action, through assessments that included laboratory analyses, some of which are ongoing. Three conceptual models have been used to describe gas generation: the so-called rates-and-potentials model, the average-stoichiometry model, and the reaction path model. These are further discussed in Section 3.21.2.3.

The amount of gas production in the repository is of considerable interest to assessment of repository disturbed and undisturbed performance. Gas pressure can counteract the brine inflow from salt, relating it to the Fluid Flow in the Salado model. Gas pressure can also drive brine out of the repository, relating it to the Actinide Transport in the Salado model. It can potentially counteract the closure of the salt around the waste, relating it to the Creep Closure model. It includes reactions that relate to the repository Chemical Conditions model and it can, thereby, also affect the Dissolved and Colloidal Actinide Source Term models. It also can affect the integrity of the Shaft Seals model. Under the various intrusion scenarios, gas is a driving force for potential releases, so it inputs to the Direct Brine Release model, as well as to the Cuttings/Cavings and Spallings models, and provides input material to the Culebra Flow and Actinide Transport models.

3.21.2. Review of Criteria

3.21.2.1. Information Used to Develop the Conceptual Model

The information used to develop the model included the quantities and compositions of the transuranic waste, particularly the quantities of radionuclides and corrodable steel and aluminum, and the quantities of water, cellulose material, and plastics, as well as any chemicals and sludges that could provide nutrients for microbial degradation of these materials. Other important information sources were the observation of brine inseepage into the underground salt cavities, and determination of the chemical compositions of brine in the Salado, in the Castile below, and in the Culebra above the repository. Direct observations were made of halophilic microbes in salt lakes in Nash Draw near the site and in repository inseepage water. Information was also obtained on corrosion-induced hydrogen generation experiments at other sites, measurements of radiolytic gas generation from plastics and water, and controlled

measurements of oxic and anoxic corrosion and microbial degradation rates of cellulose using representative brine and cultured microorganisms from the repository brine. These measurements were done for Sandia at Lawrence Livermore National Laboratory and Brookhaven National Laboratory. There is some ongoing experimental work in this latter area at the Idaho National Engineering Laboratory using actual transuranic waste materials. There is little information on the microbial degradation of plastics.

The information on brine compositions, microbe presence and populations, and the controlled experiments of corrosion and microbial processes are very useful. Due to the length of time of the experiments, no evidence for likelihood of self-limiting conditions on corrosion or microbial action were observed, although it is logical that there will be some self-limiting features that would prevent complete reaction of metal, cellulose, and plastics. A determination of whether microbial action on cellulose would have a net production or consumption of water could not be made from the information available. Experiments of potential radiolysis of water do not appear to allow direct differentiation of gas generation from dissolved versus wet particulate alpha-emitting radionuclides. The ongoing longer term experimental work being conducted at the Idaho National Engineering Laboratory could provide improved resolution of some of this information. However, overall there appear to be adequate data to develop a meaningful conceptual model of gas generation.

3.21.2.2. Validity of Model Assumptions

Regarding hydrogen generation by metal corrosion, a key assumption is that hydrogen is generated by corrosion of steel in waste drums. This is certainly valid. The model also assumes that carbon dioxide and hydrogen sulfide generated by microbial degradation will not passivate steel, which appears very valid based on the corrosion experiments and the addition of magnesium oxide as a carbon dioxide getter. Rates of steel corrosion are assumed to be higher for waste inundated or wetted in brine at the bottom of the room, and rates are somewhat lower for metals above the brine level resulting from wicking. These assumptions appear reasonable based on the direct experimental evidence. In fact, assumed rates based on the reasonably short-term iron corrosion experiments could be somewhat conservative with regard to the timing of gas generation, but probably valid for the overall amount of gas from corrosion of this source of metal.

The model ignores corrosion of aluminum, steel in rockbolts and steel netting, and other equipment to be left in the underground workings. This seems to represent an implicit assumption that corrosion of these

materials will not contribute to gas generation and is based on the relatively small amounts of these materials. Aluminum is apparently on the order of 10% by mass of the steel, based on the summary data in the 1995 Baseline Inventory Report. Aluminum is quite corrodable in brine, and rockbolts can directly contact water seeping from the anhydrite interbed above the disposal rooms. The molar quantity of hydrogen produced per mole of aluminum corrosion would be 1.5, due to the stoichiometry involved. Therefore, it seems only logical to include these materials in the corrosion model to avoid a bias.

The model also assumes that the chemical reaction representing the stoichiometry of anoxic corrosion of iron is

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H2$$

thereby yielding one mole of hydrogen per mole of iron reacted, and consumption of two moles of water. The model assumes that the corrosion of iron is not represented by the reaction

$$Fe + 4/3H_2O \rightarrow 1/3Fe3O4 + 4/3H2$$

as this reaction is not expected at low temperatures, and the amount of hydrogen generated in experiments was consistent with the first equation. Except for the initial period after repository closure, when oxygen is available, this appears valid and reasonable, especially since the chemistry conditions model predicts reducing conditions in the repository.

Regarding microbially induced gas generation, the model assumes that the probability of degradation of cellulose and plastics/rubber will be 50% and that in the event that biodegradation occurs there is a 50% probability that plastics and rubber will also be degraded. This assumption is shown schematically in the diagram below.

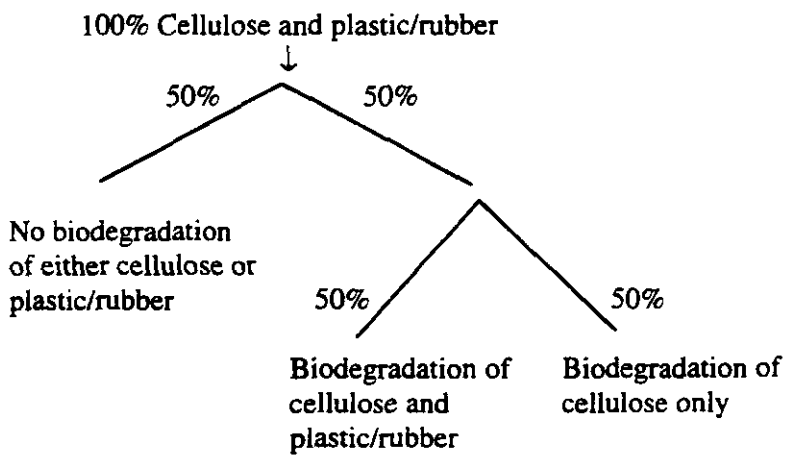

This assumption is based on major uncertainties that are described in Section 3.21.2.4 below, and represents a judgment. For performance assessment purposes, this assumption will result in less gas generation than if one were to assume total consumption of all the organic material. There is apparently no scientific evidence that plastics/rubbers degradation will occur at all with certainty, based on contemporary experience. The possibility that products from microbial degradation of cellulose, and perhaps radiolysis by alpha irradiation, could combine to break down the relatively stable plastics polymers to more consumable fragments suggests the probability should be non-zero. It is difficult to argue for a value higher or more precise than 50%, unless there were more robust long-term data, or experience with plastics degradation in, for example, landfills. Therefore, for performance assessment purposes, the assumption regarding plastics/rubber appears to be adequate.

With regard to the degradation of cellulose, the long list of uncertainties identified in Section 3.21.2.4 below suggests that less than full probability of significant microbial degradation of this more readily consumable material is a reasonably valid assumption. Also, it does not appear scientifically valid to assume that either all or none of the cellulose will be degraded in light of the significant uncertainties that microbial populations would remain viable to the extent of complete cellulose degradation. DOE is not seeking a worst case in performance assessment. Therefore the 50% probability is a reasonable assumption for modeling purposes.

3.21.2.3. Evaluation of Alternatives

The Average Stoichiometry model currently used has been in use since 1991. Its principal features and assumptions have been described in the previous sections. Two alternatives that have been seriously considered are the Rates and Potentials model from about 1989 through 1991, and the Reaction Path model, which was developed between 1992 and 1995, but has not been used.

The Rates and Potentials model used measured rates of gas generation from microbial processes and corrosion and the total potential for gas generation from the available amounts of metal and cellulose. This model assumed no gas generation from plastics, which was controversial. The results of use of this somewhat less involved model demonstrated that gas pressures could have a significant effect on the performance of the repository. This stimulated development of more complex analyses methods involving coupling gas generation with brine flow and incorporating processes of fracturing due to gas

flow into the Salado anhydrite beds. The Rates and Potentials model gave way to the Average Stoichiometry model.

The third model that has been considered is the Reaction Path model in which the reactive gases, carbon dioxide, and hydrogen sulfide produced by microbial action, were assumed to interact with and potentially passivate the surfaces of steel, thereby reducing or potentially stopping the rate of corrosion. Although some passivation was observed in experiments, corrosion films were not judged to be sufficiently adherent. Also, analysis of rates of microbial production of carbon dioxide and hydrogen sulfide showed they would not be present in sufficient quantities to provide passivation. Therefore, the reduced corrosion rates indicated could not be demonstrated reliably and effort on this model was stopped in late 1995. Furthermore, the use of a chemical getter such as magnesium oxide would absorb the carbon dioxide, raise pH and lower actinide solubility, reduce carbon dioxide pressure buildup, and somewhat lower steel corrosion rates at the higher pH.

The alternative models that were seriously considered did not offer sufficient benefits to performance assessment. However, the thermodynamic elements of the more complex Reaction Path model could, in the future, offer improved understanding and more rigorous ability to understand the complex chemical behavior in the repository room. Nevertheless, the purpose of the Gas Generation model to provide input gas generation to other models is adequately met by the Average Stoichiometry model.

3.21.2.4. Uncertainties

There appear to be greater uncertainties in the submodel describing microbial degradation than in the submodel describing metal corrosion. Uncertainties, which have been stated relative to microbial degradation, include the following:

- Will there be adequate populations of microbes capable of surviving for long periods in the disposal environment?
- Will there be adequate nutrients and electron acceptors available from the waste over long periods of time?
- Will sufficient brine enter the room to support the microbes?
- Can chemically toxic metals or radiation destroy or retard otherwise viable microbe populations?

- Will microbial degradation of plastics and rubber occur at all?
- What are the relative amounts of the various gases produced, and will microbes be net producers or consumers of water?

Despite these significant uncertainties, the Gas Generation model will predict significant but not total degradation of cellulose and plastics/rubber. Thus, these uncertainties appear to have been resolved in a conservative manner.

Uncertainties in the submodel describing corrosion-induced hydrogen gas buildup include the amount of metals present; the use of short-term metal rates of corrosion; the potential for oxic corrosion to continue due to radiolysis of water; and the potential for increased amounts of corrosion products from aluminum corrosion or increased rates from iron/aluminum galvanic couples and from corrosion of steel in the repository rock bolts and netting. It is judged that the only one of these that is potentially significant is the amount of added corrosion-induced gases from aluminum in waste and from rock bolts and netting. Another issue is whether some Fe+3 would be produced during the initial period after closure, and later due to continued generation of oxygen from radiolysis, thereby effecting actinide oxidation states.

The radiolysis of water in the waste and in brine, as well as radiolysis of plastics and rubbers, have separately been judged to have an insignificant effect on gas generation compared to the other gas generation mechanisms, and are not included in the gas generation model. For alpha particle irradiation of plastics and rubber, the measured G values (molecules of gas per 100 electron volts) were quite variable over time, leading researchers to conclude that depletion of available hydrogen atoms in plastic/rubber polymers around radioactive particles would stop the generation of such gases. However, over the long term, this conclusion is questionable since the radioactivity and waste can move around and be deformed by salt creep and gas and brine movement. Furthermore, the reported experiments involving radiolysis of brine have used soluble alpha emitters. In this situation the approximately 5 Mev per disintegration would all be dissipated in water. Depending on the solubilities, much of the actinides could remain undissolved. The review of this issue did not cover radiolysis by wetted particulate radioactive materials. This omission could be rather significant. If a significant portion of actinides are not dissolved but remain in small particulate materials that become wetted, a significant portion of the alpha energy could still be deposited in water and generate hydrogen and reactive oxygen species.

A project decision was recently made to add magnesium oxide to buffer the brine pH (in the range of approximately 10) to limit actinide solubility. The model assumes that all carbon dioxide is quickly

dissolved in brine and precipitated as magnesium carbonate, thereby also reducing gas pressure and buffering the pH at 10, rather than about 4 to 5. While this appears clearly desirable, there are significant uncertainties as to whether these benefits will be completely realized. No results have been presented of any consideration of phenomena that could limit the effectiveness of the magnesium oxide. Likewise, there have been no laboratory or pilot scale tests to demonstrate effectiveness. Some potential adverse scenarios that might be considered are as follows:

1. Brine, which slowly enters the room, bypasses the getter and penetrates the drums from below. The current design has no getter beneath the drums.

2. Carbon dioxide, which initially reacts directly in the gas phase with the magnesium oxide getter, creates an insoluble crust around the outer surfaces of the getter, thereby limiting further access of brine and carbon dioxide to the getter. Such a crust might also occur at the water level in the bags of getter stacked around the periphery of the waste rooms.

Thus, the assumption of complete and rapid removal of carbon dioxide appears quite uncertain and, for modeling purposes, seems unjustified in light of such uncertainties. The benefits being counted on in the Chemical Conditions model are extremely significant, which carries with it a very significant obligation to demonstrate the validity of this assumption.

Another uncertainty is whether the heats of the corrosion reactions, and the microbial degradation of the cellulose, will result in elevated temperatures. Analyses of thermal effects of radiogenic heat in contact-handled transuranic waste have shown this source of thermal energy is small. Likewise, analyses of radiogenic heat in remote-handled transuranic waste can result in 38-65°C in the area of canisters but only about 4°C in the repository overall. However, no thermodynamic analysis has been provided to support the single-statement conclusion in the FEP screening document that corrosion and biodegradation do not affect repository temperature due to low enthalpies of the reactions. Heat generated in contact-handled transuranic waste could not dissipate as readily as in remote-handled waste, because of the large mass and dimensions of these relatively low-conductivity wastes. Significant temperature increases could accelerate corrosion rates in the presence of brine and potentially affect other processes, such as creep closure and brine flows. This uncertainty could be resolved readily through a numerical evaluation.

3.21.2.5. Adequacy of the Conceptual Model

The Gas Generation model would represent a reasonable approximation of the most significant processes represented at the conceptual level, were it not for the four potentially significant uncertainties described above. Some modest effort to resolve these uncertainties is needed, as discussed in Section 3.21.2.8.

3.21.2.6. Adequacy of Application

The gas generation model results are applied to the overall performance modeling system known as BRAGFLO, as well as to the Chemical Conditions model. Gas pressures are calculated from molecules of gas produced and assume a reasonable equation of state. As indicated earlier, the assumption that all carbon dioxide is rapidly removed from the gas phase appears somewhat unreasonable in the absence of better chemical and engineering justification for this important assumption. Therefore, this currently represents a discontinuity in the modeling system. The processes not included in the model, including gas generation from aluminum and rock bolts and from radiolysis, represent potential changes in the model but do not affect the modeling application per se. However, if greater thermal effects due to heat generation from corrosion and biodegradation were found through analysis, this could in turn affect other system parameters and processes outside the Gas Generation model.

3.21.2.7. Accuracy of Results

In the absence of key results of the model, it is difficult to draw definite conclusions about what the accuracy of the results will be when implementing a conceptual model. If one were to properly represent the conceptual model in equations, and then properly implement the equations in a numerical system using appropriate data on parameters, the accuracy of results would presumably be that associated with the uncertainties and biases in the conceptual model above, as well as any introduced during implementation, to get numerical results.

The uncertainties and potential biases that have been identified for this model are judged to have a potentially significant effect on its accuracy in predicting gas pressures and other parameters, such as pH and actinide solubilities. However, this judgment could be tempered somewhat if key results of analyses and sensitivity studies were to indicate that the identified uncertainties and biases taken collectively were to show that the effects on waste systems releases under disturbed and undisturbed conditions were small. If this were not the case, changes to the model to account for such effects would be needed. Therefore, it is suggested that results of implementing the Gas Generation model would be useful,

including sensitivities among Gas Generation model variables and brine inflow calculations, and resulting pressure buildup over time. Also, the sensitivity of gas generation to the amounts released from human intrusion scenarios would provide useful information. Such information is believed necessary to make a more useful and informed judgment on accuracy.

3.21.2.8. Validity of Conclusions

There are two issues of concern here, first, whether the predicted outcomes in terms of inputs to other models are valid, and second, whether the outcome of larger issues on disposal system releases are valid in light of remaining issues with the Gas Generation model. A definite conclusion on either point would be somewhat speculative, at least without resolution of several of the issues raised and possibly of the results of sensitivity studies identified. One would also not want to speculate on the validity of conclusions without seeing what the conclusions might be. The following issues have not been adequately resolved:

- Analysis of hydrogen generation by corrosion of metals other than the steel in the waste is inadequate. Ignoring gases generated by corrosion of other metals could result in underestimating the gas pressure in the repository.
- Temperature increases in the repository due to corrosion and microbial degradation are not sufficiently analyzed or characterized. Higher ambient repository temperatures could increase the rates of chemical reactions, fluid flow, and halite creep.
- Due to uncertainties about the effectiveness of the magnesium oxide getter to completely remove CO_2, significant uncertainties exist regarding pH, CO_2 pressure, and actinide solubilities. The chemical conditions in the repository would significantly change if the MgO did not function as planned, and could result in underestimating radionuclide releases.
- Hydrogen and oxygen gas generation from radiolysis of dissolved and wetted particulate actinides have not been adequately evaluated. Radiolysis of cellulose and plastics without assuming local hydrogen depletion has also not been adequately evaluated. Ignoring the gases generated by these effects could result in underestimating the gas pressure in the repository.

3.21.2.9. Adequacy for Implementation

At the conceptual level, without consideration of the integration, accuracy, and conclusions criteria, the conceptual model would be adequate if the significant issues raised above are resolved. However, a bottom line assessment on whether the Gas Generation model, as used in the compliance application, represents a complete reasonable approximation of the actual disposal system, is premature unless the significant issues raised above are resolved and some key results and conclusions are available.

3.21.2.10. Dissenting Views

There were no dissenting views for this model.

3.22. Chemical Conditions

3.22.1. Model Description

This conceptual model has been developed to standardize the chemical conditions of the repository. As such, the data generated by this model are used as input parameters to other conceptual models.

The chemical conditions of the repository are a major influence on actinide solubility. It has been estimated that under specific chemical conditions (low pH), the actinide solubility may increase over expected values by up to five orders of magnitude. This model has used engineering systems to limit such variability. DOE has assumed that equilibrium has been established between the brine in the repository (Castile or Salado), waste forms, and primary minerals. In addition to this basic chemical assumption, a series of other assumptions were made to help facilitate computer code calculations. The assumptions are discussed in further detail below. The defense of model assumptions is presented in Appendix SOTERM, which was not available for the peer review.

Major variables in this conceptual model include brine compositions (fixed chemistry Salado and Castile brines), ligand concentrations, pH, fCO_2, oxidation conditions, mineral stabilities, cement inventories, actinide inventories, and MgO backfill. Of these variables, some can be held constant because of the MgO backfill. The reaction of MgO and CO_2 acts to buffer the pH of the repository and allows other variables to be fixed. The two major variables that will now be constrained are fCO_2 (low fugacity) and pH (between 9 and 10, depending on brine composition).

Certain assumptions are critical to this model. Brine and waste are modeled as a uniform mix of dissolved and solid phases. Thermodynamic equilibrium is assumed for dissolved actinides but not for redox reactions amongst the actinides. Further, chemical homogeneity and solubility equilibrium are assumed. This allows for the assumption of instantaneous reactions. Chemical microenvironments are not believed to persist for this reason. DOE assumes there will not be conditions whereby supersaturation can exist for long periods of time. Temperatures will increase a total of approximately 5.4°C (radioactive decay and exothermic reactions), and it is assumed that there will be negligible effects due to this increase.

DOE believes that calculating mixing of brine from different sources is not amenable to performance assessment. Therefore brine compositions are fixed by performance scenarios. Undisturbed performance and E2 scenarios dictate the use of Salado brine. This is because the Castile Formation is not penetrated. Scenarios E1 and E1-E2 use Castile brine as the solvent for chemical conditions.

Oxidation states of the repository are believed to be reduced. This judgment is based on the thought that available oxygen will be consumed early by oxic corrosion or aerobic microbes. Furthermore, large quantities of iron from 55-gallon drums are consumed by anoxic corrosion, producing hydrogen gas and ferrous iron. Although reducing conditions are expected, redox reactions between dissolved actinides in possible oxidation states are not addressed. DOE assumes this will produce conservative results and increase the total dissolved actinide source term.

Experimental data have shown that acidic conditions greatly enhance the solubility of actinides. Although cement materials in the waste will hydrate to $Ca(OH)_2$, CO_2 produced by microbial degradation of cellulosics will overwhelm this component and force the brine to low pH values. To reduce the potential for highly accelerated actinide dissolution, DOE decided to add MgO to the repository as backfill. The simplified reactions of concern are:

$$MgO + H_2O = Mg(OH)_2$$

$$Mg(OH)_2 + CO_2 = MgCO_3 + H_2O$$

In large enough quantities, the backfill will act as a getter of CO_2 and thereby buffer the liquid, produce low CO_2 fugacities, and provide alkaline conditions in the repository.

Because the addition of MgO will buffer the CO_2 fugacity, many processes that create time-dependent changes in the repository have been negated. The other assumptions imparted on the chemical conditions model, such as fixed ligand inventory, mineral equilibrium (halite, anhydrite, brucite), fixed brine compositions, and fixed actinide inventories have produced a fairly simple system. There is no need for a large computer code to replicate the conditions of the repository. Rather, fixed or calculated (EQ3/6) parameters (pH, fCO_2, phase equilibria, buffering equilibria) from this model are used as input to other, more complex conceptual models.

3.22.2. *Review of Criteria*

3.22.2.1. Information Used to Develop the Conceptual Model

Information used to define the Chemical Conditions conceptual model fall into four main categories: thermodynamic considerations, experimental results, numerical simulations, and results of literature reviews. The first major consideration of this model, equilibrium conditions, is a cornerstone of physical chemistry. The model uses equilibrium conditions between brine and minerals as a given; however, it dismisses the concept of redox equilibrium conditions between dissolved actinide species. The second category, experiments used in the WIPP project (especially gas generation and actinide source terms), have identified significant factors affecting the room chemistry. A clear example is that of WIPP-specific microbes generating large amounts of CO_2 gas. The third major information source is supplied by numerical modeling. Two of these examples are listed. Mineral precipitation sequences were developed from EQ3/6 computational runs. Cement inventories were produced by simple algebraic formulas. The fourth information source came from peer reviewed journal articles. An example would be that of mineral equilibria, such as Felmy and Weare (1986).

The nine FEPs were also used in the development of this conceptual model are:

1. DRG-13, Effects of chemical changes due to gas generation and corrosion.
2. Heat from exothermic reactions and concrete hydration.
3. SP-7, Heat from concrete hydration.
4. Effect of thermal gradient.
5. DR-15, Electrochemical effects.
6. DR-16, Other second-order FEPs similar to electrochemical effects.
7. RNT-25, Electrochemical effects in the repository.
8. SP-5, Chemical degradation of seals.
9. SP-8, Effects of microbial growth on concrete.

It has been decided that this gathering of information is adequate.

3.22.2.2. Validity of Model Assumptions

The major assumptions of the Chemical Conditions conceptual model have been listed in the model description above. To summarize, the assumptions are as follows:

1. Brine and waste are modeled as a uniform mix of dissolved and solid phases.

2. Thermodynamic equilibrium is assumed for dissolved actinides but not for redox reactions among the actinides.

3. Chemical homogeneity and solubility equilibrium are assumed. This allows for the assumption of instantaneous reactions.

4. DOE assumes there will not be conditions whereby supersaturation can exist for long periods of time.

5. It is assumed that there will be negligible effects due to the temperature increase (by radioactive decay and exothermic reactions) of approximately 5.4°C.

6. Brine compositions are fixed by performance scenarios.

7. Oxidation states of the repository are assumed to be reduced.

8. All CO_2 will be fixed by available $Mg(OH)_2$, thereby buffering the pH of the repository.

9. Actinide and ligand inventories are fixed.

Assumption (1) is reasonable when one considers the time frame involved for mixing and the difficulty of trying to numerically represent heterogeneous waste forms. Thermodynamics relies on the principal of equilibrium and, therefore, assumption (2) provides a mixed interpretation. Assuming equilibrium for dissolved actinides is valid, however, DOE claims conservatism by not assuming redox equilibrium. This cannot be considered valid without further explanation and demonstration of the conservatism. Equilibrium of solubilites and chemical homogeneity are a simplifying assumption (3) that should be wholly valid over the time frame involved. The corollary of this assumption, that reactions are instantaneous, is wrong. The effect of kinetics was never taken into account in the model.

Assumption (4) is valid as a simplifying assumption. The trade-off between long-term saturation versus supersaturation and precipitation is valid for modeling. Although assumption (5) may be valid, verification calculations that prove negligible differences have not been provided. Assumption (6) is valid for the scenarios described. In effect, these two brines provide end-member compositions for a

complete solution series. Assumption (7) is valid after approximately 100 years beyond closure. In the short term, oxidizing conditions would prevail. The limits allowed for total waste to be entombed at WIPP provide for assumption (9) to be valid.

Assumption (8) is probably the only assumption in this conceptual model that is physically unfounded and very problematic. From a thermodynamic viewpoint, the reactions are proper and the buffering capability is valid. However, there is no physical evidence that the MgO pellets will be allowed to completely react with the CO_2 generated by microbes. Reaction rims forming on the extremity of the MgO packages may not allow the majority of the backfill to be available for interaction. Such a chemical system would then not be buffered and the brine would become acidic. Studies have not been performed to demonstrate that the present engineering design will in fact work and allow all the MgO to react with CO_2 until the gas is exhausted. This is also discussed in Section 3.21, the Gas Generation conceptual model.

3.22.2.3. Evaluation of Alternatives

The majority of the chemical alternatives are described in Section 3.23.2.3 (Dissolved Actinide Source Term). By fixing many of the chemical parameters at reasonable values for repository conditions, the need for alternative models was not required. The primary alternative that is discussed in this section is whether a chemically reactive backfill is required.

In the early 1990s, no backfill was anticipated for emplacement in the repository rooms. When the test plan for soluble actinides was initiated, a large range of CO_2 pressures and pH values was anticipated. High CO_2 generation would produce sufficient carbonic acid to lower the brine pH to approximately 4 or 5. The basic conditions of the natural Salado Formation brine (9.4) would only allow restricted dissolution of the actinides. Under acidic conditions (pH 4) in experiments, actinide solubility was found to increase by approximately 5 orders of magnitude over that of the natural Salado brine. Such a solubility increase could conceivably present problems to the overall project.

It was then decided to buffer the chemistry of the repository and brines by addition of a reactive backfill. The addition of copious amounts of MgO as backfill is designed to react with the microbially generated CO_2 and buffer the overall chemical conditions of the repository. This would, in effect, fix both the pH and fCO_2 of the brine.

3.22.2.4. Uncertainties

Uncertainties associated with this conceptual model fall into three categories. General uncertainties associated with dissolved or colloidal actinides are discussed in Sections 3.23.2.4 and 3.24.2.4, respectively. This section is restricted itself to uncertainties associated with assumptions presented in Section 3.22.2.2 and the uncertainty of whether phase stability has been adequately characterized. In Section 3.22.2.2., four of the assumptions presented (1, 4, 6, and 9) were deemed to be valid.

The five remaining assumptions presented by DOE were not clearly shown to be valid. The point to keep in mind is what magnitude of uncertainty is associated with each assumption. Although DOE has not validated the assumption of redox disequilibrium (assumption 2), the partitioning of oxidation states into lower and higher oxidation states for model runs has effectively addressed this uncertainty. Assumption 3, that chemical reactions are instantaneous, is not valid. The impact this assumption creates on the conceptual model may be significant. Reactions that are relatively fast present no problem at all. Reactions that take a couple thousand years probably introduce very little uncertainty to the model. It is those chemical reactions that never go to full completion that may invalidate the model. This uncertainty with regard to assumption # 8 is dealt with in detail below.

Assumption #5, that a 5°C increase over STP conditions is negligible, is probably correct. Any uncertainty with this assumption could be clarified with a few verification calculations. The other assumption that contains only a small uncertainty (#7) deals with anoxic conditions in the repository. Even if oxic conditions prevail for the first 1% of the regulatory time frame, only a very small amount of iron would be tied up as oxidized iron oxides (hematite, goethite, leucophane). Although these mineral phases do not react back to reduced phases due to kinetic effects, this is not expected to have any significant effects.

The assumption that $Mg(OH)_2$ will absorb all available CO_2 generated in the repository (assumption #8) contains a very large uncertainty. As mentioned above, there is no uncertainty that the chemical reaction pathway is indeed correct. The uncertainty is whether the engineering design will be effective. If a large portion of the MgO never reacts with CO_2, then the carbonic acid will remain unbuffered and the dissolved actinide source term may increase (depending on model scenario) by up to 5 orders of magnitude. This could be considered a significant uncertainty.

The final uncertainty to be commented on is that of mineral phase stability in the repository. Although the EQ3/6 computer code has been used to qualify which phases will precipitate from solution, no formal phase-stability study has been conducted. There may be phases present that have been overlooked and the consequences of that oversight would impart an unneeded uncertainty. Schreinemakers diagrams have not been calculated to determine the phase-stability fields present in the repository.

3.22.2.5. Adequacy of the Conceptual Model

The present section addresses whether the conceptual model is adequate based on the four criteria above. Since this model strictly consists of a number of chemical condition parameters, it should be easy to evaluate whether the model is valid. It is concluded that the majority of parameters for this model are both reasonable and adequate. For the present model, the uncertainties of the previous section must be dealt with to prove that the model is adequate. Even when one considers the potential uncertainties listed in Section 3.22.2.4, only two could severely impact the adequacy of the Chemical Conditions conceptual model. These are the rigorous treatment of phase stability (Schreinemakers analysis) and the ability for the backfill to sequester the CO_2. For phase-stability analysis, only the omission of a major phase from the stability fields could jeopardize the validity of the conceptual model.

Conversely, the backfill parameter is so key to the model that without test validation that the $Mg(OH)_2$ will work as a getter, the model will not be adequate. The reason is that too many other parameters of this model hinge on the pH and fCO_2 values being fixed.

3.22.2.6. Adequacy of Application

This conceptual model does not flow as total input to a single computer code, rather it functions to set the parameters and boundaries for other conceptual models. As such, the conceptual model does not integrate to larger computer models (e.g., BRAGFLO) in the typical way. Any chemical values or constraints that the model generates should be readily integrated into other conceptual models. If the model provides a specific chemical parameter, that quantity could plug directly into performance assessment codes.

3.22.2.7. Accuracy of Results

This section discusses whether the results of performance modeling using the conceptual model within the performance system are sufficiently accurate to adequately represent the chemical processes occurring. In essence, this question is not applicable to the model in review. There should be no

opportunity to corrupt or distort parameter values from the chemical conditions conceptual model to the performance assessment model. However, this idea has not yet been confirmed by test runs of the performance assessment.

The other manner by which the performance assessment could derive inaccurate results from this conceptual model is to portray thermodynamic assumptions incorrectly. There is no way to judge whether this has happened without viewing the results of the performance assessment runs.

One would assume that the WIPP project can transfer chemical parameter values correctly from the conceptual model to the performance assessment, and that thermodynamic assumptions can be accurately implemented in the same fashion.

3.22.2.8. Validity of Conclusions

This section judges whether the key conclusions that have been drawn on the results of the Chemical Conditions conceptual model in the modeling framework are valid. The conclusions presented here rely heavily on the assumption that $Mg(OH)_2$ buffers the chemistry of the repository and that all stable equilibrium phases have been identified and appropriately considered. If the MgO backfill works as proposed, and all stable phases have been appropriately considered, then it is reasonable to state that the conclusions of this model, as they apply to the full system, are valid.

3.22.2.9. Adequacy for Implementation

The Chemical Conditions conceptual model utilizes a strategy common to the physical sciences, fixing well defined parameters to allow the study of unknowns. For the most part, the model has done a very adequate job of simulating certain physical characteristics of the repository and then determining a reasonable median value. This value has become the fixed parameter (e.g., Salado brine composition) that is then passed on to other models.

To better document that a slight temperature increase in the repository beyond standard temperature and pressure (STP) conditions does not affect the repository chemical conditions, it would be reasonable to validate the assumption with a series of appropriate thermodynamic calculations.

The assumption that chemical reactions are instantaneous led to the belief that all CO_2 released to the brine would be consumed in the repository by MgO. However, this critical chemical process (MgO backfill as buffer) has not been field tested sufficiently to be confident it will work. If the technique does

not perform correctly, then the total model would fail. At a less critical level of model completeness, there is no documentation that a phase-stability review (Schreinemakers analysis) has been performed for the chemical system in question. For these two reasons, and especially that MgO has not been tested as a buffer under WIPP-like conditions, the conceptual model is not yet adequate for implementation.

3.22.2.10. Dissenting Views

There were no dissenting views for this model.

3.23. Dissolved Actinide Source Term

3.23.1. Model Description

This model is based on thermodynamic laws to predict chemical phenomena affecting dissolved actinide concentrations in the presence of actinide-bearing solids. The actinides deemed important to the performance assessment of WIPP are thorium (Th), uranium (U), neptunium (Np), plutonium (Pu), americium (Am), and curium (Cm). The dissolved actinide source term determines the concentration of each actinide in solution by combining the oxidation state distribution of each actinide with the modeled solubility of that oxidation state at repository conditions and the appropriate scenario brine composition (Salado or Castile).

Several oxidation states can be screened out or substantially constrained. Oxidation states initially screened out are Np (+6), Pu (+5), Pu (+6), and Am (+5). The screening rationale are described in Appendix SOTERM (not provided to the Panel for review). Actinides limited to a single oxidation state are Th (+4), Am (+3), and Cm (+3). The model then assumes that the remaining three actinides will exist in only one oxidation state, but is unsure which of two possible states it will be. Therefore, the modeling assumes half the realizations will be in the reduced state (U +4, Np +4, and Pu +3) and half in the more oxidized state (U +6, Np +5, and Pu +4).

The factors controlling dissolved actinide concentrations are equilibrium with anhydrite, halite, MgO, actinide-bearing solid phases, appropriate brine, and water-soluble ligands.

The ligand concentrations used in the calculations are based on the Baseline Inventory Report and are reported to be acetate, citrate, oxalate and EDTA. The concentrations used represent dissolution of the entire ligand inventory. DOE believes this is a conservative approximation for the following two

reasons: (1) it does not reduce the ligand inventory by destruction mechanisms, and (2) although all ligands will dissolve in the first brine volume, the ligand concentration will stay constant for the full simulation.

Folded within the dissolved actinide conceptual model are several conceptual submodels. The solubility submodel is the Fracture-Matrix-Transport (FMT) model, which is based on the Pitzer activity coefficient model of the thermodynamics of highly concentrated electrolytes. This model uses an adaptation of the Harvie-Moller-Weare/Felmy-Weare (HMW/FW) data base. FTM parameters are fitted using the code NONLIN, which calculates the Pitzer parameters. No redox equations are used in FMT; instead, an oxidation state analogy and oxidation distribution state submodel are used.

Soluble actinide concentrations are based on solubility limits (maximum concentrations), or when a cell is partially depleted, by inventory limits. The actinide inventory is depleted on a cell-by-cell basis for the undisturbed, E1, and E2 scenarios. Processes affecting dissolved actinide concentrations in a computational cell are: dissolution of actinide solids, advection of dissolved actinides by brine flow from neighboring cells, diffusion or dispersion from neighboring cells, and interaction with colloidal particles. The E1-E2 scenario assumes homogeneous mixing within the panel for dissolved actinides moving up the borehole.

As mentioned above, the dissolved actinide source term model incorporates a very critical assumption, that of oxidation state analogy. It assumes that all actinides in the same oxidation state (ex. +III) will form the same aqueous species and isostructural solid phases. There is said to be a large data set confirming this for the 3+ oxidation state, but fewer data exist for the 5+ and 6+ oxidation states. It is also noted that such an analogy may not hold to be strictly true for the 4+ oxidation state. The rationale for using the oxidation state analogy is to allow a great reduction in the number of experiments that must be conducted.

A second assumption is that actinide precipitates formed in laboratory experiments will allow the crystallinity to mature with time. Since solids are typically less soluble than amorphous precipitates, laboratory solubility studies can then provide an upper concentration limit. The exception may be that radiolysis could cause certain solids to become more soluble.

A third assumption in the dissolved species model is that no adsorption will occur with immobile substrates in the disposal rooms. DOE however may take credit for adsorption of dissolved actinides to mineral phases in the Culebra Formation, via the Transport of Dissolved Actinides in the Culebra model.

A fourth assumption considers that dissolved actinide concentrations are also coupled to brine compositions in the disposal rooms. DOE expects this capability to greatly enhance their ability to look at site-specific solubilities based on disposal room brines and the effect of engineering modifications on dissolved actinide concentrations.

A fifth assumption centers on the presence of anoxic conditions in the repository setting. Actinide oxidation state distributions are presently unknown, since redox couples are not in equilibrium in low temperature systems. Although it is believed reasonable to expect the actinides to exist in their most reduced state because of anoxic conditions, alpha radiolysis oxidizes Am (III) to Am (V), and Pu (VI) is stabilized in the presence of carbonate. Another potential problem with the assumption is that the repository is actually under oxic conditions for the first few tens of years, due to relict atmosphere and nitrate reactions, and oxidized actinides may encounter kinetic effect problems in attaining their final reduced oxidation state.

3.23.2. Review of Criteria

3.23.2.1. Information Used to Develop the Conceptual Model

The main sources of information used are classical thermodynamics, information gleaned from appropriate journal articles, and experimental programs. The discipline of thermodynamics as a portion of the chemical sciences is well founded. A major assumption of this science is one of equilibrium conditions. The conceptual model has made liberal use of research published in the journals. Items transferred to the dissolved actinide conceptual model from journal articles range from algorithms (Harvie et al. 1987) to phase equilibria fields (Felmy and Weare 1986) to individual thermodynamic parameters (Pitzer 1991). Experimental work on actinide solubility was performed at a number of laboratories, including Sandia, Los Alamos, Argonne National Laboratories, Lawrence Berkeley Laboratory, Pacific Northwest Laboratory, and Florida State University.

Nine FEPs are used in the development of this conceptual model. These FEPs are: effects of chemical changes due to gas generation and corrosion (DR-13), electrochemical effects (DR-15), second order FEPs similar to electrochemical effects (DR-16), effect of thermal gradient (GG-4), heat from exothermic

reactions (GG-7), chemical degradation of seals (SP-5), heat from concrete hydration (SP-7), effects of microbial growth on concrete (SP-8), and electrochemical effects in the repository (RNT-25). Information gleaned from the FEPs was instrumental in both model conceptualization and test plan development.

3.23.2.2. Validity of Model Assumptions

The dissolved actinide source term model is extremely detailed, complex, and contains many implicit and explicit assumptions. One of the most significant of these assumptions is that equilibrium is maintained. Such an assumption is a basic part of thermodynamics and is considered valid only if firmly held to. However, this model picks and chooses when the concept of equilibrium is used. An example is that dissolved actinides are assumed to be in equilibrium with solids; however, redox reactions among actinides and supersaturation are not assumed to be in equilibrium. Such a philosophy may be correct for this model (it builds in conservatism) but each variance must be defended and justified adequately.

The ten other major assumptions are: (1) lack of adsorption onto immobile substrates; (2) anoxic conditions will dominate; (3) dissolved actinide concentrations are based on repository room brine compositions; (4) metastable phases in laboratory experiments become more stable with time; (5) all actinides in the same oxidation state will form the same aqueous species and isostructural solid phases; (6) the oxidation state analogy holds true; (7) experimental runs reached equilibrium; (8) fluids obtained in 1-liter experiments are representative of the tests; (9) all stable phases have been identified; and (10) the hydrogen fugacity system is completely buffered by $Mg(OH)_2$ - $MgCO_3$.

Assumption 1 is probably not valid, but by assuming so in the Salado, DOE has built a conservative estimate. Anoxic conditions in the repository (assumption 2) are valid in the long term, however short term oxidation phases were not considered. This is because activation energies needed to reduce certain oxidized phases may not occur in the repository, and the effect would be to isolate certain phases in an oxidized state. Assumptions 3 and 7 are considered valid. Assumption 4 (metastable phases become stable with time) is not a valid assumption. Time is not the only constraint on the stability of a phase, and there is no documentation that other criteria have been considered. Assumptions 5 and 9 are intimately tied together. The information provided does not confirm that an exhaustive phase equilibria stability study has been performed for this chemical system. In essence, DOE has not proved that the actinides will form the same aqueous species or solid phases, or that all phases have been identified. Regarding assumption 6, the oxidation state analogy is not truly valid. However, the assumption is oft

times conservative. This is the case for the +4 oxidation state that assumes Th solubility values. In the +3 oxidation state, however, values were obtained from another oxidation state (+5) and were not proven to be correct. The test runs for +6 phase (U) could not generate Pitzer parameters or characterize the associated solid phase. In an overall sense, it is probably inaccurate to assume the oxidation state analogy holds true. Assumption 8 (whether final liquids of 1 liter experiments are representative) is not valid due to microdomains and the absence of equilibrium conditions. However, it is not clear that these results were used in the final lookup tables. Finally, assumption 10 is only valid if the CO_2 gas is able to react completely with the $Mg(OH)_2$ backfill. As yet, no discussion exists that sufficiently assures that the reaction will go to completion. There is an equal chance that reaction rims will occur early in the process, isolate a large proportion of the backfill, and not allow the system to be buffered (see also Section 3.21.2.4).

3.23.2.3. Evaluation of Alternatives

The Dissolved Actinide Source Term conceptual model describes the quantity of actinides that would be mobilized as dissolved species in WIPP brine, and would migrate with the brines away from the repository. At one time or another over 18 years, six alternative models were proposed: (1) Expert Panel, (2) Inventory Limits, (3) Inventory Limits with Realistically Conservative Maximum Concentrations, (4) Fresh Water Estimates, (5) Chemical Model for Mobile Actinide Concentrations, and (6) Inventory Limits with Sorption. Of the six models, numbers 1, 4 and 6 were not defensible. As of December 1994, the Expert Panel model was questioned as to its credibility and technical suitability, the Fresh Water Estimate model was essentially undeveloped, and sorptive values for the Inventory with Sorption model were unavailable. Of the remaining three models presented, the Inventory Limits model was complete and defensible but highly conservative. The model that until recently was used as the baseline was the Inventory Limits with Realistically Conservative Maximum Concentrations model. Essentially, this was a combination of the Inventory Limits and Expert Panel models and was intended to be more judiciously conservative than the Inventory Limits model. The Chemical equilibrium model is based on thermodynamics and is robust but was only recently fully developed. The final model for the performance assessment (Chemical Equilibrium Model) will contain submodels that investigate the source terms for both dissolved and colloidal actinide species.

The other realm where a series of alternatives were considered was that of thermodynamic models for activity coefficients. Four modeling approaches were considered by DOE: the Pitzer model, Harned's

Rule (ion pairing), a hybrid of ion pairing and Pitzer formalism, and specific ion interaction (SIT) ion-pairing approach. Harned's Rule was only used for dilute solutions and not for brine more concentrated than 2 molal. Therefore the model was rejected. The SIT model assumes only species with opposite charges interact, and is limited to concentrations up to 3.5 molal. This model was also rejected because of its limitations. The Pitzer-SIT hybrid model did not compare the calculated lanthinide solubilities with data, so the hybrid model was dismissed. The Pitzer formalism has been applied frequently to concentrated electrolyte solutions and is backed by considerable peer reviewed journal articles. This model was therefore judged the most applicable format for characterizing the actinide solubilities in WIPP brines.

3.23.2.4. Uncertainties

There are five groups of relative uncertainty associated with the dissolved actinide source term conceptual model. The first uncertainty involves the experimental results produced by the Actinide Source Term (AST) program, while the other four uncertainties relate to how the experimental results are applied to the conceptual model.

The results of the experimental program exhibit a relatively small uncertainty (Novak 1995; Novak and Roberts 1994). When the solubility data and Pitzer coefficients from the experiments are implemented in FMT, the model results predict an uncertainty of an order of magnitude or less for the chemical conditions tested. The results of FMT modeling also compare favorably with the data of Kim et al. (1985).

The four uncertainties arising from FMT applications to the conceptual model are as follows: (1) is dissolution/precipitation steady state obtained, (2) can FMT data be extrapolated outside the realm of test parameters, (3) is the oxidation state analogy valid, and (4) are WIPP chemical conditions adequately defined? These uncertainties are much more difficult to quantify, therefore, a short discussion of each is given below.

Because of constraints imposed on the time involved in the performance assessment, the uncertainties of dissolution/precipitation steady state are fairly simple. The model assumes a long period of time in which brine will be in contact with waste and this would allow both dissolution and precipitation to equilibrate. Other assumptions that lower the uncertainty of this issue are reduced conditions, lack of

supersaturation, ample solid materials for nucleation and sorption, and brine homogeneity due to long-term mixing. All these assumptions reduce the uncertainties of achieving steady state conditions to a low level.

The second uncertainty, that of extrapolation beyond the realm of test results, has been significantly reduced by the use of MgO backfill. Originally, the experimental tests were carried out over a range of fCO_2 values, but did not entirely cover the conditions expected in WIPP. The use of MgO backfill to provide an $Mg(OH)_2$-$MgCO_3$ buffer has negated this uncertainty. The only potential problem would be if the buffer in effect did not work (see Section 3.23.2.3).

The uncertainties associated with the oxidation state analogy are more ambiguous. Actinides in the +3 state do show the same limited set of solubilities. The +5 (Np) and +6 (U) oxidation state analogies are based on experiments using those specific actinides. The remaining uncertainties all center on the +4 oxidation state analogy. Thorium was used as the test analog and it was determined that Pu and U were slightly less soluble under similar chemical conditions. The analogy of Np to Th in the +4 state was not discussed. The use of Th solubility values is still probably conservative and may raise the total +4 concentration by an order of magnitude.

The last major uncertainty concerns the chemical conditions in the repository of the Salado. The most important parameters are pH, fCO_2, brine major ion concentrations, waste material reducing capability, and organic ligand concentrations. The first two parameters (pH and fCO_2) are well controlled by the addition of MgO backfill. Such a buffering effect allows this uncertainty to be negated. Major ion concentration ranges are well constrained for Salado and Castile brines. They are not so well defined for intrusion of Culebra brine into the repository. DOE believes that the Culebra composition, after mixing with halite or anhydrite, is bounded by the Salado or Castile brines. For two of the four oxidation states, Culebra brines would be within an order of magnitude of other end-member solubilities. The uncertainties for the +4 and +6 oxidation state solubilities is larger than an order of magnitude but undefined. Reduction capabilities of waste are taken care of in a conservative sense by assigning a 50% probability to both the lower and higher oxidation states. The uncertainty concerning organic ligands is resolved by assigning an inventory value that is twice that calculated in the BIR, then incorporating the increased solubility effect of organic ligands on actinides.

In conclusion, the only outstanding large uncertainty (other than assumption validity) is that of the Culebra +4 and +6 oxidation state solubilites.

3.23.2.5. Adequacy of the Conceptual Model

The present section addresses whether the conceptual model is adequate based on the four criteria above. The outstanding issues that must be dealt with are the six unvalidated assumptions stated in Section 3.23.2.2 and the one uncertainty still unresolved in Section 3.23.2.4. When one considers the magnitude and complexity of this conceptual model, and the fact that so many issues are well addressed, these items are not overwhelming. A further nagging problem is that two major appendices of the CCA, NUTS and SOTERM, are not available. If the discussions entailed in the appendices are reasonable and logical, the assumptions are found to be valid, and the uncertainty is resolved properly, then the conceptual model would be wholly adequate.

3.23.2.6. Adequacy of Application

The issue here is whether the individual conceptual model is applied in an acceptable overall performance modeling element. As mentioned above, this is a very complex model with many variables. There is a well-documented data base for thermodynamic modeling of high concentration brines. Such data have served well as a foundation for the model. As an input to the mathematical code NUTS, this conceptual model would present its results in a lookup table. The table takes into account brine compositions, ligand availability, and oxidation state potentials, all of which allow a very robust model to be adequately applied to the performance assessment modeling elements. The true unknowns are to be found in the assumptions that the chemistry rapidly approaches equilibrium and that the waste has uniform characteristics and inventory. These fundamental assumptions are a basis of the conceptual model and are most probably adequate and reasonable.

3.23.2.7. Accuracy of Results

Preliminary results of the lookup tables have been provided to the Panel by a Principal Investigator for the conceptual model. If one assumes that the oxidation state analogy holds true, that the brine stays buffered at a pH of 9 to 10, and that the other assumptions mentioned are valid, then the results of the conceptual model are sufficiently accurate. The only qualification to this opinion is that the results may be too conservative. The solubilities calculated (and determined from experiments) are quite well

defined. To allow an order of magnitude variation on either side of the solubility parameter mean value is probably extreme and not truly representative of the chemical system involved.

The one remaining piece of information needed to thoroughly qualify the accuracy of the results would be a series of sensitivity analyses. These results are not currently available.

3.23.2.8. Validity of Conclusions

This section judges whether the key conclusions that have been drawn on the results of the Dissolved Actinide Source Term conceptual model in the modeling framework are valid. This decision is made more difficult by the fact that the appropriate tables and appendices of the CCA have not been supplied as of this date. If the information not yet available is reasonable and adequate in content, then it is reasonable to state that the conclusions of this model, as they apply to the full system, are valid.

3.23.2.9. Adequacy for Implementation

This model has turned out to be a very strong representation of how actinides would dissolve in the two major brines (Salado and Castile) of the repository and is adequate to support performance assessment. However, this model is closely linked to the Chemical Conditions model discussed in Section 3.22, and to the successful use of MgO to buffer pH conditions in the repository.

For the sake of completeness and accuracy, the remaining concerns listed in Sections 3.23.2.2 and 3.23.2.4 have not been thoroughly documented. These concerns are summarized below:

- What impact does the initial (approximately 100-year) oxygen-rich domain of the repository have on corrosion?
- What were the metastable phases in the laboratory experiments, and what stable phases did they transform to?
- Can a phase equilibria stability determination be performed for this chemical system (same as described in Section 3.22)?
- Is the oxidation state analogy valid for the +4 and +6 oxidation states?
- Did the AST 1-liter liquids reach equilibrium with the solids? If not, were the solubility results still used?
- Does the Culebra brine chemistry affect actinide solubility?

3.23.2.10. Dissenting Views

There were no dissenting views for this model.

3.24. Colloidal Actinide Source Term

3.24.1. Model Description

The Colloidal Actinide Source Term conceptual model describes the concentration of actinides sorbed to or contained in mobile colloidal particles in the disposal rooms and also describes the stable colloids that must be quantified for transport in the Culebra. The actinides addressed with this model are thorium (Th), uranium (U), neptunium (Np), plutonium (Pu), americium (Am), and curium (Cm). Presently, transport of colloids in the Culebra have not been rigorously modeled because of the complexities of coupling hydrogeology, geochemistry, and colloid chemistry. Because of the chemical complexities of the integrated system and high ionic strength brines present, an attempt has been made to characterize the major colloid types believed to be present in the repository.

The four types described are "hard sphere" carrier colloids (mineral fragments), microbes, soft sphere carrier colloids or hydrophilic colloids (humic and fulvic acids) , and intrinsic colloids (true colloids). These particles develop from a variety of processes in the repository, including waste degradation, microbial activity, rock decomposition, and chemical condensation. Intrinsic colloids form by condensation of dissolved actinides in the disposal rooms. Mineral fragments and humic substances provide surfaces that dissolved actinides may sorb to. Microbes actively bioaccumulate actinides intracellularly and also act as substrates for surficially extracellular sorption (Francis 1985).

Four major decisions have been made that greatly simplify this conceptual model. First, DOE has elected to disregard the effects of competition associated with the equilibrium between dissolved actinides and actinides associated with colloidal particles. Therefore, the two source terms are not inexorably linked, resulting in an overestimation of the total concentration of mobile actinides that may leave the repository. Second, in the event that the sum of the concentrations of the dissolved actinide and colloidal actinide source terms for a particular element exceed the inventory limited concentration of that element, then a partitioning scheme is utilized. Instead of basing the partitioning on an equilibrium approach, DOE has decided to use an approach based on conservatism. The concentration of a particular actinide in the inventory is first made available to the most efficient transport mode. If the inventory is not used up, then the next most efficient transport mechanism is filled. This rationale is continued until the inventory

is exhausted by assignment to the five groups of transport vehicles (four colloidal and dissolved actinide source terms). Third, thermodynamic equilibrium is achieved by actinide intrinsic and humic colloids. And fourth, DOE has assumed that microbes and mineral fragments are present in constant quantities in the aqueous phase. This allows a steady state quantity on which the actinides can sorb.

Because of the effect of high ionic strength brines on mineral fragment colloids, which collapses the electric double layer surrounding the colloid, Van der Waals forces can cause agglomeration and settling of such colloids. Laboratory experiments using WIPP brines indicate that this settling effect largely negates mineral fragments as an effective transport mechanism. Thus, DOE has conservatively assigned a mineral fragment concentration for each actinide to be 10^{-9} m/L, one order of magnitude higher than the detection limit of the experiments.

Microbes have a large study base at WIPP, primarily to provide data for the gas generation program. This information has also been helpful in the Colloidal Actinide Source Term model. The source term concentrations associated with microbes are based on actinide uptake experimentally determined from experiments with relevant bacteria cultures. Source term values range from 10^{-5} to 10^{-11} m/L.

Humic and fulvic acids are of particular concern because of their well known capability to complex metal cations, including actinides. These soft sphere carrier colloids are not affected by high ionic strength brines, so they may be important in the transport of actinides at WIPP. To determine humic substance concentrations, actinide complexation constants from WIPP experiments or from literature are coupled with site binding densities and solubilities of humic substances in WIPP brines. Source term values range from 10^{-5} to 10^{-9} m/L.

Intrinsic colloids are well represented by the Pu(IV) polymer. The mechanism of formation of this polymer has not yet been identified; however, it is known to be stable in high concentrations in highly acidic environments. There is some evidence that the polymerization is strongly linked to hydrolysis, and that it produces an amorphous macromolecule that becomes crystalline with time. This polymer is typically on the order of nanometer size range. Hence, it is assumed to act like a hard sphere carrier colloid. Experiments were conducted by over- and undersaturation at a range of pH values to determine concentrations of Pu intrinsic colloids. The source term value of this polymer is 10^{-9} m/L. Other actinide intrinsic colloids (especially Am) were found to have negligible importance.

The computer code that will describe the transport of the Actinide Source Term model is called NUTS. NUTS is dependent on BRAGFLO (chemical conditions in waste rooms) to provide brine volumes and a lookup table to provide actinide concentrations. The actinides that will be tracked in Salado and Culebra Brines by this table are thorium (Th), uranium (U), plutonium (Pu), neptunium (Np), and americium (Am). Other chemical factors originally believed to impact colloidal source terms were pH, pCO_2, major brine constituents, ionic strength, oxidation speciation and organic ligand concentrations. Fixing the brine compositions and the addition of MgO backfill has significantly reduced the number of variables in the lookup table.

3.24.2. Review of Criteria

3.24.2.1. Information Used to Develop the Conceptual Model

The main sources of information used are journal articles, experimental programs, and classical thermodynamics. The conceptual model has made liberal use of research published in the journals. Items transferred to the Colloidal Actinide Source Term conceptual model from the journal articles are voluminous and are the basis of the experimental test program. Experimental work on actinide solubility was performed at a number of laboratories, including Sandia, Los Alamos, Lawrence Livermore, and Brookhaven National Laboratories, and Florida State University. The discipline of thermodynamics as a portion the chemical sciences is well founded. A major assumption of this science is one of equilibrium conditions.

No FEPs were included in the development of this conceptual model. In fact, colloids were not considered as a conceptual model until after the 1992 performance assessment was completed. The study of Ibaraki and Sudicky (1995) is very similar to the conceptual model developed here.

3.24.2.2. Validity of Model Assumptions

The majority of the assumptions used in the colloidal actinide source term are valid, in that they are either accurate scientific extrapolations or based on conservative measures. Four major assumptions made by DOE and discussed in the model description above are most probably valid in the context of this model. To assume that Dissolved and Colloidal Actinides Source Term models do not compete for actinides is certainly conservative and will overestimate the total actinide source term. The partitioning scheme used when the inventory is exceeded is reasonable and again conservative. The assumption that

thermodynamic equilibrium is attained for intrinsic colloids and humic colloids is valid. The assumption that there is a steady state source of mineral fragments and microbes allows for conservatism, in that it provides an abundance of sorbing material.

Two other assumptions in the conceptual model concern the use of bounding calculations. Concentrations of actinides in both intrinsic colloids (Pu+4) and mineral fragments were below the detection limits of the experiments. Therefore, the actual detection limit was used as the bounding value for the intrinsic colloid, and an order of magnitude higher bounding value than the detection limit for mineral fragments. These are probably adequate, possibly overly conservative estimates for concentrations in both cases and can be considered adequate.

3.24.2.3. Evaluation of Alternatives

The Colloidal Actinide Source Term conceptual model describes the quantity of actinides that would be mobilized as colloid species in WIPP brine, and would migrate with the brines away from the repository. At one time or another over the last four years, six alternative models were proposed for the Actinide Source term. The model names are as follows: (1) Expert Panel, (2) Inventory Limits, (3) Inventory Limits with realistically conservative Maximum Concentrations, (4) Fresh Water Estimates, (5) Chemical Model for Mobile Actinide Concentrations, and (6) Inventory Limits with Sorption. Of the six models, numbers 1, 4, and 6 were not defensible. As of December 1994, the Expert Panel model was questioned as to its credibility and technical suitability, and the Fresh Water Estimate model was essentially undeveloped. Sorptive values for the Inventory with Sorption model were unavailable. Of the remaining three models presented, the Inventory model was complete and defensible but highly conservative. The model that, until recently, was used as the baseline was the Inventory Limits with Realistically Conservative Maximum Concentrations model. Essentially, this was a combination of the Inventory Limits and Expert Panel models and was intended to be more judiciously conservative than the Inventory Limits model. The Chemical equilibrium model is based on thermodynamics and is robust but was only recently fully developed. The final model for the performance assessment (Chemical Equilibrium model) will contain submodels that investigate the source terms for both dissolved and colloidal actinide species.

The actinide inventory is originally determined by projections in the Baseline Inventory Report (BIR). A series of chemical reactions that will have a major impact on the colloidal actinide source terms are as follows:

1. Actinide dissolution reactions.
2. Reactions between brines and organic waste.
3. Reactions between brines and backfill materials.
4. Reactions between actinides and dissolved ligands (organic and inorganic).
5. Reactions that produce carrier colloids.
6. Reactions among actinides to produce actinide-intrinsic colloids.
7. Reactions between actinides and carrier colloids to produce radioactive mobile substrates.
8. Actinide sorption onto immobile substrates.

Of the eight reactions listed above, the first seven have been used in developing the current model. DOE has discarded reaction number 8. This decision is thought to be conservative and allows the possibility of more actinides being transported by colloids.

3.24.2.4. Uncertainties

The only uncertainty listed by DOE for this model involves the inventory limited concentration of the actinides. If the sum of the dissolved and colloidal actinides exceeds the inventory total, the actinide concentrations will then be proportioned between the two actinide groups (dissolved and colloidal). This philosophy appears reasonable.

Three lesser uncertainties that would add clarity to the model have not been resolved. First, it has been theorized that the Pu intrinsic colloid would act as a mineral fragment with time. Studies have not proved this theory. The mechanistic operation of this intrinsic colloid has not been determined. A second uncertainty concerns site densities available on microbes for actinides. This parameter has not been determined. Third, it is assumed that humic colloids behave like dissolved actinides. This assumption has not been adequately supported.

3.24.2.5. Adequacy of the Conceptual Model

The present section addresses whether the conceptual model is adequate based on the four criteria above. The conservative bounding values for intrinsic and mineral fragment concentrations should (in a perfect world) be discarded and real measurements taken to obtain scientifically valid results. However, when one considers the magnitude and complexity of this conceptual model, and the fact that so many issues are well addressed, these items appear almost insignificant.

The outstanding issues that must be dealt with are the three unresolved uncertainties in Section 3.24.2.4. A further nagging problem exists in that two major appendices of the CCA are not available (MASS and PAR). If the discussions entailed in the appendices are reasonable and logical, and the uncertainties are qualified, then the conceptual model would be wholly adequate and much more accurate from a scientific viewpoint.

3.24.2.6. Adequacy of Application

This section assesses whether the colloidal actinide source term conceptual model is applied into an acceptable overall performance modeling element. As discussed previously, this complex model has many variables concerning the four colloid types that are merged in. There is a well-documented data base for colloids both from the laboratory experiments specific to WIPP and journal articles. Such a series of articles has served well as a foundation for the model. As an input to the mathematical code NUTS, this conceptual model would present its results in a lookup table. The table takes into account brine compositions, proportionality constants, and oxidation state potentials, all of which allow a very robust model to be applied to the performance assessment modeling elements. The true unknowns are to be found in the assumptions that the chemistry rapidly approaches equilibrium, that the microbe culture is well known, and that the waste has uniform characteristics and inventory. These fundamental assumptions are a basis of the conceptual model and are most probably adequate and reasonable.

3.24.2.7. Accuracy of Results

Draft portions of the lookup tables were provided to the Panel by a Principal Investigator for the conceptual model. If one assumes that the dissolved actinide concentration values are accurate, that the brine stays buffered at a pH of 9-10 due to the addition of MgO, and that the other assumptions mentioned are valid, then the results of the colloidal actinide conceptual model are felt to be reasonably accurate.

The only qualification to this opinion is that the results may be too conservative. To assume concentrations no greater than detection limits of analytical equipment is deemed reasonable by regulatory agencies. However, this method may easily produce inflated values (as applied to intrinsic colloids and mineral fragments). To allow an order of magnitude increase greater than the experimental detection limit for mineral fragments is probably extreme and not truly representative of the chemical system involved.

The one remaining piece of information needed to thoroughly qualify the accuracy of the results would be a series of sensitivity analyses. These results are not currently available.

3.24.2.8. Validity of Conclusions

This section judges whether the key conclusions that have been drawn on the results of the Colloidal Actinide Source Term conceptual model in the modeling framework are valid. Since this model is inexorably linked to the solubility concentrations of the dissolved actinide source term, one may conclude that this model is valid contingent on the validity of the other model (which was determined to be valid, with minor caveats). The overall decision of outcome validity is made slightly more difficult by the fact that the final complete table (6-10) and appendices (PAR and MASS) of the CCA have not been supplied as of this date. If those pieces of information not yet available are reasonable and adequate in their content, then it is sufficient to determine that the conclusions of this model as they apply to the full system, are valid.

3.24.2.9. Adequacy for Implementation

The Colloidal Actinide Source Term model is a reasonable, if somewhat overly conservative representation of how actinides would sorb onto colloids in the two major brines (Salado and Castile) available for the repository. This conceptual model is adequate to support performance assessment. However, this model is closely linked to the Chemical Conditions model (see discussion in Section 3.22 on MgO backfill).

For the sake of completeness and accuracy, the uncertainties listed in Section 3.24.2.4 that would benefit from more supporting evidence are:

- Pu intrinsic colloids are presumed to act like mineral fragments with time, but this assumption is not adequately supported.
- Colloid site densities on microbes have not been thoroughly characterized.
- Humic acid colloids are presumed to behave like dissolved actinides, but this assumption is not adequately documented.

3.24.2.10. Dissenting Views

There were no dissenting views for this model.

4.0 INTEGRATION OF CONCEPTUAL MODELS IN PERFORMANCE ASSESSMENT

For the 24 conceptual models evaluated in Section 3.0 to be collectively useful, they must be integrated into a performance assessment model that adequately represents repository performance. The following paragraphs present a structure (reminiscent of the CCA, performance assessment code sequence) within which conceptual model integration can be illustrated and discussed. The discussion addresses criteria used for the individual conceptual model evaluations in Section 3.0. Since conceptual models are not directly used in the performance assessment, the integration of these models is, in itself, a concept equal in significance to the 24 conceptual component models.

Conceptual models provide the definition of the scope and limits of the issue addressed, define processes, enumerate variables, and provide a framework for consideration of sensitivities within an integrated system definition. The conceptual model specifies the analytical formulations to be used in numerical modeling and their relationships. Process linkages and parameter sensitivities provide a basis for data base planning and data sufficiency assessment. The conceptual model supports judgments used in generalizing data distributions for populating numerical models and supports qualitative judgments like those in the FEP process. A well established and clearly validated conceptual model for each issue is a strong element in the global integration of the overall performance assessment of a site and facility. A robust set of conceptual models for an integrated set of valid issues is the best possible control of site characterization work scope and costs.

The degree of development of conceptual models and their integration within the investigation of issues varied strongly among the models reviewed. In some cases the conceptual model and estimates based on theoretical constructs suggested by the model provided most of the information on which the review was based (for example, the Salado flow model). In some cases no conceptual model relating processes and properties to test results at a useful scale could be propounded. Robust numerical models, based on well developed testing data bases and geostatistical treatments, were successfully substituted for conceptually constrained investigations in some cases (for example, Culebra flow model). The degree to which an unquestionably valid, accurate, and precise modeling result is necessary depends on the consequence of uncertainty in any model system. Some elements of the performance model system could be adequately dealt with by assigning an unquestionably conservative result or by sampling between wide limits, based on credible analytical assessment (for example, the model). Generally, the assessment of consequences and the choice of assigned alternatives depend on strong conceptual model formulations. Where conceptual models failed or were not acceptably replaced, the formulation of a clearly defined and

systematic assessment of the relationship between the issue, processes, and data seemed to be missing. The result was sometimes the overanalysis of inadequate or low quality data or the omission of the consideration of key processes, events, or features.

4.1. Model Integration

Figure 4-1 is an illustration of where the various conceptual models represent their system or subsystem within the CCA performance assessment code sequence. BRAGFLO DBR, as illustrated, is a special, short-term application of BRAGFLO related to a drilling intrusion and includes all conceptual model system representations listed under BRAGFLO plus the Direct Brine Release model. The direct brine release element illustrates that the calculated brine volume removed from the repository by a drilling intrusion is input directly to the CCDFGF. The diamond-shaped element illustrated in the figure that receives input from NUTS and directs that input to SECO TP or CCDFGF is a decision point. If a release into the Salado has occurred, the input is directly to the CCDFGF. If the release involves transport to the Culebra, the input is directed to SECO TP. It is possible for a release scenario where NUTS output is directed to both the CCDFGF and SECO TP.

Figure 4-1 illustrates the primary associations among the conceptual models and the key WIPP performance assessment codes. One conceptual model, Chemical Conditions, is shown twice because it provides primary support to both the BRAGFLO and NUTS codes. As shown in the figure, the conceptual models do not all represent their system or subsystem in the same place in the code sequence. The figure illustrates that the conceptual models, as interpreted through the various codes, are ultimately integrated at the CCDFGF where results are prepared. The figure ignores many preparatory and post-process codes and relationships between codes that are not linear and in one direction. For example, while SANTOS is illustrated as related to BRAGFLO and receiving system representation from the conceptual model for Creep Closure, creep closure results from an iterative relationship between gas pressure, compaction, and brine characterizations from BRAGFLO and the porosity surface in SANTOS.

The integration of the conceptual models, therefore, identifies the overall performance assessment model as a complex structure that represents the 24 conceptual models through preparatory, process, flow and transport, presentation, and enabling codes.

4.2. Review of Criteria

Applying evaluation criteria to the integration of conceptual models as a concept in itself, focuses the discussion on summations of the 24 individual conceptual model evaluations. For example,

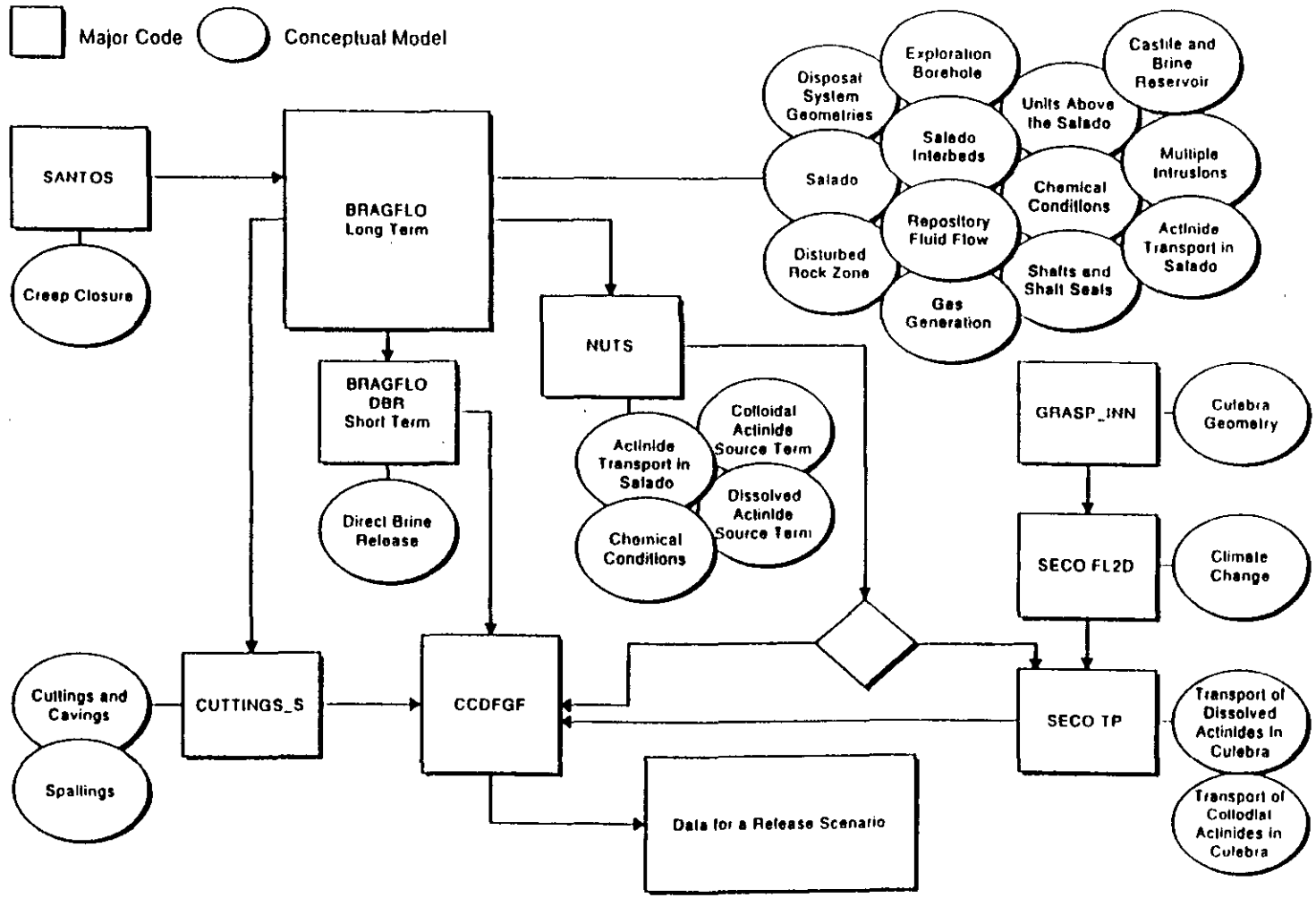

Figure 4.1. Illustration of Conceptual Model Integration

evaluations of information used in the integration, assumptions, uncertainties, adequacies, accuracy, and validity are all based on the individual conceptual models or the implementing mathematical representations or codes. The criteria have already been discussed in Section 3 for the conceptual models and without results of realizations, sensitivity analyses, and uncertainty analyses for the overall system or subsystem, conclusions cannot be made with respect to the implementing mathematics or codes.

Because the overall performance assessment modeling results were not available for Panel review, the overall adequacy for implementation of the integrated conceptual models (PA model) can only be judged at this time through the adequacy of the individual conceptual models. Some of the conceptual models are adequate but there is insufficient information (e.g., results, analysis) for the implementing structure (mathematical representations, codes, code sequence) to be judged adequate or inadequate.

5.0 SUMMARY OF EVALUATIONS

This section presents a summary of the evaluations of the WIPP Conceptual Models Peer Review Panel performed between April 2, 1996 and June 28, 1996. Over 20 years of scientific effort have been expended on the WIPP characterization project and it is beyond the scope of this report to summarize all of the positive factors and scientific evidence compiled. This section is not intended to be a reiteration of comments and discussions on the 24 individual conceptual models, but instead to provide an overview of conclusions from the evaluations. For those models found to be inadequate, the key concerns of the Panel are summarized. With the acceptable resolution of those concerns, the Panel may find most of the models to be adequate. The Culebra Hydrogeology and Units Above the Salado models are exceptions, as discussed below. The Panel's evaluations were made as a best effort over a short period of time when some models were in final development and supporting information was in flux, and therefore it is possible that some key information was available but overlooked.

Of the 24 models reviewed, 13 were found to be adequate for implementation in performance assessment for the WIPP. For most of the adequate models, minor Panel concerns remain and are identified in Section 3. These concerns primarily address issues of documentation gaps and issues with features, events, or processes that were not considered sufficiently important to find the model inadequate. The thirteen models found to be adequate are listed below.

1. Disposal System Geometry
2. Salado
3. Impure Halite
4. Disturbed Rock Zone
5. Actinide Transport in the Salado
6. Transport of Dissolved Actinides in the Culebra
7. Cuttings/Cavings
8. Multiple Intrusions
9. Climate Change
10. Creep Closure
11. Shafts and Shaft Seals
12. Dissolved Actinide Source Term
13. Colloidal Actinide Source Term

The 11 models found to be inadequate are presented in the following paragraphs with a brief discussion of the key concerns identified by the Panel. Comprehensive discussions of each of these models are presented in Section 3.

Culebra Hydrogeology

- No conceptual model was developed that explains the variability of hydrologic properties and processes in the Culebra at a scale that is useful in correlating those properties in the numerical hydrologic flow model.

- An extensive hydrologic testing data base and an apparently adequate numerical flow model were developed as a substitute for performance assessment purposes.

Although the Culebra Hydrogeology conceptual model was found to be inadequate to support numerical modeling, this inadequacy was inconsequential for performance assessment because an extensive hydrologic data base was developed and serves as an adequate substitute to support numerical modeling.

Repository Fluid Flow.

- The conceptual model and its two-dimensional numerical implementation may unrealistically restrict brine movement within the repository to the anhydrite interbeds because of the shallow depths of the borehole and shaft model cells. These restrictions could result in underestimating brine migration in the interbeds toward the accessible environment.

- The conceptual model and its two-dimensional numerical implementation do not include the presence of the unplugged ERDA-9 borehole within the wall of the operations area. This borehole could provide a pathway for gas and possibly brine to the ground surface, and no description of the plugging plan for this hole was seen in the documentation provided to the Panel.

- The sensitivity of model results to the selection of constant permeability values for the waste, panel seals, and repository DRZ has not been evaluated for the current performance assessment. Early time permeabilities may be significantly greater than the model parameter for each of these media, and could lead to underestimating radionuclide releases.

- The long-term performance of the panel closure seals has not been subjected to a detailed engineering evaluation of the type performed for the shaft seals. The role of the panel seals in restricting brine flow among the waste panels and into other parts of the repository is an important element of the conceptual model and its implementation in performance assessment.

Salado Interbeds.

- The conceptual model does not consider how the physical properties of the bounding clay seams affect model fracture propagation and permeability. Ignoring the characteristics of the

clay seams may significantly overestimate the threshold pressure at which repository gases may be released.

Units Above the Salado.

- The conceptual models and the testing data base are inadequate to exclude the Dewey Lakes Redbeds and the Magenta Dolomites as potential transport pathways for radionuclides in the event of an intrusion.

- The analysis of brine flow in the intrusion scenarios limits the quantity of radionuclides reaching the region above the Culebra to such small amounts that transport in the Dewey Lakes and Magenta have negligible consequences.

The Units Above the Salado conceptual model was found to be inadequate to support the assumption that the Culebra is the only horizon above the Salado capable of significant radionuclide transport. This inadequacy was inconsequential for performance assessment because of modeling results indicating that long-term fluid flow in exploration boreholes above the Culebra was negligible because of relatively high permeability and low pressure in the Culebra.

Transport of Colloidal Actinides in the Culebra.

- The conceptual model does not adequately support the assumption that dissolved actinides will not interact with Culebra colloids. Ignoring this phenomenon could overestimate the travel time calculated for radionuclides to reach the accessible environment.

- The experimental K_ds determined for this model are not fully defensible. Such values may overestimate the retardation of actinides in the Culebra.

- Recent experimental work to support assumptions and data for this model has not yet been published and was not available for Panel review.

Exploration Boreholes.

- The potential for releases or changes in repository conditions from borehole penetrations in the operations and experimental areas of the repository does not appear to have been evaluated. Radionuclides that may have migrated into those areas through the panel closures by diffusion or other transport mechanisms could be released to the ground surface, and gas pressures could be relieved by such boreholes. Also, brine could migrate into those areas from a borehole and then into the waste panels.

- The assumption that shorter (40 m) borehole plugs beneath the repository horizon will not significantly degrade during the 10,000-year regulatory time frame has not been adequately supported. For the two- and three-plug configurations, degradation of these plugs could result in creation of a low permeability pathway for fluid migration between the Bell Canyon and the repository. For the three-plug configuration, degradation could result in increased fluid migration from a Castile brine reservoir to the repository.

- The possibility that an effect on the repository could result from Castile brine encountered in an E1 borehole that is assigned a three-plug configuration does not appear to have been considered in the conceptual model. Castile brine could enter the repository during drilling before the borehole is cased and result in increased rates of corrosion, waste degradation, and gas production.

- The sensitivity of the performance assessment to the simplified approach taken to determine reference conditions for BRAGFLO output does not appear to have been evaluated for the current model configuration. If reference conditions are not provided at sufficiently frequent time intervals, the modeling results may be erroneous.

Spallings.

- The conceptual model for channel flow of gases toward an exploratory borehole appears to be valid but has not been adequately evaluated. Spallings is a potentially important mechanism for direct waste release to the ground surface.

- The conceptual model for waste erosion by flowing gases has not been adequately defined. The model describing the source(s) of waste erosion resistance and the parameter(s) characterizing that resistance have not been adequately evaluated. Errors in this conceptual model could lead to overestimating or underestimating the volume of waste released in the spallings process.

- The waste has not been adequately characterized and the understanding of its physical properties in its decayed state has not been adequately developed to support the Spallings model. An adequate understanding of waste erosion processes requires an adequate understanding of the properties of the waste.

Direct Brine Release.

- The basis for the assumption that radionuclides do not accompany the direct discharge of Castile brine has not been adequately supported. This assumption could lead to underestimating radionuclide releases.

- Radionuclide transport through entrainment of brine and waste solids in rapid, two-phase liquid/gas releases during inadvertent borehole intrusions does not appear to have been evaluated. This transport mechanism may be an important component of the conceptual model.

- Releases resulting from flow into an exploration borehole intersecting a disturbed rock zone in the wall of a waste panel do not appear to have been evaluated. Large, open fractures in the walls could significantly increase the local halite permeability, allowing gas and brine to migrate through the borehole to the ground surface.

Castile and Brine Reservoir.

- The basis for excluding larger, potentially depressurized brine reservoirs from performance assessment has not been adequately supported. Larger reservoirs may have greater brine flow volumes and may result in greater radionuclide releases.

- The basis for the concept of reservoir depletion through previous borehole penetrations has not been adequately supported. Non-depleted reservoirs may have greater brine flow volumes and may result in greater radionuclide releases.

- The expected probability of encountering pressurized brine beneath the waste panels has not been adequately supported, nor has the basis for apparently ignoring the quantitative value of site-specific geophysical data been presented. Unrealistically low probabilities of encountering brine may result in underestimating radionuclide releases.

Gas Generation.

- The conceptual model does not consider aluminum in the waste, steel in the rock bolts and netting, radiolysis of water by undissolved alpha emitters, and radiolysis of plastics and cellulose as sources of additional hydrogen, oxygen, and other gases. Ignoring gases generated by these effects could result in underestimating the gas pressure in the repository.

- An adequate basis has not been presented for the assumption of complete and rapid carbon dioxide removal by magnesium oxide in the waste panels. The chemical conditions in the repository would significantly change if the magnesium oxide did not function as planned, and could result in higher radionuclide releases than the model would estimate.

- An adequate basis has not been presented for ignoring the effects of heat generation from corrosion and microbial action. Higher ambient repository temperatures could increase the rates of chemical reactions, fluid flow, and halite creep.

Chemical Conditions.

- The combined temperature increase (due to radioactive decay and exothermic reactions) and its effect on repository conditions has not been adequately addressed. Significantly higher repository temperatures could accelerate chemical reactions, fluid flow, and halite creep rates.

- Phase equilibria have not been critically assessed within the chemical parameters of the conceptual model. A major element stable phase that was overlooked could significantly alter the chemical conditions of the repository and vary the actinide source terms.

- The MgO backfill has not been demonstrated to be able to react completely with CO_2 generated by microbial action. If the MgO backfill did not react as planned, the pH-buffering capability of the repository would be significantly compromised, and could result in underestimating the actinide source terms.

6.0 REFERENCES

Bachman, G.O., 1987. *Karst In Evaporates in Southeastern New Mexico.* SAND86-7078. Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L., 1987. *Interpretations of Single-Well Hydraulic Tests Conducted at and near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987.* SAND87-0039. Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L., 1989. *Interpretation of H-11b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site.* SAND89-0536. Albuquerque, NM: Sandia National Laboratories.

Berglund, J.W., 1996. *WIPP Performance Assessment User's Manual for CUTTINGS_S.* A Reference Manual on the Theory and Numerical Methods Underlying the WIPP Code CUTTINGS_S, Appendix/A (Draft).

Berglund, J.W., 1992. *Mechanisms Governing the Direct Removal of Wastes from the WIPP Repository Caused by Exploratory Drilling,* SAND92-7295. Albuquerque, NM. Sandia National Laboratories.

Berglund, J.W., and L.R. Lenke, 1995. *One Dimensional Experiment of Gas Induced Spall,* NMERI Contractor Report 1995, 3 February, 1995. WPO #27589.

Borns, D.J., 1987. *Rates of Evaporite Deformation: The Rule of Pressure Solution.* SAND85-1599. Albuquerque, NM: Sandia National Laboratories.

Borns, D.J., and J.D. Stormont, 1988. *An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone.* SAND87-1375. Albuquerque, NM. Sandia National Laboratories.

Borns, D.J., and J.D. Stormont, 1989. *The Delineation of the Disturbed Rock Zone Surrounding Excavations in Salt,* Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Proceedings of the 30th U.S. Symposium, West Virginia University, Morgantown, WV, June 19-22, 1989. Ed. A.W. Khair. SAND88-2230C, pp. 353-360. Brookfield, VT: A.A. Balkema.

Borns, D.J., M.C. Pfeifer, H.T. Andersen, C.K. Skokan, 1990. *Electrical Methods to Delineate Fluid Flow In Situ in Bedded Salt.* Society of Exploration Geophysicists Workshop on Permeability, Fluid Pressure and Pressure Seals in the Crust, Denver, CO, August 5-8, 1990. SAND90-1685A. Albuquerque, NM: Sandia National Laboratories.

Borns, D.J., 1996. *Proportion of the Waste Panel Area, WIPP Site, that is Underlain by Brine Reservoirs in the Castile Formation as Inferred from Transient Electromagnetic Method (TEM or TDEM) Surveys.* Memorandum to Margaret Chu, Albuquerque, NM: Sandia National Laboratories, 20 February.

Brinster, K.F., 1991. *Preliminary Geohydrologic Conceptual Model of the Los Medanos Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment.* SAND 89-7147. Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M., and F.T. Mendenhall, 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR Part 191, Subpart B.* SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M., S.W. Webb, and J.W. Berglund, 1994. *Disposal Room and Cuttings Models - White Paper for Systems Prioritization and Technical Baseline,* WIPP Project document.

Butcher, B.M., 1995a. *Waste Compressibility Curve Predictions,* Memorandum of Record. Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M., J.T. Holmes, 1995b. *Completion of Milestone DR015, Definition of Closure Analysis Input Parameters, Due March 31, 1995,* memo to Les Shepard and Martin Tierney. Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M. 1996. *A Summary of the Sources of Input Parameter Values for the Final Porosity Surface Calculations.* SAND96-XXXX. Albuquerque, NM: Sandia National Laboratories. Draft.

Campbell, A.R., F.M. Phillips, 1995. *Stable Isotope Study of Soil Water, WIPP Site New Mexico: Estimation of Recharge to Rustler Aquifers.* Radioactive Waste Management and Environmental Restoration (in press).

Chan, K.S., S.R. Bodner, A.F. Fossum, D.E. Munson, 1994, *Constitutive Representation of Damage Development and Healing in WIPP Salt.* SAND94-2136C. Albuquerque, NM: Sandia National Laboratories.

Chan, K.S., D.E. Munson, A.F. Fossum, and S.F. Bodner, 1995. *Inelastic Flow Behavior of Argillaceous Salt.* SAND94-3017. Albuquerque, NM: Sandia National Laboratories.

Chapman, J.B., 1986. *Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area.* EEG-35. Santa Fe, NM: New Mexico Environmental Evaluation Group.

Chieslar, J.D., 1996. *Materiel Property (Permeability, Bulk Moduli) Determination for Material WIPP Shaft Seals/Components, Calculation File 325/13/01,* prepared by RE/SPEC Inc., Rapid City, SD, for Sandia National Laboratories, Albuquerque, NM.

Christian-Frear, T.L., and S.W. Webb, 1996. *Effect of Explicit Representation of Detailed Stratigraphy on Brine and Gas Flow at the Waste Isolation Pilot Plant.* SAND94-3173. Albuquerque, NM: Sandia National Laboratories.

Corbet, T., and M.G. Wallace, 1993. *Post-Pleistocene Patterns of Shallow Groundwater Flow in the Delaware Basin, Southeastern New Mexico and West Texas,* New Mexico Geological Society Guidebook, 44th Field Conference, Carlsbad Region, New Mexico and West Texas. 321-325.

Corbet, T., 1995a. *FEP (Features, Events, and Processes) NS-8 and 8b,* Summary Memo of Record, Albuquerque, NM: Sandia National Laboratories, 21 September.

Corbet, T., 1995b. *FEP (Features, Events, and Processes) NS-9,* Summary Memo of Record - Two-Dimensional Assumption for Culebra Calculations. Albuquerque, NM: Sandia National Laboratories, 21 September.

Corbet, T., 1996a. *FEP (Features, Events, and Processes) NS-8,* Memo of Record - Clarification of NS-8 in Response to CAO Surveillance S-96-04. Albuquerque, NM: Sandia National Laboratories, 5 April.

Corbet, T., 1996b. *Non-Salado Record Package: Culebra Transmissivity Zone. Climate Index.* Memo to NWM Records Center, Albuquerque, NM: Sandia National Laboratories, 24 April.

Corbet, T., M. Wallace, 1993. *Post-Pleistocene Patterns of Shallow Groundwater Flow in the Delaware Basin, Southeastern New Mexico and West Texas.* New Mexico Geological Society Guidebook, 44th Field Conference, Carlsbad Region, New Mexico and West Texas, pp. 321-325.

CSDR, 1996. Appendix D.

Dale, T., and L.D. Hurtado, 1996. *WIPP Air-Intake Shaft Disturbed Rock Zone Study, 4th Conference on the Mechanical Behavior of Salt,* Montreal, Quebec, Canada.

de Marsily, G., 1986. *Quantitative Hydrogeology.* Academic Press, Inc., Orlando, Florida.

DOE (U.S. Department of Energy), 1995. *Waste Isolation Pilot Plant Sealing System Design Report.* DOE/WIPP-95-3117. Oak Ridge, TN: Office of Scientific and Technical Information.

DOE (U.S. Department of Energy), 1996. *Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant.* DOE/CAO-96 CCA, U.S. Department of Energy, Carlsbad Area Office, Carlsbad, New Mexico (Draft).

Domski, P.S., D.T. Upton, and R. Beauheim, 1996. *Hydraulic Testing Around Room Q: Evaluation of the Effects of Mining on the Hydraulic Properties of Evaporites.* Albuquerque, NM: Sandia National Laboratories, March 1996.

Earth Technology Corporation, 1988. *Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site.* SAND87-7144. Albuquerque, NM: Sandia National Laboratories.

EPA (U.S. Environmental Protection Agency), 1990a. *Background Document for the U.S. Environmental Protection Agency's Proposed Decision on the No Migration Variance for U.S. Department of Energy's Waste Isolation Pilot Plant.* U.S. Environmental Protection Agency, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1990b. *Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant.* Federal Register, Vol. 55, No. 220, p. 47700, November 14, 1990. Office of Solid Waste and Emergency Response, Washington, D.C.

EPA (U.S. Environmental Protection Agency), *Office of Radiation and Indoor Air, 1996.* 40 CFR 194 Compliance Application Guidance. EPA 402-R-95-015.

Felmy, A.R. and J.H. Weare, 1986. *The Prediction of Borate Mineral Equilibria in Natural Waters: Application to Searles Lake, CA,* Geochim. Cosmochim. Acta v. 50: 2771-2783.

FEP (Features, Events, and Processes) S-1, 1992 and 1993. *WIPP Performance Assessments for Screening of Features, Events and Processes (FEP).* Albuquerque, NM: Sandia National Laboratories.

Freeze, G.A., K.W. Larson, P.B. Davies, 1995. *Coupled Multiphase Flow and Closure Analysis of Repository Response to Waste-Generated Gas at the Waste Isolation Pilot Plant (WIPP).* SAND93-1986. Albuquerque, NM: Sandia National Laboratories.

Freeze, G.A., K.W. Larson, 1996. *Castile Brine Reservoir Pressure.* Memorandum to SWCF-A Records Center, WBS1.2.07.1, Albuquerque, NM: Sandia National Laboratories, May 20.

Freeze, G.A., 1996a. *Castile Brine Reservoir Porosity.* Record Package for Parameter No. 64, WPO 31083. Albuquerque, NM: Sandia National Laboratories, 14 February.

Freeze, G.A., 1996b. *Castile Brine Reservoir Permeability.* Record Package for Parameter Nos. 66, 68, 69, WPO 31070, Albuquerque, NM: Sandia National Laboratories, 14 February.

Freeze, G.A., 1996c. *Castile Brine Reservoir Rock Compressibility.* Record Package for Parameter No. 61, WPO 31084, Albuquerque, NM: Sandia National Laboratories, 14 February.

Freeze, R.A., J.A. Cherry, 1979. *Groundwater.* Prentice Hall Inc., Englewood Cliffs, New Jersey.

Harvie, C.E., J.P. Greenberg, and J.H. Weare, 1987. *A Chemical Equilibrium Algorithm for Highly Non-ideal Multiphase Systems: Free Energy Minimization,* Geochim. Cosmochim, Acta, v. 51: 1045-1057.

Helton, J.C., J.W. Garner, R.P. Rechard, D.K. Rudeen, P.N. Swift, 1992. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 4: Uncertainty and Sensitivity Analysis Results.* SAND91-0893/4. Albuquerque, NM: Sandia National Laboratories.

Helton, J.C., J.W. Garner, M.G. Marietta, R.P. Rechard, D.K. Rudeen, P.N. Swift, 1993. *Uncertainty and Sensitivity Analysis Results Obtained in a Preliminary Performance Assessment for the Waste Isolation Pilot Plant.* Nuclear Science and Engineering, Vol. 114, pp. 286-331.

Helton, J.C., D.R. Anderson, G.L. Baker, et al., 1994. *Effect of Alternative Conceptual Models in a Preliminary Performance Assessment for the Waste Isolation Pilot Plant, Abstract for Nuclear Engineering and Design.* SAND94-2312J. Albuquerque, NM: Sandia National Laboratories.

Holt, R.M., and D.W. Powers, 1988. *Facies Variability and Post-Depositional Alteration within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP-88-004. Carlsbad, NM: U.S. Department of Energy.

Howarth, S., K.W. Larson, T. Christian-Frear, R. Beauheim, D. Borns, D. Deal, A.L. Jensen, K. Knowles, D. Powers, R. Roberts, M. Tierney, S. Webb, 1995. *Salado Flow and Transport Containment Group.* Systems Prioritizations Method-Iteration 2 Baseline Position Paper. Sandia National Laboratories.

Ibaraki, M., and E.A. Sudicky, 1995. *Colloid-Facilitated Contaminant Transport in Discretely Fractured Porous Media. 1. Numerical Formulation and Sensitivity Analysis,* Water Resour. Res., 31(12), 2945-2960.

Jones, C.L., 1974. *Salt Deposits of the Mescalero Plains Area, Chaves County, New Mexico.* OFR 74-190. U.S. Geological Survey.

Jones, C.L., 1975. *Potash Resources In Part of Los Medanos Area of Eddy and Lea Counties, New Mexico.* U.S. Geological Survey Open-File Report 75-507. Denver, CO: U.S. Geological Survey.

Jones, C.L., 1978. *Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico.* U.S. Geological Survey Open-File Report 78-5. Washington, DC: U.S. Geological Survey.

Kim, J.I., Ch. Apostolidis, G. Buckau, K. Bueppelmann, B. Kanellakopoulos, Ch. Lierse, S. Mgirius, R. Stumpe, I. Hedler, Ch. Rahner, and W. Stoewer, 1985. *Chemisches Verhalten von Np, Pu und Am in verschiedenen konzentrierten Salzloesungen,* RCM 01085. Munich, Germany: Institut fuer Radiochemie der Technische Universitaet Muenchen.

Knowles, M.K., 1995a. *Subject: Seal Performance,* Memo to D.R. Anderson dated June 29, WPO 22047.

Knowles, M.K., 1995b. *Record for SP-11 Evaluation of Full Shaft Conceptual Model Seal System,* September 29, Memo to Rip Anderson dated December 20, 1995, WPO 30524.

Knowles, M.K., 1996a. *Transmittal of Seal System BRAGFLO Parameters,* memo sent to M. Tierney, January, 17, 1996. Albuquerque, NM: Sandia National Laboratories.

Knowles, M.K., 1996b. *Testing Damaged Halite Around A Rigid Inclusion. 4th International Conference on the Mechanics of Salt, Montreal, Canada.* SAND96-1151C. Albuquerque, NM: Sandia National Laboratories.

Knowles, M.K., D. Borns, J. Fredrich, D. Holcomb, R. Price, D. Zeuch, T. Dale and R.S. Van Pelt, 1996. *Testing the Disturbed Zone Around a Rigid Inclusion in Salt,* 4th International conference on the Mechanics of Salt, Montreal, Canada.

Knupp, P., 1995. *A Moving Mesh Algorithm for 3D Groundwater Flow Calculations With a Water Table and Seepage Face.* Submitted For Location.

Krieg, R.D., 1984. *Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project.* SAND83-1908. Albuquerque, NM: Sandia National Laboratories.

Lambert, S.J., D.M. Harvey, 1987. *Stable-Isotope Geochemistry of Groundwaters in the Delaware Basin of Southeastern New Mexico.* SAND87-0138. Albuquerque, NM: Sandia National Laboratories.

Lappin, A.R., R.L. Hunter, 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico.* SAND89-0462. Albuquerque, NM: Sandia National Laboratories.

Lappin, A., R. Beauheim, 1996. *Response to Request Number 14 from the Natural Barriers Peer Review Panel.* Memorandum to Victor Harper-Slaboszewicz, Albuquerque, NM: Sandia National Laboratories, 15 May.

Larson, K., 1996. *Supplemental Information on Conceptual Models.* A response to ten questions asked by the Conceptual Models Peer Review Panel on 15 April. Albuquerque, NM: Sandia National Laboratories.

Larson, K., G. Freeze, 1996. *Castile Brine Reservoir Volume Revision.* Memorandum to SWCF-A Records Center, WBS1.2.07.1, Albuquerque, NM: Sandia National Laboratories, 27 May.

LaVenue, A.M., A. Haug, V.A. Kelley, 1988. *Numerical Simulation of Groundwater Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Second Interim Report.* SAND88-7002. Albuquerque, NM: Sandia National Laboratories.

LaVenue, A.M., T.L. Cauffman, and J.F. Pickens, 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume 1: Model Calibration.* SAND89-7068/1. Albuquerque, NM: Sandia National Laboratories.

Lenke, L.R., J.W. Berglund and R.A. Cole, 1996. *Blowout Experiments Using Fine Grained Silica Sands in an Axisymmetric Geometry,* NMERI Contractor Report 1996/7/32250. March, 1996.

Mendenhall, F.T., B.M. Butcher, P.B. Davies, 1991. *Investigations Into the Coupled Fluid Flow and Mechanical Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt.* SAND91-2378. Albuquerque, NM: Sandia National Laboratories.

Marietta, M.G., S.G. Bertram-Howery, D.R. (Rip) Anderson, K.R. Brinster, R. V., Guzowski, H. Iuzzolino, R.P. Rechard, 1989. *Performance Assessment Methodology Demonstration: Methodology Development of Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant.* SAND89-2027, pp. III-14 through III-16, and pp. IV-2 through IV-49.

McTigue, D.F., 1993. *Permeability and Hydraulic Diffusivity of Waste Isolation Pilot Plant Repository Salt Inferred from Small-Scale Brine Inflow Experiments.* SAND92-1911. Albuquerque, NM: Sandia National Laboratories.

Morgan, H.S., C.M. Stone, R.D. Krieg, 1985. *The Use of Field Data to Evaluate and Improve Drift Response Models for the Waste Isolation Pilot Plant (WIPP).* Research and Engineering Applications in Rock Masses, Proceedings of the 26th U.S. Symposium on Rock Mechanics, South Dakota School of Mines and Technology, Rapid City, SD, June 26-28,1985. Ed . E. Ashworth. Brookfield, VT: A.A. Balkema, pp. 769-776.

Morgan, H.S., C.M. Stone, R.D. Krieg, 1986. *An Evaluation of WIPP Structural Modeling Capabilities Based on Comparisons with South Drift Data.* SAND85-0323. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E, A.F. Fossum, P.E. Senseny, 1989. *Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures.* SAND88-2948. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E., K.L. DeVries, 1991. *Development and Validation of a Predictive Technology for Creep Closure of Underground Rooms in Salt.* Proceedings, 7th International Congress on Rock Mechanics, Aachen, Germany, September 16-20, 1991. Ed. W. Wittke. Brookfield, VT: A.A. Balkema. Vol. 1, 127-134.

Munson, D.E., D.J. Holcomb, 1994, et al, *Correlation of Theoretical Calculations and Experimental Measurements of Damage around a Shaft in Salt.* SAND94-2134C. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E., D.J. Borns, M.K. Pickens, D.J. Holcomb and S.E. Bigger, 1995. *Rock Mechanics: Creep Fracture, and Disturbed Rock Zone (DRZ).* Systems Prioritization Method-Iteration 2 Baseline Position Paper. Albuquerque, NM: Sandia National Laboratories.

Novak, C.F., 1995. *Test Plan for the WIPP Actinide Source Term Conceptual Model, and Actinide Concentration Dissolved Submodel.*

Novak, C.F., and K.E. Roberts, 1994. *Thermodynamic Modeling of Neptunium (V) Solubility in Na-CO_3-HCO_3-Cl-ClO_4-H-OH-H_2O Systems,* Symposium on the Scientific Basis for Nuclear Waste Management, Kyoto, Japan, October 21-26.

Nowak, E.J., J.R., Tillerson, T.M. Torres, 1992. *Initial Reference Seal Design: Waste Isolation Pilot Plant.* SAND90-0355. Albuquerque, NM: Sandia National Laboratories.

Osnes, J.D., D.A. Labreche, 1995. *The Effect of Clay Seams and Anhydrite Layers on the Closure of Waste Isolation Pilot Plant Disposal Rooms and Guidelines for Simplifying the Modeled Stratigraphy,* External Memorandum RSI(RCO)-390/7-95/58, RE/SPEC Inc.

Pitzer, K.S., 1991. *Activity Coefficients in Electrolyte Solutions.* Boca Raton, FL: CRC Press, Chapters 1 through 3.

Popielak, R.S., R.L. Beauheim, S.A. Black, W.E. Coons, C.T. Ellingson, R.L. Olsen, 1983. *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant Project, Southeastern New Mexico,* TME-3153, Vols. 1 and 2. Westinghouse Electric Corporation, Carlsbad, New Mexico.

Powers, D.W., R.M. Holt, 1990. *Sedimentology of the Rustler Formation Near the Waste Isolation Pilot Plant (WIPP) Site: Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico.* Geological Society of America Field Trip 14, 1990 Annual Meeting, Dallas, Texas.

Powers, D., 1996. *Analysis Plan for Estimating the Probability that a Drillhole will Intercept a Pressurized Brine Reservoir in the Castile Formation under the WIPP Facilities.* Draft, Albuquerque, NM: Sandia National Laboratories.

Rechard, R.P., W. Beyeler, R.D. McCurley, D.K. Rudeen, J.E. Bean, and J.D. Schreiber, 1990. *Parameter Sensitivity Studies of Selected Components of the Waste Isolation Pilot Plant Repository/Shaft System.* SAND89-2030. Chapter 5, Summary and Conclusions, pp. 153-160.

Reeves, M., G.A. Freeze, V.A. Kelley, J.F. Pickens, D.T. Upton, 1991. *Regional Double-Porosity Solute Transport in the Culebra Dolomite Under Brine-Reservoir-Breach Release Conditions: An Analysis of Parameter Sensitivity and Importance.* SAND89-7069. Albuquerque, NM: Sandia National Laboratories.

Senseny, P.E., 1986. *Triaxial Compression Creep Tests on Salt from the Waste Isolation Pilot Plant.* SAND85-7261. Albuquerque, NM: Sandia National Laboratories.

Siegel, M. D., S. J. Lambert, K. L. Robinson, eds, 1990. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Siegel, M.D., K.L. Robinson, and J. Myers, 1991. *Solute Relationships in Groundwaters from the Culebra Dolomite and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico,* Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico. SAND88-0196, pp. 6-1 to 6-35. Eds. M.D. Siegel, S.J. Lambert, and K.L. Robinson. Albuquerque, NM: Sandia National Laboratories.

Silva, Matthew K., 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP.* EEG-55, Environmental Evaluation Group, Albuquerque, New Mexico.

Sjaardema, G.D., R.D. Krieg, 1987. *A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analysis of Backfilled Shaft and Drift Configurations,* SAND87-1977. Albuquerque, NM: Sandia National Laboratories.

Snyder, R. P., L.M. Gard, 1982. *Evaluation of Breccia Pipes In Southeastern New Mexico and their Relation to the Waste Isolation Pilot Plant (WIPP) Site.* OFR 82-968. U.S. Geological Survey for the U.S. Department of Energy (Interagency Agreement E (29-2)-3627).

Spiegler, P., 1982. *Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site.* EEG-17, Environmental Evaluation Group, Albuquerque, New Mexico, December.

Spiers, C.J., R.H. Brzesowsky, 1993. *Densification Behavior of Wet Granular Salt: Theory Versus Experiment,* proceedings from the Seventh Symposium on Salt, Volume I, pp. 83-92, Elsevier Science Publishers, B.V., Amsterdam.

Stone, C.M., 1996. *Final Disposal Room Structural Response Calculations.* SAND 96-XXXX. Draft, Albuquerque, NM: Sandia National Laboratories.

Stormont, J.C., 1988. *Preliminary Seal Design Evaluation for the Waste Isolation Pilot Plant.* SAND87-3083. Albuquerque, NM: Sandia National Laboratories.

Swift, P.N., 1992. *Long-Term Climate Variability at the Waste Isolation Pilot Plant, Southeastern New Mexico, USA.* SAND91-7055. Albuquerque, NM: Sandia National Laboratories.

Thompson, T.W., W.E. Coons, J.L. Krumhansl, F.D. Hansen, 1996. *Inadvertent Intrusion Borehole Permeability.* Final Draft, Carlsbad Area Office Technical Assistance Contractor (CTAC), Waste Isolation Pilot Plant, Carlsbad, New Mexico, 20 May.

Tierney, M., 1996. *DRZ Rock Compressibility*. Record Package for Parameter Nos. 175 and 191, WPO 32758 and 32871. Albuquerque, NM: Sandia National Laboratories, 28 February.

USBR (U.S. Bureau of Reclamation), 1987. *Design of Small Dams*. Third Edition, U.S. Bureau of Reclamation, Denver, Colorado.

VanSambeek, L.L., D.D. Luo, M.S. Lin, W. Ostrowski, and D. Oyenuga, 1993. *Seal Design Alternatives Study*. SAND92-7340. Albuquerque, NM: Sandia National Laboratories.

Wallace, M.G., 1994. *Three-Dimensional Groundwater Refraction Patterns in the Northern Portion of the Delaware Basin*. A Modeling Study, paper presented at the American Geophysical Union Fall 1994 Meeting, San Francisco, CA.

Wallace, D.R., 1995. *FEP (Features, Events, and Processes) NS-8*, Summary Memo of Record - Approach for NS-8 Section 11 (NS-8b), 28 September. Albuquerque, NM: Sandia National Laboratories.

Wawerski, W.R., C.M. Stone, 1986. *Stress Measurements in Rock Salt Using Hydraulic Fracturing*. SAND86-1034C. Albuquerque, NM: Sandia National Laboratories.

Webb, S.W., K.W. Larson, 1996. *The Effect of Stratigraphic Dip on Brine and Gas Migration at the Waste Isolation Pilot Plant*. SAND94-0932. Albuquerque, NM: Sandia National Laboratories.

Wood, W.W., W.E. Sanford, 1994. *Chemical and Isotopic Methods for Quantifying Ground-Water Recharge in Regional, Semi and Environment*. U.S. Geological Survey, Ms. 1 Stop 431, Reston, VA.

WIPP Performance Assessment Department, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters*. SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories.

WIPP Performance Assessment Department, 1992a. *Long-Term Gas and Brine Migration at the Waste Isolation Pilot Plant: Preliminary Sensitivity Analyses for Post-Closure 40 CFR 268 (RCRA), May 1992*. SAND92-1933. Albuquerque, NM: Sandia National Laboratories.

WIPP Performance Assessment Department, 1992b. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance*. SAND92-0700. Albuquerque, NM: Sandia National Laboratories.

WIPP Performance Assessment Department, 1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B*, SAND92-0700/4, pp. 4-1, 4-3, Section 4.1, Model Geometry.

WIPP Shaft Seal System Design Review, 1996. *Draft WIPP Shaft Seal System Compliance Submittal Design Report, Appendix C, Fluid Flow Analysis*, Albuquerque, NM: Sandia National Laboratories.

APPENDIX A - PANEL MEMBER INFORMATION

John Gibbons, Panel Member, is an independent geosciences consultant residing in Albuquerque, New Mexico. Dr. Gibbons has a Ph.D. in Geology from Syracuse University and Bachelors and Masters Degrees in Geology from the University of Arkansas. Dr. Gibbons has over 25 years of experience consulting to the nuclear industry and regulators. He has been involved since 1965 in several research and field studies of the behavior and geology of bedded salt deposits. He presently is a principal consultant to the Illinois Department of Nuclear Safety in its effort to license a low level nuclear waste disposal facility. His duties include the review of and contribution to work by world class contractors, national laboratories, and state scientific surveys in all aspects of site selection, characterization, and performance assessment. Dr. Gibbons has been a principal investigator for hydrogeology in many low level nuclear waste and uranium mine and mill tailings projects in the southwestern United States since 1976.

Darrell D. Porter, Panel Member, is a Senior Scientist and Manager with Science Applications International Corporation (SAIC). He has a Ph.D. in Mineral Engineering with a specialty in rock mechanics from the University of Minnesota. His M.S. degree from the Colorado School of Mines focused on experimental work in dynamic aspects of rock mechanics. He has 34 years of experience. Much of Dr. Porter's work has been in the field of blasting with high explosives and analyzing effects from a rock mechanics perspective. He has held technical management positions with the Rio Blanco Oil Shale Company where significant testing results paved the way for an effective process development resulting in four patents for Dr. Porter. During the past 13 years, Dr. Porter has supported the U.S. Geological Survey in their site characterization program for the Yucca Mountain Project. The work there included technical reviews, preparation of technical procedures, geological mapping programs, oversight of numerous contributing scientists involved in geologic sampling, mapping, modeling, technical data management, and preparation and implementation of quality assurance programs. He has collaborated with scientists from many of the National Laboratories and Universities on rock fracture and fragmentation issues.

Florie Caporuscio, Panel Member, is a Senior Scientist for Informatics Corporation. He received his Ph.D. in Geology from the University of Colorado, a Masters degree in Geology from Arizona State University, and a Bachelors degree in Geology from the University of Massachusetts. Dr. Caporuscio has 10 years of experience as a geochemist working on issues relating to high level and transuranic waste disposal.

Eric B. Oswald, Panel Member, is a Senior Scientist/Hydrologist-Water Resources Planning Specialist with the Morrison-Maierle Environmental Corporation in Tucson, Arizona. Dr. Oswald has a Ph.D. in Hydrology and Water Resources Administration and a Bachelors degree in Agricultural Economics, both from the University of Arizona. Dr. Oswald has over 25 years of experience relating to mine permitting, hazardous material contamination, flood control and flood plain design, resource damage and conservation, power generation, salinity, solid waste management, and water management. Dr. Oswald has managed many environmental programs for federal and state agencies, and municipalities.

Charles R. Wilson, Panel Technical Coordinator, has 26 years of experience managing a broad range of projects involving hydrogeology and geotechnical engineering, water resources planning, and environmental contamination. Dr. Wilson is a private consultant residing in New Mexico. He has a Ph.D. in Civil Engineering-Groundwater and a Masters degree in Geotechnical Engineering from the University of California at Berkeley. He received his Bachelors degree in Engineering from the University of California at Los Angeles. Dr. Wilson's work has included designing and conducting large scale hydrologic tests in very low permeability, fractured rock; design and regulatory permitting of large mixed radioactive/hazardous waste landfills; development of a national water resources planning agency for the Republic of the Philippines; and design of a site-wide groundwater monitoring system for the U.S. Department of Energy's Idaho National Engineering Laboratory.

Glen Sjoblom, Panel Member, is an independent consultant in the areas of nuclear waste management and safety management, residing in Great Falls, Virginia. He has a Master of Science in Chemical Engineering from University of California, Berkeley, a Bachelors of Science in Chemical Engineering from University of Minnesota, a Certificate in Nuclear Engineering from Bettis Atomic Power School, Pittsburgh, and a Certificate from the Course for Senior Managers in Government, JFK School, Harvard University. His graduate thesis dealt with two phase flow for heat and mass transfer; his undergraduate research dealt with solid liquid state chemical reaction kinetics. He was an officer in the United States Navy. He has held senior technical management positions in four different Federal Agencies over a thirty-year period, in Washington, D.C. He was responsible for the environmental controls aspects of the Naval Nuclear Propulsion Program, while on active Naval Service, including radiation protection, waste management, and environmental monitoring. He was Director of the Office of Radiation Programs at the Environmental Protection Agency, and directed development and promulgation of environmental standards for high level and transuranic waste, uranium mill tailings, Presidential Guidance to Federal Agencies on Occupational Radiation, and improved emergency response capability. He directed improvements in safety regulation and enforcement over nuclear fuel cycle facilities, industrial and

medical uses of radioactive materials, promoted improved cleanup of deactive nuclear facilities, and improved interagency coordination on chemical safety, while a Deputy Division Director at the Nuclear Regulatory Commission. He directed formation of an Environmental Management Advisory Board, and focused on improved public involvement and the use of risk assessment science in environmental restoration and waste management programs, while a Special Assistant Secretary for Environmental Management, Department of Energy. Throughout his career he has utilized risk assessment modeling and methods to promote sound decisions in the public interest.

DETERMINATIONS OF PEER REVIEW MEMBER INDEPENDENCE

C.R. Wilson

Determination of Peer Review Member Independence Form

___ Currently employed by DOE or DOE Contractor? Yes/No

X Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

1978 - 1983 U. of California Lawrence Berkeley Laboratory - Performed field handling study of Hanford Site

1983 - 1985 Hydrotechnique Inc, Berkeley CA - Performed consulting services to Hanford Site

1986 - 1996 Golder Associates Inc - Albuquerque NM - Performed consulting services to Hanford, INEL, Los Alamos Sites

___ Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Charles R Wilson

Date: 3/29/96

Peer Review Manager Approval: John A. Thies 4/8/96 Date

Darrell Porter

Determination of Peer Review Member Independence Form

Yes — Currently employed by DOE or DOE Contractor? Yes/No
yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

SRIC, my employer, has been active as a DOE Contractor for many years. To date I have had no work or other relationship to work on the DOE WIPP Programs.

No — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Darrell Porter

Date: March 29, 1996

Peer Review Manager Approval: John A. Thies — 4/8/96 Date

E.B. Oswald

Determination of Peer Review Member Independence Form

No — Currently employed by DOE or DOE Contractor? Yes/No
Yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

April through August, 1995. Albuquerque, N.M. S.M. Stoller Corporation. Served as Independent Review Team member assisting WIPP, WTAC in the review of data record packages.

No — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: E.B. Oswald

Date: 3/30/96

Peer Review Manager Approval: John A. Thies — 4/8/96 Date

Florie Caporuscio

Determination of Peer Review Member Independence Form

Yes — Currently employed by DOE or DOE Contractor? Yes/No

Yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

4/96 Informatics, Albuquerque NM, Staff consultant Peer Review of WIPP

8/93 – 3/96 Advanced Sciences Inc, Los Alamos Office, Project Manager and Senior technical Lead, Environmental Restoration Project

No — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical. I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Florie A. Caporuscio

Date: 4/1/96

Peer Review Manager Approval: John A. Thies — 4-1-96 Date

Glen Sjoblom

Determination of Peer Review Member Independence Form

1. Currently employed by DOE or DOE Contractor? Yes/No
2. Employed by DOE or DOE Contractor previously? Yes/No

See below

If yes, give dates, location, company, position type work performed.

1. I have a contract with Oak Ridge Institute for Science and Education, to provide an assessment of effectiveness of DOE office of Nuclear Energy Program of Assistance of nuclear reactor safety to Former Soviet Countries; this has no bearing on the proposed peer review at WIPP.
2. I was a special assistant to the Asst. Secy for Environmental Management but was not involved with activities at WIPP.

NO

Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Glen L. Sjoblom

Date: 3/29/96

Peer Review Manager Approval: John A. Thies — 4/8/96 Date

John Gibbons

Determination of Peer Review Member Independence Form

NO — Currently employed by DOE or DOE Contractor? Yes/No

Yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

Battelle ALB, IRT reviewer of WIPP DATA packages 1994-1995
APA, ALB. Site Characterization Technology Research 1992-1993
SNL Civil Systems Inc., High Level WIPP Experiment Planning
1977-1978

NO — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: [signature]

Date: NOV 29/96

Peer Review Manager Approval: [signature] John A. Thies — 4/8/96 Date

CERTIFICATIONS REGARDING ORGANIZATIONAL CONFLICTS OF INTEREST

C.R. Wilson

CERTIFICATION REGARDING ORGANIZATIONAL CONFLICTS OF INTEREST

(Complete and return if there are no known interests relevant to possible organizational conflicts of interest)

I certify to my best knowledge and belief that no facts exist concerning any past, present, or currently planned interests (financial, contractual, organizational, or otherwise) relating to the work to be performed pursuant to this solicitation and bearing on a possible organizational conflict of interest.

Solicitation No._____ Date of Offer _____

Name of Offeror:_____ Signature Charles R. Wilson

Date Signed: 3/29/96 Typed name CHARLES R. WILSON

3. SUPPLEMENTAL INFORMATION

(a) As supplemental information to the organizational conflicts of interest Disclosure or Representation, the Offeror shall provide answers to the following questions (provide a complete explanation for each answer):

(i) Does the Offeror have any involvement with or interests in technologies which may be subjects of the subcontract or which are substitutable for such technologies? This involvement or interest could take any form, including interest in relevant proprietary processes or in patents; interests in energy consuming or producing industries (utilities) or ancillary industries (oil drilling, railroads) which could be affected by the technologies; and interests in energy resources (coal, timber, natural gas, geothermal sites). ( ) Yes (X) No

(ii) Does the Offeror depend upon industries or firms, which could be affected by actions resulting from the subcontract, for a significant portion of its business, or have a relationship (financial, organizational, contractual or otherwise) with such industries or firms? ( ) Yes (X) No

(iii) Where work in support of DOE's regulatory activities is contemplated, could any impact result from these regulatory activities directly to the Offeror, or to its business clients? ( ) Yes (X) No ( ) N/A

(iv) Will Offeror perform any self evaluation or inspection of a service or product, or evaluation or inspection of another with whom a relation-ship exists, including evaluation or inspection of goods or services which compete commercially with the performer's goods or services? ( ) Yes (X) No

(v) Will any of the Offeror's chief executives, directors, or entities which they own or represent, or any of the Offeror's affiliates be involved in the performance of the subcontract? ( ) Yes (X) No

(If "yes" provide an adequate disclosure or representation statement from each such executive, director, entity or affiliate.)

(b) The Offeror shall also provide a description of its experience pertinent to the proposed effort, and resumes of key personnel, a current annual report, and a current 10K statement (if filed by the Offeror).

Darrell Porter

CERTIFICATION REGARDING ORGANIZATIONAL CONFLICTS OF INTEREST

(Complete and return if there are no known interests relevant to possible organizational conflicts of interest)

I certify to my best knowledge and belief that no facts exist concerning any past, present, or currently planned interests (financial, contractual, organizational, or otherwise) relating to the work to be performed pursuant to this solicitation and bearing on a possible organizational conflict of interest.

Solicitation No._____ Date of Offer 3/29/96

Name of Offeror: DARRELL PORTER Signature Darrell Porter

Date Signed: April 2, 1996 Typed name_____

3. SUPPLEMENTAL INFORMATION

(a) As supplemental information to the organizational conflicts of interest Disclosure or Representation, the Offeror shall provide answers to the following questions (provide a complete explanation for each answer):

(i) Does the Offeror have any involvement with or interests in technologies which may be subjects of the subcontract or which are substitutable for such technologies? This involvement or interest could take any form, including interest in relevant proprietary processes or in patents; interests in energy consuming or producing industries (utilities) or ancillary industries (oil drilling, railroads) which could be affected by the technologies; and interests in energy resources (coal, timber, natural gas, geothermal sites). ( ) Yes (X) No

(ii) Does the Offeror depend upon industries or firms, which could be affected by actions resulting from the subcontract, for a significant portion of its business, or have a relationship (financial, organizational, contractual or otherwise) with such industries or firms? ( ) Yes (X) No

(iii) Where work in support of DOE's regulatory activities is contemplated, could any impact result from these regulatory activities directly to the Offeror, or to its business clients? ( ) Yes (X) No ( ) N/A

(iv) Will Offeror perform any self evaluation or inspection of a service or product, or evaluation or inspection of another with whom a relation-ship exists, including evaluation or inspection of goods or services which compete commercially with the performer's goods or services? ( ) Yes (X) No

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(If "yes" provide an adequate disclosure or representation statement from each such executive, director, entity or affiliate.)

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E.B. Oswald

CERTIFICATION REGARDING ORGANIZATIONAL CONFLICTS OF INTEREST

(Complete and return if there are no known interests relevant to possible organizational conflicts of interest)

I certify to my best knowledge and belief that no facts exist concerning any past, present, or currently planned interests (financial, contractual, organizational, or otherwise) relating to the work to be performed pursuant to this solicitation and bearing on a possible organizational conflict of interest.

Solicitation No._____ Date of Offer 4/1/96

Name of Offeror:_____ Signature [signature]

Date Signed: _____ Typed name Eric B.Oswald

3. SUPPLEMENTAL INFORMATION

(a) As supplemental information to the organizational conflicts of interest Disclosure or Representation, the Offeror shall provide answers to the following questions (provide a complete explanation for each answer):

(i) Does the Offeror have any involvement with or interests in technologies which may be subjects of the subcontract or which are substitutable for such technologies? This involvement or interest could take any form, including interest in relevant proprietary processes or in patents; interests in energy consuming or producing industries (utilities) or ancillary industries (oil drilling, railroads) which could be affected by the technologies; and interests in energy resources (coal, timber, natural gas, geothermal sites). ( ) Yes (X) No

(ii) Does the Offeror depend upon industries or firms, which could be affected by actions resulting from the subcontract, for a significant portion of its business, or have a relationship (financial, organizational, contractual or otherwise) with such industries or firms? ( ) Yes (X) No

(iii) Where work in support of DOE's regulatory activities is contemplated, could any impact result from these regulatory activities directly to the Offeror, or to its business clients? ( ) Yes (X) No ( ) N/A

(iv) Will Offeror perform any self evaluation or inspection of a service or product, or evaluation or inspection of another with whom a relation-ship exists, including evaluation or inspection of goods or services which compete commercially with the performer's goods or services? ( ) Yes (X) No

(v) Will any of the Offeror's chief executives, directors, or entities which they own or represent, or any of the Offeror's affiliates be involved in the performance of the subcontract? ( ) Yes (X) No

(If "yes" provide an adequate disclosure or representation statement from each such executive, director, entity or affiliate.)

b) The Offeror shall also provide a description of its experience pertinent to the proposed effort, and resumes of key personnel, a current annual report, and a current 10K statement (if filed by the Offeror).

Florie Caporuscio

CERTIFICATION REGARDING ORGANIZATIONAL CONFLICTS OF INTEREST

(Complete and return if there are no known interests relevant to possible organizational conflicts of interest)

I certify to my best knowledge and belief that no facts exist concerning any past, present, or currently planned interests (financial, contractual, organizational, or otherwise) relating to the work to be performed pursuant to this solicitation and bearing on a possible organizational conflict of interest.

Solicitation No._____ Date of Offer 5/25/96

Name of Offeror: Florie A Caporuscio Signature Florie A Caporuscio

Date Signed: 4/1/96 Typed name_____

3. SUPPLEMENTAL INFORMATION

(a) As *supplemental information to the organizational conflicts of interest Disclosure or Representation*, the Offeror shall provide answers to the following questions (provide a complete explanation for each answer):

(i) Does the Offeror have any involvement with or interests in technologies which may be subjects of the subcontract or which are substitutable for such technologies? This involvement or interest could take any form, including interest in relevant proprietary processes or in patents; interests in energy consuming or producing industries (utilities) or ancillary industries (oil drilling, railroads) which could be affected by the technologies; and interests in energy resources (coal, timber, natural gas, geothermal sites). ( ) Yes (X) No

(ii) Does the Offeror depend upon industries or firms, which could be affected by actions resulting from the subcontract, for a significant portion of its business, or have a relationship (financial, organizational, contractual or otherwise) with such industries or firms? ( ) Yes (X) No

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(v) Will any of the Offeror's chief executives, directors, or entities which they own or represent, or any of the Offeror's affiliates be involved in the performance of the subcontract? ( ) Yes (X) No

(If "yes" provide an adequate disclosure or representation statement from each such executive, director, entity or affiliate.)

(b) The Offeror shall also provide a description of its experience pertinent to the proposed effort, and resumes of key personnel, a current annual report, and a current 10K statement (if filed by the Offeror).

Glen Sjoblom

CERTIFICATION REGARDING ORGANIZATIONAL CONFLICTS OF INTEREST

(Complete and return if there are no known interests relevant to possible organizational conflicts of interest)

I certify to my best knowledge and belief that no facts exist concerning any past, present, or currently planned interests (financial, contractual, organizational, or otherwise) relating to the work to be performed pursuant to this solicitation and bearing on a possible organizational conflict of interest.

Solicitation No _____ Date of Offer 3/25/96

Name of Offeror: Glen L. Sjoblom Signature Glen L Sjoblom

Date Signed: 3/29/96 Typed name _____

3. SUPPLEMENTAL INFORMATION

(a) As supplemental information to the organizational conflicts of interest Disclosure or Representation, the Offeror shall provide answers to the following questions (provide a complete explanation for each answer):

(i) Does the Offeror have any involvement with or interests in technologies which may be subjects of the subcontract or which are substitutable for such technologies? This involvement or interest could take any form, including interest in relevant proprietary processes or in patents; interests in energy consuming or producing industries (utilities) or ancillary industries (oil drilling, railroads) which could be affected by the technologies; and interests in energy resources (coal, timber, natural gas, geothermal sites). ( ) Yes (X) No

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(iii) Where work in support of DOE's regulatory activities is contemplated, could any impact result from these regulatory activities directly to the Offeror, or to its business clients? ( ) Yes (X) No ( ) N/A

(iv) Will Offeror perform any self evaluation or inspection of a service or product, or evaluation or inspection of another with whom a relation-ship exists, including evaluation or inspection of goods or services which compete commercially with the performer's goods or services? ( ) Yes (X) No

(v) Will any of the Offeror's chief executives, directors, or entities which they own or represent, or any of the Offeror's affiliates be involved in the performance of the subcontract? ( ) Yes (X) No

(If 'yes' provide an adequate disclosure or representation statement from each such executive, director, entity or affiliate.)

b) The Offeror shall also provide a description of its experience pertinent to the proposed effort, and resumes of key personnel, a current annual report, and a current 10K statement (if filed by the Offeror).

John Gibbons

CERTIFICATION REGARDING ORGANIZATIONAL CONFLICTS OF INTEREST

(Complete and return if there are no known interests relevant to possible organizational conflicts of interest)

I certify to my best knowledge and belief that no facts exist concerning any past, present, or currently planned interests (financial, contractual, organizational, or otherwise) relating to the work to be performed pursuant to this solicitation and bearing on a possible organizational conflict of interest.

Solicitation No._____ Date of Offer_____

Name of Offeror: John Gibbons Signature [signature]

Date Signed: Mar 29/96 Typed Name_____

3. SUPPLEMENTAL INFORMATION

(a) As supplemental information to the organizational conflicts of interest Disclosure or Representation, the Offeror shall provide answers to the following questions (provide a complete explanation for each answer):

(i) Does the Offeror have any involvement with or interests in technologies which may be subjects of the subcontract or which are substitutable for such technologies? This involvement or interest could take any form, including interest in relevant proprietary processes or in patents; interests in energy consuming or producing industries (utilities) or ancillary industries (oil drilling, railroads) which could be affected by the technologies; and interests in energy resources (coal, timber, natural gas, geothermal sites). ( ) Yes (✓) No

(ii) Does the Offeror depend upon industries or firms, which could be affected by actions resulting from the subcontract, for a significant portion of its business, or have a relationship (financial, organizational, contractual or otherwise) with such industries or firms? ( ) Yes (✓) No

(iii) Where work in support of DOE's regulatory activities is contemplated, could any impact result from these regulatory activities directly to the Offeror, or to its business clients? ( ) Yes (✓) No ( ) N/A

(iv) Will Offeror perform any self evaluation or inspection of a service or product, or evaluation or inspection of another with whom a relation-ship exists, including evaluation or inspection of goods or services which compete commercially with the performer's goods or services? ( ) Yes (✓) No

(v) Will any of the Offeror's chief executives, directors, or entities which they own or represent, or any of the Offeror's affiliates be involved in the performance of the subcontract? ( ) Yes (✓) No

(If "yes" provide an adequate disclosure or representation statement from each such executive, director, entity or affiliate.)

(b) The Offeror shall also provide a description of its experience pertinent to the proposed effort, and resumes of key personnel, a current annual report, and a current 10K statement (if filed by the Offeror).

APPENDIX B - SIGNATURE PAGE

I acknowledge by my signature below that I concur with the findings and conclusions documented in this Conceptual Models Peer Review Report.

Florie Caporuscio

John Gibbons

Eric Oswald

Darrell Porter

Glen Sjoblom

Charles Wilson

PEER 2 - Supplementary Information Regarding Conceptual Models Peer Review

MEMORANDUM

To: M.G. Marietta

From: T.W. Thompson, F.D. Hansen

Date: July 24, 1996

Subject: Long-term Performance of Panel Closures

---

1. INTRODUCTION

After waste has been emplaced in a panel, closures will be built to restrict flow from the panel during the remainder of the operational phase. These closures will include a length of concrete placed in the panel entries. Although it is not the intent of these closures to restrict flow over the regulatory period of 10,000 years, values for their long-term performance characteristics are required to successfully determine their contribution to overall system performance.

Flow of fluids into or out of the panels will be controlled by the conductance of the panel closure, and of the surrounding disturbed rock zone (DRZ). Performance Assessment (PA) calculations use a constant value for DRZ permeability of 10^{-15} m^2, a value which is substantiated in the records package for the waste rooms (reference). Consideration of the current panel closure designs indicates that they will maintain their structural integrity for the regulatory period. If this is the case, then the concrete element of the closure system will continue to provide resistance to inward deformation of the surrounding salt, and will prohibit the growth of the DRZ from its initial state. Since the DRZ will not increase during the regulatory period, and may decrease, the assumption of a constant DRZ permeability is reasonable.

The panel closures have been designed to limit the flow of brine and gas between panels during the operational phase, and current designs call for these operational closures to include concrete elements (Figure 1). Although these closures are designed for an operational use, it is expected that they will continue to provide fluid flow restriction during the post-closure phase. The remainder of this memorandum establishes the permeability expectations of the closures, with emphasis on the potential for concrete degradation and increase in permeability. For the purposes of these analyses the concrete elements are taken to have a length of nominally 26 ft (7.9 m) (USDOE, 1996a,b), and to be made of a material chosen so as to be compatible with the environment, such as Salado Mass Concrete (SMC: Sandia, 1996) or a similar mix. Degradation of the concrete may occur by interaction with brine flowing through the plug, or with brines flowing along the plug/salt interface or in the DRZ.

2. CONCRETE PROPERTIES

The initial permeability expected for the concrete panel closures are documented in the materials specification appendix of the Compliance Submittal Design Report (CSDR) (Sandia, 1996) developed for the shaft seal system. In addition to conventional engineering properties, the SMC has well documented permeability characteristics, permeabilities having been determined from field tests (Knowles and Howard, 1996) and laboratory studies (Pfeifle et al., 1996). Figure 2, taken from the CSDR, summarizes the available data, and indicates a permeability for as-placed SMC of between 2×10^{-21} and 1.8×10^{-17} m^2. For calculations performed in this memorandum a value of 10^{-17} m^2 is used, this being at the high end of the values used by PA for the shaft concrete components, and consistent with other data. For example, data on generic portland cement pastes shows that the permeability of oil field concrete plugs is on the order of 1×10^{-19} m^2, while data from the Bell Canyon Test indicate permeabilities for borehole concrete plugs of 5×10^{-17} m^2 (Petersen and Christensen, 1980; Christensen and Hunter, 1980).

For the purposes of calculating degradation of the concrete member an assumption of porosity is necessary. The expected value is 5 %, which is higher than the 2% estimated by Petersen and Christensen (1980) for the Bell Canyon Test plugs, but is generally consistent with practical experience of field emplaced concrete structures, and is the value for cast in-place SMC given in the CSDR (Sandia, 1996). An upper limit for porosity is taken as 10%, which is an engineering estimate for concrete.

As noted in the introduction, the concrete closure member is expected to be structurally stable for the regulatory period, and to provide support for the surrounding rock and the DRZ. In this context it can be noted that the unconfined compressive strength of SMC is greater than 4500 psi (30 MPa), and that under the confined state of stress within the closure system the ultimate strength will be greater than this (Pfeifle et al, 1996). This strength is sufficient to preclude structural failure of the concrete member in the panel entries.

3. DEGRADATION OF CONCRETE

The solid matrix that makes up concrete is composed almost entirely of amorphous to cryptocrystalline solid phases. These phases are thermodynamically unstable, and with time and exposure to water they alter into more stable and more crystalline assemblages. Thermodynamic calculations conducted by Alcorn et al (1992) have predicted the alteration phases of portland cement due to exposure to a variety of waters and brines as including tobermorite, quartz, gypsum, calcite, clays and zeolite, produced at the expense of soluble and unstable materials such as portlandite. The theoretical alteration assemblage occupies more volume than the original solids. These calculated results have been verified by subsequent experiments in which waters and cement were reacted (Onofrei et al., 1992).

At free surfaces concrete materials are not physically supported and can spall. Long term leaching experiments report that surface diffusion controlled alteration is dependent on the C_3A content of the cement and the Mg and SO_4 content of leachant (Walton et al., 1990). Creation of an alteration rind weakens the concrete and makes it subject to spalling (Wakeley et al., 1994). The mechanism for spalling is that the alteration phases occupy more volume than the original

solids, volumetric expansion increases internal pore pressures until concrete tensile strengths are exceeded and spalling occurs. Short-term, empirical studies of ordinary concrete in brine report alteration rates in the range of 0.7 to 1 mm/year (Atkinson and Hearne, 1990) - These rates are likely to be overestimates because diffusion distance varies as the square root of time. Further details are given in Appendix C of Thompson et al., 1996.

4. DEGRADATION OF CONCRETE PANEL CLOSURES

The concrete elements of the panel closures may degrade in one of two ways, either by flow of brines through the mass of the concrete element, or by flow of brines along the interface.

4.1 Flow Through the Concrete Element

An estimate of the degradation of a concrete closure element may be made based on data on the progression of concrete chemical alteration reported by Berner (1990) for both fresh water and brine leachants (Figure 3). The progression is charted in terms of the volume of water flow, and indicates that more than 100 pore volumes of leachants must pass through concrete before there is chemical evidence that the matrix is being attacked. Based on these results, it has been assumed (conservatively) that the concrete closure elements will degrade significantly after 100 pore volumes of water have passed through them. A more detailed discussion of these results is given in Thompson et. al. (1996).

This volume can be converted to performance life by using Darcy's Law and considering the flow of fluids though the plug and the surrounding DRZ. If there is a pressure difference between the panel and the rest of the repository, flow will occur through the panel closure and the surrounding DRZ, with the two elements acting as flow resistors in parallel (Figure 4). If the pressure in the panel is P_1 (Pa) and in the rest of repository is P_2 (Pa), then under brine saturated conditions, the steady state flow rate out of the panels will be Q, where:

$$Q = A*(k'/\mu)*(P_1 - P_2)/L \quad m^3/sec, \qquad (1)$$

where: A is the total flow area of the panel closure plus DRZ (m^2)
L is the flow length (m)
μ is the fluid viscosity (Pa.s)
k' is the composite permeability of the panel closure plus DRZ (m^2).

The composite permeability, k', is given by:

$$k' = (k_d A_d + k_c A_c)/(A_d + A_c), \qquad (2)$$

where: k_d, k_c are the permeabilities of the DRZ and plug closure respectively (m^2)
A_d, A_c are the flow cross-sectional areas of the DRZ and plug closure respectively (m^2).

The flow through the panel closure, q_c, will be:

$$q_c/Q = k_c A_c/(k_d A_d + k_c A_c). \qquad (3)$$

The pore volume of the panel closure (V_p) is:

$$V_p = A_c L \phi \text{ m}^3,$$

where ϕ is the porosity. The number of pore volumes (N_p) flowing through the closure in unit time will be:

$$N_p = q_c/V_p \text{ pore volumes/sec,}$$

and the time for 100 pore volumes to flow through the closure will be:

$$t_{100} = 100/(N_p * 3.154\text{x}10^7) \text{ years}$$

The current design (USDOE, 1996a,b) calls for a length of 7.9 m (26 ft) for the concrete closure, and a cross-sectional area of 39.6 m^2 (10 m wide by 3.96 m high). As noted in Section 2 an undegraded concrete permeability of 10^{-17} m^2, and a porosity ranging from 5% to 10% may be assumed. The DRZ around the closure is assumed to have a permeability of 10^{-15} m^2. Based on the BRAGFLO grid (reference) the DRZ may be assumed to have a height of 11.95 m above the closure and 2.23 m below. It is assumed that the DRZ in the pillars at either side of the closure heals due to creep closure onto the rigid concrete. The DRZ flow area may therefore be taken as 141.8 m^2 (11.95 + 2.23 m high by 10 m wide).

Given these values, the effective permeability of the closure and the DRZ, from equation (2), is $7.84\text{x}10^{-16}$ m^2, with an effective flow area of 181.4 m^2. When brine flows between the panel and the rest of the repository, from equation (3), only 0.28 % will flow through the closure, the remainder (99.72 %) will be through the DRZ.

An analysis of calculations made with BRAGFLO (reference) using a range of parameters, and assuming permeabilities for the closures and DRZ of 10^{-15} m2, indicates that the maximum cumulative flow between the panel and the rest of the repository for any likely E1 or E2 scenario will be of the order of 10^4 m^3 (Figure 5). With these flows, and the slit in flows indicated above, only 28 m^3 of brine will flow through the concrete closure in 10,000 years. For a porosity range of 5 % to 10 % the maximum cumulative flow through the concrete closure in 10,000 years will therefore be between 0.6 and 1.2 pore volumes. The same point is made in Figure 6, which shows the cumulative flow with closure permeabilities of 10^{-15} to 10^{-17} m^2. Degradation will be minimal with these flow volumes.

4.2 Flow Along the Interface

Flow along the interface may be more rapid due to the higher permeabilities in the DRZ. A maximum effect of this flow might be estimated to be equivalent to the free surface spall rate of 0.5 to 1 mm/yr. Such a degradation rate is unrealistically high, since the degradation will be controlled by the rate of fluid flow, and total loss of material will not occur in a physically constrained region. However this rate of spall is much less than the expected closure rates (measured at the order of 0.1 to 0.2 ft/yr. or 30 to 60 mm/yr in Panel 1: USDOE, 1996b) so even such a rapid spall rate would be more than compensated for by creep of the salt on the closure. It is therefore concluded that the effect of flow along the interface will be minimal. At most it will lead to an insignificant increase in the DRZ flow area.

5. CONCLUSIONS

It is concluded that the potential flow through the concrete closure is nearly two orders of magnitude too small to cause any significant degradation. Degradation caused by flow in the DRZ adjacent to the concrete will be taken up by creep closure. It is therefore concluded that the panel closures will retain their initial permeability in the post-closure phase. If this permeability is 10^{-17} m^2, then the effective permeability of the DRZ and the closure together will be about $8x10^{-16}$ m^2. An assumption of a permeability of 10^{-15} m^2 for the closure and the DRZ is reasonable.

It is also concluded that since no significant degradation is expected for the concrete members, these will maintain their structural integrity and will provide a rigid support to prevent growth of the DRZ during the regulatory period.

6. REFERENCES

Alcorn, S.R., Coons, W.E., Christian-Frear, T.L., and M.G. Wallace, 1992, "Theoretical Investigations of Grout Seal Longevity," Final Report, Stripa Project TR 92-23, SKB, Stockholm, Sweden.

Atkinson, A., Goult, D.J., and Hearne, J.A., 1985, "An Assessment of the Long-Term Durability of Concrete in Radioactive Waste Management." Materials Research Society Symposium Proceedings: Scientific Basis for Nuclear Waste Management IX, v. 50,pp 239-246.

Berner, U., 1990, "A Thermodynamic Description of the Evolution of Pore Water Chemistry and Uranium Speciation During the Degradation of Cement," Technical Report 90-12, Paul Scherrer, Villigen, Switzerland.

Bonen, D., 1996, "Petrographic Analyses of Concrete and Grout Recovered from the WIPP," The Technological Institute, Northwestern University, Interim Report, January 15, 1996, 9pp.

Christensen, C.L. and Hunter, T.O., (1980) "The Bell Canyon Test Results" SAND80-2414C. Sandia National Laboratory, Albuquerque NM

Knowles, M.K., and C.L. Howard, 1996, "Small Scale Seal Test Results," Waste Management '96, Tuscon, AZ.

Onofrei, M., Gray, M., Coons, W.E.., and S.R. Alcorn, 1992, "High Performance Cement Based Grout for Use in a Nuclear Waste Disposal Facility, " Waste Management, v.12, pp. 133-154.

Petersen, E.W., and Christensen, C.L. (1980) "Analysis of Bell Canyon Test Results" SAND80-7044C. Sandia National Laboratories, Albuquerque NM

Pfeifle, T.W., F.D. Hansen, and M.K. Knowles, 1996. "Salt-Saturated Concrete Strength and Permeability," 4th. Materials Engineering Conference, ASCE, Washington, D.C.

Sandia National Laboratories, Repository Isolation Department, 1996. "Compliance Submittal Design Report," Sandia National Laboratories, Department 6121, Albuquerque, NM

Thompson, T.W., W.E. Coons, J.L. Krumhansl, and F.D. Hansen, 1996. "Inadvertent Intrusion Borehole Permeability," Memorandum of Record, July 8, 1996, Sandia National Laboratories, Albuquerque, NM.

Wakeley, L.D., Poole, T.S., and Burkes, J.P., 1994, "Durability of concrete materials in high-magnesium brines," SAND 93-7073

Wakeley, L.D., P.T. Harrington, and F.D. Hansen, 1995, "Variability in Properties of Salado Mass Concrete," SAND94-1495, Sandia National Laboratories, Albuquerque, NM.

Walton, J.C., Plansky, L.E., and Smith, R.W., 1990, "Models for estimation of service life of concrete barriers in low-level waste repositories," NUREG/CR-5542

U.S. DOE (Department of Energy), 1995, "Waste Isolation Pilot Plant Sealing System Design Report," DOE/WIPP-95-3117.

U.S. DOE (Department of Energy), 1996a, "Detailed Design Report for an Operational Phase Panel-Closure System," DOE/WIPP-96-2150.

U.S. DOE (Department of Energy), 1996b, "Final No Migration Variance Petition," DOE/CAO-96-2160.

BRAGFLO grid (ref)

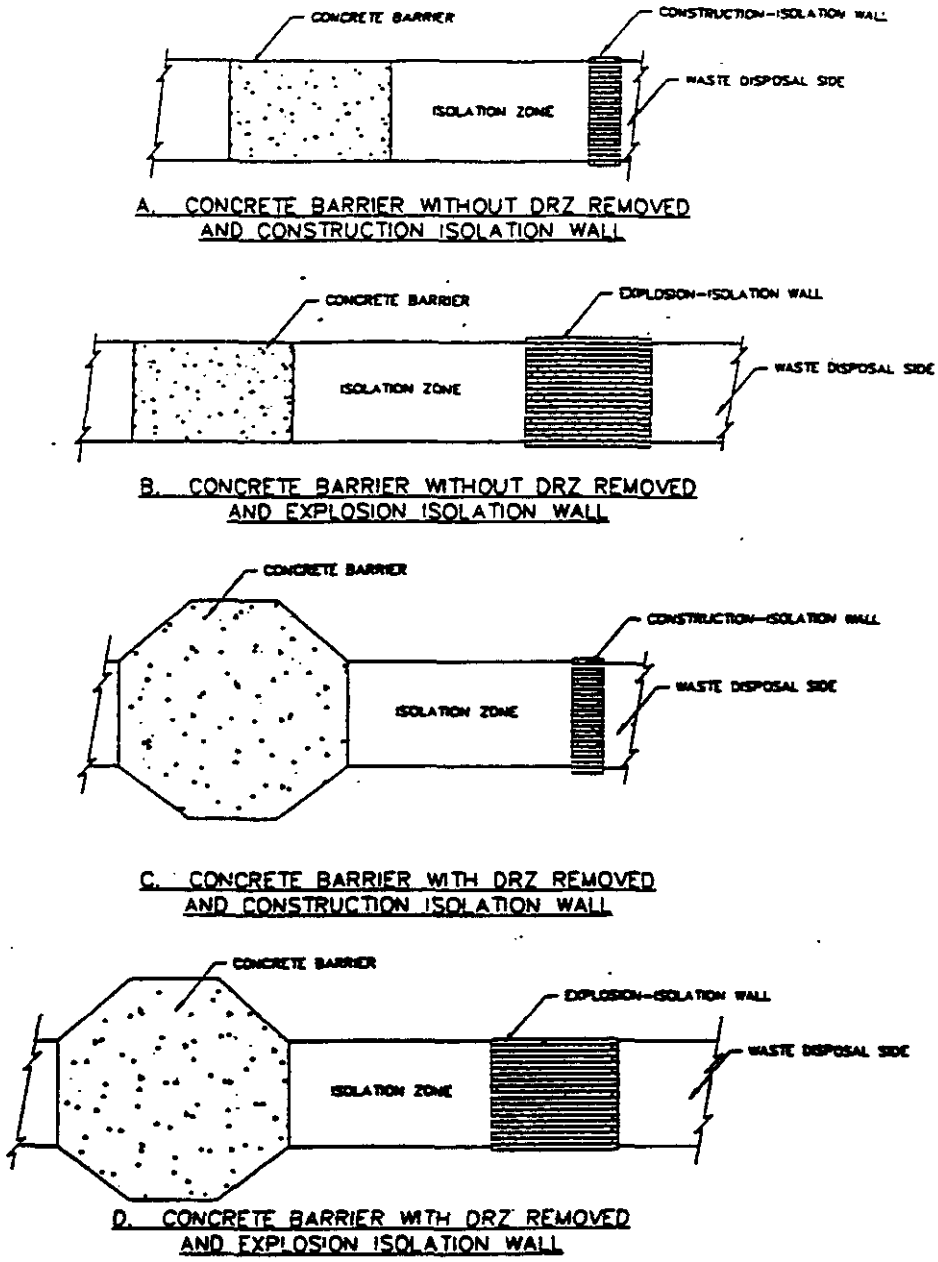

Figure 1: Panel Closure Designs (after USDOE, 1996a)

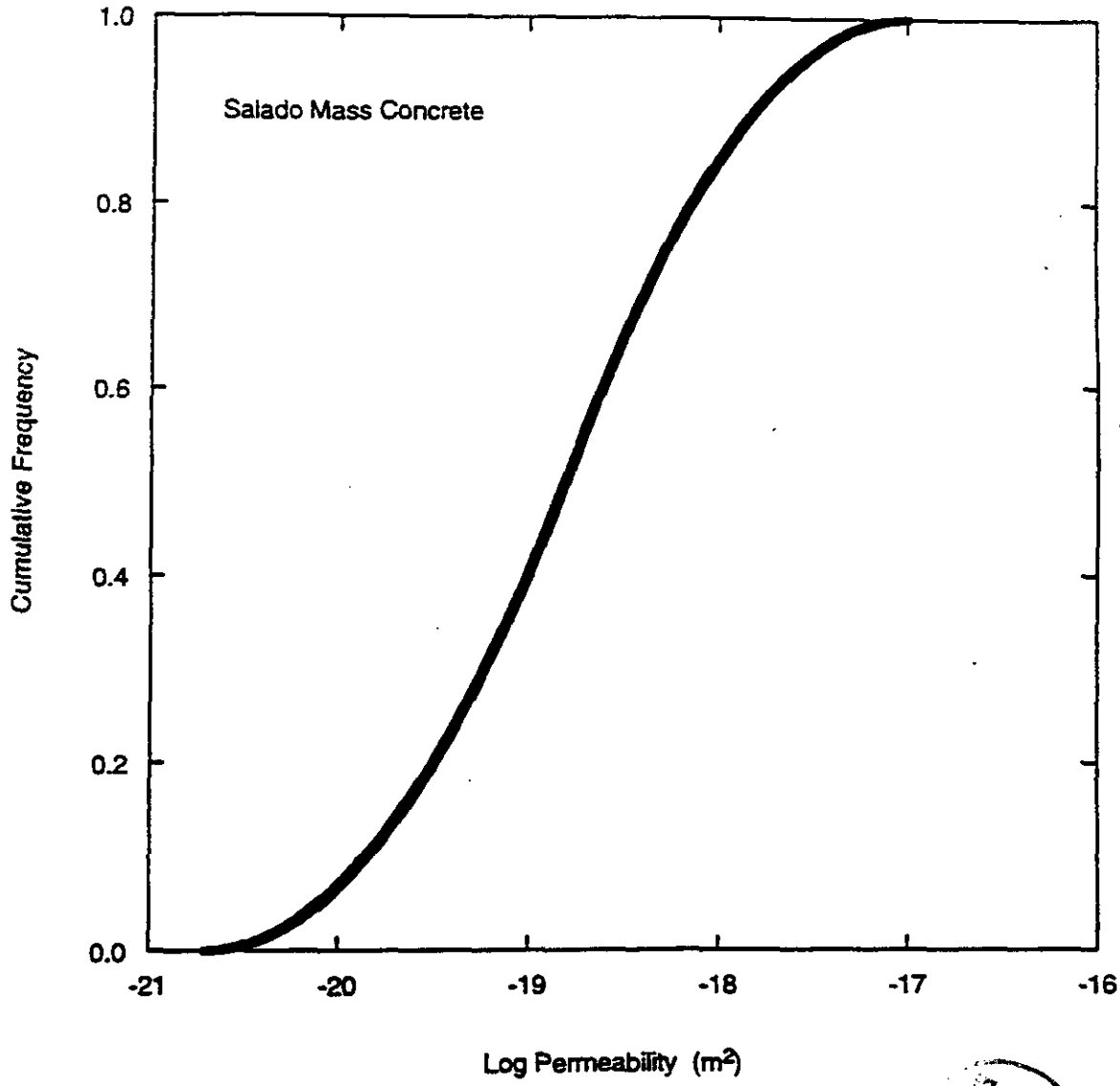

Figure 2: Cumulative Distribution Function for Permeability of SMC (after Sandia, 1996)

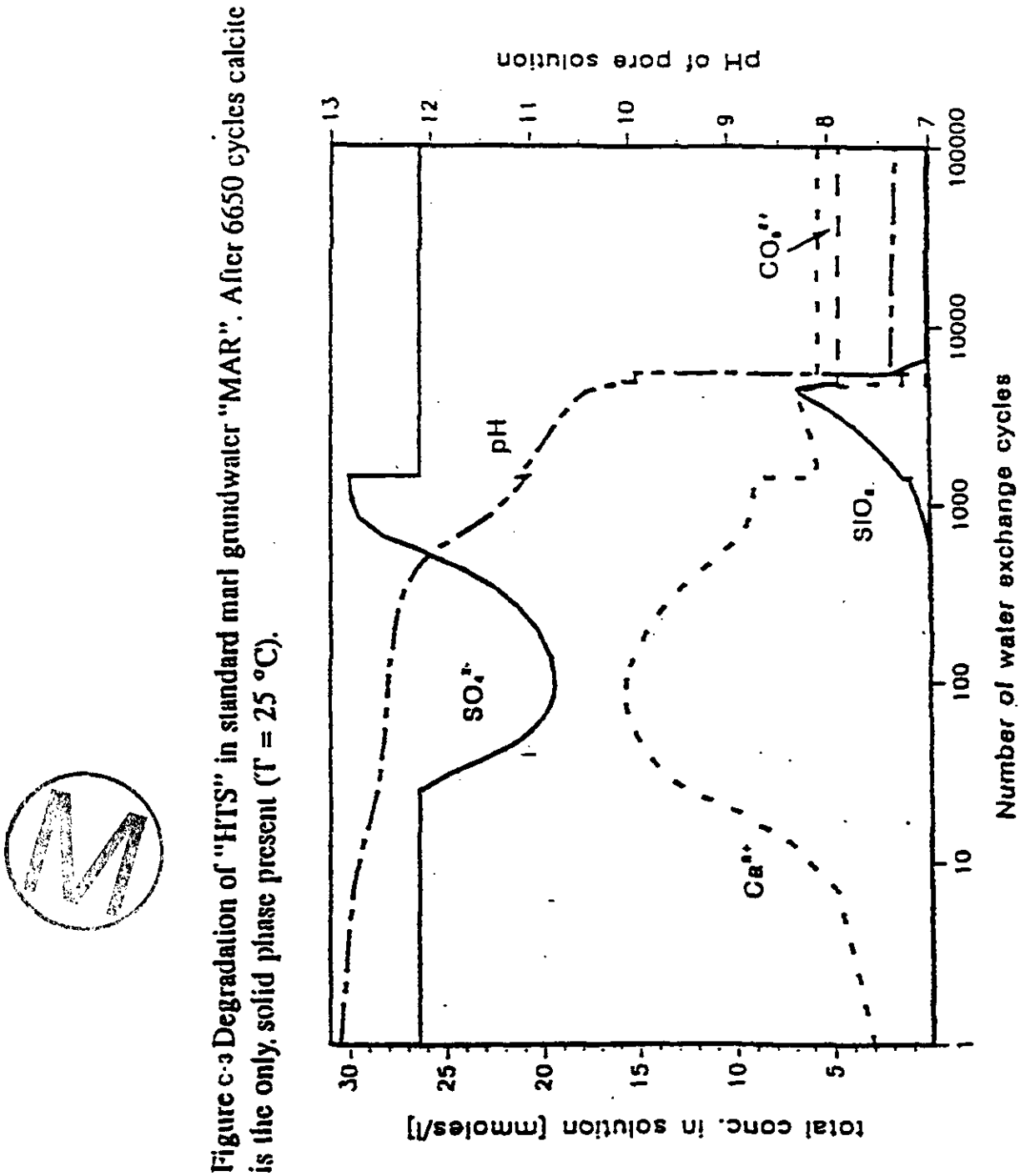

Figure 3: Degradation of Concrete in Brine (after Berner, 1990)

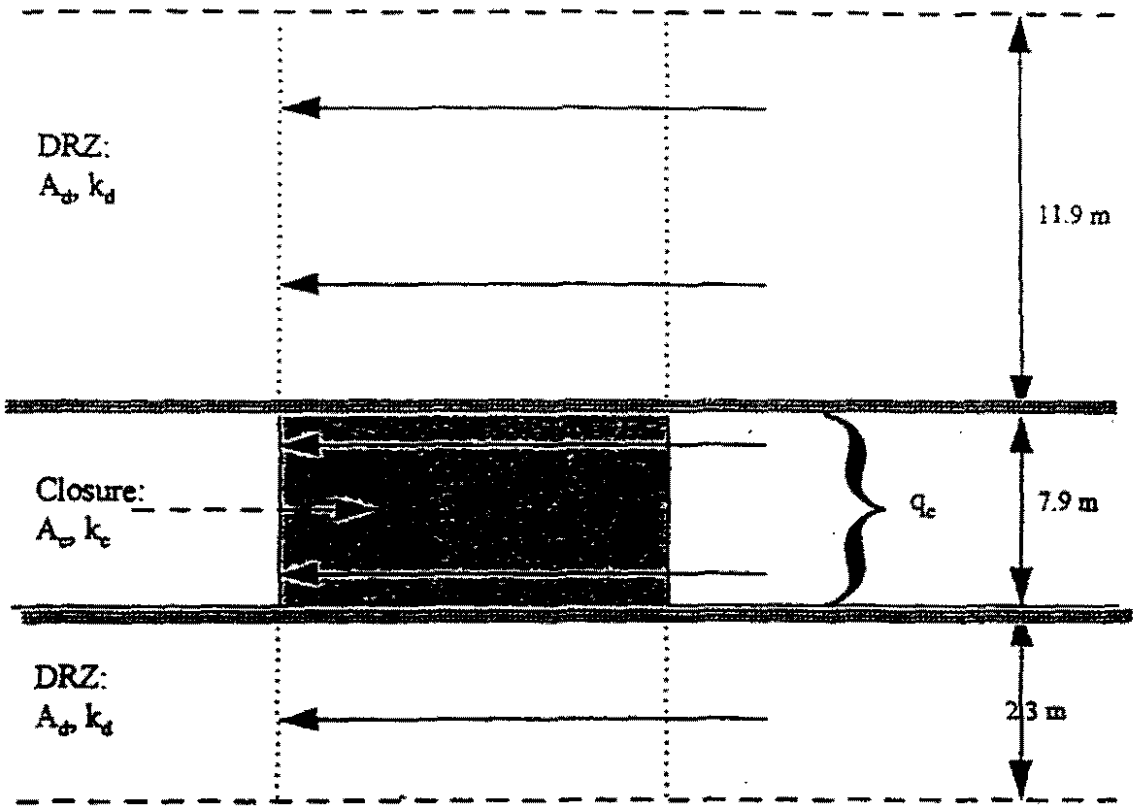

Figure 4: Parallel Flow through the Panel Closure and DRZ

SNL WIPP PA96: BRAGFLO SIMULATIONS (CCA R1 S3)

Cumulative Brine Flow across Panel Seal out of Waste Panel

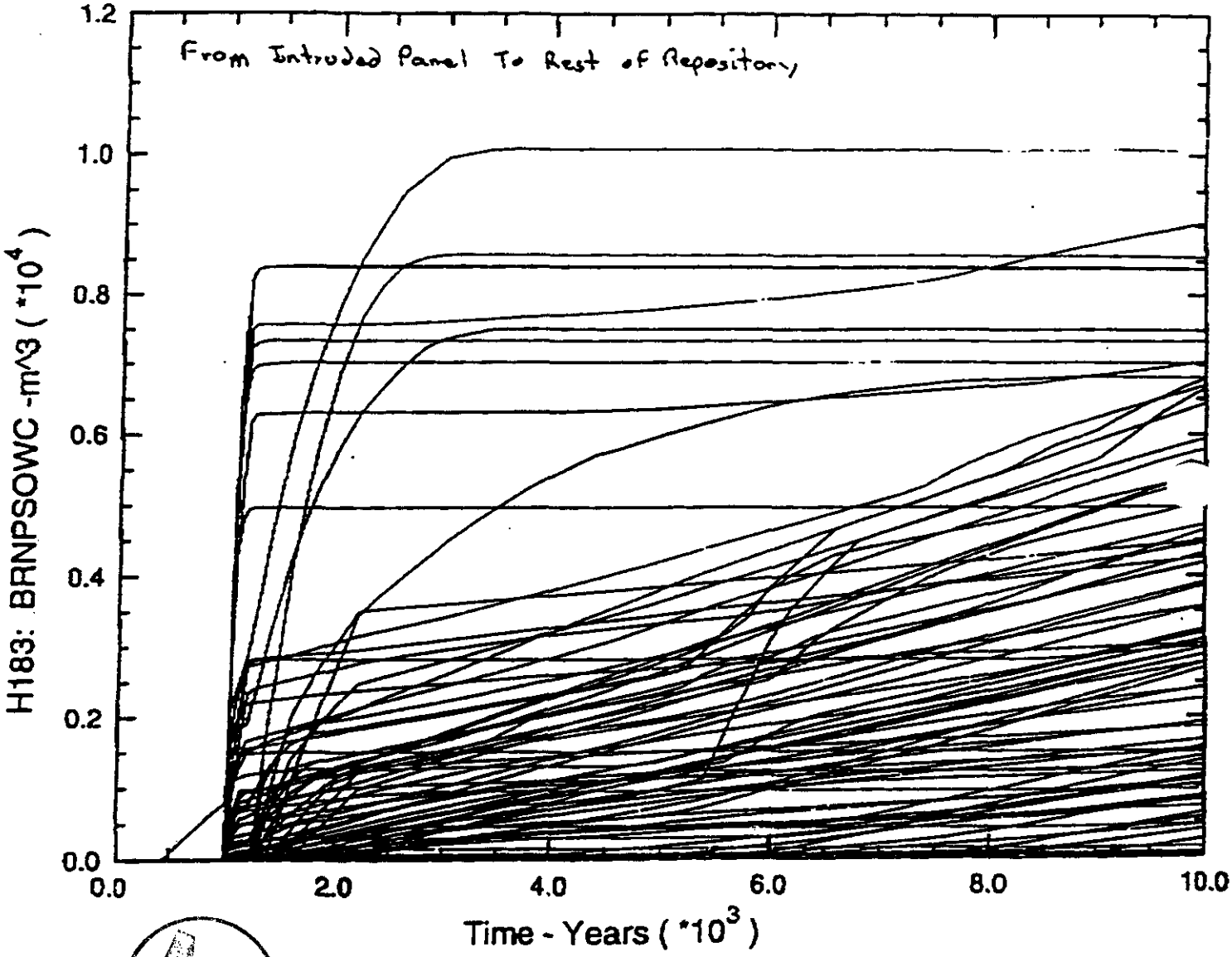

Figure 5: Cumulative flows between a panel and the rest of the repository for an E1 Intrusion at 1000 Years

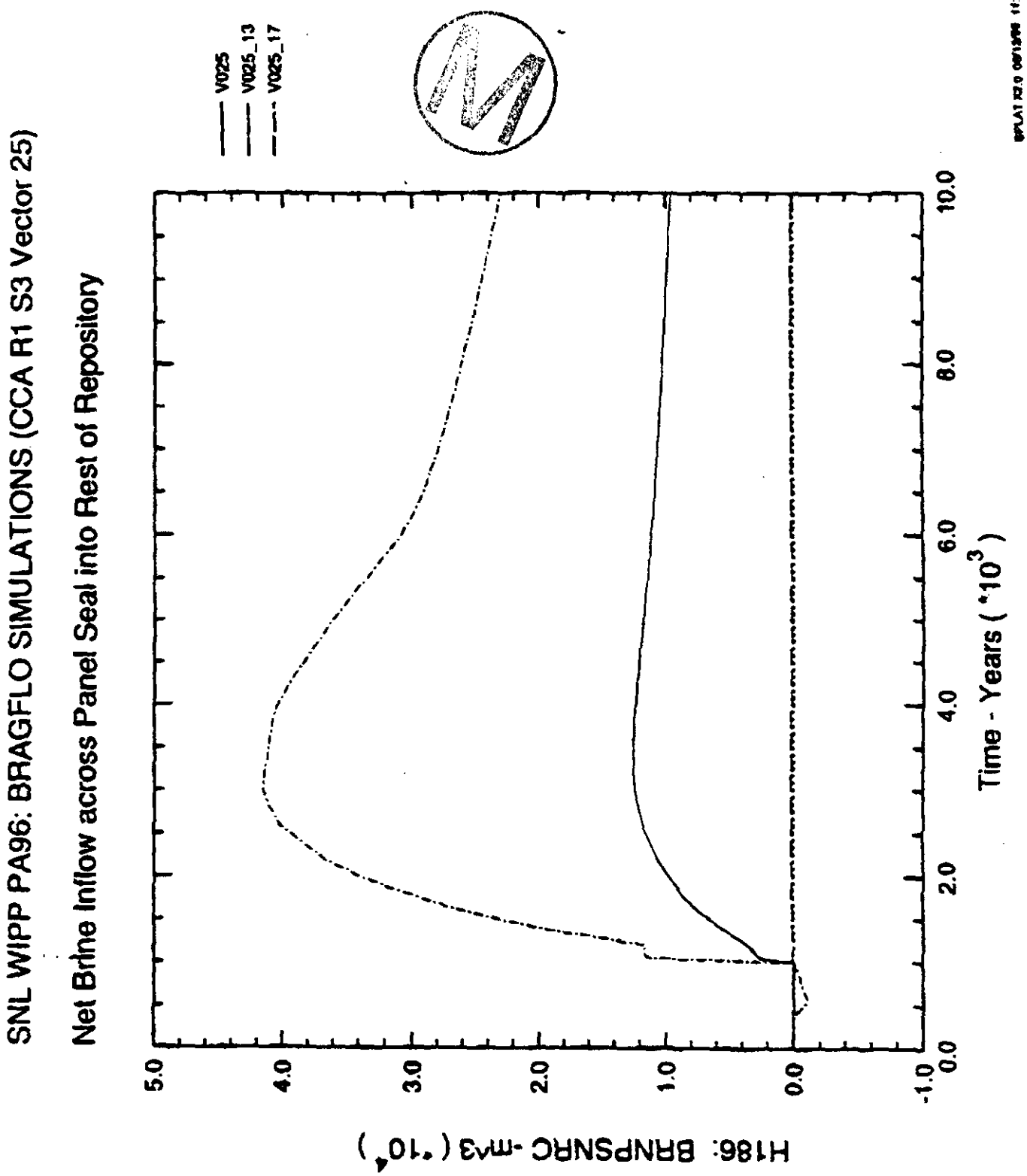

Figure 6: Cumulative flows through the Panel Closures for Permeabilities of 10^{-15} to 10^{-17} m^2. Results shown are for the Maximum Flow Case of Figure 5.

From: Kurt W. Larson
To: melord, pvaughn, msychu
Date: 1/24/96 8:24am
Subject: Fracture model ideas

A couple of ideas as the frac. model parameters are determined. I will be away next week, so Palmer you will have to see that the memo for Project office to consider gets written.

From brine-outflow meeting 1/23/96:

Wolfgang Wawersik thinks each interbed has a zone about 10cm thick which dilates. Each zone dilates identically. This means a different set of fracture parameters would be applied to each interbed. He and Norm Warpinski think the LEFM model is appropriate analogue. LEFM predicts about 1 cm dilation max with tremendous permeability change for pressures somewhat above lithostatic.

For MB 138 and 139, 1 cm dilation ~ 1% porosity change over entire thickness
For anh.A+B, 1 cm dilation ~ 3-5% porosity change over entire thickness (someone who knows modeled thickness can figure out more accurately)

dilation/fracturing begins is a continuous process, so initiation pressure should be low.

Additionally, Norm thinks pressures above 17-18 MPa are not realistic, and indicate too constrictive fracture model conditions. Thus, fracture model must be able to open up better than recent implementations (FEPs) which allowed pressures up to 23 MPa.

This leads me to the following recommendation:

Initiation pressure
about 0.2 MPa above initial pressure of cell
I
Final Pressure, Final Porosity, Final Permeability
I suggest using these as fitting parameters so that the following condition is attained

At about 2.5 MPa above initial pressure in cell, fracture porosity and permeability begin steep rise (commensurate with onset of real fracturing) - below this pressure shallower rises indicate interconnection/dilation of existing fractures

a. At about 3 MPa above initial pressure in cell, fracture porosity reaches 1% for MB 139, MB 138; 3-5% for AnhA+b.

b. At about 3 MPa above initial pressure in cell, fracture permabiltiy reaches 8? OM greater than initial.

a+b above make a fracture that is relatively long due to high permeability and narrow due to moderate increase in porosity. condition of a+b is ideal max pressure for model, and commensurate with LEFM model.

Above about 3 MPa increase, fracture porosity and permeabity continue steep rise so that increased pressures have a mechanism for blowing off steam rapidly.

If the model is set so that there is no increased porosity or permeability above about + 3 MPa, then I think some vectors will result in pressures significantly in excess of 20 MPa.

I look forward to hearing what the final values chosen are

Kurt

Date: 1/29/96

To: Margaret Chu, Dept. 6801, MS-1325

From: Michael Lord, Dept. 6749, MS-1328

Subject: **Parameters describing the variable porosity and permeability within anhydrite material.**

I have considered ways of honoring the porosity/permeability response to pressure within the anhydrite marker beds as suggested in the enclosed memo from Kurt Larson of 1/24/96 and discussions with Palmer Vaughn. The following values typical of the performance assessment data were assigned:

pressure at fracture initiation	= 12.7 MPa
pressure at full fracture condition	= 16.5 MPa
porosity at reference condition	= 0.011 (1.1%)
permeability of intact anhydrite	= 2.5E-19 m^2
permeability at full fracture condition	= 1.0E-09 m^2

The porosity at full fracture condition was then adjusted in order to produce a change in porosity of about 1% at 2.5 MPa above fracture initiation pressure or a pressure of 15.2 MPa. This was obtained with a maximum porosity of 0.05(5%). In the attached Fig. 1 the resulting porosity response is shown. The corresponding permeability response is shown in Fig. 2. At 2.5 MPa above fracture initiation pressure, the permeability is between 3 and 4 orders of magnitude larger than the intact value. This would represent the desired response in marker beds 138 and 139. A similar analysis was done for marker bed a+b where the full fracture porosity was taken to be 0.25 (25%). For this value of maximum porosity the porosity at 2.5 MPa above fracture initiation pressure is approximately 3% above the porosity at fracture initiation pressure. This is shown in Fig 3 and the result is in line with the proposed response. Fig. 4 shows the permeability at 2.5 MPa above fracture initiation pressure as approximately 4 orders of magnitude above the intact permeability.

Based on this study I would recommend assigning the fracture parameters as follows. The fracture initiation pressure should be set as done in the FEPs calculations where it is assigned a value of 0.2 MPa above the grid block initial pressure. Therefore, there could be some small variance in the fracture initiation pressure if the reference initial pressure in the Salado is sampled. Also, there will be some small variance due to the dip in the Salado formation. However, the fracture initiation pressures should be near the 12.7 MPa value. The pressure at the full fracture condition should be an increment of 3.8 MPa above the fracture initiation pressure. This would result in a full fracture pressure of approximately 16.5 MPa. The full fracture permeability can be any large sampled or assigned value such as the 1.0E-09 m^2 used in this study. The full fracture porosity for the marker beds 138 and 139 will have value 0.05 and the full fracture

porosity for the marker bed a+b will have value 0.25. With these values the p essure dependent porosity and permeability should closely approximate the LEFM predicted values.

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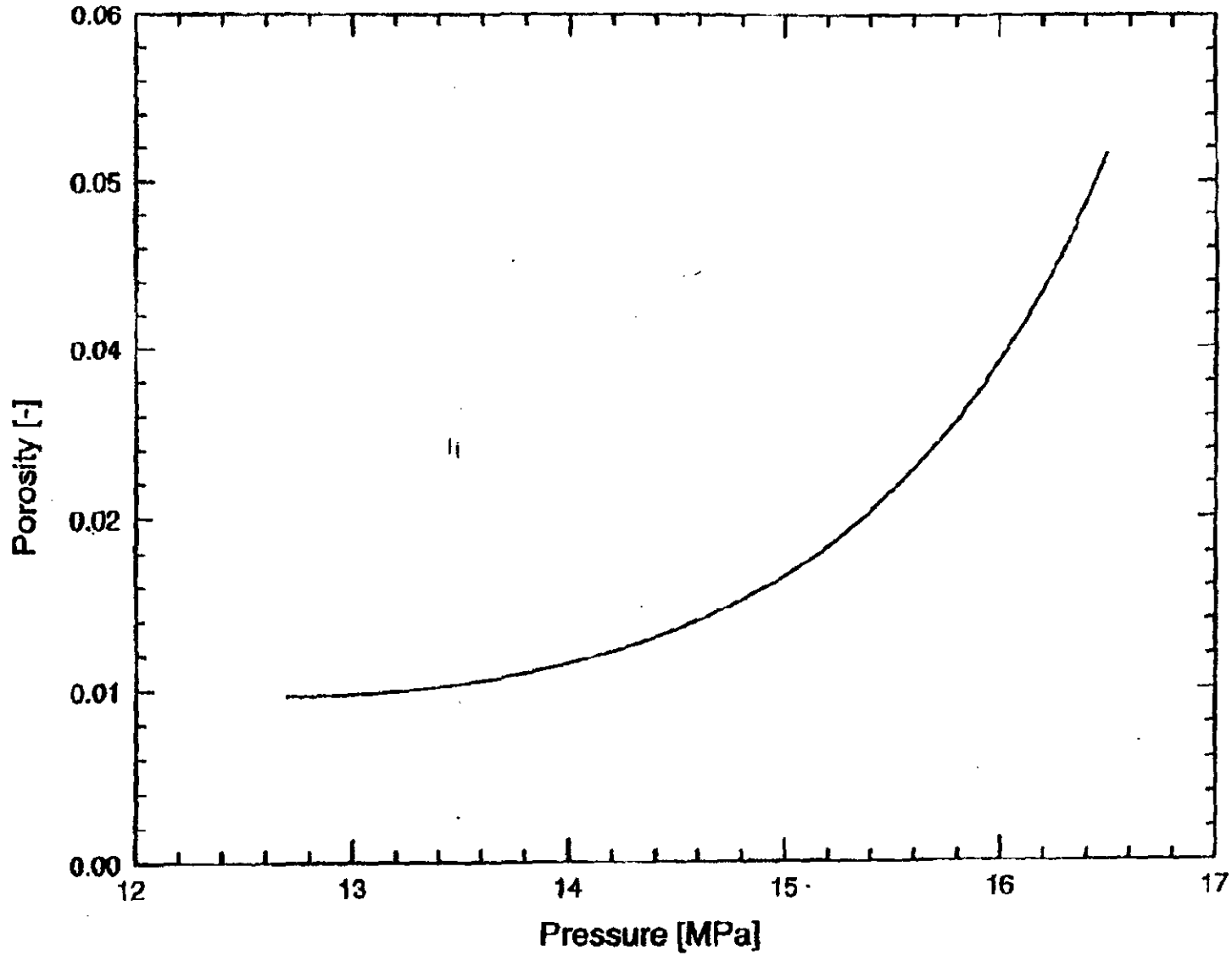

Figure 1: Porosity in Marker Bed 138 & 139 with Fracturing

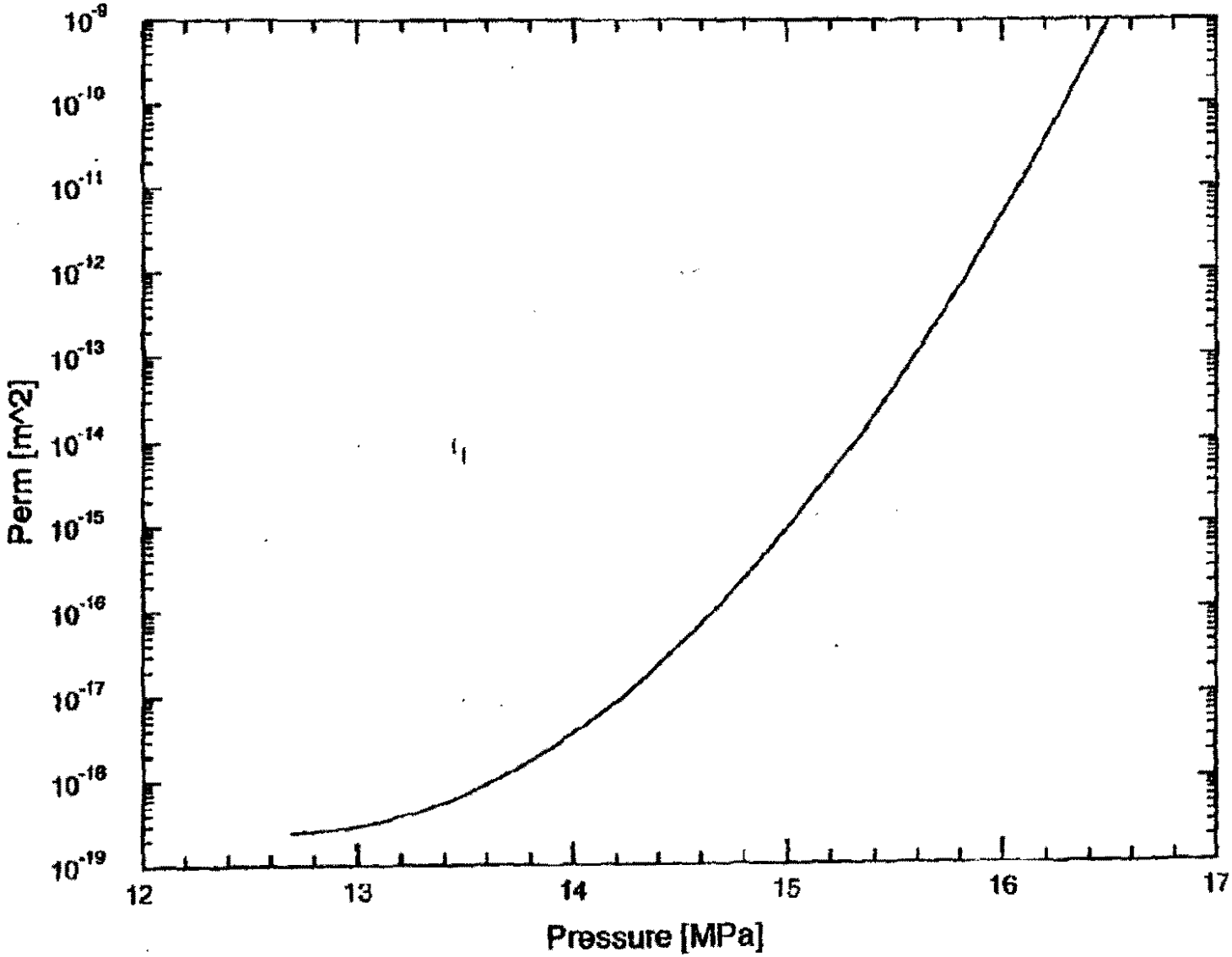

Figure 2: Permeability in Marker Bed 138 & 139 with Fracturing

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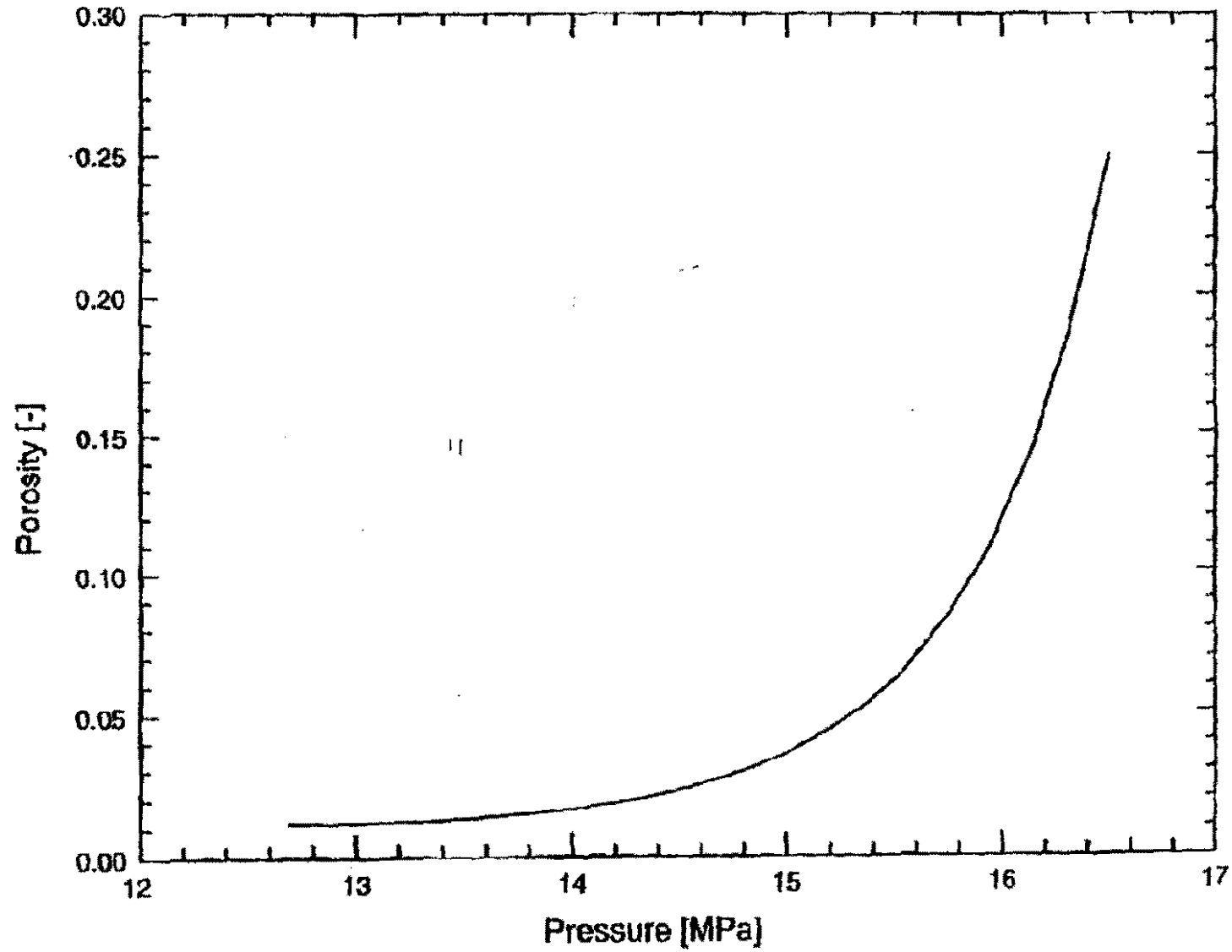

Figure 3: Porosity in Marker Bed A+B with Fracturing

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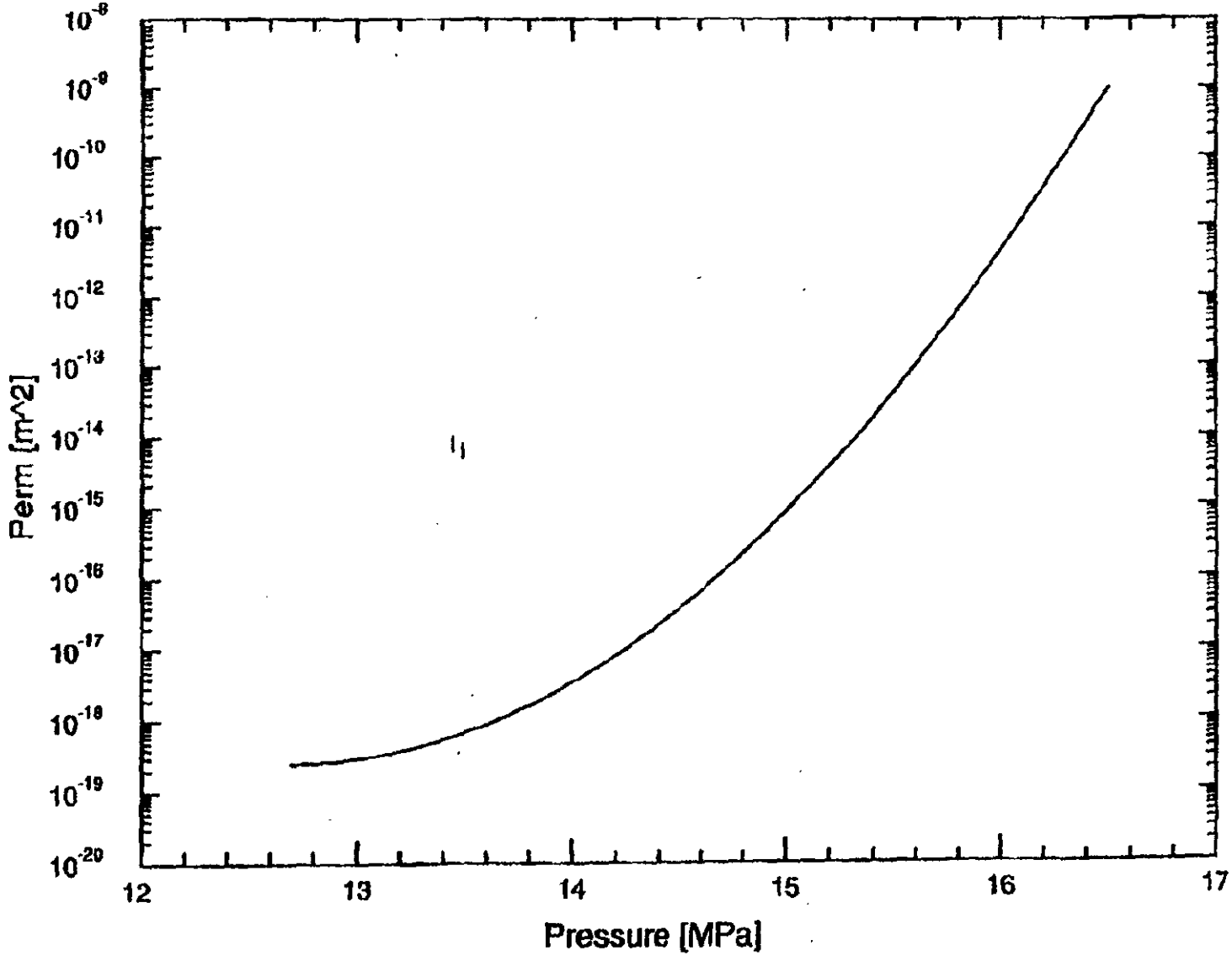

Figure 4: Permeability in Marker Bed A+B with Fracturing

Comparison of Effects of Brine Pocket Size

Daniel M. Stoelzel, Palmer Vaughn
Sandia National Laboratories, org 6848, 6849

Darien G. O'Brien, PE
Solutions Engineering

July 19, 1996

SWCF: A :DRAFT: CO/CCA

BACKGROUND

The existence and size of a Castile Brine Pocket below the WIPP repository is uncertain. Brine pockets have been found in the northern Delaware Basin but there is little information on their size. The producibility of brine from these pockets is believed to be related to the interconnectedness of a fracture system. Analysis of WIPP-12 data have led to estimates for the areal extent of several hundred meters (drainage radius as small as 230 m -- dimension smaller than the WIPP waste-area footprint) to several kilometers (drainage radius as large as 19,000 m -- dimension larger than the land withdrawal boundary). DOE does not consider the 19 km radius brine pocket a realistic size, never the less it is included for comparison to other sizes. Because of the interconnectedness of the fracture system, the thickness of the brine pocket has been estimated to be from 7 m to 24 m with a maximum possible of 133.6 m (recent estimate based upon the total thickness of the Castile formation and NOT considered in the 1996 CCA calculations).

Each time a well penetrates the brine pocket, the pressure in the surrounding drainage area depletes. This pressure depletion will extend to those portions of the brine pocket which are interconnected. Passive Institutional Controls shield a region of the Castile from exploratory drilling directly under the waste panels. The 1996 CCA calculations assume that the Castile Brine Pocket under the waste panels is weakly interconnected hydraulically (with vertical and areal extents similar to the lower estimates from WIPP-12, i.e. total brine volume between 32,000 and 160,000 m^3 [Larson & Freeze, 1996]), and is not much affected by penetrations occuring outside the waste-area footprint. Therefore, the pressure underneath the waste panels in the brine pocket is assumed to not deplete until penetrated by a borehole drilled within the panel area. If the brine pocket has an extensive fracture system (and hence is strongly interconnected), the area beneath the waste panels can be depleted by penetrations outside the waste-area footprint.

This study looks at the consequences of assuming that the brine pocket is hydraulically interconnected such that borehole penetration depletion impacts are felt throughout a larger drainage area. The total brine volume which migrates from the Castile Brine Pocket to the Culebra aquifer with depletion impacts (large drainage area) is compared against the brine volume migration without depletion (small drainage area).

THEORETICAL CONSIDERATIONS

For the 1996 CCA calculations, an abnormally pressured Castile Brine Pocket is assumed (i.e. the brine pocket pressure exceeds the anticipated hydrostatic pressure). The brine pocket is assumed to be bounded (i.e. of limited thickness and areal extent) rather than infinite acting (such as the Culebra aquifer). Consistent with DOE regulatory criteria regarding the rate of future drilling activity, it is assumed that 47 boreholes will be drilled per square kilometer over the next 10,000 years (or 0.47/100 yrs/km^2). Each penetration of the abnormally pressured brine pocket will result in flows according to the following time horizons:

1) Time of intrusion to 72 hours - brine flows from the brine pocket, past the Culebra all the way to the surface during active drilling through an open borehole (assuming steady-state flow conditions). A computation to determine the length of time during which steady-state is valid (i.e. infinite acting period when the pressure sink caused by flow into the borehole has reached the extent of the drainage area) as computed by the following [Lee, 1982]:

$$t < \frac{\phi \mu c_t A t_{DA}}{k} \qquad \text{[Equation 1]}$$

where:

t = Time (for a bounded cylindrical system is infinite acting) (sec)
ϕ = Porosity (fraction)
μ = Viscosity (Pa-sec)
c_t = Total compressibility (Pa^{-1})
A = Drainage area (defined as the land withdrawal boundary area/avg. no. of boreholes/200 years where 19.5 boreholes is taken as the average in 200 years) (m^2)
t_{DA} = Dimensionless time (which for a bounded cylindrical system = 0.10, [Lee, 1982])
k = Brine pocket permeability (m^2)

The solution to Equation 1 is approximately 7 hours. Although the steady-state flow assumption is valid only within 7 hours after penetration, a flow period of 72 hours was used. This is consistent with the 1996 CCA blowout time period to obtain direct brine releases from the WIPP repository. For the purposes of this investigation, pressure depletion during the 72 hour open flow period was not taken into account.

During the 72 hour flow period, flowrate is computed from the following (see nomenclature section for definition of variables):

$$Q_{bp} = \left\{ \frac{k_{bp} h_{bp}}{\mu \left[\ln\left(\frac{r_{e_{bp}}}{r_w} \right) - 0.5 \right]} \right\} \left(P_{bp} - P_{atm} - \rho g L_{surface} \right) \qquad \text{[Equation 2]}$$

2) 72 hours to 200 years - no brine flows from the brine pocket since the 1996 CCA calculations assume a 200 year time period immediately following intrusion during which the borehole is plugged at the Rustler and Castile formations.

3) From 200 years to 1200 years - cement plugs are no longer active. Flow occurs between the Castile Brine Pocket and the Culebra aquifer via "silty sand" abandoned boreholes with median permeabilities of 3.16E-13 m^2.

4) 1200 years to 10000 years - median abandoned borehole permeabilities are reduced one order of magnitude (3.16E-14 m^2) due to salt creep.

Abandoned Borehole Connection Between Castile Brine Pocket and Culebra Aquifer

Consider the flow rate necessary to achieve flow from the Castile Brine Pocket to the Culebra Aquifer through an abandoned borehole as depicted in Figure 1:

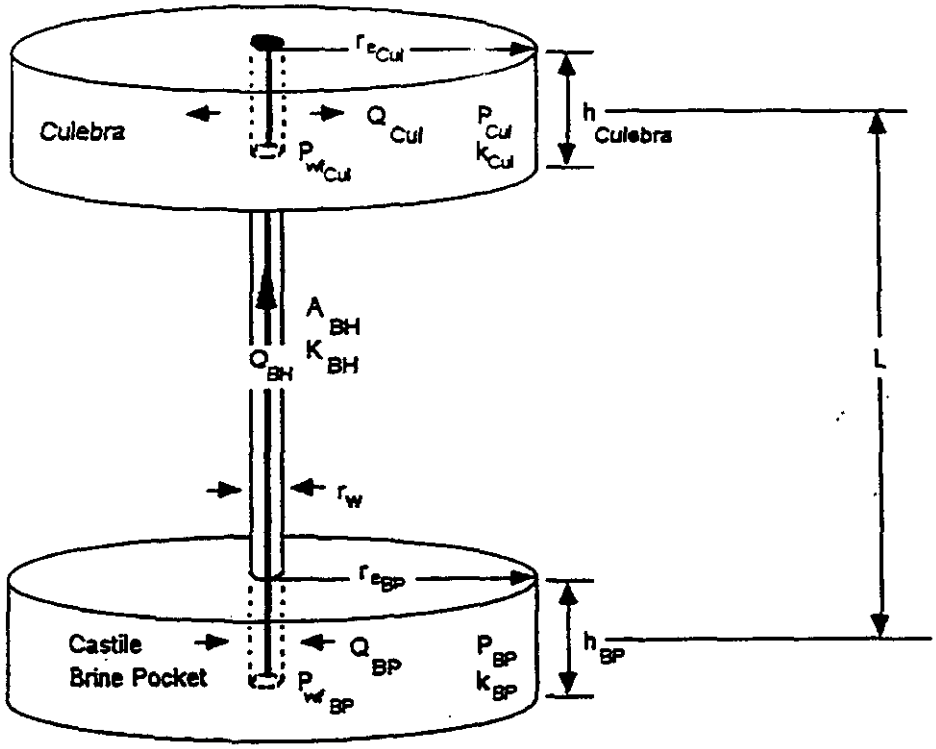

Figure 1: Representation of assumed flow path for Castile Brine Pocket to Culebra Aquifer

NOMENCLATURE

Define the following variables by:

Q = Flowrate (m^3/sec)
k = Permeability (m^2)
h = Thickness (m)
μ = Brine viscosity (Pa-sec)
ρ = Brine density (kg/m^3)
g = Acceleration due to gravity (m/sec^2)
L = Borehole length (m)
r = Radius (m)
A = Cross sectional area (m^2)
P = Pressure (Pa)
$\overline{P}$ = Average pressure between r_e and r_w (Pa)
c = Compressibility (Pa^{-1})
ϕ = Porosity (fraction)
V = Bulk volume (m^3)
ΔN = Brine volume producted between time 1 and 2 (m^3)

Define the following subscripts by:

cul = Culebra
bh = Borehole
bp = Brine pocket
e = External drainage per borehole (brine pocket area divided by number of boreholes)
w = Wellbore
wf = Abandoned wellbore flowing
atm = Atmospheric
b = Rock bulk
f = Pore volume
br = Brine
t = Total
R = Castile Brine Pocket or Culebra Aquifer
1,2 = Time 1, time 2

Refer to Figure 1, assuming steady-state flow is positive between the Castile Brine Pocket and the Culebra Aquifer, the following Darcy Law equations are used to obtain the flowrates out of the brine pocket (Q_{bp}), through the borehole (Q_{bh}) and into the aquifer (Q_{cul}), based upon the pressures, rock and fluid properties and brine pocket/abandoned borehole/aquifer geometries:

$$Q_{cul} = \left\{ \frac{k_{cul} h_{cul}}{\mu \left[\ln\left(\frac{r_{e_{cul}}}{r_w} \right) - 0.5 \right]} \right\} \left(P_{wf_{cul}} - P_{cul} \right) \qquad \text{[Equation 3]}$$

$$Q_{bh} = \left[\frac{k_{bh} A_{bh} \left(P_{wf_{bh}} - P_{wf_{cul}} - \rho g L \right)}{\mu L} \right] \qquad \text{[Equation 4]}$$

$$Q_{bp} = \left\{ \frac{k_{bp} h_{bp}}{\mu \left[\ln\left(\frac{r_{e_{bp}}}{r_w} \right) - 0.5 \right]} \right\} \left(P_{bp} - P_{wf_{bp}} \right) \qquad \text{[Equation 5]}$$

The flowrates through each of these systems are assumed to be equal (i.e. no fluid leaves the system), therefore:

$$Q_{bp} = Q_{bh} = Q_{cul} \qquad \text{[Equation 6]}$$

This results in four equations (Equations 3-6) and two unknowns (P_{wfbp} and P_{wfbp}) which can be algebraically solved for Q_{bp} as follows:

$$Q_{bp} = \frac{\left\{ \frac{k_{bp} h_{bp}}{\mu \left[\ln\left(\frac{r_{e_{bp}}}{r_w} \right) - 0.5 \right]} \right\} \left(P_{bp} - \rho g L - P_{cul} \right)}{\left[1 + \left\{ \frac{k_{bp} h_{bp}}{\mu \left[\ln\left(\frac{r_{e_{bp}}}{r_w} \right) - 0.5 \right]} \right\} \right] \left\{ \frac{\mu \left[\ln\left(\frac{r_{e_{cul}}}{r_w} \right) - 0.5 \right]}{k_{cul} h_{cul}} + \frac{\mu L}{k_{bh} A_{bh}} \right\}} \qquad \text{[Equation 7]}$$

Equation 7 is the steady-state solution for flow through the brine pocket/abandoned borehole/aquifer system. To account for bounded brine pocket/aquifer sizes, pressure drawdown can be estimated by redefining the brine pocket and aquifer pressures over a series of discrete time intervals by the following:

The pore volume compressibility (c_f) as a function of rock bulk compressibility (c_b) may be defined by:

$$c_f = \frac{c_b}{\phi} \qquad \text{[Equation 8]}$$

The total compressibility (c_t) is the sum of the brine compressibility (c_{br}) and pore volume compressibility (c_f) as follows:

$$c_t = c_{br} + c_f \qquad \text{[Equation 9]}$$

The bulk volume of the bounded brine pocket is a function of the volume of brine removed, average pressure drop, compressibility and porosity as follows:

$$V_R = A_R h = \frac{\Delta N_{1,2}}{\left(\overline{P_1} - \overline{P_2}\right) c_t \phi} \qquad \text{[Equation 10]}$$

Equation 10 can be used to solve for the average pressure at the end of a given time interval by:

$$\overline{P_2} = \overline{P_1} - \frac{\Delta N_{1,2}}{V_R c_t \phi} \qquad \text{[Equation 11]}$$

METHODOLOGY AND RESULTS

Since the size of the brine pocket is unknown, comparisons were made for various areal size and thickness as shown in the following table (consistent with interpreted results from WIPP-12 data [Larson & Freeze, 1996]):

Table 1 - Constant Brine Volumes by Varying Thickness and Areal Extent

Thickness (m)	Areal Extent 1 (m^2)	Areal Extent 2 (m^2)	Areal Extent 3 (m^2)
133.6	6.0E+07	3.0E+06	3.0E+04
66.8	12.0E+07	6.0E+06	6.0E+04
24.0	33.4E+07	16.7E+06	16.7E+04

For the Culebra aquifer, the areal extent was assumed to be 100 times the LWB for all cases (4144 km^2). All other properties were median values obtained from the 1996

CCA database. The combination of three thicknesses and three areas for the Castile Brine Pocket resulted in 9 cases for comparison. Initial brine pocket pressure was assumed to be 12.7 E+07 Pa for all cases.

Table 2 shows an example spreadsheet calculation assuming an area of 6.0 E+07 m^2 and 133.6 m brine pocket thickness.

Table 2 - Example Spreadsheet Calculation

BP area	6.00E+07 m^2
Cut area	4.14E+09 m^2
Pcut (init)	850000 Pa
U	1.80E-09 Pa-s
hCut	7.7 m
L	641.5 m
total L	708.3 m
hBP	133.6 m
Pbp (init)	1.27E+07 Pa
kBH	3.16E-13 m^2
kCUL	2.16E-14 m^2
rw	0.1886 m
Area BH	0.0760822 m^2
kBP	1.[illegible]E-12 m^2
rho	230 kg/m^3
g	9.8
rho*g*l sben	8.5E+6 Pa
rho*g*l open	11.2E+6 Pa
s/year	3.16E+07
porus BP	0.008
porus Cut	0.151
Cr BP	1.00E-10 1/Pa
Cr Cut	1.00E-10 1/Pa
Ct BP	1.25E-08 1/Pa
Ct Cut	8.625E-10 1/Pa
Cbrine	1.00E-09 1/Pa
Cbt BP	1.35E-08 1/Pa
Cbt Cut	1.68E-09 1/Pa
Brine Pocket bulk vol =	8.0E+8 m^3
Cutebra bulk vol =	31.9E+9 m^3
Open BH Ct	2.58E+05 seconds
No. open BH/Ct	2.82E+01
n BP	822.95509
Pres	101320 Pa
drip rate=	0.47 bh/km^2/100years

Time years	Num BH in BP	Number of sand BH	Number of creep BH	BP press Pa	Cut Press Pa	BP radius per sb BH m	Cut radius per well m	Const	Clop open BH per well m^3/s	delta flow open m^3
200.0	56.40	0.0	0.0	12.7E+6	850.0E+3	4.37022E+13	4.37E+13	3.56E-08	0.020465474	149.6E+3
400.0	112.80	28.2	0.0	12.5E+6	850.0E+3	822.955089	4.37E+13	1.45E-08	0.017955888	131.2E+3
600.0	169.20	84.6	0.0	12.4E+6	851.3E+3	475.133342	4.37E+13	1.56E-08	0.015578296	113.9E+3
800.0	225.60	141.0	0.0	12.2E+6	855.0E+3	368.036704	4.37E+13	1.61E-08	0.013168822	96.3E+3
1,000.0	282.00	197.4	0.0	12.0E+6	860.9E+3	311.047798	4.37E+13	1.66E-08	0.010789945	78.7E+3
1,200.0	338.40	253.8	0.0	11.9E+6	868.5E+3	274.318363	4.37E+13	1.68E-08	0.008417987	61.5E+3
1,400.0	394.80	310.2	0.0	11.7E+6	877.6E+3	248.130296	4.37E+13	1.71E-08	0.006145544	44.9E+3
1,600.0	451.20	366.6	84.6	11.6E+6	888.3E+3	228.246674	475.1333	1.73E-08	0.003876128	28.1E+3
1,800.0	507.60	366.6	84.6	11.4E+6	900.2E+3	228.246674	475.1333	1.73E-08	0.001891256	13.8E+3
2,000.0	564.00	366.6	141.0	11.3E+6	911.2E+3	228.246674	368.0367	1.73E-08	0.000178623	1.3E+3
2,200.0	620.40	366.6	197.4	11.2E+6	921.7E+3	228.246674	311.0478	1.73E-08	0	000.0E+0
2,400.0	676.80	366.6	253.8	11.1E+6	931.7E+3	228.246674	274.3184	1.73E-08	0	000.0E+0
2,600.0	733.20	366.6	310.2	11.0E+6	941.2E+3	228.246674	248.1303	1.73E-08	0	000.0E+0
2,800.0	789.60	366.6	366.6	10.9E+6	950.3E+3	228.246674	228.2467	1.73E-08	0	000.0E+0
3,000.0	846.00	366.6	423.0	10.8E+6	958.0E+3	228.246674	212.4981	1.73E-08	0	000.0E+0
3,200.0	902.40	366.6	479.4	10.6E+6	967.3E+3	228.246674	199.3869	1.73E-08	0	000.0E+0
3,400.0	958.80	366.6	535.8	10.7E+6	973.2E+3	228.246674	188.7986	1.73E-08	0	000.0E+0
3,600.0	1,015.20	366.6	592.2	10.6E+6	982.6E+3	228.246674	179.5835	1.73E-08	0	000.0E+0
3,800.0	1,071.60	366.6	648.6	10.6E+6	988.7E+3	228.246674	171.589	1.73E-08	0	000.0E+0
4,000.0	1,128.00	366.6	705.0	10.5E+6	996.4E+3	228.246674	164.581	1.73E-08	0	000.0E+0
4,200.0	1,184.40	366.6	761.4	10.5E+6	1.0E+6	228.246674	158.3778	1.73E-08	0	000.0E+0
4,400.0	1,240.80	366.6	817.8	10.4E+6	1.0E+6	228.246674	152.8189	1.73E-08	0	000.0E+0
4,600.0	1,297.20	366.6	874.2	10.3E+6	1.0E+6	228.246674	147.9071	1.73E-08	0	000.0E+0
4,800.0	1,353.60	366.6	930.6	10.3E+6	1.0E+6	228.246674	143.2581	1.73E-08	0	000.0E+0
5,000.0	1,410.00	366.6	987.0	10.3E+6	1.0E+6	228.246674	139.1048	1.73E-08	0	000.0E+0
5,200.0	1,466.40	366.6	1,043.4	10.2E+6	1.0E+6	228.246674	135.293	1.73E-08	0	000.0E+0
5,400.0	1,522.80	366.6	1,099.8	10.2E+6	1.0E+6	228.246674	131.7763	1.73E-08	0	000.0E+0
5,600.0	1,579.20	366.6	1,156.2	10.1E+6	1.0E+6	228.246674	128.524	1.73E-08	0	000.0E+0
5,800.0	1,635.60	366.6	1,212.6	10.1E+6	1.0E+6	228.246674	125.4995	1.73E-08	0	000.0E+0
6,000.0	1,692.00	366.6	1,269.0	10.1E+6	1.0E+6	228.246674	122.6789	1.73E-08	0	000.0E+0
6,200.0	1,748.40	366.6	1,325.4	10.0E+6	1.0E+6	228.246674	120.0403	1.73E-08	0	000.0E+0
6,400.0	1,804.80	366.6	1,381.8	10.0E+6	1.1E+6	228.246674	117.565	1.73E-08	0	000.0E+0
6,600.0	1,861.20	366.6	1,438.2	10.0E+6	1.1E+6	228.246674	115.2368	1.73E-08	0	000.0E+0
6,800.0	1,917.60	366.6	1,494.6	9.9E+6	1.1E+6	228.246674	113.0416	1.73E-08	0	000.0E+0
7,000.0	1,974.00	366.6	1,551.0	9.9E+6	1.1E+6	228.246674	110.9672	1.73E-08	0	000.0E+0
7,200.0	2,030.40	366.6	1,607.4	9.9E+6	1.1E+6	228.246674	109.0031	1.73E-08	0	000.0E+0
7,400.0	2,086.80	366.6	1,663.8	9.9E+6	1.1E+6	228.246674	107.1396	1.73E-08	0	000.0E+0
7,600.0	2,143.20	366.6	1,720.2	9.9E+6	1.1E+6	228.246674	105.3686	1.73E-08	0	000.0E+0
7,800.0	2,199.60	366.6	1,776.6	9.9E+6	1.1E+6	228.246674	103.6825	1.73E-08	0	000.0E+0
8,000.0	2,256.00	366.6	1,833.0	9.9E+6	1.1E+6	228.246674	102.075	1.73E-08	0	000.0E+0
8,200.0	2,312.40	366.6	1,889.4	9.9E+6	1.1E+6	228.246674	100.54	1.73E-08	0	000.0E+0
8,400.0	2,368.80	366.6	1,945.8	9.8E+6	1.1E+6	228.246674	99.07215	1.73E-08	0	000.0E+0
8,600.0	2,425.20	366.6	2,002.2	9.8E+6	1.1E+6	228.246674	97.6966	1.73E-08	0	000.0E+0
8,800.0	2,481.60	366.6	2,058.6	9.8E+6	1.1E+6	228.246674	96.31961	1.73E-08	0	000.0E+0
9,000.0	2,538.00	366.6	2,115.0	9.7E+6	1.1E+6	228.246674	95.02967	1.73E-08	0	000.0E+0
9,200.0	2,594.40	366.6	2,171.4	9.7E+6	1.1E+6	228.246674	93.79444	1.73E-08	0	000.0E+0
9,400.0	2,650.80	366.6	2,227.8	9.7E+6	1.1E+6	228.246674	92.58966	1.73E-08	0	000.0E+0
9,600.0	2,707.20	366.6	2,284.2	9.7E+6	1.1E+6	228.246674	91.43945	1.73E-08	0	000.0E+0
9,800.0	2,763.60	366.6	2,340.6	9.7E+6	1.1E+6	228.246674	90.33108	1.73E-08	0	000.0E+0
10,000.0	2,820.00	366.6	2,397.0	9.7E+6	1.1E+6	228.246674	89.26301	1.73E-08	0	000.0E+0

Figure 2 is a semilog plot comparing the number of borehole penetrations for different brine pocket areal sizes based upon the DOE criterion of 0.47/100 year/km^2 drilling rate. The same number of penetrations apply to each respective areal size regardless of thickness.

Figure 2

Comparison of Drilling Penetrations to Castile Brine Pocket for Different Areas

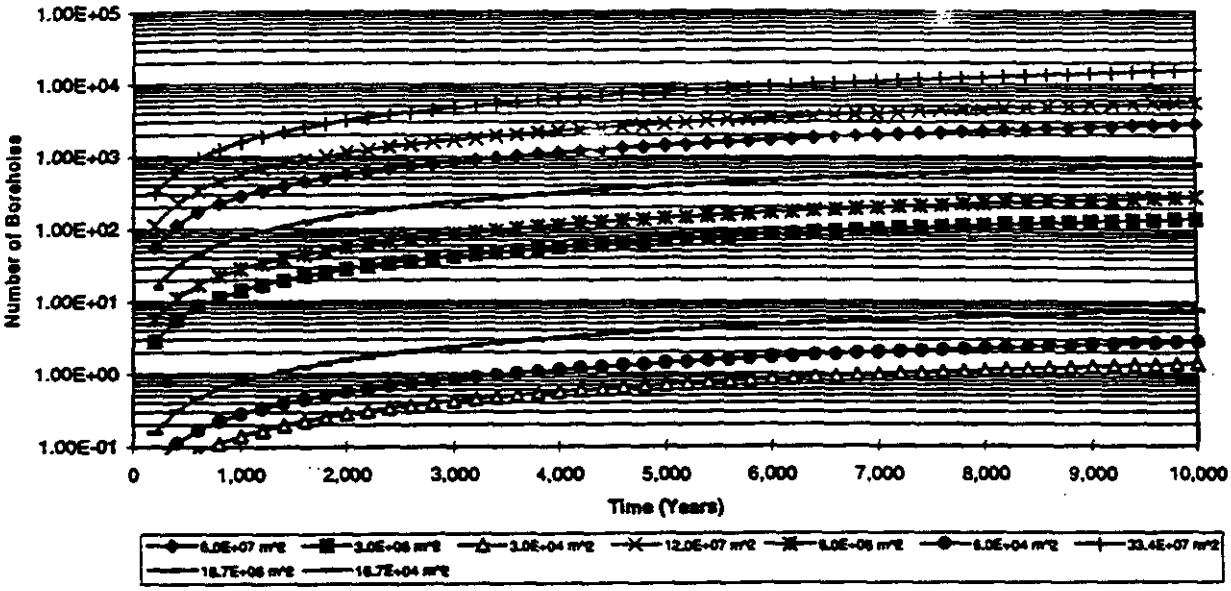

Figure 3 is a semilog plot comparing the amount of Castile brine volume which can be released. This was determined by subtracting the cumulative brine released at a given time from the total cumulative brine released at 10,000 years. The 24 m thickness cases again demonstrate faster depletion than the corresponding 133.6 m thickness cases of equivalent area. For a given thickness, the differences in remaining available flow is caused by differences in the number of depletion boreholes which is a function of the area.

Figure 3

Comparison of Remaining Castile Brine Available for Flow
(Initial Pbp = 12.7 MPa, 72 hour open flow period)

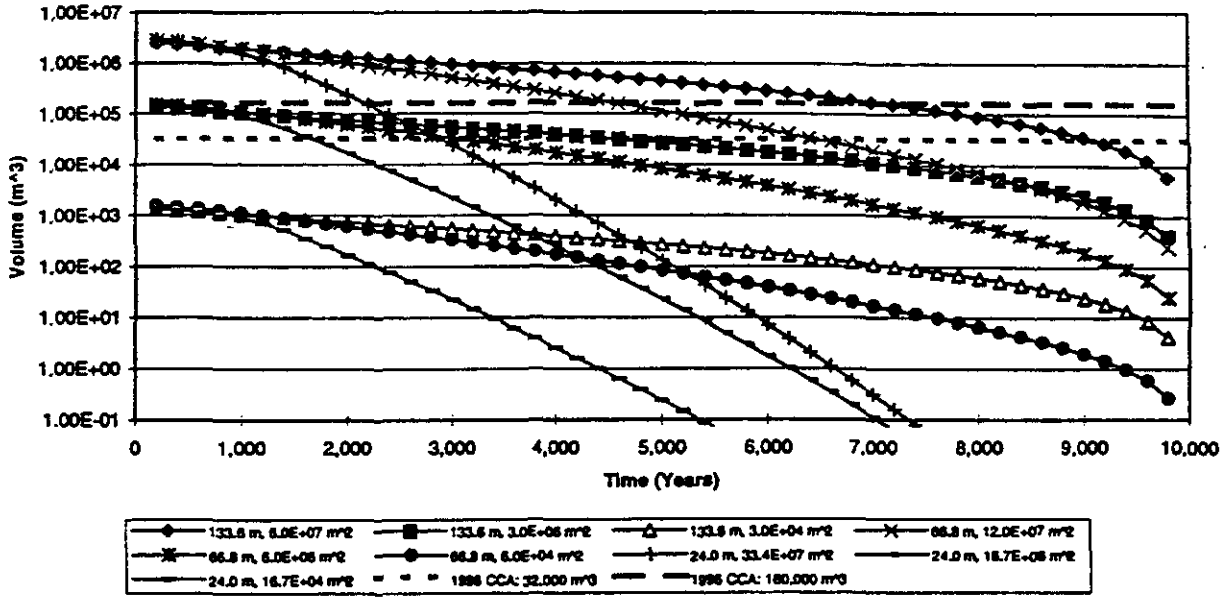

CONCLUSIONS

The 1996 CCA calculations varied the brine pocket volume from 32,000 m^3 to 160,000 m^3. From Figure 3, the only cases which show more brine available for flow for an extended period of time (~2000 to ~7000 years) are the maximum area cases. DOE does not consider the 19 km radius brine pocket to be a realistic estimate of the areal extent, rather an artifact of the unreasonably low rock compressibility ($5X10^{-12}$ pa^{-1}) used for that estimate. In addition, the DOE does not include the depressurization or volume reduction to the brine pocket that would result in numerous borehole penetrations that would statistically "miss" a WIPP panel but penetrate the brine pocket, prior to the first "E1" borehole through a panel. In the CCA calculations for E1 scenarios, the DOE assumes brine pockets of 32,000 m^3 to 160,000 m^3 pore volume at virgin (undepleted) pressures in determining potential releases to the accessible environment, which bounds the range of consequences associated with penetrating a larger but partially depleted brine pocket.

REFERENCES

[Larson & Freeze, 1996]: Larson, Kurt and Freeze, Geoff, Memorandum of Record, "Castile Brine Reservoir Volume Revision", SWCF-A:WBS1.2.07.1:PDD:NON-SALADO:PKG#19C:Castile Brine Reservoir Volume (WPO #31082), May 27, 1996.

[Lee, 1982]: Lee, John, Well Testing, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. ISBN 0-89520-317-0, 1982, (Example 1.3), p. 8, (Table 1-2), p. 9.

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Date: July 19,1996

To: Margaret Chu, MS-1335 (6801)

From: J. W. Berglund 6849, NMERI; J. Myers, IT Corp; L.R. Lenke, NMERI

Subject: Estimate of the Tensile Strength of Degraded Waste for use in Solids Blowout

A value of 1 psi (6895 Pa) was chosen to represent the tensile strength of decomposed waste for the purpose of computing blowout spall releases resulting from a drillbit intrusion into a pressurized waste panel. Such spall releases occur only if the gas pressure exceeds the hydrostatic drilling mud pressure of approximately 8 MPa. A chemical reaction between the waste and brine from the surroundings is necessary to generate the gas to raise the waste pore pressure to these levels. Without brine inflow, little gas will be generated and waste decomposition will be negligible. Thus the phenomenon of blowout spall requires both brine inflow and waste decomposition.

The future state of decomposed waste is both time dependent and unknowable. Therefore a decomposed state consisting of graded granular materials is assumed. This is consistent with the granular nature of decomposed geologic materials and corresponds to an end state of the decomposition process. Such materials lack significant composite strength from the interleaving of components and is the state found to be most troublesome in oil production where sand is produced from poorly consolidated sand layers. The value of 1 psi chosen for cementation strength for the decomposed waste can be reasonably expected to be conservative, i.e. lower than those data values found for many weak materials that are naturally occurring or that have been manufactured. Data to support this value can be found in the literature for the strengths of soils, laboratory produced mixtures of salt and clay, and mixtures of various materials with MgO; the latter added as a backfill material to the waste. A discussion of these data sources follows.

Soil Data

Tensile strengths for several compacted, cohesive soils e.g. Vicksburg buckshot clay (CH), Vicksburg lean clay (CL), and a sandy clay mixture from De Gray dam (SC) were measured using hollow cylinder tests and indirect tensile tests in Al-Hussaini (1981). The samples were prepared to optimum water content compacted and tested. Results for the hollow cylinder tests are shown in Table 1. All exceed 1 psi by factors of approximately 3 to 8 times. Similar results were obtained from the indirect tensile tests.

Table 1 Hollow Cylinder Tests

Material type	Tensile Strength (psi)
CL-1	2.95
CL-2	3.90
CL-3	3.93
CH-1	7.93
CH-2	7.41
CH-3	7.99
SC-1	5.90
SC-2	5.38
SC-3	4.49
CH-4	6.46
CH-5	6.12
CH-6	6.52

Direct tensile tests on simulated waste materials were also conducted by Berglund and Lenke, 1995, p13-14. Various mixtures of partially saturated silica sand and kaolin clay were used to represent the waste. The clay represented a natural material that was chosen to be a close surrogate to partially decomposed cellulosics and plastics. The sand represented the particulate structure expected of magnetite or other products of the iron corrosion reaction. The mixture was 85% sand and 15% clay, a ratio similar to the ratio of decomposition products anticipated for some waste conditions. The tensile strength measured in these experiments was 2.9 ± 1.4 psi. A second indirect method of measuring tensile strength in the Berglund, Lenke study implied an even higher tensile strength value of 4.3 ± 1 psi.

The tensile strength of the above materials (Al-Hussaini 1981, Berglund and Lenke 1995) occurred in the absence of any additional cementation process which would tend to increase these measured tensile strengths.

Salt Mixture Data

Some brine is expected to exist within the waste panels after closure of the facility. The most likely source is brine of Permian age that was trapped in the Salado formation at the time of evaporite deposition. Limited brine occurrences in the WIPP underground have been extensively sampled and analyzed, and the composition of Salado brine is well understood. These brines contain approximately 374 grams of dissolved constituents per liter and are in chemical equilibrium with halite (NaCl) anhydrite ($CaSO_4$), and magnesite ($MgCO_3$).

The removal of even a small amount of water from this brine by evaporation or chemical reaction will result in the precipitation of salts which will act as a cementation agent. One such chemical reaction that is anticipated to occur is the anoxic corrosion of iron and ferrous alloys, which constitute a significant percentage of the waste inventory in the form of steel drums and boxes, contaminated tools and sheet metal, etc.

The reaction of brine with metal will consume H_2O and generate hydrogen and some corrosion product. A typical anoxic reaction might be

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2$$

Consumption of H_2O by corrosion reactions will cause the mass of dissolved solids in the brine to precipitate as a series of evaporite minerals in close proximity to the surface of the

corroding metals forming encrustations which tend to cement the waste. Simulation of the removal of H_2O from one kg of Salado brine using the EQ6 code (Wolery T.J., and S.A. Daveler, 1992) yielded 534 grams of precipitates (anhydrite, bischofite, carnallite, halite, kieserite, and magnesite). The mass is greater than the mass of dissolved solids because of the hydrous nature of some of the precipitates.

Evidence for this process in the WIPP underground could be seen at the close of heated brine inflow experiments performed by SNL a number of years ago. In these experiments, a metal canister containing an electrical heater was placed in a vertical hole excavated in the floor of a room in the northern experimental area. The top of the hole was sealed, and anhydrous nitrogen was circulated within the annulus between the canister and the hole. Small amounts of brine flowed toward the hole in response to the pressure and temperature gradients surrounding the heated hole, and evaporated as it approached the canister. The nitrogen acted as a carrier gas for water vapor and was allowed to exit the hole where it flowed into an apparatus where the water vapor was extracted and quantified.

It was found at the close of the experiment that the canister has become firmly cemented in the hole by the precipitation of salts from the evaporating brine within the annulus. A work-over rig had to be employed to extract the canister from the hole. The removal of water from brine by any process, be it evaporation or corrosion reactions, will produce the same cementation effect by the precipitation of minerals at the site of water removal. This cementation will act to increase the strength of the waste.

A number of strength tests were done for consolidated crushed WIPP salt and mixtures of WIPP salt and bentonite (70 and 30% respectively) (Finley, 1996). Finley's memorandum presents estimates of tensile strengths of clay/salt mixtures based on experimental observations of unconfined compressive strengths and the extended Griffith criterion for tensile failure (Jaeger and Cook, 1976). These estimates are for 30/70 percent bentonite/salt mixtures at fractional densities of 0.83 to 0.88. Finley estimates tensile strengths between 10 and 100 psi.

The WIPP waste stream upon creep closure and subsequent brine saturation will consist of approximately 1350 kg of waste solids (assumed average solid density of the waste was taken as 2700 kg/m^3) and 188 kg of precipitated salt (based on dissolved salt solids of 374 gram/liter cited above) per cubic meter of repository. These numbers are based on a typical closure porosity of 0.5 (final room height of 1.2 m). The gravimetric ratio of salt precipitate to solid waste for these conditions is 0.14. This is a factor of 5 less than the ratio cited by Finley. Using this factor, it is not unreasonable to expect tensile strengths between 2 and 20 psi.

Effects of MgO on Strength

An additional process affecting the strength of the waste/backfill composite material is the chemical interactions that will occur between Salado brine and the MgO backfill. These interactions were simulated using the EQ3/6 code (Wolery, 1992; and Wolery T.J., and Daveler, 1992) with the Pitzer activity coefficient option and Harvie-Moller-Weare database. Five moles of MgO were reacted with one kilogram of Salado brine in a series of small steps. The dissolution of the five moles (202 grams) of MgO into the brine resulted in the precipitation of a total of 507 grams of minerals and the incorporation of 20 percent of the original kg of brine as water of hydration within the precipitates. These precipitates include Mg-oxychloride (63% by mass) and brucite (31% by mass), with minor amounts of anhydrite, halite, and magnesite. Similar results were found by Wang, 1996.

The two dominant precipitates (Mg-oxychloride and brucite) are the key phases in Sorel cement. In fact, Sorel cement is commercially prepared by mixing a magnesium-chloride brine (quite similar to Salado brine) with MgO. Sorel cement is known to have uniaxial compressive strengths in the range of 7,000 to 10,000 psi (Sax and Lewis, 1987). This range is equivalent to tensile strengths of from 490 to 700 psi (Dunham C.W., 1966). Thus the use of an MgO backfill will result in the cementation and strengthening of the waste/backfill composite material as long as sufficient brine is available for the chemical reactions to occur.

Conclusions

While tests to actually measure the binding forces between particles of simulated waste have not been performed, there are data available from several independent sources that suggest that the selection of 1 psi is well below the actual value of tensile strength that can be reasonably expected for decomposed waste. The tensile data presented for several soils without chemically generated salt precipitates exceed 1 psi by factors generally greater than 3. Estimated tensile strengths of consolidated halite-bentonite mixtures exceed 1 psi by factors of ten or more. The role of precipitated salts from anoxic reactions of brine with waste metals is expected to be similar though perhaps not as intense. MgO is added to the waste as a backfill material in large volumes. The reaction products of MgO plus brine are the principal components of Sorel cement which attains high compressive strengths and predicted tensile strengths of 490 to 700 psi.

References

Al-Hussaini, M. (1981), *Tensile Properties of Compacted Soils,* Laboratory Shear Strength of Soil, ASTM STP 740, R. N. Yong and F. C. Townsend, Eds., American Society for Testing Materials, pp.207-225.

Berglund, J.W., and Lenke, L.R., 1995, *One Dimensional Experiments of Gas Induced Spall*, NMERI 1995/3, prepared for Sandia National Laboratories, New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, NM, February 1995 WPO# 27589.

Dunham C.W., 1966, *The Theory and Practice of Reinforced Concrete*, McGraw -Hill, New York, p 36.

Finley, R.E. May 3, 1996 Memorandum to D.R. Anderson and M.S.Y. Chu, Subject: Tensile Strength of Consolidated Crushed Salt

Jaeger, J.C. and N.G.W. Cook, 1979, *Fundamentals of Rock Mechanics*, 3rd Edition, Chapman and Hall, London

Sax, N. I, and R. J. Lewis, 1987, Hawleys Condensed Chemical Dictionary, Eleventh Edition, Van Nostrand Reinhold, New York.

Wang Y., 1996, Memorandum to Malcolm Siegel, March 18, 1996, Subject: Define Chemical Conditions for FMT Actinide Solubility Calculations SWCF-A, WBS 1.1.09.1.1(BC);QA

Wolery T.J., 1992, EQ3NR, *A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations*: Theoretical Manual, Users Guide, and Related Documentation (Version 7.0). Lawrence Livermore Laboratory, Livermore California.

Wolery T.J., and S.A. Daveler, 1992, EQ6, *A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems*: Theoretical Manual, Users Guide, and Related Documentation (Version 7.0). Lawrence Livermore Laboratory, Livermore California.

cc:

MS 1330 SWCF-A:1.1.01.2.7:DRM:QA:Waste Strength, TD

> 9103

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

date: August 20, 1996

to: Distribution

from: David Bennett, Yifeng Wang, and Tim Hicks

subject: An Evaluation of Heat Generation Processes for the WIPP

1.0 Introduction

Nuclear criticality, exothermic reactions, and radioactive decay are possible sources of heat in the WIPP repository. Nuclear criticality has been eliminated from performance assessment calculations on the basis of low probability (see SNL Summary Memo of Record RNT-1). This memo discusses possible heat generating processes at the WIPP and the potential magnitude of the temperature increases they might induce. Heat from exothermic reactions is discussed in Section 2 and heat from radioactive decay is discussed in Section 3.

Conclusions are provided in Section 4. In summary, soon after disposal concrete hydration in the panel closures and shaft seals will give rise to temperature increases lasting a few decades. Heat from radioactive decay will generate a maximum temperature increase of less than 2°C above the ambient temperature (about 27°C) within 100 years after disposal. A number of potential exothermic reactions other than concrete hydration have been identified. These reactions are brine limited and will cause only minor perturbations to the temperature distribution within the disposal system. The maximum calculated rate of brine inflow to a waste disposal panel, and thus, the maximum exothermic reaction rates, occur for the S2 scenario involving an E1 drilling event at 350 years after disposal. By the time such a drilling event takes place heat generation from concrete seal hydration and radioactive decay will have decreased substantially, and the temperatures in the disposal rooms will have reduced to close to initial values. Note that active institutional controls are expected to prevent drilling within the controlled area for 100 years after disposal. Thus, exothermic reactions following a drilling intrusion into a waste disposal panel will be the only potentially significant heat generating processes at the time of a drilling intrusion.

The maximum temperature that could be achieved in the panel following a drilling intrusion at 350 years occurs as a result of aluminum corrosion; this reaction could result in a maximum temperature increase of about 6°C two years after the drilling event. This predicted value of temperature increase is based on several conservative assumptions. For example, it is assumed that no aluminum corrosion has occurred prior to the drilling event and that all the brine introduced to the waste panel is available for aluminum corrosion. In reality some aluminum corrosion is likely to have occurred prior to the drilling event, reducing the volume of aluminum available for the reaction, and other reactions with lower reaction enthalpies (such as backfill hydration) or lower reaction rates (such as microbial degradation) will compete with aluminum corrosion to consume brine resulting in a smaller temperature increase. Based on similar conservative assumptions, backfill hydration could result in a maximum temperature increase of less than 5°C. These maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability. Thus, the temperature rise of 6°C represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously.

2.0 Heat From Exothermic Reactions

Exothermic reactions in the repository will liberate heat resulting in elevated temperatures. The magnitude and duration of this temperature increase will depend on the amount and rate of energy release, the geometry of the heat source, the thermal conductivities of the surrounding rocks, and any influence of groundwater or brine flow on heat transport.

In the WIPP a range of different types of reactions will occur, including corrosion, microbial degradation, waste dissolution, and concrete and backfill hydration, and these will liberate different amounts of heat at different times. The amount of heat liberated by the different reactions will depend on the extent of reaction that occurs (for example, how much gas generation or concrete hydration takes place), and the enthalpy of the reactions. The former will depend on the inventory of materials emplaced in the WIPP, and the subsequent chemical evolution of the repository system. The latter can be assessed by considering typical enthalpies for the reaction types of interest.

Enthalpies of reaction, $\Delta_r H°$, for example reactions representing processes that may take place in the repository are given in Table 1 (from SNL Summary Memo of Record GG-7, SP-7). The reactions shown are based on the chemical conditions expected in the WIPP. Note that negative values for $\Delta_r H°$ indicate that the reactions liberate heat as they progress from left to right.

Table 1. Enthalpies of reaction, $\Delta_r H°$, for the WIPP

Reaction	Example Stoichiometry and Standard Enthalpies of Formation, $\Delta_f H°$ (kJ/mol)	Reaction Enthalpy $\Delta_r H°$ (kJ/mol)	Data Source
Backfill hydration	$MgO_{(s)} + H_2O_{(l)} = Mg(OH)_{2(s)}$ $\Delta_f H°$ -601.7 -285.8 -925.5	-38	Krauskopf, 1982, 561
Backfill carbonation	$Mg(OH)_2 + CO_2(g) = MgCO_3 + H_2O$ $\Delta_f H°$ -925.4 -393.1 -1110.3 -285.8	-77	Drever, 1982, 351-256
Microbial degradation	$C_6H_{10}O_5 + H_2O = 3CH_4 + 3CO_2$ $\Delta_f H°$ -805.5 -285.8 3 x (-74.4) 3x (-393.5)	-312	Lide, 1994, 5-16 to 5-37
Aluminum Corrosion	$Al + 3H_2O = Al(OH)_3 + 1.5H_2$ $\Delta_f H°$ 0 3x(-285.8) 1291.9 0	-434	Drever, 1982, 351-256
Anoxic corrosion of steel	$Fe_{(s)} + 2H_2O_{(l)} = Fe(OH)_{2(s)} + H_{2(g)}$ $\Delta_f H°$ 0 2 x (-285.8) -569.0 0	+2.7	Wagman et al., 1982, Table 41
Waste dissolution	$UO_{2(s,cr)} + 2H_2O_{(l)} = U(OH)_{4(aq)}$ $\Delta_f H°$ -1085.0 2 x (-285.8) -1655.8	+0.9	Grenthe et al., 1992, Table III-1
Concrete hydration	$CaO_{(s)} + H_2O_{(l)} = Ca(OH)_{2(s)}$ $\Delta_f H°$ -635.1 -285.8 -986.1	-65.2	Wagman et al., 1982, 2-26

Even though there is uncertainty surrounding the extent of reactions that will occur, the reaction enthalpies indicate that the thermal effects of anoxic corrosion of steel and the waste dissolution reaction will be endothermic and will be of low consequence to the performance of the disposal system. However, the other reactions shown in Table 1 have the potential to evolve significant amounts of heat. The potential effects of these processes on the temperature within the disposal system are discussed below.

2.1 Backfill Hydration

Potential temperature increases in the repository as a result of exothermic backfill hydration reactions have been evaluated by Wang (1996, attachment to this memo). In his analysis, Wang (1996) made the following assumptions:

- The reaction will proceed rapidly so that the rate of heat generation will be

controlled by brine availability.

- All brine entering a waste disposal panel will contact and react with the backfill in the panel uniformly.

- All of the emplaced backfill will undergo hydration.

The maximum calculated rate of brine inflow into a panel (about 200 m^3/year) occurs for the S2 scenario involving an E1 drilling event at 350 years after disposal. The molar density of water is 5.56×10^4 moles/m^3, and thus, the reaction rate of backfill hydration in the panel will be 1.1×10^7 moles/year. Based on the reaction enthalpy shown in Table 1, backfill hydration will generate a thermal load of about 13 kW. There will be about 2×10^8 moles MgO emplaced per panel and thus the reaction could continue for about 20 years if sufficient brine was available.

Wang (1996) estimated the maximum temperature that could be generated by backfill hydration within a panel. Assuming heat loss will occur by conduction through the salt forming the roof and floor of the panel and that heat losses through the side walls are negligible, Wang (1996) calculated that the maximum temperature rise in a panel, as a consequence of backfill hydration following a borehole intrusion and subsequent brine inflow, would be about 4.5°C.

2.2 Backfill Carbonation

Wang (1996) also estimated the potential temperature rise that could occur as a result of backfill carbonation. Wang (1996) assumed that the reaction will be limited by microbial CO_2 production; the maximum rate of CO_2 production is 2.9×10^5 moles/year. Based on the reaction enthalpy shown in Table 1, backfill carbonation will generate a thermal load of about 0.7 kW. About 3.6×10^7 moles CO_2 could be produced in a single panel (see Wang, 1996) and thus the reaction could continue for about 125 years. Wang (1996) estimated the maximum temperature that could be generated by backfill carbonation within a panel to be about 0.6°C.

2.3 Microbial Degradation

Wang (1996) estimated the maximum reaction rate for microbial degradation in a panel to be about 1×10^5 moles/year and the inventory to be about 1.2×10^7 moles $C_6H_{10}O_5$ per panel. Thus, the reaction could continue for about 120 years. Based on the reaction enthalpy shown in Table 1, microbial degradation will generate a thermal load of about 1 kW. Wang (1996) estimated the maximum temperature that could be generated by microbial degradation within a panel to be about 0.8°C.

2.4 Aluminum Corrosion

Wang (1996) determined that the rate of corrosion of aluminum will be controlled by brine availability. From Table 1, the reaction rate of aluminum corrosion in the panel will be about 0.4×10^7 moles/year, assuming a brine inflow rate of 200 m^3/year (1.1×10^7 moles/year). About 8×10^6 moles of aluminum will be emplaced in each panel and thus aluminum corrosion could continue for 2 years. Based on the reaction enthalpy shown in Table 1, aluminum corrosion will generate a thermal load of about 51 kW. Wang (1996) estimated the maximum temperature that could be generated by aluminum corrosion within a panel to be about 6°C.

2.5 Concrete Hydration

Concrete hydration reactions will occur in the seals and panel closures and in the waste.

2.5.1 Seals and panel closures

Concrete hydration reactions are known to proceed for extended periods (perhaps thousands of years). However, the rates of these reactions decrease with time and, within the WIPP, the greatest evolution of heat will occur during the short periods following emplacement of panel closures during the operational phase and following shaft seal emplacement and repository closure. A quantitative analysis of the thermal effects of emplacing large concrete seals in salt at the WIPP was made by Loken (1994), Loken and Chen (1995). Their analysis showed that the energy released by the hydration of the seal concrete could raise the temperature of the concrete to approximately 53° C and that of the surrounding salt to approximately 38° C one week after seal emplacement.

2.5.2 Waste

WIPP waste contains cement which is used to solidify liquids, particulates and sludges. Storz (1996) estimated that all the waste to be emplaced at the WIPP will contain a total of about 8.5×10^6 kg of cement. This is equivalent to about 1.5×10^7 moles of calcium oxide (CaO) per waste disposal panel, representing the cement as CaO. Although a substantial amount of hydration may occur prior to waste disposal, this process will continue at a slower rate after disposal. Disregarding the hydration that will occur prior to disposal and assuming a brine inflow rate of 200 m^3/year, the reaction rate of concrete hydration in the panel will be about 1.1×10^7 moles/year, and the reaction could continue for about 1.4 years. Based on the reaction enthalpy shown in Table 1, concrete hydration will generate a thermal load of about 23 kW. Thus, using analyses similar to that used by Wang (1996) the maximum temperature that could be generated by concrete hydration of the waste within a panel is about 2°C.

3.0 Heat From Radioactive Decay

Radioactive decay of the contact handled CH and remote handled RH TRU waste emplaced in the repository will generate heat. The importance of heat from radioactive decay depends on the effects that the induced temperature changes would have on mechanics, fluid flow, and geochemical processes. For example, temperature increases could result in thermally induced fracturing, regional uplift, or thermally driven flow of gas and brine in the vicinity of the repository.

According to the Waste Acceptance Criteria (WAC), the design basis for the WIPP requires that the thermal loading does not exceed 10 kilowatts per acre. The WAC also require that the thermal power generated by waste in an RH TRU container shall not exceed 300 watts, but the WAC do not limit the thermal power of CH TRU waste containers.

A numerical study to calculate induced temperature distributions and regional uplift is reported in DOE (1980, pp.9-149–9-150). This study involved estimation of the thermal power of CH TRU waste containers. The DOE (1980) analysis assumed:

- All CH TRU waste drums and boxes contain the maximum permissible quantity of plutonium. According to the WAC, the fissionable radionuclide content for CH TRU waste containers shall be no greater than 200 grams per 0.21 cubic meter drum and 350 grams per 1.8 cubic meter standard waste box (in Pu-239 fissile gram equivalents).

- The plutonium in CH TRU waste containers is weapons grade material producing heat at 0.0024 watts per gram. Thus, the thermal power of a drum is approximately 0.5 watts and that of a box is approximately 0.8 watts.

- Approximately 3.7×10^5 cubic meters of CH TRU waste are distributed within a repository enclosing an area of 7.3×10^5 square meters. This is a conservative assumption in terms of quantity and density of waste within the repository, because the maximum capacity of the WIPP is 1.756×10^5 cubic meters for all waste (as specified by the Land Withdrawal Act [LWA]) to be placed in an enclosed area of approximately 5.1×10^5 square meters.

- Half of the CH TRU waste volume is placed in drums and half in boxes so that the repository will contain approximately 9×10^5 drums and 10^5 boxes. Thus, a calculated thermal power of 2.8 kilowatts per acre (0.7 watts per square meter) of heat is generated by the CH TRU waste.

- Insufficient RH TRU waste is emplaced in the repository to influence the total thermal load.

Thorne and Rudeen (1980) estimated the long-term temperature response of the disposal system to waste emplacement. Calculations assumed a uniform initial power density of 2.8 kilowatts per acre (0.7 watts per square meter) which decreases over time. Thorne and Rudeen (1980) attributed this thermal load to RH TRU waste, but DOE (1980), more appropriately, attributed this thermal load to CH TRU waste based on the assumptions listed above. Thorne and Rudeen (1980) estimated the maximum rise in temperature at the center of a repository to be 1.6°C at 80 years after waste emplacement.

Sanchez and Trellue (1996) estimated the maximum thermal power of an RH TRU waste container. The Sanchez and Trellue (1996) analysis involved inverse shielding calculations to evaluate the thermal power of an RH TRU container corresponding to the maximum permissible surface dose; according to the WAC the maximum allowable surface dose equivalent for RH TRU containers is 1000 rem/hr. The following calculational steps were taken in the Sanchez and Trellue (1996) analysis:

- Calculate the absorbed dose rate for gamma-ray radiation corresponding to the maximum surface dose equivalent rate of 1000 rem/hr. Beta and alpha radiation are not included in this calculation because such particles will not penetrate the waste matrix or the container in significant quantities. Neutrons are not included in the analysis because, according to the WAC, the maximum dose rate from neutrons is 270 mrem/hr, and the corresponding neutron heating rate will be insignificant.

- Calculate the exposure rate for gamma radiation corresponding to the absorbed dose rate for gamma radiation.

- Calculate the gamma flux density at the surface of a RH TRU container corresponding to the exposure rate for gamma radiation. Assuming the gamma energy is 1.0 MeV the maximum allowable gamma flux density at the surface of a RH TRU container is about 5.8×10^8 gamma rays per square centimeter per second.

- Determine the distributed gamma source strength, or gamma activity, in an RH container from the surface gamma flux density. The source is assumed to be shielded such that the gamma flux is attenuated by the container and by absorbing material in the container. The level of shielding depends on the matrix density. Scattering of the gamma flux, with loss of energy, is also accounted for in this calculation through inclusion of a gamma buildup factor.

The distributed gamma source strength is determined assuming a uniform source in a right cylindrical container. The maximum total gamma source (gamma curies) is then calculated for a RH TRU container containing 0.89 cubic meters of waste. For the waste of greatest expected density (about 6,000 kilograms per cubic meter) the gamma source is about $2x10^4$ curies per cubic meter.

Calculate the total curie load of a RH TRU container (including alpha and beta radiation) from the gamma load. The ratio of the total curie load to the gamma curie load was estimated through examination of the radionuclide inventory presented in the WIPP Baseline Inventory Report (BIR) (DOE, 1995). The gamma curie load and the total curie load for each radionuclide listed in the WIPP BIR were summed. Based on these summed loads the ratio of total curie load to gamma curie load of RH TRU waste was calculated to be 1.01.

- Calculate the thermal load of a RH TRU container from the total curie load. The ratio of thermal load to curie load was estimated through examination of the radionuclide inventory presented in the WIPP BIR (DOE, 1995). The thermal load and the total curie load for each radionuclide listed in the WIPP BIR were summed. Based on these summed loads the ratio of thermal load to curie load of RH TRU waste was calculated to be about 0.0037 watts/curie. For a gamma source of $2x10^4$ curies per cubic meter the maximum permissible thermal load of a RH TRU container is about 70 watts per cubic meter. Thus, the maximum thermal load of a RH TRU container is about 60 watts, and the WAC upper limit of 300 watts will not be achieved.

Note that Sanchez and Trellue (1996) calculated the average thermal load for a RH TRU container to be less than 1 watt. Also, the total RH TRU heat load is less than 10% of the total heat load in the WIPP. Thus, the total thermal load of the RH TRU waste will not significantly affect the average rise in temperature in the repository resulting from decay of CH TRU waste.

Temperature increases will be greater at locations where the thermal power of a RH TRU container is 60 watts, if any such containers are emplaced. Sanchez and Trellue (1996) estimated the temperature increase at the surface of a 60 watt RH TRU waste container. Their analysis involved solution of a steady-state thermal conduction problem with a constant heat source term of 70 watts per cubic meter. These conditions represent conservative assumptions because the thermal load will decrease with time as the radioactive waste decays. The temperature increase at the surface of the container was calculated to be about 3°C.

In summary, analysis has shown that the average temperature increase in the WIPP repository due to radioactive decay of the emplaced CH and RH TRU waste will be about 1.6°C, with a maximum rise occurring at the center of the repository at about 80 years after waste emplacement. Temperature increases of about 3°C may occur in the vicinity of RH TRU containers with the highest allowable thermal load of about 60 watts (based on the maximum allowable surface dose equivalent for RH TRU containers).

4.0 Conclusions

Heat from exothermic reactions and radioactive decay will result in minor temperature increases in the repository. The potential temperature increases caused by these processes are summarized in Table 2.

Table 2. Maximum temperature increases at the WIPP.

Heat Source	Maximum temperature increase	Time of maximum temperature increase
Backfill hydration	4.5°C	20 years after a drilling intrusion
Backfill carbonation	0.6°C	125 years after a drilling intrusion
Microbial degradation	0.8°C	120 years after a drilling intrusion
Aluminum corrosion	6.0°C	2 years after a drilling intrusion
Concrete hydration (seals)	25°C in the shaft seal 10°C in the surrounding salt	1 week after emplacement
Concrete hydration (waste)	2.0°C	1.4 years after a drilling intrusion
Radioactive decay of CH TRU waste	1.6°C	80 years after disposal
Radioactive decay of RH TRU waste	3°C near a few containers	Within 100 years after disposal

During the operational phase and soon after disposal concrete hydration in the panel closures and shaft seals will give rise to temperature increases lasting a few decades. Heat from radioactive decay will generate a maximum temperature increase of less than 2°C within 100 years after disposal. A number of potential exothermic reactions have been identified. These reactions are brine limited and will cause only minor perturbations to the temperature distribution within the disposal system. The maximum calculated rate of brine inflow to a waste disposal panel occurs for the S2 scenario involving an E1 drilling event at 350 years after disposal. The maximum temperature that could be achieved in the panel

occurs as a result of aluminum corrosion; this reaction could result in a maximum temperature increase of about 6°C two years after the drilling event. Similarly, rapid backfill hydration could result in a maximum temperature increase of less than 5°C. These predicted values of temperature increase are based on a number of conservative assumptions. For example, the calculated temperature resulting from aluminum corrosion is based on the assumption that no corrosion has occurred prior to the drilling event and that all the brine introduced to the waste panel is available for aluminum corrosion. In reality some aluminum corrosion is likely to have occurred prior to the drilling event, reducing the volume of aluminum available for the reaction, and other reactions with lower reaction enthalpies or lower reaction rates will consume brine resulting in a smaller temperature increase.

Temperature increases of the magnitude and duration shown in Table 2 will have no significant effects on the performance of the disposal system. The effects of such temperature increases on the performance of the disposal system have been discussed in the SNL Summary Memos of Record RNT-24 (thermochemical effects), S-10 and GG-4 (thermal convection), S-11, SP-6, RM-1 (thermally-induced stress).

5.0 References

DOE (U.S. Department of Energy), 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026. Vol. 1 of 2. U.S. Department of Energy, Washington, DC.

DOE (U.S. Department of Energy) 1995. Transuranic Waste Baseline Inventory Report. DOE/CAO-95-1121, Revision 2, December 1995, Carlsbad, NM.

Drever, J.I. 1982. The Geochemistry of Natural Water. Prentice-Hall.

Grenthe, I. Fuger, J., Konings, R.J.M., Lemire, R.J., Muller, A.B., Nguyen-Trung, C., and Wanner, H. 1992. *Chemical Thermodynamics of Uranium.* Eds. H. Wanner and I. Forest. Amsterdam, London, New York: North-Holland for NEA/OECD. pp: 30-50.

Krauskopf, K.B. 1982. *Introduction to Geochemistry. Second (International) Edition.* McGraw-Hill International Series in the Earth and Planetary Sciences. McGraw-Hill Book Company. p. 561.

Lide, D.R. 1994. Handbook of Chemistry and Physics. CRC Press.

Loken, M.C. 1994. "SMC Thermal Calculations", RSI Calculation No. A141-GE-05, Prepared for Parsons Brinckerhoff, San Francisco, CA. Rapid City, SD: RE/SPEC Inc.

Loken, M.C., and Chen, R. 1995. "Rock Mechanics Analysis of SMC", RSI Calculation No. A141-GE-07, Prepared for Parsons Brinckerhoff, San Francisco, CA. Rapid City, SD: RE/SPEC Inc.

Sanchez, L. C., and Trellue, H. R., 1996. "Estimation of Maximum RH-TRU Thermal Heat Load for WIPP." Memo to T. Hicks (Galson Sciences Ltd.), January 17, 1996. Sandia National Laboratories, Albuquerque, NM. SWCF-A WBS:1.1.6.2.:PA:PBWAC - WIPP ACTIVITY.

Storz, L. 1996. *Estimate of the Amount of $Ca(OH)_2$ Contained in the Portland Cement Fraction of the Waste for Disposal in the WIPP.* Memo of June 24, 1996. SWCF (Or. 6752), WBS 1.1.09.

Thorne, B. J., and Rudeen, D. K., 1980. *Regional Effects of TRU Repository Heat.* SAND-7161. Sandia National Laboratories, Albuquerque, NM.

Wagman, D.D., Evans, W.H., Parker, V.B., Schumm, R.H., Halow, I., Bailey, S.M.,

Churney, K.L, and Nuttall, R.L. 1982. The NBS Tables of Chemical Thermodynamic Properties. Selected Values for Inorganic and C_1 and C_2 Organic Substances in SI Units. *Journal of Physical and Chemical Reference Data,* Volume 11, Supplement No. 2. American Chemical Society.

Wang, Y. 1996. *Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment: A Revised Version..* Memorandum of August 19, 1996. SWCF-A (Org. 6352), WBS 1.1.09.1.1(RC). (attached)

Attachment: memorandum of August 19, 1996, by Yifeng Wang, to Distribution. "Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment: A revised version," Sandia National Laboratories.

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date: August 19, 1996

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from: Yifeng Wang (Org. 6832)

subject: Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment: A revised version

Temperature increases caused by exothermal chemical reactions in the repository have been evaluated in the memo by Wang (1996). This memo is the revised version of the previous memo. Two revisions have been made: (1) anoxic steel corrosion reaction is no longer an exothermal reaction; (2) waste panel number is adjusted from eight to ten. All revisions made here do not change the conclusion that the thermal effect of exothermal chemical reactions in the repository is negligible.

Assumptions:

The following exothermal chemical reactions are considered:

$$MgO + H_2O \rightarrow Mg(OH)_2 \quad (1)$$

$$Mg(OH)_2 + CO_2 \rightarrow MgCO_3 \quad (2)$$

$$C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2 \quad (3)$$

$$Al + 3H_2O \rightarrow Al(OH)_3 + 1.5\ H_2\ . \quad (4)$$

Anoxic steel corrosion is a major chemical reaction expected to occur in the repository:

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2. \quad (5)$$

However, this reaction is considered here, because it is not an exothermal reaction. The enthalpy change of Reaction (5) is estimated to be 0.64 Kcal/mole Fe.

Considering that the vertical dimension of the repository (~ 1 m, B. M. Butcher, personal comm.) will be much less than the horizontal extension after room closure, we assume that the heat released from the reactions will be dissipated away mainly from the ceiling and ground of the repository and the heat loss from the side walls is negligible. We also assume that all reactions will take place uniformly in a reaction region of interest. We here restrict the reaction region in a single waste panel, for the following reason: Some of the above reactions may be limited by brine inflow. BRAGFLO simulations have shown that, in the human intrusion cases, the rate of brine inflow into a borehole-penetrated waste panel will be significantly higher than that into the rest of the repository. Choosing a panel rather than the whole repository as a reaction region will make heat generation rate per unit of volume higher and the heat dissipating surface area smaller in our calculations, and

therefore it is conservative. However, this choice will not affect the calculations for the reactions that are not limited by brine inflow, as you will see below.

Theory:

Based on these assumptions, the thermal effect of an exothermal chemical reaction can be modeled by a simplified system shown in Figure 1. The temperature distribution (T) can be described by the following equations:

$$C_p \rho \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial X^2} \tag{6}$$

$$T(X,0) = T_0 \tag{7}$$

$$R\Delta H = 2Sk \left. \frac{\partial T}{\partial X} \right|_{X=0} \tag{8}$$

$$T(\infty,t) = T_0 \tag{9}$$

where C_p is the heat capacity of surrounding rocks (J/mole/K); ρ is the molar density of surrounding rocks (moles/m^3); t is time (year); X is the spatial coordinate (m); k is the thermal conductivity of surrounding rocks (J/year/m/K); T_0 is the background temperature (K); R is the reaction rate (moles/year); ΔH is the enthalpy change of the reaction (J/mole); S is the horizontal area of a waste panel (m^2).

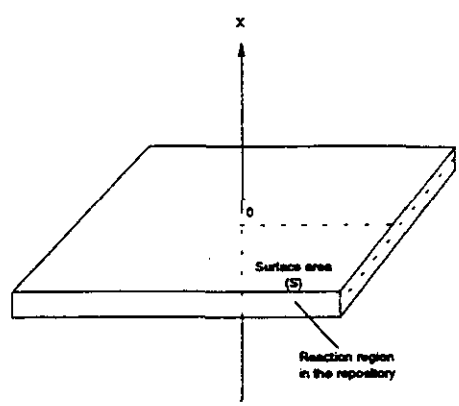

Figure 1. A modeling system for heat production and conduction.

The above equations can be solved for T with a Laplace-transformation method:

$$T - T_0 = -\frac{R\Delta H}{2S\sqrt{C_p\rho k}}\left[2\sqrt{\frac{t}{\pi}}e^{-\frac{C_p\rho X^2}{4Kt}} - \sqrt{\frac{C_p\rho}{k}}X\,erfc\left(\frac{X}{2}\sqrt{\frac{Cp\rho}{kt}}\right)\right]. \tag{10}$$

The temperature increase in the repository (ΔT) is obtained by setting X = 0 in equation (6):

$$\Delta T = T(0,t) - T_0 = -\frac{R\Delta H}{S}\sqrt{\frac{t}{\pi C_p\rho k}}. \tag{11}$$

Equation (7) shows that the repository temperature will increase with t until $t = \frac{M}{R}$, when all the reactant is consumed. Here M is the inventory of the reactant in a waste panel (moles). Therefore, the maximum temperature increase (ΔT_{max}) in the repository due to the exothermal reaction can be calculated by

$$\Delta T_{max} = T(0,t) - T_0 = -\frac{\Delta H}{S}\sqrt{\frac{RM}{\pi C_p\rho k}}. \tag{12}$$

Equation (12) shows that, for the reactions not limited by brine inflow, reducing the reaction region size does not affect ΔT_{max}, because the parameters S, R, and M will be reduced by the same factor, which is canceled out in the equation. This is not true for the brine-limited reactions, the rates of which are no longer dependent on reactant inventory.

Assuming the physical properties of the surrounding rocks can be represented by halite, we then have:

C_p = 50 J/mole/K (Lide, 1994, p. 12-158)

$\rho = 3.7\times10^4$ moles/m^3 (Lide, 1994, p. 4-149)

k = 6 W/m/K = 1.9×10^8 J/year/m/K (Lide, 1994, p. 12-165)

S = 1.2×10^4 m^2 (Sandia WIPP Project, 1992, p. 3-4).

With these parameter values, we obtain from equation (12):

$$\Delta T_{max} = 2.5x10^{-12} \Delta H \sqrt{RM} \,. \qquad (13)$$

Results:

(1) Reaction: $MgO + H_2O \rightarrow Mg(OH)_2$

We assume that this reaction is instantaneous and thus is limited by brine inflow. Based on BRAGFLO simulations for E1 scenario (Figure 2), the conservative (maximum) estimate of the rate of brine inflow into a borehole penetrated waste panel is about 200 m^3/year, equivalent to the reaction rate of $1.1x10^7$ moles/year. With $\Delta H = -3.9x10^4$ J/mole (Drever, 1982, p. 351-356) and $M = 2x10^8$ moles, we estimate ΔT_{max}, ≈ 4.5 K.

(2) Reaction: $Mg(OH)_2 + CO_2(g) = MgCO_3 + H_2O$

We assume that this reaction is limited by microbial CO_2 production. It is estimated that the maximum rate of CO_2 production (R) is $2.9x10^5$ moles/year and the total CO_2 that can be produced (M) is $3.6x10^7$ moles in a single waste panel (Wang & Brush, 1996; DOE/CAO, 1996). With $\Delta H = -0.8x10^5$ J/mole (Drever, 1982, p. 351-256), ΔT_{max}, is estimated to be 0.6 K.

(3) Microbial degradation: $C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2$

The maximum reaction rate and the inventory of $C_6H_{10}O_5$ in a single waste panel are estimated to be $1x10^5$ moles/year and $1.2x10^7$ moles (Wang & Brush, 1996; DOE/CAO, 1996). With $\Delta H = -3.1x10^5$ J/mole (Lide, 1994, p. 5-16 to 5-37), ΔT_{max}, is estimated to be 0.8 K. Because of lack of thermodynamic data for cellulose materials, we here assume that the enthalpy of $C_6H_{10}O_5$ is approximately equal to that of $C_6H_{10}O_4$.

(4) Aluminum corrosion: $Al + 3H_2O \rightarrow Al(OH)_3 + 1.5\, H_2$

The inventory of Al in a single panel is about $8x10^6$ moles (DOE/CAO, 1996). Aluminum are present as foil in the waste and its thickness is estimated to be $2.54x10^{-4}$ cm. The total surface area of Al foil is thus estimated to be ~ $2.6x10^8$ m^2. With this high surface area and the measured corrosion rate (2.9 mole H_2/m^2/year, Telander & Westerman, 1996), Al corrosion reaction is expected to be limited by brine inflow, and the maximum corrosion rate is ~ $0.4x10^7$ moles/year. With $\Delta H = -4.4x10^5$ J/mole (Drever, 1982, p. 351-356), ΔT_{max}, is estimated to be 6 K.

ire 2. SNL WIPP PA96: BRAGFLO SI(JLATIONS (CCA R1 S2)

Cumulative Brine Inflow into Waste Panel

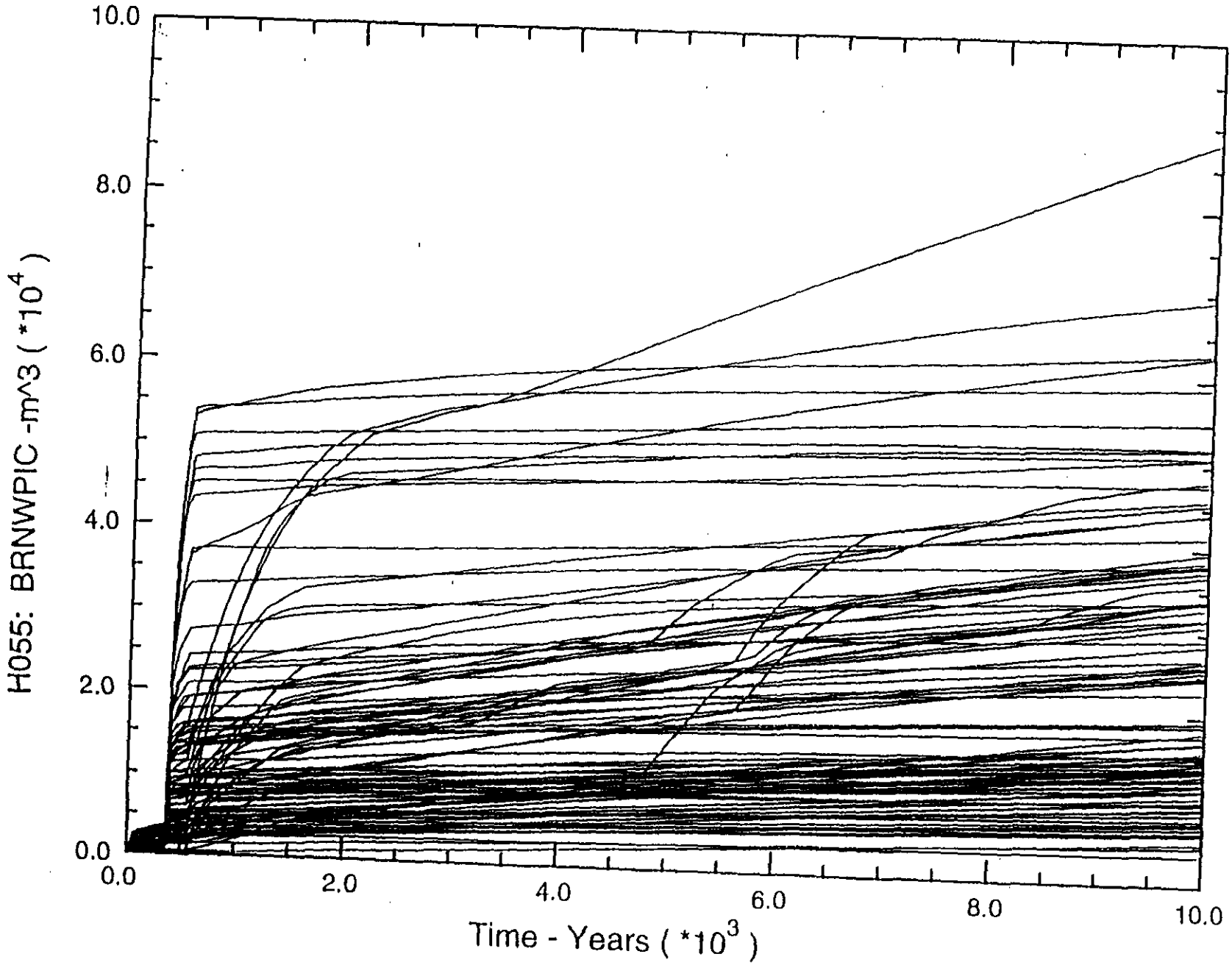

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The two brine-inflow-limited reactions - MgO hydration and Al corrosion - could possibly bring repository temperature up to 6 K. However, this temperature increase will not affect the overall repository performance, for two reasons: (1) The maximum temperature, if it is achieved, will be sustained only over a very short time period. For example, to achieve this temperature, Al has to be corroded completely within 2.5 years. After that, the accumulated heat will be dissipated away quickly. Thus, the maximum temperature, if it is attained, will last perhaps less than a year. (2) More importantly, because the two reactions are brine-limited, they will consume all free brine in the repository until all the reactants are completely consumed. Therefore, the maximum temperature will occur much earlier than enough free brine accumulates in the repository for the release of dissolved actinides. Based on the above calculations, the thermal effect of the other reactions, which are not limited by brine inflow and can last over a significant portion of 10000 year time period, are definitely negligible.

In conclusion, ignoring the thermal effect of chemical reactions (1 - 5) can not affect the overall repository performance assessment.

References:

DOE/CAO (1996) Transuranic Waste Baseline Inventory Report (Rev. 3).

Drever, J. I. (1982) The Geochemistry of Natural Water. Prentice-Hall.

Lide, D. R. (1994) Handbook of Chemistry and Physics. CRC Press.

Sandia WIPP Project (1992) Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters. SAND92-0700/3.

Telander, M. R. & Westerman R. E. (1996) Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Final Report. (Draft)

Wang, Y. & Brush, L. H. (1996) Estimate of gas-generation parameters for the long-term performance assessment. memo to M. S. Tierney, 1/26/1996, WBS 1.1.09.1.1(RC).

Wang, Y. (1996) Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment. memo to V. R. Bynum & L. H. Brush, 7/19/1996, WBS 1.1.09.1.1(RC).

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PEER 3 - Waste Characterization Peer Review

CAO PLAN
Carlsbad Area Office

Title: Waste Characterization Analysis (WCA) Peer Review Plan

(Assistant Manager, Office of Regulatory Compliance, Carlsbad Area Office) Date: 6/27/96

1. INTRODUCTION

This Waste Characterization Analysis Peer Review (WCA Peer Review) Plan describes the peer review that will be conducted to meet the peer review requirements prescribed in 40 CFR Part 194.27(a)(2).

This section stipulates that a peer review will be conducted of the analysis required in section 194.24(b), i.e., "The Department shall submit in the compliance certification application the results of an analysis which substantiates: etc." The analysis will consist of a report that describes the decisions, rationale, and determination of the list of TRU waste components and waste characteristics that are included as input to the 1996 performance assessment (PA) modeling. In addition, it will include those TRU waste components and characteristics considered and excluded from consideration in the PA. The peer review will be conducted to determine the adequacy, reasonableness, and completeness of the "Waste Characterization Analysis Report."

1.1 BACKGROUND

In accordance with the regulatory requirements specified in 40 CFR Part 191 and implemented in accordance with the criteria specified in 40 CFR Part 194, section 194.27(a)(2) "Any compliance application shall include documentation of peer review that has been conducted, in a manner required by this section, for "Waste Characterization Analysis" as required in section 194.24(b)." Section 194.27(b) further specifies the manner in which the peer reviews will be conducted, i.e., "Peer review processes required in paragraph (a) of this section, and conducted subsequent to the promulgation of this part, shall be conducted in a manner that is compatible with NUREG-1297, "Peer Review for High-Level Nuclear Waste Repositories."

The regulatory requirements governing waste characterization, as specified in 40 CFR Part 191, are implemented in part through criteria in 40 CFR Part 194.24(c)(1) requiring that any compliance application shall "Demonstrate that, for the total inventory of waste proposed for disposal in the disposal system, WIPP complies with the numeric requirements of [Sec.] 194.34 and [Sec.] 194.55 for the upper or lower limits ..., as appropriate, for each waste component identified in paragraph (b)(2) of this section, and for the plausible combinations of upper and *lower limits of such waste components that would result in the greatest estimated release.*"

Sandia National Laboratories (SNL) is responsible for the selection and development of conceptual models that reasonably represent the future states of the disposal system. These conceptual models include those processes that affect the waste disposed in the disposal system and the ability of the disposal system to contain the waste (within regulatory limits) for the regulatory period. The basis of the "Waste Characterization Analysis Report" is to identify those TRU waste components and characteristics that have been determined to be of importance to, and therefore included in, the 1996 PA modeling, as well as those that were considered and excluded.

1.2 PURPOSE

The purpose of this WIPP Peer Review Plan is to define the peer review process that will be conducted to determine the adequacy, reasonableness, and completeness of the "Waste Characterization Analysis Report."

This peer review will be conducted in accordance with the requirements of NUREG-1297 which states, "A peer review is a documented, critical review performed by peers who possess qualifications at least equal to those of the individuals who conducted the original work. These individuals must be independent of the individuals who conducted the original work. These individuals must be independent of the work being reviewed; independence from the work reviewed means that the peer was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed."

1.3 SCOPE

This WCA Peer Review Plan describes the peer review processes that the DOE Carlsbad Area Office (CAO) will utilize for the review of the "Waste Characterization Analysis Report." The peer review will be an in-depth critique of assumptions, alternate interpretations, methodology, and acceptance criteria employed, and of the conclusions drawn in the original work. This WCA Peer Review Plan defines the approach, methods, criteria, schedules, deliverables, and resources required for conducting the WCA Peer Review. The WCA Peer Review will confirm the adequacy, reasonableness, and completeness of the "Waste Characterization Analysis Report" as required by 40 CFR Part 194.24(b). The review will consider the documentation of rationale and analyses that are described in the "Waste Characterization Analysis Report." This report summarizes the decisions, rationale, and determination of the list of TRU waste components and characteristics that are included in the PA and in the TRU waste components and characteristics considered and excluded.

2. PEER REVIEW PLANNING AND IMPLEMENTATION

2.1 APPROACH

The DOE-CAO has prepared the Office of Regulatory Compliance (ORC) Team Procedure for Peer Review (TP 10.5) to document the approach for conducting the peer review process. The WCA Peer Review Panel will conduct the peer review activities associated with the confirmation of the adequacy, reasonableness, and completeness of the waste characterization analysis in accordance with TP 10.5, the Peer Review Management Plan, and this WCA Peer Review Plan. A DOE-CAO contractor, Informatics, Inc., has developed Informatics Desk Instruction (IDI) 1.0 that will be used in conjunction with TP 10.5.

DOE-CAO has prepared the "Waste Characterization Analysis Report" which was developed to meet the requirements of 40 CFR Part 194.24(b). Background documentation used to prepare this report, plus the report itself, will form the technical basis of the peer review.

2.1.1 DATA AND INFORMATION USED TO REVIEW THE WASTE CHARACTERIZATION ANALYSIS

The Peer Review Panel will utilize the CAO TRU Waste Baseline Inventory Reports (TWBIR) that describe the chemical, radiological, and physical composition of the existing waste and, to the extent practicable, the description of the chemical, radiological, and physical composition of to-be-generated waste proposed for disposal in the disposal system. The waste characterization analysis, as prescribed in 40 CFR Part 194 section 194.24(b), is described in the "Waste Characterization Analysis Report." The Waste Characterization Analysis Peer Review Report will be based on the adequacy, reasonableness, and completeness of the "Waste Characterization Analysis Report" that describes the TRU waste characteristics an components included in the PA calculations.

2.1.2 COMPOSITION OF PEER REVIEW PANEL

The WCA Peer Review Panel will be composed of a minimum of three individuals who meet requirements identified in TP 10.5. The duration of the WCA Peer Review Panel review process is anticipated to last a total of 3-5 weeks. The Peer Review Selection Committee will appoint the panel members based on their technical expertise and the requirements of TP 10.5 and this Plan.

2.1.3 LOGISTICS AND MANAGEMENT

When the WCA Peer Review Panel convenes, Panel members will receive formal orientation and training. The orientation will help to familiarize Panel members with the WIPP containment system. Each peer reviewer will be selected, oriented, and trained in accordance with approved procedures. The peer reviewers also will be familiarized with the parameter input to the PA codes and the results of prior PAs, sensitivity analyses, and critical comments from previous reviews as related to TRU waste characteristics. It is the intention of DOE-CAO to have the WCA report and other data available for review when the WCA Panel begins the review process.

2.2 METHODOLOGY

The WCA Peer Review will follow the methodology provided in NUREG-1297, as augmented by the specific requirements contained in 40 CFR Part 194.22 and is intended to meet the peer review requirements as specified in 194.27(b). The purpose for conducting a peer review of the "Waste Characterization Analysis Report" is to meet the requirement stated in 40 CFR Part 194.27(a)(2). Adequacy criteria are provided in Section 2.3.

2.3 ADEQUACY CRITERIA

Adequacy of information and analyses associated with the "Waste Characterization Analysis Report" will be based on the Peer Review Panel's determination that the information and analyses meet commonly accepted technical and scientific standards. Criteria stipulated in NUREG-1297 may include, as stipulated:

- Adequacy of requirements and criteria;
- Validity of assumptions;
- Alternate interpretations as appropriate;
- Uncertainty of results and consequences if wrong;
- Appropriateness and limitations of methodology and procedures;
- Adequacy of application;
- Accuracy of calculations; and
- Validity of conclusions.

In evaluating the existing information and analyses, the Peer Review Panel may also consider the following as appropriate:

- The source of the information and analyses, e.g., professional judgment, published source material, etc.
- The assumptions, calculations, extrapolations, interpretations, methods, and conclusions pertinent to the rationale and analyses are appropriate to identify and assess the impact of waste characteristics on the disposal system performance.

2.4 SCHEDULE

The PR Manager, working closely with CAO-ORC and SNL, has developed a preliminary schedule for conducting the WCA Peer Review. The peer review will consist of a review of the "Waste Characterization Analysis Report." Supporting data and information used to develop this document will form the basis of this review. Because of the close timing of this review and resultant report development, flexibility is required by all supporting organizations (i.e., DOE-CAO, SNL, the PR Manager, staff and panel members) to accommodate the peer review schedule and any changes made due to uncertainty in the timing of data availability. Attachment A contains a schedule of WCA Peer Review activities and milestones. This schedule will serve as the baseline schedule from which requested schedule deviations will be evaluated and approved, if appropriate. Revisions to the baseline schedule will not require revision to this plan but will be attached to the plan by reference.

2.5 DELIVERABLES

The final report for the WCA Peer Review will be submitted to DOE-CAO. A list of mandatory topics and suggested outline for the Peer Review Final Report is provided in Attachment B. This outline may be utilized to guide the review of the data and information used to confirm the adequacy, reasonableness, and completeness of the "Waste Characterization Analysis Report."

3. QUALITY ASSURANCE

The WCA Peer Review process will be conducted in a controlled manner and in compliance with TP 10.5.

4. RECORDS MANAGEMENT

Records and documentation generated as a result of peer review activities defined in this WCA Peer Review Plan are identified in TP 10.5. WCA Peer Review records will be assembled and maintained in accordance with the Peer Review Mangement Plan and IDI 1.0. Upon completion of the WCA Peer Review, a complete set of WCA Peer Review records will be delivered to DOE-CAO. Ultimately, peer review records will be dispositioned in accordance with DOE-CAO records management requirements defined in CAO-MP 4.5.

5. DOCUMENT CONTROL

All plans, procedures, and other documents that require document control will be handled in accordance with the DOE-CAO document control procedure defined in CAO-MP 4.4.

ATTACHMENT A

WASTE CHARACTERIZATION ANALYSIS PEER REVIEW SCHEDULE

	DRAFT	FINAL
WCA Peer Review Plan	6/6	6/20
PR Panel Assigned	N/A	6/24
WCA Report Plan to PR Manager	NA	7/10
Draft WCA Peer Review Report	7/24	N/A
Final WCA Peer Review Report	N/A	7/30

ATTACHMENT B

PEER REVIEW REPORT OUTLINE (SUGGESTED)

Executive Summary

1. Introduction

2. Purpose

3. Description of Work Performed

4. Evaluation of Work Performed

   A. Adequacy of Requirements and Criteria
   B. Validity of Assumptions
   C. Alternate Interpretations
   D. Uncertainty of Results and Consequences if Wrong
   E. Appropriateness and Limitations of Methodology and Procedures
   F. Adequacy of Application
   G. Accuracy of Calculations
   H. Validity of Conclusions

5. Conclusions

6. Dissenting Views

7. Summary

8. Signatures

9. Peer Review Members and Acceptability

FINAL REPORT

WASTE CHARACTERIZATION ANALYSIS PEER REVIEW REPORT

A PEER REVIEW
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Carlsbad Area Office
Office of Regulatory Compliance

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FOREWORD

The Environmental Protection Agency promulgated "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR 191 Disposal Regulations Final Rule" in Code of Federal Regulations, Title 40, 194 (40 CFR 194) on February 9, 1996. The 40 CFR 194 regulation prescribes three specific peer reviews and also provides the opportunity for the Department of Energy to use peer reviews, conducted in accordance with NUREG-1297, as a means of qualifying data and information for use in the demonstration of compliance.

This report contains the results of a peer review of the Waste Characterization Analysis used in the demonstration of WIPP compliance with 40 CFR 194. To ensure the independence of this review, the Department of Energy has directed the assignment of an independent contractor to administratively manage the peer review activities. Peer reviewers were selected based on their demonstrated independence from the work being reviewed and their technical expertise in the subject matter to be reviewed. The peer review panel members collectively possess an appropriate spectrum of knowledge and experience in the subject matter reviewed.

This peer review was conducted in compliance with the quality assurance requirements defined in 40 CFR 194.

ACRONYMS

CCA	Compliance Certification Application
CCDF	Complementary Cumulative Distribution Function
CFR	Code of Federal Regulations
CH	contract handled
DOE-CAO	U.S. Department of Energy Carlsbad Area Office
EDTA	Ethylene Diamine Triacetic Acid
EPA	U.S. Environmental Protection Agency
MDL	method detection limit
PA	performance assessment
RH	remote-handled
SNL	Sandia National Laboratory
TRU	transuranic (waste)
TWBIR	Transuranic Waste Baseline Inventory Report
WCA	Waste Characterization Analysis
WIPP	Waste Isolation Pilot Plant

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EXECUTIVE SUMMARY

A peer review was conducted, in accordance with the U.S. Department of Energy-Carlsbad Area Office (DOE-CAO) plan entitled "Waste Characterization Analysis (WCA) Peer Review Plan," to assess the adequacy, reasonableness, and completeness of Appendix WCA (draft, July 26, 1996) against the requirements stipulated in 40 Code of Federal Regulations (CFR) 194.24(b). Appendix WCA is being prepared by DOE-CAO for inclusion in the Compliance Certification Application (CCA) for the Waste Isolation Pilot Plant (WIPP). A peer review panel (Panel) consisting of four members with expertise in performance assessment (PA), chemistry, process engineering, and health physics/transuranic (TRU) waste characterization was assembled and convened to conduct the review. The Panel reviewed the WCA, as described in Appendix WCA, against the criteria listed in NUREG-1297. The Panel then examined the criteria in NUREG-1297 and combined, added, and deleted some criteria based on their applicability to the evaluation of the WCA. The evaluation criteria used in the review were:

- Validity of Assumptions
  - Alternate Interpretations
  - Uncertainties and Consequences if Wrong
- Appropriateness and Limitations of Methodology and Procedures
  - Adequacy of Applications
- Validity of Conclusions
- Description of Analysis

In addition to Appendix WCA, the Panel reviewed numerous other documents, attached to Appendix WCA by reference, and an early draft of Appendix SOTERM. The Panel's opinion was that, due to the heavy dependence of Appendix WCA on the information contained in Appendix SOTERM, it was within the scope of the review to evaluate Appendix SOTERM.

In addition to the reviewed documents, the Panel made use of technical presentations by DOE-CAO, Westinghouse Waste Isolation Division, and Sandia National Laboratories staff, and a tour of WIPP, as a means to gather information for the review. The Panel members conducted the review independently and combined their independent findings into a single set. During the process, the Panel met regularly to discuss progress and any potential dissenting views. There were no dissenting views among panel members.

It is the opinion of the Panel that Appendix WCA (draft, July 26, 1996) meets its goal in some areas, is weak but defensible in others, and is inadequate in others. Section 4 discusses conclusions relative to

waste characteristics and waste components. Section 6 presents a summary of overall conclusions for each area evaluated.

1.0 INTRODUCTION

Specific guidance for the peer review of waste characterization activities relative to the Waste Isolation Pilot Plant (WIPP) Performance Assessment (PA) is contained in the U.S. Department of Energy - Carlsbad Area Office (DOE-CAO) Plan entitled "Waste Characterization Analysis (WCA) Peer Review Plan," dated June 27, 1996. This plan specifies that a peer review will be conducted to assess the adequacy, reasonableness, and completeness of the "Waste Characterization Analysis Report" contained in Appendix WCA and prepared to address the specific requirements of 40 Code of Federal Regulations (CFR) 194.24(b). The peer review plan states in part: "The purpose of the WCA is to identify those TRU waste components and characteristics that have been determined to be of importance to, and therefore included in, the 1996 PA modeling, as well as those that were considered and excluded." Section 24(b) of 40 CFR 194 requires DOE to identify and describe qualitative information on those physical, chemical, and radiological characteristics of the waste which can influence disposal system performance.

There are two types of waste components that are important in transuranic (TRU) waste characterization: radioactive materials and certain non-radioactive material components which can affect mobility of the radioactive materials. Physical, chemical, and radiological characteristics of radioactive materials are needed to establish compliance with the containment requirements of 40 CFR 191.13. Non-radioactive materials whose characteristics affect mobility of radioactive materials must also be analyzed for their impact on migration of the radioactive materials in the WIPP.

40 CFR 194.24(b) identifies characteristics (solubility, radionuclide-containing colloidal suspensions, gas production, shear strength, and compressibility) and components (metals, cellulosics, chelating agents, water and other liquids, and radioactivity in terms of curies) as a minimal list of essential elements of the WCA. The WCA peer review was performed to determine the adequacy, reasonableness, and completeness of the Appendix WCA prepared for inclusion in the Compliance Certification Application (CCA) for WIPP.

2.0 PURPOSE

The purpose of the WCA Peer Review was to establish a formal process to determine the adequacy, reasonableness and completeness of the draft document dated July 26, 1996, Appendix WCA. A peer review panel, consisting of four members, was convened to undertake the work. This report is a documented summary of the Panel's activity in conducting the evaluation of the analyses performed on waste characteristics and components for compliance with the requirements in 40 CFR 194.24(b), as described in Appendix WCA.

This review was conducted in support of, and meets the regulatory requirements of 40 CFR 191, and the implementation of those requirements by 40 CFR 194. In 40 CFR 194, peer review of WCA is specifically identified by the U.S. Environmental Protection Agency (EPA) as an activity required to supplement the DOE's CCA for the WIPP.

According to 40 CFR 194.27, the peer review is to be conducted by following the guidelines in the U.S. Nuclear Regulatory Commission's NUREG-1297, Peer Review for High-Level Nuclear Waste Repositories. The evaluation criteria set forth in NUREG-1297 were used by the Panel as a baseline for reviewing the WCA. These criteria require an in-depth critique of assumptions, calculations, extrapolations, alternate interpretations, methodology, and acceptance criteria employed and of the conclusions drawn in the original work. The Panel examined the evaluation criteria in NUREG-1297 for their applicability to the review of the WCA. This examination led to some of the criteria in NUREG-1297 being retained, combined, deleted, and/or supplemented by additional criteria (see Section 3 of this report).

3.0 DESCRIPTION OF WORK/APPROACH

3.1. General

The WCA Peer Review Panel was assembled and convened to review and assess the adequacy of Appendix WCA. Three versions of the draft Appendix WCA were reviewed by the Panel because the final version had not been completed by DOE when the Panel undertook its review. This report is based upon the latest draft, dated July 26, 1996.

The Panel received background information on waste characterization and the regulatory requirements for review. The Panel was trained on the administrative and protocol aspects of the review. Following this training, the Panel received technical presentations by the authors of Appendix WCA from Sandia National Laboratories (SNL), Westinghouse Waste Isolation Division, and DOE-CAO staff. As part of the presentations, the Panel toured the WIPP site. SNL provided the Panel with numerous technical reports and memoranda in support of the information and conclusions contained in Appendix WCA. The Panel also received a presentation by members of the Environmental Evaluation Group on their assessment and opinions of the WCA and the TRU Waste Baseline Inventory Report. Finally, in addition to the technical presentations by SNL, the Panel had a number of technical discussions with SNL staff, both at panel members' requests and at SNL requests. These discussions, open to observers, were for clarification of specific technical issues.

The Panel requested and received a draft of Appendix SOTERM, which will also be included in the CCA. Panel members unanimously agreed that, because Appendix WCA heavily referenced Appendix SOTERM, a review of the latter was imperative in order to review Appendix WCA. Thus, the Panel reviewed Appendix WCA, Appendix SOTERM, and the numerous reports and memoranda supplied by SNL. These materials were the primary source of information the Panel used to make their assessment of the adequacy of Appendix WCA.

In its early meetings, the Panel defined and agreed on the scope of the review. It was agreed that the review will be limited to issues discussed in Appendix WCA as they pertain to defining a source term for use in the PA calculations for construction of the complementary cumulative distribution function (CCDF) required by 40 CFR 191.13. The Panel also reviewed the procedure and evaluation criteria contained in NUREG-1297, which 40 CFR 194 stipulates as the guidelines to be employed in the independent peer reviews for specified aspects of the CCA, including the WCA. Based on this review, the Panel unanimously agreed on the procedure and evaluation criteria that would be used to complete

the review and prepare this report. The evaluation and selection of the criteria are discussed in subsection 3.2.

The Panel agreed that in conducting the review, each member would focus on his/her area of expertise. One member focused on performance assessment, another on chemistry, a third on process engineering, and the fourth one on TRU waste characterization and health physics. Each panel member reviewed the aforementioned documents independently and prepared their comments accordingly. During the process, the Panel met on a regular basis to discuss progress and any other issues, as necessary, to ensure consensus. The prepared comments were then merged into this report.

3.2. Evaluation Criteria

The Panel reviewed the criteria set forth in NUREG-1297. Based on that review, some criteria were chosen, others combined, and other deleted. The results of the review of the evaluation criteria is discussed below.

3.2.1. Adequacy of Requirements and Criteria

The Panel agreed that this criterion would be deleted and not used in the review of Appendix WCA. The rationale for that decision was the Panel's interpretation that the criterion would require the Panel to evaluate the adequacy and appropriateness of the requirements set forth in 40 CFR 191 and 40 CFR 194. The Panel unanimously decided that an evaluation of the regulatory requirements was outside the scope of the review.

3.2.2. Validity of Assumptions

The Panel agreed that the essence of the review will involve an assessment of the assumptions made in the WCA, and therefore, this criterion was retained.

3.2.3. Alternate Interpretations

The Panel agreed that, in the assessment of the validity of the assumptions, the possibility of alternate interpretations would be explored. Therefore, it was agreed to retain this criterion, but as a subset of the "validity of assumptions."

3.2.4. Uncertainties and Consequences if Wrong

The Panel agreed that this criterion would also be used in assessing the validity of assumptions made, and therefore, it was retained as a subset of the "validity of assumptions" criterion.

3.2.5. Appropriateness and Limitations of Methodology and Procedures

The Panel unanimously decided that part of the review would require an assessment of the adequacy of the methods and procedures used to draw the attendant conclusions in the WCA. Therefore, this criterion was retained as a stand-alone evaluation criterion.

3.2.6. Adequacy of Applications

It was the Panel's opinion that, in evaluating the appropriateness and limitations of the methods and procedures, determining the adequacy of alternative applications would be necessary. Therefore, this criterion was made a subset of "Appropriateness and Limitations of Methodology and Procedures."

3.2.7. Accuracy of Calculations

The Panel decided to eliminate this criterion. The Panel did not have the ability to perform or repeat the calculations supporting the WCA, and consequently, it would not be possible to assess the accuracy of the calculations. Such an assessment was considered outside the scope of the review.

3.2.8. Validity of Conclusions

The Panel decided to retain this criterion as a stand-alone criterion. Assessing the validity of conclusions in the WCA was considered well within the scope of the review.

3.2.9. Description of Analysis

This particular criterion is not included in NUREG-1297; however, the Panel felt that the ability to assess the WCA would, to a large extent, depend on the adequacy, completeness, and clarity of the description of the supporting analyses in Appendix WCA and/or the referenced documents. Therefore, this criterion was added.

4.0 EVALUATION OF WORK

This section summarizes the evaluation of the WCA, as described in the draft Appendix WCA, dated July 26, 1996, by the Panel against the criteria discussed in Subsection 3.2 (Evaluation Criteria). The findings of the Panel's evaluation, as presented below, are separated into three parts consistent with 40 CFR 194.24(b): Waste Characteristics (Subsection 4.1), Waste Components (Subsection 4.2), and Exclusion of Waste (Subsection 4.3).

4.1. Waste Characteristics

This subsection summarizes the Panel's evaluation of the consideration by DOE of waste characteristics and their impact on PA. The Panel's evaluation addressed, but was not limited to, the waste characteristics listed in 40 CFR 194.24(b) (1).

4.1.1. Radionuclide Inventory and Release Limits

The analysis conducted to determine the radionuclide inventory for use in the PA, and the release limits for construction of the CCDFs is described in a series of memoranda included in Appendix WCA by reference. Characteristics of the radionuclides that are important for PA purposes are identified in various references as total curie content, TRU curie content, mass, half life, solubility, mole content, and oxidation state. This information is required in order to comply with the requirement of 40 CFR 194.24 (a), which states that a compliance application shall describe the chemical, radiological, and physical characteristics of the waste. Basic TRU waste data, and assumptions leading to preparation of additional data (such as EPA Units of Waste, EPA Units, and moles of radioactive materials), were reviewed to determine whether the information met the intent of 40 CFR 194.24(b)(1) and whether this information is considered adequate for use in PA calculations. The radioactive materials inventory was generated and calculated with the intent of addressing all radiological criteria that appear in 40 CFR 191.

Basic characteristics of the TRU wastes to be emplaced in WIPP are defined in the most recent Transuranic Waste Baseline Inventory Report (TWBIR), Revision 3. This revision was prepared specifically to support the PA, and includes descriptions of waste "currently allowed to be disposed of in WIPP." The basic inventory of TRU waste described in the TWBIR is composed of a stored waste fraction (already generated), and a projected waste fraction, based on currently authorized activities. The projected fraction does not address TRU wastes to be generated by Environmental Restoration activities or decontamination and decommissioning activities in the future, nor does it address probable changes in waste generating techniques which may serve to increase concentrations of TRU radionuclides in the waste. However, a scaling technique was applied to the stored plus projected waste inventory for contact

handled (CH) waste in order to model the impacts of a full repository at closure. This technique was performed to comply with specific requirements of 40 CFR 194.24(b). Remote handled (RH) waste was not similarly scaled-up because of its limited volume.

The TWBIR is prepared on a waste stream basis by each generating/storage site. Estimates of waste volumes, based on numbers of containers in inventory, and kinds and quantities of radioactive materials (based on radio-assay measurement) are prepared. The site waste stream data are collected and consolidated into eleven more general waste forms for CH wastes and seven waste forms for RH waste. The radionuclide inventory has been prepared by calculating the quantities of 195 specific radionuclides assumed to be present in the waste, normalizing the data (correcting for decay) to December 1995, and summing the curie quantities required to produce a normalized radioactive materials inventory in terms of total curies, and an overall waste concentration in terms of curies per cubic meter. The TWBIR has been recognized by the DOE-CAO as the solely applicable TRU waste inventory in the TRU program. DOE decided that the information contained in the TWBIR was acceptable for input into PA.

The inventory, normalized to December 1995, was projected to the year 2033, the proposed date for WIPP closure. DOE decided that the minor impact on the inventory did not justify the time and expense of revising the TWBIR and associated data. The inventory was also separated into a total curie inventory.

The TWBIR data were used to determine the total number of EPA units of waste in the "full WIPP" (4.07 EPA units). Because there is a listed release limit for each radioactive material, the number of EPA units for each radionuclide (based on total EPA units and percentage composition of each radionuclide in the waste) was also calculated in order to construct the CCDF. Other calculations were performed to convert the curie load to radionuclide mass and total moles of the radionuclides, to allow performance of radioactive material mobility calculations.

To reduce costs and time to produce the source inventory, a rationale was developed to identify and use key radionuclides in the inventory for both direct release (intrusion) and indirect release (brine migration). To assess the overall importance of thermal heating on repository performance, a calculation of the maximum RH-TRU thermal heat load was performed.

For the undisturbed scenario, brine inflow into the repository, followed by transport up a shaft through the Culebra and out to the accessible environment, a homogeneous source term was calculated. For the intrusion scenarios, a heterogeneous waste source was calculated.

4.1.1.1. Validity of Assumptions

The radionuclide inventory was estimated by using data, analyses, and other information included in the TWBIR. The TWBIR captures recent information from the different DOE generating/storage sites. These data were provided to DOE-CAO, and DOE-CAO staff and contractor personnel reviewed the information for reasonableness, and consolidated the site data into the overall TRU waste baseline inventory. This process, and the decision to use the TWBIR data as the basis for the PA radionuclide inventory analysis, appear to be reasonable and adequate.

Information and methods used to establish the basic radioactive materials data and inventory were reviewed from three perspectives: 1) adequacy of the data as input for PA calculations; 2) assurance that the inventory addresses all the requirements for compliance with 40 CFR 194.24(b); and 3) assurance that the data quality is either equivalent to that which would be produced under a formal NQA-1 Quality Assurance program, or of a quality adequate for PA.

It was concluded that, in general, the basic information on CH waste in the TWBIR to be used in the establishment of the PA radiological source term is adequate and appropriate for PA purposes. However, the method by which RH inventory was constructed is not clear. Although most fission products in the RH waste streams have been excluded from the PA database, mostly due to their short half-lives, the rationale for calculating quantities of the long-lived fission products present in the inventory, and eliminating these longer-lived radionuclides from consideration in the inventory, was not addressed.

Because there had been no prior requirements to gather these types of data under a formal quality assurance (QA) program consistent with NQA-1 requirements, and a very short response time was imposed, the sites compiled their inventories using the best available information. The Panel concluded that, given these constraints, the data submitted are conservative (overstates quantities) and the best that could be obtained within reasonable time and cost.

The decision to use the inventory as decayed to 1995, rather than to renormalize all the data to 2033 (the proposed year of WIPP closure), and to use the 1995-decayed inventory as the initial inventory seems reasonable and appropriate. It was adequately demonstrated that decaying the entire inventory for an additional 38 years will have a negligible effect on WIPP performance.

Use of a homogeneous waste source term for the undisturbed scenario was clearly explained, and seems to be a reasonable approach to estimating source term transport. However, it was difficult to discern from Appendix WCA and associated documents exactly how the heterogeneous source term was

developed and used in the intrusion scenarios. Further, it was not demonstrated that this approach is appropriately conservative.

The basis for estimating the current TWBIR projected source term is well defined. However, the fact that 70% of the waste destined for disposal at WIPP is yet to be generated makes the source term uncertain. The Panel concluded that not all available information was used to define the source term. A large fraction of the future waste volume is contained in formerly operated facilities, specifically in existing processing and air handling systems. The isotopic composition of the TRU materials is no different than that which is currently in the stored waste inventory. The Panel concluded that these facts are sufficient to allow further estimation of the radionuclide source term.

It is also known that the composition of the future generated wastes will change in the future. The current trend in TRU waste management is to minimize waste volumes, a technique that will tend to increase the TRU concentrations in the waste. Concentrations of fissile materials in the waste are expected to rise toward the fissile limit of 200 grams per drum, rather than stay at the current average level of about 10 grams per drum. Volumes of combustible waste, currently composing about 65% of the current waste volume, will be reduced, with a resultant reduction in the volume of cellulosic materials in the TRU waste. These events could have some impact on WIPP performance, yet they were not discussed in detail in the Appendix WCA.

4.1.1.2. Appropriateness and Limitations of Methodology and Procedures

It was concluded that a very thorough and systematic analysis was performed in estimating the parameters necessary to establish the radionuclide inventory and the release limits for constructing the CCDF. The most salient limitation of the approach was that the vast majority of the waste destined for disposal at WIPP is still to be generated. Therefore, the nature of that waste is, to a large degree, unknown. This uncertainty led to the need to project about 70% of the WIPP inventory based on 30% information, and then scale up the inventory to the "full WIPP" volume. The method used appears to be reasonable; however it is the Panel's opinion that not all available data were used in making the waste inventory projection.

It was difficult to discern from Appendix WCA and from other referenced documents exactly how the heterogeneous source term was constructed and used in the intrusion scenarios.

4.1.1.3. Validity of Conclusions

The radionuclide values determined for use in the PA seem, generally, to be acceptable and reasonable, given the information in the TWBIR and the known uncertainties in that information. Use of a homogeneous source term for the undisturbed scenario seems a valid and reasonable approach. The validity of the use of a heterogeneous source term for the intrusion scenarios could not be evaluated because the analysis used to determine this source term and its use was not clearly presented in Appendix WCA, or in the referenced material.

4.1.1.4. Description of Analysis

Various internal SNL memoranda referenced in Appendix WCA provide adequate description of the analysis conducted to estimate concentration of radionuclides in the waste and the release limits, as well as the scale-up of the inventory for use in the undisturbed performance scenario. On the other hand, the analysis used to determine the heterogeneous source term for the intrusion scenario was not clear; thus, it was not possible to assess its appropriateness.

4.1.2. Solubility

Appendix WCA describes the components and conditions that impact the estimation of actinide solubilities. The methods used to estimate these solubilities are described in more detail in Appendix SOTERM. As a result, a draft of the latter was also reviewed.

4.1.2.1. Validity of Assumptions

The controlling assumption governing radionuclide solubility is that the repository is going to be backfilled with magnesium oxide. This will keep the pH of the brines basic and the solubility of the radionuclides low. The median solubilities for the elements of interest in Salado brine range from 8.8E-06 to 6.0E-09. The estimates of actinide solubilities were performed using the FMT computer code. The chemical and other data and information needed to estimate the actinide solubilities were provided as input to FMT from a set of experiments. FMT estimated the median value of the solubilities and their associated uncertainty. The latter was estimated to be one order of magnitude or less for the chemical conditions tested (see Appendix SOTERM). While the estimated median values seem reasonable and consistent with available literature, the uncertainty range about the median seems unreasonably small. For example, a previous expert judgment study by SNL on actinide solubility concluded that ". . . the efforts resulted in the development of very wide probability distribution(s). . . due to the impact of both great uncertainty in room conditions and the nature of probability distributions ..." Thus, the estimated

uncertainty in the solubility predicted by using the FMT code and a limited set of experiments seems inconsistent with earlier results of the expert judgment panel. Neither Appendix WCA nor Appendix SOTERM discuss the apparent inconsistency in the estimated and elicited uncertainty ranges for actinide solubility.

The magnesium oxide will react with any carbon dioxide generated via microbial decomposition of the organics in the waste to form magnesium carbonate. Thus, the possibility of forming actinide carbonato complexes is removed. A reducing atmosphere will be established in the repository due to the large amount of low valent metal, predominately iron, that will be present as a result of the anoxic corrosion of the steel drums. In such an atmosphere, the actinides are expected to be in lower oxidation states. Only uranium is anticipated to be present as the +VI ion.

The assumption that magnesium oxide will control pH and alleviate the effect of carbon dioxide is based on sound chemistry in aqueous solutions. However, no actual experimental data exist to support these conclusions in high ionic strength liquids such as the Salado and Castile brines. Should the magnesium oxide not react with carbon dioxide under repository conditions, the calculated solubilities of the actinides will be too low by as much as several orders of magnitude. If the assumption controlling oxidation state distribution is wrong, then the existence of Pu(VI) is possible. This oxidation state is more soluble than Pu(IV) or Pu(III).

4.1.2.2. Appropriateness and Limitations of Methodology and Procedures

The experimental methods used seem satisfactory. The major limitation is the small number of experiments conducted. It is possible that the limited set of experiments did not capture the entire range of possible chemical conditions within the repository. Consequently, the uncertainty range in the numerical value of actinide solubility seems unexpectedly narrow. There is an apparent inconsistency with the results of an earlier expert judgment elicitation study which concluded that the uncertainty in repository conditions would cause, in part, a large uncertainty in solubility values.

The controlling parameter for actinide solubility is the reaction of magnesium oxide with any carbon dioxide that is generated within the repository. If this reaction occurs in high ionic strength brines, the approach taken toward the solubility of actinides is reasonable. However, there are no experimental data that show this chemistry will occur under the anticipated repository conditions. Because one single parameter was selected to dominate the control of solubility, the Panel felt that the lack of experimental data on that parameter (i.e., MgO) leaves the entire issue unresolved.

4.1.2.3. Validity of Conclusions

The conclusions based on a limited number of experiments, insofar as the uncertainty in solubility limits is concerned, do not seem to be appropriately justified. The apparent inconsistency with the results of a previous study on the same subject is not appropriately addressed. The small uncertainty (one order of magnitude or less) has not been adequately defended.

If the magnesium oxide chemistry in WIPP brines occurs as assumed, then the treatment of actinide solubility in the WCA is judged to be reasonable. However, this assumption should not be made without supporting experimental data. Without acquiring the data, it is felt that the question of actinide solubility has not been adequately addressed in Appendix WCA.

4.1.2.4. Description of Analysis

The description of the analysis performed to estimate the actinide solubilities in Appendix SOTERM and the factors that influence the solubility in Appendix WCA is adequate. The difficulty arises from conclusions based on a very limited set of experiments and a lack of experimental data that support the assumption that magnesium oxide will control actinide solubility in WIPP brines.

4.1.3. Colloids

Appendix WCA discusses the actinide colloid source term more completely than solubility; however, the discussion relies heavily on a series of memoranda that describe how the colloid source-term parameters were determined. Therefore, the review concentrated on those memoranda, which were provided as part of the package to be reviewed (see Appendix 3).

Four types of radioactive colloids are considered in the WIPP PA calculations: 1) intrinsic colloids, 2) sorption of soluble actinides onto mineral colloids, 3) sorption of actinides onto humic colloids, and 4) sorption of actinides onto microbes. These four types of colloids were identified from a thorough review of the literature. Experimental programs were then designed and carried out to determine the amount of radioactivity that would be available for release from the repository for each of the aforementioned types of colloids.

4.1.3.1. Validity of Assumptions

The possibility that colloids can form and contribute to increased mobility of radionuclides has been recognized. The literature review performed to determine the types of colloids that should be considered in the PA calculations seems to have been sufficiently thorough. The selection of the aforementioned

four types of colloids is consistent with the literature on radioactive colloids. Based on currently prevalent knowledge, the assumption that those four types of colloids should be the key ones is reasonable and adequate.

A number of experiments were designed and conducted to determine numerical values for six parameters to capture the amount of radioactivity that would be available for transport in the form of colloids. These parameters are:

CONCINT	concentration of actinides associated with mobile intrinsic colloids
CONCMIN	concentration of actinides associated with mobile mineral colloids
CAPHUM	maximum concentration of actinides associated with mobile humic colloids
CAPMIC	maximum concentration of actinides associated with mobile microbes
PROPHUM	proportionality constant of actinides associated with mobile humic colloids
PROPMIC	proportionality constant of actinides associated with mobile microbes

It seems reasonable to assume that these six parameters are sufficient to define the colloid actinide source term.

Even though it is not explicitly stated, implicit in the analyses conducted to determine these parameters is the assumption that the effect of one type of colloids is independent from the presence of other types of colloids. The experiments and interpretation of the data obtained were carried out by a series of principal investigators at different locations. There seems to have been no communication and/or discussion between the investigators to compare notes and explore whether each set of results could have been influenced by the other results obtained. Strong interdependencies between different types of colloids seem unlikely; however, because these were not discussed among the investigators, the possibility of interdependencies and their potential effect on the radionuclide source term will remain an open issue.

A key concern with the estimation of numerical values for the six parameters defining the colloid actinide source term is the manner in which the uncertainty in those parameters was determined. As stated in several of the memoranda referenced in Appendix WCA, the major source of uncertainty associated with these parameters was lack of knowledge. Only a very limited number of experiments were performed, and in many instances, the value of a parameter was determined from a single experiment. In those cases, a constant value was recommended for use in the PA calculations. For those parameters for which a distribution of values was estimated, this distribution centers about a likely value, and triangular distribution was assumed between the lower and upper limits of the distribution. It is believed that this approach does not adequately capture the uncertainty in the colloid actinide source. It

is hard to believe, with the preponderance of different interpretations in the literature regarding colloid concentrations in repository environments, that a constant value or even a two-order of magnitude distribution of values would capture the "real" uncertainty in the colloid source term. This is one situation in which the estimation of the numerical values of the six parameters and of their respective uncertainties could have greatly benefited from an expert judgment elicitation. During such an elicitation, experts could have been provided with the experimental results and asked to augment them based on their knowledge and experience to develop a parameter value distribution that more adequately describes the uncertainty in the value of the parameters.

The value of CONCINT was measured to be 10^{-10}, which was below the minimum detection limit (MDL) of the experiment (10^{-9}). The decision was made to set the value of CONCINT to 10^{-9}. This begs the question why was not the value of CONCINT set to 0 since it is an order of magnitude below the MDL? While setting the value of CONCINT to the MDL could be argued for the sake of conservatism, it would have been more reasonable and determinable from a scientific point of view to set the value to 0.

It is assumed that the only intrinsic colloid of importance is formed by Pu(IV). This colloid is expected to be kinetically destabilized by the high ionic strength brines present in the repository. Adsorption of actinides on mineral fragment colloids was also considered. The concentration was estimated to be 2.6E-09 molar. It is assumed that the mineral fragment colloids will not contribute to the overall radionuclide mobility because they are expected to be destabilized in high ionic strength brines. Humic colloids are assumed to be present as components of the emplaced waste and as microbial decomposition products. The ratios of humic-bound actinides to dissolved actinides varies from 4.3E-04 to 6.3 in Castile brine and from 5.3E-05 to 6.3 in Salado brine. Microbial colloids are assumed to play an important role in the transport of actinides. Halophilic microbes are assumed to be present in the repository and other components of the waste (nitrates and phosphates) will serve as nutrients enhancing microbial growth. Calculations have shown the microbial colloids can transport actinides in amounts several times their dissolved concentration.

The assumptions that the Pu intrinsic colloids and the mineral fragment colloids will be kinetically destabilized in high ionic strength brines is valid based on published literature. The estimations of actinides bound to humic colloids are based on experiments that determined the solubility of humic substances in high ionic strength brines, site-binding capacity, and the stability constants for actinides with humic acids. These experiments appear relevant and well done. The values provided to PA for

colloidal transport of actinides are reasonable expectations of the contribution of colloidal material to radionuclide transport.

4.1.3.2. Appropriateness and Limitations of Methodology and Procedures

The experimental methods for colloids seem adequate. Their major limitation was the fact that the number of experiments performed (for some parameters only one experiment was used) was not adequate to generate meaningful statistical samples from which the uncertainty in the values of the parameters could be defined adequately. The methodology used could have included an expert judgment elicitation process to augment the experimental results. Such a use of expert judgments would have been appropriate, and in this case, probably necessary.

4.1.3.3. Validity of Conclusions

As stated in several of the memoranda referenced in Appendix WCA, uncertainty due to lack of knowledge is the predominant uncertainty affecting the values of the parameters selected to define the colloid actinide source term. Based on this statement, it is concluded that a single value or even a two-order-of-magnitude parameter value distribution does not capture the uncertainty in the colloid actinide source term parameters adequately for purposes of PA calculations.

4.1.3.4. Description of Analysis

The various memoranda referenced in Appendix WCA adequately described the experimental process and its rationale. The experimental results are also provided, and the interested reader with proper qualifications in colloid chemistry would be able to ascertain the validity of the results and the conclusions drawn from the results. The major drawback of the analysis, as mentioned earlier, is the very few experiments that were performed for each of the parameters, and, given this situation, the fact that the analysis of the results should have been augmented with an expert judgment elicitation process.

4.1.4. Production of Gas

The production (or generation) of two gases has been considered as part of the WCA: generation of H^2 from steel corrosion and generation of CO_2 from microbial degradation of various waste components. The WCA concludes that the impact of H_2 generation will not be significant because the resulting increased gas pressures will not exceed lithostatic pressure. The WCA also concludes that the impact of CO_2 will not be significant because it will be removed primarily by reaction with the magnesium oxide backfill.

4.1.4.1. Validity of Assumptions

It is assumed that there are two major sources for gas generation, anoxic corrosion of steel and microbial degradation of organics. In the corrosion reaction, water is the oxidizing agent producing ferrous hydroxide and hydrogen. Under the conditions assumed to exist in the repository, the hydrogen will undergo no further chemistry. Microbial degradation of organics can occur by the three reactions shown below.

$$C_6H_{10}O_5 + 4.8\ H^+ + 4.8\ NO_3^- \Rightarrow 7.4\ H_2O + 6CO_2 + 24\ N_2$$

$$C_6H_{10}O_5 + 6\ H^+ + 3\ SO_4^{2-} \Rightarrow 5\ H_2O + 6CO_2 + 3\ H_2S$$

$$C_6H_{10}O_5 + H_2O \Rightarrow 3CH_4 + 3CO_2$$

The first two reactions require substantial moles of proton. It is highly unlikely that these reactions will be of any significance given the magnesium oxide backfill and the basic pH that will result. The third reaction produces 3 moles of carbon dioxide and 3 moles of methane. The carbon dioxide will react with the MgO and be of no further consequence. The disposition of the methane is not discussed in Appendix WCA.

The above assumptions concerning gas generation are judged to be valid. The only gas that would affect repository chemistry is carbon dioxide, which will be consumed by the magnesium oxide. Should it not react with MgO, then it would be available to form carbonato complexes with the radionuclides present in the waste, increasing their solubility. At closure there will exist an oxic environment in the repository for a short while. However, at this time there will not be significant concentrations of the flammable gases, hydrogen and methane, to pose a realistic explosion hazard. By the time these gases reach significant concentrations, the repository will be anoxic. It is felt that there is not a significant risk of explosion in the sealed repository.

The assumptions for concluding that gas generation will be have negligible effect on repository performance seem reasonable. For example, from a chemical standpoint, it is reasonable to expect that the presence of MgO in sufficient quantities will be enough to consume the CO_2 generated from microbial activity. It can be shown theoretically that this is a reasonable assumption; however, at this time there are no experimental data to support the assumption. Therefore, before definitive conclusions are reached on the potential insignificant impact of gas generation, experimental data ought to be collected to substantiate or negate the validity of the assumption.

4.1.4.2. Appropriateness or Limitations of Methods and Procedures

As stated above, the theoretical support for the assumptions notwithstanding, their validity will remain an open issue due to a lack of experimental data to support the assumptions.

4.1.4.3. Validity of Conclusions

Based on analytical studies, the conclusion that gas generation will not significantly impact repository performance seems reasonable. However, until experimental data supporting the conclusions are obtained, the issue will remain open.

4.1.4.4. Description of Analysis

The treatment of gas generation in Appendix WCA is generally well done. However, the Appendix does not deal with the disposition of the generated methane. This gas will be produced on a mole-per-mole basis with carbon dioxide and yet there is no mention of its fate in the repository. The experiments showing microbial production of carbon dioxide in WIPP brines are meaningful. However, they would have been more informative had they been done in the presence of the nonferrous metal concentrations anticipated in the repository.

4.1.5. Compressibility

The compressibility of the waste has been determined from tests on simulated waste materials. These tests were based on assumptions of waste content and physical characteristics. Waste compressibility was determined by combining the individual compressibilities of the different waste types into their respective proportions expected at WIPP closure. An elastic-plastic waste compaction model is used. The model and the experimental data supporting it are used as a basis for parameter determination for input into the PA.

4.1.5.1. Validity of Assumptions

Section 5.2.1 describes the basis for determination of compressibility as derived from experiments and models which assume a representative distribution of metals, plastics, combustibles, cellulosics, and sludges tested. It is apparent throughout the WCA that the exact compositions and proportions of components in a waste package are uncertain. However, the assumptions made are considered appropriate and conservative since they did not include shifts in waste form toward reduction of cellulosics and an increase in alternate waste forms.

4.1.5.2. Appropriateness and Limitations of Methods and Procedures

Use of models and experimental data are considered to be an appropriate method for developing waste compressibility parameters.

4.1.5.3. Validity of Conclusions

Even though Appendix WCA states that compressibility is expected to have a significant effect on the performance of the repository due to its impact on creep closure and waste porosity, the appendix was found to be deficient in the discussion of waste compressibility. Several previous studies are referenced that describe the analyses of waste compressibility, but Appendix WCA does not summarize the findings of the analyses. For example, Appendix WCA contains neither discussion nor references on the effect of compressibility on porosity.

4.1.5.4. Description of Analysis

Appendix WCA does not present sufficient technical information to complete an assessment of the analysis. While the Panel concurs that modeling, combined with experimental data, is an appropriate method, the Panel did not have information to assess the reasonableness or accuracy of compressibility-related parameters.

4.1.6. Strength

Waste strength properties are evaluated in the potential for release due to inadvertent human intrusion. A possible pathway for release might be created by a borehole that penetrates a waste storage room. The potential release mechanisms briefly discussed in Appendix WCA include: 1) release from the cutting actions of the drill bit itself (cuttings), 2) erosion by fluids in the borehole (caving), and 3) processes related to pressure blowout (spalling).

4.1.6.1. Validity of Assumptions

There is no discussion of the assumptions used in evaluating waste strength properties presented in Appendix WCA.

4.1.6.2. Appropriateness and Limitations of Methods and Procedures

The discussion of waste strength properties in Appendix WCA was found to be insufficient to assess reasonableness for inclusion in PA. The Panel unanimously agreed that waste strength properties should be analyzed for inclusion in PA.

4.1.6.3. Validity of Conclusions

As stated in Appendix WCA, waste strength is expected to be an important characteristic, particularly in the drilling intrusion scenario. However, the appendix does not present the rationale or technical basis for this conclusion. Similarly to compressibility, the discussion of waste strength was found to be inadequate. The Appendix makes reference to a previous study, but no indication is provided to suggest that the study discusses the analysis of waste strength.

4.1.6.4. Description of Analysis

Appendix WCA does not present adequate information to evaluate the accuracy or reasonableness of waste-strength related waste properties.

4.1.7. Porosity

There is no discussion in Appendix WCA regarding waste porosity. There is an inconsistency regarding the importance of porosity in Subsection 5.2 of Appendix WCA. In one sentence, it is stated that waste compressibility is expected to have a significant impact on repository performance because of its effect on creep closure and waste porosity, thus implying that waste porosity is important. Subsection 5.2.1 of Appendix WCA further reiterates this implication. However, in a later sentence in Subsection 5.2, it is stated also that porosity is expected to have a negligible effect on repository performance.

4.1.8. Permeability

In Subsection 5.2 of Appendix WCA, it is stated that permeability on repository performance is expected to have a negligible effect on repository performance because the waste is far more permeable than the surrounding halite. Therefore, brine flow through the halite will be the slowest step (i.e., brine flow rate is controlling). Laboratory data were cited as the supporting evidence for this conclusion. The eight orders of magnitude difference between the permeability of the halite (10^{-21} m^2) and the waste (10^{-13} m^2) supports the conclusion that waste permeability is not expected to have a significant effect on repository performance.

4.1.9. Heat Generation

Two potential sources of heat within the repository were evaluated: heat generated by RH-TRU waste and several exothermic reactions (MgO hydration and carbonization, steel corrosion, and organic biodegration). In both cases, the analyses indicate that the potential worst-case temperature rises (3° K in

one case and 7° K in another) are not sufficiently high to affect repository performance. The analyses conducted to support this conclusion seem to be sufficiently adequate.

4.2. Waste Components

This subsection summarizes the Panel's evaluation of the consideration by DOE of waste components and their impact on PA. The Panel's evaluation addressed, but was not limited to, the waste components listed in 40 CFR 194.24(b) (2).

4.2.1. Metals

Ferrous metals were considered to have significant impact on repository performance in two contexts. First, they were examined as the main agents responsible for maintaining a reducing environment in the repository, in order to enhance the likelihood that the less soluble oxidation states of the actinides predominate. Second, they were considered because metal corrosion can generate H2, thus increasing gas pressure within the repository. In the first case, the presence of ferrous metals represents a favorable condition because the overall impact is to reduce actinide mobility, whereas in the second case, there is a potentially unfavorable condition due to increased gas pressures within the repository. In the latter case, the potentially unfavorable condition was determined to have negligible impact on repository performance because calculated gas pressures never exceed lithostatic levels. The consideration of ferrous metals in these contexts seems appropriate.

4.2.1.1. Validity of Assumptions

Steel drums are the major source of non-actinide metals assumed to be present in the waste. These metals include iron, nickel, manganese, and chromium. Of these, iron and nickel are the most important. Anoxic corrosion of the steels will afford Fe(II) and Ni(II). The presence of low-valent iron will create a reducing environment in the repository. However, if a reducing environment is not present in the repository, then Pu(VI) will become a significant oxidation state. Because higher oxidation states of Pu are more soluble, actinide solubility will increase.

4.2.1.2. Appropriateness and Limitations of Methodology and Procedures

The actinide oxidation states anticipated in the repository and given in Appendix WCA are reasonable based on experimental data showing that low-valent iron is a reducing agent for Pu(VI) in high ionic strength brines.

4.2.1.3. Validity of Conclusions

The conclusions are supported by experimental data obtained under simulated repository conditions. However, if substantial passivation of the steel by carbon dioxide were to occur because of the inability of MgO to react with carbon dioxide in high ionic strength brines, then the assumption of reducing conditions in the repository may not be correct.

Non-ferrous metals were considered because of their favorable effects on preventing an increase in actinide solubility by binding organic ligands. The presence of non-ferrous metals is considered to be significant to repository performance. However, this conclusion is based on simple competing calculations for dilute solutions, because experimental data for concentrated brine solutions projected at WIPP do not exist. While the calculations conducted may suggest the purported effect of non-ferrous metals on repository performance, drawing such a strong conclusion based only on a simple analysis and under conditions considerably different from those expected at WIPP is not appropriate, without the benefits of representative experimental data.

4.2.2. Cellulosics

Cellulosic materials are considered in Appendix WCA because of their effects on radioactive colloidal particle transport and in gas generation. These materials are considered a possible means for adsorbing radionuclides in solution and forming radioactive colloids that could be transported away from the repository. Cellulosics can undergo microbial degradation and generate gases, namely, methane and CO_2.

The consideration of cellulosic materials as a potential source for the generation of radioactive colloids is discussed in detail in Appendix WCA and in the referenced studies. Even though some deficiencies were found in the conclusions reached from the analysis of radioactive colloids formed from cellulosics materials, the approach itself was well thought out.

The generation of CO_2 from the microbial degradation of cellulosics is considered to have a negligible effect on repository performance because this gas would be consumed by reaction with the hydrated MgO backfill. While this conclusion has a sound basis from a chemistry standpoint, the lack of experimental data to support the conclusion weakens the validity of the assumption.

As stated earlier, no discussion could be found in Appendix WCA regarding the impact of methane generation from microbial degradation of cellulosics. Therefore, the adequacy of the consideration of methane on repository performance could not be assessed.

4.2.3. Chelating and Organic Ligand Agents

Chelators were considered as a special class of organic ligands, and therefore, the assessment of their impact as a waste component was lumped with the impact of all organic ligands. The overall effect of organic ligands is to enhance the solubility of actinides. However, these effects are deemed to be negligible in Appendix WCA because of the presence of large quantities of metals in the repository, especially ferrous metals, that effectively bind the ligands.

4.2.3.1. Validity of Assumptions

Of the 60 organic compounds present in the waste, only four are assumed to have any potential impact on actinide mobility. These are acetate, oxalate, citrate, and Ethylene Diamine Triacetic Acid (EDTA). These four were selected because of their water solubility and significant quantities in the waste. Calculations show that actinide solubilities will increase via complexation with these ligands. However, this effect will be negligible given the large amounts of nonactinide metals present in the repository that can compete successfully for the ligands. The most significant of these are the 10,000 moles of nickel. If Ni and Fe do not form stable complexes with organic ligands under the conditions expected in the repository, then the organic ligands in the waste could have a significant effect on actinide solubility.

4.2.3.2. Appropriateness and Limitations of Methodology and Procedures.

The elimination from consideration of most of the remaining organics in the waste inventory was based on their poor solubility in water and the limited quantities identified in the TWBIR. This is a reasonable approach to use; thus, citrate, oxalate, acetate, and EDTA remain as the only organics of interest.

4.2.3.3. Validity of Conclusions

The conclusion that organic ligands will not play a significant role in contributing to actinide solubility is reasonable, but would be much more defensible if there were experimental data to support it. Of specific concern is the nature of the iron and nickel species. In low-ionic strength solutions, solvent complexes of oxygen donor ligands are more stable than chloro complexes. However, in brines, the chloro complexes may be more stable simply due to the presence of large amounts of chloride. While calculations may suggest the purported effect of non-ferrous metals on repository performance, drawing such a strong conclusion based on conditions considerably different from those expected at WIPP is not appropriate. Experiments should be performed to determine whether Ni and Fe form stable complexes with acetate, citrate, oxalate, and EDTA in high-ionic strength brines.

4.2.4. Water and Other Liquids

Only the presence of water in the waste was considered. The volume of water in the waste was assumed to be 0.06% of the total free liquid; the majority of the liquid in the repository is contained in the brine. The restriction on water content comes primarily from the WIPP Waste Acceptance Criterion. It is also assumed that the presence of portland cement and other sorbents intentionally added to the waste will absorb any free-standing water. Therefore, the effect of water and other liquids in the waste itself was assumed to be negligible. There is neither an analysis nor data available to support this conclusion. The conclusion seems to be based primarily on intuitive arguments. While these arguments seem reasonable, further analyses and generation of data would increase the credibility of the conclusion.

4.3. Exclusion of Waste

This subsection summarizes the Panel's assessment of DOE's decision to exclude from PA consideration certain waste characteristics and /or components as authorized criteria set forth in 40 CFR 194.24(b)(3). Major waste components excluded from PA were: 1) many of the radionuclides in the original inventory, and 2) the hazardous constituents in the waste.

4.3.1. Exclusion of Radionuclides

A large number of radionuclides were excluded because they are present in extremely low quantities. Five radionuclides (Pu-239, Pu-240, Am-241, U-233, and U-234) dominate 99% of the EPA unit after 2000 years, and one radionuclide (PU-238) dominates the EPA unit at earlier times. The analysis performed to support this conclusion was well done; it is methodical and complete. Therefore, the exclusion of all other radionuclides from the analysis is justifiable.

4.3.2. Exclusion of Hazardous Constituents

Hazardous waste constituents other than the chelating agents identified in the WCA are excluded from the analysis because, as stated in Appendix WCA Section 1.1, these constituents are regulated by the Resource Conservation and Recovery Act (RCRA), and many have been identified in a no migration variance petition to the EPA. Therefore, the exclusion of the hazardous waste constituents from the WCA is justifiable.

5.0 DISSENTING VIEWS

None.

6.0 CONCLUSIONS

It is the opinion of the Panel that Appendix WCA (draft, July 26, 1996) meets its goal in some areas, is weak but defensible in others, and is inadequate in others. Summary findings of the peer review are below.

Radionuclide Inventory and Release Limits

1. The analysis performed in estimating the parameters needed to establish the radionuclide inventory and release limits for estimating the complementary compliance distribution function (CCDF) was very thorough and systematic. This is a solid piece of work.

2. The analysis used to determine the heterogeneous source term for the intrusion scenario was not clearly presented in Appendix WCA, resulting in an inability to judge its validity and degree of conservation.

Solubility

1. The median values for actinide solubility are reasonable, but the uncertainty ranges about the median are too low and inconsistent with earlier results from the expert judgment panel study.

2. The issue of actinide solubility is not adequately addressed in Appendix WCA because the controlling assumption concerning MgO chemistry in the repository has no experimental data to support it.

Colloids

1. The experiments dealing with colloids in the repository were well done.

2. The uncertainty given for the colloid actinide source term is not adequate for purposes of PA calculations because the number of experiments performed does not generate meaningful statistical samples from which an uncertainty could be adequately calculated.

Production of Gas

1. Appendix WCA adequately identifies the major issues of gas generation in the waste.

2. The issue of the reaction of carbon dioxide with the MgO backfill is not adequately resolved in Appendix WCA, because of a lack of experimental data which demonstrated that this chemistry occurs under conditions anticipated in the repository.

3. Appendix WCA does not adequately address the fate of microbially generated methane.

Compressibility

Appendix WCA references studies describing the analysis of waste compressibility; however, it fails to provide any discussion of the results of these studies.

Strength

Appendix WCA references a study on waste strength but fails to discuss the results of this study in the context of its impact on disposal system performance.

Porosity

There are conflicting statements in Appendix WCA concerning the importance of porosity to the performance of the repository. As a result, the Panel was unable to evaluate the treatment of this parameter.

Permeability

There are experimental data to support the conclusions about permeability discussed in Appendix WCA. The Panel concurs with the conclusions.

Heat Generation

The analyses presented in Appendix WCA concerning heat generation are well done. The conclusion that this characteristic will have a negligible effect on performance is justified.

Metals

1. The assumption that low valent metals in the repository will maintain a reducing atmosphere in the repository is substantiated by experimental data.

2. The position taken in Appendix WCA concerning the uptake of organic ligands by the transition metals is not defensible due to lack of experimental data. It is not correct to apply results from experiments performed in low ionic strength solutions to WIPP brines.

Cellulosics

Cellulosics will be microbially degraded to carbon dioxide and methane. They also may provide a source of humic colloids. Treatment of these issues by Appendix WCA has been discussed in the appropriate sections above.

Chelating Agents

The position that transition metals will react with the organic ligands in the waste to render them unavailable for reaction with actinides should be justified with experiments done in high ionic strength brines.

Water and Other Liquids

The Panel agrees with the findings in Appendix WCA. Water in the waste is not an issue in repository performance.

Exclusion of Waste

1. The analysis performed to support the exclusion of radionuclides is methodical, complete and well done.

2. The exclusion of hazardous wastes is justified.

APPENDIX 1 - SIGNATURES

I acknowledge below that I concur with the findings and conclusions documented in this Waste Characterization Analysis Peer Review Report.

Duane C. Hrncir, Ph.D.
WCA Panel Chairman

Evaristo J. Bonano, Ph.D.
WCA Panel Member

James F. Bresson
WCA Panel Member

Patricia J. Robinson
WCA Panel Member

APPENDIX 2 - MEMBERS AND ACCEPTABILITY

Duane C. Hrncir, Panel Chairman, is an Associate Professor of Chemistry and former Head of the Chemistry Programs at the University of Texas at Dallas. He holds a Ph.D. in inorganic chemistry from Texas A&M University, an M.S. in inorganic chemistry from the University of Massachusetts at Amherst, and a B.S. in Chemistry from the University of Alabama. He has 24 years of experience in research involving the interactions of metals with organic molecules. This research includes the interactions of metals and organics with mineral surfaces and the controls these interactions have on speciation and transport in aquatic environments. His current area of research involves laboratory and field experiments to study the photoreduction of metal colloids in acidic and neutral surface waters and the control this process exerts over the biogeochemistry of the stream system. He has authored 40 publications in peer-reviewed scientific journals and has made numerous presentations at national and international scientific meetings.

Evaristo J. Bonano, Panel Member, is President and Chief Executive Officer of Beta Corporation International in Albuquerque, NM. Dr. Bonano holds a Ph.D. and an M.S. in Chemical Engineering from Clarkson University, and a B.S. in Chemical Engineering from the University of Puerto Rico. His areas of expertise include transport phenomena, waste management, risk/performance assessment, regulatory compliance, elicitation and use of expert judgments, decision analysis, and environmental management. He has been involved in performance assessment for waste disposal for more than 13 years. He directed the development of performance assessment methodologies for disposal of high-level and low-level waste for the U.S. Nuclear Regulatory Commission. He is an internationally recognized expert on performance assessment, having represented the U.S. in various working groups of the Nuclear Energy Agency/Organization for Economic Cooperation and Development in Paris, France. He participated in two independent reviews (one as lead reviewer) of the risk assessment methodology application for low- and intermediate-level waste disposal in deep geologic repositories for the U.K. Department of Environment/Her Majesty's Inspectorate of Pollution.

James F. Bresson, Panel Member, is a senior scientist, currently employed by the Informatics Corporation. He holds a Master of Public Health (MPH) degree, with emphasis on radiological and environmental health, from the University of Michigan. He has more than 35 years of experience as a health physicist and radioactive waste management specialist. Prior to his retirement from federal service in 1988, Mr. Bresson worked for the Waste Management Division of the DOE Albuquerque Operations Office, where he participated in development of the WIPP Waste Acceptance Criteria (WIPP-WAC), preparation of the DOE Order "Radioactive Waste Management (DOE 5820.2A)", and was

responsible for developing and implementing the first WIPP Waste Certification Program. Since leaving DOE, Mr. Bresson has worked for several contractors as a project manager, senior health physicist, and waste management specialist. Recently he has reviewed and commented on the WIPP Waste Characterization Quality Program Plan and related documents. In addition, he served as project manager for a task which required review of several key documents related to the Low-Level Waste Performance Assessment at the Idaho National Engineering Laboratory (INEL).

Patricia J. Robinson, Panel Member, is President and CEO of (n, p,) Energy, Inc., in Albuquerque, NM. She has a B.S. in Chemical Engineering from the University of Nevada, Reno and an M.S. in Nuclear Engineering from the University of California at Berkeley (pending). Her 18-year career has focused on the resolution of technical problems and issues related to the generation and management of high-level and low-level radioactive wastes for the DOE and the commercial nuclear power industry. Ms. Robinson managed national and international R&D programs for the Electric Power Research Institute and received a Technical Excellence Award in 1990 for her work in Low-Level Waste and Below Regulatory Concern (BRC), including the following disposal performance-related studies: 129I and TRU waste characterization at BWRs/PWRs; 14C plant uptake studies; LLW engineered barrier performance assessment modeling; development of waste characterization data for the validation of radioactive disposal site inventories; and development of an NRC petition for rule making for exemption of low radioactivity wastes. She was responsible for the technical interface with the NRC, EPA, State Regulatory Authorities for LLW and radiation protection regulatory development and enforcement issues. Ms. Robinson currently provides on-going strategic waste management, waste minimization, and pollution prevention for commercial nuclear power industry and the Department of Energy.

APPENDIX 3 - DOCUMENTS REVIEWED

Basabilvazo, G. 1996. "Waste Characterization." Fax from G. Basabilvazo. Sandia National Laboratories: Albuquerque, NM. July 22.

Berglund, J.W. 1996. "Estimate of the Tensile Strength of Degraded Waste for Use in Solids Blowout." Memo to M. Chu from J.W. Berglund. Sandia National Laboratories: Albuquerque, NM. July 19.

Brush, L.H. 1990. "Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant," SAND90-0266. Sandia National Laboratories: Albuquerque, NM.

Butcher, B.M., T.W. Thompson, R.G. VanBurskirk, N.C. Patti. 1990. "Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste," SAND90-1206. Sandia National Laboratories: Albuquerque, NM.

Butcher, B.M. and F.T. Mendenhall. 1992. "A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot plant with Regard to Compliance with 40 CFR 191, Subpart B," SAND92-0427. Sandia National Laboratories: Albuquerque, NM.

Butcher, B.M. 1996. "QAP 9-2 Documentation of the Initial Waste Water Content for the CCA." Memo to M.S. Tierney from B.M. Butcher. Sandia National Laboratories: Albuquerque, NM. January 29.

Bynum, R.V., R.F. Weiner, E.J. Nowak, D. Coffey. 1996. "Analysis Plan AP-024 Estimation of Uncertainty for Predicted Actinide Solubilities," WBS 1.1.10.1.1, Rev. 0, effective date 5/13/96. May 22.

Cambridge University Press. 1910. "Proceedings of the Cambridge Philosophical Society," Vol. XV, V. June 14.

DOE. 1995. "Remote-Handled Transuranic Waste Study." DOE/CAO 95-1095. October.

DOE. 1996. "Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant," Chapter 2. DOE/WIPP, March 6.

DOE. 1996. "Waste Characterization Analysis," Draft. DOE/WIPP 96-1186. July 26.

Drez, E. 1996. "Preliminary Estimate for SNL/NM Performance Assessment Calculations of Nitrate, Sulfate, and Phosphate Content in Transuranic Solidified Wastes Destined for Disposal in WIPP," January 26. WPO 31379.

Drez, E. 1996. Drez to J. Harvill, "Final Estimate of Complexing Agents in TRU Solidified Waste Forms Scheduled for Disposal in WIPP." March 20. WPO 35552.

EPA. 1985. "Background Information Document Final Rule for High-Level and Transuranic Radioactive Wastes." EPA 520/1-85-023. August.

EPA. 1996. "Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations." Background Information Document for 40 CFR Part 194. EPA 402-R-96-002. January.

Felmy, A.R., D. Rai, S.M. Sterner, M.J. Mason, and N.J. Hess. "Thermodynamic Models for Highly Charged Aqueous Species: Solubility of Th(IV) Hydrous Oxide in Concentrated $NaHCO_3$ and Na_2CO_3 Solutions." Pacific Northwest National Laboratory, S.D. Conradson, Los Alamos National Laboratory.

Francis, A.J. and J.B. Gillow. 1993. "Effects of Microbial Processes on Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions," Progress Report Through 1992. SAND93-7036, Brookhaven National Laboratory. Sandia National Laboratories: Albuquerque, NM.

Garner, J. 1996. James Garner to Christine Stockman "Radioisotopes to Be Used in the 1996 CCA Calculations." March 15. WPO 35202.

Glasstone, S. and D. Lewis. "Elements of Physical Chemistry" 2nd Edition.

Hobart, D.E.. 1990. "Actinides in the Environment." Los Alamos National Laboratory. October 22-23.

Hobart, D.E., C.J. Bruton, F.J. Millero, I. Chou, K.M. Trauth, and D.R. Anderson. 1996. "Estimates of the Solubilities of Waste Element Radionuclides in Waste Isolation Pilot plant Brines: A Report by the Expert Panel on the Source Term," Abstract. SAND96-0098. Sandia National Laboratories: Albuquerque, NM.

International Journal for Chemical Aspects of Nuclear Science and Technology. 1985. "Radiochimica Acta," Volume 39, No. 1.

Larson, K. 1996. "Brine-Waste Contact Volumes for Scoping Analysis of Organic Ligand Concentrations." March 13.

Larson, K. 1996. "Brine-Waste Contact Volumes for Scoping Analysis of Organic Ligand Concentration." Memo to R.V. Bynum from K. Larson. Sandia National Laboratories: Albuquerque, NM. March 13.

NIST. 1995. "Standard Reference Materials® Catalog 1995-1996." NIST Special Publication 260, N.M. Trahey, Editor. Issued March.

Novak, C.F. 1995. "The Waste Isolation Pilot Plant (WIPP) Actinide Source Term: Test Plan for the conceptual Model and the Dissolved Concentration Submodel," Abstract. SAND95-1895. WPO 31162. Sandia National Laboratories: Albuquerque, NM.

Papenguth, H.W. and Y.K. Behl. 1996. "Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant," TP96-01. WPO 31952. January 16.

Papenguth, W. 1996. Papenguth to Christine T. Stockman: "Colloidal Actinide Source Term Parameters" March 29. WPO 36770, 36771.

Papenguth, W. 1996. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7: Attachment A: Rationale for Definition of Parameter Values for Microbes. WPO 35856.

Papenguth, W. 1996. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7: Attachment A: Rationale for Definition of Parameter Values for Humic Substances. WPO 35855.

Papenguth, W. 1996. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7: Attachment A: Rationale for Definition of Parameter Values for Actinide Intrinsic Colloids. WPO 35852.

Papenguth, W. 1996. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7: Attachment A: Rationale for Definition of Parameter Values for Mineral Fragment Type Colloids." WPO 35850.

Rechard, R.P. 1993. "An Introduction to the Mechanics of Performance Assessment Using examples of Calculations Done for the Waste Isolation Pilot Plant Between 1990 and 1992," SAND93-1378. Sandia National Laboratories: Albuquerque, NM.

Sanchez and H.R. Trellue. 1996. "Estimation of Maximum RHTRU Thermal Heat Load for WIPP." January 17. WPO 31165.

Sanchez, C. 1996. Sanchez to M. Martell, April 24, "Justification for Choice of CCA Radionuclide Values. WPO 37428.

Sanchez, C. 1996. "Identification of Important Radionuclides Used in 1996 CCA WIPP Performance Assessment." April 25. WPO 37431.

SNL. 1986. "Safety Analysis Report for Packaging (SARP)," SAND83-7077/1, 83-7077/2. Sandia National Laboratories: Albuquerque, NM. May.

SNL. 1991. "The Closure of WIPP Disposal Rooms Filled with Various Waste and Backfill Combinations." 32nd U.S. Symposium on Rock Mechanics, July 10-12. SAND90-2399C.

SNL. 1991. "Compaction and Permeability of Simulated Waste." 32nd U.S. Symposium on Rock Mechanics, July 10-12. SAND90-3268C.

SNL. 1991. "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991, Vol 1: Methodology and Results." SAND91-0893/1. Sandia National Laboratories: Albuquerque, NM.

SNL. 1991. "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991, Vol. 3: Reference Data." SAND91-0893/3. Sandia National Laboratories: Albuquerque, NM.

SNL. 1992. "Long-Term Gas and Brine Migration at the Waste Isolation Pilot Plant: Preliminary Sensitivity Analyses for Post-closure 40 CFR Part 268 (RCRA), May 1992" SAND92-1933. Sandia National laboratories: Albuquerque, NM.

SNL. 1992. "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Vol. 1: Third Comparison with 40 CFR Part 191, Subpart B." SAND92-0700/1. Sandia National Laboratories: Albuquerque, NM.

SNL. 1992. "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992," Vol 3: Model Parameters. SAND92-0700/3. Sandia National Laboratories: Albuquerque, NM.

SNL. 1992. "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992," Vol 4: Uncertainty and Sensitivity Analyses for 40 CFR Part 191, Subpart B. SAND92-0700/4. Sandia National Laboratories: Albuquerque, NM.

SNL. 1996. "Parameter Packages for Hans W. Papenguth (WBS 1.1.10.2.1)," WPO 35850. Sandia National Laboratories: Albuquerque, NM. March 29.

SNL. 1996. "Waste Acceptance Criteria for the Waste Isolation Pilot Plant," DOE/WIPP-069, Revision 5. Sandia National Laboratories: Albuquerque, NM. April.

Wang, Y. and L.H. Brush.. 1996. "Estimates of Gas Generation Parameters for the Long-Term WIPP Performance Assessment." January 26.

Wang, Y. 1996. "Define Chemical Conditions for FMT Actinide Solubility Calculations," March 22. WPO 37064.

Wang, Y. 1996. "Estimate of repository pH and f(CO2) Distribution of the Long-Term WIPP Performance Assessment." March 29. WPO 36453.

Wang, Y. 1996. "Evaluation of the Thermal Effect of MgO Hydration for the Long-Term WIPP Performance Assessment." May 9. WPO 37743.

Wang, Y. 1996. "Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment," memo to R.V. Bynum from Y. Wang. Sandia National Laboratories: Albuquerque, NM. July 19.

Watkins. 1996. Watkins to L.E. Shephard. April 4, "Estimate of Cement Content in TRU Solidified Waste Forms Scheduled for Disposal in WIPP." WPO 37064.

Weiner. 1996. Weiner to C.F. Novak, March 27, "Dissolved Ligand Concentrations." WPO 36163.

Weiner, R. 1996. "Dissolved Species Parameter Principal Investigator Documentation Package for Oxidation State Distribution of Actinides in the Repository," memo from R. Weiner. Sandia national Laboratories: Albuquerque, NM. March 27.

Weiner. 1996. Weiner to L.H. Brush, "Oxidation of Plutonium by Nitrate." June 7. WPO 38259.

Determination of Peer Review Member Independence Form

_____ Currently employed by DOE or DOE Contractor? Yes/No
_____ Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

Los Alamos National Laboratory - Subcontract #38380016-8N. Contract runs from 10/1/95 - 9/30/98. Support to LANL's Waste Minimization Program Office.

_____ Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Robin J. Robinson

Date: 10/24/96

Peer Review Manager Approval: John A. Thies 6/27/96
Date

Determination of Peer Review Member Independence Form

_____ Currently employed by DOE or DOE Contractor? Yes/(No)

_____ Employed by DOE or DOE Contractor previously? (Yes)/No

If yes, give dates, location, company, position type work performed.

DOE - AL Operations Office from 1970 - 1988
1978 - 1980 WIPP Project Office
1980 - 1988 Waste Management Division - DOE - AL
1985 - 1987 - Implemented Waste Certification Program
1/88 - Retired from Fed. Gov't

_____ Do you or have you had any direct involvement or financial interest in the work under review? Yes/(No)

If yes, describe involvement.

M

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: James F Bennett

Date: 6/26/96

Peer Review Manager Approval: John A. Thies — 6/27/96 Date

Determination of Peer Review Member Independence Form

Yes Currently employed by DOE or DOE Contractor? Yes/No

____ Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

President and CEO, 1993 - Present
Beta Corporation International
6719-D Academy Road NE
Albuquerque, NM 87109

Yes Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

As a subcontractor to Advanced Sciences, Inc., reviewed and development of performance assessment strategies for the disposal of transuranic waste.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Evaristo J. Bonano, Ph.D.

Date: 7/11/96

Peer Review Manager Approval: John A. Thies 7/12/96 Date

Determination of Peer Review Member Independence Form

_____ Currently employed by DOE or DOE Contractor? Yes No

_____ Employed by DOE or DOE Contractor previously? Yes No

If yes, give dates, location, company, position type work performed.

_____ Do you or have you had any direct involvement or financial interest in the work under review? Yes No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: _____

Date: 5/7/96

Peer Review Manager Approval: _____ John A. Thies

5/28/96 Date

PEER 4 - Engineered Alternatives Cost/Benefit Study
Peer Review

ENGINEERED ALTERNATIVES COST/BENEFIT STUDY

PEER REVIEW REPORT

CAO PLAN
Carlsbad Area Office

Title: Engineered Alternatives Cost/Benefit Study Peer Review Plan

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(Assistant Manager, Office of Regulatory Compliance, Carlsbad Area Office) Date: 5/7/96

1.0 Introduction

This Engineered Alternatives Cost/Benefit Study Peer Review Plan describes the peer review process and the documentation requirements the Department of Energy (DOE) Carlsbad Area Office (CAO) will use to ensure that the processes used in the Engineered Alternatives Cost/Benefit Study (EACBS) are appropriate for use in the demonstration of compliance.

1.1 Background

The Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR 191 Disposal Regulations, require an analysis of engineered barriers to be performed. This analysis will become background information in the selection or rejection of engineered barriers for use in the disposal system design. The DOE has generated the Engineered Alternatives Cost/Benefit Study (EACBS) to fulfill this requirement. This Peer Review Plan details the requirements, methods and procedures to be used to perform the peer review of the EACBS.

1.2 Purpose

The purpose of the peer review of the EACBS is to satisfy the requirements of 40 CFR 194.27. The rule requires DOE to conduct peer reviews of three specific elements of the WIPP program, one of which is the EACBS.

The Department of Energy initiated the EACBS to provide a technical basis for the selection and rejection of Engineered Alternatives (EAs) for the WIPP should it be determined that additional barriers are needed for assurance purposes. *(Engineered Alternatives: Engineered barriers that are technically feasible processes, technologies, methods, repository designs, or waste form modifications which make a positive impact on the disposal system in terms of uncertainty in performance calculations or improving long-term performance.)* This study includes a qualitative assessment of estimated costs, potential risks, benefits, and relative repository performance impacts resulting from the implementations of EAs. Although the EACBS does not directly supply input data to the performance assessment (PA), decisions resulting from the EACBS final report may influence PA parameters such as solubility, permeability, and waste strength.

This peer review is not intended to assess the validity of the requirement to perform the EACBS, nor the validity of the 40 CFR 194.44 analysis requirements. The peer review is only to assess the validity of the assumptions and the technical approach used in the EACBS.

1.3 Scope

This Peer Review Plan describes the process that the Carlsbad Area Office (CAO) will utilize for the review of the EACBS. The peer review will be an in-depth critique of assumptions, alternate interpretations, methodologies and acceptance criteria employed, and of the conclusions drawn in the original work. This EACBS Peer Review Plan defines the approach, methods, criteria, schedules, deliverables and the resources required to perform the review.

2.0 Peer Review Planning and Implementation

2.1 Approach

The DOE-CAO has prepared the "Office of Regulatory Compliance (ORC) Team Procedure for Peer Review" (TP 10.5) to document the approach for conducting the peer review process. The EACBS Peer Review Panel will conduct the peer review activities in accordance with NUREG-1297, TP 10.5 and this Plan.

The EACBS Peer Review Panel will develop procedures in accordance with guidelines set forth in NUREG-1297 and TP 10.5. Specifically, the EACBS Peer Review Panel will:

- Administer and document QA aspects of the peer review process, including preparation, logging and archiving of written minutes. In the QA process, the EACBS Peer Review Panel's Manager will ensure that all aspects of the peer review conform to NUREG-1297 and TP 10.5
- Communicate interim peer review finding in hardcopy to the ORC Peer Review Coordinator
- Produce a type written report and include a disk copy in WordPerfect compatible format

2.2 Composition of Peer Review Panel

The Peer Review Panel will consist of approximately 10 national, academic and industrial experts. The Peer Review Panel will have the following areas of expertise:

1. Waste Management
2. Waste Processing
3. Transportation Risk Assessment
4. Industrial Hygiene
5. Probabilistic Risk Assessment and Statistical Assessment
6. Mine Engineering
7. Radiation Risk Assessment
8. Cost and Schedule
9. Radionuclide Movement and Solubility
10. Public Relations

The rationale for selection of members of the Peer Review Panel shall be documented in accordance with the requirements of TP 10.5 and maintained as a QA record.

2.3 Peer Review Panel Member duties

Each Peer Review Panel member shall:

- Complete and document the necessary training prior to the start of the Peer Review process at a minimum to include:
  - 40 CFR Part 191, as amended on December 20, 1993
  - 40 CFR Part 194 dated February 9, 1996
  - NUREG-1297, Peer Review for High-Level Nuclear Waste Repositories, published February 1988
  - CAO Quality Assurance Program Description (QAPD) CAO-94-1012, latest revision
  - CAO Procedure 10.5, Revision 0, Office of Regulatory Compliance (ORC) Team Procedure for Peer Review
  - This Peer Review Plan
  - The EACBS Executive Summary, Chapters 1 & 2, and Appendix D
- Perform an in-depth critique of the EACBS documented assumptions, calculations, extrapolations; alternate interpretations, methodologies, and acceptance criteria employed; and of conclusions drawn in the original work in accordance with approved technical and quality assurance requirements, and the applicable Peer Review Plan(s)

- Interact with other Peer Review Panel members to ensure that sufficient consideration is given to interdisciplinary and coupled data and information
- Prepare Peer Review Report(s) on those specific areas reviewed
- Sign the Peer Review Final Report to show concurrence

3.0 Peer Review Process

The Peer Review shall be conducted in accordance with TP 10.5. The Peer Review process shall consist of an in-depth critique of documented assumptions, calculations, extrapolations, alternate interpretations, methodologies, and acceptance criteria employed, and of conclusions drawn in the original work in accordance with approved technical and quality assurance requirements.

A trained facilitator will aid in the direction of Panel meetings by maintaining "flip chart" records of the major issues, comments, etc. Two technical people will also be available to take more detailed minutes of the meetings. These daily records of meetings, deliberations, and activities will be the basis for developing the final report, and will become part of the QA record.

3.1 Evaluation Criteria

The Peer Review Panel shall evaluate the EACBS and report on:

- Adequacy of requirements and criteria
- Validity of assumptions
- Alternate interpretations
- Uncertainty of results and consequences if wrong
- Appropriateness and limitations of methodology and procedures
- Adequacy of application
- Accuracy of calculations
- Validity of conclusions

Full and frank discussions between the Peer Reviewers and the original performers of the work are encouraged.

3.2 Schedule and Deliverables

Attachment A contains a schedule of EACBS Peer Review activities and milestones. This schedule will serve as the baseline schedule from which requested schedule deviations will be evaluated and approved, if appropriate. Revisions to the baseline schedule will not require revision to this plan, but will be attached to the plan by reference.

3.3 Evaluation Format

The Peer Review Panel activities will follow the format of the EACBS. The EACBS was performed in three phases:

- Compile EAs, screen and optimize
- Analyze optimized EAs through an eight factor analysis
- Report analysis results in a practical format that compares the EAs performance against the repository baseline design performance.

The peer review will be performed on each of these phases and may review the analysis of EAs through the entire EACBS analysis to validate the approach. The Peer Review Panel shall perform their review in the same areas and order as listed above.

4.0 Meetings and Peer Review Activities

Meetings of the Peer Review Panel are scheduled for May 7-10 in Carlsbad, and May 29-31, and July 8-10, in Albuquerque, New Mexico. The initial meeting in Carlsbad, New Mexico is for the orientation and training of the Peer Review Panel, in accordance with TP 10.5, and to tour the WIPP site. Written minutes, including graphic or calculated materials utilized in the meetings, shall be prepared for meetings, deliberations, and other activities of the Peer Review Panel.

4.1 Observer Protocol

Observer protocol shall be conducted in accordance with TP 10.5 Attachment V. Additional protocol for the Peer Review process will meet the following conditions:

1. Internal observers are WIPP project participants, i.e., CAO, CTAC, WID and Sandia National Laboratories employees. External observers, such as employees of the U.S. Environmental Protection Agency, State of New Mexico, etc. are considered guests of the CAO.
2. International Technology, Inc. (IT), will act as the point of contact between the work originator observers and the Peer Review Panel. IT will help respond to questions regarding work performed for the EACBS raised by the Peer Review Panel.
3. Peer Review meeting minutes shall be compiled and transmitted to the Peer Review Coordinator after each meeting has taken place.

4.2 Preliminary Peer Review Meeting Agenda

May 8-10, Carlsbad, New Mexico (three days): The Peer Review Panel will receive a three-day orientation in Carlsbad on the scope, screening process, and subject matter to be covered during the performance of the EACBS peer review. The orientation will include:

- A presentation on WIPP
- Background information on the EACBS
- Formation of the peer review panel groups and assignment of EACBS appendices to be reviewed by each group
- Identification of the IT Corporation to serve the role as the work originator point-of-contact and provide clarification/input to the experts on techniques used to compile the report *(Note: Other observers are allowed, but they are strictly considered non-participants and will follow the observers rules and regulations identified by NUREG-1297 and TP 10.5)*
- Duties and responsibilities of each Panel member
- Tour of the WIPP site (half-day trip)

The remainder of the first meeting will be spent on the review of the original EACBS and how it was conducted, including coverage of the EA screening process and the initial eight factors used to rank the technologies.

May 29-31, Albuquerque, New Mexico (three days): The Peer Review Panel will convene to complete the initial EACBS review and experts from each of the ten areas identified previously, will discuss their concerns, agreements and disagreements. The agenda for this meeting will be determined after the May 7-10 orientation and submitted to the ORC Peer Review Coordinator.

July 8-10, Albuquerque, New Mexico (three days): The Peer Review Panel will have a conclusion meeting to discuss drafting the final report, due on July 19. The discussion will focus on Panel consensus, differences and final conclusions.

Specific dates of the Peer Review Panel meetings may vary slightly, depending on the availability of the Panel members.

4.3 Peer Review Daily Caucus

When Peer Review activities are conducted, the Peer Review Panel Leader shall schedule and conduct daily caucuses of the Peer Review Panel to address issues, concerns, questions or conflicts. The Peer Review Panel Leader shall resolve caucus issues, concerns, etc., as they arise.

4.4 Peer Review Report

The Peer Review Report shall as a minimum:

- Be signed by each Peer Review Panel member individually
- Describe the work or issue that was reviewed
- Describe the conclusions reached by the Peer Review Panel
- Provide individual statements by the Peer Review Panel members reflecting dissenting views or additional comments as appropriate
- List the Peer Review Panel members and provide acceptability information (i.e., technical qualifications and independence) for each member, including potential technical, and/or organizational partiality.

The Peer Review final report will be a documented, in-depth report of the proceedings and findings of the Peer Review Panel. It will be prepared under the direction of the chairperson of the Peer Review Panel and signed by each member of the Panel individually. It will clearly state the work and issues that were peer reviewed and the conclusions reached by the peer review process. The report will include individual statements by the Peer Review Panel members reflecting dissenting views or additional comments as appropriate. A preliminary outline is shown in Attachment B.

5.0 Quality Assurance Records

QA records shall be processed and maintained in accordance with the requirements of CAO Management Procedure MP 4.5, *Records Management,* Revision 0. QA records shall be maintained by the Peer Review Manager until completion of the peer review process. Duplicate records shall be generated and maintained at separate facilities. Upon completion of the peer review process the QA records shall be delivered to CAO for retention.

References

Carlsbad Area Office Team Procedure 10.5, *Peer Review*, Revision 0, March 1996.

Engineered Alternatives Cost/Benefit Study Final Report for the Waste Isolation Pilot Plant, U.S. Department of Energy. WIPP/WID 95-2135, Rev. 0. September 1995.

NUREG-1297, Peer Review for High-Level Nuclear Waste Repositories, Generic Technical Position. U.S. Nuclear Regulatory Commission. February 1988.

ATTACHMENT A

Preliminary Schedule for the EACBS Peer Review

May 7-10: Orientation, Training, and tour of the WIPP Facility

May 29-31: Peer Review Panel Meetings (Albuquerque, N.M.)
- Subcommittee Meetings

June 11: Panel Members Begin Draft Final Report Review

June 21: Preliminary Panel Member Comments on Draft Final Report Due

July 8-10: Peer Review Panel Meetings (Albuquerque, N.M.)
- Discuss Outstanding Issues
- Editorial Review of Final Report
- Panel Members Sign Final Report

July 19: Final Report Submitted to the ORC Peer Review Coordinator

ATTACHMENT B

PEER REVIEW REPORT OUTLINE

Executive Summary

1. Introduction

2. Purpose

3. Description of Work Performed

4. Evaluation Work Performed
   - A. Adequacy of Requirements and Criteria
   - B. Validity of Assumptions
   - C. Alternate Interpretations
   - D. Uncertainty of Results and Consequences if Wrong
   - E. Appropriateness and Limitations of Methodology and Procedures
   - F. Adequacy of Application
   - G. Accuracy of Calculations
   - H. Validity of Conclusions

5. Conclusions

6. Dissenting Views

7. Summary

8. Signatures

9. Peer Review Members and Acceptability

INDEPENDENT PEER REVIEW of the U.S. DEPARTMENT OF ENERGY WASTE ISOLATION PILOT PLANT ENGINEERED ALTERNATIVES COST/BENEFIT STUDY FINAL REPORT

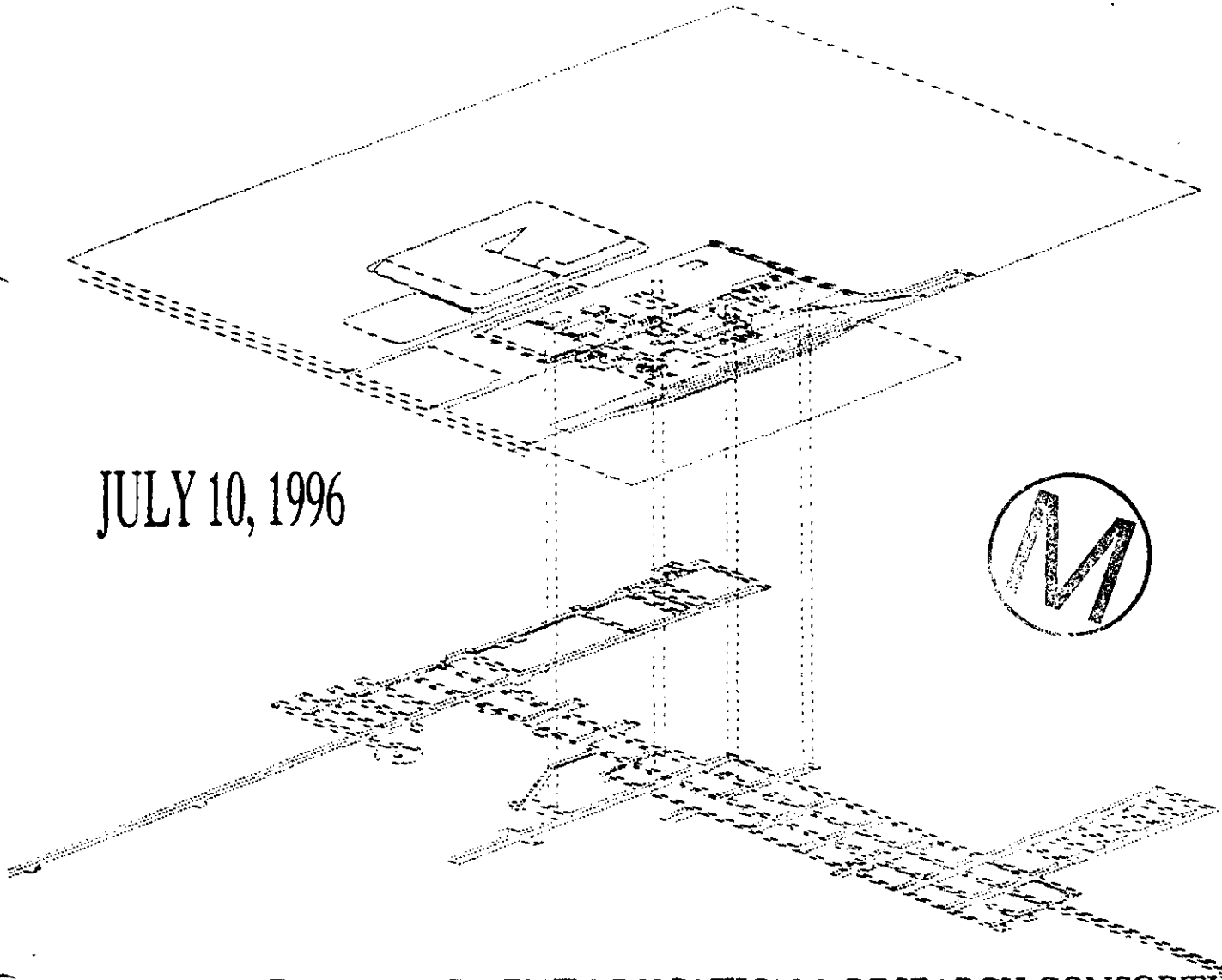

JULY 10, 1996

WASTE-MANAGEMENT EDUCATION & RESEARCH CONSORTIUM

INDEPENDENT PEER REVIEW

OF THE

U.S. DEPARTMENT OF ENERGY

WASTE ISOLATION PILOT PLANT

ENGINEERED ALTERNATIVES COST/BENEFIT STUDY

FINAL REPORT

JULY 10, 1996

Prepared by an independent Peer Review Panel organized by the Waste-management Education and Research Consortium for Westinghouse Waste Isolation Division, the operating contractor for the U.S. Department of Energy's Waste Isolation Pilot Plant

ACKNOWLEDGEMENTS

The Waste-management Education and Research Consortium wishes to thank the following for their contribution: panel members C.T. Aimone-Martin, R.K. Bhada, A. Duran, D.J. Kuhns, C.R. Lewis, J.D. Navratil, J. Rostami, D.M. Smith, and K.K. Wahi; peer review staff A. Ghassemi, L.E. Cummins, T.J. Carlson; and M.R. Nolen; G.K. Perkins (WERC) for word processing; International Environmental Training and Consulting, Inc. for contract administration and management for peer panel members; presenters of information on the EACBS report: S.W. Wagner (Westinghouse), J. Myers (IT Corp.), M.E. Crawley (IT Corp.), and J.H. Maes (DOE-CAO).

AGREEMENT OF REPORT CONTENTS

The panel members who performed the peer review for the U.S. Department of Energy's Waste Isolation Pilot Plant Engineering Alternatives Cost Benefit Study have read in the entirety this peer review report dated July 1996 and concur with the contents herein. This peer review was conducted in May, June, and July 1996.

Rohinton K. Bhada (peer panel chair)	July 10, 1996 date
Catherine T. Aimone-Martin	July 10, 1996 date
Arturo Duran	July 10, 1996 date
Douglass J. Kuhns	July 10, 1996 date
Cindy R. Lewis	7/10/96 date
James D. Navratil	July 10, 1996 date
Jamal Rostami	July 10, 1996 date
Dennis M. Smith	July 10, 1996 date
Krishan K. Wahi	July 10, 1996 date

EXECUTIVE SUMMARY

An independent peer review committee assembled by the Waste-management Education & Research Consortium (WERC) has provided to the U.S. Department of Energy (DOE) this review of the Waste Isolation Pilot Plant's (WIPP) Engineered Alternatives Cost/Benefit Study (EACBS) Final Report (DOE, 1995a). This study and the peer review are requirements of the U.S. Environmental Protection Agency (EPA) as part of the compliance application for the permitting of WIPP to receive and dispose transuranic waste. The DOE initiated the EACBS, required by EPA regulation Title 40 U.S. Code of Federal Regulations Part 194 (40 CFR 194; *Criteria for the Certification and Re-certification of the Waste Isolation Pilot Plant's compliance with the 40 CFR Part 191 Disposal Regulations;* EPA, 1996), to provide a technical basis for the selection or rejection of engineered alternatives (EAs) for the WIPP should it be determined that additional barriers are needed to satisfy the assurance requirements of 40 CFR 191. EAs are defined as technically feasible processes, technologies, methods, repository designs, or waste modifications which make a significant positive impact on the WIPP disposal system in terms of uncertainty in performance calculations or improving long-term performance. The EACBS includes a qualitative and to a limited extent quantitative assessment of estimated costs, potential risks, public acceptance, benefits, and relative repository performance impacts resulting from the implementation of engineered alternatives.

The peer review of the EACBS was conducted during May, June, and July 1996 in accordance with the U.S. Nuclear Regulatory Commission *NUREG-1297 Peer Review for High-level Nuclear Waste Repositories* (NRC, 1988) and the DOE Carlsbad Area Office *Peer Review Procedure* TP 10.5 (DOE, 1996). The objective of the peer review was to assess the validity of the assumptions and the technical approach used in the EACBS, and to evaluate the adequacy of the work. It was not to assess the validity of the WIPP project, the requirement to perform the EACBS, 40 CFR Part 194 analysis requirements, nor the ability of the WIPP to meet compliance standards. The review focused on determining the reasonableness of the report's conclusions.

The panel reviewed several parts of the study. However, to provide in-depth review of major factors, the peer panel divided itself into three subcommittees to address certain areas of the study. Subcommittees were established for reviewing the eight different EA evaluation factors identified under 40 CFR 194.44 with reviewers divided by expertise that was most appropriate for each set of factors. Eventually, all subcommittee findings were reviewed by the entire peer panel.

Based on presentations by the EACBS authors, discussions with the authors and DOE staff, and review of the EACBS and supporting documents, the overall conclusions of the peer review panel are:

- the information presented within the EACBS is of high quality,
- the approach taken is valid,

- the conclusions drawn are reasonable, and

- the analysis was conducted in accordance with 40 CFR 194.44 requirements.

The peer review panel also notes the following observations:

- The screening process for identifying EAs and the EA analysis itself was not iterative. After the screening was completed, it was not reevaluated with regard to the detailed alternative evaluation criteria. For example, if waste removal or costs were considered by DOE to be a major factor for decision-making, then several alternatives that did not pass the EA screening process should be reevaluated. The review committee feels that this is acceptable because of additional costs that would have to be incurred by repeated iterations and the conclusions would probably not change significantly.

- The EACBS report is ambiguous about the significance of early intrusion with respect to the relative benefits of the EAs. The Measure of Relative Effectiveness (MREs) for some alternatives do show a dependence on time of intrusion, particularly when the releases are solubility-limited.

- Creep closure modeling did not consider uncertainty in creep parameters nor did it incorporate important advances in creep modeling. Different time periods for closure would have likely resulted which may have changed the relative ratings of the EAs, but the conclusions will probably not change.

- The effectiveness of EAs with clay backfill or treated by vitrification was underestimated because the enhanced immobilization of actinides within these matrices was not assumed.

- The relative nature of the alternatives comparison decreases the chance that uncertainties in assumptions used in the evaluation process would have an impact on the evaluation results; e.g., if costs are consistently high by 50%, the relative importance of the cost estimates will not change.

- Waste removal assumptions do not include a short-term removal scenario from the regulatory closure of the repository to the geological closure of the rooms. Had short-term removal been considered in the analysis, the inter-EA comparisons may be different.

- Public confidence could have benefited from involvement of the public from states neighboring New Mexico and possibly from states which intend to ship waste to WIPP. Although this involvement was not evident in the EACBS, it was not felt to be a significant issue that would have altered the results and conclusions.

- With respect to the adequacy of requirements and criteria, panel members agreed that these were prescribed by regulation for most of the factors and was therefore beyond the scope of their review.

- The EACBS focused on evaluating measures that exceed compliance and are added assurance of performance beyond the baseline requirements. The major consequence of implementing an alternative based on a slightly incorrect evaluation is probably the expenditure of greater dollars than necessary and the addition of more time to implement the alternative. Safety is not impaired.

- As described in the EACBS, the identification/screening process is not clearly documented. There is also confusion in some of the terminology used (e.g., "screening," "optimization," "prioritization"). In order that the process is well understood, it is recommended that clarification be added to the report, particularly to describe how the alternatives list went from the 54 recommended by the Engineered Alternatives Screening Working Group to the 18 evaluated in the EACBS report.

- Remote-handled waste was not considered. This issue may have implications to the compliance application.

- We believe that the DOE would gain better insight by considering the post-closure performance separately (as distinct from pre-closure activities) to fully appreciate the benefits (or detriments) of a given EA.

Results of the EACBS peer review evaluation are summarized in Table ES-1.

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Table ES-1. *Summary of the Peer Review of the EACBS Evaluation Factors and Criteria*

Engineered Alternatives Evaluation Factors	A. Adequacy of Requirements and Criteria	B. Validity of Assumptions	C. Alternative Interpretations	D. Uncertainty of Results and Consequences if Wrong	E. Appropriateness and Limitations of Methodology and Procedures	F. Adequacy of Application	G. Accuracy of Calculations	H. Validity of Conclusions
Evaluation of the EA Screening Process	Generally considered to be adequate, although some other potential EAs could have been added.	Evaluation was qualitative and was to assess assurance, not compliance. This assumption was prescribed by law and was therefore considered valid.	None.	The screening process was conservative in nature and was thus more inclusive than exclusive.	The screening process was considered to be appropriate. A better description of the process would have enhanced the report.	The sequence of comparing, scoring, prioritizing, etc. was adequate to achieve the results.	The use of algorithms and professional judgement were deemed appropriate.	The final list of EAs selected for further analysis was reasonable.
1. Long Term Repository Performance **2. Uncertainty in Compliance Assessment**	Adequate	Broad Level: Appropriate. Detailed Level: Intrusion scenarios assumed to occur at 5,000 years; and actinide solubility assumptions were conservative. Broad Level: Appropriate; Detailed Level: Uncertainty in creep parameters was not considered. Differences in creep closure estimates could affect the quantity and rates of release; early intrusion could result in significantly different releases; and EAs with plasma processing or clay backfill were not credited with enhanced Pu immobilization.	Different creep closure models or model coefficients may affect the relative benefits of EAs; and the effects of future mining nearby could have been considered as an additional human intrusion scenario.	Uncertainty will result due to the uncertainty of input parameters; however, no severe consequences if wrong; conservative parameter estimates were used. Relative nature of analysis allows meaningful conclusions to be drawn. Discussion of uncertainty in the results does not fully reflect the uncertainty analysis that was in fact carried out.	Use of the DAM model to predict performance was appropriate; however, important advances in creep modeling were not used. Model did not (and cannot) consider stratigraphy (e.g., anhydrite layers) in the mechanical response calculations.	Compressive strengths of waste/backfill EAs is misleading; and intrusion before creep closure not adequately analyzed. Methods used are completely applicable for comparative screening process	Creep rate calculations checked and qualitatively agree.	Effectiveness of some EAs may have been underestimated due to simultaneous consideration of pre-closure and post-closure risks.
3. Worker and Public Risk	Adequate	Risk assumptions are conservative, conventional, and adequate for the work performed.	None.	Uncertainties err on the side of safety and risks are likely overstated.	Methodology did not account for risks inherent in current waste handling methods. For example, relative risks could have been different for these EAs having long development/processing time.	Methods are applicable for the comparative screening process.	Calculations are reasonable and consistent.	Risk conclusions for CH waste appear valid. Risk conclusions for RH waste are absent.
4. Impact on Waste Removal	200 year period for waste removal requires justification; different time frames have a major impact on the methods used for retrieval.	Assumed excavation technology is appropriate, but the data used in the calculations is not state-of-the-art. For long term retrieval, assumptions and methodology used for mining rate and time estimates are correct; quantitative studies are needed. Short term retrieval method, rate, and schedule not addressed.	Alternative methods for recovery based on different time frames could have been performed.	Uncertainty associated with the compressive strength of the EAs is not critical to the relative comparison of EAs. The waste is removable with today's technology and the decisions made based on the EACBS are not irreversible.	Methodology was appropriate to estimate time required for long-term removal; however, some of the assumptions, data, and terminology were not suitable for the application.	Time of waste removal was not adequately addressed.	Overall, calculations could not be checked for accuracy; there is no reference to machine type, specifications, and utilization.	Although the quantitative results of the analysis can not be directly used for assessment of the EAs, the general conclusions based on a qualitative comparison with the baseline are valid and acceptable for long-term removal. Consideration of short-term removal could change the results.

Table ES-1 (continued). Summary of the Peer Review of the EACBS Evaluation Factors and Criteria

Engineered Alternatives Evaluation Factors	A. Adequacy of Requirements and Criteria	B. Validity of Assumptions	C. Alternative Interpretations	D. Uncertainty of Results and Consequences if Wrong	E. Appropriateness and Limitations of Methodology and Procedures	F. Adequacy of Application	G. Accuracy of Calculations	H. Validity of Conclusions
5. Transportation Risk	Adequate	Risk analysis assumes 20 year active life, yet the WIPP operational window is for 33 to 35 years. Transportation is by truck only, no explanation why rail is not evaluated. Overall, however, risk assumptions are conservative, reasonable and well within contemporary transportation risk analysis.	There is no reasonable alternative interpretation.	Population densities will be different if the period of transportation and disposal is greater than 20 years. An added risk could occur for those EAs which have a longer time frame.	The methodologies were considered to be generally appropriate. Limitations include addressing only CH waste, a "bounding" accident not being evaluated, and lack of justification for selected values. The limitations should not compromise the EA evaluation so long as the 20 versus 35 year issue is recognized.	Methods used are applicable for comparative screening process	Calculations appear to be reasonable and consistent with the methodology.	The conclusions drawn for purposes of a qualitative comparison of the transportation risks of the various EAs appears valid.
6. Public Confidence in the Performance of the Disposal System	Adequate	Assumptions regarding the public's concerns as to content, categorization, timeliness, and affected in-state population are reasonable. Although out of state populations were not addressed, this is not considered to be a major deficiency.	Slightly different interpretations are possible, but would not affect the conclusions of the study.	Uncertainty is low regarding the public's position on the EAs and slight misinterpretations are not considered serious.	The methodology used to assess public confidence was appropriate. A limitation is the lack of opportunity for out of state public comment.	Application of the methodology was considered proper.	Categorization of public comments was checked and determined to be relatively accurate with only minor discrepancies.	The conclusions appear appropriate.
7. System Cost and Schedule	Adequate	Cost and schedule assumptions are considered to be valid with uncertainty of approximately 30 percent associated with the uncertainty of the waste inventories.	A few alternate interpretations may originate from the guidance documents. However, they would have little effect on the study's results.	The estimated costs and schedules were reasonable.	The methodology for cost and schedule evaluation is considered appropriate.	Methodologies were appropriately applied.	Spot checks determined that calculations were performed according to accepted methods and procedures.	In general, the conclusions are valid.
8. Impact on Other Disposal Systems	Adequate	The assumptions of waste type and volume have uncertainties associated with them that may impact other disposal systems. The assumptions used appear reasonable.	The uncertainties associated with waste volume can be interpreted in different ways. Some interpretations will result in higher volumes while others will result in lower volumes.	Uncertainty of results are +10% to -25% based on waste volume uncertainty. No serious negative consequences should occur because of this uncertainty.	Procedures used are technically defensible. A limitation of the methodology is the reliance on the accuracy of waste volume.	The techniques used were adequate to meet the intended goal.	The basis of calculations was not provided in the EACBS; however, using reasonable assumptions, data spot checks were found to be accurate.	The conclusions reached are valid and support the end use of the report.

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1.0 INTRODUCTION

In March 1996 the U.S. Department of Energy (DOE) Carlsbad Area Office (CAO) requested through its operating contractor, Westinghouse - Waste Isolation Division, that the Waste-management Education & Research Consortium (WERC) provide a peer review of the Waste Isolation Pilot Plant (WIPP) Engineered Alternatives Cost/Benefit Study (EACBS) Final Report (DOE, 1995a). The WIPP is a DOE project designed to provide for the safe disposal of transuranic (TRU) waste in deep, geologic, bedded salt. As required by U.S. Environmental Protection Agency (EPA) regulations promulgated under Title 40 Code of Federal Regulations 191 (40 CFR Part 191: *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-level and Transuranic Radioactive Wastes;* EPA, 1985) DOE was required to examine additional engineered barriers beyond the salt itself to provide added assurance against waste migration. The DOE initiated the EACBS, required by EPA regulation 40 CFR 194 (*Criteria for the Certification and Re-certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations;* EPA, 1996), to provide a technical basis for the selection and rejection of engineered alternatives (EAs) for the WIPP should it be determined that additional barriers are needed to satisfy the assurance requirements of 40 CFR 191. EAs are defined as technically feasible processes, technologies, methods, repository designs, or waste modifications which make a significant positive impact on the disposal system in terms of reducing uncertainty in performance calculations or improving long-term performance. The EACBS includes a qualitative assessment of estimated costs, potential risks and benefits, and relative repository performance impacts resulting from the implementation of engineered alternatives. The EACBS was conducted as required by Section 194.44 of 40 CFR 194. Additionally, for purposes of convenience, the nine evaluation factors prescribed in 40 CFR 194 were rolled up into eight equivalent factors.

2.0 PURPOSE

The purpose of the peer review of the EACBS is to satisfy quality assurance requirements of 40 CFR 194. This final rule requires DOE to conduct a peer review of three specific elements of the WIPP program, one of which is engineered barriers. Because of the potential uncertainty in most geotechnical data and their analyses, the need to make projections over thousands of years, the lack of unanimity among experts, and the first-of-a-kind nature of geologic repository technical issues, expert judgement will need to be utilized in assessing the adequacy of work. Peer reviews are a mechanism by which these judgements may be made.

WERC (a consortium consisting of New Mexico State University, University of New Mexico, New Mexico Institute of Mining and Technology, Navajo Community College, Los Alamos

National Laboratory, and Sandia National Laboratory) was selected to organize this peer review because of its ability to assemble a panel of experts from diverse academic and industrial settings.

Background of the WIPP EACBS: The deep, geologic, bedded salt repository known as the WIPP is the United States' proposed permanent solution for disposal of TRU waste currently stored and generated by DOE. The WIPP repository is located in the Northern Delaware Basin in southeastern New Mexico (Figure 1) at a depth of approximately 2,150 feet below surface in a bedded salt (halite) formation. A cut-away view of the planned WIPP repository is shown in Figure 2. (See EACBS for greater detail concerning the geology and layout of the WIPP.) TRU waste identified for disposal is generated from DOE defense-related activities, including weapons production, research, and development and are stored at various DOE sites across the country. The majority of TRU waste is material contaminated with alpha emitting radionuclides (e.g., plutonium-239) with half lives greater than 20 years and activities greater than 100 nanocuries per gram of waste. Once salt is excavated to form disposal rooms, natural closure due to creep (plastic flow) of the surrounding salt formation on the order of a few inches per year occurs. In time, complete consolidation of the waste within the host rock occurs.

Under the *Waste Isolation Pilot Plant Land Withdrawl Act* (U.S. Congress, 1992) the 16 square mile area at the WIPP site has been withdrawn from public use and has been set aside for use in the safe disposal of TRU waste. Also by law, disposal of TRU waste must comply with rules and regulations promulgated by the EPA. The disposal system design consists of multiple barriers, both natural and man-made, located in the geologic salt deposit. These barriers were selected because of their ability to permanently isolate the waste from the accessible environment as required to comply with Subparts B and C of 40 CFR 191. As a part of the assurance requirements, 40 CFR 191.14 requires that barriers of different types shall be used to isolate the waste. The WIPP design uses both geologic (natural) and engineered barriers for waste isolation as specified by these regulations. However, to provide additional confidence in performance assessment calculations used to demonstrate compliance with the containment requirements, EAs could be used to provide additional assurance measures beyond those used to meet the containment requirements. These engineered alternatives, if used, function as barriers to the release of radioactive material.

The DOE initiated the EACBS to evaluate EAs for potential use as assurance measures. The EACBS evaluated these EAs using the following assumptions and guidance

- The baseline design (as defined in 1995) of the disposal system and its predicted performance meet the containment requirements of 40 CFR 191 without additional EAs. The baseline does not include waste processing above that required by the WIPP Waste Acceptance Criteria and does not include backfill around the containers of waste as an option.

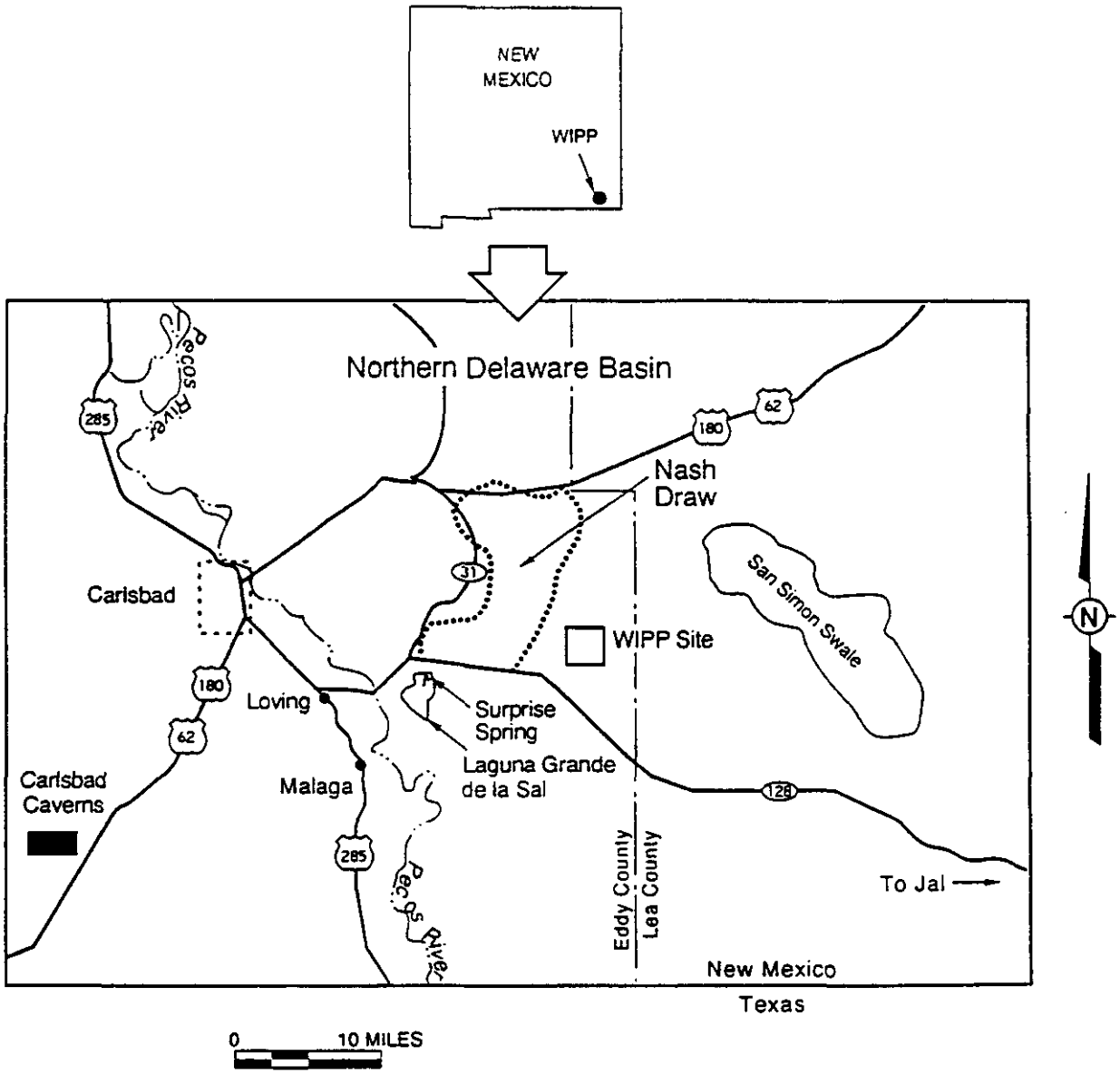

Figure 1
The WIPP Location in Southeastern New Mexico

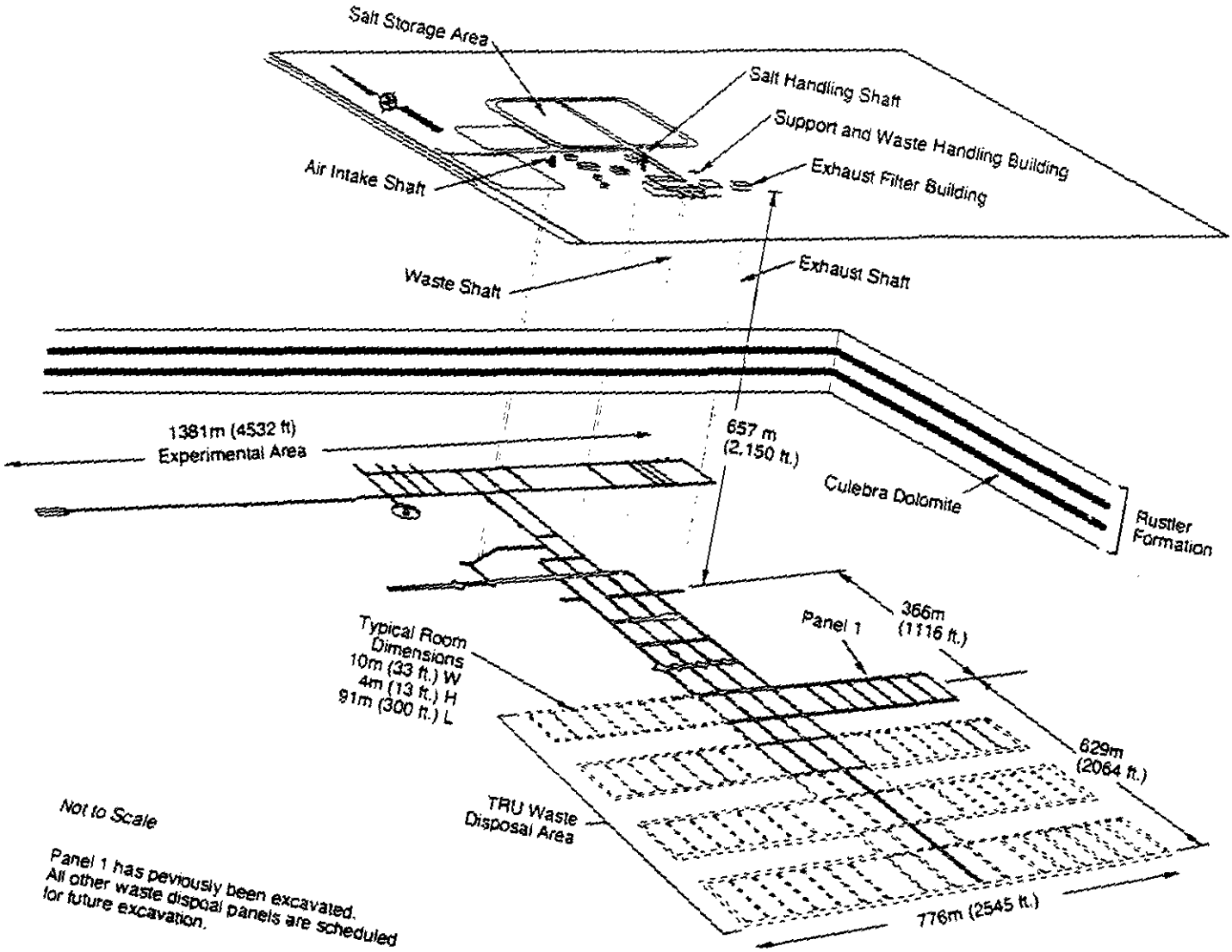

Figure 2
Proposed WIPP Repository Showing Both TRU Disposal Areas and Experimental Areas

- The information presented in the EACBS is to be used to select or reject EAs for assurance purposes only and is not for demonstrating compliance with the containment requirements.

- The results of the EACBS analysis are qualitative. However, both qualitative and quantitative methods are used to generate the output information.

- The output of the EACBS compares the results of the EAs analysis with the baseline and not to each other. Numerical ranking of EAs is not provided.

- The EAs analysis uses a multi-factor approach that evaluates the cost, the risk (both incidental and accidental), and the benefit and schedule impacts that could be expected from the implementation of each individual EA. The factors are not ranked or weighted.

- TRU waste destined for WIPP can be grouped into three basic waste forms: sludges, solid organics, and solid inorganic materials.

- All waste shipped to WIPP will meet the Waste Acceptance Criteria. These requirements reflect any necessary waste treatment or processing requirements to safely transport and emplace the waste.

3.0 PEER REVIEW PROCESS

The peer review of the EACBS was conducted in accordance with the U.S. Nuclear Regulatory Commission NUREG-1297 *Peer Review for High-level Nuclear Waste Repositories* (NRC, 1988), and the DOE Carlsbad Area Office *Peer Review Procedure* TP 10.5 (DOE, 1996). Peer review panel members and their affiliations are:

Ron K. Bhada (peer panel leader)	WERC and New Mexico State University
Catherine T. Aimone-Martin	New Mexico Institute of Mining and Technology
Arturo Duran	Environmental Consulting and Engineering
Douglass J. Kuhns	Lockheed Martin Idaho Technologies Company
Cindy R. Lewis	Parsons Engineering Science
James D. Navratil	Rust Federal Services
Jamal Rostami	Colorado School of Mines
Dennis M. Smith	Technical & Management Systems & Services, Inc.
Krishan K.Wahi	Geologic Repository Assessment Methodologies, Inc.

The peer review management team members are:

Abbas Ghassemi (project manager)	New Mexico State University/WERC
Tim Carlson	Rust Federal Services, Inc.
Laura Cummins	Rust Federal Services, Inc.
Mark Nolen	New Mexico State University

Biographic sketches of the panel members and the management staff used to generate the peer review report are included in Appendix A. Meetings of the peer panel were held on April 29, 30 and May 1 in Carlsbad, and May 29-31, and July 8-10, in Albuquerque, New Mexico. The initial meeting in Carlsbad, NM, was for orientation and training of the peer review panel, and to tour the WIPP site. The review of the initial screening process also was performed at this time by the Peer Review Committee. 40 CFR 194.27 prescribes that the peer review shall be conducted in a manner compatible with NUREG-1297. Panel members performed their evaluation of the EACBS based on the following criteria prescribed in 40 CFR 194:

- validity of assumptions
- alternate interpretations
- uncertainty of results and consequences if wrong
- appropriateness and limitations of methodology and procedures
- adequacy of application
- accuracy of calculations
- validity of conclusions
- adequacy of requirements and criteria

Agendas for all three meetings are presented in Appendix B. During these meetings, full and frank discussions between the peer reviewers and the original performers of the work occurred. The intent of the peer review was to assess the validity of the assumptions and the technical approach used in the EACBS, and to confirm the adequacy of the work. It was not to assess the validity of the WIPP project, the requirement to perform the EACBS, the 40 CFR 194 analysis requirements, nor the ability of the WIPP to meet compliance standards. The review conducted was a high-level analysis, focused on determining the reasonableness of conclusions reached in the EACBS. The intent of the review was not to reproduce the calculations and results of the report in great detail.

In the EACBS report, each alternative considered was analyzed with respect to eight different factors specified in 40 CFR 194 (the regulation actually specifies nine factors, two of which were combined for the EACBS[1]). Those factors are as follows:

- Factor 1 — Long term repository performance
- Factor 2 — Uncertainty in compliance assessment
- Factor 3 — Impact on public and worker exposure
- Factor 4 — Impact on waste removal
- Factor 5 — Transportation risk
- Factor 6 — Public confidence
- Factor 7 — Impact on system cost and schedule
- Factor 8 — Impact on other disposal systems

The EACBS relies heavily upon previously published documents for backup of the identification and evaluation of the EAs. These include the *Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force* (DOE, 1991a), *Office of Environmental Management Programmatic Environmental Impact Statement* (DOE, 1994a), *Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capacities and Technologies* (DOE, 1993), *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report* (DOE, 1995b), *Comparative Study of Waste Isolation Pilot Plant Transportation Alternatives* (DOE, 1995c), *Waste Acceptance Criteria for the Waste Isolation Pilot Plant* (DOE, 1991b), *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant* (DOE, 1990), and the *Final Environmental Impact Statement, Waste Isolation Pilot Plant* (DOE, 1980). Because the EACBS is not a stand alone document for peer review purposes, the peer panel also reviewed relevant portions of these documents.

To review the large amount of information provided in the EACBS, the peer panel divided itself into three subcommittees to address specific factors of the study. Subcommittees were established for reviewing the eight different EA evaluation factors identified in 40 CFR 194 with reviewers divided by expertise that was most appropriate for each set of factors. The subcommittees were composed of the following:

- Group 1 - Factors 1 and 2 - Cathy Aimone-Martin, Jim Navratil, and Krishan Wahi.
- Group 2 - Factors 3, 4, and 5 - Cindy Lewis, Jamal Rostami, and Dennis Smith.
- Group 3 - Factors 6, 7, and 8 - Ron Bhada, Arturo Duran, and Doug Kuhns.

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[1] Two of the original factors were combined into Factor 1. Those factors were: (1) the ability of the engineered barrier to prevent or substantially delay the movement of water or waste toward the accessible environment, and (2) the effects on mitigating the consequences of human intrusion.

The subcommittee reports (presented in Appendix C) represent the principal observations/conclusions drawn by the peer panel in accordance with the 8 evaluation criteria specified previously in this section. Highlights of these reports are contained in Section 4.0 and are summarized in Section 5.0. The entire peer review panel agrees with the substance of this peer review report.

4.0 EVALUATION OF WORK PERFORMED

The evaluation of the alternative identification/screening process was completed by the peer review panel as a whole. Detailed evaluation of the eight factors used to perform the EACBS was completed by subcommittees of the peer panel; these evaluations were subsequently reviewed by the entire panel. This section of the report summarizes the results of the evaluation process conducted by the peer review panel members. Subcommittee reports, with results organized by individual evaluation criteria, can be found in Appendix C. The major findings of those reports are presented here. Subcommittee reports are summarized in Table 1 in Section 5 of this report. The discussion in this section covers only the main points identified in the evaluation process.

For the most part, panel members focused their evaluation on discretionary issues that were under the control of the report preparers, rather than those that were prescribed by regulation. In addition, it was recognized that the EACBS report is one of many other studies that have been completed or are ongoing for the WIPP facility. Other assumptions, standards, etc., may have been established in previous work that also feed into the EACBS report. A critique of prior work was beyond the scope of this review.

4.1 Results of the Engineered Alternatives Identification/Screening Process

In general, the peer panel members thought that the identification/screening process was adequate. However, members felt that the EACBS report was not very clear on the description of the screening process to clearly understand the steps and criteria involved. Only after presentations by and discussions with those involved in the identification/screening process did the members come to a mutual understanding of how the process was carried out. Among the findings of the panel are the following:

- Clarification is needed in the text of the report on the steps involved in the identification/screening process, including steps that occurred after the Engineered Alternatives Task Force performed their initial evaluation. Better define what is meant by "screening," "optimization," and "prioritization." Clearly state the criteria used for each stage of the process.

- Some concern was expressed that the screening process was conducted independent of a consideration of the eight factors used in evaluating the EAs. If the screening process and

evaluation of EAs according to the eight factors had been iterative, the list of EAs analyzed as well as the results of both the screening process and the evaluation of the EAs may have been different. However, this would probably be an endless process of iterations and not justified because of cost and time involved.

- Remote-handled waste was not considered. This issue may have implications to the compliance application.

4.2 Evaluation of Factors 1 and 2: Impacts on Long-term Repository Performance and Uncertainty in Compliance Assessment

These factors focused primarily on the analyses performed with the Design Analysis Model (DAM) computer simulation program. This program was used to predict the future performance of the repository with different engineered alternatives given three different human intrusion scenarios. Values for several parameters are required as input to the model. Many input parameters were treated as being uncertain; i.e., ranges and distributions were assigned to such parameters. Other parameters were given constant (single point) values. The panel members checked many of these parameters, as well as quality assurance documentation for the computer simulation itself. No major discrepancies or errors were noted. It was noted that much of the information used in the model was selected to be consistent with the Performance Assessment (PA) being conducted by Sandia National Laboratories (SNL).

Among the findings of the evaluation of factors 1 and 2 are the following:

- The simplifying assumptions used in the model are valid given that the results are to be used in a relative, not absolute, manner. Actual calculated releases of radionuclides, although not absolute, are acceptable for comparison purposes.

- Creep closure modeling did not consider uncertainty in creep parameters nor did it incorporate important advances in creep modeling. Different time periods for closure would have likely resulted which may have changed the relative ratings of the EAs, but the conclusions will probably not change.

- The EACBS report assessed the effect of human intrusion at 5000 years as well as additional simulations for the baseline and nine selected alternatives at 200, 2000, and 7000 years. This assessment concluded that the Measures of Relative Effectiveness (MREs) are insensitive to the time of intrusion once the physical properties (density and permeability) of the composite material in the room reaches a steady-state condition. This occurs some time between 200 and 2000 years. One exception is the MREs at 200 years which differ by several percent from the MREs at later years because the composite material in the rooms at 200 years is still in the process of consolidating from creep closure, and this consolidation occurs at different rates for each alternative. Consolidation of the composite material is complete by 2000 years, so the MREs remain constant thereafter. Had the analysis included radionuclide

transport within the Culebra, it is likely that the results would have shown a stronger sensitivity to the time of intrusion (e.g., within a few hundred years).

- The uncertainty analysis in the EACBS report focused on uncertainty associated with input parameters. Uncertainty associated with the model itself and with the future state of the disposal system were not considered.

- Because the study focuses on potential benefits of EAs beyond the baseline design, consequences of reaching a wrong conclusion are not expected to be severe.

- Lack of a user's manual for the DAM code makes it difficult to independently verify calculations in the EACBS report.

- The comparative, unweighted approach used for evaluating alternatives results leads to an inevitable trade-off between long-term performance and short-term risk. The DOE can avoid this pitfall by separately evaluating the merits of each EA in the post-closure phase only. Specifically, by comparing only the first two columns of results in Figure E-4 (of the EACBS report), one can more clearly see the long-term benefits offered by each EA.

- The effectiveness of EAs with clay backfill or vitrification treatment was underestimated because the enhanced immobilization of actinides within these matrices was not assumed.

4.3 Evaluation of Factor 3: Impact of Engineered Alternatives on Worker and Public Risk

Review of Factor 3 indicated that the methodology used for assessing alternatives for worker and public risk was consistent with accepted, conservative techniques. Methods and assumptions used are defensible. Major concerns expressed are as follows:

- An evaluation of risks associated with processing of remote-handled (RH) waste is absent. It would be useful to include a discussion of the possible relative comparison between the risks associated with contact-handled (CH) and RH waste. For example, one can draw conclusions based on radionuclide difference, radionuclide mobility, potential for release, transport mechanisms, and exposure scenarios associated with both waste processing and long-term performance.

- Many of the assumptions used in assessing worker and public risk appear to be borrowed from the Draft Waste Management Programmatic Environmental Impact Statement (WMPEIS; DOE, 1995d). While these assumptions may be valid, additional discussion of them in the text of the EACBS would provide further clarification.

- Additional risks posed by allowing the waste to remain above ground for longer time periods necessitated by some of the EAs were not evaluated. This could underestimate risks associated with those EAs.

4.4 Evaluation of Factor 4: Waste Removal Impact

The evaluation of Factor 4 was conducted in the context of the 40 CFR 194.44, assuming that the removal of the emplaced waste and backfill (after the regulatory closure) is possible. The factor considers the impact of EAs on waste removal after 200 years with no justification. The methodology used and the conclusions made based on a qualitative comparison using the volume and the time required for removal is acceptable. However, the following issues were raised with respect to this factor:

- Short-term removal of the waste and backfill (from regulatory closure of the repository to geological closure of the rooms) was not considered. Had the short term removal scenarios been considered, the results of relative comparison may be different.

- If waste removal had been one of the evaluation criteria, different alternatives may have reached the detailed evaluation stage (e.g., the EAs which passed through each screening process may have included one or more additional alternatives than the EAs contained in the final list).

- The results of implementing any of the EAs would not be irreversible and waste could be removed after disposal, using current technology.

- The assumptions and conclusions should be used for comparative purposes only. Some assumptions used for quantitative calculations were inappropriate for the circumstances but serve the purpose for a comparative study.

4.5 Evaluation of Factor 5: Impact of the Engineered Alternatives on Transportation Risk

Generally, the evaluation of transportation risk was conducted according to standard, accepted practices, particularly for radionuclides. Standard risk calculation methods were used and were determined to be conservative, conventional, and appropriate. The major points raised through the peer review are as follows:

- The "worst case" accident considered in the reference document for the EACBS (the Final Supplement Environmental Impact Statement; DOE, 1990) appears to have been eliminated from consideration in the EACBS with no justification. RADTRAN accounts for accident severity categories within its code. Therefore modeling of an additional worst-case accident would not provide substantive additional information.

- For chemical hazards, risks are calculated solely on a consideration of wasteform characteristics. Transportation-related aspects of the scenario (e.g., mileage, population density) were not included; an accidental release was simply assumed. This full range of transportation impacts cannot, therefore, be evaluated.

- The analysis in the EACBS relied heavily on previous work done for the WIPP Final Environmental Impact Statement (FEIS) and Final Supplement Environmental Impact Statement (FSEIS). However, methods used in these previous reports varied; information was not provided in the EACBS to indicate which methods came from original documents and what the justification was for using the methods selected in the EACBS.

- The risk analysis assumes a 20-year active life for transportation and disposal of waste; however, the operational window for WIPP is approximately 35 years. Additional population densities might affect the impact analysis of alternatives that require treatment and greater than 20 years to complete transportation and disposal. The panel members do not feel that the apparent discontinuity in this assumption is limiting to the assessment of transportation-related risks.

4.6 Evaluation of Factor 6: Impact of Engineered Alternatives on Public Confidence

Public confidence was assessed by conducting general and focused public meetings over a six-year period (not all meetings were specific to receiving input on EAs). Input received by members of the public through this process indicates that the majority of public sentiment is not directly related to any specific EA, but is mostly related to an overall perception of the Department of Energy's credibility. Methods used to collect and analyze information were deemed to be appropriate, though subject to interpretation. The conclusions of the EACBS report are appropriate and reasonable. The only issue raised was the lack of public input from New Mexico's neighboring states. However, because of the diverse nature of the public input, no significant impact on the conclusions of the EACBS report is expected.

4.7 Evaluation of Factor 7: Total System Costs and Schedule Estimates

The evaluation of this factor focused largely on the assumptions and methodologies used and the results of their application. The assumptions, methodologies and results were divided into five separate categories for review: (1) waste processing, (2) transportation, (3) backfill emplacement, (4) waste emplacement handling, and (5) schedule. Overall, the panel members found no significant flaws in the estimates for costs and schedules. Standard references were used to compile this information along with experience gained through work on other comparable DOE projects. The panel members agreed that development of the schedule and cost estimates was appropriate, reasonable, and defensible. They also concurred with the observation made in the EACBS that none of the EAs presents significant benefits over the baseline with regard to cost or schedule considerations. Finally, they agreed that when looking at the schedules alone for each of the alternatives, no alternative presents significant detriments relative to the baseline for the closure of WIPP.

4.8 Evaluation of Factor 8: Impact on Other Waste Disposal Programs

This factor is defined in the EACBS as the determination of major impacts an EA will have on other waste disposal and processing programs, including low-level and mixed low-level waste. Therefore, the focus in evaluating this factor was on volumes of waste generated through the implementation of the EAs considered in the EACBS report. It was acknowledged that a great deal of uncertainty is involved in estimating waste volumes that will require disposition; however, the panel members determined that estimates were based on the best available information at the time. It is recommended that these volume estimates be updated as more accurate information becomes available to ensure adequate facilities and resources for disposal. Other findings from a review of data related to this factor are as follows:

- Except for plasma arc, all other EAs that include treatment are assumed to result in waste volumes similar to cementation processes used at Rocky Flats (an increase of 75%). An additional 30% (of the total waste volume) of secondary waste is anticipated to be generated, resulting in a total of 2.275 drums from the treatment of a single drum.

- The EACBS report for this factor is difficult to follow at times and could benefit from clarification and the use of examples to show how waste volume estimates were made.

- It is not clear by reading the EACBS report how the volumes of waste destined for WIPP are factored in to the report. A best estimate of waste to be disposed should be provided for WIPP operations personnel.

- Percentages of secondary waste generated vary widely with respect to the type of EA implemented. However, the report uses a 50% figure for both low-level and low-level mixed secondary waste. The use of the actual average percentages would provide a more accurate estimate of waste volumes generated.

- The actual waste that may be generated by implementing an EA may be as much as 10% higher or 25% lower than estimated volumes after treatment, which are provided in the EACBS. This uncertainty is acceptable at this time, as no definitive information is available to provide a more accurate estimate. These estimates should be revisited and revised as more information becomes available.

- The report could benefit by a discussion of other possible impacts on the different DOE disposal systems, not just waste generation.

5.0 SUMMARY OF PEER REVIEW RESULTS

The panel, as a whole, evaluated the reasonableness of the alternatives identification/screening process. The EACBS peer review panel was then divided into three separate subcommittees to assess the validity and reasonableness of the alternatives with respect to the eight factors prescribed in 40 CFR 194. Each factor was evaluated using eight evaluation criteria established in NUREG-1297. This review was based on information provided by the authors of the report and the DOE Carlsbad Area Office; detailed review of the EACBS and supporting documents; and follow-up interviews with the authors of the report. While time did not allow a total evaluation of all the details embodied within the EACBS (e.g., all calculations were not checked), the peer review panel did establish an overall understanding of the process by which it was generated and the fundamental philosophy for its development. The results of this evaluation are summarized in Table 1 and reflect the overall assessment of the EACBS by the peer review panel.

Table 1. Summary of the Peer Review of the EACBS Evaluation Factors and Criteria

Engineered Alternatives Evaluation Factors	A. Adequacy of Requirements and Criteria	B. Validity of Assumptions	C. Alternative Interpretations	D. Uncertainty of Results and Consequences if Wrong	E. Appropriateness and Limitations of Methodology and Procedures	F. Adequacy of Application	G. Accuracy of Calculations	H. Validity of Conclusions
Evaluation of the EA Screening Process	Generally considered to be adequate, although some other potential EAs could have been added.	Evaluation was qualitative and was to assess assurance, not compliance. This assumption was prescribed by law and was therefore considered valid.	None.	The screening process was conservative in nature and was thus more inclusive than exclusive.	The screening process was considered to be appropriate. A better description of the process would have enhanced the report.	The sequence of comparing, scoring, prioritizing, etc. was adequate to achieve the results.	The use of algorithms and professional judgement were deemed appropriate.	The final list of EAs selected for further analysis was reasonable.
1. Long Term Repository Performance 2. Uncertainty in Compliance Assessment	Adequate	Broad Level: Appropriate. Detailed Level: Intrusion scenarios assumed to occur at 5,000 years; and actinide solubility assumptions were conservative. Broad Level: Appropriate; Detailed Level: Uncertainty in creep parameters was not considered. Differences in creep closure estimates could affect the quantity and rates of release; early intrusion could result in significantly different releases; and EAs with plasma processing or clay backfill were not credited with enhanced Pu immobilization.	Different creep closure models or model coefficients may affect the relative benefits of EAs; and the effects of future mining nearby could have been considered as an additional human intrusion scenario.	Uncertainty will result due to the uncertainty of input parameters; however, no severe consequences if wrong; conservative parameter estimates were used. Relative nature of analysis allows meaningful conclusions to be drawn. Discussion of uncertainty in the results does not fully reflect the uncertainty analysis that was in fact carried out.	Use of the DAM model to predict performance was appropriate; however, important advances in creep modeling were not used. Model did not (and cannot) consider stratigraphy (e.g., anhydrite layers) in the mechanical response calculations.	Compressive strengths of waste/backfill EAs is misleading; and intrusion before creep closure not adequately analyzed. Methods used are completely applicable for comparative screening process	Creep rate calculations checked and qualitatively agree.	Effectiveness of some EAs may have been underestimated due to simultaneous consideration of pre-closure and post-closure risks.
3. Worker and Public Risk	Adequate	Risk assumptions are conservative, conventional, and adequate for the work performed.	None.	Uncertainties err on the side of safety and risks are likely overstated.	Methodology did not account for risks inherent in current waste handling methods. For example, relative risks could have been different for these EAs having long development/processing time.	Methods are applicable for the comparative screening process.	Calculations are reasonable and consistent.	Risk conclusions for CH waste appear valid. Risk conclusions for RH waste are absent.
4. Impact on Waste Removal	200 year period for waste removal requires justification; different time frames have a major impact on the methods used for retrieval.	Assumed excavation technology is appropriate, but the data used in the calculations is not state-of-the-art. For long term retrieval, assumptions and methodology used for mining rate and time estimates are correct; quantitative studies are needed. Short term retrieval method, rate, and schedule not addressed.	Alternative methods for recovery based on different time frames could have been performed.	Uncertainty associated with the compressive strength of the EAs is not critical to the relative comparison of EAs. The waste is removable with today's technology and the decisions made based on the EACBS are not irreversible.	Methodology was appropriate to estimate time required for long-term removal; however, some of the assumptions, data, and terminology were not suitable for the application.	Time of waste removal was not adequately addressed.	Overall, calculations could not be checked for accuracy; there is no reference to machine type, specifications, and utilization.	Although the quantitative results of the analysis can not be directly used for assessment of the EAs, the general conclusions based on a qualitative comparison with the baseline are valid and acceptable for long-term removal. Consideration of short-term removal could change the results.

Table 1 (continued). Summary of the Peer Review of the EACBS Evaluation Factors and Criteria

Engineered Alternatives Evaluation Factors	A. Adequacy of Requirements and Criteria	B. Validity of Assumptions	C. Alternative Interpretations	D. Uncertainty of Results and Consequences if Wrong	E. Appropriateness and Limitations of Methodology and Procedures	F. Adequacy of Application	G. Accuracy of Calculations	H. Validity of Conclusions
5. Transportation Risk	Adequate	Risk analysis assumes 20 year active life, yet the WIPP operational window is for 33 to 35 years. Transportation is by truck only, no explanation why rail is not evaluated. Overall, however, risk assumptions are conservative, reasonable and well within contemporary transportation risk analysis.	There is no reasonable alternative interpretation.	Population densities will be different if the period of transportation and disposal is greater than 20 years. An added risk could occur for those EAs which have a longer time frame.	The methodologies were considered to be generally appropriate. Limitations include addressing only CH waste, a "bounding" accident not being evaluated, and lack of justification for selected values. The limitations should not compromise the EA evaluation so long as the 20 versus 35 year issue is recognized.	Methods used are applicable for comparative screening process	Calculations appear to be reasonable and consistent with the methodology.	The conclusions drawn for purposes of a qualitative comparison of the transportation risks of the various EAs appears valid.
6. Public Confidence in the Performance of the Disposal System	Adequate	Assumptions regarding the public's concerns as to content, categorization, timeliness, and affected in-state population are reasonable. Although out of state populations were not addressed, this is not considered to be a major deficiency.	Slightly different interpretations are possible, but would not affect the conclusions of the study.	Uncertainty is low regarding the public's position on the EAs and slight misinterpretations are not considered serious.	The methodology used to assess public confidence was appropriate. A limitation is the lack of opportunity for out of state public comment.	Application of the methodology was considered proper.	Categorization of public comments was checked and determined to be relatively accurate with only minor discrepancies.	The conclusions appear appropriate.
7. System Cost and Schedule	Adequate	Cost and schedule assumptions are considered to be valid with uncertainty of approximately 30 percent associated with the uncertainty of the waste inventories.	A few alternate interpretations may originate from the guidance documents. However, they would have little effect on the study's results.	The estimated costs and schedules were reasonable.	The methodology for cost and schedule evaluation is considered appropriate.	Methodologies were appropriately applied.	Spot checks determined that calculations were performed according to accepted methods and procedures.	In general, the conclusions are valid.
8. Impact on Other Disposal Systems	Adequate	The assumptions of waste type and volume have uncertainties associated with them that may impact other disposal systems. The assumptions used appear reasonable.	The uncertainties associated with waste volume can be interpreted in different ways. Some interpretations will result in higher volumes while others will result in lower volumes.	Uncertainty of results are +10% to -25% based on waste volume uncertainty. No serious negative consequences should occur because of this uncertainty.	Procedures used are technically defensible. A limitation of the methodology is the reliance on the accuracy of waste volume.	The techniques used were adequate to meet the intended goal.	The basis of calculations was not provided in the EACBS; however, using reasonable assumptions, data spot checks were found to be accurate.	The conclusions reached are valid and support the end use of the report.

6.0 OBSERVATIONS AND CONCLUSIONS

In its deliberations during May, June, and July 1996 the peer panel identified that much of the information presented within the EACBS is of high quality and the approach taken is valid with conclusions drawn being reasonable. The peer review panel also noted the following observations and conclusions associated with the EACBS:

- The EA identification/screening process used a multiple step approach that included not only technical considerations, but also a consideration of regulatory constraints and professional judgement. The screening process, although not iterative, was considered to be appropriate.

- The screening process could be designed to be iterative with the factor analysis by including some EAs that could have major impact on results of specific factors (i.e., EAs using different container material such as ceramics/glass could have major impact on waste removal although they did not pass the screening process).

- Had the analysis included radionuclide transport within the Culebra, it is likely that the results would have shown a stronger sensitivity to the time of intrusion (e.g., within a few hundred years).

- Creep closure modeling did not consider uncertainty in creep parameters nor did it incorporate important advances in creep modeling. Different time periods for closure would have likely resulted from such considerations which may have changed the relative ratings of the EAs.

- The effectiveness of EAs with clay backfill or vitrification treatment were underestimated because the enhanced immobilization of actinides within these matrices was not assumed.

- The methodology did not account for risks inherent in current waste handling methods. For example, relative risks could have been different for those EAs having longer development/processing times.

- The costs and schedules identified in the EACBS are adequate and are based on data typically used for similar studies. As cost and schedule information is refined, these data can be revised to reflect current knowledge.

- Uncertainty in waste inventory requires a reexamination as new information becomes available that could influence the decision making process.

- The relative nature of the alternatives comparison decreases the chance that uncertainties in assumptions used in the evaluation process would have an impact on the evaluation results.

- Short-term removal of the waste and backfill (from regulatory closure of the repository to geological closure of the rooms) was not considered. Had short-term removal scenarios been considered, the results of relative comparison could have been different.

- Public confidence could have benefited from involvement of the public from states neighboring New Mexico and those that plan to ship waste to WIPP. Although this involvement was not evident in the EACBS, it was not felt to be a significant issue that would have substantially altered the results.

- With respect to the adequacy of requirements and criteria, the panel members agreed that these were prescribed by regulation for most of the factors and was, therefore, beyond the scope of their review.

- The EACBS focused on evaluating measures that exceed compliance and are added assurance of performance beyond the baseline requirements. The major consequence of implementing an alternative based on a slightly incorrect evaluation is probably the expenditure of greater dollars than necessary and the addition of more time to implement the alternative. Safety is not impaired.

- To maximize the usefulness of the EACBS it will either need to be revised or certain sections (such as waste volume information) will need to be updated. This document can assist all DOE sites with their planning so it will be helpful to share the report across the complex.

- Some discrepancies are noted regarding waste volumes and the methodology used to evaluate Factor 8 (impact on other disposal systems). This confusion should be resolved in the future.

- Factor 8 only analyzed the impacts on other waste disposal programs. It would be beneficial to consider the DOE complex as a whole where additional impacts may be felt.

- Remote-handled waste was not considered. This issue may have implications to the compliance application.

APPENDIX A

M

Biographic Sketches of

Peer Panel Members

and Staff

APPENDIX A

SHORT BIOGRAPHICAL SKETCH OF PEER PANEL MEMBERS AND STAFF

D.1 Peer Panel Members

AIMONE-MARTIN, Catherine T. - Dr. Aimone-Martin received her BS degree in Geological Engineering from Michigan Tech and a PhD from Northwestern University in Mineral Resources Engineering and Management and Civil (Geotechnical) Engineering. She is currently Associate Professor and Department Chair of the Mineral and Environmental Engineering Department at New Mexico Institute of Mining and Technology in Socorro, New Mexico. Prior to joining New Mexico Tech in 1981, Dr. Aimone-Martin worked in the Canadian mining industry as a geological engineer evaluating ore reserves and mine planning options for an Ontario iron ore mine and a British Columbian copper mine. She further worked as a Geotechnical Engineer for Golder Associates in Seattle on geophysical exploration projects involving uranium and coal in South America. While working for STS, Ltd. in Chicago, she assisted project managers in foundation design and analysis and field quality control for large construction projects. While at New Mexico Tech, she was co-founder and Research Engineer of the Center for Explosives Technology Research. Dr. Aimone-Martin worked with Los Alamos National Labs, as a Lab Affiliate on shock attenuation experiments and seismic wave analysis (1983-1994). She served as Director of the State Mining and Mineral Resource Research Institute (1989-1994) and is currently a member of the U.S. National Committee for Rock Mechanics with the National Academy of Sciences. She instructs in the areas of laboratory and field assessment of rock and soil properties and behavior, instrumentation, applied mechanics and design of earth structures, geochemical evaluation of ore deposits, and numerical methods. She has co-authored numerous publications and has made presentations in the areas of rock mechanics, explosives engineering and structural response to blasting vibrations.

BHADA, Rohinton (Ron) - Dr. Bhada received his BS, MS and PhD degrees in Chemical Engineering from the University of Michigan and earned an MBA in Management from the University of Akron. He joined New Mexico State University as Department Head of Chemical Engineering in 1988 and currently holds the academic title of Associate Dean of Engineering at NMSU. He also directs the Waste-management Education and Research Consortium (WERC). For the 29 years before joining NMSU, Dr. Bhada held various positions at the Babcock and Wilcox Company and worked primarily in the areas of pollution control and energy conversion. In the early years of his career, his work was directly in research related to the above areas and resulted in many publications and new inventions, including a patent in the remediation area. In the later years at Babcock and Wilcox, he managed the New Products and Advanced Technologies Department. His professional activities include active work for the American Institute of Chemical Engineers, the American Academy of Environmental Engineers, the

American Society of Engineering Education and the National Society of Professional Engineers. Dr. Bhada is a registered professional engineer and was recently awarded the title of Diplomate of the American Association of Environmental Engineers. He is the author of over 100 papers and publications in the fields of energy conversion, thermodynamics and environmental engineering. He is also the co-editor or contributor to several textbooks in the area of environmental management and technology transfer.

DURAN, Arturo - Mr. Duran received his MS and BS degrees in Chemical Engineering from the New Mexico State University located in Las Cruces, NM. Mr. Duran has seven years of environmental professional experience as a private consultant and as a project manager with the Environmental Protection Agency (EPA). Mr. Duran's environmental expertise includes environmental management, environmental regulations, soil and ground water remediation, mixed waste treatment and disposal, hazardous waste management, and waste water engineering. Mr. Duran has worked as a project manager on more than 50 environmental projects including site investigations, feasibility studies, landfill closure, remedial design, construction and operation of groundwater and soil treatment systems and permitted RCRA storage, treatment and disposal facilities. Mr. Duran served as a member of the mixed-waste working group for the Western Governors' Development of On-Site Innovative Technologies (DOIT) Initiative. Mr. Duran has also participated in several expert panels regarding risk management and mixed waste treatment and disposal. Mr. Duran is coauthor of publications on Ion Exchange and Adsorption Processes.

KUHNS, Douglass J. - Mr. Kuhns received his BS degree in Geology and MS degree in Safety Science from the Indiana University of Pennsylvania. He is currently an advisory scientist/engineer for the Lockheed-Martin Idaho Technologies Corporation at the Idaho National Engineering Laboratory, which he joined in 1989. At the Idaho National Engineering Laboratory Mr. Kuhns has held a number of various positions in the environmental restoration/waste management arena. Some of his most interesting projects include the intrusive characterization and assessment of a mixed waste liquid disposal pit; an evaluation and recommendation concerning reported significant quantities of buried mercury; considerable effort on the assessment, treatment, storage, disposal, waste management, and characterization of buried mixed waste; preparation of a comprehensive plan to assess and remediate buried mixed waste tanks; a variety of remedial actions ranging from soil vapor extraction to landfill capping; and substantial effort with the Department of Energy's Technology Development office. He is also frequently involved in strategic planning initiatives designed to prepare the environmental restoration program for the future. Mr. Kuhns currently holds the Associate Safety Professional designation and is a member of the American Society of Safety Engineers. He is responsible for providing program and project management expertise, technical direction, supervision, leadership, and guidance for a number of environmental restoration projects where he frequently interacts with state and federal agencies.

LEWIS, Cindy - Ms. Lewis received her BS in Chemical Engineering from the University of Maryland. She is certified in Comprehensive Practice by the American Board of Industrial Hygienists. She is currently acting as a Chemical Engineer and Risk Assessment Specialist in the Mobile, Alabama office of Parsons Engineering Science, Inc. She previously managed the Environmental Safety and Health Department for Smith Environmental Technologies Corporation and acted as Risk Assessor under subcontract to the Department of Energy at the Grand Junction Project Office. Ms. Lewis has provided guidance and technical support for risk assessments conducted as part of environmental restoration efforts conducted under authority of RCRA and CERCLA for DOE (INEL and Savannah River) and DOD (Westover AFB, Plant PJKS, O'Hare AFB, Plant 36, and Redstone Arsenal). In addition, Ms. Lewis has developed methods and conducted occupational exposure risk assessments for a variety of industrial applications.

NAVRATIL, James D. - Dr. Navratil received his BA, MS and PhD degrees in Chemistry from the University of Colorado, Boulder, CO. He is Chief Scientist with Rust Federal Services and has more than 25 years of waste management and waste treatment experience. He has extensive experience with radioactive, hazardous and mixed wastes, actinide chemistry and radionuclide solubilities. His experience was mainly acquired at the US Department of Energy's Rocky Flats Plant, but he has also spent significant time with the International Atomic Energy Agency, DOE's Energy Technology Engineering Center and Chemical Waste Management's Geneva Research Center. Dr. Navratil taught chemical engineering and extractive metallurgy subjects at The University of New South Wales, Australia from 1987 to 1990. He has more than 200 publications, including several patents and 20 books, to his credit. He is a member of the American Chemical Society, the American Institute of Chemical Engineers and Sigma Xi, a Fellow of The Royal Australian Chemical Institute and of the American Association for the Advancement of Science.

ROSTAMI, Jamal - Mr. Rostami received his BS in Mining Engineering from faculty of engineering of the University of Tehran in 1987. He received his MS in the department of Mining Engineering of the Colorado School of Mines (CSM) in 1991. He is currently a senior research associate at the Earth Mechanics Institute (EMI) while preparing to defend his PhD thesis in the Department of Mining Engineering. He joined CSM in 1989 and started working at EMI in 1990. Prior to joining CSM, he worked at various capacities in Iranian Institute of Mineral Research and Application in the field of mineral processing. He has affiliations with several professional societies in the field of mining and tunneling. Presently, he is chairman of publication of mechanical mining unit committee of the Society of Mining Engineers (SME). His area of interest and expertise includes mechanical excavation, machine design and selection, cutterhead layout and design optimization, performance prediction and analysis, mechanized mining, underground mining of coal, industrial mineral, and hard metallic rock, micro-tunneling and trench-less technology, geotechnical testing and exploration, feasibility study, and surface mining. He has

made several presentations, given many lectures, and taught in several short courses. He has been project manager and principle investigator on several projects and has a number of reports, as well as several papers, in conference publications and journals.

SMITH, Dennis, M. - Mr. Smith received his BS degree in Environmental Health from Colorado State University (1976) and his MS in Environmental Chemical Hazard Analysis (1990) from the University of Pittsburgh. Completion of his ME in Engineering Management from the University of Colorado is expected in 1997. He is currently president of Technical & Management Systems & Services Inc,. an environmental management consulting firm in Littleton, Colorado. Mr. Smith's background includes nearly 20 years of progressive environmental science and engineering highlighted by 13 years in the hazardous waste industry. For three years (1990 - 1993) Mr. Smith was manager of risk and remedial action analysis for the DOE's environmental restoration program at Rocky Flats. In that position he was responsible for overall risk assessment and risk management activities for environmental remediation programs. In addition, he has spent nearly 11 years in the environmental consulting industry. Mr Smith is a board certified industrial hygienist with extensive experience in the fields of occupational safety and health, and radiation protection. Major areas of Mr. Smith's expertise include: human and ecological risk analysis, cost-benefit evaluation, remedial action assessment and strategic regulatory consulting. Mr. Smith has participated in third party reviews, technical and managerial oversight, and independent consulting for numerous clients.

WAHI, Krishan K. - Dr. Wahi received his BS, MS and PhD in Mechanical Engineering from the University of Washington. After completing his PhD in 1974, he joined Physics International Company as a Senior Physicist and participated in hydrodynamic code development and simulation of ground motion due to thermonuclear blasts and projectile penetration. From 1975 until 1986, he worked as a Senior Engineer and a manager at Science Application International Corporation. Since February, 1986, Dr. Wahi has been the President/Owner of GRAM, Inc., providing waste management and environmental restoration consulting and support services. He has 20 years of experience in nuclear waste management, specializing in geomechanics, numerical modeling, performance assessment of geological repositories and coupled processes. He has served on several expert panels on topics related to the management of nuclear waste. His PhD work focused on mechanics of head injuries and fragility of brain tissue. Dr. Wahi's past work includes development and application of salt creep models, performance assessment methodologies, thermomechanical response, and dynamic structural response calculations. He is a member of the American Society of Mechanical Engineers, International Society for Rock Mechanics, and Sigma Xi, and serves on the advisory board of Waste-management Education and Research Consortium. He is the author or co-author of more than fifty technical papers, book articles, and reports. He was a 1996 nominee for the New Mexico "Small Business Person of the Year" award.

D.2 Peer Review Staff

CARLSON, Timothy J. - Mr. Carlson received his BS in Civil Engineering and MS in Environmental Engineering at Arizona State University and is a registered Professional Engineer in Colorado. He has more than twenty years experience in the environmental cleanup arena working in the private sector with various states, EPA regions, and Federal agencies (DOE, DOD, Corps of Engineers, and the National Park Service). Mr. Carlson's projects have included the planning, design, construction management, and operation assistance for numerous waste treatment systems under the regulatory authority of the Clean Water Act and CERCLA. As a Principal Scientist for RUST Geotech Inc. at the Grand Junction Projects Office, work on DOE projects has included several CERCLA actions that have lead to Records of Decisions; DOE Headquarters support on the identification of needs for the Environmental Restoration Program and the relationship of technology efforts to meeting those needs; and the development and coordination of a comprehensive implementation program for several innovative treatment technologies. Another aspect of Mr. Carlson's capabilities has been the organization and performance of high level peer reviews of environmental technologies. These included an overall assessment of existing technologies for DOE's radioactive and mixed-waste problems, molten salt oxidation for the treatment of organic wastes, and a proprietary Russian technology for the separation of cesium and strontium from high-level wastes. Mr. Carlson has participated on two peer panels which evaluated the technology options for treating mixed waste at Los Alamos National Laboratory and at the Savannah River Site.

CUMMINS, Laura E. - Dr. Cummins received her MS and BS degrees in Geology from Bowling Green State University and her PhD at Florida State University in Geology. She is a registered professional geologist in the State of Florida and a member of the Geological Society of America. Dr. Cummins is currently a Principal Scientist for a Department of Energy contractor in Grand Junction, CO. In her work for DOE she has served in a key role on a number of projects related to furthering the use of innovative environmental technologies. She has been involved in the development of publications, databases, videotapes, and other types of information dissemination mechanism. Dr. Cummins worked for several years in a technical support/oversight role for the environmental restoration program at the Idaho National Engineering Laboratory. Prior to her work for the DOE, Dr. Cummins served as a hazardous waste cleanup project manager for the State of Florida where she was responsible for cleanup of Superfund and state-funded sites. In addition, she worked as a project manager in Florida's underground storage tank cleanup program. Dr. Cummins' experience also includes two years as an assistant professor of geology at Angelo State University in San Angelo, TX, where she was responsible for teaching upper level undergraduate courses in mineralogy, structural geology, petrology, and optical mineralogy.

GHASSEMI, Abbas - Dr. Ghassemi received his BS from the University of Oklahoma and his MS and PhD in Chemical Engineering from New Mexico State University in Las Cruces, NM. He has more than 15 years of industrial, academic, chemical, and environmental hands-on engineering experience. Dr. Ghassemi is an Associate Professor Chemical Engineering and is the Liaison Technology Officer and Associate Director of the Waste-management Education and Research Consortium (WERC). Over the past four years, Dr. Ghassemi has been responsible for managing the following WERC programs: Industrial Affiliates, Summer Environmental Design Institute, International Environmental Design Contest, outreach, technology transfer and demonstration, new business development and new technology development programs. Prior to joining NMSU, Dr. Ghassemi compiled extensive experience in technical and marketing management, process control, process operation and optimization by more than ten years of employment at Fisher Controls International and Monsanto Company. He has extensive experience in the environmental field including pollution prevention, waste management, environmental remediation, and technology identification. He has served as technical expert in several environmental litigation cases as well as technical peer review panels and international training projects in the environmental health and risk assement fields. He is the author of more than 75 papers and publications in the fields of process control, thermodynamics, environmental engineering and education. He is also co-editor and contributor to several textbooks in the area of environmental technology and management.

NOLEN, Mark R. - Mr. Nolan received his BBA degree in accounting and his MBA in planning and policy from the University of New Mexico, Albuquerque, NM. He is currently a fourth-year doctoral student studying management at New Mexico State University , Las Cruces, NM. Mr. Nolan's facilitation experience includes training and coordinator roles in the installation of financial management information systems in healthcare, state government, and electric utility industries. He has been a part-time instructor at the University of Phoenix, Albuquerque, NM and Santa Teresa, NM campuses for eight years in the areas of strategic management and business research. As a doctoral graduate assistant, he teaches introductory management and human relations courses.

APPENDIX B

Peer Review Meeting

Minutes

Meeting Minutes
WIPP EACBS Peer Review
Session 1, May 7-10, 1996

May 7, 1996

Introduction of peer panel members, EACBS staff who participated in the production of the report, and the WERC peer review management staff (see attached list).

Review of agenda (attached)

Orientation and training consisted of:

- Scope of the peer review; what is intended to be accomplish and what it is not intended to be a part of the process
- Duties of the peer panel
- Roles of the performers of the work
- Roles of observers
- Roles of the peer review management
- *CAO EACBS Peer Review Plan*
- Collection of *Peer Review Panel Member Independence Forms*
- Collection of *Peer Review Panel Member Verification of Education/Employment Forms*
- Collection of *Peer Review Panel Training Forms*
- James Maes, CAO/DOE, provided an introduction of the WIPP EACBS and the peer review process.
- Jonathan Myers, IT Corporation, presented information on the
  - History of the Waste Isolation Pilot Plant
  - Regulations
  - WIPP Waste Inventory
  - Engineered Alternatives Task Force
- Steve Wagner, Westinghouse - Waste Isolation Division, presented information on
  the WIPP facility description

May 8, 1996

Orientation and training continued with

- Mark Crawley, IT Corporation, providing information on
  - Extent of drilling activities
  - Geophysical surveys
  - Hydrologic investigations
  - Isotope studies
  - Resources evaluation
  - Environmental monitoring activities

Changes amended to meeting minutes
underlined in red.

May 8, 1996 continued

- Steve Wagner, Westinghouse, presented information on
  - EACBS technical approach
- Jonathan Myers, IT Corporation, presented information on
  - Design analysis model
- James Maes, DOE/CAO, wrapped up the orientation and training session.

Following the orientation and training portion of the peer review, discussion centered on the process for identifying engineered alternatives and the screening process for reducing the original number from 111 to 18 found in the EACBS. Issues raised by the peer review panel included a need for the EACBS to better clarify the process for (1) how the initial alternatives were identified, (2) how they were subsequently reduced to 53, (3) how Westinghouse narrowed the list to 14, and (4) how DOE finalized the list at 18. The peer panel was not in disagreement that the process likely resulted in a good range of alternatives, but rather felt that the EA Task Force might have been in a better position to reduce the list from 53 to 14. James Maes, DOE/CAO, provided additional clarification of how the screening process worked which helped the panel members better understand the process.

James Maes, DOE/CAO, identified that the RCRA application includes the use of MgO as the preferred engineered alternative. Although MgO was not included in the EACBS, DOE considers the engineered alternatives using CaO as representative of a classification of stabilization alternatives. The peer panel suggested that any revision to the EACBS include this specific alternative since it is the preferred choice. James Maes indicated that DOE/CAO would be willing to amend the EACBS to reflect recommendations of the peer review panel.

May 9, 1996

James Maes, DOE/CAO, presented an overview of each of the 8 evaluation factors used in the EACBS.

Discussions lead by Ron Bhada, peer panel leader, centered on the format for the peer review report as described in the *CAO EACBS Peer Review Plan*. It was agreed that subcommittee reports should closely follow this same format. Subcommittees were established for reviewing the 8 different evaluation factors with reviewers divided by expertise that appeared most appropriate for each set of factors. The subcommittee are:

- Long term repository performance and uncertainty in compliance acceptance - Jim Navratil, Krishan Wahi, and Cathy Aimone-Martin.

- Worker and public risk, impact on waste removal, and transportation risk - Jamal Rostami, Cindy Lewis, and Dennis Smith.

- Public confidence, system cost and schedule, and impact on other disposal systems - Arturo Duran, Doug Kuhns, and Ron Bhada.

Subcommittees broke up into their separate groups, reviewed specific areas of responsibility, and

May 9, 1996 continued

the approach they intend to take. Following these discussions, the peer panel reconvened and discussed the process they are proceeding with. Two of the evaluation criteria were further discussed with the following general guidance agreed upon:

- Adequacy of Requirements and Criteria - Requirements are generally prescribed by 40CFR194 and other requirements for the peer review under NUREG1297. As such, these requirements cannot be evaluated and will be so stated.

- Accuracy of calculations - It was apparent that there is insufficient time to check all calculations; therefore, calculations will be checked for accuracy by performing spot checks on selected calculations, determining if computer models and codes were verified, determining if QA was performed, and checking results for order of magnitude variability. Subcommittees will identify which areas of the EACBS require additional explanations by DOE or its contractors for the next peer review meeting.

An additional evaluation criteria (General Comments) may be used by the subcommittees to document concerns/issues that the prescribed criteria do not cover.

The agendas for the next two meetings was agreed upon (attached).

May 10, 1996

A tour of the WIPP facilities was provided by DOE.

Peer Review Session 1
END

Approval of minutes as amended

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MINUTES - WIPP EACBS PEER REVIEW MEETING; MAY 29-31, 1996

Wednesday, May 29

All peer review panel members were in attendance at this meeting, as were representatives from IT, Westinghouse-WIPP, and DOE-CAO. In addition, several observers were present. The meeting began with introductions and brief review of observer protocol. Panel members were asked if there were any general issues that needed discussion. It was noted that some of the terminology used in describing the screening process might be misleading. The term "optimization" was said to be particularly misleading in that it was conducted using many of the same criteria as the initial screening.

Following general discussion, each subcommittee reported on where it stood in terms of the review process. Some general concerns were also noted at this time. In general, all groups felt that they had made good progress since the orientation meeting and that they could have a substantially complete report prepared by the end of the present working meetings. All subcommittees reported the need to seek additional clarification and information from the report preparers.

Each subcommittee provided an overview of the general findings of its evaluation to date. The subcommittees are designated as follows:

- Group 1 - Factors 1 and 2. Cathy Aimone-Martin, Krishan Wahi, James Navratil
- Group 2 - Factors 3, 4, 5. Jamal Rostami, Cindy Lewis, Dennis Smith
- Group 3 - Factors 6, 7, 8. Ron Bhada, Arturo Duran, Doug Kuhns

Some issues raised by Group 1 included

- The adequacy of requirements and criteria are largely prescribed and are essentially a non issue in the evaluation of the EAs. The other subcommittees agreed on this point.
- There is some question about what level of detail to use in determining validity of assumptions. The group has both higher level and more detailed information. They will try to take a systems approach in their evaluation. IT noted that some of the assumptions made were selected to be consistent with the performance assessment being conducted by Sandia National Laboratory in Albuquerque and that those assumptions were external to their control. The suggestion was made to concentrate on assumptions made internal to EACBS preparers.
- The question was raised about how to deal with requirements of 40 CFR 194, which were not in place at the time the EACBS was in preparation (e.g., the waste retrieval scenario). A supplement to the report will probably be recommended to deal with these issues.
- The group felt that the relative comparison of alternatives in the report appears to be valid. However, some items need clarification. The group will focus on those during the working session this week.

Group 2 also felt that the report was generally done according to acceptable protocols. It was felt that the risk assessment portions of the report were conservative and health-protective. Among the concerns raised by this group were

- 40 CFR 194 requires that waste retrieval be evaluated. The concern was expressed that all the EAs involve disposal of wastes in steel drums. The statement was made that the evaluation of the retrieval scenario would be much different if the EACBS had included alternatives that used material other than steel for the waste drums.
- The point was made that evaluation of chemical transportation risks were dependent strictly on wasteform and that transportation probability issues (e.g., miles travelled) were not considered.

Group 3 distributed preliminary drafts of its evaluation results. In general the group felt that reasonable, accepted methods were used in assembling information on factors 6, 7, and 8. Some points that were made during this group's discussion include

- The fact that the EACBS uses a relative comparison of alternatives, not an absolute evaluation, reduces the effect that uncertainty in the evaluation process might otherwise have.
- The focus of the group was on major assumptions, not the more numerous smaller ones.
- The EACBS contains much detail. It would be easier to use if some "big picture" tables were used to summarize the information in an easy manner.
- The report used the best available information. Some of this information will change, however, and provision should be made to take this into consideration up until a decision regarding the use of EAs is made.

The peer panel broke into subcommittees to continue work on their reports.

The committee reconvened at the end of the day for general discussion. Points raised included:

- the distinction between EAs that focus on pre-closure versus post-closure measures
- the role of remote-handled waste in the evaluation of performance (IT explained that RH waste makes up only 7% by volume of total and that after a few 100 years, it would decay sufficiently to be indistinguishable from contact-handled wastes)
- If groups need more time to prepare their reports, it can be worked into the schedule. A quality product will not be sacrificed just to meet an interim deadline.

Minutes of the first peer review meeting were distributed for review by the panel members. Sucommittees were each requested to prepare brief subcommittee minutes to document their working meetings.

Thursday, May 30

The group met as a whole to review the previous meetings minutes. Changes were noted. The

panel review leader, Ron Bhada, noted that subcommittees would probably come across things in their review that were notable, but beyond the scope of their task. He suggested listing these separately from the subcommittee report; these items will be submitted to DOE in a separate letter report.

The panel broke into subcommittees to work on their reports.

In the afternoon caucus session, the issue of dissenting opinions was raised. It was determined that the dissenting opinions would be based on the review of the report in its entirely; discussion regarding dissenting opinions would therefore take place during the next panel meeting in July.

Friday, May 31

Groups continued to meet to produce draft reports. The entire committee was convened for a final time to bring up any final points. A question was raised as to whether any subcommittee had identified issues that might affect other subcommittees. IT made the point that waste inventory and volume reduction figures probably figure into all groups and that this might be something to consider in review of the peer review report. The issue was also raised about whether there should have been some interaction between the screening process and the evaluation of alternatives against the eight factors. The opinion was expressed that this might have had an impact on the selection of alternatives for detailed analysis. IT noted that an attempt was made to include alternatives that spanned the range of variables involved and that they tried to be as inclusive as possible, considering the time and money allotted.

Each subcommittee turned in a draft report before departing the meeting.

QA Surveillance

Surveillance of the peer review process was conducted by representatives of DOE's Quality Assurance Office, the USEPA, and EEG. Minor findings were noted and corrective action taken.

July 9, 1996
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MINUTES - WIPP EACBS PEER REVIEW MEETING; JULY 8-10, 1996

Monday, July 8

The objective of this three day session was to finalize the Peer Review document with approval by all panel members of the final report on July 10, 1996. The meeting centered on additional comments provided by the peer panel members on the June 26th version of the report (Rev. 1). This report had received an earlier review by the peer members that was sent to them as a June 7 version (Rev. 0). Following receipt of comments the report was revised for further comment.

Tuesday, July 9

The panel members received and reviewed the Rev. 2 version of the peer review report (July 8) and made additional comments. These comments were subsequently incorporated into the report as Rev. 3 on July 9.

The panel members discussed a letter received from the EEG concerning the EACBS and the peer review. The panel members determined that it would be appropriate for Dr. Bhada, the panel chair, to write a written response explaining that the contents of the letter from EEG were beyond the scope of work that the peer panel was directed to perform. The issues raised are more appropriately directed to the regulatory agencies responsible for permitting the WIPP facilities.

Wednesday, July 10

Final comments to the Draft Peer Review report (Rev. 3, July 9) were made by the peer members and incorporated into the final document. The final document was completed and signed by the peer panel members as being complete and accurate.

P.M. [illegible] July 10, 1996

[illegible] 7-10-96

[illegible] 7-10-96

R.K. Bhada 7-10-96

[illegible] 7/10/96

[illegible] 7/10/96

[illegible] 7/10/96

James O. Naumann July 10, 1996

[illegible] July 10, 1996

APPENDIX C

Committee/Subcommittee

Reports

APPENDIX C-1

PANEL REPORT ON EVALUATION OF THE SCREENING PROCESS

C-1.1 Description of the Identification/Screening Process

The first task of the EACBS peer review panel was to evaluate the identification and screening process that was used in generating the list of 111 initial engineered alternatives (EAs) and in reducing these potential alternatives down to the 18 that were considered for detailed evaluation. The identification of initial EAs was drawn from a consideration of multiple sources. The initial list of 111 comprises

- 64 individual EAs from the 1991 Engineered Alternatives Task Force Final Report
- 14 combination and 1 baseline from the 1991 Engineered Alternatives Task Force Final Report (DOE, 1991a)
- 20 EAs considered by Sandia National Laboratories for System Prioritization Method
- 10 EAs listed by the EPA in 40 CFR 194, section 194.44(b)
- 2 EAs added during the subsequent screening process

The screening was conducted using a multiple-step process that included not only technical considerations, but also a consideration of regulatory constraints and professional judgement. In the initial screening phase each alternative was evaluated to determine if it met the definition of an "engineered alternative" as defined by 40 CFR 191. Additionally, EAs were compared against two "must satisfy" criteria —regulatory compliance and technical feasibility —to determine if these criteria could be met. EAs failing to meet the definition or the must satisfy criteria were dropped from further evaluation. The evaluation process was conducted by an independent Engineered Alternatives Screening Working Group (EASWG); the EASWG reduced the initial 111 alternatives to a total of 53.

In the next phase of the screening process, a small number of WIPP Westinghouse engineers "optimized" and "prioritized" the remaining 53 EAs based on the following:

- effectiveness for specific factors (gas generation, solubility, permeability, human intrusion consequences)
- overall effectiveness
- feasibility for each factor
- "technological merit"
- overall feasibility

This evaluation was made using the results compiled by the EASWG in their scoring of the alternatives for feasibility and effectiveness along with some of the same evaluation criteria used in the initial screening process. This part of the screening process also involved the use of

professional judgement. The process was limited by constraints on time and funding available. Some of the 53 EAs were combined to form a subset of the final EAs. Of the 53 alternatives entering the process, 14 EAs were submitted to DOE-CAO and recommended for continued evaluation.

DOE-CAO further refined the Westinghouse recommendations based on the following:

- the most important performance parameters (gas generation was no longer considered critical)
- feasibility of implementation
- addressing all EPA technologies specified in 40 CFR 194
- conflicts with other permit applications and positions

Using these considerations, the DOE dropped some of the EAs and added several others. Upon conclusion of the screening process, 18 EAs remained for a cost/benefit evaluation, that was conducted in the EACBS.

C-1.2 Description of the Peer Review Panel Screening Process Evaluation

In preparation for review of the screening process, members of the peer review panel read the section of the EACBS report that detailed this process (section 2.0). Authors of the EACBS report and other participants in the screening process made presentations to the panel on how the process was conducted. The panel understands that a supplement to the EACBS will be prepared by the DOE that will also provide additional information on the screening process. Discussions between the presenters and panel members followed until everyone adequately understood how the screening process was carried out. Results of the peer panel review are listed below according to the review criteria.

C-1.3 Adequacy of Requirements and Criteria

- Panel members agreed that use of the definition of an EA and technical/regulatory acceptability were reasonable for the initial screening to reduce the 111 EAs to 53.

- Panel members were in agreement that the additional performance criteria applied to the 53 EAs to reduce them to 14 was reasonable. Use of EASWG evaluation results was appropriate.

- Panel members agreed that DOE used appropriate criteria to modify the 14 EAs to the final 18. They felt it was justified for DOE to use additional non-technical criteria, such as conflicts with other permits, in this process. It was also appropriate to ensure that all technologies specified by EPA in 40 CFR 194 were included. As a general note, for the

DOE-CAO part of the screening process, it was felt that "other permit applications and positions" could be better explained in the EACBS report.

- Panel members agree that criteria used in identifying the initial 111 EAs were appropriate.

C-1.4 Validity of Assumptions

- The evaluation was designed to be qualitative and was to assess assurance, not compliance. These conditions were prescribed by law; as such, the panel members agreed that they were valid.

C-1.5 Alternate Interpretations

- The panel members did not identify a reasonable alternate interpretation that could have been developed through the screening process.

C-1.6 Uncertainty of Results and Consequences if Wrong

- During the screening process, a conscious attempt was made to ensure that the final list of EAs spanned the range of possible options based on technology types represented, implementation costs, and other pertinent factors. Having a diversity of alternatives for final evaluation decreases the amount of uncertainty associated with the screening process and ensures that the impact of any error made through the process has a minimal impact on the overall results. The process, in fact, turned out to be a conservative one. After final evaluation of the 18 EAs, some alternatives that had appeared to be promising turned out to be unsatisfactory. Thus the process was more inclusive than exclusive. Therefore negative consequences were not a significant concern.

C-1.7 Appropriateness and Limitations of Methodology and Procedures

- The panel agreed that the process of screening the 111 to 53 EAs was appropriate, using a multidisciplinary EASWG. Panel members felt that members of the EASWG were qualified to perform the analysis. It was felt that the application of the screening criteria and the scoring process was also appropriate.

- In screening EAs from 53 to 14, the panel generally felt that the process used was appropriate (using additional performance criteria and combining alternatives). While qualified individuals conducted this part of the screening, the panel thought that it might have been more appropriate if this screening has been done by the EASWG.

- The panel felt that it was appropriate for the DOE to modify the recommended 14 alternatives to the final 18. The DOE had specific insight and knowledge of other factors (than those used in initial screening phases) to adjust the final list accordingly.

- As a general note, the panel felt that the screening process was not clearly spelled out in the EACBS report and that the description of this process could benefit from some additional clarification and modification.

C-1.8 Adequacy of Application

- The panel felt that the application of criteria used in the screening process was appropriate for each phase of the process. The sequence of comparing, scoring, prioritizing, etc., was adequate to achieve the desired results (i.e., a list of suitable alternatives for further evaluation).

C-1.9 Accuracy of Calculations

- Part of the process required the use of algorithms that appeared to be adequate for the process objectives. Part of the process was based on professional judgement rather than quantitative techniques; the panel deemed this to be appropriate.

C-1.10 Validity of Conclusions

- There was general agreement among panel members that the final list of EAs selected for further analysis was reasonable. No obviously feasible alternatives were omitted and no clearly inferior alternatives were retained. While panel members admitted that the initial starting list of EAs was not all-inclusive, there were no signficant misgivings about the final results.

C-1.11 General Note

As described in the EACBS, the identification/screening process is not clearly documented. There is also confusion in some of the terminology used (e.g., "screening," "optimization," "prioritization"). In order that the process is well understood, it is recommended that clarification be added to the report, particularly to describe how the EAs list went from the 53 recommended by the EASWG to the 18 evaluated in the EACBS report.

APPENDIX C-2

REPORT OF SUBCOMMITTEE 1

FACTOR 1 - LONG TERM REPOSITORY PERFORMANCE

FACTOR 2 - UNCERTAINTY IN COMPLIANCE ASSESSMENT

C-2.1 Scope and Tasks of Subcommittee

The subcommittee was assigned the tasks of evaluating the EACBS using the criteria specified in 40 CFR 194 for the study of Factors 1 and 2. Factor 1 analysis involved the long-term performance of the disposal system for selected Engineered Alternatives (EAs) relative to the baseline performance. The Design Analysis Model (DAM) computer simulation program was used to predict the changes in performance in terms of a measure of impact that each EA had on the release of radionuclides into the surface and groundwater environments for three human intrusion scenarios. Factor 2 analysis dealt with the consideration of uncertainties of the DAM input parameters as well as the propagation of uncertainties in the results. Engineered alternatives that were considered consisted primarily of combinations of various waste processing and backfill types. One series of alternatives (Alternatives 77a through 77d) also considered a variation of the emplacement room height. The DAM code considered coupled processes of creep closure, brine inflow, gas generation and the migration of radionuclides. Parameters considered in the DAM for each alternative further included the porosity and permeability of the waste/backfill, rates of brine inflow, waste/backfill shear strength, and radionuclide solubility.

The three scenarios of human intrusion included drilling a borehole through the repository into a pressurized brine pocket (E1), drilling a borehole to the base of the repository (E2), and a combination of E1 and E2 scenarios (E1E2). The same three scenarios have been considered in SNL's performance assessment.

Radionuclide releases were computed for each case and the impact was expressed in terms of a "Measure of Relative Effectiveness" (MRE) which represents each EA's impact relative to the baseline. This MRE is a measure of the magnitude of the reduction or increase in releases for the three intrusion scenarios with respect to the baseline disposal system design.

Members of the Subcommittee reviewed the EACBS and related documents pertaining to the methodology, procedures, assumptions and the results of their collective application made in the preparation of the Study. Further, members conducted discussions with representatives of Westinghouse, DOE, International Technology (IT) Corporation and others to interpret and clarify points made in the document.

This report summarizes the review conducted by the Subcommittee with regard to the assumptions, methodologies and procedures, applications, interpretations, results and consequences and validity of conclusions of the study.

C-2.2 Adequacy of Requirements and Criteria

The requirements and criteria for the study are prescribed by regulations and, as such, judging their adequacy is beyond the scope of this review. The requirements set forth by 40 CFR 194 specify that the applicant must consider EAs for the purpose of providing additional assurance in the performance of the waste disposal system. Specifically, Section 194.44, "Engineered Barriers," states that in selecting any engineered barrier(s) for the disposal system, the DOE shall evaluate the benefit and detriment of engineered barrier alternatives. The study was performed in strict conformance with criteria and requirements (as prescribed) and satisfies the objective of the regulation.

C-2.3 Validity of Assumptions

The Subcommittee considered assumptions of the analysis on two levels. On one level, assumptions were evaluated from a broad perspective and involved the processes considered in the model and the performance measure for representing and comparing radionuclide releases. The second level involved specific details used in computations such as ranges and distributions of input parameters to the model.

C.2.3.1 Broad Level, Factor 1

The subcommittee felt that the approach taken to parallel the Sandia National Laboratories (SNL) Performance Assessment (PA) was appropriate. The advantage of this approach is that the results are expected to be on the same scale as, and comparable to, the PA. Similarities are drawn in the conceptual models, input parameters, and to the human intrusion scenarios. The primary differences between this study and the SNL PA approach are:

- In the EACBS, radionuclide releases are predicted as flux into the Culebra Formation, and transport within the Culebra is not modeled. By contrast, the SNL PA considered transport within the Culebra and predicted integrated releases at the accessible environment.

- The SNL PA only dealt with the baseline design and did not consider engineered alternatives. Further, the DAM processes that were simulated are "coupled". These processes include gas generation, brine inflow, radionuclide migration and creep closure.

- Representation of processes and repository geometry are considerably more simplified in the EACBS when compared to the SNL PA.

Simplifying assumptions made in the analysis of many processes (e.g., modeling creep with a function fit to empirical creep data and excavation geometry) are valid within the context of the EACBS report in that relative, not absolute, performance is used to compare alternatives. Such simplifications may not be valid when used to measure the (absolute) releases of radioactive materials into the accessible environment. Performance was assessed using an approach required by EPA to demonstrate compliance by computing a normalized integrated release (Q value) into the environment.

C.2.3.2 Broad Level, Factor 2

The general approach taken in dealing with uncertainties by treating variabilities in the DAM input parameter adheres to 40 CFR 191 and 40 CFR 194 compliance assessment requirements. However, a complete description of the uncertainty analysis is not made in the EACBS; e.g., Complementary Cumulative Distribution Functions (CCDFs) are not presented or analyzed although the model results contain the necessary raw data. Therefore, it is difficult to assess: (1) the approach taken in calculating the statistics for Factor 2 analysis, (2) the interpretation of results, and (3) how these data should be used in comparison with the data for Factor 1 analysis.

C.2.3.3 Detailed Level, Factors 1 and 2

Specific details that are deemed important in the creep modeling process include the following:

- lack of stratigraphy in the deformation model may affect the closure rates, therefore a measure of uncertainty about creep closure is introduced;

- the assumption of a constant effective stress in the vicinity of the room can result in inaccurate creep closure estimates (also see Item C-2.8);

- uncertainly in creep parameters was not considered. Had uncertainty been included for the creep parameters, room closure times could have been different (e.g., creep closure could have taken place over a longer period of time instead of 200 years). Sensitivity/uncertainty analysis of the creep parameters may have been left out because the SNL PA did not consider it. This could be a significant weakness of the analysis because creep closure response directly affects the permeability in the vicinity of the waste and, hence, quantity and rates of release of radionuclides.

The EACBS performed a detailed analysis of the intrusion scenarios, with intrusion occurring at a time of 5,000 years. Additional simulations for the baseline and nine selected alternatives were performed at intrusion times of 200, 2,000, and 7,000 years. The study concluded that, in general, the MREs are insensitive to the time of intrusion once the density and permeability of the

composite material (waste, backfill, host rock) reaches a steady-state condition. Notwithstanding that conclusion, this subcommittee maintains that an earlier intrusion time (say, before complete closure) could result in significantly different releases than those predicted by any current scenario. Section 194.33, "Consideration of drilling events in performance assessments," requires that drilling events be assumed to occur in the Delaware Basin at random intervals in time and space during the regulatory time frame. This random occurrence was not modeled.

The model used the most recent conservative actinide solubility data. For example, for plutonium (the most abundant radioisotope present in the long term), the highest solubility of all the oxidation states (trivalent state) was used. The presence of organic complexing agents was also considered, but not all possible organics, e.g. tributyl phosphate and its hydrolysis products; these complexes may be stable over long periods of time and could be more mobile than aqueous complexes of Pu(III).

The study also assumed solubility-limited source terms in the model. This would tend to underrate the performance for high-fired plutonium dioxide which would be the species present in the plasma processing option. For example, the leaching and solubilization of high-fired PuO_2 in a glass matrix would be much slower than PuF_4 coated on paper and plastic waste.

Adsorption of actinides on clays was not considered in the model since no K_D (distribution coefficient) data were available on the uptake of actinides in brine by these materials. The strong adsorption of plutonium species on clay materials is well known; in fact, adsorbed plutonium cannot be eluted or removed with brine solution. Thus the advantage of clays in immobilizing plutonium and other radionuclides was not credited in EAs using clay.

C-2.4 Alternate Interpretations

There are alternative interpretations that could have been made with respect to the repository phenomena, undisturbed performance and intrusion scenarios. Consideration of these alternatives may affect the conclusions of the relative benefit of a given engineered alternative. For instance, a more sophisticated analysis would include the WIPP site stratigraphy and radionuclide transport within the Culebra dolomite as is the case with the SNL PA. Because the EACBS descends from the EATF study and strives to parallel the SNL PA with respect to intrusion scenarios, consideration of alternate interpretations was precluded to a large extent. Note, however, that prior to deciding which conceptual models best represent the WIPP repository system, SNL had considered many alternatives, compared and benchmarked state-of-the-art computer codes, and used expert judgement in selecting the basis of its PA analysis. Even today, the PA methodology is amenable to other conceptual models that might increase the confidence level in the predictive calculations.

C-2.4.1 Models Affecting the Coupled Response

Other simulation techniques and/or numerical models could have been used. Although the report claims a fully coupled approach, the DAM code processes are only weakly coupled (i.e., the equations are not coupled or solved simultaneously) in that relevant effects of one process are sequentially passed on as an incremental change in one of the parameters to the next process solved. The objectives of this study are not compromised despite the simplifications and the empirical approach of the DAM code.

C-2.4.2 Intrusion Scenarios

At the time this study was conducted, 40 CFR 194 had not yet been finalized. Section 194.32 of the final rule contains a requirement for DOE to consider the effects of excavation mining, allowing assessments to be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system from excavation mining for natural resources. Note that the EACBS did not consider effects of mining within the land withdrawal boundary.

C-2.5 Uncertainty of Results and Consequences if Wrong

Data and parameter uncertainty was addressed and was an "inherent" part of quantifying "relative" measures/benefits. Accordingly, the results contain uncertainty due to the uncertainty in input parameters. Other types of uncertainty such as model uncertainty and uncertainty in the future states of the disposal system are not addressed.

Because this study is investigating potential benefits of engineered alternatives (and not revisions to the baseline design), the consequences of reaching wrong conclusions (based on wrong results) are not severe. At worst, an engineered alternative may be underrated or overrated due to a faulty analysis. The relative nature of the performance measure (i.e., MRE) allows meaningful conclusions to be drawn even if some of the modeling details are not accurate in the absolute sense.

C-2.6 Appropriateness and Limitations of Methodology and Procedures

Use of EPA's sum rule to compute and compare the releases for each EA relative to the baseline is appropriate. Use of a simplified model (e.g., DAM) is also appropriate and consistent with other analyses where a Monte Carlo approach is utilized to treat uncertainty.

The coupling of the processes contributing to the release measures as modeled in the DAM code is appropriate based on the nature of the complex interactions of these processes. However, there is no user's manual for the DAM code. As such, members of the Subcommittee felt that a lack of

a user's manual limits the ability to independently verify calculations and somewhat diminishes the ability to assess the quality assurance of the associated results.

Representatives from IT Corp. did provide access to QA records and documentation of changes made to the DAM code since the EATF study. Procedures followed in the execution of calculations are comparable to other modeling efforts in that input data files and output files were reviewed by independent personnel.

The subcommittee notes that Appendix S (Factor-Specific Quality Assurance) of the EACBS does not identify Factor 1 as one for which specific QA measures were taken. However, the intent on the part of IT Corp. personnel was to lump Factors 1 and 2 together for the purpose of addressing issues presented in Appendix S.

The DAM model uses a fixed state of stress in and around the openings and does not recompute (or update) the deviatoric stress, σ_e. Other more sophisticated mechanical models (such as SNL's SANCHO code) perform continuous updates of the state of stress in the host rock at every computational cycle. It is not known whether the simplifications in the DAM materially affect the final results. Hypothetically, one would expect complete closure of the emplacement room at a different time when a variable state of stress is used in the model. Whereas the need for simplicity is recognized, the use of a modified Chabannes' equation to represent creep deformation ignores important advances in creep modeling.

C-2.7 Adequacy of application

The following comments are made with respect to the adequacy of application:

- In the Executive summary, Table E-3 lists input values for the compressive strength of what it calls the waste/backfill. Values are listed for the baseline case (no backfill) and all EAs considered. Since the baseline case has no backfill, the 25 megaPascals (MPa) value assigned to it seems high, especially because it is the highest value listed. After consultation with the authors of the report, it was determined that the strength value is, in fact, that for an equivalent room volume of a composite mixture of waste, backfill (if any) and host rock (i.e., the salt that has closed in around the waste) following room closure. For the baseline case as well as for several EAs, the compressive strength of the composite is dominated by the salt properties. Whereas, for EAs when backfill is added, the strength value is more representative of the consolidated backfill.

- Data Bases from International Atomic Energy Agency (IAEA) and International Union of Pure and Applied Chemistry (IUPAC) were not considered. These data bases include selected solubility values for several actinide compounds compiled by experts in the field. However, the solubility data used in the model are conservative and are similar to selected values in the IAEA and IUPAC computations.

- Section C-2.3.3 above alluded to the possiblility of complete closure due to creep taking place over a longer period of time than predicted in the EACBS. It is conceivable that human intrusion could take place before complete closure. If that were the case, the porosity in the vicinity of the waste would be higher, and one or more of the EAs may be more effective in a relative sense.

- By definition, an alternate repository design is one of the ways in which the requirement to evaluate engineered alternatives is met. Indeed, one series of engineered alternatives (EA 77a through 77d) considers a modified repository design by using a room height of 6 ft, instead of the baseline design of 13 ft. It would have been very useful to also model EA 77 with a room height of 13 ft to isolate the effects of a different repository design to assess the sensitivity of a different room design. This, however, was not done in the EACBS.

C-2.8 Accuracy of Calculations

Calculations related to Factors 1 and 2 are extensive and form the foundation for the analyses of these factors. Because creep closure is a major driving force contributing to the measure of relative performance, members of this review panel performed a check of the creep calculations by independently solving the creep equation used in the DAM. Using representative values of stress and emplacement room dimensions as input, early time creep closures predicted by our independent calculation were in good agreement with the DAM code predictions identified in the report.

It is assumed that QA procedures were followed as stated in the report by performing hand calculations of the subroutines models used in the DAM code. QA files and spreadsheet calculations were reviewed by members of the subcommittee. Selected items were checked for accuracy and consistency between the data files and the values in the EACBS Report. MRE values extracted from the DAM output for various alternatives, and each scenario, were tabulated. These tables are available in IT Corp.'s QA records. Model output values of MRE for Scenario E1 (integrated release at 10,000 years via groundwater flow path) were compared with the values reported in Table E-3 of EACBS and were found to match to the accuracy in Table E-3.

Selected subroutines of the DAM code were examined for programming errors, and none were found. Two new subroutines, SATURATION and GASGENERATE, were added to the EATF version of the DAM in addition to a few other model refinements. QA file F058 documents these changes in the form of revised flow charts and accompanying text. The data input files for various EAs were scanned and spot checked for accuracy. Several input files showed hand-corrected numbers. For example, EA 94f data file shows a printed value of 3.42E8 for MOLCAOH2, and a hand-written value of 4.66E7. QA file F047 notes that Alternatives 77d, 83, and 94f had input errors for the number of moles of portlandite (MOLCAOH2). These computer runs were not

repeated with correct input. The analysts contend that, "the error would not significantly affect the final scoring."

C-2.9 Validity of Conclusions

The effectiveness of some of the EAs appears to have been undermined by the comparison technique used in the EACBS (see Figure E-4). Specifically, by choosing not to assign relative significance (i.e., weights) to individual factors, the study ends up with trade-offs between long-term performance enhancement (or reduction of uncertainty) and short-term risks that could be mitigated.

There may be possible contradictions regarding conclusions drawn upon the results of this study in the Executive Summary in that conclusions are offered on p. xvi. In the first paragraph, EAs 1, 6, and 10 are compared to the Baseline and are found to present short-term disadvantages. In the paragraph under the second bullet, the last sentence concludes the backfill alternatives improve long-term disposal system performance. This is not evident in Figure E-4, which is on the following page.

C-2.10 Other Observations/Issues

The following observations and issues were identified during the review of Factors 1 and 2:

- Many of the statements in Section 3.2, "Uncertainty in Compliance Assessment" are not completely correct. Some of the discussion related to treatment of uncertainty is very difficult to follow and contains conclusive remarks that do not logically fall out of the discussion that preceded.

- The distinction between, and the need for, two separate calculations of the 95th percentile values of MRE is not adequately explained (see columns 5 and 7 in Table 3-5, p. 3-26). Section 3.2.1 states, "Because the largest improvement in assurance that adequate containment will be achieved derives from reducing the spread of large releases (which are closest to the EPA limit), the second measure calculates an MRE based on the factor by which the 95th percentiles of value of radionuclide transport are reduced by each EA." Apparently the objective of the second 95th percentile value is to quantify the shift in the median as well as the narrowing (or broadening) of the output distribution relative to the baseline.

- The quantity MRU, "Measure of Relative Uncertainty," is defined as a performance measure in Table E-2 of the Executive Summary but is never used in Section 3.2 in discussing the results of the uncertainty analysis.

- The screening process description is unduly cumbersome. It appears that some of the steps have different labels but, in effect, have significant overlap with other steps.

- The fact that some of the EAs actually provide a reduction in uncertainty (because a sensitive input parameter's uncertainty is lower) is not clearly communicated by the report. For example, at the top of p. ix of the Executive Summary there are confusing statements about the treatment of uncertainty without taking sufficient credit for the ability of certain EAs to reduce uncertainty in the results. A quick study of the figures in Appendix J reveals how, for example, EA 10 lowers the uncertainty for the parameter RADFAC.

- The juxtaposition of results for all eight factors in Figure E-4, and other similar figures, tends to downplay the substantial benefit provided by several EAs (e.g., EA 10) with respect to Factors 1 and 2. The report, likewise, tends to look at the net outcome based on a collective assessment for Factors 1 through 8 in judging the merit of a given EA. Interestingly, in this study an EA that improves the long-term performance, or increases compliance confidence, tends to increase the operational phase risk. However, DOE can mitigate the higher short-term risks but has no control over risk once the WIPP facility is decommissioned. We feel that the spirit of 40 CFR 194 was to focus on long-term benefits or detriments of EAs.

- The Engineered Alternative Task Force (EATF) study predicts improvements of one to four orders of magnitude for selected EAs. Comparable EAs in the EACBS do not appear to provide the same magnitude of improvement. The reasons for this discrepancy are not clear.

APPENDIX C-3

REPORT OF SUBCOMMITTEE 2

FACTOR 3 - IMPACT ON PUBLIC AND WORKER EXPOSURE

C-3.1 Scope and Tasks of Subcommittee

The task of this subcommittee is to review the study conducted by Westinghouse and the DOE of the relative impact on worker and public risk of the different engineered alternatives (EA). This was accomplished by reviewing Section 3.3 and Appendix K of the EACBS, as well specific portions of the 1995 Draft Waste Management Programmatic Environmental Impact Statement (WMPEIS, DOE, 1995d).

This section summarizes the review of the subcommittee, including a review of the requirements and criteria, assumptions, results and inferred consequences, methods and procedures used, and validity of the conclusions.

C-3.2 Adequacy of Requirements and Criteria

The requirements of the study conducted by Westinghouse and DOE are specified in 40 CFR 191 and 40 CFR 194. The specific criteria, as used in this study adequately satisfy the intent of the requirements set forth by the regulation.

C-3.3 Validity of Assumptions

The principal assumptions underlying the assessment of worker and public risks associated with implementation of the various engineering alternatives, as identified by the subcommittee are:

- Methods used for computing risks, doses, and hazard indices are appropriate, and they effectively express the actual worker and public risks associated with exposure stemming from each EA. A review of the methods, through inspection of the referenced documents (i.e., WMPEIS; DOE, 1995d), indicates that the methods come from the EPA, the International Committee on Radiation Protection, and the American Conference of Governmental Industrial Hygienists guidance. These methods in and of themselves are based on conservative assumptions, they are conventional, are commonly used in assessments such as the EACBS, and are extensively documented in the literature.

- Application of the methods in the EACBS relies heavily on the assumption that the human receptor exposure scenarios for workers and the public, developed for the WMPEIS, are sufficiently similar to those pertaining to the current situation that they can be amended and applied to this case. That assumption was not evaluated by Westinghouse and the

DOE as part of this EACBS; however, our review suggests that the assumption is appropriate and defensible.

- It was clearly acknowledged that waste consolidation in the DOE complex, and process configurations used in the WMPEIS do not exactly match those described in the EACBS. It was assumed that the differences were minor and that scaling factors (identified below) could adequately accommodate the modification of WMPEIS risk estimates to the EACBS. The subcommittee's review of the WMPEIS indicates that the WMPEIS scenarios are reasonably similar to those used in the EACBS (except for the "worst case" accident for Factor 5).

- It is assumed that the operating life of the WIPP is 20 years, but does not document the basis for this assumption. In other places in the EACBS, reference is made to a 33 to 35 year operational period. Therefore, the validity is somewhat questionable. However, most of the risk computations were based on waste throughput - not time, and waste throughput was assumed to be the maximum WIPP capacity. Two important aspects embodied in this approach are: 1) the assumed time frame (e.g. 20 to 35 years) can be accommodated by a single human generation, and 2) it encompasses processing the entire inventory of waste destined for WIPP. Consequently, in concept, a single human receptor could receive the maximum exposure to the waste stream processed through a given facility regardless of the exact processing period (so long as it is reasonably within this envelope). Dose, risk and exposures computed on this basis, therefore, constitute a conservative assumption which tends to override the uncertainty in the time-frame assumption.

- In order to convert estimated WMPEIS risks to estimated EACBS risk, and to accommodate differences in throughput, scaling factors were developed based on an assumed full WIPP capacity. It was assumed that these scaling factors adequately reflect the anticipated EACBS risk and that the WIPP would be loaded to full capacity. In light of the suppositional nature of a future risk scenario, these assumptions appear reasonable and adequate.

- Overall, the founding assumptions of the assessment are regarded as conservative, yet reasonable within the realm of contemporary risk analysis practice.

C-3.3 Alternate Interpretations

The methods used are widely recognized in the risk assessment field and, in light of the needs to assess risks quantitatively in a defensible manner, there are no reasonable alternative interpretations.

C-3.4 Uncertainty of Results and Consequences if Wrong

The nature of the uncertainties is addressed in the EACBS which states that the uncertainties inherent in the WMPEIS assumptions are also applicable to this report, but do not specify what they are or what the impact might be (i.e., the uncertainties cascade). The WMPEIS addressed

uncertainties in a semi-qualitative fashion and pointed out that, for purposes of making relative comparisons between alternatives, systematic bias does not compromise the comparison process because the same type and degree of uncertainty will be embodied in each estimation. A limited uncertainty evaluation in the WMPEIS, based on sensitivity analysis of key input parameters, suggests that uncertainties are not unreasonable for the type analysis performed. Uncertainties in scaling factors were not addressed, but may be within the range of uncertainty in the original assessment. Notwithstanding this issue, based on the methods used in the WMPEIS and in the EACBS, there is a systematic bias to err on the side of safety which means that the risks are likely to be overstated. Thus, uncertainties are controlled so that the consequences are to report risks in a manner that would lead to a health protective action, possibly at the expense of managerial efficiency.

C-3.5 Appropriateness & Limitations of Methodology and Procedures

The subcommittee found the methods to be appropriate and within the bounds of convention. One limitation noted was that effects of EAs were only assessed for contact-handled (CH) waste, not for remote handled (RH) waste. Presumably the impact to worker health from processing RH waste could be significant. While, in general RH waste processing was not a variable, the subcommittee felt that the impacts of its handling could have been addressed by considering its "risk" as a constant which could have been added to the CH risk thereby introducing more realism to the evaluation. No significant compromise is introduced in the comparative analysis through omitting the RH waste contribution to worker and public risk.

The method for assessing risk did not address the inherent risks associated with mishaps occurring during interim storage of TRU wastes at the various DOE facilities over differing EA time intervals. The probability of a mishap resulting in a release and subsequent worker or public exposure during interim storage is low (e.g., container spill and release, failure resulting in leakage, occurrence of natural event [e.g., earthquake]). Nonetheless, if an EA has a significantly longer waste processing implementation period thereby increasing the probability of events (e.g., fork lift puncture of a drum) , and/or if extended processing is scheduled to occur at a facility more prone to natural disasters (e.g., prone to tornadoes) then qualitatively considering the waste processing period in inter-EA comparison could be beneficial. Neglecting this component of risk could result in understating the relative risks associated with the EAs that require significant development time (e.g., Plasma Arc and Supercompaction). Appendix K does not appear to address the method used to estimate emplacement impact, although it is referred to in that discussion.

C-3.6 Accuracy of Calculations

They appear to be reasonable and consistent with the methodology. The example scaling equation provided in Appendix L appeared to be accurate. The subcommittee did not check the fundamental computations referenced in the WMPEIS. The subcommittee's familiarity with the source of those computations and their description in the WMPEIS implies computational integrity.

C-3.7 Validity of Conclusions:

The subcommittee did not see anything that would invalidate the conclusions drawn for CH waste, but does question the absence of an evaluation of risks associated with processing RH waste. Overall, the subcommittee believes that the results can be used with confidence for the relative comparison of the impacts on worker and human health between EAs.

C-3.8 General/Documentation

The discussion in the body of the text was weakened by the lack of a discussion of the scenarios depicted in the WMPEIS, upon which so much of this evaluation rests. Appendix K's introduction does not track with the rest of the section.

APPENDIX C-4

REPORT OF SUBCOMMITTEE 2

FACTOR 4 - IMPACT ON WASTE REMOVAL

C-4.1 Introduction

This section explains the review of Factor 4 of the EACBS, the Impact of Engineering Alternatives (EAs) on Waste Removal. The EACBS is the study performed in compliance with Section 194.44 of the 40-CFR-194. The study of the ease and the impact of EAs on waste removal is specifically mentioned in the Sec. 194.44 part C-1-iii, which was also referred to in Section 194.46.

C-4.2 Scope and Task of Subcommittee

The task of this subcommittee is to review the study conducted by Westinghouse and the DOE of the relative impact of the EAs on waste removal. This was accomplished by reviewing section 3.4 of the EACBS.

This section summarizes the review by the subcommittee, including a review of the requirements and criteria, results, and inferred consequences, methods and procedures used, and validity of the conclusions.

C-4.3 Adequacy of Requirements and Criteria

The study performed under Factor 4 for qualitative comparison of the impact of various EAs on waste removal was required under Section 194.44 and 194.46 of the 40-CFR-194. In these sections, no reference to a particular time frame was made. Factor 4 was mainly structured to satisfy 194.44 which refers to waste removal within the context of an overall multi-parameter qualitative study of the EAs and their impact on the performance of repository. This factor is designed on the basis that "no provisions are made with any of the EAs that specifically facilitate removal. Such provisions are not required by the disposal standard" (P 3-72, line 23).

The ease of removal, the rate and hence time required for removal is related to the physical properties and strength of the material and the volume of the waste plus the surrounding area to be removed. The factor addresses these issues along with the occupational hazards and accidents associated with underground mining for waste removal. This satisfies the overall objective of the factor, which is to provide a qualitative measure to compare the EAs (including Baseline).

The underlying value used for the comparison purposes was mining time and related accident rates. The objective of the study and the degree of importance of these parameters are not very clear (i.e., minimization of accidents, minimization of time, cost etc.).

C-4.4 Validity of Assumptions

The factor was based on the criteria that the waste removal operation will be resumed 200 years after emplacement and disposal. This parameter, "time", has a major impact on the condition of the waste and the methods to be used for removal. Considering that the waste in all forms (Baseline or the EAs) is contained in steel drums, the time frame for the retrieval must be considered in three distinct phases, including: (1) from disposal to complete closure of the rooms (by creep), (2) room closure to deterioration and corrosion of the drums, and (3) long-term removal scenario (after corrosion of steel drum). Waste retrieval, which refers to retrieval during the operational life of the repository was not considered in the EACBS, and according to this defnintion (given by Westinghouse) it was not required by 40 CFR Section 194.44.

Any analysis of the waste removal must be performed with respect to the prospective time frame. The 200 years period, even though it is not related to the aforementioned phases, can be considered to address the third phase. Therefore, Factor 4 seems to be based on the long term retrieval scenario. Some clarification to that effect and the justification of a 200-year time frame needs to be made.

The conceptual approach to the problem is, in general, acceptable. In other words, the mining rate being a function of specific energy of excavation (specific energy being a function of strength, and strength being a function of compaction etc.) will satisfy the basic requirements for the estimates in the lack of actual measurements and field data from waste removal operation. Yet the specific values and terminology used for the calculation has to be applied more cautiously. The assumptions made to evaluate the impact of EAs on waste removal within this factor and their validity are subject to discussion.

The direct use of the cited data for strength, specific energy, and mining rate calculation, specially with the consideration of the recent advancement in excavation technology, is not justified. Besides, utilizing data from disc cutter application for excavation of the waste in the forms identified in the EACBS alternatives is not suitable. Also, the mining rate calculations had to be repeated and new performance curves established with respect to the specification of a given machine (i.e., the mining equipment presently used at the WIPP) to be used for this purpose at WIPP. The use of the mining rate achieved in the WIPP to date would be more suitable as the basis for the calculations, which could be factored to account for different expected material properties.

Altogether, the assumptions made for the conceptual mining method (for long term retrieval) and the methodology used for mining rate and time estimates is correct but the quantitative measures need to be reexamined more thoroughly in a more detailed study. No reference has been made to the short term retrieval methods, rate, schedule, or the removal of RH waste. The results of the study (comparing the EAs) will be the same based on the volumetric approach and will not be affected by the values used in the calculations.

C-4.5 Alternative Interpretations

The analysis could have been based on alternative methods for recovery and removal of the waste depending on the time frames discussed earlier. However, since the study is a qualitative comparison of the EAs, the alternative methodologies do not seem to have a major impact on the results. Briefly, the interpretations made based on the current methodology are not very sensitive to the variation of the waste processing or disposal method.

C-4.6 Uncertainty of Results and Consequences If Wrong

In this factor, the percent porosity is used to estimate the unconfined compressive strength (UCS) of the material. There is some uncertainty involved with this assumption since the chemical bonding between the grains and the intrinsic characteristics of the material have more impact than the porosity alone. The extent of chemical interaction between the material (waste or backfill) is controlled also by the presence of fluids, which for the most part is inaccessible or very restricted except for wet backfills. In addition, UCS is used to estimate the specific energy requirements and that in turn is used as a basis for mining rate and other analysis. It is noteworthy that the UCS is dominant, but not the only parameter controlling the specific energy. The calculations following this stage using specific energy are straight forward and are not prone to uncertainties.

However, in either case, the impact of these uncertainties is not crucial in waste retrieval since the material can be removed by the current state of technology. The different materials anticipated to be encountered in the retrieval operations can be cut even if their strength is higher than the estimated UCS (Table 3-29) by a large margin. The difference will obviously change the mining rate, time, and the human exposure to hazardous environment that must be accounted for in the calculations.

The outcome and result of the analysis done in factor 4 and its impact on the selection of the EAs is not irreversible. Finally, since the study is a qualitative comparison and the volume of waste to be removed is used for estimation of the time and accidents, the impact of the errors are not prohibitive and the consequences is not very severe.

C-4.7 Appropriateness and Limitations of Methodology and Procedures

The subcommittee found the methodology used in this factor to be, in general, appropriate and within the bounds of convention. This refers to the use of rock strength, specific energy, and mining rate to estimate the time required for removal and accident rates. However, some of the assumptions, procedures, data, and terminology used in the analysis were not suitable for this application.

C-4.8 Adequacy of Applications

This parameter was discussed in more detail in the section about the assumptions and criteria (see Section C-4.4).

C-4.9 Accuracy of Calculations

The accuracy of the calculations cannot be checked since the rates quoted are based on the continuous mining of the material without any reference to the machine specifications and power. Back calculation of the machine power from the figure 3-9 using a 50% efficiency and 6 Megajoule per cubic meter (MJ/m^3) specific energy results in the assumption of using a machine with a cutterhead power of 80 Kilowatts (KW). This is below the installed power of the machines used to excavate the rooms at the site. More powerful machines are currently available in the market that can increase the rate even further. Also, the daily advance rates are based on the mining rate and the utilization, which is not mentioned in the text. Back calculation from the graphs shows that a utilization of 75% might have been used, but it is not clear.

Overall, the relationship in Figure 3-8 is not given and cannot be checked beyond visual inspection of the curve. Also, since no reference was cited, it could be concluded that the graph was made for this study (the graph was directly adopted from one of the reference articles but it is not mentioned in the report). In any case, the scale used (0-350 MPa) in the graph is well beyond the range of anticipated strengths. Figure 3-9 also seems incorrect from the basic theory of a cutting point of view unless some other assumptions were made in the calculations which were not mentioned in the text or tables. Likewise, the graph in Figure 3-10, provides no reference to the machine parameters and utilization.

The calculation for 77 series EAs must be reconsidered based on the selection of the excavation machine. Most machines (i.e., Dosco and Marrieta machines used at WIPP) cannot practically work in rooms below 6 ft height unless special provisions and set ups are made. The advance rates (for either size rooms) could be estimated from the volume per linear meter since the calculations are based on the volumetric excavation.

Overall, with the amount of information available, checking the calculations was not possible.

This does not necessarily imply that the calculations are invalid or the estimated daily advance rates are inaccurate. Nonetheless, the direct use of data from the sources for the calculations is not justified. However, since the calculated figures are used in a relative comparison, the outcome of the study could still be valid.

C-4.10 Validity of Conclusions

The result of the analysis and especially the numerical output of Factor 4 can not be directly used for assessment of the EAs. It must be emphasized that the mining method perceived for application in the waste removal (continuous mining) is considered only for long-term operation of the repository and removal of the waste. The conclusions made based on the results of the Factor 4 analysis must address the time frame more clearly. Had the short-term removal of waste and backfill been studied, the final results could have been different.

The general conclusions based on relationship between the volume of material to be removed and the time required for mining and, thus, the human exposure and accident is acceptable and valid. In other words, for the purpose of comparison (impacts and difficulty of removing the waste) between the EAs and the baseline, it is reasonable to favor EAs with super-compact (77 EAs) or reduced waste volume. The conclusion made by the analysis (that the difference between the other alternatives and the baseline is marginal) is also acceptable. The quantitative comparison should only be considered indicative, leading to distinction of the EAs.

C-4.11 General/Documentation

Factor 4 is designed to evaluate the impact(s) of the various Engineered Alternatives (EAs) on waste removal and their comparison with the baseline design. The method of waste removal selected was the same as the method for excavation of the rooms in the repository, which is continuous mining. Due to some uncertainties, especially with respect to cutting of the steel drums, different mining methods may need to be considered for this purpose to account for the effects of time on the waste containers. The assumptions made with respect to the mining procedure and cuttability of the material(s) needs some further investigation for the same reason. Therefore, the calculation of the specific energy, mining rate, and time required to excavate the waste is uncertain. This issue must be examined more thoroughly and mining rates estimated based on a mining method which is more appropriate for this type of conditions.

Overall, the impact of the selected EAs for final evaluation on the waste removal compared to the baseline design seems to be marginal. The underlying conclusion of the analysis with respect to the increased time and accidents with the increase in the volume of waste is reasonable. This is irrespective of the material to be removed. The exact impact of the EAs on the schedule and actual method used for the removal is dependent on the time. The alternative approaches do not change the outcome of the analysis significantly. The quantitative comparison should only be

considered indicative and used for the comparison, but not for further calculations of time, schedule, or cost.

Had Factor 4 been considered in the screening process, EAs using different container material (i.e., EA 64) such as ceramic/glass could be considered for further evaluation. The process could be designed to be interactive with the factors in such way that if there was an EA which could significantly impact the results of a factor, it could be included in the studies. This does not imply that all 54 EAs had to be studied at the final level with all factors, rather it refers to a quick/rough review of the EAs with respect to the general scope of each factor.

APPENDIX C-5

REPORT OF SUBCOMMITTEE 2

FACTOR 5 - TRANSPORTATION RISK

C-5.1 Scope and Tasks of Subcommittee

The task of this subcommittee is to review the study conducted by Westinghouse and the DOE of the relative impact on transportation risk of the different engineered alternatives (EA). This was accomplished by reviewing Section 3.5 and Appendix L of the Engineered Alternatives Cost Benefit Study (EACBS) as well as specific portions of the RADTRAN4 Users Guide (Rodgers Engineering, 1994), the Comparative Study of Waste Isolation Pilot Plant Transportation Alternatives (DOE, 1995c) and the Final Supplement Environmental Impact Statement (DOE, 1990). Additionally, the subcommittee spent time discussing technical features of the work with the principal authors.

This section summarizes the review of the subcommittee, including a review of the requirements and criteria, assumptions, results and inferred consequences, methods and procedures used, and validity of the conclusions.

C-5.2 Adequacy of Requirements and Criteria

The requirements of the study conducted by Westinghouse and DOE are specified in 40 CFR Part 191 and 40 CFR Part 194. The specific criteria, as used in this study adequately satisfy the intent of the requirements set forth by the regulation.

C-5.3 Validity of Assumptions

- The methods used for computing risks, doses and hazard indices, and hazard quotients are appropriate, and they effectively express the worker and public risks associated with exposure stemming from each traffic accident associated with each EA. Additionally, several "off-the-shelf" transportation accident projection codes (e.g., RADTRAN) were used. A review of the methods, through inspection of the referenced documents (i.e., the FSEIS) indicates that the methods come from EPA, the International Committee on Radiation Protection, the American Conference of Governmental Industrial Hygienists guidance and the US Nuclear Regulatory Commission. These methods in and of themselves are based on conservative assumptions, they are conventional, are commonly used for this type of application, and are extensively documented in the literature.

- The report assumes current population densities and 20 year active life, with no documentation. Elsewhere in the Report, the WIPP operational window is stated to be 33 to 35 years. It is possible that population dynamics may change over the period of performance, thereby affecting population impacts. However, the subcommittee does not feel that the apparent discrepancy in assumptions is limiting to the assessment of transportation related risks. This is because of other conservative assumptions as will be discussed below.

- Exclusion of RH waste overall is questionable from an absolute perspective (Table 3-33 provides information for baseline and decentralized configurations, but Traffic Index (TI) values are only provided for baseline conditions. Effectively, it was assumed that RH waste was not a variable in the EACBS because the individual EAs addressed only the handling of CH waste. Overall, this is a valid assumption for the inter-EA comparisons because the RH related risks become a constant across all EAs. Therefore, negating the additive impacts of RH waste does not compromise the inter-EA comparison process.

  Results are provided for RH waste, but details of the derivation are not provided in either the EACBS or the FSEIS.

- The EACBS assumes only truck transport with no explanation. The subcommittee understands that it is possible that rail transportation could be used, though truck transportation will be the dominant mode of transport. The subcommittee cannot determine whether this assumption is valid. However, considering the magnitude of the projected risks, omission of rail risks does not compromise the inter-EA comparisons of transportation risks.

- It was assumed that the total overland inventory was equal to the WIPP design capacity. However, currently, the estimated inventory of TRU waste is roughly one-half the WIPP capacity. Thus, the total number of highway miles traveled, the number of incidents, their effects, and doses from non-incident travel are overestimated. This conservative assumption is justified and typical of the type of conservatism embodied in contemporary risk analysis.

- Other assumptions appear to be reasonable. Overall, the basic assumptions of the assessment are regarded as reasonable and well within the envelope of contemporary transportation risk assessment practice.

C-5.4 Alternate Interpretations

If the operating life of the WIPP significantly exceeds 20 years, the population densities could vary significantly. However, this variation is not a limiting factor. The methods used are widely recognized in the risk assessment field and, in light of the need to assess risks quantitatively in a defensible manner, there are no reasonable alternative interpretation.

C-5.5 Uncertainty of Results and Consequences if Wrong

Understating population densities would underestimate cumulative risks between EAs. This is because the variation in highway miles and population density between EAs (i.e., persons at risk is a function of linear miles and population density along the linear miles) This could produce a higher estimate of risk on a inter-EA comparison basis because the different configurations (i.e., central vs regional processing options) have varying linear miles and population densities. The effect of this subtlety are not easily quantifiable at this point.

The nature of the uncertainties is addressed in the report. However, the authors do not address the effect on their analysis of the consequences of errors stemming from uncertainties. The subcommittee feels that, overall, there would be little effect on an inter-EA comparison basis.

C-5.6 Appropriateness and Limitations of Methodology and Procedures

The subcommittee's review indicates that the methods used were generally appropriate. However, several imitations were noted as discussed below. The underlying document, the FSEIS, evaluates risks from a "bounding" accident (being the absolute worst case). This appears to have been eliminated from the EACBS evaluation, with no justification. For chemical hazards, calculated worst case airborne concentrations resulting from a category VIII accident were compared with the relevant Emergency Response Planning Guidance (ERPG) value. When the calculated values were less than the ERPG, no excess risk was assumed. This method evaluates individual risk only and is, therefore, based solely on waste form characteristics. Impacts on cumulative human health risks from transportation (mileage, population density, etc.) of the processed wastes is not considered.

The full range of transportation impacts cannot, therefore, be evaluated. The respirable release fractions calculated in the DSEIS were modified to account for variations in the waste form caused by the various engineered alternatives. This procedure is appropriate. However, the text does not provide adequate justification for the selected values of release fraction. For instance, Page 3-107 states that "the fraction of material released from failed containers was reduced by one third ... reflecting greater crush resistance of the drums..." Similar statements are included for each of the processing options (i.e., "fraction of material entrained to the environment was reduced by an order of magnitude..."). The bases of these modifications should be addressed. Not withstanding these limitations, the subcommittee found the methods to be appropriate and within the bounds of convention. The limitations, while notable, should not compromise the use of the assessment for inter-EA comparisons, so long as the issue of the 20 versus 35 year time schedule and an EA significantly encroaching into the margin (e.g., the later 15 years) is not overlooked.

C-5.7 Accuracy of Calculations

The calculations appear to be reasonable and consistent with the methodology. The subcommittee did not check the computations referenced in the SEIS. They appear to be reasonable and the subcommittee's familiarity with the source of those computations and their description in the WMPEIS implies computational integrity.

C-5.8 Validity of Conclusions

The subcommittee's review did not uncover issues that would invalidate the conclusions drawn for the purposes of comparing transportation risk associated with the different EAs. Unfortunately, the reliance on "individual" chemical risk evaluations versus "cumulative" risk evaluations for radiation impairs the comparability (between chemical and radiological risks) of the conclusions somewhat. As is the case with radiation risk, the impacts to human health risk from transportation of hazardous chemicals is also a function of distance traveled, population density, as well as waste form. While these methodology discrepancies are inherent in the techniques used, they do not significantly impact the overall inter-EA evaluation.

Overall, the subcommittee believes that the results can be used with confidence for the relative comparison of the impacts on worker and human health between EAs.

C-5.9 General/documentation

Section 3.5.2 states that the analyses were conducted similarly to assessments included in the WIPP FEIS and FSEIS. However, the FSEIS explicitly states that the methodology used in that document differs from that in the FEIS, and provides justification for that difference. The EACBS should identify which methods were taken from what original documents, and state the reasons for the selection. Also, it would be helpful if the general procedures were summarized in this document (i.e., reliance on accident frequency/severity probabilities rather than on risks associated with individual accidents.)

APPENDIX C-6

REPORT OF SUBCOMMITTEE 3

FACTOR 6 - IMPACT ON PUBLIC CONFIDENCE

FACTOR 7 - IMPACT ON SYSTEM COST AND SCHEDULE

FACTOR 8 - IMPACT ON OTHER DISPOSAL SYSTEMS

C-6.1 Factor 6: Impact on Public Confidence in the Performance of the Disposal System.

C-6.1.1 Scope and Tasks of Subcommittee

The task of this subcommittee is to review the study conducted by Westinghouse and the Department of Energy relative to the impact of engineered alternatives on public confidence in performance of the disposal system at WIPP. Specifically, the subcommittee reviewed Section 3 of the study conducted by Westinghouse, DOE, and its subcontractors on identifying and understanding public concern about real or perceived risks associated with WIPP in its post-closure state that can assist DOE in:

- planning and executing sound engineered alternatives as needed to address public concerns
- providing credible scientific basis and data to assist the public in understanding risk as related to possible concerns and comments
- actively involving the general public to insure a two-way flow of information

This section summarizes the review of the subcommittee, including a review of the requirements and criteria, assumptions, results and consequences, methodology and procedure, and validity of conclusions.

C-6.1.2 Adequacy of Requirements and Criteria

The requirements of the study conducted by Westinghouse and the DOE are set forth by EPA rules 40 CFR Part 191 and 40 CFR Part 194 with reference to public participation. The specific

criteria, as used in this study and as noted above in the Scope and Task, adequately satisfy the intent of the requirements set forth by the regulations.

C-6.1.3 Validity of Assumptions

The major assumptions associated with this section of the study are that 1) the public's concerns (questions and input) can be understood by comments from regulatory review meetings and focus group programs and 2) these concerns can be categorized to evaluate how well the engineered alternatives address the public concerns. These assumptions were made in order that not every engineered alternative needs to be specifically addressed by the public. A review of the opinions, questions and concerns obtained at the public meetings and focus group meetings lead us to agree that these assumptions are reasonable since these opinions and concerns do apply to the alternatives. (There are also some technical assumptions that are available to the public.)

Another assumption, in this study, is that public concerns that were voiced during meetings relative to 40 CFR part 191 and 40 CFR part 194 and the 1990 Final Supplement Environmental Impact Statement (FSEIS) reviews are still valid. This is also reasonable since these meetings were held within the last six years and the opinions appear to be applicable today.

An additional assumption is that focus group meetings that were held in three primary cities—Albuquerque, Carlsbad, and Santa Fe, NM—would be valid for other geographic areas affected by the WIPP site. This too seems reasonable since these cities are the primary population areas in New Mexico. The only possible suggestion here from the subcommittee is that concerns should also have been obtained from some of the neighboring states (e.g., Texas) so that if different concerns are voiced by citizens of the neighboring states these could have been considered in the study of the engineered alternatives. In any case, communication with the other states might have been beneficial. Similarly, the DOE sites that plan to ship waste to WIPP could also have been surveyed for public opinions. However, we feel these are minor concerns and not worth repeating for the study.

C-6.1.4 Alternate Interpretations

The comments were analyzed qualitatively from Phase I and quantitatively from Phase II. The application of the comments to the engineered alternatives could be interpreted in slightly different ways, but our judgement is that this would not affect the conclusions of the study.

C-6.1.5 Uncertainty of Results and Consequences if Wrong

There may be some misinterpretation since generalized comments were applied to specific engineered alternatives. However, this uncertainty is low and the consequences of slight misinterpretation are not serious since the majority of the comments (greater than 60%) were comments relative to trust in DOE rather than on impact of engineered alternatives. The other

comments on engineered alternatives are straightforward and of minimum impact because most of them also apply equally to the baseline technology.

Tests of statistical significance were not utilized. However, the method used is adequate, given the qualitative nature of the comments and the tenuous connection of public confidence to costs/benefits.

C-6.1.6 Appropriateness of Methodology and Procedures

As noted previously, the methodology used was to first analyze public comments that were made in the past six years relative to 40 CFR 191, 40 CFR 194, and the Final Supplement Environmental Impact Statement (DOE, 1990). This Phase I analysis covered several conditions, as well as siting and design factors. This was followed by a specific Phase II study conducted in three major population areas of New Mexico with focus group comments which covered several additional factors specific to the engineered alternatives. These public concerns were then analyzed in depth and applied to each of the engineered alternatives.

This methodology is quite appropriate, although one could argue that every engineered alternative could have been posed to the focus group and comments obtained. This is, however, unrealistic and in our opinion would not be a prudent use of taxpayers time and money since the comments made by the focus groups are easily applicable to the engineered alternatives. The focus groups would have had to spend an inordinately large amount of time addressing every alternative and would still probably provide comments similar to what they have already done.

The primary suggestion we can make is that, in order to provide greater confidence, one engineered alternative could have been taken and studied specifically with a focus group as a validation of the analysis. This would have required getting the focus group together again and would have taken additional time; the benefits would not be worth the cost. Another limitation might be that the study of focus groups could also have taken place in other states as pointed out previously (e.g., Texas). Again, it is doubtful that any signficant new results would have been obtained. Therefore, this subcommittee concludes that the methodology and procedure was appropriate.

C-6.1.7 Adequacy of Application

Having studied the methodology and other material, as well as the analysis, we feel that the application was proper in using the public concerns to understand the impact of engineered alternatives on the public. Specifically:

- The process used by the moderators is appropriate.
- The cities are representative of those most affected by WIPP in the State of New Mexico and, therefore, are appropriate.
- The sample represented adequately those with significant interest in WIPP.

C-6.1.8 Accuracy of Calculations

The only calculations involved are those of grouping the concerns together into major categories relative to the performance of WIPP. These categories were chosen to evaluate performance, i.e. human health, waste characteristics, waste repository technology, etc. We have spot-checked these calculations for developing groupings and feel that these are accurate with minor discrepancies within the interpretation of the comments. Different interpretations might have led to slightly different percentages in the grouping, but this would have been a small change and would not create any critical limitations.

C-6.1.9 Validity of Conclusions

The major conclusion from the study is that the overall spread of results does not lend itself to signficant differentiation. Therefore, all engineered alternatives are indicated as unchanged from the baseline for the impact element (i.e., the public views the alternatives performance to be approximately the same as the baseline performance). Although some may make an argument that selected EA performance is somewhat better, rather than the same as baseline, this is marginal at best and the EACBS conclusion is appropriate in view of the review that we have conducted.

C-6.2 FACTOR 7: IMPACT ON SYSTEM COST AND SCHEDULE

6.2.1 Scope and Tasks of Subcommittee

Factor 7 is defined as the determination of the impacts each EA will have on cost and schedule where cost is composed of waste processing, transportation, repository backfill and emplacement handling costs for the different EAs in different configurations. Schedule impacts look at the length of time an EA will require to be implemented and consequently the EA's desireability. The scope and tasks of the Peer Review Subcommittee regarding this factor was to conduct an assessment of the validity of the assumptions and the technical approach used in the work performed. This included an in-depth critique of assumptions, alternate interpretations, methodologies and acceptance criteria employed, and of the conclusions drawn.

C-6.2.2 Adequacy of Requirements and Criteria

This peer review was conducted to satisfy quality assurance (QA) requirements of 40 CFR Part 194, Criteria for the Certification and Re-certification; and NUREG-1297 of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 194 Disposal Regulations. The evaluation of the PRS was not intended to assess the validity of the requirement to perform this work, nor the validity of the 40 CFR 194.44 analysis requirements.

C-6.2.3 Validity of Assumptions

The subcommittee conducted the evaluation of the assumptions utilizing a two-tiered approach. The first tier consisted of grouping the assumptions in the following five categories: 1) waste processing cost assumptions; 2) transportation cost assumptions; 3) backfill emplacement costs assumptions; 4) waste emplacement handling costs assumptions and 5) schedule assumptions. The second tier consisted of conducting a qualitative analysis of the assumptions in light of their completeness, appropriateness, and uncertainty associated with all calculated costs and schedule duration for each of the engineering alternatives.

A list of the assumptions based on the five categories mentioned above is included in Attachment A. The following sections describe the results of the subcommittee qualitative analysis of the validity of the assumptions.

C-6.2.3.1 Validity of Waste Processing Cost Assumptions — The subcommittee evaluated the completeness of the assumptions based on the information necessary to carry out the waste processing cost methodology. The subcommittee determined that the following information was necessary to calculate the waste processing costs: 1) waste mass and volumes rates: 2) processing period; 3) percent of inventory of waste requiring retrieval; 4) percent of stored wastes requiring

re-grouting; and 5) qualitative cost comparison information of similar waste processing engineering alternatives. During the review of the assumptions, the subcommittee determined that the list of assumptions included in Attachment A encompassed all the above information. Therefore, the subcommittee concluded that the assumptions were complete. The subcommittee also evaluated the unstated assumption that no new treatment facilities will be constructed after the initial facility has been constructed (i.e., a treatment facility is expected to remain operational for the 20 year processing period.) This assumption is considered to be acceptable given the 30 percent maintenance cost addition discussed in the EACBS.

The evaluation of the appropriateness of the assumptions was focused on the assumptions made to calculate the mass and volumes rates which have the greatest impact on the overall processing cost. The mass and volume throughput were calculated using data from the Waste Isolation Pilot Plant Baseline Inventory Report (WIPP BIR) (DOE, 1995e) which assumed a 20 year processing period and 4,032 working hours a year. The subcommittee evaluated the processing period of 20 years based on the expected 35 years operational life for WIPP. The subcommittee considered the 10 years estimated period to start up processing operations and the additional time for emplacement of waste at WIPP, and determined that the 20 years processing period will be consistent with the expected 35 years operational life for WIPP. The 4,032 working hours were calculated assuming 240 working days a year, and three working shifts a day at 70 percent availability. The 240 working days a year appeared to be appropriate to the PRS. Also, the subcommittee considered that three working shifts a day will be an effective waste processing operation because it will avoid unnecessary shut down of the systems. In looking at the 70 percent availability the subcommittee considered it a little low. Usually, the operational availability of processing systems is assumed to be about 85 percent. However, after the subcommittee considered that the processing alternatives in this report were innovative technologies, the subcommittee determined that this 70 percent availability may be appropriate because of potential problems associated with the operation of these innovative processing systems. Therefore, the subcommittee concluded that the assumptions were appropriate. In regards to the uncertainty associated with the assumptions, the subcommittee agreed that the probable accuracy of the estimate is plus or minus 30% (Peters et al., 1991).

C-6.2.3.2 Validity of Transportation Cost Assumptions — The transportation costs assumptions were derived primarily by specific waste density and waste containment shipment requirements. The subcommittee analyzed the assumptions, and found them consistent with packaging and transportation requirements. Therefore, the subcommittee concluded that the assumptions were complete and appropriate. The subcommittee concluded that the assumptions are valid.

C-6.2.3.3 Validity of Backfill Emplacement Costs Assumptions —The assumptions were developed based on the proposed backfill emplacement method. The subcommittee evaluated the proposed backfill emplacement method, and found it to be effective because it avoids interruption to waste emplacement activities. Therefore, the subcommittee determined that the assumptions

were complete and appropriate. Assumptions are valid as long as the batch method for backfill emplacement is implemented at WIPP.

C-6.2.3.4 Validity of WIPP Waste Operations Emplacement Cost Assumptions — The subcommittee evaluated the assumptions based on their consistency with the estimated 35 years operational life for WIPP and the estimated quantities of waste to be sent to WIPP. The subcommittee reviewed the estimated waste inventories and waste operation's rates at WIPP, and determined that the assumptions were consistent with the 35 years operational life for WIPP. Therefore, the Subcommittee found these assumptions to be complete and appropriate.

The waste operations costs are mainly driven by the estimated quantities of waste to be sent to WIPP. Therefore, the subcommittee concluded that the assumptions are valid based on their consistencies with waste inventories.

C-6.2.3.5 Validity of Schedule Assumptions — The subcommittee assessed the completeness and appropriateness of the schedule assumptions based on their consistency with the broad spectrum of engineering alternatives and the expected 35 years operational life for WIPP. The subcommittee found the schedule assumptions consistent with the type of engineering alternatives (waste processing and backfill) and the 35 years operations at WIPP. Therefore, the subcommittee determined that the schedule assumptions were complete and appropriate.

In regards to the uncertainty associated with the assumptions, the subcommittee noted that the schedule assumptions were very generic in nature and had insignificant effect on the actual development of the schedule duration for each of the engineering alternatives. Therefore, The subcommittee concluded that there was little uncertainty associated with any of the schedule assumptions.

C-6.2.4 Alternate Interpretations

The subcommittee evaluation of the costs and schedules was performed based on the input of information and methodologies used in this comparative analysis. A great amount of the information and methodologies were adopted from other source documents. Although there may be a few alternate interpretations originated from the guidance documents, the subcommittee determined that they will have an insignificant effect on the results of the study.

C-6.2.5 Uncertainty of Results and Consequences if Wrong

The subcommittee performed a qualitative evaluation of the results to ensure that there were no significant flaws or shortcomings with the calculations. At first, the subcommittee was concerned that the estimated costs were based on 1994 cost data and did not account for any cost increases in the future. Also, the subcommittee was concerned that the life cycle cost methodology did not consider any costs associated with the need to further develop a specific engineered alternative. However, in looking at these potential cost increases, the subcommittee determined that they will

have an insignificant effect in the overall cost for each engineered alternative. Therefore, the subcommittee concluded that the estimated costs and schedules provided a reasonable approximation of the actual costs and schedule duration for each engineering alternative. A detailed discussion of the evaluation of the results is presented in the following sections.

C-6.2.5.1 Evaluation of Processing Cost Results — The subcommittee performed a comparison between similar processing schemes for each of the engineered alternatives in order to verify similar processing costs and agreed with the following results: alternatives 33, 35(a&b), 83, and 111 should be identical to the baseline; alternative 77 (a-d) should be identical to alternative 1.

The subcommittee also conducted a comparison of the processing costs among centralized, regionalized and decentralized processing facilities. Based on this comparison, the subcommittee agreed that centralized facilities resulted in the lowest cost and decentralized facilities in the highest cost. This conclusion was justified due to lower operation and maintenance costs being applied to a smaller number of facilities (1 for centralized vs. 10 for decentralized.)

The subcommittee also agreed that the baseline alternative was the least expensive due to less throughput values for the treatment modules. The cost of alternative 10 - (Plasma) was lower than the cost of alternative 94 (a-f) - Enhanced Cementation - because full-scale Plasma facilities are planned to soon exist at the Idaho National Engineering Laboratory. Therefore, the subcommittee determined that alternative 94 (a-f) - Enhanced Cementation was the most costly because of the need to construct new facilities.

In regards to the uncertainty of the results, the subcommittee agreed that the uncertainty should be the same as the level of uncertainty associated with the information utilized in the calculations. For the purpose of this comparative analysis, the subcommittee concluded that the process cost uncertainty will not change the results because the same level of uncertainty exists for all of the alternatives.

C-6.2.5.2 Evaluation of TRU Waste Transportation Cost Estimation Results — The subcommittee evaluated the results based on the following two factors which have the greatest impact on the transportation cost calculations: 1) certain waste processing alternatives increase the density of the waste making it mass limited; and 2) the cost of transportation is directly proportional to the waste volume/weight and required number of trips.

Looking at factor 1 above, the subcommittee agreed that the increase of density of the waste offsets the benefits of the waste treatment resulting in volume reduction because of waste volume transportation restrictions for high density waste.

Based on factor 2 above, the subcommittee determined that the transportation cost calculations were a straightforward analysis and found no issues with the calculations.

C-6.2.5.3 Evaluation of Backfill Emplacement Cost Results — The subcommittee reviewed the calculations of the backfill emplacement costs. Specifically, the subcommittee evaluated the estimated volumes, materials type, and associated cost of backfill materials.

The subcommittee determined that the estimated volumes of backfill and associated cost were reasonable. Also, in regards to the cost of backfill materials, the subcommittee determined that the overall cost evaluation was conducted properly because the costs accounted for the utilization of mined materials where backfill material consisting of salt was to be used.

C-6.2.5.4 Evaluation of WIPP Waste Operations Emplacement Cost Results — The subcommittee determined that the following factors were directly proportional to the waste operations emplacement costs: 1) period of operations for each alternative; 2) crew configuration; and 3) size of the crew.

Based on these factors, the subcommittee agreed with the results showing that alternative 10 - Plasma and 1 - Supercompaction provided the highest handling savings due to a 25 years operations rather than 35 years.

C-6.2.5.5 Evaluation of Schedule Results —The subcommittee evaluated the estimated schedule duration for each engineered alternative. During the evaluation, the subcommittee agreed that the duration of the National Environmental Policy Act process and permitting process should be longer for processing alternatives such as Plasma and Supercompaction due to public and regulatory agency concerns with these alternatives. Therefore, the subcommittee determined that the implementation schedules were justified for Plasma (36 years) and Supercompaction (35.5 years).

In regards to implementation schedules for alternatives where facilities currently exist, the subcommittee considered it reasonable that waste would be available for emplacement at WIPP by 1998. The subcommittee also considered that the processing start up period of 11 to 12 years was reasonable for alternatives that require new facilities.

Finally, looking at the schedules alone for each of the alternatives, the subcommittee also agreed that no alternative presents significant benefits or detriments relative to the baseline.

C-6.2.6 Appropriateness and Limitations of Methodology and Procedures

The subcommittee conducted a thorough evaluation of the methodologies and procedures used to develop the cost and schedule estimates. Detailed discussion of this evaluation is included in the following sections.

C-6.2.6.1 Evaluation of the Processing Cost Methodology — The Subcommittee assessed the cost methodology used in light of its ability and appropriateness to estimate the costs without having to perform a conceptual design and detailed cost estimate for each of the process configurations. During this evaluation, the Subcommittee determined that the cost approach provided an effective mechanism to calculate the costs associated with each of the process configurations. Specifically, the Subcommittee considered it appropriate to segment waste management facilities into discrete modules based on various waste management functions. This will allow flexibility in the costing methodology to consider existing facilities into the overall processing cost. Finally, the subcommittee determined that the cost methodology was appropriate because it was designed to consider the life cycle cost for each process configuration.

C-6.2.6.2 Evaluation of the TRU Waste Transportation Cost Estimation Methodology — The subcommittee considered the transportation cost methodology a straightforward analysis. Specifically, the subcommittee determined the following costing approach to be appropriate for this comparative analysis: 1) the cost per loaded mile (CPLM) have to be calculated considering carrier costs and hardware costs; 2) the costs are derived from the number of shipments which are applied to the CPLM and the round-trip mileage; and 3) the fixed costs are added to calculate the total cost.

The subcommittee examined that the uncertainty of the methodology was not an issue. The subcommittee determined that any uncertainty with the calculated costs will be originated from any uncertainty associated with the information used on waste inventory and other documents used as guidance.

C-6.2.6.3 Evaluation of Backfill Emplacement Costs Estimation Methodology — The subcommittee's evaluation of the methodology consisted of the assessment of the appropriateness of the following factors: capital costs, working rate of backfill emplacement operations, and maintenance costs.

The capital costs were given by the actual costs of the equipment needs. The equipment needs were identified considering the tons per day of emplacement capacity based on the number of TRUPAC-IIs per day. The subcommittee found the capital costs to be acceptable for the required backfill emplacement operations.

The subcommittee evaluated the appropriateness of the working rate of backfill emplacement operations based on the method of emplacement. The method of emplacement consisted of a batch operation in order to avoid waste emplacement interruptions. For batch operations, the subcommittee considered the assumed working rate of 960 hours a year acceptable. However, the working rate may need to be modified if the method of emplacement is changed in the future.

The maintenance cost was assumed to be 30 percent of the capital equipment costs. The subcommittee considered this a standard practice for estimating maintenance costs. Therefore, the subcommittee determined that the estimated maintenance cost was appropriate.

The methodology used included a 25 percent contingency in all costs including the baseline. The subcommittee determined that this was appropriate due to the level of uncertainty of plus or minus 30 percent resulting from the cost information provided in the Society of Mining Engineering Handbook (Hartman, 1992). In addition, the overall backfill emplacement cost for each alternative is about 1 to 2 percent of the total cost associated with each alternative, thus this cost is a minor component of the entire cost picture.

Overall, the subcommittee concluded that the methodology used was applicable and appropriate to estimate the backfill emplacement operation cost.

C-6.2.6.4 Evaluation of the Waste Emplacement Operations Cost Estimation Methodology — The subcommittee evaluation of the appropriateness of the cost methodology was based on the following two cost factors: throughput rate, and man power requirements for handling operations.

The subcommittee considered it acceptable to estimate the throughput rate by dividing the number of waste shipments by the operational period of WIPP. Also, the subcommittee considered that two working shifts a day will be acceptable to perform the waste handling operations at WIPP. Since the cost of waste emplacement operations is based primarily on the two factors mentioned above, the subcommittee determined that the methodology used was acceptable.

C-6.2.6.5 Evaluation of the Schedule Methodology — The information of schedule duration applied to the methodology was based on the duration of similar activities at DOE sites. This schedule duration was the main factor impacting the overall schedule for each engineering alternative. Based on professional judgment, the Subcommittee determined that it was reasonable to use information based on past schedule duration of similar activities in order to develop more realistic schedules. Also, the Subcommittee performed a spot check of selected schedules and they look reasonable.

In general, the Subcommittee determined that the schedule methodology considered the necessary implementation activities associated with each engineering alternative. Also, the schedules developed were consistent with the estimated 35 years operational life for WIPP. Therefore, the Subcommittee determined that the schedule methodology was adequate.

C-6.2.7 Adequacy of Application

Based on the review and evaluation of the assumptions, and methodologies used to estimate the overall cost and implementation schedule for each engineered alternative, the subcommittee determined that all the assumptions and methodologies were adequately applied to the work performed.

C-6.2.8 Accuracy of Calculations

On May 16, 1996, the subcommittee attended a meeting in Albuquerque, New Mexico to discuss the accuracy of the calculations performed in this Engineered Alternative Cost/Benefit Study Final Report (EACBS). The primary authors of the EACBS were available at the meeting (in person and by teleconference). At this meeting, the subcommittee asked several questions regarding the cost methodologies and assumptions used to calculate the overall costs and schedules for each engineering alternative. The primary authors provided satisfactory answers and clarification on each of the issues raised by the subcommittee.

Based on the meeting discussions, the subcommittee conducted a spot check of the calculations and determined that the calculations were performed in accordance with widely accepted methodologies and procedures. Therefore, the subcommittee determined that any uncertainty associated with the calculations were derived from uncertainty associated with input information such as waste inventories and other information gathered from guidance documents. The subcommittee finally concluded that this uncertainty should not impact the accuracy of the results of this comparative analysis.

C-6.2.9 Validity of Conclusions

The subcommittee agreed with the main body of the report which states that when looking at the schedules alone for each of the alternatives, no alternative presents significant benefits or detriments relative to the baseline for the closure of WIPP. However, Figure 5-4 shows that the schedule for alternatives involving waste processing was significantly worse than the corresponding baseline schedule. This is correct for the required schedule to send first waste to WIPP, but is not correct for the life cycle of WIPP or at WIPP closure. In order to avoid confusion, the Subcommittee suggests that Figure 5-4 makes this clarification.

In general, other than what is noted above in this section, the subcommittee concluded that the conclusions of this comparative analysis are valid.

ATTACHMENT A
COST AND SCHEDULE ASSUMPTIONS

Waste Processing Cost Assumptions

1. Mass and volume rates are calculated using a 20-year processing period and a 4,032-hour working year.
2. Mass and volume changes occur during certain processing activities.
3. The mass of unknown wastes is assumed to be zero because no information is available regarding the density of this waste and the volume of this waste is small compared to the total volume of waste destined for WIPP.
4. Thirty percent of stored waste at Los Alamos National Laboratory, Savannah River Site, Argonne National Laboratory-West, and Handford requires retrieval.
5. Twenty-five percent of stored sludges at Los Alamos and Idaho requires re-grouting and all of the stored sludges at Oak Ridge require grouting.
6. All waste within a major waste form category ((i.e., sludges, solid organic, solid inorganic) can be treated using a specified technology.
7. The supercompaction module does not include shredding.
8. Cost for a vitrification unit are considered adequate for the costs for a plasma melter.
9. Costs for enhanced cementation processing are identical to costs for grouting except for material costs.
10. Costs for shredding and adding clay are identical to costs for grouding except for material costs.
11. Costs for shredding and compacting are analyzed as a modified cost module for supercompaction.
12. Start up processing operations will take 10 years.

Transportation Cost Assumptions

1. It is assumed that all CH TRU waste will be shipped by truck in TRUPACT-II containers, which have mass, volume, and radionuclide restrictions that limit the amount of waste transported in one shipment.
2. Shipments may include as many as 42 drums of low density waste or as little as 14 drums of high density waste.

Backfill Cost Assumptions

1. The backfill is emplaced daily as a batch and will not interrupt the waste emplacement activites.
2. The working rate for backfill emplacement is assumed to be 960 hours per year for 35 years.

WIPP Waste Operations Emplacement Cost Assumptions

1. The waste emplacement operations at WIPP consist of two eight hour shift operations five days a week
2. Waste emplacement is dependent upon the number of TRUPACT-IIs received per day.
3. The cost estimation for the impacts associated with the WIPP operations only analyzed the incremental costs to the actual activities associated with waste handling and emplacement.

Schedule Assumptions

1. Treatment units would be capital projects.
2. The operational life of WIPP would be 35 years.
3. Funding is unconstrained for the purposes of developing the schedules.
4. The Baseline and Shred and Compact scenarios are assumed to have the shortest schedules because they employ the simplest technologies, followed in order of complexity by Shred and Compact, Enhanced Cement, Supercompact and Plasma.
5. Durations for the Resource Conservation and Recovery Act permitting and National Environmental Policy Act documentations increase for the Plasma melter because of the likelihood of significant public and agency comments.

C-6.3 FACTOR 8: IMPACT ON OTHER WASTE DISPOSAL PROGRAMS

C-6.3.1 Scope and Tasks of Subcommittee

This factor is defined in the EACBS as the determination of the major impacts an Engineered Alternative (EA) will have on other waste disposal and processing programs, including low level and mixed low level waste. Major impacts were assessed based on additional waste generated by TRU waste processing EAs in accordance with the guidance outlined in 40 CFR 194 Section 194.44(c)(1)(viii) Engineered Barriers which stated: "In conducting the evaluation of engineered barriers alternatives, the following shall be considered, to the extent practicable: The impact, if any, on other waste disposal programs from the incorporation of engineered barriers (e.g. the extent to which the incorporation of engineered barriers affects the volume of waste.)" Non-processing or backfill-type EAs did not impact the assessment.

C-6.3.2 Adequacy of Requirements and Criteria:

40 CFR 194 specifies the 8 factors required to be evaluated in this EACBS. As such the adequacy of the requirements and criteria governing the conduct of this work are considered to be fixed and are not subject to modification as a result of this peer review. Other requirements which relate to this study are found in 40 CFR 191.

C-6.3.3 Validity of Assumptions:

A large number of assumptions are utilized, some inherent and others explicit, in the evaluation of Factor 8. Each of these key assumptions is listed and discussed in the following section:

- Treatment processes evaluated, other than plasma processing which assumes no secondary waste generation, are assumed to generate waste volumes similar to cementation processes currently in use at the Rocky Flats Plant. Further it is assumed that any new cementation processes at other DOE facilities will generate similar volumes. The EACBS used a volume increase factor of 1:2.5 which results in 0.75 drums of secondary waste generated per drum of input waste. Further, the report uses an average of 0.3 drums of secondary waste generated per drum of output cemented waste. Types of secondary waste include: oil, glovebox gloves, glovebox filters, line metal, non-line wet combustibles, line wet combustibles, non-line metal, plastic, personal protective equipment (PPE), dry combustibles, laboratory waste, cement, empty bottles, sludge, filtrate, insulation, glass, etc.

  Assuming the calculations to support the volume increases are accurate (and there is no reason to believe they are not accurate because they make sense intuitively and spot checks verified some of the calculations), this is a safe and conservative assumption, one that is key when determining life-cycle cost, schedule, and scope for a project. It would

be a great help to the reader and for the EACBS to clearly show where and how these volumes were derived, and to provide an example. This assumption may over-estimate the volumes of secondary waste to be processed, handled, and disposed, but this over-estimation is not expected to be significant in the overall waste handling and disposal process. One key area where this assumption may have a larger impact in the future is during the actual waste emplacement process. Based on this assumption, one can safely assume WIPP operations will plan for the appropriate amount of storage space. If this amount is greatly overestimated it will not have significant impacts because well before the additional space has been mined, these estimates will be refined. Further, waste estimates from DOE sites are typically highly variable and are subject to change as each site learns more about its waste inventory and as regulatory requirements change. Thus, this assumption is valid in the context of EACBS but should be revisited periodically to determine the implications of the new knowledge each site will gain with respect to their waste inventory volumes. The text of the report does not clearly state it, but the volumes of waste exiting the different treatment processes do change based on the type of treatment the waste undergoes (e.g., cementation produces the largest volume of secondary waste and compaction produces a smaller volume.)

These sections of the report (3.8 and Appendix R) are difficult to follow at times. The subcommittee recommends these sections be revised to clearly show the rationale for and an example of all volumes (before, during and after treatment). It is not clear in reading the report the tie between the fractional increases (0.3 and 0.75) in waste volume, including whether these percentages are additive or mutually exclusive. The subcommittee further recommends this revision not take place until sometime in the future when the document will be revised for other purposes (i.e., the subcommittee's request is not sufficient justification to revise the document until there are other reasons to modify the report.) It is important to note that in talking with the authors of the EACBS telephonically and in person, subcommittee 3 gained an understanding of the basis used in the EACBS. The following information shows the relation of the changes in volume discussed above which has led to some confusion.

> 1 drum ——> treatment (this process adds 0.75 drums [based on the worst case scenario] additional waste per drum input waste) = 1.75 drums ——> secondary waste which increases by as much as 0.3 drums waste per drum of the previously treated waste (this process can add as much as 0.525 drums because the volume of secondary waste is based on the output volume of the treated waste [i.e. 1.75 X 0.3 = 0.525 drums secondary waste generated as a maximum]) ——> which means that as much as 2.275 drums of waste may be generated from the initial 1 drum of input waste (1.75 + 0.525 = 2.275 drums of waste potentially generated per drum of input waste.)

This maximum volume increase only relates to those EAs with the highest treatment volume increase (i.e., cementation) and the largest number of applicable modules that generate secondary waste (e.g., characterization). Other EAs will have volumes ranging between the minimum and maximum and these differing volumes are so indicated in Table R-6.

- The waste characterization step, which is key in some aspects of the waste shipping process, is assumed to generate secondary low level waste at the same rate as the input treatment processes. This volume of waste has only been calculated for the volume of waste estimated to be in need of characterization, which amounts to approximately 30% of stored waste and 10% of projected waste. This volume of secondary waste generated is the same for the baseline and all alternatives because this step is required independent of the EA that may be implemented.

  All of the applicable waste is expected to undergo the same waste characterization processing regardless of the EA chosen, thus the estimated volume of characterization waste (21,848 cubic meters) is the same regardless of the alternative (i.e. the generation of this waste is independent of the EA, therefore the assumed volume is acceptable). Also, the assumption that the generation rate is the same as the input treatment process is reasonable. It would be beneficial to describe the characterization process envisioned, in detail, to ensure a complete understanding of the processes involved. This is especially important when one realizes that non-intrusive characterization methods will be employed to the maximum extent possible to minimize waste (i.e. maximizing the use of non-intrusive methods will reduce the volumes of waste generated).

- All secondary waste characterized as TRU or low level is assumed to be low level and all secondary waste characterized as TRU mixed, hazardous, or low level mixed is assumed to be low level mixed.

  This assumption conservatively estimates the volumes of these waste types the DOE complex low level waste programs will have to account for in their processes and plans. It is not clear by reading the report, however, how the volumes of waste destined for WIPP are factored in to the report (i.e. if the entire volume of secondary wastes are going to low-level waste disposal, then does the report count this waste twice?) It should be clarified for the WIPP operations personnel what the best estimate of the volume of waste they will be required to dispose of is.

- When a treatment process listed a generation rate as "variable" or "insufficient data" the EACBS used a generation rate based on similar processes or wastes.

  In spot checking the areas where the authors of the EACBS made assumptions concerning these generation rates, it was determined by the subcommittee that the author(s)' assumptions are valid and are applicable within the context they are used.

- When a generation rate was not identified based on volume, it was calculated using assumed densities based on Rocky Flats data and/or the Baseline Inventory Report (DOE, 1995b).

  This assumption is technically appropriate although it is difficult to follow the steps listed in the assumption in Appendix R where the volumes have been detailed. It would be a great assistance to the reader and end-user of this document to clarify the tie between the Baseline Inventory Report, the Rocky Flats data, the densities, the initial mass, Section 3.8 and Appendix R of the EACBS. Subcommittee 3 spot checked some of the specific rates that were derived from densities. The assumed rates are considered to be appropriate based on this review.

- The non-cementation EAs are assumed to generate similar volumes of secondary waste relative to the cementation EAs, on an input basis, other than plasma which is estimated to have no secondary waste.

  This assumption is adequate and considered to be conservative on the high side in estimating volumes. Cementation is well known for increasing waste volumes, sometimes significantly. Thus, the volumes estimated in the EACBS for the non-cementation EAs are expected to be higher than will actually be seen when the waste processing begins. Even in the worst case, secondary waste volumes from other (non-cementation) processes will not exceed the volume from cementation.

- The percentages of low level and mixed low level secondary waste generation varied considerably with respect to the type of processes evaluated in the report. Based on this variability the author(s) assumed 50 percent of the generated waste is low level and 50 percent is mixed low level.

  These estimates (50% for each waste type) are based on the calculated averages of 56% low level and 44% mixed low level waste generated from the processes evaluated. It is unclear from the report why 50% of each waste type was used in these calculations instead of the actual averages calculated. A suggestion is to add the information based on the calculated averages to the report which is not a difficult task but will provide the "best guess" of these waste volumes. When the individual DOE sites begin using the information contained in the report, a more accurate estimate will be desireable for planning purposes. Once again though, this information will be refined in the future and it is not critical for these values to be precise at this time. In fact these values cannot be precisely predicted at this time because the actual technologies that may ultimately be used have not yet been determined. The EACBS or similar report must be a living document that will be periodically updated as new information comes to light.

- The author(s) used two primary reports for total DOE waste inventories and projections, the 1993 Integrated Data Base Report (DOE, 1993) and the 1994 Mixed Waste Inventory

Report (DOE, 1994b). The inherent assumption in the use of these reports is they are accurate and represent each sites best estimate of their inventories.

These reports are widely used in the DOE community to estimate waste volumes. The data in the reports are by no means 100% accurate but they are the best information available at any one time. Significant effort goes into the preparation of the reports so it is not appropriate to second guess the data contained therein. It is critical to understand that projected waste volume data is a moving target and as additional data is learned at a particular DOE site, the volumes will be refined. In addition, site-specific agreements across the country will further determine the amount of waste generated, retrieved, and ultimately shipped to WIPP. Changing the volumes identified in the reports would be purely arbitrary at this time and would not provide DOE with a better basis in the EACBS. It is recommended, however, that the data in these reports can be reviewed in the future to determine if there have been any signficant changes that may impact the WIPP.

C-6.3.4 Alternate Interpretations:

There are several alternate interpretations that can be made with respect to the volume of secondary waste generated when the processes outlined in the EACBS are implemented. The majority of these alternative interpretations are a direct function of the assumptions made and thus they are no more correct than those identified in the report. Some of the specific modifications other than what has been discussed above include but are not limited to:

- Significant work is underway across the nation to minimize the volumes of waste generated in any and all waste treatment processes. As these technologies mature there will be new and potentially better techniques which can be used to reduce the volumes of waste the DOE complex must deal with. Consequently it is expected the processes used as the basis for the estimates found in the EACBS will be improved upon. Assuming this is true, the volumes identified in the EACBS will be on the conservative (high) side.

- DOE sites are actively working to refine non-intrusive characterization techniques such as real time radiography, integrity testing, drum venting, gas sampling, and passive/active neutron assay systems. Assuming these technologies prove to be successful, (and they are presently widely used and have been accepted by most individuals) the volumes of characterization waste will be reduced beyond what is described in the report.

- Estimates of secondary waste volumes after compaction could be better defined by contacting private industry and other organizations that perform this function. There are several companies involved in this process that can provide additional estimating information. Using the assumption that compaction will generate similar volumes in comparison to the other treatment processes results in an overestimation of the total waste generated. Consequently this number can be refined.

- The most significant alternate interpretation is that the EACBS only evaluated the impacts of secondary waste generation on other waste disposal and processing programs. As discussed above, 40 CFR 194 Section 194.44(c)(1)(viii) explicitly requires this information to be evaluated. However, the regulation does not specify this is the only impact that should be evaluated. It merely provides the effects of the EAs on waste volume as an example. Since this report is a cost/benefit study the subcommittee expected to see a clear and concise description of the costs and benefits of the EAs.

  Other impacts that could be assessed in this report include:
  - The life-cycle cost and schedule impacts on the waste generation sites as well as to WIPP. Although cost/schedule information is included in Section 3.7 of this report, a clear tie needs to be made between Sections 3.7 and 3.8. The subcommittee envisions a high level table with a textual description that can be added to Section 3.8 to describe this tie. This information is critical to maximize the usefulness of the EACBS to the DOE community and the public but is not expected to be incorporated into the report until other reasons dictate a revision or addendum is necessary.

  - DOE programs across the nation struggle with the question of "where do we ship our waste"? Consequently as more information is learned and waste quantities are further defined, the question provided in Factor 8 must be reconsidered. A specific example relates to buried waste which has not yet been accepted for disposal at WIPP. If this waste does eventually get shipped, there is a definite need to revise this section of the report with respect to the new volume data.

M

C-6.3.5 Uncertainty of Results and Consequences if They are Wrong:

It can be clearly stated that the results presented in the report are not accurate with respect to the volumes of waste that will be generated by the waste processing EAs and that they have a confidence interval associated with them. This confidence interval is qualitatively estimated by the subcommittee to be +10% to -25% (i.e., the volumes may be as much as 10% higher or 25% lower than estimated in the report). However, since there is no way to definitively know the volumes of waste that will be generated, there is no need to quantify the associated waste volumes at this time. There are presently no serious negative consequences if the results are erroneous because the fact of the matter is the volumes identified in this report are based on the best available data and the methods used to determine the volumes are defensible.

C-6.3.6 Appropriateness and Limitations of Methodology and Procedures:

The procedures used to estimate the volumes are technically defensible and have sound justification. There are some limitations inherent in the approach used in the report including:

1. The basis for the volume estimates assumes the data provided in existing references is accurate. Although the information in these documents is not totally accurate, it is the best data available. The limitation is that all of this data is subject to change which can ultimately impact the results of this study. The results of the EACBS must be viewed as the first step. As the DOE complex clearly defines the processes they will use as they relate to this study, the volumes of secondary waste generated will also be better defined.

2. The methods used to estimate the volumes also have uncertainty built into them. The assumptions used however are defensible and are therefore considered to be acceptable.

C-6.3.7 Adequacy of Application:

The methods applied to the estimation of the volumes of waste generated have been discussed above. It is felt the techniques used were adequate to meet the intended goal of the EACBS report.

C-6.3.8 Accuracy of Calculations:

There are few calculations required to be conducted to support this section of the report, but the bases for the calculations necessary are not detailed in either Section 3.8 or Appendix R. As such it is not possible to definitively determine the accuracy of the calculations used (i.e. the tables simply show the results of the calculations and the text explains how the tables were developed.) It would assist the reader to add a minimum of one example showing how the data were derived. This will also support any future activities which will be necessary when a revision to the report or data contained in the report is required.

Based on the textual description of the techniques used to estimate the volumes however, the process used appears to be appropriate according to the end use of the data. The subcommittee did perform spot checks on the data that are presented in the tables (such as averages) and found these to be accurate.

During some of the subcommittee's spot checks it was noted that the report had slightly different values in comparison with the input data received from the authors of the report. These differences were minor and will not affect the results of the EACBS. During spot checks of the data found in Appendix O with the Baseline Inventory Report, several discrepancies were noted with respect to waste volumes (e.g., Table O-6 of Appendix O of the EACBS is not consistent with Table 6-1 of the Baseline Inventory Report). Although inconsistent, the data erred on the conservative side, once again. The subcommittee recommends that these data be quality checked during the next revision to the EACBS. The changes that result must be accounted for in the analysis of several of the other factors.

C-6.3.9 Validity of Conclusions:

The conclusions reached in Section 3.8 are valid and support the end use of the report. Once again, it is important to explain that the data described in Section 3.8 must be revisited as more information is learned regarding the processes that will be used at the WIPP as well as the rest of the DOE complex.

APPENDIX D

References

APPENDIX D

REFERENCES

Hartman, H.L., 1992, Society of Mining Engineers, *Mining Engineering Handbook*, 2nd Ed., Society of Mining Engineers.

Peters, M.S., and K.D. Timmerhaus, 1991, *Plant Design and Economics for Chemical Engineers*, 4th ed., McGraw Hill, Inc., New York, New York.

U.S. Congress, October 30, 1992, *Waste Isolation Pilot Plant Land Withdrawal Act*, Public Law 102-579.

U.S. Department of Energy, 1980, *Final Environmental Impact Statement, Waste Isolation Pilot Plant*, DOE/EIS-0026.

U.S. Department of Energy, 1990, *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant*, DOE/EIS-0026-FS, Office of Environmental Restoration and Waste Management.

U.S. Department of Energy, 1991a, *Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force*, DOE/WIPP 91-007, Revision 0, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy, 1991b, *Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, WIPP-DOE-069, Revision 4, Carlsbad, New Mexico.

U.S. Department of Energy, 1993, *Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capacities and Technologies*, DOE/NBM-1100, WIPP Project Integration Office, Albuquerque, New Mexico.

U.S. Department of Energy, 1994a, *Office of Environmental Management Programmatic Environmental Impact Statement*, DOE/EIS-0200.

U.S. Department of Energy, 1994b, *National Data Base System for the Final Mixed Waste Inventory Report, Draft User's Guide*.

U.S. Department of Energy, 1995a, *Engineered Alternatives Cost/Benefit Study Final Report*, DOE/WIPP 95-2135, Revision 0, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy, 1995b, *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report*, CAO-94-1005, Revision 1, Carlsbad, New Mexico.

U.S. Department of Energy, 1995c, *Comparative Study of Waste Isolation Plant Transportation Alternatives*, DOE/WIPP 93-058, Carlsbad, New Mexico.

U.S. Department of Energy, 1995d, *Draft Waste Management Programmatic Environmental Impact Statement*, DOE/EIS-0200-D.

U.S. Department of Energy, 1996, *Peer Review Procedure*, TP10.5, Carlsbad Area Office.

U.S. Environmental Protection Agency, 1985, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-level and Transuranic Radioactive Waste*, Title 40 U.S. Code of Federal Regulations Part 191, (40 CFR 191).

U.S. Environmental Protection Agency, 1996, *Criteria for the Certification and Re-certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations*, Title 40 U.S. Code of Federal Regulations Part 194, (40 CFR 194).

U.S. Nuclear Regulatory Commission, 1988, *Peer Review for High-level Nuclear Waste Repositories*, NUREG-1297.

APPENDIX E

Acronyms and Initialisms

ACRONYMS and INITIALISMS

CAO	Carlsbad Area Office
CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
CH	contact-handled
CPLM	cost per loaded mile
DAM	Design Analysis Model
DOE	U.S. Department of Energy
DSEIS	Draft Supplement Environmental Impact Statement
EA	Engineered Alternative
EACBS	Engineered Alternatives Cost/Benefit Study
EAs	Engineered Alternatives
EASWG	Engineered Alternatives Screening Working Group
EATF	Engineered Alternatives Task Force
EMPEIS	Environmental Management Programmatic Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ERPG	Emergency Response Planning Guidance
FEIS	Final Environmental Impact Statement
FSEIS	Final Supplement Environmental Impact Statement
FTE	Full Time Equivalents
IAEA	International Atomic Energy Agency
IUPAC	International Union of Pure and Applied Chemistry
K_d	distribution coefficient
KW	kilowatts
MJ/m^3	mega joules per cubic meter
MPa	megaPascals
MRE	Measure of Relative Effectiveness
MRU	Measure of Relative Uncertainty
NUREG-1297	U.S. Nuclear Regulatory Commission *Peer Review for High-level Nuclear Waste Repositories*
PA	Performance Assessment
QA	Quality Assurance
RH	remote-handled
SNL	Sandia National Laboratories
TRU	Transuranic
UCS	unconfined compressive strength
WERC	Waste-management Education & Research Consortium
WIPP	Waste Isolation Pilot Plant
WMPEIS	Waste Management Programmatic Environmental Impact Statement

WASTE-MANAGEMENT EDUCATION & RESEARCH CONSORTIUM

Administrative Office:
New Mexico State University, Box 30001, Department WERC, Las Cruces, New Mexico 88003-8001, (505) 646-2038, FAX (505) 646-4149

MEMORANDUM

Date: August 29, 1996

To: James Muss; DOE-CAO
Steve Wagner; Westinghouse-WID

From: Abbas Ghassemi, Peer Review Manager

Re: Peer Review Panel response to DOE comments

Gentlemen:

The peer review of the EACBS was conducted in accordance with the U. S. Nuclear Regulatory Commission *NUREG-1297 Peer Review for High-level Nuclear Waste Repositories* (NRC,1988) and the DOE Carlsbad Area *Office Peer Review Procedure TP 10.5*(DOE, 1996).

One key component of the TP 10.5 is the formal verification of the independence of each peer review panel member, which was completed as a part of the EACBS peer review process. The documentation and the evidence for this process can be found in the records package of the EACBS peer review. If there are any questions, please do not hesitate to contact me at (505) 646-1719.

cc: Peer Review Panel Members

PEER 5 - Engineered Systems Data Qualification Peer Review

Title: ENGINEERED SYSTEMS PEER REVIEW (ESPR) PLAN 007

(Assistant Manager, Office of Regulatory Compliance, Carlsbad Area Office) Date: 6/25/96

1. INTRODUCTION

This Engineered Systems Peer Review (ESPR) Plan describes the peer review and documentation the Waste Isolation Pilot Plant (WIPP) Project will use to ensure that the data used in the models describing engineered systems for rock mechanics and shaft/borehole seals in the performance assessment (PA) are qualified for use in the demonstration of compliance.

1.1 BACKGROUND

In accordance with the regulatory requirements specified in 40 CFR Part 191 and implemented in accordance with the criteria specified in 40 CFR Part 194, section 194.22 (b), "Any compliance application shall include information which demonstrates that data and information collected prior to the implementation of the quality assurance program required pursuant to paragraph (a) (1) of this section (194.22) have been qualified in accordance with an alternate methodology, approved by the administrator or the administrator's authorized representative, that employs one or more of the following methods: peer review, conducted in a manner that is compatible with NUREG-1297, "Peer Review for High-Level Nuclear Waste Repositories"; corroborating data; confirmatory testing; or a quality assurance program that is equivalent in effect to ASME NQA-1-1989 edition, ASME NQA-2a-1990 addenda, part 2.7, to ASME NQA-3-1989 edition (excluding Section 2.1 (b) and (c) and Section 17.1)." The DOE has generally opted to employ the peer review methodology to qualify existing data that it cannot demonstrate was collected in accordance with a quality assurance program that was equivalent to the quality assurance defined above. Accordingly, a peer review will be conducted to confirm the adequacy and completeness of data utilized to define parameter values as applied in conceptual models and scenarios that have been determined to be significant to waste containment. To facilitate review of the data, the data qualification peer reviews have been divided into the following three associated waste containment subsystems:

- Natural barriers (Salado and non-Salado flow and transport);
- Engineered systems (rock mechanics and shaft/borehole seals); and
- Waste form and the disposal room.

Sandia National Laboratories (SNL) is responsible for the selection and development of conceptual models that reasonably define the WIPP containment system, and for the identification and development of mathematical models, numerical models, and computer codes utilized to assess the performance of the WIPP containment for the statutory confinement period. SNL is responsible for

identifying data for which it cannot provide assurance that the information was collected under a qualified quality assurance program (as defined above). These data will then be reviewed under a peer review process conducted in accordance with NUREG-1297. Therefore, to meet the regulatory requirements cited above, this peer review on engineered systems for rock mechanics and shaft/borehole seals will assess the qualification of data used in performance assessment for the WIPP.

1.2 PURPOSE

The purpose of this WIPP peer review plan is to define the peer review process that will be conducted to *determine if (Rev. 1)* existing unqualified experimental subsystems data and information *are qualified to be (Rev. 1)* used in the demonstration of compliance. As stated above, the DOE has determined the peer review process to be the most appropriate method to demonstrate that all engineered subsystems are qualified for use in the demonstration of compliance. These peer reviews will be conducted in accordance with the requirements of NUREG-1297 that state, "A peer review is a documented, critical review performed by peers who possess qualifications at least equal to those of the individuals who conducted the original work. These individuals must be independent of the work being reviewed; independence from the work reviewed means that the peer, a) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed."

1.3 SCOPE

This ESPR Plan describes the peer review process that the DOE Carlsbad Area Office (CAO) will utilize for the review of those existing data and information that form the basis for determining the parameter values of the conceptual models that form the engineered systems subsystems. The peer review will be an in-depth critique of assumptions, alternate interpretations, methodology, and acceptance criteria employed, and of the conclusions drawn in the original work. This ESPR Plan defines the approach, methods, criteria, schedules, deliverables, and resources required for conducting the ESPR to confirm: 1) the adequacy and completeness of the data; and 2) the data and information are qualified for use in the demonstration of compliance. See Attachment A for a description of the data to be reviewed and its intended use in PA.

The conceptual models and codes to be used in the PA of the engineered systems include:

Engineered Systems - Rock Mechanics and Shaft/Borehole Seals

Model	Code
Disposal Room Geometry	BRAGFLO
Creep Closure	BRAGFLO
Repository Fluid Flow	BRAGFLO
Shafts and Shaft Seals	BRAGFLO
Disturbed Rock Zone	BRAGFLO

Existing unqualified data and information which was utilized to establish the parameter values will form the basis of this ESPR.

2. PEER REVIEW PLANNING AND IMPLEMENTATION

2.1 APPROACH

The DOE-CAO has prepared the "Office of Regulatory Compliance (ORC) Team Procedure for Peer Review" (TP 10.5) to document the approach for conducting the peer review process. The ESPR Panel will conduct the peer review activities for the qualification of data in accordance with TP 10.5, this Plan and IDI 1.0.

Similarly, SNL has prepared a procedure to provide the data and information necessary to support peer review of the qualification of data. The SNL data packages to be provided to the ESPR Panel will include: 1) identification of the applicable conceptual model parameter(s); 2) assignment of a parameter value or range of values; 3) description of the source of the data used to construct the parameter value or ranges of values; 4) a description of the process whereby the data was scaled up to parameter value(s); and 5) designation of data qualification status.

2.1.1 DATA USED IN THE DEMONSTRATION OF COMPLIANCE

The peer review of existing unqualified SNL data and information (see Attachment A) is to confirm and document its adequacy and completeness. The data and information qualification peer review will confine itself strictly to providing this confirmatory information.

2.1.2 COMPOSITION OF PEER REVIEW PANEL

The ESPR Panel will be composed of a minimum of three individuals who meet requirements identified in TP 10.5. The duration of the ESPR Panel review process is expected to last between three to six weeks. The ESPR Panel may include up to two members of the Conceptual Model Peer Review Panel. The peer review selection committee will appoint the remaining panel member(s) based on his/her technical expertise which will be equivalent to that required to do the original work. Experience areas to be represented on this panel include geotechnical/mining/civil engineering and geohydrology.

Through a formal orientation process, each panel member will become familiar with the WIPP containment system and the basis of the engineered systems models, data, parameters and information that describe the containment system. In addition, panel members will be provided with a basic description of how the models are represented in numerical models, algorithms, and codes. The peer reviewers will be familiarized with the parameter inputs to the PA codes and the results of prior PAs, sensitivity analyses, and critical comments from previous reviews. Each peer reviewer will be selected, oriented, and trained in accordance with approved procedures.

2.1.3 LOGISTICS AND MANAGEMENT

When the ESPR Panel convenes to perform the peer review process, the intent is to have all the data packages accessible for review. However, not all information necessary to support peer review of the qualification of data for the engineered systems may be available at the beginning of the review. Therefore, it may be necessary to conduct the ESPR in a phased manner, depending upon the availability of information.

2.2 METHODOLOGY

The ESPR will follow the methodology provided in NUREG-1297 as augmented by the specific requirements contained in 40 CFR Part 194.22. The purpose for conducting a peer review of data associated with this WIPP subsystem is to ensure that those data that cannot be qualified by virtue of their collection under a QA program (equivalent in effect to ASME NQA-1-1989 edition, ASME NQA-2-1990 addenda, part 2.7, ASME NQA-3-1989 edition [excluding Section 2.1 (b) and (c) and Section 17.1]) are qualified for use in the demonstration of compliance. To facilitate the conduct of the peer review, a checklist containing potential areas of review is included in this plan as Attachment B. The basis of the peer review will be to determine the adequacy and completeness of specific unqualified data used to demonstrate compliance. Adequacy criteria are provided in Section 2.3.

2.3 ADEQUACY CRITERIA

Adequacy of data associated with the conceptual models that nominally comprise the engineered systems subsystem will be based on the peer review panel's determination that these data meet commonly accepted technical and scientific standards. Criteria utilized to make this determination include:

- Adequacy of requirements and criteria;
- Validity of assumptions;
- Alternate interpretations as appropriate;
- Uncertainty of results and consequences if wrong;
- Appropriateness and limitations of methodology and procedures;
- Adequacy of application;
- Accuracy of calculations; and
- Validity of conclusions.

In evaluating the existing data, the peer review panel shall also consider the following:

- The sources of the parameters and data, e.g., professional judgment, published source material, field tests, laboratory experiments, etc.;
- The processes used to produce the parameters from data are appropriate for the intended use; and
- The assumptions, calculations, extrapolations, interpretations, methods, and conclusions pertinent to the data are appropriate for the development of parameters used as input to the WIPP PA and are traceable.

2.4 SCHEDULE

The PR Manager, working closely with SNL, has developed a preliminary schedule that provides the necessary information on an "as available" basis. Flexibility is required by all supporting organizations, (i.e., DOE-CAO, SNL, the PR Manager, staff, and panel members) to accommodate the peer review

schedule and any changes made due to uncertainty in the timing of data availability. Attachment C contains a schedule of ESPR activities and milestones in accordance with the Peer Review Management Plan. This schedule will serve as the baseline schedule from which requested schedule deviations will be evaluated and approved, if appropriate. Revisions to the baseline schedule will not require revision to this plan but will be attached to the plan by reference.

2.5 DELIVERABLES

A final report for the ESPR will be submitted to DOE-CAO. A list of mandatory topics and suggested outline for the final ESPR report is provided in Attachment D. This outline may be utilized to guide the review of each data package to ensure adequate review of the data packages.

3. QUALITY ASSURANCE

The ESPR process will be conducted in a controlled manner and in compliance with TP 10.5.

4. RECORDS MANAGEMENT

Records and documents generated as a result of peer review activities defined in this peer review plan are identified in the CAO Team Procedure, TP 10.5. ESPR records will be assembled and maintained in accordance with the Peer Review Management Plan and the Informatics Desk Instruction, IDI-1.0. Upon completion of the peer review process, a complete set of ESPR records will be delivered to CAO. Ultimately, peer review records will be dispositioned in accordance with DOE-CAO records management requirements.

5. DOCUMENT CONTROL

All plans, procedures, and other documents which require document control will be handled in accordance with applicable DOE-CAO controlled document procedures (MP 4.4).

ATTACHMENT A

PEER REVIEW PANEL DATA PACKAGE DESCRIPTIONS

M

DATA	INTENDED USE
Salado Mass Concrete Bulk Modulus (Pore Volume Compressibility)	Shaft Seals
Salado Mass Concrete Porosity	Shaft Seals
Crushed Salt Bulk Modulius Analysis Basis	Shaft Seals
Crushed Salt Permeability	Shaft Seals
Concrete Permeability	Shaft Seals
Clay Permeability	Shaft Seals
Waste Densities	Disposal Room
Waste Mechanical Properties	Disposal Room
Initial Waste Water Content	Disposal Room
Waste Intrinsic Permeability	Disposal Room
Cuttings, Cavings, Spallings, including Cementation Strength	Disposal Room
Final Porosity Surface Data	Disposal Room
Halite and Anhydrite	Rock Mechanics
Transition Zone Properties	Disturbed Rock Zone

ATTACHMENT B

SUGGESTED METHODS CHECKLIST

PEER REVIEW CHECKLIST	
STUDY/EXPERIMENT IDENTIFICATION	
	COMMENTS
1.0 Scientific Technical Items	
1.1 Were the technical objectives clearly stated in documents accompanying the data?	
1.2 Are all the stated objectives addressed by the data?	
1.3 Was there any test-to-test interference and/or was the impact of test-to-test interference on results adequately evaluated?	
1.4 Were the tests performed in accordance with: a) nationally recognized standards?	
b) modified recognized standards or specially prepared test procedures?	
c) modified recognized standards or specially prepared test procedures?	
d) If so, are they documented in sufficient detail to be repeatable?	
e) Were they justified, evaluated, and approved by a cognizant individual/organization?	
1.5 Were the test procedures correctly implemented?	
1.6 Were testing irregularities and interruptions described?	
1.7 Was documentation of corrective actions sufficiently detailed?	
1.8 Were data reduction processes appropriate for the objectives of the test?	
1.9 Is the reduced data a true representation of all raw data acquired?	
1.10 Are the interpretations well supported by the data?	
1.11 Is the data quality adequate?	
a) Does the age of the data affect the results?	
b) Were the analytic methods used adequate?	
c) Were detection limits adequate?	
d) Is the range of uncertainty associated with each measurement adequate to satisfy the objectives of the test?	
e) Is the uncertainty associated with the cumulative data low enough to make a decision?	
f) Has invalid data been identified?	
g) Has valid data been characterized by providing qualitative or quantitative statements as to the validity and use?	
h) Is there a redundancy in measurements that provide checks of/on the data?	
1.12 Were the number of data points taken enough to provide an adequate level of confidence in the results?	
1.13 Is there internal consistency between the sets of data for similar tests?	
1.14 Are the data complete?	
1.15 Can credible blocks be improved, or supported by: a) correlation with complementary or confirmatory data?	
b) additional work?	
1.16 Is any source of confirmatory data identified in database documents?	

1.17 Is the data good enough to support the intended use?	
2.0 Summary of Conclusions	
2.1 Did the data meet adequacy of requirements and criteria?	
2.2 Did the data show validity of assumptions?	
2.3 Were there alternate interpretations of the data?	
2.4 Was there a discussion of uncertainty of results and consequences?	
2.5 Was there appropriateness and limitations of methodology and procedures?	
2.6 Was adequacy of application demonstrated for the data?	
2.7 Was the accuracy of calculations demonstrated?	
2.8 Was the validity of conclusions demonstrated?	
2.9 Were the sources of the parameters and data considered in evaluating the existing data?	
2.10 Were the processes used to produce the parameters from the data appropriate for the intended use?	
2.11 a) Were the assumptions, calculations, extrapolations, interpretations, methods, and conclusions pertinent to the data appropriate for the development of parameters used as input to the WIPP PA?	
b) Were they traceable?	

ATTACHMENT C

ENGINEERED SYSTEMS PEER REVIEW SCHEDULE

	DRAFT	FINAL
ESPR Plan	3/11	3/29
PR Panel Assigned	NA	4/12
ESData Package to PR Manager	4/5	4/12
Initiate ESPR	NA	4/22
Complete ESPR	NA	5/31
Submit ESPR Report	6/7	6/14

ATTACHMENT D

PEER REVIEW REPORT OUTLINE

Executive Summary

1. Introduction
2. Purpose
3. Description of Work Performed
4. Evaluation Work Performed
   - A. Adequacy of Requirements and Criteria
   - B. Validity of Assumptions
   - C. Alternate Interpretations
   - D. Uncertainty of Results and Consequences if Wrong
   - E. Appropriateness and Limitations of Methodology and Procedures
   - F. Adequacy of Application
   - G. Accuracy of Calculations
   - H. Validity of Conclusions
5. Conclusions
6. Dissenting Views
7. Summary
8. Signatures
9. Peer Review Members and Acceptability

ENGINEERED SYSTEMS DATA QUALIFICATION

PEER REVIEW REPORT

M

FINAL REPORT

WASTE ISOLATION PILOT PLANT ENGINEERED SYSTEMS DATA QUALIFICATION PEER REVIEW REPORT

A PEER REVIEW

CONDUCTED BY

Dermot Ross-Brown, John Gibbons, Darrell Porter, John Schatz

for

U. S. Department of Energy
Carlsbad Area Office
Office of Regulatory Compliance

July 1996

FOREWORD

The Environmental Protection Agency promulgated "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule" in Code of Federal Regulations, Title 40, Part 194 (40 CFR Part 194) on February 9, 1996. The 40 CFR Part 194 regulation prescribes three specific peer reviews and also provides the opportunity for the Department of Energy to utilize peer reviews, conducted in accordance with NUREG 1297, as a means of qualifying data and information for use in the demonstration of compliance.

This report contains the results of a peer review of specific engineered system parameters used in the demonstration of WIPP compliance with 40 CFR Part 194. To ensure the independence of this review, the Department of Energy has directed the assignment of an independent contractor to administratively manage the peer review activities. Peer reviewers were selected based on their demonstrated independence from the work being reviewed and their technical expertise in the subject matter to be reviewed. The peer review panel members collectively possess an appropriate spectrum of knowledge and experience in the subject matter reviewed.

This peer review was conducted in compliance with the quality assurance requirements as defined in 40 CFR Part 194.

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ACRONYMS AND ABBREVATIONS

SNL	Sandia National Laboratory
SMC	Salado Mass Concrete
DRZ	disturbed rock zone
WIPP	Waste Isolation Pilot Plant
PA	performance assessment
WES	Waterways Experiment Station
IRT	Independent Review Team
SSSPT	Small-Scale Seal Performance Tests
QA	quality assurance
DCCS	dynamic compaction of crushed salt
ASTM	American Society for Testing Materials
PDF	probability density function
CH	contact-handled
TRU	transuranic (waste)
WAC	waste acceptance criteria
INEL	Idaho National Engineering Laboratory
DOE	U.S. Department of Energy
RFP	Request for Proposal
CDF	cumulative distribution function
RM	reduced modulus
MD	Multi-Deformational
MDCF	Multimechanism Deformation Coupled Fracture

1.0 EXECUTIVE SUMMARY

The Engineered Systems Peer Review was conducted by four panel members (Panel), who examined the 14 parameters (or parameter groups) submitted to them for qualification by Sandia National Laboratories (SNL). The 14 parameters are listed in Table 1.1, together with the qualification status for each that resulted from this review.

Table 1.1. Summary of Qualification Status of Parameters, as a Result of the Engineered Systems Peer Review

Subsystem	Parameter Name	Qualification of Parameter
Shaft/Shaft Seal	Porosity of Salado Mass Concrete (SMC)	Qualified
	Pore Volume Compressibility of SMC	Minor change to value suggested
	Bulk Modulus of Crushed Salt	Qualified
	Permeability of Crushed Salt	Requires further analysis by SNL
	Permeability of SMC	Qualified
	Permeability of Compacted Clay	Qualified
Disposal Room/Rock Mechanics	Initial Density of Waste	Qualified
	Mechanical Properties of Waste	Qualified
	Initial Water Content of Waste	Qualified
	Permeability of Consolidated Waste	Minor change to value suggested
	Strength of Waste for "Blowout"	Insufficient data to qualify
	Properties of Halite and Anhydrite	Qualified, based on limited review
	Data on Final Porosity Surface	Qualified, based on limited review
Disturbed Rock Zone	Characterization of Disturbed Rock Zone	Concepts qualified

In summary, the Panel was able to qualify seven of the well-defined parameters, and two of the parameter groups (properties of halite and anhydrite, and data on final porosity surface) based on a limited review. In the opinion of the Panel, minor changes should be made to an additional two parameters (pore volume compressibility of Salado Mass Concrete (SMC), and permeability of consolidated waste).

It is the opinion of the Panel that further analysis by SNL is needed on the permeability of crushed salt, and the strength of the waste for the "blowout" scenario. With regard to the disturbed rock zone (DRZ) around the shaft, the Panel concurred with SNL's general treatment of the DRZ from an engineering point of view.

A summary of the evaluation of the individual parameters follows:

- Porosity of SMC. The Panel is able to qualify the value of 5%. However, this value is not a unique property of SMC; rather it is a property that needs to be controlled in the field during the mixing and placing of the concrete.

- Pore Volume Compressibility of SMC. There were little data in the data package to enable this value to be calculated. The Panel was able to find some new data which SNL should consider in deriving a modified value for this parameter.

- Bulk Modulus of Crushed Salt. The Panel was able to qualify the values for this parameter (ranging from 5.74 to 20.67 GPa) at five different time intervals during the consolidation process.

- Permeability of Crushed Salt. Based on current data, the Form 464 values may be too low; however, new data being analyzed by SNL may establish the validity of these values or lead to their modification. The Panel is unable to form a conclusion until this analysis is completed.

- Permeability of SMC. The Panel concurs with the selected values for this parameter. Up to 400 years this is a triangular distribution with a best estimate of 1.78×10^{-19} m^2. After 400 years the SMC is assumed to deteriorate and acquire the permeability of a dense soil with a best estimate value of 1×10^{-14} m^2.

- Permeability of Compacted Clay. The Panel is able to qualify the value of 5×10^{-19} m^2 for the bentonite seals. The validity of this number depends to a large extent on how the bentonite is emplaced during construction and its consistency, particularly with regard to density.

- Initial Density of Waste. The Panel concurs with the average value of 559.5 kg/m^3, which is used for room porosity calculations of the current inventory.

- Mechanical Properties of Waste. The Panel is able to qualify five elastic-plastic constants for the waste, together with a pressure-relative density table for the waste during the consolidation process. These values are appropriate for use in disposal room closure calculations.

- Initial Water Content of Waste. The Panel is able to qualify the value of 1.5%, which represents the initial waste container saturation by volume.

- Permeability of Consolidated Waste. Based on a review of the data and discussions with SNL, a new value of 2.4×10^{-13} m^2 has been calculated by SNL.

- Strength of Waste for "Blowout." There are little data to support any value for this parameter, and the Panel's opinion is that further analysis be undertaken by SNL.

- Properties of Halite and Anhydrite. The Panel is able to qualify these parameter values for use in mechanical response models for room closure predictions.

- Data on Final Porosity Surface. The porosity surface is a valid method of describing disposal room closure as an input to BRAGFLO. The Panel is able to qualify the final porosity surface as defined in WPO#35697.

- Characterization of the DRZ. The Panel concurs with the engineering concepts regarding the DRZ and its impacts on effective shaft sealing. The Panel was not asked, however, to qualify any parameter values.

2.0 PURPOSE

The purpose of the Engineered Systems Peer Review was to seek qualification of scientific data by performing a systematic qualifying review of unqualified parameters and subsystems used in the models describing engineered systems for rock mechanics and shaft/shaft seals in the Waste Isolation Pilot Plant (WIPP). This review is one of three recognized methods for providing assurance that scientific data collected are qualified for intended use. A peer review panel (Panel), consisting of four members, was convened to undertake the work. The peer review was conducted in a manner that was compatible with NUREG-1297, Peer Review for High-Level Nuclear Waste Repositories. This report is a documented summary of the Panel's work and of the evaluation performed on selected parameters identified by Sandia National Laboratory (SNL). The report is intended primarily for use by the technical personnel at SNL/WIPP. It may also be included as supporting material in the WIPP Compliance Certification Application submitted to the Environmental Protection Agency.

The parameters evaluated consisted of information used as input to the WIPP performance assessment (PA), which in turn is to be incorporated in the demonstration of compliance. The Panel evaluated existing data and information that form the basis of the parameter values used in the mathematical expression of conceptual models for the engineered systems and subsystems. The parameters selected for evaluation had not previously been fully qualified for use in PA. The conceptual models used in the performance assessment of the engineered systems include components of 1) Disposal Room Geometry, 2) Creep Closure, 3) Repository Fluid Flow, 4) Shafts and Shaft Seals, and 5) Disturbed Rock Zone.

3.0 DESCRIPTION OF WORK PERFORMED

The Engineered Systems Peer Review Panel evaluated 14 parameters, parameter sets and data sets against the eight review criteria cited in NUREG-1297. The review involved selected elements of the following subsystems listed in Table 3.1: 1) Shaft/Shaft Seals, 2) Disposal Room, 3) Rock Mechanics, and 4) Disturbed Rock Zone. In some subsystems, individual parameter values were evaluated and a determination made of their adequacy as used in the WIPP performance assessment program. In several instances, sub-parameters of parameter sets were evaluated to determine their collective contribution to a subsystem concept. This approach resulted in some parameters treated to varying levels of detail in which their intended uses were evaluated with respect to their application in lieu of the effect of their quantitative value.

The Panel performed an in-depth critique of assumptions, alternate interpretations, methodology and acceptance criteria employed, and of the conclusions drawn in the original work. In evaluating the existing unqualified data, the peer review panel members considered the following:

- The sources of the parameters and data (e.g., professional judgment, published source material, field tests, laboratory experiments, etc.).
- The appropriateness of the parameters and data for their intended use.
- The assumptions, calculations, extrapolations, interpretations, methods, appropriateness, validity, sensitivities, and conclusions pertinent to the parameters and data used as input to the WIPP performance assessment.

The Panel, in conducting its work, reviewed information packages provided by SNL for each parameter. In addition, technical reports and documents obtained from the SNL waste management library and records center were used to supplement the information in the parameter packages. Both formal and informal technical discussions were held with SNL principle investigators to more fully understand the concepts and parameter derivation and application in the PA. Table 3.1 identifies the subsystems, parameter names, and number of parameters and sub-parameters the Panel evaluated. The Panel collectively devoted about 20 man-weeks of effort to the technical review and this report.

Table 3.1. Listing of Parameters With Approximate Number of Parameters and Sub-Parameters

Subsystem	Parameter Name	Number of Parameters and Sub-Parameters
Shaft/Shaft Seal	Porosity of Salado Mass Concrete (SMC)	1
	Pore Volume Compressibility of SMC	3
	Bulk Modulus of Crushed Salt	6
	Permeability of Crushed Salt	19
	Permeability of SMC	9
	Permeability of Compacted Clay	33
Disposal Room/Rock Mechanics	Initial Density of Waste	6
	Mechanical Properties of Waste	6
	Initial Water Content of Waste	1
	Permeability of Consolidated Waste	3
	Strength of Waste for "Blowout"	1
	Properties of Halite and Anhydrite	94
	Data on Final Porosity Surface	110
Disturbed Rock Zone	Characterization of Disturbed Rock Zone	

4.0 EVALUATION OF SHAFT/SHAFT SEAL PARAMETERS

4.1. Porosity of SMC

4.1.1. General Evaluation

SMC is a specially-designed salt-saturated concrete that is compatible with the salt host rock. It is durable, has low permeability and provides a viable seal in the shaft, with adequate strength to support overlying seal components and promote natural healing processes within the DRZ in the salt around the shaft.

There are three identical concrete components in the Salado shaft sealing system, each one composed of three elements: an upper concrete plug, a central asphalt waterstop and a lower concrete plug. The overall design length of each component is 15m. There is also a 6m SMC plug in the Rustler formation. In addition, SMC is used to construct a concrete monolith at the base of the shaft; however, this is not considered to be part of the shaft sealing system (Sandia WIPP, 1996, pp. 25-29).

The porosity of the SMC is a basic property of the hardened concrete that influences other properties, such as strength and permeability, important to performance assessment of the shaft seal system. Porosity is used also to derive a key BRAGFLO parameter, the pore volume compressibility of SMC (see Section 4.2). The value assigned to the porosity of the SMC is 0.05 or 5% (Form 464, Parameter #2484).

4.1.2. Adequacy of Requirements and Criteria

The requirement is to know the porosity of the concrete, i.e., the proportion of the total volume of the cured concrete that is voids, expressed as a percentage by volume (ASTM C457-90). It excludes the submicroscopic voids within the aggregate and the cement paste. The volume of void space is often measured by absorption (taking a dry specimen, immersing it in water and measuring the increase in weight). Various other procedures can be used that may provide a wide range of results (Neville, 1973, pp. 383-4).

Porosity can also be measured microscopically in both hardened concrete (ASTM C457-90) and freshly mixed concrete by observing the change in volume of a concrete sample with a change in pressure (ASTM C231-91b). Both methods were employed in evaluating SMC at the U.S. Army Corps of Engineers Waterways Experiment Station (WES).

Note that the concrete industry uses its own terminology. For instance "air content" refers to the proportion of air voids in the total volume of concrete, where "air voids" are usually more than a few mm in diameter; the term includes both entrapped and entrained voids. A "water void" is a void occupied by water at the time of setting (ASTM C457-90, p. 1). The terms air content, percentage of air voids, and quantity of air entrainment are often used loosely to mean the same as the definition of porosity given above.

Air entrainment, often induced using pozzolans and special procedures, is a desired feature of mass concrete since it produces a marked improvement in durability, plasticity and workability, together with a reduction in segregation and bleeding. There is also a reduction in strength, which can be minimized in the design process by reducing the quantity of paste, increasing aggregate size and reducing the water-cement ratio. Hence, air entrainment is a desireable quality in concrete, especially in concrete subject to freezing and thawing, provided that the air voids are uniformly distributed within the concrete and the overall air content generally meets recommended values of about 3 to 4.5% (e.g., Table A5.6 in ACI, 1993). The Panel considers that the inclusion of Class F fly ash and the 4.5% porosity obtained from the truck-mixed concrete at WES places SMC in the air-entrained category (ACI, 1993, No. 211.1-91, p. 8).

4.1.3. Assumptions

It is generally implied in the documentation that the different methods of measuring porosity employed at WES yield comparable values of concrete porosity, and that these values are appropriate for correlation with fluid flow as well as strength properties of the concrete. It is also assumed that the test samples are representative of the SMC that eventually will be used to construct the shaft seals.

4.1.4. Alternate Interpretation

As mentioned in Section 4.1.2, there are different levels of porosity in concrete depending upon the measurement scale used. For example, Neville (1973) p. 383, states that the gel pores in the cement paste constitute about 28% of the paste volume, and that capillary pores within the cement paste can vary between 0 and 40% of the paste volume depending on the water/cement ratio and the degree of hydration. In addition, the coarse and fine aggregate particles themselves contain pores. Such measurements of submicroscopic porosity are often valuable in concrete research, but they are not used in normal porosity evaluations.

The definition of porosity discussed in Section 4.1.2 is a purely practical one. It includes only the interconnected pores and the larger entrained air bubbles. It is often used as an index value for

correlating porosity with strength and permeability of the hardened concrete under field conditions, although these correlations tend to be imprecise. Despite the limitations mentioned above, the concrete industry has developed a large body of information on concrete porosity and related field behavior, and there are no other practical alternatives to using industry standards at this time.

4.1.5. Uncertainties and Consequences

Due to heterogeneities, measurements of porosity will vary throughout a concrete sample, similar to measurements of porosity in geologic materials such as clay and argillaceous salt. For practical purposes, an average porosity value is usually sufficient for problems at "room scale" or "repository scale."

Different measurement techniques can yield different results, so caution should be taken in comparing results obtained by different methods (Aarre, 1995); comparisons between porosities obtained using the same method are generally more meaningful. In the WES documents, differences in porosity obtained by the different measurement techniques are not discussed. Also, there is little or no discussion as to which measurements of porosity are most meaningful for deriving parameters related to fluid flow, such as pore volume compressibility (see Section 4.2).

Concrete is unlike most geologic materials in that engineers can design the mix to meet specific performance goals; this can include a small, defined range of values for the porosity. Whether these goals are met in practice depends on the care taken to mix and place the concrete during construction. This requires the implementation of a strict process and quality control program, including frequent sampling and testing of the concrete itself, as well as its individual constituents.

The consequences of poor design and poor quality control are that porosities in the field could be highly variable, incompatible with design specifications, and/or unknown. This could lead eventually to loss of function, i.e., the concrete might not be strong enough or impermeable enough to fulfill its function as a sealing component.

4.1.6. Appropriateness and Limitations of Methodology and Procedures

The determination of the porosity of the SMC is largely based on the experimental work reported in Wakeley et al., 1995. This experimental work consisted of measurements on small experimental batches and large volume batches (approximately 5 yd^3) of salt-saturated concrete produced between April 1993 and February 1994.

The small experimental batches ranged in size from 1.5 to 14.0 ft^3 (these are the units reported by Wakeley et al., 1995). Each batch was a variation of SMC mixtures identified in previous studies as being likely candidates for use in shaft seals at the WIPP. Hence, the batches were similar in composition. They were mixed intermittently for two hours using the procedure outlined in Appendix B of Wakeley et al., 1995. Air entrainment measurements were made at two distinct times in each batch, once at the beginning of the mixing and once at the end of mixing (approximately after 2 hours). The values of air entrainment, as summarized in Table 4-2 of RE/SPEC (1996), ranged from 1.1 to 3.3%. Measurements at the start of mixing averaged 2.05% and measurements at the end of mixing averaged 1.91% air entrainment.

Two large-volume batches were prepared from pre-bagged materials and mixed in a truck-mounted concrete mixer, using the procedure described in Wakeley et al., 1995, pp. 22-25. Air entrainment values measured for the 161SM3 and the 231SM3 mixtures during the two-hour mixing period ranged from 1.7 to 2.4%, with an average of 2.03%. This is similar to the air entrainment values measured in the small experimental batches.

A portion of each of these two batches was discharged into separate oval metal tanks approximately 4 ft by 8 ft by 3 ft deep, following the description found in Wakeley et al., 1995, pp. 30-32. Air entrainment data were obtained from concrete cores. The results are summarized in Table 4-3 of RE/SPEC (1996) and Table 4-6 of Wakeley et al., 1995. For batch 231SM3 (which was vibrated 12 times for a duration of 6-8 seconds for each insertion) the air entrainment values ranged from 1.5 to 3.2%, with an average of 2.23%.

For batch 161SM3 (which was vibrated four times for a duration of 3 seconds per insertion) the air entrainment values ranged from 3.3 to 4.5%, with an average of 4.08%; at the far end of this tank the air entrainment values averaged 4.45%.

Based on these tests, the following tentative conclusions may be drawn:

- During mixing, the air entrainment values are about 2% regardless of whether the batches are mixed in a laboratory mixer or in a 10 yd^3 mobile mixer.
- When cast in a monolith, the air entrainment values increased up to 4.5%; the values increased as the amount of vibration decreased and as the flow distance increased.

Hence, it would appear from the data in Wakeley et al. (1995) that the range for air entrainment in SMC is between 2 and 5% for SMC mixed and placed under conditions similar to that for batch 161SM3. In

practice, it is expected that flow distances of 2m beyond the discharge point of the tremie line will be representative of flow conditions when the SMC shaft seals are being placed. However, it is not planned to use vibration at WIPP. These issues are discussed further in Section 4.1.7.

Review of Laboratory Records

The two monoliths created from the large truck-mixed batches were cored and analyzed microscopically for total air content and evidence of possible aggregate segregation. These data are summarized in Table 4-6 of Wakeley et al., 1995 (note the typing error in the table; the samples should be labeled 161SM3 and 231SM3).

Since the Independent Review Team (IRT) previously had approved the technical adequacy of the work reported in Wakeley et al., 1995, the review by the Panel of the records package concentrated on the key data pertaining to the field porosity of SMC.

For example, the WIPP Records Package (WPO 28380) contains CRD-C42 forms based on ASTM C457 for the microscopic determination of total air in the cored specimens. According to Wakeley et al., 1995, one determination was made at each location, except at the far ends of the monoliths where two determinations were made (and the results averaged for insertion into Table 4-6); this implies the existence of 16 such forms. The Records Package (WPO 28978) appears to contain only 12 completed data forms, however, and the missing forms are those for the far end of the minimally-vibrated concrete (i.e., 161SM3 C&D cores). The missing forms contain the data most relevant to expected conditions when the SMC is placed in the shaft as a seal component.

A memorandum for Dr. Lillian Wakely faxed on 2/15/94 (WPO 28979) gives the total air content at the far end of the batch for 161SM3 C as 6.6% (top) and 6.0% (bottom). This appears to represent data derived from two of the missing sheets.

Other concerns are raised in a memo written by Billy D. Neeley on 1/4/94 (WPO 29097, Item 2). Although these were only preliminary observations by Mr. Neeley, he specifically states that cores taken from the top 4-6 inches of the first placement (161SM3) "indicated large entrapped air voids" and "the cohesiveness of the SMC mixture makes it difficult for the entrapped air to migrate to the top." He also states that "considerable vibration is necessary to eliminate the air entrapped during placing."

The comments of Mr. Neeley need to be considered together with the following previously mentioned facts:

- Four CRD-C42 forms are missing for the total air measured at the far end of the 161SM3 monolith. However, a memorandum exists which refers to the results of two of these data sheets as stating 6% and 6.6% total air content.

- The subsequent decision that was made to use no vibration when placing SMC in the shaft.

The missing forms should be found to support the selected porosity value of 5% for the low vibration situation. The WES data indicate that a porosity value above 5% may need to be selected for the no vibration case, or else vibration must be retained as a option to control the field porosity of SMC (other options include recoring the 161SM3 monolith, or repeating the experiment without vibration). The data examined do *not* conclusively support an overall porosity value of 5%, if vibration is excluded during construction.

4.1.7. Adequacy of Application

The preparation and placement of the SMC in the shaft is described in Appendix A, p. 10, of Sandia WIPP (1996). The concrete will be batched and mixed on the surface in mobile mixers, which will discharge the fresh concrete into a hopper feeding a slick line down the shaft. A tremie line will minimize entrained air by discharging the concrete below the surface level of the concrete already placed. Vibration is not planned (except for the monolith at the base of the shaft) and concreting will be continuous until each concrete segment is complete.

Planned preparation methods in the field are similar to those used at WES up to the point that the concrete is placed in the slick line hopper. What then is the effect on air entrainment of dropping the wet concrete 2000 ft or so down the shaft and emplacing it via a tremie line?

It is reported in the literature that the total air content of air-entrained concrete has been observed to increase, decrease or remain unaffected by pumping (ACI, 1995, No. 92-M48, p. 458). In practice, the final porosity of the mass concrete in the shaft depends on the placement technique. While free fall directly onto the already placed concrete can increase the overall porosity of the concrete, the proposed techniques to break the fall of the wet concrete and place it via a tremie line can be expected to reduce the overall porosity. It is reported that vertical dropping of concrete in a pipeline can reduce the porosity by up to 1.5% (ACI, 1993, No. 92-M48, p. 458). This is particularly true of flowable concrete mixes, discharged vertically downwards in a pipe (NRMCA, 1992, CIP 21).

On the one hand, the planned lack of vibration during placement will tend to produce a porosity higher than the 5% values obtained from the low-vibrated monolith at WES. On the other hand, specifically-

planned concrete placement procedures could reduce the air content by up to 1.5% (below the 5% value at WES). These are off-setting effects. This means that a final (in-place) porosity for the SMC of 5% is achievable. In practice it will depend on how the concrete is handled. Therefore, in order to meet the parameter value, it will be necessary to maintain process and quality control in the field, including regular sampling at the truck discharge point (before the concrete enters the slick line) and at the surface of the wet concrete in the shaft away from the discharge point. Handling procedures can be modified, if necessary, to maintain the porosity at around 5% or less. This could include vibration of the wet concrete, as needed.

4.1.8. Accuracy of Calculations

Although the volume of the concrete mass is simple to measure, the volume of air voids is more difficult. (This tends to be the source of differences in porosity values.) The calculation of porosity is merely the ratio of the two numbers. Hence the calculations of porosity are relatively simple and are adequately accurate.

4.1.9. Validity of Conclusions

The value assigned to the porosity of SMC of 5% (Form 464, Parameter #2484) is reasonable and valid for the following reasons:

- The report by Wakeley et al. (1995) and its WIPP Records Package (WPO 28380) demonstrate that a porosity of 2% is typical for small batches of SMC prepared in the laboratory. The porosity of 5 yd^3 batches prepared in a mobile mixer (more representative of field conditions) ranged from 1.5 to 6.6%; lower porosities were achieved with shorter flow distances, and more consolidation through vibration.

- To a large extent, the porosity of SMC in the field can be controlled by careful mixing, transportation, placement and consolidation through vibration. Therefore, a field porosity of 5% for SMC is achievable and reasonable.

However, the WES data do not conclusively prove that a 5% porosity is achievable without vibration. Hence, vibration should be kept as an option to be employed if needed during construction.

In order to produce an SMC shaft seal with a porosity of 5% or less, a rigid process and quality control program will be needed at the site during mixing and placing, which should include frequent porosity testing of the emplaced concrete and timely corrective actions as necessary.

4.1.10. *Dissenting Views*

None

4.2. Pore Volume Compressibility of SMC

4.2.1. *General Evaluation*

SMC is a specially-designed concrete that will be incorporated into the shaft sealing system and used to construct a concrete monolith at the base of the shaft. A general description of SMC is included in Section 4.1.1. Further information can be obtained from Wakeley et al., 1995, and Sandia WIPP, 1996.

The Pore Volume Compressibility is a parameter used in BRAGFLO that has to be specified for all materials in the potential flow path. It is a porous material property, defined as the fractional change in pore volume with a unit change in fluid pressure (Kelley et al., 1996, p. 11).

The value assigned to the pore volume compressibility of SMC is 1.2 GPa^{-1} (Form 464, Parameters #2464, 2481 and 3052).

Derivation of Pore Volume Compressibility

The bulk modulus, *K*, is an elastic material property that relates volume changes to changes in mean stress or pressure applied to that material (RE/SPEC, 1996, p. 6). It can be measured directly from a drained hydrostatic compression test in the laboratory or, in isotropic materials, it can be calculated from other elastic properties such as Young's modulus, E, and Poisson's ratio, ν, as follows:

$$K = \frac{E}{3(1-2\nu)}$$

Rock compressibility or bulk compressibility, C_r, is equal to the fractional change in volume of the solid rock matrix with a unit change in pressure (Kelley et al., 1996, p. 11). It is the inverse of the bulk modulus:

$$C_r = \frac{1}{K}$$

BRAGFLO, however, uses the pore volume compressibility, C, as defined above. It can be obtained by dividing the rock compressibility by the porosity of the rock, ϕ:

$$C = \frac{C_r}{\phi}$$

Hence, for WIPP the pore volume compressibility is a derived property of the material, rather than a directly measured value. It is calculated from the following three measured parameters for a material such as SMC:

- Young's modulus, E
- Poisson's ratio, ν
- Porosity, ϕ

4.2.2. Adequacy of Requirements and Criteria

The strategy that will be used here to evaluate the pore volume compressibility of SMC will be to evaluate the following three parameters: Young's modulus, Poisson's ratio, and porosity. These will then be combined to derive the pore volume compressibility. (This strategy is similar to the strategy employed by SNL.) Note that there is often a difference in usage between rock mechanics specialists and hydrologists of the terms rock compressibility and pore volume compressibility. Hence, it may be necessary to derive the actual numerical value in each case to see what it represents.

Young's modulus and Poisson's ratio

These parameters are considered together since they both can be derived from the same unconfined compressive strength test in which strains are measured. Several tests are required, however, to obtain reasonable average values. Note that Young's modulus of concrete generally increases with age during the first year, and that Poisson's ratio initially increases with time but then becomes relatively constant after only a few days (Labreche and Van Sambeek, 1988, p. 95). By way of comparison with SMC, ordinary and lightweight concretes have a Poisson's ratio generally in the range 0.15 to 0.20 (Neville, 1973, p. 320).

The U.S. Army Corps of Engineers Waterways Experiment Station (WES) measured Young's modulus from one preliminary batch and one pre-bagged batch of SMC-3 concrete (Wakeley et al., 1995). For batch 153SM3 (trial batch) Young's modulus increased from 15.4 GPa (2.2 x 106 psi) at 7 days to 39.8 GPa (5.7 x 106 psi) at 180 days. For batch 161SM3 (large volume batch) Young's modulus ranged from 18.2 GPa (2.6 x 10-6 psi) at 7 days to 37.0 GPa (5.3 x 106 psi) at 180 days. The full set of test results demonstrate how Young's modulus increases with curing time, at a decreasing rate of gain. These values

are of a similar magnitude to those measured in preliminary tests (Mixture 6R, mixed 040692 and 081392) as reported in Wakeley et al. (1993), p. 29.

RE/SPEC performed one triaxial compression test on SMC batched and cast at WES. This test, on specimen No 40 SM4 - 19/2-1/1, produced a value of E=36.3 GPa and v=0.185 (RE/SPEC, 1996, p. 7) listed as test 3 in Table 4.2.1. Later, RE/SPEC conducted three other tests on SMC at various confining pressures; these results are listed as tests 4, 5, and 6 in Table 4.2.1 (Pfeifle, Hansen, and Knowles, 1996).

Table 4.2.1. Measured Values of Young's Modulus and Poisson's Ratio for SMC

Specimen Identification	Young's modulus GPa	Poisson's ratio	Reference
1. Trial Batch 153SM3 at 180 days (WES)	39.8	--	SAND 94-1495, p. 28
2. Large Batch 161SM3 at 180 days (WES)	37.0	--	SAND 94-1495, p. 28
3. 40SM4 - 19/2 - 1/1 (RE/SPEC)	36.3	0.185	RE/SPEC, 1996, p. 7
4. 32SM4- 25/1 - 1/1 σ_3 = 5 MPa (RE/SPEC)	30.5	0.20	Pfeifle, Hansen and Knowles, p. 7
5. 40SM4 - 11/2 - 1/1 σ_3 = 10 MPa (RE/SPEC)	36.7	0.35	Pfeifle, Hansen and Knowles, p. 7
6. 40SM4 - 2/1 - 1/1 σ_3 = 15 MPa (RE/SPEC)	32.2	0.20	Pfeifle, Hansen and Knowles, p. 7
7. MAC 313-2/1 from SSSPT (RE/SPEC)	40.8	0.278	RE/SPEC, 1996, p. 7
8. MAC 314-1/1 from SSSPT (σ_3 = 5 MPa) (RE/SPEC)	41.9	0.264	RE/SPEC, 1996, p. 7

RE/SPEC also conducted several triaxial compression tests on concrete recovered from the WIPP Small-Scale Seal Performance Tests (SSSPT). The two tests at zero confining pressure yielded results close to each other but with values higher than that for SMC, particularly for Poisson's ratio (RE/SPEC, 1996, p. 7). The SSSPT concrete is an expansive salt-water concrete (described in Labreche and Van Sambeek, 1988, p. 8); its expansivity is attributable to the inclusion of Chem Comp III cement and plaster. Due to minor differences in composition, the results from the SSSPT are only indirectly comparable with SMC. They are included in the list of relevant test results (see Table 4.2.1, lines 7 and 8).

Porosity

The porosity of SMC is an independent parameter that appears on the WIPP Parameter list as Parameter #2467. It has an assigned value of 0.05 (Form 464, Parameter #2467).

This Panel has investigated this parameter (see Section 4.1), and determined that the value of 0.05 is reasonable and achievable. This value, however, is not a unique property of a particular SMC mix, rather

it is dependent on the procedures employed in mixing, transporting, placing and compacting (through vibration) the concrete under field conditions. This is a property largely under the control of field personnel at the time of concrete placement. In the Panel's opinion, the likely range of porosities that could be achieved in the field varies from about 0.03 to about 0.07.

Derivation of Pore Volume Compressibility

For purposes of deriving pore volume compressibility, the porosity value for SMC of 0.05 selected by SNL (Form 464, Parameter #2484) is accepted and treated as a constant. It should be noted, however, that pore volume compressibility is quite sensitive to the porosity value.

Experimental measurements of Young's modulus and Poisson's ratio for SMC and SSSPT concrete are included in Table 4.2.1. Since the SSSPT represents a similar but different data set, the SSSPT results are included for comparison purposes only. The first six test results in Table 4.2.1 for Young's modulus of SMC are not widely scattered and average 35.4 GPa. There are four measurements for Poisson's ratio of SMC, which average 0.235.

Table 4.2.2 lists three data sets for the measured or assumed parameters (E, ν, ϕ) from which the derived parameters bulk modulus (K), rock compressibility (C_r), and pore volume compressibility (C) are calculated. Line A includes the elastic constants selected by RE/SPEC in Calculation No. 325/13/02 (RE/SPEC, 1996, p. 7, line 4). From these values, the pore volume compressibility value of 1.2 GPa-1 is derived, which corresponds to the Form 464 value for this parameter.

Table 4.2.2. Sensitivity of Pore Volume Compressibility to Variations in Elastic Constants

Basis for Measured Parameters	Measured Parameters			Derived Parameters		
	Young's modulus (E) GPa	Poisson's ratio (ν) --	Porosity (ϕ) --	Bulk modulus (K) GPa	Rock Compressibility (Cr) Gpa^{-1}	Pore Volume Compressibility (C) GPa^{-1}
A. Calc. No 325/13/02	30.0	0.20	0.05	16.67	0.060	1.2
B. SMC Sample 40SM4-19/2-1/1	36.3	0.185	0.05	19.21	0.052	1.04
C. All 6 SMC samples	35.4	0.235	0.05	22.26	0.045	0.89
D. Average of 2 SSSPT samples	41.4	0.271	0.05	30.13	0.033	0.66

In reviewing Table 4.2.1 it appears that the values of E and ν in RE/SPEC (1996) may be somewhat low. Hence, three other data sets were selected from Table 4.2.1 to see how sensitive the pore volume

compressibility is to variations in the elastic constants. Line B takes the data from the SMC sample in which both E and ν were measured at zero confining pressure. This gives a pore volume compressibility value of 1.04 Gpa^{-1}. Line C is based on the averages from all six tests on SMC; this gives a pore volume compressibility value of 0.89 Gpa^{-1}. What happens if the SSSPT elastic constants turn out to be more representative of the SMC than the SMC tests? This scenario is investigated in Line D. It yields a pore volume compressibility of 0.66 GPa^{-1}, approximately half of the Form 464 value.

Based on the limited data set for the elastic constants (Table 4.2.1), the Panel has concluded that the pore pressure compressibility for SMC lies in the range 0.7 to 1.2 GPa^{-1}, with the most probable value at about 0.9 GPa^{-1}. Thus, SNL's selected value of 1.2 GPa^{-1} represents a value close to the upper bound for this parameter. The difference between the Panel's value and SNL's value is due to the inclusion of recent data from Pfeifle, Hansen, and Knowles (1996). The Panel's conclusion is that a value of 0.9 GPa^{-1} for the pore volume compressibility of SMC is a more reasonable number to use in future PA calculations.

4.2.3. Assumptions

The assumptions used in deriving the pore volume compressibility of SMC include treating SMC as an elastic material in which the structural components are effectively incompressible and strain occurs only through reduction in pore space. It is also assumed that SMC is relatively homogeneous (with uniform porosity), and that it is reasonable to average the pore volume compressibility and treat it as a constant in BRAGFLO calculations. For SMC these are not unreasonable assumptions.

4.2.4. Alternate Interpretation

Alternate interpretations include treatment of pore volume compressibility as a spatially distributed parameter, since the value will change to the extent that porosity changes. In fact, the pore volume compressibility is quite sensitive to changes in porosity but, from a practical point of view, it is not possible to measure porosity changes within a large mass of concrete without destroying the concrete itself (the same also holds for Young's modulus and Poisson's ratio). Hence, it will be necessary to rely on good process control to ensure that a uniform concrete is emplaced in the shaft. In the Panel's opinion, it is reasonable to use average values of porosity, Young's modulus, and Poisson's ratio to determine an average value of pore volume compressibility. This is because SMC is relatively homogeneous and isotropic when compared to the geologic materials that also are in the potential flow path from the emplaced waste to the accessible environment.

4.2.5. Uncertainties and Consequences

There were four measurements of Poisson's ratio for SMC, with bounds of 0.19 and 0.35. SNL's selected value of 0.2 (see Line A in Table 4.2.2) could understate Poisson's ratio by up to 35% (compare with Line D in Table 4.2.2). This, together with uncertainties in the other measured parameters in Table 4.2.2, could reduce the Form 464 value of the pore volume compressibility by up to 50%, although 25% is more likely (Line C, Table 4.2.2).

The consequences of making an error of 25% or 50% in the average value of pore volume compressibility to the results of the BRAGFLO calculation is beyond the scope of this investigation.

4.2.6. Appropriateness and Limitations of Methodology and Procedures

The methodology used in calculating pore volume compressibility is straightforward. It is calculated from three other measured values, as demonstrated in Table 4.2.2. The limitations of the methodology are due mainly to limitations in determining the averages of the individual parameters, rather than in the method of measurement. Several measurements are needed to obtain meaningful averages. The average for Poisson's ratio is the least well-defined parameter.

4.2.7. Adequacy of Application

The application of the concept of pore volume compressibility appears to be appropriate. It is frequently used in hydrologic modeling. The concept appears to be appropriate for SMC to the extent that it is appropriate to apply it to the geologic materials that are in the potential flow path from any pressurized zones to the repository, and from the repository to the accessible environment, taking into account human intrusion scenarios. The Panel, however, has not investigated how and where this parameter is utilized in WIPP performance assessment calculations. Such an investigation is beyond the scope of this review.

4.2.8. Accuracy of Calculations

The value of pore volume compressibility of 1.2 Gpa^{-1} on the Form 464 was checked by the Panel, using the formulae listed in Section 4.1 (see Line A, Table 4.2.2), and the calculation was found to be accurate, based on the data used.

4.2.9. Validity of Conclusions

The pore volume compressibility is derived from three other measured parameters. Two of the three parameters, Young's modulus and porosity, are reasonably well defined. Only four measurements were made of Poisson's ratio for SMC, however, so its accuracy is not as well known as the other two parameters.

The Panel's best estimate of pore volume compressibility based on the available data is 0.9 GPa^{-1}. This is reasonably close to the 1.2 GPa^{-1} value chosen by SNL (Form 464, Parameter #2464), but the Panel's estimate includes new data taken from Pfeifle, Hansen, and Knowles (1996). SNL's value likely lies close to the upper bound for SMC.

In addition to its use as a shaft seal in four main locations, SMC also will be used to construct the monolith at the bottom of the shaft. The concrete in the monolith will be vibrated during placement and it is assumed that quality control of concrete during construction will ensure that a porosity of about 5% is maintained. Hence, for practical purposes, a value of pore volume compressibility of 0.9 GPa^{-1} can be applied to all three applications of SMC (this value applies to Parameters #2464 (CONC_T1), #2481 (CONC_T2), and #3052 (CONC_MON)).

4.2.10. Dissenting Views

None

4.3. Bulk Modulus of Crushed Salt

4.3.1. General Evaluation

The parameter evaluated here is the bulk modulus of salt, which is used in the PA calculation of crushed salt shaft seal pore volume compressibilities and permeabilities at specified times after emplacement. The bulk moduli developed for these calculations are presented in Table 4.3.1 (RE/SPEC, 1996).

Bulk modulus is the property that relates volume changes of a material to changes in mean stress or pressure. Bulk modulus can be measured directly from a drained hydrostatic compaction test in which the mean stress is increased and changes in volume are measured, or it can be calculated from other elastic properties such as Young's modulus and Poisson's ratio. In the sealing materials studies for WIPP (RE/SPEC, 1996), bulk moduli for salt have been estimated by fitting a curve (Figure 4.3.1) to hydrostatic test results of compaction of crushed salt from Holcomb and Hannum (1982) and RE/SPEC

(1996), and to a bulk modulus for intact WIPP rock salt recalculated from values given in Sjaardema and Krieg (1987) on the basis of new density measurements by Brodsky (1994B). The model employed for curve fitting is from Sjaardema and Krieg (1987). The constitutive relationship represented by the model was used to calculate bulk moduli for mid-seal depths (515 m) for times after emplacement of 0, 50, 100, 200, and 400 years for calculation of permeability values for handoff to the performance assessment (Table 4.3.1).

Table 4.3.1. Best Estimators for Bulk Modulus of Compacted Crushed Salt at a Depth of 515 m

Time After Seal Emplacement (Years)	Density[a] ($kg\ m^{-3}$)	Bulk Modulus (GPa)
0	1.944	5.74 [b]
50	2.038	10.60 [b]
100	2.121	18.22 [b]
200	2.160	20.67 [c]
400	2.160	20.67 [c]

[a] After Chieslar [1996].

[b] Calculated from Equation 5-1 (after Sjaardema and Krieg [1987]).

[c] Bulk modulus of intact salt.

From RE/SPEC 1996

Densities for this calculation are from Chieslar (1996). The fit of the experimental data to the curve predicted by the modified Sjaardema and Krieg model displays some systematic scatter (Fig. 4.3.1). Callahan et al. (1996) attributes this misfit between the model and experimental results to the absence of shear compaction data in the Sjaardema and Krieg model and considers two alternative models (Zeuch 1990, Speirs and Brzesowsky 1993) using some yet-to-be qualified data and some recent (qualified) experimental data. The Zeuch and Spiers models (modified) and the modified Sjaardema and Krieg models are not greatly different in terms of predicted strain versus time behavior. None of the models fit the strain/time curves for shear compaction well, perhaps reflecting the inclusion of questionable data from the Zeuch tests. It appears that the Sjaardema and Krieg model fits the hydrostatic test results acceptably and the resultant constitutive equation is an acceptable and conservative basis from which to predict moduli for seal consolidation.

4.3.2. Adequacy of Requirements and Criteria

The bulk moduli are intermediate parameters in the calculation of seal permeabilities. The methodology is to fit a curve to preexisting data (Figure 4.3.1) and use the resulting empirical constitutive relationships to calculate moduli. The quality of the plotted data and scatter about the fitted curve must be acceptable

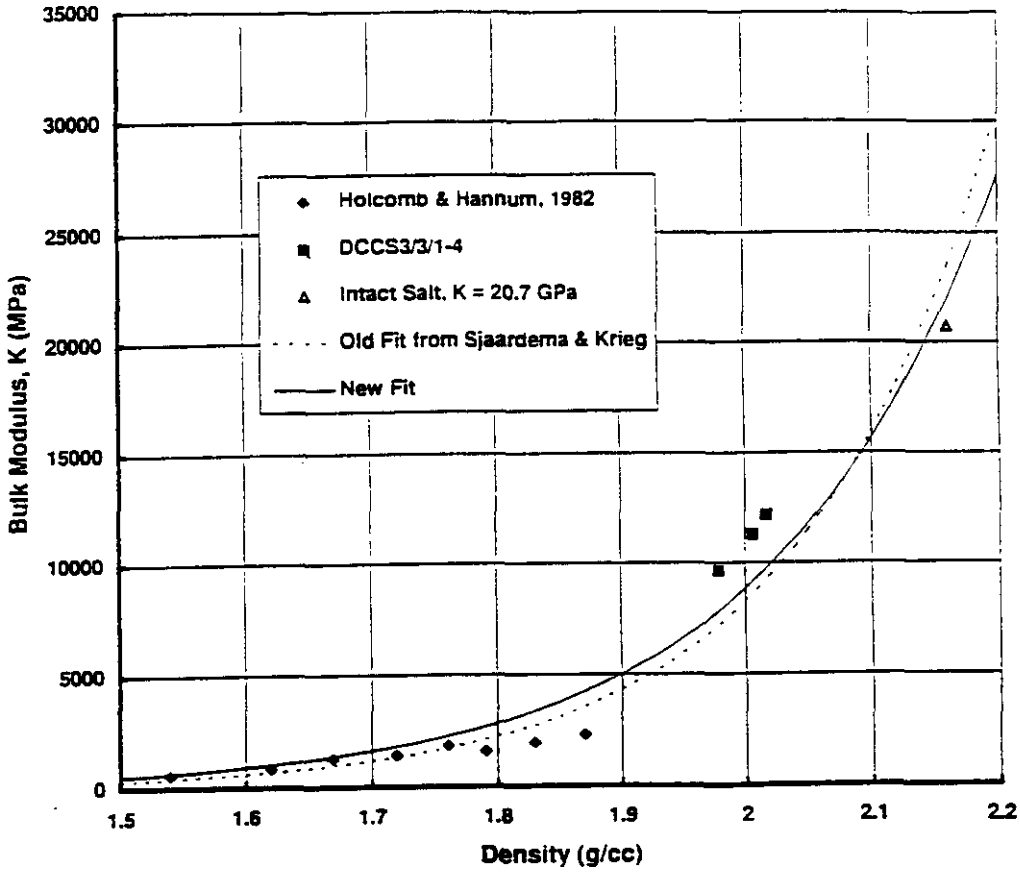

from RE/SPEC, 1996

Figure 4.3.1. Bulk Modulus Versus Density for WIPP Crushed Salt

for the results to be credible. Only the Holcomb and Hannum data were not developed under acceptable SNL quality assurance (QA) protocol.

The objectives of the Holcomb and Hannum (1982) Quasistatic (Hydrostatic) tests were to determine whether saturated crushed salt was impeded in its consolidation by trapped pore brines. It is apparent from the results of the tests conducted under excellent scientific protocols that some reduction in the rate of compaction occurred at higher fractional densities due to trapped pore waters. This condition occurred when drainage stopped during a drained test before all the water which had been added to the crushed salt specimen was expressed. Compaction did proceed, however, at a reduced rate. This reduction of rate may account for the deviation of bulk moduli at the higher densities achieved during testing from the Sjaardema and Kreig curve (Figure 4.3.1). The results were consonant with Holcomb

and Hannum's objectives and provide an understandable basis for evaluating their results relative to the constitutive model of Sjaardema and Kreig.

4.3.3. Assumptions

Sjaardema and Krieg (1987) have developed a nonlinear elastic model and fitted it to the Holcomb and Hannum (1982) data to define material constants for use in an empirical exponential relationship [$K = K_o \exp(K_1 \rho)$] to define bulk modulus, where K_o and K_1 are empirical material constants based on curve fit and ρ is density. This relationship was subsequently fit to the results of laboratory determinations of the bulk modulus of compacted salt from the Dynamic Compaction of Crushed Salt (DCCS) Experiment (RE/SPEC, 1996, and Hansen and Ahrens, 1996) and a newly determined value based on a new determination of the bulk density of intact Salado salt (RE/SPEC 1996, Brodsky 1994B) (Fig. 4.3.1). The primary assumption in the development of the moduli (RE/SPEC, 1996) is that the modified curve fits the experimental data well enough to validate the use of the derivative equation and materiel constants to adequately calculate the needed bulk moduli for handoff to the performance assessment. Holcomb and Hannum's (1982) data fit the curve very well at low densities but the trend of the data diverge from the curve at the middle of the density range (Fig. 4.3.1). The DCCS results lie significantly above the curve at densities around 2g/cc. The corollary assumption that the data are valid and adequately represent the variability of distribution of bulk moduli of compacted crushed salt for the defined conditions is central to the acceptance of the calculated moduli (Table 4.3.1) and their usefulness in predicting shaft seal consolidation.

The assumption that the Holcomb and Hannum data are representative is central to modulus development and those data are subject to some qualifications. Holcomb and Hannum's (1982) data were rejected by the IRT review primarily on the grounds of the absence of complete QA documentation. The quasistatic tests excerpted from the data for bulk modulus calculation were developed under adequate scientific protocol and controls which are equivalent to the general requirements of the current QA structure. Technical comments from that review show that some concern exists about specimen homogeneity. The specimens were constructed by loading "mine run" salt below the size of 1 mm into the sample sleeves (14 mm) without regard for sorting. The blockage of specimen drainage at a late stage of the test may also have affected results.

The DCCS data were developed under the current SNL QA plan and are fully qualified. The data are, however, from an experiment which consisted of weight-drop dynamic compaction of a large volume of crushed salt (Hansen and Ahrens, 1996). This compaction methodology may not have produced

homogeneous compaction of the highly unsorted salt used in the experiment. Compaction under strong dynamic loading may have significantly changed grain size distribution. The relatively central fit of the curve and the existence of data over much of the range of densities from densities of 1.5 g/cc to 2.16 g/cc implies a reasonably good fit to the model of data having potentially significant variability as a result of experimental procedure and the calculation of the intact salt bulk modulus from non-Salado literature values (see Section 4.3.2).

4.3.4. Alternate Interpretation

Callahan et al. (1995, 1996) have considered alternative models to the Sjaardema and Krieg model, principally models that incorporate shear compaction (Zeuch 1990, and Spiers and Brzewowski 1993) and that specifically identify micro-mechanical strain mechanisms such as pressure solution. Modeling results from Callahan et al. (1996) imply relatively small differences between the predicted behavior of the alternative models and a poor fit between all the models and the experimental results (Fig. 4.3.2). The poor fit to the experimental data may be due to the inclusion of shear test data from Zeuch (1990) which Zeuch identifies as aberrant and internally contradictory. The consideration of alternative models does not indicate that the Sjaardema and Krieg model is inadequate or erroneous, nor is there any apparent advantage in using the alternative models.

4.3.5. Uncertainties and Consequences

Uncertainty in this parameter is represented by the scatter of measured bulk modulus/density plots about the corrected (new fit) curve shown on Figure 4.3.1. At low and high densities the fit is very good, with increasing uncertainties in the mid-range of the curve. The intact salt bulk modulus in this plot was re-calculated from rock salt bulk modulus values from the literature for non-Salado salt (Hume and Shakoor, 1981) and densities measured for Salado salt by Brodsky (1994). Bulk moduli predicted by the modified Sjaardema and Krieg model, combined with fractional density predictions from Chieslar (1996) imply that the crushed salt-seal material at the midshaft region (515m depth) will reach *in situ* salt densities (and perhaps permeability) in about 140 years (Fig. 4.3.3). This is very early in the predicted brine-inflow and gas-generation histories predicted for the repository. Further, the sense of the uncertainty represented by the DCCS data in the mid-range of the model is toward more rapid densification. It appears that the consequence of uncertainty is not great if compaction were a little slower than predicted and the only available indicator of uncertainty (relative weight of data scatter)

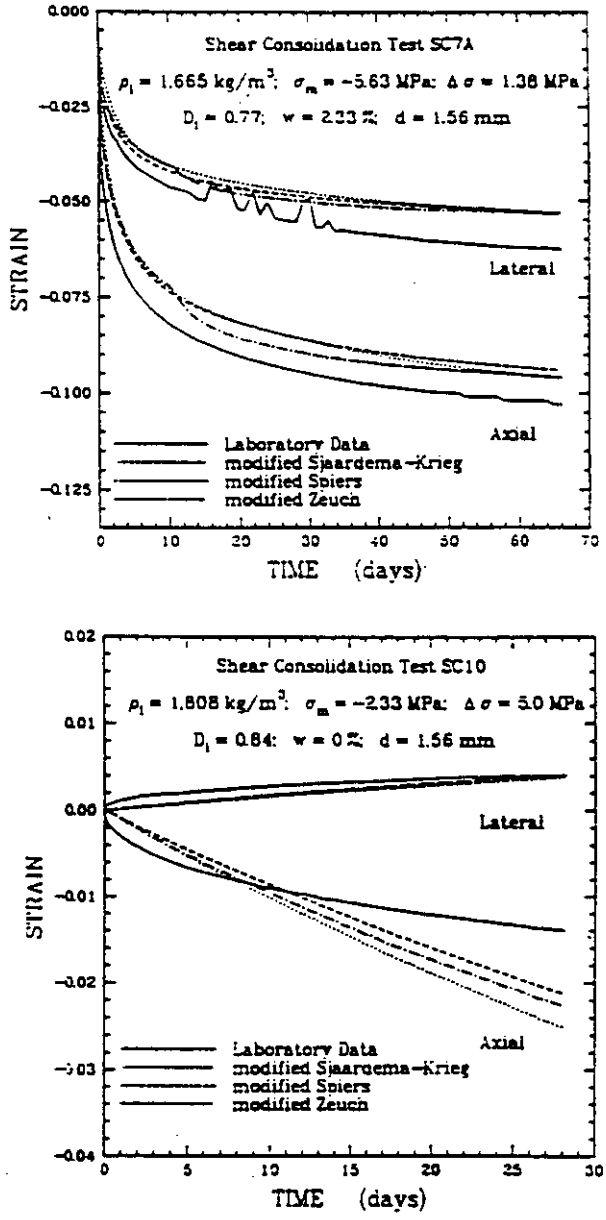

from Callahan et al., 1996

Figure 4.3.2. Comparison of Model Predictions and Experimental Data

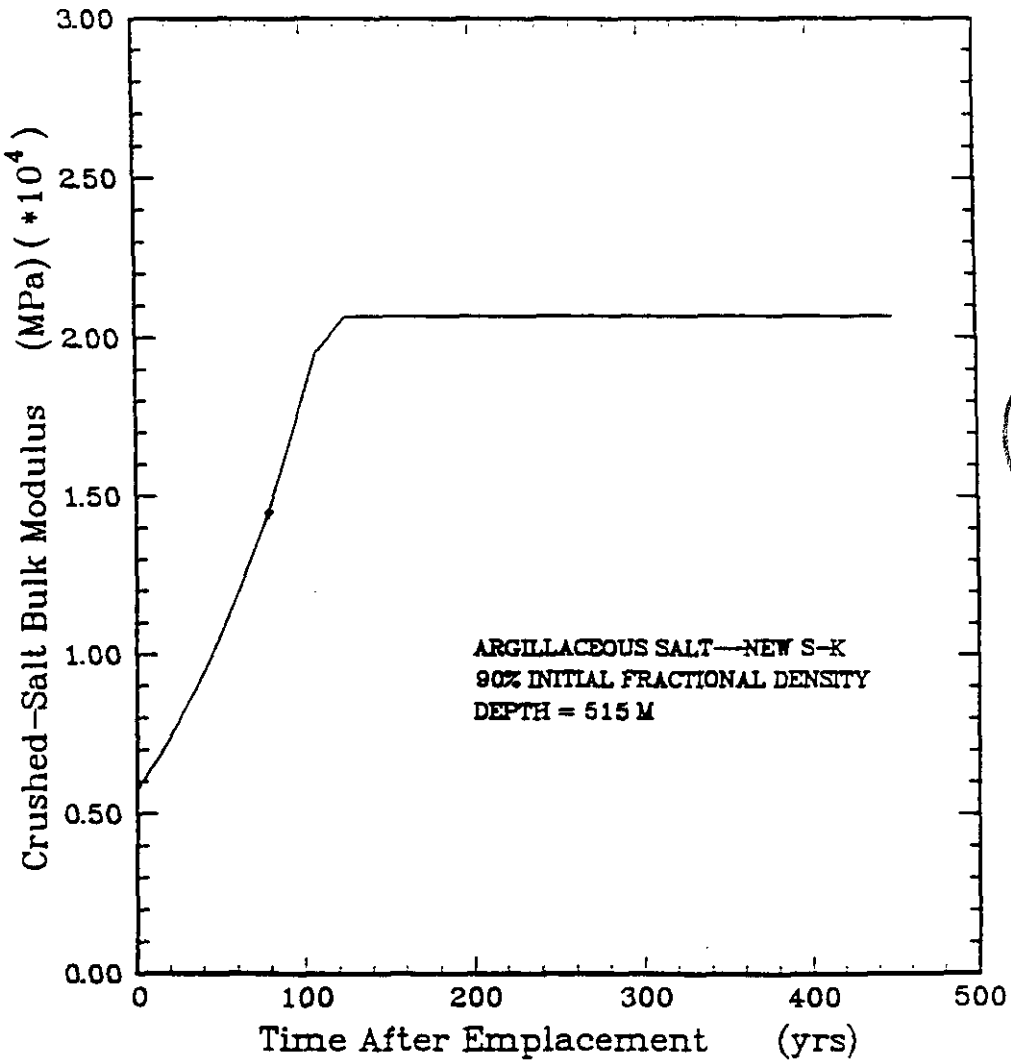

from RE/SPEC, 1996

Figure 4.3.3. Bulk Modulus Versus Time for the Compacted Crushed Salt Column at a Depth of 515m

implies that the consequence of uncertainty in the region of most uncertainty is toward more rapid compaction.

4.3.6. Appropriateness and Limitations of Methodology and Procedures

With regard to the Holcomb and Hannum data, specifically the quasistatic tests, there are no recognized standards such as ASTM. These tests were among the first of their kind. The quasistatic tests were performed according to appropriate methods and met the needs of the intended use of the data.

4.3.7. Adequacy of Application

The test procedures were correctly implemented and irregularities were identified and described. Predictable variation in the behavior of late stages of Holcomb and Hannum's testing may have resulted in departure of the calculated bulk moduli from the Sjaardema and Kreig curve. These departures were related to elevated pore pressures caused by the entrapment of brine in the interstices of the crushed salt specimens. This was an expected experimental result and the influence on the data was noted. Data points were sufficient, traceable and consistent. The data are adequate to the intended use and their PA application is appropriate.

4.3.8. Accuracy of Calculation

Calculations of bulk moduli from the data (Table 4.3.1) were simple and accurately made. A revision of the curve resulting from the constitutive model shown in Figure 4.1 was appropriately made when a critical parameter (density of intact rock salt from WIPP) was revised.

4.3.9. Validity of Conclusions

The relationship represented by the analyses of data from Holcomb and Hannum and other qualified sources (Hansen and Ahrens, 1996 and Chieslar, 1996, and Brodsky, 1994B) are purely empirical in nature. Some scatter of the data is apparent, but the sources of scatter appear to be inherent in the testing and the calculation of the intact modulus from non-Salado literature values and probably do not represent significant sources of error in the basic constitutive relationship (Sjaardema and Kreig, modified) used to calculate parameters for performance assessment. The moduli shown in Table 4.3.1 are valid for their intended use.

4.3.10. Dissenting Views

None

4.4. Permeability of Crushed Salt

4.4.1. General Evaluation

The parameter being evaluated is the permeability of crushed salt, which is time dependent. The Form 464 values are given in the last three columns of Table 4.4.1.

Table 4.4.1. Crushed Salt Permeabilities

Time	RE/SPEC, 1996, m^2			RE/SPEC, 1996, log_{10} m^2			Form 464, log_{10} m^2		
	lower	"best"	upper	lower	"best"	upper	lower	median	upper
0 to 10							-17.301	-14.7825	-12.2652
10 to 25							-17.301	-14.7825	-12.2652
25 to 50							-17.301	-14.7825	-12.2652
0 to 50	5.00E-18	1.65E-15	5.43E-13	-17.301	-14.7825	-12.2652			
50 to 100	1.33E-23	6.83E-18	1.12E-14	-22.8761	-17.1656	-13.9508	-22.8761	-17.1656	-13.9508
100 to 200	1.33E-23	5.27E-20	3.75E-16	-22.8761	-19.2782	-15.426	-22.8761	-19.2782	-15.426
200 to 10,000	1.33E-23	5.35E-21	2.15E-18	-22.8761	-20.2716	-17.6676	-22.8761	-20.2716	-17.6676

Crushed salt will be used as a major component of the shaft sealing system over a 170m depth interval in the Salado formation. Screened (for elimination of coarse material) mine-run salt will be dynamically compacted along with a small amount of added water (about 1% by weight) and then allowed to compact further with time by the natural forces of creep closure of the shaft walls. This is all for the purpose of creating a very low-permeability shaft seal. Because the crushed salt interval is an important part of the seal system, its permeability as a function of time is an important part of PA calculations.

Crushed salt permeability as a parameter is described as a log triangular distribution of values over six time intervals: 0-10 years, 10-25 years, 25-50 years, 50-100 years, 100-200 years, and 200-10,000 years. Full consolidation (and the lowest permeability) is assumed to be reached at 200 years. A recent compilation and explanation of the crushed salt permeability values to be used by WIPP is provided by RE/SPEC (1996), although some work is still ongoing. The values in the RE/SPEC document (p. 47) correspond exactly to the values in the WIPP PA Form 464 for ID Numbers: 2940-2942, 2948-2950, 2956-2958, 2964-2966, 2972-2974, and 2980-2982. The values from both of these sources are listed in Table 4.4.1. Note that although six time intervals are listed in the table, the values for the first three

Form 464 intervals (times up to 50 years) are identical, so only four unique intervals are actually used by WIPP.

The method of determining crushed salt permeability vs. time involves several steps. In the first step, various measurements of crushed salt permeability versus "relative density" (sometimes called fractional density) are obtained (Brodsky, 1994A; Hansen and Ahrens, 1996; and Brodsky et al., 1996). Relative density, as defined here, means the density of the crushed salt as tested, divided by the density of the "intact" salt, determined to be 2160 kg/m^3 by Brodsky (1994B). (The actual measured densities of the intact salt had variations of about +10/-30 kg/m^3 from this value.) Intact salt, as defined here, may contain pore space (about 1% or less), may be either clean or argillaceous, and is assumed to be at the equilibrium long-term density of salt at the site. In the second step, crushed salt density versus time is predicted by a creep compaction model as outlined in RE/SPEC (1996) (but not itself a subject of this review). In the third step, the time-dependent densities thus obtained are expressed as time-dependent permeabilities by assuming that density and permeability are uniquely related. Finally, error analysis is used to assign a probability distribution to the results. The values finally reported also appear in Sandia WIPP, 1996.

Several different types of permeability measurements and samples were used to obtain the raw data. These included brine permeabilities on laboratory-made and compacted specimens, and gas permeabilities on field-precompacted specimens from three different dynamic compaction demonstrations. One permeability measurement was actually made *in situ* in the dynamic compaction chamber. In all, 27 measurements are represented, as shown in Figure 4.4.1. The values in Figure 4.4.1 are from RE/SPEC (1996).

The power-law trend line in Figure 4.4.1 (created for this review using the Excel spreadsheet) is similar to the trend line used to generate the current permeability values used by WIPP, as shown in the references. Statistical analysis by WIPP then gives the maxima and minima used to generate the final parameter values. (Please note that the trend line shown in Figure 4.4.1 is derived independently of WIPP analyses and is shown for purposes of the present discussion only.)

Since both the sample preparation and test methods are distinctly different for the two types of permeability tests, it may be legitimate to develop two independent trend lines for the two sets of test results. These lines are shown in Figure 4.4.2. Although the multiple trend lines are close to falling within the overall limits for permeability specified by WIPP, they do not actually fall within those limits. Furthermore, the long-time low permeability trends, corresponding to the highest fractional density

values, are especially different from those specified by WIPP. In particular, the higher value implied by the gas permeabilities is above the WIPP range. The causes and ramifications of this discrepancy will be discussed further below.

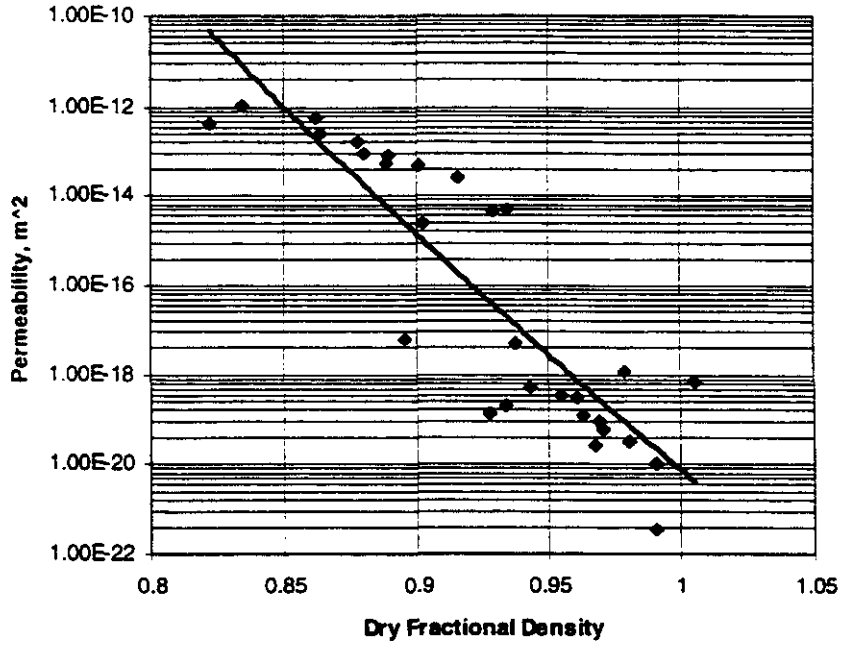

Figure 4.4.1. Crushed Salt Permeability Data, With Single Power-Law Trend Line

The brine permeability test results reported by Brodsky, 1994A, and emphasized at the bottom of Figure 4.4.2, had considerable variability and were questionable with regard to reproducibility because of time-changing values. The majority of these test specimens were prepared by screening and saturating mine-run WIPP salt, followed by hydrostatic pre-consolidation in the pressure vessel. Most of the permeability tests (to brine) showed a high initial flow rate, which then decreased after a number of days. Discounting storage mechanisms (which were not discussed but should have ceased within this period of time), solution/precipitation was identified as the likely cause of the decrease, and only the early time (higher values for permeability) were suggested for use (and shown in Figure 4.4.1), although all were reported in the original document. Another mechanism of systematic error not discussed is that flow during permeability measurements in granular specimens is frequently hindered by the motion and or rotation of grains. The relatively high confining pressures and long times of these tests may restrict this effect, but it cannot be completely discounted.

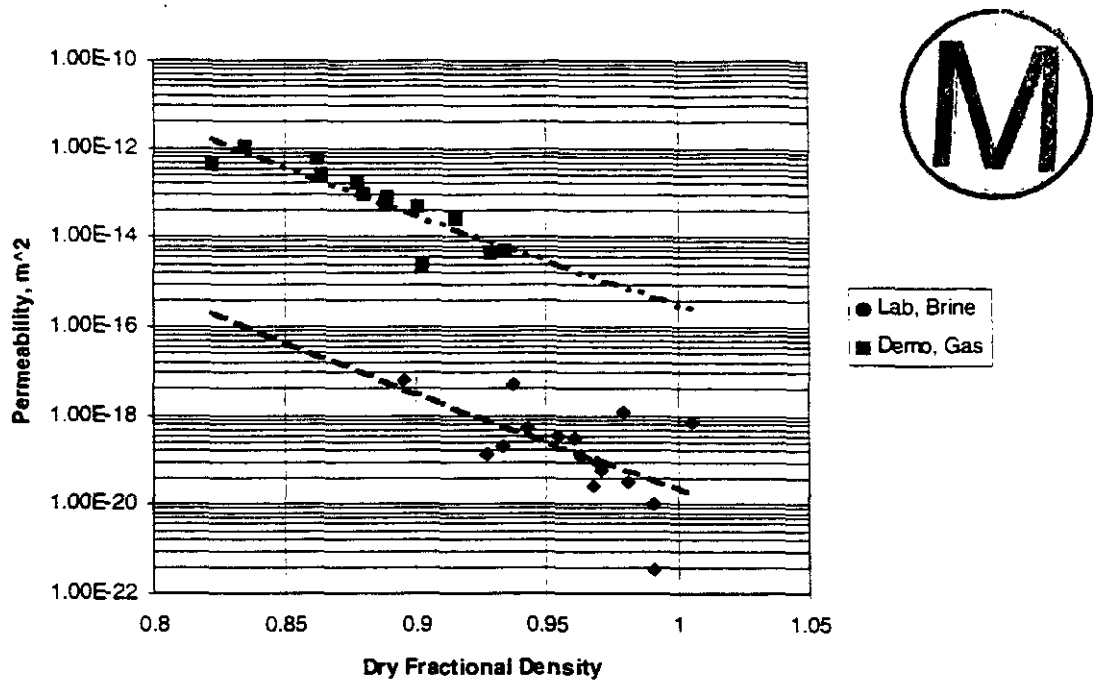

Figure 4.4.2. Crushed Salt Permeability Data (Same Data as Figure 4.4.1), With Two Power-Law Trend Lines Representing Brine Permeabilities on Lab-Prepared Samples and Gas Permeabilities on Field Demonstration Samples

The gas permeability test results reported by Brodsky et al. (1996) and emphasized at the top of Figure 4.4.2, seem to have less variability and were possibly more reproducible than the brine permeability tests, although the raw data were not made available for this review. These test specimens were prepared (preconsolidated) by SNL in several medium- to large-scale field dynamic consolidation demonstrations from which intact samples were taken and cored. In all of these specimens, larger particles would have been present in the original mixes, and extreme particle size distribution changes would have been caused by the method of preconsolidation (as compared to the laboratory hydrostatic method). The laboratory tests then consisted of further dry consolidation under hydrostatic conditions, along with gas permeability tests. These values appear high as compared to the brine values. A possible reason for this is that the field-compacted specimens might have been unusually dry when finally tested in the laboratory (Pfeifle and Hansen, 1996), and therefore not representative of the permeability/density relation that would be obtained by damp compaction of the field specimens, as will actually occur in the shaft.

4.4.2. Adequacy of Requirements and Criteria

Specifying crushed salt permeability versus time is an important part of the shaft seal performance assessment, and may be used elsewhere in WIPP as well. This requirement is therefore adequate.

Specifying that predicting a density-time relationship is sufficient to predict a permeability-time relationship via density-time coupling, without full experimental or theoretical justification, may not be adequate, although recent work (Pfeifle and Hansen, 1996) suggests that positive progress is being made to support this adequacy.

4.4.3. Assumptions

The main assumptions of the current analysis appear to be that (a) intact density is the same everywhere, (b) the experimental results using very different sample preparation and test techniques may be treated as part of the same data population, and (c) the relationship of permeability to fractional density is unique and is time- or structure-independent. Assumption (a) is weak but not damaging since density variations are not large. Assumptions (b) and (c) have strong effects which could lead to results outside of the currently stated range of crushed salt permeability values.

4.4.4. Alternate Interpretation

The alternate data interpretation issue centers around whether the single trend line in Figure 4.4.1 or the multiple trend lines in Figure 4.4.2 are most appropriate. The WIPP project has chosen a trend like the single one shown in Figure 4.4.1. The reasons for the approach chosen by the project is not well-established in the current documentation. New data (Pfeifle and Hansen, 1996) may indicate that the extreme dryness of the original gas permeability specimens may make those results (the upper trend line in Figure 4.4.2) by themselves uncharacteristic. This would tend to support the single-trend line. Another argument in favor of the single-trend approach is that all available data should be considered without bias. However, a counter argument also can be made that the sample preparation and test technique for the two types of data are so different that the existence of two completely separate sets of results must be considered seriously, as suggested by the two trend lines shown in Figure 4.4.2. If new data then become available, they should be assigned to the most appropriate population. The Panel could identify no overwhelming scientific or engineering reason why a single-trend line should be chosen instead of the two based on the current published documentation. This is not to say that the WIPP-chosen interpretation is wrong, but simply to say that there may be a reasonable alternative, or that more data should be examined.

If the upper-trend line in Figure 4.4.2 were chosen instead of the single-trend line in Figure 4.1.1, the crushed salt permeabilities at long times would be higher than are used now to provide the parameter values. This interpretation might be questioned, in that the consolidated permeabilities from this trend

are much higher than most measurements of undamaged intact halite permeabilities. This either means that the data are suspect, or that the method of consolidating crushed salt to near *in situ* densities by the method used and in the time period involved does not create the same decrease of permeability as natural consolidation over longer time periods. That is, although the porosity is reduced as expected by the laboratory tests, narrow flow channels do not close as compared to intact salt. One would expect such flow channels to close eventually with time, but then the assumed method of using density/time predictions to directly create porosity/time predictions is brought into question. Perhaps a safer method of data interpretation, lacking additional data, would be to use both trend lines in Figure 4.4.2 to establish a new range of crushed salt permeability values. Or, an alternative method of correlating permeability with time other than the unique permeability/density relationship might be considered. Certainly, one reasonably expects near-intact permeabilities to be reached at some time. The question is whether this occurs by the 50-200 years currently modeled, or after a longer period. Recent data (Pfeifle and Hansen, 1996) may suggest that the upper trend drops to much lower permeabilities at high relative densities in damp specimens. Perhaps a third trend line might exist (were there enough data) for field dynamic compaction samples that are maintained at the appropriate water content of about 1% by weight. This third trend line might resemble the first trend line in Figure 4.3.1 and thus justify the current WIPP parameter choice.

Even if the data population interpretation issue were settled on the above grounds, the issue of alternate interpretation remains, stemming from WIPP's assumption that density-time uniquely relates to permeability-time. In support of this assumption are the photomicrographs (Brodsky, 1996A) showing that flow channels close by pressure solution in the dynamically compacted specimens as they are further compacted in the laboratory, but this interpretation has not been discussed or supported in the documentation.

4.4.5. Uncertainties and Consequences

Based on the original assumptions and analyses presented in the documentation, uncertainties in the data are appropriately carried through to create the PA parameter ranges. In this sense, the uncertainties and their consequences in terms of a distribution are clear. However, alternate interpretations, as discussed above, may introduce larger uncertainty ranges. In particular, a higher mean and upper limit of crushed salt permeability may exist for longer times than is now currently used, unless new data, now forthcoming, decrease this uncertainty. Without new data and further data analysis, the crushed salt seal

may have to be assumed to be more permeable with time than currently specified. Only PA calculations can determine the ultimate importance of this change, should it be made.

4.4.6. Appropriateness and Limitations of Methodologies and Procedures

Permeability/compaction testing on these types of specimens is very difficult. The work to date is appropriate and is apparently state-of-the-art but, as discussed above, this may not yet be enough. Limitations exist in determining the best methods of permeability sample selection, sample handling compaction method, and test method, in showing data accuracy and reproducibility, and in determining the best method of data analysis and parameter prediction. Therefore, although the fully published work done to date is appropriate, it is overly limited in its quantity and scope. Work underway would seem to be addressing this problem.

4.4.7. Adequacy of Application

Based strictly on the original assumptions (which here have been brought into question), the application is adequate. When the questioning of assumptions is allowed, the presently published data are not sufficient to support the application of current permeability-time predictions. Emerging data and interpretations may resolve this issue.

4.4.8. Accuracy of Calculations

The calculations in the original brine-flow test program, based on the reports, appear accurate. The conversions to relative density relationships are somewhat adversely affected by the assumption of only one intact density, but this does not appear critical. The Panel cannot assess accuracy of the latest gas-flow tests because detailed data reports were not available. The accuracy of final long-term permeability results are brought into question by the choice of assumptions and interpretations discussed above.

4.4.9. Validity of Conclusions

To obtain the permeability-time parameter values, appropriate test data were obtained and reduced by accepted methods. However, the currently published conversion of the test data into the Form 464 pass-off values to PA are severely in question because of the reasonable alternate assumptions and interpretations that are possible (discussed above), but are not yet fully addressed by the project. In particular, the high end of the long-term (times greater than 200 years) permeability distribution range may be too low. The Panel therefore finds that the conclusions as currently drawn, based on published reports and PA handoff, with regard to long-term crushed salt permeability are not fully valid. It appears

however, that presently ongoing work, including new tests and data interpretations, may resolve this validity issue in a positive sense. This ongoing work should be fully documented, understood, and reviewed in order to establish the validity of the long-term crushed salt permeability values.

In the opinion of the Panel, the crushed salt permeability data should be re-evaluated by SNL, with the inclusion of the new data and explanation of interpretations as appropriate. The Panel cannot come to a conclusion of validity of the interpretation of these data until such a re-evaluation is done.

4.4.10. Dissenting Views

None

4.5. Permeability of SMC

4.5.1. General Evaluation

The intrinsic permeability of SMC is a parameter needed to model the performance of the shaft sealing system.

As described in Section 4.1.1, there are three identical concrete components in the Salado shaft sealing system, each one composed of three elements: an upper concrete plug, a central asphalt waterstop and a lower concrete plug. The overall design length of each component is 15m. There is also a 6m long SMC plug in the Rustler formation. In addition, SMC is used to construct a concrete monolith at the base of the shaft; however, this is not considered to be part of the shaft sealing system (Sandia WIPP, 1996, pp. 25-29).

There are three applications of SMC for which permeability is needed:

- The concrete column in the shaft for the first 400 years (CONC_T1).
- The concrete column in the shaft from 400 to 10,000 years (CONC_T2).
- The degraded concrete monolith at the shaft base (CONC_MON).

The permeability of interest is the permeability of brines passing up and down the shaft. (Generally, gas permeabilities will be at least an order of magnitude higher, i.e., more permeable than brine permeabilities. This depends on a variety of factors, including the moisture content of the concrete).

In general, permeability values are needed in all three orthogonal directions (one vertical and two horizontal). Since SMC concrete is expected to be homogeneous and isotropic, however, its permeability is assumed to be uniform in all directions.

In BRAGFLO, SMC permeability is treated as a triangular distribution during the first 400 years of its life. It is then assumed to degrade immediately and then is treated as a constant (from 400 years to 10,000 years). Permeability is expressed in its log form. The parameters listed on Form 464 and their assigned values are given in Table 4.5.1.

Permeability of Concretes

Concretes are designed to be durable. Lack of durability may be due to internal causes within the concrete itself and/or a variety of external causes. SMC has been specially designed to be durable under the conditions to which it will be exposed in the WIPP. Its success as a seal will depend on many factors, including the quality of construction and its ability to remain relatively impervious for a long period of time, i.e., to maintain a low value of permeability.

The permeability of the paste largely determines the permeability of the concrete. Generally, concrete permeability decreases as the water/cement ratio is decreased, and as the age of the concrete increases and hydration progresses. By way of comparison, Neville (1973, p. 387) quotes typical values for the permeability of concrete used in dams in the U.S. as being in the range of 8 to 35 x 10^{-12} m/s (8 to 35 x 10^{-19} m^2, assuming water to be the permeant).

Test Results for SMC Concretes

RE/SPEC performed gas permeability tests on concrete specimens from an SMC sample batched by the WES and from two cores recovered from the SSSPT at the WIPP facility. The results are summarized in RE/SPEC (1996, p. 14). The permeability of the SMC specimens ranged from 2.1 to 7.5 x 10^{-21} m^2, with an average of 4.71 x 10^{-21} m^2. The SSSPT specimens had a range of 0.3 to 5.0 x 10^{-19} m^2 with an average of 2.18 x 10^{-19} m^2.

Knowles and Howard (1996) have published the results of field permeability tests carried out in the SSSPT boreholes using gas and brine. Overall seal system permeabilities were determined using gas and ranged from 1.0 x 10^{-20} m^2 to 1.0 x 10^{-17} m^2 for tests carried out from 1985 through 1987, and from 1.0 x 10^{-23} m^2 to 1.0 x 10^{-19} m^2 for the 1993 through 1995 tests. Testing using brine gave values of 1 x 10^{-19} m^2 for the 1985 through 1987 tests, and from 1.0 x 10^{-22} m^2 to 1.0 x 10^{-19} m^2 for the 1993 through 1995 tests.

Table 4.5.1 Assigned Values to the Permeability of SMC, as Recorded on Form 464

id	idmtrl	idpram	tblmateri	units	distyp	mean	mode	std dev	max	min
2470	CONC_T1	PRMX_LOG	Concrete column; 0 to 400 years	log (m^2)	TRIANGULAR	-18.8160	-18.7496	0.7550	-17.0000	-20.6990
2471	CONC_T1	PRMY_LOG	Concrete column; 0 to 400 years	log (m^2)	TRIANGULAR	-18.8160	-18.7496	0.7550	-17.0000	-20.6990
2472	CONC_T1	PRMZ_LOG	Concrete column; 0 to 400 years	log (m^2)	TRIANGULAR	-18.8160	-18.7496	0.7550	-17.0000	-20.6990
2486	CONC_T2	PRMX_LOG	Concrete column; 400 to 10,000 years	log (m^2)	CONSTANT	-1.400E+01	-1.400E+01	0	-1.400E+01	-1.400E+01
2487	CONC_T2	PRMY_LOG	Concrete column; 400 to 10,000 years	log (m^2)	CONSTANT	-1.400E+01	-1.400E+01	0	-1.400E+01	-1.400E+01
2488	CONC_T2	PRMZ_LOG	Concrete column; 400 to 10,000 years	log (m^2)	CONSTANT	-1.400E+01	-1.400E+01	0	-1.400E+01	-1.400E+01
3059	CONC_MON	PRMX_LOG	Degraded concrete monolith	log (m^2)	CONSTANT	-1.400E+01	-1.400E+01	0	-1.400E+01	-1.400E+01
3060	CONC_MON	PRMY_LOG	Degraded concrete monolith	log (m^2)	CONSTANT	-1.400E+01	-1.400E+01	0	-1.400E+01	-1.400E+01
3061	CONC_MON	PRMZ_LOG	Degraded concrete monolith	log (m^2)	CONSTANT	-1.400E+01	-1.400E+01	0	-1.400E+01	-1.400E+01

(It appears that SMC is about an order of magnitude more permeable to gas than brine.) These permeability ranges encompass the range of permeabilities measured in the laboratory by RE/SPEC. The permeabilities of the individual seal components were not determined in the field tests. Concrete permeabilities were derived as a result of computer simulations of brine and gas flow behavior.

Derivation of the Intrinsic Permeability of SMC Up To 400 Years

The SMC laboratory data on permeability are very consistent, with an average value of 4.7×10^{-21} m^2 (RE/SPEC, 1996, p. 13). It is possible that the consistency is largely due to the fact that all tests were performed on one batch of SMC prepared in the laboratory under carefully controlled conditions. The wider range of values obtained in the SSSPT may be more representative of the range that will be found when SMC is placed in the field.

By including the SSSPT data set with the SMC data set, RE/SPEC has effectively increased the permeability of SMC to an average value (mode) of 1.78×10^{-19} m^2 (or 38 times more permeable than the laboratory average). This increase in permeability tends to account for the following uncertainties:

- Less procedural consistency (and therefore higher permeability values) when the SMC is placed under field conditions.
- The samples contained some moisture. Drying the samples typically increases gas permeability measurements by 1 to 2 orders of magnitude. This may be largely offset, however, by the Klinkenberg correction, which was not applied, and usually would reduce the gas permeability by about an order of magnitude. Under field conditions the concrete will not be dried out, so the laboratory values of permeability obtained by RE/SPEC are probably representative of the emplaced concrete.
- The tendency for concrete to degrade over time.
- The possibility of leakage at the concrete/salt interface.

RE/SPEC has used the data in RE/SPEC, 1996, p. 14, to determine the probability density function (PDF) for the SMC, defined by a log triangular distribution with a best estimate of 1.78×10^{-19} m^2 and with lower and upper limits of 2.0×10^{-21} m^2 and 1.0×10^{-17} m^2, respectively (RE/SPEC, 1996; Pfeifle, 1996). These values are reasonable and consistent with the SSSPT seal system permeabilities of SMC reported by Knowles and Howard (1996) in Table III.

Permeability of Degraded Concrete

The SMC is specially designed for use as a shaft seal in the Salado formation. Sufficient salt is added as a dry aggregate to saturate the hydration water with sodium chloride. Even without protection it is

unlikely that the SMC monoliths will be exposed to large quantities of brine that could cause alteration of the cement paste and removal of mass. The concrete monoliths are protected in the shaft, however, with asphalt and clay, which are designed to almost entirely eliminate any kind of transport of the concrete constituents (Hansen, 1996).

RE/SPEC has largely discounted the function of the concrete after 400 years, assuming that the concrete has deteriorated and is comparable to a dense soil with a permeability range from 1×10^{-17} m^2 to 1×10^{-12} m^2, with a best estimate of 1×10^{-14} m^2 (Pfeifle, 1996). This is similar to the earthen fill used higher in the shaft. These assumptions are conservatively reasonable (i.e., the permeability average will probably be higher than projected, especially in the near to intermediate term of 400 to 1000 years). This value of 1×10^{-14} m^2 is applied to the shaft concrete (CONC_2) from 400 to 10,000 years, and to the degraded shaft monolith (CONC_MON). It is a constant value of permeability and applies to all three orthogonal directions (x, y, and z).

4.5.2. Adequacy of Requirements and Criteria

The performance requirements for SMC have been stated in many documents (e.g., Wakeley, Harrington, and Hansen, 1995, chapter 2; Wakeley, 1994). SNL and WES have worked together to develop a highly placeable and reproducible salt-saturated mass concrete that will bond with the Salado host rock and is designed to be stable in the Salado formation for a long period of time. It is also designed to have a very low permeability initially and for at least 400 years.

4.5.3. Assumptions

It is assumed that appropriate process and quality controls will be maintained when the concrete is mixed and placed underground, and that the SMC samples tested by RE/SPEC are representative of the concrete that will be emplaced during construction of the seals. It is also assumed that the clay and asphalt seals will be constructed as designed so as to afford additional protection to the concrete seals from brine-flow associated damage. It is assumed that there is no significant deterioration in the permeability of the SMC for the first 400 years of its life.

It is assumed that the concrete behaves as designed, so that no shrinkage cracks develop during curing; fractures would likely increase the overall permeability of the concrete mass, since porous flow is assumed rather than fracture flow.

It is assumed that the concrete will act as a rigid inclusion within the Salado formation, and that salt creep will eliminate the DRZ around the shaft within a short time (probably a few years) and provide a tight interface with the emplaced concrete. The interface is included in the value of permeability for the SMC, while the DRZ effect is handled in the PA model. It is assumed that the concrete remains in a compressive environment and does not fracture.

4.5.4. Alternate Interpretation

Alternate interpretations include the converse of the assumptions discussed in Section 4.5.3. For example, there may be some geologic circumstances that would place some of the SMC in tension, leading to the development of cracks within the concrete. The tendency for salt to creep, however, and the fact that the SMC is a "stiff" plug in a "soft" environment of salt, argues against significant tension developing in the concrete. This also seems unlikely, based on the experience of placing bulkheads in shafts to control mine flooding in South Africa. Based on evidence in placing mass concrete in bulkheads and gravity dams, shrinkage cracks are deemed unlikely and are avoidable through proper design and emplacement processes.

There is a possibility of minor degradation at the concrete/salt interface. This is expected to be superficial based on decades of experience with borehole plugs, and the experience of building an emergency bulkhead in a salt horse at the Rocanville Mine in Saskatchewan, that has been withstanding 8.7 MPa of hydraulic pressure for over eight years without leakage at the interface. In any case, it has been demonstrated at WIPP that there is a tendency for the salt to creep around a rigid inclusion, eliminating the DRZ and tightening the interface (Knowles et al., 1996).

There is some uncertainty concerning the long-term performance of the concrete because magnesium-rich brines cause degradation of concrete (Wakeley et al., 1994). Degradation is time-dependent, but the time scale for SMC is not known. At the WIPP, stress and strain measurements reported by Knowles and Howard (1996) showed that seal compressive stresses rose rapidly after concrete seal construction and reached steady state in 100 to 200 days. There was no visual evidence of spalling or structural degradation, and the salt-saturated concrete has maintained its integrity for more than 10 years. During extraction of concrete/host rock interface material, breakage occurred preferentially in the concrete seal material rather than along the interface (hence, leakage at the interface is unlikely). In addition, the calculated gas permeabilities showed that in the immediate vicinity of the concrete seal, a disturbed zone did not exist (implying that the DRZ had completely healed). In conclusion, the performance so far has

been excellent and bodes well for long-term performance, especially within the 400-year time frame required by PA for this material.

4.5.5. Uncertainties and Consequences

The SMC is an excellent mix for its intended function as a shaft seal in salt. If it is not mixed and placed as designed (i.e., there is poor quality control during construction), it may not function as intended. This is deemed unlikely given the emphasis on quality work and quality assurance in the WIPP program.

The extreme consequences of poor quality control are loss of function of the concrete (i.e., it is not strong enough or impermeable enough to function as an effective shaft seal).

4.5.6. Appropriateness and Limitations of Methodology and Procedures

The procedures used to design the mix and test it are at current state-of-the-art, and were performed by knowledgeable and experienced personnel at WES. However, only five permeability measurements were made at RE/SPEC on a single specimen of SMC. Measurements from other batches are desireable to ensure that these low permeabilities can be reproduced in multiple batches of SMC.

4.5.7. Adequacy of Application

Even though the samples were not dried out prior to determining the gas permeability of the concrete in the laboratory, the moisture conditions in the samples are fairly representative of moisture conditions that will be encountered in the emplaced concrete. Hence, the selected best estimate value of 1.7×10^{-19} m^2 is probably fairly representative of brine permeability.

The laboratory values of permeability were effectively increased to take into account uncertainties in placing the concrete, the tendency for concrete to degrade over time, and the possibility of minor leakage at the concrete/salt interface. This is an appropriate adjustment. The resulting permeability is consistent with the SSSPT field measurements reported by Knowles and Howard (1996).

4.5.8. Accuracy of Calculations

The individual calculations of permeability appear to be accurate. They are based on laboratory tests on SMC specimens and SSSPT specimens. The inclusion of the SSSPT data in the data set increases the permeability derived for the SMC. This produces a conservative overall number for SMC, since lower permeabilities are desireable and, conversely, higher permeabilities are less desireable. This distribution

function was calculated by RE/SPEC using equations derived by others. These calculations were not checked in detail; however, they appear to be reasonable and yield reasonable results.

4.5.9. Validity of Conclusions

The permeability of SMC during its first 400 years of life has been defined by a triangular distribution with a best estimate of 1.78×10^{-19} m^2, and with lower and upper limits of 2×10^{-21} m^2, and 1.0×10^{-17} m^2, respectively. This is adequate and reasonable.

After 400 years the concrete is assumed to degrade to the permeability of a dense soil, 1×10^{-14} m^2. This estimate is also applied to the concrete monolith at the bottom of the shaft. Although this appears to be a conservative estimate (i.e., the concrete probably will not degrade as quickly in practice), given the uncertainties in predicting the durability of the concrete a long time into the future, the estimate of 1×10^{-14} m^2 is not necessarily unreasonable, especially for time periods exceeding 1000 years.

4.5.10. Dissenting Views

None

4.6. Permeability of Compacted Clay

4.6.1. General Evaluation

A large portion of the shaft seals consists of compacted bentonite clay. The intrinsic permeability of the clay is needed to model the performance of the overall shaft sealing system.

The compacted clay columns will be constructed in three locations: the Lower Salado immediately above the shaft station monolith (one interval 28 to 33m in length depending on the shaft being sealed), the Upper Salado between the middle and upper concrete components (102 to 105m in length), and the Rustler formation (approximately 71m in length) (Sandia WIPP, 1996). The permeability of the compacted clay is required by PA for different time periods (0 - 10 years, 10 - 25 years, 25 - 50 years, 50 - 10,000 years).

Depending on the depositional climate, the permeability of natural clays is frequently different in the vertical and horizontal directions. Hence, it is common practice to determine the permeability in three orthogonal directions (one normal and two parallel to the bedding). In remolded clays the permeability is usually isotropic, as in the case of the compacted clay at WIPP.

In BRAGFLO the permeability of the compacted clay is treated as a triangular distribution and expressed in its log form. The permeability parameters for compacted clay contained in Form 464 are shown in Table 4.6.1, together with their assigned values. The best estimate value for the permeability of the compacted clay is 5×10^{-19} m^2.

Permeability of Compacted Clay

Clays are natural materials that are generally stable and have low permeability. In nature, clay layers often comprise the aquitards of natural flow systems and act as natural seals, so it is not surprising that reconstituted clay is being considered as backfill or a sealing agent at the WIPP site.

The specifications for the compacted clay seals in the Salado and Rustler formations is for a well-sealing grade of sodium bentonite (Kelley, Jones, and Ogintz, 1996). The composition is typically 80 to 90% montmorillonite, with the remaining portion dominated by quartz or feldspars. The age of candidate bentonite sources in Wyoming and Canada ranges from 10^6 to 10^8 years (Gray, 1993, pp. 167-168). The seals will be emplaced at a dry density of 1.8 g/cm^3 (112 lb/ft^3) or better.

Kelly, Jones, and Ogintz, 1996, have summarized a large body of data from the literature concerning the hydraulic conductivity and permeability of compacted bentonite in Tables 2-1 and 2-2 of their report. The permeabilities are plotted in Figures 2-1, 2-2 and 2-3 of that report, generally as a function of density. Figure 2-3, reproduced here as Figure 4.6.1, shows the relationship of permeability versus density. The permeability of reported bentonites range from 1×10^{-21} to $1 \times 10^{-15} m^2$.

Experiments have shown that sand can be added to the bentonite without affecting the overall permeability of the bentonite/sand mix, provided that the clay content remains above 50% and the equivalent dry density remains the same (Cheung, Gray, and Dixon, 1987). Nevertheless, it is the opinion of the Panel that for long-term performance the seals should be as rich as possible in clay minerals and that any dilution with quartzitic materials be avoided (or minimized).

Two factors that affect the permeability of bentonite are the dry density at emplacement and the salinity of the permeant fluid. Work by Ran and Daeman, 1995, for SNL demonstrates how the permeability of bentonite is reduced from 10^{-18} m^2 at a density of 1.4 g/cm^3, to 10^{-21} m^2 at a density of 2.1 g/cm^3. Clearly, higher densities are desirable, and the achievement of low permeabilities in the field will depend largely on emplacement techniques and quality control.

Table 4.6.1. Assigned Values to the Permeability of Compacted Clay, as Recorded on Form 464

id	idmtrl	tblmateri	idpram	units	distyp	mean	mode	std dev	max	min
2385	CL_M_T1	Upper Salado clay; 0 to 10 years	PRMX_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2386	CL_M_T1	Upper Salado clay; 0 to 10 years	PRMY_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2387	CL_M_T1	Upper Salado clay; 0 to 10 years	PRMZ_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2453	CL_M_T5	Upper Salado clay; 100 to 10,000 years	PRMX_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2454	CL_M_T5	Upper Salado clay; 100 to 10,000 years	PRMY_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2455	CL_M_T5	Upper Salado clay; 100 to 10,000 years	PRMZ_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2351	CL_M_T2	Lower Salado clay; 10 to 25 years	PRMX_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2352	CL_M_T2	Lower Salado clay; 10 to 25 years	PRMY_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2353	CL_M_T2	Lower Salado clay; 10 to 25 years	PRMZ_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2368	CL_M_T3	Lower Salado clay; 25 to 50 years	PRMX_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2369	CL_M_T3	Lower Salado clay; 25 to 50 years	PRMY_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2370	CL_M_T3	Lower Salado clay; 25 to 50 years	PRMZ_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
3078	CL_M_T4	Lower Salado clay; 50 to 10,000 years	PRMX_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
3079	CL_M_T4	Lower Salado clay; 50 to 10,000 years	PRMY_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
3080	CL_M_T4	Lower Salado clay; 50 to 10,000 years	PRMZ_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
3009	CLAY_RUS	Rustler compacted clay	PRMX_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
3010	CLAY_RUS	Rustler compacted clay	PRMY_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
3011	CLAY_RUS	Rustler compacted clay	PRMZ_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2317	CLAY_BOT	Shaft bottom clay	PRMX_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2318	CLAY_BOT	Shaft bottom clay	PRMY_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000
2319	CLAY_BOT	Shaft bottom clay	PRMZ_LOG	log (m^2)	TRIANGULAR	-18.8670	-18.3010	0.7811	-17.3010	-21.0000

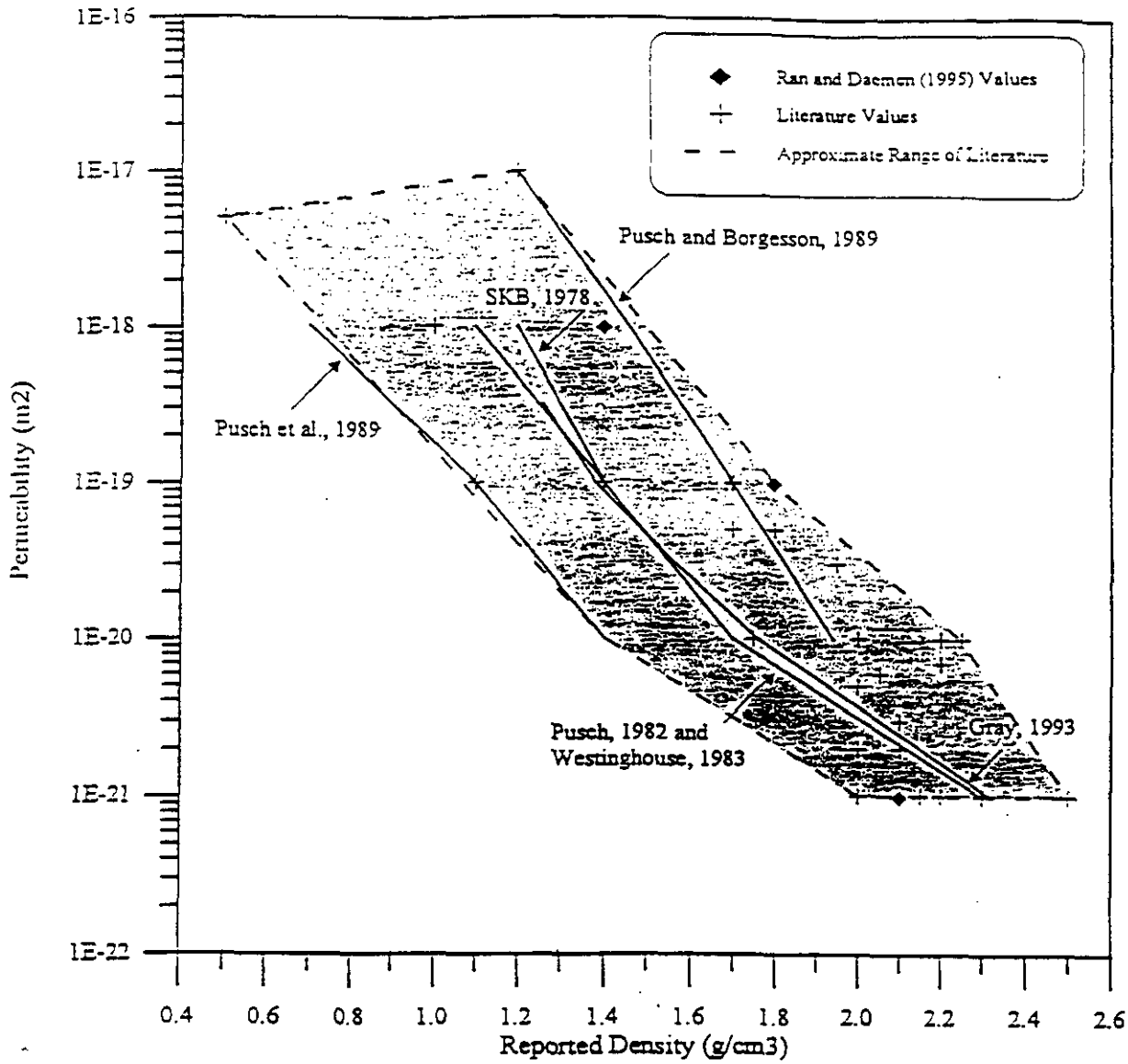

(Kelley, Jones and Ogintz, 1996)

Figure 4.6.1. Sodium Bentonite Permeability Versus Density

In general, permeability increases as salinity increases because electrolyte concentration reduces swelling pressure in the bentonite. This effect is less noticeable at higher densities, another reason for achieving high emplacement densities in the field. Kelley, Jones, and Ogintz (1996) recommend that permeabilities measured using fresh water be increased by a factor of 5 to account for the degrading effects of water salinity on the shaft seals. The factor of 5 is based on work undertaken as part of the Swedish (SKB) borehole plugging program (Pusch et al., 1987; see Section 4.6.5); however, it appears to be a

conservative number (i.e., a higher factor than expected) based on the work of Cheung et al., 1987, Table 1.

Field Tests at the WIPP

The Series D tests, carried out as part of the SSSPT, tested two 100% bentonite seals in vertical boreholes within the Salado formation at the repository horizon. Each seal was 0.91m in diameter and 0.91m in length. The initial clay densities were 1.8 and 2.0 g/cm^3. Brine pressure differentials of 0.72 and 0.32 MPa were maintained for several years, and no visible brine has been observed at the downstream end of the seals. Knowles and Howard (1996) have reported a bounding calculation of brine permeability for these seals of 1×10^{-19} m^2 (i.e., this is the highest possible value for permeability). Gas flow tests on one of the bentonite seals exhibited negligible gas flow until the test interval pressure exceeded 4 MPa.

Derivation of Intrinsic Permeability of Compacted Bentonite Clay

Kelley, Jones, and Ogintz (1996) have specified the distribution function for the permeability of the compacted clay to be used as seals at the WIPP as follows:

- It is a triangular distribution, in which the maximum and minimum permeabilities are 5×10^{-18} m^2 and 1×10^{-21} m^2, respectively.
- The best estimate is 5×10^{-19} m^2.

4.6.2. Adequacy of Requirements and Criteria

The requirement is to establish a permeability value (or distribution) representative of the emplaced seal material, so that this value can be used in PA calculations.

In the field, the requirements are to emplace the clay so that it is an effective shaft seal with a very low permeability. Natural bentonite is a stable material that generally will not change significantly over a period of 10,000 years. Consequently, it is incumbent upon WIPP not to add anything to the bentonite that will compromise its ability to provide a long-term seal, and to ensure that the bentonite is compatible with the formations (Salado, Rustler) in which it is placed. Moisture content and density must be controlled during emplacement. The specifications call for a minimum clay density of 1.8 g/cm^3 (the calculations allow 1.6 g/cm^3). This must be maintained and verified through standard field control methods for emplacement of soils.

4.6.3. Assumptions

It is assumed that densities achieved will be 1.6g/cm^3 or better; this is achievable. It is also assumed that Salado brines will not cause the permeability of the bentonite seal to increase by more than a factor of five, when compared to tests conducted using fresh water. As discussed in Sections 4.6.2 and 4.6.4, this factor appears to be a conservative number (i.e., it is at the higher end of the range based on current research). Again, it is assumed that the repository environment does not allow the bentonite to dry out and allow shrinkage cracks to develop; this is most unlikely, but if it did occur, re-wetting would immediately cause the bentonite to swell and thereby maintain the seal.

4.6.4. Alternate Interpretation

Since the flow of brines within the DRZ is accounted for in the PA model, the interface and DRZ effects do not have to be accounted for in specifying the permeability of the clay.

Alternate interpretations include the converse of scenarios discussed in Section 4.6.3. As discussed by Gray (1993), the compacted bentonite seal could be disrupted by externally applied forces, or the internal structure of bentonite could alter to the point where it would be unable to sustain the loads to which it is subjected. Fluid flow properties, including permeability, could be affected by either or both of these mechanisms.

Three internal mechanisms could affect the sealing properties of bentonite: illitization, silification and charge change (Gray, 1993). Illitization is the transformation of the montmorillonite to illite, which involves the substitution of Al^{3+} for Si^{4+} within the montmorillonite layers. Since illite clay crystals are larger than those of montmorillonite, the clays are less active and have a higher permeability. Although there are many uncertainties in estimating the rate at which montmorillonite converts to illite, the SKB work (Gray, 1993) concluded that at 60° C (higher than the *in situ* temperature at WIPP and therefore conservative), there would be negligible transformation over a period of 100,000 years.

Silification is the deposition of silica within the clay structure, which tends to strengthen the clay but can also increase permeability. As part of the SKB work, samples of bentonite were heated and subjected to water pressure in an autoclave to try and accelerate the processes of illitization and silification. Exposing bentonite to an Na-rich solution caused virtually no increase in hydraulic conductivity (1×10^{-7} m/s) at temperatures below 100° C. Also, there was little silification below 100° C. Between 60 and 100° C, the number of water layers found between the clay crystals was reduced from 2 to 1. These tests, together with a study of natural bentonite deposits, indicated that K^+ montmorillonite clays will convert to

materials rich in hydrous mica but, in the absence of significant heat, it would take millions of years for the composition of the montmorillonite to be significantly altered.

4.6.5. Uncertainties and Consequences

As part of the SSSPT program at WIPP, bentonite seals have proved effective in preventing the flow of saline solutions. These tests, however, are relatively short term (about 10 years). Extrapolation to 10,000 years is only possible by combining this experience with natural clay analogs.

Stress measurements within a 100% bentonite core seal tested as part of the SSSPT program at WIPP indicated a reduction in stress at approximately 1400 days (Knowles and Howard, 1996, Figure 11). Knowles and Howard suggest that this may be related to ion-exchange with permeant brines in the bentonite fabric. This is under investigation and the impact, if any, is unknown at this time.

Pusch et al. (1987) discuss the effect of chemical composition of the groundwater on the borehole sealing tests at Stripa, using clay rich in montmorillonite from Wyoming with sodium as a major adsorbed cation. Cations from the groundwater can diffuse into the clay plug and replace the initially adsorbed sodium. Another possibility is that salt water, still having sodium as a dominant cation, can increase the salinity of the clay porewater. Both processes cause a drop in swelling pressure and an increase in hydraulic conductivity. Pusch et al. (1987) estimate that for bulk densities in the range 1.8 to 1.9 g/cm^3 (similar to that expected at WIPP), the swelling pressure when passing from the sodium state to the calcium state may drop by 20 to 50%, while the hydraulic conductivity increases 2 to 5 times. They estimate that if the salinity of the clay porewater increases "to that of the oceans" (quite likely at WIPP, especially at the edges of the clay seal), then the hydraulic conductivity could increase 5 times. This is the basis of the factor of 5 for the degrading effects of salinity recommended by Kelley, Jones, and Ogintz (1996), discussed in Section 4.6.1. Mitigating factors at WIPP include the low permeability of the salt host rock (so that little groundwater is brought into contact with the clay seal), and the thickness of the clay seal (which means that any degradation will start at the periphery of the seal and gradually work its way inward). The low permeability of the host rock mitigates against the possibility of erosion and removal of the bentonite, which was a concern in the fractured crystalline rocks at Stripa (Pusch et al., 1987).

The main uncertainty in defining this parameter is the quality of construction at the time the seals are emplaced. Given the emphasis at WIPP on the use of standard operating procedures and quality of work, and the fact that this represents standard construction practice, it need not be a concern.

4.6.6. Appropriateness and Limitations of Methodology and Procedures

The procedures used for determining the permeability of the compacted clay are standard in the industry. There is also a wide body of published results in the literature to back up the value chosen.

4.6.7. Adequacy of Application

Bentonite is a stable, geologic material containing mainly montmorillonite clay, which has remained unchanged in nature for millions of years. When adopted by man for engineering uses it has proved to be an effective seal in the long term.

4.6.8. Accuracy of Calculations

The calculations of permeability are standard in hydrology. They are straightforward, uncomplicated, and appear to be accurate. The fact that there is much data contributed by many different researchers, and that these data are generally consistent, increases the Panel's confidence in the overall result.

4.6.9. Validity of Conclusions

The use of bentonite as a shaft seal is proven technology. For a bentonite seal placed according to standard construction techniques with a density above 1.6 g/cm^3 (the value used in the design calculation, although the construction specifications call for a density above 1.8 g/cm^3), the chosen distribution for clay permeability is appropriate and valid (the best estimate value is 5 x 10^{-19} m^2). Since properly placed bentonite is not expected to deteriorate with time, this triangular distribution of permeability is isotropic, and applies to all the time-dependent parameters listed in Table 4.6.1.

4.6.10. Dissenting Views

None

5.0 EVALUATION OF DISPOSAL ROOM/ROCK MECHANICS PARAMETERS

5.1. Initial Density of Waste

5.1.1. General Evaluation

The initial density of the waste (prior to consolidation due to overburden pressure) is needed for the PA. Butcher and Holmes (1995) have derived an overall average value for all waste components of 559.5 kg/m^3, which is currently being used in PA calculations.

The disposal room is treated in the WIPP PA as an area with time-varying porosity driven by creep closure, waste compaction, brine or gas inflow/outflow, gas pressure generation and possible outflow (see Section 5.6). The pore space thus defined can contain both gas and liquid. The room also has certain internal fluid-flow properties (Sandia WIPP, 1992). Waste densities are one group of parameters ultimately needed to determine initial disposal room porosity and changes of room porosity with time. The objective of determining waste densities is therefore clear. For the purposes of this review, waste densities are here defined as "initial" waste densities. That is, they are the densities of waste components as delivered to the WIPP. Although the units are those of a conventional density (kg/m^3) the actual meaning is "mass of solid waste per unit volume of container." Furthermore, these densities are summed into a single total "density" for subsequent calculations. Changes of waste density (if any) during the life of the WIPP are discussed in Sections 5.2 and 5.6. "Waste" is usually defined as the total of waste containers (such as drums) and their contents, although the exact use of the term waste is not entirely consistent throughout the WIPP project literature. (In some cases, waste has been used to describe the solid contents of containers. In the case reviewed here, waste volume includes the solid contents of the containers and the void space in the containers, but does not include the mass of the containers.) Waste densities are listed by Butcher, 1996A, B, and C and derived largely from the current baseline inventory, WTAC, 1995A. They are shown in Table 5.1.1. The solid densities used to derive these densities (by using the individual weight fractions) are provided in Table 5.1.2.

As shown, the waste components are metallics, sorbents, cellulose, rubber and plastics (grouped together), and sludges. The total inventory estimates are not necessarily accurate, because waste has not been characterized and assayed in detail. Instead, some assumptions are made by WIPP in determining waste content and character. With the assumed component solid densities and fractions, as listed in the references, the initial total waste density used for current calculations, as stated above, is 559.5 kg/m^3.

Table 5.1.1. Mass Quantities of Solid Waste Per m^3

Name	Value
Metallic	122 kg
Sorbents	40 kg
Cellulose	170 kg
Rubber and Plastic	84 kg
Sludges	143.5 kg
Total: Initial Waste Density	559.5 kg/m^3

Table 5.1.2. Waste Solid Densities

Name	Value
Metallic	7830 kg/m^3
Sorbents	3000 kg/m^3
Cellulose	1100 kg/m^3
Rubber and Plastic	1200 kg/m^3
Sludges	2200 kg/m^3
Waste Solid Density	1757 kg/m^3

That is, there are 559.5 kg of "solid" waste in 1 m^3 of drum volume. The term solid is here placed in quotation marks because some of the solid waste, such as rags and sludge, contains internal liquid-filled porosity that is considered part of the solid, but in actuality might later become free liquid. From the initial waste densities and component fractions, an initial waste porosity of 0.681 is calculated and used in subsequent calculations of room porosity for input to PA.

5.1.2. Adequacy of Requirements and Criteria

Clearly, a solid density is required as a starting point for any room porosity calculation. This waste density (and its contributing component densities) parameter serves that purpose.

5.1.3. Assumptions

Other than assuming the validity of standard concepts of density and porosity, the main assumptions appear to be: (a) the waste solids do not themselves contain liquids, (b) only contact-handled transuranic (CH-TRU) waste (including drums but no boxes) need be considered, and (c) the volume of steel in the drums and plastic in the liners can be ignored. Assumption (a) will lead to no error in initial density but possibly to a small error in subsequent compaction calculations. Assumptions (b) and (c) could result in some dense material being ignored, thereby leading to a slightly lower initial waste density than may

actually exist in the repository. However, in view of other uncertainties in waste content, room geometry, and the ongoing determination of whether or not backfill will be used, these assumptions and subsequent minor inaccuracies do not appear to have any critical effects (see Section 5.1.5).

5.1.4. Alternate Interpretation

A second revision of the baseline inventory report (WTAC, 1995B) is discussed by Butcher, 1996B. Here, the presence of some vitrified waste is assumed, where before it was not. This change increases the proportion of metal-based waste, and therefore probably increases the initial component waste density, but may either increase or decrease waste porosity, depending on the packing density. Because of the uncertainties in composition and packing, and the fact that calculations were already underway, the waste density changes that would be caused by the second revised baseline inventory were not made (Butcher, 1996B.) This omission does not appear to have a major effect on subsequent porosity calculations, in view of the overall uncertainties involved.

5.1.5. Uncertainties and Consequences

From the documentation, it is apparent that the exact composition and proportions of the waste packages to be delivered to WIPP are somewhat uncertain. The present waste density estimates reflect this. However, the present waste density uncertainties are not excessive and do not have any adverse consequences on PA calculations.

5.1.6. Appropriateness and Limitations of Methodologies and Procedures

The basic methodologies for calculating waste densities (and waste porosity) are documented in Butcher, 1996C. These are standard definitions and equations and the methodologies and procedures are appropriate.

5.1.7. Adequacy of Application

The method of incorporating waste densities by adding fractional mass is appropriate and adequate for use in room porosity calculations, which is its use within PA.

5.1.8. Accuracy of Calculations

The present calculations of initial waste density are sufficiently accurate. However, additional accuracy could be achieved by accounting for components according to the current best inventory estimates based

on improved waste characterization analysis for waste containers such as drums and boxes. If new PA calculations are required in the future, minor adjustments should be made to account for any new information concerning these factors.

5.1.9. Validity of Conclusions

Conclusions with regard to waste densities are reasonable and valid, as based on current data and assumptions. This validity applies specifically to the initial waste density value of 559.5 kg/m^3 currently used as input to room porosity calculations.

5.1.10. Dissenting Views

None

5.2. Mechanical Properties of Waste

5.2.1. General Evaluation

Closure of the waste disposal room to encapsulate the waste will be resisted by the physical strength, or crush resistance, of the waste containers and waste components within the containers (and also any gas/liquid pressure and backfill in the room). Thus, the mechanical properties of the waste are key to determining the ultimate closure magnitude and closure rate of the room/panel system. These properties are part of the disposal room porosity surface generated by the SANTOS code and used in PA calculations (defined in Section 5.6). In this section, only the waste mechanical properties are discussed.

To allow for systematic and predictable waste compaction, a model is required and the parameters of that model must be determined. If feasible, these parameters should be determined by experiments, since little or no information exists on compaction measurements of these material types or configurations. Such experiments have been conducted by WIPP on simulated waste and are described by Butcher et al., 1991 and Thompson and Luker, 1990. Furthermore, the development and use of an elastic-plastic waste compaction model are described in Weatherby et al., 1991; Sandia WIPP, 1992; Butcher and Mendenhall, 1993; Stone, 1996; and Butcher, 1996A. Following the approach used in these references for the WIPP PA, waste mechanical properties are expressed as five elastic-plastic parameters and a pressure-relative density table (Tables 5.2.1 and 5.2.2).

Table 5.2.1. Waste Elastic-Plastic Constants

Name, Unit	Value
Shear modulus (G), MPa	333
Bulk Modulus (K), MPa	222
Yield Parameter a_0, MPa	1.0
Yield Parameter, a_1	3.0
Yield Parameter, a_2	0.0

Table 5.2.2. Pressure-Relative Density Relationship for Waste (Drums)

Pressure, MPa	$\ln(\rho/\rho_o)$
1.53	0.510
2.03	0.631
2.53	0.719
3.03	0.786
3.53	0.838
4.03	0.881
4.93	0.942
12.0	1.140

The elastic parameters and yield parameters (Table 5.2.1) are assumptions only. Only the pressure-relative density (ρ/ρ_o) values are based on the experimental data, as summarized in Butcher et al., 1991. The parameter values in Table 5.2.1 assure that plastic flow and the onset of compaction occur very early in the loading process and dominate the behavior. Thus, the exact values of the Table 5.2.1 parameters are relatively unimportant, and the Table 5.2.2 parameters dominate the waste mechanical behavior. This method (of assuming the values of elastic and yield parameters and measuring the values of volume compaction parameters) is justified by the fact that the phenomenon of inelastic volume compaction is shown by the data to completely dominate the behavioral regime of relevance.

At first, it may seem that the last value of pressure (12 MPa) in Table 5.2.2 is not high enough to cover the expected range of behavior at the repository depth (where overburden stress is about 14 MPa). However, for SANTOS, the pressure values in Table 5.2.2 are assumed to be mean stress values in the case of axial drum compaction, with no net lateral stress. That is, $P = (\sigma_{axial} + 2\sigma_{lateral})/3$. Therefore, the pressure value of 12 MPa corresponds to a maximum axial stress on the drums of 36 MPa, which is more than sufficient to cover the applicable range of behavior.

5.2.2. Adequacy of Requirements and Criteria

Waste compaction is an important element of room closure and room total porosity determination. Requiring that laboratory measurements be made of the most important aspect of this behavior (the non-elastic compaction) and that the results be evaluated in the form of a model, even given the uncertainties in waste content, is an essential and adequate requirement for this aspect of WIPP modeling.

5.2.3. Assumptions

The main assumptions leading to the identification of waste mechanical properties appear to be: (a) the simulated waste tested is representative (in both type and geometry) of the actual waste, (b) waste compaction is independent of other events or processes, (c) waste compaction is rapid (in comparison to the time required for room closure), (d) the elastic-plastic compaction model chosen to represent behavior is representative, and (e) for purposes of parameter determination, the waste compacts primarily in the axial direction. Certain subsidiary assumptions made during the course of test analysis and modeling are discussed later.

For assumption (a) that the simulated waste tested is representative, the WIPP principal investigators started with the published baseline inventory, and then selected sample types and amounts consistent with this inventory, using local sources of similar materials. Of course, the actual waste will have more variability than the simulated waste tested, and may even be different on average. With regard to assumption (b) the independence of behavior, there may be several ways that this may be violated. The most likely is that corrosion and decay of the waste can cause it to abruptly lose its mechanical strength. Assumptions (c) and (d) are appropriate and require no discussion. With regard to assumption (e) of axial compaction, most of the actual data exist for axial compaction, and room closure will be primarily axial, as is shown by subsequent calculations of the porosity surface (Section 5.6).

Although some of the above assumptions may not be completely valid, none of them change the essential behavior of starting from a set density/porosity, and compacting smoothly to a reasonable end state, which are the important aspects of this behavior. The Panel therefore finds that none of the assumptions are likely to lead to any critical oversight.

5.2.4. Alternate Interpretation

Changes in the assumptions or changes in data reduction procedures (Section 5.2.8) can lead to alternate interpretations. However, clearly, the waste must compact, and the end state of the compaction is to an

equivalent of its initial solid volume or slightly less, if internal porosity is accounted for. With room expansion, the waste should rebound within an elastic limit, but for other porous materials, this phenomenon will occur with an equivalent stiffness much greater than its stiffness for compression. Within these bounds of behavior, there is room for other interpretations of the data based on other models. However, all of these interpretations will have similar end points and will likely proceed smoothly between the two end points. This means that alternate interpretations are not likely to cause critical differences in results. For the waste mechanical compaction parameters, it is only necessary to use a data interpretation that provides results in a reasonable, physically realistic range, which the current experiments and interpretations do. Only if PA requires more detailed sampling of the waste mechanical properties (which it currently does not) should alternate interpretations be considered seriously. In the current situation, the interpretation used is adequate.

5.2.5. Uncertainties and Consequences

The waste composition and geometries are uncertain, the effect of packing and compositional variability are uncertain, and the stress state on the waste is uncertain. These uncertainties generally apply to the interpretation of laboratory data for waste mechanical properties as well as to the WIPP itself (except that the simulated waste composition is known in the laboratory). All of these uncertainties could contribute to changes in the resulting data interpretation and model behavior. However, the consequences will be to somewhat alter the shape of the final porosity surface (Section 5.6) but not to significantly alter closure behavior with regard to the performance of the repository. The assumed elastic-plastic parameters are in a reasonable range for a weak porous material and appear to be of little consequence except possibly in the case of room expansion and the associated unloading of waste. Then they would have some effect on the expansion rate. It does not seem, however, from the subsequent calculation of the porosity surface (Section 5.6) that the waste expansion plays a significant role as compared to the elastic and reverse creep properties of the halite. Therefore, no severe consequences result from uncertainties.

5.2.6. Appropriateness and Limitations of Methodologies and Procedures

Two types of waste compaction laboratory data were acquired and described in Butcher et al., 1991, Thompson and Luker, 1990, and associated data packages (WIPP Records Package, WPO26468). These data consist of a fairly large number of small-scale tests on specific materials in a relatively small 4-inch diameter oedometer (a rigid-walled axial compaction device), and four full-scale tests on drums with simulated waste mixtures. (Only two drum tests were used to assist in eventual parameter determination.) The major advantage of using the small oedometer is that a fairly large number of tests

could be done to characterize individual waste types and estimate some short-term creep compaction end-points. The major disadvantages of the oedometer are that unknown effects exist related to size scaling, wall friction, and lateral stresses. The major advantage of full-scale drum tests is that they are at full size with realistic waste contents. The major disadvantages of the full-scale drum test are that only a few could be run and no lateral confining stress could be applied. Both test types suffer from unknown effects of packing, sampling, and scale.

The oedometer tests on specific waste components allow the response of a variety of waste mixes to be calculated later, if required, by use of a volumetric mixing law. The major purpose of the small number of drum tests on mixed wastes was to substantiate the use of the oedometer tests to predict drum results.

Considering the limitations mentioned, the test methodology and procedures are adequate to determine simulated waste compaction curves and are certainly much better than pure estimates made without the benefit of laboratory testing. It is highly unlikely that the true compaction curves will lie completely outside the range measured in the laboratory, or far enough from the derived recommended curves to adversely affect appropriateness.

5.2.7. Adequacy of Application

The data and interpretations presently obtained for waste mechanical properties are adequate for use in disposal room porosity surface calculations and as input to PA. If the results of more precise waste characterization become available, waste compaction properties can be re-calculated as required.

5.2.8. Accuracy of Calculations

To establish recommended drum compaction curves, an assumption concerning data interpretation had to be made so that oedometer test results could be re-calculated to become equivalent drum compaction curves. Three methods were attempted: (a) treat the drums as metallic waste in a mixture, (b) use the observed "ring-compaction" geometry to estimate a conversion, and (c) ignore the drums. Method (c) gave the best agreement with data, and was therefore used. That method (a) should produce results that are too stiff, which it did, was anticipated because the thin-walled drums are not as mechanically strong as smaller metallic waste parts. However, why method (c) worked best is not well-explained in the documentation. It is possible that the oedometer tests could be expected to be systematically too stiff, due to size scaling and wall friction effects. If so, a systematic correction in the softening sense would be required to make the drum results agree with the oedometer results. Ignoring the drum itself would

fortuitously apply such a correction. This makes the choice of data interpretation model also somewhat fortuitous, but the results still make sense and unreasonable errors are avoided.

Another aspect of the results possibly affecting accuracy is that compaction curves are derived in terms of axial stress on the drums only. In the repository, some lateral stress will certainly exist. Therefore, the issue is to ascertain the importance of shear stresses (proportional to the difference between axial and lateral stresses) on compaction. Butcher et al., 1991, show that assuming the presence or absence of shear stresses may make little difference. However, to reasonably allow for some shear stresses, and yet maintain simplicity, the assumption that lateral stress is zero is made to calculate a final compaction curve. As shown in the Butcher report, this convenient simplification has only a small effect as compared to the variation in results caused by waste composition.

5.2.9. Validity of Conclusions

Many uncertainties exist in measuring and modeling the waste mechanical properties to obtain model parameters. However, some data and/or model relationship is needed to allow the starting waste porosity to translate into the compacted porosity, and to reflect the role the waste plays in resisting closure of disposal rooms. A combination of experimental procedures, assumptions and calculations are used to arrive at the five elastic-plastic parameters given in Table 5.2.1 and the pressure-relative density given in Table 5.2.2. The conclusions and values derived for these waste mechanical properties are substantially reasonable, valid, and useful for the purpose of disposal room closure calculations.

5.2.10. Dissenting Views

None

5.3. Initial Water Content of Waste

5.3.1. General Evaluation

The initial waste water content is a parameter used to quantify the initial source of water in the BRAGFLO calculations for gas generation and transport of radionuclides. It is identified as SAT.IBRN. The value assigned to SAT.IBRN is .015, which represents 1.5% waste container saturation by volume (Form 464, Parameter #669).

Many of the models in the WIPP PA fundamentally require that the waste be characterized for contents of the stored drums, including water content. This need ranges from physical properties including waste

strength, density and porosity to inventory such as rags, paper, metals, and woods. The conceptual models dependent on these parameters range from gas generation, nuclear actinide loading, and resistance to room creep closure, to accidental release. Water from the waste drums is added to water from other sources as part of the disposal system (such as brine inflow following repository closure) mostly in order to accurately calculate the time history of gas production that leads to other modeling considerations. Because it is difficult to get an accurate profile of free water in the radioactive waste, this parameter is derived by calculations made from assumed values based on bounding conditions. The lower bound is determined by assuming no water to be present. The upper bound can be assumed to coincide with the limit of free water permitted by the Waste Acceptance Criteria (WAC) for transportation of the waste. This maximum value for free liquids is 1.0% by volume of pure water. A mid value can be computed between these bounds from data acquired by the Idaho National Energy Laboratory (INEL) on Rocky Flats waste.

5.3.2. Adequacy of Requirements and Criteria

The objective was to provide an estimate of the total initial water content of waste for PA calculations. This was done by using assumed water content values per drum, which w[illegible] converted to a percent saturation of available void space in the waste container. Restraints were placed on the actual water content per drum by limiting it to free water, not to include any sorbed waters. This is believed to be due to difficulties in characterizing the waste and determining the amount of moisture it might contain when it is placed in the repository.

5.3.3. Assumptions

The assumption is that the unknown characterized state of the waste inventory requires a designated value. In this case, it is assumed that the waste compacted within the containers is are totally dry, with no adsorbed or absorbed water. The only water to be considered is free water, which is limited by the bounds of 0 to the 1.0% limit for shipping. This water is further assumed to be pure.

5.3.4. Alternate Interpretation

No alternate interpretation of the parameter was found except in regard to the average actual water content as determined by INEL to be approximately 0.181 pints per drum. Calculations showed this average value to be well within the range calculated by the bounding limits.

5.3.5. Uncertainties and Consequences

The uncertainties discussed in sections 5.3.2 and 5.3.3 are important to the parameter value; however, the consequences appear to be insignificant (less than 2.5% of potential brine inflow) when viewed in reference to a brine inflow scenario in which up to 30,000 m^3 of brine flow into the repository during the storage period (a PA assumption).

5.3.6. Appropriateness and Limitations of Methodology and Procedures

Nothing was found to indicate the data input as defined and converted is inappropriate, but it can be constrained by limitations due to problems the U.S. Department of Energy (DOE) has in characterizing the waste.

5.3.7. Adequacy of Application

It is inherent that the presence of water in the drums contributes to the chemistry and gases produced during the repository life. The methodology used to arrive at the actual liquid content of a "typical" drum might be more exacting and definitive if justified by scientific requirements. However, within the context of its overall impact on chemical and gas calculations, the assigned parameter value is believed to be adequate.

5.3.8. Accuracy of Calculations

The calculations that convert the assumed volumes of water in the waste drums were checked and found to be accurate. (The use of six significant digits in some of the numbers below is probably unwarranted.)

Elliott (1993) suggests that because of the availability of INEL database of Rocky Flats Plant (RFP) waste, it would be "more realistic" to use these data than to use bounding water values as previously used. The INEL data base shows values ranging from zero to 0.39208 pints, with an average of 0.18109 pints water per drum (Elliott, 1993). This average is much less than the upper bound established by the WAC of one percent or 4.4 pints per 55-gallon container.

In summary, the SNL calculations show the waste water saturation in the container to be 0% minimum, .060% average, and 1.468% maximum, with the average computed from the INEL data and the maximum resulting from WAC input. For additional conservatism, when additional water from a 5% probability of a one-gallon sealed container of water per drum is included the maximum saturation increases to 1.57%. The parameter value established for WIPP PA use is 1.5% by volume, a compromise between the two

maximum computed values. The computations were checked and found to be accurate. It should be noted that the calculation sheet implies a room saturation basis, but true to the parameter need, the value as calculated is actually in terms of percent of available void volume within the waste containers.

5.3.9. Validity of Conclusions

There appears to be no reason for concern that the conclusion of the stated parameter is invalid. However, it should be clear from the comments above that because of the difficulty in obtaining accurate waste characterization data, the waste water content is somewhat subjective. The bounds, as limited by regulation, bracket quite well the available values of water content in waste drums in storage at INEL (Elliott, 1993). Therefore, since the parameter constant, listed as SAT. IBRN (Id 669) and discussed in Section 5.3.8, represents the upper end of the regulatory range (.015), this value should be considered valid, meaningful, and conservative.

5.3.10. Dissenting Views

None

5.4. Permeability of Consolidated Waste

5.4.1. General Evaluation

The permeability of compacted drums of TRU radioactive waste is used in modeling contaminated brine flow in the WIPP repository.

The value currently assigned to the overall permeability of the waste is 1.7×10^{-13} m^2. It applies to all three orthogonal directions (one vertical and two horizontal). In BRAGFLO, waste permeability is treated as a constant and expressed in its log form. Hence, there are three Form 464 parameters: Parameter 663 (PRMX_LOG), Parameter 664 (PRMY_LOG), and Parameter 665 (PRMZ_LOG), each with the same assigned value of -12.769 log m^2.

Laboratory Testing Program

The CH TRU waste to be stored at WIPP consists of a variety of materials that can be broadly categorized into metals, combustibles (plastics and fibers), and sludge. These will be mostly contained in 55-gallon drums and stored in backfilled rooms in the WIPP. Creep closure of the rooms is expected

eventually to collapse the drums and compact the waste, leading to a reduction in its overall porosity and permeability.

Butcher's (1989) analysis of the likely composition of the waste delivered to WIPP from various sources was used as the basis for selecting eight different mixtures of materials (Luker et al., 1991, p. 694). Two laboratory tests were performed on each simulated waste mixture. Each mixture was placed in the oedometer (4" ID) , the sample holder was filled with brine (which was allowed to drain as necessary), and the sample was compacted under a maximum axial stress of 14 MPa (2000 psi), equivalent to the overburden stress. After compaction (which took from 24 to 1414 hours depending on the material mixture), brine permeabilities of the waste were determined by establishing a constant flow rate through the sample and then measuring flow rate and pressure drop. Multiple flow rates were used in several tests. A backup flowmeter system also was used to measure flow rate, which generally gave good agreement with the primary electronic system. Details of the test set-up and procedures are given in Thompson and Luker (1990).

The test results are summarized in Luker et al. (1991, p. 700). Permeabilities varied with materials, and sometimes varied considerably between different samples of the same material. Most waste materials had permeabilities of the order of 10 to 100 mD (1 to 10 x 10^{-14} m^2). Granular magnetite and limonite had values on the order of 100 - 1000 mD (10 to 100 x 10^{-14} m^2), while values for crushed salt and metals varied from less than 100 mD to over 1000 mD (<10 to >100 x 10^{-14} m^2).

Waste Permeabilities for Different Material Groups

Permeabilities for the three material groups are summarized in Sandia WIPP, 1991, pp. 3-130 and 3-131. These data have been transferred into the first three columns of Table 5.4.1. All permeability data in this table are expressed in 10^{-14} m^2. The last two columns in Table 5.4.1 compare the median value (in column 3) with the experimental results from Butcher (1990) in column 4, and Luker et al. (1991) in column 5.

Line A considers combustibles. The value of 1.7 is the mean of the tests on material #4 in Butcher, 1990. It is also the value obtained by one of the tests in Luker et al., 1991; the mean of all four tests on combustibles in the latter program is 4.6 x 10^{14} cm^2. This is only a factor of 2.7 higher than the "median" quoted in column 3. In practical terms, this agreement is acceptable considering the variability in the combustibles tested and the expected variability in the waste material that will be delivered to WIPP.

Table 5.4.1. Comparison of Waste Permeabilities, Averaged for the Principal Material Groups, in Various Documents (All Units are 10^{-14} m^2)

Materials	Waste Permeability (10^{-14} m^2) SAND91-0893/3 pp. 3-131 to 3-132		Median compared to Butcher, 1990, p. 6	Median compared to Luker, Thompson & Butcher, 1991, p. 700
	Range	Median		
A. Combustibles	0.2 to 20	1.7	Yes, material #4	Same as Test 1-2. Average of 4 tests = 4.6 x 10^{-14} cm^{-2}
B. Metals/Glass	0.4 to 120	50	No; 50 represents the highest value measured	Average of 10 relevant mixtures (excluding Test 15-8) = 27.4 x 10^{-14} m^2
C. Sludge*	0.0011 to 0.017	0.012	No data	No data

* Permeabilities of sludges are based on cement data from the literature

Line B considers metals and glass. [Note the typing error on page 3-130 of Sandia WIPP, 1991 (SAND91-0893/3), in which the lower end of the range for metals/glass should be 4 x 10^{-15} instead of 4 x 10^{-14}]. The median value of 50 represents the highest value obtained from the tests discussed in Butcher, 1990. There are 10 tests in Luker et al. (1991) which involve mixtures containing metals and/or glass that have reasonably well-defined permeabilities. The average of these 10 tests is 27.4 x 10^{-14} m^2. Again, in view of the variability of the mixtures, this is reasonably close to the chosen "median" value of 50 x 10^{-14} m^2 in column 3 of Table 5.4.1.

Line C considers sludges. In the absence of any test data, Butcher (1990) based the range of values on that of ordinary Portland cement (minimum value) and high-alumina cement mixed with flyash for the maximum value (values were selected from Coons et al., 1987). Butcher chose a "median" value of 0.012 x 10^{-14} m^2 towards the high end of that range.

Derivation of an Overall Permeability Value for the Waste

In Lappin et al. (1989) p. 4-56, there is a discussion on how the average permeability depends on whether the flow paths through the different materials are parallel or in series; the cemented-sludge permeability of 4 x 10^{-16} m^2 dominates the series path, and the metal waste permeability of 4 x 10^{-13} m^2 dominates the parallel path. In that report, flow in parallel was conservatively assumed by assigning a permeability of 1 x 10^{-13} m^2 to the room contents. The assignment of this value also assumes that any compacted backfill does not form a continuous zone within the room, so that the controlling permeability is that of the metallic waste.

In the 1992 PA calculations the same average permeability of 1×10^{-13} m^2 was used for the permeability of the waste (Sandia WIPP, 1992, p. 3-57).

In Sandia WIPP, 1991 (pp. 3-130 to 3-134) it is argued that the effective distribution of a collapsed drum is the weighted sum of uniform distributions (from the minimum to the maximum values for each waste component), the weights being percent by volume of each component. Based on 40% combustibles, 40% metals/glass, and 20% sludge, the expected permeability is actually calculated as 2.1×10^{-13} m^2. This is different from the value of 1.7×10^{-13} m^2 recorded on Form 464.

This discrepancy was discussed with Martin Tierney of SNL, who pointed out another discrepancy on page 3-131 (Sandia WIPP, 1991). The permeability components are cumulative distributions rather than uniform distributions. The distribution is best represented by a piecewise-linear cumulative distribution function (CDF) similar to that shown in Figure 5.4.1. The expected value of the mean can be derived from the range and an estimate of the median using the general equations for cumulative distribution given in Tierney (1990), p. II-6, and the specific equations supplied by Tierney, which are included in Figure 5.4.2.

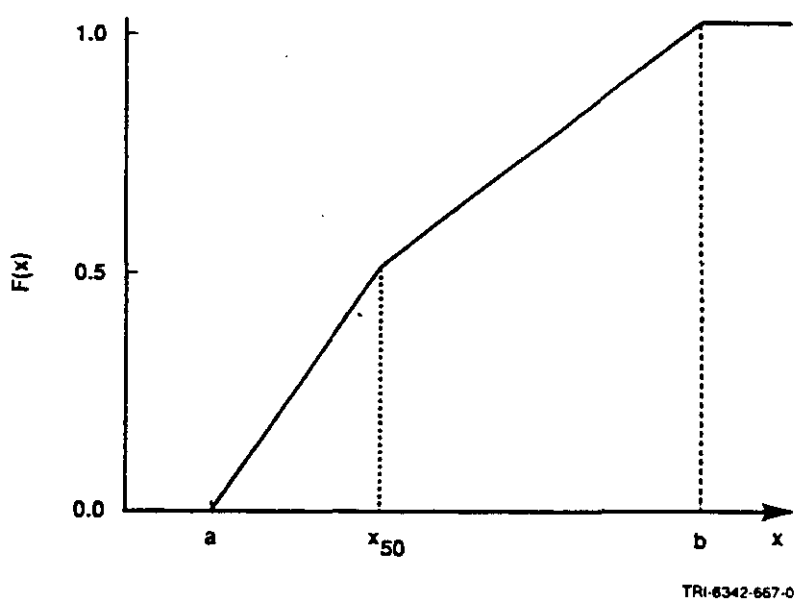

Figure 5.4.1. Piecewise-Linear CDF Based on Range and Median Value (Tierney, 1990)

Cumulative Distribution

A Cumulative Distribution (also called a *Constructed Distribution)* is described by a set of N ordered pairs:

$$(x_1,0),(x_2,P_2),(x_3,P_3),\cdots,(x_N,1) \quad \{i.e. \quad P_1 = 0 \quad and \quad P_N = 1 \quad always\}$$

where $x_1 < x_2 < x_3 < \cdots < x_N$ *and* $0 < P_2 < P_3 < \cdots < P_{N-1} < 1$

Due to the nature of the data, the probability density function (pdf) for this distribution takes the form :

$$P(\xi) = \begin{cases} 0 & if\ \xi < x_1 \\ \dfrac{P_n - P_{n-1}}{x_n - x_{n-1}} & if\ x_{n-1} \le \xi \le x_n, \quad n = 2,3,\cdots,N \\ 0 & if\ \xi \ge x_N \end{cases} \qquad (1)$$

and so the cumulative distribution function (CDF) takes the form:

$$P_n\{X \le \xi\} \approx \Pi(\xi) = \begin{cases} 0 & if\ \xi < x_1 \\ P_{n-1} + \dfrac{(P_n - P_{n-1})(\xi - x_{n-1})}{(x_n - x_{n-1})} & if\ \dfrac{x_{n-1} \le \xi \le x_x}{n = 2,3,\cdots,N} \\ 1 & if\ \xi > x_N \end{cases} \qquad (2)$$

Expected Value: $$E(X) = \sum_{n=2}^{N}(P_n - P_{n-1})\frac{(x_n + x_{n-1})}{2} \qquad (3)$$

Variance: $$V(X) = \sum_{n=2}^{N}(P_n - P_{n-1})\frac{(x_n^2 + x_n x_{n-1} + x_{n-1}^2)}{3} - \{E(X)\}^2 \qquad (4)$$

Median: $$X_{0.50} = x_{m-1} + (x_m - x_{m-1})\frac{(0.50 - P_{m-1})}{(P_m - P_{m-1})} \quad \text{where } P_{m-1} \le 0.50 < P_m. \qquad (5)$$

When use of the cumulative distribution is appropriate:

The cumulative distribution takes its name from the fact that it closely resembles the empirical cumulative distribution function(Blom 1989; pg. 216) obtained by plotting the empirical percentiles of the data set ($x_1,x_2,x_3,\ldots,x_N$). Usually, the cumulative distribution (in the sense used here) is the result of plotting the *subjectively determined* percentile points (x_1,P_1), (x_2,P_2), (x_3,P_3) ... , that arise in a formal elicitation of expert opinion concerning the form of the distribution of the parameter in question. Also, a simple form of the cumulative distribution is appropriately used when the range [a,c] of the parameter is known and the analyst believes that his or her "best estimate" value, b, is also the median (or 50th percentile) of the unknown distribution. In this case, the subjectively determined percentile points take the form: (a, 0.0), (b, 0.5), (c, 1.0).

The cumulative distribution is the *Maximum Entropy* distribution associated with a set of percentile points (x_1,P_1), (x_2,P_2), ..., (x_N, P_N), no matter how that set of percentile points is obtained (i.e. independent of whether the points are empirically or subjectively derived).

Figure 5.4.2. Equations Describing a Cumulative Distribution (Supplied by M. Tierney, Sandia)

Applying equation (3) in Figure 5.4.2, the expected mean values for combustibles, metals/glass, and sludge are 5.9 x 10^{-14} m^2, 5.5 x 10^{-13} m^2, and 1.05 x 10^{-16} m^2, respectively. When these are combined based on respective volume percents of 40, 40, and 20, the overall permeability of the waste was calculated by Tierney to be 2.4 x 10^{-13} m^2.

5.4.2. Adequacy of Requirements and Criteria

The requirement is to provide an estimate of the overall permeability of the compacted waste (i.e., after the rooms have collapsed and the waste has compacted to a "final" density under full overburden loading). This is needed for modeling the WIPP hydrologic system in BRAGFLO. It also indirectly impacts some of the borehole intrusion scenarios, such as "blowout."

5.4.3. Assumptions

It is assumed that the composition of the waste to be emplaced at WIPP is already known, that it is reasonable to divide the waste into just three components (combustibles, metals/glass, and sludge), that the laboratory mixtures tested were representative of the individual components, that scale effects (between the large drums of actual waste and the small laboratory samples) were appropriately accounted for, that the CDF's for the different components were appropriately derived, and that the components were combined appropriately (using realistic volume percents) to produce a realistic overall permeability for the compacted waste.

5.4.4. Alternate Interpretation

Alternate interpretations include the converse situations listed under assumptions. All of these situations have been taken into account to the extent possible, during SNL's assessment of waste permeability.

5.4.5. Uncertainties and Consequences

The largest uncertainty is the make-up of the transuranic waste delivered to WIPP. Will this be placed in a uniform manner, so that it is reasonable to assign a constant value of permeability to the waste in the repository? This might not be reasonable if, for instance, all the combustibles are placed together in one section of the repository, with the other components in their own separate sections.

There is some uncertainty over the role of the drums and how long it will take them to collapse and/or disintegrate. This, in turn, will change with the use or non-use of backfill around the drums (the use of backfill should speed up the consolidation process).

In the opinion of the Panel, these uncertainties could cause the waste permeability to vary by up to an order of magnitude. Since the waste permeability is about four orders of magnitude higher than any other geologic or seal component, any fluid flow will occur within the waste relatively quickly. Overall travel

times to the accessible environment are expected to be fairly insensitive to waste permeability changes within an order of magnitude, but a detailed assessment of this effect is beyond the scope of this review.

5.4.6. Appropriateness and Limitations of Methodology and Procedures

The methodology used in deriving the overall permeability of the waste appears to be appropriate. The laboratory testing that was carried out on different material mixtures is valuable, since it provides a scientific basis for deriving the permeability distributions of the different waste components.

5.4.7. Adequacy of Application

Approximate scale effects were taken into account in selecting the composition and size of the individual waste elements for each laboratory sample prior to testing. The application of these data to the field scale appears adequate and reasonable. However, if the nature and composition of the waste changes significantly from that assumed by Butcher (1989), on which the current waste permeability value is based, this issue will need to be re-examined.

5.4.8. Accuracy of Calculations

Typing errors in the documents caused some initial confusion, but they were easily resolved from information within the documents, without the need to consult the authors.

At some point it appears that there was miscommunication between the different disciplines at SNL in specifying the nature of the probability distribution functions (PDF) for the three waste components. Some thought they were uniform distributions, while the statistician considered them to be piece-wise cumulative distributions. This led to an error in the final calculation of the overall permeability.

The Panel resolved these discrepancies with Dr. Tierney of SNL, and checked his new calculated value of 2.4×10^{-13} m^2.

5.4.9. Validity of Conclusions

It is useful to compare the waste permeability results with those for municipal landfills. Based on a pumping test and a search of the literature, Oweis et al. (1990) concluded that "a saturated conductivity of 10^{-3} cm/sec (10^{-12} m^2 using water as the permeant) is a reasonable first estimate for typical municipal waste that has good compaction." A falling head field test on compact waste (density of 50 to 90 lb/ft^3) produced a hydraulic conductivity of 1.5×10^{-4} cm/sec (1.55×10^{-13} m^2). The average overburden

thickness was about 75 ft (0.27 MPa) at these landfills, compared to the 14 MPa of overburden at the WIPP site. Once allowance is made for the greater densities and overburden pressures at the WIPP site, permeabilities of about 2.4 x 10^{-13} m^2 for the waste do not appear to be unreasonable.

As calculated by Tierney, a more realistic value for parameters 663, 664 and 665 recorded on Form 464 is 2.4 x 10^{-13} m^2 (instead of 1.7 x 10^{-13} m^2).

5.4.10. Dissenting Views

None

5.5. Strength of Waste for Blowout

5.5.1. General Evaluation

In this section the Panel evaluates the strength of the disposed waste as a property relating to its ability to resist particulate separation from the waste's mass due to forces created by gas movement. This property is called "cement" on the parameter list. The value assigned (Form 464, Parameter #3245) is 6895.0 Pa (1.0 psi).

During the controlled years, a possible pathway for release might be created by a borehole that penetrates a waste storage room. Three concepts are used to describe the possible mechanisms of this intrusion: 1) those resulting from the cutting actions of the drill bit itself and mechanical friction (cuttings); 2) those associated with erosion by fluids in the borehole (cavings); and 3) those related to processes that produce debris as a result of pressure change or turbulence in the gases and fluids (spalling). The cuttings mechanism is the easiest to address because the volume of waste cuttings is a simple calculation of the borehole cross-section across the room height. The cavings mechanism is somewhat more complicated as it must incorporate the erosional effects on the borehole wall as a result of abrasive laden fluids and drill pipe friction.

Spallings are defined as waste introduced into the drilling fluid caused by the release of waste-generated gas escaping to the lower-pressure borehole. This requires a repository gas pressure that exceeds the hydrostatic pressure of the drilling mud. Spallings can be further subdivided into three regimes: blowout, gas erosion and stuck pipe. These are dependent upon the state of waste permeability and gas pore pressure at the time of intrusion. Blowout is the direct release to the surface of waste entrained in waste decomposition gas that ejects the borehole annulus of drilling mud and flows freely to the surface.

Gas erosion occurs when low permeability waste is pressed against the drillstring due to stresses from escaping decomposition gas and is subsequently eroded by the flowing drilling mud. Stuck pipe is low permeability waste that is pressed against the drillstring sufficiently hard to prevent normal drilling. This occurs at high gas pressures. Brine flow and brine slurry, two additional contributors to spallings, occur when solid wastes are transported via brine movement to the borehole and then to the surface.

Numerous parameters are associated with the intrusion release processes. Many of these have been previously qualified or are obtained under controls of a qualified QA program. This report covers only one specific parameter relating to those processes that need to have a property depicting the ability of pieces of waste to separate from the compressed, stored mass. This is the tensile strength of the waste, herein called waste strength for blowout.

5.5.2. Adequacy of Requirements and Criteria

The need to establish a limiting process to determine the amount of waste ejected by a gas blowout required the development of a process description. In the process, the high pressure gases begin to exit via the drill hole annulus of the drill pipe in the borehole. Particulates become entrained in the gas and are swept away. This process would eventually erode channels from initial weaknesses (e.g., cracks) in the compacted waste. At some point of pressurization and distance from the exit port, the particles will no longer be able to separate from the waste mass and/or be lofted into the gas stream, at which time the waste release will cease. The state at which this process ceases is believed to be a function of the velocity of gas passing the waste surface (lofting and entrainment), and the cohesive strength or other strength property to resist movement. Until recently, in the spall blowout model the ability of the waste to resist flaking or breaking away from its compressed mass was assumed to be due to capillary tension. Experimental results showed that this type of strength was not enough to influence the releases to be simulated. Typical values for capillary tension are on the order of less than 0.5 psi. It was realized that this level of tensile strength is most applicable in the realm of small diameter particles, which experience large capillary forces (Butcher, 1996E). Other mechanisms of cohesive or adhesive forces also contribute to the tensile strength, including particle cementation. Testing scenarios mentioned by Butcher (1996E) resulted in a plausible tensile strength value of 1.0 psi, based on cementation and other factors.

The requirements and criteria for the waste strength parameter are that it be representative of a material that will enable calculation of waste movement by a natural process, but also one that recognizes

conditions controlling and bounding the process. There are few analogues for this process to assist with the phenomenology involved. The SNL approach also will be discussed in Section 5.5.3.

The establishment of this parameter, and its value, is a process that includes both reasonable assumptions and scientific conjuring. Even the mechanisms of the waste strength appear still to be speculative, but the reasonings for its applicability appear to be appropriate. The question is whether the mechanism is, for example, cementation, cohesion, capillary, tension, or a combination of these. Once defined, however, the strength must be quantified for specified conditions and a plausible value must be found.

Physically, 1.0 psi hypothetically represents the strength at which a suspended lengthening column of cohesive sand-like material will break at 12 inches. This analogy helps the Panel to envision that the waste has strength to resist breaking, but can easily be eroded. While the parameter value for waste strength seems highly speculative, it is important to recognize that the condition and properties of the waste at any given time of intrusion is highly uncertain and a definitive strength concept and value are not easily derived. It is believed that the requirements of and criteria for this parameter have been well thought through, and the value assigned is plausible.

5.5.3. Assumptions

For the technology current at the time of this writing, it appears that the waste strength is assumed to be derived from cementation forces. It also appears that this cementation is assumed to be attributed to crystallized salt precipitated from supersaturated brines that have wicked into the wastes or their residual decay products. Both assumptions appear realistic, although they are not necessarily all inclusive of the process. For purposes of this parameter, however, no tests were found to be performed on these assumptions, probably due to the infancy of this concept. No assumption is made concerning moisture in the waste and its effect on the waste strength. Also the particle size is not prescribed. To date, mechanistic testing has centered on sparging high-pressure air radially through a compressed bed of uniform fine Ottowa silica sand (Lenke, Berglund, and Cole, 1996) as an evaluation of the capillary bonding theory, but not the cementation theory. Scoping tests described by Butcher (1996E) reveal that the value of 1.0 psi is realistic for purposes of their calculations. If any parameter correction is required, it would probably be because an unrealistically high volume of waste release is produced by the blowout spall resulting from an inappropriate bounding characteristic that is a function of the waste strength.

5.5.4. Alternate Interpretation

In order to be able to model the removal of solid waste, alternative interpretations would require a change in the phenomenology involved. One such alternative could be to assume all waste is in a granular or powdered state subject to movement by only modestly turbulent gas movement to loft the waste into the gas stream. In this case, waste strength or capillary forces are not important. This does not seem plausible, however, and would require even further wide-ranging assumptions than does the subject parameter. Another alternative is that the dominant size of the decayed waste is sufficiently coarse to resist movement by any flowing gases. This consideration may have merit on a selective basis, but it probably would be eliminated because it is not conservative. No alternate interpretations were found in the records, other than the spallings concept caused by a high-pressure steep gradient at a surface, which is another part of this model.

5.5.5. Uncertainties and Consequences

Uncertainties are numerous and the consequences are high. The condition or physical state of the waste at any time in the project cycle is unknown. The mechanism causing separation of the particulates is uncertain. Conditions of the waste room atmosphere, such as state of room closure or open channels for gas movement, are speculative. Finally, any serious misrepresentation of this parameter could result in erroneous or unrealistic calculation of radioactive releases, which would negate the purpose for modeling this specific event instead of using an assumed release value. A convincing argument can be made for assuming an unresolved process that would provide a prescribed volume of waste from a defined distance at the opening of the borehole in the repository. Such an assumption would make the calculations more certain and straightforward, and could be sampled in the PA calculations.

5.5.6. Appropriateness and Limitations of Methodology and Procedures

Although speculative, the thought processes, scientific reasoning, and methodology used in establishing the waste tensile strength appear to be appropriate and fundamentally sound. The assigned value may be subject to change based on development of further phenomenology, or PA results that show unreasonable values for a calculation that requires a self-limiting release (see Section 5.5.2).

5.5.7. Adequacy of Application

Technically, SNL appears to have concluded that the parameter value of "cement" at 1.0 psi is sufficiently representative for realistic calculated release values based on the current model. There is no

established scientific school of experience nor any data base available for determining the mechanisms that this parameter supports. Furthermore, because of the uncertainty of waste conditions at the time of intrusion, it requires an assumption that the standard waste composition and condition will be a granular material of a density approximating unconsolidated lightly cemented sand of unknown porosity and low moisture. The only data (and it is sparse) in the literature is for clays, which approximates these conditions for strength properties (Lenke et al., 1996). Therefore, at this stage of process development, and considering the absence of defining conditions, it is not possible to ascertain if the value of 1.0 psi tensile strength is adequate. For the phenomenal concept being modeled, however, the parameter value is probably adequate to carry forward the study for the current stage of development and present purpose. If the concept is to survive, more research and development will be required to establish a definitive value of waste strength for a set of prescribed conditions and definitions.

5.5.8. Accuracy of Calculations

This parameter is not the product of any calculation or result. It is an assumed constant used in a calculation that produces a result basic to a conceptual model. This result will be evaluated by another Panel reviewing the conceptual models and discussed in the report of that Panel.

5.5.9. Validity of Conclusions

In the event intrusion were to occur, it appears highly probable that the process supported by the waste strength parameter will contribute significantly to the release calculation in the PA. Definitions of such an important parameter should not be based on science that is yet in its infancy. If this model and parameter become critical to the PA calculations, more data and back-up scientific evidence are required. As of this writing, the validity of the concept of the parameter "cement" appears to be appropriate within the confines of the model described, but there is not adequate information for the Panel to determine the qualification of a definite value.

5.5.10. Dissenting Views

None

5.6. Properties of Halite and Anhydrite

5.6.1. General Evaluation

Because of assigned limitations of scope, the Panel has provided just an overview of these properties, and the individual parameters listed below are not considered at the same level of detail as those reviewed in other sections of this report.

Massive halite (both clean and argillaceous) and relatively thin beds of anhydrite (and some clay layers) surround the repository rooms. The anhydrite volume is small compared to the halite volume, but anhydrite occurs in several very important beds that can affect both disposal room mechanical response and hydrologic behavior. The properties to be reviewed here are discussed in the memo by Munson, 1995. This memo provides the current status of mechanical, thermal and stratigraphic properties (including overburden stress). This review will concentrate on mechanical properties of halite and anhydrite, which are primarily used in the porosity surface calculations (Section 5.7). Thermal properties will not be discussed at all, since previous studies have shown few, if any, thermal effects in the repository environment, and no thermal properties appear to be used in the current WIPP calculations. Polyhalite properties, although they are listed in the memo, will not be discussed since they do not appear in calculations. Hydrologic properties, such as permeabilities, are also important to repository design and PA, and do appear in other WIPP PA calculations. However, they are not included in the parameter package to be reviewed here and are discussed elsewhere. The review in this section encompasses many individual parameters.

The current halite/anhydrite parameters (Munson, 1995) consist of the values given in Tables 5.6.1 through 5.6.10, and Figure 5.6.1.

Table 5.6.1. Three Elastic Constants for Both Halite and Argillaceous Halite

#	Name	Value
1	G (shear modulus)	12,400 MPa
2	E (Young's modulus)	31,000 MPa
3	v (Poisson's ratio)	0.25

Table 5.6.2. Eighteen Creep Constants for the MDCF Model for Halite

#	Name	Value
1	A_1	8.386 E22 /s
2	Q_1	25 Kcal/mol
3	n_1	5.5
4	B_1	6.086 E06 /s
5	A_2	9.672 E12 /s
6	Q_2	10 Kcal/mol
7	n_2	5.0
8	B_2	3.034 E-02 /s
9	σ_o	20.57 MPa
10	q	5.335 E03
11	m	3.0
12	K_o	6.275 E05
13	c	9.198 E-03
14	α	-17.37
15	β	-7.738
16	α	-2.69
17	β	-1.00
18	R	1.987 cal/mol-deg

Table 5.6.3. Eighteen Creep Constants for the MDCF Model for Argillaceous Halite

#	Name	Value
1	A_1	1.407 E23 /s
2	Q_1	25 Kcal/mol
3	n_1	5.5
4	B_1	8.998 E06 /s
5	A_2	1.314 E13 /s
6	Q_2	10 Kcal/mol
7	n_2	5.0
8	B_2	4.289 E-02 /s
9	σ_o	20.57 MPa
10	q	5.335 E03
11	m	3.0
12	K_o	2.470 E06
13	c	9.198 E-03
14	α	-14.96
15	β	-7.738
16	α	-2.69
17	β	-1.00
18	R	1.987 cal/mol-deg

Table 5.6.4. Nineteen Fracture Constants for the MDCF Model for Halite

#	Name	Value
1	x_1	6
2	x_2	9
3	x_{3s}	5.5
4	x_{3t}	40
5	x_4	3
6	χ_s ($\sigma>\sigma_0$)	231.0 MPa
7	χ_s ($\sigma<=\sigma_0$)	351.1 MPa
8	χ_t	15.15 MPa
9	x_6	0.75
10	x_7	1.0 MPa
11	x_8	0.1
12	c_o	5 E04
13	c_2	850
14	c_3	10
15	c_4	6
16	c_5	25 MPa
17	t_0	1 s
18	n_3	3
19	ω_0	>=1 E-4

Table 5.6.5. Twenty Fracture Constants for the MDCF Model for Argillaceous Halite

#	Name	Value
1	x_1	6
2	x_2	9
3	x_{3s}	5.5
4	x_{3t}	40
5	x_4	3
6	χ_s ($\sigma>\sigma_0$)	231.0 MPa
7	χ_s ($\sigma<=\sigma_0$)	351.1 MPa
8	χ_t	15.15 MPa
9	x_6	0.75
10	x_7	1.0 MPa
11	x_8	0.1
12	c_o	5 E4
13	c_2	850
14	c_3	10
15	c_4	6
16	c_5	25 MPa
17	t_0	1 s
18	n_3	3
19	ω_0	>=1 E-4
20	p_1 ($\rho_a>0.0$)	20.6

Table 5.6.6. Four Elastic Constants for the RM Model for Both Halite and Argillaceous Halite

#	Name	Value
1	μ (shear modulus)	0.992 GPa
2	E (Young's modulus)	2.480 GPa
3	K (bulk modulus)	1.656 GPa
4	ν (Poisson's ratio)	0.25

Table 5.6.7. Three Creep Constants for the RM Model for Halite

#	Name	Value
1	A	1.66 E14 /s
2	Q	12 Kcal/mol
3	n	4.9

Table 5.6.8. Three Creep Constants for the RM Model for Argillaceous Halite

#	Name	Value
1	A	4.99 E14 /s
2	Q	12 Kcal/mol
3	n	4.9

Table 5.6.9. Four Elastic Constants for Anhydrite

#	Name	Value
1	μ (shear modulus)	27.8 GPa
2	E (Young's modulus)	75.1 GPa
3	K (bulk modulus)	83.4 GPa
4	ν (Poisson's ratio)	0.35

Table 5.6.10. Two Drucker-Prager Plasticity Parameters for Anhydrite

#	Name	Value
1	a	0.45
2	C	1.35 MPa

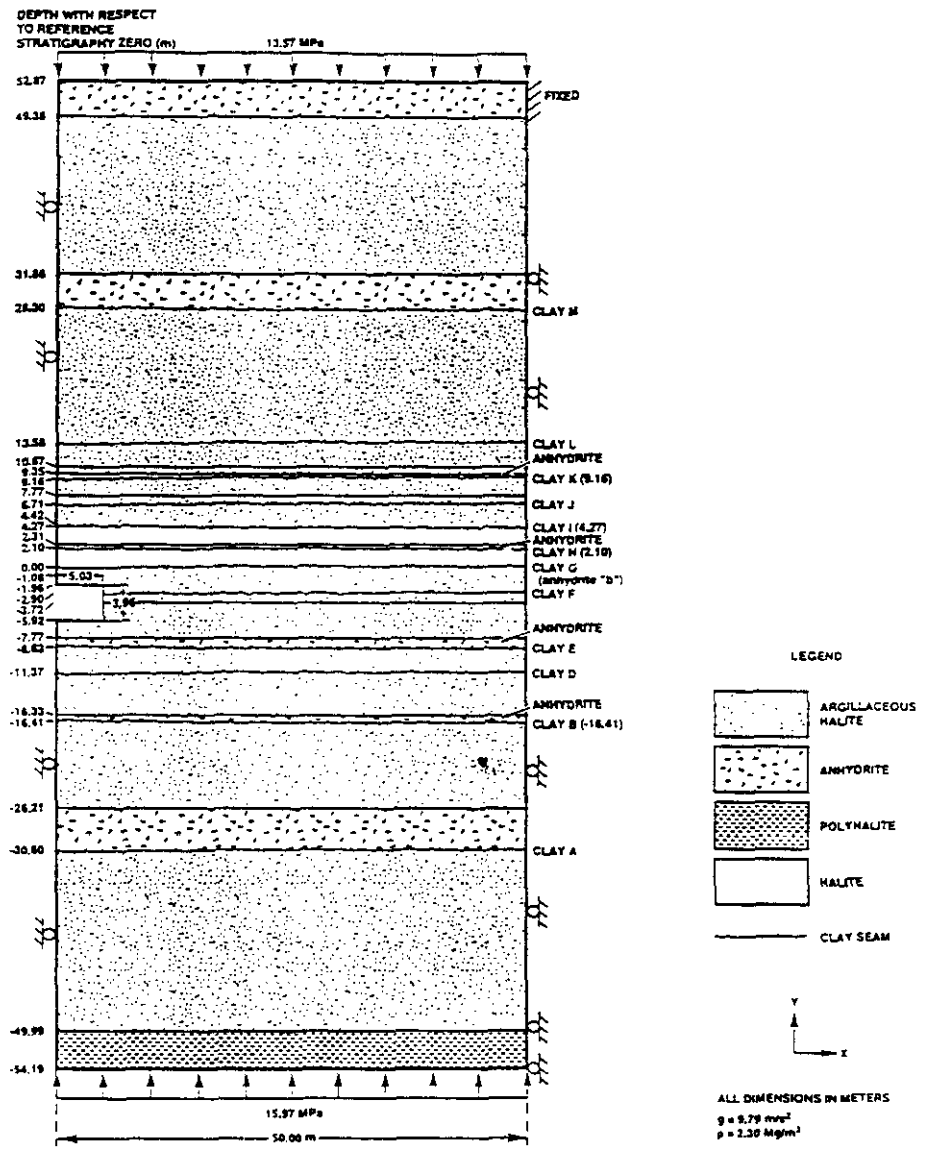

Figure 5.6.1. WIPP Stratigraphic Boundaries

Of the listed parameters, the creep parameters for halite (both types) would appear to be the most important in long-term calculations of disposal room response. The Multimechanism Deformation Coupled Fracture (MDCF) model is an extension of the original Multimechanism Deformation (MD) creep model for halite intended for use in the DRZ. Without the fracture components, the model reduces to the original MD model. In the porosity surface calculations (Section 5.7), currently the major user of these halite/anhydrite parameters, only the MD model for halite (both clean and argillaceous) is used.

The reduced modulus (RM) model is a creep model used in some earlier and current approximation calculations.

The following introductory discussion is broken down by the parameter categories in the tables above.

a) ***Three elastic constants for both halite and argillaceous halite (Table 5.6.1)*** - These constants are obtained from literature-referenced measurements on rock salt and discussed by Munson et al., 1989. They are also summarized by Butcher, 1996A.

b) ***Eighteen creep constants for the MDCF model for halite (Table 5.6.2)*** - A good initial reference for the work on halite creep is Munson and Dawson, 1979. Early tests and modeling are summarized. Most of the parameter values and concepts established here changed very little as the WIPP evolved. The early data used for parameter development is primarily from Wawersik and Hannum, 1979. More data are contributed by Senseny, 1986 and discussed by Munson et al., 1989. The raw creep data contributing to the creep models have been qualified elsewhere and are not a subject of this review. Derived parameter values, which are a subject of this review, have not apparently changed from the point of the last report mentioned above (except for the addition of the fracture parameters as discussed below).

c) ***Eighteen creep constants for the MDCF model for argillaceous halite (Table 5.6.3)*** - See discussion for b) above.

d) ***Nineteen fracture constants for the MDCF model for halite (Table 5.6.4)*** - A damage model, including fracture (in a continuum sense) has been added to the MD model for use primarily in the DRZ. It is supported by some new data. This model is presented in Chan et al., 1995. Since this model is not currently in use for PA-related calculations, it is not reviewed further here.

e) ***Twenty fracture constants for the MDCF model for argillaceous halite (Table 5.6.5)*** - See discussion for d) above.

f) ***Four elastic constants for the RM model for both halite and argillaceous halite (Table 5.6.6)*** - For calculational efficiency, earlier room calculations used a much simpler model for salt creep and elastic response. This model is still based on an activation energy creep law. Because of its simplicity, elastic modulus reduction (by a factor of 12.5) was required to simulate early-time

behavior. This model is discussed in Mendenhall et al., 1991. Current room closure calculations use the MD model only.

g) ***Three creep constants for the RM model for halite (Table 5.6.7)*** - See discussion for f) above.

h) ***Three creep constants for the RM model for argillaceous halite (Table 5.6.8)*** - See discussion for f) above.

i) ***Four elastic constants for anhydrite (Table 5.6.9)*** - Anhydrite properties are discussed in Krieg, 1984, and Munson and Morgan, 1986. The anhydrite elastic properties were determined in earlier laboratory tests.

j) ***Two Drucker-Prager plasticity parameters for anhydrite (Table 5.6.10)*** - Anhydrite properties are also discussed in Krieg, 1984 and Munson and Morgan, 1986. The anhydrite Drucker-Prager plasticity parameters are estimated from the same earlier laboratory tests as mentioned in h) above.

k) ***Stratigraphic boundaries (Figure 5.6.1)*** - Stratigraphic boundaries for the halite and anhydrite units are discussed by Munson et al., 1989 (as modified from Krieg, 1984.)

5.6.2. Adequacy of Requirements and Criteria

Halite (both clean and argillaceous), and anhydrite properties are important to the behavior of the repository over time. All of the documents and test data reports leading up to the current values of the mechanical parameters for these materials appropriately recognize that role and are evaluated in accordance with adequate requirements and test and evaluation criteria.

5.6.3. Assumptions

Because of the complexity of the natural environment and number of parameters evaluated, several assumptions are required to make the process of modeling and mechanical parameter evaluation possible. The most important of these follow.

a) Thermal effects can be ignored since little waste heat generation is expected. This assumption is reasonable.

b) Within halite and anhydrite layers, these materials can be treated as continua. This assumption is probably necessary in view of current computer modeling methods. It is also reasonable in view

of program requirements and data accuracy. However, discontinuous surfaces certainly exist within the assumed continuous layers. A good example is given by the few "anomalous" creep results reported by Senseny, 1986, which were not included in the final creep parameter determination. Some of these occurred in samples that contained distinct linear clay seams. The effect of ignoring such data and other similar effects by assumption is not severe with regard to the final results, but should not be forgotten. The effect of this will be discussed in Section 5.6.4.

c) Size scale effects can be ignored. Most geologic media exhibit a size scale effect. More often than not, this takes the form (in mechanical properties) of moduli reduction with size. In the case of WIPP, one might also expect an increase of creep rate with size. Size effect is briefly noted by Munson et al. 1989, but no model changes are proposed. Such effects are frequently attributed to discontinuities, which have differing properties as functions of scale. The assumption of no size scale effects therefore ties in with the continuum assumption discussed previously, and will also be mentioned in Section 5.4.4. Despite these cautions, ignoring scale effects seems reasonable within the realm of available data and accuracy of prediction required for these massive formations.

d) The "unknown" long-term creep mechanism can be described by a standard equation and its parameters determined by relatively short-term tests. Virtually all of the halite creep during the lifetime of the repository will occur in response to a mechanism labeled as "unknown." Therefore, the equation used for this mechanism, although a standard and acceptable activation equation, must also be labeled as unknown. This may have consequences with respect to long-term predictions. From the viewpoint of repository performance, the consequences are probably not severe since the parameters of the unknown mechanism have been empirically determined with some confidence.

e) The presence of water can be ignored as an explicit mechanical properties material parameter. In most geologic media, saturation state strongly affects material properties. Here, with small amounts of water, one can argue that the explicit effects can be ignored. It does not appear that the WIPP project has investigated this, but the results are probably not severe. One area of caution is the possible conversion of anhydrite to gypsum upon water absorption. This event, if it occurs, will make the affected anhydrite zone softer and more plastic than now calculated. However, since the anhydrite beds tend to be zones of weakness to begin with, a severe adverse effect on subsequent modeling is not anticipated.

5.6.4. Alternate Interpretation

Given the general acceptance of the models used and reasonableness of the assumptions made, we find no critically different alternate interpretations of mechanical data. The data are therefore well-interpreted in that sense. However, with the number of parameters used here, the number of small model variations that might be possible, and the fact that creep data are interpreted by the use of an assumption regarding unloading effects during mining and coring, alternate interpretations are certainly possible. Most of the alternate data interpretations that can be envisioned seem to speed the long-term creep or increase the deformation. These include the now-ignored effects of discontinuities, water, and small clay seams. Therefore, current closure calculations may be viewed as conservative, and are quite acceptable in that sense.

5.6.5. Uncertainties and Consequences

The major uncertainty arises from interpreting a large number of material parameters from a relatively small number of tests on small-sized specimens that probably are pre-selected for their continuous nature. A very positive and encouraging result in this regard is that the two primary sets of laboratory creep data obtained are quite similar. However, this remains as a classical problem in geotechnical testing. For example, if some of the "anomalous" results reported by Senseny (1986) were retained in the data set, a different set of creep parameters would result. To some extent, Fossum et al., 1994, attempt to account for this by statistical sampling for creep parameters; however, this approach is presently not used by the project, nor does it seem to be needed. In the future, if some sensitivity to creep proves high, the creep parameters should be sampled for the PA results. This also implies that the porosity surface (Section 5.7) need not be developed from sampled creep parameters. Thus, the present uncertainties are acceptable and no severe consequences seem to arise.

With regard to elastic properties, the moduli of halite are developed from literature-referenced test results only, and these are not on WIPP salt. Munson et al., 1989 refers to the use of "ultrasonic wave velocity" measurements as reported in Hume and Shakoor, 1981, as the source. This reference is a review paper of many earlier original sources of measurements, including ultrasonic, hydrostatic, and uniaxial tests on a broad variety of rock salt types. Studying the reference, it is unclear which of the reported data were used to obtain the WIPP halite properties. None of the reported data (either static or ultrasonic) correspond exactly to the reported WIPP values. The WIPP value of 0.25 for Poisson's ratio appears reasonable, although a "bedded salt" from the GNOME drift in New Mexico, which might be similar to WIPP salt, was reported to have a Poisson's ratio value of 0.31. The WIPP value of 31 GPa for Young's

modulus is near the high end of the range of reported values of about 16 to 38 GPa, clustering near 25 GPa. It is probably possible to pick a subset of the reported values that, when averaged, would correspond to the WIPP values. Assuming that these actually were ultrasonic test results, it is likely that the Young's modulus, and subsequently calculated bulk modulus, are somewhat too large for predicting the static elastic response of large samples, as has been found for many other geologic materials. To be sure, this effect may be minimized in the relatively continuous and homogenous WIPP halite, but it is unlikely to be non-existent. Therefore, some of the "moduli reduction" recognized in the earlier MD model may actually be real. However, since elastic response is seen as an early-time phenomenon or one of lesser magnitude, little adverse effect is anticipated from this in WIPP PA except perhaps for the case of gas over-pressurization and subsequent elastic rebound of the room. Again, the adverse effects of such a miscalculation of elastic parameters would seem to be relatively small. The possible overestimation of intact halite static bulk modulus may have an observable effect on crushed salt bulk modulus predictions, as discussed in Section 4.2.

5.6.6. Appropriateness and Limitations of Methodologies and Procedures

Considering the data available and the state of the modeling science, the methodologies and procedures leading to halite and anhydrite properties are appropriate. If anything, the model used for salt creep, leading to a large number of parameters to be determined, is too complex to be fully justified for engineering use. We see, however, no technically adverse consequences or limitations arising from this, aside from the need for additional computation time.

5.6.7. Adequacy of Application

The parameters discussed here are primarily applied to the porosity surface calculations to be described and discussed in Section 5.7. They appear to be quite sufficient and adequate to calculate that surface.

5.6.8. Accuracy of Calculations

The documentation shows that halite and anhydrite parameter calculations were repeated, checked, and discussed at length. The Panel has made approximate spot checks of calculational accuracy, but because of the limited scope of this review, the Panel has not thoroughly re-checked these calculations.

5.6.9. Validity of Conclusions

Based on this overview evaluation, the halite and anhydrite parameter values derived for WIPP appear to be valid, suitable and sufficiently accurate with regard to use in the mechanical response models used for

room closure predictions. Because of the limited scope of this review and the large number of these parameters, the values have not been checked at the same level of detail used in some other sections of this report; the parameters have only been broadly reviewed and spot-checked. The Panel has not seen anything, however, to suggest that any severe problems of validity exist.

5.6.10. Dissenting Views

None

5.7. Data on Final Porosity Surface

5.7.1. General Evaluation

Since the porosity surface as defined below is treated as a tabular parameter by PA, even though it is actually a submodel with many input parameters of its own, the Panel has chosen (because of scope limitations) to approach this review as an overview of the porosity surface concept and results. This means that the individual parameters contributing to the porosity surface will not be treated at the same level of detail as those direct PA parameters discussed in other sections of this report.

In the present WIPP project performance assessment calculations (using BRAGFLO) the details of the mechanics of disposal room closure and/or eventual expansion are not explicitly calculated. Instead, the room-rock system behavior is obtained from a three-dimensional lookup table entitled the "porosity surface." In this table, the three dimensions are time, total room porosity, and mass of gas in the room. Current calculations are described by Stone, 1996, and Butcher, 1996D. The porosity surface record package is labeled WPO#35697. A graphical example of a porosity surface from Butcher and Mendenhall, 1993, is shown in Figure 5.7.1.

The porosity surface is itself calculated prior to the BRAGFLO runs using the SANTOS code. This procedure is followed to avoid the massive computational effort that would be required to fully calculate (in an iterative sense) the mechanics of room closure for each PA instance. At first, this may seem to be an invalid decoupling of the external environment and the disposal room. However, if the room porosity can be shown to be described with sufficient accuracy as a variable dependent only on time and gas mass

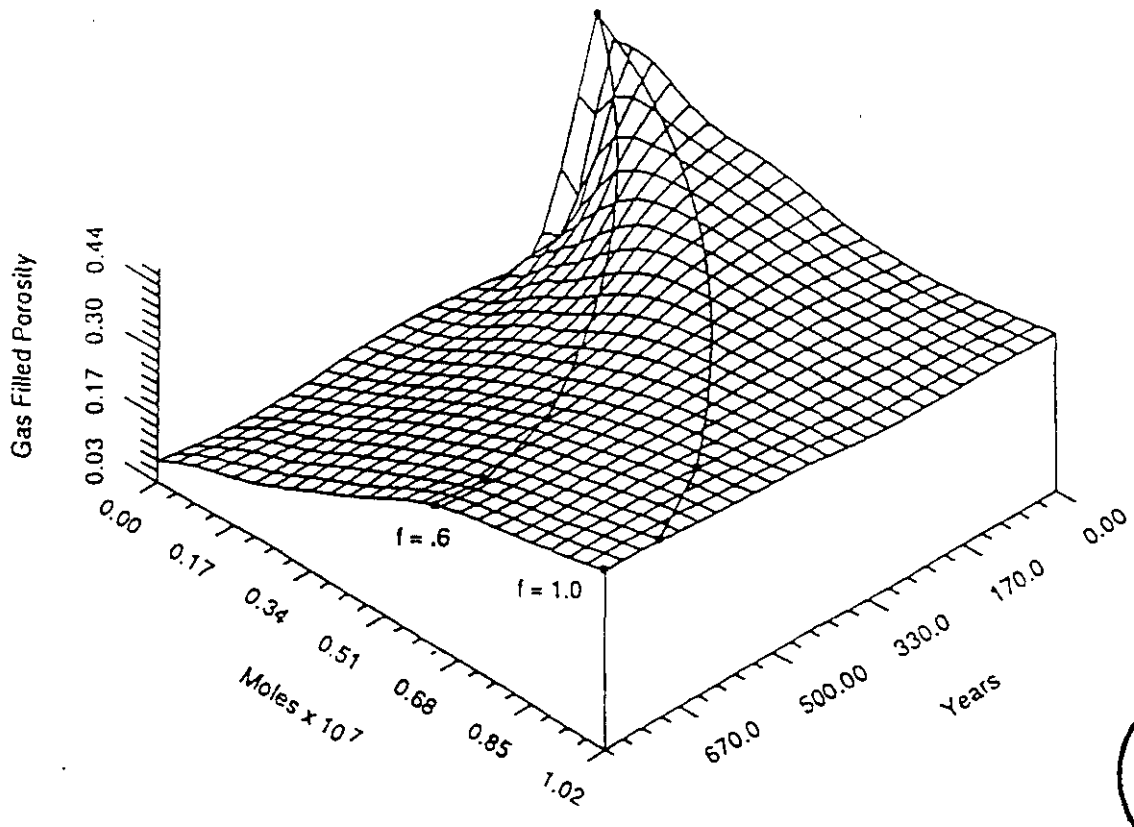

Figure 5.7.1. Example of Porosity Surface (from Butcher and Mendenhall, 1993)

(which is itself dependent only on time in the current model) then this approach is quite justified in view of its simplicity and calculational efficiency. Note that brine content of the room is not mentioned at this point, nor are there any brine parameters on the list. This is a consequence of the calculational method and interaction with BRAGFLO, and will be discussed below. Actually, 13 porosity surfaces are submitted to PA, corresponding to the assumption of 13 possible multiples of the gas generation rate vs. time in the room as compared to the nominal rate. These multipliers, expressed as the SANTOS parameter "f," are 0.0, 0.025, 0.05, 0.10, 0.2, 0.4, 0.5, 0.6, 0.8, 1.0, 1.2, 1.6, and 2.0 (see Table 5.7.13). Inputs to the porosity surface calculations are most of the parameters considered in Sections 5.1, 5.2, and 5.6 plus such additional parameters as geometry and gas production. All of the parameters contributing to the porosity surface are listed in the following tables. These tables have been adapted from Butcher, 1996A, but are re-grouped (with comments) for the purposes of this review.

Table 5.7.1. Room Initial Dimensions

#	Name	Value	Reference(s)	Comments
1	Room height	3.96 m	Sandia WIPP Project, 1992, p. 3-5.	This is a design dimension
2	Room width	10.06 m	Sandia WIPP Project, 1992, p. 3-5.	This is a design dimension
3	Room length	91.44 m	Sandia WIPP Project, 1992, p. 3-5.	This is a design dimension
4	Initial room volume	3644 m^3	Butcher, 1996, p 4.	Calculated directly from Items 1, 2, and 3 in this table. However, the repository volume will be greater than simply room volume due to the presence of access drifts, etc. This will cause a 10-20% difference in results if these other volumes are connected to the rooms and not backfilled. This will have an corresponding effect on the porosity surface, mainly in that initial porosity will be slightly greater.

Table 5.7.2. Waste Initial Dimensions

#	Name	Value	Reference(s)	Comments
1	Number of drums per room	6804	Sandia WIPP Project, 1992, p. 3-11.	This is a design number.
2	Number of 7-packs per room	972	Butcher, 1996, p. 4.	Calculated from Item 2 in this table.
3	Drum external volume	0.2539 m^3	Sandia WIPP Project, 1992, p. 3-10.	This is a design number.
4	Waste volume	1728 m^3	Butcher, 1996, p.4.	Calculated from Table 5.7.1 and Item 3 in this table. "Waste volume" is here defined as the total volume of the drums.
5	Waste height	2.676 m	Sandia WIPP Project, 1992, p. 3-12.	This is the height of 3 drums stacked, including the plastic pallets.
6	Nominal waste width with voids between drums	8.6 m	Stone, 1996, p. 9.	Apparently calculated from Sandia WIPP Project, 1992, p. 3-12, with an adjustment made to average the width.
7	Nominal waste length with voids between drums	89.1 m	Stone, 1996, p. 9.	Taken from Sandia WIPP Project, 1992, p. 3-12.
8	Width of waste continuum	7.35 m	Stone, 1996, p. 9.	Calculated from an equation that removes the void space between the drums by assuming lateral (but not vertical) instantaneous change at time = 0. This has the effect of slightly stiffening the waste at early times.
9	Height of waste continuum	2.676 m	Stone, 1996, p. 9.	Initial height is as emplaced, with no changes. See Item 8 in this table.
10	Length of waste continuum	87.85 m	Stone, 1996, p. 9.	Same as Item 8 in this table.

Table 5.7.3. Computational Configuration (for SANTOS)

#	Name	Value	Reference(s)	Comments
1	Pillar thickness	30.5 m	Sandia WIPP Project, 1992, p. 3-5.	See Item 4 in Table 5.7.1.
2	Half room width	5.03 m	Butcher, 1996, p 5.	Calculated from Table 5.7.1 above.
3	Distance from center of room to center of pillar	20.27 m	Butcher, 1996, p 5.	Calculated from Table 5.7.1 above.
4	Clay G (Anhydrite B)	0.0 m	Munson, 1995, p. 24/24.	Current reference stratigraphy.
5	Top boundary of calculation	52.87 m	Munson, 1995, p. 24.	Current reference stratigraphy.
6	Bottom boundary of calculation	-54.19 m	Munson, 1995, p. 24.	Current reference stratigraphy.
7	Disposal room floor	-6.39 m	Stone, 1996, p. 1.	This is treated as a slip surface with regard to the waste. This appears to be the current best estimate using MB 139 as a reference. There might be an 0.2 m or so variation here.
8	Disposal room ceiling	-2.43 m	Stone, 1996, p. 1.	See comment for Item 7 in this table.
9	Argillaceous salt boundaries, first bed	-54.19 m to -8.63 m	Munson, 1995, p. 24.	Current reference stratigraphy.
10	Anhydrite MB 139 boundaries	-8.63 m to -7.77 m	Munson, 1995, p. 24.	Current reference stratigraphy.
11	Argillaceous salt boundaries, second bed	-7.77 m to 0.0 m	Munson, 1995, p. 24.	Current reference stratigraphy.
12	Clean salt boundaries	0.0 m to 4.27 m	Munson, 1995, p. 24.	Current reference stratigraphy.
13	Clay I	4.27 m	Munson, 1995, p. 24.	Current reference stratigraphy.
14	Argillaceous salt boundaries, third bed	4.27 m to 52.87 m	Munson, 1995, p. 24.	Current reference stratigraphy.
15	Traction on upper boundary of calculation	13.57 MPa	Munson, 1995, p. 24.	See Section 5.5. This is treated as a vertical confining stress. It is calculated from a log-based overburden.
16	Traction on lower boundary of calculation	15.97 MPa	Munson, 1995, p. 24.	This is treated as a vertical confining stress. It is calculated from a log-based overburden.
17	Mesh configuration	table	Butcher, 1996, App. D.	Ties in with SANTOS verification.

Table 5.7.4. Halite Elastic Properties

#	Name	Value	Reference(s)	Comments
1	G (shear modulus)	12,400 MPa	Munson, 1995, p. 1.	Butcher, 1996, gives these units as GPa. This is a typographical error in the draft and will be corrected. The units are actually MPa, as shown here, from the original Munson reference.
2	E (Young's modulus)	31,000 MPa	Munson, 1995, p. 1.	See Section 5.5. See Item 1 in this table.
3	ν (Poisson's ratio)	0.25	Munson, 1995, p. 1.	See Section 5.5.

Table 5.7.5. Clean Halite Creep Properties

#	Name	Value	Reference(s)	Comments
1	A_1	8.386 E22 /s	Munson, 1995, p. 1-2.	See Section 5.5.
2	Q_1	25 Kcal/mol	Munson, 1995, p. 1-2.	See Item 1 above.
3	n_1	5.5	Munson, 1995, p. 1-2.	See Item 1 above.
4	B_1	6.086 E06 /s	Munson, 1995, p. 1-2.	See Item 1 above.
5	A_2	9.672 E12 /s	Munson, 1995, p. 1-2.	See Item 1 above.
6	Q_2	10 Kcal/mol	Munson, 1995, p. 1-2.	See Item 1 above.
7	n_2	5.0	Munson, 1995, p. 1-2.	See Item 1 above.
8	B_2	3.034 E-02 /s	Munson, 1995, p. 1-2.	See Item 1 above.
9	σ_o	20.57 MPa	Munson, 1995, p. 1-2.	See Item 1 above.
10	q	5.335 E03	Munson, 1995, p. 1-2.	See Item 1 above.
11	m	3.0	Munson, 1995, p. 1-2.	See Item 1 above.
12	K_o	6.275 E05	Munson, 1995, p. 1-2.	See Item 1 above.
13	c	9.198 E-03	Munson, 1995, p. 1-2.	See Item 1 above.
14	α	-17.37	Munson, 1995, p. 1-2.	See Item 1 above.
15	β	-7.738	Munson, 1995, p. 1-2.	See Item 1 above.
16	δ	0.58	Munson, 1995, p. 1-2.	See Item 1 above. Also, this parameter does not appear in the Munson reference (but only in the Butcher reference). However, 3 additional parameters do appear in the Munson reference. The difference is caused by the MD to MDCF (fracture) model change.

Table 5.7.6. Argillaceous Halite Creep Properties

#	Name	Value	Reference(s)	Comments
1	A_1	1.407 E23 /s	Munson, 1995, p. 3-4.	See Section 5.5.
2	Q_1	25 Kcal/mol	Munson, 1995, p. 3-4.	See Item 1 above.
3	n_1	5.5	Munson, 1995, p. 3-4.	See Item 1 above.
4	B_1	8.998 E06 /s	Munson, 1995, p. 3-4.	See Item 1 above.
5	A_2	1.314 E13 /s	Munson, 1995, p. 3-4.	See Item 1 above.
6	Q_2	10 Kcal/mol	Munson, 1995, p. 3-4.	See Item 1 above.
7	n_2	5.0	Munson, 1995, p. 3-4.	See Item 1 above.
8	B_2	4.289 E-02 /s	Munson, 1995, p. 3-4.	See Item 1 above.
9	σ_o	20.57 MPa	Munson, 1995, p. 3-4.	See Item 1 above.
10	q	5.335 E03	Munson, 1995, p. 3-4.	See Item 1 above.
11	m	3.0	Munson, 1995, p. 3-4.	See Item 1 above.
12	K_o	2.470 E06	Munson, 1995, p. 3-4.	See Item 1 above.
13	c	9.198 E-03	Munson, 1995, p. 3-4.	See Item 1 above.
14	α	-14.96	Munson, 1995, p. 3-4.	See Item 1 above.
15	β	-7.738	Munson, 1995, p. 3-4.	See Item 1 above.
16	δ	0.58	Munson, 1995, p. 3-4.	See Item 1 above. Also, see Item 16 in Table 5.7.5.

Table 5.7.7. Anhydrite Properties

#	Name	Value	Reference(s)	Comments
1	E (Young's) modulus	75.1 GPa	Munson, 1995, p. 18.	See Section 5.5.
2	ν (Poisson's ratio)	0.35	Munson, 1995, p. 18.	See Section 5.5.
3	a	0.45	Munson, 1995, p. 19.	See Section 5.5.
4	C	1.35 MPa	Munson, 1995, p. 19.	See Section 5.5.

Table 5.7.8. Waste Composition

#	Name	Value	Reference(s)	Comments
1	Metallic	122 kg/m^3	Baseline Inventory Report, 1995	See Section 5.1. These are not densities in the usual sense, but actually the actual mass of each material in a cubic meter of waste.
2	Sorbents	40 kg/m^3	Baseline Inventory Report, 1995	See Item 1 in this table.
3	Cellulose	170 kg/m^3	Baseline Inventory Report, 1995	See Item 1 in this table.
4	Rubber and Plastic	84 kg/m^3	Baseline Inventory Report, 1995	See Item 1 in this table.
5	Sludges	143.5 kg/m^3	Baseline Inventory Report, 1995	See Item 1 in this table.
6	Initial Waste Density	559.5 kg/m^3	Butcher, 1996, p. 16.	This is the sum of Items 1-5 in this table.

Table 5.7.9. Waste Solid Densities

#	Name	Value	Reference(s)	Comments
1	Metallic	7830 kg/m^3	Butcher, 1995, p. 1.	See Section 5.1.
2	Sorbents	3000 kg/m^3	Butcher, 1991, p. 9.	See Item 1 in this table.
3	Cellulose	1100 kg/m^3	Butcher, 1991, p. 14.	See Item 1 in this table.
4	Rubber and Plastic	1200 kg/m^3	Butcher, 1991, p. 40.	See Item 1 in this table.
5	Sludges	2200 kg/m^3	Butcher, 1991, p. 67.	See Item 1 in this table.
6	Waste Solid Density	1757 kg/m^3	Butcher, 1996, App. C.	This value is treated as a constant, even though some of the "solid" waste is compressible itself, such as wood, rags, sorbents, etc.

Table 5.7.10. Waste Volume Fractions

#	Name	Value	Reference(s)	Comments
1	Metallic	0.218	Butcher, 1996, p.17	Calculated from Tables 5.7.8 and 5.7.9 as described in reference.
2	Sorbents	0.071	Butcher, 1996, p.17	See Item 1 above.
3	Cellulose	0.304	Butcher, 1996, p.17	See Item 1 above.
4	Rubber and Plastic	0.150	Butcher, 1996, p.17	See Item 1 above.
5	Sludges	0.256	Butcher, 1996, p.17	See Item 1 above.
6	Initial waste porosity	0.681	Butcher, 1996, p.17	Calculated from above tables as described in reference. Note that 'waste porosity' here means drum porosity.
7	Initial waste solid volume	551.2 m^3	Butcher, 1996, p.17	Calculated from above tables as described in reference. Note that 'waste solid volume' here means the 'solids' within the drums, even though those solids may be themselves somewhat porous.
8	Initial room porosity	0.849	Butcher, 1996, p.17	Calculated from above tables as described in reference.

Table 5.7.11. Waste Mechanical Properties

#	Name	Value	Reference(s)	Comments
1	G (shear modulus)	333 MPa	Weatherby, 1991, p 922.	See Section 5.2.
2	K (bulk modulus)	222 MPa	Weatherby, 1991, p 922.	See Section 5.2.
3	a_0	1.0 MPa	Weatherby, 1991, p 922.	See Section 5.2. See also Stone, 1996.
4	a_1	3.0	Weatherby, 1991, p 922.	See Section 5.2. See also Stone, 1996.
5	a_2	0.0	Weatherby, 1991, p 922.	See Section 5.2. See also Stone, 1996.

Table 5.7.12. Waste Pressure-Volume Relation

#	P, MPa	$\ln(\rho/\rho_o)$	Reference(s)	Comments
1	1.53	0.510	Butcher, 1995, 1991.	See Section 5.2. Derived from experimental curves, with some assumptions.
2	2.03	0.631	Butcher, 1995, 1991.	See Item 1 above.
3	2.53	0.719	Butcher, 1995, 1991.	See Item 1 above.
4	3.03	0.786	Butcher, 1995, 1991.	See Item 1 above.
5	3.53	0.838	Butcher, 1995, 1991.	See Item 1 above.
6	4.03	0.881	Butcher, 1995, 1991.	See Item 1 above.
7	4.93	0.942	Butcher, 1995, 1991.	See Item 1 above.
8	12.0	1.14	Butcher, 1995, 1991.	See Item 1 above.

Table 5.7.13. Gas Generation

#	Name	Value	Reference(s)	Comments
1	Corrosion gas production rate	1 mole/yr/drum	Brush, 1991, p. A-35	Assumed to be inundated.
2	Corrosion gas potential	1050 moles/drum	Beraun and Davies, 1992, p. A-11	See also, Butcher, 1996, App. B.
3	Microbial gas production rate	1 mole/yr/drum	Brush, 1991, p. A-35	Assumed to be inundated.
4	Microbial gas potential	550 moles/drum	Beraun and Davies, 1992, p. A-11	See also, Butcher, 1996, App. B.
5	Scaling factor f	0.0-2.0	Butcher, 1996	A range variable of gas generation rates for input to BRAGFLO.
6	Gas constant R	8.23 m^3Pa/g-mole K	Handbook	
7	Gas temperature	300 K	Sandia WIPP, 1992	Design parameter

The porosity surface calculations using SANTOS, and with the parameters in the above tables as input, are described by Stone, 1996. The main features of these plane-strain calculations are the use of a simplified stratigraphic model with boundaries at 50 m from the disposal room, the inclusion of the main clean halite and argillaceous halite layers, and the inclusion of the two anhydrite layers of influence (MB 139 below and Anhydrite "b" above), but no explicit inclusion of clay seams. The waste containers are lumped into a single rectangular mass bounded by slip surfaces that correctly reproduces the initial waste density and porosity (Section 5.1). The simplified geometry used (as compared to the reference stratigraphy) is justified by Stone, 1996, with supporting calculations given by Osnes and Lebreche, 1995. In justifying the simplification, it is shown that the inclusion of at least two types of salt and the anhydrite beds are necessary to provide the model sensitivity needed to support observations, but that the clay seams and additional complexities do not contribute further to accuracy and sensitivity. Thus, only halite and anhydrite properties are included as formation material properties in the parameters listed for the porosity surface. No roof failure of the room is considered in these calculations. The porosity surface and its parameters have also been discussed by Butcher, 1996A, and Butcher et. al., 1995.

The first published full explanation of the porosity surface and its justification that the Panel can find appears in Butcher and Mendenhall, 1993. Since the pressure in the room depends on the amount of gas and the volume, and this pressure creates the "back stress" resisting closure, the porosity surface can uniquely represent the room behavior if the relationship between gas mass and time is known. Since that relationship is specified (by corrosion rates and/or intrusion scenarios) the porosity surface can be used as prescribed. A complication occurs, however, when brine is allowed to flow into or out of the room. Then, the porosity evaluated from the porosity surface is treated as the gas-filled porosity and added to

the brine-filled porosity to become the total porosity required in the PA calculations using BRAGFLO. It is also possible that gas dissolution in the brine should be considered. Furthermore, BRAGFLO, which is a fluid flow code, must be used to provide the brine content of the room for this iterative calculation. This coupling is only valid if the fluid flow is slow, which is a good assumption in the case of WIPP. Also, it must be assumed that the brine pressure is the same as the gas pressure within the room, which is true for high waste permeability.

5.7.2. Adequacy of Requirements and Criteria

The disposal room volume-pressure-time relationship is a key part of the WIPP PA model. Therefore, its description and associated parameters are also key. Justifiable simplifications are necessary to make PA calculations practical. To require a "porosity surface" and its parameters is an adequate approach to the solution of this problem.

5.7.3. Assumptions

Many assumptions apply to the determination of the porosity surface and its parameters. These assumptions are discussed fairly extensively in Butcher et al., 1995. The most general and important of the assumptions is the validity of the porosity surface concept itself. Other important assumptions are related to waste mechanical properties, halite and anhydrite mechanical properties, gas generation rates, and brine presence and inflow-outflow rates. The waste and halite/anhydrite mechanical properties have been addressed in Sections 5.1, 5.2, and 5.5. Gas generation rates are specified and qualified elsewhere in the project.

Brine inflow/outflow calculations are part of BRAGFLO and are also qualified elsewhere. However, the dissolution of gas within the brine in the room is apparently not accounted for in the SANTOS calculations leading to the porosity surface. This would have the effect of creating an error on the values on the gas quantity axis of the porosity surface.

An assumption not addressed elsewhere is that the halite above the rooms will deform continuously up to Anhydrite Bed "b" (Figure 5.6.1). Although the weakness in shear of the anhydrite is accounted for in the present porosity surface model, the possibility of discontinuous roof failure and collapse to the level of the bed is not explicitly accounted for. It seems that this would be a likely occurrence under many possible scenarios. This will be discussed further below. From the viewpoint of parameters, this means that a measure of halite tensile strength and the influence of associated blocky failure on the porosity surface have been ignored.

5.7.4. Alternate Interpretation

If roof collapse occurs to the level of Anhydrite Bed "b" (Figure 5.6.1), the porosity surface could be interpreted as that of a much larger room containing blocks of salt as well as gas, brine, and waste. The porosity surface model would still appear to be appropriate in this case. However, the "room" would now be a much larger (primarily taller) room. If the room is made taller, the creep closure rate might be changed. One possibility is that collapse is associated with stress redistribution that slows the rate. A range of new SANTOS calculations could help project participants understand whether this alternate is important. Given that the porosity surface appears appropriate in any case, one would expect that accounting for room collapse would change the magnitude of the surface but not the character, which is its most important aspect, but the alternate should still be investigated.

5.7.5. Uncertainties and Consequences

Uncertainties are associated with all of the porosity surface parameters. Most of these have been discussed in Sections 5.1, 5.2, and 5.5. Given the number of parameters involved, the porosity surface must be considered an approximation. It appears that with the exceptions of the brine dissolution and roof collapse scenarios, the porosity surfaces as currently provided reasonably bound expected behavior.

The impact of gas dissolution in brine would probably shift the values of the porosity with respect to the gas quantity axis. The shift would be approximately in proportion to the ratio of dissolved gas to free gas. The basic character of the surface would not change, and only near a few end points (high pressure, low gas volume), would the magnitudes change much. The impact of including the roof collapse scenario would be to create a larger room containing salt blocks, but with no instantaneous change in porosity. This means that the boundary conditions for creep would change at that time. It seems that the net effect of this on the porosity might be small, but the calculation has not been done.

5.7.6. Appropriateness and Limitations of Methodologies and Procedures

The porosity surface and its parameters are an appropriate method of approaching and simplifying the room closure problem. Full coupling with the other systems away from the disposal room is sacrificed in order to model the room in some detail. The important aspects of coupling, however, are retained.

5.7.7. Adequacy of Application

The application of the porosity surface is in PA using BRAGFLO. If this code couples to the surface smoothly (that is, time steps are not too large), the application of the porosity surface is adequate. (It is

not within the scope of this review to investigate the validity of the BRAGFLO code itself.) The parameters used to calculate the porosity surface are also adequate. Adequacy issues mentioned above with regard to brine flow, gas dissolution, and roof fall, do not appear to affect significantly the adequacy of application, although if any opportunities arise to investigate these areas, the project should consider doing so.

5.7.8. Accuracy of Calculations

The calculational methods of determining the porosity surface using SANTOS and its parameters are adequately described in the references. The accuracy of SANTOS itself is assumed in this review. It is not within the scope of this review to determine the accuracy of SANTOS.

5.7.9. Validity of Conclusions

The porosity surface is a valid method of describing disposal room closure as an input to BRAGFLO. Although full explicit coupling with the repository system away from the disposal rooms is sacrificed, the improvement in overall simplicity and disposal room modeling accuracy are well worth the sacrifice. The parameter values leading to the porosity surface have been checked by survey and spot-checked in detail. They appear to be valid. Some questions that still exist with regard to brine flow, gas dissolution, and roof fall do not substantially affect the validity of the porosity surface and its parameters, although further investigation of these areas might improve the accuracy of results.

Overall, the porosity surface is a good concept, and the final porosity surface data, as defined in WPO#35697, appear to be valid and adequate for their intended use.

5.7.10. Dissenting Views

None

6.0 EVALUATION OF DISTURBED ROCK ZONE PARAMETER

6.1. Characterization of Disturbed Rock Zone

6.1.1. General Evaluation

This section presents the Panel's evaluation of the DRZ as it relates specifically to the shaft seals program. Although the DRZ has associated parameters, such as porosity, permeability, and time, this evaluation focuses on the mechanistic properties of the DRZ, including its generation and healing concepts. The Panel was not asked to evaluate specific parameter values. A final conclusion relates to the impact the DRZ has on the permeability of the shaft zone.

The engineering behavior of the DRZ is being qualified because some of the data used in characterizing the behavior of the shaft DRZ have not previously been qualified. This behavior is not incorporated directly into the PA calculations. Instead, it is used to develop an effective permeability for each shaft seal member, which incorporates the DRZ effect into the seal member permeability. Hence, the engineering behavior of the DRZ is supporting information for the permeabilities of the individual seal members, the values of which are to be found in the respective Form 464.

As continuum creep deformation of the salt adjacent to an underground opening occurs, conditions for formation of microfractures are favorable. The salt experiences a progressive increase in microfracturing and as the fractures become interconnected, a zone of increased permeability in the formation surrounding an excavated opening develops. This region, known as the DRZ, was first identified and technically addressed by Borns and Stormont (1988, 1989), and Stormont et al. (1987, 1990, 1991, 1992).. It was measured using geophysical methods by Pfeifer et al., (1989) and found to be irregular in thickness. Tests in the WIPP air intake shaft (Dale and Hurtado, 1996) investigated this phenomenon through permeability measurements in three radial boreholes spaced 120 degrees at two levels 283 meters apart. They found the permeability reached its ambient conditions at approximately 2.3 m maximum, which translates to about 0.7 times the shaft radius.

Laboratory testing has been used to show that a halite DRZ is self-healing. The investigations of Wawersik and Hannum (1989), Brodsky (1990), Holcomb and Shields (1987), and others have shown that, given the proper confining pressures and adequate time, fractured halite will reconsolidate. In the case of shaft seals, once the seals are in place they provide the near rigid support needed to resist creep, resulting in literal re-establishment of the ambient stress field (Chan et al., 1994) and erasing the

evidence of the micro-fractured zone. The Chan analysis, in collaboration with SNL, shows this phenomenon can be effective within a projected 25 years.

Within the repository the disturbed zones are considered to be part of potential pathways for release of repository gases, brines, and radioactive materials. This evaluation of the DRZ encompasses only the rock zones surrounding the shafts and boreholes, as opposed to other DRZ locations such as those that pertain to rock surrounding the waste storage rooms where the stress field is different and there is no rigid back support to effect the healing process in the early years. Numerous parameters are associated with a DRZ in the proposed WIPP repository. The most important parameters are porosity, permeability, and creep properties that most significantly impact calculations relative to the storage rooms. Since it is concluded for PA that the shaft DRZ can be considered as part of the seal permeability, no additional parameter qualifications beyond those addressed in the Natural Barriers Peer Review (1996) are important to this qualifying evaluation.

6.1.2. Adequacy of Requirements and Criteria

The objective of evaluating a DRZ is to characterize a potential enhanced ability to transmit gases and fluids in the rock mass that surrounds openings, thereby providing a basis for the mitigation of DRZ flow pathways in shaft seal design. No requirements were found to be met for this evaluation but the criteria are that the properties of the zone, its extent, and any transition behavior must be determined. Munson (1995) considers the DRZ to be primarily the result of microfracturing during tertiary creep and believes that it can account for as much as 3% of the total strain due to creep. Constitutive equations have been developed to account for this phenomenon. Munson (1995), and Chan et al. (1994), have found reasonable correlation to DRZ behavior. Both Munson's and Chan's further analyses suggest that the DRZ behavior in salt under continued stress can be described by two mechanisms: fracture closure and fracture healing. Analysis has shown that both mechanisms are positive factors to the seals program at WIPP.

Chan et al. (1995) characterized the DRZ thickness in layers exposed in the air intake shaft and estimated the healing time in salt for different shaft seal material zones for an assumed DRZ thickness of 0.8 of shaft radii. Analysis of the data showed results similar to data from the Q-room experiments; extension of the curves suggests that full healing can be realized within as little as 25 years following placement of the rigid shaft seals. Therefore, the permeability of a DRZ surrounding vertical shafts and boreholes becomes lower than that of the seals and the DRZ then does not appear to be the dominant contributor to the permeability of the shaft zones. In order to account for a DRZ contribution to this permeable zone,

its permeability is incorporated into the shaft seals models as a fractional addition to the overall seal material permeability. The concepts for understanding the DRZ, its extent, and behavior to resume the original rock conditions are believed to adequately resolve that the conditions created initially by a DRZ by mining are appropriately addressed.

6.1.3. Assumptions

In order to mitigate the risk of seal failure due to deteriorating performance of any one seal material, it is assumed that a series of shaft plugs made of uniquely different materials would be used. These include recompacted crushed halite, neat and sand-rich asphalts, compacted clay, and saturated brine concrete. It is assumed that the outer reaches of the DRZ will heal in the near term; and that the DRZ fractures will close and heal once seal material is placed in the open shaft. Early data developed at SNL clearly support these conclusions (Knowles et al., 1996). A disk-shaped collar (kerf) around the shaft filled with non-permeable asphalt will effectively interrupt any flow that might penetrate the DRZ. Given these assumptions, all potential flow in the shafts is attributed to the permeability of the shaft seals materials with an adjustment to account for any DRZ component to the permeability. The shaft DRZ then is not a unique input as a parameter to the PA exercise in relation to the shaft seals.

6.1.4. Alternate Interpretation

Fracture zones in the walls of excavations have always been of concern to the mining and construction industries. In most cases, however, this fracturing occurs in brittle materials with elastic behavior, which is largely not the case in the WIPP repository viscoelastic host rock. Resolution of the salt formation DRZs, as described in this report, would be applicable within most salt formations. However, other than in the Salado formation at the WIPP site, such as in the Culebra, Magenta and other members of the Rustler formation, the DRZ will not obey the concepts put forward. The DRZ in Marker beds 138 and 139 do pose a concern for the open fractured DRZ, but this concern is dealt with in the seals design (Sandia WIPP, 1996).

6.1.5. Uncertainties and Consequences

It is projected that a concrete monolith will be placed in the shaft station drifts to aid the seal from the repository horizon and to support the shaft seals components as they are placed. Because this monolith in essence provides a base plate for the seals column, it in effect provides a base reference on the floor of the repository rather than at the roof where it can float with the salt mass as it creeps to fill the repository void. It is conceivable that because of the far field repository creep closing effects, as envisioned the

designed monolith might cause sufficient stress on the walls to create a shear zone with increased permeability at that interface. No evidence could be found that this situation has been addressed and found to be benign.

A DRZ thickness of 0.8 shaft radius appears to be conservative. Munson et al., 1994 (SAND94-2134C) states that from the air intake shaft data (Dale and Hurtado, 1996) the extent of the damaged rock zone, at 6 years, is certainly less than 1.0 shaft radii, and probably only 0.7 radii. From using these same data. Chan et al., 1994, show a reasonable correlation between the test data and calculations from the MDCF model. No data were found to evaluate the effects of time between excavation and closure on this relationship.

6.1.6. Appropriateness and Limitations of Methodology and Procedures

Mitigation of the deleterious conditions produced by the DRZ appear to be positively addressed in two ways: 1) taking advantage of the creep closure mechanisms of salt, and 2) providing an impermeable waterstop ring around the shafts that protrudes beyond the zone, as revealed by the Sandia Shaft Seals testing program. This asphalt waterstop is even more plastic than the host salt rock and should provide an excellent barrier. However, its placement by means of a mechanically produced kerf introduces its own DRZ that extends the primary DRZ even further out from the shaft wall. This "secondary" kerf should be far less invasive because of the size and constraints of the opening and the short time the kerf is open. Application of the MDCF model would be expected to show that this DRZ extension would heal quickly. However, no suggestions are found of what has been done, or is possible to do, to mitigate this secondary event. Comments on this secondary DRZ are offered only to be especially conservative in discussions of the DRZ. Because of what is stated above, it is probably not important to consider further research into the extent, effects, and mitigation of this secondary DRZ surrounding the shafts and boreholes.

6.1.7. Adequacy of Application

Recognition of the DRZ phenomenon around the shafts and measurements of its effects is an important contribution to waste containment; these effects are among the few WIPP conditions that can be dealt with in an engineering fashion. It was important to find that the DRZ nearly completely heals once there is adequate support within the shaft or borehole against which the creeping salt will reestablish its original state of stress. Because of the healed state and because tests show conservatively that the DRZ areas of influence are within 1.0 shaft radii, it is possible to demonstrate that the DRZ permeability is

lower than that of the seals. This appropriately allows the PA calculations to treat the DRZ permeability as an integral part of the seal. It is important to recognize that this healing factor is a function of the seal's mechanical properties and its time of placement.

6.1.8. Accuracy of Calculations

Several significant calculations were made concerning the DRZ around a shaft. The air intake shaft data (Dale and Hurtado, 1996) was reduced to show the extent of damage resulting from the shaft excavation to be less than one shaft radii. Other analysis from related data and observations from the air intake shaft tests (Munson 1995; Chan et al. 1994) also show that the extent of the DRZ is related to the shaft size, which makes the phenomenon amenable to incorporation in a mechanistic model. The collaboration of Munson et al. (1989) and Chan et al. (1994) has produced one such model through coupling the DRZ fracture to the creep model (the MDCF model). Other calculations include the determination of fracture healing time and projections of the effects of shaft seals' mechanical properties on fracture healing. Permeability calculations are straightforward and in accordance with well-tested technology. It should be recognized that the modeling results largely represent an early stage in this technological development and are subject to corrections as more data become available.

Because of predicted low impact of the DRZ on sealed shaft permeability a few years after seal placement (see section 6.1.2), it appears totally appropriate to adjust permeability of the shaft seal components for the small contribution that the DRZ will contribute to the PA calculations.

6.1.9. Validity of Conclusions

All observed considerations of analysis, study, and proposed engineered applications regarding the DRZ and its impacts on effective shaft sealing appear to be valid. The understandings developed of DRZ phenomena reveal that the increased permeability of the DRZ, with a relatively short time frame, can have a significant affect on the overall performance of sealing the shaft areas. From analysis of the relatively small amount of data, however, it appears that all considerations of this impact and the conclusions discussed here are sound and valid.

6.1.10. Dissenting Views

None

7.0 CONCLUSIONS

The Panel carefully reviewed the 14 parameters (or parameter sets) and data sets submitted for peer review. Each is considered in Sections 4 through 6. The reader is referred to the individual conclusions for details of qualification information on each parameter in its respective section.

As an overall summary:

The Panel is in general agreement with the parameter values chosen for:

- Porosity of SMC (Section 4.1)
- Bulk modulus of crushed salt (Section 4.3)
- Permeability of SMC (Section 4.5)
- Permeability of compacted clay (Section 4.6)
- Initial density of waste (Section 5.1)
- Mechanical properties of waste (Section 5.2)
- Initial water content of waste (Section 5.3)

In the Panel's opinion, changes should be made to two of the parameters:

- Pore volume compressibility of SMC (Section 4.2)
- Permeability of consolidated waste (Section 5.4)

Three of the "parameter" packages involved overviews of parameter subsets or concepts rather than detailed evaluations of individual parameters. The Panel's findings with regard to these parameters are as follows:

- Properties of halite and anhydrite: An overview of this parameter group indicated that they are valid (Section 5.6).
- Data on final porosity surface: The Panel is in agreement with the validity of the concept, its parameters, and the calculated porosity surfaces (Section 5.7).
- Characterization of disturbed rock zone: The Panel is in general agreement with the scientific work and with SNL's level of understanding of the DRZ for modeling studies and for guiding actions to mitigate its adverse effects (Section 6.1).

The conclusions with regard to the two remaining parameters are:

- Strength of waste for blowout: The Panel agreed with the concept, but concludes that the data are insufficiently developed to qualify the value of this parameter at this time (Section 5.5).
- Permeability of crushed salt: The Panel concludes that the permeability of crushed salt should be re-evaluated. Based on current data, the assigned values and ranges may be too

low, but new data now being analyzed may establish the validity of existing values or cause a modification of these values (Section 4.4).

During its work, the Panel became aware of the many complexities involved in developing Form 464 for use in the PA at the WIPP. The work reviewed appeared to be well thought through, and the supporting data were generally good. SNL's investigations at WIPP involve a broad range of scientific disciplines and the investigators are to be commended for the overall quality of their work.

8.0 SIGNATURES

I, by signature, acknowledge that I concur with the findings and conclusions within my area of expertise of this Engineered Systems Peer Review Report.

Dermot Ross-Brown, Ph.D. ESPR Panel Chairman	Rock Mechanics
John Gibbons, Ph.D. ESPR Panel Member	Geomechanics
Darrell Porter, Ph.D. ESPR Panel Member	Mineral Engineering
John Schatz, Ph.D. ESPR Panel Member	Geophysics

9.0 PEER REVIEW MEMBERS AND ACCEPTABILITY

Dermot Ross-Brown, Panel Chairman, is an independent consultant, as well as a part-time consulting employee with SAIC, based in Golden, Colorado. Dr. Ross-Brown has a Ph.D. in Rock Mechanics from the University of London, and an M.S. in Foundation Engineering and a B.S. in Mining Engineering, both from the University of Birmingham, England. He has six registrations as a Professional Engineer, and has more than 30 years of experience as a mining/civil engineer. Relevant experience includes working underground as a shift boss in production and shaft sinking, as well as conducting numerous rock mechanics investigations. For four years Dr. Ross-Brown was an expert witness involved in all geotechnical aspects of a major lawsuit resulting from a brine flood into the world's largest potash mine; the initial leak was followed by more than 30 subsequent leaks. He has been heavily involved in nuclear waste disposal since 1975, including the GEIS, and planned repositories in salt, granite and tuffs. He has been an independent reviewer on many aspects of this work (including mining, rock mechanics and regulatory compliance) for several clients including DOE/ONWI, DOE/YM, DOE/WIPP, NRC, AECL and EPRI.

John Gibbons, Panel Member, is an independent geosciences consultant residing in Albuquerque, New Mexico. Dr. Gibbons has a Ph.D. in Geology from Syracuse University and B.S. and M.S. degrees in Geology from the University of Arkansas. Dr. Gibbons has over 25 years of experience consulting to the Nuclear Industry and Regulators. He has been involved in several research and field studies of the behavior and geology of bedded salt deposits since 1965. He is presently a principal consultant to the Illinois Department of Nuclear Safety in its effort to license a low-level nuclear waste disposal facility. His duties are the review of and contribution to work by world class contractors, national laboratories and state scientific surveys in all aspects of site selection, characterization and performance assessment. Since 1976, Dr. Gibbons has been a principal investigator for hydrogeology in many low-level nuclear waste and uranium mine and mill tailings projects in the southwestern United States.

Darrell D. Porter, Panel Member, is a Senior Scientist and Manager with Science Applications International Corporation (SAIC). He has a Ph.D. in Mineral Engineering with a specialty in rock mechanics from the University of Minnesota. His MS degree from the Colorado School of Mines focused on experimental work in dynamic aspects of Rock Mechanics. He has 34 years of experience. Much of Dr. Porter's work has been in the field of blasting with high explosives and analyzing blasting results in terms of rock mechanics. He has had technical management positions with the Rio Blanco Oil Shale Company where significant field testing accomplishments paved the way for an effective process

development resulting in four patents for Dr. Porter. During the past thirteen years, Dr. Porter supported the U.S. Geological Survey in their site characterization program for the Yucca Mountain Project. The work there included technical reviews, preparation of technical procedures, geological mapping programs, oversight of numerous contributing scientists involved in geologic sampling, mapping, modeling, and technical data management, and preparation and implementation of a quality assurance program. He has collaborated with scientists from many of the National Laboratories and Universities and consulted with numerous clients on rock fracture and fragmentation issues.

John Schatz, Panel Member, is an independent geosciences consultant residing in Del Mar, California. Dr. Schatz has a Ph.D. in geophysics and a B.S. in physics, both from the Massachusetts Institute of Technology, and is an expert in the physical properties of geologic materials. He has 29 years of experience in rock properties testing and analysis, including nuclear waste-related activities at the national laboratories and in commercial industry. This includes some aspect of testing, analysis, project or peer review contributions to virtually all of the DOE nuclear-waste projects. Dr. Schatz has obtained or analyzed data on repository geologic media and backfill materials for crystalline rock and salt repositories, and has acted on review panels (including the DOE/WIPP TSG and IRT Panels over the past 4 years) with the special purpose of independently reviewing parameter packages and conceptual models

10.0 REFERENCES

ACI. 1993. *Standard Practice for Selecting Properties for Normal, Heavyweight and Mass Concrete (ACI 211.1-91)*, Manual of Concrete Practice, 1993 edition. Detroit, MI: American Concrete Institute.

ACI. 1995. Proposed Report: *Placing Concrete by Pumping Methods (92-M48)*, ACI Materials Journal, July-August, 1995. Detroit, MI: American Concrete Institute.

ASTM C231-91b. *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.* American Society for Testing and Materials.

ASTM C457-90. *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.*

Aarre, T. 1995. *Influence of Measurement Technique in the Air-Void Structure of Hardened Concrete.* ACI Materials Journal, V92 No. 6, pp. 599-604.

Beraun, R., and P.B. Davies, 1991. Memo: *Baseline Design Input Data Base to be Used During Calculations Effort to be Performed by Division 1514 in Determining the Mechanical Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt.* 9/12/91. Sandia National Laboratories.

Berglund, J.W., and L.R. Lenke, 1995. *One Dimensional Experiment of Gas Induced Spall,* NMERI Contractor Report 1995, 3 February, 1995. WPO #27589.

Borns, D.J., and J.C. Stormont. 1988. *An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone.* SAND87-1375. Albuquerque, NM: Sandia National Laboratories.

Borns, D.J., and J.C. Stormont. 1989. *The Delineation of the Disturbed Rock Zone Surrounding Excavations in Salt,* Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Proceedings of the 30th U.S. Symposium, West Virginia University, Morgantown, WV, June 19-22, 1989. Ed. A.W. Khair. SAND88-22230C. Brookfield, VT: A.A. Balkema. pp. 353-360.

Brodsky, N.S. 1990. *Crack Closure and Healing Studies in WIPP Salt Using Compressional Wave Velocity and Attenuation Measurements.* SAND90-7076. Albuquerque, NM: Sandia National Laboratories.

Brodsky, N.S. 1994A. *Hydrostatic and Shear Consolidation Tests with Permeability Measurements on Waste Isolation Pilot Plant Crushed Salt.* SAND93-7058. Albuquerque, NM: Sandia National Laboratories.

Brodsky, N.S. 1994B. *Determination of Intact Density of WIPP Salt Specimens,* Calculation File 325/3.4/01, Prepared by RE/SPEC Inc., Rapid City, SD, for Sandia National Laboratories, Albuquerque, NM.

Brodsky, N.S., F.D. Hansen, and T.W. Pfeifle. 1996. *Properties of Dynamically Compacted WIPP Salt,* Draft, for presentation at North American Rock Mechanics Symposium, Montreal, Canada.

Brush, L.H. 1991. Appendix A: *Current Estimates of Gas Production Rates, Gas Production Potentials, and Expected Chemical Conditions Relevant to Radionuclide Chemistry for the Long Term WIPP Performance Assessment,* Preliminary Comparison with 40 CFR Part 191, Subpart for the Waste Isolation Pilot Plant, December 1991. Volume 3: Reference Data. WIPP Performance Assessment Division. Eds. R.P. Rechard, et al.

Butcher, B.M. 1989. *WIPP Simulated Waste Composition and Mechanical Properties.* SAND89-0372. Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M. 1990, memo to M. G. Marietta entitled *Disposal Room Porosity and Permeability Values for Disposal Room Performance Assessment.* 7/24/90. Included in SAND89-2408, pp A-95 to A-102.

Butcher, B.M., T.W. Thompson, R.G. Van Buskirk, and N.C. Patti. 1991. *Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste.* SAND90-1206. Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M. and F.T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B.* SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M. 1995A. *Waste Compressibility Curve Predictions,* Memorandum of Record.

Butcher, B.M. 1995B. *Initial Waste Water Content,* memorandum to M.E. Fewell, Sandia National Laboratories, including attachment "Mathcad Calculation" dated 10/16/95.

Butcher, B.M., and J.T. Holmes. 1995. *Completion of Milestone DR015, definition of closure analysis input parameters, due March 31, 1995,* memo to Les Shepard and Martin Tierney.

Butcher, B.M., S.W. Webb, and J.W. Berglund. 1995. *Systems Prioritization Method - Iteration 2 Baseline Position Paper: Disposal Room and Cuttings Models,* Volume I. WPO #28729.

Butcher, B. M. 1996A. *A Summary of the Sources of Input Parameter Values for the Final Porosity Surface Calculations.* SAND96-XXXX. Albuquerque, NM: Sandia National Laboratories. Draft.

Butcher, B. M. 1996B. *Baseline Inventory Assumptions for the Final Porosity Surface Calculations,* memo Appendix B of Butcher, 1996A.

Butcher, B. M. 1996C. *Calculation of solid density for the inventory listed in the Baseline Inventory Report Rev 1, February, 1995,* in Appendix C of Butcher, 1996A.

Butcher, B.M. 1996D. *Completion of Milestone a. DR040: Final Porosity Surface Data to PS Values,* memo to J.T. Holmes and M.A. Tierney, WPO #31367.

Butcher, B. M. 1996E. *Justification for Assuming 1 psi for the Cementation Strength Parameter in the CUTTINGS_S Model,* memorandum of record, May 30, 1996. WPO#38241.

Callahan, G.D., M.C. Loken, L.L. Van Sambeek, R. Chen., T.W. Pfeifle, J.D. Nieland, F.D. Hansen. 1995. *Evaluation of Potential Crushed-Salt Constitutive Models.* SAND95-2143. Albuquerque, NM: Sandia National Laboratories.

Callahan, G.D., M.C. Loken, L.D. Hurtado and F.D. Hansen. 1996. *Evaluation of Constitutive Models for Crushed Salt*, unpublished draft. RE/SPEC Inc., and Sandia National Laboratories.

Chan, K.S., S.R. Bodner, A.F. Fossum, and D.E. Munson. 1994. *Constitutive Representation of Damage Development and Healing in WIPP Salt.* SAND94-2136C. Albuquerque, NM: Sandia National Laboratories.

Chan, K.S., D.E. Munson, A.F. Fossum, and S.F. Bodner. 1995. *Inelastic Flow Behavior of Argillaceous Salt.* SAND94-3017. Albuquerque, NM: Sandia National Laboratories.

Cheung, S.C.H., M.N. Gray, and D.A. Dixon. 1987. "Hydraulic and Ionic Diffusion Properties of Bentonite-Sand Buffer Materials," *Coupled Processes Associated with Nuclear Waste Repositories.* pp 393-407. Chin-Fu Tsang, Ed. Orlando, FL: Academic Press, Inc.

Chieslar, J.D. 1996. *Materiel Property (Permeability, Bulk Moduli) Determination for Material WIPP Shaft Seals/Components*, Calculation File 325/13/01, Prepared by RE/SPEC Inc., Rapid City, SD, for Sandia National Laboratories, Albuquerque, NM.

Coons W., A. Bergstrom, P. Gnirk, M. Gray, B. Knecht, R. Pusch, J. Steadman, B. Stillborg, M. Tokonami, M. Vaajasaari. 1987. *State-of-the-art Report on Potentially Useful Materials for Sealing Nuclear Waste Repositories*, SKB Stripa Project Technical Report 87-12, Swedish Nuclear Fuel and Waste Management Co. (SKB), Box 5864, S-102 48 Stockholm, Sweden, June, 1987.

Dale, T. and L.D. Hurtado. 1996. *WIPP Air-Intake Shaft Disturbed Rock Zone Study, 4th Conference on the Mechanical Behavior of Salt*, Montreal, Quebec, Canada.

Elliott, I.R. 1993. *Free Liquid Content of Waste Stored at Idaho National Engineering Laboratory and Dispositioned As Waste Isolation Pilot Plant Certified*, letter 234-8291 to L.R. Finch, DOE ES & H.

Fossum, A.F., T.W. Pfeifle, and K.D. Mellegard. 1994. *Probability Distributions for Parameters of the Munson-Dawson Salt Creep Model.*

Gray, M.W., ed. 1993. *Engineered Barriers*, OECD/NEA International Stripa Project, Overview Volume III, SKB.

Hansen, F.D. 1996. Memo to L.D. Hurtado and K.M. Knowles, *Distribution Functions for Seal Materials*, 1/14/96.

Hansen, F.D. and E.H. Ahrens. 1996. *Large Scale Dynamic Compaction Demonstration Using WIPP Salt:* Fielding and Preliminary Results, Proceedings of the 4th Conference on the Mechanical Behavior of Salt, Montreal, Quebec, Canada.

Holcolmb, D.J. and D.W. Hannum. 1982. *Consolidation of Crushed Salt Backfill Under Conditions Appropriate to the WIPP Facility.* SAND82-0630. Albuquerque, NM: Sandia National Laboratories.

Holcolmb, D.J. and Marlene Shields. 1987. *Hydrostatic Creep Consolidation of Crushed Salt with Added Water*, SAND87-1990. Albuquerque, NM: Sandia National Laboratories.

Hume, H.R., and A. Shakoor. 1981. *Chapter 3. Mechanical Properties. Physical Properties Data for Rock Salt.* NBS Monograph 167. National Bureau of Standards. Washington, D.C.

Kelley, V., T. Jones and J. Ogintz. 1995. Memo to L.D. Hurtado *WIPP Seal System Parameters for Performance Assessment: BRAGFLO Compliance Calculations.* 1/15/95.

Kelley V.A., T.L. Jones, and J.B. Ogintz. 1996. *WIPP Shaft Seal System Parameters Documentation to Support Performance Assessment BRAGFLO Compliance Calculations.* INTERA. Austin, Texas.

Knowles, M. K., D. Borns, J. Fredrich, D. Holcomb, R. Price, D. Zeuch, T. Dale and R.S. Van Pelt. 1996. *Testing the Disturbed Zone Around A Rigid Inclusion in Salt. 4th International Conference on the Mechanics of Salt.* Montreal. Canada.

Knowles, M. K., and C.L. Howard. 1996. *Field and Laboratory Testing of Seal Materials Proposed for the Waste Isolation Pilot Plant.* Proceedings of the Waste Management 1996 Symposium. Tucson, Arizona, February 25-29, 1996.

Krieg, R.D. 1984. *Reference Stratigraphy and Rock Properties for the Waste isolation Pilot Plant (WIPP) Project.* SAND83-1908. Albuquerque, NM: Sandia National Laboratories.

Labreche, D.A., and L.L. Van Sambeek. 1988. *Analysis of Data from Expansive Salt-Water Concrete Seals in Series B Small-Scale Performance Tests.* SAND87-7155. Albuquerque, NM: Sandia National Laboratories.

Lappin, A.R., R.L. Hunter, D.P. Garber, P.B. Davies, 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, WIPP, Southeastern New Mexico, March 1989.* SAND89-0462. UC-70. Albuquerque, NM: Sandia National Laboratories.

Lappin, A.R., R.L. Hunter, D.P. Garber, P.B. Davies, R.L. Beauheim, D.J. Borns, L. H. Brush, B.M. Butcher, T. Cauffman, M.S.Y. Chu, L.S. Gomez, R.V. Guzowski, H.J. Iuzzolino, V. Kelley, S.J. Lambert, M.G. Marietta, J.W. Mercer, E.J. Nowak, J. Pickens, R.P. Rechard, M. Lenke, L.R., Berglund, J.W., and Cole, R.A. 1996. *Blowout Experiments Using Fine Grained Silica Sands in an Axisymmetric Geometry,* NMERI Contractor Report 1996/7/32250. March, 1996.

Lenke, L.R., , J.W. Berglund and R.A. Cole, *Blowout Experiments Using Fine Grained Silica Sands in an Axisymmetric Geometry,* NMERI Contractor Report 1996/7/32250. March, 1996.

Luker, R.S., T.W. Thompson and B.M. Butcher. 1991. *Compaction and Permeability of Simulated Waste,* 32nd U.S. Symposium of Rock Mechanics, Oklahoma.

Mendenhall, F.T., B.M. Butcher, and P.B. Davies. 1991. *Investigations into the Coupled Fluid Flow and Mechanical Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt.* SAND91-2378. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E., and P.R. Dawson. 1979. *Constitutive Model for the Low Temperature Creep of Salt with Application to WIPP.* SAND79-1853. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E., and P.R. Dawson. 1982. *A Transient Creep Model for Salt During Stress Loading and Unloading,* SAND82-0962. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E., and H.S. Morgan. 1986. *Methodology for Performing Parallel Design Calculations.* SAND85-0324. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E, A.F. Fossum, and P.E. Senseny. 1989. *Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures.* SAND88-2948. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E., and D.J. Holcomb. 1994, et al. *Correlation of Theoretical Calculations and Experimental Measurements of Damage around a Shaft in Salt.* SAND94-2134C. Albuquerque, NM: Sandia National Laboratories.

Munson, D.E. 1995. *Mechanical Parameters for Update of Reference Data Report,* memo to M.S. Tierney 09/26/95.

Munson, D.E., D.J. Borns, M.K. Pickens, D.J. Holcomb, and S.E. Bigger. 1995. *Systems Prioritization Method - Iteration 2 Baseline Position Paper: Rock Mechanics: Creep, Fracture, and Disturbed Rock Zone.*

Natural Barriers Peer Review. DOE/WIPP, 1996.

Neville, A.M. 1973. *Properties of Concrete.* Pitman Publishing.

NRMCA, 1992. *What, Why and How? Loss of Air Content in Pumped Concrete.* CIP 21, November, 1992. National Ready Mixed Concrete Association.

Oweis, I.S., D.A. Smith, R.B. Ellwood and D.S. Greene. 1990. *Hydraulic Characteristics of Municipal Refuse.* Journal of Geotech Eng., Volume 116, pp. 539-553.

Osnes, J.D., and D.A. Labreche. 1995. *The Effect of Clay Seams and Anhydrite Layers on the Closure of Waste Isolation Pilot Plant Disposal Rooms and Guidelines for Simplifying the Modeled Stratigraphy,* External Memorandum RSI (RCO)-390/7-95/58, RE/SPEC Inc.

Pfeifer, M.C., D.J. Borns, C.K. Skokan, H.T. Anderson, and J.M. Starrett. 1989. *Geophysical Methods to Monitor Development of the Disturbed Rock Zone Around Underground Excavations in Bedded Salt.* SAND89-7055A. Albuquerque, NM: Sandia National Laboratories.

Pfeifle, T.W. 1996, fax sent to F.D. Hansen et al., *Best Estimators and Distribution Functions for Concrete Seal Properties,* 13 pp., 1/10/96.

Pfeifle, T.W., F.D. Hansen. 1996. *Assumptions Used in the Development of the Permeability-Versus-Fractional Density Relationship for Crushed Salt,* External Memorandum RSI(RCO)-325/6-96-20, RE/SPEC Inc. to D. Diane Hurtado June 7, 1996.

Pfeifle, T.W., F.D. Hansen and K.M. Knowles. 1996. *Salt Saturated Concrete,* draft paper for the ASCE Conference, Washington, 9/96.

Pusch, R., L. Borgesson and G. Ramqvist (1987a). *Final report of the borehole, shaft and tunnel sealing test - Volume I: shaft plugging.* Stripa Project TR 87-01. SKB, Stockholm, Sweden.

Ran, C., and J. Daemen. 1995. *Bentonite Properties with Corrections.* Memorandum to F. Hansen, Sandia National Laboratories, December 4, 1995. (Included in Appendix A of RE/SPEC, 1996.)

Reeves, K.L. Robinson, and M.D. Siegel. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* SAND89-0462. Albuquerque, NM: Sandia National Laboratories.

RE/SPEC. 1996. *Probability Distribution Functions for Hydraulic Parameters of Waste Isolation Pilot-Plant Shaft Sealing Materials for Handoff to WIPP Performance Assessment,* Calculation No. 325/13/02, February, 1996, Prepared for Sandia National Laboratories by RE/SPEC Inc., Rapid City, SD.

Sandia WIPP. 1991. *Preliminary Comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant, December 1991.* SAND91-0893/3, pp 3-130 to 3-134. Albuquerque, NM: Sandia National Laboratories.

Sandia WIPP. 1992. *Preliminary Performance Assessment for Waste Isolation Pilot Plant, December, 1992.* Volume 3: Model Parameters," SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories.

Sandia WIPP. 1996. *Draft WIPP Shaft Seal System Compliance Submittal Design Report, Including Appendices A, through E.* Albuquerque, NM: Sandia National Laboratories.

Senseny, P.E. 1986. *Triaxial Compression Creep Tests on Salt from the Waste Isolation Pilot Plant.* SAND85-7261. Albuquerque, NM: Sandia National Laboratories.

Sjaardema, G.D. and R.D. Krieg, 1987. *A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analysis of Backfilled Shaft and Drift Configurations,* SAND87-1977. Albuquerque, NM: Sandia National Laboratories.

Spiers, C.J. and R.H. Brzesowsky, 1993. *Densification Behavior of Wet Granular Salt: Theory Versus Experiment,* proceedings from the Seventh Symposium on Salt, Volume I, pp 83-92, Elsevier Science Publishers, B.V., Amsterdam.

Stone, C. M. 1996. *Final Disposal Room Structural Response Calculations.* SAND 96-XXXX. Albuquerque, NM: Sandia National Laboratories. Draft.

Stormont, J.C., E.W. Peterson, and P.L. Lagus. 1987. *Summary of and Observations about WIPP Facility Horizon Gas Flow Measurements through 1986.* SAND87-0176. Albuquerque, NM: Sandia National Laboratories.

Stormont, J.C., 1990. *Discontinuous Behavior Near Excavations in a Bedded Salt Formation,* International Journal of Mining and Geological Engineering. Vol. 8, no. 1, 35-56.

Stormont, J.C., C.L. Howard, and J.J.K. Daemen. 1991. *In Situ Measurements of Rock Salt Permeability Changes Due to Nearby Excavation.* SAND90-3134. Albuquerque, NM: Sandia National Laboratories.

Stormont, J.C., J.J.K. Daemen, and C.S. Desai. 1992. *Prediction of Dilation and Permeability Changes in Rock Salt,* International Journal for Numerical and Analytical Methods in Geomechanics. Vol. 16, no. 8, 545-569.

Thompson, T.W. and R.S. Luker. 1990. *Compaction and Permeability of Simulated Waste.* SAIC Report for Sandia National Labs.

Tierney, M. 1990. *Constructing Distributions of Uncertain Variables in Models of the Performance of the Waste Isolation Pilot Plant: The 1990 Performance Simulations.* SAND90-2510. Albuquerque, NM: Sandia National Laboratories.

Wakeley, L.D., J.J. Ernzen, B.D. Neeley, and F.D. Hansen. 1993. *Salado Mass Concrete: Mixture Development and Preliminary Characterization.* SAND 93-7066. Albuquerque, NM: Sandia National Laboratories.

Wakeley, L.D., 1994, memo to F.D. Hansen, Proposed Input to SAND94-0170. 2/1/94. Albuquerque, NM: Sandia National Laboratories.

Wakeley, L.D., T.S. Poole, and J.P. Burkes, 1994. *Durability of Concrete Materials in High-Magnesium Brine,* SAND93-7073, prepared for Sandia National Laboratories.

Wakeley, L.D., P.T. Harrington, and F.D. Hansen. 1995. *Variability in Properties of Salado Mass Concrete.* SAND94-1495. Albuquerque, NM: Sandia National Laboratories, Albuquerque, NM.

Wawersik, W.R., and D.W. Hannum. 1979. *Interim Summary of Sandia Creep Experiments on Rock Salt from the WIPP Study Area, Southeastern New Mexico,* SAND 79-0115. Albuquerque, NM: Sandia National Laboratories.

Weatherby, K.R., W.T. Brown, B.M. Butcher. 1991. *Closure of WIPP Disposal Rooms Filled with Various Waste and Backfill Combinations,* SAND90-2399C. Albuquerque, NM: Sandia National Laboratories.

WIPP Records Package: *Final Porosity Surface Data,* WPO #35697.

WIPP Records Package: *Mechanical Compaction of WIPP Simulated Waste,* 2 volumes and 6 supporting packages, WPO#26468.

WIPP Records Package: *Variability in Properties of Salado Mass Concrete* (3 volumes) WPO28380.

WTAC, 1995A, *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report,* Revision 1, CAO-94-1005.

WTAC, 1995B, As above, Revision 2.

Zeuch, D.H.. 1990. *Isostatic Hot Pressing Mechanism Maps for Pure and Natural Sodium Chloride: Applications to Nuclear Waste Isolation in Bedded and Domol Salt Formations,* International Journal of Rock Mechanics and Mineral Sciences and Geomechanical Abstracts, Volume 27, pp 505-524. Also SAND84-1106. Albuquerque, NM: Sandia National Laboratories.

Determination of Peer Review Member Independence Form

M

_____ Currently employed by DOE or DOE Contractor? (Yes) No
_____ Employed by DOE or DOE Contractor previously? (Yes) No

If yes, give dates, location, company, position type work performed.

- EMPLOYED BY SAIC (A DOE CONTRACTOR) FROM 1978 - 1983 AND 1985 - PRESENT. WORKED ON NUMEROUS DOE PROJECTS ALL OVER USA - SEE RESUME.
- HAVE NOT WORKED ON THE WIPP EXCEPT AS A REVIEWER THROUGH WTAC.

_____ Do you or have you had any direct involvement or financial interest in the work under review? Yes (No)

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: [signature]

Date: 4/17/96

Peer Review Manager Approval: [signature] John A. Thies 4/25/96 Date

Determination of Peer Review Member Independence Form

NO — Currently employed by DOE or DOE Contractor? Yes/No

Yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

Battelle, Alb., IRT reviewer of WIPP Data Packages 1994-1995
ARA, Alb. Site Characterization Technology Research 1992-1993
SNL Civil Systems Inc., High Level WIPP Experiment Planning
1977-1978

NO — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Carl F. Gill II

Date: NOV 29/96

Peer Review Manager Approval: John A. Thies — 4/8/96 Date

Determination of Peer Review Member Independence Form

Yes — Currently employed by DOE or DOE Contractor? Yes/No
yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

SAIC, my employer, has been active as a DOE Contractor for many years. To date I have had no work or other relationship to work on the DOE WIPP programs.

No — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Darrell Porter

Date: March 29, 1996

M

Peer Review Manager Approval: John A. Thies — 4/8/96 Date

Determination of Peer Review Member Independence Form

NO Currently employed by DOE or DOE Contractor? Yes/No

YES Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

(1) 1992 - 1993 - ALBUQUERQUE - DOE/TSG SUB TO SAIC AND ASI - PRIMARILY WORK ON PARAMETER REVIEW - LOOKING AT THE BACKGROUND OF PARAMETER VALUES - NO DESIGN WORK DONE, NO FORMAL REVIEW

(2) 1995 - CARLSBAD SUB TO J.M. STOWER - IAT TEAM WORK - STRICTLY QA RELATED

NO Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: [signature]

Date: 4/18/96

Peer Review Manager Approval: [signature] John A. Thies 4/25/96 Date

PEER 6 - Waste Form & Disposal Room Data Qualification Peer Review

Title: WASTE FORM AND DISPOSAL ROOM PEER REVIEW (WF&DRPR) PLAN

(Assistant Manager, Office of Regulatory Compliance, Carlsbad Area Office) Date: 6/25/96

1. INTRODUCTION

This Waste Form and Disposal Room Peer Review (WF&DRPR) Plan describes the peer review and documentation the Waste Isolation Pilot Plant (WIPP) Project will use to ensure that the data used in the models describing waste form and disposal room for disposal room closure and chemistry in the performance assessment (PA) are qualified for use in the demonstration of compliance.

1.1 BACKGROUND

In accordance with the regulatory requirements specified in 40 CFR Part 191 and implemented in accordance with the criteria specified in 40 CFR Part 194, section 194.22 (b), "Any compliance application shall include information which demonstrates that data and information collected prior to the implementation of the quality assurance program required pursuant to paragraph (a) (1) of this section (194.22) have been qualified in accordance with an alternate methodology, approved by the administrator or the administrator's authorized representative, that employs one or more of the following methods: peer review, conducted in a manner that is compatible with NUREG-1297, "Peer Review for High-Level Nuclear Waste Repositories"; corroborating data; confirmatory testing; or a quality assurance program that is equivalent in effect to ASME NQA-1-1989 edition, ASME NQA-2a-1990 addenda, part 2.7, to ASME NQA-3-1989 edition (excluding Section 2.1 (b) and (c) and Section 17.1)." The DOE has generally opted to employ the peer review methodology to qualify existing data that it cannot demonstrate was collected in accordance with a quality assurance program that was equivalent to the quality assurance defined above. Accordingly, a peer review will be conducted to confirm the adequacy and completeness of data utilized to define parameter values as applied in conceptual models and scenarios that have been determined to be significant to waste containment. To facilitate review of the data, the data qualification peer reviews have been divided into the following three associated waste containment subsystems:

- Natural barriers (Salado and non-Salado flow and transport);
- Engineered systems (rock mechanics and shaft/borehole seals); and
- Waste form and the disposal room.

Sandia National Laboratories (SNL) is responsible for the selection and development of conceptual models that reasonably define the WIPP containment system, and for the identification and development of mathematical models, numerical models, and computer codes utilized to assess the performance of the WIPP containment for the statutory confinement period. SNL is responsible for

identifying data for which it cannot provide assurance that the information was collected under a qualified quality assurance program accordance with NUREG-1297. Therefore, to meet the regulatory requirements cited above, this peer (as defined above). These data will then be reviewed under a peer review process conducted in review on waste form and disposal room for disposal room closure and chemistry will assess the qualification of data used in PA for the WIPP.

1.2 PURPOSE

The purpose of this WIPP peer review plan is to define the peer review process that will be conducted to *determine if (Rev. 1)* existing unqualified waste form and the disposal room subsystems data and information *are qualified to be (Rev. 1)* used in the demonstration of compliance. As stated above, the DOE has determined the peer review process to be the most appropriate method to demonstrate that all waste form and disposal room subsystems are qualified for use in the demonstration of compliance. These peer reviews will be conducted in accordance with the requirements of NUREG-1297 that state, "A peer review is a documented, critical review performed by peers who possess qualifications at least equal to those of the individuals who conducted the original work. These individuals must be independent of the work being reviewed; independence from the work reviewed means that the peer, a) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed."

1.3 SCOPE

This WF&DRPR Plan describes the peer review process that the DOE Carlsbad Area Office (CAO) will utilize for the review of those existing data and information that form the basis for determining the parameter values of the conceptual models that form the waste form and disposal room subsystems. The peer review will be an in-depth critique of assumptions, alternate interpretations, methodology, and acceptance criteria employed, and of the conclusions drawn in the original work. This WF&DRPR Plan defines the approach, methods, criteria, schedules, deliverables, and resources required for conducting the WF&DRPR to confirm: 1) the adequacy and completeness of the data; and 2) the data and information are qualified for use in the demonstration of compliance. See Attachment A for a description of the data to be reviewed and its intended use in PA.

The conceptual models and codes to be used in the PA of the waste form and disposal room subsystem include:

Waste Form and Disposal Room - Disposal Room Closure and Chemistry

Model	Code
Gas Generation	BRAGFLO
Chemical Conditions	NUTS
Dissolved Actinide Source Term	NUTS
Colloidal Actinides Source Term	NUTS

Existing unqualified data and information which was utilized to establish the parameter values will form the basis of this WF&DRPR.

2. PEER REVIEW PLANNING AND IMPLEMENTATION

2.1 APPROACH

The DOE-CAO has prepared the "Office of Regulatory Compliance (ORC) Team Procedure for Peer

Review" (TP 10.5) to document the approach for conducting the peer review process. The WF&DRPR Panel will conduct the peer review activities for the qualification of data in accordance with TP 10.5, this Plan and IDI 1.0.

Similarly, SNL has prepared a procedure to provide the data and information necessary to support peer review of the qualification of data. The SNL data packages to be provided to the WF&DRPR Panel will include: 1) identification of the applicable conceptual model parameter(s); 2) assignment of a parameter value or range of values; 3) description of the source of the data used to construct the parameter value or ranges of values; 4) a description of the process whereby the data was scaled up to parameter value(s); and 5) designation of data qualification status.

2.1.1 DATA USED IN THE DEMONSTRATION OF COMPLIANCE

The peer review of existing unqualified SNL data and information (see Attachment A) is to confirm and document its adequacy and completeness. The data and information qualification peer review will confine itself strictly to providing this confirmatory information.

2.1.2 COMPOSITION OF PEER REVIEW PANEL

The WF&DRPR Panel will be composed of a minimum of two individuals who meet requirements identified in TP 10.5. The duration of the WF&DRPR Panel review process is expected to last between three to six weeks. The WF&DRPR Panel may include up to two members of the Conceptual Model Peer Review Panel. The peer review selection team will appoint the remaining panel member(s) based on his/her technical expertise which will be equivalent to that required to perform the original work. Experience areas to be represented on this panel include actinide chemistry, corrosion chemistry, and colloid chemistry.

Through a formal orientation process, each panel member will become familiar with the WIPP containment system and the basis of the engineered systems models, data, parameters and information that describe the containment system. In addition, panel members will be provided with a basic description of how the models are represented in numerical models, algorithms, and codes. The peer reviewers will be familiarized with the parameter inputs to the PA codes and the results of prior PAs, sensitivity analyses, and critical comments from previous reviews. Each peer reviewer will be selected, oriented, and trained in accordance with approved procedures.

2.1.3 LOGISTICS AND MANAGEMENT

When the WF&DRPR convenes to perform the peer review process, the intent is to have all the data packages accessible for review. However, not all information necessary to support peer review of the qualification of data for the engineered systems may be available at the beginning of the review. Therefore, it may be necessary to conduct the WF&DRPR in a phased manner, depending upon the availability of information.

2.2 METHODOLOGY

The WF&DRPR will follow the methodology provided in NUREG-1297 as augmented by the specific requirements contained in 40 CFR Part 194.22. The purpose for conducting a peer review of data associated with this WIPP subsystem is to ensure that those data that cannot be qualified by virtue of their collection under a QA program (equivalent in effect to ASME NQA-1-1989 edition, ASME NQA-2-1990 addenda, part 2.7, ASME NQA-3-1989 edition [excluding Section 2.1 (b) and (e) and Section 17.1]) are qualified for use in the demonstration of compliance. To facilitate the conduct of the peer

review, a checklist containing potential areas of review is included in this plan as Attachment B. The basis of the peer review will be to determine the adequacy and completeness of specific unqualified data used to demonstrate compliance. Adequacy criteria are provided in Section 2.3.

2.3 ADEQUACY CRITERIA

Adequacy of data associated with the conceptual models that nominally comprise the waste form and disposal room subsystem will be based on the peer review panel's determination that these data meet commonly accepted technical and scientific standards. Criteria utilized to make this determination include:

- Adequacy of requirements and criteria;
- Validity of assumptions;
- Alternate interpretations as appropriate;
- Uncertainty of results and consequences if wrong;
- Appropriateness and limitations of methodology and procedures;
- Adequacy of application;
- Accuracy of calculations; and
- Validity of conclusions.

In evaluating the existing data, the peer review panel shall also consider the following:

- The sources of the parameters and data, e.g., professional judgment, published source material, field tests, laboratory experiments, etc.;
- The processes used to produce the parameters from data are appropriate for the intended use; and
- The assumptions, calculations, extrapolations, interpretations, methods, and conclusions pertinent to the data are appropriate for the development of parameters used as input to the WIPP PA and are traceable.

2.4 SCHEDULE

The PR Manager, working closely with SNL, has developed a preliminary schedule that provides the necessary information on an "as available" basis. Flexibility is required by all supporting organizations, (i.e., DOE-CAO, SNL, the PR Manager, staff and panel members) to accommodate the peer review schedule and any changes made due to uncertainty in the timing of data availability. Attachment C contains a schedule of WF&DRPR activities and milestones in accordance with the Peer Review Management Plan. This schedule will serve as the baseline schedule from which requested schedule deviations will be evaluated and approved, if appropriate. Revisions to the baseline schedule will not require revision to this plan but will be attached to the plan by reference.

2.5 DELIVERABLES

A final report for the WF&DRPR will be submitted to DOE-CAO. A list of mandatory topics and suggested outline for the final WF&DRPR report is provided in Attachment D. This outline may be utilized to guide the review of each data package to ensure adequate review of the data packages.

3. QUALITY ASSURANCE

The WF&DRPR process will be conducted in a controlled manner and in compliance with TP 10.5.

4. RECORDS MANAGEMENT

Records and documents generated as a result of peer review activities defined in this peer review plan are identified in the CAO Team Procedure, TP 10.5. WF&DRPR records will be assembled and maintained in accordance with the Peer Review Management Plan and the Informatics Desk Instruction, IDI-1.0. Upon completion of the peer review process, a complete set of WF&DRPR records will be delivered to CAO. Ultimately, peer review records will be dispositioned in accordance with DOE-CAO records management requirements.

5. DOCUMENT CONTROL

All plans, procedures, and other documents which require document control will be handled in accordance with applicable DOE-CAO controlled document procedures (MP 4.4).

ATTACHMENT A

PEER REVIEW PANEL DATA PACKAGE DESCRIPTIONS

DATA	INTENDED USE
Actinide Solubility	Waste Form & Disposal Room Chemistry

ATTACHMENT B

SUGGESTED METHODS CHECKLIST

PEER REVIEW CHECKLIST	
STUDY/EXPERIMENT IDENTIFICATION	
	COMMENTS
1.0 Scientific Technical Items	
1.1 Were the technical objectives clearly stated in documents accompanying the data?	
1.2 Are all the stated objectives addressed by the data?	
1.3 Was there any test-to-test interference and/or was the impact of test-to-test interference on results adequately evaluated?	
1.4 Were the tests performed in accordance with: a) nationally recognized standards?	
b) modified recognized standards or specially prepared test procedures?	
c) modified recognized standards or specially prepared test procedures?	
d) If so, are they documented in sufficient detail to be repeatable?	
e) Were they justified, evaluated, and approved by a cognizant individual/organization?	
1.5 Were the test procedures correctly implemented?	
1.6 Were testing irregularities and interruptions described?	
1.7 Was documentation of corrective actions sufficiently detailed?	
1.8 Were data reduction processes appropriate for the objectives of the test?	
1.9 Is the reduced data a true representation of all raw data acquired?	
1.10 Are the interpretations well supported by the data?	
1.11 Is the data quality adequate?	
a) Does the age of the data affect the results?	
b) Were the analytic methods used adequate?	
c) Were detection limits adequate?	
d) Is the range of uncertainty associated with each measurement adequate to satisfy the objectives of the test?	
e) Is the uncertainty associated with the cumulative data low enough to make a decision?	
f) Has invalid data been identified?	
g) Has valid data been characterized by providing qualitative or quantitative statements as to the validity and use?	
h) Is there a redundancy in measurements that provide checks of/on the data?	
1.12 Were the number of data points taken enough to provide an adequate level of confidence in the results?	
1.13 Is there internal consistency between the sets of data for similar tests?	
1.14 Are the data complete?	
1.15 Can credible blocks be improved, or supported by: a) correlation with complementary or confirmatory data?	
b) additional work?	
1.16 Is any source of confirmatory data identified in database documents?	
1.17 Is the data good enough to support the intended use?	

2.0 Summary of Conclusions	
2.1 Did the data meet adequacy of requirements and criteria?	
2.2 Did the data show validity of assumptions?	
2.3 Were there alternate interpretations of the data?	
2.4 Was there a discussion of uncertainty of results and consequences?	
2.5 Was there appropriateness and limitations of methodology and procedures?	
2.6 Was adequacy of application demonstrated for the data?	
2.7 Was the accuracy of calculations demonstrated?	
2.8 Was the validity of conclusions demonstrated?	
2.9 Were the sources of the parameters and data considered in evaluating the existing data?	
2.10 Were the processes used to produce the parameters from the data appropriate for the intended use?	
2.11 a) Were the assumptions, calculations, extrapolations, interpretations, methods, and conclusions pertinent to the data appropriate for the development of parameters used as input to the WIPP PA?	
b) Were they traceable?	

M

ATTACHMENT C

WASTE FORM AND DISPOSAL ROOM PEER REVIEW SCHEDULE

	DRAFT	FINAL
WF&DRPR Plan drafted	3/11	3/29
PR Panel Assigned	NA	4/29
WF&DR Data Package to PR Manager	4/22	4/29
Initiate WF&DRPR	NA	5/6
Complete WF&DRPR	NA	6/14
Submit WF&DRPR Report	6/14	6/28

ATTACHMENT D

PEER REVIEW REPORT OUTLINE

Executive Summary

1. Introduction

2. Purpose

3. Description of Work Performed

4. Evaluation Work Performed
   - A. Adequacy of Requirements and Criteria
   - B. Validity of Assumptions
   - C. Alternate Interpretations
   - D. Uncertainty of Results and Consequences if Wrong
   - E. Appropriateness and Limitations of Methodology and Procedures
   - F. Adequacy of Application
   - G. Accuracy of Calculations
   - H. Validity of Conclusions

5. Conclusions

6. Dissenting Views

7. Summary

8. Signatures

9. Peer Review Members and Acceptability

WASTE FORM AND DISPOSAL ROOM DATA QUALIFICATION

PEER REVIEW REPORT

M

FINAL REPORT

WASTE ISOLATION PILOT PLANT
WASTE FORM AND DISPOSAL ROOM DATA QUALIFICATION
PEER REVIEW REPORT

A PEER REVIEW
CONDUCTED BY

Duane Hrncir, Robert Knecht

for

U. S. Department of Energy
Carlsbad Area Office
Office of Regulatory Compliance

July 1996

FOREWORD

The U.S. Environmental Protection Agency promulgated "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule" in Code of Federal Regulations, Title 40, Part 194 (40 CFR Part 194) on February 9, 1996. The 40 CFR Part 194 regulation prescribes three specific peer reviews and also provides the opportunity for the Department of Energy to use peer reviews, conducted in accordance with NUREG 1297, as a means of qualifying data and information for use in the demonstration of compliance.

This report contains the results of a peer review of specific waste form and disposal room data used in the demonstration of Waste Isolation Pilot Plant (WIPP) compliance with 40 CFR Part 194. To ensure the independence of this review, the Department of Energy has directed the assignment of an independent contractor to administratively manage the peer review activities. Peer reviewers were selected based on their demonstrated independence from the work being reviewed and their technical expertise in the subject matter to be reviewed. The peer review panel, in aggregate, represents an appropriate spectrum of knowledge and experience in the subject matter reviewed.

This peer review was conducted in compliance with the quality assurance requirements as defined in 40 CFR Part 194.

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ACRONYMS

WIPP	Waste Isolation Pilot Plant
SNL	Sandia National Laboratories
PA	performance assessment
QA	quality assurance

1.0 EXECUTIVE SUMMARY

The Waste Form and Disposal Room Peer Review was conducted by two panel members (Panel) who examined the 26 parameters submitted to them for qualification by Sandia National Laboratories (SNL). The 26 parameters are listed in Table 1.1, together with the qualification status that resulted from this review.

In summary, the Panel was able to qualify all 26 of the parameters based on a thorough review of experimental data, literature reports, and confirmatory calculations.

Table 1.1. Listing and Status of Reviewed Parameters

A. Inorganic Chemistry Controlled by $Mg(OH)_2/MgCO_3$

ID number	Species	Brine	Status
WP037105	Am(III)	Salado	Qualified
WP037106	Am(III)	Castile	Qualified
WP037109	Pu(III)	Salado	Qualified
WP037108	Pu(III)	Castile	Qualified
WP037129	General An(III)	Salado	Qualified
WP037125	General An(III)	Castile	Qualified
WP037110	Pu(IV)	Salado	Qualified
WP037111	Pu(IV)	Castile	Qualified
WP037115	Th(IV)	Salado	Qualified
WP037112	U(IV)	Salado	Qualified
WP037130	General An(IV)	Salado	Qualified
WP037126	General An(IV)	Castile	Qualified
WP037131	General An(V)	Salado	Qualified
WP037127	General An(V)	Castile	Qualified
WP037113	U(VI)	Salado	Qualified
WP037114	U(VI)	Castile	Qualified
WP037132	General An(VI)	Salado	Qualified
WP037128	General An(VI)	Castile	Qualified

B. Organic Chemistry Controlled by $Mg(OH)_2/MgCO_3$

ID number	Species	Brine	Status
WP037116	General An(III)	Salado	Qualified
WP037121	General An(III)	Castile	Qualified
WP037117	General An(IV)	Salado	Qualified
WP037122	General An(IV)	Castile	Qualified
WP037118	General An(V)	Salado	Qualified
WP037123	General An(V)	Castile	Qualified
WP037120	General An(VI)	Salado	Qualified
WP037124	General An(VI)	Castile	Qualified

2.0 PURPOSE

The purpose of the Waste Form and Disposal Room Peer Review was to seek qualification of scientific data by performing a systematic review of unqualified parameters used in the models describing the waste form and disposal room subsystem in the Waste Isolation Pilot Plant (WIPP). This review is one of three recognized methods for providing assurance that scientific data collected are qualified for intended use. A peer review panel (Panel), consisting of two members, was convened to undertake the work, and the peer review was conducted in a manner compatible with NUREG-1297, Peer Review for High-Level Nuclear Waste Repositories. This report is a documented summary of the Panel's work and of the evaluation performed on selected parameters identified by Sandia National Laboratories (SNL). The report is intended primarily for use by the technical personnel at SNL/WIPP. It may also be included as supporting material in the WIPP Compliance Certification Application submitted to the Environmental Protection Agency.

The parameters evaluated consisted of information used as input to the WIPP performance assessment (PA), which in turn is to be incorporated in the demonstration of compliance. The Panel evaluated existing data and information that form the basis of the parameter values used in the mathematical expression of conceptual models for the waste form and disposal room subsystem. The parameters selected for evaluation had not previously been fully qualified for use in PA. The conceptual models used in the PA of the waste form and disposal room subsystem include components of 1) Gas Generation, 2) Chemical Conditions, 3) Dissolved Actinide Source Term, and 4) Colloidal Actinide Source Term.

3.0 DESCRIPTION OF WORK PERFORMED

The Waste Form and Disposal Room Peer Review Panel evaluated 26 parameters against the eight review criteria given in NUREG-1297. The parameters were solubilities of the actinides proposed to be at issue in the repository waste. The solvents were brines from the Salado and Castile formations.

The approach used by the Panel in its evaluation was to compare each calculated solubility parameter to those published in the peer-reviewed literature when such data were available. In order to make this comparison, the Panel had to consider compatibility of solvents, solution pH, and the absence of potentially ligating carbonate. The latter criterion is an imposed condition controlling the disposal room chemistry. When no literature value was available, the Panel used experimental data derived from several different laboratories. In using these data, the Panel was careful to evaluate the experimental approach, being certain that the methods used for data acquisition and interpretation were consistent with recognized standards.

No experimental data were available for some of the parameters. For these cases, the Panel examined the method of calculation used to derive the value. The experimental data used as input to the calculation were evaluated. The validity of the calculation result was critiqued relative to similar calculated values where experimental data were available.

During the course of its work, the Panel reviewed information packages provided by SNL for each parameter. In addition, technical reports, published literature, and internal documents were used to supplement the information in the parameter packages. Formal and informal discussions were held with SNL personnel in order to more fully understand the concepts and parameter derivation.

4.0 EVALUATION OF ACTINIDE SOLUBILITY PARAMETERS

Performance assessments for a nuclear waste repository require solubility data to determine ground water compositions. Concentrations of actinides (Th, U, Np, Pu, and Am) influence the performance of the WIPP repository. Chemical reactions that occur within the repository potentially produce or consume gases and also modify the brine chemistry. These reactions occur between influx brine, waste, backfill, and/or other materials used during the construction of the repository. Reactions modify the solution environment and affect the solubility of the gases and actinides in the brine.

Prediction of solution chemistry at various locations and under various conditions add to the understanding of actinide transport and support the calculations for WIPP performance assessment. As Brush (1990) noted

> "Laboratory studies with nonradioactive simulated waste and, in some cases, radioactive simulated waste provide a unique opportunity to develop a mechanistic understanding of repository and radionuclide chemistry."

Two different solvents were considered, Salado brine and Castile brine. It is assumed that conditions in the disposal rooms will be such that the brine compositions will be in equilibrium with brucite, $Mg(OH)_2$, and magnesite, $MgCO_3$. Therefore, the calculated solubilities were derived using the condition that the brines are saturated with brucite and magnesite and that this saturation is maintained regardless of any chemistry that may affect the brines. The Castile Formation brine used in this analysis of actinide solubility is designated ERDA-HA-An-Mg; the Salado Formation brine is designated SPC-HA-An-Mg.

Investigators calculate solubility using an FMT code, based on a thermodynamic model. The code uses the Harvie-Moller-Weare (HMW) parameterization of the Pitzer activity coefficient model to calculate aqueous solution concentrations (solubility). Based on code calculations, these parameters (shown in Table 4.1) feed performance assessment models NUTS and GRIDFLOW.

4.1. Adequacy of Requirements and Criteria

The dissolved concentrations of the actinides in each of the brines given above were determined using equilibrium calculations constrained to fit the conditions anticipated in the disposal rooms. The calculations were targeted to fit an accuracy within one order of magnitude for the solubility predictions.

Table 4.1. Solubility Parameters for Disposal Room Dissolved Species Studies

Material	Parameter	Median	High	Low
SOLMOD3	SOLSOM	4.5E-06	4.5E-07	4.5E-05
	SOLCOM	2.9E-06	2.9E-07	2.9E-05
	SOLSIM	3.8E-06	3.8E-07	3.8E-05
	SOLCIM	3.6E-07	3.6E-08	3.6E-06
SOLSIM	SOLAM3	3.8E-06	3.8E-07	3.8E-05
	SOLPU3	3.8E-06	3.8E-07	3.8E-05
SOLCIM	SOLAM3	3.6E-07	3.6E-08	3.6E-06
	SOLPU3	3.6E-07	3.6E-08	3.6E-06
SOLMOD4	SOLSOM	4.4E-06	4.4E-07	4.4E-05
	SOLCOM	5.7E-07	5.7E-08	5.7E-06
	SOLSIM	4.4E-06	4.4E-07	4.4E-05
	SOLCIM	6.0E-09	6.0E-10	6.0E-08
SOLSIM	SOLTH4	4.4E-06	4.4E-07	4.4E-05
	SOLU4	4.4E-06	4.4E-07	4.4E-05
	SOLPU4	4.4E-06	4.4E-07	4.4E-05
SOLCIM	SOLPU4	6.0E-09	6.0E-10	6.0E-08
SOLMOD5	SOLSOM	7.7E-06	7.7E-07	7.7E-05
	SOLCOM	7.4E-05	7.4E-06	7.4E-04
	SOLSIM	2.3E-06	2.3E-07	2.3E-05
	SOLCIM	2.2E-06	2.2E-07	2.2E-05
SOLMOD6	SOLSOM	1.0E-05	1.0E-06	1.0E-04
	SOLCOM	7.0E-05	7.0E-06	7.0E-04
	SOLSIM	8.7E-06	8.7E-07	8.7E-05
	SOLCIM	8.8E-06	8.8E-07	8.8E-05
SOLSIM	SOLU6	8.7E-06	8.7E-07	8.7E-05
SOLCIM	SOLU6	8.8E-06	8.8E-07	8.8E-05

The results of the calculations are given as a range that spans two orders of magnitude about the median. This approach is sound, and the solubilities that result from the equilibrium calculations are values that can be compared with those empirically determined and published in the literature.

No inorganic model exists for the calculation of An(VI) solubilities in the WIPP disposal room environment. The dissolved concentration of the +VI actinides in the brines are estimates based on an analysis of empirical solubility experiments in brines similar to those anticipated in the disposal rooms. The confidence in the estimate becomes a function of the quality of the experimental data.

Migration of actinides to the accessible environments depends on their oxidation state and concentration in the brines. Hydrolysis affects the solubility, precipitation, and complexation of actinides in the brine solutions. Dissolved species concentrations also depend on solid phases to control solubility. The goal of the dissolved species study is to calculate valence-specific solubility for actinides, which are used directly in WIPP repository brine models for performance assessment. Based on the decision to backfill the disposal room, the scope of the work is reduced to focus on the chemically invariant point defined by the backfill (MgO) material.

Dissolved species parameters characterize solubility for oxidation states III, IV, V, and VI in Castile and Salado brines, with and without organic ligands. To achieve this goal, several specific tasks were implemented to investigate specific systems as analogs for the four oxidation states. Specific objectives related to these tasks were:

- To examine the solubility of Am(III) and Pu(III) in simulated brines under low carbonate conditions.
- To examine the solubility of U(VI) in simulated brines under low carbonate conditions.
- To examine the solubility of Th(IV) and U(IV) in carbonate solutions.
- To examine the solubility of Np(V) in K_2CO_3 media.
- To document the complexation of ligands with actinides in NaCl media.
- To review model parameters that represent solubility data.

4.2. Validity of Assumptions

The controlling assumption in the calculations is that the chemistry of the disposal room will be dominated by the saturation of the brines by brucite and magnesite. This condition will effectively keep the pH of the brine solutions basic. Thus, the pH calculated for the Castile and Salado brines is 9.24 and 8.69, respectively. An additional consequence of brucite and magnesite saturation is that any carbonate generated as a result of microbially produced carbon dioxide will be consumed. The calculations ignored the possibility of the formation of actinide carbonato complexes. Were these complexes to form, the effective solubility for some of the actinides in the disposal room brines would be larger than those under consideration. This is reflected in a calculation where the constraint of equilibrium with the magnesium minerals is removed. The calculated An(III) solubility increases by two orders of magnitude.

Weiner (1996) defined organic ligand concentrations based on proposed inventory of waste materials and the brine volume of the repository area. Bynum, in a meeting with the reviewers, clarified that the brine volume equals 75% of the remaining void volume of the repository area.

The actinides anticipated to be present in the disposal rooms in the +III oxidation state are Am and Pu. The median solubility of Am(III) under brucite/magnesite saturation is 3.8E-06 in Salado brine and 3.6E-06 in Castile brine (WP037105 and WP037106, respectively). The median solubility of Pu(III) under brucite/magnesite saturation is 3.8E-06 in Salado brine and 3.6E-06 in Castile brine (WP037109 and WP037108, respectively). Since the only +III actinides anticipated to be present in the disposal room are Am and Pu, an analysis of the calculated values for these elements will also be applicable to the general +III oxidation state model (WP037129 and WP037125).

Uranium and plutonium are the radionuclides present in the waste that have a potentially significant +VI chemistry. However, it is assumed that because of the reducing atmosphere anticipated in the disposal rooms, Pu(VI) will be reduced to lower oxidation states. Therefore, U(VI) is the only species at issue.

Solubilities for the IV and V oxidation states were calculated from thermodynamic codes refined and qualified for the WIPP Project. These codes assume that equilibrium thermodynamics applies and that the data represent equilibrium conditions. Thermodynamic parameters were obtained from literature sources and experimental studies.

A majority of the supporting documentation presents experimental data which varies as a function of time. Authors discuss test periods which extend for days, weeks, and even months to approach equilibrium conditions. According to Brush (1990), concentrations of actinides are assumed to reach equilibrium values instantaneously. Rates of dissolution depend on the chemical and physical nature of the solid phase. Since the waste form is heterogeneous and difficult to characterize and the concentrations of actinides are dilute, a study of the dissolution kinetics becomes extremely complex and difficult. A more appropriate statement of the assumption may be that the kinetics are not significant in terms of the brine concentration with respect to the transport mechanisms and contact times. Transport mechanisms in the vicinity of the disposal areas are slow, on the order of meters per days. Contact time between the brine and solids is long. Rates of dissolution are, therefore, assumed not significant since the brine has sufficient time to approach equilibrium, and equilibrium thermodynamics applies.

Actinides [Am(III), Th(IV), and Np(V)] serve as prototypes to validate thermodynamic models for actinides in the III, IV, and V oxidation states. Studies of Pu(IV) solubility pose a problem since this

oxidation state tends to form colloids. Although Th(IV) is more soluble than Pu(IV), the data introduce less uncertainty. Thorium, therefore, is used an analog for Pu(IV) and U(IV). Neptunium provides a good analog for Pu(V).

4.3. Alternate Interpretations

Code calculations set the precedence for determination of solubility parameters. Experimental studies provide data to define input variables to the code. An alternate approach focuses on empirical studies in which various actinides are added to raw or simulated brines. Simulated brine solutions, exposed to actinide solids, would ultimately reach a steady state concentration of actinides representative of the disposal room environment. A disadvantage of this approach, recognized by Brush (1990), is the complexity of the system, which diminishes the ability to obtain input variables to the code. The extent of the test program may become so complicated that it could not be implemented in a timely or cost effective manner. Empirical tests, however, should be implemented to verify that the results of the code (solubility in the simulated brines) adequately represent experimental results.

The nature of the value, a solubility parameter derived from available empirical data, does not lend itself to alternate interpretations. The important question to ask is what is the level of confidence associated with the value. This directly relates to the quality of the experimental data available and is addressed in Section 4.5.

4.4. Uncertainties and Consequences

There are no stated uncertainties associated with the solubility parameter. Instead, what is quoted is a range of solubilities for a given actinide under a given set of brine chemistry. The range spans two orders of magnitude and is adequate to describe the concentrations likely to be found in the disposal room. The solubility limits identify "source terms" for potential releases of actinides to the accessible environment. A conservative approach is presented, specifically with respect to the ranges (uncertainty), primarily because of the lack of experimental data for the effects of ligands on the solubility limits. Although the ranges bound the median, parameters consistently overestimate experimental values.

4.5. Appropriateness and Limitations of Methodology and Procedures

It is assumed that the repository environment will readily reduce metals as a result of excessive amounts of elemental iron and soluble iron (II). Table 4.2 lists the expected actinides and their proposed oxidation states in the disposal room.

Table 4.2. Oxidation States and Representative Actinides for Disposal Room Dissolved Species Studies

Oxidation	III	IV	V	VI
	Am	Th	Np	U
	Pu	Pu		
		U		

Experimental studies, published in the literature, document in detail procedures used to perform solubility tests. Three studies, Nitsche et al. (1994), Erten et al. (1994) and Rai (1995), illustrate a conventional and detailed procedure for solubility tests. The procedure consists of five basic activities:

1. Prepare the solutions.
2. Set up the experimental apparatus.
3. Conduct the experiment.
4. Analyze the materials (liquids and solids).
5. Analyze the results.

The Analysis Plan (Novak 1996) describes a four-step procedure "to render thermodynamic data into a consistent model and parameter framework that can be used to calculate actinide solubilities." Implementation of this procedure may require knowledge or experience with the software required to process the data.

Thermodynamic parameters are used to produce values of total actinide dissolved concentrations as a function of brine composition and chemical properties. These variables are incorporated into the CHEMDAT database file. Dissolved species parameters, characterized in terms of major actinides listed in table II, are input variables to the WIPP Compliance Certification Application. Accuracy of these parameters is specified at one order of magnitude, although code results compare more favorably with experimental data in brines without organic ligands. Experimental studies in brines that contain organic ligands have not been completed.

The solubility parameters for the actinides are calculated using calculated brine compositions. It would have been better to have measured actual brine composition under the conditions employed for the calculation (e.g., a Salado brine in equilibrium with halite, anhydrite, brucite and magnesite) in order to have a more realistic picture of the actual solvent characteristics. However, it is felt that the overriding consideration in solubility is not so much exact elemental composition as it is total ionic strength. The differences are not significant to the outcome of the calculation. In fact, the approach used to gage the relevance of the calculated solubility parameter is to compare it with literature values, when available, or

with other defendable experimentally determined values. These values were obtained in simulated brines. The compositions of the five brines used in the analysis are given in molarity in Table 4.3.

Table 4.3. Brine Comparison

ERDA6-HA-An-Mg		Spc-HA-An-Mg	Yamazaki et al. (1992)	Khalili et al. (1993)	Nitsche (1994)
H	97.6	96.8	111	111	111
O	49.7	48.8	55.6	55.7	55.7
Na	5.45	4.09	1.82	1.82	2.40
K	.096	.92	.767	.768	.031
Mg	.039	.444	1.44	1.44	.074
Ca	.012	.029	.015	.015	.029
Cl	5.25	5.82	5.39	5.39	2.48
S	.168	.52	.044	.044	.075
B	.062	.024	.02	.02	.004
Br	.011	.012	.005	.005	.001

It is clear that there are no significant differences in these compositions that would be an issue in determining the appropriateness of the calculated solubility parameter, especially in light of the two order of magnitude range that is used.

The use of Nd(III) as a surrogate for +(III) actinides is a well-established and accepted protocol. Khalili et al. (1993) have reported on the solubility of Nd in a brine of relevance to the WIPP project. At pH = 8.4, they found the Nd(III) solubility to be 2.3(+0.1)E-06. This value compares very favorably to the median calculated value of 3.8E-06 for Am(III) in the SPC-HA-An-Mg brine at pH = 8.7. In ERDA6-HA-An-Mg the calculated Am(III) solubility at pH = 9.2 is 3.6E-07. Khalili, et al. (1993) do not have a measurement at this pH. However, at pH = 10.4 the [Nd(III)] is below the detection limit of 3E-08. The Am(III) calculated value is intermediate between the measured value at pH = 8.4 and that at pH = 10.4. The value for the Am(III) solubility in Castile Formation brine is very acceptable based upon this analysis.

Americium(III) is used as an analog for Pu(III) (Brush, 1990). The analysis detailed above can be used to justify the calculated values for Pu(III), 3.8E-06 in SPC-HA-An-Mg and 3.6E-07 in ERDA6-HA-An-Mg. There is one report dealing with the measured solubility of Pu(III) in a synthetic brine at pH = 7.1 (Nitsche et al., 1994). They report a value of 1.63(+.52)E-07. The solubility of actinides generally decreases as the pH is raised. Therefore, the calculated values are at the high end of what would be anticipated based on the Nitsche data. They are not so high as to be unreasonable, however. The Nd

data, which were acquired at pH conditions more closely resembling those anticipated on the disposal room, should be weighed more heavily.

The final two calculated solubility values for the +III oxidation state are those in which a nonspecified +III species is dissolved in ERDA6-HA-An-Mg and SPC-HA-An-Mg (3.6E-07 and 3.8E-06, respectively). Since the only two +III radionuclides at issue are Am and Pu, the analysis above also applies to these general cases. The only other +III species possible in the disposal room is Fe(III). However, at pH values greater than 8, all of the iron will be precipitated as the very insoluble hydroxide and should not be a consideration.

Because no model exists from which to calculate a solubility parameter for U(VI) in Salado and Castile brines controlled by magnesium mineralogy, the values used in the PA were developed from a compilation of literature data. This approach is fine as long as the literature data are determined in conditions similar to what is anticipated in the disposal rooms.

Pashalidis et al. (1993) determined U(VI) solubilities under conditions of high (100%) and low (0.03%) carbon dioxide. Their values ranged from 1E-03 to 1E-06, at a pH of 4 to 5 for the low carbon dioxide environment. Their data were collected in solutions of low ionic strength, 0.1m. This value is vastly different from that of the disposal room brines. The Salado brine has a calculated ionic strength of 6.29m and the Castile brine, 4.99m. Ionic strength is an important parameter controlling actinide solubility, and the difference between the Pashalidis conditions and those of the disposal rooms requires that these values not be considered in the development of the U(VI) solubilities. Choppin calculated a U(VI) solubility of 1E-06, based on an ionic strength of zero (Hobart et al., 1996). He assigns a high uncertainty to this value.

Yamazaki et al. (1992) measured the solubility of U(VI) in the synthetic brine given above. The ionic strength of this brine is 3.8m. At pH = 10.4 under low carbonate conditions, they report a U(VI) solubility of 2E-07. Uranium solubility in 5.2m NaCl solution was determined by workers at Lawrence Livermore National Laboratory. At pH = 9.75 they report a solubility of 2.75E-06. This value was obtained after 119 days (Palmer 1996). There is no indication from the available data that the reaction was at steady state. A group at Argonne has studied the solubility of U(VI) in Castile brine in the absence of carbonate at pH = 10 (Reed et al., 1996). They have determined a value of 7.94(+1.2)E-07 for the U(VI) solubility after 149 days. The values of U(VI) solubility being submitted to the PA are 8.7E-06 in Salado brine (WP037113) and 8.8E-06 in Castile brine (WP037114). Based on the values determined at Lawrence Livermore, and especially the data from the Argonne group, the numbers being

submitted to the PA are valid. It follows that the values for the general +VI model of 8.7E-06 and 8.8E-06 (WP037132 and WP037128, respectively) are valid as well.

Thorium(IV) is chosen as the analog for the (IV) oxidation state actinides. As reported in The Chemical Thermodynamics of Actinide Elements and Compounds (1976), tetravalent thorium is the only stable ionic species in solution and at higher pH, dimer and polymer hydrolyzed species become increasingly important. Calculated concentrations of thorium in saturated brine solutions are several orders of magnitude more concentrated, as illustrated in Figure 1. Calculated thorium concentrations in synthetic brine solutions contacted with magnesium and calcium solids, however, correlate well with experimental data. Solubility parameters for the (IV) oxidation state correspond to values for the brine contacted with magnesium. Overall, (IV) oxidation state solubility parameters for neutralized brines (contacted with magnesium and calcium) compare with experimental data better than the uncertainty (order of magnitude), and represent a conservative value for performance assessment.

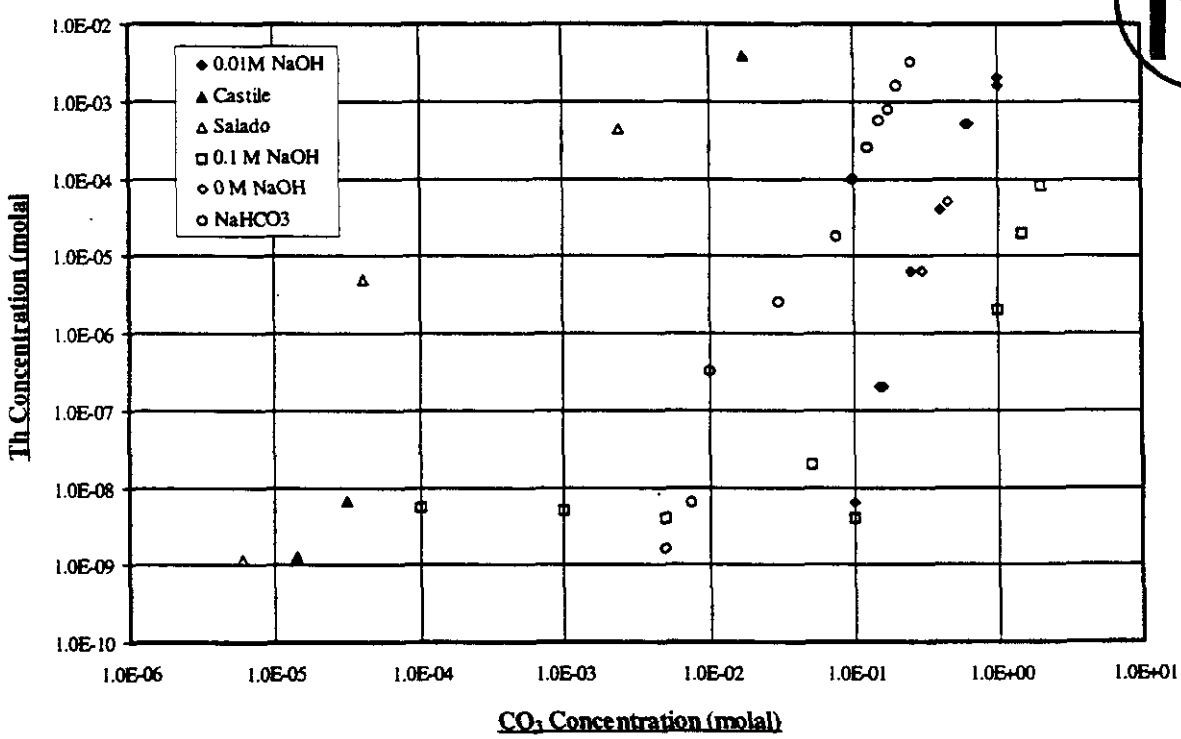

Figure 1. Comparison of Calculated Brine Solubility of Thorium with Experimental Data.

Thorium solubility exceeds uranium solubility by several orders of magnitude, and the predominate species is the $Th(CO_3)_5^{-6}$, consistent with the calculated data. Hydrolyzed species may play a greater role in the solubility under these conditions.

Neptunium(V) is chosen as the analog for the (V) oxidation state actinides. As described in The Chemical Thermodynamics of Actinide Elements and Compounds (1976), pentavalent neptunium occurs from the dissolution of and hydrolysis of crystals in acid solution. The (V) oxidation state, which exists as NpO_2^+, forms stable carbanato complexes, reported by Ueno and Saito (1975). Concentrations vary between E-04 and E-06 for carbonate systems and decrease as the strength of the chloride solution increases. Calculated neptunium concentration in synthetic brine solutions, including solutions contacted with magnesium and calcium solids, correlate well with a representative suite of experimental data from Novak (1995), Ueno and Saito (1975), and Neck et al. (1994), illustrated in Figure 2. These data illustrate similarity of neptunium solubility for sodium systems. Novak (1995) reports data which include samples run in triplicate to demonstrate consistency and to estimate experimental error. These data indicate an experimental error of approximately 3%, reasonable for solubility studies. Calculated concentrations decrease with the addition of magnesium and calcium. Solubility parameters for the (V) oxidation state correspond to values for the brine contacted with magnesium. Overall, (V) oxidation state solubility parameters compare with experimental data better than the uncertainty (order of magnitude) and represent a conservative value for performance assessment.

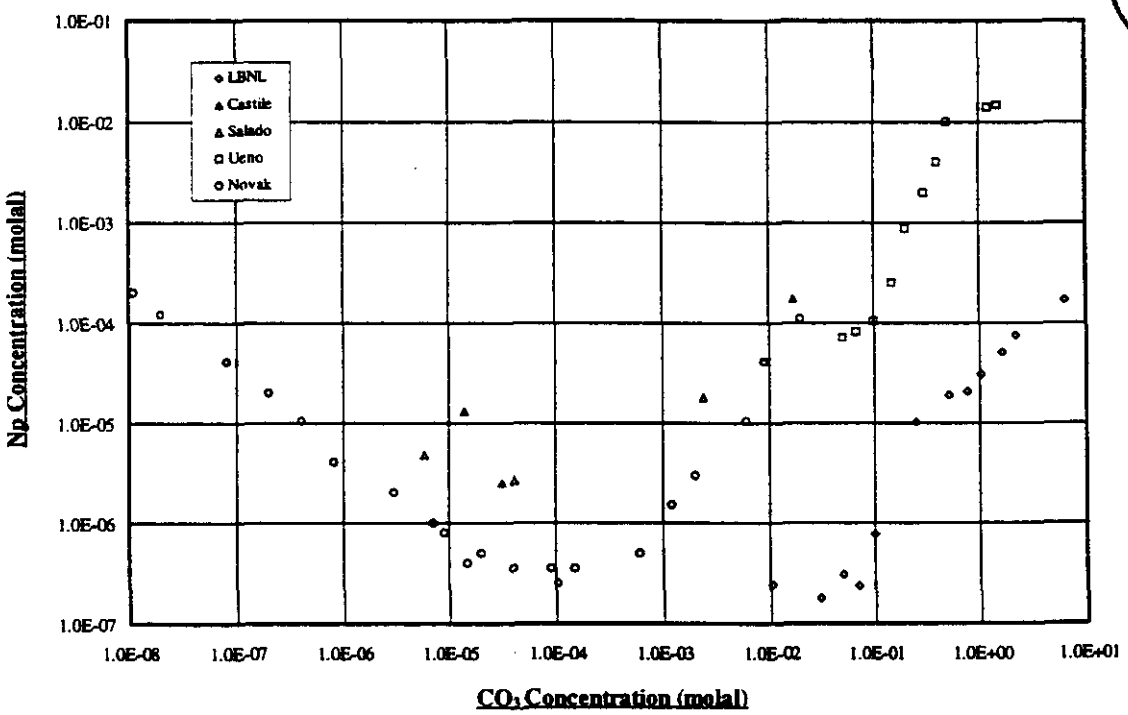

Figure 2. Comparison of Calculated Brine Solubility of Neptunium with Experimental Data.

A portion of the waste composition contains various organic ligands which influence the solubility of actinides. Since no experimental data are provided with respect to the effects of organic ligands on the

actinide solubility in brines, this review focuses on similarity between these procedures with those for actinide solubility in brines without ligands. Chemical potentials and interaction coefficients are determined from both extraction and solubility, illustrated by Novak and Roberts (1994). These experiments produce data that are added to the data base used to calculate solubility. A similar procedure is used to obtain thermodynamic data for interactions between actinides and organic ligands. These data are obtained from extraction studies. Procedures and data are reported in various monthly project documents produced by Choppin (Choppin 1994 through 1996). His students determine chemical potentials and interaction coefficients, which are used to calculate actinide solubilities in the presence of organic ligands. Since the procedures are equivalent with and without organic ligands, calculated solubilities most probably represent solution compositions. Nothing in Choppin's data suggest that calculated solubilities will be any less accurate than solubility in brines without organic ligands. Experimental studies should be conducted in brines containing organic ligands in order to validate calculated solubilities under these conditions. Currently, studies are in progress to determine the effects of organic ligands on the solubility of actinides in brine solutions. Data from these experiments were not available for this review.

Calculated solubility falls within the ranges set for the solubility parameters for actinides in brine solutions without organic ligands. Similar conditions are expected for solubility in brines with organic ligands, although experimental data are not available to verify this expectation. Ranges are set on the basis that studies with organic ligands have not been completed. Methodologies used to determine input variables to thermodynamic codes calculate solubility parameters that slightly overestimate experimental parameters in simulated brine solutions without organic ligands. Researchers currently use similar methodologies to produce input variables for systems with organic ligands. These data should also simulate experimental parameters.

4.6. Adequacy of Application

Documentation of solubility studies, conducted under the QA program, track implementation of experimental tests and qualification of the codes used to process data and calculate solubility of actinides in brines.

Researchers conduct experimental studies for individual species in simulated solutions in order to determine input parameters to thermodynamic codes. These codes calculate solubility parameters for both single-species systems and multicomponent systems, such as the Salado and Castile brine systems. Overall results of calculations for the multicomponent systems correlate with experimental data,

supporting observations that interactions potentially play a lesser role under these dilute conditions. Data presented in Figure 2 illustrate a consistency of data for neptunium based on experimental studies reported by various authors. An order of magnitude range demonstrates a conservative approach based on the lack of data to verify the effects of organic ligands. This approach coincides with a methodology of updating current input values in order to improve (refine) these values, noted by Novak (1995).

Calculated values for solubility parameters continue to improve as additional information and data become available to improve values for chemical potential and interaction coefficients. Calculated values for both Salado and Castile brines in contact with magnesium minerals coincide with solubility parameters tabulated in Table 4.4 for An(IV) and An(V) species. Only a portion of available information has been included in this report to illustrate consistency and adequacy of the data. Additional experimental data enhance the accuracy of the data, as well as the confidence that the data represent brine conditions.

The calculated values for the solubility of +III radionuclides of interest to the WIPP disposal room agree very well with the experimental data available. The approach of using equilibrium calculations to determine these values seems quite justified.

The numbers being submitted to the PA for the U(VI) solubility are consistent with the values determined by experiments.

4.7. Accuracy of Calculations

There are no uncertainty limits given for the calculated solubilities. This is rather unusual; however, their omission does not seriously compromise the value of the results, given that the acceptable range spans two orders of magnitude.

The An(VI) values being submitted to the PA are not calculated but, rather, are estimates based on the available empirical data. There is a paucity of U(VI) solubility data in high ionic strength solutions. Only three pieces of data were available to judge the confidence of the PA values, Yamazaki et al. (1992), the Lawrence Livermore experiments, and the Argonne work. More data upon which to evaluate the numbers would have been preferred, but it does not appear to exist.

Input to thermodynamic codes is determined from regression of experimental data. The codes estimate the solubility parameters. Verification of the accuracy of these calculations is beyond the scope of this

peer review, as well as being limited by access to the codes. Accuracy, however, is indirectly illustrated in the comparison presented in Figures 1 and 2.

Table 4.4. Comparison of Solubility Parameters and Brine Calculations

Material	Parameter	Median	SPC	ERDA6
SOLMOD3	SOLSOM	4.5E-06		
	SOLCOM	2.9E-06		
	SOLSIM	3.8E-06		
	SOLCIM	3.6E-07		
SOLSIM	SOLAM3	3.8E-06		
	SOLPUS	3.8E-06		
SOLCIM	SOLAM3	3.6E-07		
	SOLPU3	3.6E-07		
SOLMOD4	SOLSOM	4.4E-06	5.03E-06	
	SOLCOM	5.7E-07		6.50E-06
	SOLSIM	4.4E-06	4.98E-6	
	SOLCIM	6.0E-09		6.78E-09
SOLSIM	SOLPU4	4.4E-06	4.98E-6	
	SOLU4	4.4E-06	4.98E-6	
	SOLTH4	4.4E-06	4.98E-6	
SOLCIM	SOLPU4	6.0E-09		6.78E-09
SOLMOD5	SOLSOM	7.7E-06	8.75E-06	
	SOLCOM	7.4E-05		8.40E-05
	SOLSIM	2.3E-06	2.64E-06	
	SOLCIM	2.2E-06		2.53E-06
SOLMOD6	SOLSOM	1.0E-05		
	SOLCOM	7.0E-05		
	SOLSIM	8.7E-06		
	SOLCIM	8.8E-06		
SOLSIM	SOLU6	8.7E-06		
SOLCIM	SOLU6	8.8E-06		

4.8. Validity of Conclusions

Experimental data consistently fall below values defined for the solubility parameters. Several examples (both records and literature) illustrate the importance of interaction coefficients to adequately represent the solubility data. This program produced thermodynamic data to enhance calculated values and frequently demonstrated that the procedure produced data which confidently simulated experimental

conditions. These observations strengthened expectations that data to be obtained for the effects of organic ligands will also verify calculated values.

It is the opinion of the Panel that the values represented by the following reference numbers are valid and justifiable based on comparison with available experimental data and literature reports.

WP037110	WP037131	WP037130	WP037126	WP037127	WP037115
WP037111	WP037112	WP037105	WP037106	WP037108	WP037109
WP037113	WP037114	WP037125	WP037128	WP037132	WP037129

The following reference numbers are for solubility values in the presence of organic ligands. There are not sufficient experimental data available to justify these values based on comparison of published numbers. However, these calculated values were derived using the same procedures as those above. Since these calculations produced valid numbers for solubility ranges in the absence of organic ligands, we have no reason to doubt that the calculated solubilities in the presence of organics are outside the range of those found under disposal room conditions. The stability constants being input to the calculation are being determined by Choppin, a researcher known for producing quality experimental results. The Panel's opinion is that the solubility parameters represented by the following reference numbers are valid for use in the PA.

WP037122	WP037116	WP037120	WP037121	WP037124	WP03118
WP037117	WP037123				

4.9. Dissenting Views

None.

5.0 CONCLUSIONS

The Panel carefully reviewed each of the 26 parameters submitted for peer review. The details of the review and the individual conclusions for each parameter are presented in Section 4. In summary, the Panel agrees with the 26 values (listed below) being submitted to the WIPP PA for actinide solubility under repository conditions.

- Inorganic Chemistry
  - Am(III) in Salado and Castile brines
  - Pu(III) in Salado and Castile brines
  - General An(III) in Salado and Castile brines
  - Th(IV) in Salado brine
  - U(IV) in Salado brine
  - Pu(IV) in Salado and Castile brines
  - General An(IV) in Salado and Castile brines
  - General An(V) in Salado and Castile brines
  - U(VI) in Salado and Castile brines
  - General An(VI) in Salado and Castile brines
- Organic Chemistry
  - General An(III) in Salado and Castile brines
  - General An(IV) in Salado and Castile brines
  - General An(V) in Salado and Castile brines
  - General An(VI) in Salado and Castile brines

Determination of actinide solubilities in high ionic strength media is an experimentally difficult procedure. The Panel found the quality of the experimental data to be quite good and would like to commend the responsible scientists for a job well done.

6.0 SIGNATURES

I, by signature, acknowledge that I concur with the findings and conclusions within my area of assignment and expertise of this Waste Form and Disposal Room Peer Review Report.

Duane Hrncir, Ph.D.
WF&DR Panel Chairman

Inorganic Chemistry

Robert Knecht, Ph.D.
WF&DR Panel Member

Chemical Engineering

7.0 PEER REVIEW MEMBERS AND ACCEPTABILITY

Duane C. Hrncir, Panel Chairman, is an Associate Professor of Chemistry and former Head of the Chemistry Programs at the University of Texas at Dallas. He holds a Ph.D. in inorganic chemistry from Texas A&M University, an M.S. in inorganic chemistry from the University of Massachusetts at Amherst, and a B.S. in Chemistry from the University of Alabama. He has 24 years of experience in research involving the interactions of metals with organic molecules. This research includes the interactions of metals and organics with mineral surfaces and the controls these interactions have on speciation and transport in aquatic environments. His current area of research involves laboratory and field experiments to study the photoreduction of metal colloids in acidic and neutral surface waters and the control this process exerts over the biogeochemistry of the stream system. He is the author of 40 publications in peer-reviewed scientific journals and made numerous presentations at national and international scientific meetings.

Robert D. Knecht, Panel Member, is a Research Professor at the Colorado School of Mines. Dr. Knecht holds a Ph.D. and an M.S. in Chemical-Petroleum Refining Engineering from the Colorado School of Mines, as well as a Ph.D. in Metallurgical Engineering. His research interests include conventional recovery and separation technologies to treat environmental and municipal wastes. He has served as a consultant, providing technical and management assistance to the energy, minerals, and wastes industries. He has supervised a project management support team to assist the U.S. Geological Survey with management requirements for the Yucca Mountain Project. Additional consulting work includes the extraction of uranium from acidic solutions, the recovery of synthetic fuels from various feed stocks, and the design of a research program to simulate the leaching of heavy metals from spent catalyst feed stocks.

8.0 REFERENCES

8.1. Cited References

Brush, L.H., 1990. Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant. SAND90-0266. Albuquerque, New Mexico: Sandia National Laboratory.

Choppin, G. R. Monthly Progress Report for April 1996 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 1 May 1996.

Choppin, G. R. Monthly Progress Report for March 1996 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 1 April 1996.

Choppin, G. R. Monthly Progress Report for February 1996 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 1 March 1996.

Choppin, G. R. Monthly Progress Report for January 1996 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 30 January 1996.

Choppin, G. R. Monthly Progress Report for December 1995 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 30 December 1995.

Choppin, G. R. Monthly Progress Report for November 1995 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 30 November 1995.

Choppin, G. R. Monthly Progress Report for October 1995 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 31 October 1995.

Choppin, G. R. Monthly Progress Report for September 1995 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 1 October 1995.

Choppin, G. R. Monthly Progress Report for August 1995 to Dr. Robert Moore, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 25 August 1995.

Choppin, G. R. Monthly Progress Report for July 1995 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 4 August 1995.

Choppin, G. R. Monthly Progress Report for June 1995 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 28 June 1995.

Choppin, G. R. Monthly Progress Report for April 1995 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 28 April 1995.

Choppin, G. R. Monthly Progress Report for March 1995 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 31 March 1995.

Choppin, G. R. Monthly Progress Report for February 1995 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 27 February 1995.

Choppin, G. R. Monthly Progress Report for January 1995 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 31 January 1995.

Choppin, G. R. Monthly Progress Report for December 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 29 December 1994.

Choppin, G. R. Monthly Progress Report for October 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 31 October 1994.

Choppin, G. R. Monthly Progress Report for September 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 30 September 1994.

Choppin, G. R. Monthly Progress Report for August 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 31 August 1994.

Choppin, G. R. Monthly Progress Report for July 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 27 July 1994.

Choppin, G. R. Monthly Progress Report for May 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 31 May 1994.

Choppin, G. R. Monthly Progress Report for April 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 28 April 1994.

Choppin, G. R. Monthly Progress Report for March 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. March 1994.

Choppin, G. R. Monthly Progress Report for February 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. February 1994.

Choppin, G. R. Monthly Progress Report for January 1994 to Dr. Craig F. Novak, Sandia National Laboratories, SWCF/RNC, SWF 1.1.1.1.4.1.1.5.1.2, Contract #AH-5590. 28 January 1994.

Erten, H.N., A.K. Mohammed, and G.R. Choppin, 1994. "Variation of Stability Constants of Thorium and Uranium Oxalate Complexes with Ionic Strength." Radiochimica Acta, Vol 66/67: 123-128.

Hobart, D.E., C.J. Bruton, F.J. Millero, I-M. Chou, K.M. Trauth, and D.R. Anderson, 1996. "Estimates of the Solubilities of Waste Element Radionuclides in Waste Isolation Pilot Plant Brines: A Report by the Expert Panel on the Source Term," SAND96-0098.

Hobart, D.E. and R. Moore, 1996. "Analysis of (UVI) Solubility Data for WIPP Performance Assessment," Memorandum, March 28, 1996.

Khalili, F.I., V. Symeopoulos, J-F. Chen, and G.R. Choppin, 1993. "Solubility of Nd in Brine," Radiochimica Acta, 66, pp. 51-54.

Neck, V., J.I. Kim, and B. Kanellakopulos, 1994. "Thermodynamisches Verhalten von Neptunium (V) in Konzentrierten NaCl und NaClO4 Losungen," KfK5301, Institut fur Nukleare Entsorgungstechnik, Institut fur HeiBe Chemie, Kernforschungezentrum Karlsruhe.

Nitsche, H., K. Roberts, R. Xi, Y. Prussin, K. Becraft, I. Al Mahamid, H.B. Silber, S.A. Carpenter, R.C. Gatti, and C.F. Novak, 1994. "Long Term Plutonium Solubility and Speciation Studies in a Synthetic Brine." Radiochimica Acta, Vol 66/67: 3-8 (also SAND93-3846C).

Novak, C.F., 1996. Analysis Plan: The Interpretation of Chemical Data to Obtain Thermodynamic Parameters, WIPP document, Sandia National Laboratories, Albuquerque, NM.

Novak, C.F., 1995. "Revised Analysis of LBNL Data of the Solubility of Np(V) in K2CO3 Media," memorandum to I. Al Mahamid, 17 October 1995.

Novak, C.F. and K.E. Roberts, 1994. *Thermodynamic Modeling of Neptunium (V) Solubility in Na-CO3-HCO_3-Cl-ClO_4-H-OH-H_2O Electrolytes.* SAND94-0805C. Albuquerque, New Mexico: Sandia National Laboratories. Presented at the 1994 Scientific Basis for Nuclear Waste Management Symposium, 21-26 October 1994, Kyoto, Japan..

Palmer, C.E.A, 1996. "Private Communication to Vann Bynum."

Pashalidis, I., W. Runde, and J.I. Kim, 1993. AA Study of Solid-Liquid Phase Equilibria of Pu(VI) and U(VI) in Aqueous Carbonate Systems.," Radiochimica Acta, 66, p. 141.

Rai, D., A.R. Felmy, D.A. Moore, and M.J. Mason, 1995. "The Solubility of Th(IV) and U(IV) Hydrous Oxides in Concentrated NaHCO3 and Na2CO3 Solutions." Mat. Res. Soc. Symp. Proc., Vol 353: pp. 1143-1150.

Reed, D.T., D.G. Wygmans, and M.K. Richmann, 1996. "Stability of Pu(VI), Np(VI), and U(VI) in Simulated WIPP Brine," Argonne National Laboratory Interim Report.

The Chemical Thermodynamics of Actinide Elements and Compounds, International Atomic Energy Agency, Vienna, Austria, 1976.

Ueno, K. and A. Saito, 1975. "Solubility and Absorption Spectra of a Carbonato Complex of Pentavalent Neptunium," Radiochemical and Radioanalytical Letters, Vol 22, no 2, 127-133.

Wang, Y., 1996. "Define Chemical Conditions for FMT Actinide Solubility Calculations." memorandum to M.D. Siegel, 18 March 1996.

Weiner, R.F. 1996. "Dissolved Ligand Concentration." Memorandum to C.F. Novak. 27 March 1996.

Yamazaki, H., B. Lagerman, V. Symeopoulos, and G.R. Choppin, 1992. "Solubility of Uranyl in Brine," High Level Radioactive Waste Management Proceedings of the Third International Conference, Las Vegas, NV, April 12-16, 1992.

8.2. Additional References

Geochimica et Cosmochimica Acta, Vol. 48 (1984), No. 4.

Geochimica et Cosmochimica Acta, Vol. 50 (1986), No. 12.

Geochimica et Cosmochimica Acta, Vol. 51 (1987), No. 5.

High Level Radioactive Waste Management, Proceedings of the Third International Conference.

Journal of Alloys and Compounds, Vol. 202 (1993).

Journal of Chemical and Engineering Data, Vol. 33 (1988), No. 3.

The Journal of Chemical Thermodynamics, Vol. 3 (1971).

The Journal of Physical Chemistry, Vol. 77 (1973), No. 19.

The Journal of Physical Chemistry, Vol. 96 (1992), No. 26.

Journal of Solution Chemistry, Vol. 6 (1977), No. 11.

Journal of Solution Chemistry, Vol. 20 (1991), No. 9.

Journal of Solution Chemistry, Vol. 21(1992), No. 5.

Journal of The Chemical Society: "Dalton Transactions," Royal Society of Chemistry, 1984.

Radiochemical and Radioanalytical Letters, Vol. 22 (1975), No. 1.

Radiochimica Acta, Vol. 52/53 (1991), Part I.

Radiochimica Acta, Vol. 55 (1991), No. 4.

Radiochimica Acta, Vol. 61 (1993), No. 3/4.

Radiochimicia Acta, Vol. 69 (1995), Issue 1.

Radiochimicia Acta, Vol. 69 (1995), Issue 3.

Choppin, G.R. and J.N. Mathur, 1990. "Hydrolysis of Actinyl (VI) Cations."

Drever, J.I., 1982. "The Geochemistry of Natural Waters."

Fanghanel, T., V. Neck, and J.I. Kim, 1995. "Thermodynamics of Neptunium (V) in Concentrated Salt Solutions: II. Ion Interaction (Pitzer) Parameters for Np (V) Hydrolysis Species and Carbonate Complexes."

Goldberg, R.N., 1979. "Evaluated Activity and Osmotic Coefficients for Aqueous Solutions: Bi-Univalent Compounds of Lead, Copper, Manganese, and Uranium." J. Phys. Chem. Ref. Data, Vol. 8, No. 4, pp 1005-1050.

Grenthe, I. (Chairman), 1992. "Chemical Thermodynamics of Uranium," Nuclear Energy Agency Organisation for Economic Co-operation and Development.

Harvie, C.E., N. Moller, and J.H. Weare, 1984. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O System to High Ionic Strengths at 25°C."

Martell, A.E. and R.M. Smith, 1977. Critical Stability Constants, Vol. 3: Other Organic Ligands".

Nick, V., T. Fanghanel, G. Rudolph, and J.I. Kim, 1995. "Thermodynamic of Neptunium (V) in Concentrated Salt Solutions: Chloride Complexation and Ion Interaction (Pitzer) Parameters for the NpO_2^+ Ion."

Pitzer, K.S., 1991. "Activity Coefficients in Electrolyte Solutions," 2nd Edition.

Rai, D., A.R. Felmy, S.P. Juracich, and L. Rao, 1994. "Estimating the Hydrogen Ion Concentration in Concentrated NaCl and Na_2SO_4 Electrolytes. "Sand 94-1949.

Robinson, R.A. and R.H. Stokes, 1959. "Electrolyte Solutions."

Robinson, R.A. and R.H. Stokes, 1959. "Electrolyte Solutions: The Measurement and Interpretation of Conductance, Chemical Potential and Diffusion in Solutions of Simple Electrolytes," 2nd Ed.

Silva, R.T. (Chairman), 1995. "Chemical Thermodynamics of Americium: Nuclear Energy Agency Organisation For Economic Co-Operation and Development."

Sombert, C.G., 1991. "Scientific Basis for Nuclear Waste Management XV," Materials Research Society Symposium Proceedings, Vol. 257.

Worley, T.J., 1992. "EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide and Related Documentation Version 7.0."

Worley, T.J. and S.A. Daveler, 1992. "EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, Users Guide and Related Documentation, Version 7.0."

Determination of Peer Review Member Independence Form

_____ Currently employed by DOE or DOE Contractor? Yes/No

_____ Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

_____ Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: _____

Date: 5/7/96

Peer Review Manager Approval: _____ John A. Thies 5/28/96 Date

Determination of Peer Review Member Independence Form

_____ Currently employed by DOE or DOE Contractor? Yes/No
_____ Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

I have had & have now a contract through DOE Rocky Flats to study (research) SO_x & NO_x treatment for flue-gas stream. Current project will terminate Feb 28, 1997.

_____ Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Robert Thurk

Date: May 7, 1996

Peer Review Manager Approval: John A. Thies 5/28/96 Date

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PEER 7 - Natural Barriers Data Qualification Peer Review

Title: NATURAL BARRIERS PEER REVIEW (NBPR) PLAN

C10

(Assistant Manager, Office of Regulatory Compliance, Carlsbad Area Office)

Date: 6/25/96

1. INTRODUCTION

This Natural Barriers Review (NBPR) Plan describes the peer review and documentation the Waste Isolation Pilot Plant (WIPP) Project will use to ensure that the data used in the models describing waste form and disposal room for disposal room closure and chemistry in the performance assessment (PA) are qualified for use in the demonstration of compliance.

1.1 BACKGROUND

In accordance with the regulatory requirements specified in 40 CFR Part 191 and implemented in accordance with the criteria specified in 40 CFR Part 194, section 194.22 (b), "Any compliance application shall include information which demonstrates that data and information collected prior to the implementation of the quality assurance program required pursuant to paragraph (a) (1) of this section (194.22) have been qualified in accordance with an alternate methodology, approved by the administrator or the administrator's authorized representative, that employs one or more of the following methods: peer review, conducted in a manner that is compatible with NUREG-1297, "Peer Review for High-Level Nuclear Waste Repositories"; corroborating data; confirmatory testing; or a quality assurance program that is equivalent in effect to ASME NQA-1-1989 edition, ASME NQA-2a-1990 addenda, part 2.7, to ASME NQA-3-1989 edition (excluding Section 2.1 (b) and (c) and Section 17.1)." The DOE has generally opted to employ the peer review methodology to qualify existing data that it cannot demonstrate was collected in accordance with a quality assurance program that was equivalent to the quality assurance defined above. Accordingly, a peer review will be conducted to confirm the adequacy and completeness of data utilized to define parameter values as applied in conceptual models and scenarios that have been determined to be significant to waste containment. To facilitate review of the data, the data qualification peer reviews have been divided into the following three associated waste containment subsystems:

- Natural barriers (Salado and non-Salado flow and transport);
- Engineered systems (rock mechanics and shaft/borehole seals); and
- Waste form and the disposal room.

Sandia National Laboratories (SNL) is responsible for the selection and development of conceptual models that reasonably define the WIPP containment system, and for the identification and development of mathematical models, numerical models, and computer codes utilized to assess the performance of the WIPP containment for the statutory confinement period. SNL is responsible for

identifying data for which it cannot provide assurance that the information was collected under a qualified quality assurance program (as defined above). These data will then be reviewed under a peer review process conducted in
accordance with NUREG-1297. Therefore, to meet the regulatory requirements cited above, this peer review on natural barriers for Salado and non-Salado flow and transport will assess the qualification of data used in performance assessment for the WIPP.

1.2 PURPOSE

The purpose of this WIPP peer review plan is to define the peer review process that will be conducted to *determine if (Rev. 1)* existing unqualified natural barriers subsystems data and information *are qualified to be (Rev. 1)* used in the demonstration of compliance. As stated above, the DOE has determined the peer review process to be the most appropriate method to demonstrate that all natural barriers subsystems are qualified for use in the demonstration of compliance. These peer reviews will be conducted in accordance with the requirements of NUREG-1297 that state, "A peer review is a documented, critical review performed by peers who possess qualifications at least equal to those of the individuals who conducted the original work. These individuals must be independent of the work being reviewed; independence from the work reviewed means that the peer, a) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed."

1.3 SCOPE

This NBPR Plan describes the peer review process that the DOE Carlsbad Area Office (CAO) will utilize for the review of those existing data and information that form the basis for determining the parameter values of the conceptual models that form the natural barriers subsystems. The peer review will be an in-depth critique of assumptions, alternate interpretations, methodology, and acceptance criteria employed, and of the conclusions drawn in the original work. This NBPR Plan defines the approach, methods, criteria, schedules, deliverables, and resources required for conducting the NBPR to confirm: 1) the adequacy and completeness of the data; and 2) the data and information are qualified for use in the demonstration of compliance. See Attachment A for a description of the data to be reviewed and its intended use in PA.

The conceptual models and codes to be used in the PA of the natural barriers subsystem related to Salado and non-Salado flow and transport include:

Natural Barriers - Salado and Non-Salado Flow and Transport

Model	Code
Disposal System Geometry	BRAGFLO
Culebra Model Geometry	SecoFL/2D/SecoTP2D
Repository Fluid Flow	BRAGFLO
Salado	BRAGFLO
Impure Halite	BRAGFLO
Salado Interbeds	BRAGFLO
Disturbed Rock Zone	BRAGFLO
Actinide Transport (Salado)	BRAGFLO
Units Above the Salado	BRAGFLO
Dissolved Actinides (Culebra)	SecoTP2D

Colloidal Actinides (Culebra)	SecoTP2D
Exploration Boreholes	BRAGFLO/GRIDFLOW
	CUTTINGS/PANEL
Cuttings/Caving	CUTTINGS/PANEL
Spallings	CUTTINGS/PANEL
Blowout	CUTTINGS/PANEL
Castile and Brine Reservoir	CUTTINGS/PANEL
Multiple Intrusions	CUTTINGS/PANEL
Climate Changes	CUTTINGS/PANEL

Existing unqualified data and information which was utilized to establish the parameter values will form the basis of this NBPR.

2. PEER REVIEW PLANNING AND IMPLEMENTATION

2.1 APPROACH

The DOE-CAO has prepared the "Office of Regulatory Compliance (ORC) Team Procedure for Peer Review" (TP 10.5) to document the approach for conducting the peer review process. The NBPR Panel will conduct the peer review activities for the qualification of data in accordance with TP 10.5, this Plan and IDI 1.0.

Similarly, SNL has prepared a procedure to provide the data and information necessary to support peer review of the qualification of data. The SNL data packages to be provided to the NBPR Panel will include: 1) identification of the applicable conceptual model parameter(s); 2) assignment of a parameter value or range of values; 3) description of the source of the data used to construct the parameter value or ranges of values; 4) a description of the process whereby the data was scaled up to parameter value(s); and 5) designation of data qualification status.

2.1.1 DATA USED IN THE DEMONSTRATION OF COMPLIANCE

The peer review of existing unqualified SNL data and information (see Attachment A) is to confirm and document its adequacy and completeness. The data and information qualification peer review will confine itself strictly to providing this confirmatory information.

2.1.2 COMPOSITION OF PEER REVIEW PANEL

The NBPR Panel will be composed of a minimum of three individuals who meet requirements identified in TP 10.5. The duration of the NBPR Panel review process is expected to last between three to six weeks. The NBPR Panel may include up to two members of the Conceptual Model Peer Review Panel. The peer review selection committee will appoint the remaining panel member(s) based on his/her technical expertise which will be equivalent to that required for the original work. Experience areas to be represented on this panel include geohydrology and/or geology.

Through a formal orientation process, each panel member will become familiar with the WIPP containment system and the basis of the engineered systems models, data, parameters and information that describe the containment system. In addition, panel members will be provided with a basic description of how the models are represented in numerical models, algorithms, and codes. The peer reviewers will be familiarized with the parameter inputs to the PA codes and the results of prior PAs, sensitivity analyses, and critical comments from previous reviews. Each peer reviewer will be selected, oriented, and trained in accordance

with approved procedures.

2.1.3 LOGISTICS AND MANAGEMENT

When the NBPR convenes to perform the peer review process, the intent is to have all the data packages accessible for review. However, not all information necessary to support peer review of the qualification of data for the natural barriers may be available at the beginning of the review. Therefore, it may be necessary to conduct the NBPR in a phased manner, depending upon the availability of information.

2.2 METHODOLOGY

The NBPR will follow the methodology provided in NUREG-1297 as augmented by the specific requirements contained in 40 CFR Part 194.22. The purpose for conducting a peer review of data associated with this WIPP subsystem is to ensure that those data that cannot be qualified by virtue of their collection under a QA program (equivalent in effect to ASME NQA-1-1989 edition, ASME NQA-2-1990 addenda, part 2.7, ASME NQA-3-1989 edition [excluding Section 2.1 (b) and (c), and Section 17.1]) are qualified for use in the demonstration of compliance. To facilitate the conduct of the peer review, a checklist containing potential areas of review is included in this plan as Attachment B. The basis of the peer review will be to determine the adequacy and completeness of specific unqualified data used to demonstrate compliance. Adequacy criteria are provided in Section 2.3.

2.3 ADEQUACY CRITERIA

Adequacy of data associated with the conceptual models that nominally comprise the natural barriers subsystem will be based on the peer review panel's determination that these data meet commonly accepted technical and scientific standards. Criteria utilized to make this determination include:

- Adequacy of requirements and criteria;
- Validity of assumptions;
- Alternate interpretations as appropriate;
- Uncertainty of results and consequences if wrong;
- Appropriateness and limitations of methodology and procedures;
- Adequacy of application;
- Accuracy of calculations; and
- Validity of conclusions.

In evaluating the existing data, the peer review panel shall also consider the following:

- The sources of the parameters and data, e.g., professional judgment, published source material, field tests, laboratory experiments, etc.;
- The processes used to produce the parameters from data are appropriate for the intended use; and

- The assumptions, calculations, extrapolations, interpretations, methods, and conclusions pertinent to the data are appropriate for the development of parameters used as input to the WIPP PA and are traceable.

2.4 SCHEDULE

The PR Manager, working closely with SNL, has developed a preliminary schedule that provides the necessary information on an "as available" basis. Flexibility is required by all supporting organizations, (i.e., DOE-CAO, SNL, the PR Manager, staff and panel members) to accommodate the peer review schedule and any changes made due to uncertainty in the timing of data availability. Attachment C contains a schedule of NBPR activities and milestones in accordance with the Peer Review Management Plan. This schedule will serve as the baseline schedule from which requested schedule deviations will be evaluated and approved, if appropriate. Revisions to the baseline schedule will not require revision to this plan but will be attached to the plan by reference.

2.5 DELIVERABLES

A final report for the NBPR will be submitted to DOE-CAO. A list of mandatory topics and suggested outline for the final NBPR report is provided in Attachment D. This outline may be utilized to guide the review of each data package to ensure adequate review of the data packages.

3. QUALITY ASSURANCE

The NBPR process will be conducted in a controlled manner and in compliance with TP 10.5.

4. RECORDS MANAGEMENT

Records and documents generated as a result of peer review activities defined in this peer review plan are identified in the CAO Team Procedure, TP 10.5. NBPR records will be assembled and maintained in accordance with the Peer Review Management Plan and the Informatics Desk Instruction, IDI-1.0. Upon completion of the peer review process, a complete set of NBPR records will be delivered to CAO. Ultimately, peer review records will be dispositioned in accordance with DOE-CAO records management requirements.

5. DOCUMENT CONTROL

All plans, procedures, and other documents which require document control will be handled in accordance with applicable DOE-CAO controlled document procedures (MP 4.4).

ATTACHMENT A

PEER REVIEW PANEL DATA PACKAGE DESCRIPTIONS

DATA	INTENDED USE
DRZ Compressibility	Salado
Undisturbed Halite Pressure	Salado
Undisturbed Halite Compressibility	Salado
Undisturbed Halite Permeability	Salado
Undisturbed Anhydrite Pressure	Salado
Undisturbed Anhydrite Compressibility	Salado
Brine Salt Mass Fracture	Salado
Brine Viscosity	Salado
Brine Density	Salado
Brine Compressibility	Salado
Castile Brine Reservoir Rock Compressibility	Non-Salado/Castille
Castille Brine Reservior Porosity	Non-Salado Castile
Castile Brine Reservoir Permeability	Non-Salado/Castile
Castile Brine Reservior Pressure	Non-Salado/Castile
Castile Brine Reservoir Volume	Non-Salado/Castile
Non-Salado Bulk Compressibility	Units Above the Salado
Non-Salado Effective Porosity	Units Above the Salado

Non-Salado Presure	Units Above the Salado
Non-Salado Permeability	Units Above the Salado
Culebra Permeability	Units Above the Salado
Culebra Index	Units Above the Salado
Culebra Transmissivity	Units Above the Salado
Culebra Thickness	Units Above the Salado
Culebra Storativity	Units Above the Salado
Culebra Fluid Density	Units Above the Salado
Culebra Steady-State Heads	Units Above the Salado
Culebra Transient Pressures	Units Above the Salado
Culebra Dolomite Grain Density	Units Above the Culebra
Effective Culebra Thickness	Units Above the Salado
Advective Porosity	Units Above the Salado
Half Matrix Block Length	Units Above the Salado
Diffusive (Matrix) Porosity	Units Above the Salado
Diffusive (Matrix) Tortuosity	Units Above the Salado

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ATTACHMENT B

SUGGESTED METHODS CHECKLIST

PEER REVIEW CHECKLIST	
STUDY/EXPERIMENT IDENTIFICATION	
	COMMENTS
1.0 Scientific Technical Items	
1.1 Were the technical objectives clearly stated in documents accompanying the data?	
1.2 Are all the stated objectives addressed by the data?	
1.3 Was there any test-to-test interference and/or was the impact of test-to-test interference on results adequately evaluated?	
1.4 Were the tests performed in accordance with: a) nationally recognized standards?	
b) modified recognized standards or specially prepared test procedures?	
c) modified recognized standards or specially prepared test procedures?	
d) If so, are they documented in sufficient detail to be repeatable?	
e) Were they justified, evaluated, and approved by a cognizant individual/organization?	
1.5 Were the test procedures correctly implemented?	
1.6 Were testing irregularities and interruptions described?	
1.7 Was documentation of corrective actions sufficiently detailed?	
1.8 Were data reduction processes appropriate for the objectives of the test?	
1.9 Is the reduced data a true representation of all raw data acquired?	
1.10 Are the interpretations well supported by the data?	
1.11 Is the data quality adequate?	
a) Does the age of the data affect the results?	
b) Were the analytic methods used adequate?	
c) Were detection limits adequate?	
d) Is the range of uncertainty associated with each measurement adequate to satisfy the objectives of the test?	
e) Is the uncertainty associated with the cumulative data low enough to make a decision?	
f) Has invalid data been identified?	
g) Has valid data been characterized by providing qualitative or quantitative statements as to the validity and use?	
h) Is there a redundancy in measurements that provide checks of/on the data?	
1.12 Were the number of data points taken enough to provide an adequate level of confidence in the results?	
1.13 Is there internal consistency between the sets of data for similar tests?	
1.14 Are the data complete?	
1.15 Can credible blocks be improved, or supported by: a) correlation with complementary or confirmatory data?	
b) additional work?	
1.16 Is any source of confirmatory data identified in database documents?	

1.17 Is the data good enough to support the intended use?	
2.0 Summary of Conclusions	
2.1 Did the data meet adequacy of requirements and criteria?	
2.2 Did the data show validity of assumptions?	
2.3 Were there alternate interpretations of the data?	
2.4 Was there a discussion of uncertainty of results and consequences?	
2.5 Was there appropriateness and limitations of methodology and procedures?	
2.6 Was adequacy of application demonstrated for the data?	
2.7 Was the accuracy of calculations demonstrated?	
2.8 Was the validity of conclusions demonstrated?	
2.9 Were the sources of the parameters and data considered in evaluating the existing data?	
2.10 Were the processes used to produce the parameters from the data appropriate for the intended use?	
2.11 a) Were the assumptions, calculations, extrapolations, interpretations, methods, and conclusions pertinent to the data appropriate for the development of parameters used as input to the WIPP PA?	
b) Were they traceable?	

ATTACHMENT C

NATURAL BARRIERS PEER REVIEW SCHEDULE

	DRAFT	FINAL
NBPR Plan	3/11	3/29
PR Panel Assigned	NA	4/29
NBPR Data Package to PR Manager	4/22	4/29
Initiate NBPR	NA	5/6
Complete NBPR	NA	6/14
Submit NBPR Report	6/14	6/28

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ATTACHMENT D

PEER REVIEW REPORT OUTLINE

Executive Summary

1. Introduction

2. Purpose

3. Description of Work Performed

4. Evaluation Work Performed
   - A. Adequacy of Requirements and Criteria
   - B. Validity of Assumptions
   - C. Alternate Interpretations
   - D. Uncertainty of Results and Consequences if Wrong
   - E. Appropriateness and Limitations of Methodology and Procedures
   - F. Adequacy of Application
   - G. Accuracy of Calculations
   - H. Validity of Conclusions

5. Conclusions

6. Dissenting Views

7. Summary

8. Signatures

9. Peer Review Members and Acceptability

NATURAL BARRIERS DATA QUALIFICATION

PEER REVIEW REPORT

FINAL REPORT

WASTE ISOLATION PILOT PLANT NATURAL BARRIERS DATA QUALIFICATION PEER REVIEW REPORT

A Peer Review
Conducted By

Florie Caporuscio, Paul L. Cloke, Darrel E. Dunn,
David A. Sommers, Charles Wilson, Chuan-Mian Zhang

for

U.S. Department of Energy
Carlsbad Area Office
Office of Regulatory Compliance

August 1996

FOREWORD

The Environmental Protection Agency promulgated "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule" in Code of Federal Regulations, Title 40, Part 194 (40 CFR Part 194) on February 9, 1996. The 40 CFR Part 194 regulation prescribes three specific peer reviews and also provides the opportunity for the Department of Energy to use peer reviews, conducted in accordance with NUREG 1297, as a means of qualifying data and information for use in the demonstration of compliance.

This report contains the results of a peer review of specific natural barriers data used in the demonstration of WIPP compliance with 40 CFR Part 194. To ensure the independence of this review, the Department of Energy has directed the assignment of an independent contractor to administratively manage the peer review activities. Peer reviewers were selected based on their demonstrated independence from the work being reviewed and their technical expertise in the subject matter to be reviewed. The peer review panel members collectively possess an appropriate spectrum of knowledge and experience in the subject matter reviewed.

This peer review was conducted in compliance with the quality assurance requirements as defined in 40 CFR Part 194.

ACRONYMS

CCA	Compliance Certification Application
CDF	cumulative distribution function
CH	contact-handled
DC	direct current
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
DST	drill stem tests
EPA	U.S. Environmental Protection Agency
GTFM	Graph Theoretical Field Model
PA	performance assessment
QA	quality assurance
SNL	Sandia National Laboratory
TDS	total dissolved solids
TRU	transuranic (waste)
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Plant

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1.0 EXECUTIVE SUMMARY

The Natural Barriers Peer Review was conducted by six panel members (Panel) who evaluated the 142 parameters submitted to them by Sandia National Laboratories (SNL) for qualification. These parameters were organized into 32 parameter packages, some of which contained more than one parameter. The parameter packages were grouped into three subsystems, Salado, Castile, and Units Above the Salado, to facilitate the review process. Table 1.1 identifies the 32 parameter packages, the appropriate subsystem and the qualification status for each.

Table 1.1 Summary of Parameter Qualification Status

Parameter Package	Subsystem	Qualification of Parameter
DRZ Compressibility	Salado	Adequate
Undisturbed Halite Pore Pressure		Adequate
Undisturbed Halite Compressibility		Adequate
Effective Halite Porosity		Adequate
Undisturbed Halite Permeability		Adequate
Undisturbed Anhydrite Pressure		Adequate
Undisturbed Anhydrite Rock Compressibility		Adequate
Brine Salt Mass Fraction		Adequate
Brine Viscosity		Adequate
Brine Density		Adequate
Brine Compressibility		Adequate
Castile Brine Reservoir Rock Compressibility	Castile	Adequate
Castile Brine Reservoir Porosity		Adequate
Castile Brine Reservoir Pressure		Adequate
Castile Brine Reservoir Permeability		Adequate
Castile Brine Reservoir Volume		Adequate
Non-Salado Effective Porosity	Units Above the Salado	Adequate
Non-Salado Pressure		Adequate
Non-Salado Permeability		Adequate
Culebra Permeability		Adequate
Climate Index		Adequate
Culebra Transmissivity Data		Adequate*
Culebra Thickness		Adequate
Culebra Storativity		Adequate
Culebra Fluid Density		Adequate
Culebra Steady-State Freshwater Heads		Adequate
Culebra Dolomite Grain Density		Adequate
Effective Culebra Thickness		Adequate
Advective Porosity		Adequate
Half Matrix Block Length		Adequate
Diffusive Porosity		Adequate
Diffusive Tortuosity		Adequate

*The transmissivity value interpreted for one well (P-18) was found to be inadequate.

In summary, the Panel was able to qualify all 32 of the parameter packages. The only exception, as noted in the table, was the transmissivity value from one of the 43 wells used to determine the transmissivity field that was deemed to be inadequate.

2.0 PURPOSE

The purpose of the Natural Barriers Peer Review was to seek qualification of scientific data by performing a systematic review of unqualified parameters used in the models describing the natural barriers subsystems in the Waste Isolation Pilot Plant (WIPP). This review is one of three recognized methods for providing assurance that scientific data collected are qualified for intended use. A peer review panel (Panel), consisting of six members, was convened to undertake the work. The peer review was conducted in a manner that was compatible with NUREG-1297, Peer Review for High-Level Nuclear Waste Repositories. This report is a documented summary of the Panel's work and of the evaluation performed on selected parameters identified by Sandia National Laboratory (SNL). The report is intended primarily for use by the technical personnel at SNL/WIPP. It may also be included as supporting material in the WIPP Compliance Certification Application submitted to the Environmental Protection Agency (EPA).

The parameters evaluated consisted of information used as input to the WIPP performance assessment (PA), which in turn is to be incorporated in the demonstration of compliance. The Panel evaluated existing data and information that form the basis of the parameter values used in the mathematical expression of conceptual models for the natural barriers subsystem. The parameters selected for evaluation had not previously been fully qualified for use in PA. The conceptual models used in the PA on the natural barriers subsystem include components of:

1. Culebra Model Geometry
2. Repository Fluid Flow
3. Salado
4. Impure Halite
5. Salado Interbeds
6. Disturbed Rock Zone
7. Units Above the Salado
8. Dissolved Actinides (Culebra)
9. Colloidal Actinides (Culebra)
10. Castile and Brine Reservoir
11. Climate Changes.

3.0 DESCRIPTION OF WORK PERFORMED

The Natural Barriers Peer Review Panel evaluated 142 parameters against the eight review criteria cited in NUREG-1297. The evaluation of these parameters was organized into the following subsystems listed in Table 3.1: 1) Salado, 2) Castile, and 3) Units Above the Salado. In some subsystems, individual parameter values were evaluated and a determination made of their adequacy as used in the WIPP PA program. In others, sets of parameters were evaluated to determine their collective contribution to a combined parameter value.

Table 3.1 Summary of Parameters Reviewed

Parameter Package	Subsystem	Number of Parameters
DRZ Compressibility	Salado	2
Undisturbed Halite Pore Pressure		1
Undisturbed Halite Compressibility		1
Effective Halite Porosity		1
Undisturbed Halite Permeability		3
Undisturbed Anhydrite Pressure		2
Undisturbed Anhydrite Rock Compressibility		3
Brine Salt Mass Fraction		1
Brine Viscosity		1
Brine Density		1
Brine Compressibility		1
Castile Brine Reservoir Rock Compressibility	Castile	1
Castile Brine Reservoir Porosity		1
Castile Brine Reservoir Pressure		1
Castile Brine Reservoir Permeability		3
Castile Brine Reservoir Volume		1
Non-Salado Effective Porosity	Units Above the Salado	6
Non-Salado Pressure		4
Non-Salado Permeability		6
Culebra Permeability		3
Climate Index		1
Culebra Transmissivity Data		100 Values
Culebra Thickness		1
Culebra Storativity		1
Culebra Fluid Density		32 Values
Culebra Steady-State Freshwater Heads		31 Values
Culebra Dolomite Grain Density		1
Effective Culebra Thickness		1
Advective Porosity		1
Half Matrix Block Length		1
Diffusive Porosity		1
Diffusive Tortuosity		1

The Panel performed an in-depth critique of assumptions, alternate interpretations, methodology and acceptance criteria employed, and of the conclusions drawn in the original work. The Panel collectively

devoted about 40 weeks of effort to the peer review and this report. In evaluating the existing unqualified data, the peer review panel members considered the following:

- The source of the parameters and data (e.g., professional judgment, published source material, field tests, and laboratory experiments).
- The appropriateness of the parameters and data for their intended use.
- The assumptions, calculations, extrapolations, interpretations, methods, appropriateness, validity, sensitivities, and conclusions pertinent to the parameters and data used as input to the WIPP PA.

The Panel, in conducting its work, reviewed 32 parameter packages provided by SNL. In addition, technical reports and documents obtained from the SNL waste management library and records center were used to supplement the information in the parameter packages. Both formal and informal technical discussions were held with SNL principal investigators to more fully understand the concepts and parameter derivation and application in the PA. Table 3.1 identifies the parameter package names, the associated subsystem, and the number of parameters the Panel evaluated.

4.0 EVALUATION OF SALADO SUBSYSTEM PARAMETERS

4.1. Disturbed Rock Zone (DRZ) Compressibility

DRZ compressibility is a parameter that is used in the BRAGFLO modeling of fluid movement into and out of the repository. The parameter description follows:

Parameter: DRZ Compressibility

ID#: 175, 191

Form 464: WPO 32758, entered 2/12/96

Parameter Package: WPO 32037

Distribution: Constant

Value: 7.41E-10 Pa-1

Definition: Formation compressibility of DRZ rock. Formation compressibility is $\alpha = 1/VT\ (dVT/d\sigma e)$

where:

α = formation compressibility

VT = total volume (volume of solids plus volume of voids)

σe = effective stress (stress applied to the solids of the medium)

This parameter describes the change in volume of a unit of rock mass due to stress applied to the solids of the rock.

Intended use: Used as input for BRAGFLO modeling of fluid movement into and out of the repository. In BRAGFLO, formation compressibility is expressed in terms of porosity and fluid pressure:

$$\alpha = 1/\phi\ d\phi/dp$$

where:

ϕ = porosity

p = fluid pressure

which is equivalent to the defining equation given above.

Derivation: DRZ compressibility was developed from pressure testing nine boreholes in the underground facility. The tests are designated C2H01GZ-B, C2H01-C, S0P01, L4P51-A, L4P51-B, S1P71-B, S1P72GZ-A, S1P73-B, and S1P74-B (draft parameter data package for transition rock dated 1/19/96). The testing yielded a specific storage (Ss) value for each test interval. In the present case, specific storage is the volume of fluid released from a unit volume of rock due to expansion of the fluid and compression of the rock under a unit decline in hydraulic head. The following equation expresses specific storage in terms of compressibilities and was used to obtain formation compressibility for each borehole:

$$Ss = \rho_f g(\alpha+\phi\beta)$$

where:

ρ_f = fluid density

g = acceleration of gravity

α = formation compressibility

ϕ = porosity

β = formation fluid compressibility

Rearranging this equation results in:

$$\alpha = Ss/\rho_f g-\phi\beta$$

A spot check of a compressivity value indicated that the equation was solved for formation compressibility by supplying the following values:

ρ_f = 1.22 kg/l (SAND90-0083, p. 38)

ϕ = 0.01 (SAND90-0083, p. 36)

β = 3.0E-10 Pa^{-1} (SAND90-0083, p. 38)

The mean value for the compressibilities thus obtained was 7.41E-10 Pa^{-1}.

4.1.1. Adequacy of Requirements and Criteria

An objective of the DRZ testing was to characterize quantitatively the parameters that are input to BRAGFLO. No written requirements or criteria were found in the documents accompanying the peer review parameter package. However, the data and analyses must adequately support the compressibility value that is supplied to BRAGFLO.

Optimum test conditions for obtaining adequate data supporting this parameter would include the following items:

- The test zone in each borehole represents the DRZ or a portion of it,
- The test tool works properly, and
- The data acquisition system works properly.

The required condition that the test zone in each borehole adequately represent the DRZ was not met on the basis of test zone location, because some tests (SOP01, L4P51-A, L4P51-B, and S1P71-B) were for intervals below Marker Bed (MB) 139, which puts them below the DRZ as it is represented in BRAGFLO. BRAGFLO treats the DRZ as the region extending from the floor of the repository downward to the base of MB139 and extending from the ceiling of the repository upward to the base of MB138 (memo from Palmer to Chu 1/24/96, WPO32288). Some of the tests were also at greater depths than the depth of the DRZ below the repository (simulated as 2.23 m).

The required condition that the test tool be working properly was satisfied. Examination of pressure curves for the tests revealed no test tool problems that precluded the use of the data. Also, the condition that the data acquisition system be working properly appears to have been satisfied. The pressure curves look normal, and test and guard zone pressures are consistent. However, it is noteworthy that significant pressure was transmitted from the test zone to the guard zone during C2H01B testing. This pressure was thought to be transmitted by tool compliance and was used to estimate formation hydraulic parameters.

In summary, optimum test conditions for obtaining DRZ compressibility were not met because test zones that are not in the DRZ were used. However, this deficiency does not preclude the use of 7.41E-10 Pa^{-1} if it adequately represents DRZ compressibility.

4.1.2. Validity of Assumptions

Assumptions related to DRZ compressibility are those involved in the analysis of the test data. Important assumptions of the mathematical models used to analyze the test data include the following:

- Darcy flow,
- Homogeneity and isotropy of concentric rings of materials in the zone of test influence, and
- Radial flow.

The assumption of Darcy flow has been adequately discussed in SAND92-0533 (Sections 6.2 and 7.2.2). The observation that Darcy-flow models can match pressure curves produced by different pressure differentials applied to the same test intervals supports the utility of Darcy's law as applied to the interpretation of the tests. Using the same hydraulic parameters, including permeability, under different head gradients supports the assumption of a linear relationship between flow and head gradient contained in Darcy's law. As with many linear relationships used in scientific applications, it is probably not a completely accurate assumption, but rather a useful and practical simplification.

The assumption of homogeneity and isotropy is not completely satisfied in natural materials. However, these assumptions allow for practical quantitative testing that has been found by practicing hydrologists to be useful in predicting behavior of ground water systems. These assumptions are appropriate for the analysis of the Salado borehole test data, in that more realistic modeling methods would be unlikely to reduce uncertainty significantly.

The radial flow assumption is related to the assumptions of homogeneity and isotropy because inhomogeneities and anisotropy will result in deviation from truly radial flow. However, there will be radial flow components, and this fact results in the utility of such methods in estimating permeability and associated hydraulic parameters.

An additional assumption that is relevant to formation compressibility is that the volume of formation fluid released (or gained) from an elemental volume of porous material due to pressure change is proportional to the pressure change and is released (or gained) instantaneously. Again, the fit between pressure data and theoretical curves under different pressure pulses applied to the same test interval

supports the utility of the assumption when applied to the test conditions. Some uncertainty is introduced into the modeling relative to the effects of long-term plastic deformation of the halite.

4.1.3. Alternate Interpretation

The sensitivity analyses reported in SAND90-0083 show that specific storage can vary as much as four orders of magnitude without much adverse effect on the fit of data to the theoretical curves. However, no alternate interpretations that would better satisfy the objectives of the testing were identified. The degree of effect of tool compliance on the pressure curve was analyzed (SAND90-0083), and tool compliance does not seem to affect the test results to a degree that can not be accommodated in the analysis of the data.

4.1.4. Uncertainty and Consequences

Uncertainties related to obtaining a DRZ compressibility value include the following:

- Uncertainty in specific storage values due to lack of a test method that provides a unique and accurate value for specific storage, and

- Uncertainty in the value for porosity that must be used to calculate formation compressibility from specific storage.

Uncertainty in the DRZ compressibility contributes to uncertainty in BRAGFLO modeling because the compressibility is related to porosity in the conservation equations. A high compressibility would be conservative in that it would increase simulated inflow and outflow from the repository when fluid pressure changes in the repository.

4.1.5. Appropriateness and Limitations of Methodology and Procedures

As indicated in the preceding sections, the methodology was appropriate and the limitations of the methodology are acceptable. The test procedures used are described in SNL reports (for example, SAND90-0083, Section 6). The SAND reports give references to scientific literature that is subject to technical review (for example, Pickens et al. 1987). No information was lost via the computerized data reduction used for redundant pressure data, as indicated by the frequency of the remaining points. Although the compressibility of the DRZ probably varies with time, the effects of such variation are covered by the treatment of uncertainty described above. The test equipment functioned well for the tests utilized for DRZ compressibility, and detection limits were adequate, as indicated by the pressure curves themselves. Specific storage values calculated from different segments of the data derived from pressure test data sequences provided checks on the general representativeness of the test results.

4.1.6. Adequacy of Application

As indicated in the preceding sections, the data used to develop the DRZ compressibility value were adequate except that some data did not come from the DRZ, as it is defined for BRAGFLO simulation. Examination of the times when adjacent boreholes were tested and examination of pressure curves yielded no evidence of test-to-test interference. Test irregularities and interruptions, such as malfunctions of tools, are shown on the test data curves and were adequately dealt with.

4.1.7. Accuracy of Calculations

No hand calculations or spreadsheet calculations were found in the records cited in the parameter package. Re-calculation of formation compressibility from QPP05 specific storage, as an example, showed that the value was correctly calculated. Inspection of other compressibility values indicated that calculated values, such as converted units, were properly executed.

4.1.8. Validity of Conclusions

The constant value of 7.41E-10 Pa^{-1} selected for DRZ compressibility is conservative and reasonable for use in PA modeling. As noted in Section 4.1.4, high values for compressibility tend to be conservative. The value 7.41E-10 Pa^{-1} is exceeded by only two values from the nine boreholes included in the data Parameter Package. The range of the values for the nine boreholes is from 1.85E-13 to 3.27E-9.

Although some of the tests used to develop the DRZ compressibility were not in the DRZ, as represented in the BRAGFLO model, the value selected is adequate. The average compressibility from tests of rock in the DRZ between MB139 and the repository floor is 2.72E-10 Pa^{-1}, which is not significantly different from 7.41E-10 Pa^{-1}. The compressibilities used to calculate 2.72E-10 Pa^{-1} were from boreholes C2H01Gz-B, S1P72GZ-A, C2H01-A, and QPP05. The reason for calculating compressibility for rock above MB139 to check the adequacy of the value selected for BRAGFLO input is that it is material through which contaminants must traverse vertically to reach MB139. MB139 is an anhydrite interbed that might have an important role in lateral repository inflow/outflow.

4.1.9. Dissenting Views

None.

4.2. Undisturbed Halite Pore Pressure

The Parameter Package contains the Form 464, which has attached two data sheets from the 1992 PA showing undisturbed halite pore pressure data from boreholes QPPO5 and QPP15 drilled adjacent to Room Q and referencing the source document, SAND92-1172. The hydraulic tests conducted in these two boreholes need to be qualified by the peer review process to support this parameter.

Parameter: Undisturbed Halite Pore Pressure (brine far-field pore pressure)

ID #: 546

Form 464: WPO 34394, entered 2/8/96

Parameter Package: WPO 31221

Distribution: Uniform

Parameter Values: Minimum: 11.04 MPa

Maximum: 13.89 MPa

Definition: The Brine far-field pore pressure (also known as the Undisturbed Salado Halite Pressure) is the pressure of the fluid in the halite unit within the Salado formation, under natural undisturbed conditions.

Intended Use: The intended use of the parameter is for entry into the BRAGFLO model as one of several specific initial scientific parameters describing the rock properties of the repository area within the Salado Formation in its natural state upon decommissioning.

Derivation: The Undisturbed Halite Pore Pressure is based on interpretation of Graph Theoretical Field Model (GTFM) 6.0 simulation of pressure, fluid volume withdrawal, temperature, axial test-tool movement, and radial borehole closure recorded during two hydraulic tests, of an isolated test interval of the undisturbed halite, performed in two boreholes, QPP05 and QPP15, adjacent to Room Q.

Discussion: No fluid movement could be clearly identified in the tested halite in either QPP05 or QPP15, due to the extremely low permeabilities of the test zones. Therefore, there are uncertainties about pressure values obtained from GTFM 6.0 analyses of the halite test zone data.

4.2.1. Adequacy of Requirements and Criteria

Inspection of the logs and tool configuration diagrams in SAND92-1172 indicates that the test zones in boreholes QPP05 and QPP15 were within the Salado halite unit and that the collected data most likely represent information from the halite unit.

The tests conducted in boreholes around Room Q were designed to help reduce uncertainties about brine flow and provide information on the Salado Formation pressure, permeability, and flow potential both within the zone of potential influence of the WIPP excavations and in the undisturbed, so called, "far field" parts of the Salado. Thus, in that sense, the tests did meet the adequacy of requirements, although there are some limitations on the interpretations, as discussed in SAND96-0435 (see Section 4.3.3).

4.2.2. Validity of Assumptions

The assumptions made during testing of the undisturbed Salado halite interval were that Darcy flow and borehole closure were the only forms of pressure/flow transmission during the hydraulic testing.

For those particular tests in boreholes QPP05 and QPP15, the absence of flow precludes confirmation of the assumptions.

4.2.3. Alternative Interpretations

A normal part of the analysis of hydrologic flow data involves use of standard "type curves" to match theoretical curves of different flow conditions with the collected data. Therefore, different interpretations may be possible depending on the assumptions used in the analysis. With regard to borehole QPP15 data for the constant-pressure flow test (SAND96-0435, Fig. 7-69), three alternative interpretations were analyzed for the curve, matching flow rate against elapsed flow time. These alternative interpretations were for spherical, radial, or linear flow. As can be seen in the Figure 7-69, the data match for radial flow is obviously the most reasonable fit, starting after one day of flow and ending slightly past 100 days, whereas, the linear flow type curve for the same data points does not match the data. Therefore, it appears that the interpretation used in selecting the values to estimate formation transmissivity is reasonable and appropriate.

4.2.4. Uncertainty and Consequences

With regard to the field data from boreholes QPP05 and QPP15, there is some uncertainty about the accuracy of these data as the pressures dropped a few tenths of a MPa after fluid injection and then stabilized at arbitrary and different pressures. This is thought to reflect extremely low pre-mining

permeability of the halite (i.e., 1.1E-24 m^2 for QPP05). In addition, the GTFM 6.0 simulation could not match these pre-mining pressure decreases without adding a skin effect of higher permeability for a skin thickness of 0.87 cm around the borehole. It may be reasonable to assume that there was a thin layer of borehole "damage" around the borehole as a result of drilling. On the other hand, it may be possible that the early-time pressure changes and high early time flow rates are due to tool movement and/or packer-compliance effects.

According to SAND96-0435 (p. 81),

> "The simulation is non-unique because the pre-mining pore pressure could not be estimated with the available data. The value used in the simulation, 7.5 (sic) MPa was chosen arbitrarily and similar fits could be obtained by simultaneously adjusting the transmissivity and pore pressure."

The uncertainties in the data are: 1) the value (13.9 MPa) selected for the maximum pre-mining halite pore pressure in borehole QPP05, because this value was obtained by GTFM 6.0 simulation, which involves uncertainty; 2) in general, any of those parameters used to match the data measured in QPP05 during the post-mining time period for the reason that the test and guard zones were in hydraulic communication; and 3) the value (11.0 MPa) for the maximum pre-mining pressure of the undisturbed halite pore pressure in borehole QPP15, because this value was obtained by GTFM 6.0 simulation using post-mining test sequence parameters, which showed the effects of disturbance (i.e., after mining Room Q, the borehole QPP15 test zone was within the DRZ, as was the test zone in borehole QPP05).

4.2.5. Appropriateness and Limitations of Methodology and Procedures

The testing apparatus used in 1989 was fabricated from off-the-shelf components which, to a large extent, dictated the methodologies and procedures used to measure pressure and permeability directly in the boreholes.

The 0-200 psi strain-gage pressure transducers used to measure pressure in the test and guard zones were accurate to 1 psi over the rated pressure range. The packer pressures were monitored using 0-3000 psig pressure transducers accurate to 30 psi over their rated pressure range.

Data from the tests were reduced for presentation in SAND92-1172 by sorting according to borehole number, recording time, and measurement type, calculating all measurements to a time interval since zero-hour, converting all measurements from U.S. to metric units, and filtering out redundant values with a data filter. Although SAND92-1172 does not document that the reduced data are an accurate

representation of all data, it is apparent by reviewing the curves of pressure vs time in the test zone that the data appear to be representative of test conditions.

The description of the test equipment, tool installation, test startup and results of testing presented in SAND92-1172 indicate that the test procedures were correctly implemented.

4.2.6. Adequacy of Application

Regarding possible test-to-test interference as shown in SAND96-0435, a visual comparison of QPP04 test-zone pressure (Fig. 6-28) and QPP05 test-zone pressure (Fig. 6-35) shows no obvious effects of QPP04 test activities on QPP05. Likewise, a comparison of QPP14 test-zone pressure (Fig. 6-66) and QPP15 test-zone pressure (Fig. 6-73) shows no obvious effects of QPP14 test activities on QPP15, as shown in SAND96-0435.

The observed pressure changes may have been affected by changes in the packer-inflation pressures brought about by borehole deformation resulting from salt creep, and possible associated movement of the borehole test tools.

There was no direct identification (i.e., measured core from the borehole) of the stratigraphic interval being tested in the borehole. Thus, it is possible that the test-intervals could overlie units above or below the expected test stratigraphic zone.

In Table 7-1 of SAND96-0435, which shows a pore pressure value of 13.9 MPa for borehole QPP05, there is a notation that the value has a high relative uncertainty. In Appendix C (SAND92-1172 p. c-30) there is a notation at the bottom of the operational log for borehole QPP15 that during the period 5/13/90-7/16/90 the QPP15 test region pressure transducer was being used a QPP14 and therefore the closure data should be ignored for this period.

There are no specific statements regarding data confidence in the SAND92-1172 report, although it can be inferred from the operational logs of each borehole (SAND92-1172, Appendix C) that the data can be considered reliable by the reason that data are specifically identified in the QAC and CAC section of the operational log.

4.2.7. Accuracy of Calculations

The source reference (SAND92-1172) listed in the 1992 PA does not contain calculations, nor does the interpretative report, SAND96-0435, which only shows graphs and charts of the results of interpretation from various analytical and numerical models.

4.2.8. Validity of Conclusions

Reportedly, the maximum pore pressure that would be expected to be found in the Salado halite at the WIPP repository, under a normal geothermal gradient, would be lithostatic pressure of approximately 14.8 MPa (~2150 psi). Therefore, using a value of 13.9 MPa (the maximum value of undisturbed halite pressure obtained by GTFM 6.0 simulation) in BRAGFLO, as the maximum pore pressure value of undisturbed halite, would appear to be reasonable.

The value of formation pore pressure of 11.0 MPa was obtained with GTFM 6.0 simulation by using a skin thickness of 1.5 cm around the borehole with corresponding skin transmissivity of 1.8E-15 m^2/s, whereas, the formation transmissivity value used was 2.8E-17 m^2/s. Therefore, it appears that the GTFM 6.0 simulation of the QPP15 borehole pressure data does not provide an accurate estimation of the undisturbed ("far field") halite pore pressure. It does, however, seem reasonable to use this value as a minimum, because it represents approximately 74% of lithostatic pressure at that depth. Plus, it is consistent for formations with a poor hydraulic connection to units under hydrostatic pressure.

In summary, considering all factors, the reliability of conclusions regarding the undisturbed halite pore pressure in the Salado evaporites, as obtained from the testing of boreholes QPP05 and QPP15, seems reasonable for use in the BRAGFLO model, as the maximum pressure value of 13.89 MPa is fairly close to the calculated maximum lithostatic pressure of 14.8 MPa at the depth of the testing in the Salado (i.e., ~ 2150 feet bgs).

4.2.9. Dissenting Views

None.

4.3. Undisturbed Halite Compressibility

The adequacy of undisturbed Salado halite bulk (or rock) compressibility data is addressed in this section.

Parameter: Bulk Compressibility

ID #: 541

Form 464: WPO 34210, entered 2/14/96

Parameter Package: WPO 31220

Distribution: Uniform

Parameter Values: Maximum: 1.92E-10

Minimum: 2.94E-12

Definition: Formation compressibility is $\alpha = -(1/VT)(\partial VT/\partial \sigma e)$

where:

VT = total volume of the rock

σe = effective stress.

Intended Use: This parameter is needed in BRAGFLO in order to simulate the flow from brines in the Salado formation into or out of the repository.

Derivation: The data were derived from two hydraulic tests in boreholes in undisturbed halite. The code GTFM 6.0 was used to obtain specific storage values which were used to calculate the compressibility.

Discussion: These data were developed from specific storage values determined from analysis of pre-mining hydrologic tests in Room Q boreholes QPP05 and QPP15. This methodology yielded rock compressibility values ranging from 2.94E-12 Pa-1 to 1.92E-10 Pa-1. These tests and analysis of the results obtained are presented in SAND92-1172 and SAND96-0435.

4.3.1. Adequacy of Requirements and Criteria

The requirements for the tests were not specifically stated in the source documents, but for purposes of this parameter they are inferred to have been to obtain data that represent the range of compressibilities of Salado halites for use in repository flow modeling. These requirements are adequate for purposes of the PA.

4.3.2. Validity of Assumptions

The compressibilities were calculated from specific storage parameters obtained from analysis of borehole tests using the GTFM 6.0 code. The relationship among these parameters is commonly expressed by the following equation:

$$Ss = \rho g(CR + \phi\beta)$$

where:

Ss = specific storage

ρ = brine density

g = acceleration of gravity

CR = rock compressibility

ϕ = rock porosity

β = brine compressibility

The test zones in boreholes QPP05 and QPP15 were found to have the lowest permeabilities of any zones tested around Room Q. The test zone in QPP05 is in halite map unit MU-6. It is probably the closest to pure halite of any of the tested zones around Room Q and has an average of less than 0.5% clay and polyhalite (SAND92-1172 p. A-5). The test zone in QPP15 includes part of halite unit 0 which contains up to 5% clay, and part of polyhalitic unit PH-4 which contains up to 3% polyhalite and scattered anhydrite and clay (SAND92-1172 p. A-6). The range of average degree of impurities in the tested units approximately spans the range typically observed in the Salado halites; however, the degree of impurities present in the actual test zones is not known and could be different from the average. If the test zone lithologies were typical of the units as a whole, the test results could be expected to provide an appropriate range of rock compressibilities. The very low permeability and storativity determined for

QPP05 suggests, however, that this test zone may not be typical of the Salado halites and that the calculated compressibilities may favor the low end of the range.

4.3.3. Alternate Interpretations

The very low permeabilities of the test zones resulted in the lack of a clear indication of fluid movement in the halite during the tests, which in turn made the analysis results highly uncertain. The test data were analyzed for a number of combinations of permeability and specific storage, each of which provided a good match to the test data, but most of which had unreasonably high or low values for specific storage. Although the adopted results provided a reasonable set of parameters, they were non-unique and other reasonable values of specific storage (and hence rock compressibility) could have been inferred.

4.3.4. Uncertainty and Consequences

The interpretations made in analyzing the test results are acknowledged in SAND96-0435 (p. 27) to carry a high relative uncertainty and a general discussion of test uncertainty is presented in SAND96-0435 (p. 23). In both QPP05 and QPP15 the principal uncertainty results from the aforementioned lack of a clear indication of fluid movement in the halite. Specific storage and permeability are linked in the analysis because to maintain a good match to field data, specific storage must be increased as permeability is decreased. Although the adopted test results published in SAND96-0435 (Table 7-1) provide a reasonable balance among permeability, specific storage, and the other parameters considered in the analysis, other parameter sets that would also be considered reasonable could have resulted in specific storage values that varied by at least an order of magnitude. The value of halite porosity is also uncertain, as described in Section 4.4 of this report (undisturbed halite porosity), which adds to the uncertainty of the calculated compressibilities. Further discussion of the uncertainty of results from these borehole tests is presented in Section 4.5.4 of this report (undisturbed halite permeability).

The consequences of error from using the derived compressibility values in hydrologic analysis would be to increase or decrease the rate at which pressure transients are propagated in the undisturbed Salado halites, with errors in early time flow rates resulting from these transients. Later time flow rates approach steady state and would be less affected. These consequences are not considered significant because of the long time periods over which pressure transients in the undisturbed halite occur in long term performance assessment calculations. A relatively low sensitivity of model results to variations in rock compressibility was found during studies reported in SAND93-1986 (pp. 6-7 to 6-10).

4.3.5. Appropriateness and Limitations of Methodology and Procedures

The test methodology and procedures are well described in SAND92-1172 and SAND96-0435. Further discussion of methodology and procedures is presented in Section 4.5.5 of this report (undisturbed halite permeability). The principal limitations of using the results of these tests to calculate rock compressibility are associated with the high degree of uncertainty in the specific storage values from which the compressibilities were calculated, and the lack of direct evidence that the compressibilities actually represent the range of compressibilities for the undisturbed Salado halites. A comparison with specific storage values determined from the results of tests in other Room Q boreholes (SAND96-0435, Table 7-1) supports the validity of this range, but most of the results of the other tests also carried a high degree of uncertainty.

If taken without the additional supporting information noted below, the approach adopted to determine halite bulk compressibility would not be adequate for use in performance assessment because of the high uncertainties in the results of the specific borehole tests and a lack of confirmation that the data appropriately represent the range of values for the parameter. To provide an independent check, halite compressibility (C_R) was determined from elastic theory using the following relationships for an isotropic medium:

$$CR = 1/K$$

and

$$K = E/\,(3(1-2\sigma))$$

where:

K = halite bulk modulus

E = halite Young's modulus

σ = Poisson's ratio.

Adopting values of E = 31 GPa and $\sigma = 0.25$ (SAND88-2948, p. 26), C_R was calculated to be 4.8E-11 Pa^{-1}. This value is considered to be on the low side (the method used to determine Young's modulus may overestimate that value), with roughly estimated uncertainty resulting in a range of approximately 3.0E-11 Pa^{-1} to 5.0E-10 Pa^{-1}. Although the calculated elastic theory value lies approximately in the

middle of the performance assessment range of 2.94E-12 Pa^{-1} to 1.92E-10 Pa^{-1}, that range may also be on the low side because the very low values of permeability and specific storage obtained from the QPP05 test suggest an atypically tight test interval.

4.3.6. Adequacy of Application

Although the supporting information suggests that the low end of the range of undisturbed halite compressibilities used in performance assessment may not be realistic for the large scale rock mass behavior, the effect on the performance assessment is expected to be small for the reasons given in Section 4.3.5. This observation is supported by sensitivity studies of repository response to a variety of parameters reported in SAND93-1986 (pp. 6-7 to 6-10), where the sensitivity of selected performance measures to halite rock compressibility was found to be intermediate to low. However, the compressibility values evaluated in SAND93-1986 did not go so low as the low end of the range used in performance assessment. Application of the selected range of compressibility values to performance assessment is expected to be adequate; however the reliability of the low end of the range is questionable.

4.3.7. Accuracy of Calculations

The calculation of compressibility from the equation for specific storage in Section 4.3.2 was checked using the parameter values of $\rho = 1220\ kg/m^3$, $g = 9.7917\ m/s^2$, $\phi = 0.013$, and $\beta = 3.1E\text{-}10\ Pa^{-1}$ given in the Parameter Package, and was found to be accurate.

4.3.8. Validity of Conclusions

The results obtained from using a range of 2.94E-12 Pa^{-1} to 1.92E-10 Pa^{-1} for undisturbed halite compressibility as reported on Form 464 WPO 34210, entered 2/14/96, should be appropriate for use in performance assessment.

4.3.9. Dissenting Views

None.

4.4. Effective Halite Porosity

The data Parameter Package contains two major references as attachments for the data source for the constructed distribution of effective halite porosity. The first is p. A-II-5 in SAND93-1986, which is the data page for Salado Porosity dated 08/31/93. This, in turn, references the earlier "drying experiments" of samples of the Salado evaporites conducted by Powers (SAND78-1596) and the DC resistivity measurements made underground at the WIPP site by Skokan (SAND87-7174). The second major reference is p. 2-41 through 2-43, dated 12/29/92, of SAND92-0700/3.

Parameter:	Effective Halite Porosity (Undisturbed)
ID #:	544
Form 464:	WPO 34387, entered 2/22/96
Parameter Package:	WPO 30601
Distribution:	Cumulative
Parameter Values:	Minimum: 1.0E-03 0.0 Prob
	Maximum: 3.0E-02 1.0 Prob
	Median: 1.0E-02 0.5 Prob

Definition: The Effective Halite Porosity is the ratio of the volume of interconnected pore space to the volume of the rock matrix within the halite unit in the Salado Formation under natural conditions, not disturbed by mining, or other man-induced activities.

Intended Use: The intended use of the parameter is for entry in the BRAGFLO model as the parameter defining the ratio of interconnected pore space through which fluids can migrate in the undisturbed halite of the repository zone.

Derivation: The effective halite porosity values have been inferred from the results of thermogravimetric analyses (water loss during heating) of Salado halite core from early drill holes in the repository, electrical resistivity experiments conducted at the WIPP site, and calculations of porosities based on parameters for Archie's Law used in core damage and Room-D seal studies (Borns 1996).

The maximum value for halite porosity of 0.03 (3%) was originally based on a reported 10-ohm DC-resistivity value made underground at the WIPP site (SAND87-7174, p. 13). However, upon scrutiny, it appears that SAND87-7174 (p.13) contains a typographical error in that the 10-ohm value actually should have been reported as 100 ohms. A 100-ohm value used in Figure 7 (SAND87-7174, p. 6) instead of the 10-ohm value, would yield a weight percent of water reasonably close to the bulk water content in the salt, about 2% by weight stated in the report (SAND87-7174, p. 13). This would translate into a porosity volume of approximately 3.4% for a maximum effective halite porosity as discussed below.

A maximum effective halite porosity value of 0.034 also is supported by other calculations showing effective Salado halite porosity of 0.036 based on parameters entered in Archie's Law equation as used in core damage and Room-D seal studies (Borns 1996).

The lower limit (minimum) of 0.001 (0.1%) effective halite porosity was inferred from the drying experiments of Powers (SAND78-1596).

Discussion: The median effective porosity value of 0.01 listed on Form 464 was inferred from geophysical resistivity measurements at the WIPP site. A similar value can be calculated from grain density and bulk density of halite, using the formula:

$$\rho b = (1 - \phi)\rho g$$

where:

ρb = bulk density

ρg = grain density

Using a measured halite bulk density value of 2.14E+03 kg/m^3 from tests on collected Salado halite samples, and a referenced halite grain density of 2.163E+03 kg/m^3 (p. 2-22 of SAND92-0700/3), a median value of 0.01 (1%) for halite porosity was calculated (SAND92-0700/3, p.2-42).

The relationship between volume percentage of effective porosity and weight percent of water (brine) is dependent upon the brine density (approximately 1.22 g/cm^3) and salt density (approximately 2.2 g/cm^3). Therefore, the volume percentage of effective porosity will be greater than the weight percentage of brine by a factor of approximately 1.7, or conversely, the weight percentage of brine would be approximately 60% of the volume of effective porosity.

As previously discussed under derivation, the 10-ohm value cited in the Parameter Package (WPO 30601) is considered to be erroneous. Therefore, the discussions herein regarding the DC electrical resistivity studies do not consider a 10-ohm value for the lower limits, but rather a 100-ohm value.

4.4.1. Adequacy of Requirements and Criteria

The estimation of the undisturbed effective halite porosity parameter value from geophysical studies of electrical resistivity of the evaporite beds at the WIPP site (SAND87-7174), introduces some uncertainty. The resistivity data collected by the Geonics model EM-31, which uses induction coils separated by a distance of 3 m, measures rock resistivity at shallow penetration depths (1-2 m). The EM-31 data probably are representative of the resistivity of the halite (and other evaporite beds) as measured near the edge of the shaft excavation in a disturbed zone. Thus, the resistivity values indicating possible moisture contents as high as 0.8 to 2.0%, interpreted from Figure 7 and reported in SAND87-7174, may represent resistivity of partially saturated rocks in the DRZ.

The resistivity data collected by the Geonics model EM-34 measures resistivity at greater depth penetrations (10-20 m) and it shows resistivity values considerably lower than those measured by the EM-31 for the same lithology in nearly the same location. This suggests, using Figure 7 (SAND87-7174), that the same salt at greater distance from the shaft excavation has a higher water content (2-3%) than the salt adjacent to the shaft. A possible explanation for the higher water content away from the shaft may be that the salt adjacent to the shaft had been dried by the air flow in the shaft and was only partially saturated with brine.

4.4.2. Validity of Assumptions

The gross results (interpretations) of the geophysical survey measuring earth resistivity as presented in the report (SAND87-7174) tend to show a general agreement among the different methods used, for example, 1) source DC current from the land surface, and 2) electromagnetic coupling equipment using two different induction coil separation distances. Therefore, it appears that the assumptions used regarding the three-layer earth model are probably valid for the DC electrical resistivity measurements.

The results of the static heating experiments on halite (SAND78-1596) provide reasonable data useful for the calculation of free water content in halite, which is indicative of effective porosity assuming that all the water released by heating is from the interconnected pore spaces. This suggests that the test design, data collection and analysis were appropriate for the intended use of the data.

Measurement of moisture content in halite by thermogravimetric analysis and static heating could include moisture released from the total porosity (including inclusions) of the halite, depending on the maximum temperature to which the sample was heated. The moisture content would also depend on the composition of individual samples, and could include moisture from dehydration of clay minerals. As long as the definition of undisturbed halite is for a pure halite with only trace amounts of impurities, then the measurement reported by SNL of moisture content released during heating up to 102° C should be a reliable indicator of the total amount of free water within the total effective porosity in the halite.

4.4.3. Alternative Interpretations

In the case of the static heating tests of the halite (SAND78-1596), there do not appear to be alternative interpretations, other than explaining those minor differences in weight loss among different samples. This apparently was a result of differing amounts of different trace mineral impurities in the halite tested, and, possibly, loss of water from sample handling and storage techniques.

The DC electrical resistivity investigations are subject to alternative interpretations, depending on which earth model is used to calculate apparent resistivities. The three-layer model was used to account for the stratigraphy at the WIPP site and accepted as appropriate, whereas the uniform earth model was used to model the site and determined to be inadequate.

4.4.4. Uncertainty and Consequences

There is no discussion in SAND87-7174 of the uncertainty of results for the geophysical resistivity measurements.

The static heating experiments on halite (SAND78-1596) indicate that, depending on sample constituents, the moisture loss at 70°C ranged from zero to 1.9% by weight, with values typically in the 0.20 to 0.30% range. The range of weight loss at 102°C was from zero to 3.5%, with the majority of samples showing less than 0.5% weight loss. This would suggest a range of effective porosities of the heated halite from near zero to approximately 5.9%. Thus, it seems apparent that the low end value of 0.001 (0.1%) for effective porosity listed on the Form 464 would be within the low-end range of weight loss values indicated by the static heating experiments. The high end value of 5.9% (weight loss of heated sample at 3.5%) may reflect the result of impurities, (e.g., clay) in the sample that may have released water. Thus, the high end values from the heating experiments are probably not representative of pure halite.

4.4.5. Appropriateness and Limitations of Methodology and Procedures

It would appear that the DC-source geophysical resistivity values obtained (SAND87-7174) for the halite at the WIPP site would represent gross values averaged over several tens to hundreds of meters distance. As such, the values obtained would provide a reference value to compare with other values representing more discrete zones that might be obtained through other scientific methods.

At the time (1978) the static heating experiments were conducted with the halite samples (SAND78-1596), the methods used were appropriate and remain so today (1996). However, the static heating and thermogravimetric methods of Powell (1978) were subject to uncertainty due to probable water loss in samples during sampling, transport and preparation in the laboratory. This water loss, the result of evaporation of the pore fluids, may have left chemical precipitates in the pore throats which would reduce the degree of interconnectivity and plugged pore throats. This could have reduced the amount of water that escaped the sample upon heating, thus, indirectly resulting in a reduction in the estimate of effective porosity.

4.4.6. Adequacy of Application

The geophysical resistivity data originally were collected to determine if this technique could be used to detect and map fractures and brine concentration in the salt layers. The investigation and data collection were not conducted with the specific purpose of determining a value for halite porosity. Estimation of halite porosity for the PA was made by inferring values of porosity from Figure 7 (SAND87-7174), a chart diagram of apparent resistivity vs water content. The estimated 1.0 to 3.0% weight of water as interpolated from Figure 7 using the EM-31 and-34 resistivity measurements, is equivalent to an upper limit for effective porosity of approximately 1.7 to 5.1% of undisturbed halite, whereas, the interpretation of a 100-ohm resistivity value from the DC resistivity survey using Figure 7 would provide a weight percent water content of approximately 3.0%, equivalent to approximately 5.10% effective porosity. Thus, the results of the two geophysical methods are in fairly close agreement.

The static heating experiments (SAND78-1596) indicated a range of weight loss values at 102 ± 5° C for the Salado salt samples from 0.0 to 3.5% with the majority of samples showing losses less than 0.5%. Thus, the effective porosity values for the Salado halite, based on the static heating experiments, would range from approximately zero to 5.9%, but the majority of the values would be less than 0.85%. For use in the PA, the low end values are probably more appropriate; thus, a value of minimum effective halite porosity of 0.001 or even less than 0.001 appears reasonable.

4.4.7. Accuracy of Calculations

It is not possible to check the accuracy of the calculations for the geophysical resistivity investigation (SAND87-7174) because critical numbers used in the equations presented are not provided in the report, nor are tables of the collected data. Likewise, calculations of weight loss are not shown for the static heating experiments (SAND78-1596). Thus, checking the accuracy of these calculations is not easily accomplished.

4.4.8. Validity of Conclusions

Geophysical resistivity data supporting the porosity interpretation in SAND87-7174 are not presented. However, the conclusions are supported indirectly by the results of other investigations of the halite, e.g., static and thermogravimetric heating studies (SAND78-1596) and core damage and Room-D seal studies (Borns 1996).

From the results of the static heating studies (SAND78-1596) it has been estimated that the lower limit of undisturbed halite is 0.001 (0.1%). This minimum porosity value could be high, but is considered a conservative and realistic number. Some of the test results on halite indicated no measured weight loss upon heating to 102° C, which suggests that a minimum value of porosity for some volumes of undisturbed pure halite approaches zero.

The results of the static heat weight loss studies on some samples of halite heated to 102°C were recorded as 0.0%, the split of one of these 0.0% weight loss samples analyzed by thermogravimetric techniques showed a weight loss of 0.15 % at 70° C. Thus, it appears that a lower limit at 0.001 (0.10%), for construction of the distribution of undisturbed halite, is probably a reasonable minimum value for this parameter.

The maximum value of 0.03 (3%) for effective porosity of the halite is based on the interpretation of electrical resistivity from geophysical investigations conducted at the WIPP site. This value may be slightly low, as discussed in Sections 4.4.4 and 4.4.6. The minimum, maximum and mean values selected for the cumulative distribution are reasonable for use in BRAGFLO.

4.4.9. Dissenting Views

None.

4.5. Undisturbed Halite Permeability

This section reviews the data from which the logarithm of intrinsic permeability for intact Salado halite was derived.

Parameter:	Log of intrinsic permeability, x direction
ID #:	547
Form 464:	WPO 34397, entered 3/6/96
Parameter Package:	WPO 31218
Distribution:	Uniform
Parameter Values:	Maximum: -21.0 [log(m2)] (1.0E-21 m2)
	Minimum: -24.0 [log(m2)] (1.0E-24 m2)
Parameter:	Log of intrinsic permeability, y direction
ID #:	548
Form 464:	WPO 34399, entered 3/6/96
Parameter Package:	WPO 31218
Distribution:	Uniform
Parameter Values:	Maximum: -21.0 [log(m2)] (1.0E-21 m2)
	Minimum: -24.0 [log(m2)] (1.0E-24 m2)
Parameter:	Log of intrinsic permeability, z direction
ID #:	549
Form 464:	WPO 34401, entered 3/6/96
Parameter Package:	WPO 31218

Distribution: Uniform

Parameter Values: Maximum: -21.0 [log(m2)] (1.0E-21 m2)

Minimum: -24.0 [log(m2)] (1.0E-24 m2)

Definition: The intrinsic permeability is defined as $k = K\mu/\rho g$

where:

K = hydraulic conductivity

μ = fluid viscosity

ρ = fluid mass density

g = gravitational constant

Intended Use: The intrinsic permeability is required by BRAGFLO for modeling the brine flow in and out of the repository.

Derivation: The data were derived from two hydraulic tests in boreholes in undisturbed halite. The code GTFM 6.0 was used to estimate the permeability.

Discussion: The adequacy of undisturbed halite permeability data from hydraulic tests in boreholes QPP05 and QPP15 is addressed in this section. These boreholes were two of fifteen test holes drilled as part of the Room Q experiment. Parameter numbers 547, 548, and 549 refer to the components of the undisturbed halite permeability tensor in the x, y, and z directions. The following discussion addresses only those parts of the field tests performed under undisturbed conditions before Room Q was excavated.

4.5.1. Adequacy of Requirements and Criteria

The requirements and criteria for the tests were adequately defined. The test objectives, as stated in SAND92-1172, Section 1.3 and SAND96-0435, Section 6.1, and as applicable to this parameter, were to "determine formation permeability [under undisturbed conditions] ... before ... Room Q mine-by." (SAND92-1172, p. 2). The tests were conducted within the Salado halites at ambient temperatures using a dual test-packer/guard-packer configuration and brine as a test fluid. The data are considered

representative of the halite in the immediate vicinity of the tests; however, because of limited test durations and the extremely low permeability of the tested halite, the permeability of the halite could not be uniquely determined.

4.5.2. Validity of Assumptions

The tests were designed and analyzed assuming Darcy flow in isotropic porous media. Temperature, borehole closure, and residual pressure transients from prior test activities were accounted for in the analysis. Temperatures were monitored inside the test tool in the guard zone but not in the test zone. Temperatures in both holes were seen to rise when Room Q was mined, and then drop back over time to the premining ambient level of about 26.7 ± 0.1°C. The long test duration, lack of significant short-term transients, lack of significant heat sources within the test tool, high thermal conductivity of the salt, and close proximity of the guard zone to the test zone suggest that the temperature of brine in the guard zone is an adequate surrogate for the temperature of brine in the test zone.

The assumption of Darcy flow appears to have been appropriate for tests conducted in adjacent boreholes where the halite was more permeable, and by inference is considered appropriate for the tested halite. However, this assumption cannot be confirmed by the test results because no fluid movement could be clearly identified in the tested halite in either QPP05 or QPP15, due to the extremely low permeabilities of the test zones.

The assumption that the tested halite behaves as an isotropic porous medium is probably inaccurate: the test zone in QPP05, although probably the closest to pure halite of all zones tested around Room Q, has an average of less than 0.5% clay and polyhalite, which could cause anisotropy. The test zone in QPP15 includes part of halite unit 0 and part of polyhalitic unit PH-4, which have different fractions of polyhalite and are likely to have different permeabilities. In both test zones, the vertical permeability would be expected to be less than the horizontal permeability. Despite these limitations in the validity of the assumption of isotropy, field tests for anisotropy require measurement of pressure perturbations at multiple points around the test zone, which would not have been feasible in the nearly impermeable halite. Further, the test results are likely to be biased toward the higher conductivity flow directions and, therefore, conservative for purposes of performance assessment. Given the limitations in field testing and the conservative nature of the test interpretations, the assumptions made in test design and analysis are adequate and appropriate.

4.5.3. Alternate Interpretation

In very low permeability media such as pure halite the influence of molecular forces not considered in Darcy flow may become significant and cause a model (BRAGFLO) based on Darcy flow to overestimate flux. However, the Darcy flow assumption is clearly shown to be appropriate for impure and disturbed halite, based on the success in modeling pressure changes during tests in these more permeable media, and provides a conservative approach to BRAGFLO modeling. On the basis of these observations, the Darcy flow model is considered adequate and appropriate for both test analysis and performance assessment.

4.5.4. Uncertainty and Consequences

The interpretations made in analyzing the test results are acknowledged in SAND96-0435 (p. 27) to carry a high relative uncertainty. A general discussion of test uncertainty is presented in SAND96-0435 (p. 23). In both QPP05 and QPP15 the principal uncertainty results from the aforementioned lack of a clear indication of fluid movement in the halite. This response is appropriately considered by SNL to indicate that the undisturbed halite has a very low permeability. This response is not likely to have resulted from an equipment or design problem because fluid movement was detected in these test zones when the halite was disturbed and the permeability increased following excavation of Room Q. Because of a lack of formation response in the undisturbed halite, the key parameter of formation pressure could not be measured or approximated from the test data, and instead was estimated from the results of other pressure measurements at Room Q and elsewhere in the repository, the applied lithostatic pressure, and an awareness of the very low permeabilities of the test zones.

Permeability is sensitive to formation pressure, and the lack of formation pressure data resulted in a non-unique and therefore uncertain estimate of permeability. The published test results, 1.1E-24 m^2 for QPP05 and 5.4E-24 m^2 for QPP15, should therefore be considered rough, order-of-magnitude estimates and not precise quantitative values. This conclusion is also noted in SAND96-0435 for both tests, where it is stated: "The sole purpose of presenting this simulation is to provide an indication of how low the transmissivity of the QPP05 test zone would need to be to produce the observed pressure responses." (See p. 46 and a similar statement for QPP15 on p. 81.)

The test results support the conclusion that the test zone permeabilities are very low. Based on the sensitivity of the test design and instrumentation inferred from the results obtained in other boreholes, the test zone permeability in QPP05 and QPP15 is probably less than 1.0E-22 m^2, and values on the order of 1.0E-24 m^2 are considered reasonable estimates. The consequences of errors in these estimates are not

likely to be significant if they are properly used as lower bounding values for undisturbed halite in the performance assessment.

4.5.5. Appropriateness and Limitations of Methodology and Procedures

The test design and analysis methodology and procedures closely approximate the state-of-the-art at the time they were performed and are well described in SAND92-1172 and SAND96-0435. The test procedures were appropriately implemented and no interference was detected from adjacent tests or activities prior to mine-by. Brief compressibility tests conducted to detect air trapped in the test zones and power supply problems in QPP15 did not appear to influence test results.

The principal limitations of the approach are related to the difficult task of measuring test-induced pressure responses in the field in very low permeability rock in relatively short periods of time. Although the test methodology was appropriate for most of the test zones around Room Q, it was not capable of measuring the very low permeabilities in QPP05 and QPP15. Another limitation of the undisturbed halite tests is the assumption of two-dimensional, radial flow in test analysis. This limitation is discussed in SAND96-0435, but is of relatively minor consequence compared with the already large uncertainty in the QPP05 and QPP15 results.

4.5.6. Adequacy of Application

The undisturbed halite permeability values from the QPP05 and QPP15 tests are appropriate for use in performance assessment, with the aforementioned limitation that they be considered lower bound rather than precise, quantitative values.

4.5.7. Accuracy of Calculations

Although the data were analyzed where feasible using published analytical solutions (SAND96-0435, p. 20), the primary data analysis tool was the numerical wellbore simulator GTFM 6.0. Although no checks were made of the numerical model results, the hand calculations were spot-checked and found to be accurate.

4.5.8. Validity of Conclusions

The results from QPP05 and QPP15 are among the lowest permeability values measured in the Salado halites and were properly used to establish a lower bound of 1.0E-24 m^2 for the permeability of the Salado halite in the performance assessment model. Uncertainty in the halite permeability is accounted for by establishing an upper bound of 1.0E-21 m^2 and assuming a uniform distribution between the upper

and lower bounds. The basis for these limits is explained in the SNL memos Davies to Tierney dated March 7, 1996, and Lappin and Beauheim to Harper-Slaboszewicz dated May 15, 1996. In summary, permeability measurements made at distances of greater than approximately 10 m from the underground workings are considered to represent undisturbed conditions as demonstrated by an approximate stabilization of both pore pressures and halite permeabilities.

The trend of the supporting permeability data presented in the SNL memos was informally compared by the peer review team with pre-mining permeability estimates from Room Q borehole tests that were made at a distance of about 23 m from the underground workings. These are technically adequate for comparative purposes, but were apparently not considered by SNL as supporting information because they were not obtained under current QA standards. Permeability data from five of the six Room Q borehole tests for which halite permeabilities were estimated were found to lie within the range of values used in the PA.

Review of undisturbed halite permeability data supports the range of values used in the WIPP PA, and the lack of a central tendency due to the scatter in the data supports use of a uniform distribution. The results obtained from the QPP05 and QPP15 borehole tests, and the use of those results in supporting the WIPP PA are reasonable and appropriate.

The results from QPP05 and QPP15 are among the lowest permeability values measured and were properly used to establish a lower bound of 1.0E-24 m^2 for the permeability of the Salado halite in the performance assessment model as reported on Forms 464 WPO 34397, WPO 34399, and WPO 34401, entered 3/6/96.

4.5.9. Dissenting Views

None.

4.6. Undisturbed Anhydrite Pressure

This section reviews the data from which the brine far-field pore pressure in Salado MBs 138 and 139 were derived.

Parameter:	Brine far-field pore pressure
ID#:	569
Form 464:	WPO 34863, entered 2/13/96
ID#:	590
Form 464:	WPO 34532, entered 2/13/96
Parameter Package:	WPO 31185
Distribution:	Student-t
Parameter Values:	Mean: 11.63E+06 Pa
	Median: 11.63E+06 Pa
	Std. Dev.: 1.273E+06 Pa
	(**Note:** no upper or lower bound was placed on the range to be sampled)

Definition: The brine far-field undisturbed anhydrite pore pressure is that pressure exerted by brines existing within the interconnected pore spaces of the Salado anhydrite beds 138 and 139 in regions sufficiently remote from mining, drilling, and other human activities that might disturb the environment.

Intended Use: The brine far-field pore pressure is used in BRAGFLO as the initial pressure in these anhydrite marker beds. Anhydrite beds exhibit higher permeabilities than the surrounding halite and represent potential pathways to the accessible environment. Consequently, the initial pressure must be reasonably well known in order to calculate the influx of waste-contaminated brine into these units.

Derivation: The parameter was derived from tests in boreholes QPP03, QPP13, C2H02, L4P51-C1, and SCP01-A. At the beginning of these tests the test zones were cleaned, packers installed, the test and guard zones filled with NaCl saturated brine to a low initial pressure, and the holes shut in. The

subsequent pressure buildup toward static conditions, along with the rest of the borehole history (e.g., the length of time that the borehole was left empty after being drilled), was modeled with the code GTFM 6.0 to estimate the undisturbed pressure. The five results of this modeling were averaged to obtain the mean of 11.63E+06 Pa. The standard deviation reported on Form 464 was calculated from $\sqrt{\{[n\Sigma x2 - (\Sigma x)2]/n2\}}$, which applies to an entire population.

Discussion: The five boreholes investigated pressure histories in different anhydrite beds and at different locations. QPP03 was drilled at a small upward angle from horizontal above Room Q; QPP13 at about the same angle downward below Room Q; C2H02 westward at 45° downward from room C2; SCP01-A at 13° below horizontal at S45°W from the Core Storage Library; and L4P51-C1 vertically downward from room L4. Most of the interval tested in borehole QPP03 lies within the lower part of map unit 9 of the Salado, but it also intersects anhydrite bed b, to which most of the flow and pressure buildup is attributed. Most of the test zone in QPP13 lies in MB 139. Hole L4P51, as originally drilled, intersected MB 139, underlying halite, polyhalitic halite, and clay D. Later it was deepened to intersect MB 140 within which tests labeled L4P51-C1 were performed. Only data from boreholes QPP03, QPP13 and C4P51-C1 require qualification.

4.6.1. Adequacy of Requirements and Criteria

One objective of the analysis was to provide initial pore pressures for input to BRAGFLO. The formation pressure is also needed for the design of effective plugs and seals for waste panels and evaluation of backfill performance. No written requirements or criteria were found in the relevant documents; however, the data must satisfy these objectives.

The procedures for obtaining the formation pressure were 1) measuring pressure buildup in shut-in boreholes for a limited time (short of achievement of constancy; for example, before the mine-by in Room Q), and 2) fitting the data with the code GTFM 6.0 to obtain the desired pressure. This constitutes an inverse problem.

Test conditions required for obtaining adequate data on the formation pressure in undisturbed anhydrite beds are:

1. Pressure buildup in the test zone in each borehole must result from inflow of brine dominantly from the anhydrite beds and not from other units (notably from halite rock).

2. The test tool must work properly.

3. The test must provide results from essentially undisturbed anhydrite.

4. The data acquisition system must work properly.

The first condition was addressed by: 1) Intentionally drilling boreholes into or through anhydrite beds, or using boreholes for which post-drilling examination showed the presence of anhydrite; 2) Using boreholes which intersected only halite and anhydrite, because data for halite and from zones drilled exclusively in halite indicate essentially zero permeability.

The handling of the second condition varied from hole to hole. In QPP03, the test-zone packer never functioned but the guard packer apparently did. The test consisted first of closing in the hole and observing the pressure rise, interrupted part way through by a pulse withdrawal of brine. The next stage consisted first of lowering the pressure in the test zone and excavating Room Q (a large borehole). Then the hole was shut in again and the pressure rise observed, followed by intentional withdrawals to measure brine flow. At that time the packer was removed and replaced by another one set up to isolate the same portion as before, namely from the guard packer to the end of the hole. Finally, the pressure rise was measured after the installation of the new tool. Because the post-mining test zone pressure began to stabilize at about the same level as during the first interval following the mine-by, it might be inferred that the guard packer in the initial shut-in test functioned correctly. This does not seem to be stated explicitly in the relevant documents, but is taken here, together with the consistency of results with other measurements, to indicate acceptability of the data.

The pressure recovery in borehole QPP13 following the pulse withdrawal was anomalous. This probably resulted from communication through the formation of the test zone with the guard zone, which was depressurized sometime between the day before the pulse test and about 20 days later (p. 62, SAND96-0435). Indeed, comparison of Figure 6-58 in SAND92-1172, test-zone pressure, with Figure 6-60, guard-zone pressure, suggests that this communication existed throughout the entire pressure buildup; the pressures are nearly the same, which would be consistent with slow leakage past the test-zone packer throughout the test. If so, the pressures measured in the test zone would likely be lower at any given time than they would have been had the test-zone packer been working correctly. In turn, this would have led to a low estimate in the undisturbed pressure as calculated by GTFM 6.0. The guard packer may have functioned properly, but no data were found to confirm this. This does not bolster confidence in the reliability of the results but, because the pressure attained is close to that found in hole QPP03, does not rule out acceptability.

A draft document (Chace 1996) provides some detail about the tests in L4P51-C1. The log for the hole indicates some problems with the tool, including replacement early in the test period, but the report does not discuss the interpretation of the data nor provide details of how the pressure curves were fitted. The information provided does not permit a full evaluation of the adequacy of the data.

The third condition, obtaining data from essentially undisturbed anhydrite, was addressed by drilling boreholes from the outermost portions of the excavations. In addition, for QPP03 and QPP13, pressures were measured both before and after a mine-by to evaluate the effect of excavation, thereby providing at least an approximate measure of the difference between disturbed and undisturbed conditions. Hole C2H02 was intentionally placed to intersect MB 139 below a rib (wall), rather than an excavation in order to minimize the effects of mining on the test. Hole SCP01-A was drilled from the Core Storage Library because that excavation was only ten months old at the time and no other excavations existed nearby. The test zone was 10 m from the excavation. Both of these conditions tend to minimize the effect of mining on the test. L4P51, however, was bored vertically downward from Room L4, which is less desirable from the perspective of meeting this third condition.

The fourth condition, proper functioning of the recording equipment, was met, as evidenced by the large amount of data plotted in graphs (e.g., Figures 6-17 to 6-23, SAND91-1172). Whereas some of this equipment did fail, it did so only after the tests relevant to this parameter were completed.

In summary, it is clear that not all of the requirements were met for tests in all boreholes. This casts some doubt on the adequacy of the data for the intended purpose.

4.6.2. Validity of Assumptions

Heavy reliance was placed on the use of the code GTFM 6.0. Assumptions used in the development of this code were (Pickens et al. 1987): 1. The formation whose response is being simulated is homogeneous (vertically), is confined, has a constant thickness, and has a finite radius centered upon the borehole. 2. The major influences on the formation behavior are the borehole and conditions imposed in the borehole. 3. All flow is radially away from or toward the test interval of the borehole. 4. The pressure in the formation is uniform and constant radially at the start of a drilling period or a test sequence. 5. The borehole and formation fluids are homogeneous within the test interval. 6. The effects of fluid temperature changes in the formation may be neglected in comparison to any thermally induced pressure changes in the borehole during testing.

Because the anhydrite beds in question are confined between significantly less permeable halite zones, assumption 1 appears reasonable. Assumption 3 involves the additional assumption that, although the flow into the borehole was from beds that were, in most cases, not perpendicular to the hole, an equivalent radial flow can be considered adequate. This is of greatest concern for holes QPP03 and QPP13 because the deviation between the plane of the bed and the direction of the hole is notably larger than 75°, the maximum deviation to which the equivalent flow has been evaluated as resulting in little error (SAND96-0435, p.22). Nevertheless, consideration of the likely consequences, the geometry of the hole and anhydrite beds, and the constraints on flow directions, it seems likely that little error, compared to other uncertainties, would have resulted. Thus, assumption 3 appears to have been sufficiently well satisfied. In respect to assumption 6, temperatures were measured in the test zones in boreholes L4P51-C1 (and, incidentally, in C2H02 and SCP01A); temperatures varied by only a few tenths of a degree C. Thermocouples were also mounted outside the test zone in holes QPP03 and QPP13. Comparison with Figure 7 in Pickens et al. (1987) suggests that this would produce correspondingly a few tens of meters of water head change (i.e., a few tenths of a MPa). This is small compared to the measured pressures and their uncertainties.

Assumption 2 is handled through knowledge of the borehole conditions as required for input to the code. The remaining assumptions, 4 and 5, are judged adequate for the intended use and application.

Assumptions stated in SAND96-0435 are that hydraulic properties are constant during the test (Section 6.2) and flow is radial toward borehole (Section 6.3). The latter implies an isotropic state, which, as pointed out in the report, probably does not correspond to the actual case in anhydrite. A second assumption in Section 6.3 is that the equivalent-vertical-borehole approach is acceptable for QPP03 and QPP13 (see discussion above). For some boreholes, available data show that the assumptions on homogeneity, isotropy, and radial flow seem to have been met. On this basis, these assumptions are judged to have been adequately met for this parameter.

4.6.3. Alternate Interpretation

An alternative to the representation that the measured pressures and modeling produce reasonable far-field pore brine pressures is that most of the measured pressures are low, for one reason or another. The expectation was that the formation pressure for the Salado undisturbed anhydrite should be approximately lithostatic, about 14.8 MPa (SAND92-1172, p. 3). By contrast, the formation pressure derived from modeling is considerably less, about 11.63 MPa. Also expected is that the undisturbed anhydrite pressure would approximately, if not exactly, equal the undisturbed halite pressure. Form 464

for the undisturbed halite pressure (WPO 34394) lists a mean and median of 12.47 MPa; on this Form 464 the parameter name is "Brine far-field pore pressure." See Section 4.2 of this report for discussion of the reliability of these data. The parameter name on the Forms 464 WPO 34532 and 34863, corresponding to the parameters under evaluation here ("Undisturbed Anhydrite Pressure"), is the same: "Brine far-field pore pressure." For these purposes the designation "undisturbed" is taken to mean conditions sufficiently far from any drilling or excavation that no perceptible effects from these operations have occurred. Thus, the various data and expectations appear inconsistent. This suggests that the various problems encountered during testing, perhaps exacerbated in some cases by the long times that corresponding holes were left open, gave rise on average to a somewhat low mean value. If, in spite of some indications that the guard packers in boreholes QPP03 and QPP13 operated properly, they instead leaked slightly, then the measured pressures in these boreholes could have been systematically low.

An observation that may explain a low measured pressure in borehole C2H02 was the presence of 91% hydrogen in gas recovered at the end of the test. This hydrogen evidently resulted from the corrosion of aluminum components of the tool caused by the reaction of water with the metal, producing aluminum oxides and hydroxides, and thereby reducing the partial pressure of water and increasing that of hydrogen in the pores. Hydrogen is notorious for its high rate of diffusion through most materials; possibly it diffused through the packers, thereby resulting in the rather low measured pressures. The net result of these changes is not obvious, but almost surely would produce some net change in the pressure. No statements were found to the effect that the modeling code GTFM 6.0 can take this gas pressure buildup into account and compensate for it. It is concluded that use of the pressure data from this hole is questionable, without evaluating the resultant change.

Because the pressure is measured directly, alternate interpretations (such as that above) could only mean that the formation pressure is different than that obtained by the fitting and modeling procedures. These procedures are intended to compensate for the fact that it was impractical to run the tests long enough to reach steady state conditions and to take into account several disturbing factors (e.g., conditions prior to the beginning of the test and temperature effects on pressure).

4.6.4. Uncertainty and Consequences

Numerous difficulties in conducting the tests gave rise to notable uncertainty. For tests conducted in association with Room Q, these problems are described in SAND96-0435 (p. 9) where failure of closure measurement devices is noted (p. 14), where computer failure is noted (p. 19), where it is pointed out that

the shut-in tests were not run for as long as should ideally have been done (p. 24), and specific tests described in Section 7 -- pressure changes caused by changes in packer-inflation pressures, movement of test tools, leaks around the packers, etc. The discussion on pp. 23-24 also indicates that there is some uncertainty as to the actual stratigraphy within the test zone, including the thickness of the anhydrite beds. In QPP03 the test-zone packer never functioned. After the flow test in QPP13 the test tool in this hole was replaced and the test region was filled with nitrogen and shut-in. This resulted in initially slow pressure buildup in the subsequent test. The anomalous pressure recovery after the pulse withdrawal was interpreted as communication with the guard zone. Test-zone and guard-zone packer pressures are poorly documented, and an apparent release of test-zone pressure is undocumented. Late in the test in QPP13, test-zone pressure decreased and was evaluated as probable equipment failure. In addition, of course, there is always some uncertainty in parameters obtained by fitting curves to data. These potential sources of error gave rise to concern by the panel on the adequacy of the data.

The alternative interpretation presented in Section 4.6.3 could be viewed as, in effect, a statement about the uncertainty. The estimated lithostatic pressure, 14.8 MPa for the anhydrite bed at the repository level, differs by more than two standard deviations from 11.63 MPa. The halite brine far-field pore pressure, 12.47 MPa (WPO 34394) lies less than one standard deviation (WPO 34532) above 11.63 MPa, and 11.63 MPa lies just slightly more than one standard deviation (WPO 34394) below 12.47 MPa. The number of data points (five) is small. Difficulties encountered for three of the boreholes give reason to view the derived pressures with some skepticism. The pressure for a fourth well, L4P51-C1, seems anomalously low. The pressure for C2H02, 11.11 MPa, lies well below the expected lithostatic pressure and below the average of all five data points. Also, at the conclusion of the test in C2H02, a high content of hydrogen was detected in the gas and brine collected, indicating corrosion of the aluminum parts. The effect of this corrosion on brine pressure remains unknown. The corrosion reaction would result from reaction of water with metal to produce aluminum oxides and hydroxides plus hydrogen. Presumably, the consumption of the water would cause pressure changes in the brine.

Some potential impacts of uncertainties were not discussed. Specifically, leaving the test regions of borehole QPP03 open for one month and QPP13 open for two months prior to shut-in may have allowed the rock surrounding the holes to dry out partially. The subsequent filling of the test and guard zones with brine would presumably result in imbibing some of this brine into the walls of the holes. It is rather unlikely that this brine would have been in equilibrium with the rock and, through dissolution or precipitation of soluble solids such as halite and anhydrite, would likely have changed the hydrological properties. The swabbing of QPP13 prior to testing may have produced a similar effect. This type of

impact appears not to have been evaluated. Nevertheless, any effect should be limited to the vicinity of the boreholes (i.e., within the "skin") and, because the analysis discounts changes in that zone, should not have affected the quality of the data. Thus, only one test, in SCP01, appears to be free of recognized concerns.

4.6.5. Appropriateness and Limitations of Methodology and Procedures

As indicated in the previous sections, the methodology was appropriate and the intrinsic limitations of the methodology are acceptable. In practice, several difficulties arose which make the appropriateness of the data for the intended application doubtful. Several documents describe the procedures (e.g., SAND92-1172, SAND96-0435, SAND90-7000, and SAND90-7072). No information was lost as a consequence of the computerized data reduction used for pressure data..

4.6.6. Adequacy of Application

As indicated in preceding sections, it appears that data from only one borehole are entirely free of doubts about their accuracy. It is hard to justify using data from a single hole as being representative. Reasons for doubt include partial failures of the downhole tools, communication between guard and test zones, lack of documentation of pressure changes induced by temperature changes and tool corrosion, and discrepancies with the undisturbed halite pressure and the estimated lithostatic pressure.

4.6.7. Accuracy of Calculations

No hand or spreadsheet calculations were found in the relevant documents. Hand calculation of the mean of the mean pressures derived from the GTFM 6.0 fits for the five boreholes confirmed the mean reported on the Form 464. The results of the computer calculations fit well with the measured data and visual extrapolation from the plots for boreholes QPP03 and QPP13 to estimate the pressure that would result from extremely long tests matches the derived formation pressures satisfactorily. Pickens et al. (1987) cite several examples of comparison calculations using other codes and applied to several problems; all show good agreement with the GTFM 6.0 calculations for the same cases. All these results indicate that the calculations are sufficiently accurate.

4.6.8. Validity of Conclusions

In evaluating the adequacy of the data for their intended use, the Panel considered the impact of using the questionable data on conservatism. It was agreed that low undisturbed anhydrite pressure values would lead to higher rates of flow and enhanced estimated releases from the repository. Thus, the consequence of using the data is to increase conservatism by some factor that only relevant modeling would reveal.

Moreover, a Student-t distribution, properly limited so as not to allow sampling of the distribution at pressures greater than lithostatic nor less than hydrostatic, would appropriately incorporate some of the uncertainties noted in preceding subsections into PA calculations. Because of the conservatism of the impacts and the uncertainty incorporated by means of the Student-t distribution, the data are found to be suitable for the intended use. Specifically, this refers to the mean value of 11.63E+06 Pa and the standard deviation of 1.273E+06 Pa reported on Form 464, WPO 34863, entered on 2/13/96.

4.6.9. Dissenting Views

None.

4.7. Salado Undisturbed Anhydrite Rock Compressibility

Three individual Form 464s listing bulk compressibility as a parameter for the Salado anhydrite beds a and b (ID# 521), the Salado MB 138 (ID# 560), and the Salado MB 139 (ID# 580), are provided in the Parameter Package. All three Form 464s list the identical values for the parameter and both beds a and b and MB 138 Form 464 are referenced to the analogue of COMP_RCK for MB 139.

Four data points given in the source document (SAND92-1172) were used to fit a Student-t distribution for the mean value of rock compressibility. These four data points, attached to the Form 464, are themselves the mean values of rock compressibility derived from GTFM 6.0 simulation of measurements from each of four boreholes drilled adjacent to Room Q. These boreholes are QPP03, QPP13, C2H02, and 5CP01-A. Only the data associated with boreholes QPP03 and QPP13 are required to be qualified by the peer review process to support this parameter.

Parameter:	Undisturbed Anhydrite Rock Compressibility (Bulk Compressibility)
ID #:	521, 560, 580
Form 464:	WPO 34135, 34439, 34574, entered 2/14/96
Parameter Package:	WPO 31186
Distribution:	Student-t
Parameter Values:	Mean: 8.263E-11 Pa-1
	Median: 8.263E-11 Pa-1
	Std Dev: 1.115E-10 Pa-1

Definition: The Salado anhydrite rock compressibility is the change in volume of the rock induced by an applied stress. The rock compressibility (CR) is considered the reciprocal of the rock's bulk modulus, i.e., CR = 1/K

where:

K = Bulk modulus, Pa

Intended Use: The intended use of the parameter anhydrite rock compressibility is for entry into the BRAGFLO model as the amount of change in the volume of anhydrite rock as a result of an applied stress, such as removal (withdrawal) of fluid from the interconnected pore spaces (effective porosity).

Derivation: The anhydrite rock compressibility values are obtained from GTFM 6.0 simulation of pressure vs time data, collected from specific boreholes having test zones within the anhydrite, and using specified ranges of input parameters for fluid density, formation porosity, and fluid compressibility in Domenico's (1972) equation for Specific Storage, Ss:

$$Ss = \rho f g(\alpha + \phi\beta)$$

where:

ρf = fluid density

g = acceleration of gravity

α = vertical formation compressibility

ϕ = formation porosity

β = fluid compressibility

Knowing the volume of fluid released (Ss) during the testing period, the equation is rearranged and solved for α, the formation compressibility.

Discussion: In strict rock mechanics terms, the bulk modulus is considered as the slope of the pressure-volumetric strain curve in the elastic strain region after fissures have closed as a result of an applied stress. For the BRAGFLO model, the fissure closing region of the pressure-volumetric strain curve must be considered. Therefore, using only the reciprocal of bulk modulus (as obtained from laboratory testing of small rock samples) to calculate anhydrite rock compressibility using Green and Wang's (1990) equation, may underestimate the effect of fracture porosity in the anhydrite. The anhydrite rock compressibility values provided by GTFM 6.0 simulation employing a range of input parameters based on hydraulic tests of anhydrite in boreholes, using Domenico's equation, may provide more reliable values than may be obtained using bulk modulus.

4.7.1. Adequacy of Requirements and Criteria

The estimation of the undisturbed Salado anhydrite compressibility parameter was determined from tests conducted in boreholes (QPP03 and QPP13) around Room Q. The tests were designed to help reduce uncertainties about brine flow and provide information on the Salado formation pressure, permeability, and flow potential both within the zone of influence of the WIPP excavations and in the undisturbed far field parts of the Salado. Thus, in that sense, the results of the interpretation of the data provided from the tests met the adequacy of requirements, although there are minor limitations on the interpretations as discussed in SAND96-0435.

4.7.2. Validity of Assumptions

The major assumptions used in the performance of the tests conducted on boreholes QPP03 and QPP13 were: 1) fluid flow is radial toward the test boreholes; 2) the hydraulic test responses in the test zones of the slanted boreholes can be accurately portrayed by an equivalent vertical borehole geometry, with length equal to the vertical thickness of the tested strata and a borehole diameter equal to the average of the major and minor axes of the ellipse formed by the intersection of the slanted borehole and a horizontal plane; 3) fluid flow obeys Darcy's Law; and 4) borehole closure and Darcy flow are the only forms of pressure/flow transmission during the hydraulic testing in undisturbed anhydrite.

The validity of these assumptions is supported by the analysis and interpretation of the data as presented in SAND96-0435. For instance, the best fit match points on the curves of pressure flow test and pressure buildup test data are those for radial flow, and the data can be modeled quite reliably using analogs with Darcy flow. Numerical modeling of the slanted borehole equivalent borehole geometry indicates that the tests can be interpreted with little error for boreholes with slants up to 75° from vertical and for horizontal-to-vertical permeability ratios greater than or equal to 10 (SAND96-6435, p. 22). However, it was concluded that "the tests of anhydrite layers conducted in bores QPP01, QPP03, and QPP13 can probably be interpreted reliably using the equivalent-vertical borehole approach" (SAND96-6435, p.22).

4.7.3. Alternative Interpretations

As reported in SAND96-0435, for many analyses of pressure data, there is often more than one method of analysis that can be applied and more than one interpretation of analyses results. For instance, the test results for QPP13 post-mining, test zone pressure were analyzed by four GTFM 6.0 simulations (SAND96-0435, pp. 62 - 71); i.e., test-zone pressure vs time, brine production vs time, brine flow rate vs time, and post-flow test pressure buildup. The specified and fitted parameters were the same for all four simulations, which showed an anhydrite test zone compressibility value of 1.0E-09 Pa^{-1}.

4.7.4. *Uncertainty and Consequences*

SAND92-1172 is a data report and, consequently, does not contain a discussion of uncertainty of results. SAND96-0435, on the other hand, is an interpretative report and data uncertainties are discussed, although the consequences of the uncertainties are not discussed.

There was no direct identification (i.e., measured core from the borehole) of the stratigraphic interval being tested in the borehole. Thus, it is possible that the test-intervals could overlie units above or below the expected test stratigraphic zone. However, post-testing video logging completed on the boreholes verified the position of the test zones in selected boreholes.

Although there is uncertainty in some of the data (for instance, the anomalous pressure recovery after the pulse withdrawal in borehole QPP13 during day 151 [1989] of the pre-mining period was probably due to communication with the guard zone which was depressurized at the time, according to SAND96-0435 [p.62]), the uncertainty associated with the cumulative data appear to be low enough so that decisions can be made, as shown by the numerous examples of the interpretation of the data through numerical simulation in SAND96-0435 (Section 7.2 Test Interpretation, p. 114).

In addition, the late-time data of the pressure recovery following the flow test shows a decreasing pressure trend for well QPP13 (SAND96-0435, Fig. 7-54, p. 66), which has been attributed to equipment problems and not changes in the formation properties, although limited storage of brine in the formation may have contributed to the pressure decline.

Based on the review of the source documents and the interpreted values for undisturbed Salado anhydrite compressibility, it seems evident that the range of values presented are a reasonable estimation of true values that might be expected in far field conditions.

4.7.5. *Appropriateness and Limitations of Methodology and Procedures*

The testing apparatus used at the time was state-of-the-art equipment fabricated from off-the-shelf components which, to a large extent, dictated the methodologies and procedures used to measure pressure and permeability directly in the boreholes. The description of the test equipment, tool installation, test startup and results of testing, as presented in SAND92-1172, indicate that the test procedures were correctly implemented.

Data from the tests were reduced for presentation in SAND92-1172 by sorting according to borehole number, recording time, and measurement type, calculating all measurements to a time interval since

zero-hour, converting all measurements from U.S. to metric units, and filtering out redundant values with a data filter. In addition, it is apparent by viewing the graphs of pressure vs time of the test zone pressures (SAND92-1172) that the reduced data are representative of the collected data.

The SAND96-0435 report contains the results of interpretations gleaned from analyses of the data using standard and customized analytical and numerical methods, which were appropriate for the data.

A review of SAND92-1172 and the conclusions in SAND96-0435 indicates that the assumptions, calculations, extrapolations, methods and conclusions pertinent to the data were appropriate for the development of the parameters to be used as input to the WIPP PA.

4.7.6. Adequacy of Application

The SAND96-0435 report provides interpretation of the results (i.e., values for required parameters) from analytical and numerical simulation of the data that demonstrates the adequacy of the application.

A visual comparison of the various graphs (Figures 6-17 through 6-25, SAND92-1172) for test zone pressure, packer pressure, and guard zone pressure in borehole QPP03, against similar graphs (Figures 6-26 through 6-31) for borehole QPP04 (the closest borehole to QPP03) indicates no obvious interference effects between the two boreholes. A visual comparison of QPP13 vs QPP14 also reveals no obvious interference effects between the two boreholes.

The description of the test equipment, tool installation, test startup and results of testing presented in SAND92-1172 indicate that the test procedures were correctly implemented.

SAND92-1172 is a basic hydrologic data report for tests conducted at Room Q. It summarizes thousands of data points into simplified diagrams to illustrate graphically the results of the testing. An explanation of corrective actions for the testing is presented in SAND96-0435, the interpretative report for the Room Q tests.

There are no specific statements regarding data reliability in SAND92-1172, although it can be inferred from the operational logs of each borehole (Appendix C) that the data can be considered reliable by the reason that poor data are specifically identified in the QOC and CAC section of the operational log.

The close match of the simulated flow rate to that measured during the tests (Fig. 7-16, p. 39, SAND96-0435) suggests that the hydraulic properties of the formation and the near-borehole region are adequate for their intended use.

The processes used to produce the parameters involved the collection of the field data (measurements of *in situ* rock properties, e.g., pore pressure, brine flow, and temperature over time), the filtering, reduction, cataloging, and presentation of the data in data plots, and the interpretation of the data through the use of analytical and numerical techniques. These processes are appropriate to produce the parameters for their intended use in the BRAGFLO model.

4.7.7. Accuracy of Calculations

Neither source reference (SAND92-1172 or SAND96-0435) contains calculations that can be checked for accuracy. The calculations are all completed within the analytical and/or numerical models and GTFM 6.0 simulations. Because the GTFM 6.0 simulations provide such close fits to the collected data, it is assumed that the calculations have been done accurately.

4.7.8. Validity of Conclusions

The graphs and charts of the results of interpretation from various numerical model simulations of pressure vs time for QPP03 and QPP13, as presented in SAND96-4035, demonstrate the validity of the conclusions regarding the testing of the Salado evaporites. Those conclusions are that the changes in hydraulic properties and pore pressures can be attributed to one or a combination of three processes: stress reduction, changes in pore connectivity, and flow toward Room Q. Due to redundancy in data of the same type of tested intervals, interpretation of the data has provided several reliable estimates of anhydrite compressibility.

4.7.9. Dissenting Views

None.

4.8. Brine Salt Mass Fraction

The adequacy of values obtained for brine chemical analyses (salt mass fraction = 32%) from samples 195776, 195777, 195778, and 195779 are addressed in this section. The brine was sampled from the floor of Room Q in late 1991 and early 1992 by either sponge collection or vacuum techniques. The brine samples were then sent to Chem-Nuclear Geotech Lab for chemical analyses. Specific elements were analyzed by flame atomic absorption spectrometry, inductively coupled plasma atomic emission spectrometry, and ion chromatography. Specific gravity and Total Dissolved Solids (TDS) values were obtained by comparison to deionized water and EPA Methods 160.1-160.4, respectively. The brine salt mass fraction was calculated by dividing TDS by specific gravity. The objective for brine salt mass fraction determination is as follows. The final value will be used for density calculations and determination of amount of pure water available for chemical reactions.

The parameter description is as follows:

Parameter:	Brine Salt Mass Fraction WTF 57 (Mass Fraction of Salt and Brine)
ID#:	57
Form 464:	WPO 31552, entered 2/13/96
Parameter Package:	WPO 31171
Distribution Type:	Student-t
Parameter Value:	Mean: 0.324
	Std Dev: 0.00983
	Minimum: 0.302
	Maximum: 0.332
Definition:	The TDS (Kg/L) of a brine divided by its specific gravity (Kg/L).
Intended Use:	Parameter will be used for density calculation and pure water budget determination.

Derivation: Brine samples collected from Room Q and analyzed by Chem-Nuclear Geotech Lab for Total Dissolved Solids and specific gravity.

4.8.1. Adequacy of Requirements and Criteria

The requirements and criteria for this parameter determination are adequately defined. No rationale for obtaining this parameter was given in SAND92-1173. The Parameter Package states that the data were collected "for input to the WIPP Data Entry Form and for use by Performance Assessment personnel making parameter estimates." The criteria and requirements were adequately addressed in writing by an issue resolution response (memo, Christian Frear to Caporuscio, 5/15/96).

4.8.2. Validity of Assumptions

Originally, it is unclear what assumptions were used in making a determination of the Salt Mass Fraction. Two major assumptions should have been addressed, at a minimum. The assumptions are : 1) that the Room Q brine is representative of Salado Formation brine, and 2) that TDS is truly a good indication of dissolved ions in the brine. The first assumption was qualified by issue resolution. Hundreds of analyses were evaluated and these four samples represent halite brine. If anhydrite brine were included, the final mean value of salt mass fraction would be approximately 30%. The second assumption was also reasonably addressed by issue resolution (memo, Christian-Frear to Caporuscio, 5/15/96). Therefore the brine salt mass fraction value would be of use in estimating brine density in the Salado Formation.

4.8.3. Alternate Interpretations

The brine composition of the Salado Formation was determined solely from a series of four samples taken in Room Q. It would have been reasonable to take other brine samples from undisturbed locations in the repository to confirm that the brine is homogeneous. DOE/WIPP 91-009 contains 171 brine chemical compositions. These brine samples from the repository may be contaminated with fresh water used to abate the dust. This issue was addressed by the Principal Investigator, who concluded that the DOE/WIPP 91-009 values could not be referenced, but that the four samples in question are representative of halite brine.

4.8.4. Uncertainty and Consequences

Since the chemical compositions of the four brine samples were all the information provided for this parameter, it is difficult to assess the uncertainty of the results. There is an apparent difference between the TDS value and the sum of analyzed cations and anions for each brine sample (typically 10 to 14% difference). It was unresolved what the unidentified cations and anions were. This difference may have

a consequence if in fact the TDS analyses are systematically high. In fact, TDS is a reasonable value to use for this definition of salt mass fraction. A second uncertainty is the aforementioned question concerning the degree of homogeneity in Salado Formation brine. The consequence of the accuracy of this value involves how this parameter is used in BRAGFLO. Since this parameter is primarily used to calculate the density of the brine, it may not have large consequences if the results are variable.

4.8.5. Appropriateness and Limitations of Methodology and Procedures

Two items are worthy of discussion in this section for the determination of brine salt mass fraction. The items involve the actual physical collection of the brine in Room Q and the types of chemical analyses performed on the brines.

Of the two methods used for brine collection in Room Q, the vacuum technique would be preferable over that of collecting brine with a sponge. The former collection method dictates that an appreciable amount of liquid be present, while the latter can collect thin layers of fluid. Although the vacuum technique requires more brine to be present, it is much less likely that the brine will become contaminated. It was never apparent how the four brine samples of concern were collected. The reason for this concern is that one sample (195776) has a chemistry that is substantially different from the other three. It was found by issue resolution response that the sample with slightly lower values was collected by vacuum and a "small amount of sediment was left in the original sample bottle" (memo, Christian-Frear to Caporuscio, 5/15/96).

The chemical analyses of the brines may be questioned. Because of the systematic difference in the totals of the two analyses, it is presumed that TDS analyses determined a fuller suite of constituents.

Other than these two minor concerns, it is felt that the methods and procedures used to obtain the brine salt mass fraction parameter are appropriate.

4.8.6. Adequacy of Application

The brine salt mass fraction parameter, as calculated by TDS divided by specific gravity, is probably reasonable for the application of determining brine density.

4.8.7. Accuracy of Calculations

Without the accuracy and precision determinations of the analyses, one cannot determine the accuracy of the calculations. The final calculation to provide the mean value for the brine salt mass fraction is straightforward and would provide an adequate result.

4.8.8. Validity of Conclusions

The brine salt mass fraction value (32%) calculated from the chemical analyses of brine in Room Q is acceptable for halite brine. If anhydrite-bearing brine were included, the resulting mass fraction would be decreased to 30%.

4.8.9. Dissenting Views

None.

4.9. Brine Viscosity

The adequacy of Salado brine viscosity data is addressed in this section.

Parameter: Viscosity

ID#: 55

Form 464: WPO 31548, entered 2/16/96

Parameter Package: WPO 31168

Distribution: Constant

Parameter Value: 2.1 E-03 Pa-s (units of Pascal-second)

Definition: The viscosity of a fluid is the property that allows fluids to resist relative motion and shear deformation during flow. The viscosity, or dynamic viscosity, is equal to the shear stress divided by the velocity gradient.

Derivation: The viscosity data were developed from capillary viscometer measurements using brine collected from borehole QPB02. This borehole extends approximately 3.1 m into the floor of the repository, penetrating strata PH-4, MB-139, and H-4. The results of these measurements are described in SAND92-1911.

4.9.1. Adequacy of Requirements and Criteria

The requirements for the tests were not specifically stated in SAND92-1911, but are inferred to have been to obtain viscosity data for Salado brine over a range of temperatures, including the repository ambient temperature, for use in repository flow modeling. These requirements are adequate for purposes of the PA.

4.9.2. Validity of Assumptions

The tests were performed assuming the brine collected from borehole QPB02 was representative of Salado brines. The observed variations in Salado brine chemistry are not expected to significantly affect viscosity, and this assumption is considered adequate.

4.9.3. Alternate Interpretation

Viscosity is a well-known and routinely measured fluid property. No significant alternate interpretations need to be considered.

4.9.4. Uncertainty and Consequences

Uncertainties in the results of the viscosity measurements are discussed in SAND92-1911, p. 72. Brine flow rates are inversely related to brine viscosity in a linear manner; however, while the uncertainty in viscosity may be a few percent, the uncertainty in other parameters (such as permeability) may be orders of magnitude and would dominate the aggregate uncertainty in the flow calculation. The uncertainty in the brine viscosity measurements is expected to be low and of small consequence to the PA calculations.

4.9.5. Appropriateness and Limitations of Methodology and Procedures

The test methodology was not well described in SAND92-1911; however, standard testing equipment was used and the manufacturer's procedures for this test are expected to have been followed. Other, slightly lower values of brine viscosity have been used in previous WIPP-related studies and reports. These include values of 1.6 centipoise (cp) (1cp = 1.0E-03 Pa-s) in SAND88-0112 and SAND92-0533 for analysis of brine inflow experiments; 1.77 cp in TME 3153 1983 and EEG-17 1982 for studies of Castile brine reservoirs; and 1.8 cp in SAND92-0700/3 for the 1992 Performance Assessment. None of these values, however, appear to have been derived from direct measurement of Salado or Castile brines and are therefore considered less appropriate than the directly measured value of 2.1 cp selected for the CCA PA. Based on these observations, the methodology and procedures are considered to have provided appropriate Salado brine viscosity data for use in the PA.

4.9.6. Adequacy of Application

A single value of brine viscosity (2.1 cp) is used for Salado brines in the PA. Viscosity is temperature sensitive, and this value is for 28°C. This temperature is used elsewhere in the WIPP as representing ambient repository conditions (for example, SAND88-0112, p. 16). Although the repository temperature may rise several degrees from the heat output of the waste (CCA Appendix SCR Section 2.2.2), and temperature data from other sources suggest slightly lower ambient temperatures (on the order of 26.5 to 27°C -- see temperature data in SAND92-1172 for the Room Q borehole tests), the viscosity change in this temperature range is expected to be on the order of only -0.01 cp/°C. Small changes in temperature are therefore expected to have no significant effect on brine viscosity. Use of a single value instead of distributed values for viscosity is also expected to have little effect on the PA because of the relative

accuracy with which this value is known. Overall, application of this parameter to the PA is considered appropriate.

4.9.7. Accuracy of Calculations

The calculation of viscosity from raw test data was not checked; however, brine viscosity increases with increasing solute mass fraction, and comparison of the brine viscosity value proposed for the PA with projected values for NaCl solutions presented in the CRC Handbook of Chemistry and Physics (75th edition 1995, p. 6-246) indicates that a viscosity of 2.1 cp is reasonable and appropriate for the solute mass fraction of 32.4% used in the PA. Minor changes in solute mass fraction will have relatively minor effects on brine viscosity.

4.9.8. Validity of Conclusions

The constant value of 2.1 cp for brine viscosity is reasonable and appropriate for use in performance assessment.

4.9.9. Dissenting Views

None.

4.10. Brine Density

This section reviews the estimation of the Salado brine density. The information about the parameter presented in the Form 464 is as follows:

Parameter: Brine Density

ID#: 49

Form 464: WPO 031541, entered 2/2/96

Parameter Package: WPO 31175

Distribution Type: Constant

Parameter Value: 1,220 kg/m3

Definition: The Salado brine density is defined as the density of brine at the WIPP site at the approximate depth of the repository. Brine density is a function of temperature and pressure.

Intended Use: The intended use of the Salado brine density is as one of the initial scientific parameters in BRAGFLO. In BRAGFLO, the Salado brine density is calculated as a function of pressure based on the assumption that the Salado brine compressibility was assumed to be a constant.

Derivation: The Salado brine density was estimated based on the Brine Sampling and Evaluation Program (BSEP) Phase II Report (DOE/WIPP 87-010). The measured brine density values were presented along with the geochemical analysis results (Table 3-1, page 27, DOE/WIPP87-010) based on the ten samples collected from April 1987 to June 1987. The mean of the ten values of the measured brine density is 1,220 kg/m3, with a maximum value of 1,224 kg/m3 and a minimum value of 1,215 kg/m3.

4.10.1. Adequacy of Requirements and Criteria

The requirements and criteria for estimation of the Salado brine density were not defined in the referenced documents. Based on the intended use, the parameter should adequately represent the average formation fluid density in the vicinity of the repository. This requirement is satisfied by the sampling processes.

4.10.2. Validity of Assumptions

No assumptions were stated specifically for brine density estimation. In the BSEP Phase II Report, it was stated that the ten brine samples were collected by repeatedly bailing over a sufficiently long period of time so that any contamination resulting from compounds introduced during drilling is considered minimal. The brine samples collected from the bottom of those 15-m drillholes were considered to result in some mixing of brine from discrete sources. In addition, the locations of these boreholes include upholes and downholes monitored during the BSEP in Rooms A1, A2, A3, B, and G. Therefore, the collected data were assumed to well represent the spatial variability.

4.10.3. Alternate Interpretation

Density is a well known and routinely measured fluid property. No significant alternate interpretations need to be considered. However, another set of data was found in the BSEP 1989 report (DOE/WIPP 91-009). In that report, analytical results of 169 additional Salado brine samples were presented for geochemical analysis, including brine density. The values of brine density in this report present a slightly greater variation than reported in the Phase II report (DOE/WIPP87-010), ranging from 1,140 kg/m^3 to 1,260 kg/m^3. However, most of the values are equal to 1,220 kg/m^3, which is identical to the mean value reported in the Form 464.

Therefore, the additional brine density measurements in the 1989 report are in support of the conclusion presented in the Form 464. Since the sample size from the BSEP 1989 report is much larger than the Phase II report, support from these additional data makes the conclusion more representative of the Salado Formation brine density.

4.10.4. Uncertainty and Consequences

Uncertainties and consequences of the estimated results were not discussed in the related documents. Brine density is used in many ways, such as in estimation of fluid pressure and fluid compressibility. If brine density estimation is off by a few percent, the impact on fluid pressure or fluid compressibility is limited. In addition, fluid pressure and fluid compressibility will not dominate the aggregate uncertainty in the flow and transport calculations in the PA calculations. The uncertainty in the Salado brine density estimation is expected to have minimal consequences on the PA evaluations.

4.10.5. Appropriateness and Limitations of Methodology and Procedures

The brine samples were collected with care regarding the representativeness of naturally occurring Salado Formation brines for the geochemical analysis, as documented in the BSEP Phase II report.

Measurement of fluid density in the laboratory is a standard procedure. For these reasons the methodology and procedures are judged to be appropriate and acceptable.

4.10.6. Adequacy of Application

The Salado brine density was estimated to be a constant in the Form 464. As fluid density is a function of pressure and temperature, it is necessary to provide the reference conditions for the estimated value. However the calculation of the brine density under the *in situ* conditions by the reviewer illustrated that the change of the density with pressure was negligible. Thus, the estimated Salado brine density is adequate for the intended application.

4.10.7. Accuracy of Calculations

The calculation was checked and the results are the same as provided in the Form 464.

4.10.8. Validity of Conclusions

The estimated average Salado brine density of 1,220 kg/m^3 provided in the Form 464 is adequate for the intended use.

4.10.9. Dissenting Views

None.

4.11. Brine Compressibility

Brine Compressibility is a parameter used in the BRAGFLO modeling of fluid movement into and out of the repository. The parameter description follows:

Parameter: Brine Compressibility

ID#: 48

Form 464: WPO 31540, entered 2/9/96

Parameter Package: WPO 31174

Distribution Type: Constant

Value: 3.1E-10 Pa-1

Definition: Compressibility of brine in the Salado Formation. Brine compressibility is

$\beta = 1/Vw\ (\partial Vw/\partial pf)T$

where:

β = brine compressibility,

Vw = volume of a given mass of brine,

pf = fluid pressure

Intended Use: Used as input for BRAGFLO modeling of fluid movement into and out of the repository.

Derivation: Brine Compressibility was developed from reported values for laboratory brine composed of NaCl dissolved in distilled water and from reported values of the compressibility of water saturated with gas.

4.11.1. Adequacy of Requirements and Criteria

No written requirements or criteria were found in the primary documents. However, the brine compressibility value supplied to BRAGFLO must satisfy the requirements of the PA. It must adequately represent the physical behavior of the brine and not introduce significant uncertainty that is not treated by

the PA modeling. It is reasonable to expect the physical behavior of the Salado brine to be close to the behavior of the laboratory brine. The amount of uncertainty introduced due to the effects of dissolved gas and dissolved chemical species is not significant compared to the uncertainties in other model parameters that are treated via frequency distributions.

4.11.2. Validity of Assumptions

No significant assumptions were involved in developing the value for brine compressibility.

4.11.3. Alternate Interpretation

No alternate interpretations are relevant to brine compressibility.

4.11.4. Uncertainty and Consequences

The uncertainty related to brine compressibility is so low compared to uncertainties related to other parameters used in Salado modeling that it should have no significant effect on the PA.

4.11.5. Appropriateness and Limitations of Methodology and Procedures

As indicated in the preceding sections, the method of estimating brine compressibility using values reported in the literature was appropriate and the limitations of the method are acceptable.

4.11.6. Adequacy of Application

The application of a value for brine compressibility obtained from the scientific literature is acceptable and reasonable. The value selected is consistent with other values reported in the literature.

4.11.7. Accuracy of Calculations

No hand calculations or spreadsheet calculations related to brine compressibility were in the primary references. Inspection of other brine compressibility values reported in the scientific literature indicated that the brine compressibility value is reasonable; therefore, any calculated values, such as converted units, must have been properly executed.

4.11.8. Validity of Conclusions

As indicated in the preceding sections, the compressibility value developed for input to the PA model is an adequate representation of Salado brine compressibility, and the uncertainty related to the value is not significant.

4.11.9. Dissenting Views

None.

5.0 EVALUATION OF CASTILE SUBSYSTEM PARAMETERS

5.1. Castile Brine Reservoir Rock Compressibility

This section reviews the data from which the bulk compressibility in the hypothesized Castile brine reservoir were derived.

Parameter:	Bulk Compressibility
ID#:	61
Form 464:	WPO 31561, entered 4/12/96
Parameter Package:	WPO 31084
Distribution:	Triangular
Parameter values:	Minimum: -11.3, log Pa^{-1} (5.0E-12 Pa^{-1})
	Maximum: -8.0, log Pa^{-1} (1.0E-08 Pa^{-1})
	Mode: -10.0, log Pa^{-1} (1.0E-10 Pa^{-1})

Definition: The definition of bulk compressibility is $\alpha = -(1/V)(\partial V/\partial p)_T$

where:

V = volume,

p = pressure,

T = constant temperature.

Thus, bulk compressibility means this relationship as applied to a medium consisting of an essentially homogeneous mixture of phases, such as solid and void space.

Intended Use: This parameter is needed in BRAGFLO in order to simulate the flow from a hypothesized brine reservoir in the Castile Formation should a borehole penetrate such a reservoir after closure of the repository.

Derivation: Laboratory strain tests and acoustic logs in borehole WIPP-12 were used to derive bulk compressibility of fractured anhydrite. The laboratory strain tests provide direct measurements of compressibility of dry unfractured samples. The acoustic logs provide data on *in situ* (hence, wet) compressibility for essentially unfractured anhydrite. These measurements provided, on average, identical compressibilities. The compressibility for fractured anhydrite was approximated by multiplying these measurements by a factor of 2 to 10 to obtain the low end and the mode of the distribution, respectively. The high end was taken from Freeze and Cherry (1979) as the high end of the range for rock compressibility for a fractured or jointed rock.

5.1.1. Adequacy of Requirements and Criteria

The primary need for this parameter is to provide quantitative data on compressibility of anhydrite in the Castile formation, envisaged as possibly being a reservoir rock for brine underlying the repository. This was accomplished through laboratory measurements of unfractured rock and interpretation of acoustic logs in "intact Anhydrite III" in borehole WIPP-12, coupled with estimates of the magnitude of increased compressibility for fractured anhydrite. No written requirements or criteria were found in the relevant documents. However, the data must adequately satisfy this objective of the testing.

Conditions required to obtain adequate data for determining bulk compressibility are:

- Proper operation of laboratory testing equipment.
- Proper operation of *in situ* testing equipment.
- Proper operation of data acquisition systems.

The first condition was presumed to be met by proper calibration procedures, which should exist in the archival records for these tests. Calibration and testing procedures are referenced in SAND81-7063, but not in SAND81-0858.

It is also presumed that calibration procedures would have indicated any difficulties in the data acquisition systems and that any relevant documentation exists in archival records. No difficulties were noted in the documents reviewed, except that in one instance the volumetric strain data were poor and the data were not used.

Upon a request for documentation on acoustic logs, the Panel was given "Log Review 1 (1974), Dresser Atlas, Dresser Industries, Inc." This document is older than the reference given in TME 3153, which

cites "Dresser Atlas (1981) Acoustic Logs, Dresser Industries, Inc." This reference does provide sufficient detail to indicate how in general the tests were done. However, the 1974 documentation provided does not state which of several downhole tools was actually used and provides no calibration guidance for acoustic tools. The acoustic logs were not run by SNL, but were acquired through an independent contractor (Westinghouse). It is presumed that the procurement for these services specified the accuracy required. Investigating those records is beyond the scope of this review.

5.1.2. Validity of Assumptions

Assumptions relate primarily to whether the values obtained from dry samples in the laboratory, or the data obtained from acoustic logs in borehole WIPP-12 (bearing in mind the boring will to some extent disturb the formation), properly represent conditions in a saturated reservoir. Because the same value was derived from the laboratory tests on dry specimens and from the acoustic tests in WIPP-12, the available evidence suggests that any effect of wet vis-a-vis dry conditions is insignificant. The taking of cores for the laboratory tests does, of course, allow expansion of the specimens compared to *in situ* conditions. However, the specimens all still consist of unfractured rock, whereas the objective is to obtain an adequate representation of fractured rock. Thus, any increase in compressibility in the test specimens, or in the borehole, will be small compared to the increase needed to adjust the measured values to properly represent *in situ* conditions in the formation as a whole. Thus, the assumptions are judged to be valid.

5.1.3. Alternate Interpretation

The interpretations of laboratory and acoustic log data were proper and straightforward. No others are needed.

5.1.4. Uncertainty and Consequences

The uncertainty of individual laboratory measurements is far less than the range of likely values in the formation or reservoir. The range of values for unsmoothed data is quite large, but is generally greatly reduced by the smoothing procedure. Nevertheless, after smoothing, the data are quite consistent, such that the suitability for the objectives is judged adequate. The uncertainty in the cumulative laboratory measurements is far less than the range of likely values in the formation or reservoir. The application can readily accommodate the intended usage. The uncertainty is sufficiently low for laboratory data. The consequences for the application are judged to be inconsequential.

Examination of the Dresser Atlas Log Review 1 (1974) shows that numerous sources of uncertainty exist in respect to acoustic logs; whereas the magnitudes of these uncertainties are not discussed. Therein, the variability shown in example logs, taken together with estimates of other uncertainties (e.g., effect of the tool being canted in respect to the hole, accuracy of measurement of travel times), was estimated at being perhaps 10% of the measurement. This uncertainty is far less than others involved in deriving the parameter and is thus judged acceptable.

5.1.5. Appropriateness and Limitations of Methodology and Procedures

As indicated in the previous sections, the methodology for laboratory tests was appropriate and the limitations of the methodology are acceptable. All of the data obtained from laboratory experiments were used. For each anhydrite interval of the boreholes tested by acoustic logging only an average of the velocity in the unit is needed. This can be obtained within a few percent by visual examination of the log. Alternatively, some form of electronic smoothing or averaging may have been used. Neither case really amounts to data reduction in the usual sense.

The laboratory and acoustic log estimations of the bulk modulus agree very well, as shown by converting the units in TME-3153, p. G-33, and data tables in SAND81-0858 and SAND81-7063 to the same units. These correspond to unfractured rock. The conversion to conditions for fractured rock is less certain, but agrees with the limited data (Ibrahim et al. 1989; Freeze and Cherry 1979). Ibrahim et al. (1989) is an expanded abstract. Also relevant is Jung et al. (1991), pp. 37-39. Their measurements in salt pillars showed compressional velocities on corners and sides to be less than those in undisturbed salt by factors of about 2 to 4, which equate to increases in bulk modulus by factors of 4 and 16, respectively. The velocity decrease is attributed to post-mining fracturing. The factor 2 was obtained from the abstract and used in SAND90-0082. The effect of fracturing estimated in obtaining the bulk compressibility in the Castile reservoir was conservatively estimated to be considerably larger than this measured effect.

The methods used are well established for the laboratory data. The data from acoustic logs were input into well known equations relating velocity to seismic velocities and solved for the bulk modulus. No hand calculations or other means of demonstrating the accuracy were noted in the relevant documents. However, during this review a few approximate calculations were done that adequately confirmed the data derived from laboratory results.

No problems were identified in the examination of the primary laboratory data reports (SAND81-0858 and SAND81-7063). The acoustic data are also judged adequate.

5.1.6. Adequacy of Application

The data are judged adequate for the intended application.

5.1.7. Accuracy of Calculations

No hand calculations or other means of demonstrating the accuracy were noted in the relevant documents. However, during this review a few approximate calculations were done that adequately confirmed the data derived from laboratory results.

5.1.8. Validity of Conclusions

The data presented on Form 464, WPO number 31561, as indicated at the beginning of Section 5.1, are judged adequate for the intended application. Specifically, these are a minimum of 5.0E-12 Pa^{-1}, a maximum of 1.0E-08 Pa^{-1}, a mode of 1.0E-10 Pa^{-1}, and a triangular distribution.

5.1.9. Dissenting Views

None.

5.2. Castile Brine Reservoir Porosity

Castile Brine Reservoir Porosity is a parameter used in BRAGFLO modeling of flow of brine from a hypothetical brine reservoir for a borehole intrusion scenario. The parameter description follows:

Parameter:	Porosity
ID#:	64
Form 464:	WPO 31610, entered 1/31/96
Parameter Package:	WPO 31083
Distribution:	Student-t
Value:	Mean: 0.0087
	Std Dev: 0.0057
	Minimum: 0.002
	Maximum: 0.016
Definition:	Interconnected porosity of Castile brine reservoirs

Intended use: Used in BRAGFLO modeling of flow of brine in a borehole that could result from a hypothetical brine reservoir below the repository being penetrated by a borehole as part of an intrusion scenario.

Derivation: Core analysis of three pieces of Castile anhydrite by saturating dried core with toluene. Two pieces were from WIPP-12, located less than 3.2 km north of the waste panels, and one piece was from ERDA-6, located over 8 km northeast.

5.2.1. Adequacy of Requirements and Criteria

No written requirements or criteria were found in the primary documents. However TME 3153 (page G-29) states that estimates of porosity of the anhydrite that forms the brine reservoir in the Castile Formation are important to hydrologic evaluations and are used to approximate formation compressibility

and reservoir volumes. Consequently, an implicit requirement is that the porosity estimate be adequate to support the development of such parameters, and to support the PA modeling of borehole intrusion.

5.2.2. Validity of Assumptions

The statistical assumption involved in developing the t-distribution is that Castile brine reservoir porosity measured from three core samples of anhydrite reservoir rock obtained from two wells can be treated as random samples of Castile brine reservoir rock. This treatment may not be strictly correct because one well, ERDA-6, was drilled on the crest of a domal structure and would tend to encounter higher fracture porosity than wells located elsewhere, biasing the sample toward higher porosity. Since the sample is biased toward higher porosity, it would be in the conservative direction of overestimating the brine volume and yield of the reservoir.

5.2.3. Alternate Interpretation

No alternate interpretations are relevant to Castile brine reservoir porosity.

5.2.4. Uncertainty and Consequences

The uncertainty associated with the Castile brine reservoir porosity is expressed in the t-distribution. As discussed above, the treatment of this uncertainty is conservative, tending to overestimate the brine volume and reservoir yield.

5.2.5. Appropriateness and Limitations of Methodology and Procedures

As indicated in the preceding sections, the method of estimating the Castile brine reservoir porosity is conservative. The actual core analyses were performed according to API standards, which is appropriate. It is difficult to measure fracture porosity at such low values, and some of the fractures might be induced or opened by the coring process. This limitation tends to produce error in the conservative direction. Geophysical borehole logging and fracture aperture analysis also indicated very low porosity.

5.2.6. Adequacy of Application

The application of values for reservoir porosity parameters obtained from core analysis to the development of a frequency distribution for the PA is adequate and conservative.

5.2.7. Accuracy of Calculations

No hand calculations or spreadsheet formulas related to Castile brine reservoir porosity were found in the primary documents. The porosity values reported are reasonable, and porosities obtained by more than one method are in agreement.

5.2.8. Validity of Conclusions

As indicated in the preceding sections, the Castile brine reservoir porosity parameters developed for input to the PA indicate very low porosity. The maximum and minimum values (0.002 and 0.016) are reasonable, and the t-distribution is conservative because it is biased toward high porosity. The spread of the t-distribution, for the small number of samples, adequately represents the uncertainty.

5.2.9. Dissenting Views

None.

5.3. Castile Brine Reservoir Pressure

The purpose of estimating the Castile brine reservoir pressure is to provide the initial Castile brine reservoir pressure for model BRAGFLO in PA. The information about the parameter in the Form 464A is as follows:

Parameter Package: Brine reservoir pressure

ID#: 66

Form 464A: WPO 31612, entered 3/2196

Parameter Package: WPO 31072

Distribution Type: Triangular

Values: Mode: 12.7 MPa

Minimum: 11.1 MPa

Maximum: 17.0 MPa

Definition: The Castile brine reservoir pressure is defined as the initial brine reservoir pressure that may be encountered by a hypothetical borehole drilled through the repository into a hypothesized pressurized brine reservoir in the Castile Formation below the repository.

Intended Use: The estimated Castile brine reservoir pressure and its statistical distribution are used as the potential initial pressure in model BRAGFLO under the hypothetical case that a borehole is drilled through the repository and into the hypothesized pressurized brine reservoir in the underlying Castile Formation.

Derivation: The Castile brine reservoir pressure estimation was based on several documents, including SAND92-0700/3, SAND89-7069, SAND89-0462, and TME-3153. Basic data of the Castile brine reservoir pressure in the WIPP area include the measured pressures at WIPP-12, ERDA-6, Belco, and Gulf Covington, and the estimated pressures at nine other locations (Table H-1, TME-3153). The measured pressures range from 12.6 MPa to 14.3 MPa at various depths and different locations in the vicinity of the WIPP. Among those, the measured pressure at WIPP-12 of 12.7 MPa is considered most

representative of the site conditions because it is the closest one to the waste-storage area, and the reservoir encountered at WIPP-12 has been studied and characterized through many tests and analyses.

The possible range of the initial brine reservoir pressure was estimated by extrapolating the measured pressures at various depths to the WIPP-12 depth (140 m above sea level [masl]). Pressure extrapolation using either a hydrostatic adjustment or a lithostatic adjustment was completed by the following equation:

$$P_a = P + \rho g (h - 140) / 1.0E\text{-}06$$

where:

P_a = adjusted pressure [MPa]

P = measured/estimated pressure [MPa]

ρ = assumed density [kg/m^3]

g = gravitational constant [9.8 N/kg]

h = brine reservoir elevation at measurement point [masl]

An average brine fluid density of 1,240 kg/m^3 was used for hydrostatic adjustment and an average formation density of 2,400 kg/m^3 was used for lithostatic adjustment.

The maximum pressure in the Castile brine reservoir was estimated to be 85% of the lithostatic pressure at WIPP-12 depth. The minimum pressure was estimated to be the smallest value among the hydrostatic adjusted pressures, and the lithostatic adjusted pressures reduced by 15%. The measured WIPP-12 pressure of 12.7 Mpa was assigned to be the value of mode.

5.3.1. Adequacy of Requirements and Criteria

The requirements and criteria for the estimation were not specifically stated in the Parameter Package. Based on the intended use of the initial Castile brine reservoir pressure, the estimation should be representative of the most likely reservoir conditions at the WIPP site. Since the Castile brine reservoirs are heterogeneous, discontinuously fractured zones of limited extent within the Castile anhydrites, the initial pressure at the time when a hypothetical borehole is drilled through may vary. This requires the estimation to cover this spatial variability of the pressure, and to present the most likely pressure

associated with a high probability, based on the existing data. The data collection, interpretation, and parameter estimation processes have met these requirements.

5.3.2. Validity of Assumptions

The primary assumptions involved in the estimation of the initial reservoir pressure at the center of the brine reservoir at WIPP-12 depth, based on measured and estimated Castile brine reservoir pressures, include the following:

Assumption 1 Initial pressures of the Castile brine reservoir lie between hydrostatic pressure and lithostatic pressure.

This is a reasonable assumption because the Castile brine reservoirs could be either interconnected or isolated by impermeable zones. Hydrostatic adjustment would be appropriate if the reservoirs are interconnected and lithostatic adjustment would be appropriate if the reservoirs are isolated.

Assumption 2 The fluid pressures in the Castile brine reservoirs are assumed to be no greater than 85% of the lithostatic pressures.

This assumption was developed based on the examination of the relationship between the fluid pressures at the reservoir depths and the interpreted lithostatic pressures at the reservoir depths using the WIPP-11 density log. The data involved in the examination include both measured and estimated pressures in anhydrite units in the Castile (13 data points) and Salado (5 data points) Formations. The percentages of fluid pressure vs lithostatic pressure range from 50% to 86%, with an average ratio of 67% and a median ratio of 64%. Assumption 2 is based on the site-specific conditions and is considered appropriate. Based on this assumption, the pressure value obtained by lithostatic adjustment using the equation was further adjusted by reducing it by 15%.

5.3.3. Alternate Interpretation

The interpretation based on the first assumption discussed in Section 5.3.2 led to two sets of interpreted pressures using hydrostatic and lithostatic extrapolations. The measured or estimated pressures at 12 locations other than WIPP-12 were converted to equivalent pressures at the depth of WIPP-12. Interpreted results provide a greater range of brine reservoir pressures varying from 10.7 MPa to 20 MPa, which could potentially cover the uncertainty due to the formation heterogeneity.

Based on the second assumption discussed in Section 5.3.2, the estimation was changed to a slightly smaller range varying from 11.1 MPa to 17.0 MPa. Since this estimation was developed based on the site-specific analysis by examining the relationship between measured or estimated fluid pressures and calculated lithostatic pressures, it is considered more representative of the site conditions.

5.3.4. Uncertainty and Consequences

The uncertainties of the initial Castile brine reservoir pressures may be primarily related to different origins of the Castile brine reservoirs, and related to the heterogeneity of the Castile formation. These uncertainties have been well exhibited in the measured and estimated brine pressures at 13 borehole locations.

The uncertainty is expressed as the estimated distribution of the parameter. The assigned distribution in the Form 464A is a triangular distribution with a mode value of 12.7 MPa, which is the measured value at WIPP-12. Based on the characteristics of a triangular distribution, a high probability was assigned to the mode. This is reasonable because the location of WIPP-12 is the closest to the center of the repository room (1.5 km away), and the measured pressured of 12.7 MPa has been supported by various tests and evaluated by many analyses.

The possible consequence of the uncertainty of the estimation was not documented in the related parameter package. As discussed in SAND89-7069, the Castile brine reservoir pressure was identified as the second most sensitive parameter in the estimation of peak-release and 10,000-year cumulative release under the hypothetical case. The initial brine reservoir pressure is one of the components used in calculation of change of pressure with time. The possible consequence of underestimating or overestimating the initial pressure would underestimate or overestimate the potential flow rate of brine through a borehole under the hypothetical borehole intrusion case. However, the dominant factor in calculation of the potential release is identified as borehole transmissivity, as stated in SAND92-0700/4.

5.3.5. Appropriateness and Limitations of Methodology and Procedures

The test methodology and procedures for measurement of brine reservoir pressure at WIPP-12 were well documented in TME-3153. Summary of appropriateness and limitations of measurements and interpretations of the brine reservoir pressure at WIPP-12 was given in SAND89-7069. Pressure was measured with downhole transducers, surface transducers, and mechanical pressure gages at the wellhead. Downhole transducers could not be left downhole for long periods, because of the extremely corrosive nature of the brine. Measured surface pressures were extrapolated to pressures at brine

reservoir depth based on an estimated fluid column density of 1,240 kg/m^3. Uncertainties related to the estimation of fluid column density, and related to the influence of a gas cap formed during the pressure buildup period, were evaluated to be minor.

5.3.6. Adequacy of Application

Since the estimated parameter and its distribution are representative of the site-specific conditions and the potential variation, they are considered adequate for the intended use in BRAGFLO.

5.3.7. Accuracy of Calculations

The calculation for interpretation was spot-checked, showing that the interpretation results provided in the package are correct in calculation.

5.3.8. Validity of Conclusions

The estimation of the initial Castile brine reservoir pressure, following a triangular distribution with a mode of 12.7 MPa, a minimum of 11.1 MPa, and a maximum of 17.0 MPa, is considered adequate for the intended use.

5.3.9. Dissenting Views

None.

5.4. Castile Brine Reservoir Permeability

Castile Brine Reservoir Permeability is a parameter that is used in BRAGFLO modeling of the borehole intrusion scenario. The parameter description follows:

Parameter:	Castile Brine Reservoir Permeability
ID#:	67, 68, 69
Form 464:	WPO 31613, entered 2/16/96
Parameter Package:	WPO 31070
Distribution type:	Triangular
Values:	Mode: 1.5E-12 m^2
	Maximum: 1.5E-10 m^2
	Minimum: 2.0E-15 m^2

Definition: Permeability of hypothetical brine reservoir in the Castile that might be intersected by a well penetrating the repository.

Intended use: Used in BRAGFLO modeling of the borehole intrusion scenario, wherein a borehole intersects a fractured anhydrite layer in the Castile formation and conducts brine upward into the repository.

Derivation: The Castile brine reservoir permeability parameters are based on testing of WIPP-12 and ERDA-6, which are the only Castile wells near the WIPP site that have been subject to detailed quantitative testing (TME 3153, page H-3). WIPP-12 is located about a mile from the site center, and ERDA-6 is about five miles northeast of the site center. The mode $10^{-11.8}$ m^2 of the triangular distribution is from GTFM analysis of WIPP-12 flow and pressure buildup tests (SAND89-7069). The minimum value 2.0E-15 m^2, is from Flow Test #2 of ERDA-6, and is the lowest value from any flow test of ERDA-6 and WIPP-12. The maximum 1.5E-10 m^2 is an order of magnitude higher than the highest measured value.

5.4.1. Adequacy of Requirements and Criteria

No written requirements or criteria were found in the primary documents. However, an objective of WIPP-12 and ERDA-6 testing was to determine reservoir transmissivity (TME 3153, page H-7). Consequently, an implicit requirement is that the test data be adequate to support quantitative estimation of Culebra brine reservoir transmissivity. These requirements were addressed by performing drill stem tests (DSTs) and flow tests and analyzing the data via Horner analysis and GTFM 6.0 analysis, respectively.

5.4.2. Validity of Assumptions

The critical assumptions related to quantitative estimation of transmissivity of the Castile brine reservoirs are those related to the analysis of the test data. The assumptions of greatest interest with respect to adequate characterization of brine reservoir permeability are:

- Darcy flow,
- Radial flow to the well, and
- Concentric zones of homogeneous permeability.

The details on assumptions of GTFM 6.0 analysis are presented in Pickens et al. (1987).

The Darcy flow assumption may be applied to large scale flow in fractured media within commonly encountered flow velocity ranges due to the analogy between equations for porous media flow and flow between parallel plates, and due to the similar behavior of fractured media to porous media at large volume scales. The assumption of radial flow is commonly made and is reasonable for flow to a borehole, even though there will be deviations from radial flow due to heterogeneity and anisotropy in permeability caused by variation in fracture spacing, openness, and orientation. The assumption of concentric zones of homogeneous permeability is not likely to be met, due to the complexity of fractured reservoirs and the low probability that a borehole would be drilled in the place where permeability is highest or lowest. Nevertheless, the concentric permeability zone model allows a simplified treatment that is realistic enough to deal with the complex system. The concentric model is reasonable because permeability in an isolated reservoir will begin to change at some distance from a well that penetrates the reservoir.

5.4.3. Alternate Interpretation

No alternate interpretations were identified that would improve the estimate of Castile brine reservoir permeability. More complex models could be used in the analysis of the data, but they are not warranted by the amount of data available. The amount of data available is adequate for the purpose of supplying permeability frequency distribution parameters for the intrusion scenario modeling.

5.4.4. Uncertainty and Consequences

The uncertainty associated with the Castile brine reservoir permeability is expressed in the triangular distribution. Since the maximum and minimum permeabilities used in the distribution are extremely large and small values, the treatment of this uncertainty is conservative, tending to overestimate the degree of uncertainty. The consequence of this overestimation will be to increase uncertainty in the PA modeling.

5.4.5. Appropriateness and Limitations of Methodology and Procedures

The methodology of testing the boreholes by flow testing and DSTs, as documented in TME 3153 and SAND89-7069, is appropriate. The flow testing and GTFM 6.0 analysis is in accordance with hydrologic theory and the observation that fracture systems behave like porous media at large volume scales. Drill stem testing is in accordance with established practice in the petroleum industry, and the analysis of DST data by the Horner method is supported by hydrologic theory, including the similar form of equations describing flow in porous media and flow between parallel walls. The field methodology included the use of flow meters in parallel, so that when salt deposition affected meter performance a second meter could be used while the first was cleaned.

5.4.6. Adequacy of Application

The application of values for reservoir permeability parameters obtained from GTFM 6.0 and DST analysis to the development of a frequency distribution to be sampled during intrusion scenario modeling is adequate and conservative. More than one test was performed in each borehole. Descriptions of the field tests and the results presented on the pressure graphs indicate that the conduct of the tests was adequate for the analyses to be performed. Test irregularities such as gas liberation, salt buildup in flow lines and meters, and choke effects were described and appear to have been dealt with adequately. Potential interference by pressure recovery from previous tests was evaluated. The main tests for estimating permeability were WIPP-12 Flow Test 2 and Flow Test 3. GTFM 6.0 analysis was used for these tests. Consequently, pre-test history could be included directly in the analysis of the data. Horner

analysis showing relatively high permeability near the WIPP-12 borehole supports the GTFM 6.0 concentric double-permeability interpretation.

5.4.7. Accuracy of Calculations

No hand calculations or spreadsheet formulas related to Castile brine reservoir permeability were found in the primary documents. The permeability values reported are reasonable, and permeabilities obtained by more than one test and more than one method are in reasonable agreement with the concentric double-permeability model used in the interpretation of the data.

5.4.8. Validity of Conclusions

As indicated in the preceding sections, the Castile brine reservoir permeability parameters developed for input to the PA modeling are reasonable and adequate. The uncertainty in the permeability of the Brine Reservoir that might be penetrated by an intrusion borehole is adequately treated by the triangular frequency distribution. The estimated mode, minimum, and maximum permeability, were adequately supported by the data and analyses reported in TME 3153 and SAND89-7069. Conclusions were supported by GTFM analysis applied to two flow tests and their recovery (Horner analysis indicating relatively high permeability near the WIPP-12 borehole), and adequate treatment of field problems (salt deposition, gas dissolution).

5.4.9. Dissenting Views

None.

5.5. Castile Brine Reservoir Volume

Parameter: Castile Brine Reservoir Volume

ID # : 2918

Form 464A: WPO 31625, entered 3/20/96

Parameter Package: WPO 31082

Distribution: Constant

Parameter Values: Minimum: 4.0E+06 m^3

Definition: The Brine Reservoir Volume is the volume of reservoir rock within the Castile Formation that is hypothesized to contain a brine reservoir located approximately 250 m below the WIPP repository.

Intended Use: The intended use of the parameter is to provide a value of the rock reservoir volume that can be used to calculate a brine volume for entry in the BRAGFLO model. The value in BRAGFLO would be a determination of the volume of brine that would be present in the Castile Formation to enter a borehole that might penetrate the repository and intercept the hypothesized brine reservoir in the Castile Formation. Using the reservoir volume of 4.0E+06 m^3 and an effective porosity of 0.008, the volume of brine has been calculated as 32,000 m^3.

Derivation: The total brine reservoir volume parameter is based on measured pressure and volume of brine as produced from drill stem tests (DSTs) and flow tests of the Castile Brine Reservoir zone conducted during 1981 to 1983 in boreholes (wells) WIPP-12 and ERDA-6. The pressure and brine volume data used for the parameter calculation are contained in SAND89-7069 and TME 3153.

The brine reservoir volumes shown in the Table of Calculated Castile Reservoir Volumes appended to the Form 464A were calculated using the following equations based on Domenico's (1972) equation:

$$\Delta V = S\ A\ \Delta h$$

where:

ΔV = volume of brine released from storage over an area A

Δh = given pressure head change

S = storage coefficient.

The storage coefficient is:

$$S = \rho\, g\, \Delta z\, (C_R + \phi\, C_W)$$

where:

ρ = fluid density

g = acceleration of gravity

Δz = aquifer thickness

C_R = bulk rock compressibility

ϕ = porosity

C_W = fluid compressibility.

By combining terms, these equations can be rewritten as:

$$V = \Delta V / (C_R + \phi C_W)\, \Delta p$$

Thus, the total volume of the rock reservoir (V) can be calculated knowing the total pressure change (Δp) that has occurred as a result of fluid volume release (ΔV), making assumptions about the reservoir rock and fluid compressibilities.

Discussion: The volume of the brine reservoir listed on the Form 464A is not the actual value used in BRAGFLO. The volume of the brine reservoir on Form 464A is used to calculate the brine volume, by multiplying the reservoir volume of 4.0E+06 m^3 times its effective porosity of 0.008. The reservoir volume of 4.0E+06 m^3 was calculated using a maximum rock compressibility value of 1.0E-08 Pa^{-1}. The actual parameter being used in the BRAGFLO model is a brine volume (Sommers 1996). As

per the memo to Martin Tierney (Larson 1996), the volume of brine to be used in the BRAGFLO calculations is 32,000 m^3 per brine reservoir. The memo further states that for any particular realization there may be between one and five reservoirs, some or all of which might be contiguous (*what is really meant is interconnected*). Therefore, the volume of brine (stored in effective porosity) to be used in the performance assessment could range from 32,000 to 160,000 m^3. The rationale for the brine reservoir volume parameter is provided in a pre-signature final draft memo of record dated May 27, 1996 (Freeze 1996), attached to the Parameter Package.

5.5.1. Adequacy of Requirements and Criteria

The technical information used for the computation of the brine reservoir volume in the Castile Formation is gleaned from the hydrology section of the TME 3153 report (pp. H-46 to H-48 for ERDA-6 and pp. H-53 to H-55 for WIPP-12). The report presents the results of the geological, hydrological, and geochemical investigation of the brine reservoirs in the Castile Formation. The objectives of the study were not clearly stated in the report. However, it can be inferred that the objectives were to determine the potential impact of the brine reservoirs on the integrity of the WIPP facility and determine the origin and nature of the brine reservoirs.

The requirements and criteria of the data are not indicated in the TME 3153 or SAND89-7069, so it is difficult to judge whether adequacy of requirements and criteria have been met. However, using the data from the tests of WIPP-12 and ERDA-6 in combination with other data from the TME 3153 investigation, it is possible to calculate a valid estimate of brine reservoir volume. This was accomplished by using the aforementioned reservoir volume equations under assumed conditions of Castile brine reservoir rock compressibility.

5.5.2. Validity of Assumptions

The assumptions made for the calculations in the Parameter Package are that the brine reservoir volume can be calculated from the volume of fluid produced and the corresponding decline in pressure in the reservoir using the equations of Domenico (1972). Using the data from the tests of WIPP-12 and other parameter values of porosity, brine compressibility, brine reservoir rock compressibility, reasonable value of reservoir volume has been calculated which demonstrates the validity of the assumptions.

5.5.3. Alternate Interpretations

It is obvious from the aforementioned reservoir volume equations that the brine reservoir volume can be changed by varying the rock compressibility values. Thus, there can be alternative interpretations of brine

reservoir volume, depending on the values of the rock compressibility chosen for use in the reservoir volume equation.

5.5.4. Uncertainty and Consequences

Although erroneous data were identified and eliminated from use in the analyses of the pressure/flow data from WIPP-12, there was no discussion of the consequences of the uncertainty of the results in TME 3153. In SAND89-7069 (p. A-5) mention was made of the fact that the possible impact of multi-phase flow on long-term brine reservoir behavior has not been quantified and that it should be considered a potentially important cause of uncertainty in brine reservoir breach simulations.

Section 3.2, Measurements (TME 3153, pp. H-10 to H-14) discusses: 1) the problems of gas liberation upstream of the flow meters at the surface during the DSTs, causing the meters to register erroneously high flow rates, 2) the salt precipitation in the flow lines restricting flow and incapacitating recording instruments, and 3) the choke effects during the DST flow periods which caused higher pressure readings to be recorded than would have occurred without the choke effect.

The problems of gas/brine separation were rectified when gas/liquid separators were installed and the brine flows subsequently measured downstream from the separator after the gas had been removed from the flow line. However, in order to operate the separator, the well was backpressured during Flow Test 1 and the corresponding pressures and flow rates were not reported in D'Appolonia reports; therefore, the reservoir parameters for that test could not be interpreted, according to SAND89-7069 (Appendix A, p. A-4). Other factors affecting the quality of the measurements, such as corrosion of flow meters from brine and hydrogen sulfide, are discussed in TME 3153, pp. H-10 to H-14. Further discussion of these is beyond the scope of this review.

5.5.5. Appropriateness and Limitations of Methodology and Procedures

At the time of testing of boreholes ERDA-6 and WIPP-12, there were industry-accepted standard procedures for the performance, analysis, and interpretation of DSTs and flow tests which had been used for a number of years by the petroleum industry. The results of the flow tests were analyzed by traditional petroleum industry analytical techniques (i.e., Horner method) and classical U.S. Geological Survey ground water aquifer flow analysis techniques. These techniques were the classic Theis and Jacob-Lohman methods, and standard petroleum reservoir engineering methods involving interpretation of DSTs by the Horner semi-log plot of pressure buildup vs the log of lapsed buildup time.

According to TME 3153, the actual details of the flow tests and analyses are contained in a series of reports from D'Appolonia to Westinghouse Electric Co., another SNL subcontractor. These reports and others regarding the drilling and testing are archived at SNL. These detailed reports were not reviewed.

There is no discussion of detection limits of the instrumentation used in the DSTs in TME 3153 or SAND89-7069. This information is provided in the earlier D'Appolonia reports, which were not reviewed.

There were two sets of DSTs and three flow and recovery tests performed on the Castile brine reservoir penetrated by WIPP-12. Although the tests were of different durations and at different times, there was enough redundancy to provide checks on the data.

The methods and procedures used to obtain the pressure/flow data from WIPP-12 and ERDA-6 were standard for the petroleum industry and ground water resources investigations. Some of the limitations of the testing were caused by the corrosive nature of the hydrogen sulfide-laden brine fluid and the evolution of gas, which required modifications to the equipment and procedures.

By comparison of the results of analyses (TME 3153, pp. H-15 to H-35) of the pressure/flow data from WIPP-12 by several different analytical techniques, it is apparent that the data quality is adequate. A review of TME 3253 and SAND89-7069 indicates that the assumptions, calculations, extrapolations, methods, and conclusions pertinent to the data were appropriate for the calculation of the brine reservoir parameter on the Form 464A.

5.5.6. Adequacy of Application

Based on the data provided in TME 3153, it appears that test-to-test interference did not occur between wells WIPP-12 and ERDA-6, which were approximately 10 km apart. However, it is not clear whether subsequent tests within the same well might have been affected by the previous testing. The report (p. H-35) does acknowledge that considerable amounts of data had to be rejected as unreliable because of technical limitations of the instrumentation used (i.e., the choke effect in DST tool entry ports) or operational /mechanical deficiencies (e.g., heavy mud in the hole affecting flow rates, and leaky blowout preventers or lubricator). However, it is reported that only the most reliable data and only the analytical methods best suited to the actual reservoir conditions were used to quantify reservoir properties in the report. TME 3253 (p. H-35) states that, "All data acquired during the present testing program were thoroughly examined." In many cases, however, the data had to be rejected as unreliable because of technical limitations of the instrumentation used or operational deficiencies. The description of the

testing equipment and testing procedures as presented in TME 3153 (Section 3.1 Testing, pp. H-7 to H-10, Section 3.2 Measurements, pp. H-10 to H-15) indicate that the test procedures were correctly implemented.

The interpretations of analyses of these physical data (i.e., water pressures and flow rates), are not affected by the age of the data. The basic physical properties of the brine reservoir are not believed to have changed materially through natural causes in thousands of years.

In order to estimate the change in reservoir pressure during the length of the testing period, it was necessary to extrapolate surface pressures at the well head to pressures at brine-reservoir depth by assuming an estimated fluid column density. This estimation of fluid column density was complicated by the buildup of a gas cap at the well head in WIPP-12. Unfortunately, adequate records of the gas cap evolution were not recorded because the gas cap formed slowly and the amount of gas produced during buildup reportedly was small. The effect of the gas cap over time would be that of decreasing the density of the brine fluid column and thus, producing anomalous pressure responses at the well head.

In using the Jacob-Lohman method for analyzing constant-pressure flow data (TME 3153, pp. H-24 and H-25), it was determined that only flow tests ERDA-6/Flow test #3 and WIPP-12/Flow test # 2 meet the requirements of: 1) constant friction head loss in the well casing and discharge line; 2) constant fluid density; and, 3) constant backpressure or unrestricted flow which are necessary for maintaining constant pressure. Therefore, only these two tests were analyzed by the Jacob-Lohman method, as other flow tests were eliminated due to non-constant fluid density and changing backpressure caused by salt crystallization in the flow lines.

Of the two flow tests presenting data that could be used for analysis, Flow test #2 had a flow period of 0.23 days and recovery of 2.69 days, while Flow test # 3 had a flow period of 7.0 days and a recovery period of 278.4 days. Thus, the number of data points was enough to provide an adequate level of confidence in the results, but only for the reservoir's short-term behavior. There is internal consistency between data sets in that both tests show pressure buildups and flow rates. However, the Horner plot of pressure vs elapsed time for Flow tests #2 and #3 shows different curves with widely different characteristics (SAND89-7069, p. A-7) for each test. The calculated transmissivities determined by Horner's semi-log method for each test differ by nearly three orders of magnitude. The reason for these inconsistencies is that Flow test #2 was short and may have stressed the well-connected fractures near the wellbore, which may have yielded a higher permeability (transmissitivity). However, Flow test #3 lasted 7 days and had a buildup of 278 days. Thus, over the greater time period of Flow test #3, it may have

stressed a much larger portion of the brine reservoir, reaching into areas with a lower permeability (transmissivity).

Nevertheless, the data appear to be complete enough to make reasonable estimations of brine reservoir volume based on interpretation of flow tests and pressure changes during the flow tests. The calculation of the brine reservoir volume has utilized the data analyzed from the pressure/flow tests of WIPP-12 and shown the adequacy of application.

The interpreted results of the type-curve analyses (SAND89-7069) and the GTFM 6.0 simulation of the pressure/flow data from WIPP-12 and ERDA -6 indicate that the data are sufficient to support the intended use.

5.5.7. Accuracy of Calculations

The value for the volume of the brine reservoir listed on Form 464A was checked against the original well data interpretations in the TME 3153 report. Reservoir volumes were hand calculated using the TME 3153 data and values provided in the tables within the Parameter Package for the Form 464A. The hand calculated volume estimations were nearly identical to those on the Form 464A, thus verifying the reasonableness of the calculations.

5.5.8. Validity of Conclusions

The brine reservoir volume value listed on the Form 464A and recorded in the Parameter Package was interpreted from used values of initial pressure, final pressure, pressure change and volume of brine produced during the hydraulic testing of ERDA-6 and WIPP-12, as reported in TME 3153 (pp. H-46 to H-48 and H-53 to H-55). These data have been checked and found to be reasonable values representing the brine reservoir conditions at the time of testing. The analysis and interpretation methodology and results also were found to be appropriate. Thus, the parameter value of 4.0E+06 m^3 for the brine reservoir volume is considered to be reasonable for its intended use.

5.5.9. Dissenting Views

None.

6.0 EVALUATION OF UNITS ABOVE THE SALADO SUBSYSTEM PARAMETERS

6.1. Non-Salado Effective Porosity

The estimated effective porosity values for six Non-Salado Formations, including Culebra, Dewey Lake, Forty-niner, Magenta, Tamarisk, and unnamed, were reviewed in this section. Information provided in the Form 464s are as following:

CULEBRA:

Parameter:	Effective Porosity
ID#:	140
Form 464:	WPO 32769, entered 2/9/96
Parameter Package:	WPO 30608
Distribution Type:	Constant
Parameter Values:	0.151

DEWEY LAKE:

Parameter:	Effective Porosity
ID#:	158
Form 464:	WPO 2731, entered 2/20/96
Parameter Package:	WPO 30608
Distribution Type:	Student-t
Parameter Values:	0.143

FORTY-NINER:

Parameter:	Effective Porosity
ID#:	2088

Form 464: WPO 32995, entered 2/20/96

Parameter Package: WPO 30608

Distribution Type: Student-t

Parameter Values: 0.082

MAGENTA:

Parameter: Effective Porosity

ID#: 2100

Form 464: WPO 32531, entered 2/9/96

Parameter Package: WPO 30608

Distribution Type: Student-t

Parameter Values: 0.138

TAMARISK:

Parameter: Effective Porosity

ID#: 2186

Form 464: WPO 34568, entered 2/20/96

Parameter Package: WPO 30608

Distribution Type: Student-t

Parameter Values: 0.064

UNNAMED:

Parameter: Effective Porosity

ID#: 2200

Form 464: WPO 34692, entered 2/20/96

Parameter Package: WPO 30608

Distribution Type: Student-t

Parameter Values: 0.181

Definition: The effective porosity is defined as the ratio of the interconnected pore volume to the bulk volume of the rock. The term porosity is used in the following discussion for simplicity.

Intended Use: The values of non-Salado porosity for each unit above Salado are used as initial input into BRAGFLO. Specifically, initial porosity is used to calculate pressure-dependent porosity (Compliance Certification Application (CCA) Section 6.4 contains the Conceptual Model descriptions) under three scenarios: (1) undisturbed conditions, (2) a borehole intrusion penetrating the repository and a Castile brine reservoir, and (3) a borehole intrusion penetrating only the repository. The use of the initial porosity is expressed in the following equation:

$$\phi = \phi o \exp [C(p - p_o)]$$

where:

ϕo = initial porosity, the parameter that needs to be reviewed in this section

po and p = initial pressure and pressure at a subsequent time

C = bulk rock compressibility.

Derivation: Non-Salado porosity was estimated for six units above the Salado, including the Culebra, Dewey Lake, Forty-niner, Magenta, Tamarisk, and unnamed. The data for Culebra were based on two sources: (1) the core analyses for selected samples from the Culebra dolomite from 20 boreholes

at the WIPP site (SAND90-7011), and (2) the data from borehole H-19b4 and AIS obtained from the memorandum, Terra Tek, dated Jan. 8, 1996. The measurement processes for effective porosity were documented in detail in SAND90-7011. The data for the other five units using core analyses were based on samples from borehole H-19b1 and analyzed by Terra Tek recently. This recent work was done under a qualified quality assurance (QA) program and is not part of this peer review.

6.1.1. Adequacy of Requirements and Criteria

The objectives of the core analyses, clearly stated in SAND90-7011, were to understand the physical properties of the pore structure of the Culebra better and to augment the Culebra data base for site characterization and performance assessment studies. The sampling and analyses processes documented in SAND90-7011 have demonstrated that the requirements and criteria were adequate to meet the objectives. The adequacy of the requirements can be summarized as follows:

- More than 100 samples, including whole-core and core-plug samples from 22 boreholes located in the WIPP area were used.
- Results from different phases and different laboratories were evaluated and were consistent.
- Tests were performed under a quality assurance plan.

6.1.2. Validity of Assumptions

One assumption related to the estimation of porosity of the Culebra is that the selected samples are a reasonable representation of the Culebra dolomite, which statistically represents the porosity distribution of the Culebra physical textures. This appears to be a reasonable assumption based on the large number of samples collected from 22 boreholes at different locations. However, as stated in SAND90-7011, the selected core samples were based on the availability of samples. Since many core samples that were in apparently porous and fractured parts of the Culebra have been destroyed and not recovered during coring, the measured samples may not completely represent the physical characteristics of the Culebra.

In the porosity estimation for the other units, the underlying assumption is that the core samples collected from borehole H-19b1 are a reasonable representation of the entire unit at the WIPP site. This assumption in general may not be acceptable if the objective was to characterize the physical texture of the formation. However, for the intended use of the porosity in BRAGFLO, this assumption can be accepted because the objective of BRAGFLO is to estimate the brine flow rate entering the Culebra

under the intrusion senarios. All the other units are much less transmissive than the Culebra; whether the parameter is representative is not important.

6.1.3. Alternative Interpretations

Porosity estimation by the helium method is a standard and well known process. No significant alternate interpretations need to be considered.

6.1.4. Uncertainty and Consequences

The primary uncertainty related to the pore volume measurements used to estimate the porosity for Culebra is stated in SAND90-7011. Specifically, for many WIPP wells the incomplete core recovery may correspond to the porous and fractured parts of the Culebra. Therefore, the parameter distributions obtained from the recovered core samples may represent only the relatively less fractured and competent parts of the Culebra at the WIPP site.

The uncertainty of the porosity estimation may have only minor effect on the calculation of the flow rate entering the Culebra because the dominant factors for flow rate calculation are the borehole transmissivity and pressure gradient (SAND89-7069). The uncertainty associated with estimation of porosity may be well covered by the uncertainty associated with the estimation of borehole transmissivity and pressure gradient.

The estimation of porosity for units other than the Culebra is less important. The permeability value for the Forty-niner, Tamarisk, and unnamed units have been set equal to zero (Memorandum from L. Dotson, February 1, 1996) for the purposes of the PA. These units in BRAGFLO are treated as impermeable so that the model will not allow fluid flow from a borehole or shaft that penetrate these formations. Therefore, the porosity in these formations will have no effect in the model.

The estimation of porosity for the Dewey Lake and Magenta is considered adequate for the intended use. The objective of BRAGFLO is to simulate the brine flow rate entering the Culebra in the vicinity of the WIPP site under the hypothetical borehole intrusion scenario. The potential flow rate entering Dewey Lake and Magenta would be significantly less than the potential flow rate into the Culebra, based on the significant differences in permeability and pressure values. The consequences and uncertainty associated with the estimation of porosity for these two units are negligible.

6.1.5. Appropriateness and Limitations of Methodology and Processes

The methodology and processes for the measurement of porosity for the Culebra were documented in detail in SAND90-7011. They are considered appropriate for the characterization of the physical properties of the Culebra.

The basic approach used for measurement of porosity is the helium method based on Boyle's Law. Helium is a non-adsorbing gas and has a minimum deviation in behavior from an ideal gas. The helium method is supposed to provide an approximation of total interconnected porosity. Advantages of the Boyle's Law helium method are that it is: (1) very accurate, (2) fairly rapid except for extremely low-permeability (< 1.0E-18 m^2) samples, and (3) non-destructive, allowing the samples to be reused for other analyses (SAND90-7011).

The water resaturation method was also used to measure porosity. The resaturation method is supposed to provide an estimate of the interconnected porosity for ground water flow, and also to have the advantage of determining the void volume when the mineral samples are wet, as the *in situ* condition. The resaturation method using deionized water was applied on part of the samples that had been used to measure porosity using the helium method. Results of applying both methods show close agreement.

The core analyses documented in SAND90-7011 were performed in two phases from 1985 to 1986 and from 1987 to 1988, and were conducted by two laboratories, Terra Tek and K&A Laboratories. Consistency between the two phases and the two laboratories was checked by duplicate analyses on the same samples. The results were consistent.

Based on the description in SAND90-7011, the methodology and procedures used for measurement of porosity are considered appropriate.

6.1.6. Adequacy of Application

The estimated porosity, as constant values for each unit above the Salado, is used as the initial porosity under referenced conditions in BRAGFLO. BRAGFLO calculates the porosity as a function of change of pressure under the borehole intrusion scenario. The estimated average values of porosity for the Culebra, and for other units, are considered adequate for the intended use.

6.1.7. Accuracy of Calculations

Calculations for estimation of porosity based on measured bulk volume and pore volume were not presented in the report. The average porosity based on each core sample measurement for the Dewey Lake was recalculated and found to be correct.

6.1.8. Validity of Conclusions

For the intended use of porosity in BRAGFLO, the estimated average porosity in the Form 464s, as presented at the beginning of this section, are considered adequate.

6.1.9. Dissenting Views

None.

6.2. Non-Salado Pressure

This section reviews the data from which the brine far-field pore pressures in units overlying the Salado were derived.

Parameter:	Brine far-field pore pressure
ID#:	2101
Form 464:	WPO 32539, entered 2/20/96
Parameter Package:	WPO 30713
Distribution:	Constant
Parameter value:	9.17E+05 Pa
ID#:	142
Form 464:	WPO 32774, entered 2/20/96
Parameter Package:	WPO 30713
Distribution:	Constant
Parameter value:	8.22E+05 Pa
ID#:	343
Form 464:	WPO 33544, entered 2/20/96
Parameter Package:	WPO 30713
Distribution:	Constant
Parameter value:	1.01325E+05 Pa
ID#:	160

Form 464: WPO 32733, entered 2/20/96

Parameter Package: WPO 30713

Distribution: Constant

Parameter value: 1.01325E+05 Pa

Definition: The brine far-field pore pressure is that pressure exerted by fluids existing within the interconnected pore spaces in the stratigraphic units above the Salado in regions sufficiently remote from mining, drilling, and other human activities that may have disturbed the environment.

Intended Use: The brine far-field pore pressure is used in BRAGFLO as the initial pressure in these stratigraphic units. The Magenta and Culebra units in particular exhibit significantly higher permeabilities than the surrounding rocks and represent potential pathways to the accessible environment. Consequently, the initial pressure must be reasonably well known in order to calculate the influx of brine contaminated with waste into these units.

Derivation: The pore pressures in the Magenta and Culebra Members were determined by isolating these units in separate wells (e.g., H-4A for the Magenta and H-4B for the Culebra) drilled 100 feet distant from H-4A. The wells were drilled to a depth just above the unit of interest, cased, and grouted, and then drilled deeper through the strata to be investigated. After cleaning and bailing the wells, water/brine was allowed to flow into the well over long time spans (up to several years). Knowledge of the depths below surface of the resultant water level and the depths to the top and bottom of the respective member in the well, and also the measured density of the saline water, permitted calculation of the pressure at the mid-point of the unit. Pressures obtained in this way were averaged for several wells to get an estimate of the average over the area covered by the WIPP site. This was entered as a constant into the data base (Form 464) for input to BRAGFLO. Pore pressures in strata above the water table were assumed equal to atmospheric.

Discussion: Six wells were used for the estimation of the average pore pressure at the mid-depth of the Magenta Member, and nine for the Culebra. The calculated pressures showed considerable variability -- a standard deviation of about 30% as calculated by the reviewer. Differences were noted between the initial reports of depths to water level and formation boundaries and later reports, possibly

due to observations of depth to water at later times and to relogging of cores, but generally suggesting an uncertainty of perhaps 10% in the pressures.

The Parameter Package for initial pore pressures above the Salado supports four Data Entry Forms 464, one each for the Magenta Member, the Culebra Member, the Santa Rosa Formation, and the Dewey Lake Red Beds. The Santa Rosa and the upper part of the Dewey Lake are unsaturated and are assigned a pore pressure equal to atmospheric: 1.01325E+05 Pa. The water table in four wells lies close to 980 m above mean sea level within the Dewey Lake. No pore pressure is assigned to the lower portion of this unit. An initial constant pore pressure of 9.17E+05 Pa was assigned to Magenta; 8.22E+05 Pa to the Culebra.

6.2.1. Adequacy of Requirements and Criteria

An objective of the analysis was to provide initial pore pressures for input to BRAGFLO. No written requirements or criteria were found in the relevant documents. However, the data must satisfy this objective.

The measurements required for obtaining these data are:

- The elevations of the tops and bottoms of the formations in several boreholes must be known with sufficient accuracy.
- The elevation of the static water table in these holes must be adequately known. This stand of water must approximate the undisturbed pre-drilling state sufficiently well.
- The density of the water must be well known and uniform throughout the well.
- The water in the well must come predominantly from the formation under investigation.

Details of how the elevations of the formation boundaries were determined were not apparent from the relevant documents. Presumably, considering the date of the investigation, they were determined from core logging. Because cores are never continuous, errors of a few feet may occur owing to uncertainty in the footage of core lost in unrecovered intervals. To some degree this can be corrected by comparing against measures of core recovery. Examination of relevant documents revealed small to rather considerable discrepancies between early reports of depths to formation boundaries, e.g., U. S. Geological Survey Water-Resources Investigation Reports (WRIR) 81-36 and 82-19, and in the primary data source, WRIR 83-4016. These discrepancies possibly arose from relogging of the core; otherwise,

the depths should be accurate to within several centimeters. In any event, the first requirement must have been addressed by measurements of depths.

The second requirement was addressed by allowing water to enter the borehole over long time periods with the expectation that it would eventually stabilize at or close to the undisturbed pre-drilling state. Again, early measurements may have been superseded by later ones, giving rise to discrepancies noted between data in WRIR 81-36 and 82-19 as compared to WRIR 83-4016.

The third requirement was addressed by taking samples of the water, either by swabbing or by use of a bailer. These techniques would allow some change of density owing to loss of gases and evaporation; however, these effects should be small. Subsequently, the density was presumably measured by accurate laboratory methods. Thus, little error is expected from this source.

The fourth was often addressed by boring separate boreholes to each of the regions of greatest importance. Thus, "H" wells, whose designation ends in A, were finished just below the Magenta Member, the portion of the hole above this member having previously been cased and cemented. Thus, water flowing into the borehole would come only, or very predominantly, from the Magenta Member. The Culebra Member was similarly isolated in separate "B" wells located 100 feet distant. These measures provide reasonable assurance that the fourth requirement was met and that the uniformity aspect of the third requirement was met.

6.2.2. Validity of Assumptions

One assumption is that the measurements are sufficiently accurate for the intended use. Because only single, rather than multiple, determinations of density and of depths to formation boundaries and water levels were reported, it was not possible to evaluate this implicit assumption. A second assumption is that the pore pressure in the unsaturated zone is atmospheric. This seems very reasonable.

6.2.3. Alternate Interpretation

Because of the requirements of BRAGFLO to use constant values of the initial pore pressure in units above the Salado, the various measurements of pore pressure were averaged for both the Magenta and Culebra Members. An alternative interpretation might well have been that the pore pressures were not sufficiently constant regionally and that instead, a distribution of values would be more appropriate.

6.2.4. Uncertainty and Consequences

Uncertainty is difficult to assess. However, if one assumes for individual wells that the differences between data in WRIR 81-36 and 83-4016 represent uncertainty associated with the determinations, then the uncertainty can be as much as 10%. On the other hand, if the variability shown in measuring the depth to water shown in figures 5-17 , -18, -19 , -21, and -22 in SAND86-2311 is used instead, the uncertainty becomes much less. In any case, 10% uncertainty seems acceptable for the intended application.

The standard deviations of the data sets for the Magenta and Culebra, calculated by the reviewer from data in the accompanying Parameter Package, WPO 30713, dated 3/20/96, provide some measure of the uncertainty regionally. The standard deviation of the six determinations of initial pressure in the Magenta, 2.79E+05, seems large compared to the mean (9.17E+05) for the intended use. A similar large standard deviation, 2.94E+05, compared to the mean (8.22E+05) exists for the nine measurements for the Culebra. Because the initial pressure of these units is an important parameter in BRAGFLO, it is somewhat questionable whether designation as a constant adequately represents the parameter distribution. No sensitivity analyses of the effects of varying this parameter are known to the reviewer. Whereas the number of data points is small, it appears to be enough to provide a reasonable average and spread of the pressures. As noted above, the assumption of atmospheric pressure in the unsaturated zone is considered acceptable. The elevation of the water table was measured in four boreholes within the Dewey Lake and found to be very consistent, 980m ± about 1 m above mean sea level.

6.2.5. Appropriateness and Limitations of Methodology and Procedures

The method of calculating initial pore pressure appears adequate. It was calculated for the mid-point of the formation in each of the boreholes used and employed elementary physical concepts. The only obvious limitation is that the level of water in the borehole at the time of measurement may not have recovered to pre-drilling levels.

6.2.6. Adequacy of Application

Demonstration of adequacy would require examination of BRAGFLO results, such as might show sensitivity to different choices of initial pressure over the range of variability identified. None were provided. However, use of a constant for this parameter seems questionable, at least for the Culebra.

Because there is expected to be no flow into the Magenta, the use of a constant initial pore pressure is not a concern for this Member.

6.2.7. Accuracy of Calculations

The only calculations were those reported in spreadsheets. These were checked by hand calculation and found to be accurate.

6.2.8. Validity of Conclusions

The review of the data permits the following conclusions to be drawn. The average value of the parameter in each of the units considered is judged acceptable for the intended use. Specifically, a constant value of 1.01325E+05 Pa is judged suitable for the Santa Rosa Formation and that portion of the Dewey Lake Red Beds that lies above the water table. The values of 9.17E+05 Pa and 8.22E+05 Pa are deemed acceptable for the average initial far-field brine pore pressure in the Magenta Member and the Culebra Member, respectively. The elevation of the water table at 980 m above mean sea level is also found to be acceptable. These conclusions apply to WPO numbers 32539, 32539, 33544, and 33544, as noted at the beginning of this section. The choice of a constant instead of a distribution to be sampled for the Culebra Member, however, is questionable. This is not of concern for the Magenta because no flow is expected into this member.

6.2.9. Dissenting Views

None.

6.3. Non-Salado Permeability

The permeability values for Non-Salado formations were estimated for the WIPP site for input used in BRAGFLO. The package only includes permeability estimation for two units: Magenta and Dewey Lake. For other Non-Salado units, the values of permeability were assumed to be 1.0E-35 m^2 for the purposes of the PA, according to the memorandum from L. Dotson (Feb. 1, 1996). The information included in the Form 464s for Magenta and Dewey Lake is as follows:

MAGENTA

Parameter: Log of intrinsic permeability

ID#: 2102, 2103, 2104

Form 464: WPO 32545, entered 2/16/96

Parameter Package: WPO 30607

Distribution Type: Constant

Parameter Value: -15.2 log(m^2) (6.3E-16 m^2)

DEWEY LAKE

Parameter: Log of intrinsic permeability

ID#: 161, 162, 162

Form 464: WPO 32734, entered 2/22/96

Parameter Package: WPO 30607

Distribution Type: Constant

Parameter Value: -16.3 log(m^2) (5.0E-17m^2)

Definition: Intrinsic permeability is a physical property of a medium alone, which represents the conductive capability of a medium. It is often defined as $k = K\mu/\rho g$

where:

K = hydraulic conductivity

μ = fluid viscosity

ρ = fluid density

g = gravitational constant.

Intended Use: The estimated values of the intrinsic permeability for the Non-Salado units are used as input parameters in BRAGFLO in simulation of the hypothetical breach of the repository room.

Derivation: Permeability for the Magenta was derived from one of the transmissivity test results obtained from the USGS report (USGS 83-4016). For the Dewey Lake, laboratory permeability data on core samples from Borehole H-19b1 were by provided Terra Tek.

6.3.1. Adequacy of Requirements and Criteria

The requirements and criteria for the estimation of the Non-Salado permeability were not documented in the related package. According to the intended use in BRAGFLO, permeability of Non-Salado formations will be used as a constant for each unit in the vicinity of the WIPP site. As long as the parameter is representative for the formation in the area of the WIPP site, it should be considered adequate in the PA. Since the purpose of BRAGFLO is to estimate the potential breach flow rate into the Culebra, estimation of permeability of other Non-Salado units is considered less important.

6.3.2. Validity of Assumptions

The intrinsic permeability was assumed to be 1.0E-35 m^2 for the Forty-niner, Tamarisk, and Unnamed Lower Members of the Rustler Formation according to the memorandum from L. Dotson (Feb. 1, 1996). This simply assumes that these units are impermeable. This treatment is conservative because allowing flow from a breach borehole or shaft into these units would reduce the flow into the Culebra.

Assumptions for estimation of permeability for the Magenta and Dewey Lake were not given explicitly. In the USGS report (USGS 83-4016), there are 12 transmissivity data available (p. 105). Only the value for H-1, which is located within the WIPP site, was used to convert to the value of permeability. The reason for selection of this value was not given. Since this value is the smallest value among the values

of the other test boreholes located in the vicinity of the WIPP site, the underlying assumption for the Magenta appears to be that the lowest permeability in the available data is representative and most conservative for the purpose of the PA.

6.3.3. Alternate Interpretation

Since the permeability of these formations is substantially lower than that in the Culebra, the effect of these formations in BRAGFLO is less important. Alternate interpretations do not need to be considered.

6.3.4. Uncertainty and Consequences

On the basis of the limited data base, the estimations of the permeabilities of the Magenta and Dewey Lake are very uncertain. However, the potential consequences associated with the uncertainties in the PA may be insignificant based on the roles of these formations in BRAGFLO.

6.3.5. Appropriateness and Limitations of Methodology and Procedures

Descriptions for the methodology and procedures for both tests on Magenta transmissivity and on Dewey Lake core analyses were not available. According to the Parameter Package, the core analyses for samples of H-19b1 were conducted under a qualified assurance plan in general accordance with ASTM 5084-90. The samples for the Magenta from H-19b1 were found to be contaminated by oil, according to the memorandum attached with the Parameter Package. This may be the reason for converting Magenta transmissivity from the USGS report to permeability.

6.3.6. Adequacy of Application

Adequacy of application of these parameters should be acceptable based on the limited effect of these parameters in BRAGFLO.

6.3.7. Accuracy of Calculations

The calculations were checked for permeability values for both the Magenta and the Dewey Lake. The conversion from transmissivity to permeability for Magenta is correct. The calculation of the average horizontal permeability for Dewey Lake is correct.

6.3.8. Validity of Conclusions

The estimated values of average intrinsic permeability for the Magenta and Dewey Lake are considered adequate for their intended use in BRAGFLO.

6.3.9. Dissenting Views

None.

6.4. Culebra Permeability

This section reviews the Culebra permeability presented in the Form 464 as follows:

Parameter: Log of intrinsic permeability

ID#: 143, 144, 145

Form 464: WPO 32775, entered 2/16/96

Parameter Package: WPO 31167

Distribution: Constant

Parameter value: -13.678 log(m^2) (2.1E-14 m^2)

Definition: The intrinsic permeability is defined as $k = K\mu/\rho g$,

where:

K = hydraulic conductivity

μ = fluid viscosity

ρ = fluid mass density

g = gravitational constant.

Intended Use: The intrinsic permeability is required by BRAGFLO for modeling the flow of ground water in and near the repository.

Derivation: The data package associated with this Form 464 does not encompass any derivations of parameters from measured data. Instead it simply states how the equation given under the definition calculates the intrinsic permeability from data provided from other sources.

Discussion: This package simply takes a value for the hydraulic conductivity, K, and converts it to intrinsic permeability, as required by BRAGFLO. Other data required to effect this conversion are the density, ρ, the dynamic viscosity, μ, and gravitational constant, g. K was derived from

70 transmissivity fields used in the 1992 PA analyses (SAND92-0700/3). The density was taken from SAND92-0700/3, Table 4.1-1, p. 4-1, which in turn cites SAND89-7068/2. The dynamic viscosity is taken from the same table, citing SAND86-7167. The gravitational constant for earth conditions is well known.

6.4.1. Adequacy of Requirements and Criteria

The only requirement is that an adequate value for intrinsic permeability be provided for use in BRAGFLO. On the assumption that the input data are adequate, the value entered on Form 464 is acceptable. The value used should represent adequately the average K of the Culebra in the region modeled.

6.4.2. Validity of Assumptions

The only stated assumption is that the median areal weighted average value of the hydraulic conductivity, derived from the 70 transmissivity fields used in the 1992 PA, is acceptable for use in the 1996 PA. This assumption is accepted because there is no expectation that new data will result in a major change in the data base for the Culebra transmissivity. The derivation of hydraulic conductivity from reported transmissivity involves a simple calculation; for the purposes of this review it is accepted that this calculation was done correctly. Implicit assumptions are that the values used for the fluid viscosity and density are also adequate.

6.4.3. Alternate Interpretation

This data package merely records the conversion of one parameter to another using well recognized equations found in hydrology reference books. There is no other interpretation.

6.4.4. Uncertainty and Consequences

The only (rather minor) uncertainties are for the data used as input to the conversion equation. These have been addressed under Section 6.5.2. The uncertainty for the viscosity seems moderate. This parameter was calculated according to an equation proposed by SAND81-0557. The equation starts with the viscosity of pure water at the appropriate temperature. Any uncertainty in the temperature transfers to an uncertainty in this value. The equation then adds corrections, using temperature dependent coefficients, for the effect of each of the dissolved ions in the solution. The simplifying assumption that the fluid contains only NaCl, therefore, adds some unquantified uncertainty by not taking into account the effects of, for example, magnesium and sulfate. Divalent cations, such as Mg^{++}, have a greater effect

on density than univalent ones, which suggests that uncertainties of the order of magnitude of the apparent calculational error noted in Section 6.5.7 will be present.

6.4.5. Appropriateness and Limitations of Methodology and Procedures

The methodology used for the conversion is appropriate.

6.4.6. Adequacy of Application

The conversion is adequate for the intended application. The value of the parameter and its distribution, as a constant, are judged adequate; BRAGFLO requires only an average value in addressing the intended use, even though individual determinations show a variability of at least two orders of magnitude.

6.4.7. Accuracy of Calculations

The conversion of K to k, using the values provided for K, μ, ρ, and g, was calculated by hand and found to be correct.

In respect to the calculation of the fluid viscosity, it is here assumed that the equation and the temperature dependent coefficients proposed by SAND81-0557 are sufficiently accurate for the purpose at hand. SAND86-7167, p. 3-19, states that "a mean fluid density of 1.05 g/cm^3 was considered to be representative of the formation fluid within the model area." It is here noted that the fluid density used in the calculation of the intrinsic permeability was 1.090 g/cm^3. The implications of this difference are noted below. Another statement in SAND86-7167 (p. 3-19) is "Thus, a density of 1.05 g/cm^3 corresponds to a NaCl concentration of about 0.86 mol/l." This appears to be somewhat in error. Table 6.4.7-1, below, shows some of the data from Hodgman (1959) together with conversions of g/L to mol/L done by the Panel.

Linear interpolation between densities of 1.0413 and 1.0559 indicates that a density of 1.05 g/cm^3 corresponds approximately to 1.29 mol/L, not 0.86 mol/L as stated in SAND86-7167. On the other hand, if a liter of the fluid (e.g., 1050 g) is taken and it is assumed that this consists of 1000 g of water and 50 g of NaCl, then one does obtain about 0.86 mol of NaCl. Apparently this is what was done, but it ignores the fact that the total volume of most aqueous electrolyte solutions does not equal the volumes of the constituent salts plus water before mixing. Normally, the volume is less, owing to the disruptive effect of the ions on the structure of water, causing a partial collapse. Correspondingly, if the representative density is instead 1.09 g/cm^3, the molarity is about 2.23. Use of these data in an equation cited in

SAND81-0557 yields a value of μ equal to 1.027 Pa-s for a density of 1.05 g/cm^3, and equal to 1.105 Pa-s for a density of 1.09 g/cm^3. This discrepancy from the value actually used seems to be of very minor significance for the intended use; the uncertainty in other parameters (such as permeability) may be orders of magnitude and would dominate the aggregate uncertainty in the flow calculation.

Table 6.4.7-1 g/L to mol/L Conversions

Specific Gravity	Concentration		
	%NaCl	g/L	mol/L
1.0053	1	10.05	0.1719
1.0125	2	20.25	0.3464
1.0268	4	41.07	0.7027
1.0413	6	62.48	1.0689
1.0559	8	84.47	1.4453
1.0707	10	107.1	1.8323
1.0857	12	130.3	2.2293
1.1009	14	154.1	2.6364
1.1162	16	178.6	3.0556

6.4.8. Validity of Conclusions

The conversion is valid. The value of 2.1E-14 m^2 (of which the logarithm is -13.678) is judged adequate for the intended application. This value is entered on the Form 464, as noted at the beginning of this section. The adequacy of the values input to the conversion is also considered to be sufficient.

6.4.9. Dissenting Views

None.

6.5. Climate Index

This section reviews the data and procedures from which the climate index was derived.

Parameter: Climate index

ID#: 223

Form 464: WPO 33031, entered 5/3/96

Parameter Package: WPO 36425

Distribution: Cumulative

1.0 1.25 1.50 2.25 Value

0.0 0.75 0.75 1.00 Prob

Parameter values: Mean: 1.31

Median: 1.17

Std. Dev.: 0.348

Definition: The climate index provides a multiplier for the increases in the lateral ground water flow in the Culebra Member compared to that which exists at the present and that which may be caused by future climatic changes. It does not provide an indication in any direct manner of the corresponding increase in precipitation or infiltration responsible for producing this increase. Thus, the index relates to changes in ground water fluxes caused by climate change, not directly to climate change itself. It is applied uniformly to PA realizations as a sampled factor by which lateral flow in the Culebra may be altered by climatic changes.

Intended Use: The climate index is needed as a sampled parameter for input to SECOFL2D to simulate the effects of potentially increased precipitation in the future.

Derivation: The climate index is derived from numerous computer runs that use different values of infiltration and different values (three choices for each) for hydraulic conductivities in the disrupted zone, anhydrite, and Dewey Lake Red Beds. For each of these simulations the rate at which

ground water flows out of the Culebra Member at the side boundaries is calculated. Two types of scenarios are examined. In one the assumption is that precipitation rapidly increases to the point where the water table is raised to near the ground surface, such that many seeps are formed, but no standing bodies of water. The lateral flow ratio, or climate index, was calculated from the lateral flow out the sides of the modeled area at steady state for a recharge rate of 2.0 mm/yr, which is sufficient to raise the water table to or close to the surface divided by the lateral flow out the sides of the modeled area at steady state for a recharge rate of 0.2 mm/yr, which resembles the present day situation. Some of the combinations of the parameters mentioned at the beginning of this section lead to unrealistic results, which are rejected. In the other scenario it is assumed that the pattern of alternating wet and dry periods deduced for the Holocene continues for 10,000 more years. For this case, the lateral flow out at 10,000 years in the future is divided by the lateral flow out now for simulations that start in both cases at the end of the last glacial maximum. These calculations yield the bimodal distribution reported on the Form 464. The first case is thought to be unlikely and is assigned an overall probability of occurrence of 0.25. Different simulations indicate a climate index for this case varying from about 1.50 to 2.25. The Holocene case is assigned an overall probability of 0.75; the lateral flow ratio varied from somewhat less than one to about 1.25. Those simulations which resulted in lateral flow ratios less than one were rejected as being non-conservative. Thus, the range for this scenario is from 1.00 to 1.25, as indicated above and on the Form 464.

Discussion: Documentation supplied with this parameter consists of Parameter Package SWCF-A:WBS1.2.07.1:PDD:QA. As stated in this package, the Climate Index increases flow magnitudes by the same factor at all locations within the flow fields used in the PA calculations. It was evaluated by running 54 steady-state and 17 transient SECOFL3D simulations in the Culebra, with input parameters thought to represent the range of likely future climates over the next 10,000 years. The Parameter Package describes the concepts, rationale, assumptions, and objectives in considerable detail. Existing data on past climates derived, for example, from plant and animal remains (sometimes fossilized) and radioisotope dating, are reviewed. Essentially, the conclusion is drawn that climate may vary between present day conditions and those present at the last glacial maximum during the Pleistocene (the Wisconsin). Two approaches were considered: 1) Oscillating climates in which 1000-year-long spikes of higher recharge occur at 500, 2000, 4000, 6000, 8000, and 10000 years in the future, with recharge rates of 0.2, 0.4, and 0.6 mm/yr; and 2) A sudden step to higher recharge which thereafter remains constant. The first concept resembles the historical pattern since the Wisconsin glaciation, and

the second the onset of another continental glaciation. The probability of the first was assessed at 75%, and the latter at 25%. This leads to a bimodal distribution.

6.5.1. Adequacy of Requirements and Criteria

The requirement is to provide a parameter for SECOFL2D that may be sampled by PA for evaluating the effect of changing future climate. The numerous runs noted above, however, were run on SECOFL3D, which lends credence to the probability of meeting the requirement.

6.5.2. Validity of Assumptions

The main assumptions are:

1. The ground water basin conceptual model applies.
2. The lateral boundaries are flow divides (i.e., no-flow boundaries) during the period simulated.
3. Flow in the unsaturated zone can be neglected.
4. The flow system was in equilibrium with a recharge rate sufficient to maintain the water table near the land surface at the start of the simulations.

The first assumption is widely accepted for regional ground water flow studies.

The lateral boundaries coincide with topographic depressions and highs on the land surface that surround the site. It is assumed that these boundaries represent ground water divides, i.e., no flow boundaries, whose position remains fixed over the range of past and future climates. The boundary of the region modeled, in general, is several kilometers from the WIPP site. Figure 2 in the Parameter Package includes a topographic map showing the boundary, but it does not include a distance scale. Comparison with Figure 2-1 in SAND78-1596 suggests that where the boundary is closest to the site, toward Nash Draw to the west, the distance is 5 to 6 km. (The site boundaries for WIPP differ between the two figures, and the topographic contours in the Parameter Package are generalized, making comparison difficult.) In any case the separation of the model boundary from the site is large enough that a moderate error in the location of the hydrologic divides from the positions assumed should make little difference in the modeling.

The third assumption, negligible flow in the unsaturated zone, is acceptable. In this region of very low precipitation there will be very little lateral migration of ground water in the unsaturated zone.

Moreover, many of the simulations show rise of the water table to the surface, such that in those cases most of the rock will be saturated.

The fourth assumption applies only to transient simulations which began at the last glacial maximum. At that time it is reasonable that the water table would be at or close to the ground surface.

6.5.3. Alternate Interpretation

Interpretations are of two kinds. The first is how to view the knowledge of the paleoclimatological observations. Numerous investigators have concluded that the climate has varied since the Wisconsin glaciation. Therefore, the only doubts or alternative interpretations would be by how much and over what time frames. The evidence does not indicate that large bodies of standing water were present during the Holocene; therefore, the assumption that precipitation and infiltration were at most sufficient to produce seeps, but not lakes, represents a conservatively high value. In other words, an alternative assumption would be less conservative. In practice, three different recharge rates were assumed for transient conditions and two for a single step to glacial conditions; these are in keeping with the conservatism just noted and provide an indication of the effect of lower values. No other alternatives seem needed in respect to magnitude of recharge. In respect to transient conditions, the frequency and duration of spikes of higher recharge need to be specified. The approach taken was to assume that the future will resemble the past. The simulations show relatively little sensitivity to various choices of recharge rate, suggesting that sensitivity to changes in frequency and duration is similarly small. Although such scenarios were not tested, there appears to be little need to do so in view of other uncertainties.

The second type of interpretation deals with how to derive appropriate values and a distribution function from the computer results. Full details of the logic are presented in the Parameter Package. Briefly, for six of the simulations that did not yield unrealistic results and address the uncertainty in Holocene recharge rate, the lateral flow rate ratio varied from 1.6 to 2.1. This range was increased somewhat to account for uncertainty of the results to 1.5 to 2.25. Examination and consideration of the remaining acceptable runs did not provide sufficient reason for changing these choices. Thus, the climate index (the lateral flow ratio, defined as well as possible as the rate of lateral flow under wet conditions divided by present day conditions) for steady-state (glacial) conditions was determined to be 1.5 to 2.25. However, the probability of recurrence of full glacial conditions within the next 10,000 years was deemed to be low, in keeping with most thinking found in the literature. Therefore, the overall probability of such

conditions was taken at 0.25, a rather speculative value and perhaps conservatively on the high side. For transient conditions, the results of the modeling of which are shown in figure 10 in the Parameter Package, the lateral flow ratio varies between 1.0 and about 1.25. With time these ratios decrease, i.e., future lateral flows sometimes are simulated as less than at present. These were rejected as being non-conservative, and the range taken instead as 1.0 to 1.25. The overall probability of these conditions was taken as 0.75. Other interpretations could be made, but little advantage is seen in doing so.

6.5.4. Uncertainty and Consequences

Obviously, there is a great deal of uncertainty, and even speculation, about what future climates will be. These are discussed in some detail above, but overall, the distribution presented on the Form 464 seems very reasonable.

6.5.5. Appropriateness and Limitations of Methodology and Procedures

The approach used strikes the Panel as being much more appropriate than attempting to do actual future climate modeling by use of complicated computer codes. The modeling of flow rates under various assumed conditions appears to capture the main elements and variability of what can be reasonably be expected and takes these limitations into account in the distribution function selected.

6.5.6. Adequacy of Application

The adequacy of application cannot really be addressed without having knowledge of future climates. From what can be deduced from present knowledge, the application in PA will be reasonable and adequate.

6.5.7. Accuracy of Calculations

All calculations were performed with SECOFL3D. The scope of this review does not include evaluating the adequacy or accuracy of computer results. It is assumed that the results are sufficiently accurate.

6.5.8. Validity of Conclusions

The review of the data and models used to derive the values and distribution of the climate index permits the following conclusion to be drawn, namely that the cumulative distribution of the climate index is judged adequate for the intended use because it is conservative. Specifically, the climate index consists of values 1.0, 1.25, 1.50, and 2.25, with corresponding cumulative probabilities of 0.0, 0.75, 0.75, and 1.00, as indicated on Form 464, WPO number 33031 and at the beginning of Section 6.6.

6.5.9. Dissenting Views

None.

6.6. Culebra Transmissivity Fields

Culebra Transmissivity Fields, based on 43 measurements in test wells spread over an area roughly 22 by 32 km, is used as input to GRASP-INV code suite. Taking the field values and using iterative solutions, GRASP-INV generates a set of fields that define transmissivity values at every node in the model of ground water flow in the Culebra Dolomite throughout the 22 by 32 km area. These transmissivity fields are then used by the two-dimensional SECOFL2D to calculate the ground water flow field in the Culebra Dolomite in the vicinity of the WIPP site. These transmissivity fields are randomly selected from numbers 1 through 100 to represent the transmissivity fields ranked according to travel times from the repository to the accessible environment.

Parameter: Culebra Transmissivity Field Indices

ID #: TRANSIDX

Form 464: There is no Form 464 for Culebra Transmissivity Fields

Parameter Package: WPO 35406

Distribution: TRANSIDX has integers from 1 to 100

6.6.1. Culebra Transmissivity Data

Culebra transmissivity data are transmissivity values obtained from the analysis and interpretation of hydraulic tests in the 43 wells mentioned in Section 6.6.

Values: Range: 0.00007 to 830 ft^2/day (see attached Table 6.7.8 - 1)

Definition: Culebra Transmissivity quantitatively describes the ability of the water-bearing portion (aquifer) of the Culebra Dolomite to transmit ground water (fluid). Transmissivity is expressed as the rate of ground water (fluid) flow, in $feet^2$ /day (m^2/second), through a vertical strip of the aquifer 1 foot (1 m) wide, extending the full saturated thickness of the water-bearing zone (aquifer), under a unit decline in potentiometric surface (hydraulic gradient of 100%) at prevailing water (fluid) temperature.

Intended Use: The intended use of the transmissivity values is for entry into GRASP-INV for the purpose of creating a set of calibrated transmissivity fields for use by SECOFL2D to calculate ground water flow fields within the Culebra.

Derivation: The Culebra transmissivity values were obtained from the hydraulic testing of wells.

Discussion: Since the value of transmissivity is the product of hydraulic conductivity times aquifer thickness, it is apparent that the values of Culebra transmissivity can differ by approximately 300% just due to the change in thickness (5 to 13 m) from one location to another in the Culebra Dolomite over the WIPP site. However, this difference is small compared to the several orders of magnitude variation in Culebra transmissivity values interpreted from hydraulic testing of wells at the WIPP site. These variations in transmissivity appear to be due largely to the influence (presence) of open fractures within the Culebra and their density and degree of interconnectivity at any particular well site.

Numerous interpretations of the results of well hydraulic testing across the WIPP site have demonstrated that at many locations, the Culebra Dolomite behaves as a double-porosity medium with unrestricted interporosity flow. In this type of aquifer system, the fractures are believed to have higher permeability and provide lower storage, while the primary matrix porosity has less permeability, but a much higher storage capacity.

The Culebra Transmissivity data package provides Culebra transmissivity values to be used as input to GRASP-INV calculations. The data are based on 43 field hydraulic tests, of which the data from 21 wells require qualification. These wells are H2c, H3b2, H3b3, H4b, H4c, H5b, H6b, H7b1, H8b, H9, H10b, H16, H17, H18, DOE1, P18, WIPP-27, WIPP-28, WIPP-30, ENGLE, and USGS-1.

The data requiring qualification are essentially those collected from constant- or multi-rate pumping tests, slug tests, shut-in tests, and DSTs performed on individual wells, as conducted by the USGS from 1978 to 1981 and by SNL between 1983 and 1987. A list of the wells and transmissivity values is shown in the attached Table 6.6.1.8-1.

6.6.1.1. Adequacy of Requirements and Criteria

The data used to obtain values of Culebra transmissivity were collected from hydraulic testing of the Culebra Dolomite by conducting pumping tests, slug tests, bailing tests, and DSTs in boreholes that penetrated the formation. These methods of testing formations for hydraulic properties are appropriate, and indeed, are about the only known method of obtaining the hydraulic properties of the formations.

The earlier hydraulic tests (1978 to 1981) conducted at the WIPP site by the USGS were the first attempt at hydrogeological characterization of the Culebra. These tests, for the most part, were bailing tests, slug tests, or short-term pumping tests. Frequent equipment problems complicated the data interpretation or rendered the data useless. The interpretation of the data, while accurate for the most part, was limited dominantly to the manual curve matching methods of Cooper et al. (1967).

Later (1983 to 1987) hydraulic testing of the Culebra was conducted by SNL, or its subcontractors, under stricter quality assurance programs, and with the benefit of increased knowledge of the Culebra as a result of the previous work. Thus, the newer pumping tests were much longer in duration, used multiple observation wells and electronic pressure transducers with a DAS to record many more measurements. The data from the tests were simulated by sophisticated technical software programs that can differentiate between single and double porosity permeability in an aquifer to provide more enlightened interpretation. In addition, some of the boreholes were retested and reinterpreted using the newer software programs to obtain an improved understanding of transmissivity values.

Thus, the requirements and criteria for the hydraulic testing and data interpretation for transmissivity values are adequate for the intended use.

6.6.1.2. Validity of Assumptions

Many estimates of transmissivity of the Culebra Dolomite have been obtained by fitting observation well data, from pumping tests of other wells, to the analytical line-source solution of Theis (1935). There are several implicit assumptions for the use of the line-source solution to simulate observation well response. The first is that the aquifer is areally homogeneous because the ground water supplying the pumping well is derived equally from all directions (i.e., the hydraulic conductivity is everywhere the same in the aquifer).

The results of the 1984 pumping test No 1. of H-3b3, as shown in the drawdown data (Fig. 6-3 and 6-4, SAND86-2311) for two nearby observation wells (H-3b1 & H-3b2), suggest that the Culebra Dolomite aquifer acts as a double-porosity medium with unrestricted interporosity flow in the vicinity of the pumping well. That is, fractures provide the bulk of the aquifer's permeability, while the matrix pores provide the majority of the storage capacity. In addition, the permeability of fractures varies from location to location. Thus, it appears that the first Theis assumption of a homogeneous aquifer is invalid.

The second assumption is that, on the areal scale of the observations, the aquifer behaves like a single-porosity medium. [This assumption is said to be justified in a double-porosity medium if the observation well is far enough away from the pumping well that only the total-system response is observed (SAND86-2311, p. 60).] With respect to DOE-1, used as an observation well (approximately 5200 feet away) during the pump testing of H-3b3, the plot of pressure vs lapsed time (SAND86-2311, Fig. 6-5, p. 61) does not exhibit a double-porosity effect. Thus, this second assumption appears to be valid in the case of DOE-1 and H-3b3.

6.6.1.3. Alternative Interpretations

Observation-well responses to pumping tests were interpreted by fitting to the line-source solution derived by Theis (1935). With regard to the 1985 pump test of H-3b2 and the use of observation wells including DOE-1 (5200 feet away), there were pre-test pressure/water level trends in the Culebra Dolomite that needed to be taken into consideration by modifying the observed data. Thus, there are two possible interpretations: the best fit to the observed data with no modifications and the best fit including a linear compensation for the pretest trend. In the first case, there is no compensation for the rising pressure/water level, so the data show less drawdown and more rapid recovery than if the trend had been absent. This results in a transmissivity that is too high and a slightly erroneous storativity in order to simulate a fit for these data. Applying a linear correction derived from the pretest behavior to the observed test data probably results in overcompensation, particularly in late time. The simulated fit to these data uses a transmissivity that is probably a minimum, as well as a slightly erroneous, storativity. According to SAND86-2311, p. 72, the two interpretations should provide limits to the apparent transmissivity value.

The transmissivity value of 7.0E-05 ft^2/day for well P-18 was obtained from interpretation of late time match parameters (after 600 hours since test inception) by using semi-log slug test type curves on the semi-log plot of H/H_o vs elapsed time (SAND87-0039, p. 99). Use of the late time curve match for the transmissivity value seems questionable in this case, as the early time (first 600 hours) data represent the aquifer characteristics in the vicinity of the well, <u>before</u> boundary effects. Furthermore, the late time data might reflect packer leakage that might have occurred after the pressure across the packer reached a critical value. Thus, use of the late time data, after boundary effects, seems inappropriate and slightly speculative to obtain a transmissivity value for the well and its immediate environs. Further, the early time (first 600 hours) interpreted value of 4.3E-03 ft^2/day is fairly close to the 1.0E-03 ft^2/day value provided by the interpretation of a previous bailing test by the USGS (USGS 83-4016)

6.6.1.4. Uncertainty and Consequences

With any science involving interpretation of natural phenomena, there always will be uncertainties. Thus, as is to be expected, there are uncertainties about some of the results of the hydraulic testing at the WIPP site and the estimated values of transmissivity. However, for the most part, the degree of uncertainty about the transmissivity values is not so much as to limit the intended use.

As an example, the following is a discussion of the uncertainty about the results of the ENGLE well pumping test. Interpretation of the data from the 1983 hydraulic testing of the ENGLE well provides a transmissivity value of 43 ft^2/day based on a single porosity medium interpretation using INTERPRET simulation of the drawdown data. [*Note: The recovery data for the well was stopped after one hour and not used in the interpretation. Due to a decrease in the pumping rate during the latter part of the test, the drawdown had actually decreased to approximately 46% of its maximum by the time the pump was stopped and water level recovery recorded. After only one hour the recovery pressure exceeded the initial pressure by 10.44 psi and measurements were stopped. No explanation in SAND87-7125 or SAND87-0039 was provided for the reason for the difference between final and initial water levels.*]

The INTERPRET simulated curves (SAND87-0039, p. 107) of the drawdown data for the ENGLE well match very closely except for the very late time data, implying that the single porosity model is appropriate for the analysis. The uncertainty about the 43 ft^2/day transmissivity value is related to the fact that the pumping tests for a number of other wells (DOE-1, DOE-2, H-3, H-8, H-11 and WIPP-13) with a transmissivity greater than 1.0 ft^2/day, as analyzed with INTERPRET, have shown a double porosity effect and negative skin factors; whereas, the ENGLE well is interpreted as having a relatively high transmissivity, but also a positive skin factor (Assuming a Culebra porosity of 20%, a total system compressibility of 1.0E-05 psi^{-1}, a fluid viscosity of 1.0 cp, the skin factor for the simulation can be calculated as 4.2.) and single-porosity behavior, which appears to be anomalous. It is reported (SAND87-0039, p. 108) that a possible explanation may be that the low volume windmill pump at the ENGLE well never stressed the aquifer. The relatively high pumping rate of 10 gpm for sustained periods of time, during the pumping test and the preceding step drawdown tests, may have developed the well. The acidizing and developing of well DOE-2, as well as its subsequent change from single porosity to double porosity hydraulic response, is cited as an example of this phenomenon. This well development theory might also partly explain why the post recovery water levels (pressures) were greater than the initial

water level. The well also may have still been recovering from the nearly three hours of step-drawdown testing the day before the test.

6.6.1.5. Appropriateness and Limitations of Methodology and Procedures

For the most part, the data requiring qualification were collected from hydraulic testing (constant- or multi-rate pumping tests, slug tests, shut-in tests, and DSTs) performed on individual wells, as conducted by the USGS from 1978 to 1981 and by SNL between 1983 and 1987. Although, at the time, there was no national certifying organization for these types of tests, there were published references by the USGS, the Bureau of Reclamation, EPA and the American Petroleum Institute.

The testing conducted by both the USGS and SNL were performed in accordance with specially developed internal test procedures for slug-tests and pumping tests, while the DST procedures had been developed and used for a number of years by the petroleum industry. As a matter of administrative procedure, all USGS testing and reporting on projects generally required approval by cognizant authorities within the organization. The SNL testing programs also were generally evaluated by internal review teams and authorized by cognizant management authorities.

The general procedures for the pumping tests and slug tests are documented in enough detail to be repeatable, although specific details are lacking in the SAND reports referenced. Some of the very specific test details are probably only available in old project data files and may be difficult to locate.

Many types of reports were reviewed as part of the evaluation of transmissivity values. The SNL HDRs contained substantial amounts of data which were largely reduced from the enormous amount of raw data accumulated by the DAS for the numerous hydraulic tests conducted at a number of wells. These data were sorted by borehole number, recording time, and measurement type, converting all measurements to a time interval using Julian days and converting electrical voltage inputs from the recording instruments into pressure, while converting all measurements from English to metric, as well as filtering out redundant data. Some of the older USGS reports on earlier phases of testing presented all the raw data as well as the interpretations in the same report. At that time, it was standard policy to provide the raw data in the reports. This also was at a time when automated data collection systems were just being developed. It was not yet obvious, as it later became, that data reduction would be necessary in order to minimize the tremendous quantities of data that could be supplied by the DAS and the use of electronic transducers providing data points every few seconds/minutes for days, weeks, months, or even years at a time.

In those cases where the data have been reduced (mostly the SAND reports where the field data were collected with a DAS using electronic pressure transducers), the reduced data accurately portray the raw data except for extraneous data, which sometimes have been purposely omitted. For instance, a spot check of the reduced pump test data in Table II.B.11 (SAND85-7206, pp. 89-94) for pumped well H-6b for test H6008, compared to the original data in Appendix C (SAND85-7206, pp. 471-500), shows a reasonably close correlation, as does the comparison of the reduced data points of drawdown and time with the graphs of drawdown vs time for the three wells at the H-6 hydropad (SAND85-7206, pp. 471-473).

The quality of the data reviewed is essentially sufficient to provide data plots with enough data points that reasonable interpretations can be made of the hydraulic characteristics of the Culebra Dolomite in order to calculate representative transmissivity values.

Many of the slug test (and DST) results in the USGS and SAND reports were interpreted by using type curve-matching techniques on semi-log plots of pressure (drawdown) vs time based on the classic work of Cooper et al (1967). This analytical technique is a well qualified, time-proven method for determining aquifer transmissivity and storativity.

During the hydraulic testing, the water levels (pressure) were measured to the nearest 1/100 of a psi (0.023 feet) which, for this type of testing, is satisfactory. The measurements of pressure (water levels) were generally recorded on a logarithmic basis such that, as a minimum, five or more data points would fall within each log cycle on the semi-log plot, which is adequate for analysis and interpretation. The hydraulic testing completed with a DAS and pressure transducers literally produced thousands of data points, which then required data reduction techniques to produce manageable quantities of data for automatic plotting and analysis/interpretation techniques through computer simulation.

In the beginning phases of the WIPP site characterization of the hydrogeology, the initial testing was completed by the USGS using standard hydraulic testing techniques, such as slug tests and well shut-in tests, and measuring water levels before, during, and after the testing.

As more was learned about the complexities of the site, the testing by the USGS and SNL became more sophisticated to deal with the need for more site-specific and stratigraphic horizon-specific hydrological information. In the early phases of investigation many of the Culebra wells indicated low permeability and slug tests were determined as the appropriate testing mechanism for the low yield wells. In some

cases, however, the flows from the formation into the wells were higher than expected and the slug tests could not be completed satisfactorily (e.g., the H-6b testing by the USGS [Dennehy 1982, p. 18]). In this case, SNL contracted for additional testing of H-6b and later performed more testing at the H-6 hydropad (SAND85-7206, p. 43, 106-7, and 410+) and were able to obtain values for transmissivity.

Later phases of testing at other wells either contracted by or conducted by SNL (SAND86-2311) used downhole strain-gage transducers and automated DAS to store raw millivolt output from the transducers and calculate pressures. Analyses of hydraulic test data were performed with INTERPRET well-test interpretation code. These later tests were certainly appropriate for the task and had few, if any limitations of methodology and procedures.

Review of the various source documents for the transmissivity values indicates that the assumptions, calculations, extrapolations, methods, and conclusions pertinent to the data were appropriate for the development of the parameters used as input to the WIPP PA, except as noted in Section 6.6.1.8.

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6.6.1.6. Adequacy of Application

Analysis of the results of the 1985 pumping test of H-3b2 indicate that at late time, a significant portion of the well recovery was related to additional stresses other than the pumping test (SAND86-2311, p. 62). For example, it is known that the wells at the H-3 hydropad were still recovering from the step-drawdown test and three other pumping episodes related to pump testing before the start of the 62-day pump test of H-3b2. Figure 6-7 (SAND86-2311, p. 62) showing the linear-linear plot of both drawdown and recovery data of H-3b2 and the INTERPRET simulation of the test data, indicates the static formation pressure specified for the simulation is several psi higher than the pressure measured at the beginning of the step-drawdown test. Toward the end of the recovery period, the simulation predicts increasingly less recovery than was observed. This late time difference in pressure recovery data shown in the simulation plot would seem to demonstrate the possible additive effect of sealing of the Exhaust Shaft in July 1985. The additive effects of the multiple pre-test pumping were included in the simulation.

In a review of the reports on all these wells, it appears that the test procedures were correctly implemented, except as discussed in Section 6.6.1.8.

In order to calculate the transmissivity of well H-5B from the water level recovery data measured during Shut-in Test #1 (USGS WRI 82-19), using the Theis recovery method, the average discharge (or recharge) of water (Q) to the test zone is required. As described in USGS WRI 82-19, the Q value was

obtained by placing a pressure transmitter into the well after the bailing had ceased and measuring the rate of change in pressure (water level) as the well gradually filled back up with water from the formation to the level before the well was shut-in. Because of the well depth, the time needed to install and set the packer assembly into the well before the shut-in period amounted to several hours, during which time there were no measurements. The pressure measurements made during the brief open hole recovery period of continually decreasing discharge, represented flow rates that would have been larger than discharge rates, as measured later in the shut-in period. Consequently, the calculated value of Q is undoubtedly larger than the actual average discharge for the entire flow period. Therefore, the computed transmissivity, using Theis's Equation, probably is larger than the actual value for the Culebra Dolomite at well H-5B.

At well P-18, (SAND87-0039, p. 99) during the withdrawal slug test, it was noted that when the packer in the tubing was deflated the pressure recorded did not match the water level as estimated using the measured density correction factor of 1.05. Because more confidence was placed in the specific gravity measurements made when the tubing was last bailed, than in trying to match initial water level by changing the density to 1.14, it was assumed that the transducer depth was incorrect and the depth was increased by 7.5 feet. These changes in the initial depth to water and the static depth of water were used in the final interpretation of the transmissivity from the P-18 slug test.

The parameters (water levels, water pressures, density, discharge volumes) that were measured during the hydraulic testing of the Culebra Dolomite are dependent on the natural physical properties of the water-bearing formation, such as permeability and effective porosity, which are not expected to change much in the next 10,000 years. The values of the measured parameters, however, may change over time, but the age of the data (or date collected) does not materially affect the quality of the data or the results of the interpretation of the data.

SAND86-2311 (p. 32) states that, "because of data noise, a degree of subjectivity is involved in defining response times for the various wells (i.e., H-6 and others). Also, for wells exhibiting rising water-level trends before the test, drawdown was considered to begin when water levels actually started declining, even though the effects of pumping must have been felt sooner to reverse the upward trend. Consequently, the response times presented in Table 5-1 should be considered approximations, and are most likely overestimates."

For much of the hydraulic testing, there were multiple tests of the Culebra Dolomite at the same hydropad using one of the three wells first as a pumping well and then in the next test of another well at the pad, using the former test pump well as the observation well. An example of this was the pump test of H-3b3, using H-3b1 and H-3b2 as observation wells, and then further use of H-3b3 as an observation well while pump testing H-3b2, as reported in SAND86-2311.

The numerous graphs of the drawdown and recovery data from the pumping/slug/DST tests of the wells show that an adequate number of data points were collected to make accurate representations of the changes in the measured parameters during the testing and recovery periods.

As reported in SAND86-2311 (p. 54-61), for the H-3 pumping test, the interpreted transmissivity values from the three wells for the two pumping tests (first test with H-3b3 pumping and H-3b1 and H3b2 as observation wells, and second test with H-3b2 pumping and H-3b1 and H-3b3 as observation wells) varied among the three wells only 3.3% for the first test and 5.5% for the second test, although the transmissivity value for the second test was approximately 60% of the first test.

The intended use of the data is for input into GRASP-INV code to provide a distribution of transmissivity values of the Culebra Dolomite across the WIPP site. Thus, the values of transmissivity provided by the 43 well locations provides a fairly reliable indication of the variation in transmissivity within the Culebra Dolomite at and near the WIPP site.

The analysis of pumping tests of the H-3 pad (SAND86-2311, pp. 54-59) provides reasonable interpretations of the Culebra transmissivity from numerical simulations of the data from the H-3b3 well. This demonstrates that the test measurements follow a predictable pattern which indicates the adequacy of the application.

6.6.1.7. Accuracy of Calculations

No calculations are shown in the reports reviewed by the panel.

6.6.1.8. Validity of Conclusions

The data used in the interpretations of pumping tests of H-4c, H-8b. H-16, H-17, H-18, DOE-1, ENGLE, P-18, and WIPP-30 (as reported in SAND87-0039) are the same as those shown in the HDRs and other referenced reports. In other cases, such as the USGS slug testing of well H-6b in 1978 (USGS WRI 82-8,

p. 18), it has been duly reported that the data are inadequate or incomplete and no interpretations were attempted.

The range of uncertainty for each measurement is not stated within the reports reviewed, although it seems apparent from the numerous graphs of drawdown vs time and the simulated curve matching that reliable estimations of transmissivity can be made using those data.

The general conclusions regarding the Culebra transmissivity values gleaned from the interpretation of hydraulic test results of selected wells as reported in various reports reviewed can be summarized as: 1) a wide range (several orders of magnitude) of transmissivity values is apparent which demonstrates the areal heterogeneity of the Culebra Dolomite over the WIPP site, 2) the Culebra behaves as a double porosity medium with unrestricted interporosity flow in several wells, while other wells clearly demonstrate only single porosity flow. This suggests that fractures may provide the bulk of the permeability within the Culebra Dolomite, while the rock matrix pores provide the majority of storage. The reliability of these conclusions is demonstrated by the results of a large number of repetitive tests and retests of numerous wells over the WIPP site which yield very similar values.

The sources of the data were the hydraulic tests (e.g., slug tests, bailing tests, DSTs and pumping tests) conducted on single wells, the effects of which were measured in other single observation wells. Thus, to some extent, the wide range in Culebra transmissivity values reflects not only the heterogeneous nature of the Culebra Dolomite, but also the volume of rock that was stressed during the specific hydraulic testing as a result of the type and length of test and the location. At a single location, the transmissivity value can differ, depending on the type of test, because the volume of rock hydraulically stressed during a pumping test would be much larger than that stressed during a slug test and would represent conditions of a different spatial scale within the Culebra Dolomite radially outward from the borehole tested.

The processes used to produce the transmissivity values involved the collection of the field data (measurements of water levels, and flow discharge rates over time), the filtering, reduction, cataloging, and presentation of the data in data plots, and the interpretation of the data through the use of analytical and numerical techniques. These processes are appropriate to produce the transmissivity values for their intended use in GRASP-INV.

It is concluded that the transmissivity values, as listed in Table 6.6.1.8-1, are adequate and appropriate for their intended use in GRASP-INV, with the exception of the well P-18 value discussed below.

Table 6.6.1.8-1 Summary of Transmissivity Data Review

Well No.	Reported Culebra Transmissivity Values			Status
	ft^2/day	m^2/sec	log m^2/sec	
H-2c	0.79	8.5E-07	-6.07	A
H-3b2	2.3	2.5E-06	-5.62	A
H-3b3	2.3	2.5E-06	-5.62	A
H-4b	0.77	8.3E-07	-6.08	A
H-4c	0.77	8.3E-07	-6.08	A
H-5b	0.2	2.2E-07	-6.67	A
H-6b	37	4.0E-05	-4.40	A
H-7b1	830	8.9E-04	-3.05	A
H-8b	8.2	8.8E-06	-5.05	A
H-9	100	1.1E-04	-3.97	A
H-10b	0.73	7.8E-07	-6.11	A
H-16	0.79	8.6E-07	-6.07	A
H-17	0.21	2.3E-07	-6.63	A
H-18	1.85	2.0E-06	-5.54	A
DOE-1	11.0	1.2E-05	-4.93	A
P-18	0.00007	7.5E-11	-10.12	I
WIPP-27	200	2.2E-04	-3.67	A
WIPP-28	240	2.6E-04	-3.59	A
WIPP-30	0.175	1.9E-07	-6.73	A
ENGLE	43.0	4.6E-05	-4.34	A
USGS-1	514.0	5.5E-04	-3.26	A

Explanation:

A = Adequate
I = Inadequate

Well P-18 - the transmissivity of 7.0E-05 ft^2/day for well P-18, as reported in the Draft Culebra Transmissivity Database (July 1,1996), represents a value obtained from interpretation of late time match parameters (after 600 hours since test inception) rather than early time data using semi-log slug test type curves on the semi-log plot of H/H_o vs elapsed time (SAND87-0039, p. 99). Use of the late time semi-log curve match for the transmissivity value seems questionable in this case, as the late time data do not represent the aquifer characteristics in the vicinity of the well, before boundary effects. Use of the late time data, after boundary effects, appear inappropriate since the theory presented by Cooper et al. (1967) does not include boundary effects. Further, the early time (first 600 hours) interpreted transmissivity

value of 4.3E-03 ft^2/day (SAND87-0039, p. 99) is in fairly close agreement with the 1.0E-03 ft^2/day value provided by the interpretation of a preceding bailing test by the USGS (USGS 83-4016).

6.6.1.9. Dissenting Views

None.

6.6.2. Culebra Thickness

Culebra thickness is a parameter that supports the development of the Culebra transmissivity fields. The parameter description follows:

Parameter: Culebra dolomite thickness

ID#: 2071

Form 464: WPO 32790, entered 5/3/96

Parameter Package: WPO 36445

Distribution: Constant

Value: 7.75 m

Definition: Representative thickness of the Culebra dolomite.

Intended use: This parameter has been used in a particle tracking program to calculate travel time from the repository to the accessible environment (SAND92-0700/3, p. 2-91). Travel time is calculated for each transmissivity field, and the transmissivity fields are ranked by travel time. Transmissivity field index numbers are assigned according to this ranking. These index numbers are integers from 1 to 100. During PA modeling, transmissivity fields are selected by sampling the index numbers. The transmissivity fields are treated as equally likely.

Derivation: The constant 7.75 m is an average of 68 thickness values. Each value is either a thickness from an individual borehole or the average thickness from boreholes at a hydropad. A table of these thicknesses was provided with the Parameter Package (Table B.1a-d, SAND89-7068/2). The individual thicknesses in this table ranged from 5.49 m in H-2c near the repository, to 11.3 m at the H-7 hydropad and in well FFG-165. These last two wells are located over 4 km southwest of the WIPP site.

6.6.2.1. Adequacy of Requirements and Criteria

The mean value for Culebra thickness is in the data base primarily for use in ranking transmissivity fields. Consequently, the value should be sufficiently representative to support this use. This requirement is satisfied by using a large number of boreholes scattered throughout the regional flow

modeling domain. The locations of the boreholes are somewhat concentrated in the vicinity of the repository, which will not adversely affect the use of the average, since the repository area is relatively important.

6.6.2.2. Validity of Assumptions

No assumptions are involved in the derivation of the Culebra thickness parameter.

6.6.2.3. Alternate Interpretation

The CCA (p. 2-41) mentions an alternate interpretation of the thickness of the Culebra in which a thin organic upper interval was not included in thickness calculations. When this alternate interpretation was used, the average thickness was about a meter less than the thickness calculated by other investigators (CCA, Table 2-3, p. 2-42). This alternate interpretation was not followed in the calculation of the average thickness of 7.75 m given on the Form 464. The existence of the alternate interpretation has no effect on the adequacy of the average thickness for use in the development of the transmissivity field index. A smaller thickness value would decrease travel times but not change the relative travel times. Consequently, the ordering of the transmissivity fields would not be changed.

6.6.2.4. Uncertainty and Consequences

Minor uncertainties are associated with the Culebra thickness. Choosing the depth to the top and bottom of the Culebra involves uncertainties in interpretation of core recovery (intervals represented by missing core), borehole samples, and borehole geophysical logs. Errors in depth measurement are possible, but no evidence for such error was seen. Such uncertainties will not have a significant effect on PA modeling. Where the thickness is used to rank the transmissivity fields, the rank is related to relative travel times and would not be sensitive to uncertainty in average thickness. A high average thickness would increase travel times and a low value would decrease travel times, but the ranking of the travel times would not be affected.

6.6.2.5. Appropriateness and Limitations of Methodology and Procedures

The best method for determining depth to top and bottom of Culebra would be using core descriptions where core recovery was complete and the entire Culebra was cored. Less accurate methods involve combinations of interpretation of geophysical borehole logs, drill cuttings, and drilling time. It is beyond the needs of this review to determine the method used for each of the boreholes. All of these commonly used methods are appropriate.

The Parameter Package indicated that where gamma ray logs are used to support the determination of the depths to the top and bottom of the Culebra, the top is indicated by an increase in natural gamma radiation above that in the lower Tamarisk, and the bottom is indicated by a further increase in gamma radiation reflecting clay in the unnamed lower member of the Rustler formation. The gamma ray log for H-8c (USGS WRI 82-4118, in pocket) was inspected to see whether these inflections are present. They were, indeed, identifiable. Other gamma ray logs also exhibit these deflections at the top and bottom of the Culebra (Mercer and Orr 1979).

The lack of anomalies in the thickness data of Table B.1a-d suggests that their adequacy was not adversely affected by limitations of the various methods.

6.6.2.6. Adequacy of Application

The application of the Culebra thickness is given as input to SECOFL2D on the Form 464. Details of the uses of the parameter are not provided, but it has been used along with effective porosity for particle tracking to rank the transmissivity field indices according to travel time to the accessible environment. The thickness is judged to be adequate for this purpose. The ranking of the transmissivity indices is based on relative travel time, so any error in the Culebra thickness used would have little effect.

6.6.2.7. Accuracy of Calculations

Calculations were not included in the parameter data package. The calculations are very simple and, as a spot check, the thickness of the Culebra in H-8c was investigated by examining the core description and geophysical logs. This thickness was found to be adequately determined.

6.6.2.8. Validity of Conclusions

The value of 7.75 m for Culebra thickness (treated as a constant) is an adequate representation of this parameter for PA modeling. This value is a mean, which is a measure of central value that is commonly and correctly used to represent a variable quantity. The fact that reported thicknesses have deviated as much as 3.65 m from this value will not have any significant effect on PA calculations, because the selection of index numbers is a random process that would not be adversely affected by any minor variation in ranking of transmissivity fields.

6.6.2.9. Dissenting Views

None.

6.6.3. Culebra Storativity

Culebra Storativity is a parameter that supports the development of the Culebra transmissivity fields. The parameter description follows:

Parameter: Measured storativity

ID#: 3418

Form 464: WPO 37664, entered 5/3/96

However, the storativity value is from recent reinterpretation of pumping test data from the H-2 and H-11 hydropads. This reinterpretation was under a qualified QA program. Furthermore, the H-11 pumping test was conducted in 1996 under a qualified QA program. Consequently, the present peer review covers data collected at the H-2 hydropad in 1981, which are reported in field notes covering the period 4/29/81 to 5/15/81. The review does not cover any other data or analyses that support the parameter value on the Form 464.

Parameter Package: WPO 37664

Distribution: Constant

Value: 1E-05

Definition: Representative Storativity for Culebra Dolomite.

Intended use: Input to GRASP-INV for generation of transmissivity fields.

Derivation: This parameter is based on analysis of data from pumping tests at the H-2 and H-11 Hydropads, which were performed in 1981 and 1996, respectively. The data from the H-2 test have been reanalyzed under a qualified QA program (Ruskauff and Beauheim, WPO 38487), and the data from H-11 were collected during a 1996 pumping test. The H-2 pumping test data have not been qualified.

6.6.3.1. Adequacy of Requirements and Criteria

The value for Culebra storativity is used in GRASP-INV to calculate transient head data for producing calibrated transmissivity fields. Consequently, the data used to estimate the storativity should be adequate for this use. This requirement is satisfied by the H-2 1981 pumping test data. The field notes show that the pumping rate was held constant and the pressure in the observation well was measured at acceptable time intervals and to acceptable accuracy. The drawdown values obtained from the test adequately fit a theoretical curve, which supports the adequacy of the requirements imposed for the pumping test.

6.6.3.2. Validity of Assumptions

No significant assumptions are involved in the pumping test data being reviewed. The assumptions in the subsequent analysis of the data include aquifer homogeneity and isotropy, which are not strictly valid, but are adequate for the purpose of estimating storativity. The test is conventional, and the resulting storativity is reasonable. For example, see Freeze and Cherry (1979, p. 60), where the typical range for storativity is given as 5.0E-03 to 5.0E-05. The pore volume compressibility, and hence the storativity of a fractured dolomite aquifer, would tend to be near the lower end of this range. The relatively good fit of the data to the theoretical curve supports the reasonableness of using the simplifying assumptions to analyze the data.

6.6.3.3. Alternate Interpretation

The pumping test data represent the response of the Culebra near the hydropad to the hydraulic stress imposed by the pumping, and no alternate interpretation of the hydraulic significance of the data is apparent. The subsequent interpretation of the H-2 test data by fitting to analytical drawdown curves appears to be adequate. (Interpretation is qualified under recent SNL QAPD.)

6.6.3.4. Uncertainty and Consequences

Very little uncertainty is associated with the pressure and pumping rate values obtained from the pumping test. However, no pre-test water level data were recorded with the pumping test data to help evaluate the effects of any rising or falling water level trends on the test analysis. The following information indicates that no significant trend existed. This pumping test preceded shaft construction and most other WIPP activities that might affect it, and the test data indicate there was sufficient time for recovery from the hydraulic effects of previous pumping for tracer testing at the H-2 hydropad, which

stopped on 4/7/81, leaving 21 days for recovery. Recovery from the test reviewed (pumping from 4/29 to 5/2) approaches initial static water level within 13 days after pumping stopped, suggesting no significant rising trend from the previous testing.

6.6.3.5. Appropriateness and Limitations of Methodology and Procedures

The methodology for collecting the pumping test data involved using pressure transducers for measuring pressure (which may be converted to hydraulic head). This procedure is adequate, and produces accurate data measured at adequate time intervals. The method of measuring pumping rate is not explicitly given, but it is recorded in milliliters per minute, suggesting a container and stop-watch. This procedure would be appropriate for such a small discharge rate. The pumping rate was recorded in the field notes often enough to establish that it was sufficiently constant, varying from 0.246 to 0.257 gallons per minute.

6.6.3.6. Adequacy of Application

The application of the Culebra storativity value obtained from H-2 is as input to GRASP-INV to develop calibrated transmissivity fields for the PA modeling. This storativity is adequate for this purpose. It is obtained from an adequate data set, in which the recovery data are consistent with the drawdown data. The fit to the Theis curve is good, and the H-2 hydropad is near the upstream end of the simulated critical path of flow to the accessible environment. The storativity value obtained from H-2 is representative for this flow path.

6.6.3.7. Accuracy of Calculations

The important calculations related to the acquisition of the data were done using the DAS software. Conversion of discharge rates in the field notebook were checked and found to be correct. Calculations related to the analysis of the data to obtain storativity were performed by INTERPRET/2 software, which is not part of this review.

6.6.3.8. Validity of Conclusions

The pumping test data from the 1981 H-2 hydropad test are adequate to support the analysis that yielded a value of 1.0-E05 for storativity. The pumping rate was held constant, pressure was measured accurately and at adequate time intervals, and no conditions were found that would prevent the data from yielding an acceptable storativity. The data fit a theoretical drawdown curve. Type-curve matching is appropriate and conforms to conventional practice for estimating storativity. Furthermore, the storativity

obtained is reasonable. It is near the lower end of the range of published storativities where the storativity of fractured dolomite would be expected.

6.6.3.9. Dissenting Views

None.

6.6.4. Culebra Fluid Density

Culebra formation fluid density is a parameter that supports the development of the Culebra transmissivity fields. The parameter description follows:

Parameter: Culebra Fluid Density

ID#: N/A

Form 464: There is no Form 464 for Culebra fluid density. Culebra formation fluid density is used under Analysis Plan AP-018, Version 00, "Ground Water Modeling Analysis Plan for the Generation of Transmissivity Fields for the Culebra Flow and Transport Calculations," which references data package WPO 35843. This data package contains a table of Culebra fluid density. Fluid density data in the table were reviewed for this peer review package.

Parameter Package: WPO 35843

Distribution: Not applicable. See the section on intended use below.

Value: Formation fluid density values are in Table II of WPO 35843.

Definition: *In situ* Culebra fluid density (g/cm^3).

Intended use: The Culebra fluid densities are input data for GRASP-INV in accordance with a memorandum from March LaVenue to AP-018 dated 5/3/96. These data are kriged to determine the fluid density values at each of the model grid blocks (cells). The density at a cell enters into the code's calculation of hydraulic potential for the cell. Density is held constant in each cell while GRASP-INV is calculating transmissivity fields.

Derivation: The density values in Table II of WPO 35843 are from SAND89-7068/2, Table E.1, except the density from H-19, which was obtained under an approved QA plan. The water quality sampling that was performed to get the values in Table E.1 is described in Appendix F of SAND89-7068/2.

6.6.4.1. Adequacy of Requirements and Criteria

The table of values for Culebra formation fluid density (except the value for WIPP-27, which is outside of the model area) is in the data base for use in GRASP-INV as dens.dat (Attachment G of the memo of 5/3/96 cited above). Consequently, the values in the table should be sufficiently representative to support this use. This requirement is satisfied by sampling wells scattered throughout the regional flow modeling domain. The wells were adequately purged before collecting the sample used for the determination of density.

6.6.4.2. Validity of Assumptions

No significant assumptions are involved in the derivation of the Culebra formation fluid density parameter. Approximations involved in calculating density from chemical composition might result in insignificant errors (SAND86-7167, Appendix E).

6.6.4.3. Alternate Interpretation

Fluid density for most wells is a direct measurement and no alternate interpretations are involved. A few densities were calculated based on chemical composition of water samples (from SAND89-7068/2, Table E.1). Calculated densities correlate well with directly measured densities (SAND86-7167, p. E-6).

6.6.4.4. Uncertainty and Consequences

Annual density data reported on Table E.1 generally varies 0.002 g/cm^3 or less for an individual well, due either to natural variation or measurement error (by inspection). This amount is typically equivalent to about 0.2 m difference in hydraulic head. The variation will not affect transmissivity fields because it is small. Furthermore, the model is calibrated to freshwater hydraulic head, and head gradients will be similar in all runs regardless of any such variations in fluid densities.

6.6.4.5. Appropriateness and Limitations of Methodology and Procedures

The methodology and procedures for measuring the formation fluid densities were appropriate. Pumping a well until the well is purged and water quality parameters stabilize will result in reliable measurement of the *in situ* fluid density. Calculation of density from the chemical composition of the water is also appropriate. Limitations in the accuracy of the density measurements are discussed in the previous section.

6.6.4.6. Adequacy of Application

The application of the Culebra formation fluid density to GRASP-INV is an adequate way to satisfy the input requirement of the code. The densities are a reasonable representation of densities in the ground water system because they are accurately derived and scattered throughout the model area.

6.6.4.7. Accuracy of Calculations

Peer review calculations of formation fluid density at Culebra pressure and temperature for a few wells showed that the densities were calculated accurately.

6.6.4.8. Validity of Conclusions

The Culebra formation fluid density values contained in the Culebra Fluid Density Data table of the Culebra Fluid-Density Data Parameter Package (WPO 35843) are adequate for the intended use in GRASP-INV. They are sufficiently accurate and are adequately distributed over the model area.

6.6.4.9. Dissenting Views

None.

6.6.5. Culebra Steady-State Freshwater Heads

Culebra steady-state heads is a distributed parameter that supports the development of the Culebra transmissivity fields. The parameter description follows:

Parameter: Culebra Steady-State Heads

ID#: N/A

Form 464: There is no Form 464 for Culebra steady-state heads. Culebra steady-state heads (undisturbed fresh-water heads) is used under Analysis Plan AP-018, Version 00, "Ground Water Modeling Analysis Plan for the Generation of Transmissivity Fields for the Culebra Flow and Transport Calculations," which references SAND89-7068/2. This report contains estimated heads that were reviewed and reselected for use in the steady-state calibration. The heads used in the calibration are in Section II of the Parameter Package: Culebra Steady-State Freshwater Heads, Date of Record, April 25, 1996. The Parameter Package is identified as WPO 37288 in a memo from Al Lappin to Karen Schmiege, dated June 3, 1996, Head data in Section II of the Parameter Package were reviewed for this peer review package.

Parameter Package: WPO 37288

Distribution: Not applicable. See the section on intended use below.

Value: Undisturbed freshwater heads for Culebra are in the table titled "1996 Culebra Undisturbed Head Values and Uncertainties" in the Parameter Package identified above.

Definition: Representative values for undisturbed Culebra freshwater head during the period from 1977 to 1989. Undisturbed means not affected by WIPP activities.

Intended use: The undisturbed Culebra freshwater heads are input to GRASP-INV as pressure for the steady-state calibration phase of developing transmissivity fields.

Derivation: The undisturbed heads are interpreted from hydrographs of water level measurements in observation wells from 1977 through 1989.

6.6.5.1. Adequacy of Requirements and Criteria

The table of values for undisturbed Culebra freshwater heads (except the value for WIPP-27, which is outside the model area) is in the data base for use in GRASP-INV (Attachment I of the memo of 5/3/96 from Marsh LaVenue to AP-018). Consequently, the values in the table should be sufficiently representative to provide an initial steady-state calibration target during calculation of the transmissivity fields. This requirement is satisfied by measuring water levels and borehole fluid density in wells scattered throughout the regional flow modeling domain.

6.6.5.2. Validity of Assumptions

No significant assumptions are involved in the measurement of the water levels. Judgment and logic must be used to interpret which parts of the hydrographs represent undisturbed head and what value from the hydrograph should be picked as representative.

6.6.5.3. Alternate Interpretation

Interpretation of the undisturbed heads could vary. In fact the same set of data originally interpreted in SAND89-7068/2 has been reinterpreted to get the 1996 values. However, the interpretations differ only slightly. Difference in interpretation will not significantly affect the transmissivity fields because they do not significantly affect the head contour surface. Since some of the hydrographs have been variously affected by WIPP shaft activities and hydrologic testing, quantitative methods of calculating representative head (averaging, integrating) would not be appropriate.

6.6.5.4. Uncertainty and Consequences

Most uncertainty in the measurements is due to uncertainty in borehole fluid density. Measures of this uncertainty are presented in a table in the Parameter Package that augments Table G.2 of SAND89-7068/2. The uncertainty ranges up to 2 m and may average about 1 m. Inspection of head contour maps, such as Figure 2.12 of SAND89-7068/2, indicates that this level of uncertainty will not change the general character of the potentiometric surface. Consequently, it will not adversely affect the representativeness of the transmissivity fields.

6.6.5.5. Appropriateness and Limitations of Methodology and Procedures

Borehole fluid density was adequately addressed in calculating freshwater head. The procedure for picking undisturbed head involved choosing an average head where long-term data were unaffected by WIPP activities, and correlating to disturbed hydrographs to find relatively unaffected sections. This

procedure is appropriate because the hydrographs of most wells are affected by WIPP shaft activities and hydrologic testing, and these effects preclude the use of quantitative methods, such as averaging heads or integrating areas between hydrographs and the best-fit line.

6.6.5.6. Adequacy of Application

The application of the representative undisturbed freshwater heads to GRASP-INV is an adequate way to proceed with calibration to produce a transmissivity field. It will improve the kriged transmissivity field and provide a starting point for further improvement by calibration to transient features on the hydrographs.

6.6.5.7. Accuracy of Calculations

Calculations involved in measuring water levels and converting them to freshwater heads are relatively simple, and the consistency of the data points on the hydrographs indicates that they were done accurately. A spot check of the value for pressure for H-1 in the GRASP-INV input file referenced above demonstrated that the pressure was correctly calculated from freshwater head, borehole fluid density, acceleration of gravity, and height of the water column.

6.6.5.8. Validity of Conclusions

The Culebra undisturbed freshwater head values contained in the Section II of the Parameter Package Culebra Steady-State Freshwater Heads dated April 25, 1996, are reasonable and are adequate for the intended use in GRASP-INV. They are sufficiently representative and are adequately distributed over the model area.

6.6.5.9. Dissenting Views

None.

6.7. Culebra Physical Transport

6.7.1. Culebra Dolomite Grain Density

This section reviews the data from which the grain density in the Culebra Dolomite were derived and the value obtained.

Parameter: Culebra Dolomite Grain Density

ID#: 843

Form 464: WPO 32689, entered 6/11/96

Parameter Package: WPO 37232

Distribution: Constant

Parameter values: 2.82 g/cm^3

Definition: The grain density is the average density of solids in the formation. In this case this means mostly dolomite with small percentages of gypsum, halite, and clays.

Intended Use: A parameter needed for calculation of solute retardation.

Derivation: This parameter was derived from the bulk and pore volumes measured for numerous core samples.

Discussion: The calculation is straightforward, but requires, in addition, either a bulk density of the sample or the weight of the sample. Presumably such data exist in the archives of INTERA Technologies who made the determinations. There is no reason to doubt the measurements inasmuch as they are quite simple and are covered under the INTERA QA plan.

6.7.1.1. Adequacy of Requirements and Criteria

An objective of the analysis was to provide data on the grain density in the Culebra Dolomite needed for calculation of solute retardation, as stated in SAND89-7079, p. 2-50. The measurements required for obtaining these data are two out of three of bulk volume, pore volume, and volume of solids, together with some measure of the weight of either the bulk volume or the volume of solids. The bulk volume was determined in most instances by taking caliper measurements of core samples. However, in some

instances the core was deeply striated and in those cases the volume was measured by an Archimedes technique using toluene in order to avoid affecting the volume of expandable clays. The pore volume was determined most reliably by helium porosimetry and also, in some cases, by resaturation of dry samples with distilled water or brine. From these data, and presumably the weight of the bulk sample, the grain density was calculated.

The largest potential measurement error is probably that for the pore volume. An approximate confirmatory measurement was made by measuring the pore volume via saturation with distilled water, or in one instance with brine. These measurements agreed on average to within ±0.4% porosity as compared with an average porosity of 14.9%. Thus, the least certain measurement is adequate for the intended application.

6.7.1.2. *Validity of Assumptions*

The only assumption was that a constant value for grain density is adequate. The data indicate that this assumption is sufficiently reliable for the intended use.

6.7.1.3. Alternate Interpretation

The interpretation is based on very simple analysis of the raw data and simple statistics. There is no need for an alternative interpretation, even though a distribution could be constructed and sampled.

6.7.1.4. Uncertainty and Consequences

Uncertainties were presented in the form of statistics and by a comparison between two alternative methods of measuring porosity. Consequences for the intended application were implicitly discussed in the rationale for selecting a constant value for the parameter.

6.7.1.5. Appropriateness and Limitations of Methodology and Procedures

The measurement techniques were appropriate. The limitation of reduced precision at low porosities was evidently taken into consideration in rejecting a single anomalous value.

6.7.1.6. Adequacy of Application

Results of the application were not presented in the documentation provided. However, on the assumption that the manner in which this parameter is used in performance assessment is correct, there is no reason to suspect anything other than adequacy for the intended use. Presumably, solute retardation is

calculated through use of surface area of adsorbing solids, notably the surface density of sorbing sites. Thus, density is related to both grain size and grain density.

6.7.1.7. Accuracy of Calculations

Visual examination of the data indicated little variability, with the exception of one value, which evidently was excluded from the calculation of the statistics. This examination provided reasonable assurance that the mean was reliable.

A single value grain density of 2.33 g/cm^3 reported in Appendix B of SAND90-7011 does not appear in the recalculation of the statistics reported in the data record. However, this sample was clearly anomalous because it had a much lower pore volume, which would mean that it could not have been measured with comparable precision. Exclusion of this value for this reason is appropriate, even though no explanation such as given in this paragraph was found in the relevant documents.

6.7.1.8. Validity of Conclusions

The conclusion is that the constant value of grain density, 2.82g/cm^3, may be used for the intended application.

6.7.1.9. Dissenting Views

None.

6.7.2. Effective Culebra Thickness

Effective Culebra thickness is a parameter that supports Culebra Physical Transport modeling. The parameter description follows:

Parameter: Effective Culebra Thickness

ID#: 3462

Form 464: WPO 37727, entered 5/7/96

Parameter Package: WPO 37727

Distribution type: Constant

Value: 4.0 m

Definition: Effective Culebra Thickness represents the median Culebra total thickness within the land withdrawal boundary minus the thickness of Unit 1 (upper Culebra) as defined by Robert Holt (Memo from Lucy Meigs to Jim Ramsey dated May 6, 1996).

Intended use: The Effective Culebra Thickness is used for PA transport simulations using SECOTP2D.

Derivation: The thickness (3.0 m) of Unit 1 was calculated as the median of 12 thicknesses measured in nine wells located within the land withdrawal boundary and in the waste handling, exhaust, and air intake shafts. This thickness was subtracted from the total thickness. The total thickness (7.0 m) is from the Meigs Memo, May 6, 1996.

6.7.2.1. Adequacy of Requirements and Criteria

The Effective Culebra Thickness is used for PA transport simulations via SECOTP2D. The parameter is used to calculate ground water velocity from volumetric flux, so it affects the rate of movement of contaminants in the transport model. Consequently, the value should be sufficiently representative to provide a realistic estimate of the ground water velocity. The rationale for the value selected is that the Culebra may be divided into four hydrostratigraphic units that are recognizable in cores, and the upper unit (Unit 1) conducts much less water than the other three. The median thickness of this unit measured

in representative wells and the three shafts is subtracted from the median total thickness of the Culebra to obtain the representative thickness of the more permeable lower part of the Culebra that conducts most of the water. The requirement is, then, that Unit 1 be recognizable and measured with reasonable accuracy. Inspection of core logs and shaft wall descriptions indicates that Unit 1 is indeed recognizable as a relatively massive unit with significantly fewer vugs and fractures that are not filled with gypsum and anhydrite.

6.7.2.2. Validity of Assumptions

The assumption that the more massive upper part of the Culebra contributes little to ground water flow is supported by injection testing described in USGS WRI 79-98. This testing was completed on wells H-1, H-2c, H-3 and P-14. In these tests, interpretation of tracer and temperature logs indicates no fluid loss in the upper 3 to 4.3 m. Furthermore, data from recent tests at the H-19 hydropad are said to indicate that the upper Culebra does not play a significant role in solute transport (Culebra Effective Thickness Parameter Package, Attachment 1, WPO 37223). H-19 testing is not included in this peer review because it was conducted under the SNL QA program (Parameter Package WPO 37223).

6.7.2.3. Alternate Interpretation

The effective thickness actually varies from well to well. In some wells, most of the flow probably comes from a thickness that is less than 4.0 m. For example, in H-3 injection testing, over half of the fluid was lost in the lower two feet (0.6 m) of the formation (Mercer and Orr 1979, pp. 45 to 46). At some locations, especially where permeability throughout the Culebra is low, the flow may be distributed more uniformly over the entire thickness of the Culebra. In the Waste Handling Shaft, the entire Culebra section was wet, but no obvious local source for the water was observed (Holt and Powers 1984, p. 4-11).

Basing the effective thickness on stratigraphic units is supported by the data, but is a matter of judgment. It represents a compromise between using more than the lower unit, which is appropriate in some places, and less than the lower unit, which is appropriate where a very small interval conducts most of the water. At most locations, there is adequate information on the thickness of the hydrostratigraphic units, but no direct hydraulic data on which interval is the most permeable.

6.7.2.4. Uncertainty and Consequences

Uncertainty in Effective Culebra Thickness is caused by (1) uncertainty in how adequately the median thickness of the lower units derived from 11 data points represents the actual thickness of these units, and

(2) how adequately the permeability is correlated with the lower units. The consequence of the uncertainty is that if the effective thickness is under-estimated, the effect on solute transport modeling is conservative, but if it is over-estimated the effect is non-conservative. The effect on solute transport rates would be roughly proportional to the degree of under- or over-estimation.

6.7.2.5. Appropriateness and Limitations of Methodology and Procedures

The methodology is appropriate. As mentioned in Section 6.7.2.3, it strikes a balance between using the entire thickness of the Culebra and using a very small value for effective thickness. The entire thickness would be inappropriate because the evidence strongly indicates that much of the thickness does not contribute significantly to flow at most localities. A very small value would be inappropriate because core descriptions, shaft descriptions, and tracer testing indicate it is not the general condition. Using the median thickness of the hydrostratigraphic units that contain most of the permeable material is appropriate. The thickness of the Culebra and its hydrostratigraphic units is fairly constant in the land withdrawal area, and the quality of the core descriptions is adequate. Furthermore, injection tracer testing and temperature logging in wells not used to calculate the effective thickness support the interpretation that most of the ground water movement is in the lower part of the Culebra.

6.7.2.6. Adequacy of Application

The application of effective thickness to simulating solute transport is an adequate way to account for the low permeability of the upper part of the Culebra. If the entire Culebra thickness were used in solute transport modeling, the simulated rate of movement of contaminants would tend to be too slow. Using the thickness of the more permeable part of the Culebra, and assuming all the fluid moves through this unit, will tend to increase the simulated rate of movement of contaminants and is, therefore, more conservative. Not using an effective thickness that is less than the thickness of lower permeable part of the Culebra is reasonable because the data do not indicate that a single, thinner unit in the lower Culebra has widespread excess permeability.

The wells used to calculate the effective thickness are areally distributed to provide representative information on Culebra stratigraphy and permeable intervals. The core descriptions and shaft wall descriptions are good enough to establish the presence of an upper, less permeable layer in the Culebra. Intervals where core was not recovered suggest the presence of fracture porosity.

6.7.2.7. Accuracy of Calculations

Calculations involved in developing the value for effective thickness are relatively simple, and documents reviewed contained nothing that indicated any thicknesses were miscalculated.

6.7.2.8. Validity of Conclusions

The Effective Culebra Thickness of 4.0 m on Form 464, WPO 37727 dated 5/7/96, is reasonable and is adequate for the intended use in solute transport modeling by SECOTP2D in the land withdrawal area. Inspection of core descriptions and descriptions of shaft walls indicates that the upper part of the Culebra is more massive than the lower part and that the vugs and fractures tend to be filled with gypsum and anhydrite. The value of 4.0 m is sufficiently representative of the thickness of the part of the Culebra that conducts most of the ground water. It will provide adequate representative ground water velocities for simulating the rate of movement of contaminants.

6.7.2.9. Dissenting Views

None.

6.7.3. Advective Porosity

This section reviews the estimation of the advective porosity used in model SECOTP to simulate potential contaminant transport in the Culebra in the PA. The information about this parameter provided in the Form 464 is as follows:

Parameter:	Culebra advective porosity
ID#:	3487
Form 464:	WPO 38358, entered 6/14/96
Parameter Package:	WPO 37227
Distribution Type:	Log-uniform
Parameter Values:	Minimum = 1.0E-04
	Maximum = 1.0E-02

Definition: Advective porosity is defined to be fracture porosity of a fractured porous medium. The physical concept of advective porosity is the pore volume of total fractures divided by the bulk volume in a fractured porous medium at a given scale.

Intended Use: The Culebra advective porosity is used in model SECOTP as one of the input parameters to simulate contaminant transport in the Culebra under the hypothetical case of borehole intrusion. Specifically, advective porosity is used to calculate velocity of advective transport that is supposed to occur only in fractures (SAND92-1579).

Derivation: Since the Culebra advective porosity and matrix block length (Section 6.7.4) were derived from the same process, the discussion of the derivation covers both parameters. Derivation of the Culebra advective porosity and the half matrix block length involves three major steps: (1) tracer tests in the field, (2) numerical simulations to fit the observed breakthrough curves obtained from the tracer tests, and (3) integration of simulation results to generate a parameter value for input to SECOTP. A brief description of the three steps follows.

Numerous hydraulic tests including tracer tests were conducted at the WIPP site in order to identify the

hydraulic and solute transport properties of the Culebra. Among those, the tracer tests conducted at hydropad H-3, H-11, and H-19 were selected as the main basis for development of the Culebra advective porosity and matrix block length for the PA. These hydropads are located along the identified flow pathway within the Culebra dolomite from the waste-storage area to the accessible environment.

Numerical simulations using SWIFT II and THEMM have been performed to fit the breakthrough curves obtained from the tracer tests and to identify the possible ranges of the solute transport parameters, including the advective porosity and matrix-block length. Results of the numerical simulations are provided in Table 1 of the memorandum by Meigs dated July 2, 1996.

The solute transport parameters generated from the simulations of the tracer tests at the local hydropad scale were integrated and analyzed further to derive the transport parameters and their statistical distributions for model SECOTP at the PA model scale.

Discussion: Because the distribution of fractures is discontinuous and scale-dependent, advective porosity is scale-dependent. Advective porosity is a fitting parameter which can be obtained by simulation of field tracer test. It characterizes the feature of a fractured porous flow system in conjunction with matrix-block length and other parameters based on a double-porosity solute transport conceptual model. Advective porosity is generated based on an idealized conceptual model. This parameter is model-dependent. Different conceptualizations, different numerical codes, or different values of other parameters in the model, may result in different values for this parameter.

6.7.3.1. Adequacy of Requirements and Criteria

Since the Culebra advective porosity and matrix block length were derived from the same process, the discussion of adequacy of requirements includes both parameters. The requirements for estimation of the Culebra transport properties were clearly stated in the related documents (McCord and Meigs, 1996; Beauheim et al. 1995). The objective of estimation of the transport parameters of the Culebra was to provide reasonable input parameters for the PA model to simulate potential radionuclide transport in the Culebra from the disposal facility to the accessible environment.

The tracer tests were designed and conducted under specific requirements in order to characterize the transport properties of the Culebra. Specific requirements designed for the tracer tests at H-19 and H-11 were discussed in detail in Beauheim et al. (1995).

The simulations to match the tracer test results were also designed and conducted under specific requirements in order to characterize the transport properties of the Culebra and to improve the conceptual models. Specific requirements for the simulations of the tracer tests were discussed in detail in McCord and Meigs (1995).

The rationale for integration and conversion of the parameters to the PA model SECOTP was discussed in the two memorandums (Meigs 1996; McCord 1996).

It should be noted that model simulations have not been completed at this time (as of July 2, 1996). The current estimations of advective porosity and matrix block length were based on part of the curve fitting results of the tracer test at H-3, H-11, and H-19. The results have provided upper and lower bounds of the parameters at those hydropads. The current work has indicated that the estimation of advective porosity and matrix block length may further be improved, but they will lie within the upper and lower bounds estimated based on the completed simulations.

In general, the requirements for the derivation of the parameters are adequate. Even though the model simulations have not been completed, using the currently estimated bounds will not adversely affect the PA calculation. The completion of the tracer test simulations may better identify the distribution of the parameter at the hydropad scale. It is not expected to change the upper and lower bounds of the distribution of the parameters.

6.7.3.2. Validity of Assumptions

There are many assumptions associated with all processes involved in the derivation of the parameter. The assumptions related to step 1 and step 2 of the parameter derivation are not discussed here, since they are considered appropriate. This section focuses on the evaluation of the assumptions used in conversion of the parameter at the hydropad scale (10-30 m) to the PA model scale (2.5 km). Some assumptions evaluated here may not be explicitly discussed in the related document, but they are implied in the derivation processes.

Assumption 1 -- The Culebra is assumed to be a double-porosity medium for the entire area of the WIPP site in terms of transport property.

The Culebra, in general, is characterized as a fractured dolomite with non-uniformly distributed fractures and vugs based on the field data, including borehole logs, shaft logs, hydraulic tests, and tracer tests. It

has been recognized that the hydraulic and transport properties of the fractures at any location depend on such features as whether the fractures are open or filled with gypsum, their frequency, and the degree of interconnection between fractures and vugs over distances (Beauheim et al. 1995). The dominant transport processes may vary due to the spatial variation of the distribution of fractures and their features. In areas where fractures are not open, transport may occur slowly in the matrix. In areas where open fractures with large apertures exist, advective flow may primarily occur in the fractures, while the matrix only acts as storage for diffusive transport in accordance with concentration gradient. In cases where both fractures and matrix allow ground water to flow, advective transport may occur in both. In summary, the degree of double-porosity behavior varies spatially at the site.

Even though the double-porosity behavior varies in space, it is reasonable to generalize the entire dolomite at the WIPP site as a double-porosity medium. Such an assumption may allow model results to be more flexible when parameters vary, and also allow model results to be more conservative.

Assumption 2 -- Transport properties observed from the tracer tests at H-3, H-11, and H-19 are assumed to be representative of the entire PA model.

This is a reasonable assumption because H-3, H-11, and H-19 are located along the flow pathway from the repository area to the boundary of the PA model. The transport properties along the flow path are the most important concern.

Assumption 3 -- The advective porosity is assumed to be uniform for the entire PA model with an uncertainty approximately equal to the range of values derived from the simulation results of the tracer tests.

This is a highly simplified assumption. It is inconsistent with the field data, and inconsistent with the heterogeneous flow model used in the PA. The tracer tests conducted at H-3, H-11, and H-19 indicated that there is great spatial variability of the transport properties along the flow path. The variability does exist between the hydropads, and between the boreholes at each hydropad. The estimated advective porosity for H-3, H-11, and H-19 are approximately 1.0E-03, 5.0E-05, and 5.0E-02, respectively (Table 1, Meigs 1996), with three orders of magnitude difference.

With such an assumption, spatial variability observed from the three tracer tests was converted to the uncertainty of an average advective porosity over the entire flow pathway of 2.5 km. This means that any value randomly selected from the estimated range is assumed to be a possible average advective porosity

for the Culebra for the entire PA model. The simulation result of using this value constitutes one of the realizations of possible contaminant transport.

It should be noted that the advective porosity is a scale-dependent fitting parameter. Spatial variability at different locations at a small scale is not equivalent to the uncertainties of the average advective porosity at a large scale. Simply applying this assumption may cause the PA model to result in an unrealistically large range of simulation results.

Some results may represent the average conditions of transport. Some may not be realistic for the actual conditions. Advective velocity is determined by dividing the Darcy velocity by advective porosity. The smaller the advective porosity, the faster the peak concentration of solute occurs and the greater the peak concentration, when the other parameters are fixed. The migration of contaminant may be either too slow when the average advective porosity is equal to the high end of the estimation or too fast when the low end of the estimation, is used for the entire area.

Assumption 4 -- The estimated range of advective porosity at hydropad scale using SWIFT II and THEMM is truncated based on the professional judgment, and is assumed to be representative at the PA model scale using SECOTP.

The range of advective porosity values obtained from SWIFT II and THEMM simulations based on the tracer test results at small scale of 10-30 m is from 4E-05 to 9E-02 (Table 1 in Memorandum from Meigs July 2, 1996). Based on professional judgment at SNL, the range of advective porosity in the Form 464 is reduced to 1.0E-04 to 1.0E-02 for the PA model, at a scale of 2.5 km. As stated in the memo (Meigs 1996), "We strongly feel that the extreme values of advective porosity less than 1.0E-04 and greater than 1.0E-02 will not occur over regions as large as the existing pathway, and thus aerial averages lie between these two end points."

The reduction of the range of estimation is considered reasonable by the peer review panel. The spatial variability demonstrated at H-11, H-3, and H-19 indicates that the average advective porosity along the entire pathway should lie between the extreme values obtained from the individual hydropads. However, the quantitative analysis of how much the range should be truncated was not given in the related document.

Assumption 5 -- A log-uniform distribution is assumed to represent the probability of the uncertainty of the average advective porosity in the PA model.

Due to lack of sufficient data, a meaningful distribution based on three tracer test results is not possible. Based on orders of magnitude difference in the advective porosity obtained at H-3, H-11, and H-19, a log-uniform distribution is a close solution. It is also a conservative solution, since a log-uniform distribution tends to have high probability for the low values than for the high values of advective porosity. The low value of advective porosity will lead to fast transport.

6.7.3.3. Alternate Interpretation

Alternate interpretations exist in several ways. Three alternate interpretations are evaluated here, including (1) alternate approaches for applying the double-porosity model to curve fitting the tracer test results, (2) alternate approaches for converting local scale parameters to regional scale model, and (3) alternate conceptual models for simulation of a fractured porous medium system.

1. Two approaches have been used by SNL to simulate the tracer test results. One is designated as a homogeneous layer approach using SWIFT II, and the other is designated as a heterogeneous approach used in code THEMM. Both models were used to fit the breakthrough curves from the tracer tests. The fitted advective porosity values from the two models deviate somewhat (Table 1 in the Memorandum by Meigs July 2, 1996). The differences are within one order of magnitude. The differences are expected because the advective porosity is a model dependent parameter as discussed in the definition. However, in terms of estimation of the range of the parameter, both models yielded consistent results. Therefore, alternate interpretations yielded essentially similar estimations.

2. An alternate representation of transport parameters in the PA model was investigated by SNL. Possibility of zonation of transport parameters associated with hydraulic parameters, which are the distributed transmissivity in the PA flow model, was evaluated, as discussed in the memorandum by McCord (1996). The scatter plots between advective porosity (or matrix block length) and transmissivity in Figure 1 (McCord 1996) do not indicate obvious correlation between transport parameters and hydraulic parameters. Therefore, zonation approach was not considered in the PA. However, it should be noted that the presented scatter plots may not represent the real correlation between transmissivity and the actual transport properties. The physical evidence does exist that both hydraulic and transport properties are related to the distribution of fractures, including the degree of opening, degree of interconnection, and their frequency.

3. An alternate conceptual model has been investigated by SNL (McCord 1996). A multirate/ multiporosity model was found to be able to better simulate the physical transport processes of the Culebra.

6.7.3.4. Uncertainty and Consequences

The primary uncertainties of the estimated advective porosity are due to the lack of knowledge of the actual transport properties along the flow path in the PA model. Using average advectivity porosity in

the PA model with a much greater scale than the tracer test scale will unavoidably introduce great uncertainty.

The consequences of the uncertainty of the average advective porosity may result in an unrealistic large range of the PA simulation results. Given a fixed Darcy's velocity, two orders of magnitude difference in advective porosity may result in two orders of magnitude difference in fracture flow velocity. Therefore, the uncertainty of advective porosity may have a strong impact on the travel time of peak concentration and on the magnitude of peak concentration at the boundary of the accessible environment.

Another concern of the uncertainty is how much is the appropriate amount for truncation of the range of the parameter. It certainly has impact on the results. Quantitative evaluation is not available.

However, since log-uniform distribution is assigned to the parameter, the chances of random selection of the small values are greater than the changes of random selection of large values. Therefore, it is expected that the uncertainties of the PA results due to the uncertainty of the Culebra advective porosity are on the conservative side.

6.7.3.5. Appropriateness and Limitations of Methodology and Procedures

The tracer test at H-3 was performed in 1984. The tracer test at H-11 was performed twice, in 1988 and in 1996. The tracer test at H-19 was performed in 1995 and in 1996. The tracer tests done after 1988 were conducted under a qualified QA program.

The methodology and procedures used for the past tracer tests at H-3 and H-11 were not designed as rigorously as for the recent tests. Evaluation was done of the test conditions and test results (Lappin and Chocas 1996; SAND85-7206; SAND89-7065; SAND92-1579) for these two hydropad tests.

The repeated tracer tests at H-11 were conducted twice (in 1988 and in 1996) under similar conditions. Comparisons between the testing conditions and breakthrough curves between the two tests indicate that the H-11 test result of 1988 is not significantly different from the results obtained in 1996. The peak concentrations occur at the same time, about a half day for H-11b3, and about 5 days for H-11b2. The peak concentrations for H-11b3 (12.5 mg/l) in 1996 is somewhat higher than the peak concentration in 1988 (8 mg/l). For H-11b2, the peak concentrations are identical. From this point of view, the test results obtained in 1988 are considered adequate.

The observed breakthrough curves at H-3 obtained from the 1984 tests are not as smooth as expected. This may be due to the limitations of the equipment and procedures applied in 1984. However, the unexpected non-smoothness does not appear to change the general shape of the curves; therefore, it should not affect the interpretation results of the parameters.

6.7.3.6. Adequacy of Application

Application of the advective porosity in SECOTP is based on the assumptions discussed in Section 6.7.3.2. Given the conceptual model and approach designed for simulations of the Culebra transport in the PA, the application of the estimated advective porosity with a log-uniform distribution is expected to be conservative.

6.7.3.7. Accuracy of Calculations

All the simulations and calculations were performed under a qualified QA program. Therefore, calculations were judged to be accurate.

6.7.3.8. Validity of Conclusions

The tracer test results from H-3 (1984) and H-11 (1988) were reviewed and are considered adequate for the derivations of the transport parameters at those hydropads. The estimated range (1.0E-04 to 1.0E-02) and distribution (Log-uniform) of the Culebra advective porosity provided in Form 464 (WPO 38358, entered 6/14/96) is acceptable for the intended use.

6.7.3.9. Dissenting Views

None.

6.7.4. Half Matrix Block Length

This section reviews the estimation of the half matrix block length used in model SECOTP to simulate potential contaminant transport in the Culebra in the PA. The information about this parameter provided in the Form 464 is as follows:

Parameter: Culebra half matrix-block length

ID#: 3485

Form 464: WPO 38356, entered 6/13/96

Parameter Package: WPO 37225

Distribution Type: Uniform

Parameter Values: Minimum = 0.05 m

Maximum = 0.5 m

Definition: Matrix block length defined in a double-porosity fractured porous medium model represents effective fracture spacings (SAND92-1579). Half matrix block length is effective distance from fracture to center of the matrix block.

Intended Use: The Culebra matrix block length is one of the input parameters in model SECOTP which simulates contaminant transport in the Culebra under the hypothetical case for a breach of the repository. Specifically, matrix block length is used to simulate physical retardation of transport due to diffusion between fractures and matrix and within matrix in response to concentration gradient (SAND92-1579).

Derivation: See "Derivation" in Section 6.7.3.

Discussion: Similar to advective porosity, matrix block length is a fitting parameter, rather than a measured one. It is scale-dependent, model-dependent, and dependent on variation of other parameters in a double-porosity model.

Matrix block length has a clear physical meaning. It describes the amount of surface area available for matrix diffusion along a given flow path (SAND92-1579). However, matrix block length does not

describe the actual geometry of a fracture system. It only represents the effective fracture spacings, not actual structure spacings. Since matrix block length is a fitting parameter, it unavoidably involves model errors, computational errors, and possibly uncertainty of the other parameters.

Given the flow pathway length and the effective layer thickness, the larger the matrix block length, the smaller the surface area available for matrix diffusion. If matrix block length is very small, diffusion occurs as soon as flow occurs through fractures. Then transport behavior approaches that in a porous medium of single porosity. If the matrix block length is large, diffusion takes longer, acting as a physical retardation of solute transport. Then the medium is considered to have significant double-porosity behavior. The direct effect of matrix block length on solute transport is that the larger the parameter, the greater the peak concentration, and the sooner peak concentration occurs.

6.7.4.1. Adequacy of Requirements and Criteria

See Section 6.7.3.1.

6.7.4.2. Validity of Assumptions

There are many assumptions associated with all processes involved in the derivation of the parameter. The assumptions related to step 1 and step 2 of the parameter derivation are not discussed here, since they are considered appropriate. This section focuses on the evaluation of the assumptions used in conversion of the parameters at the local scale hydropad to the one used in the PA model. Some assumptions evaluated here may not be explicitly discussed in the related document, but they are implied in the derivation processes.

Assumption 1 -- The Culebra is assumed to be a double-porosity medium for the entire area of the WIPP site in terms of its transport properties.

The Culebra, in general, is characterized as a fractured dolomite with non-uniformly distributed fractures and vugs based on the field data, including borehole logs, shaft logs, hydraulic tests and tracer tests. It has been recognized that the hydraulic and transport properties of the fractures at any location depend on such features as whether the fractures are open or filled with gypsum, their frequency, and the degree of interconnection between fractures and vugs over distances (Beauheim et al. 1995). The dominant transport processes may vary due to the spatial variation of the distribution of fractures and their features. In areas where fractures are not open, transport may occur slowly in the matrix. In areas where open fractures with large aperture exist, advective flow may primarily occur in fractures, while the matrix only

acts as storage for diffusive transport in response to concentration gradient. In cases where both fractures and matrix allow ground water to flow, advective transport may occur in both. In summary, the degree of double-porosity behavior varies spatially over the site.

Even though the double-porosity behavior varies spatially, it is reasonable to generalize the entire Culebra dolomite at the WIPP site as a double-porosity medium. The double-porosity model allows great flexibility through varying parameters that control the degree of interaction between fractures and matrix.

Assumption 2 -- *The transport properties observed from the tracer test results at hydropads H-3, H-11, and H-19 are assumed to represent the transport properties of the entire PA model.*

This is a reasonable assumption because H-3, H-11, and H-19 are located along the flow pathway from the repository area to the boundary of the WIPP site. The transport properties along the flow pathway are the most important concern.

Assumption 3 -- The matrix block length is assumed to be uniform for the entire area of the PA model, with an uncertainty value approximately equal to the range of values derived from the simulation results of the tracer tests.

This is a highly simplified assumption. It is inconsistent with the field data, and inconsistent with the heterogeneous flow model used in the PA. The tracer tests conducted at H-3, H-11, and H-19 indicated that there is great spatial variability of the transport properties along the flow path. The variability does exist between the hydropads, and between the boreholes at each hydropad. The estimated matrix block length from the tracer test analysis results in a range of 0.015 m to 1.76 m (Table 1, Meigs 1996), with two orders of magnitude difference.

With such an assumption, the spatial variability observed from the three tracer tests was converted to the uncertainty of an average matrix block length over the entire flow pathway of 2.5 km. This means that any value randomly selected from the estimated range is assumed to be a possible representative matrix block length for the Culebra of the entire model area. The simulation result of using this value constitutes one of the realizations of possible contaminant transport.

It should be noted that the spatial variation of the parameter at local scales is not equivalent to the estimate of the uncertainty of the average parameter over large distance. Simply applying this assumption may cause the PA calculations to cover an unrealistic, large range of results. Some results

may represent the average conditions of physical retardation of transport. Some may not be realistic for the actual conditions (i.e., the matrix diffusion along with transport is overestimated when the average matrix block length is equal to the low end, or the contaminant release is overestimated when the high end is used as the average matrix block length for the entire area).

Assumption 4 -- The estimated range of matrix block length at hydropad scale using SWIFT II and THEMM is truncated based on professional judgment, and is assumed to represent a conservative estimation at the PA model scale using SECOTP.

The range of the half matrix block length obtained from SWIFT II and THEMM simulations, based on the tracer test results at hydropad scale of about 20 m, is from 0.0075 m to 0.88 m (Table 1 in Memorandum from Meigs July 2, 1996). The range of the half block length in the Form 464 is reduced to 0.05 m to 0.5 m for the PA model at a scale of 2.5 km. The low end was truncated (increased) by more than half order of magnitude, while the high end is only truncated by less than a factor of 2. Based on the concept of the matrix block length, the larger the value, the smaller the surface area, and the less the physical retardation. Therefore, more truncation at the low end and less truncation at the higher end provides a conservative range of estimation.

The reduction of the range of estimation is reasonable and conservative as explained by Meigs (1996).

First, as demonstrated at H-11, H-3 and H-19, the spatial variability of the matrix block length has two orders magnitude difference (Table 1, Meigs 1996). Along such a variable flow path, the actual average over the entire flow path is expected to lie between the extreme values obtained from the individual hydropads of a local scale. The decision to truncate the low end and high end was based on the professional judgment. As stated in Meigs (1966), "We strongly feel that the extreme values of matrix block length greater than 1.0 m will not occur over regions as large as the exit pathway." This statement is well accepted under the condition that assumption 2 is true. The extreme value observed at a local scale is not possible to represent an average value over the entire flow pathway, which has a spatial variability of two orders of magnitude. However, quantitative analysis about the amount of truncation was not performed to support the estimation of the range of the parameter.

The second reason is that there is a difference in conceptualization of fractured systems in SWIFT II and SECOTP. The simulations of the tracer tests were based on the conceptualization of a fractured porous medium using a 3D intersecting fracture sets approach. The SECOTP is developed based on a 2D

parallel plates concept. This means that if the same matrix block length is used in both models, the surface area in the 3D model is three times the one in the 2D model. The effect of matrix diffusion therefore will be three times greater in a 3D model than in a 2D model, under the condition that matrix block has not been completely saturated. As discussed in the memorandum by Meigs (1996), if matrix blocks become saturated, a double porosity model will approach a single porosity model. The total porosity (matrix porosity + fracture porosity) will be immediately accessible by solutes. Model results using 3D or 2D configurations under saturated conditions will be equivalent. Therefore, applying the matrix block length identified from SWIFT II to SECOTP should lead to conservative results, (i.e., shorter travel time for peak and higher concentration for peak).

Assumption 5 -- A uniform distribution is assumed to represent the probability of uncertainty of the average matrix block length in the PA model.

Based on assumptions 3 and 4, a uniform distribution was assigned to the Culebra matrix block length in the Form 464. Due to lack of sufficient data, a meaningful distribution based on three tracer test results is not possible. Based on professional judgment, a uniform distribution is assumed. This distribution implies that equal probability is assigned to any value within the range. Based on the discussion in assumption 4, a uniform distribution is considered appropriate.

6.7.4.3. Alternate Interpretation

Alternate interpretations of the double-porosity conceptual model exist. Two approaches were used by SNL to simulate the tracer test results. One is designated as a homogeneous layer approach using SWIFT II, and the other is designated as a heterogeneous approach used in code THEMM. Both models were used to fit the breakthrough curves from the tracer tests. The fitted matrix block length values from the two models are very close (Table 1 in the Memorandum by Meigs July 2, 1996). Alternate interpretations yielded essentially similar estimates.

Another alternate interpretation of transport parameters was investigated by SNL. The possibility of zonation of transport parameters associated with hydraulic parameters, which is the distributed transmissivity in the flow model in the PA, was evaluated in the Memo from McCord to Meigs (1996). The scatter plots between advective porosity or matrix block length with transmissivity shown in Figure 1, do not indicate correlation between transmissivity and transport parameters. Therefore, zonation was not considered in the 1996 PA. However, poor correlation presented in the scatter plots

does not mean there is no correlation between hydraulic and transport properties. The physical evidence supports that both hydraulic and transport properties are strongly related to the distribution of fractures.

6.7.4.4. Uncertainty and Consequences

Matrix block length is probably the most import parameter in the double-porosity transport model. In the 1992 PA report, it is ranked as the sixth most important parameter in the overall PA (SAND92-0700/4 pp. 9-8). Uncertainty in the estimation of the matrix block length will have significant impact on the PA results.

The consequences of applying average matrix block length over the entire PA model may result in an unrealistic, large range of the PA simulation. Since the range of matrix block length covers one order of magnitude, the difference in the characteristic diffusion time will be two orders of magnitude, as expressed in Equation (5-13) in SAND92-1579 (p. 5-47). Therefore, the uncertainty of matrix block length may have a strong impact on the time for peak concentration to occur and on the magnitude of peak concentration at the boundary of the accessible environment. As illustrated in the example in Attachment 1 of the memorandum by McCord (1996), one order of magnitude difference in matrix block length yields about 1.5 orders of magnitude difference in peak concentration and 1.5 orders of magnitude difference in peak travel time.

Based on the discussion in assumption 4, the uncertainties of the Culebra matrix block length are expected to result in a conservative consequence in the PA calculation.

6.7.4.5. Appropriateness and Limitations of Methodology and Procedures

See Section 6.7.3.5

6.7.4.6. Adequacy of Application

Application of the matrix block length in SECOTP is based on the assumptions discussed in Section 6.7.4.2. Given the conceptual model and approach designed for simulations of the Culebra transport in the PA, the application of the estimated matrix block length is considered conservative.

6.7.4.7. Accuracy of Calculations

All the simulations and calculations were performed under a qualified QA program. Therefore, the calculations are judged to be accurate.

6.7.4.8. Validity of Conclusions

The tracer test results from H-3 (1984) and H-11 (1988) were reviewed and are considered adequate for the derivation of the transport parameters at those hydropads. The estimated range of the Culebra half matrix block length (0.05 m to 0.5 m) and its distribution (uniform) provided in Form 464 (WPO 38356, entered 6/13/96) is acceptable for the intended use.

6.7.4.9. Dissenting Views

While I agree that the log-uniform distribution with minimum and maximum values of 0.05 and 0.5 m is adequate for use in the PA, and realistically represents the uncertainty in this parameter, I do not agree that this range should be described as conservative, as it is stated at various places in this section. I do not think the use of this range of values is so cautious as to be described as conservative in the sense of a tendency to cause containment concentrations or transport rate to be overestimated.

Darrel E. Dunn

Paul L. Cloke

David A. Sommers

6.7.5. Diffusive Porosity

This section reviews the estimation of the diffusive porosity used in model SECOTP to simulate the potential contaminant transport in the Culebra in the PA. The information about this parameter provided in the Form 464 is as follows:

Parameter: Diffusive Porosity for Culebra Dolomite

ID#: 3486

Form 464: WPO 38357, entered 6/13/96

Parameter Package: WPO 37228

Distribution Type: Cumulative

Parameter Values:

Value	Probability
0.10	0.0
0.11	0.10
0.12	0.25
0.16	0.50
0.18	0.75
0.19	0.90
0.25	1.00

Definition: Diffusive porosity is defined as matrix porosity that allows diffusion to occur according to the concentration gradient in the matrix. This porosity is the interconnected porosity of a medium, which is equal to the interconnected pore volume divided by the bulk volume.

Intended Use: The Culebra diffusive porosity is used in model SECOTP as one of the input parameters to simulate contaminant transport in the Culebra under the hypothetical borehole intrusion

case. Specifically, diffusive porosity is part of the storage of a double porosity model. Diffusion into the storage contributes to retardation of solutes.

Derivation: The Culebra diffusive porosity was derived based on the laboratory measurements of more than 100 core samples from 21 boreholes (Parameter Package, WPO 37228). The core analyses for H-19b4 and AIS were conducted recently by Terra Tek under a qualified QA program. The rest of the core analyses were conducted in two periods, 1985 to 1986 and 1987 to 1988, and are documented in SAND90-7011.

6.7.5.1. Adequacy of Requirements and Criteria

Porosity is a basic physical property of a medium. The measurement of the Culebra porosity based on core samples was designed carefully and conducted by several approaches. The objectives of the core analyses, clearly stated in SAND90-7011, were to better understand the physical properties of the pore structure of the Culebra, and to augment the Culebra data base for site characterization and performance assessment studies. The sampling and analyses processes documented in the report (SAND90-7011) have demonstrated that the requirements to meet the objectives were adequate. The adequacy of the requirements can be summarized as following:

More than 100 samples, including whole-core and core-plug samples, from 21 different boreholes located in the WIPP area were measured.

Some of the samples were measured using both the helium approach and the water resaturation approach.

Results from different phases and from different laboratories were consistent.

Tests were performed under a quality assurance plan.

6.7.5.2. Validity of Assumptions

The assumptions related to the estimation of porosity of the Culebra include the assumption that the selected samples are a reasonable representation of the Culebra dolomite, which statistically represents the porosity distribution of the Culebra physical textures. This appears to be a reasonable assumption based on large number of samples collected.

Another assumption implied in the derivation of the range of porosity is that the average porosity of core samples from a borehole was used as a representation of the porosity of the Culebra at the borehole

location. This is a reasonable assumption because in the model the porosity represents the average porosity of the Culebra layer of 4 m. Due to this data reduction, the range of porosity was reduced to 0.10 to 0.25 from the range of 0.03 to 0.30, which is based on core sample results.

In SAND90-7011, it was mentioned that the selected core samples were based on the availability of samples. Since a lot of core samples that were in apparently porous and fractured parts of the Culebra have been destroyed and not recovered during coring, the measured samples may not be a complete representation of the physical characterization of the Culebra. This is true in general; however, for the intended use of the diffusive porosity in SECOTP, the measured porosity from core analyses can be considered representative because the fracture porosity is addressed by another parameter separately in model SECOTP.

6.7.5.3. Alternate Interpretation

Porosity measurement by the helium method is a standard and well known process. An alternate measurement approach is the water saturation method. Both methods resulted in almost identical results. Detailed discussion of both approaches is presented in Section 6.7.5.5.

6.7.5.4. Uncertainty and Consequences

The estimated Culebra porosity and its distribution are considered reasonable and not associated with significant uncertainties.

6.7.5.5. Appropriateness and Limitations of Methodology and Procedures

The methodology and processes for the measurement of the Culebra porosity were documented in detail in SAND90-7011. They are considered appropriate for characterization of the physical properties of the formation.

The basic approach used for measurement of porosity is the helium method based on Boyle's Law. Helium is a non-adsorbing gas and has a minimum deviation in behavior from an ideal gas. The helium method is supposed to provide an approximation of total interconnected porosity. Advantages of Boyle's Law helium method are: (1) it is very accurate, (2) it is fairly rapid except for extremely low-permeability (less than 1.0E-18 m^2) samples, and (3) it is non-destructive, allowing the samples to be reused for other analyses (SAND90-7011).

Water-resaturation approach was also used to measure the porosity of cores. The resaturation method is supposed to provide an estimate of the interconnected porosity for ground water flow and solute transport modeling, and also have the advantage of determining the void volume when the mineral samples are wet, as is the case *in situ*. The resaturation method using deionized water was applied on part of the samples that had been used to measure porosity using the helium method. Results of applying both methods show good agreement.

The core analyses documented in SAND90-7011 were performed by two phases, 1985 to 1986 and 1987 to 1988, and were conducted by two laboratories, Terra Tek, and K&A Laboratories. Results from two phases and two laboratories were checked for consistency by duplicate analyses on the same samples. The results were consistent.

Based on the description in SAND90-7011, the methodology and procedures used for measurement of porosity are considered appropriate.

6.7.5.6. Adequacy of Application

Application of the Culebra matrix porosity in SECOTP, based on the estimated range and its distribution, appears to be adequate. The matrix porosity plays a role of storage for physical retardation of a transport process. Since the estimation of porosity is representative, its application in the model is considered adequate.

6.7.5.7. Accuracy of Calculations

All the calculations to estimate the borehole average porosity and its distribution were performed under a qualified QA program. Therefore, the calculations are judged to be accurate.

6.7.5.8. Validity of Conclusions

The estimated Culebra diffusive porosity ranging from 0.1 to 0.25 with a cumulative distribution provided in the Form 464 is adequate for the intended use.

6.7.5.9. Dissenting Views

None.

6.7.6. Diffusive Tortuosity

This section reviews the estimation of the diffusive (matrix) tortuosity used in model SECOTP to simulate potential contaminant transport in the Culebra in the PA. The information about this parameter provided in the Form 464 is as follows:

Parameter: Diffusive tortuosity

ID#: 3474

Form 464: WPO 38345, entered 6/11/96

Parameter Package: WPO 37226

Distribution Type: Constant

Parameter Value: 0.11

Definition: Tortuosity is conceptually defined as a measure of the effect of the shape of the flowpath followed by water molecules in a porous medium (Fetter 1993). It can be represented by the ratio between a straight-line length and the length of the actual pathway between the ends of a tortuous flowpath.

Intended Use: The Culebra tortuosity is one of the input parameters in model SECOTP, which simulates contaminant transport in the Culebra under the hypothetical case for a breach of the repository. Specifically, tortuosity is used in the calculation of the coefficient of molecular diffusion in the model. It contributes to matrix diffusion and partially contributes to hydrodynamic dispersion. In general, the smaller the tortuosity value, the slower the rate of matrix diffusion.

Derivation: The estimation of the Culebra tortuosity was based on the results of 36 core samples from the core analyses reported in SAND90-7011 and from the core analyses on H-19b4 recently conducted by Terra Tek. The constant parameter value provided in the Form 464 is the median of the 13 borehole average tortuosity values.

Tortuosity for each sample was calculated based on the formation factor and porosity using the following equation (SAND90-7011):

$$\tau = 1 / (F \phi) \qquad (1)$$

where:

F = Formation factor

ϕ = Matrix porosity

Formation factor is a standard parameter used by the petroleum industry (Archie 1942). It is determined by $F = R_b / R_w$, where R_b is the measured electrical resistivity of the porous medium saturated with fluid of electrical resistivity R_w. The greater the formation factor, the greater the electrical resistance of the formation, which indicates the flow path is more tortuous.

6.7.6.1. Adequacy of Requirements and Criteria

Tortuosity is a basic physical property of a porous medium. However, methods of direct measurement of tortuosity are not available. The indirect measurements of the Culebra tortuosity, as reported in SAND90-7011, were based on the formation factor concept for core sample analysis. The results of the various approaches were compared with each other for a quality control check. The sampling and analyses methodologies are documented in SAND90-7011 and have demonstrated that the requirements were adequate to meet the objectives.

6.7.6.2. Validity of Assumptions

No assumption is explicitly given in the Parameter Package. The parameter value of 0.11 is the median value based on the borehole average values from the 13 boreholes. The reason for using a constant rather than a distribution, given in the Parameter Package (WPO 37226), is that "there is a relatively small range to the data with a few outliers."

Using the borehole average as the basis for development of the parameter is reasonable because the parameter used in SECOTP represents the tortuosity of the entire thickness of the Culebra. Particularly, there exists great vertical variability of tortuosity, as demonstrated by the 21 core samples from borehole H-19b4, ranging from 0.017 to 0.203. However, the borehole average tortuosity values from the other boreholes, except H-11, are based on single sample results. Thus, they may not be a reasonable representation of the borehole average at those locations.

Two borehole average values out of 13 are considered representative. One is borehole H-19b4, with 21 core samples, and the other is borehole H-11, with four core samples. The borehole average values are

0.11 and 0.09 for H-11 and H-19b4, respectively. By reviewing these two values, the selected parameter value of 0.11 is considered at least representative of the borehole average along the flow pathway from the repository to the WIPP boundary.

In summary, the assumption that the parameter was derived from the borehole average is a good intended assumption, but it was not supported by a sufficient data base. Nevertheless, through comparison of the selected value to the borehole average values along the pathway, the tortuosity of 0.11 is considered acceptable.

6.7.6.3. Alternate Interpretation

There are alternate interpretations of tortuosity. One of them is based on correlation analysis between tortuosity and matrix porosity. The correlation analysis between tortuosity and porosity is shown in Figure 4.16 (SAND90-7011). There is a general trend of increasing tortuosity with increasing porosity. The estimation of the formation factor uses Archie's equation

$$F = 1.0 / \phi^{2.13} \qquad (2)$$

where the power of 2.13 represents the cementation factor, which is obtained based on the data. Figure 4.17 (SAND90-7011) plots the formation factor values determined from electrical-resistivity measurements and determined by using Eq. (2). It has an R^2 of 0.77 for the linear regression, which indicates that there is some correlation between porosity and tortuosity. Tortuosity is also related to the distribution of pores in the sample. If the porosity values of two samples are the same, but the distribution of the grain sizes are different, the tortuosity values may be different. The value of tortuosity should be smaller for the non-uniform grain size sample than for the uniform grain size sample.

If Eq. (2) is substituted into Eq. (1), an alternative approximation of the range of tortuosity of 0.07 to 0.21 will be obtained based on the range of porosity of 0.10 to 0.25 (Section 6.7.5). Since the number of samples for porosity is much larger, and the distribution of porosity is much more representative (Section 6.7.5), estimated tortuosity based on the data base of porosity may be an alternative interpretation, but not necessarily a better interpretation.

6.7.6.4. Uncertainty and Consequences

The estimation of the Culebra tortuosity appears to involve some uncertainties. This can be demonstrated by Figure 4.15 (SAND90-7011), the relative frequency histogram for calculated tortuosity

values, which does not provide a continuous distribution. The uncertainties may be associated with many factors, including but not limited to the following: (1) the number of samples is not large enough, (2) measurement of electrical resistivity of porous medium may not be accurate enough, and (3) the indirect approaches involve approximations.

The associated uncertainty of the estimated tortuosity is not considered to have significant impact on model SECOTP in the PA. The importance of tortuosity is less significant than the other three parameters in model SECOTP. Particularly, tortuosity is used with matrix block length and free-water diffusion coefficient to calculate the characteristic diffusion time (SAND92-1579, p. 5-47). The effect of variation in matrix block length on diffusion time will be much greater than the effect of variation in tortuosity. Thus, the uncertainty associated with tortuosity is not critical.

6.7.6.5. Appropriateness and Limitations of Methodology and Procedures

The methodology and processes for the measurement of the Culebra tortuosity were documented in detail in SAND90-7011. They are considered appropriate in support of the characterization of the physical properties of the formation, and adequate for the intended use of the parameter.

Specifically, different approaches were used to cross-check the results. Three approaches were used to estimate tortuosity, including the electrical resistivity method using Eq. (1), Archie's equation using Eq. (2), and the diffusion studies. Evaluations for the results from these three approaches were conducted. Differences in the estimation of formation factor values from the electrical resistivity method and diffusion studies were attributed to dead-end pore space, constrictivity, and grain-to-fluid interface phenomena. Since the samples used in the diffusive studies are somewhat biased to the low porosity side, it was difficult to make meaningful conclusions. Results of the comparison indicate that the estimates of tortuosity involve some uncertainties, which appear to be due to the limitations of the approach.

6.7.6.6. Adequacy of Application

In model SECOTP, the Culebra tortuosity is treated as a constant, even though the measurement results of core samples indicate that tortuosity values vary significantly vertically and horizontally. The application of tortuosity as a constant is acceptable considering the relatively small impact of the variations of the parameter in the model simulations. However, treating tortuosity as a constant may potentially result in an increase of uncertainty in the matrix block length in simulations of tracer test

breakthrough curves. An increase of matrix block length increases diffusion time, which resembles the effect of a decrease in tortuosity (not equivalent in magnitude).

6.7.6.7. Accuracy of Calculations

All the calculations to estimate the borehole average tortuosity and its distribution were performed under a qualified QA program. Therefore, the accuracy of calculations are judged to be assured.

6.7.6.8. Validity of Conclusions

The estimated average Culebra tortuosity of 0.11 provided in the Form 464 (WPO 38345, entered 6/11/96) is adequate for the intended use.

6.7.6.9. Dissenting Views

None.

7.0 CONCLUSIONS

The Panel carefully reviewed the 32 parameter packages and the related parameter values submitted for peer review. Each is considered in Sections 4 through 6. The reader is referred to the individual conclusions in the appropriate sections for details of qualification information on each parameter.

As an overall summary:

The Panel is in general agreement with the parameter values chosen for:

Salado

- ☐ DRZ Compressibility (Section 4.1)
- ☐ Undisturbed Halite Pressure (Section 4.2)
- ☐ Undisturbed Halite Compressibility (Section 4.3)
- ☒ Undisturbed Halite Porosity (Section 4.4)
- ☐ Undisturbed Halite Permeability (Section 4.5)
- ☐ Undisturbed Anhydrite Pressure (Section 4.6)
- ☐ Undisturbed Anhydrite Compressibility (Section 4.7)
- ☐ Brine Salt Mass Fraction (Section 4.8)
- ☐ Brine Viscosity (Section 4.9)
- ☒ Brine Density (Section 4.10)
- ☐ Brine Compressibility (Section 4.11)

Castile

- ☐ Castile Brine Reservoir Rock Compressibility (Section 5.1)
- ☐ Castile Brine Reservoir Porosity (Section 5.2)
- ☐ Castile Brine Reservoir Pressure (Section 5.3)
- ☒ Castile Brine Reservoir Permeability (Section 5.4)
- ☐ Castile Brine Reservoir Volume (Section 5.5)

Units Above the Salado

- ☒ Non-Salado Effective Porosity (Section 6.1)
- ☐ Non-Salado Pressure (Section 6.2)
- ☐ Non-Salado Permeability (Section 6.3)
- ☒ Culebra Permeability (Section 6.4)
- ☐ Climate Index (Section 6.5)
- ☒ Culebra Thickness (Section 6.6.2)
- ☐ Culebra Storativity (Section 6.6.3)
- ☒ Culebra Fluid Density (Section 6.6.4)
- ☐ Culebra Steady-State Freshwater Heads (Section 6.6.5)
- ☐ Culebra Dolomite Grain Density (Section 6.7.1)
- ☒ Effective Culebra Thickness (Section 6.7.2)

- Advective Porosity (Section 6.7.3)
- Half Matrix Block Length (Section 6.7.4)
- Diffusive Porosity (Section 6.7.5)
- Diffusive Tortuosity (Section 6.7.6)

The conclusions with regard to the remaining parameters are:

- Culebra Transmissivity Data (Section 6.6.1)

  The transmissivity value interpreted for one well (P-18) was found to be inadequate. This value is one of 43 values used to determine the transmissivity fields.

The interrelations among the many parameters involved with the natural barriers and the complexity of developing data packages and Forms 464 became very evident during the Panel's work. In view of the large number of parameters, and in some cases very limited data, the Panel concluded that SNL's investigators performed remarkably well. As noted above, nearly all parameters proved to be adequate for the intended use. This surely reflects the overall competence of the SNL staff, whether working under an approved QA plan or not. The Panel commends them for their work.

8.0 SIGNATURES

I, by signature, hereby affirm that to the best of my knowledge and belief the findings and conclusions of this Natural Barriers Peer Review Report presents a true and accurate evaluation of the parameters reviewed and I concur with these findings and conclusions within the areas of assignment and expertise.

Darrel E. Dunn Ph.D.
NB Panel Chairman — Hydrogeology

Florie Caporuscio, Ph.D.
NB Panel Member — Geology

Paul L. Cloke, Ph.D.
NB Panel Member — Geological Sciences

David A. Sommers, Ph.D.
NB Panel Member — Hydrogeology

Charlie Wilson, Ph.D.
NB Panel Member — Hydrogeology

Chuan-Mian Zhang, Ph.D.
NB Panel Member — Ground Water Hydrology

9.0 PEER REVIEW MEMBERS AND ACCEPTABILITY

Darrel E. Dunn, Panel Chairman, is an independent consultant in hydrogeology with 38 years of experience. He has a Ph.D. in geology from the University of Illinois, Urbana; and is a registered professional geologist in Wyoming. Relevant education includes graduate credit in hydrogeology, petroleum reservoir engineering, engineering geology, stratigraphy, sedimentation, sedimentary petrology, clay mineralogy, mathematics, and statistics. Relevant experience includes five years of petroleum work involving supervision of oil well drilling, drill stem testing, coring, and borehole geophysical log interpretation. He has taught advanced hydrogeology courses at Montana State University, and the University of Toledo, Ohio. Dr. Dunn has been involved in finite-difference modeling of ground water and vadose systems since 1967 and has performed pumping tests and analyzed the data for a wide range of aquifer types and transmissivities. He has developed Fortran codes for finite-difference modeling and other hydrogeologic applications. He has been heavily involved in nuclear waste disposal since 1988. Nuclear work has included modeling uranium transport using SWIFT III at the DOE Feed Material Production Center, Fernald, Ohio; pumping tests and finite-difference ground water flow and transport modeling at the DOE Rocky Flats Site, Golden, Colorado; and analytical ground water solute transport modeling at Hanford and the Idaho National Engineering Laboratory.

Florie Caporuscio, Panel Member, majored in geology at the University of Massachusetts (Amhurst) where he graduated with a B.S. in 1977. He then completed his M.S. in geology/chemistry at Arizona State University in 1980. Following three years of work as a staff geologist at Los Alamos National Laboratory on the Yucca Mountain Project, he went to the University of Colorado for a doctorate. The Ph.D. was completed in 1988 in geology and a one-year post-doctoral fellowship in Italy followed. While at the Universite de Paris, Dr. Caporuscio pursued crystallographic studies to characterize trace radioactive element substitution in major mineral phases. He is a geochemist with 12 years of experience in high level and transuranic radioactive waste disposal, with primary responsibilities in the characterization of ash flow tuffs, their alteration products, and the technical analysis of bedded salt deposits. He has also worked in the fields of low level radioactive and mixed waste contamination, remediation and disposal. He has demonstrated efficient management of projects from inception to completion, and effective liaison with Federal, state, and local government agencies to enhance projects, inform the public, and meet environmental standards.

Paul L. Cloke, Panel Member, has 42 years of post-Ph.D. experience in geological science. Dr. Cloke majored in geological sciences, including most courses required of chemistry majors, at Harvard College, graduating with an A.B., Magna cum Laude, in 1954. He majored again in geological science at

Massachusetts Institute of Technology with a doctoral minor in mathematics to earn his Ph.D. in 1954. Following a few years working for the Anaconda Company, he returned as a post doctoral fellow in geochemistry at Harvard University from 1957 to 1959. Much of his experience has dealt with geochemistry and economic geology, but for the past eleven years has focused on problems in the disposal of nuclear wastes. This includes interfaces among hydrology, geochemistry, waste package design, climate modeling, and performance assessment. Frequent participation as a technical specialist on quality assurance audits involved most of those areas of investigation. For about five years he worked in performance assessment departments, first on the former U.S. Department of Energy Salt Repository Project and later on the Yucca Mountain Site Characterization Project. The former also involved significant interaction with the West German nuclear waste disposal program and to some extent with the Waste Isolation Pilot Plant program. For nearly three years he managed the Scientific Investigation Support Department under the Technical and Management Support Service Contract between Science Applications International Corporation and the U.S. Department of Energy. This Department dealt mostly with hydrology, geochemistry, and general geology (e.g., economic, field mapping). During the past two to three years, especially, he has had significant interactions with European nuclear waste programs (Germany, Switzerland, Sweden, Spain, Great Britain) as well as the Canadian and Japanese programs. Thus, he has had extensive experience in applying chemistry, computing, physics, and mathematics to solving geologic and nuclear waste management problems. Dr. Cloke has managed and overseen numerous projects ranging from neutron activation and gas chromatographic analyses to field sampling and analysis of lake sediments and modeling of evaporative lakes. He has wide knowledge of metallic and non-metallic commodities and how they are processed to manufacture end products. He also has considerable experience in designing and writing waste management plans.

David A. Sommers, Panel Member, is an independent consultant based in Newport Beach, California. Dr. Sommers has a Ph.D. in Geology from the University of Massachusetts, an M.S. in Geology from the University of Rochester, and a B.A. in Geology from the University of Cincinnati. He has over 30 years of experience as a professional hydrogeologist, with registration in several states, and certification by the European Federation of Geologists. His professional experience has involved hazardous waste site evaluations, soil and ground water remediation, industrial and municipal ground water supply development, mine dewatering and environmental site assessments/characterizations of industrial and commercial properties, and managing QA/QC functions spanning a broad range of investigative, engineering, and design efforts. Dr. Sommers served on the NRC/NAS Committee on Ground Water Resources and Coal Mining and is frequently retained as a technical expert to support litigation and provide expert testimony. Dr. Sommers has been involved in nuclear-related projects since 1971. He

directed the hydrology studies for the PSARs for three planned nuclear power plants, was a member of a team completing the GEIS for planned nuclear waste repositories, completed the hydrology investigations for two uranium mills in Utah and Wyoming, conducted dewatering studies for a planned underground uranium mine in New Mexico and completed feasibility studies for *in situ* mining of uranium in Colorado and Washington. Since 1995, Dr. Sommers has been an independent reviewer for DOE/WIPP-IRT and DOE/WIPP-PRP.

Charles Wilson, Panel Member, is responsible for managing a broad range of projects involving hydrogeology and geotechnical engineering, water resources planning, and environmental contamination. Activities within these projects have addressed such specialized topics as designing and conducting large-scale hydrologic tests in very low permeability, fractured rock, design and regulatory permitting of large mixed radioactive/hazardous waste landfills; development of a national water resources planning agency for the Republic of the Philippines; and design of a sitewide ground water monitoring system for the U.S. Department of Energy's Idaho National Engineering Laboratory. His broad expertise and extensive experience combine to provide innovative solutions to difficult technical problems.

Chuan-Mian Zhang, Panel Member, has a Ph.D. from the Civil Engineering Department of Colorado State University. She has more than 10 years of experience in surface water and ground water hydrology, including hydrogeology and contaminant transport, ground water and watershed modeling, conjunctive use of surface water and ground water, water resources management, statistic applications in hydrology and soil and water quality assessment, and geochemical analysis. She has completed numerous surface water and ground water investigations under various conditions, using analytical or numerical models. She has developed innovative quantifiable numerical or analytical approaches or tools to address practical problems and meet specific project needs. Recent work has included extensive involvement at Rocky Flats, one of DOE's environmental investigation sites. The work at Rocky Flats includes ground water and contaminant transport modeling, surface water and sediment transport modeling, hydrogeologic analyses, statistical background comparison of chemical and geochemical data, and geochemical analyses.

10.0 REFERENCES

10.1. Cited References

Beauheim, R.L. and L.C. Meigs. 1995. "Culebra Transport Program, Test Plan: Tracer Testing of the Culebra Dolomite Member of the Rustler Formation at the H-19 and H-11 Hydropods on the WIPP Site." G.J. Saulnier, Jr. and W.A. Stensrud, INTERA, Inc. (Contractor Report). Sandia National Laboratories: Albuquerque, NM. November 30, 1995.

Borns, D., 1996, "Response Regarding Effective Halite Porosity, Peer Review Panel Request for Clarification of Form 464 Source Documents," Internal SNL E-Mail Communication to S. Howarth, received June 4, 1996.

CCA. 1996. "Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant," Chapter 2, US DOE, CAO. March 6, 1996.

Cooper, H.H., Jr., J.D. Bredehoeft, and I.S. Papadopoulos, 1967. "Response of a Finite-Diameter Well to an Instantaneous Charge of Water." Water Resources Research 3(1): pp. 263-269.

Dennehy, K.F. 1982. "Results of Hydrologic Tests and Water Chemistry Analysis, Wells H-6A, H-6B, and H-6C, at the Proposed Waste Isolation Pilot Plant Site, Southeastern New Mexico." U.S. Geological Survey Water-Resources Investigations Report 82-8. U.S. Geological Survey: Albuquerque, NM.

DOE/WIPP 877-010, "Brine Sampling and Evaluation Program Phase II Report." U.S. Department of Energy, Waste Isolation Pilot Plant. December 1987.

DOE/WIPP 91-009, "Brine Sampling and Evaluation Program 1989 Report." D.E. Deal, R.J. Abitz, D.S. Belshi, J.B. Clark, M.E. Crawley, M.L. Martin (Contractor Report). U.S. Department of Energy, Carlsbad, NM. July 1991.

Domenico, P.A., 1972, Concepts and Models in Ground Water Hydrology, McGraw Hill, New York.

Dotson, L. "Parameter Values for Forty-Niner, Tamarisk, and Unnamed Lower Members of the Rustler Formation." Addendum to Record Packages 21, 22, 23, 24. Memo from L. Dotson, February 1, 1996.

EEG-17, "Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site," P. Spiegler, Environmental Evaluation Group, Health and Environment Department, State of New Mexico. December 1982.

Freeze, R.A. and J.A. Cherry, 1979. "Ground Water" Prentice-Hall, Inc. Englewood Cliffs, N.J.

Green, D.H. and H.F. Wang. 1990. "Specific Storage as a Poroelastic Coefficient." Water Resources Research, Vol. 26, No. 7, pp. 1631-1637. July 1990.

Hodgman, C.D., Editor-in-Chief, 1959. "Handbook of Chemistry and Physics," 41st ed., 1959-1960, p. 2044. Chemical Rubber Publishing Company, Ohio.

Holt, R. M. and D. W. Powers. 1984. Geotechnical Activities in the Waste Handling Shaft, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico; U.S. Department of Energy, WTSD-TME 038.

Howarth, S. 1995. "Salado Planning Documentation," SNL memo. WPO 3597. August 30, 1995.

Ibrahim, A.W., D.J. Borns, and Y. Jung. 1989. "Mapping Fractures in Salt with the Seismic Method." Society of Exploration Geophysicists, 59th Annual International Meeting, Dallas, TX, October 29 - November 2, 1989. Vol. 59, pp. 252-254.

Jung, Y., A.W. Ibrahim, and D. Borns. 1991. "Mapping Fracture Zones in Salt: High-resolution, Cross-gallery Seismic Tomography." Geophysics: The Leading Edge of Exploration, pp. 37-39. April 1991.

Lappin, A. and C. Chocas. 1996. "Submittal of Additional 'Roadmaps' For Use by the Data-Review Group," SNL memo. WPO 39499. May 28, 1996.

Larson, K. and G. Freeze. 1996. Internal SNL Memo to Martin, "Volume of Brine in the Castile Brine Reservoir," March 20, 1996.

LaVenue. "Documentation of Raw Data used in Input Files for GRASP-INV CCA Calculations." Memo from LaVenue to AP-018, 3 May 1996.

Martell, M.A. 1996. "Support Documentation (Salado, non-Salado, Shaft Seals) to Request the Need or Intended Use of WIPP BRAGFLO Parameters," SNL memo to file. WPO 3597. March 25, 1996.

McCord, J.T. and L.C. Meigs. 1996. "Physical Transport in the Culebra Dolomite" WPO 39167. July 11, 1996.

McCord, J.T. to L. Meigs, July 1, 1996. Discussions Related to No Parameter Cross-Correlations, No Zoning, and the Relative Conservatism of Double Porosity Compared to Multirate. Internal Memorandum, Sandia National Laboratories: Albuquerque, NM.

McCord, J.T., 1996. "Discussions Related to No Parameter Cross-Correlations, No Zoning, and the Relative Conservatism of Double Porosity Compared to Multirate. Internal SNL Memorandum. 1 July 1996.

Meigs, L. to K. Schmiege for Chuan-Mien Zhang, July 2, 1996. Information for Natural Barriers Review. Internal Memorandum, Sandia National Laboratories: Albuquerque, NM.

Meigs, L., Sandia National Laboratories, to J. Ramsey, February 21, 1996. Analysis Plan for Culebra Dolomite Physical Transport Parameters. Internal Memorandum.

Mercer, J. W. and B. R. Orr. 1979. Interim Data Report on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico; U.S. Geological Survey Water-Resources Investigations 79-98.

Pickens, J.F., G.E. Grisak, J.D. Avis, D.W. Belanger, and M. Thury. 1987. "Analysis and Interpretation of Borehole Hydraulic Tests in Deep Boreholes: Principles, Model Development, and Applications," Water Resources Research. Vol. 23, no. 7, pp. 1341-1375.

Rushauff and Beauheim. 1996. "Culebra Hydraulic Tests Analysis Package," Vol. I, II, III, May 88 to April 1996. WPO 38487.

SAND78-1597/Vol. I and II, Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico." D.W. Powers, S.J. Lambert, S. Shaffer, L.R. Hill, W.D. Weart, Editors, Sandia National Laboratories: Albuquerque, NM. August 1978.

SAND81-0557, "Geochemical Parameters Used in the Bedded Salt Reference Repository Risk Assessment Methodology." A.B. Muller, Sandia National Laboratories: Albuquerque, NM. September 1981.

SAND81-0858, "Mechanical Properties of Anhydrite and Polyhalite in Quasi-Static Triaxial Compression." L.W. Tenfel. Sandia National Laboratories: Albuquerque, NM. October 1981.

SAND81-7063, "Elastic-Plastic Deformation of Anhydrite and Polyhalite as determined from Quasistatic Triaxial Compression Tests." R.W. Pfeifle, P. E. Senseny, RESPEC Inc., Sandia National Laboratories: Albuquerque, NM. May 1981.

SAND85-7206, "WIPP Hydrology Program Waste Isolation Pilot Plant, SENM. Hydrologic Data Report #1." HydroGeo Chem, Inc. (Contractor Report). Sandia National Laboratories: Albuquerque, NM. September 1985.

SAND86-2311, "Analysis of Pumping Tests of the Culebra Dolomite conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site. R.L. Beauheim. Sandia National Laboratories: Albuquerque, NM. March 1987.

SAND86-7167, "Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report." A. Haug, V.A. Kelley, A.M. LaVenue, J.F. Pickens, INTERA Technologies, Inc. (Contractor Report). Sandia National Laboratories: Albuquerque, NM. March 1987.

SAND87-0039, "Interpretations of single-Well Hydraulic Tests conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987. R.L. Beauheim. Sandia National Laboratories: Albuquerque, NM. December 1987.

SAND87-7125, "WIPP Hydrology Program Waste Isolation Pilot Plant, Southeastern New Mexico." W.A. Stensrud, M.A. Berne, K.D. Lontz, A.M. LaVenue, J.B. Palmer, G.J. Saulnier, Jr., INTERA, Inc. (Contractor Report). Sandia National Laboratories: Albuquerque, NM. October 1987.

SAND87-7144, "Final Report for Time Domain Electromagnetic Survey at the WIPP." The Earth Technology Corporation (Contractor Report).

SAND87-7174, "Studies of Electrical and Electromagnetic Methods for Characterizing Salt Properties at the WIPP Site, New Mexico", C.I. Skokan, M.C. Pfeifer, G.V. Keller, H.T. Andersen, Dept. of Geophysics, Colorado School of Mines (Contractor Report). Sandia National Laboratories: Albuquerque, NM. June 1989.

SAND88-0112, "Brine Inflow to WIPP Disposal Rooms: Data, Modeling, and Assessment." E.J. Nowak, D.F. McTigue, R. Beraun. Sandia National Laboratories: Albuquerque, NM. September 1988.

SAND88-2948, "Advances in Resolution of Discrepancies Between Predicted and Measured *In Situ* WIPP Room Closures," D.E. Munson, A.R. Fossum, and P.E. Senseny. Sandia National Laboratories: Albuquerque, NM. 1988.

SAND89-0462, "Systems Analysis, Long-Term Radionuclide Transport and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico: March, 1989. A.R. Lappin, R.L. Hunter, D.P. Garber, and P.B. Davies, Editors. Sandia National Laboratories: Albuquerque, NM. March 1989.

SAND89-7056, "WIPP Hydrology Program Waste Isolation Pilot Plant, Southeastern New Mexico Hydrologic Data Report #8. W.A. Stensrud, M.A. Baume, K.D. Lontz, J B. Palmer, G.J. Saulnier, Jr., INTERA, Inc. (Contractor Report). Sandia National Laboratories: Albuquerque, NM. April 1990.

SAND89-7068/2, "Ground-Water Flow Modeling of the Culebra Dolomite." Volume II: Data Base. T.L. Cauffman, A.M. LaVenue, J.P. McCord, INTERA Technologies, Inc. (Contractor Report). Sandia National Laboratories: Albuquerque, NM. October 1990.

SAND89-7069, "Regional Double-Porosity Solute Transport in the Culebra Dolomite Under Brine-Reservoir-Breach Release Conditions: An Analysis of Parameter Sensitivity and Importance." M. Reeves, G.A. Freeze, V.A. Kelley, J.F. Pickens, D.T. Upton, P.B. Davies, INTERA Inc. (Contractor Report). Sandia National Laboratories: Albuquerque, NM. February 1991.

SAND90-0083, "Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: first Interim Report." R.L. Beauheim, G.J. Saulnier Jr., J.D. Avis. Sandia National Laboratories: Albuquerque, NM. August 1991.

SAND90-7011, "Core Analyses for Selected Samples from the Culebra Dolomite at the Waste Isolation Pilot Plant Site." V.A. Kelley and G.J. Saulnier, Jr. Sandia National Laboratories: Albuquerque, NM. November 1990.

SAND92-0533, "Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report." R.L. Beauheim, R.M. Roberts, T.F. Dale, M.D. Fort, W.A. Stensrud. Sandia National Laboratories: Albuquerque, NM. December 1993.

SAND92-0700/3, "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992." Volume 3: Model Parameters." Sandia WIPP Project, Sandia National Laboratories: Albuquerque, NM.

SAND92-0700/4, "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992." Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B. Sandia National Laboratories: Albuquerque, NM. December 1992.

SAND92-1172, "Room Q Data Report: Test Borehole Data From April 1989 Through November 1991." A.L. Jensen, C.L. Howard R.L. Jones T.P. Peterson. Sandia National Laboratories: Albuquerque, NM. March 1993.

SAND92-1173, "Large-Scale Brine Inflow Data Report for Room Q Prior to November 25, 1991." A.L. Jensen, R.L. Jones, E.N. Lorusso C.L. Howard. Sandia National Laboratories: Albuquerque, NM. March 1993.

SAND92-1579, "Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site." T.L. Jones, V.A. Kelley, J.F. Pickens, D.T. Upton, R.L. Beauheim, P.B. Davies. August 1992.

SAND92-1911, "Permeability and Hydraulic Diffusivity of Waste Isolation Pilot Plant Repository Salt Inferred From Small-Scale Brine Inflow Experiments." D.F. McTigue. Sandia National Laboratories: Albuquerque, NM. June 1993.

SAND93-1986, "Coupled Multiphase Flow and Closure Analysis of Repository Response to Waste-Generated Gas at the Waste Isolation Pilot Plant (WIPP)." G.A. Freeze, K.W. Larson, and P.B. Davies. Sandia National Laboratories: Albuquerque, NM. October 1995.

SAND96-0435, "Hydraulic Testing Around Room Q: Evaluation of the Effects of Mining on the Hydraulic Properties of Salado Evaporites." P.S. Domski, D.T. Upton, R.L. Beauheim. Sandia National Laboratories: Albuquerque, NM. March 1996.

Sommers, D. 1996. Memo to file, "Castile Brine Reservoir Volume, Personal communication with Palmer Vaughn regarding Form 464 Inconsistencies." June 4, 1996.

Theis, C.V. 1935. "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," Trans AGU2: pp. 519-524.

TME-3153, "Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico." R.S. Popielak, R.L. Beauheim, S.R. Black, W.E. Coons, C.T. Ellingson, and R.L. Olson. U.S. Department of Energy. March 1983.

USGS 79-98, "Interim Data Report on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico." U.S. Geological Survey Water-Resources Investigations. Prepared in cooperation with the U.S. Department of Energy.

USGS 81-36, Results of Hydrologic Tests and Water Chemistry Analyses, Wells H-4A, H-4B, and H-4C at the Proposed Waste Isolation Pilot Plant, Southeastern New Mexico.

USGS 82-19, Results of Hydrologic Tests and Waster-Chemistry Analyses, Wells H-5A, H-5B, and H-5C, at the Proposed Waste Isolation Pilot Plant Site, Southeastern New Mexico.

USGS 82-4118, Geologic and Well-Construction Data for the H-8 Borehole Complex Near the Proposed Waste Isolation Pilot Plant Site, Southeastern NM.

USGS 82-8, "Results of Hydrologic Tests and Water Chemistry Analyses, Wells H-6A, H-6B, and H-6C, at the Proposed Waste Isolation Pilot Plant Site, Southeastern New Mexico.

USGS 83-4016, "Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, southeastern New Mexico. J.W. Mercer. U.S. Geological Survey WRIR 83-4016. 1983.

Vaughn, P. 1996. "Revision to DRZ and TZ Properties to be Used in the BRAGFLO CCA Calculations," SNL memo to Chu. WPO 032288. 1/24/96.

10.2. Additional References

CRC Handbook of Chemistry and Physics, 75th edition, 1995.

Data File Report, "ERDA-6 and WIPP-12 Testing" D'Applonia Consulting Engineers, Inc. (Contractor Report).

Data File Report, "ERDA-6 and WIPP-12 Testing, Addendum 2." D'Applonia Consulting Engineers, Inc. (Contractor Report).

Davies, Peter, 1996. Necessary changes to the parameter package for far-field permeability of Salado halites. Memorandum to Martin Tierney, March 7.

Freeze, G. and Larson, K., 1996, SNL Memorandum of Record, "Castile Brine Reservoir Volume Revision," May 27, 1996.

Lappin, Al, and Rick Beauheim, 1996. Response to Request Number 14 from the Natural Barriers Peer Review Panel. Memorandum to Victor Harper-Slaboszewicz, May 15.

Pickens, J. F., G. E. Grisak, J. D. Avis, D. W. Belanger, and M. Thury. 1987. "Analysis and Interpretation of Borehole Hydraulic Tests in Deep Boreholes: Principles, Model Development, and Applications'" Water Resources Research. Vol. 23, no. 7, 1341-1375.

SAND78-1596, "Geological Characterization Report for the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico," D.W. Powers, et al. Vol. II, Albuquerque, New Mexico, Sandia National Laboratories. 1978.

SAND82-2922, "Waste Isolation Pilot Plant (WIPP) Site Gravity Survey and Interpretation." L.J. Barrows, S. Shaffer, W.B. Miller J.D. Fett. Sandia National Laboratories: Albuquerque, NM.

SAND86-7109, "WIPP Hydrology Program Waste Isolation Pilot Plant Southeastern New Mexico Hydrologic Data Report #3." INTERA Technologies, Inc. (Contractor Report).

SAND90-7000, "WIPP" Salado Hydrology Program Data Report #1." G.J. Saulnier, Jr., P.S. Domski, J.B. Palmer, R.M. Roberts, W.A. Stensrud. INTERA. INC. (Contractor Report), A.L. Jensen, Fluid Flow and Transport Div., Sandia National Laboratories: Albuquerque, NM. May 1991.

SAND92-7072, "Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2." W. A. Stensrud, T.F. Dale, P.S. Domski, J.B. Palmer, R.M. Roberts, M.D. Fort, G.J. Saulnier, Jr., INTERA, Inc. (Contractor Report), A.L. Jensen, Fluid Flow and Transport Department, Sandia National Laboratories: Albuquerque, NM.

SAND94-0472, "Porosity, Since-Phase Permeability, and Capillary Pressure Data from Preliminary Laboratory Experiments on Selected Samples from Marker Bed 139 at the WIPP," Abstract. S.M. Howarth, T. Christian-Frear.

SAND94-3173, "Effect of Explicit Representation of Detailed Stratigraphy on Brine and Gas Flow at the Waste Isolation Pilot Plant." T.L. Christian-Frear, S.W. Webb.

SAND96-0561, "Modeling Brine Inflow To Room Q: A Numerical Investigation of Flow Mechanisms," Abstract. G.A. Freeze, T.L. Christian-Frear. Sandia National Laboratories: Albuquerque, NM. 1996.

SAND96-0561, "Modeling Brine Inflow to Room Q: A Numerical Investigation of Flow Mechanics." Draft. G.A. Freeze, INTERA Inc., (Contractor Report). T. Christian-Frear and S.W. Webb. Sandia National Laboratories: Albuquerque, NM. March 1996.

Determination of Peer Review Member Independence Form

No — Currently employed by DOE or DOE Contractor? Yes/No
Yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

10/88 - 5/90; Fernald, Ohio; IT Corp; Hydrogeologist; Groundwater modeling
9/90 - 2/96; Denver, CO; AST; Hydrogeologist; Geology, hydrology, groundwater modeling, project management
1/93 - 7/93; Albuquerque, NM; AST; Hydrogeologist; WIPP Parameter Review, Technical Support Group QA
7/93 - 3/94; Richland, WA; AST; Hydrogeologist; Hanford Remedial Action EIS
2/95 - 5/95; Albuquerque; AST; Hydrogeologist; WIPP Independent Review Team QA
1/91 - 5/91; Idaho Falls, ID; AST; Hydrogeologist; Groundwater Modeling

No — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Daniel E. Dunn

Date: 4/23/96

Peer Review Manager Approval: John A. Thies — 4/25/96 Date

Determination of Peer Review Member Independence Form

Yes — Currently employed by DOE or DOE Contractor? Yes/No

Yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

4/96 Informatics, Albuquerque NM, staff consultant Peer Review of WIPP

8/93 – 3/96 Advanced Sciences Inc, Los Alamos Office, Project Manager and Senior technical Lead, Environmental Restoration Project

No — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Flore A Caporuscio

Date: 4/1/96

Peer Review Manager Approval: John A. Thies — 4-1-96 Date

Paul Cloke

Determination of Peer Review Member Independence Form

No — Currently employed by DOE or DOE Contractor? Yes/No
Yes — Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

1985-1988 Battelle Memorial Institute under contract to DOE Salt Repository Project (HLW). Advice to DOE + management of subcontracts, mostly for geochemistry

1988-1995 Science Applications International Corporation — similar to above. Numerous audits of (Quality assurance) of contractor work. — See resume

1993 — Served as consultant on review panel for data used for performance assessment of WIPP site. Subcontract from ASI to SAIC.

No — Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Paul F. Cloke

Date: May 10 1996

Peer Review Manager Approval: John A. Thies — 5/14/96 Date

Determination of Peer Review Member Independence Form

NO Currently employed by DOE or DOE Contractor? Yes/No

YES Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

July & August 1995 Sandia Nat Labs in Albuquerque, NM as member of The Independent Review Team for Advanced Sciences, Inc. as expert hydrogeologist reviewing data packages for shaft hydrology studies

NO Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed. and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: (DAVID A. SOMMERS, PH. D.)

Date: April 29, 1996

Peer Review Manager Approval: John A. Thies

Date 4/25/96

Determination of Peer Review Member Independence Form

___ Currently employed by DOE or DOE Contractor? Yes/No

X Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

1978 - 1983 U. of California Lawrence Berkeley Laboratory - Performed field hydrology study of Hanford Site

1983 - 1985 Hydrotechnique Inc, Berkeley CA - Performed consulting services to Hanford Site

1986 - 1996 Golder Associates Inc - Albuquerque NM - Performed consulting services to Hanford, INEL, Los Alamos Sites

___ Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical. I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Charles R Wilson

Date: 3/29/96

Peer Review Manager Approval: John A. Thies — 4/8/96 Date

TOTAL P.03

Chuan-Mian Zhang

Determination of Peer Review Member Independence Form

NO Currently employed by DOE or DOE Contractor? Yes/No

YES Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

During 1993 – 1995. Work for Rocky Flats for EG&G.
Performed Groundwater modeling, Surface water modeling.
Hydrogeologic analysis, and statistical analysis
work for operable unit No. 2 and No. 6.
Work was performed during my employment with WCFS at Denver.

NO Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: [signature]

Date: 5/11/96

Peer Review Manager Approval: [signature] John A. Thies 5/14/96 Date

PEER 8 - Passive Institutional Controls Peer Review

CAO PLAN
Carlsbad Area Office

Title: Passive Institutional Controls (PICs) Peer Review Plan

(Assistant Manager, Office of Regulatory Compliance, Carlsbad Area Office) Date: 5-28-96

1. INTRODUCTION

This Passive Institutional Controls (PICs) Peer Review Plan describes the peer review process that will be implemented to confirm that the PICs proposed by the U.S. Department of Energy (DOE) at the Waste Isolation Pilot Plant (WIPP) will reasonably preserve the knowledge about the location, design, and contents of the WIPP disposal system and reduce the likelihood of inadvertent intrusion.

1.1 BACKGROUND

Under 40 CFR Part 191.12, PICS are defined by the Environmental Protection Agency (EPA) to include markers, public records and archives, government ownership of regulated or affected land, and other appropriate methods for preserving knowledge about the site. The assurance requirements found in 40 CFR Part 191.14(c) stipulate that "Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of their location." The regulatory requirements governing PICs, as specified in 40 CFR Part 191, are implemented through criteria in 40 CFR Part 194.43(a) requiring that "Any compliance application shall include detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system." The Carlsbad Area Office (CAO) has selected a method other than that suggested by the EPA in the preamble to 40 CFR Part 194 (61 FR 5232). In the preamble, expert judgment is suggested as the process for considering the specific PICs to be implemented at the WIPP by DOE in accordance with the requirements of 40 CFR Part 194.26. However, the language provided in 40 CFR Part 194.43 ("Passive Institutional Controls") makes no mention of the expert judgment process with regard to PICs, thereby allowing DOE the latitude to use the peer review as the means to evaluate the measures that DOE shall employ to preserve knowledge about the location, design, and contents of the disposal system. The "detailed descriptions" of these measures will be developed by DOE. The function of the PICs Peer Review Panel will be to confirm the "adequacy" and "reasonableness" of the detailed description, using a process conducted in accordance with NUREG-1297.

The requirements of NUREG-1297 state that "A peer review is a documented, critical review performed by peers who possess qualifications at least equal to those of the individuals who conducted the original work. These individuals must be independent of the work being reviewed. [I]ndependence from the work being reviewed means that the peer, a) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed, and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed."

To confirm that the PICs proposed by the DOE will reasonably preserve the knowledge about the location, design, and contents of the disposal system and reduce the likelihood of inadvertent intrusion, the DOE will conduct a peer review of the reports and analyses that document the systems to be employed. The peer review will be conducted to confirm the adequacy and reasonableness of the measures used to characterize PICs at the WIPP.
Under 40 CFR Part 194, the Compliance Certification Application (CCA) must address the impacts of PICs in restricting or deterring possible drilling and mining activities; this information must also be incorporated into the performance assessment (PA). Under 40 CFR Part 194.43(a), the CCA shall include detailed information regarding the PICs. A proviso is made in section 43(c) that while DOE may assume credit for the PICs reducing the likelihood

of human intrusion, it is understood that there is a limited time under which the PICs may be considered effective (i a period of up to 700 years).

1.2 PURPOSE

The purpose of this PICs Peer Review Plan is to define the peer review process that will be conducted to confirm that the detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system are adequate and have a reasonable expectation of meeting their intended purpose (i.e., reducing the likelihood of inadvertent intrusion) during the prescribed period of effectiveness.

1.3 SCOPE

This PICs Peer Review Plan describes the peer review process the DOE-CAO will implement for the review of the measures that will be employed to preserve knowledge about the design, location, and contents of the disposal system and reduce the likelihood of inadvertent intrusion. The Plan defines the approach, methodology, criteria, schedules, deliverables, and resources that the PICs Peer Review Panel will use to confirm the adequacy and reasonableness of the measures DOE intends to use to demonstrate compliance.

2. PEER REVIEW PLANNING AND IMPLEMENTATION

2.1 APPROACH

The DOE-CAO has prepared the "Office of Regulatory Compliance (ORC) Team Procedure for Peer Review" (TP 10.5) to document the approach for conducting peer reviews. The PICs Peer Review Panel will conduct the peer review activities for the evaluation of PICs measures in accordance with TP 10.5 and this PICs Peer Review Plan. A DOE-CAO contractor, Informatics, Inc., has developed Informatics Desk Instruction (IDI) 1.0 that will be used in conjunction with TP 10.5.

The data and information necessary to support the PICs Peer Review has been prepared by those CAO participating organizations responsible for preparation of the PICs reports and analyses.

2.1.1 DATA USED IN THE DEMONSTRATION OF COMPLIANCE

The "PICs Efficacy Report," "PICs Conceptual Design Report," and supporting data and information will serve as the inputs to the PICs Peer Review.

2.1.2 COMPOSITION OF PEER REVIEW PANELS

The PICs Peer Review Panel will be composed of a minimum of three individuals who will represent the spectrum of experience required to review the documentation and analyses and to develop the PICs Final Report. The Peer Review Selection Committee will identify and select the Panel member(s) based on the candidates' ability to meet the peer reviewer requirements as defined in TP 10.5.

2.1.3 LOGISTICS AND MANAGEMENT

When the PICs Peer Review Panel convenes, Panel members will receive formal orientation and training. The orientation will help to familiarize Panel members with the WIPP disposal system, the regulatory and technical basis of the PICs, and their intended impact on reducing the potential for future human intrusion, through either drilling or mining activities within the WIPP controlled boundaries, during the period of the PICs' regulatory effectiveness. Each peer reviewer will be selected, oriented, and trained in accordance with approved procedures.

It is the intention of DOE-CAO to have the PICs reports and other data available for review when th. PICs Peer Review Panel begins the review process. However, not all information necessary to support peer review of the PICs documents will be available at the beginning of the review. It may be necessary,

therefore, to conduct the PICs Peer Review in a phased manner, depending upon the availability of the information.

2.2 METHODOLOGY

The PICs Peer Review will be conducted in accordance with the general guidance provided in NUREG-1297. Requirements for developing the methodology are presented in TP 10.5 which states that "suggested methods" shall be included in the specific Peer Review Plan. The PICs Peer Review Panel will also refer to 40 CFR Part 194.43 for specific guidance as it reviews PICs documents and other related information.

2.3 ADEQUACY CRITERIA

Adequacy of data associated with the PICs will be based on the PICs Peer Review Panel's determination that these data meet commonly accepted technical and scientific standards. Criteria stipulated in NUREG-1297 include, as applicable:

1. Adequacy of requirements and criteria;
2. Validity of assumptions;
3. Alternate interpretations as appropriate;
4. Uncertainty of results and consequences if wrong;
5. Appropriateness and limitations of methodology and procedures;
6. Adequacy of application;
7. Accuracy of calculations; and
8. Validity of conclusions.

In its review, the PICs Peer Review Panel may also consider, as appropriate, the following:

- The sources of the parameters and data, e.g., professional judgment, published source material, field tests, laboratory experiments, etc.;
- The processes used to produce the parameters from data are appropriate for the intended use; and
- The assumptions, calculations, extrapolations, interpretations, methods, and conclusions pertinent to the data are appropriate for the development of parameters used as input to the WIPP PA and are traceable.

2.4 SCHEDULE

The PICs Peer Review Panel review is expected to last between three to four weeks. The Peer Review Manager, working closely with the CAO-ORC staff, has developed a preliminary schedule that provides the necessary information in a manner that will allow the final report to be developed in accordance with the schedule shown in Attachment A. This schedule will serve as the baseline schedule from which requested schedule deviations may be evaluated and approved, if appropriate. Revisions to the baseline schedule will not require revision to this Plan but will be attached to the Plan by reference.

2.5 RESOURCES

The resource needs for completing the PICs Peer Review are listed in Attachment B.

2.6 REPORT FORMAT

A list of mandatory topics and a suggested outline for the Peer Review Final Report is provided in Attachment C.

3. QUALITY ASSURANCE

The PICs Peer Review will be conducted in a controlled manner and in compliance with TP 10.5.

4. RECORDS MANAGEMENT

Records and documents generated as a result of the peer review activities defined in this Peer Review Plan are identified in TP 10.5. Records will be assembled and maintained in accordance with the Peer Review Management Plan and IDI 1.0. Upon completion of the PICs Peer Review, a complete set of PICs Peer Review records will be delivered to the DOE-CAO. Ultimately, the PICs Peer Review records will be dispositioned in accordance with DOE-CAO records management requirements defined in CAO-MP 4.5.

5. DOCUMENT CONTROL

All plans, procedures, and other documents which require document control will be handled in accordance with applicable DOE-CAO controlled document procedures defined in CAO-MP 4.4.

ATTACHMENT A

TENTATIVE SCHEDULE

PANEL REVIEW -- MEETING 1

May 28

8 a.m. - 12 p.m.	Administrative Orientation
1 p.m. - 5 p.m.	Review Training Materials

May 29

8 a.m. - 3 p.m.	Background Information on WIPP Review Background Information Meet with Panel

PANEL REVIEW -- MEETING 2

June 4

3 p.m.	Travel to Carlsbad (4:05 flight)

June 5

8 a.m. - 5 p.m.	WIPP Site and Facility Tour (pick-up at hotel by Westinghouse at 8 a.m.

June 6

8 a.m. - 12 p.m.	Technical Presentation at DOE
12 p.m.. - 4 p.m.	Travel to Albuquerque (1:05 p.m. flight)

June 7

???	Optional meeting in Albuquerque

TBD -- Conference calls and express mail exchanges, as needed

PANEL REVIEW -- MEETING 3

June 24 - 27

TBD	Peer Review Work Session

DRAFT DOCUMENT DUE	***June 20, 1996***
FINAL DOCUMENT DUE	**June 27, 1996**

ATTACHMENT B

ESTIMATED PEER REVIEW RESOURCE REQUIREMENTS

Subject Matter Experts	1,200 hours
Technical Coordinator	300 hours
Clerical Support	300 hours

ATTACHMENT C

SUGGESTED OUTLINE FOR PEER REVIEW REPORT

Executive Summary

1. Introduction

2. Purpose

3. Description of Work Performed

4. Evaluation Work Performed

   a. Adequacy of Requirements and Criteria
   b. Validity of Assumptions
   c. Alternate Interpretations
   d. Uncertainty of Results and Consequences if Wrong
   e. Appropriateness and Limitations of Methodology and Procedures
   f. Adequacy of Application
   g. Accuracy of Calculations
   h. Validity of Conclusions

5. Conclusions

6. Dissenting Views

7. Summary

8. Signatures

9. Peer Review Members and Acceptability

PASSIVE INSTITUTIONAL CONTROLS QUALIFICATION

PEER REVIEW REPORT

FINAL REPORT

WASTE ISOLATION PILOT PLANT
PASSIVE INSTITUTIONAL CONTROLS
PEER REVIEW REPORT

A PEER REVIEW
CONDUCTED BY

Jessica Glicken, Elizabeth Hocking, Paul La Pointe

for

U.S. Department of Energy
Carlsbad Area Office
Office of Regulatory Compliance

July 1996

FOREWORD

The U.S. Environmental Protection Agency promulgated "Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule" in Code of Federal Regulations Title 40, Part 194 (40 CFR Part 194) on February 9, 1996. The 40 CFR Part 194 regulation prescribes three specific peer reviews and provides an opportunity for the U.S. Department of Energy to use peer reviews, conducted in accordance with NUREG 1297, as a means of qualifying data and information in the demonstration of compliance.

This report contains the results of a peer review of passive institutional controls used in the demonstration of Waste Isolation Pilot Plant compliance with 40 CFR Part 194. To ensure the independence of this review, the Department of Energy has directed the assignment of an independent contractor to administratively manage the peer review activities. Peer reviewers were selected based on their demonstrated independence from the work being reviewed and their technical expertise in the subject matter. The peer review panel members collectively possess an appropriate spectrum of knowledge and experience in the subject matter reviewed.

This peer review was conducted in compliance with the quality assurance requirements as defined in 40 CFR Part 194.

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ACRONYMS

CAO	Carlsbad Area Office
CAG	Compliance Application Guidance
CCA	Compliance Certification Application
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
FR	Federal Register
NRC	U.S. Nuclear Regulatory Commission
PA	Performance assessment
PIC	Passive institutional control
PTF	Passive Institutional Controls Task Force
SNL	Sandia National Laboratories
TP	Team Procedure (Carlsbad Area Office)
WIPP	Waste Isolation Pilot Plant

1.0 EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is a proposed repository of transuranic waste located in Carlsbad, New Mexico. Owned and operated by the U.S. Department of Energy (DOE), WIPP is scheduled to open in 1998 and will be in operation until the year 2033 (estimated). Upon closure of WIPP, DOE is required to maintain active institutional controls at the 16-square-mile disposal site for 100 years. Following the end of the period of active controls, DOE intends to rely upon a variety of passive institutional controls to warn and inform future societies about the presence of WIPP and the nature of its contents. These passive institutional controls will include berms, stone markers or monoliths, buried record storage rooms, land use records (e.g., drilling permits), and archival information placed at various libraries, government buildings, and other centers in the United States and abroad.

During a 5-week period beginning in May 1996, a three-member panel of experts was convened to conduct an independent peer review of the system of passive institutional controls designed by DOE. The panel reviewed the findings of the Passive Institutional Controls Task Force (PTF), evaluating detailed descriptions of the measures DOE has proposed to preserve knowledge about the location, design, and contents of the WIPP disposal system. The primary focus of the evaluation was to determine whether the passive institutional controls designed by DOE are adequate and have a reasonable expectation of meeting their intended purpose of reducing the likelihood of inadvertent intrusion during the prescribed period of effectiveness (i.e., approximately 700 years). The results of the panel's review are documented in this report.

In preparation for their peer review, panel members familiarized themselves with requirements regulating activities at WIPP (40 Code of Federal Regulations [CFR] Parts 191 and 194) and requirements for the conduct of peer reviews (NUREG-1297 and Carlsbad Area Office Team Procedure [TP] 10.5). Following briefings by members of the PTF, panel members were given two documents that formed the basis of their peer review: *Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments* (hereinafter referred to as the *PICs Efficacy Report*) and *Passive Institutional Controls Conceptual Design Report* (hereinafter referred to as the *Conceptual Design Report*). Supplemental information requested by the panel was also used in the evaluation.

The approach used by the peer review panel was to evaluate the assumptions and results presented in the *PICs Efficacy Report* using the following criteria: adequacy and legitimacy of assumptions, appropriateness and accuracy of the methodology used to develop and assess the assumptions and the

failure probability of the passive institutional controls, uncertainty associated with the credit calculations, consequences of inaccurate or incomplete assumptions, and validity of the conclusions. The panel's findings relating to these criteria are presented below.

1.1. Adequacy and Completeness of Assumptions

In general, the panel found that the PTF's interpretation of the regulations regarding passive institutional controls was adequate and reasonable given the indeterminate quality of some of the regulations. However, the panel expressed concern about the way in which the PTF's interpretations were applied. In many cases, the panel found the PTF's assumptions to be reasonable but unsupported and/or incomplete. In other cases, the panel determined that the PTF failed to discuss assumptions that were: 1) implicit in, and necessary to, the assumptions they presented, or 2) made by expert panels and incorporated into the overall design of the passive institutional controls (e.g., validity of archetypes as a communications vehicle).

Another area of concern dealt with the PTF's failure to develop and/or discuss the communications and activities process models that underlie the conceptual design of the controls. Such models would: 1) look at passive institutional controls as communications vehicles, and 2) assume a general pattern of activity that will lead to an inadvertent intrusion event.

The panel's assessment of the individual assumptions presented in the *PICs Efficacy Report* resulted in a consensus about the general adequacy and reasonableness of the information contained in the document. However, panel members noted their concern about areas within the *PICs Efficacy Report* that may be in need of clarification or modification. These include:

- ***Basic human attributes.*** Several assumptions regarding human characteristics are poorly supported or in need of other modifications. For example, explicit assumptions should be provided relating to human evolution and associated biological and sociocultural capabilities.
- ***Government.*** The PTF does not adequately define "government" and offers poor support for the assertions made in the *PICs Efficacy Report*. Also, some of the assumptions made by the PTF are actually conclusions or second-order assumptions.
- ***Language.*** Assumptions made by the PTF should be supported by references. Also, assumptions regarding other aspects of communication are not captured.
- ***Natural resources.*** The panel found these assumptions to be generally reasonable and consistent with the requirements.

- ***Estimating the effectiveness of passive institutional controls.*** Four assumptions are made that require additional support. Furthermore, the panel believes that social institutions other than government should be considered as potential facilitators of passive institutional controls since there are strong and effective mechanisms of social control other than government.

1.2. Adequacy of the Technical Presentation

In addition to evaluating the adequacy and completeness of the assumptions made by the PTF, the peer review panel evaluated the adequacy of the PTF's technical presentation using the following criteria:

- ***Application of the systems approach.*** The panel found that the redundancy of the individual components was well-supported and explained, but that the sufficiency of the individual components to effectively deter inadvertent intrusion in the absence of any other component was unevenly supported. The panel noted the PTF's failure to discuss the "Gestaltic" nature of the system, in which the whole is more effective in deterring intrusion than the sum of its parts.

- ***Assessment of the durability and comprehensibility of individual components of the system.*** The panel examined descriptions of markers, archives, records centers, government control of land use, and other passive institutional controls. The panel concluded that the materials (e.g., granite) and plans for the storage and retention of records appear to be adequate, but that there is uncertainty attached to both the durability and comprehension of all passive institutional controls and that this uncertainty has not been taken into account by the PTF.

- ***Assessment of completeness of failure scenarios.*** The panel found that at least two failure scenarios were not discussed by the PTF: collateral damage due to war and inadvertent intrusion due to horizontal drilling.

- ***Evaluation of credit calculations.*** The panel's analysis suggested that the PTF's credit calculations may be incorrect or incomplete. For example, failure rates and the uncertainty surrounding failure rates should be calculated for each component.

- ***Consequences for performance assessment.*** The panel concluded that: 1) uncertainties relating to the failure of various passive institutional controls components were not addressed properly, 2) certain credible failure scenarios were not considered, 3) adequate evidence for calculating failure probabilities of various components was not provided, and 4) the systems nature of passive institutional was not appropriately considered when calculating the probabilities that individual components and/or the system will fail.

The overall conclusions presented by the panel regarding the passive institutional controls described and supported in the *PICs Efficacy Report* and the *Conceptual Design Report* suggest that: (1) the evidence provided in the reports does not adequately demonstrate that passive institutional controls will have a failure probability of 0.01 or less and (2) the level of uncertainty as it applies to the passive institutional controls is higher than 0.0.

2.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a proposed repository of transuranic waste located in Carlsbad, New Mexico. Owned and operated by the U.S. Department of Energy (DOE), WIPP is scheduled to open in 1998 and will be operational until the year 2033 (estimated). Upon closure of WIPP, the DOE is required to maintain active institutional controls at the 16-square-mile disposal site for a period of 100 years. At the end of the period of active controls, DOE intends to rely upon a variety of passive institutional controls (PICs) to warn and inform future societies about the presence of WIPP and the nature of its contents. These passive institutional controls will include berms, stone markers or monoliths, buried record storage rooms, land use records (e.g., drilling permits), and archival information placed at various libraries, government buildings, and other centers in the United States and abroad.

Beginning in May 1996, a three-member panel of experts was convened to conduct an independent peer review of the passive institutional controls system designed by DOE. The panel was one of five peer review panels that were appointed to assess various elements of WIPP to determine whether the work done by DOE and its contractors met the requirements of adequacy and reasonableness set forth in guidance developed by the U.S. Nuclear Regulatory Commission (NRC), Peer Review for High-Level Nuclear Waste Repositories, commonly known as NUREG-1297 (NRC 1988). Using the peer review process to evaluate components of the WIPP disposal system is authorized by 40 Code of Federal Regulations (CFR) Part 194, and is to be conducted in accordance with NUREG-1297. The findings of these panels will be considered by DOE in preparing the Compliance Certification Application (CCA) that will be submitted to the U.S. Environmental Protection Agency (EPA) to signify DOE's readiness to accept waste at WIPP.

The three members of the Passive Institutional Controls Peer Review Panel worked during a 5-week period to review the findings of the Passive Institutional Controls Task Force (PTF) led by Sandia National Laboratories (SNL). The panel evaluated the adequacy and reasonableness of the detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the WIPP disposal system. The primary focus of the evaluation was to determine whether the passive institutional controls designed by DOE are adequate and have a reasonable expectation of meeting their intended purpose (i.e., reducing the likelihood of inadvertent intrusion) during the prescribed period of effectiveness (approximately 700 years). This report presents the results of the panel's evaluation.

The following sections describe the review and evaluation process undertaken by the peer review panel and the results of the process. Section 3 describes the work performed, including methods and resources used by the panel. Section 4 evaluates the validity of assumptions made by the PTF with regard to the various passive institutional controls and their effectiveness. Section 5 evaluates the adequacy of the technical presentation. Section 6 presents the panel's conclusions and summary. Section 7 consists of a signature page, with signatures indicating passive institutional controls panel members' concurrence with the findings and conclusions of the report. Section 8 provides a brief description of each panel member's education and relevant experience. References are provided in Section 9.

3.0 DESCRIPTION OF WORK PERFORMED

The peer review for passive institutional controls was initiated on May 28, 1996, with a 1-day administrative orientation and training session in Albuquerque, New Mexico. The session allowed the peer review panel members to familiarize themselves with the primary regulations and other guidance relevant to WIPP and the peer review process, including:

- 40 CFR Part 191, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.*
- 40 CFR Part 194, *Criteria for the Certification and Re-certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations.*
- NUREG-1297, *Peer Review for High-Level Nuclear Waste Repositories.*
- Carlsbad Area Office (CAO) Team Procedure 10.5 (TP 10.5), *Peer Review.*

The initial training was supplemented with reports on the activities of the Futures and Markers panels; these reports were provided to panel members by SNL.

The panel members were given a technical orientation in Carlsbad, New Mexico, on June 5 to 6, 1996. On June 5, panel members were given a tour of the WIPP site and surrounding area to acquaint themselves with the facility and the general layout of the 16-square-mile area that encompasses WIPP. On June 6, panel members met for briefings by representatives of DOE-CAO, SNL, and their subcontractors who had participated in the PTF. Following the briefings, panel members were given two documents: *Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments* (Trauth et al. 1996) (hereinafter referred to as the *PICs Efficacy Report*) and *Passive Institutional Controls Conceptual Design Report* (DOE 1996a) (hereinafter referred to as the *Conceptual Design Report*). These two reports, together with supplemental information requested by the panel, were the basis of the peer review of the system of passive institutional controls designed by DOE.

In its review of documentation prepared by SNL, the peer review panel followed the requirements set forth in NUREG-1297 and 40 CFR Part 194 regarding the conduct of peer reviews and the development of passive institutional controls. Although panel members were aware of the CCA content requirements for passive institutional controls, their evaluation was guided not by the *Compliance Application Guidance* (CAG) for 40 CFR Part 194 developed by EPA to assist in preparation of the CCA, but by the requirements of 40 CFR Part 194 (EPA 1996a). Panel briefings, deliberations, meetings, information

requests, and records management were conducted in accordance with TP 10.5 and Informatics Desk Instruction 1.0.

The adequacy criteria in NUREG-1297 provided guidance for the review of the documents and processes being evaluated. The following evaluation criteria were applied by the peer review panel to the assumptions underlying the development and assessment of passive institutional controls:

- Completeness of the assumption (legitimacy and adequacy of assumptions).
- Appropriateness and accuracy of methodology used to develop and assess the assumptions and the passive institutional controls.
- Uncertainty associated with the credit calculations.
- Consequences associated with inaccurate or incomplete assumptions.
- Validity of conclusions.

During the peer review process, panel members were able to request any supporting information they required, including reports, regulations, and presentations by or question/answer sessions with representatives from SNL, DOE-CAO, EPA, and the Environmental Evaluation Group (EEG). The information provided by these resources was discussed during panel meetings and conference calls during June 1996. The various resources used by the panel are cited throughout the report and are compiled in Section 9.

The composition of the peer review panel followed the guidance of NUREG-1297 that peer reviewers have technical qualifications that are "at least equivalent to those needed for the original work under review." Due to the nature of the work being reviewed, peer reviewers were also selected on the basis of their diverse backgrounds. The names and areas of expertise of the Passive Institutional Controls Peer Review Panel members are: Jessica Glicken, Ph.D., Cultural Anthropology; Elizabeth Hocking, J.D., Environmental Law; and Paul La Pointe, Ph.D., Natural Resources Engineering. Additional information about the panel members is provided in Section 8.

4.0 ASSUMPTIONS

4.1. Interpretation of Regulations Regarding Passive Institutional Controls

4.1.1. Definitions and Descriptions

Passive institutional controls are defined in 40 CFR 191 as:

> (1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system (40 CFR Part 191.12).

Passive institutional controls are identified at 40 CFR Part 191.14 as one of the provisions that must be followed in the disposal of transuranic wastes to ensure that the waste containment requirements of 40 CFR Part 191.13 will be met. The regulation states that:

> Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location (40 CFR Part 191.14(c)).

40 CFR Part 194 refers to passive institutional controls as the "measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system." Details of the elements these measures must include are provided in 40 CFR Part 194.43(a). In brief, passive institutional controls must include:

- Markers designed, fabricated, and emplaced to be as "permanent as practicable" to identify the controlled area.
- Records placed in archives and record systems "that would likely be consulted by individuals in search of unexploited resources." These records will describe the location and characteristics of the disposal system and wastes.
- Other controls that would "indicate the dangers of the waste and its location" (40 CFR Part 194.43(a)).

Although the *PICs Efficacy Report* discusses markers, records, and other controls, its quotation of 40 CFR Part 194.43(a) is not an accurate or complete representation of "the measures that will be employed to preserve knowledge" of the site and its dangers (p. 2-3). The quotation lists markers as the only measure; it ignores the reference in the regulation to records and other controls even though the regulation states that all three types of passive institutional controls "shall" be included as measures.

While this may be an oversight, this section should be revised to avoid the appearance that the PTF is minimizing the role of records and other passive institutional controls.

4.1.2. Active Institutional Controls versus Passive Institutional Controls

Active institutional controls are described in the regulations as:

> (1) Controlling access to a disposal site by any means other than passive institutional controls. (2) performing maintenance operations or remedial actions at a site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance (40 CFR Part 191.12.)

Neither the regulations nor the CAG includes any further discussion of active institutional controls (other than restricting their credit value to a maximum of 100 years) as opposed to passive institutional controls.

In the *PICs Efficacy Report*, the PTF draws a distinction between active institutional controls and passive institutional controls. In the former, an institution deters intrusion; in the latter, the institutional control itself is the deterrent (p. 2-2). This distinction is a reasonable interpretation of the regulations, given their indeterminate quality. In the course of its discussion, the PTF expanded on the distinction between the two types of controls by stating that passive institutional controls are intended to control, allow, or disallow certain activities that would take place whether the repository existed or not. Active institutional controls are intended to control, allow, or disallow activities that are repository-specific (Trauth 1996). However, this definition ignores the marker system that is described in the regulations as a passive institutional control and that would only be in existence because of the repository. The PTF may want to consider providing examples of both active institutional controls and passive institutional controls to delineate the distinction between the two for performance assessments.

4.1.3. Future States Assumptions

Because EPA wished to minimize the potentially endless speculation about the future states that passive institutional controls must serve, 40 CFR Part 194 requires the developers of passive institutional controls to assume that the "characteristics of the future remain what they are at the time the compliance application is prepared" with the exception of hydrogeologic, geologic, and climactic conditions (40 CFR Part 194.25(a)). Although the regulations say nothing more about future state assumptions, EPA states that there are:

> . . . certain societal 'common denominators' . . . that could be considered in the discussion of [passive institutional controls]. These common denominators are patterns of human behavior that may be detected throughout history and around the world (CAG, p. 61).

The EPA lists the following as examples of these societal common denominators:

- Existence of some form of government and some level of regulatory control over the exploration for and development of resources.
- Ability of pictures to convey meaning.
- Curiosity of humans.
- Expectation that some people will avoid, ignore, or be ignorant of governmental controls.
- Use of the written word to transmit information and concepts.
- Storytelling or the generational 'passing down' of history (CAG, p. 61).

EPA describes this list as not comprehensive and expects DOE to "establish a framework of assumptions for [passive institutional controls] that is a prudent extrapolation of the future state assumptions" (CAG, p. 60). Thus, the regulations and accompanying guidance grant DOE almost complete freedom to develop future state assumptions for the development of passive institutional controls as long as it can "demonstrate—based on the particular measures at issue and documented, reasoned justification—why any assumptions made in these circumstances are sound" (CAG, p. 60).

The peer review panel believes that the PTF has interpreted this requirement correctly. The PTF's execution of the interpretation is evaluated in Section 4.2 of this report.

4.1.4. Expert Judgment and Peer Review

The use of expert judgment, either by an individual expert or a panel of experts, is permissible under 40 CFR Part 194.26(a) to support the information in the CCA if that information cannot reasonably be obtained through data collection or experimentation. The preamble to the rule includes the statement that one of the situations in which expert judgment is typically used is to elicit "essentially unknowable information, such as which features should be incorporated into passive institutional controls that will deter human intrusion into the repository" (61 Federal Register [FR] 5224, 5228). Although the preamble language specifically describes passive institutional controls as a prime subject for the use of expert judgment, and states that "DOE's proposed reduction in the likelihood of human intrusion due to [passive institutional controls] would probably be conducted through an expert judgment process" (61 FR 5224,

5232), the actual regulation is silent on the role of expert judgment in the development and assessment of passive institutional controls. Indeed, the rule does not even require that expert judgment be used to support the CCA when information cannot be supported through data collection and experimentation; it simply says that expert judgment "may" be used in those instances (40 CFR Part 194.26(a)).

Part 194.27(a)(1) of 40 CFR requires conceptual models selected and developed by the DOE to be peer reviewed. The rule does not define conceptual models.

The conceptual design principles presented in the *Conceptual Design Report* seem to rely heavily on the results of the expert judgment process described in Trauth et al. (1992). However, the future state assumptions relied upon in the *PICs Efficacy Report* either are based on the examples cited in the CAG or are attributed to the PTF.

Since the regulations do not clearly define passive institutional controls as a conceptual model, thereby requiring neither peer review nor expert judgment, the process of developing and assessing passive institutional controls is essentially unregulated (although it is guided by the regulations). The PTF and preparers of the *Conceptual Design Report* have somewhat blurred the line between reliance on expert judgment and the peer review process by incorporating both processes; their approach is certainly not precluded by the regulations. Section 1.4 of the *PICs Efficacy Report* does describe the four-step process used to develop and assess passive institutional controls, but the reasoning behind the process is not explained (pp. 1-7 to 1-8). The regulations do not require such an explanation, but the documents may be strengthened if an explanation is included.

4.1.5. Credit for Passive Institutional Controls

DOE may receive credit, in the form of reduced likelihood of human intrusion, for its passive institutional controls if it demonstrates that credit is warranted because the controls are expected to endure, and be understood by potential intruders, for the time period approved by EPA (40 CFR Part 194.43(c)). The regulation states that the credit shall not be extended to more than several hundred years, although the preamble to the rule states that credit can be given for up to 700 years (61 FR 5224, 5231).

EPA states that DOE's expectation that passive institutional controls will endure is "likely to require a deterministic analysis, based on scientific data, that takes into account" future state assumptions based upon societal common denominators (CAG, p. 60). EPA expects that the second aspect of the effectiveness determination for passive institutional controls (i.e., that they be understood by potential intruders) will "require qualitative analysis and discussion" (CAG, p. 60).

Part 191.13(b) of 40 CFR clarifies that a "reasonable expectation" of assurance with the containment requirements is called for in the performance assessments rather than "complete assurance" because of the "substantial uncertainties in projecting disposal system performance." Therefore, although the use of passive institutional controls at WIPP is required to ensure compliance with disposal requirements (e.g., 40 CFR Part 191.14), proof of that assurance need not be asserted with complete certainty. The PTF assumes that the "reasonable expectation" requirement of 40 CFR Part 191.13(b) also applies to the estimation of the effectiveness of passive institutional controls and that "absolute proof of the longevity of a marker, a records system, or a message is neither achievable nor required to take credit for passive institutional controls in the [performance assessment] calculations" *(PICs Efficacy Report*, pp. 2-5 to 2-6). This assumption is in accordance with the regulations and the CAG.

4.1.6. "Practicability" Considerations

The PTF states that the conceptual design for passive institutional controls "requires the consideration of what is 'practicable'" *(PICs Efficacy Report*, p. 5-1). The *Conceptual Design Report* relies on a practicability evaluation of the three marker design options to select the preferred option. 40 CFR Parts 191.14(c) and 194.43 incorporate practicability considerations but do not include a definition. The PTF's interpretation of, and reliance upon, practicability of passive institutional controls is appropriate.

4.1.7. Deterring Inadvertent Human Intrusion into the Area of Concern for Drilling

The peer review panel believes that the PTF accurately interprets the nature of inadvertent human intrusion that must be protected against. It defines the area of concern for this intrusion as the repository and the Withdrawal *(PICs Efficacy Report*, p. 2-7). The regulations in 40 CFR Parts 194.32 and 194.33 require that the effects of inadvertent drilling and mining on the "disposal system" be considered, but do not define the disposal system precisely as the repository footprint or the Withdrawal. Part 143.43(a)(1) of 40 CFR does require "identification of the controlled area by markers" and 40 CFR Part 191.12 defines the controlled area and describes it in relation to the accessible environment.

Although the regulations are silent on the definition of the disposal system, the preamble to 40 CFR Part 194 does reference the effects of mining in the "Land Withdrawal Area" (61 FR 5224, 5233). The peer review panel believes that, in assuming the areas of concern to be addressed by the passive institutional controls are the footprint and the Withdrawal, the PTF is reasonable but the execution of the assumption is incomplete. While the use of markers to delineate the footprint and the Withdrawal is acceptable, the peer review panel believes that technological advances (e.g., horizontal drilling) make it imperative that

the land outside the Withdrawal be considered in the development of passive institutional controls. Information stored in records centers and archives should also contain warnings relating to activities in the land beyond the Withdrawal.

4.2. General Technical Assumptions

The following discussion examines the assumptions used by the PTF to estimate the effectiveness of passive institutional controls in deterring future inadvertent human intrusions. The accuracy of these assumptions and the completeness of the set is critical in assessing the passive institutional controls. If the assumptions are incorrect or incomplete, the conclusions drawn from them will be invalid.

In general, the peer review panel found that the assumptions were correct but poorly supported in the document or by reference to other material. The panel felt that this section needed a great deal of "beefing up" to withstand challenge. (It should be noted that, in the comments that follow, Trauth et al. [1992] is referenced a number of times. Many of the assertions in Trauth et al. were based on other literature and information supplied to the expert panelists and the PTF. These resources are referenced in Section 9. Except where noted, this peer review report assumes that the way in which Trauth et al. used the supporting resources is appropriate.)

4.2.1. Assessment of Individual Assumptions

The following material reviews (in sequence) the subsections of Section 3, Assumptions Used in Estimating the Effectiveness of PICs in Deterring Future Inadvertent Human Intrusions (*PICs Efficacy Report* [pp. 3-1 to 3-7]).

Section 3.0 (Untitled introductory material)

The language of this section is unclear and its logical progression confusing. However, the peer review panel believes that the argument presented is as follows:

- There is no accepted methodology to make accurate long-term predictions of the future of mankind.
- DOE shall assume that all present-day conditions, with the exception of geologic, hydrologic, and climatic, will remain as they are today.
- The assumption that all present-day societal and demographic factors will remain constant is unacceptable.

The logical conclusion that the panel can draw from this is that the "conditions" referred to in the second bullet do not refer to present-day societal and demographic factors. The PTF concluded that those "conditions" referred to certain "societal 'common denominators'" or "patterns of human behavior that may be detected throughout history and around the world." This appears to be a reasonable conclusion based on the regulatory guidelines.

There now are six subsections to Section 3 of the *PICs Efficacy Report:* 3.1, Basic Human Attributes, 3.2, Government, 3.3, Language, 3.4, Natural Resources, 3.5, Estimating Passive Institutional Controls Effectiveness, and a Summary. If the purpose of Section 3 is to enumerate the assumptions defining these "societal common denominators," the peer review panel suggests the following structure:

- Basic Human Attributes
  - General
  - Society and Culture (Government)
  - Communications (Language)
- Natural Resources
- Summary

Many of the assumptions currently listed under Section 3.5, Estimating Passive Institutional Controls Effectiveness, actually are assumptions about human attributes. There are some basic assumptions about the human species that have been omitted entirely from the list; these could be included in a "General" section. The assumptions under Section 3.2, Government, are actually assumptions about the maintenance of social order. Government is but one institution or social mechanism for such maintenance. Section 3.3, Language, deals only with a small subsection of the communications process. For the sake of completeness, it should delineate broader assumptions about the process.

Section 3.1 Basic Human Attributes

Assumption 1: Curiosity of humans [will continue]. Although this is supported by the PTF through a simple reference to the CAG, the peer review panel could make a strong argument for this as a biological trait of the species and therefore one unlikely to change over the compliance period.

Assumption 2: The use of the written word to transmit information and concepts [will continue]. This assumption is supported only by reference to the CAG. The PTF may want to note that Trauth et al. (1992) (e.g., p. F-44) also supports this statement.

Assumption 3: Storytelling or the generational "passing down" of history [will continue]. This teaching/learning of abstract information is one of the distinguishing characteristics of culture and of

human beings. This assumption is a much more important part of this foundation of assumptions than is presented here. It needs to be supported in the document and not simply presented as an article of faith.

Assumption 4: The ability of pictures to convey meaning [will continue]. This also is strongly supported by Trauth et al. (1992) (e.g., pp. F-42ff) and should be indicated here.

Assumption 5: Some people will avoid, ignore, or be ignorant of government controls. This assumption actually incorporates two different types of assumptions that should be stated separately. To "avoid" or "ignore" governmental controls is a function of the psychological makeup of individuals and needs to be supported by reference to literature on rebellion and psychological dysfunctioning. To "be ignorant" of government controls is a function of the dissemination of information throughout a society. In large societies, this dissemination tends to be uneven: in small societies, information of this type is more likely to be known by all members. This assumption seems to state that the PTF assumes that the societies in place during the regulatory period will be large enough to promote uneven dissemination of certain types of information.

Assumption 6: Individuals will continue to look out for their own self-interests. This has been a statement of strong debate within the social science community (generally in the rhetoric of sociobiology) over many decades, and this debate has been expressed within the philosophical community for millennia. The PTF must be sure that it can, and is willing to, support this position.

Section 3.2 Government

Assumption 7: The existence of some form of government [is assumed]. This assumption would follow from the general species characteristic of sociability outlined at the beginning of this section. The PTF should be clear on what it means by "government," since this could easily be questioned. This definition also is important because the PTF considers "the government" to be the controlling institution for the archives and records, as well as other portions of the passive institutional controls. It also should be noted that the last sentence of the supporting language for this assumption could be seen as contradictory to Assumption 6 (i.e., "The 'individual' or 'group' in control makes decisions either for its own benefit or the benefit of the association" [emphasis added]). Can the governor (either group or individual) be altruistic?

Assumption 8: [Government will exert] some level of regulatory control. It is unclear how this adds to Assumption 7. This leads the peer review panel to ask again if the PTF can clearly define what it means by government. This is important to the effectiveness of passive institutional controls because it does

assume a supra-individual agent that might force the individual to act in a fashion that might appear to be counter to his or her self-interest. The definition of government and the way the government exerts its authority also depend heavily on assumptions about the nature of man. The PTF should be aware that there is literature and a scholarly tradition stretching back to the classical Greeks that address this question. It is a crucial question that underlies much of the philosophy and theory of our own governmental structures and actions.

Assumption 9: Governments will require and maintain records as part of the procedure to maintain controls. The peer review panel assumes that the PTF does not necessarily mean some kind of recording (which assumes a permanent means of marking), but rather the preservation of information that could also be accomplished through oral means. Also, this assumption builds on Assumptions 3, 7, and 8 and so may be termed a second-order assumption.

Assumption 10: Governments will continue to protect property rights. The PTF should document the assertions contained in the language supporting this assumption with reference to current and historic forms of governments that perform this function. This assumption could be more broadly stated as "society will continue to protect property rights" and government is one social mechanism that may perform that function. (This also depends upon how one defines "government.") The peer review panel also notes that, as with Assumption 9, this assumption builds on others given here (i.e., Assumptions 5, 6, 7, 8, and perhaps 9) and so may be termed a second-order assumption.

Section 3.3 Language

Assumption 11: Current English will continue to increase in the size of its vocabulary and the areas of use, but the basic vocabulary and structure will resist change. While this statement may be intuitively obvious, it should be supported by reference to scholarly work on linguistic evolution and change. This is particularly true of the second part of the sentence (the basic vocabulary and structure will resist change). Historical linguistics should be able to provide some evidence of probable rate of change. This would provide a basis for what are now unsupported statements in the document, such as the statement found in the *Conceptual Design Report* (p. 27) where the PTF states that "with the advent of printing and more recently the advancement of worldwide communication the rate of change of language has probably slowed considerably."

Assumption 12: Current English will remain decipherable by future generations of English readers for at least 1,000 years after disposal. This assumption is supported in the text by some references.

Additional references to the sections of Trauth et al. (1992) that discuss this issue would strengthen the argument.

Assumption 13: English will continue to be read by the natural-resources exploration and exploitation industries. This should be supported by reference to Trauth et al. (1992).

Section 3.4 Natural Resources

Assumption 14: Resource exploration and extraction will be conducted using drilling technology that is basically the same as today's. This assumption states that resource exploration and extraction technology will be essentially equivalent to that in current practice. Assumption 14 is clearly based on 40 CFR Part 194.33(c)(1) and is entirely consistent with this and other relevant regulations. DOE interprets Assumption 14 as conservative since a more developed technological society would also have better means of detecting the repository and radioactivity and would be less likely to inadvertently drill into the repository. A less-developed technological society would be less likely to have the means to drill into the repository.

It seems somewhat facetious to argue that the present represents a unique moment in history in which drilling rates are maximal. Analysis of drilling records contained in commercial oil and gas databases show that oil wells were drilled in the United States to below the proposed repository depth during the early decades of this century. This activity took place before methods for measuring gravity in oil were developed, such as the pendulum and the modern gravimeter that originated in the 1930s. Ground-based instruments to measure the magnetic field of rocks were introduced for mineral exploration in the 1920s and were used occasionally for oil exploration. For example, the Hobbs Field in Lea County, New Mexico, was discovered in 1927 based, in part, upon a magnetic survey of the area (Dobrin 1960, p. 318). Seismic reflection and refraction methods also originated largely in the late 1920s and early 1930s. These activities show that it was certainly technically possible to drill to repository depths although none of the standard exploration techniques of gravity, magnetic, and seismic reflection existed. Moreover, the regulatory environment in states like New Mexico or Texas at the beginning of the century exerted very little control over oil exploration and drilling. Prior to regulatory control, it was not uncommon for competing drillers to complete wells at a spatial density many times higher than is allowed under current regulations. This suggests that markers designed to be detected by geophysical methods may have less than a 1.0 probability of detection.

Assumption 15: Because of the uncertainties associated with predicting future natural resources, the historical drilling rates for oil and gas in the Delaware Basin are to be used in the PA as surrogates for future drilling rates for these unknown resources. The peer review panel believes this is a reasonable assumption, given that it is impossible to predict drilling practices for as yet unknown resources. The *PICs Efficacy Report* has adopted this assumption, which is entirely consistent with 40 CFR Part 194.33.

Assumption 16: There will always be natural resources of value within the Delaware Basin that will attract future exploration and support exploitation efforts. The *PICs Efficacy Report* adopts this assumption that is reasonable and consistent with 40 CFR Part 194.33.

Assumption 17: There will be virtually continuous natural-resource exploration and exploitation activities in the Delaware Basin during the entire regulatory time period. The *PICs Efficacy Report* correctly follows this assumption since drilling rates and densities are assumed to be constant over the regulatory period. While there might be some justification for arguing that exploitation of petroleum resources will diminish over the next several hundred years, the assumption of constant exploitation at current rates is consistent with 40 CFR Part 194.33 and is probably conservative.

Assumption 18: Resource exploration and exploitation is not a casual activity. This assumption is not required by 40 CFR Part 194, but is a logical assumption. The *PICs Efficacy Report* states that this assumption implies that those entities active in exploration and exploitation of natural resources will make an effort to access records. This follows logically and should enhance the performance of the records centers in preventing inadvertent intrusion.

Section 3.5 Estimating Passive Institutional Controls Effectiveness

Assumption 19: The determination of intrusion as inadvertent or intentional is not based solely on the actions of an individual but is also based on the actions of government in carrying out its responsibilities. As it is stated here, this is an incomplete assumption in the context of this exercise. "Inadvertent intrusion" is defined in this document as "any human activity that disrupts the disposal system" (*PICs Efficacy Report*, p. 2-7). The Markers and Futures panels defined "inadvertent intrusion" as occurring when "the integrity of a repository is unintentionally compromised by the activities of humans . . . " (e.g., Hora et al. 1991, p. I-1). The actions of a government may contribute to the lack of knowledge that would lead to such unintentional compromise, but such actions are only one among what may be many contributory factors. Therefore, to single out the government is correct, but incomplete. The panel believes that the discussion should include the possibility of other social institutions

performing the records maintenance, education, or other activities related to the prevention of inadvertent intrusion.

Assumption 20: Communicating with future societies using words, pictographs, symbols, and diagrams through a variety of media is possible. This assumption may be concluded from the work of the futures and Markers panels. It also may be deduced from an assumption regarding the unchanging biological nature of Homo sapiens over the compliance period and the continuing, associated ability of the species to engage in symbolic behavior. This assumption also embodies other assumptions about the ways in which Homo sapiens will internalize information from the physical environment (e.g., visually).

Assumption 21: Historical analogs of structures, media, and messages that have withstood the test of time allow the DOE to design for success. The Markers panel report spends a great deal of time discussing historical analogs. Both teams note that, while structures and media exist that have lasted for a time equal to approximately half the compliance period (about 5,000 years), we are less sure of the messages the artifacts were intended to convey (e.g., what is Stonehenge trying to tell us?). Therefore, while DOE probably can design structures and use media that will last for the compliance period, the evidence is not nearly as strong that it can develop messages that will continue to be comprehensible.

Assumption 22: Today's scientific and engineering communities have the capability to create PICs that will perform at least as effectively as historical analogs. While this is intuitively true, it should be supported with a statement or two about our enhanced knowledge of materials, structural design, and the like, instead of being presented as a statement of faith.

4.2.2. Completeness and Adequacy of Assumptions

This section discusses three aspects of "completeness." It begins with assumptions that are implicit in the list above, but that the peer review panel suggests be made explicit to ensure sufficiency of the assumption set. It then discusses two process models that underlie much of the work of the PTF and that the peer review panel believes should be made explicit to facilitate understanding and to explain the PTF's position on certain issues. Finally, the discussion addresses assumptions made by the expert panels that are incorporated into the PTF's work, but that are not made explicit.

Underlying the first three subsections of Section 3 (3.1, Basic Human Attributes, 3.2, Government, and 3.3, Language) are assumptions related to human evolution and associated human biological and social/cultural capabilities that are not made explicit. While these assumptions do not contradict or undermine the assumptions or the conclusions presented in this report (in fact they strengthen them), it is

necessary to state them because they underlie and support the assumptions presented in the document. Several assumptions that could be included in the PTF report to support their existing assumptions are described below.

Punctuated equilibrium is a theory of evolutionary development that postulates long periods of very slow change interrupted by short bursts of very rapid change. If one assumes an evolutionary paradigm of punctuated equilibrium and looks at the history and rate of change of human evolution, it would be reasonable to assume that Homo sapiens will exist over the entire compliance period of 10,000 years unless that period happened to include one of the major step changes that a punctuated equilibrium process includes. This is important for the following reasons:

- This assumes no significant major change in cranial capacity and associated cognitive capabilities, including information acquisition and processing.
- The ability to "symbol," one of the distinguishing features of Homo sapiens and a feature that underlies language and therefore much of culture, will continue.
- The social nature of the species will continue, leading to the conclusion that there will be some form of governance of the group as is the case for all social animals.
- Physical features that allow for the development of material culture, such as bipedal, upright locomotion and the opposable thumb, will continue to be displayed and will not change significantly.

In a related area, the peer review panel interprets the assumptions pertaining to the section on government as referring in a broader sense to "society," with government being one social institution by which the social control activities could be carried out. This allows non-secular institutions of social control, such as religion and other similar control institutions (e.g., kinship networks), to be introduced. This would have implications for continuity should there be profound social change in the society managing or controlling the site, archives, and/or records centers. Finally, the peer review panel believes that the section on language could be broadened to encompass "communication." This would allow for the inclusion of assumptions related to icons, indices, archetypes, and means of communication other than language upon which the success of the passive institutional controls might rely.

In its work, the PTF assumed but did not delineate some model of the communication process, either as an individual event or as a social activity. *Fundamentally, passive institutional controls are communication vehicles.* Therefore, inclusion of such a model is very important because it would demonstrate the relationship between data and information (i.e., data that has been "turned into" something meaningful), and between the existence of information and the way in which that information

is internalized to prevent intrusion. This relates to the understandability dimension, as distinct from the endurability component, of the passive institutional controls.

The communications process, shown in Figure 4.2.2-1, is usually diagrammed as follows:

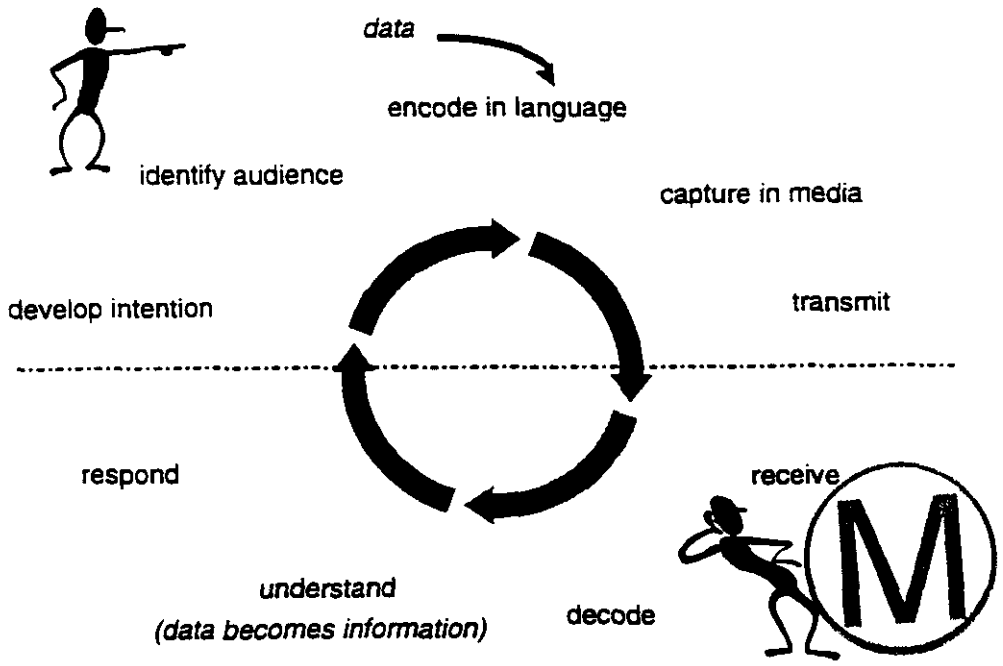

Figure 4.2.2-1. Standard communication model

This model is important because it can delineate some assumptions about the scope of the passive institutional controls. For example, will the effectiveness of the passive institutional controls be based on how well the data is captured in various media? (Some of the arguments advanced by EEG against potential effectiveness have to do with incorrect capture of data [Silva and Channell 1992].) Will the effectiveness of passive institutional controls be based upon whether the message is (a) received by an initial receiver or (b) received, correctly decoded, understood, and retransmitted (as might happen if there were more than one agency or institutional structure involved in the process)? Incorporation of a communication model could better demonstrate where and how passive institutional controls might fail.

The second process model, shown in Figure 4.2.2-2, is related. It describes the activities the PTF believes will occur for inadvertent intrusion to take place. It also describes the passive institutional controls associated with each activity that are designed to forestall such intrusion. The peer review panel developed this model from its readings and from information elicited from members of the PTF.

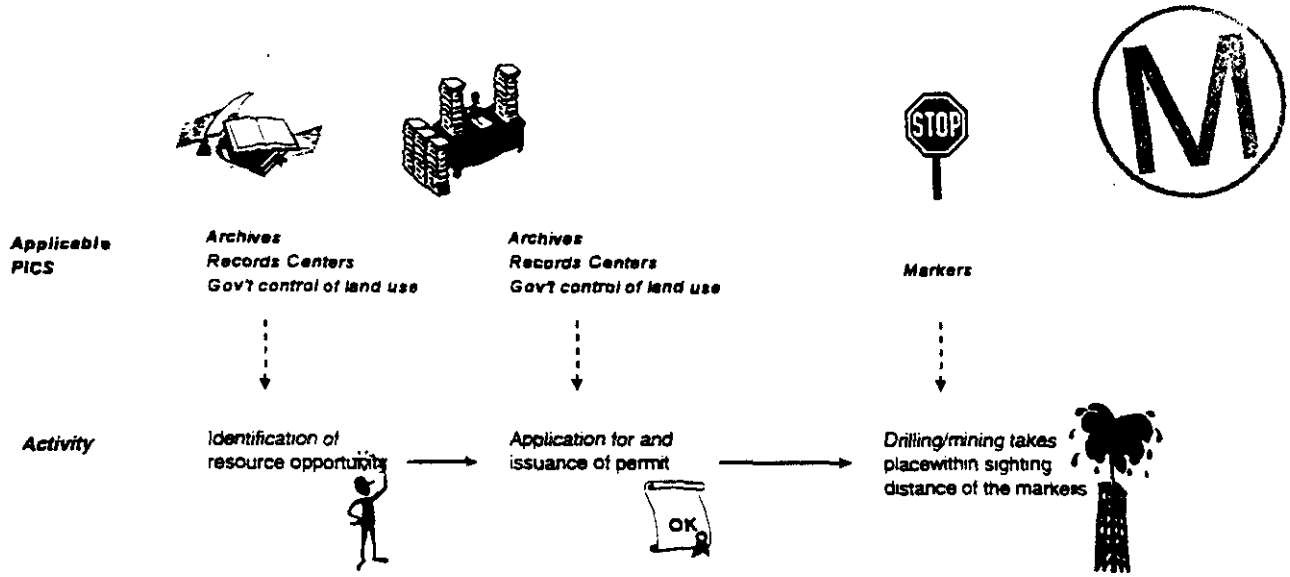

Figure 4.2.2-2. Model used by PTF as interpreted by the peer review panel

Figure 4.2.2-2 illustrates the association of specific passive institutional controls with different activities leading up to a possible inadvertent intrusion event. It should be noted that this model assumes that any inadvertent intrusion activity must encounter the markers and at least one of the other passive institutional controls.

Team A of the PTF spent a great deal of time discussing archetypes and their importance in fulfilling the requirements of 40 CFR Part 194. This appears to underlie the design concept presented in the *Conceptual Design Report*. Therefore, the validity of archetypes should be stated as an assumption.

40 CFR Part 194.33 (b)(2) requires that drilling events be treated as random in space and time during the regulatory time frame of performance assessment. While the concept of "random" admits many interpretations, the *PICs Efficacy Report* clearly interprets this to mean that rates are uniform over the regulatory period and that drilling density is uniform in the Delaware Basin, including the Withdrawal area, with all areas having an equal probability of being drilled (e.g., *PICs Efficacy Report* Section 3-6, p. 3-7, and discussion of Assumption 17). A uniform distribution is one of many types of random distributions, but it is somewhat inconsistent with the idea of *random intervals* (40 CFR 194.33 (b)(2)). Random intervals imply non-constant intervals. An alternative interpretation would be that drilling events be treated as stochastic in space and time according to a Poisson process, which is commonly done in modeling other types of events for performance assessment calculations. This type of model also is consistent with the requirement that drilling events could occur at any time or place within the Delaware Basin with equal prior probability and constant mean density and mean rate of occurrence. The intervals in time or space are random, not constant. The difference is that in a Poisson process, only the mean rate

and density are constant. Other alternatives to uniform and Poisson processes are also possible that are consistent with the requirement in 40 CFR Part 194.33 to treat drilling events as random in space and time. In this respect, the *PICs Efficacy Report* does not adequately describe alternative models nor sufficiently defend the choice of the uniform model that has been adopted for performance assessment calculations.

4.3. Summary

The PTF interpretation of the applicable regulations is reasonable and adequate. The general technical assumptions presented by the PTF are correct but inadequately supported. References that could be used to support the assumptions are readily available; their use would make the assumptions more defensible and satisfy the requirements of the CAG. Additionally, the PTF assumptions could be further buttressed by including the assumptions stated above and by describing the conceptual communication and activity models assumed in the design concepts.

5.0 ADEQUACIES OF TECHNICAL PRESENTATION

5.1. Systems Approach

Section 4.1 of the *PICs Efficacy Report* (pp. 4-1 to 4-2) describes passive institutional controls as a system of deterrence components:

> . . . the DOE has extended the systems concept to incorporate archives, records, government land ownership and control, and other means of communication into the total PICs design (*PICs Efficacy Report*, p. 4-1).

The *PICs Efficacy Report* also makes three claims regarding this system:

1. Redundancy of individual components.
2. Sufficiency of each individual component to effectively deter inadvertent intrusion in the absence of any other component.
3. A "Gestaltic" nature, in which the system as a whole is more effective in deterring intrusion than the sum of its parts.

The *PICs Efficacy Report* states that this system contains redundancy in several forms that are described in Section 4.0 of the report (pp. 4-1 to 4-5). It is clear that the system of passive institutional controls proposed by DOE is redundant, as described in Section 4.0 of the *PICs Efficacy Report*.

The peer review panel does not believe that the *PICs Efficacy Report* adequately substantiates the second claim regarding the sufficiency of each individual component of the passive institutional controls. A system consists of individual components, credible intrusion scenarios (or a series of activities associated with the intrusions), and a relation that describes the interaction between the deterrent components and the intrusion mechanisms. The *PICs Efficacy Report* does not describe such a system. This may be due to the fact that each component is assumed to sufficiently deter any inadvertent intrusion with zero failure rate. In this case, it would be pointless to diagram system interactions and components. However, the peer review panel does believe that the model of the "system" with which the PTF is working resembles the one presented in Figure 4.2.2-2, based upon conversations with a member of the PTF, K. Trauth (Trauth 1996).

Figure 4.2.2-2 illustrates an important point. The *PICs Efficacy Report* assumes that the marker component of the passive institutional controls is the last line of deterrence for all intrusion scenarios; therefore, the markers must be 100 percent reliable if the *system* is to be 100 percent reliable. If, for

some reason, the markers are not encountered by a particular credible intrusion scenario, or the markers do not have 100 percent reliability, the system cannot have 100 percent reliability. In the former case, the convolution of the individual reliabilities (or failure rates) for the archives, record centers, and governmental controls determines the overall system effectiveness. In the latter case, the system effectiveness is equal to the marker reliability.

The peer review panel believes that there are credible intrusion scenarios and marker failure scenarios that make both of these types of system failures possible (see Section 5.3). The panel thus believes that the *PICs Efficacy Report* has not sufficiently described or defended its particular system model and that the consequences of this particular passive institutional controls system model have not been adequately calculated for determining passive institutional controls credits.

In regard to the claim in the *PICs Efficacy Report* concerning the Gestaltic nature of the passive institutional controls system, the peer review panel finds little support in the document. There are two themes recurring in the *PICs Efficacy Report* and related documents that deal with systems. One concerns redundancy as a characteristic of certain kinds of systems; the other addresses a principle of systems, i.e., that the whole conveys more than each individual part and more than the sum of the parts (this is the idea behind Gestalt). A Gestalt implies nothing about redundancy; if the whole is greater than the sum of the parts, it does not follow that each part carries the message of the whole. The expert panels cited in Trauth et al. (1992, pp. F-28, G-34) strongly recommended adoption of the principle of Gestalt. The presentations in the *PICs Efficacy Report* and the *Conceptual Design Report* adopt the redundancy characteristic but do not adequately describe or defend the Gestaltic nature of the proposed system of passive institutional controls, despite the recommendations of expert panels.

5.2. Individual Components of the System

5.2.1. General Considerations

The regulations in 40 CFR Part 194 identify four different types of passive institutional controls: markers, records/archives, government ownership or control over land, and "other." By far, the bulk of the effort has focused on markers. There appears to have been little work invested in the last three types of passive institutional controls; no rationale has been given for the uneven effort. The PTF noted (in verbal communication with the peer review panel) that, since there is a large body of existing research and literature on archives and records, the PTF did not feel it necessary to create new information as it did with the Markers panels (Peer Review Panel Meeting, June 7, 1996). However, that literature is not

referenced in either of the two documents under review. Furthermore, the work cited by the PTF appears to have primarily addressed the Vatican archives, a repository maintained not by a government but by a religious institution (Peer Review Panel Meeting, June 7, 1996). While this does not negate its value for this project, none of the assumptions refer to any social institutions other than "government." It could be argued that religious institutions do constitute a form of government; however, the peer review panel can only assume that the PTF is referring to secular institutions of state government (where state refers to any political entity and could include a nation, a city, or some other secular jurisdiction), unless some definition of "government" is provided to allow the panel to assume otherwise. Therefore, for the PTF to make a legitimate extrapolation from the Vatican to secular government, some assumptions must be stated about the relationship between secular and religious institutions and their mechanisms of control over repositories such as those in question.

In the *PICs Efficacy Report*, the PTF states "the DOE has maintained the design considerations of the Markers panel recommendations while modifying the specific recommended designs in order to be practicable" (p. 5-1). The peer review panel emphasizes that the recommendations of the Markers panel were directed toward a markers system only, not to the other passive institutional controls identified in 40 CFR Part 191. How the design considerations were extended to the records and archives systems and to the government land-use controls is unclear in the documents under review.

The absence of a formal communication model leads to some questions about the scope of the passive institutional controls and the way the various elements of the system interact. Will the effectiveness of the passive institutional controls be based upon how well the data are captured in various media? (Some of the arguments advanced by EEG against potential effectiveness in EEG-50 have to do with incorrect capture of data [Silva and Channell 1992]). Will the effectiveness of passive institutional controls be based upon whether the message is received by an initial receiver, or received, correctly decoded, understood, and retransmitted (as might happen if there were more than one agency or institutional structure involved in the process)?

The *PICs Efficacy Report* states that the markers and records components are expected to survive with a probability of 1.0. The evidence presented for this probability is based on both historical analogs and an understanding of factors/processes that might degrade the markers or records over time. The panel believes that historical analog survival data must be used with care for the following reasons:

- We only have records about historical analogs that have survived. Analogs that did not survive are not observable. Thus, the survival of ancient analogs demonstrates that such man-

made structures can survive, but do not necessarily form the basis for calculating a failure rate.

- Processes that could have led to the destruction of the historical analogs in current-day society differ from the processes over the past 800 years. For example, the nose of the Sphinx survived for millennia until it was used for target practice. The ancient peoples in Egypt could not have vandalized the Sphinx as effectively. Thus, the survivability of some of the ancient analogs might have been reduced if present-day conditions had prevailed since their creation.

These potential pitfalls in using historical analogs to estimate failure probabilities for markers, records, etc., suggest that there should be some uncertainty associated with the durability/survivability of the passive institutional controls components. At the least, some evidence should be presented to show that the uncertainty is effectively 0.0.

5.2.2. Markers

Permanent markers consist of five distinct components: the berm, surface monuments, the information center, buried storage rooms, and small buried markers. The criteria used to conceptually design each of these components is described in the *PICs Efficacy Report* and the *Conceptual Design Report*. 40 CFR Part 194.43 requires DOE to demonstrate that there is a reasonable expectation that these markers will endure for the several-hundred-year period following repository closure in order to receive credit for performance assessment. As different materials and designs are envisioned in the *PICs Efficacy Report* for the five marker components, each is evaluated separately.

5.2.2.1. Durability

Berms

Trauth et al. (1992) have considered several issues in creating a berm surrounding the disposal area footprint. The berm would be based upon sound engineering considerations. These are summarized in Section III of the *Conceptual Design Report*. The PTF has considered three classes of failure mechanisms: erosion, burial by dunes, and deliberate removal through vandalism or mining. These mechanisms seem to be the only plausible means by which the berms could be threatened during the regulatory period. The peer review panel finds that the design solutions suggested in the *Conceptual Design Report* and the *PICs Efficacy Report* (Section 5.2.1.5, p. 5-6) provide reasonable assurance that these potential failure mechanisms can be mitigated. The panel believes that there is a very high probability that the berms, as described, will survive throughout the 700-year period following closure. The panel concludes that it is reasonable to use a failure probability with regard to durability of 0.0, but

that the failure probability should have some very low value of uncertainty. However, Section 6.2 of the *PICs Efficacy Report* (p. 6-9) states "the PTF has taken no credit for these components in the effectiveness estimates" for determining credits for passive institutional controls, so the credit issue may be moot.

Surface Monuments And Information Room

The choice of materials and the design of the surface monuments and the information room are described in Sections 5.2.2 and 5.2.3 of the *PICs Efficacy Report* (pp. 5-6 to 5-14). Six potential failure mechanisms have been considered. The PTF has addressed each of these potential failure mechanisms from the standpoints of durability and survivability. The peer review panel believes that the choice of granite is well-founded from a historical perspective, from the standpoint of practicality, and from evidence that granite will provide a very durable material due to its physical and chemical properties. The physical and chemical basis for assuming that granite will resist weathering more than 700 years is well described in Trauth et al. (1992), Appendix G. The panel concludes that weathering and erosion are unlikely to cause the failure of the marker system and that a mean failure rate of 0.0 with small uncertainty is justifiable for performance assessment credit calculations.

The panel also concurs that the failure rate due to dune burial, museum removal, and recycling has been successfully mitigated by various features in the conceptual design, and could reasonably be expected to have a very low (perhaps 0.0) failure rate with low uncertainty.

Of the other possible failure mechanisms, the panel believes that defacement through vandalism, souvenir hunting, and destruction poses the greatest threat, and that the failure rate of 0.0 for these scenarios has not been justified.

Section 5.2.2.6 of the *PICs Efficacy Report* does not discuss situations in which massive destruction of structures has occurred (pp. 5-9 to 1-10). For example, many structures with far more durable materials, size, government control, etc., have been obliterated by bombing campaigns during times of war or during weapons testing. Various military targets exist in the vicinity of WIPP; it is possible that the surface marker facilities could suffer collateral or intentional damage. Vandals in urban areas of the United States have destroyed or defaced entire buildings. Moreover, souvenir hunters have dismantled and carted off paintings and pieces of many ancient buildings throughout the world, in spite of active governmental controls specifically put in place to prevent this type of vandalism. The report has failed to adequately address the extent of damage that historical or present-day vandalism has wrought upon

markers, monuments, and surface structures. As a consequence, the panel believes that a failure rate of near 0.0 has not been justified by evidence presented in the *PICs Efficacy Report* or in the *Conceptual Design* Report for either surface markers or the information center.

Buried Storage Rooms

The two buried storage rooms will be constructed of granite. In general, the durability issues and conclusions germane to the surface markers and information center pertain to the subsurface rooms, with a few modifications. First, surface weathering, erosion, and dune migration are of less consequence since the potential for surface processes is reduced, even if the buried rooms are partially uncovered at some future date. Likewise, defacement due to vandalism, souvenir hunting, or war-related damage is probably reduced since burial offers additional protection from these failure mechanisms. As in the case of the surface components, these buried components may still face non-zero failure rates due to war, vandalism, or souvenir hunting. The panel does not believe that a 0.0 failure rate for the buried rooms has been justified in the reports under consideration.

Small Buried Markers

The small buried markers consist of slabs that are approximately 1 foot (ft) in dimension. They are to be buried randomly at depths ranging from 2 to 6 ft and spaced so that the markers will be within 15 to 40 ft of one another. They are to be made of granite, aluminum oxide (sapphire), or fired clay (*PICs Efficacy Report*, Section 5.2.5.1, p. 5-19). The primary purpose of these markers is for them to be encountered during the preparation of a site for drilling operations. The *PICs Efficacy Report* cites four possible failure mechanisms: weathering, previous excavation, museum removal, and recycling removal (Section 5.2.5.6, p. 5-20).

In Trauth et al. (1992, pp. F105-F107), Team A presents reasonable evidence that these materials have survived and should survive for periods longer than the regulatory time frame in the face of weathering or erosion. The panel also believes that the design solutions described in Section 5.2.5.6 of the *PICs Efficacy Report* can ensure that at least some of the buried markers survive throughout the regulatory period (p. 5-20). However, if some of the markers are removed for recycling or other purposes, and nothing is put in their place, then the 100 percent detectability during a standard drill pad preparation operation would be reduced since there may be "holes" left that are now large enough to accommodate the drilling operation. The *PICs Efficacy Report* should address how gaps left by marker removal will affect the probability that a small buried marker will be encountered during an inadvertent drilling operation.

5.2.2.2. Comprehension

Design and Comprehension

The PTF provides a reasonable discussion of the way in which the components of the markers system are expected to interact to convey a comprehensible message. The peer review panel believes that the assumptions outlined in Section 3.0 of the *PICs Efficacy Report* (pp. 3-1 to 3-7) and the historical analogs provided in Section 5.0 (pp. 5-1 to 5-32) would reasonably indicate that there is a high probability the messages will be comprehensible over the approximately 700 years of the compliance period. The panel believes that the PTF has legitimately demonstrated how it will address the various aspects of the communication model present in Figure 4.2.2-1 of this report. However, the peer review panel also believes that there is some significant, albeit low, level of uncertainty that should be assigned to this probability (i.e., uncertainty is not 0.0) due to the reasons discussed below.

Team A provided its marker system as an example of the way the concepts and principles it recommended could be put into operation. It did not provide a specific recommendation for a particular design, but rather a set of design guidelines (Trauth et al. 1992, p. F-49ff), suggesting that there are many possible ways these guidelines could be put into operation. This put a burden on the PTF to demonstrate how the design it developed addressed the performance-based guidelines. While the *Conceptual Design Report* did include most of these guidelines in its design criteria, it missed a few important ones (e.g., that the center should be a non-place and that regular, geometric forms are to be avoided). Furthermore, the *Conceptual Design Report* used the example of the system presented by Team A to illustrate its principles as the design put forward by Team A. The peer review panel believes this impoverishes the work presented by Team A by reducing its principles to a recommended design; uses its example design inappropriately; and does not recognize the uncertainty associated with the selection of this one possible example from the many possible examples Team A could have used.

Team A "recommends the use of vertical masonry markers, if their form feels dangerous, more like jagged teeth and thorns than ideals embodied" (Trauth et al. 1992, p. F-41). This also is reinforced later in the document when it is stated that "Design of the entire site and its subelements should *avoid those forms* that humans regularly tend to use to represent the 'ideal,' 'perfection,' or 'aspiration.' Ideal and perfect ones are the perfect forms of symmetrical geometry and of regular crystalline structures" (Trauth et al. 1992, p. F-52, emphasis in original). Team A reiterates this theme when it says to "Note our use of *irregular geometries and the denial of craftsmanship*" (Trauth et al. 1992, p. F-59, emphasis in original). Team A also strongly recommends an empty center, noting that "making a center . . . is the first act of

marking order (Cosmos) out of undifferentiation (Chaos). All further meanings of 'center' derive from this original positive valence . . . . In this project, we want to invert this symbolic meaning . . . we suggest that the largest portion of the Keep, its center, be left *open* . . . so that symbolically it is: uninhabited, shunned, a void, a hole, a non-place" (Trauth et al. 1992, p. F-52, emphasis in original).

Team B proposed a more geometrically regular design, including a focused center, but did not give the same level of defense of such regularity as Team A did of its counterproposal. The design developed in the *Conceptual Design Report* adopts the principle of regularity and of a strong center, but does not give a rationale for adopting this course rather than the other. Again, this suggests the possibility of alternatives to the design the PTF is proposing and introduces uncertainty.

Both expert panels that addressed developing a marker system emphasized the Gestalt/systems or "whole" nature of the markers as a communication vehicle. Team A suggested that "our medium of communication is the entire environment experienced near and at the WIPP site" (Trauth et al. 1992, p. F-28). Team B suggested that ". . . the probabilities and performance characteristics proposed above for the individual markers would be greatly enhanced by their inclusion within a larger, well-integrated marking system" (Trauth et al. 1992, p. G-34). The peer review panel does not see evidence that the PTF incorporated this principle of systems into its proposed design (see Section 5.2.1 for further discussion).

Human error and variability among individuals must not be ignored. While curiosity is indeed a species characteristic (Assumption 1), this statement is a relative one (Homo sapiens exhibits more curiosity than other species) and some individuals are more curious than others. It is possible that the individuals assigned to visit a field site for a drilling/mining activity may encounter the markers but may not be motivated enough to investigate (see Trauth 1993, p. F-139ff). A more detailed psychosocial profile of the species may indicate the uncertainty that needs to be associated with this. The possibility of human error either in encoding or decoding the message is illustrated in the *Conceptual Design Report*, which gives sample text for the messages on the monuments. The text states that "The waste is buried 655 kilometers deep" (p. 123). While the probabilities of such error may be small, they do exist. Both these points (i.e., the variability of curiosity level between species members and human error) introduce uncertainty into the calculation.

Communication Vehicles

Both Markers panels suggested that the development and adoption of an international symbol to identify the sites is a critical part of making a markers system effective (Trauth et al. 1992, pp. F-25, G-46).

There is no effort to do this in DOE's proposed conceptual design for passive institutional controls. In fact, the *Conceptual Design Report* simply says "No international standards exist. If, in the future, standards are developed and adopted by the United States, they will be evaluated for incorporation as appropriate in preparing the final permanent marker design" (p.17). Since both teams felt that such an international standard is a very important part of the effectiveness of the markers system, the peer review panel believes that the conceptual design should include a proposal to develop such a standard, especially since the absence of such a standard will increase the uncertainty associated with any design.

Both Markers panels suggest using the languages of the United Nations as the languages of inscription. The peer review panel believes that the United Nations languages were chosen by the United Nations founders for political reasons, not for reasons germane to a long-lived markers system. While some of the languages chosen fit both rationales, others may not. The panel believes that this is an incorrect criterion for language selection for this project and contributes to the uncertainty factor.

Team A suggested Navajo as the seventh language for the on-site system, Team B suggested Mescalero Apache. Navajo was adopted into the conceptual design by the PTF with no accompanying justification for why it, rather than Apache, was adopted.

Testing

Both Markers panels suggest testing elements of the proposed system on extant populations, controlling for variables such as levels of technology development, race, sex, and culture (Trauth et al. 1992, pp. F-46, G-73ff). There is a section entitled "Testing" in the *Conceptual Design Report* (pp. 74-77). In this section, only one paragraph is devoted to testing for comprehensibility; the remainder of the section is devoted to testing for durability. The descriptions of the comprehensibility tests are cursory and incomplete. References to those tests are missing from the *PICs Efficacy Report*.

5.2.2.3. Summary

Based upon the assumptions and the work done by the Markers panels and others, the peer review panel believes that individual components of the design probably will work. However, the entire design could be made stronger by incorporating the Gestalt/systems principle and by developing and testing some of the communication vehicles. Such development and test programs should be part of the conceptual design. The peer review panel believes that the probability that the messages captured in the markers will be understood is very high but also believes that there is some uncertainty associated with that probability.

5.2.3. *Archives*

5.2.3.1. Durability

The *PICs Efficacy Report* states that "The initial form of the information will be archival-quality paper" (Section 5.3.1, pp. 5-20 to 5-22). The location of these archives has not been established, but the *PICs Efficacy Report* suggests several possible candidates. Two classes of failure mechanisms were assessed: (1) durability of the archival material and (2) survivability of the archive.

Decay of the paper or degradation of the ink would be addressed by using archival paper, carbon black ink, and controlled storage environments. These design solutions could be reasonably expected to ensure that the archived material will not succumb to normal aging with a failure rate close to 0.0.

The other failure mechanisms describe threats to the archived materials' survival. These include theft, misfiling, natural disasters, recycling, inadvertent disposal, loss, or deliberate destruction. Virtually any large organization archives written records; it is a common experience that archived records disappear after a few decades (or less) despite the fact that these records may have significant financial value to the organization. Neither the *PICs Efficacy Report* nor the *Conceptual Design Report* present evidence for the survival rate of archived material, although institutions such as the Library of Congress could provide such data. The examples of archives that have survived, as mentioned in Section 5.2.1, only demonstrates that archives can survive and cannot be used to estimate failure rates. For this reason, the peer review panel does not believe that a failure rate of 0.0 for archive durability has been justified in the documents under review.

5.2.3.2. Comprehension

The discussion on comprehensibility of the archives assumes the information is captured in some document and is in a repository. However, the peer review panel believes that a successful communication event (i.e., one in which the intention of the speaker is captured and "understood" by the listener) depends upon successful execution of all steps in the communication process (see Figure 4.2.2-1). This includes appropriate encoding in language (i.e., capturing the necessary data in appropriate language and form), capturing in media (i.e., inscribing using appropriate materials), and transmitting (i.e., actually getting the documents from the creators to the appropriate archives). The peer review panel believes that the PTF did not adequately address these steps.

In the *Conceptual Design Report*, the PTF states that "the DOE will develop a WIPP summary document" (p. 92). How will its contents be determined? For example, why was so much effort put into

developing a prototype of a level IV message for the markers system when no sample table of contents for this document was presented? Who will request archives to locate and catalog that volume? (The sentences in the reports under review which describe these activities are written in the passive voice and, hence, the agency is unclear.) Is a request from that source likely to be heeded? In what language(s) will these documents be written?

The *Conceptual Design Report* gives a list of documents recommended for inclusion in the archived information portfolio (p. 93). What is the logic that drove the creation of this list? What were the criteria for selection?

The *Conceptual Design Report* states that "the most likely strategy for long term protection of the information is through widespread distribution" (p. 94). How is "widespread" defined? Geographically? Functionally? Politically? For example, would it be safer to have a copy stored in a church repository in Monterrey, Mexico, or one in a laboratory archive at Brookhaven National Laboratory? As a related question, what is the logic behind the list of archives presented immediately following?

The *Conceptual Design Report* also states that the "DOE archivist will develop a filing code system specifically for the WIPP material" (p. 94). How will this system speak to cultural logics of which we know little or nothing? How will it be developed?

The *Conceptual Design Report* further states that "each volume containing documents will be labeled with a warning that the intent of providing the archived material is to ensure its preservation for the 10,000 year regulatory time frame stipulated in the United States Government's regulations controlling the disposal of Transuranic Waste" (p. 94). Is it not the intent of the archived material to provide an "awareness trigger" (see comments re: Section 5.4) to alert the reader that he or she needs to be educated as to what is going on at the site and not to "ensure its [the archived material's] preservation . . . ?"

5.2.3.3. Summary

The primary concerns of the peer review panel with this portion of the conceptual design are: (1) what gets into the archives and (2) how it gets there. Because this part of the communication process is inadequately explained by the PTF, the peer review panel believes that the probability of a successful communication event is low and the uncertainty is high. The peer review panel does note that it is possible to increase this probability and decrease the uncertainty by developing arguments based upon the assumptions in Section 3.0 of the *PICs Efficacy Report* and by using other readily available materials.

5.2.4. Records

5.2.4.1. Durability

The issues that pertain to the durability/physical survival of the archived materials are essentially the same for the records. The difference is that the survival probabilities considered reasonable for the archives should be less for the records since "Record centers . . . would generally permit freer access by members of the public and do not normally exercise the degree of environmental control and information-medium selection to be found in modern archives" (*PICs Efficacy Report*, Section 5.4.1, pp. 5-25 to 5-27). The peer review panel believes that a failure probability of 0.0 with little or no uncertainty has not been substantiated by the reports under review.

5.2.4.2. Comprehension

As with the archives, the peer review panel believes that the records centers were given extremely short shrift, particularly given the process model in Figure 4.2.2-2 and the associated argument we present that underscores that the records centers and archives may have to serve as the only deterrent. This criticism is bolstered by the PTF's adoption of the redundancy or "defense-in-depth" approach.

The comments made in Section 5.2.3 (Archives) regarding the accurate capture of appropriate information into a document and the placing of that document in a repository also pertain to the records center. In addition, the comments regarding a summary document and an admonitory label on the cover relative to the archives are relevant here.

The *Conceptual Design Report* gives a list of recommended records centers (p. 95). What is the logic that drove the creation of this list? What were the criteria for selection? The list is introduced by the statement ". . . these Federal and State Libraries/agencies include:" Are there others?

5.2.4.3. Summary

The peer review panel's assessment of the records center is the same as its assessment of the archives. The primary concerns consider what gets into the records centers and how it gets there. Because this part of the communication process is inadequately explained by the PTF, the peer review panel believes that the probability of a successful communication event is low and the uncertainty is high. The peer review panel does note that it is possible to increase this probability and decrease the uncertainty by developing arguments based upon the assumptions in Section 3.0 of the *PICs Efficacy Report* and by using other readily available materials.

5.2.5. Government Land-Use Control

5.2.5.1. Durability

There are no durability issues concerned with government land-use control.

5.2.5.2. Comprehension

The *Conceptual Design Report* and the *PICs Efficacy Report* discuss current land-use controls through government ownership. They make no mention of, or reference to, how these controls will continue beyond the lifetime of existing institutions. The peer review panel believes that the PTF should use the assumptions presented in Section 3.0 of the *PICs Efficacy Report* and other material, as appropriate, to develop reasonable and defensible projections (pp. 3-1 to 3-7).

5.2.5.3. Summary

The PTF has provided no information in either the *PICs Efficacy Report* or the *Conceptual Design Report* to indicate how government land-use controls will continue as a deterrent or awareness trigger over the 700 years in question.

5.2.6. Other Passive Institutional Controls

5.2.6.1. Durability

There are no durability issues related to the "awareness triggers" described in Section 5.6 of the *PICs Efficacy Report* (pp. 5-30 to 5-31).

5.2.6.2. Comprehension

What is the logic behind the list of cartographic and geographic organizations that will receive location and hazards information for mapping purposes (*Conceptual Design Report*, p. 97)? How will this list be developed? Who will develop it?

What is the logic behind the identification of "companies providing energy and resource-related data to commercial ventures . . ." that receive location and hazards information (*Conceptual Design Report*, p. 97)?

Is the list of other passive institutional controls given in the *Conceptual Design Report* (pp. 99 to 100) an inclusive one? How will these controls be handled?

5.3. Completeness of Failure Scenarios

In general, the *PICs Efficacy Report* presents a wide-ranging review of possible failure mechanisms for the passive institutional controls components and addresses these problems through credible and practical design solutions.

5.3.1. Horizontal Drilling

The peer review panel believes that failure due to horizontal drilling from outside the Withdrawal area has not been adequately discussed and constitutes a credible scenario for inadvertent intrusion. Current technology for drilling horizontal wells would make it possible to drill a horizontal lateral from outside the Withdrawal into the repository. Horizontal well drilling technology is rapidly advancing and it is not unreasonable that the current length of horizontal wells will increase by thousands of feet within 1 to 2 years. Team A in Trauth et al. (1992, p. F-108) indicated that protecting against even a 15-degree slant hole would require marking 2 miles beyond the footprint of the waste panels, which includes areas outside of the Withdrawal. However, the current system of passive institutional controls, as described in the *PICs Efficacy Report* and *Conceptual Design Report*, does not describe a marking system outside of the Withdrawal area.

This credible failure scenario is particularly important since the surface or buried monument system does not necessarily deter this type of intrusion. Section 4.1 of the *PICs Efficacy Report* assumes that the proposed passive institutional controls constitute an integrated, redundant system of components (pp. 4-1 to 4-2). This means that "the effectiveness of the PICs system . . . will remain high even if the effectiveness of individual components is compromised by some failure mechanism." The *PICs Efficacy Report* also states that "potential future intruders should be effectively deterred from drilling into the Withdrawal as long as one of these component remains sufficiently intact to provide a warning" (Section 4.4, pp. 4-4 to 4-5).

These statements suggest that any of the four defined passive institutional controls components—markers, record centers, archives, and government control of land-use—are sufficient to deter intrusion without help from other components. The deterrence would need to come from record centers and government control of land-use. However, the *PICs Efficacy Report* implies that the survival of only the marker components would be an effective deterrent to horizontal drilling. It is not clear that the reports under review have justified this implication.

5.3.2. *Collateral Damage Due to War*

The *PICs Efficacy Report* does not discuss situations in which massive destruction of surface or subsurface monuments has occurred due to war-related activities. For example, many structures larger than the proposed markers at WIPP, constructed of far more durable materials, and protected by very active government controls, have been obliterated by bombing campaigns or artillery fire. War is discussed in the context of the historical survival of archives and records centers in the *PICs Efficacy Report* but, for unknown reasons, is not discussed as a potential failure mechanism of the markers.

A credible failure scenario for the surface and subsurface marker system is important since the loss of this system would dramatically increase the likelihood of inadvertent drilling and mining and would imply that the failure rate of the permitting process for mineral extraction would govern the probability of intrusion.

5.4. Credit Calculations

5.4.1. *Regulatory Standard*

As stated in 40 CFR Part 194.43(3)(c), credit to reduce inadvertent drilling and mining intrusions may be granted if the applicant can justify that passive institutional controls "are expected to endure and be understood by potential intruders for a time period approved by the Administrator." The CAG states that this justification should "require a deterministic analysis, based on scientific data." The peer review panel interprets this to mean that the credit should be expressed quantitatively and that its calculation should be an obvious and defensible logical progression from scientific observations. The panel is concerned that the method of credit calculation is inconsistent with passive institutional controls system presented in the *PICs Efficacy Report* and is inadequate for the purposes of 40 CFR Part 194.43.

5.4.2. *Inadequacy/Inconsistency of Calculation Methodology*

The *PICs Efficacy Report* claims that the proposed passive institutional controls constitute a redundant system to prevent inadvertent intrusion. A system is made up of components. In this case, the system has several identifiable components such as the surface markers, the berm, the subsurface markers, the archives, and the records centers. It is common practice to estimate the probability of system failure from the reliability (or failure rate) of the constituent components, as is done for the Combined Cumulative Distribution Function performance assessment of the WIPP project at a much higher level of aggregation. This requires a numerical estimate of the failure rate of each component, uncertainty

surrounding this value, and a structure that captures how the various failure mechanisms interact with the passive institutional controls components that have been emplaced to deter them.

The *PICs Efficacy Report* does not follow this method in assessing the reliability of passive institutional controls to prevent inadvertent intrusion (or tacitly assumes that their failure rate is 0.0 with no uncertainty). No numerical values for individual components are provided, nor are uncertainties, with the sole exception of inadvertent drilling rig mislocation. This is probably because the report concludes that the failure rate for each of the passive institutional controls components is 0.0 with no uncertainty in this value. Likewise, there is no discussion of how the failure mechanisms interact with the passive institutional controls deterrents. As discussed in Section 5.3, the prevention of credible intrusion scenarios (such as horizontal drilling) requires the survival of records and governmental control of land-use. It is debatable that the survival of subsurface markers will have any deterrent effect. Thus, the estimate of the credit given to passive institutional controls should be based upon the estimates of the failure rates of each component and how they interact with each other and the intrusion scenarios.

5.4.3. Consequences for Performance Assessment Calculations

Uncertainty for reliability or failure for any of the passive institutional controls components was scarcely addressed in the *PICs Efficacy Report*. In Section 5.0, which discusses the failure of the constituent components, failure rates are not calculated (*PICs Efficacy Report*, pp. 5-1 to 5-32). However, the discussion in Section 6.4 implies that the failure rates are 0.0 since the only possible failure mechanism discussed with regard to performance assessment is inadvertent mislocation of drilling rigs (*PICs Efficacy Report*, pp. 6-10 to 6-11). The report indicates that there is no uncertainty in the 0.0 failure rate for the markers, records, archives, and government land-use control systems and indicates that the comprehension probability for all passive institutional controls is extremely high. The peer review panel finds that this high level of probability and confidence has not been substantiated by the discussion in the *PICs Efficacy Report* or in its supporting documentation.

Discussions with Peter Swift of SNL (Swift 1996) were held concerning the sensitivity of performance assessment calculations to drilling rates. Swift indicated that the calculations of release were very sensitive to drilling rates, something on the order of a linear scaling in which doubling the drilling rate doubles the release. Thus, the amount of credit given to the passive institutional controls is very important for performance assessment, which implies the consequences of any uncertainty surrounding the passive institutional controls credit may be very significant.

The peer review panel did not find that the *PICs Efficacy Report* adequately discussed the uncertainty surrounding failure rates for passive institutional controls components, given the significant consequences on the calculated releases if the assumed failure rates are wrong.

Uncertainty is discussed for the inadvertent mislocation of drilling rigs in Section 6.4 of the *PICs Efficacy Report* (pp. 6-10 to 6-11). A bounding value of 0.01 for failure is assumed. The derivation of this number is not based on any calculation but is felt to be highly conservative since it is several orders of magnitude greater than the historical drilling. Credible estimates of mislocated drilling operations in Texas and New Mexico suggest that the mislocation rate was on the order of 1 in 100,000 or less. However, the panel finds that there are other credible failure scenarios whose rate may be higher but that are not addressed in the present reports. Moreover, the failure rates for the passive institutional controls components are assumed to be 0.0 and, with the exception of mislocated drilling operations, have an uncertainty of 0.0. The panel does not believe that the 0.0 failure rate or the 0.0 level of uncertainty has been substantiated in many of the failure scenarios, as described in Section 5 of this report.

The peer review panel also believes that the credit for the passive institutional controls should be calculated using a systems approach in which the failure rates and their uncertainties are aggregated into a cumulative probability distribution. The mathematical model for the system, which consists of the failure probabilities for each passive institutional controls component and its relation to all identified credible intrusion scenarios, should match the system implied in the reviewed reports.

6.0 CONCLUSIONS

The following conclusions regarding the calculation of the credit for passive institutional controls were given in the *PICs Efficacy Report;* the panel's comments follow each conclusion.

1. This report concludes that the sole cause of failure is incorrect location of a drilling rig. The panel believes that there are other failure scenarios that have not been taken into account—specifically, horizontal drilling, collateral damage due to war, and vandalism.

2. The effectiveness of the deterrence afforded by the passive institutional controls components is such that any component, in isolation from all other components, effectively deters inadvertent intrusion. This conclusion ignores the systems nature of the passive institutional controls in that, despite all of the system redundancy, some components do not have the same level of deterrent efficacy as others for every credible intrusion scenario.

3. The report describes historical analogs for the passive institutional controls in order to justify a 0.0 failure rate for durability. However, failure rates ascribed on the basis of historical analogs do not account for the fact that similar monuments or constructions have not survived.

4. The report concludes that vandalism and souvenir hunting will be effectively defeated by the passive institutional controls design. The panel believes that this conclusion has not considered the historical destruction of similar types of monuments, markers, and constructions during periods of war or loss of active governmental control.

5. The report concludes that the marker system is 100 percent reliable with no uncertainty, and that the records/archives/land-use controls are highly reliable with no uncertainty. The panel believes that there is uncertainty attached to comprehension of all the passive institutional controls and that the records centers and archives, as described in the documents under review, are highly likely to fail as communication events.

7.0 SIGNATURES

I, by signature, acknowledge that I concur with the findings and conclusions of this Passive Institutional Controls Peer Review Report.

Jessica Glicken, Ph.D.
PICs Panel Chairman

Elizabeth Hocking, J.D.
PICs Panel Member

Paul La Pointe, Ph.D.
PICs Panel Member

8.0 PEER REVIEW MEMBERS AND ACCEPTABILITY

Jessica Glicken, Panel Chairman, is a Senior Anthropologist with ecological planning and toxicology, inc. (ep&t) in Albuquerque, New Mexico. She has a Ph.D. in anthropology from Cornell University with a geographic specialty in Southeast Asian studies and a theoretical specialty in cultural linguistics and symbolic anthropology. She holds two master's degrees, one in Cultural Anthropology from Cornell University and one in Social Anthropology from the University of Michigan. Dr. Glicken has over 14 years of experience in communications, strategic and organizational development and management, and policy analysis. She develops communication strategies for both public- and private-sector clients, which includes identifying stakeholder groups; developing, implementing, and analyzing communication vehicles; and analyzing responses. Dr. Glicken is an experienced policy analyst in national and international energy and sustainable development programs, and has worked extensively on government and organizational structure and management. Dr. Glicken has published and given presentations on public participation, decision analysis, energy policy (foreign and domestic), and intelligence strategies.

Elizabeth K. Hocking, Panel Member, is a Legislative Analyst and Section Manager with Argonne National Laboratory, based in Washington, D.C. She holds a J.D. from the Washington College of Law at American University. Ms. Hocking provides technical, legal, and programmatic analyses of current statutes, regulations, and judicial decisions affecting DOE and the energy industry. Ms. Hocking's work in the area of passive institutional controls has included the identification and analysis of salient legal (statutory, regulatory, and common law), policy, and practical issues related to the use of institutional controls on real property owned and transferred by the DOE. She has also investigated the limitations, implementability, enforceability, and fairness of reliance on institutional controls, providing support to DOE in its decision-making regarding the use of passive institutional controls. Her publications and conference presentations have focused on recycling, pollution prevention, and federal facility compliance under the Resource Conservation and Recovery Act.

Paul R. La Pointe, Panel Member, is a Mathematical Geologist, Rock Mechanics Engineer, and Associate with Golder Associates in Redmond, Washington. He has a Ph.D. in mining engineering and an M.S. in geology, both from the University of Wisconsin. Dr. La Pointe has more than 16 years of experience in the oil and gas, mining, and natural resource development industries. He is currently responsible for management and technical direction of reservoir engineering and characterization projects for domestic and international petroleum companies. His projects have included geological analysis, reservoir characterization, and flow simulation for fractured reservoirs in the United States,

Canada, and Europe. He has served as an expert advisor to the U.S. Geological Survey to review methodology for the 1995 National Petroleum Resource Assessment. Dr. La Pointe has also performed technical analyses for a variety of hazardous and nuclear waste-related projects in the United States and abroad. Flow-through rock fracture systems are a prominent concern in these projects. Dr. La Pointe has conducted several workshops and short courses for professional geological societies and private companies in the petroleum and nuclear waste industries. He has authored or co-authored numerous papers and three books on the mathematical characterization of geological systems. Dr. LaPointe has served as an editor of the International Journal of Rock Mechanics and Mining Sciences since 1983.

9.0 REFERENCES

Berry, W.E. 1983. *Durability of Marker Materials for Nuclear Waste Isolation Sites.* ONWI-474. Columbus, OH: Battelle Memorial Institute.

Dobrin, M.B. 1960. *Introduction to Geophysical Prospecting.* Second Edition. New York: McGraw-Hill Book Co.

Environmental Evaluation Group. *Compilation of correspondence between EEG and DOE regarding mineral leases and drilling activity in the vicinity of the WIPP.* Binder prepared by EEG for Passive Institutional Controls Panel. Cover letter dated June 11, 1996.

Givens, D.B. 1982. "From Here to Eternity: Communicating with the Distant Future." Et cetera, pp. 159-179.

Goad, D. 1979. *A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes.* EEG-1. Albuquerque, NM: Environmental Evaluation Group.

Guzowski, R.V. and M.M. Gruebel (Editors). 1991. *Background Information Presented to the Expert Panel on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND91-0928. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. Von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Human Interference Task Force. 1984. *Reducing the Likelihood of Future Human Activities That Could Affect Geologic High-Level Waste Repositories.* BMI/ONWI-537. Columbus, OH: Battelle Memorial Institute.

International Atomic Energy Agency. 1996. *Maintenance of Records for Deep Geological Repositories.* 1996-05-31.

Kaplan, M.F. 1982. *Archaeological Data and Basis for Repository Marker Design.* ONWI-354. Reading, MA: The Analytic Sciences Corporation.

Public Law 102-579, *Land Withdrawal Act of 1992.*

Sebeok, T.A. 1984. *Communication Measures to Bridge Ten Millennia.* BMI/ONWI-532. Columbus, OH: Battelle Memorial Institute.

Silva, M.K. 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP.* EEG-55. Albuquerque, NM: Environmental Evaluation Group.

Silva, M.K., and J.K. Channell. 1992. *Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards.* EEG-50. Albuquerque, NM: Environmental Evaluation Group.

Swift, Peter. 1996. Peer Review Panel Meeting. Albuquerque, NM: Sandia National Laboratories. June 7, 1996.

Tannenbaum, P.H. 1984. *Communication Across 300 Generations: Deterring Human Interference With Waste Deposit Sites.* BMI/ONWI-535. Columbus, OH: Battelle Memorial Institute.

Trauth, K.M. 1996. Peer Review Panel Meeting. Albuquerque, NM: Sandia National Laboratories. June 24, 1996.

Trauth, K.M., R.V. Guzowski, C.G. Pflum, and R.J. Rodriguez. 1996. *Effectiveness of Passive Institutional Controls in Reducing Inadvertent Human Intrusion into the Waste Isolation Pilot Plant for Use in Performance Assessments.* WIPP/CAO-06-3168. U.S. Department of Energy.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1992. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

DOE. 1996a. *Passive Institutional Controls Conceptual Design Report.* Rev. 0. U.S. Department of Energy.

DOE. 1996b. *Compliance Certification Application: Appendix DEL.* U.S. Department of Energy. Draft appendix of application to be submitted to the U.S. Environmental Protection Agency, October 1996.

EPA. 1985. "40 CFR Part 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule." U.S. Environmental Protection Agency. *Federal Register,* Vol. 50, No. 182, pp. 38066-38089.

EPA. 1993. "40 CFR Part 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule." U.S. Environmental Protection Agency. *Federal Register,* Vol. 58, No. 242, pp. 66398-66416.

EPA. 1996a. *Compliance Application Guidance for 40 CFR Part 194.* EPA 402-R-95-014. Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

EPA. 1996b. "40 CFR Part 194, Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations, Final Rule." U.S. Environmental Protection Agency. *Federal Register,* Vol. 61, No. 28, pp. 5224-5245.

EPA. 1996c. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document. Chapter 12.* EPA 402-R-96-002. Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air.

EPA. 1995a. *Environmental Protection Agency Technical Workshop on WIPP Compliance Issues: February 14-16, 1995.* Washington, D.C.: U.S. Environmental Protection Agency (Neil R. Gross).

EPA. 1995b. *Minutes of September 6-7, 1995, Meeting of WIPP Review Committee National Advisory Council for Environmental Policy and Technology (NACEPT).* Washington, D.C.: U.S. Environmental Protection Agency, Office of Air and Radiation.

NRC. 1988. *Peer Review for High-Level Nuclear Waste Repositories.* NUREG-1297. Washington, D.C.: U.S. Nuclear Regulatory Commission.

Weitzberg, A. 1982. *Building on Existing Institutions to Perpetuate Knowledge of Waste Repositories.* ONWI-379. Rockville, MD: NUS Corporation.

Determination of Peer Review Member Independence Form

M

_____ Currently employed by DOE or DOE Contractor? Yes/(No)

_____ Employed by DOE or DOE Contractor previously? (Yes)/No

If yes, give dates, location, company, position type work performed.

7/92 - 1/96 Albuquerque, NM Sandia National Laboratories

position: member of technical staff manager

type of work: policy analysis, strategic planning, management

see attached letter for further information

_____ Do you or have you had any direct involvement or financial interest in the work under review? Yes/(No)

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed. and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: [signature]

Date: 5/22/96

M

Peer Review Manager Approval: [signature] John A. Thies

5/28/96 Date

Determination of Peer Review Member Independence Form

_____ Currently employed by DOE or DOE Contractor? Yes/No

_____ Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

12-89 to present — I am employed by Argonne National Laboratory and work in the Washington DC office. I am a policy analyst and work on environmental, statutory and regulatory issues affecting federal facilities (DOE specifically).

_____ Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Elizabeth K. Hoelzer

Date: 22 May '96

M

Peer Review Manager Approval: John A. Thies

5/28/96
Date

Determination of Peer Review Member Independence Form

YES Currently employed by DOE or DOE Contractor? Yes/No
Employed by DOE or DOE Contractor previously? Yes/No

If yes, give dates, location, company, position type work performed.

See attached descriptions
Descriptions relate to projects carried out by Golder Associates Inc.
Personal Involvement:
#25 : translation of two french technical articles concerning grouts
#39 : spatio-temporal analysis of vulcanism at Yucca Mt.
development of interface between fehmn and fracman codes
#40 : data analysis support for fracture flow models at Yucca Mt.
#42: Reservoir engineering/geology at Yates Field for tertiary recovery process.

NO Do you or have you had any direct involvement or financial interest in the work under review? Yes/No

If yes, describe involvement.

I hereby certify that the above information is correct to the best of my knowledge. I was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed, and to the extent practical, I have sufficient freedom from funding considerations to ensure the work is impartially reviewed.

Signature: Paul R. LaPorte

Date: 5/6/96

M M

Peer Review Manager Approval: John A. Thies 5/28/96 Date

Prime Contract No.	Prime Contractor	Subcontract Number	Subcontractor	Subtier Contract No.	Contract Type	Period of Performance	Contract Value	Contract Summary
DE-AC06-87RL10930 1	Westinghouse Hanford Company POC: Mr. David Wilsor PO Box 1970 Richland, WA 99352 Phone: (509) 376-0372	MLW-SVV-073750	Science Applications International Corp. POC: Mr. PK Brockman 3250 Port of Benton Blvd Richland, WA 99352 Phone: (509) 372-7700	16-910011-61	Task Order CPFF	Jun 91 - Apr 95	$11.447 M	Geotechnical support services
W-7405-Eng-36 2	University of California POC: Mr. George Daly Los Alamos National Laboratory PO Box 990 Los Alamos, NM 87545 Phone: (505) 665-7891	9-X69-C4500-1	Not applicable	Not applicable	CPFF	Jun 89 - Sep 93	$145 K	Technical support for site characterization of Yucca Mountain, NV
W-7405-Eng-36 3	University of California POC: Ms. Allison Bailey Los Alamos National Laboratory PO Box 990 Los Alamos, NM 87545 Phone: (505) 665-3900	9-XS2-F2078-1	ERM Program Management Company POC: Mr. Pat Heenan 855 Springdale Drive Exton, PA 19341 Phone: (610) 524-3899	LANL-PMC-Sub1	Task Order CPFF	Jul 92 - Jul 97	$5.644 M	Environmental support services to LANL Environmental Restoration Program
DE-AC07-76IDO1570 4	EG&G Idaho, Inc. POC: Mr. Robert Crowton PO Box 1625 Idaho Falls, Idaho 83415 Phone: (208) 526-7746	C92-120273	Not applicable	Not applicable	CPFF	Feb 92 - Sep 92	$174K	Technical support services in support of the OCE Subsurface Science Subprogram
DE-AC07-76IDO1570 5	EG&G Idaho, Inc. POC: Ms. Tonya Pearson PO Box 1625 Idaho Falls, Idaho 83415 Phone: (208) 526-1544	C91-103366	Not applicable	Not applicable	CPFF	Apr 91 - Sep 92	$185 K	Support to NPR
DE-AC07-76IDO1570 6	EG&G Idaho, Inc. POC: Ms. Tonya Pearson PO Box 1625 Idaho Falls, Idaho 83415 Phone: (208) 526-1544	C91-103242	Not applicable	Not applicable	CPFF	Apr 91 - Sep 92	$893 K	Synthesize existing data and perform studies necessary to establish the seismic design for the NPR site and to determine risk from other geologic hazards.
DE-AC07-76IDO1570 7	EG&G Idaho, Inc. POC: Ms. Linda Baum PO Box 1625 Idaho Falls, Idaho 83415 Phone: (208) unavailable	C88-1131159	Not applicable	Not applicable	Task Order CPFF	Dec 88 - Sep 91	$2.621 M	Technical support service in the area of radioactive waste management
DE-AC07-76IDO1570 8	EG&G Idaho, Inc. POC: Mr. Scott Hancock PO Box 1625 Idaho Falls, Idaho 83415 Phone: (208) 526-2499	C90-132736	Not applicable	Not applicable	Task Order CPFF	May 90 - Jul 93	$4.403 M	Support services for radioactive and hazardous waste management
DE-AC06-87RL10930 9	Westinghouse Hanford Company Ms. Lynn Aman PO Box 1970 Richland, WA 99352 Phone: (509) 376-4811	MRY-SVV-301407	Not applicable	Not applicable	FFP, T&M	Sep 93 - Sep 94	$84 K	Engineering suport for WRAP and solid waste projects. Provide engineering services to design a trench
DE-AC06-87RL10930 10	Westinghouse Hanford Company Ms. Sylvia Horais PO Box 1970 Richland, WA 99352 Phone: (509) 376-6777	MSH-SVV-315905	Not applicable	Not applicable	Fixed Unit Rates	Aug 94 - Sep 95	$200 K	Validate chemical and radiochemical data packages and provide summary reports of validated data from site characterization activities
DE-AC06-87RL10930 11	Westinghouse Hanford Company Mr. Robert Young PO Box 1970	MJK-SVV-301401	Not applicable	Not applicable	Labor Hours	Jan 93 - Dec 93	$36 K	Design, engineering and inspection services in support of W-025 Project.

5/6/94

Prime Contract No.	Prime Contractor	Subcontract Number	Subcontractor	Subtier Contract No.	Contract Type	Period of Performance	Contract Value	Contract Summary
	Richland, WA 99352 Phone: (509) 376-6766							
DE-AC06-87RL10930 12	Westinghouse Hanford Company Mr. Robert Young PO Box 1970 Richland, WA 99352 Phone: (509) 376-6766	MRV-SVV-666693	Not applicable	Not applicable	Task Order CPFF	Oct 89 - Sep 93	$1.975 M	Geotechnical support services
DE-AC06-76RLO 1830 13	Battelle Pacific Northwest Laboratory Ms. Robin Rosengrant PO Box 999 Richland, WA 99352 Phone: (509) 375-4587	293407-A-B2	Not applicable	Not applicable	Labor Hours	Jun 94 - May 95	$20 K	In-situ vitrification geotechnical support of Hanford field demonstration
DE-AC06-76RLO 1830 14	Battelle Pacific Northwest Laboratory Ms. Robin Rosengrant PO Box 999 Richland, WA 99352 Phone: (509) 375-4587	283446-A-B2	Not applicable	Not applicable	Labor Hours	Sep 94 - Nov 94	$13 K	Analysis of stability of overburden for Oak Ridge National Laboratory in-situ vitrification design
DE-AC06-87RL10930 15	Westinghouse Hanford Company Ms. Tracey A. Burch PO Box 1970 Richland, WA 99352 Phone: (509) 376-7206	TTB-SLC-352143	Not applicable	Not applicable	Task Order CPFF	Jan 94 - Sep 97	$8.649 M	Support Hanford environmental compliance program including waste site permitting, vadose dose and groundwater characterizations, and geophysical investigations
DE-AC06-76RLO 1830 16	Battelle Pacific Northwest Laboratory POC: Ms. Nancy K. Powell PO Box 999 Richland, WA 99352 Phone: (509) 375-3771	110720-A-P1	Not applicable	Not applicable	CPFF	Sep 90 - Dec 90	$46 K	Support PASS Program and OCRWM through application of FracMan to describe fracture systems within Yucca Mt.
DE-AC06-76RLO 1830 17	Battelle Pacific Northwest Laboratory POC: Ms. Nancy K. Powell PO Box 999 Richland, WA 99352 Phone: (509) 375-3771	110707-A-P1	Not applicable	Not applicable	Labor Hour	Jun 90 - Feb 91	$89 K	Coordinate US participation in INTRAVAL Cooperative Study for DOE HQ
DE-AC06-76RLO 1830 18	Battelle Pacific Northwest Laboratory POC: Ms. Kala Suhadolnik PO Box 999 Richland, WA 99352 Phone: (509) 376-8818	151579-B-C5	Not applicable	Not applicable	Labor Hours	Oct 93 - Jul 94	$41 K	Complete validation studies and perform sensitivity and uncertainty analyses of the Hanford Environmental Dose Reconstruction dose calculation codes
DE-AC06-76RLO 1830 19	Battelle Pacific Northwest Laboratory POC: Ms. Nancy K. Powell PO Box 999 Richland, WA 99352 Phone: (509) 375-3771	76940-A-B1	Not applicable	Not applicable	Task Order Labor Hours	Mar 89 - Dec 91	$50 K	Technical support to include: remedial investigation planning, remedial investigation execution, site assessments, feasibility studies, and independent reviews and regulatory analyses.
DE-AC06-76RLO 1830 20	Battelle Pacific Northwest Laboratory POC: Mr. Doug Gilbertson PO Box 999 Richland, WA 99352 Phone: (509) 375-5907	134571-A-P1	Not applicable	Not applicable	Labor Hours	Mar 91 - Sep 92	$269 K	Support PASS Program and OCRWM through application of rock mechanics in performance assessment of high-level wastes in mined geologic repositories.

Prime Contract No.	Prime Contractor	Subcontract Number	Subcontractor	Subtier Contract No.	Contract Type	Period of Performance	Contract Value	Contract Summary
DE-AC06-76RLO 1830 21	Battelle Pacific Northwest Laboratory POC: Ms. Julie Wilson PO Box 999 Richland, WA 99352 Phone: (509) 375-6785	228298-A-B3	Not applicable	Not applicable	Labor Hours	Sep-94	$120 K	Conduct field sampling projects at Cerro Negro, NM, and Parachute, CO, in support of DOE's Deep Microbiology Subprogram.
DE-AC04-76DP00789 22	Sandia National Laboratories Mr. Bill Peters PO Box 5800 Albuquerque, NM Phone: (505) 844-4438	AA-1994	Not applicable	Not applicable	Labor Hours	Jan 92 - Dec 92	$45K	Technical review of plans and procedures for hydraulic fracturing and hydrologic tests. Review and provide recommendations for specific analytical approaches.
DE-AC04-94AL85000 23	Sandia National Laboratories Mr. Craig Amundson PO Box 5800 Albuquerque, NM Phone: (505) 844-0814	AL-7026	Not applicable	Not applicable	Time & Materials	Dec 94 -Oct 95	$200 K	Conduct baselining and quality assurance of the Repository Integration Program in the System Prioritization Methodology and modify RIP conceptual model as required.
DE-AC04-94AL85000 24	Sandia National Laboratories Mr. Bill Peters PO Box 5800 Albuquerque, NM Phone: (505) 844-4438	AM-8859	Not applicable	Not applicable	Task Order CPFF	May 95 - Sep 96	$422 K	Technical support services to include: interpretation of post-test characterization data enhance/extend EnviroTRADE databases
DE-AC04-76DP00789 25	Sandia National Laboratories Mr. Bill Peters PO Box 5800 Albuquerque, NM Phone: (505) 844-4438	87-3497	Not applicable	Not applicable	Time & Materials	Dec 91 - May 95	$1.993 M	Support DOE/EM's International Technology Exchange Program by developing methodology for decision making on ER of contaminated sites and testing of grout barriers
W-31-109-Eng-38 26	Argonne National Laboratory Mr. John Wray 9700 Cass Avenue South Argonne, IL 60439 Phone: (708) 252-548[illegible]	92722402	Not applicable	Not applicable	Labor Hours	Oct 89 - Apr 91	$172 K	Support the Stripa Fracture Flow Task Force and the OECD/NEA Site Evaluation and Design of Experiments Working Group through test interpretation and predictive modelling
W-31-109-Eng-38 27	Argonne National Laboratory Mr. John Wray 9700 Cass Avenue South Argonne, IL 60439 Phone: (708) 252-548[illegible]	9029-W	Not applicable	Not applicable	FFP	Jan 91 - Jul 91	$591 K	Site characterization, monitoring, analysis and test plan for the EBR II leach pit
W-31-109-Eng-38 28	Argonne National Laboratory Mr. Michael Janik 9700 Cass Avenue South Argonne, IL 60439 Phone: (708) 252-548[illegible]	942682403	Not applicable	Not applicable	Labor Hours	Oct 94 - Dec 96	$110 K	Review of service experience related to steam generator tube degradation in commercial reactors. Coordinate and facilitate information exchange with Electric Power Research Institute.
W-31-109-Eng-38 29	Argonne National Laboratory Mr. Michael Janik 9700 Cass Avenue South Argonne, IL 60439 Phone: (708) 252-5481	2352401	Not applicable	Not applicable	Labor Hours	Nov 90 - Sep 93	$894 K	Alternative licensing strategies investigation and strategic plan for site suitability determination
W-31-109-Eng-38 30	Argonne National Laboratory Mr. Michael Janik 9700 Cass Avenue South Argonne, IL 60439 Phone: (708) 252-5481	942682402	Not applicable	Not applicable	Labor Hours	Jun 94 - Feb 95	$28 K	Conduct high resolution subbottom profiling high resolution seismic reflection profiling, medium resolution seismic reflection profiling, and seismic refraction sounding in the waters near Aberdeen Proving Ground

Prime Contract No.	Prime Contractor	Subcontract Number	Subcontractor	Subtier Contract No.	Contract Type	Period of Performance	Contract Value	Contract Summary
W-31-109-Eng-38 31	Argonne National Laboratory Mr. Steve Gihring 9700 Cass Avenue South Argonne, IL 60439 Phone: (208) 533-7708	31-109-38-8322-W	Not applicable	Not applicable	Fixed Unit Rates	Jan 94 - Apr 95	$353 K	Investigation and characterization of liquid effluent discharges
DE-AC06-89RL11165 32	DOE - Richland Operations Office Ms. Sally Sieracki PO Box 550 Richland, WA 99352 Phone: (509) 376-2955		Not applicable	Not applicable	FFP, CPFF	Oct 89 - Dec 94		Perform A-E services for definitive design, engineering during construction, engineering field services, and Part B Permit engineering support for radioactive mixed waste land disposal facility - Non Drag Off
DE-FG06-92ER61507 33	DOE - Richland Operations Office Ms. Marjie Parker PO Box 550 Richland, WA 99352 Phone: (509) 376-6227		Not applicable	Not applicable	CR grant	Oct 93 - Sep 96	$1.6 M	Subsurface science geologic data interpretation and technical support
DE-AC04-93AL96904 34	Advanced Sciences, Inc. POC: Ms. Frances Lopez PO Box 1270 Carlsbad, NM 88221 Phone: (505) 885-0085	9121-803-016	Not applicable	Not applicable	Labor Hours	Nov 95 - Sep 96	$155 K	Performance assessment modelling of Waste Isolation Pilot Program. Technical Reviews of WIPP site documents.
DE-AC04-93AL96904 35	Advanced Sciences, Inc. POC: Mr. Mike Holston 6738 Academy Road, NE Albuquerque, NM 87109 Phone: (505) 828-0859	9622-BR-15-94	Not applicable	Not applicable	Labor Hours	Feb 94 - Sep 95	$616 K	Performance assessment modelling of Waste Isolation Pilot Program. Technical Reviews of WIPP site documents.
W-7405-Eng-82 36	Ames Laboratory POC: Mr. Jack Cummings 133 Spedding Hall Iowa State University Ames, Iowa 50011-3020 Phone: (515) 294-1790	PO # A4-2604	Not applicable	Not applicable	Fixed Unit Rates	Mar-94	$10 K	Expedited site characterization demonstration
DEAC07-88-ID12735 37	MSE, Inc. POC: Mr Charles Reis PO Box 4078 Butte, MT 59702 Phone: (406) 723-8213	95-C289-CR	Not applicable	Not applicable	CPFF	Jul 95 - Sep 95	$81 K	Post-injection characterization of foreign grout study at the Richland Municipal Landfill
DE-AC34-90-RF62349 38	EG&G Rocky Flats, Inc. Rocky Flats Plant POC: Mr. D. Patrick Timbes PO Box 464 Golden, CO 80402 Phone: (303) 966-8592	MTS 225469DB	Not applicable	Not applicable	Labor Hours	Aug 92 - Sep 95	$5.392 M	Environmental and waste management sampling support and associated technical analysis
DE-AC01-91RW0 0134 39	TRW Environmental Safety Systems POC: Mr. Jeff Shuse 2650 Park Tower Drive, Suite 800 Fairfax, VA 22033 Phone: (703) 204-8500	DX1426KP2L DX1466KP3S	Not applicable	Not applicable	CPFF	Oct 93 - Jul 95	$$651 K	Use of RIP software in performance assessment modelling of Yucca Mt in support of DOE INTRAVAL program
DE-AC01-92EW30030 40	BDM Federal, Inc. POC: Mr. Steven Fuick 1501 BDM Way McLean, VA 22030 Phone: (703) 848-5745	08S20016 08S2005504 08S3008804	Not applicable	Not applicable	CPFF	Oct 93 - Sep 95	$685 K	Technical support for WIPP including modelling and demonstration of disposal of transuranic waste
34-CR-95-SA-1023 41	Golder Associates 4104 148th Ave. NE Redmond, WA 98052 (206) 883-0777				FFP	Apr 95 - Apr 96	$32K	

5/3/95

DE-AC22-94PC91005	BDM-Oklahoma 220 NW Virginia Ave Bartlesville, OK 74005 POC: Dr. M. Madden (918) 337-4261	G4S51728	FFP	Performance Mar 96 - Nov. 98	Amount $743K

#42

PEER 9 - National Academy of Sciences

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF MAY 1, 1979

S

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

TTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

May 1, 1979

Dr. Earnest F. Gloyna, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

Dear Dr. Gloyna:

As part of its continuing responsibility to review criteria and guidelines for the location, design, construction, and operation of a proposed radioactive waste isolation pilot plant (WIPP), this Panel has reviewed the WIPP Draft Site Characterization Report (DSCR), SAND 78-1596, prepared by Sandia Laboratories for the Department of Energy. The DSCR, which has subsequently been published, with the same report number, as "Geological Characterization Report (WIPP)," is a compilation of the known geotechnical information about the proposed site and the surrounding region, with chapters devoted to regional geology, site geology, seismology, hydrology, geochemistry, resources, and special studies of WIPP repository rocks. It does not address such matters as socioeconomic considerations, accessibility, transportation and failure modes, which will need to be included in a complete site characterization.

The following brief account, which must be viewed in conjunction with the DSCR itself, is intended for a very limited audience of readers fully conversant with the contents of the basic document.

As a first step in this review, individual chapters of the DSCR were examined in detail by subgroups of the Panel with special expertise in the disciplinary areas involved, after which their separate comments were discussed by the full Panel in a meeting with the Sandia authors of the document.

The Panel then reviewed the extent to which the information contained in the DSCR provides sound geotechnical support for an environmental impact analysis and related decisions leading to the selection of an

appropriate site for the proposed pilot plant. The review focused on the Report's exposition of geotechnical information with critical bearing on the site's probable ability to provide the desired long-term isolation of emplaced waste, e.g. seismic or tectonic uplift, intrusion of groundwater, thermal and mechanical characteristics of the host rock, and retardation effects along possible migration pathways. The Report did not treat, nor did the Panel consider, the effect of the emplacement of waste or the waste itself on the long term integrity of the repository. Although recognizing the considerable coverage and detail of the information presented, the Panel noted a few areas where additional data are desirable to more fully characterize the geotechnical aspects of the area under consideration. These include the following:

a) A major disagreement between conclusions reached in the DSCR and the views of R. Y. Anderson is mentioned in several places. Anderson, a professor of geology at the University of New Mexico at Albuquerque, who has specialized in the study of evaporite deposits in the Delaware Basin, was commissioned by Sandia Laboratories to prepare a report on the deep dissolution of salt in the region around the proposed WIPP site. Basing his argument on a postulated unconformity at the base of the Salado formation and on his hypothesis that the so-called "breccia pipes" are localized features of deep dissolution which originated as collapse chambers in salt beds immediately overlying the reef and basin aquifers, Anderson suggested that dissolution may be so rapid that the entire salt formation will disappear within a million years. The DSCR, on the other hand, considers only dissolution at the western edge of the salt beds and concludes that present rates will ensure preservation of the Salado at the WIPP site for at least a few million years. The Panel feels that a more thorough explanation should have been provided as to why the authors of the DSCR consider their views preferable to Anderson's hypothesis. On this same issue of salt dissolution, the DSCR estimates of the rate of retreat of the solution front two or three miles west of the site are evidently based on the assumption of uniform dissolution over a wide area under average conditions. A rational basis should be provided for this assumption, vis a vis the possibility of accelerated dissolution rates in local areas, with selective removal of salt from beneath the present sedimentary cover, particularly if pluvial conditions were to change in the future.

b) Additional data and analyses would be helpful to determine with greater confidence the current rates of tectonic uplift in the region and whether, as a result, the salt may be exposed to accelerated erosion at some time in the foreseeable future.

c) The so-called "breccia pipes" need more detailed analyses to determine whether they may serve as conduits for water that may have promoted, or may in the future promote, deep dissolution of the salt beds.

d) There appears to be sufficient information to resolve the question regarding the likelihood of upward flow from the Bell Canyon formation through the Salado, where the proposed repository horizons are located, to the overlying Rustler. This should be addressed.

e) Because rock properties have a strong influence on mine design, more detailed information is needed on the various rock types in the area and on their permeability, fracture, and thermal properties under conditions as similar as possible to those that would be found in a repository. Both laboratory and field tests approximating in-situ conditions will be required to develop this information.

f) The information on sorption of the important radionuclides by materials to be expected in possible migration paths, under conditions resembling those near a possible repository, seems to be sparse. As soon as the types of waste to be stored in the repository are known, a more complete discussion should be presented of the retardation anticipated in the migration paths.

g) The most recent episode of any recrystallization in the Salado formation near the proposed WIPP site is reported to have occurred about 200 million years ago. The Panel urges confirmation of this important date by further studies and other techniques, as described in Section 7.8 of the DSCR.

In summary, the Panel views the DSCR as a progress report on a continuing program of geotechnical data collection and analysis, conducted under the constraint of no perturbation of the potential site. The Panel considers the report to be useful as a compendium of the information available to the authors on the character of the unperturbed geological formation at the Los Medanos site and the dynamics of the geochemical/hydrological system. On the basis of this available information, further investigation of the site is warranted. However, final decisions regarding repository site selection must take into account more information than is contained in this report. Most importantly, they must take into account the effect of the emplacement of the waste and the waste itself on the repository and its surroundings. These decisions must be based also on supplementary data acquisition and analyses such as those suggested above; the additional studies delineated in the document itself; crucial in-situ studies conducted throughout the construction phase; and additional definition of design objectives, criteria for safe operation, and waste forms to be accommodated.

Sincerely,

Frank L. Parker

Frank L. Parker, Chairman
Panel on the Waste Isolation
Pilot Plant

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF SEPTEMBER 10, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES

2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

September 10, 1979

Dr. E. Bright Wilson, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C. 20418

Dear Dr. Wilson:

During the past year, the Panel on the Waste Isolation Pilot Plant (WIPP) has become familiar with the findings of the various extensive geological explorations, including boreholes from the surface and attendant geotechnical studies, attempting to characterize the proposed WIPP site and provide a basis for judging this aspect of the site's suitability for a waste repository. This familiarization process has included briefings by representatives of Sandia Laboratories and the U. S. Geological Survey, study of both the published and unpublished technical literature, site visits, examination of actual borehole cores, and discussions with other experts in selected geotechnical areas.

Our efforts have brought to light no disqualifying results from these explorations and studies to rule out further consideration of the proposed site at this stage. The Panel has reached this conclusion after taking into account the comments made in my letter of May 1, 1979, reporting on our review of the WIPP Draft Site Characterization Report (issued as SAND78-1596, Geological Characterization Report), pointing out that certain effects have been observed which can be interpreted as indicating the possible existence of significant anomalies. Additional information is clearly required before these anomalies can be resolved

and a decision made regarding the adequacy of the proposed WIPP site for the construction of a repository. Furthermore, continued commitments to final details of repository design in the absence of additional site-specific information may be both misleading and wasteful.

The Panel is of the unanimous opinion that continuing efforts to acquire the necessary additional information solely by means of surface exploration, including boreholes, have reached the point of diminishing returns and cannot resolve all the major remaining uncertainties. Accordingly, the Panel recommends that:

(1) An exploratory shaft be sunk at the site of one of the proposed access shafts as soon as practicable, to the depth of the proposed repository horizon.

(2) Drilling be done and tunnels developed in the salt as necessary to conduct the measurements and observations needed to resolve remaining site-specific geotechnical uncertainties and to ascertain the degree to which the site is suitable for the excavation of a repository.

Development of the shaft, tunnels, and any other exploratory excavations should be consistent with applicable environmental and safety standards, strict quality assurance procedures, and should be compatible with an actual repository, if one is constructed at this site.

Sincerely,

Frank L. Parker

Frank L. Parker
Chairman, Panel on the
Waste Isolation Pilot Plant

NATIONAL ACADEMY OF SCIENCES

CONTINUING EVALUATION OF THE CARLSBAD SITE

Report No. DOE/CH/93023-1

CONTINUING EVALUATION OF THE CARLSBAD SITE

A Report to the U. S. Department of Energy, prepared by the Panel on the Waste Isolation Pilot Plant of the Committee on Radioactive Waste Management.

COMMISSION ON NATURAL RESOURCES
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
Washington, D. C.
July 28, 1980

N O T I C E

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ABSTRACT

It is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements, set forth in his February 12, 1980, message to the Congress, for evaluation of this site as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

NOTICE: The project that is the subject of this report was authorized by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. Such authorization reflects the Board's judgment that the project is of national importance and appropriate with respect to both the purposes and resources of the National Research Council. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

The report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee of the National Academy of Sciences.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its Congressional charter of 1863, which establishes the Academy as a private, non-profit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

Funded by the U. S. Department of Energy
Contract No. EY-76-C-02-2708-023

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NOTE: Two Panel members did not participate in the deliberations leading to this report; John W. Winchester was out of the country on sabbatical leave, and Karl P. Cohen is a new member of the Panel.

CONTINUING EVALUATION

OF THE CARLSBAD SITE

The Panel on the Waste Isolation Pilot Plant (WIPP) was organized by the National Academy of Sciences in 1978, under the Committee on Radioactive Waste Management of the National Research Council, to review the scientific and technical criteria and guidelines for designing, constructing, and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere, with specific attention to a proposed site near Carlsbad, New Mexico.

On February 12, 1980, President Carter transmitted to the Congress "A Report on His Proposals for a Comprehensive Radioactive Waste Management Program." This report states the President's decision that the WIPP project, currently authorized for the unlicensed disposal of defense transuranic waste and for research and development using high-level defense waste, should be cancelled; but that the Carlsbad site will continue to be evaluated, along with other sites in other locations, for possible use as a licensed repository for defense and commercial high-level wastes.

The Panel has reviewed in depth the work of the DOE contractors on the geologic characteristics of the Carlsbad site, the characteristics of the defense and spent-fuel radioactive wastes that have been considered for emplacement, and the conceptual design of the repository. The WIPP Draft Environmental Impact Statement has been analyzed with

respect to the potential impact on public health and safety.

As a result of these deliberations, the Panel has previously concluded that continued investigation of the Carlsbad site is warranted and has recommended that the project proceed with an exploratory shaft to determine in greater detail the geologic, hydrologic, and structural features of the candidate salt beds, and with in-situ tests as necessary to evaluate the geotechnic adequacy of this site for a waste repository. The Panel considers these in-situ tests to be no less timely and technically desirable within the framework of the President's statement.

In connection with the Carlsbad site, a talented team of scientists and engineers has been assembled, and extensive geological exploration has been conducted. Laboratory facilities are excellent, important experiments on waste disposal are under way, and underground engineering designs have been developed. The project has gained momentum that would be difficult to recapture if it were to be interrupted. There are sound technical reasons for continuing the exploratory work:

1. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

   The analyses made thus far, supported by ongoing and planned testing programs to validate these analyses,

lead to the reasonable expectation that the site may be suitable not only for its original limited purpose as a defense transuranic waste repository but also as a licensed repository for both defense and commercial high-level and transuranic waste. The present experimental program will yield results that can be applied to the expanded purpose envisioned in the President's program. The exploratory shaft, now planned and ready to be constructed to a depth suitable for transuranic waste, can be extended to a lower horizon, where there is another salt bed that may be better suited for high-level wastes. The information obtained from this exploratory work will not only be useful for further evaluation of the Carlsbad site but can also be applied to other candidate salt formations.

2. <u>The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives.</u>

Very long lead times are involved in the President's proposed new program of selecting alternative sites, constructing test facilities at each, choosing a first repository site, and eventually constructing one or more licensed repositories.

The extensive information already obtained on the Carlsbad site and the demonstrated expertise of the existing investigative teams provide an

opportunity to proceed much sooner with in-situ testing at a potential candidate site--a capability which will have to be developed before this or any other site can be selected for a first actual repository.

More is known about the Carlsbad site than about any of the other sites under consideration. Questions remain that will require resolution by additional analyses and testing, but such questions are normal for this stage of an investigation.

The Panel concludes that it is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements for evaluation of this site, as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. If so reoriented, the project could contribute by:

- providing prototype experience in site qualification;
- testing, in situ, performance assumptions about the geologic medium; and
- developing techniques and information which will be required in the licensing process.

If given this new mission, work should proceed on constructing the exploratory shaft, acquiring hands-on repository mining experience, conducting in-situ tests and measurements at various depths, verifying engineering design assumptions, and developing analyses for licensing review.

NATIONAL ACADEMY OF SCIENCES

PROGRESS REPORT: JULY 1, 1978 TO DECEMBER 31, 1979

DOE/NE/93023-2

REVIEW OF THE CRITERIA FOR THE SITE SUITABILITY, DESIGN, CONSTRUCTION, AND OPERATION OF THE PROPOSED WASTE ISOLATION PILOT PLANT (WIPP)

PROGRESS REPORT: JULY 1, 1978, to DECEMBER 31, 1979

Prepared for
the U.S. Department of Energy
under Task Agreement No. DE-AT01-76NE93023

PANEL ON THE WASTE ISOLATION PILOT PLANT

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT

COMMISSION ON NATURAL RESOURCES

NATIONAL RESEARCH COUNCIL

WASHINGTON, D.C. SEPTEMBER 1981

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In March 1978, the Department of Energy (DOE) asked the National Research Council "to review the scientific and technical criteria and guidelines for designing, constructing and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere." The National Research Council assigned the study to the Committee on Radioactive Waste Management under the Commission on Natural Resources. The Committee organized the Panel on the Waste Isolation Pilot Plant to "review the scientific and technical adequacy of the site-suitability criteria; the guidelines for the site confirmation studies; the design criteria for the repository, including the waste acceptance criteria, the design philosophy, and the operational philosophy; the criteria for determining the environmental safety of future planned operations, viewed from the perspective of the environmental conditions of the repository site; and the design criteria for the experimental testing program of the behavior of the waste-geologic medium interaction."

In July 1978, when this study began, the Waste Isolation Pilot Plant (WIPP) was to be a mined repository in bedded salt in Eddy County, New Mexico, for the disposal of transuranic (TRU) waste, with experimental facilities for studying the interactions of high-level waste with the host rocks. At that time, though not officially part of the project mission, DOE was also considering use of this repository for disposal of a limited number of commercial spent fuel elements as an alternative waste form. This option was discussed frequently in technical briefings of the Panel and in supporting documentation. The Panel has examined some of the generic issues related to this possible course of action, as well as those concerns raised solely by the proposed disposal of transuranic waste in the particular salt formations at the WIPP site.

This report recounts the Panel's findings through the end of 1979--the first half of the originally contemplated three-year study. By that time, several major program documents had been issued and examined by the Panel, including the Geological Characterization Report (Sandia Laboratories 1978), the Title I Design Report (Bechtel National, Inc. 1979), and the Draft Environmental Impact Statement (U.S. DOE 1979). This report is based on analysis of the contents of these and other documents, numerous technical briefings, extensive

discussions with representatives of DOE and its contractors, and several field visits.

Not all of the views expressed herein are currently pertinent. During 1980 and early 1981, following the period covered by this report, the WIPP project experienced major changes in direction and scope, as well as varying degrees of administrative certainty regarding its future. Many of the technical deficiencies that were perceived to exist at the end of 1979 have since been remedied by additional investigations and design changes. During 1980, a Final Environmental Impact Statement, a Safety Analysis Report, and a Revised Title I Design have been issued, and work has now begun on the Site and Preliminary Design Validation Program. Evaluation of these more recent efforts, in the context of the currently defined mission of WIPP as a repository for defense-originated TRU waste only, is a matter for future deliberation by the Panel.

CHAPTER 1

INTRODUCTION AND BACKGROUND

The history of the Waste Isolation Pilot Plant (WIPP) project was presented to this Panel at a study planning session on June 5, 1978. As far back as March 1974, the Oak Ridge National Laboratory had begun site investigations for a terminal radioactive waste repository in a region selected by the U.S. Geological Survey in the Los Medanos area of New Mexico. In May of that year, this work was suspended in favor of the concept of retrievable surface storage, and the land-withdrawal action that had been initiated was deferred in December 1974. The Albuquerque Operations Office of the U.S. Atomic Energy Commission (AEC) and the Sandia Laboratories were then requested by AEC headquarters to become involved in the program to locate a site for a radioactive waste disposal pilot plant for defense low- and intermediate-level transuranic waste, with some provisions for experimentation with high-level waste. When drilling began at the Los Medanos region in 1975, unanticipated subsurface geological conditions were found, including high-pressure brines and gases. Consequently, the first drilling site was rejected, and the U.S. Geological Survey and Sandia recommended a new site 7 mi (11.2 km) to the southwest. The general location of the site and a geologic section through the Los Medanos area are shown in Figures 1.1 and 1.2, respectively. In January 1976, the geological investigations were resumed at the newly proposed site, and the project was given its present name: Waste Isolation Pilot Plant.

The drilling of ERDA 9, the first hole at the new site, commenced in April 1976. In October 1976, funding was requested for an architect-engineer, and a new land-withdrawal notice was placed in the Federal Register in December 1976. In April 1977, a preliminary version of the Draft Environmental Impact Statement was distributed by the Department of Energy (DOE) for comment, and it was announced that WIPP would be a licensed facility. In June, the final version of the conceptual design was issued. In September, Bechtel was selected as the architect-engineer, and in November, the DOE sent a letter to the Nuclear Regulatory Commission saying they intended to request a license.

In February 1978, the "Deutch Report" (U.S. DOE 1978) called for a demonstration of the experimental emplacement of high-level waste and possibly ultimate disposal of commercial spent fuel at the WIPP site. Objections were raised by the U.S. House Armed Services Committee,

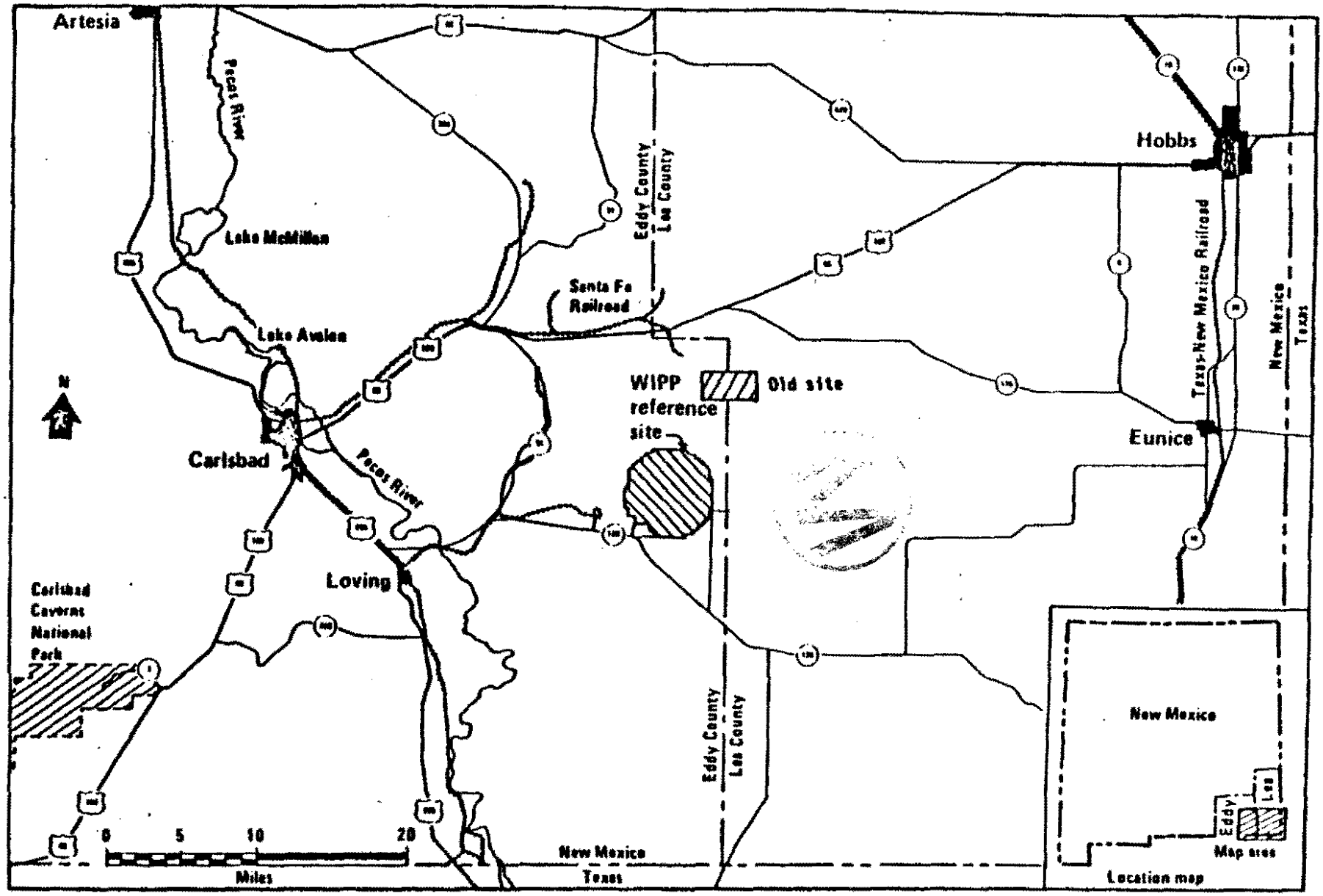

FIGURE 1.1. General location of the WIPP site.
SOURCE: U.S. Department of Energy (1979).

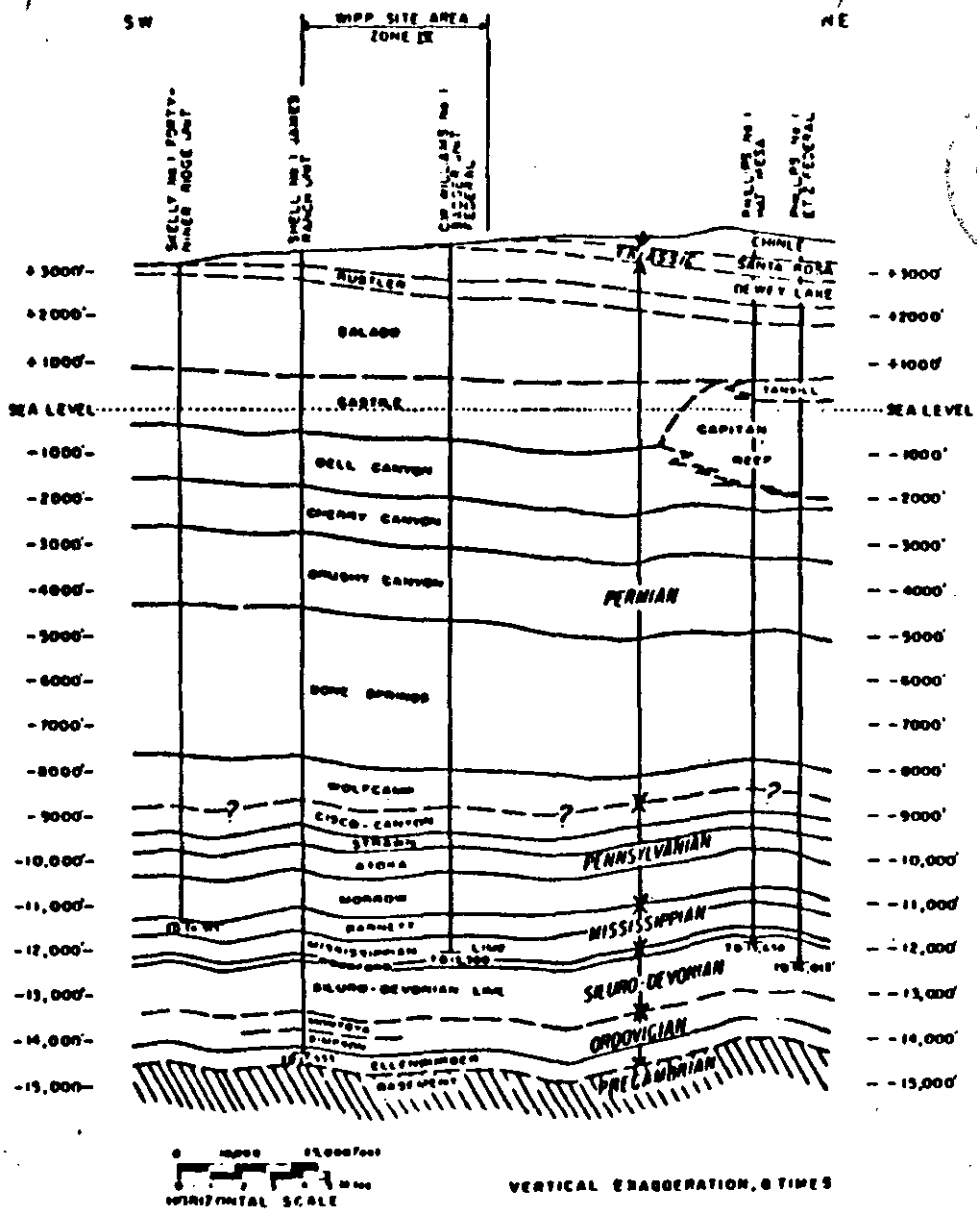

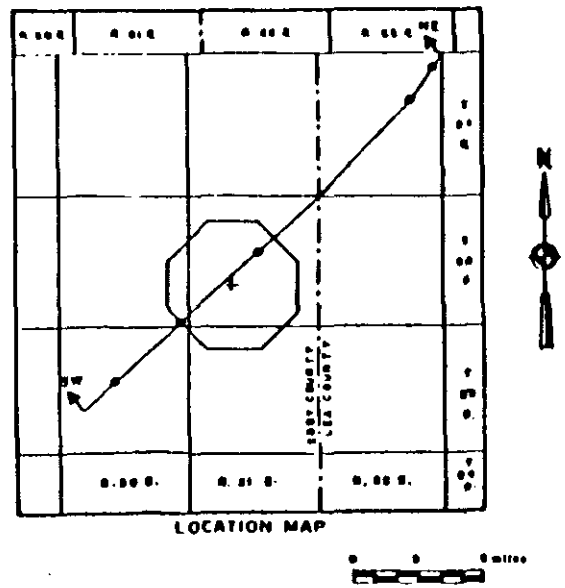

FIGURE 1.2. Generalized site stratigraphic section.
SOURCE: Sandia Laboratories (1979); after Netherland, Sewell and Associates (1974).

which held that the site should be unlicensed and used only for defense waste.

The Geological Characterization Report (Sandia Laboratories 1978), a compilation of geotechnical information available as of August 1978 and judged to be relevant to WIPP studies, was published in December 1978.

In March 1979, an Inter-Agency Review Group (IRG) appointed by President Carter reported (IRG 1979) on its review of the progress of the U.S. waste disposal program and suggested four alternative technical strategies, one of which would specify salt as the host geologic medium for the first mined repository. The following month, the WIPP Draft Environmental Impact Statement, or DEIS (U.S. DOE 1979), including consideration of the possibility of disposal of limited quantities of commercial spent fuel, was issued for public comment. As of the end of 1979, no decision had been made among the several options suggested by the IRG, and the DEIS was still undergoing public review and comment.

Independently of this DOE-sponsored study by the National Research Council, the state of New Mexico itself has set up four groups concerned with WIPP--an Environmental Evaluation Group (EEG); a Radioactive Waste Consultation Task Force, composed of three members of the governor's cabinet; a Radioactive Waste Consultation Committee, composed of eight members of the state legislature, and a Governor's Advisory Committee on WIPP.

WIPP program activities were in progress during the course of this study; thus the Panel was evaluating existing data and concepts while new information was being obtained and analyzed. This report is not a summary of WIPP activities, but an analytical commentary on those aspects that the Panel reviewed through the end of 1979. For completeness, material has been included that was incorporated previously in two letter reports (Appendixes A and B) that dealt with the suitability of the site from a geological and hydrological standpoint and the limitations of surface exploration of underground formations.

CHAPTER 2

SITE SELECTION CRITERIA

The criteria used in selecting the WIPP site include the generic criteria commonly cited in proposals for waste isolation in bedded salt (National Research Council 1970, 1978) and seem technically and scientifically adequate. They require (1) a bed of rock salt (halite) at least 60 m thick, as pure as possible, to minimize complications from brine of complex composition and from water released from hydrous minerals; (2) a depth greater than 300 m to ensure freedom from surface influences; (3) a depth less than 1,000 m to ensure acceptable creep rates in the salt; (4) approximate horizontality to minimize difficulty in mining operations; (5) little indication of recent tectonic or igneous activity; (6) sufficient distance from an exposed edge or underground aquifer where salt dissolution is occurring; and (7) an area without sizable economic resources.

Two additional criteria specific to the Carlsbad area were suggested by previous experience at Lyons, Kansas (Bradshaw and McClain 1971) and at an earlier WIPP site mentioned in the DEIS: location of the repository at least 1.6 km from the nearest borehole penetrating as deep as the selected beds, and at least 8 km from the Capitan Reef, to avoid a zone of disturbed bedding known to parallel the reef.

With these criteria in mind, lines were drawn on a map to outline areas where salt beds of requisite thickness at proper depths were known to occur and to exclude areas within 1.6 km of known deep boreholes, within 8 km of the Capitan Reef, within 1.6 km of the dissolution front, or with known potash or hydrocarbon resources. Two areas of reasonable size outside these lines were identified (see Figure 2.1). One seemed less suitable because it had deeper salt beds and was closer to an oil field where water flooding may be used for secondary recovery in the future. Both sites have the advantages of nearly flat topography, an arid climate, and sparse population. The major regional geologic structures in the vicinity are shown in Figure 2.2.

Although the generic criteria as applied to the WIPP site are in considerable measure satisfied, questions about three of them have not been completely answered. Most troublesome of the three is the problem of economic resources: recent evaluation of resources during site characterization indicates the likely presence of economically significant quantities of potash and natural gas at the site. Because

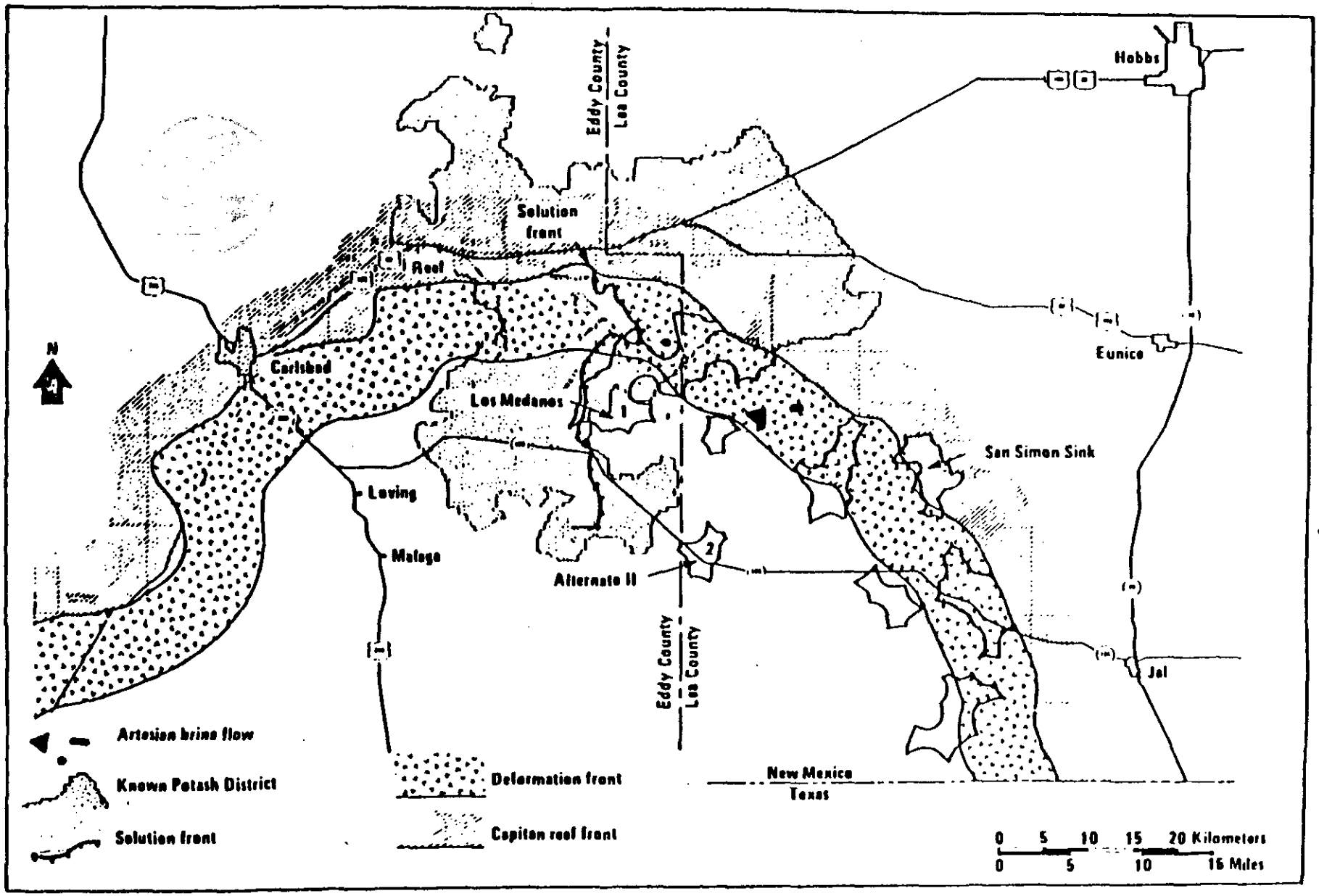

FIGURE 2.1. Application of the site selection criteria.
SOURCE: U.S. Department of Energy (1979).

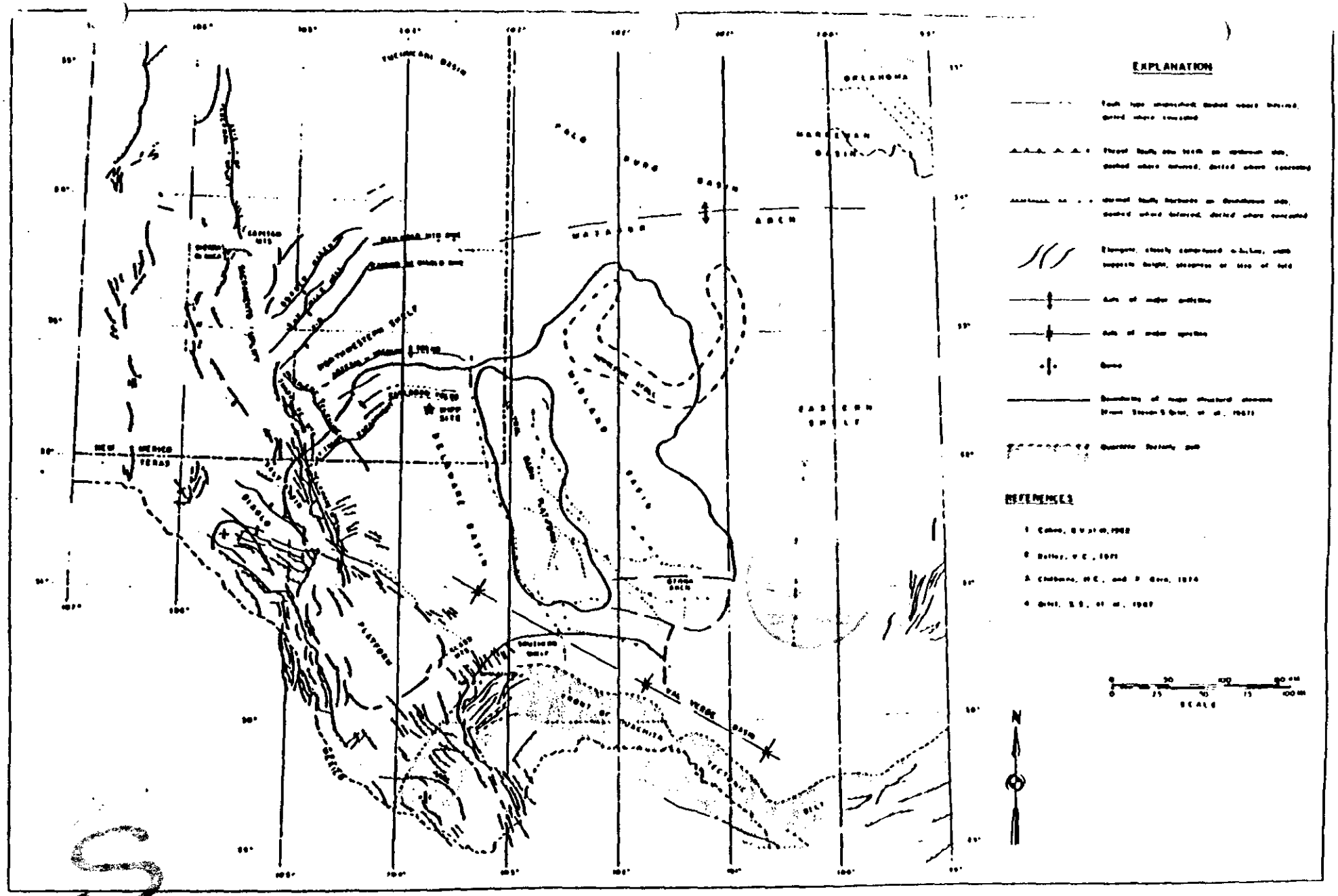

FIGURE 2.2. Major regional structures in the vicinity of the WIPP site.
SOURCE: Sandia Laboratories (1978).

the potash deposit is 400 to 800 ft (120 to 240 m) above the proposed repository horizons, it could probably be mined without disturbing a repository beneath. The natural gas is below the repository beds and could probably be tapped by angle drilling. The existence of the potash and hydrocarbons means that the criterion specifying minimal conflict with natural resources may not be satisfied; but the possibility of recovering both materials without jeopardizing a repository site implies that acceptability of the site is not necessarily compromised. Further study is needed for a decision as to whether recovery of the potash and hydrocarbons must precede construction of a repository, in which case government subsidy of the operation would be needed, or whether recovery could be safely deferred to a later date, after the repository is completed, when the value of the resources might be greater or less and their exploitation might be more or less economically attractive.

A second unresolved question concerns the possibility of salt dissolution by upward-moving water from aquifers below the salt beds. If the dissolution were concentrated in isolated fissures in the underlying beds, fluid circulation might be set up that would lead to active dissolution of the salt in small areas and possible subsequent collapse of the overlying salt beds. This hypothetical mechanism is a possible explanation for the vertical pipe-like masses of broken rock, the so-called "breccia pipes," that have been found in a few places in this region. The number and significance of these features remain conjectural. The pipes are difficult to recognize in geologic mapping at the surface, because their outcrops are easily confused with local areas of breccia formed by near-surface dissolution of evaporite and carbonate minerals. All the drilling done through 1979 has identified only three pipes, and these are all over the Capitan Reef or its back reef facies, which are prolific aquifers. Despite extensive potash mining in the Delaware Basin, only a single pipe has so far been encountered underground. Because no pipes are recognized or suspected at the WIPP site, and because no certain evidence of present-day pipe-forming activity has been reported elsewhere in the region, the chance of damage to a waste repository from this source seems small. The effects of such a connection are discussed in Chapter 5.

Nevertheless, either the presence of an old, inactive pipe in an area being considered as a repository site or the formation of a pipe during or after repository construction could have consequences serious enough to require attention. The danger from an inactive pipe is the possibility that the fractured material in the pipe itself, or the disturbed salt beds near the pipe, might be more permeable than the surrounding salt and could thus serve as a conduit for groundwater movement into or away from a repository. No evidence of greater permeability has been reported in or near the pipes examined to the end of 1979, and the areas of disturbed beds caused by pipe formation are limited to zones a few tens of meters in diameter. Hence inactive pipes beyond the periphery of the WIPP site would not jeopardize a repository, and a pipe within the site could be avoided in repository construction; but the possibility of more permeable material in a pipe is great enough that pipes within the site should be located and

carefully studied. The danger from formation of a new pipe is the obvious one that collapse of salt beds beneath a repository as the pipe works its way upward would open the site to inflow of groundwater. Any evidence for present-day pipe-forming activity would therefore be important, even though such activity at a distance of several kilometers from the WIPP site would not constitute a direct threat to repository integrity.

The distribution of existing pipes in and near the WIPP site can be determined by horizontal drilling into the Salado beds from the base of an exploratory shaft and by drilling from the surface in places where rock structure or topography gives an indication of disturbance that might be caused by breccia pipes beneath. Present breccia-forming activity, if it exists, would presumably show itself by areas of subsidence at the land surface, such as San Simón sink; drilling into such areas could demonstrate whether the subsidence actually results from breccia formation at depth. Furthermore, any deep dissolution that may be occurring would probably be concentrated along zones of fracturing, and such zones may betray themselves on LANDSAT imagery. Mapping of lineaments from the images could be used to guide additional drilling. Such mapping would be useful also in locating places where nearer-surface groundwater flow may be concentrated, particularly in aquifers in the Rustler formation.

Further study of the nature and distribution of breccia pipes is obviously desirable, but how extensive the study should be is not clear. Certainly all scientific questions about these structures need not be answered for purposes of site characterization. A consequence analysis of the possible effects of breccia pipes is needed and is in fact being planned by Sandia scientists (as of the end of 1979). Preparatory to this analysis a program to characterize existing pipes is under way, with respect to porosity, deformation of adjacent beds, movement of hydrocarbons, and probable age. When this program is completed a decision should be possible as to whether the hazard to a repository posed by existing or potential future pipes is sufficient to warrant fuller investigation.

Two additional possible problems are (1) the pockets of pressurized brine that are known to be present in the Castile formation and could be present in the Salado and (2) the thin layers of breccia, possibly formed by widespread subsurface dissolution within the salt beds, that have been noted in a few drill cores from boreholes outside the WIPP site (Anderson 1980). A large brine pocket would indeed be a major hazard to workmen if it were penetrated unexpectedly during excavation of a repository, but the pockets can be located in advance of construction by exploratory drilling or geophysical techniques and can be drained by well-known engineering procedures. Interpretation of the breccia beds is controversial, but no confirmatory evidence for extensive interbed dissolution has been suggested except near the salt edge on the west side of the basin. Neither breccia beds nor brine pockets appear to constitute a serious problem on the basis of present knowledge, but their significance can be better evaluated when subsurface exploration is undertaken.

Dissolution at the salt edge west of the WIPP site has been in progress for a long time, and of course is continuing today. The maximum rate of lateral retreat, estimated from the conservative assumption that the Salado formation extended to the Capitan Reef on the eastern edge of the basin at the end of Ogallala time, is 6 to 8 mi (9.6 to 12.8 km) per million years. The rate of vertical lowering of the salt by dissolution has been estimated (from rates of brine discharge into the Pecos River and streams east of the basin) at 330 to 500 ft (100 to 150 m) per million years. Since the Rustler-Salado contact where dissolution is active at present lies 2 mi (3.2 km) west of the center of the WIPP site, a repository at a depth of 1500 ft (450 m) below this contact would not be jeopardized by salt dissolution for at least a few million years.

The possibility of rapid dissolution along particular zones in the salt should be explored, however, to make sure that the rate of retreat of the front through the long future is adequately represented by extrapolation of average values. Such exploration (which is currently in progress) will require detailed surface mapping, supplemented by trenching and shallow drillholes. The probability of local dissolution rates greatly exceeding the average is so remote, however, that the sinking of an exploratory shaft should not be delayed on this account.

The third criterion that has recently been called into question is the tectonic stability of the region in which the WIPP site is located. Because fault movement and eruptions of basalt are known to have occurred in the Rio Grande valley 250 km west of the site during the past few million years, because recent faulting has occurred at the salt graben 70 km west of the site, and because precise leveling has shown evidence of continued slow displacement of rocks underlying the valley, the WIPP site is thought by some to be in jeopardy. It is even speculated that fault motion might be occurring today beneath the salt beds, not noticeable at the surface because the motion would be taken up by plastic deformation in the salt. Considerable distance separates the WIPP site from the Rio Grande valley, however, and there is neither seismic evidence for significant crustal movement near the site nor geologic evidence for tectonic disturbance or volcanic activity during the past several million years. The faults and lava flows in the Rio Grande valley have been known for a long time and were critically considered when the WIPP site was chosen; recent work has added no convincing new evidence for tectonic effects at this distance from the valley.

Because there is no evidence of tectonic effects of any magnitude and because minor tectonic disturbance, in any event, would not significantly damage a well-engineered repository, the Panel thinks that the site satisfies the criterion of tectonic stability. Additional evidence regarding tectonic activity is desirable, of course, and measurements to provide such evidence are under way. The criterion of tectonic stability seems so well satisfied, however, that these measurements should not be cause for postponing underground exploration.

Through 1979, study of the WIPP site has been limited to geologic mapping and geophysical measurements at the surface, examination of

boreholes and drill cores, and laboratory experiments on salt samples. Assurance that the salt beds do not have structures that might complicate repository construction or serve as channels for groundwater movements--faults, anticlinal folds, shale interbeds, breccia pipes--has been provided only by such surface observations. Further work of this sort is still needed, particularly to provide data on the number and nature of breccia pipes in the vicinity and on details of dissolution at the salt edge. In many respects, however, exploration from the surface has been so complete and so detailed that it has reached a point of diminishing returns, not to mention the risk to the integrity of a future repository that could result from additional deep boreholes. Even if long continued, these efforts are unlikely to provide the critical evidence regarding details of the physical and chemical characteristics of the candidate salt beds that will be needed for a decision as to whether the site is or is not suitable for a repository. This kind of evidence can be obtained only by study of the salt in place, which requires sinking a shaft and exploring the salt bed or beds by tunnels and horizontal drilling.

In summary, study of the WIPP site and its environs has shown that the criteria for site selection were in considerable measure satisfied; the Panel thinks probable site suitability has been demonstrated sufficiently to justify the sinking of an exploratory shaft without delay, as was recommended in the letter attached as Appendix B.

CHAPTER 3

DESIGN OF UNDERGROUND FACILITIES

Once a suitable site for an underground nuclear waste repository has been selected, one of the most important factors--if not the most important one--contributing to the successful use of deep underground excavations for the disposal of radioactive waste is the design and construction of the excavations that constitute the repository. Unfortunately, the initial conceptual repository designs of which the Panel is aware, including the design proposed for the WIPP site, reveal neither a clear understanding nor recognition of the important difference between a mine and a repository. Mining engineering provides a wealth of experience related to the design and construction of a repository, but the function of a repository is very different from that of a mine. The principal objective in mining is to remove as much of the ore as is practicable, consistent with short-term safety. The principal objective in making repository excavations is to disturb the geologic media as little as is practicable, so as to ensure long-term safety and isolation.

The WIPP repository has already progressed to the stage of preliminary (Title I) design. According to DOE definitions, Title I design ". . . utilizes the conceptual design and design criteria that have been prepared for the project as design bases." It involves the refinement of descriptive information and the development of more detailed outline specifications that will serve as the firm basis for definitive (Title II) design. The Title I Design Report by Bechtel National, Inc. (1979) reveals concepts and details that raise questions concerning design safety and adequacy.

Adequate conceptual design of an underground repository requires recognition that the properties of a geologic medium, even salt, are unlikely to be uniformly satisfactory over dimensions of interest and that many variations in the properties and structure of the salt at the depth of the repository will be revealed only as the excavations are made. Some of these variations may lead to unexpected difficulties or may adversely affect the ability of the salt or the overlying strata to isolate the wastes from the biosphere. Accordingly, it may prove desirable to be able to treat some portions of the repository differently from others and perhaps even exclude some portions of the site from use for the disposal of waste.

For these reasons, and to limit the extent of any accidents that may occur prior to final sealing of the repository, such as the intersection of a major brine reservoir or the outbreak of a fire, the repository should be laid out as a number (say, four to six) of independent modules. Substantial barriers of undisturbed salt should be left between modules, to ensure that each module is isolated effectively from every other module. As few accessways as necessary for safe development of a module should penetrate these barriers, and each accessway should be provided with a bulkhead, which can be closed quickly at either end of the barrier. Ultimately, these accessways must be sealed permanently with a fill having low porosity and permeability.

As shown in Figure 3.1, the original Title I design [note: changes in this design made since the end of 1979 should be reviewed by the Panel in its subsequent deliberations] showed the repository essentially as sets of four rooms 32 ft (9.7 m) wide, separated by support pillars 25 ft (7.6 m) wide, and separated from adjacent sets of rooms and pillars by abutment pillars 360 ft (109 m) wide, penetrated at intervals of 268 ft (81.2 m) by crosscuts. This design gives an overall extraction ratio of about 26 percent. Kaiser Engineers, Inc., note that "A room with a central pillar is not favored because high extraction ratio is counterproductive for a repository, where safety is reduced and cost increased as extraction is increased" (Watson et al. 1979).

This original Title I design incorporated a degree of modular design through the use of the large abutment pillars, but the integrity of the pillars was destroyed partially by the crosscuts. The Panel was advised that these crosscuts would be closed by bulkheads at each end and that, finally, the space between bulkheads would be sealed by filling each crosscut, in an endeavor to restore the integrity of the abutment as a whole. The original Title I drawings, however, show that these crosscuts are to be used for the disposal of waste. The isolation that would be provided by the bulkheads in the event of fire, flooding, or leakage of waste is questionable, and thus even the modest degree of modularization in the original design is compromised. The Panel is convinced that truly modular repository design would make better provision for geological variations and would provide more inherent safety, by preventing accidents or failures in one part of the repository from spreading throughout the repository.

A well-established rule of thumb from wide mining experience is that adjacent excavations should occupy less than a third of the plan area if there is to be no adverse interaction between them. Figure 3.2 was prepared by Serata (1978) of Serata Geomechanics, Inc., consultants to Bechtel on the design of the underground excavations at the WIPP facility who have a wealth of experience in evaporite mining. The figure illustrates the interaction between two adjacent circular cavities in weak and strong salt at various depths as a function of the ratio of their separation to their diameter. From this figure it is clear that this ratio must be greater than 4 to preclude excessive interaction. Serata claims that at ratios of less than unity the plastic deformation of the salt between cavities is stable, but it

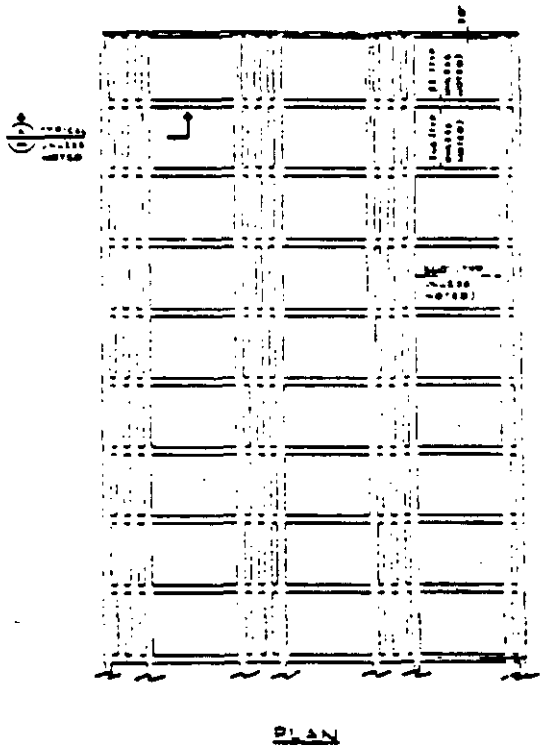

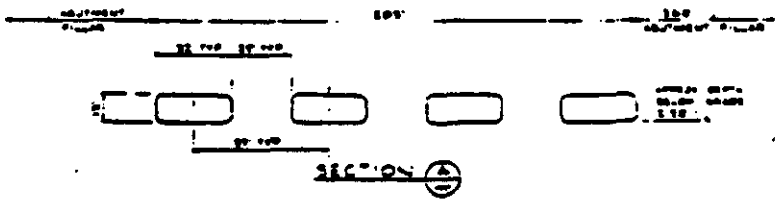

FIGURE 3.1. Repository room design.
SOURCE: Bechtel National, Inc. (1979).

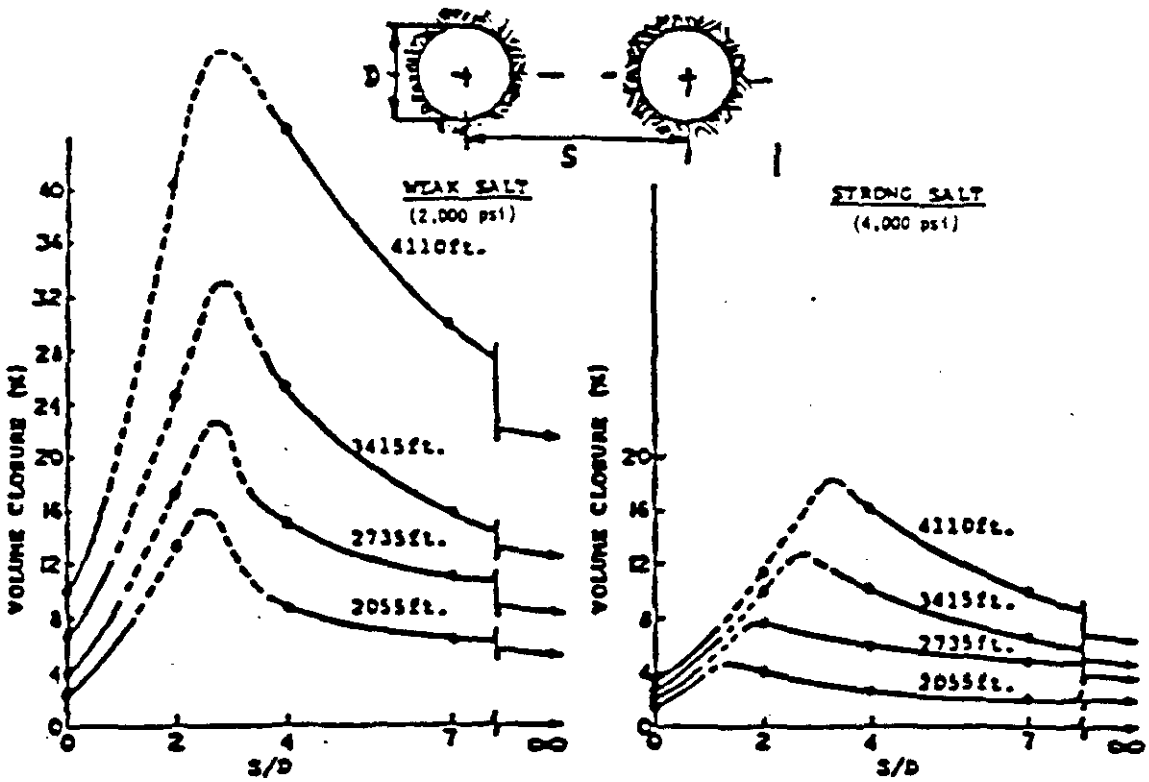

FIGURE 3.2. Critical separation distance of double cavities at various depths.
SOURCE: Serata (1978).

would seem to be most imprudent to design a radioactive waste repository, especially an early repository, in such a way that there was any question whatsoever about the behavior and stability of the salt between the excavations.

If the above arguments and evidence are accepted, the ratio of the center-line spacing of the cavities to the cavity diameter in the Title I design is much too small. Interaction between these excavations must be expected, and no one can be sure that it will not impair the safety and stability of these excavations. Accordingly, on the basis of much experience and Serata's data, the Panel believes strongly that the "separation distance" (S/D) between adjacent excavations everywhere should be greater than 4, giving an extraction ratio of 25 percent or less.

Using the SANCHO finite-element large-strain creep code, Sandia has done a structural analysis of the Title I design and compared this with two alternative layouts of the repository excavations (Krieg et al. 1979). In this analysis, a "standard structural model" for the geology was based on data from the ERDA 9 borehole (Wawersik 1979); mechanical properties for the salt were taken from SAND79-1853 (Munson and Dawson 1979); and, for other rocks and seams, properties were taken from the literature or estimated. The two alternative layouts both comprised uniformly spaced rooms: one layout with rooms 33 ft (10 m) wide separated by pillars on centers of 127 ft (38.6 m), giving the same overall extraction ratio as that in the Title I design; and the other with rooms 50 ft (15.2 m) wide separated by pillars on centers of 236 ft (71.7 m), giving a slightly smaller extraction ratio.

Even though the analysis was made for periods up to only 10 years, the two alternative layouts were shown to be superior to the Title I design, which showed horizontal convergence of the excavations as much as 4 times greater than that for a single-drift configuration. In the far field, a stress disturbance was found to extend over the entire horizontal span of the pillars, tending to confirm the criterion that the local extraction ratio should not exceed 25 percent.

An analysis such as this, based on limited data, uses many assumptions and may contain important omissions. In view of the pervasive changes in stress that occur within 10 years and of stress concentrations at stratigraphic discontinuities, it should be noted that Serata chose pillars 360 ft (109 m) wide to achieve isolation between sets of adjacent rooms. In any event, the incorporation of a limited number of major barrier pillars several hundred feet in width, as proposed in the modular design, would make it unnecessary to rely on pillars 100 ft (30.4 m) wide acting infallibly as "infinite pillars." Although, as stated above, the local extraction ratio within each module could safely be as high as 25 percent, the overall extraction ratio for the repository, including these barriers, should be significantly lower.

The analysis shows far-field effects brought about by relatively small amounts of convergence across the excavations in the short term (10 years). Waste and backfill in these excavations are likely to have a void space of about 40 percent, unless special procedures are developed for greater compaction. In the longer term, partial

compression of this void space will occur as a result of much greater convergence across these excavations than that calculated in the analysis. Correspondingly greater far-field effects, particularly at stratigraphic discontinuities, may disrupt the salt in a very different way than would geologic events in the absence of man-made perturbations. Assumptions based on the behavior of salt in its pristine conditions may not be valid. Accordingly, analyses of this kind should be done for much longer periods of time--say 50, 100, and 1,000 years. Such analyses should address the question whether, if the intrinsic self-healing, viscous properties of the salt are to be used to ensure isolation, closure of the excavations will need to be limited to values much lower than those that would prevail if the cavities were filled with waste and backfill having an initial total void space of about 40 percent. A finding that closure should be limited would have important implications for waste forms and backfills.

Closure of the excavations, even in the long term--say between 100 and 1,000 years--is not likely to reduce the void space in the waste and backfill to a negligible value. A void space of the order of 10 percent is a likely equilibrium condition, and such a void space will result in a hydraulic permeability significantly greater than that of the pristine salt. Thus the excavations of a repository make up a network of interconnected hydraulic conduits in the salt mass. Although stratigraphic discontinuities, breccia pipes, and brine reservoirs are known to occur in salt, geological evidence indicates that the self-healing properties of the salt in its undisturbed condition make these relatively unimportant in connection with the dissolution of salt beds. However, the perturbation of these geologic features by the repository excavations and the establishment within the salt of an extensive interconnected network of hydraulic conduits may change the effects of these geological features and render the salt much less stable than has been assumed.

A careful analysis of such effects should be made, though they would not be expected to be greater than those resulting from scenarios of water flow between two aquifers (Bingham and Barr 1979). There has recently been discussion of increasing the extraction ratio to accelerate closure of the excavations and, perhaps, create additional space for the disposal of waste. Very careful consideration must be given to such proposals. At some point, the degree to which the salt is perturbed by the excavations will affect adversely the safety of the repository and the ability of the salt to isolate the waste from the biosphere.

The implication of the proposals to accelerate closure--that excavations should not be left standing with significant void space--is probably correct and is, in fact, another aspect of the concerns discussed above. An adequate study of these problems should be made to determine whether it is necessary to seal the excavations in such a way that their void space and permeability are very much less than is currently envisaged. Such a study is needed to show that the intrinsic properties of salt can be taken advantage of to effect safe isolation of radioactive waste by deep geologic disposal.

CHAPTER 4

ACCEPTANCE CRITERIA FOR TRANSURANIC WASTE

A table of acceptance criteria for transuranic (TRU) waste, from the WIPP DEIS (U.S. DOE 1979), is reproduced here as Table 4.1. These criteria are principally concerned with factors that affect the short-term operational aspect of WIPP, that is, the emplacement and 10-year retrievability of containers of waste. The only long-term concern that is covered by a criterion is that of gas generation. Environmental impacts of transportation of waste packages to WIPP are not considered to be part of the waste acceptance criteria. These impacts are treated in Section 3.2.3 of the DEIS.

The most debatable of the acceptance criteria for TRU waste is the inclusion of organic materials such as wood, paper, plastics, and fabrics. The presence of these materials raises questions about fire in the short term and about gas generation and formation of organic complexes with radioactive materials in the long term.

FIRE

The criteria in the DEIS place no limit on combustibles, as long as they are enclosed in steel drums or in wooden containers with steel overpacks. This decision is supported by analysis of various accident scenarios, and the consequences of the accidents are estimated from fire tests documented in Section 4 of Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP (Sandia 1979).

The relevance of these tests is open to question, because all were made in the open rather than in the confined spaces where operations will actually be carried out; that is, within the surface processing buildings and underground. In a sense this is a conservative evaluation, because a fire in a confined space tends to extinguish itself as the available oxygen is depleted. However, there are important factors operating in the other direction. Firefighters are quickly incapacitated or panicked by accumulation of smoke and heat, failure of lighting, and depletion of oxygen. Furthermore, the forced-draft ventilation system that must be used in underground workings may have the effect of propagating and intensifying the fire.

TABLE 4.1. Interim Waste Acceptance Criteria for Contact-Handled TRU and Remotely Handled TRU Waste

Criterion	Contact-handled TRU waste	Remotely handled TRU waste
	WASTE FORM	
Combustibility	No limit, must be packaged in steel containers or overpack	No criterion; quantities are insignificant, and processing will probably not be available
Gas Generation	Gas-generating materials in any single storage room may not exceed 10% by weight	No criterion for above reasons
Immobilization	Powders, ashes, etc., must be bound in glass, concrete, ceramic, or other approved matrix; double containment allowed for special cases; sludges must contain no free liquid	Same as for CH TRU waste
Explosives	Not allowed	Same as for CH TRU waste
Pyrophorics	Small quantities of radionuclide-metal pyrophorics may be accepted with other waste forms	Same as for CH TRU waste
Hazardous materials	Allowed only with special procedures and precautions	Same as for CH TRU waste
	CONTAINER	
Design Life	10 years to allow retrievability	Same as for CH TRU waste
Structure	Type A requirements	Same as for CH TRU waste
	PACKAGE	
Structure	Type A; any damaged container must be overpacked	Same as for CH TRU waste
Handling	Devices to allow handling by means of a forklift	Axial lifting pintle
Weight	Less than 12,000 pounds	Less than 10,000 pounds
Dimensions	Not larger than 8 by 12 by 9 feet	24-inch diameter, 15-foot length
Radiation		
Surface-dose rate	Not exceeding 200 mrem/hr; sources producing more than 5000 ft^3/yr must produce waste with a 3-month average of less than 10 mrem/hr	Less than 100 rem/hr
Surface contamination	49 CFR 173.398	49 CFR 73.398
Criticality	49 CFR 173, Subpart H	30-gallon drum, 100 grams fissile; 55-gallon drum, 200 grams fissile; DOT-7A, 500 grams fissile
Thermal power	Color code if greater than 0.1 W/ft^3	No criterion

SOURCE: U.S. Department of Energy (1979).

Fires underground are well known from mining experience. They are particularly difficult to control. To extinguish such a fire it is generally necessary to cut off the supply of air. In principle this can be achieved by interrupting the ventilation air, or by supplanting the air by steam or some other noncombustible gas. In practice, it has proved to be very difficult to cut off completely the flow of air to underground fires. Even a low rate of combustion can generate high temperatures, because underground combustion sites are well insulated thermally. If the fire is successfully extinguished by ventilation control, the burned area may take a long time, even months, to cool off by conduction. Readmission of air before temperatures have dropped below the ignition point merely restarts the fire.

Fire control should be easier in a salt repository than in a mine. It is probable that a dependable fire-extinguishing system can be designed, using some combination of dry powder, foam (to control burning diesel fuel), and fog (to cool the burning material and displace air). For fire safety to be fully credible, however, a waste disposal configuration should be stipulated that will self-extinguish without any fire control measures whatever. Such a configuration involves both waste acceptance criteria and repository design.

To provide a self-extinguishing configuration it is not necessary to be concerned about the manner in which the fire starts, other than to assume that the initial energy is a pulse of finite magnitude and duration. It is further assumed that the mixture of combustible and noncombustible materials is arranged in a tunnel-like configuration, supplied with a continuous and unidirectional flow of ventilation air at ambient temperature, which carries the combustion products and the associated heat of combustion over and through the unburned material. Whether or not the fire propagates under these conditions depends on the heat balance; that is, on whether the heat liberated by reaction of oxygen with a combustible component of the tunnel contents is sufficient to raise the temperature of neighboring components to the ignition point. This heat balance should be calculated for various ratios of combustibles (boxes, plastics, etc.) to noncombustibles (steel containers, concrete, backfill salt, and the nitrogen of the ventilation air).

A meaningful fire test could be carried out in a tunnel packed with simulated TRU waste packages in a proposed repository configuration, with or without salt backfill, supplied with forced ventilation. The fire could be started with diesel oil or any other source of an intense heat pulse.

GAS GENERATION

Gas generation by TRU waste and the possible pressurization of the repository are considered briefly in the WIPP DEIS (pages 9-133 to 9-136) and exhaustively in several Sandia reports (Molecke 1979a,b; Sandia 1979). These documents conclude that bacterial action is the dominant potential source of gas production, with gas production from the plywood boxes covered with fiberglass-reinforced polyester (FRP)

being the largest single contributor in this category. This conclusion is independent of whether aerobic or anaerobic environmental conditions are assumed.

The analysis of gas generation sources has been carried out by resolving every doubt in the direction of higher gas generation potential. In an apparent effort to get measurable gas evolution in a reasonable time, the experimenters added water and nutrient salts to comminuted organic waste and then used the results of these accelerated tests to estimate possible gas evolution rates. It is not clear from the text whether any determination was made of the magnitude of the acceleration factor implicit in the tests. Such a factor might have been estimated by carrying out the tests at a series of controlled relative humidity levels that could be extrapolated to the level expected in the sealed repository.

Humidity obviously has important relevance to both bacterial action and corrosion, and efforts should be made to measure or estimate it reliably. It would not be surprising to find that the true gas generation rate is quite low, owing to the desiccant effect of the large mass of salt surrounding a sealed repository. The metabolic activity of protoplasm effectively ceases if the material is dried to the point of rigidity. Many organisms can survive for an extended period in a dry environment, but they do not interact with the environment under these conditions. The recovery of wood, cloth, and mummified animal remains from Egyptian tombs after more than 3,000 years is a well-documented example of the preservative effect of moderately low humidity. The contents of steel drums will be exposed to this desiccation, because the plastic gaskets used to seal the lids are relatively permeable to water vapor. It is reasonable to assume that during a storage period of hundreds of years the contents of the drums will reach a humidity level dictated by the ambient salt.

A neglected element in the evaluation of the potential for repository pressurization by biologically generated gas is the fact that metabolic activity is usually poisoned by the accumulation of metabolic products. On this score alone it is doubtful that methane or carbon dioxide pressures of hundreds of atmospheres could be produced through biological activity. Published literature in this area should provide sufficient information to place a reasonable upper limit on this type of pressurization.

The other major potential gas source is the steel drums themselves. A chemical reaction can be hypothesized that would generate large quantities of hydrogen by reaction of metallic iron with the water contained as brine in the surrounding salt. The DEIS concludes that this reaction will not occur to a significant extent in the initially aerobic environment of the drums. This conclusion is correct, because gaseous oxygen will depolarize the cathodic portions of the metal surface before the potential reaches a level sufficient to generate gaseous hydrogen from water. There is, however, a great deal of steel and a limited supply of air after the repository is sealed, so there is a distinct possibility that the repository will reach an anaerobic state. In this condition, and assuming an adequate supply of water (brine inundation), the DEIS predicts that hydrogen will be generated at the rate of 0.5 mole/m^2 year.

This rate would appear to be an overestimate. It is known from practical experience that, at ordinary temperatures, iron does not decompose water to liberate hydrogen unless the pH reaches 3 to 4. The pH of the Salado brines is not reported in the documentation. It seems unlikely to be so low, unless sour gases (CO_2, H_2S) are present at high partial pressures.

Radiolysis was also discussed as a source of gas generation. In view of the low level of total radioactivity in TRU waste, however, the rate of radiolytic gas generation estimated in the DEIS is negligibly small--only a fraction of that assumed for microbial action.

The computational model used to calculate the repository pressurization associated with gas generation is straightforward. The conclusion that the repository pressure will be below the lithostatic pressure even for the bounding 0.5 microdarcy case is acceptable, especially in view of the fact that the source term used for the gas generation rate is probably too high by orders of magnitude, as just discussed.

In view of the minor importance of gas generation for projected TRU waste, it is suggested that consideration be given to dropping the waste acceptance criterion relating to gas generation, while restricting the disposition of organic materials in accordance with the self-extinguishment criterion stated above.

COMPLEXATION

So many variables are involved in the quantitative evaluation of the effect of complexation on the transport of dissolved radwaste elements in an aquifer that writers of the DEIS have calculated transport rates both with and without allowance of credit for adsorptive retardation. Neglecting retardation is equivalent to assuming that all dissolved ions are fully complexed, which is highly unlikely.

IMMOBILIZATION

This criterion specifies that waste sludges must contain no free liquid, such as drained or exuded water. It is necessary to specify somewhere how the presence of free liquid is to be detected if this criterion is retained.

The criterion implies that sludges not associated with free liquid are acceptable. This contradicts the recommendation in supporting document SAND79-1305 (Sandia 1979) that sludges should not be accepted. Perhaps the question of the acceptability of sludges could be resolved by a measurement or calculation of the quantity of moisture that can be absorbed by a quantity of crushed Salado salt.

PACKAGE STRUCTURE

It would be well to be specific about the disposition of any drums that give evidence of being internally pressurized (bulging head or bottom). Limited field test data (Sandia 1979) suggest that only small overpressures (4 psi) will be encountered, but it is necessary to be alert, in view of the field observations that flammable and explosive gases can occur within these drums.

The amount of void space present within the waste packages is probably significant, particularly in packages filled with clothing, wipes, and the like. This volume should be estimated and added to the void volume associated with the backfilling operation, because the packages will surely be crushed during the planned convergence of the repository walls.

SOLUTION RATES

Solution rates become a significant consideration in the long-term release scenarios discussed in SAND78-1730 (Bingham and Barr 1979) in which the repository is flooded. Questions of solution rates and mechanisms were finessed in these scenarios by making the estimate that the wastes dissolve as though they were salt.

It is desirable to consider separately each radioisotope-bearing material in TRU waste and make some sort of conservative but realistic estimate of its solution rate. The materials in question are identified in several sources as plutonium oxide, plutonium metal, "first-stage sludge," sludge concrete, and pyrolysis slag (in case pyrolysis is carried out).

The solution rate of pyrolysis slag, for example, might conservatively be taken as equal to the leach rate of one of the proposed waste disposal glasses in the bulk leach test, that is, about 10^{-6} g/cm^2 day, decreasing by a factor of 10 in one year and remaining constant thereafter. Pyrolysis slag will have a higher content of silica and alumina than borosilicate waste disposal glass, and these are the network-forming components that impart durability to glass.

Hydrothermal conditions need not be considered, because there is no significant generation of heat in transuranic wastes. The fact that the leachant is brine rather than pure water needs to be taken into consideration. Data on leach rates for glasses in brine are only now becoming available.

CHAPTER 5

ENVIRONMENTAL EFFECTS

This chapter is based on the Panel's review of the WIPP Draft Environmental Impact Statement (DEIS). One of the main purposes of that document is to estimate possible radiation exposure of both project employees and the general public. Such exposures could arise from transportation of the waste to the repository site, surface storage of waste at the WIPP site preparatory to emplacement, and accidents that may occur during normal operation of the facility. In addition, radioactive waste will be generated in the course of operating the repository, and all of these may result in exposures to persons both on-site and off-site. Finally, there may be releases of radioactive material to the environment if the repository is breached sometime in the future. These potential sources of exposure have been examined in the DEIS and are discussed here.

TRANSPORTATION TO THE REPOSITORY

Transportation of radioactive materials has been regulated for years by the Department of Transportation, the U.S. Postal Service, and, in the case of intrastate shipments, by the U.S. Nuclear Regulatory Commission and the states. Regulations have been promulgated that prescribe the methods of packaging, the maximum quantity of radioactive materials that can be included in any one package, and the maximum number of packages that can be included in any one shipment. Hundreds of thousands of shipments have been made over a period of more than three decades, and although many vehicles carrying radioactive waste have been involved in accidents, the procedures have thus far been successful in safeguarding the public. It should, of course, be emphasized that most of the shipments involve very small quantities of radioactivity.

Quantitative estimates of the doses to be expected to crews involved in the shipments, to passing motorists, and to inhabitants along the shipping route have been made by means of RADTRAN, a computer code approved by the U.S. Nuclear Regulatory Commission for making estimates of occupational and public exposure from shipments en route. The dose estimates are of the order of one thousandth of the dose normally received from natural radioactivity (U.S. DOE 1979, pages 6-15 to 6-19).

Of greater concern are the doses that might result from transportation accidents. DOT Type B containers are assumed to be used in all shipments of high-level waste and spent fuel. The standard test sequence required by DOT and NRC for Type B containers involves the following:

a) A 30-ft drop onto an unyielding target
b) A 40-in. drop onto a 6-in. diameter probe
c) A 30-min fire at 1475°F (802°C)
d) An 8-h submersion in water

From statistical studies reported in the literature, the DEIS concludes that more than 99.5 percent of all accidents will be less severe than the test conditions required by the regulatory standards. The DEIS then proceeds to analyze the consequences of accidents more severe than those covered by the regulations.

Four such scenarios are presented: a rail accident involving contact-handled TRU waste, a truck accident involving contact-handled TRU waste, a rail accident involving remotely handled TRU waste, and a rail accident involving spent fuel.

The dose calculations associated with the four scenarios are typically conservative (i.e., they estimate the worst-case dose), in that the meteorological conditions that lead to the highest population doses were chosen and the accidents were assumed to occur in urban areas.

Inhalation was chosen as the principal pathway to humans, and the doses were calculated by using the computer code AIRDOS II. For the meteorological conditions assumed, the maximally exposed individual would be about 0.5 mi (0.8 km) from the accident and would receive a whole-body dose of about 1 rem. If the accident occurred in a small urban area, about 6,000 people would be exposed, for a total dose of about 4,000 person-rems. (A person-rem is the unit of population exposure obtained by summing individual dose-equivalent values for all people in the population. Thus, the number of person-rems contributed by 1 person exposed to 100 rems is equal to that contributed by 100,000 people each exposed to 1 mrem (National Research Council 1980).) A spent fuel accident in a large urban area would expose about 106,000 people, who would receive a whole-body dose of 8,300 person-rems and a bone dose of 9,400 person-rems. The dose commitment to the lung would be somewhat less, about 2,300 person-rems. On the basis of the projected number of shipments, actuarial records on the type and frequency of transportation accidents, and the known distribution of the various environmental parameters, the annual frequencies of the accidents described in the four scenarios are estimated to have upper limits ranging from 1.9×10^{-6} to 8.6×10^{-5} (1.9 to 86 chances in a millon of occurring each year).

Under the most pessimistic of the assumptions adopted in the DEIS for transportation accidents, the dose to the maximally exposed individual would be within the legally permissible dose limits applied to certain types of accidents involving nuclear facilities. The population dose exposure in person-rems suggests that, in the most

pessimistic scenario, the exposures would result in a maximum of about one additional cancer during the lifetime of the exposed population.

Intentional destructive acts are considered briefly in the DEIS. The Panel accepts the conclusion that such acts are not likely to produce consequences more significant than those resulting from the other accident scenarios described.

SURFACE AND UNDERGROUND RELEASES DURING NORMAL OPERATION

Waste delivered by either rail or truck to the WIPP site will be unloaded and passed through airlocks to the waste-handling building. The handling procedures are described in detail, and a number of unlikely assumptions are made as to the levels of contamination. For example, it is assumed that all waste packages are contaminated to the maximum level of surface contamination permitted by U.S. NRC/DOT regulations. The total radioactivity that would be released to the environment from both surface and underground operations is estimated to be 8.3 Ci/year, of which 94 percent would be ^{85}Kr. Throughout the analysis, the assumptions are conservative, so the final dose estimates are exaggerated.

The requirements of the DEIS for radiological impact analysis during normal operations could probably be met by simply noting that many years of experience with the handling of properly packaged waste provide assurance that the dose to the employees can be kept well within prescribed limits and that the dose off-site would be so low as to be undetectable.

The occupational doses to forklift operators at WIPP from handling the contact waste are estimated to range from 15 to 1,900 mrems (0.015 to 1.9 rems) per year. The occupational doses from remotely handled waste have not yet been evaluated. The estimated doses, though within acceptable limits, are too high for routine operations, since other exposures from nonroutine events may occur.

The results of rather straightforward dose calculations, based on a conservative set of assumptions, show that for an individual at the closest point of habitation, the maximum dose (to the bone) is 0.003 percent of that received from natural radioactivity, and the whole-body dose would be less than 0.0001 percent of background (U.S. DOE 1979, page 3-10).

ACCIDENTAL RELEASES DURING OPERATION OF THE FACILITY

Accidents that may occur in the course of handling the radioactive waste will have a potential for exposure to both employees and nearby inhabitants. The consequences of a waste-handling accident are examined by analysis of 43 scenarios ranging from a vehicle collision in the receiving area (no radioactive material released) to various failures of the drums and canisters from collisions, drops down mine shafts, spontaneous combustion, and external fires. The radiation doses are calculated from estimates of the quantities of radioactivity

released, the atmospheric concentration at a given location per unit of radioactivity released based on meteorological observations at the site, and measured population distributions.

The worst case for contact-handled TRU waste involves an underground fire, in which case the 50-year bone dose commitment off-site is estimated to be about 0.01 microrem. For remotely handled waste, the worst case would be an accident in which a spent fuel cask is dropped down the waste shaft, in which case the maximum dose to a nearby inhabitant would be 10 microrems to the lung. The "population doses" have also been calculated for the worst sector, inhabited by 28,700 people; it is estimated that they would be less than one-millionth the dose received from natural radiation.

LONG-TERM EFFECTS: RELEASE OF RADIONUCLIDES AFTER CLOSURE OF THE REPOSITORY

To assess the long-term performance of the proposed WIPP repository in terms of possible and potential releases of radionuclides, several release modes are analyzed in the WIPP DEIS. The most serious of the cases considered is development of a postulated fault that diverts water from the Rustler formation above the repository such that water flows down into the repository and dissolves the salt and radioactive waste. The resulting saturated brine solution then flows back up to the Rustler formation and eventually out to the Pecos River at Malaga Bend. It is assumed that the diversion of the water from the Rustler aquifer into the repository can occur at any time after the closure of the repository and that some hypothetical individual relies on the Pecos River water as his only source of potable water. The dose to that individual is then calculated. The available data indicated that the presently understood hydrology of the proposed WIPP site does not lead to any expectation that water from an upper or lower aquifer could or would be so diverted as to flow into the repository.

Inadvertent drilling could also establish a hydraulic connection between the Rustler formation and the repository. Bingham and Barr (1979) estimate the probabilities of breaching the repository salt formation by inadvertent drilling to be 0.1 at 1,000 years, decreasing to 0.001 at 10,000 years and later, as the importance of hydrocarbons in the economy decreases. The Sandia analysis assumes that once water intrudes into the repository it will eventually contact the waste. The repository is assumed to contain TRU waste, as specified earlier in this report, and an array of 6,000 spent fuel elements, each in a stainless steel canister.

The water entering the repository is assumed to dissolve the salt until it reaches the concentration of saturated brine. When the dissolution front intersects a package of TRU waste or a canister of spent fuel, the waste material is assumed to dissolve at the same rate as the surrounding salt; the much lower solubility of the waste material and the relative insolubility of some of the contained radionuclides are disregarded. But even this extremely unrealistic assumption yields such small dose estimates that more detailed

calculations taking into account the actual dissolution rates of the waste material are not made in the DEIS. However, the use of such a simplistic model of the waste material will lead many readers into believing incorrectly that little additional protection is offered by the long-term stability and corrosion resistance of the waste material.

The release model assumes that the saturated brine solution, with its dissolved radionuclides, flows back up to the Rustler aquifer. Various possible mechanisms for the upward flow have been considered in the Sandia analysis (Bingham and Barr 1979). For example, degradation of the waste by the intruded water might generate gas, with an accompanying pressure rise. If accompanied by sequential breaching, closure, and rebreaching, a pressure gradient forcing upward flow could occur. A more plausible mechanism, not considered by Sandia, would be the venting of pressurized brine during operation of the repository or after its closure. It is also possible that this driving force could be caused by a rise in fluid potential within the Bell Canyon aquifer in the event of a return to pluvial conditions. These possibilities require further consideration, though they have been bounded by existing scenarios.

Sandia also considers the possible creation of upflow by thermal convection, resulting from heating of the brine solution by spent fuel, which is the only heat-generating waste considered in the DEIS. If this were to occur, it would be limited to the heat-generating period of about 1,000 years. But the number of spent fuel elements considered in this analysis is in fact too small to set up sufficient thermal convection for the creation of an upflow from the repository. The properties of the waste material and the placement geometry preclude the possibility of nuclear criticality, with its accompanying heat generation. It can only be concluded that a plausible mechanism by which the saturated brine could flow back up to the Rustler aquifer has not been identified in the DEIS.

Having assumed that a contaminated and saturated brine solution does reenter the upper Rustler aquifer, Sandia then calculates the hydrological transport of this contaminated brine through the aquifer to the Pecos River, over an assumed distance of 21 km--the shortest or straight-line distance from the repository to the Pecos. Transport is assumed to occur largely through the dolomitic rock. Further, the assumed range of hydraulic gradients and permeabilities used in their analysis result in velocities of water transport varying from 0.23 to 4.6 m/year and water transport time varying from 5,000 to 100,000 years. These estimates appear to have been suitably conservative for the Rustler hydrology because the pathway for groundwater flow is expected to be twice as long as the straight-line distance used in the calculations. The transport distance has been estimated with the use of more recent and more abundant water level data obtained from drillholes completed in the Rustler aquifer.

Still not adequately addressed, however, is the possible presence of zones of fracture concentration that may be revealed by fracture traces and lineaments that may provide distinct, more conductive channels for water flow than considered in the Sandia analysis. Such privileged pathways, if present, could cause groundwater to flow along

still undefined pathways with orientations different from those assumed, and at greater velocities. The maximum volumes are limited by the observed flows into the Pecos River along the Salado-Rustler contact zone (U.S. DOE 1979, page 7-69). The presence of privileged pathways need not be defined by flow lines drawn at right angles to equipotential lines using the most up-to-date Rustler water level data or by test holes located with other site selection criteria in mind. Their presence and potential significance to water flow can be determined by mapping fracture traces and lineaments, matching permeability data obtained from existing test holes with locations of existing test holes and lineaments, and from controlled drilling and field testing of one or more lineament-related structures if none have been penetrated to date. Shorter, more abundant rock fractures and joints are harder to map lacking adequate outcrops but are more apt to be penetrated by existing drillholes and be reflected in field-derived permeability data.

Using the present analyses, the dissolution and transport processes take over 5,000 years for even the nonsorbing radionuclides and far longer for the sorbing species. Even if fission products are included among the wastes, this gives ample time for ^{90}Sr and ^{137}Cs to decay without the additional delaying effect of sorption. Sorption by the dolomite precludes the release of the transuranics, although some of their more toxic decay daughters, such as ^{226}Ra, contribute to the later doses to man (U.S. DOE 1979, page K-20). Weakly sorbed fission-product radionuclides, such as ^{129}I and possibly ^{99}Tc, are also contributors.

The sorption data listed in the DEIS were derived from more than one source. It is not clear to what extent these data are applicable to the geochemistry of the Rustler formation and to sorption from solutions containing appreciable concentrations of dissolved salt. These uncertainties affect the estimated doses from ^{226}Ra but not the estimated doses from the weakly sorbing species, such as ^{129}I. No discussion of the effects of such sorption uncertainties has been found in the report.

The exact procedures by which the dose estimates have been made are not fully explained in the DEIS. The dose estimates were made by the U.S. Nuclear Regulatory Commission computer code LADTAP, but the required input data are not given. From consultation with the Sandia staff, however, it has been determined that the maximally exposed individual is one who is located at the Malaga Bend of the Pecos River, where he catches and eats 21 km of fish per year. He also consumes 730 liters per year of the highly saline, nonpotable water from the Pecos River at Malaga Bend, and he spends 82 hours per year in recreation on the river or its shoreline. His recreational use of the river contributes insignificantly to the dose received. Because exposure is thus from ingestion of food and water, the dose varies from organ to organ, depending on the metabolic characteristics of the individual nuclides.

The doses to the maximally exposed individual are estimated in the DEIS to be small, as can be seen from the following summary:

Organ	Annual Dose, mrem/year
Whole body	0.4
Thyroid	1.9
Bone	2.1
Kidney	0.41
Lower large intestine	0.16

(The dose from natural radioactivity is about 100 mrem/year in most localities (NCRP 1975, page 108).)

The scenario selected in the DEIS as the bounding case appears to be totally implausible. Apart from the implausible mechanisms for water intruding into the repository and returning to the aquifer, the assumptions in each step of the analysis tend to exaggerate the dose estimates. For example, the waste is assumed to dissolve as rapidly as salt; no solubility limits for the waste material and for its radionuclides are considered; upper values of the Rustler hydraulic permeability and transmissivity measured to date are assumed; the sorption coefficients may be lower than realistic; and the transport distance assumed for the analysis is less than the actual distance, though fracture flow is not considered. Finally, no allowance is made for the fact that the radionuclides emerge into the Pecos River, the water of which is already not potable because of high salinity. It is not consumed by man or beast, and the river does not support a significant population of fish or shellfish.

If this scenario is discarded, another becomes the bounding case. It is nearly as implausible and results in even lower doses. But it is not even clear that the scenarios described in the DEIS do include the bounding case. For example, however unlikely the probability that solution mining will be practiced at the WIPP site, the consequences of doing so might be far more severe than the scenarios considered in the DEIS.

Though fracture flows could yet be discovered, their total flow would be limited and would be mixed in the saline Pecos River. With this exception, by compounding implausibility on implausibility and conservatism on conservatism, the DEIS does indeed convey the message that the long-term risk to future populations from the hydrological transport of radionuclides from the WIPP repository is likely to be extremely small.

CHAPTER 6

IN-SITU TESTS AND EXPERIMENTS

Assuming the prior conduct of extensive laboratory and field investigations, calculations, and analyses, a sequence of confirmatory underground in-situ tests and experiments will be required when access to the proposed repository horizon has been provided by means of an exploratory shaft. First, geotechnical uncertainties in the characterization of the essentially unperturbed site will need to be resolved by direct observation. Second, if the site is not disqualified by the results of these observations, other in-situ tests and experiments will be needed to evaluate the physical characteristics of the host media that contribute to the achievement of acceptable isolation. Third, if the site still appears to be suitable, additional tests will be required to corroborate the design of the repository, demonstrate the viability and effectiveness of underground techniques such as backfilling, and obtain measurements of initial rock response to excavation and waste emplacement as part of the predictive modeling effort.

Such a neat sequence is unlikely to occur in practice. For instance, comprehensive plans have been made for in-situ experiments, aimed at the second and third of the purposes listed above, to be conducted in potash mines in southeastern New Mexico. Detailed plans should be developed and thoroughly reviewed prior to sinking an exploratory shaft for the purposes of in-situ investigations. To the extent possible, such plans should be developed well in advance, specifying the issues that need to be resolved, the criteria to be satisfied, the measurements to be made, the instrumentation required, and the proposed methods of interpreting the expected data. In-situ work will be the final step in the process of learning what is not known and confirming what is thought to be known, before commitment to actual repository construction and operation. This may require a degree of redundancy and the concurrent conduct of many different kinds of experiments. Consistency among several different measurements often proves to be an important basis for confidence in experimental findings.

It must be recognized that instruments capable of reliable operation underground for years--or even decades--may not exist. Difficulties have been experienced, for example, in making even simple temperature measurements for such periods. Major emphasis therefore must be placed on the development of suitable instrumentation.

It is very difficult to accelerate in-situ tests without raising serious doubts as to the validity and interpretation of their results. Accordingly, every advantage should be taken of opportunities to begin such tests early, to conduct them on a sufficiently large scale, and to continue them for as long as is practicable prior to the operational emplacement of radioactive waste.

The Panel is not in a position to draft a plan for such tests and experiments. But after several briefings and examination of reports on the subject, we take this opportunity to point out a few areas of concern and what appear to be some deficiencies in existing plans.

RESOLUTION OF GEOTECHNICAL UNCERTAINTIES

An exploratory shaft will provide an opportunity to verify the geologic and hydrologic data obtained from the eight deep holes already drilled on site. The Panel understands that, as of the end of 1979, plans call for the sinking of an exploratory shaft 12 ft (3.6 m) in diameter to the level of the proposed repository by downhole drilling, using reversed mud circulation. A tubular steel lining, extending about 820 ft (249 m) from the surface to the top of the Salado formation, will be grouted in place. The location of this exploratory shaft is presumably coincident with the proposed storage exhaust shaft, placing it some 500 ft (150 m) northwest of the ERDA 9 test drillhole. In this location, the shaft should pass through the Santa Rosa sandstone, the Dewey Lake Red Beds, and the Rustler formation, as well as more than 1,000 ft (300 m) of the Salado formation, in which it will be unlined.

The Santa Rosa sandstone is the principal aquifer in several areas (although not at the site or in areas to which the site would discharge); the Dewey Lake Red Beds contain no aquifers. The Rustler formation contains two water-bearing dolomite beds, and a third brine aquifer is located at the contact with the Salado. In view of this geologic sequence, through which every shaft of the proposed repository will have to pass, it seems unfortunate that the method of sinking the exploratory shaft precludes visual observations and, to a large extent, other testing of the sequence for which this shaft will provide the first opportunity. Careful consideration should be given to using some other method of sinking this shaft that would permit geologic mapping and hydrologic testing of the different rock layers.

The Salado formation itself is not simple: it contains interbedded salt, anhydrite layers, clay seams, and partings, all of which have been taken into account in specifying the depth of the proposed repository and in its underground design (Krieg et al. 1979). Moreover, there remains a possibility that breccia pipes, large brine pockets, or intrusive dikes may be encountered. Once the exploratory shaft has reached the proposed depth of the repository, parallel horizontal exploratory drifts consistent with the planned design should be driven out as far as safety permits, to obtain first-hand information concerning the structure, properties, and behavior of the salt at the horizon of the proposed repository excavations.

Furthermore, differences can be expected between the properties of laboratory test specimens from the Salado formation and properties of the formation en masse. In-situ measurements should reveal these differences and allow them to be taken into account in the design and predicted performance of the repository.

ISOLATION MECHANISMS AND FAILURE-MODE EXPERIMENTS

The specific characteristics--or even the feasibility--of certain in-situ tests will, of course, be determined by the nature of the waste eventually to be accommodated. For instance, meaningful in-situ experiments on brine migration or radiolysis would be difficult to design and perform--and probably unnecessary--in the temperature and radiation regimes that would prevail if only defense transuranic waste were emplaced in the repository.

Regardless of waste type, however, some important work could be undertaken as soon as an exploratory shaft has been sunk. Evaluation could be commenced with waste packages, including engineered barriers but not necessarily containing radioactive material. Drifts developed from the shaft could be instrumented for large-scale tests of hydrological effects such as mass transport and nuclide migration. Large-scale permeability of the salt might be determined by psychrometric measurements of air flowing into and out of a sealed section of tunnel.

If the emplacement of heat-producing waste is contemplated, early in-situ tests and experiments on the effects of temperature should be undertaken. Initially, it is probably prudent not to emplace radioactive waste for this purpose but to use electrical heaters to simulate the thermal effects of canisters of waste and yet obviate the hazard of having to retrieve radioactive materials. The results of such a simulation should remove many uncertainties and increase the level of confidence with which a decision can be made whether or not to emplace high-level waste or spent fuel rods in the repository. The effects of radiation and possible synergistic effects between radiation and temperature, of course, would have to be tested separately, but this could be done with less risk on a much smaller scale.

The proposed experimental high-level waste emplacement would constitute an in-situ investigation of major importance, but it should not be attempted until and unless the development of the site has gone well beyond the exploratory shaft phase. The underground design should have been validated by in-situ testing, and all the additional shafts and equipment necessary for safe, large-scale excavation and materials handling should be in place and proven by a period of successful operation.

The radioactive waste in these experiments (except for special tests) will be encased in metallic canisters with walls thick enough to ensure that corrosive action, if any, will be detected by routine monitoring and inspection long before any radioactive material is exposed. In many cases there will also be overpacks of absorbent substances, and the holes in the salt in which the canisters will be

placed may be lined with steel. Corrosion of metals is therefore the main concern. Corrosive substances include oxygen from the surrounding air, salt, and possibly brine. The surface temperature of the waste canisters will be one of the experimental variables.

Corrosion of mild steel in a salt environment has been studied extensively. Dilute brines are very corrosive in the presence of air, especially when the surface is alternately exposed to liquid and gas. Concentrated brines are not intrinsically corrosive to steel, as attested by the long and successful use of carbon steel heat-exchange piping in ice-houses. Even aeration causes little corrosion because of the low solubility of oxygen in saturated brine. Accordingly, it appears that whether or not there is brine migration along the temperature gradient associated with a high-level waste canister, corrosion of steel hole liners should be minimal during in-situ experiments lasting a few decades at most. A paper (Pigford 1981) discussing brine migration is being prepared by one of the Panel members.

On the other hand, stainless steel canisters that have been filled with hot glass may fail rapidly in contact with brine by stress corrosion cracking, although this type of failure can be postponed indefinitely by the use of overpacks and hole liners. In the experimental program, some of the canisters should be deliberately exposed to conditions that are expected to cause this type of failure. Of course, provision must be made for detecting failure in situ and for retrieving cracked canisters.

Corrosion of ferrous alloys may be expected if the repository is designed with such a dense loading of heat-producing waste that the temperature rises high enough to liberate HCl from the hydrated $MgCl_2$ present in the brine. This process is fairly rapid at or above 200°C. The Panel would not recommend use of a loading density that would cause such high temperatures in a repository, unless for experimental purposes.

Mild steel will corrode rapidly in an acidic (pH $\leq$ 3 to 4) aqueous solution. No data have been found in the DEIS or supporting documents on the pH of the brines that may be encountered in the Salado formation. If this information is in fact unknown, an effort should be made to obtain it.

Corrosion or other failures of the liners should be monitored during the experimental program, when any failures will give valuable information without significant environmental consequences.

VALIDATION OF UNDERGROUND DESIGN

If the results of preliminary exploration by horizontal drilling and lateral drifts are encouraging, consideration probably will have to be given to a second shaft, for reasons of safety and more complete evaluation of the site. However, prior to making any decision about a second shaft, test areas adjacent to the first one but far enough from it to avoid adverse effects should be set aside for several important tests that will be needed to validate whatever underground design is

eventually decided upon. One of those should be a section designed according to the same methods as those used for the repository excavation but with much higher local stresses, so that excessive closure or other difficulties, such as instability of pillars, are expected to occur. This section should be instrumented as early as is practicable with closure meters, extensometers, and inclusion stressmeters, so that the behavior of the salt can be measured and compared with the design predictions and laboratory measurements of the properties of salt. Another important test would be a fully instrumented replica of the proposed repository excavations to ensure, at least in the short term before commitment to excavation of the full repository, that they behave as predicted by design.

The exploratory shafts and tunnels will provide the first opportunity to develop and prove in place the techniques for shaft sealing that will be a critical consideration. This may involve developing sections of test shafts parallel to the exploratory shaft especially for this purpose. In any event, tests of proposed sealing methods should be commenced as soon as practicable.

An item of particular concern is the Title I design proposal to store the salt on the surface and wet it for dust suppression. Even in the absence of wetting, salt stored on the surface will absorb water, and since it is proposed also to use this salt for backfilling the repository, the addition of water in the vicinity of the waste by this process does not appear to be well advised. Moreover, the porosity and permeability of the backfilled salt will far exceed that of the undisturbed salt deposit; unless proper precautions are taken, the backfilled tunnels could provide a ready access route for any intrusive waters.

Numerous in-situ tests and experiments will no doubt be needed to develop, prove, and demonstrate safe repository and equipment operation under normal and accident conditions. Although such tests and experiments may not be regarded as fundamental to deciding whether or not a particular site is suitable for a waste repository, two factors must be borne in mind. First, many aspects of repository design and operation will be determined to a large extent by the geological conditions encountered at the site. Second, unless the necessary equipment can be developed and operated safely, even the best potential site cannot be used.

CHAPTER 7

NATURAL RESOURCES AT THE WIPP SITE

A variety of natural resources underlie the reference site currently being considered for WIPP. Included are caliche, gypsum, salt, sylvite, langbeinite, crude oil, natural gas, and distillate, but potash and hydrocarbons are generally considered to be the most significant resources. A deposit of the potash mineral langbeinite [$K_2Mg_2(SO_4)_3$] is located 1,500 to 1,700 ft (450 to 510 m) below the surface; oil and gas resources are inferred to be located 4,000 to 14,000 ft (1,200 to 4,200 m) below the surface. Langbeinite is an unusual form of naturally occurring potash, important for preparation of potassium fertilizers in which chloride ion is absent (since chloride ion is harmful to some plants). The Carlsbad Potash District is by far the largest potash-processing area in the United States.

The objectives of this chapter are twofold: to evaluate the adequacy of the technical data base used to depict natural resources at the WIPP site, and to assess the adequacy of programs intended to evaluate the extent and implications of the presence of natural resources as it affects the suitability of the site as a repository for radioactive waste. The two chief problems arising from the presence of natural resources at the site are (1) the threat to repository safety that past or future exploration for the resources might entail and (2) the long-term denial of natural resources.

THE LONG-TERM DENIAL OF RESOURCES

The review of the WIPP DEIS and associated data base indicates that the analyses to date for valuing denied resources are adequate in terms of current market prices, assuming updating to reflect recent economic changes. More problematic, however, is the economic value to be assigned to long-term denial of resources.

The DEIS does not assign an economic value to denied resources. Rather, it indicates the significance of resources (and reserves) by comparing those present at the reference site with available resources in the region, the United States, and the world (see Table 7.1). For more detailed economic valuation of resources, it is necessary to consult the back-up studies. The value of denied resources in these studies is invariably calculated at present prices, with escalators

TABLE 7.1. Significance of the Resources and Reserves at the Reference Site

Deposit	Reference Site	Region	United States	World
		RESOURCES[a]		
Sylvite				
Quantity, million tons K_2O	10.44	500	1,000	100,000
Percentage at reference site		2.1	1.0	0.0104
Langbeinite				
Quantity, million tons K_2O	16.15	No estimate available		
Crude Oil				
Quantity, million barrles	37.50	1,915	200,000	Not Available
Percentage at reference site		2.0	0.019	
Natural Gas				
Quantity, billion cubic feet	490	25,013	855,000	Not Available
Percentage at reference site		2.0	0.057	
Distillate				
Quantity, million barrels	5.72	293	Not Available	
Percentage at reference site		2.0		
		RESERVES[b]		
Sylvite[c]				
Quantity, million tons K_2O	3.66	106	206	11,206
Percentage at reference site		3.4	1.8	0.033
Langbeinite				
Quantity, million tons K_2O	4.41	38[d]	38[d]	Not Available
Percentage at reference site		11.6	11.6	
Crude Oil				
Quantity, million barrels	Nil	471.7	29,486	646,000
Percentage at reference site		0	0	0
Natural Gas				
Quantity, billion cubic feet	36.85	3,865	208,800	2,520,000
Percentage at reference site		0.95	0.018	0.0015
Distillate				
Quantity, million barrels	0.55	169.1	35,500	Not Available
Percentage at reference site		0.32	0.0014	

[a]Data Sources: Hydrocarbons, Foster (1974) for the site and region; potash salts, John et al. (1978) for the site and region; Brobst and Pratt (1973) for U.S. oil and gas and the world resources of sylvite.

[b]Data Sources: Hydrocarbons, Keesey (1976) for the site; American Petroleum Institute (1978) for the region, the United States, and the world; potash salts, U.S. Bureau of Mines (USBM, 1977).

[c]The U.S. Bureau of Mines (USBM, 1977) does not consider any sylvite to be commercial today. However, one bed (mining unit A-1) of sylvite was marginal and has been added to the reserve list.

[d]Not an official estimate by the U.S. Geological Survey; see Section 9.1.4.

SOURCE: U.S. Department of Energy (1979).

built in for projected price increases. It is apparent that, with rapidly escalating prices, the value of hydrocarbon resources has been greatly underestimated. The estimate therefore needs to be updated.

In the case of potash, current prices were used to derive the estimate of potash products that could be produced economically. However, prices in the potash industry have been notoriously unstable over time (Bingham and Barr 1979), a factor that makes any long-term projections of resource value extremely difficult.

The valuations of natural resource denial may be quite sensitive to the economic assumptions underlying the projections. To cite several examples from the Bureau of Mines potash valuation (U.S. BOM 1977):

- "there will be a 2.9 percent annual growth in U.S. consumption of fertilizer (compared with a recent growth rate of 6.3 percent)." [page 33]
- "U.S. potash consumption will double by the year 2000, but domestic production will supply less than 10 percent of the total." [page 35]
- "there will be increasing physical limitations on potash consumption due to such things as the decline of available land for farming, more efficient use of fertilizer, new technology in the use of fertilizer, and a possible decline in the foreign market for U.S. food products." [page 33]

The data base at present contains only limited information on the size of potash reserves available elsewhere in the world. The substitutability of other sources (e.g., brines at Searles Lake, California, and Great Salt Lake, Utah; and synthetic langbeinite produced by solar evaporation of seawater) and their economic feasibility receive only passing mention in the DEIS and merit greater attention.

On the whole, the resource analysis, with the caveats noted above, appears to provide adequate baseline information. The commitment of the site for a waste repository would involve denial of natural resources, but such denial would probably have only a marginal impact on mineral resources at the national and even regional level, particularly if controlled drilling and mining are allowed within the outermost zone of the repository site.

Further research on the opportunity costs involved in natural resource denial is currently under way at the University of New Mexico.

NATURAL RESOURCES AND REPOSITORY SAFETY

Of considerably greater concern, however, are the implications of the presence of significant natural resources at a repository site for the long-term integrity of the repository. Numerous shallow holes have been drilled to evaluate potash resources, and some deep holes have been drilled for hydrocarbon assessments. Possible breach of the repository as a result of resource exploration at some future date, after records of its siting and purpose may have been lost, is a troublesome issue.

A wide variety of sources, including the National Research Council (1978), have formulated site suitability criteria (see Goad 1979) addressing the natural resources issue, and recent critics have directed attention to the risk implications of such resources at the WIPP site (R.W. Foster, memorandum to the WIPP Review Committee, n.d.; Sierra Club 1979). In a letter to DOE dated December 21, 1978, on the suitability of the Los Medanos study area as a repository site, Sandia itself notes that the natural resources site selection criterion is "not well satisfied by the WIPP site" and that "these concentrations of minerals may prove an enticement for future exploration and exploitation."

The chief risk studies that bear upon this issue are the analyses of 19 scenarios presented in Bingham and Barr (1979) and the 94 scenarios covered in the WIPP DEIS. Of the 19 Bingham and Barr scenarios, 5 include drilling for resources as a risk element. The study finds that 10,000 years from now drilling is still one of the most probable scenarios, but the consequences to the general public associated with nearly all these scenarios are estimated to be quite small. None of the included scenarios treats the purposeful mining of the radioactive materials themselves, although this has been cited previously as an intrusion factor.

The scenarios developed in the DEIS are consistent with Bingham and Barr's findings. The worst-case analysis for high-level waste involves the accidental transfer of radioactive materials to the surface of the earth, resulting from drilling activities involved in the search for natural resources 100 or 1,000 years from now. The maximum individual dose in that case is calculated to be 90 rems to the whole body. Such a dose, while exceeding the maximum permissible occupational exposure for one year, results in a risk that is small compared to that from nonradiological industrial hazards.

This scenario, however, may fail to bound the maximum credible event arising from natural resources conflict. Either solution mining for table salt 100 years after closure of a high-level waste repository or mining of radioactive materials themselves, whether purposeful or not, could produce consequences greater than those indicated in the worst-case analysis containing currently accepted bounding conditions. A recent study (Harwell 1979) argued both a high probability of human intrusion at salt domes and unacceptably large possible consequences. The significance of this assessment for the WIPP site should be carefully evaluated.

A major additional issue is the possible storage of spent fuel elements in the repository. Such waste is in fact a resource that increases in value over time. There is a strong possibility that sooner or later someone will seek to recover the material, whether or not there is still a historical record of it.

Bingham and Barr (1979) assign probabilities for intrusion in only a highly speculative and subjective manner. As a result, the ranking of scenarios by likelihood is open to legitimate debate. Given the residual uncertainties associated with the intrinsic inability to define probabilities of future human intrusion except in a gross and subjective way, and possible substantial consequences, the concern over resource conflict at the WIPP site appears merited.

The possibility of breach of the repository during exploration for potash and hydrocarbon after records of its location and contents have been lost must therefore be taken into account. It should be pointed out, however, that a repository for spent fuel or reprocessed high-level waste, even in a region free from mineral resources, may give rise to a geophysical anomaly that provides an incentive to explore it by drilling anyway.

No studies have been found that deal with the possible impacts upon long-term repository safety of exploitation of natural resources other than minerals (e.g., solar energy and its future effects upon population densities or undiscovered water resources). In its Geological Criteria for Repositories for High-Level Radioactive Wastes (National Research Council 1978), the Committee on Radioactive Waste Management of the National Research Council adopted, among others, the criterion, "No area with a present or past record of resource extraction, other than for bulk material won by surface quarrying, should be considered as a geological site for radioactive wastes" (page 13). That report also calls specific attention to the hazard posed by the spent fuel elements themselves if they are disposed of in a nonretrievable manner. While the Committee criteria are not intended as absolute or even of equal importance, they are intended "as a basis for the determination of the suitability of the repository site" (page 1). It is reasonable to infer that the burden of proof for long-term safety is on the developer if a criterion is to be overridden.

REDUCING THE RESOURCES CONFLICT

Given the difficulties posed for the long-term integrity of the site by the presence of natural resources, particularly langbeinite and hydrocarbons, and the value of the resources that must be foregone, the possibility of extracting these resources prior to, during, or after repository operation needs to be explored. It may be possible, for example, to hold the upper zones of potash as a reserve and mine them after the site is decommissioned or some time after sealing, if this can be done without compromising the integrity of the repository. The same tactic could be used for oil and natural gas--employing directional drilling--if the exploratory group can prove the existence of a probable trap that can contain hydrocarbons.

The safety issues involved in such a venture need to be carefully assessed. For example, is there any possibility that the extraction of hydrocarbons from underneath the repository horizon will facilitate the entrance of radioactive materials into an aquifer? Would the mining of the potash from above the repository possibly weaken the repository roof, or could it act as a depot for collecting a head of water that at some time could enter the repository? It needs to be pointed out, moreover, that extraction of the resources would not in any case resolve the future intrusion threat, for it is the perception of likely resources that will motivate future resource seekers. The proximity of significant natural resources in the site area will remain as a residual safety problem.

REFERENCES

Anderson, R.Y. (1980) Summary of his comments, in Geotechnical Considerations for Radiological Hazard Assessment of WIPP: A Report of a Meeting Held on January 17-18, 1980. EEG-6. Santa Fe, NM: Health and Environment Department.

Bechtel National, Inc. (1979) Waste Isolation Pilot Plant: Title I Design Report. Bechtel Job 12484, prepared for the U.S. Department of Energy. San Francisco, CA.

Bingham, F.W., and G.E. Barr (1979) Scenarios for Long-Term Release of Radionuclides from a Nuclear-Waste Repository in the Los Medanos Region of New Mexico. SAND78-1730. Albuquerque, NM: Sandia Laboratories.

Bradshaw, R.L., and W.C. McClain, eds. (1971) Project Salt Vault: A Demonstration of the Disposal of High-Activity Solidified Wastes in Underground Salt Mines. ORNL-4555. Oak Ridge, TN: Oak Ridge National Laboratory.

Goad, D. (1979) A Compilation of Site Selection Criteria, Considerations and Concerns Appearing in the Literature on the Deep Geologic Disposal of Radioactive Wastes. Santa Fe, NM: Health and Environment Department.

Harwell, M.A., et al. (1979) Reference Site Initial Assessment for a Salt Dome Repository. PNL 2955. Richland, WA: Pacific Northwest Laboratory.

Interagency Review Group (1979) Report to the President by the Interagency Review Group on Nuclear Waste Management. TID-29442. Washington, D.C.

Krieg, R.D., C.M. Stone, and S.W. Key (1979) Calculations for CH-TRU Storage Room Design. Memo to J.R. Wayland, October 23. Albuquerque, NM: Sandia Laboratories.

Molecke, M.A. (1979a) Gas Generation from Transuranic Waste Degradation: An Interim Assessment. SAND79-0117, prepared for the U.S. Department of Energy. Albuquerque, NM: Sandia Laboratories.

Molecke, M.A. (1979b) Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation. SAND79-1245, prepared for the U.S. Department of Energy. Albuquerque, NM: Sandia Laboratories.

Munson, D.E., and P.R. Dawson (1979) Constitutive Model for the Low Temperature Creep of Salt (with Application to WIPP). SAND79-1853. Albuquerque, NM: Sandia Laboratories.

National Council on Radiation Protection and Measurements (1975) Natural Background Radiation in the United States, NCRP Report No. 43. Washington, D.C.

National Research Council (1970) Disposal of Solid Radioactive Wastes in Bedded Salt Deposits. Committee on Radioactive Waste Management, Commission on Natural Resources. Washington, DC: U.S. Government Printing Office.

National Research Council (1978) Geological Criteria for Repositories for High-Level Radioactive Wastes. Committee on Radioactive Waste Management, Commission on Natural Resources. Washington, DC: National Academy of Sciences.

National Research Council (1980) The Effects on Population of Exposure to Low Levels of Ionizing Radiation. Committee on the Biological Effects of Ionizing Radiations, Division of Medical Sciences, Assembly of Life Sciences. Washington, DC: National Academy of Sciences.

Netherland, Sewell and Associates (1974) Evaluation of Hydrocarbon Potential, AEC Study Area, Southeast New Mexico, Based on Geological and Enginering Studies as of May, 1974. ORNL/SUB-74/38284. Oak Ridge, TN: Oak Ridge National Laboratory.

Pigford, T.H. (1981) Migration of Brine Inclusions in Salt. To be published.

Sandia Laboratories (1978) Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. Edited by D.W. Powers, S.J. Lambert, S.-E. Shaffer, L.R. Hill, and W.D. Weart. SAND78-1596. Albuquerque, NM.

Sandia Laboratories (1979) Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP. SAND79-1305. Albuquerque, NM.

Serata, S. (1978) Geochemical Basis for Design of Underground Salt Cavities. Publication 78-PET-59. New York: American Society of Mechanical Engineers.

Sierra Club (1979) Comments on the Waste Isolation Pilot Plant Draft Environmental Impact Statement, September 6. San Francisco.

U.S. Bureau of Mines (1977) Valuation of Potash Occurrences within the Waste Isolation Pilot Plant Site in Southeastern New Mexico. Prepared for the U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (1978) Report of Task Force for Review of Nuclear Waste Management. DOE-ER-0004/D. Washington, DC.

U.S. Department of Energy (1979) Draft Environmental Impact Statement: Waste Isolation Pilot Plant. DOE-EIS-0026-D. Washington, DC.

Watson, D.L., J.S. Busch, H.L. Julien, and J.S. Ritchie (1979) Optimization of Mine Layout for Nuclear Fuel Assembly Storage. Oakland, CA: Kaiser Engineers, Inc.

Wawersik, W.R. (1979) Preliminary Idealization of CH-Level Stratigraphy for WIPP Structural Calculations Based on Drillhole Data for ERDA #9, Depth 1975-2375 ft. Memo to R.D. Krieg and J.R. Wayland, October 4. Albuquerque, NM: Sandia Laboratories.

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REVIEW OF THE CRITERIA FOR THE SITE SUITABILITY, DESIGN, CONSTRUCTION, AND OPERATION OF THE PROPOSED WASTE ISOLATION PILOT PLANT (WIPP)

INTERIM REPORT: JULY 1, 1978 to JULY 31, 1982

Panel on the Waste Isolation Pilot Plant

BOARD ON RADIOACTIVE WASTE MANAGEMENT

Commission on Physical Sciences, Mathematics, and Resources

NATIONAL RESEARCH COUNCIL

Washington, D.C. 1983

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In March 1978, the Department of Energy (DOE) asked the National Research Council "to review the scientific and technical criteria and guidelines for designing, constructing and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere." The National Research Council assigned the study to the Committee on Radioactive Waste Management under the Commission on Natural Resources.* The committee organized the Panel on the Waste Isolation Pilot Plant to "review the scientific and technical adequacy of the site-suitability criteria; the guidelines for the site confirmation studies; the design criteria for the repository, including the waste acceptance criteria, the design philosophy, and the operational philosophy; the criteria for determining the environmental safety of future planned operations viewed from the perspective of the environmental conditions of the repository site; and the design criteria for the experimental testing program of the behavior of the waste-geologic medium interaction."

In July 1978, when this study began, the Waste Isolation Pilot Plant (WIPP) was to be a mined repository in bedded salt in Eddy County, New Mexico, for the disposal of transuranic (TRU) waste, with experimental facilities for studying the interactions of high-level waste with the host rocks. At that time, use of this repository for disposal of a limited number of commercial, spent-fuel elements was also being considered, although this was not part of the project's mission. This option was discussed frequently in technical briefings of the panel and in supporting documentation. The panel has examined some of the generic issues related to this possible course of action, as well as those concerns raised solely by the proposed disposal of transuranic waste in the particular salt formations at the WIPP site.

With a few exceptions to take account of more recent information, this report recounts the panel's findings through the end of July 1982. By that time, several major WIPP program documents had been issued, including the Geological Characterization Report (Powers et al. 1978),

*Now the Board on Radioactive Waste Management under the Commission on Physical Sciences, Mathematics, and Resources.

the Title I Design Report (Bechtel National, Inc. 1979), the Final Environmental Impact Statement (U.S. Department of Energy 1980), and the Safety Analysis Report (U.S. Department of Energy 1980-1982). The present report is based on analysis of the contents of these and other documents, numerous technical briefings, extensive discussions with representatives of DOE and its contractors, comments by interested members of the public, and several field visits.

Some of the documents have been available only in draft form, some are undergoing major revision, and still others remain to be issued. Evaluation of the adequacy of criteria in the final versions of such material is a matter for future consideration by the panel. The panel expects to evaluate work through approximately December 31, 1983.

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The panel has evaluated the scientific and technical adequacy of work being done on the WIPP project to satisfy the charge to the panel set out in Chapter 1. It has found that the scientific work has been carried out with a high degree of professional competence, and that the presently unresolved hydrological and geological uncertainties about the WIPP site will not interfere with the completion of the WIPP research and development mission. With a flexible approach, there is time yet to resolve these uncertainties before large-scale transuranic (TRU) waste emplacement begins. The panel regards all WIPP facility planning and design to be provisional at the present time and subject to revisions in the light of future findings of the WIPP R&D program.

The engineering aspects of the many WIPP studies by DOE contractors have not yet reached the final stage, so our conclusions on these matters are limited.

Although the panel's conclusions and recommendations appear at the end of each chapter, they are collected in this section for the reader's convenience.

CONCLUSIONS

Chapter 2: Site Selection and Characterization

o Although the evidence now suggests that hydrocarbons and potash might be extracted from Zone IV without harm to the repository, the integrity of the repository must be the first consideration. Each proposal to develop the resources should be examined rigorously on a case-by-case basis, with the burden of proof resting with the proposer (pp. 14, 16; see also Appendix D).

o The long distance from fault displacements and basaltic eruptions in the Rio Grande Valley and the lack of evidence of major seismic events near the site seem sufficient to ensure tectonic quiescence at the site during the period of interest (p. 16).

o Deformation of evaporite beds at the repository site is slight. The rate of deformation, if any is going on at present, is so small that it would not present a credible risk to the repository (pp. 16, 17).

o Evidence is good that karst-forming processes are unlikely for a period of more than a million years to disturb the repository site (pp. 17, 18).

o The location of existing "breccia pipes" and of the hydrologic and stratigraphic conditions capable of containing and supporting large solution voids apparently necessary to cause them, indicate that the likelihood of encountering an old pipe or a new one forming de novo near the WIPP site is practically nonexistent (pp. 18, 19; see also Appendix E).

o Evidence seems good that because of its low permeability, high salinity, and isotopic composition the Bell Canyon Formation cannot function as a source or transporting agent for solutions that could form breccia pipes by density flow, nor could it be responsible for extensive interstratal dissolution (p. 18, 19).

o The preponderance of evidence does not support the hypothesis that large-scale recent strata-bound dissolution might endanger a repository at the WIPP site, but evidence against the hypothesis is not conclusive (pp. 19-23).

o The brine reservoirs encountered in the Castile Formation near the WIPP site are most likely isolated pockets of fluid not connected with or residual from recent solutions moving long distances through the formation (22, 23). Even if the WIPP-12 pressurized brine reservoir in the Castile extended directly beneath the WIPP site, this should not adversely affect the operating facility, and there is insufficient justification to delay progress on the WIPP.

Chapter 3: In-Situ Tests and Experiments

o The opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in a real underground salt repository at depth, is an important aspect of the WIPP program (pp. 32-34).

Chapter 4: Waste-Acceptance Criteria

o The possibility of self-sustaining underground fires can be eliminated by embedding combustible materials in a matrix of noncombustible material in a suitable proportion (pp. 35, 37).

o The criteria related to biological gas generation are based on a rather superficial analysis. The extreme nature of the repository environment imposes many conditions that are not adequately taken into account. It is possible that the humidity (water activity) in a sealed repository is low enough to inhibit biological activity completely (pp. 37, 38).

o If there is biological activity, the presence of sulfate in the salt makes it likely that hydrogen sulfide, rather than methane, would be the major product (pp. 37, 38).

o From the WIPP viewpoint, the quality assurance system is inadequate, in that it requires no on-site verification of conformance of package contents to the certification (pp. 39, 40).

Chapter 5: Design and Operation of Facilities

o The present plan to develop the storage areas to the south of the shafts and the experimental areas to the north of the shafts is commendable (p. 44).

o The layout of the eight panels of storage rooms separated by barrier pillars is well considered, provided the penetrations of these barriers are sealed adequately (p. 44).

o Details of devices for temporary and permanent closure of the penetrations through the barriers have not been provided (p. 44).

o Recently the repository design has changed from four to three shafts. The four-shaft system had a far greater degree of redundancy and flexibility, both in terms of the system and of operations, than does the three-shaft system (pp. 47, 48).

o The panel has not seen an adequate quantitative evaluation of the economic advantages of the three-shaft system that justifies forgoing the flexibility and safety of the four-shaft system (pp. 47, 48).

o The system as presently proposed with three shafts has redundancy more typical of conventional mining practice than of nuclear industry practice (p. 48).

Chapter 6: Performance Assessment

o The dosages calculated to be received by humans as a result of normal operations and accidents are within prescribed limits for workers and far below the dosages from normal background radiation for members of the public. There is a great deal of experience in these types of operations, and confidence in the accuracy of the calculations is high (pp. 50, 51). (Since this analysis was completed, the lower limit of concentration for classifying transuranic wastes has been changed [9/30/82] by the Department of Energy from 10 to 100 nanocuries per gram. The amount of waste affected, the cost to handle it, and the safety consequences of this change have not yet been published).

o The long-term release scenarios, shown in Figures 6-1 to 6-6, lack experimental verification. Nevertheless, the scenarios appear to set outside limits to what would be credible releases. Though only a consequence analysis is performed, the resulting dose commitments (50 years) are well within prescribed limits (maximum 170 mrem whole body) and far below the dosages from normal background radiation (average 50 years, 5,000 mrem) (pp. 51-57).

RECOMMENDATIONS

Chapter 2: Site Selection and Characterization

o It is practicable to evaluate the effects of resource extraction in Zone IV on a case-by-case basis to assess whether or not such extraction poses any significant threat to the safety and integrity of the repository. Though present extraction techniques pose no significant threats to the repository, the Department of Energy should obtain the right to deny mineral and hydrocarbon extraction in Zone IV, as well as Zones I, II, and III, during the operational and administrative control period, unless such extraction can be shown to pose no significant threat to the repository (pp. 14, 16).

o To test the extent of deep strata-bound dissolution, Sandia's plans for further field and analytical work should be implemented. These plans include (a) making firmer estimates of the amount of salt deposited and removed by comparing in detail drill cores and borehole logs from many parts of the basin, and (b) studying in detail the water flow and residues in anhydrite beds (pp. 19, 20).

o One or both of the remaining hydrologic test holes planned to be drilled in 1983 should be located on lineaments or fracture traces if such features are revealed on satellite images and high-altitude areal photographs. Hydrologic test holes so located would help to determine if zones of fracture concentration exist within dolomite at the WIPP site and if they are influencing differential salt dissolution and/or secondary permeability development. Such narrow and elongate zones of more closely spaced fractures should exist in dolomite at the WIPP site judging from their observed presence in reef and other strata southwest of the site and elsewhere. The hydrologic significance of shorter, more numerous rock fractures, or anisotropy, have been revealed at three Rustler dolomite sites by Gonzalez (1982). The basic short-term hydrologic investigations planned and being carried out by Sandia National Laboratories to refine understanding of the nature and distribution of permeability within Rustler aquifers are well conceived and should be continued (pp. 19, 20).

Chapter 3: In-Situ Tests and Experiments

o Operational experience with the handling and emplacement of various types of waste package shapes and sizes containing TRU wastes at the WIPP site should be obtained in a timely manner so that this experience can be factored into final choices for large-scale disposal of TRU wastes (p. 32).

o The later stages of the WIPP R&D program should be kept flexible to accommodate changes suggested by early WIPP results or by progress in waste disposal technology by other organizations. Active efforts should be made to solicit ideas and participation from the general scientific community. Publishing project R&D results in the refereed literature would encourage such participation. Outside developments in automated

sensing, robotics, instrumentation in hostile environments, etc., should be systematically screened for application or testing at the WIPP facility (p. 33).

o Procedures for handling defense high-level waste in the experimental R&D areas should include special safety precautions, which may not be needed for facility construction or emplacement of TRU waste (p. 33).

o The matrix of tests on waste form, waste package, overpack, and backfill to be investigated at the WIPP facility should be supplemented by aboveground laboratory tests to validate the latter form of testing and thus permit expansion of the matrix by less expensive experiments (pp. 33, 34).

Chapter 4: Waste Acceptance Criteria

o As soon as feasible, standardized waste packages should be adopted in a minimum number of sizes (p. 35).

o The storage of combustible waste should be controlled so that noncombustible material is intermixed with combustible packages in such a way as to render the mixture incapable of self-sustaining combustion in a current of air (pp. 35, 37).

o The existing deficiency in the SAR on procedures for fighting transient underground fires should be remedied (p. 37).

o The humidity of still air in equilibrium with the salt and the pH of the salt at the storage horizon should be measured. These fundamental quantities are significant for the evaluation of biological and chemical degradation processes (p. 38).

o The restrictions on permissible mass of organic material per unit volume of waste should be dropped from the gas-generation criterion if measurement shows the relative humidity of a sealed enclosure in the salt at the repository horizon to be 60 percent or less (p. 38).

o If the humidity of the air is higher than 60 percent, a competent biological specialist should be engaged to evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment (p. 38).

o State-of-the art equipment should be provided at the WIPP facility for nondestructive verification of compliance with those elements of the waste-acceptance criteria for which such equipment exists (p. 39).

o The existence of a practical alternative should be ensured for handling those TRU wastes that arrive at the WIPP site and that fail to meet the WIPP TRU waste-acceptance criteria. The alternative should be available at the time that it is needed (p. 40).

o Waste-acceptance criteria should be defined for the defense high-level waste that is to be used in the experimental program. The definition should be early enough to allow time for review before experimental operations begin (p. 40).

Chapter 5: Design and Operation of Facilities

o Explicit mechanisms for the transfer of information from SPVD experiments and information gathered during construction and development to final design must be established (p. 42).

o Displacements of the salt in the far field that occur as a result of long-term closure of excavations must be shown to be sufficiently small that they do not significantly increase the permeability of the bulk of the salt (pp. 44, 47).

o It should be shown that sealing the repository is sufficient to preclude unacceptable increases in hydraulic conductivity across the repository horizon (p. 47).

o The justification for using diesel motive power for salt transport underground should be reexamined (pp. 47, 48).

o The effects of changes in the configuration of the surface facilities, the number of shafts, the ventilation system, and the electrical backup need to be further elaborated in terms of operational safety, efficiency, and nuclide releases (pp. 44, 45).

Chapter 6: Performance Assessment

o Hydrologic investigations and monitoring programs should be continued to more adequately resolve the differences between recent and initial interpretations of potentiometric maps and to provide a more consistent and confident definition of the rates and directions of groundwater flow within Rustler aquifers above and immediately adjacent to the site (pp. 56, 58).

o Though karst-type flow in the Rustler occurs near Nash Draw, the extent to which it reaches eastward is not clearly delineated. If this type of flow should be joined by connected fractures to the WIPP site area, the time of travel of the nuclides and their retardation would be sharply reduced. Both the probability of such flows and their effect upon radiation dosages need to be determined (p. 58).

CHAPTER ONE

INTRODUCTION AND BACKGROUND

The history of the Waste Isolation Pilot Plant (WIPP) project was presented to this panel at a study planning session on June 5, 1978. As far back as March 1974, the Oak Ridge National Laboratory had begun site investigations for a terminal radioactive waste repository for commercial high-level waste in a region selected by the U.S. Geological Survey in the Los Medanos area of New Mexico. In May of that year, this work was suspended in favor of the concept of retrievable surface storage, and the land-withdrawal action that had been initiated was deferred in December 1974. The Albuquerque Operations Office of the U.S. Atomic Energy Commission (AEC) and the Sandia National Laboratories were then requested by AEC headquarters to become involved in the program to locate a site for a radioactive waste disposal pilot plant for defense-related low- and intermediate-level transuranic waste, with some provisions for experimentation with defense high-level waste. When drilling began in 1975 at a site in the Los Medanos region recommended by Sandia, irregular subsurface geological conditions were found, including high-pressure brines and gases. Consequently, the first site was rejected, and a new one was identified independently by Sandia National Laboratories and the U.S. Geological Survey 11.2 km to the southwest. The general location of the site and a geologic section through the Los Medanos area are shown in Figures 1-1 and 1-2, respectively. In January 1976, the geological investigations were resumed at the newly proposed site, and the project was given its present name: Waste Isolation Pilot Plant.

The drilling of ERDA-9, the first hole at the new site, commenced in April 1976. In October 1976, funding was requested for an architect-engineer, and a new land-withdrawal notice was placed in the Federal Register in December 1976. In April 1977, a preliminary version of the Draft Environmental Impact Statement was distributed by the U.S. Department of Energy (1979) for comment, and it was announced that WIPP would be a licensed facility. In June, the final version of the conceptual design was issued. In September, Bechtel was selected as the architect-engineer, and in November, the DOE sent a letter to the Nuclear Regulatory Commission saying it intended to request a license.

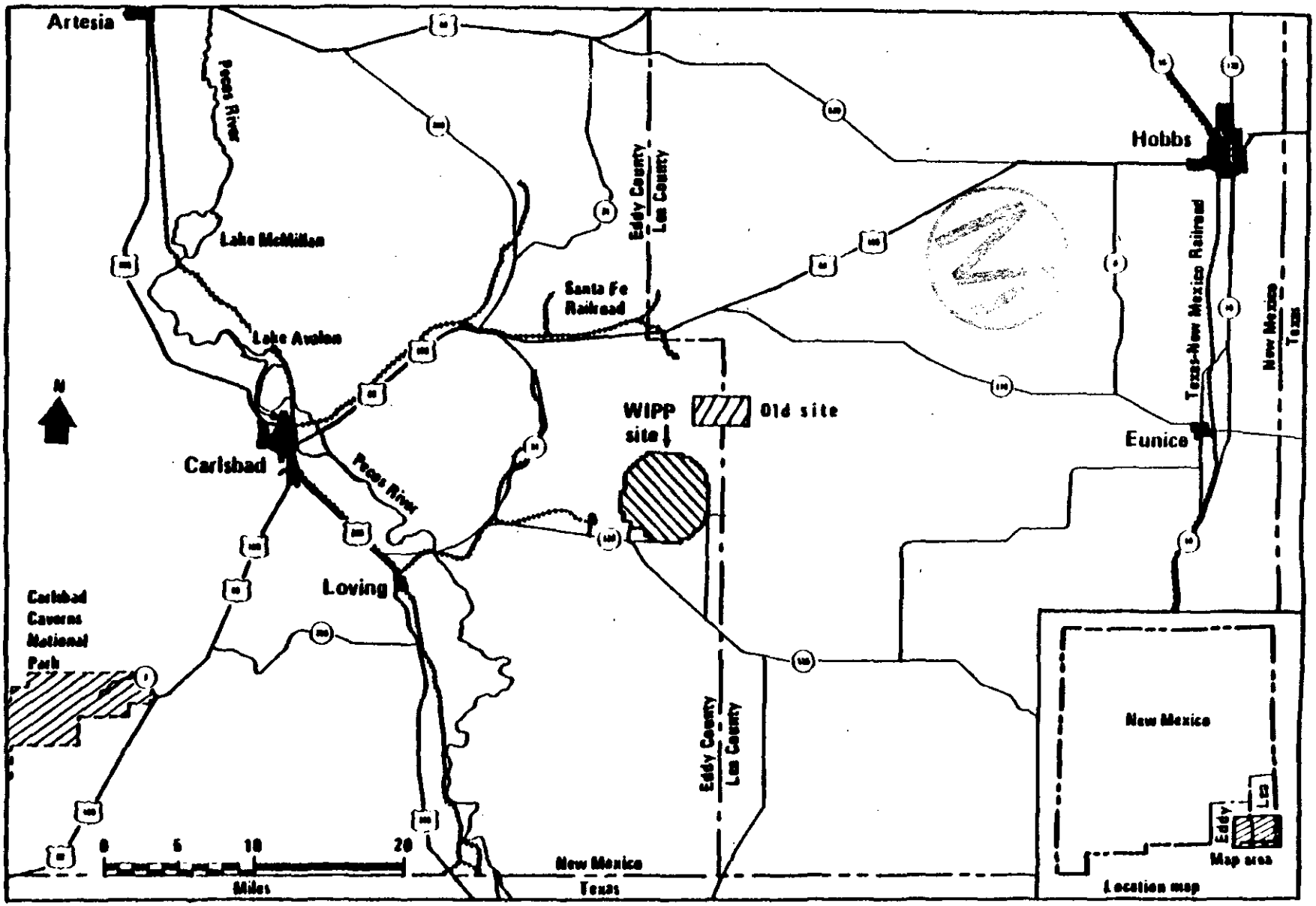

FIGURE 1-1 General location of the WIPP site. Source: U.S. Department of Energy (1980).

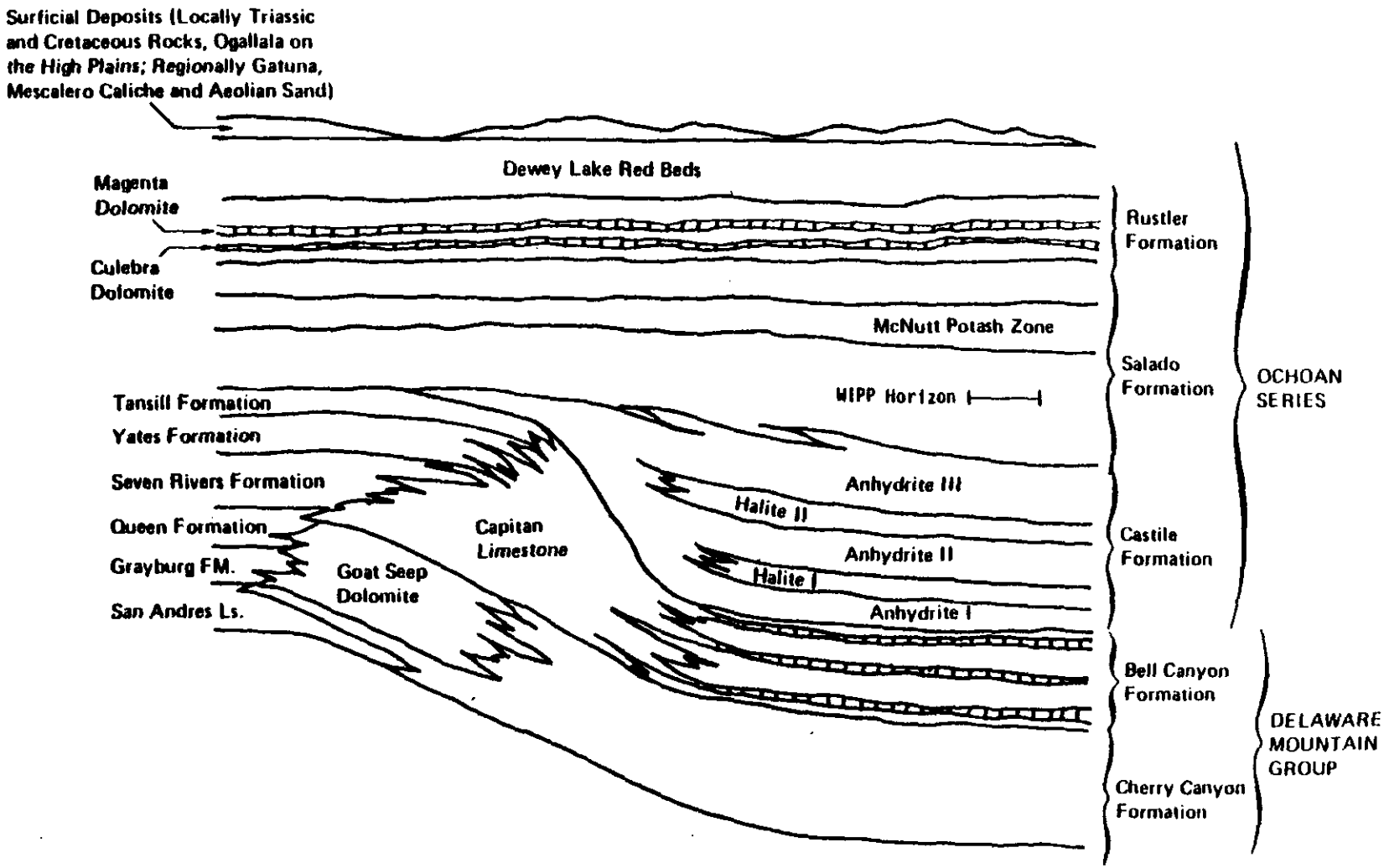

FIGURE 1-2 Diagrammatic section showing stratigraphy of the Delaware Basin. Not to scale. Source: Lambert (1982).

In February 1978, the "Deutch Report" (U.S. Department of Energy 1978) called for a demonstration of the experimental emplacement of high-level waste and possibly ultimate disposal of commercial spent fuel at the WIPP site. Objections were raised by the Committee on Armed Services, U.S. House of Representatives, which insisted that the site should be unlicensed and used only for defense waste. This view eventually prevailed.

The Geological Characterization Report (Powers et al. 1978), a compilation of geotechnical information available as of August 1978 and judged to be relevant to WIPP studies, was published in December 1978.

In March 1979, an Interagency Review Group (IRG) appointed by President Carter reported on its review of the progress of the U.S. waste disposal program and suggested four alternative technical strategies, one of which would specify salt as the host geologic medium for the first mined repository (Interagency Review Group 1979). The following month, DOE issued for public comment the WIPP Draft Environmental Impact Statement, or DEIS (U.S. Department of Energy 1979), including consideration of the possibility of disposal of limited quantities of commercial spent fuel.

Public Law 96-164, enacted in December 1979, authorized WIPP as a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission. Within three months, President Carter announced his intention to recommend cancellation of WIPP and requested rescission of previously appropriated funds. Congress did not act on the rescission request, however, and the project continued, as authorized by PL 96-164.

The WIPP Safety Analysis Report, or SAR (U.S. Department of Energy 1980-1982), was issued in February 1980 and has been updated by amendments in September 1980, January 1981, October 1981, and September 1982.

In October 1980, DOE issued a Final Environmental Impact Statement, or FEIS (U.S. Department of Energy 1980), which included responses to comments received from the public and from government agencies, and which reflected changing policies and legislative requirements. In the new document, the concept of an intermediate-scale facility for the disposal of spent fuel and the associated two-level underground layout were eliminated. Also deleted was the proposal for licensing of the repository.

Thus, as of this writing, the WIPP repository is intended as an unlicensed facility for the disposal of TRU waste generated in U.S. defense programs and for the experimental emplacement of a small quantity of high-level waste. No permanent disposal of high-level waste is planned. TRU waste, it should be noted, differs from high-level waste in that very little heat is generated. Calculations indicate that the maximum temperature rise in the center of the repository will be less than 2°C, so that the effects of heating on the salt beds will be negligible.

One of the first official acts of the Reagan administration was the January 1981 issuance of a Record of Decision to proceed with the project; but in April, the State of New Mexico filed suit against DOE to

require acquisition of extensive additional technical information and the resolution of a number of controversial issues. Under the resulting Stipulated Agreement, signed in July 1981, a number of technical reports are being prepared and are being examined by the panel as they become available.

Independently of this DOE-sponsored study by the National Research Council, the State of New Mexico itself has set up four groups concerned with WIPP--an Environmental Evaluation Group (EEG); a Radioactive Waste Consultation Task Force, composed of three members of the governor's cabinet; a Radioactive Waste Consultation Committee, composed of eight members of the state legislature; and, until June 1, 1981, a Governor's Advisory Committee on WIPP.

WIPP program activities were in progress during the course of this study; thus the panel was evaluating existing data and concepts while new information was being obtained and analyzed. This report is not a summary of WIPP activities, but an analytical commentary on those aspects that the panel has reviewed. For completeness, some material has been included that was incorporated originally in three special reports (Appendices A, B, and C) that dealt with site suitability of the proposed site near Carlsbad, New Mexico, from a geological and hydrological standpoint; the limitations of surface exploration of underground formations, and continued evaluation of the Carlsbad site. A September 1981 Progress Report (National Research Council 1981) on the first 18 months of this study has also been drawn upon, as appropriate.

CHAPTER TWO

SITE SELECTION AND CHARACTERIZATION

HISTORY

The criteria that were used in selecting the WIPP site reflect the criteria commonly cited in proposals for waste isolation in bedded salt (National Research Council 1970) and the geological criteria for repositories (National Research Council 1978) and seem technically and scientifically adequate. The recommendations include (1) a bed of rock salt (halite) at least 60 m thick, of purity sufficient to minimize chemical complications from brine of complex composition and from water released from hydrous minerals; (2) a depth greater than 300 m to ensure freedom from surface influences; (3) a depth less than 1,000 m to ensure acceptably low creep rates in the salt; (4) approximate horizontality to minimize difficulty in mining operations; (5) little indication of recent tectonic or igneous activity; (6) sufficient distance from an exposed edge or underground aquifer where salt dissolution is occurring; and (7) an area without a history of resource extraction and sizable economic resources. Although many sites in the United States would probably satisfy these criteria, a site in southeastern New Mexico was chosen as described in Chapter 1.

Two additional criteria specific to the Carlsbad area were suggested by the conclusions of a study (Bradshaw and McClain 1971) at Lyons, Kansas, and by observations at an earlier WIPP site (a site near borehole ERDA-6): the repository should be located at least 1.6 km from the nearest borehole penetrating through the salt beds, and at least 8 km from the Capitan Reef to avoid a zone of disturbed bedding known to parallel the reef.

With these criteria in mind, lines were drawn on a map to outline areas where salt beds of requisite thickness at proper depths were known to occur and to exclude areas within 1.6 km of known deep boreholes, within 8 km of the Capitan Reef, within 1.6 km of the dissolution front, or with known potash or hydrocarbon resources. Two areas of reasonable size outside these lines were identified (see Figure 2-1). Site 2 seemed less suitable because it had deeper salt beds and was closer to an oil field where water flooding may be used for secondary recovery in the future, even though Site 1 was closer to the reef and the potash zone. Both sites have the advantages of nearly flat topography, an arid

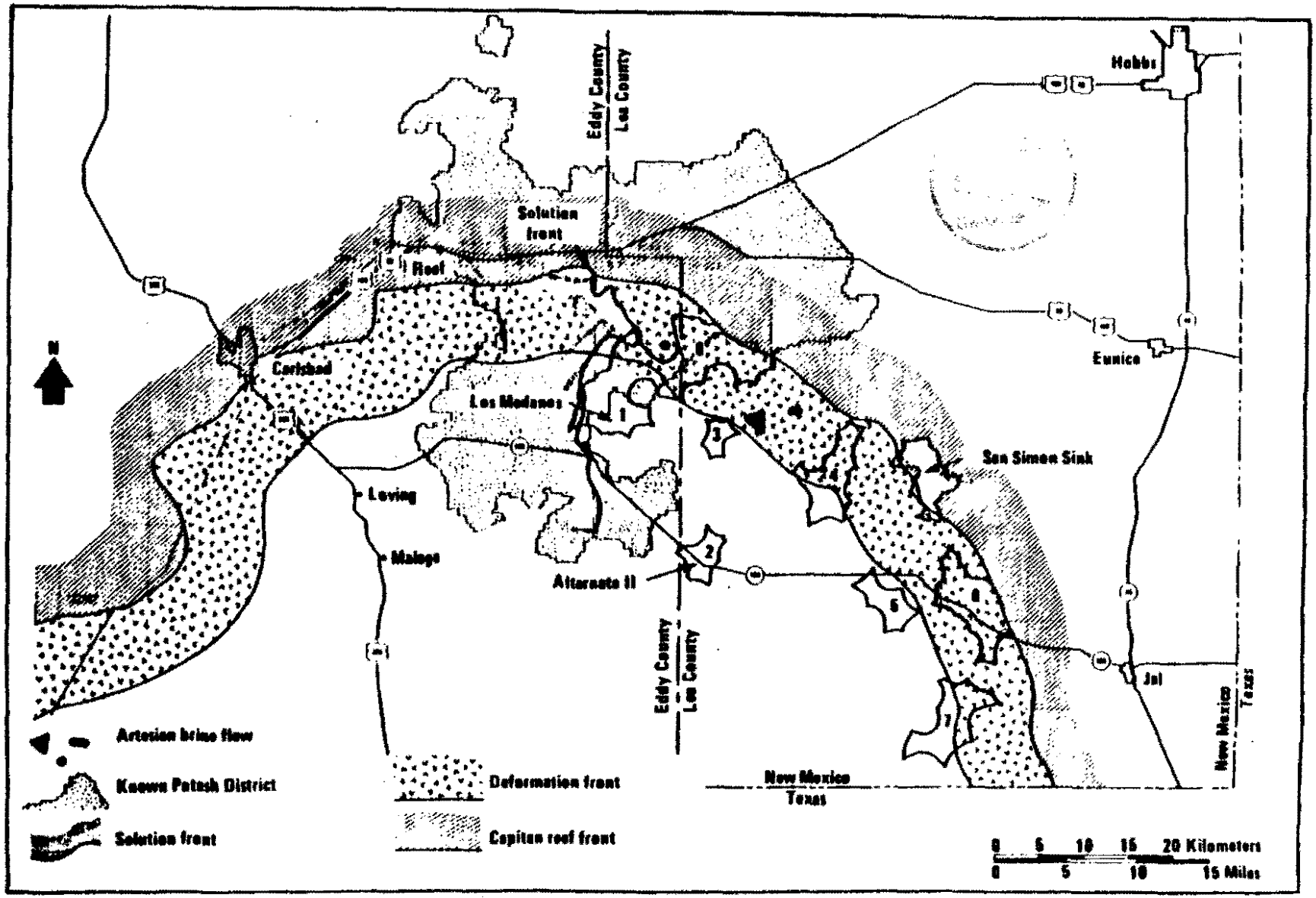

FIGURE 2-1 Application of the site-selection criteria. Source: U.S. Department of Energy (1980).

climate, and sparse population. The major regional geologic structures in the vicinity are shown in Figure 2-2.

Site 1 was chosen and subsequently an exploratory shaft was constructed. The part of the Salado Formation preselected for repository construction was mapped in great detail from exposures in the shaft. For the shaft station, a location was picked in the thickest layer of halite, containing only minor polyhalite and a few thin clay seams. The precise stratigraphic position was chosen during a technical discussion among experts from DOE and its principal contractors; personnel of the USGS and EEG were kept informed, and their comments were solicited (Jarolimek and McKinney 1982).

REMAINING UNCERTAINTIES

Although the generic criteria as applied to the WIPP site are in large measure satisfied, questions have been raised about the suitability of the site to satisfy a few of the criteria in detail. Grounds for these questions include: (1) the likely presence of economically significant quantities of potash and natural gas at the site; (2) possible tectonic instability of the site; (3) possible continued movement of the kind that produced the distorted structures in the evaporite beds of the "disturbed zone," ultimately affecting the now undisturbed beds in the middle of the WIPP site; (4) possible disturbance of the site by karst-forming processes; (5) possible local collapse of the salt beds as a result of solutions moving up from aquifers beneath the salt beds, leading to formation of vertical chimneylike masses of breccia (so-called breccia pipes); (6) possible strata-bound dissolution of salt adjacent to layers of fractured or brecciated anhydrite, especially near the Castile-Salado contact, supposedly rapid during the late Cenozoic and continuing today; and (7) possible presence of pressurized-brine reservoirs.

These objections to the WIPP site have been expressed many times over the past several years. Many of the objections have been partially answered and so have become less serious in the course of time, but valid questions remain about a few. The following discussion is focused on recent attempts to deal with the remaining questions.

Natural Resources

Further study after the site had been picked showed that probable potash and hydrocarbon resources were greater than had been thought originally, though they are still not economically worth recovering with present techniques and at current prices. Because of these resources, the ability of the site to satisfy the criterion relating to natural resource potential seemed dubious, and two years ago this question loomed as a major flaw in the case for site suitability. A recent study indicates, however, that most current techniques of mineral exploitation can be safely employed in the outer part of the site area (Zone IV, shown in Figure D-1, Appendix D) (Brausch et al. 1982), so that a large

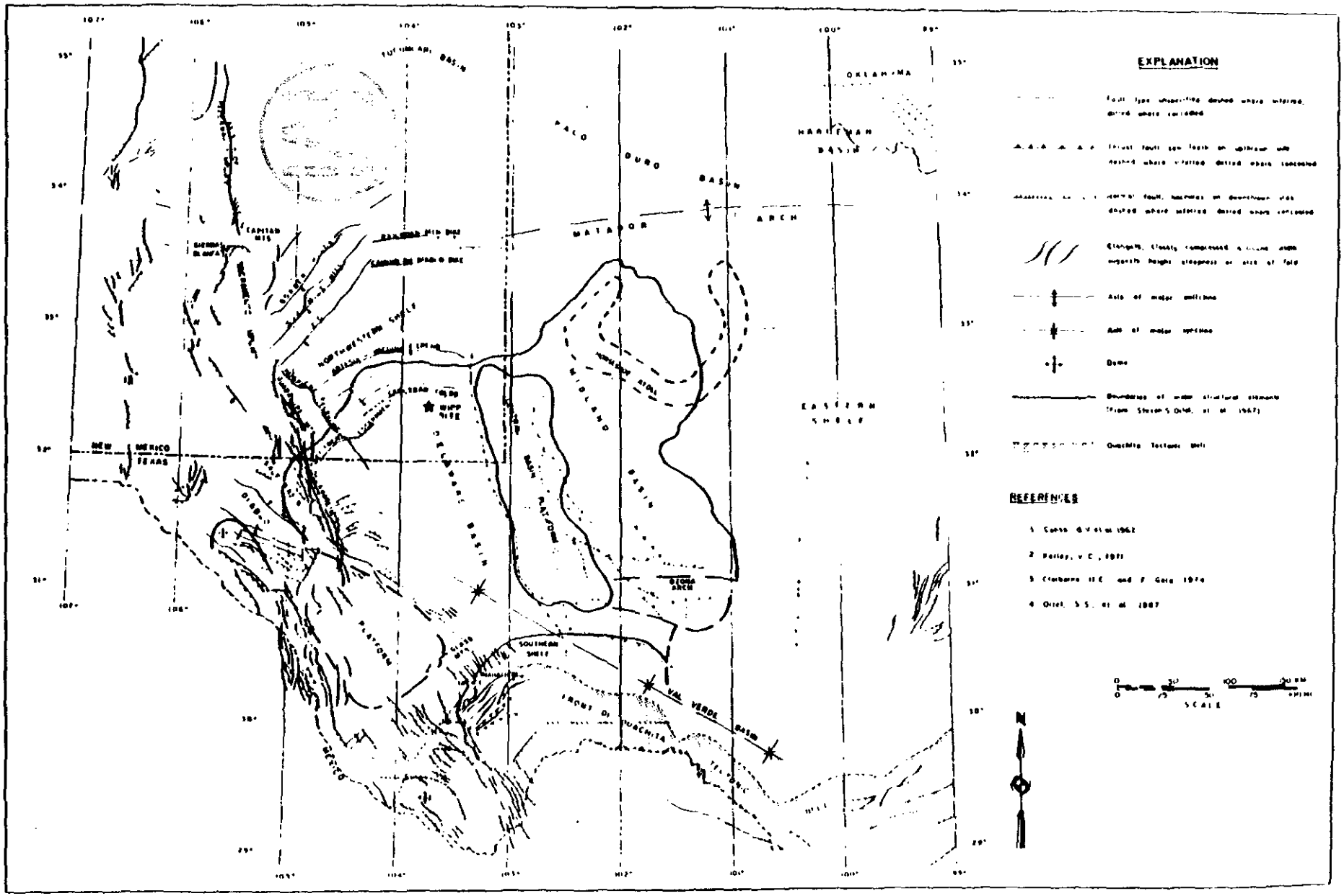

FIGURE 2-2 Major regional geologic structures. Source: U.S. Department of Energy (1980).

part of the hydrocarbon and potash resources may be recoverable with no appreciable hazard to the waste facility. The panel accepts this conclusion only with the proviso that each proposal to develop the resources should be carefully examined, with the burden of proof as to its safety made the responsibility of the proposer.

That is, subsidence and increased hydraulic conductivity due to the use of mining techniques such as hydraulic fracturing ("hydrofracking") or solution mining would not affect the integrity of the repository if these activities were restricted to Zone IV. However, this does not reduce the attractiveness of the site to future generations for mineral exploration.

More detailed discussion of the value of natural resources and the consequences of mining them is included in Appendix D.

Tectonic Stability

The well-known occurrence of fault displacements and basaltic eruptions during the Quaternary epoch in the Rio Grande Valley 250 km west of the site was cited a few years ago as posing a possible risk of future tectonic disturbance at the waste facility. The risk is not wholly negligible, of course, but to most observers the long distance from the Rio Grande coupled with complete absence of seismic evidence for significant crustal movement and of geologic evidence for recent tectonic disturbance or volcanic activity has seemed sufficient to assure tectonic quiescence at the site. The only recent evidence bearing on the question is simply the continued lack of anything but very minor seismic events recorded by the seismic network established near the site.

The "Disturbed Zone"

The "disturbed zone" is an area adjacent to the Capitan Reef in the northern and eastern parts of the Delaware Basin in which evaporite beds are deformed, as shown by borehole data and seismic profiles. The deformed beds are in part strongly tilted, folded, and faulted, and in places show marked increases and decreases of their normal thickness. In general, the intensity of deformation decreases away from the Capitan Reef, and at the distance of the WIPP site is relatively mild. Deformed rocks at the margin of the disturbed zone have been encountered in boreholes in the northern part of the WIPP area, and stronger deformation is found beyond its borders to the northeast. In addition to the disturbed zone, small isolated areas of somewhat deformed rocks occur elsewhere in the basin, but none within 3 miles of the WIPP site.

Concern has been expressed about the possibility that deformation may be continuing today, and may affect the presently almost undisturbed strata in the middle of the WIPP site at some time in the future. Strong movements in the beds containing a waste facility, it is feared, might disrupt the stored waste and permit entry of solutions that could dissolve and transport some of the radioactive material.

To investigate this possibility, an intensive study of deformation processes in the salt beds has been undertaken (Borns et al. 1983). The study includes detailed descriptions of the kinds of deformation present, evidence regarding the age of deformation, and discussion of several hypotheses of origin. Although the authors conclude that evidence is insufficient to give a firm date for the time (or times) of deformation or to establish beyond question the mechanism by which the deformation occurred, they note that by any reasonable hypothesis of origin, the time involved in forming the observed structures is very long, on the order of a million years or more. Hence, the deformation, even if it is continuing now, would not "present a major hazard to the construction and operational stages of the facility." Later deformation might result in minor distortion of a repository, but according to Borns et al. (1983), this would not lead to appreciable movement of radionuclides because there is no evidence for involvement of solutions in the deformation at this horizon beyond small amounts of interstitial fluids.

Karst-forming Processes

The Los Medanos region, like other areas of the world underlain by soluble rocks, is subject to locally rapid and potentially widespread dissolution wherever undersaturated solutions come in contact with the rocks beneath. The dissolution in part works down from the surface and in part is caused by groundwater moving through permeable beds and channels below the surface. As parts of the rock dissolve, overlying material collapses into the open spaces. The result is a distinctive kind of topography called karst, characterized by sinkholes, caves, valleys without stream channels, and underground drainage (Bachman 1980, p. 46)--features prominently displayed in parts of southeastern New Mexico near the WIPP site. Although no karst features have been noted at the site itself, the presence of such features within several kilometers, particularly in Nash Draw (about 10 km west of the site) has led to worry that karst may work its way into the site in the near geologic future and provide pathways for water to reach a subsurface waste facility.

Dissolution is clearly in progress on the uptilted edges of the evaporite beds in the western part of the Delaware Basin, and can be expected to work its way slowly eastward. Important questions, then, concern the rate of present dissolution and possible future changes in the rate due to climatic change or tectonic disturbance.

The rate of dissolution has been estimated in various ways. In Nash Draw, where geologically recent dissolution has removed much of the Rustler Formation and part of the upper Salado, two Pleistocene formations, the Gatuna and the Mescalero, in part lie undisturbed on an old karst surface and in part have collapsed as a result of continuing dissolution. From these facts Bachman (1980) concludes that present karst features have formed during and since the deposition of these beds. The older one (Gatuna) can be confidently dated (from an included bed of volcanic ash) as about 600,000 years old, and from the thickness

of evaporite strata removed since Gatuna time, Bachman derives an average rate of vertical dissolution of 10 cm in 1,000 years. A similar figure has been estimated from the amount of salt currently being dissolved and discharged by streams and springs in the basin (U.S. Department of Energy 1980, p. 7-98). For the rate of horizontal dissolution, Bachman and Johnson (1973) estimated 10 to 13 km per million years, on the assumption that "at the end of Ogallala time the Salado Formation extended to the Capitan Reef on the western edge of the basin." These estimates suggest that a waste facility at the WIPP site should be secure from karst-forming processes for at least a million years.

Implicit in this conclusion is the assumption that the future climate of southeastern New Mexico will be similar to the average climate over the past 600,000 years. During this period in the past, the climate has fluctuated from dry to pluvial, but on the whole has been fairly arid. There is little reason to expect that average climates in the future will deviate greatly from this pattern (Bachman 1980); nor is it likely, as noted in the last section, that tectonic movement in the next few hundred thousand years will elevate this region sufficiently to cause a marked change in average rainfall.

The panel recognizes that estimates of dissolution rates and guesses about future climates are based on somewhat slender evidence, but the assumptions involved seem reasonably conservative, and the general conclusion that a repository at the WIPP site would not be disturbed by karst-forming processes for a million years or more seems well founded.

Breccia Pipes

The possibility of forming vertical pipelike masses of breccia by collapse induced by solutions working their way upward into the repository in the salt beds from aquifers beneath, similar to breccia pipes observed elswhere in the basin, has been raised repeatedly over the past several years (Anderson and Kirkland 1980; Anderson 1981a, b). Two years ago the favored form of this hypothesis envisioned solutions in the Bell Canyon Formation (of the Delaware Mountain Group below the evaporite beds) as the active agents of dissolution, and postulated that the solutions not only formed the collapse pipes, but also worked their way along the Castile-Salado contact, dissolving the lower Salado salt (in which the repository would be sited) as they moved. In other words, at that time a combination of the fifth and sixth uncertainties mentioned previously was proposed--active formation of breccia pipes and widespread dissolution of salt in the lower Salado, in part by solutions rising into the pipes from below.

More recently, the formation of breccia pipes near the waste facility has been shown to be highly improbable, and the Bell Canyon Formation has been proved incapable of generating solutions that could either form breccia pipes or cause widespread dissolution (Lambert 1982; Wood et al. 1982). Demonstration that formation of breccia pipes poses no appreciable hazard to the WIPP site depends on a recent theoretical argument and additional field data. Until recently the formation of

breccia pipes has been attributed to a mechanism of "density flow"--the rise of unsaturated solutions into overlying salt beds, the dissolving of salt to form more saturated and hence more dense solutions, and the descent of these dense solutions to make room for fresh injections of unsaturated fluid (Anderson and Kirkland 1980). On theoretical grounds this mechanism could produce pipes of collapsed material only if dissolution at the base of the salt section is fairly rapid. With fast-enough dissolving of salt, a cavity or zone of weakness might be produced into which overlying beds would collapse by brittle fracture; but if the dissolving is slow, the salt would gradually subside by plastic flow to form a funnel-shaped volume of somewhat deformed beds rather than a pipe of brecciated salt (Davies 1983). Rapid dissolution at the WIPP site could only be caused by fluids in the Bell Canyon Formation, which immediately underlies the salt. Recent data on this formation, however, indicate that it is not a credible source of such fluids: The permeability of this formation is low and practically restricted to a few small sand stringers with little hydraulic interconnection; the amount of water is small, it moves only slowly, and it contains too much dissolved material to be an effective solvent (Lambert 1982, p. 119). Spiegler (1982), using reasonable numbers for the properties of salt and the solutions in the Bell Canyon, has calculated that the rate of plastic flow of salt would be on the order of a hundred times its rate of removal by dissolution.

A more likely cause of breccia pipes is sudden collapse into an opening dissolved out of an underlying brittle rock such as limestone. All known pipes in the Los Medanos area have been shown to exist only in places where the salt beds overlie parts of the limestone of the Capitan Reef; and the near certainty that collapse originated in the limestone has been established by deep drilling in one of the pipes that showed breccia persisting downward to the bottom of the drill hole, only a few meters above the reef (Snyder and Gard 1982).

Since the WIPP site is 8 km from the nearest part of the reef, and since solutions in the Bell Canyon Formation are unlikely to cause sudden collapse in the salt itself, the formerly suggested danger of encountering an old pipe at the WIPP site, or of a pipe forming de novo under the waste facility, seems remote. More details on breccia pipes are found in Appendix E.

Deep Strata-bound Dissolution

Anderson has continued to express concern about possible extensive deep interstratal dissolution caused by solutions generated by infiltration of meteoric water, moving long distances through layers of fractured anhydrite near the Castile-Salado contact and dissolving halite from the beds above and below (Anderson 1982a). The evidence for such dissolution is chiefly the absence of much of the lower Salado salt under the western part of the basin (Anderson 1981b, 1982a; Anderson et al. 1972). The amount of missing salt was estimated by extrapolating salt thicknesses, from areas where salt is believed to be intact to areas where salt is thinned or missing. Detailed matching of fine

laminations ("varves") in the evaporite sequence, particularly in anhydrite beds, in cores from drillholes at intervals across the site, indicated that Salado salt was originally deposited throughout the Delaware Basin. The gap in the salt sequence is thought to be due to dissolution; the anhydrite breccias ("dissolution breccias" formed as residues of salt dissolution) in some of the cores from the western half of the basin are cited as further evidence. It is thought that some of the surface depressions above the supposed dissolution front were formed by subsidence due to dissolving out of salt beneath, and from failure to find sediments older than Pleistocene in these depressions, Anderson concludes that rapid dissolution is limited to the past few million years and is probably continuing today. Water for dissolving the salt is assumed to be of meteoric origin (Anderson 1982a). It descends into the upturned salt edge in the western part of the basin, traverses layers of fractured and brecciated anhydrite near the Castile-Salado contact, and leaves the basin through cavities in the buried Capitan Reef on the east side. The brine reservoirs encountered in the ERDA-6 and WIPP-12 drillholes are cited by Anderson as ponded remnants of the solutions that have moved, or are moving, through the brecciated anhydrite layers.

The validity of this hypothesis is difficult to judge against alternative ideas. Scientists at Sandia National Laboratories agree that strata-bound dissolution of the sort described above is possible, and may well be responsible for formation of some of the surface depressions in the Los Medanos area (Lambert 1982). They disagree with regard to the scale and recency of the dissolution process. The earlier hypothesis envisions solutions moving completely through the evaporite basin to the Capitan Reef, concentrated in strata near the Castile-Salado boundary, and active primarily in the last few million years. By contrast, the Sandia scientists consider strata-bound dissolution to be a relatively minor process today and in the recent geologic past; they think of it rather as a phenomenon that was active adjacent to many anhydrite beds at various times since the Permian, is restricted to the western part of the basin, and is limited in its range by escape of the solutions into various debris-filled depressions. In the previous hypothesis the dissolution is active enough and extensive enough to be a serious threat to a waste facility at the WIPP site; to the Sandia scientists, the interstratal dissolution is simply a minor part of the slow, general dissolution of the evaporite sequence that has gone on intermittently for hundreds of millions of years and poses no appreciable hazard to the proposed facility.

A choice between the two viewpoints must rest on answers to several subsidiary questions: (1) What is the magnitude of salt removal, particularly from the lower Salado? (2) Can actual movement of large volumes of fluid through anhydrite beds near the Castile-Salado contact be demonstrated, either as present-day movement or movement in the recent geologic past? (3) What is the evidence for major dissolution in the late Cenozoic, as opposed to dissolution at intervals since the Permian?

(1) Amount of Salt Removed

That some of the thick, lower Salado halite present in the eastern part of the basin is missing toward the west is well established, but explanations for its absence differ. Anderson, in support of his hypothesis, estimates the amount of missing salt by painstaking comparison of many tens of thousands of thin stratigraphic units based on geophysical logs in drillcores from boreholes across the basin, and ascribes the absence of salt entirely to removal by geologically recent dissolution (Anderson et al. 1972). Lambert (Lambert 1982, Chapter IX) questions the validity of some of the stratigraphic correlations, and attributes the missing part of the salt sequence to several phenomena: nondeposition of halite on elevated parts of the original evaporite basin, deposition of anhydrite rather than halite in parts of some continuous beds (as is common in evaporite sequences elsewhere), removal of some halite by erosion during the Permian (as evidenced by an unconformity separating parts of the Castile and Salado), and removal of some halite by dissolution at several periods since the Permian. A clear-cut choice between the two views is not possible on the basis of present knowledge, but a detailed review of borehole cores and geophysical logs being undertaken by Sandia will probably provide the additional information for a resolution of the conflicting hypotheses.

(2) Movement of Fluid Through Anhydrite

Anderson (1982b) regards brine reservoirs like those encountered in Castile anhydrites in the ERDA-6 and WIPP-12 boreholes as prime evidence for his present hypothesis. The brine reservoirs, in his view, are isolated pockets containing samples of the solutions that have moved or perhaps are moving through the anhydrite layers. As a source for the dissolution fluids, Anderson suggests either rainfall in an area of gravels near the west margin of the Delaware Basin (Black River gravels) or water from the Pecos River where it crosses the uptilted Salado-Castile contact; as a sink for the solutions he proposes the cavernous Capitan Reef limestone on the east and northeast sides of the basin. Lambert (1982) argues, on the other hand, that analysis of the brines in the reservoirs shows that they cannot be the result of simple dissolution of halite, because neither the observed chemical composition nor isotopic composition would result from such a process. It was also pointed out that fractured anhydrite lacks some expected characteristics of a dissolution breccia (no concentration of residual clay minerals and none of the gypsum that should form if water-filled open spaces develop in anhydrite) and is more likely produced by deformation of the salt beds. He regards the brine reservoirs as pockets of brecciated material created by slight movement in the salt layers near the edge of the "disturbed zone" adjoining the Capitan Reef; the brine has accumulated from a variety of sources, perhaps largely by "kneading out" of fluids from halite beds during deformation (Borns et al. 1983), and remains immobile. The facts that the brine reservoirs have pressures well above hydrostatic, that flow of solutions from one reservoir has no effect on

nearby reservoirs, and that anhydrite from most boreholes that penetrate this horizon is not fractured and contains no fluids, are good evidence that the reservoirs are not part of a widespread interconnected aquifer, at least not one at the present time. As an additional test of Anderson's views, scientists at Sandia National Laboratories plan a study of the detailed characteristics of residual breccias formed by dissolution, to establish criteria for distinguishing such breccias from similar fractured material produced by salt movement; anhydrite for the study will come from residual breccias higher in the evaporite sequence where dissolution is known to be taking place.

(3) Dissolution Limited Chiefly to the Quaternary

Anderson (1981a, b) grants that some salt dissolution has taken place at various times since the Permian, but contends that the major part is geologically recent and hence is probably active at present. This conclusion is based on two kinds of evidence: the supposed recency of the eastward tilting of beds in the Delaware Basin (late Tertiary), which triggered the dissolution, and the supposed lack of sediments older than Pleistocene in depressions whose origin is ascribed to dissolution of the salt beneath. The Sandia workers (Lambert 1982; Powers 1982) counter that the time of tilting of the evaporite beds is uncertain, but if it is part of the widespread disturbance that formed basin-and-range structures in the western states, it should be dated as mid-Tertiary rather than late Tertiary. They point out also that little is actually known about the age of deposits in depressions in the Los Medanos area; certainly the depressions contain Pleistocene sediments, but these sediments may conceal older beds beneath. Information about maximum age of the depression fills might be obtainable from boreholes drilled for this purpose; but datable material is so scarce in such sediments that definitive dating might require many boreholes, and it can be questioned whether the expense of such an enterprise would be justified. A clear decision about the timing of most salt dissolution seems impossible on the basis of presently available evidence. Further information on salt dissolution is found in Appendix F.

Because clear evidence for salt removal from the lower Salado is found 20 miles south of the WIPP site itself, because evidence for major dissolution in the late Cenozoic rests on the questionable Quaternary age of the entire thickness of sedimentary fill in solution basins, and because no adequate sink for postulated dissolution brines of the present day has been located, the panel doubts that deep dissolution, even if it is occurring as Anderson supposes, is progressing fast enough to jeopardize the integrity of a repository within the next million years.

Pressurized-Brine Reservoirs

Pressurized brine accompanied by carbon dioxide, methane, and hydrogen sulfide has been encountered in several wells penetrating the Castile

Formation (Griswold 1980; egister 1981). The brine occurs in fractured anhydrite in places where the salt beds are deformed, most of them in the zone of deformation near the Capitan Reef. An especially large brine pocket [estimated volume 2.7 x 10^6 m^3 (17 x 10^6 bbl)] was encountered during the deepening of drillhole WIPP-12 in November 1981, only about 1 mile north of the projected repository site, and this finding has led to concern that (1) the brine in this and other reservoirs may be part of an interconnected flow of brine through the anhydrite layer, and (2) a similar large reservoir may exist at or near the repository site and could cause flooding of the repository.

Investigation of the WIPP-12 occurrence, together with previous studies of other brine pockets, has shown that such concerns are without substance (Wood et al. 1982). The principal lines of evidence are the following:

- In the Salado Formation (in which the repository is to be constructed), no brine pockets have been found except small ones at low pressures.
- The chemical and isotopic composition of brines in different reservoirs is different from one to another, and also different from the composition of groundwater in aquifers above and below the salt beds.
- Brine pockets can be emptied by allowing the brine to flow.
- Salt beds are undeformed at the repository site.
- Even if the reservoir found in WIPP-12 should extend under the repository site, or if another reservoir should exist at the site, the anhydrite layer is 244 m (800 ft) below the proposed repository horizon in the Salado Formation.

On the basis of this evidence, the panel concludes that brine reservoirs do not pose a threat to the integrity of a repository at the selected site.

SUMMARY

The panel believes that the criteria used to show that there is little appreciable hazard to a waste facility at the WIPP site from breccia pipes, tectonic disturbance, brine pockets, or extension of the "disturbed zone" are sufficient. If the hydrocarbon and potash resources at the site prove to be economic, with proper limitations much of the resources can be recovered without hazard to the repository. The preponderance of evidence, in the panel's opinion, does not support Anderson's hypothesis of large-scale, recent strata-bound dissolution that might endanger a repository at the WIPP site, but the evidence against the hypothesis is not conclusive. Further analytical and field work are necessary to make firmer estimates of the amounts of salt deposited and removed by comparing in detail drillcores and borehole logs from many parts of the basin. In addition, definitive evidence regarding water flow and dissolution residues in anhydrite beds is needed.

CONCLUSIONS

o Although the evidence now suggests that hydrocarbons and potash might be extracted from Zone IV without harm to the repository, the integrity of the repository must be the first consideration. Each proposal to develop the resources should be examined rigorously on a case-by-case basis, with the burden of proof resting with the proposer (pp. 14, 16; see also Appendix D).

o The long distance from fault displacements and basaltic eruptions in the Rio Grande Valley and the lack of evidence of major seismic events near the site seem sufficient to ensure tectonic quiescence at the site during the period of interest (p. 16).

o Deformation of evaporite beds at the repository site is slight. The rate of deformation, if any is going on at present, is so small that it would not present a credible risk to the repository (pp. 16, 17).

o Evidence is good that karst-forming processes are unlikely for a period of more than a million years to disturb the repository site (pp. 17, 18).

o The location of existing "breccia pipes" and of the hydrologic and stratigraphic conditions capable of containing and supporting large solution voids apparently necessary to cause them, indicate that the likelihood of encountering an old pipe or a new one forming de novo near the WIPP site is practically nonexistent (pp. 18, 19; see also Appendix E).

o Evidence seems good that because of its low permeability, high salinity, and isotopic composition the Bell Canyon Formation cannot function as a source or transporting agent for solutions that could form breccia pipes by density flow, nor could it be responsible for extensive interstratal dissolution (p. 18, 19).

o The preponderance of evidence does not support the hypothesis that large-scale recent strata-bound dissolution might endanger a repository at the WIPP site, but evidence against the hypothesis is not conclusive (pp. 19-23).

o The brine reservoirs encountered in the Castile Formation near the WIPP site are most likely isolated pockets of fluid not connected with or residual from recent solutions moving long distances through the formation (22, 23). Even if the WIPP-12 pressurized brine reservoir in the Castile extended directly beneath the WIPP site, this should not adversely affect the operating facility, and there is insufficient justification to delay progress on the WIPP.

RECOMMENDATIONS

o It is practicable to evaluate the effects of resource extraction in Zone IV on a case-by-case basis to assess whether or not such extraction poses any significant threat to the safety and integrity of the repository. Though present extraction techniques pose no significant threats to the repository, the Department of Energy should obtain the right to deny mineral and hydrocarbon extraction in Zone IV, as well as Zones I, II, and III, during the operational and

administrative control period, unless such extraction can be shown to pose no significant threat to the repository (pp. 14, 16).

o To test the extent of deep strata-bound dissolution, Sandia's plans for further field and analytical work should be implemented. These plans include (a) making firmer estimates of the amount of salt deposited and removed by comparing in detail drill cores and borehole logs from many parts of the basin, and (b) studying in detail the water flow and residues in anhydrite beds (pp. 19, 20).

o One or both of the remaining hydrologic test holes planned to be drilled in 1983 should be located on lineaments or fracture traces if such features are revealed on satellite images and high-altitude areal photographs. Hydrologic test holes so located would help to determine if zones of fracture concentration exist within dolomite at the WIPP site and if they are influencing differential salt dissolution and/or secondary permeability development. Such narrow and elongate zones of more closely spaced fractures should exist in dolomite at the WIPP site judging from their observed presence in reef and other strata southwest of the site and elsewhere. The hydrologic significance of shorter, more numerous rock fractures, or anisotropy, have been revealed at three Rustler dolomite sites by Gonzalez (1982). The basic short-term hydrologic investigations planned and being carried out by Sandia National Laboratories to refine understanding of the nature and distribution of permeability within Rustler aquifers are well conceived and should be continued (pp. 19, 20).

CHAPTER THREE

IN-SITU TESTS AND EXPERIMENTS

THE WIPP R&D PROGRAM

The WIPP R&D program seeks answers to questions about repository development and waste package interactions, as shown in Table 3-1 (Matalucci et al. 1982). This program consists of projects for verification of the various models, laboratory and field testing of components, and in-situ tests with and without radioactivity. The initial phase of the in-situ tests, termed Site and Preliminary Design Validation (SPDV), consists of certain geomechanical measurements to be made underground from two shafts and an experimental area. As of August 1982 the shaft borings had been completed and geomechanical test instruments were being installed for the SPDV measurement program, scheduled to commence in late 1982.

A variety of in-situ experiments are planned for the WIPP R&D program (Table 3-2) extending to the 1990s (Table 3-3), to be carried out in a special area (Figure 3-1). Although planning for and design of the eventual construction and operation of the WIPP facility for permanent disposal of defense-generated transuranic (TRU) wastes is already underway (U.S. Department of Energy 1980-1982) and discussions for its layout are in progress (Rockwell International 1982), the WIPP facility design is subject to change, depending on findings from the in-situ tests. Even the abandonment of the WIPP site altogether would be possible if the findings prove that permanent disposal of TRU waste is not feasible at the WIPP site. The panel regards all WIPP facility planning and design to be provisional at the present time and subject to revision in the light of future findings of the WIPP R&D program. Therefore, the panel has directed its attention to the adequacy of the R&D program for providing the information needed to construct and to ensure the safety of an adequate WIPP facility.

THE SPDV PHASE

As described in sections 8.2.1 and 8.9.1 of the FEIS (U.S. Department of Energy 1980), two underground shafts have been constructed for in-situ testing in the SPDV program. These shafts, which were sunk in

TABLE 3-1 WIPP R&D Program

	TECHNICAL DEVELOPMENT			IN SITU TESTS WITHOUT RADIOACTIVITY			IN SITU TESTS WITH RADIOACTIVITY		
	MODEL DEVELOPMENT	LAB TESTING	FIELD TESTING	SPDV	TECHNOLOGY EXPS (TEs)	TECHNOLOGY DEMO	RADIATION-SOURCE EXPS (RSEs)	DHLW TESTS	TECHNOLOGY DEMO
SITE CHARACTERIZATION AND EVALUATION	●	●	●	●					
REPOSITORY DEVELOPMENT									
THERMAL/STRUCTURAL INTERACTIONS	●	●	●	●	●				
PLUGGING AND SEALING	●	●	●		●				
OPERATIONS		●	●			●			●
WASTE PACKAGE INTERACTIONS									
WASTE PACKAGE PERFORMANCE	●	●	●		●		●	●	
NEAR-FIELD EFFECTS	●	●	●		●		●		

SOURCE: Matalucci et al. (1982).

TABLE 3-2 WIPP In-Situ Tests

	WITHOUT RADIOACTIVITY			WITH RADIOACTIVITY		
	SPDV	TECHNOLOGY EXPERIMENTS	DEMONSTRATIONS	RADIATION-SOURCE EXPERIMENTS (OPTIONAL)	DHLW TESTS	DEMONSTRATIONS
SITE CHARACTERIZATION AND EVALUATION	• SITE VALIDATION INVESTIGATION					
REPOSITORY DEVELOPMENT						
THERMAL/STRUCTURAL INTERACTIONS	• PRELIMINARY DESIGN VALIDATION	• 12 W/m^2 MOCKUP • DHLW OVERTEST • GEOMECHANICAL EVALUATION • HEATED AXISYMMETRIC PILLAR • IN SITU STRESS FIELD • DIRECT SHEAR OF CLAY SEAM				
PLUGGING AND SEALING		• PERMEABILITY MEASUREMENTS • SIZE EFFECTS • PLUG TEST MATRIX				
OPERATIONS			• MOCK DHLW EMPLACEMENT AND RETRIEVAL • MOCK TRU WASTE HANDLING			• SMALL-SCALE TRU WASTE (OPTIONAL) • FULL-SCALE TRU WASTE DISPOSAL • DHLW EMPLACEMENT AND RETRIEVAL
WASTE PACKAGE INTERACTIONS						
WASTE PACKAGE PERFORMANCE		• SIMULATED-WASTE PACKAGE PERFORMANCE • SIMULATED-TRU-WASTE DRUM DURABILITY		• RADIOACTIVE-WASTE PACKAGE PERFORMANCE	• DHLW TESTS	
NEAR-FIELD EFFECTS		• BRINE MIGRATION (THERMAL)		• BRINE MIGRATION (THERMAL AND RADIATION)		

SOURCE: Matalucci et al. (1982).

TABLE 3-3 Schedule for WIPP In-Situ Tests

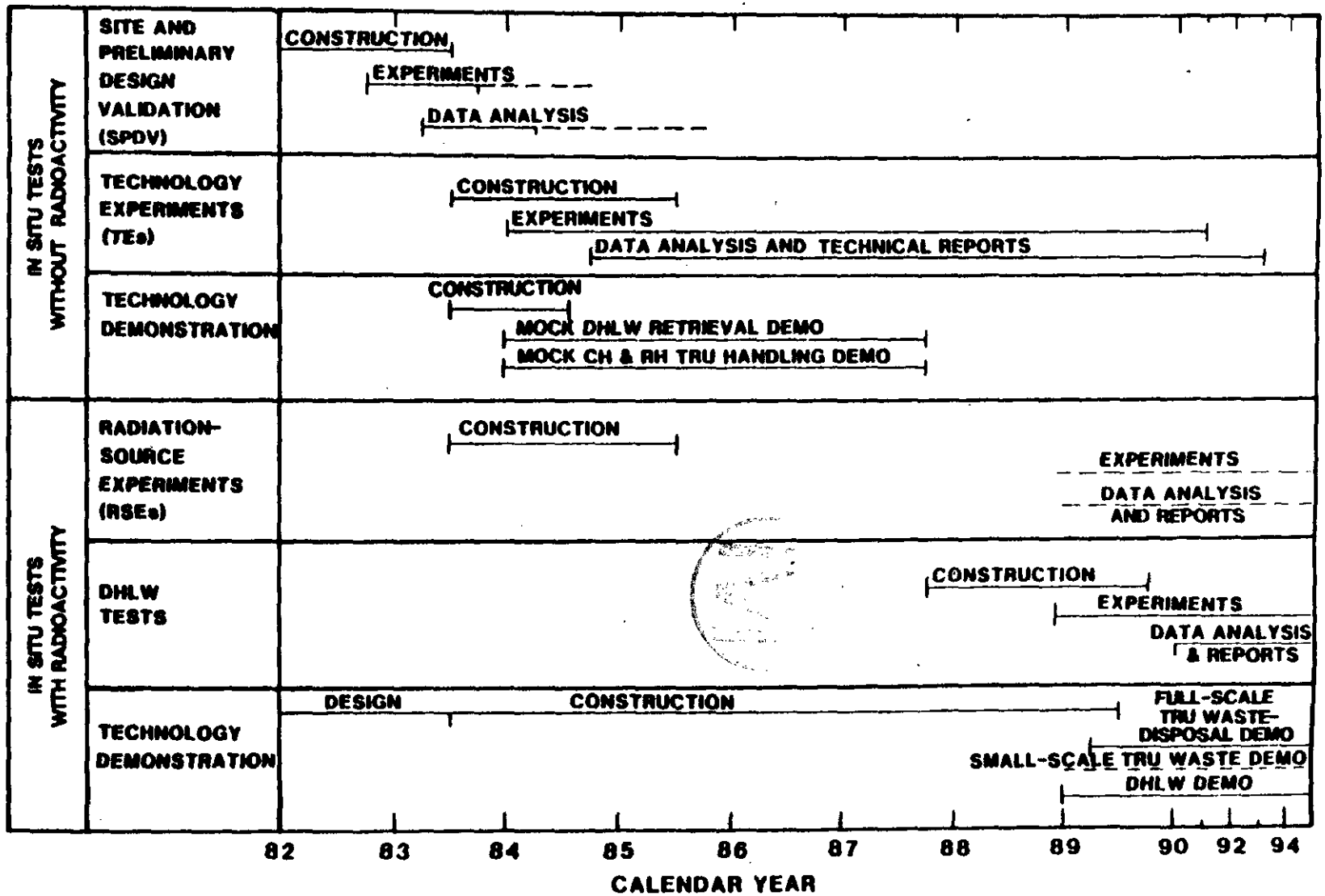

SOURCE: Matalucci et al. (1982).

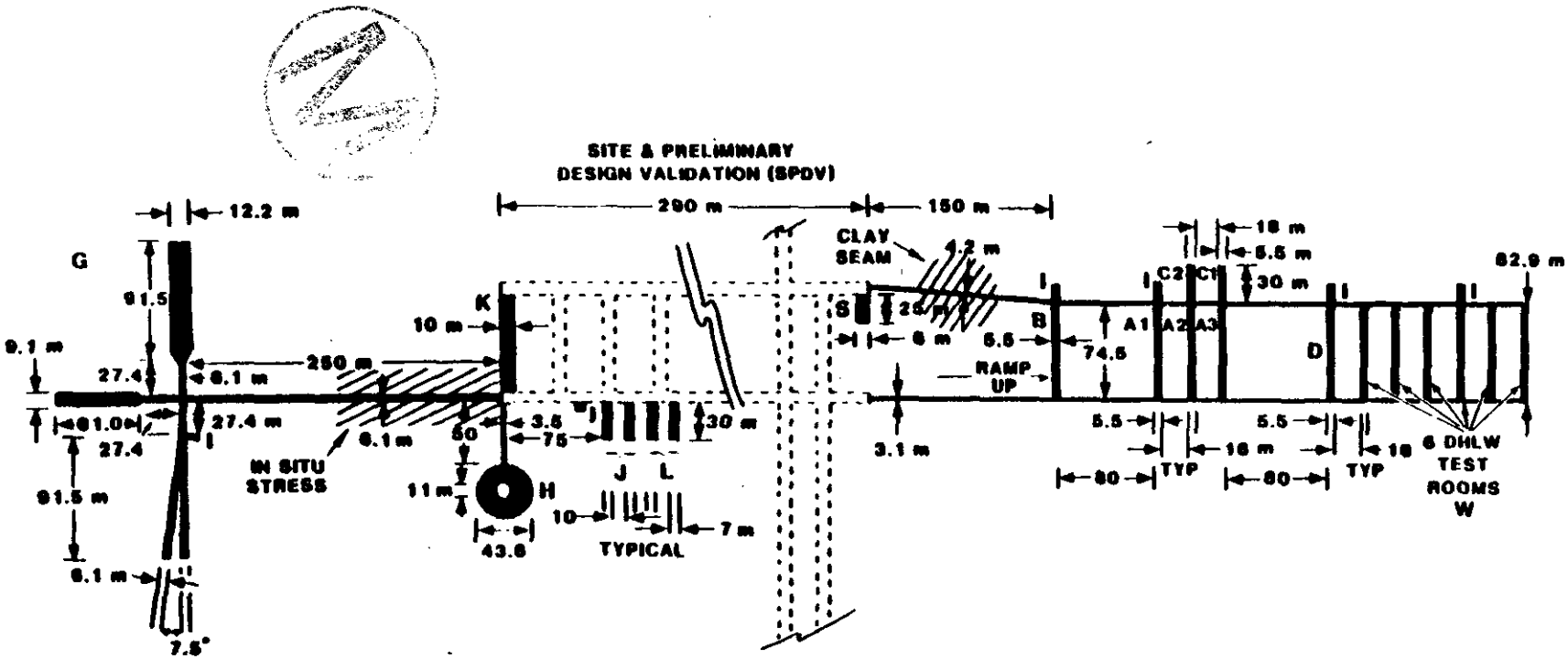

NOTES:

G. THE GEOMECHANICAL EVALUATION TESTS ARE ILLUSTRATED AS ONE TEST CONFIGURATION, BUT THEY CAN BE MODIFIED OR SEGREGATED INTO SEPARATE TESTS AT DIFFERENT LOCATIONS. FINAL CONFIGURATION WILL DEPEND ON FURTHER DESIGN CONSIDERATIONS.

I. INSTRUMENTATION ALCOVES
(5 m WIDE, 10 m LONG, 3.1 m HIGH, TYPICAL)

S. WORKSHOP ALCOVE

(ALL DIMENSIONS IN METRES)

TESTS:

A. 12 W/m^2 MOCKUP
B. DHLW OVERTEST
C. MOCK DHLW EMPLACEMENT/RETRIEVAL DEMO
D. RADIATION-SOURCE EXPERIMENTS
G. GEOMECHANICAL EVALUATION
H. HEATED PILLAR
J. TRU DRUM DURABILITY (CH)
K. MOCK TRU DEMO (CH AND RH)
L. PLUGGING AND SEALING
W. DHLW TESTS

FIGURE 3-1 Layout of WIPP in-situ tests. Source: Matalucci et al. (1982).

accordance with a previous recommendation by the panel (Appendix B), are 3.7 m (12 ft) and 1.8 m (6 ft) in diameter, about 700 m (2,300 ft) and 670 m (2,200 ft) deep, respectively, and extending more than 411 m (1,350 ft) into the 610 m (2,000 ft)-thick Salado salt formation (Figure 1-2). The SPDV underground experimental area at the facility depth adjacent to the shafts is not yet constructed.

Because the mechanical properties of the salt are considered by DOE to be important for facility design, geomechanical experiments have been given the first priority for in-situ testing and are the only tests planned in the SPDV phase. These consist of convergence and radial motion measurements of the shafts, piezometers for water pressure build-up behind the shaft liner, strain measurements in unlined sections of the shaft, optional monitoring of shaft key loading and strain at the contact of the Salado salt with overlying Rustler Formation, survey measurements at geometric grid points, and geologic mapping of lithology and structure. Matalucci et al. (1982) expect the SPDV tests to meet the following objectives:

- To validate the design for the WIPP access shafts and TRU waste disposal demonstration rooms.
- To evaluate the amount and rate of shaft convergence and room creep deformation and to correlate these data with model predictions.
- To perform a preliminary evaluation of creep in salt and of the steady-state creep model.
- To evaluate instrumentation systems for accuracy and the reliability of measurements made with them in rock salt and to document the suitability of the system for future measurements.
- To evaluate the response of the in-situ formations such as clay seams and other material layers in addition to the salt.
- To collect a large number of samples of rock salt and other materials and to conduct laboratory and bench-scale tests to determine the mechanical properties of these samples.

Tests of interaction between waste and surrounding rock will follow the SPDV phase.

The WIPP design has to allow for long-term repository closure ($>$ 200 years) by plastic flow and short-term access ($\leq$ 20 years) for waste package emplacement and retrieval. A key problem of the SPDV is to verify by very short-term measurement ($\sim$2 years) that predictions from the (two-dimensional computer program) model of repository behavior over the long term are correct. The SPDV implies that this is a routine check, with little expectation of surprises. Longer-term observations will be needed to confirm that the design requirements will really be met.

IN-SITU TESTING PLAN

Bedded salt is a prime candidate to be the geologic medium for the emplacement of high-level radioactive wastes, both civilian and

military. The main information presently available on such emplacement comes from Project Salt Vault, a program begun in 1963 by the Oak Ridge National Laboratory using canister and instrumentation technology of the time in a salt mine. The WIPP facility offers an opportunity for professionally executed emplacement experiments, using present waste form concepts and equipment, in an actual repository operation. This will be possible years before any comparable repository is available. Results of experiments with high-level waste in WIPP can bring decisive experience to the design of future repositories. Consequently, the opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in a real underground salt repository at depth, is an important aspect of the Waste Isolation Pilot Plant (WIPP) program.

Plans have been formulated and reported by V. F. Likar (1979) and Matalucci et al. (1982) for an R&D program that includes emplacement and retrieval of contact-handled TRU waste, remotely handled TRU waste, and defense high-level waste (DHLW); the investigation of interactive effects of heat- and radiation-generating waste packages with a salt repository; and the investigation of repository backfilling, plugging, and sealing. The program (see Table 3-2 and Figure 3-1) is scheduled to begin in 1983 and continue through the life of the facility. The test sequence begins with thermal-structural interactions to verify the ability of structural models to predict long-term repository response, and (assuming these results are positive) continues in stages to demonstration of DHLW retrieval from corroded and failed waste packages. Obviously, the earlier experiments are better defined than are the later experiments, which will allow for incorporation of the results from the early WIPP experiments and the on-going parallel experimental programs into the plans for the later WIPP experiments. This is appropriate since, although the general philosophy appears to be that the experiments are "verifications" of present concepts and models, it is almost inevitable that surprises will be encountered and that new concepts and models relating to waste forms, waste package materials, design, dimensions, and heat outputs will evolve over the next decade. To take maximum advantage of progress in waste disposal technology worldwide, the periodic revisions of the experimental program should be preceded by deliberate solicitation of ideas for experiments, instrumentation, and equipment from outside the DOE (cf. National Research Council 1979).

At present, WIPP is designed to accommodate a considerable variety of waste packages. While operational smoothness would benefit from fewer and better-characterized packages and waste forms, the experimental program should take advantage of the present lack of uniformity to make an operational input into the recommendations for size, shape, weight, and other criteria for the waste packages that will be used on a large scale.

The over-all facility design is as yet not fixed. A recent major revision has reduced facility cost substantially, at the expense of the rate of waste emplacement and of operational flexibility. The plant electrical system has lost some redundancy, which means that the electrical supply system for the experimental program cannot be relied

on for those experiments and systems that demand an uninterrupted power supply (such as the brine migration experiments). The alternative facility orientation now being evaluated, which extends the storage area to the south of the present shafts instead of to the north, would isolate the experimental area (assuming it remains at its earlier-planned location north of the shaft) by 823 m (2,700 ft) from the storage area and from continuing construction and storage activities. This would benefit both the experimental and the storage activities in a number of ways, including reduced chance of interference and continued availability.

The WIPP FEIS and SAR (through Amendment 3) recognize that accidents associated with the experiments with DHLW constitute the largest risk of environmental contamination, of plant contamination, and of operator exposure. Complete procedures for carrying out these important experiments have not yet been written (nor is it reasonable to do so before more operational experience with less hazardous experiments has been gained). Previous hazard analyses contemplated no changes in the standard ventilation precautions, i.e., high efficiency particulate air (HEPA) filters normally off-line, and cut in on detection of radioactivity in the vent stream. However, special precautions, such as putting the HEPA filters in line in advance of the experiment, might be considered as part of the operational procedures for experiments involving the handling of degraded DHLW canisters. The special ventilation requirements of the room experiments on brine corrosion, if a significant H_2S content is introduced with the brine, also need to be developed.

The demonstration emplacement and retrieval activities will reveal any weaknesses (such as excessive time for operations) in the storage concepts (e.g., the side-wall emplacement of remotely handled TRU waste) or in the equipment procured to implement them, and should be given sufficient priority to allow alterations in advance of large-scale waste emplacement operations in the storage area. We may confidently expect remarkable progress in the next half-dozen years in such areas as automated sensing devices, robotics, remote imaging, and instrumentation and control for hostile environments. These developments should be continually screened for application to waste isolation by testing in the WIPP R&D program.

Accelerated tests, such as room closure measurements with a heat source four times reference design conditions, experiments with higher-than-expected radiation levels, and corrosion experiments on deliberately compromised canisters or overpacks, tackle the difficult problem of investigating long-term effects within the lifetime of one generation of experimenters. Overall, the approach is reasonable. Extrapolations from these experiments would be more convincing with practicable three-dimensional models and improved computer programs. One can reasonably expect to have these with the next generation or so of computers.

Since the number of experiments that can be undertaken in the WIPP project itself is finite, the number of variables that can be dealt with in the many combinations of waste package, overpack, backfill, and sleeve, or of plugs and seals, is limited. One could improve the

usefulness of the WIPP tests by concentrating on the difference between in-situ tests and smaller scale laboratory experiments. Laboratory tests paralleling the WIPP tests would be helpful in validating the former, thus improving the eventual rate of development of new materials. In general, inaugurating the WIPP in-situ testing program does not decrease the importance of the laboratory and field research programs that have contributed so much to the choice of materials for the WIPP project.

CONCLUSIONS

o The opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in a real underground salt repository at depth, is an important aspect of the WIPP program (pp. 32-34).

RECOMMENDATIONS

o Operational experience with the handling and emplacement of various types of waste package shapes and sizes containing TRU wastes at the WIPP site should be obtained in a timely manner so that this experience can be factored into final choices for large-scale disposal of TRU wastes (p. 32).

o The later stages of the WIPP R&D program should be kept flexible to accommodate changes suggested by early WIPP results or by progress in waste disposal technology by other organizations. Active efforts should be made to solicit ideas and participation from the general scientific community. Publishing project R&D results in the refereed literature would encourage such participation. Outside developments in automated sensing, robotics, instrumentation in hostile environments, etc., should be systematically screened for application or testing at the WIPP facility (p. 33).

o Procedures for handling defense high-level waste in the experimental R&D areas should include special safety precautions, which may not be needed for facility construction or emplacement of TRU waste (p. 33).

o The matrix of tests on waste form, waste package, overpack, and backfill to be investigated at the WIPP facility should be supplemented by aboveground laboratory tests to validate the latter form of testing and thus permit expansion of the matrix by less expensive experiments (pp. 33, 34).

CHAPTER FOUR

WASTE ACCEPTANCE CRITERIA

The definitive statement of the TRU waste acceptance criteria for the WIPP project is contained in WIPP-DOE-069 (U.S. Department of Energy 1981). A summary of these criteria appears in Table 4-1.

The waste acceptance criteria are for the most part quite straightforward. They are concerned with establishing standards on dimensions, weight, radiation levels and the like, such that operational difficulties at the WIPP site will be minimized when waste emplacement actually begins. The criteria have a permissive flavor, which reflects the real-world consideration that existing stored wastes are very heterogeneous in terms of composition, physical state, and package configuration. Evidently, the philosophy has been adopted that inconveniences at the WIPP site are less consequential than those that would occur at the various storage sites if highly restrictive criteria were adopted. These inconveniences are acceptable on an interim basis, but it should be a stated objective of the lead management organization of the defense TRU waste program to work as rapidly as possible in the direction of standardized packaging of fully characterized and thoroughly stabilized waste.

The most debatable of the criteria are those related to the inclusion of organic materials in the waste. The presence of such material in sufficient quantity raises questions about combustibility in the short term and about gas generation, complexation, and possibly accelerated radionuclide transport in the long term.

FIRE

Fires underground, as is well known from coal mining experience, are particularly difficult to control. In practice it has proved to be very difficult to extinguish such fires because underground combustion sites are so well insulated thermally.

Fire prevention and control will, of course, be easier in a salt repository than in a coal mine. For fire safety to be fully credible, however, a waste disposal configuration should be stipulated that will self-extinguish without any fire control measures whatever.

A self-extinguishing configuration can be provided by stacking of the waste packages in such a way that combustible and noncombustible

TABLE 4-1 Waste-Acceptance Criteria for Contact-Handled and Remotely Handled TRU Waste

Criterion	Contact-handled TRU waste	Remotely handled TRU waste
	WASTE FORM	
Combustibility	No limit, must be packaged in steel containers or overpack.	Same as for contact-handled TRU waste
Gas generation	Gas generation by all mechanisms must not exceed 10 moles/m^3 of disposal-room volume per year under repository conditions. In terms of waste composition, this criterion may be interpreted to mean that the average organic content of contact-handled TRU waste may not exceed 14 lb/ft^3 for waste in 55-gallon drums and 6 lb/ft^3 for waste in other containers.	No criterion; quantities are insignificant
Immobilization	Powders, ashes, etc., must be bound in glass, concrete, ceramic, or other approved matrix; free liquids are not allowed.	Same as for contact-handled TRU waste
Explosives	Not allowed.	Same as for contact-handled TRU waste
Pyrophorics	Small quantities (up to 1% of the waste by weight) of radionuclide-metal pyrophorics may be accepted with other waste forms if they are dispersed throughout the waste.	Same as for contact-handled TRU waste
Toxic and corrosive materials	Toxic materials allowed only with special materials procedures and precautions; corrosive materials will not be accepted.	Same as for contact-handled TRU waste
Sludges and free liquids	Sludges and other waste forms containing readily desorbable water under repository conditions will not be accepted; free liquids will not be accepted.	Same as for contact-handled TRU waste
	CONTAINER	
Design life	10 years to allow retrievability.	Same as for contact-handled TRU waste
Structure	Type A requirements.	Same as for contact-handled TRU waste
	PACKAGE	
Structure	Type A; any damaged container must be overpacked.	Same as for contact-handled TRU waste
Handling	Devices to allow handling by a forklift.	Axial lifting pintle
Weight	Less than 25,000 pounds.	Less than 7000 pounds
Dimensions	Not larger than 8 by 12 by 8.5 feet.	24-inch diameter, 10-foot length
Surface-dose rate	Not exceeding 200 mrem/hr; containers with a surface-dose rate in excess of 10 mrem/hr must be color coded.	Less than 100 rem/hr
Surface contamination	5% of 49 CFR 173.397.	5% of 49 CFR 173.397
Criticality	30-gallon drum, 100 grams fissile; 55-gallon drum, 200 grams fissile; DOT-7A, 350 grams fissile or less than 5 grams in any cubic foot.	49 CFR 173, Subpart H; less than 5 grams in any cubic foot
Thermal power	Container must be color coded if the thermal power exceeds 0.1 W/ft^3.	Less than 500 watts per canister

SOURCE: U.S. Department of Energy (1981)

materials are intermixed in a proportion such that the heat liberated by oxidation of the combustible component is dissipated. Thereby the temperature of the mixture is prevented from reaching the ignition point of the organic materials. A conservative a priori calculation of sufficient accuracy should be quite simple, given the data on maximum organic content of each package that is part of the waste certification documentation.

A self-extinguishing configuration does not, of course, eliminate the possibility of transient underground fires arising from transporter accidents, such as electrical faults and welding, that may involve one or more waste packages. The provision for handling such situations has not yet been specified (U.S. Department of Energy 1980-1982). This must not be overlooked in the Title II design.

GAS GENERATION

The gas-generation limit of 10 moles/m^3 of disposal-room volume per year (Table 4-1) is briefly explained in DOE-069 (U.S. Department of Energy 1981), with reference to supporting experimental data in SAND 79-1305 (Sandia National Laboratories 1979). The number was derived from a consequence analysis based on the effective permeability (taken as 0.1 microdarcy) of the geologic formation, with the condition that lithostatic pressure of 0.15 N/m^2 (150 bars) at the repository depth should not be exceeded.

From the gas-generation limit the permissible organic content of the waste was derived through the experimentally based conclusion that the major source of gas is the bacterial decomposition of the cellulosic component of the waste--primarily the plywood boxes. This conclusion is independent of whether aerobic or anaerobic conditions are assumed. Under the expected anaerobic conditions, methane is presumed to be the major constituent of the gas.

The limiting microbial gas-generation rates given in SAND 79-1305 are derived from experiments carried out under conditions that do not give adequate weight to certain fundamental facts of microbiology:

- Micro-organisms are critically sensitive to ambient humidity. Most species require a humidity of 90 percent or higher for growth, and there are no confirmed reports of growth at humidity below approximately 60 percent (Horowitz 1979).
- Metabolic activity is poisoned by the accumulation of metabolic products. This will limit the magnitude of the pressure generated by a gaseous metabolic product.
- Methanogenesis does not normally occur in the presence of sulfates. Hydrogen sulfide is a primary metabolic product in such systems. Sulfates are plentiful in the Salado Formation.

The likelihood of biological gas generation should be reexamined in the light of these generalizations, and others that may be discovered by study of the specialized literature on life in extreme environments.

The restriction imposed by humidity may be particularly significant. A saturated NaCl brine has a relative humidity of 70 to 75 percent at ordinary temperatures. If traces of calcium and/or magnesium chlorides are present in Salado salt, the humidity of a sealed repository could fall as low as 20 percent. Now that the SPDV program has made the Salado directly accessible, measurement of humidity should be made in a suitable still-air cavity.

The tendency for H_2S formation by sulfate-metabolizing bacteria suggests a possibility worthy of attention: that this gas, and the CO_2 likely to be a coproduct, might maintain the pH of a brine-inundated repository low enough (below 3-4) to cause corrosive dissolution of steel drums with generation of substantial amounts of gaseous hydrogen. The chemical part of this scenario is well known from oil field experience with "sour" gases under pressure (Shock 1953). The biological part, of course, depends on the ability of the organisms in question to thrive in the repository environment.

Radiolysis was also discussed as a source of gas generation. Because of the low level of total radioactivity in TRU waste, the rate of radiolytic gas generation estimated in the FEIS (U.S. Department of Energy 1980, p. 9-153) is negligibly small--only a small fraction of that assumed for microbial action.

The computational model used to calculate the repository pressurization associated with gas generation is straightforward. The conclusion that the repository pressure will be below the lithostatic pressure even for the bounding case is acceptable, especially in view of the fact that the source term used for the gas-generation rate is probably too high by orders of magnitude, as just discussed.

In view of the minor importance of gas generation for projected TRU waste, it is suggested that consideration be given to dropping the waste acceptance criterion relating to gas generation, particularly if the humidity in the repository proves to be less than 60 percent. However, the emplacement density of organic materials should be limited to conform with the self-extinguishment criterion stated above. Rough calculations indicate that the restriction on organic material imposed by the self-extinguishing requirement is easily met.

COMPLEXATION

Many documents, including the SAR (U.S. Department of Energy 1980-1982), examine the consequences of scenarios in which the Salado salt containment is breached. Radionuclides then move upward into the aquifers of the Rustler Formation and thence by hydrologic flow to the surface at Malaga Bend or elsewhere. Sorption by the clays and dolomites of the aquifers has been experimentally shown to be very strong for plutonium and its daughters, which leads to a significant retardation of the transport of these species with respect to the groundwater flow. Complexation by organic materials included with or derived from the organic component of the waste will interfere with the sorption process and shorten transport time accordingly.

A sensitivity analysis of the consequences of the reduction of K_d, the partition coefficient, by complexation is reported in SAND 79-1305 (Sandia National Laboratories 1979), and a similar analysis appears in EEG-8 (Wofsy 1980). Both analyses conclude that even complete elimination of the sorption effect would not increase the dose commitment to the maximally exposed individual to parity with the dose received from natural sources, owing to the long travel time for the water.

The FEIS does not even mention complexation as a factor in the establishment of waste acceptance criteria. Within the limits of the particular scenarios considered in the FEIS the omission probably is justifiable. In other possible scenarios, where flow occurs through fracture systems, or in the extreme case through karst, travel time would be reduced and sorption would become a matter for more careful evaluation, especially since in these two instances opportunity for sorption is materially reduced. The credibility of such scenarios needs further study (see also Chapter 6).

CERTIFICATION

The best possible set of waste-acceptance criteria is of doubtful effect unless compliance is systematically certified. Misgivings on this point have been expressed by the New Mexico Environmental Evaluation Group (EEG) and by this panel. Recent briefings and recently released documents (U.S. Department of Energy 1982; Whitty et al. 1982) are making it clearer how compliance can be assured.

A particularly important part of the certification strategy, and one that this panel supports, is the policy of beginning certification with newly generated waste. This postpones the serious problem of determining exactly what is contained within old packages that have inadequate documentation. Certification will not begin at any waste-generating site until appropriate procedures have been developed, facilities built, and personnel trained, all of which are easier with newly generated waste.

Less satisfactory is the proposed procedure for verifying compliance after the packages are received at the WIPP. The FEIS specifies only that each container be inspected for damage and contamination; then if the certification documents are in order, the container is ready for transportation underground. This panel would prefer to see a policy of having the WIPP equipped with state-of-the-art nondestructive examination devices, so that at least a sample from each shipment can be subjected to an independent verification.

After newly generated wastes have all been certified, it will be necessary to deal with stored wastes. Those of recent origin--since 1970, approximately--are stored retrievably and are comparatively well documented. Wastes in this category that are stored at Idaho National Engineering Laboratory (INEL) will be processed along with newly generated waste. Stored waste from other sites will be processed later, with technology developed at INEL in the Stored Waste Examination Pilot

Plant (SWEPP) and Processing Experimental Pilot Plant (PREPP) programs. Technology for preparation and transportation of remotely handled TRU waste is also to be developed in this second phase.

Another category is the special-case wastes, which include buried pre-1970 TRU wastes, uncertifiable stored wastes, contaminated soils, and the like. This panel endorses the proposed strategy of postponing decisions about these wastes until the other categories of wastes have been dealt with, additional technical or institutional developments have occurred, and more information has been obtained on costs and hazards.

These troublesome certification procedures could be simplified and transportation facilitated by shredding and pyrolyzing all the waste. Against this must be weighed the monetary costs and particularly the hazards to the operators of pyrolysis facilities. Evaluation of the factors on both sides of the option is highly subjective because practical experience is scanty. It is the judgment of this panel that the strategy proposed by Rockwell International (1982) is a reasonable compromise at the present state of knowledge. Further information on such issues as complexation might shift the balance to pyrolysis. That part of the waste which is readily certifiable is currently expected to be transported and emplaced without pyrolysis; that which is undocumented or for other reasons falls in the "special case" category is to be processed by whatever technology appears to be appropriate, including any of several varieties of pyrolysis. A substantial amount of practical information on pyrolytic processing is already available from experience with pilot facilities, and pilot testing of other techniques is already operating or in the planning stage.

In the view of this panel it is particularly important that the pyrolysis option or something functionally equivalent should be available. A certification procedure cannot be truly meaningful unless there exists a practical alternative for handling those wastes that fail to meet the criteria.

DEFENSE HIGH-LEVEL WASTE

The WIPP mission includes a program of experiments with retrievably emplaced, high-level waste, presumably solidified in glass and contained in metal canisters. No criteria have been written for this class of waste, even though the experimental area has been laid out and tentative plans for experiments have been formulated. It is important to have these criteria prepared well in advance of need.

CONCLUSIONS

- The possibility of self-sustaining underground fires can be eliminated by embedding combustible materials in a matrix of noncombustible material in a suitable proportion (pp. 35, 37).
- The criteria related to biological gas generation are based on a rather superficial analysis. The extreme nature of the repository environment imposes many conditions that are not adequately taken into

account. It is possible that the humidity (water activity) in a sealed repository is low enough to inhibit biological activity completely (pp. 37, 38).

o If there is biological activity, the presence of sulfate in the salt makes it likely that hydrogen sulfide, rather than methane, would be the major product (pp. 37, 38).

o From the WIPP viewpoint, the quality assurance system is inadequate, in that it requires no on-site verification of conformance of package contents to the certification (pp. 39, 40).

RECOMMENDATIONS

o As soon as feasible, standardized waste packages should be adopted in a minimum number of sizes (p. 35).

o The storage of combustible waste should be controlled so that noncombustible material is intermixed with combustible packages in such a way as to render the mixture incapable of self-sustaining combustion in a current of air (pp. 35, 37).

o The existing deficiency in the SAR on procedures for fighting transient underground fires should be remedied (p. 37).

o The humidity of still air in equilibrium with the salt and the pH of the salt at the storage horizon should be measured. These fundamental quantities are significant for the evaluation of biological and chemical degradation processes (p. 38).

o The restrictions on permissible mass of organic material per unit volume of waste should be dropped from the gas-generation criterion if measurement shows the relative humidity of a sealed enclosure in the salt at the repository horizon to be 60 percent or less (p. 38).

o If the humidity of the air is higher than 60 percent, a competent biological specialist should be engaged to evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment (p. 38).

o State-of-the art equipment should be provided at the WIPP facility for nondestructive verification of compliance with those elements of the waste-acceptance criteria for which such equipment exists (p. 39).

o The existence of a practical alternative should be ensured for handling those TRU wastes that arrive at the WIPP site and that fail to meet the WIPP TRU waste-acceptance criteria. The alternative should be available at the time that it is needed (p. 40).

o Waste-acceptance criteria should be defined for the defense high-level waste that is to be used in the experimental program. The definition should be early enough to allow time for review before experimental operations begin (p. 40).

CHAPTER FIVE

DESIGN AND OPERATION OF FACILITIES

INTRODUCTION

Plans for the WIPP design, construction, and operation have changed continuously, and further changes can and should be expected. Flexible planning enables changes to be made to the design, construction, and operation of the proposed facility in the light of new information that emerges from the WIPP program and from other relevant programs. One important result of such changes has been to improve confidence in the predicted performance and safety of the facility. In this respect, it is particularly important that explicit arrangements be made to utilize the results from the SPDV experiments in the final design and performance assessment of the repository. Another important result has been to effect economies in the design of the proposed facility. However, great care must be taken to ensure that such economies do not impair the performance and safety of the facility.

SPDV EXPERIMENTS

The results of the SPDV experiments are regarded as crucial in establishing the performance and safety of the WIPP repository, and these results will provide a wealth of data concerning the behavior and properties of salt.

It is important that effective and timely comparisons be made between theoretical prediction of the SPDV experimental results and data obtained underground during these experiments. Such comparisons provide an essential mechanism for developing and helping to validate the theories upon which the design of the storage excavations are based. However, the extent to which the behavior and properties of the salt in the experimental area is similar to, or different from, the salt in the storage area must be taken into account in transferring knowledge gained in the former to design and prediction in the latter. Therefore, it is important that detailed observations of the properties of the salt be made and recorded during excavation of both the experimental and of the storage areas. Predictions of the results of the SPDV experiments will have to be made on the basis of theoretical calculations. Theory and calculational methods developed for the SPDV experiments and refined in

the light of results from those experiments provide an important basis for the qualitative and quantitative evaluation of the design of the storage area. It is important that the design of the storage area reflect the knowledge gained as a result of the SPDV experiments.

The value of the SPDV experiments will be enhanced greatly by prompt publication of their results in scientific and technical journals, so as to facilitate their consideration by the scientific and engineering community, rather than only by those individuals involved directly with the WIPP project.

UNDERGROUND EXCAVATIONS

Once a suitable site for an underground nuclear waste repository has been selected, one of the most important factors--if not the most important one--contributing to the successful disposal of radioactive waste is the design of the excavations and associated facilities that constitute the repository. Mining engineering provides a wealth of experience related to the design and construction of a repository, but the function of a repository is very different from that of a mine. The principal objective in mining is to remove as much of the ore as is practicable, consistent with short-term safety. The principal objective in making repository excavations is to disturb the geologic media as little as is practicable, so as to ensure long-term safety and effective isolation of the wastes.

Adequate conceptual design of an underground repository requires recognition that the properties of a geologic medium, even salt, are unlikely to be uniformly satisfactory over the dimensions of the proposed repository site, and that many variations in the properties and structure of the salt at the depth of the repository will be revealed only as the excavations are made, and related underground experiments are done. Some of these variations may lead to unexpected difficulties in excavation or they may adversely affect the ability of the salt or the overlying strata to isolate the wastes from the biosphere. Accordingly, it may be desirable to treat some portions of the repository differently from others and perhaps even exclude some portions of the site from use for the waste disposal.

For these reasons, and to limit the extent of any accidents that may occur prior to final sealing of the repository, such as the intersection of a major brine reservoir or the outbreak of a fire, the repository should be laid out as a number of independent modules. Substantial barriers of undisturbed salt should be left between modules, to ensure that each module can be isolated effectively from every other module. No more accessways than are necessary for safe development of a module should penetrate these barriers, and each accessway should be provided with a bulkhead, which can be closed quickly at either end of the barrier. Ultimately, these accessways should be sealed permanently with a fill having low porosity and permeability. Devices for temporary closure of accessways, in the form of ventilation doors and other fabricated bulkheads, have been developed and are used extensively in the mining industry. In mining, permanent closure of accessways is

usually effected by the construction of concrete plugs. For the WIPP site, a salt aggregate could be used. No details are given in the program documents available to the panel of either devices for temporary or permanent closure of accessways.

The current design (Figures 5-1, 5-2) comprises three shafts: (1) a construction, salt-handling, and intake-ventilation shaft; (2) a waste shaft; and (3) an exhaust shaft. An experimental area is laid out to the north of these shafts and the storage area is laid out to the south of them. Access from the shafts to the experimental and storage areas is by parallel entries, two to the experiments, and four to the storage area. The entries to the storage area (Figure 5-2) are separated from one another by pillars about 42 m (138.5 ft) thick and are penetrated by cross cuts at 61 m (200 ft)- and 91 m (300 ft)-intervals.

The storage area, measuring 629 m (2,064 ft) by 778 m (2,552 ft), comprises four panels on each side of the main entries. Within each panel are seven storage rooms, measuring about 10 m (33 ft) wide by 4 m (13 ft) high by 91 m (300 ft) long, with their long axes parallel to the main entries, and separated by salt pillars 30 m (100 ft) thick. The panels are separated from one another by barrier pillars 61 m (200 ft) thick. Access from the main entries to the panels is by cross cuts at intervals of about 91 m (300 ft) and 61 m (200 ft), the length of rooms and the thickness of the intervening barrier pillars, respectively. The overall extraction ratio is less than 25 percent, and the layout of the panels constitutes effective modularization, provided that the penetrations of the pillars can be closed effectively, both temporarily in an emergency and permanently after storage has been completed.

Using the SANCHO finite-element, large-strain creep code, Sandia has done a structural analysis of the original Title I design and compared this with two alternative layouts of the repository excavations (Krieg et al. 1979). In this analysis, a "standard structural model" for the geology was based on data from the ERDA-9 borehole (Wawersik 1979); mechanical properties for the salt were taken from SAND 79-1853 (Munson and Dawson 1979); and, for other rocks and seams, properties were taken from the literature or estimated. The analysis of the original design showed far-field effects that disturbed the superincumbent strata and were brought about by relatively small amounts of convergence across the excavations in the short term (10 years). These effects would increase continually with time, until ultimately the backfill becomes consolidated. Waste and backfill in these excavations are likely to have a void space of about 40 percent, unless special procedures are developed for greater compaction. In the longer term, this void space will allow much greater convergence across these excavations than that calculated in the analysis of the short term. Correspondingly greater far-field effects, particularly at stratigraphic discontinuities, may disrupt the salt in a very different way than would geologic events in the absence of man-made perturbations. Assumptions based on the behavior of salt in its pristine conditions may not be valid. Accordingly, analyses of the far-field effects should be done for much longer periods of time--say 50, 100, and 1,000 years--to show whether or not closure of the excavations will need to be limited. The amount of closure that would prevail if the cavities were filled with waste and

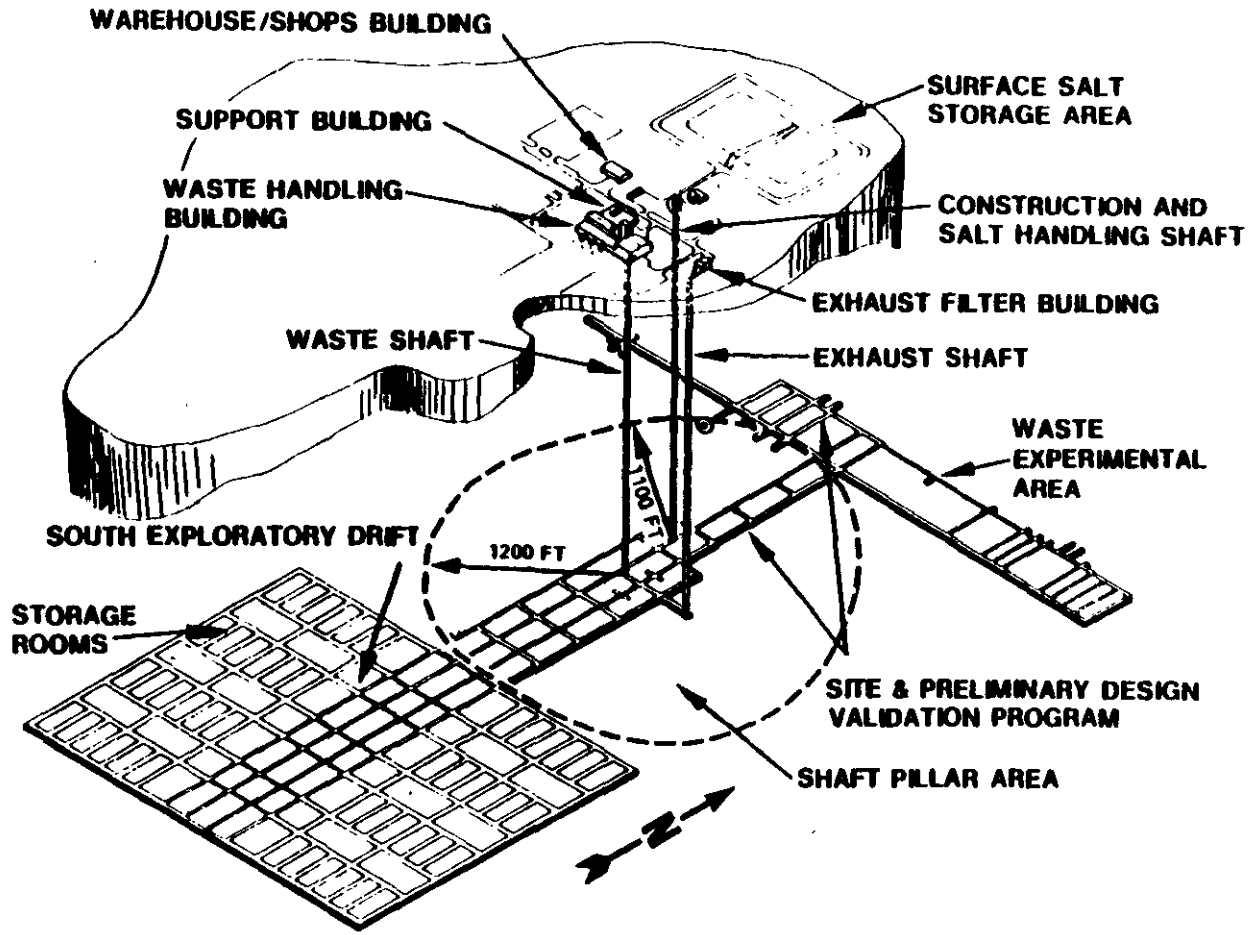

FIGURE 5-1 Cutaway diagram of the WIPP underground design. Source: Bechtel National, Inc. (1983).

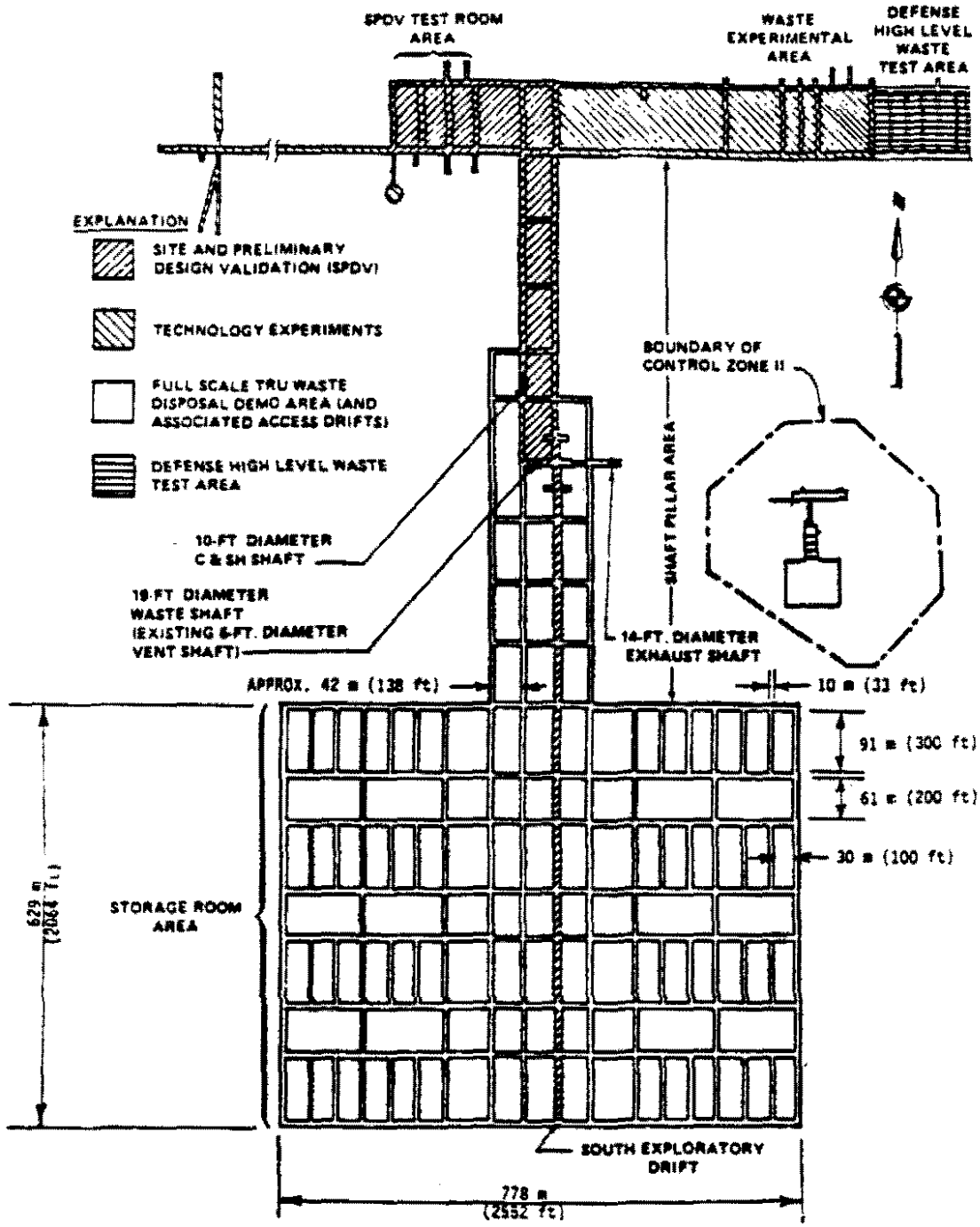

FIGURE 5-2 Representative WIPP underground layout.
Source: Bechtel National, Inc. (1983).

backfill having an initial total void space of about 40 percent may be unacceptable. A finding that closure should be limited would have important implications for waste forms, backfills, excavation layout, and extraction ratio.

In the near field, the excavations of a repository make up a network of interconnected hydraulic conduits in the salt mass at the repository horizon. Closure of the excavations, even in the long term, say beyond 1,000 years, may not reduce the void space in the waste and backfill to a negligible value, so that the backfill may have a permeability much greater than that of the intact salt. This residual void space may result in a hydraulic conductivity through the repository excavations that is significantly greater than that of the pristine salt.

A careful analysis of the effects of void space on the hydraulic conductivity should be made, though the consequences would not be expected to be greater than those resulting from scenarios of water flow between two aquifers (Bingham and Barr 1979).

CHANGE FROM FOUR SHAFTS TO THREE SHAFTS

The recently proposed change (U.S. Department of Energy 1982) from a system of four shafts comprising:

- a waste-handling shaft;
- a construction, exhaust, and salt-handling shaft;
- a storage, exhaust shaft; and
- a ventilation, supply, and service shaft

to a system of three shafts comprising:

- a waste-handling and personnel shaft;
- a construction, salt-handling, and intake shaft; and
- an exhaust shaft

has profound effects for repository construction and operation.

The four-shaft system allowed for complete separation between construction and storage. Each of these two operations was planned to proceed concurrently and independently of the other, except for ventilation supply through a common shaft. This concept provided an exceptional degree of flexibility, redundancy, and safety.

The three-shaft system interlinks construction and storage operations in many ways. It involves cyclical and sequential operations on two shifts a day: One shift is for construction, the other is for storage. To operate on either shift in the three-shaft system, the ventilation subsystems in both the construction and storage areas must work. This requires that all three of the ventilation fans run on both shifts to provide about 83 m^3/sec (175,000 cfm) of air flow. In contrast, in the four-shaft system, the use of six fans was envisaged, only four of which were required at any time.

The principal ventilation load derives from the decision to use diesel trucks for underground transport. Ventilation requirements could

be reduced if electric-shuttle cars and electric conveyors instead of diesel trucks, were used to transport salt underground. Diesel vehicles could still be used for the transport of men. If diesels were not used underground for the transport of salt, the ventilation requirements would be reduced to two fans, of which one would suffice in an emergency.

Electrical power to back up the 32 km (20-mile)-long high-voltage line from the substation to the WIPP site has been reduced to one manually operated 800-kw diesel generator, from two automatic 2,500-kw diesel generators sufficient to operate the man hoist and one fan. There are reported to have been two substation outages with duration longer than 8 hours over the past 5 years.

It should be noted that the proposed three-shaft system has redundancy more typical of that in conventional mining practice than of that in nuclear industry practice.

CONCLUSIONS

o The present plan to develop the storage areas to the south of the shafts and the experimental areas to the north of the shafts is commendable (p. 44).

o The layout of the eight panels of storage rooms separated by barrier pillars is well considered, provided the penetrations of these barriers are sealed adequately (p. 44).

o Details of devices for temporary and permanent closure of the penetrations through the barriers have not been provided (p. 44).

o Recently the repository design has changed from four to three shafts. The four-shaft system had a far greater degree of redundancy and flexibility, both in terms of the system and of operations, than does the three-shaft system (pp. 47, 48).

o The panel has not seen an adequate quantitative evaluation of the economic advantages of the three-shaft system that justifies forgoing the flexibility and safety of the four-shaft system (pp. 47, 48).

o The system as presently proposed with three shafts has redundancy more typical of conventional mining practice than of nuclear industry practice (p. 48).

RECOMMENDATIONS

o Explicit mechanisms for the transfer of information from SPVD experiments and information gathered during construction and development to final design must be established (p. 42).

o Displacements of the salt in the far field that occur as a result of long-term closure of excavations must be shown to be sufficiently small that they do not significantly increase the permeability of the bulk of the salt (pp. 44, 47).

o It should be shown that sealing the repository is sufficient to preclude unacceptable increases in hydraulic conductivity across the repository horizon (p. 47).

- The justification for using diesel motive power for salt transport underground should be reexamined (pp. 47, 48).
- The effects of changes in the configuration of the surface facilities, the number of shafts, the ventilation system, and the electrical backup need to be further elaborated in terms of operational safety, efficiency, and nuclide releases (pp. 47, 48).

CHAPTER SIX

PERFORMANCE ASSESSMENT

This chapter is based primarily on the panel's review of the WIPP Final Environmental Impact Statement (FEIS) (U.S. Department of Energy 1980), the Safety Analysis Report (SAR) (U.S. Department of Energy 1980-1982) and Modeling Verification Studies: Long-Term Waste Isolation Assessment (D'Appolonia Consulting Engineers 1981). One of the main purposes of these documents was to estimate possible radiation exposure of both project employees and the general public. Such exposures could arise during preparation and loading of the wastes at the Idaho National Engineering Laboratory (INEL), transportation of the waste to the repository site, surface storage of waste at the WIPP site preparatory to emplacement, and as a result of accidents that may occur during operation of the facility. In addition, there may be releases of radioactive material to the environment if the repository is breached at some future time.

While the panel has reviewed the plans for packaging the wastes at INEL and transporting them to the WIPP site to determine how this affects the materials that will be emplaced in the repository, a detailed review of the consequences of routine and accidental events during these processes is beyond the scope of this study.

RELEASES AND OCCUPATIONAL DOSES DURING NORMAL OPERATION

Wastes delivered by either rail or truck to the WIPP site will be unloaded and passed through airlocks to the waste-handling building. The handling procedures are described in detail in the FEIS, and a number of conservative assumptions are made as to the levels of contamination. For example, it is assumed that all waste packages are contaminated to the maximum level of surface contamination permitted by National Regulatory Commission (NRC) and Department of Transportation (DOT) regulations. The total radioactivity that would be released to the environment from both surface and underground operations, from both residual surface contamination and leakage from damaged canisters of remotely handled waste, is estimated to be 0.004 Ci/yr. Throughout the analysis, the assumptions are conservative, so the final dose estimates are exaggerated.

The requirements of the FEIS for radiological impact analysis during normal operations could probably be discharged by simply noting that many years of experience with the handling of properly packaged wastes provide assurance that necessary calculations can easily be made.

The maximum annual occupational doses to workers at the WIPP facility from waste handling are estimated to reach an average of 0.8 rem for workers handling contact-handled waste and an average of 0.6 rem for workers with remotely handled waste. Although such doses, taken singly, are within acceptable limits, they may be too high for routine operations, since the same people may handle both types of waste, and other exposures from nonroutine events may occur.

The results of rather straightforward dose calculations, based on a conservative set of assumptions, show that for an individual at the closest point of habitation, the maximum dose (to the bone) is 0.007 percent of that received from natural radioactivity, and the whole-body dose would be less than 0.0002 percent of background (U.S. Department of Energy 1980, p. 9-30).

ACCIDENTAL RELEASES DURING OPERATION OF THE FACILITY

Accidents that may occur in the course of handling the radioactive wastes will have a potential for exposure to both the employees and nearby inhabitants. The consequences of a waste-handling accident are examined by analysis of 43 scenarios ranging from a vehicle collision in the receiving area (no radioactive material released) to various failures of the drums and canisters from collisions, drops down mine shafts, spontaneous combustion, and external fires. The radiation doses are calculated from estimates of the quantities of radioactivity released, the atmospheric concentration at a given location per unit of radioactivity released based on meteorological observations at the site, and measured population distributions.

The worst case for contact-handled TRU waste involves an underground fire, in which case the 50-year bone dose commitment off-site is estimated to be about 4×10^{-3} mrem. For remotely-handled waste, the worst case would be an accident in which a spent-fuel cask is dropped down the waste shaft, in which case the maximum dose commitment to a nearby inhabitant would be 2×10^{-3} mrem to the bone (U.S. Department of Energy 1980, p. 9-107). The maximum dose commitment to a worker from an accident would be 140 rem from an underground fire.

REPOSITORY BREACH SCENARIOS

For breach of the repository and effects upon the biosphere, there must be an event to breach the repository, a means to bring the wastes out of the repository, and finally a place for the wastes to move to at a lower fluid potential energy level than that of the repository. Without all three conditions, movement to the biosphere will not occur. In a number of the scenarios considered in the FEIS (U.S. Department of Energy 1980, p. 9-131 ff), not all of the above conditions are fulfilled.

Nevertheless, the calculations were carried out to determine the consequences of the implausible events. Finally, the studies were consequence analyses rather than risk analyses (i.e., the consequence of certain events are evaluated without regard to their likelihood). This methodology is particularly useful if the consequences are then found to be so small that the frequency of the event is not material. In all cases, the waste material is assumed to dissolve congruently with the salt, i.e., at the same rate as the salt.

The first scenario in the FEIS assumes a connection between the Rustler and Bell Canyon (of the Delaware Mountain Group) Formations through the repository with flow upwards and out of the Rustler into the Pecos River at Malaga Bend (see Figure 6-1). Though the flow may actually be in the opposite direction, this is a conservative assumption since the transmissivity and hydraulic conductivity of the Rustler are orders of magnitude greater than those properties in the Bell Canyon (i.e., greater flows and shorter residence times [U.S. Department of Energy 1980]). The Magenta and Culebra Members of the Rustler are treated as a single unit.

The second scenario assumes unsaturated flow through a drill pipe from the Rustler through the repository and saturated flow back to the Rustler and to Malaga Bend. The driving force for this scenario appears to be lacking, since the unsaturated water (8,000 ppm) flow does not appear to have the potential to push the saturated (400,000 ppm) flow out of the repository (see Figure 6-2).

The third scenario allows communication of the total waste storage horizon with the Rustler, but with no flow through the repository (i.e., the transfer is by diffusion only). Then, the flow is through the Rustler to Malaga Bend (see Figure 6-3).

The fourth scenario allows the total flow of the Rustler above the waste repository to flow through the repository and then back to the Rustler and out to the Pecos River at Malaga Bend (see Figure 6-4).

The fifth scenario deals with drilling into the waste repository and, in particular, with the dose to the drill crews. Bingham and Barr (1979) estimate the probabilities of breaching the repository salt formation by inadvertent drilling in the distant future.

A recent analysis (Woolfolk 1982) predicts the probability and consequence of a pressurized brine pocket below the repository with subsequent release to the ground surface (see Figure 6-5).

The consequences of drilling and using a water well near the site have also been evaluated (U.S. Department of Energy 1980-1982; Spiegler 1981).

Though it is not intended that solution mining will be carried out at the waste site, the consequences of doing so are more severe than the liquid breach scenarios but less severe than the drilling scenario considered in the FEIS and SAR as shown by the EEG report (Little 1982) for the maximally exposed individual. The population dose due to solution mining is much greater.

Some perspective on the total amount of radioactivity to be permanently isolated at the WIPP site might be gained by noting that the total inventory of the WIPP is expected to be 6×10^6 curies (Ci) (U.S. Department of Energy 1980-1982, Figure 8.1-4) and after 1,000

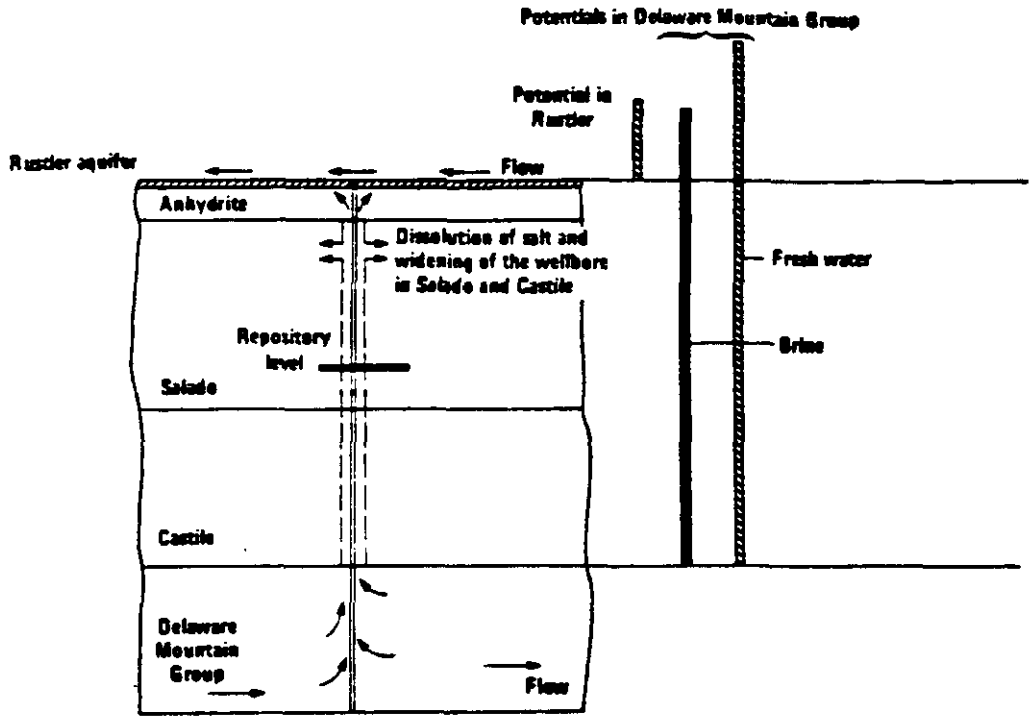

FIGURE 6-1 Schematic representation of scenario 1. Source: U.S. Department of Energy (1980).

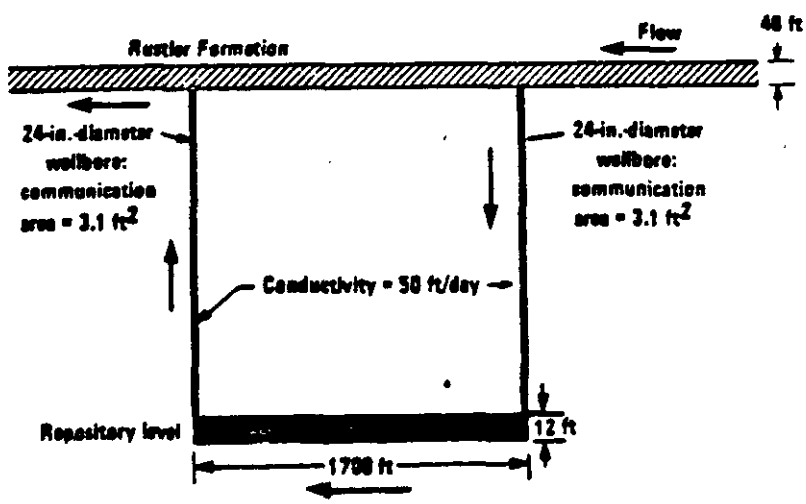

FIGURE 6-2 Schematic representation of scenario 2. Source: U.S. Department of Energy (1980).

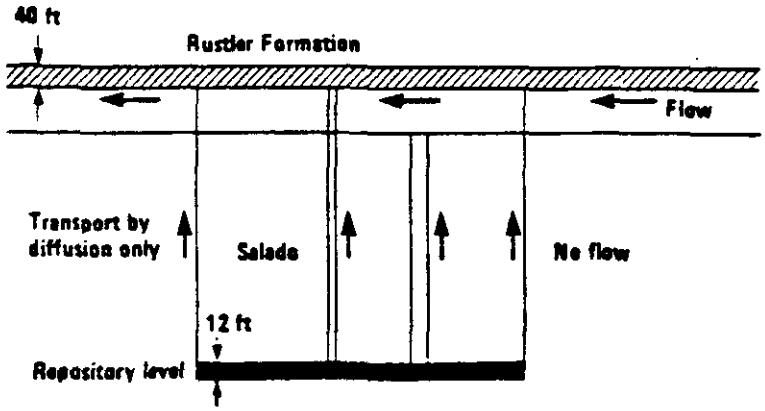

FIGURE 6-3 Schematic representation of scenario 2. Source: U.S. Department of Energy (1980).

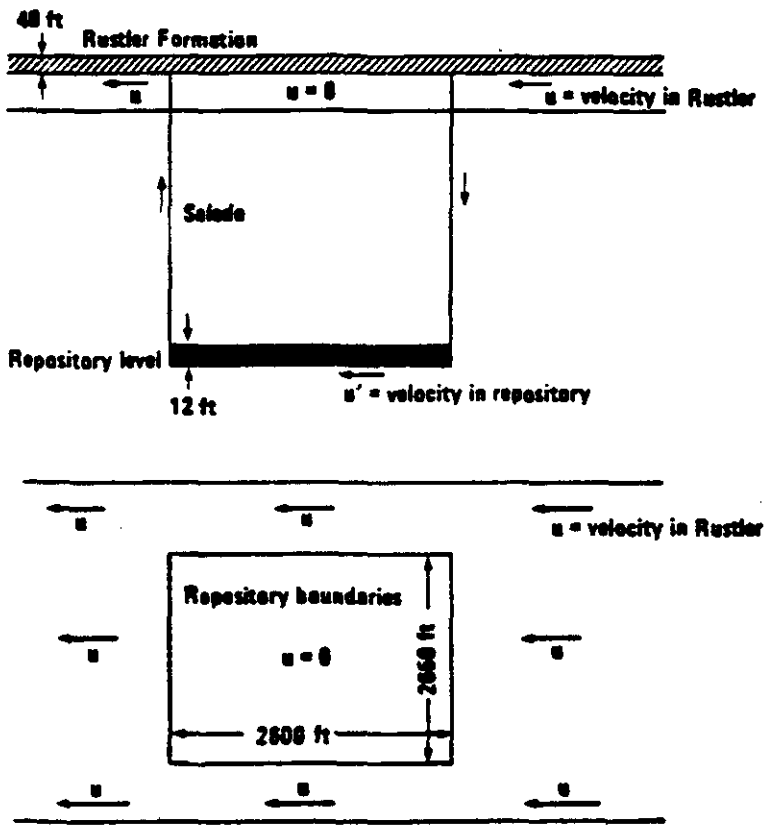

FIGURE 6-4 Schematic representation of scenario 4, showing the bounding condition (top) and velocities in the Rustler during the bounding condition (bottom). Source: U.S. Department of Energy (1980).

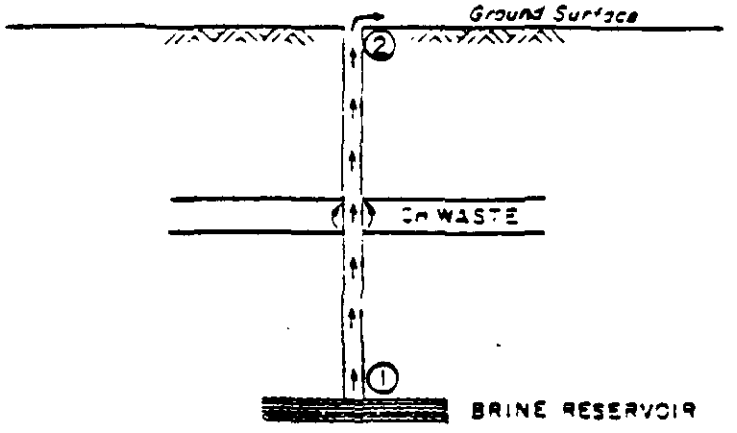

A. SINGLE BOREHOLE

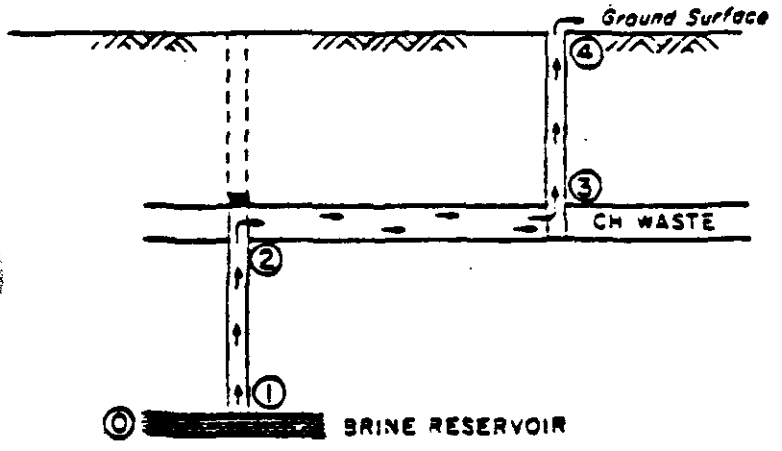

B. FIRST BOREHOLE CONNECTING BRINE RESERVOIR TO CH WASTE, SECOND BOREHOLE CONNECTING CH WASTE TO GROUND SURFACE

FIGURE 6-5 Schematic representation of scenario involving a brine reservoir below the repository and release to the ground surface. Source: Case et al. (1982).

years is still expected to be about 5×10^5 Ci (U.S. Department of Energy 1980-1982, Table 8.2-3). At the present time, the city of Albuquerque is expecting to use 15×10^6 Ci of cesium-137 for sterilization of sewage sludge.

Water flow times in the Rustler Formation from above the WIPP site to the Pecos River at Malaga Bend are calculated from models of flow through porous media to range from 5,000 to 100,000 years based upon point measurements. For the consequence analyses, the shorter flow times are used together with the shortest distance between the site and Malaga Bend. The actual flow paths may be substantially longer and particularly for the Culebra where there is some indication of an arcuate route to the Pecos. Substantially shorter flow times, 1,850 years, have also been postulated (D'Appolonia Consulting Engineers, Inc. 1981).

The sorption data listed in Appendix K-20 of the FEIS were derived from more than one source. It is not clear to what extent these data are applicable to the geochemistry of the Rustler Formation and to sorption from solutions containing appreciable concentrations of dissolved salt, nor whether precipitation may not be a more important mechanism than sorption. These uncertainties affect the estimated doses from radium-226. No discussion of the effects of such sorption uncertainties has been found in the report.

Using the porous-media analyses, the dissolution and transport processes take over 5,000 years for even the nonsorbing radionuclides and far longer for the sorbing species. Even considering wastes containing fission products, this gives ample time for strontium-90 and cesium-137 to decay without the additional delaying effect of sorption. Sorption by the dolomite delays the release of the transuranics, although some of their more toxic decay daughters, such as radium-226, contribute later to doses to man (U.S. Department of Energy 1980, p. 9-139).

The dosages (50-year commitment) to the maximally exposed individual (as well as the dose to the maximally exposed worker in the drilling scenario) from each of these scenarios, are given in Table 6-1. These doses were computed on the basis of International Commission on Radiological Protection (ICRP) reports ICRP-2 and ICRP-6. The revised permissible limits for neptunium-237 of ICRP-30 were not factored into these calculations. However, analysis of the dose calculations indicates that the portion of dose contributed by neptunium-237 is substantially less than one-two-hundredths of the total and, therefore, will have no effect on the dose numbers in Table 6-1.

The doses are calculated based upon very long transport times ranging from 1,200,000 to 1,400,000 years for the time for the peak concentrations to reach Malaga Bend (U.S. Department of Energy 1980, Table 9-60).

The scenarios selected in the FEIS would appear to be the bounding cases. Apart from the implausible mechanisms for water intruding into the repository and returning to the aquifer, the assumptions in each step of the analysis tend to exaggerate the dose estimates. For example, the waste is assumed to dissolve as rapidly as salt; no solubility limits for the waste material and for its radionuclides are

TABLE 6-1 Fifty-Year Dose Commitments for Maximally Exposed Individual from Bounding Scenarios of Breaches of the WIPP Repository (mrem)

Scenario	Whole Body	Lung	Bone
Bell Canyon to Rustler	7.7×10^{-3}	4.4×10^{-6}	1.3×10^{-2}
Restricted Rustler to Rustler Flow	1.7×10^{-3}	9.3×10^{-7}	2.8×10^{-3}
Diffusion Flow to the Rustler	7.0×10^{-5}	4.0×10^{-8}	1.2×10^{-4}
Unrestricted Rustler to Rustler Flow	1.5×10^{-2}	1.2×10^{-5}	2.6×10^{-2}
Drill into Repository	9.1×10^{-6}	1.7×10^{-5}	2.7×10^{-4}
Pressurized Brine Reservoir Flow to the Surface	7.3×10^{1}	3.2×10^{2}	1.5×10^{2}
Worker	1.7×10^{2}	6.6×10^{2}	------
Solution Mining of Halite	7.2×10^{1}	------	------
Natural Background	5×10^{3}	9×10^{3}	5×10^{3}

SOURCE: U.S. Department of Energy (1980, Tables 9-3, 9-64, 9-65, 9-66, 9-67); Little (1982, Table 4).

considered. Finally, no allowance is made for the fact that the radionuclides emerge into the Pecos River, the water of which is presently not potable because of high salinity. The water is not consumed by man or beast, and the river does not support a significant population of fish or shellfish. Even for these bounding cases, the dosages are so small that it is not worthwhile to consider more plausible cases. Confidence in the accuracy of these calculations of low dosages is strengthened by the independent calculations carried out by the EEG on transportation accidents, breccia pipe release mechanisms, withdrawal through wells, transport induced by pressurized brine reservoirs and long-term release scenarios. The dose commitments calculated by the EEG are similar to those shown in the FEIS, SAR, and brine reservoir report (Channell 1982).

Questions have been raised about the possibilities of reducing the time of travel of these higher-water-velocity flow paths by fractures or karst-type openings. Though recent publications (e.g., Gonzalez 1982) have dealt with the possibility of shortening the flow time by transport through fractures, rather than porous media, and thereby reducing the sorptive capacity of the Rustler Formation, no comprehensive analyses of the probability and consequences of fracture flow through the repository and Rustler to the Pecos have been made. This obviously needs to be done. Because it may be very difficult to prove that no connected fracture flow exists or is likely to exist, the problem might be finessed by computing the total water flow and flow rate through the aquifers above the WIPP site and, using the solubility limits of the individual nuclides, calculating the maximum amount of radioactive material that could be put into solution and transported to the Pecos.

CONCLUSIONS

o The dosages calculated to be received by humans as a result of normal operations and accidents are within prescribed limits for workers and far below the dosages from normal background radiation for members of the public. There is a great deal of experience in these types of operations, and confidence in the accuracy of the calculations is high (pp. 50-51). (Since this analysis was completed, the lower limit of concentration for classifying transuranic wastes has been changed [9/30/82] by the Department of Energy from 10 to 100 nanocuries per gram. The amount of waste affected, the cost to handle it, and the safety consequences of this change have not yet been published).

o The long-term release scenarios, shown in Figures 6-1 to 6-6, lack experimental verification. Nevertheless, the scenarios appear to set outside limits to what would be credible releases. Though only a consequence analysis is performed, the resulting dose commitments (50 years) are well within prescribed limits (maximum 170 mrem whole body) and far below the dosages from normal background radiation (average 50 years, 5,000 mrem) (pp. 51-57).

RECOMMENDATIONS

o Hydrologic investigations and monitoring programs should be continued to more adequately resolve the differences between recent and initial interpretations of potentiometric maps and to provide a more consistent and confident definition of the rates and directions of groundwater flow within Rustler aquifers above and immediately adjacent to the site (pp. 56, 58).

o Though karst-type flow in the Rustler occurs near Nash Draw, the extent to which it reaches eastward is not clearly delineated. If this type of flow should be joined by connected fractures to the WIPP site area, the time of travel of the nuclides and their retardation would be sharply reduced. Both the probability of such flows and their effect upon radiation dosages need to be determined (p. 58).

REFERENCES

Anderson, R. Y. 1981a. Progress of Salt Dissolution in the Delaware Basin, Texas and New Mexico. Special Publication No. 8. New Mexico Geological Society.

Anderson, R. Y. 1981b. Deep-seated Salt Dissolution in the Delaware Basin, Texas and New Mexico. Special Publication No. 10. New Mexico Geological Society, pp. 133-145.

Anderson, R. Y. 1982a. Deformation-dissolution potential of bedded salt, WIPP site, New Mexico. 5th International Symposium on the Scientific Basis of Radioactive Waste Management, Berlin, Federal Republic of Germany, June 7-10.

Anderson, R. Y. 1982b. Upper Castile Brine Aquifer, Northern Delaware Basin. Attachment to a May 23 letter to G. Goldstein.

Anderson, R. Y., W. E. Dean, D. W. Kirkland, and H. I. Snider. 1972. Permian Castile varved evaporite sequence, West Texas and New Mexico. Geological Society of America Bulletin, 83:59-86.

Anderson, R. Y., and D. W. Kirkland. 1980. Dissolution of salt deposits by brine density flow. Geology, 8:66-69.

Bachman, G. O. 1980. Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico. OFR 80-1099. U.S. Geological Survey, Denver, Colo.

Bachman, G. O., and R. B. Johnson. 1973. Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico, with a section on Dissolved Salts in Surface Water by F. A. Swenson. OFR 73-14. U.S. Geological Survey, Denver, Colo.

Bechtel National, Inc. 1979. Waste Isolation Pilot Plant: Title I Design Report, Vols. 1 and 1a. Nuclear Fuel Operations, San Francisco, Calif.

Bechtel National, Inc. 1983. Waste Isolation Pilot Plant: Preliminary Design Validation Report. Job 12484. Nuclear Fuel Operations, San Francisco, Calif.

Bingham, F. W., and G. E. Barr. 1979. Scenarios for Long-Term Release of Radionuclides for a Nuclear-Waste Repository in the Los Medanos Region of New Mexico. SAND 78-1730. Sandia National Laboratories, Albuquerque, N.Mex.

Borns, D. J., L. J. Barrows, D. W. Powers, and R. P. Snyder. 1983. Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site. SAND 82-1069. Sandia National Laboratories, Albuquerque, N.Mex.

Bradshaw, R. L., and W. C. McClain, eds. 1971. Project Salt Vault: A Demonstration of the Disposal of High-Activity Solidified Wastes in Underground Salt Mines, ORNL-4555. Oak Ridge National Laboratory, Tenn.

Brausch, L. M., A. K. Kuhn, and J. K. Register. 1982. Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3156. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Case, J. B., S. M. Dass, J. G. Franzone, and A. K. Kuhn. 1982. Analysis of Potential Impacts of Brine Flow Through Boreholes Penetrating the WIPP Storage Facility. TME 3155 (Appendix to TME 3151). U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Channell, J. K. 1982. Calculated Radiation Doses from Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine. EEG 11. Environmental Evaluation Group, State of New Mexico, Santa Fe, N.Mex.

D'Appolonia Consulting Engineers, Inc. 1981. Modeling Verification Studies: Long-Term Waste Isolation Assessment. NM 78-648-701. Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. Westinghouse Electric Corporation, Albuquerque, N.Mex.

Davies, P. B. 1983. Structural Characteristics of a Deep-Seated Dissolution Collapse Chimney in Bedded Salt. Paper given at 6th International Symposium on Salt, Toronto, Ontario, Canada, May 24-28.

Gonzalez, D. D. 1982. Fracture Flow in the Rustler Formation: Waste Isolation Pilot Plant (WIPP) Southeast New Mexico. Draft Interim Report. SAND 82-1012. Sandia National Laboratories, Albuquerque, N.Mex.

Griswold, G. B. 1980. Presentation reported in Geotechnical Consideration for Radiological Hazard Assessment of WIPP. EEG-6, a report of a meeting held on January 17-18. Environmental Evaluation Group, State of New Mexico, Santa Fe, N.Mex.

Horowitz, N. H. 1979. Biological water requirements. Life Sciences Research Report 13, Moshe Shilo, ed. Verlag Chemie, Weinheim, New York, N.Y. pp. 15-29.

Interagency Review Group. 1979. Report to the President by the Interagency Review Group on Nuclear Waste Management. TID-29442. U.S. Department of Energy, Washington, D.C.

Jarolimek, L., and R. F. McKinney. 1982. Selection of the WIPP Facility Horizon and Geologic Investigation of the Shaft Station Vicinity in the Exploratory Shaft. June 10 memo to D. K. Shukla.

Krieg, R. D., C. M. Stone, and S. W. Key. 1979. Calculations for CH-TRU Storage Room Design. October 23 memo to J. R. Wayland. Sandia National Laboratories, Albuquerque, N.Mex.

Lambert, S. J. 1982. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. Interim Report, SAND 82-0461. Sandia National Laboratories, Albuquerque, N.Mex.

Likar, V. F. 1979. WIPP Project Retrievability Demonstration Plan. TME 2967. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Little, M. S. 1982. Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP. EEG-12. Environmental Evaluation Group, State of New Mexico, Santa Fe.

Matalucci, R. V., C. L. Christensen, T. O. Hunter, M. A. Molecke, and D. E. Munson. 1982. Waste Isolation Pilot Plant (WIPP) Research and Development Program: In Situ Testing Plan. SAND 81-2628. Sandia National Laboratories, Albuquerque, N.Mex.

Munson, D. E., and P. R. Dawson. 1979. Constitutive Model for the Low Temperature Creep of Salt (with Application to WIPP). SAND 79-1853. Sandia National Laboratories, Albuquerque, N.Mex.

National Research Council. 1970. Disposal of Solid Radioactive Waste in Bedded Salt Deposits. Panel on Disposal in Salt Mines, Committee on Radioactive Waste Management. National Academy of Sciences, Washington, D.C.

National Research Council. 1978. Geological Criteria for Repositories for High-Level Radioactive Wastes. Panel on Geological Site Criteria, Committee on Radioactive Waste Management. National Academy of Sciences, Washington, D.C.

National Research Council. 1979. Implementation of Long-Term Environmental Radiation Standards: The Issue of Verification. Panel on the Implementation Requirements of Environmental Radiation Standards, Committee on Radioactive Waste Management. National Academy of Sciences, Washington, D.C.

National Research Council. 1981. Review of the Criteria for the Site Suitability, Design, Construction, and Operation of the Proposed Waste Isolation Pilot Plant (WIPP): Progress Report July 1, 1978 to December 31, 1979. DOE/NE/93023-2. Panel on the Waste Isolation Pilot Plant, Committee on Radioactive Waste Management. National Academy of Sciences, Washington, D.C.

Powers, D. W. 1982. Personal communication at Woods Hole meeting of the Panel on the Waste Isolation Pilot Plant, August 12-13.

Powers, D. W., S. J. Lambert, S.-E. Shaffer, L. R. Hill, and W. D. Weart, eds. 1978. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND 78-1596, Vols. I and II. Sandia National Laboratories, Albuquerque, N.Mex.

Register, J. K. 1981. Brine Pocket Occurrences in the Castile Formation, Southeastern New Mexico. TME 3080. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Rockwell International. 1982. Defense Transuranic Waste Program Strategy Document. DOE-TRU-8202. Energy Systems Group, Rocky Flats Plant, Colo.

Sandia National Laboratories. 1979. Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP. SAND 79-1305. Albuquerque, N.Mex.

Shock, D. A. 1953. Acidity of condensate well waters. Chapter XIII in Condensate Well Corrosion. Natural Gas Association of America, 422 Kennedy Bldg., Tulsa, Okla.

Snyder, R. P., and L. M. Gard. 1982. Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, With a Section on Drill-Stem Tests. OFR 82-968. U.S. Geological Survey, Denver, Colo.

Spiegler, P. 1981. An Approach to Calculating Upper Bounds on Maximum Individual Doses from the Use of Contaminated Well Water Following a WIPP Repository Breach. EEG-9. Environmental Evaluation Group, State of New Mexico, Santa Fe, N.Mex.

Spiegler, P. 1982. Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository. EEG-13. Environmental Evaluation Group, State of New Mexico, Santa Fe, N.Mex.

U.S. Department of Energy. 1978. Report of Task Force for Review of Nuclear Waste Management. DOE/ER-0004/D. Directorate of Energy Research, Washington, D.C.

U.S. Department of Energy. 1979. Draft Environmental Impact Statement (DEIS): Waste Isolation Pilot Plant, Vols. 1 and 2. DOE/EIS-0026-D. Washington, D.C.

U.S. Department of Energy 1980. Final Environmental Impact Statement (FEIS): Waste Isolation Pilot Plant, Vols. 1 and 2. DOE/EIS-0026. Washington, D.C.

U.S. Department of Energy. 1980-1982. Waste Isolation Pilot Plant Safety Analysis Report. WIPP SAR. (Includes Amendments 1-4.) Albuquerque Operations Office, N.Mex.

U.S. Department of Energy. 1981. TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant. WIPP-DOE-069, Revision 1. Albuquerque Operations Office, N.Mex.

U.S. Department of Energy. 1982. Environmental Analysis, Waste Isolation Pilot Plant (WIPP) Cost Reduction Proposals. WIPP-DOE-136. Albuquerque Operations Office, N.Mex.

Wawersik, W. R. 1979. Preliminary Idealization of CH-Level Stratigraphy for WIPP Structural Calculations Based on Drillhole Data for ERDA 9, Depth 1975-2375 ft. October 4 memo to R. D. Krieg and J. R. Wayland. Sandia National Laboratories, Albuquerque, N.Mex.

Whitty, W. J., C. A. Ostenak, and K. K. S. Pillay. 1982. Preliminary Identification of Interfaces for Certification and Transfer of TRU Waste to WIPP. LA-9207-MS. Los Alamos National Laboratory, N.Mex.

Wofsy, C. 1980. The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP. EEG-8. Environmental Evaluation Group, State of New Mexico, Santa Fe, N.Mex.

Wood, B.J., R. E. Snow, D. J. Cosler, and S. Haji-Djafari. 1982. Delaware Mountain Group (DMG) Hydrology--Salt Removal Potential. TME-3166. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Woolfolk, S. W. 1982. Radiological Consequences of Brine Release by Human Intrusion into WIPP. TME 3151. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

APPENDIX A

LETTER REPORT, PARKER TO GLOYNA, May 1, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D.C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 334-6727

May 18, 1979

Mr. Sheldon Meyers
Program Director
Office of Nuclear Waste Management
Department of Energy (MS B-107)
Washington, D. C. 20545

Dear Mr. Meyers:

I am pleased to forward the enclosed letter report by the Panel on the Waste Isolation Pilot Plant (WIPP) on its review of the WIPP Draft Site Characterization Report (SAND 78-1596). The Committee on Radioactive Waste Management has discussed the substance of this letter and endorses the views of the Panel expressed therein.

I hope these observations will be useful in the continuing process of geotechnical characterization of the proposed WIPP site.

Sincerely,

Earnest F. Gloyna
Chairman

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NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

May 1, 1979

Dr. Earnest F. Gloyna, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

Dear Dr. Gloyna:

As part of its continuing responsibility to review criteria and guidelines for the location, design, construction, and operation of a proposed radioactive waste isolation pilot plant (WIPP), this Panel has reviewed the WIPP Draft Site Characterization Report (DSCR), SAND 78-1595, prepared by Sandia Laboratories for the Department of Energy. The DSCR, which has subsequently been published, with the same report number, as "Geological Characterization Report (WIPP)," is a compilation of the known geotechnical information about the proposed site and the surrounding region, with chapters devoted to regional geology, site geology, seismology, hydrology, geochemistry, resources, and special studies of WIPP repository rocks. It does not address such matters as socioeconomic considerations, accessibility, transportation and failure modes, which will need to be included in a complete site characterization.

The following brief account, which must be viewed in conjunction with the DSCR itself, is intended for a very limited audience of readers fully conversant with the contents of the basic document.

As a first step in this review, individual chapters of the DSCR were examined in detail by subgroups of the Panel with special expertise in the disciplinary areas involved, after which their separate comments were discussed by the full Panel in a meeting with the Sandia authors of the document.

The Panel then reviewed the extent to which the information contained in the DSCR provides sound geotechnical support for an environmental impact analysis and related decisions leading to the selection of an

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appropriate site for the proposed pilot plant. The review focused on the Report's exposition of geotechnical information with critical bearing on the site's probable ability to provide the desired long-term isolation of emplaced waste, e.g. seismic or tectonic uplift, intrusion of groundwater, thermal and mechanical characteristics of the host rock, and retardation effects along possible migration pathways. The Report did not treat, nor did the Panel consider, the effect of the emplacement of waste or the waste itself on the long term integrity of the repository. Although recognizing the considerable coverage and detail of the information presented, the Panel noted a few areas where additional data are desirable to more fully characterize the geotechnical aspects of the area under consideration. These include the following:

a) A major disagreement between conclusions reached in the DSCR and the views of R. Y. Anderson is mentioned in several places. Anderson, a professor of geology at the University of New Mexico at Albuquerque, who has specialized in the study of evaporite deposits in the Delaware Basin, was commissioned by Sandia Laboratories to prepare a report on the deep dissolution of salt in the region around the proposed WIPP site. Basing his argument on a postulated unconformity at the base of the Salado formation and on his hypothesis that the so-called "breccia pipes" are localized features of deep dissolution which originated as collapse chambers in salt beds immediately overlying the reef and basin aquifers, Anderson suggested that dissolution may be so rapid that the entire salt formation will disappear within a million years. The DSCR, on the other hand, considers only dissolution at the western edge of the salt beds and concludes that present rates will ensure preservation of the Salado at the WIPP site for at least a few million years. The Panel feels that a more thorough explanation should have been provided as to why the authors of the DSCR consider their views preferable to Anderson's hypothesis. On this same issue of salt dissolution, the DSCR estimates of the rate of retreat of the solution front two or three miles west of the site are evidently based on the assumption of uniform dissolution over a wide area under average conditions. A rational basis should be provided for this assumption, vis a vis the possibility of accelerated dissolution rates in local areas, with selective removal of salt from beneath the present sedimentary cover, particularly if pluvial conditions were to change in the future.

b) Additional data and analyses would be helpful to determine with greater confidence the current rates of tectonic uplift in the region and whether, as a result, the salt may be exposed to accelerated erosion at some time in the foreseeable future.

c) The so-called "breccia pipes" need more detailed analyses to determine whether they may serve as conduits for water that may have promoted, or may in the future promote, deep dissolution of the salt beds.

d) There appears to be sufficient information to resolve the question regarding the likelihood of upward flow from the Bell Canyon formation through the Salado, where the proposed repository horizons are located, to the overlying Rustler. This should be addressed.

e) Because rock properties have a strong influence on mine design, more detailed information is needed on the various rock types in the area and on their permeability, fracture, and thermal properties under conditions as similar as possible to those that would be found in a repository. Both laboratory and field tests approximating in-situ conditions will be required to develop this information.

f) The information on sorption of the important radionuclides by materials to be expected in possible migration paths, under conditions resembling those near a possible repository, seems to be sparse. As soon as the types of waste to be stored in the repository are known, a more complete discussion should be presented of the retardation anticipated in the migration paths.

g) The most recent episode of any recrystallization in the Salado formation near the proposed WIPP site is reported to have occurred about 200 million years ago. The Panel urges confirmation of this important date by further studies and other techniques, as described in Section 7.8 of the DSCR.

In summary, the Panel views the DSCR as a progress report on a continuing program of geotechnical data collection and analysis, conducted under the constraint of no perturbation of the potential site. The Panel considers the report to be useful as a compendium of the information available to the authors on the character of the unperturbed geological formation at the Los Medanos site and the dynamics of the geochemical/hydrological system. On the basis of this available information, further investigation of the site is warranted. However, final decisions regarding repository site selection must take into account more information than is contained in this report. Most importantly, they must take into account the effect of the emplacement of the waste and the waste itself on the repository and its surroundings. These decisions must be based also on supplementary data acquisition and analyses such as those suggested above; the additional studies delineated in the document itself; crucial in-situ studies conducted throughout the construction phase; and additional definition of design objectives, criteria for safe operation, and waste forms to be accommodated.

Sincerely,

Frank L. Parker

Frank L. Parker, Chairman
Panel on the Waste Isolation
Pilot Plant

APPENDIX B

LETTER REPORT, PARKER TO WILSON, SEPTEMBER 10, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

September 12, 1979

Mr. Sheldon Meyers
Program Director
Office of Nuclear Waste Management
U. S. Department of Energy (MSB-107)
Washington, D. C. 20545

Dear Mr. Meyers:

I am pleased to forward the enclosed letter, by the Panel on the Waste Isolation Pilot Plant (WIPP), regarding the desirability of sinking an exploratory shaft at the proposed repository site. The Committee on Radioactive Waste Management has reviewed the letter and endorses the Panel's views expressed therein.

Sincerely,

E. Bright Wilson

E. Bright Wilson
Chairman
Committee on Radioactive
Waste Management

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NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6722

September 10, 1979

Dr. E. Bright Wilson, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C. 20418

Dear Dr. Wilson:

During the past year, the Panel on the Waste Isolation Pilot Plant (WIPP) has become familiar with the findings of the various extensive geological explorations, including boreholes from the surface and attendant geotechnical studies, attempting to characterize the proposed WIPP site and provide a basis for judging this aspect of the site's suitability for a waste repository. This familiarization process has included briefings by representatives of Sandia Laboratories and the U. S. Geological Survey, study of both the published and unpublished technical literature, site visits, examination of actual borehole cores, and discussions with other experts in selected geotechnical areas.

Our efforts have brought to light no disqualifying results from these explorations and studies to rule out further consideration of the proposed site at this stage. The Panel has reached this conclusion after taking into account the comments made in my letter of May 1, 1979, reporting on our review of the WIPP Draft Site Characterization Report (issued as SAND78-1596, Geological Characterization Report), pointing out that certain effects have been observed which can be interpreted as indicating the possible existence of significant anomalies. Additional information is clearly required before these anomalies can be resolved

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and a decision made regarding the adequacy of the proposed WIPP site for the construction of a repository. Furthermore, continued commitments to final details of repository design in the absence of additional site-specific information may be both misleading and wasteful.

The Panel is of the unanimous opinion that continuing efforts to acquire the necessary additional information solely by means of surface exploration, including boreholes, have reached the point of diminishing returns and cannot resolve all the major remaining uncertainties. Accordingly, the Panel recommends that:

(1) An exploratory shaft be sunk at the site of one of the proposed access shafts as soon as practicable, to the depth of the proposed repository horizon.

(2) Drilling be done and tunnels developed in the salt as necessary to conduct the measurements and observations needed to resolve remaining site-specific geotechnical uncertainties and to ascertain the degree to which the site is suitable for the excavation of a repository.

Development of the shaft, tunnels, and any other exploratory excavations should be consistent with applicable environmental and safety standards, strict quality assurance procedures, and should be compatible with an actual repository, if one is constructed at this site.

Sincerely,

Frank L. Parker

Frank L. Parker
Chairman, Panel on the
Waste Isolation Pilot Plant

APPENDIX C

CONTINUING EVALUATION OF THE CARLSBAD SITE, July 28, 1980

REPORT NO. DOE/CH/93023-1

Report No. DOE/CH/93023-1

CONTINUING EVALUATION OF THE CARLSBAD SITE

A Report to the U. S. Department of Energy, prepared by the Panel on the Waste Isolation Pilot Plant of the Committee on Radioactive Waste Management.

COMMISSION ON NATURAL RESOURCES
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
Washington, D. C.
July 28, 1980

N O T I C E

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ABSTRACT

It is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements, set forth in his February 12, 1980, message to the Congress, for evaluation of this site as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

NOTICE: The project that is the subject of this report was authorized by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. Such authorization reflects the Board's judgment that the project is of national importance and appropriate with respect to both the purposes and resources of the National Research Council. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

The report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee of the National Academy of Sciences.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its Congressional charter of 1863, which establishes the Academy as a private, non-profit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

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Staff Officer

NOTE: Two Panel members did not participate in the deliberations leading to this report; John W. Winchester was out of the country on sabbatical leave, and Karl P. Cohen is a new member of the Panel.

CONTINUING EVALUATION OF THE CARLSBAD SITE

The Panel on the Waste Isolation Pilot Plant (WIPP) was organized by the National Academy of Sciences in 1978, under the Committee on Radioactive Waste Management of the National Research Council, to review the scientific and technical criteria and guidelines for designing, constructing, and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere, with specific attention to a proposed site near Carlsbad, New Mexico.

On February 12, 1980, President Carter transmitted to the Congress "A Report on His Proposals for a Comprehensive Radioactive Waste Management Program." This report states the President's decision that the WIPP project, currently authorized for the unlicensed disposal of defense transuranic waste and for research and development using high-level defense waste, should be cancelled; but that the Carlsbad site will continue to be evaluated, along with other sites in other locations, for possible use as a licensed repository for defense and commercial high-level wastes.

The Panel has reviewed in depth the work of the DOE contractors on the geologic characteristics of the Carlsbad site, the characteristics of the defense and spent-fuel radioactive wastes that have been considered for emplacement, and the conceptual design of the repository. The WIPP Draft Environmental Impact Statement has been analyzed with

respect to the potential impact on public health and safety.

As a result of these deliberations, the Panel has previously concluded that continued investigation of the Carlsbad site is warranted and has recommended that the project proceed with an exploratory shaft to determine in greater detail the geologic, hydrologic, and structural features of the candidate salt beds, and with in-situ tests as necessary to evaluate the geotechnic adequacy of this site for a waste repository. The Panel considers these in-situ tests to be no less timely and technically desirable within the framework of the President's statement.

In connection with the Carlsbad site, a talented team of scientists and engineers has been assembled, and extensive geological exploration has been conducted. Laboratory facilities are excellent, important experiments on waste disposal are under way, and underground engineering designs have been developed. The project has gained momentum that would be difficult to recapture if it were to be interrupted. There are sound technical reasons for continuing the exploratory work:

1. <u>Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.</u>

   The analyses made thus far, supported by ongoing and planned testing programs to validate these analyses,

lead to the reasonable expectation that the site may be suitable not only for its original limited purpose as a defense transuranic waste repository but also as a licensed repository for both defense and commercial high-level and transuranic waste. The present experimental program will yield results that can be applied to the expanded purpose envisioned in the President's program. The exploratory shaft, now planned and ready to be constructed to a depth suitable for transuranic waste, can be extended to a lower horizon, where there is another salt bed that may be better suited for high-level wastes. The information obtained from this exploratory work will not only be useful for further evaluation of the Carlsbad site but can also be applied to other candidate salt formations.

2. <u>The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives.</u>

Very long lead times are involved in the President's proposed new program of selecting alternative sites, constructing test facilities at each, choosing a first repository site, and eventually constructing one or more licensed repositories.

The extensive information already obtained on the Carlsbad site and the demonstrated expertise of the existing investigative teams provide an

opportunity to proceed much sooner with in-situ testing at a potential candidate site--a capability which will have to be developed before this or any other site can be selected for a first actual repository.

More is known about the Carlsbad site than about any of the other sites under consideration. Questions remain that will require resolution by additional analyses and testing, but such questions are normal for this stage of an investigation.

The Panel concludes that it is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements for evaluation of this site, as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. If so reoriented, the project could contribute by:

- providing prototype experience in site qualification;
- testing, in situ, performance assumptions about the geologic medium; and
- developing techniques and information which will be required in the licensing process.

If given this new mission, work should proceed on constructing the exploratory shaft, acquiring hands-on repository mining experience, conducting in-situ tests and measurements at various depths, verifying engineering design assumptions, and developing analyses for licensing review.

APPENDIX D

NATURAL RESOURCES AT WIPP

OCCURRENCE OF POTASH AND HYDROCARBONS

The originally proposed controlled-access area at the WIPP site, including Zones I, II, III, and IV, has recently been reduced by the proposed elimination of Zone IV. The area of Zone III has been slightly increased to give a square area comprising 16 sections, as shown in Figure D-1. This means that most of Zone IV is now open for exploitation of its mineral resources. The consequences to repository integrity of the contraction of the controlled-access zone are discussed below.

The resources currently considered within the original area include caliche, gypsum, salt, sylvite, langbeinite, crude oil, natural gas, and distillate. Of these, the potash minerals and hydrocarbons (Table D-1) are generally considered to be the most significant (Brausch et al. 1982). The deposits of caliche, gypsum, and salt are not considered economic reserves (defined as resources that can be extracted profitably by existing techniques and under present economic conditions).

Hydrocarbons

The new proposal is that within the time limits of repository control, no drilling will be allowed within Zones I, II, and III. Since the hydrocarbon horizons are below the salt sequences, directional drilling from Zone IV could be considered to explore for hydrocarbons. The exploration for and possible removal of hydrocarbons could be accomplished without penetrating the repository. However, the panel believes that DOE should have the authority to review and approve each proposed drilling and recovery project in Zone IV in order to assure procedures consistent with repository integrity.

Potash

The Carlsbad region has been the principal source of potash in the United States for many years. The established mines are located to the north and west of the WIPP site. These potash zones are also known to

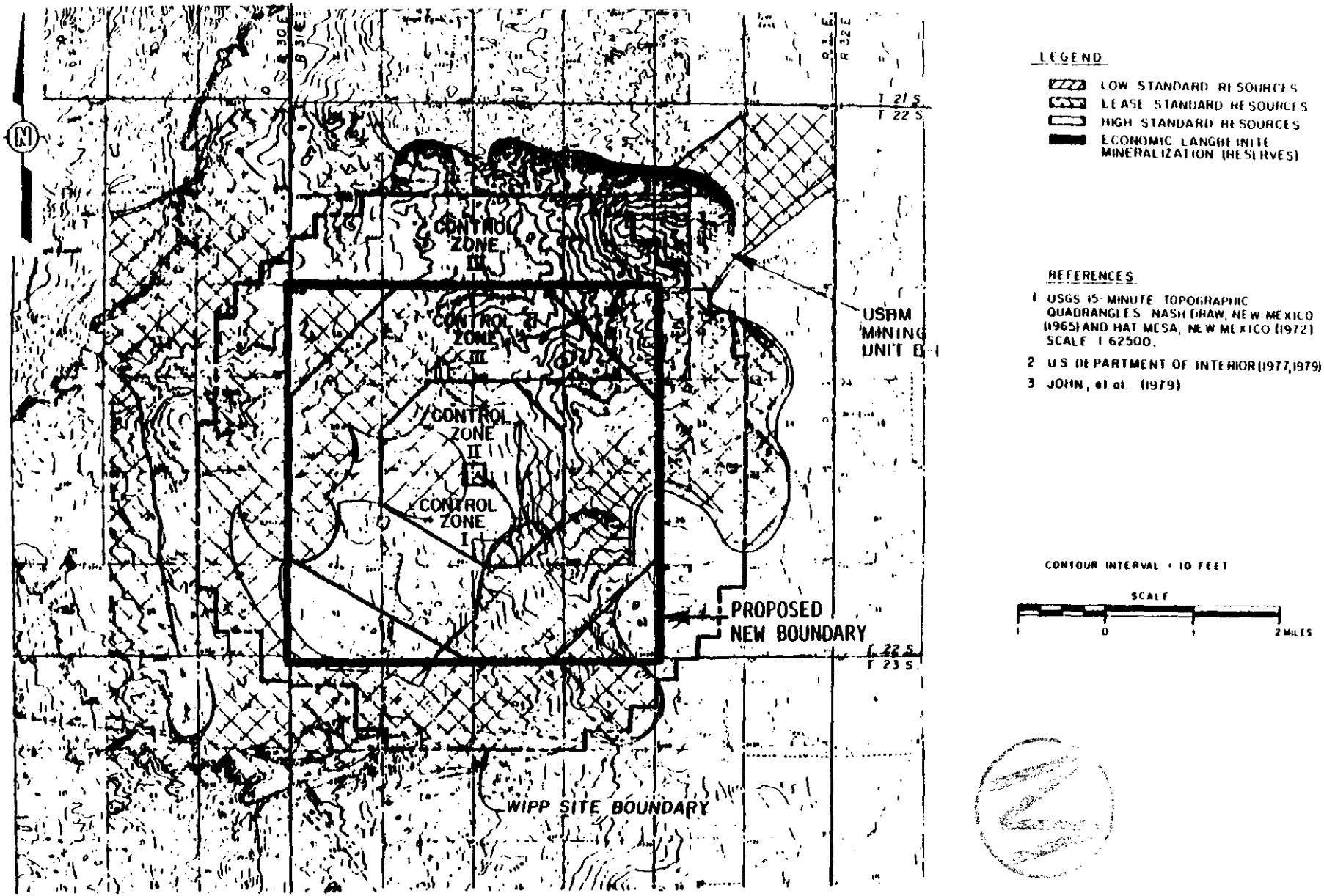

FIGURE D-1 Proposed new control zone boundary and potash deposits at the WIPP site. Source: Brausch et al. (1982).

TABLE D-1 Significance of the Resources and Reserves at the WIPP Reference Site

Deposit	Reference Site	Region	United States	World
		RESOURCES[a]		
Sylvite				
Quantity, million tons K_2O	10.44	500	1,000	100,000
Percentage at reference site		2.1	1.0	0.0104
Langbeinite				
Quantity, million tons K_2O	16.15	No estimate available		
Crude Oil				
Quantity, million barrels	37.50	1,915	200,000	Not Available
Percentage at reference site		2.0	0.019	
Natural Gas				
Quantity, billion cubic feet	490	25,013	855,000	Not Available
Percentage at reference site		2.0	0.057	
Distillate				
Quantity, million barrels	5.72	293	Not Available	
Percentage at reference site		2.0		
		RESERVES[b]		
Sylvite[c]				
Quantity, million tons K_2O	2.66	106	206	11,206
Percentage at reference site		3.4	1.8	0.033
Langbeinite				
Quantity, million tons K_2O	4.41	38[d]	38[d]	Not Available
Percentage at reference site		11.6	11.6	
Crude Oil				
Quantity, million barrels	Nil	471.7	29,486	646,000
Percentage at reference site		0	0	0
Natural Gas				
Quantity, billion cubic feet	36.85	2,863	208,800	2,520,000
Percentage at reference site		0.85	0.018	0.0015
Distillate				
Quantity, million barrels	0.55	169.1	35,800	Not Available
Percentage at reference site		0.32	0.0014	

[a]Data Sources: Hydrocarbons, Foster (1974) for the site and region; potash salts, John et al. (1978) for the site and region; Broost and Pratt (1973) for U.S. oil and gas and the world resources of sylvite.

[b]Data Sources: Hydrocarbons, Keesey (1976) for the site; American Petroleum Institute (1978) for the region, the United States, and the world; potash salts, U.S. Bureau of Mines (USBM, 1977).

[c]The U.S. Bureau of Mines (USBM, 1977) does not consider any sylvite to be commercial today. However, one bed (mining unit A-1) of sylvite was marginal and has been added to the reserve list.

[d]Not an official estimate by the U.S. Geological Survey; see Section 9.1.4.

SOURCE: U.S. Department of Energy (1979).

be present east of the WIPP site, becoming deeper toward the east. The extent of the potash beds throughout the basin has not been thoroughly investigated, but fragmentary data from oil well logs indicate these beds are not of high grade in potash content or thickness. The potash ore horizons at the WIPP site are from 457 m (1,500 ft) to 549 m (1,800 ft) below the surface and, in general, are insufficient in either grade or thickness to make the mining economically attractive at the present time. The mineral langbeinite [$K_2Mg_2(SO_4)_3$] may have some economic value as it has a special application in fertilizer for the types of plants that are sensitive to chloride ions. Within the new limits of Zone III, the reserves of langbeinite are estimated to be about 12 million metric tons (13.3 million tons), and sylvite is not present. The areal extents of sylvite and langbeinite ore in the new and revised Control Zones are shown in Figure D-1.

Questions regarding the classification of these potash deposits as reserves or resources and the timing of future development are complex. The discovery of potash deposits in the Michigan Basin, which are of significant quantity and quality, could affect the value and, therefore, the classification of the Carlsbad deposits (Mathews 1970). The Michigan deposits are some 3,130 m (7,000 ft) to 3,440 m (8,000 ft) deep, and their economic recovery has yet to be determined; however, the geographical location with relation to the fertilizer market, water availability, land availability, and other such factors, favor their value and might depress the value of the potash deposits in the Carlsbad region. The extraction of potash in Zone IV is not presently economic.

CONSEQUENCES OF NATURAL RESOURCE EXTRACTION ON CONTROL ZONE IV

Consideration of the possibility of permitting mineral exploration and extraction on Control Zone IV has been justified as a balancing of the fact that "the primary concern of the DOE is protecting the public health and safety" against the recognition that, in addition to such concern, "the state of New Mexico . . . does rely upon the royalties generated from resource recovery as a significant source of revenue" (Brausch et al. 1982). Zones III and IV each provide a 1-mile buffer around the repository excavations under Zone II. Zone II is defined as the "area of approximately 1,800 acres which overlies the area of maximum potential underground development." The depth of the repository has been set at a depth of approximately 655 m (2,150 ft). The resources of concern are principally the potash salts which are located 61 m (200 ft) to 122 m (400 ft) above the repository depth, and potential hydrocarbon resources which are well below the repository depth. The other resources, such as salt, gypsum, and caliche, were considered of insufficient importance to warrant concern, as their abundance throughout the area is such that the withdrawal of this area would have no impact on their availability.

Subsidence

The effects that may be anticipated on the extraction of resources by excavating the repository cavity are principally those related to the redistribution of rock forces. Thus, the questions to be addressed are: (1) How will the location and construction of the repository affect the removal of potash beyond the control zones? and (2) Will the possible exploration for and removal of hydrocarbons endanger the repository? These questions are all concerned with predicting the effects of subsidence. The potash deposits are above the cavity, and the hydrocarbon removal would be related to the subsidence below the repository.

Subsidence at the surface or at points below cannot exceed the height of the entry. The distance of the subsidence is related to the extent of extraction and other factors unique to the overlying strata. Thus, with a 3-m (10 ft)-high entry and 25 percent extraction, the maximum subsidence above the cavity would be 0.76 m (2.5 ft). Since the salt will flow plastically and the rooms and entries are to be backfilled, this would decrease the subsidence at least by 50 percent or 0.38 m (1.25 ft). In addition, because there are 610 m (2,000 ft) of overburden, the bulking factor would be sufficient to make this subsidence over the entry even less. These are reasonable assumptions in agreement with mining practice (Society of Mining Engineers 1973) The extent of the effects of subsidence are discussed at some length in the Natural Resources Study report by Brausch et al. (1982). Using unconsolidated sand as a model, the angle of draw would be 45°C. Thus, for an excavation at a depth of 610 m (2,000 ft), the area that could be disturbed at the surface would extend 610 m (2,000 ft) beyond the excavation perimeter. If the horizon from which resources are to be mined is 61 m (200 ft) above the repository horizon, the limit of the zone of influence of the repository would be 61 m (200 ft) beyond the excavated edge of the repository. The angle of draw for salt is quoted at various values. The study report states that for New Mexico potash mines, the angle of draw is typically considered to be 45°C.

The nature of subsidence effects from hydrocarbons extraction is significantly different from mined extraction. Since the hydrocarbon horizons are well below the repository and there is a considerable thickness of salt in the Salado and Castile formations, there is no evidence that there would be a measurable subsidence effect by their withdrawal.

Potash Operations

Developing potash reserves involves three sequential steps: (1) exploration, (2) mining, and (3) ore processing. The exploration step requires the drilling of boreholes completely through the potash zone and something less than 6 m (20 ft) beyond to establish mine floor conditions. Since the depth and lateral control of such boreholes is between 1.5 (5 ft) and 3 m (10 ft), and the depth of the potash zone is some 61 m (200 ft) to 122 m (400 ft) above the repository, there is

little chance of any detectable influence from the repository particularly if the mining and prospecting are not permitted in Zone III, which extends one mile beyond the repository limit.

Potash mining is done by shaft sinking and room and pillar development. If water zones are encountered they are sealed by grouting. The New Mexico mines are typically free from water intrusion and the occasional incidence seems to come from pockets of limited volume. Several approaches have been made to evaluate the limiting distance of influence from the repository toward the nearest possible mine. It should be pointed out that this distance is between the outermost repository excavations at 655 m (2,150 ft) and the nearest potash excavation at the potash zone level, e.g. 61 m (200 ft) to 122 m (400 ft) above the repository entry. Using the empirical 45° angle of draw and a difference in depth of 61 m (200 ft), there is no effect beyond 61 m (200 ft) from the repository, and at a 122 m (400 ft) difference, the limit is 122 m (400 ft) from the repository, etc. Brausch et al. (1982) present several more sophisticated analysis methods, with the conclusion that the effects of the WIPP facility would extend a maximum distance of 115 m (376 ft). They conclude that a potash zone 610 m (2,000 ft) deep and a repository 655 m (2,150 ft) deep would show no interaction if separated by 213 m (700 ft) or more. On the surface above the site the repository could have an influence to 655 m (2,150 ft) beyond the boundary between Zone II and Zone III, and the influence of a potash mine at a depth of 610 m (2,000 ft) in Zone IV could extend inward 610 m (2,000 ft) from the Zone III-Zone IV boundary. This would leave some 305 m (1,000 ft) of surface undisturbed. Nearer the repository horizon, the distance would be proportionally greater.

Stress-induced increases in hydraulic conductivity were examined (Brausch et al. 1982) for the inert gases and several hydrocarbons. It was concluded that while the mining of potash "would result in a zone immediately surrounding the openings in which the hydraulic conductivity of the rock would be greatly increased," further from the mine, the hydraulic conductivity would be less and "therefore no preferential paths for groundwater flow between a potash mine developed within Control Zone IV and the WIPP facility would be expected to be created due to stress induced change in hydraulic conductivity."

Hydrocarbon Exploration and Production

The hydrocarbon development in the vicinity of the WIPP site requires drilling and removal of its hydrocarbon values. Since the target reservoirs are considerably below the repository, deviated drill holes are applicable. Standard well techniques of casing, cementing, and production can assure that minimal damage to the rock system will take place. Recovery and stimulation methods, e.g., acidizing and hydraulic fracturing are all at sufficient depth and under sufficient control to have no effect on the integrity of the repository (Brausch et al. 1982).

Solution Mining

The technique of solution mining has generally been excluded as a mining method to be considered. The technique has, however, been suggested as a means of making storage cavities for hydrocarbons. While this mining system requires water to dissolve the salt, the stresses and water convection problems do not differ from standard mining when the shape and size of the cavities are taken under consideration. It is possible that Zone IV could be considered for storage sites. It is quite obvious, however, that there is no apparent reason to locate a storage cavern in any of these Zones as any location with 244 m (800 ft) of overburden and a minimum of 9 m (30 ft) thickness of salt will be sufficient to make a suitable storage cavity. Thus, while there is little technical reason for prohibiting storage cavities to be constructed within Zone IV, there is no obvious advantage in doing so. Solution cavities should be restricted from Zone II and III.

REFERENCES

Brausch, L. M., A. K. Kuhn, and J. K. Register. 1982. Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3156. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Mathews, R. D. 1970. Distribution of Silurian Potash in the Michigan Basin. 6th Forum on Geology of Industrial Minerals, April 2-3. Department of Geology, University of Michigan.

Society of Mining Engineers 1973. Roof and ground control. Chapter 13 in Mining Engineering Handbook, Vol. 1. American Institute of Mining Engineers, New York, N.Y.

U.S. Department of Energy. 1979. Draft Environmental Impact Statement (DEIS): Waste Isolation Pilot Plant, Vols. 1 and 2. DOE/EIS-0026-D. Washington, D.C.

APPENDIX E

BRECCIA PIPES

Of the various karst landforms and deposits observed in the Delaware Basin, only three have been shown to be breccia pipes, despite the many miles of geophysical surveys (Figure E-1), the drilling of 71 shallow and deep exploration holes in the vicinity of the WIPP site, examination of 300 oil and gas well records adjacent to the WIPP site, the detailed mapping of subsurface and surficial deposits, and the extensive mining of McNutt potash on three sides of the WIPP site. By 1976, 142 km^2 (55 sq miles) of potash mines were developed in the region above backreef, reef, and forereef deposits in the Delaware Basin. Despite these extensive excavations, only one breccia pipe was encountered, Hill C (Figure E-2). Another possible pipe other than Hills A and C was reported to have been penetrated by one of more than 300 potash exploration holes drilled in the region. No conclusion can be drawn from this report because data were scanty.

These observations indicate that breccia pipes are exceptions, rather than the rule, in the Delaware Basin, and are far more restricted in their distribution than originally implied by Anderson. Anderson and Kirkland's model (1980) for pipe formation requires the concentrated solution removal of salt at depth (they postulated the Bell Canyon Aquifer), presence of unsaturated groundwater at some time in the history of the pipe, an aquifer or aquifers with sufficient hydraulic conductivities and porosities to allow groundwater to transport salt from the aquifer, sufficient gradients to induce groundwater flow, and an outlet or sink for both the water and dissolved salt. The bounding calculations of Wood et al. (1982) for necessary rates of groundwater circulation and salt dissolution show that necessary and sufficient conditions for breccia pipe development in the number, size, and time frame required to threaten the integrity of a WIPP repository cannot be met within the Bell Canyon Aquifer. This is in agreement with Lambert's (1982) geochemical and isotopic data.

Conditions could be met for breccia pipe formation only within the Capitan Reef of the Delaware Basin and near its forereef and backreef environment. An abrupt collapse of Salado and Rustler roof rock into a large void temporarily supported by an anhydrite "beam" within salt (Snyder and Gard 1982) or related resistant layer within salt could account for breccia pipe characteristics observed as well as the large diameter and large volume of rock instantaneously displaced into Kermit

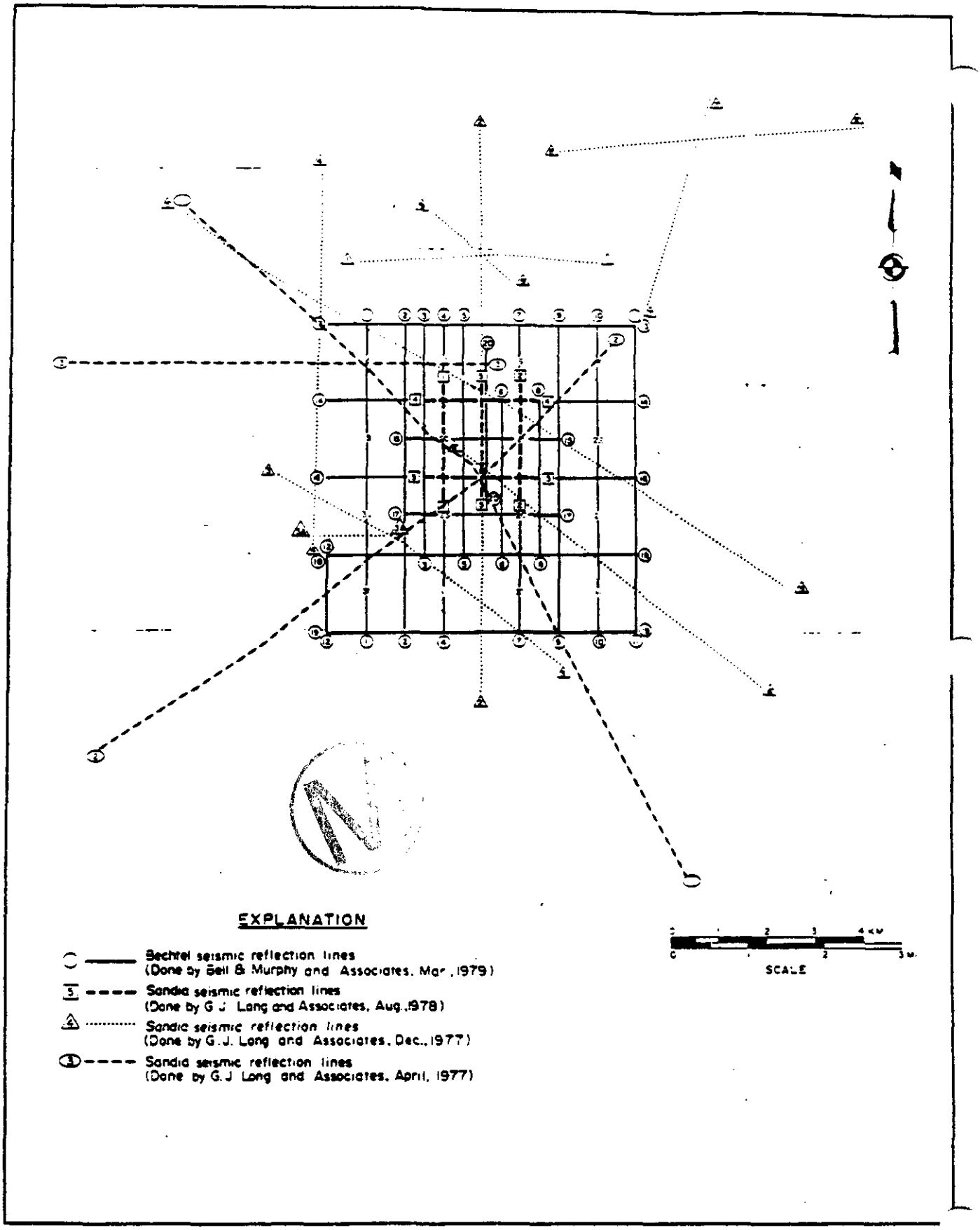

FIGURE E-1 Seismic reflection lines. Source: U.S. Department of Energy (1980-1982).

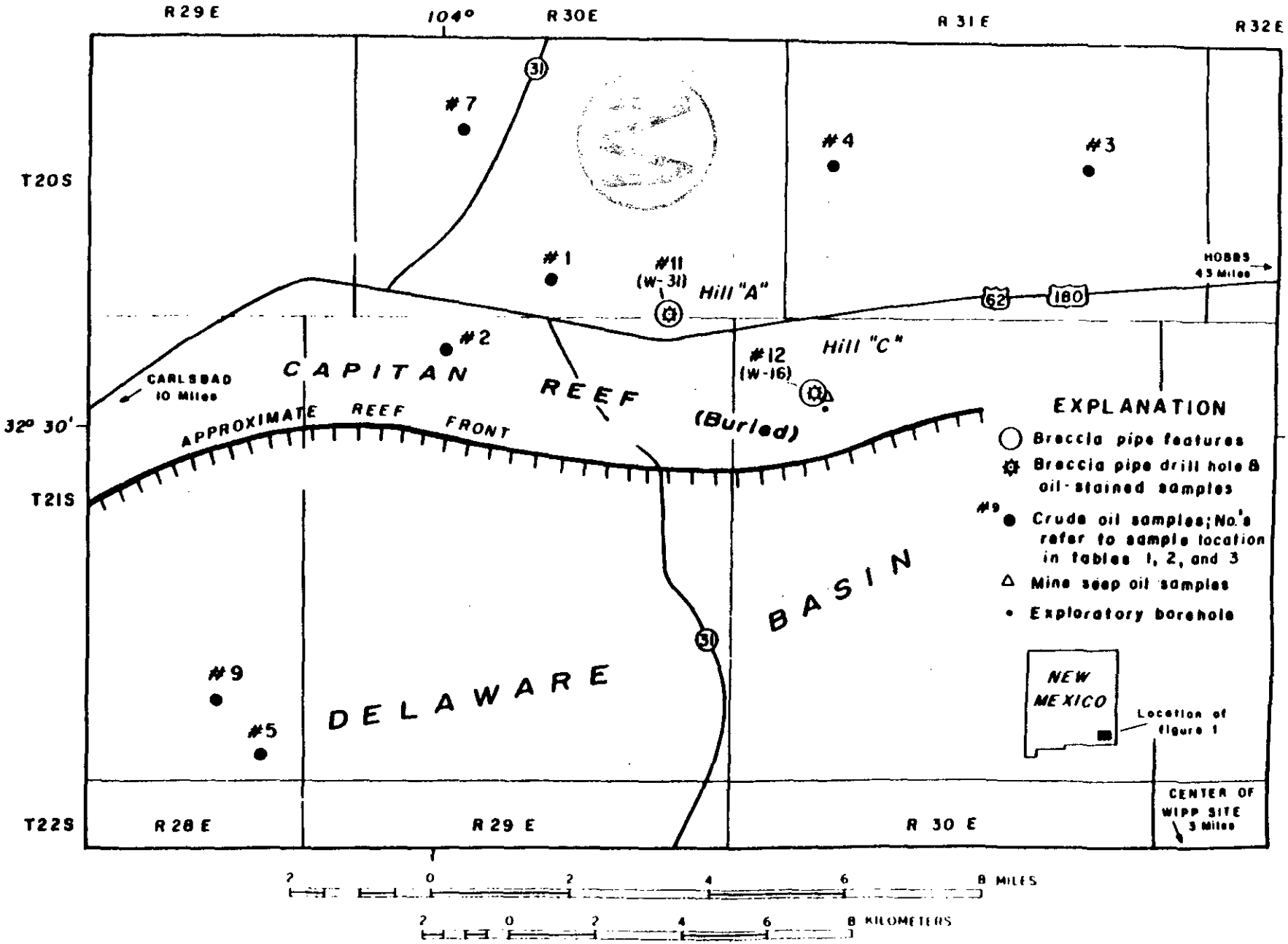

FIGURE E-2 Location of breccia pipe features; breccia pipe, mine seep, and crude oil samples; and approximate Capitan Reef front in Eddy County, New Mexico. W-16 and W-31 are drill holes at breccia pipe features. Source: Palacas et al. (1982).

sink, San Simon sink, and possibly other related karst features observed near or above the Capitan Reef in the Delaware Basin.

Hill C (Dome C in Vine 1960) and Hill A have been shown to be deep-seated "breccia pipes." R. P. Snyder (U.S. Geological Survey, personal communication to the WIPP panel, 1982) points out that they are not unlike a rubble chimney caused by the detonation of a buried nuclear device. Because of their size and potentially disruptive nature, breccia pipes require better understanding, because they are a mechanism that could affect a repository.

Drill-stem tests in borehole AEC-7 indicate that: (a) the 8 m to 10 m thick Lamar Shale Member that occurs near the upper portion of the Bell Canyon is practically impermeable, and (b) the permeability of the brine-producing zone of the Ramsey Sandstone in borehole AEC-7 is about 1.2 m/yr (Lynes, Inc. 1979). Hiss (1975) constructed a potentiometric surface map for the Delaware Mountain Group, using a large number of control points. His potentiometric surface map and chloride concentration gradients show that flow is generally to the northeast within the northern part of the Delaware Basin. The average hydraulic gradient, using potentiometric data corrected for fluid density, is about 0.0025 m/m (Wood et al. 1982) and the computed flow rates in the Bell Canyon, is about 0.135 m^3/yr per meter width of aquifer. Allowing for probable ranges in hydraulic conductivity, effective aquifer thickness and hydraulic gradient, probable flow rates were estimated to range from 0.02 to 0.40 m^3/yr per meter.

Groundwater quality analyses of samples taken from the Bell Canyon Formation reveal that chloride concentrations range from 1 to 190 kg/m^3, and that total dissolved solids typically exceed 20 kg/m^3 for much of Bell Canyon groundwater (Hiss 1975). Hiss' contours of equal chloride concentration (isochlors) roughly parallel the potentiometric surface for the Bell Canyon and increases from southwest to northeast near the WIPP site. Wood et al. (1982) and Lambert (1982) indicate that the specific source of chloride is difficult to determine, although some of it may be derived from the overlying Castile Formation, having been derived from a more regional, rather than concentrated site originating from a few distinct points, and from reactions within the Bell Canyon Aquifer. Wood et al. (1982) computed the water particle velocity to be approximately 0.03 m per year within the Bell Canyon near the WIPP site based on an average hydraulic conductivity of 1.8 m/yr, a porosity of 0.16 and hydraulic gradient of 0.0025 m/m. This travel time in the Bell Canyon from underneath the center of the WIPP site to the nearest known point on the Capitan Reef, is approximately 500,000 years. A mechanism is lacking, however, for getting nuclides into the Delaware Mountain Group (DMG). At present, heads in the DMG stand above the proposed repository level.

Wood et al. (1982) analyzed two major mechanisms for deep-seated dissolution of salt from halite horizons through the agency of an underlying aquifer at the WIPP site:

- molecular diffusion along grain boundaries and through fractures in the intervening anhydrite layer; and

o solute-driven convection, either through a single wide fracture or through a permeable porous zone or fracture network between halite and aquifer horizons.

The latter is a worst case example similar to that postulated by Anderson.

To demonstrate the dissolution capabilities of the salt removal mechanisms, one-dimensional analytical equations describing the mechanisms of salt dissolution and their interrelationship have been applied to the Delaware Basin. Two-dimensional numerical modeling of flow and mass transport has provided a more precise study of salt dissolution in the Castile Formation and mass transfer to the Bell Canyon Aquifer. The results of the Wood et al. (1982) modeling are consistent with observed chloride concentration levels associated with dissolved halite in the Bell Canyon Aquifer (Lambert 1982). Conditions required to support dissolution within the Bell Canyon Aquifer include a concentration gradient to drive the diffusion process and a density gradient to initiate convection. Additionally, convection is dependent on the fracture size or porous zone (fracture network) permeability. As shown in the Wood et al. (1982) analysis, convection can be substantially greater than diffusion for a fracture greater than 0.0015 m, or for intrinsic permeabilities greater than 10^{-16} m^2. However, for conditions in the Delaware Basin, the Bell Canyon Formation will limit the dissolution mechanism because the concentration and density gradient will be controlled by the aquifer transport rate. The Bell Canyon Aquifer water transport rate is inadequate to transport the necessary amounts of salt implied by Anderson's original brine-density model.

Two implausible worst case scenarios were also developed by Wood et al. (1982), and the sizes of associated solution cavities estimated. Based on the calculated solution cavities, the possible implications of development of a dissolution cavity at the Halite I horizon on the integrity of the underground WIPP facility were assessed.

The following conclusions were reached:

o Observed site features which provide evidence for deep-seated dissolutioning are located at the Capitan Reef margin and consist primarily of breccia pipes. The origin of other dissolution features observed in the basin is open to interpretation, although near-surface rather than deep-seated dissolutioning appears more plausible.

o The residence time of groundwater in the Bell Canyon Aquifer is relatively long, with a flow rate which requires more than two million years to travel from recharge near the west reef margin to discharge at the east section of the Capitan Reef.

o The potential dissolution mechanisms include diffusion and convection from halite zones to the aquifers. Computation of the present dissolution rate, based on observed chloride concentration levels in the Bell Canyon, indicates that diffusion and possibly very weak convection result in the removal of halite from the Castile

Formation. However, convection may be considerably more significant at locations adjacent to the Capitan Reef Aquifer.

o Evaluation of the present DMG hydrogeologic and geochemical conditions and review of their potential range of values, indicate that halite dissolution associated with the Bell Canyon Aquifer will not impact the underground WIPP facility. A solution zone of less than 0.1 m in height was calculated, based on the maximum dissolution rate in 10,000 years.

o Based on an analysis of potential changes in the hydrologic characteristics (i.e. hydraulic gradient) of the Bell Canyon Aquifer, a possible increase in flow rate of one order of magnitude in the future would not impact the WIPP facility over the period of investigation, 10,000 years.

o Based on an analysis of the maximum potential dissolution rate associated with convective and diffusive dissolution mechanisms at the Bell Canyon Aquifer-Castile Formation interface (i.e. worst case), no impact should be observed at the underground WIPP facility during the period of investigation, 10,000 years.

The analysis by Wood et al. (1982) of deep-seated dissolution due to diffusion and convection (brine density flow; Anderson and Kirkland 1980), and the significance of the parameters which influence these dissolution mechanisms are revealing. Brine density flow or convective dissolution as a potential mechanism for removal of halite is possible in areas overlying and immediately adjacent to the Capitan Reef Aquifer where high rates of groundwater flow can occur and water is undersaturated with respect to NaCl. However, geochemical data suggest that convective dissolution by the Bell Canyon Aquifer is not very significant and results in dissolutioning at the rate no greater than associated with the diffusive dissolution mechanism. Furthermore, the very low flow rate of the Bell Canyon Aquifer and the associated salt transport rate indicate that significant convective dissolution of halite in the overlying Castile Formation would be precluded due to the inability of the aquifer to maintain the density gradient for any significant period of time (Wood et al. 1982).

The deep dissolution analysis by Wood et al. (1982) has adequately set bounds on the rates and unimportance of sub-Castile dissolution process.

Several questions remain unanswered: Where are conditions favorable for possible future breccia pipe formation? Are San Simon Sink and Kermit Sink modern examples of breccia pipes in various stages of formation? Are there possible circumstances available for renewed breccia pipe formation at or near the WIPP site? How might specific high risk sites for future pipe development be identified?

It is important to be sure that the reef facies margin immediately northwest, north, and northeast of the WIPP site is accurately known, and that there are no smaller fringing reefs present between the site and the main reef that may be hydraulically connected with it. Reef masses tend to be rather complex when traced in their development through time and space. However, no such reef occurrences were noted in test holes, and a number of industry deep well logs, borehole

geophysical data, and seismic refraction data were used in test holes AEC-7 and AEC-8 to show that the southern edge of the reef is at least seven miles away from the northern edge of the WIPP site.

Judging from the importance that zones of fracture concentration have on the location of Carlsbad and other caves in the Guadalupe Mountains (Parizek 1979), similar structures also most likely contributed to the formation of caves and conduits within buried reef rock. Fracture trace and lineament related structures that intersect reef rock are major candidate sites for possible present and future sinkhole and breccia pipe development.

REFERENCES

Anderson, R. Y., and D. W. Kirkland. 1980. Dissolution of salt deposits by brine density flow. Geology, 8:66-69.

Hiss, W. L. 1975. Stratigraphy and Groundwater Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas. Unpublished Ph.D. dissertation. University of Colo.

Lambert, S. J. 1982. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. Interim Report, SAND 82-0461. Sandia National Laboratories, Albuquerque, N.Mex.

Lynes, Inc. 1979. Drill Stem Test Results for Boring AEC #7. Houston, Tex.

Palacas, J. G., R. P. Snyder, J. P. Baysinger, and C. N. Threlkeld. 1982. Geochemical Analysis of Potash Mine Seep Oils, Collapsed Breccia Pipe Oil Shows and Selected Crude Oils, Eddy County, New Mexico. OFR 82-421. U.S. Geological Survey, Denver, Colo.

Parizek, R. L. 1979. Recommended Locations for Flood Water Recharge wells for Cornudas, North, C. and L., and Washburn Draws, Hudspeth County, Texas. Soil Conservation Service, U.S. Department of Agriculture, Fort Worth, Tex.

Snyder, R. P., and L. M. Gard. 1982. Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, With a Section on Drill-Stem Tests. OFR 82-968. U.S. Geological Survey, Denver, Colo.

Vine, J. D. 1960. Recent domal structures in southeastern New Mexico. American Association of Petroleum Geologists Bulletin 44(12):1903-1911.

Wood, B.J., R. E. Snow, D. J. Cosler, and S. Haji-Djafari. 1982. Delaware Mountain Group (DMG) Hydrology--Salt Removal Potential. TME-3166. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

APPENDIX F

SALT DISSOLUTION

Containment of radioactive wastes at the WIPP facility hinges on the long-term integrity of the evaporite section which will be subjected to persistent dissolution, to perturbation during the development of the repository and following its decommissioning, and to possible future human intrusion.

Salt dissolution can progress from the top of the salt section, from below, and within individual salt beds. The rate of dissolution is directly related to the volume of water that comes in contact with salt in a given time period, the chemical quality of this water, and the rate at which dissolved salt can be transported within and from the aquifer. On a geological time scale, the dissolution can be rapid. Few outcrops of soluble salt beds are ever observed in humid regions or even in moderately arid regions because the shallow, unprotected salt has long since been leached away. However, salt that is deeply buried, or covered by poorly-permeable strata that restrict groundwater circulation, can survive for long periods of geological time even in basins with active groundwater circulation. Permian-aged salts of the Delaware Basin of New Mexico and west Texas are good examples, for they have persisted for more than 200 million years despite active dissolution at some points.

Reliable estimates of the total amount of Salado and Castile evaporites removed to date by dissolution are difficult to make because of (a) original heterogeneities of deposition, (b) ambiguous identification of members or marker beds, (c) partial removal of halite by dissolution or early subaerial erosion, and (d) perturbation of original bedding thicknesses by localized deformation (Lambert 1982).

Episodes of uplift accompanied by erosion and dissolution of evaporite beds are described by Powers, et al. (1978):

> Periods of terrestrial deposition alternated with erosional episodes, so that a series of non-marine deposits separated by angular unconformities blanket the evaporite beds at the site. These angular unconformities represent intervals during which salt beds at the WIPP site were tilted and subjected to potential dissolution. At least four erosional episodes separated by depositional intervals are recognized: (1) early

Triassic time in which the Dewey Lake Redbeds were tilted and eroded to a slight angular unconformity before deposition of the Upper Triassic Dockum Group; (2) Jurassic-Early Cretaceous time in which the Dockum Group was tilted and eroded to a wedge before marine inundation in Washitan time (latest Early Cretaceous); (3) a Late Cretaceous through mid-Tertiary erosional interval when the region was again tilted and the Triassic Dockum Group of sediments was bevelled for a second time; and (4) a post-Ogallala (post-Pliocene) uplift and erosion in early Pleistocene time, prior to which deposition of the (Kansan?) Gatuna formation took place. Subsequent to deposition of the Gatuna, there probably were pluvial intervals corresponding to the Illinoisian and Wisconsin glaciations during which accelerated erosion in these wetter times occurred in the area of the WIPP site.

Each period of tilting, which was accompanied by the potential for renewed erosion, also afforded an opportunity for salt flow by plastic deformation along the imposed gradient and salt deformation as the salt impinged against reef abutments or responded to uneven, differential sediment loading or erosional unloading. Salt deformation of this type may account for the origin and distribution of isolated pressurized brine reservoirs found in the Castile. To the extent that some "deep dissolution" features are recognized today in salt at depths of several thousand feet below the surface, it seems likely that subsurface dissolution of salt could have been initiated at comparable depths beneath the surface as soon as early-Triassic time. Episodes of active dissolution most likely occurred during the Jurassic and late-Cretaceous-to-mid-Tertiary erosional intervals, as well as during the several pluvial periods corresponding to Pleistocene glacial stages.

Recent regional rates of salt removal from the top and bottom of the Delaware Basin evaporite have been estimated from a knowledge of salt dissolution mechanisms, regional groundwater flow systems, and the geochemistry of its groundwaters (Powers et al. 1978; Wood et al. 1982). Concentrated, more localized dissolution processes may give rise to breccia pipes, such as Hills A and C (Figure E-2, Appendix E), and sinkholes, such as San Simon Sink, Kermit (Wink) Sink, and other large-scale, deep-seated karst features. Some of these karst features formed in part in a localized catastrophic manner rather than by slow regional subsidence. Abrupt collapse of large volumes of consolidated and unconsolidated strata, as occurred at San Simon and Kermit Sinks, is possible only where void space formed at depth by slow differential dissolution of soluble strata. Each of these salt dissolution processes will be reviewed briefly as they pertain to the long-term geological stability of WIPP.

The present rate of salt dissolution has been estimated for the top of the halite within the Rustler and Salado Formations (Powers et al. 1978; Bachman 1974, 1980), and more recently for the base of the Castile

Formation at the Castile-Delaware Mountain Group contact (Wood et al. 1982). Many lines of convergent evidence were reviewed by Wood et al. (1982) and Lambert (1982) to help bound rates of salt dissolution. Local and basin-wide stratigraphic and structural observations were considered in these analyses, as well as mineralogical and textural relationships observed in caves and cores. Lambert (1982) presented additional data obtained from chemical and isotopic analyses of rocks and solutions regarding equilibrium relationships of brines and other groundwaters obtained from various sources in the Delaware Basin. These lines of evidence provide support for estimates of dissolution rate that previously were based largely on stratigraphic and geomorphic evidence. Additional evidence regarding dissolution rate is currently being sought from incongruent phase relations (Lambert 1982).

Erosion by solution and fill is a mechanism originally proposed by Lee (1925) for shallow dissolution of gypsum terrain, characterized by incision of dendritic drainage patterns and development of underground drainage channels that collapse as soluble materials are dissolved. Bachman (1980) thinks that this mechanism is active in sections of the Delaware Basin underlain by gypsum, resulting in a chaotic jumble of less soluble rock as an end product.

Bachman (1980), Christiansen (1971), Jagnow (1979), and others describe a shallow process of phreatic dissolution of soluble rocks within open conduits which contain freely circulating groundwater that is undersaturated with respect to the rocks (such as carbonate rocks, anhydrite, gypsum, and halite) being dissolved. This process is differential in nature and can produce large open cavities, such as Carlsbad and related caverns in the Guadalupe and Delaware Mountains and smaller cavities noted in Nash Draw. Many of these caverns in the Capitan Limestone exhibit structural control, i.e., zones of fracture concentration, which are also likely to influence present development of solution permeability within Capitan Reef rock where buried by Salado, Rustler, and other strata. Similar zones of fracture concentration are present in the back reef sediments of the Artesia Group that lies shelfward of the Capitan Reef and appear to have helped to localize numerous sink holes and collapse structures.

A different origin for some karst deposits and landforms is proposed by Anderson (1978). He suggests that many of these features were created by deep-seated solution activity, which he thinks is an ongoing process within the Delaware Basin. He believes that the region of concentrated salt dissolution activity has migrated from west to east through geologic time, as well as along and away from the margins of the Capitan Reef. In support of his hypothesis of deep-seated dissolution, Anderson cites the presence of many sinks, domes, and breccia pipes in various parts of the Delaware Basin, and the thinning of halite layers I, II and III deposits in the Castile Formation near the western margin of the basin.

As a corollary of the deep-seated dissolution hypothesis, Anderson and Kirkland (1980) proposed a brine-density flow model to account for breccia pipes in the Delaware Basin. For this mechanism to operate, fractures must expose the base of the evaporite section to undersaturated solutions that begin to dissolve salt. As salt

dissolves, water becomes more dense and sinks into the lower part of the aquifer, allowing new unsaturated waters to come in contact with the salt in a self-perpetuating manner. Overlying strata collapse into the cavity created by the dissolution. As the aquifer providing the undersaturated solution, Anderson and Kirkland suggested the Bell Canyon Formation, which immediately underlies the salt sequence.

Recent work, however, has cast doubt on the ability of the Bell Canyon Formation to supply the necessary flow of undersaturated fluid (Lambert 1982; Wood et al. 1982). Five lines of evidence are presented by Lambert (1981) to show that the Bell Canyon is an unimportant aquifer:

- o extremely limited quantities of water produced from but a few thin Bell Canyon Formation horizons;
- o Bell Canyon water is highly saline, but not completely saturated with sodium chloride under the evaporites (Hiss 1975);
- o the salinity does not rise abruptly from west to east as evaporites appear in the overlying section (Hiss 1975);
- o the water contains solutes in combinations not found in the evaporites (Lambert 1978); and
- o there is little evidence for appreciable movement of water in the Bell Canyon (Mercer and Orr 1979).

Anderson (1982a) now agrees that the Bell Canyon is an unlikely source of solutions for the brine-density mechanism, and suggests instead that deep dissolution is concentrated in layers of fractured anhydrite near the Salado-Castile contact. The alleged flow in this layer, called "blanket" or "stratabound" dissolution, involves the lateral movement of water along a permeable bed, adjacent to which soluble rock dissolves. More rock dissolves as new void space is created. Such dissolution in this and other anhydrite beds, according to Anderson (1981b), has removed nearly 50 percent of the halite in the Delaware Basin by a process that he thinks is still active and still proceeding eastward at significant rates. More recently, Anderson (1981b, 1982a) has tied this process to the origin of brine reservoirs in Castile anhydrites as well. He has dropped the Bell Canyon as an important aquifer for significant salt removal and breccia pipe formation as proposed in his earlier papers.

Bachman (1980) and Lambert (1982) agree that stratabound dissolution occurs, but think that it operates only near to points of recharge where waters are more likely to be undersaturated with salts and where groundwater sinks are available for salt and water removal. They do not agree with Anderson that this mechanism is widespread or is responsible for pressurized brine reservoir formation. To date, no evidence has been provided to show that anhydrite beds within the Castile or Salado Formations serve as regionally interconnected aquifers in the basin.

Hydraulic heads in the Bell Canyon Aquifer stand above the proposed repository level and no foreseeable mechanism exists for introducing radionuclides into the Bell Canyon. Extraction of oil and mostly gas in the northern section of the Delaware Basin has not caused a drawdown in potentiometric heads within sub-Bell Canyon reservoirs that have reversed hydraulic gradients in the Bell Canyon. Also, estimated flow

rates in the Bell Canyon show that nearly 500,000 years may be required for its waters to move from beneath the WIPP site to the Capitan Limestone Aquifer, assuring that it is hydraulically interconnected to the Bell Canyon Aquifer.

The Capitan Limestone is an important aquifer, with extensive solution porosity where exposed west of the WIPP site as well as where buried in the northern and eastern margin of the Delaware Basin. Hiss (1975) reports high porosity zones within buried reef rock as shown by five occurrences of bit drops during drilling of 3.6 to 18m (12 to 60 ft). Hiss' model for regional groundwater flow within the Capitan Limestone and adjacent strata has been modified by Lambert (1982) to be consistent with current isotopic data. Lambert concludes:

- o virtually no involvement of the Bell Canyon exists in either groundwater recharge or discharge from the Capitan;
- o the reef shelf system may be divided into various units that can act as either recharge or discharge areas for the Capitan; and
- o the Bell Canyon Formation is not being actively and continuously recharged by any known meteoric or groundwater source in the Delaware Basin as revealed by isotopic data (Lambert 1978).

All current lines of evidence have led Lambert (1982) to conclude that water movement in the Bell Canyon, Castile and Salado Formations in the north central Delaware Basin is either imperceptibly slow or non-existent and that stratabound dissolution in unspecified beds, most likely anhydrite layers, is the most plausible model for efficient removal of evaporites at depth. What to do with the saturated brine of dissolution origin remains a major problem with the stratabound model. This is the same issue on which Anderson's thesis is vulnerable. A plausible water and solute sink needs to be located for salt to be removed.

Dissolution processes described by the Lambert model are not likely to disrupt surface support facilities during operation of the facility, but in time, could increase the permeability of the Magenta and Culebra Dolomite Members within the Rustler Formation as salt is slowly dissolved from the Rustler and the top of the Salado. This could influence the permeability of the Rustler Formation near the upper portions of shafts and borehole seals following backfilling of the repository. Permeability increases within any of the Rustler units will: (a) increase groundwater flow rates, (b) accelerate rates of salt dissolution by a feedback loop mechanism, and (c) reduce the thickness of the protective salt layer above the proposed repository. None of these changes, however, are likely to be significant under present climatic conditions or before TRU wastes decay to acceptable levels.

The formation of a breccia pipe under a repository according to Anderson and Kirkland's (1980) model might have caused serious disruption. The work of Wood et al. (1982), however, greatly restricts the location in the Delaware Basin where breccia-pipe formation might be possible; i.e., above the permeable Capitan Limestone. The distribution of the Capitan Limestone and its southern limits are well known. The northern outer edge of Zone IV is at least 7 miles south of the mapped

southern extension of the reef; hence, there is no chance for a future Capitan Reef breccia pipe to disrupt the repository.

Anderson's (1982a) hypothesis for intraformational removal of salt well within the basin is difficult to test. He concludes that fractured anhydrite beds observed within the Castile Formation are regionally interconnected, and that they serve as aquifers containing actively circulating water that may be quite young and is capable of dissolving significant amounts of salt. Lambert's (1982) stratabound hypothesis is testable, but not enough data have yet been compiled to support a final conclusion. However, the many cores taken from Castile anhydrite beds do not show open fractures and brine except where brine reservoirs have been encountered along anticlinal structures near the Capitan Reef. This suggests that brine reservoirs are genetically related to folding of evaporite beds and derive their built-in and confined pressures from sources other than from existing groundwater recharge areas. Many oil and gas industry wells in the basin have been geophysically logged. These do not show brine saturation within the Castile anhydrite beds nor did they penetrate brine reservoirs. These observations weaken the argument that most oil and gas wells just missed open fractures inferred to be present and widely distributed.

Shut-in pressures measured for brine reservoirs also are high enough to induce artesian flows. If fractured anhydrite reservoirs served as regionally interconnected aquifers within the Delaware Basin, these pressures could not be sustained for prolonged periods of time. This also indicates that overlying salt beds are poorly permeable.

Powers et al. (1978), Register (1981), and others regard the Castile Formation as an aquiclude that isolates poorly permeable Delaware Mountain Group aquifers from overlying Rustler Aquifers and the Salado Formation. Wastes are to be contained in salt beds of the lower Salado Formation, which is located between these aquifers (Figure 1-2). The porosity of Salado halite and the underlying Castile Formation is very low and interconnected pores are virtually non-existent (Register 1981).

Although open fractures are precluded in individual salt beds by the viscoelastic-viscoplastic behavior of salt, small openings containing both brine and gas can exist between grains of halite, and small pockets of brine may be encountered. Fluid inclusions also are present on a much smaller scale. Less common are the larger cavities and pockets containing halite-saturated brine and associated gas which have been encountered in Castile anhydrites. These pressurized brine reservoirs are under enough pressure to displace drilling fluids and brine to surface when encountered during drilling. The quality of record describing these occurrences is variable, especially with respect to brine flow rates and initial downhole pressures (Register 1981). All of the larger occurrences of brine appear to be confined to the Castile Formation, although smaller brine pockets have been encountered in the Salado Formation. Griswold (1980) indicates that no written records are available that describe these Salado encounters; however, from accounts given by miners who have worked the McNutt potash, the pockets have been reported as small and not highly pressurized. Estimated brine volumes in three mines are 720 m^3 (190,000 gal) (PCA mine, 17 miles from the

WIPP site); 9.5 m^3 (2,500 gal) (Duval Nash Draw Mine, 5 miles from the WIPP site); and 57 m^3 (15,000 gal) (Kerr-McGee Mine, 10 miles from the WIPP site), according to the Safety Analysis Report (SAR) (U.S. Department of Energy 1980-1982). When encountered, the Salado pockets are allowed to bleed into the mine until depleted before mining is resumed. Routinely, shallow boreholes are drilled into roof strata in potash mines to explore for and bleed off such fluids under controlled conditions. This same practice will be followed during repository development following initial more elaborate development of test holes drilled in advance of the working face during early stages of repository development. All such fluids are to be removed from the repository (U.S. Department of Energy 1980-1982).

Register (1981) summarizes pressurized brine pocket occurrences in the Castile Formation in the vicinity of the WIPP site (Figure F-1, Table F-1). These pockets, usually associated with hydrogen sulfide gas, have been encountered mainly in the Castile Formation (exploratory holes ERDA-6, AEC-7 and WIPP-12) by various oil and gas drilling companies and Sandia National Laboratories. Register reports that of 62 deep boreholes drilled into the Castile Formation, ten (16 percent) penetrated pressurized brine reservoirs. All brine encounters, except AEC-7 that flowed only one or two liters of brine and hence should be excluded from the list, flowed to the surface with initial rates estimated between 600 and 200,000 barrels per day and initial downhole pressures of from 1,630 to 2,222 psi. Snyder (1982) shows that in each case where stratigraphic data are available, Castile brines issued from the Anhydrite III member, or the uppermost anhydrite in those wells where all anhydrite members are not present. Nine of these ten occurrences were associated with the deformation front abutting the Capitan Reef. Eight of the nine were associated with known anticlinal structures in the Castile Formation. The other occurrence (Belco - Federal) is located about three miles southwest of the WIPP site and is closely associated with an anticline. A much smaller probability of penetrating a pressurized brine reservoir within the Castile Formation is noted if one draws a circle about the WIPP site, with a radius large enough to circumscribe up to 350 deep oil and gas wells and outermost brine reservoirs. In this case, only a 3 percent chance of occurrence is noted (W. D. Weart, Sandia National Laboratories, personal communication to the WIPP Panel 1982).

The deepening of the WIPP-12 borehole to the basal Castile member (Anhydrite I) resulted in the interception of a brine reservoir at a depth of 919 m (3,015 ft) within fractures in Anhydrite III. The shut-in pressure recorded at the well prior to substantial brine removal, was 0.014 N/m^2 (208 psi). On April 15, 1982, the shut-in pressure after brine removal was 0.012 N/m^2 (168 psi) and still rising. For this reason, no final estimate was made on the WIPP-12 reservoir volume by Black et al. (1982). R. S. Popielak, D'Appolonia Consulting Engineers, Inc. (personal communication to WIPP Panel 1982), indicated that the well-head pressure appeared to have stabilized at about 0.012 N/m^2 (170 psi) by May 17, 1982. Preliminary analysis of the WIPP-12 reservoir volume suggests it may have a capacity on the order of 5×10^5 m^3 (3×10^7 bbl), but the well may still be

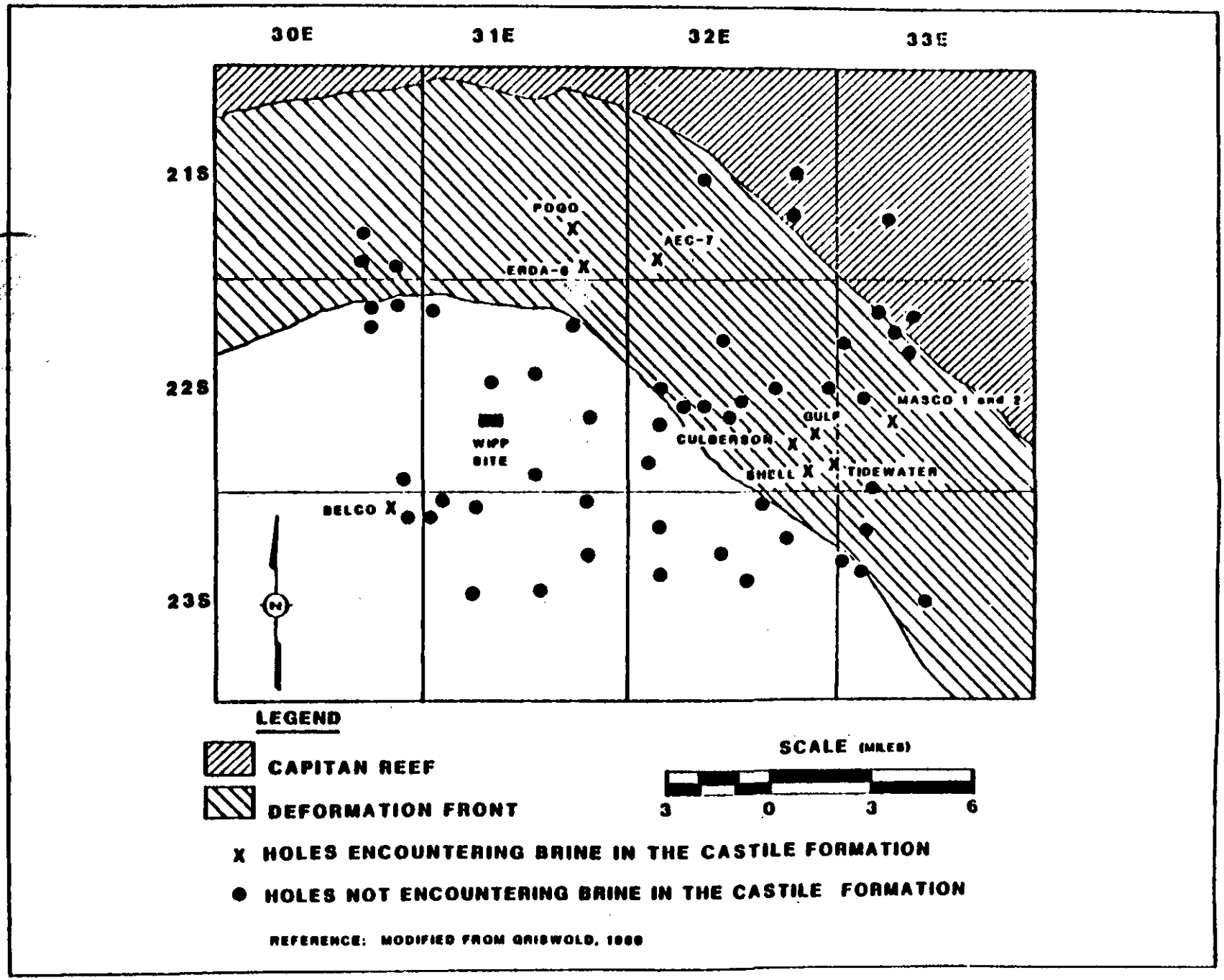

FIGURE F-1 Location map of deep boreholes in WIPP site vicinity. Source: Register (1981).

TABLE F-1 Brine Pocket Data

WELL DESIGNATION (Ground Elev., ft)	LOCATION (Sec. T.R.)	YEAR DRILLED	BRINE DEPTH (ft)	RESERVOIR PRESSURE (psi)	INITIAL FLOW (bbl/day)
ERDA-6 (3,540)	35 21S 31E	1975	2710	1900(2)	660
AEC-7 (3,662)	31 21S 32E	1979	Unknown	No Flow	No Flow
Belco (3,298)	1 23S 30E	1974	2802	2075(3)	12,000
Culbertson-1 (3,727)	26 22S 32E	1945	3515	1860(2)	3,000(4)
Gulf (3,761)	25 22S 32E	1975	3600	2010(3)	5,000(4)
Mascho-1 (3,621)	20 22S 33E	1937	3320	1760(2)	8,000
Mascho-2 (3,618)	20 22S 33E	1938	3240 3298	No Flow 1750(2)	No Flow 3000
Pogo (3,533)	26 21S 31E	1979	3322	2260(3)	1440(5)
Shell (3,775)	36 22S 32E	1964	3671	1950(2)	20,000
Tidewater (3,755)	36 22S 32E	1962	3730	2330(2)	Not Available

(1) Data from oil drilling histories filed with the USGS.
(2) Minimum pressure to displace saturated brine or drilling mud from the well.
(3) Pressure measured at the well head with a full column of mud.
(4) Total volume of brine flow to surface.
(5) Flow during circulation of 14.8 pounds per gallon drilling mud.

SOURCE: Register (1981).

building up pressure; hence, this estimate is regarded as only approximate. Assuming that its storage space is 5×10^5 m^3 (3×10^7 bbl), and using other assumptions that have not been verified, one can estimate a value of 1 km for the approximate radius of this brine reservoir. The WIPP-12 borehole is located on an anticline where the brine occurs 275 m (900 ft) to 290 m (950 ft vertically below and a minimum horizontal distance of 170 m (558 ft) from the proposed waste storage facility. Given the apparent size of this brine reservoir, it is reasonable to assume that a portion of it may underlie a facility oriented northward from the shaft.

What are the potential consequences, if any, of such a brine reservoir to the WIPP facility? This depends upon (1) the chances for brine communication between such reservoirs and the repository during its development; (2) chances for communication following closure and accidental man-made penetrations; and (3) the potential for concentrated, significant, and rapid salt dissolution immediately above such pressurized brine reservoirs that may help expose wastes to a regional groundwater flow system. The only plausible mechanisms for communication between this WIPP-12 Castile brine reservoir and the operating facility would be through (a) the encounter or development of extensive vertical fractures within salt and anhydrite located between the brine reservoir and repository; (b) the existence of unknown, unplugged, or inadequately plugged boreholes; or (c) the development of new fractures by whatever mechanism during repository development. Penetration by drilling would pose the greatest risk following closure and is the only mechanism that appears mechanically possible for breaching deep brine reservoirs in the near geological future.

The viscoelastic-viscoplastic behavior of salt under confining pressures present at repository and greater depths, precludes the presence of open, water-bearing fractures in rock salt. There is no known mechanism that would allow for the development and persistence of rock fractures in the salt beds that could serve to channel brine between the WIPP-12 reservoir and a working repository. The very presence of high pressure brine and gas reservoirs supports strongly the lack of, or extremely limited nature of, vertical or horizontal connectedness.

Estimates of initial downhole pressures for various flowing brine wells range from 1,630 to 2,322 psi. These pressures are insufficient to hydrofracture the nearly 265 m (870 feet) of salt and anhydrite that separate the WIPP-12 brine reservoir from the proposed repository at this depth. This is also true when the repository is under atmospheric conditions during development. For these reasons, WIPP-12 brines should remain confined, even if the repository were to lie directly above the brine reservoir.

No oil and gas wells that penetrate the evaporite sequence are known to exist within Zone III at the WIPP site. The chances of one or more unplugged wells venting these brines into the repository during development are minimal because major test well sites and access roads are hard to obscure in the desert environment. Scars from these activities persist for years and are easy to detect. Further, if

unplugged wells did exist, there should be ample evidence of brine discharges, such as vegetation kills, salt pans, and erosion gullies.

Finally, chances for strata-bound dissolution of salt above the WIPP-12 brine reservoir in Anhydrite III, as suggested by Anderson (1981a), and the breaching of the repository from below are very remote. Castile brine pockets have the highest hydrostatic heads of any groundwaters measured in the region. For this reason, Black et al. (1982) concluded that these pockets cannot receive recharge from other nearby sources. The erratic differences between hydrostatic heads observed within individual brine pockets and their geographic and stratigraphic separation suggest no communication between individual brine pockets. Flow data from the ERDA-6 borehole indicate a finite reservoir. The apparent permanent pressure drop within this brine pocket, associated with a measured amount of discharge, indicates to Black et al. (1982) and others a completely bounded and isolated reservoir that receives no detectable recharge. Further, the lack of a pressure response there during flow testing at the WIPP-12 borehole only four miles away, also indicates that these are isolated brine pockets, despite their large sizes. Erratic head variations noted for Castile brine reservoirs, the unique geochemistry and isotopic content of their fluids, their limited volume estimated from flow test data, and the lack of pressure responses in adjacent wells during flow tests all suggest that brine pockets are not regionally interconnected (Black et al. 1982). These authors also note that brine reservoirs are found only in anticlinal structures, the vast majority of which are closely associated with the Capitan Reef disturbed zone. In all probability these pockets are isolated, and diagenetically-pressurized from lithostatic loads, biogenetic gas generation, and/or reaction of gypsum to anhydrite plus water.

The evidence cited indicates that the chance of significant strata-bound deep dissolution of the Castile and Salado Formations by pressurized brine reservoirs from above or below is small, and that the likelihood of pressurized brines communicating with the repository during its development is minimal.

A more plausible mechanism for nuclide release would be penetration of both the repository and a pressurized brine reservoir by drillholes following closure. This could lead to release of pressurized brine along a drill hole into the repository, and then to the land surface or into one or more Rustler Aquifers.

The consequences of this scenario (Scenario II) were considered by Woolfolk (1982), and were reviewed by the panel. It was assumed that 200 years elapsed before drilling, brine had entered a single room containing backfilled water as a result of the drilling of one well, pressurized brine flowed into the room, and up to 342 cubic feet of contaminated brine was released to the surface. The conclusion was that no significant impact to public health and safety would result (G. L. Hohmann, Westinghouse Electric Corporation, personal communication to the WIPP panel 1982).

It is entirely reasonable that at least some porosity and permeability will persist within backfill and between waste containers for 200 years following closure and that these pore spaces will become

saturated in time. The presence of confined water during the salt creep filling of residual pore space should preclude the complete loss of permeability in backfill materials before 200 years; hence the backfilled repository environment is expected to remain more permeable than the original salt for some years to come. Under lithostatic loading, brine-filled pore spaces should tend to close, thereby reducing permeability, but processes of pressure solution should tend to maintain porosity. The rate at which repository induced porosity and permeability will be reduced following backfilling in the presence or absence of brine cannot be reliably predicted, as selection of backfill materials and methods of emplacement are still under consideration.

REFERENCES

Anderson, R. Y. 1978. Deep Dissolution of Salt, Northern Delaware Basin, New Mexico. Report to Sandia National Laboratories, Albuquerque, N.M.

Anderson, R. Y. 1981a. Progress of Salt Dissolution in the Delaware Basin, Texas and New Mexico. Special Publication No. 8. New Mexico Geological Society.

Anderson, R. Y. 1981b. Deep-seated Salt Dissolution in the Delaware Basin, Texas and New Mexico. Special Publication No. 10. New Mexico Geological Society, pp. 133-145.

Anderson, R. Y. 1982a. Deformation-dissolution potential of bedded salt, WIPP site, New Mexico. 5th International Symposium on the Scientific Basis of Radioactive Waste Management, Berlin, Federal Republic of Germany, June 7-10.

Anderson, R. Y. 1982b. Upper Castile Brine Aquifer, Northern Delaware Basin. Attachment to a May 23 letter to G. Goldstein.

Bachman, G. O. 1974. Geological Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico. OFR 74-194. U.S. Geological Survey, Denver, Colo.

Bachman, G. O. 1980. Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico. OFR 80-1099. U.S. Geological Survey, Denver, Colo.

Black, S. R., W. E. Coons, R. L. Olsen, and R. S. Popielak. 1982. ERDA-6 and WIPP-12 Testing, Interim Data Analysis (April 1982), Waste Isolation Pilot Plant (WIPP). TME 3153. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Christiansen, E. A. 1971. Geology of the Crater Lake collapse structure in southeastern Saskatchewan. Canadian Journal of Earth Sciences 8:1505-1513.

Griswold, G. B. 1980. Presentation reported in Geotechnical Consideration for Radiological Hazard Assessment of WIPP. EEG-6, a report of a meeting held on January 17-18. Environmental Evaluation Group, State of New Mexico, Santa Fe, N.Mex.

Hiss, W. L. 1975. Stratigraphy and Groundwater Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas. Unpublished Ph.D. dissertation. University of Colo.

Jagnow, D. H. 1979. Cavern Development in the Guadalupe Mountains. Cave Research Foundation, P.O. Box 26, Mammoth Cave, Ken.

Lambert, S. J. 1978. Geochemistry of Delaware Basin groundwaters. Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas. Circular 159. New Mexico Bureau of Mines and Mineral Resources. pp. 33-38.

Lambert, S. J. 1982. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. Interim Report, SAND 82-0461. Sandia National Laboratories, Albuquerque, N.Mex.

Lee, W. T. 1925. Erosion by solution and fill (Pecos Valley, New Mexico). Contributions to Geography in the United States. USGS Bulletin 760-C. U.S. Geological Survey, Washington, D.C.

Mercer, J. W., and B. R. Orr. 1979. Review and Analysis of Hydrogeologic Conditions Near the Site of a Potential Nuclear-Waste Repository, Eddy and Lea Counties, New Mexico. OFR 77-123. U.S. Geological Survey, Denver, Colo.

Parizek, R. L. 1979. Recommended Locations for Flood Water Recharge Wells for Cornudas, North, C. and L., and Washburn Draws, Hudspeth County, Texas. Soil Conservation Service, U.S. Department of Agriculture, Fort Worth, Tex.

Powers, D. W., S. J. Lambert, S.-E. Shaffer, L. R. Hill, and W. D. Weart, eds. 1978. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND 78-1596, Vols. I and II. Sandia National Laboratories, Albuquerque, N.Mex.

Register, J. K. 1981. Brine Pocket Occurrences in the Castile Formation, Southeastern New Mexico. TME 3080. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

U.S. Department of Energy. 1980-1982. Waste Isolation Pilot Plant Safety Analysis Report. WIPP SAR. (Includes Amendments 1-4.) Albuquerque Operations Office, N.Mex.

Wood, B.J., R. E. Snow, D. J. Cosler, and S. Haji-Djafari. 1982. Delaware Mountain Group (DMG) Hydrology--Salt Removal Potential. TME-3166. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Woolfolk, S. W. 1982. Radiological Consequences of Brine Release by Human Intrusion into WIPP. TME 3151. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

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REVIEW OF THE SCIENTIFIC AND TECHNICAL CRITERIA FOR THE WASTE ISOLATION PILOT PLANT

DOE/DP/48015-1

Review of the Scientific and Technical Criteria for the Waste Isolation Pilot Plant (WIPP)

Panel on the Waste Isolation Pilot Plant
Board on Radioactive Waste Management
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

NATIONAL ACADEMY PRESS
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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In March 1978 the U.S. Department of Energy (DOE) asked the National Research Council "to review the scientific and technical criteria and guidelines for designing, constructing and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere." The National Research Council assigned the study to the Committee on Radioactive Waste Management under the Commission on Natural Resources (now the Board on Radioactive Waste Management under the Commission on Physical Sciences, Mathematics, and Resources). The committee organized the Panel on the Waste Isolation Pilot Plant to "review the scientific and technical adequacy of the site-suitability criteria; the guidelines for the site confirmation studies; the design criteria for the repository, including the waste acceptance criteria, the design philosophy, and the operational philosophy; the criteria for determining the environmental safety of future planned operations viewed from the perspective of the environmental conditions of the repository site; and the design criteria for the experimental testing program of the behavior of the waste-geologic medium interaction."

In July 1978, when this study began, the Waste Isolation Pilot Plant (WIPP) was to be a mined repository in bedded salt in Eddy County, New Mexico, for the disposal of transuranic (TRU) waste, with experimental facilities for studying the interactions of high-level waste with the host rocks. At that time, use of this repository for disposal of a limited number of commercial spent-fuel elements was also being considered, although this was not part of the project's mission. This option was discussed frequently in technical briefings of the panel and in supporting documentation. The panel has examined some of the generic issues related to this possible course of action, as well as those concerns raised solely by the proposed disposal of transuranic waste in the particular salt formations at the WIPP site; but current plans do not include use of the facility for disposal of commercial waste.

The panel issued an interim report (National Research Council 1983) recounting its findings through the end of July 1982. By that time, several major WIPP program documents had been issued, including the Geological Characterization Report (Powers et al. 1978), the Title I Design Report (Bechtel National, Inc. 1979), the Final Environmental Impact Statement (U.S. Department of Energy 1980), the Safety Analysis Report (U.S. Department of Energy 1980-1983).

The panel's final report evaluates work through December 31, 1983, and is based on analysis of the contents of documents issued to that date, technical briefings, discussions with representatives of DOE and its contractors, comments by interested members of the public, and a number of field visits.

CONCLUSIONS AND RECOMMENDATIONS

The panel has evaluated the scientific and technical adequacy of work being done on the Waste Isolation Pilot Plant (WIPP) project to satisfy the charge to the panel set out in Chapter 1. The panel concluded that the scientific work has been carried out with a high degree of professional competence. The panel notes that the geology revealed by shaft sinking and excavation of drifts and the preliminary measurements generally confirm the geologic expectations derived from surface explorations and boreholes. The purity and volume of the salt, the absence of brine pockets at the repository horizon in the areas excavated, the absence of breccia pipes and of toxic gases, and the nearly horizontal bedding of the salt indicate that a repository can be constructed that will meet the geologic criteria for site selection. Thus, the important issues about the geology at the site have been resolved, but there remain some issues about the hydrology and design of the facility that should be resolved before large-scale transuranic (TRU) waste emplacement begins.

Some engineering aspects of the many WIPP studies by the U.S. Department of Energy (DOE) and its contractors have not yet reached the final stage, so the panel's conclusions on these matters are likewise not final. The final design will need to incorporate the findings of the experimental program and construction activities, or it will have to be shown that findings in the experimental program, if different than predicted (e.g., the larger amounts of water in Marker Bed 193, unexpected rates of closure in the drifts, and the permeability of the backfilled drifts), will not affect the safety of the repository.

The packaging of waste at the originating sites, transport to the site, transport vehicles, and disposal of heat-generating waste are beyond the scope of this study and are not dealt with in this report.

The health and safety consequences of the postulated repository failure mechanisms appear to be so minimal that simplifications in design may be justified, and cost-effectiveness studies should be carried out to determine whether they would be acceptable. However, the probability and the consequences of potentially rapid flow of brine solutions, containing radionuclides, through more permeable formations have not been completely determined. Once these have been resolved, conventional safety considerations (e.g., number of shafts and packaging of waste for highway transport) might determine the optimum design.

Relaxation of the WIPP waste acceptance criteria (e.g., elimination of the incineration of some of the waste at the Process Experimental Pilot Plant (PREPP) facility and removal of the requirement for the use of steel-case overpack of the wooden boxes) may also have minimal consequences.

Although the panel's conclusions and recommendations appear at the end of each chapter, they are collected in this section for the reader's convenience.

CONCLUSIONS

Chapter 2: Site Selection and Characterization

o The presence of hydrocarbon and potash resources at the WIPP site is not a seriously adverse feature, because it should be feasible to recover much of the potash from the former Zone IV and the hydrocarbons from under the entire site by oblique drilling without harm to the repository. The effects of such extraction can be evaluated on a case-by-case basis (p. 11).

o Long-term tectonic quiescence at the WIPP site seems assured by its great distance from faults of recent displacement and areas of volcanic rocks, and by the lack of evidence of major seismic events nearby (p. 11).

o Deformation of evaporite beds at the repository site is slight. The rate of deformation, if any is going on at present, is so small that it should not present a significant risk to the repository (pp. 11, 13).

o Evidence is good that, for a period of more than a million years, karst-forming processes are unlikely to expose the repository (pp. 13-14). Further studies will determine if the karst is likely to affect hydrologic transport in the site area.

o The location of existing "breccia pipes" and of the hydrologic and stratigraphic conditions capable of containing and supporting large solution voids apparently necessary to cause breccia pipe formation indicates that the likelihood of encountering an old pipe or of a new one forming near the WIPP site is practically nonexistent (pp. 14-15; see also Appendix E).

o Evidence seems good that the strata below the salt beds (the Bell Canyon Formation) cannot function as a source or transporting agent for solutions that could form breccia pipes by density flow, nor could they be responsible for extensive interstratal dissolution (pp. 15-17).

o The preponderance of evidence does not support the hypothesis that large-scale interstratal dissolution might endanger a repository at the WIPP site (pp. 16-19).

o The brine reservoirs encountered in the Castile Formation near the WIPP site are isolated pockets of fluid not connected with or residual from solutions that have recently moved, or are moving for long distances through the formation (p. 19). Even if the pressurized-brine reservoir encountered in the WIPP-12 borehole in the Castile Formation were to extend directly beneath the WIPP site, this should not adversely

affect the operating facility, and the existence of this reservoir is insufficient justification to stop the WIPP project.

Chapter 3: In-Situ Tests and Experiments

o The in-situ test program is logically designed to explore the local waste package-repository interactions that would result from the emplacement, retrieval, and long-term isolation of TRU and high-level defense waste in salt beds (pp. 22-30).

o The opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in an underground salt repository at depth, is an important aspect of the WIPP program (p. 29).

Chapter 4: Waste Acceptance Criteria

o The possibility of self-sustaining underground fires can be eliminated by embedding combustible materials in a matrix of noncombustible material in a suitable proportion (p. 34).

o Criteria related to biological gas generation are based on a rather superficial analysis. The extreme nature of the repository environment imposes many conditions that are not adequately taken into account. It is possible that the humidity (water activity) in a sealed repository is low enough to inhibit biological activity (p. 36).

o If the repository should become flooded with brine, the presence of sulfates might entail a new scenario: the biological generation of hydrogen sulfide and chemical dissolution of the steel drums, with generation of hydrogen (p. 37).

o From the viewpoint of the WIPP facility, the quality assurance system is inadequate in that it requires no on-site verification of conformance of package contents to the certification (p. 40).

o The Certification Committee procedure is cumbersome and may even be counterproductive (pp. 39-40).

o The PREPP incineration process appears to be an appropriate and practical technology for processing contact-handled waste that cannot be certified in the original packages (pp. 40-41).

o No procedure has been established for dealing with uncertifiable remotely handled waste (p. 41).

Chapter 5: Design and Construction of Underground Facilities

o The layout of the eight panels of storage rooms separated by barrier pillars is well considered, provided the penetrations of these barriers are sealed adequately (p. 45).

o Details of devices for temporary and permanent closure of the penetrations through the barriers have not been provided (p. 45).

o Recently, the repository design has changed from four to three shafts. Although the three-shaft design appears to be functionally

adequate, it does not possess the flexibility and redundancy of the four-shaft design (p. 49).

Chapter 6: Performance Assessment

o The dosages calculated to be received by humans as a result of normal operations and accidents are within prescribed limits for workers and far below the dosages from normal background radiation for members of the public. There is a great deal of experience in these types of operations, and confidence in the accuracy of the calculations is high (p. 52).

o The long-term release scenarios, shown in Figures 6-1 to 6-5, lack experimental verification. Nevertheless, the scenarios appear to set outside limits to what would be credible releases. Though only a consequence analysis is performed, the resulting dose commitments (50 years) are well within permissible limits for the general population (170 mrem whole body) and far below the dosages from normal background radiation (average over 50 years of 5,000 mrem) (p. 58). Further analyses will be needed to conform to the Environmental Protection Agency (EPA) requirements.

RECOMMENDATIONS

Chapter 2: Site Selection and Characterization

o Each proposal to develop resources in the former Zone IV should be examined rigorously on a case-by-case basis, with the burden of proof as to its safety resting on the proposer. The U.S. Department of Energy should obtain the right to deny mineral extraction from the salt beds and hydrocarbon extraction from deep levels below the salt in the old Zone IV, as well as Zones I, II, and III, during the operational and administrative control period, unless such extraction can be shown to pose no significant threat to the repository (pp. 10-11).

o To test the extent of deep strata-bound dissolution, the plans of Sandia National Laboratories for further field and analytical work should be implemented (pp. 17-18).

Chapter 3: In-Situ Tests and Experiments

o Operational experience with the handling and emplacement of various types of waste package shapes and sizes containing TRU waste at the WIPP site should be obtained in a timely manner so that this experience can be factored into final choices for large-scale disposal of TRU waste (p. 29).

o The later stages of the WIPP R&D program should be kept flexible to accommodate changes suggested by early WIPP results or by progress in waste disposal technology by other organizations. Outside developments in automated sensing, robotics, instrumentation in hostile environments,

and so on, should be systematically screened for application or testing at the WIPP facility (pp. 29-30).

o Active efforts should be made to solicit ideas and participation from the general scientific community. Publishing project R&D results in the refereed literature would encourage such participation (p. 29).

o Separate radiation-monitoring equipment should be installed for the experimental rooms and the TRU waste emplacement areas (p. 29).

o Procedures for handling defense high-level waste in the experimental R&D areas should include special safety precautions, which may not be needed for facility construction or emplacement of TRU waste (p. 30).

o The matrix of tests on waste form, waste package, overpack, and backfill to be investigated at the WIPP facility should be supplemented by aboveground laboratory tests to validate that form of testing so that the matrix of tests can be expanded by the less expensive laboratory experiments rather than by further in-situ testing (p. 30).

Chapter 4: Waste Acceptance Criteria

o As soon as is feasible, standardized waste packages should be adopted in a minimum number of sizes (p. 32).

o The storage of combustible waste should be controlled so that noncombustible material is intermixed with combustible packages in such a way as to render the mixture incapable of self-sustaining combustion in a current of air (p. 34).

o The existing deficiency in the Safety Analysis Report (U.S. Department of Energy 1980-1983) on procedures for fighting transient underground fires should be remedied (p. 34).

o The humidity of still air in equilibrium with the salt and the pH of moisture in contact with the salt at the storage horizon should be measured. These fundamental quantities are significant for the evaluation of biological and chemical degradation processes (p. 36).

o The restrictions on permissible mass of organic material per unit volume of waste should be dropped from the gas generation criterion if measurement shows the relative humidity of a sealed enclosure in the salt at the repository horizon to be 60 percent or less (pp. 35-36, 38).

o If the humidity of the air is higher than 60 percent, a competent biological specialist should be engaged to evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment (pp. 35-36).

o The certification procedures, especially those for inspection of waste packages upon delivery to WIPP, should be redesigned to simulate those used commercially in the purchasing of commodities (p. 39).

o Procedures should be established for dealing with (1) uncertifiable remotely handled waste and (2) high-curie contact-handled waste (pp. 37-38).

o Waste acceptance criteria should be defined for the defense high-level waste that is to be used in the experimental program. The

criteria should be written early enough to allow time for review before experimental operations begin (p. 41).

o Consideration should be given to relaxing the waste acceptance criterion relating to gas generation due to bacterial action (p. 38).

Chapter 5: Design and Construction of Underground Facilities

o Results from the Site and Preliminary Design Validation (SPDV) and in-situ experiments and information gathered during construction and development to final design must be incorporated with the final design of the WIPP repository (p. 44).

o Models should be used to assess whether or not closure of the excavations and consequent encapsulation of the waste in salt are likely to occur, and to determine the period of time within which they may occur (p. 48).

o It should be shown that sealing the repository is sufficient to preclude unacceptable increases in hydraulic conductivity across the repository horizon (p. 48).

o The Final Environmental Impact Statement (U.S. Department of Energy 1980) should be reissued to correspond with the present design (p. 49).

Chapter 6: Performance Assessment

o Though karst-type flow in the strata above the salt beds (the Rustler Formation) is known to occur near Nash Draw several kilometers to the west, the extent to which it reaches eastward is not delineated clearly. If this type of flow should be joined by connected fractures to the WIPP site area, the time of travel of the nuclides and their retardation would be reduced sharply. The probability of such flows, their degree of development east of the Pecos River, and the effect of such flows upon radiation dosages need to be determined (pp. 58-60).

o For consistency, and to permit direct comparison among all the modes of release, it would be useful if all dosages were calculated on the same basis (i.e., if recommendations of ICRP-26 and ICRP-30 were used, rather than those of ICRP-2) (pp. 58-59).

CHAPTER ONE

INTRODUCTION AND BACKGROUND

The history of the Waste Isolation Pilot Plant (WIPP) project was presented to this panel at a study planning session on June 5, 1978. As early as March 1974, the Oak Ridge National Laboratory had begun to look for an underground terminal radioactive waste repository for commercial high-level waste in a region selected by the U.S. Geological Survey (USGS) in the Los Medanos area of New Mexico. In May of that same year, this search was suspended in favor of the concept of retrievable surface storage, and the land-withdrawal action that had been initiated was deferred in December 1974.

The Albuquerque Operations Office of the U.S. Atomic Energy Commission (AEC) and the Sandia National Laboratories were then requested by AEC headquarters to become involved in the program to locate a site for a radioactive waste disposal pilot plant for defense-related transuranic (TRU) waste, with some provisions for experimentation with defense high-level waste. When drilling began in 1975 at a site in the Los Medanos region recommended by Sandia, irregular subsurface geological conditions were found, including high-pressure brines and gases. Consequently, the first site was rejected, and a new one was identified independently by Sandia and USGS 11.2 km to the southwest. The general location of the site and a geologic section through the Los Medanos area are shown in Figures 1-1 and 1-2, respectively. In January 1976 the geological investigations were resumed at the newly proposed site, and the project was given its present name: Waste Isolation Pilot Plant.

The drilling of ERDA-9, the first hole at the new site, commenced in April 1976. In October 1976, funding was requested for an architect-engineer, and a new land-withdrawal notice was placed in the Federal Register in December 1976. In April 1977 a preliminary version of the Draft Environmental Impact Statement was distributed by the U.S. Department of Energy (DOE) for comment, and it was announced that WIPP would be a licensed facility. In June the final version of the conceptual design was issued. In September, Bechtel was selected as the architect-engineer, and in November the DOE sent a letter to the U.S. Nuclear Regulatory Commission saying it intended to request a license.

In February 1978 the "Deutch Report" (U.S. Department of Energy 1978) called for a demonstration of the experimental emplacement of

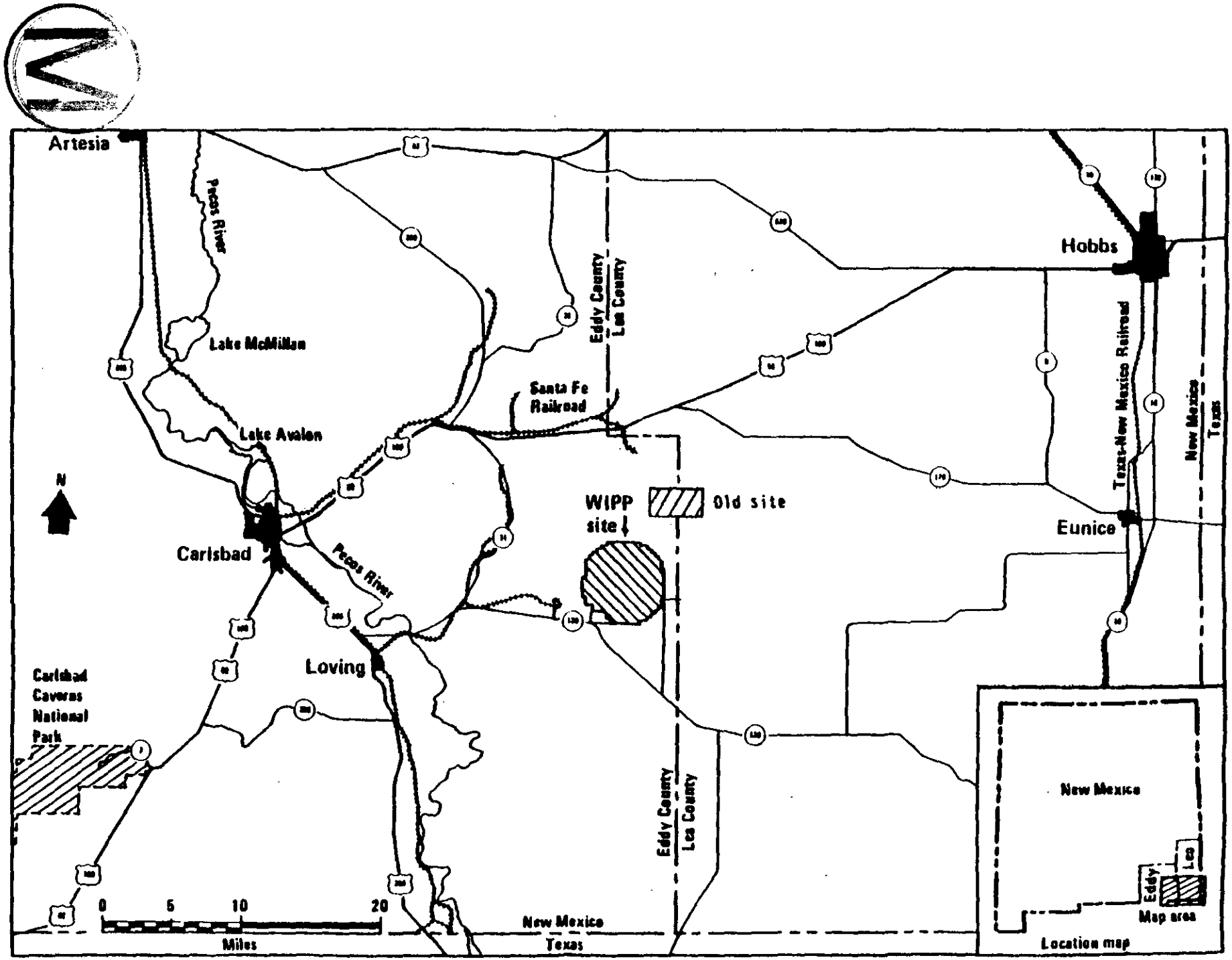

FI( ) 1-1 General location of the WIPP site. Sour) U.S. Department of Energy (1980).

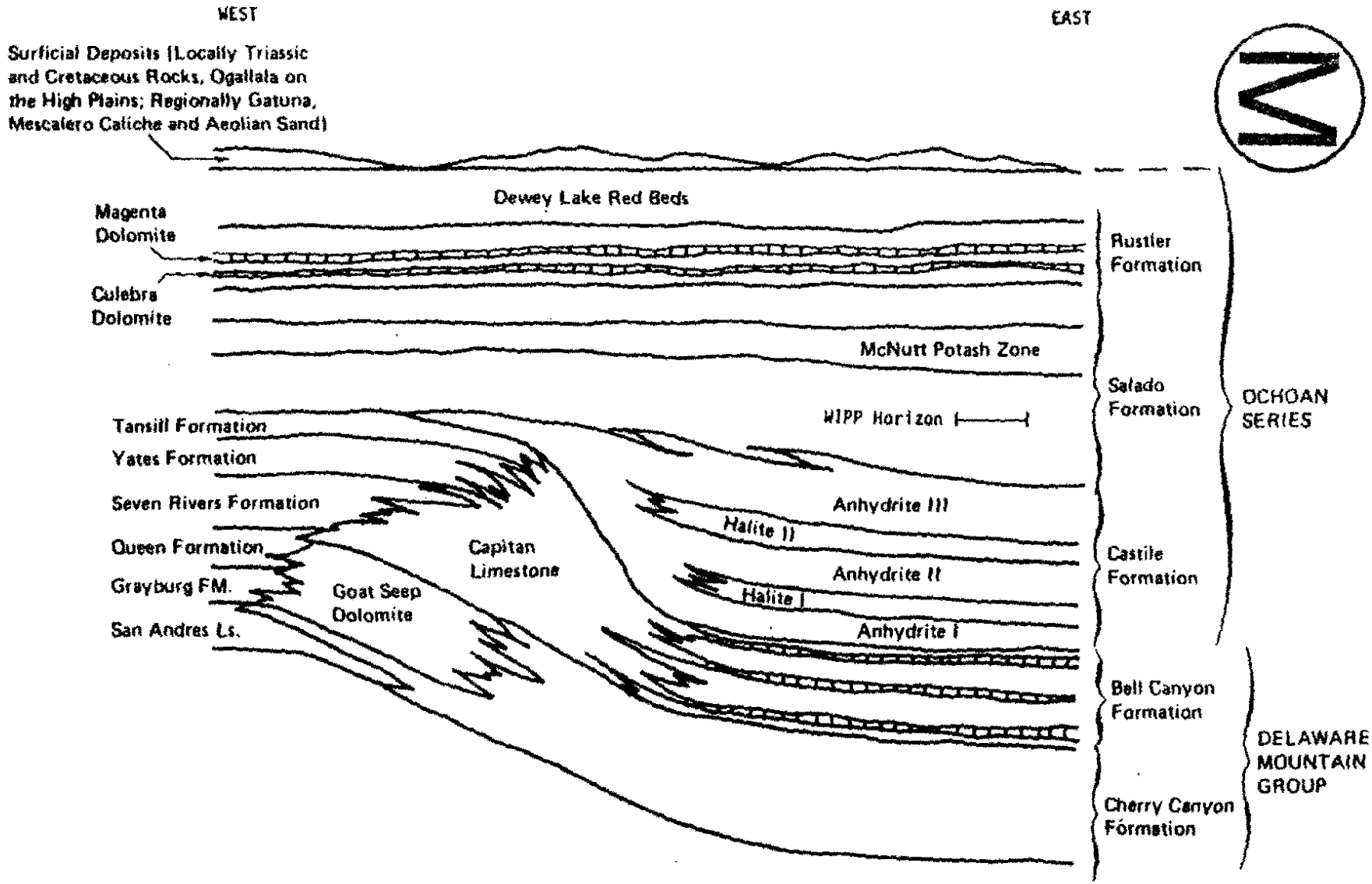

FIGURE 1-2 Diagrammatic section showing stratigraphy of the Delaware Basin. Not to scale. Source: Lambert (1983).

high-level waste and possibly ultimate disposal of commercial spent fuel at the WIPP site. Objections were raised by the Committee on Armed Services of the U.S. House of Representatives, which insisted that the site should be unlicensed and used only for defense waste. This view eventually prevailed.

The Geological Characterization Report (Powers et al. 1978), a compilation of geotechnical information available as of August 1978 and judged to be relevant to WIPP studies, was published in December 1978.

In March 1979 an Interagency Review Group (IRG) appointed by President Carter reported on its review of the progress of the U.S. waste disposal program and suggested four alternative technical strategies, one of which would specify salt as the host geologic medium for the first mined repository (Interagency Review Group 1979). The following month, DOE issued for public comment the WIPP Draft Environmental Impact Statement, or DEIS (U.S. Department of Energy 1979), including consideration of the possibility of disposal of limited quantities of commercial spent fuel.

Public Law 96-164, enacted in December 1979, authorized WIPP as a research and development facility to demonstrate the safe disposal of radioactive waste resulting from the defense activities and programs of the United States exempted from regulation by the U.S. Nuclear Regulatory Commission. Within three months, President Carter announced his intention to recommend cancellation of WIPP and requested rescission of previously appropriated funds. Congress did not act on the rescission request, however, and the project continued, as authorized by PL 96-164.

The WIPP Safety Analysis Report, or SAR (U.S. Department of Energy 1980-1983), was issued in February 1980 and has been updated by amendments in September 1980, January and October 1981, September 1982, and January and March 1983.

In October 1980 DOE issued a Final Environmental Impact Statement, or FEIS (U.S. Department of Energy 1980), which included responses to comments received from the public and from government agencies and which reflected changing policies and legislative requirements. In this document the concept of an intermediate-scale facility for the disposal of spent fuel and the associated two-level underground layout were eliminated from the DEIS. Congressional action eliminated the proposal for licensing of the repository. Now, in view of further changes in WIPP plans as a result of efforts such as the cost reduction proposals mentioned below, this FEIS needs to be updated.

As of this writing, the WIPP repository is intended as an unlicensed facility for the disposal of TRU waste generated in U.S. defense programs and for the experimental emplacement and removal of a small quantity of high-level defense waste. No permanent disposal of high-level waste is planned. TRU waste, it should be noted, differs from high-level waste in that much less heat is generated. Calculations indicate that the maximum temperature rise in the center of the repository will be less than 2°C, a temperature rise that should cause negligible effects of heating the salt beds.

One of the first official acts of the Reagan administration was the January 1981 issuance of a Record of Decision to proceed with the

project; but in April, the State of New Mexico filed suit against DOE to require acquisition of extensive additional technical information and the resolution of a number of controversial issues. Under the resulting Stipulated Agreement, signed in July 1981, a number of technical reports have been prepared by DOE and its contractors and examined by the panel.

In July 1982 DOE proposed simplification and reduction in scope of the WIPP facility and evaluated (U.S. Department of Energy 1982) the environmental consequences that might result from this cost reduction program. These were matters of particular interest to the panel and were the topics of several technical briefings.

A decision to "proceed with full facility construction" was announced by DOE in June 1983, following reports (U.S. Department of Energy 1983a,b) on the results of the recently completed Site and Preliminary Design Validation (SPDV) Program.

Independently of the current DOE-sponsored study by the National Research Council, the State of New Mexico itself has set up four groups concerned with WIPP--an Environmental Evaluation Group (EEG); a Radioactive Waste Consultation Task Force, composed of three members of the governor's cabinet; a Radioactive Materials Committee, composed of eight members of the state legislature; and, until June 1, 1981, a Governor's Advisory Committee on WIPP.

In addition to issuing a number of technical reports, the EEG has organized several conferences and field trips in which panel members have participated.

Waste Isolation Pilot Plant program activities were in progress during the course of this study; thus the panel was evaluating existing data and concepts while new information was being obtained and analyzed. This report is not a summary of WIPP activities, but an analytical commentary on certain aspects of those activities, as specified in the panel's charge stated in the Preface. For completeness, some material has been included that was incorporated originally in three special reports that dealt with site suitability of the proposed site near Carlsbad, New Mexico, from a geological and hydrological standpoint (see Appendix A); the limitations of surface exploration of underground formations (see Appendix B); and continued evaluation of the Carlsbad site (see Appendix C). An interim report (National Research Council 1983) on the first three years of this study has also been drawn upon, as appropriate.

CHAPTER TWO

SITE SELECTION AND CHARACTERIZATION

HISTORY

The criteria that were used in selecting the WIPP site reflect the criteria commonly cited in proposals for waste isolation in bedded salt (National Research Council 1970) and the geological criteria for repositories (National Research Council 1978) and seem technically and scientifically adequate. The recommendations include (1) a bed of rock salt (halite) at least 60 m thick, of purity sufficient to minimize chemical complications from brine of complex composition and from water released from hydrous minerals; (2) a depth greater than 300 m to ensure freedom from surface influences; (3) a depth less than 1,000 m to ensure acceptably low creep rates in the salt; (4) approximate horizontality to minimize difficulty in mining operations; (5) little indication of recent tectonic or igneous activity; (6) sufficient distance from an exposed edge or underground aquifer where salt dissolution is occurring; and (7) an area without a history of resource extraction and lacking sizable economic resources. Although other sites in the United States may also satisfy these criteria, a site in southeastern New Mexico was chosen, as described in Chapter 1.

Two additional criteria specific to the Carlsbad area were suggested by the conclusions of a study (Bradshaw and McClain 1971) at Lyons, Kansas, and by observations at an earlier WIPP site (a site near borehole ERDA-6): The repository should be located at least 1.6 km from the nearest borehole penetrating through the salt beds to avoid possible entry of surface water and at least 8 km from the Capitan Reef to avoid a zone of disturbed bedding known to parallel the reef (the "deformation front" on Figure 2-1).

With these criteria in mind, lines were drawn on a map to outline areas where salt beds of requisite thickness at proper depths were known to occur and to exclude areas within 1.6 km of known deep boreholes, within 8 km of the Capitan Reef, within 1.6 km of the dissolution edge, or with known potash or hydrocarbon resources. Two areas of reasonable size outside these lines were identified (see Figure 2-1). Site 2 had the disadvantages of deeper salt beds and closeness to an oil field where water flooding may be used for secondary recovery in the future. Thus, Site 1 seemed more suitable even though it was closer to the reef

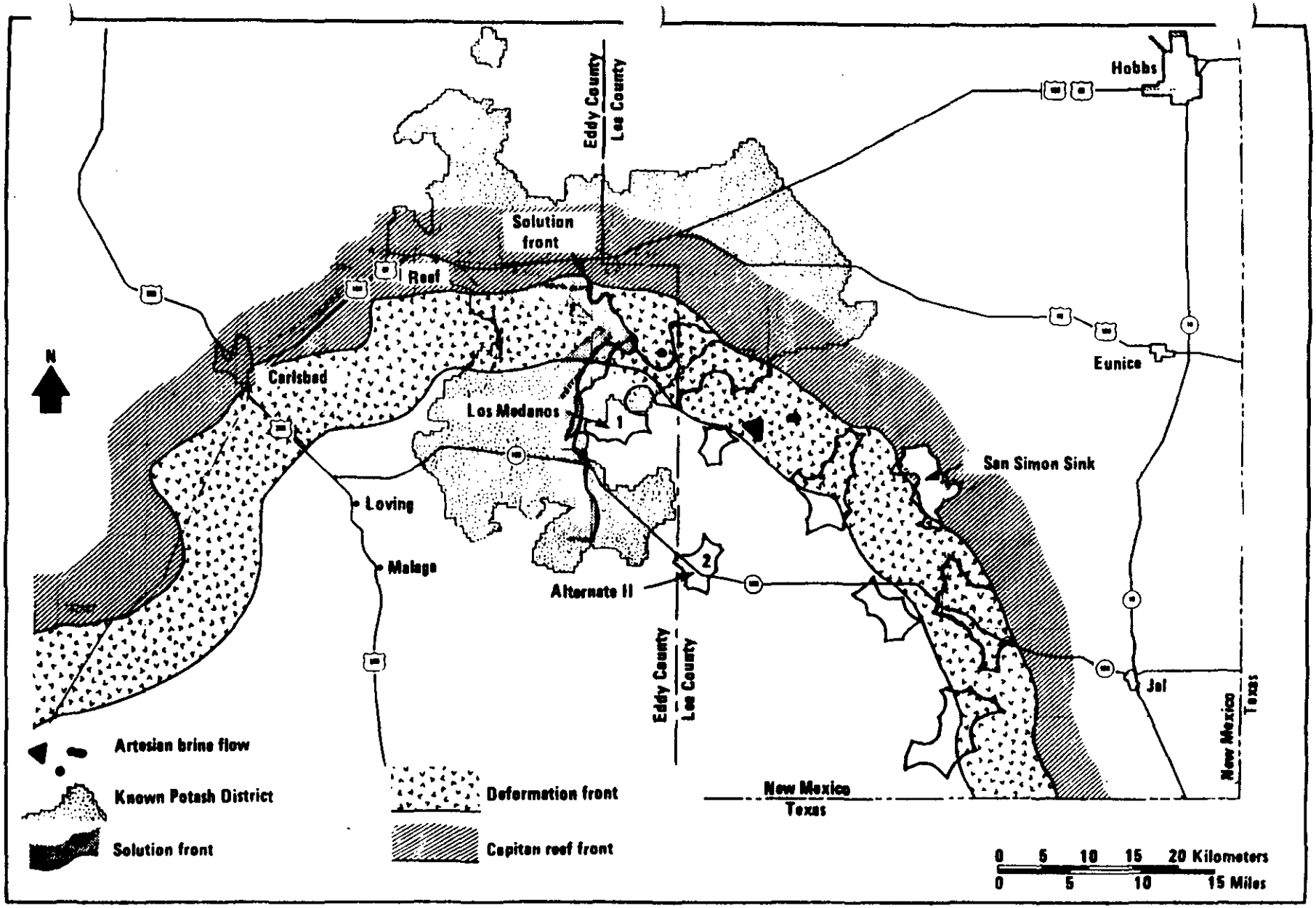

FIGURE 2-1 Application of the site-selection criteria. Source: U.S. Department of Energy (1980).

and the potash zone. The major regional geologic structures in the vicinity are shown in Figure 2-2, and a geologic section in Figure 2-3.

Site 1 was chosen and an exploratory shaft was constructed. The part of the Salado Formation preselected for repository construction was studied and logged in great detail where exposed to view in the shaft. For the shaft station a stratigraphic position was picked in a thick layer of halite containing only minor polyhalite, anhydrite, and a few thin clay seams. This precise position was chosen during a technical discussion among experts from DOE and its principal contractors; personnel of the USGS and EEG were kept informed, and their comments were solicited (Jarolimek and McKinney 1982).

REMAINING UNCERTAINTIES

Although the generic criteria as applied to the WIPP site are in large measure satisfied, questions have been raised about the suitability of the site to satisfy a few of the criteria in detail. Grounds for these questions include (1) the likely presence of economically significant quantities of potash and natural gas at the site; (2) possible tectonic instability of the site; (3) possible continued movement of the kind that produced the distorted structures in the evaporite beds of the "deformation front," ultimately affecting the now undisturbed beds in the middle of the WIPP site; (4) possible disturbance of the site by karst-forming processes; (5) possible local collapse of the salt beds as a result of solutions moving up from aquifers beneath the salt beds, leading to formation of vertical chimneylike masses of breccia (so-called breccia pipes); (6) possible interstratal ("strata-bound") dissolution of salt adjacent to layers of fractured or brecciated anhydrite, especially near the Castile-Salado contact, supposedly rapid during the late Cenozoic and continuing today; and (7) possible presence of pressurized-brine reservoirs.

These objections to the WIPP site have been expressed a number of times over the past several years. Some of the objections have been partially answered by recent work and so have become less serious, but valid questions remain about a few. The following discussion is focused on recent attempts to deal with these remaining questions.

Natural Resources

Further study after the site had been picked showed that probable potash resources, located in a zone 126 m to 240 m above the planned repository horizon, were greater than had been thought originally. The amount of possible hydrocarbon resources in strata below the salt beds was estimated during the study. Because of these resources, the ability of the site to satisfy the criterion relating to natural resource potential seemed dubious, and for a time this question loomed as a major flaw in the case for site suitability. A recent study indicates, however, that most current techniques of mineral exploitation can be safely employed in the outer part of the original site area (the former Zone IV, shown

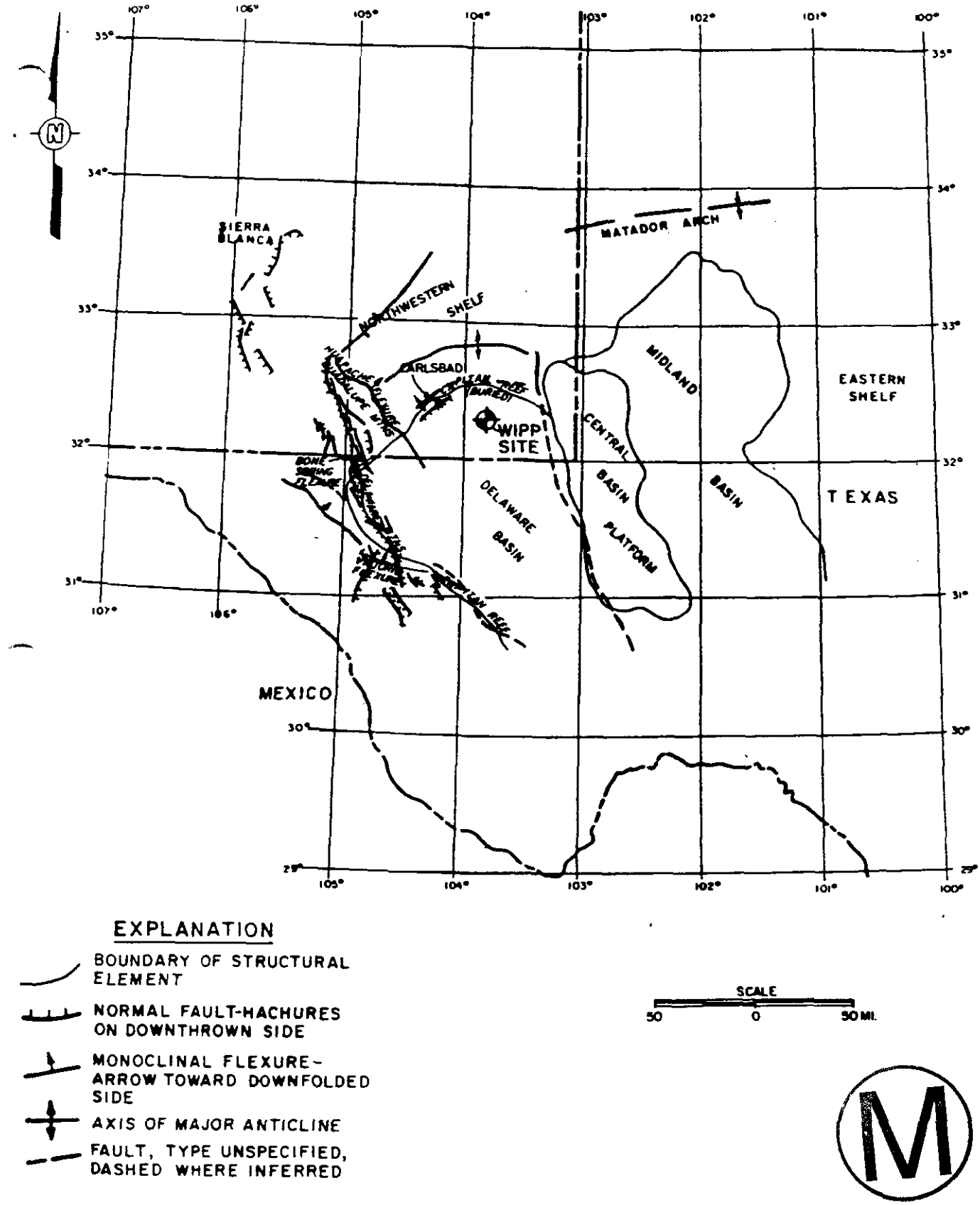

FIGURE 2-2 Major regional structures. Source: After Popielak et al. (1983).

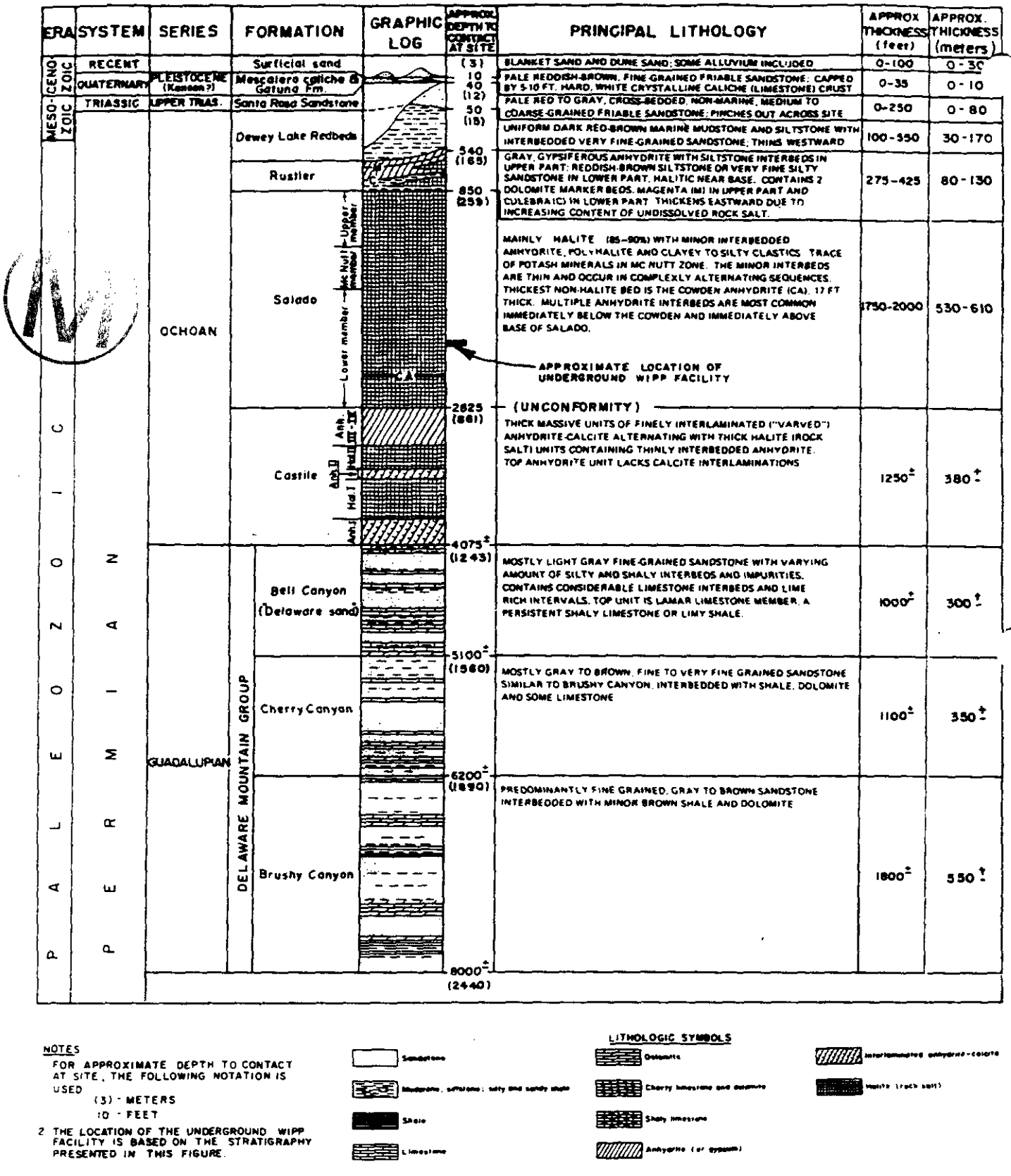

FIGURE 2-3 Geologic section at WIPP site. Source: After Popielak et al. (1983).

in Figure 2-4) (Brausch et al. 1982), so that a large part of the hydrocarbon and potash resources may be recoverable with no hazard to the waste facility. The main concern would be a disruption of water flow in the Rustler Formation, leading to possible reduced travel time to the Pecos River; but the analysis of Brausch et al. (1982) indicates that consequences would not be serious as long as exploitation is confined to Zone IV. The panel accepts this conclusion with the proviso that each proposal to develop the resources should be carefully examined, with the burden of proof as to its safety made the responsibility of the proposer.

More detailed discussion of the value of natural resources and the consequences of mining them is included in Appendix D.

Tectonic Stability

The well-known occurrence of fault displacements and basaltic eruptions during the Quaternary epoch in the Rio Grande Valley 250 km west of the site has been cited as indicating a possible risk of future tectonic disturbance at the waste facility. The risk is not wholly negligible, of course, but in the panel's opinion the long distance from the Rio Grande and from other areas of recent fault displacement, coupled with complete absence of seismic evidence for significant crustal movement and of geologic evidence for recent tectonic disturbance or volcanic activity, has seemed sufficient to assure long-term tectonic quiescence at the site. A seismic network established near the site has recorded nothing but minor tremors, most of them explicable by oil field flooding related to secondary recovery efforts along the Central Basin Platform to the east (Figure 2-2).

The "Deformation Front"

The "deformation front" is an area adjacent to the Capitan Reef in the northern and eastern parts of the Delaware Basin (Figure 2-1) in which evaporite beds are deformed, as shown by borehole data and seismic profiles. The deformed beds are in part strongly tilted, folded, and faulted, and in places show marked increases and decreases of their normal thickness. In general, the intensity of deformation decreases away from the Capitan Reef, and at the distance of the WIPP site is very slight. Deformed rocks at the margin of the disturbed zone have been encountered in boreholes in the northern part of the WIPP area, and stronger deformation is found beyond its borders to the northeast. In addition to the disturbed zone, small isolated areas of somewhat deformed rocks have been noted elsewhere in the basin, but none within 4 km of the WIPP site.

Concern has been expressed about the possibility that deformation may be continuing today and may affect the currently almost undisturbed strata in the middle of the WIPP site at some time in the future. Strong movements in the beds containing a waste facility, it is feared,

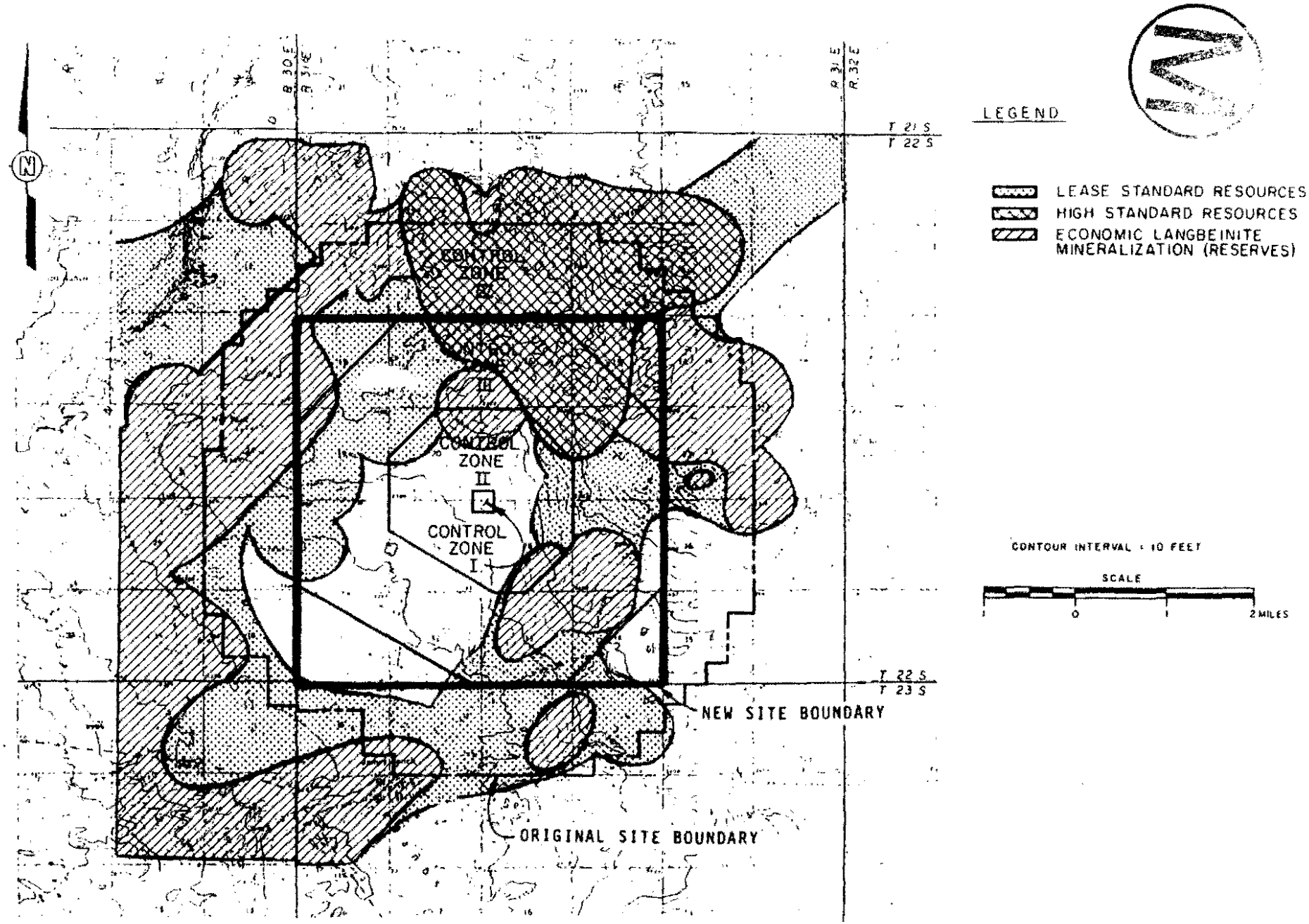

FIGURE 2-4 New control zone boundary and potash deposits at the WIPP site. Source: After Brausch et al (1982).

might disrupt the stored waste and permit entry of solutions that could dissolve and transport some of the radioactive material.

To investigate this possibility, an intensive study of deformation processes in the salt beds was carried out (Borns et al. 1983). The study includes detailed descriptions of the kinds of deformation present, evidence regarding the age of deformation, and discussion of several hypotheses of origin. Although the authors concluded that evidence is insufficient to give a firm date for the time (or times) of deformation episodes or to establish beyond question the mechanism by which the deformation occurred, they noted that by any reasonable hypothesis of origin, the time involved in forming the observed structures is very long, at least many tens of thousands of years. Hence the deformation, even if it is continuing now, would not "present a major hazard to the construction and operational stages of the facility."

Karst-forming Processes

The Los Medanos region, like other areas of the world underlain by soluble rocks, is subject to locally rapid (meaning times of the order of thousands of years) and potentially widespread dissolution wherever undersaturated solutions come in contact with the rocks beneath. Some of the dissolution may be due to water working down from the surface and some to groundwater moving through permeable beds and channels below the surface. As parts of the rock dissolve, overlying material collapses into the open spaces. The result is a distinctive kind of topography called karst, characterized by sinkholes, caves, valleys without stream channels, and underground drainage (Bachman 1980, p. 46)--features prominently displayed in parts of southeastern New Mexico near the WIPP site. Although no karst features have been noted at the site itself, the presence of such features within several kilometers, particularly in Nash Draw (about 10 km west of the site), has led to concern that karst may work its way into the site in the near geologic future and provide pathways for water to reach a subsurface waste facility.

Dissolution is undoubtedly in progress on the buried uptilted edges of the evaporite beds in the western part of the Delaware Basin, and can be expected to work its way slowly eastward. Important questions, then, relate to the rate of present dissolution, the predictability of this rate, and possible future changes in the rate due to climatic change or tectonic disturbance.

The rate of dissolution has been estimated in various ways. In Nash Draw, where geologically recent dissolution has removed much of the Rustler Formation and part of the upper Salado, two Pleistocene formations, the Gatuna and the Mescalero, in part lie undisturbed on an old karst surface and in part have collapsed as a result of continuing dissolution. From these, facts Bachman (1980) concluded that present karst features have formed during and since the deposition of these beds. The older one (Gatuna) can be confidently dated, from potassium-argon dating of an included bed of volcanic ash, as about 600,000 years old. From the thickness of evaporite strata removed since

Gatuna deposition, Bachman derives an average rate of vertical dissolution of 10 cm in 1,000 years. A similar figure has been estimated from the amount of salt currently being dissolved and discharged by streams and springs in the basin (U.S. Department of Energy 1980, p. 7-98). For the rate of advance of horizontal dissolution, Bachman and Johnson (1973) estimated 10 to 13 km per million years, on the assumption that "at the end of Ogallala time the Salado Formation extended to the Capitan Reef on the western edge of the basin." These estimates suggest that a waste facility at the WIPP site should be secure from karst-forming processes for at least a million years.

Implicit in this conclusion is the assumption that the future climate of southeastern New Mexico will be similar to the average climate over the past 600,000 years. During this period in the past, the climate has fluctuated from arid to pluvial, but on the whole has been fairly arid. Average climates in the future probably will not deviate greatly from this pattern (Bachman 1980); nor is it likely, as noted in the previous section, that tectonic movement in the next few hundred thousand years will elevate this region sufficiently to cause a marked change in average rainfall.

The panel recognizes that estimates of dissolution rates and guesses about future climates are based on somewhat slender evidence, but the assumptions involved are reasonably conservative, and the general conclusion that a repository at the WIPP site would not be disturbed by karst-forming processes for a million years or more seems well founded.

Breccia Pipes

The possibility of the formation of vertical pipelike masses of breccia by collapse induced by solutions working their way upward into the repository in the salt beds from aquifers beneath, similar to breccia pipes observed elsewhere in the basin, has been raised repeatedly over the past several years (Anderson and Kirkland 1980, Anderson 1981a,b). An early form of this hypothesis envisioned solutions in the Bell Canyon Formation (of the Delaware Mountain Group below the evaporite beds) as the active agents of dissolution and postulated that the solutions not only formed the collapse pipes, but also worked their way along the Castile-Salado contact, dissolving the lower Salado salt (in which the repository would be sited) as they moved. In other words, a combination of the fifth and sixth uncertainties mentioned previously was proposed--active formation of breccia pipes and widespread dissolution of salt in the lower Salado, in part by solutions rising into the pipes from below.

More recently, the formation of breccia pipes near the waste facility has been shown to be highly improbable (Wood et al. 1982, Lambert 1983), and none has been encountered during SPDV excavation activities. The demonstration that formation of breccia pipes poses no appreciable hazard to the WIPP site depends on a recent theoretical argument and additional field data. Until recently, the formation of breccia pipes has been attributed to a mechanism of "brine density

flow"--the rise of unsaturated solutions into overlying salt beds, the dissolving of salt to form more concentrated and hence more dense solutions, and the descent of these dense solutions to make room for fresh injections of unsaturated fluid (Anderson and Kirkland 1980). On theoretical grounds, this mechanism could produce pipes of collapsed material only if dissolution at the base of the salt section were fairly rapid. With fast-enough dissolving of salt, a cavity or zone of weakness might be produced into which overlying beds would collapse by brittle fracture; but if the dissolving were slow, the salt would gradually subside by plastic flow to form a funnel-shaped volume of somewhat deformed beds rather than a pipe of brecciated salt (Davies 1983c).

Sufficiently rapid dissolution for producing a pipe at the WIPP site could only be caused by fluids in the Bell Canyon Formation, which underlies the salt. Recent data on this formation, however, indicate that it is not a credible source of such fluids. The permeability of this formation is currently in dispute (Davies 1983a, Lambert 1983), but even the higher of the proposed values would supply insufficient water for breccia pipe formation by the brine-density flow mechanism (Neill et al. 1983, p. 8; L. Chaturvedi, New Mexico Environmental Evaluation Group, personal communication, 1983). An additional argument against the efficacy of water from the Bell Canyon Formation has been advanced by Spiegler (1982): using reasonable numbers for the properties of salt and solutions in the Bell Canyon, he calculated that the rate of plastic flow of salt would be on the order of a hundred times its rate of removal by dissolution, so that possible channels leading to breccia pipes could not remain open. Still another argument is the simple fact that the Bell Canyon Formation does not extend under any of the known breccia pipes.

A more likely cause of breccia pipes is sudden collapse into an opening dissolved out of an underlying brittle rock such as limestone. All known pipes in the Los Medanos area have been shown to exist only in places where the salt beds overlie parts of the limestone of the Capitan Reef; and the near certainty that collapse originated in the limestone has been established by deep drilling in one of the pipes that showed breccia persisting downward to the bottom of the drill hole, presumably only a few meters above the reef (Snyder and Gard 1982).

Since the WIPP site is 8 km from the nearest part of the reef, and since solutions in the Bell Canyon Formation are unlikely to cause sudden collapse in the salt itself, the formerly suggested danger of encountering an old pipe at the WIPP site, or of a pipe forming anew under the waste facility, seems remote. More details on breccia pipes are found in Appendix E.

Deep Interstratal Dissolution

Anderson (1982a) has continued to express concern about possible extensive deep interstratal dissolution caused by solutions generated by infiltration of meteoric water, moving long distances through layers of fractured anhydrite near the Castile-Salado contact and dissolving

halite from the beds above and below. The evidence for such dissolution is chiefly the absence of much of the lower Salado salt under the western part of the basin (Anderson et al. 1972, Anderson 1981b, 1982a). The amount of missing salt was estimated by extrapolating salt thicknesses from areas where salt is believed to be intact to areas where salt is thinned or missing. Detailed matching of fine laminations ("varves") in the evaporite sequence, particularly in anhydrite beds, in cores from drill holes at intervals across the site, suggested an assumption that Salado salt was originally deposited throughout the Delaware Basin. The gap in the salt sequence supposedly is due to dissolution; the anhydrite breccias ("dissolution breccias" formed as residues of salt dissolution) in some of the cores from the western half of the basin are cited as further evidence. Some of the surface depressions above the supposed dissolution front, according to this hypothesis, were formed by subsidence due to dissolving out of salt beneath; from the fact that sediments near the surface in these depressions are no older than Pleistocene, Anderson has concluded that rapid dissolution is limited to the past few million years and is probably continuing today. Water for dissolving the salt is assumed to be of meteoric origin (Anderson 1982a). It descends into the upturned salt edge in the western part of the basin, traverses layers of fractured and brecciated anhydrite near the Castile-Salado contact, and leaves the basin through cavities in the buried Capitan Reef on the east side. The brine reservoirs encountered in the ERDA-6 and WIPP-12 drill holes are cited as ponded remnants of the solutions that have moved, or are moving, through the brecciated anhydrite layers.

The validity of this hypothesis is difficult to judge against alternative ideas. Scientists at Sandia National Laboratories have agreed that strata-bound dissolution of the sort described above is possible and may well be responsible for formation of some of the surface depressions in the Los Medanos area (Lambert 1983). They disagreed with regard to the scale and recency of the dissolution process. The earlier hypothesis envisions solutions moving completely through the evaporite basin to the Capitan Reef, concentrated in strata near the Castile-Salado boundary, and active primarily in the last few million years. By contrast, the Sandia scientists considered strata-bound dissolution to be a relatively minor process today and in the recent geologic past; they regarded it rather as a phenomenon that was active adjacent to many anhydrite beds at various times since the Permian, is restricted to the western part of the basin, and is limited in its range by escape of the solutions into various debris-filled depressions. According to the earlier hypothesis, the dissolution is active enough and extensive enough to be a serious threat to a waste facility at the WIPP site; to the Sandia scientists, the interstratal dissolution is simply a minor part of the slow, general dissolution of the evaporite sequence that has gone on intermittently for hundreds of millions of years and poses no appreciable hazard to the proposed facility.

An example of a structure that may have been formed by deep interstratal dissolution has been pointed out by Davies (1983a). This is the so-called FC-92 depression, an area 2 km north of the WIPP site

where geophysical data indicate a pronounced funnel-shaped subsidence depression in Salado beds. The subsidence could be the result of slow dissolution by fluid moving upward from the Bell Canyon Formation or from flow along an anhydrite stratum in either the Castile or lower Salado. Modeling by Sandia scientists (A. Lappin, Sandia National Laboratories, personal communication, 1983) has shown that subsidence due to fluid from the Bell Canyon Formation is unlikely because the amount of subsidence would require greater groundwater flow in the Bell Canyon than can be postulated even with the most generous assumptions about permeability. The origin of the depression remains uncertain: it cannot have formed by dissolution over a period of a few million years by Bell Canyon fluids, but it does provide a possible indication of dissolution by some sort of deep interstratal solution at some time in the past, perhaps by undersaturated brine moving along an anhydrite bed well above the Bell Canyon.

Thus, the question of the extent and timing of deep dissolution is still unsettled. In one hypothesis, dissolution is extensive, largely limited to the last few million years, and probably still active; in the other hypothesis, dissolution is very slow and has been in progress for most of the last 200 million years. In the panel's opinion, the preponderance of evidence favors the second, but the evidence is not conclusive. A choice between the two viewpoints depends on answers to two questions: (1) Can actual movement of large volumes of fluid through anhydrite beds near or below the Castile-Salado contact be demonstrated, either as present-day movement or movement in the recent geologic past? and (2) Is there evidence for major dissolution only in the late Cenozoic, as opposed to dissolution at intervals since the Permian?

Movement of Fluid Through Anhydrite

Brine reservoirs like those encountered in Castile anhydrites in the ERDA-6 and WIPP-12 boreholes were regarded by Anderson (1982b) as prime evidence for his hypothesis. The brine reservoirs, in his view, are isolated pockets containing samples of the solutions that have moved or perhaps are moving through the anhydrite layers. As a source for the dissolution fluids, he has suggested either rainfall in an area of gravels near the west margin of the Delaware Basin (Black River gravels) or water from the Pecos River where it crosses the uptilted Salado-Castile contact; as a sink for the solutions, he proposes the cavernous Capitan Reef limestone on the east and northeast sides of the basin. Lambert (1983) argued, on the other hand, that analysis of the brines in the reservoirs shows that they cannot be the result of simple dissolution of halite, because neither the observed chemical composition nor isotopic composition is compatible with such a process. He pointed out also that fractured anhydrite lacks some expected characteristics of a dissolution breccia (no concentration of residual clay minerals and none of the gypsum that should form if water-filled open spaces develop in anhydrite) and is more likely produced by deformation of the salt beds. The brine reservoirs he regarded as pockets of brecciated

material created by slight movement in the salt layers near the edge of the "disturbed zone" adjoining the Capitan Reef; the brine has accumulated from a variety of sources, perhaps partly from fluids that traveled through once-permeable portions of the Castile and partly by "kneading out" of fluids (Borns et al. 1983) from halite beds during deformation, and remains immobile. The facts that the brine reservoirs have pressures well above hydrostatic, that flow of brine from one reservoir has no effect on nearby reservoirs, and that anhydrite recovered from most boreholes that penetrate this horizon is not fractured and contains no fluids, are good evidence that the reservoirs are not part of a widespread interconnected aquifer, at least not one that contains brine circulating at the present time.

As additional tests of Anderson's views, scientists at Sandia National Laboratories plan two kinds of study: the first making firmer estimates of the amount of salt deposited and removed by comparing in detail drill cores and borehole logs from many parts of the basin, and the second studying in detail the characteristics of residual breccias formed by dissolution in anhydrite beds, to establish criteria for distinguishing such breccias from similar fractured material produced by salt movement.

Dissolution Limited Chiefly to the Quaternary

Some dissolution of salt undoubtedly has taken place at various times since the Permian, but Anderson (1981a,b) has concluded that the major part is geologically recent and hence is probably active at present. This conclusion is based on two kinds of evidence: the supposed recency of the eastward tilting of beds in the Delaware Basin (late Tertiary), which triggered the dissolution, and the supposed lack of sediments older than Pleistocene in depressions whose origin is ascribed to dissolution of the salt beneath. The Sandia workers (D. W. Powers, Sandia National Laboratories, personal communication, 1982; Lambert 1983) have stated that the time of tilting of the evaporite beds is uncertain, but if it is part of the widespread disturbance that formed basin and range structures in the western states, it should be dated as mid-Tertiary rather than late Tertiary. They have pointed out also that little is actually known about the age of deposits in depressions in the Los Medanos area; certainly the depressions southeast of the WIPP site (the so-called Maley-Huffington troughs) contain Pleistocene sediments at the surface, but these sediments may conceal older beds beneath. Information about maximum age of the depression fills might be obtainable from boreholes drilled for this purpose, but datable material is probably so scarce in such sediments that definitive dating might require many boreholes, and it is uncertain whether the expense of such an enterprise would be justified. A clear decision about the timing of most salt dissolution seems impossible on the basis of currently available evidence. Further information on salt dissolution is found in Appendix F.

Because clear evidence for salt removal from the lower Salado is found no closer than 20 to 30 km south of the WIPP site itself, because

evidence for major dissolution in the late Cenozoic rests on the questionable Quaternary age of the entire thickness of sedimentary fill in solution basins, and because the existence of a connection to an adequate sink for postulated dissolution brines of the present day is questionable, the panel doubts that deep dissolution, even if it is occurring as Anderson supposes, is progressing fast enough to jeopardize the integrity of a repository within the next million years.

Pressurized-Brine Reservoirs

Pressurized brine accompanied by carbon dioxide, methane, and hydrogen sulfide has been encountered in several wells penetrating the Castile Formation (Griswold 1980, Popielak et al. 1983). The brine occurs in fractured anhydrite in places where the salt beds are deformed, most of them in the zone of deformation near the Capitan Reef. An especially large brine pocket (estimated brine volume of 2.7×10^6 m^3) was encountered during the deepening of drill hole WIPP-12 in November 1981, only about a mile north of the center of the projected repository site, and this finding has led to concern that (1) the brine in this and other reservoirs may be part of an interconnected flow of brine through the anhydrite layer, and (2) a similar large reservoir may exist at or near the repository site and could cause flooding of the repository.

Investigation of the WIPP-12 occurrence, together with previous studies of other brine pockets, has shown that such concerns are without substance (Popielak et al. 1983). The principal lines of evidence are the following:

- In the Salado Formation, where the repository is to be constructed, no brine pockets have been found except fairly small ones (9.5 to 720 m^3) at low pressures (Griswold 1980).
- The chemical and isotopic composition of brines differs from resevoir to reservoir and is also different from the composition of groundwater in aquifers above and below the salt beds.
- Brine pockets can be emptied by allowing the brine to flow.
- Salt beds are undeformed at the repository site.
- Even if the reservoir found in WIPP-12 should extend under the repository site, or if another reservoir should exist at the site, the anhydrite layer is nearly 250 m below the proposed repository horizon in the Salado Formation.

On the basis of this evidence and observations made as part of the SPDV program, the panel concludes that brine reservoirs do not pose a threat to the integrity of a repository at the selected site.

SUMMARY

The panel believes that sufficient data exist to show that there is little appreciable hazard to a waste facility at the WIPP site from breccia pipes, tectonic disturbance, brine pockets, or extension of the

"disturbed zone." If the hydrocarbon and potash resources at the site prove to be economically worth recovering, with proper limitations much of these resources can be recovered without hazard to the repository. The preponderance of evidence, in the panel's opinion, does not support Anderson's hypothesis of large-scale, recent strata-bound dissolution that might endanger a repository at the WIPP site, but the evidence against the hypothesis is not conclusive. Further evidence is obviously desirable, and the panel endorses the plans of Sandia National Laboratories to obtain firmer estimates of the amounts of salt deposited and removed by comparing drill cores and borehole logs from many parts of the basin, and to seek definitive evidence about water flow and dissolution residues in anhydrite beds.

CONCLUSIONS

o The presence of hydrocarbon and potash resources at the WIPP site is not a seriously adverse feature, because it should be feasible to recover much of the potash from the former Zone IV and the hydrocarbons from under the entire site by oblique drilling without harm to the repository. The effects of such extraction can be evaluated on a case-by-case basis (p. 11).

o Long-term tectonic quiescence at the WIPP site seems assured by its great distance from faults of recent displacement and areas of volcanic rocks, and by the lack of evidence of major seismic events nearby (p. 11).

o Deformation of evaporite beds at the repository site is slight. The rate of deformation, if any is going on at present, is so small that it should not present a significant risk to the repository (pp. 11, 13).

o Evidence is good that, for a period of more than a million years, karst-forming processes are unlikely to expose the repository (pp. 13-14). Further studies will determine if the karst is likely to affect hydrologic transport in the site area.

o The location of existing "breccia pipes" and of the hydrologic and stratigraphic conditions capable of containing and supporting large solution voids apparently necessary to cause breccia pipe formation indicates that the likelihood of encountering an old pipe or of a new one forming near the WIPP site is practically nonexistent (pp. 14-15; see also Appendix E).

o Evidence seems good that the strata below the salt beds (the Bell Canyon Formation) cannot function as a source or transporting agent for solutions that could form breccia pipes by density flow, nor could they be responsible for extensive interstratal dissolution (pp. 15-17).

o The preponderance of evidence does not support the hypothesis that large-scale interstratal dissolution might endanger a repository at the WIPP site (pp. 16-19).

o The brine reservoirs encountered in the Castile Formation near the WIPP site are isolated pockets of fluid not connected with or residual from solutions that have recently moved, or are moving for long distances through the formation (p. 19). Even if the pressurized-brine reservoir encountered in the WIPP-12 borehole in the Castile Formation

were to extend directly beneath the WIPP site, this should not adversely affect the operating facility, and the existence of this reservoir is insufficient justification to stop the WIPP project.

RECOMMENDATIONS

o Each proposal to develop resources in the former Zone IV should be examined rigorously on a case-by-case basis, with the burden of proof as to its safety resting on the proposer. The U.S. Department of Energy should obtain the right to deny mineral extraction from the salt beds and hydrocarbon extraction from deep levels below the salt in the old Zone IV, as well as Zones I, II, and III, during the operational and administrative control period, unless such extraction can be shown to pose no significant threat to the repository (pp. 10-11).

o To test the extent of deep strata-bound dissolution, the plans of Sandia National Laboratories for further field and analytical work should be implemented (pp. 17-18).

CHAPTER THREE

IN-SITU TESTS AND EXPERIMENTS

THE WIPP R&D PROGRAM

The WIPP R&D program seeks answers to questions about repository development and waste package interactions, as shown in Figure 3-1 (Matalucci et al. 1982). This program consists of projects for verification of the various models, laboratory and field testing of components, and in-situ tests with and without radioactive material. The initial phase of the in-situ tests, termed Site and Preliminary Design Validation (SPDV), consisted of establishing baseline values of geomechanical properties in the early excavations (cf. Figure 5-2 for the SPDV area) and preliminary measurements of changes in these properties. As of October 1983, instruments had been installed and measurements had been made in the SPDV. Measurements will continue in the next phase of work, the in-situ experimental program.

A variety of in-situ experiments are planned for the WIPP R&D program (Figure 3-2) extending to the 1990s (Figure 3-3), to be carried out in a special area (Figure 3-4). Although planning for and design of the eventual construction and operation of the WIPP facility for permanent disposal of defense-generated transuranic (TRU) waste is already under way (U.S. Department of Energy 1980-1983) and discussions of its layout are in progress, the WIPP facility design is subject to change, depending on findings from the in-situ tests. Even the total abandonment of the WIPP site would be possible if the findings prove that permanent disposal of TRU waste s not feasible at the WIPP site. The panel regards WIPP facility plan ng and design to be subject to revision in the light of future findings of the WIPP R&D program. Therefore, the panel has directed its attention to the adequacy of the R&D program for providing the information needed to construct and to ensure the safety of the WIPP facility.

THE SPDV PHASE

Two underground shafts were available for in-situ testing in the SPDV program. These shafts, which were sunk in accordance with a previous recommendation by the panel (Appendix B), are 3.7 m and 1.8 m in

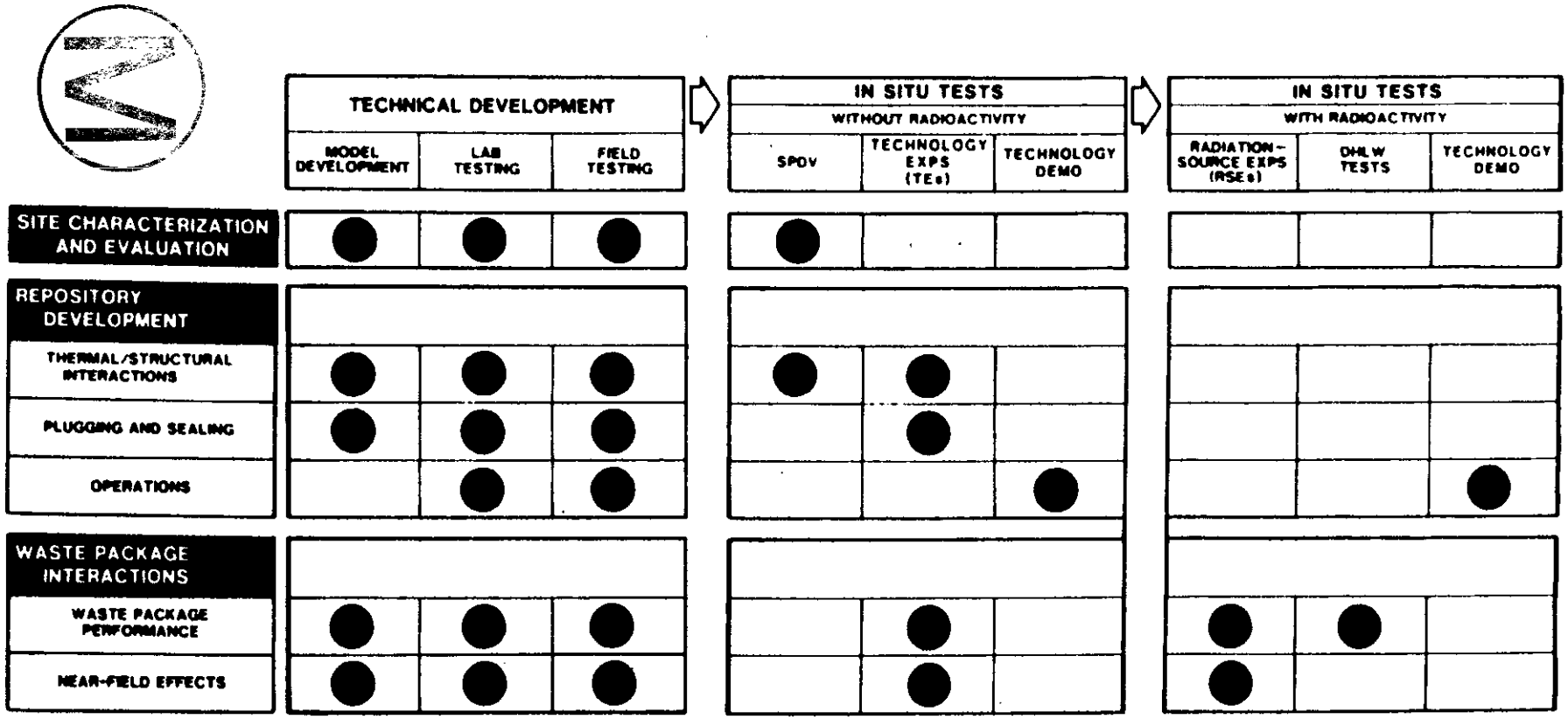

FIGURE 3-1 WIPP R&D program. Source: Matalucci et al. (1982).

	WITHOUT RADIOACTIVITY			WITH RADIOACTIVITY		
	SPDV	TECHNOLOGY EXPERIMENTS	DEMONSTRATIONS	RADIATION-SOURCE EXPERIMENTS (OPTIONAL)	DHLW TESTS	DEMONSTRATIONS
SITE CHARACTERIZATION AND EVALUATION	• SITE VALIDATION INVESTIGATION					
REPOSITORY DEVELOPMENT						
THERMAL/STRUCTURAL INTERACTIONS	• PRELIMINARY DESIGN VALIDATION	• 12 W/m^2 MOCKUP • DHLW OVERTEST • GEOMECHANICAL EVALUATION • HEATED AXISYMMETRIC PILLAR • IN SITU STRESS FIELD • DIRECT SHEAR OF CLAY SEAM				
PLUGGING AND SEALING		• PERMEABILITY MEASUREMENTS • SIZE EFFECTS • PLUG TEST MATRIX				
OPERATIONS			• MOCK DHLW EMPLACEMENT AND RETRIEVAL • MOCK TRU WASTE HANDLING			• SMALL-SCALE TRU WASTE (OPTIONAL) • FULL-SCALE TRU WASTE DISPOSAL • DHLW EMPLACEMENT AND RETRIEVAL
WASTE PACKAGE INTERACTIONS						
WASTE PACKAGE PERFORMANCE		• SIMULATED-WASTE PACKAGE PERFORMANCE • SIMULATED-TRU-WASTE DRUM DURABILITY		• RADIOACTIVE-WASTE PACKAGE PERFORMANCE	• DHLW TESTS	
NEAR-FIELD EFFECTS		• BRINE MIGRATION (THERMAL)		• BRINE MIGRATION (THERMAL AND RADIATION)		

URE 3-2 WIPP in-situ tests. Source: Matalucci et al. (1982).

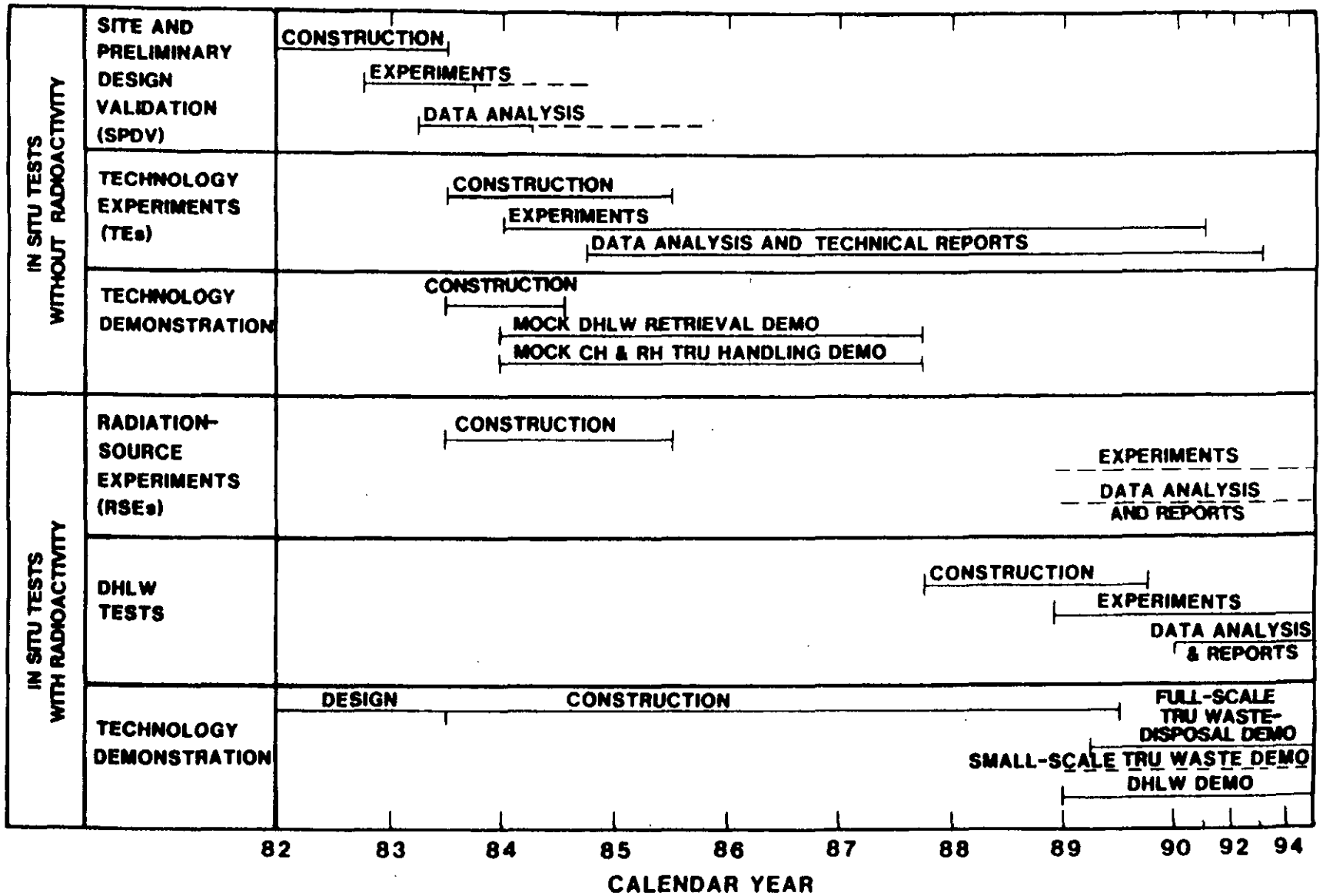

FIGURE 3-3 Schedule for WIPP in-situ tests. Source: Matalucci et al. (1982).

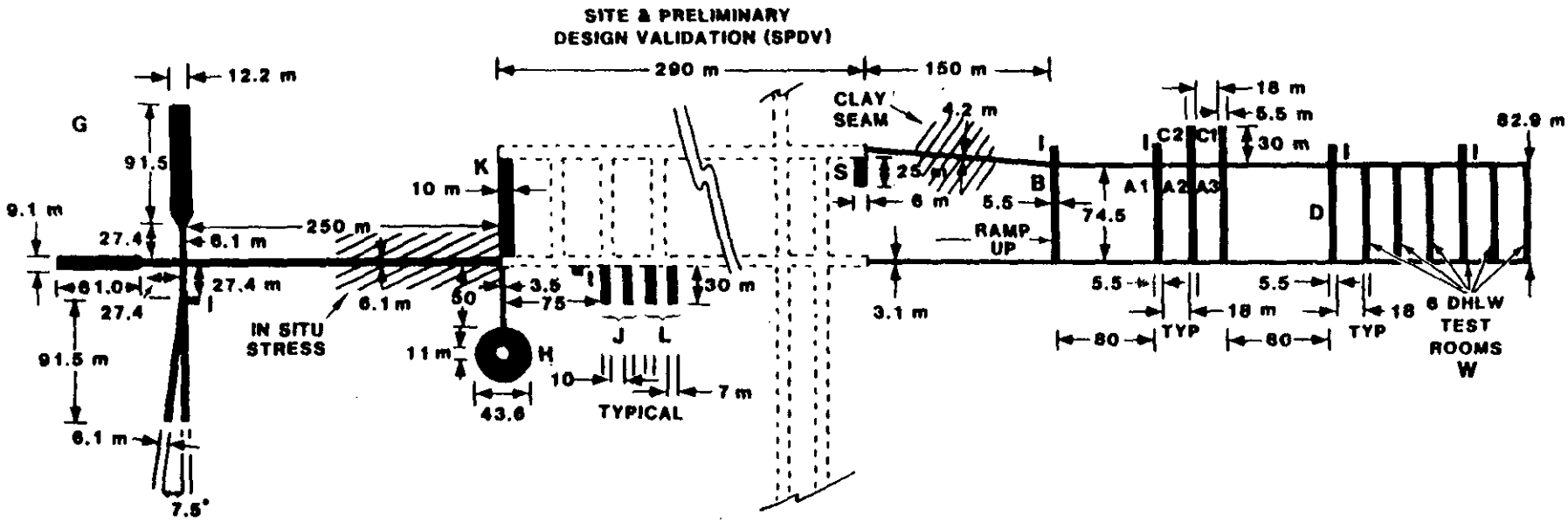

NOTES:

G. THE GEOMECHANICAL EVALUATION TESTS ARE ILLUSTRATED AS ONE TEST CONFIGURATION, BUT THEY CAN BE MODIFIED OR SEGREGATED INTO SEPARATE TESTS AT DIFFERENT LOCATIONS. FINAL CONFIGURATION WILL DEPEND ON FURTHER DESIGN CONSIDERATIONS.

I. INSTRUMENTATION ALCOVES
(5 m WIDE, 10 m LONG, 3.1 m HIGH, TYPICAL)

S. WORKSHOP ALCOVE

(ALL DIMENSIONS IN METRES)

TESTS:

A. 12 W/m^2 MOCKUP
B. DHLW OVERTEST
C. MOCK DHLW EMPLACEMENT/RETRIEVAL DEMO
D. RADIATION-SOURCE EXPERIMENTS
G. GEOMECHANICAL EVALUATION
H. HEATED PILLAR
J. TRU DRUM DURABILITY (CH)
K. MOCK TRU DEMO (CH AND RH)
L. PLUGGING AND SEALING
W. DHLW TESTS

FIGURE 3-4 Layout of WIPP in-situ tests. Source: Matalucci et al. (1982).

diameter, about 700 m and 670 m deep, respectively, and extend more than 411 m into the 610-m-thick Salado Formation (Figure 1-2). The SPDV four-room test panel at the facility depth adjacent to the shafts has been completed.

Because the mechanical properties of the salt are considered by DOE to be important for facility design, geomechanical experiments were given the first priority for in-situ testing and were the only tests planned in the SPDV phase. These experiments consist of convergence and radial-motion measurements of the shafts, determinations of water pressure buildup behind the shaft liner, strain measurements in unlined sections of the shaft, monitoring of shaft-key loading and strain at the contact of the Salado with the overlying Rustler Formation, survey measurements at geometric grid points, and geologic mapping of lithology and structure. Matalucci et al. (1982) expected the SPDV tests to meet the following objectives:

- To validate the design for the WIPP access shafts and TRU waste disposal demonstration rooms.
- To evaluate the amount and rate of shaft convergence and room creep deformation and to correlate these data with model predictions.
- To perform a preliminary evaluation of creep in salt and of the steady-state creep model.
- To evaluate instrumentation systems for accuracy and the reliability of measurements made with them in rock salt and to document the suitability of the systems for future measurements.
- To evaluate the response of lithologic discontinuities such as clay seams and layers of other material in addition to the salt.
- To collect a large number of samples of rock salt and other materials and to conduct laboratory and bench-scale tests to determine the mechanical properties of these samples.

The WIPP design has to provide for long-term repository closure (which may extend beyond 200 years) by plastic flow, and also provide for short-term access (up to 25 years) for waste package emplacement and retrieval. A key problem of the SPDV was to test by very short-term measurement (~9 months) the validity of predictions from the (two-dimensional computer program) model of repository behavior over the long term. The SPDV report (U.S. Department of Energy 1983a, Table II, last row), implies that this is a routine check, with little expectation of surprises. Longer-term observations will be needed to confirm the degree to which the design requirements will be met.

The SPDV objectives that require extended observations have not as yet been fully achieved. Since the SPDV measurement phase will merge into the in-situ testing program, these objectives should be realized later in the program. For example, tests of interaction between waste and surrounding rock will follow the SPDV phase.

The panel regards the results of the SPDV and in-situ experiments as crucial in establishing the performance and safety of the WIPP repository. These results will provide a wealth of data concerning the behavior and properties of salt under repository conditions. The

information could also be of great value in connection with other waste disposal activities.

It is important that effective and timely comparisons be made between theoretical predictions and actual measurements and observations made underground during these experiments, and during continued construction. Such comparisons provide an essential mechanism for developing and helping to validate the theories and understanding of behavior and properties upon which the design of the storage excavations is based. Theory and calculational methods used to predict the results of the experiments, and refined in the light of results from those experiments, provide an important basis for the qualitative and quantitative evaluation of the design of the storage area. It is important that the design of the storage area reflect the knowledge gained as a result of the experiments.

The principal purpose of the SPDV program was to verify whether or not the WIPP site is suitable for a waste repository. Geological and geophysical investigations from the surface, supplemented by drilling, had indicated that the Salado Formation and the adjacent strata would be a suitable host for a waste repository. However, surface exploration is necessarily limited in the extent to which it can resolve all factors of concern in the design and construction of a repository, especially where those factors involve details such as the stratigraphy within the Salado. It was, therefore, necessary to confirm the major characteristics of the site inferred from surface exploration by direct observation and measurement in underground excavations, as well as to resolve by underground experiments and observations many structural details and other factors affecting the design and ability to construct a repository.

IN-SITU TESTING PLAN

Bedded salt is a prime candidate to be the geologic medium for the emplacement of high-level radioactive waste, both civilian and military. The main information currently available on such emplacement comes from Project Salt Vault, a program conducted from 1965 to 1967 by the Oak Ridge National Laboratory using canister and instrumentation technology of the time in a salt mine. The WIPP facility offers an opportunity for professionally executed emplacement experiments, using present waste form concepts and equipment, in an actual repository operation. This will be possible years before any comparable repository is available. Results of experiments with high-level waste in WIPP can bring useful experience to the design of future repositories. Consequently, the opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in a real underground salt repository at depth, is an important aspect of the WIPP program.

Plans have been formulated and reported by Likar (1979) and Matalucci et al. (1982) for an R&D program that includes emplacement and retrieval of contact-handled TRU waste, remotely handled TRU waste, and

defense high-level waste (DHLW); the investigation of interactive effects of heat- and radiation-generating waste packages with a salt repository; and the investigation of repository backfilling, plugging, and sealing. The program (see Figure 3-2 and Figure 3-3) began in 1983 and is scheduled to continue through the life of the facility. The test sequence begins with thermal-structural interactions to verify the ability of structural models to predict long-term repository response, and (assuming these results are positive) continues in stages to demonstration of DHLW retrieval from corroded and failed waste packages. Obviously, the earlier experiments are better defined than the later, which will allow for incorporation of the results from the early WIPP experiments and the ongoing parallel experimental programs into the plans for the later WIPP experiments. This is appropriate because, although the general philosophy appears to be that the experiments are "verifications" of present concepts and models, surprises almost certainly will be encountered, and new concepts and models relating to waste forms, waste package materials, design, dimensions, and heat outputs will evolve over the next decade.

The value of the experiments would be enhanced greatly by prompt publication of their results in scientific and technical journals in order to facilitate their consideration by the scientific and engineering community rather than only by those individuals involved directly with the WIPP project. To take maximum advantage of progress in waste disposal technology worldwide, the periodic revisions of the experimental program should be preceded by deliberate solicitation of ideas for experiments, instrumentation, and equipment from outside the DOE (cf. National Research Council 1979).

At present, WIPP is designed to accommodate a considerable variety of waste packages. While operational smoothness would benefit from fewer and better-characterized packages and waste forms, the small-scale mock contact-handled (CH) and remotely handled (RH) TRU waste-handling demonstrations in the experimental program (cf. Figures 3-2 and 3-3) should take advantage of the present lack of uniformity to make an operational input into the recommendations for size, shape, weight, and other criteria for the waste packages that will be used on a large scale.

Plans for the aboveground facilities and the number of shafts have recently been changed to reduce facility cost substantially, but at the expense of the rate of waste emplacement and of operational flexibility (see Chapter 5 for further discussion of these changes). The plant electrical system has lost some redundancy, which means that the electrical supply system for the experimental program cannot be relied on for those experiments and systems that demand an uninterrupted power supply (such as the brine migration experiments). The alternative facility orientation that has been chosen extends the storage area to the south of the present shafts instead of to the north, and would isolate the experimental area by 823 m from the storage area and from continuing construction and storage activities. This benefits both the experimental and the storage activities in a number of ways, including reduced chance of interference and continued availability. To complete the separation of experiments from construction and emplacement, it would be desirable to have separate radiation-monitoring facilities.

The WIPP FEIS and SAR (through Amendment 6) recognize that accidents associated with the experiments with DHLW constitute the largest risk of environmental contamination, of plant contamination, and of operator exposure. Complete procedures for carrying out these important experiments have not yet been written (nor is it reasonable to do so before more operational experience with less hazardous experiments has been gained). Previous hazard analyses contemplated no changes in the standard ventilation precautions, i.e., high-efficiency particulate air (HEPA) filters normally off-line, and cut in on detection of radioactivity in the vent stream. However, special precautions, such as putting the HEPA filters on line in advance of the experiment, might be considered as part of the operational procedures for experiments involving the handling of degraded DHLW canisters. The special ventilation requirements of the room experiments on brine corrosion, if a significant hydrogen sulfide content is introduced with the brine, also need to be developed.

The demonstration emplacement and retrieval activities will reveal any weaknesses (such as excessive time for operations) in the storage concepts (e.g., the sidewall emplacement of remotely handled TRU waste) or in the equipment procured to implement them, and deserve sufficient priority to allow alterations in advance of large-scale waste emplacement operations in the storage area. Remarkable progress is expected in the next half-dozen years in such areas as automated sensing devices, robotics, remote imaging, and instrumentation and control for hostile environments. These developments should be continually screened for application to waste isolation by testing in the WIPP R&D program.

Accelerated tests, such as room closure measurements with a heat source four times reference design conditions and experiments with higher-than-expected radiation levels, tackle the difficult problem of investigating long-term effects within the lifetime of one generation of experimenters. Overall, the approach is reasonable. Extrapolations from these experiments would be more convincing with practicable three-dimensional models and improved computer programs. One can reasonably expect to have these with the next generation or so of computers.

Since the number of experiments that can be undertaken in the WIPP project itself is finite, the number of variables that can be dealt with in the many combinations of waste package, canister overpack, backfill, or plugs and seals is limited. The usefulness of the WIPP tests could be improved by concentrating on the comparisons of in-situ tests with smaller-scale laboratory experiments. Laboratory tests paralleling the WIPP in-situ tests would reveal the differences, if any, between results of the two types of tests. This would serve to validate the cheaper and more convenient aboveground tests, thus improving the eventual rate of development of new materials. In general, inaugurating the WIPP in-situ testing program does not decrease the importance of the laboratory and field research programs that have contributed greatly to the choice of materials for the WIPP project.

CONCLUSIONS

o The in-situ test program is logically designed to explore the local waste package-repository interactions that would result from the emplacement, retrieval, and long-term isolation of TRU and high-level defense waste in salt beds (pp. 22-30).

o The opportunity to carry out R&D on emplacement and retrieval of a variety of waste forms, particularly high-level waste, in an underground salt repository at depth, is an important aspect of the WIPP program (p. 29).

RECOMMENDATIONS

o Operational experience with the handling and emplacement of various types of waste package shapes and sizes containing TRU waste at the WIPP site should be obtained in a timely manner so that this experience can be factored into final choices for large-scale disposal of TRU waste (p. 20).

o The later stages of the WIPP R&D program should be kept flexible to accommodate changes suggested by early WIPP results or by progress in waste disposal technology by other organizations. Outside developments in automated sensing, robotics, instrumentation in hostile environments, and so on, should be systematically screened for application or testing at the WIPP facility (pp. 29-30).

o Active efforts should be made to solicit ideas and participation from the general scientific community. Publishing project R&D results in the refereed literature would encourage such participation (p. 29).

o Separate radiation-monitoring equipment should be installed for the experimental rooms and the TRU waste emplacement areas (p. 29).

o Procedures for handling defense high-level waste in the experimental R&D areas should include special safety precautions, which may not be needed for facility construction or emplacement of TRU waste (p. 30).

o The matrix of tests on waste form, waste package, overpack, and backfill to be investigated at the WIPP facility should be supplemented by aboveground laboratory tests to validate that form of testing so that the matrix of tests can be expanded by the less expensive laboratory experiments rather than by further in-situ testing (p. 30).

CHAPTER FOUR

WASTE ACCEPTANCE CRITERIA

The definitive statement of the TRU waste acceptance criteria for the WIPP project is contained in WIPP-DOE-069 (U.S. Department of Energy 1981). A summary of these criteria appears in Table 4-1.

The waste acceptance criteria are for the most part quite straightforward. They are concerned with establishing standards on dimensions, weight, radiation levels, and the like, such that operational difficulties and health hazards at the WIPP site will be minimized when waste emplacement actually begins. The criteria permit a surprisingly wide variety of containers and waste forms, but this reflects the practical consideration that existing stored waste is heterogeneous in terms of composition, physical state, and package configuration.

Evidently, the philosophy has been adopted that minor inconveniences at the WIPP site are less consequential than the major ones that would occur at the various storage sites if highly restrictive criteria were adopted. These inconveniences are acceptable on an interim basis, but it should be a stated objective of the lead management organization of the defense TRU waste program to work as rapidly as possible toward standardized packaging of fully characterized and thoroughly stabilized waste.

The most debatable of the criteria are those related to the inclusion of organic materials in the waste. The presence of substantial amounts of such materials raises questions about combustibility in the short term and about gas generation, complexation, and possibly accelerated radionuclide transport in the long term.

FIRE

Underground fires, as is well known from coal mining experience, are particularly difficult to control. In practice, it has proved to be very difficult to extinguish such fires because underground combustion sites are so well insulated thermally.

Fire prevention and control will, of course, be easier in a salt repository than in a coal mine. For fire safety, however, the waste disposal configuration should be such that a fire would self-extinguish without any control measures whatever.

TABLE 4-1 Waste Acceptance Criteria for Contact-Handled and Remotely Handled TRU Waste

Criterion	Contact-Handled TRU Waste	Remotely Handled TRU Waste
	WASTE FORM	
Combustibility	No limit, must be packaged in steel containers or overpacked in steel. Packages containing over 25 volume percent combustibles shall be color coded.	Noncombustible containers
Gas generation	Gas generation by all mechanisms must not exceed 10 moles/m^3 of disposal-room volume per year under repository conditions. In terms of waste composition, this criterion may be interpreted to mean that the average organic content of contact-handled TRU waste may not exceed 14 lb/ft^3 for waste in 55-gallon drums and 6 lb/ft^3 for waste in other containers.	No criterion; quantities are insignificant
Immobilization	Powders, ashes, etc., must be bound in glass, concrete, ceramic, or other approved matrix if over 1 percent by weight of fines less than 10μ, or 15 percent less than 200μ.	Same as for contact-handled TRU waste
Explosives and compressed gases	None, as defined by 49 CFR 173, Subparts C and G.	Same as for contact-handled TRU waste
Pyrophorics	Small quantities (up to 1 percent of the waste by weight) of radionuclide-metal pyrophorics may be accepted with other waste forms if they are dispersed throughout the waste. Larger quantities must be processed to remove their hazardous properties.	Same as for contact-handled TRU waste
Toxic and corrosive materials	Toxic materials allowed only with special authorization and precautions; corrosive materials must be neutralized or otherwise rendered noncorrosive.	Same as for contact-handled TRU waste
Sludges and free liquids	Sludges shall be packaged in such a way that internal corrosion protection is provided for the waste container.	Same as for contact-handled TRU waste
	CONTAINER	
Structure	Type A requirements, noncombustible, with 15-year design life after emplacement, to allow retrievability. If visibly bulged or damaged, must be overpacked.	Same as for contact-handled TRU waste
Handling	Devices to allow handling by a forklift, etc.; no interference with stackability.	Axial lifting pintle only
Weight	No more than 25,000 lb.	No more than 7,000 lb.
Dimensions	Not larger than 8 by 12 by 8.5 ft.	24-in diameter, 10-ft length
Surface-dose rate	Not exceeding 200 mrem/h at any point. Containers with a surface-dose rate in excess of 10 mrem/h must be color coded.	Less than 100 rem/h
Surface contamination	Not more than 50 pCi/100 cm^2 for alpha, and 450 pCi/100 cm^2 for beta-gamma emitters.	Same as for contact-handled TRU waste
Criticality	30-gal drum, 100 g fissile; 55-gal drum, 200 g fissile; DOT 7 a package, 350 g fissile; other boxes less than 5 g in any cubic foot.	No more than 5 g/ft^3, unless specifically authorized by WIPP
Thermal power	Container must be color coded if the thermal power exceeds 0.1 W/ft^3.	No more than 300 watts per package.
Labeling	In addition to other requirements: a package identification number, and weight in kilograms.	Identification number only

SOURCE: After U.S. Department of Energy (1981).

A self-extinguishing configuration can be provided by stacking of the waste packages in such a way that combustible and noncombustible materials are intermixed as intimately as package configurations permit, in a proportion such that the heat liberated by oxidation of the combustible component is sufficiently dissipated to prevent the temperature of the mixture from reaching the ignition point of the organic materials. A conservative a priori calculation of sufficient accuracy should be quite simple, given the data on maximum organic content of each package that is part of the waste certification documentation. Naturally, the backfill salt is important as a noncombustible component in this calculation.

A self-extinguishing configuration does not, of course, eliminate the possibility of transient underground fires arising from transporter accidents, electrical faults, or welding that may involve one or more waste packages. The provision for handling such situations has not yet been specified (U.S. Department of Energy 1980-1983). This must not be overlooked as the operational period approaches. In particular, in the case of fire it is recommended that the flow of ventilation air not be interrupted, so that the flow of heat and fumes will be away from personnel and into the waste stack, where combustion will soon self-extinguish. It is also recommended that major reliance be placed on small, portable, fire extinguishers kept in the operational areas, rather than on large, centralized fire equipment.

GAS GENERATION

Pure polycrystalline halite, well consolidated, is nearly impermeable to fluids. This is one of the properties that first drew attention to bedded salt as a desirable medium for the storage of nuclear waste. However, given the fact that organic waste will almost certainly generate a certain amount of gas, it becomes necessary to examine the possibility that a sealed repository might self-pressurize to a degree that would be dangerous. A reasonable choice for the danger point is a gas pressure equal to the lithostatic pressure at the repository depth. For WIPP, this is approximately 150 atmospheres (15 MPa).

Machine computations have been made of predicted gas pressure, with time and permeability as parameters. The added effect of salt flow was considered in some cases, but the model on which specifications were based was a rigid void of the intended drift dimensions, filled to 75 percent with incompressible material. Gas was dissipated by porous-medium flow in two dimensions (U.S. Department of Energy 1981, Sandia National Laboratories 1979).

A crude estimate of the anticipated gas generation rate was made in the same documents, as follows: A reference 210-liter waste drum was defined to contain 60 kg of organic waste, of which 20.5 kg was polyethylene and the remainder other plastics and cellulose. A total gas generation potential of 5,600 mol per drum was projected by assuming that through some combination of processes, all the organic material could be converted to gas. For example, it was assumed that each methane subunit of polyethylene could be converted to 1 mole of hydrogen

and 1 mole of carbon oxides. In recognition of the certainty that conversion would not be complete, the practical gas production potential was arbitrarily scaled down to 2,000 mol per standard drum. Using the assumption that the gas generation period is 400 years, a mean gas generation rate of 5 mol per drum per year was indicated.

This gas generation rate, combined with a permeability of 0.1 microdarcy, was computed to give a peak (not steady-state) pressure somewhat less than that of the overburden in 400 years. Gas permeabilities measured in Salado boreholes gave somewhat variable results of the order of 10 microdarcies. It was concluded that a gas generation rate of 5 mol/yr per drum is acceptable. In the panel's opinion, the safety factor of 100 is adequate to allow for the evident uncertainty in the actual effective value of the permeability. The higher permeability figures from the field are in fact likely to be more realistic, because the bedding-plane seams of clay and anhydrite are likely to be major contributors to in-situ permeability.

The gas generation limit in terms of disposal-room volume (10 mol/m^3) was derived from consideration of the repository space allotted to each drum. This same limit, restated in terms of organic waste per unit of package volume, is lower for boxes because they pack more densely than do drums.

Another estimate of the probable gas generation rate was made by totaling the contributions of four processes: radiolysis, thermal degradation, bacterial degradation, and chemical corrosion. Production of helium by alpha decay was found to be negligible. After an extensive program of literature study and experimental work, a "most probable overall average" gas generation rate for existing Idaho National Engineering Laboratory (INEL) TRU waste was estimated to be 0.3 to 1.4 mol/yr per drum, with 0.0005 mol/yr as the lower limit, and 2.8 as the upper limit (Molecke 1979).

Thus, the crude a priori estimate and the experimentally grounded estimate give comparable results, and the gas generation rate in both cases is comfortably within the limit determined by the pressurization criterion.

The panel thinks that the "most probable" gas generation estimate is probably too high. It has been reported (Sandia National Laboratories 1979) that the process making the major contribution to gas generation is bacterial attack on organic materials contained in the waste. However, the experiments upon which this conclusion was based did not address adequately a basic question: Is the repository humidity* high enough to support active microbial metabolism after exhaustion of the moisture in the drums? Microorganisms are critically sensitive to ambient humidity because of their high surface-to-volume ratio. Most species require a humidity of 90 percent or higher for growth (inactive spores may of course survive at low humidity for long periods). A

*Relative humidity of the repository atmosphere at equilibrium with the host rock. This is a measure of the thermodynamic activity of water in the microbial environment.

literature survey (Horowitz 1979) found no confirmed reports of growth at humidity below 60 percent.

Air in contact with saturated sodium chloride brine has a humidity of 70 to 75 percent. If calcium and magnesium chlorides are present as grain-boundary phases in Salado salt, their saturated aqueous phases could maintain the humidity of a sealed repository as low as 20 percent. Now that the SPDV program has made the Salado directly accessible, measurements of humidity should be made in a freshly excavated still-air cavity.

Even without measurements, the existence of low humidity, coupled with a large water-absorption capacity at the storage horizon, may be inferred on thermodynamic grounds. The anhydrous calcium sulfate (anhydrite) that occurs plentifully in seams throughout the Salado would have become hemihydrite or gypsum had the thermodynamic activity of water been high enough. Dissociation pressures of calcium sulfate hydrates and other salt phases taken from the chemical literature should set an upper limit for the humidity of the repository after sealing.

The desiccating effect of the salt will not, of course, immediately penetrate to the interior of sealed drums, but the appropriate time scale on which to evaluate the "breathing" of drums may be centuries. During such a lengthy time period, a drum sealed in the conventional manner with an elastomeric gasket can be expected to lose most of its initial water content. Internal corrosion and eventual crushing by drift closure will tend to hasten the release of water.

The experimental work reported by Sandia National Laboratories (1979) may not have considered the general principle that metabolic activity is poisoned by the accumulation of metabolic products. This will tend to limit the pressure generated by any gaseous metabolic product. The study failed to observe methanogenesis, which indicates that anaerobic conditions were not fully achieved in the experiments.

Questions about the availability of adequate supplies of phosphorus and fixed nitrogen were handled by making the conservative arbitrary assumption that these are not limiting factors.

The discussion of microbial gas generation in DOE's TRU waste acceptance criteria (U.S. Department of Energy 1981) makes no mention of the possible role of the sulfates that are present in the Salado salt. It is known that methanogenesis does not normally occur in the presence of sulfates (Weiss et al. 1982). Hydrogen sulfide, carbon dioxide, and hydrogen are produced instead. The role of sulfates will not be significant unless the repository becomes flooded; otherwise there is no mechanism for bringing sulfates into intimate contact with the organic substrates. However, should flooding occur, a worst-case scenario is conceivable in which the gases generated by ordinary microbial action are augmented by hydrogen sulfide, and the pressure of the acidic gases, carbon dioxide and hydrogen sulfide, builds to the point that the brine dissolves the steel of the drums and of the box overpacks. This will generate up to 430 mol of additional hydrogen per drum. The corrosion of steel by pressurized brines containing acidic-gas solutes is well known from oil field experience (Shock 1953).

The biochemical situation is obviously very complex, but our knowledge of life in extreme environments can probably serve as a basis

for reliable predictions. The probability of flooding of the repository following decommissioning is likely to be quite small for a long but undefined period because salt has such low permeability. However, it is the opinion of the panel that the potential for flooding merits further study, because some geologists believe that void spaces in salt repositories will eventually fill with brine. Water may flow along shaft backfills, along sheaths of damaged rock located immediately adjacent to shafts and drill holes, above rooms and tunnels, and through clay and anhydrite interbeds and salt. Salt may be capable of transporting brine from adjacent sources, especially if confining beds are adversely disturbed by repository development.

RADIOLYSIS

Radiolysis is also discussed in the references already cited. Because of the low level of radioactivity in typical TRU waste, even the remotely handled TRU waste, the rate of radiolytic gas generation is considered to be a small fraction of that assumed for microbial action. The panel accepts the position that radiolytic gas generation can be neglected from the standpoint of repository pressurization.

There is, however, an interesting special case of radiolytic gas generation. New Mexico's Environmental Evaluation Group (EEG) called attention to this in EEG-24 (Neill and Channell 1983). The Savannah River Plant and Los Alamos National Laboratory produce substantial amounts of waste contaminated with plutonium-238 as a by-product of the fabrication of nuclear heat sources. Because of the relatively short half-life of this isotope, a drum of such waste may be quite high in alpha activity. It has been estimated that 700 to 1,000 drums of currently stored waste contain more than 100 Ci per drum. Many (perhaps most) of these drums contain cellulosics and polyethylene. It is known from laboratory studies (Bibler 1976) that hydrogen and carbon dioxide, with traces of carbon monoxide and methane, are produced by alpha radiolysis of these materials. The G value (molecules of gas produced by absorption of 100 eV of radiant energy) is dependent on both dose and dose rate, but an appropriate figure is 1.9. Thus, a drum containing 100 Ci of plutonium-238 would be expected to produce 0.055 mol/d of a mixture of hydrogen and carbon dioxide. The proportion of the two gases depends on the substrate. Polyethylene yields nearly pure hydrogen, but cellulosics yield about 0.7 mol of carbon dioxide per mole of hydrogen.

Pressurization of drums from radiolysis has been found not to be a problem because the standard elastomeric seal ring is not entirely leak-tight. Furthermore, hydrogen diffuses especially rapidly through elastomers.

Bibler (1976) has observed that the oxygen initially present in the container is essentially all consumed by reaction with carbonaceous material before significant accumulation of hydrogen occurs, regardless of the nature of the organic substrate. This means that the generation of an explosive mixture within a waste drum is unlikely except for special circumstances such as the "breathing" of a drum during temperature or altitude changes. Field reports of the occurrence of

explosive mixtures (Ryan 1982) are to be ascribed to this, and to contamination of samples by air.

The term "explosive mixture" gives an erroneous impression of the hazard associated with mixtures of hydrogen and oxygen that are extensively diluted with nitrogen and carbon dioxide and that occupy the interstices of a container filled with solid waste. Even if a source of ignition is present, the inert gases and solid waste cool and slow the flame front so that the resulting pressure transient is very gentle. After the reaction, the pressure in the drum will fall below ambient because a small volume of liquid water replaces a larger volume of hydrogen and oxygen.

A potentially serious situation might develop if a transport container (TRUPACT) were entirely filled with high-curie waste drums, each drum exhaling a gas mixture rich in hydrogen. The TRUPACT is vented, but not ventilated; so given time, an explosive mixture might develop (NRC regulations do not permit such venting). Obviously, it will be prudent to set a reasonable limit on the number of high-curie packages that may be shipped in a single TRUPACT when and if it is decided that high-curie drums will be sent to WIPP.

In view of the minor importance of gas generation for projected TRU waste, consideration should be given to relaxing the waste acceptance criterion relating to gas generation, particularly if the humidity in the repository proves to be less than 60 percent. Nevertheless, the emplacement density of organic materials should be limited to conform with the criterion of self-extinguishment stated above. Rough calculations indicate that the restriction on organic material imposed by this requirement is easily met.

COMPLEXATION

Many documents, including the SAR (U.S. Department of Energy 1980-1983), examine the consequences of scenarios in which the Salado salt containment is breached. Radionuclides then move upward into the aquifers of the Rustler Formation and thence by hydrologic flow to the surface at Malaga Bend or elsewhere. Sorption by the clays and dolomites of the aquifers has been experimentally shown to be very strong for plutonium and its daughters, which leads to a significant retardation of the transport of those species with respect to the groundwater flow. Complexation of the actinides by organic materials included with or derived from the organic component of the waste will interfere with the sorption process and shorten transport time accordingly.

A sensitivity analysis of the consequences of the reduction of K_d, the distribution coefficient, by complexation is reported in SAND 79-1305 (Sandia National Laboratories 1979), and a similar analysis appears in EEG-8 (Wofsy 1980). Both analyses conclude that even complete elimination of the sorption effect would not increase the dose commitment to the maximally exposed individual to parity with the dose received from natural sources, owing to the long travel time for the water.

The FEIS does not mention complexation as a factor in the establishment of waste acceptance criteria. Within the limits of the particular scenarios considered in the FEIS, the omission probably is justifiable. In other possible scenarios, where flow occurs through fracture systems, or in the extreme case through karst, both travel time and solution-soil contact would be drastically reduced. Sorption would then become a matter for more careful evaluation. The possibility of fracture flow is discussed briefly at the close of Chapter 6.

CERTIFICATION

The best possible set of waste acceptance criteria is of doubtful effect unless compliance is continually and systematically verified. Misgivings on this point have been expressed by the New Mexico EEG and by this panel. Recent briefings and recently released documents (U.S. Department of Energy 1982; Whitty et al. 1982) are making it clearer how compliance can be assured.

A particularly important part of the certification strategy, and one that this panel supports, is the policy of beginning certification with newly generated waste. This postpones the serious problem of determining exactly what is contained within old packages that have inadequate documentation. Certification will not begin at any waste-generating site until appropriate procedures have been developed, facilities built, and personnel trained, all of which are easier with newly generated waste.

At an October 1983 briefing, the panel was given an outline of the review process that is to occur before certification begins at any waste shipment site. Each of the 10 sites is to design a Certification Plan and submit it to the five-member Waste Acceptance Criteria Certification Committee. This committee has authority to require an iterative reworking of each plan.

Next, the New Mexico EEG is given an opportunity to comment, which may lead to further iterations. Finally, if the WIPP Project Office finds the plan acceptable, the shipper is notified and waste certification may begin at that site, subject to periodic quality assurance audits.

This procedure is obviously quite cumbersome. Rocky Flats, the first site to submit a plan in December 1981, was in its sixth iteration in October 1983. Final approval is projected for 1984.

The panel believes that much of this red tape and delay could be eliminated by following the procedures universally and successfully used by major purchasers of commodity items in the world of commerce. A specification is published and suppliers ship only goods that they believe will meet the specification. Compliance with the specification is verified by the purchaser at the location where the goods are delivered. Off-specification goods are returned or accepted with an appropriate penalty to the supplier.

The elaborate Certification Committee procedure was apparently conceived in an effort to forestall any possibility of the arrival at

WIPP of goods (waste packages) that do not meet the specifications (the waste acceptance criteria). Yet, WIPP does not (and cannot) rely entirely on prior certification. The WIPP Project Office, in fact, plans to have at the receiving building the equipment necessary for making a thorough final inspection of at least a sample of the waste packages as they are delivered. It is, therefore, not clear what is accomplished by the lengthy iterative procedure. The procedure will, in fact, be counterproductive if it tempts WIPP to place complete reliance on inspections carried out before shipment at a remote site. Centuries of commercial experience have taught that inspection of goods on delivery is the only reliable way to ensure quality.

After all newly generated waste has been certified, it will be necessary to deal with stored waste. That of recent origin--since 1970, approximately--is stored retrievably and is comparatively well documented. Waste in this category that is stored at Idaho National Engineering Laboratory (INEL) will be processed along with newly generated waste. Stored waste from other sites will be processed later, with technology developed at INEL in the Stored Waste Examination Pilot Plant (SWEPP) and Process Experimental Pilot Plant (PREPP) programs. Technology for preparation and transportation of remotely handled TRU waste is also to be developed in this second phase.

The purpose of SWEPP is to effect a separation of the stored waste packages into two groups: (1) those that can be immediately certified and (2) those that cannot. For certification purposes, the waste acceptance criteria have been elaborated as "Compliance Requirements" in the WIPP/DOE-137 report (Rockwell International 1982). This document addresses the rather troublesome question of how to treat those packages that may be certifiable, but are not adequately documented as to contents.

Apparently it is intended that undocumented packages not be opened: "nondestructive examination" will be undertaken. The techniques to be used are not adequately described, and indeed are evidently still under development. Briefing has revealed that visual inspection will be supplemented by ultrasonic determination of metal thickness where corrosion is suspected, neutron assay for fissionable-isotope content, and "real-time radiography" for internal examination.

It is anticipated that as much as 30 percent of the waste will have to be classified as uncertifiable for one reason or another. Such packages will be transferred to the PREPP. A test unit was constructed in 1982, and the operating principles were adequately demonstrated in tests on simulated waste in September of that year. The plant includes an impact mill that is capable of coarsely shredding both metal drums and wooden boxes. The product is fed to a gas-fired incinerator. The resulting ash is screened. The coarse residues are loaded into steel drums and "potted" in a hydraulic cement that includes the fine fraction as part of the aggregate.

The panel has not had an opportunity to inspect the PREPP, but it is reassuring to learn that the incineration process is much like that which is used routinely in the disposal of municipal waste. The more elegant but less familiar concept of fusing the ash into a slag has been abandoned as impractical.

The panel has not received any safety analysis of the PREPP operation, but standard techniques should be sufficient for protection of operators and the environment, particularly if only contact-handled waste is to be processed. There is apparently no intention to use the PREPP technique with remotely handled waste.

A certification procedure cannot be truly meaningful unless a practical alternative exists for handling waste that fails to meet the criteria. The pyrolysis option, or possibly others, should be pursued vigorously for this purpose.

DEFENSE HIGH-LEVEL WASTE

The WIPP mission includes a program of experiments with retrievably emplaced, high-level waste, presumably solidified in glass and contained in metal canisters. No criteria have been written for this class of waste, even though the experimental area has been laid out and tentative plans for experiments have been formulated. These criteria should be prepared well in advance of need.

CONCLUSIONS

- The possibility of self-sustaining underground fires can be eliminated by embedding combustible materials in a matrix of noncombustible material in a suitable proportion (p. 34).
- Criteria related to biological gas generation are based on a rather superficial analysis. The extreme nature of the repository environment imposes many conditions that are not adequately taken into account. It is possible that the humidity (water activity) in a sealed repository is low enough to inhibit biological activity (p. 36).
- If the repository should become flooded with brine, the presence of sulfates might entail a new scenario: the biplogical generation of hydrogen sulfide and chemical dissolution of the steel drums, with generation of hydrogen (p. 37).
- From the viewpoint of the WIPP facility, the quality assurance system is inadequate in that it requires no on-site verification of conformance of package contents to the certification (p. 40).
- The Certification Committee procedure is cumbersome and may even be counterproductive (pp. 39-40).
- The PREPP incineration process appears to be an appropriate and practical technology for processing contact-handled waste that cannot be certified in the original packages (pp. 40-41).
- No procedure has been established for dealing with uncertifiable remotely handled waste (p. 41).

RECOMMENDATIONS

- As soon as is feasible, standardized waste packages should be adopted in a minimum number of sizes (p. 32).

o The storage of combustible waste should be controlled so that noncombustible material is intermixed with combustible packages in such a way as to render the mixture incapable of self-sustaining combustion in a current of air (p. 34).

o The existing deficiency in the Safety Analysis Report (U.S. Department of Energy 1980-1983) on procedures for fighting transient underground fires should be remedied (p. 34).

o The humidity of still air in equilibrium with the salt and the pH of moisture in contact with the salt at the storage horizon should be measured. These fundamental quantities are significant for the evaluation of biological and chemical degradation processes (p. 36).

o The restrictions on permissible mass of organic material per unit volume of waste should be dropped from the gas generation criterion if measurement shows the relative humidity of a sealed enclosure in the salt at the repository horizon to be 60 percent or less (pp. 35-36, 38).

o If the humidity of the air is higher than 60 percent, a competent biological specialist should be engaged to evaluate the metabolic prospects for particular classes of microorganisms that might contribute to gas generation in the expected repository environment (pp. 35-36).

o The certification procedures, especially those for inspection of waste packages upon delivery to WIPP, should be redesigned to simulate those used commercially in the purchasing of commodities (p. 39).

o Procedures should be established for dealing with (1) uncertifiable remotely handled waste, and (2) high-curie contact-handled waste (pp. 37-38).

o Waste acceptance criteria should be defined for the defense high-level waste that is to be used in the experimental program. The criteria should be written early enough to allow time for review before experimental operations begin (p. 41).

o Consideration should be given to relaxing the waste acceptance criterion relating to gas generation due to bacterial action (p. 38).

CHAPTER FIVE

DESIGN AND CONSTRUCTION OF UNDERGROUND FACILITIES

Plans for the WIPP design, construction, and operation have changed continuously, and further changes can and should be expected. Flexible planning enables changes to be made to the design, construction, and operation of the proposed facility in the light of new information that emerges from the WIPP program and from other relevant programs. One important result of such changes has been to improve confidence in the predicted performance and safety of the facility. In this respect, explicit arrangements should be made to utilize the results from the in-situ tests in the final design and performance assessment of the repository. Another important result has been to effect economies in the design of the proposed facility. However, great care must be taken to ensure that such economies do not impair the performance and safety of the facility.

Although collection and analysis of data from the Site and Preliminary Design Validation (SPDV) program are not yet complete, the data that have become available as a result of sinking two shafts, driving drifts to the north and south edges of the repository, and excavating of the four test rooms, have provided important and necessary verification of the suitability of the WIPP site as a host for a repository and of the constructability of a repository at this site.

Both the exploratory and the ventilation shafts were sunk by large-diameter drilling. This has not only proved the practicability of construction, but has also provided essential verification and further detail of the lithologic and petrologic succession. The exploratory shaft has a steel lining that terminates in a concrete key at a depth of 268 m below surface, that is, at the contact between the Rustler and Salado formations. Accordingly, detailed inspection of the strata penetrated by this shaft could be made only below this depth. However, the ventilation shaft is lined to a much shallower depth, and this has permitted direct evaluation and logging of the beds from a depth of 30 m to about 660 m below surface. The horizontal persistence of the strata and lithology to the north and south edges of the repository area has been checked by logging at elevations from about 15 m above the repository horizon to about 15 m below it and by correlations established in the horizontal drifts and core holes drilled from them. This information has allowed a selection to be made of the best depth below surface for the proposed repository excavations.

Observations in the shafts and in the horizontal drifts have confirmed that the geology at the WIPP site very closely resembles that inferred from the surface exploration, and sinking of the shafts and excavation of the drifts have shown that there are no major practical impediments to the construction of a repository at this site. Nevertheless, many important factors that may still affect the design and construction and final performance of the proposed repository remain to be evaluated. These factors include the important effects of stratigraphic discontinuities in the Salado on the mechanical and hydrological integrity of the repository, the effects of creep closure of the excavations on retrievability, on the ultimate encapsulation of the waste by the salt, and on the reconsolidation of the backfill. Extensometer measurements in the shafts, horizontal drifts, and test rooms of the SPDV already provide important data concerning these factors, and the planned in-situ tests will provide more such data. Analysis of these data is essential to ensure that the mechanical properties of the salt and the effects of the stratigraphic discontinuities that these data reflect are taken into account properly in the final design of the repository and in the assessment of its performance and safety. Where measurements and observations produce unexpected results, it is necessary to incorporate the findings of these results into the final design of the repository or, at a minimum, to show that they are not indicative of behavior and conditions that would affect the performance and safety of the repository adversely.

UNDERGROUND EXCAVATIONS

Once a suitable site for an underground nuclear waste repository has been selected, one of the most important factors--if not the most important one--contributing to the successful disposal of radioactive waste is the design of the excavations and associated facilities that constitute the repository. Mining engineering provides a wealth of experience related to the design and construction of a repository, but the function of a repository is very different from that of a mine. The principal objective in mining is to remove as much of the ore as is practicable, consistent with short-term safety. The principal objective in making repository excavations is to remove only limited amounts of rock and thereby disturb the geologic media as little as is practicable, so as to ensure long-term safety and effective isolation of the waste.

Adequate conceptual design of an underground repository requires recognition that the properties of a geologic medium, even salt, may not be uniformly satisfactory over the dimensions of the proposed repository site, and that many variations in the properties and structure of the salt at the depth of the repository will be revealed only as the excavations are made and related experiments are carried out. Some of these variations may lead to unexpected difficulties in excavation or they may adversely affect the ability of the salt or the overlying strata to isolate the waste from the biosphere. Accordingly, it may be desirable to treat some portions of the repository differently from

others and perhaps even to exclude some portions of the site from use for the waste disposal.

For these reasons, and to limit the extent of any accidents that may occur prior to final sealing of the repository, such as the intersection of a brine-filled void or the outbreak of a fire, the repository has been laid out as a number of independent modules. Substantial barriers of undisturbed salt will be left between modules to ensure that each module can be isolated effectively from every other module. No more accessways than are necessary for safe development of a module should penetrate these barriers, and each accessway should be provided at either end with a bulkhead that can be closed quickly if necessary. Ultimately, these accessways should be sealed permanently with a fill having low porosity and permeability. Devices for temporary closure of accessways, in the form of ventilation doors and other fabricated bulkheads, have been developed and are used extensively in the mining industry. In mining, permanent closure of accessways is usually effected by the construction of concrete plugs. For the WIPP site, a salt aggregate could be used so as to give the plugs properties compatible with those of the surrounding salt. No details are given in the program documents available to the study panel of devices for either temporary or permanent closure of accessways.

The current design (Figures 5-1 and 5-2) comprises three shafts: (1) a construction and salt-handling shaft, (2) a waste shaft, and (3) an exhaust shaft. An experimental area is laid out to the north of these shafts, and the storage area is laid out to the south of them. Access from the shafts to the experimental and storage areas is by parallel entries, two to the experiments and four to the storage area. The entries to the storage area (Figure 5-2) are separated from one another by wide pillars penetrated at intervals by crosscuts.

The storage area, measuring 629 m by 778 m, comprises four panels on each side of the main entries. Within each panel are seven storage rooms, measuring about 10 m wide by 4 m high by 91 m long, with their long axes parallel to the main entries, and separated by salt pillars 30 m thick. The panels are separated from one another by wide barrier pillars. Access from the main entries to the panels is by crosscuts at intervals corresponding to the length of the rooms and the thickness of the intervening barrier pillars, respectively. The overall extraction ratio is less than 25 percent, and the layout of the panels constitutes effective modularization, provided that the penetrations of the pillars can be closed effectively, both temporarily in an emergency and permanently after storage has been completed.

A fundamental advantage of salt as a medium for a waste repository is the prospect it offers for the ultimate encapsulation of the waste and sealing of the excavations by creep deformation of the salt. Every effort should be made to determine whether or not sealing and encapsulation will in fact occur and, if it does occur, when it will become effective as a means for isolating the waste. The extensometer measurements reflect the influence of many different factors on the response of the salt to the repository excavations. These factors include the mechanical properties of the salt and some of the effects of discontinuities, such as layers of clay or anhydrite within the salt, as

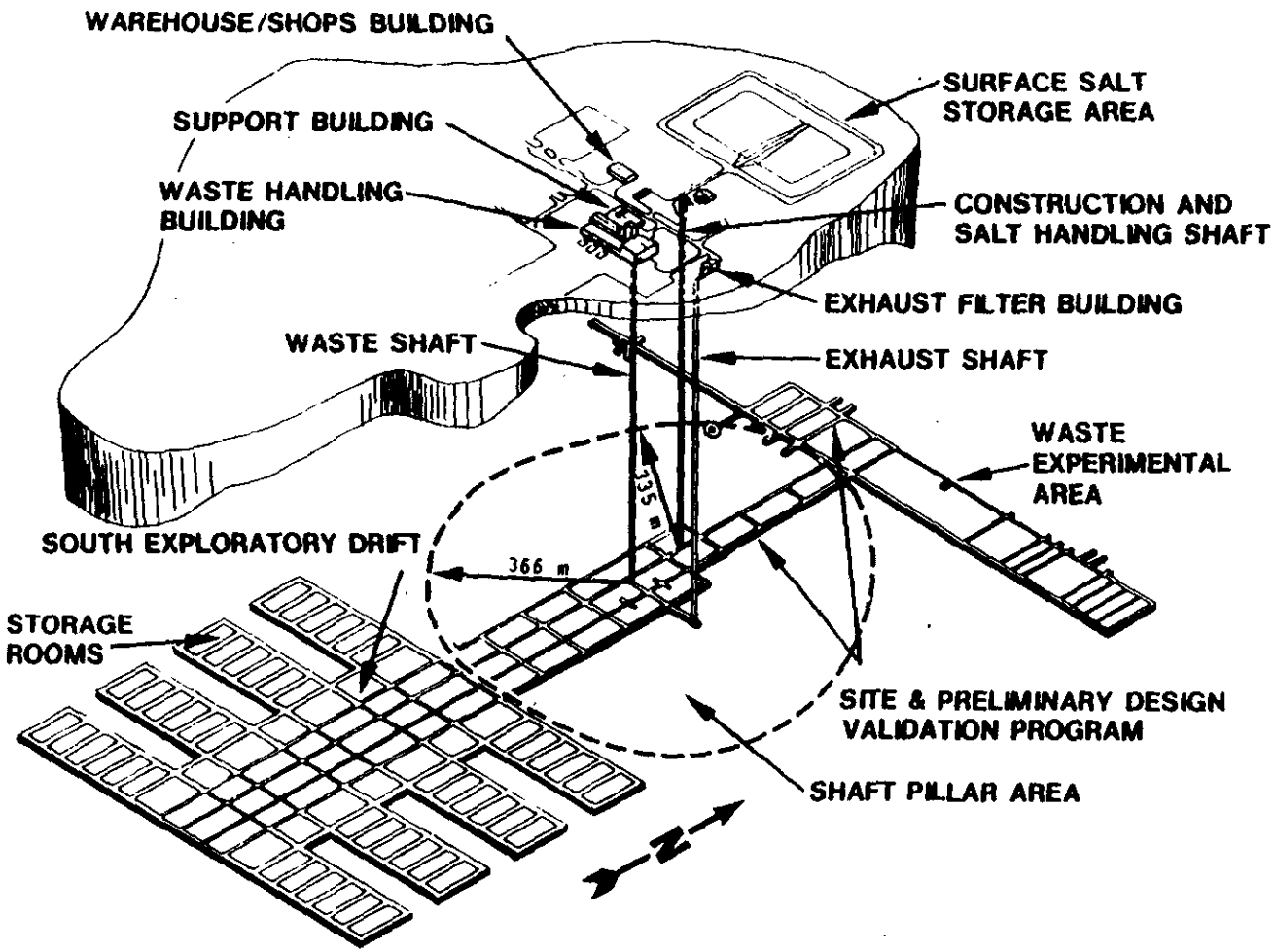

FIGURE 5-1 Cutaway diagram of the WIPP underground design. Source: After Bechtel National, Inc. (1983).

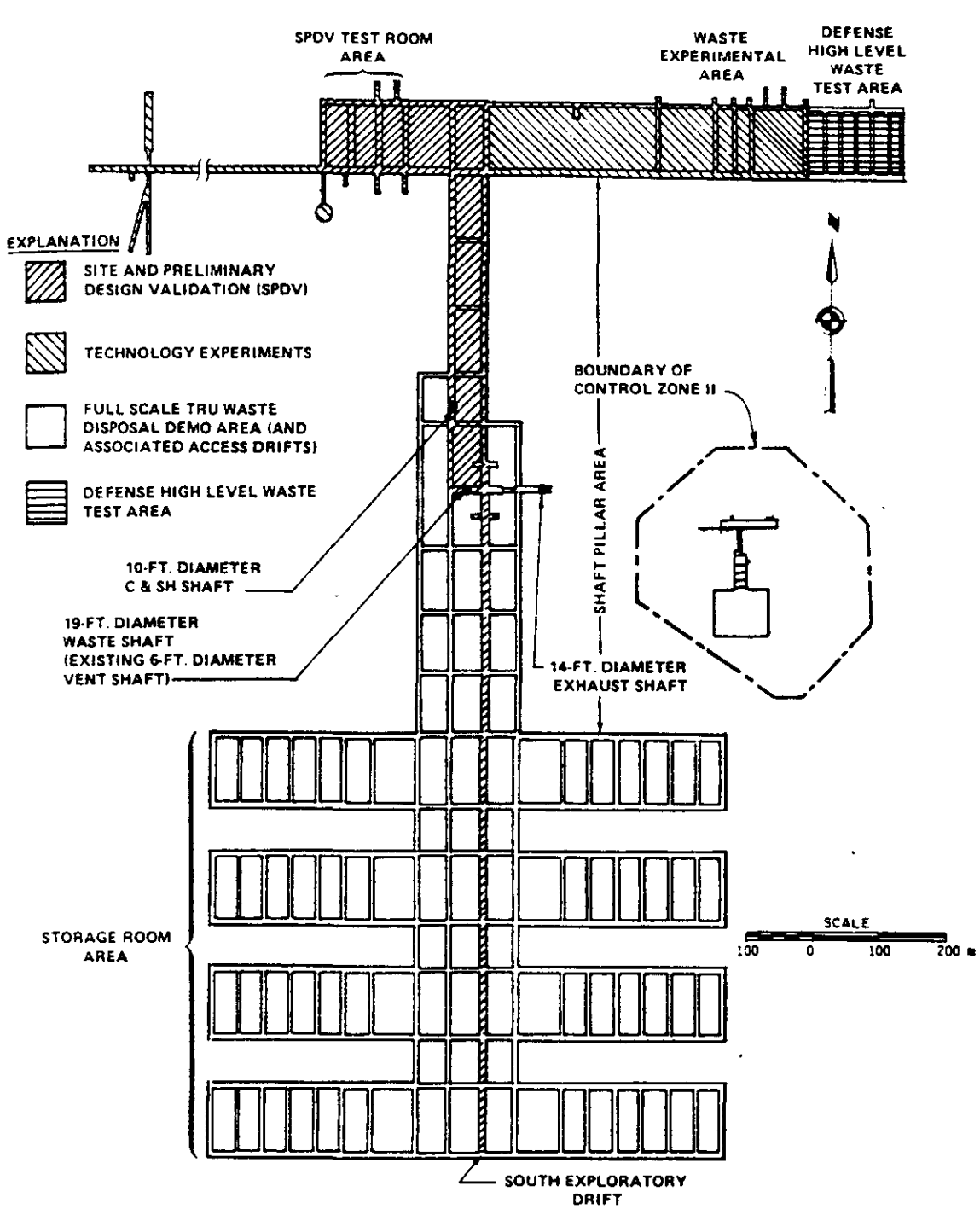

FIGURE 5-2 Plan view of WIPP excavations. Source: After Bechtel National, Inc. (1983).

well as the effects of the geometry of the excavations. Numerical models that have been used and will be used to evaluate the design and performance of the repository must include all these factors. It is unlikely that the properties of the salt over all times, from several seconds to thousands of years, can be represented by a single constitutive law. However, it may prove practicable to place bounds on maximum creep rates and hence on the minimum period of time before closure and encapsulation are effective. Many other factors such as the geometry of the excavations and stratigraphic discontinuities in the salt will be important in the evaluation of the behavior and response of the salt around the excavation at different times.

Measurements of deformation and closure from the SPDV and in-situ tests should be examined using numerical and theoretical models, both in the short term, when they can be compared with actual measurements, and in the long term, to assess what constraints the logic of the models and assumptions about the constitutive laws for salt impose on the closure of the repository excavations. Specifically, models should be used to explore closure of the excavations in the long term, say 100 years, 1,000 years, and more. Although validation of the models for such long periods may be impractical, it is important to assess qualitatively and quantitatively the rates of long-term closure and to determine how these rates are affected by the properties of the salt and the geometry of the excavation.

A proper analysis of long-term closure is necessary to arrive at a decision concerning the function of backfilling. If closure and encapsulation of the waste will occur within a usefully short period of time, say, 1,000 years, the backfill will be needed only for a period of time shorter than this. On the other hand, if closure cannot be relied upon to seal the waste in an impermeable surround of salt, the backfill probably will have to be designed to fulfill a long-time performance role. Finally, the nature of the backfill itself may affect the time to closure; low-porosity backfill may be used to shorten the time taken to achieve closure of the excavation. Salt removed during repository excavation is to be stored on the surface and eventually used as backfill material. Excessive moisture in the backfill salt is not expected to be a problem, in view of the generally arid climate and the protective crust that forms on the piles during surface storage. However, prior to actual backfilling, the matter of moisture content of the material should be reexamined.

In the near field, the excavations of a repository make up a network of interconnected hydraulic conduits in the salt mass at the repository horizon. Closure of the excavations, even in the long term, say beyond 1,000 years, may not reduce the void space in the waste and backfill to a negligible value, so that the backfill may have a porosity much greater than that of the intact salt. Unless it can be shown that this residual void space does not result in a hydraulic conductivity through the repository excavations that is significantly greater than that of the pristine salt, a careful analysis of the effects of void space on the hydraulic conductivity should be made. Alternatively, it may be shown that the consequences of such conductivity would not be expected

to be greater than those resulting from scenarios of water flow between two aquifers (Bingham and Barr 1979).

CHANGE FROM FOUR SHAFTS TO THREE SHAFTS

The original designs for a repository at WIPP (Bechtel National, Inc. 1979) were based on a system of four shafts comprising

- a waste-handling shaft,
- a construction exhaust and salt-handling shaft,
- a storage exhaust shaft, and
- a ventilation supply and service shaft.

Subsequently, as part of a cost reduction program (U.S. Department of Energy 1982), the number of shafts was reduced to three, comprising

- a waste shaft,
- a construction and salt-handling shaft, and
- an exhaust shaft.

This change has profound effects on repository construction and operation and on costs.

The four-shaft system allowed for complete separation between construction and storage. Each of these two operations was planned to proceed independently of the other and concurrently, except for ventilation supply through a common shaft. This concept provided an exceptional degree of flexibility, redundancy, and safety. However, the rates at which waste is expected to become available for disposal at the WIPP site are very low in relation to the rates at which excavations can be made and waste can be emplaced in a four-shaft repository. Therefore, four shafts can be justified only insofar as they may be needed to provide the degrees of redundancy and safety required for nuclear facilities.

The three-shaft system interlinks construction and storage operations in many ways. It involves cyclical and sequential operations on two shifts a day: One shift is for construction and the other is for storage, but each does provide ample opportunity for the projected rates of excavation and disposal. To operate on either shift in the three-shaft system, the ventilation subsystems in both the construction and the storage areas must work.

Electrical power to back up the 32-km-long high-voltage line from the substation to the WIPP site has been reduced to one manually operated 800-kW diesel generator, from two automatic 2,500-kW diesel generators sufficient to operate the man hoist and one fan.

In general, although the three-shaft system appears to be functionally adequate, it does not include the degree of redundancy that is common in nuclear industry practice.

As a result of the design changes the WIPP SAR has required extensive revision. As of the end of 1983, six amendments had been issued. The FEIS, issued in 1980, however, is badly out of date. While

the environmental impact of the new facility design may not be significantly different from that of the original design, the FEIS should be reissued to correspond with the present design.

CONCLUSIONS

- The layout of the eight panels of storage rooms separated by barrier pillars is well considered, provided the penetrations of these barriers are sealed adequately (p. 45).
- Details of devices for temporary and permanent closure of the penetrations through the barriers have not been provided (p. 45).
- Recently, the repository design has changed from four to three shafts. Although the three-shaft design appears to be functionally adequate, it does not possess the flexibility and redundancy of the four-shaft design (p. 49).

RECOMMENDATIONS

- Results from the Site and Preliminary Design Validation (SPDV) and in-situ experiments and information gathered during construction and development to final design must be incorporated with the final design of the WIPP repository (p. 44).
- Models should be used to assess whether or not closure of the excavations and consequent encapsulation of the waste in salt are likely to occur, and to determine the period of time within which they may occur (p. 48).
- It should be shown that sealing the repository is sufficient to preclude unacceptable increases in hydraulic conductivity across the repository horizon (p. 48).
- The Final Environmental Impact Statement (U.S. Department of Energy 1980) should be reissued to correspond with the present design (p. 49).

CHAPTER SIX

PERFORMANCE ASSESSMENT

This chapter is based primarily on the panel's review of the WIPP Final Environmental Impact Statement (FEIS) (U.S. Department of Energy 1980), the Safety Analysis Report (SAR) (U.S. Department of Energy 1980-1983) and Modeling Verification Studies: Long-Term Waste Isolation Assessment (D'Appolonia Consulting Engineers, Inc. 1981). One of the main purposes of these documents was to estimate possible radiation exposure of both project employees and the general public. Such exposures could arise during preparation and loading of the waste at the originating facility, transportation of the waste to the repository site, and surface storage of waste at the WIPP site preparatory to emplacement, and also as a result of accidents that may occur during operation of the facility. In addition, there may be releases of radioactive material to the environment if the repository is breached at some future time.

While the panel has reviewed the plans for packaging the waste at the Idaho National Engineering Laboratory (INEL), a major source of TRU waste destined for WIPP, and transporting them to the WIPP site to determine how this affects the materials that will be emplaced in the repository, a detailed review of the consequences of routine and accidental events during these processes is beyond the scope of this study.

RELEASES AND OCCUPATIONAL DOSES DURING NORMAL OPERATION

Waste delivered by either rail or truck to the WIPP site will be unloaded and passed through airlocks to the waste-handling building. The handling procedures are described in detail in the FEIS and in the cost reduction proposals (U.S. Department of Energy 1982). A number of appropriately conservative assumptions are made as to the levels of contamination. For example, all waste packages are assumed to be contaminated to the maximum level of surface contamination permitted by U.S. Nuclear Regulatory Commission (NRC) and U.S. Department of Transportation (DOT) regulations. The total radioactivity that would be released to the environment from both surface and underground operations, from both residual surface contamination and leakage from damaged canisters of remotely handled waste, is estimated to be

0.004 Ci/yr. Throughout the analysis, the final dose estimates are upper limits.

The requirements of the FEIS for radiological impact analysis during normal operations could probably be discharged by simply noting that many years of experience with the handling of properly packaged waste provide assurance that necessary calculations can easily be made.

The annual occupational doses to workers at the WIPP facility from waste handling are estimated to reach an average of 0.9 rem for workers handling contact-handled waste and an average of 0.8 rem for workers with remotely handled waste. Although such doses, taken singly, are within permissible limits (5 rem), they may be too high for routine operations, because the same people may handle both types of waste, and other exposures from nonroutine events may occur.*

The results of rather straightforward dose calculations, based on a conservative set of assumptions, show that for environmental releases during normal operations, an individual at the closest point of habitation would receive a maximum dose (to the bone) of 0.007 percent of that received from natural radioactivity; and the whole-body dose would be less than 0.0002 percent of background (U.S. Department of Energy 1980, p. 9-30).

ACCIDENTAL RELEASES DURING OPERATION OF THE FACILITY

Accidents that may occur in the course of handling the radioactive waste will have a potential for exposure to both the employees and nearby inhabitants. The consequences of a waste-handling accident are examined by analysis of a number of scenarios ranging from a vehicle collision in the receiving area (no radioactive material released) to various failures of the drums and canisters from collisions, drops down mine shafts, spontaneous combustion, and external fires. The radiation doses are calculated in the conventional manner from estimates of the quantities of radioactivity released, the atmospheric concentration at a given location per unit of radioactivity released based on meteorological observations at the site, and measured population distributions.

The worst case described in the SAR (U.S. Department of Energy 1980-1983) for contact-handled TRU waste involves an underground fire, in which case the maximum 50-year bone-dose commitment offsite is estimated to be about 450 mrem. For either remotely handled TRU or experimental high-level waste, the worst case would be a hoist failure in which a container is dropped down the waste shaft. In these cases, the maximum bone-dose commitment to an off-site individual is calculated to be 24 mrem for the RH TRU accident and 49 mrem for the experimental high-level waste case. The maximum dose commitment to a worker from an accident is calculated to be 33 rem to the bone from an underground fire.

*DOE notes that exposures will be administratively monitored to assure that no individual exceeds 1 rem/yr from routine operations.

REPOSITORY BREACH SCENARIOS

For breach of the repository and effects upon the biosphere, there must be (1) an event to breach the repository, (2) a mechanism to bring the waste out of the repository, and (3) a place at a lower fluid potential energy level than that of the repository (water flows downhill) to which the water can move. Without all three conditions, movement to the biosphere will not occur. In a number of the scenarios considered in the FEIS (U.S. Department of Energy 1980, pp. 9-131ff), not all of the above conditions are fulfilled. Some of the scenarios have been and are being updated and augmented in the SAR. Calculations were carried out to determine the consequences of the sometimes implausible events. Finally, the studies were consequence analyses rather than risk analyses (i.e., the consequences of certain events are evaluated without regard to their likelihood). This methodology is particularly useful if the consequences are then found to be so small that the frequency of the event is not material. In all cases, the waste material is assumed to dissolve congruently with the salt, i.e., at the same rate as the salt.

The first scenario in the FEIS assumes a connection between the Rustler and Bell Canyon formations (of the Delaware Mountain Group) through the repository with flow upward and out of the Rustler into the Pecos River at Malaga Bend (see Figure 6-1). Though the flow may actually be in the opposite direction, this is a safe assumption because the transmissivity and hydraulic conductivity of the Rustler are orders of magnitude greater than those properties in the Bell Canyon (i.e., greater flows and shorter residence times (U.S. Department of Energy 1980)). The Magenta and Culebra Members of the Rustler are treated as a single unit.*

The second scenario assumes flow of dilute brine through a drill pipe from the Rustler through the repository and saturated flow back to the Rustler and to Malaga Bend. The driving force for this scenario appears to be lacking because the unsaturated water (8,000 ppm salt) flow does not appear to have the potential to push the saturated (400,000 ppm salt) flow out of the repository (see Figure 6-2).

The third scenario allows communication of the total waste storage horizon with the Rustler, but with no flow through the repository (i.e., the transfer is by diffusion only). Then, the flow is through the Rustler to Malaga Bend (see Figure 6-3).

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*More recent data allow analyses for movement through the Magenta and Culebra, the individual beds of the Rustler Formation, as well as the Rustler-Salado interface. Calculations by Barr et al. (1983) using these more recent data yield fluid travel times in excess of 130,000 years to a point 8 mi south of the center of the site, as compared to the 11 "bounding and conservative" FEIS calculations of about 3,600 years to a point 23 mi distant. Data collected since issuance of the FEIS and analysis of the breach events presented in the SAR allow depiction of distinct potentiometric maps for the three aquifers (Gonzalez 1983a,b; Mercer 1983).

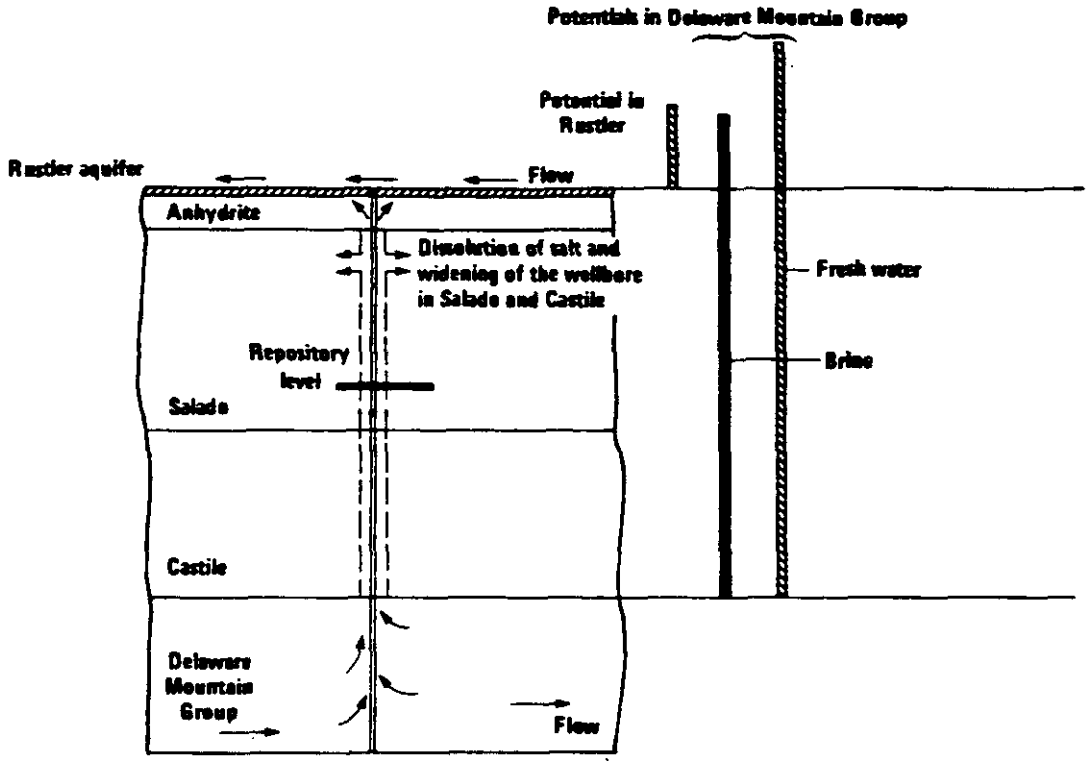

FIGURE 6-1 Schematic representation of scenario 1. Source: U.S. Department of Energy (1980).

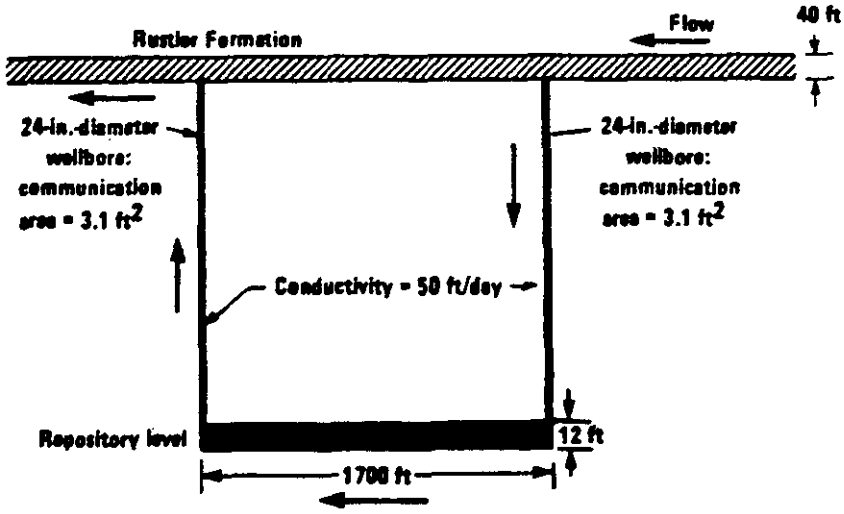

FIGURE 6-2 Schematic representation of scenario 2. Source: U.S. Department of Energy (1980).

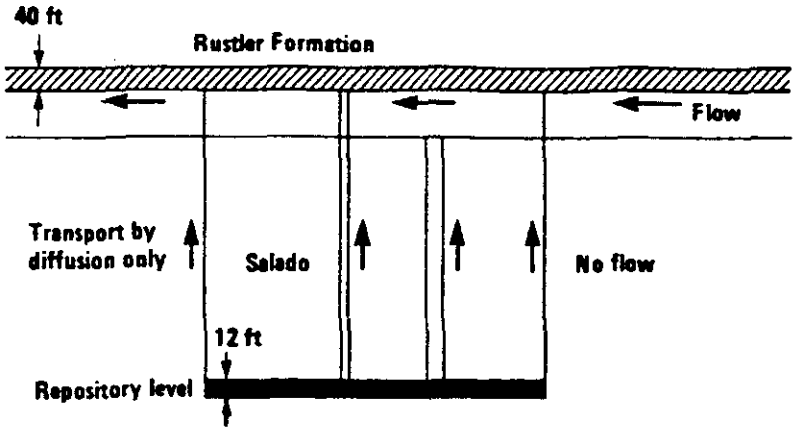

FIGURE 6-3 Schematic representation of scenario 3. Source: U.S. Department of Energy (1980).

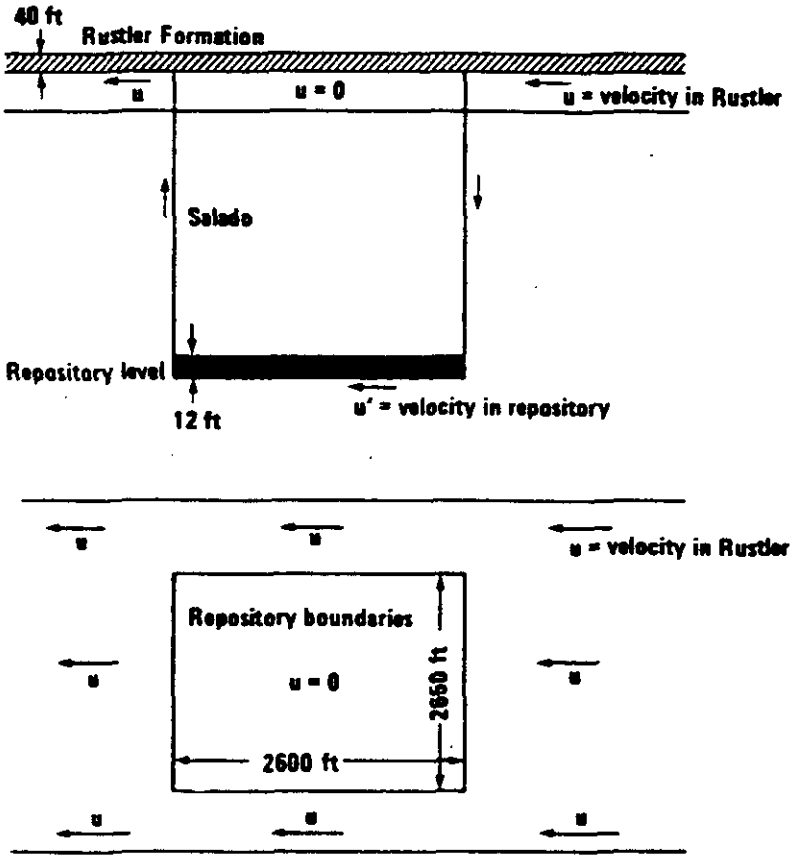

FIGURE 6-4 Schematic representation of scenario 4, showing the bounding condition (top) and velocities in the Rustler during the bounding condition (bottom). Source: U.S. Department of Energy (1980).

The fourth scenario allows the total flow of the Rustler above the waste repository to flow through the repository and then back to the Rustler and out to the Pecos River at Malaga Bend (see Figure 6-4).

The fifth scenario deals with drilling into the waste repository and, in particular, with the dose to the drill crews. Bingham and Barr (1979) estimated the probabilities of breaching the repository salt formation by inadvertent drilling in the distant future.

Recent analyses (Channell 1982, Bard 1982, Woolfolk 1982) have predicted the probability and consequence of a pressurized-brine pocket below the repository with subsequent release to the ground surface (see Figure 6-5).

The consequences of drilling and using a water well near the site have also been evaluated (U.S. Department of Energy 1980-1983, Spiegler 1981).

Though solution mining undoubtedly will be prohibited at the waste site, the consequences of this type of mining would be more severe than the liquid breach scenarios but less severe than the drilling scenario considered in the FEIS and SAR as shown by the EEG report (Little 1982) for the maximally exposed individual. The population dose due to solution mining is much greater.

Water flow times in the Rustler Formation from above the WIPP site to the Pecos River at Malaga Bend are calculated from models of flow through porous media to range from 5,000 to 100,000 years based upon point measurements.* For the consequence analyses, the shorter flow times are used together with the shortest distance between the site and Malaga Bend. The actual flow paths may be substantially longer, particularly for the Culebra where there is some indication of an arcuate route to the Pecos. Substantially shorter flow times, 1,850 years, have also been postulated (D'Appolonia Consulting Engineers, Inc. 1981).**

The sorption data listed in Appendix K-20 of the FEIS (U.S. Department of Energy 1980) were derived from more than one source. It is not clear to what extent these data are applicable to the geochemistry of the Rustler Formation and to sorption from solutions containing appreciable concentrations of dissolved salt. Furthermore, under actual conditions, precipitation may be more important than

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*Analyses of the data in the Barr et al. (1983) report indicate that for the distances affected by pumping th wells (point measurements), drawdown values fit a porous medium model better than a fracture model. Mercer (1983), however, believed that the flow is through fractures through the porous media. The Barr assumption is satisfactory because the dolomite is thin and the fractures closely spaced, at least where halite still remains below the Culebra aquifer.

**Since the previously noted studies were conducted, studies of fluid movement in the Rustler have continued to allow refinement of knowledge of the regional hydraulics over an area larger than within the site boundaries. These studies led to development of a more up-to-date flow model for the Rustler (Barr et al. 1983). As additional hydrological data on the Rustler are collected, this model will be modified appropriately.

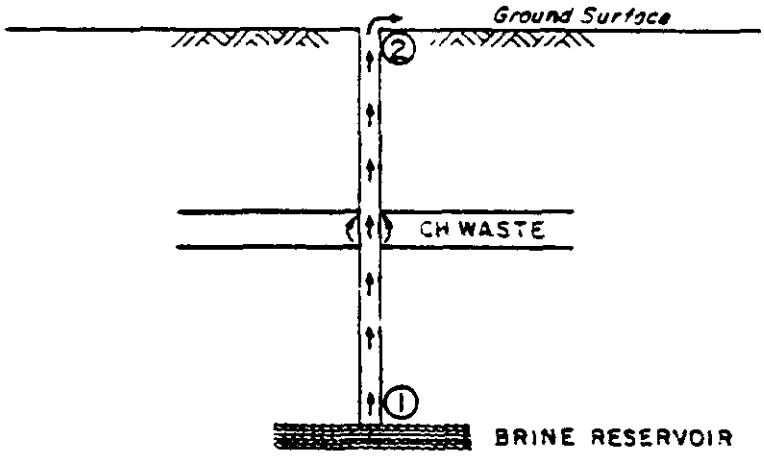

A. SINGLE BOREHOLE

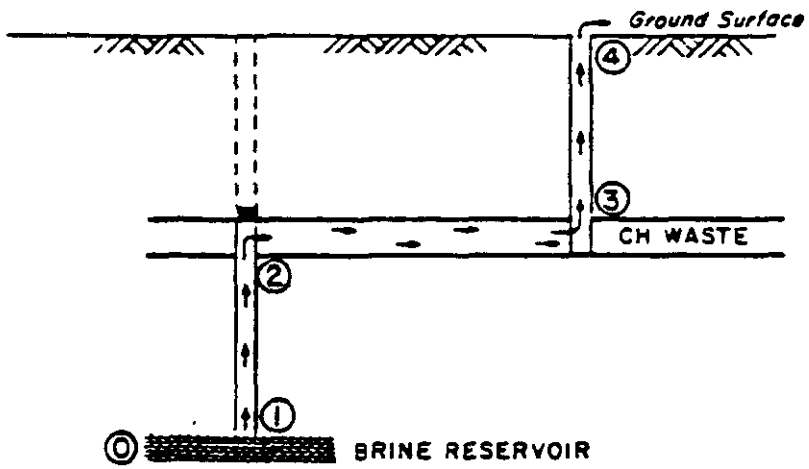

B. FIRST BOREHOLE CONNECTING BRINE RESERVOIR TO CH WASTE, SECOND BOREHOLE CONNECTING CH WASTE TO GROUND SURFACE

FIGURE 6-5 Schematic representation of scenario involving a brine reservoir below the repository and release to the ground surface. Source: Case et al. (1982).

sorption. These uncertainties affect the estimated doses from radium-226. No discussion of the effects of such sorption uncertainties has been found in the FEIS.

Using the porous-medium model, the dissolution and transport processes take over 5,000 years for even the nonsorbing radionuclides and far longer for the sorbing species. Even considering waste containing fission products, this gives ample time for strontium-90 and cesium-137 to decay without the additional delaying effect of sorption. Sorption by the dolomite delays the release of the transuranics, although some of their more toxic decay daughters, such as radium-226, contribute later to doses to man (U.S. Department of Energy 1980, p. 9-139).

The dosages (50-year commitment) to the maximally exposed individual (as well as the dose to the maximally exposed worker in the drilling scenario) from each of these scenarios are given in Table 6-1. These doses were computed on the basis of International Commission on Radiological Protection (ICRP) reports ICRP-2 and ICRP-6. The revised permissible limits for neptunium-237 of ICRP-30 were not factored into these calculations. However, analysis of the dose calculations indicates that the portion of dose contributed by neptunium-237 is substantially less than one two-hundredths of the total and, therefore, will have no effect on the dose numbers in Table 6-1.

The nuclide releases from the two brine-repository scenarios were compared with the proposed release limits for plutonium-239, plutonium-240, and americium-241 in EPA's proposed rule on 40 CFR 191 (U.S. Environmental Protection Agency 1982). If one assumes that such releases are very unlikely, then all are at least a factor of 20 below their release limits. If the event results in "reasonably foreseeable releases," then the americium-241 is a factor of 2 less than the permissible amount and plutonium-239 and plutonium-240 are less than the permissible amounts by factors of approximately 3 and 10, respectively.

The doses are calculated based upon very long transport times ranging from 1,200,000 to 1,400,000 years for the time for the peak concentrations to reach Malaga Bend (U.S. Department of Energy 1980, Table 9-60).

The scenarios selected in the FEIS would appear to be the bounding cases. Apart from the implausible mechanisms for water intruding into the repository and returning to the Rustler aquifer, the assumptions in each step of the analysis tend to exaggerate the dose estimates. For example, the waste is assumed to dissolve as rapidly as salt; no solubility limits for the waste material and for its radionuclides are considered. Finally, no allowance is made for the fact that the radionuclides emerge into the Pecos River, the water of which is currently not potable because of high salinity. The water is not consumed by man or beast, and the river does not support a significant population of fish or shellfish. Even for these bounding cases, the dosages are so small that it is not worthwhile to consider more plausible cases. Confidence in the accuracy of these calculations of low dosages is strengthened by the independent calculations carried out by the EEG on transportation accidents, breccia pipe release mechanisms, withdrawal through wells, transport induced by pressurized-brine

TABLE 6-1 Fifty-Year Dose Commitments for Maximally Exposed Individual from Bounding Scenarios of Breaches of the WIPP Repository (mrem)

Scenario	Whole Body	Lung	Bone
Bell Canyon to Rustler	1.1×10^{-2}	--	2.1×10^{-2}
Restricted Rustler to Rustler flow	8.3×10^{-3}	--	1.6×10^{-2}
Diffusion flow to the Rustler	2.1×10^{-6}	--	4.2×10^{-6}
Unrestricted Rustler to Rustler flow	1.5×10^{-2}	1.2×10^{-5}	2.6×10^{-2}
Local well (Bell Canyon to Rustler)	1.3	--	1.7
Drill into repository	6.1×10^{-3}	2.1×10^{-2}	1.1×10^{-2}
Drill crew member	2.2×10^{1}	--	--
Pressurized brine[a] reservoir flow to the surface	5.6×10^{2}	2.2×10^{3}	9.8×10^{2}
Worker	2.8×10^{2}	1.1×10^{3}	4.9×10^{2}
Solution mining of halite	7.2×10^{1}	--	--
Natural background	5×10^{3}	9×10^{3}	5×10^{3}

[a]Calculated using recommendations of ICRP-26 and ICRP-30. All others calculated using recommendations of ICRP-30.

SOURCE: U.S. Department of Energy (1980, 1980-1983), Little (1982).

reservoirs, and long-term release scenarios. The dose commitments calculated by the EEG are similar to those shown in the FEIS, SAR, and brine reservoir report (Channell 1982).

Questions have been raised about the possibilities of reducing the time of travel of these higher-water-velocity flow paths by fractures or karst-type openings, but seem to have been answered in part in the Barr et al. (1983) publication. As is well known, such studies cannot prove

the existence or nonexistence of karst-type flow within the region sampled. It is very difficult to prove that no connected fracture flow exists or is likely to exist. The problem might be bounded by computing the total water flow and flow rate through the aquifers above the WIPP site and, using the solubility limits of the individual nuclides, calculating the maximum amount of radioactive material that could be put into solution and transported to the Pecos.

CONCLUSIONS

o The dosages calculated to be received by humans as a result of normal operations and accidents are within prescribed limits for workers and far below the dosages from normal background radiation for members of the public. There is a great deal of experience in these types of operations, and confidence in the accuracy of the calculations is high (p. 52).

o The long-term release scenarios, shown in Figures 6-1 to 6-6, lack experimental verification. Nevertheless, the scenarios appear to set outside limits to what would be credible releases. Though only a consequence analysis is performed, the resulting dose commitments (50 years) are well within permissible limits for the general population (170 mrem whole body) and far below the dosages from normal background radiation (average over 50 years of 5,000 mrem) (p. 58). Further analyses will be needed to conform to the Environmental Protection Agency (EPA) requirements.

RECOMMENDATIONS

o Though karst-type flow in the strata above the salt beds (the Rustler Formation) is known to occur near Nash Draw several kilometers to the west, the extent to which it reaches eastward is not delineated clearly. If this type of flow should be joined by connected fractures to the WIPP site area, the time of travel of the nuclides and their retardation would be reduced sharply. The probability of such flows, their degree of development east of the Pecos River, and the effect of such flows upon radiation dosages need to be determined (pp. 58-60).

o For consistency, and to permit direct comparison among all the modes of release, all dosages should be calculated on the same basis (i.e., if recommendations of ICRP-26 and ICRP-30 were used rather than those of ICRP-2) (pp. 58-59).

REFERENCES

Anderson, R. Y. 1981a. Progress of Salt Dissolution in the Delaware Basin, Texas and New Mexico. Special Publication No. 8. New Mexico Geological Society.

Anderson, R. Y. 1981b. Deep-seated Salt Dissolution in the Delaware Basin, Texas and New Mexico. Special Publication No. 10. New Mexico Geological Society, pp. 133-145.

Anderson, R. Y. 1982a. Deformation-dissolution potential of bedded salt, Waste Isolation Pilot Plant site, Delaware Basin, New Mexico. Pp. 449-458 in Scientific Basis for Nuclear Waste Management V, W. Lutze, ed. Materials Research Society Symposia Proceedings, Vol. 11. New York: Elsevier Science Publishing Company.

Anderson, R. Y. 1982b. Upper Castile Brine Aquifer, Northern Delaware Basin. Attachment to a May 23 letter to G. Goldstein.

Anderson, R. Y., and D. W. Kirkland. 1980. Dissolution of salt deposits by brine density flow. Geology, 8:66-69.

Anderson, R. Y., W. E. Dean, D. W. Kirkland, and H. I. Snider. 1972. Permian Castile varved evaporite sequence, West Texas and New Mexico. Geological Society of America Bulletin, 83:59-86.

Bachman, G. O. 1980. Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico, OFR 80-1099. U.S. Geological Survey, Denver, Colo.

Bachman, G. O., and R. B. Johnson. 1973. Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico, with a section on Dissolved Salts in Surface Water by F. A. Swenson. OFR 73-14. U.S. Geological Survey, Denver, Colo.

Bard, S. T. 1982. Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon--A Single Hole Scenario. EEG-15. Environmental Evaluation Group, State of New Mexico, Santa Fe.

Barr, G. F., W. B. Miller, and D. D. Gonzalez. 1983. Interim Report on the Modeling of the Regional Hydraulics of the Rustler Formation. SAND 83-0391. Sandia National Laboratories, Albuquerque, N.Mex.

Bechtel National, Inc. 1979. Waste Isolation Pilot Plant: Title I Design Report, Vols. 1 and 1a. Nuclear Fuel Operations, San Francisco, Calif.

Bechtel National, Inc. 1983. Waste Isolation Pilot Plant: Preliminary Design Validation Report. Job 12484. Nuclear Fuel Operations, San Francisco, Calif.

Bibler, N. E. 1976. Radiolytic Gas Production During Long-Term Storage of Nuclear Wastes. DP-MS-76-51. Paper presented at the 28th Southeastern Regional Meeting of the American Chemical Society, Gatlinburg, Tenn.

Bingham, F. W., and G. E. Barr. 1979. Scenarios for Long-Term Release of Radionuclides for a Nuclear-Waste Repository in the Los Medanos Region of New Mexico. SAND 78-1730. Sandia National Laboratories, Albuquerque, N.Mex.

Borns, D. J., L. J. Barrows, D. W. Powers, and R. P. Snyder. 1983. Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site. SAND 82-1069. Sandia National Laboratories, Albuquerque, N.Mex.

Bradshaw, R. L., and W. C. McClain, eds. 1971. Project Salt Vault: A Demonstration of the Disposal of High-Activity Solidified Wastes in Underground Salt Mines. ORNL-4555. Oak Ridge National Laboratory, Tenn.

Brausch, L. M., A. K. Kuhn, and J. K. Register. 1982. Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3156. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Case, J. B., S. M. Dass, J. G. Franzone, and A. K. Kuhn. 1982. *Analysis of Potential Impacts of Brine Flow Through Boreholes* Penetrating the WIPP Storage Facility. TME 3155 (Appendix to TME 3151). U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Channell, J. K. 1982. Calculated Radiation Doses from Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine. EEG 11. Environmental Evaluation Group, State of New Mexico, Santa Fe.

D'Appolonia Consulting Engineers, Inc. 1981. Modeling Verification Studies: Long-Term Waste Isolation Assessment. NM 78-648-701. Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. Westinghouse Electric Corporation, Albuquerque, N.Mex.

Davies, P. B. 1983a. Assessing the Potential for Deep-Seated Salt Dissolution and Subsidence at the Waste Isolation Pilot Plant (WIPP). Prepared for the St te of New Mexico Environmental Evaluation Group (EEG) Confe ence on WIPP Site Suitability for Radioactive Waste Disposal, May 12-13, 1983, Carlsbad, N.Mex. Unpublished. 62 pp.

Davies, P. B. 1983b. A review of USGS Open-File Report 82-968, "Evaluation of Breccia Pipes: Southeastern New Mexico and Their Relation to the WIPP Site," by R. P. Snyder and L. N. Gard, Jr. Prepared for the Environmental Evaluation Group, Santa Fe. 7 pp.

Davies, P. B. 1983c. Structural Characteristics of a Deep-Seated *Dissolution Collapse Chimney in Bedded Salt. Paper presented at* 6th International Symposium on Salt, Toronto, Ontario, Canada, May 24-28. Salt Institute, 206 N. Washington St., Alexandria, Va.

Gonzalez, D. D. 1983a. Groundwater Flow in the Rustler Formation, Waste Isolation Pilot Plant (WIPP), Southeast New Mexico (SENM): Interim Report. SAND 82-1012. Sandia National Laboratories, Albuquerque, N.Mex.

Gonzalez, D. D. 1983b. Hydrogeochemical Parameters of Fluid-Bearing Zones in the Rustler and Bell Canyon Formations: Waste Isolation Pilot Plant (WIPP), Southeast New Mexico (SENM). SAND 83-0210. Sandia National Laboratories, Albuquerque, N.Mex.

Griswold, G. B. 1980. Presentation reported in Geotechnical Consideration for Radiological Hazard Assessment of WIPP. EEG-6, a report of a meeting held on January 17-18. Environmental Evaluation Group, State of New Mexico, Santa Fe.

Horowitz, N. H. 1979. Biological water requirements. Life Sciences Research Report 13, Moshe Shilo, ed. Verlag Chemie, Weinheim, New York, pp. 15-29.

Interagency Review Group. 1979. Report to the President by the Interagency Review Group on Nuclear Waste Management. TID-29442. U.S. Department of Energy, Washington, D.C.

Jarolimek, L., and R. F. McKinney. 1982. Selection of the WIPP Facility Horizon and Geologic Investigation of the Shaft Station Vicinity in the Exploratory Shaft. June 10 memo to D. K. Shukla, D'Appolonia Consulting Engineers, Inc. Unpublished.

Lambert, S. J. 1983. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. SAND 82-0461. Sandia National Laboratories, Albuquerque, N.Mex.

Likar, V. F. 1979. WIPP Project Retrievability Demonstration Plan. TME 2967. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Little, M. S. 1982. Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP. EEG-12. Environmental Evaluation Group, State of New Mexico, Santa Fe.

Matalucci, R. V., C. L. Christensen, T. O. Hunter, M. A. Molecke, and D. E. Munson. 1982. Waste Isolation Pilot Plant (WIPP) Research and Development Program: In Situ Testing Plan. SAND 81-2628. Sandia National Laboratories, Albuquerque, N.Mex.

Mercer, J. W. 1983. Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico. Water-Resources Investigation Report 83-4016. U.S. Geological Survey, Albuquerque, N.Mex.

Molecke, M. A. 1979. Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation. SAND 79-1245. Sandia National Laboratories, Albuquerque, N.Mex.

National Research Council. 1970. Disposal of Solid Radioactive Waste in Bedded Salt Deposits. Panel on Disposal in Salt Mines, Committee on Radioactive Waste Management. National Academy of Sciences, Washington, D.C.

National Research Council. 1978. Geological Criteria for Repositories for High-Level Radioactive Wastes. Panel on Geological Site Criteria, Committee on Radioactive Waste Management. National Academy of Sciences, Washington, D.C.

National Research Council. 1979. Implementation of Long-Term Environmental Radiation Standards: The Issue of Verification. Panel on the Implementation Requirements of Environmental Radiation Standards, Committee on Radioactive Waste Management. National Academy of Sciences, Washington, D.C.

National Research Council. 1983. Review of the Criteria for the Site Suitability, Design, Construction, and Operation of the Proposed Waste Isolation Pilot Plant (WIPP), Interim Report July 1, 1978 to July 31, 1982. DOE/NE/93023-3. Panel on the Waste Isolation Pilot Plant, Board on Radioactive Waste Management. National Academy of Sciences, Washington, D.C.

Neill, R. H., and J. K. Channell. 1983. Potential Problems from Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP. EEG-24. Environmental Evaluation Group, State of New Mexico, Santa Fe.

Neill, R. H., J. K. Channell, L. Chaturvedi, M. S. Little, K. Rehfeldt, and P. Spiegler. 1983. Evaluation of the Suitability of the WIPP Site. EEG-23. Environmental Evaluation Group, State of New Mexico, Santa Fe.

Popielak, R. S., R. L. Beauheim, S. R. Black, W. E. Coons, C. T. Ellington, and R. L. Olsen. 1983. Brine Reservoirs in the Castile Formation, Southeastern New Mexico. TME 3153. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Powers, D. W., S. J. Lambert, S.-E. Shaffer, L. R. Hill, and W. D. Weart, eds. 1978. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND 78-1596, Vols. I and II. Sandia National Laboratories, Albuquerque, N.Mex.

Rockwell International. 1982. TRU Waste Certification Compliance Requirements for Contact-Handled Wastes Retrieved from Storage for Shipment to the WIPP. WIPP-DOE-137. Energy Systems Group, Rocky Flats Plant, Golden, Colo.

Ryan, J. P. 1982. Radiogenic Gas Accumulation in TRU Waste Storage Drums. DP-1604. Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, S.C.

Sandia National Laboratories. 1979. Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP. SAND 79-1305. Albuquerque, N.Mex.

Shock, D. A. 1953. Acidity o condensate well waters. Chapter XIII in Condensate Well Corrosion. Natural Gas Association of America, 422 Kennedy Bldg., Tulsa, Okla.

Snyder, R. P., and L. M. Gard. 1982. Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, with a Section on Drill-Stem Tests. OFR 82-968. U.S. Geological Survey, Denver, Colo.

Spiegler, P. 1981. An Approach to Calculating Upper Bounds on Maximum Individual Doses from the Use of Contaminated Well Water Following a WIPP Repository Breach. EEG-9. Environmental Evaluation Group, State of New Mexico, Santa Fe.

Spiegler, P. 1982. Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository. EEG-13. Environmental Evaluation Group, State of New Mexico, Santa Fe.

U.S. Department of Energy. 1978. Report of Task Force for Review of Nuclear Waste Management. DOE/ER-0004/D. Directorate of Energy Research, Washington, D.C.

U.S. Department of Energy. 1979. Draft Environmental Impact Statement (DEIS): Waste Isolation Pilot Plant, Vols. 1 and 2. DOE/EIS-0026-D. Washington, D.C.

U.S. Department of Energy. 1980. Final Environmental Impact Statement (FEIS): Waste Isolation Pilot Plant, Vols. 1 and 2. DOE/EIS-0026. Washington, D.C.

U.S. Department of Energy. 1980-1983. Waste Isolation Pilot Plant Safety Analysis Report. WIPP SAR (includes Amendments 1-6). Albuquerque Operations Office, N.Mex.

U.S. Department of Energy. 1981. TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant. WIPP-DOE-069, Revision 1. Albuquerque Operations Office, N.Mex.

U.S. Department of Energy. 1982. Environmental Analysis, Waste Isolation Pilot Plant (WIPP) Cost Reduction Proposals. WIPP-DOE-136. Albuquerque Operations Office, N.Mex.

U.S. Department of Energy. 1983a. Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program. WIPP-DOE-161. Albuquerque Operations Office, N.Mex. March.

U.S. Department of Energy. 1983b. Results of Site Validation Experiments, Volumes I and II. TME 3177. Albuquerque Operations Office, N.Mex.

U.S. Department of Energy. 1983c. Quarterly Geotechnical Field Data Report. WIPP-DOE-177. Albuquerque Operations Office, N.Mex. October.

U.S. Environmental Protection Agency. 1982. Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. Proposed Rule (40 CFR Part 191). Federal Register 47(250):58196-58206. December.

Weiss, A. J., R. L. Tate, III, and P. Columbo. 1982. Assessment of Microbial Processes on Gas Production at Radioactive Low-Level Waste Disposal Sites. BNL 51557. Brookhaven National Laboratory, Upton, N.Y.

Whitty, W. J., C. A. Ostenak, and K. K. S. Pillay. 1982. Preliminary Identification of Interfaces for Certification and Transfer of TRU Waste to WIPP. LA-9207-MS. Los Alamos National Laboratory, N.Mex.

Wofsy, C. 1980. The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP. EEG-8. Environmental Evaluation Group, State of New Mexico, Santa Fe.

Wood, B. J., R. E. Snow, D. J. Cosler, and S. Haji-Djafari. 1982. Delaware Mountain Group (DMG) Hydrology--Salt Removal Potential. TME-3166. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Woolfolk, S. W. 1982. Radiological Consequences of Brine Release by Human Intrusion into WIPP. TME 3151. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

GLOSSARY

activity	A measure of the rate at which a material emits nuclear radiation, usually given in terms of the number of nuclear disintegrations occurring in a given length of time. The unit of activity used in this document is the curie (Ci).
anhydrite	A mineral consisting of anhydrous calcium sulfate: $CaSO_4$. It is gypsum without its water of hydration and is denser, harder, and less soluble than gypsum.
anticline	A fold of rocks whose core contains the stratigraphically older rocks; it is convex upward.
aquifer	A body of rock that contains enough saturated permeable material to transmit groundwater and to yield significant quantities of groundwater to wells and springs. The opposite of an aquiclude.
argillaceous rocks	Rocks, especially shale, containing appreciable amounts of clay.
artesian	Refers to water confined underground under pressure so that it will rise in a well. Sometimes the word is used to mean that the water flows out at the surface, but that, strictly speaking, is "flowing artesian."
background radiation	Radiation in the human environment from naturally occurring elements, from cosmic radiation, and from fallout.
bedded salt	Consolidated layered salt separated from other layers by distinguishable planes of separation.
Bell Canyon Formation	A sequence of rock strata that forms the topmost unit of the Delaware Mountain Group.

biotransport (biosphere transport)	Movement of radionuclides through the biosphere, as in food chains. Used in contrast to geotransport.
breccia pipe	As used in this report, a vertical geologic structure composed of angular broken rock fragments, in a fine-grained matrix or held together by a mineral cement; formed by the collapse of rock overlying an opening, as by foundering of the roof of a cave.
brine aquifer	Same as shallow-dissolution zone.
brine inclusion	A small opening in a rock mass (salt) containing brine; also, the brine included in such an opening. Some gas is often present.
canister	As used in this report, a container, usually cylindrical, for remotely handled waste, spent fuel, or high-level waste. The waste will remain in this canister during and after burial. A canister affords physical containment but not shielding; shielding is provided during shipment by a cask.
Capitan Reef	A buried fossil limestone reef of Permian age that rings the Delaware Basin except in the south.
Carlsbad Potash District	The area east of Carlsbad and north and west of the Los Medanos site formally designated by the U.S. Geological Survey as having potentially economic grades of potash mineralization.
Castile Formation	A formation of evaporite rocks (interbedded halite and anhydrite) of Permian age that immediately underlies the Salado Formation in which the WIPP repository will be located.
characterization, site	The process of making geologic and environmental studies to identify potential sites for mined geologic repositories. Detailed site characterization goes further: all additional data are collected that would be necessary if a license application is to be submitted.
clastic rock	Rock made up of broken fragments of preexisting rocks.

complexation The formation of a molecular or ionic complex, usually between an inorganic ion such as uranium or plutonium and a larger organic molecule. Such complexes are often quite stable and have chemical and physical properties, such as solubility and chemical reactivity, that are different from their components.

conservative When used with predictions or estimates, leaning on the side of pessimism. A conservative estimate is one in which the uncertain inputs are used in the way that maximizes the impact.

contact-handled waste Waste that does not require shielding other than that provided by its container.

containment The retention of radioactivity within prescribed boundaries, such as within a waste package. In this document, usually retention within a system to the exclusion of its release to the biosphere in unacceptable quantities or concentrations.

contamination Undesirable radioactive material present on outside surfaces. This contamination can be either transferable or fixed. Radiation penetrating the walls of a waste package from within is not contamination.

control zones Areas of land around the WIPP site whose use is governed by controls and restrictions.

creep closure Closure of underground openings, especially openings in salt, by plastic flow of the surrounding rock under lithostatic pressure.

crystalline rock Rock designated as being either igneous or metamorphic, not sedimentary; rock consisting wholly of mineral crystals or fragments of crystals.

Culebra dolomite The lower of two layers of dolomite within the Rustler Formation that are locally water bearing.

decay, radioactive The decrease in the number of radioactive nuclei present in a radioactive material due to their spontaneous transmutation. Also, the transmutation of a radionuclide into another nuclide by the emission of a charged particle.

decontamination	The removal of unwanted material (especially radioactive material) from the surface or from within another material.
defense waste	Nuclear waste deriving from the manufacture of nuclear weapons and the operation of naval reactors. Associated activities such as the research carried on in the weapons laboratories also produce defense waste.
deformation front	Boundary of a zone of folding, faulting, shearing compression, or extension of the rocks as a result of various Earth forces.
Delaware Basin	An area in southeastern New Mexico and adjacent parts of Texas where a sea deposited large thicknesses of evaporites some 200 million years ago. It is partially surrounded by the Capitan Reef.
Delaware Mountain Group	A set of three formations that underlie the Castile Formation at the Los Medanos site. The uppermost of these is the water-bearing Bell Canyon Formation.
direct-access scenario	A postulated sequence of events in which radionuclides are carried directly to the surface, such as by means of drilling.
discharge point or area	In groundwater hydraulics, the point (or area) where water comes out of an aquifer onto the surface.
disposal	Permanent disposition of waste in a repository. Use of the word "disposal" implies that no need for later retrieval is expected.
dissolution	The process whereby a space or cavity in or between rocks is formed by the solution of part of the rock material.
dissolution front	The boundary of a geologic region within which rock is dissolving. In this document, the term particularly refers to the wedgelike leading edge of salt dissolution at the interface between the Rustler and the Salado formations.
distribution coefficient	In an aquifer, the ratio of the concentration of a substance sorbed by the rock to the concentration of the substance remaining in solution. A large distribution coefficient implies that the substance moves much more slowly than the groundwater. It is measured in units of cm^3/g or equivalent.

dolomite	A sedimentary rock consisting mostly of the mineral dolomite: $CaMg(CO_3)_2$. It is commonly found with limestone.
dome (breccia pipe)	A type of hill found near the Los Medanos site; under at least some of these hills lies a roughly cylindrical volume of breccia (rock reconstituted from coarse rock fragments).
dose equivalent commitment	The total dose equivalent that results from an intake of radioactive materials during all the time from the intake to the death of the organism. For people, the dose is usually evaluated for a period of 50 years from the intake. Units are man-rems. Less formally, dose commitment.
dose (radiation)	A general term indicating the amount of energy absorbed per unit mass from incident radiation.
dose rate	The rate at which dose is delivered.
drift	A horizontal mine passageway.
evaporite	A sedimentary rock composed primarily of minerals produced by precipitation from a solution that has become concentrated by the evaporation of a solvent, especially salts deposited from a restricted or enclosed body of seawater or from the water of a salt lake. In addition to halite (NaCl), these salts include potassium, calcium, and magnesium chlorides and sulfates.
fault	A surface or zone of rock fracture along which there has been displacement.
fluid inclusion	Brine inclusion. An opening in a rock mass (salt) containing brine; also the brine included in such an opening. Some gas is often also present.
formation (geologic)	The basic rock-stratigraphic unit in the local classification of rocks. It consists of a body of rock (usually sedimentary) generally characterized by some degree of internal lithologic homogeneity or distinctive features.
geotransport	In this report, movement of radionuclides through subsurface soils and rocks, especially movement with the groundwater. Used in contrast to biotransport.

gypsum — A soft and, when pure, white mineral consisting of hydrous calcium sulfate:

$$CaSO_4 \cdot 2H_2O.$$

half-life — The time required for the activity of a group of identical radioactive nuclei to decay to half its initial value.

halite — The mineral rock salt: NaCl.

high-level waste — Radioactive waste resulting from the reprocessing of spent fuel. Discarded, unreprocessed spent fuel is also high-level waste. It is characterized by intense, penetrating radiation and by high heat-generation rates. Even in protective canisters, high-level waste must be handled remotely.

high-standard resources — Potash mineralization of 8 percent K_2O as langbeinite, or 14 percent K_2O as sylvite, or equivalent grade of mixed langbeinite-sylvite occurring in a minimum 4-foot interval. Roughly equivalent to the grade of ores currently being mined in the Carlsbad district.

horizon — In this report, an underground level. For instance, the waste-emplacement horizon in the WIPP is the level about 650 m deep at which openings would be mined for waste disposal.

hydraulic conductivity — A quantity defined in the study of groundwater hydraulics that describes the rate at which water flows through an aquifer. It is measured in feet per day or equivalent units. It is equal to the hydraulic transmissivity divided by the thickness of the aquifer.

hydraulic gradient — A quantity defined in the study of groundwater hydraulics that describes the rate of change of head with distance of flow.

hydraulic potential (hydraulic head) — Hydraulic pressure corrected for the potential energy of elevation. In an aquifer it is equivalent to the highest level of a column of water that the pressure in the aquifer will support. It is measured relative to a specified level, in this document, sea level.

hydraulic transmissivity	A quantity defined in the study of groundwater hydraulics that describes the rate at which water may be transmitted through an aquifer.
hydraulic transport	The transport of dissolved substances by groundwater.
hydraulics, hydrology	These two terms tend to be used interchangeably, but they do not mean quite the same thing. Hydraulics is an engineering discipline; hydrology is the related science. Hydraulics deals with the flow of water. Hydrology deals with water: its properties, circulation, and distribution, from the time it falls as rainwater until it is returned to the atmosphere through evapotranspiration or flows into the ocean.
hydrologic modeling	The process of using a mathematical representation of a hydrologic system (as embodied in a computer code) to predict the flow of groundwater and the movement of dissolved substances.
in situ	In the natural or original position. Used in this document to distinguish in-place experiments, rock properties, and so on, from those in the laboratory.
interstitial brine	Brine distributed in very small openings throughout a salt mass.
ion exchange	A phenomenon in which chemical species in one phase or material exchange with similar species in another phase.
irradiation	Exposure to any form of radiant energy.
isotope	A species of atom characterized by the number of protons and the number of neutrons in its nucleus. In most instances an element can exist as any of several isotopes, differing in the number of neutrons but not in the number of protons in their nuclei. Isotopes can be either stable or radioactive. The latter are called radioisotopes or radionuclides.
karst	A type of topography that is formed on limestone, gypsum, and other rocks by dissolution; characterized by sinkholes, caves, and underground drainage.

langbeinite	A mineral, $K_2Mg_2(SO_4)_3$, used in the fertilizer industry as a source of potassium sulfate.
leaching	The process of extracting a soluble component from a solid by the percolation of a solvent (in this report, water) through the solid.
lease-standard resources	Potash mineralization of 4 percent K_2O as langbeinite, or 10 percent K_2O as sylvite, or equivalent grade of mixed langbeinite-sylvite occurring in a minimum 4-foot interval. If located on federal land, can be acquired only through competitive bid.
liquid-breach scenario	A postulated sequence of events in which radionuclides are carried by groundwater and released.
lithostatic pressure	Subsurface pressure due to the weight of overlying rock or soil.
Los Medanos	In this report, the area in southeastern New Mexico surrounding the site proposed for the WIPP repository of alternative 2. In Spanish it means "dune country," and has a tilde over the n: Los Medaños.
low-level waste	Any gaseous, liquid, or solid radioactive waste not classified as high-level waste, TRU waste, spent nuclear fuel, or byproduct material.
Magenta dolomite	The upper of two layers of dolomite within the Rustler Formation that are locally water-bearing.
Malaga Bend	A sharp bend in the Pecos River 20 miles southeast of Carlsbad, New Mexico, and directly east of the town of Malaga. The discharge points of the Rustler aquifers are a series of brine seeps and springs nearby.
man-rem	A unit of population dose.
maximally exposed person	A hypothetical person who is exposed to a release of radioactivity in such a way that he or she receives the maximum possible individual dose or dose commitment. For instance, if the release is a puff of contaminated air, this is a person at the point of largest ground-level concentration who stays there during the whole time of cloud passage. The use of this term is not meant to

imply that there really is such a person, but only that thought is being given to the maximum exposure a person could receive.

maximum — The highest dose delivered to the whole body or to an individual dose individual organ that a person can receive from a release of radioactivity. The hypothetical person who receives this dose, the maximally exposed person, is one whose location and activities maximize the dose.

Nash Draw — A shallow 5-mile-wide valley open to the southwest located to the west of the WIPP reference site.

natural background radiation — Radiation in the human environment from naturally occurring elements and from cosmic radiation.

nuclide — Isotope.

overcoring — A process for removing waste from its burial in salt by extracting a cylinder of salt that surrounds and contains the waste.

overpack — A container put around another container. In the WIPP, overpacks would be used on damaged or otherwise contaminated drums, boxes, and canisters that would not be practical to decontaminate.

packer — A device used in drilled holes to isolate geological strata from one another in order to carry out hydrologic studies of particular formations.

Paradox Basin — A 10,000-square-mile area in southeastern Utah and southwestern Colorado underlain by a series of salt-core anticlines.

permeability — Equivalent to hydraulic conductivity.

Permian Basin — A region in the central United States where, during Permian times 280 to 225 million years ago, there were many shallow seas that laid down vast beds of evaporites. The Delaware Basin is a part of the Permian Basin.

polyhalite — An evaporite mineral that is hard, poorly soluble, and with no economic value:

$$K_2MgCa_2(SO_4)_4 \cdot 2H_2O.$$

population dose	The sum of the radiation doses received by the individual members of a population.
potash	In this report, a potassium compound, especially as used in agriculture or industry.
potentiometric surface	The surface of the hydraulic potentials of an aquifer. It is usually represented in figures as a contour map, each point in which tells how high the water would rise in a well tapping that aquifer at that point.
radiolysis	Chemical decomposition by the action of radiation.
recharge point (or area)	In groundwater hydraulics, the point (or area) where surface water enters an aquifer.
rem	A unit of individual radiation dose equivalent.
remotely handled waste	Waste that requires shielding in addition to that provided by its container in order to protect people nearby.
repository	A facility for the storage or disposal of radioactive waste.
reprocessing	The process by which spent fuel from a reactor is separated into waste material and uranium and plutonium to be reused as nuclear fuel.
reserves	Mineral resources that can be extracted profitably by existing techniques and under present economic conditions.
resources	Reserves plus all other mineral deposits that may eventually become available--either known deposits that are not economically or technologically recoverable at present, or deposits that may be inferred to exist but have not yet been discovered.
retrievable	Describes storage of radioactive waste in a manner designed for recovery without loss of control or release of radioactivity.
risk	The product of probability and consequence. In this report, the radioactive risk of a scenario is the population dose resulting from that scenario multiplied by the probability that the scenario will actually occur.

Rustler Formation	The evaporite beds, including mudstones, of probable Permian age that immediately overlie the Salado Formation in which the WIPP disposal levels may be built.
Salado Formation	The evaporite formation of Permian age within which wastes would be disposed of in the WIPP repository of alternative 2.
Salt Vault, Project	A field experiment carried out by ORNL between 1965 and 1967 in an abandoned salt mine at Lyons, Kansas. Its purpose was to demonstrate the feasibility and safety of the concept of emplacing high-level waste in salt, to demonstrate equipment and techniques for handling packages of highly radioactive solids, and to secure data for the design of an actual disposal facility. Its results are reported in Bradshaw and McClain (1971).
San Simon Sink	The central, most depressed area of San Simon Swale.
San Simon Swale	A broad depression about 15 miles east of the Los Medanos site, open to the southeast.
scenario	A particular chain of hypothetical circumstances that could, in principle, release radioactivity from a repository.
shaft	A man-made hole, either vertical or steeply inclined, that connects the surface with the underground workings of a mine or a repository.
shallow-dissolution zone	Also called a brine aquifer. A zone of residual material at the interface of the Rustler and Salado formations left after dissolution of the original salt. It is highly permeable and contains much brine.
sorption	The binding of one substance to another on a microscopic scale, such as by adsorption or ion exchange. In this report, the word is used especially with reference to the sorption of solutes onto aquifer solids.
spent fuel	Nuclear-reactor fuel that, through nuclear reactions, has been sufficiently depleted of fissile material to require its removal from the reactor.

storage	Temporary disposition in a repository. Use of the word storage implies keeping open the possibility of retrieving the waste for reprocessing, for moving it elsewhere, etc. Storage usually implies the need for continued surveillance.
sylvite	A mineral, KCl, used as a fertilizer.
tectonic activity	Movement of the Earth's crust such as uplift and subsidence and the associated folding, faulting, and seismicity.
thermal gradient	The rate of change of temperature in the direction of increasing temperature.
transuranic nuclide	A nuclide with an atomic number greater than that of uranium (92). All transuranic nuclides are produced artificially and are radioactive.
TRU waste	Waste with a specific transuranic alpha activity of 100 nCi/g or greater. This waste can vary greatly in its specific gamma activity.

ABBREVIATIONS AND ACRONYMS

AEC	U.S. Atomic Energy Commission
CH	Contact-Handled
DOE	U.S. Department of Energy
DEIS	Draft Environmental Impact Statement
DHLW	Defense High-Level Waste
DMG	Delaware Mountain Group
DOT	U.S. Department of Transportation
EEG	State of New Mexico Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration
FEIS	Final Environmental Impact Statement
HEPA	High-Efficiency Particulate Air (a type of filter)
ICRP	International Commission on Radiological Protection
INEL	Idaho National Engineering Laboratory
IRG	Interagency Review Group
NRC	U.S. Nuclear Regulatory Commission
PREPP	Process Experimental Pilot Plant
R&D	Research and Development
RH	Remotely Handled

RSE	Radiation Source Experiment
SAR	Safety Analysis Report
SPDV	Site and Preliminary Design Validation
SWEPP	Stored Waste Experimental Pilot Plant
TE	Technology Experiment
TRU	Transuranic (refers to nuclides beyond uranium in the periodic table)
TRUPACT	Transuranic Package Transporter
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

APPENDIX A

LETTER REPORT, PARKER TO GLOYNA, May 1, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

May 18, 1979

Mr. Sheldon Meyers
Program Director
Office of Nuclear Waste Management
Department of Energy (MS B-107)
Washington, D. C. 20545

Dear Mr. Meyers:

I am pleased to forward the enclosed letter report by the Panel on the Waste Isolation Pilot Plant (WIPP) on its review of the WIPP Draft Site Characterization Report (SAND 78-1596). The Committee on Radioactive Waste Management has discussed the substance of this letter and endorses the views of the Panel expressed therein.

I hope these observations will be useful in the continuing process of geotechnical characterization of the proposed WIPP site.

Sincerely,

Earnest F. Gloyna
Chairman

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NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

May 1, 1979

Dr. Earnest F. Gloyna, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

Dear Dr. Gloyna:

As part of its continuing responsibility to review criteria and guidelines for the location, design, construction, and operation of a proposed radioactive waste isolation pilot plant (WIPP), this Panel has reviewed the WIPP Draft Site Characterization Report (DSCR), SAND 78-1596, prepared by Sandia Laboratories for the Department of Energy. The DSCR, which has subsequently been published, with the same report number, as "Geological Characterization Report (WIPP)," is a compilation of the known geotechnical information about the proposed site and the surrounding region, with chapters devoted to regional geology, site geology, seismology, hydrology, geochemistry, resources, and special studies of WIPP repository rocks. It does not address such matters as socioeconomic considerations, accessibility, transportation and failure modes, which will need to be included in a complete site characterization.

The following brief account, which must be viewed in conjunction with the DSCR itself, is intended for a very limited audience of readers fully conversant with the contents of the basic document.

As a first step in this review, individual chapters of the DSCR were examined in detail by subgroups of the Panel with special expertise in the disciplinary areas involved, after which their separate comments were discussed by the full Panel in a meeting with the Sandia authors of the document.

The Panel then reviewed the extent to which the information contained in the DSCR provides sound geotechnical support for an environmental impact analysis and related decisions leading to the selection of an

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appropriate site for the proposed pilot plant. The review focused on the Report's exposition of geotechnical information with critical bearing on the site's probable ability to provide the desired long-term isolation of emplaced waste, e.g. seismic or tectonic uplift, intrusion of groundwater, thermal and mechanical characteristics of the host rock, and retardation effects along possible migration pathways. The Report did not treat, nor did the Panel consider, the effect of the emplacement of waste or the waste itself on the long term integrity of the repository. Although recognizing the considerable coverage and detail of the information presented, the Panel noted a few areas where additional data are desirable to more fully characterize the geotechnical aspects of the area under consideration. These include the following:

a) A major disagreement between conclusions reached in the DSCR and the views of R. Y. Anderson is mentioned in several places. Anderson, a professor of geology at the University of New Mexico at Albuquerque, who has specialized in the study of evaporite deposits in the Delaware Basin, was commissioned by Sandia Laboratories to prepare a report on the deep dissolution of salt in the region around the proposed WIPP site. Basing his argument on a postulated unconformity at the base of the Salado formation and on his hypothesis that the so-called "breccia pipes" are localized features of deep dissolution which originated as collapse chambers in salt beds immediately overlying the reef and basin aquifers, Anderson suggested that dissolution may be so rapid that the entire salt formation will disappear within a million years. The DSCR, on the other hand, considers only dissolution at the western edge of the salt beds and concludes that present rates will ensure preservation of the Salado at the WIPP site for at least a few million years. The Panel feels that a more thorough explanation should have been provided as to why the authors of the DSCR consider their views preferable to Anderson's hypothesis. On this same issue of salt dissolution, the DSCR estimates of the rate of retreat of the solution front two or three miles west of the site are evidently based on the assumption of uniform dissolution over a wide area under average conditions. A rational basis should be provided for this assumption, vis a vis the possibility of accelerated dissolution rates in local areas, with selective removal of salt from beneath the present sedimentary cover, particularly if pluvial conditions were to change in the future.

b) Additional data and analyses would be helpful to determine with greater confidence the current rates of tectonic uplift in the region and whether, as a result, the salt may be exposed to accelerated erosion at some time in the foreseeable future.

c) The so-called "breccia pipes" need more detailed analyses to determine whether they may serve as conduits for water that may have promoted, or may in the future promote, deep dissolution of the salt beds.

d) There appears to be sufficient information to resolve the question regarding the likelihood of upward flow from the Bell Canyon formation through the Salado, where the proposed repository horizons are located, to the overlying Rustler. This should be addressed.

e) Because rock properties have a strong influence on mine design, more detailed information is needed on the various rock types in the area and on their permeability, fracture, and thermal properties under conditions as similar as possible to those that would be found in a repository. Both laboratory and field tests approximating in-situ conditions will be required to develop this information.

f) The information on sorption of the important radionuclides by materials to be expected in possible migration paths, under conditions resembling those near a possible repository, seems to be sparse. As soon as the types of waste to be stored in the repository are known, a more complete discussion should be presented of the retardation anticipated in the migration paths.

g) The most recent episode of any recrystallization in the Salado formation near the proposed WIPP site is reported to have occurred about 200 million years ago. The Panel urges confirmation of this important date by further studies and other techniques, as described in Section 7.8 of the DSCR.

In summary, the Panel views the DSCR as a progress report on a continuing program of geotechnical data collection and analysis, conducted under the constraint of no perturbation of the potential site. The Panel considers the report to be useful as a compendium of the information available to the authors on the character of the unperturbed geological formation at the Los Medanos site and the dynamics of the geochemical/hydrological system. On the basis of this available information, further investigation of the site is warranted. However, final decisions regarding repository site selection must take into account more information than is contained in this report. Most importantly, they must take into account the effect of the emplacement of the waste and the waste itself on the repository and its surroundings. These decisions must be based also on supplementary data acquisition and analyses such as those suggested above; the additional studies delineated in the document itself; crucial in-situ studies conducted throughout the construction phase; and additional definition of design objectives, criteria for safe operation, and waste forms to be accommodated.

Sincerely,

Frank L. Parker

Frank L. Parker, Chairman
Panel on the Waste Isolation
Pilot Plant

APPENDIX B

LETTER REPORT, PARKER TO WILSON, SEPTEMBER 10, 1979

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

September 12, 1979

Mr. Sheldon Meyers
Program Director
Office of Nuclear Waste Management
U. S. Department of Energy (MSB-107)
Washington, D. C. 20545

Dear Mr. Meyers:

I am pleased to forward the enclosed letter, by the Panel on the Waste Isolation Pilot Plant (WIPP), regarding the desirability of sinking an exploratory shaft at the proposed repository site. The Committee on Radioactive Waste Management has reviewed the letter and endorses the Panel's views expressed therein.

Sincerely,

E. Bright Wilson

E. Bright Wilson
Chairman
Committee on Radioactive
Waste Management

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NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (202) 389-6727

September 10, 1979

Dr. E. Bright Wilson, Chairman
Committee on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue
Washington, D. C. 20418

Dear Dr. Wilson:

During the past year, the Panel on the Waste Isolation Pilot Plant (WIPP) has become familiar with the findings of the various extensive geological explorations, including boreholes from the surface and attendant geotechnical studies, attempting to characterize the proposed WIPP site and provide a basis for judging this aspect of the site's suitability for a waste repository. This familiarization process has included briefings by representatives of Sandia Laboratories and the U. S. Geological Survey, study of both the published and unpublished technical literature, site visits, examination of actual borehole cores, and discussions with other experts in selected geotechnical areas.

Our efforts have brought to light no disqualifying results from these explorations and studies to rule out further consideration of the proposed site at this stage. The Panel has reached this conclusion after taking into account the comments made in my letter of May 1, 1979, reporting on our review of the WIPP Draft Site Characterization Report (issued as SAND78-1596, Geological Characterization Report), pointing out that certain effects have been observed which can be interpreted as indicating the possible existence of significant anomalies. Additional information is clearly required before these anomalies can be resolved

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and a decision made regarding the adequacy of the proposed WIPP site for the construction of a repository. Furthermore, continued commitments to final details of repository design in the absence of additional site-specific information may be both misleading and wasteful.

The Panel is of the unanimous opinion that continuing efforts to acquire the necessary additional information solely by means of surface exploration, including boreholes, have reached the point of diminishing returns and cannot resolve all the major remaining uncertainties. Accordingly, the Panel recommends that:

(1) An exploratory shaft be sunk at the site of one of the proposed access shafts as soon as practicable, to the depth of the proposed repository horizon.

(2) Drilling be done and tunnels developed in the salt as necessary to conduct the measurements and observations needed to resolve remaining site-specific geotechnical uncertainties and to ascertain the degree to which the site is suitable for the excavation of a repository.

Development of the shaft, tunnels, and any other exploratory excavations should be consistent with applicable environmental and safety standards, strict quality assurance procedures, and should be compatible with an actual repository, if one is constructed at this site.

Sincerely,

Frank L. Parker

Frank L. Parker
Chairman, Panel on the
Waste Isolation Pilot Plant

APPENDIX C

CONTINUING EVALUATION OF THE CARLSBAD SITE, July 28, 1980

REPORT NO. DOE/CH/93023-1

NATIONAL RESEARCH COUNCIL
COMMISSION ON NATURAL RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT

(202) 389-6727

August 1, 1980

Ms. June Wiinikka
Contracts Management Office
U.S. Department of Energy
9800 South Cass Avenue
Argonne, IL 60439

Re: Task Agreement DE-AT02-76CH93023

Dear Ms. Wiinikka:

Enclosed are six (6) copies of a report prepared under the referenced Task Agreement, together with a completed DOE Form IR-427.

Sincerely,

John T. Holloway
Staff Officer
WIPP Panel

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

Report No. DOE/CH/93023-1

CONTINUING EVALUATION OF THE CARLSBAD SITE

A Report to the U. S. Department of Energy, prepared by the Panel on the Waste Isolation Pilot Plant of the Committee on Radioactive Waste Management.

COMMISSION ON NATURAL RESOURCES
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
Washington, D. C.
July 28, 1980

N O T I C E

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ABSTRACT

It is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements, set forth in his February 12, 1980, message to the Congress, for evaluation of this site as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives. Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.

NOTICE: The project that is the subject of this report was authorized by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. Such authorization reflects the Board's judgment that the project is of national importance and appropriate with respect to both the purposes and resources of the National Research Council. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

The report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee of the National Academy of Sciences.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its Congressional charter of 1863, which establishes the Academy as a private, non-profit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

Funded by the U. S. Department of Energy
Contract No. EY-76-C-02-2708-023

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Florida State University

John T. Holloway
Staff Officer

NOTE: Two Panel members did not participate in the deliberations leading to this report; John W. Winchester was out of the country on sabbatical leave, and Karl P. Cohen is a new member of the Panel.

CONTINUING EVALUATION

OF THE CARLSBAD SITE

The Panel on the Waste Isolation Pilot Plant (WIPP) was organized by the National Academy of Sciences in 1978, under the Committee on Radioactive Waste Management of the National Research Council, to review the scientific and technical criteria and guidelines for designing, constructing, and operating a Waste Isolation Pilot Plant for isolating radioactive wastes from the biosphere, with specific attention to a proposed site near Carlsbad, New Mexico.

On February 12, 1980, President Carter transmitted to the Congress "A Report on His Proposals for a Comprehensive Radioactive Waste Management Program." This report states the President's decision that the WIPP project, currently authorized for the unlicensed disposal of defense transuranic waste and for research and development using high-level defense waste, should be cancelled; but that the Carlsbad site will continue to be evaluated, along with other sites in other locations, for possible use as a licensed repository for defense and commercial high-level wastes.

The Panel has reviewed in depth the work of the DOE contractors on the geologic characteristics of the Carlsbad site, the characteristics of the defense and spent-fuel radioactive wastes that have been considered for emplacement, and the conceptual design of the repository. The WIPP Draft Environmental Impact Statement has been analyzed with

respect to the potential impact on public health and safety.

As a result of these deliberations, the Panel has previously concluded that continued investigation of the Carlsbad site is warranted and has recommended that the project proceed with an exploratory shaft to determine in greater detail the geologic, hydrologic, and structural features of the candidate salt beds, and with in-situ tests as necessary to evaluate the geotechnic adequacy of this site for a waste repository. The Panel considers these in-situ tests to be no less timely and technically desirable within the framework of the President's statement.

In connection with the Carlsbad site, a talented team of scientists and engineers has been assembled, and extensive geological exploration has been conducted. Laboratory facilities are excellent, important experiments on waste disposal are under way, and underground engineering designs have been developed. The project has gained momentum that would be difficult to recapture if it were to be interrupted. There are sound technical reasons for continuing the exploratory work:

1. <u>Much of the information from the investigation of the Carlsbad site and all of the technology being developed by this project are applicable to any repository located in domed or bedded salt and licensed for high-level and transuranic defense and commercial wastes.</u>

   The analyses made thus far, supported by ongoing and planned testing programs to validate these analyses,

lead to the reasonable expectation that the site may be suitable not only for its original limited purpose as a defense transuranic waste repository but also as a licensed repository for both defense and commercial high-level and transuranic waste. The present experimental program will yield results that can be applied to the expanded purpose envisioned in the President's program. The exploratory shaft, now planned and ready to be constructed to a depth suitable for transuranic waste, can be extended to a lower horizon, where there is another salt bed that may be better suited for high-level wastes. The information obtained from this exploratory work will not only be useful for further evaluation of the Carlsbad site but can also be applied to other candidate salt formations.

2. <u>The President's announced objectives can be achieved sooner, and with greater certainty of success, if the work begun under the WIPP Project is continued but reoriented toward these new objectives.</u>

Very long lead times are involved in the President's proposed new program of selecting alternative sites, constructing test facilities at each, choosing a first repository site, and eventually constructing one or more licensed repositories.

The extensive information already obtained on the Carlsbad site and the demonstrated expertise of the existing investigative teams provide an

opportunity to proceed much sooner with in-situ testing at a potential candidate site--a capability which will have to be developed before this or any other site can be selected for a first actual repository.

More is known about the Carlsbad site than about any of the other sites under consideration. Questions remain that will require resolution by additional analyses and testing, but such questions are normal for this stage of an investigation.

The Panel concludes that it is technically feasible to reorient the work on the Carlsbad site to fulfill the President's requirements for evaluation of this site, as one of several candidate sites, for later decisions regarding development of a licensed facility for defense and commercial high-level and transuranic wastes. If so reoriented, the project could contribute by:

- providing prototype experience in site qualification;
- testing, in situ, performance assumptions about the geologic medium; and
- developing techniques and information which will be required in the licensing process.

If given this new mission, work should proceed on constructing the exploratory shaft, acquiring hands-on repository mining experience, conducting in-situ tests and measurements at various depths, verifying engineering design assumptions, and developing analyses for licensing review.

APPENDIX D

NATURAL RESOURCES AT WIPP

The resources of concern are principally the potash salts, which are located in 11 ore zones from 126 m to 240 m above the repository depth, and potential hydrocarbon resources, which are well below the repository depth (see Table D-1). Other possible resources, such as salt, gypsum, and caliche, are considered of insufficient importance to warrant concern, as their abundance throughout the area is such that the withdrawal of this area would have no impact on their availability (Brausch et al. 1982).

Groundwater is not considered a resource at the WIPP site, because water in greater volume and of better quality is available from other areas nearby. Quality of water in the Los Medanos area is extremely variable; for example, total dissolved solids in water from the Magenta dolomite range from 5,460 to 270,000 ppm; in the Culebra dolomite from 3,200 to 420,000 ppm; and in the Bell Canyon Formation from 1,000 to more than 300,000 ppm (U.S. Department of Energy 1980-1983).

The originally proposed controlled-access area at the site, including Zones I, II, III, and IV, has recently been reduced by the elimination of most of Zone IV. The new site boundary encompasses a square area comprising 16 sections, as shown in Figure 2-4. This means that most of the former Zone IV is now open for exploitation of its mineral resources. Zone III provides a 1-mile-wide buffer zone between the repository excavations and the site boundary.

Within the time limits of repository control, no drilling for hydrocarbons and no mining for potash will be allowed within Zones I, II, and III. Since the hydrocarbon horizons are below the salt sequences, directional drilling from outside the new site boundary could be considered to explore for hydrocarbons. Potash mining might be permitted outside the site boundary. However, the panel believes that DOE should have the authority to review and approve each proposed drilling and recovery project in the former Zone IV in order to assure procedures consistent with repository integrity.

HYDROCARBONS

If directional drilling is used for hydrocarbon exploration and production, standard well techniques of casing, cementing, and

TABLE D-1 Significance of Resources and Reserves at the WIPP Site

Deposit	WIPP Site	Region	United States	World
		RESOURCES[a]		
Sylvite (at lease grade)				
Quantity, million tons ore	88.5	4,260	8,500	850,000
Percentage at WIPP site		2.1	1.0	0.010
High grade	54.0			
Low grade	133.2			
Langbeinite (at lease grade)				
Quantity, million tons ore	264.2	1,140	No estimate available	
Percentage at WIPP site		23 (21.5 as K_2O)		
High grade	77.6			
Low grade	351.0			
Crude Oil				
Quantity, million barrels	37.50	1,915	200,000	Not
Percentage at WIPP site		2.0	0.019	available
Natural Gas				
Quantity, billion cubic feet	490	25,013	855,000	Not
Percentage at WIPP site		2.0	0.057	available
Distillate				
Quantity, million barrels	5.72	293	Not available	
Percentage at WIPP site		2.0		
		RESERVES[b]		
Sylvite[c]				
Quantity, million tons K_2O	3.66	106	206	11,206
Percentage at WIPP site		3.4	1.8	0.033
Langbeinite[d]				
Quantity, million tons K_2O	0.92[d]	9.3	9.3	Not
Percentage at WIPP site		10	10	available
Crude Oil				
Quantity, million barrels	Nil	471.7	29,486	646,000
Percentage at WIPP site		0	0	0
Natural Gas				
Quantity, billion cubic feet	44.62	3,865	208,800	2,520,000
Percentage at WIPP site		1.15	0.021	0.0018
Distillate				
Quantity, million barrels	0.12	169.1	35,500	Not
Percentage at WIPP site		0.07	0.003	available

[a]*Data Sources: Hydrocarbons, Foster (1974) for the site and region; potash salts,* John et al. (1978) for the site and region; Brobst and Pratt (1973) for U.S. oil and gas and the world resources of sylvite.
[b]Data Sources: Hydrocarbons, Keesey (1979) for the site; American Petroleum Institute (1978) for the region, the United States, and the world; potash salts, U.S. Bureau of Mines (USBM 1977).
[c]The U.S. Bureau of Mines (USBM 1977) does not consider any sylvite to be commercial today. However, one bed (mining unit A-1) of sylvite was marginal and has been added to the reserve list.
[d]Estimated from the AIM (1979) study. The USBM estimate for the WIPP site is 4.41 million tons K_2O equivalent, but no comparable USBM estimate is available for the entire district.

SOURCE: U.S. Department of Energy (1980).

production can assure minimal damage to the rock system. Recovery and stimulation methods, e.g., acidizing and hydraulic fracturing, would all be at sufficient depth and under sufficient control to have no effect on the integrity of the repository (Brausch et al. 1982).

Solution mining would not be considered as an extraction method at the WIPP site, but the technique has been suggested as a means of making storage cavities for hydrocarbons. While this mining system requires water to dissolve the salt, the stresses and water convection problems do not differ from those of standard mining when the shape and size of the cavities are taken into consideration. The old Zone IV could possibly be considered for storage sites. Obviously, construction of a storage cavern in any of these zones would not be likely, because any location with 244 m of overburden and a minimum of 9 m thickness of salt will be sufficient to make a suitable storage cavity. Thus, while there is little technical reason for prohibiting storage cavities to be constructed just outside the current site boundary, there is no obvious advantage in doing so. Solution cavities should be prohibited within the site boundary.

POTASH

The Carlsbad region has been the principal source of potash in the United States for many years. The established mines are to the north and west of the WIPP site. The potash zones are also known to be present east of the WIPP site, becoming deeper toward the east. The extent of the potash beds throughout the basin has not been thoroughly investigated, but fragmentary data from oil well logs indicate these beds are not of high grade in potash content or thickness. The potash ore in the vicinity of the WIPP site is in the McNutt Potash Zone, from 412 m to 525 m below the surface and, in general, is insufficient in either grade or thickness to make mining economically attractive at the present time. The mineral langbeinite, $K_2Mg_2(SO_4)_3$, may have some economic value as it has a special application in fertilizer for the types of plants that are sensitive to chloride ions. Within the new site boundary, the reserves of langbeinite are estimated to be about 12 million metric tons, and sylvite is not present.

Questions regarding the classification of these potash deposits as reserves or resources and the timing of future development are complex. The discovery of potash deposits in the Michigan Basin, which are of significant quantity and quality, could affect the value and, therefore, the classification of the Carlsbad deposits (Mathews 1970). The Michigan deposits are some 3,130 m to 3,440 m deep, and their economic recovery has yet to be determined; however, the geographical location with relation to the fertilizer market, water availability, land availability, and other such factors favor their value and might depress the value of the potash deposits in the Carlsbad region.

Although extraction of potash just outside the site boundary may be permitted, it is not currently economic.

The possible effect on potash mining in the former Zone IV of subsidence over the repository excavation in Zone II has been considered

by Brausch et al. (1982). Subsidence at the surface or at points below cannot exceed the height of the entry. The distance of the subsidence is related to the extent of extraction and other factors unique to the overlying strata. Thus, with a 3-m-high entry and 25 percent extraction, the maximum subsidence above the cavity would be 0.76 m. Because the salt will flow plastically and the rooms and entries are to be backfilled, this would decrease the subsidence at least by 50 percent, or 0.38 m. In addition, because there are 651 m of overburden, the bulking factor would be sufficient to make this subsidence over the entry even less. These are reasonable assumptions in agreement with mining practice (Society of Mining Engineers 1973). Brausch et al. (1982) use 45 degrees as the angle of draw, noting that this is the value commonly used for salt in New Mexico potash mining operations. Thus, for an excavation at a depth of 651 m, the area that could be disturbed at the surface would extend 651 m beyond the excavation perimeter. If the horizon from which resources are to be mined is 126 m above the repository horizon, the limit of the zone of influence of the repository would be 126 m beyond the excavated edge of the repository.

Potash mining is done by shaft sinking and room and pillar development. If water zones are encountered, they are sealed by grouting. The New Mexico mines are typically free from water intrusion, and the occasional flowing brine seems to come from pockets of limited volume. Several approaches have been made to evaluate the limiting distance of influence from the repository toward the nearest possible mine. It should be pointed out that this distance is between the outermost repository excavations at 651 m and the nearest potash excavation at the potash zone level, i.e., 126 m to 240 m above the repository entry. Using the empirical 45° angle of draw and a difference in depth of 126 m, there is no effect beyond 126 m from the repository, and at a 240-m difference, the limit is 240 m from the repository, and so on.

Brausch et al. (1982) present several more sophisticated analysis methods, with the conclusion that the effects of the WIPP facility would extend a maximum distance of 115 m. They conclude that a potash zone 610 m deep and a repository 655 m deep would show no interaction if separated horizontally by 213 m or more. On the surface above the site the repository could have an influence up to 655 m beyond the outer boundary of Zone II, and the influence of a potash mine at a depth of 610 m in the old Zone IV could extend inward 610 m from the current site boundary. This would leave some 305 m of surface undisturbed, and the distance would be proportionally greater nearer the repository horizon.

Stress-induced increases in hydraulic conductivity were examined (Brausch et al. 1982) for the inert gases and several hydrocarbons. It was concluded that while the mining of potash "would result in a zone immediately surrounding the openings in which the hydraulic conductivity of the rock would be greatly increased," further from the mine the hydraulic conductivity would be less and "therefore no preferential paths for groundwater flow between a potash mine developed within Control Zone IV and the WIPP facility would be expected to be created due to stress induced change in hydraulic conductivity."

REFERENCES

Brausch, L. M., A. K. Kuhn, and J. K. Register. 1982. Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3156. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Mathews, R. D. 1970. Distribution of Silurian Potash in the Michigan Basin. 6th Forum on Geology of Industrial Minerals, April 2-3. Department of Geology, University of Michigan.

Society of Mining Engineers. 1973. Roof and ground control. Chapter 13 in Mining Engineering Handbook, Vol. 1. American Institute of Mining Engineers, New York.

U.S. Department of Energy. 1980. Final Environmental Impact Statement (FEIS): Waste Isolation Pilot Plant. DOE/EIS-0026. Washington, D.C.

U.S. Department of Energy. 1980-1983. Waste Isolation Pilopt Plant Safety Analysis Report. WIPP SAR (includes Amendments 1-6). Albuquerque Operations Office, N.Mex.

APPENDIX E

BRECCIA PIPES

The possibility of the formation of new vertical pipelike masses of breccia collapse induced by solution working upward into the repository in salt beds from several possible underlying aquifers (Bell Canyon Formation or Castile anhydrite) has been raised (Anderson and Kirkland 1980).

Of the various deep-seated karst landforms and deposits observed in the Delaware Basin, only two have been confirmed by coring to be breccia pipes (Hills A and C), despite the many miles of geophysical surveys (Figure E-1), the drilling of 71 shallow and deep exploration holes in the vicinity of the WIPP site, examination of records of 300 oil and gas wells adjacent to the WIPP site, the detailed mapping of subsurface and surficial deposits, the extensive mining of McNutt potash on three sides of the WIPP site, and excavations and shafts completed as part of SPDV. By 1976, 142 km^2 of potash mines were developed in the region above backreef, reef, and forereef deposits in the Delaware Basin. Despite these extensive excavations, only one breccia pipe was encountered during potash mining, Hill C (Figure E-2). Hills A and C were both cored (WIPP-31 and WIPP-16) and showed breccia present at depth. Two other possible pipes other than Hills A and C were reported (Hills B and Wills-Weaver). One was reported to have been penetrated by one of more than 300 potash exploration holes drilled in the region, and geological and geophysical studies indicate that these most likely are breccia pipes as well. No conclusion can be drawn from the potash drill hole report because data were scanty.

These observations indicate that breccia pipes are exceptions, rather than the rule, in the Delaware Basin, and are far more restricted in their distribution than originally implied by Anderson. Anderson and Kirkland's model (1980) for pipe formation requires the concentrated solution removal of salt at depth (they postulated the Bell Canyon aquifer), presence of unsaturated groundwater at some time in the history of the pipe, an aquifer or aquifers with sufficient hydraulic conductivities and porosities to allow groundwater to transport salt from the aquifer, sufficient gradients to induce groundwater flow, and an outlet or sink for both the water and the dissolved salt. The bounding calculations of Wood et al. (1982) for necessary rates of groundwater circulation and salt dissolution showed that necessary and sufficient conditions for breccia pipe development in the number, size,

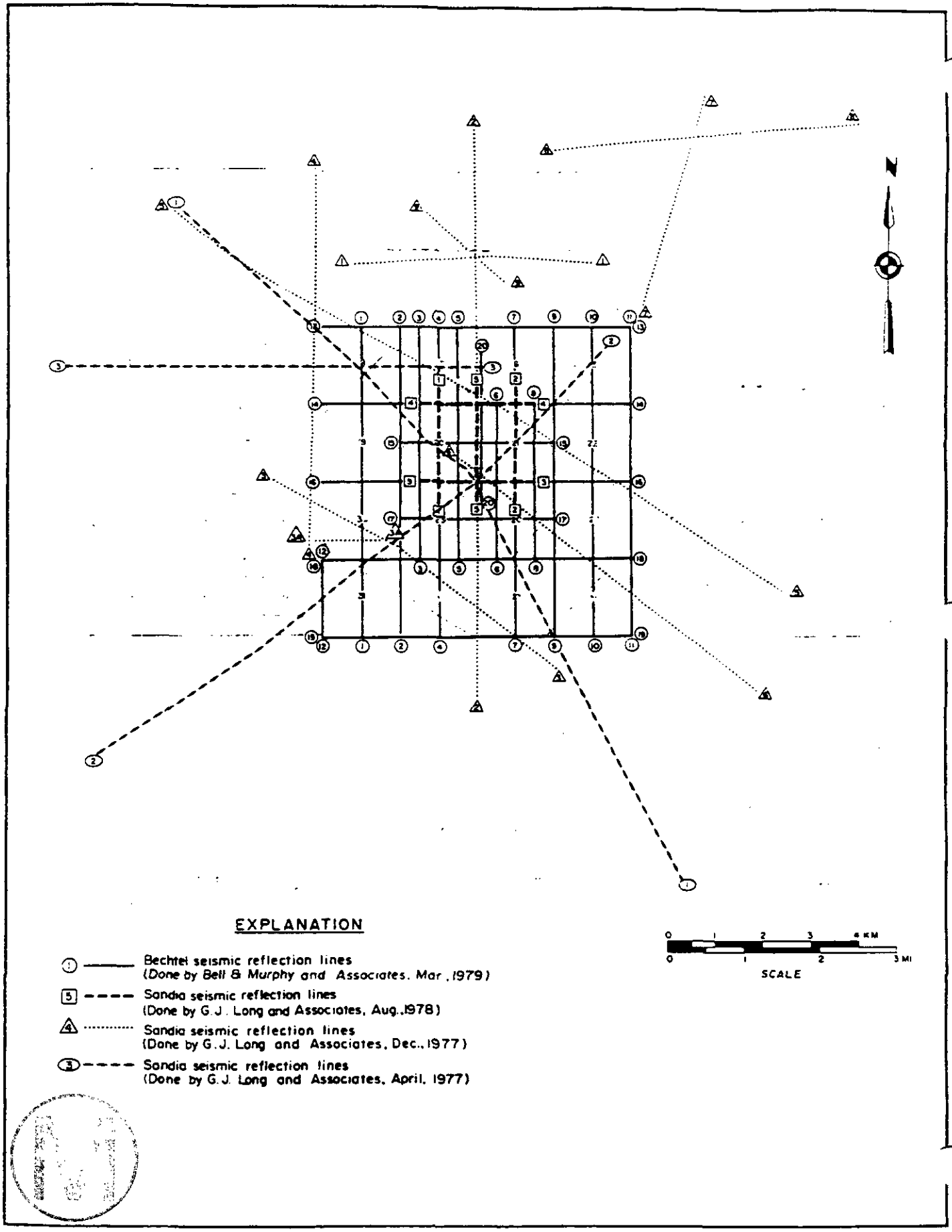

FIGURE E-1 Seismic reflection lines. Source: U.S. Department of Energy (1980-1983).

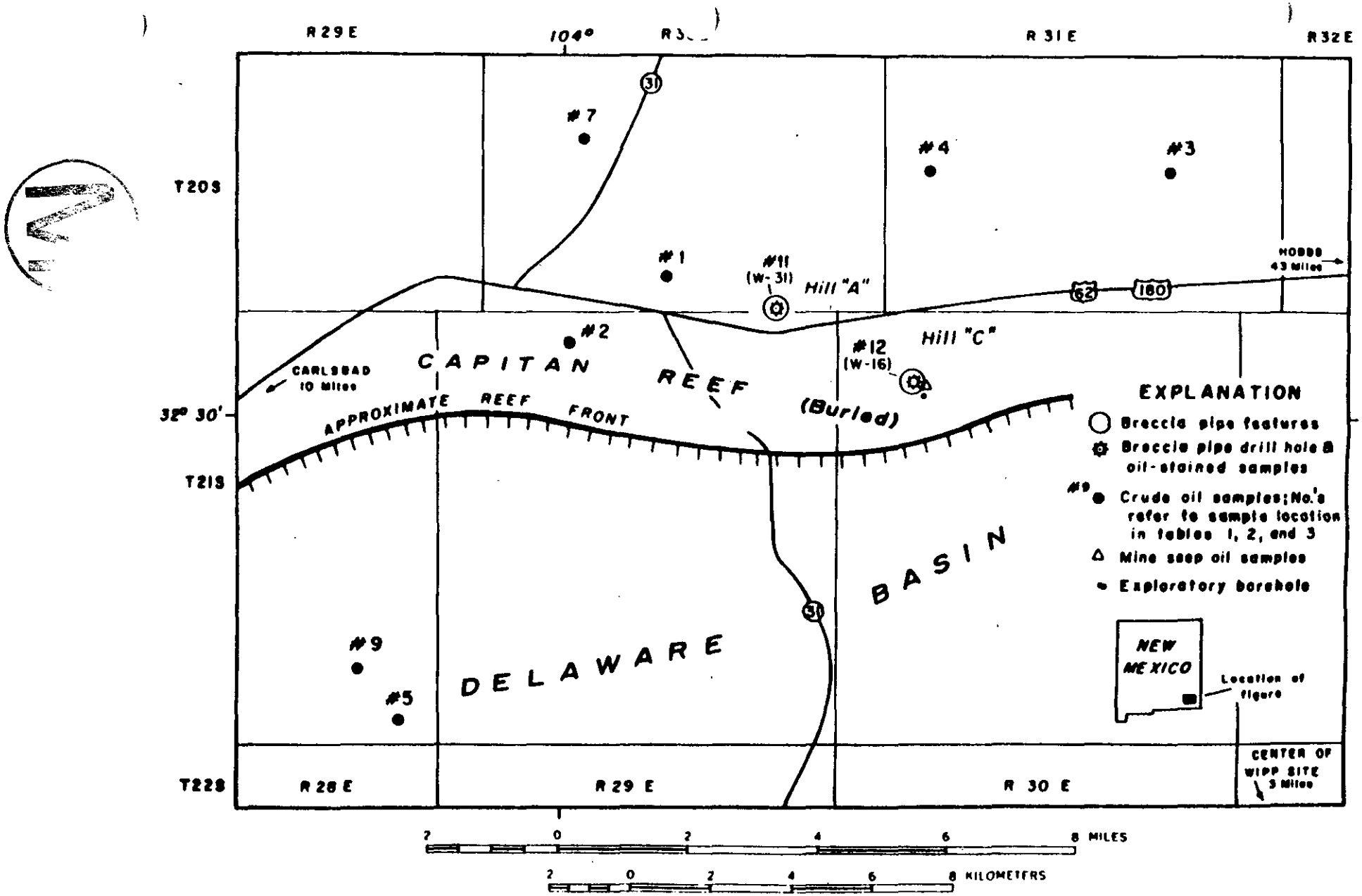

FIGURE E-2 Location of breccia pipe features; breccia pipe, mine seep, and crude oil samples; and approximate Capitan Reef front in Eddy County, New Mexico. W-16 and W-31 are drill holes at breccia pipe features. Source: Palacas et al. (1982).

and time frame required to threaten the integrity of a WIPP repository cannot be met within the Bell Canyon aquifer. This is in agreement with Lambert's (1983) geochemical and isotopic data. More recent data provided by Davies (1983), however, do draw attention to the possibility of zones of higher permeability being present in the Bell Canyon than inferred by Wood et al. (1982) and Lambert (1983). Williamson (1979), for example, proposed a mechanism for the development of deep-sea channels trending toward the basin that may contain thicker, more permeable sands than recognized by Lambert (1983), Wood et al. (1982), and others.

Most workers now agree that conditions could be met for breccia pipe formation only within the Capitan Reef of the Delaware Basin and near its forereef and backreef environment. An abrupt collapse of Salado and Rustler roof rock into a large void temporarily supported by an anhydrite "beam" within salt (Snyder and Gard 1982) or related resistant layer within salt could account for breccia pipe characteristics observed as well as the large diameter and large volume of rock instantaneously displaced into Kermit sink (Baumgardner et al. 1981), San Simon sink, and possibly other related karst features observed near or above the Capitan Reef in the Delaware Basin.

Hill C (Dome C in Vine 1960) and Hill A have been shown to be deep-seated "breccia pipes." R. P. Snyder (U.S. Geological Survey, personal communication to the WIPP panel, 1982) points out that these structures are not unlike a rubble chimney caused by the detonation of a buried nuclear device. Because of their size and potentially disruptive nature, breccia pipes require better understanding, because they are a mechanism that could affect a repository.

Drill-stem tests in borehole AEC-7 indicate that: (a) the 8 m to 10 m thick Lamar Shale Member that occurs near the upper portion of the Bell Canyon is practically impermeable, and (b) the hydraulic conductivity of the brine-producing zone of the Ramsey sandstone in borehole AEC-7 is about 1.2 m/yr (Lynes, Inc. 1979). Hiss (1975) constructed a potentiometric surface map for the Delaware Mountain Group, using a large number of control points. His potentiometric surface map and chloride concentration gradients show that flow is generally to the northeast within the northern part of the Delaware Basin. The average hydraulic gradient, using potentiometric data corrected for fluid density, is about 0.0025 m/m (Wood et al. 1982) and the computed flow in the Bell Canyon is about 0.135 m^3/yr per meter width of aquifer. Allowing for probable ranges in hydraulic conductivity, effective aquifer thickness and hydraulic gradient, probable flow rates were estimated to range from 0.02 to 0.40 m^3/yr per meter of width.

Groundwater quality analyses of samples taken from the Bell Canyon Formation reveal that chloride concentrations range from 1,000 to 190,000 ppm, and that total dissolved solids typically exceed 20,000 ppm for much of Bell Canyon groundwater (Hiss 1975). Hiss's contours of equal chloride concentration (isochlors) roughly parallel the potentiometric surface for the Bell Canyon and increases from southwest to northeast near the WIPP site. Wood et al. (1982) and Lambert (1983) have indicated that the specific source of chloride is difficult to

determine, although some of it may be derived from the overlying Castile Formation, having been derived from a more regional, rather than concentrated site originating from a few distinct points, and from reactions within the Bell Canyon aquifer. Wood et al. (1982) computed the water particle velocity to be approximately 0.03 m per year within the Bell Canyon near the WIPP site based on an average hydraulic conductivity of 1.8 m/yr, a porosity of 0.16 and hydraulic gradient of 0.0025 m/m. This travel time in the Bell Canyon from underneath the center of the WIPP site to the nearest known point on the Capitan Reef is approximately 500,000 years. A mechanism is lacking, however, for getting radioactive material from the repository into the Delaware Mountain Group (DMG). At present, heads in the DMG stand above the proposed repository level.

Wood et al. (1982) analyzed two major mechanisms for deep-seated dissolution of salt from halite horizons through the agency of an underlying aquifer at the WIPP site:

- molecular diffusion along grain boundaries and through fractures in the intervening anhydrite layer; and
- solute-driven convection, either through a single wide fracture or through a permeable porous zone or fracture network between halite and aquifer horizons.

The latter is a worst-case example similar to that postulated by Anderson.

To demonstrate the dissolution capabilities of the salt removal mechanisms, one-dimensional analytical equations describing the mechanisms of salt dissolution and their interrelationship have been applied to the Delaware Basin. Two-dimensional numerical modeling of flow and mass transport has provided a more precise study of salt dissolution in the Castile Formation and mass transfer to the Bell Canyon aquifer. The results of modeling by Wood et al. (1982) are consistent with observed chloride concentration levels associated with dissolved halite in this aquifer (Lambert 1983). Conditions required to support dissolution within the Bell Canyon include a concentration gradient to drive the diffusion process and a density gradient to initiate convection. Additionally, convection is dependent on the fracture size or porous zone (fracture network) permeability. As shown in the Wood et al. (1982) analysis, convection can be substantially greater than diffusion for a fracture greater than 0.0015 m, or for intrinsic permeabilities greater than 10^{-16} m^2. However, for conditions in the Delaware Basin, the Bell Canyon Formation will limit the dissolution mechanism because the concentration and density gradient will be controlled by the aquifer transport rate. The quantity of water currently moving through the Bell Canyon aquifer is inadequate to transport the necessary amounts of salt implied by Anderson's original brine-density model.

Two implausible worst-case scenarios were also developed by Wood et al. (1982), and the sizes of associated solution cavities estimated. Based on the calculated solution cavities, the possible implications of

development of a dissolution cavity at the Halite I horizon on the integrity of the underground WIPP facility were assessed.

The following conclusions were reached:

o Observed site features that provide evidence for deep-seated dissolutioning are at the Capitan Reef margin and consist primarily of breccia pipes. The origin of other dissolution features observed in the basin is open to interpretation, although near-surface rather than deep-seated dissolutioning appears more plausible. One exception may be the FC-92 structural depression 2 km north of WIPP, discussed by Davies (1983).

o The residence time of groundwater in the Bell Canyon aquifer is relatively long, with a flow rate that requires more than 2 million years to travel from recharge near the west reef margin to discharge at the east section of the Capitan Reef.

o The potential dissolution mechanisms include diffusion and convection from halite zones to the aquifers. Computation of the present dissolution rate, based on observed chloride concentration levels in the Bell Canyon, indicates that diffusion and possibly very weak convection result in the removal of halite from the Castile Formation. However, convection may be considerably more significant at locations adjacent to the Capitan Reef aquifer.

o Evaluation of the present DMG hydrogeologic and geochemical conditions and review of their potential range of values indicate that halite dissolution associated with the Bell Canyon aquifer will not impact the underground WIPP facility. A solution zone of less than 0.1 m in height was calculated, based on the maximum dissolution rate in 10,000 years.

o Based on an analysis of potential changes in the hydrologic characteristics (i.e. hydraulic gradient) of the Bell Canyon aquifer, a possible increase in flow rate of one order of magnitude in the future would not impact the WIPP facility over the period of investigation, 10,000 years.

o Based on an analysis of the maximum potential dissolution rate associated with convective and diffusive dissolution mechanisms at the Bell Canyon aquifer-Castile Formation interface (i.e., worst case), no impact should be observed at the underground WIPP facility during the period of investigation, 10,000 years.

The analysis by Wood et al. (1982) of deep-seated dissolution due to diffusion and convection (brine density flow)(Anderson and Kirkland 1980), and the significance of the parameters that influence these dissolution mechanisms are revealing. Brine density flow or convective dissolution as a potential mechanism for removal of halite is possible in areas overlying and immediately adjacent to the Capitan Reef aquifer where high groundwater flow can occur and water is undersaturated with respect to NaCl. However, geochemical data suggest that convective dissolution by water from the Bell Canyon aquifer is not very significant and results in dissolution at the rate no greater than that associated with the diffusive dissolution mechanism. Furthermore, the very low flow of the Bell Canyon aquifer and the associated salt

transport rate indicate that significant convective dissolution of halite in the overlying Castile Formation would be precluded due to the inability of the aquifer to maintain the density gradient for any significant period of time (Wood et al. 1982). The potential significance of channel sandstones with hydraulic conductivities ranging from $\sim 10^{-7}$ to 10^{-4} cm/sec as described by Davies (1983) was not considered by Wood et al. (1982).

The deep dissolution analysis by Wood et al. (1982) has adequately set bounds on the rates and unimportance of sub-Castile dissolution process to breccia pipe formation. The question of more regional subsidence deformation discussed by Davies (1983) warrants further study, even though such subsidence is unlikely to be as disruptive to a repository when compared to pipe formation. Davies points out that the rate of subsidence will have an important bearing on the mechanical behavior of salt. For ductile subsidence, a repository constructed in the middle of the salt unit would maintain its hydrologic integrity through a large portion of the subsidence. Intermediate time rates of subsidence might have a different result.

Several questions remain unanswered: Where are conditions favorable for possible future breccia pipe formation? Are San Simon Sink and Kermit Sink modern examples of breccia pipes in various stages of formation? Are there possible circumstances available for renewed breccia pipe formation at or near the WIPP site? How might specific high-risk sites for future pipe development be identified?

It is important to be sure that the reef facies margin immediately northwest, north, and northeast of the WIPP site is accurately known, and that there are no smaller fringing reefs present between the site and the main reef that may be hydraulically connected with it. Reef masses tend to be rather complex when traced in their development through time and space. However, no such fringing reef occurrences were noted in test holes, and a number of industry deep well logs, borehole geophysical data, and seismic refraction data were used in test holes AEC-7 and AEC-8 to show that the southern edge of the reef is at least 11 km away from the northern edge of the WIPP site.

Judging from the importance that zones of fracture concentration have on the location of Carlsbad and other caves in the Guadalupe Mountains (Parizek 1979), similar structures also most likely contributed to the formation of caves and conduits within buried reef rock. Fracture trace-related and lineament-related structures that intersect reef rock are major candidate sites for possible present and future sinkhole and breccia pipe development. In any event, the first available reef rock is rather distant from WIPP, and breccia pipe development at a distant site would be of no consequence to WIPP. These structures are more likely to influence rates of water flow and salt dissolution within the Rustler Formation above the repository.

REFERENCES

Anderson, R. Y., and D. W. Kirkland. 1980. Dissolution of salt deposits by brine density flow. Geology, 8:66-69.

Baumgardner, R. W. Jr., A. D. Hoadley, and A. G. Goldstein. 1981. Formation of Wink Sink, a Salt Dissolution and Collapse Feature, Winkler County, Texas. Draft Report. Bureau of Economic Geology, University of Texas, Austin.

Davies, P. B. 1983. Structural characteristics of a deep-seabed dissolution subsidence chimney in bedded salt. Proceedings of Sixth International Symposium on Salt, Toronto, Canada (May 1983). In press.

Hiss, W. L. 1975. Stratigraphy and Groundwater Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas. Unpublished Ph.D. dissertation. University of Colorado.

Lambert, S. J. 1983. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. SAND 82-0461. Sandia National Laboratories, Albuquerque, N.Mex.

Lynes, Inc. 1979. Drill Stem Test Results for Boring AEC #7. Houston, Tex.

Palacas, J. G., R. P. Snyder, J. P. Baysinger, and C. N. Threlkeld. 1982. Geochemical Analysis of Potash Mine Seep Oils, Collapsed Breccia Pipe Oil Shows and Selected Crude Oils, Eddy County, New Mexico. OFR 82-421. U.S. Geological Survey, Denver, Colo.

Parizek, R. L. 1979. Recommended Locations for Flood Water Recharge Wells for Cornudas, North, C. and L., and Washburn Draws, Hudspeth County, Texas. Soil Conservation Service, U.S. Department of Agriculture, Fort Worth, Tex.

Snyder, R. P., and L. M. Gard. 1982. Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, with a Section on Drill-Stem Tests. OFR 82-968. U.S. Geological Survey, Denver, Colo.

U.S. Department of Energy. 1980-1983. Waste Isolation Pilot Plant Safety Analysis Report. WIPP SAR (includes Amendments 1-6). Albuquerque Operations Office, N.Mex.

Vine, J. D. 1960. Recent domal structures in southeastern New Mexico. American Association of Petroleum Geologists Bulletin 44(12):1903-1911.

Williamson, C. R.. 1979. Deep-sea sedimentation and stratigraphic traps, Bell Canyon Formation (Permian), Delaware Basin, in Sullivan, N.M., ed., Guadalupian Delaware Mountain Group of West Texas and Southeast New Mexico: Society of Economic Paleontologists and Minerologists (Permian Basin Section). Publication 79-18. pp. 39-74.

Wood, B. J., R. E. Snow, D. J. Cosler, and S. Haji-Djafari. 1982. Delaware Mountain Group (DMG) Hydrology--Salt Removal Potential. TME-3166. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

APPENDIX F

SALT DISSOLUTION,

BRINE RESERVOIRS, AND KARST

Containment of radioactive wastes at the WIPP facility hinges on the long-term integrity of the evaporite section, which will be subjected to persistent dissolution, to perturbation during the development of the repository and following its decommissioning, and to possible future human intrusion.

Salt dissolution can progress from the top of the salt section, from below, and within individual salt beds. The rate of dissolution is directly related to the volume of water that comes in contact with salt in a given time period, the chemical quality of this water, and the rate at which dissolved salt can be transported within and from the aquifer. On a geological time scale, the dissolution can be rapid. Few outcrops of soluble salt beds are ever observed in humid regions or even in moderately arid regions because the shallow, unprotected salt has long since been leached away. However, salt that is deeply buried, or covered by poorly permeable strata that restrict groundwater circulation, can survive for long periods of geological time even in basins with active groundwater circulation. Permian salts of the Delaware Basin of New Mexico and west Texas are good examples, for they have persisted for more than 200 million years despite active dissolution within some regions of the basin.

Reliable estimates of the total amount of Salado and Castile evaporites removed by dissolution, especially in relatively recent times, are difficult to make because of (a) original heterogeneities of deposition, (b) ambiguous identification of members or marker beds, (c) partial removal of halite by dissolution or early subaerial erosion, and (d) perturbation of original bedding thicknesses by localized deformation (Lambert 1983).

Episodes of uplift accompanied by erosion and dissolution of evaporite beds are described by Powers et al. (1978):

> Periods of terrestrial deposition alternated with erosional episodes, so that a series of non-marine deposits separated by angular unconformities blanket the evaporite beds at the site. These angular unconformities represent intervals during which salt beds at the WIPP site were tilted and subjected to potential dissolution. At least four erosional episodes separated by

depositional intervals are recognized: (1) early Triassic time in which the Dewey Lake Redbeds were tilted and eroded to a slight angular unconformity before deposition of the Upper Triassic Dockum Group; (2) Jurassic-Early Cretaceous time in which the Dockum Group was tilted and eroded to a wedge before marine inundation in Washitan time (latest Early Cretaceous); (3) a Late Cretaceous through mid-Tertiary erosional interval when the region was again tilted and the Triassic Dockum Group of sediments was bevelled for a second time; and (4) a post-Ogallala (post-Pliocene) uplift and erosion in early Pleistocene time, prior to which deposition of the (Kansan?) Gatuna formation took place. Subsequent to deposition of the Gatuna, there probably were pluvial intervals corresponding to the Illinoisian and Wisconsin glaciations during which accelerated erosion in these wetter times occurred in the area of the WIPP site.

Each period of tilting, which was accompanied by the potential for renewed erosion, also afforded an opportunity for salt flow by plastic deformation along the imposed gradient and salt deformation as the salt impinged against reef abutments or responded to uneven, differential sediment loading or erosional unloading. Salt deformation of this type may account for the origin and distribution of isolated pressurized-brine reservoirs found in the Castile. To the extent that some "deep dissolution" features are recognized today in salt at depths of several thousand feet below the surface, it seems likely that subsurface dissolution of salt could have started at comparable depths beneath the surface as soon as early-Triassic time. Episodes of active dissolution most likely occurred during the Jurassic and late-Cretaceous to mid-Tertiary erosional intervals, as well as during pluvial periods corresponding to Pleistocene glaciation.

Recent regional rates of salt removal from the top and bottom of the Delaware Basin evaporite have been estimated from a knowledge of salt dissolution mechanisms, regional groundwater flow systems, and the geochemistry of its groundwaters (Powers et al. 1978, Wood et al. 1982). Concentrated, more localized deep dissolution processes may give rise to breccia pipes, sinkholes, and other large-scale karst features such as the FC-92 structural depression 2 km north of WIPP (Davies 1983). Some of these karst features formed in part in a localized catastrophic manner rather than by slow regional subsidence. Abrupt collapse of large volumes of consolidated and unconsolidated strata, as occurred at the San Simon and Kermit sinks, is possible only where void space formed at depth by slow differential dissolution of soluble strata. Each of these salt dissolution processes will be reviewed briefly as it pertains to the long-term geological stability of WIPP.

The present rate of salt dissolution has been estimated for the top of the halite within the Rustler and Salado formations (Powers et al. 1978; Bachman 1974, 1980), and more recently for the base of the Castile Formation at the Castile-Delaware Mountain Group contact (Wood et al.

1982). Many lines of convergent evidence were reviewed by Wood et al. (1982) and Lambert (1983) to help bound rates of basal Castile salt dissolution. Local and basinwide stratigraphic and structural observations were considered in these analyses, as well as mineralogical and textural relationships observed in caves and cores. Lambert (1983) presented additional data obtained from chemical and isotopic analyses of rocks and solutions regarding equilibrium relationships of brines and other groundwaters obtained from various sources in the Delaware Basin. These lines of evidence provide support for estimates of dissolution rate that previously were based largely on stratigraphic and geomorphic evidence. Additional evidence regarding dissolution rates is currently being sought from incongruent phase relations (Lambert 1983).

Erosion by solution and fill is a mechanism originally proposed by Lee (1925) for shallow dissolution of gypsum terrain, characterized by incision of dendritic drainage patterns and development of underground drainage channels that collapse as soluble materials are dissolved. Bachman (1980) concluded that this mechanism is active in sections of the Delaware Basin underlain by gypsum, resulting in a chaotic jumble of less soluble rock as an end product.

Bachman (1980), Christiansen (1971), Jagnow (1979), and others have described a shallow process of phreatic dissolution of soluble rocks within open conduits that contain freely circulating groundwater that is undersaturated with respect to the rocks (such as carbonate rocks, anhydrite, gypsum, and halite) being dissolved. This process is differential in nature and can produce large open cavities, such as Carlsbad and related caverns in the Guadalupe and Delaware mountains and smaller cavities noted in Nash Draw. Many of these caverns in the Capitan limestone exhibit structural control, i.e., zones of fracture concentration, which are also likely to influence present development of solution permeability within Capitan Reef rock where buried by Salado, Rustler, and other strata. Similar zones of fracture concentration are present in the back reef sediments of the Artesia Group that lies shelfward of the Capitan Reef and appear to have helped localize numerous sink holes and collapse structures.

A different origin for some karst deposits and landforms was proposed by Anderson (1978, 1982a). He has suggested that many of these features were created by deep-seated solution activity, which he considered to be an ongoing process within the Delaware Basin. It was his view that the region of concentrated salt dissolution activity has migrated from west to east through geologic time, as well as along and away from the margins of the Capitan Reef. In support of his hypothesis of deep-seated dissolution, Anderson cited the presence of many sinks, domes, and breccia pipes in various parts of the Delaware Basin, and the thinning of halite layers I, II, and III deposits in the Castile Formation near the western margin of the basin.

As a corollary of the deep-seated dissolution hypothesis, Anderson and Kirkland (1980) proposed a brine-density flow model to account for breccia pipes in the Delaware Basin. For this mechanism to operate, fractures must expose the base of the evaporite section to undersaturated solutions that begin to dissolve salt. As salt dissolves, water becomes more dense and sinks into the lower part of the

aquifer, allowing new unsaturated waters to come in contact with the salt in a self-perpetuating manner. Overlying strata collapse into the cavity created by the dissolution. Anderson and Kirkland suggested the Bell Canyon Formation as the aquifer providing the undersaturated solution. It immediately underlies the salt sequence.

Recent work, however, has cast doubt on the ability of the Bell Canyon Formation to supply the necessary flow of undersaturated fluid (Lambert 1983, Wood et al. 1982). Five lines of evidence were presented by Lambert (1983) to show that the Bell Canyon is an unimportant aquifer:

- extremely limited quantities of water produced from but a few thin Bell Canyon Formation horizons;
- Bell Canyon water is highly saline, but not completely saturated with sodium chloride under the evaporites (Hiss 1975);
- the salinity does not rise abruptly from west to east as evaporites appear in the overlying section (Hiss 1975);
- the water contains solutes in combinations not found in the evaporites (Lambert 1978); and
- there is little evidence for appreciable movement of water in the Bell Canyon (Mercer and Orr 1979).

Anderson (1982a) has agreed that the Bell Canyon is an unlikely source of solutions for the brine-density mechanism but has suggested instead that deep dissolution is concentrated in layers of fractured anhydrite near the Salado-Castile contact. The alleged flow in this layer, called "blanket" or "strata-bound" dissolution, involves the lateral movement of water along a permeable bed, adjacent to which soluble rock dissolves. More rock dissolves as new void space is created. Such dissolution in this and other anhydrite beds, according to Anderson (1981b), has removed nearly 50 percent of the halite in the Delaware Basin by a process that he believed to be still active and still proceeding eastward at significant rates. More recently, Anderson (1981b, 1982a) has tied this process to the origin of brine reservoirs in Castile anhydrites as well. He has dropped the Bell Canyon as an important conduit for significant salt removal and breccia pipe formation as proposed in his earlier papers. Davies (1983) indicated that the Bell Canyon may still be capable of producing more widespread salt removal and that new bounding calculations are justified.

Bachman (1980) and Lambert (1983) have agreed that strata-bound dissolution occurs, but have stated that it operates only near points of recharge where waters are more likely to be undersaturated with salts and where groundwater sinks are available for salt and water removal. They did not agree with Anderson that this mechanism is widespread or is responsible for pressurized-brine reservoir formation. To date, no evidence has been provided to show that anhydrite beds within the Castile or Salado formations serve as regionally interconnected aquifers in the basin.

Hydraulic heads in the Bell Canyon aquifer stand above the proposed repository level, and only human intrusion could introduce radionuclides into the Bell Canyon. Extraction of oil and mostly gas in the northern section of the Delaware Basin has not caused a drawdown in

potentiometric heads within sub-Bell Canyon reservoirs that have reversed hydraulic gradients in the Bell Canyon. Also, estimated flow rates in the Bell Canyon show that nearly 500,000 years may be required for its waters to move from beneath the WIPP site to the nearby Capitan limestone aquifer, assuming that it is hydraulically interconnected to the Bell Canyon aquifer.

The Capitan limestone is an important aquifer, with extensive solution porosity where exposed west of the WIPP site as well as where buried in the northern and eastern margin of the Delaware Basin. Hiss (1975) reported high porosity zones within buried reef rock as shown by five occurrences of bit drops during drilling of 3.6 to 18 m. Hiss's model for regional groundwater flow within the Capitan limestone and adjacent strata has been modified by Lambert (1983) to be consistent with current isotopic data. Lambert concluded that

- virtually no involvement of the Bell Canyon exists in either groundwater recharge or discharge from the Capitan;
- the reef shelf system may be divided into various units that can act as either recharge or discharge areas for the Capitan; and
- the Bell Canyon Formation is not being actively and continuously recharged by any known meteoric or groundwater source in the Delaware Basin as revealed by isotopic data (Lambert 1978).

All current lines of evidence have led Lambert (1983) to conclude that water movement in the Bell Canyon, Castile, and Salado formations in the north central Delaware Basin is either imperceptibly slow or nonexistent and that strata-bound dissolution in unspecified beds, most likely anhydrite layers, is the most plausible model for efficient removal of evaporites at depth. What to do with the saturated brine of dissolution origin remains a major problem with the strata-bound model. This is the same issue on which Anderson's thesis is vulnerable. A plausible water and solute sink needs to be located for salt to be removed.

Dissolution processes described by the Lambert model are not likely to disrupt surface support facilities during operation of the facility, but in time could further increase the permeability of the Magenta and Culebra dolomite members within the Rustler Formation as salt is slowly dissolved from the Rustler and the top of the Salado. In the long term, this could influence the permeability of the Rustler Formation near the upper portions of shafts and borehole seals following backfilling of the repository. Permeability increases within any of the Rustler units will (1) increase groundwater flow rates, (2) accelerate rates of salt dissolution by a feedback loop mechanism, and (3) reduce the thickness of the protective salt layer above the proposed repository. None of these changes, however, is likely to be significant to waste isolation under present climatic conditions or before TRU waste decays to acceptable levels if no mechanisms are provided for releasing radionuclides into the Rustler aquifer.

The formation of a breccia pipe under a repository according to Anderson and Kirkland's (1980) model might have caused serious disruption. The work of Wood et al. (1982), however, greatly restricts

the location in the Delaware Basin where breccia pipe formation might be possible, i.e., above the permeable Capitan limestone. The distribution of the Capitan limestone and its southern limits are well known. The northern outer edge of Zone IV is at least 11 km south of the mapped southern extension of the reef; hence, there is no chance for a future Capitan Reef-related breccia pipe to disrupt the repository.

Anderson (1982a) concluded that fractured anhydrite beds observed within the Castile Formation are regionally interconnected, and that they serve as aquifers containing actively circulating water that may be quite young and is capable of dissolving significant amounts of salt. Lambert's (1983) strata-bound hypothesis is testable, but not enough data have yet been compiled to support a final conclusion. However, the many cores taken from Castile anhydrite beds do not show open fractures and brine except where brine reservoirs have been encountered along anticlinal structures near the Capitan Reef. This suggests that brine reservoirs are genetically related to folding of evaporite beds and derive their built-in and confined pressures that exceed hydrostatic pressure from sources other than existing groundwater recharge areas. The very numerous oil and gas industry wells in the basin do not show brine saturation within the Castile anhydrite beds nor did they penetrate brine reservoirs. These observations are hard to reconcile with Anderson's hypothesis, but do not completely prove it wrong.

REFERENCES

Anderson, R. Y. 1978. Deep Dissolution of Salt, Northern Delaware Basin, New Mexico. Report to Sandia National Laboratories, Albuquerque, N.Mex.

Anderson, R. Y. 1981a. Progress of Salt Dissolution in the Delaware Basin, Texas and New Mexico. Special Publication No. 8. New Mexico Geological Society.

Anderson, R. Y. 1981b. Deep-seated Salt Dissolution in the Delaware Basin, Texas and New Mexico. Special Publication No. 10. New Mexico Geological Society, pp. 133-145.

Anderson, R. Y. 1982a. Deformation-dissolution potential of bedded salt, Waste Isolation Pilot Plant site, Delaware Basin, New Mexico. Pp. 449-458 in Scientific Basis for Nuclear Waste Management V, W. Lutze, ed. Materials Research Society Symposia Proceedings, Vol. 11. New York: Elsevier Science Publishing Company.

Anderson, R. Y. 1982b. Upper Castile Brine Aquifer, Northern Delaware Basin. Attachment to a May 23 letter to G. Goldstein, Secretary of New Mexico Health and Environmental Department.

Anderson, R. Y., and D. W. Kirkland. 1980. Dissolution of salt deposits by brine density flow. Geology, 8:66-69.

Bachman, G. O. 1974. Geological Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico. OFR 74-194. U.S. Geological Survey, Denver, Colo.

Bachman, G. O. 1980. Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico. OFR 80-1099. U.S. Geological Survey, Denver, Colo.

Bachman, G. O. 1981. Geology of Nash Draw, Eddy County, New Mexico. OFR 83-31. U.S. Geological Survey, Denver, Colo.

Barrows, L. 1982. WIPP Geohydrology--The Implications of Karst. Unpublished manuscript. Sandia National Laboratories, New Mexico. May. 21 pp.

Black, S. R., W. E. Coons, R. L. Olsen, and R. S. Popielak. 1982. *ERDA-6 and WIPP-12 Testing, Interim Data Analysis (April 1982)*, Waste Isolation Pilot Plant (WIPP). TME 3153. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Christiansen, E. A. 1971. Geology of the Crater Lake collapse structure in southeastern Saskatchewan. Canadian Journal of Earth Sciences, 8:1505-1513.

Davies, P. B. 1983. Structural characteristics of a deep-seated dissolution subsidence chimney in bedded salt. Paper presented at *Sixth International Symposium on Salt, Toronto, Ontario, Canada*, May 24-28, 1983. Proceedings in press.

Gonzalez, D. D. 1983. Groundwater Flow in the Rustler Formation: Waste Isolation Pilot Plant (WIPP) Southeast New Mexico (SENM). SAND 82-1012. Sandia National Laboratories, Albuquerque, N.Mex.

Griswold, G. B. 1980. Presentation, in Geotechnical Consideration for Radiological Hazard Assessment of WIPP. EEG-6, a report of a meeting held on January 17-18. Environmental Evaluation Group, State of New Mexico, Santa Fe, N.Mex.

Hiss, W. L. 1975. Stratigraphy and Groundwater Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas. Unpublished Ph.D. dissertation. University of Colorado.

Jagnow, D. H. 1979. Cavern Development in the Guadalupe Mountains. Cave Research Foundation, P.O. Box 26, Mammoth Cave, Ky.

Lambert, S. J. 1978. Geochemistry of Delaware Basin groundwaters. Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas. Circular 159. New Mexico Bureau of Mines and Mineral Resources, pp. 33-38.

Lambert, S. J. 1983. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. SAND 82-0461. Sandia National Laboratories, Albuquerque, N.Mex.

Lee, W. T. 1925. Erosion by solution and fill (Pecos Valley, New Mexico). Contributions to Geography in the United States. USGS Bulletin 760-C. U.S. Geological Survey, Washington, D.C.

Mercer, J. W., and B. R. Orr. 1979. Review and Analysis of Hydrogeologic Conditions Near the Site of a Potential Nuclear-Waste Repository, Eddy and Lea Counties, New Mexico. OFR 77-123. U.S. Geological Survey, Denver, Colo.

Popielak, R. S., R. L. Beauheim, S. R. Black, W. E. Coons, C. T. Ellington, and R. L. Olsen. 1983. Brine Reservoirs in the Castile Formation, Southeastern New Mexico. TME 3153. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Powers, D. W., S. J. Lambert, S.-E. Shaffer, L. R. Hill, and W. D. Weart, eds. 1978. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND 78-1596, Vols. I and II. Sandia National Laboratories, Albuquerque, N.Mex.

Register, J. K. 1981. Brine Pocket Occurrences in the Castile Formation, Southeastern New Mexico. TME 3080. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

U.S. Department of Energy. 1980-1983. Waste Isolation Pilot Plant Safety Analysis Report. WIPP SAR (includes Amendments 1-6). Albuquerque Operations Office, N.Mex.

Wood, B. J., R. E. Snow, D. J. Cosler, and S. Haji-Djafari. 1982. Delaware Mountain Group (DMG) Hydrology--Salt Removal Potential. TME-3166. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

Woolfolk, S. W. 1982. Radiological Consequences of Brine Release by Human Intrusion into WIPP. TME 3151. U.S. Department of Energy, Albuquerque Operations Office, N.Mex.

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF APRIL 1987
PLANNED SORBING-TRACER FIELD TESTS

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Mr. John Mathur
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Mr. Mathur:

The Waste Isolation Pilot Plant (WIPP) panel of the Board on Radioactive Waste Management (BRWM) has considered in detail the sorbing-tracer field test planned at the WIPP site, and herewith presents comments on some aspects of the plan.

The test is required as an item in the Working Agreement for Consultation and Cooperation between DOE and the State of New Mexico. In requesting the test, the State (through its Environmental Evaluation Group) pointed out the uncertainties in the use of laboratory-determined K_d (distribution coefficient) values for predicting retardation of radionuclide movement in flowing ground-water, and the consequent need to have in-situ K_d data for scenario analyses.

The scenarios for which the data are needed involve the effects of migration of ground-water containing dissolved radionuclides from the WIPP repository into the Culebra member of the Rustler Formation (about 400 meters above the repository), and then through the Culebra into the accessible environment. The movement of the groundwater could be caused by: (1) collapse of salt following repository closure, forcing any liquid contained in the repository up the shaft; or (2) injection of overpressured brines from somewhere beneath the repository; or (3) drilling of wells into the buried waste at some future time when existence of the repository has been forgotten. Although unlikely, these are often-cited scenarios. If a radionuclide solution does find its way into the Culebra member, this rock unit (consisting chiefly of fractured dolomite) is known to be an aquifer that could permit long-distance movement. The rate of travel of the radionuclides would be determined in part by how effectively they are sorbed on the dolomite, and it is this sorption that the test is designed to measure.

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The original plans for the test, as described to the panel at its meeting in February 1986, involved the injection of several tracers into the Culebra dolomite in one well and their detection in adjacent wells after various time intervals. Prior injection of nonsorbing tracers would give a measure of the rate of ground-water flow, and the ratio of rates of movement of sorbing and nonsorbing tracers would indicate the amount of retardation. Retardation factors so determined could then be used in performance-assessment models designed to test compliance with EPA standards for escape of radionuclides into the accessible environment. The factors also would be useful, it was hoped, for comparison with retardation factors calculated from laboratory K_d measurements, a comparison intended to provide information on the reliability of laboratory data as a basis for predicting retardation in natural environments. At the time of the February meeting no decisions had been made as to the specific substances to be used as sorbing and nonsorbing tracers; because it was assumed that use of radioactive substances would not be permitted, a variety of possible analog elements was under consideration.

A more detailed and somewhat revised plan for the test was presented to the panel at its meeting in September 1986, in the form of a memorandum from Al Lappin (of the Sandia National Laboratories) to Dick Crawley (DOE/WPO) and Mary Wilson (DOE/ALO), dated 23 September. The memorandum noted that fielding of the test had been delayed by budgetary constraints; that a probable starting date was still uncertain; but that the target date for completion of the final performance assessment for the repository (end of fiscal year 1992) would require that the test be started within the next two or three years. The memorandum records progress in field and laboratory work related to the test, and is optimistic about the possibility of obtaining permission to use radioactive tracers rather than analog elements. It is recommended in the memorandum that starting the test be delayed until a good deal of additional field and laboratory investigation has been completed to provide an adequate hydrologic and geochemical background. The following are included among the recommended research projects: field studies of matrix and fracture flow in order "to determine relevant transport mechanisms within the Culebra"; experiments "investigating matrix diffusion within the Culebra Dolomite"; autoradiography for sorption of transuranic elements; study of cation exchange on the clays of the Culebra; investigation of possible coprecipitation of radionuclides with carbonates and sulfates; and oxidation/reduction experiments to study potential effects of pyrite and organic matter as sorbers of some radionuclides.

The panel was skeptical of the usefulness of the test as described in the original plans. Grounds for skepticism were: (1) doubt that results would be significant, in view of the then-incomplete knowledge of Culebra hydrology; (2) doubt that results could be generalized to the Culebra as a whole, from data obtained at a single hydropad, in view of the known variability in Culebra geochemistry and fracture geometry; (3) insufficient allowance for changes in ground-water chemistry due to drilling fluids, fluids added for nonsorbing-tracer tests, and exposure to air; and (4) poor choice of elements planned for use as analogs. Some panel members were so dubious about the possibility of getting meaningful results, and so impressed with the probable waste of time

and money, that they favored abandoning the test altogether; others, although recognizing the strong chance of failure, thought that the test was important enough to be worth trying, with some suggested modifications.

The revised plans for the test, as described in the Lappin memorandum, have impressed the panel more favorably. There is still a difference of opinion about the probability of obtaining useful results, but in view of the need to fulfill a commitment to the State of New Mexico and in view of the often expressed desirability of obtaining in-situ K_d values (for example, Letter Report on the Proceedings of the NRC/ORNL Workshop of 13-15 May 1986, page 6), the panel agrees that the test should be carried out.

The panel strongly urges that the timing and conduct of the test be based on the Lappin memorandum rather than the proposal of February 1986. The panel emphasizes the following specific recommendations, some of them similar to those in the memorandum and others somewhat modified:

(1) The test should be preceded by a calculation of the probable rate of release to the accessible environment of the important radionuclides in TRU waste on the assumption of no retardation due to sorption, i.e., that $K_d = 0$. The calculation will give a rough idea of the amount of retardation that must be assigned to sorption if the release is to meet EPA requirements. If the calculation shows that the release is within EPA limits without help from sorption, the sorbing-tracer test would seemingly be superfluous. But the uncertainty in such calculations is necessarily large, and the test should proceed regardless of the numbers that the calculation produces.

(2) The drillholes selected for injection and recovery should be ones for which the history since drilling is well known, particularly with respect to the composition of the drilling fluid and any other fluid that has been subsequently added. These fluids must be flushed before the experiment is started. Preferably, the selected holes should be ones that were drilled with air only.

(3) Of the additional research recommended in the Lappin memorandum, the items regarded by the panel as most important are further field study of Culebra hydrology in different parts of the WIPP site and autoradiographic study of Culebra specimens to determine what phases are active sorbents for transuranic elements. The panel thinks that these two items should be completed before the test is started, but suggests that preparations for the test be made while the research is in progress.

Other recommended research items, in the panel's opinion, need not be completed so expeditiously, since they could lead to long delays in getting the test underway. It would be desirable, certainly, to know more about details of matrix diffusion, about cation exchange on clay minerals in the dolomite, about coprecipitation of radionuclides, and about possible effects of pyrite and organic matter, but these could easily become long-term research projects and are not directly relevant to the empirical determination of retardation factors for performance assessment purposes.

(4) The panel strongly urges the use of radionuclides rather than analog elements as sorbing tracers. A possible exception might be made for strontium, since the chemical behavior of the nonradioactive form is identical to that of ^{90}Sr; another possible exception would be lanthanum as an analog for the chemically very similar americium. But the plutonium and neptunium have no close analogs, and use of radioactive isotopes is essential. Objection can be raised on the grounds that these isotopes would contaminate the subsurface so that future sampling efforts would give ambiguous results. This difficulty can probably be surmounted by the use of isotopes or isotope ratios different from those in the waste, so that contamination from the test would be recognizable. The panel further recommends that the test be limited to a few tracers, perhaps only Sr, Pu, and Am, rather than the large number listed in the original proposal. For the non-sorbing tracer the Panel recommends the use of both ^{3}H or ^{81}Kr.

(5) In the absence of sufficient information about the variability of the formation, it is not possible to determine the number of hydropads needed to obtain a statistically significant result. The test should be performed at more than one hydropad, preferably at at least three, to give some sense of the possible variability. The geochemistry and characteristics of graoundwater flow vary greatly from place to place in the Culebra aquifer, and results of the test at a single hydropad would not be representative of the aquifer as a whole. Even with three hydropads the results will not be truly representative, but three will be better than one.

(6) Preferably the field test should be accompanied by laboratory determinations of K_d, using chunks of dolomite from drillcores with their bentonitic drilling mud. This recommendation is less important than the others, but such measurements would be a useful contribution to the on-going argument as to whether laboratory measurements of K_d can be depended on as a guide to the extent of sorption in natural environments.

Sincerely,

Konrad B. Krauskopf
Chairman, WIPP Panel

KBK:PBM:jc

NATIONAL ACADEMY OF SCIENCES

REPORT OF MARCH 3, 1988
BRINE ACCUMULATION IN THE WIPP FACILITY

MAR - 4 1988

NATIONAL RESEARCH COUNCIL

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

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March 3, 1988

MEMORANDUM

TO: Attendees of the February 18-19, 1988 WIPP Panel Meeting

FROM: Peter B. Myers PBM/JK

SUBJECT: Report on Brine Accumulation in the WIPP Facility

The enclosed report was presented to, and discussed with, the New Mexico Congressional Delegation on March 3, 1988 at 2:30 p.m.

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of 18-19 February 1988

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Report on Brine Accumulation in the WIPP Facility

Background

The Waste Isolation Pilot Plant (WIPP) facility, a proposed repository for transuranic radioactive waste, is being constructed in a thick bed of salt 650 m (2150 ft) under the surface in southeastern New Mexico. When the repository has been filled with waste and sealed, the salt is expected to move by plastic flow into repository openings and ultimately to lock the waste in a solid mass of crystalline salt. In this manner the waste would have minimal contact with moving groundwater, because no appreciable continuous flow of water is possible through the nearly impermeable structure of an undisturbed salt bed. It has been known for a long time, however, that the salt does contain some water (averaging about 0.5 percent), in the form of brine both within and between the salt crystals. The presence of water at WIPP is shown by efflorescences that appear on walls of rooms and tunnels, by salt icicles that form where brine drips from the ceiling, and by the brine that collects in some of the holes drilled into the floor. The amount of brine is small, so that the workings are kept dry by normal ventilation procedures and will remain dry as long as the repository is open. When the repository has been sealed after filling with waste, however, brine is expected to accumulate slowly in repository openings. The amount of this accumulation is uncertain, and different estimates of the amount have recently aroused controversy.

Scientists at the Sandia National Laboratories (SNL), the technical consulting agency for DOE, maintain that the amount of brine accumulation is small, and calculations indicate that it will be absorbed by the backfill material to be placed in the rooms and tunnels. Thus no interference is expected on the basis of preliminary observations with the plastic flow of salt into disposal rooms and around the waste packages. A contrary view* has been expressed recently by a local group of scientists, most of them from the University of New Mexico (the Scientists Review Panel: SRP), who suggest that the amount of accumulation may be large enough to entrain both backfill and waste in a mobile radioactive "slurry." Such a fluid would prevent consolidation of the salt and might move to the surface to release radioactive material in quantities exceeding EPA standards. Because of this concern, SRP recommends a hold on repository construction and on DOE's plan to start bringing large numbers of waste drums to the site in October 1988 for a projected five-year pilot phase of the repository operation. Scientists in the State of New Mexico's Environmental Evaluation Group (EEG), while not advocating a halt on repository excavation or on experimental work with radioactive waste in the repository tunnels, also feel that uncertainty regarding the quantity of brine is sufficient to warrant serious study before large numbers of waste drums are placed underground.

The National Academy of Sciences, through its Board on Radioactive Waste Management and its WIPP Panel, has been asked to express an opinion as to how well existing data resolve these conflicting viewpoints. In response to this request, the Panel has reviewed pertinent documents and convened a special meeting in Albuquerque (18-19 February 1988) at which scientists from SRP, SNL, and EEG presented their views. The Panel was assisted in its review by several members of the Board and three invited consultants. This report is a record of the augmented Panel's conclusions.

Statement of the Problem

The essential issue is one of balance between several rates, principally: (1) the rate at which brine seeps into repository openings from the salt; (2) the rate at which the openings are closed by plastic flow of the salt; and (3) the rate at which gases are generated in the drums and dissipated. If the first rate is slow enough, the plastic creep can be expected ultimately to immobilize the waste in solid salt; this is the goal of SNL's repository design. If brine inflow and gas generation are too fast, complete consolidation of the salt would be prevented, and mobile fluids (liquid plus gas and entrained solids) would collect in the remaining open spaces of the waste-filled rooms; this is the result feared by SRP and recommended for further study by EEG. The issue of balance has been recognized for a long time, but because all three rates are known only over such broad ranges of measured values, complete resolution has not been possible.

(1) The rate of brine inflow depends chiefly on the permeability of the salt and the difference in pressure acting on brine within the salt and in the repository openings. Permeability measurements have been attempted in many ways, all of which give ranges of values—hardly surprising, since salt beds vary in composition and structure from place to place. Measured values lie predominantly in a narrow range of very low permeability (10^{-8} to 10^{-9} darcy), but locally the values are somewhat higher and a very few are several orders of magnitude larger still. Visual observations of tunnel walls (both during previous visits by the Panel to the WIPP site and as shown on numerous photographs displayed by SNL) indicate that areas of higher permeability occur in discrete zones of limited extent. In estimating rates of brine inflow, SNL uses permeability values at the high end of the in-situ measured range. The larger values used by SRP were from drill stem boreholes made by oil exploration companies, and these tests are not considered as reliable as those made for the express purpose of determining permeability at the emplacement horizon.

The initial difference in pressure between the salt and open disposal rooms can be specified in a narrower range, as somewhere between the hydrostatic and lithostatic pressure in salt at a depth of 650 m (2150 ft) [roughly between 70 and 140 bars (1000 and 2000 psi), respectively]. The pressure difference will decrease markedly at the very end of the period of salt consolidation (and brine inflow will be correspondingly smaller), because any fluid that exists in repository voids will be tightly squeezed.

(2) The rate of closure of the WIPP excavations due to salt movement has been monitored over the past several years. Results to date show that measured rates are substantially faster than initial theoretical predictions, and that complete closure can be expected in about 100 years. The rate of closure will decrease in the final stages because of resistance offered by the compacted waste, backfill, and any brine or gas that may be present.

(3) The rate of gas generation is difficult to estimate. The principal gas to be expected is carbon dioxide from decomposition of organic material in the waste, possibly aided by bacterial activity. A little hydrogen may be produced by radiolysis of waste and water, and larger amounts by corrosion of steel in the waste containers. Small quantities of nitrogen will remain from entrapped air. SNL suggests an overall rate of 220 gm (half a pound) of gas per waste drum in 100 years, but this is no more than an educated guess and is not based on quantitative measurements of actual waste drums in a repository environment. SRP considers this figure too low but makes no specific estimate.

In summary, the important variables on which accumulation or non-accumulation of abundant mobile fluid depends can be known only roughly on the basis of available data. SNL calculates a maximum expectable rate of brine inflow of about 43 m^3, or slightly over 1 percent of the initial volume of the empty room, in each disposal room in 100 years, an amount that preliminary experiments show could be readily absorbed by the planned backfill and would not form a mobile fluid. SRP rightly points out that the amount could be much larger if salt permeabilities higher in the measured range of values are used for the calculation.

Critique of the SRP Scenario

The following discussion will consider whether the chance of fluids accumulating in the amounts, character and with the resulting hazard to the environment that are pictured in SRP's scenario is significant. SRP supposes that abundant brine enters voids in the repository from permeable parts of the salt; that the brine moves through the backfill, corrodes the steel containers of the waste, and becomes a thin and mobile "slurry" containing dissolved and particulate material from the waste, backfill, and corroded metal; that radionuclides exist in the liquid partly as dissolved compounds and partly as attachments to suspended particles; that abundant gas is generated and pressure builds up both from the gas and from salt creep; and that the liquid is forced to the surface either through leaks in the shaft seals or through exploratory drill-holes that happen to penetrate the repository sometime in the future when all records of WIPP's existence have been lost. The various parts of this scenario are discussed in the following paragraphs.

Inflow of abundant brine. As noted previously, abundant inflow is possible but only if it comes from exceptionally permeable parts of the salt, or if the effective bulk permeability is much greater than the average of that measured locally in a few boreholes. Permeable zones in the salt will probably be obvious during repository construction, and it seems likely that they can be avoided as the disposal rooms are excavated. As mentioned above, the amount of brine to be expected is more reasonably estimated from the low permeabilities measured by SNL.

Corrosion of steel containers. Both SRP and SNL assume that the steel will corrode not long after the repository is closed. SRP expects the "soft-steel waste containers [to] disintegrate within ... 20 years"* and become part of the "slurry." The products are more likely to be iron in solution and solid chunks of the container metal that have been partly or completely oxidized or sulfidized.

Formation of "slurry." The term "slurry" in the SRP paper appears to connote a free-flowing liquid containing dissolved and particulate material derived from partial disintegration of backfill, waste, and corroded metal. Most of the backfill is more likely to persist as a dense mush of salt crystals and bentonite, the waste would be in pieces and shreds of various solids, and the corroded metal would form in discrete chunks. The remaining void space, as yet undetermined, will contain brine and gas, and if the permeability is as low as current estimates by SNL suggest, the amount of liquid brine will be small.

Entrainment of radionuclides. The radionuclides from the waste are assumed to be partly dissolved in the "slurry" and partly attached to its constituent particles, and in either form to be freely moving. Because the principal radioactive species is plutonium, which is insoluble in neutral reducing solutions and strongly sorbed by both bentonite and iron oxide, the amount in dissolved form should be very small. It can be reasonably assumed that there would be some particles containing plutonium but this would be only a fraction of the total radioactive material present, and the particles would not travel far if the "slurry" were to move through small openings.

Generation of gas. As noted above, some formation of gas is very likely, particularly carbon dioxide from the decomposition of organic materials in the waste. SRP postulates in addition abundant hydrogen sulfide, which seems improbable because even if it does appear, it would react readily with dissolved iron to form solid ferrous sulfide. Accumulation of much gas and build-up of high pressure by salt creep as the repository openings are compressed appear to be unlikely, because the gas would slowly move out through the salt or through leaks in the seals of shafts and tunnels. If the salt is permeable enough for much brine to leak in, it is likely that gas would tend to leak out as the gas pressure rises toward lithostatic.

Movement of "slurry" to the surface. SRP assumes that radionuclides can reach the surface by two possible routes: (1) through leaks in shaft seals up into an aquifer in the overlying Rustler formation, thence to the surface with groundwater flow in the aquifer; and (2) through exploratory drill-holes that accidentally strike the repository in the distant future. Release by either route could be prompted by the development of high pressure from gas generation or salt creep; release through drill-holes is possible also without pressure, by the entrainment of waste in fluids used for drilling. If the existence of sufficient mobile fluid is assumed, any of these alternatives could bring radioactive material to the surface in amounts exceeding releases specified by EPA standards. In support of the first alternative, SRP notes that SNL has not yet demonstrated a completely satisfactory method of shaft sealing. Recent SNL in-situ experiments with various sealing techniques, however, are very promising. Release to a Rustler aquifer requires that leaks in the seals be not only present but large enough for passage of particulate matter in the "slurry, a requirement that puts an additional strain on the credibility of this route. The postulated releases through drill-holes are the more plausible of the two routes.

It is worth noting that the radioactive releases just described, even if they were to occur, would not result in a major catastrophe at or near the site. Escape of contaminated brine through a drill-hole from a pressurized cavity would cause a temporary spurt of radioactive liquid, and entrainment of waste in drilling fluid might lead to longer-lasting flow; but both events would mean only brief surface contact between a few individuals and slightly radioactive liquid. Serious harm would be highly unlikely. Release to a potable aquifer could be more dangerous because the fluid would be disseminated over a wider area and ingestion could lead to possible significant exposure; but water from Rustler aquifers is not now potable and is not likely to become so in the future. Meeting EPA standards is a requirement, although failure to achieve compliance at this particular site and with this particular assumed sequence of events would not pose a major threat to the health and safety of a large community.

Thus SRP has presented a scenario of radioactive release at WIPP that could conceivably happen but that seems highly improbable. Given extraordinary permeabilities of salt with continuity to a source of water near the disposal rooms, backfill that takes the form of very small particles, steel containers that corrode in a nearly neutral reducing brine or disintegrate into tiny grains of iron oxide, and heterogeneous waste that generates abundant gas as it breaks down into particles—given all these preconditions, it would indeed be possible for a mobile fluid to form that could bring radionuclides to the surface in amounts exceeding EPA standards. But the necessary assumption of a sequence of improbable events coupled to the drilling of exploratory holes that strike disposal rooms does not make the result credible. It will probably be forever impossible to devise a repository so perfect that someone cannot think of a way in which it might be breached; but such a breaching event must prove credible through a sound program of experimental investigation. Nevertheless, it is essential to have a well conceived experimental program at WIPP to reduce remaining uncertainties as a basis for a conservative performance assessment.

Conclusions and Recommendations

In response to the request by the New Mexico congressional delegation, the Panel concludes from its study of currently available evidence that the formation of an abundant mobile fluid in a repository at the WIPP site, as postulated by SRP, is very improbable. SRP has nevertheless highlighted some of the uncertainties, long recognized by the Panel, that remain in the existing data, and by so doing has performed a service. To resolve the uncertainties, the Panel makes the following recommendations:

1. The uncertainties are not considered sufficient to warrant a hold on the research activities currently planned at WIPP. A comprehensive, systematic experimental program is needed and should continue, to reduce the uncertainties and to support a conservative performance assessment as required by EPA. Experimental work is particularly important on the permeability of the salt (in particular, the nature, location, extent and continuity of zones of above average permeability) and the generation of gas from the waste. These

quantities are essential for predicting the amount, character, and migration of any fluid that accumulates, and major uncertainties still exist regarding them; the goal of the experimental program should be to reduce the uncertainties with minimal risk.

2. As a first priority, the planned experimental program for a 5-year period must be better defined. Detailed descriptions of the intended experiments have not yet been published, and, without seeing such descriptions, neither the Panel nor any other scientific group has a basis for a meaningful judgment about their ability to reduce current uncertainties.

3. Some of the experiments will require the use of drums containing radioactive waste, and there should be no change in present plans to bring such drums to WIPP beginning in October 1988. Because of continued uncertainty about achieving compliance with EPA standards, the Panel agrees with EEG* that no more drums than those to be used in well-described and necessary experiments be placed underground. Only when the experimental work has substantially reduced the uncertainties about brine accumulation to which EEG and SRP have called attention should additional waste containers be emplaced.

4. Experiments should be designed to lessen uncertainties, not to "verify" preconceived ideas about their probable results. Thought should be given to an appropriate course of action if experimental results turn out contrary to expectation.

5. As experimental results are obtained, performance assessment calculations should be continually refined to test the confidence of achieving compliance with EPA standards.

6. Multiphase models (gas + liquid + solid) should be developed to describe the behavior of the possible complex fluids that may form as brine enters the repository and gas is generated from the waste.

7. Effort should commence immediately to investigate the feasibility of possible technical "fixes" if the problem of fluids in the repository is determined by the recommended experiments to be serious. Examples of such "fixes" are:

   a. the use of "getters" to reduce or control the amounts of gas generated from the waste;

   b. the use of inhibitors to suppress bacterial activity;

   c. methods by which brine in the repository might be drained, for example into some sort of sump;

   d. a decision to leave the repository open for a long period, perhaps 100 years, with ventilation and appropriate monitoring, to ensure consolidation of salt around the waste unhindered by brine or gas pressure build-up;

   e. addition of material to the waste drums to increase sorptive capacity and reduce void space; and

f. as an extreme measure, processing the waste into dense, chemically stable forms before emplacement in the repository.

References

*Evaluation of the Waste Isolation Pilot Plant (WIPP) as a water-saturated nuclear waste repository. Scientists Review Panel on WIPP, Albuquerque, New Mexico, January 1988.

#Potential problems resulting from the plans for the first five years of the WIPP project. Environmental Evaluation Group, State of New Mexico, Santa Fe, New Mexico, February 1988.

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF DECEMBER 1988
EXPERIMENTS ON ROOM CLOSURE RATES

NATIONAL RESEARCH COUNCIL

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

2101 Constitution Avenue Washington, D.C. 20418

BOARD ON
RADIOACTIVE WASTE MANAGEMENT
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Room 462
2001 Wisconsin Avenue, N.W.

December 30, 1988

Mr. Critz George
U.S. Department of Energy
Office of Defense Waste
and Transportation Management
DP-124/Forrestal
Washington, DC 20545

Dear Mr. George:

The Waste Isolation Pilot Plant (WIPP) Panel of the Board on Radioactive Waste Management (BRWM) has reviewed the data on room closure rates from laboratory tests and in-situ experiments. What follows is a suggested design for an intermediate-scale experiment to better define the sources of the discrepancy between the predicted and observed salt creep rates, as requested by the Department of Energy.

Summary

Measurements in underground test rooms [of the order of 5.5m (wide) x 5.5m (high) in cross-section] at the WIPP site indicate room closure rates three to six times greater than the rate predicted by numerical computational codes used to model the deformational behavior of the rooms and associated pillars. The codes incorporate mechanical properties for the salt around the rooms identical to the properties derived from deformation behavior observed in laboratory creep tests on small (i.e., of the order of 50mm diameter x 100mm high) core samples taken from the WIPP site.

It is important to establish the reasons for this discrepancy in order to assess better the extent to which such codes can be used to predict quantitatively the field performance of repository excavations in salt.

For this purpose, a limited number (two to five) of in-situ tests are recommended to observe closure rates around horizontal, circular excavations intermediate in scale (i.e., one meter or so in diameter) between the above mentioned field and laboratory tests. Such tests, by providing a "third set" of independent data, will assist in identifying likely and unlikely causes of the observed discrepancies.

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Discussion

Evaporite rocks such as the salt formations at the WIPP site exhibit time dependent deformational behavior when subjected to load. The deformation is related in a complex, non-linear way to the applied stress, temperature, time--and possibly to other variables. Lomenick, McClain and Starfield, for example, used an empirical relationship of the form:

$$E_t = E_o + A\sigma^a T^b t^c \qquad (1)$$

where	E_t	is	the strain of the material at any time t
	E_o	is	the instantaneous (or "elastic") strain that develops immediately upon load application--and is recovered immediately upon unloading
	σ	is	the applied stress (some function of the three-dimensional stress rate)
	T	is	the absolute temperature (^oK)
	t	is	time
	A,a,b,c	are	constants

to analyze deformations around underground openings as part of Project Salt Vault studies at Oak Ridge National Laboratories ["a" for example, was found to be approximately 3, i.e., strain (and strain rate, convergence, and convergence rate) was proportional to the cube of the stress]. The empirical power law was found to provide good agreement with observed behavior for periods of the order of weeks to months.

Sandia staff, as part of their research to predict deformation behavior with good accuracy over the period of the repository loading operations, i.e., of the order of 50 years, have attempted to develop an expression for creep behavior that directly incorporates fundamental creep processes that are operative within the internal structure of the salt. The expression is more complicated than equation (1) above, with a greater number of variables, whose magnitude is determined from analysis of the laboratory test data. Incorporation of the expression into the numerical codes allows modeling of the excavations and prediction of the convergence and convergence rates for the excavations.

Finding that the observed rates of room closure are three to six times larger than those predicted from the laboratory results, Sandia explains the difference by:

(1) refining the creep expression (or "constitutive relationship") to incorporate additional fundamental mechanisms; or

(ii) attempting to assess whether strains occurring during the very early times after the theoretically "instantaneous" (but practically finite duration) load applications are properly taken into account in the measured deformations; or

(iii) speculating that the process of coring and removing samples from the in-situ environment and preparing specimens for laboratory testing significantly changes the observed deformational response to load.

Sandia staff have also noted that an empirical reduction of the in-situ modulus of elasticity of the salt mass by an order of magnitude (factor of 12.5) compared to the laboratory measured value will bring laboratory and field results into quite close correspondence for the periods of field observation used. Although no specific justification is given for this reduction, it is well known that a rock mass may contain cracks and fissures too large to be included in a small test specimen. These cracks can reduce the stiffness (or modulus) of the rock mass compared to small specimens--by as much as a factor of one hundred or so at low stress levels, i.e., when cracks are open and compliant.

With the exception perhaps of the modulus reduction approach, the above explanations of the discrepancy suggest a belief that the laboratory test procedures and results, properly interpreted, are capable of explaining the field observations, i.e., that the "errors of interpretation" lie fully with the laboratory tests. While this may be true, it is also certainly plausible that there may be influences in the field scale tests that are absent (or at least different in degree) in the laboratory situation.

The most obvious of these influences are:

1. Scale. The volume of rock undergoing deformation in the field is very much larger than in the laboratory.

Although the strength of some rock types is known to decrease with an increase in the loaded volume (due to the greater possibility of large, weakening flaws in the larger volume), evaporites are often considered to be less subject to size effects than other rock types. Flaws in evaporites tend to heal with time.

2. Geometry. The laboratory tests are conducted on small (initially unloaded) cylindrical specimens; an axial load is applied to the specimen by a testing machine. The field tests involve rectangular openings in an essentially infinite medium, which deform as a result of the redistribution of preexisting (overburden and lateral) loads.

It is known from laboratory tests that the compressive strength of a hydrostatically compressed specimen in the form of a hollow thick-walled cylinder is several times greater than the strength of a standard solid (cylindrical) test specimen. Thus, geometry does influence strength--although apparently not in a way that would explain the observations at WIPP, where salt around the large rectangular holes is apparently weaker (i.e., creeps more rapidly) than salt in the small, solid cylindrical test specimens.

Tests have been conducted to determine the in-situ state of stress at the repository horizon, to see whether orientation of stress might help to explain the discrepancy between field and laboratory data. Results tend to confirm the expected condition that the principal stresses are all approximately equal to the overburden stress (i.e., "lithostatic"). In addition, although there is some variation with direction in the observed rates of closure of the excavations, this variation is of the order of ±25% of the mean of all observed rates, and hence much less than the 300% (or more) difference between field results and the predictions from laboratory results. Nor can the difference be ascribed to computational error: the numerical code SANCHO used to predict the field results has been "benchmarked" (i.e., shown to give results consistent with other numerical codes and with analytical solutions).

It would appear that in the specific situation of the WIPP site, there are a number of possibilities for explaining the observed discrepancy, in addition to the general scale and geometry effects, and those noted in (i), (ii), and (iii), above. For example:

1. The three-dimensional stress distributions imposed by the size and cylindrical geometry of the laboratory specimens and the testing machine (relatively rigid steel loading) may effectively inhibit deformation compared to the field loading situation, where the loads are applied naturally, i.e., without a mechanical interface.

2. Structural features within the "significantly affected region" around the excavation may contribute to the development of deformation mechanisms that are (a) not possible in the smaller, "effectively more confined" specimens, and (b) not incorporated in the numerical models. Buckling of "slender beams" resulting from sedimentary interfaces close to the wide excavations (i.e., Marker Bed 39 and roof shearing in other areas), and perhaps incipient buckling associated with cracks and fissures in the vicinity of the excavation, are all examples of possibilities for mechanisms that will not be seen in laboratory tests on small specimens.

With only two situations available for comparison, i.e., the small-scale laboratory and the large-scale in-situ case, it will be very difficult to:

a. identify whether or not the differences in scale, geometry, and loading conditions of the two situations introduce, eliminate, or modify mechanisms and causes for deformation in one case compared to the other, and

b counter assertions that agreement between predictions based on laboratory tests and observed field results is a consequence of "curve fitting" (i.e., selecting arbitrary values of disposable variables in the constitutive relationship so as to optimize agreement with observations).

The possible effect of differences in scale and geometry could be investigated by an intermediate-scale experiment. The availability at WIPP of special equipment for drilling 36-in.-diameter horizontal holes into the salt would make such an experiment feasible, providing an opportunity both to assess specific mechanical properties (e.g., the in-situ modulus of elasticity of salt around the excavation), and to assess the effects of scale and geometry on the rate of closure of excavations in the salt. Observations on closure around a 36-in.-diameter hole would provide data on a scale intermediate between the current two situations (laboratory-scale and full-scale) and for a geometry that more closely resembles the full-scale excavation than the laboratory tests. It would also be possible to instrument the region adjacent to the (proposed) hole before it is drilled, thereby allowing determination of in-situ deformation behavior and its variation with time from the instant that the large hole is drilled.

Recommendation

Given that equipment is available underground at WIPP for drilling large diameter (one meter or so) boreholes into the salt, it seems feasible to undertake tests to observe time dependent deformations around such holes and to compare those predicted by the numerical model. The possibility of such tests has been explored with Sandia staff in discussions and visits to a possible site underground.

Figure 1 shows the site and test layout recommended on the basis of the discussions. In essence, a 36-in.-diameter, 100-ft.-long borehole would be drilled between two drifts in a 9-ft.-thick layer of uniform ("clean") salt at an elevation midway between two anhydrite layers. At this spacing the influence of the anhydrite layers on the deformation behavior of the borehole should be negligible. Installation of stress change and deformation gauges in the vicinity of the 36-in.-hole prior to coring should allow observation of all deformation, including the "early-time" deformation, resulting from drilling the hole. This early deformation was not observed in the full-scale tests.

Such a test has the following additional attributes that should help reduce the present uncertainties:

1. The salt being studied is not removed from its natural environment--as are the laboratory test specimens.

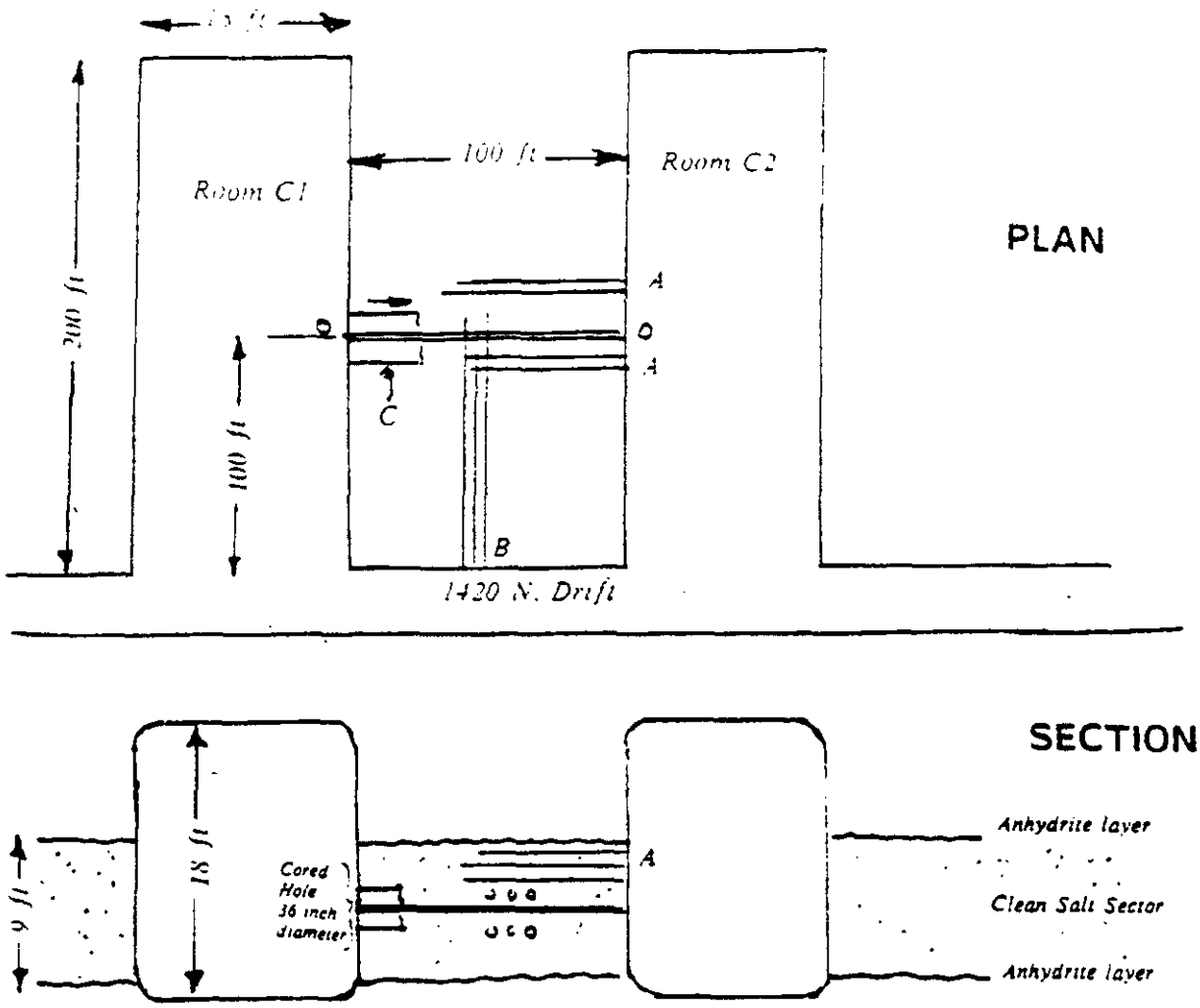

FIG 1. Recommended Layout of Intermediate Scale Time-Dependent Deformation Test

Test Procedure

Phase 1. (a) Drill one or more small diameter (2 to 3 inch) holes O-O horizontally between the two rooms. Instrument - to observe early deformations ahead of large coring drill as hole is being cored

(b) Drill three dimensional array of horizontal holes (A, B) at various heights [around path of (future) 36 inch hole] from Room C2 and 1420 N Drift, to observe stress changes and deformations induced in the vicinity of the large hole C as it is being drilled

Phase 2. Drill 36 inch diameter hole C horizontally from room C1 to room C2. Instrument to observe time dependent radial deformation imposed on the borehole. This deformation rate will be different at various cross sections due to the variation in stress concentrating effects of Rooms C1, C2,--hence several loading conditions can be simulated

2. There is no mechanical interface in the loading system.

3. The test is approximately one order of magnitude smaller in scale than the room excavation tests and one order of magnitude larger than the laboratory tests--so that it will allow evaluation of scale effects.

4. The test geometry is somewhat similar to that of the room excavation (long uniform cross-section) and the overburden pressure is comparable so that the three-dimensional stress conditions are reasonably similar. In both cases (room and borehole), the test scales are much larger than the salt grain size--so that scale effects due to the salt structure itself should be the same in the two cases. Salt structure scale effects may be significant in the laboratory test.

5. Anhydrite and clay seams occur within the region of stress redistribution around the full-size excavation. At the site recommended for the intermediate-scale experiment, the possibility of such influences on the time-dependent deformation around the hole is very much reduced.

Some Possible Outcomes of an Intermediate-Scale Experiment

- If the field/laboratory comparison for the intermediate-scale experiment proves to be essentially the same as for the full-scale tests (i.e., actual deformations 300% or so greater than numerical model predictions), then the differences are probably not the result of the volume of salt under high (deviatoric) stress, but more likely the result of the basic difference between laboratory and field testing procedures. The influence of differences in geometry between the cylindrical specimen tests and the field tests could be assessed by performing laboratory tests of radial creep behavior in thick hollow cylinders (e.g., 2-in. internal diameter, 10- to 12-in. outside diameter) subjected to external hydrostatic loading--this geometry would closely approximate that of the intermediate-scale test.

- If the intermediate-scale test results fall between those of the laboratory and field results, then it would appear that some form of scale effect is operative. This would indicate that more detailed laboratory studies of creep of uniaxially loaded solid cylinders will not suffice to explain the observed differences between field and laboratory behaviors. (The hollow cylinder laboratory tests mentioned above would help separate the influences of geometry and size on the result.)

- If the intermediate-scale results fall outside the range of the laboratory and full-scale results, it would again be important to assess the significance of test geometry (i.e., conducting laboratory hollow cylinder tests to allow comparison between tests of

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essentially similar geometries for the three existing series of tests). If the intermediate-scale results are still outside the range of the other tests, this would strongly suggest that removal of the salt from the original environment and preparation of test specimens significantly change the creep response. This would indicate that current understanding of the processes of creep in salt (and especially in laboratory specimens of salt) is inadequate to allow reliable prediction of the rate of closure of full-scale excavations from observations on laboratory specimens. In the case of the WIPP repository, this would imply that predictions of long- term excavation closures must rely on in-situ observations. The finding would also have considerable general implications, e.g., for cases where borehole cores only are available for testing (i.e., during site exploration, before direct underground access and testing are possible).

Thus, although of course results of the intermediate-scale tests cannot be anticipated, the tests do have the potential for providing important insights into the causes of the observed discrepancies between model predictions based on the laboratory tests and full-scale field observations.

Konrad B. Krauskopf

Konrad B. Krauskopf
Chairman, Panel on the
Waste Isolation Pilot Plant Project

NATIONAL ACADEMY OF SCIENCES

REVIEW COMMENTS ON DOE/WIPP 89-011
DRAFT TEST PHASE PLAN

July 19, 1989

REVIEW COMMENTS ON DOE DOCUMENT DOE/WIPP 89-011: DRAFT PLAN FOR THE WASTE ISOLATION PILOT PLANT TEST PHASE: PERFORMANCE ASSESSMENT AND OPERATIONS DEMONSTRATION

SUMMARY OF RECOMMENDATIONS

1. *DOE should develop and publish within the next six months a short, integrated, overall systematic assessment of long-term safety of the WIPP repository, as currently understood.*

2. *Urgent attention should be given to (i) defining the combined effects of gas generation, room closure and sealing, brine inflow, and other effects on the potential for long-term build-up of gases in the repository to lithostatic (i.e., overburden) pressure, with respect to the long-term isolation capability of the WIPP repository, and (ii) examining options for modifications to the waste as part of the resolution of the gas generation issue.*

3. *Given the urgent need to resolve questions concerning gas generation after emplacement of TRU waste, the Panel agrees that the bin-scale and room-scale experiments, involving approximately 0.5% by volume of the capacity of WIPP, are warranted and should begin without delay.*

4. *Data from laboratory tests (including tests at high ambient pressures), information from studies on gas generation from waste packages now stored at various sites, and information on experience abroad (e.g., U.K.) should be collected and studied, together with engineering modifications, as expeditiously as possible to assist in arriving at a sound, early solution to the gas generation issue.*

5. *The Department of Energy should include in the Plan a discussion of the risks associated with transportation of TRU waste to WIPP, relative to the transportation of other hazardous materials.*

6. *Demonstration of operational readiness should not start until several important issues concerning underground emplacement of waste for permanent isolation at WIPP have been resolved.*

INTRODUCTION

Copies of DOE/WIPP 89-011 (full title: "Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration") were distributed in April to all members of the WIPP Panel for individual review. Topics for later discussion were selected by the Panel based on this review. The Panel assembled to consider the Draft on June 6-8 at the National Academy of Sciences (NAS) Green Building in Washington, DC. DOE staff and contractors made presentations and answered questions.

The Draft Plan (including the addendum dated June 16, 1989) proposes the underground emplacement of TRU waste equal to 2.7% by volume of the total design capacity of WIPP in the repository during the three-year period September 1989-September 1992 (Phase 1). This consists of 0.5% to be emplaced for experimental purposes and 2.2% for Operations Demonstration purposes. At the end of the three-year period DOE proposes to

> institute a holdpoint to analyze the results of the Performance Assessment and Operations Demonstration Programs up to that point. If, after a formal review of the results of the programs, there is reasonable confidence that WIPP will comply with the EPA Standard, 40 CFR 191, Sections 13 and 15 (as amended), and that Operations with actual TRU waste have been successfully performed in a safe and effective manner, a second part of the Test Phase will be undertaken. Test Phase activities and waste quantities for this part of the program

would be determined based on needs and requirements identified during the holdpoint review [DOE addendum (June 16, 1989)].

Several relevant documents (listed in Appendix A) were provided between the time of delivery of the Draft Plan and the WIPP Panel meeting; others were distributed at the meeting. These documents, together with the presentations and discussions during the June 6-8, 1989 meeting, yielded substantial information and insight on the proposed 5-year (Draft) Plan. Many of the conclusions and recommendations in the Panel's letter report are based on this more complete appreciation of the Plan.

PANEL FINDINGS

The Plan contains two principal sections, one entitled Performance Assessment, the other Operations Demonstration. The two sections will be discussed separately. The conclusions and recommendations are presented in *italics*; associated discussions are presented in standard type immediately following the particular conclusion or recommendation.

PERFORMANCE ASSESSMENT

Conclusions

Although the Plan is valuable in that it provides, for the first time, a comprehensive directory of all of the investigations, current or planned, under the WIPP program, and clearly indicates how these are related to the overall performance assessment activity, there are serious deficiencies in this Draft. In its present form, the Plan does not

(i) develop research priorities or identify critical problems;
(ii) identify or make appropriate use of the essential logic and rationale underlying the performance assessment process, i.e., the iterative, evolutionary selection and pursuit of investigations designed to establish the overall suitability of the WIPP site as a repository for safe, long-term isolation of TRU radioactive waste.

Failure to describe the iterative reassessment process and how it has been, and is being used at WIPP is a serious omission, since the entire program of experimental studies now underway, and many of those planned, have presumably been decided on this basis. From presentations made at this and other meetings of the NAS/NAE/NRC WIPP Panel it is clear that DOE and its contractors have, in fact, followed a process, albeit less well-defined and more intuitive than the formalized performance assessment system now under development.

Notably absent from the investigations described in the Plan is any consideration of the influences of radionuclide solubilities or engineered modifications on repository isolation performance. Although no details were provided, DOE and its contractors stressed, during the meeting, that engineered modifications are now being given serious attention as contributors to overall isolation performance. The Panel has long advocated consideration of the merits of engineered modifications to improve the waste isolation performance of the WIPP repository, if improvements should indeed be necessary.

While the performance assessment methodology described in Chapter 2.4, and illustrated graphically in Figure 2.4 (p. 2-21) of the Plan, seems to be appropriate for the formal assessment of compliance with 40 CFR 191, Sub-Part B (EPA Standard), it is unlikely that this methodology will have a substantial impact on the experiments planned, at least during the early part of the five-year Plan. It is also unlikely that the results of the experiments will be available for, or have any significant impact on, the performance assessment.

Recommendation 1

DOE should develop and publish within the next six months a short, integrated, overall systematic assessment of the long-term safety of the WIPP repository, as currently understood.

The immediate purposes of such an assessment would be to

(i) identify critical risks and issues
(ii) articulate and document the rationale for currently proposed programs
(iii) establish priorities for these programs with respect to their expected contributions to the safe-repository objective (see Appendix)
(iv) stimulate early development of the iterative process of performance assessment priorities that is missing in the compliance-oriented "total system modeling" approach now being pursued (see Appendix).

The proposed assessment procedure would also complement the current performance assessment activities in the manner suggested by the Environmental Protection Agency (EPA) viz. in Appendix B, "Guidance for Implementation of Sub-Part B" [of 40 CFR Part 191] (Sept. 19, 1985).

> In making these various predictions [of overall disposal system performance] it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well. (Emphasis added.)

Additional discussion of Recommendation 1 is presented in the Appendix B to this report.

Recommendation 2

Urgent attention should be given to (i) defining the combined effects of gas generation, room closure and sealing, brine inflow, and other effects on the potential for long-term build-up of gases in the repository to lithostatic (i.e., overburden) pressure, with respect to the long-term isolation capability of the WIPP repository, and (ii) examining options for modifications to the waste as part of the resolution of the gas generation issue.

Considerable attention was given, during the meeting, to the suggestion in the Plan that the combined long-term effects of repository closure and gas generation due to corrosion of the waste package, and bacteriological and radiological decomposition of the TRU waste, could result in the development of gas pressures of the order of the lithostatic (i.e. overburden) pressure in the sealed repositories. Such pressures could give rise to potentially serious effects such as the generation of radial fractures, originating from the repository and able to propagate away from the repository, thereby allowing transport of radionuclides outside the repository. Computations suggest that the *intact* salt formations are likely to be essentially impermeable to gases; hence pressure leak-off may not occur.

On the other hand, it is possible that salt permeability may increase due to micro-fracturing caused by gas pressures (acting within the underground cavity) as they approach lithostatic pressure. This needs to be examined. Also, recent studies have revealed the development of circumferential fractures in the immediate vicinity of the underground excavations (the so-called "disturbed rock zone"). These fractures develop progressively as the excavations close, and may serve as high permeability paths along the periphery of the excavations. These paths would allow the gas to escape from the storage excavations as it is generated, at least until the fractures reheal due to creep closure around repository seals.

Studies have been started to examine the combined effects of gas generation, disturbed-rock-zone development, and engineered (chemical) modifications to the waste package on gas generation, long-term, in the overall repository environment. Laboratory, and perhaps in-situ, tests, even at a small-scale, to determine the gas permeability of intact salt as the pressure inside a "sealed" cavity approaches lithostatic pressure, would be very informative with regard to this problem.

Because the time necessary for gas pressure build-up to occur is considerably longer than the five-year period of the proposed DOE Plan, it is important that efforts be undertaken now that can reduce or eliminate concern that gas generation will affect safety. Such measures include changes in container materials, waste modification, and engineering modifications.

Underground Experiments

Conclusion

Determination of the rate, quantity, and composition of gases generated by the very heterogeneous mixtures of existing TRU wastes will require both laboratory (bench) and large-scale experiments, the latter involving assemblies of drums of TRU waste.

Recommendation 3

Given the urgent need to resolve questions concerning gas generation after emplacement of TRU waste, the Panel agrees that the bin-scale and room-scale experiments, involving approximately 0.5% by volume of the capacity of WIPP, are warranted and should begin without delay.

Conclusion

Underground test results alone will not suffice for an early decision on appropriate strategies for addressing gas generation in waste package and underground emplacement, since much of the important data will still be accumulating at the end of the currently scheduled test phase (i.e., September 1991).

Recommendation 4

Data from laboratory tests (including tests at high ambient pressures), information from studies on gas generation from waste packages now stored at various sites, and information on experience abroad (e.g., U.K.) should be collected and studied together with engineering modifications as expeditiously as possible to assist in arriving at a sound, early solution to the gas generation issue.

The gases generated by the emplaced waste will be so low in radioactivity as to be considered non-radioactive. The processes by which gases are generated under repository conditions, including corrosion and radiolysis, do not produce radioactive isotopes. The repository gases should include only trace amounts of the noble gas fission products released from the wastes.

OPERATIONS DEMONSTRATION

Panel discussion of the need for demonstrating the ability of the WIPP facility to "be safely and effectively operated as intended by Congress in PL 96-164" [DOE statement of purpose of operations demonstration], was divided into two main topics:

1. Transportation and associated emergency preparedness issues (accident prevention, states training and education)

2. The need for early demonstration of operational readiness and pre-operational testing, including underground emplacement of TRU waste.

Transportation and Emergency Preparedness

Conclusion

The system proposed for transportation of TRU waste to WIPP is safer than that employed for any other hazardous material in the United States today and will reduce risk to very low levels.

The Panel was impressed with the WIPP program activities in transportation of TRU waste and emergency preparedness. The program is both very comprehensive and thorough, and will undoubtedly result in low levels of risk associated with surface transfer of TRU waste from current storage locations to the WIPP facility.

Recommendation 5

The Department of Energy should include in the Plan a discussion of the risks associated with transportation of TRU waste to WIPP, relative to the transportation of other hazardous materials.

Panel members expressed concern that there was no indication, in either the Plan or the oral presentations, of a relationship between (a) the assessment of risk and safety associated with the various aspects of transportation of TRU waste and (b) the emergency planning and education program. Also, the 'high profile' and comprehensiveness of the states training and education program may give a false impression that TRU waste is more hazardous than a variety of other hazardous materials, some posing a significantly greater risk, that are routinely handled in the same states and on the same highways with no special precautions. In the Panel's view, the Department is being exemplary and responsible in giving a high level of attention to TRU waste transport. Such attention is appropriate for shipment of all hazardous materials, almost all of which pose greater risk than the TRU shipments.

Demonstration of Operational Readiness

Conclusions

Demonstration of operational readiness is an important phase of the overall WIPP program.

Pilot-plant and prototype testing are essential scale-up steps in the sound development of new technological systems. Given also the unique nature of the WIPP facility, such operations demonstration activities become particularly important. Transportation and underground emplacement of TRU waste on a pilot-scale are necessary parts of the overall demonstration that the WIPP facility can be operated safely for TRU waste isolation.

The overall public health consequences of the proposed operations demonstration are likely to be very small, given

(i) the low risks associated with transportation of TRU waste (discussed above), and
(ii) the inherently high security of the WIPP underground location, especially on a monitored storage basis, as is contemplated for the five years of the Plan.

Recommendation 6

Demonstration of operational readiness should not start until several important issues concerning underground emplacement of waste for permanent isolation at WIPP have been resolved.

The Panel discussed the desirability of starting the operations demonstration activities at the same time as the underground experiments. It was noted that significant waste handling experience will be gained by emplacement of the waste for the gas generation experiments.

Although it was acknowledged that early experience with operational activities (i) would expose, in a timely manner, problem areas that are manifested only in integrated plant operations, and (ii) could provide needed guidance on realistic alternatives between longer-term engineered isolation and permanent isolation options, there are important unresolved issues that could significantly affect the method of packaging and emplacement of TRU waste underground at WIPP.

These issues include, for example, (i) appropriate method(s) of dealing with gases generated from the waste containers stored underground; (ii) appropriate back-fill composition and back-filling procedures that may be considered necessary; and (iii) other engineering modifications that may prove necessary for the safe isolation of TRU waste.

DOE is, in fact, not yet ready or able to undertake a demonstration of operations as they will be conducted during waste emplacement for long-term isolation. As a consequence, the Panel does not consider in any detail the DOE proposed plans for operations demonstration.

APPENDIX A

DOCUMENTS DISTRIBUTED TO WIPP PANEL TO SUPPLEMENT DOE DRAFT PLAN (DOE/WIPP 89-011)

- Draft Supplement Environmental Impact Statement, Waste Isolation Pilot Plant (2 vols) April 1989. DOE/EIS-0026-DS.
- Plan for the Disposal System Characterization and Long-Term Performance Evaluation for the Waste Pilot Plant SAND 89-0178 (by S.G. Bertram-Howery and R.L. Hunter) 1989.
- Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessment, Waste Isolation Pilot Project. (A. R. Lappin and R. L. Hunter, Editors); SAND 89-0462 April 1989.
- Draft Test Plan - WIPP Bin-Scale CH TRU Waste Tests TP-BIN1 5/8/89 (by Martin A. Molecke) May 1989.
- Test Plan - WIPP In-Situ Room-Scale CH TRU Waste Tests TPROOM1 6/05/89 (by Martin A. Molecke) June 1989.

No details were provided on plans for proposed laboratory experiments on gas generation. These are an essential complement to the proposed bin- and room-scale experiments. Details of the laboratory experiments would have allowed a more complete review of the bin- and room-scale tests. Also, the documents TP-BIN1 and TPROOM1 were distributed at the meeting in provisional, unreviewed draft form. Hence the primary source of information on the Bin- and Room-scale tests was the oral presentation by Dr. Molecke, and the Panel's conclusions were based on this presentation.

APPENDIX B

ADDITIONAL COMMENTS ON THE DEVELOPMENT OF COMPLEMENTARY APPROACHES TO PERFORMANCE ASSESSMENT

It is clear from reading 40 CFR 191 that EPA, in setting the Standard, recognized the difficulty of making precise quantitative predictions of the radionuclide releases from a given geological repository over periods of the order of 10,000 years or longer. In noting the merit of having "expert judgment" and "qualitative judgment" to assist in arriving at release estimates [See quotation in discussion of Recommendation 1, (Page 3)], EPA is acknowledging the uncharted and unprecedented nature of the computational task. The primary goal of 40 CFR 191 is to ensure that a repository poses no significant health risk to the public; the standards set for compliance represent EPA's best estimate of what is required to achieve this goal. To date, however, these standards have never been applied to a specific repository.

The Panel believes that the above-mentioned primary goal can best be achieved by focusing performance assessment activities on demonstrating that the WIPP repository will be *safe*, i.e, pose no significant risk to the public health and safety, rather than by an *uncritical*, formal adherence to compliance with the current EPA standard. The latter approach could result in neglect of possible long-term dangers or, conversely, unnecessarily detailed analyses of issues that can readily be shown to be of negligible consequence on simple qualitative grounds.

Clearly, it will be necessary to show compliance with the 40 CFR 191; and it is probable that the "*safe repository*" approach will lead to a design that is in compliance with the EPA standard. It is also probable that the experience gained by following this approach in the WIPP performance assessment process could lead to the identification of shortcomings in the present repository standards.

The recommended approach would be complementary to the present performance assessment effort, and it is anticipated that the initial effort of identifying critical issues and risks could be performed over a period of several days only. Division of the scenarios according to time periods (e.g., 10 yrs, 100 yrs, 1,000 yrs, 10,000 yrs) could illuminate the issues and risk management options. The scenarios are defined by (a) an initiating event (e.g., containment failure, gas generation, and fluid invasion); (b) undesirable consequences (e.g., fatalities and radionuclide release); (c) specific events that map (a) to (b). This approach forces an integration of the whole system and identification of the manner in which all components (hardware, procedures, software, and people) interact. The desired result is an *early* identification of the top several scenarios that currently appear most important on a risk basis. Simple bounding models, such as envisaged for this assessment, may well suffice to demonstrate acceptably low risk. Such models also have the advantage of being more comprehensible to the layperson than the complex models being developed for 40 CFR 191 Sub-Part B compliance purposes.

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COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES

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NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF APRIL 1991
SUMMARY OF RECOMMENDATIONS

A Letter Report

by the

Panel on The Waste Isolation Pilot Plant

Board on Radioactive Waste Management

April 1991

Commission on Geosciences, Environment, and Resources
National Research Council

Washington, D.C. 1991

A LETTER REPORT
BY THE
PANEL ON THE WASTE ISOLATION PILOT PLANT
BOARD ON RADIOACTIVE WASTE MANAGEMENT
NATIONAL RESEARCH COUNCIL/NATIONAL ACADEMY OF SCIENCES

SUMMARY OF RECOMMENDATIONS, APRIL 1991

INTRODUCTION

This letter report summarizes the views of the Panel on the Waste Isolation Pilot Plant (WIPP) on the status of the Department of Energy's (DOE) scientific and technical program to assess the WIPP's ability to isolate transuranic (TRU) waste and to demonstrate compliance with the relevant regulations.

For the summary, the Panel used as a point of departure its letter report of July 1989 which reviewed the DOE's draft plan for the WIPP's test phase. In the 1989 report, the Panel made six specific recommendations regarding the scientific tests, performance assessment progress, consideration of engineering alternatives to address some of the relevant issues, and operational readiness of the WIPP.

This report reviews the progress made in the WIPP program since the 1989 report, summarizes the responses made by DOE to the earlier recommendations, provides an overview of the Panel's views on the overall safety of the WIPP facility and presents some new recommendations to address unresolved issues.

RECOMMENDATIONS

1. Performance Assessment

o Since performance assessment calculations indicate that human intrusion into the repository is the scenario of dominant concern with respect to successful long-term waste isolation, the Panel recommends continued detailed study of the effects of human intrusion on repository performance.

o The U.S. Department of Energy (DOE) has made significant progress in the area of performance assessment procedures and should now extend these procedures to the engineered alternatives identified by the Engineered Alternatives Task Force (EATF). Application of performance assessment procedures is necessary to assess the merits of engineered modification of the waste form and/or the repository to address the issues of gas generation and human intrusion.

o DOE should be guided by performance assessment analysis, to the extent feasible, to determine a substantive basis for the long-term extrapolation of the repository behavior.

2. System Risk Analysis

o The various engineered alternatives should be assessed in terms of total system risk--including worker exposure, transportation and other risks--to evaluate the impacts on the entire transuranic (TRU) waste management system.

3. Experimental Program

Based on the results of performance assessment analysis, DOE should develop a well-designed experimental program and schedule that are sufficiently flexible to permit important scientific and technical issues to be addressed.

o The most recent sensitivity analyses suggest that the repository performance is affected significantly by radionuclide retardation in the rock strata above the repository. Intensive study of whether or not it is possible to determine reliable conservative estimates of field retardation coefficients for use in performance assessment is recommended. If retardation is found to be essential for adequate isolation of untreated TRU waste under the human intrusion scenario, for example, such studies could be crucial before a decision is made on the level of waste treatment that would be required.

o Understanding the nature of brine flow through salt over long time scales is important for determining the amount of brine likely to flow into repository excavations. DOE should continue the full-scale Room Q experiments with minimal interruption, together with intermediate-scale (900-mm-diameter) borehole inflow tests, since these experiments may provide conclusive evidence concerning the permeability of the repository salt to resolve the brine inflow question. DOE should give serious consideration to constructing another full-scale room for additional brine inflow studies, using the improved instrumentation, seals, and excavation equipment now available at the WIPP site.

o The likelihood of large volumes and pressures of gases being generated from the decomposition of TRU-contaminated waste in sealed repository excavations remains an important unresolved issue. The Panel is concerned that the bin experiments, which are designed to provide information about gas generation, are of such large scale and complexity that they might not yield significant gas generation data within an acceptable time frame. DOE should ensure that the effort and the resources devoted to the bin experiments do not impede other important experiments that may help to reduce significantly uncertainties in the assessment of repository performance.

4. Participation with the Scientific Community

o DOE should actively support vigorous international discussion of scientific and technical issues affecting repository safety, including gas generation. In addition, DOE should encourage critical review of the WIPP program through broader publication of its research findings in refereed scientific journals.

INTRODUCTION

As a part of a continuing effort to provide an objective scientific and technical evaluation of the Department of Energy's (DOE) program to determine the suitability of the Waste Isolation Pilot Plant (WIPP) as a repository for the safe permanent disposal of intermediate level transuranic (TRU) radioactive waste, the Board on Radioactive Waste Management's Panel on WIPP occasionally issues a status report on the WIPP's progress in addressing relevant scientific issues.

The last such report, issued in July 1989, commented on the U.S. Department of Energy (DOE) Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration. In commenting on this draft plan, the WIPP Panel addressed a number of important unresolved scientific and technical issues facing the WIPP Project and made six specific recommendations regarding the planned scientific tests, progress in performance assessment procedures and analysis, the need to consider engineering alternatives to address unresolved issues of potential gas generation and human intrusion, and the operational readiness of the WIPP.

The present report uses that 1989 report as its point of departure to comment on the progress made by DOE and its contractors in response to those recommendations, as well as to identify and comment on several additional issues.

Information about the progress made by DOE and its contractors was provided by quarterly briefings to the full WIPP Panel, supplemented by detailed periodic technical discussions between DOE contractors and specialists from the WIPP Panel.

The recommendations in the July 1989 Panel report are restated below, together with explanatory comments and discussions of relevant developments since the report was issued.

STATUS OF ISSUES ADDRESSED IN THE JULY 1989 RECOMMENDATIONS

Recommendation 1 (July 1989)

> **DOE should develop and publish within the next six months a short, integrated, overall systematic assessment of the long-term safety of the WIPP repository, as currently understood.**

The concern behind this recommendation, as described in the July 1989 report, was that the WIPP Project was not making appropriate use of performance assessment to develop research priorities or to identify critical problems. In addition, the Project was not adequately pursuing performance assessment as an iterative, evolutionary process designed to investigate (1) the overall suitability of the WIPP site as a repository for the safe, long-term isolation of TRU radioactive waste, and (2) the possibilities for increasing the assurance of isolation by engineering modifications to the waste form and/or the repository. Since this recommendation was made, the performance assessment group at Sandia National Laboratory has made significant progress in

performance assessment, and has done so following the iterative approach recommended.

The performance assessment studies indicate that (1) under the undisturbed condition, the repository is likely to meet all the performance requirements of the remanded U.S. Environmental Protection Agency (EPA) standard for radioactive wastes, and (2) human intrusion into the repository is the scenario of dominant concern. (The EPA standard, which was vacated by court order in 1987, has not yet been repromulgated by EPA, but EPA has informally circulated working drafts for comment.)

The Panel notes that geologic isolation of radioactive wastes was originally proposed, and historically has been developed, without the possibility of human intrusion as a primary consideration. Human intrusion differs from other repository isolation considerations for the WIPP in that it is the only one that "short-circuits" geologic isolation. The topic warrants continued study of methods to reduce the probability and consequences of human intrusion at WIPP. In addition, a critical reexamination of the human intrusion issue is needed, which should include analysis of the long-term probability, consequences, risk, and the overall responsibility to design deterrents to both inadvertent and intentional human intrusion. The human intrusion scenario is of concern for geologic repositories in general and is receiving attention in other countries as well.

The performance assessment studies for WIPP include a substantial effort to assess analytical uncertainties and sensitivities. The most recent sensitivity analyses suggest that the repository performance is affected significantly by radionuclide retardation in the rock strata overlying the repository, especially because of limited radionuclide solubilities. Under a human intrusion scenario, the adequacy of the repository to isolate the waste may be critically dependent on radionuclide retardation. (The July 1989 report noted that the DOE/WIPP Draft Plan lacked consideration of the influence of radionuclide solubilities on repository isolation performance.) Details of DOE work on radionuclide retardation will be presented to the WIPP Panel at a forthcoming meeting, so the Panel cannot now provide informed comments on how effective this work has been.

High priority should be given to applying performance assessment procedures to the engineering alternatives identified by the Engineered Alternatives Task Force (EATF). The EATF was established recently to develop and evaluate engineering methods for increasing repository safety. DOE is to be commended for responding to the Panel's concerns in this area, after the July 1989 letter report noted the absence of any consideration of engineered modifications on repository isolation performance. The methods identified by the EATF include modification of both the waste form and the repository design. The application of performance assessment analysis to various engineering alternatives is important to the appropriate consideration of each alternative and to DOE's decision whether or not to modify the waste and/or the repository. Although engineering modifications of the waste form might eliminate or substantially reduce gas generation, these modifications might also introduce significant additional risks of worker exposures to radionuclides and might have profound effects on costs and schedules. It is very important that the health effects associated with any proposed

scheme of modification or those associated with the continued storage of waste in its present location be carefully examined in terms of the entire system.

The various engineered alternatives should be assessed in terms of total system risk--including worker exposure, transportation, and other risks--to evaluate the impacts on the entire TRU waste management system. A framework for looking at the risks of the overall system should start with consideration of the risks from storage, handling, treatment, transport, and disposal and should include consideration of the timing of waste disposal. The study should also consider costs and schedules of the various alternatives.

Overall, the Panel is impressed with the technical quality of the performance assessment analysis and with the amount of work done in a relatively short time. The Panel is concerned, however, that the present schedule leaves little opportunity for an iterative, evolutionary performance assessment process to be realized and that major elements of the repository evaluation are proceeding without the results of key experiments.

Recommendation 2 (July 1989)

> Urgent attention should be given to (1) defining the combined effects of gas generation, room closure and sealing, brine inflow, and other effects on the potential for long-term build-up of gases in the repository to lithostatic (i.e., overburden) pressure, with respect to the long-term isolation capability of the WIPP repository, and (2) examining options for modification of the waste as part of the resolution of the gas generation issue.

Theoretical analyses have been made of the combined influences of (1) gas generation, (2) repository room closure, and, to a lesser extent, (3) brine inflow into the rooms. These analyses indicate the following:

o Gas pressure of more than twice the lithostatic pressure could be reached and sustained indefinitely, assuming that gas is generated slowly (i.e., over several hundred years) in a very tightly sealed repository.

o As gas pressure rises, brine inflow would decrease correspondingly. (See also the paragraph below on Room Q findings.) This gas pressure increase would also result in some reenlargement of the rooms after the initial room closure (on the order of 300 years or so later).

o If the gas in the rooms could communicate with permeable layers in the salt, such as the anhydrite Marker Bed 139, the maximum expected volume of gas could be accommodated without exceeding lithostatic pressure. Rooms could be designed to ensure this communication. The rate and distance of gas flow would depend on the permeability of the anhydrite and on how the layers are connected to the rooms.

The Room Q experiments are short-term (i.e., 2- to 5-year) observations that may provide conclusive, fundamental evidence on the long-term behavior of the salt with respect to brine inflow. However, the Room Q experiments have not yet run long

enough to provide definitive data. The Panel strongly recommends that the current Room Q experiments be continued without interruption, or with only minimal interruption as needed to improve the room seal. Additional intermediate-scale tests, including tests with 900-mm-diameter holes, should also be conducted to determine the brine inflow mechanism. Serious consideration should be given to the possibility of obtaining more conclusive information by conducting a second full-scale experiment using the improved instrumentation and seals now available for use on site. Carefully planned and instrumented to avoid the deficiencies of the Room Q Test – especially with respect to data on brine inflow in the early stages after excavation of the room – these tests could help corroborate (or contradict) the apparent very low permeability of the salt indicated by the Room Q experiments. There is still a fundamental question about the mechanism of brine inflow. Two hypotheses are put forward: (1) brine is released only from a disturbed zone around the room and (2) the brine represents Darcy-type flow from the far field. Every attempt should be made to resolve this fundamental issue.

As already noted, considerable uncertainty remains concerning the rate and volume of gas generation that might result from the waste emplaced underground at WIPP. However, recent results regarding brine inflow suggest that the amount of gas produced by corrosion may be substantially less than the theoretical maximum. It may also be possible that the environment could be conditioned to inhibit long-term biological gas generation.

If engineering modifications do not remove gas generation as a critical issue, or if performance assessment results do not indicate that WIPP performs acceptably for all plausible rates of gas generation, further progress in resolving important questions of gas generation will depend on the outcome of the laboratory and underground gas generation experiments currently planned. Given the relatively short times envisaged for these experiments (on the order of 5 years compared to repository gas generation times on the order of 300 years), it is prudent to prepare for the possibility that the results of the experiments may be inconclusive. This implies that studies by the EATF to seek practical measures for addressing the gas generation and gas pressure issues must be pursued vigorously and be closely associated with the performance assessment effort.

Recommendation 3 (July 1989)

> **Given the urgent need to resolve questions concerning gas generation after emplacement of TRU waste, the Panel agrees that the bin-scale and room-scale experiments, involving approximately 0.5 percent by volume, of the capacity of WIPP, are warranted and should begin without delay.**

EPA has recently approved the no-migration variance petition submitted by DOE to allow these underground experiments. Efforts are under way at the TRU waste generator sites to characterize the waste to ensure that the waste placed underground for the experiment is a representative sample of the TRU waste to be stored in full-scale operations. These efforts are proving to be onerous for both scientific and

regulatory reasons. To date, no TRU waste has been shipped to WIPP for the proposed bin- and room-scale experiments, and no realistic schedule for doing so has been proposed.

The Panel is concerned that the large scale and great complexity of the proposed bin experiments may result in significant uncertainties (which were noted above in the discussion of Recommendation 2) as to whether useful data will be obtained within an acceptable time frame. Great efforts are being made in some aspects of the planned experiments (e.g., in considering whether the bins contain statistically representative wastes), whereas in other aspects the experimental design is weak. The inability to sample brine to determine its composition in the bins throughout the experiments, for example, is a serious shortcoming that ought to be resolved. Overall, the Panel is concerned that the bin experiments are consuming more resources than anticipated, yet not progressing at a rate adequate to yield useful information within an acceptable time frame. If the bin experiments are to be completed as presently planned, it may be necessary to provide additional resources for other important parts of the program, such as radionuclide retardation, to be sure they are adequately supported.

Recommendation 4 (July 1989)

> **Data from laboratory tests (including tests at high ambient pressures), information from studies on gas generation from waste packages now stored at various sites, and information on experience abroad (e.g., UK) should be collected and studied together with engineering modifications as expeditiously as possible to assist in arriving at a sound, early solution to the gas generation issue.**

Although significant information has been obtained from laboratory tests, no studies on gas generation from waste packages have been conducted to date. Contacts have been established between DOE contractor scientists and their counterparts in the United Kingdom. The gas generation problem in the geologic isolation of radioactive waste is now recognized in other countries. International discussions among scientists and engineers involved in the difficult technical issues of radioactive waste isolation is a vital and very cost-effective way of ensuring that the U.S. program incorporates the best and latest developments available worldwide and that programs in other countries benefit from experience in the U.S. program. The Panel again strongly urges the active support by DOE of vigorous international exchange, both on gas generation and on the variety of other scientific and technical issues of waste isolation. Further comments regarding the program of experiments appear below in the section Supplementary Comments.

Recommendation 5 (July 1989)

> **The Department of Energy should include in the Plan a discussion of the risks associated with transportation of TRU waste to WIPP, relative to the transportation of other hazardous materials.**

This recommendation reflected the Panel's view that steps taken to reduce the risks associated with transportation of TRU waste to WIPP were extraordinary in comparison to those steps taken for transport of other hazardous materials. A published comparison of the risks associated with transportation of other hazardous materials was suggested as a way to place the TRU waste transportation issue into better perspective. The Panel recently received a study from DOE of the risks associated with the transportation of other hazardous materials and is currently reviewing it.

Recommendation 6 (July 1989)

> Demonstration of operational readiness should not start until several important issues concerning underground emplacement of waste for permanent isolation at WIPP have been resolved.

DOE has the operational readiness demonstration part of the Draft Plan on hold, essentially as recommended by the July 1989 Letter Report.

SUPPLEMENTARY COMMENTS

In July 1989, the WIPP Panel expressed a major concern that the performance assessment of WIPP was not being used to identify critical issues that needed to be resolved in order to establish and demonstrate the long-term isolation capability of WIPP. DOE and its contractors have responded to this concern. Several critical issues have been identified either directly from the performance assessment studies or from studies in support of performance assessment. The long-term potential for gas generation by TRU waste in the repository and the radionuclide retardation capability of the Culebra formation are two such issues; human intrusion is a third.

Reduction of repository performance uncertainties associated with such issues will probably depend on the results of experiments, both in the laboratory and at the WIPP underground facility. The Panel is becoming increasingly concerned that, despite the vigorous and intensive efforts by dedicated staff, continuing delays in mounting the experiments may make them of little value in the current plan to determine whether or not the WIPP facility can meet the applicable EPA standards for waste isolation within the next several years. The Panel is, however, very reluctant to suggest that any currently proposed experiments be eliminated. The Panel is acutely aware that previous gas generation experiments, terminated reportedly because of budgetary constraints, would likely have provided information of significant value in current attempts to resolve gas generation questions.

The Panel is similarly aware that it advised against a proposed radionuclide retardation test in the Culebra formation some years ago. Although the Panel recognized that this was an important issue, it could not envision a field experiment that seemed likely to yield meaningful results. If the future performance assessment of

human intrusion scenarios continues to indicate that radionuclide retardation in the Culebra formation is necessary to demonstrate that the EPA standards can be met, serious attention must be given to designing field experiments that can determine valid retardation coefficients. There is a considerable body of evidence to suggest that laboratory retardation values are not reliable indicators of retardation values in the field. It should also be noted that there are still unresolved issues with respect to the Culebra hydrogeology that add uncertainty to predictions of long-term flow and further complicate the assessment of radionuclide retardation in the Culebra formation.

A severe and pervasive difficulty in all of these issues is the need to make credible extrapolations (1) from laboratory- to field-scale behavior and (2) from information gathered over the short term to the long-term involved in repository performance. The Panel recommends that DOE avail itself of the expertise of leading members of the U.S. and international scientific communities, especially in microbiology and corrosion, to undertake (1) a thorough reexamination of its current strategy with respect to gas generation and (2) the demonstration of repository safety. These experts should address such questions as the following:

o How critical are the currently proposed gas generation experiments to the near-term (2-3 years) demonstration of compliance with EPA guidelines? DOE needs to be more aggressive in its efforts to resolve the issue of corrosion and microbial gas generation.

o Are there arguments based on fundamental principles of science that can be invoked as a basis from which to develop credible extrapolations predicting the volumes, pressures, and compositions of the gases generated over the long term under salt repository conditions?

o With respect to radionuclide retardation in the overall performance assessment of a repository at WIPP, what are reasonable assumptions and what evidence can be used to support those assumptions?

o Are reasonable engineering alternatives available that reduce or eliminate the need for experimental results on gas generation? The engineering alternatives work should be more closely coupled with performance assessment, so that the effectiveness of alternatives can be compared to the performance of the current reference design for WIPP.

DOE needs to work harder to understand gas generation and radionuclide retardation on the basis of the available information. Moreover, it is important for DOE to address human intrusion and repository performance in general, not just for WIPP. This issue is receiving increased attention abroad, and further work on this question is warranted.

As a further general observation, DOE should encourage critical review of the WIPP program through broader publication of its research findings in refereed scientific journals. This would give due recognition to the researchers involved, stimulate contributions from leading scientists worldwide, and bring greater overall credibility to the program.

The credible conclusion of this project requires careful and timely handling in a number of important issues: (1) a well-designed experimental program, (2) the establishment of a substantive basis for the long-term extrapolation of repository behavior, to the extent feasible, and (3) a schedule that is sufficiently flexible to allow changes to be made if important scientific and technical issues take longer to resolve than is currently anticipated.

In summary, the results that have been obtained since the July 1989 report (that is, those obtained from the assessment of undisturbed performance and the Room Q experiment) tend to support the view that WIPP can safely serve as a geologic repository for TRU waste. However, important issues such as human intrusion, gas generation, and radionuclide retardation remain.

NATIONAL ACADEMY OF SCIENCES

LETTER REPORT OF JUNE 1992

A Letter Report

by the

Panel on the Waste Isolation Pilot Plant

Board on Radioactive Waste Management

June 1992

Commission on Geosciences, Environment, and Resources
National Research Council

Washington, DC 1992

A LETTER REPORT
BY THE
PANEL ON THE WASTE ISOLATION PILOT PLANT

BOARD ON RADIOACTIVE WASTE MANAGEMENT
NATIONAL RESEARCH COUNCIL/NATIONAL ACADEMY OF SCIENCES

MAJOR CONCLUSIONS

Current performance assessment (PA) studies by the Department of Energy (DOE) indicate a high probability that the Waste Isolation Pilot Plant (WIPP) would perform successfully as a transuranic (TRU) waste repository. For some time, however, the panel has been concerned that questions identified as most critical by PA, particularly solubility and retardation, were not being given adequate or timely attention. The highest priority should now be given to conducting those tests that can determine the validity of the critical assumptions used in the PA calculations, especially the recently initiated solubility and dual porosity flow studies, and the proposed investigations on retardation in the Culebra.[1]

The February 1992 DOE/WIPP report[2] is a clear statement of the 15 critical information needs and associated experiments necessary to assess the long-term performance of the repository. However, the report fails to indicate how the results of the experimental program at all scales (laboratory, bin, alcove, and field tests) will be integrated to assess the long-term performance of the repository. DOE needs to articulate a convincing scientific rationale for the proposed test program in terms of the performance of WIPP as a TRU repository.

The panel has not been convinced by the scientific rationale, as presented, for the underground gas generation tests. In particular, the plan to conduct a large number of expensive bin tests and to terminate the experiments after five years has no discernible scientific basis. The possibility that the underground bin tests, as currently planned without brine sampling, will contribute to advances in the understanding of the overall long-term performance of a repository at WIPP is small.

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[1]The panel's conclusions and recommendations are underscored.

[2]WIPP Test Phase Activities in Support of Critical Performance Assessment (40 CFR 191B) Information Needs, February 1992. This report is referred to simply as the "February 1992 report" in this letter report.

PANEL FINDINGS

Introduction

The panel reaffirms its conviction that performance assessment is the appropriate basis for setting priorities in the research and testing program for WIPP. In the panel's opinion, DOE is making excellent progress with its ongoing performance assessment efforts. For completing the studies, DOE lists 15 critical needs in Figure 1 of the February 1992 report. This figure is incorporated as Appendix A of this letter report, with a numbering of the items added for ease of discussion. In the following paragraphs several of these items are considered, followed by comments on the proposed experiments with real waste underground at WIPP.

Studies Requiring Highest Priority

Among the 15 critical information needs required to evaluate repository performance, the panel considers those associated with description of the natural barriers to radionuclide releases, i.e., retardation, solubility, and flow studies, to be the most important. The overriding importance of natural barriers is directly related to the need to consider the consequences of human intrusion, since performance assessment studies indicate that, without human intrusion, radionuclides can be contained safely within the Salado formation. The highest priority should now be given to conducting those tests that can determine the validity of the critical assumptions used in the PA calculations, especially the recently initiated solubility and dual porosity flow studies, and the proposed investigations on retardation in the Culebra.

The three specific information needs that the panel regards as most important are radioactive retardation data (item 1); dual porosity flow analysis (item 2); and radionuclide solubility/leaching data (item 12). The panel is impressed by the high quality of the initial studies in these three areas and urges that DOE continue to pursue them vigorously. As more details of the overall test program in these areas become available, the panel will be able to make more detailed comments. Currently, only a draft version of the laboratory solubility/leaching program (SAND 91-2111, M.L.F. Phillips and M.A. Molecke) has been reviewed; retardation experiments have only recently been started on a laboratory scale, and investigation of the feasibility of field-scale retardation tests in the Culebra dolomite is in the initial stages. If field tests are found to be feasible, the panel recommends that they be started as soon as is realistically possible, in view of the decade or longer that may be required for meaningful results.

Also, item 3 (Salado gas and brine flow data), including Room Q and related experiments, is important to an understanding of the basic nature of fluid flow at the site and to the selection of appropriate performance models.

Three of the critical needs (items 9, 13, and 14) are associated with gas generation and dissipation. Recent analyses suggest that gas generation could have beneficial effects on repository performance (e.g., retardation of brine inflow). Also, although the salt itself may be effectively impermeable, gas could dissipate into fissured anhydrite layers immediately above and below the repository. Overall, there is sufficient uncertainty in the magnitude and consequences of gas generation by TRU waste in a repository at the WIPP and in the likelihood of gas flow in fissured layers to warrant continued study of this issue.

Gas Generation Studies with Real Wastes

Of the 15 identified critical needs, only one, gas generation data (item 13), concerns the proposed experiments with real waste underground at WIPP. The February 1992 report presents a list of justifications, both technical and organizational, for conducting gas generation tests, especially the bin and alcove tests, at the WIPP facility (see pp. 2-23 to 2-27). The panel, however, has reservations about the need for all of the proposed tests. A discussion of these considerations follow.

(i) Laboratory Experiments on Gas Generation

Laboratory experiments on corrosion and microbial action are underway, but the studies are not yet complete enough to allow a reasonable prediction of the importance of either corrosion or microbial activity in the repository. It is not clear how these experiments can be used to determine gas generation rates under repository conditions. The duration of the experiments, two years or less, is much too short to obtain usable and defensible results. Also, there is no compelling scientific rationale for conducting these experiments at the WIPP facility.

(ii) Bin Tests

In terms of resources allocated, by far the major component of the current WIPP experimental program is the plan for underground gas generation experiments. Since the bins are loaded and sealed before being shipped to WIPP, the wastes do not come into contact with the WIPP environment, except with respect to temperature, and hence the tests could be conducted anywhere.

The panel emphasizes that it supports the notion of underground testing with TRU wastes, provided that the underground location does not prevent important tests from being carried out (e.g., the measurement of brine compositions in contact with real waste or progression of gas generation experiments without purging), and that the tests can be continued for sufficient time to provide useful information. The five-year duration proposed for the underground tests is likely to be shorter than is desirable for such tests.

- Dry bin tests

  Dry bin tests will not provide useful information regarding long-term gas generation in a TRU waste repository. A few dry bin tests may be of some value in developing experimental procedures as a precursor to wet bin experiments. The search for statistical reliability in the results of dry bin experiments has led DOE to propose about 60 dry bin tests. The panel considers this a serious misallocation of resources that could be much more effectively used in other parts of the WIPP Program.

- Wet bin tests

  The panel considers the proposed wet bin tests to be potentially the most informative of the underground test program, with respect to both gas generation and contaminant concentration in the brine. However, the panel is concerned that constraints on the tests may be imposed by the underground location. Specifically, purging of flammable gases could make the wet bin experiments unrepresentative of the behavior of actual waste in the repository. [We note that "new bin designs are being studied that will allow the gas compositions to evolve to whatever values the chemistry will allow" (February 1992 report, p. 2-23). Such bins would eliminate the need for purging.] If underground testing precludes sampling of brine in the wet bins, the tests should be done elsewhere, where brine could be sampled, and where tests could be continued for as long as useful data are being generated.

  Based on a review of the roof reinforcement system installed in the proposed bin test room, and the associated monitoring program, the panel is confident that the test rooms, so reinforced, will be stable on the order of ten years or longer. It is essential that the monitoring program be continued.

(iii) *Alcove Tests*

Obviously, alcove tests can only be conducted underground. Plans for alcove tests have not yet been developed to the point where the panel can review them. Also, the February 1992 report indicates that ".. [the alcove] test program will occur if the laboratory and bin programs do not [suffice?] to satisfy the WIPP regulations that sufficient gas generation information is known for performance assessment." This statement clearly indicates that the alcove tests may not be carried out at all. In the absence of the alcove tests, only a very limited amount of radioactive waste will be required for the experimental program at WIPP.

In summary, the panel has not been convinced by the scientific rationale, as presented, for the underground gas generation tests. In particular, the plan to conduct a large number of expensive bin tests and to terminate the experiments after five years has no discernible scientific basis. The possibility that the underground bin tests, as currently planned without brine sampling, will contribute to advances in the understanding of the overall long-term performance of a repository at WIPP is small.

Plugs and Seals Test Plan

The panel has not reviewed the plugging and sealing test plan in sufficient detail to comment on the plan at this time. However, given that human intrusion (item 11) appears to be the only reasonable or possible cause of radionuclide release to the accessible environment at WIPP, the panel thinks that the performance of plugs and seals (items 5-8, and indirectly, item 10) is probably of secondary significance in the overall performance of the repository.

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-5	General	Yes	I am not confident from the information provided that I properly understand the nature and volumes of water flows in, around and through the shaft sealing systems. The time for system saturation remains unclear. This has bearing on the functionality of the shaft sealing system.	x		Clarification of the assumptions and conditions under which the repository would saturate will be added. If nothing is placed in the shafts and free flow of Rustler brines is allowed, the repository would fill in tens of years. With the seal system, as currently proposed, very little flow would enter the repository. These discussions will appear in the fluid flow analysis sections. In addition, the period required to resaturate the shaft will either be quantified explicitly or included generally, depending on advances in calculations.	X	

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-4	General	Yes	It is clear from the careful selection of the sealing materials that consideration has been given to their durability and longevity characteristics. However, in neither the preliminary nor the detailed documentation, are these issues discussed in detail. Durability and longevity issues present constraints that can also lead to the materials specifications. How have possible changes in material performance parameters with time (say over the period of 10,000 years) been applied to total system performance assessment modeling? Do short term effects influence long term performance? Mechanisms such as creep, fluid flow, microbiological degradation (and associated gas generation), seal material interactions, seal material-rock interactions, mineral transformation, silicification, dissolution and precipitation can all lead to changes in material and, hence, seal system performance characteristics. I suggest that the documentation should be expanded to provide confidence that these factors have been thoroughly considered as part of the generation of the sealing materials specifications and seal designs.	x		Substantiation will be added to the materials sections of the CSDR to support the current contention that longevity characteristics of the proposed materials are "as advertised". In particular, an "awareness" of concerns noted by the author will be demonstrated or identified and discussed in at least some detail based on information from the literature. Discussion of mechanisms such as creep, fluid flow and microbial degradation, seal material interactions and seal material/rock/brine interactions, mineral transformation and other issues raised by the reviewer will be expanded to address material change (or potential change) with time.	X	

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-3	General	Yes	With continuing regard to derived constraints and criteria, it appears that all of the seals, but particularly the clay (bentonite-based) seals are intended not only to limit the migration of brines and, particularly, possibly contaminated brines, but also to limit the migration of gases from the repository horizon to the biosphere. (Are these gases radioactive?). I understand that the proposed application of the clay seals as a barrier against gas movement is derived in major part from an in situ test carried out at the WIPP site. Experiments carried out at the University of Manitoba (Kirkham, 1995) tend to confirm the results of the in situ tests in that 25 mm thick specimens of water saturated compacted bentonite (g_d~1.3 Mg/m^3) resisted breakthrough pressures of up to 10 MPa. Similar results have been obtained from experiments in Japan (Hara, personal communication). A general rule of thumb seems to be that gases break readily through bentonite layers when and if the degree of saturation decreases below about 80 to 85 %. This rule is conventionally applied in the modeling of oil and gas reservoirs. These results conflict with conventional published wisdom (Pusch, 1985) which suggests that gas breakthrough pressures are related to bentonite swelling pressure. This is an area of concern and question and discussion of the uncertainty and it's effects on the materials specification, associated design assumptions (such as those regarding the rate of resaturation of the clay barriers and the rate of gas generation) and the method of clay seal emplacement are absent from the design documents (both preliminary and detailed). With regard to the method of seal emplacement it is currently proposed that the clay seals should be placed as precompacted blocks. The effects of joints between the blocks need to be considered. During design refinement activities, the method of deep dynamic compaction investigated and proposed for placing the salt seals should be considered as a method for the generation of homogenous almost saturated bentonite seals (see item 1 above). The use of bentonite-salt (sand-sized) mixtures should be considered as a possible alternative to the currently proposed 100% bentonite seals.	X		Further substantiation of bentonite as a gas barrier will be provided in construction and materials appendices. In particular, suggestions of the reviewer will be incorporated to add confidence that a gas barrier is obtainable upon construction. Additional documentation drawn from sources identified by the reviewer will be sought to establish gas permeability and breakthrough performance. Further text identifying assumptions of rates of gas generation and resaturation of the clay barriers will be added in the appropriate sections of the design documents. Text and basis for dynamic compaction construction alternative will be added. Discussion, such as use of sand additive to bentonite as a means to compact the material to densities approaching 95%, saturation will be added. We propose to leave the construction method for the clay column as blocks with further development of the basis for dynamic compaction.	X	

Document Review and Comment Form

Form Number: 430-A Effective 3/31/96

Procedure: QAP 6-3 Revision 1

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-2	General	Yes	I have a general and abiding concern with the relationships between derived design constraints and criteria as they relate to materials specifications. I understand that, generally, the materials specifications have been made to provide constructable seal elements with as minimum as practical permeability and that the properties of *the as-placed materials have been* incorporated into total system performance assessment models. The derived design criteria were not clear to me from either the documentation provided or the presentations made. From the data provided, it appears that all of the sealing materials being proposed for use ensure that chemical diffusion is the dominant mechanism of radionuclide transport in a possibly saturated repository at WIPP (see, for example, J.K. Mitchell, 1992). Is this usable as a derived criterion for the specification of the sealing systems?	x		While the use of low permeability materials approach conditions where diffusion could be the dominate transport mechanism, we don't believe such a condition can be invoked advantageously to a seal design criterion. By severely limiting brine flow, we place a de facto limit on nuclide migration. We propose *to leave the language as a* discussion of "low flow" and not of contaminate migration.	X	

Document Review and Comment Form

Form Number: 430-A Effective 3/31/96

Procedure: QAP 6-3 Revision 1

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-1	General	Yes	Many of my previous concerns related to the constructability of the sealing systems. I was impressed by the amount and rigour of work that has been carried out to confirm the constructability of the seals and I am satisfied that the design that I understand will be proposed in the detailed design document will be workable within the constraints of existing engineering practice or reasonably simple extrapolations therefrom. To provide absolute confidence in the constructability of the proposed sealing systems it will be necessary, with time, to effect programs which demonstrate the practicality of the extrapolated technologies	x		Construction procedures and associated design modifications consistent with review comments and discussions with panel member Steve Phillips will be completed in preparation of the CSDR. While we concur with the author's opinion that future work will increase confidence in the sealing methods, recommendations for such work will not appear in the report itself, but constitute the types of alternatives or options to be considered in future design refinements.	X	

WASTE ISOLATION PILOT PLANT

Sandia National Laboratories

Document Review and Comment Form

Form Number: 430-A Effective 3/31/96

Procedure: QAP 6-3 Revision 1

This form may be used for test plans, procedures, reports, design packages, abstracts, Technical Operating Procedures, and other documents.

Section of document to be reviewed and review criteria: (See sample criteria in QAP 6-3.).

Review Requester: Robert Stinebaugh Date: 4/24/96

Response Prepared By: [signature] Date: 4/26/96
Signature of Author/Designer

Reviewed By: M. N. GRAY Date: 4/26/96

Response Concurrence: [signature] Date: 4/26/96

Review Type: ☒ Independent Technical ☐ QA ☐ Management ☐ Other Specify:

Title of Document to be Reviewed: Waste Isolation Pilot Plant Sealing System Design Review

☒ Pre-Publication
Signature of Reviewer

☐ Post-Publication
Signature of Reviewer

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject

SUMMARY STATEMENT
BY STEVE PHILLIPS

The seal design uses existing technology and materials that have reasonably proven track records of durability. The redundancy in the design provides added assurance to mitigate against those areas where some uncertainties still exist and it is possible that all these will never be completely resolved.

It is considered improbable that the seal design, as presented including the revisions recently discussed, can be significantly and practically improved within the limits of existing construction materials and technologies, except in some areas where optimization of materials and methods of emplacement can be achieved.

The design, as presented, with modifications as discussed and documented April 24 - April 26, 1996, are likely to meet the general requirement of very low flow in and around the shafts. Over the next years, and prior to the emplacement of the seals at the WIPP site, new technology and materials will undoubtedly become available to provide additional improvements and added confidence in the shaft sealing.

Steve Phillips.

will meet design guidelines beyond the broad PA analyses performed to date on an equivalent "generic" design which does not account for any performance allocation amongst the system components. The seal system has been conservatively designed with what is considered to be the best available technologies, materials and construction procedures. If the design does not quantitatively meet the performance requirement, then it might be necessary to consider adopting the use of new technologies, materials or procedures.

In regards to whether the design can be implemented, it is my opinion that the seal system can be constructed as set forth. The concepts and procedures selected are not unusual compared to industrial construction practices. Suggestions have been made for minor enhancements focusing on ensuring emplaced material properties can be attained.

John P. Simmons 4/26/96

SUMMARY STATEMENT
BY JOHN TINUCCI

The design that has been put forth presents one way of efficiently sealing shafts. Recognizing that other ways could also be made to work, the design presented here is similar to other suggested by the scientific community for sealing deep geologic nuclear waste repositories. The concepts presented have been developed from sound engineering judgment and sound analyses techniques. The anticipated performance of individual sealing components are within reasonable expectations based on currently available field and laboratory data, albeit limited. To address the wide scale of uncertainties, the design has been conservatively laid-out with redundant multiple-barrier components so that the overall seal system performance is not dependent on the functionality of an individual component. The design as it exists today is a conceptual design since it describes basic concepts and provides sufficient backup analyses to demonstrate that those concepts will reasonably satisfy the qualitative design guidelines.

In the review process several issues were raised where minor enhancements to the design might provide better confidence in the overall performance of the system, especially in the short-term where performance is critical. These suggestions included investigating the use of grouts around SMC concrete plugs, complete removal of the liner in the Rustler formation, dynamically compacted clay column, repressurizing asphalt waterstops, etc.

It is my opinion that the Performance Assessment portion of the waste disposal program dealing with Seal System Performance has a shortcoming in that it has not assigned a target performance range for developing designs, at least as put forth in the documentations. It is recognized that the conceptual design has been developed for all 4 shafts but analyses limited to single isolated (AIS) shaft. However, the designers are unsure of how quantitatively this design

The materials being used to form the seals are the same as those being suggested in the scientific and engineering literature as appropriate for sealing deep geologic repositories for radioactive wastes. When constructed as proposed, it is likely that the shaft seals will ensure that water flow rates from the repository level to the biosphere will be very low within the seals and in the immediate vicinity of the sealed shafts. In some places the shaft seal designs being proposed appear to be excessively complex. It is likely that simplification of the design and material placement methods will lead to a more constructable sealing system without compromising system performance.

M

PEER 10 - Supplementary Information Regarding the National Academy of Sciences

Department of Energy
Washington, DC 20585

AUG 18 1989

Dr. Peter B. Myers
Staff Director
Board on Radioactive Waste Management
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Dear Dr. Myers:

In June, at my request, you provided me with the series of Academy reports to the Department of Energy containing recommendations on the Waste Isolation Pilot Plant (WIPP). You also provided me with the status of 44 recommendations. I have asked the WIPP staff to review the documents and prepare responses on each of the recommendations which was not marked "complete". Enclosed are the responses for each of the five reports. These responses provide information on how the recommendations were accommodated. With respect to recommendations in the two most recent Academy reports (Enclosures 4 and 5), we have cited specific areas in the current plans for the test phase where the relevant investigations are described.

It appears that in the past, the Department of Energy addressed many of the recommendations through informal presentations to the WIPP panel. I regret these were not better confirmed with a more consistent documentation process. I would appreciate your suggestions as to the steps that could provide more continuity and rigor to this process. In addition, could you and the WIPP panel review the enclosures in order to identify for me any issues which need more attention at this time. If more information is needed, perhaps it could be provided at your next meeting in September.

After we have received comments from the Environmental Protection Agency and the Environmental Evaluation Group, we will be revising the Test Plan which was reviewed in the panel's July 19, 1989, report. I will keep you informed as to our plans as they develop.

Sincerely,

Leo P. Duffy
Special Assistant to the Secretary
for Coordination of
DOE Waste Management

5 Enclosures

ENCLOSURE 1: RESPONSES TO RECOMMENDATIONS CONTAINED IN DOE/NE/93023-3, NATIONAL RESEARCH COUNCIL (1983) WIPP INTERIM REPORT FOR THE PERIOD JULY 1, 1978 TO JULY, 1982.

The following two reports are referenced below: DOE 89-011, draft Management Plan for Performance Assessment and Operations Demonstration for the Waste Isolation Pilot Plant, April, 1989; and SAND89-0178, Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant, Sandia National Laboratories, S. G. Bertram-Howery and R. L. Hunter, editors, April, 1989.

1. Evaluate the practical effects of resource extraction in zone four to assess whether such extraction poses significant threat to the safety and integrity of the repository.

Response: During the WIPP Site and Preliminary Design Validation (SPDV) effort, it was determined that resource extraction from within Zone 4, especially removal of hydrocarbon resources, would be acceptable. Therefore, Zone 4 was removed from consideration, and the land made available for drilling activities. At present, there is no DOE control outside the "land-withdrawal boundary," i.e., outside the 16-square-mile area contained in Zone 3.

2. Locate one or both of the remaining hydrologic test holes planed to be drilled in 1983 in limenants or fracture traces if such features are revealed on satellite images or high altitude areal photographs. Test holes so located will help determine fracture concentrations.

Response: Since 1983, eight hydrologic exploration holes have been drilled in the site area (H-11, H-12, H-14, H-15, H-16, H-17, H-18, DOE-2). Hole DOE-2 was sited (see issue 2, above) to address the issue of deep-seated evaporite dissolution; Rustler hydrologic data were secondary. Of the other holes, four (H-11, 12, 15, and 17) were drilled specifically to define a suspected high transmissivity zone within the Culebra in the southeastern portion of the WIPP site. In addition, multipad interference tests have been completed at the H-3 and H-11 hydropads to better define this zone (by agreement with the State of New Mexico). Completed reports that deal specifically with the hydrologic role of fracturing in the Culebra include Haug et al., 1987, SAND86-7167 and LaVenue et al., 1988, SAND88-7002. Also, radar profiling of the surface area of the site to delineate possible lineaments was completed in September 1987; none were identified.

This topic was addressed in the "Results of H-3 Multipad Test" briefing to the NAS WIPP Panel by Beauheim and Tomasko on 5/12/86. It has also been discussed in the Beauheim

presentations in October 1983, May 1985, November 1985, and December 1986.

3. Obtain in a timely manner operational experience with handling and placement of various types of waste packages at WIPP site.

Response: The NAS comment reflected their desire for WIPP to use few and less variety of waste package sizes and shapes to benefit operational smoothness. NAS proposed gaining operational experience with the various sizes and shapes available to select a few optimum sizes that would be best for WIPP Waste Handling Operations. Since then the project has progressed to the point where DOE has designed the TRUPACT II shipping container and committed to the state of New Mexico for its use to ship waste to WIPP. With the TRUPACT II shipping container, the vast majority of waste will be packaged as 7-packs of drums or in standard waste boxes. Only very small quantities of waste would be shipped in other than these two standard containers and would still be required to fit within the TRUPACT II shipping container (approximately 6 feet in diameter x 6 feet high). See DOE/WIPP 89-011, Chapter 3.0.

4. Keep the WIPP R&D program flexible to accomodate changes suggested by early WIPP results or other waste disposal technologies by other organizations.

Response: The program's response to WIPP results as well as to lessons learned from other technologies is reflected in each annual program plan. These changes are addressed in the summary reports for site characterization and technology development, SAND88-0157 and SAND88-0844, respectively. The NAS WIPP Panel and staff officer received copies of these reports and were briefed on changes as they occurred. The program also benefited from the interactions with the commercial salt repository program until its cancellation and from the interactions with the West German repository program as part of the FRG/US Bilateral Agreement. As reflected in the FOREWORD and the INTRODUCTION (p.I-1) of SAND89-0178, the R&D program will remain flexible. As feedback is obtained from experiments and performance assessment, plans will be modified.

5. Include special safety precautions in the procedures for handling defense high-level waste in the experimental R&D areas.

Response: Defense high-level waste experiments have been deleted from the WIPP Project effective September, 1988 per direction from DOE HQ.

6. Supplement the tests on waste form, package, overpack, and backfill with above-ground laboratory test.

Response: There has been a continuous laboratory test program addressing the salt/bentonite mixture properties of the backfill, brine sorption, nuclide sorption and solubilities, gas generation, effectiveness of backfill additives, and mechanical behavior of waste and backfill for modeling. These tests have guided and complimented the in situ tests being done at WIPP. The most recent presentation to the NAS WIPP Panel was in February, 1988. See DOE/WIPP 89-011, activities S.1.1.1 through S.1.1.5, S.1.2.6, and Appendix A. See SAND89-0178, activities 1.1.1 through 1.1.6, 1.2.7, and App. A.

7. Remedy existing deficiency in Safety Analysis Report procedures for fighting transient underground fires.

Response: The WIPP Waste Acceptance Criteria requires that all containers for emplacement at WIPP must be noncombustible. Any damaged containers will be overpacked before emplacement. This criterion is documented in WIPP/DOE - 069, Revision 3, "TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant". A study was completed in April of 1987 that indicated that the probability of a propagating or transient fire in the waste stacks was on the order of $3x10^{-8}$ per year. This probability is so low that this accident scenario can be eliminated from consideration in the FSAR as a non-credible event (based on DOE/AL Order 5481.1A). This study was presented to the NAS WIPP Panel in 1987.

8. Drop restrictions on permissible mass of organic materials per unit volume of waste from the gas generation criteria if relative humidity of the sealed enclosure at the repository is 60 percent or less.

Response: The NAS WIPP Panel considers issues 11 and 13 to be resolved. Therefore, 12 is also resolved because it relates to the case where the relative humidity is less than 60%, while the relative humidity is greater than 60% at the WIPP. Presentations were made on this subject in an Ad Hoc Brine Room Meeting with interested individuals from the the NAS WIPP Panel on 4/15/88 by D. Deal and J. Nowak ("Review of Ongoing Brine Inflow Studies"), on 12/6/88 by L. Brush ("Radioactive Waste Experiments - Laboratory Tests"), and on 6/7/89 by L. Brush ("Gas Generation").

9. Define the waste acceptance criteria for the defense high-level waste to be used in the experimental program.

Response: Defense high-level waste experiments have ben deleted from the WIPP Project effective September, 1988 per direction from DOE HQ.

10. Establish explicit mechanism for the transfer of information from experiments and information gathered during construction and development to final design.

Response: The mechanism used to transfer data from experiments and tests is the preparation and issue of formal reports. For example, the results of the SPDV program were published in a special report, and geologic data gathered since that time is published annually in the Geologic Field Data and Analysis Report. This data was used in final design and construction of the facility and is used to determine if modifications or changes are necessary.

Each formal report is distributed to public libraries located throughout the United States. All SNL reports are also sent to public libraries, to technical personnel internal and external to the Project, and the NAS Panel members.

Briefings are provided on a quarterly basis to the NAS WIPP Panel, the Environmental Evaluation Group, and to the New Mexico Environmental Improvement Division.

11. Determine if displacement of salt in the far field occurring as a result of long-term closure of excavations significantly increases the permeability of the bulk of the salt.

Response: There are three physical domains of interest surrounding the WIPP excavations:

a) The near-field domain, in which dilation, dewatering, and/or fracturing have occurred. The permeabililty of this domain appears to be several orders of magnitude larger than that of the undisturbed far-field domain. (see Stormont et al., 1987, SAND87-0176).

b) The far-field domain, in which hydrologic properties are "not significantly affected" by mechanical deformation. Measurements to date in this region indicate a very low halite permeability of 1 to 10 nanodarcies (see, for example, Nowak et al., 1988, SAND88-0122; Deal and Case, 1987, DOE-WIPP-87-008).

c) The far-field domain, as ultimately affected by subsidence. No measurements have been made to date in this region, since significant subsidence has not occurred. However, since deformation at these greater distances will be smaller than in areas already measured, no increase in permeabilities above values reported under (b) above are expected.

In addition, as described in SAND89-0178 and presented at the June, 1989 meeting with the WIPP NAS panel, there is an active ongoing program to investigate the variability of Salado permeability. See DOE/WIPP 89-011, activities S.3.1.x, S.3.2.x, and S.3.3.x. See SAND 89-0178 activities 3.1.x, 3.2.x, and 3.3.x.

12. Determine if sealing the repository is sufficient to preclude unacceptable increases in hydrologic conductivity across the repository horizon.

Response: The sealing program was presented to the NAS WIPP Panel on 8/85, 11/85, 9/86, and 3/88. The results of the WIPP seal evaluation have been documented in SAND87-3083 and SAND88-0844; both documents were distributed to the panel members and the staff officer. The evaluation determined that nothing has been discovered that would prevent the effective sealing of WIPP.

13. Delineate the through karst-type flow in the rustler aquifer near Nash Draw.

Response: The Project recognizes the potential for karstic processes near the WIPP site, as at the unique structure at hole WIPP-33. In addition, the Project has investigated the potential for karstic structures on the surface at the WIPP site itself. The conclusions of these studies are that:

a) Surficial depressions at and near the WIPP site, with the exception of the WIPP-33 structure, are not due to karstic activity, but are due to wind erosion (Bachman, 1985, SAND84-7178).

b) Within Nash Draw, evaporite karst is expressed by development of caverns in near-surface gypsums and anhydrites of the Rustler, not as caverns within the Rustler dolomites (see Bachman, 1987, SAND86-7078). Therefore, we conclude that karstic flow is real within Nash Draw, but that it effects portions of the Rustler other than the Rustler dolomites that dominate flow in the Site area.

ENCLOSURE 2: RESPONSES TO RECOMMENDATIONS CONTAINED IN 3/27/87 LETTER, FRANK L. PARKER, CHAIRMAN, NAS BOARD ON RADIOACTIVE WASTE MANAGEMENT, TO THOMAS ANDERSON, DOE.

1. This letter from the Board on Radioactive Waste Management forwarded the results of its review of "The Defense Waste Management Plan for Buried Transuranic Waste, Transuranic-Contaminate Soil, and Difficult to Certify Transuranic Waste."

Response: Attached is a copy of the response provided to the NAS originally. The DOE believes these recommendations were addressed in the revised Plan.

JUN 3 1987

Frank L. Parker, Ph.D., Chairman
Board on Radioactive Waste Management
National Research Council,
National Academy of Sciences
2101 Constitution Avenue
Washington, DC 20418

Dear Dr. Parker:

Thank you and the Board on Radioactive Waste Management for your review of the Defense Waste Management Plan for Buried TRU-Contaminated Waste, TRU-Contaminated Soil, and Difficult-to-Certify TRU Waste. I am enclosing a copy of the final report as submitted for printing for your information. The final printed document will be available in a few weeks, and copies will be provided to the Board. The Board's comments were very helpful in developing the final document.

I am also taking this opportunity to respond to the Board's comments contained in your March 27, 1987, letter, as follows:

It is not yet clear as to how the various hazardous waste laws and regulations apply to the Department of Energy (DOE) buried tru sites. Even the process for determining how these criteria would apply is felt to be beyond definition at this time. In response to your comment, discussion was added to the plan to note that specific criteria are not yet available and to identify the regulations and statutes to which each DOE site is currently responding.

The determination of which specific disposal options or alternatives may be evaluated at each site will be made during the process of site compliance with DOE Order 5480.14, CERCLA, RCRA and other applicable requirements. The alternatives used in the plan are intended to illustrate the possibilities, and they will be finalized based on site specific requirements developed during characterization and feasibility investigations.

Based on the comments received at the Board meeting on March 26, 1987, we have included additional information on responsibilities for studies, trade-off analyses, and decision recommendations, reviews and approvals. For your information, although DOE is responsible for the evaluations and decisions, state and Federal regulatory agencies, state and local governments, and interested parties will also be involved in the decision making process.

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In further response to the Board's comments at our meeting, we have reviewed the potential for a category of "orphan" wastes to be created during the certification process. For your information, the plan notes that any waste which may remain at the end of the inventory workoff period will be specifically evaluated and a disposition method determined. Possibilities include development of a certification process for the waste, application to WIPP for a waiver of certification, or alternative disposal method (such as greater confinement disposal). DOE plans to address all retrievably stored and newly generated TRU waste, and have a plan for its disposal by the end of the inventory workoff period.

Finally, in regard to the Board's comment on the Maximum Contaminent Level Goals discussed at our meeting, we deleted reference to these requirements in the plan since it was felt that discussion in regard to the buried TRU sites was premature.

Again, thank you for your comments. The Board's comments were most helpful in our timely completion of the document.

Sincerely,

/S/

Thomas C. Anderson
DP/NAS Liaison
Office of Defense Waste
and Transportation Management

Enclosure

cc:
Peter Myers

bcc: J. Mathur, DP-123

Distribution:
so: Addressee
1bcc: DP124 RDR
1bcc: CHRON
2bcc: DP/MF
2bcc: DP-12
DP-124:TAnderson:ald:353-3253:6/2/87:WANG1937H

MIRS
File Code 5180.
Coordination
DOE-HQ yes ✓ no ___ name Mathur org. DP/123
DOE-Field yes ___ no ✓ name ___ org. ___
Interagency yes ___ no ✓ name ___ org. ___
Other yes ✓ no ___ name D Thompson org. RK
Controversial Subject? yes ___ no ✓
Policy Issue? yes ___ no ✓
Budget Issue? yes ___ no ✓
Comments:

CONCURRENCES
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INITIALS/SIG. TAnderson
DATE 6/2/87
RTS SYMBOL DP-123
INITIALS/SIG. JMathur
DATE 6/2/87
RTS SYMBOL DP-124
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ENCLOSURE 3: RESPONSES TO RECOMMENDATIONS CONTAINED IN 4/16/87 LETTER, KONRAD B. KRAUSKOPF, CHAIRMAN, NAS WIPP PANEL TO JOHN MATHUR, DOE.

The following two reports are referenced below: DOE 89-011, draft Management Plan for Performance Assessment and Operations Demonstration for the Waste Isolation Pilot Plant, April, 1989; and SAND89-0178, Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant, Sandia National Laboratories, S. G. Bertram-Howery and R. L. Hunter, editors, April, 1989.

1. Determine by calculations, the probable rate of release to the accessible environment of the important radionuclides in TRU waste on the assumption of no retardation due to sorption.

Response: Such calculations are explicitly included in a detailed sensitivity study of radionuclide transport within the Culebra (Reeves et al., 1987 SAND87-7105). In addition, both flow and transport properties within the Culebra were "degraded" from "expected" values as part of transport studies included in the DSEIS (see Lappin et al., 1989, SAND89-0462).

The conclusion, based on calculations contained in SAND89-0462, is that, while WIPP performance appears quite reliable if "expected" properties are controlling, it is possible for WIPP to not comply, if "degraded" properties are controlling, including both flow properties and greatly reduced sorption within the Culebra (K_ds near zero). The probabilities of property degradations must be factored into the probabilistic compliance measure before projections of compliance (or non-compliance) can be made.

2. Select drillholes for injection and recovery for which the history since drilling is well known with respect to the composition of the drilling fluid.

Response: This test has been cancelled, for a combination of budgetary and technical reasons. Technically, the conclusion was reached by Sandia and communicated to the NAS panel in September, 1987, that greater reliability could be gained by a combination of laboratory experiments and additional hydrologic work than could be gained by operation of a single sorbing-tracer experiment. From a budget point of view, funding was simply not available to perform both the sorbing-tracer test and the desirable additional hydrologic studies.

Detailed agreement was reached with the State of New Mexico (EEG) concerning "studies in lieu of the sorbing- tracer test." This agreement is documented as part of the Appendix to the Agreement for Cooperation and Consultation between US DOE and the State of New Mexico. The agreed studies, including the completion of a multipad interference test at the H-11 hydropad have largely been completed.

3. Recommend additional research in the study of the Culebra hydrology in different parts of the WIPP site to determine what phases are active sorbents for transuranic elements.

Response: This work is ongoing, as agreed to with the State of New Mexico as an activity "in lieu of the sorbing-tracer test," and as documented in SAND89-0178. The level of effort has been somewhat impacted by the effort required in completion of a hydrochemical facies report (Siegel et al., in press, SAND88-0196).

4. NAS urges using radionuclides rather than analog elements as sorbing tracers.

Response: See response to item 2.

5. Conduct tests at more than one hydro pad to give some sense of the possible variability of the formation in order to obtain statistically significant results.

Response: See response to item 2.

6. Conduct a field test accompanied by laboratory determinations of K_d using chunks of dolomite from drill cores with their surfaces and fractures kept in a state as close as possible to natural conditions.

Response: Concerning operation of a field sorbing-tracer test, see response to item 2. Flow tests using both intact and fractured core are included in present planning, as described in SAND89-0178.

ENCLOSURE 4: RESPONSES TO COMMENTS AND RECOMMENDATIONS CONTAINED IN 3/3/88 LETTER, FRANK PRESS, CHAIRMAN, NATIONAL RESEARCH COUNCIL, TO JOHN S. HERRINGTON, DOE.

The following two reports are referenced below: DOE 89-011, draft Management Plan for Performance Assessment and Operations Demonstration for the Waste Isolation Pilot Plant, April, 1989; and SAND89-0178, Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant, Sandia National Laboratories, S. G. Bertram-Howery and R. L. Hunter, editors, April, 1989.

1. Establish a well conceived experimental program to reduce remaining uncertainties as a bases for conservative performance assessment.

2. Establish a comprehensive systematic experimental program to reduce uncertainties and support performance assessment as required by EPA.

3. Better define the planned experimental program for five years.

Response: Over the past two years the WIPP Performance Assessment Group has been refocusing the experimental program to supply the needs of the Performance Assessment program. This PA program has been designed on the same basis as that used by EPA in developing the Standard promulgated in 40 CFR Part 191 and appears to be the methodology described in the Guidance (Appendix B) to Subpart B of 40 CFR Part 191. A management plan describing this program has been published and was presented to the NAS on June 6, 1989. The management plan is based on a detailed plan prepared by Sandia National Laboratories. (See section 2.6, of DOE/WIPP 89-011 and all of SAND89-0178).

4. Only when the experimental work has reduced uncertainties about brine accumulation should additional waste containers be emplaced.

Response: The Performance Assessment process is iterative. During the last two years, estimates have been made of the impacts of brine in the rooms at WIPP during and after closure. Additional in situ permeability measurements have been and are being made and mathematical models of brine inflow are being improved. The results are that the Project is relatively certain that that the very low permeabilities that have been measured in situ will allow very little brine to flow into the room before it creeps closed. However, these very low permeabilities suggest that the gases that will evolve from the wastes over time may not dissipate through the host rock. The result is a possible gas problem for the WIPP. Experiments are planned to be conducted in the laboratory, in bins underground, and in room-scale alcoves underground to help quantify the gas problem. The uncertainties in brine inflow have been drastically reduced. The brine room experiment will provide observations in situ to test the current hypothesis. This subject was discussed with

the NAS WIPP Panel 2/18/88. See DOE/WIPP 89-011, activities S.3.3.6, s.3.3.7, S.3.3.8, and S.3.3.9; and SAND89-0178, activities 3.3.5, 3.3.6, 3.3.7, and 3.3.8.

5. Experiments should be designed to lessen uncertainties not to verify preconceived ideas about probable results.

Response: The WIPP experimental program has shifted from one that identifies the important processes operating at and on the repository to one that develops the modeling tools and data needed for completing a performance assessment and evaluating compliance with 40 CFR Part 191. In the process, those experiments designed to test hypotheses have been modified to address hypotheses pertinent to the PA. Models and data are still needed for design and testing of the individual components of the system (e.g., panel seals). These models do attempt to develop the best designs based on preconceived ideas. See DOE/WIPP 89-011, section 2.6 and all of SAND89-0178.

6. Continually refine performance assessment calculations as experimental results are obtained to test confidence in achieving compliance with EPA standards.

Response: Performance Assessment is an iterative process. As new experimental results are acquired, the impacts on compliance with the EPA Standard are assessed. An example of this process for the WIPP program is given in the response to issue 4, above. As new calculations are completed, they will be reported to the NAS, NM EEG, and the scientific community via presentations, memoranda, and technical reports. Preliminary scoping calculations done by the Performance Assessment team were presented to the NAS WIPP Panel in September 1987. The second iteration of calculations was presented to the Panel in February 1988.

7. Develop multiphase models to describe behavior of complex fluids that may form as brine enters repository and gas is generated from waste.

Response: Consideration of the need for two-phase flow is a recent development and was discussed in a preliminary manner in SAND89-0178 (p. 2.24 and activity 3.2.6) and in DOE/WIPP 89-011 (p.2-15 and activity S.3.2.5) Preliminary two-phase calculations should be available near the end of FY89.

8. Investigate feasibility of possible technical "fixes" if the problem of fluids in the repository is serious.

Response: The review of the brine inflow concerns in 2/88 and subsequent tests have provided data that has consistently shown that brine inflow is not a major problem. SAND88-0112 and SAND89-0462 document these results. The brine inflow problem is continually being investigated as a significant input to the PA for WIPP.

See DOE/WIPP 89-011, activities S.1.1.1, S.1.2.1, S.1.1.2, and S.1.2.3; also see SAND89-0178, activities 1.1.1, 1.1.2, 1.1.4, 1.2.1, 1.2.3, and 1.3.1.

A much higher priority and a significantly greater effort will be directed toward the investigation of possible engineering enhancements. A special task force of selected technical experts will conduct this investigation.

ENCLOSURE 5: RESPONSES TO RECOMMENDATIONS CONTAINED IN 12/30/88 LETTER, KONRAD B. KRAUSKOPF, CHAIRMAN, NAS WIPP PANEL, TO CRITZ GEORGE, DOE. TO CRITZ GEORGE, DOE.

The following two reports are referenced below: DOE 89-011, draft Management Plan for Performance Assessment and Operations Demonstration for the Waste Isolation Pilot Plant, April, 1989; and SAND89-0178, Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant, Sandia National Laboratories, S. G. Bertram-Howery and R. L. Hunter, editors, April, 1989.

1. Recommend a limited number of in-situ tests to observe closure rates around horizontal circular excavations.

2. Investigate the possible effect of differences in scale and geometry by experiment.

3. Determine closure around a 36-inch diameter hole to provide data on a scale intermediate between laboratory scale and full scale.

4. Undertake tests to observe time dependent deformations around holes to compare against numerical model.

Response: The WIPP Project is designing the intermediate-scale borehole test and developing a test plan. The preliminary plan was presented to the NAS WIPP Panel in 1988. See DOE/WIPP 89-011, activity S.3.3.2 and SAND89-0178, activity 3.3.1.

NATIONAL RESEARCH COUNCIL
COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND RESOURCES
2101 Constitution Avenue Washington, D.C. 20418

BOARD ON
RADIOACTIVE WASTE MANAGEMENT
(202) 334-3066

Office Location:
Milton Harris Building
Room 462
2001 Wisconsin Avenue, N.W.

October 17, 1989

Mr. Leo Duffy
Special Assistant to the Secretary for
Coordination of DOE Waste Management
U. S. Department of Energy
Washington DC 20585

Dear Mr. Duffy:

Thank you for your letter dated August 18, 1989 containing the notes by DOE staff concerning actions taken on past recommendations by the WIPP Panel. Your letter and the notes were provided to the Panel during its September 18-19, 1989 meeting in Albuquerque.

It is clear that the listed recommendations by the Panel cover a range of issues that have assumed greater or lesser importance since they were submitted to DOE. The responses, similarly, are varied in detail and current significance.

In several instances, the responses refer to presentations to the Panel by DOE and its contractors subsequent to the recommendations; in many of these cases it is not clear what reaction the WIPP Panel had to these presentations.

Rather than comment in detail on specific recommendations from the past, the Panel believes it is more productive to note the great improvement in climate of dialogue and mutual responsiveness that now exists between DOE and its contractors and the WIPP Panel, as displayed during the September 18-19 meeting. As members stated during the meeting, the Panel was impressed by the prompt, substantial and, to a large degree, effective actions taken on the recommendations made in the July 16, 1989 letter report. Your concern for frank, professional discussion of issues during the meeting was obvious and much appreciated. The Panel looks forward to continuation and further development of this productive interchange of information.

Yours sincerely,

Peter B. Myers
Staff Director

PBM:jk

cc: Charles Fairhurst, WIPP Chairman
Frank L. Parker, BRWM Chairman

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PEER 11 - Performance Assessment Peer Review Panel - Trauth Memorandum

Sandia National Laboratories

P.O. Box 5800
Albuquerque, New Mexico 87185-1341

December 19, 1995

Dr. James Mewhinney
U.S. Department of Energy
Carlsbad Area Office
P.O. Box 3090
Carlsbad, NM 88221

Subject: Performance Assessment Peer Review Panel--Description and Issue Resolution

Dear Dr. Mewhinney:

Enclosed you will find material that discusses the function of the Performance Assessment Peer Review Panel (PAPRP), its charter, scope of reviews, and how the Project has addressed some of the issues raised by the PAPRP. This text includes material developed by Peter Swift and Marilyn Gruebel.

I sent a draft of this material to Dr. G. Ross Heath, Chair of the PAPRP, for his review to ensure that the description of the issues and their resolution was correct.

Please call me at (505) 848-0686 if you have any questions.

Sincerely,

Kathleen M. Trauth

Kathleen M. Trauth
WIPP Compliance Support Department

Enclosure

Copy (w/ enclosure):

G.R. Heath, University of Washington
MS-1328 D.R. Anderson (6749)
MS-1328 H.N. Jow (6741)
MS-1341 D.R. Schafer (6747)
MS-1341 K.M. Trauth (6747)
MS-1395 L.E. Shephard (6800)
MS-1395 P.N. Swift (6821)
MS-0734 M.M. Gruebel

SWCF-A: 1.2.07.2;PER;NQ; issues resolution (2 copies)

WIPP PERFORMANCE ASSESSMENT PEER REVIEW PANEL

The Performance Assessment Peer Review Panel--Scope of Reviews, Membership, and Document Reviews

History

The integral role of peer review in the development and the implementation of the WIPP PA methodology (and the accompanying documentation) has been recognized and documented for a number of years, and predates the Peer Review requirements in the proposed 40 CFR Part 194. Planning for the Performance Assessment Peer Review Panel (PAPRP) began in 1986, and the first meeting of the Panel was held July 27-28, 1987.

A philosophy statement first outlined in the 1990 PA (Bertram-Howery et al., 1990) states that the WIPP performance assessment is based on four ideas:..."Fourth, adequate documentation and independent peer review are essential parts of a performance assessment, without which informed judgments on the suitability of WIPP as a waste repository are not possible. An extensive effort is being devoted to documenting and peer reviewing the WIPP performance assessment and the supporting research, including techniques, models, data, and analyses."

The PAPRP was established to be a standing group under contract to the PA Department. The purpose of a standing review group was to ensure that the Panel members could build upon their individual areas of expertise to develop a base of knowledge specific to the WIPP performance assessment. With this knowledge base, the Panel members will be competent to perform a thorough review, within the context of previous performance assessments, management decisions, regulatory constraints, etc. An ever-changing Panel would not be able to develop the depth of knowledge and understanding required to review documents within the time constraints imposed. The purpose of a contractual relationship with Panel members is to ensure that they are able to spend sufficient time on the reviews. The depth of review required would not be possible with a volunteer group.

Questions as to the independence of a peer review panel paid for by DOE can be addressed by examining several pieces of information. First, the credentials of the Panel members show their stature in their respective professional communities. Second, the Charter under which the Panel operates requests comments, both favorable and unfavorable. Third, the set of comments prepared by the Panel for each document review is maintained in the Sandia WIPP Central Files, without censure. These comments concern many difficult issues. This evidence indicates that the Panel performs critical reviews and is not ignoring important issues.

The Peer Panel operates under a Charter (Sandia WIPP Central Files--PA00107), pertinent text of which is reproduced below.

"A peer review is a documented, in-depth, critical evaluation performed by individuals who are independent of the document being reviewed and who have technical expertise at least equivalent to that of the authors. An external Peer Review Panel has been established for significant PA documentation so that the DOE can be assured that the performance evaluation is well-conceived and being carried out with professional competence, and so that scientists and state officials can be assured that the DOE's conclusions as to the suitability of the WIPP as a repository are credible. The participation of the Peer Review Panel will demonstrate to the public and state officials that the performance assessment is being subjected to continuing independent peer review to assure technical validity."

"In addition, those PA reports that document significant task completion or are milestones will be reviewed by the Peer Review Panel."

"The integrated expertise of the Panel will constitute a substantial "reasonableness" check on PA documentation. Because of the limited time available for Panel reviews, however, identification of problems such as computational errors or the use of inaccurate data in PA calculations is beyond the scope of Panel reviews. As with science published in peer-reviewed scientific journals, the ultimate test of PA work will be through independent validation of PA predictions and replication of PA results. Peer Panel review constitutes only one step, albeit an important step, in the evaluation of PA results."

"In addition to workshops for reviewing selected PA reports, the Peer Review Panel will be provided with analysis plans, assumptions, data bases, and documentation in semiannual or quarterly information meetings so that Panel members can maintain the necessary level of understanding of the performance assessment as it progresses. For information meetings, the PA staff will identify technical issues to be addressed, provide working papers or background materials on each topic, give status of knowledge, identify issues that need resolution, and present plans and methodology, all in the context of the overall project. Opportunities will be provided in the presentations for discussions with the Panel. These information meetings will not constitute peer reviews requiring quality assurance documentation. Minutes of meetings will be incorporated into the PA quality assurance files. The Peer Review Panel will not serve as technical advisors to the WIPP PA."

"The Peer Review Panel will not review directly the scientific experiments and observations used by the PA group in its calculations. The Panel may comment on such experiments and observations, either favorably or unfavorably, with emphasis on their completeness, appropriateness, adequacy of documentation, and/or

adequacy of review. Similarly, the Peer Review Panel will not participate directly in reviewing PA calculations by, for example, checking data bases or computer codes. However, the Panel may consider the adequacy of the rationale for using a particular approach and the adequacy of the documentation and review of the PA system."

Membership

"The Sandia PA Program Manager [the manager of the Sandia Performance Assessment Department] will select a Chair for the Peer Review Panel. The Chair will, in turn, select five permanent members of the Peer Review Panel (subject to approval by the Sandia PA Program Manager). Peer Review Panel members will be selected on the basis of their professional stature within the university/scientific/engineering community. Members will be neither directly associated with the WIPP Project nor employees of Sandia. The collective technical expertise of the group will span, as far as possible, the technical issues and areas to be reviewed."

"The Panel Chair will ascertain that no permanent or temporary Panel member has a conflict of interest. If an apparent or potential conflict of interest exists, the Panel Chair and the PA Program Manager will determine if one does exist and how to resolve it."

Document Reviews

"Whenever possible, the peer reviewers will meet with the PA Task Leader [the Sandia staff member who is the task leader for the work being reviewed], author(s), and other PA participants for a workshop to discuss the comments. The Panel Chair will lead the discussion of comments, including comments of any Panel members who cannot attend the workshop, and facilitate agreement on each comment. Changes or additions to the draft in response to Panel comments are limited to those agreed upon by the Panel and concurred with by the PA Task Leader, authors, and PA Program Manager. Conclusions regarding each issue discussed will be recorded to document the workshop proceedings."

"Each Panel member will address the following areas as applicable:

1. Validity of basic assumptions and extrapolations,
2. Alternative interpretations or approaches,
3. Appropriateness, logic and limitations of methodology,
4. Uncertainty of results,
5. Supportability of the conclusions drawn,
6. Consequences of incorrect assumptions or conclusions, and

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7. Other issues appropriate to the review subject."

"The Panel Chair and the Peer Panel Task Leader [the Sandia staff member assigned to work with the Peer Panel] will prepare a Peer Panel Review Report. The report will contain all Peer Panel review comments submitted to the PA by the Panel as a whole, including rationale and references, with each comment identified as mandatory or non-mandatory. A statement of potential impact will be presented if the results of the Peer Panel review are considered to have significant effect upon Project schedules. Recommendations such as document revision or need for further data or analyses will be included. The Peer Panel Review report will also include the Peer Panel Review announcement memorandum, the Peer Panel review workshop minutes, and a cover page identifying the Peer Review Panel and containing approval signatures of Panel Members."

Responses to Peer Panel Comments

The Panel Charter was revised in December 1992 to include a formal procedure for resolving comments. Individual volumes of the 1992 PA reviewed after the revision date, and subsequent document reviews, are subject to this requirement.

"The PA Task Leader for the document being reviewed is responsible for obtaining responses from the document authors for all comments identified by the Peer Panel as mandatory."

"After the PA Task Leader has obtained the initial written responses to comments, the Peer Panel Task Leader will review the responses and compile those mandatory comments for which the author of the document did not provide a response that was compatible with the action requested by the Peer Panel. In some instances, an author may not be able to respond to a comment (e.g., because the magnitude of the task is incompatible with available resources or with externally-mandated publication deadlines). In other cases, an author may choose not to respond to a comment (e.g., the author, on reflection, disagrees with the argument in a comment or with its "mandatory" designation). In these instances, the author will prepare, in memo form, an explanation of his or her position and a proposed resolution for each unresolved comment. These explanations, after review by the PA Program Manager or his or her designee, will be forwarded to the Chair of the Peer Review Panel by the Peer Panel Task Leader."

"If the Chair finds that the proposed resolution, either as submitted or with minor modification, is justified by the author's explanation, the Chair will indicate that the mandatory comment has been resolved. If the Chair does not find that the proposed resolution is adequately justified by the author's explanation, the Chair will refer the comment and its proposed resolution back to the Peer Review Panel

for further review and discussion. Final resolution will be established by the PA Program Manager following negotiations between the author of the document and the Peer Review Panel. The Peer Panel Task Leader will prepare a memo for each report reviewed by the Peer Panel that indicates the final disposition of each of the previously unresolved comments."

Permanent Peer Review Panel

"Dr. G. Ross Heath, Chair of the Performance Assessment Peer Review Panel; Dean of the College of Ocean and Fishery Sciences and Professor of Oceanography, University of Washington

Dr. Robert J. Budnitz, Physicist—Energy/Environmental Research and Nuclear Safety; President, Future Resources Associates, Inc., Berkeley, California

Dr. Thomas A. Cotton, Analyst—Public Policy Research and Development; Senior Associate, JK Research Associates, Inc., Washington, DC

Dr. C. John Mann, Professor of Geology, University of Illinois—Urbana

Dr. Thomas H. Pigford, Professor of Nuclear Engineering, University of California—Berkeley

Dr. Frank W. Schwartz, Ohio Eminent Scholar in Hydrogeology, The Ohio State University"

The only change in the membership of the Panel has been the appointment of Dr. Schwartz in 1990 with the resignation of a previous member to fulfill a Presidential appointment to the Nuclear Waste Technical Review Board.

Performance Assessment Peer Review Panel--Issues Resolution

PA is reviewed by various organizations and receives their comments, in addition to comments developed through document reviews conducted by the PAPRP. The WIPP Panel of the National Academy of Sciences (NAS) and the Environmental Evaluation Group (EEG) are among those entities reviewing and commenting on the entire WIPP Project, along with the EPA itself. More than one review group may have raised an issue. In addition, issues may have also been raised internally. The following is not necessarily an exhaustive list.

Issue 1: Need to display confidence bounds around the mean CCDF. This issue was raised in 1989 and 1990 by the NAS, the EEG, and the PAPRP.

Resolution: Beginning in 1990, the WIPP PA has used a methodology that allows for construction of a family of CCDFs from which both a mean curve and selected percentile curves can be derived. This methodology is first discussed in detail in the 1990 PA (Bertram-Howery et al., 1990), and is further discussed in Volumes 1 and 2 of the 1991 PA and Volume 2 of the 1992 PA. References for additional publications can be found in Volume 2 of the 1992 PA. Note that all CCDFs presented in WIPP PAs are conditional on the modeling and data assumptions used in the analyses.

Issue 2: Question on how best to construct scenarios from the events and processes that remain following the screening process (raised by the PAPRP in 1988).

Resolution: Since 1988, the WIPP PA has used a "logic diagram" procedure to construct all possible combinations of events. This procedure differs from the "event tree" approach used in reactor safety assessments and in earlier WIPP PAs in that order of occurrence is not considered, and a smaller number of scenarios can be considered while maintaining comprehensiveness. Documentation of this technique is available in the 1990 PA (Bertram-Howery et al., 1990), in Volume 1 of the 1991 PA, in Guzowski (1990), and in Cranwell et al. (1990).

Issue 3: Need to provide automated data flow between subsystem level computational models within the PA. This issue was raised internally and by the PAPRP in 1988 and 1989 as being the most computationally efficient approach as well as essential for QA.

Resolution: The PA Department began development of CAMCON (Compliance Assessment Methodology Controller) in 1988 to automate linkages between major codes. Development is being finalized. QA procedures for software, parameters, and analyses were written in 1991 and 1992, and were in effect in March of 1993. Documentation of CAMCON is available in Rechard ed. (1992) and Rechard et al. (1993).

Issue 4: Need to provide a means to estimate the probability of human intrusion and to quantify the effectiveness of potential passive marker systems, other than by ad-hoc estimates of fixed probabilities. This issue is based on interpretations of regulatory guidance, and was raised internally, by the PAPRP, and by the EPA Office of Radiation Programs in 1990.

Resolution: Beginning in the 1990 PA, a Poisson model for intrusion probability (intrusions are random in time, with a maximum expected value equal to the EPA guidance of 30/km/10,000 yr), was substituted for previous ad hoc estimates of probability. Expert panels were convened to consider future societies and the degree to which passive markers would be effective in communicating with them. Results of the expert judgment were used in the 1992 PA. Documentation of the Poisson model is available in Volume 2 of the 1991 and 1992 PAs, and in references provided therein. Documentation of the expert judgment elicitation is provided in Hora et al. (1991) and Trauth et al. (1993). The algorithm for deriving drilling rates from the expert judgment is described in a memorandum by Hora in Appendix A of Volume 3 of the 1992 PA.

Issue 5: Need to include effects of gas generation and 2-phase flow in PA modeling. This issue was raised by the NAS, the EEG, and the PAPRP in 1989 and earlier.

Resolution: PA developed the capability to model 2-phase flow in human intrusion scenarios in the fall of 1990, using the BRAGFLO code developed in house. Gas-generation reactions and their dependency on reactant (i.e., brine, iron, and cellulosic waste) availability were included in the code. Technical complexities related to the short time steps required to model rapid pressure drops during intrusion precluded the use of other 2-phase flow codes prior to the development of BRAGFLO. The use of BRAGFLO is first documented in the 1990 PA (Bertram-Howery et al, 1990), and subsequently described in Volume 2 of the 1991 and 1992 PAs, as well as in Volume 4 of the 1992 PA and in SAND92-1933.

Issue 6: Need to display uncertainty in performance estimates resulting from alternative conceptual models for waste-form properties and radionuclide transport in the Culebra. These issues were raised by the NAS, the EEG, and the PAPRP in 1989 and 1990.

Resolution: Beginning in 1990, the PA Department examined conceptual model uncertainty by performing ceteris paribus Monte Carlo analyses, in which vectors of input values were the same for each conceptual model except for the parameters used to describe the specific model change. This technique allows direct comparison of probabilistic outcomes from system-level models using alternative conceptual models for those cases in which the alternative models can be described by parameter variations within the existing conceptual models. For example, potential effects of waste-form modification were examined by repeating the Monte Carlo analyses using various fixed values for radionuclide solubility and waste-form porosity and hydraulic conductivity. Dual- and single-porosity transport models for the Culebra were compared by repeating dual-porosity simulations with matrix porosity set to zero. The first of these analyses are described by Bertram-Howery and Swift (1990). Later analyses are described in the 1990 PA (Bertram-Howery et al., 1990), in the 1991 PA (Helton et al., 1992), and in Volume 4 of the 1992 PA.

Issue 7: Need to couple creep closure process with gas generation and 2-phase flow. This issue was raised by the NAS and the PAPRP in 1990 and 1991.

Resolution: The 1992 PA included the effects of creep closure for the first time. Computational complexity prevented a full coupling of the mechanistic creep model SANCHO with the 2-phase flow code BRAGFLO, and instead SANCHO output, in the form of waste/backfill porosity as a function of moles of gas generated, was used to define time and pressure-dependent waste/backfill porosity in BRAGFLO calculations. See Volume 4 of the 1992 PA for additional information.

Issue 8: Need to include effects of pressure-dependent fracturing of anhydrite interbeds in the Salado Formation. This issue was raised by the NAS, the EEG, and the PAPRP in 1992 and 1993.

Resolution: Beginning in the fall of 1993, PA calculations have used an approximation of pressure-dependent fracturing in which porosity and permeability of the anhydrite interbeds are

varied as a function of pressure at pressures close to lithostatic. Additional data are needed to evaluate the adequacy of this approximation (or to develop another) and to justify the parameter distributions used.

Issue 9: Need to reexamine the event and process screening procedure used in scenario construction. The EEG, the PAPRP, and other reviewers have noted since 1991 that some of the evidence used in screening is out of date, some is incomplete, and some events have never been adequately analyzed.

Resolution: The PA Department has undertaken a major effort in reviewing the screening of features, events, and processes (FEPs) for inclusion in scenarios, some of which involves sample calculations. Supporting documentation for those FEPs screened from consideration on regulatory grounds (specifically excluded from consideration by 40 CFR Part 191 or its supporting documentation, or excluded because of low probability or low consequence as per 40 CFR Part 191) and technical grounds are being developed, and will be maintained in the Sandia WIPP Central Files.

Issue 10: Need to confirm adequacy of two-dimensional modeling in the repository environment (BRAGFLO) and the Culebra (SECO) with three-dimensional modeling. This issue has been raised by the PAPRP, the NAS, and other reviewers.

Resolution: The PA Department is addressing these two questions through the FEPs effort. Calculations performed for FEP S1 "Verification of 2D-radial flaring using 3D geometry [room to room processes]" is being addressed by comparing 2D BRAGFLO calculations against 3D TOUGH28W and 3D BRAGFLO calculations, based on the same physical representation (i.e., model) of the WIPP site. TOUGH28W is a version of TOUGH2 with WIPP-specific features such as creep closure and pressure-induced anhydrite fracturing.

FEP NS9 "Justification of SECO 2D approximations" addresses the SECO issue and the current rationale and justification are documented in a Summary Memo of Record written by T. Corbet. This memo summarizes the use of three-dimensional simulations to evaluate the amount of flow across the upper and lower surfaces of the Culebra.

Issue 11: After reviewing the 1990 and 1991 PAs, the PAPRP requested a more complete and accessible presentation of the data used in the PA calculations.

Resolution: Volume 3 of the 1991 PA contains a first attempt at providing data tables. Further improvements were made for Volume 3 of the 1992 PA which contains data tables that include the new categories of "correlation", "usage" (in mathematical and computational models) and "ranking in past sensitivity analyses".

References

Bertram-Howery, S.G. and P.N. Swift. 1990. *Status Report: Potential for Long-Term Isolation by the Waste Isolation Pilot Plant Disposal System*. SAND90-0616. Albuquerque, NM: Sandia National Laboratories.

Bertram-Howery, S.G., M.G. Marietta, R.P. Rechard, P.N. Swift, D.R. Anderson, B.L. Baker, J.E. Bean, W. Beyeler, K.F. Brinster, R.V. Guzowski, J.C. Helton, R.D. McCurley, D.K. Rudeen. J.D. Schreiber, and P. Vaughn. 1990. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990*. SAND90-2347. Albuquerque, NM: Sandia National Laboratories.

Cranwell, R.M., R.V. Guzowski, J.E. Campbell, and N.R. Ortiz. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste: Scenario Selection Procedure*. NUREG/CR-1667, SAND80-1429. Albuquerque, NM: Sandia National Laboratories.

Guzowski, R.V. 1990. *Preliminary Identification of Scenarios That May Affect the Escape and Transport of Radionuclides From the Waste Isolation Pilot Plant, Southeastern New Mexico.* SAND89-7149. Albuquerque, NM: Sandia National Laboratories.

Helton, J.C., J.W. Garner, R.P. Rechard, D.K. Rudeen, and P.N. Swift. 1992. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991--Volume 4: Uncertainty and Sensitivity Analysis Results.* SAND91-0893/4. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Rechard, R.P., ed. 1992. *User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller Version 3.0.* SAND90-1983. Albuquerque, NM: Sandia National Laboratories.

Rechard, R.P., A.P. Gilkey, H.J. Iuzzolino, D.K. Rudeen, and K.A. Byle. 1993. *Programmer's Manual for CAMCON: Compliance Assessment Methodology Controller*. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991--Volume 1: Methodology*

and Results. SAND91-0893/1. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991--Volume 2: Probability and Consequence Modeling.* SAND91-0893/2. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991--Volume 3: Reference Data.* SAND91-0893/3. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department. 1992. *Long-Term Gas and Brine Migration at the Waste Isolation Pilot Plant: Preliminary Sensitivity Analyses for Post-Closure 40 CFR 268 (RCRA), May 1992.* SAND92-1933. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992--Volume 2: Technical Basis.* SAND92-0700/2. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992--Volume 3: Model Parameters.* SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992--Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B.* SAND92-0700/4. Albuquerque, NM: Sandia National Laboratories.

PEER REVIEW PANEL CHARTER

Date	Rev. #
September 1988	0
September 1990	1
August 1991	2
December 1992	3

INFORMATION MEETINGS

Date of Meeting
July 27-28, 1987
November 10-11, 1987
April 25-26, 1988
August 3, 1989
February 28, 1990
August 28, 1990
April 9-10, 1991
July 26, 1991
April 5, 1994

DOCUMENT REVIEW MEETINGS

Date of Meeting	Document Reviewed
Sept. 26-27, 1989	SAND89-2027 (Methodology Demo) SAND88-1452 (Draft Forecast)
Oct. 22-23, 1990	SAND90-2347 (90 Prelim Comp)
Nov. 28-29, 1990	SAND90-7103 (90 Sensitivity Analysis) SAND90-2510 (Probability Dists)
Oct. 7-8, 1991	SAND91-0893/1 SAND91-0893/2
Jan. 7-8, 1992	SAND91-0893/3
March 6, 1992	SAND91-0893/4[1]
July 28-29, 1992	SAND91-0893/6[2]
Sept. 30-Oct. 1, 1992	SAND92-0700/3
Dec. 14, 1992	SAND92-0700/1
Feb. 18-19, 1992	SAND92-0700/2
April 13-14, 1993	SAND92-0700/4
May 20-21, 1993	SAND92-0700/5

[1] SAND91-0893/5 was deleted from the publication schedule.

[2] Later renumbered SAND92-1933.

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PEER 12 - Design Review Comments Regarding Shaft Seals

WPO 37382

Final

WIPP Shaft Seal System

Design Review

SWCF-A:1.1.03.2.2 DES: Final WIPP Shaft Seal System Design Review

1. Introduction

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2. Review Panel Summary Letters

3. Comment/Resolution Documentation

4. Review Material

5. Attendance Record

Sandia National Laboratories
Albuquerque, New Mexico 87185
Livermore, California 94551-0969

date: April 27, 1996

to: Distribution

R. E. Stinebaugh

from: R. E. Stinebaugh, 5165

subject: WIPP Shaft Seal System Design Review

The review of the Compliance Submittal Design (CSD) for the Waste Isolation Pilot Plant (WIPP) shaft sealing system was held in Albuquerque on April 24, 25, and 26, 1966. The review package was provided to reviewers on April 1, 1996 in preparation for the comment resolution meeting.

The review panel consisted of the following individuals:

- R. E. Stinebaugh, Sandia Laboratories Organization 2165 (Chairperson)
- Malcolm Gray of AECL Whiteshell laboratories located in Pinawa, Manitoba, Canada
- John Tinucci of the Itasca Consulting Group located in Minneapolis, Minnesota
- Stephen Phillips of Phillips Mining located in Tucson Arizona

During the first half of the 24th, the WIPP technical staff made presentations aimed at providing the review panel with additional information covering the design, laboratory and in-situ experimentation results, and analyses that have been completed. These presentations provided the WIPP staff opportunity to answer questions relating to the design and the information provided in the review package. This session proved to be very helpful, in retrospect its main impact was that it provided the reviewers a new perspective on the amount of work that has been done and the rigor of the analyses that support the design. After the presentations were completed, the reviewers finished the 24th working on individual comments.

During the morning of the 25th, the designers and the reviewers met in smaller groups tailored specifically to match the reviewers with the designers and analysts that could best address questions relating to the reviewer's area of expertise. These sessions proved to be very efficient and effective exchange of information. At the close of this day, the reviewers had essentially completed their comments. The completed comments were provided to the WIPP staff so that they could started preparation of responses.

Residual comments were provided to the WIPP staff early on the 26th. Comment resolution was started by mid-morning and was completed by approximately 2:00 PM.

This is the second review of the WIPP seal system design accomplished by this review panel. The first (preliminary review) was the review of design concepts documented in the Waste Isolation Pilot Plant Sealing System Design Report (DOE/WIPP95-3117). The records package for the preliminary review is "Waste Isolation Pilot Plant Sealing System Design Report" and contains the review plan, reviewers' qualifications, and training records applicable to the current CSD review. In a number of instances, the comments from the first review were resolved with promised action to be reflected in the CSD. In some instances, the reviewers accepted these responses conditionally. At the conclusion of the CSD review, the reviewers, without exception, stated that they believed the actions promised in the responses to the first review had been completed.

Full or conditional acceptances were obtained for all comments made by the reviewers. It should be noted that in some cases, the WIPP staff, in response to the review panel comments, promised to make certain changes or additions to the design drawings, the documentation of the analyses, or the report text. The panel conditionally accepted these responses on the bases of the agreed to changes. It is imperative that the WIPP staff follow through with the actions promised and provide the reviewers with evidence that the requested actions have been implemented.

In summary, I thank the review panel and the WIPP staff for what I believe was a very thorough review. I would particularly like to note that I feel that the review panel was exceptional in both expertise and depth of experience. The WIPP staff did an exceptional job in presenting the material in a manner that clearly conveyed the magnitude and quality of the work that has been done and in working with the reviewers to develop mutually agreeable responses to their comments. Additionally, I would like to thank Sheryl Vahle and Mike Schuhen for their support in recording comments and resolutions and in overseeing the quality aspects of the review.

The report documenting this design review is divided into 5 sections, these sections are described as follows:

1. Introduction

2. Summary letters written by the reviewers concerning the Compliance Submittal Design are contained in this section.

3. The completed comment/resolution forms are contained in this section.

4. The review package (Extended A/O and 5 CSDR Appendices) primarily made up of the CSD is included in this section. This section is completed only in those copies of this design review report that will be placed in The WIPP Central File.

5. The attendance record for the design review is included in this section

Distribution w/review materials:
SWCF-A:1.1.03.2.2 DES:Sealing System Design Report
Review Documents

Distribution w/o review materials:
M. Gray
S. Phillips
J. Tinucci
D. Galbraith, DOE/CAO
B. Thompson, CTAC
MS 0483 R. Stinebaugh
MS 1395 L. Shephard
MS 1330 M. Chu
MS 0701 D. Lynch
MS 1322 J. Tillerson
MS 1322 E. Ahrens
MS 1322 A. Dennis
MS 1395 F. Hansen
MS 1322 L. Hurtado
MS 1322 K. Knowles
MS 1322 M. Schuhen
MS 1322 S. Vahle

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AECL EACL

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TO: Robert E. Stinebaugh, SNL, NM 87185

FROM: Malcolm Gray

1996, April 25

RE: WIPP Sealing System Design Report -
Review Comment Resolution

Further to our discussions and in consideration of the information provided by SNL staff and contractors at the meeting held in Albuquerque on 24 and 25 April, I have reappraised my previous comments of 1996, March 7.

The information provided by SNL staff and contractors has satisfied many of the comments that I provided after my review of the preliminary design document. Accordingly, I withdraw the conditions that, previously, I placed on acceptance of all of the responses that were given to my initial comments and questions.

In brief, I accept previous responses to comments MG-1 to MG-25 on Form No 430-A (14 pages) and dated 4/24/96 (attached) with the following remarks and observations.

1. Many of my previous concerns related to the constructability of the sealing systems. I was impressed by the amount and rigour of work that has been carried out to confirm the constructability of the seals and I am satisfied that the design that I understand will be proposed in the detailed design document will be workable within the constraints of existing engineering practice or reasonably simple extrapolations therefrom. To provide absolute confidence in the constructability of the proposed sealing systems it will be necessary, with time, to effect programs which demonstrate the practicality of the extrapolated technologies
2. I have a general and abiding concern with the relationships between derived design constraints and criteria as they relate to materials specifications. I understand that, generally, the materials specifications have been made to provide constructable seal elements with as minimum as practical permeability and that the properties of the as-placed materials have been incorporated into total system performance assessment models. The derived design criteria were not clear to me from either the documentation provided or the presentations made. From the data

provided, it appears that all of the sealing materials being proposed for use ensure that chemical diffusion is the dominant mechanism of radionuclide transport in a possibly saturated repository at WIPP (see, for example, J.K. Mitchell, 1992). Is this usable as a derived criterion for the specification of the sealing systems?

3. With continuing regard to derived constraints and criteria, it appears that all of the seals, but particularly the clay (bentonite-based) seals are intended not only to limit the migration of brines and, particularly, possibly contaminated brines, but also to limit the migration of gases from the repository horizon to the biosphere. (Are these gases radioactive?). I understand that the proposed application of the clay seals as a barrier against gas movement is derived in major part from an in situ test carried out at the WIPP site. Experiments carried out at the University of Manitoba (Kirkham, 1995) tend to confirm the results of the in situ tests in that 25 mm thick specimens of water saturated compacted bentonite (γ_d~1.3 Mg/m^3) resisted breakthrough pressures of up to 10 MPa. Similar results have been obtained from experiments in Japan (Hara, personal communication). A general rule of thumb seems to be that gases break readily through bentonite layers when and if the degree of saturation decreases below about 80 to 85 %. This rule is conventionally applied in the modelling of oil and gas reservoirs. These results conflict with conventional published wisdom (Pusch, 1985) which suggests that gas breakthrough pressures are related to bentonite swelling pressure. This is an area of concern and question and discussion of the uncertainty and it's effects on the materials specification, associated design assumptions (such as those regarding the rate of resaturation of the clay barriers and the rate of gas generation) and the method of clay seal emplacement are absent from the design documents (both preliminary and detailed). With regard to the method of seal emplacement it is currently proposed that the clay seals should be placed as precompacted blocks. The effects of joints between the blocks need to be considered. During design refinement activities, the method of deep dynamic compaction investigated and proposed for placing the salt seals should be considered as a method for the generation of homogenous almost saturated bentonite seals (see item 1 above). The use of bentonite-salt (sand-sized) mixtures should be considered as a possible alternative to the currently proposed 100% bentonite seals.

4. It is clear from the careful selection of the sealing materials that consideration has been given to their durability and longevity characteristics. However, in neither the preliminary nor the detailed documentation, are these issues discussed in detail. Durability and longevity issues present constraints that can also lead to the materials specifications. How have possible changes in material performance parameters with time (say over the period of 10,000 years) been applied to total system performance assessment modelling? Do short term effects influence long term performance? Mechanisms such as creep, fluid flow, microbiological degradation (and associated gas

generation), seal material interactions, seal material-rock interactions, mineral transformation, silicification, dissolution and precipitation can all lead to changes in material and, hence, seal system performance characteristics. I suggest that the documentation should be expanded to provide confidence that these factors have been thoroughly considered as part of the generation of the sealing materials specifications and seal designs.

5. I am not confident from the information provided that I properly understand the nature and volumes of water flows in, around and through the shaft sealing systems. The time for system saturation remains unclear. This has bearing on the functionality of the shaft sealing system.

6. Other reviewers have addressed the effects of the disturbed rock zone, which appears to have been extensively and adequately studied for it's mechanical performance characteristics. The hydraulic characteristics of the zone are less clear and consideration of the possible coupling of hydrogeochemical, hydrogeothermal and hydromechanical processes and phenomena is not directly evident. Hence the importance of these coupled phenomena, if any, is not made clear

7. Results from experiments at AECL's Underground Research Laboratory in Canada (Graham, in preparation) show that in low permeability, low porosity, saturated rocks, due to phenomena that can be described by theories of thermo-elasto-porosity, minor changes in temperature may signficantly affect the hydraulic flow fields in the temperature affected zones. The changes may be reversible but hysteresis may be a factor to consider in the systems and the time required for reversibility may be long. Due to a lack of clear understanding of these phenemonena and their influence, the use of materials and processes that cause changes in rock temperature should be very carefully reconsidered and alternatives should be presented. Specifically in this regard, I note my understanding that for the hydraulic models being applied for the total system and shaft seal system analyses isothermal conditions are assumed.

I offer these comments and items of information for your consideration in the preparation of the detailed design document that you intend to submit. I appreciate that it may not be possible to fully respond to all of my concerns and questions. In many instances the concerns are recognized internationally as being unresolved or, possibly, irresolvable. In such instances I should be satisfied with recognition of the concern in the documentation and a description of approaches in the design that minimise the effects of the uncertainties.

In summary and conclusion, I consider that when completed as stated immediately above, it is likely that the documents being developed will present a design that will meet the general requirement of shaft sealing systems that will mitigate against water and gas flows from the repository to the biosphere and that can be built using existing technologies or reasonable extrapolation therefrom.

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Information Needs for 40 CFR 191 with Limited Input for RCRA PA

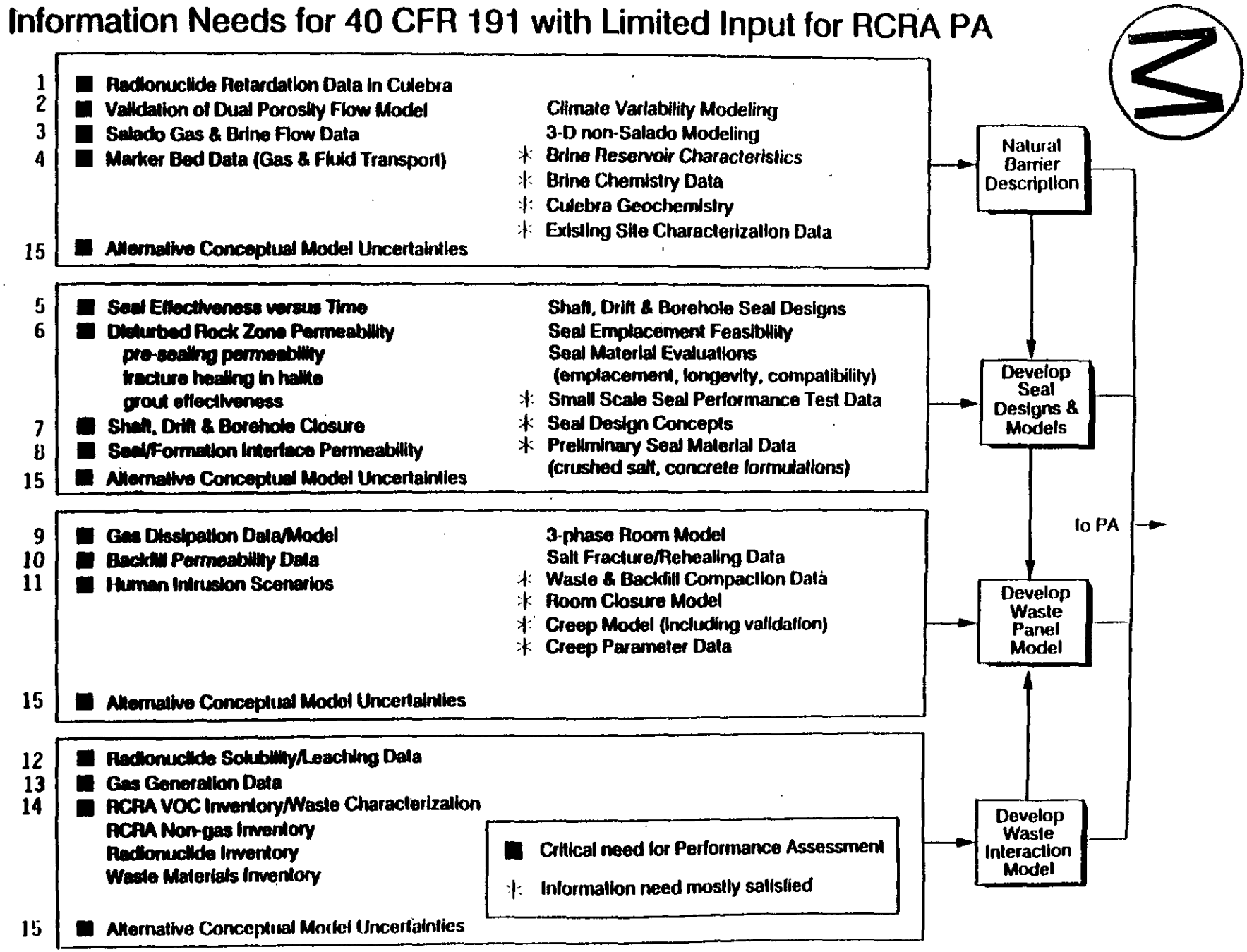

PANEL ON THE WASTE ISOLATION PILOT PLANT (WIPP)
ROSTER

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Document Review and Comment Form

Form Number: 430-A Effective 3/31/96

Procedure: QAP 6-3 Revision 1

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-6	General	Yes	Other reviewers have addressed the effects of the disturbed rock zone, which appears to have been extensively and adequately studied for it's mechanical performance characteristics. The hydraulic characteristics of the zone are less clear and consideration of the possible coupling of hydrogeochemical, hydrogeothermal and hydromechanical processes and phenomena is not directly evident. Hence the importance of these coupled phenomena, if any, is not made clear	x		Hydrologic characterization of the DRZ and its hydromechanical influence on the seal system are addressed in response to other review comments. Geochemical effects--or possibilities--are proposed to be addressed within the context of *longevity* in response to reviewer's Comment #4. Response to this comment has been discussed with the reviewer and the intent is demonstrate awareness of potential issues and at least address the impact, or lack thereof. As an example, potential flow of brine through the DRZ into the clay column could effect performance of the clay via mineral alteration. Recognition of the hydrogeothermal regime caused by hot asphalt and hydrating concrete will be made--but probably not quantified--as noted in response to Comment #7. Resolution will be to raise and discuss these items--not to resolve all issues--but to demonstrate awareness.	X	

Document Review and Comment Form

Form Number: 430-A Effective 3/31/96

Procedure: QAP 6-3 Revision 1

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
MG-7	General	yes	Results from experiments at AECL's Underground Research Laboratory in Canada (Graham, in preparation) show that in low permeability, low porosity, saturated rocks, due to phenomena that can be described by theories of thermo-elasto-porosity, minor changes in temperature may significantly affect the hydraulic flow fields in the temperature affected zones. The changes may be reversible but hysteresis may be a factor to consider in the systems and the time required for reversibility may be long. Due to a lack of clear understanding of these phenemonena and their influence, the use of materials and processes that cause changes in rock temperature should be very carefully reconsidered and alternatives should be presented. Specifically in this regard, I note my understanding that for the hydraulic models being applied for the total system and shaft seal system analyses isothermal conditions are assumed.	x		Current design element will remain unchanged with text recognition of the reviewer's concerns. Phenomena caused by heat, caused be concrete hydration and placement of heated materials.	X	

WASTE ISOLATION PILOT PLANT Sandia National Laboratories	**Document Review and Comment Form** **Form Number: 430-A Effective 3/31/96**
	Procedure: QAP 6-3 Revision 1 — Page 1 of 7

This form may be used for test plans, procedures, reports, design packages, abstracts, Technical Operating Procedures, and other documents.

Section of document to be reviewed and review criteria: (See sample criteria in QAP 6-3.).

Review Requester: Robert Stinebaugh Date: 4/24/96

Response Prepared By: [signature] Signature of Author/Designer Date: 4/26/96

Reviewed By: John Pinucci Date: 4/26/96

Response Concurrence: [signature] Date: 4/26/96

Review Type: ☒ Independent Technical ☐ QA ☐ Management ☐ Other Specify:

Title of Document to be Reviewed: Waste Isolation Pilot Plant Sealing System Design Review

☒ Pre-Publication ☐ Post-Publication

Signature of Reviewer [signature] Signature of Reviewer

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject

Document Review and Comment Form

Form Number: 430-A Effective 3/31/96

Reviewer's Comment				Author/Designer's Response			Reviewer's Response	
Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
JT-1	General	Yes	Alternatives are not presented but critical to providing confidence that construction can obtain specified performance. Suggest adding discussion of alternatives (without minimizing the selected option).	✓		Text in report will include appropriate mention of alternative construction methods; for example, emulsified asphalt vs heated asphalt, dynamic compacted clay vs clay blocks, ultra-high density clay pellets vs clay blocks, concrete water stops vs asphalt water stops. Mention will also be made of the rationale for using "overkill" materials when it is just as cost effective as switching to another material. The report presents a single design that can be built and will work and primary recognition must be retained because the report is primarily for regulatory purposes, not to present a detailed design or specifications for bidding purposes.	CA*	
JT-2	General	Yes	Analyses Results are presented as deterministic "lines" but there are many factors influencing these values (analysis methods, assumptions, properties, etc.). It is suggested that "bands" be added to bracket response	✓		To the extent they are available and appropriate, bounds on expected results or properties will be added. The purpose of the bounds will be to establish the range in results that different properties or analysis methods might produce, and will also demonstrate the conservatism of the approach used in this document.	CA	

*CA is a conditional response whereby I agree with the response to the comment but require a copy of the marked up document to remove the condition for full acceptance

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JT-3	General	Yes	The DRZ, especially along 1 ft near wall, seems to have been analyzed in a "simplified" manner. Reviewer does not feel that it has been demonstrated that the mechanical DRZ compares well with the hydrologic DRZ. Suggest adding comparison curves of conductivity vs vol. strain and mechanical damage vs vol. strain. Also add a comparison of ongoing lab tests of damage vs conductivity (if possible) and the need for the 32 parameter constitutive relation in salt.	✓		For clarification, a figure will be included in the report that ties field observations and model DRZ characterizations together; for example, a figure will be included to compare calculated and measured DRZ extents and how the calculated DRZ depends on the method or criteria chosen to define it. This will essentially involve overlaying Figure 3-1 (Appendix C) on Figure D-19 (Appendix D). The DRZ based on mechanical considerations can be defined in two ways: either the historical stress-strain history (damage evolution) or the existing stress conditions. The required complexity of the constitutive law for salt depends on the chosen DRZ characterization. Because the DRZ in salt is the key to seal system performance, argumentative characterization based on damage is more appropriate. Tracking of damage evolution and healing requires a complex constitutive relationship for the salt. A simpler model can only provide qualitative characterization of the DRZ. This aspect of constitutive model selection will be discussed in the main report as well as in Appendix D.	GA	

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JT-4	General	Yes	It wasn't clear how DRZ conductivity was input to Flow Model (i.e., integration across the area). Suggest adding description and discussion on mesh sensitivity to add confidence . The results (i.e. inflows) would not be vastly different.	✓		Radial integration of permeability across the mechanically calculated extent of the DRZ yields an average conductance which is applied to a fixed grid (mesh) of the hydrological analysis. More thorough descriptions and justifications of the approach and mesh selection will be provided in Appendices C and D.	CA	
JT-5	General	Yes	Has the pressure difference across the waterstop been examined in detail? Will the asphalt flow down the DRZ? It won't matter if there isn't any pressure difference. Suggest quantifying the magnitude to eliminate the issue. Concrete waterstop would eliminate this issue and should be considered.	✓		The detailed design will determine appropriate asphalt viscosities such that neither brine (uppermost waterstop) nor gas (lowermost waterstop) will "wormhole" asphalt, because of a pressure difference across the waterstop. Whether or not asphalt will flow into the DRZ surrounding the waterstop (or elsewhere) depends on the asphalt viscosity, which will be specified in the detailed design. At this time the design assumes that the asphalt has a viscosity after cooling that prevents significant migration into the DRZ. See JT-1 relative to concrete-filled waterstops.	✓	

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JT-6	General	Yes	Many analyses have been performed to look at sensitivities to input properties (eg Leo's tables of clay stiffness vs DRZ, etc.) Reviewer doesn't get a feel from reading the document for which components and seal properties are critical. Suggest adding summary tables or curves to indicate range and where within that range the specifications fall. This will provide basis for trade-off between properties and performance.	✓		The cross-sectional seal materials (concrete, asphalt, clay, and eventually crushed salt) are assumed to be adequate in sealing the shaft cross section. Therefore the fluid flows will be most sensitive to the path afforded by the surrounding DRZ. Different materials cause differences in healing of the DRZ surrounding the shaft. The effectiveness for healing is directly relatable to the stiffness of the seal material. A summary table from the calculation file will be included in the report to better illustrate the significance of stiffness on the DRZ extent at representative times.	CA	

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JT-7	General	Yes	The design description only describes what the components are and where they are located. There is no basis for why they are located where they are (eg why is there a concrete bulkhead between MB135 & MB136). Suggest adding brief basis to Section 4 and tie it back to how it qualitatively ties back to design guidance in Sec. 3.	✓		Discussions will be provided of why *certain seal materials are located* where they are can be provided in the text. For example, the upper concrete seal is located well below the top of salt for the following reasons: 1) so the concrete and waterstop are situated in clean salt, 2) so no significant marker beds intersect the emplacement, 3) so any water migration from the Rustler through the DRZ will have become salt-saturated before reaching behind the structure, and, 4) so the asphalt column can be placed across the Rustler/Salado contact and in the region of the shaft key. The crushed salt is placed as low as feasible in the shaft so that the maximum benefit can be obtained from shaft closure induced salt consolidation. A lower clay component is placed lowest in the shaft in order to: 1)provide an immediately effective gas barrier across the shaft cross section at the repository horizon and, 2) to restrict flow of gases from marker beds immediately above the repository (for example, clay seams "a" and "b").	CA	

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JT-8	General	Yes	To address the long-term issue of subsidence influence on shaft seals, it would be useful to have a plot of lateral displacement along the length of the shaft in Section D.6.2.	✓		The shaft seal within the Salado are outside the angle-of-draw for any horizontal displacements caused by the subsidence over the waste panels. *Moreover, horizontal strains* caused by subsidence induced by closures within the shaft pillar are compressive in nature and insignificant in magnitude. Supplementary calculations of horizontal strains and differential horizontal displacements are not warranted. This point will be made in the text of the report.	CA	
JT-9	General	Yes	The document does not provide a clear basis for "Why does the shaft need sealing and why has a complicated *redundant system been selected*". Suggest adding preliminary findings from PA analyses (10 -12 won't work; it looks more like 10 -17 will and conservative vs lack of data approach) in order to provide this basis.	✓		When the annotated outline is expanded into a report, it will include discussion that resolve this comment.	CA	
JT-10	General	Yes	The report presents results nicely in appendix but does not tie conclusions back to guidance criteria. Suggest adding discussion in Sec. 9 Conclusions as to how sealing components meet criteria set forth in Table 3-1.	✓		When the annotated outline is expanded into a report, it will include discussion that resolve this comment.	CA	

WASTE ISOLATION PILOT PLANT

Sandia National Laboratories

Document Review and Comment Form

Form Number: 430-A Effective 3/31/96

Procedure: QAP 6-3 Revision 1

This form may be used for test plans, procedures, reports, design packages, abstracts, Technical Operating Procedures, and other documents.

Section of document to be reviewed and review criteria: (See sample criteria in QAP 6-3.).

Review Requester: Robert Stinebaugh Date: 4/24/96

Response Prepared By: [signature] Signature of Author/Designer Date: 4/26/96

Reviewed By: SHE Phillips Date: 4.26.96

Response Concurrence: SHE Phillips Date: 4.26.96

Review Type: ☒ Independent Technical ☐ QA ☐ Management ☐ Other Specify:

Title of Document to be Reviewed: Waste Isolation Pilot Plant Sealing System Design Review

☒ Pre-Publication Signature of Reviewer

☐ Post-Publication Signature of Reviewer

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Item No.	Ref. Loc.	Mandatory	Comment	Accept	Reject	Reasoning	Accept	Reject
SP-1	95-3117 Pg 33	Yes	If all the lining is not removed, the seal is only as good as that existing between the liner and the rock, including the DRZ. It is therefore over-kill to fill the shaft with a very low permeability material where the lining is not removed and the DRZ permeability are not reduced by grouting. The overall system is optimized by removing all the *lining, having previously grouted the* DRZ; a daunting task.	X		Based on discussions with the reviewer, the lining will be retained throughout the mudstone underlying the Culebra for safety/structural reasons and the lining will be removed as follows below the Culebra: Waste Shaft - below the 769 ft level to top of plug AIS Shaft - below the 760 ft level to top of plug Exhaust Shaft - below the 776 ft level to top of plug Salt Handling Shaft - below the 758 ft level to top of plug The portion of the key remaining in each shaft will be grouted to limit early time flow in the DRZ and along the interface. Elevations listed above may be changed if modification is required by other design considerations. *Optimization of the design is not part* of the mission of this design effort. Optimization studies during detailed design will resolve such concerns.	✓	

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SP-2	95-3117 Pg 45	Yes	Throughout the text there are generalized statements regarding the sealing of the shafts. However, they are not always put completely into contents. Undoubtedly, the asphalt will increase redundancy and add assurance that the transport of brine down the ***inside*** (previously open) portion of the shaft, is precluded. The asphalt will not however, seal the DRZ initially but it will allow the DRZ of the Salado to seal over a period of time. These statements should be put completely into context.	x		The report will be reviewed for clarification of this point . The general shaft sealing strategy will be better explained in the text. For instance, greater emphasis will be given to explaining why redundancy is incorporated in the design philosophy and why cross-sectional seals and DRZ "seals" are both required in the system.	✓	
SP-3	95-3117 Pg 46	Yes	Specifications for the asphaltic components should be such that they optimize the sealing in the various locations. For example, the properties for the asphalt in the waterstop should be such that they promote rapid healing of the DRZ around the waterstop. The specs for the asphalt filler for component 6 may need to be very different as some penetration into the DRZ may be beneficial.	x		The review comment is absolutely correct that different asphalt properties may be desired when comparing the asphalt column (migration into the DRZ desired) to the waterstops (pressurization to induce salt healing desired). The properties of the asphalt waterstop should provide fast (i.e. two years) healing rates around the waterstops. Properties of the asphalt column should allow some migration into the surrounding DRZ. The text will include a "qualifier" that the viscosity will be tailored in the detailed design to provide the desired properties of the asphalt.	✓	

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SP-4	95-3117 PG D8	Yes	There will be interface flow, the extent of which will depend upon how well the various components can be placed against the rock wall and the characteristics of the rock wall, i.e. either blasted or drilled/reamed. The interface flow are initially expected to be a minimum past the asphaltic seals (if a relatively low viscosity asphalt is used) and probably reasonably low past a plug constructed with concrete having a high workability.	x		Construction of vertical shaft seals provides the ideal situation for minimizing interfaces between the rock and seal materials. Concrete and asphalt will flow under their own weight to provide intimate contact; this was shown for concrete in the SSSPT tests. Dynamic compaction will provide an as yet undetermined residual lateral stress which will ensure a tight interface. This construction method does completely close the interface, as demonstrated in the "thumper" test on salt. In similar construction situations interface grouting is usually performed and will be attempted in the appropriate locations. The impact of a flow along interfaces was previously analyzed during a preliminary study of the Rustler sealing system. These calculations showed that downward flow rate is controlled by the Salado DRZ conductance.	✓	

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SP-5	95-3117 General	Yes	The characteristics, and the eventual sealing, of the DRZ around the shafts, especially in the lower Rustler will have a significant effect on the eventual shaft seal achieved. The DRZ immediately above the Salado will never heal and never be completely sealed. Therefore, there is a potential for unsaturated brine to enter the top of the Salado. The asphalt filled waterstop at elev. 2420 ft. is the primary seal against brine migration downwards through the Salado. This should therefore be located as high as possible in the Salado and every effort made to seal its DRZ as soon as possible, eg. apply a head to the asphalt. Similarly, the short term effectiveness of the asphalt column in component 6 could be improved by completely removing the existing key and applying a head to the asphalt and/or grout to accelerate healing of the upper Salado.	x		Additional liner removal in this region and grouting the remaining portion of the key and around the Rustler concrete plug have been added to the design. These steps will provide an additional short-term barrier to downward migration of Rustler groundwater. Grouting will be performed in all areas where the liner is removed (10 ft above and below the removed sections will also be grouted) and throughout the length of the key. This grout will provide flow control in the DRZ during seal system construction and for some time following completion of the seal system. The reviewer is correct in stating that the asphalt filled waterstop is an important short-term seal for the DRZ. For this reason, the design has placed the upper waterstop at an elevation of 2420 ft amsl in what is considered "good" salt. We do not consider it appropriate to move the waterstop to any higher elevation because it could move it into poorer quality salt and undermine its function. Based on discussions with the reviewer, the length of the asphalt column (i.e., head on the asphalt column), will not be increased to achieve greater effectiveness in sealing the DRZ. Consistent with the reviewers' comment, the healing of the Rustler DRZ was not considered in performance models.	✓	

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SP-6	General	Yes	The overall performance of the shaft seal is very dependent upon the short term ability to form a seal in the upper Salado. It appears to be a race against time. Will the Rustler undersaturated brines penetrate the DRZ to the upper concrete component before the asphalt waterstop becomes 100% effective? The calculations given, indicate that the flow is minimal and that the waterstop will seal in 2 years. I suspect that the calculations are sensitive to the value of the permeability chosen for the DRZ in both the Rustler and top of Salado. *Please explain the rationale used to* determine the permeabilities used in the DRZ of the Rustler. Will there be any difference between the *permeabilities in the same formation in* different shafts, bearing in mind the differing construction methods? Will the fact that the Rustler brines are undersaturated, make any difference to the permeabilities used in the flow calculations? Will this influence the final outcome?	x		DRZ permeabilities in the Rustler are not based upon field data but are assumed values. However, the DRZ permeability in the Rustler is not the controlling factor in flow through the seal system. The hydraulic conductance (ka) of the DRZ in the Salado is the limiting factor. Therefore, increasing the DRZ permeability of the Rustler will not significantly impact total flow. No distinction is drawn between treatment of shaft DRZ based upon shaft excavation methods. However, we feel that the conservative conceptualization of DRZ permeability in the Salado likely encompasses any possible variation between shafts. Currently we use *conservative estimates of halite skin* permeability and DRZ extent relative to field results. In addition, we hold the skin permeability at its maximum value throughout the DRZ healing period. The skin permeability dominates the calculation of the effective permeability. The potential for dissolution of salt within the DRZ will be considered and added to the final document.	✓	

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SP-7	General	Yes	Does the 2 year time frame for the healing of the new DRZ formed by the waterstop include the time taken to refill the space formed by shrinkage during cooling of the asphalt? Is it worth considering pressurizing the waterstop by grouting to speed the healing of the salt?	x		The 2-year time frame associated with the complete healing of the DRZ around waterstops did not explicitly account for closing any open volume of the waterstop caused by cooling of the asphalt. Cooling could cause about a 0.6 inch gap across the shaft below the concrete component for a 10 deg. C temperature change. The creep of salt will rapidly compress the asphalt and close this gap, especially when the salt has been heated. An alternative would be to inject additional asphalt or grout to fill the gap (and pressurize the asphalt, if desired). Pressurizing the waterstop will cause initiation of healing of the DRZ around the waterstop. Consideration will likely be given to this approach at the time of construction.	✓	
SP-8	General	Yes	Every effort is made to eliminate/reduce the DRZ in critical areas. Removal of the lining in some areas of the Rustler will help, but the placement of asphalt or compacted clay will not seal the DRZ. Is it worth considering grouting around some of the concrete plugs to reduce the permeability of this area by a few orders of magnitude and to apply some state of confinement to the plug?	x		Text of Appendix B will be modified to include grouting of the concrete plug in the Rustler formation. A spin grout pattern, similar to that used to grout the Rustler in areas where the liner is removed, will be used.	✓	

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SP-9	General	Yes	Should the downward movement of surficial water not be restricted as much as possible?	x		Section 4.3.3, Supra-Rustler Subsystem, briefly addresses this point in the 2nd paragraph on page 16 of the draft report. The text will be expanded to state that the shaft fill materials in the Dewey Lake and overlying units will be compacted to inhibit the migration of surficial water into the shaft cross section. Flow is further decreased by a 40-foot long concrete plug at the top of the Dewey Lake.	✓	
SP-10	General	Yes	How will any existing inflow into the shafts be handled during construction?	x		Text to be added is: A water gathering system (similar to the one currently in place at the bottom of the concrete liner) will be moved upward as seal emplacement proceeds. Water collected will be hoisted to the surface for disposal. Additionally, significant inflow, if any, will be located and minimized by grouting	✓	
SP-11	General	Yes	Will the electromagnet holding the tamper be absolutely safe if men are to be working in the bottom?	x		Text to be added: The tamper will be mechanically secured to the polar crane before personnel are allowed under it.	✓	

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SP-12	General	Yes	Should the locking devices not be on the bottom deck rather than the top deck?	x		No text/drawing changes at this time since discussion with the reviewer indicates agreement that the location currently shown will function *satisfactorily. This change may be* incorporated in future optimization of the system.	✓	
SP-13	General	Yes	The long blade of the undercutter should be confined both top and bottom in the salt when cutting. It may be necessary to use a short rigid blade to make the sequential, circumferential cuts for the excavation for the plugs.	x		The text in Appendix B, Section 4.2.2 will be modified to state that two cutter bars will used to make the necessary excavations for the upper, middle, and lower concrete components. The notches for the concrete plugs will be excavated using a short cutter bar (minimum length necessary to excavate notch) and the kerf for the asphalt waterstop will be excavated using a long cutter bar (length sufficient to make a 1 radius excavation).	✓	
SP-14	General	Yes	It may be necessary to cut both upper and lower plug excavation together so that the muck does not have to be cleaned off the top of the asphalt.	x		The text in Appendix B, Section 4.2.2 will be modified to state that the notches for the upper and lower concrete plugs of the concrete components will be cut before the concrete for lower plug is placed. This will insure that muck from the upper notch does not have to be cleaned off the top of the asphalt.	✓	

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SP-15	General	Yes	The work deck could be assembled in the shaft collar. The work scheduled to be performed on the surface beneath to bottom deck of the work deck could also be done with the stage just below the collar. This would allow a smaller headframe to be used and the asphalt pipes to be handled in 20 ft. rather than 10 ft. lengths.	x		We agree that assembly of the stage in the shaft may result in a cost saving. However, the ability to raise the stage 10 ft above the collar provides operational flexibility for: a. maintenance of the polar crane, b. installation and removal of the salt undercutter, and c. installation and removal of the tamper. Therefore, since the design as presented will work, it will not be changed at this time. However, considerations such as this are likely to be part of future optimization activities.	✓	

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SP-16	General	Yes	Will dust be a problem during dynamic compaction, or will the water added keep it to manageable proportions?	x		Per discussions with reviewer, salt dust generated during dynamic compaction is not expected to be a problem - Text to be added is: Experience gained during the large-scale salt compaction demonstration indicated that dust generation during the compaction of WIPP salt is minimal. Additionally, fresh air will flow down over the workers to the vent duct located below the lowest deck of the stage. Therefore, any dust will be exhausted directly out of the working environment.	✓	
SP-17	General	Yes	For safety reasons no major work items should be performed on the top deck. Can the lining be removed on the bottom deck and the material collected off the bottom of the shaft? It would be safer to move up the shaft, breaking out the lining so that no one is working below the unsupported wall.	x		The following text will be added to Appendix B: For safety reasons, no major work will be performed on the top deck. Shaft liner removal will proceed from the bottom up, working from the bottom deck. Broken pieces of the liner will be allowed to fall to the fill surface below. Broken concrete will be gathered by a mucking device, placed in a hoisting bucket, and removed to the surface for disposal.	✓	

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SP-18	General	Yes	Grouting prior to lining removal will be more effective if it proceeds from the bottom and moves upwards. Primary and secondary sequencing of drilling and grouting should also be used. If any formation has significant vertical fracture, the holes should be "spun".	x		Text to be added is: Grouting prior to liner removal will proceed from the bottom up. Holes will be drilled, using reverse circulation diamond drill equipment to avoid plugging fractures with fine-grained drill cuttings. The holes will be drilled in a spin pattern at 45 degrees above horizontal, in the form of an upward opening cone. The holes will be drilled and grouted, using stage grouting procedure and will utilize primary, secondary, and, if needed, tertiary grout holes.	✓	
SP-19	General	Yes	Would it be simpler to construct the Shaft Station Monolith from the shaft?	x		The construction description for the Shaft Station Monolith in Appendix B, Section 4.2.2, will be revised to state that the Shaft Station Monolith concrete will be placed from the multi-deck stage in the shaft. Additionally text will be modified to explain the basis for this choice.	✓	

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SP-20	General	Yes	The dynamic compaction of bentonite in the shaft (when a proven technique) should provide a much higher degree of confidence in the density achieved for this material. Installing blocks will be a very time consuming, labor intensive activity with difficult quality control on first outcome.	x		We agree that dynamic compaction of bentonite is both efficient and cost effective. However, at this time it has not been established that dynamic compaction will produce the required average bentonite density of 1.8 g/cc. Therefore, the design will retain bentonite block as the construction method for the bentonite columns.	✓	

WIPP CSDR Attendance Record						
Name	Organization	Phone	FAX/e-mail	24-Apr	25-Apr	26-Apr
Ernst Ahrens	6121	848-0606	848-0605	X	X	X
Michael Schuhen	6121	848-0646	848-0605	X	X	X
David Mann	Parsons Brinckerhoff	815 281 8700	281-8707	X	X	X
FRANK D. HANSEN	SNL 6121	CB → 505-234-0066 ABQ → 505-848-0609	505-887-1691 505-848-0605	✓	✓	✓
BILL THOMPSON	CTAC	505 865 4730	505 887 5494	✓	✓	✓
Don Galbraith	DOE/CAO	(505) 234-7460	(505) 234-7430	DG	DG	DG
Malcolm Gray	AECL	(204) 753 2311	204 753 8486	✓	MG	MG ✓
John Tinucci	Hasco	612/371-4711	612/ 371-4717	X	X	X
STEPHEN PHILLIPS	PMH.	520 297 2162	520 297 2162	X	X	X
LEO L VAN SAMBEEK	RE/SPEC	605 394 6457	LVSAMBE@RESPEC.COM 605 394 6456	X	X	X
M. Kathryn Knowles	SWN/6121	5058480611	5058480605 mkknowl@nwer.sandia.gov	X	X	X
L. Diane Hurtado	SNL/6121	505-848-0541	505-848-0605 ldhurta@nwer.sandia.gov	X	[illegible]	
Marc Loken	RE/SPEC	605 394 6423	MCLOKEN@RESPEC.COM 605 394 6456	X	X	X
Mark Reeves	INTERA	(512) 346-2000	346-9436	X	X	X
Van Kelley	INTERA	512 346 2000	346 9436	X	X	X
Al Dennis	Sandia, 6121	505-848-0607	505-848-0605	X	X	X
JOE R. TILLERSON	SANDIA - 6121	505-848-0602	Fax 505-848-0605	X	X	X
MARK MATTHEWS	DOE	505-234-7467	234-7430		✓	✓
DICK LAAR	DOE/CAO	505-234-7446	7430	X	X	

WIPP CSDR Attendance Record						
Name	Organization	Phone	FAX/e-mail	24-Apr	25-Apr	26-Apr
R.E. STINEBAUGH	SNL /2165	(505) 844-2534	(505) 844-8745	✓	✓	✓

REVIEW PLAN

SHAFT SEAL SYSTEM DESIGN FOR THE WASTE ISOLATION PILOT PLANT (WIPP)

Principal Investigator: _____ Date: 12/21/95
F. D. Hansen, Dept. 6121

Review Chairman: _____ Date: 1/12/96
R. E. Stinebaugh, Dept. 5105

Approved By: _____ Date: 1-9-96
J. R. Tillerson, Dept. 6121

Approved By: _____ Date: 12-21-95
S. Y. Pickering, Acting QA Chief

Introduction

Sandia National Laboratories is responsible for production of a credible shaft seal design as part of the Compliance Certification Application (CCA) being prepared by the Department of Energy (DOE) for the Environmental Protection Agency (EPA). The CCA will demonstrate compliance with the requirements outlined in Title 40, Part 191 (or 194, if promulgated) of the Code of Federal Regulations for the permanent disposal of transuranic wastes. Much of the technical content of the shaft seal system design will be included in the CCA. Ultimately, the shaft seal system will be published as a comprehensive, stand-alone document including design considerations beyond the scope of the CCA.

Design activities have been conducted by Sandia and subcontractors under the auspices of an approved quality assurance program. This design review will adhere to requirements of SNL Quality Assurance Procedure (QAP) 3-2, entitled Verification of Design Adequacy, Revision 1, approved 7/31/95.

Scope

This review plan governs preliminary and final review of the WIPP shaft seal system. Preliminary design is embodied in a single published report. Final design will include considerable additional detail developed on the basis of the preliminary design. Final design documents include but are not limited to: 1) an enhanced annotated outline of the compliance design report, 2) design drawings, 3) framework of material specifications, 4) fluid flow analyses, and 5) structural analyses.

Preliminary Design Review will consider the adequacy of design concepts summarized in the report entitled Waste Isolation Pilot Plant Sealing System Design Report (SSDR) (DOE/WIPP-95-3117, Printed October 1995). The report includes descriptions of the WIPP setting, design guidance derived from the regulations, a description of the design, materials comprising the seal components, and preliminary evaluations of the shaft seal system. The report itself is the only document that will be reviewed in the preliminary design review. Based on the information included in the SSDR, the review panel will be asked for their evaluations of the following general questions:

- Will this shaft seal system satisfy design guidance?
- Are there elements of the design which will prevent the sealing system from meeting design requirements?
- Can the design be successfully implemented?

The panel is not expected to optimize the design summarized in the SSDR, though comments will be resolved in keeping with QAP 3-2. Resolution of comments may include details of analyses, drawings or specifications that will be addressed and included in the package presented for the final design review.

Final design review will consider several products:

- An enhanced annotated outline for the compliance shaft seal design report
- Detailed drawings
- Material specifications framework
- Structural calculations in topical summaries
- Fluid flow calculation in topical summaries

The final design report for compliance is scheduled to be published in August 1996. The enhanced annotated outline used in the review process will be developed into the compliance design report and incorporate the final design review comments. The compliance design SAND report will be subjected to peer review in keeping with established Quality Assurance procedures for publications. The products identified for examination during final design review will address comments generated during preliminary design review.

Review Panel Members

Members of the design review team are selected on the basis of their respective knowledge, experience and independence from the WIPP shaft seal design effort. Independence does not mean total lack of experience with any WIPP activities, rather independence means no involvement with the seal design, analysis or materials development.

Name/Organization	Key Review assignment	Phone Number
Robert E. Stinebaugh/SNL	Review Team Chairman	505-844-2534
Malcomb Gray/AECL	Scientist/Programmatic	204-753-2922
John Tinucci/Itasca	Modeling/Analyses	612-371-4711
Steve Phillips/Phillips Mining	Materials/Safety	520-297-2162

Schedule

The schedule presented in this plan is based on the assumptions that the panel members will be available on the dates specified and that the material to be reviewed will also be available on these dates. This schedule may be revised by the Chairman to accommodate any or all parties to this review without revision of this plan.

Approval of design review plan: On or before 12/22/95
Note: Approval of the design review plan includes assignment of the review chairman and review panel members.

Preliminary design review: 01/10/96 through 02/13/96

01/04/96-01/09/96:	Distribute seal design report (DOE/WIPP-95-3117) to review panel.
01/10/96-01/23/96:	Review design package per review plan instructions.
01/23/96:	Formal comments submitted to Chairman.
01/30/96:	Comment resolution complete. The Chairman has the discretion to hold a summary meeting to discuss resolutions.
02/13/96:	Preliminary design report completed by Chairman and delivered to Sandia QA for review and approval. Pending QA approval, the preliminary design review package will be submitted to the Sandia WIPP Central File (SWCF). Delivery of the design report to SWCF concludes the preliminary design review.

Final design review: 03/21/96 through 04/29/96

03/21/96:	Distribute an enhanced annotated outline of the Seal System Compliance Design Report and supporting documents to the review panel. Distribution will be accomplished in a joint meeting wherein the design and supporting calculations are presented to the review panel.
03/22/96-04/03/96:	Review design package.
04/04/96:	Submittal of all review comments to the Chairman.
04/05/96-04/18/96:	Comment resolution.
04/19/96-04/23/96:	Verify resolution acceptance by review panel.
04/24/96-04/26/96:	Prepare design review report.
04/29/96:	Submit design review report to SNL QA for review, approval and submittal to the SWCF.
04/30/96:	Milestone SS002--Complete design review of Shaft Sealing System Compliance Design

The concept of "comment resolution" for purposes of design reviews means that agreement is reached on how a comment will be addressed as the design progresses. Resolution does not require the solution to the comment be completely obtained or achieved. Certification of completion of review comments rests with the Chairman.

This schedule supports two project milestones: 1) Seal design input to CCA (07/96), and 2) Publication of the Seal System Compliance Design Report (08/96).

Review Procedure

The Chairman has the authority to make schedule changes and logistical arrangements as felt necessary to accomplish the reviews, if such arrangements do not jeopardize quality, the ability to complete the review in a technically competent fashion, or the milestone date for completion (04/30/96). If practical, design reviews will be initiated at a central location to provide an opportunity for presentation of the products by Sandia. If it is not possible for a panel member to meet at the designated location and time, the Chairman can implement alternative arrangements for initiating the design reviews.

The Chairman will provide guidance for the review process including training in accordance with QAP 3-2. Training forms and other QA documentation will be assembled early in the review process. The Chairman will instruct reviewers to stay within their areas of expertise and offer concise comments suitable for a technical response. The guidance will include methods for comments submittal and resolution (a standard form #430 from QAP 6-3 or an equivalent word processing form will be used). Unresolved comments (disputes) will be resolved by majority of the panel. If the panel cannot achieve resolution, a final decision regarding the unresolved comment will be made by the Department Manager, J. R. Tillerson in consultation with DOE. Minority opinions can be included in the Chairman's report.

The Chairman's report on the preliminary and final design will include:

- The Review Plan.
- The reviewed material.
- Reviewer's qualifications in accordance with SNL WIPP QAP 2-1.
- Guidance for the review. This may include materials such as view graphs used for technical presentations or instructions.
- Documentation of training and orientation of reviewers.
- Completed review and comment forms consistent with QAP 6-3.
- Discussion of minority opinions, if appropriate.
- Summation of the review process, if appropriate.

PEER 13 - Engineered Alternatives Task Force Report Peer Review Comments

INTERNATIONAL
TECHNOLOGY
CORPORATION

June 26, 1996

Project No 767014

Mr. Steven Wagner
Waste Isolation Division
Westinghouse Electric Corporation
P. O. Box 2078
Carlsbad, New Mexico 88221

Transmittal of Information on the 1991 Peer Review of the Engineered Alternatives Task Force Report

Attached please find as requested, copies of the signed Engineered Alternatives Task Force (EATF) peer review comment resolution forms. These forms document the external peer review that was performed on the EATF report entitled "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force" (DOE/WIPP 91-007, Rev 0, Vol I and II) during the first half of 1991. Four peer reviewers were selected for the review:

H. Eric Nutall, Ph.D., Nutall & Associates, Inc.
Douglas Brookings, Ph.D., University of New Mexico
Robert J. Budnitz, Ph.D., Future Resources Associates, Inc.
Donald E. Shaw, P.E., Engineering and Management Consultant

The reviewers comments and agreed-upon dispositions are contained in the four attachments to this letter. Please don't hesitate to call me at (505)262-8726 if you need any additional information regarding this peer review.

Respectfully submitted,

IT CORPORATION

Jonathan Myers
Senior Technical Associate

cc: Mark Crawley
Project File

Regional Office
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IT Corporation is a wholly owned subsidiary of International Technology Corporation

DONALD E. SHAW, P.E.
ENGINEERING AND MANAGEMENT CONSULTANT

1123 FAWCETT STREET
WHITE OAK, PA 15131

TEL. (412) 672-1607
FAX. (412) 672-2614

July 30, 1991

Project No. 91-003

Mr. Mark S. Abashian
IT Corporation
5301 Central Avenue, NE
Suite 700
Albuquerque, NM 87108

Letter of Transmittal
Comment Resolution Forms
Peer Review EATF Final Report

Dear Mark,

Enclosed are the comment resolution forms for the risk assessment portion of the EATF Final Report that you sent me on June 13, 1991. I apologize for the delay in returning them. Unfortunately, they arrived while I was involved with other projects. I could not get to them sooner. Since you have sent me a copy of the report, it is obvious that the report was released before I could return them. I hope that the delay did not cause much inconvenience.

I have signed all of the comment resolution forms. There are no problems with the resolutions given. As a general note I might add that if additional work is done on the EATF issue, some of my comments might be included in the work scope. I am referring particularly to tieing the risk assessment to the FEIS. While this was necessary in order to use the relative risk approach adopted, there are issues such as providing input for decisions among various treatment alternatives that were not an issue for the FEIS, but would be for the EATF. This would mean that an absolute as opposed to relative approach to the risk assessment would be required, but it may be worthwhile if treatment becomes a necessity because of problems with the existing design.

Once again I want to commend you and the others at IT on the effort represented by the EATF report. It represents a viable approach to examining repository performance issues and should find considerable utility in the future. Give me a call if you have any questions regarding my comments.

Sincerely,

Don Shaw

Donald E. Shaw

DOCUMENT REVIEW COMMENT BOARD

1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
b. Reviewer: Donald E. Shaw
c. Date: 3/04/91 b. Page 1 of 22
3. Report Title: EATF Final Report of the Engineered Alternatives Task Force, Vol. II (Draft, Jan. 1991)
4. Approval for Report Issuance: Donald E Shaw Date: 7/24/91

5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
GENERAL COMMENTS			
N GEN		The risk assessment represents a comprehensive analysis of risks associated with the alternative waste forms. However, as a general comment, the scope of the risk assessment appears to be inconsistent with the scope of the evaluation of engineered alternatives. The primary difficulty lies in the objective of the risk assessment which appears to have been to perform a relative risk evaluation as if no other factors were involved in the tradeoff among the various alternative. Actually the relative risks associated with various waste treatment alternatives and location options are an ingredient in the overall evaluation of feasible waste alternatives and siting scenarios. Transportation risks are a part of the total transportation issues including RCRA sampling, waste acceptability, etc. Occupational and public risks from waste treatment facility operation are part of the total infrastructure issue relative to the question of multiple vs. a central treatment facility. Unfortunately, while totally correct for a stand-alone risk assessment, the aggregation of risk components masks the ingredients of various alternative waste treatments and location options that might be amenable to remediation in the alternative treatment design.	This is somewhat beyond our scope, but the information has been provided in Attachment G.4. See Attachment G.4.
N GEN		One important factor in the risk assessment is the weighting functions assigned to the relative risk indices. As noted there was insufficient time for a panel survey and it was necessary to select a set of weighting factors. A question that arises is to the degree of sensitivity of risk analysis results to the assumed weighting factors. Additional analyses varying the factors could have provided insight into the importance of the weighting factors to the overall conclusions of the risk assessment.	See above.

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1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N GEN		Another factor relative to the combination of the weighting factors and the aggregation of risk components is that the influence of voluntary as opposed to involuntarily assumed risks. Occupational risks tend to be voluntarily in that workers assume the risk for the perceived benefits of employment. Society, while not unconcerned about worker risks, is probably less concerned about such risks that are voluntarily assumed than it is about involuntary risks associated with cancers or genetic effects. Thus the weight of occupational and public risks to the same scenario with the same consequences could be significantly different. A key issue is the degree to which transportation related risks are seen as voluntary or involuntary. Risks to transport crews are probably viewed as voluntary while risks to the public are probably considered involuntary. Risks to transport crews would seem to represent a larger component of transportation risk than risk to the public because of the exposure times and probabilities of being involved in an accident. While probably much smaller in terms of risk public involuntary assumption of these risks may result in a higher weighting factor compared with transport crew risks. Yet a weighting factor which varies directly with the level of risk could result in exactly the opposite in the analysis. Aggregation over all transportation risks masks these differences.	Aggregation in Attachment G takes this into account and thus does not mask these differences. See Attachment G.

RA:Shew.Comm

DOCUMENT REVIEW COMMENT BOARD

1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
b. Reviewer: Donald E. Shaw
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4. Approval for Report Issuance: Donald E Shaw Date: 7/24/91

5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
E GEN		The Appendix I report could probably be restructured with significant benefit to the reader if more of the discussion of assumptions and result tables were contained in a main body of the report with the equations and technical details appendicized. As it is with an executive summary and attachments it is not clear what portion constitutes the report and what portions are material meant to amplify the report information. Along that line there are mathematical discussions which probably are at a higher level than most readers are familiar with unless they work in the area of risk assessment. At times the mathematical issues appear more like technical papers than a portion of an applied risk assessment with almost no mention of the problem at hand. To the degree possible specific comments have been made along these lines where appropriate.	Text revised so that there is an executive summary, main body of the report, and appendices. The structure is already strongly "appendicized". I do not think that further disjunction would be useful. The mathematical parts form the backbone of the comparison. ok
E GEN		Throughout the report the references to equations and tables tend to need checking. In many cases equation numbers appear to have a portion of the number missing. This appears to be a result of changes in section numbering which were not caught in the equation numbers. Such instances are pointed out where they have been found, but no attempt was made to review the entire report with the objective of checking equation, table and figure numbers.	Done. ok
E GEN		Throughout the risk assessment appendix there are headings followed by subheadings followed by sub-subheading with no text between. While there is nothing wrong with that approach, it is not the one used for Volume 1 where general introductory remarks were made for following subsections. As a matter of preference, introducing the material to be discussed in the subsections seems to provide a better flow.	Done where appropriate. ok

RA:Shaw.Comm

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1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N GEN		In the derivation of risk reduction factors for the various scenarios given in Attachment E, more explanation of how the basic equation is derived might be helpful. In some cases the first equation written for a given risk reduction factor is not evident from the list of symbols and the issues of the scenario.	Done where appropriate. ok
N GEN		In some of the attachments, particularly E and F, there are blank sections with notations of additional material to be supplied. Also, there are table or figure numbers or references which are not fully specified. It was assumed that these issues would be taken care of such that no mention is made of missing sections.	Now supplied. ok
EXECUTIVE SUMMARY			
E I-ES 1 1		The Executive Summary has an Executive Summary. This raises confusion as to what the remainder of the section entitled Executive Summary is. At first it appeared as if it is the main body of Appendix I. However, much of the important discussion does not occur in the Executive Summary section, but is located in the attachments. Some restructuring is required.	That was a labeling error. See new Executive Summary on pages I-i to I-iv. ok
E I-ES 1 2		The combinations of risks and scenarios might be depicted graphically in some form as an aid to the reader. Are such graphics available in the FEIS or FSAR? If so, it might be worthwhile to extract them if possible.	I wish there were such a graph! ok So do I.
M I-ES 8 4		This paragraph was selected because it contains the reference to what is called Table 2-1. The table number should be fixed if the convention used is to number tables with the section that contains them. Also, the table itself should be modified to correct the location option numbers to agree with the way they are referred to in the text, Option Nos. 0 through 4.	Old table was inserted by mistake. See new Table I-2-1 on page I-7. ok

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1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
E I-ES 18 3		Is there a significance to the designation of scenarios as N1, C2, etc. It probably doesn't have to be explained, but it might be helpful to use a table. The primary problem is that not everything discussed is assigned a designation. Note in Volume I, the three human intrusion scenarios were designated E1, E2 and E1E2. Are the N1, C1 designations a result of another document such that these designations are standard to those involved routinely with WIPP?	Taken from FSEIS, FSAR, and calculation briefs. ok
M I-ES 19 4		Are stops at traffic signals included in those considered to be due to road conditions? If not, should they be included?	We are bound by RADTRAN assumptions. Why? Comment?
M I-ES 20 4		In the first paragraph of Section 2.3.2.1.1, there is a sentence that states, "The drum is assumed to contain the 12.9PE-Ci cited as the average alpha radioactivity per drum." What about beta particles and gamma radiation? Several times mention is made of penetrating radiation that is presumed to be gamma. In the drum drop what happens regarding beta particles and gamma radiation?	The average drum has a certain level of α, β, and γ-activity and neutrons. Neutrons and gammas always come out; beta and alphas only in a spill. Put such a remark in assumptions in Sections 2.2.1.1 and 2.4.1. See pages I-5 and I-25. ok
M I-ES 24 1		It would seem that accidents associated with treatment facilities would represent a primary issue in a risk analysis which is focusing on relative risks among various treatment options. While scope limitations are understandable, it is difficult to understand omitting events which are a result of the reasons for performing the assessment. Is there anything which can substantiate the claim that the bias won't be severe enough to invalidate basic conclusions. Industrial accidents would seem to be a source of risk which is not greatly smaller than forklift accidents. Or, if there is data that says otherwise, it could be cited to substantiate omitting treatment facility accidents.	The reason given is that routine exposures are highest. Accidents have larger consequences but occur less frequently, otherwise health and safety will change the SOPs. ok

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-ES 27 3		The sixth dot under this paragraph states, "Maximally exposed individuals are not considered." What does this mean? It sounds as if the risks to persons receiving maximum possible exposures from a given scenario are not considered which is confusing.	No, it means "by themselves". They are, of course, included in the averages. Text amended. See page I-25. ok
M I-ES 28 1		In the second dot under the first paragraph, it states, "The treatment of the waste is assumed not to affect isotope leachability." What does this mean? It seems as though isotope leachability is an important item if it refers to leaching by groundwater in the repository.	Very important. But there are no data. Model calculations are outside of scope. This assumption introduces a bias, but on the small 5000-year risks. ok
M I-ES 28 3		What are the regional averages given in the FEIS relative to fractions of travel in urban, suburban, and rural regions? It would seem that the location of the various possible treatment facilities would differ considerably relative to demographics. This may be accounted for in the FEIS data. Defining the term regional average and possibly giving a table of values or showing them on maps would be helpful.	A complete set of these values were provided in Table E.6 on pages I-215 to I-217. ok
E I-ES 32, 1		In the first paragraph at the top of the page, reference is made to Figure 3-1. A Figure 3-1 was not found.	Corrected to Figure B-1. See pages I-31 and I-70. ok
M I-ES 32 4		There is something wrong in the first sentence of this paragraph, "The weight with which the single attribute utility functions are multiplied in the linear combination and the social value judgments for each risk component."	Typo Corrected. See page I-32. ok

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1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-ES 33 1		Relative to the issue of ranking and uncertainties, the uncertainties are considered to provide a more conclusive ranking of alternatives and location options so that clearly defined differences can be found. Is ranking a primary issue associated with the risk assessment? If the risk analysis were to be used solely as the basis for decision making it would be. However, when the risk analysis results represent one of other issues associated with decision making, does a ranking based solely on risk have meaning to the overall objective. The ranking of primary concern is the ranking of location options and treatment alternatives in view of all constraining parameters including effectiveness in solving gas generation and human intrusion problems, technical feasibility etc.	Ranking of alternatives is outside the scope of this effort, as such rankings require the subjective assignments of weighting factors for risk, cost, schedule, etc. ok
M I-ES 35 3		In the paragraph on Risks in Post-Closure to Human Intrusion, a sentence states, "The reduction factors for the public risk by inhalation are the same as those of the drill crew for all scenarios." Considering that the drill crew is in the immediate vicinity of the borehole and could inhale volatiles contained in drill cuttings, while the public would presumably be further away from the borehole where doses would be less due to air dispersion, this assumption seems questionable. It is recognized that any assumptions regarding the circumstances surrounding the actions of people 5000 years in the future is speculation, but if the scenarios are to be evaluated, the assumptions should be as realistic as possible. It is probably conservative to assume the public reduction factors are the same as the drill crew, but the conservatism should be cited as the basis for the assumption.	This is an "absolute risk" argument. Equations (E.1.1) and (E.1.2) show that statement is correct, not conservative. See page I-147. Cegza

DOCUMENT REVIEW COMMENT BOARD

1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N	I-ES 38 1	The sentence in this paragraph that states, "It is prudent to discard some small risks because a larger risk of the same exposure is already being considered." If the weights reflecting the perceptions of both risks are the same, the smaller risk can be neglected because it does not add anything of significance. However, "prudent" is probably not the right word to describe neglecting the smaller risk. If the weights reflecting the perceptions are not the same and the weighting of the smaller risk compensates for the larger, neglecting the smaller may not be reasonable even though they both arise from the same scenario. The example of cancer and genetic damage may not be a good one because genetic damage may be perceived to be a much greater risk.	I agree. The word "prudent" has been substituted by "expedient" and some further comments (Section 4.3.1, first paragraph). See page I-38. ok
E	I-ES 38 5	In the first sentence of the last paragraph, insert "changes resulting from treatment" after the word "volume."	Done. See page I-39. ok
E	I-ES 39 2	The reference to Table 4-1 should be changed to "Table 4.2-1." Also, in Table 4.2-1, the left hand column could include the list of aggregated risks from page I-ES-38.	Table reference changed to "Table I-4-1." See page I-41. ok No room and, I think, no real need.
M	I-ES 41 4	How dependent are the results on the weighting factors given in Table 5-1? Could some sensitivity study be done to determine this? If the results change significantly relative to each other with changes in these weighting factors, the results just reflect the weighting factors. Since the all the risks associated with treatments generally all increase relative to the baseline, the chance is that while the augmented risk reduction indices would change with a change in weighting functions, their relative values would remain about the same.	This is correct, but there is a sensitivity to the relative weights assigned to the components. The sensitivity is that assigned here to the decision maker's weights. ok

DOCUMENT REVIEW COMMENT BOARD

1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N I-ES 41 4		A problem with the method of aggregating risks is that it incorporates both voluntary and involuntary components in the same aggregated risk. The importance of this is that weighting factors for voluntary and involuntary risk components may vary considerably. For example the weighting factor for a truck driver hauling TRUPACT containers getting cancer could be considerably less than the weighting factor for the public getting cancer from transport of wastes because in the case of the driver the risk is voluntary while *it is involuntary for the public. Aggregating* both of these under the risk cancer masks the voluntary/involuntary nature of the risks.	Not aggregated across voluntary and involuntary risks. Thus no masking. See Attachment G. ok
M I-ES 42 1		The first sentence at the top of the page says that "absolute and relative weights are given in Table 5-1." There is only one weight given in Table 5.1 and it is labelled Normalized Weight.	Corrected. See page I-44. ok
E I-ES 43 1		Table 5-2 could be better portrayed in matrix form with alternative numbers and brief descriptions across the top and location options with brief descriptions along the left side (or vice versa). The mathematical symbols should be avoided if possible.	Done. See Figure I.5-1 on page I-47. ok

DOCUMENT REVIEW COMMENT BOARD

1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-ES 43 2		While a formal indifference analysis indicates that only 12 of the possible 120 combinations show confirmed indifference (inability to distinguish between two risk augmentation indices as being significantly different) an engineering view of the results would indicate that all of the values are essentially the same. A problem with the numerical aspects of the analysis is that input for things like uncertainties in risk reduction factors as well as the factors themselves are entered with one significant figure accuracy and results are produced to three significant figures. While this is done repeatedly today because of computers, an old professor once engraved it in our brains forever that you cannot have more significant figures in the output than you have in the input. If this is used, most of the values in Table 5-2 become 1 while maybe three could be 2 if the error is additive. While that professor has long since passed away, there is an issue here. How can precision be manufactured, and while the trends among the values generally agree with what would be expected, is the input sufficiently well defined to support a precise analysis? Or, could it equally be concluded that to the level of precision in the input, there is really no significant difference in risk among the various alternatives and location options? (All of the input was not checked to see with what precision it is known, but when it comes to the really global issues associated with a risk analysis it is doubtful that more than 1 significant figure accuracy is available.)	All error calculations are done correctly and there is no fabrication of false accuracy. Only one digit more than justified is carried throughout to avoid rounding problems. In the final results the error determines the number of significant digits of the result. See Section 2.4.6 on page 1-27. DL

DOCUMENT REVIEW COMMENT BOARD

1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N I-ES 46 1		In plotting the probability distributions, different line styles should be used (recognizing that there are a great number of lines) to distinguish between the different distributions. Particularly where the distributions are plotted as negative values Figure 5-1 gives the appearance that what is actually plotted are continuous functions that rise above and dip below the line at places. All ~~over calculations are done correctly and there is no fabrication of false accuracy. Only one digit more than justified is carried throughout to avoid rounding problems. In the final results the error determines the number of significant digits of the result. See Section 2.4.6~~.	Comments on Figure I-5-1 to avoid this misunderstanding. VL
M I-ES 47 1		In the first dot under the first paragraph, Level III should be Level II if the information on Table 5-3 has been interpreted correctly.	Corrected. See page 1-50. VL
ATTACHMENT B			
E I-B 1 1		Attachment B is so mathematical and essentially not tied to any specifics of the risk assessment, it seems that it should perhaps be pushed farther back in the document after those attachments that give models and data relative to the risk assessment. While providing the requisite background, Attachment B, is not necessary for readers concerned primarily with modeling and results.	The presentation is disaggregated enough. Attachment B is not background information; it is the crux of the whole method. VL
E I-B 2 4		Is Eq. B.2.3 correct? It is the same as B.2.2 and the range of subscripts is shown as from 1 to I while the text states 1 to J.	No, wrong copy of equation. Corrected. See page 1-65. VL

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1 a. Author/Editor: Mark Abashian/Fritz Seiler 2. a. Project Number: 301302.09.02.02
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3. Report Title: EATF Final Report of the Engineered Alternatives Task Force, Vol. II (Draft, Jan. 1991)
4. Approval for Report Issuance: Donald E Shaw Date: 7/24/91

5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
E I-B 11 2		In the text, a utility, capital theta k is mentioned, but it does not show up in Eq. B.3.11. While it can be deduced, it might be less confusing to define it.	It is U_k not Θ_{kj}. See page I-76. oh
M I-B- 12 3		Reference is made to Eq. B.5. There is no B.5 and it appears the reference should be B.2.5. Also later in the paragraph is a reference to Eq. B.7 which should be B.2.7. This problem occurs throughout Attachment B. Where found it is noted, but the equation references should be checked relative to the equation numbers.	(B.2.5) and (B.3.3) corrected. See page I-72. oh
M I-B 12 4		In the first sentence there is a reference to Appendix C.1, Aggregation of Risk Components. There is no Appendix C. There is an Attachment C and Section C.1, but C.1 deals with propagation of errors and the derivation of the algebraic form of Eq. B.3.13. Section C.2 appears to deal with aggregation, and the derivation appears to be given in Section C.2.1.1. This should be checked and corrected. Later in the same paragraph Eq. B.8 should be B.2.8.	Corrected. See page I-72. oh
M I-B 14 2		There is a reference to Appendix C.1 should probably be Attachment C.2.	Done. See page I-74. oh
E I-B 17 1		There is a typo. Eq. B.27 should be B.2.7.	oh Changed to B.4.2 which is the right equation number in the revised version. See page I-80.

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
ATTACHMENT C			
E I-C 2 3		Perhaps Eq. C.1.2 and C.1.3 could be switched, giving the more general form when the x quantitatives are not independent then specializing for the case where they are independent.	C.1.3 is more general but is an appendage here - more an afterthought. ok
N I-C 3 3		It could be mentioned that underlying probabilities of risk components are almost never know and that some assumed distribution is almost always used, and that the normal distribution is often approached with large samples.	The central limit theorem is not really the point here. It is not what we are doing here. ok
N I-C 4 6		It might be mentioned that Eq.C.1.13 is for the case where the stochastic parameters are independent.	Done. ok
N I-C 6 3		Table C.1-1 is referenced in this paragraph. It might be more instructive of a figure showing the variation of the contribution with the ratio B.	Both done. See page I-94. ok
ATTACHMENT D			
N I-D 3 1		It might be mentioned that using forklift accident data from similar industries is likely to be conservative because of improved safety procedures associated with waste handling and treatment facilities.	True at the beginning, but after a few years? Since forklift incidences are given as a rough estimate only (1% of occupational accidents). I did not consider it appropriate to introduce such a reduction factor. With better data, yes, I would. ok

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-D 3 3		Neglecting accidents in waste handling and treatment facilities is probably not a good idea simply because it amounts to neglecting a risk associated with the objective of the study which is to evaluate relative risks associated with treatment. Since specific forms of some treatments are not known and the form of the plants are not known, there is probably no basis for thinking that they would be any more or less prone to accidents than other processing plants. Could an approach similar to that for forklifts have been used in which accident data from chemical processing plants could be cited as to probabilities. Such a citation could provide additional justification for neglecting accidents in treatment facilities.	Specific radiation accidents are important for credibility but yield small risks due to H&S restrictions. Evaluating them is far beyond the scope of this study. ok
M I-D 3 5		The statement that "Such risks do not fall under the scope of evaluating overall changes in risks due to treatment of the wastes" relative to diesel exhaust is confusing. If treatment processes have greater needs for diesel powered transporters than the baseline condition, the risk should increase in proportion to the different amount of anticipated use. Thus the risk reduction factor would be less than 1 and could vary among the different treatment alternatives.	Nonsense due to a mixup of several garbled statements. See third paragraph of Section D.1.4 on pages I-101 and I-102. ok
M I-D 4 2		Why not consider the risks mentioned? Are they sufficiently small to be neglected? Or are they a washout that would enter all alternatives including the baseline to the same degree? Some justification should be provided relative to the expected effect on the results of neglecting events.	Not treated in FSEIS or FSAR. ok

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-D 10 3		Taking the systematic error equal to the random error was arbitrary. If nothing is known about systematic errors, it's probably as good an assumption as anything else. How sensitive are results to assumptions such as this? Was a similar approach used elsewhere relative to systematic errors? The reason of differences between the treatment facilities as a basis for systematic errors relative to increased manpower needs would also apply to other issues. This is an example of level of precision in input vs. level of precision in output.	Manpower is a very important quantity. Therefore, an effort was made here to include effects of a systematic error. Effort to do that everywhere is beyond time and money limits. ok
M I-D 12 2		The assumption that the population exposure around a treatment facility is the same as around WIPP probably biases the results toward WIPP or western treatment sites because it seems that larger populations would be expected at eastern treatment sites.	Resulting in permitting restrictions assumed to pull it down to similar values. ok
M I-D 18 3		In the last sentence of the last paragraph, a strain rate of 0.10 ± 0.03 is assumed for creating the perforation. Is there a reference for that value, it seems pretty specific, particularly the 0.03 error, for just an assumption. If there is no reference, how sensitive are the results to this assumption?	The sensitive quantity in equations (D.3.20) is y^2 not ε. Reference given. The sensitivity for ε is taken into account by the error propagation calculation. The errors should be large enough involving 0 and 0.2 at the 2% level. ok
E I-D 26 1		Line spacing changed from single to space and a half at this point.	ok
M I-D 26 1		In Eq.D.3.32, there is a one plus epsilon on the right side with epsilon defined as a small fraction. In Table D.3-7 the value given is 1 ± 0 or epsilon is 0. This should be checked as to which is correct. If epsilon is zero it should be stated after the definition of epsilon as to why it is zero.	$\varepsilon = 0$ due to model assumption. Inserted sentence to that effect. See page I-124. ok

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-D 26 2		The reference to Eq. 3.14 should probably be B.3.14. Also Eq. B.3.34 gives values of *1/0.4 while Table D.3.7 shows 1±0.3 for these values.*	Typing error; corrected. See page I-124. ok
M I-D 32 1		There is a typo in the last line of the first paragraph. "shortage" should be "storage".	Corrected. See page I-126. ok
ATTACHMENT E			
M I-E 1 3		The f sub "exp" in this paragraph should be f sub "dep".	Done. See page I-147. ok
M I-E 3 3		In the last paragraph it is argued that because of modular construction the same fraction of total personnel is assumed to be exposed. Since treatment facilities are essentially undefined from some treatments, is it reasonable to assume, modular construction or not, that the same fraction of personnel would be exposed?	Yes. The accident will happen in one module only, so the crew of that module only will be exposed. *Corresponding text change made.* See page I-150. ok
E I-E 4 3		Switching back and forth between occupational and public risks becomes confusing. Perhaps subsection headings could be used to distinguish between the two. This comment applies throughout Attachment E.	Too much potential for typos if a change is attempted. Besides, we follow FSEIS scenarios. ok
M I-E 11 2		It is stated that ratios are the same for occupational and public risks. This is confusing. If the exposure is underground, how is the public exposed? It would seem that the only risk component would be worker exposure in the underground environment.	They are. See equations (E.1.1) and (E.1.2) on page I-147. ok

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-E 18 4		The first sentence of this paragraph beginning with "As long as the last three ..." should be extended with "for each treatment" after the word "same" which is at the end of the sentence as written. Otherwise it reads as if the public and occupational risk reduction factors are the same which does not follow from the assumption that the factors are independent of treatment.	See resolution to preceding comment. ok
E I-E 73 1		There is something wrong with the last line of this paragraph.	Last sentence deleted. ok
M I-E 78 1		An explanation that treatment alternatives affect the number of truck miles travelled because of volume changes resulting from treatment as the basis for the expression in Eq. B.6.1 would be helpful. At first, it would appear that the risk of a traffic fatality would be independent of treatment because an accident would not be dependent on what the truck was hauling.	Done. See page 1-213. ok
M I-E 86 1		Does the term L sub "s", the distance between stops include stops at traffic signals?	No, L is a distance, stops affect time. ok
M I-E 89 1		It would seem that the exposure for vehicles travelling in the opposite direction would involve some time while the vehicle is in the proximity of the TRUPACT truck, and that the duration would depend on the speed of the vehicle, the speed of the TRUPACT truck, and an exposure distance. There does not seem to be a duration or speed of other vehicles in the list of parameters.	Given by RADTRAN scenarios to which we are tied. ok

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-E 90 1		In the last line of this paragraph should the reference be to Eq. E.6.4 or E.6.14?	It has been corrected to E.6.14. ok
M I-E 93 1		For vehicles travelling in the same direction the maximum exposure would occur during overtaking, passing, and leaving the truck behind with an envelope around the truck during which exposure would occur. The length of that envelope would seem to set the duration of the exposure. Assuming an envelope length of 100 feet and an incremental speed of the passing vehicle of 10 mph (14.7 fps) it would require about 6.8 seconds to overtake, pass, and leave the exposure zone. What is the basis for the 2 seconds given in the list of symbols?	Again, a RADTRAN scenario. ok
E I-E 106 3		Is there something missing before the start of the last paragraph? From the last line of the preceding paragraph it appears that an expression is missing.	Orphaned equation (WordPerfect 5.1 idiosyncrasy). This has been corrected. ok
E I-E 110 3		Just before the last line on the page, it appears that an equation is missing based on the last line of the previous paragraph ending in "given by."	Same as above. ok
M I-E 119 6		The assumption relative to public exposure from drill cuttings being essentially zero seems appropriate, but in earlier discussions in the Executive Summary it appeared that the two were considered to be the same.	The risk reduction factors are the same, the risks are minute. ok

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
ATTACHMENT F			
E I-F 1 1 4 1		Line spacing changed from space to space and a half.	Corrected.
M I-F 3 1		If understood correctly, the purpose of Section F.2.1 is to develop baseline risk coefficients so that risk reduction factors can be determined for the various treatments, and that this necessary because there are no associated baseline risks in the FEIS. If this is the case, an introductory paragraph to that effect at the start of Section F.2.1 would be helpful in understanding the remaining sections. The introduction should discuss how the industry wide data was applied to the estimate of treatment baseline risks.	No. The risk coefficients are developed in Section D.4.11. ok

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4. Approval for Report Issuance: Donald E Shaw Date: 7/24/91

5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
ATTACHMENT G			
M I-G 1 2		In the discussion of the risk components which were dropped in the aggregation process, the 45 components dealing with genetic damage, while smaller than the cancer risks, may be considered more important in terms of weighting to some evaluators. While the basis for dropping them is understood, it would be helpful if numeric comparisons of the genetic and cancer components were made in support of the decision to drop them. Concerning the six components dealing with non-cancer risks from chemical toxicants, their uncertainty would not seem to be a good basis for dropping them. If there is considerable uncertainty, their risks could be higher than anticipated. What would happen if they were included with large error coefficients. Would they remain very small?	Reference made to the BEIR III, IV and V reports. Sentence changed to convey relative sizes. See page I-307. ah

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-G 4 1		Eqs G.1.2 and G.1.3 highlight a problem relative to weights in aggregation of risks into supercomponents that was troublesome where it was discussed in Attachment C. Weighting by the relative contribution to the total risk does not treat perceptions of risk. While using the law of diminishing marginal utility in the sense that a small additional component of risk causes a small additional disutility, the issues of voluntary vs. involuntary risks is not considered. In the transportation supercomponent, the risk of traffic fatalities overwhelms the other risks of cancers caused by radiation exposure to the point that the latter two can be essentially dropped. However, traffic fatalities occur with or without hauling TRU nuclear waste and when a person gets in a car and goes out on the highway, he voluntarily assumes the risk of traffic fatalities that could result from truck accidents because of the perceived benefits of his travel. On the other hand, most drivers on the road would not voluntarily assume the risk of cancers due to radiation exposure. Thus, in this case the largest component is voluntary risk and the two small components are involuntary. Consequently, the small components may have far, far greater disutility than the largest component. By weighting traffic impact fatalities the heaviest, the effect is to say that the risk associated with the various alternatives is merely due to the presence of more trucks on the road and the same risk could be obtained if it were newsprint being transported in the same quantities over the same distances. This would seem to produce a totally different reaction in the publics acceptance of the risk compared to cancers caused by radiation which they did not know they were exposed to.	Perceptions of risk components dictate the grouping of aggregates. The actual weighting is done separately. Grouping here scrupulously separates voluntary and involuntary risks. OK
M I-G 6 1		The heavy weighting of risk components on impact injuries does not include consideration of voluntary vs. involuntary risks. See comment on transportation fatalities. This supercomponent also turns out to be simply a measure of the effect of more trucks on the road regardless of what they are carrying.	The scope includes <u>all</u> short-term risk components. New Section G.4 discusses the influences of transport general occupation and radiation exposure. See page I-357. OK.

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M I-G 8 1		What are the relative contributions of the two components? This supercomponent is an example of another problem with aggregating risks. Since the objective of the risk assessment is to provide information for decision- makers relative to determining optimum strategies for waste treatment if necessary because of problems with the existing design, there are other factors involved in the decision beyond risk, and the individual components may have an impact on decisions. For example if fork lift accidents far outweigh general industrial accidents, there may be a basis for the development of treatment alternatives that mitigate forklift problems such as different packaging and handling schemes. Understanding of risk components is important to that process.	I agree but that is a different use of risk analysis than the one discussed here. Agreed, but if there's more cook-done, this would provide useful information.
M I-G 31 1		The absolute weights shown in Table G.2-1 give 56% weight to transportation related risks which essentially are impact accidents that are independent of what the trucks are carrying. Considering the voluntary aspects of assuming risks of highway travel, this weighting seems far too high and essentially unrelated to radioactive aspects of the TRU waste disposal. It seem that a heavy weighting on non radioactive aspects waste treatments unfairly biases the results against treatment technologies.The point is that the same conclusion would be reached if the issue were questions of whether to manufacture shoes at a variety of facilities or at a central facility and that the shoe manufacturing process involved some degree of chemical carcinogenic and non-carcinogenic risk. Could the risk augmentation indices be recalculated using societal weighting factors which weight supercomponents 1 and 2 with a combined normalized weight of no more than 10 percent. Better yet could the weights for 1 and 2 be varied over a range with curves produced for the results.	56% is less than some nationally recognized experts propose. Again the new section G.4 discusses the different contribution. What is proposed in the comment is outside the scope of this study. See Section G.4. Again, this would provide of basis for additional work.

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1 a. Author/Editor: Mark Abashian/Fritz Seiler
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4. Approval for Report Issuance: H. B. Nuttall Date:

5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
E	Ex. Sum. Pg. XVII Para. 3	Second sentence beginning with some seems unnecessarily vague.	Sentence has been reworded. See page ES-i. (SC)
E	Ex. Sum. Pg. XXIII Para. 2	"This is caused by the assume coupling between anoxic corrosion and brine inflow." (Explain coupling)	A brief explanation has been provided. Also, this section has been reworded as per comments from Mr. Donald Shaw. (SC) An explanation of the coupling has been included in a detailed discussion of the processes and coupling in a revised Chapter 2. See page ES-viii and Section 2.1. (SMD)
E	Ex. Sum. Pg. XXIII Para. 4	"Improvements of one order of magnitude *in pressure*"	The improvements are one order of magnitude in the measure of relative effectiveness (MRE). See page ES-ix. (SMD)
E	Ex. Sum Pg. XXV Para. 2	Shorter work of periods--does this mean payoff times? Clarify!	A definition of "work-off" periods is provided in the latest revision of the report. See page ES-x. (SC)

NUTTALL & ASSOCIATES, INC.

1445 HONEYSUCKLE DRIVE, N.E. ☐ ALBUQUERQUE, NEW MEXICO 87122 ☐ 505/293-2250

5/16/91

Mr. Mark S. Abashian
IT Corporation
5301 Central Avenue, NE
Suite 700
Albquerque, NM 87108

Dear Mr. Abashian:

Enclosed are the signed comment resolution sheets. I appreciated the opportunity to review the EATF draft Final Report.

Regards,

H. E. Nuttall

H. E. Nuttall, PhD

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1. a. Author/Editor: Mark Abashian/Fritz Seiler
   b. Reviewer: Nuttall
   c. Date: 3/21/91

2. a. Project Number 301302.01.06.02
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4. Approval for Report Issuance: N. S. Nuttall Date:

5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
E	Ex. Sum Pg. XXV Para. 2	Last sentence seems unclear. "bottoms up" needs to be better defined.	Sentence has been reworded for better clarity. See page ES-x. (SC)
M	Chap. 3 Pg. 3-9 Table	Type! The units for hydraulic conductivity needs to be shifted to that column.	Comment already incorporated in latest revision of the report, page 3-7. (SC)
E	Chap. 3 Pg. 3-10 Para. 1	Add a glossary of acronyms.	Comment cannot be incorporated because a list of acronyms <u>already exists</u> in the report. It can be located immediately after the Table of Contents, and is also listed in the Table of Contents. See pages xii-xiii. (SC)
E	Chap. 3 Pg. 3-17 Para. 3	First sentence. Hydraulic conductivity is not considered in a glass. Change wording.	Sentence reworded, "It is important to note that fluid movement within certain materials such as glass, is due to diffusion or . . .". See page 3-17. (DV)

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M	Chap. 3 Pg. 3-17 Para. 3	Several questions about the hydraulic conductivities presented in this paragraph. Also concern about hydraulic conductivities in unsaturated flow.	Brine flow through the waste/backfill composite is assumed to be saturated. A more detailed discussion of brine flow and hydraulic conductivities is included in the revised Chapter 2.0 (Section 2.1). (SMD)
M	App. B.3 Pg. B-5 Para. B.3-1	Why assume that the brine flow stops when lithostatic rather than hydrostatic pressure is exceeded?	A discussion of the assumptions is provided in text along with some justification (page 2-8). (SMD)
E	App. B.4 Pg. B-8 Para. 3	Replace air gap with void space.	The term air gap has been replaced with the term clearance. See page B-13. (SMD)
M	App. B.6 Pg. B-11	Show and explain 1-D transient flow equation. I am not familiar with hydraulic diffusivity.	The 1-D transient flow equation is provided and the term hydraulic diffusivity is defined as the ratio of the hydraulic conductivity to the specific storage. See page B-16. (SMD)

WP EATF 1991 Nuttall

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4. Approval for Report Issuance: Date:

5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N	GEN	The chemical and physical processes at the proposed WIPP facility are exceedingly complex and involve many coupled interactions. The approach used in this report seems both practical and logical given the nature of the problem. The fact that the models have not been validated is an important consideration and should be of high priority for future work. I have some concerns about the aspects of two phase flow during gas generation with brine intrusion and if the repository can truly maintain pressures well in excess of lithostatic. In summary, given the complexity of the problem and the degree of required assumptions, this study is a reasonable approach and produced interesting results.	

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1 a. Author/Editor: Mark Abashian/Fritz Seiler
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2. a. Project Number: 301302.01.06.02
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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
E	Ch. 1 Pg. 4 Para. 2	The sentence "All of the types of waste are in a chemically stable.....". Add the reference that documents that this is the case. (Brookins)	The appropriate reference, NuPac (1989), has been added. See page 1-6. (SC)
E	Ch. 1 Pg. 6 Para. 2	Add reference at end of paragraph. (Brookins)	Comment has already been incorporated into Revision 1 of the document. See page 1-8. (SC)
M	Ch. 1 Pg. 7 Para. 4	Last sentence on page... provide detail showing that processes that can dissipate gas pressures are "slow". This is important, for if these processes are rapid, then a built-in depressurization mechanism exists. (Brookins)	The sentence has been reworded to read, "As shown later in Section 4.0, these processes are slow relative to the . . .". See pages 1-9 to 1-10. (SC)
N	Ch. 2 Pg. 1 Bullet 4	Give predicted range of brine inflow here. (Brookins)	No absolute range has been established. (SMD)
M	Ch. 2 Pg. 4 Eqtn. 2.3-1	I am not convinced that this is the critical reaction involved. (Brookins)	Other reactions will be provided in the final version of the report. (SMD)

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N	Ch. 2 Pg. 7 Para. 3, second bullet	Give range of Salado Formation permeabilities as well as average. (Brookins)	Text modified to reflect range of $1 \times 10^{-22} m^2$ to $1 \times 10^{-16} m^2$ with an expected permeability of 3.4×10^{-21} (Rechard, et al., PA-9, 1990). See page 2-9. (SMD)
M	Ch. 2 Pg. 8 Para. 1, first sentence on page	This needs a reference; some data (i.e. argon) argues for advection of gas by the Salado. (Brookins)	The threshold pressure is so large that advection into the Salado Formation may be ruled out for any gas. See Section 2.1. (SMD)
M	Ch. 3 Pg. 1 Para. 5, last sentence on page	This is a very confusing sentence: "..solubility...investigated...lack of...data." If investigated, aren't there limits on data that can be used? (Brookins)	Sentence reworded as, "Investigations in radionuclide solubility (Rai et al., 1983; Felmy et al., 1989; Marietta et al., 1989) have shown variabilities of six orders of magnitude. The EATF has therefore assumed a value of 1×10^{-6} molar for all radionuclide solubilities (Marietta et al., 1989)." See page 3-1. (DV)

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N	Ch. 3 Pg. 2 Para. 5 RE...bentonite	Add reference for this section. (Brookins)	Reference is (Butcher, 1990b). See page 1-12. (DV)
M	Ch. 3 Pg. 3 note 4	Assumption needs justification (i.e., 50% void filling). (Brookins)	The following has been added to footnote (4), "This assumption results from uncertainties in backfill emplacement methodology and the use of slip-sheets between layers of drums." See Table 3-1, page 3-3. (DV)
M	Ch. 3 Pg. 10 Para. 2	Assumption of contaminated liquid stabilized by cementation needs verification. (Brookins)	Sentence changed to read, "The contaminated liquid is concentrated and then solidified by cementation (Allen et al., 1982." See page 3-8. (DV)
N	Ch. 4 Pg. 1 Para. 2 (last sentence of page)	This assumption is contradictory to earlier assumptions (RE gas generation, C 2). (Brookins)	This sentence has been deleted. (SMD)

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M	Ch. 4 Pg. 2 Para. 2 through pg. 4 para. 5	This entire discussion of fracturing is weak and needs to be strengthened. The reader is left in the dark. Data from fracture distributions, etc., during mining and other operations should be available. (Brookins)	The prediction of fracturing and subsequent propagation is a complex issue which is being investigated by SNL (DOE/WIPP 89-011 WIPP Test Phase Plan: Performance Assessment Document). This has been stated in the text. See page 4-2. (SMD)
N	Ch. 4 Pg. 3 Para. 3 last sentence	*What is justification for using maximum H_2 generation rate?* (Brookins)	A maximum H_2 generation rate based on a SNL number is assumed if sufficient brine is available to maintain this generation rate; otherwise the reaction rate is scaled down in the *Design Analysis Model*. (SMD)

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N	Ch. 4 Pg. 7 Para. 5 last sentence	"...pressurizing smaller void volume...". Is advection by backfill and other surroundings in this assumption? Not clear. (Brookins)	The void volume within the waste/backfill composite is assumed to be available for gases to occupy. This void volume will be less for the case of a vented repository than for the baseline case since venting will permit higher creep closure and subsequent reduction in this void space, since the fluid pressure does not build up during the first 100 years. Text has been revised accordingly. See page 4-8. (SMD)
N	Ch. 4 Pg. 11 Para. 5	Have the anhydrite beds been tested for gas behavior (i.e., argon, radon, etc.)? This would be useful information. (Brookins)	No gas behavior test data is currently available, but testing is underway. (SMD)
N	Ch. 6 Pg. 8 Para. 6 last sentence	I think there are studies on behavior of cementiferous materials in evaporite environments... references? (Brookins)	We are looking for references, though the statement in the text is a result of the Cement Panel. (DV)

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M	Ch. 6 Pg. 9 Para. 1 entire pp.	Potential for increasing handler/operator exposure is increased in shredding; this should be mentioned. (Brookins)	This is mentioned in Section 6.3.7, "All components of the overall risk that involve the actual treatment of the wastes lead to additional injuries and fatalities." (DV)
M	Ch. 6 Pg. 27 Para. 4 entire pp.	A statement on the relative risk of the various scenarios with those from other types of waste treatment would be appropriate here. (Brookins)	Outside the scope of this work. (SC)
N	Ch. 6 Pg. 29 Para. 2 entire pp.	Compare to non-TRU waste shipments would be helpful here. (Brookins)	Outside the scope of this work. (SC)
N.	Ch. 6 Pg. 37 Para. 1 last sentence	What is basis for EID interpretation of RCRA? Factual information (if so, should be documented) or guesswork? (Brookins)	The reference for this information is Paul Drez of IT Corporation. (DV)
N	Ch. 7 Pg. 4 Para. 2,3 entire pps.	I suggest cartoon-like figures to illustrate the text for these paragraphs. (Brookins)	Comment noted; we will try to find appropriate renderings of the processes. (DV)

WP:EATF.1991:Com-Brookins

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N	Ch. 8 Pg. 1 Para. 4 general	If gas-sorbing backfill is used, gas pressure might not build up f(v). (Brookins)	Comment noted, though gas sorbing backfill is a separate alternative. The paragraph is limited to minimization of space around the waste. (DV)
M	Ch. 8 Pg. 3 Para. 1 general	Yes, elimination of Fe containers greatly reduces the already small amounts of gas that might be generated, yet this would involve additional handling and exposure and extreme cost. Not a well thought through alternative. (Brookins)	Disagree. Relative to the cost of not opening WIPP or other waste treatment alternatives, container cost is cheap. Addition exposures will result as with any other treatment alternative. (DV)
M	Ch. 10 entire chapter (references)	References are incomplete in many cases and inappropriate. All personal communications should be so listed in the text and not included in the references. All legitimate references must have exact title, exact pagination, exact and complete location materials, etc. (Brookins)	The format followed in the report for personal communication references is the standard IT format. Efforts are underway to make references as complete as possible. (SC)
N	Ch. B Pg. 29 Para. 5 (B.13)	I suggest some commentary on other reactions that may be likely that could depressurize the system. (Brookins)	Other reactions that may be likely will be included in the final version of the report. (SMD)

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
M	Ch. B Pg. 50 Para. 3(?) last sentence on p.	Why is instantaneous dissolution of radionuclides in brine assumed? This needs verification and precise referencing, or a good explanation. (Brookins)	Leachability of the waste forms is difficult to quantify at this time. SNL has not yet attempted to do this for PA and are assuming an infinite leach rate, i.e., instantaneous dissolution (Rechard et al., 1990, p III-19). (SMD)
M	Ch. D Pg. 1,5 Assumptions	These assumptions need precise documentation! Of the assumptions listed, I agree with the last one (*...far-field pressure...remains constant*) but not necessarily with the others. (Brookins)	A more detailed discussion of the assumptions will be provided in the final version of the report. (SMD)
N	Ch. E Pg. 1 Reactions E-1,2,3	The pH of many attacked cements is above 10, hence CO_3, not HCO_3 may be the product. Reaction of the calciferous materials with other materials present (i.e., bentonite) should also be considered. (Brookins)	While other reactions and products can be produced, there is insufficient data to justify those reactions. The effect of portlandite reactions on peak index pressures is a negligible phenomena. The use of bentonite was not considered in the alternatives. (SMD)
M	Ch. F Pg. 4 bullet three; assumptions	I do not agree that assumptions have been adequately described... and justified. (Brookins)	A more detailed discussion of assumptions and their justification will be provided in the final version of the report. (SMD)

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N	Ch. G Pg. 3 Para. 4 (Microbial activity)	I recommend some discussion of the role of H_2S earlier in the report; i.e., either refute its importance/role early on or include proper discussion of it. (Brookins)	A brief note about the role of H_2S has been added in the revised Chapter 2. See page 2-3. (SC)
N	Ch. G Pg. 7 Para. 2 generic comment	Salt stored at the surface at WIPP has a recrystallized salt armor on it; would it be possible to re-create this kind of armor on the outer part of salt used as backfill? (Brookins)	Recrystallized salt armor requires the addition of water to the backfill. Addition of water underground is not advised. (MSA)
N	Ch. 1-D Pg. 2 Para. 3 (all)	Give reference for justification of sludge proportion. (Brookins)	Given, Vetter, 1990 (page 1-100). (FS)
N	Ch. 1-D Pg. 3 Para. 5 (generic comment)	It would be useful to provide an estimate of the non-radiological health effects. (Brookins)	Too complex to explain here. (FS)

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N	Ch. 1-D Pg. 5 Para. 5 (RE: chemical wastes...)	Some VOCs may be partially encapsulated in solids and released only when shredded, thus the assumption made here may not be totally valid. (Brookins)	Added sentence in D.2.2.3, page I-103. (FS)
E	Ch. 1-D Pg. 18 Para. 4	Provide date for Bennet et al. (Brookins)	Done. See page I-116. (FS)
M	Ch. 1-E Pg. 2 Para. 5 Re comment on linear hypothesis	Many studies (i.e., NAS-NRC) argue convincingly that a quadratic, not linear, relationship holds for dose-health effect for radiation. Further, threshold must be considered. Further, hormesis must be considered. These possibilities, even if blatantly ignored for the purposes of this document, must be mentioned to the reader. (Brookins)	Only BEIR III, IV and V used by FSEIS and this study. (FS)
N	Ch. 1-E Pg. 14 Para. 2 ...density... self adsorption...	A reference to document the assumptions made here is needed. (Brookins)	Done by explanation. See page I-158. (FS)
E	Ch. 1-E Pg. 82 Para. 1	Provide reference where indicated. (Brookins)	Done. (FS)

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N	Ch. 1-E Pg. 107 Para. 2 -- early effect... radiation...	I am hard pressed to believe TRU wastes could be released in point-source quantities to cause radiation sickness! (Brookins)	So am I! Yet the neutrons and gammas could - just barely. (6.4.2.1, first paragraph). See page I-241. (FS)
M	Ch. 1-E Pg. 108 Para. 1 ...cancer...etc.	Even if the linear hypothesis is used, then in all fairness, a relative risk chart showing the same calculation for workers, others exposed to radiation from coal (mining, processing, transport, disposal) and from earth excavation operations where Th, U are above background is needed so that the reader of this document can put the TRU releases into proper perspective. (Brookins)	Absolute risks are for the FSEIS to discuss. Our scope is more narrow. (FS)
M	Ch. 1-E Pg. 119 Para. 2 ...wind erosion...	Comparative figures for fly ash, cement wastes, uranium mill tailings, other mine wastes, coal piles and coal wastes are, again, needed to accurately inform the reader of the relative TRU risks involved. (Brookins)	Same as above. (FS)
E,M	Ch. 1-F Pg. 8	Section on discussion of Table F.2-2 is missing (Brookins)	Inserted. See page I-281. (FS)

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N	GEN	The mathematical treatment seems rigorous and complete. The numerous assumptions made throughout, however, may range from those that are strong to those that are weak. It is not always clear, even with discussion of errors, how the weighing of all parameters is carried out and, further, if the conservative approach used throughout is necessary.	It is not! See discussion in Section 5.2.3, page I-49. (FS)
N	GEN	This document is, I think, intended to address high- to low-probability types of scenarios or incidents in which public health and environment can be impacted by TRU handling, transport and disposal. For the most part this objective is reached.	Comment appreciated.
N	GEN	However, in order to put this document and its appendices into proper perspective, it is necessary to provide a ranking of relative risk for similar types of operations more familiar to the lay public. For example: risk of TRU transported wastes vs. transport of coal, chemical wastes, gasoline-other flammables, etc.; release radiation to the environment (on site workers to away from site) from coal processing, burning, disposal of wastes; cement production; comparison of TRU payload to arsenic, selenium, cadmium, lead, mercury from numerous operations (all with higher interaction potential to the public) such as coal, earth excavation, mining, processing, and so on.	Outside the scope. (FS)
N	GEN	Further, would the scenarios presented in this report result in greater or less risk if applied to handling of chemicals? of coal? of petroliferous materials? of non-U mine wastes? and so on. In order for the public to get a true feel for the relative risk of TRU disposal at WIPP, a few of these scenarios should be run through for comparative purposes.	Would be fun, but outside scope. (FS)

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N	GEN	No discussion is provided on background radiation and studies of areas of high (i.e., Minas Gerais, Brazil, Kerala, India) or normal-slightly elevated background radiation (i.e. China) areas. A comparison of worst case release of TRU radiation to increase in total US background radiation due to coal transport-process-burning and commentary on normal US background radiation fluctuations is highly recommended. Comparison with indoor radon risk is necessary, also.	Same as above. (FS)
N	GEN	Even though the calculated probabilities for many of the scenarios are low, the text does not always emphasize this fact; hence the reader may be falsely concerned about low-probability incidents.	I tried to address that in many places. (FS)
N	GEN	Some in-depth discussion of applicability of the linear hypothesis to radiation releases is a must. Without such a discussion, the report is severely weakened.	As far as needed, see Section 2.4.5, page I-27. (FS)

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N	GEN	The various sections on gas generation and behavior could be stronger; i.e., possibly discussed in greater detail or more fully referenced, etc.	A more detailed discussion of gas generation and coupling with other processes has been included in a revised Chapter 2.0, Section 2.1. (SMD)

WP:EATF 1991:Com-Brookins

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2000 Center Street, Suite 418, Berkeley, California 94704 (415) 644-2700 FAX (415) 644-1117

20 June 1991

TO: Mark S. Abashian
International Technology Corporation

FROM: Robert J. Budnitz
President

SUBJECT: Review Comments on Appendix I of Report DOE/WIPP 91 - 007

A few days ago I received "comment resolution" responses intended to respond to my comments to IT on the referenced report. My comments had been provided in letters to Fritz Seiler of IT dated March 8 and March 22, 1991.

I have studied the information you sent, and I have no problem with any of it. I have signed the relevant sheets on each page, and am pleased to return them to you.

I continue to believe that one key criticism of mine holds. However, I suppose that on this matter Fritz Seiler and I will continue to "agree to disagree". This issue is fundamental to the whole study, and revolves around my conclusion that the use of risk reduction factors (RRFs) as the key figure of merit for the study, and especially the use of aggregations of RRFs, is not a sensible way to carry out the analysis nor to present the study results. Fritz disagrees. Oh, well.

Thank you very much for the opportunity to have participated in this effort, If there are any further questions, please don't hesitate to contact me.

Robert J. Budnitz, President

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N GEN		Technical Risk-Analysis Work: The complex technical risk-analysis work, aimed at determining risk-reduction factors for the many different risk endpoints and for 16 different alternative scenarios, is of high quality and deserves commendation. The technical information buried in the back of the Attachments to this report can provide an excellent basis for decision-makers to understand the various risk issues, and to make decisions about them. The choice of alternative scenarios, the assumptions made to limit the scope of the analysis, the risk endpoints identified, and the analysis methods used are all fully acceptable to me. I am particularly pleased with how the analysis of the specific risk endpoints was accomplished in a way that focused on the key issues relevant to the alternative scenarios. This part of the report can be a goldmine for further study by experts, as well as of use to decision-makers if presented properly.	Comment appreciated.
		Some vital information is unfortunately missing--specifically, the base-case absolute numerical risk numbers are missing for some of the risk endpoints, because they were not otherwise available and were not developed specifically for this analysis. As I will discuss below, I believe that this missing information is essential to enable decision-makers to make sense of the overall results and then to make sensible decisions based on the analysis.	See later comments.

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N GEN		A Single Figure-of-Merit Useful for Decision-Makers: Although the admire the attempt to come up with a single figure-of-merit, useful to decision-makers, by which to judge the overall benefit/disbenefit of each of the various scenarios being studied, in my view the effort has not succeeded. The methodology does use established decision-theory methods to identify and calculate such a single figure-of-merit, and seems to break some new ground, but in my opinion the single figure-of-merit identified is not sufficiently useful to decision-makers to justify the continuation of work along these lines. In fact, I believe that the use of a single figure-of-merit obscures rather than illuminates the situation. Decision-makers are in my opinion fully capable of dealing with multiple attributes presented separately, and of weighing them their own ways for decision-making purposes--this goes on every day in the upper-management board rooms of large enterprises and agencies. But to make these judgments, decision-makers need the best available disaggregated information about the issues at hand, in this case the best absolute numbers and uncertainties about the specific risk endpoints. I don't believe that high-level decision-makers generally use aggregated information very much or very well, and I certainly don't believe that the aggregated information based on the single figure-of-merit developed in this report will be of much use.	In our direct discussions we agreed to disagree. While I grant the use of disaggregated information by many decision makers in finance and industry, I maintain that you need a procedure such as the one proposed here if you must document and defend your decision before your superiors or in an adversarial procedure in court. In that situation, a "gut-feeling" evaluation process will not do. While a decision maker may arrive at a decision in this way, he may then use his insights in a quantified procedure such as the one suggested here. This is a major difference between private industry and the Department of Energy.

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N GEN		Risk Reduction Factors and Their Aggregation: In my view, the approach of identifying and working with risk-reduction factors (RRFs) is a very useful intermediate step toward what is actually needed. Indeed, calculating RRFs is often simpler than calculating absolute magnitudes of risks, for reasons cited well in the report. However, I believe that for decision-makers these RRFs cannot adequately substitute for knowing the actual magnitudes of the risks involved as well as the RRFs, except in special cases, such as when almost no changes occur (RRF near unity) or when the absolute risk magnitudes are minuscule small for both the base-case scenario and the alternative scenarios. I also do not believe that there is any sensible way for decision-makers to use an aggregated figure-of-merit developed by combining various different risk-reduction factors. Since RRFs are one step removed from the actual risks themselves, the aggregation of RRFs further obscures rather than illuminates the information, no matter which aggregation method is used. While I am especially bothered by the logic supporting aggregation by geometrical averaging--that is, averaging the logarithms--I don't think that any method of RRF aggregation can be helpful to decision-makers without the underlying information about the absolute risk magnitudes.	I agree with the basic observations. The baseline risk is important for any evaluation. However, an appropriate aggregation process does not obscure the issues; in fact, the weighted geometric average used here will result in meaningful supercomponents, if the aggregation extends over an appropriate set of risk reduction factors.

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
N GEN		My Recommendation: I recommend that this project's effort be redirected toward the objective of developing absolute risk information for each of the many risk endpoints being studied (for the base case as well as the 16 alternative scenarios). Most of this information is already contained in the report, so developing the missing information does not seem very difficult, and especially because for some of the missing risk endpoints a bounding estimate can be used to establish that the risk is tiny, and can be dismissed. Since all of the RRFs have already been developed, the absolute risk information can then be put together with the RRFs (multiplied) to provide a tabulation of all of the different risk endpoints for the base case and each alternative scenario. This should be the project's final product. I believe that it can be easily accomplished, and will in my opinion satisfy the needs of decision-makers about as well as is currently feasible using today's state-of-the-art in risk assessment. Without this absolute risk information, I do not believe that decision-makers can make effective decisions. Certain of the many risk endpoints can be combined when they are fully commensurate--that is, when they are measured in the same units and decision-makers can otherwise easily figure out what the combined numerical values mean, and why. As an example, it may be helpful to decision-makers to add all near-term occupations deaths from all causes into a single aggregate figure. This will be relatively easy to do once earlier objectives are completed. To summarize my perspective: As I see it, besides (i) the very nice risk-analysis work itself, the project has to date emphasized as its endpoint objectives the following two "products": (ii) developing RRFs and (iii) developing a single figure-of-merit as its approach to assist decision-makers.	Absolute risks for the alternatives are beyond the scope of this study, and are not one of the project deliverables.. As for the rest, see earlier responses to comments on pages 2 and 3.

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		In my view, each of these two latter objectives is incorrect. There are thus two fundamental *differences between what I would like to see and what has been accomplished so far in this project.* They are:	See responses on page 4.
		• I do not believe that risk-reduction factors are, by themselves, useful pieces of information for risk decision-making, absent the underlying numerical values of the risks themselves. Thus my emphasis would be different--I'd emphasize absolute risks, not RRFs.	
		• I do not believe that it is feasible to "combine" different incommensurable risks into a single figure-of-merit in a way that helps decision-makers. In my view, decision-makers require knowledge in disaggregated form about each of the many different risk attributes. Thus in my view efforts at combining them into a single figure-of-merit are intrinsically a waste of effort because rational decision-makers will always want the disaggregation. Again, my emphasis would be different--I'd develop a tabulation, including estimated uncertainties, and I'd be sure to annotate it thoroughly.	
		Given the two points, it follows that I also do not *believe at all in the usefulness of approaches that* combined RRFs.* [*As a subsidiary but key point, I also cannot conceive of <u>any</u> weighting method for RRFs that would be useful to decision-makers except one that weighs by the sizes of the underlying absolute risks.] To me, combining them, absent the underlying absolute risk numbers, produces a second layer of opacity that further obscures progress toward what should be the overall objective (giving useful information to decision-makers.)	

DOCUMENT REVIEW COMMENT BOARD

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c. Date: 3/08/91 b. Page 6 of 11

3. Report Title: EATF Final Report of the Engineered Alternatives Task Force (Draft, Jan. 1991)

4. Approval for Report Issuance: Date:

5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
	Page I-ES-1 First Para.	The text says that the purpose of the study is "to evaluate numerically the balance between the changes in the short-term risk components and compare them to the expected improvement in the long-term risks." I concur in this broad objective. I question whether the approach of using a single figure-of-merit can best meet this objective. Since the short-term and long-term risk components are not commensurable (and not solely because of the discount-rate issue!), I believe that the only reasonable approach is developing a tabulation for a decision-maker to ponder.	See earlier response to comment on "single figure of merit" on page 2.
	Page I-ES-1 Second Para.	The 4X4 matrix of four site combinations and four treatment options is in my view a fully acceptable approach to this study. It is rich enough to provide meaningful insights but not so complex as to overwhelm the decision-maker.	Now put in executive summary. See pages I-ii and I-iii.
	Page I-ES-2 Last Sentence on Page	I don't agree that the "general result" is "insensitive even to the largest source of bias, the decision maker." How can this be so? Furthermore, it isn't necessary, or even desirable, that it be so! Quite the opposite--I'd like the decision-maker to weigh the multiple attributes in his head. In any event, the case is not made anywhere that I saw in the text to support this statement as written.	In direct discussion we agreed to that statement if it pertains to the narrow grouping of Level II treatments and the spread of level III treatments.
	Page I-ES-3 Second Para.	The text tells us that scaling the risk components "to the level of activity required by the different treatment options" was "one of the primary challenges." I don't understand this comment. This seems on its face to be not nearly as difficult as many other aspects of the analysis, not the least of which is doing the risk analyses of the various components themselves.	Toned down to "primary tasks". See page I-1.

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
	Page I-ES-3 (Third Para) through I-ES-6 (at top)	The text here presents a very nice summary of the range of issues covered in the risk analyses themselves.	--
	Page I-ES-7 First full para.	The text says that the "risk comparison" . . . is based on the evaluation of the complete mathematical expression for the risk and a study of the treatment dependence of each parameter." This isn't correct as written. In any event it isn't necessary to develop such a "complete mathematical expression" to carry out the objective of this project. The results and insights don't require such, nor is it in fact achievable.	In order to avoid such an exact reading, the sentence has been reworded using "approximating the risk." See page I-4.
	Page I-ES-7 Sec. 2.2.2.1	The assumptions here are fully acceptable, and even though they introduce biases the biases shouldn't be debilitating if explained clearly to decision-makers.	--
	Page I-ES-8 (Sec. 2.2.1.2) and Table 2.1	The table is confusing, and doesn't track one-to-one with the text. I had a difficult time, at first, figuring out what was what, and finally did not only by going back to the main text.	Erroneous insertion of an old table corrected. See Table I-2-1 on page I-7.

RA:Budnitz.Comm

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
	Page I-ES-18 Sec. 2.3	The scenario descriptions are very helpful as introductions to the main analysis. The accident scenarios (Sec. 2.3.2) are especially nicely written, and at the right level of detail for an executive summary. However, I'd suggest that it would be helpful to add, for each scenario, exact descriptions of the one or more risk endpoints that will be calculated. If placed either in the text or in tabular form, such descriptions could help guide the reader to just what is actually to be analyzed in the body of the report.	Will be done in final draft in July which will include a table of all components, end points, etc. (new Attachment A).
	Page I-ES-24 Sec. 2.3.5	The discussion of the human-intrusion scenarios is too abbreviated in my view. If I were not already intimately familiar with the scenarios from other work for Sandia/WIPP, I would not have been able to follow them well enough. These need some further explanations, for example to describe what risk endpoints are to be analyzed, and why, and how. The reader ought to be introduced, for example, to the issue of driller doses vs. homeowner doses at the 5,000-year time horizon, and the issues of direct consumption vs. airborne pathways vs. ingestion pathways. this is the place to discuss those ideas, to give the decision-makers an overview of the issues.	Descriptions are expanded. See pages I-22 and I-23.
	Page I-ES-27 over to I-ES-28	The assumptions all seem OK to me, except for one: what does it mean that "somatic effects of radiation are not evaluated"? I believe that cancer is a somatic effect, and that the term "somatic effects" is usually used mainly to distinguish them from genetic and/or teratogenic effects.	Corrected to "somatic effects other than cancer". See page I-25.
	Page I-ES-29 Sec. 3.1.1	This is a nice description of risk in terms of scenarios, consequences, and probabilities.	--

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
	Page I-ES-29 over to Page 30 (top)	The last sentence on p. 29 says that "For any multi-component risk, this means that a formulation must be found to reduce the multitude of component values to one characteristic measure which can then be compared to two alternatives." I strongly disagree with this sentence. By analogy, can there ever be one single measure of a baseball shortstop's effectiveness? Don't hitting, fielding, running, teamwork, and so on, all need to be evaluated? And don't different situations? Why pretend that they can be lumped into "one characteristic"?	See earlier response to comment on "single figure of merit" on page 2. Added a paragraph on evaluations based on more detailed information. See pages 1-28 and 1-29.
	Page I-ES-30 Sec. 3.1.3 First Para.	There are a number of advantages to using risk-reduction factors, and they are cited well here. However, this does not lead logically to the conclusion in Section 3.1.4 (see next comment).	See next statement.
	Page I-ES-31 Sec. 3.1.4 Second Para.	The text tells us that "aggregation is best done at the level of risk reduction factors." I strongly disagree, for reasons cited above. I also believe that the text doesn't support this conclusion, either here or in the backup material in Attachments B and C. The text goes on to tell us, concerning the problem of large RRFs on small risks dominating the arithmetic, that "weighted averaging of the components will avoid that problem." Furthermore, an "unweighted geometric average is usually preferable." This is wrong in my view. I have already stated why I think that any weighting scheme not tied directly to the underlying absolute risk values cannot be correct. But I'm all the more mystified by the geometric-average approach. Elegant mathematics aside, how can it be correct as a matter of common sense? If a very large RRF applied to a minuscule risk really makes no difference to a decision-maker, then it is best ignored, not geometrically averaged! The only way to "ignore" it is to consider the absolute size of the risk, thereby observing how small it actually is. No other way can or will work.	The appropriate weighting scheme is discussed in more detail now, particularly in Attachment G to illustrate that the principles of the report and those here are in agreement and are adhered to as far as possible. See Attachment G.

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
	Page I-ES-32 Sec. 3.2.2	The elegance and rigor of using multi-attribute utility functions cannot substitute for the observation that they are not useful to decision-makers, in my view. Therefore, although they are attractive to me theoretically, I recommend that they be abandoned, "unique interpretation" (Page I-ES-32, last paragraph) or not.	See earlier statement.
	Page I-ES-33 Sec. 3.3	This section on ranking, and the backup material in the body of the text, are interesting but not very useful. I don't think anybody needs lessons on how to decide whether or when the ordinal ranking of things is "indifferent." People intrinsically do this sort of thing every day, and mathematical rigor is not very helpful to them.	This study was in luck insofar as the errors do not overlap too much, so that these criteria are not needed except in a few cases.
	Page I-ES-33 Sec. 4 on Scaling	Much of the text here was very useful, but the discussion on "scaling" in the first two paragraphs seems trivial to me, although I suppose that it needs to be said.	--
	Page I-ES-38 Sec. 4.3.2	The discussion of "supercomponents" is very useful, although the logic of dealing with RRF averages is wrong in my view, as stated earlier. Some nice insights can found in this section!	--
	Page I-ES-41 Sec. 5.1.1	The text on societal weighting bothers me. I cannot find any justification for the relative weights of 10, 7, 5, and 4 chosen for the first four risk supercomponents--nor can I find justification here or elsewhere for the weights of 1, 0.3, 0.1, and 0.2 for the last four. In my opinion, this is precisely where decision-makers need to intervene before, not after, the analysis is completed and the details obscured by the weighting process.	The decision maker does come in, right here. More text has been added here and in Section G to stress this point. See pages I-43 to I-45.

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5.a M,N,E	b. Where Located	c. Comments/Corrections	d. Disposition
	Page I-ES-44, Figure 5-1.	The figure is marvelous as a means of displaying information, including the uncertainties! Unfortunately, the information displayed is flawed in my view for reasons cited elsewhere. Congratulations on this figure!	--
	Page I-ES-46 Sec. 5.2.2	This section is very useful, although because of the way that the aggregation of RRFs was done, I cannot know whether this information is actually robust based on the underlying analysis.	Added a section on biases. See pages I-49 and I-50.
	Page I-ES-47 Sec. 5.2.3	This section, like 5.2.2, puzzles me. In the third paragraph, the text says that "The unavoidable use of unweighted aggregation introduces biases of unknown amounts and signs. It is believed that, by the choice of supercomponents and the use of the geometrical averages, their influence is kept as small as possible." I do not believe this.	As we discussed, this is based on the low risks of all accidents combined.

RESOLUTION TO COMMENTS ON ATTACHMENTS D, E, AND F

Page 1, Section entitled "Introduction"

No resolution deemed necessary.

Page 1 and 2, Section entitled "Conservatism versus Realism"

We acknowledge that, at times, the analysis is extremely conservative and does approach worst-case scenarios which are unlikely to happen in reality. However, from our experience thus far in the area of transuranic (TRU) waste (especially in our dealings with various regulatory agencies), we find that more often than not a worst-case scenario is required or recommended by these agencies. As an example, although the estimated time of transporting TRU waste from the sites to WIPP is about 3 to 5 days, the Nuclear Regulatory Commission (NRC) requires that many of the calculations (e.g., decay heat limits for each waste category) are based on an extremely conservative shipping duration of 60 days. Thus, our experience tells us that it is preferable to err on the side of being overly conservative rather than being realistic.

Page 2, Section entitled "Simplicity"

No resolution deemed necessary.

Page 3, Section entitled "Applicability"

We agree with the reviewer that, by necessity, the models were often a bit too crude, as is the case of the C10 accident. Also, the assumptions are frequently too pessimistic. We are, however, bound here by the assumptions of the FSEIS, which are part of the baseline risk. In some cases, altogether too pessimistic assumptions can be canceled by an appropriate scaling model. Unfortunately, the "no respirators are donned . . ." assumption, for which the absolute risks are calculated in the FSEIS, is not of that type. A comment on biases introduced into a risk comparison by the practice of calculating "worst case" risks and a place for using "best estimate" risks can be found in Section 5.2.3.

Overall, we agree with the reviewer that some of the modeling assumptions are "crude and probably pessimistic." The underlying bases behind some of these assumptions are explained above. Also, as pointed out by the reviewer, the applicability of the models seems adequate for the job at hand, given the complexity of the issues and the time constraints involved in the project.

Page 4, Section entitled "Linearity"

It is true that the assumption of linearity may not always be valid for every situation imaginable. However, as the reviewer himself points out, such issues are not generally expected to

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"invalidate" the analyses, given the approximate nature of these analyses. We believe that under the constraints involved, a deviation from the linearity assumption would have complicated the analyses beyond the scope of the project.

Page 4, Section entitled "Broad Comments on the Data Used in RRF Analysis"

We agree with the reviewer that it is important for the decision makers to know that "those insights dependent on detailed numerical values are probably less useful than those in which the specific numbers don't matter much." The limitations of the risk analyses presented in Appendix I, and recommendations to decision makers about its applicability, are explained in Section 9.2 of the revised version of the report. Please see highlighted text on pages 9-7 and 9-8 of Revision 2 of the report.

Page 5, Section entitled "Broad Comments on the Assumptions"

The reason behind selecting worst-case scenarios instead of realistic ones is explained by the resolution to similar comment earlier.

Page 5, Section entitled "Uncertainties"

We agree that uncertainties in the risk modeling are often understated, particularly because no time was available to do a decent job on estimating the influence on systematic errors. In some cases, we are also convinced that the standard random errors should be larger, but by how much? There simply was not enough time to do a proper evaluation. In the final version, there will be a new Section 5.2.4, inserted before Section 5.2.5, Conclusions, which will discuss the underestimate of the standard errors and their consequences.

Page 6, Section entitled "Overview or Summary Comments"

We agree with the reviewer that additional effort is needed to calculate absolute risks to assist the decision maker. We acknowledge the importance of the absolute risk values, but would like to reiterate that these were not one of the deliverables for this project. The highlighted text on pages 9-7 and 9-8 from the latest version of the report underlines the importance of calculating absolute risk values.

(Section 9.2.3). Thus, the decision maker must weigh the uncertainties involved against the relative importance of schedule concerns, and then decide if additional data are required to make a decision.

- Application of EATF Regulatory Analysis - The EATF analysis presented in Section 6.0 shows that significant uncertainty exists in the area of regulatory compliance, and therefore it is difficult to estimate the time periods required for permitting a facility. The EATF has considered the experience of other projects in various states, and also the different state and federal regulations that affect the permitting process. It has been observed that in general, the timeframe required for facility permitting varies with the type of facility being considered (i. e., Level II or Level III), and the proposed facility location.

  As discussed in Section 6.0, waste characterization may be required to comply with the New Mexico EID or RCRA requirements. The extent of waste characterization required by RCRA will have a significant influence on the choice of an alternative, especially if the cost of such characterization is comparable to the cost of processing the waste. At the moment, the extent of characterization required by RCRA is not well defined, and thus increases the uncertainties of estimating the requirements for regulatory compliance. Therefore, although the various factors that affect the regulatory issues have been explained in Section 6.0, the EATF has refrained from presenting precise estimates of facility permitting time.

- Application of EATF Risk Assessment - The risks associated with implementing candidate alternatives can be compared with the baseline design using the results of the risk assessment summarized in Section 6.0 and discussed in detail in Appendix I. Although the analysis presented in Section 6.0 relates to Alternatives 1, 2, 4, and 8, and does not include all 14 alternatives, the four options analyzed by the EATF represent the whole range of treatments involved in the 14 alternatives. For example, the waste treatment involved in Alternative 5 is similar to that of Alternative 4, and the waste treatment involved in Alternatives 9 and 13 are similar to Alternative 8.

  The results of the EATF risk assessment show that Level II treatments result in a slight increase in risk relative to the baseline design, and this increase is generally independent of the number of facilities. In contrast, for Level III treatments, the dominance of transportation risks favors treatment of wastes at multiple facilities before transporting the wastes to WIPP. This is because the Level III treatment of waste before shipment substantially reduces the transportation risks, and this reduction more than compensates for the increase in occupational risks associated with the Level III treatment of waste.

  Since risk is an abstract quantity, the results of any risk analysis are often used by equating risk to some tangible quantity (e. g., the number of lives saved by an unit decrease in absolute risk). However, the use of such an approach is not recommended for the results of the EATF risk assessment for reasons outlined below.

  The EATF analysis has involved estimating the risks of alternatives as ratios relative to the baseline case. This approach was used to cancel the uncertainties that are common to the baseline case and the alternatives. In theory, one could take the relative risk reduction ratios estimated by the EATF, and combine these numbers with the absolute baseline risk provided in the FSEIS/FSAR to arrive at an absolute risk for each alternative. However, it should be noted that this would only serve to bring back the uncertainties present in the FSEIS/FSAR calculations, and therefore not advisable.

If it is not possible to make a decision without the absolute risk values for the alternatives, then the EATF recommends either one of two optional approaches. The first approach involves an estimation of the absolute baseline risks using a more rigorous method than the one used in the FSEIS/FSAR. This should reduce the uncertainties, and the EATF results of relative risk could then be combined to arrive at absolute risks for the alternatives. The second approach is less rigorous, and involves expressing the value of relative risk reduction for each risk component (e. g., transportation fatalities, etc.) in terms of a tangible quantity such as the number of lives saved, etc. Once each of the eight components considered by the EATF have been expressed in terms of a tangible quantity, they could then be aggregated using societal weights for each component to arrive at a tangible value of risk reduction for each alternative.

Thus, while applying the results of the risk assessment, the reader should remember the limited scope of this study. As explained in detail in Table I-ES-1 in Appendix I, the different combinations of alternatives and treatment locations fall into four different risk groups. The EATF feels that while a more rigorous analysis might change the numerical values of the risk reduction factors within each of the four groups, it is unlikely to result in reclassification of any option from one group to another.

9.2.3 Selection of an Optimal Engineered Alternative

Once the data on the effectiveness and feasibility of candidate alternatives have been compiled, the next step is to use the data to select an optimal alternative. As shown in Figure 9-1, the optimal alternative should be decided by simultaneous consideration of five different components for each alternative. These are effectiveness, cost, schedule, regulatory considerations, and the health and safety risk associated with an alternative. The reader should note that while a relative measure of these factors can be obtained for each alternative using the results of the EATF, their relative importance needs to be decided by the eventual decision maker (e. g., the DOE). Unless the relative importance of these factors is established, the results of the EATF for each factor will remain mutually exclusive, and therefore cannot be aggregated for optimizing the choice of an alternative.

The interactive processes that are expected to be involved in such an optimization process are illustrated below with an example. Assuming that the candidate alternatives are limited to Alternatives 3 and 4, the analysis of the EATF would provide the reader with the following results:

Effectiveness - Alternative 4 would reduce peak index pressures to lithostatic. Alternative 3 would be ineffective in reducing pressures to lithostatic, and the maximum peak index pressures predicted for this alternative are 20% higher than the lithostatic pressure. In general, Alternative 3 may be more effective against human intrusion, whereas Alternative 4 is more effective for addressing gas generation.

Cost - Project costs for Alternative 4 are expected to be substantially higher than for Alternative 3.

Schedule - Alternative 3 would take 5-7 years for implementation, whereas Alternative 4 would take 8-11 years.

Regulatory Considerations - Since Alternative 4 involves thermal treatment, it would be expected that the regulatory requirements for this alternative would be more extensive than Alternative 3.

PEER 14 - Blue Ribbon Panel Review Report and Senate Hearing Testimony

REPORT TO THE SECRETARY OF ENERGY

Prepared by Dr. Thomas Bahr
Member, WIPP Blue Ribbon Panel

October 23, 1989

EXECUTIVE SUMMARY

In August 1989, the Secretary of Energy created a five-member Blue Ribbon Panel (BRP) to provide independent advice on three selected issues to the Waste Isolation Pilot Plant (WIPP). They include:

1. The concept and timing of DOE's proposed WIPP Operations Demonstration (OD) as part of the overall test plan.
2. Whether or not the OD should be conducted in parallel with the Performance Assessment (PA).
3. An evaluation of DOE's validation plan for certification of transuranic (TRU) waste to meet the WIPP Waste Acceptance Criteria (WAC).

Recommendations:

1. Full ramp up of the Operations Demonstration portion of the WIPP project should be delayed until results of Performance Assessment testing better clarifies the need for possible engineering modifications to drums and/or the repository environment. The OD is, without question, an important element of the WIPP test phase and some limited experience

will be gained through emplacement of waste for test purposes even if full ramp up is delayed. It is possible that an early full ramp up done in parallel with PA testing could later result in having to remove waste if certain engineering modifications are indicated. Removal of this amount of waste for purposes of doing engineering modifications does not represent a particularly difficult task nor should this activity result in any unusual health or safety risks. The primary risk and reason to delay the OD is one of almost certain loss of public confidence in DOE should waste have to be removed.

2. DOE should require full-time waste management inspectors on waste generation lines who report to superiors who are not employed by nor contractors of the waste generation facility. Audits should be more frequent and audit teams should include non-DOE employees should be more than simply observers but rather an integral part of the overall audit process.

3. DOE should immediately incorporate into its waste certification and validation program provisions to characterize the hazardous RCRA constituents of TRU mixed waste. The waste acceptance criteria should accordingly be modified to incorporate anticipated RCRA permit requirements. The DOE has a long history of dealing with radioactive materials and has developed comprehensive criteria for its safe handling, packaging and transport. In the present day regulatory environment it is absolutely essential for DOE to develop the same capability for the hazardous component of mixed TRU waste regardless of

how innocuous it may appear relative to the nuclear hazards of the waste.

4. DOE should incorporate at the WIPP site a capability similar to that at the Idaho National Engineering Laboratory for waste drum assays and expand the capability to enable hot cell inspection of drums, repackaging and waste retreatment, overpacking and the necessary facilities to examine and characterize the hazardous constituents in mixed TRU waste. DOE should also prepare to embark on a new program of new technology development directed at non-destructive qualitative and quantitative analysis of RCRA constituents. Planning for this effort should be done in close consultation and collaboration with those entities that will ultimately administer the RCRA Part B permit, most notably, the State of New Mexico.

5. DOE should immediately place a high program priority on the management of mixed TRU waste. There should be dual emphasis on characterizing existing mixed waste (see recommendations 3 and 4) and management of newly generated waste for the purpose of better characterizing, minimizing, segregating and perhaps even treating hazardous constituents. DOE should identify "in-house" personnel qualified to develop and implement this program and, if necessary, train, contract with or otherwise acquire the needed team. Administratively, they should be fully integrated into not only the waste management side of the agency but also into those production units that generate the waste.

6. The experimental portion of the Performance Assessment needs to be more closely integrated with those aspects of the WIPP that deal with the Waste Acceptance Criteria and transportation.

7. DOE needs to place additional emphasis on generating creative solutions to the long-term containment requirements of 40 CFR 191, particularly in reference to human intrusion scenarios. The reasonableness of assuming that no institutional controls can exist after 100 years should be seriously questioned and DOE should request the National Academy of Sciences or other independent scholarly body to evaluate this issue.

TEXT

Introduction:

The Secretary of Energy named a five member "Blue Ribbon Panel" (BRP) to provide advice on certain aspects of the Waste Isolation Pilot Plant (see Executive Summary). This report was developed over a two month period and it presents findings and conclusions of a general nature designed to provide broad guidance for DOE's WIPP project. The report does not represent a consensus of the BRP nor should it be construed to be a balanced treatment of opinions held by the many interest groups who have watched the evolution of this project over the years.

The author has been careful to be factually correct but it should be noted that this document has not been reviewed by anyone. Because of the short amount of time for analysis this report should be considered preliminary in nature and subject to further revision after consideration of new information should it become available.

General findings:

The DOE WIPP technical team, scientific and engineering contractors and outside evaluators have collectively undertaken what is perhaps the most complex and significant waste management project in this nation's history. Progress on this project over the paste decade has indeed been remarkable, especially in view of the fact that nuclear waste disposal

is such an emotionally charged issue across the nation. The project is nearing the time when WIPP will receive its first shipment of TRU waste for experimental purposes. This event is seen by many as perhaps the most significant milestone for the entire project. As this date nears, groups who have long opposed the project for various reasons can be expected to become increasingly vocal in their opposition and search for any reason to shut it down. The general public, long aware of this debate, will also give this project more and more scrutiny and opinions are already beginning to take shape. While scientific and regulatory agency review of the soundness of the project will certainly be a factor in public acceptance of WIPP, a more important factor will be the credibility of DOE in the eyes of the public.

Methodology:

The WIPP BRP first met as a group from September 11-14 to be briefed by DOE officials and to review operations on site at the WIPP, Idaho National Engineering Laboratory (INEL) and the Rocky Flats Plant (FRP). Later in the month on September 24-26 the BRP again met with DOE personnel in Denver to discuss questions submitted by the BRP to DOE. In terms of scope of our contact with DOE we had an opportunity to visit with nearly every decision-making manager that presently has WIPP responsibilities.

Findings:

Observation #1

The DOE will soon begin a series of tests both in the laboratory and in situ at the WIPP for the purpose of better understanding gas generation

and interactions with brine. Bin and alcove experiments, especially if they include performance assessments of different engineering fixes, will be valuable in deciding how final waste emplacement will be accomplished. Until certain test results are in it will be difficult to determine the need for additional waste treatment and other engineering enhancements required to meet the PA.

Recommendation #1

Full ramp up of the Operations Demonstration portion of the WIPP project should be delayed until results of Performance Assessment testing better clarifies the need for possible engineering modifications to drums and/or the repository environment.

Discussion #1

The OD is, without question, an important element of the WIPP test phase and some limited experience will be gained through emplacement of waste for test purposes even if full ll ramp up is delayed. An early full ramp up done in parallel with the PA testing could result in having to remove waste if certain engineering modifications are indicated. Removal of this amount of waste for purposes of retrofitting engineering modifications does not represent a particularly difficult task nor should it result in unusual risk. The primary reason to delay the OD is that of possible loss of public confidence in the event that waste would have to be removed.

Observation #2

The production of nuclear materials by DOE is in large part driven by external factors, most notably the need to fulfill Defense Department needs. As would be expected, careful attention has been given to QA/QC programs on production lines because the quality and timely delivery of the final product is essential to this nation's defense. Not only does the Defense Department demand a quality product, but the nation as a whole demands it. In contrast to production of nuclear devices, DOE's management of nuclear waste generated by production is much less influenced by external factors such as meeting the needs of the Defense Department.

Recommendation #2

DOE should require full-time waste management inspectors on waste generation lines who report to superiors who are not employed by nor contractors of the waste generation facility. Audits should be more frequent and audit teams should include non-DOE employees, including state agency regulators, who would have the appropriate security clearances to witness any operation that generates waste. The non-DOE employees should be more than simply observers but rather an integral part of the overall audit process.

Discussion #2

The observation that QA/QC program related to waste management are less subject to external forcing influences than production management is not to say that DOE is insensitive to the need for safe management of its waste. Quite the contrary. It is clearly apparent that DOE has devoted

much time and effort and has made significant progress in recent years toward this end. This progress is a result of a highly conscientious and professionally administered program of self-regulation. The QA/QC programs for waste certification for the current WAC have been well thought out and with further modifications and fine tuning there is every reason to believe that from a technical standpoint the waste product should be acceptable for transport and ultimate emplacement in the WIPP repository. None-the-less, most of this program and its particular product are self-certified. Opponents to WIPP are well aware of the degree to which DOE self regulates its Waste Acceptance criteria and the associated QA/QC programs. Public confidence in DOE's ability to manage waste can significantly improve if DOE subjects more of its oversight to outside professionals and regulators, particularly on matters of waste certification and verification.

Observation #3

The present version of DOE's waste acceptance criteria seems to have evolved primarily out of concerns for radiological health and safety for workers and transporters and possible radiation exposure to the public. Until only recently, RCRA and its impact on management of TRU mixed waste has been recognized as being relevant to DOE operations. Characterization of the hazardous components of TRU mixed waste is needed for RCRA compliance however this is difficult to do. What knowledge that does exist is based on "process knowledge" and little if any direct verification has been done.

Recommendation #3

DOE should immediately incorporate into its waste certification and validation program provisions to characterize the hazardous RCRA constituents of TRU mixed waste. The waste acceptance criteria should accordingly be modified to incorporate anticipated RCRA permit requirements

Discussion #3

The DOE has a long history of dealing with radioactive materials and has developed comprehensive criteria for its safe handling, packaging and transport. In the present day regulatory environment it is absolutely essential for DOE to develop the same capability for the hazardous component of mixed TRU waste regardless of how innocuous it may appear relative to the nuclear hazards of the waste.

Observation #4

The present thinking of DOE is to implement a program of self certification at generating sites. This couples with an effective QA/QC program along with a statistically sound validation program is intended to produce acceptable waste drums ready for loading on TRUPACT's to be transported to and unloaded in the waste handling building at the WIPP. Present plans call for gas sampling from the TRUPACT's for archival purposes, several levels of swab checks for removable contamination, surface dosimetry, cross checks on labeling to verify that the correct drums are on a particular shipment and some other measurements. Not planned at this time are any spot checks using real time radiography (RTR), passive/active neutron assays, drum headspace gas sampling and

analysis or any other more rigorous examination to give a final verification of what is in a population of drums on receipt at the WIPP site.

Recommendation #4

DOE should incorporate at the WIPP site a capability similar to that at the Idaho National Engineering Laboratory for waste drum assays and expand that capability to enable hot cell inspection of drums, repackaging and waste retreatment, overpacking and the necessary facilities to examine and characterize the hazardous constituents in mixed TRU waste. DOE should also prepare to embark on a new program on a new program of new technology development directed at non-destructive qualitative and quantitative analysis of RCRA constituents. Planning for this effort should be done in close consultation and collaboration with those entities that will ultimately administer the RCRA Part B permit, most notably, the State of New Mexico.

Discussion #4

The final configuration of waste emplacement in the WIPP repository may well require room by room segregation of various waste forms. Tests during performance assessment, particularly those dealing with gas generation, may indicate an advantage in placing similar gas generating drums in the same room to optimize the use of gas "getters" in backfill material. Likewise, it may be found that certain waste forms need to be segregated because of chemical incompatibility, particularly with some of the hazardous components of mixed waste. Should some form of segregation as described above prove to be an important factor in

complying with regulatory standards, it would seem prudent to have some form of final verification of waste content before it is "sent down the hole".

The New Mexico EID will soon be the agency to administer the federal RCRA program and they indicate that as a requirement of the Part B Permit they will be required to do sampling for hazardous constituents in the mixed TRU waste at the WIPP site. Such sampling can be a hazardous undertaking and must be approached with great care. Specialized facilities and equipment will be needed and new assay technologies will have to be developed. This would be a significant undertaking yet considering the magnitude of the DOE weapons production program and the investment already made in the WIPP project, tooling up for such a final verification program at the final destination makes sense not only from a comparative economic standpoint but adds another element of safety that could only enhance public confidence in the operations of the DOE.

Observation #5

The DOE appears to have done little toward achieving effective administrative coordination between TRU mixed waste management and other elements of the WIPP program.

Recommendation #5

DOE should immediately place a high program priority on the management of mixed TRU waste. There should be dual emphasis on characterizing existing mixed waste (see recommendations 3 and 4) and management of

newly generated waste for the purpose of better characterizing, minimizing, segregating and perhaps even treating hazardous constituents. DOE should identify "in-house" personnel qualified to develop and implement this program and, if necessary, train, contract with or otherwise acquire the needed team. Administratively, they should be fully integrated into not only the waste management side of the agency but also into those production units that generate the waste.

Discussion #5

Organizational realignment is a matter of best left to policy officials in DOE headquarters and the above recommendation is self explanatory.

Observation #6

The long-term performance assessment will require the human mind to predict events 10,000 years into the future. To do so, scientists are put into a position of having to use todays knowledge and technology for developing in exact assumptions and then plug them into a model driven by the exact science of mathematics. To further add to the challenge, the same scientists must assume that all human knowledge of the WIPP site will somehow be lost after 100 years and there will be subsequent human intrusion into the repository.

Recommendation #6

DOE needs to place additional emphasis on generating creative solutions to the long-term containment requirements of 40 CFR 191, particularly in reference to human intrusion scenarios. The reasonableness of assuming that no institutional controls can exist after 100 years should be

seriously questioned and DOE should request the National Academy of Sciences or other independent scholarly body to evaluate this issue.

Discussion #6

Any creditable challenge to a federal rule by a regulatory agency should arise from outside any agency being regulated by the rule. In such an evaluation by the NAS or other scholarly body on this issue it would be important to include representatives from disciplines such as history, philosophy and political science in addition to the "hard" sciences.

WASTE ISOLATION PILOT PLANT
BLUE RIBBON PANEL

REPORT OF
ROBERT W. BISHOP, ESQ.

MEMBER,
WIPP BLUE RIBBON PANEL

OCTOBER 23, 1989

WASTE ISOLATION PILOT PLANT
BLUE RIBBON PANEL

REPORT OF ROBERT W. BISHOP, ESQ.
MEMBER
WIPP BLUE RIBBON PANEL

Executive Summary

The Waste Isolation Pilot Plant (WIPP) Blue Ribbon Panel was established by the Secretary of Energy to advise the Secretary on various aspects of the WIPP program for the disposal of transuranic (TRU) wastes. Specifically, the Blue Ribbon Panel was to advise the Secretary of the Panel members' independent views of the concept and timing of the proposed WIPP Performance Assessment and Operations Demonstration Test Phase and the proposed validation plan for the certification of TRU waste generated at the Department's Rocky Flats Plant.

My observations and recommendations are provided under each of the individual subject headings. My general conclusions appear at the end of each section, and are collected here for the reader's convenience.

A. WIPP Test Phase: Performance Assessment and Operations Demonstration

An Operations Demonstration is necessary to provide information and experience to enable a determination to be made of whether the WIPP facility, with its associated waste management system, is suitable for use as a permanent disposal facility. Upon satisfying applicable statutory and regulatory responsibilities, and verifiying the operational readiness of the WIPP facility, DOE should immediately commence the Operations Demonstration. TRU wastes must be shipped to support commencement of experiments, using actual waste emplaced in the WIPP facility, which are necessary to support the completion of the WIPP Performance Assessment and to develop practical experience in the operation of the TRU waste management system. The Operations Demonstration should continue after completion of waste emplacement for the experimental program until such time as a determination of the suitability of all aspects of the waste management system operation can be made in accordance with defined acceptance criteria.

B. Rocky Flats TRU Waste Certification Program Validation Plan

DOE should immediately implement a validation program of the Rocky Flats Plant wastes which have been certified to the WIPP Waste Acceptance Criteria. This should be accomplished by conducting an independent evaluation at the Idaho National Engineering Laboratory, through its Stored Waste Examination Pilot Plant, of a representative random sample of Rocky Flats Plant certified wastes currently in storage in Idaho to

verify the contents of those waste packages to the criteria under which those wastes were certified. Concurrently, an audit should be done of the Rocky Flats Plant certification process to evaluate the adequacy of the certification process and to recommend appropriate corrective actions, if any. Both of these programs should be accomplished by experienced operators and quality assurance personnel who have not been previously associated with the Rocky Flats Plant and with the participation, in an advisory role, of designated representatives of each of the states of Colorado, New Mexico and Idaho.

C. Systems Integration

DOE should establish an administrative mechanism to ensure the interaction of and coordination among the various DOE offices, contractors and subcontractors involved in all aspects of the WIPP program so that coordinated policy decisions can be made with the knowledge of the implications those decisions could have on various aspects of the program and so that those decisions can be implemented in a consistent and timely manner. The recently created DOE WIPP Task Force may be able to accomplish the systems and task integration necessary as long as it is appropriately staffed and given sufficient authority. In addition to DOE Headquarters personnel on the WIPP Task Force, a mechanism should be established, perhaps through topically-oriented Advisory Committees to the Task Force, to assure that the broad perspective of experienced operating personnel at each site and the principal contractors responsible for engineering and technical activities can be evaluated and considered in the decision-making process. The WIPP Task Force should also be responsible for considering and responding to the comments made by reputable groups involved in the WIPP evaluation process (e.g., National Research Council's WIPP Panel, Environmental Evaluation Group) and ensuring that the adoption of appropriate recommendations are implemented in an integrated manner.

D. Regulatory Requirements

A comprehensive review of all statutory and regulatory requirements applicable to the WIPP program should be conducted to ensure that all requirements are identified and integrated to ensure compliance or the timely preparation of requests for such regulatory exemptions as may be appropriate and technically justifiable because of the unique nature of the WIPP program. This analysis is necessary not only to evaluate the suitability of the WIPP program to begin operations but throughout the duration of the WIPP program as well. A high priority task should be to establish editorial and technical consistency on all substantive matters between the various regulatory submittals that have been prepared.

Fundamentally, both DOE and EPA are responsible for implementing national policy regarding the proper disposal of TRU waste. Neither agency can shirk its statutory responsibilities, but both must recognize that their responsibilities in this area are joint and not severable.

DOE and EPA must ensure, in the context of the WIPP project, that the responsibility for safe, permanent disposal of TRU wastes and the requirements of Parts 191 and 268 are reconciled. It is not in the nation's best interest for TRU waste, safe though it may be in temporary storage, to remain in that state ad infinitum because of a failure of government agencies to work together to develop a facility that can safely, permanently dispose of TRU wastes.

E. Waste Acceptance Criteria

The WIPP Waste Acceptance Criteria is but one of the criteria to which the waste generators must ensure that the TRU waste is packaged. These requirements should be integrated so that a single certification process that meets all criteria can be conducted and a single, comprehensive waste manifest completed. Ambiguous requirements should be clarified and all related documentation revised accordingly. The need to acknowledge that correct waste management is an important priority must be inculcated at all waste generating sites.

A monitoring system should be installed at WIPP to ensure that the containers as received meet the WAC and RCRA criteria that may be applicable. WIPP should also have the capability to repackage or otherwise disposition any drums received that do not meet the applicable criteria.

F. Project Documentation

DOE should establish, at a minimum, two Public Document Rooms, one in Albuquerque or Carlsbad, New Mexico, and one in Washington, D.C., in which all documents associated with the WIPP project would be located to facilitate review of those documents by the public, regulatory agencies (both state and federal), and the various DOE offices and their contractors and subcontractors. The WIPP project is an important national effort of great technical and political complexity; it is critical to informed decision-making that documentation of WIPP-related issues be made available for scrutiny.

G. Continuing Oversight

An independent advisory body, such as the WIPP Blue Ribbon Panel, should be charged with the responsibility of evaluating (1) the response to and implementation of recommendations made by the WIPP Blue Ribbon Panel members which are adopted by the Secretary, and (2) the Rocky Flats Plant waste certification validation plan, once it is developed, and the results of the validation program upon its completion.

Please refer to the associated report for the analysis upon which these conclusions are based.

REPORT OF ROBERT W. BISHOP, ESQ.
MEMBER
WASTE ISOLATION PILOT PLANT BLUE RIBBON PANEL

I. WASTE ISOLATION PILOT PLANT BLUE RIBBON PANEL

On August 11, 1989, Secretary of Energy James D. Watkins announced the establishment of a Blue Ribbon Panel to review the plans of the U. S. Department of Energy (DOE) for experiments and operational tests at the Waste Isolation Pilot Plant (WIPP) regarding the disposal of transuranic (TRU) wastes. Specifically, the Blue Ribbon Panel was to be responsible for providing an independent, technical review of WIPP operational issues relating to the concept and timing of the proposed WIPP Performance Assessment and Operations Demonstration Test Phase and the proposed validation of the certification of TRU wastes generated at the DOE Rocky Flats Plant for disposal at WIPP. The Panel consisted of five members: three members were nominated by the Governors of Colorado, Idaho and New Mexico, and two members were appointed by Admiral Watkins. The responsibility of the Panel members was to evaluate the information provided by DOE representatives, contractors and such other individuals and groups as each Panel member might determine appropriate and to each submit an independent report to DOE of our individual conclusions and recommendations, which would then be used as input to DOE's decisions concerning WIPP activities.

The Panel collectively met on September 11-14, 1989, with representatives of DOE and its major contractors and representatives of the National Research Council's WIPP Panel and the Environmental Evaluation Group (an independent advisory group located in Albuquerque, New Mexico). The Panel also toured the WIPP facility and TRU waste-related activities at the Idaho Nuclear Engineering Laboratory in Idaho Falls, Idaho and the Rocky Flats Plant in Jefferson County, Colorado. The Panel met with additional Department and contractor representatives at a meeting on September 25, 1989, that was called by the Panel to discuss questions that Panel members had identified as a result of the tour and associated presentations and the review of additional material that individual Panel members had requested.

Written material was provided to each Panel member, and Panel members were encouraged to request additional information that they thought might be helpful in their evaluation. In addition, Panel members were encouraged to address any questions they might have to representatives of DOE, contractors associated with the WIPP project, the National Research Council's WIPP Panel or the Environmental Evaluation Group. Changes in certain aspects of the project have apparently already occurred based on questions raised by Panel members during the Panel's investigation. Although this is a positive sign, it also means that a number of observations made by the Panel members in

their individual reports may no longer accurately reflect the status of that matter.

Attachment A is a listing of resource material that I reviewed, either completely or in part as pertinent to the Panel's Charter, to assist me in my understanding of the WIPP Project and to assist me in formulating the recommendations contained in this report. In addition to responding to the responsibilities delineated in the Panel's Charter, I have offered observations and recommendations on other aspects of the WIPP Project that I thought might be beneficial, based on my experience with nuclear matters over the last twenty-five years.

II. BACKGROUND

A. The Waste Isolation Pilot Plant

DOE is responsible for managing radioactive waste from defense activities and programs pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, and the Department of Energy Organization Act of 1977. One type of radioactive waste resulting from the production of nuclear weapons is transuranic (TRU) wastes. TRU wastes are materials contaminated with alpha-emitting radionuclides having atomic numbers greater than uranium (i.e., 92) with half-lives longer than 20 years and in concentrations greater than 100 nanocuries per gram. The TRU wastes result primarily from plutonium reprocessing and fabrication, as well as research and development activities at various DOE defense facilities. The wastes exist in a variety of forms, ranging from unprocessed laboratory trash (e.g., tools, glassware and gloves) to solidified sludges from treatment of waste water. Approximately 60% of the TRU wastes also contain hazardous chemical constituents; TRU wastes containing hazardous chemical constituents have physical and radiological characteristics similar to those of TRU wastes that do not contain these constituents. Since 1970, pursuant to a decision of the U. S. Atomic Energy Commission to store TRU waste by methods designed to keep it retrievable for at least 20 years rather than to continue the practice of shallow land burial, TRU wastes have been stored separately from other radioactive wastes produced at defense facilities for permanent emplacement in a geologic repository.

In 1957, a committee of the National Academy of Sciences suggested salt formations as a suitable geologic medium for the permanent disposal of radioactive wastes. Work started in 1975 on a conceptual design for a repository at a site in Eddy County, New Mexico, primarily to dispose of TRU wastes stored in retrievable form at the Idaho National Engineering Laboratory. The disposal facility, denoted the Waste Isolation Pilot Plant (WIPP), was first authorized, and designated as Project 77-13-f, by Public Law 95-183. The Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Public Law 96-164), enacted on December 29, 1979, authorized the WIPP facility "for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive waste resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission."

The WIPP site, located in southeastern New Mexico approximately 26 miles southeast of Carlsbad, New Mexico, encompasses 18,960 acres of semi-arid land, all either federal or state land, of which nearly 17,000 acres would be used for buffer zones around the underground repository area.

In terms of geology, the site is in the north-central part of the Delaware Basin, a region in which evaporation in a shallow sea deposited about 3600 feet of evaporites during the Permian Period 280-225 million years ago. The repository would be excavated from a bed of nearly pure salt in the Salado Formation, which is approximately 2000 feet thick, with a mined disposal level 2150 feet below the surface. Although underground dissolution of salt in the region is still an active process, the rate of dissolution is so slow

that the zone of salt considered for the repository is expected to remain unaffected for two to three million years.

In accordance with the requirements of the National Environmental Policy Act of 1969 (NEPA), an environmental analysis was done of the WIPP site and a Draft Environmental Impact Statement (DEIS) published in April 1979. The Final Environmental Impact Statement (FEIS) for the WIPP project, which included responses to comments received from the public and other government agencies, was published in October 1980. The preferred alternative delineated in the FEIS was to continue storing TRU wastes at the Idaho National Engineering Laboratory until a repository is available to receive it and to use the Los Medanos site in southeastern New Mexico for the construction and operation of a facility designed for the disposal of TRU wastes.

On January 28, 1981, DOE issued a Record of Decision on the WIPP project pursuant to the regulations of the Council on Environmental Quality (46 Fed. Reg. 9162). In that decision, DOE analyzed the environmental impacts of the authorized WIPP project and the alternatives thereto as identified in the FEIS. DOE determined that the long-term impact on the human environment resulting from taking no action was unacceptable: leaving the TRU wastes in surface storage could lead to very high radiation exposures both to individuals and the general population as a result of possible future volcanic action or human intrusion after governmental entities no longer controlled the site. DOE concluded that the environmental impacts predicted for the use of the Los Medanos site appeared acceptable for long-term disposal of TRU wastes "with minimal risk of any release of radioactivity to the environment. There was no indication that an alternate site for the demonstration would pose reduced risks." It was concluded that use of that site would solve the unacceptable long-term environmental problem of the surface storage of TRU wastes in the shortest amount of time and avoid the inflationary costs attributable to delay in constructing a facility. In conclusion, the Record of Decision stated that "DOE has weighed the benefits of proceeding with the authorized WIPP project against its potential environmental impacts and costs, and after consideration of the benefits, impacts and costs of reasonably available alternatives, has determined to proceed with the phased construction and operation of the authorized WIPP project." Consistent with NEPA requirements, DOE also stated that any significant new environmental information would be reviewed and the decision to proceed with the phased construction and operation reexamined as appropriate.

Construction of the WIPP project at the Los Medanos site commenced in April 1981. A decision to proceed with full facility construction was announced by DOE in June 1983, following conclusion of the Site and Preliminary Design Validation (SPDV) Program.

A draft Supplement to the Environmental Impact Statement (SEIS) was published in April 1989 to update the environmental record established in 1980 by evaluating the environmental impacts associated with new information, new circumstances, and proposed facility modifications from those originally envisioned. The SEIS documented a major modification to the WIPP schedule: WIPP would operate under a "Test Phase" for approximately five years during which time certain tests and operational demonstrations would be conducted.

The purpose of the Test Phase would be to reduce uncertainties associated with the prediction of natural processes that might affect long-term performance of the underground waste repository to assist in the determination of the ability of WIPP to meet applicable federal standards for the long-term protection of the public and the environment. The operational demonstrations would be conducted to evaluate the ability of the TRU waste management system to certify, package, transport and emplace TRU wastes in the WIPP safely and efficiently. Upon completion of the Test Phase, DOE would determine, based upon a performance assessment, whether WIPP would comply with the U. S. Environmental Protection Agency (EPA) standards for the long-term disposal of TRU wastes (i.e., 40 C.F.R. Part 191, Subpart B). If a determination of compliance is made, WIPP would enter a permanent disposal phase of approximately 20 years to demonstrate the safe disposal of TRU wastes. After completion of waste emplacement, the surface facilities would be decommissioned and the WIPP underground facilities would then serve as the permanent TRU waste repository.

B. Agreements with the State of New Mexico

In April 1981, the State of New Mexico filed suit against DOE concerning the acquisition of additional technical information and resolution of a number of controversial issues. The State of New Mexico's concerns included (1) that the final decision to commence construction and operation of WIPP should not be reached until the results of the SPDV tests were available, (2) that the State of New Mexico be provided with the opportunity to address and resolve off-site state government concerns prior to the decision to commence with construction, (3) that the State of New Mexico be entitled to enter into a binding and enforceable Consultation and Cooperation Agreement with DOE, and (4) that the withdrawal provisions of the Federal Land Policy and Management Act be complied with, including public hearings to be held before decisions were made to withdraw lands from the public domain for the WIPP project. In July, 1981, a Stipulated Agreement was executed by the State of New Mexico and DOE to address these issues. An Agreement for Consultation and Cooperation between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant was executed simultaneously and revised a number of times through April 1988. In December 1982, a Supplemental Stipulated Agreement was executed to address the state's off-site concerns regarding state liability, emergency response preparedness, independent monitoring of WIPP by the State, and upgrading and repair of state highways. A 1987 modification to the Agreement for Consultation and Cooperation limited TRU waste receipt to 15 percent prior to there being a demonstration of compliance with EPA disposal standards contained in 40 C.F.R. 191, Subpart B.

C. Environmental Evaluation Group

In 1978, the State of New Mexico established the Environmental Evaluation Group (EEG), with funds provided by DOE, to be responsible for conducting an independent technical evaluation of WIPP. The National Defense Authorization Act, Fiscal Year 1989, assigned EEG to the New Mexico Institute of Mining and Technology. Of particular pertinence to the Blue Ribbon Panel's investigation were reports EEG-40, 41 and 42 and EEG's Interim Evaluation of

Quantities of Transuranic Waste to be Brought to WIPP for Performance Assessment and Operational Demonstration, dated July 9, 1989 (Refs. 55-58).

D. National Research Council

The National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, was asked in March 1978 by DOE to "review the scientific and technical criteria and guidelines for designing, constructing and operating a waste isolation pilot plant for isolating radioactive wastes from the biosphere." An interim report was issued in 1983 and a final report, Review of the Scientific and Technical Criteria for the Waste Isolation Pilot Plant (WIPP), was issued by the National Research Council Commission on Physical Sciences, Mathematics, and Resources' Board on Radioactive Waste Management, Panel on the Waste Isolation Pilot Plant (hereinafter referred to as the "National Research Council's WIPP Panel"), in 1984.

Subsequently, the National Research Council's WIPP Panel was requested to review DOE's draft plan for conducting certain experimental and operational tests (Ref. 8). On July 19, 1989, the National Research Council's WIPP Panel issued its observations and recommendations on that plan.

E. WIPP Operational Prerequisites

Prior to initiation of the Test Phase, which necessarily involves the emplacement of TRU waste at the WIPP facility, the following actions must be accomplished: (1) land withdrawal, either administrative or legislative, completed; (2) a final Safety Analysis Report for the facility approved; (3) a Resource Conservation and Recovery Act (RCRA) No-Migration Variance Petition granted by EPA; (4) a Certificate of Compliance issued by the U. S. Nuclear Regulatory Commission (NRC) for TRUPACT II (the container in which the TRU waste will be shipped to the WIPP facility); (5) the Supplement to the Final Environment Impact Statement (SEIS) completed and DOE's Record of Decision issued; and (6) the Secretary must determine that the facility is ready to begin operations. Pursuant to the agreements with the State of New Mexico, the facility must also be in compliance with the requirements of 40 C.F.R. Part 191, Subpart A - Environmental Standards for Management and Storage.

Prior to commencement of operations following the Test Phase, the facility must be in compliance with 40 C.F.R. Part 191, Subpart B - Environmental Standards for Disposal, which includes the completion of a performance assessment and other demonstrations of the capability of the facility to meet certain radiological limits for 1,000 years after disposal and for 10,000 years after disposal.

At the time of this report, the following is the status of the required actions: both administrative and legislative land withdrawal proceedings are pending; the final Safety Analysis Report is expected to be issued in late October 1989 and approved in January 1990; the No-Migration Variance Petition was filed in February 1989, and EPA review is expected to be completed in January 1990 and action on the petition is expected in April 1990; the TRUPACT II Certificate of Compliance was issued on August 30, 1989; the final SEIS

is scheduled for issuance in mid-January 1990, and the Record of Decision is scheduled to be issued in February 1990. Completion on these activities on this schedule would support a Secretary's decision on WIPP readiness on or about June 1, 1990, and if that decision is to proceed, the facility could begin the Test Phase on or about July 1, 1990.

III. PROGRAM APPRAISAL

A. WIPP Test Phase: Performance Assessment and Operations Demonstration

Background

In April 1989, DOE issued its "Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration" (DOE/WIPP 89-011) (hereinafter referred to as the "Draft Plan"). The Draft Plan, and a subsequent Addendum dated June 16, 1989, details the process whereby scientific and technical data will be collected that DOE has determined to be necessary for it to be able to make a decision on whether to designate the WIPP facility as a permanent repository for TRU waste. The Test Phase is described as having two objectives: (1) determination of compliance, through development of a performance assessment, with EPA regulations contained in 40 C.F.R. Part 191, Subpart B, and (2) completion of an operations demonstration to evaluate the safety and effectiveness of the TRU waste management system's ability to emplace TRU waste in the WIPP facility at the designed rate.

The Draft Plan describes a two-part program. Part One covers the first three years and concludes at a holdpoint where results will be evaluated and a determination made whether to proceed with Part Two, which would involve conducting any additional necessary tests. DOE has concluded that, consistent with its goal of minimizing the amount of waste emplaced while still being able to conduct a technically valid operations demonstration, it would limit the amount of waste emplaced in Part One to not exceed 3% of WIPP's capacity. As described in the Draft Plan, this would entail the emplacement of approximately 22,600 drums of contact-handled (CH) waste and three canisters of remote-handled (RH) waste. (CH wastes are those in which the dose rate at the surface of the waste package is not greater than 200 mR/hr; RH wastes are those with a dose rate at the surface of the waste package that is greater than 200 mR/hr, but not greater than 1000 R/hr).

In addition to being evaluated by the WIPP Blue Ribbon Panel, the Draft Plan has also been critically analyzed by the National Research Council's WIPP Panel and the Environmental Evaluation Group.

Observations and Recommendations

Performance Assessment

Fundamentally, there appears to be broad consensus that *in situ* testing with actual TRU wastes is necessary to validate design concepts and models to be used for the Performance Assessment and to complement past, current and future laboratory testing. I concur. The only way in which laboratory simulation and small-scale tests can be determined to provide a reasonable representation of real conditions is to validate them in the actual environment they are meant to simulate. When system performance over a 10,000 year period is to be examined, a critical factor in the analysis is the ability to

ascertain and minimize the degree of uncertainty in the calculations. A great deal is known about the geologic formation in which WIPP is located and the characteristics and effects of TRU wastes, but potentially significant uncertainties remain. A major uncertainty is the rate and volume of gases generated as a result of bacterial action, as byproducts of metal corrosion, and as the volatile products of radiolysis. The duration of the time period, and the complexity of chemical and radiological reactions that may occur, require the use of realistic rather than ostensibly conservative estimates because it may be that what were expected to be conservative assumptions are not, in fact, conservative. The planned experiments are not required to demonstrate regulatory compliance but rather to reduce uncertainties associated with the waste form and the response of the physical environment to the emplacement of those wastes.

As to the particulars of the planned laboratory tests, bin-scale tests and alcove tests, their timing, priority and detailed procedures, I have no opinion: the Draft Plan does not detail the purpose, protocol and evaluation process of these tests, but I do not believe it to be appropriate to attempt to definitively establish at a fixed point in time what must by necessity be an evolving, iterative process. For example, significant questions remain concerning the volume and rate of gas generated through decomposition of the wastes and the containers, and the effect of that gas generation on repository performance. It may even be that room-scale tests containing a sufficient volume of TRU waste to ensure homogeneity of the constituents will be necessary to perform an effective experiment.

Under the present schedule, data from some of the experiments (e.g., those associated with different types and configurations of backfill material) will not be available in time to support the Performance Assessment development. I do not believe that is a fundamental flaw in the Test Phase, because the regulatory criteria may be able to be satisfied without the need to adopt engineering enhancements which might otherwise be desirable. Those enhancements may be as simple as segregating the drums, based on their content codes, to separate nitrogen-generating wastes from those that will generate primarily hydrogen and carbon dioxide. Or, it may be that all of the wastes emplaced during the experimental program and the operations demonstration (which could be as much as 165,000 cubic feet), and all of that currently in storage (approximately 2,300,00 cubic feet), may have to be unpacked, treated in some way, and repacked with attendent costs and occupational exposures. These effects could be massive. The experimental program can provide valuable results regarding the potential benefit or detriment associated with various engineering enhancements or waste form modifications that may be determined to be necessary to meet facility criteria. If regulatory criteria cannot be satisfied without those enhancements, a decision must be made at that time regarding those modifications which should be instituted. Additional experiments may need to be conducted, based on those enhancements having been implemented, to be able to justify facility operation.

The experimental program appears to be well thought-out and should result in the achievement of two complementary goals: the validation, or modification as may be appropriate, of the understanding of the chemical, radiological, and geological phenomena of import to this project; and the reduction of

uncertainties in the evaluation of the project's ability to meet the required criteria. However, DOE should describe the uncertainties that each test is designed to address and when results are anticipated to be available. The key is to ensure that the tests are designed to reduce the uncertainties associated with the critical parameters. These experiments should begin as soon as possible to provide the maximum amount of useful data to support the conduct of the Performance Assessment and to evaluate what engineering enhancements or additional experiments, if any, may be necessary or desirable.

I fully expect the experimental program to generate data that will help to narrow the analytical uncertainties associated with the project, and it may well suggest the need for further experiments in an iterative fashion to provide data necessary to support a decision of whether the WIPP facility is suitable for operation. Although I appreciate the need to establish some reasonable parameters, I would strongly resist the imposition of definitive limits which would preclude the flexibility necessary to ensure that the experiments are properly conducted and result in the most meaningful data. At this point, it is impossible to know when enough will be known regarding waste and repository performance. I do not believe that the Nation has the luxury of waiting until we know all that we wish we knew about everything that could affect this project.

Operations Demonstration

The Operations Demonstration is characterized in the Draft Plan as that portion of the Test Phase which begins at the conclusion of the shipments necessary to support the experimental program and ends with a period of demonstrated capability to handle and emplace waste at the facility's design rate of 60 shipments per month.

In fact, the Operations Demonstration portion of the Test Phase really begins with the shipment and receipt of the first shipment of TRU waste for the experimental program. Shipments of waste for the experimental program will be made from both the Rocky Flats Plant and the Idaho National Engineering Laboratory and thus will provide the first practical experience of the operation of the TRU waste management system. Consequently, I do not consider the Test Phase to have a segregatable segment entitled the Operations Demonstration; rather, I would separate the Operations Demonstration into two phases. The first phase would consist of the management and emplacement of TRU wastes necessary to conduct the experiments to support the development of a viable Performance Assessment (including those wastes that may be necessary to support alcove or room-scale tests that may be determined to be necessary), with the second phase being such additional shipments as may be necessary to further evaluate the waste management system and facility operation.

Regarding the conduct of the Operations Demonstration, criteria should be established for each phase of the waste management system operation whereby it can be concluded, when the criteria is met, that no further experience in that phase is necessary. Although RH wastes comprise a small fraction of the total amount of TRU waste and shipments, I believe that a demonstrated

capability to safely handle RH waste should be a prerequisite to the Secretary's decision of operational readiness of the facility. It would be a mistake to wait too long to derive experience with the waste management system such that any modifications would end up being on the critical path for WIPP operation, but it would also be a mistake to completely staff and train personnel to be able to handle full system design through-put and be forced to have that trained cadre wait months or years from their time of training and operational experience until the repository begins full-scale operation.

After the initial campaign of shipments necessary to support the experimental phase, it should be determined what, if any, and when additional experience is necessary to accomplish the independent purpose of waste management system operational viability. Achieving the right balance should be the responsibility of operating personnel on an iterative basis, with the ramp-up rates of the number of shipments adjusted accordingly, as developments affecting the facility's schedule occur. Within the constraint of the 3 percent of the WIPP facility volume now specified in the Draft Plan, there is an ample margin for sufficient wastes to be transported to demonstrate the viability of the system. This would include such additional amounts as may be appropriate to validate the system after modifications to the system have been made as a result of lessons learned from earlier experience.

The relatively small volume associated with a maximum amount of waste that would be emplaced under the Draft Plan (i.e., 3 percent) is not likely to cause a significant perturbation in facility long-term performance if the results of the experiments lead to a determination that the wastes to be emplaced at WIPP (and perhaps only the 97 percent of the wastes that had not yet been emplaced in WIPP at that point) must be modified, segregated, repacked or in some other way managed to meet the applicable performance criteria. All of the wastes emplaced as part of the Operations Demonstration that are not associated with the experiments will not be backfilled -- thus, the wastes could be reconfigured for segregation purposes and/or backfill material added even once the waste was emplaced. This would further reduce the likelihood that those wastes would have to be retrieved.

Retrieval of the wastes emplaced, whether required for waste reconfiguration and/or the addition of engineering enhancements or because a determination is made that WIPP is not a suitable disposal facility, can be accomplished if necessary. This has been demonstrated by the performance of a very well-planned and executed mock retrieval exercise that validated the ability of the facility to retrieve emplaced wastes (Ref. 59). It has been estimated that the costs of retrieval for the full amount of the wastes emplaced in the Operations Demonstration (i.e., up to 3 percent) would be in the range of $1 million. Concurrent with the development of the criteria that will be used to determine what waste management experience beyond that associated with the experimental program is needed, DOE should develop a contingency plan on how and where it would deal with wastes that might have to be retrieved after having been emplaced as part of the Operations Demonstration, including those wastes associated with the experimental program.

The decision of how much experience in waste system management is necessary beyond that gained with the wastes emplaced for the experimental phase is, at heart, a risk/benefit equation. It is my conclusion that the risk, both in terms of cost and occupational radiation exposure for emplacing wastes up to the 3 percent maximum, are reasonably balanced against the benefit of ensuring that the system works in a timely fashion. Any necessary modifications can be made in time to support facility operation. I believe the 3 percent limit established in the Draft Plan is not unreasonable, but that the decision should be made, and periodically reconsidered, by operating personnel as to how much experience (in addition to that gathered in the experimental phase) is necessary and appropriate, up to the 3 percent limit. The fundamental decision should be how to gain the maximum experience, at the opportune time, with the minimum amount of waste. The waste volume utilized should be as small as possible so that the cost, both economic and in terms of human resources, of retrieval is as small as possible if it is subsequently determined that the wastes must be repackaged or that the WIPP project is not viable, but the waste volume must be large enough to validate system operability. It should not be arbitrarily set in advance but rather be the responsibility of the WIPP management staff to accomplish on a timely basis against the criteria established in advance. Evaluating performance against criteria of acceptability determined in advance is a good management practice.

General Conclusion

An Operations Demonstration is necessary to provide information and experience to enable a determination to be made of whether the WIPP facility, with its associated waste management system, is suitable for use as a permanent disposal facility. Upon satisfying applicable statutory and regulatory responsibilities, and verifiying the operational readiness of the WIPP facility, DOE should immediately commence the Operations Demonstration. TRU wastes must be shipped to support commencement of experiments using actual waste emplaced in the WIPP facility which are necessary to support the completion of the WIPP Performance Assessment and to develop practical experience in the operation of the TRU waste management system. The Operations Demonstration should continue after completion of waste emplacement for the experimental program until such time as a determination of the suitability of all aspects of the waste management system operation can be made in accordance with defined acceptance criteria.

B. Rocky Flats Plant TRU Waste Certification Program Validation Plan

Background

Consistent with the WIPP Waste Acceptance Criteria (WAC), each DOE facility that generates TRU waste is required to establish its own waste certification program and associated quality assurance plan. Particular questions have been raised concerning the validity of the waste certification program conducted at the Rocky Flats Plant, and that concern was heightened by a Federal Bureau of Investigation (FBI) search of that facility begun on June 16, 1989, as part of a U. S. Department of Justice investigation.

Evaluation of a validation plan of the Rocky Flats Plant certification program was one of the primary responsibilities assigned to the WIPP Blue Ribbon Panel.

At the Panel's meeting with DOE and contractor representatives in Idaho on September 13, 1989, a proposed validation plan was discussed. At the Panel's subsequent meeting held on September 25, 1989, it became clear that the proposed validation plan was designed to evaluate the Rocky Flats Plant certified wastes to criteria other than those used in the certification process at Rocky Flats Plant and thus was preordained to conclude that the Rocky Flats certification program was inappropriately executed. Consequently, it would not satisfy the goal of determining whether the Rocky Flats Plant certification process had been correctly performed. An alternative validation plan was received on October 19, 1989, which was too late for the detailed evaluation and interaction with staff that such an important matter requires.

Observations and Recommendations

The primary purpose of the validation plan should be to determine whether the Rocky Flats Plant certification program was correctly administered and that the wastes evaluated in accordance with that program were correctly certified. Whatever validation program is adopted, it should have the following attributes: (1) it should be conducted by independent, technically qualified personnel in such a manner as to minimize occupational exposure, both to the radiological and the hazardous constituents contained within the waste drums; (2) it should be planned so as to minimize costs and system disturbance; (3) it should avoid additional transportation of the wastes if possible; (4) it should minimize the generation of additional wastes during the conduct of the validation program; (5) it should be conducted in a timely fashion to remove the cloud of suspicion associated with the Rocky Flats Plant certification program, or, if the program were flawed, to be able to identify discrepancies so that they can be corrected in a timely fashion; and (6) it should be conducted with comparable equipment calibrated to equivalent standards so as not to invalidate the Rocky Flats Plant certification program merely because of advances in technology that have occurred since the time those wastes were certified.

Separately, there may be value in reexamining, with currently available, more sensitive equipment, wastes previously certified by the Rocky Flats Plant and those wastes certified prior to the change in the concentration criteria of TRU wastes from 10 nanocuries per gram to 100 nanocuries per gram in accordance with DOE Order 5820.2A. It appears likely that a significant amount of the waste determined to be TRU waste could, in accordance with the revised criteria, be appropriately classified as either low-level radioactive waste, hazardous waste or mixed waste (rather than TRU or TRU-mixed waste). It may be possible to accomplish this reanalysis at the same time the validation program of the Rocky Flats Plant certification process is undertaken, but the purpose of the different evaluations should not be compromised. The purpose of the validation program is to determine whether the Rocky Flats Plant certification program was correctly administered, whereas the purpose of the second program is be to evaluate the waste with more sensitive equipment and to different criteria. The two programs may be able to be applied simultaneously, but the results should be separately evaluated.

Further, the implementation of either of these programs may provide a reasonable opportunity to evaluate the hazardous constituents within the TRU waste. That analysis can be very important to verify the process knowledge otherwise used in determining the presence and amount of hazardous constituents in the TRU waste and may provide empirical data that could be very important to the completion of the Performance Assessment and the No-Migration Variance Petition. I do not advocate the opening of a large number of containers merely to conduct this analysis, but an evaluation should be undertaken of an appropriate sample size and sampling technique that could provide additional, and probably very important, data while minimizing the exposure to these materials to the individuals conducting the evaluation. Use of available technology (e.g., head gas sampling evaluated by gas chromatography/ mass spectrometry) and techniques could significantly reduce personnel exposures while ensuring that the wastes are properly characterized.

General Conclusion

DOE should immediately implement a validation program of the Rocky Flats Plant wastes which have been certified to the WIPP Waste Acceptance Criteria. This should be accomplished by conducting an independent evaluation at the Idaho National Engineering Laboratory, through its Stored Waste Examination Pilot Plant, of a representative random sample of Rocky Flats Plant certified wastes currently in storage in Idaho to verify the contents of those waste packages to the criteria under which those wastes were certified. Concurrently, an audit should be done of the Rocky Flats Plant certification process to evaluate the adequacy of the certification process and to recommend appropriate corrective actions, if any. Both of these programs should be accomplished by experienced operators and QA personnel who have not been previously associated with the Rocky Flats Plant and with the participation, in an advisory role, of designated representatives of each of the states of Colorado, New Mexico and Idaho.

C. Systems Integration

Background

Early in the Panel's investigation, it became obvious that there was an institutional lack of communication among the various DOE offices involved in the WIPP project and the various contractors who were tasked with specific work product responsibilities by those offices. Examples abound and range from the inconsequential to the very consequential. For instance, operating personnel at the Rocky Flats Plant had not informed those individuals responsible for conducting the WIPP Performance Assessment about the nature of compaction to be accomplished at the Rocky Flats Plant; the compaction of the TRU wastes could directly affect criticality and gas generation calculations, both of which are critical parameters in evaluating WIPP facility performance.

Observations and Recommendations

At best, this results in an inefficient way to address significant problems, particularly when dealing with issues of a complex nature associated with a major project like the WIPP project. Frequently the result can be counterproductive activity. An additional deleterious result can be the lack of cross-fertilization between professionals and the resulting lack of different perspectives and insight which could hamper the development of innovative solutions to problems. In my judgment, the WIPP project and its associated waste management system cannot be managed correctly if engineering, technical and operating personnel are not responsible for interacting frequently with each other and with DOE staff. It is encouraging that DOE has recently established an interdisciplinary WIPP Task Force to oversee WIPP-related activities, and I advocate that it be provided with the responsibility, and sufficient authority, to ensure that the integration of these important activities occurs promptly.

In addition, there does not appear to be any on-going process to take advantage of the insight provided by independent groups evaluating aspects of the WIPP project or to respond to comments made at Congressional hearings (e.g., Ref. 10) and other types of relevant communications. This is not to imply that the observations and recommendations of the National Research Council's WIPP Panel, the Environmental Evaluation Group or even of the Blue Ribbon Panel itself should be blindly adopted, or categorically rejected either. There is evidence that at least some of these reports have been evaluated (e.g., Ref. 50). However, there does not seem to be an established policy that such a review and analysis should always be conducted. A mechanism should be established for those observations and recommendations to be carefully considered -- by technical, engineering and operating personnel, and staff who have policy perspective and responsibility -- for the value that such independent insights might provide. The results of those evaluations should be documented and a response provided to the issuing organization.

The WIPP project has completed its construction phase and now is poised to begin operations under the Test Phase. Therefore, a start-up team should be assembled, perhaps under the auspices of the WIPP Task Force, to ensure that the necessary transition is accomplished in a coordinated fashion (e.g., ensuring that all documents and plans reflect the as-built configuration). The team should be headed by an individual with major project start-up experience and include representatives of the Albuquerque Operations Office, the WIPP Project Office, the DOE Office of Environmental Safety & Health, the DOE Office of General Counsel, and operations personnel from the waste generating sites. This group must also have the authority commensurate with its responsibilities to ensure the safe and timely commencement of operations under the Test Phase.

General Conclusion

DOE should ensure that coordination takes place among the various DOE offices, contractors and subcontractors involved in all aspects of the WIPP program so that coordinated policy decisions can be made with the knowledge of the implications those decisions could have on various aspects of the

program and so that those decisions can be implemented in a consistent and timely manner. The recently created DOE WIPP Task Force may be able to accomplish the systems and task integration necessary, as long as it is appropriately staffed and given sufficient authority. In addition to DOE Headquarters personnel on the WIPP Task Force, a mechanism should be established, perhaps through topically-oriented Advisory Committees to the Task Force, to assure that the broad perspective of experienced operating personnel at each site and the principal contractors responsible for engineering and technical activities can be evaluated and considered in the decision-making process. The WIPP Task Force should also be responsible for considering and responding to the comments made by reputable groups involved in the WIPP evaluation process (e.g., National Research Council's WIPP Panel, Environmental Evaluation Group) and ensuring that the adoption of appropriate recommendations are implemented in an integrated manner.

D. Regulatory Requirements

Background

EPA regulations contained in 40 C.F.R. Part 191, Subpart A - Environmental Standards for Management and Storage, and Subpart B - Environmental Standards for Disposal, which were adopted in 1985, are the fundamental regulatory requirements that the WIPP facility must meet. The requirements of Subpart A are also mandated as a condition of the Stipulated Agreement between DOE and the State of New Mexico. Basically, Subpart A imposes a requirement that DOE operate the facility such as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from discharges of radioactive material and direct radiation from such management and storage shall not exceed 25 mrem to the whole body and 75 mrem to any critical organ. Subpart B establishes individual protection requirements such that any member of the public in the accessible environment will not, for 1,000 years after disposal, receive a dose to exceed 25 mrem to the whole body or 75 mrem to any critical organ from the undisturbed performance of the disposal system and containment requirements for cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal, with associated assurance requirements. Although disposal facilities are required to install permanent markers, records, and other passive institutional controls to indicate the danger of the wastes disposed of and their location, no contribution from active institutional controls for more than 100 years after disposal may be assumed in the analysis.

Subpart B requires that a performance assessment be conducted, which is an analysis that identifies the processes and events that might affect the disposal system, examines the effects of these processes and events on the performance of the system and estimates the cumulative releases of radionuclides caused by all significant processes and events, considering all associated uncertainties. Those estimates are then incorporated into an overall probability distribution of cumulative release that is measured against the EPA criteria. The EPA standards, both in the regulations, in the supplementary information associated with the final rule, and in the Draft Environmental Impact Statement associated with the final rule, are replete

with qualifications associated with the lack of specificity and technical justification because of the long time periods involved and the very nature of the events and processes that can take place during that time which create substantial uncertainties in projecting, and attempting to assure, system performance. In recognition of those uncertainties, both Subpart A and Subpart B contain provisions allowing for the issuance of alternate standards or substitute provisions, based upon appropriate analysis and explanations, as may be necessary to achieve the goals of the regulations. It is not clear whether legal analysis has been undertaken and advice provided regarding interpretation of the regulatory requirements and their application to the WIPP facility, as well as possible courses of action available.

Observations and Recommendations

It is possible, notwithstanding the best efforts of the most competent professionals available, that a demonstration of the ability of the facility to meet these criteria cannot be justified with the requisite level of certainty. EPA's own analyses demonstrate that a bedded salt formation is clearly a preferable geologic repository for radioactive waste, and the WIPP facility has attributes superior to those analyzed by EPA in reaching that conclusion.

It is also clear that the Part 191 requirements were based primarily on an analysis of the radiological constituents and waste forms associated with high-level radioactive waste. Because of the unique characteristics of TRU waste and because the WIPP facility is located in what EPA has determined to be a geologically superior type of formation, EPA should be closely involved in the experimental program and the development of the Performance Assessment to assure that the data collected and analyses performed satisfy EPA, both with respect to the established criteria and to the development of technical justification that may be required for seeking administrative modification of those requirements as may be appropriate for the WIPP facility. As the National Research Council's WIPP Panel observed, "[t]he primary goal of 40 CFR 191 is to ensure that a repository poses no significant health risk to the public; the standards set for compliance represent EPA's best estimate of what is required to achieve this goal. To date, however, these standards have never been applied to a specific repository." (Ref. 49, App. B). The National Research Committee's WIPP Panel further stated that "[t]he Panel believes that the above-mentioned primary goal can best be achieved by focusing performance assessment activities on demonstrating that the WIPP repository will be safe, i.e., pose no significant risk to the public health and safety, rather than by an uncritical, formal adherence to compliance with the current EPA standard" (emphasis in original). I agree.

Because approximately 60% of the TRU waste to be emplaced at WIPP contains hazardous wastes regulated under the Solid Waste Disposal Act, the Resource Conservation and Recovery Act of 1976, and the Hazardous and Solid Waste Amendments Act of 1984, the provisions of 40 C.F.R. Part 268 must be addressed. These regulations provide, inter alia, that a petition must be filed with EPA "demonstrating, to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit . . . for as long as the wastes remain hazardous." Such a petition, commonly referred to as the

"No-Migration Variance Petition," was filed in February 1989. As was recommended for addressing Part 191 requirements, DOE should work closely with EPA to address Part 268 requirements and ensure that the application of those requirements to the WIPP facility is justifiable in terms of the unique nature of the TRU wastes being disposed of at WIPP and because of the fundamental purpose of the WIPP program.

The WIPP Final Safety Analysis Report (FSAR) and the Supplement to the Environmental Impact Statement (SEIS) also address environmental issues. Because of the evolutionary nature of the WIPP project, and particularly the developing understanding of the physical phenomena and geologic characteristics associated with the WIPP facility in the recent past, many of the documents that have been prepared and issued to address a variety of statutory and regulatory requirements (including the FSAR, SEIS and No-Migration Variance Petition) do not accurately reflect the current knowledge; they are being evaluated on the basis that they correctly represent the facts, yet they are different in significant respects (e.g., the assumptions associated with and the evaluation of consequences of hazardous chemical releases). Many of these documents were prepared by different individuals or groups to satisfy specific requirements and it appears that there was, and potentially still is, little interaction between those groups, which only exacerbates the problem.

General Conclusions

A comprehensive review of all statutory and regulatory requirements applicable to the WIPP program should be conducted to ensure that all requirements are identified and integrated to ensure compliance, or timely requests are prepared for such regulatory exemptions as may be appropriate and technically justifiable because of the unique nature of the WIPP program. This analysis is necessary not only to evaluate the suitability of the WIPP program to begin operations but throughout the duration of the WIPP program as well. A high priority task should be to establish editorial and technical consistency on all substantive matters between the various regulatory submittals that have been prepared.

Fundamentally, both DOE and EPA are responsible for implementing national policy regarding the proper disposal of TRU waste. Neither agency can shirk its statutory responsibilities, but both must recognize that their responsibilities in this area are joint and not severable. DOE and EPA must ensure, in the context of the WIPP project, that the responsibility for safe, permanent disposal of TRU wastes and the requirements of Parts 191 and 268 are reconciled. It is not in the Nation's best interest for TRU waste, safe though it may be in temporary storage, to remain in that state ad infinitum because of a failure of governmental agencies to work together to develop a facility that can safely, permanently dispose of TRU wastes.

E. Waste Acceptance Criteria

Background

The WIPP Waste Acceptance Criteria (WAC) establish limits for the physical, radiological, and chemical composition of the TRU waste that is to be emplaced at the WIPP facility. The primary objectives of the WAC are to ensure that all TRU wastes are packaged so that handling and subsequent disposal are performed safely and that the repository is able to isolate the waste from the environment in accordance with regulatory requirements. These criteria were developed so that TRU waste generators could design their waste processing systems such that the waste packages will be acceptable for geologic disposal in an embedded salt environment.

The WAC is established and administered by the Waste Acceptance Criteria Certification Committee (WACCC). In addition to establishing and modifying the WAC as it may deem appropriate, WACCC is responsible for reviewing and approving certification plans and associated quality assurance plans at all TRU waste generating and storage sites. WACCC is also responsible for conducting field audits to ensure that plans and programs associated with WAC are properly implemented. The WACCC is comprised currently of seven individuals, one of whom is required by the WACCC charter to have a formal QA background. All members of the WACCC are associated with the WIPP project: none of the waste generating facilities are directly involved in the formulation or modification of the WAC or the policies of the WACCC other than through applying to the WACCC for approval of their certification process and for supporting an annual audit conducted by the WACCC.

The WAC was developed from the perspective of disposal facility constraints. Different, and in some cases more stringent criteria, must be applied to the waste to meet the requirements of the TRUPACT II waste container, the U. S. Department of Transportation (DOT) and EPA regulations, and regulations of the State of New Mexico (e.g., no hydrogen generation limit vs. no more than 5 percent generated in a 60 day period; no criteria for flammable organics vs. 500 parts per million). For example, there apparently is a significant volume of TRU wastes that are certified to the WAC but do not meet the TRUPACT II criteria. Further, there is no evidence that the limitations imposed by the agreements with the State of New Mexico have been recognized in the WAC. (See Ref. 12, page 5).

Observations and Recommendations

I have a number of observations concerning the WAC and its implementation. First, the various criteria imposed (e.g., WAC, DOT and EPA regulations, TRUPACT II) should be integrated into a single set of criteria and a comprehensive data collection form developed that would satisfy all applicable requirements. Further, it does not appear that the need to determine the presence and amount of hazardous constituents has been evaluated from either a technical (i.e., to support the Performance Assessment development) or legal perspective. The WACCC should ensure that the appropriate data is collected during the certification process to support a determination that the criteria had been complied with (e.g., sampling the drum head space for

volatile organic compounds to ensure that the hazardous waste constituents are properly characterized to comply with EPA requirements). Second, there appears to be very little communication between waste generators, who might be able to learn from one another's experience, and those individuals who are involved in other aspects of the WIPP project (e.g., the scientists and engineers conducting the Performance Assessment); a result is that the interpretation given to the WAC by the WACCC may be dramatically different than that assumed by other individuals associated with the WIPP project. Third, whenever changes are made to the WAC or to the implementation of the WAC (e.g., the conclusion to allow, as a matter of course, free liquids up to 1 percent by volume), they must be immediately communicated to the individuals responsible for conducting the Performance Assessment and to those individuals who are responsible for assuring that the facility meets applicable regulatory requirements. Fourth, there are a number of instances where the criteria established in the WAC, and accompanying QA criteria, include phrases such as meeting "applicable" requirements without any guidance on how that determination should be made, by whom, and in reference to what. Fifth, various of the guidance documents appear to be internally inconsistent (e.g., Ref. 36 relies in its analysis on the use of a corrosive-resistent inner liner to satisfy the pertinent criteria, yet in Ref. 37 the use of corrosion-resistent liners is only recommended; Ref. 36 concludes that radioactive mixed wastes will be packaged, transported and disposed of in a manner "more stringent than regulations applying to other types of toxic substances," yet no technical justification is given for that conclusion: that issue is subject to considerable doubt, which is the focus of the petition filed with the EPA under Part 268). Sixth, there are a number of specific provisions that suggest additional consideration should be given to revising the WAC to include experience garnered to date (e.g., the requirement that labels be affixed to individual waste packages does not require that the labels be located in a manner that would aid in the quality assurance, transportation, receipt and emplacement operations -- for example, requiring labels to be located on the top and bottom and 120 degrees apart on the exterior sides of the drum). These are not critical issues, but they can have a dramatic effect on the ability of the program to function smoothly.

With respect to the operations of the WACCC, I have the following observations. First, once the WAC is established, the WACCC functions primarily in a quality assurance (QA) role, yet only one of its members is required to be experienced in QA activities and there is no requirement for any of the WACCC members to have operational experience. Second, it does not appear that the WACCC, in its QA role, is independent of line management, which experience suggests is a necessary attribute to ensure the independence of QA-related conclusions. Third, the audits of the generating facilities are conducted annually on an announced basis; experience suggests that more valuable audit insight could be achieved by conducting unannounced audits at a random frequency. Fourth, there apparently has not been any effort by the WACCC to evaluate trends that may be present in the individual site certification processes to be able to determine equipment degradation or any programmatic or personnel weaknesses; under the current system, a significant number of records are not required to be retained past a subsequent WACCC audit, nor is there any intent to retain package-specific records (e.g., routine assays and inspections, non-conformance reports) post-emplacement

that might facilitate problem resolution if one were to occur during facility operation.

In addition, I would make the following general observations. First, each site apparently develops its own three-digit "content code." It would seem to facilitate quality assurance activities, as well as waste emplacement and possible retrieval, for a uniform set of content codes to be developed for the general categories that are not likely to change and for each site to have the ability to use a defined block of numbers for any necessary additional site-specific content codes. Finally, DOE Order 5820.2A requires that radioactive and mixed wastes be managed in a manner that minimizes the generation of such wastes, yet it is apparent that little thought has been given at the Rocky Flats Plant, and presumably at other DOE production facilities, to conducting their operations in a manner that would minimize radioactive and mixed waste generation and would manage whatever wastes are generated in an integrated manner to minimize the handling of these materials; systems integration is clearly necessary if DOE's goal of effective waste management are to be achieved.

As currently envisioned, there would be no receipt inspection of TRU waste packages at WIPP other than a visual inspection for external package deterioration and both a radiation and surface contamination survey. Thus, once the wastes have been packaged and certified, there would be no further evaluation conducted (e.g., to determine if void spaces were created due to settling during transit; to determine if condensation during storage resulted in an increased amount of free liquid) even though conceivably these wastes could have been in surface storage for up to 20 years. This may not meet RCRA requirements. Further, the WIPP facility's only current capability to treat waste drums that are found to be not acceptable upon receipt is to overpack them.

General Conclusions

The WIPP Waste Acceptance Criteria is but one of the criteria to which the waste generators must ensure that the TRU waste is packaged. These requirements should be integrated so that a single certification process that meets all criteria can be conducted and a single, comprehensive waste manifest completed. Ambiguous requirements should be clarified and all related documentation revised accordingly. The need to acknowledge that correct waste management is an important priority must be inculcated at all waste generating sites.

A monitoring system should be installed at WIPP to ensure that the containers as received meet the WAC and RCRA criteria that may be applicable. WIPP should also have the capability to repackage or otherwise disposition any drums received that do not meet the applicable criteria.

F. Project Documentation

Observations and Recommendations

In the course of the investigation by the Blue Ribbon Panel, individual Panel members requested a number of documents that were referenced in other project-related documents or were otherwise pertinent to this investigation. In my experience, DOE and contractor personnel were, without exception, very willing to supply all documents requested. However, with the best of intentions, it frequently became a laborious process to locate where certain of the documents resided so that copies or excerpts could be made. The difficulty of that task strongly suggests that many of the documents that could be helpful to various DOE offices and contractors themselves in pursuing specific topics were not readily available to them and, in fact, they may not have known of their existence or how to obtain them if their existence was identified.

In a similar fashion, the need for individuals or groups not directly responsible for the WIPP project (e.g., National Resource Council's WIPP Panel, Environmental Evaluation Group) and regulatory agencies whose responsibilities affect the WIPP project (e.g., EPA, DOT, NRC), to say nothing of interested members of the media and general public, could be beneficially addressed by having all applicable documents collected in a central location. This would also be advantageous to DOE offices and contractors directly involved in WIPP and to DOE offices and contractors, as well as other regulatory agencies, involved in other projects (e.g. the high-level radioactive waste disposal facility to be developed in accordance with the provisions of the Nuclear Waste Policy Act of 1982) that might benefit from the knowledge of the lessons learned through the course of the development of the WIPP project.

General Conclusion

DOE should establish, at a minimum, two Public Document Rooms, one in Albuquerque or Carlsbad, New Mexico, and one in Washington, D.C., in which all documents associated with the WIPP project would be located to facilitate review of those documents by the public, regulatory agencies (both state and federal), and the various DOE offices and their contractors and subcontractors. The WIPP project is an important national effort of great technical and political complexity: it is critical to informed decision-making that documentation of WIPP-related issues be made available for scrutiny.

G. Continuing Oversight

Observations and Recommendations

The total time in which the WIPP Blue Ribbon Panel has been involved in conducting its investigation and evaluation has been very limited, primarily because of the necessity of DOE to have the ability to analyze the Panel members' insight in a timely fashion and to implement such modifications to the WIPP program as DOE may deem appropriate based upon that insight. Because

Panel members were, by the press of available time and resources, unable to have all of their inquiries pursued to resolution, it may be beneficial to provide the Panel with an additional opportunity to meet with DOE and contractor rerpresentatives at some time in the future to address the Panel members' observations and recommendations. It may also be beneficial for DOE to have an opportunity to interrogate individual Panel members to ensure that their views are understood. In addition, there may be benefit to DOE for the Panel members to consider their colleagues' analyses and reports and determine if, based on that further insight, additional or modified recommendations could be made that may be helpful to DOE.

As described in Section I of this report, one of the defined responsibilities of the Panel was to evaluate and comment upon a proposed validation plan of the Rocky Flats Plant certified waste program. In that a validation plan has not yet been developed, the Panel cannot at this time satisfy that responsibility. However, the Panel member's several observations and comments on the recent draft plan (Ref. 69) may assist DOE in developing an appropriate validation plan. Once a plan is developed and implemented, there may also be advantage to having an independent body, such as the Blue Ribbon Panel, evaluate the results of the validation program to assist DOE in determining what, if any, additional actions would be appropriate with respect to the Rocky Flats Plant certified waste or certification program.

General Conclusion

An independent advisory body, such as the WIPP Blue Ribbon Panel, should evaluate (1) the response to and implementation of recommendations made by the Panel members which are adopted by the Secretary, and (2) the Rocky Flat Plant waste certification validation plan, once it is developed, and the results of the validation program upon its completion.

IV. OVERALL OBSERVATIONS

The WIPP facility appears to have been well-planned and constructed, and the pride of the individuals responsible for those tasks was evident. It has the hallmarks of a professionally designed and staffed facility. It 's well-maintained, organized to have a low ambient noise level and operated in a consistent manner, and is designed to provide sufficient space for planned operations with extra space to facilitate dealing with unexpected situations or subsequent system modifications that may be required.

Even in the short time in which the Panel has been active, it is clear that there are a great number of competent and motivated individuals, both professional and support staff, who are committed to doing their best to do this project correctly. That statement applies at each of the offices that we visited, to both staff and operating personnel, and to government employees and contractors alike. There may be relative strengths and weaknesses among the personnel, but there was no evidence of people being satisfied with doing less than a responsible job, whatever their responsibility might have been. They did not always agree with one another, nor I with them, but that does not diminish my respect for their willingness to tackle a very difficult task.

If WIPP is not determined to be a suitable facility as a geologic repository, it does not appear that it will be for the lack of many individuals doing their best to do the job right.

On February 12, 1980, the President of the United States established a comprehensive program for the management of radioactive waste. In a message to Congress on that date, President Carter observed that "[m]any citizens know and all must understand that this problem will be with us for many years. We must proceed steadily and with determination to resolve the remaining technical issues while ensuring full public participation and maintaining the full cooperation of all levels of government. We will act surely and without delay, but we will not compromise our technical or scientific standards out of haste. I look forward to working with the Congress and the states to implement this policy and build public confidence in the ability of the government to do what is required in this area to protect the health and safety of our citizens." A decade has expired since that call to action was made, and its principles remain apt today, as the recently issued DOE Environmental Restoration and Waste Management Five-Year Plan (Ref. 68) demonstrates. We <u>must</u> find the way to address and resolve these issues without delay.

Attachment A

WASTE ISOLATION PILOT PLANT

References

1. Department of Energy National Security and Military Applications of Nuclear Energy Authorizaton Act of 1980, Public Law 96-164.

2. Final Environmental Impact Statement, Waste Isolation Pilot Plant (DOE/EIS-0026), Executive Summary, Volumes I & II, October 1980.

3. U.S. Department of Energy, Waste Isolation Pilot Plant, Record of Decision, (46 Fed. Reg. 9162 - January 28, 1981).

4. Design Criteria: Waste Isolation Pilot Plant (WIPP), Site and Preliminary Design Validation (SPDV)(WIPP-DOE-72 Rev.1)(October 1981).

5. Project Plan for the Waste Isolation Pilot Plant (DOE - January 19, 1982).

6. Review of the Scientific and Technical Criteria for the Waste Isolation Pilot Plant (DOE/DP/48015-1), National Research Council Commission on Physical Sciences, Mathematics and Resources Board of Radioactive Waste Management Panel on the Waste Isolation Pilot Plant (1984).

7. Draft Supplement, Environmental Impact Statement, Waste Isolation Pilot Plant (DOE/EIS-0026-DS), Volumes I & II, April 1989.

8. Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration (DOE/WIPP 89-011), April 1989.

9. Addendum to the Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration (DOE Albuquerque Operations Office, Jack B. Tillman, Project Manager), June 16, 1989).

10. Hearing on the Status of the Waste Isolation Pilot Plant Project, U.S. House of Representatives Environment, Energy, and Natural Resources Subcommittee of the Committee on Government Operations, June 12, 1989.

11. State of New Mexico - U.S. Department of Energy Stipulated Agreement (July 1, 1981) and Supplemental Stipulated Agreement Resolving Certain State Off-Site Concerns over WIPP (December 27, 1982).

12. Agreement for Consultation and Cooperation Between Department of Energy and the State of New Mexico on The Waste Isolation Pilot Plant (Updated to April 18, 1988).

13. DOE Order 5400.1 - General Environmental Protection Program (November 9, 1988).

14. DOE Order 5400.3 - Hazardous and Radioactive Mixed Waste Program (February 22, 1989).

15. DOE Order 5480.1b - Environment, Safety, and Health Program for Department of Energy Operations (September 23, 1986).

16. DOE Order 5480.11 - Radiation Protection for Occupational Workers (Chg. 1: July 20, 1989).

17. DOE/AL Order 5481.1B - Safety Analysis and Review System (January 27, 1988).

18. DOE Order 5484.1 - Environmental Protection, Safety and Health Protection Information Reporting Requirements (June 9, 1981).

19. DOE Order 5500.2A - Emergency Planning, Preparedness and Response for Operations (April 13, 1988).

20. DOE Order 5632.6 - Physical Protection of DOE Property on Unclassified Facilities (February 9, 1988).

21. DOE Order 5632.7 - Protective Forces (February 9, 1988).

22. DOE Order 5700.6b - Quality Assurance Program (September 23, 1986).

23. DOE Order 5820.2A - Radioactive Waste Management, (September 26, 1988).

24. DOE Order 6430.1A - General Design Criteria (Draft)(December 25, 1987).

25. DOE Environmental Compliance Guide (DOE/EV-0132).

26. 40 C.F.R. Part 61, National Emissions Standards for Hazardous Air Pollutants, Subpart H, Standards for Radionuclides.

27. 40 C.F.R. Part 191, Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. 19, 1985).

28. Draft Environmental Impact Statement for 40 CFR 191: Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Environmental Protection Agency (EPA 520/1-82-025 - December, 1982).

29. Final Regulatory Impact Analysis, 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Environmental Protection Agency (EPA 520/1-85-027 - August 1985).

30. Assessing Compliance With the EPA High-Level Waste Standard: An Overview (NUREG/CR-4510; SAND86-0121), Sandia National Laboratories (October, 1986).

31. Compliance Strategy for 40 CFR Part 191 (DOE-WIPP 86-013), Sandia National Laboratories and Westinghouse Electric Corporation, March 17, 1989.

32. Natural Resources Defense Council, et al. v. EPA (1st Cir. - July 17, 1987).

33. Resource Conservation and Recovery Act of 1976 (42 U.S.C. & 6901 et seq.), as amended.

34. 40 C.F.R. Part 268, Land Disposal Restrictions.

35. Waste Isolation Pilot Plant No-Migration Variance Petition (DOE/WIPP-89-003), Executive Summary and Chapter 3, IT Corporation (February 1989).

36. TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant (WIPP/DOE-069, Rev. 3), January 1989.

37. TRU Waste Certification Compliance Requirements for Acceptance of Newly Generated Contact-Handled Waste (WIPP/DOE-114, Rev. 2), January 1989.

38. Quality Assurance Requirements for Certification of TRU Waste for Shipment (WIPP/DOE-120, Rev. 2), August 1988.

39. TRU Waste Certification Compliance Requirements for Acceptance of Contact-Handled Waste Retrieved from Storage (WIPP/DOE-137, Rev. 2), January 1989.

40. Data Package Format for Certified TRU Waste (WIPP/DOE-157, Rev. 2), January 1989.

41. TRU Waste Certification Compliance Requirements for Remote-Handled Waste for Shipment (WIPP/DOE-158, Rev. 1), January 1989.

42. Integrated Database for 1988: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics (DOE/RW - 0006, Rev 4), September 1988.

43. Various Reports of and Audits Conducted by the Waste Acceptance Criteria Certification Committee.

44. Waste Isolation Pilot Plant - Waste Transportation Manual (WP 06-2, Rev.0) Westinghouse, December 1988.

45. TRUPACT II, Safety Analysis Report, Rev.1 (May 1989), Section 2.7.

46. TRUPACT II, Response to NRC Request for Information of May 10, 1989; Attachment B to NuPac Letter Ref. No. L-9853.

47. Nuclear Regulatory Commission Briefing on Certification of DOE Transuranic Waste Package -- TRUPACT II, August 11, 1989.

48. Requirements of the WIPP Waste Acceptance Criteria (WAC) and the TRUPACT-II Authorized Method for Payload Control (TRAMPAC)(WIP:0494).

49. Review Comments on DOE Document DOE/WIPP 89-011, National Research Council Commission on Physical Sciences, Mathematics and Resources, Board on Radioactive Waste Management (Frank L. Parker, Chairman), July 20, 1989.

50. Response of the Department of Energy to the recommendations of the National Academy of Science's Board on Radioactive Waste Management concerning the Waste Isolation Pilot Plant (Leo Duffy, Special Assistant to the Secretary for Coordination of DOE Waste Management), August 18, 1989.

51. National Research Council's Board on Radioactive Waste Management, Waste Isolation Pilot Plant Panel, agenda and presentation material, September 18-20, 1989 meeting, Albuquerque, New Mexico.

52. Potential Problems Resulting from the Plans for the First Five Years of the WIPP Project, Environmental Evaluation Group, Proceedings -- Waste Management '88.

53. Technical and Programmatic Evaluation of WIPP, Environmental Evaluation Group, Proceedings -- Waste Management '89.

54. Review of the Final Safety Analysis Report (Draft), DOE Waste Isolation Pilot Plant (EEG-40), Environmental Evaluation Group, May 1989.

55. Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant (EEG-41), Environmental Evaluation Group, July 1989.

56. Interim Evaluation of Quantities of Transuranic Waste to be Brought to WIPP for Performance Assessment and Operational Demonstration, Environmental Evaluation Group, July 9, 1989.

57. Evaluation of the DOE Plans for Radioactive Experiments and Operational Demonstrations at WIPP (EEG-42), Environmental Evaluation Group, September 1989.

58. Final Report for the Contact-Handled Transuranic Waste Mock Retrieval Demonstration (DOE/WIPP 88-006), January 28, 1988.

59. Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant, Sandia National Laboratories (SAND89-0178), April 1989.

60. Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; (SAND89-0462) Sandia National Laboratories, March 1989.

61. Interpretations of Single-Well Hydrostatic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987, (SAND87-0039), Sandia National Laboratories, December 1987.

62. Program Plan for Certification of INEL Contact-Handled Stored Transuranic Waste, EG&G Idaho (WM-PO-88-011-2: SWEPP-CERT PLAN-1, Revised September, 1988) and Certification Plan Attachment (SWEPP-CERT PLAN ATT-1, Revised August, 1987).

63. SWEPP Quality Assurance Plan, EG&G Idaho (SWEPP-QAP-1, Rev.2), September, 1986.

64. Quality Assurance Program for TRU Waste Certification, Rocky Flats Plant (WC-4500-D), October 28, 1988.

65. Application and Affidavit for Search Warrant, Rocky Flats Plant, FBI Special Agent Jon S. Lipsley, June 1989.

66. Rockwell International Corp. v. Department of Justice, Department of Energy, Environmental Protection Agency, et al. (filed D.C. Cir. - September 21, 1989).

67. Preliminary Nonradionuclide Inventory of CH-TRU Waste, International Technology Corporation, May 1989.

68. Environmental Restoration and Waste Management Five-Year Plan, U.S. Department of Energy (DOE/S-0070), August 1989.

69. Rocky Flats Waste Recertification Program Plan for the Waste Isolation Pilot Plant (DOE/WIPP 89-025), Westinghouse Electric Corporation, October 1989.

WASTE ISOLATION PILOT PLANT

BLUE RIBBON PANEL

MEMBER REPORT

Dr. Arthur S. Kubo
October 23, 1989

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WASTE ISOLATION PILOT PLANT
BLUE RIBBON PANEL
MEMBER REPORT

Dr. Arthur S. Kubo

October 23, 1989

I. INTRODUCTION

The Waste Isolation (WIPP) Blue Ribbon Panel (BRP) was established by the Secretary of Energy on August 31, 1989. Each panel member is individually chartered to review, assess, and report on the following WIPP issues (Statement of Work):

> Independent validation of the certification of Rocky Flats Plant (RFP) waste at both Rocky Flats and at Idaho National Engineering Laboratory (INEL) for shipment to WIPP.
>
> Concept and timing for the WIPP Operations Demonstration Test Plan.
>
> Whether the WIPP Program can perform an operations demonstration in parallel with the conduct of performance assessment experiments.

II. ASSESSMENT METHODOLOGY

This assessment of WIPP issues is based on two WIPP BRP briefing sessions/meetings augmented by individual review of data and follow-up of specific questions. Various members attended separate briefings and meetings and made reports as appropriate to the panel.

On September 11 through 14, 1989, the BRP toured and attended briefings (Reference 80, Appendix A) at DOE's Albuquerque Operations Office, the WIPP Facility (Carlsbad, NM), the SWEPP and the TRU Waste Temporary Storage Facility (INEL, ID), and the Rocky Flats Plant (RFP, CO). The principal WIPP technical, management, and program personnel were introduced. EEG and NAS representatives made presentations in Albuquerque. The introductory tour was well organized, informative, and candid.

On September 25 and 26, 1989, a BRP-requested follow-up meeting in Denver occurred. Selected personnel from WIPP/INEL/RFP and supporting contractors (Westinghouse, Sandia, and IT) attended the meeting. The BRP requested answers to a list of questions (Appendix B) organized in nine subject areas: Organizational Relationships; The Legal Basis and Requirements for WIPP; The Methodology to Reduce Technical Uncertainty; The Interrelationships Between the Waste Acceptance Criteria (WAC), Performance Assessment (PA), and No Migration Petition (NMP); The WAC Certification (WACC), Quality Assurance/Quality Control (QA/QC), and Security; The RFP Waste Certification Validation Program; PA and Operations Demonstration (OD); Transportation; and Miscellaneous.

The BRP was provided with a substantial library of documents and, in turn, requested numerous other references. In addition to the documents, verbal information obtained outside of the formally-convened BRP meetings is referenced in Appendix A. This panel report is based on the review of information provided in Appendix A.

III. EXECUTIVE SUMMARY

The Executive Summary is presented in viewgraph format in Figures 1 through 3.

IV. ASSESSMENT

The major findings can be summarized into four statements:

(1) The various technical, plant, and operational groups supporting the WIPP Program demonstrate technical competence and excellent motivation;

(2) The WIPP Program embraces three important and entwined national issues -- development of a geologic disposal facility for nuclear wastes, implementation and rationalization of current conflicting mixed waste regulations, and management of TRU wastes as part of the production of defense nuclear materials;

(3) The TRU/Mixed TRU Waste and WIPP Program requirements have developed based on dynamic national defense, technical, public, and regulatory needs. The current unfocused program strategy and execution reflect this erratic process; and

(4) The TRU/Mixed TRU Waste and WIPP Program effectiveness, organizational charters, programmatic and technical integration, and conflict resolution lag behind the unfolding requirements.

These findings contribute greatly to the current WIPP dilemma and, in a significant way, have lead to the specific BRP assessment issues. In addition to the responses to the specific questions posted to the panel, these findings lead to the following major recommendations:

(1) DOE should develop a proactive DOE-wide Mixed Waste Management strategy; establish a program management structure aligned with the strategy; assign a full-time HQ-field program management organization and staff to execute the strategy in an integrated, coherent manner; and centralize authority at the HQ level; and

(2) DOE should adopt a formal systems engineering approach to the design, testing, and operation of the WIPP. This process should begin with the systematic identification of all requirements that must be meet to establish an operational WIPP facility and a Management Plan to achieve the desired program goals.

The remainder of this report provides the rational for the recommendations outlined in the Executive Summary.

V. OBSERVATIONS, RECOMMENDATIONS AND DISCUSSION:

A. Validation of RFP Waste Certifications

The circulated RFP Certified Waste Verification Program Plan, September 13, 1989, Reference 60, was withdrawn for further DOE staff coordination. The review of the WIPP WAC and the RFP WAC Certification Process suggests five issues that underlie the certification process.

1. Is the management of the standard appropriate to the WIPP and TRU/Mixed TRU Waste Program?

OBSERVATION A.1:

The WIPP WAC is the integrating configuration control document for DOE's TRU Waste Management Program, but it does not fully integrate the TRUPACT II, Performance Assessment, Consultation and Cooperation (C&C) Agreement, Stipulated Agreement, and RCRA requirements to establish a single standard for TRU/Mixed TRU waste acceptable for disposal at WIPP.

FIGURE 1: VALIDATION OF RFP WASTE CERTIFICATIONS

WIPP BLUE RIBBON PANEL CHARTER

INDEPENDENT VALIDATION OF THE CERTIFICATION OF ROCKY FLATS PLANT (RFP) WASTE AT BOTH ROCKY FLATS AND AT IDAHO NATIONAL ENGINEERING LABORATORY (INEL) FOR SHIPMENT TO WIPP

KEY QUESTIONS:

- *IS THE MANAGEMENT OF THE WAC STANDARD APPROPRIATE?*
- *IS THE WAC WASTE PACKAGE CERTIFICATION PROCESS ADEQUATE?*
- *IS THE WIPP WASTE INFORMATION SYSTEM DATA BASE ACCURATE?*
- *IS THE WIPP WAC QA PROGRAM EFFECTIVE?*
- *WHAT SHOULD THE RFP RECERTIFICATION PLAN BE BASED ON?*

IS THE MANAGEMENT OF THE WAC STANDARD APPROPRIATE?

RECOMMENDATION A.1:

- SEPARATE THE WAC APPROVAL AUTHORITY FROM THE CERTIFICATION AND AUDIT FUNCTIONS
- CHARTER A TRU/MIXED TRU WASTE ACCEPTANCE CRITERIA CONFIGURATION MANAGEMENT BOARD TO INTEGRATE, COORDINATE, AND APPROVE THE WIPP WAC
- RECHARTER THE WIPP WAC CERTIFICATION COMMITTEE TO CERTIFY AND AUDIT THE WAC CERTIFICATION PROCESS AT THE OPERATING SITES

IS THE TRU/MIXED TRU WASTE CERTIFICATION PROCESS ADEQUATE?

RECOMMENDATION A.2:

- SAMPLE WASTE PACKAGES AT RFP ROUTINELY
- DEVELOP AND USE HAZARDOUS WASTE ASSAY INSTRUMENTATION
- CROSS-CALIBRATE ASSAY INSTRUMENTATION AMONG OPERATING SITES
- OBTAIN RCRA HAZARDOUS MATERIALS DATA DURING ROUTINE PACKAGE SAMPLING
- ASSESS RTR TECHNICIAN PERFORMANCE ON A ROUTINE BASIS
- DOCUMENT RTR TECHNICIAN PREREQUISITE SKILLS AND WORK FUNCTIONS.

IS THE WIPP WASTE INFORMATION SYSTEM (WWIS) DATA BASE ACCURATE?

RECOMMENDATION A.3:

- ESTABLISH GLOBAL WWIS SECURITY AND QA STANDARDS
- AUTOMATE DATA TRANSFER AS MUCH AS POSSIBLE TO REDUCE HUMAN ERROR
- VERIFY ON ARRIVAL AT WIPP EACH PACKAGE DATA DESCRIPTION USING AN EASILY MEASURED PARAMETER (SUCH AS WEIGHT)

FIGURE 1: VALIDATION OF RFP WASTE CERTIFICATIONS (CONT)

IS THE WIPP WAC QA PROGRAM MANAGED AND EXECUTED EFFECTIVELY?

RECOMMENDATION A.4:

- CONDUCT AN INDEPENDENT REVIEW OF THE WIPP WAC QA PROGRAM

WHAT SHOULD THE RFP RECERTIFICATION PLAN BE BASED ON?

RECOMMENDATION A.5:

- INCORPORATE IN THE RECERTIFICATION PROCESS:
  - CERTIFIED AND PROPER TECHNICAL PROCEDURES WITH RANDOM PHYSICAL PACKAGE INSPECTION
  - RFP ON-SITE WASTE RECERTIFICATION BY OTHER THAN RFP EMPLOYEES
  - FULL-TIME WACCC AUDIT TEAM PRESENCE DURING CERTIFICATION PROCESS
  - 100 PERCENT COMPARISON OF ORIGINAL VS NEW RTR TAPES OF EACH ON-SITE RFP TRU WASTE PACKAGE AT SWEPP

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RECOMMENDATION A.5 (CONT):

- CONDUCT AN UNANNOUNCED AUDIT OF RFP RECORDS BASED ON A CONTROLLED AUDIT PLAN
- PREBRIEF RECERTIFICATION GOALS AND PROCEDURES TO ALL AFFECTED STATE GOVERNMENTS
- POST BRIEF ALL AFFECTED STATE GOVERNMENTS ON THE RESULTS OF THE AUDIT
- ANNOUNCE PROGRAM RESULTS PUBLICLY

FIGURE 2: THE RELATIONSHIP BETWEEN THE PERFORMANCE ASSESSMENT AND OPERATIONAL DEMONSTRATION

WIPP BLUE RIBBON PANEL CHARTER

CONCEPT AND TIMING FOR THE WIPP OPERATIONS DEMONSTRATION TEST PLAN

WHETHER THE WIPP PROGRAM CAN PERFORM AN OPERATIONS DEMONSTRATION IN PARALLEL WITH THE CONDUCT OF PERFORMANCE ASSESSMENT EXPERIMENTS

KEY QUESTIONS:

- WHAT IS THE TECHNICAL PURPOSE AND PHASING OF THE PA AND OD?
- WHAT SHOULD BE DONE TO ENSURE OPERATIONAL READINESS FOR THE OD?
- WHAT IS THE RELATIONSHIP OF WIPP TO THE DEFENSE NUCLEAR MATERIALS PROGRAM?

WHAT IS THE TECHNICAL PURPOSE AND PHASING OF THE PA AND OD?

RECOMMENDATION B.1:

- SEPARATE THE WIPP TEST PLAN INTO THE TWO DISTINCT PARTS (PA AND OD) AND CLEARLY DEFINE THE GOALS FOR EACH
- START THE PA AT WIPP AS SOON AS THE LAW PERMITS
- START A LESS-THAN-FULL SYSTEM OD BEGINNING WITH THE EMPLACEMENT OF PA WASTE
- TECHNICALLY START A FULL-SYSTEM OD WITH THE FILLING OF THE BACKFILLED ALCOVE TESTS AND TIME FULL-CAPACITY TESTING TO BRIDGE WITH THE START OF WIPP DISPOSAL OPERATIONS
- SCOPE THE OD TO DEMONSTRATE TECHNICAL GOALS OF FULL-SCALE TRU/MIXED TRU WASTE MANAGEMENT TEST

WHAT SHOULD BE DONE TO ENSURE OPERATIONAL READINESS FOR THE OD?

RECOMMENDATION B.3:

- IDENTIFY ALL STATUTORY, REGULATORY, AND TECHNICAL REQUIREMENTS TO EXECUTE THE OD
- CONDUCT A READINESS REQUIREMENTS REVIEW USING A FORMALLY TASKED MULTIDISCIPLINARY REVIEW GROUP

WHAT IS THE RELATIONSHIP OF WIPP TO THE DEFENSE NUCLEAR MATERIALS PROGRAM?

RECOMMENDATION B.3:

- ISOLATE WIPP, AS MUCH AS POSSIBLE, FROM THE OPERATIONAL REQUIREMENTS OF THE DEFENSE NUCLEAR MATERIALS PRODUCTION PROGRAM
- DEVELOP A TRU/MIXED TRU WASTE STORAGE PLAN TO ADDRESS THE DEFENSE NUCLEAR MATERIALS PRODUCTION WASTE STORAGE ISSUE
- DEVELOP A PREAPPROVED RETRIEVAL AND STORAGE PLAN IF WIPP IS PROPOSED AS A TEMPORARY STORAGE FACILITY FOR CURRENT RFP PRODUCTION WASTE

FIGURE 3: THE MAJOR TRU/MIXED TRU WASTE MANAGEMENT PROGRAM ISSUES

IMPORTANT FINDINGS

THE FINDINGS OUTLINED ON THE FOLLOWING PANELS CONTRIBUTE IN A MAJOR WAY TO THE CURRENT WIPP DILEMMA AND THE SPECIFIC BLUE RIBBON PANEL ISSUES.

- *THE WIPP TEAM IS IMPORTANT TO THE PROPER AND SAFE EXECUTION OF THE TEST PLAN*
- *THE WIPP PROGRAM ADDRESSES THREE MAJOR NATIONAL ISSUES*
- *A MIXED WASTE MANAGEMENT POLICY AND STRATEGY ARE NEEDED*
- *THE MANAGEMENT OF THE MIXED WASTE PROGRAM SHOULD BE RESTRUCTURED*

THE WIPP TEAM IS IMPORTANT TO THE PROPER AND SAFE EXECUTION OF THE WIPP PROGRAM

RECOMMENDATION C.1:

- ASSESS THE IMPACT OF WIPP PROGRAM DELAYS ON TEAM EFFECTIVENESS AND PERSONNEL RETENTION

THE WIPP PROGRAM ADDRESSES THREE MAJOR NATIONAL ISSUES

RECOMMENDATION C.2:

- SEPARATE THE THREE ISSUES – DEFENSE MATERIALS PRODUCTION, MIXED WASTE REGULATION, AND WIPP FACILTY DEVELOPMENT
- ADDRESS EACH ISSUE ON ITS OWN MERIT
- IDENTIFY EXPLICITLY THE COMMON ISSUES OF CONCERN AND THE TRADE-OFFS

A MIXED WASTE MANAGEMENT POLICY AND STRATEGY ARE NEEDED

RECOMMENDATION C.3

- DEVELOP A NATIONAL MIXED WASTE MANAGEMENT STRATEGY
- WORK COOPERATIVELY, AT AN ACCELERATED PACE, WITH EPA TO DEVELOP A COHERENT MIXED-WASTE REGULATORY FRAMEWORK (INDEPENDENT OF THE WIPP PROJECT)

FIGURE 3: THE MAJOR TRU/MIXED TRU WASTE MANAGEMENT PROGRAM ISSUES (CONT)

THE MANAGEMENT OF THE MIXED-WASTE PROGRAM SHOULD BE RESTRUCTURED

RECOMMENDATION C.4:

- **ESTABLISH A FULL-TIME TRU/MIXED TRU WASTE MANAGEMENT OFFICE AT HQ WITH THESE SUBFUNCTIONS:**
  - **STRATEGIC PLANNING AND REQUIREMENTS**
  - **WIPP PROGRAM**
  - **WIPP WAC CONFIGURATION MANAGEMENT**
  - **WIPP WAC AUDIT OFFICE**
  - **WIPP WASTE INFORMATION SYSTEM**

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RECOMMENDATION A.1:

DOE should separate the WAC approval authority from the WAC Certification and Audit functions. A TRU/Mixed TRU Waste Acceptance Criteria Configuration Management Board (WACCMB) should be established to review and approve the WAC and modifications to it. The WACCMB should report to the person responsible for DOE's TRU/Mixed TRU Waste Management Program in order to (af)fix? accountability. The WIPP WAC Certification Committee (WACCC) should be rechartered to certify and audit the WAC certification process employed at the generation and storage sites.

DISCUSSION A.1:

WIPP safety and the management and integrated control of DOE's TRU/Mixed TRU Waste Management Program is based on the WAC and the WIPP Waste Information System (WWIS). The WAC development, approval, and modification process should be independent from the certification and audit function, the WIPP Program, and the generation/storage sites. A separately chartered WACCMB reporting to a single individual responsible for managing the DOE TRU/Mixed TRU Waste Management Program would provide this independence.

The present WAC does not integrate TRUPACT II requirements, the PA parameters, agreements with the State of New Mexico, and RCRA requirements. The WAC and TRUPACT II requirements differ, and the current RCRA requirements are not incorporated in the WAC. Coordination with the New Mexico Environmental Improvement Division (EID) is necessary to ensure regulatory consistency between the WAC, the State EPA-equivalent licensing requirements, and the terms of agreements with the State of New Mexico. Presently, there is inadequate integration of the WAC and the definition of the physical characteristics of the waste source term used in PA analyses. Previous PA and Safety Analyses have treated hazardous materials separate from radioactive ones. For example, the current PA does not assume hazardous materials as contaminants (except for lead); it ignores the waste liquids as a potential carrier medium; and it does not consider various volatile organic compound (VOC) transport mechanisms.

The WAC is the integrating document that ultimately establishes the physical character of the WIPP source term and, hence, is an important factor in the long term safety of the facility.

2. **Is the TRU/Mixed TRU waste certification process adequate?**

OBSERVATION A.2:

M

The current waste certification process uses process knowledge to characterize hazardous waste streams. The process knowledge methodology tends to classify mixed wastes conservatively. Current hazardous waste data are based on a few samples of waste package analysis. The Real-Time-Radiography (RTR) operation is the most subjective aspect of the certification process and requires well-trained technicians.

RECOMMENDATION A.2:

RFP should, as part of its routine QA function, physically sample certified waste drums on a random basis to ensure compliance with the WAC and verify RTR certification. During the sampling, additional hazardous material data should be gathered. Hazardous waste assay instrumentation should be developed to better document the hazardous waste component. Assay instrumentation should be cross-calibrated among operating sites. RTR operator performance should be routinely

assessed. Furthermore, the current RTR operators should be evaluated to determine what individual skills are required to maintain a high level of performance. This study will provide a basis for future RTR training, selection, and certification of candidate technicians.

DISCUSSION A.2:

There is an inconsistency of technical effort, waste characterization, and data as it pertains to the radioactive and hazardous waste components of the TRU/Mixed TRU wastes.

The methodology for long-term radioactive waste disposal safety evaluation requires a performance assessment with potential human intrusion; whereas, RCRA requirements are being met based on a successful No Migration Petition (NMP) which does not model human intrusion. If the NMP is denied or substantively challenged, quantitative data are inadequate to support a detailed RCRA safety and health analysis. Except for sludges, current waste is RCRA type classified based on process knowledge using very conservative estimates for hazardous material content. Given the risks and technical difficulties in obtaining representative data, process characterization is a reasonable methodology, but nondestructive hazardous materials assay methodologies should be investigated to increase the available data.

Furthermore, if these conservatively estimated quantities of hazardous materials are present in the source term, detailed analyses of potential leakage from the disposal site do not consider the liquid components as adding to the total liquid volume nor as hazardous components in long-term safety studies. Current PA analyses do not consider the hazardous material, except lead, as potential contaminants for safety analysis.

The data establishing hazardous material quantities are based on a few sampled drums (not including sludges). All waste drums are being vented, and this process may provide an opportunity to sample the volatile compounds in the drum head space. The gas data could provide the basis for estimating the VOC content.

At present, RFP does not routinely open drums to supplement the nonintrusive certification procedure. Additionally, at RFP (as at SWEPP), the certification process depends on the subjective judgement of the RTR technician. This and the process knowledge waste classification methodology are the most subjective aspects of TRU/Mixed TRU Waste certification. Over the past four years, RTR technicians have complied an outstanding record. QA checks of RTR tapes are made for one in three certified and for all uncertifiable drums. QA has yet to dispute the judgement of the on-line RTR technician. Notwithstanding this exemplary record, the prerequisite skills and work load/functions required of an RTR technician to maintain this quality standard should be documented.

3. Is the WIPP Waste Information System (WWIS) data base accurate?

OBSERVATION A.3:

The WWIS is central to effectively execute the TRU/Mixed TRU Waste Management Program. Local data management systems that feed WWIS were developed to meet individual operating needs and conditions. Substantial data are manually entered into the local data bases. No consistent security or QA standard is applied to the total (local and WWIS) system.

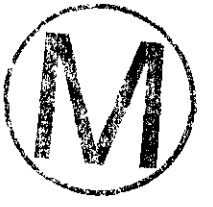

RECOMMENDATION A.3:

A security and QA review of the WAC Program, especially the WWIS and local waste management data bases, should be conducted to assess its vulnerability to deliberate malfeasance

and sabotage and to reduce the potential for human transcription error. Methods to automatically transfer WAC data during the certification process should be considered. Finally, waste package data should be verified upon receipt at WIPP. An easily measured parameter, such as weight, could be used.

DISCUSSION A.3:

The WWIS is central to the effective execution of the TRU/Mixed TRU Waste Management Program. The WWIS provides the data for all TRU/Mixed TRU waste, the coordinating link in transferring this waste between generation, storage, and transportation and ultimately to the WIPP. After the waste package is certified and labelled, there is no verification step to ensure that the package and the data base entry are consistent and that gross package content changes have not occurred.

The WWIS receives data from various local generating and storage site data bases. For example, the local data base at RFP evolved over many years to meet operational requirements without regard to consistency with WIPP requirements. The current RFP system user passwords are permanently assigned, a carry over from an earlier working procedure. Although a security standard has been implemented for the WWIS, there is no consistent security standard applied to the total system, comprised of this variety of data bases.

Currently, RFP waste certification technicians manually enter data developed during the waste package certification process. A waste certifier verifies each entry by comparing the process data sheets and the data file. Although independent checks are being accomplished (RFP is upgrading its system to automate data entry), manual data entry is a potentially large source of inadvertent or deliberate error.

4. **Is the WIPP WAC Quality Assurance Program managed and executed effectively?**

OBSERVATION A.4:

There was insufficient time for the panel to fully review the WIPP WAC Quality Assurance Program.

RECOMMENDATION B.4:

A review of the WIPP WAC Quality Assurance (QA) Program should be reviewed by an independent body. It could be a potential future BRP agenda item or could be accomplished by an outside Federal agency, e.g., the National Bureau of Standards.

DISCUSSION A.4:

The WIPP WAC QA serves as an important safeguard to ensure that the characteristics of the wastes repository source term remain consistent with the WAC criteria and with the parameters assumed for the PA analysis. Furthermore, Federal and state agencies will regulate the waste package contents.

5. **What should the major elements of the validation plan for the RFP-certified wastes be based on?**

OBSERVATION A.5:

Recertifying the RFP TRU/Mixed TRU wastes should accomplish two objectives: (1) proper technical certification of the RFP wastes based on

the WIPP WAC; and (2) assuring the public assurance that the certification process is properly conducted.

RECOMMENDATION A.5:

Recertification of the RFP TRU/Mixed TRU waste must be executed in a manner that is technically correct and which incorporates random physical inspection of the waste packages. Results should be made public. An unannounced audit of the RFP WAC certification process and waste records should be performed, and there should be a full-time presence of the WACCC audit team and a representative of the state regulatory agency during the recertification process. The actual recertification should be conducted by other than the RFP generating contractor and include a 100-percent QA check on all RTR tapes.

DISCUSSION A.5:

The RFP mixed-waste recertification dilemma has been caused, in part, by the change in the definition of TRU waste (lower limit changed upward from 10 nCi to 100 nCi per gram), the availability of more sensitive assay instrumentation, and the RFP practice of conservatively classifying the waste. The current estimate is that 10 percent or more of the RFP TRU/Mixed TRU waste at RFP, and a larger fraction of the RFP wastes at INEL, will be reclassified LLW/mixed LLW.

To improve the acceptability of the recertification results, the following are also proposed:

(1) An on-site WACCC Audit Team consisting of appropriate outside representation should monitor the total waste recertification process at RFP;

(2) Appropriate state regulatory and technical experts should be briefed and also observe recertification;

(3) An unannounced audit of RFP TRU/Mixed TRU waste records should be conducted specifically for technical accuracy and potential malfeasance;

(4) The RFP waste certification procedures and supporting waste information system should be reviewed to assess existing security measures;

(5) Calibration of all recertification systems, e.g., assay equipment, should be traceable to an appropriate standard and should be cross-calibrated between INEL SWEPP and RFP facilities;

(6) A 100-percent review of all RTR records of currently on-site RFP TRU/Mixed TRU waste should be conducted by INEL SWEPP or another qualified facility. The RTR tapes for each drum should be compared on an A-B basis--original certification versus recertification, with appropriate salting to ensure quality control. Furthermore, appropriate chain-of-custody rules must be established for all tapes;

(7) A predetermined number of all RFP waste containers should be opened to verify the waste classification;

(8) The RFP waste management system audit should be based on a limited-access audit plan;

(9) The objectives of the RFP waste recertification program should be made public and include proposed actions to improve the process; and

(10) The governors of Colorado, Idaho, and New Mexico should be briefed on the recertification plan, its objectives, and results.

B. <u>The Performance Assessment and Operations Demonstration Sequence in the Overall WIPP Test Plan</u>

The sequence of the OD vis-a-vis the PA in executing the WIPP Test Plan raises the four issues that are addressed below:

1. <u>What is the technical purpose of the PA and OD Tests, and what should their execution phasing be?</u>

<u>OBSERVATION B.1:</u>

As depicted by the briefings and documents, the PA experiments are designed to obtain the data for the final design of the WIPP and the supporting PA analysis for compliance with 40CFR191/286. Presently, the data are inadequate to accomplish final WIPP design. The full TRU Waste Management Systems OD test will assess the proper integration of the certification/packaging, transportation, and disposal subsystems, and operator training performance. The less-than-full system OD will begin with the insitu PA experiments. The full-system OD, an equivalent sub-scale WIPP demonstration, begins with the last two alcove tests that will be backfilled.

<u>RECOMMENDATION B.1</u>:

The WIPP Test Program should be divided into two distinct parts -- PA and OD -- with the objectives for each clearly identified. The insitu PA tests and experiments with actual waste should start as soon as the law permits. Based on technical reasons only, the planned start of the full-system OD should occur when the WIPP design is analytically finalized and the PA analysis based on this design meets the requirements of 40CFR191/286. The technical start of the full-system OD should begin with filling the backfilled alcoves. The scope of the system OD should be established to demonstrate that the TRU Waste Management System works as expected. The final ramp-up to full-scale operational rates should occur to blend naturally with the start of WIPP full operations. DOE should consider that a potential outcome of the PA might be that compliance with 40CFR191 cannot be reasonably achieved unless the waste is processed.

<u>DISCUSSION B.1</u>:

The WIPP facility is by far a safer concept for long term disposal than any of the current surface or near-surface storage facilities for TRU/Mixed TRU wastes. Furthermore, the technical and safety issues facing the WIPP Program are solvable with today's technology, but data are necessary to solve the technical issues.

The PA tests and experiments phase is intended to demonstrate the technical feasibility of the project and to establish the detailed WIPP disposal concept. Insufficient data are available today to specify the final design incorporating the five barriers that influence the release of waste materials from WIPP to the biosphere--the salt bed, the waste form, the aquifer, the prevention of inadvertent human intrusion, and the quantity of waste at risk if the salt barrier is breached. Until the design criteria and the credit allocable to each of these barriers are established and a safety analysis that meets 40CFR191

Part B (or its equivalent) is completed, the technical feasibility of the WIPP facility concept will not have been demonstrated. The PA goal is to establish the basis for the WIPP design that can be demonstrated in a subsystem OD.

The OD portion of the WIPP Test Program is a systems test of the TRU/Mixed TRU Waste Management System. The OD is very important to demonstrating that the waste management system is properly integrated, it can operate effectively, and it will operate safely. This system consists of three subsystems: waste packaging and classification; waste transportation; and WIPP operations. Each of these subsystems can be tested individually. In fact recertification of the RFP TRU/Mixed TRU waste is a limited scope OD of a generator and a storage site. Thus, two subsystems and a portion of the third subsystem will be operationally tested during the PA phase of the WIPP Test Program. Only the final room configuration, waste form, and anti-intrusion elements will not be tested. The technical start of the OD should coincide with the beginning of the last two alcove tests when the engineered modifications and backfill are incorporated with the waste package emplacement.

Until sufficient data are obtained during the PA portion of the WIPP Test Program and the final engineered modifications are completed, moving additional waste to the WIPP site incurs the risk of future retrieval, relocation, and processing and the associated loss of public credibility. There is a much smaller risk to public safety associated with transportation to the WIPP site. The degree of acceptable risk is a management decision. The real risk is public credibility. Moving the waste to a facility whose safety is not demonstrated analytically will be based largely on a "trust me" argument. Additionally, the acquisition of new knowledge and the ever-changing regulatory environment may require substantial modification of the WIPP disposal concept. This will result in further erosion of public confidence in the WIPP.

Even with the completion of the PA portion of the WIPP Test Program, there will be risks in beginning the movement of waste to WIPP. The slow processes that occur in the salt bed which enhance the long-term safety of the repository concept also require analysis and validation over a substantial time period: 100 to 200 years until the site achieves lithostatic equilibrium. Beginning with the PA, and continuing through the OD and full operations, there should be a test program to monitor filled rooms and provide early warning of potential problems. There will always be the concern for unexpected and unpredictable behavior of the repository even beyond the five-year test program (Consultation and Cooperation Agreement).

Finally, DOE should consider that a potential outcome of the test program might result in the conclusions that there is no reasonable way to demonstrate compliance with 40CFR191 without extensive modification. If the salt disposal concept is one of the safest geologic disposal options available (NRC-NAS 1957 and subsequently), what alternatives are available to remedy the current near-surface storage situation?

2. <u>What should be done to ensure operational readiness before and during the OD?</u>

<u>OBSERVATION B.2</u>:

The complex issues surrounding the WIPP Program necessitate a broad-based demonstration readiness program. It encompasses technical, systems, legal, regulatory, management, training, safety, and recovery planning.

RECOMMENDATION B.2:

A formal multidisciplinary review of the WIPP Program Operational Readiness requirements should be conducted.

DISCUSSION B.2:

No single individual can reasonably verify that all the OD readiness requirements have been identified and that the current plan has considered all the potential issues that could arise. A multidisciplined team of legal, regulatory, technical, safety, transportation, and Federal and state experts will be required to reasonably conduct such a review. The current status of the WIPP Program suggests a need for this review.

3. What is the relationship between WIPP and the Defense Nuclear Materials Production Program?

OBSERVATION B.3:

The WIPP development program is unnecessarily burdened by the perceived requirement to store operational TRU/Mixed TRU wastes in support of nuclear materials and weapons production.

RECOMMENDATION B.3:

DOE should separate WIPP from the operational defense nuclear material production program and develop a TRU/Mixed TRU Waste Storage Plan separate from the WIPP Test Plan.

DISCUSSION B.3:

Public Law 96-164 authorizes WIPP as "providing a research and development facility to demonstrate the safe disposal of radioactive wastes...." Further, the Consultation and Cooperation Agreement between DOE and the State of New Mexico establishes a five year test period during which the WIPP cannot be operated as a disposal facility. Prematurely incorporating WIPP into the defense nuclear materials production program jeopardizes the success of WIPP as a R&D demonstration project.

The TRU/Mixed TRU waste storage plan may include the WIPP facility. If WIPP is included, an agreed upon retrieval and temporary storage plan must be established among all involved parties to designate temporary storage facilities before implementation.

C. The Major TRU/Mixed TRU Waste Management Program Issues

1. The WIPP Team is important to the proper and safe execution of the WIPP Program.

OBSERVATION C.1:

A motivated and well trained WIPP Technical, Operations, and Management Team is essential to the success of the Program.

RECOMMENDATION C.1:

DOE should assess the personnel impacts of delays in the WIPP Program.

DISCUSSION C.1:

The WIPP Team has prepared itself technically and organizationally for a 1989-90 start to demonstrate an important national project. Circumstances beyond their control could delay this start, perhaps for many years. The retention of the highly trained and motivated team will be an important factor to the successful and safe execution of the test and evaluation phase of the WIPP Program. If a significant period of time lapses between the Test Phase and full operations, the OD results maybe rendered inappropriate.

2. The WIPP Program is attempting to address three major national issues.

OBSERVATION C.2:

The WIPP Program is faced with three major national issues: developing WIPP, establishing a workable set of mixed waste regulations, and supporting defense nuclear materials production.

RECOMMENDATION C.2:

DOE should separate the three issues and address each independently. The items common to two or more programs should be identified. Common issues can be solved for the common good; but the common items should be deliberately assessed, and the options specifically addressed to define the trade-offs that will occur.

DISCUSSION C.2:

The TRU/Mixed TRU Waste and WIPP Program is embroiled in three significant and conflicting requirements: developing a geologic disposal facility for nuclear waste, defining the mixed-waste regulatory requirements, and supporting a TRU/Mixed TRU waste management program to meet defense nuclear weapons production requirements. The Program does not have the management resources to adequately execute this complex, internally-conflicting program. Furthermore, a single solution to resolve these conflicting requirements is fraught with inconsistencies and jeopardizes the successful execution of the WIPP Program.

On the other hand, these three issues are intertwined and have intersections that are of common concern. An approach DOE might elect to pursue would be to identify all such items of common concern, then address each item explicitly and develop alternative solutions by identifying the trade-offs and impacts on each issue. A good start at systematically ordering these issues was provided to the BRP as a large graphic accompanying the Draft Decision Plan for WIPP, Revision 0, October 11, 1989.

3. A Mixed Waste Management Policy and Strategy are urgently needed.

OBSERVATION C.3:

The historic focus of the WIPP, WAC, PA, and DOE has been on the radiological hazards associated with TRU/Mixed TRU waste. The WIPP is establishing a regulatory precedent for managing mixed waste. This

precedent will affect the commercial power industry at the HLW repository project, current low-level mixed-waste storage and disposal sites and future options. Establishing mixed-waste regulations has a broader impact on national policy than just the WIPP Program.

RECOMMENDATION C.3:

DOE should establish an Office for Mixed-Waste Management and Policy and accelerate efforts to reconcile, with EPA, the differences between the RCRA and Radioactive Waste management regulations and develop a coherent DOE policy for managing and disposing of all US mixed-waste, commercial and defense. This office should be independent from the WIPP Program.

DISCUSSION C.3:

There is a fundamental conflict of interest in permitting the needs of the WIPP Program to drive the mixed-waste regulatory discussion. These regulations should be addressed from the national standpoint. Mixed-waste regulations will affect LLW disposal and storage and the HLW repository project. Future commercial nuclear power may use mixed fuels. Determining the future of this important regulatory arena based solely on a current program need is nearsighted.

4. **Management of the TRU/Mixed TRU Waste Program should be restructured.**

OBSERVATION C.4:

The management structure of DOE's TRU/Mixed TRU Waste Management Program is not clearly defined and is inadequately stated to provide dedicated, coherent top-level program direction. Indicators are that there is no coherent strategy or systems integration function for the TRU Waste Management Program to successfully transition WIPP from a research and development project to a waste disposal facility. As a result, there is an appearance of reactive rather than proactive program execution to achieve DOE TRU/Mixed TRU Waste Management goals.

RECOMMENDATION C.4:

DOE should establish a TRU/Mixed TRU Waste Program Office staffed, resourced, and chartered to manage this program. This office should be organized to establish a strategic planning and requirements function, the WIPP Development Program (i.e., the R&D, facility construction and operations, and safety analysis/EIS documentation), the WIPP WAC Configuration Management Board, the WIPP WAC Audit Office, and the Mixed Waste Information Systems Office.

DISCUSSION C.4:

The importance of WIPP to the national defense and the nuclear power industry cannot be overstated. Its success facilitates the execution of future defense programs, establishes an important milestone in the safe geologic disposal of nuclear waste, and indicates reconciliation of current conflicting environmental regulations governing mixed-waste.

During the past few years, the legal and operating requirements for WIPP have changed substantively, causing programmatic and technical redirection. The complexity of this management task has challenged DOE: there are indications that the program leadership has continually been placed in the position of responding rather than leading. Each of the program functional areas

demonstrates consistent and excellent technical knowledge, motivation, and dedication; however, more active management, integration, and planning would benefit the program. The following are examples of WIPP Program items where improvements can be made:

(1) A coherent, long-term schedule and detailed requirements statement for the TRU/WIPP Program;

(2) An active plan to work with the New Mexico Environmental Improvement Division (EID) to ensure that future regulations are consistent with the approved waste form (WAC);

(3) A formal risk assessment of the TRU/WIPP Program that identifies key issues with associated management action plans to resolve these issues;

(4) A clear definition of the PA and OD technical goals, separate from the nuclear materials production requirements;

(5) A Management Plan to take the TRU/WIPP Program through its various phases to eventual closure;

(6) A vigorous and proactive initiative to resolve the Mixed Waste Issue at the Inter-Agency Level;

(7) An integrated WAC process that formally incorporates input from the PA Analysis, the TRUPACT II requirements, the C&C Agreement, and the potential effect New Mexico RCRA regulations may have on the WIPP as a disposal facility;

(8) An aggressive effort to reconcile, with EPA, the mixed-waste regulations to meet national needs; and

(9) A coordinated WIPP retrieval and storage plan.

Appendix A

LIST OF REFERENCES

Appendix A

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1. "Agreement for Consultation and Cooperation" on WIPP by the State of New Mexico and U.S. Department of Energy, July 1, 1981, U.S. District Court for the District of New Mexico, Civil Action No. 81-0363 JB.
   a. First Modification to the July 1, 1981 "Agreement for Consultation and Cooperation" on WIPP by the State of New Mexico and U.S. Department of Energy, November 30, 1984.
   b. Second Modification to the July 1, 1981 "Agreement for Consultation and Cooperation" on WIPP by the State of New Mexico and U.S. Department of Energy, August 4, 1987.

2. Anderson, R., Sandia National Laboratory, telephone correspondence with author on Performance Assessment Analysis, September 21, 1989.

3. Bretzke, D'Ann, Building Manager, Rocky Flats Plant, telephone correspondence with author on Waste Certification, October 6, 1989.

4. Caldwell, John, Pajarito Scientific Research, telephone correspondence with author on Assay Instrumentation, September 21, 1989.

5. Cannon, Jonathan Z., U.S. Environmental Protection Agency, letter to Mr. Jack B. Tillman, U.S. Department of Energy, WIPP Project Office, on the EPA completeness review of the WIPP no-migration petition, June 7, 1989.

6. Chaturvedi, Lokesh, Evaluation of the DOE Plans for Radioactive Experiments and Operational Demonstration at WIPP, Environmental Evaluation Group, EEG-42, September 1989.

7. Chaturvedi, Lokesh, Invited Testimony by Lokesh Chaturvedi–Deputy Director, EEG–to Environment, Energy and Natural Resources Subcommittee of the committee on Government Operations–U.S. House of Representatives, June 12, 1989.

8. Chaturvedi, Lokesh, James K. Channell, Jenny B. Chapman, "Potential Problems Resulting from the Plans for the First Five Years of the WIPP Project", Waste Management '88, Vol. 2, University of Arizona, 1988.

9. Comptroller General of the United States, letter to the Honorable Mike Synar, Chairman, Environment, Energy, and Natural Resources Subcommittee, Committee on Government Operations, House of Representatives, on whether there is legal authority for the Governor of Idaho to close the state's borders to TRU waste shipments, June 1, 1989.

10. Duffy, Leo P., U.S. Department of Energy, letter to Dr. Peter B. Myers, Board on Radioactive Waste Management, National Academy of Sciences, containing responses to NAS recommendations not completed, August 18, 1989.

11. Environmental Evaluation Group, Interim Evaluation on Quantities of Transuranic Wastes to be Brought to WIPP for Performance Assessment and Operational Demonstration Prior to Demonstrating Compliance With EPA Disposal Standards, July 9, 1989.

12. Environmental Evaluation Group, Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, April 1989, EEG-41, July 1989.

13. Environmental Evaluation Group, Review of the Final Safety Analysis Report (Draft), DOE waste Isolation Pilot Plant, December 1988, EEG-40, DOE/AL/10752-40, May 1989.

14. Fultz, Keith O., Statement of Keith O. Fultz, Director, Energy Issues Resources, Community, and Economic Development Division–before the Environment, Energy, and Natural Resources Subcommittee–committee on Government Operations–U.S. House of Representatives, June 12, 1989.

15. Harlan, Ron, Rocky Flats Plant, telephone correspondence with author on Nuclear Instrumentation Development, October 6, 1989.

16. Hilbig, Jean, Rocky Flats Plant, telephone correspondence with author on Non-Weapons Quality Assurance Waste Inspection, October 6, 1989.

17. Hunter, Kent, U.S. Department of Energy, unpublished comments on the Validation of the RFP Certification Program. October 4, 1989.

18. Hunter, R.L., R.M. Cranwell, and M.S.Y. Chu, Assessing Compliance with the EPA High-Level Waste Standard: An Overview, Sandia National Laboratories for the U.S. Nuclear Regulatory Commission, NUREG/CR-4510, SAND86-0121, October 1986.

19. IT Corporation, presentation to the NAS titled Engineered Alternatives Task Force–Technical Approach, September 19, 1989.

20. IT Corporation, Waste Isolation Pilot Plant No Migration Variance Petition–Executive Summary, DOE/WIPP-89-003, February 1989.

21. Longsworth, Paul, Department of Energy, Letter to author transmitting summary documents on:
   a. Scenario Development and Screening
   b. Tests with CH-TRU and Simulated Wastes
   c. Schedule for laboratory Studies of Wipp Repository Chemistry
   d. Assumptions used in Scheduling of Bin-scale and Alcove Tests

22. Lowrance, Sylvia, Statement of Sylvia K. Lowrance–Director of the Office of Solid Waste–U.S. Environmental Protection Agency–before the Subcommittee on Environment, Energy, and Natural Resources of the Committee on Government Operations–U.S. House of Representatives, June 12, 1989.

23. Lytle, Jill E., Statement of Jill E. Lytle–Deputy Assistant Secretary for Nuclear Materials–Defense Programs–U.S. Department of Energy–before the Subcommittee on environment, Energy, and Natural Resources Committee on Government Operations–U.S. House of Representatives, June 12, 1989.

24. Meyers, Peter S., NAS, telephone correspondence with author on the proceedings of the NAS Board on Radioactive Waste Management Meeting September 18-19, 1989.

25. National Research Council, Board on Radioactive Waste Management, Review Comments on DOE Document DOE/WIPP 89-011: Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration, July 19, 1989.

26. National Research Council, Board on Radioactive Waste Management, Report on Brine Accumulation in the WIPP Facility, March 3, 1988.

27. Neill, Robert H. and Lokesh Chaturvedi, "Technical and Programmatic Evaluation of WIPP", Proceedings, Waste Management '89, Vol. 1, pp. 253-259, University of Arizona, 1989.

28. Neill, Robert H., EEG, letter to Mr. Jack B. Tillman, U.S. Department of Energy, WIPP Program Office, summarizing the results of a review of the "Draft Plan for the WIPP Test Phase: Performance Assessment and Operation Demonstration, DOE/WIPP 89-011, April 1989", May 15, 1989.

29. Newspaper Articles on WIPP from August 25 through September 26, 1989.

30. Newspaper Articles on: WIPP, Rocky Flats, Idaho/INEL for the Blue Ribbon Panel on WIPP, for September 1-22, 1989.

31. Public Law 96-164 [S. 673]; Title 1–National Security Programs, Section 213–Waste Isolation Pilot plant, Delaware Basin, New Mexico, December 29, 1979.

32. Rockwell International, Quality Assurance Program for TRU Waste Certification, WC-4500-3-D, October 28, 1988.

33. Rockwell International, TRU Waste Compliance Program for WIPP-WAC, WO-4500-6, January 16, 1989.

34. Rocky Flats Plant Item Description Codes, March 3, 1989.

35. Sandia National Laboratories, Disposal Room Systems Division, presentation titled Engineered Modifications–A Status Report on Laboratory and Systems Studies, undated.

36. Sandia National Laboratories, Disposal Room Systems Division, presentation titled Lab and Modeling Studies of Repository and Radionuclide Chemistry, undated.

37. Sandia National Laboratories, Division 6345, presentation titled Summary Status of WIPP "Gas Testing", undated.

38. Sandia National Laboratories, Nuclear Waste Technology Division, presentation titled WIPP In Situ CH TRU Waste Tests, undated.

39. Sandia National Laboratories, Performance Assessment Division, presentation titled Methodology Demonstration–September 18-19, 1989.

40. Sandia National Laboratories, Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant, ed. by S.G. Bertram-Howery and R.L. Hunter, SAND89-0178, UC-70, April 1989.

41. Sandia National Laboratories, Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant, Southeastern New Mexico; March 1989, ed. by A.R. Lappin and R.L. Hunter, SAND89-0462, UC-70, April 1989.

42. Tillman, Jack B., U.S. Department of Energy, WIPP Program Office, letter to Mr. Robert H. Neill, EEG, defining the rationale for the Rocky Flats Plant changes in Draft Revision H of TRU Waste compliance Program, January 18, 1989.

43. Tillman, Jack B., U.S. Department of Energy, WIPP Program Office, letter to Dr. Arthur S. Kubo, WIPP Blue Ribbon Panel, transmitting documents describing WWIS security, undate (ca October 10, 1989).
   a. WWIS Data Security and Integrity Report, Undated.
   b. WIPP Waste Information System (WWIS), WP 05-301, Rev 0, December 6, 1988.
   c. WIPP Waste Information System (WWIS), WP 05-302, Rev 0, December 6, 1988.
   d. WIPP Waste Information System (WWIS), WP 05-303, Rev 0, December 6, 1988.

44. U.S. Department of Energy, Assistant Secretary for Defense Programs, Draft Supplement Environmental Impact Statement–Waste Isolation Pilot Plant, Volume 1 of 2, DOE/EIS-0026-DS, April 1989.

45. U.S. Department of Energy, Assistant Secretary for Defense Programs, Final Environmental Impact Statements–Waste Isolation Pilot Plant, Vols 1 and 2, October 1980.

46. U.S. Department of Energy, Assistant Secretary for Defense Programs, Draft Supplement Environmental Impact Statement–Waste Isolation Pilot Plant, Vols 1 and 2, DOE/EIS-0026-DS, April 1989.

47. U.S. Department of Energy, Assistant Secretary for Defense Programs, Quality Assurance Program Description for the Office of Defense Waste and Transportation Management, DOE/DP-0058, May 1989.

48. U.S. Department of Energy, Attachment B to NuPac letter Ref. No. L-9853, Responses to the Request for Information in NRC Letter of May 19, 1989.

49. U.S. Department of Energy, Draft Decision Plan on WIPP (includes Interim Storage for RFP Waste and a large blueprint of Key Milestones for the WIPP Program), October 1989.

50. U.S. Department of Energy, Executive Summary–Environmental Impact Statement–Waste Isolation Pilot Plant, DOE/EIS-0026, October 1980.

51. U.S. Department of Energy, Management Organization Charts, transmitted August 25, 1989.

52. U.S. Department of Energy memorandum, Subject: Accelerated Effort to Complete Site-Wide As-built Drawings, May 8, 1989.

53. U.S. Department of Energy memorandum, Subject: EH Oversight of the Waste Isolation Pilot Project, Jun 1, 1989.

54. U.S. Department of Energy memorandum, Subject: RFP Salt Scrub Process Waste Information, August 7, 1989.

55. U.S. Department of Energy memorandum, Subject: Waste Isolation Pilot Plant Onsite Review of the Final Safety Analysis Report (FSAR) Trip Report, April 24-28, 1989, May 4, 1989.

56. U.S. Department of Energy, NuPac TRUPACT-II Safety Analysis Report, excerpts, Revs 0 and 1, May 1989.

57. U.S. Department of Energy, Office of Safeguards and Security, Security Education Handbook, undated.

58. U.S. Department of Energy various Organizational Charts, dated February 1988 through August 1989.

59. U.S. Department of Energy, presentation titled DOE Response to NAS/NRC/WIPP Panel Report, September 18, 1989.

60. U.S. Department of Energy, presentation titled Rocky Flats Plant Certified Waste Verification Program Plan, September 13, 1989.

61. U.S. Department of Energy, presentation titled Timing of Experiments Versus Performance Assessment Needs, undated.

62. U.S. Department of Energy, presentation to the Board on Radioactive Waste Management, National Academy of Sciences, titled Research, Development, Demonstration, Testing, and Evaluation for the Environmental Restoration and Waste Management Five-Year Plan, July 17, 1989.

63. U.S. Department of Energy, TRansUranic PACkage Transporter Model I (TRUPACT-I) Safety Analysis Report, undated.

64. U.S. Department of Energy, various memoranda on RFP Quality Assurance Program, dated April 19, 1984 through December 20, 1988.

65. U.S. Department of Energy, various memoranda on WIPP Waste Acceptance Criteria Certification Committee Audit dated June 6, 1985 through October 28, 1988.

66. U.S. Department of Energy, Waste Acceptance Criteria Certification Committee, comments on the RFP RTR Sampling Plan Draft, 87-RF-xxxx, March 11, 1988.

67. U.S. Department of Energy, Waste isolation Pilot Plant--Project Plan, approved April 6, 1984.

68. U.S. Department of Energy, Waste Isolation Pilot Plant--Project Plan, approved February 23, 1982.

69. U.S. Department of Energy, WIPP Project Office, Audit of TRU Waste Certification Activities at Rocky Flats Plant, Golden, Co, September 29 - October 3, 1986.

70. U.S. Department of Energy, WIPP Project Office, Audit of TRU Waste Certification Activities at Rocky Flats Plant, Golden, Colorado, July 15 - 19, 1985.

71. U.S. Department of Energy, WIPP Project Office, Audit of TRU Waste Certification Activities--Rocky Flats Plant, Golden, Colorado, August 3-7, 1987.

72. U.S. Department of Energy, WIPP Project Office, Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration, DOE/WIPP 89-011, April 1989.

73. U.S. Department of Energy, WIPP Project Office, Partial Audit of Rocky Flats Plant Attachment X--TRU Waste Certification Activities, April 14, 1987.

74. U.S. Department of Energy, WIPP Project Office, Plan for WIPP Performance Assessment and Operations Demonstration, March 20, 1989.

75. U.S. Department of Energy, WIPP Project Office, Reaudit of TRU Waste Certification Activities at Rocky Flats Plant, Golden, Colorado, February 24 - 25, 1987.

76. U.S. Department of Energy, WIPP Project Office, Waste Acceptance Criteria Certification Committee Audit Report, Audit Report Number W89-1, January 9-13, 1989.

77. U.S. Environmental Protection Agency, Part 191--Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, 40 CFR Ch. 1 (7-1-87 Edition).

78. U.S. Environmental Protection Agency, Working Draft 1 of 49 CFR Part 191, June 2, 1989.

Appendix B

BLUE RIBBON PANEL QUESTIONS FOR SEPTEMBER 25-26, 1989 MEETING

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Appendix B

BLUE RIBBON PANEL QUESTIONS FOR SEPTEMBER 25-26,1989 MEETING

1. ORGANIZATIONAL RELATIONSHIPS

a. Who is the single person at DOE HQs who is in charge of WIPP, and TRU and Mixed TRU waste management? (Kubo)

b. What is the line management organization beginning with the single person identified in 1.a. (DOE HQs) to the WIPP Principle contractors, e.g. Westinghouse, Sandia, Bechtel, etc? Clearly establish the TRU/Mixed TRU Waste Management Configuration Control Manager, the WIPP Engineering Change Proposal Approving Authority, and the Performance Assessment, QA/QC and the Waste Acceptance Criteria (WAC) Functions within the organization. (Kubo)

c. What is the line management relationship between the TRU waste generators and the WAC Certification Committee (WACCC)? Is there a DOE Order that requires TRU waste generators to comply with the WAC? What is the authority of the WACCC to conduct unannounced onsite audits of TRU/MIXED TRU WACC? (Kubo)

d. Who is the approving authority to modify process/production lines that generate TRU wastes? (Kubo)

e. What is the DOE practice to respond to comments made on the WIPP program (e.g., GAO and EEG testimony at 6/12/89 Synar Subcommittee hearing; the NAS 1984 report)? (Bishop)

f. Who has the authority to begin the Performance Assessment and Operations Demonstration (GAO at the 6/12/89 Subcommittee hearing stated that only Congress could approve; EEG stated that compliance with 40 CFR 191 Subpart A must be determined prior to commencement of the Operations Demonstration)? (Bishop)

g. If the Performance Assessment concludes that some type of waste segregation is important at the generating sites for overall system viability, does the WACCC have the authority to implement those requirements? If not, who does? (Bishop)

h. Has an evaluation of Rocky Flats Plant waste generation been undertaken on an integrated systems engineering basis (i.e., treating the waste as a product line)? Do waste activities compete with product activities for budget dollars? (Bishop)

i. Wouldn't membership on the WACCC of appropriate representatives from INEL and RFP better ensure the integration and coordination of activities and the implementation of a "no surprises" doctrine? (Bishop) As a follow-on, shouldn't the WACCC be chartered by DOE and have all generating sites represented? Clearly the WACCC is the configuration control group for TRU/Mixed TRU. (Kubo)

j. Why isn't waste treatment and disposal a component of DOE's determination at RFP and other manufacturing facilities of the Economic Discharge Limit (EDL)? (Bishop)

k. Are the DOE responses to the EPA questions regarding the No Migration Variance Petition being coordinated with the revision to the Supplemental Environmental Impact Statement and the Final Safety Analysis Report? (Bishop)

l. Please identify all the methods and locations currently used by DOE to store TRU and Mixed wastes? (Squyres)

m. What are the pros and cons (comparative costs and benefits) associated with continuing to store TRU and mixed wastes at the locations and with the methods set forth above, including regulatory, safety, national security and environmental issues? (Squyres)

n. What DOE organization is responsible for developing the WIPP waste retrieval plan? Is the approval of this plan on the critical path for the decision to ship waste to WIPP for experiments and the operations demonstration? (Slosky)

2. THE LEGAL BASIS AND REQUIREMENTS FOR WIPP

a. What is the legal basis to establish WIPP? What special or unusual authority was given DOE to design, construct, activate and operate/maintain WIPP? (Kubo)

b. What are the legal requirements for WIPP to begin the in-ground Performance Assessment (PA) experiments with actual wastes? (Kubo)

c. What are the RCRA and EPA requirements that WIPP must meet to begin the Operations Demonstration (OD)? Routine Operations and Maintenance? How does the No-Migration Petition fit into this? (Kubo)

d. How will the anticipated PA requirements differ from the remanded version of 40 CFR 191? (Kubo)

e. Has DOE evaluated the opportunity provided in 40 CFR Section 191.17 to advocate WIPP-specific criteria because of the unique characteristics of TRU waste and the WIPP facility? (Bishop)

f. Have any policy discussions been held with EPA to discuss the possibility that failure to meet the disposal standards of 40 CFR 191 (which may be without technical justification and thus arbitrary) will result in temporary storage for an indefinite period of time (which would provide a much greater hazard to the environment)? (Bishop)

g. Who at DOE is responsible for identifying statutory and regulatory requirements pertaining to WIPP and ensuring, on an integrated basis, that all WIPP related activities comport with those requirements? (Bishop)

h. Where and how is data on hazardous materials going to be collected and analyzed to satisfy RCRA requirements? (Bishop)

i. There appears to be a significant conflict between the EPA's regulation of (1) TRU waste; (2) hazardous waste; and (3) mixed wastes. How has DOE addressed this problem internally and with other members of the Executive Branch? (Squyres)

j. From a legal standpoint, can waste be put underground at WIPP before compliance with 40 CFR 191 Part B is demonstrated? (Slosky)

k. What type of RCRA Part B permit is required for WIPP? What other EPA permits (e.g., Safe Drinking Water Act) are required for WIPP? (Slosky)

l. Can land-banned wastes continue to be generated by DOE if the no migration petition is not approved? (Slosky)

3. THE METHODOLOGY TO REDUCE TECHNICAL UNCERTAINTY

a. What are the key technical issues that must be resolved to meet the PA and RCRA requirements for an operational WIPP? Which are known and what are uncertain? (Kubo)

b. What is the research plan to address the key technical issues identified above? (Kubo)

c. Explain the rationale for the room test if the waste drum positioning and the backfill composition will not resemble an operational configuration. Specifically, how do you assess the data obtained to extrapolate it to the actual waste disposal configurations and over time periods of 200 years. (Kubo)

d. Describe the areal extent of the mixing cell to assess the total release of hazardous and TRU materials to the environment. What portion of the repository is assumed to be the source term for the 10,000 year human intrusion scenario? (Kubo)

e. Has an analysis been made of the uncertainties identified in the data, models and analysis to date to ensure that the Performance Assessment Test Program is correctly focused at reducing those uncertainties to acceptable limits in support of the Performance Assessment? (Bishop)

f. Is DOE evaluating the technologies available to determine the hazardous material and organic components of each TRU Waste stream or package if either of those categories of materials become important in terms of the Performance Assessment or the facility's ability to comply with RCRA? (Bishop)

g. Is the WACCC requirement that generating sites estimate organic material to the nearest 10% sufficiently accurate for the site suitability analysis? Is the Performance Assessment evaluation using a probabilistic risk assessment for organic content? (Bishop)

h. Has the use of standard mixtures and weight percentages of radionuclides, as developed by INEL, been validated against actual waste being generated and has it been subjected to independent Quality Assurance assessment? Is the data consistent with the data being utilized in the SEIS, FSAR, No Migration Variance Petition, and Performance Assessment? (Bishop)

i. If the laboratory test described in DOE/WIPP 89-011, 2-84, will "bracket the times and conditions of interest for each important gas for 10,000 years," why does waste characterization, both as to radionuclides and non-radioactive materials, matter? (Bishop)

j. Has thought been given to using a supercompactor to simulate the salt creep and the resulting lithostatic pressure to which the waste will be subjected in WIPP? (Slosky)

k. What quantity of waste is needed for the bin-scale and the alcove-scale tests? What portion of the waste is scheduled to come from RFP and INEL? (Slosky)

l. Is RH waste needed for underground experiments at WIPP? If not, how will the performance of RH waste be assessed? (Slosky)

m. What technical information will the alcove-scale tests provide that the bin-scale tests will not? (Slosky)

n. Why can compliance (with 40 CFR 191 Part B) of the high-level waste repository be demonstrated without placing waste underground, when waste must be put underground to demonstrate WIPP's compliance? (Slosky)

o. What is the current thinking on the type of backfill to be used? What experiments (at WIPP or elsewhere) are planned to evaluate alternative backfill materials? (Slosky)

p. What is the current thinking on the types of room and shaft seals to be used? What experiments (at WIPP or elsewhere) are planned to evaluate alternative sealing approaches? (Slosky)

q. What is the current thinking on potential engineering enhancements? What experiments (at WIPP or elsewhere) are planned to evaluate alternative engineering enhancements? (Slosky)

r. What is the schedule for decisions on backfill, room and shaft seal and engineering enhancements? When will such decisions be incorporated into the PA? (Slosky)

s. What approaches are being used to determine the permeability of the collapsed waste rooms? (Slosky)

t. What is the sensitivity of the PA results to aqueous and organic liquids in the wastes? (Slosky)

u. Under the 3 or 5 year test plan, will the bin-scale and the alcove-scale test run long enough to produce sufficient data on gas generations? (Slosky)

4. <u>THE INTERRELATIONSHIPS BETWEEN THE WAC, PA AND NO MIGRATION PETITION (NMP)</u>

a. Define the legal and technical interrelationships between the WAC, PA and NMP? (Kubo)

b. What is the management plan to integrate the legal and technical compliance interrelationships between the WAC, PA and NMP? (Kubo)

c. What are the parameters assumed for the TRU/Mixed TRU source term for the PA calculations, e.g., initial and final conditions for density, initial hazardous and radioactive waste inventories, liquid content, etc? Additionally, what is the source for the data used to establish the source parameters? (Kubo)

d. How does DOE intend to address the inconsistencies between the No Migration Variance Petition and the Performance Assessment? (Bishop)

e. What mechanisms are in place to ensure the coordination of the Waste Acceptance Criteria with the facility operational analysis being undertaken to support the Performance Assessment (e.g., WAC allowance of 1% free liquid, compaction ratios to be achieved by RFP super compactor)? (Bishop)

f. What studies have been done to assess the long-term (200 year) performance of solidified waste forms? (Slosky)

g. What studies are currently underway and planned regarding waste treatment and the performance of treated waste forms in WIPP? How will the results of these studies be incorporated in the PA? (Slosky)

h. How will the fact that the WACCC can grant exemptions from the WAC be accounted for in the PA and the NMP? (Slosky)

i. What is the time schedule for the PA and the RCRA Part B application, and how do these relate to the various activities producing the data needed for the PA and the RCRA permit? (Slosky)

j. What is the difference between the PA and the consequence analysis? (Slosky)

k. How is criticality considered in assessing the performance of WIPP? (Slosky)

5. THE WAC CERTIFICATION (WACC), QA/QC AND SECURITY

a. Describe the WACC QA/QC procedures. Based on current WAC procedures, describe the range of uncertainties in percent of the nominal value for each measured WAC item, e.g. weight, fissile material content, hazardous material content, curie content, material species, etc. How are the range of uncertainties verified? (Kubo)

b. Describe the basis for each WAC item, the specific safety issue it addresses and why the limit was established. (Kubo)

c. Describe the procedures in place today that ensure the security of the WAC data base. For example, password control, administrative controls, etc. (Kubo)

d. Describe the experiments that validate the use of the carbon-carbon vent filters on the drums as it pertains to filter degradation with moisture and moisture entering the drum due to normal pressure differential aspiration. Once these vents are installed, how long can the drums be stored without a verification that the drum contents remain the same? (Kubo)

e. Are independent and routine reviews of the RTR tapes conducted to verify the quality of each operator? (Kubo)

f. The Waste Acceptance Criteria identifies 18 Quality Assurance program elements, yet it states that all 18 are not applicable to each Site Certification Plan. Why aren't they? (Bishop)

g. What evaluation was done to validate the Waste Acceptance Criteria against the requirements of 49 CFR 173 for Type A packages? (Bishop)

h. Does the WACCC intend to use its annual generating site audits to develop data that might be useful in trend identification and analysis of personnel and equipment performance? (Bishop)

i. Why aren't package specific records required to be retained post-emplacement to facilitate any problem resolution if it occurs (WIPP/DOE-120 P.13)? Similarly, why aren't certification records maintained beyond a subsequent audit so as to provide an ability for the WACCC to trend equipment degradation or programmatic weaknesses (WIPP/DOE-120, 12)? (Bishop)

j. If all generating site plans require the use of plastic liners, why doesn't the Waste Acceptance Criteria mandate their use (WIPP/DOE-114, Criterion 4.6)? (Bishop)

k. Why aren't specific requirements imposed by the WACCC regarding the number and location of labels to aid in potential package retrievability as well as to facilitate operations and associated quality assurance? (Bishop)

l. The Waste Acceptance Criteria specifies that no liquid waste form is acceptable, but allows minor liquid residue. This is apparently interpreted in practice to mean up to 1%; further conversations at INEL and RFP suggest that there was some correlation between the level allowed by the process and the detectability of liquids by RTR. Using ostensibly similar RTR equipment and trained operators, it was suggested that INEL uses a limit of .75 and RFP allows none (based on a discrimination threshold of "one teaspoon"). What is the real criteria, what is its basis, and what is the threshold of detection by the RTR? Why are adsorption materials not required to reduce free liquids to the minimum detectable? (Bishop)

m. What actions have been taken to identify the types and quantities of 40 CFR 261 Subpart C and D hazardous wastes that may be present in waste packages destined for WIPP? (Slosky)

n. How do the TRU waste generators and INEL determine compliance with the WAC for: corrosives, pyrophorics, explosives, and hazardous wastes (40 CFR 261 Subparts C and D)? (Slosky)

o. Does RFP and/or INEL have the laboratory equipment to determine the quantities of characteristic (40 CFR 261 Subpart C) and listed (40 CFR 261 Subpart C) hazardous wastes present in waste streams destined for WIPP? Does RFP or INEL participate in EPA's Contract Laboratory? (Slosky)

p. Have there ever been any TRU pyrophoric, explosive, or waste incompatibility problems at INEL or any of the TRU waste generating sites? (Slosky)

q. What methodology is being used at RFP for the Waste Characterization Study? (Slosky)

r. What methodology is used at RFP to "automatically designate" hazardous wastes? (Slosky)

s. Is it correct that the WAC do not require corrosives to be neutralized if a rigid liner is present? (Slosky)

t. Did the FY-83 through FY-85 TRU sampling program directly measure the radioactive and/or hazardous waste content of waste packages? Will the new sampling program make such measurements? (Slosky)

u. Are there radionuclides present in the TRU waste destined for WIPP that meet the RCRA definition of pyrophoric? (Slosky)

v. How has process knowledge been used to determine that explosive mixtures cannot occur in the TRU wastes? (Slosky)

w. Explain in more detail how the Passive-Active Neutron Assay system works. How does the system determine: fissile mass, total alpha, Pu-239 equivalent activity, and thermal power? (Slosky)

x. What are the capabilities and status of more accurate equipment to characterize the radioactive content of the TRU wastes? What modifications are being made to the SWEPP facility? (Slosky)

y. What activities are planned or underway to determine if some of the TRU waste in storage at INEL and RFP is actually LLW? Can these activities be accelerated? (Slosky)

z. What action is taken if a container is found to have more than 1000 curies of Pu-239 equivalent activity? (Slosky)

aa. Why are surface dose rate, surface contamination, and thermal power not rejection criteria? Is the PA based upon actual data on these parameters or the WAC for these parameters? (Slosky)

bb. Does WIPP/DOE-069 (page 42) correctly state that the surface contamination of the waste containers will result in the contamination of the WIPP waste handling building? (Slosky)

cc. What is the percentage contribution of the various processes (e.g., organic matter decay) to the total waste package gas generation? (Slosky)

dd. What is the status of the PREP facility? Can its operation be accelerated? Is the plan to grout the entirety of the drums processed through PREP or only the fine particles? (Slosky)

ee. What are the types and quantities of TRU waste that do not meet the WIPP WAC? (Slosky)

ff. What are the RECAP/PROP programs? (Slosky)

6. THE ROCKY FLATS PLANT (RFP) WASTE CERTIFICATION VALIDATION PROGRAM

a. How are hazardous waste identifiers and data entered into the waste data base? (Kubo)

b. What role should representative sampling of the waste barrels using the RTR methodology as an independent check of the physical opening of drums? (Kubo)

c. With respect to Rocky Flats Plant waste certification validation, has the proposed validation plan been evaluated against having INEL evaluate RFP wastes through the SWEPP process as an alternative to determine if the RFP certification process was properly conducted? What is the expected cost, both in terms of dollars and radiation exposure, of the proposed validation plan? What would the incremental costs be of evaluation of the same wastes through the SWEPP process? (Bishop)

d. If the proposed RFP certification validation program is approved wouldn't it be a wise use of resources to collect data on hazardous material and organic constituents to provide further insight in support of the No Migration Variance Petition and the Performance Assessment, as well as to provide data to substantiate potential modifications to the TRUPACT II Certificate of Compliance to handle the TRU waste which cannot presently be carried in TRUPACT II? (Bishop)

e. Has an assessment been made of the costs to locate a waste repackaging facility at WIPP sop that only wastes emplaced during the "Test Phase" that might have to be repackaged (instead of merely being overpacked) could be done on-site? (Bishop)

f. Does DOE have a plan for addressing the storage of TRU and mixed wastes that are WAC certified but not TRUPACT II certified? (Squyres)

g. In light of the FBI investigation, will a validation program conducted at the RFP or by RFP personnel have credibility? (Slosky)

h. Will the radiological and hazardous chemical contents of waste packages be directly measured in the validation program? (Slosky)

7. PERFORMANCE ASSESSMENT AND OPERATIONS DEMONSTRATION

a. What is the basis for the decision on the amount of waste to be used in the Performance Assessment and Operations Demonstration? Was a cost-benefit evaluation, including personnel exposure, conducted as part of the evaluation? (Bishop)

b. What are the estimated costs of conducting (1) the Performance Assessment Test Programs, (2) the Operations Demonstration, and (3) complete retrieval of wastes emplaced under both programs? (Bishop)

c. How was the airborne release set point in the WIPP exhaust shaft established? What time delay will occur from a release in an alcove or room at a locally hazardous level before that release exceeds the set point in the exhaust shaft to trigger the ventilation shaft, assuming appropriate ventilation dilution

factors? What local airborne monitoring system will be utilized when waste emplacement operations, either in the experimental rooms or as part of the Operations Demonstration, are underway? Will local alarms, both audible and visual, be provided and what personnel protective equipment will be provided to the site workers? (Bishop)

d. Please explain what DOE believes are the most severe adverse effects of the failure to begin the PA within the near term (3-5 months), the intermediate term (6-9 months) or the long term (beyond 9 months)? (Squyres)

e. The NAS review of the WI>PP Performance Assessment and Operations Demonstration draft plan (DOE/WIPP 89-011) states in the last paragraph of page 2 that it is unlikely that results of the experiments will be available for, or have any significant impact on the performance assessment. I'm told by EEG that results of the bin scale experiments will factor into the performance assessment but that alcove experiments may not. Is this the case? If so, what good will the alcove tests serve? Does DOE plan to delay the October 1992 decision data on performance assessment in order to factor in alcove test results that may come in after that date? (Bahr)

f. One concern about the operations demonstration program is if engineering modifications need to be made after emplacement of the waste, drums would have to be removed and perhaps be repackaged or in some other way modified. Should this be the case, where would the modifications be done? At the WIPP? At INEL? At generator sites? Who would make that decision? (Bahr)

g. Does DOE plan to enter into any agreements with New Mexico, Idaho, Colorado or any other state regarding the disposition of waste in the event it has to be retrieved from WIPP? (Bahr)

h. Who is responsible for the overall waste shipping plan, eg., which specific drums are shipped from where and when? Is there such a plan? How are the needs of performance assessment testing factored into this plan? The needs of the operations demonstration? (Bahr)

i. What information would be gained using "live" waste in the operations demonstration that cannot be gained by using "mock" waste for the operations demonstration? (Slosky)

8. TRANSPORTATION

a. Will a TRUPACK-II loaded with supercompacted CH drums (along with the tractor and trailer) exceed the 80,000 legal highway weight limit? (Slosky)

b. Will the total transportation unit for RH waste (cask, waste, tractor, and trailer) exceed the 80,000 legal highway weight limit? (Slosky)

c. Please provide a brief written comparison of the WIPP WAC to the NRC TRUPACT-II certification requirements. (Slosky)

d. What are the types and quantities of TRU and TRU-mixed wastes that cannot be shipped in TRUPACT-II? (Slosky)

9. MISCELLANEOUS

a. What is the capacity of WIPP with respect to: post-1970 TRU waste in storage at INEL and RFP, new TRU waste generation by the entire DOE complex, pre-1970 TRU waste buried at INEL, and anticipated TRU waste generation from DOE site cleanup actions? (Slosky)

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REPORT

TO THE UNITED STATES SECRETARY OF ENERGY

ON THE

WASTE ISOLATION PILOT PLANT

BY

Leonard C. Slosky

Member

WASTE ISOLATION PILOT PLANT

BLUE RIBBON PANEL

October 23, 1989

WASTE ISOLATION PILOT PLANT

BLUE RIBBON PANEL

REPORT BY

LEONARD C. SLOSKY

October 23, 1989

I. BACKGROUND

The Waste Isolation Pilot Plant (WIPP), as established by Public Law 96-164, is being developed by the United States Department of Energy (DOE) to demonstrate the safe disposal of transuranic (TRU) waste from the nation's nuclear weapons program.

WIPP is a mined repository located 2,150 feet below the surface of southeastern New Mexico. The repository is within a 2,000 foot thick formation of 225 million year old bedded salt. WIPP is designed to dispose of nearly six million cubic feet of TRU wastes produced between 1970 and the year 2013. It is the only TRU waste disposal facility under development in the United States.

II. INTRODUCTION

The WIPP Blue Ribbon Panel (BRP) was established by the Secretary of the United States Department of Energy (DOE) on August 31, 1989. Each of the five Panel members was charged to independently report on the following issues related to WIPP:

- The concept and timing of the draft plan for the WIPP test phase: the performance assessment (including the waste experiments) and the operations demonstration.
- Whether the operations demonstration should be conducted at the same time as the waste experiments and the performance assessment.
- The adequacy of plans to ensure that the TRU wastes generated by the Rocky Flats Plant (RFP) meet the waste acceptance criteria (WAC) for the WIPP.

The short amount of time allotted to the BRP, together with the complexity and extensive history of WIPP project, presented the BRP with a formidable task. Because of this, this report should be considered preliminary in nature. It also should be noted that the BRP was not charged and has not attempted to review all of the important issues concerning WIPP. In particular, the Panel has not addressed the operational readiness of WIPP.

III. BLUE RIBBON PANEL ASSESSMENT METHODOLOGY

The following methodology has been used by the BRP:

- During September 11-14, 1989, the BRP toured the WIPP, portions of the Idaho National Engineering Laboratory (INEL), and portions of the RFP. During this period the BRP was briefed by numerous DOE officials and contractors; Dr. Peter B. Myers, Staff Director of the National Academy of Sciences/National Research Council Board on Radioactive Waste Management; Mr. Robert H. Neill, Director and Dr. Lokesh Chaturvedi, Deputy Director and Engineering Geologist of the Environmental Evaluation Group, New Mexico. Most of the people who briefed the Panel also provided written materials.

- On September 25-26, 1989, the BRP convened a follow-up meeting in Denver, Colorado. At this meeting, a select group of DOE officials, DOE contractors, and a representative of the United States Environmental Protection Agency (EPA) were requested to respond to ten pages of questions prepared by the BRP.

- The BRP has been provided an extensive number of DOE documents, including *Draft Plan For The Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration*, April 1989 and June 1989 Addendum. DOE/WIPP 89-011; *TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, January 1989. WIPP/DOE-069, Revision 3.

- The BRP and individual Panel members have requested and been provided additional documents from DOE. Individual Panel members have held discussions with a broad range of individuals knowledgeable about WIPP.

Throughout the process, officials from DOE have been quite informative, candid, and helpful to the BRP.

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IV. EXECUTIVE SUMMARY

Following is a summary of the principal observations and recommendations.

1. The Waste Isolation Pilot Plant (WIPP) program is of major national importance even beyond the transuranic (TRU) waste management system. The success or failure of WIPP will have extensive impacts on the United States Department of Energy (DOE) as well as on civilian radioactive waste management programs.

2. DOE should implement an integrated management system for TRU waste and the WIPP program.

3. A considerable amount of work must be completed before WIPP can receive waste for the test phase. A number of potential legal challenges could impede the beginning of the test phase.

4. Rather than only including technical issues, the WIPP waste retrieval plan should address the regulatory and institutional actions required to store the waste if retrieval from WIPP becomes necessary.

5. Significant technical questions exist regarding the ability of WIPP to comply with the applicable regulatory requirements: the environmental radiation protection standards, the no migration exemption from the land disposal restrictions, and the hazardous waste facility standards. Despite the unresolved technical issues, bedded salt continues to offer outstanding qualities for the long-term isolation of TRU waste.

6. DOE should develop and publish within the next six months an integrated and coherent set of documents on the WIPP program:

First, a systematic assessment of the current understanding of the long-term performance of the WIPP repository, as recommended by the National Research Council. This document should include a sensitivity analysis and should clearly indicate existing uncertainties and the data needed to determine if WIPP complies with regulatory requirements.

Second, a generalized description of the laboratory, bin, and alcove experiments. This document should clearly indicate how the experiments address the data needs identified in the first document.

Third, a detailed technical description of the laboratory, bin, and alcove experiments.

7. Essential data from the bin and alcove experiments (particularly concerning gas generation) may not be available as soon as DOE expects. It is also very possible that the results from the planned tests will raise new issues that necessitate additional experiments. Thus, it may take longer than the three to five years DOE projects to determine WIPP's regulatory compliance.

8. It is imperative that the test phase not only obtain data on important technical issues such as gas generation, but also test solutions to these problems. Therefore, the alcove and particularly the bin tests should be expanded to include a broad range of: nonmetallic containers, treated waste forms, and additives to prevent gas build up.

9. Increased attention should be directed to evaluating potential waste treatment technologies. In contrast to other parameters affecting the performance of the repository (e.g., hydrogeologic processes), the waste form is one of the most controllable variables. Since about 90 percent of the total waste volume to be emplaced at WIPP is yet to be generated or will likely require repackaging, the opportunity exists to develop a more stable waste form that would moot a number of the unresolved technical issues and would dramatically improve the ability of WIPP to meet regulatory standards.

10. The bin experiments should begin as soon as possible. If WIPP cannot receive waste for experimental purposes by (or shortly after) mid-1990, the bin tests should be promptly initiated at another location.

11. The alcove tests are an important part of the WIPP test phase because they integrate important repository conditions that laboratory and bin tests cannot fully represent. However, current scheduling calls for the "final" performance assessment to be conducted before the majority of the alcove test results are likely to be available.

12. In total, about 5,900 drum-equivalents of waste are justified for the currently planned test program. This is equal to about 0.8 percent of total WIPP capacity. With the recommended expansion of the test program, about 8,800 drum-equivalents of waste (equal to about 1.2 percent of WIPP capacity) may be needed.

13. An operations demonstration is an important element in ensuring the operational readiness of a "production" facility. However, given the current degree of uncertainty regarding the ability of WIPP to meet regulatory requirements, it is not prudent to transport large quantities of waste (i.e., 2.5 percent of total capacity) to WIPP. In addition, since WIPP design and operational configurations are uncertain, an operations demonstration in the near-term would not be representative of actual repository conditions. If DOE wants to obtain more experience in the operation of the WIPP system at full-capacity, drums and standard waste boxes containing nonradioactive materials could be used. The Operations Demonstration should be separated from the Test Plan in order to avoid confusion.

14. It is not clear that a comprehensive assessment has been made of the applicability of federal and state hazardous waste regulations to the WIPP program. Considerably more attention to hazardous waste compliance issues is needed to prevent potentially serious delays in WIPP. DOE should aggressively work to resolve the applicability of the Safe Drinking Water Act's underground injection control requirements to WIPP.

15. DOE should expeditiously prepare a comprehensive hazardous waste compliance strategy. DOE should work closely with the State of New Mexico on the promulgation of mixed waste regulations and in the preparation of permit applications.

16. DOE should develop a comprehensive plan to characterize the hazardous (nonradioactive) components of TRU-mixed wastes being generated and in storage. The characterization plan must include substantial laboratory waste analyses.

17. DOE should take advantage of the opportunity to obtain hazardous waste characterization information when wastes are being processed for other purposes. This includes laboratory analyses when waste packages are opened and physically inspected for compliance with the waste acceptance criteria (WAC); head space gas analysis when waste packages are vented; and analysis of liquids resulting from the supercompaction of wastes.

18. Waste packages in the TRU waste inventory that are actually low-level wastes should be removed from the TRU waste inventory.

19. DOE needs to ensure that the databases being used for the performance assessment and other regulatory purposes are consistent with the WAC. It is not clear how the performance assessment will take into consideration the authority of the Waste Acceptance Criteria Certification Committee (WACCC) to exempt wastes from the WAC in the future.

20. DOE should integrate the WAC, the TRUPACT-II shipping requirements, and future hazardous waste restrictions into comprehensive criteria for certifying wastes for WIPP. Waste containers that are aspirated in non-humidity controlled environments should be subject to real-time radiography immediately prior to shipment to ensure that the criterion for liquids is not exceeded.

21. DOE should actively encourage and facilitate observers from the New Mexico Environmental Improvement Division, the Colorado Department of Health, the State of Idaho, and the Environmental Evaluation Group to accompany the DOE waste certification auditors.

22. Unannounced audits at each TRU waste generator facility should be conducted at least annually. The audits should include radiological assaying and real-time radiographic examination of a sufficient number of waste packages to ensure at least a 95 percent confidence level that wastes are being properly certified.

23. State representatives should be encouraged to observe the Rocky Flats waste recertification audits and inspections. The Rocky Flats waste recertification program should include the selection of waste packages by the audit team/state observers for radiological assaying and real-time radiographic examination under the audit team's review.

V. OBSERVATIONS, RECOMMENDATIONS, AND DISCUSSION

A. MANAGEMENT OF THE WIPP PROGRAM

Observation A.1:

The WIPP program is of major national importance even beyond the defense TRU waste management system. The success or failure of the WIPP program will have extensive impacts on the entire defense program of DOE, as well as on civilian radioactive waste management programs, both inside and outside of DOE. WIPP is an important test case for how the "DOE Culture" can adapt to the new environment of outside regulation and public scrutiny.

Observation A.2:

The DOE TRU waste management system is sufficiently complex as to necessitate a sophisticated systems management approach. Currently it appears that an adequate systems management approach is lacking.

Discussion:

It is acknowledged that integrating ten TRU waste generators (producing many different waste streams) with the first deep geological repository in the United States, while the regulatory environment is in flux, is far from a trivial matter. However, much greater emphasis on systems integration is needed for the DOE TRU waste management system to function effectively. The problem is not that individual elements of the program are inadequately managed. Many of the managers who briefed the BRP appeared to be doing an outstanding job with respect to their particular area of responsibility. Rather, the shortcoming is in the effective integration of the many elements comprising the DOE TRU waste management system.

Following are a few examples illustrating TRU waste management elements that do *not appear to be adequately integrated*:

- There does not appear to be a direct linkage between TRU waste generators implementing new waste treatment technologies and the performance of the WIPP site. There does not appear to be a central management focus for assessing question such as: What impact does the supercompaction of waste from the RFP have on the performance of WIPP? Does supercompaction pose repository critacility concerns? How are plans for changes in waste forms communicated to the WIPP performance assessment team? Who has the authority and the responsibility to determine if a new waste form will be acceptable at WIPP?

- The Waste Acceptance Criteria Certification Committee (WACCC) has the authority to approve wastes for disposal at WIPP that do not meet the WAC. How is this accounted for in the WIPP performance assessment? How can it be accounted for in the performance

assessment when the WACCC can exempt waste from the WAC years after the performance assessment is completed?

Recommendation A.1:

DOE should implement a comprehensive, integrated management system for TRU waste generation, treatment, transportation, storage, and disposal. The management system should encompass all DOE TRU waste generators and should include planning, research, and operational aspects of TRU waste management.

B. "DOE CULTURE"

Observation B.1

A number of the DOE managers who briefed the BRP exhibited a frustrated attitude, implying that WIPP is obviously an exemplary facility; why don't people just let us use it?

Discussion:

At a time when the preliminary performance assessments conducted by DOE indicate that WIPP does not comply with the Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes 40 CFR Part 191, Subpart B (EPA Standard) for human intrusion scenarios, such an attitude can easily be perceived as arrogant, sloppy, and unconcerned about safety and the environment. Such perceptions do not facilitate rational issue resolution.

Recommendation B.1:

DOE managers should recognize and exhibit in their attitudes that WIPP is being developed in a new era of external regulation. The mission of DOE is to carefully, scientifically, and systematically assess whether or not WIPP complies with the EPA Standard and other regulatory requirements. This means that all of the facts (and uncertainties), whether favorable or unfavorable to WIPP, need to be clearly presented and publicly debated.

C. PREREQUISITES TO THE RECEIPT OF WASTE AT WIPP FOR EXPERIMENTAL PURPOSES

Observation C.1:

A number of actions must be completed before waste can be received at WIPP, even for experimental purposes. The important milestones include, but may not be limited to:

- Obtaining a Resource Conservation and Recovery Act (RCRA) Part A Interim Status Permit by filing a complete Part A application pursuant to 40 CFR Part 270. Before this can occur, the State of

New Mexico must receive authorization from EPA to regulate mixed wastes.

- Receiving approval of the No Migration Petition from EPA to exempt WIPP from the Land Disposal Restrictions pursuant to 40 CFR Part 268.6.

- Demonstrating compliance with the EPA regulations on Environmental Standards for Management and Storage of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste, 40 CFR Part 191, Subpart A.

- Completing the Final Safety Analysis Report (FSAR).

- Completing the Operational Readiness Review (ORR).

- Complying with the Agreement for Consultation and Cooperation (C&C) between the United States Department of Energy and the State of New Mexico.

- Obtaining Land Withdrawal approval.

- Publishing the Final Supplement Environmental Impact Statement (FSEIS) on WIPP and issuing the Record of Decision (ROD).

- Issuing the final WIPP waste retrieval plan. Successfully completing the bin and alcove retrieval tests.

- Completing the Performance Assessment (PA) Plan.

Observation C.2:

Although the Secretary's Draft Decision Plan on WIPP (October 1989) identifies these actions, this list is provided to emphasize the considerable amount of work that must be completed for WIPP to receive waste for experiments, and to illustrate the numerous opportunities for legal challenges with which the WIPP program may have to contend.

Observation C.3:

DOE is currently developing a WIPP waste retrieval plan to address the technical aspects of waste retrieval, if WIPP is found unsuitable as a permanent repository.

Recommendation C.1:

The WIPP waste retrieval plan should address the regulatory and institutional requirements for implementing each waste retrieval alternative. Without consideration of such requirements, the institutional feasibility of the plan may be nil.

Observation C.4:

While many of the elements of the test program have been provided in various DOE documents, DOE has not adequately articulated the need for and design of the test program in an integrated manner.

Recommendation C.2:

DOE should develop and publish within the next six months a hierarchial, integrated, and coherent set of documents on the WIPP test phase. This set of documents should include:

- Preliminary WIPP Performance Assessment 1989--A systematic assessment of the current understanding of the long-term performance of the WIPP repository, as recommended by the National Research Council. This document should include analyses of a range of scenarios (including human intrusion) and a comprehensive sensitivity analysis. The report should elucidate the critical issues, uncertainties in data and models, and the parameters for which additional data are needed.

- Conceptual WIPP Test Phase Plan--A generalized description of the laboratory, bin-scale, and alcove-scale experiments already underway and planned for the test phase. This document should clearly indicate how the on-going and planned experiments address the data needs identified in the Preliminary Performance Assessment 1989, above. This document should replace the *Draft Plan For The Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration*.

- WIPP Experimental Design--A detailed technical description of the laboratory, bin-scale, and alcove-scale experiments to be conducted during the test phase. This document should be a more detailed technical version of the Conceptual WIPP Test Phase Plan, above. As with the Conceptual Plan, this document should indicate how the experiments will provide the data needs identified in the Preliminary Performance Assessment 1989.

D. CONCEPT AND TIMING OF THE WIPP TEST PHASE AND OPERATIONS DEMONSTRATION

1. Test Phase

Observation I.D.1:

Significant technical questions regarding the ability of WIPP to meet the EPA Standard and other regulatory requirements remain to be resolved. A carefully planned, integrated, and implemented suite of tests--laboratory, bin-scale, and alcove-scale--is needed to provide additional data for the performance assessment (to determine compliance with the EPA Standard), the no migration

petition, and the RCRA Part B permit application. Despite the substantial unresolved technical issues, bedded salt continues to offer outstanding qualities for the long-term isolation of TRU waste.

Observation I.D.2:

DOE plans call for a hold point after the first three years of the test phase to analyze the results of the performance assessment up to that point. If this review concludes that there is reasonable confidence that WIPP will meet the EPA Standard, then a decision will be made on the need for and the design of the second portion of the test phase. This approach has great merit. Because of the issues discussed below, it is likely that the second portion of the test phase will be required.

Observation I.D.3:

Because of the complexity and interaction of the technical issues that must be resolved, it may take longer than five years for adequate test results to be available to determine compliance with the EPA Standard. It is also very possible that either the laboratory, bin-scale, or alcove-scale tests will raise new issues requiring additional experiments.

Observation I.D.4:

One of the key questions the test phase needs to resolve is the net rate of gas generation/diffusion which results from at least five processes: chemical corrosion of the waste containers and metal within the wastes; biological decomposition of the organic matter in the wastes; radiolytic decomposition of waste materials; inflow of naturally occurring gas in the salt; and the diffusion of gas into the salt formation.

Because of the incomplete understanding of these processes and potential interactions among the processes, both the bin-scale and the alcove-scale tests may need to be conducted for a longer period of time than is anticipated in the test plan in order to obtain adequate data. This in turn means that the data needed for the "final" performance assessment may not be available in time to conduct the performance assessment on the current schedule.

Recommendation I.D.1:

The bin-scale and the alcove-scale tests should be continued at least until the decision is made regarding the suitability of WIPP as a permanent disposal site, and probably as long as WIPP is operational (25 or more years).

Observation I.D.5:

It is very important for the test phase not only to gather data on important technical issues such as gas generation, but also to test solutions to the potential technical problems. This means that the scope of the test phase experiments may need to be expanded. For example, it may be advisable to

include in the bin-scale tests nonmetallic containers (e.g. high integrity containers) and several different treated waste forms to address the gas generation issue. This means that an increased number of bins and a corresponding larger quantity of waste may be needed for the test phase. If such an approach is not taken, it is possible that following completion of the currently planned test phase, a subsequent test phase will be needed.

Recommendation I.D.2:

The test phase and the bin-scale experiments in particular should be expanded to include a broad range of potential solutions to the gas generation problem such as: gas getters, preventers, and recombiners; several treated waste forms; nonmetallic containers; etc.

Observation I.D.6:

Current plans call for the TRU waste to be emplaced in the WIPP repository in an essentially untreated form. In contrast with the other parameters affecting the performance of the repository (e.g., hydrogeologic processes), the waste form is one of the most controllable variables. Since about 90 percent of the total volume of contact-handled waste to be emplaced at WIPP is yet to be generated or is expected to require repackaging, the opportunity exists to develop a more stable waste form that would moot a number of the existing technical issues and would dramatically improve the ability of WIPP to meet the EPA Standard.

Recommendation I.D.3:

The test phase and the bin-scale experiments in particular should be expanded to include a broad range of potential treated waste forms, such as drum grouting, shredded waste, thermal treatments, etc.

Recommendation I.D.4:

On a periodic basis, DOE should assess the trade-offs between continuing to attempt to demonstrate compliance with the EPA Standard and other regulatory requirements using existing TRU waste forms versus committing to waste treatment(s) that would simplify and resolve many of the regulatory compliance issues.

Observation I.D.7:

The inclusion of the Operations Demonstration (which is perceived by some as a pretext to ship large quantities of waste to WIPP before compliance with the EPA Standard has been demonstrated) has confused the purpose of the test phase and has undermined its credibility.

Bin-Scale Tests

Description:

The bin-scale tests are divided into three phases as described below.

> Phase 1: Generally as-received waste, no backfill. Will utilize 40 bins containing about 210 drum-equivalents of uncompacted waste. In place 7/90.
>
> Phase 2: As-received and compacted waste, backfill in drums. Will utilize 76 bins containing about 390 drum-equivalents of uncompacted waste. In place 4/91.
>
> Phase 3: Largely undefined, but intended to incorporate contingencies and engineering modifications to waste and/or backfill. In place 12/91.

Phases 1 and 2 will require about 600 total drum-equivalents of waste. This is equal to about 0.08 percent of the total capacity of WIPP (for contact-handled waste).

Observation 1.D.8:

The bin-scale tests are an essential portion of the test program. The results of the bin-scale tests may be needed in order to obtain approval by EPA of the no migration petition. It is possible that regulatory or operational issues could delay the receipt of waste at WIPP for experimental purposes significantly beyond mid-1990.

Recommendation 1.D.5:

The bin-scale tests should begin as soon as possible. If WIPP cannot receive waste for experimental purposes by (or shortly after) mid-1990, the bin-scale tests should be promptly initiated at another location permitted for such purposes.

Observation 1.D.9:

Two important pieces of information are needed for the bin-scale tests that do not currently appear to be available: (1) chemical characterization of the Salado brine; and (2) characterization of the TRU waste inventory for hazardous waste components.

Discussion:

If the bin-scale tests are initiated and it is then determined that the Salado brine (which will interact with the waste in the repository) is significantly different in chemical composition than the brine used in the bin-scale tests, the bin-scale tests may not be representative of repository conditions and may need to be repeated. Likewise if the hazardous waste components of the waste

used for the bin-scale tests are not known or if they are found to be significantly different from the overall TRU waste inventory, the bin-scale tests will not have addressed important issues concerning repository performance and regulatory compliance.

Recommendation I.D.6:

The bin-scale tests should preferably use actual Salado brine or secondarily utilize simulated Salado brine developed after the Salado brine is adequately characterized. The wastes to be used for the bin-scale tests should be characterized for hazardous waste components. Further work is needed to determine how the hazardous waste characterization of TRU-mixed wastes can best be accomplished.

Alcove-Scale Tests

Description:

The alcove-scale tests consist of two phases as follows.

Phase 1: Intended to simulate the operational phase of WIPP; consists of two alcoves:

Alcove 1--empty (no waste) gas baseline-reference. Utilizes zero drums. In place 7/90.

Alcove 2--as received waste, no backfill. Utilizes 1,050 drum-equivalents. In place 7/90.

Phase 2: Intended to simulate the post-operational phase of WIPP; consists of four alcoves:

Alcove 3--specially prepared non-compacted waste with brine and backfill within drums. Will utilize 1,050 drum-equivalents. In place 5/91.

Alcove 4--specially prepared compacted waste with brine and backfill within drums. Will utilize 1,050 drum-equivalents. (Due to compaction, 350 drums will be shipped to WIPP.) In place 11/91.

Alcove 5--specially prepared, non-compacted waste with brine and backfill within drums. Also with external backfill in alcove. Will utilize 1,050 drum-equivalents. In place 11/91.

Alcove 6--specially prepared compacted waste with brine and backfill within drums. Also with external backfill in alcove. Will utilize 1,050 drum-equivalents. (Due to compaction, 350 drums will be shipped to WIPP.) In place 4/92.

In total, the alcove-scale test phases 1 and 2 will utilize about 5,250 drum-equivalents of waste. This is equal to about 0.7 percent of the total capacity of WIPP (for contact-handled waste).

Observation I.D.10:

The alcove-scale tests are an important part of the WIPP test phase. The alcove-scale tests are needed to investigate important repository conditions that *laboratory* and *bin-scale tests cannot fully represent*. Alcove-scale tests have the advantage of being able to more realistically represent:

- o *Potentially* synergistic effects of the repository itself (i.e., gases and brines released from the host rock, mine biochemistry, etc.) on the rates and modes of waste degradation and gas generation.
- o The full-scale size of the repository.
- o The radiological and hazardous waste source terms included in the large number of TRU waste types intended for disposal at WIPP.

Observation I.D.11:

While the experiments are planned to be conducted for a relatively short period of time (five years), the experiments are intended to provide information to allow prediction of repository behavior over the long-term (1,000 to 10,000 or even 100,000 years). The geohydrologic complexity of the WIPP repository makes the collection of meaningful and reliable experimental results extremely difficult. For example, will the disturbed rock zone interfere with measurements of the long-term salt permeability, as well as brine and gas inflow into the waste rooms? Will the disturbed rock zone have to be instrumented in order to determine its impact? Can the disturbed rock zone be instrumented without changing its properties.

Recommendation I.D.7:

Since alcove 1 (gas baseline-reference) does not require any waste it should be *initiated as soon as possible, preferably before 7/90.*

Timing of the Test Phase

Following is a listing of key events in the WIPP test program and their scheduling, as presently understood or inferred from a number of DOE documents and presentations to the BRP. This timeline assumes that waste receipts at WIPP begin in July 1990. This listing is not intended to indicate all of the important (or even critical-path milestones); it has been prepared to illustrate apparent problems in the sequencing of test phase activities. Therefore, what is important are not the specific dates but the sequence of events. (The current DOE schedule for the test phase is unclear; written

materials presented to the BRP within the last several weeks have different dates for a number of these activities.)

Activity	Date
Phase 1 bin experiments initiated	7/90
Alcove 1 experiment initiated	7/90
Alcove 2 experiment initiated	7/90
Engineering enhancements report, preliminary	8/90
Backfill selection complete	10/90
Engineering enhancements report, final	12/90
Large-scale room seal experiments complete	1/91
Phase 2 bin experiments initiated	1/91
Alcove 3 experiment initiated	2/91
Phase 1 bin experiments initial results	3/91
Alcove 4 experiment initiated	7/91
Decision on engineering enhancements	9/91
Phase 2 bin experiments initial results	10/91
Phase 3 bin experiments (with engineering fixes) initiated	12/91
Alcove 5 experiment initiated	1/92
Alcove 1 reliable results available	6/92
Alcove 2 reliable results available	6/92
Alcove 6 experiment initiated	7/92
Phase 3 bin experiments initial results	9/92
Latest date that data from the experiments can be used in "final" performance assessment	9/92
Alcove 3 reliable results available	5/93
Hold point for review of performance assessment	7/93

Draft EPA compliance report released	9/93
Alcove 4 reliable results available	11/93
Alcove 5 reliable results available	1/94
Alcove 6 reliable results available	9/94
Final EPA compliance report released/ Decision on WIPP as a disposal facility	9/94

Observation 1.D.12:

The scheduling of the test phase assumes that useful data will be rapidly available from the experiments. It is not likely that obtaining adequate data on gas generation will require significantly longer time periods.

Observation 1.D.13:

The scheduling of the test phase assumes that enough is known about the performance of TRU waste in salt to concurrently conduct the three scales of testing: laboratory, bin, and alcove. Given the current range of uncertainties and the complexity of the interactions, this assumption has a significant probability of turning out to be incorrect.

Observation 1.D.14:

Results from the engineering enhancements study will not be available until relatively late in the test phase. By the time decisions are made on engineering enhancements (9/92), all of the phase 1 and phase 2 bin tests will already be underway, as will alcove tests 1, 2, 3, and 4. This means only alcoves 5 and 6, and a third phase of bin-scale tests will be able to incorporate engineering enhancements that may be necessary for WIPP to comply with the EPA Standard.

Observation 1.D.15:

According to the existing schedule, the latest date that data can be input to the "final" performance assessment is 9/92. As of this date, reliable results from alcove tests 3, 4, 5, and 6 are unlikely to be available. In addition, if a third phase of bin-scale tests are needed, data from such tests are also unlikely to be available by 9/92. Thus, a significant portion of the data to be produced in the test phase will not be available in time to be used in the "final" performance assessment.

Recommendation 1.D.8:

Aside from delaying the "final" performance assessment, which may turn out to be inevitable, the primary action to increase the utility of the test phase is to increase the range of experiments conducted at the alcove-scale and particularly at the bin-scale.

Observation 1.D.16:

Alcoves 1 and 2 are scheduled to be sealed five months before the large-scale room seal experiments are scheduled to be complete. This is of concern because maintaining an airtight seal (to maintain anoxic conditions as will exist in the repository) is essential to the alcove tests.

Observation 1.D.17:

The alcove 3 experiment is scheduled to begin before significant data from the bin-scale experiments is likely to be available. This means that the backfill to be used in the drums in alcove 3 will be chosen before it is known if that backfill was effective in the bin-scale tests.

2. Operations Demonstration

Description:

The Operations Demonstration plan calls for the shipment of a large quantity (approximately 18,900 drums, which is equal to about 2.5 percent of the capacity of WIPP for contact-handled waste) of waste to WIPP essentially concurrently with the conduct of the bin-scale and alcove-scale experiments. This activity is intended to demonstrate the operational capability of the entire WIPP-related TRU waste management system including: generators' waste certification and TRUPACT-II loading, the transportation system, and waste receipt and emplacement at WIPP. The operations demonstration will not provide data useful in determining compliance with the EPA Standard.

Observation 2.D.1:

An operations demonstration is an important element in ensuring the operational readiness of a "production" facility. However, given the current degree of uncertainty regarding the ability of WIPP to meet the EPA Standard, it is not prudent to transport large quantities of waste to WIPP in the next several years. If WIPP is determined not to comply with the EPA Standard, all waste emplaced at WIPP would have to be removed and shipped elsewhere for storage, treatment, and/or disposal.

Observation 2.D.2:

Until a detailed study of engineering enhancements has been completed and reviewed, at least interim results are available from the bin-scale and alcove-scale experiments, and compliance with the EPA Standard has been demonstrated through performance assessment, the specific design and operational configuration of the WIPP underground will not be known. Thus, an operations demonstration prior to this point cannot demonstrate actual operational conditions. Therefore, a near-term operations demonstration will have limited value.

Observation 2.D.3:

The preparation of TRUPACT-II shipments by the generators, shipments along the transport routes, and emplacement of waste for the bin-scale and the alcove-scale experiments will provide significant operational experience. Assuming that 4,450 drums will be shipped to WIPP for waste experiments, about 106 TRUPACT-II shipments will be needed. If DOE believes that it is necessary, during the next few years, to obtain more experience or to demonstrate the operation of the WIPP system at full-capacity, nonradioactive simulated drums and standard waste boxes should be used.

Observation 2.D.4

The results of the test phase may necessitate the redesign of the waste rooms (e.g., smaller rooms to reduce the source term available for human intrusion) or treatment of the waste. If an operations demonstration is conducted prior to the resolution of such issues, it is possible that all of the waste emplaced for demonstration purposes would have to be moved to smaller rooms, removed for treatment at WIPP, or shipped elsewhere for treatment. This would result in significant additional radiation exposures to personnel, expense, and work effort.

Observation 2.D.5:

Plans for the Operations Demonstration appear to have been driven more by the need for additional TRU waste management capacity to serve defense program operational requirements than by the need for technical information related to WIPP. Regardless of the technical safety of storing wastes in WIPP, if DOE stores more waste in WIPP than is needed for waste performance experiments, DOE will be perceived as moving too fast, or of putting operational needs ahead of environmental and safety concerns.

Recommendation 2.D.1:

An operations demonstration with radioactive waste should be delayed until WIPP has been determined to comply with the EPA Standard and until the design and operational configuration of WIPP is resolved.

Recommendation 2.D.2:

The Operations Demonstration Plan should be separated from the Test Plan in order to avoid confusion. While the Operations Demonstration Plan and the Test Plan should be separated, it is important to recognize and maintain the interrelationships between these two programs.

E. REPROMULGATION OF THE ENVIRONMENTAL RADIATION PROTECTION STANDARD

Observation E.1:

It is not clear that the repromulgated EPA Standard (Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes 40 CFR Part 191, Subpart B) will satisfy the objections contained in the 1987 decision by the United States *Court of Appeals For the First Circuit*, or that the repromulgated standard will be able to withstand legal challenges on other grounds.

Although DOE is following the development of the new standard by EPA, until the standard is actually promulgated and any legal challenges resolved, it is not known what performance standard WIPP will be required to meet as a permanent disposal facility. This "moving target" subjects WIPP to a considerable amount of regulatory uncertainty.

Observation E.2:

One of the reasons the Court remanded the Standard to EPA in 1987 was that the Court believed WIPP to be an underground injection well and that the EPA Standard was less stringent than, and therefore inconsistent with the standard under the Safe Drinking Water Act to which underground injection wells are regulated.

Recommendation E.1:

DOE should explore options for resolving this issue, including determining if an underground injection control permit is needed for WIPP and statutorily clarifying the applicability of the Safe Drinking Water Act to WIPP.

F. COMPLIANCE WITH FEDERAL AND STATE HAZARDOUS WASTE REGULATIONS

Observation F.1:

It is not clear that a comprehensive and systematic assessment of the applicability of federal and state hazardous waste regulations to the WIPP program has been conducted. Without such planning, hazardous waste requirements have the potential to stall the WIPP program at numerous points.

It is not clear that all of the plans for WIPP are in compliance with applicable hazardous waste regulations. For example, the operational procedures for WIPP clearly state that waste containers will not be opened at WIPP. However, the federal regulations specifying Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (40 CFR Part 264) appear to require that waste analyses be conducted at the disposal facility.

Discussion:

Planning by DOE is needed to minimize the chance that federal or State of New Mexico hazardous waste regulations do not catch the WIPP program by surprise. For example, there could be significant uncertainty in the RCRA Part B permitting process for WIPP. It is not uncommon for the RCRA Part B permitting process for land disposal facilities to take three or more years. Nationally, very few permits have been issued under the "Miscellaneous Units" provision to which WIPP is subject (40 CFR 264.600). No RCRA permit has ever been issued for a deep geologic repository.

Recommendation F.1:

DOE should promptly conduct a comprehensive and systematic assessment of the WIPP program's compliance with federal and State of New Mexico hazardous waste regulations. The assessment should identify each of the specific provisions of federal and state regulations that apply to the WIPP program. Following this assessment, a compliance strategy should be developed for each applicable provision. DOE should work closely with the State of New Mexico on the promulgation of mixed waste regulations and the preparation of hazardous waste permit applications.

Observation F.2:

Inadequate analytic data are available on the types and quantities of hazardous wastes in the TRU wastes intended to be disposed in WIPP.

Discussion:

Almost all existing waste characterization information is based on process knowledge. Process knowledge may provide a reasonably accurate characterization of hazardous wastes for the newly generated TRU-mixed waste. However, process knowledge may not provide sufficiently accurate characterizations for wastes generated nearly 20 years ago. Hazardous waste characterization data are needed for a number of purposes including: the performance assessment, the no migration petition, and the RCRA Part B permit application. Hazardous waste characterization data are also needed to comply with federal or state hazardous waste regulations at every site at which TRU-mixed wastes are generated and/or stored. Without actual measurements of the hazardous components in both old and newly generated TRU-mixed wastes, the WIPP program will continue to suffer a credibility problem and is also likely to encounter regulatory challenges.

It is recognized that conducting hazardous waste characterizations on TRU-mixed wastes presents formidable technical and personnel exposure problems that need to be addressed.

Recommendation F.2:

DOE should promptly develop a comprehensive, Department-wide plan to

characterize the hazardous (nonradioactive) components of TRU-mixed waste being generated and in storage.

When TRU wastes are being examined for other purposes, DOE should take advantage of the opportunity to obtain information on the hazardous components in the wastes. Several such opportunities are:

- When waste packages are opened and physically inspected for compliance with the WAC.
- When waste packages are vented.
- When wastes are supercompacted.

Discussion:

Since all waste packages are required to be vented prior to shipment to WIPP (in TRUPACT-II), the opportunity is readily available to sample the head space gas from essentially all of the WIPP wastes. Analysis of the head space gas from, for example, ten percent of the waste packages (preferably at an elevated temperature) has the potential of producing a highly reliable database of the volatile organic compounds present. Some methods development would probably be needed, and the approach should be validated by more invasive analysis techniques.

The RFP plans to begin compacting all of its TRU wastes in 1990. It is likely that in the supercompacting process liquids will be pressed out of some of the packages being supercompacted. These liquids need to be removed for solidification or other treatment. Prior to treatment, these liquids could be sampled and analyzed for hazardous components.

Observation F.3:

Documents prepared by the RFP indicate that several types of hazardous materials used at the RFP and several hazardous wastes that are produced at the RFP do not end up in the TRU waste inventory. Further work by the BRP is needed to confirm that this is the case.

G. MANAGEMENT OF THE TRU WASTE INVENTORY

Observation G.1:

A significant percentage of the waste packages currently in the TRU waste inventory at the RFP and at INEL (the only two generator/storage sites reviewed to date by the BRP) are believed to be low-level waste and not TRU waste. RFP and INEL estimate that eight to ten percent and around 50 percent, respectively, of their TRU waste inventory is expected to be low-level waste. This "misclassification" has resulted from a change in the TRU waste criterion from 10 nCi/g to 100 nCi/g of TRU radionuclides, and the use of less sophisticated assay equipment.

Recommendation G.1:

All waste packages in the TRU waste inventory at all DOE facilities that may contain less that 100 nCi/g of TRU radionuclides should be reassayed as soon as possible and removed from the TRU waste inventory, if the TRU radionuclide content is less than 100 nCi/g.

Discussion:

The retention of low-level waste in the TRU waste inventory has the potential to needlessly consume significant resources through "over management" of such waste. This misallocation of resources can occur in the consumption of valuable TRU waste storage space, certification of waste packages that need not go to WIPP, and the misuse of expensive disposal capacity at WIPP.

H. WASTE ACCEPTANCE CRITERIA FOR WIPP

To date there has been insufficient time to fully assess the WAC for WIPP. While further time is needed to complete this assessment, some initial and preliminary thoughts are provided below.

Observation H.1:

It is not clear that the WAC are consistent with the source term databases being used for the performance assessment, the no migration petition, and the RCRA Part B permit application.

Recommendation H.1:

DOE needs to ensure that the databases being used for the performance assessment, the no migration petition, and the RCRA Part B permit application are consistent with the WAC. The databases should not assume that the WAC are controlling elements of the source term that the WAC in reality are not.

Observation H.2:

It is not clear how the performance assessment, the no migration petition, and the RCRA Part B permit application will take into consideration the authority of the WACCC to exempt wastes from the WAC in the future.

Recommendation H.2:

The WACCC should not grant any exemptions from the WAC until after WIPP has been demonstrated to comply with the EPA Standard. Exemptions to the WAC should be granted only if a technical assessment indicates that the performance of the repository will not be materially affected.

Observation H.3:

It is not clear that adequate methods are being used to ensure that the WAC for corrosives, pyrophorics, explosives, and RCRA constituents are being met. The BRP should pursue this matter further.

Observation H.4:

It is possible that waste containers that are vented and then allowed to aspirate in a high humidity environment (such as out-of-doors) may accumulate a significant amount of liquid.

Recommendation H.3:

Waste containers that are aspirated in non-humidity controlled environments should be subject to real-time radiography immediately prior to shipment to ensure that the criterion for liquids is not exceeded.

Observation H.5:

In addition to the WAC, wastes to be shipped to WIPP in TRUPACT-II must also comply with the conditions specified in the United States Nuclear Regulatory Commission's Certificate of Compliance, some of which are more restrictive than the WAC. In the future, the RCRA Part B permit for WIPP may impose additional restrictions on the wastes that can be received at WIPP.

Recommendation H.4:

DOE should develop comprehensive, integrated criteria and a unified certification process for determining what wastes can be shipped to WIPP. The WACCC should audit waste generators for compliance with this integrated set of criteria.

I. AUDITING COMPLIANCE WITH THE WASTE ACCEPTANCE CRITERIA

Observation I.1:

The audit program conducted by the WACCC is a vital mechanism for ensuring that the TRU waste generators are properly certifying waste according to the WAC. While the existing audit approach has significant merit, additional steps would increase the effectiveness and credibility of the WAC and the auditing program.

Recommendation I.1:

DOE should actively encourage and facilitate observers from the New Mexico Environmental Improvement Division, the Colorado Department of Health, the State of Idaho, and the Environmental Evaluation Group to accompany the WACCC auditors.

Recommendation I.2:

The WACCC should conduct an unannounced audit at each TRU waste generator facility at least annually. In addition to reviewing the waste generators' certification records, the audit team should randomly select drums from the generators' inventory for radiological assaying and examination by real-time radiography under the audit team's observation. Audits of each generator should include enough waste packages to ensure at least a 95 percent confidence level that wastes are being properly certified.

J. ROCKY FLATS WASTE RECERTIFICATION PROGRAM

A revised draft of the Rocky Flats Waste Recertification Program Plan (DOE/WIPP 89-025) was not received for review by the BRP until October 18, 1989. This revised plan was prepared in response to questions raised by the BRP. While this responsiveness is appreciated, the recent receipt of this document has not permitted thorough review nor has it allowed opportunity for discussion with DOE officials. Therefore, the following comments are very preliminary.

Observation J.1:

The recertification plan appears to be generally headed in the correct direction.

Discussion:

An important change from prior plans is the exclusion of low-level waste (waste having less than 100 nCi/g of TRU radionuclides) prior to recertification. Inclusion of state observers on the audit teams will improve public confidence in the recertification program. For the plan to have credibility, the level of observation/inspection needs to be very nearly full-time. The plan calls for the audit team to review each of the drums to be reassayed at the RFP. Given the on-going criminal investigation, limiting the audit team reviews to only the drums to be reassayed does not seem adequate. The plan does not include unannounced audits of RFP waste being recertified at INEL. The plan includes the opening of a number of waste containers and the physical inspection of contents, both at the RFP and at INEL. This presents an opportunity to collect data on the hazardous components in the wastes that will be useful in the performance assessment, the no migration petition, the RCRA Part B application, and other hazardous waste compliance issues regarding WIPP.

Recommendation J.1:

DOE should actively encourage and facilitate observers from the New Mexico Environmental Improvement Division, the Colorado Department of Health, and the Environmental Evaluation Group in the recertification audits/inspections.

Recommendation J.2:

In addition to the recertification procedure to be conducted by RFP personnel, the audit team should, on an unannounced basis, randomly select drums from each of major waste types in the RFP inventory for radiological assaying and real-time radiographic examination under the audit team's observation

Recommendation J.3:

Because the RFP and INEL will have the same contractor during the recertification program (and because of the on-going criminal investigation), unannounced audits of the recertification activities at INEL should be conducted to increase public credibility.

Recommendation J.4:

Since the recertification plan involves the opening of waste containers and the inspection of their contents, serious consideration should be given to obtaining data on the hazardous constituents of the wastes.

WASTE ISOLATION PILOT PLANT (WIPP)

BLUE RIBBON REVIEW PANEL MEMBER REPORT

Newal Squyres
Boise, Idaho

October 23, 1989

EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) Blue Ribbon Panel was established by the Secretary of Energy in late August of this year. The five members of the panel were each asked to provide an independent assessment of certain issues related to the recertification or validation of Rocky Flats Plant waste for shipment to WIPP and to the Draft Plan for the WIPP Test Phase: Performance Assessment and Operations Demonstration. Those issues and my recommendations are as follows:

1. The proposed plan to validate Rocky Flats Plant certification of waste for shipment to WIPP.

The latest draft of the Rocky Flats Waste Recertification Program Plan (DOE/WIPP 89-025) was received as this paper was being finalized. Although more detail needs to be provided, particularly concerning the audit of RFP's certification processes, it appears to contain most of the elements necessary to provide assurance that RFP generated waste has been properly certified. For waste at INEL, the plan should be developed in conjunction with the September 1989 draft RWMC/SWEPP Compliance Plan for TRUPACT-II Authorized Methods for Payload Control (TRAMPAC). Both plans should be circulated to EEG and/or other representatives of Colorado, New Mexico and Idaho for comment. No RFP waste should be shipped from INEL to WIPP unless it

complies with the TRAMPAC plan, which requires a re-evaluation and examination of the certification for each drum to be shipped; and post-1985 INEL stored waste, which was WIPP/WAC certified by RFP, should not be shipped until validation of RFP's waste certification program. A Colorado representative should have the opportunity to observe each step of the planned re-examination of certain RFP waste to see whether it is properly classifiable as LLW, rather than TRU. RFP stored waste not examined under this procedure should not be shipped to WIPP unless it conforms to TRAMPAC, and its previous certification has been validated. Newly generated RFP waste should be certified to WIPP/WAC under any new procedures or compliance requirements flowing from the recertification/validation process.

2. The concept and timing of the WIPP Demonstration Test Plan and the relationship between the performance assessment and operations demonstration.

a) Operations Demonstration: The operational capability of WIPP to safely and efficiently receive and place waste underground is a critical component in fulfilling WIPP's research and development mission of demonstrating the safe disposal of defense generated radioactive waste. An operations demonstration will begin with the receipt of the first waste for use in the performance assessment process. Included in the scope of the operations demonstration must be the capability to retrieve all waste placed underground during the PA; retrieval plans must be correlated to the nature of the PA experiments and be sufficient for the scientific and

technical community to believe they will work. The PA will be an evolving, iterative process. A full fledged operations demonstration should begin when sufficient data is received from the PA to establish with reasonable confidence the conditions (backfill and other engineering modifications) under which particular waste will be disposed of. Final decisions about the optimum design and use of the underground space, including such things as how the waste is stacked and whether some waste is segregated from other waste, will depend on information from the PA. Pending the satisfactory resolution of the institutional, technical and legal/regulatory considerations concerning WIPP's use as a permanent repository, serious consideration should be given to its use as an interim storage facility. In this capacity an operations demonstration would be conducted, which should provide useful information in the research and development process for WIPP.

b) <u>Performance Assessment</u>: The PA process involves TRU and mixed-TRU waste and different regulatory issues and approaches result from these distinctions in waste form. The regulatory requirements need to be clarified so the PA can provide the information necessary to satisfy the regulations or so that necessary changes and modifications can be made to the manner in which the waste is stored (including engineering modifications) or to the methods and procedures under which the waste is initially handled and packaged for shipment to WIPP. Lab scale experiments must begin as soon as possible. Bin-scale and room-scale (alcove) tests will begin as soon as operational readiness and regulatory authority are obtained. All of these tests are necessary to

achieve regulatory compliance and to determine the conditions under which permanent disposal can begin. Based on the unique nature of WIPP and its research and development mission, the performance assessment phase should begin in full as soon as operational readiness is obtained. DOE should explore with ways to allow the experiments to begin even if final regulatory approval has not been obtained by the time operational readiness is achieved. DOE should continue to integrate and expand the PA database, based on WIPP/WAC and TRAMPAC compliance as well as the updating and expansion of the Preliminary Nonradionuclide Inventory for CH-TRU Waste (IT Corporation, May 1989). Information concerning the character of the waste, gathered to satisfy various compliance requirements, needs to be reported uniformly by generator site and coordinated with the process of determining whether, or in what manner, WIPP can comply with applicable regulatory standards. Better knowledge can be gained in the PA by making full use of all available information about the wastes to be shipped to WIPP. The PA process should take into consideration the fact that waste destined for WIPP has not been generated and thus the results of the PA and the needs of the facility may affect the way waste is stored and handled at its inception. There should be a regular, formalized process of interaction and communication between the PA, WIPP/WAC personnel and the generator sites. The underlying assumptions about the character of the waste and the storage methodology used in the PA should be continually reexamined to insure that regulatory compliance and/or public confidence are not undermined by worst case scenarios or other assumptions which have no realistic basis in fact or which could be modified. The PA plan should not be

constricted by unrealistic or arbitrary time limits that do not consider the research and development mission of WIPP or that do not reasonably correspond with the gathering of data necessary to determine the long term acceptability of WIPP as a permanent disposal site. Performance assessment, broadly defined, should continue as long as data is generated which supports modifications/improvements in the use of WIPP to demonstrate the safe disposal of TRU/Mixed-TRU waste. Based on the knowledge gained from using the facility, the waste management disposal systems at WIPP will probably not remain static. Changes may occur because of alterations or modifications in the character of waste shipped to WIPP, considering the time period when the waste was generated, the effect of RFP's waste minimization plan, the effect of compaction or other unanticipated changes which might flow from the increase in knowledge about WIPP. The PA is the principal mechanism to implement the congressionally mandated goal of demonstrating that a geological repository such as WIPP is a viable solution to the need for a safe long term disposal site. Continuing consultation and interaction with the EPA, NAS and EEG is appropriate and necessary to achieve this goal.

DISCUSSION

I. INTRODUCTION

The primary statutory basis for WIPP is contained in section 213(a) of Public Law 96-164, the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980. This section directed the Secretary of Energy to proceed with construction of the Waste Isolation Pilot Plant and further provided:

> Notwithstanding any other provision of law, the Waste Isolation Pilot Plant is authorized as a defense activity of the Department of Energy, administered by the Assistant Secretary of Energy for Defense Programs, <u>for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive waste resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission.</u>

Congress required the Secretary of Energy to consult and cooperate with officials of the state of New Mexico in carrying out WIPP's mission and further provided in section 213(c):

> No law enacted after the date of the enactment of this act shall be held, considered, or construed as amending, superseding, or otherwise modifying any provision of this section unless such law does so by specifically and explicitly amending, repealing or superseding this section.

It is now nine years since Congress established WIPP's mission, and numerous groups, including this panel, are involved in addressing issues associated with beginning to use WIPP as a site for the disposal of TRU and mixed-TRU waste resulting from defense activities and programs of the United States.

At the initial briefing held for the panel, the representative from the National Academy of Sciences stressed the need to move forward with the test phase for WIPP in order to obtain the information necessary to determine the conditions under which WIPP can serve as a permanent disposal site. At the present time, TRU and mixed-TRU waste are stored "temporarily" at various sites throughout the United States with the vast majority being stored at the Idaho National Engineering Laboratory. A relatively small amount of more recently generated waste is stored at the Rocky Flats Plant (RFP) in Colorado, but there are currently strict limitations on the amount this may increase. Similar waste is being generated on a regular basis due to national security requirements. There is thus a strong national interest in storing and permanently disposing of this waste safely. WIPP was established by Congress (and has been funded in the total amount of $780 million through fiscal year 1989) to determine whether such a geologic repository can demonstrate its capability to serve as a permanent disposal site. That final decision cannot be made yet, but it is now time to do what is necessary for the research and development process to go forward.

II. VALIDATION/RECERTIFICATION OF ROCKY FLATS PLANT WASTE FOR SHIPMENT TO WIPP

Because of recent events at the Rocky Flats Plant concerning, broadly speaking, its handling and disposal of waste from nuclear weapons production. DOE has perceived a need to validate or recertify waste previously certified by RFP to WIPP's Waste Acceptance Criteria standards. I am not aware of any allegations that directly relate to the WIPP/WAC certification program at RFP. No assertions have been made that any individuals associated with the certification process intentionally or negligently did something to raise any substantial concern about the original waste certification process. In addition, there have been periodic audits and inspections of the RFP WAC certification program conducted by WACCC, non-RFP personnel. My understanding is that an EEG representative has accompanied suc.. audit teams and that no substantial problems have been identified. These are relevant considerations in evaluating the scope and efficacy of a plan to recertify Rocky Flats waste.

There are at least three interrelated, yet distinct, categories of waste involved in the validation/recertification program. First, there is a portion of previously certified RFP waste that may be properly classifiable as low level waste, rather than TRU. Re-examination of this limited category of waste will be conducted by re-assaying the waste with more sophisticated equipment than was used initially. The object is

to determine whether a particular container has a sufficiently low amount of radioactive material to be characterized as low level radioactive waste, rather than TRU. Because this re-assay process may create an ability to continue storing this waste at RFP without contributing to the 1601 cubic yard limit agreed to by DOE and the state of Colorado, it is particularly important for an appropriate representative from Colorado to have the opportunity to be present during each step of the re-examination process. The Colorado representative should be fully briefed for a thorough understanding of how the waste was originally assayed; how the waste was identified for re-examination; and how the new equipment differs from the old, including the use of controls to assure that the new equipment is being operated and functions accurately to produce measurements that are not open to question. In summary, DOE should make the necessary arrangements with the Governor of Colorado to obtain the presence of a technically competent representative to sign off on this portion of the validation/recertification process.

The second category subject to the validation/recertification plan is waste now being stored at RFP, which was previously WIPP/WAC certified by RFP. Before this waste can be shipped to WIPP, it must also be certified for shipment under the TRUPACT-II authorized methods for payload control (TRAMPAC). The latest draft Rocky Flats Waste Recertification Program Plan (DOE/WIPP 89-025, October 1989) was received as this report was being prepared and has not been reviewed in detail. However, the plan for this category of waste contemplates an unannounced audit process administered by the WACCC. The audit will include quality assurance and record keeping activities but will focus on

activities associated with initially packaging and certifying the waste. This appears to be an acceptable audit process but more information is needed concerning the actual scope and duration of the audit.

In addition, substantially more detail is needed concerning the plan to recertify that portion of the 1200 drums, less that determined to be low level in the re-assay process, to be shipped to WIPP. This portion of the plan should include a re-examination of each drum and its original certification by individuals not involved in the original certification. At least a significant number of randomly selected drums should be recertified by different people. Finally, the validation/recertification of this category of waste must be observed to the extent deemed appropriate by the states involved, and measures should continue to be taken to provide the opportunity for independent oversight in the development and implementation of the recertification program.

The third category of waste subject to this plan involves approximately 8800 drums of waste certified by RFP prior to shipment to INEL; this waste has been stored at INEL since 1985. The purpose of the draft RWMC/SWEPP Compliance Plan for TRUPACT-II Authorized Methods for Payload Control (TRAMPAC) is to provide the methodology for examining each of these drums to make sure it can be shipped to WIPP in accordance with TRAMPAC criteria. Unfortunately, the TRAMPAC criteria were developed somewhat independently from the WIPP/WAC criteria, and it is possible that waste may be certifiable for acceptance at WIPP but not meet the criteria for TRUPACT-II shipment. As this plan is finalized, it could serve as a basis to integrate the WIPP/WAC with

the TRAMPAC requirements so that one certification process satisfies both. In any event, DOE should make certain that compliance with WIPP/WAC will also provide compliance with TRAMPAC.

Because each container now stored at INEL and intended for shipment to WIPP must be re-examined to insure compliance with TRAMPAC, and because that process will begin in the very near future, the plan for the validation/recertification of RFP certified waste at INEL should be developed in conjunction with the TRAMPAC compliance plan. It appears that the draft TRAMPAC compliance plan contemplates an examination of the data generated when the waste was originally certified by the RFP, a 100% real time radiography (RTR) examination of each container and a random sampling process, all conducted at the SWEPP site. There should be an integration between the TRAMPAC compliance plan and the RFP recertification plan. An opportunity should be provided for comment on the proposed plans by the EEG and/or other appropriate state representatives, and arrangements should be made for independent observation of the implementation of the plans, if requested. Before going forward with a plan to validate or recertify RFP waste, DOE should be satisfied that appropriate groups and state representatives are in essential agreement with the plan's scope and methodology. This, plus a thorough briefing concerning the basis for DOE's confidence in RFP's certification processes, are necessary to blunt public skepticism concerning RFP's waste certification processes.

III. CONCEPT AND TIMING OF THE WIPP DEMONSTRATION TEST PLAN; RELATIONSHIP BETWEEN THE PERFORMANCE ASSESSMENT AND OPERATIONS DEMONSTRATION

A. Operations Demonstration: An operations demonstration is necessary and will begin with the waste to be used in the test phase. The object of the performance assessment portion of the test plan is to develop the necessary information to determine the conditions under which the waste will be stored or disposed of to achieve regulatory compliance and the overall suitability of WIPP as a permanent repository for TRU/Mixed-TRU waste. Until the information from the PA becomes available to begin to make such decisions, an operations demonstration, conducted on the basis of assumptions about how the waste will be stored, seems premature. It has been continually stressed that the PA will involve an iterative, step by step learning process. The operational activities associated with receiving and placing the waste underground will be significantly influenced by what is learned in the PA concerning the behavior of the waste and the geologic repository. Because of uncertainties associated with the results of the PA and thus with any measures that may be necessary to counter unexpected or adverse conditions, flexibility needs to be maintained concerning the commencement of waste acceptance at capacity or near capacity rates. Essentially, I agree with NAS's observations and recommendation 6 of the Review Comments on DOE document DOE/WIPP 89-011: Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and

Operations Demonstration, July 19, 1989. At this juncture, the operations demonstration process should obviously make every effort to maximize what can be learned from emplacement of the waste needed for the PA. A plan should be developed to determine how best to maximize from an operational standpoint the experience gained with the waste to be used in the PA.

Perhaps an unspoken concern, at least in the limited experience of this member, is the belief that the current operations demonstration plan may provide a method for the temporary storage of waste, until the PA process is far enough along to make some final decisions concerning the use of WIPP to solve obvious problems existing in the management of TRU/Mixed-TRU waste. Stated simply, there is too much waste and no readily acceptable place to put it. Until sufficient information is available to demonstrate regulatory compliance of WIPP and to demonstrate its safety as a long term disposal site, issues concerning the temporary or interim storage of waste will be present.

In this regard, the NAS representative that met with the panel at its first meeting said, perhaps unofficially, that although the question had not been asked he did not oppose placing waste underground so long as it was recognized that the waste was not necessarily put there on a permanent basis. Common sense virtually compels the conclusion that waste is better stored underground at WIPP than it is above the surface, and this appeared to be the position of the NAS representative. Although the subject has been covered in part in the supplemental environmental impact statement, a detailed and thorough analysis needs to be done of the costs and benefits of continuing to store TRU and mixed-

TRU waste at interim sites not developed to assure the safe handling of such waste. There would appear to be certain beneficial effects from the use of WIPP as an interim storage facility in terms of an operations demonstration. These benefits alone would not justify such use but could be achieved through a well considered, conservative plan for using a portion of the facility for interim storage. The subject should be addressed with the regulatory agencies, including appropriate participation by those groups (EEG and NAS) long involved in evaluating WIPP and its proposed use.

B. Performance Assessment. The plans associated with the performance assessment to demonstrate regulatory compliance do not appear to take into consideration the difference in the regulatory scheme for radioactive waste (40 CFR 191, Subpart B) and hazardous waste (40 CFR 268). These differences are illustrated, for example, by different definitions of "disposal". With respect to radioactive TRU waste, "disposal of waste in a mined geologic repository occurs when all of the shafts to the repository are backfilled and sealed." 40 CFR 191.02(l). On the other hand, for hazardous waste, "land disposal" means placement in the land and includes placement in a salt bed formation, underground mine or cave. 40 CFR 268.2(a). An estimated 50% to 60% of the defense generated waste to be emplaced at WIPP is mixed, containing both hazardous constituents and TRU radioactive waste. The regulatory process needs to address these facts about the waste WIPP must contend with to fulfill its mission.

The Environmental Protection Agency is currently considering DOE's no migration petition, filed pursuant to 40 CFR 268.6. Until the no migration petition is approved, mixed waste apparently will not be put underground at WIPP. If the no migration petition is not approved or is delayed, current plans for the PA will have to be modified. The term of a no migration petition may be only 10 years, and this could pose downstream problems for waste emplaced at WIPP in reliance on the no migration petition exemption. Even if the no migration petition is granted, what appears to be an inconsistent regulatory approach, or perhaps better termed a non-approach, to the regulation of TRU/Mixed-TRU waste creates potentially fertile ground for future problems. An effort should be made to reconcile or harmonize what appear to be conflicting regulatory approaches. DOE should probably not assume that the no migration petition will be granted in a timely fashion and should therefore begin to develop contingency plans for the PA, specifically including an early approach to EPA to develop a way to begin the presently planned experiments at WIPP as soon as operational readiness is achieved.

A combination of lab scale, bin-scale and alcove tests are clearly necessary to develop the information for a satisfactory performance assessment, and just as importantly, to gather data necessary to predict the net behavior of the rooms for long term disposal purposes. The performance assessment/experimental program must adequately address the concerns, and seek solutions, raised by the presence of hazardous constituents, particularly volatile organics, in the waste intended for disposal at WIPP. An increased effort should be made

to insure that as much pertinent and uniform data as possible is gathered for these purposes from all available sources, including the WIPP/WAC and TRAMPAC compliance process and an ongoing update of the Preliminary Nonradionuclide Inventory for CH-TRU waste.

DOE and its contractors appear to be making progress in responding to NAS recommendations concerning the performance assessment/experimental test program. Scientific and public confidence in this program is obviously enhanced by input received from NAS, EEG and EPA together with the recognition that the process is an iterative one, which requires constant flexibility and openness in recognizing potential problems and developing solutions, so that regulatory compliance can be achieved and decisions made about permanent disposal. A formal mechanism should be established so that the personnel involved with performance assessment/experimental test program work closely with the personnel, from WIPP and the generator sites, responsible for WIPP/WAC and TRAMPAC compliance. This will provide for early identification and implementation of measures intended to remedy known or anticipated problems.

There should be a direct relationship between the results, even preliminary, from the performance assessment and the conduct of an operations demonstration. Planning for the performance assessment and the first receipt of waste, including the timing and volume of waste received, should be conducted so as to maximize the opportunity to test, verify and modify, if appropriate, the operational plan for waste receipt and emplacement.

Short term goals, such as compliance with 40 CFR 191 and reaching an early decision concerning permanent disposal, cannot predominate over the long term goal of establishing the conditions for WIPP's use as a final repository for TRU and mixed-TRU waste. The solutions to the gas generation and brine inflow issues, for example, may evolve and may permit a portion of the facility to be used as a final repository but nevertheless warrant modifications or changes in both the waste form and repository usage for another portion of the site. Regulatory issues may be resolved differently at one point in time than another, because of the continuing learning process. In terms of complying with 40 CFR 191, PA personnel should continue to consider NAS's suggestion to supplement the numerical predictions of a performance assessment with qualitative judgments. It may be necessary to continue aspects of the performance assessment/experimental program even after a final decision is made that certain portions of the repository can be used for permanent disposal.

IV. ADDITIONAL CONSIDERATIONS AND CONCLUSION

Progress appears to have been made by the DOE in recognizing the need for better coordination and integration among various people and groups with responsibility for WIPP. In order to make the transition from the site selection/construction phase of WIPP to its actual use to fulfill the congressionally mandated goal of providing a research and development facility to demonstrate the safe disposal of defense weapons production generated waste, DOE and its contractors are now required to focus realistically on the so-called institutional concerns and decide what needs to be done to put WIPP in use. Resolution of these institutional concerns should be enhanced by the progress made in meeting the concerns expressed by the NAS and EEG concerning the performance assessment/experimental program phase.

From an operational and technical standpoint, WIPP is about ready to begin receiving waste as the project moves from the construction phase to the test phase. Significant institutional and regulatory issues remain to be resolved but these issues do not go to the merits of WIPP's functional ability to serve as a valuable national resource of providing a place to store defense generated nuclear waste. Once operational readiness is achieved, there is no reason not to go forward with the test phase, which should be conducted to the maximum extent possible on site at WIPP. So long as the ability to retrieve the emplaced waste is maintained, WIPP should be put to use. If funds need to be set aside in order for public confidence to exist with respect to

retrievability, then that should be done. WIPP is a unique facility, whose very existence and current status are the result of the hard work and dedication of numerous groups both inside and outside the government. There are an infinite number of variables associated with the way WIPP may ultimately be used as a disposal site, and there will no doubt be troublesome issues that must be resolved in the course of making the decisions about that use. But those decisions are not being made in a vacuum or without the opportunity for oversight by groups representing the public interest, particularly the states directly involved. It is reassuring that not once during my involvement in this project did anyone suggest that a particular course of action should be taken for national security reasons. Clearly, there are national security issues associated at stake when one considers the disposal of defense-generated waste. But the history of WIPP's development clearly illustrates that decisions about its use will not be made in secret or without significant involvement of groups outside of DOE and its contractors. To this point, decisions about WIPP appear to have been made based on the best available technical and scientific input from numerous sources. This should continue as decisions are made about its future use as a repository for actual waste, for only in this manner will the proper decisions be made, in the national interest, about WIPP's ultimate suitability as a permanent repository.

EM0022706

HEARING BEFORE THE SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES

APRIL 26, 1990, 2:00 P.M.

DIRKSEN SENATE OFFICE BUILDING

ROOM 366

STATEMENT OF DR. TOM BARR	TAB A
TESTIMONY OF ROBERT W. BISHOP	TAB B
STATEMENT OF DR. ARTHUR S. KUBO	TAB C
STATEMENT OF LEONARD SLOSKY	TAB D
STATEMENT OF NEWAL SQUYRES	TAB E

STATEMENT AND ACCOMPANYING
DOCUMENTS OF

DR. TOM BAHR
MEMBER OF THE DEPARTMENT OF
ENERGY'S BLUE RIBBON PANEL ON WIPP

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

APRIL 26, 1990

My name is Dr. Tom Bahr and I am here today speaking as a member of the Waste Isolation Pilot Plant (WIPP) Blue Ribbon Panel. The Blue Ribbon Panel was established by the Secretary of Energy in August 1989 as an independent oversight group to provide advice on selected issues relating to WIPP.

I am presently an employee of New Mexico State University serving as Director of the New Mexico Water Resource Research Institute. Between 1987 and 1989, I spent 2 1/2 years on leave from the university serving in state government as Cabinet Secretary for the New Mexico Energy, Minerals and Natural Resources Department. As part of my responsibilities, I chaired the statutory Radioactive Waste Consultation Task Force, commonly called the WIPP Task Force. This Task Force serves as the primary liaison between the U. S. Department of Energy and the executive branch of state government in New Mexico. My work with the WIPP Task Force dealt largely with policy issues and to some extent technical matters within my personal area of expertise.

My views on WIPP have in part been shaped by that experience in state government, but to a lesser degree than the insights I have gained during the past 8 months as a member of the WIPP Blue Ribbon Panel. My remarks today are as an independent member of the Panel and they do not necessarily reflect the views of the State of New Mexico or New Mexico State University. I should stress that the Blue Ribbon Panel is not charged with arriving at consensus on any particular issue nor are we constituted as an official advisory body. We have no chairman and our written and verbal reports to the Secretary of Energy and his staff are done as individuals.

The original charge to members of the Blue Ribbon Panel was to analyze and report on three issues: 1) The concept and timing of DOE's proposed WIPP Operations Demonstration program; 2) Whether or not the Operations Demonstration program should be conducted in parallel with the Performance Assessment; and 3) An evaluation of DOE's validation plan for the certification of transuranic waste to meet the WIPP waste acceptance criteria.

During September and October of 1989, the Blue Ribbon Panel conducted site visits of the Waste Isolation Pilot Plant, Idaho National Engineering Laboratory and the Rocky Flats Plant. We were briefed by a host of DOE employees, contractors and others and we had the opportunity to question most decision-making managers having anything to do with the WIPP. We also reviewed thousands of pages of documents furnished by DOE and others. On October 23, 1989 we submitted individual reports to the Secretary of Energy. Mr. Chairman, I would like to request that my report be included for the record, if it is agreeable with the Committee.

Following the submission of our reports, the Blue Ribbon Panel was asked to continue its service to the DOE by providing our individual observations and recommendations to the Department in three areas: 1) continued review of DOE plans to characterize Rocky Flats Plant transuranic and mixed waste; 2) assist DOE in developing a strategy for achieving compliance with RCRA and other environmental regulations at WIPP; and 3) evaluate the Final Test Plan and ancillary documents. More recently, DOE expanded our charge to include a management review of the WIPP project, review of the rationale and plans to characterize waste for the test phase, review of plans for engineered alternatives relating to the waste form with the overall general focus being placed on an evaluation of DOE efforts on preparing for the test phase at the WIPP.

In addition to issues identified by the DOE, the Blue Ribbon Panel was also asked in late November 1989 to comment on questions submitted by members of the New Mexico Congressional Delegation. The questions were essentially two: 1) What is the rationale for conducting in-situ experiments at the WIPP rather than at existing waste generation and storage sites along with some discussion of how much waste would need to be emplaced at the WIPP for the experiments; and 2) Our recommendations regarding DOE's proposed)perational Demonstration experiments.

On December 28, 1989, I responded to these questions in writing to each member of the New Mexico Delegation. Two members of our Delegation who sit on this committee have seen my responses but for the benefit of others on this committee who may have not,

the following were my answers:

"1. Rationale and need for In Situ experiments at WIPP.

Experiments with actual transuranic waste being proposed by DOE to be conducted in situ at the WIPP range from small-scale bin tests to larger room-scale alcove tests. Bin experiments would be done in metal boxes containing assorted waste forms, brines and other additives, for the purpose of generating data on gas generation, biological and chemical reactions, etc. Alcove experiments would test the effects of actual room conditions on drums, backfill and seal performance, etc.

In my opinion, bin testing could be conducted elsewhere without significantly compromising test results so long as careful temperature control is maintained. To do so, however, would require facility construction and associated time delays. According to DOE, this could cost as much as $10 million. Alcove testing must be done in situ at WIPP to have any scientific credibility at all. The actual room conditions represent a complex set of interactions that simply cannot be duplicated elsewhere. Of particular significance are the interactions of gas pressure on brine inflow and the ultimate "wetness" of the room environment after closure. Alcove experiments over a 5-year period could generate valuable data on initial rates of these processes under real conditions and provide insight into physical, chemical and biological mechanisms that will affect long-term performance.

The DOE currently plans to emplace approximately 600 drum equivalents for bin tests and alcove testing would require close to 4,000 drums. The Blue Ribbon Panel has not been asked by DOE to make recommendations on the amount of waste needed for experimental purposes and we have not therefore evaluated that issue. I will say, however, that short-term health and safety concerns raised due to handling real transuranic waste during the experimental phase must be balanced against the knowledge gained by these experiments in making the facility safer in the long run. Put another way, DOE needs to find out as soon as possible whether there are design flaws

that could compromise the long-term integrity of the repository so they can be corrected before waste is no longer retrievable.

It would appear prudent to increase rather than decrease the amount of waste experiments if one is looking for flaws in the final repository configuration. The U.S. EPA has already recommended that DOE significantly increase the amount of waste emplaced for experimental purposes to include filling two full-scale rooms. My general recommendation about the amount of waste to be used for experimental purposes is to error on the high side with hopes of gaining new knowledge to improve long-term safety than to error on the low side and stand the chance of overlooking an important design flaw. So long as the waste is retrievable and agreement is reached on where waste would ultimately go after it is retrieved (should it need to be), the amount of waste used for experimental purposes should not represent a major issue so long as the experiments provide meaningful information. I think it is safe to say that there is general agreement among the scientific community that performance assessment modeling is now seriously constrained by the lack of real experimental data. Levels of uncertainty with respect to understanding the interaction of brine inflow, gas generation and rates of various chemical and biological processes span several orders of magnitude. Experiments need to begin as soon as possible to significantly reduce this uncertainty.

2. *My recommendations regarding Operations Demonstration.*

My recommendation is that the full "ramp up" of the operations demonstration portion of the project should be delayed until test results better clarify the need for engineering modifications to the waste form or repository environment (see page 5 of my report). It is my personal opinion that in order for WIPP to satisfy long-term containment criteria, it will be necessary to incorporate some engineering modifications to the waste and/or room environment. Knowledge gained from carefully planned experiments can be used to identify the most appropriate blend of engineering modifications. These modifications would be used to force the chemistry, biology and

physics of the repository to known conditions and thereby better assure long-term safety of the facility. In view of the fact that the final engineering configuration for the waste has yet to be determined, it does not seem reasonable to emplace waste drums in the WIPP for the purpose of gaining experience in drum handling when there is a significant chance the drums would have to be removed at a later date to be modified in one way or another.

My view of Operations Demonstration is that it is not a scientific experiment but rather a gradual phase in of drum emplacement for ultimate disposal. Operations Demonstration is an essential component to full-scale operation of any complex facility. The entire waste handling complex including generator sites, transportation systems, emergency response and tracking systems along WIPP routes, performance of safety testing and waste handling at the WIPP site to the final emplacement of drums in rooms, backfilling and sealing are all elements of a comprehensive Operations Demonstration program. Quantitative performance criteria need to be developed for each element of the system and then tested as the disposal program phases in.

In my opinion, valuable experience has already been gained and more will be gained during the experimental phase of WIPP. A full blown "ramp up" of an Operations Demonstration, however, must wait until such time as there is reasonable assurance that WIPP can comply with 40 CFR 191 Subpart B. That is not a scientific conclusion but rather a prudent management conclusion."

At this point Mr. Chairman, rather than going into my specific observations and recommendations and then having each of the panel members do the same, we decided in order to save time that I would very briefly summarize the general observations of the panel to date. The first and most significant observation in my opinion is that each member of the Blue Ribbon Panel has independently arrived at similar conclusions on each of the issues we were asked to evaluate. Also noteworthy is the high level of congruence of our findings with those of the Advisory Committee on Nuclear Facility Safety (Ahearne Committee). We have also participated in meetings with the WIPP Panel of the National

Academy of Sciences and I can report that we also generally share the same views on those issues we have both looked into. Let me now highlight those items upon which members of the Blue Ribbon Panel seem to agree.

1. The deep bedded salt repository at the WIPP appears to be a safe site for long term isolation of transuranic waste; certainly safer than where this waste is presently stored. Radioactive releases over the long term for an undisturbed WIPP site will probably meet EPA standards (40 CFR 191 Subpart B). Meeting this standard having to consider human intrusion scenarios will be more difficult. Treating the waste so as to change the waste form and thereby force the repository environment to known conditions will significantly reduce present uncertainties. The most controllable variable in the design of the repository environment is the waste form.

2. In situ testing is important and necessary and should begin as soon as possible. Results of bin and alcove testing should significantly increase the confidence of long range predictions undertaken in the performance assessment. Individual members of the Blue Ribbon Panel agree that the quantity of waste emplaced for experimental purposes should not be limited such as to preclude justifiable experiments. A limit of approximately 1% of the WIPP waste capacity is reasonable. A limit of 0.5% may be too restrictive by precluding the opportunity to undertake important Phase III bin testing of different waste forms resulting from different engineered modifications.

3. Members of the Blue Ribbon Panel agree conceptually that the EPA suggestion of adding two filled rooms for monitoring purposes is worthy of further consideration by DOE. This approach, however, should be evaluated in the context of verifying facility performance and not considered as part of the test phase itself. We have not, however, been asked to evaluate EPA's suggestion.

4. On the subject of Operations Demonstration, our panel agrees that such an undertaking will provide valuable information because of the practical experience gained in system-wide operations. We are in general agreement, however, that a full

"ramping up" of an Operations Demonstration should be postponed until such time as the final waste form and repository configuration are determined and that there is a high level of certainty that the Subpart B standard can be met.

5. We also have general agreement that DOE had underestimated the complexity and level of effort required to comply with RCRA in managing its transuranic-mixed wastes.

Mr. Chairman, I have touched the high points and obviously skipped over many details. Other panel members may wish to elaborate on these and other items. In closing, there is one last item of strong agreement expressed by all panel members. We are very impressed by the responsiveness of DOE to our suggestions. Some examples include 1) The significant improvements that have been made in the DOE organization toward overall systems integration, both vertically and horizontally among the varied elements of transuranic and mixed-transuranic waste management; 2) The significant increase in effort being placed on evaluation of engineered alternatives and waste treatment; 3) The accelerated activity and seriousness with which DOE is now placing on dealing with RCRA and in particular on waste characterization issues; and finally 4) The decision by the Secretary to postpone the start up of the Operations Demonstration program.

Mr. Chairman, thank you for the opportunity to present testimony on this important subject.

TESTIMONY OF
ROBERT W. BISHOP, ESQ.

MEMBER
U.S. DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT BLUE RIBBON PANEL

BEFORE THE
COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

April 26, 1990

STATEMENT

Mr. Chairman and Members of the Committee, I welcome this opportunity to speak to you today. By way of background, I have been involved in various aspects of nuclear power for almost 26 years. That experience includes design, construction and operations of both naval nuclear propulsion plants and commercial nuclear power plants. I am here as a member of the U.S. Department of Energy's Waste Isolation Pilot Plant Blue Ribbon Panel.

The Blue Ribbon Panel is one of a number of oversight groups that have been created to assist the Department in identifying and resolving issues associated with the potential utilization of the WIPP facility as the Nation's research and development operation to validate the ability to dispose of radioactive wastes in a manner that would protect public health and safety as well as the environment. The Panel consists of five members: three members were nominated by the governors of Colorado, Idaho and New Mexico, and two members (including myself) were appointed by Admiral Watkins. The responsibility of the Panel members was to evaluate the information provided by DOE representatives, contractors and such other individuals and groups as each Panel member might determine appropriate, and to each submit an independent report to DOE of our individual conclusions and recommendations, which would then be used as input to DOE's decisions concerning WIPP activities.

The initial responsibility of the Panel was to evaluate the concept and timing of the WIPP Operations Demonstration Test Plan and to address the validation of the waste characterization at the Rocky Flats Plant.

Subsequently, the Blue Ribbon Panel was asked to continue in existence to complete its review of DOE plans to characterize transuranic wastes at the Rocky Flats Plant; to assist DOE in developing a strategy for achieving compliance with the Resource Conservation and Recovery Act ("RCRA") and other environmental regulations at WIPP, and to evaluate the final Test Plan and ancillary documents. Three weeks ago, we were also asked to provide continued management review of the WIPP Project (especially the revised Waste Acceptance Criteria), the plans for characterizing wastes for the Test Phase, and the engineered alternatives plan and associated activities. Fundamentally, our responsibility is to provide independent advice and counsel to DOE on various activities, including those that are necessary to satisfy the Department's Decision Plan requirements relating to the conduct of the Test Phase at WIPP.

My observations, conclusions and recommendations are contained in my report to Admiral Watkins dated October 23, 1989, and a supplemental report dated February 15, 1990, both of which I request be included in the record of this hearing. I would also ask that a copy of my responses to the questions posed by the members of the New Mexico Congressional Delegation at the end of last year also be included in the record.

My colleagues on the WIPP Blue Ribbon Panel have also documented their observations, concerns, and recommendations in our individual reports to the Department, as have the Advisory Committee on Nuclear Facility Safety and the National Research Council's WIPP Panel. I would commend those reports to the Committee's attention for the insight they might provide in more depth

relating to the Committee's consideration of legislative land withdrawal or any further matters concerning WIPP.

In the eight months that the Blue Ribbon Panel has been in existence, significant changes have occurred in the WIPP Project. The most significant changes have been made in the areas of systems and task integration and in planning, which is best evidenced by the creation of the Draft Decision Plan which documents the major tasks that are necessary to support the Secretary's decision of when the Test Phase at WIPP will be able to commence.

I should emphasize throughout this process the Department has been very forthright in its dealings with the Panel and in supplying any information that has been requested. This process may have made their job more difficult, but I think there is no question that it has made the result significantly better. They are certainly to be commended for that view of their responsibilities, and for thoroughly considering the Panel Member's recommendations and taking actions responsive to many of those recommendations.

It is important to remember that the National Security and Military Applications of Nuclear Energy Authorization Act of 1980 authorized the WIPP facility "for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive waste resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." In my judgment, and I believe it is consistent with the views of my fellow Blue Ribbon Panel Members

and those of the Advisory Committee on Nuclear Facility Safety and the National Research Council's Management WIPP Panel, the Test Phase to be conducted at the WIPP facility, which involves in situ tests with actual transuranic ("TRU") wastes, is necessary and should begin promptly. The only way to determine if WIPP is a suitable research and development facility, consistent with the mission articulated by Congress in 1979, is to collect and evaluate data to reduce the uncertainties associated with assessing the facility's long-term performance. As Admiral Watkins and Mr. Duffy testified at the Committee's April 3, 1990 hearing, the only practical, reasonable and effective way to be able to assess whether WIPP is an appropriate disposal facility is to proceed with the Test Phase.

The Test Phase, to satisfy those objectives, must be flexible with respect to the number and type of experiments that will be conducted -- results of currently planned tests may indicate the need to conduct additional tests to resolve what may then be newly identified issues. The fundamental decision that DOE must make is how to gain the maximum experience, and therefore data, at the opportune time and with a minimum amount of waste. The waste volume to be used in the experiments should be as small as possible so that the cost, both economic and in terms of resources, of retrieval is as small as possible if it is subsequently determined that the waste must be repackaged, the waste form altered, or that the WIPP project is not viable. However, the waste volume must be large enough to ensure that appropriate data can be collected so that an informed decision can be made of whether WIPP is suitable to serve as an appropriate disposal facility.

The Admiral has stated that he intends to emplace no more waste during the Test Phase than is necessary, and my experience suggests that the Admiral honors his commitments. It is clear to me that DOE does not intend to use the Test Phase at WIPP as a subterfuge to alleviate the TRU mixed waste storage constraint imposed at the Rocky Flats Plant. To enact an arbitrary limit on the Test Phase that is too low, and thereby preclude the Test Phase from accomplishing its necessary objectives to provide data to enable informed judgments to be made about facility performance, would not be in the public interest.

It is also important to remember that DOE has committed to retrieving any waste emplaced in the Test Phase if the determination is made that WIPP is not suitable for service as a disposal facility. That retrievability plan was provided to the Blue Ribbon Panel for its review, and our comments and recommendations have been provided to DOE.

I do not believe that a numerical cap on the amount of waste to be emplaced in the Test Phase is necessary or desirable; setting an arbitrary limit may prove to be counterproductive to gathering data necessary to enable an informed decision to be made regarding the appropriate waste form and the facility and site suitability. However, if Congress determines that it should legislatively impose some numerical cap on the volume of waste that could be utilized to conduct the Test Phase, a reasonable level should be set (e.g., one percent) of total facility design volume to allow for the potential, and necessary, evolution of the tests and experiments to be conducted as part of

the Test Phase, which may include the need to evaluate waste forms different from those that currently exist.

At the Committee's hearing on April 3, 1990, a number of questions were raised regarding the purpose and scope of the two rooms that EPA recommended that DOE establish for monitoring and subsequent evaluation. At the present time, DOE is evaluating the feasibility and value of creating those rooms, but it should be emphasized that the purpose of that proposal was to provide data over a period of many years to evaluate actual facility performance against expected facility performance. The purpose of that program is fundamentally different from the purpose of the Test Phase, which is to gather data to support the evaluations to be contained in the Performance Assessment to ascertain whether WIPP is a suitable disposal facility. Although the Blue Ribbon Panel has not evaluated this matter, I believe that EPA's suggested program might be an appropriate adjunct to the WIPP facility operation, but it should not be undertaken unless and until there is reasonable confidence as to the appropriate waste form for the TRU waste to be emplaced at WIPP and reasonable confidence that WIPP is a suitable disposal facility.

During the Blue Ribbon Panel's deliberations, and in fact during the Committee's hearing on April 3, 1990, questions continued to arise concerning the provisions and application of the EPA's "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" which is codified in 40 C.F.R. Part 191 Subparts A and B. Similar questions have also arisen concerning the applicability of provisions of the Resource Conservation and Recovery Act ("RCRA") and EPA's implementing

regulations contained in 40 C.F.R. Part 268. Of particular pertinence at this time is DOE's submittal of a No-Migration Variance Petition under those regulations and EPA's recent announcement of its proposed decision on that submittal.

Because of the importance of these requirements and their application to WIPP, I reviewed the pertinent parts of the Nuclear Waste Policy Act, 40 C.F.R. Part 191, and that rule's associated Regulatory Impact Analysis and Draft Environmental Impact Statement. I also reviewed the applicable provisions of RCRA and the implementing regulations codified in 40 C.F.R. Part 268, as well as EPA's Notice of Proposed Decision on DOE's No-Migration Variance Petition of April 6, 1990.

Fundamentally, I am deeply troubled by the realization that EPA, at least as detailed in the critical documents in the public record that support the adoption of the current Part 191, did not consider TRU waste or the WIPP facility in the development of Part 191. Thus, Part 191 does not provide a reasoned and responsible regulatory structure appropriate to the disposal of TRU wastes. In addition, as currently drafted, those standards establish release limits and are not based on an evaluation of the risk to public health and safety. EPA has announced its intent to issue revised Part 191 regulations, with a proposed rule scheduled to be issued for comment late in 1990 and a final rule promulgated in mid-1992. The NRC's Advisory Committee on Nuclear Waste has committed to the NRC that it would provide specific recommendations to the NRC regarding appropriate revisions to the EPA standards as they relate to spent fuel and high-level waste. DOE should do

nothing less with respect to TRU waste. I have recommended most strongly to DOE that it work with EPA, and the NRC as appropriate, and provide EPA with the technical justification that would support EPA's adoption of Part 191 standards appropriate to TRU waste and, as appropriate, the WIPP facility.

As a National Research Council's WIPP Panel observed in its 1989 report to DOE that Dr. Fairhurst referred to in this Committee's April 3, 1990 hearing, "[t]he primary goal of 40 C.F.R. 191 is to ensure that a repository poses no significant health risk to the public; standards set for compliance represent EPA's best estimate of what is required to achieve this goal. To date, however, these standards have never been applied to a specific repository." The Panel further stated that, "[t]he Panel believes that the above-mentioned primary goal can best be achieved by focusing performance assessment activities on demonstrating that the WIPP repository will be safe, i.e., pose no significant risk to public health and safety, rather than by an uncritical, formal adherence to compliance with the current EPA standard" (emphasis in original). I agree.

Dr. Rice testified at the Committee's hearing on April 3, 1990, regarding the concerns of the Advisory Committee on Nuclear Facility Safety about whether EPA has made proper judgments, based on justifiable assumptions, in its development of standards. The goal should not be to ascertain merely whether EPA standards are satisfied, but whether human health and the environment, consistent with the finding of Congress in RCRA, and the responsibilities delineated under the Atomic Energy Act, are being adequately protected both now and into the future. It appears self-evident that RCRA and

Part 191 were, by Congressional intent and EPA practice, based on concerns for materials and issues far different than TRU waste and TRU mixed waste.

I am also very concerned about the potential consequences of the regulatory duplication and conflict between EPA and NRC regulation of mixed wastes. I have provided for the record a copy of a letter from Congressman Udall to NRC Chairman Carr and EPA Administrator Reilly regarding the lack of resolution of the mixed waste issue and a copy of the responses of Messrs. Carr and Reilly. My specific concerns relate to the application of certain RCRA requirements to TRU mixed wastes, not only because of the current lack of regulatory resolution for the entire mixed waste issue, but also because of the very real occupational hazards that will likely result from slavish adherence to current RCRA requirements for hazardous material testing and identification that were developed for far different purposes and therefore are not appropriate in this situation. Workers should not be subjected to unnecessary occupational exposures to conduct waste testing if the test results will have no bearing on decisions related to facility performance and the experiments to be undertaken during the Test Phase to reduce the uncertaintites associated with assessing facility performance.

As I emphasized in my October 1989 report to Admiral Watkins, both DOE and EPA are responsible for implementing national policy regarding the proper disposal of TRU waste. Neither agency can shirk its statutory responsibilities, but both must recognize that their responsibilities in this area are joint and not severable. DOE and EPA must ensure, in the context of the WIPP project, that the responsibility for safe, permanent disposal of TRU

wastes and the requirements of Parts 191 and 268 are reconciled. It is not in the Nation's best interest for TRU waste, safe though it may be in temporary storage, to remain in that state ad infinitum because of a failure of governmental agencies to work together to develop a facility that can safely, permanently dispose of TRU wastes.

With respect to Congressional consideration of legislative land withdrawal, it should be emphasized that the experiments planned for the Test Phase are not required to demonstrate regulatory compliance, but rather to reduce uncertainties associated with the waste form and the response of the physical environment to the emplacement of those wastes. I strongly support the prompt passage of appropriate land withdrawal legislation so that the Test Phase, a necessary precondition to the determination of whether WIPP is a suitable disposal facility, can begin as soon as Admiral Watkins determines that it is appropriate to do so.

In conclusion, the WIPP facility appears to have been well-planned and constructed -- it has the hallmarks of a professionally designed and staffed facility. Even in the relatively short time in which the Blue Ribbon Panel has been active, it is clear that there are a great number of competent and motivated individuals, both professional and support staff, who are committed to doing their best to complete this project correctly. If WIPP is not determined to be a suitable facility as a geologic repository for transuranic waste, it does not appear that it will be for the lack of many individuals doing their best to do the job right.

In 1980, the President of the United States established a comprehensive program for the management of radioactive waste. In a message to Congress, President Carter observed that "[m]any citizens know and all must understand that this problem will be with us for many years. We must proceed steadily and with determination to resolve the remaining technical issues while ensuring full public participation and maintaining the full cooperation of all levels of government. We will act surely and without delay, but we will not compromise our technical or scientific standards out of haste. I look forward to working with the Congress and the states to implement this policy and build public confidence in the ability of the government to do what is required in this area to protect the health and safety of our citizens."

A decade has expired since that call to action was made, and its principles remain apt today. We <u>must</u> find the way to address and resolve these issues without delay, and continued Congressional support is required if those goals are to be able to be achieved.

STATEMENT OF

Dr. ARTHUR S. KUBO

PANEL MEMBER

THE SECRETARY OF ENERGY'S WASTE ISOLATION PILOT PLANT BLUE RIBBON PANEL

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

APRIL 26, 1990

TEL No. 301 601 9407 Apr 24,90 13:33 P.02

I am Dr. Arthur S. Kubo and am pleased to appear before you today as a member of the Secretary of Energy's Waste Isolation Pilot Plant (WIPP) Blue Ribbon Panel to discuss the Department of Energy's (DOE) proposed legislation entitled the "Waste Isolation Pilot Plant Land Withdrawal Act."

I submit for the record copies of my Panel Report of October 23, 1989 and a letter provided to Senator Domenici addressing issues raised by the New Mexico Congressional Delegation. Similar letters were provided to Senator Bingaman, and Congressmen Skeen, Schiff and Richardson.

To begin with, I endorse Dr. Tom Bahr's Introductory Remarks on behalf of the Blue Ribbon Panel and reiterate the importance of proceeding with the needed experimental program as part of the assessment of the long term safety of WIPP. My further remarks will emphasize two points:

1. The WIPP Test Program now focuses on demonstrating the technical feasibility of the WIPP concept and is separate from the operational management of TRU/Mixed TRU waste, and

2. A well understood and predictable waste form reduces the uncertainty in assessing the long-term safety performance of WIPP.

A. WIPP PROOF OF CONCEPT: In my report of October 23, I commented that the WIPP Program was attempting to address three major national issues: demonstrating the technical soundness of the WIPP concept, evolving a workable set of mixed waste regulations, and supporting the defense nuclear materials waste management program. I recommended, along with others, that the WIPP Test Program should focus on the technical feasibility of WIPP and be separated from the DOE's operational TRU waste management program. The Performance Assessment Experiments are designed to provide the technical data to reduce the uncertainty in assessing the long-term safety performance of the waste repository. This goal should not be intertwined with the need to manage TRU/Mixed TRU waste generated by the defense nuclear weapons production program.

The more realistic the Test Program the less likely we will be confronted with future surprises. Although the bin tests can be conducted off-site with further delay and additional cost, the most realistic test bed for the WIPP experiments is underground at WIPP. The research and development program must first demonstrate that WIPP is a safe Mixed TRU waste disposal facility. DOE is focusing the test program on obtaining the scientific data necessary to support a WIPP technical feasibility assessment in the near future and has separated it from the defense nuclear weapons production waste management program.

B. WASTE FORM: There are two factors that significantly affect the long-term performance of the WIPP as a deep geologic nuclear waste repository. These factors are (a) the geologic and hydraulic characteristics of the site and (b) the waste form characteristics. Obtaining and interpreting valid geologic and hydraulic data is difficult. The current and projected waste inventory is heterogeneous and subject to regulation as both radioactive and hazardous waste. A significant portion of the inventory is mixed waste, will generate gas, and has an unpredictable brine solubility and permeability. DOE may be unable to fully characterize, regardless of the extent of their experiments and tests at WIPP, the site geology and hydrology, and the TRU waste inventory. There will always remain a degree of uncertainty in assessing the long term repository performance. The waste form is one of the few variables we can control that significantly reduces the uncertainty of future WIPP performance.

This uncertainty can be reduced by better defining the waste forms that are proposed for burial. One method of better defining the waste forms is by accomplishing waste characterization studies. DOE currently is developing plans to accomplish this. DOE will be technically ready to begin the bin and alcove tests on-site when they have appropriately characterized the test waste and developed a plan to characterize the current and projected waste inventory.

Waste treatment is an alternative method to control the waste and packaging characteristics to fix the disposal site environment. Modifying the waste form would reduce the leachability of radionuclides on the off chance of repository disruption and preclude or reduce the gas generation phenomenon common to the current waste forms and packaging. This approach is technically more conservative and potentially more costly; however, this conservatism may be necessary to open WIPP as the first deep geologic repository of a National Program to safely dispose of all nuclear waste. DOE is currently conducting a study of Engineered Alternatives that addresses these issues.

In conclusion, the WIPP technical issues are all solvable, but the test and experimental program must go forward to obtain the data necessary to assess long term safety. WIPP was originally conceived as a test and demonstration facility. I can think of no better location to conduct realistic performance assessment testing than at WIPP.

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IV

STATEMENT OF

LEONARD C. SLOSKY

MEMBER OF THE SECRETARY OF ENERGY'S

BLUE RIBBON PANEL ON THE

WASTE ISOLATION PILOT PLANT (WIPP)

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

APRIL 26, 1990

04. 26. 90 04:18PM RAUL RODRIGUEZ, ESQ.

I am pleased to have this opportunity to share with the Senate Energy and Natural Resources Committee my views regarding the Decision Plan for the Waste Isolation Pilot Plant (WIPP).

My involvement with WIPP began in August 1989, when Governor Romer of Colorado and the Secretary of Energy asked me to serve on the WIPP Blue Ribbon Panel. After a very intense review, my initial report was presented to the Secretary on October 23, 1989. I have submitted a copy of that report for the record. Since that time I have provided the Secretary with several letter reports. The Blue Ribbon Panel is continuing to review and provide advice to the United States Department of Energy (DOE) on several aspects of WIPP. In addition to receiving many documents, the Blue Ribbon Panel generally meets and receives briefings every month or two.

Progress in the Transuranic Waste Management Program

Since the fall of 1989, DOE has made considerable progress in the transuranic (TRU) waste management program. I am also pleased to report that DOE has been responsive to many of the recommendations of the Blue Ribbon Panel members. As a result of recommendations from the members of the Blue Ribbon Panel (and in some cases other groups as well) DOE has:

- Initiated the development of a headquarters-directed integrated TRU waste management system.

- Removed WIPP from the pressures of managing waste from the defense program's production facilities (i.e., Rocky Flats).

- Decided to postpone the "Operations Demonstration."

- Increased attention to the technical and regulatory issues relating to the hazardous chemicals in TRU wastes (particularly those regulated by the Resource Conservation and Recovery Act (RCRA)).

- Committed to publish periodically the results of performance assessment calculations.

- Began revising and expanding the WIPP waste acceptance criteria (WAC) and the procedures used to audit compliance with the WAC.

DOE has also made considerable progress toward completing the many actions needed to begin waste experiments at WIPP.

WIPP Experimental Program

It is clear to me that further progress in determining whether or not WIPP is suitable for TRU waste disposal cannot be made without the bin and alcove experiments using real TRU wastes. The uncertainty in the predictions of how WIPP will perform cannot be substantially reduced without real world data. Therefore, the bin and alcove experiments should begin as soon as possible.

The bin experiments are to be conducted in enclosed metal containers isolated from the surrounding environment. Thus, the bin experiments can be conducted at WIPP or any suitable facility. Unless unexpected delays occur, the bin experiments could be initiated at WIPP as quickly or more quickly as another facility could be constructed and be in compliance with applicable legal requirements. However, if significant delays occur in initiating the experiments at WIPP, the bin experiments should be conducted elsewhere.

The alcove tests, on the other hand, can only be conducted at WIPP. Because the alcove experiments are needed to study the complex interactions between the wastes and the disposal environment (the Salado formation), they can only be conducted in the WIPP underground. While there has been much discussion of the quantity of gas that will be generated, there are other critical issues (i.e., the permeability of the Salado to gas) that the alcove experiments are designed to address. The alcove experiments also have the advantage of being close to the full-scale size of the disposal rooms. This means that the alcove tests will be more representative (than the bin tests) of the actual repository

conditions, including utilizing a large number of waste packages that will be more typical of the radiological and chemical constituents in the large number of TRU waste types intended for disposal at WIPP.

Waste Characterization

This hearing has addressed several issues that could delay the initiation of waste experiments at WIPP. A primary area that has been discussed (and which is largely beyond DOE's control) is the United States Environmental Protection Agency's (EPA) final decision of the No-Migration Petition. There is an additional area with which I am concerned that has received little public attention. This is the issue of waste characterization or composition. EPA's proposed Conditional No-Migration Variance requires DOE to submit results of detailed waste characterization and analysis of the wastes to be used in the bin and alcove experiments. In addition to this and other regulatory requirements for waste analysis (e.g., 40 CFR 264, the RCRA Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities), there are critical technical reasons why substantially more information is needed on waste composition.

Based upon a review of DOE's efforts to characterize the hazardous chemicals in the TRU wastes on the basis of "process knowledge," I have concluded that, at best, only semi-quantitative estimates are possible. Is it possible to develop reasonably reliable estimates of the quantities of hazardous chemicals in TRU wastes generated 15 years ago, based upon "process knowledge?" There are important reasons why reasonably accurate waste characterization data are needed.

The first is a fundamental scientific principle: If you do not know the initial conditions of an experiment (the hazardous chemicals that go into the bin and alcove tests), you may not be able to understand the results of the experiment. For example, certain organic chemicals that may be present in the TRU wastes (or may be produced by their decomposition) could greatly increase

the solubility of the plutonium in the wastes. This is important because an increase in the solubility of plutonium could increase the mobility of the wastes in the environment.

The second reason is that the wastes to be used in the bin and alcove experiments must be representative of the universe of wastes to be disposed in WIPP. If you do not use the same types of wastes in the experiments that you intend to dispose at WIPP, the experiments may not be relevant to how WIPP will actually perform. There have already been substantial technical surprises in the WIPP program. The rooms have been found to close two to three times faster (at least initially) than originally estimated. The permeability of the salt has been less than estimated (resulting in the need for more accurate data on gas generation). At the conclusion of the several hundred million dollar WIPP test phase, it would be disappointing to discover that more detailed waste characterization information is needed.

Thus, based on my present understanding, I do not think that the bin or alcove experiments should proceed without reasonably accurate quantitative data on the organic chemicals in the TRU wastes. Given the potential technical difficulties in obtaining such data, it is possible that waste characterization could delay the initiation of waste experiments into 1991. A waste characterization plan is expected from DOE in the next several months. Hopefully there will soon be a solution to this problem.

The waste form or the need for waste treatment is a second issue that has not received much public attention. Based upon the review by the Blue Ribbon Panel and particularly from discussions with the National Academy of Sciences, I have concluded that the technical uncertainties regarding the performance of WIPP are considerable and are much greater than generally understood. For example, in modeling the long-term performance of WIPP, it is not unusual for the range of an input parameter to be four or six orders of magnitude. This means that for important measures of the properties of the Salado, the current state of knowledge is such that the actual number is somewhere between 1 and 10,000 or

1,000,000. Given the complexity of waste decomposition processes and interactions with the reconsolidating Salado formation, it is likely that at the end of a five-plus year experimental program, substantial uncertainties regarding the performance of WIPP will remain.

So what can be done to reduce these uncertainties? The salt is fundamentally a given. The design of the repository (e.g., the size of the rooms) can be changed, but such alterations are unlikely to enhance the performance of WIPP dramatically. Greater use of engineered barriers is possible, but their performance over 1,000 to 10,000 years is highly questionable. The one variable in the WIPP equation that is clearly changeable (i.e., can be dramatically improved) is the waste form. For example, waste treatment technologies are currently available that will essentially eliminate gas generation.

I believe that it is important to assess the likelihood of success by continuing to use an essentially untreated waste form versus producing a more stable waste form through treatment. In making this assessment it is important to consider the cost, timing, regulatory/institutional, and personnel exposure issues involved. While recognizing that waste treatment may be a substantial undertaking (depending upon the degree of treatment needed), I believe that it may be necessary to dispose permanently of TRU wastes in the foreseeable future.

Because of the potential importance of waste treatment to the performance of WIPP, a broad range of potential treated waste forms should be included in the bin and alcove experiment at the earliest possible time. I concur with the position of the Environmental Evaluation Group (EEG) that the test phase, in addition to quantifying gas generation, should include potential solutions to this problem. The DOE study of engineering alternatives that is now in progress is expected to address this issue.

04. 23. 90 04:15PM *RAUL RODRIGUEZ. ESG.

Quantity of Waste Needed for Experiments

I believe that DOE has justified the need for using waste volumes totaling about 0.5 percent of WIPP's capacity for the bin and alcove experiments. The Blue Ribbon Panel has not yet reviewed the EPA suggestion that DOE assess the technical feasibility of two large-scale instrumented rooms containing about 1.5 percent of WIPP's capacity. However, it seems advantageous to obtain the type of mid-term performance data intended to be provided by the EPA rooms. While such data are desirable, as EPA recognizes, obtaining these data may not be technically feasible. In any case, a decision on whether or not to include such rooms in the experimental program is at least several years away. It would not be prudent to begin such large-scale experiments until well into the test program when waste form and disposal configuration issues have been finally resolved. Otherwise, one risks having substantial quantities of waste in WIPP that have to be removed for treatment or disposal elsewhere.

Because of the importance of including treated waste forms (and other engineering alternatives) in the bin and alcove experiments, I would recommend that Congress authorize the use of waste volumes of up to 1.0 percent of WIPP's capacity for the bin and alcove experiments.

Land Withdrawal Legislation

In my view it is preferable that the land withdrawal be done legislatively rather than administratively. Legislative land withdrawal has the advantages of being able to address the concerns of a number of interested parties as well as bolstering public confidence in the WIPP program.

The timing of land withdrawal legislation is also an important issue. I am hesitant to comment on this because it may be a "chicken or egg" problem depending on one's perspective. While everyone acknowledges that additional actions need to be completed before waste experiments can begin at WIPP, would it be in the national interest for the experiments to be significantly delayed

4. 23. 90 04:15PM *RAUL RODRIGUEZ, ESQ. P08

while the current Congress is in recess or the 102nd Congress is in its start-up period? It would appear to me that Secretary Watkin's feet have been adequately singed by the fire. What substantive purpose would be served by holding the land withdrawal legislation "hostage?" DOE is now internally motivated to begin waste experiments at WIPP at the earliest possible time that they can be conducted safely and in compliance with all legal and institutional requirements. Is there any new information anticipated that would affect the provisions of the land withdrawal legislation? It would seem to me that Congress could now move to debate and resolve the remaining land withdrawal issues. The legislation could be passed through committee, and if deemed necessary, held for final passage until DOE satisfies Congress that it is ready to begin the experimental phase.

In conclusion, it is my observation that despite our focus on the problems of developing this nation's first permanent repository for TRU waste, bedded salt continues to be an outstanding medium for waste disposal and WIPP is a very good site. I know of nothing that indicates that WIPP has a "fatal flaw." While some type of waste treatment may be found to be necessary or expeditious, WIPP has a high probability of ultimately satisfying very stringent short-term and long-term health and environmental protection criteria. However, as a general matter, it should be recognized that there is inherent risk in any program that pursues a single approach without contingencies.

I will be pleased to respond to any questions.

STATEMENT OF

NEWAL SQUYRES

MEMBER

DEPARTMENT OF ENERGY'S

BLUE RIBBON PANEL ON WIPP

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES

UNITED STATES SENATE

April 26, 1990

STATEMENT

Mr. Chairman and Members of the Committee, I appreciate the opportunity to appear before you with the other members of the Secretary of Energy's Blue Ribbon Panel on the Waste Isolation Pilot Plant (WIPP). I practice law in Boise, Idaho, and became a member of this group as a result of Admiral Watkins' request of Governor Cecil Andrus to nominate someone from Idaho to serve on this Panel. My views on WIPP are my own and do not necessarily represent the views of Governor Andrus or the State of Idaho. Initially, the five members of the Panel were each asked to provide an independent assessment of certain issues related to WIPP, involving primarily the scope and direction of the test phase. My report to the Secretary of Energy was submitted on October 23, 1989, and will be submitted to the Committee for the record as an addendum to this prepared statement. That report, although somewhat dated by subsequent events and the Panel's continuing involvement on certain issues, continues to reflect my overall views on WIPP.

Congress established WIPP's mission in 1980, when it directed the Secretary of Energy to proceed with construction "for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive waste resulting from the defense activities and programs of the United States . . . ." Pub. L. No. 96-164, § 213(a) (1980). To put this mission in perspective in terms of the test phase now at issue, it

is important to remember several things. WIPP's total capacity is 880,000 drum equivalents of TRU and/or mixed-TRU waste. The test phase as currently configured contemplates the use of approximately 4,500 drum equivalents. There are over 280,000 drum equivalents of this waste stored "temporarily" at sites throughout the United States in facilities not designed or intended for permanent disposal. There are approximately 180,000 drums in temporary storage in Idaho planned for shipment to WIPP.

DOE has made significant progress in the last eight months in moving WIPP from the construction phase to the experimental phase of its development. This test phase is necessary to aid in establishing regulatory compliance and, more importantly, to determine whether, or under what conditions, WIPP may serve as a permanent repository for the disposal of defense generated TRU and mixed-TRU waste.

At the first meeting of the Blue Ribbon Panel in Albuquerque, New Mexico, on September 11, 1989, the representative from the National Academy of Sciences (NAS) said there were no significant safety issues associated with using WIPP for the test phase. At that time, however, there were institutional and regulatory matters that had to be resolved before the test phase could begin. Technical issues related to the scientific experiments for the test phase were also still being addressed.

Resolution of these outstanding issues has followed in a steady progression since the Secretary's draft decision plan for

WIPP was issued last October. My understanding is that WIPP is very close to being operationally ready to receive the limited amount of waste necessary to begin the test phase. The EPA's decision earlier this month on DOE's no migration petition provides the opportunity to satisfy critical regulatory requirements under RCRA. The proposed conditional variance would allow DOE to place untreated mixed waste into WIPP for the purpose of testing and experimentation. The public comment period is now underway, and EPA contemplates being in a position to finalize its proposed variance by September of this year. I believe the most significant remaining hurdle to beginning the test phase is the land withdrawal legislation now under consideration by this committee. I strongly support DOE's effort to obtain appropriate land withdrawal legislation during this term of Congress so that the test phase can begin as soon as possible.

There is another consideration which should not go unnoticed as decisions are made concerning WIPP's future. There are a number of independent oversight groups, not to mention federal and state regulatory agencies, involved in the decisionmaking process. The presence of these groups provides substantial assurance of adequate peer review for the scientific and technical issues and will prevent decisions from being hidden or being made in a vacuum. I have been continually impressed by DOE's willingness to accept and respond to suggestions and criticism from these independent groups.

As the closing speaker, I want to emphasize the opening remarks of Dr. Tom Bahr from New Mexico. Although there has been no effort by the members of this Panel to arrive at agreement on the subjects we have considered, agreement has naturally evolved from our independent evaluation of the issues. Moreover, our conclusions on the primary issues have been in accord with the other groups providing advice on various aspects of WIPP. This is significant when one considers the differences in background, training and experience of the individual members of these groups. In my judgment, those areas of agreement are as follows:

- It is in the national interest to safely manage the disposal of the waste (existing and future) generated by the production of nuclear weapons.
- WIPP is safe from the standpoint of being ready to proceed with the test phase.
- The operations demonstration should not begin until enough data is gathered from the test phase to indicate with some assurance what the final disposal methods will be.
- The test phase should be conducted at WIPP.
- DOE should continue to fully explore changes in waste form and other engineering modifications.
- The quantity of waste for the test phase should permit flexibility to expand the currently proposed experiments with additional waste, if scientifically justified.

I have not heard anyone suggest in the last eight months that there is a better place to store or dispose of the waste in question than WIPP. The taxpayers have spent over $800 million for WIPP, and there appears to be no sound reason not to put WIPP to its intended use as a research and development facility. It is a mistake not to recognize that WIPP is a unique place and that its potential to provide a meaningful solution to some of this nation's waste management problems is an outstanding accomplishment. It would be a sad day indeed if we do not seize the opportunity to go forward with WIPP's development.

Thank you for the opportunity of appearing before you today; I would be pleased to attempt to answer any questions you might have.

PEER 15 - Advisory Committee on Nuclear Facility Safety Review Reports

Advisory Committee on Nuclear Facility Safety

to the

United States Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

December 11, 1989

Honorable James D. Watkins
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Dear Admiral Watkins:

As you requested, the Advisory Committee on Nuclear Facility Safety has conducted a brief but comprehensive review of the Waste Isolation Pilot Plant (WIPP) Project. The purpose of this report is to provide our assessment of those elements of the project that relate to health and safety and to identify potential safety concerns.

The major observations and perspectives discussed below are derived from analyses of selected issues from several key areas. The key areas included unresolved technical problems, the Final Safety Analysis Report (FSAR), and WIPP management, organization and staffing policies and practices. Certain areas were not selected for review based on the nature of their separate resolution (i.e., Land Withdrawal, RCRA No Migration Petition, and certification of the TRUPACT shipping container) or lack of full program development (i.e., Remote Handled TRU waste).

The review involved the full committee. However, much of the detailed review was performed by the WIPP Subcommittee which was chaired by Paul Rice, and included committee members William Kastenberg, James Martin, M. J. Ohanian, Robert Seale and Gerald Tape. In addition, Thomas Pigford and Konrad Krauskopf assisted us in the assessment of unresolved technical issues. Other expert consultants assisted in examining the adequacy of the FSAR and the conduct of operations. A complete list of consultants and staff is appended. The full committee visited WIPP in June 1989, and several members of the subcommittee made a follow-up visit to the WIPP site in August 1989. In addition, subcommittee members visited the Sandia National Laboratories, the Rocky Flats Plant, and the Idaho National Engineering Laboratory.

The committee commends the Department for its support and encouragement of reviews and analyses from organizations external to WIPP line management. Important input has been provided by the State of New Mexico Environmental Evaluation Group, the National Academy of Sciences, and the Department's own Environmental, Health and Safety reviewers. The committee has considered the inputs and recommendations from these sources.

You have established requirements for the Department's nuclear activities that we found to be particularly relevant to our review of WIPP. These are (1) the long-term protection of public health and the environment and (2) a culture of management and operation that clearly demonstrates a commitment to excellence by agency and contractor managers and employees. Although we examined many details and could comment on numerous specifics (most of which have been identified in other reviews), we believe our best service to you is to provide comments and recommendations on the more important issues. We have organized our discussions and recommendations that follow into two major sections. First, we discuss the long-term environmental performance of WIPP. Second, we discuss issues which are more of a short-term nature and provide recommendations on actions necessary to assure safety in the day-to-day conduct of operations.

Long-Term Environmental Performance

Environmental Standards

The major issue for interment of TRU wastes in WIPP is whether reliable long-term isolation occurs. The Department acknowledges this requirement; however, it has not yet assembled and published in a suitable form the results of work it has done to show how WIPP is expected to perform against the Environmental Protection Agency (EPA) standards.

You have indicated that DOE will comply with 40 CFR Part 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Wastes. Here we consider only TRU waste. Subpart A applies specifically to management and storage, with the interest and capability to readily retrieve such wastes for subsequent use, processing or disposal. For the purpose of carrying out in situ tests and experiments and for gaining operations experience, Subpart A requirements are satisfactorily met. The ultimate objective of WIPP is to demonstrate and to become a "disposal" site, that is to provide for permanent isolation of TRU waste from the accessible environment with no intent of recovery. Subpart B, Sections 13 (containment) and 15 (individual protection) set forth the requirements directly applicable to WIPP. (Note that Subpart B is in the process of revision; for reference purposes, the draft revision is used here.)

The Department's scientific advisor for WIPP, Sandia National Laboratories, has prepared a systems analysis involving long-term radionuclide transport and dose assessment (SAND 89-0462), in which potential health effects to individuals are calculated for several hypothetical scenarios but not specifically compared with EPA standards. When the EPA default parameter values are used in the deterministic assessment, the results may, in some cases, be unecessarily conservative. Nevertheless, except for human intrusion, all of the scenarios lead to limits that could be expected to satisfy EPA requirements. To be more specific:

- If the expected results of the ongoing gas generation assessment and "representative" properties of waste, backfill, and borehole sealing can be confirmed, then the performance assessment should provide a high degree of

confidence that the undisturbed performance of the WIPP is not expected to result in any release of radionuclides to the Culebra Dolomite or to the surface for well over 10,000 years.

- If the results or properties are worse than those now assumed, it should be possible to gain the high degree of confidence of compliance by initiating engineering modifications to the waste or to the facility (e.g., backfill).

The results presented for the human-intrusion scenario are deterministic and may be physically unrealistic when taken as a whole "because each calculation assumes different repository and geosphere characteristics." (Sandia Report SAND89-0462, April 1989). Therefore, the parameters lead to projected releases that may exceed EPA standards. This scenario includes a drilling event with a probability of 1.0 for penetrating through a repository panel and connecting a brine pool in the lower Castille formation with an upper aquifer; a flow pattern of Castille brine within a panel that allows the emergent brine to have a radioactive concentration based on the solubility of the elements in brine; sealing of the borehole in a manner that results in porous material (a condition not consistent with predictions of current WIPP seal performance); and no credit given for passive markers and records. While we understand the desire to satisfy EPA requirements using conservative parameters, we believe that the assumptions used in the intrusion scenario, taken collectively, may lead to an overall condition that is more conservative than necessary.

The EPA standards and implementing guides recognize that determining expected performance of sites for long-term isolation of wastes involves "reasonable projections" using models and parameters that may require "qualitative judgments"(the quoted terms are from Appendix 3 of 40 CFR 191). In this regard, we believe that the Department should develop a carefully considered intrusion scenario that would include considerations such as expectations for future borehole sealing at least as good as the current state-of-the-art and the effects of Department actions to provide passive markers and records. Such a scenario should take into account what future humans can be expected to do, since we must believe they will exercise reasonable care about their environment and be aware that failure to take basic precautions in areas such as monitoring and borehole sealing could adversely affect their environment. If the intruder scenario is considered with such "reasonable projections" as we believe are allowed by EPA guidance, especially in the area of borehole sealing, we expect WIPP can be shown to meet EPA long-term performance requirements with satisfactory margins of safety.

However, if the Department prefers to address the intruder scenario using the default values in the EPA guidance, then we believe that insufficient margins exist to demonstrate compliance and it will be necessary to soon plan for engineering enhancements of the waste and/or repository configuration. Since the issue is more one of which methodology should be used for demonstrating compliance with EPA Subpart B standards, not whether WIPP is indeed safe, we recommend that the Department take the lead to develop "reasonable projections" of long-term per-

formance and interact with EPA on the adequacy of these important performance assessment inputs.

A "test phase" has been proposed in order to reduce the uncertainty in parameters such as brine inflow, solubility of waste forms, gas production rates, and gas/liquid two-phase flow, and to better confirm performance against EPA standards. The Department can use data from those experiments, to be obtained over the next few years while the waste is retrievable, to build additional confidence in the facility. However, it appears that these tests will not in-and-of-themselves provide the type of results that will significantly change performance assessment results currently being developed and scheduled for issue in December 1989. For this and other reasons discussed below, the Department should not delay its environmental performance assessment until such tests are done. Instead, the Department should proceed to prepare an assessment of the long-term environmental performance with the objective of laying out a basis for reasonable assurance that WIPP meets the EPA environmental standards and for obtaining a consensus among involved parties.

In our opinion, such a document is also essential to focus the "test phase" experiments and assure that they serve to reduce uncertainties in the performance assessment assumptions, to identify any engineering modifications that may be necessary to accommodate present TRU wastes, and to indicate whether justifiable improvements should be made in future waste forms to prevent or mitigate gas generation. The proposed tests could also be most useful in determining whether future waste forms can reasonably be improved (see below), a program we encourage.

We believe that, prior to your decision to allow emplacement of waste shipments underground at WIPP, it would be prudent for you to have a preliminary performance assessment that provides you with reasonable confidence that EPA Subpart B standards can eventually be shown to be met. This summary document should contain a carefully considered human-intrusion scenario and should clearly identify the key parameters and assumptions in the performance assessment that need to be addressed in the "test phase" to improve their certainty. When this has been done, we believe it would be proper to proceed immediately to the proposed in situ testing at WIPP when other ongoing prerequisite actions are complete. If the review of the performance assessment by involved parties provides a high degree of confidence that EPA standards will be met, as we expect, then you could proceed with the operational performance phase as a gradual emplacement program to evaluate and work out operational issues identified in various reviews. Of course, any decision to go to production-oriented operation will require assurance that EPA Subpart B standards are satisfied.

In summary, there appears to be acceptable confidence that the EPA requirements of Subpart A can be met to allow use of WIPP as a test facility and, therefore, to begin the emplacement of waste as part of the test program. The major technical issue facing WIPP is whether Subpart B can be met. From our review, we conclude that with the exception of the human-intrusion scenario, Subpart B requirements can be shown to be met using the work being completed by Sandia. The human-intrusion scenario, as developed by the DOE under its current application of EPA

guidelines, is not likely to meet the present Subpart B requirements. We see three major options:

1. Plan that the test program will produce results that will enable Subpart B to be met. We believe this is unlikely because of the relatively short time for testing as compared to the time period for the key phenomena and the limited effect of the parameters tested on the human-intrusion scenario.

2. Abandon WIPP. We do not believe this is necessary, prudent, or responsible.

3. Further address the EPA Subpart B human-intrusion scenario requirements, an approach we recommend below. We see two basic parts for this approach:

   a. Use more reasonable projections, for example, that future borehole seals would meet or exceed the current Sandia state-of-the-art form. DOE should take the lead to discuss these assumptions and approach with the EPA.

   b. Examine what engineering modifications would be required to meet the Subpart B requirements without changing the current assumptions.

Recommendations:

> *The Department should promptly assemble the data necessary to provide reasonable confidence that WIPP can eventually be shown to meet the release quantities and undisturbed site doses as required by EPA Subpart B standards, including a carefully considered intrusion scenario based on "reasonable projections." Having established this confidence, initiate TRU waste emplacement in support of the performance assessment program.*
>
> *The Department should, upon determination that a high degree of confidence exists that EPA Subpart B requirements will be met, initiate the operational test phase as a gradual emplacement program committed to deliberative steps to evaluate and work out various operational issues identified in various reviews.*

Gas Generation

Evaluation of the brine inflow question identified that the permeability of the salt formation was much less than originally thought. As a result, gas generated by radiolysis of water and organic matter in the waste, by bacterial decomposition of organic matter, and by corrosion of metal in the waste and its containers may produce high pressures in the repository because its escape is slowed by the impermeability of the surrounding salt. Current efforts by Sandia are focused on analysis to show whether potential gas buildup could result in a failure mode that would release unacceptable amounts of radionuclides to the environment and on methods of ameliorating gas buildup, if necessary. Members and consultants reviewed this issue, and we are of the view that DOE's evaluation program is proceeding properly.

The potential problem of gas generation raises questions concerning the current waste form and future DOE management of TRU wastes that are worthy of further review. Specifically, a reduction in the amount of metals and organics or a change in the form of organic materials could reduce the gas generation. We do not believe that an attempt to change the form of existing TRU waste would be justified in view of the risks and cost it would entail. Therefore, to the extent necessary, efforts to ameliorate gas generation within the repository appear to be the most reasonable approach. For future TRU waste, however, a different form that would reduce significantly gas generation should be considered. The engineering enhancement study underway should explore practical measures for reducing the quantities of decomposable waste, of using nonmetallic containers, and of stabilizing the waste by incineration or vitrification. Such measures could be beneficial if they can be conducted at reasonable cost and without appreciable risk to the personnel involved. Such an effort would be consistent with recently stated goals of improved waste management throughout the Department.

Recommendation:

> ***DOE should continue its studies of ways of mitigating any undesirable build-up of gas pressure from the disposal of existing TRU waste and should investigate justifiable improvements in future TRU waste forms that would greatly reduce gas generation.***

Safety Issues Related to Conduct of Operations

Radiological Safety

Good radiological safety is perhaps the single most important aspect of day-to-day WIPP operations. Previous internal DOE reviews have identified numerous deficiencies and needed improvements which are being corrected. Critical action items remaining fall into the areas of equipment modifications, technician staffing, completion of training programs, and management personnel qualifications and attrition.

In the category of radiological equipment required for safe operation, the likely critical path for start-up involves the Continuous Air Monitors (CAMs). The CAMs have a long history of problems starting with poor designs, slow recognition and correction of the basic problems and questionable maintenance practices. Actions are in progress to resolve the CAMs issues. We also identified a design deficiency in the interlock system which, as currently installed, would allow the simultaneous opening of airlock doors that could expose the environment to potential or actual contaminated areas. Examples of other radiological equipment which must be completed for safe operation include the decontamination facility exhaust ventilation and contamination control equipment associated with unloading the TRUPACT shipping container.

Both Westinghouse and DOE WIPP management have identified that the current number of trained radiological technicians is not sufficient to start up without significant augmentation by the Westinghouse health physics professional staff

or outside contract radiological technicians. Close management attention will be required to complete technician staffing and associated training, including off-site hands-on training, in order to insure a safe start-up. Several actions relating to radiological programs development need to be completed to insure long-term safety and credibility. These include accreditation of the WIPP dosimetry program and demonstration of the planned capability of the internal dosimetry program.

The committee observed that the WIPP Project has demonstrated a significantly improved trend in attention-to-detail and facility preparations during the first half of 1989. These improvements are due, in part, to the addition of competent health physics professionals and managers to the WIPP Project staff. In this regard, the committee has two fundamental concerns.

First, three different people have held the senior Westinghouse health physics manager position during the past year. We believe that stability in management staffing is important to maintaining the recent improvements in radiological protection and providing the vitality necessary for safe operations.

Second, DOE needs to emphasize the importance and priority of radiological activities to the safe and successful operation of the WIPP facility. Although radioactivity is the unique factor that differentiates WIPP operations from other industrial operations, current organizational reporting relationships (both Westinghouse and the DOE) would indicate that radiation safety is just another set of requirements for routine operations (This is not peculiar in DOE to the WIPP project). For example, WIPP organization charts and the FSAR show the senior manager directly responsible for all radiation programs is positioned at three levels below the top manager and one level below the managers of Public Affairs, Human Resources, and Administrative Services. Neither the FSAR nor WIPP organization charts indicate a direct access line to the senior facility manager.

Recommendations:

Define an organizational structure that provides senior radiation program management with sufficient authority and with direct access to senior Westinghouse facility management.

Both Westinghouse and DOE management at WIPP provide close follow-up and attention to the completion of critical hardware actions and validation of equipment operation.

Expedite completion of radiological staffing and training plans. Define formal contingency plans for attrition and develop procedures for requalification and testing of technicians.

Fire Protection

The WIPP facility has a number of impressive fire protection features including a loop-type fire main system above ground with a dual water supply capability

including a diesel driven fire pump in case of loss of power. Underground areas are protected by a non-water fire protection system. The committee did have concerns regarding specific features in three areas.

First, the committee questions whether adequate risk analysis has been performed for the increased impact of a fire in the underground storage areas when a number of drums are exposed due to a lack of backfill. For example, the FSAR Waste Acceptance Criteria preclude packages that could sustain the propagation of fire from one drum or box to the next by limiting pyrophoric loading within drums and overpacking combustible boxes with metallic cladding. The basis of the FSAR exclusion is not clear, particularly in the area of characterizing the chemical source terms for combustion in old drums. Further, the apparent assumption that the only credible source for initiation of fires involving waste underground is the spontaneous combustion of a waste container falls short in view of other sources associated with normal and abnormal operations.

Second, the committee noted the lack of a smoke detection system in the high bay normal work area of the Waste Handling Building and questions whether this design feature is actually justified by administrative actions such as fire loading controls or routine watchstander inspection requirements.

Third, the committee is concerned that the water fire suppression system does not include the location of the Waste Handling Building exhaust high efficiency particulate air (HEPA) filters.

Recommendations:

> *A risk assessment of the pre-closure operations of WIPP, including a fire risk analysis addressing fires underground and the adequacy of fire detection and suppression systems, should be undertaken. This assessment should evaluate the acceptability of fire risks, should identify dominant contributors to this risk, and should evaluate and select among risk reduction tactics, if appropriate.*
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> *Until a fire risk assessment can be completed to evaluate the specifics and focus on any necessary corrective actions, stringent administrative controls may be required to control all combustibles and possible ignition sources during routine and non-routine operations.*

Final Safety Analysis Report

The committee was specifically requested to review the Final Safety Analysis Report (FSAR) and did so through extensive and detailed examinations by members, staff and consultants. Also considered were the results of reviews by other organizations (EH&S, EEG, etc.). These examinations identified a large number of specific concerns and weaknesses in the FSAR. These problems included (1) missing or incomplete commitments necessary to envelop safety criteria, (2) inconsistent information between FSAR sections, (3) questionable operational safety requirements, (4) lack of differentiation between descriptive matter and commitments, and (5) unacceptable application of certain quality assurance (QA) program requirements. These specific issues were discussed with WIPP management personnel in the DOE and Westinghouse organizations.

Subsequent reviews of actual practices being implemented showed that a majority of these concerns were either due to omissions or were editorial in nature, the likely result of lack of understanding of the management philosophy for the FSAR discussed above or inattention to detail by internal reviewers.

The fundamental issue with the FSAR concerns its basic purpose, its content and how it is handled, both in terms of initial approval and future approval of changes. Applicable DOE Orders, both at the Headquarters and field office levels, are not precise on this matter. To address this issue, committee members interviewed senior DOE managers that control WIPP policy, including the Headquarters program managers in the Office of Defense Programs, oversight managers in the Office of Environment, Safety and Health, the manager of the Albuquerque Field Office, and the manager of the WIPP Project Office. All of these managers agreed that the FSAR was intended to be the top level safety document for WIPP that would contain all of those commitments necessary to envelop the safety analysis to insure the safe operation of WIPP throughout its life. They further agreed that the FSAR is a living document that would be approved at a senior level of management and be maintained up-to-date, and, that future changes would be handled in the same manner as the original approval. The committee strongly supports the position of your managers and urges prompt revision to DOE policies to clarify FSAR requirements and define it as the top level commitments document.

Both DOE and Westinghouse WIPP managements have not been aggressive enough in promptly resolving issues raised in external reviews of the FSAR (and other areas) such as those raised by the Office of Environment, Safety and Health and the State of New Mexico Environmental Evaluation Group.

The committee believes that a thorough review and revision of the FSAR, based on updated DOE policies and on the various external reviews, is a key step to insure long term consistent application of commitments and eliminate deficiencies that could adversely affect long-term safe operation.

Recommendations:

Revise applicable DOE policies and orders to define the FSAR as the top level safety document that will be:

- *a compilation of all commitments necessary to ensure safe operation of the facility,*

- *approved at a senior level of management, and*

- *kept up-to-date as a living document with future changes handled in the same manner as the original approval.*

Review and revise the WIPP FSAR based on the revised DOE policies and on existing critiques. Give priority to resolving all open issues.

Quality Assurance

As a result of initial reviews of policy documents such as the FSAR, the committee had serious reservations about the structure and adequacy of the quality assurance program. However, subsequent reviews of actual program practices showed that most of the concerns were unfounded and had resulted from poor descriptions and other inadequacies in the FSAR. The committee reviewed a number of different aspects of the actual WIPP quality assurance program being implemented and found it to contain most of the features one would expect at a more complex facility such as a reactor. WIPP has obtained quality assurance professionals with previous experience who understand both the technical and administrative aspects of a full featured quality assurance program. Previous DOE reviews have identified a number of quality assurance program deficiencies, most of which have been corrected.

The committee did observe several areas which require further management attention and corrective action. While some of these issues do not relate to the Quality Assurance Department, they are discussed below within the broader definition of the WIPP quality assurance program.

The committee considers that the General Criteria for Quality Assurance defined in the FSAR forms a sound basis for both the operation of the facility and for associated experimental activities. However, the application of the General Criteria is inconsistent between the operational and experimental activities and could degrade the overall performance of important experimental efforts.

Many organizations are involved in the resolution of outstanding safety related technical and procedural problems requisite to the start-up of WIPP. The committee was satisfied that most of these outstanding issues were identified on one or more of the work off schedules. However, the committee was concerned that there is no simple master tracking system to insure that relatively straightforward safety issues do not become "lost" or needlessly become the critical path. Further, lack

of such a system deprives management of a tool to detect early adverse trends and imbalanced work loads.

Training programs have been initiated and a significant amount of training has been accomplished. However, the committee is concerned that too much emphasis has been placed on "self-study" to the detriment of formal presentations. In the commercial nuclear power industry, the use of self-paced study is very limited and is used in conjunction with evaluation methods to assure the intent of the self-study is realized. Also, it appeared to the committee that the training department does not have sufficient input to senior WIPP management to resolve training problems, particularly as the work pace increases and there is less time for ongoing training.

Recommendation:

- *WIPP management should complete open quality assurance related corrective actions, correct inconsistencies in the application of Quality Assurance General Criteria, consolidate and upgrade current tracking systems, and insure that Training Department management has access to senior management.*

Organization and Management

The committee found that the DOE, Westinghouse, and Sandia National Laboratories have each established organizations that should be capable of performing WIPP operations in a safe and coordinated manner. This, of course, assumes that open issues in the areas of staffing and training are properly resolved. However, the committee has concerns regarding the lack of clear definition of certain reporting relationships that could result in confusion as to "who's in charge". In particular, the FSAR defines the Management and Operating Contractor (MOC) and the Scientific Advisor (Sandia) as holding equal levels of authority under the DOE WIPP Project Office Manager (WPO). This leads to the conclusion that the WPO manager will provide day-to-day line direction and coordination for facility operation. In actual practice, most of the hands-on experimental work in the facility will be carried out by an experimental division within the MOC organization. It appears to the committee that simple but important changes should be made to the FSAR to eliminate any confusion that the MOC is singularly responsible and accountable to the DOE for the safe and proper operation of WIPP.

Your recently announced policy is to establish a clear, straight line reporting relationship from operating facilities to the Headquarters program official and then to you. The current situation at WIPP appears to have two reporting chains to Headquarters. One of these runs from WIPP to the Operations Office to the Under Secretary while the other runs from WIPP to the Operations Office to the Assistant Secretary for Defense Programs (DP).

During the construction and testing phases of the WIPP project, many organizations have necessarily directed the development of various aspects of WIPP programs. Typically, the weight of influence changes among the Architect Engineer,

the Constructor, the Laboratory and the Operating Contractor as the project develops. However, there comes a time on any major project when responsibility for "ownership" must shift to the MOC. That time is now for WIPP. The committee found several instances where the MOC has deferred to outside direction involving operating practices without first determining that such practices did not degrade safety.

The committee is very encouraged by the recent trend of improvements at WIPP which are the result of positive actions by DOE and Westinghouse managers and, in particular, their actions to bring qualified seasoned managers and staff onto the project. However, these trends are fragile and could reverse. The two most likely causes for a downturn would be failure to maintain very high standards in replacing managers and staff who leave through normal attrition and the departure of the best people for "greener pastures" unless clear, achievable goals are set and met for operating the WIPP facility.

Recommendations:

- *Redefine organizational responsibilities so that operational safety responsibility runs from a single operating contractor to the WIPP Project Office to a Headquarters Program senior official.*

- *DOE WIPP management should clearly indicate that Westinghouse has the responsibility to insure that all inputs relating to facility operations are properly reviewed for safety implications.*

- *In the event of attrition, high importance must be placed on proper replacements to insure the continuation of recent improving trends. Start-up plans need to consider the schedule effects on motivation, and thus retention, of the current DOE and MOC staff.*

TRU Waste Certification

The committee's review shows that appropriate plans, procedures, and work practices appear to be in place for the certification of TRU wastes to be shipped to the WIPP site from both the Rocky Flats Plant and the Idaho National Engineering Laboratory. The techniques for the real-time x-ray radiography of drums were observed and appeared to be very effective, particularly for the detection of free liquids that might have accumulated in the drums. Procedures for the detection of loose surface contamination were sound. While the committee identified no safety significant concerns related to the waste certification program, there are several areas which should be strengthened to assure a high level of continued performance.

Recommendations:

Audits conducted by the WIPP-Waste Acceptance Criteria (WIPP-WAC) Committee should be more frequent than the now specified one

per year, particularly during the initial start-up phase. These should include unannounced audits and increased surveillance.

- *The WIPP - WAC should be reviewed in detail to insure full compliance with all applicable Department of Transportation (DOT) requirements.*

The Department should review and standardize to the maximum extent possible the criteria applied to the numerous separate generator "sites" within the overall Rocky Flats complex and develop a systems approach to the preparation and shipment of TRU waste from the complex.

The variability of results from TRU waste content measuring techniques should be investigated and resolved to reduce the uncertainties that result from such differences.

There should be increased communication among generators, shippers, and the DOE and Westinghouse staff, especially on "lessons learned", consistent application of good practices, measurement techniques, and changes in waste forms.

Summary

The committee's review of the WIPP project focussed on short-term operational related issues and long-term performance of the repository. The operational issues are readily soluble and we have provided recommendations consistent with other comprehensive reviews, to address open safety questions.

Our review of the long-term performance issues has led to the primary recommendations we are making to the Department. The discussions presented above lead to the following major recommendations:

1. Perform an analysis of long-term performance relative to EPA Subpart B standards as a basis for initiating the experimental test phase (bin and alcove). The test phase would be conducted in compliance with 40 CFR Part 191 Subpart A after all other required permits/approvals have been obtained.
2. Emplace TRU waste for the experimental test program upon determining that there is reasonable confidence that WIPP can eventually be shown to meet release quantities and undisturbed site doses as required by EPA Subpart B, including a carefully considered intrusion scenario based on "reasonable projections". The basis for these projections should be explored with EPA as they apply to intrusion and distant time frames.
3. Continue performance assessment and experimental test programs, including study of the gas generation issue, and engineering enhancement studies to gain higher confidence in the expectation of achieving compliance with Subpart B. If the Department finds it necessary to use the EPA default values

in the performance assessment, it will need to consider use of engineering enhancements.

4. Upon determination that a high degree of confidence exists that EPA Subpart B requirements will be met, initiate the operational test phase as a graded emplacement program committed to deliberate steps to evaluate and work out operational issues identified in various reviews.

5. After formal documentation of compliance with Subpart B standards, implement the full program for long-term isolation of TRU waste.

Once these steps are taken for the operational and long-term issues addressed, we believe the WIPP will be a responsible repository for the disposal of TRU waste.

I would be pleased to discuss any of these issues further.

Sincerely,

John F. Ahearne
Chairman

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Final Report

on

DOE Nuclear Facilities

by the

Advisory Committee on Nuclear Facility Safety

to the

Secretary of Energy

November 1991

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FINAL REPORT

on

DOE NUCLEAR FACILITIES

A Report to the
Secretary of Energy

by the
Advisory Committee on Nuclear Facility Safety
to the
U.S. Department of Energy

November 1991

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[1]. Because of other commitments, Dr. Schull did not participate in the preparation of the final report.

TERMS SERVICE FOR ACNFS MEMBERS

NAME	BEGINING	ENDING
1. Ahearne, John F.	March 2, 1988	November 12, 1991
2. Auxier, John A.	March 2, 1988	August 30, 1988
3. Bayne, J. Phillip	January 2, 1989	April 1, 1991
4. Cleveland, Jesse M.	May 16, 1990	November 12, 1991
5. Culler, Floyd L.	May 11, 1990	November 12, 1991
6. Denning, Richard E.	March 2, 1988	February 20, 1991
7. Fabrikant, Jacob I.	February 1, 1990	November 12, 1991
8. Kastenberg, William E.	March 2, 1988	November 12, 1991
9. Lash, Terry R.	June 6, 1990	November 12, 1991
10. Lewis, Harold R.	March 2, 1988	November 12, 1991
11. Martin, James E.	March 2, 1988	November 12, 1991
12. Ohanain, Mirhan J.	March 2, 1988	March 1, 1990
13. Powers, Dana A.	March 2, 1988	November 12, 1991
14. Rice, Paul D.	March 2, 1988	October 22, 1990
15. Schull, William J.	February 1, 1990	November 12, 1991
16. Schwartz, Elmer G.	March 2, 1988	March 1, 1990
17. Seale, Robert L.	March 2, 1988	November 12, 1991
18. Sears, C. Frederick	Janaury 2, 1991	November 12, 1991
19. Tape, Gerald F.	Janaury 2, 1988	November 12, 1991
20. Tschinkel, Victoria J.	March 2, 1988	November 12, 1991

The Committee was orginally chartered November 13, 1987 and was renewed on November 13, 1989. In a letter to Dr. John F. Ahearne, Chairman, dated February 1, 1991, the Secretary of Energy stated his intention not to renew the ACNFS charter.

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Advisory Committee on Nuclear Facility Safety
to the
United States Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

November 12, 1991

The Honorable James D. Watkins
Secretary of Energy
US Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Dear Admiral Watkins:

In your letter of February 1, 1991 notifying us that our charter would end in November, you requested that the Committee provide for an orderly turnover of any issues or ongoing reviews which are currently under consideration by the Committee. The charter of the Advisory Committee on Nuclear Facility Safety ends November 12, 1991, and this letter and attachments will be the final report, and follows the plan submitted to you by the Office of Nuclear Energy in September 1991. Here we review our major conclusions and recommendations and we discuss some key pending matters, including summaries of unfinished business that in your letter of October 17, 1991 you requested be provided to the Office of Nuclear Safety. Most of our reports to you and your predecessor have focused on safety concerns at a single Departmental site or facility, or on safety issues in a single aspect of DOE's nuclear safety program. In this report, however, we give you our perspective on the state of the Department's safety programs by commenting on a critical few issues that apply DOE-wide. Attachment 1 provides a summary of conclusions and recommendations in addition to those in this letter. Attachment 2 provides more detailed discussions of these recommendations and issues in the report chapters developed by our Subcommittees.[1] Each chapter also contains discussions and recommendations regarding additional, more specific concerns. We urge that appropriate persons within the Department consider the applicability to their respective programs of the comments and recommendations.

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[1]. The ACNFS had twelve subcommittees, covering the following areas: PRA and Severe Accidents, Research and Test Reactors, Process Facilities, Health Physics, Rocky Flats Plant, Waste Isolation Pilot Plant, Environmental Cleanup, Safety Policy, Savannah River Reactor, New Production Reactor, High Flux Beam Reactor, and High Flux Isotope Reactor.

GENERAL STATUS

Nearly four years of involvement on the Advisory Committee have provided us with an overall perspective on safety issues within the DOE. In many ways there have been positive changes. In others, there has been little or no progress. The DOE of November 1991 is much improved over that of March 1988, when the Advisory Committee held its first meeting. Perhaps the most obvious improvement is a better understanding of nuclear safety issues by DOE, by Congress, and by the public. The DOE staff and contractors now show an awareness that the past level of performance in many areas is no longer acceptable. The barrier that prevented knowledge of commercial safety practices from entering the weapons production community has been broken, and practices developed over the last decade in commercial nuclear safety have begun to be introduced into the weapons complex. Preceding this recognition of how to improve has been a growing awareness of how much improvement is necessary, and an understanding of how serious are the conditions in DOE's nuclear facilities complex.

As more information has become available outside the Department, the public has become disturbed about the perceived conditions at the weapons facilities. We heard this concern expressed often at our public meetings. The Advisory Committee held 32 meetings at 11 DOE sites, including 15 meetings in Washington, D.C. Our meetings were open to the public. This afforded the public the opportunity to hear the DOE staff and contractors. At each of our Committee meetings, an opportunity was provided for the public to comment. Some of these sessions were heavily attended and heated. All were mutually informative. We frequently have been told that our meetings provided the best opportunity for the public to hear what DOE was doing. Furthermore, the public, bitter and angry at DOE, praised our willingness to give them an opportunity to air their views. We encourage the Department to have public meetings in which management officials listen to the public. Congress also is highly critical of the DOE's weapons production facilities, although it shares responsibility with the Executive Branch for the decades of neglect.

We know that DOE's goal is to have a safe, efficient DOE weapons complex. DOE now stresses that safe operations, environmental protection, and meeting production and research goals are simultaneously achievable objectives. You have directed that there be negotiations among DOE, EPA, and state governments, thereby ending years of agency reticence to work with regulators. We recognize that noticeable progress has been made in providing access by the states to DOE plans and in discussing environmental cleanup. However, adequate progress in providing radioactive waste management facilities is not

being made. In particular, the means for disposal of mixed low level wastes and mixed TRU wastes is still unresolved.

The Department faces many problems that have developed over decades. The Department in some respects is demoralized and weakened in talent. The rapid proliferation of advisory and oversight groups has identified problems at a greater rate than available resources can be found to address and solve the problems. A distressing level of confused and unfocused thinking still exists, and the interrelation among headquarters, field offices, and the contractors continues to be characterized by change, overlap, and unclear guidance.

As stated above, DOE and its contractors have made progress in recognizing both the many safety issues and the attention that must be given to their resolution. In particular, significant effort has been placed on identification of weaknesses and the actions necessary to place safety on par with production and research. DOE has addressed deficiencies and has shut down facilities while corrective actions are taken. Modern concepts and technologies for improvement of safety are being accepted and used. For example, probabilistic risk assessments are being used for evaluation of risk and risk management, and unusual occurrences are being subjected to root cause analysis.

The concerns for the very high operating power densities in certain of the test and material irradiation reactors, and the related problem with irradiation damage to structure, pressure vessels and piping, have been addressed. The Category A research reactors are all currently authorized for operation. Significant improvements followed from the consolidation of the DOE management responsibility for Category A research reactor operations in the Office of Nuclear Energy. For example, the lines of communication from DOE Headquarters through to the contractors' reactor operations groups now are clear and unambiguous. Where problems have occurred, the flow of information has been prompt and problem solving responses have been forthcoming.

Specific initiatives regarding the research reactors include definition of the minimum staffing requirements for control rooms, the scope and uses of approved procedures, training program requirements and objectives, detailed review of safety of normal operation and accident consequences, the evaluation of plant aging affects, enhanced communication between the DOE reactor operating contractors, and the preparation of Level 1 probabilistic risk assessments. The DOE contractors established the Association for Excellence in Reactor Operations (AERO) to provide professional interchange of technical and operational information between the operating staffs of the DOE Category A reactors, thereby correcting a significant weakness.

Notwithstanding these improvements, it must be recognized that most of the Department's research reactors are being operated beyond their initial design lifetimes. Increased maintenance costs and costs associated with facility safety upgrades, coupled with reduced performance, will make continued operation of the aged reactors quite unattractive when compared to the potential safety features and high level of performance that can be designed into a modern reactor facility. If the Department foresees a long-term mission for its research and test reactors, then the Department should move forward expeditiously to replace the aging reactors.

As we conclude our role as your Advisory Committee, we must emphasize that significant deficiencies remain. These problems are addressed in the following sections.

ACHIEVING SAFETY

There are many possible variations in the means used to achieve an acceptable level of safety in DOE operations, but four elements are common to all of them. For each, we will first simply state the essentials in bare-bones form, then provide more detail, specifically noting where we believe the current DOE safety program falls short.

Safety Policy

First, there must be a safety policy. This means that the goals of the safety program must be set out in terms clear enough to all the participants that the means do not become a surrogate for the ends. The goals must be expressible in an objective and explicit form, so that it will be possible for different individuals to agree whether they have been met. It is desirable that they be numerical. It is essential that they be objectively measurable. A policy of "continuous improvement" is no substitute for a goal.

A clear and precise safety policy serves many purposes. It must relate the safety program to the Department's mission and its risk profile, and it must resolve the conflicts between safety on the one hand and production schedule and other mission objectives on the other. If that is not done in the safety policy, it will not be done. The safety policy sets the framework for the various elements of the Department who are responsible for drafting the many rules, orders, guides, and manuals that themselves form the body of a safety management plan. It ensures that the structure erected by the many different participants is internally consistent, while providing criteria through which upper management can judge the program.

It can also further enhance public understanding of the intent of the Department's safety program, which can only be beneficial in the political arena. In addition to promoting

public understanding of the DOE nuclear safety program, such a statement would give the Department an integrated framework for assessing whether proposed new or revised nuclear safety requirements and criteria are needed, are consistent with existing requirements and criteria, and are likely to produce safety benefits commensurate with the expected costs of their implementation.

A few years ago the Department had an active program to develop a meaningful safety policy and a set of policy goals. Good progress was being made in this effort. In the course of various reorganizations this program was dropped. The Department has now issued SEN-35-91 as its safety policy. In our view, SEN-35-91 falls far short of being a meaningful safety policy in each of the areas cited above. Its focus and objectives are too narrow, and it contains no criteria for determining whether the limited safety goals it does define have been met. It draws its quantitative standards from those of the Nuclear Regulatory Commission, which regulates different kinds of risk to different people, in regulated facilities. There are limited similarities between the two cases. The DOE policy substitutes "continuous improvement" for measurable standards, pays little attention to the largely chemical nature of the risk at some Department facilities, neglects the major risk to the workers, and treats the inevitable conflict between the Department's safety and production responsibilities by simply asserting that they are "compatible." That is inadequate guidance for those who must, in the end, make practical day-to-day decisions.

We continue to believe that a program for developing a set of safety goals should be reestablished, using the resources available to the Department, and that it should be regarded as a precursor to a safety management plan, not a consequence thereof.

The alternative to a meaningful safety policy is confusion, public opposition, disarray in the establishment of safety regulations, inconsistency among organizations, undisciplined regulation, and, ultimately, disaster.

Safety Management

There must also be a management plan, and supporting resources, both aimed at, and adequate for, the achievement of the goals. This plan should, in particular, spell out the roles and responsibilities of all the participants, the chain of authority, an appropriate mechanism for the allocation of resources, and a means by which each individual will be made aware of his or her place in the effort. Where there is a shortage of the needed skills, the management plan must include provisions for alleviating the problem.

The Department's facilities are, for the most part, contractor-operated, and the front-line responsibility for the safe operation of the plants clearly lies with those on the scene. Yet

they have to function according to standards and criteria established by the Department, according to priorities which must be set at the highest levels of the Department. Such matters as the importance of the nation's need for the materials produced at the facilities cannot be delegated to the contractors, yet these priorities determine resource allocation at the lowest levels. It is not easy to practice effective management without drifting into micromanagement, but that is inevitable if the management plan is not carefully drawn to clarify the issue of roles.

Much has been said of the new "safety culture" within the Department, and there is no doubt that safety considerations, long neglected in the past, have been accorded greater significance in the last seven or eight years. But there is little likelihood that safety will take a clear and appropriate position in the values held at the working level if its position is not clearly understood within the Department itself. People need to know not only that safety is important, but why it is important, and also just how important it is. To say "safety first" to the workers is to avoid the issue—they have heard that before. Safety is not first; its priority is one of many that must be set in context, in view of the Department's responsibilities. A safety management plan should provide the mechanism, while the safety policy provides the perspective.

We have often heard reports of safety appraisals and Tiger Teams, in which the result is characterized as some large number of deficiencies, often in the hundreds. But our experience is that it is rare that any of them are life-threatening, and even less often are they specific to the DOE chemical/nuclear plant. If there is any effort at all to set priorities, it is in very broad categories, leaving the contractor with no sense of an alternative to simply doing everything at once. The failure to set priorities results in too little attention to the most important safety issues. It is the Department's responsibility to provide a clear mechanism through which priorities can be set, and resources allocated.

Safety Assessment

The Secretary has issued SEN-6, 6B, 6C and 6D making line managers responsible for safety and directing them to have self assessment through an established office to assure that they act. Currently managers are treating self-assessment as another identifiable and auditable entity to which people and resources can be assigned, but they need to build self assessment for safety into what they do every day. These offices tend to be more inspection than assessment oriented. The various offices and NS in particular have undertaken to produce guides on performing self assessment, but this just perpetuates what SEN-6 set out to avoid; i.e., managers cannot depend on other entities for assuring safety, they must do it themselves. However, they do need to understand how DOE

oversight will measure whether and how they have embraced safety for their operations. Our reviews indicate that it will be some time before effective self assessment will occur.

There must be an agreed means of measuring both success and progress that is objective. Senior management reviews, oversight committees, and Tiger Teams are of little use if the criteria on which they base their judgments are hidden or unclear. Again, the goals need not be numerical, but the standards against which the participants will be judged must be expressible in such a way as to minimize inconsistency among judges.

What has been described above is closely related to what is called "management by objective" in the business world. An essential part of this approach is a means of judging to what extent the objectives have been met, without which programs have a tendency to feed on themselves, long past the point of diminishing returns. Not only organizations, but also individuals, have inertia, and a safety plan must have some objective means through which its achievements can be measured and compared to its goals.

There is a trend toward the increasing use of probabilistic risk assessment as a methodology for the assessment of residual risk, and of progress toward the reduction of risk, in part because its use has led to considerable improvements in safety understanding where it has been used. There are other less systematic disciplines in use in industry and government. It is not our purpose here to advocate any particular approach. But we do believe strongly that management judgment by itself is an inadequate tool for the measurement of progress in the reduction of risk. Management, quite simply, is biased. Similarly, conformance to all "federal, state, local, and DOE" regulations is not equivalent to a safety assessment, although often required for other reasons. It requires a great leap of faith to believe that these disparate entities have somehow assembled a collection of requirements both necessary and sufficient to guarantee that compliance is a measure of safety.

Criteria for success should be objective and defensible. There will always be those who contend that not enough has been done, as there will always be those urging that too much has been done. It is the responsibility of the Department to state its goals in sufficiently clear terms that success or failure in meeting them is measurable. While it is possible to define quantitative goals and measures for each of the risks, and it would be of great benefit to do so where possible, it would be difficult to find a single numerical statement for the Department's safety goals. There are alternatives, like the comparison with other normally accepted risks, but, whatever the goals, they must serve as the Department's answer to the question of "how safe is safe enough." It is not necessary that the full and complex methods of probabilistic risk assessment or cost/benefit analysis be

brought to bear here, but it is necessary that people of divergent views be able to find a consistent measure and position on the Department's achievements.

We recognize that it will be difficult to set standards and goals sufficiently broad to encompass all the risks we have recommended the DOE consider. Nevertheless, the absence of standards and goals allows undisciplined regulation. Unless there is a means of determining the extent to which the stated goals have been met, there is no basis for adjustment of the safety goals or the safety management program, for knowing whether to be proud or ashamed of one's achievements, or for knowing when to stop. While we do not recommend a specific measure here, we think that it is a subject of equal importance to the formulation of a coherent safety policy, and that the group charged with that task (if our recommendation in that regard is accepted) should make the choice of measure an integral part of the policy.

Feedback

Channels must exist for the transmission of information up the chain of command, so the program can strengthen itself dynamically. The state of the effort in each area should make its way from the continuous assessment implied in Safety Assessment to the management and resource allocation scheme required by Safety Management. Indeed, the wisdom gained in operating the program may easily result in modifications to the goals expressed in the Safety Policy. It is easy for managers to believe that they have provided for such channels, while people down the line perceive the situation as quite different. It is the latter perception that matters.

It is possible to manage an old, static, and simple organization with only one-way communication, in which well-established methods and rules are promulgated and distributed to the lower level personnel, who are expected simply to conform to time-tested procedures. In the case of the relatively recent Department recognition of the importance of safety, in a period in which the DOE is finding its way to a balanced posture, and given the extraordinary complexity of the organization, this is clearly not possible at DOE. It is therefore important to make the best of the experience gained in restructuring the Department's safety posture, to acknowledge failures when they occur, and to derive the benefits of the accumulated experience of the work force. This can only be done if the management is receptive to information from below, both good and bad, and if this receptivity is known and trusted throughout the complex. The pattern is set at the highest levels.

In an attempt to implement the new philosophy, DOE has rushed to address various safety issues. When new problems are identified, unrealistic resolution schedules are often

announced prior to development of a clear understanding of the problems, or of what is necessary to resolve them. This insistence on rapid response without adequate understanding has produced premature action plans and decisions, with resultant frequent schedule revisions, organizational changes, and unclear explanations of the need and bases for the actions and decisions. Workers may be left with no alternative but to consider production in fact as the continuing, dominant priority, and safety as simply a passing fancy of the current Secretary. Thus, too often workers may continue to perform and think as they did in the past, with no significant improvement in either their safety or the basic safety of operations. Further, as a result of the demand for progress, there appears to be a growing reluctance within DOE and contractor organizations to identify problems or to admit lack of progress to higher management, because this would appear nonsupportive of management's plan. Inculcation of the "new culture" has gone slowly, and we have heard many accounts suggesting upper management unwillingness to receive bad news. This is ultimately bound to be self-defeating.

ENVIRONMENTAL POLICY

The Department of Energy has embarked on a massive cleanup effort to remedy decades of neglect, and this undertaking may become the most costly environmental remediation effort in history. Unfortunately, DOE's cleanup goals are vague. Unless clear policy is developed and implemented, the difficulties that the EPA has experienced with the Superfund Program will be dwarfed by those that the DOE will face.

As the Department recognizes, not enough is understood about all of its contaminated areas to allow development of effective plans for cleaning them up. The process of gathering the needed information and developing clean up plans will take many years. The decision process for selecting cleanup approaches, which is both technically and institutionally complicated, requires substantial time. Moreover, cost-effective and politically permissible technologies do not yet exist for cleaning up many sites.

The most critical issue facing the Department in this area is the need to adopt a practical, specific policy on cleanup. The Department has set as a general goal the cleanup of all of its facilities by the year 2019. But the goal has not been defined in terms that will enable determining when the goal has been achieved. Confusion and frustration at the local level have resulted from the current approach.

The Committee recommends that the Department use land use planning as the approach to a workable environmental cleanup policy. The purpose of land use planning would be to designate which parts of DOE sites may eventually be released for unrestricted use, which parts may be released for restricted use (e.g., commercial, industrial, wildlife habitat,

recreational, etc.), and which parts probably will never be released for any purpose. We recognize that this approach would cause controversy because it would make explicit what is widely understood but not openly spoken: taxpayers cannot afford to return all of DOE's contaminated land to pristine conditions.

A policy based on the concept of land use planning would lead naturally to the appropriate selection of new cleanup criteria based on an initial assessment of environmental risk, rather than on the assessment of an ill-defined future public health risk with its attendant uncertainties. It also would lead to a better understanding of the need for improvement of existing, and the development of new, technologies for removing or containing contaminants. A land use planning approach would focus DOE Headquarters on overall guidance and would free the field offices to deal with the diversity of cleanup problems at the local level.

A land use planning focus also might obviate the need for an environmental impact statement on the total cleanup program, because such a statement would be inconsistent with the localized nature of land use planning. This focus would encourage a "bias for action", that emphasizes near-term actions at the most important contaminated areas as defined by the land use planning process.

OTHER ITEMS

The attached list of Conclusions and Recommendations identifies the major points regarding other areas which the Committee believes should be stressed. More complete descriptions of these issues, as well as those presented in this letter, can be found in the report chapters in Attachment 2.

CONCLUSIONS

Most facilities of the DOE weapons production complex are old. The underlying problems developed over decades. In the last three years, major facilities at Rocky Flats, Savannah River, and Hanford have been shut down by the Department to undergo changes needed to bring them into compliance with modern safety standards, procedures and practices. Some of these facilities will not be brought back on line (N-Reactor), some have been put in stand-by condition (Purex, PFP), and substantial upgrades are being made at Savannah River and Rocky Flats. Even after several organizational changes, false starts in the development of new procedures and training to the new procedures, and system and equipment upgrades of the facilities, the job is far from complete. Operational Readiness Reviews are uncovering further problems. Some problems can be solved quickly. Others can be addressed, but their correction will take into the next century.

In view of the Advisory Committee's charge, we have focussed on broad areas of concern: the general status of safety issues within the DOE, achieving safety, nuclear safety policy, nuclear safety management, safety assessment, and environmental policy. From our observations, deliberations, reports, and letters, we submit herewith key conclusions and recommendations on the Risk Analysis, Research Reactors, Process Facilities, Radiation Protection, Rocky Flats Plant, Waste Isolation Pilot Plant, Environmental Cleanup, and Safety Policy (Attachment 1).

The recent announcement by President Bush, making another major step in ending the nuclear standoff with the "Soviet Union", significantly increases the pressure on rethinking what kind of nuclear weapons complex is needed. During this period, emphasis on safety must be increased. With the elimination of production pressures and, as we have frequently noted, employee attitude that production is most important, complacency may become the dominant attitude, leading to carelessness, and, finally, accidents.

The members of the Advisory Committee join me in expressing our appreciation for the privilege of serving on the Committee. It has been an interesting, challenging, and educational experience for each of us. We hope that the comments and recommendations the Committee has made in our 39 letters over the last three and one-half years have been of benefit to the Department.

We thank you for the opportunity to advise on matters of major national importance. We offer the very best wishes for success in what often must seem an endless and thankless task.

Sincerely,

John F. Ahearne
Chairman

Attachments
As Stated

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ATTACHMENT 1
KEY CONCLUSIONS AND RECOMMENDATIONS

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Note to Reviewers:

Pages 14 through 20 of this ACNFS report were not reproduced for Appendix PEER; these pages pertain to facilities other than the WIPP.

- Once deficiencies identified in the operational readiness reviews have been corrected and a new operational readiness review is conducted successfully, Building 559 could be restarted to support rehabilitation of the Rocky Flats facilities and waste handling.

7. WASTE ISOLATION PILOT PLANT (WIPP)

The WIPP project is very important to the continued operation of DOE's facilities generating transuranic waste, and to future radioactive waste disposal projects that will have to comply with EPA's radioactive and mixed waste disposal requirements. Success or failure with WIPP will set precedents for the waste disposal program for years to come. The Advisory Committee believes, therefore, that DOE should take every reasonable initiative now to assure that WIPP succeeds in a manner that supports future waste disposal projects. Unfortunately, the Advisory Committee has serious concerns about whether DOE's current program will be able to demonstrate, in a timely manner, compliance with EPA's proposed long-term performance and human intrusion requirements (40 CFR 191) for disposal of TRU and high-level radioactive wastes.

To increase the probability of successful compliance with EPA's proposed standards in a shorter period of time, DOE should take the following steps with regard to WIPP long-term performance:

- Prepare a concise report in a timely manner comparing the expected performance of WIPP with the requirements in EPA's proposed standard (40 CFR 191). This report should specifically focus on those parameters that are currently significantly uncertain and set forth the actions including alternatives, necessary to reduce the uncertainties to acceptable levels for demonstrating regulatory compliance.

- Change current project priorities by putting more emphasis on the use of experts. At this time, panels of experts will provide more significant input to the demonstration of compliance with EPA standards than will the results of the Dry Bin Tests. The Bin Test Program should continue to be focused on reducing uncertainties in those parameters that are most important in determining compliance with EPA's proposed standards.

- Initially dispose only the contact handled TRU waste that will not pose a gas generation problem. Other TRU wastes can be safely stored above ground until it is determined whether they can be buried at WIPP in compliance with regulatory requirements or have to be treated so that disposal at WIPP is acceptable.

- Immediately begin development and implementation of engineered alternatives, especially for newly generated waste. DOE should be a technological leader in waste management and this initiative should go forward even if it were not specifically required to demonstrate compliance with EPA's proposed standards.

The Advisory Committee recommends that DOE take the following steps with regard to operational issues:

- Place additional emphasis on the importance of radiation protection to the safety and successful operation of the facility, and increase the authority of radiation protection managers and their access to senior management.

- Give more extensive consideration to potential incidents at WIPP that, although not a radiation risk to the general public, could either pose risks to workers or create a substantial negative public reaction to continued operation of the facility.

As the first of a kind radioactive waste disposal facility, WIPP will be very carefully scrutinized and expectations of performance will be high. As with nuclear power plants and other nuclear facilities, performance that only protects the public from receiving significant doses of radiation is not good enough to maintain public support.

ATTACHMENT 2
REPORT CHAPTERS

Risk Analysis

Research Reactors

Process Facilities

Environmental Cleanup

Radiation Protection

Rocky Flats Plant

Waste Isolation Pilot Plant

Safety Policy

Other Activities

Note to Reviewers:

Pages 24 through 174 of this ACNFS report were not reproduced for Appendix PEER; these pages pertain to facilities other than the WIPP.

WASTE ISOLATION PILOT PLANT

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WASTE ISOLATION PILOT PLANT

INTRODUCTION

In January 1989, the Deputy Secretary of Energy requested that the Advisory Committee on Nuclear Facility Safety (ACNFS) be briefed on the Waste Isolation Pilot Plant (WIPP) and that the Committee comment on any safety considerations [Ref. 1]. In May 1989, Secretary Watkins reaffirmed that request and asked for the Committee's "assessment of WIPP's safety and the identification of any potential safety concerns" [Ref. 2].

The Advisory Committee, in response to this request, visited WIPP in June 1989, at which time a Subcommittee was formed to review safety issues in further detail [Ref. 3]. The Subcommittee subsequently revisited WIPP and other related facilities: Sandia National Laboratory, the Department's scientific advisor on WIPP, and the Idaho National Engineering Laboratory and the Rocky Flats Plant, two sources of waste that would be shipped to WIPP. Areas selected for review were unresolved short-term technical and operational issues, including the Final Safety Analysis Report (FSAR), WIPP management and staffing policies, actual work practices in the field, and long-term environmental performance. A report to the Secretary was issued by the Advisory Committee on December 11, 1989 [Ref. 4].

The Waste Isolation Pilot Plant (WIPP) was authorized by Public Law 96-164 in 1979 to provide "a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States." Operation of the WIPP is expected ultimately to include receipt, handling, and permanent disposal of transuranic waste. It is classified in accordance with DOE orders as a "low

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hazard facility," meaning that it is expected to have only minor on-site and negligible off-site impacts to people and the environment.

The Department of Energy (DOE) is using a phased approach, leading to a decision whether to designate WIPP an operating disposal facility. The construction phase of WIPP is essentially complete, except for the roof supports being installed to preclude failure of the ceilings in the test rooms. The objective of the Dry Bin Test Phase is to collect additional technical data to improve confidence in the prediction of the long-term behavior of the waste forms. Current DOE plans call for the facility to be evaluated at the conclusion of the 5-year (approximately) Test Phase to determine whether it is suitable for permanent disposal of TRU wastes. If WIPP is judged to be suitable, including meeting EPA standards and State of New Mexico requirements, DOE intends to initiate a 20-year Disposal Phase.

The Advisory Committee's review of the WIPP project was focused on two major aspects of the program, namely, environmental performance over the long-term and operational issues principally of short-term concern.

LONG-TERM PERFORMANCE

TRU wastes must be isolated from the general environment for many centuries. Predicting the performance of WIPP in isolating TRU wastes is a challenging task. The Environmental Protection Agency (EPA) is developing long-term performance standards (40 CFR 191 - still to be formally adopted) with which DOE will have to comply.

The ACNFS proposed a phased approach for the Department that would permit the Secretary to make an early determination of compliance and proceed with disposal of CH (contact handled) TRU waste [Ref. 4]. Briefly this called for the Department promptly to assemble the data to provide reasonable confidence that WIPP could eventually be shown to meet the EPA requirements and, having established this confidence, initiate TRU waste emplacement in support of the performance assessment program. The second phase recommended that, upon determination that a high degree of confidence exists that EPA Subpart B requirement will be met, DOE initiate the operational test phase as a gradual emplacement program committed to working out operational issues. This approach more likely would lead to disposal of TRU waste at WIPP earlier, and it more likely would assure compliance with EPA's proposed standard. The Advisory Committee urges DOE to revisit this approach.

COMPLIANCE WITH EPA STANDARDS

The major issue for WIPP continues to be whether long-term isolation can be predicted to occur in compliance with EPA's proposed standard. The Department unfortunately has not yet assembled and published in a suitable form the results of work it has done to show how WIPP is expected to perform against EPA standards, 40 CFR-191, Subpart B. (Subpart A requirements, which apply to management, storage, and capability to readily retrieve such wastes, are satisfactorily met.) We continue to believe that the Secretary should expect a high level of confidence that compliance can be demonstrated before he is asked to make a decision about permanent waste emplacement.

The Department's scientific advisor for WIPP, Sandia National Laboratories, in its performance assessment program, has continued to prepare analyses involving long-term radionuclide transport and dose assessment for several scenarios, the recent versions of which have included some comparisons with EPA standards [Ref. 5]. As refinements in methodology have been made and uncertainties in parameter values reduced, the results show that all of the scenarios lead to values that approach or are within the release limits stated in EPA requirements, including a reasonable human intrusion scenario.

The results of expert panels formed by Sandia, e.g., radionuclide solubility, retardation in the Culebra, future societies, have been most useful to the outcome and confidence in recent performance assessments. Sandia has plans to form additional important expert panels, e.g., design features of passive communication to the public, and waste form performance. Some panels have been delayed because of budget restrictions, yet their costs are small. Considering the relative value of the outputs of the expert panels in demonstrating compliance with EPA standards, we believe the Department should fund them now, even if it means some delay in the Dry Bin Test Program.

We believe that the Department can now provide "reasonable assurance" that release quantities in Subpart B would be achieved. It appears to us that DOE's recent analyses have interpreted the guides appropriately, and that it is not necessary to analyze WIPP performance for conditions worse than the EPA default values. We believe DOE should promptly prepare a report using these "reasonable projections" based on available data and expert judgment and move forward with a firm decision on graded operations at WIPP. A success oriented approach is warranted.

The Department should not delay carefully documenting its environmental performance assessment until the Dry Bin Tests are completed, because we believe these tests will not-in-and-of-themselves provide the type of results that will significantly change the perfor-

mance assessment. We strongly believe that DOE will eventually have to base its decision on professional judgments that it can make now or in the near term.

The report directed toward documenting compliance with EPA standards would serve many objectives. It would provide the basis for discussions with other parties, especially EPA; it would provide a focus for the "test phase" experiments to assure that they serve to reduce uncertainties in performance assessments assumptions; it would identify key laboratory measurements needed; it should identify any engineering modifications that may be necessary to accommodate present TRU wastes, and to indicate whether justifiable improvements should be made in future waste forms to prevent or mitigate gas generation. The Department can use data obtained over the next few years, while the waste is retrievable, to build additional confidence in the facility. The proposed tests could also be more useful in determining whether future waste forms can reasonably be improved (see below), a program we encourage.

GAS GENERATION

The Advisory Committee's original report urged DOE to expedite obtaining and using reasonable parameters to evaluate the potential effects of gas generation and other events on the performance assessment for WIPP [Ref. 4]. We believed then (as well as now) that the performance assessment for meeting EPA standards is a critical demonstration. Some of the original objectives of the bin tests have been deferred, for example Wet Bin Tests that involve brine and moist microbial processes. Thus data from future bin tests are expected to be utilized more for confirmatory purposes.

The potential problem of gas generation raises questions concerning the current waste form and future DOE management of TRU wastes that are worthy of further review. Specifically, a reduction in the amount of metals and organics or a change in the form of organic materials could reduce the gas generation. We do not believe that an attempt to change the form of existing TRU waste would be justified in view of the risks and cost it would entail. Therefore, to the extent necessary, efforts to ameliorate gas generation within the repository appear to be the most reasonable approach. For future TRU waste, however, a different form that would significantly reduce gas generation should be considered. The recent engineering enhancement study explored various measures for reducing the quantities of decomposable waste, of using nonmetallic containers, and of stabilizing the waste by incineration or vitrification [Ref. 6]. Some of these appear quite practical for the TRU waste shipments that WIPP will eventually manage, and could be beneficial if they can be conducted at reasonable cost and without appreciable risk to the personnel involved. Such an effort would be consistent with recently stated goals of improved waste management throughout the Department. The Department should

consider changing the waste form, at least for newly generated wastes, so that satisfactory long-term performance can be shown to comply with EPA's standard for disposal for these wastes [Ref. 4]. Disposal could then begin, and the Department could continue the gas generation study for those existing waste forms which would remain stored until adequate performance could be assured or necessary modifications made.

OPERATIONAL AND TECHNICAL ISSUES

A wide variety of issues, described under the general heading of Conduct of Operations in the December 1989 letter to the Secretary [Ref. 4], were raised by the Advisory Committee. Recommendations were made, DOE has acted and closure has been obtained [Ref. 12]. Before initiation of the Dry Bin Test, the Committee was requested to review the FSAR Addendum that specifically addresses that test [Ref. 7]. A few of the more significant actions are highlighted here.

FINAL SAFETY ANALYSIS REPORT (FSAR)

The fundamental issue with the FSAR concerns its basic purpose, its content and how it is handled, both in terms of initial approval and future approval of changes. In response to an Advisory Committee recommendation, a Policy Statement on the WIPP Project was issued by DOE [Ref. 5] which states that:

> The configuration and operations of the Waste Isolation Pilot Plant (WIPP) facility are controlled to remain consistent with the Operational Safety Requirements (OSRs), the FSAR, and approved changes thereto. Changes to the WIPP OSRs will require approval at the same management level as the original FSAR approval (i.e., by EM).
>
> The WIPP FSAR is the top level safety commitments document that presents facility descriptions, design basis operational limits, and safety analyses of the facility as a whole and of individual structures, systems, and components.

The Advisory Committee strongly supports this policy.

The Committee was requested [Ref. 7] to review the FSAR Addendum on the Dry Bin-Scale Test Program and concluded that there are no significant risks in excess of those estimated in the FSAR to the workers, the public, and the environment and that this test program can be conducted safely [Ref. 8].

Subsequent to the Committee's review, DOE was faced with the question of the long-term stability of the test rooms (roof falls). DOE convened two external expert panels, one to address geo-technical aspects and the other to review the Department's proposed corrective actions. The design that has been adopted and is being implemented is described in the FSAR Addendum - Dry Bin Scale Test approved by Mr. Duffy on August 30, 1991 [Ref. 13].

RADIOLOGICAL SAFETY

Good radiological safety will be the single most important aspect of day-to-day WIPP operations after disposal begins. Several reviews, including ours, have emphasized ways to improve radiological safety, and progress has been made. In response to the Advisory Committee recommendations, DOE made a slight revision to the organizational structure, and hired a capable Radiation Safety Program Manager for DOE-WIPP, while Westinghouse pursued equipment modifications, increased the number of technicians, and improved training programs (Refs. 9 and 10). Obtaining and retaining a senior health physicist for the Westinghouse Radiation Safety Program continues to present difficulties.

DOE needs to place additional emphasis on the importance and priority of radiological activities to the safety and successful operation of the WIPP facility. Although radioactivity is the unique factor that differentiates WIPP operations from other industrial operations, current organizational reporting relationships (both Westinghouse and the DOE) would indicate that radiation safety is just another set of requirements for routine operations. (This is not peculiar to the WIPP project within DOE, unfortunately.) For example, WIPP organization charts and the FSAR show the senior manager directly responsible for all radiation programs still positioned at well below the top manager and below the managers of Public Affairs, Human Resources, and Administrative Services (Refs. 9 and 10). Although the FSAR and WIPP organization charts indicate a direct access line to the senior facility manager, it is a dotted one that must bypass other line manager levels. While this may suffice for incidents and highly important events, it deprives the manager of the day-to-day perspectives that must exist to deal with this most important aspect of an operational facility. We believe DOE and Westinghouse should define a better organizational structure that provides senior radiation program management with sufficient authority and with direct access to senior facility management.

FIRE RISK

The Advisory Committee recommended that a fire risk assessment of the pre-closure operations of WIPP be performed. This assessment, which has now been completed [Ref. 11], concludes that the radiological risk to the public posed by fire to be extremely

low. Risks associated with injury to the workers and stoppage of waste handling operations were also considered, but the evaluations concentrated on the radiological risk to the public.

The Advisory Committee is concerned that the Department is giving insufficient attention to low probability events that present a negligible radiological risk to the public, but that may be significant when worker safety or plant shut-down is considered. These latter cases may not even be radiation related. This is not an issue unique to WIPP.

TRU WASTE CERTIFICATION

Since accident analyses have been based upon specific bin loading and since programmatic results are dependent upon knowledge of specific loadings, there is a strong need for quality control in waste loading and certification. The Advisory Committee's review shows that appropriate plans, procedures, and work practices appear to be in place for the certification of TRU wastes to be shipped to the WIPP site from both the Rocky Flats Plant and the Idaho National Engineering Laboratory. Committee recommendations in several areas (e.g., audits, compliance with Department of Transportation requirements, and the variability of results from TRU waste content measuring techniques) have been suitably addressed by the DOE (Refs. 9 and 10).

CONCLUSIONS AND RECOMMENDATIONS

The WIPP project is very important to the continued operation of DOE's facilities generating transuranic waste, and to future radioactive waste disposal projects that will have to comply with EPA's radioactive and mixed waste disposal requirements. Success or failure with WIPP will set precedents for the waste disposal program for years to come. The Advisory Committee believes, therefore, that DOE should take every reasonable initiative now to assure that WIPP succeeds in a manner that supports future waste disposal projects. Unfortunately, the Advisory Committee has serious concerns about whether DOE's current program will be able to demonstrate, in a timely manner, compliance with EPA's proposed long-term performance and human intrusion requirements (40 CFR 191) for disposal of TRU and high-level radioactive wastes.

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REFERENCES

1. Letter from J. F. Salgado to John F. Ahearne, January 19, 1989.

2. Letter from J. D. Watkins to John F. Ahearne, May 8, 1989.

3. Minutes of Meeting of Advisory Committee on Nuclear Facility Safety, Carlsbad, New Mexico, June 30, 1989.

4. Letter from J. F. Ahearne to J. D. Watkins, December 11, 1989.

5. "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990," SAND90-2347.

6. "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force," DOE/WIPP 91-007, Revision 0, July 1991.

7. Letter from J. E. Lytle to J. F. Ahearne, February 1, 1991.

8. Letter from J. F. Ahearne to J. D. Watkins, April 11, 1991.

9. Letter from L. P. Duffy to J. F. Ahearne, April 19, 1990.

10. Letter from L. P. Duffy to J. F. Ahearne, June 12, 1990.

11. "WIPP Fire Hazards and Risk Analysis," May 1991.

12. Letter from J. E. Lytle to J. F. Ahearne, August 19, 1991.

13. Memorandum from L. P. Duffy to Manager, DOE Field Office Albuquerque, "Waste Isolation Pilot Plant Final Safety Analysis Report Addendum: Dry Bin Scale Test Approval," August 30, 1991.

PEER 16 - Performance Assessment Review Team Peer Review

Janet U. Cummings

February 1994

PERFORMANCE ASSESSMENT REVIEW TEAM'S INDEPENDENT REVIEW OF WIPP PERFORMANCE ASSESSMENT ACTIVITIES (40 CFR 191 AND 40 CFR 268.6) FOR EM-342

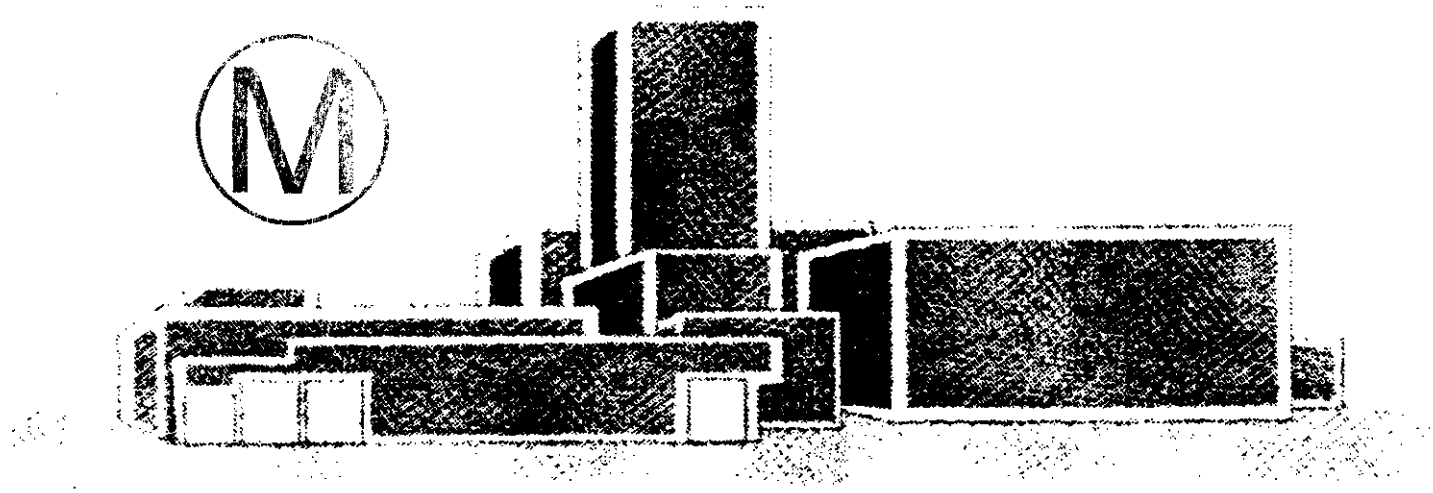

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EXECUTIVE SUMMARY

This report presents the findings of the Performance Assessment Review Team (PART), convened in 1992 to perform a limited, independent review of the Performance Assessment (PA) Program at the Department of Energy's (DOE's) Waste Isolation Pilot Plant (WIPP). The six-member team was mandated by the Environmental Restoration and Waste Management WIPP Project Management Division (EM-342) of DOE to assess the adequacy of the WIPP PA program for meeting relevant regulatory standards for the disposal of radioactive and hazardous wastes, to identify any deficiencies in the program, and to make recommendations for improvements. In preparing its report, the PART reviewed the pertinent PA documents and activities, toured the WIPP site, and interviewed members of the project staff. The review team finds that the work on WIPP has generally been perceptive, incisive, and fundamentally sound. However, for compliance with current standards and regulations, substantial progress and improvements will be necessary in certain areas where additional investigations and documentation may be required; the PA department is fully aware of most of them. These areas include PA documentation, parameter evaluation, conceptual model justification, time-dependent behavior of natural and engineered barriers to fluid migration from the coupled disposal system, and a total system model.

The 10,250-acre WIPP site, located in the Permian age salt beds east of Carlsbad, New Mexico, was authorized by Congress (in Public Law 96-164) in 1979. The PART report begins with a history of the site selection and development and a summary of background information, focusing particularly on the facility's mission to investigate methods for the safe and permanent disposal of mixed transuranic (TRU) wastes in salt rock. Because of salt's impermeability, strength, and ability to "creep" and self-heal over time, waste emplaced in rooms mined from salt and backfilled and scaled with crushed salt will eventually be encapsulated and become part of the stable rock formation. If approved, the current WIPP plan would provide for the emplacement of 6.2 million ft^3 of waste in storage areas laid out in eight panels, each consisting of seven rooms.

The ultimate decision to license WIPP as a permanent repository and allow it to proceed with full-scale operations will depend on the ability of the DOE demonstration that the site is likely to satisfy the requirements of the various Federal and state regulations and address concerns of the oversight bodies (e.g., the National Environmental Policy Act (NEPA), the Resource Conservation and Recovery Act (RCRA), and the State of New Mexico's Environmental Evaluation Group (EEG)). In particular, the PART focused on the WIPP PA activities which address the long-term criteria in two key regulations:

- *40 CFR 191*–This regulation details the Environmental Protection Agency's (EPA's) standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Waste. Disposal systems are required to provide "a reasonable expectation" of adherence to specified limits on cumulative releases to the accessible environment, dose to the public, and groundwater contamination for 10,000 years. 40 CFR 191 Subpart B further decrees the use of specific methods for the containment and isolation of wastes (e.g., multiple barriers, both natural and engineered) and an evaluation of the possibility of inadvertent human intrusion into the disposal site. Sandia National

Laboratories (SNL) has the primary responsibility for performing the PA regarding 40 CFR 191 at WIPP.

- *40 CFR 268.6*–This RCRA regulation states that facilities planning to emplace untreated hazardous waste must obtain a No-Migration Determination (NMD) by demonstrating "to a reasonable degree of certainty" that there will be no migration of wastes for "as long as the wastes remain hazardous" (interpreted in this instance as 10,000 years). In 1990, WIPP was granted a ten-year conditional NMD for the Test Phase, and it is part of the duty of Westinghouse Waste Isolation Division (WID), which has responsibility for PA activities pertaining to 40 CFR 268.6, to supply the required annual reports to the EPA.

Differences or conflicts between the two regulations were reconciled by DOE in the draft Regulatory Criteria Document (RCD) in 1992. This set of integrated criteria was used by PART as the basis for its review, which examines the PA approaches of SNL and WID in terms of such issues as scenario selection and evaluation, conceptual modeling, performance measures, sensitivity and uncertainty analyses, and probabilistic approaches.

PART finds that the current PA documentation provides neither the framework nor history required for demonstrating reasonable expectation of compliance. The WIPP PA issues need to be tracked and documented from the time they are identified through their evaluation and eventual resolution. Of particular importance is the need to clearly document conceptual models of the disposal system and its components including the underlying assumptions, supporting information and any unresolved issues and their importance. From a performance measure standpoint, simple bounding calculations would be useful for building confidence and understanding of complex system models. Combined, these efforts would eventually lead to a well-documented, complete system model that will more clearly demonstrate whether the WIPP site complies with applicable regulations.

A substantial portion of the PART report is devoted to a review of the investigations of the stratigraphy, hydrology, structural state and chemistry of the host rock formations and the likely interactions between the disposal system and its natural surroundings. Despite considerable work on a constitutive relation for WIPP salt creep, which still requires improved understanding of the transient component, the relation has not yet been incorporated into models of repository closure. The effects of brine inflow and gas generation on room closure and sealing are beginning to be considered realistically in coupled, three-phase flow models but these models are not yet fully developed. Apart from uncertainties in the far-field hydraulic properties of the Salado Formation, the nature and projected behavior of the disturbed rock zone (DRZ) surrounding the excavation have not been well-characterized. The DRZ provides the primary potential pathway through time for the migration of gas and brine from disposal rooms to the accessible environment. Therefore, the representation of the DRZ is crucial in system performance models.

In conjunction with the natural barrier system, engineered barriers are designed to minimize releases to the accessible environment. Engineered barriers include repository design features, shaft and panel seals and plugs, and backfill; these components have not yet been incorporated into system performance models. The PART found that while substantial progress is being made towards characterizing natural barriers, more work will be required on engineered barriers before compliance can be demonstrated.

The final section of the investigation addresses undisturbed and disturbed repository scenarios considered by the PA. The undisturbed or base-case scenario assumes only naturally-occurring events and processes and modeling shows that lateral brine and gas releases in 10,000 years are very limited, as are vertical releases if shaft seals behave as expected. Disturbed repository scenarios investigated focus on future disruption by exploratory drilling for resources and consider probabilities and consequences of both direct and indirect releases to the accessible environment. For all three summary scenarios modeled, including a physically unreasonable and conservative one, releases estimated are well below the EPA regulatory limit. However, for both undisturbed and disturbed scenarios, only 2-D simulations using incomplete system models have been carried out, again emphasizing the need for complete systems performance modeling. Sensitivity analyses based on component models will not necessarily identify the most important variables and parameters for reducing uncertainty about the performance of the entire system.

The review team concludes that, although WIPP's work is generally solid, the current PA does not provide enough information or documentation on the underlying assumptions, controversial issues, and evolution of understanding to provide the confidence on the part of regulators and the public to support licensing of the WIPP facility. In addition to making specific suggestions regarding technical issues and uncertainties still in need of investigation and resolution, the necessity for including engineered barriers in future PAs, and the relative merit of more and less complex modeling efforts, the PART emphasizes the overall need for an integrating PA process which clearly relates ongoing WIPP activities to compliance-based objectives.

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) of the United States Department of Energy (DOE), located near Carlsbad, New Mexico (**Figure 1-1**), was created as a research and development facility to demonstrate the safe disposal of the transuranic (TRU) wastes generated by national defense programs. Performance assessment is a key element in the ongoing development and potential certification of the facility. This report contains the findings and conclusions of the Performance Assessment Review Team (PART), which was formed by the Environmental Restoration and Waste Management WIPP Project Management Division (EM-342) of DOE to perform an independent review of the WIPP Performance Assessment (PA) Program.

1.1 AN OVERVIEW OF "PART'S INDEPENDENT REVIEW OF WIPP PA ACTIVITIES FOR EM-342"

EM-342 has oversight responsibility for the entire WIPP Project, including performance assessment activities. The objectives of the PART review were to assess the adequacy of the WIPP PA Program for meeting regulatory requirements, to identify any deficiencies in the program, and to make recommendations for program improvement.

The PART performed a limited review of relevant PA activities and documents and conducted interviews and discussions with WIPP Project staff, including the WIPP Project Integration Office (WPIO), Westinghouse Waste Isolation Division (WID), and Sandia National Laboratories (SNL) Performance Assessment Department. The review included an examination of the conceptual models used to represent the significant processes associated with a repository system at WIPP, the parameters defining the components of these models, and the activities for characterizing the site and reducing uncertainty in the long-term performance of the repository system. The results of these activities are summarized in this report.

Section 1 provides background information about the selection of WIPP as a disposal site for TRU waste, the history of its development, an overview of the regulations that govern the disposal of radioactive and hazardous waste in geologic repositories, and a summary of the general content of the PART review. Section 2 provides an overview of the PA requirements specified in the two Federal regulations governing geologic disposal of radioactive and hazardous waste. Section 2 also discusses similarities and differences in the current approaches taken for demonstrating compliance with these regulations.

Information about the WIPP site and the repository disposal system are provided in Sections 3, 4, and 5. Section 3 describes some of the conceptual models of key features and processes associated with the WIPP site and disposal system, including those aspects that were present before the WIPP facility was constructed and those that may be important in the distant future (i.e., during the next 10,000 years). Section 4 provides hydrologic and geologic data about the host rock and the formations above and below the repository. Emphasis is given to undisturbed properties to provide the basis for describing perturbations that occur or may occur as a result of repository construction and waste disposal. The possible impact of these activities on the long-term performance of the disposal system is discussed in Section 5.

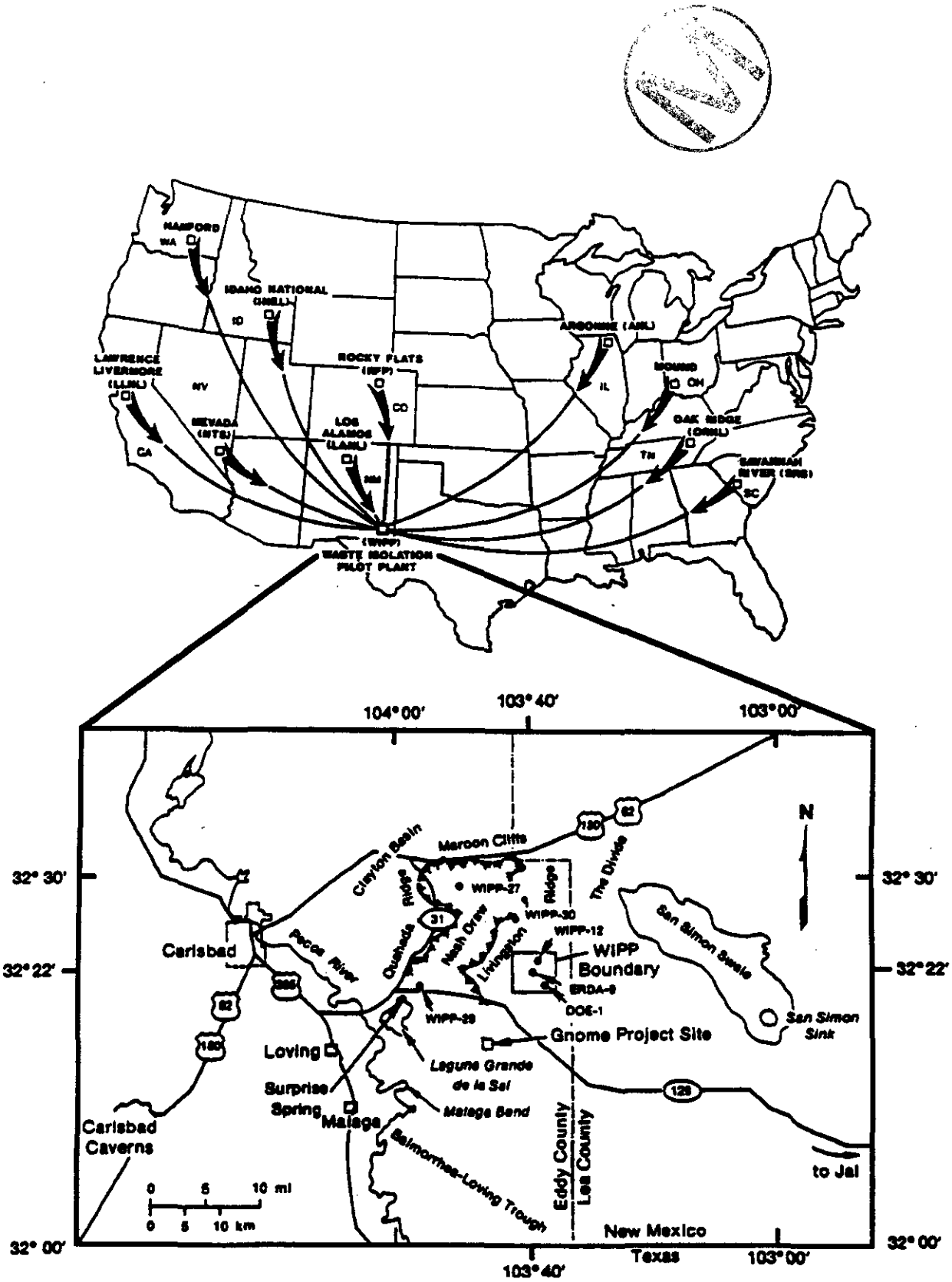

Figure 1-1. Location of WIPP in Southeastern New Mexico (after Rechard, 1989, Figure 1.2).

Section 6 contains an overview of the proposed engineered barrier system at WIPP, the associated standards in the regulations, and the relevant analyses and testing that have been performed. The section also identifies several issues concerning the treatment of the engineered barriers in the WIPP PA.

Scenarios of possible future events and processes at WIPP are presented in Section 7. The base case scenario for WIPP is presented in Subsection 7.1. This scenario ignores the possibility of human intrusion by mining or exploratory drilling and concentrates on expected changes in the natural system over the next 10,000 years. Inadvertent human intrusion scenarios are discussed in Subsection 7.2.

Section 8 discusses the major issues identified as part of the review that may affect the ability of DOE to demonstrate regulatory compliance. Observations are made concerning the difficulty of identifying all the sources of information relevant for the review and the reporting process, and recommended changes are provided. Areas of significant uncertainty and possible importance related to the natural and engineered components of the repository system are also discussed in Section 8. The significance of these findings cannot be assessed until a more comprehensive PA model is available.

1.2 BACKGROUND

This section provides background information on the WIPP project. It describes the history of its physical and regulatory development, as well as the nature and character of the wastes it is designed to handle. Numerous oversight and regulatory groups are also described in this section. Because the PART review examined the adequacy of the current PA program at WIPP for addressing the long term regulations, these regulations are described and their differences noted. The PART organization, the base set of information it used, the WIPP Project organizations that participated in the review, the meetings, the interviews and the tour that provided valuable inputs to PART, and the final report development are all described in this section.

Defense nuclear waste generation began in the 1940s. By the end of 1991, there were approximately 65,000 m^3 (2.3 million ft^3) of defense-related TRU wastes produced and/or temporarily stored at the various DOE facilities around the country (Figure 1-1). Projections indicate that by 2018 there will be 133,000 m^3 (4.7 million ft^3) of such wastes (DOE/RW-0006, Rev. 8, DOE/WIPP 89-011, Rev 1).

These wastes, containing less than 1% free liquids, consist of various items that must be discarded because they have become contaminated with long-lived radioactive elements like plutonium-239 (with a 24,000-year half-life), that are heavier than uranium (i.e., having an atomic number greater than 92). These items typically include rags, rubber gloves, shoe covers, discarded glass/metalware, plastic bags, pumps, motors, hand and machine tools, sludges and so forth. A significant portion of the TRU-contaminated waste, which can emit increasingly penetrating alpha, beta, and gamma radiation, also includes materials that are themselves designated as hazardous wastes by the Environmental Protection Agency (EPA)—e.g., volatile organic compounds (VOCs) such as carbon tetrachloride and metals such as lead (DOE/WIPP 89-011, Rev. 1).

Most TRU wastes (97%) are categorized as contact-handled (CH) TRU (less than 200 millirem/hr). Safe handling and storage are provided by packaging them in 55-gallon drums or

boxes which will be stacked for disposal in the WIPP underground, as shown in **Figure 1-2**. The metallic drums or boxes provide sufficient shielding from the less penetrating alpha and beta radiation emitted by these wastes, and no additional shielding is required. The remaining small volume of TRU wastes (3%) is designated as remote-handled (RH) TRU waste. The RH TRU wastes emit sufficient quantities of gamma radiation (greater than 200 millirem/hr but less than 1000 rem/hr, with no more than 5% of the total greater than 100 rem/hr), and additional special shielding is required to protect workers and the public from radiation exposure during the transportation and emplacement of these wastes. Following a decision to store TRU wastes permanently at WIPP, TRU waste from the ten DOE facilities (Figure 1-1) that temporarily store and/or generate it, will be transported by truck to WIPP in NRC-certified Type B shipping containers (e.g., TRUPACT-II containers for CH-TRU, as illustrated in **Figure 1-3**).

The time sequence of events shown in **Figure 1-4** illustrates the complex intermingling of the events and periods of activity at WIPP with the times of passage of applicable public laws. Following the beginning of waste generation in the 1940's, the National Academy of Sciences (NAS) began investigating the feasibility of geological disposal of defense generated nuclear waste in the early 1950's. The NAS investigation resulted in the recommendation in 1957 (NAS-NRC 1957) of salt deposits as a promising medium for disposal of radioactive wastes for the following reasons:

- Salt is virtually impervious and has a natural "plastic-like" quality that enables it to flow or creep and self-heal over time under the effects of heat and stress found at proposed repository depths. As a result, waste emplaced in mined rooms within the salt deposits and backfilled with salt will eventually be encapsulated and become part of the stable rock formation .
- Circulating groundwaters are historically absent within salt formations (as shown by the existence of salt deposits), and the composition of inter- and intra-granular brines is consistent with connate water from the 225-million-year-old Permian Sea.
- Vast salt deposits are found in relatively stable geological areas with little earthquake activity.
- Salt is relatively easy to mine, and is as strong as ordinary concrete in the short term, but weak and ductile in the long-term.

Following the NAS recommendation, the United States Geological Survey (USGS) identified the salt beds of the Permian Basin of the southwestern U.S. (**Figure 1-5**) as a workable location for a repository in 1962. Subsequently, the Oak Ridge National Laboratory, following USGS recommendations, studied various potential repository locations in the Permian Basin and conducted extensive testing of sites in Kansas and New Mexico which included large-scale field experiments near Lyons, Kansas. The search ended and the WIPP site investigation period began in 1974, when a portion of the Northern Delaware Basin east of Carlsbad, New Mexico was chosen as the most promising location for a TRU waste repository.

In 1979, Public Law 96-164 established WIPP as a first-of-a-kind project to meet the national need for a long-term, safe method for disposal of TRU wastes from the nation's defense programs. WIPP's research and development mission was to study the characteristics of salt rock and how it interacts with, and can safely contain, TRU wastes; and to implement a three-to-seven-year production-scale test program to determine if TRU wastes can be safely disposed in a deep, underground, bedded salt formation.

Figure 1-2. Stacks of Drums at WIPP.

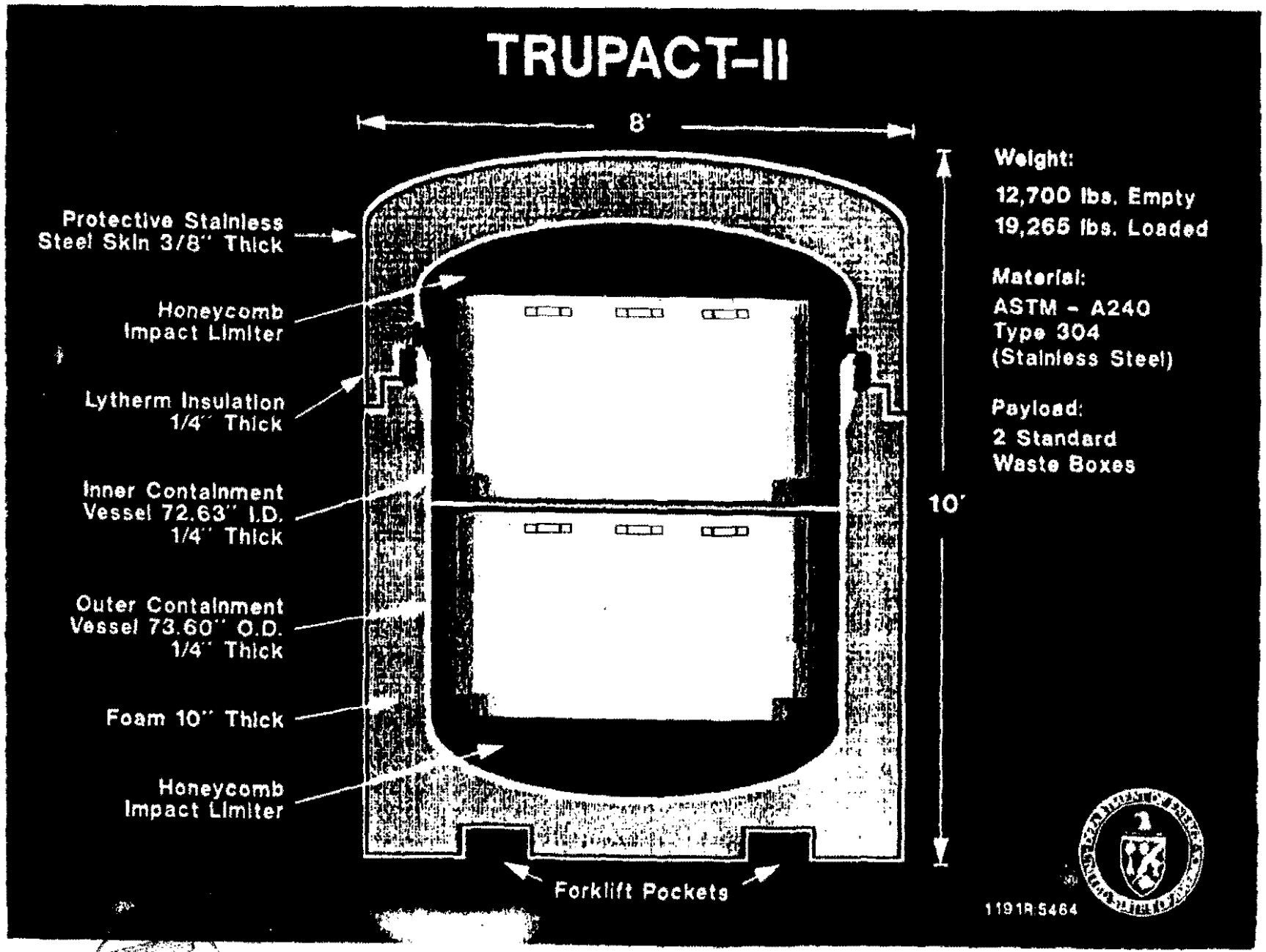

Figure 1-3. Diagram of the TRUPACT-II Double Containment Vessel for Transport of Wa[illegible] WIPP.

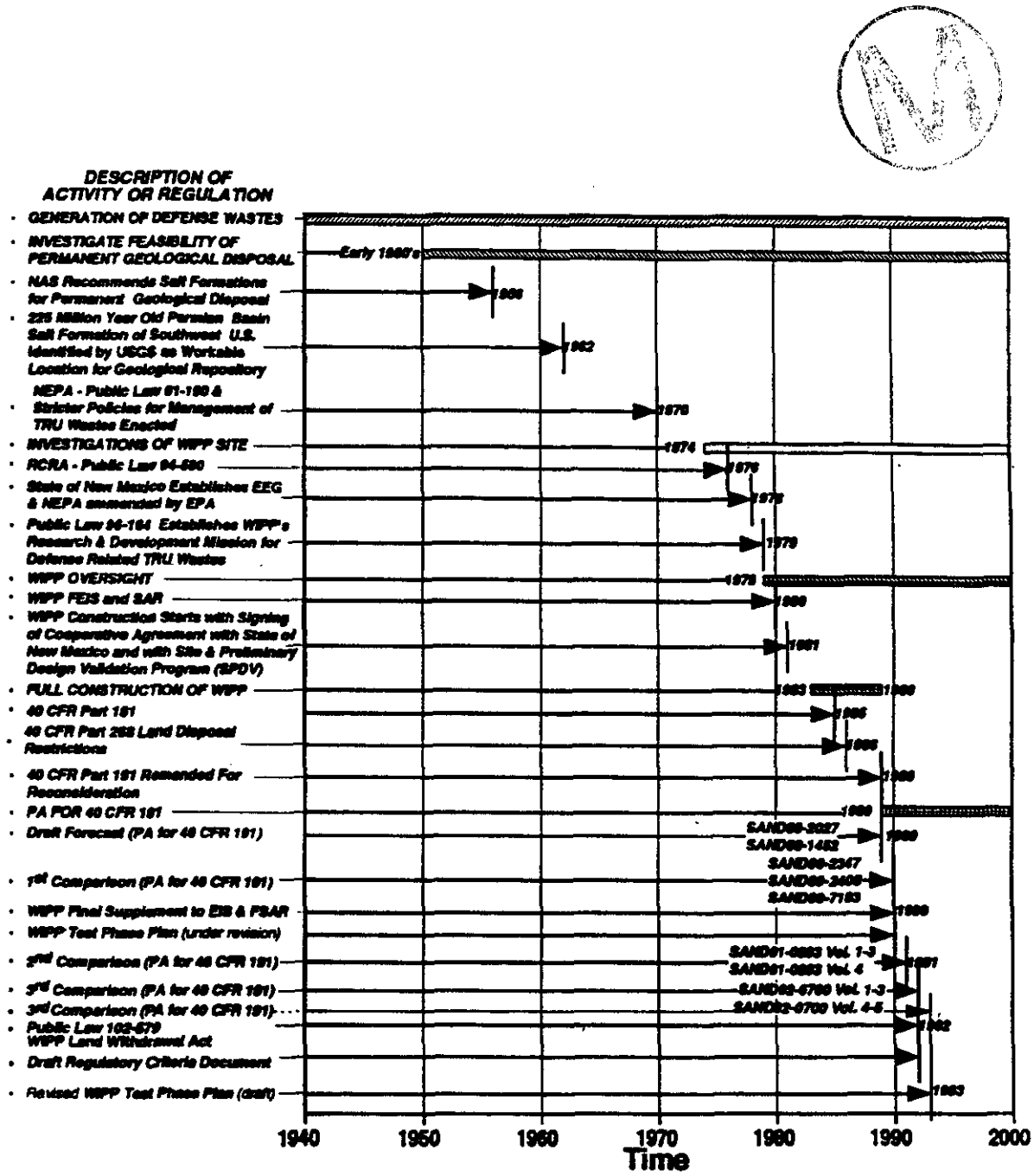

Figure 1-4. Timing of WIPP Events and Actions.

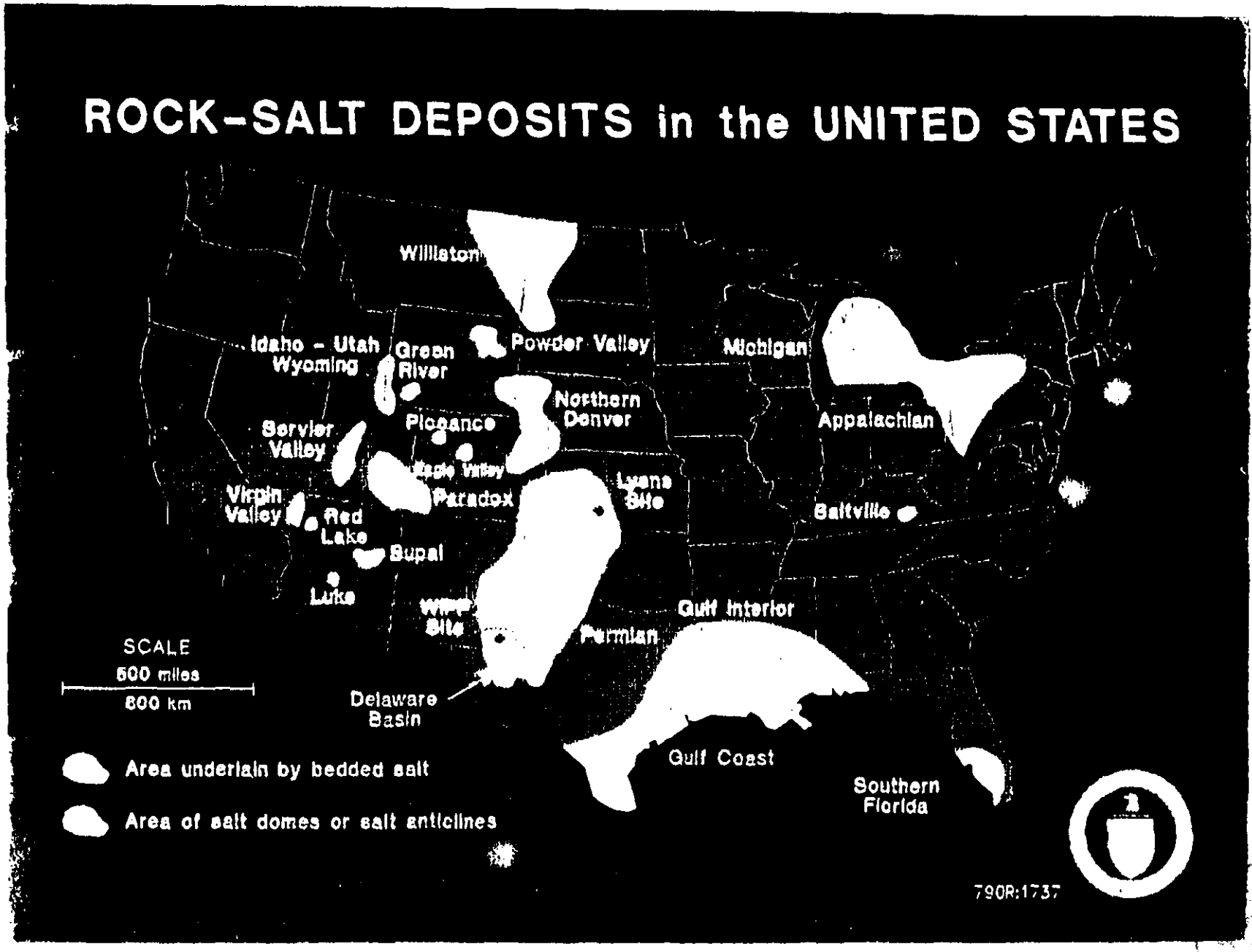

Figure 1-5. Location of Variou ck-Salt Deposits in the United States

If the tests prove successful, and a decision is made to store mixed TRU wastes permanently at WIPP, the facility will operate as a repository for approximately twenty years before closure.

Between the site selection period and 1979, when the WIPP site was authorized by Congress, important events occurred that impacted WIPP significantly. The National Environmental Policy Act (NEPA) became law, and stricter policies for the management of TRU wastes were enacted by Congress in 1970. The Resource Conservation and Recovery Act (RCRA) was enacted (1976), NEPA was amended (1978), and the Environmental Evaluation Group (EEG) was established to provide a comprehensive overview of soon-to-be-authorized WIPP Project activities.

1.2.1 Development and Construction of WIPP

Before construction of the facilities could begin, the following three reports were prepared to develop the facility design and establish technical adequacy:

- Final Environmental Impact Statement (FEIS), issued in 1980 to implement NEPA,
- Safety Analysis Report (SAR), also issued in 1980, and
- Site and Preliminary Design Validation (SPDV) report, initiated in 1981.

While construction started at WIPP in 1981 with the SPDV Program, full construction of all facilities did not begin until 1983; construction of surface facilities was completed in 1989.

Figure 1-6 illustrates a 1991 northwest-looking aerial view of the WIPP surface facilities, and **Figure 1-7** shows a northeast-looking isometric view of the layout of WIPP's surface and the underground footprint. The plan view diagram of the WIPP underground shown in **Figure 1-8** differentiates between completed and proposed excavations. As indicated in these figures, WIPP consists of both underground facilities and surface facilities that house site personnel and equipment for operational and research activities. Underground facilities include a series of horizontal storage rooms, alcoves, and tunnels, and four vertical shafts (i.e., salt handling, waste, exhaust, and air intake shafts). Figure 1-8 illustrates the basic dimensions of the underground workings and shows that they consist of a waste storage area and an active experimental area. Current design provides for emplacement of 175,564 m^3 (6.2 million ft^3) of TRU waste in storage areas to be laid out in ten panels. These ten panels include eight main panels and two equivalent panels to be developed in the access tunnels during the last stages of disposal (i.e., a northern and a southern panel), as illustrated in Figure 1-8. The main panels consist of seven rooms (dimensions 4.0 m high, 10.0 m wide, 91.4 m long {13 ft high, 33 ft wide, 300 ft long}) and the connecting passages. By 1990, approximately 16 km (10 mi) of underground structure had been excavated. This required the removal of 800,000 tons of rock salt or about 50% of the estimated 1.6 million tons to be removed if a decision to dispose is reached. In addition to the 16 km (10 linear mi) of tunnels more than 16 km (10 vertical mi) of drill holes have been completed to characterize the site.

Figure 1-9 shows the WIPP-area stratigraphic column and an idealized geologic profile illustrating the surface buildings and four shafts going down to the repository level 655 m (2,150 ft) below the surface. The underground facility is roughly centered in the sequence of evaporite deposits that make up the Salado Formation. The 914 m (3,000 ft) thick Permian-age salt beds at WIPP are some of the thickest in the United States. These 245- to 285-million-year-old Permian Basin salt deposits, which underlie a large portion of eastern New Mexico, have remained stable and unaffected by folding, faulting, or earthquake activity since the time of their deposition.

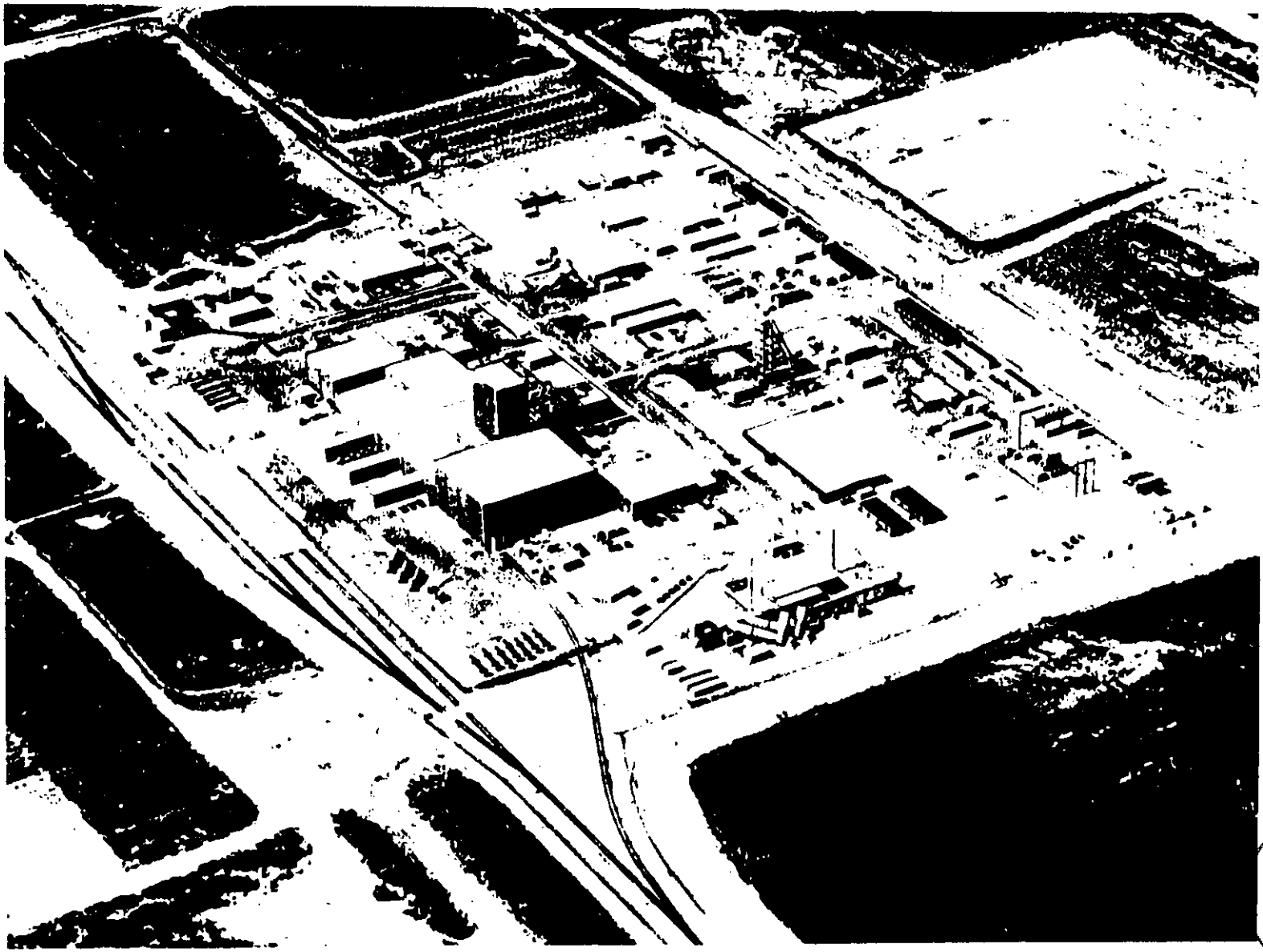

Figure 1-6. Aerial View of the WIPP Sr Facilities Looking to the Northwest.

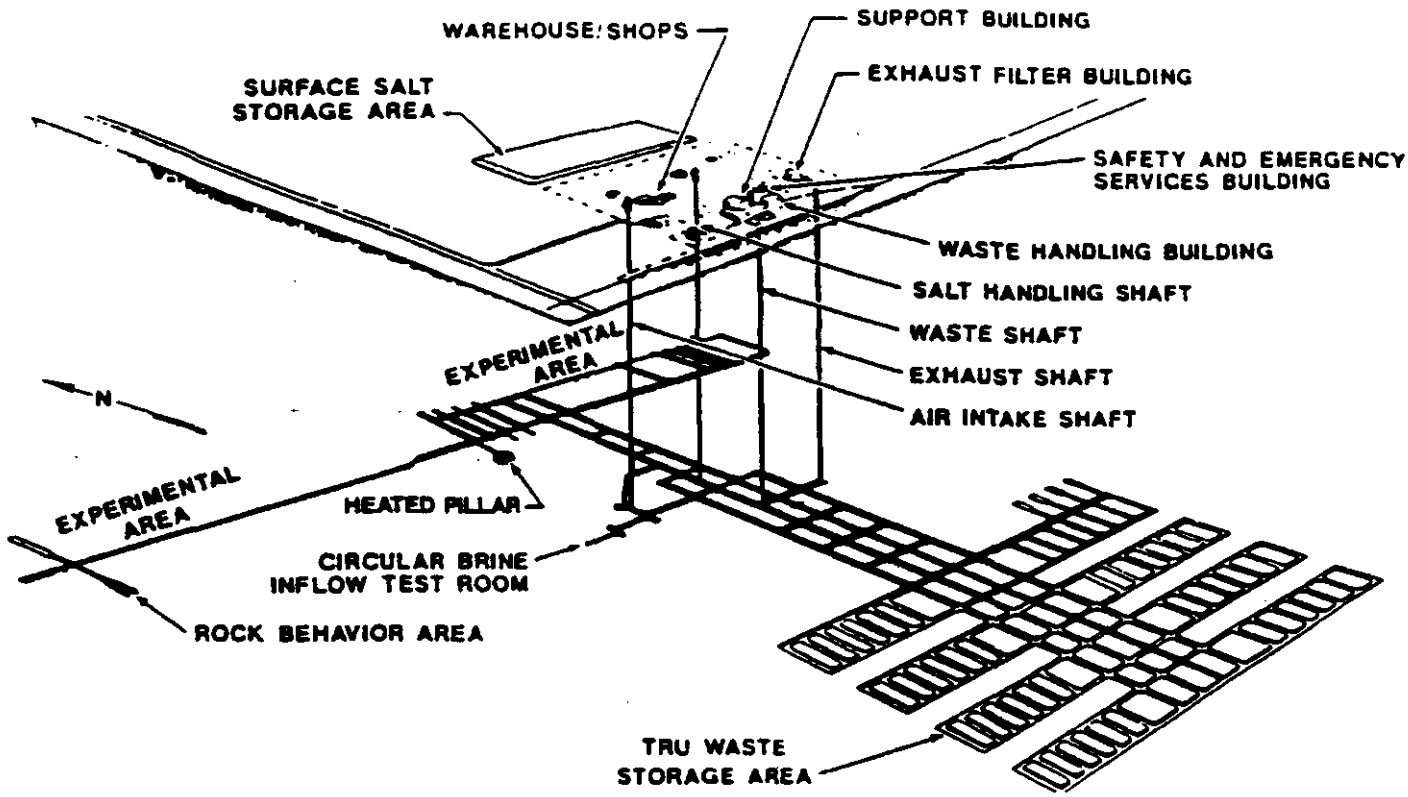

Figure 1-7. Isometric View of the Surface and Underground Footprint Looking to the Northeast. (Solid lines represent actual underground openings and hollow lines represent proposed waste panels.)

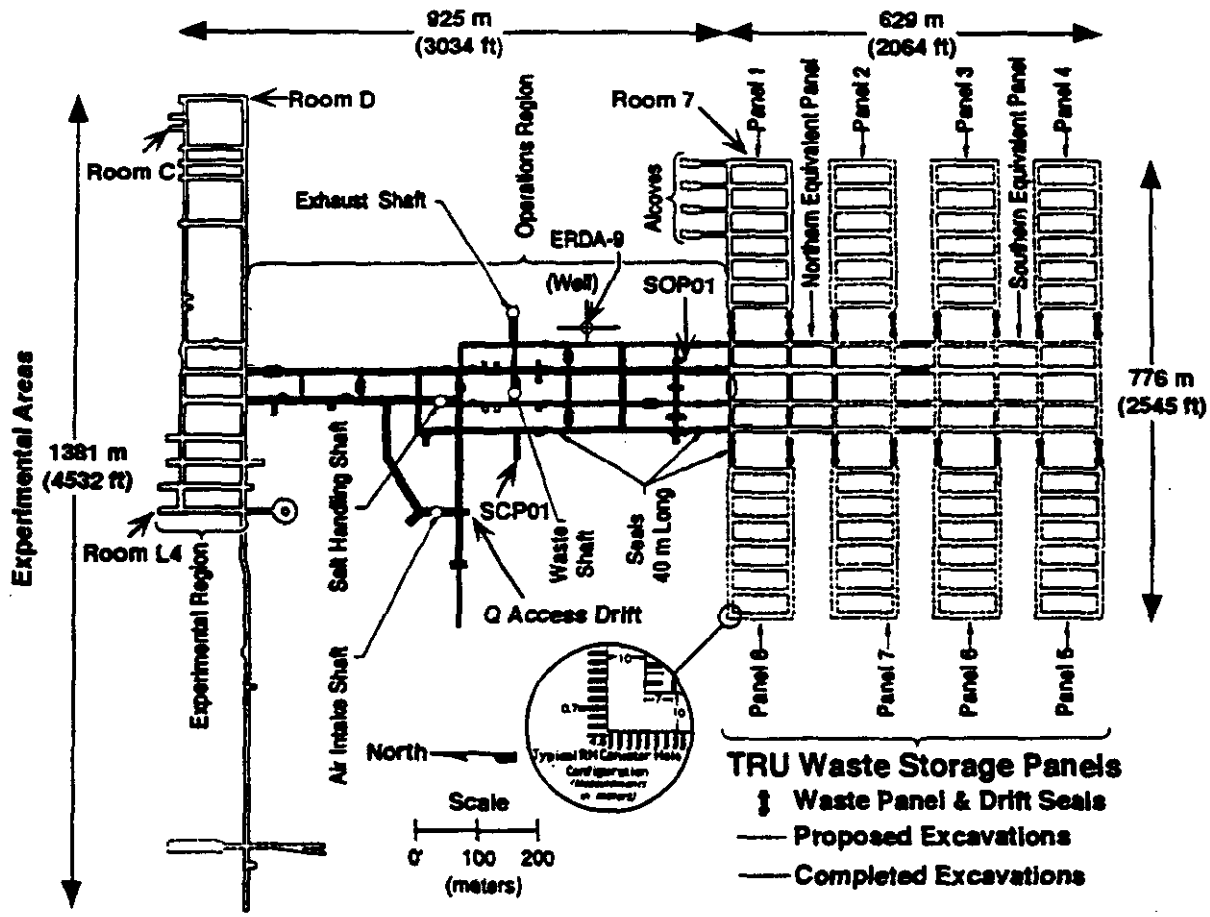

Figure 1-8. Plan View of WIPP Completed and Proposed Excavations.

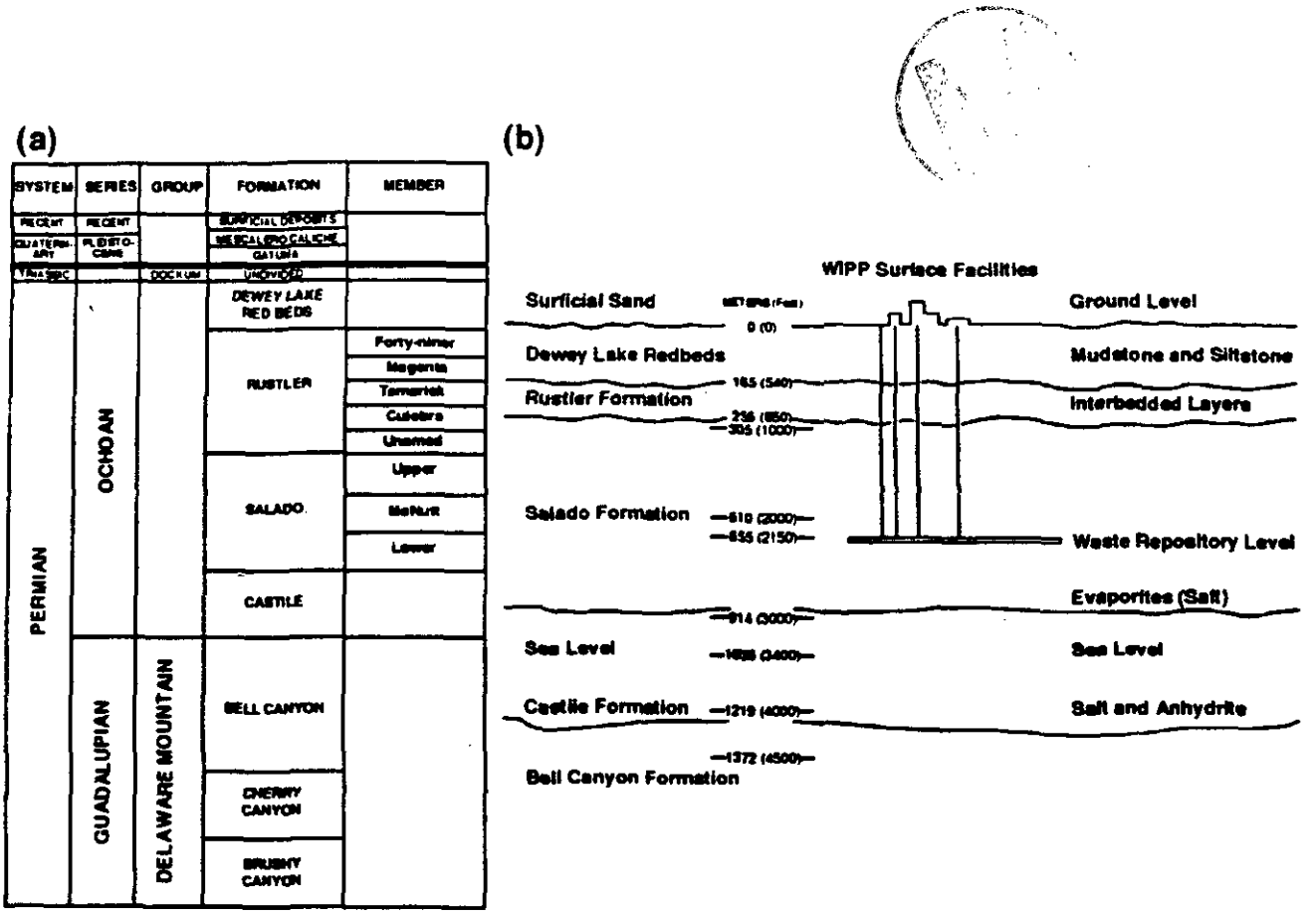

Figure 1-9. **(a) WIPP-Area Stratigraphic Column and (b) the Geologic Profile at WIPP Illustrating the Location of the WIPP Underground Workings in the Profile.**

1.2.2 *WIPP Experimental Programs*

Scientific studies and experiments, ongoing at WIPP since 1983, include:

- Thermal/structural interactions (TSI) studies to determine: (1) the stability of the excavated rooms during waste emplacement and possible retrieval, and (2) the long-term deformation of the disposal room and the room's ability to encapsulate the waste (see Section 5);

- Repository plugging and sealing studies designed to develop and test seal materials for the boreholes, shafts, and underground openings (see Section 6);
- Studies to determine important characteristics (e.g., permeability, pore pressures, chemistry of formation fluids) that control transport in the Rustler and Salado Formations (see Section 3);
- Waste package and materials studies to test the safety and performance of waste drums that would hold CH-TRU wastes;
- Brine inflow studies to increase understanding of this phenomenon, since migration of the small amounts of naturally occurring moisture in salt (1 wt % water) to excavated surfaces is important for evaluating the potential for waste container corrosion and waste decomposition (see Sections 5 and 6); and
- Gas generation studies to evaluate type, volumes, and maximum rates of gases generated by corrosion, biodegradation, and radiolysis (see Section 5).

1.2.3 Applicable Regulations and Laws

Details regarding the applicable laws and regulations as they relate to the various phases of the WIPP Project in general (i.e., during both the operational and long-term phases), and to this review effort specifically, will be discussed in Subsection 1.3. In this subsection, applicable laws and regulations are discussed from a historical perspective. Following are the important public laws and associated regulations for the WIPP Project.

- The Atomic Energy Act of 1954, as amended by Reorganization Plan No. 3 of 1970 and the Nuclear Waste Policy Act of 1982. This amended law was the basis for the 40 CFR Part 191 regulations promulgated by EPA in 1985 that deal with the environmental radiation protection standards for the management and disposal of spent nuclear fuel, and high-level and TRU wastes. 40 CFR Part 191 deals with both the operational and the long-term disposal phases of radioactive waste handling, as well as final disposal.

  However, it is the WIPP Project activities for addressing the disposal phase that are the focus of this review and that resulted in the first, second, and third comparisons with the long-term requirements of 40 CFR 191, Subpart B.

- Public Law 91-190, or the National Environmental Policy Act, which was passed in 1970 with regulations issued by EPA in 1978. This law requires that the full environmental impact of proposed projects be evaluated openly with public comment. The regulations for enforcement of NEPA were subsequently promulgated by the Council on Environmental Quality (CEQ). EPA's responsibility for reviewing and publicly commenting on the potential environmental impacts of major Federal action resulted in the 1980 FEIS and the supplement in 1990 (Figure 1-5).

- The Solid Waste Disposal Act (SWDA), as amended by Public law 94-580, the Resource Conservation and Recovery Act, in 1976, and the subsequent Hazardous and Solid Waste Amendments (HSWA) to RCRA (1984). Regulations implementing RCRA were promulgated by EPA and provide for the management of the hazardous waste components of the mixed wastes proposed for disposal at WIPP. 40 CFR 264, Subpart X, applies to the operational phases of the WIPP Project, and land disposal regulations, such as 40 CFR 268, that apply to the testing and disposal phases of the WIPP Project.

- Public Law 96-164, passed by Congress in 1979, authorized WIPP as a US DOE project and defined its research and development mission.

- Public Law 102-579, the WIPP Land Withdrawal Act of 1992 (LWA). This law permanently withdraws the 41.44 sq. km (16 sq. mi) of Federal (i.e., Bureau of Land Management) Lands associated with the WIPP Project (Figure 1-10) from the public domain. The law addresses a broad range of WIPP Project issues, such as the WIPP Test Phase, disposal operations, environmental laws and regulations, waste retrievability, mine safety, transportation, access to information, economic assistance, and miscellaneous payments to the State of New Mexico (DOE/WIPP 89-011, 1993).

The statutory and regulatory requirements for WIPP have changed significantly at the same time as WIPP program work was underway. As illustrated in Figure 1-4, the primary long-term disposal regulations (40 CFR Part 191 and 40 CFR Part 268) applicable to the WIPP Project were passed midway through the construction effort (1983-1989). All this happened after the 1980 FEIS and SAR, and subsequent to the initial design documentation (i.e., the 1981 SPDV) and some of the initial WIPP testing and characterization efforts.

The two sets of regulations (40 CFR 191 and 40 CFR 268) associated with the geologic disposal of mixed wastes have created some uncertainty as to how to proceed in some areas. Several of the requirements that deal with similar topics often suggest different approaches. For example, 40 CFR 268 requires deterministic calculations, whereas 40 CFR 191B is more focused on probabilistic models for achieving confidence in long-term predictions. To reconcile differences in these regulations, DOE has developed a draft Regulatory Criteria Document (RCD 1992) to facilitate disposal and post-disposal decisions for any defense-generated TRU repository. The RCD provides integrated criteria for a common interpretation and approach to the various regulations. DOE plans to use the integrated criteria in the RCD to provide the basis for developing a WIPP-specific regulatory compliance strategy that will guide the planning and conduct of activities at WIPP.

1.2.4 WIPP Performance Assessment

WIPP PAs of the WIPP disposal system will be used to demonstrate compliance with the long-term performance requirements of both 40 CFR 191 and 40 CFR 268.6. It should be noted that PA has specific meanings defined within the context of each of these standards. Long-term PA analyses must be performed and compliance satisfactorily demonstrated before any TRU and TRU mixed wastes can be disposed at WIPP. Furthermore, Section 6 of the LWA requires DOE to publish biennial PA reports that document the long-term performance of WIPP once the test phase at WIPP begins. While additional PAs are needed to demonstrate compliance with the short-term requirement of these regulations and other regulations (e.g., 40 CFR 264, Subpart X), it is the long-term PAs and the approach to their preparation that are the focus of this PART study.

Sandia National Laboratories has been preparing for and conducting preliminary assessments for comparison with the long-term regulatory requirements of 40 CFR 191, Subpart B, since the mid 1980s. The first draft PA forecast was issued in 1989 by Bertram-Howery et al. (SAND88-1452); subsequently first, second, and third comparisons with 40 CFR 191, Subpart B, have been released (Bertram-Howery et al., SAND90-2347, 1990; SNL-SAND91-0893/1,2,3, 1991; SNL-SAND92-0700/1,2,3, 1992). Each of the assessments in the series incorporated new understanding and information gained from the ongoing experimental, site characterization, and PA activities at WIPP.

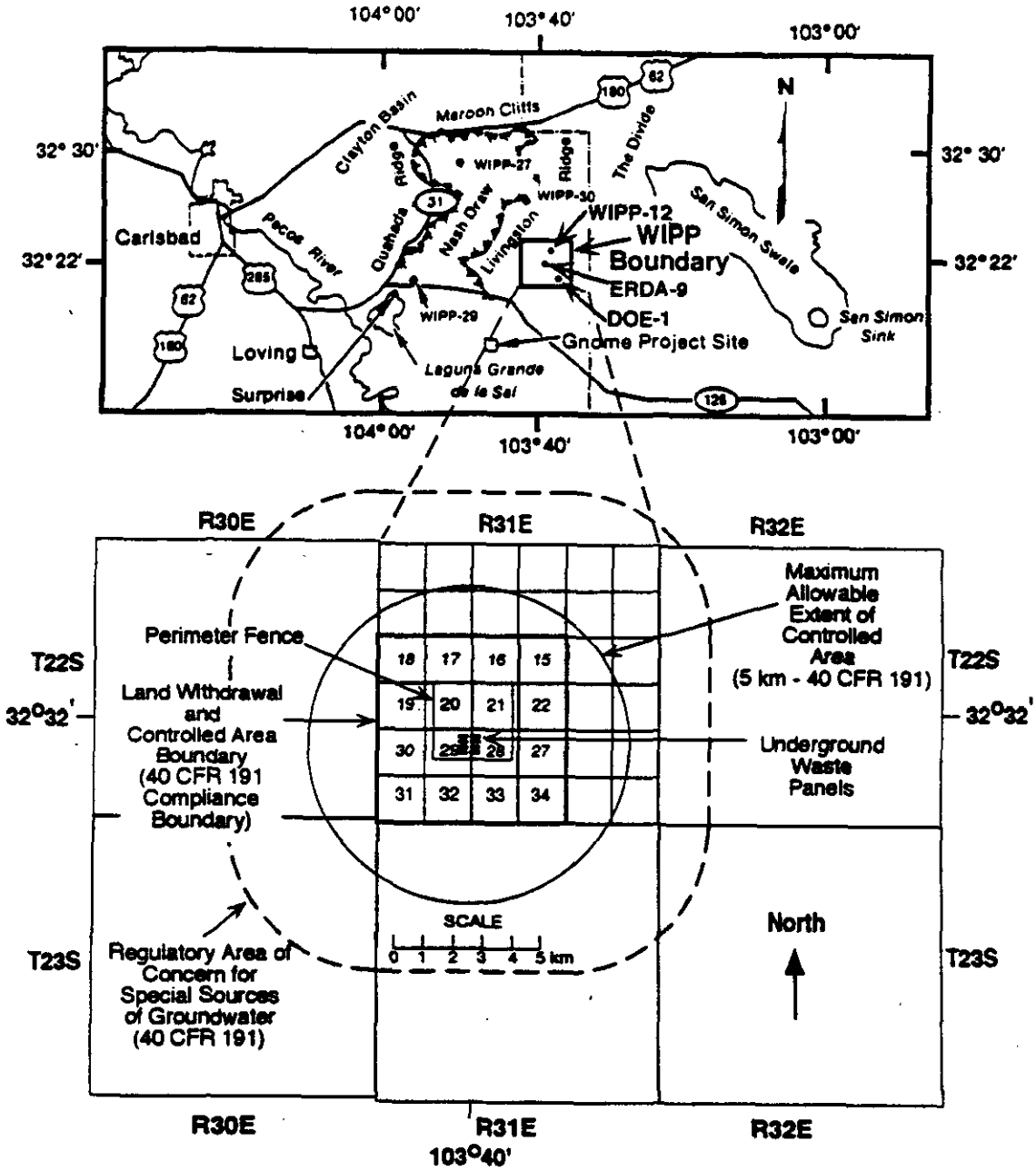

Figure 1-10. **Plan View Location Map Showing the Perimeter Fence, Land Withdrawal Boundary, Maximum Allowable Extent of the Controlled Area, and Compliance Boundary (coincident with the land withdrawal boundary) for the WIPP Site Relative to the WIPP Underground Workings.**

The Westinghouse Waste Isolation Division (WID) is responsible for performing the PA that documents compliance with the other long-term regulations applicable to the WIPP Project (i.e., those of 40 CFR 268). These land-disposal restrictions prohibit disposal of any hazardous wastes not meeting treatment standards specified by EPA unless, as provided for by 40 CFR 268.6, it can be demonstrated to a reasonable degree of certainty that there will be no migration beyond the disposal unit boundary for as long as the wastes remain hazardous. Because of the nature of the TRU and TRU mixed wastes being considered for the disposal at WIPP, DOE is not currently planning to treat these wastes to meet any of EPA's specified standards, and, as a result, DOE must petition EPA for a no-migration determination (NMD) for the disposal phase. Preliminary sensitivity analyses were undertaken for the WIPP Project Integration Office (WPIO) by Sandia (SNL-SAND92-1933, 1992) to provide project guidance, while the strategy for complying with 40 CFR 268.6 is being developed by WID. Although the specific PA requirements of 40 CFR 268.6 are somewhat different from those of 40 CFR 191, a similar methodology and common data set are envisioned (DOE/WIPP 89-011, 1993).

DOE petitioned EPA (under the provisions of 40 CFR 268.6) in March, 1990, for an NMD, and EPA granted a limited determination for the WIPP test phase (up to 10 years) in November, 1990. This determination permits the emplacement of a limited amount of untreated mixed wastes for testing purposes, but it imposes various conditions that include the issuance of annual NMD reports (DOE/WIPP 91-059, 1991; DOE/WIPP 92-057, 1992), along with the requirement that any emplaced wastes be removed if DOE cannot demonstrate the long-term acceptability of the disposal site by the end of the test period.

1.2.5 WIPP Project Experimental Program

Public Law 96-164 that established the WIPP Project in 1979 authorized the scientific and engineering activities that have been ongoing at WIPP since the FEIS was issued in 1980. This law defined a test phase for the WIPP Project that was to consist of two primary programs (i.e., a PA program and an operations demonstration program) to collect the additional technical data and information necessary for determining whether or not to proceed to the disposal phase of the project. The test phase and the PA program were to investigate the behavior of the salt rock and its interactions with emplaced TRU waste in order to evaluate the long-term performance of the waste disposal system. The operations demonstration program was to demonstrate the safe and efficient handling, transportation, and emplacement of TRU waste in an actual facility.

The test phase at WIPP actually began in 1990, when EPA granted the NMD discussed in the previous section. However, the LWA (Public Law 102-579) defined the test phase as beginning when the first shipment of CH-TRU waste was actually received at WIPP for testing. The LWA required DOE to submit a test phase plan and a waste retrieval plan to EPA within seven months of its enactment and specifically prohibited the transport and emplacement of RH-TRU waste during the test phase. These earlier testing activities at WIPP have since been classified as "pre-test phase" activities and were authorized as discussed in the previous paragraph (DOE/WIPP 89-011, 1993). On October 21, 1993, the Department announced its decision not to conduct tests with radioactive waste at the WIPP facility. Instead, the Department would conduct an enhanced laboratory program to collect the data that was to have been provided by the radioactive waste tests at WIPP. Thus, the test

phase, as defined by the WIPP Land Withdrawal Act, will not be conducted. In place of the test phase, the Department will undertake an experimental program. The overall purpose of the experimental program is to develop pertinent information and assess whether disposal of TRU waste and TRU mixed waste in the planned WIPP repository can be conducted in compliance with the environmental standards for disposal. The experimental program to be conducted prior to the disposal phase encompasses (1) performance assessment conducted to evaluate compliance with the applicable EPA regulations; (2) studies designed to provide the scientific basis or enhance confidence in performance assessments; and (3) the process by which the decision will be made as to whether TRU waste can be emplaced in the repository for permanent disposal.

1.2.6 Other WIPP Project Phases

The WIPP Project has been developed in distinct phases.

- Siting Phase. The earliest, or siting, phase of the project was protracted. As illustrated in Figure 1-4, it began with feasibility studies initiated in the early 1950s and identified salt as a medium for permanent disposal in 1956. The Permian Basin was identified in 1962; investigations of the WIPP area began in 1974; and finally, the WIPP site was formally selected in 1979 with the passage of Public Law 96-164. The siting phase officially ended in 1980 with the publication of the FEIS.
- Design (or SPDV) Phase. The site and preliminary design validation program that began in 1981 followed from the DOE Record of Decision (DOE, 1981). This SPDV program involved some initial construction and development at the WIPP site, starting in 1981. Two shafts were sunk to excavate an underground testing area and at that time various geologic, hydrologic, and geotechnical studies were initiated.
- Construction Phase. Full-scale construction began at the site in 1983 and was completed in 1989. This phase formally ended with publication of the Final Supplemental Environmental Impact Statement (FSEIS) and the Final Safety Analysis Report (FSAR) in 1990.
- Predisposal Phase. This phase encompasses the time frame during which experimental activities gathering information needed to support the compliance application through performance assessment calculations will be completed. These calculations are an integral part of compliance with 40 CFR Part 191 and 40 CFR Part 268.6. This time frame also includes the preparation of the compliance documents, establishment of the administrative record, submission of required documents and applications to EPA, and appropriate rulemaking by EPA. During this period, other key WIPP program activities required to support a WIPP disposal decision must also be completed.
- Disposal Phase. This phase would follow the WIPP test phase if a decision to dispose is reached by DOE after demonstration of compliance with applicable laws, regulations, and other requirements. This phase is expected to last approximately twenty years and would begin with the first emplacement of the waste and end with the emplacement of the last panel seal that contacts the waste.
- Decommissioning Phase. This phase, expected to take approximately ten years, includes the time from the emplacement of the last panel seal that contacts the waste through the emplacement of the last shaft seal.
- Post-Decommissioning Phase. This final phase is the 10,000-year period following the decommissioning phase.

1.2.7 WIPP Oversight/Regulatory Groups and Review

Since 1979, the WIPP Project has received independent technical review from the Environmental Evaluation Group (EEG). This oversight function was established by Congress (Public Law 100-456) with funding provided by DOE. The EEG has conducted and published review comments on all major WIPP Project activities and produced more than fifty reports and more than twenty papers on all aspects of the Project (i.e., the site, design and operation, transportation, and long-term integrity). The EEG also conducts independent environmental surveillance on- and off-site by obtaining their own samples of water, soil, biota, and air (e.g., EEG's air sampling equipment is located next to DOE's) or using samples obtained by the WIPP Regulatory and Environmental Programs. EEG is expected to continue to function during the test phase and is given specific authority by the LWA (e.g., to review and comment on the biennial PA during the test phase).

In 1981, DOE and the State of New Mexico entered into an agreement for consultation and cooperation (DOE and State of New Mexico, 1981) that was amended in 1984, 1987, and 1988. This agreement includes provisions for State involvement in oversight and consultation, imposes requirements on DOE with regard to development and operation of WIPP (e.g., waste retrievability), and specifies provisions for involvement of the State in the WIPP Project {DOE/WIPP 89-011, 1993}). The State of New Mexico exercises its oversight, consultation, regulatory, and monitoring functions through various state agencies. (1) The New Mexico Environmental Department (NMED) regulates WIPP activities under the New Mexico Hazardous Waste Act, the New Mexico Water Quality Act, and the New Mexico Air Control Act. NMED reviews and controls various activities at WIPP for the State and also for the EPA under RCRA, based on authority provided by EPA. During the test phase, NMED will review and comment on the biennial PA developed by DOE and will annually review DOE's basis for retrievability. The New Mexico Bureau of Mines is responsible for inspection of WIPP mining activities, and the New Mexico Highway and Transportation Department is responsible for highway routing.

A variety of other external groups and agencies, besides the EEG and the State of New Mexico, have provided independent oversight and review of various aspects of the WIPP Project. For example, the NAS has a standing panel on WIPP which has repeatedly reviewed the project. The panel consists of scientists and technical experts from various relevant fields. NAS has been involved in site selection and characterization. The NAS WIPP Panel provides quarterly reviews that have covered repository PA, pre-operational test activities, geotechnical issues, and hydrologic issues. The NAS WIPP Panel reports to the NAS Board on Radioactive Waste Management that, in turn, makes recommendations to DOE and Congress. The NAS Panel also provides comments to Congress. NAS has continuing authority under the LWA to provide oversight and review of the WIPP Project. Some of these are required by the LWA, which assigned specific regulatory and oversight responsibilities to various groups including State and Federal agencies. For example, the EPA is assigned as the certifying agency by the LWA. The EPA must (1) certify compliance with the 40 CFR 191; (2) determine compliance with the RCRA/No-Migration Determination; (3) approve by rule the Test Phase Plan; and (4) approve by rule the Retrieval Plan.

This PART review further illustrates DOE's routine use of outside technical expertise to examine various aspects of the WIPP Project.

Following are various other WIPP oversight and review groups, along with a brief description of their function.

- The Defense Nuclear Facility Safety Board (DNFSB) was established by Congress in 1988 to review and evaluate the content and implementation of DOE standards relating to the design, construction, operation, and decommissioning of defense nuclear facilities. The DNFSB provides DOE oversight in the form of operational safety reviews.
- The Occupational Safety and Health Administration (OSHA) has specific regulatory and oversight responsibility with regard to emergency response training by the LWA.
- The National Institute of Occupational Safety and Health (NIOSH) also has specific regulatory and oversight responsibility with regard to emergency response training by the LWA.
- The Mine Safety and Health Administration has specific regulatory and oversight responsibility with regard to underground room stability and mine safety by the LWA.
- The Nuclear Regulatory Commission (NRC) is assigned specific regulatory and oversight responsibility with regard to transportation casks by the LWA.
- The Bureau of Mines has specific regulatory and oversight responsibility with regard to underground safety by the LWA.
- The Bureau of Land Management provides DOE with consultation and oversight on lands issues.
- The Blue Ribbon Panel (disbanded in November 1991), provided review/guidance on waste characterization, the Waste Acceptance Criteria Certification Committee, the test phase program, the test phase plan, and long-term safety.
- The Advisory Committee on Nuclear Facility Safety (also disbanded in November of 1991) provided guidance on operational and long-term safety.

1.3 REGULATIONS CONSIDERED IN PART REVIEW

Figure 1-11 is a time-line that illustrates the relationships between the key regulations applicable to the WIPP Project during the various project phases and identifies plausible dates and regulatory time periods; (the actual dates are for reference purposes only and do not reflect any established schedule). The PART review examined the adequacy of the current PA program at WIPP for addressing the two long-term regulatory requirements. These specific regulations are shaded in Figure 1-11 to illustrate the applicable time periods and the phases of repository development to which they apply.

- The long-term regulation that applies to the radioactive components of the proposed waste – 40 CFR 191 Subpart B, Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Waste, applies to the post-decommissioning phase of repository development.
- The long-term regulation that applies to the hazardous constituents of the proposed waste – 40 CFR 268.6, Land Disposal Restrictions of the RCRA—applies to the disposal, decommissioning, and post-decommissioning phases of repository development.

At the time that the PART review was conducted, SNL had the primary responsibility for supporting the WIPP testing program and performing the PA for DOE with regard to evaluating compliance of the WIPP with 40 CFR 191 Subpart B. External technical review of these SNL activities is provided by a special panel from the National Research Council/National Academy of

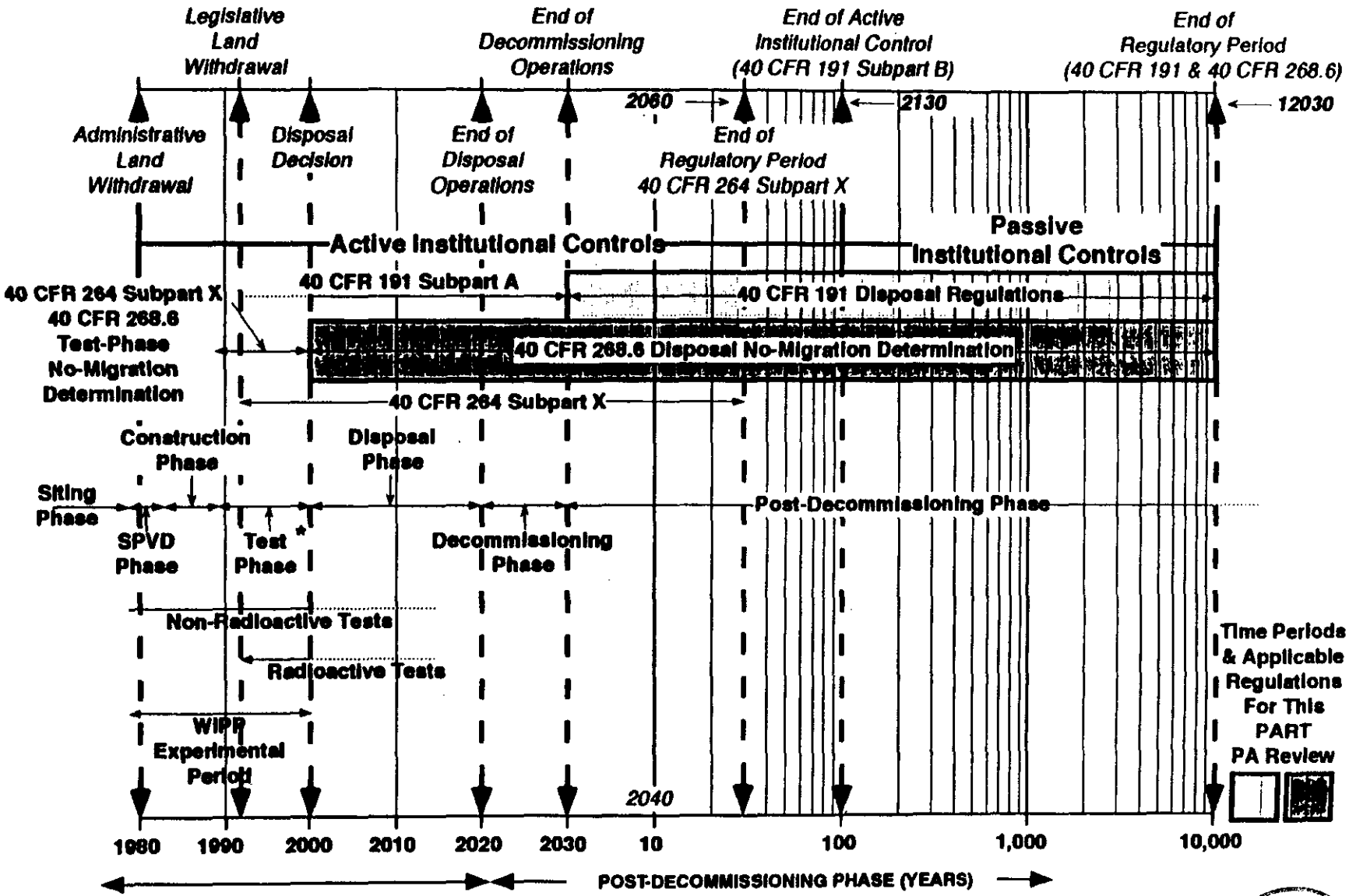

NOTE: This schematic is meant to show sequence; the years are identified to indicate relative timing and should not be interpreted as a schedule.

*Test Phase as defined in Legislative Land Withdrawal Act

Figure 1-11. Time-Line Showing the Relationships Between the Various Phases of the WIPP Project and the Applicable Regulations and Their Periods of Applicability. Note that the shaded regulations, project phases, and time periods are the focus of this PART review.

Sciences. SNL also supports DOE in these same activities with regard to RCRA 40 CFR 268.6 regulations. WID is responsible for supporting the WIPP activities with respect to evaluating compliance with both the short- and long-term needs of the 40 CFR 268.6 regulations and, as mentioned earlier, prepares the annual Test Phase NMD report to the EPA. As the managing and operating contractor, WID is also responsible for preparing the no-migration variance petition (NMVP) required for the disposal, decommissioning, and post-decommissioning phases. WID is thus responsible for performing the PA to evaluate whether the WIPP is expected to comply with the regulations during these additional phases of repository development; if so, WID must prepare the NMVP used to demonstrate compliance with this RCRA regulation (40 CFR 268.6). The PART has reviewed SNL and WID activities relative to the PA needs of both of these sets of regulations.

This subsection contrasts the differences in approach and specific requirements of the two long-term regulations as they relate to WIPP. Ambiguities and differences between 40 CFR 191 and RCRA regulations were reconciled by DOE into integrated criteria in the draft RCD in December, 1992. These draft integrated criteria have been examined by PART to determine the applicable subset, given the specific purpose of the PART review (Appendix A lists this subset).

1.3.1 40 CFR Part 268.6 Approach

The RCRA land disposal restrictions of 40 CFR Part 268.6 that apply to the hazardous constituents of the mixed wastes proposed for disposal at WIPP are very detailed. The regulation depends on process knowledge and control of the waste form to ensure disposal safety. It requires characterization of the waste so that specific treatment methods can be selected and carried out prior to emplacement of the treated waste in or on the land. To emplace any untreated waste, as is planned at WIPP, DOE must petition for and be granted an exemption under 40 CFR 268.6. This petition must demonstrate, "to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit or injection zone for as long as the wastes remain hazardous." This allowance for a petition for "no-migration" or the "no-migration determination" (NMD), recognizes the need for flexibility in applying the concept of proper waste treatment before land disposal.

1.3.2 Specific Requirements of 40 CFR 268.6

The petition to allow disposal of prohibited (i.e., untreated) waste under 40 CFR 268.6 requires a demonstration of no migration, as discussed above. The important requirements for this demonstration include the following:

- Identification of the specific disposal unit and the specific waste;
- Chemical and physical characterization of waste to be disposed and a comprehensive characterization of the disposal unit's chemical and physical parameters and current environmental conditions, using approved methods for sampling, testing, and estimation that are as accurate and reproducible as possible;
- Simulation models for the site and waste that have been calibrated and verified for accuracy through comparisons with measurements for demonstrating compliance with the no migration provision;

- Analyses that identify and quantify the uncertainty in the various aspects of this demonstration, including evaluation of the consequences of predictable future events (e.g., earthquakes, floods, other natural phenomena);
- A detailed monitoring plan for detection of migration at the earliest possible time; and
- Quality assurance and a quality control plan for all aspects of demonstration.

The current regulation (40 CFR 268.6) is not specific with regard to what constitutes no-migration, the disposal unit, the time period (i.e., "as long as the waste remains hazardous"), or reasonable degree of certainty. Additionally, there is no approved guidance with regard to the modeling and preparation of the no-migration variance petition and no specific discussion as to whether the consequences of human intrusion must be addressed as a possible future event and system state as part of the no-migration demonstration. Some of these issues were and are in the process of being resolved as a result of the following:

- The conditional NMD for the activities of the test phase period at WIPP that DOE was granted in 1990 (EPA, 1990; Federal Register Vol. 55 No. 220, 47,700-47,721);
- EPA's recently published draft of a guidance manual for petitioners seeking no-migration variances (EPA, 1992; EPA 530-R-92-023), by providing EPA's interpretations and suggested procedures for compliance with 40 CFR 268.6 (DOE/WIPP 89-001, 1993); (however, PART has not yet completed formal review of the guidance); and
- Proposed rulemaking for the revisions to the no-migration standard published in the *Federal Register*, August 11, 1992.

Following are current definitions or interpretations by DOE of the important issues:

- Disposal unit. The 40 CFR 268.6 disposal unit boundary for WIPP has been interpreted to extend vertically from the top to the bottom of the host rock (the Salado Formation) and laterally where the 6.44 km x 6.44 km (4 mi x 4 mi) land withdrawal boundary cuts through the host rock, as shown in **Figure 1-12.**
- As long as the waste remains hazardous. The demonstration of no-migration for a period *of 10,000 years has been interpreted to be sufficiently long.*
- No-migration. No-migration is concentration- and not detection-based; (i.e., no-migration means no movement of concentrations above health-based levels beyond disposal unit boundaries).
- Reasonable degree of certainty. 40 CFR 268.6(a) A reasonable degree of certainty will be delineated through discussions between DOE and EPA and through technical and public review and comment on a proposed NMD. The delineation will pertain primarily to the adequacy and completeness of information provided to the regulatory by DOE, which will be the basis for an EPA determination. The adequacy and appropriateness of simulation modeling and associated assumptions and uncertainties are key to this definition. Uncertainties will be systematically evaluated. Since uncertainty will always exist in any analysis of events occurring in a 10,000-year time frame, it is important that the implications of the uncertainties in regard to repository performance evaluations be understood.
- Modeling and analysis. The regulation (40 CFR 268.6) is not specific with regard to whether a deterministic or a probabilistic modeling approach is required. However, the wording of the regulation—"Simulation models must be calibrated for the specific waste and site conditions, and verified for accuracy by comparison with actual measurements"—implies that a deterministic approach is expected. The regulation also clearly indicates that a sensitivity and uncertainty analysis is required to identify and quantify any aspects of the demonstration that contribute significantly to uncertainty" for current and predictable future conditions.

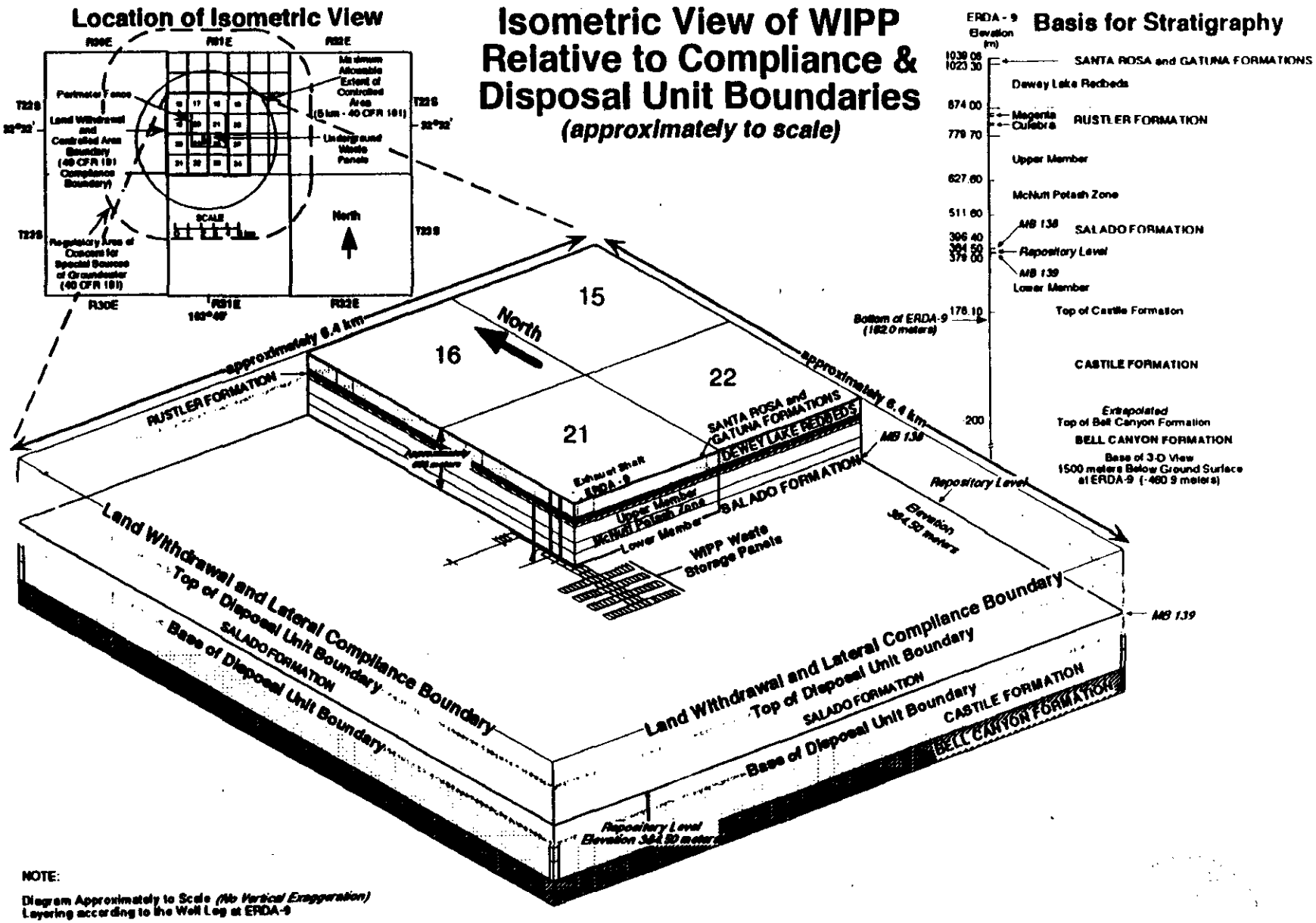

Figure 1-12. Isometric View of WIPP Relative to Compliance and Disposal Unit Boundaries.

- Human intrusion. The regulation requires that "This analysis must include an evaluation of the consequences of predictable future events, including, but not limited to, earthquakes, floods, severe storm events, droughts, or other natural phenomena." This language seems to exclude an examination of the consequences of human intrusion (unless inadvertent human intrusion is considered to be a predictable future event or natural phenomenon). This interpretation is also supported by the guidance (EPA, 1992; EPA 530-R-92-023) for preparing the no-migration petition. The guidance does not require inadvertent human intrusion to be considered in the demonstration.

1.3.3 40 CFR 191 Subpart B Approach

In contrast to 40 CFR 268.6 regulations, the environmental radiation protection standards of 40 CFR 191 through Subpart B define environmental standards for geologic disposal that are more general in that they do not place specific restrictions on the type of radioactive materials that can be disposed or how they can be disposed. Instead, this regulation requires the "disposal system" (i.e., any combination of engineered and natural barriers that isolate the waste) to comply with the four different requirements of 40 CFR 191 Subpart B, shown graphically in **Figure 1-13**. The containment requirements (§191.13) and the two protection requirements (individual, §191.15, and ground water, §191.16) are quantitative and begin as follows: "Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation."

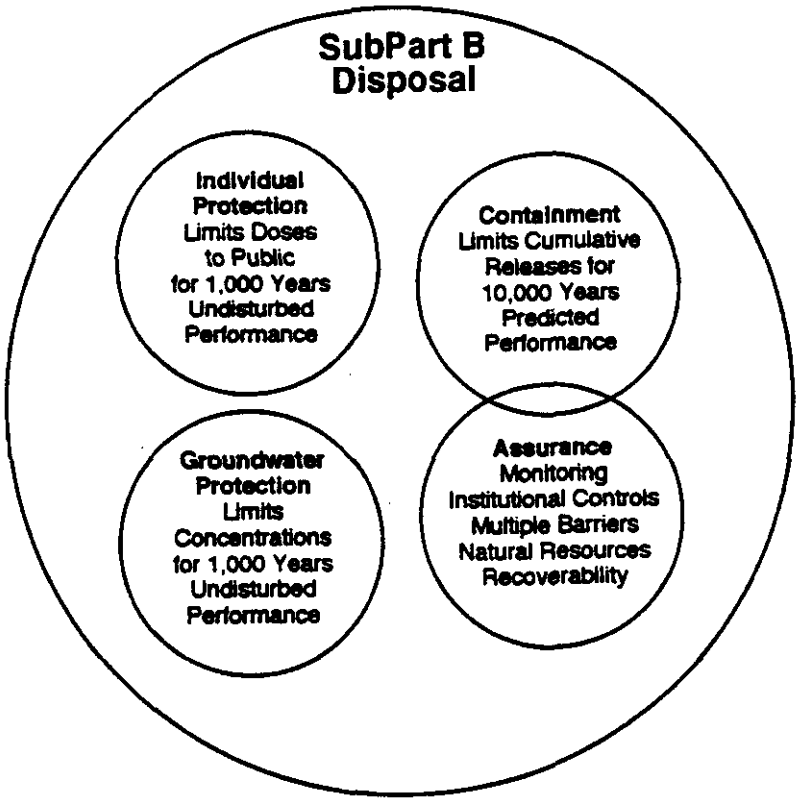

Figure 1-13. Graphical Representation of the Four Requirements of Subpart B of 40 CFR Part 191 (after Sandia 1993; SAND92-0700/1) Illustrating the Overlapping of the containment Requirements Will Be Met Containment and Assurance Requirements to Increase Confidence that the C.

They then go on to describe what different numerical criteria must be met to satisfy each of the different sections: limited cumulative releases, limited doses, and limited concentrations. The assurance requirement (§191.14), through its provisions for design (e.g., multiple barriers, recoverability), for monitoring, for the use of active and passive institutional controls, and for evaluating adverse factors related to site selection (e.g., natural resources and exploration potential), was developed to provide additional confidence that the long-term compliance (10,000 years) with the containment requirements of §191.13 can be met.

1.3.4 Specific Requirements of 40 CFR 191 Subpart B

Following are the important requirements for this regulation.

- The Federal Government is committed to permanent ownership of the disposal site.
- Active institutional control of the disposal site will be maintained for as long as practicable; (PA must assume loss of active control after 100 years).
- Passive institutional control of disposal sites will be maintained through permanent markering, records, and other means "to indicate dangers of wastes and their location."
- Disposal site selection must avoid places "where there is a reasonable expectation of exploration for scarce or easily accessible resources" unless this exploration potential is compensated for by the site's favorable characteristics.
- Disposal system designs must include multiple engineered and natural barriers to isolate wastes, and the design must not preclude removal for a reasonable period of time after disposal.
- The disposal system must be monitored after disposal "to detect substantial and detrimental deviations from expected performance" in ways "that do not jeopardize isolation of the wastes" until any significant concerns are addressed.
- Performance modeling must be provided to show compliance with the numerical requirements of §191.13, §191.15, and §191.16. A probabilistic modeling approach that evaluates long-term (decommissioning to 10,000 years) predictions of disposal system performance is specified as well as implied. This evaluation of performance must identify all the significant processes and events (probability greater than one chance in 10,000 of occurring in 10,000 years) that could affect the disposal system. The evaluation must account for the associated uncertainties (of determining the likelihood of events, of understanding the various processes, of developing conceptual models, and of determining the parameters) and examine the effects that these uncertainties have on predicted performance of the total disposal system; (all portions, both natural and engineered, should be considered even if the performance is uncertain).

  Compliance with the numerical containment requirements (§191.13) is to be through a single "complementary cumulative distribution function" (CCDF) that considers both disturbed and undisturbed conditions. Compliance with the individual and groundwater protection requirements (§191.15 & 191.16) will be based upon "best estimate" predictions (i.e., the mean or median of the appropriate distribution, whichever is higher) for "undisturbed conditions" (i.e., not disrupted by human intrusion or unlikely natural events). It should be noted that the probability cutoff for unlikely events is not specifically defined.
- Inadvertent human intrusion must be considered. Inadvertent human intrusion into the repository by exploratory drilling (no greater than 30 boreholes per square km per 10,000 years in sedimentary geologic formations and 3 boreholes per square kilometer

per 10,000 years in other geologic formations), which is soon realized by the intruders, is the most severe intrusion scenario that needs to be assumed.

It should be noted that unlike the applicable RCRA regulation (40 CFR 268.6), 40 CFR 191 Subpart B does not call for specific quality assurance or a quality control plan. (The significance of this is discussed in Section 8.)

In contrast to the RCRA no-migration regulation (40 CFR 268.6), the wording of 40 CFR 191 Subpart B (§191.13-16), its definitions (§191.12), and the wording in the guidance for its implementation (Appendix B of the regulation) are generally much more specific regarding the issues that were of concern in the RCRA no-migration regulation: compliance boundary, time periods of concern, reasonable expectation, modeling-analysis approach, and human intrusion. Following are current interpretations of these equivalent issues for 40 CFR 191 Subpart B.

- Compliance boundary. The maximum allowable compliance boundary under §191.13 and §191.15 is defined as the accessible environment, which is the atmosphere, land surfaces, surface-water, oceans, and all the lithosphere beyond the controlled area. The controlled area is all the subsurface underlying a surface location that must be identified by passive institutional controls, encompassing no more than 100 square km and extending no more that 5 km (3 mi) beyond the outer boundary of any emplaced wastes. For WIPP this maximum allowable extent boundary is as shown in Figure 1-10. However, for WIPP only the 6.44 km x 6.44 km (4 mi x 4 mi) land withdrawal boundary will be marked by passive institutional controls, and so the accessible environment (or compliance boundary) becomes the entire land surface and atmosphere and all of the rest of the environment beyond this land withdrawal boundary. Figure 1-12 is a cutaway isometric view of the WIPP site, showing the subsurface stratigraphy drawn approximately to scale according to the interpretations of the ERDA-9 borehole. The drawing, which is also approximately to scale, shows the WIPP completed and proposed subsurface excavations, as well as the location where the 6.44 km x 6.44 km (4 mi x 4 mi) land withdrawal boundary cuts through the subsurface to form the lateral limits of the non-accessible environment, which forms the vertical compliance boundary with the accessible environment. The land surface within the 6.44 km x 6.44 km (4 mi x 4 mi) land withdrawal boundary forms the upper compliance boundary that separates the non-accessible subsurface environment from the accessible environment above.
- Reasonable expectation. There is no explicit interpretation or guidance regarding the meaning of this phrase. However, the wording of both Part B of the containment requirement (§191.13) and the guidance for implementation of the regulation (Appendix B) clearly indicates that EPA requires a reasonable expectation, on the basis of the record before the implementing agency, that compliance with §191.13(a) will be achieved. The guidance for this regulation indicates that the implementing agency is expected to use prevalent expert judgment in making the various numerical predictions and that "the implementing agency may choose to supplement such predictions with qualitative judgments as well."
- Modeling-analysis approach. As discussed above, a probabilistic modeling approach is specified for the containment requirement (§191.13) and implied by the wording for the individual (§191.15) and groundwater (§191.16) protection requirements.
- Human intrusion. Inadvertent human intrusion must be specifically addressed, as discussed above.

1.3.5 Concerns Related to the Regulations

DOE and EPA will be treading on new regulatory ground as the WIPP project moves forward. Furthermore, there are basic differences in these regulations that have yet to be resolved. Some of the concerns include the following:

- the question of whether there is a need to evaluate the consequences of inadvertent human intrusion as part of the no-migration demonstration for 40 CFR 268.6;
- the need to get precise definitions and interpretations for important regulatory and guidance terms (e.g., "likely", "unlikely") and concepts (e.g., calibration and verification for accuracy through comparisons with measurements, when such long time periods are involved);
- the lack of specified Quality Assurance (QA) requirements for 40 CFR 191 Subpart B (should be contained in 40 CFR 194, which is currently being developed by EPA);
- the need for identification of the specific waste with a chemical and physical characterization as part of the demonstration for 40 CFR 268.6 when a good fraction of the waste has not been generated;
- possible conflict between the requirement for a detailed monitoring plan for detection of migration at the earliest possible time for 40 CFR 268.6 and the long-term disposal concerns that monitoring can jeopardize the isolation of the wastes; and
- the need to develop consensus on the meaning of "reasonable expectation" and "reasonable degree of certainty."

1.4 PART APPROACH

This subsection discusses the organization of the PART, what was reviewed, and the process used to perform the review. It also briefly discusses the role of the Golder simplified PA modeling approach and the planned assessments.

The PART effort consists of periodic briefings to WIPP Project Division, Office of EM-342, and this final report issued to the Director, EM-342. To prepare the report, PART members have:

- Performed a limited review of relevant PA and PA-related literature and on-going PA efforts, including discussions with WPIO, WID compliance staff, and the SNL PA staff, their principal investigators, and their contractors;
- Evaluated the conceptual models and input parameters used in the PA analyses that describe the site conditions for the repository system and the processes involved;
- Evaluated the level of confidence associated with the performance predictions that the repository system will meet 10,000-year performance requirements; and
- Begun development and use of a simplified PA model for verifying SNL PA analysis, and evaluated the effect of alternative conceptual models, parameter distributions, etc., that were identified during the review.

[The results of the PART effort will be issued as two separate reports so that PART recommendations can be considered for 1994 PA activities.] This first report documents the PART evaluation of the adequacy of the current PA program for meeting 40 CFR 191 and 40 CFR 268.6 requirements, and contains PART recommendations for improving the PA program. The second report will document the results of the verification analysis and describe the simplified PA models and methodology used, results of the verification analysis, and significant discrepancies, alternative models, etc., identified by the PART.

1.4.1 PART Organization

The Director of EM-342 and the PART Chairperson selected the PART members on the basis of their knowledge of components and processes associated with salt repository and their independence from the WIPP Project. More specific criteria included (1) familiarity with geologic repositories, especially salt; (2) PA expertise or knowledge of risk assessment techniques; (3) knowledge of RCRA and/or 40 CFR 191 requirements; and (4) no direct association with any of the PA activities for the WIPP.

PART members, their assignment, affiliation, and area of expertise are as follows:

DUTY & Name	AFFILIATION	AREA OF EXPERTISE
Chairperson		
Bryan Bower	US Department of Energy	Site Operations, Test Programs, and PA
Deputy Chairperson		
Charles Voss	Golder Associates Inc.	Engineered Barriers
Members:		
James Russell	Texas A&M University	Creep and Room Closure
Neville Carter	Texas A&M University	Brine Migration
Pamela Doctor	Pacific Northwest Laboratory	PA Methodology
Charles Cole	Pacific Northwest Laboratory	Flow and Transport

1.4.2 WIPP Participation

The following WIPP Project organizations participated in this review:

- EM-342. The Director, EM-342 authorized the PART review and report for management purposes.
- WPIO. The WIPP Project Integration Office provided administrative support in assembling reference material from SNL and WID, scheduled the interviews with the SNL Performance Assessment staff, and coordinated the WPIO, the WIPP Project Site Office (WPSO) and SNL review of the draft PART Report.
- WPSO. The WIPP Project Site Office provided administrative support by scheduling interviews with the WID compliance staff and coordinating the WPSO and WID review of the draft PART Report.
- SNL. Sandia National Laboratories provided the reference material required to support the independent review, made members of its staff available for interviews by the PART, clarified written documentation, answered specific questions, and coordinated the review of the draft PART Report by their staff as directed by WPIO.
- WID. Westinghouse Waste Isolation Division provided the reference material required to support the independent review, made members of its staff available for interviews by the PART, clarified written documentation, answered specific questions, and coordinated the review of the draft PART Report by their staff as directed by WPIO.

1.4.3 Basis of the Review

Members of the PART have used, to the extent possible, the latest information available to carry out this limited review of the WIPP PA Program. Sources of information include (1) the base (or minimal) set of documents listed below; (2) a WIPP site tour; (3) a series of interviews with various SNL, WPIO, WID, and EEG staff; and (4) any other relevant documents or reference material that the PART identified as relevant in the course of their review. The EM-342 PA Manager coordinated the

assembly and distribution of the reference material required for the review with the appropriate WPIO managers.

PART members, at a minimum, have had access to the following base set of information: SAND92-0700/1-3 Preliminary Comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant, December 1992, Volumes 1-3; SAND91-0893/1-4 Preliminary Comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant, December 1991, Volumes 1-4; WIPP Waste Characterization Program Plan; WIPP Waste Analysis Plan; WIPP Test Phase Plan; Technical Needs Assessment Document; Regulatory Criteria Document for the Disposal of Defense Transuranic Mixed Waste in a Geologic Repository; the 1991 No-Migration Determination Annual Report to EPA; EPA comments on the 1991 Annual Report; the 1992 No-Migration Determinations Annual Report to EPA; and EEG comments on SAND91-0893.

A one-day tour of the WIPP site was conducted early in the review process to acquaint the PART members with the specifics of the site. The full-day tour was conducted by Tom Schultheis (SNL) and Ken Aragon (WID). The underground portion of the tour included Panel 1, Room Q, Room H, Site and Preliminary Design Validation (SPDV), as well as the Construction and Salt Handling and the Waste shaft areas. The surface tour concentrated on the Waste Handling Building, particularly the CH bay. The tour concluded with a question and answer session with Tom Schultheis.

1.4.3.1 PART Meetings and Interviews

After an initial meeting in Germantown, Maryland (December 11, 1992), the PART members studied review material made available to them and began a series of interview meetings following the tour of the WIPP facility. The purpose of these interviews was to gather additional information not available in the base documentation listed above and other references. PART interviews were coordinated by the PART Chairperson with WPIO, WPSO, SNL, WID and EEG and included interviews with the WPIO Technical Support Group (TSG), the WID compliance staff, the SNL PA staff and principal investigators, as well as the EEG staff.

The first PART meeting was held on January 15, 1993, following the WIPP site tour on January 14, 1993. PART members met with John Arthur, Mark Matthews, and Pat Higgins of WPIO, as well as members of the WPIO TSG, who discussed current and planned activities with regard to PA. A considerable amount of time was spent discussing a QA database for critical PA parameters. The second PART meeting was held on February 4-5, 1993, in Albuquerque, New Mexico. The purpose of the meeting was to conduct interviews with the SNL PA staff. In addition to Rip Anderson, PART interviewed Mel Marietta, Fred Mendenhall, Rick Beauheim, Joe Tillerson, Palmer Vaughn and Jon Helton. On March 11-12, 1993, the PART again met in Albuquerque, New Mexico, this time to interview the WID compliance staff and the SNL principal investigators. The PART had discussions with Bob Kehrman, Rohit Jain and Elaine Gorham.

The next meeting of PART was in Seattle, Washington, on April 5-6, 1993, at the office of Golder Associates, Inc. PART was briefed by Lokesh Chaturvedi and William Lee of the EEG on EEG's concerns regarding WIPP PA testing activities. Major concerns expressed by the EEG were related to scenario definition, solicitation of expert judgment for the rate of inadvertent human

intrusion, gas generation and fracturing, the use of data versus judgment, the lack of information on source terms, and the incomplete documentation of computer codes.

In May, PART held two meetings: one in Germantown, Maryland, on May 6-7, 1993, and one in Albuquerque, New Mexico, on May 27, 1993. The meeting on May 6-7, 1993, was to update Mark Frei and Steve Schneider on the status of PART activities. The meeting on May 27, 1993, was an interview with Dori Ellis and Wendell Weart to discuss SNL management's role in PA decision making. Additional meetings were held by the PART in June in Seattle, Washington, and conference calls were conducted in July and August to discuss report preparation.

As noted in Subsection 1.3, the PART has identified a subset of the integrated requirements from the draft RCD (DOE, 1992) as a partial basis for evaluation of the WIPP PA program. This subset and the relationship to the RCD requirements are given in Appendix A. These requirements are summarized in this subsection; they provide the basis for the development of the partial issue tree and the conceptual model because the objectives of modeling/analysis should drive the needs of the conceptual and numerical modeling and other analysis efforts (Simmons and Cole, 1985).

Summarizing from the specific draft RCD requirements that form part of the basis for this review, the SNL PA staff (WID compliance staff) [a] must undertake two major efforts.

1.0 The staff must evaluate compliance of the total WIPP geologic disposal system with the regulations of 40 CFR 191 Subpart B *(40 CFR 268.6)* through the use of compliance analyses consisting of both quantitative PA modeling and qualitative analyses. The modeling and analyses shall consider the likelihood and consequences of natural processes and events that may disturb the disposal system (PC1.004, PC1.012, and PC1.014 a) from the time of emplacement of the wastes. The likelihood and consequences of human intrusion will also be evaluated through the use of compliance analyses consisting of both quantitative PA modeling and qualitative analyses. Additionally, an evaluation to determine whether there are special sources of groundwater within or less than 5 km (3 mi) beyond the controlled area (the dashed boundary line in Figure 1-13) must also be conducted (PC2.001 a-b).

1.1 These evaluations and compliance analyses must consider the contributions of all components of the geologic disposal system (i.e., the natural and engineered barriers as well as the radionuclide and hazardous constituent content and characteristics of the emplaced waste), except those components that can be demonstrated to make a negligible contribution (PC1.009 a-b, and PC1.008 a). This evaluation must also demonstrate the disposal system's ability to control, minimize, or eliminate waste release (PC1.008 b) for the likely natural processes and events; others can be ignored (PC1.0013 a-e). Likely processes and events are those having an estimated probability of occurrence greater than 1 in 10,000 over 10,000 years.

1.2 The evaluations and analyses must address all pathways for release (groundwater, surface water, soil, and air) at the boundary of the control area (at the top and bottom of the disposal unit boundary or its lateral extent as defined by the intersection with the vertical boundary of the control area) as illustrated in Figure 1-13 (PC1.003 a-b, PC2.001 a, and PC2.002 a-e).

[a] In general, there is little difference in the RCD requirements for the WID compliance staff and the SNL PA staff. However, when they are different, the requirements for the WID compliance have been placed in parentheses and italicized.

1.3 The compliance analyses and evaluations must be supported by laboratory and field studies, as well as by expert judgment (PC1.003 a-b and PC1.004).

1.4 The models used in the SNL compliance analyses for 40 CFR 191 Subpart B and the WID compliance analyses 40 CFR 268.6 must have the following attributes:

1.4.1 These models must use identical physical descriptions of the disposal system (PC1.019);

1.4.2 The pathways considered by these models must be consistent (PC1.011);

1.4.3 These compliance analyses must use comparable conceptual models as the basis for their mathematical and computational models (PC1.020);

1.4.4 These models must simulate the expected behavior of the disposal system (PC1.018) and predict any resulting releases of hazardous or radioactive constituents from the time of waste emplacement until 10,000 years following closure (PC1.021 a);

1.4.5 These compliance models must be evaluated (PC1.025).

1.5. Specific engineered barrier system design and evaluation constraints and the requirements important to these compliance analyses include the following:

1.5.1 The design must be physically and chemically compatible with the natural barrier system (PC6.001 a-b); and

1.5.2 Design of engineered barriers, as well as the analyses that assess their adequacy, must be supported by analytical data (PC6.002 a-c).

1.6. An assessment must be carried out with these compliance models that excludes consideration of water wells within the controlled area and that estimates the annual dose equivalent from the undisturbed disposal system to any member of the public for 1,000 years after disposal (PC1.024 a-b-c).

1.7. An evaluation of the likelihood and consequences of human intrusion must be carried out with these compliance models under the following constraints:

1.7.1 The likelihood of human intrusion must consider the controls imposed to make it less likely, and furthermore, the evaluation of likelihood will be primarily based on the effectiveness of these primary markers (PC1.015 a-d); and

1.7.2 In evaluating the consequences of human intrusion, only single isolated one-time intruder events that are no more severe than inadvertent and intermittent human intrusion by exploratory drilling for resources (other than the waste) will be considered. It must be assumed that systematic or persistent exploration within the controlled area does not occur (PC1.016 a-d).

1.8. Sensitivity and uncertainty analysis of the compliance modeling must be performed that includes the following:

1.8.1 the uncertainty in processes and events (PC1.027 a);

1.8.2 the likelihood and consequences of alternative conceptual models (PC1.027 b);

1.8.3 representation of model parameters (PC1.027 c);

1.8.4 sensitivity studies of the models (PC1.027 d); and

1.8.5 an assessment of the accuracy of the model that includes model verification results (PC1.027 e).

2.0 The staff must develop a demonstration based on these compliance analyses (1.0 above) and document the basis for this demonstration (PC1.005 and PC1.006).

2.1. This demonstration must establish whether there is a reasonable expectation that the WIPP geologic disposal system will comply with the quantitative radionuclide limits

specified in 40 CFR 191 Subpart B *(the quantitative health based hazardous constituents limits of 40 CFR 268.6)* for all the expected processes and events (PC1.002 a-b, PC1.013 c, PC1.014 b, and PC1.021 b-c). Further specifics for this demonstration include the following:

2.1.1 This demonstration must be routinely updated (along with the PA modeling and analyses) with the latest new and relevant information until the time of repository closure (PC1.007);

2.1.2 In this demonstration the PA results for 40 CFR 191 Subpart B §191.13 compliance comparisons must be presented as a single complementary cumulative distribution function (CCDF) that indicates the probability of exceeding the cumulative release standard (PC1.022 a-b);

2.1.3 The demonstration must show that waste migration prediction models were calibrated to specific site conditions, physical features, and emplaced wastes (PC1.026 c);

2.1.4 The demonstration must show that modeling results are consistent with actual field measurements and representative of the actual physical system (PC1.026 d).

2.2. General requirements are that the documentation must include discussions of the records of quantitative and qualitative evidence used to develop the PA models as well as any supplementary information such as natural analogs, evidence that supports the process models, parameter ranges, geometric conceptual models, hypotheses, and any simplifying assumptions used (PC1.006). Specifics for this documentation are as follows.

2.2.1 The documentation must describe boundaries of the control area and disposal unit (PC2.001 b).

2.2.2 The documentation must include discussions regarding the consequences of the human intrusion events evaluated and a description of these analyses (PC1.016 d).

2.2.3 The documentation must include justification for the selection or generation of the single CCDF for comparison with 40 CFR 191 Subpart B standards (PC1.023).

2.2.4 The compliance models and their evaluation must be documented (PC1.025).

2.2.5 The documentation must present discussions of the model results, including:

2.2.5.1 simplifying assumptions in the conceptual, mathematical, and computational models (PC1.026a);

2.2.5.2 rationale for selection of the waste components modeled (PC1.026 b);

2.2.5.3 calibration of waste migration prediction models (see 1.1.4 above) and the comparisons that show modeling results are consistent with actual field measurements and the comparisons that show that the models are representative of the actual physical system based on the consistency of model results with the actual field measurements (PC1.026 c-d); and

2.2.5.4 comparison of model results with observations and an explanation of any differences (PC1.026 e).

2.2.6 The documentation must include a comprehensive, detailed description of the natural system. This documentation of the natural system must describe the geology as well as the surface and groundwater hydrology of the repository site and setting (PC4.001 b), and must also provide an analysis of the geochemistry

of the system relevant to waste migration and including a characterization of the rock, soil, air, and water chemistry (PC4.001 a).

1.4.4 PART Report Development and Preparation

Reviews of the base set of documents (Subsection 1.4.3) and other requested reference material, along with participation in interviews, and discussions among the PART members themselves, formed the basis for their evaluations of the technical adequacy of the WIPP PA program and the formulation of their recommendations for program changes. PART members did not necessarily perform a complete review of the base set of documents or the supplementary documentation requested during the course of the review. The members were free to select the scope and depth of review performed on each document. In general, each member conducted a review within his or her own area of expertise.

The predecisional draft report was issued to PART members only. Members had the opportunity to comment on the entire report and the Chairperson attempted to resolve any conflicts among PART members. The findings in the report reflect the consensus of the PART. Conflicts not satisfactorily resolved were documented as an appendix to the main report and provided to the EM-342 Director. Once the final draft report was accepted by PART, it was concurrently issued to the EM-342 Director, WPIO, WPSO, WID, and SNL for review and comment. After the comments were resolved, the final report was signed by PART members and sent to the Director, EM-342. Receipt of the final report by the EM-342 Director completed the PA independent review.

1.4 VERIFICATION CALCULATIONS

This portion of the review involves the performance of independent PA calculations to verify and perform sensitivity assessments for the calculations done by SNL. This work is ongoing, and will be published separately at a later date.

The work uses Golder Associates' Repository Integration Program (RIP) PA model, which is a high-level model designed for rapid, simplified PA calculations. The work is being conducted in two phases: (1) the verification phase, in which RIP is used with the same conceptual models and data sets as SNL's published studies, in order to verify the SNL results, and (2) the sensitivity phase, in which RIP is used with alternative conceptual models developed by the review team, in order to evaluate their potential significance for repository safety. It is expected that the significance of alternative potential pathways, and of alternative modeling of disruptive events, will be key areas to be investigated.

1.5 TOPICS EXCLUDED BY PART

As outlined in the Performance Assessment Independent Review Management Plan, PART focused on a review of those PA activities which were directly related to a determination of compliance with the applicable regulations. However, certain aspects of the PA program were, or are, being reviewed by other organizations within DOE which have those functional authorities. For example, PART did not review the validity of data or the data collection techniques or the quality control of the data. This activity was part of a separate review being conducted jointly by WPIO and EM-342. The PART assumed that all data presented in the SNL reports were accurate.

The PART also restricted its review to the priorities assigned to PA activities. Activities associated with repository operation, environmental safety and health, safeguards and security, and budget and scheduling were specifically excluded from the review. However, PART did investigate how decisions were made and schedules were developed in support of PA .

The PART concentrated on PA activities for the demonstration of compliance with the long-term disposal standards contained in 40 CFR 191 Subparts B and C (proposed) and 40 CFR 268.6. This review specifically excluded those activities and regulations that would apply to the operation of the facility for the disposal phase.

2.0 PERFORMANCE ASSESSMENT METHODOLOGY

This section summarizes the approaches being taken by WIPP, through Sandia National Laboratories and Westinghouse Waste Isolation Division, to address the long-term performance standards in 40 CFR Part 191 Subpart B and 40 CFR Part 268.6, respectively. It is these regulations which determine the PA methodology to be used. Subsection 2.1 describes the requirements of 40 CFR Part 191 Subpart B in detail. Subsection 2.2 discusses the SNL approach to addressing the requirements of §191.12(q) (quantitative PA modeling) and §191.13(a) (probabilistic assessment of cumulative releases). This discussion includes a description of the scenarios, including the scenario selection and evaluation process, the performance measure, the modeling approach, and the sensitivity and uncertainty analyses. The subsection concludes with a brief discussion of the application of the probabilistic approach and the complementary cumulative distribution function (CCDF). Following the same format as Subsection 2.2, Subsection 2.3 considers the WID approach to addressing the requirements of 40 CFR Part 268.6, looking at scenarios, performance measure, modeling approach, sensitivity and uncertainty analysis, and probabilistic approach and the CCDF. The WID approach is different from that of SNL because the long-term performance standards of 40 CFR 268.6 are not as detailed or prescriptive from a methodological standpoint as those of 40 CFR 191, Subpart B.

2.1 40 CFR PART 191 SUBPART B

The provisions of 40 CFR Part 191 Subpart B state that the repository must meet certain performance standards in order to be licensed. These regulations mandate a quantitative assessment of the performance of the disposal system, and describe specific performance measures in terms of

1) radioactive material releases to the accessible environment (§141.13),
2) radiation doses received by the public (§191.14), and
3) radioactive contamination of certain sources of groundwater in the vicinity of the disposal system (§191.16).

The performance measures for the containment requirement are, as stated in §191.13(a), that "... the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

1) have a likelihood of less than one chance in ten of exceeding the quantities calculated according to Table 1 (Appendix A); and
2) have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)."

Table 1 in Appendix A of 40 CFR 191 gives limits for cumulative releases over 10,000 years for twelve specific radionuclides and any other alpha-emitting or non-alpha-emitting radionuclide (with a half-life of over twenty years) in curies per unit of waste. The estimated cumulative release for a particular radionuclide is divided by the corresponding limit in Table 1 to produce a normalized cumulative release. If the ratio is less than one, then compliance is determined for both requirements (1) and (2). If more than one radionuclide is present in the disposal system, then the sum of the ratios for the individual radionuclides should be less than one to demonstrate compliance for both requirements (1) and (2).

The quantitative standards of §191.13(a) are stated in terms of likelihoods (i.e., probabilities) because it is recognized that there are uncertainties in the predictions of cumulative releases over 10,000 years. The uncertainty in the cumulative release prediction can be expressed by presenting the result in terms of a probability density function (PDF), illustrated in **Figure 2-1a**. This is simply a plot of the probability of the various possible cumulative release results. Hence, to obtain the probability of the result falling between the value A and the value B (see figure), one need only to integrate under the PDF between these two values.

An alternative manner of presenting the same information is the cumulative distribution function (CDF). This is developed by integrating over the entire PDF, and is illustrated in **Figure 2-1b.** By definition, integrating over the PDF from the lower limit of its range to the upper limit of its range yields a value of 1.0, and the CDF therefore ranges from 0.0 to 1.0. As shown in the figure, a particular point (e.g., $[r_i, p_1]$) on the CDF is interpreted as follows: p_1 is equal to the probability that the result (the cumulative release) is *less* than or equal to r_i.

A third way of presenting this information is the complementary cumulative distribution function (CCDF). The CCDF is illustrated schematically in **Figure 2-1c**. As shown in the figure, a particular point (e.g., $[r_i p_2]$) on the CCDF is interpreted as follows: p_2 is equal to the probability that the result (the cumulative release) is *greater* than r_i (i.e., p_2 is equal to the probability of exceeding r_i). As indicated by its name, the CCDF is the complement of the CDF. That is, $p_2 = 1 - p_1$. Note that the containment requirements of §191.13(a) are stated in terms of complementary cumulative probabilities (i.e., probabilities of exceedence). Therefore, release predictions can be directly compared to the standard if they are presented in terms of a CCDF. Because the two complementary cumulative probabilities of §191.13(a) differ by two orders of magnitude (0.1 and 0.001), it is most effective to present the CCDF on a log-log scale. In such a plot, the horizontal axis represents the logarithm of the normalized release over 10,000 years, and the vertical axis represents the logarithm of the probability of the magnitude of such a release. **Figure 2-2** shows an example of a log-log CCDF with the 191.13(a) containment standards superimposed. In this particular example, the predicted release does not exceed the standards.

If the repository is simulated in terms of various mutually-exclusive scenarios (each of which is described by disjoint subsets of uncertain parameters), a separate CCDF will be produced for each scenario. In order to compare such results to the containment standards, it is necessary to combine the results of the scenarios in an appropriate manner. This is accomplished by multiplying the probability axis of each curve by a weighting factor and adding them together. The weighting factor for each curve is simply the probability of that particular scenario. (The total "weight" for all scenarios must add to one.) An example of how CCDFs for two scenarios (having probabilities of 0.99 and 0.01) are combined is shown in **Figure 2-3.** The character of this combined CCDF is representative of results of the analysis in Sandia PA documents.

The process of developing a CCDF appears to be objective and straight-forward. However, uncertainties in the development of the conceptual model of the components of the repository system and assumptions required for mathematical modeling are difficult to capture in the CCDF. For example, unless all components of a repository system are represented in the numerical model, the

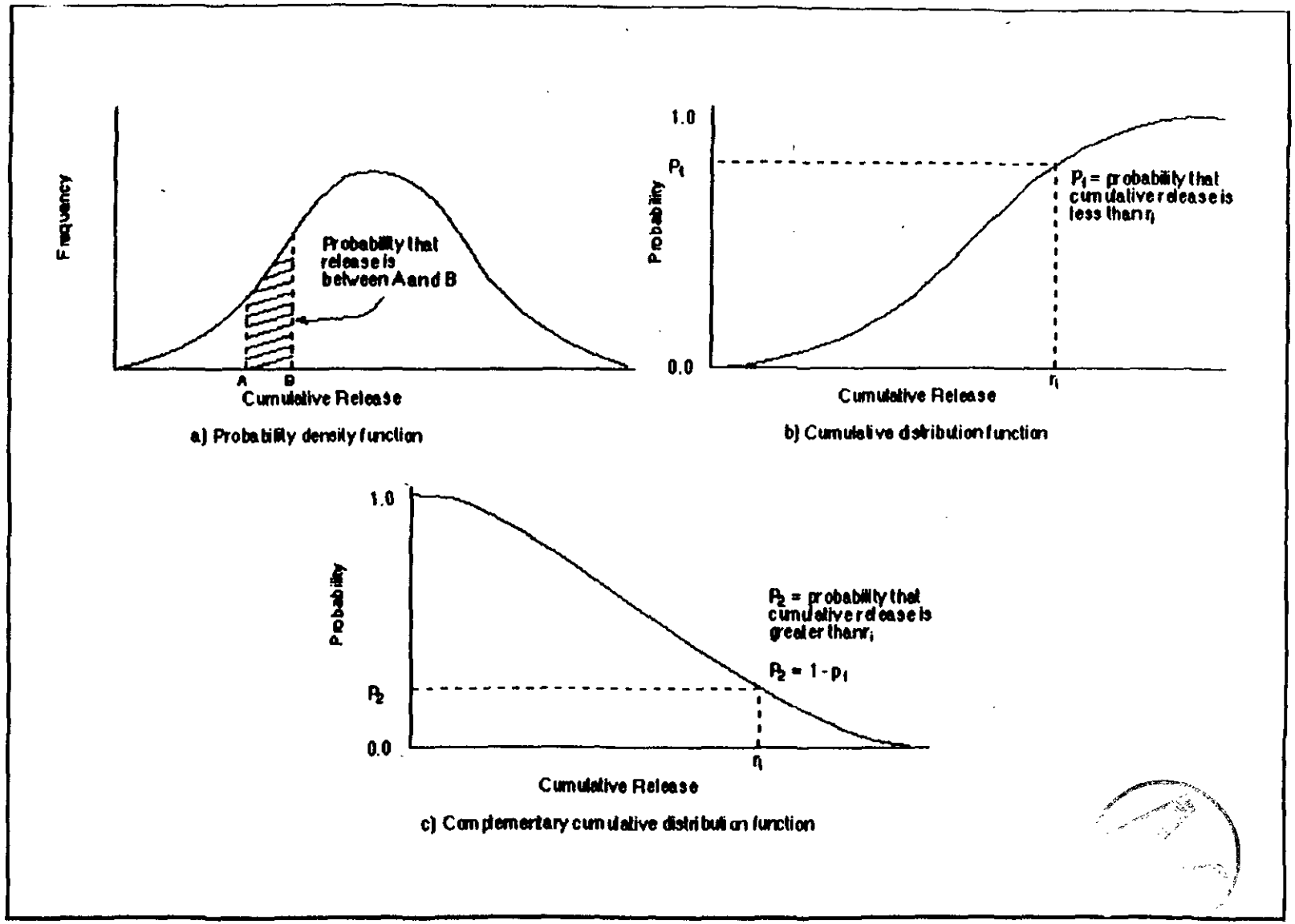

Figure 2-1. Presentation of Probabilistic Results.

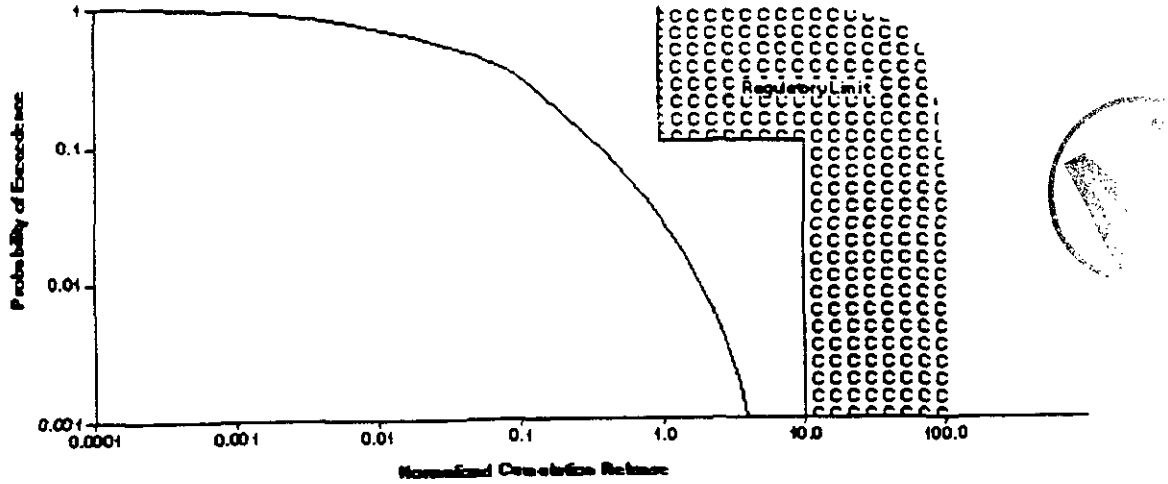

Figure 2-2. Log Log CCDF For Cumulative Release.

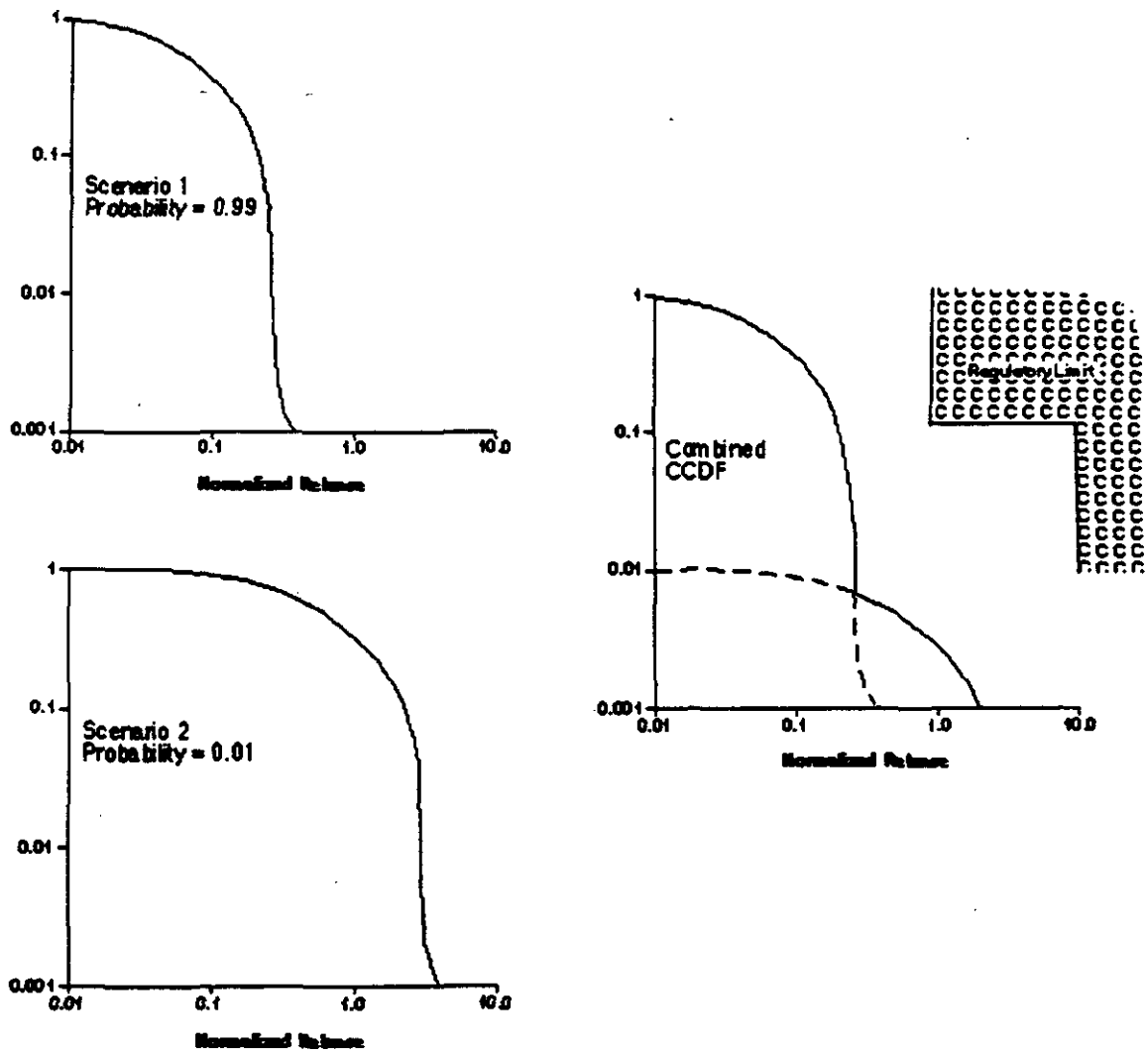

Figure 2-3. Combining CCDFs.

results in terms of a calculated CCDF do not describe the true uncertainty in cumulative release. This issue is discussed in more detail in Subsection 2.2.4. The acknowledgment of remaining uncertainty is further developed in §191.13(b): "Performance assessments need not provide complete assurance that the requirements of §191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation (emphasis added) on the basis of the record before the implementing agency, that compliance with §191.13(a) will be achieved."

It is the role of DOE to decide when the description of the current state of the repository system is sufficiently detailed and when the processes potentially acting upon it are sufficiently understood that the likely performance of the repository can be estimated. The other sections of this report address the sufficiency issue of whether the record being developed that includes PA will be able to satisfy the "reasonable expectation" requirement.

The provisions of §191.14 require active institutional controls for 100 years after closure, monitoring for the period of active institutional control, and the use of engineered, as well as natural, barriers to contain the waste. It also states that areas that have experienced mining for resources should be avoided as locations of a repository, "unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future." Impacts of resource extraction will be discussed in Subsection 3.2.2.2.

The provisions of §191.15 mandate specific quantitative limits for annual exposures (25 millirem whole body and 75 millirem to any critical organ) to the public up to 1,000 years after disposal, assuming undisturbed performance of the repository. All exposure pathways have to be considered, but this article specifically requires that the drinking water pathway be analyzed assuming 2 liters/day from any significant source of ground-water outside the controlled area surrounding the repository. These requirements are not stated in probabilistic terms, and therefore, presumably do not require the calculation of a CCDF.

The groundwater protection requirements of §191.16 set quantitative limits on the permissible concentrations of specific radionuclides and a cap on the annual dose equivalent from all radionuclides combined to 4 millirem from 2 liters/day consumption of groundwater.

2.2 SNL APPROACH FOR 40 CFR PART 191 SUBPART B

The SNL PA approach is being developed within the requirements of §191.12(q) (quantitative PA modeling) and §191.13(a) (probabilistic assessment of cumulative releases). The major steps in the PA process, as defined in Marietta et al. (1989), are the following:

1) characterize disposal system and site;
2) develop scenario;
3) analyze scenario consequences;
4) perform sensitivity and uncertainty analyses; and
5) assess compliance with regulations.

Each of these five steps represents many activities, in which there are major feedback loops and interconnections. The following discussion of the SNL PA approach will touch briefly on the following issues, which are subsets of the five steps listed above:

- General description of conceptual model and scenarios (Steps 1 and 2);
- Performance measure (Step 3);
- Modeling approach (Step 3);
- Uncertainty and sensitivity analyses (Step 4); and
- Probabilistic approach and CCDF (Step 5).

The SNL approach for addressing the requirements of 40 CFR191 Subpart B has been to develop most of the needed computer codes in house. However, the availability of documentation on these codes has lagged behind the reporting of the results of analyses in the annual performance assessment summaries. The lack of formal documentation can be problematic from a compliance standpoint because the codes will not be familiar to regulators, nor will they have undergone independent peer review. This lack of formal documentation may make it more difficult to demonstrate a reasonable expectation of compliance.

2.2.1 General Description of Scenarios

In order to demonstrate compliance with the performance requirements of 40 CFR 191, the DOE must consider the undisturbed performance and the possible events that may disrupt the repository system (§191.12(p)). Undisturbed performance refers to the behavior of the repository system assuming natural structural, hydrogeologic and chemical processes. The conceptual model for the WIPP repository system includes salt creep; brine inflow; gas generation from anoxic corrosion, microbial action, and radiolysis; brine and gas outflow into interbeds in the Salado Formation and also to the accessible aquifer (the Culebra Dolomite Member of the Rustler Formation) above the Salado Formation by way of backfilled and sealed shifts; and engineered barriers.

The WIPP Performance Assessment Department used a scenario selection and evaluation process similar to that described in Cranwell et al. (1982a and reissued in 1990), which systematically defines the events and processes that could affect the integrity of the repository system, evaluates the probability of an event occurring, and assesses its potential for leading to a release of radioactive constituents to the accessible environment. The methodology is described conceptually in **Figure 2-4**. The sample space S represents all possible 10,000-year time histories of the disposal system at the WIPP. The scenarios are screened on the basis of the likelihood of their occurrence and their potential consequence. Subset S_B contains all time histories that fall within the bounds of reasonably anticipated occurrences of natural processes (greater than 1 in 10,000 in 10,000 years) acting on the disposal system over 10,000 years, which represent undisturbed performance. Subsets S_M, S_L, and S_E are associated with disruptive events, such as volcanism. Subset S_M contains time histories that include disruptive events that may occur with probability greater than 1 in 10,000 in 10,000 years, but the consequences do not compromise repository performance. Subset S_L represents time histories that can be reasonably screened out of consideration because they include disruptive events that are of sufficiently low probability of occurrence (less than 1 in 10,000 in

10,000 years). Time histories that can be excluded by regulatory criteria are contained in subset S_E These three subsets are not mutually exclusive, and the shaded area represents the overlap. Finally, Subset S_O contains all of the time histories that include disruptive events that are left after the scenario screening process. The S_i in the cross-hatched area within S_O represents sets of parameters which give rise to specific time histories containing disruptive events that can significantly affect repository performance.

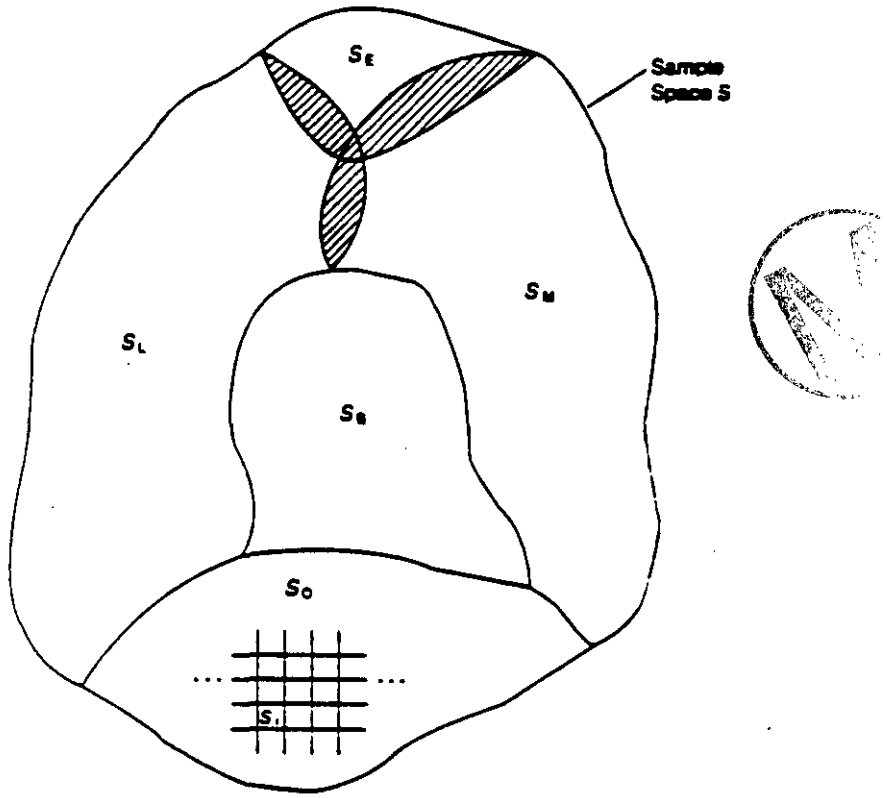

S_B = anticipated base case
S_M = disruptive events, little consequence
S_L = low probability events
S_E = excluded by regulatory criteria
S_O = remainder

Figure 2-4. Conceptual Description of the SNL Scenario Selection Process.

According to the methodology, subsets of the time histories that have to be analyzed by performance assessment are the ones that fall within subsets S_B, S_O, or S_M. In practice, the methodology is not followed rigorously, because it is not possible to enumerate and evaluate all possible time histories of all possible combinations of natural processes, subjected to all possible sequences of disruptive events that can significantly compromise repository performance. Guzowski (1990) amended the methodology to make use of earlier scenario analyses efforts to develop a set of scenarios for WIPP that is more practical to evaluate.

The amended scenario selection process screened some 49 natural and human-induced events and processes. Seven of the processes—erosion, sedimentation, climate change, seismic activity, Rustler-Salado contact dissolution, shaft and borehole seal degradation, excavation-induced fractures, and gas generation (WIPP PA 1992, Volume 2, Table 4.2)—are expected to occur over the 10,000 years. Therefore, these processes are considered non-disruptive and have been retained for the undisturbed case, Subset S_B, also called the base case.

For analysis purposes, the base case subset (S_B) and the subset containing disruptive events of no consequences (S_M) are considered to consist entirely of no-release scenarios over the 10,000-year simulation period. Subset S_L, containing events considered to be not credible by the WIPP performance assessment staff (e.g., tectonic activities) are excluded from consideration due to low probabilities. Since subset S_E is excluded based on regulatory considerations, only subset S_O remains to be considered for analysis. That is, only time histories resulting from parameter sets within S_O are assumed to result in any kind of release.

Within S_O, a set of mutually-exclusive scenarios was defined (starting with the base case) based on a logic-diagram type of analysis that developed sequences of disruptive events that could potentially lead to the escape of radionuclides from the repository and migration to the accessible environment. The mutually-exclusive scenarios resulting from this process are defined by their different model and code configuration requirements for the performance assessment analysis.

According to the scenario selection process described in Guzowski and Helton (1991), three possible types of events that may disrupt the repository stem from human intrusive activity; they are:

- potash mining in the WIPP vicinity and associated surface subsidence,
- one or more boreholes passing through a waste panel and penetrating a brine pocket, and
- one or more boreholes passing through a waste panel without penetrating a brine pocket.

The 1992 PA, Volume 1, lists seven scenarios representing all possible combinations of these three events and a base case, which corresponds to undisturbed performance, that are to be carried forward for the performance assessment.

2.2.2 Performance Measure

Most of the performance assessment effort to date has gone into assessing whether the WIPP repository performance will comply with the containment requirements of §191.13(a). Therefore, the measure that the performance assessments concentrate on is the normalized release of radionuclides to the accessible environment. The analyses used to assess this performance measure provide the necessary intermediate calculations to address the individual and groundwater protection performance measures of §191.15 and §191.16, respectively.

Part of the rationale given for not conducting analyses to address §191.15 and §191.16 is that, according to the results of the performance assessment modeling for the undisturbed or base case, there are no releases to the biosphere. However, since the modeling done to date assumes perfect seal performance, the conclusion that there are no releases to the biosphere in the undisturbed case is suspect. Performance assessments done to date do not specifically address individual and groundwater protection requirements.

2.2.3 Modeling Approach

The WIPP Performance Assessment Department developed an assessment logic and structure, shown in **Figure 2-5** (Figure 2-5 of Marietta et al., 1989) that describes the assumed physical and environmental processes and disruptive events that must be considered in order to address the

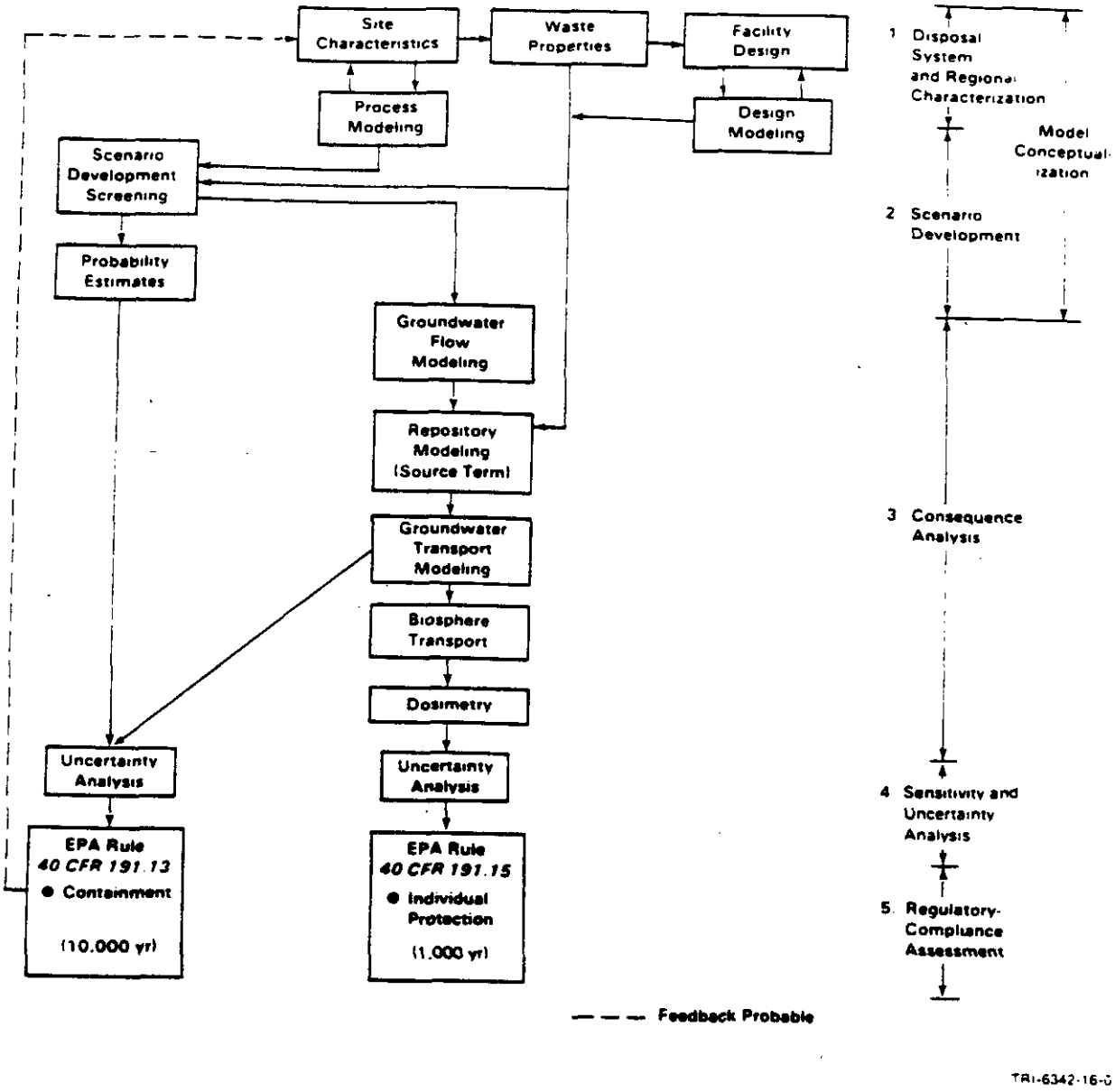

Figure 2-5. Compliance Assessment Methodology Structure (modified from Rechard, 1989).

compliance requirements of §191.13(a). The figure shows that, at the present time, the performance assessments are focused on the containment requirements (§191.13), and that the individual protection requirements (§191.15), which require biosphere transport and human dose modeling, are being deferred to a later time. The figure also shows the iterative nature of the PA process; however, discussions with principal investigators suggest that the feedback is not as extensive as implied by the figure. This is discussed in more detail in Section 8.

The execution of even a single PA analysis for a single scenario requires the assimilation of qualitative and quantitative information and the sequential calculation of many different interim quantities. The WIPP Performance Assessment Department has developed a computer system to manage the flow of information throughout the PA and to provide a structure to maintain quality assurance records. An overview schematic diagram that shows the sequence of calculations and the flow of information through a PA analysis is provided in **Figure 2-6** (Figure 2-8 in Marietta et al., 1989). This figure shows the complexity of the information needs and calculations required to demonstrate compliance with §191.13.

The modules that are used by the PA systems include finite element, finite difference and analytical model codes. The models used in the 1992 PA analyses and their functions are listed in **Table 2-1**. The constitutive relationships and input parameter requirements of these models for simulating the described processes is discussed in the other sections. **Figure 2-7** (Figure 1-1, Volume 2, of the 1992 PA analyses) shows the flow of information among the models described in the 1992 PA analyses. Not all of the system is automated since GRASP-INV, SANCHO, and CUTTINGS are run outside the CAMCON system, and manual data transfers are used for the analyses.

Table 2-1. Computer Codes Used in the 1992 WIPP Performance Assessment (after Table 3-1 in Volume 2 of 1992 PA)

CODES	FUNCTION
BRAGFLO	Multiphase flow of gas and brine through porous heterogeneous reservoir
CCDFPERM	Probabilities for human intrusion drilling
CUTTINGS	Quantity of radioactive material brought to surface in cuttings and cavings generated by drilling
GRASP-INV	Simulation of transmissivity fields calibrated from measurements and pressure fields
PANEL	Rate of, and cumulative discharge of radionuclides from repository panel through an intrusion borehole
SANCHO	Porosity of waste as function of time and moles of gas generated
SECO2D	Single-phase Darcy flow for ground water in two dimensions
SECOTP	Fluid flow and transport of radionuclides in fractured porous media

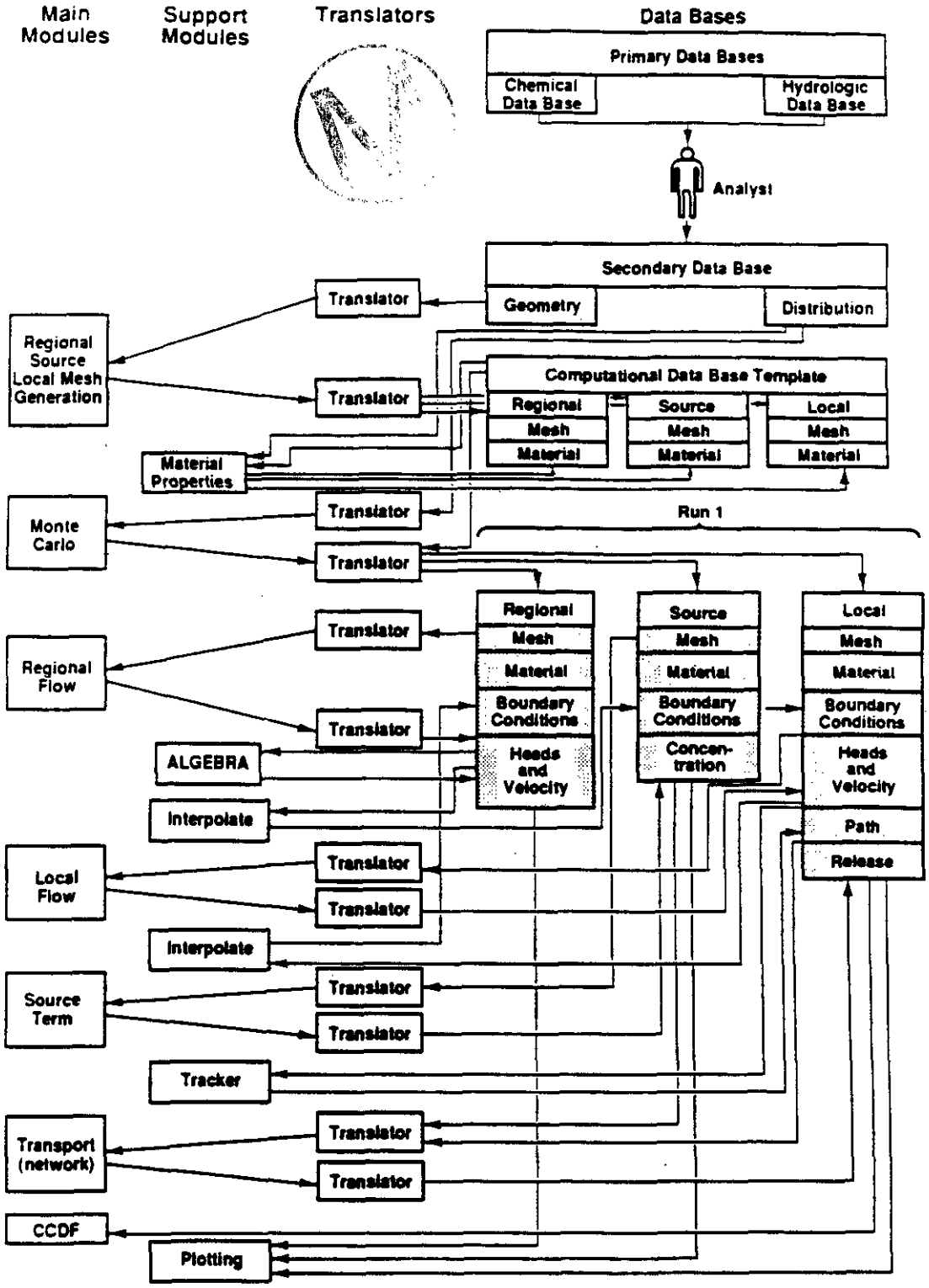

Figure 2-6. Algorithm for Logical Data Flow During Compliance Assessment (Rechard, 1989).

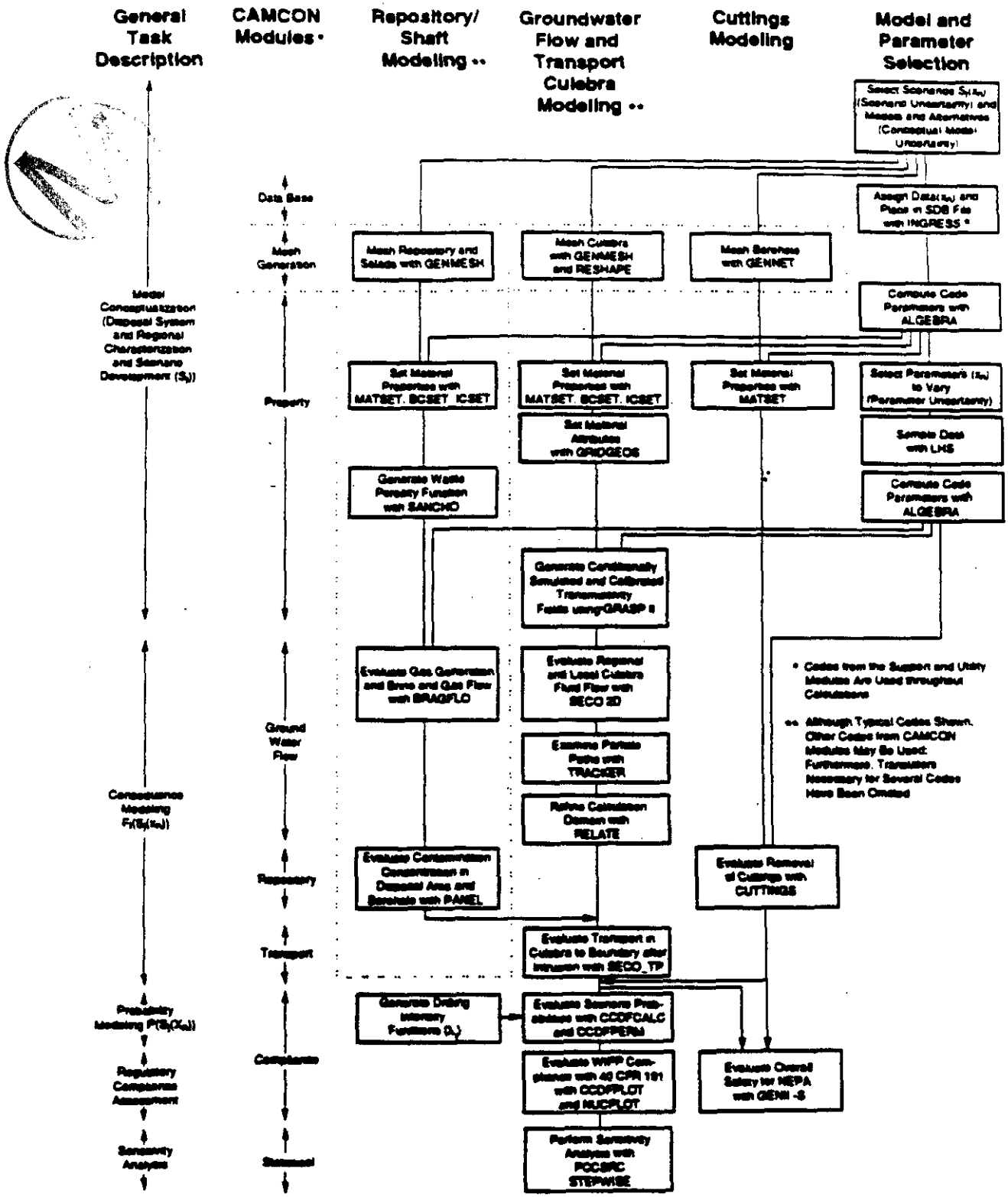

Figure 2-7. 1992 Organization of Programs in CAMCON (after Rechard, 1992).

2.2.4 Sensitivity and Uncertainty Analyses

The probabilistic nature of the containment performance standard detailed in §191.13 requires that a quantitative estimate be made of the uncertainty in the value of the performance measure in order to assess the probability of exceeding the standard. Because of the complexity of the models, the sequential nature of the calculation and the number of input parameters involved, error propagation methods of estimating uncertainty are not appropriate. The uncertainty analysis approach used by the WIPP Performance Assessment Department is Monte Carlo simulation (Marietta et al., 1989).

In a Monte Carlo simulation, the values of the input parameters are assumed to be uncertain. These parameters are therefore represented using probability distributions which are sampled to produce an empirical probability distribution (and a CCDF) of the values of the output performance measure. The Monte Carlo approach to uncertainty analysis, although it directly leads to the desired CCDF, can be computationally intensive if the number of input parameters is large and the models are complex. This is certainly the case for the SNL performance assessments, despite the fact that the PA models are somewhat simplified. McKay et al., (1979) and Iman and Conover (1982) developed a statistical sampling scheme for Monte Carlo simulations, called Latin Hypercube Sampling, that reduces the number of model runs but still achieves high precision in the estimate of the CCDF. The WIPP Performance Assessment Department is using this methodology.

The timing of an intrusive event has a large impact on the potential for radioactive material being released into the environment, and the importance of timing has a large impact on the computational resources of the WIPP Performance Assessment Department. The probability of a drilling event is estimated by the Poisson model (WIPP Performance Assessment Department, 1992, Volume 2). However, because of the computational demands of coupling random drilling with the parameter uncertainty discussed in the previous section, simplifying assumptions, in terms of fixed times for drilling at 1,000, 3,000, 5,000, 7,000, and 9,000 years, were made for the 1991 PA calculations. The 1992 calculations assumed drilling intrusions take place at 125, 175, 250, 1,000, 3,000, and 7,250 years.

The side benefit of a Monte Carlo uncertainty analysis is that it provides a set of input parameters and their associated performance measure values that allows further analyses, such as statistical sensitivity analyses (Helton et al., 1991) to determine which parameters are the most important in determining the value of the performance measure. Sensitivity analyses help focus scientific and site investigations by providing information that will ultimately be used for the performance assessments.

The primary focus of the SNL sensitivity and uncertainty analyses to date has been on the parameters within the models. However, this approach cannot adequately deal with uncertainties in the choice of the conceptual models of the physical processes that affect repository performance. The issues related to the choice of the constitutive relationships that are embodied in a performance assessment code are often more important in determining the adequacy of the performance assessment than the effects of parameter uncertainty. That information can be obtained by comparing results of the principal investigators' constitutive models with those of the performance assessment models. This is particularly important, since the performance assessment models tend to

be chosen for computational efficiency for the Monte Carlo computing environment. More formal sensitivity studies that compare the results of the constitutive and performance assessment models will help to establish the appropriateness and adequacy of the PA models.

2.2.5 Probabilistic Approach and the CCDF

The probabilistic requirements of the §191.13 standard are partially met by the Monte Carlo uncertainty analysis methods described in the previous section; a CCDF can be computed easily from the results of a Monte Carlo analysis. The Monte Carlo methods work well when dealing with the parameter uncertainty within a specific scenario. However, the need to evaluate the results of multiple scenarios, such as disruptive events, and combine them into a single CCDF requires estimates of the probabilities of occurrence of the scenarios. **Figure 2-8** illustrates how the consequences (cS_i) of the individual scenarios S_i are combined into the overall CCDF using the weighting factors pS_i, which are the probability of occurrence of the scenarios.

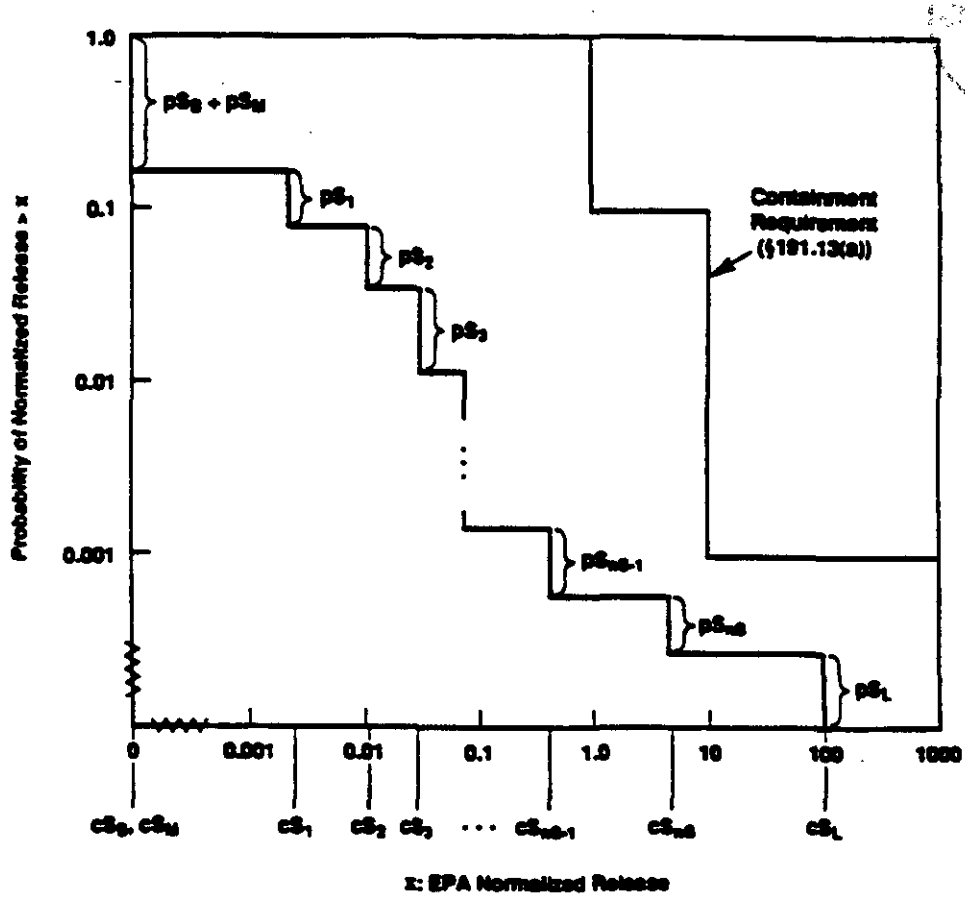

Figure 2-8. **Construction of a CCDF for Comparison with the EPA Release Limits. (Note that the location of cS_B at the lower left of the plot is correct for the WIPP–where no releases are predicted from the undisturbed base case–but is not a generic requirement for all sites.**

As discussed previously, Monte Carlo techniques are used to characterize the uncertainty in the results by repeatedly sampling the uncertain parameters. Such an analysis produces a family of CCDFs. The variability within the family of CCDFs obtained from the sampling can be represented by the mean, median, and 10% and 90% quantile CCDFs in **Figure 2-9**.

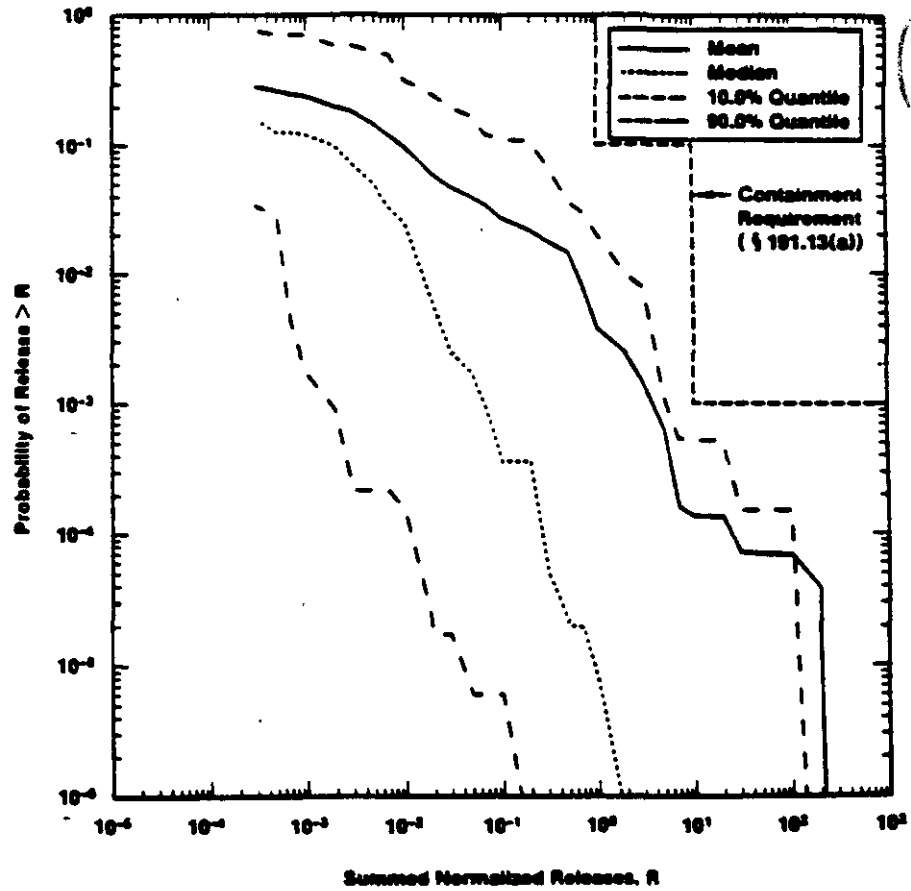

Figure 2-9. Example Summary Curves Derived from an Estimated Distribution of CCDFs. Curves were obtained by calculating the mean and indicated percentiles for each consequence value (PA, 1992, 2, Figure 3-3).

The SNL PA department (1992 PA, Volume 2) recognizes that the CCDFs cannot describe conceptual model uncertainty because, by their construction, they are conditional on the assumptions of the analysis. To evaluate conceptual model uncertainty, the complete Monte Carlo analysis is repeated for alternative conceptual models by changing only those portions of the analysis specific to the alternative models. The shift in the location of the CCDF relative to the others gives an indication of the uncertainty introduced by alternative conceptual models; it is also an indication of the sensitivity of the conceptual model itself in terms of affecting disposal system performance.

Although these conceptual model sensitivity and uncertainty analyses provide valuable information, they cannot address differences in the conceptual model that cannot be described by the existing PA models. These analyses may not necessarily adequately address the different conceptual models represented by the more detailed constitutive models of the principal investigators as discussed in the previous section.

2.3 40 CFR PART 268.6

The long-term performance requirements of 40 CFR 268.6 are not as detailed or prescriptive from a methodological standpoint as those of 40 CFR 191. The regulation requires demonstration "to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit . . . for as long as the wastes remain hazardous" (40 CFR 268.6(a), U.S. EPA, 1986).

The EPA's draft guidance manual for 40 CFR 268.6 describes general requirements for what must be addressed in a no-migration determination petition. Examples of the requirements are that the relevant physical processes must be addressed, some type of quantitative modeling is desirable, and formal quality assurance/quality control measures must be applied to the computer codes. Specific technical details are to be worked out in negotiations with the EPA.

2.4 WESTINGHOUSE APPROACH TO 40 CFR PART 268.6

The basis of the PART's review of the Westinghouse approach to compliance with 40 CFR Part 268.6 was a presentation by Westinghouse Waste Isolation Division staff and their contractors. To facilitate comparison of the SNL and WID approaches to performance assessment, the outline of the discussion follows the same format as used in Subsection 2.2.

In contrast to the SNL approach to PA modeling, which uses code for which published documentation is not publicly available, the WID PA approach uses numerical models that are relatively simple to use and preferably "off the shelf," so that they can be easily transferred to EPA for execution and evaluation.

2.4.1 General Description of Scenarios

The 40 CFR Part 268.6 regulations do not specifically require that human intrusion be addressed to demonstrate long-term performance. As implied by the presentation by WID and its contractor staff, the scenarios that are being addressed pertain to expected repository conditions and are based on the description of the model selection phase. It has been stated in the two No-Migration Determination Annual Reports (DOE/WIPP 91-059 and DOE/WIPP 92-057) and in the presentation that the WID PA conceptual model is consistent with the SNL PA conceptual model for 40 CFR Part 191 Subpart B. In fact, the results for PA that are reported in these two documents are those reported in the annual performance assessments for 40 CFR 191, although they are results for radionuclides, and 40 CFR 268.6 pertains to hazardous constituents.

2.4.2 Performance Measure

The performance measure is not defined specifically in the regulations as it is for the containment requirements in §191.13 and the individual and groundwater protection in §191.15, and §191.16, respectively. Under 40 CFR 268.6 there is only what might be construed as an overall system performance requirement — i.e., no migration beyond the disposal unit boundary for as long as the wastes remain hazardous (Subsection 1.3.1).

2.4.3 Modeling Approach

The WID modeling approach is divided into near- and far-field categories. The near-field model requires a site-specific description of the repository engineered barrier system in order to assess the ability of the system to prevent the transport of hazardous components (i.e., volatile organic compounds, non-volatile organics and heavy metals) in the waste to the unit boundary. The Design Analysis Model (DAM), which was used to analyze the options for waste treatment for the Engineered Alternatives Study (DOE/WIPP 91-007), is proposed for this analysis. The PA models used by SNL for comparison with 40 CFR 191 Subpart B requirements do not describe the performance of the engineered barrier of candidate room, panel and shaft seals.

The WID approach to PA accepts the physical processes that the SNL Performance Assessment Department has determined to be important for far-field performance. The WID model selection process focuses on deterministic models that are considered readily available. Using criteria that had to do with availability of documentation and published verification exercises, WID selected the TOUGH2 code. The desired capabilities for the WID far-field model are given in **Table 2-2**.

Table 2-2. Desired Capability for WID Far-Field Performance Assessment Modeling

Two-phase flow	Thermal effects
Multi-phase, multi-component transport	Transport processes
	Advection
Transient effects	Dispersion
High dimensionality	Diffusion
Material properties	Chemical interactions
Anisotropy	Sorption
Heterogeneity	Decay
	Dissolution/precipitation
	Ion Exchange
	Leaching

2.4.4 Sensitivity and Uncertainty Analyses

WID has chosen to utilize the same methodology for sensitivity and uncertainty analyses that are used by the Sandia Performance Assessment Department for 40 CFR Part 191 Subpart B. This includes a Monte Carlo approach to a deterministic model, using Latin Hypercube Sampling of the model input, and rank correlation techniques to induce known dependencies among the input

variables. The current plans are to do uncertainty and sensitivity analyses separately for the DAM and TOUGH2 models. No analyses have been completed to date.

2.4.5 Probabilistic Approach and the CCDF

The language of 40 CFR Part 268.6 does not specify a probabilistic approach to demonstrating compliance. From a regulatory standpoint, it is not required in the performance assessment methodology to include the calculation of the CCDF driven by §191.13(a). Demonstrating compliance with a deterministic standard and addressing uncertainty by means of quantitative and qualitative analyses may be easier than using a probabilistic standard. From a methodological standpoint, estimating small exceedance probabilities, such as those used in the §191.13(a) standard, requires estimating the size of the tails of a CDF. Estimates of the tails are subject to more uncertainty than estimates of the mean or median of a CDF.

3.0 WIPP CONCEPTUAL MODELS AND IDENTIFICATION OF ISSUES

In the preceding section, the Sandia National Laboratory (SNL), Westinghouse, and PART approaches to performance assessment methodology were discussed. Constructing the total system PAs of the WIPP repository involves developing appropriate conceptual model(s) of the WIPP site and disposal system, both for now and for future time periods (10,000 years). This is extremely important to system PA and the planning of data acquisition as well as to laboratory and field scale experimental programs (as described in Subsection 3.1). Section 3 describes two types of conceptual models: Pre-WIPP Facility Conceptual Models and Post-Decommissioning Conceptual Models. The Pre-WIPP Conceptual Models are discussed in Subsection 3.2 in terms of the pathways that existed before construction of the WIPP facility from the proposed location of the waste panels to the compliance boundaries, and in terms of significant driving forces and processes that govern the movement of fluids or the transport of dissolved chemical species contained in these fluids. Subsection 3.3 addresses Post-Decommissioning Conceptual Models at an outline level, and describes the pathways, driving forces, and processes that could be expected to result through time from interactions between the components of the natural system, the waste, and any of the engineered emplacements or components of the disposal system.

3.1 BASIC WIPP DISPOSAL SYSTEM CONCEPTS AND HIGH LEVEL ISSUES

The basic WIPP disposal concept is rooted in the promising features of salt deposits identified by NAS in the early 1950s (see Subsection 2.2). The WIPP site is part of a vast Permian age salt deposit located in a relatively stable geological area with little earthquake activity (**Figures 3-1** and **3-2**). Waste emplaced in the mined rooms of the disposal panels (**Figure 3-3**) will eventually be encapsulated and become part of the stable rock of the Salado Formation, as a result of the natural "plastic-like" quality of salt that enables it to flow or creep under the effects of heat and stress found at the 655 m (2,150 ft) proposed repository depth. Isolation of the radioactive waste from the accessible environment and retention of the hazardous waste within the boundaries of the disposal unit for the required regulatory periods is expected because of the waste encapsulation, the virtually impervious nature of the undisturbed Salado Formation salt deposits at repository depths (permeabilities near 10^{-22} m^2), and the absence of flowing groundwaters within the formation for the transport of any leached wastes. The various issues that must be addressed are a result of trying to provide a credible basis for the different assumptions in this basic design concept; (e.g., could gas generation prevent encapsulation and sealing of the wastes in the rooms and seals? or are there natural processes such as dissolution or breccia pipes that could breach the Salado?). The great difficulties are mainly associated with the various uncertainties that arise because of the long time frames for which repository performance must be demonstrated.

3.1.1 High Level Regulatory Related Issues

The highest level regulatory issue is related to the differences in approach between the regulations applicable to the hazardous wastes and the regulations applicable to the radioactive wastes as summarized below.

- Disposal of radioactive wastes under 40 CFR 191, recognizing the uncertainties in predicting behavior over the long time periods that radioactive wastes remain hazardous, is based on the concept of a waste isolation system within a 5 km (3 mi) controlled zone (**Figure 3-4**). This

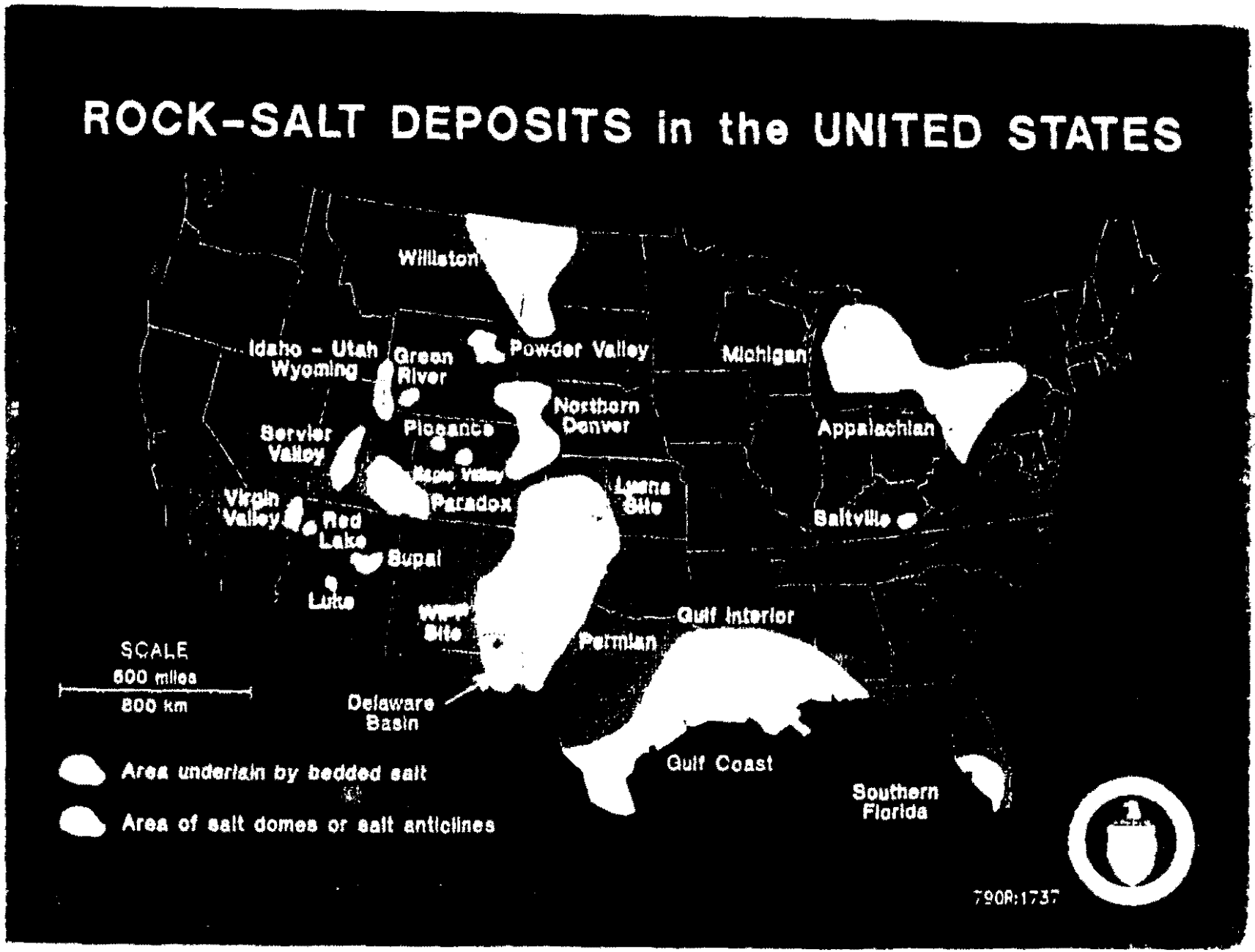

Figure 3-1. Location of Various Rock-Salt Deposits in the United States.

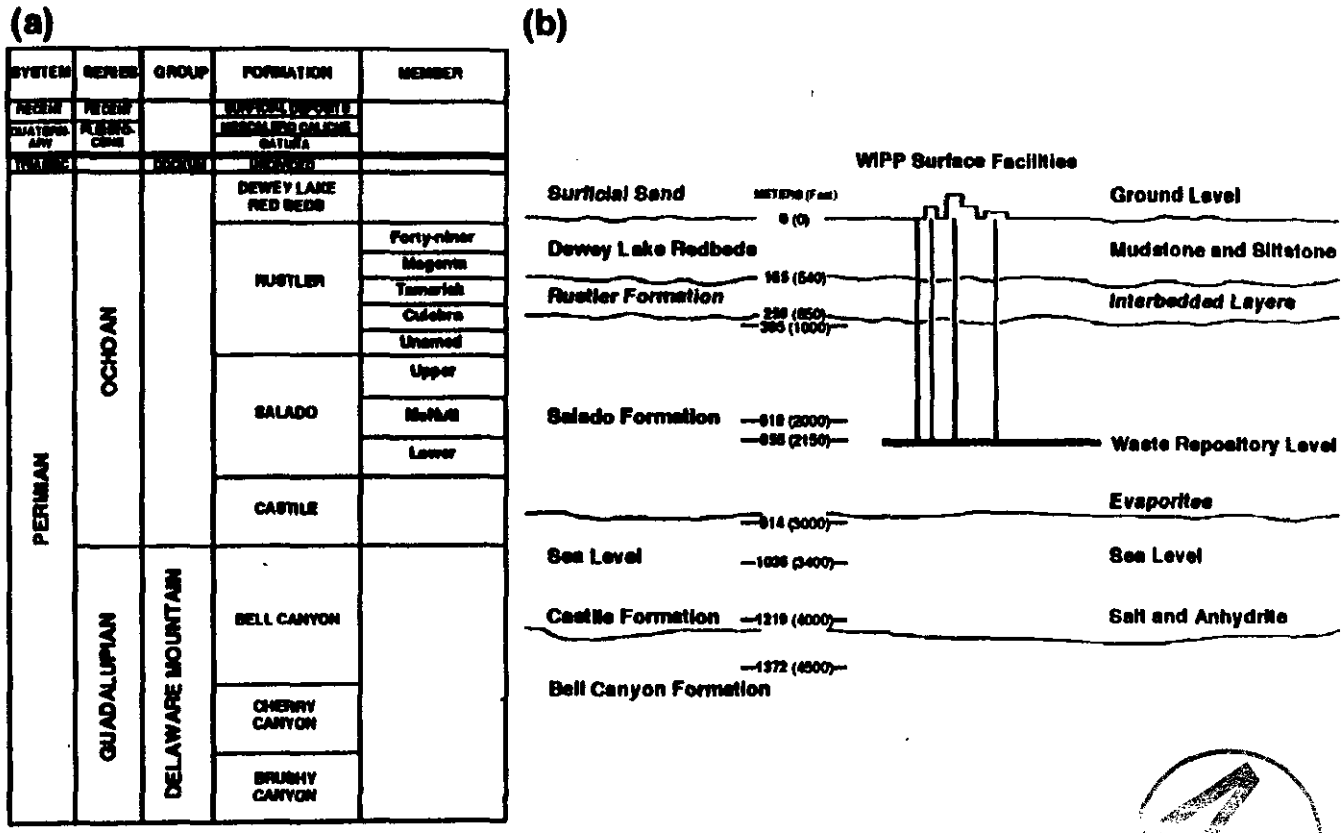

Figure 3-2. (a) WIPP-Area Stratigraphic Column and (b) the Geologic Profile at WIPP Illustrating the Location of the WIPP Underground Workings in the Profile.

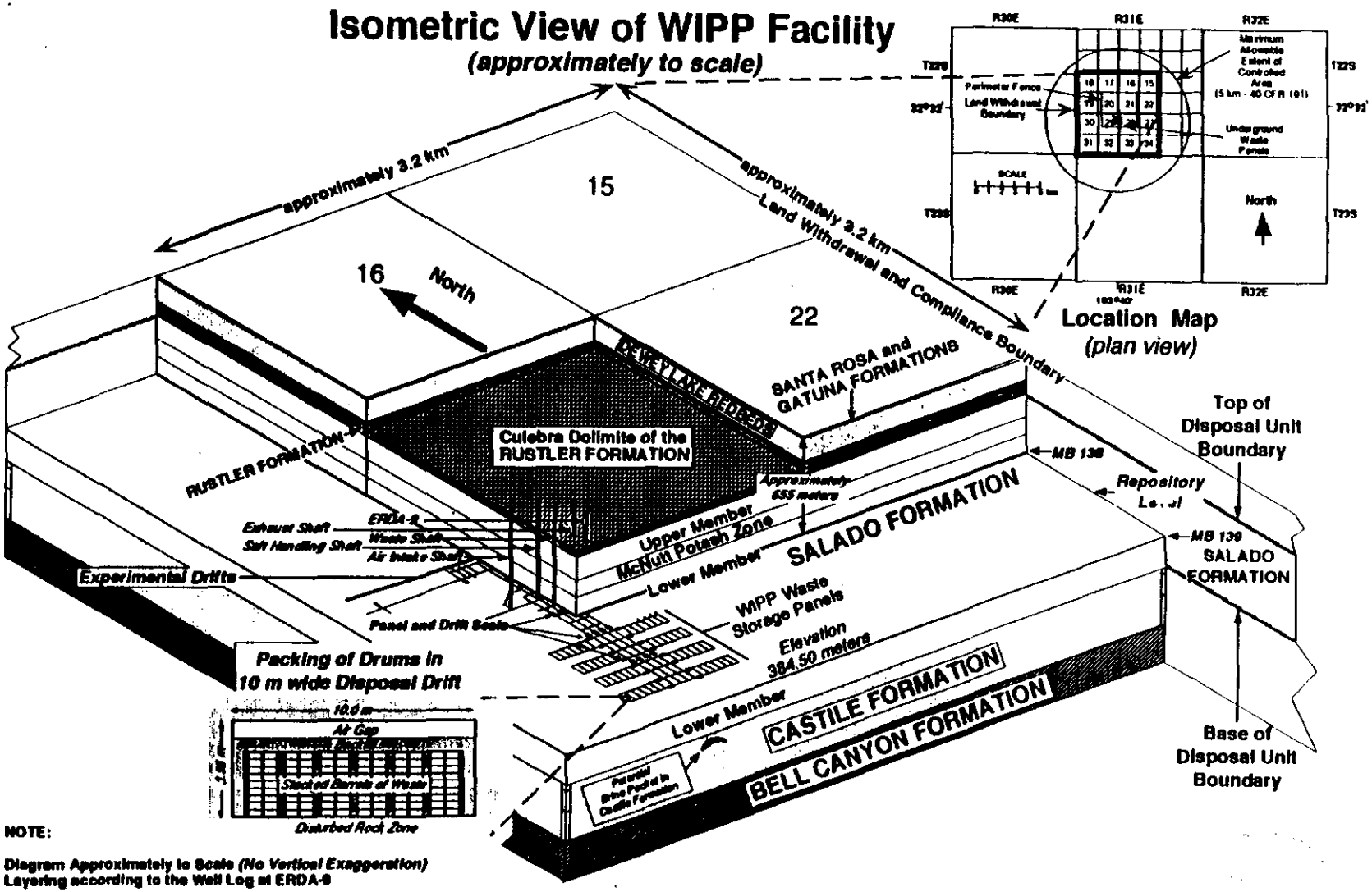

...ded Three-Dimensional Cutaway View of the WIPP SITE (approximately to scale
... Underground. Access Shafts, Location of
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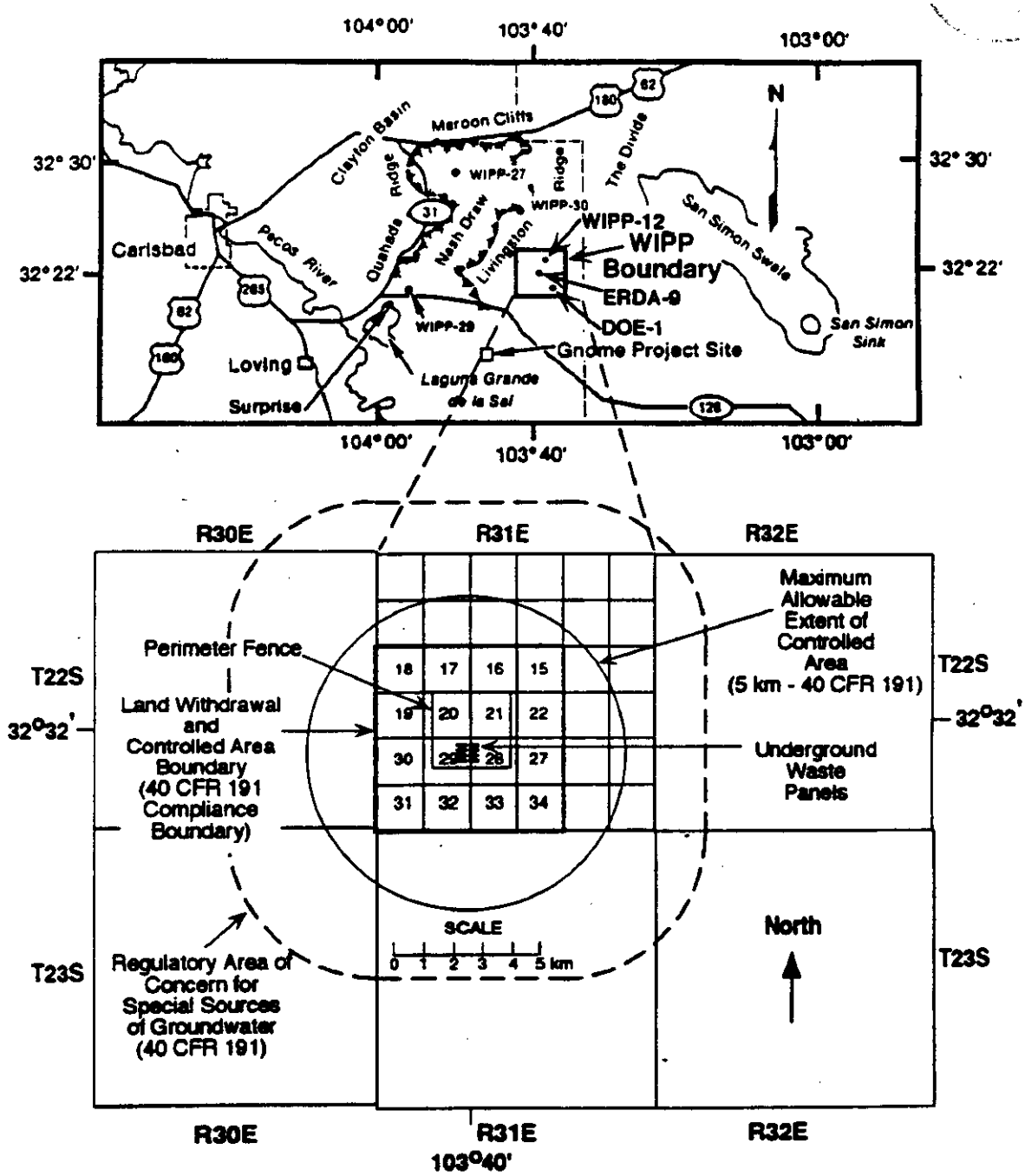

Figure 3-4. **Plan View Location Map Showing the Perimeter Fence, Land Withdrawal Boundary, Maximum Allowable Extent of the Controlled Area, and Compliance Boundary (coincident with the land withdrawal boundary) for the WIPP Site Relative to the WIPP Underground Workings.**

zone defines the boundary of the isolation system, which consists of multiple natural and engineered barriers (including the waste itself) to control, minimize, or eliminate waste release and account for these uncertainties through the redundancy of multiple independent barriers (Subsections 1.3.2 and 1.3.3).

- Disposal of hazardous wastes under 40 CFR 268 requires having detailed knowledge of the waste form so that appropriate treatment can be prescribed for assurance of disposal safety (Subsection 1.3.2). Co-disposal of untreated hazardous wastes that are radioactive or contaminated with radioactivity, as proposed by the DOE, is through the exemption provision (40 CFR 268.6) that requires a demonstration of no migration beyond the disposal unit or injection zone (Subsection 1.3.2).

Some of the difficulties created by these differences have already been resolved, but others remain.

For 40 CFR 191, the disposal system design must be shown to meet three numerical requirements: isolation, individual protection, and groundwater protection. The repository design is also constrained through the assurance requirement to use multiple natural and engineered barriers (which can include the waste itself) within a controlled volume excluded from the accessible environment, to incorporate recoverability, to provide for monitoring, to use active and passive institutional controls, and to evaluate adverse factors related to site selection.

Under 40 CFR 268, any design requirements are actually for the waste form itself, which must meet very specific treatment requirements based on careful characterization of the waste. There is also no specified concept of a disposal system with design requirements and constraints embodied in 40 CFR 268 as there is in 40 CFR 191. DOE expects to petition for an exemption to allow the land disposal of untreated, prohibited, hazardous wastes through preparation of a demonstration of no migration, as provided for under 40 CFR 268.6. Under 40 CFR 268.6, there is only what might be construed as an overall system performance requirement - i.e., no migration beyond the disposal unit boundary for as long as the wastes remain hazardous (Subsection 2.3.2). Issues have been raised regarding what is meant by the following phrases from 40 CFR 268.6 with respect to the WIPP. These have been resolved as follows.

- *"No-migration."* Resolution - above health-based limits (55 FR 220, pg. 47704). The issue is whether the possible movement of even one molecule outside the disposal unit boundary, or the taking of one reading above a detection limit, constitutes a violation of no-migration. The resolution of the issue is to adopt a position that no-migration requires that the measured or predicted concentration at or beyond the disposal unit boundary be below health-based concentration limits.
- *"Disposal unit boundary."* Resolution - top and bottom of the Salado Formation and laterally where the vertical extension of the land withdrawal boundary intersects with the Salado Formation (Figure 2.11, 55 FR 220 pg. 47704).
- *"As long as the waste remains hazardous."* Resolution - 10,000 years "No migration variances to the hazardous waste land disposal prohibitions: A Guidance Manual for Petitioners." draft July 1992, U.S. EPA, Office of Solid Waste, Washington, D.C.

A potential issue that arises related to "no migration," now being defined as dependent on health-based release limits, is that the treatment and/or removal of hazardous wastes from any part of the proposed waste streams could reduce the quantity of hazardous waste potentially available for release, and thus reduce migration.

3.1.2 WIPP Design Objectives/Constraints

The two disposal system concepts of 40 CFR 191 and 40 CFR 268, with their different design objectives/constraints, can be viewed as a single waste disposal system concept, in which the disposal system, the basic design requirements, and constraints for the full disposal system are as defined for 40 CFR 191. However, the requirements of 40 CFR 268.6 impose an additional performance objective for the disposal unit component of the 40 CFR 191 disposal system (i.e., for the Salado Formation and all components of the disposal system within it). This additional requirement is that there be no migration of hazardous wastes above health-based limits beyond the disposal unit boundary (Figure 3-3) for the next 10,000 years.

3.1.3 WIPP Compliance and Other Boundaries

The regulations define the maximum extent limits for a controlled area (Subsections 2.3.1.4 and Figure 3-4) that can be identified by passive institutional controls in order to define the lateral limits of the controlled volume of the subsurface that is excluded from the accessible environment. This boundary between the controlled zone of the subsurface (i.e. the geologic disposal system) and the accessible environment forms the compliance boundary. The LWA established the subsurface below the 4-mile-by-4 mile land withdrawal boundary (i.e., subsurface below Sections 16-22 and Sections 27-34 R31E, T22S) as the controlled volume whose outer boundary forms the compliance boundary for 40 CFR 191, as discussed in Subsection 1.3.3. The dashed line around the land withdrawal boundary in Figure 3-4 illustrates the regulatory area of concern for special sources of groundwater.

3.2 CONCEPTUAL MODEL, THE ASSUMPTIONS AND ISSUES

The information discussed in this subsection is needed to develop the various issues that the PART review team has identified and considered in evaluating the adequacy of WIPP PA, measurement, and experimental activities, as well as the decision making process that relates to these activities.

Constructing the total system PAs of the WIPP repository involves developing appropriate conceptual model(s) of the WIPP site and disposal system (Subsection 3.2.2) both for now and for future time periods (at least 10, 000 years). The conceptual model(s) must describe

- the current state of the WIPP site;
- the various projected likely, as well as unlikely, future states of the WIPP site and disposal system components, so that estimates of the disposal system performance (i.e., projected release and movement of both hazardous and radioactive waste beyond 40 CFR 191 compliance and 40 CFR 268 disposal unit boundaries) can be made for various plausible future scenarios or states that could result from the disposal system emplacement as a result of interactions between the wastes and other components of the disposal system;
- plausible and likely natural processes and events; and
- human intrusion events of severity no greater than mandated by the regulations (Subsections 2.3 and 3.1).

Conceptual modeling is extremely important to system PA and the planning of data acquisition, as well as to laboratory and field scale experimental programs. The need for subjective judgments in the

development of conceptual models arises as a result of the uncertainty associated with geologic systems, due to their complexity and variability, and the limited number of observations in both space and time. Plausible alternative conceptual models, based on available information and understanding and of appropriate complexity to address the objectives of the effort, must be established. Only then can appropriate system response and parameter measurements be identified, with the correct spatial and temporal frequencies to reveal the true nature of the system being observed.

A conceptual model, no matter how technically complex, will always be a simplified picture of the real system. Current understanding, data-gathering capabilities, and computer technology simply do not allow a geologic disposal system to be described in every detail. Conceptual model development, therefore, involves forming a sufficiently representative simplified picture of those aspects of the system which are important in demonstrating compliance (Subsection 3.1). Development of plausible conceptual models requires identification of (1) the relevant and interacting processes that control the important attributes of disposal system behavior; (2) appropriate ways to parameterize the system, and (3) the appropriate way to extrapolate knowledge of these processes, measurements, and observation into the spatial and sometimes temporal distributions of parameters and response that are required to model the current and future likely states of the system. Various technical issues considered and addressed, the decisions, the supporting reasoning, and the parameters and observations used to form this sufficiently representative simplified picture (i.e., the conceptual model) must be clearly identified and documented (Subsection 3.1.2). Technical issues are simply questions about what constitutes the best way to describe the system to be modeled in terms of relevant pathways, processes, parameterization, and numerical models. The issues stem from limitations in current physical and chemical understanding, data gathering capabilities, and computer modeling capabilities. In many cases, these technical issues cannot be absolutely resolved.

3.2.1 High Level Description of the WIPP Disposal System Conceptual Models

This subsection contains a high level discussion limited to identifying the major issues and assumptions that must be resolved and justified to provide the required support for the various conceptual models that form the basis of both the mathematical and the numerical models used for compliance analyses (Subsection 3.1). Clear identification and documentation of these important conceptual model issues and assumptions and the way they were resolved and justified (including the laboratory and field measurements and other experimental evidence, expert panel findings, or numerical studies) are key to attaining a reasonable expectation (or degree of certainty) with regard to the results from these compliance models (substeps 2.1.3, 2.1.4, 2.2.5.1 and 2.2.5.3 of Subsection 1.4.3.1).

Compliance analysis models, for the various compliance time frames of interest (Subsections 1.3.1 and 1.3.3), must be able to predict short- and long-term behavior as a result of the changing states of the various components of the WIPP disposal system (e.g., the rooms, drifts, various panel, shaft, and drift seals discussed in Subsection 3.2.2), as well as the integrated behavior of the overall WIPP disposal system in response to both natural processes and events and human intrusion events of limited severity, as specified in the regulations (Subsections 3.1, 1.3.2, and 1.3.3). Expressing this in terms of Kaplan and Garrick's (1981) risk triplet, which is the basis of the WIPP PA methodology and which is discussed in the 1992 WIPP PA (SAND92-0700/1), these compliance models must predict, "the consequences of these

things (scenarios) happening" as a result of "What can happen? (scenarios)," and these various possible consequences can be weighted by "how likely are things to happen? (probabilities of scenarios)."

While, as discussed by Guzowski (SAND89-7149, 1990), the term "scenario" is not defined and does not appear in the actual regulations (and only once in Appendix B of 40 CFR 191), scenarios are commonly taken to be those combinations of continuous processes (e.g., long-term slowly acting agents such as dissolutioning and climate change) and events (e.g., short time frame changes such as emplacement of the WIPP repository, human intrusion through exploratory drilling, or faulting in response to an earthquake) that result in a significant change in the state of the disposal system or its components. Therefore, the consideration of the following kinds of changes in important conceptual model factors is required:

- emergence of new or previously ignorable pathways or interconnections of previously isolated components, or cessation of existing pathways or interconnections;
- emergence of new or previously ignorable driving forces, significant changes in their values, or their cessation;
- emergence of new or previously ignorable mechanisms, or their cessation;
- significant changes in parameter values, the applicable parameters, and/or the spatial and/or temporal scales of the parameters;
- changes to other important conceptual model factors.

As a result, conceptual modeling cannot be carried out in isolation from the scenario analysis (which identifies these states and their likelihood) and vice versa. This is because the conceptual models must reflect these various scenarios (i.e., system states) and the scenario analysis must reflect any subsequent change in system state that might result from the long-term effects of the pathways, processes, and interactions identified through the conceptual modeling (e.g., development of a new pathway related to dissolutioning, fracturing due to gas pressure build-up).

In some sense, the separate steps of scenario analysis and conceptual modeling are more related to a limitation in current system modeling capability. Most of the component models used in the disposal system model assume fixed states for fixed spatial and time scales and for a fixed set of processes. Therefore, they cannot easily deal with temporal changes in model geometry, model scale, parameters, model processes considered, and other factors required for stochastically modeling the likely pathways through future disposal system state space as a result of the associated uncertainties in disposal system characterization and understanding. To overcome these difficulties, there is a need to identify these likely discrete disposal system state sequences, so that time can be divided into the appropriate periods and the appropriate fixed state models can be selected, interconnected and applied to determine consequence. To develop the overall disposal system conceptual and PA model, as well as the various disposal system component conceptual and PA models, approaches (SAND92-0700/2, 1992; SAND91-0893/1, 1991; SAND89-7149, 1990; and Cranwell et al., SAND80-1429, 1990) are required for selecting and screening these sequences of future disposal system states and for determining the probability of occurrence of each sequence. During the PART discussions with EEG, an issue arose regarding scenarios which really applies to many aspects of the PA process. Are the scenario selection and the scenario implementation processes ever revisited? Of concern to the EEG group was the implementation of the cuttings scenario.

Perhaps a formal documented method for dealing with issue identification and resolution would provide the means to deal with these types of concerns.

3.2.2 Components of the WIPP Disposal System

The WIPP disposal system is composed of both natural and engineered components.

1) The natural barriers within the compliance boundary (or non-accessible environment, as described in Subsection 2.1.3.3) include the following primary and secondary natural barriers.
   a) The Salado Formation forms the primary natural barrier. It consists of that portion of the Salado Formation within the limits of the land withdrawal boundary (Figure 2.13). This primary barrier is also classified as the disposal unit under 40 CFR 268.6.
   b) The geological formations above the Salado Formation and below the land surface within the limits of the land withdrawal boundary (i.e., Rustler, Dewey Lake Redbeds, and others shown in Figure 3-2) form one group of secondary natural barriers, should pathways and the necessary driving forces develop that connect the waste storage panels in the Salado to these units and the accessible environment beyond the compliance boundary.
   c) The various geological formations below the Salado Formation within the limits of the land withdrawal boundary (i.e., Castile, Bell Canyon, Cherry Canyon, and others as shown in Figure 3-2) form an additional group of secondary natural barriers between the waste storage panels in the Salado and the accessible environment beyond the compliance boundary, should pathways and the necessary driving forces develop.
2) The current reference design for the repository and the various engineered components was developed by Bechtel in 1986 (SAND92-0700-3). The attributes of this reference design and the associated engineered barriers are described below.
   a) The waste itself (Figures 1-2 and 1-3) and the waste containers can be considered engineered components if their properties are such that non-negligible credit can be taken for their ability to control, minimize, or eliminate release of hazardous or radioactive components that they contain.
   b) The ten equivalent waste storage panels of the reference repository design, shown in plan view in Figure 3-5, provide for the disposal of the projected 6.2 million cubic feet of TRU waste (97% CH-TRU, 3% RH-TRU) (Subsection 1.2.1). Waste is to be stacked in drums (three high) or standard waste boxes (SWBs) (Figure 3-5) in the 10.0-m-wide-by-3.96-m-high (33-ft-wide-by-13-ft-high) waste disposal rooms, as illustrated in the blowup of Figure 3-3 and then each of the rooms and drifts are to be backfilled with tamped salt (60% theoretical density), leaving a 0.71 m (2.3 ft) air gap. The design capacity of each waste room is 6,804 drums or their equivalent in SWBs. It should be noted, however, that there is some uncertainty regarding the actual capacity, since final plans for the stacking of SWBs are uncertain (SAND92-0700-3).
   c) The 847 horizontal RH canister holes in each waste panel are to be 4.6 m (15 ft) deep and emplaced 2.4 m (8 ft) apart along the walls of the disposal rooms of the disposal panels, as illustrated in the blowup portion of Figure 3-5. This provides storage for the other 3% of the waste that is expected to be of higher activity and classified as RH-TRU waste (Subsection 1.2.1). It should be noted that there is some uncertainty regarding the actual capacity provided by the current design, since the proposed spacing provides for only 6000 m^3 of RH-TRU waste per panel, while intended reference design capacity is 7,080 m^3 (SAND92-0700-3).

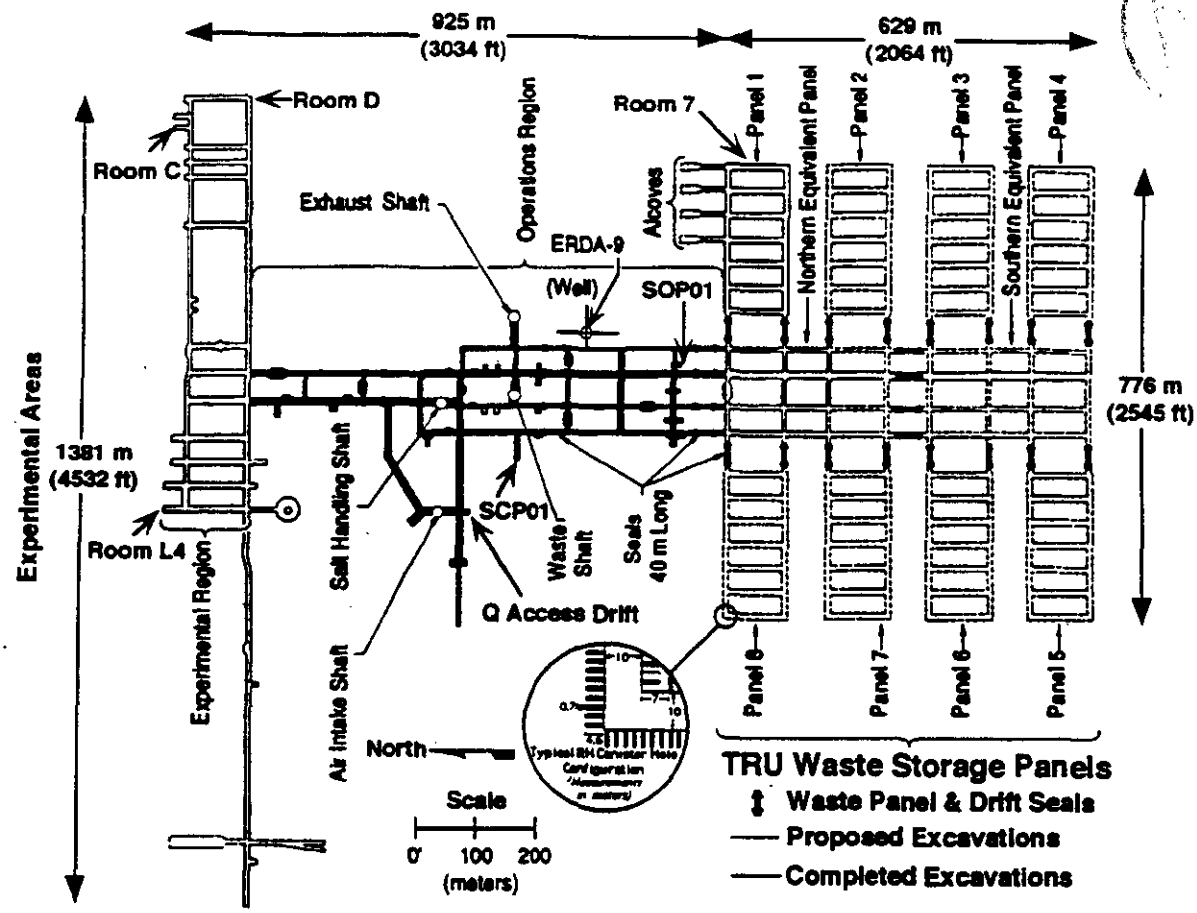

Figure 3-5. Plan View of WIPP Completed and Proposed Excavations.

d) The disposal system design also provides for the drifts of the operations area, the experimental area, and the test alcoves of the disposal area (Figure 3-5). The drifts of these areas will be sealed off from the disposal area and backfilled with crushed tamped salt during the disposal phase.

e) Access to and operation of the experimental region and the disposal system are provided for by the system of four access shafts (**Figure 3-6** and 3-3).

f) The reference design sealing strategy for the Salado Formation (SAND92-700/3) makes the following assumptions.

- All openings in the waste storage area will be backfilled with tamped crushed salt (to at least 60% Salado halite density) that is presumed to reconsolidate eventually to nearly pre-emplacement density (95%) and permeabilities, as a result of creep closure of the openings;

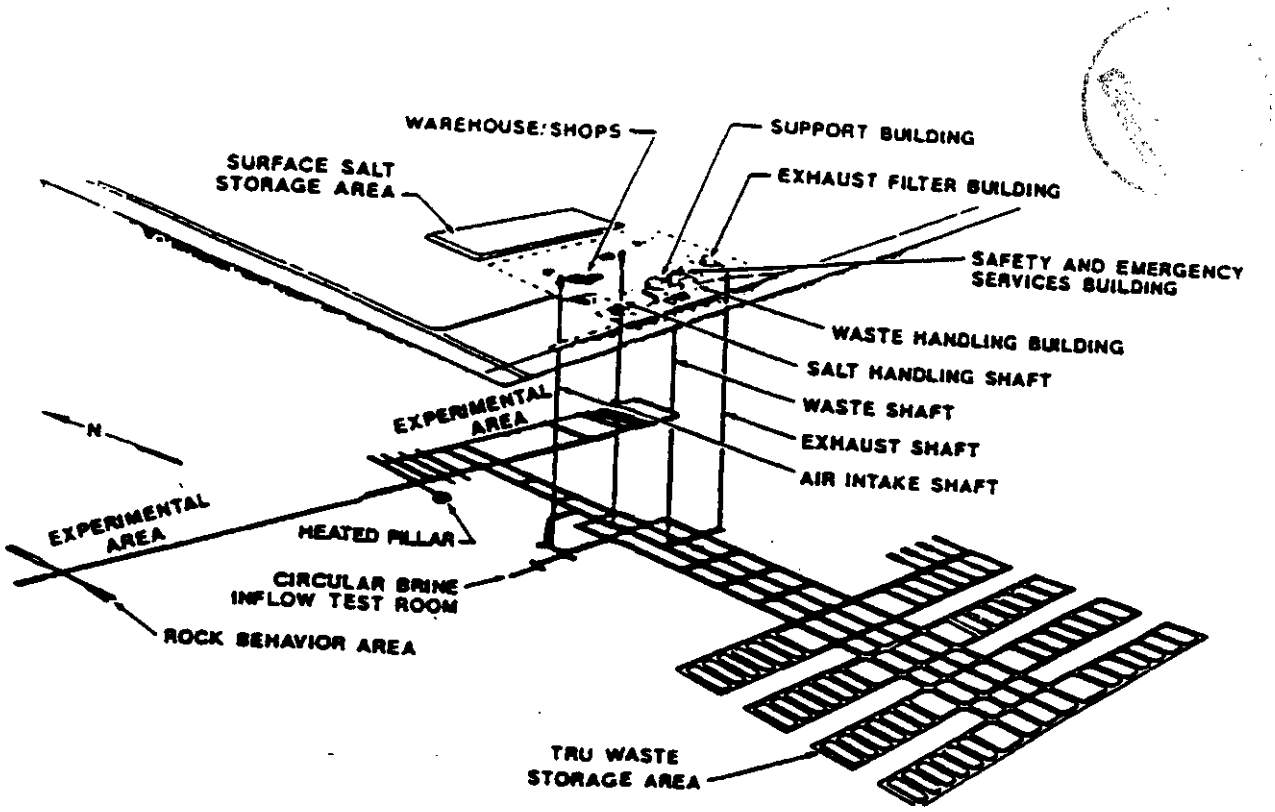

Figures 3-6. Isometric View of the WIPP Surface and Underground Footprint Looking to the Northeast. (Solid lines represent actual underground openings and hollow lines represent proposed waste panels.)

- Redundant, accelerated (i.e., within approximately 100 years after installation), high quality sealing is to be provided for by fitting the specific portions of the access shafts and the waste disposal and operational area drifts indicated in Figure 3-5 and Figure 3-7 with combinations of short- and long-term engineered seal components (Figure 3-7). The short-term components of the engineered seals, typically concrete and clays specifically developed for WIPP, are expected to provide initial sealing until the long-term components, typically preconsolidated salts emplaced at 80% of the Salado halite density (e.g., in a manner similar to the experimental seal shown in Figure 3-8) become fully functional. Sealing of the four access shafts/penetrations of the Salado Formation is to be with a combination of lower shaft concrete plugs and preconsolidated crushed salt, as illustrated in Figure 3-7. The waste panel seals and the operational drift area seals are to be constructed as shown schematically in Figure 3-7 and located as illustrated in Figures 3-5 and 3-3.

g) The reference design sealing strategy for the water bearing units above the Salado Formation penetrated by the four access shafts (Figure 3-3) makes use of multi-component plugs constructed and located as illustrated in Figure 3-7 (SAND92-700/3).

The discussion of conceptual models that follows is divided into two parts: (1) Pre-WIPP Facility Conceptual Models; and (2) Post-Decommissioning Conceptual Models.

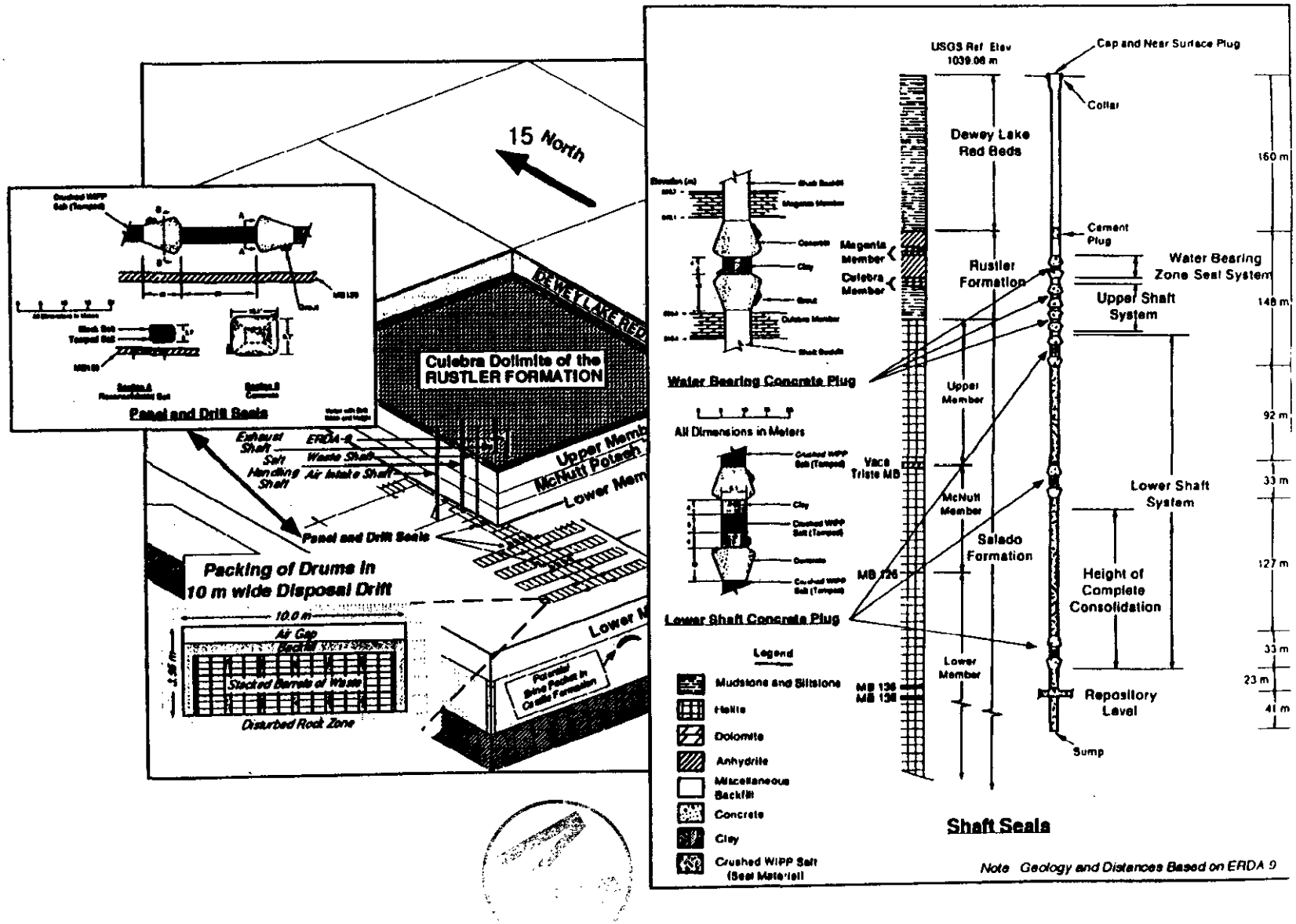

Figure 3-7. **Reference Design Diagrams for Drift and Panel Seals, Typical Backfilled Access Shaft, Water Bearing Concrete Plugs, and Lower Shaft Concrete Plugs (after SAND91-0893/3, Nowak et al. 1990).**

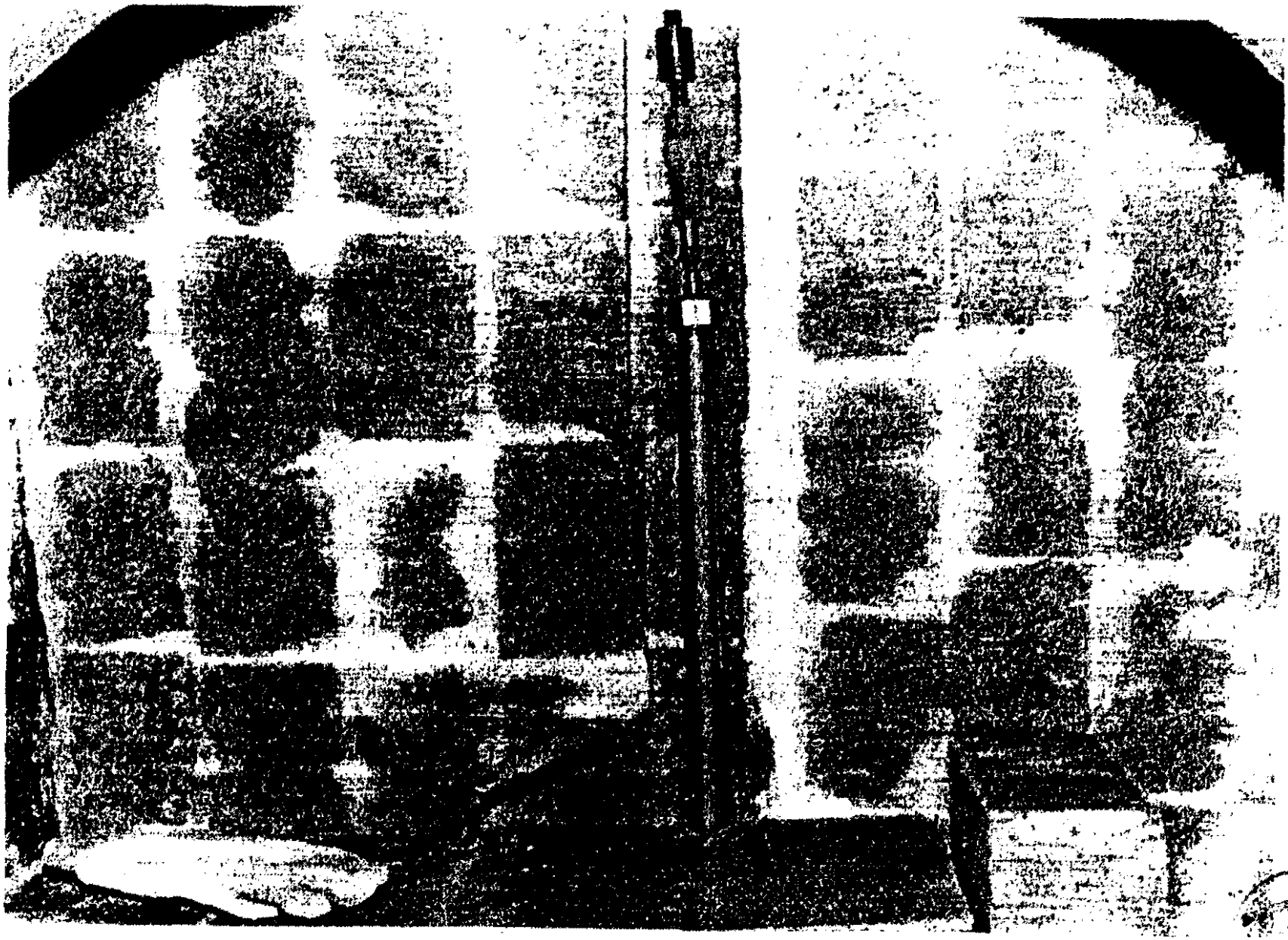

Figure 3-8. **Example of Reconsolidated Salt Blocks Used to Seal a Horizontal Chamber at WIPP as Part of a Small-Scale Seal Performance Test in Room M (SAND87-2382, 1988).**

3.2.2.1 Pre-WIPP Facility Conceptual Model

The pathways that existed before construction of the WIPP facility from the proposed location of the waste panels to the compliance boundaries (Subsection 3.1.3 and Figure 3-3), as well as the significant driving forces and processes that govern the movement of fluids or the transport of dissolved chemicals species contained in these fluids, are discussed in this subsection. All effects of the waste and its emplacement in the repository are ignored.

Connective disruptions, such as might be caused by human intrusion into the waste disposal area of the Salado by exploratory drilling, have the potential for interconnecting the waste disposal area to the significant water bearing formations above (the Rustler) and below (the Bell Canyon) the Salado Formation, and thus providing a transport path from the disposal rooms of the waste disposal area (Figure 3-3) to the accessible environment compliance boundary (40 CFR 191) illustrated in Figure 3-3 by three possible routes. These include transport through the Rustler, the Salado, and the Bell Canyon. The Castile Formation is not considered for transport since it is neither transmissive nor rechargeable, and it contains only isolated brine pockets. It is important to model the pre-WIPP undisturbed state, since this provides a way to demonstrate understanding of the geohydrologic system and setting, and it may provide the only chance to compare model results with data on such a large spatial scale and within such a long time frame. Discussions with SNL Department 6119 indicated that the PIs are currently undertaking this kind of regional modeling effort. The results from these initial efforts appear to be providing a better understanding of the temporal relationships between the five transmissive units of the Rustler (**Figure 3-9**) and their sources of and responses to recharge changes resulting from climate variations, as well as the potential for inter-communication between these units.

The Salado Formation (the most important natural barrier of the WIPP disposal system) is part of a thick (up to 4,000 m (13,000 ft)) sequence of marine sediments deposited in a structural depression known as the Delaware Basin that formed approximately 300 to 245 million years ago during the Late Pennsylvanian and Permian periods (SAND92-0700/2, 1992), and the WIPP site is located close to the northern boundary of the basin (**Figure 3-10**). A Guadalupian reef complex, consisting of the Capitan Limestone and equivalent carbonate units, forms the basin margins (Figure 3-10) and deep water shale, sandstones, and limestone of the Guadalupian Delaware Mountain Group (Figure 3-2), deposited during the initial period of rapid basin subsidence, form the basin floor for the Ochoan Series of evaporitic rocks (i.e., Dewey Lake, Rustler, Salado and Castile Formations) that eventually filled the basin during Permian time. In response to waning subsidence in the Late Permian time, the thick halite of the Salado extended across this Guadalupian reef complex, as illustrated in **Figure 3-11** (Mercer, 1983; SAND92.0700/2, 1992)

The Bell Canyon Formation, which is the uppermost member of this Guadalupian Delaware Mountain Group, is the first transmissive and rechargeable water bearing unit (total dissolved solids of 180,000 to 270,000 mg/l) below the Salado. Its upper units contain the most porous sandstones of the entire Delaware Mountain Group and are targets for hydrocarbon exploration (Mercer, 1983; SAND92-0700/2, 1992). The structure contours for the Lamar Shale, (the uppermost member of the Bell Canyon Formation {**Figure 3-12**}), illustrate the gentle dip to the east (approximately 1 degree) common to all the Permian units in the basin (Mercer, 1983). **Figure 3-13** shows the interpreted potentiometric surface for the upper part of the Bell Canyon. Mercer (1983) concludes that regional flow begins with waters entering in the Delaware and Guadalupe Mountains to the west and then, restricted by intervening siltstones,

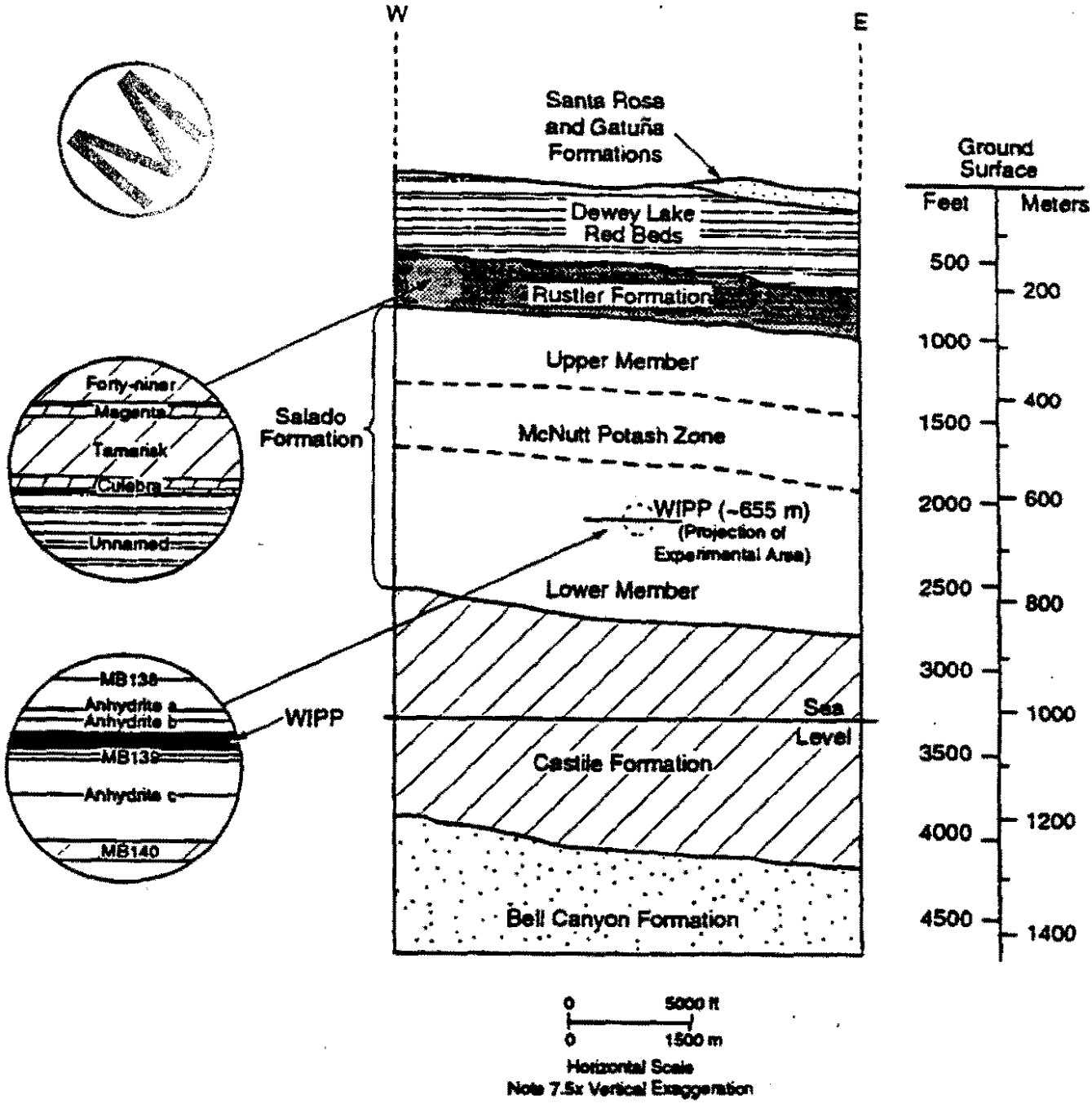

Figure 3-9. **Generalized WIPP Stratigraphy Across the Land Withdrawal Area (after DOE/WIPP 89-011, 1993).**

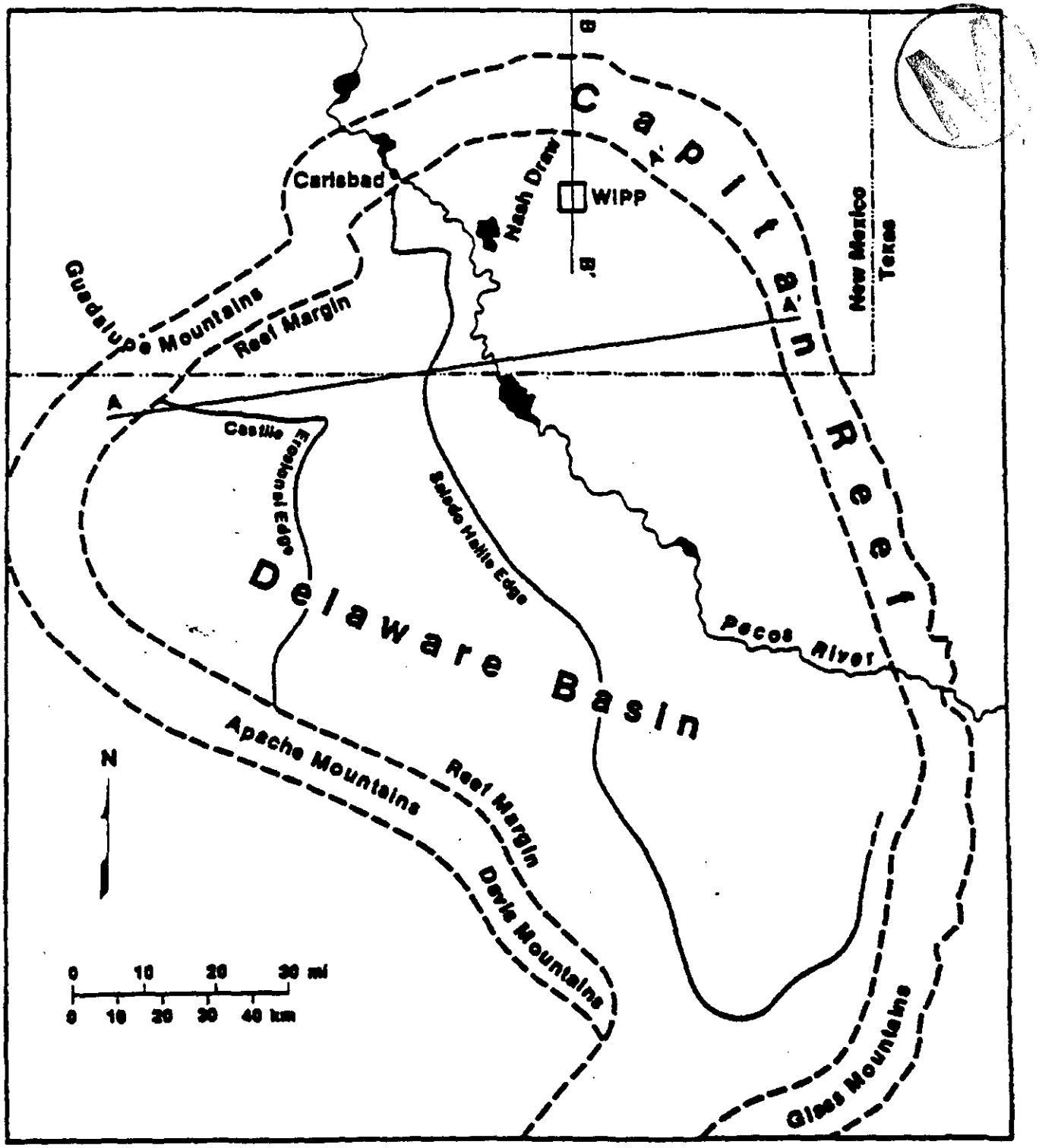

Figure 3-10. **Generalized Geology of the Delaware Basin, Showing the Location of the Capitan Reef and the Erosion Limits of the Basinal Formation (from SAND92-0700/2, 1992, after Lappin, 1988).**

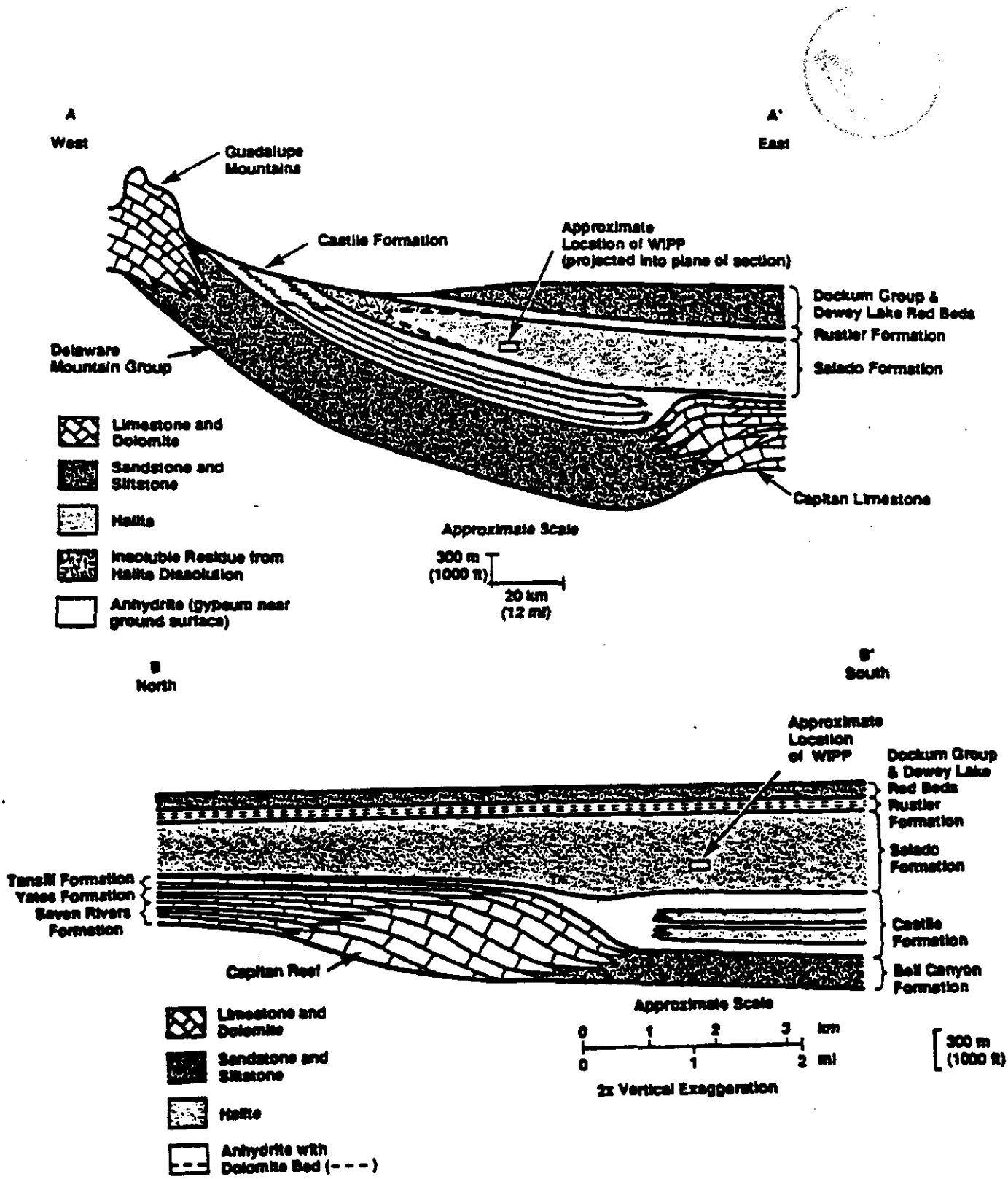

Figure 3-11. Schematic East-West (A-A') and North-South (B-B') Cross-Sections through the Northern Delaware Basin (from SAND92-0700/2, 1993, after Davies, 1984).

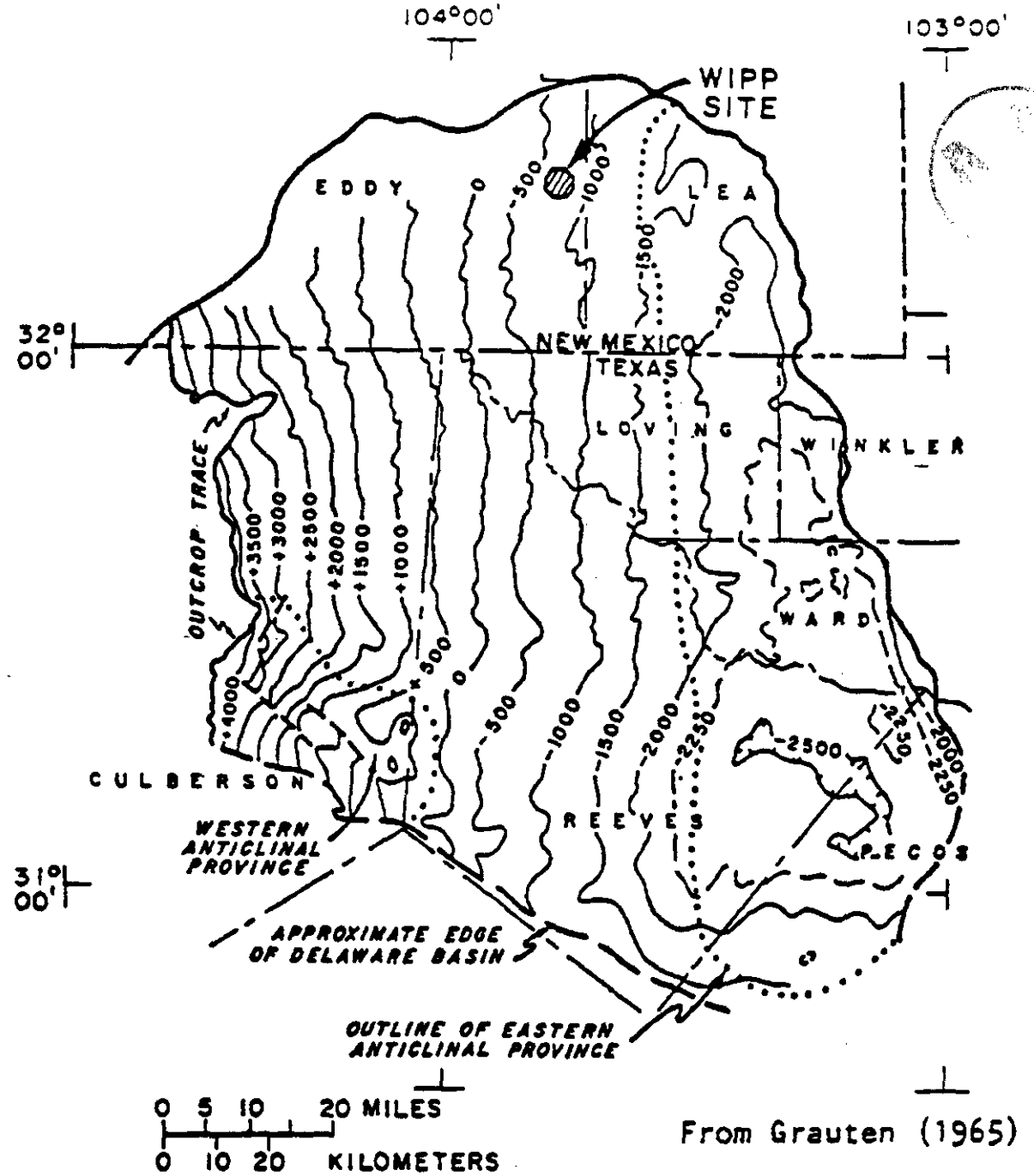

EXPLANATION

1500 STRUCTURE CONTOUR--Shows altitude of top of Delaware Mountain Group. Dashed where approximately located. Contour intervals 250 and 500 feet. Datum is sea level.

Figure 3-12. Generalized Structure Contours on Top of the Lamar Shale of the Bell Canyon Formation (from Mercer, 1983).

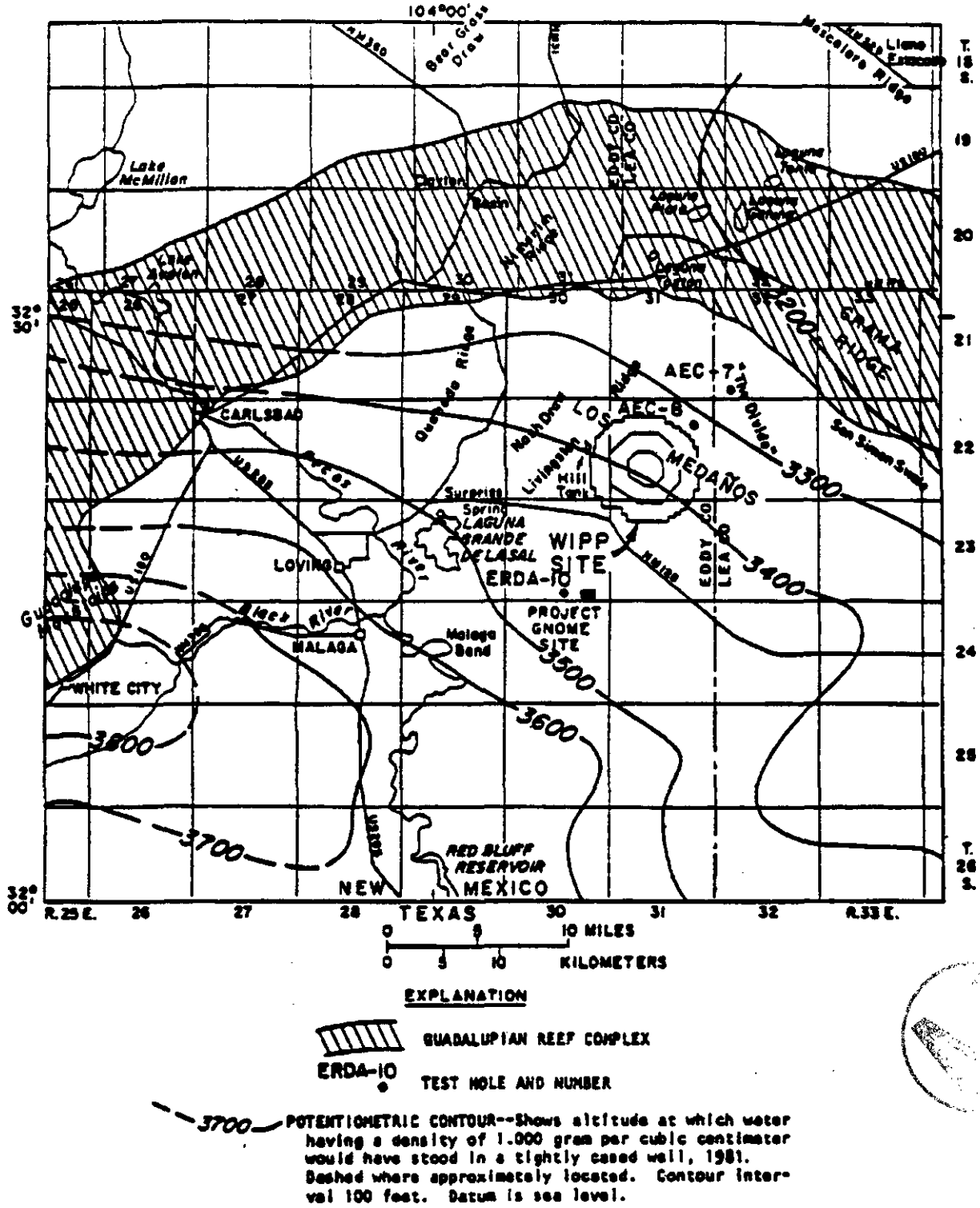

Figure 3-13. **Potentiometric Surface of the Hydrologic Unit in the Upper Part of the Bell Canyon Formation (from Mercer, 1983).**

slowly moving to the northeast, nearly paralleling the regional structural trend under gradients of 0.005 to 0.008.

It is postulated (SAND92-0700/2, 1992) that responses to regional tectonic adjustments, which gave rise to decreases in the supply of clastic sediments and intermittent connection with the open ocean, resulted in the thick evaporitic sequence of the Ochoan series that covered the Bell Canyon of the Guadalupian series. The Ochoan series are described in order of deposition.

- The Castile Formation consists of thick anhydrite beds with thin interbeds of salt and is of importance to WIPP because it is the first layer below the Salado and contains isolated pockets of pressurized brine and hydrogen sulfide gas in fractured anhydrite beds that have thus far only been found to be associated with structural features. Mercer concludes that these isolated pockets are discontinuous and form no regional flow system within the basin (although localized systems have developed within outcrop areas). He further concludes that the unit acts as a confining layer for water moving in the Bell Canyon below it. The isolated pressurized pockets of brine and gas are of concern because they supply a limited source and driving force for liquids and gas for potential human intrusion scenarios associated with exploratory drilling. This unit has also been of much concern in the past under the "breccia pipe" theory of Anderson (1978, 1981) which postulates development of vertical circulating flow paths in the fractures of this unit that would allow the waters of the Bell Canyon to rise under a density gradient and fall as saturated brines after dissolving the halites of the Salado (Mercer, 1983).

- The Salado Formation has been divided into three stratigraphic units — an Upper Member, the McNutt Potash Zone, and a Lower Member (Figure 3-9) — near WIPP by Jones (1975), in describing the potash resources of the area. It can be differentiated from the Castile because it principally consists of halite in thick interbeds that have been interpreted to be part of repeated multiple bedded sequences (generally on the scale of 0.1 to 1.0 m). These sequences are assumed to be part of a rhythmic fundamental evaporite sedimentation cycle, interpreted by Jones (1973) as an evaporite cyclothem. The cycle starts with deposition of clastic at the base and grades upward through sulfate, halite, and a mixed halite-clastic and then repeats. These beds are generally laterally persistent over large areas, as evidenced by the 45 numbered, anhydrite marker beds 100 through 144 (SAND89-0462, 1989), that are used for stratigraphic control within the vicinity of WIPP by the potash industry. (The 45 numbered interbeds are inconsistent with the 44 in SAND92-0700/2, 1992.)

  While small pockets of brine have been encountered in mining and drilling operations and pockets of nonflammable gases and air have been encountered during the drilling of stratigraphic test holes that have caused blowouts of the drilling fluid, there has been no evidence of flowing water found during the drilling of test holes or during investigations for potash mining. Mercer (1983) indicates that no or very slow natural groundwater flow is suspected to occur in the intact, undisturbed portions of the Salado Formation because there is no evidence of flowing waters and because the slow plastic flow (creep) of the principal formation component (halite) is thought to prevent the maintenance of primary intergranular porosity, solution channels, or open fractures. However, this does not imply that the formation is dry. Brine does seep into the WIPP excavations (brine production rates of 0.01 l/day/m-of-excavation-length have been estimated, as discussed in SAND92-0700/2, 1992).

  Inconsistencies, such as far-field pore pressure measurements that are not in equilibrium (Section 4.2) and which imply flow from the more permeable anhydrites to the less permeable Salado may have led Guzowski (1990) to conclude that sufficient data are not currently available to determine the natural pattern of groundwater flow in the Salado, if it

does exist (SAND92- 0700/2). Gathering sufficient information to resolve some of these inconsistencies completely is complicated by what might be described as the nemesis of geologic disposal (i.e., the "best natural systems" for containment and slow release are the "most difficult to characterize").

Measurement generally requires emplacing probes to measure responses to a disturbance propagated over the spatial measurement scale of interest (e.g., by injecting a fluid) and then observing the response of the system as it returns to equilibrium. However, the long time required for perturbations to propagate in low permeability formations (generally considered the best for waste isolation) restricts such measurements to a small spatial scale with questionable relevance to repository performance. Additionally, when measurements are made at these small scales, the volumes of rock disturbed by emplacement of measurement probes and perturbation (e.g., injection) holes, and the volumes and properties of the probes become significant relative to the volume of undisturbed rock, thus increasing the uncertainty and biasing of the measurement.

An additional issue and source of uncertainty is related to the validity of the assumption that Darcy's law governs the flow of fluids in the halites of the Salado, (as is discussed in more detail in Subsection 4.2). It is apparent that full resolution of the above issues (e.g., removal of all measurement bias, reduction of measurement uncertainty, determination of exactly the conditions for transition from Darcy to non-Darcy flow) is neither possible nor necessary to demonstrate that there is a reasonable expectation of compliance. Since determining what can and needs to be done to demonstrate compliance can be a difficult and controversial process, it would seem that a more formal method is required that attempts to assess realistically what can be achieved in an appropriate time frame and for an appropriate cost; (see Section 3.2).

- The Rustler Formation (discussed in more detail in Subsection 4.3) is described by Mercer (1983) as the youngest of the Ochoan evaporite sequence containing the most transmissive units above the Salado, as illustrated in the hydrostratigraphic column in **Figure 3-14**. The Magenta and Culebra are dolomites, and the others (unnamed, Tamarisk, and Forty-Niner) consist of differing amounts of anhydrite, siltstone, claystone, and halite (SAND89-0462, 1989). Of these, the Culebra dolomite is the most laterally continuous and productive unit in the vicinity of WIPP; however its waters, which vary from saline to briny, are of little use because of the marginal quality and variability in the yields (Mercer, 1983). The conceptual model for regional flow in these units is dependent on other regional setting factors and is discussed in subsequent paragraphs.
- The Dewey Lake Redbeds (discussed in more detail in Subsection 4.4) are the uppermost unit of the Ochoan Series and the last of the Permian System rocks. They consist largely of siltstones and claystones that serve to buffer recharge from above because of their low permeability (SAND89-0462, 1989).

The Culebra dolomite of the Rustler Formation (a secondary natural barrier at WIPP) is an important part of the hydrologic system that exists in the supra-Salado sediments (above the Salado) in the vicinity of WIPP. In addition to the Culebra dolomite, the other more permeable and areally extensive units of this hydrologic system (Figure 3-14) include the Magenta dolomite, which has nearly the same areal extent as the Culebra, and the "brine aquifer," which is of limited extent and is located in the dissolution residuum of the Rustler-Salado contact zone in Nash Draw (**Figure 3-15**). The influence of near-surface dissolution of the evaporites is apparent in the topography of the area (**Figures 3-16** and **3-17**), which gently rises to the topographic high of the "caprock" of the Llano Estacado along Mescalero

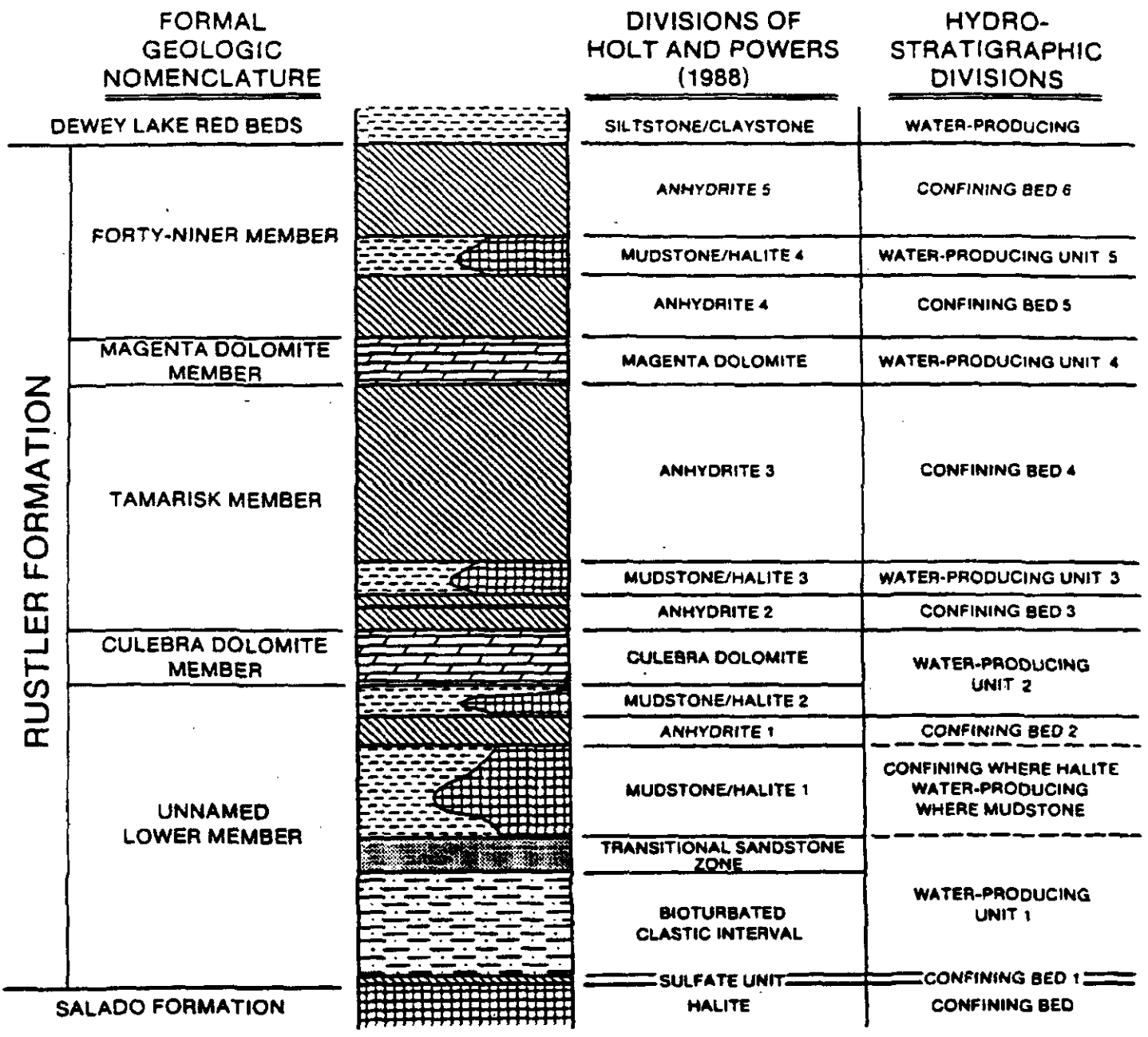

Figure 3-14. Hydrostratigraphic Column of the Rustler Near the WIPP Site (Beauheim and Holt 1990).

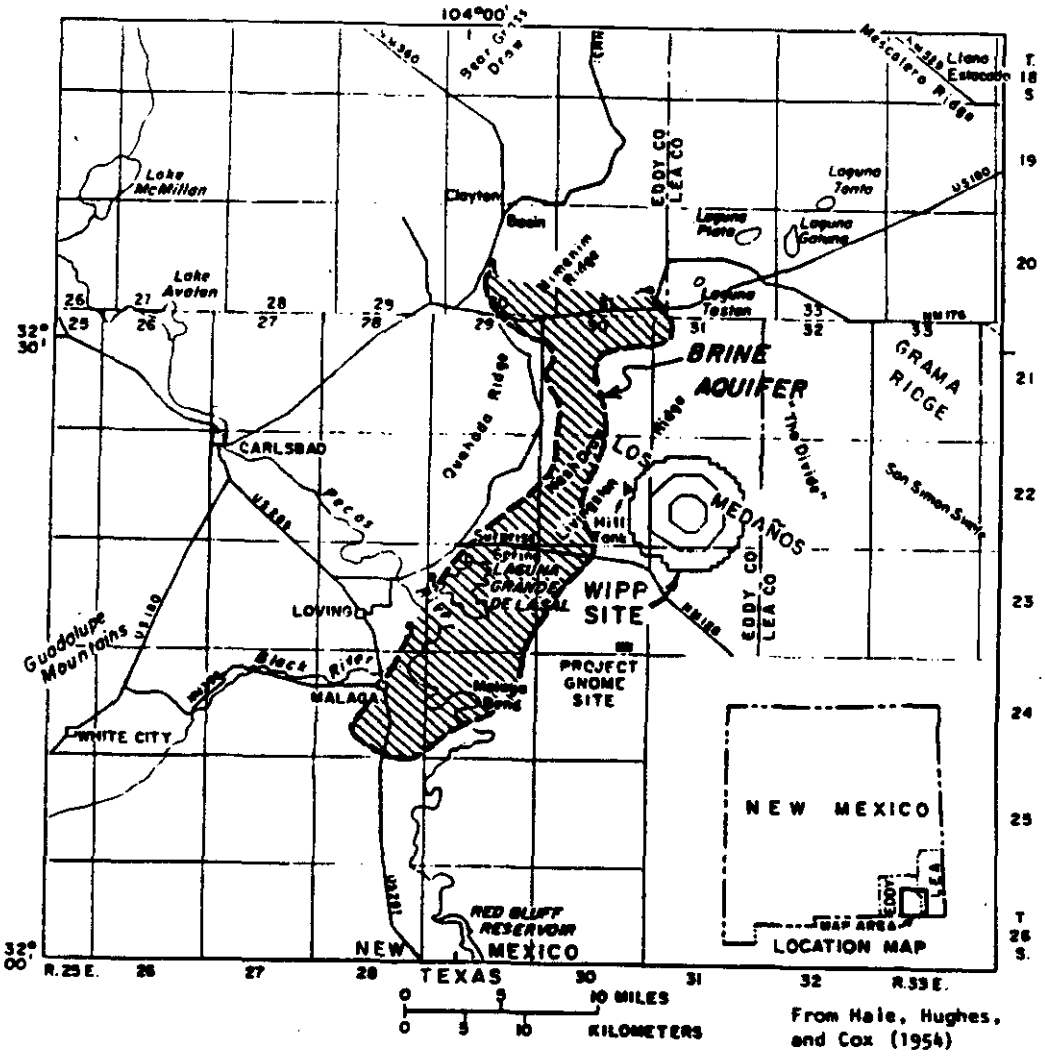

From Hale, Hughes, and Cox (1954)

Figure 3-15. Approximate Extent of the "Brine Aquifer" Near WIPP (from Mercer, 1983).

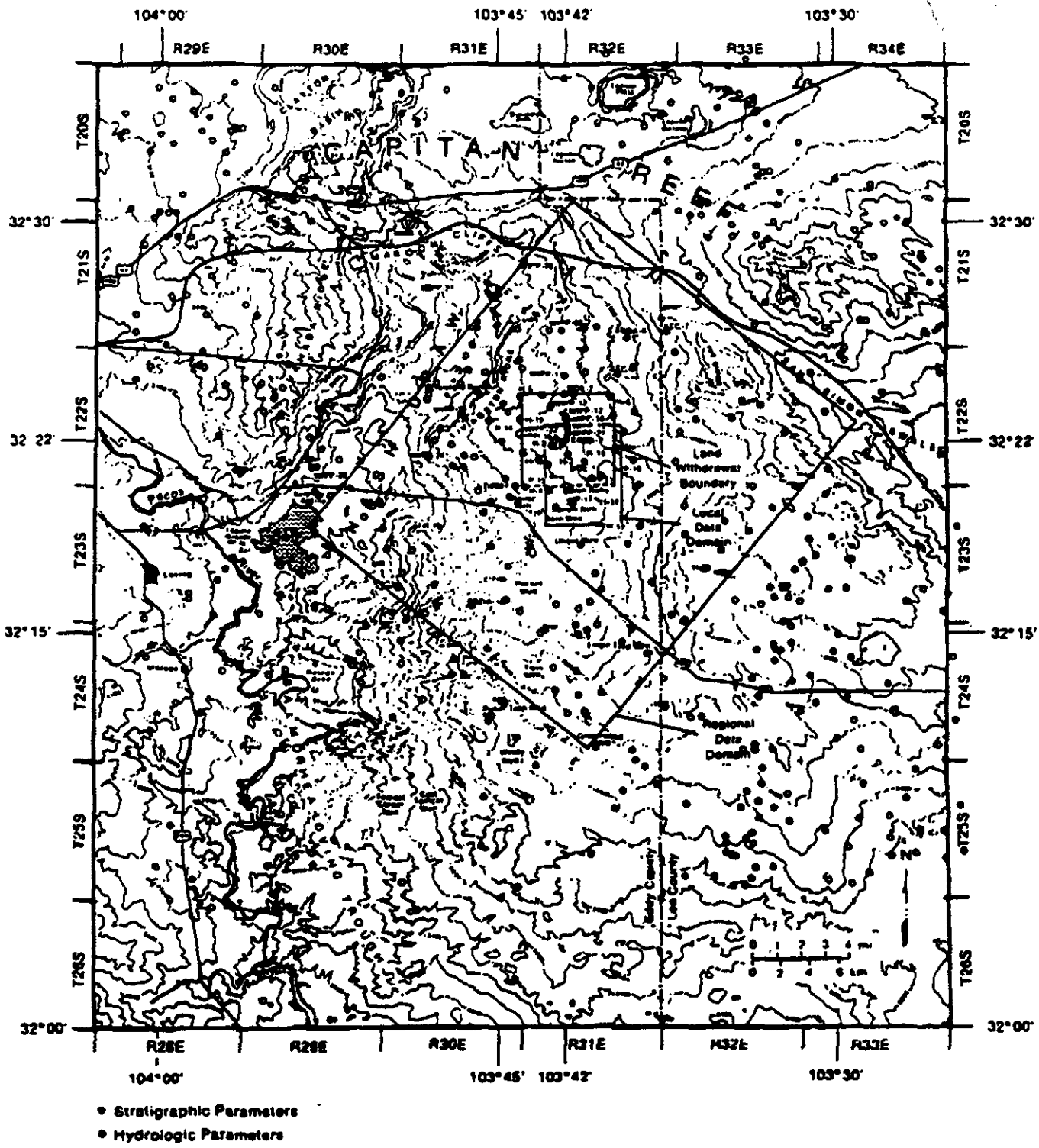

Figure 3-16. **Topography of the WIPP Area, Locations of Wells for Defining General Stratigraphy, and the Regional and Local Data Domains Used in the WIPP PA (SAND92-0700/3, 1992).**

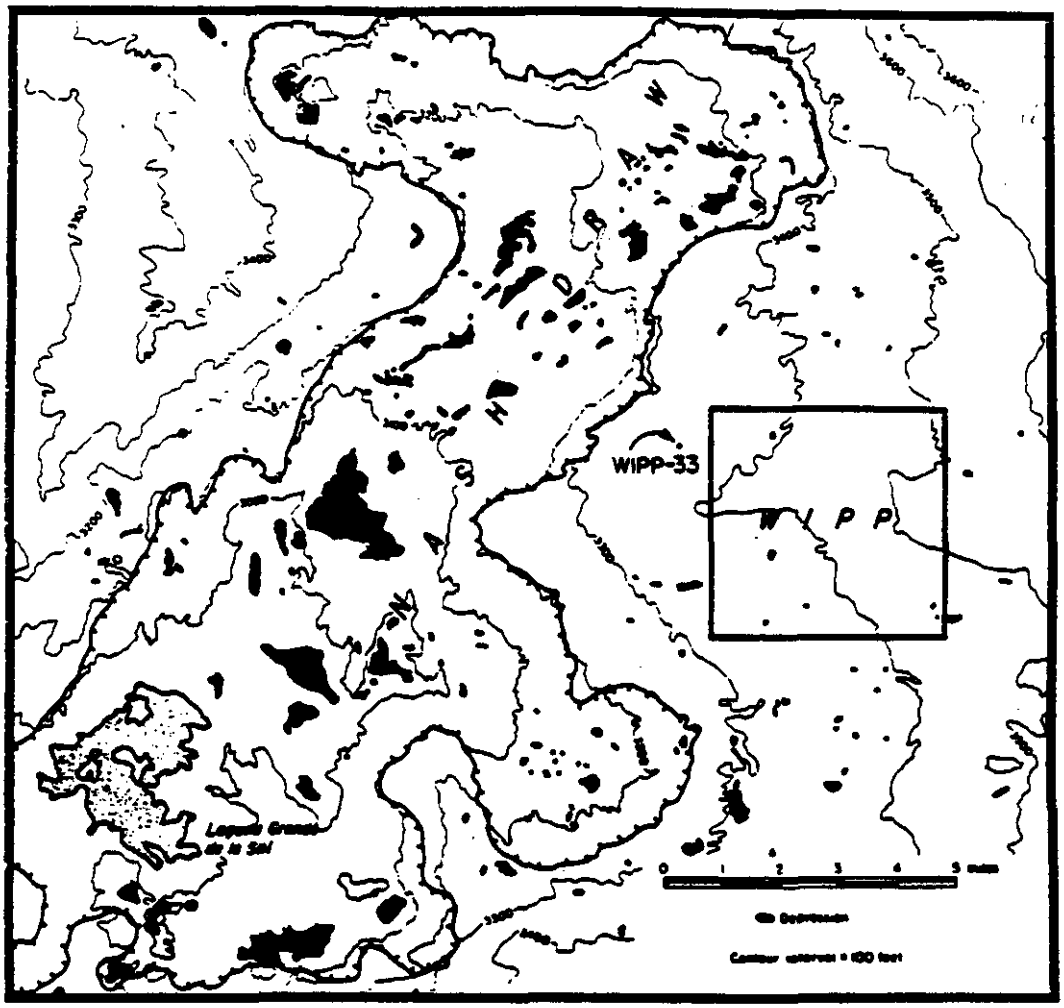

Figure 3-17. **Topography Contours (100 ft interval) for the General Area Around the WIPP Site and Nash Draw, Showing Areas of Closed Topographic Depressions and the Location of WIPP 33 (from Chaturvedi and Channell, 1985).**

Ridge (Figure 3-15) as one proceeds to the east and north from the Pecos River to the south, and the depressions associated with the three nearest karst dissolution features: the Balmorhea-Loving Trough to the south of WIPP, Nash Draw to the west , and Clayton Basin to the northwest (Mercer, 1983; Chaturvedi and Channell, 1985; SAND92-0700/2). The topography also gently rises as one proceeds to the west and north from the Pecos River, Nash Draw, and the Clayton Basin (Figures 3-16 and 3-17). The area is covered with sand dunes (which can enhance infiltration and thus recharge) and is vegetated with mesquite, scrub oak, and other typical northern Chihuahuan desert plants that exist with the 28-34 cm/yr of precipitation (which is dominated by a late summer monsoon) and the 17.1°C average annual temperature that gives rise to a surface water or pan evaporation of 280 cm/yr (Mercer, 1983; SAND92-0700/2).

Development of a conceptual model for flow in this supra-Salado hydrologic system is complicated by a variety of interpretational issues.

- There is a potential for the various members of the Salado and supra-Salado Formations (Bachman, 1980 and 1985; Snyder, 1985; Chaturvedi and Channell, 1985; Lowenstein, 1987; Holt and Powers, 1988) to
  - dissolve (e.g., the halites, dolomites, and gypsum) and form solution cavities and channels/conduits (e.g., WIPP 33, Figure 3-17) or to give rise to more rapid removal of unit as related to their average proximity to recharge sources from the surface through time (**Figures 3-18** and **3-19**),
  - subsequently slump and fracture harder units (e.g., the anhydrites and dolomites), and
  - convert anhydrite to gypsum (with the associated expansion, fracturing, and sealing capabilities) which itself eventually dissolves as a result of the movement of circulating groundwaters (**Figure 3-20**).

  In the words of Snyder (1985), there is a potential for a member unit to "feed upon itself" and alter its own geohydrologic and geochemical properties in response to fresh (or low TDS) water circulating from recharge sources to discharge locations.
- There is the associated difficulty and debate (Bachman, 1980 and 1985; Snyder, 1985; Chaturvedi and Channell, 1985; Lowenstein, 1987; Holt and Powers, 1988; SAND92-0700/2) surrounding conclusive determination of the origin, timing, and locations of syndepositional versus post-burial dissolution zones, and the current status of any dissolutioning or alteration that has taken (or is taking) place within the Rustler.
- It is not possible to relate observations of hydrochemical facies (**Figure 3-21**) to current flow patterns inferred from adjusted potentiometric contours in these variable fluid density geohydrologic systems because these systems may be in a transient state that is out of equilibrium with both current and past climatic/recharge conditions. (**Figures 3-22, 3-23**, and **3-24** are the adjusted potentiometric contours for the Rustler-Salado contact zone, Culebra dolomite, and Magenta dolomite respectively.)
- There are difficulties associated with characterizing low permeability and heterogeneous geohydrologic systems because the support volume associated with any of the measurements is very small (the nemesis of geologic disposal discussed earlier).

The limited review of the data and abundant literature on the supra-Salado geohydrologic system in the vicinity of WIPP suggests the possibility of using a Toth type of local topographic-driven conceptual model for the periods of more humid climate during Gatuna time (**Figure 3-25**; SAND92-0700, 1992),

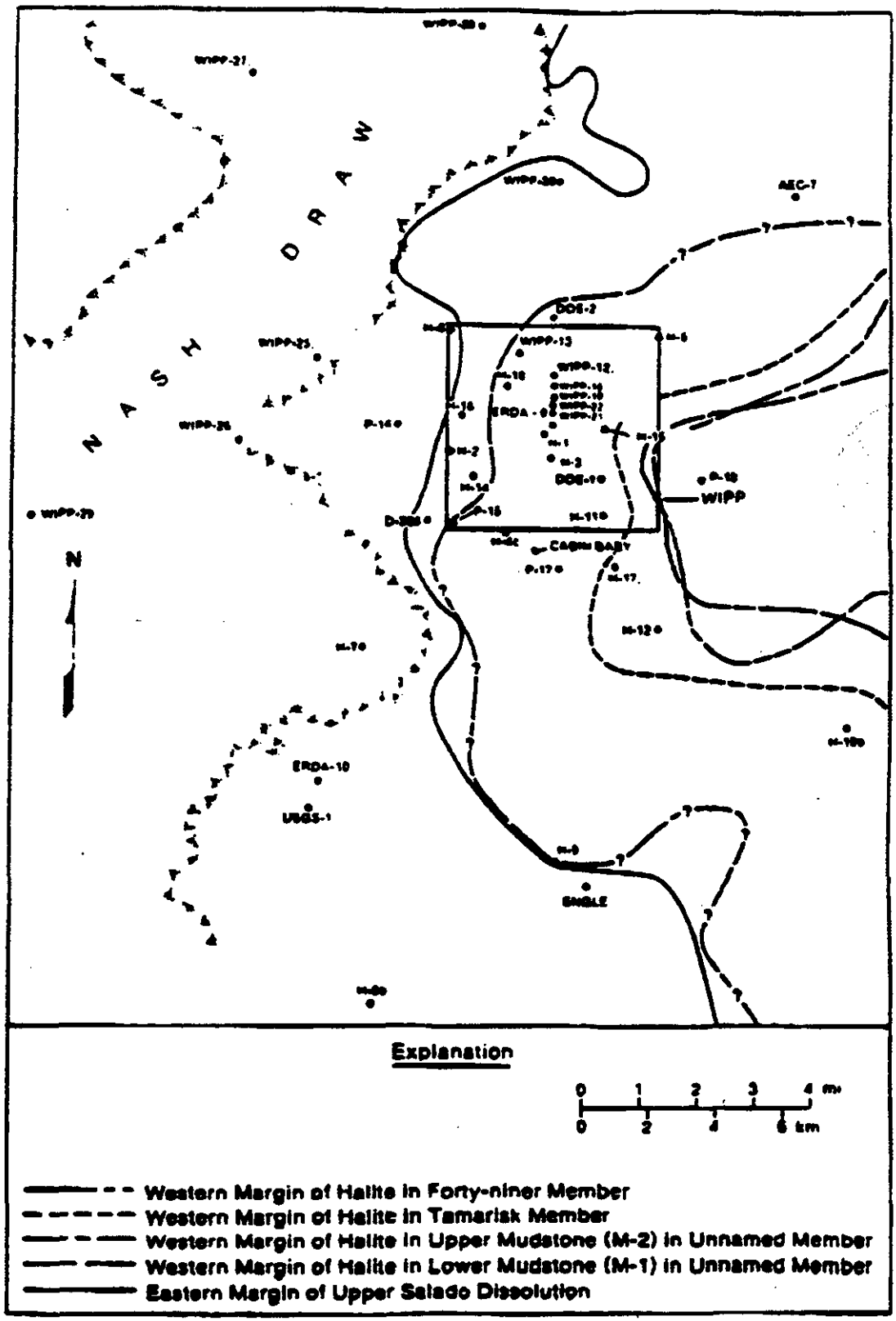

Figure 3-18. **Eastern Margin of Upper Salado Dissolution and Western Margins of Rustler Formation Halite Around WIPP (reproduced out of SAND92-0700/2 from Lappin et al. 1989).**

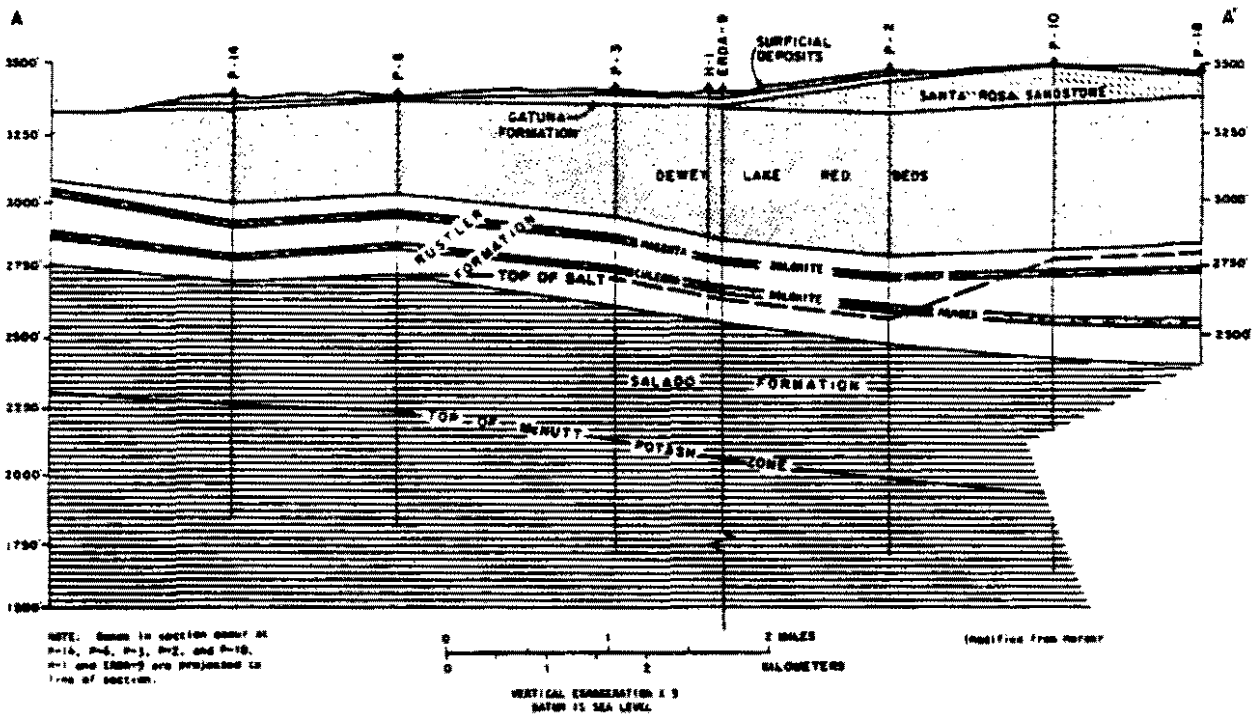

Figure 3-19. **Geologic Section Across the WIPP Site Showing Approximate Location of Salt in the Rustler (from Mercer, 1983).**

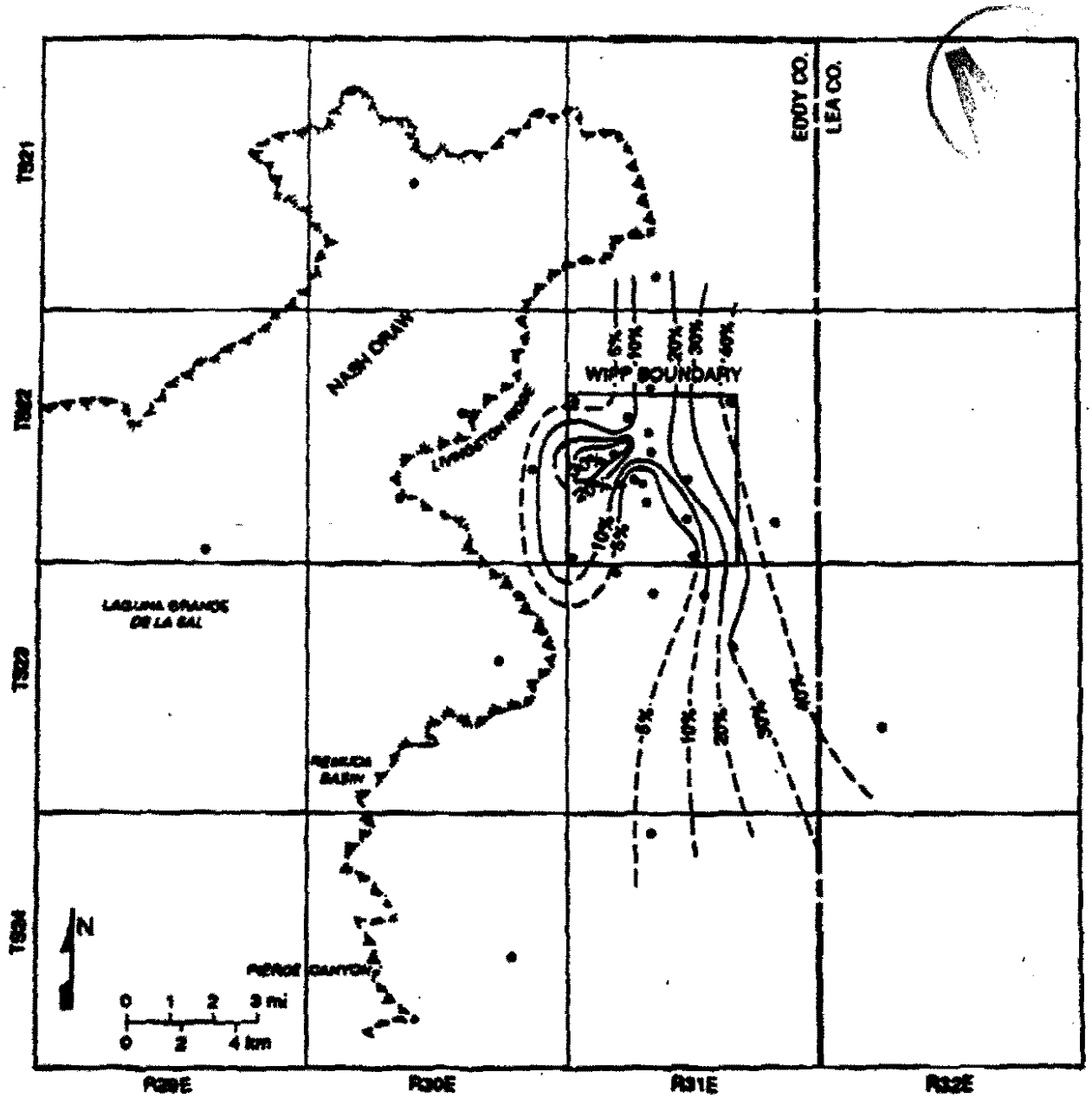

Figure 3-20. Percentage of Natural Fractures in the Culebra Dolomite Member Filled with Gypsum (reproduced from SAND92-0700/2, 1992, after Beauheim and Holt, 1990).

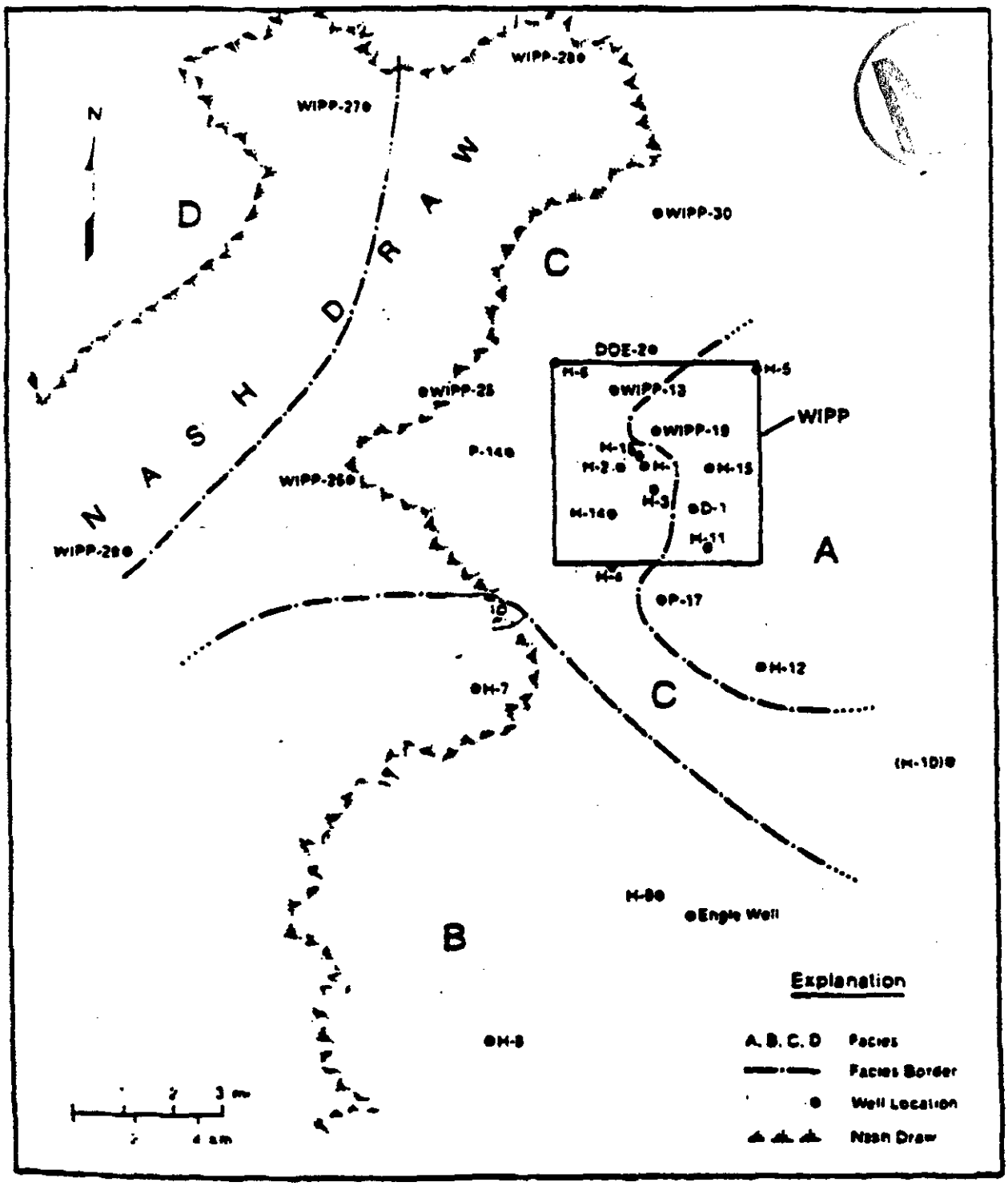

Figure 3-21. **Hydrochemical Facies in the Culebra Dolomite Member of the Rustler Formation (reproduced from SAND92-0700/2, 1992, after Siege et al. 1991).**

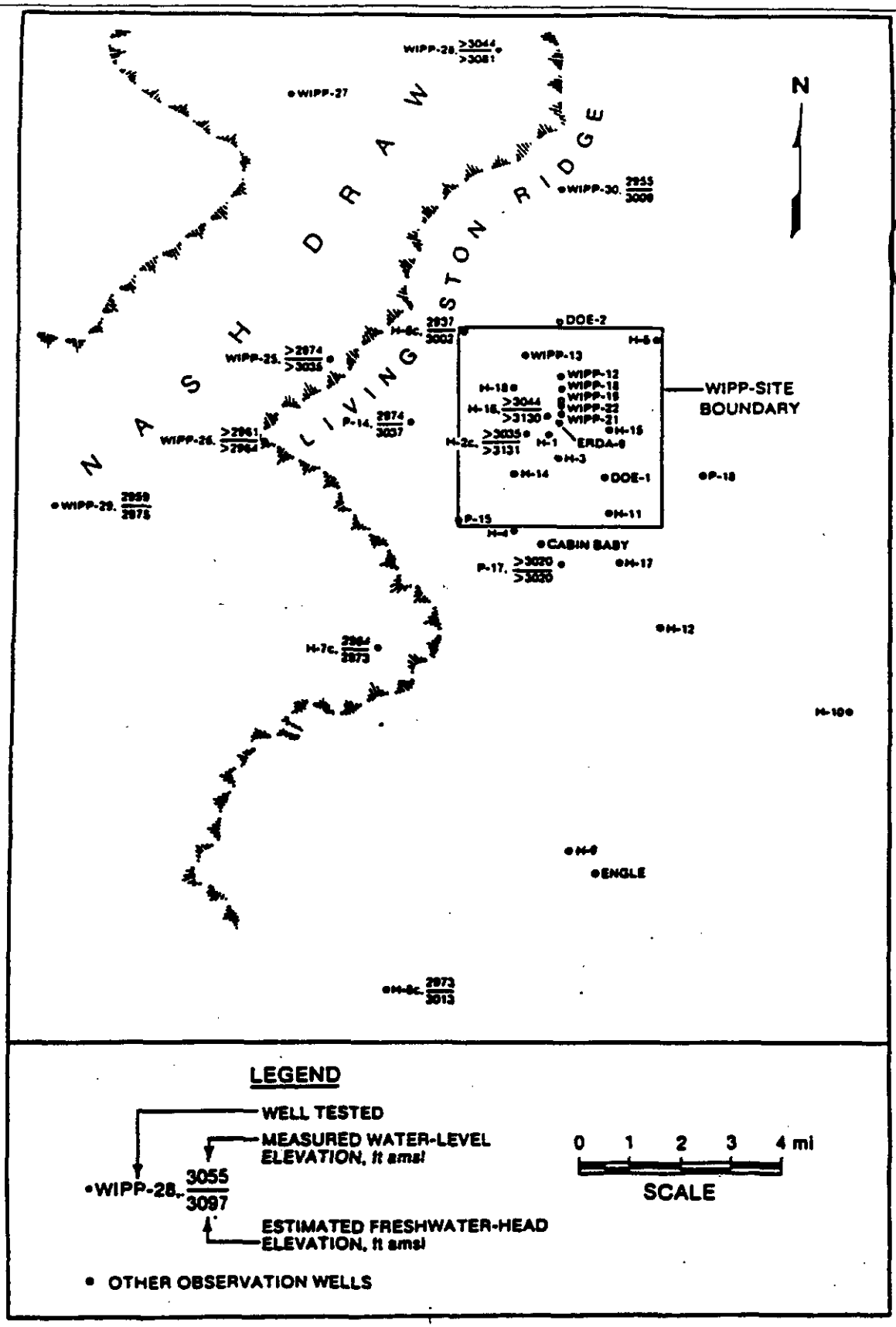

Figure 3-22. **Measured Water Level and Estimated Freshwater Head Elevation of the Unnamed Lower Member of the Rustler and/or Residuum along the Rustler/Salado Contact (from Holt et al., 1989)**

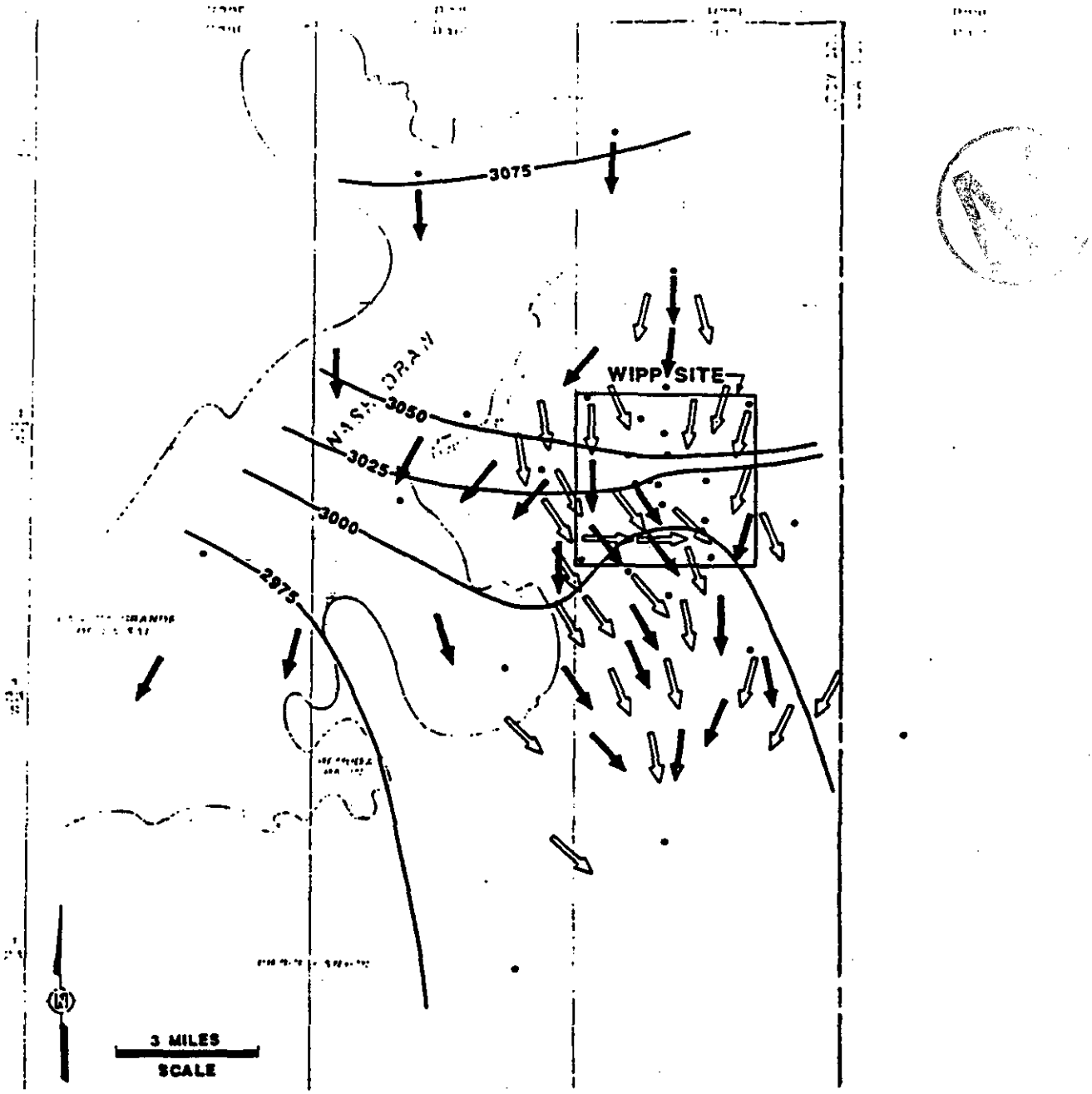

Figure 3-23. **Estimated Culebra Dolomite Member Freshwater Heads and Flow Directions (from Holt et al., 1989).**

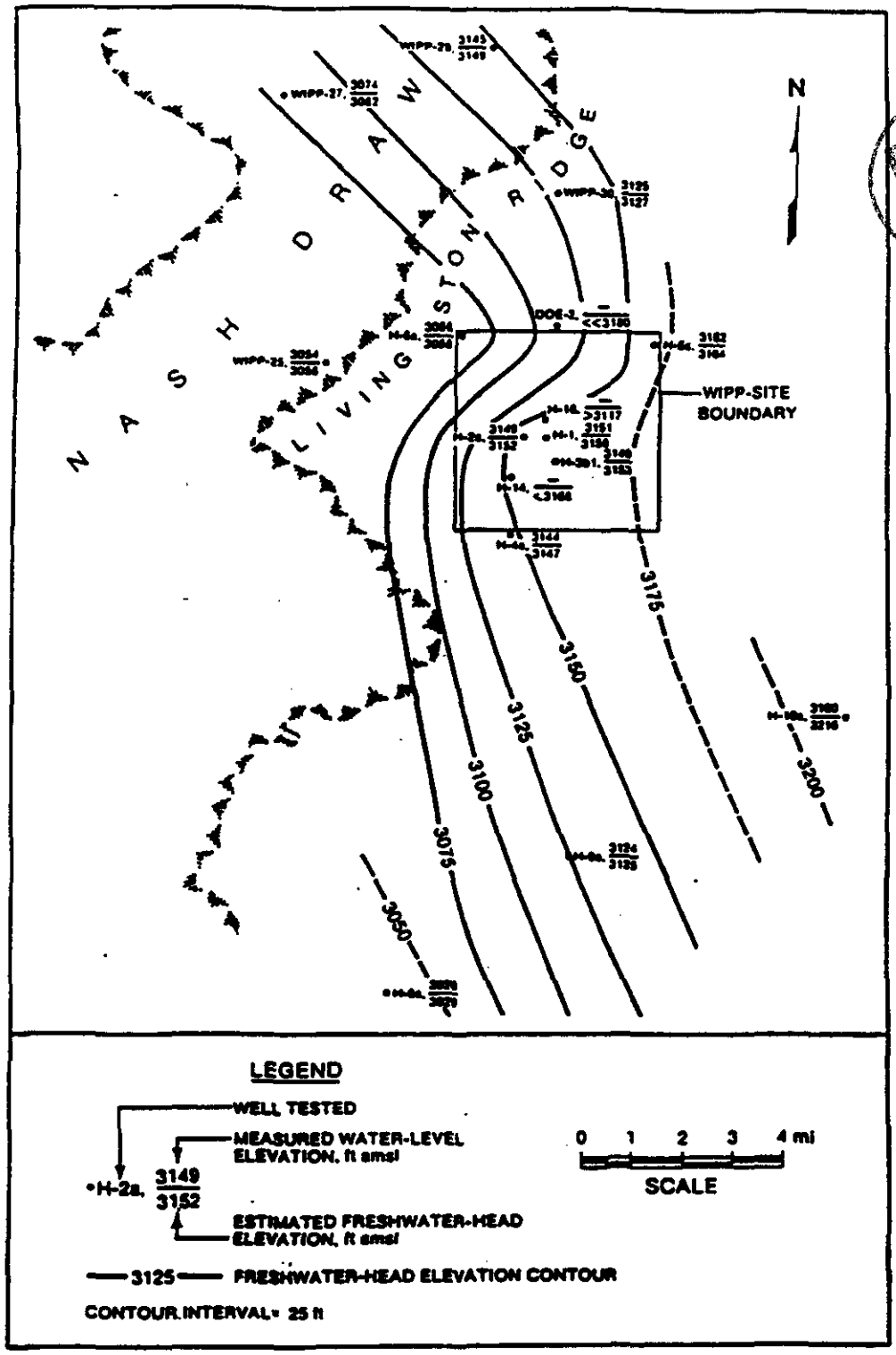

Figure 3-24. **Measured Water Level and Estimated Freshwater Head Elevation, Magenta Dolomite Member (from Holt et al., 1989).**

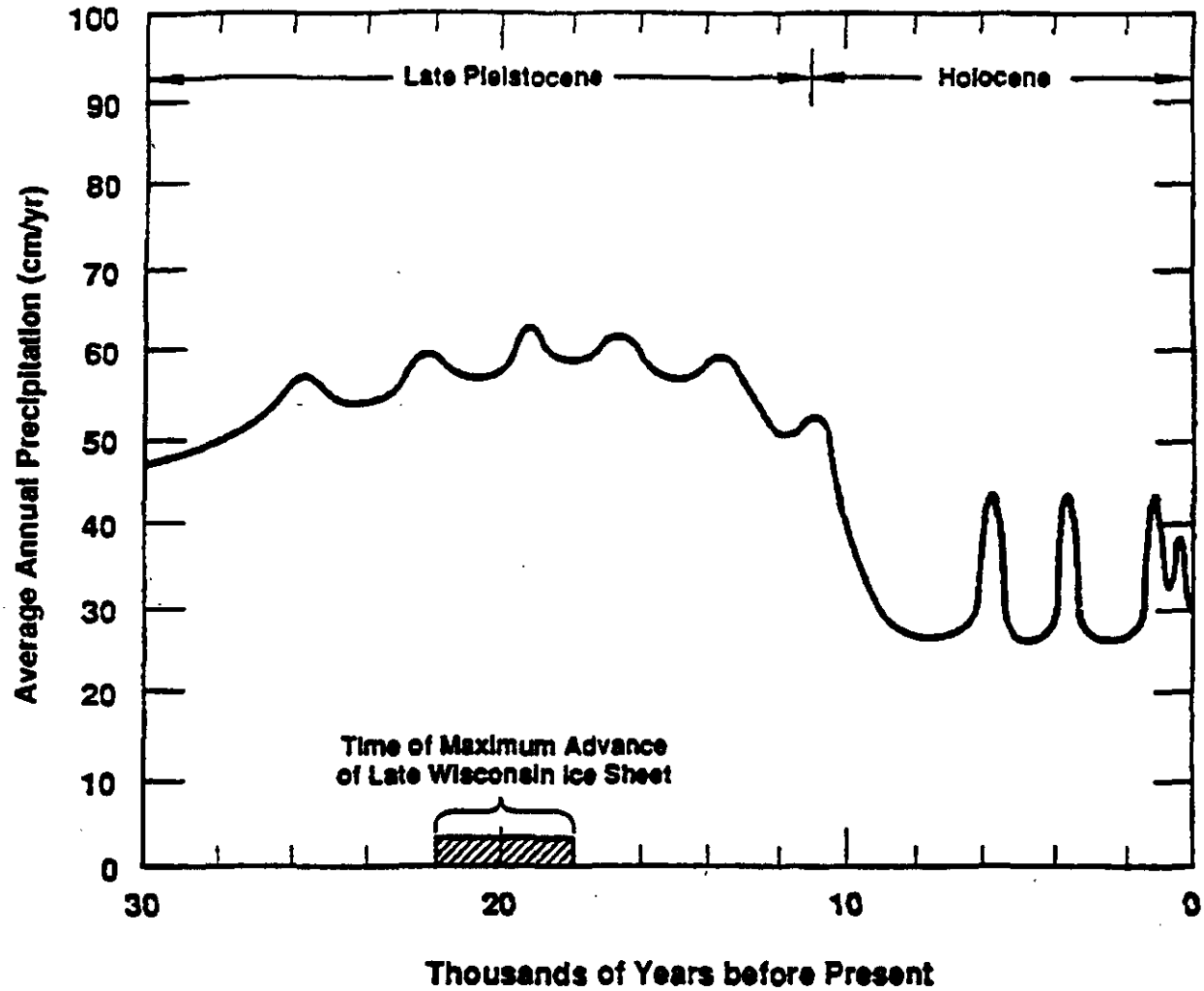

Figure 3-25. **Estimated Mean Annual Precipitation at the WIPP during the Late Pleistocene and Holocene (reproduced from SAND92-0700/2, 1992, as modified from Swift, 1992).**

when surface streams (**Figure 3-26**) were postulated to exist in the vicinity of WIPP (Bachman. 1985), and a change to larger intermediate or more regional circulation during the dry periods. During periods of greater precipitation, higher and more uniformly distributed recharge moved through the supra-Rustler sediments (e.g., the 10^{-8} m/s hydraulic conductivity of the Dewey Lake Redbeds could allow up to 30 cm/yr to infiltrate under unit gradient conditions of unsaturated flow) and a higher water table, whose contours would probably have mimicked some subdued version of the local topography. Recharge would move vertically downward and then laterally, where it would discharge to both local and more regional surface water drainages. Hydrologic systems, during these humid times, circulate more and fresher (i.e., lower TDS) groundwaters. As a result, most of the post-burial (and not syndepositional) dissolutioning and alteration of the Rustler (Figure 3-18 and 3-20) took place during these times, since observed patterns of halite removal and hydrochemical facies dissolution (Figures 3-18 and 3-21) are more consistent with directions of flow inferred from a subdued version of the topography. These periods of more humid climate may have been followed by dryer climate periods (Figure 3-25) that would result in very low or potentially spotty recharge through the supra-Rustler sediment, such as proposed by Mercer, (1983) for the Dewey Lake, or through the runoff to closed depressions (Figure 3-17), and subsequent deep infiltration as proposed by Chaturvedi and Channell (1985). Under this model, the low flows of the dry periods would cause the flow directions of the higher permeability units (e.g., the Culebra) to change more rapidly in response to the change in recharge locations and quantities, as proposed by Siegel and Lambert (1991) and discussed in SAND92-0700/2 (1992).

The reasonableness of local recharge can be demonstrated by simple hand calculations of flow through the Culebra, since it probably carries the majority of the flow. These calculations of flow and recharge are based on the following:

gradient	=	0.003 (from 932 m and 914 m contour along east side of WIPP, Figure 3-23);
mean thickness	=	7 m (SAND92-0700/2);
width	=	20 km (distance from southeastern corner of WIPP site to eastern edge of Figure 3-23);
K	=	10^{-4} m/s to 2×10^{-10} m/s (hydraulic conductivity, SAND92-0700/2) ;
flow estimate	=	0.4 m^3/s to 8×10^{-7} m^3/s (compare this to the 0.91 m^3/s estimated to recharge the Pecos River from stream gage data, SAND92-0700/2, 1992).

The calculations translate to a uniformly distributed recharge equivalent (if presumed to all take place in the 20-km-by-20-km (12-mi-by-12-mi) area in the upper left corner of Figure 3-24) that ranges from a minimum of 7×10^{-6} cm/yr to a maximum of 3 cm/yr *{i.e., $0.42\times3.15\times10^{7}\times100/(20{,}000\times20{,}000)$}*. It should be noted that the high estimate is still only 0.1 of annual rainfall and that even this maximum recharge estimate would only require a saturated hydraulic conductivity of approximately 10^{-8} m/s under unit gradient conditions. To support this conceptual model further, hand calculations could be carried out to estimate the potential volume of halite that could have been dissolved, and deterministic modeling could be undertaken to test various aspects of this conceptual model that would lead to the selection of the appropriate model for compliance calculations.

These discussions of a Toth-type conceptual model for the supra-Rustler hydrologic system were presented to raise several issues, discussed below, that PART believes are important to the WIPP development of a PA document and documentation trail adequate for licensing decisions.

- **Conceptual Model Documentation and Assumption Justification.** The current PA (SAND92-0700/1-3, 1992) provides no coherent presentation of the plausible conceptual

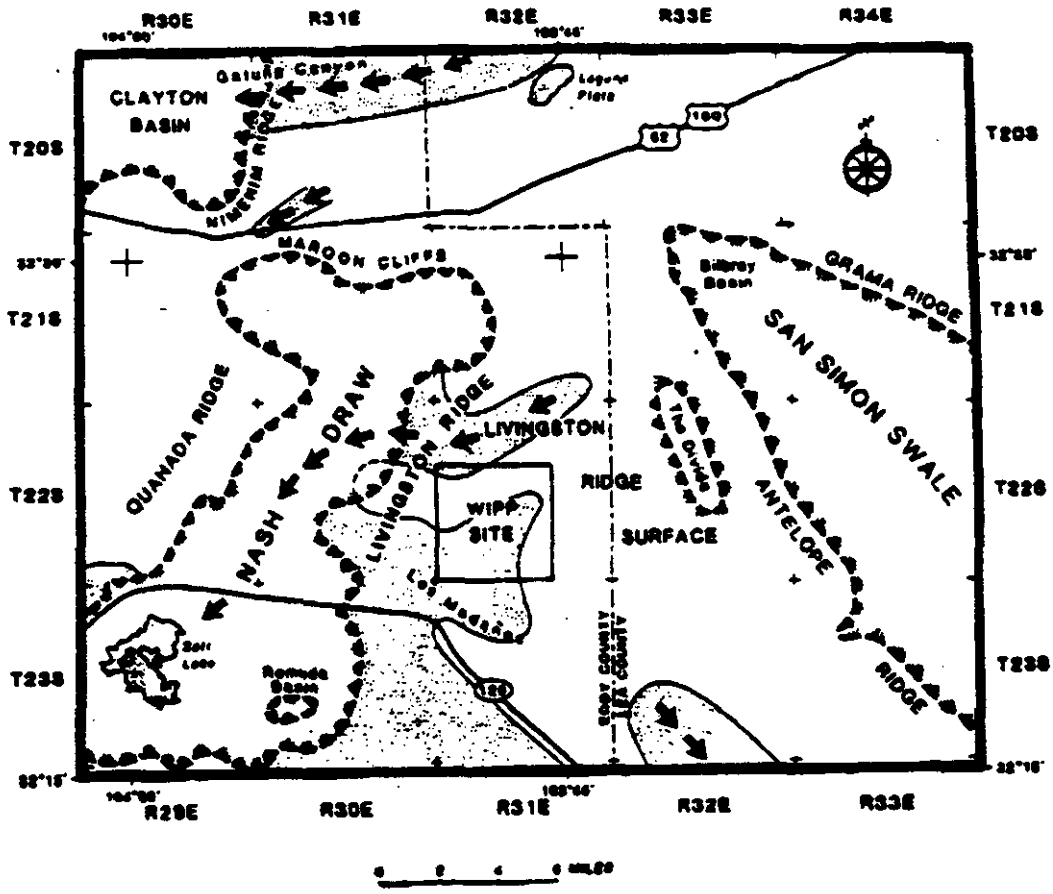

Figure 3-26. **Distribution of Gatuna Formation in the Vicinity of WIPP (stippled) and Probable Course of Streams During Gatuna Time (arrows) (reproduced from Bachman, 1985).**

model(s) for the supra-Salado hydrologic system in the vicinity of WIPP. This is a significant issue because the interpretation of measurements and observations, as well as the selection of an appropriate way to model the Culebra, is dependent on an understanding of the supra-Salado hydrologic system conceptual model. The PA must contain a coherent discussion of the(se) model(s) in order to address the major interpretational issues discussed above and to properly discuss and document the Culebra conceptual model and justify the various associated assumptions. The Culebra conceptual model and major assumptions are discussed in some detail within the current PA, although evidence is not generally presented to justify/support them; (see Subsection 4.3 for PART's detailed discussions of the Culebra).

For example the PA discusses pressure measurements at four wells that indicate upward flow from the Magenta and the claystone unit of the Forty-Niner and concludes: "This observation offers no insight into the possibility of infiltration reaching the Forty-Niner Member, but it rules out the possibility of infiltration reaching the Magenta dolomite or any deeper units at these locations." The context (i.e., the supra-Salado hydrologic system conceptual model assumptions) for this interpretation is not discussed, and the reader wonders how this low permeability clay unit came to be under-pressurized when the logic offered for the lowered pressure in the Culebra (relative to the pressure in the lower conductivity Magenta) was that faster drainage occurred because of its higher conductivity. The reader wonders what zero recharge means. Are these formations so tight that recharge through them is zero and yet the halite disappears? Or, does this conceptual model require the Holt and Powers (1988) assumption of syndepositional distribution of halite?

This same evidence (i.e., Magenta to claystone pressure comparisons at four wells - DOE-2, H-3, H-14, and H-16 - which actually showed upward gradients, with one highly uncertain downward gradient at DOE-2, Beauheim, 1987) would be interpreted quite differently based on the hypothetical Toth-type conceptual model for the supra-Salado hydrologic system discussed above. First, only spotty recharge zones would be expected and these would be located in places where enhanced infiltration is more likely (e.g., closed contours like those at WIPP-33, where surface runoff from high intensity storms could accumulate, and near sand dunes where recharge is at a maximum even in arid environments).

Second, these lower permeability water bearing units of the Rustler (Figure 3-14) could be expected to be out of equilibrium with the higher permeability water bearing units (e.g., Magenta and Culebra), as previously discussed, and yet these higher permeability water bearing units could still be in vertical communication with each other through these spotty recharge windows.

Lappin (1989) discusses some modeling efforts (Haug et al. 1987; Davies, 1989) that suggest that this current PA modeling assumption of no vertical communication needs to be investigated, and it now seems, as discussed earlier in this section, that SNL PIs are investigating a regional hydrologic model of WIPP that examines vertical recharge from the surface through time and includes the various members of the supra-Salado hydrologic system.

Finally, as with all the issues, there is the problem of determining what is sufficient for closure from a compliance-based perspective. What level of realism must be achieved in developing and demonstrating the credibility of the supra-Salado hydrologic system conceptual model and its basic assumptions?

- **Hand Calculations and Supportive Modeling.** As discussed and simply demonstrated for the hypothetical Toth conceptual model, hand calculations can be used to demonstrate the reasonableness of assumptions and should be presented in the PA. The PART performed

many hand calculations as part of this review. A progression of simple deterministic or stochastic models is typically investigated as part of the process of examining and justifying the various conceptual model assumptions, and additional modeling analysis is performed to determine the appropriate level of model for compliance analysis. This progression needs to be clearly documented as part of the PA.

These hand calculations, along with brief documentation of the results of this progression of simpler modeling efforts used to justify assumptions, will clearly help achieve those qualitative features of "reasonable degree of certainty" and "reasonable expectation." It is also important to justify and document the analyses that lead to the model selected for compliance, especially when it appears to leave out important processes (see Subsection 5.1.5).

- **Documentation of Issues** ***(Especially Resolved Past Issues)***. During the PART review efforts, a variety of important past issues were encountered in the literature. From the chronology of the documents in the literature, it seems as if they were resolved; (e.g., many documents appear regarding an issue, and then no more articles appear). However, the status and resolution of most of these issues were never discovered in the course of this limited PART review. Furthermore, many of these were never alluded to in the current PA documents, and it is likely that future reviewers will encounter the same difficulties unless some methodical way to document these issues and their resolution status is provided. These issues may have been adequately resolved, but there is less credibility when both the issue and its resolution, or lack thereof, are not transparent. An important example is the whole series of issues and controversies regarding the regional dissolution in the Rustler Formation, many of which are summarized in LaVenue et al. (1990). Relevant issues that arose in the course of this review include the following:
  - Why are there no estimates of the rate of advance from west to east of the Rustler dissolution front?
  - How important is a good understanding of the regional dissolution process(es) to the interpretation of the current groundwater flow system and the predicted possible state(s) over the next 10,000 years? Is it necessary to resolve the controversy regarding syndepositional versus post-depositional dissolution of the halites?

  In order to achieve those qualities of "reasonable degree of certainty" and "reasonable expectation," there is a need to document these issues and their status of resolution through a series of issue resolution documents to aid both the licensing reviewers and any other interested parties. The PA should contain a brief summary of the major resolved and unresolved issues and provide a reference to these issue resolution documents. These documents need to identify and define the issue; identify and summarize the chronology of literature, workshops, and important meetings; summarize the method of resolution; and document the consensus and any dissent. These documents should be prepared under strict QA, with appropriate documented external review by qualified experts.

- **Compliance-Based Issue Resolution.** What must be known and resolved in order to reach compliance is an overriding and difficult issue. Without clearly understanding each issue, getting agreement on its definition, and determining what needs to be known and how well, DOE cannot proceed to the next steps. These involve determining
  - what can be done to demonstrate compliance and how well;
  - what needs to be done; and, finally,

- how closure or resolution (successful or otherwise) will be determined or judged (e.g., what kind of evidence is needed and what kind of consensus is required).

3.2.2.2 Post-Decommissioning Conceptual Models

This section discusses pathways, driving forces, and processes that may result from interactions between the natural system, the creation of underground openings, the waste, and the sealing of the WIPP facility. These topics are discussed in greater detail in Sections 5 and 6. Independent system PA calculations are being performed using the Golder Associates' RIP PA model and will be documented separately as part of this PART effort, as discussed in Subsection 1.4.5. This subsection only discusses the primary natural barrier (i.e., the Salado), since the important interactions between the wastes and engineered barriers/components are all expected to be with Salado Formation rocks.

Figure 3-27 illustrates a modified version of an initial pathways flow chart that separates the 40 CFR 191 and 40 CFR 268.6 pathways. The plain boxes represent the possible component models, the labeled arrows indicate the possible paths (coupling) between the components, and the label along the path indicates both the fluid that would be transporting the waste or interacting with the next component and the driving force or important governing process. There are several pathways for transport of waste from the shadowed box in the center to the two compliance boundaries the shadowed boxes at the top.

The only additional pathway to the compliance boundary identified in Figure 3-27, beyond what is considered in the current PA, includes an additional type of borehole intrusion. This pathway considers a depressurization of the Bell Canyon as a result of oil and gas production outside the land withdrawal boundary (see the dense drill grid pattern east of the site, **Figure 3-28**), that could result in contaminated fluids moving from a disposal room to the Bell Canyon through an exploratory borehole (inadvertent human intrusion). The fluids may then migrate to the accessible environment (40 CFR 191 compliance boundary), with the potential exposure pathway being associated with oil/gas production outside the land withdrawal boundary. The PART also discussed the possible impacts of potash mining, but other than enhancements of the current pathways in the Rustler, no clear new pathway could be envisioned. The likely sequence of events includes slumpage of the surface that would lead to the formation of a catchment for summer high intensity storms, as well as a fracturing of the slumped harder rocks of the Rustler (e.g., Magenta and Culebra). The net effect would be localized enhancement of both the permeability of the Culebra and fresh water recharge. The enhanced recharge would in turn lead to enhanced dissolution of the soluble Rustler rocks.

SNL has not yet implemented a potash mining scenario, although it is one of the events that survived the scenario screening. The natural resource issue was one of EEG's concerns, presented in their discussions with the PART. As illustrated in **Figure 3-29** and discussed in Guzowski (1990), there are no potash resources over most of the waste panel area, but there are economical reserves to the north and northeast. However, EEG indicated that much of the area around the land withdrawal boundary is either leased, in litigation, or soon to be leased, and that potential impacts should be evaluated. An additional concern raised by EEG was related to the drilling frequency used in the PA calculations. By their calculations, the drilling rate has been 340 borehole/km^2/10,000 years (63 oil and gas wells in a 2 mile strip from 1977 to 1992), while the EPA maximum rate for intermittent drilling is 30. While the guidance to the regulations is very clear on the 30 borehole/km^2/10,000 years, and it is obvious that the EEG rate is a systematic exploitation rate and not a long-term intermittent exploration rate, as discussed in the guidance, there may be a need to address this issue. Because of the resource potential in the vicinity of

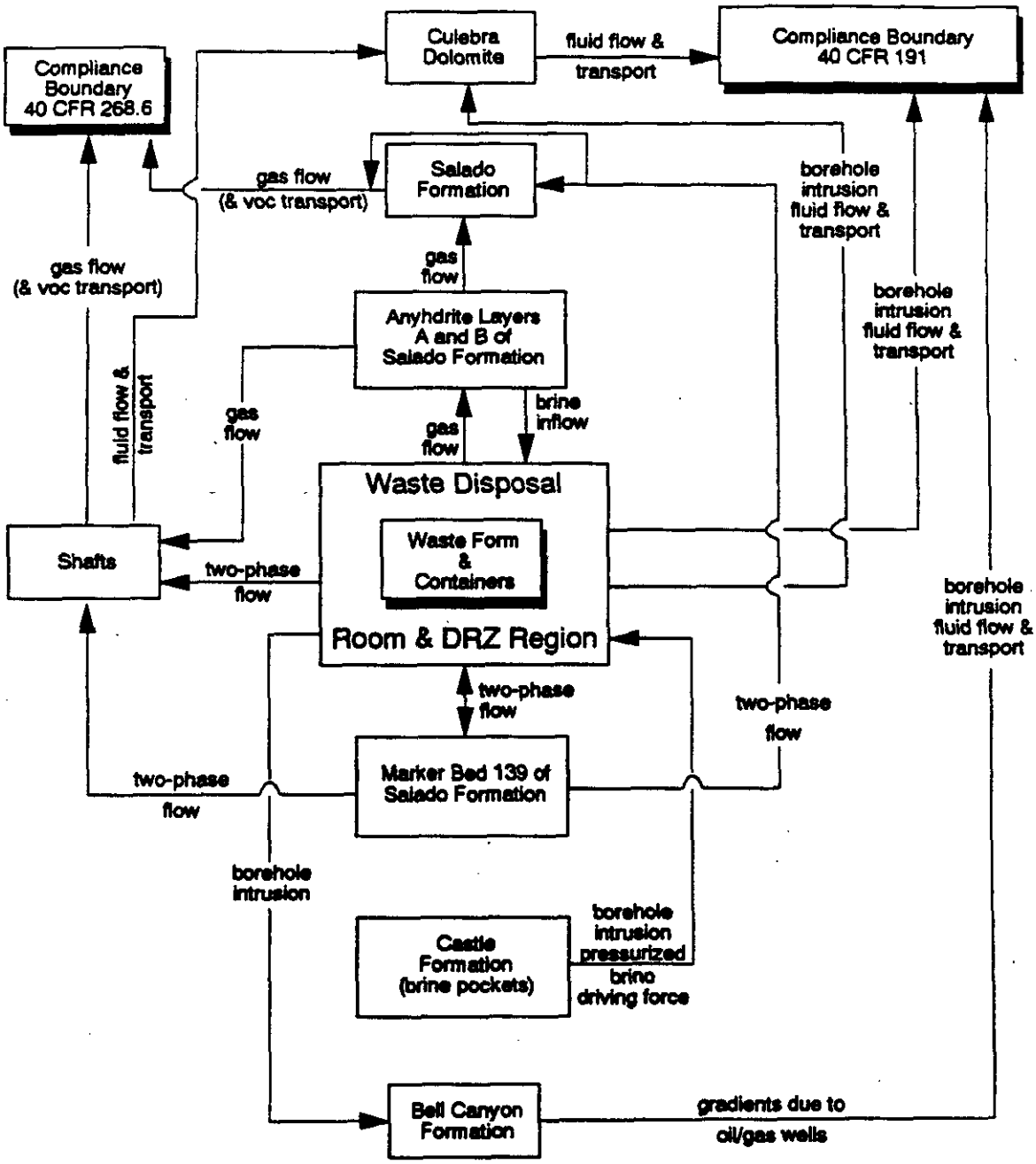

Figure 3-27. Potential Pathways and Models for the Post-Commissioning Time Period.

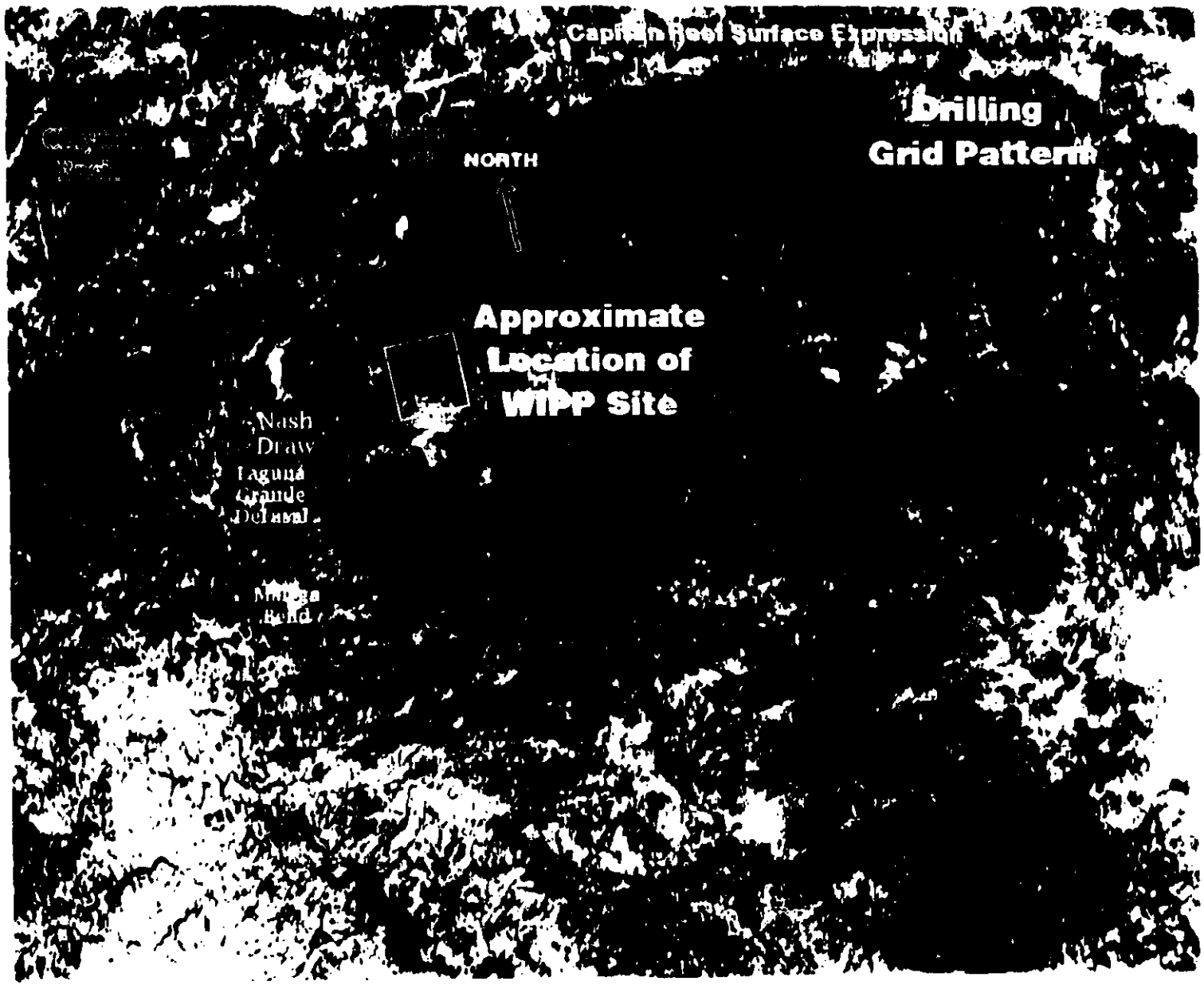

Figure 3-28. LANDSAT-1 Satellite Image of Southeast New Mexico (October 18, 1974) Showing the Approximate Location of the WIPP S[illegible]ative to the Dense Drilling Grid Pattern East of the Site.

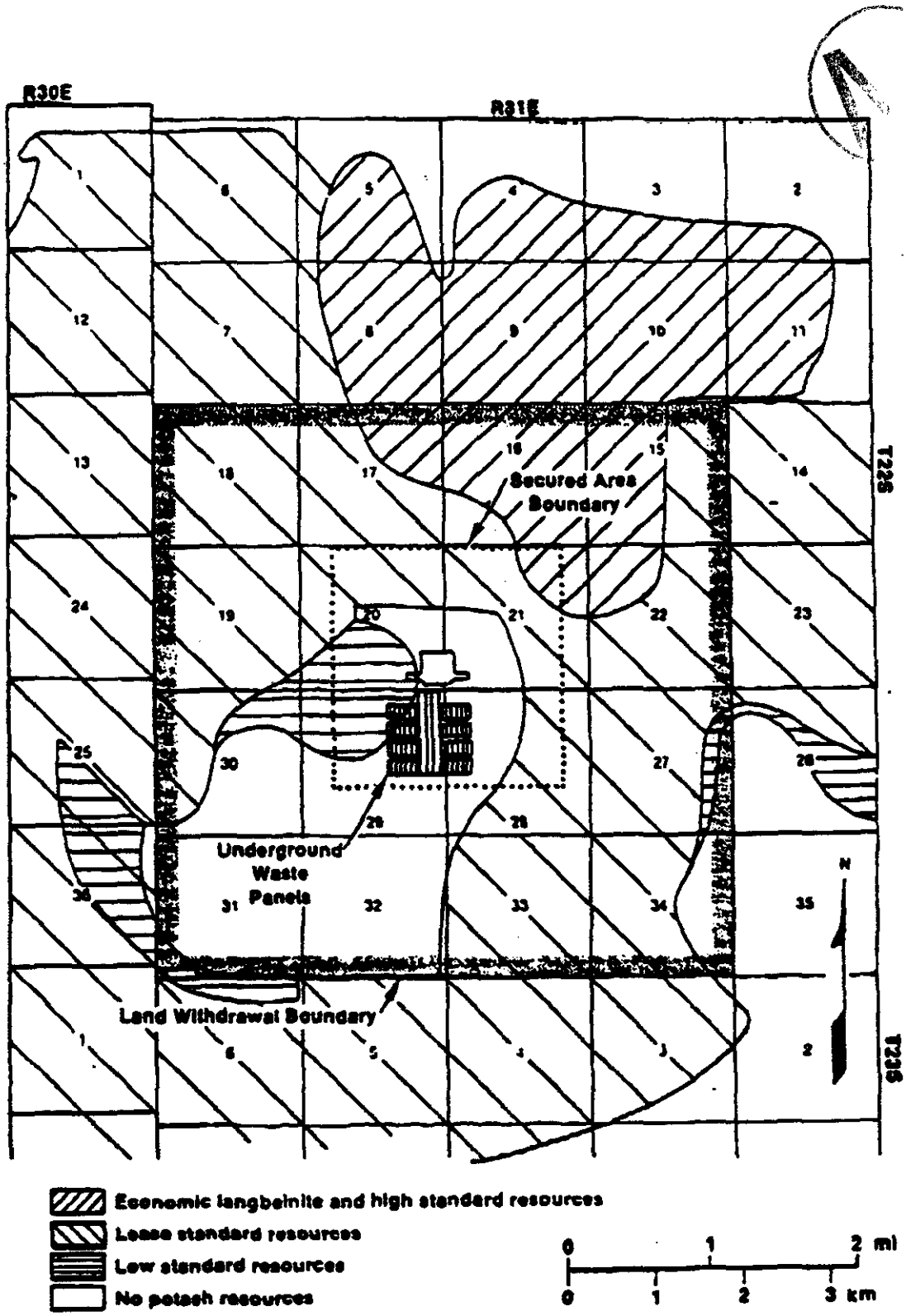

Figure 3-29. **Generalized Distribution of Potash Resources in the Vicinity of the WIPP (reproduced from Guzowski, 1990; potash distribution from Brausch and others, 1982; base map from DOE, 1986).**

the WIPP, the PART believes that the natural resource issue as raised in §191.14 (e), must be openly examined, in order to determine and clearly state DOE's position regarding the oil/gas and potash resources around the WIPP and address the EEG concerns regarding potash mining and drilling frequencies. The regulations do not preclude siting disposal systems in areas with natural resources, but they do require that the pros and cons be evaluated and clearly stated.

An additional geometric scale concern relates to dissolution and collapse features at the regional scale, see **Figure 3-30.** These sinks may be naturally occurring or may result from water injected in petroleum recovery processes, as noted by Baumgardner et al. 1982, p. 33: "Although the Wink Sink may be the result of natural processes, oil field operations in the area may be related to its formation." Given the proximity of petroleum operations to the WIPP site, care should be taken to monitor the salinity of injected and produced water and to monitor the ratio of water in to water out. This failure scenario may belong to a class of scenarios that have been addressed in the past and dismissed as not being of concern to the WIPP. Unfortunately, these previously considered and dismissed scenarios are not covered in the Annual PA Reports and are not currently available in a summary document. Such a summary document of the history of WIPP is being developed but will not be completed in time for the current review (Wendell Weart, May 27, 1993, personal communication).

Although large scale subsidence at the WIPP site appears unlikely, barring solution phenomena discussed above and given the relatively low extraction ratio, PA personnel, researchers, and designers should be aware that substantial subsidence has occurred over mine workings in the Carlsbad mining district. Miller et al. (1958), report on underground movement and subsidence over United States Potash Company Mine, which is located 22 miles east of the city of Carlsbad. These and other presumably abandoned mine workings may perturb the assumed hydrogeologic field in the repository region.

Beyond the issues related to inadvertent human intrusion, the major technical issues are associated with performing experiments and modeling to develop a credible characterization and understanding of the rocks and fluids of the Salado and the interactions of these rocks and fluids with the wastes and the engineered barriers and their various components, so that the required compliance analyses can be developed for the post-decommissioning phase. The first step involves understanding and characterizing the rocks of the Salado prior to the post-decommissioning phase, as this knowledge is needed to provide the initial conditions for the PA modeling of the post-decommissioning phase.

The technical issues prior to the post-decommissioning phase are associated with understanding and characterizing

- the initial development of the disturbed rock zone (DRZ), around each disposal room (**Figure 3-31**), the access drifts, and the shafts during construction (e.g., size and extent, and the effect on undisturbed rock properties);
- the subsequent evolution (during the various phases of repository development until post-decommissioning) of the DRZ surrounding the rooms and access drifts as a result of:
  - a) the plastic flow of the salt due to high stress gradients,
  - b) any excessive forces or high strain rates that could result in fractures developing as hypothetically shown in Figure 3-31, and
  - c) the drying of the DRZ and surrounding rock mass as a result of drainage of the intergranular brines from the salt and nearby interbeds due to the altered properties of the

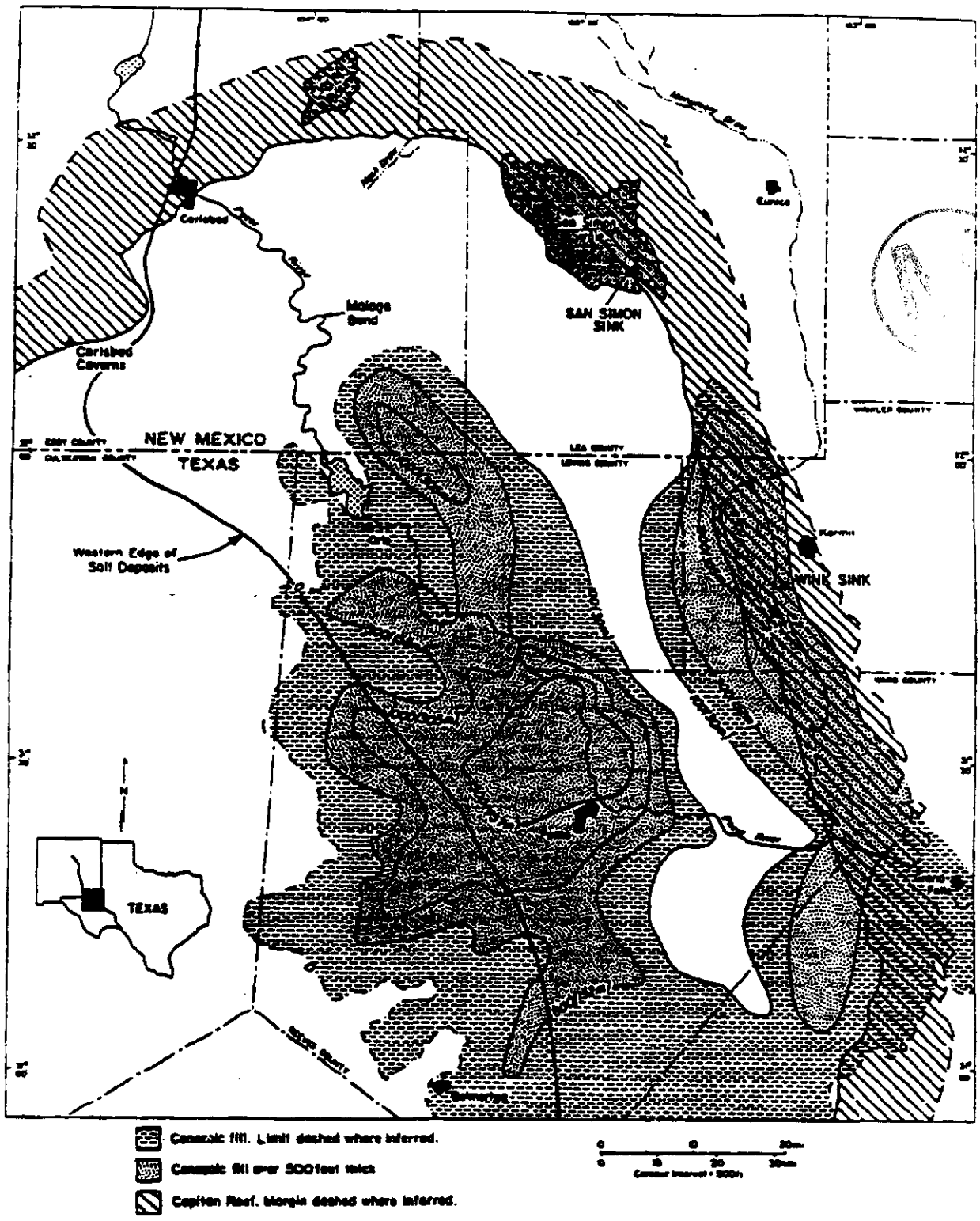

Figure 3-30. **Dissolution and Collapse Features, and Isopach Map of Cenozoic Sediments, Delaware Basin. Cenozoic sediments more than 152 m (500 ft) thick (stippled area) overlie salt dissolution zones in center of basin and along eastern side. Other dissolution features coincide with subsurface trend of Capitan Reef on northeast side of basin. Adapted from Maley and Huffington (1953), Nicholson and Clebsch (1961), Hiss (1975), and Bachman (1976).**

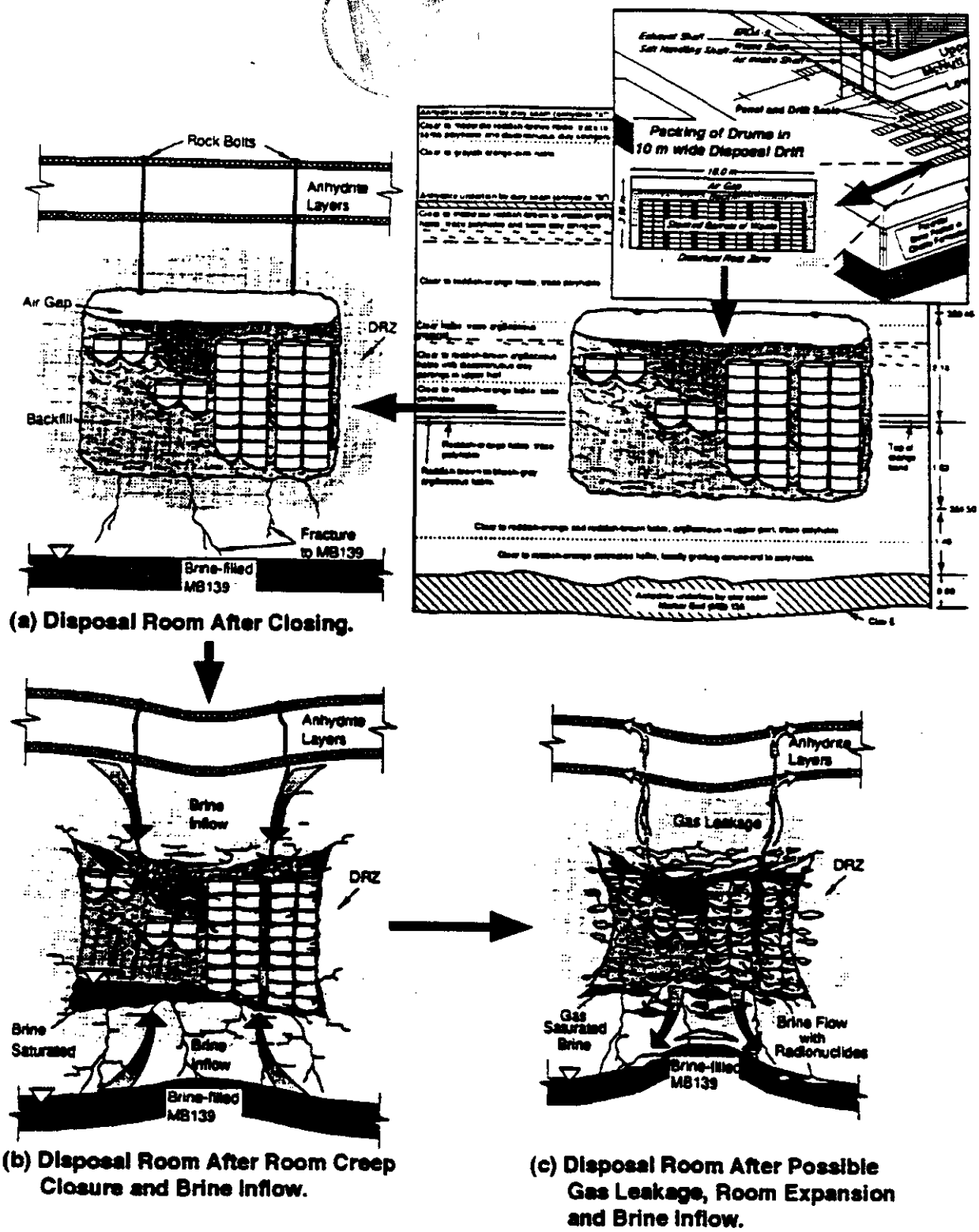

Figure 3-31. **Diagram Illustrating the Conceptual Evolution of a Disposal Room Within a WIPP Waste Panel. Illustrated in the upper left is the setting for a typical disposal room relative to the stratigraphy at depth and the progression of states, starting with (a) an idealized depiction of the disposal room after closure; (b) the disposal room after creep closure and brine inflow, and (c) the disposal room after possible gas leakage, room expansion and brine inflow. (Reference 1991 PA)**

DRZ, coupled with the tremendous gradients toward the openings and the enormous drying potential of the mine ventilation system;

- interactions with and effects on the closest interbeds above the drifts (anhydrite B, which is penetrated by rock bolts and underlain by clay seams, Figure 3-31) as well as the very heterogeneous marker bed 139 below the drifts, **(Figure 3-32).**

As illustrated in Figures 3-30 and 3-31, even the "thick halite" sections at the room emplacement horizon are rarely pure halite, but rather consist of various mixtures of halite, polyhalite, and argillaceous materials, as well as clay discontinuities.

The technical issues that must be investigated by compliance-based experimentation, characterization, and observations during the test phase and confirmed during the subsequent disposal phase are outlined in the following paragraphs. Some of the uncertainty in the following issues can possibly be addressed by avoidance through design changes (e.g., engineering aimed at preventing excessive pressure buildup in the disposal rooms) and by DOE planning (e.g., reducing the uncertainty in gas-generation rates and volumes through waste form requirements for that large fraction of the TRU wastes that has not yet been generated).

An understanding must be developed regarding how the DRZ and any associated fractures or other disturbances heal during creep closure of the drifts and shafts as the rock mass in the surrounding units of the Salado equilibrate with the emplaced wastes and room backfill, drift backfill, and seals, shaft seals, and any other emplaced engineered components (e.g., rock bolts). Two basically different conditions must be examined.

1) **Closure Under Conditions of Little Gas Generation.** Understanding is required for those conditions expected to occur (a) around shaft seals where there would only be interactions of the DRZ with the highly layered and heterogeneous Salado rocks along the vertical shafts (Figure 3-32) and the rather uniform and preconsolidated crushed salt backfill being considered for the shaft seals, and (b) in the partially backfilled access drifts and rooms of the operations region and experimental area (Figure 2.8).

   In these areas, and under these conditions, there would be few additional driving forces opposing room or shaft closure and DRZ healing as the entire system returns to pre-emplacement equilibrium. There is likely to be a small component of gas generation related to corrosion of the rock bolts and some resistance encountered as a result of compression of residual atmospheric gases in the void space above the crushed salt backfill in the drifts of the operational and experimental regions. These gases will compress and slowly dissipate into the surrounding accessible pore space, and some will dissolve in the intergranular brines that should move into the region during closure and healing.

2) **Closure Under the Conditions of Gas Generation.** Understanding is also required for those conditions expected to occur in disposal rooms where interactions among the waste, engineered components, and the Salado rocks and fluids (i.e., intergranular brines) will generate gases as a result of a variety of processes (e.g., anoxic corrosion of metals such as Fe and Al in the proposed containers, the waste, and engineering components like the rock bolts; microbial degradation of organic wastes such as cellulosics and rubber; radiolysis of brine and other waste components such as plastics; and volatilization of radioactive and hazardous VOCs).

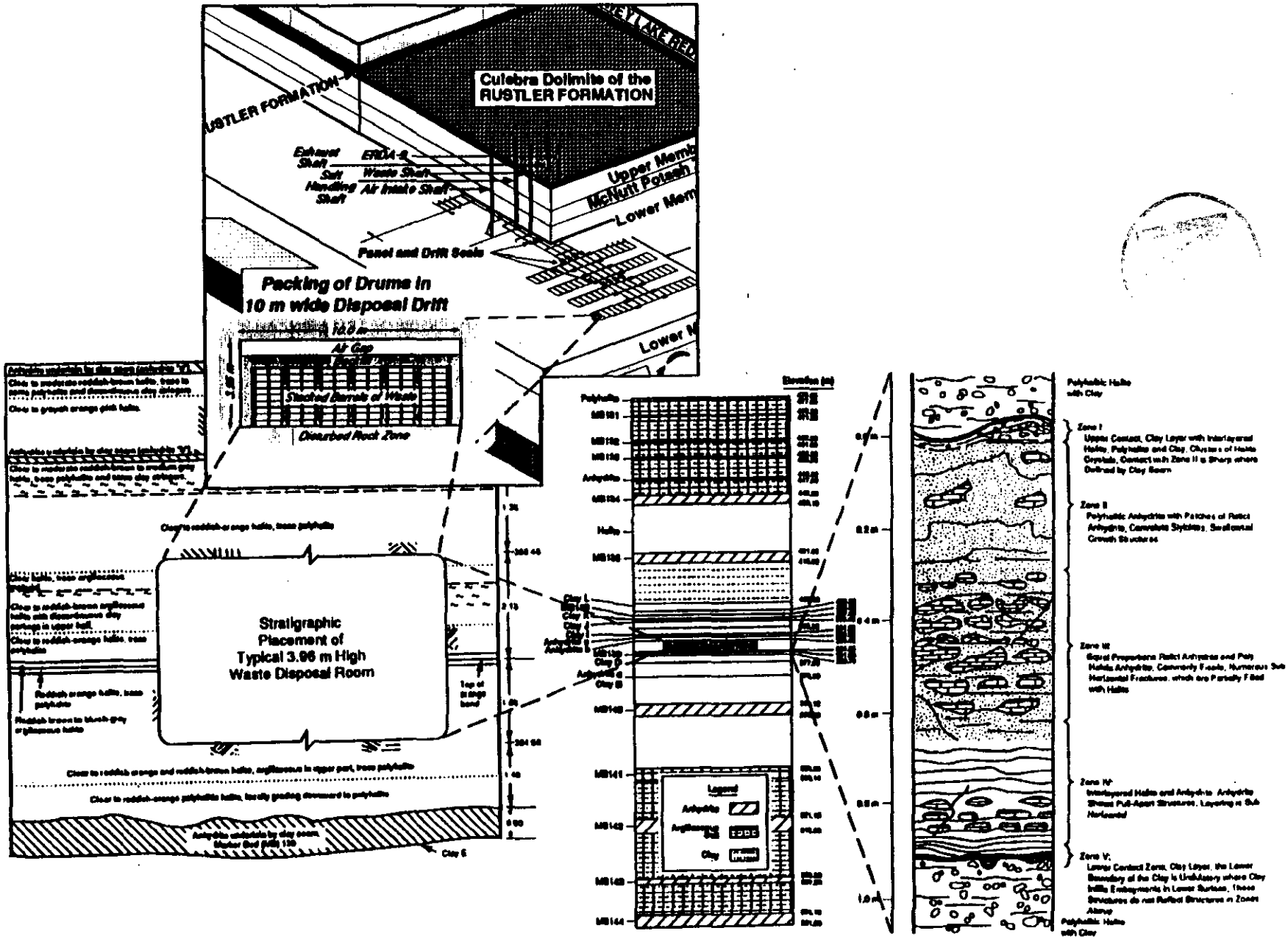

Figure 3-32. **Illustration of the Various Scales of Spatial and Lithological Variation within the Salado Formation Near a Disposal Room and the Disposal Horizon.**

Under these conditions, the behavior is much more difficult to understand fully and thus to predict with certainty because of the complicated coupling and interactions among the various processes involved. For ease of discussion, let "disposal room pore space" be defined as the combined pore space in (a) the wastes in various states of compression and degradation, (b) any remaining headspace in the disposal room drift (i.e., the air gap illustrated in Figure 3-31), (c) the backfill located in the disposal room drifts around the waste, and (d) the DRZ and any fractures associated with these drifts. While the processes and interactions are complex, it is believed that if gas is produced in the appropriate volumes, transport toward the accessible environment can occur (most likely through the anhydrite layer B or MB-139, Figure 3-31) as illustrated in the pathways diagram, Figure 3-27. The increased pressure associated with gas generation provides the driving force, and the generated gases provide the vehicle for transport of any hazardous and radioactive wastes that might volatilize into the disposal room pore space. The various processes expected to be active and their principal effects are outlined below, borrowing five items from the discussions in DOE/WPIO/001-92, 1992; Chan et al., 1992; Davies et al., 1991; and Davies, 1991.

- *Gas generation processes* increase the volume of gas in the disposal room pore space. It is also important to note that both the rate of generation and the total volume of gas generated are dependent on the rate of brine inflow. Gas generation rate therefore can be modulated (i.e., increased or decreased) in response to changes in the brine inflow rate to the disposal room pore space.
- *Mechanical processes* of room closure and consolidation of the materials within result in a reduction of the disposal room pore space and changes in other physical properties of the materials being consolidated (e.g., lowering of the permeability). This process is driven by lithostatic forces that can be opposed by the backstress on the salt provided by fluid pressure buildup in the disposal room pore space.
- *Multiphase fluid flow and transport processes* control the flow of fluids (i.e., gases and brine) into and out of the disposal room pore space and the pore space of the surrounding Salado rocks. Flow is driven by the differences in pressure between the fluids of the surrounding Salado rocks and the fluids in the disposal room pore space in a nonlinear way that is highly dependent on the state of connectivity of the wetting (i.e., brine) and non-wetting (i.e., gases) fluid phases . According to Davies (1991), large threshold pressures may be required to initiate gas penetration and movement in the brine-saturated matrix of Salado rocks that is highly dependent on the type and purity of the Salado evaporites; see Subsection 5.4 for a discussion of threshold pressures.
- *Pore space dilatation* can result if excessive pressures build up in the disposal room pore space, and a phase of disposal room expansion can result. These excessive pressures can give rise to pressure-sensitive inelastic flow that can result in interface separation in the bedded salts of the Salado, fracture extension/expansion, and other forms of damage evolution in crystalline evaporite solids of the Salado.
- *Dissolution and exsolution of gases* occur when gases in the disposal room pore space and gases migrating in the interbeds come into and remain in equilibrium with the gases dissolved in the brines that can coexist in the pore space by moving into and out of solution, depending on the pressure/solubility relationship.

As discussed in Davies et al. (1991), the above processes are highly coupled. The actual pressure history in the disposal room pore space is dependent on the volume of disposal room pore space (mechanical processes of room closure and consolidation; pore space dilatation) and the difference between the rate of gas generation and the rate that fluids can leave the disposal room pore space (multiphase fluid flow and transport processes).

One possible sequence of states is illustrated in Figure 3-31 (a-c) and details will be discussed in Sections 6 and 7.

The potential for the waste to generate gas requires that any potentially negative responses to gas generation be evaluated. For example, if sufficient quantities of gas are generated and released to the nonhalite interbeds, there is a possibility for this generated gas to (a) disrupt the drift and panel sealing process (depending on how soon the release occurs), and/or (b) transport hazardous gaseous wastes (e.g., VOCs) to the compliance boundary (DOE/WPIO/001-92, 1992). If the disposal rooms or panels seal sufficiently to form pockets of highly pressured brine and gases, these localized pockets could potentially increase or decrease the effects associated with human intrusion. These effects, and the various possible methods for dealing with the uncertainties associated with room closure, under conditions of gas generation, need to be evaluated. Some of the general sources of uncertainty include lack of an appropriate level of knowledge regarding

- the actual character of the waste;
- the potential amount and type of gases that can form;
- the rate of gas generation;
- the potential closure sequences and end closure states; and
- the processes needed to predict the potential closure and consolidation sequences and the end closure states.

4.0 WIPP SITE NATURAL SYSTEM

Critical to any PA is the geology of the site where the waste will be emplaced. In this section, the undisturbed natural hydrologic and other properties of the geologic formations at the WIPP site are described in order to provide a starting condition from which to evaluate subsequent perturbations. The formations described in this section are the Castile (Subsection 4.1), which begins about 200 m (650 ft) beneath the repository level; the Salado (Subsection 4.2), which is the host formation; the Rustler (Subsection 4.3), which is considered to contain the most likely pathway for transport of radionuclides to the accessible environment, and the Dewey Lake Redbeds which, although they may not represent a pathway for the migration of radionuclides, may control the flow of recharge to the underlying units of the Rustler Formation.

According to Mercer (1983), the majority of geologic studies in the area prior to the beginning of the WIPP project in 1972 were confined to the Bell Canyon Formation and units below it, although extensive work has been done by the potash industry in the overlying strata. These units below the Salada Formation have been heavily studied for more than fifty years because of their oil/gas resource potential. The first discussions of the geologic units above the Bell Canyon were by Lang in 1937. This geologic study was followed closely by the first hydrologic study of the area (Robinson and Lang, 1938), which, in turn, initiated a series of studies continued until at least 1980, on the Malaga Bend salinity problem. The other significant geologic and hydrologic studies conducted in the area (particularly the Rustler) were undertaken as part of the Gnome experiment (Figure 3-15) which involved an underground nuclear test in salt.

Early WIPP investigations began with a review of the geology and hydrology of the Carlsbad potash area by Brokaw et al. (1972), according to Mercer (1983). Other early WIPP efforts included studies by Jones et al. (1973) and by Mercer and Orr (1977) on the Los Medanos area and the regional hydrology of the WIPP area, respectively and by Powers et al. (1978). Also, as discussed in Mercer (1983), hydrologic study details are presented in data reports by Mercer and Orr (1979) and Mercer and Gonzalez (1981).

According to Lappin et al. (1989), the data on the Rustler Formation presented in DOE's 1980 FEIS were derived from testing performed at eight locations, while Mercer indicates that his 1983 study, data collection and interpretations were based on efforts undertaken and hydrologic data collected from tests conducted over seven years, starting in 1975, at thirty-nine wells which were drilled for or converted to hydrologic test holes. Mercer's 1983 efforts provided estimates for determining potential hydrologic boundaries (Figure 3-15), potentiometric head distributions (e.g., Figure 3-13), groundwater chemistry, hydrologic properties from pumping, slug, pressure-pulse, and tracer tests, and the location of dissolution fronts based on halite distribution. The discussions on the Rustler presented by Lappin et al. (1989) were based on information collected from a total of forty-one well locations.

From the limited number of documents reviewed by the PART, it appears that Mercer's hydrologic investigation and interpretation form the basis for much of the regional interpretation of the supra-Salado hydrologic system at WIPP. The 1992 PA discusses a preliminary geohydrologic conceptual model developed by Brinster (1991), but this report was not reviewed by PART.

Dissolution in the WIPP area is complex and is considered in a series of articles on the Cenozoic history of the area starting with Bachman in 1973 (Mercer, 1983). Mercer further indicates that additional

interpretations of dissolution have been prepared by Anderson, 1978 and 1981, and Lambert, 1982. The whole series of issues and controversies regarding the origin of the regional dissolution in the Rustler Formation is summarized in LaVenue et al. (1990). Some of the authors and studies reviewed by PART include Bachman (1980 and 1985); Snyder (1985); Chaturvedi and Channell (1985); Lowenstein (1987); and Holt and Powers (1988).

The eleven groundwater modeling studies of the Rustler and/or the Culebra through the 1991 modeling by the WIPP PA division are illustrated and summarized in **Figure 4-1**, taken from LaVenue and RamaRao (1992). The LaVenue and RamaRao modeling study discusses the use of a completely automated inverse procedure to develop seventy calibrated conditional simulations for the Culebra transmissivity field based on the use of steady-state and transient field pressure data. These seventy realizations were the basis for the 1992 PA calculations. Lappin et al. (1989), as well as Davies (1989) and LaVenue et al. (1989), summarize many of these studies through 1990. Davies' study represents the only variable density modeling (a 2D subhorizontal section model). Current PA models assume the Culebra to be a totally confined, vertically homogeneous, and laterally isotropic unit with no vertical flux, even though the Davies (1989) and Haug et al. (1987) studies support the vertical flux concept, (Lappin et al., 1989).

SAND88-0196 edited by Siegel et al. (1991) is a compendium of six hydrochemical studies of the Rustler. Their brief interpretation of these studies is that modern flow within the Culebra is largely north to south; however, as already discussed in Subsection 3.2.2, this flow direction (assumed equilibrium) is inconsistent with the salinity distributions in the region. Siegel et al. (1991) also postulate that eastward increasing $^{234}U/^{238}U$ activity ratios could imply a Pleistocene infiltration zone flowing from the west-northwest and thus imply a change in flow direction during the last 30,000 to 12,000 years.

4.1 CASTILE FORMATION

The Castile Formation, beginning about 200 m beneath the repository level, consists of about 470 m of interbedded anhydrite and halite resting on the Bell Canyon Formation. The uppermost anhydrite layer of the Castile contains isolated pockets of pressurized brines that occur in limited reservoirs characterized by fracture porosity in a very tight matrix (Popielak et al., 1983; Lappin et al., 1989). These brine pockets have been encountered in thirteen of about 100 wells that have penetrated the Castile Formation, including the WIPP-12 reservoir 1.6 km (1 mile) north of the center of WIPP (Lappin et al., 1989, Figure 3-26). Time domain electromagnetic methods (TDEM; Ertech, 1988) measurements detected the brine occurrence at WIPP-12 and indicate that brines may be present within the Castile Formation under a portion of the WIPP waste panels (Lappin, 1988).

Popielak et al. (1983), in a characterization of Castile brine occurrences and detailed discussion of ERDA-6 and WIPP-12 testing, found the reservoirs to be chemically distinct from each other and from local groundwaters. The ERDA-6 and WIPP-12 halite-saturated brine reservoirs, with estimated volumes of 1.0×10^5 and 2.7×10^6 m^3, respectively, are located in fractured anhydrites above thickened halite. About 5% of the brine volume is stored in large open fractures; the remainder occurs in low-permeability microfractures. Median parameter values (PA 1992, 3, pp. 4-10) for permeabilities of the intact and fractured anhydrite matrix are 1×10^{-19} m^2 and 1×10^{-13} m^2, respectively, an intact porosity of 5×10^{-3}, fluid pressure of 12.7 MPa (lithostatic and hydrostatic pressures are about 20 and 9 MPa, respectively), and bulk storativity of about 0.2 m^3/Pa (volume of fluid discharged/unit decrease in reservoir pressure).

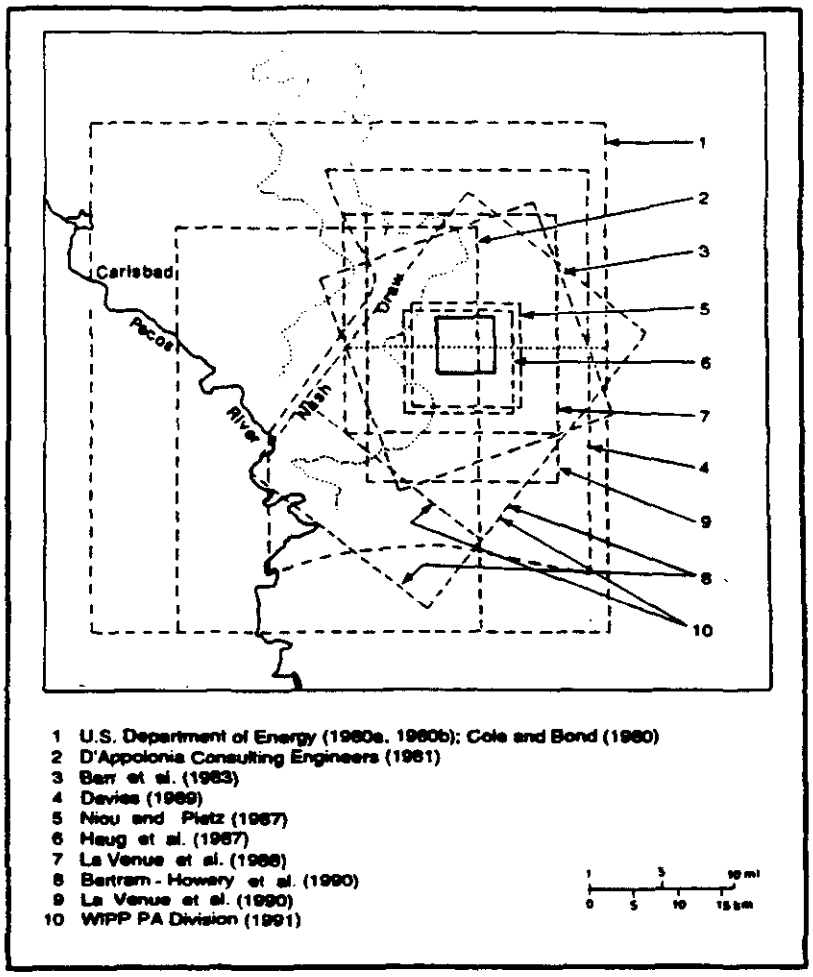

Reference	Hydrogeologic Unit Modeled	Head Calibration
U.S. DOE (1980a,b)	Rustler	Steady State
D'Appolonia (1981)	Rustler	Steady State
Cole and Bond (1980)	Rustler	Steady State
Barr et al. (1983)	Culebra	Steady State
Davies (1989)	Culebra	Steady State
Niou and Pietz (1987)	Culebra	Transient
Haug et al. (1987)	Culebra	Steady State
LaVenue et al. (1988)	Culebra	Steady State
Bertram-Howery et al. (1990)	Culebra	Steady State
LaVenue et al. (1990)	Culebra	Steady State/Transient
WIPP PA Division (1991)	Culebra	Steady State

Figure 4-1. **Summary of Early Rustler and/or Culebra Modeling Studies: (a) Approximate Boundaries of Groundwater Flow and Transport Models in the WIPP Region (reproduced from Lappin et al., 1989, from Davies, 1989); (b) Summary of these Investigations (reproduced from LaVenue and RamaRao, 1992).**

These brine pockets are of limited extent, have been isolated for long periods of time, and pose no threat to the overlying repository in the undisturbed state.

4.2 SALADO FORMATION

Bedded salts (**Figure 4-2**) in general contain appreciably more water (0.1 to 1.0 wt %) than do domal salts (less than .01 wt %), not only because of interbedded clays and other hydrous impurities within the halite layers, but also because of fluid inclusions (**Figure 4-3**) trapped by rapidly accreting halite crystal faces. Knauth and Beeunas (1986) studied oxygen (^{18}O) and deuterium isotope concentrations in brines from fluid inclusions in halite crystals from Salado salt and found that the brine has a composition consistent with that of connate waters trapped during evaporation of Permian seas. Intracrystalline brine inclusions in the Salado, however, do not constitute a viable source for brine because high temperatures and substantial thermal gradients are required for their migration to boundaries of halite crystals. Intergranular water, that between grains forming the rock salt layers, may be available for transport and does exist in the Salado, as evidenced by weeps in the WIPP rooms (e.g. Deal and Case, 1987; Nowak et al., 1988; Tyler et al. 1988; Bredehoeft, 1988; Lappin et al., 1989). However, these mined surfaces and boreholes have been disturbed by the excavations, and at the very low permeability of undisturbed Salado salt (less than 10^{-21} m^2), even extremely slow flow of brine through the salt is both questionable and negligible.

Forty-five anhydrite- and polyhalite-rich interbeds or marker beds (MB) in the Salado Formation have been identified and numbered; other thinner, but laterally persistent, interbeds of clay, anhydrite, and polyhalite occur throughout the unit. Waste disposal panels are excavated between MB 138 and MB 139; floors of rooms are 1.4 m (4.55 ft) above MB 139 and roofs are 12 m (39 ft) below MB 138. These interbeds, especially MB 139, along with anhydrate layers A (5 m {16.25 ft} above the roofs) and B (2.6 m{8.45 ft}above roofs), are regarded as primary potential pathways for migration of brine and gas because of their higher intrinsic permeability compared to halite layers and their brittle behavior relative to the ductile or plastic and self-healing behavior of the halite. Borns (1985) described the petrologic character of the heterogeneous, 1 m-thick (3.3 ft) MB 139 (Figure 3-32). The top of the bed is defined by a clay layer with intercalated halite, polyhalite, and clay. This thin layer grades downward to a 0.6 m-thick (1.95 ft) layer first dominated by polyhalitic anhydrite containing patches of relict anhydrite, followed by a zone of equal proportions of the two rock types. This lower zone, about 0.3 m-thick (0.97 ft), is readily separated along subhorizontal planes (fissile) and contains subhorizontal fractures partially filled with halite. The base unit of MB 139 consists of 0.15 m-thick (0.49 ft) interlayered halite and anhydrite, grading into the lowermost contact zone, an undulating clay layer.

Halite's undisturbed permeabilities, estimated primarily from multipacker test-fluid pulse withdrawal results, range from too low to measure to 6.8 X 10^{-22} m^2. Anhydrite far-field values range from 3 X 10^{-20} to 4.4 x 10^{-20} m^2, generally one to two orders of magnitude higher than for the halite (Gorham et al., 1992, Table 3). Far-field pore pressure in the anhydrite is apparently well-established at near 12.5 MPa, whereas that in nearby halite is about 3 MPa lower; these values may be compared with hydrostatic and lithostatic pressures of about 7.0 and 14.8 MPa, respectively (1992 PA, Volume 3, p. 2-40). Porosity of both halite and anhydrite in the far-field, based on drying experiments, and electromagnetic and DC resistivity measurements, ranges from .001 to .03 with a median value of .01, in accord with grain and bulk density determinations (PA, 1992, Volume 3). The flow properties of the Salado Formation are very heterogeneous; each tested halite layer and interbed has its own characteristics

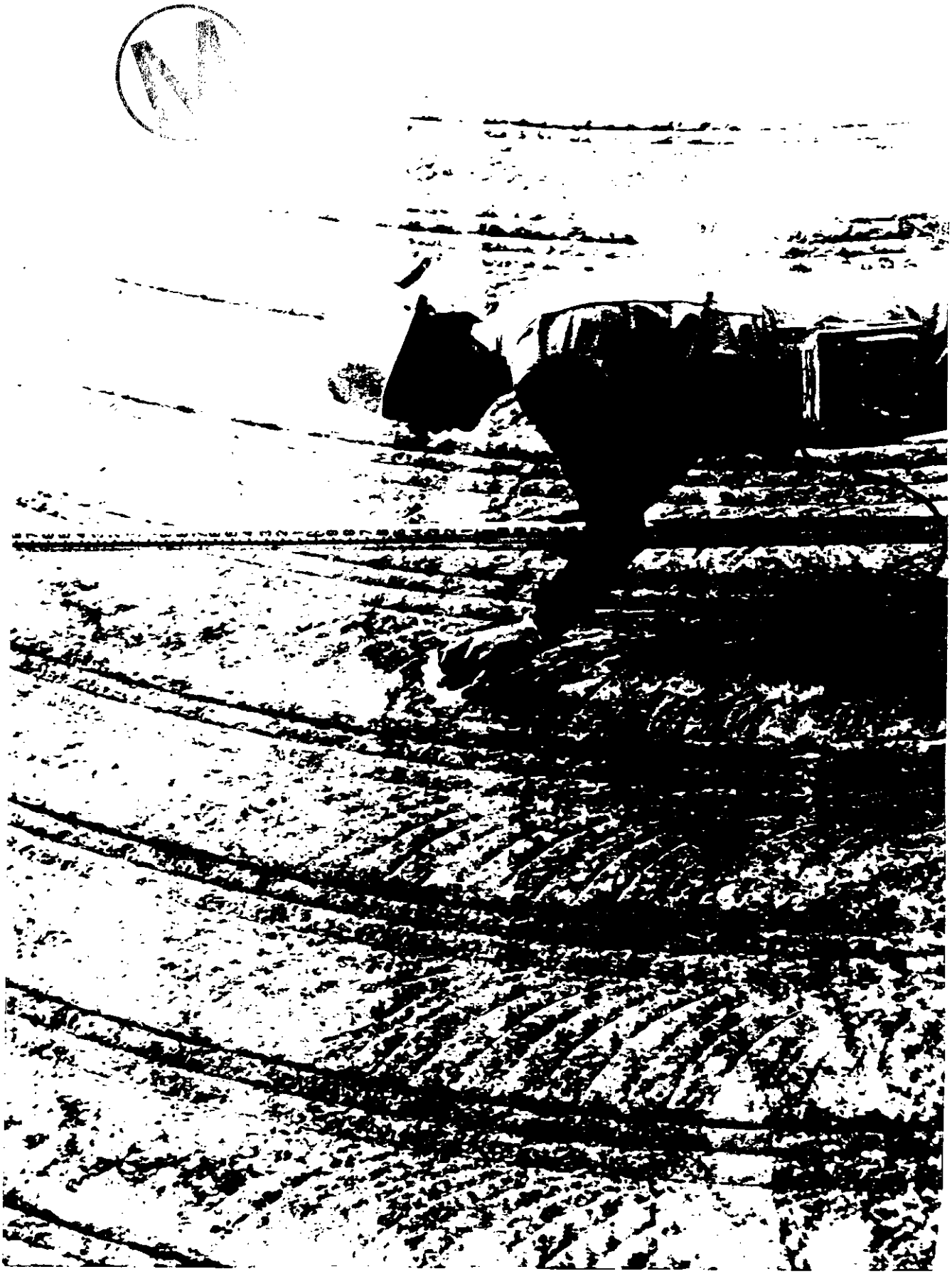

Figure 4-2. Photograph of the Salado Formation at the Repository Horizon. Dark vertical lines were created by the mining equipment. The pink horizontal bands are composed of relatively pure (light) and impure (dark) halite.

Figure 4-3. Fluid Inclusions in Halite Crystal.

(Howarth et al., 1991). As pointed out by Beauheim et al. (1991), information available is still insufficient to validate the assumption that brine migration through halite of the Salado Formation occurs by Darcy flow through a porous medium in response to continuous pore pressure gradients, rather than by flow initiated through connections of isolated pores following a disturbance (McTigue et al., 1989).

4.3 RUSTLER FORMATION

The Rustler Formation (**Figure 4-4**) is considered to contain the most likely pathway for transport of radionuclides to the accessible environment (SAND92-0700/2, 1992), since it lies directly above the Salado Formation and contains the most productive hydrostratigraphic units in the WIPP area (Mercer, 1983). Specifically, the Culebra Dolomite Member of the Rustler Formation has been identified in the scenarios developed for long-term performance assessment as the unit that could provide a path to the accessible environment in the event of inadvertent human intrusion for petroleum resources (DOE/WIPP 89-011, 1993). Subsection 4.0 discussed the general stratigraphy, geohydrologic setting, and geohydrology of the supra-Salado hydrologic system for the area around the WIPP site. This subsection presents more detailed information on the Rustler Formation, specifically the Culebra Member, and discusses ongoing and planned activities as they relate to the PA modeling of the Culebra.

4.3.1 Rustler Formation Stratigraphy, Hydrology, and Chemistry

According to Mercer, the Rustler Formation, which is a key marker of the Permian, was named by Richardson (1904), and the five-fold division of the Rustler (left side of Figure 4-4) was described by Vine (1963). Five transmissive Rustler units are now recognized, as illustrated in Figure 4-4 instead of the three (Culebra, Magenta, and the residuum at the Rustler-Salado contact) recognized at the time of the FEIS (Lappin et al., 1989). As illustrated in Figure 4-4 a water producing mudstone/halite unit has been identified within both the Forty-Niner and Tamarisk Members. The variation in the thickness of the Rustler Formation from 8.5 m (27 ft) west of the site through 95 m (309 ft) at WIPP to 216 m (712 ft) east of the site is attributed to thinning by dissolution and erosion (SAND92-0700/2, 1992). This is attested to by the three breccia and claystone zones (**Figure 4-5**) that abut their corresponding halite zones within the Rustler. These zones, interpreted by Chaturvedi and Channell (1985), are referred to as the upper, middle, and lower dissolution residues. However, the laterally-varying depositional facies model of Holt and Powers (1988) has considerable merit. As indicated in Snyder (1985), a complete unaltered thickness of all members of the Rustler can only be found east of the WIPP site. The lithology, thickness variation, and other hydrologic characteristics of the five members of the Rustler Formation are briefly summarized in the following subsections, starting at the top of the Salado Formation.

4.3.1.1 The Unnamed Lower Member

This member is 36 m (117 ft) thick at the WIPP site (SAND92-0700/2, 1992) and consists of laminated to massive dark-gray siltstones and fine grained sandstones overlain by alternating beds of halite, siltstone, and anhydrite (Snyder, 1985; Lowenstein, 1987). Increasing amounts of halite are present to the east (Figure 4-5), and a contact residuum (**Figure 4-6 c**) that is quite variable in thickness (2.4 to 33 m {7.8 to 1.07 ft}) underlies the Rustler in the area of Nash Draw (Mercer, 1983; SAND92-0700/2, 1992). The basal unit of this member is the transmissive hydrologic unit, and its transmissivity increases to the west in Nash Draw due to fracturing of the basal siltstones and sandstones, possibly a

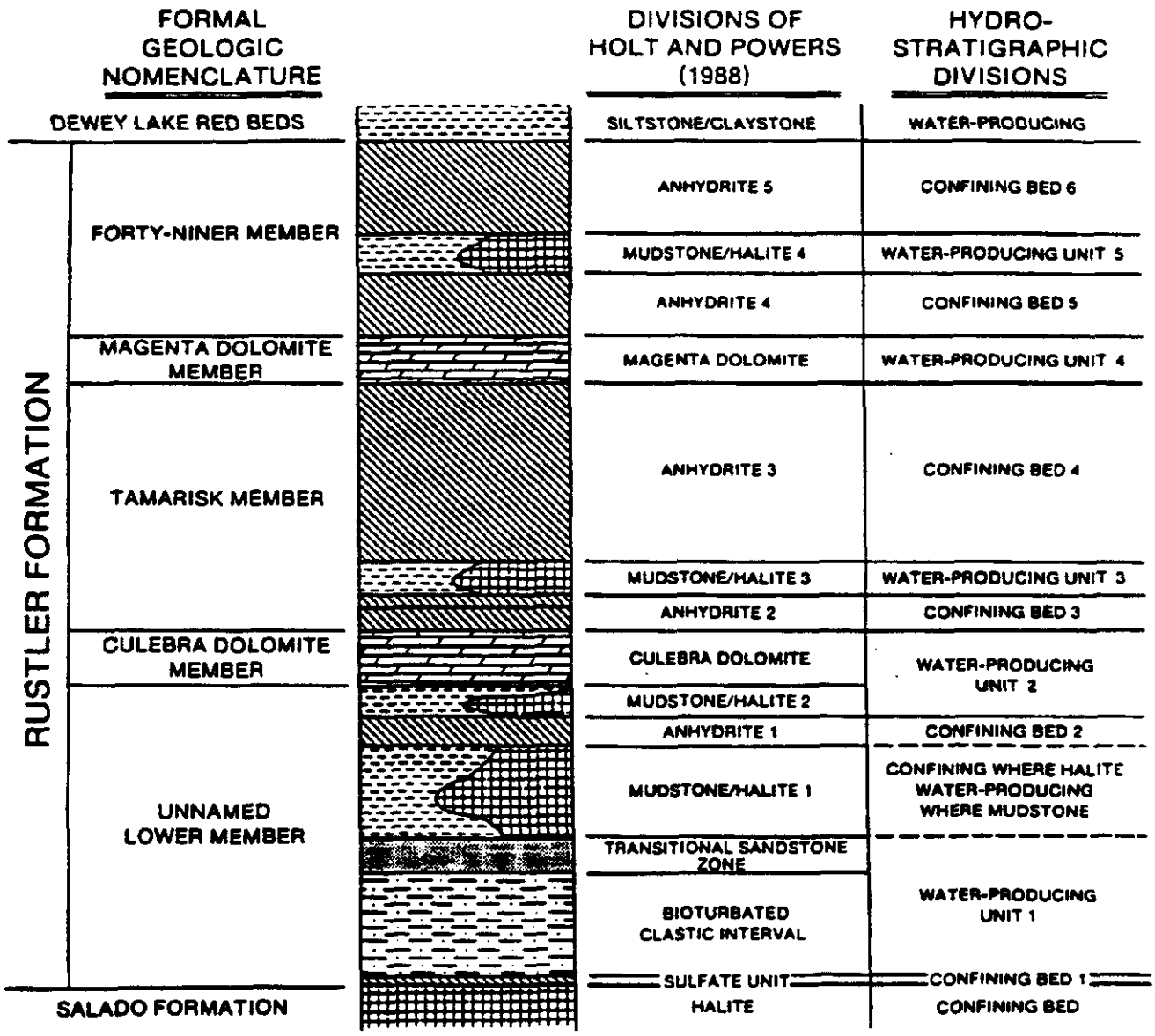

Figure 4-4 **Hydrostratigraphic Column of the Rustler Near the WIPP Site (reproduced from SAND89-0462, 1989, but prepared by Beauheim and Holt, 1990).**

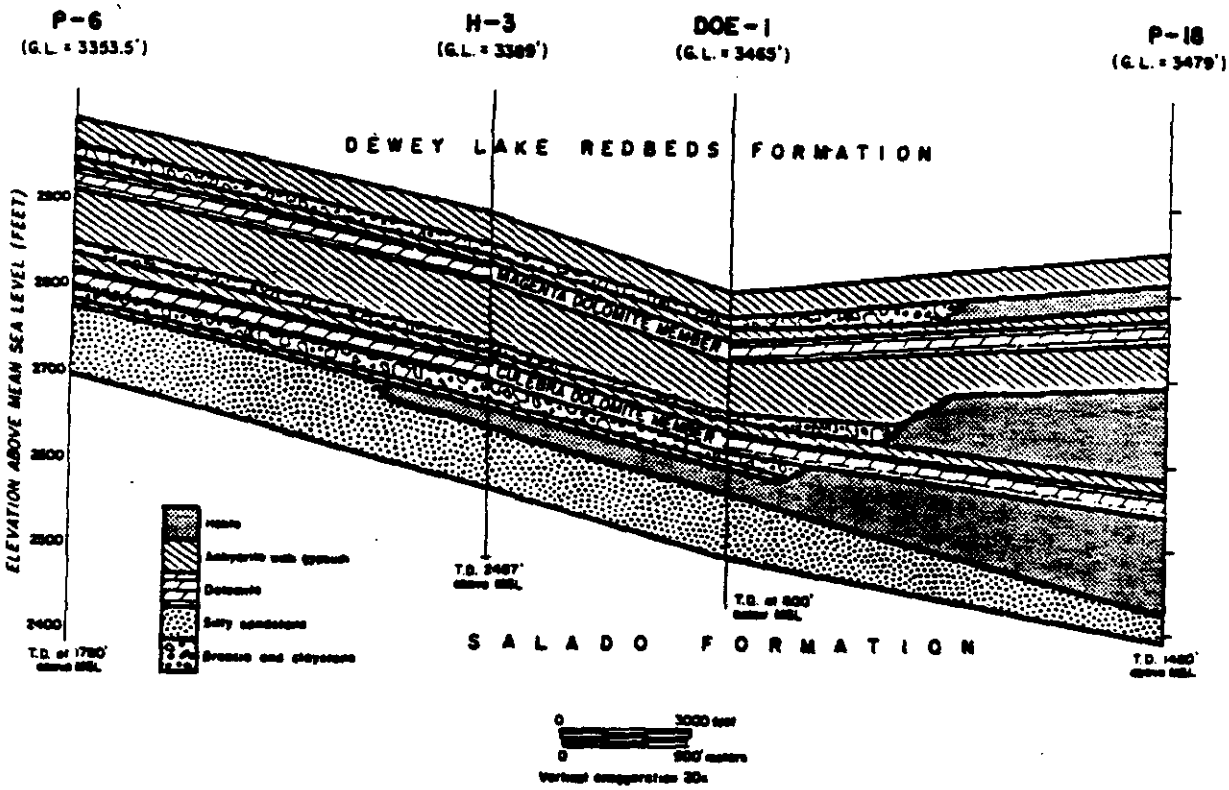

Figure 4-5 **Geologic Cross Section of the Rustler Formation at the WIPP Site (reproduced from Chaturvedi and Channell,1985).**

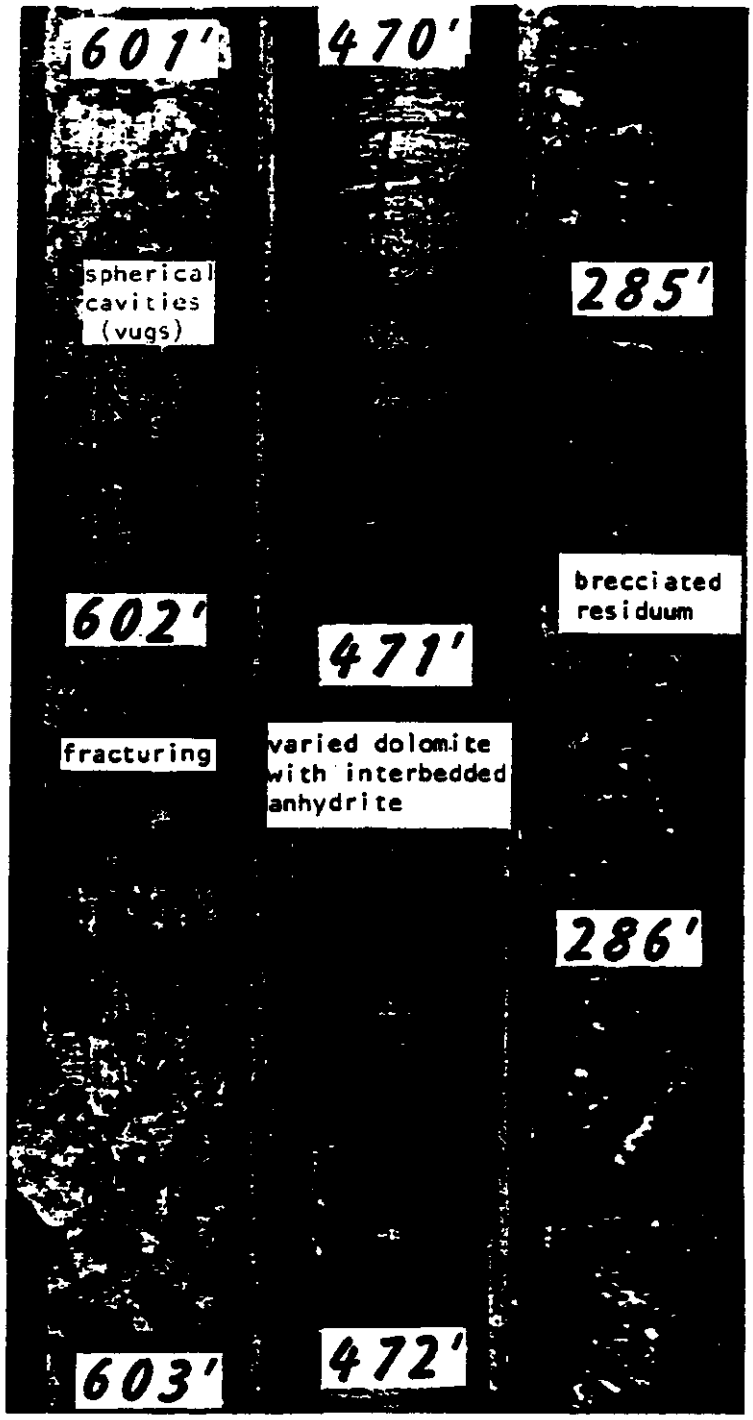

Figure 4-6. **Core sections from Hydrologic Units of the Rustler and Salado Formations (reproduced from Mercer, 1983): (a) H-8C, Culebra Dolomite Member; (b) H-8A, Magenta Dolomite Member; (c) H-7C, Rustler-Salado Contact Residuum.**

result of dissolutioning of the Upper Salado Formation and subsequent subsidence (SAND92-0700/2, 1992). The interpreted potentiometric surface for this hydrostratigraphic unit (Figure 3-22) was presented earlier (Subsection 3.2.2.1).

As discussed in chapter 1 of Siegel et al. (1991), most of the data from the non-Culebra units overlying the Salado are reported in Mercer (1983) and Beauheim (1987). Mercer (1983) indicates that waters in the Rustler-Salado contact zone or in the residuum contain the highest concentrations of TDS (79,800 mg/l at H-7 to 480,000 mg/l at H-1) in the WIPP area. Mercer assumes that large magnesium concentrations result from brines having had time for extensive interaction with their host rock and thus represent no or very slow circulation. He observed that these concentrations decrease one to two orders of magnitude in the area (**Figure 4-7**) and constructed an isoconcentration line (2000 milliequivalents per liter of potassium and magnesium combined, Figure 4-7) that approximates a dividing line between the zones of generally small concentrations to the west and the rapidly increasing concentrations to the east; [he also indicates that it represents a division of minute eastern transmissivity, 10^{-4} m^2/day (10^{-3} ft^2/day), to greater western transmissivity, 10^{-2} m^2/day (10^{-1} ft^2/day)]. Given his basic assumption and the lack of residuum east of this line, he concludes that it separates the active circulation zones to the west from the undeveloped flow system east of this line.

4.3.1.2 Culebra Dolomite Member

The Culebra Dolomite Member varies in thickness in the WIPP area from 4 to 11.6 m (13 to 37.7 ft) (mean 7 m {22.7 ft}; the PA Department uses 7.7 m {25 ft}) and is described as a vuggy microcrystalline dolomite or dolomitic limestone some of whose solution cavities (vugs) contain halite or gypsum (Figure 4-6 a), (Mercer, 1983; Snyder, 1985; SAND92-0700/2-3, 1992). This member is confined over most of the area by the mudstone/halite and anhydrite units of the unnamed lower member that it overlies and the thick anhydrite unit of the Tamarisk that overlies it (**Figure 4-8**), (Mercer, 1983). The structural character of the Culebra, according to Mercer (1983), is directly related to the character of dissolutioning of underlying units, and, as noted in SAND92-0700/2 (1992), "there is an apparent correlation between the absence of halite and increased transmissivity in the Culebra Dolomite Member." This is a result of subsidence and subsequent fracturing of the dolomite, as illustrated in **Figure 4-9**, which shows the highly fractured Culebra Dolomite resulting from halite removal at outcrop (Mercer, 1983). Discussion in the 1992 PA (SAND92-0700/2) indicates that the majority of the variability in hydraulic conductivity is believed to be controlled by open fractures (although no measurements of the density of open fractures is available due to poor recovery) because little variability was observed in the depositional environment and "primary features" of the unit. These discussions also indicate suspected correlations between open fracture density and the following features:

- overburden thickness,
- halite in surrounding members of the Rustler Formation,
- dissolution of halite, and
- the distribution of gypsum filling in fractures.

Other evidence of the variable nature of the Culebra structure is illustrated by the variable nature of the horizontal cores removed from Culebra units 3A and 3B (within 55 ft of each other horizontally and 5 ft vertically) in the air intake shaft at WIPP (**Figure 4-10**). These cores will be used in retardation experiments (to be conducted by Fred Gelbard, SNL, who was interviewed by the PART) that are

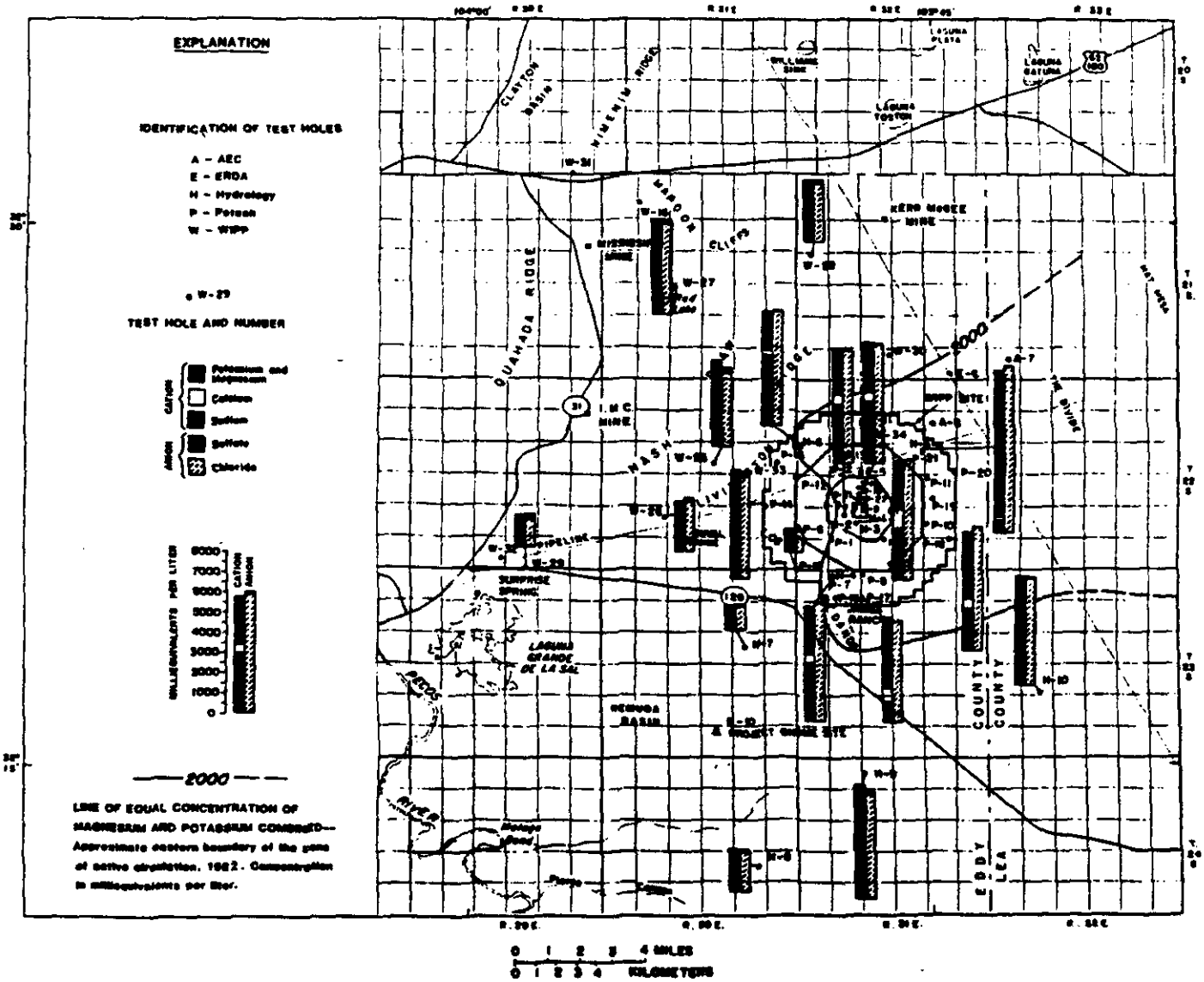

Figure 4-7. **Concentrations of Major Chemical Constituents in Water from the Rustler-Salado Contact Residuum at and Near the WIPP Site (reproduced from Mercer, 1983).**

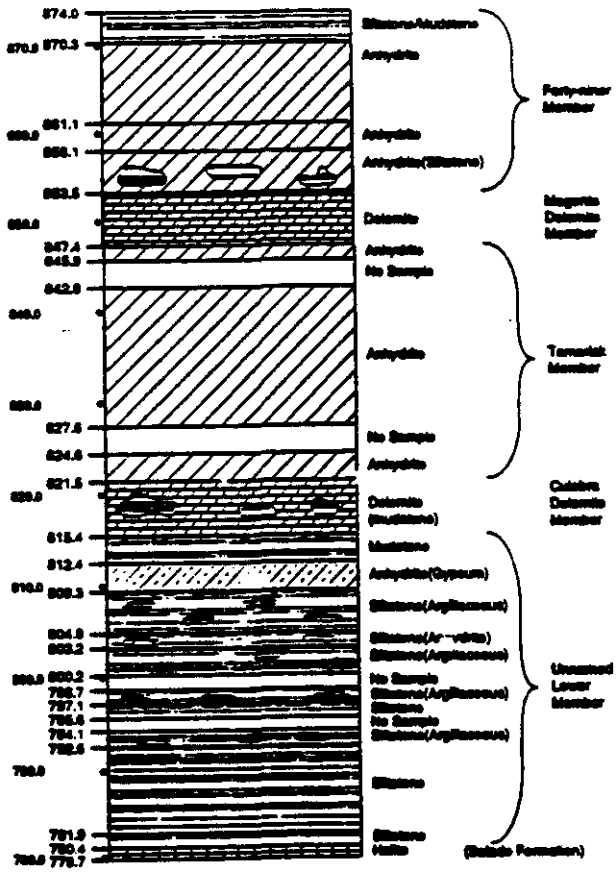

Figure 4-8. **Detailed Lithology of Rustler Formation at ERDA-9 (reproduced from SAND92-0700/3; after SNL and USGS, 1982)**

Figure 4-9. Outcrop of Culebra Dolomite Member of the Rustler Formation Where Removal of Underlying Halite Has Caused Fracturing (reproduced from Mercer, 1983)

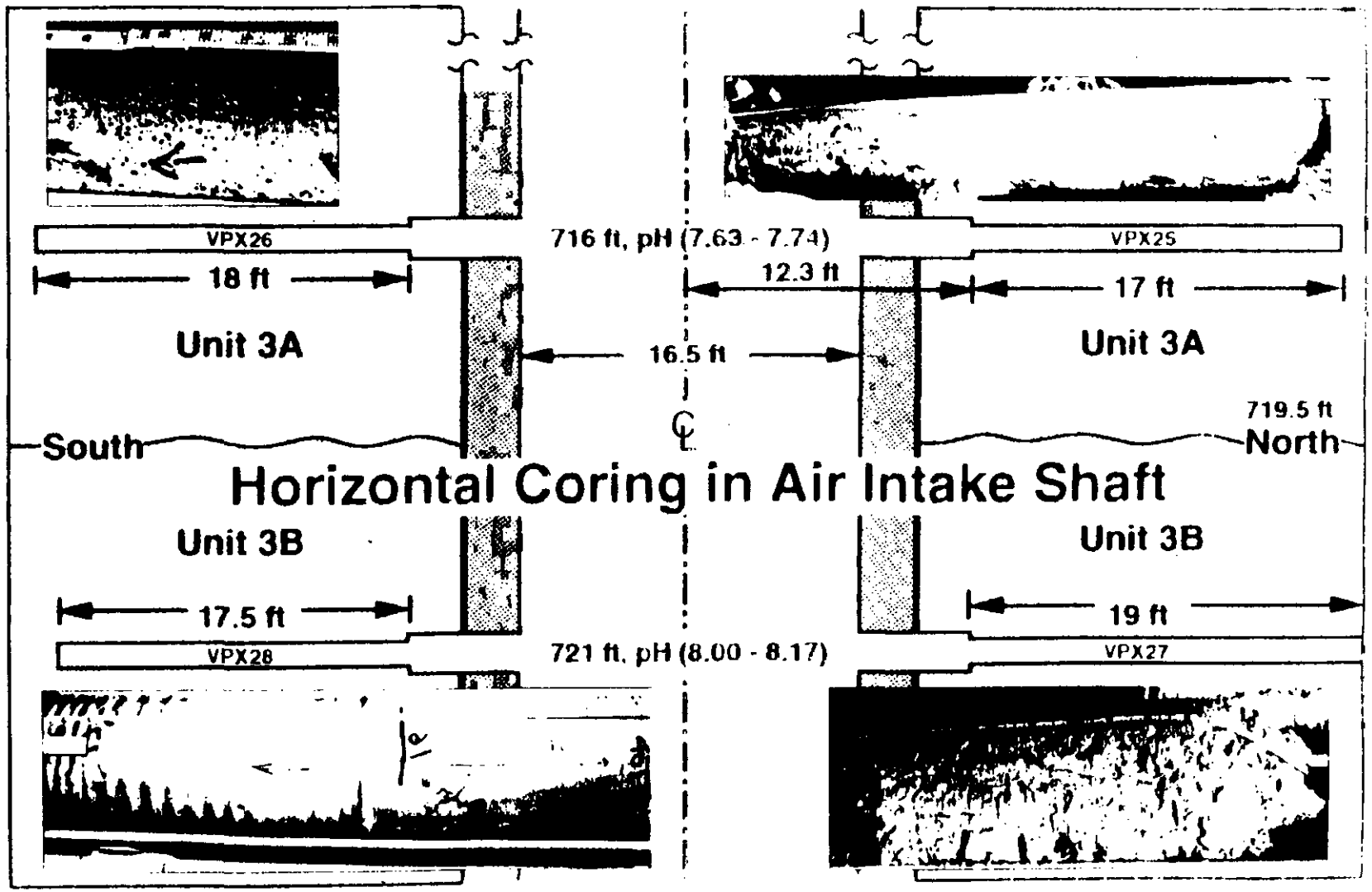

Figure 4-10. **Horizontal Cores Removed from Culebra Units 3A and3B (Within 55 ft of each other horizontally and 5 ft vertically) in the Air Intake Shaft at WIPP. This modified figure was part of a October 20-21, 1992 presentation to the NAS WIPP Review Panel by Fred Gelbard (SNL) and was supplied by Fred Gelbard for use in this PART report.**

discussed later. Gelbard, in his presentations to the PART, indicated that (as can be seen by inspection of the cores in Figure 4-10) the nature of the four cores was quite different, as was the capability of the four coreholes to produce water; (VPX27 produced nearly all the water).

Variability is also verified by the Culebra hydraulic conductivity tests which show a six order of magnitude variation from east to west ($2x10^{-10}$ m/s at P-18 to $1x10^{-4}$ m/s in Nash Draw), as is discussed in SAND92-0700/2, 1992. Mercer (1983) lists values for transmissivity at twenty wells and eight values for storage. The twenty-three single-well hydraulic tests conducted at WIPP between 1983 and 1987 (Beauheim, 1987) added fifteen values at new locations and seven retest values (SAND89-0462, 1989). Other early testing in the Culebra is discussed in SAND89-0462, 1989. Hydraulic test information (e.g.. transmissivities, storativity, fluid densities, transient and undisturbed freshwater heads with their uncertainties) is summarized in the form of tables and plots in Cauffman et al. (1990). The log hydraulic conductivity variation for the Culebra is shown in **Figure 4-11** from the 1992 PA (SAND92-0700/2), and the available data on transmissivities presented in Cauffman et al. (1990) is shown in **Figure 4-12**.

The interpreted potentiometric surface presented in the 1992 PA (SAND92-0700/2) was discussed in Subsection 3.2.2 (Figure 3-23). Cauffman et al. (1990) interpreted values of freshwater head (**Figure 4-13**) based on fluid densities and their estimation of when the pressure data (in the transient history recorded at the well) was representative of undisturbed conditions (**Figure 4-14**). LaVenue et al., 1990, also Cauffman et al. (1990) LaVenue and RamaRao (1992) discuss how hydraulic stresses since the summer of 1981 related to construction and testing (e.g., drilling and excavating shafts and boreholes, long running tracer and hydraulic tests such as at H-4) have resulted in the formation of what Haug et al. (1987) describe as a 7 km (4.2 mi) drawdown cone 33 m (107 ft) deep at the shafts and 12.2 m (39 ft) and 7.1 m (23 ft) at the maximum at H-1 and H-2 respectively. LaVenue et al. (1990), after updating some of the freshwater head estimates of Cauffman et al. (1990), produced an interpretation of the undisturbed freshwater head contours (**Figure 4-15**) that was the basis for initial Culebra dolomite model calibration efforts as well as for the current WIPP PA (SAND92-0700/2-3) pilot point method of generating seventy transmissivity realizations (LaVenue and RamaRao {1992}).

As discussed earlier, Siegel et al. (1991) summarize the hydrogeochemical studies of the Rustler Formation. Hydrochemical facies in the Culebra were discussed and presented earlier (Subsection 3.2.2, Figure 3-21) as was the fracture filling. The $^{234}U/^{238}U$ activity ratios that were the basis for the west-northwest paleoflow system postulated by Siegel et al. (1991) are shown in **Figure 4-16.**

Conservative tracer tests (e.g., convergent-flow and two-well recirculating) were performed at the H-2, H-3, H-4, H-6, and H-11 hydropads (i.e., locations where three to four wells are within tens of meters of each other) during the period from 1983 to 1988 (Jones et al., 1992). The results of preliminary interpretations of the H-2 hydropad tests and the H-3 and H-4 hydropad tests reported by Hydro Geo Chem (1986) and Kelly and Pickens (1986), respectively, are summarized and integrated with the interpretations of all the tracer tests completed in the Culebra to date in the report by Jones et al. (1992). This study examined various all or nothing (both homogeneous and heterogeneous) conceptualizations of double-porosity-fracture-matrix transport, single-porosity-fracture-only transport, or single-porosity-matrix-only transport and found that the best of the three models varied depending on the location. Results can be summarized as follows:

- double-porosity-fracture-matrix at H-3, H-6, and H-11 under the interpretation of a heterogeneous system or equally well as a horizontally anisotropic system,

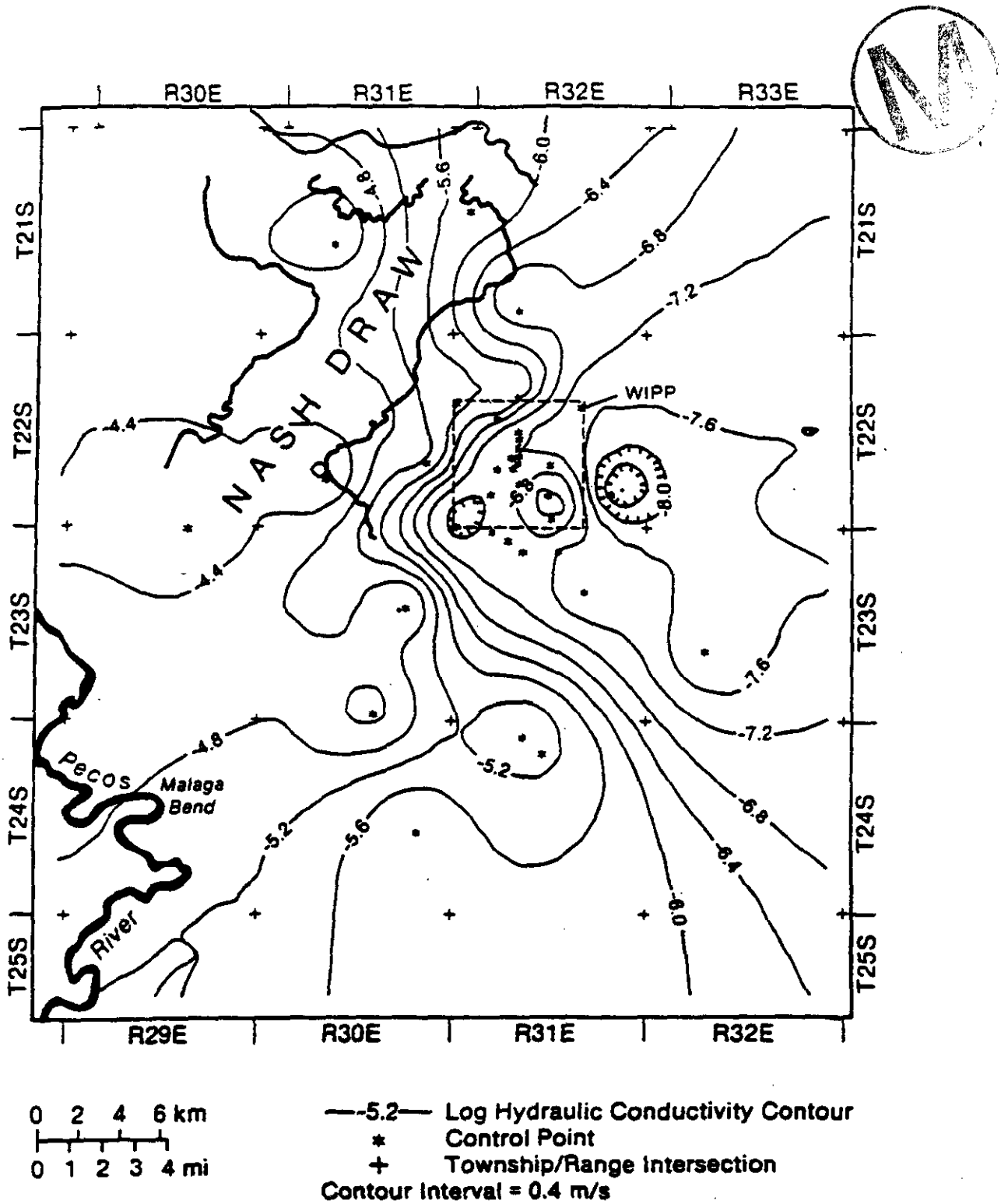

Figure 4-11. **Log Hydraulic Conductivity Variation (m/s) for the Culebra Dolomite Member of the Rustler Formation (reproduced from SAND92-0700/2; after Brinster, 1991)**

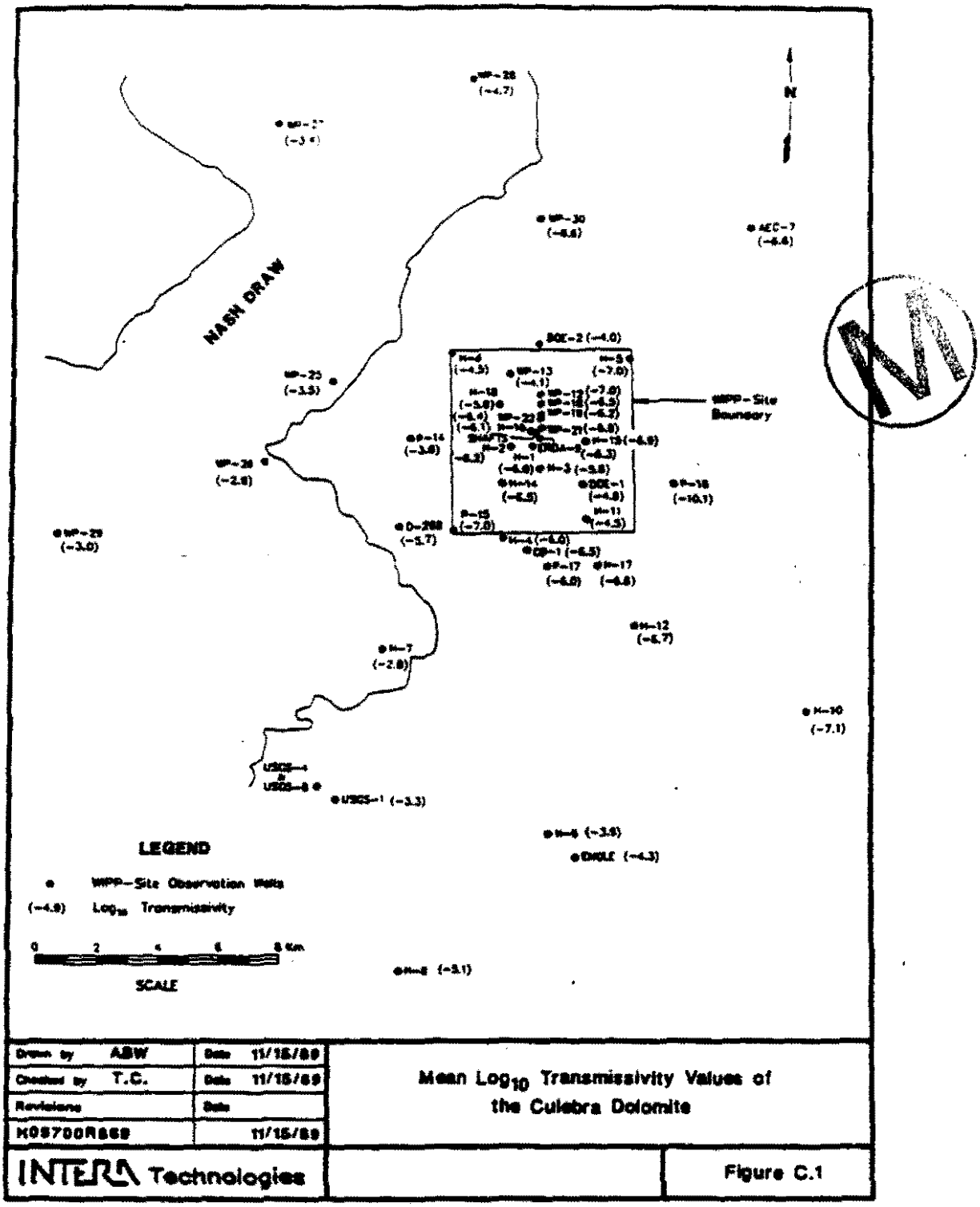

Figure 4-12. **Calculated Culebra Mean Log_{10} Transmissivity Assigned at Each Borehole in m^2/s (reproduced from Cauffman et al., 1990).**

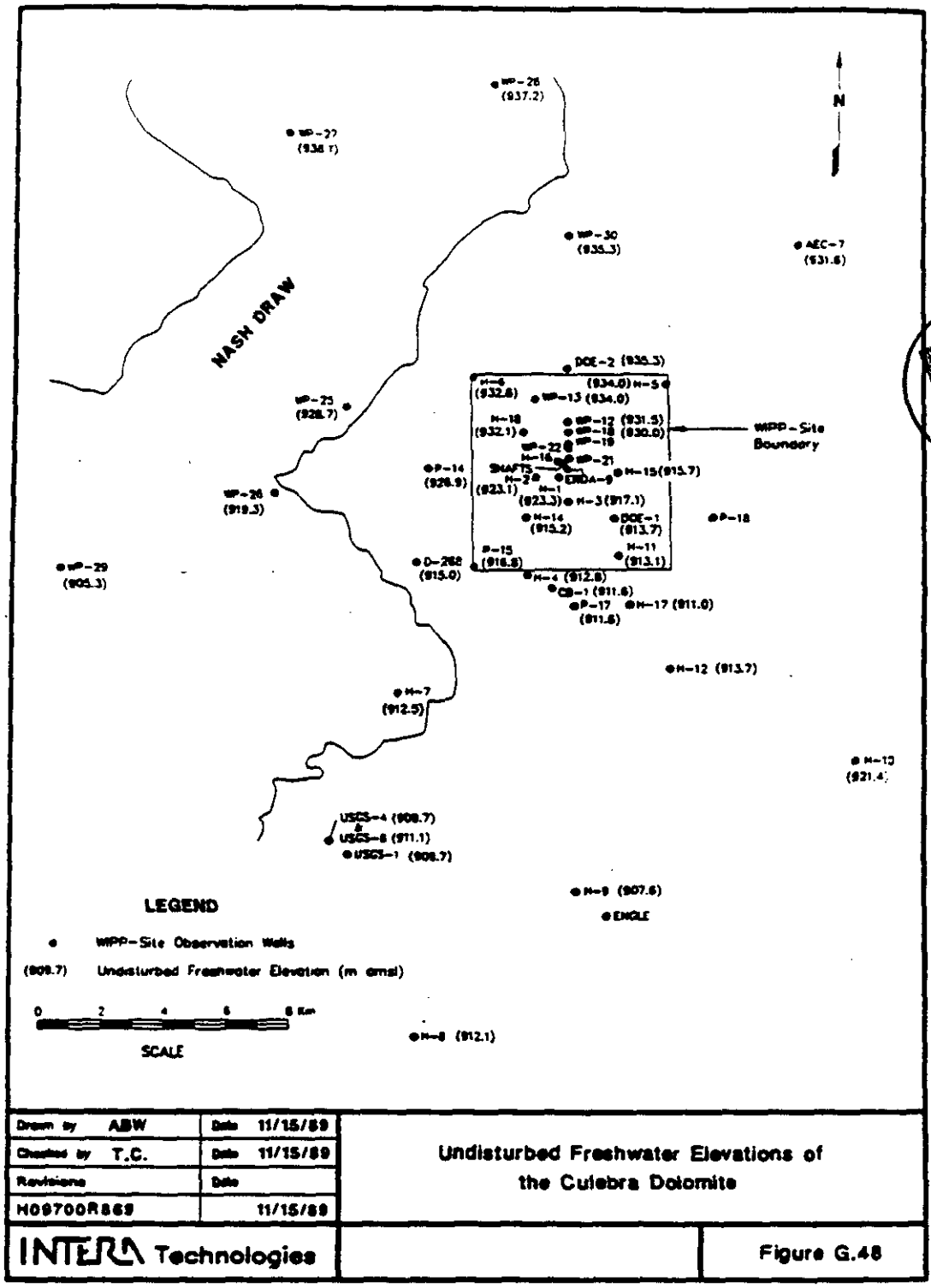

Figure 4-13. **Estimates of Undisturbed Freshwater Elevations in the Culebra at Each Borehole in Meters (reproduced from Cauffman et al., 1990).**

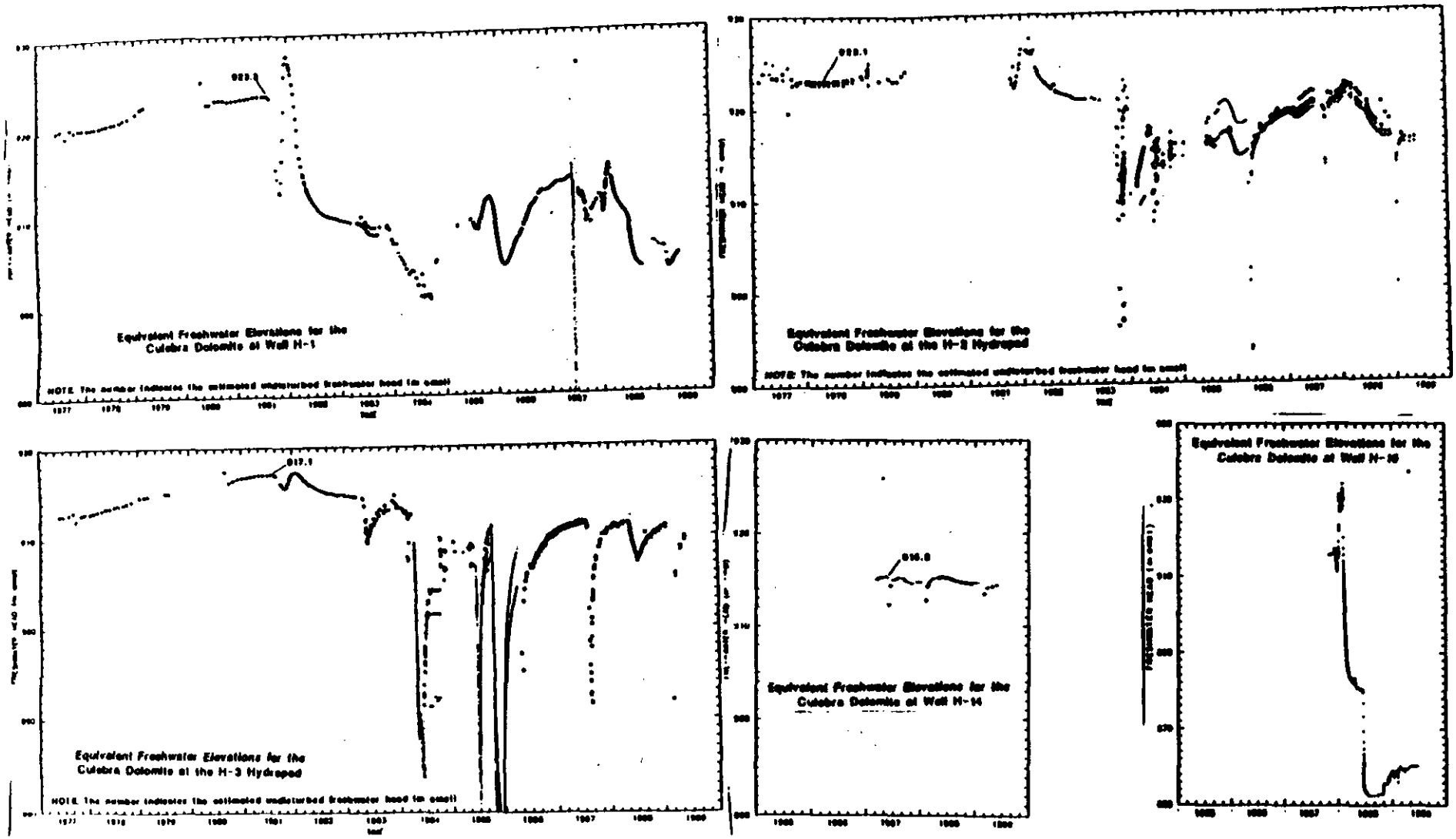

Figure 4-14. **Example Transient Freshwater Head Hyudrographs for the Culebra Illustrating the Effects of WIPP Activities (reproduced from Cauffman et al., 1990).**

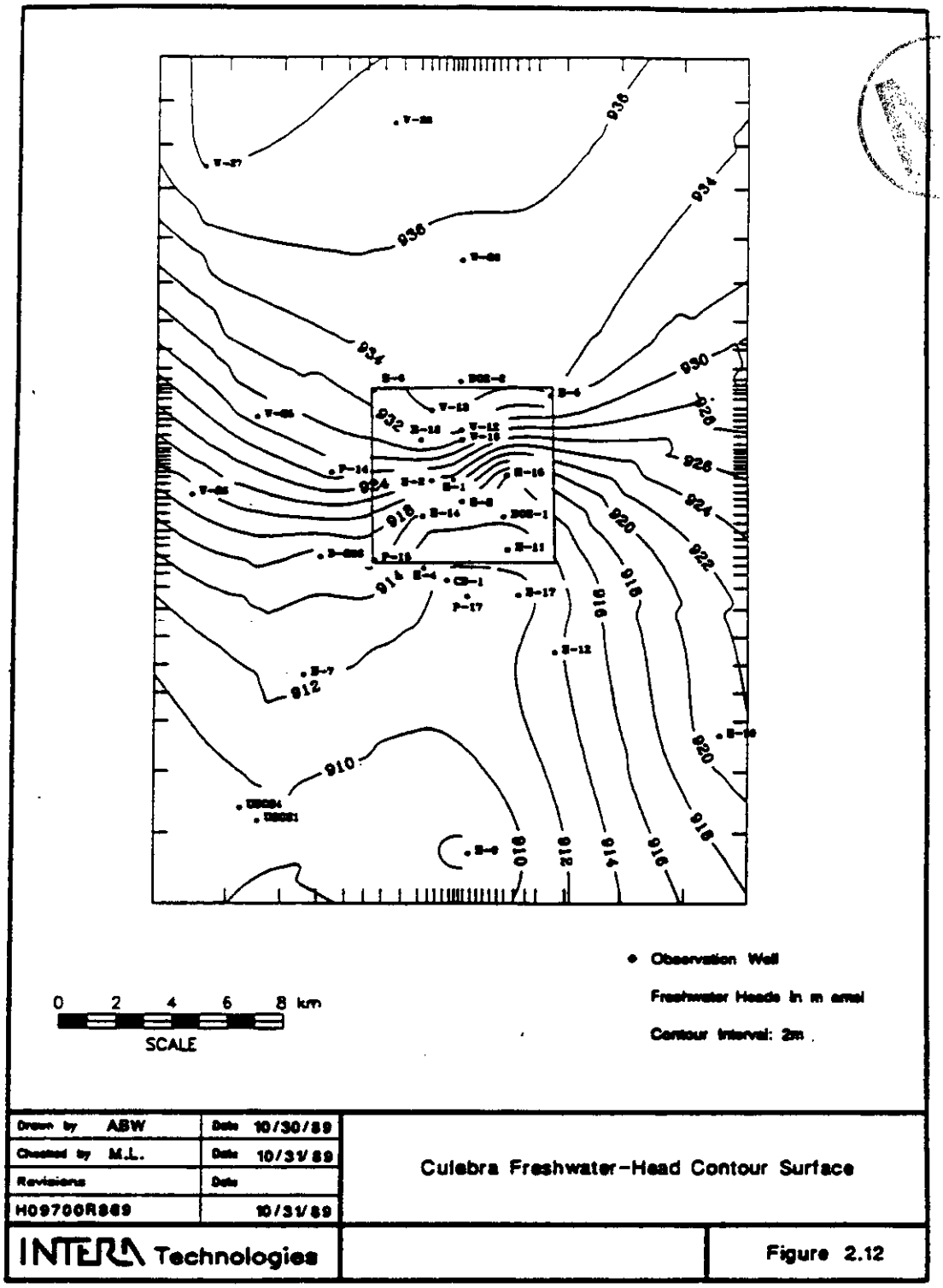

Figure 4-15. Undisturbed Freshwater Head Contours in the Culebra Interpreted by LaVenue et al, 1990 (repreduced from LaVenue et al., 1990).

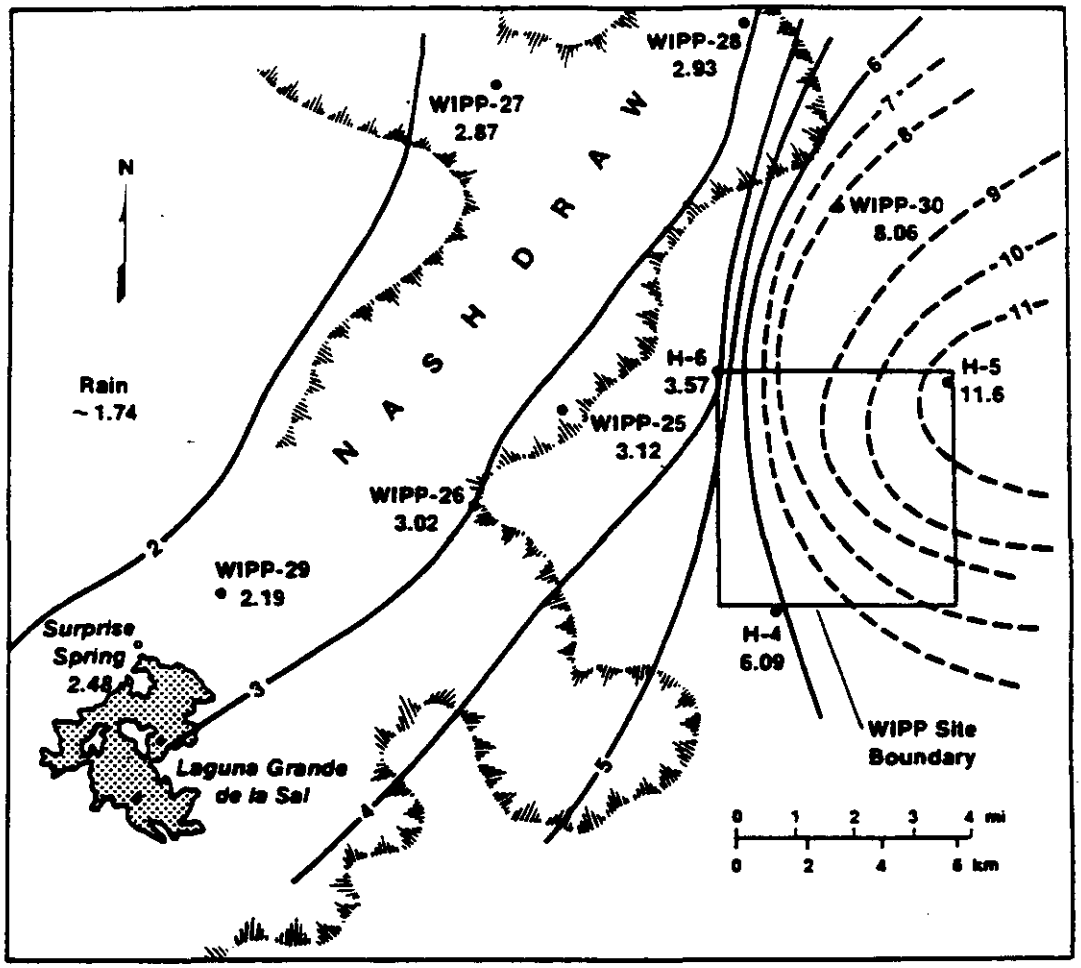

Figure 4-16. **Contour Map of the $^{234}U/^{238}U$ Activity Ratio in Groundwater from the Culebra Dolomite Member of the Rustler Formation (reproduced from Siegel et al., 1991 from Figure 5.11 from Lambert and Carter, 1987).**

- homogeneous single-porosity-matrix-only most representative at H-2 and inadequate at H-3, H-6, and H-11, and
- single-porosity-matrix-only through a vertically heterogeneous system the most representative at H-4 and inadequate at H-3, H-6, and H-11.

Jones et al. (1992) additionally conclude that a double porosity representation seems the most consistent with the observations (e.g., the large matrix porosities, 0.03 to 0.30) and that, as a result, matrix diffusion is an important process. They also point out that while observed tracer test behavior has been successfully simulated with the double-porosity-fracture-matrix model, other conceptualizations are possible and should be assessed. It should be pointed out, as discussed in the 1992 PA, that no fracture porosity measurements have been made. Interpreted values by Kelly and Pickens (1986) from the tracer test interpretations range from 1×10^{-3} to 2×10^{-3} (SAND92-0700/2, 1992).

4.3.1.3 Tamarisk Member

The Tamarisk Member of the Rustler Formation varies in thickness between 8 m and 84 m (26 ft and 273 ft) (36 m {117 ft} at WIPP) and is composed of three distinct layers (SAND92-0700/2, 1992) whose thickness may reflect lateral variations in deposition or dissolution. In areas unaffected by dissolutioning (Figure 4-5), the lower anhydrite layer, the thick middle section of halite and minor siltstone (sometimes polyhalite), and the upper anhydrite layer (Snyder, 1985) act as a confining unit (Mercer, 1983). In areas that may have been affected by dissolutioning of the evaporites, the Tamarisk exists in various intermediate states that affect both its volume and its other physical and hydrologic characteristics; (e.g., in Nash Draw only a few meters of residues of the original Tamarisk remain). Attempts to measure the permeability of this "water producing" unit at H-14 and H-16 (Figure 3-14), whose undisturbed hydraulic heads have never been successfully measured (Lappin et al., 1989), were abandoned when it was concluded that the transmissivity of the unit is too low to measure on the time scale of days (Beauheim, 1987).

4.3.1.4 Magenta Dolomite Member

The Magenta Dolomite Member of the Rustler Formation varies in thickness between 4 m and 8 m (13 ft and 26 ft) (6 m {19.5 ft} at WIPP) and is a distinct purplish-red (magenta) rock contains minor crossbeds as well as laminae of anhydrite and dolomite (Figure 4-6-b; Snyder 1985). Hydraulic conductivity (Figure 4-17) ranges over five orders of magnitude from 5.0×10^{-10} to 5.0×10^{-5} m/s (SAND92-0700/2, 1992). This variation, according to Mercer (1983) and Snyder (1985), is caused by the vertical movement of the rocks below the Magenta. This movement, as discussed earlier in Subsection 3.2.2.1, is related to either a collapse process, whose magnitude varies with the amount of dissolved halite, or an expansion process, whose magnitude varies with the amount of hydrated anhydrite.

The interpreted potentiometric surface presented in the 1992 PA (SAND92-0700/2) was discussed in Subsection 3.2.2.1 (Figure 3-24). While no porosity measurements have been made 0.20 has been assumed for interpretation of well tests (SAND92-0700/2, 1992). TDS of the Magenta range from 5,460 mg/l to 270,000 mg/l (Mercer, 1983). Comparisons of the Magenta to the Culebra indicate that

- Magenta generally has lower hydraulic conductivity (approximately two orders of magnitude), as discussed in SAND92-0700/2, 1992;

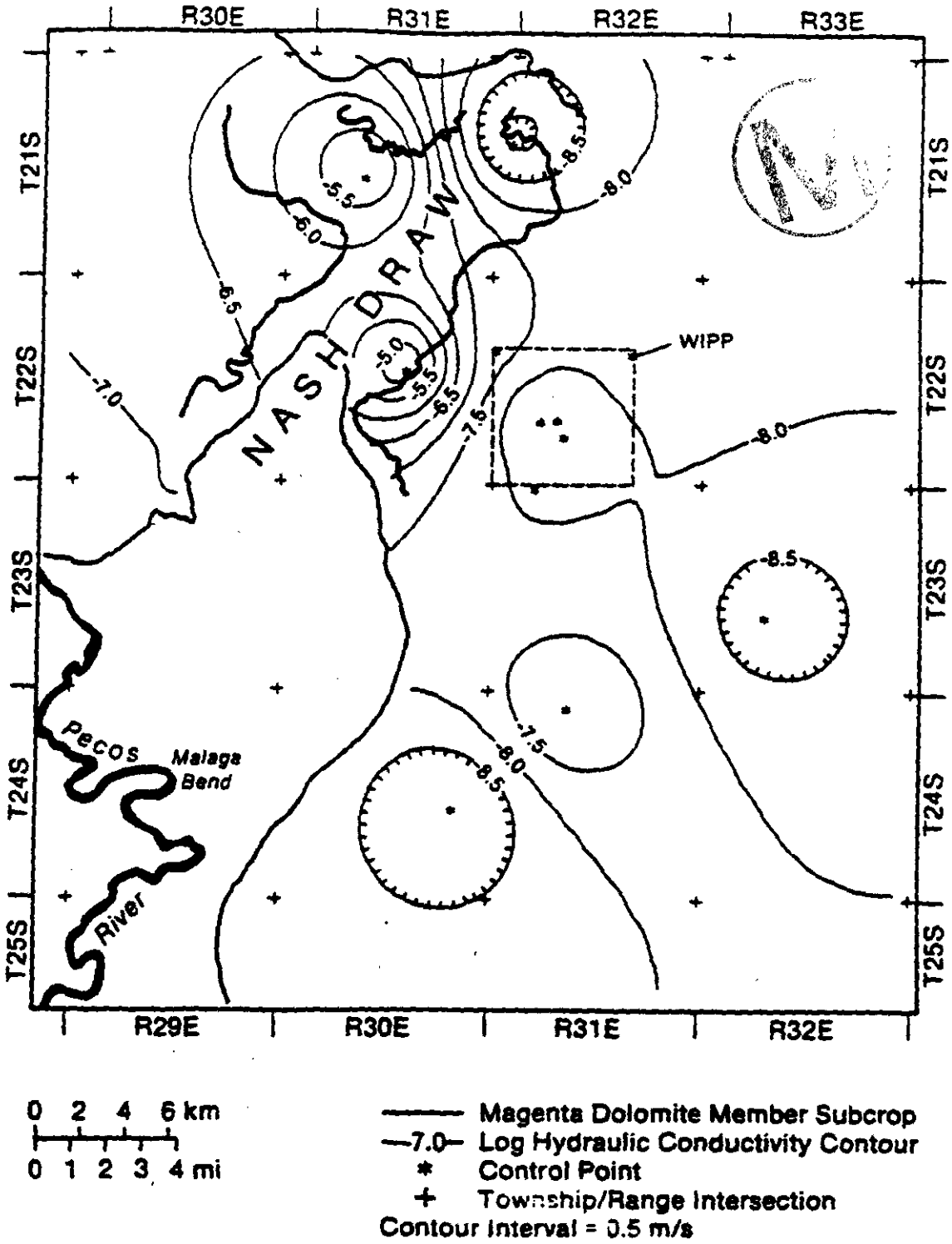

Figure 4-17. **Log Hydraulic Conductivity Variation (m/s) for the Magenta Dolomite Member of the Rustler Formation (reproduced from SAND92-0700/2; after Brinster, 1991).**

- Magenta generally has higher heads with the differences increasing eastward (LaVenue et al., 1990); and
- *TDS in the Magenta is generally lower* (Mercer, 1983).

4.3.1.5 Forty-Niner Member

The Forty-Niner Member of the Rustler Formation is a relatively uniform 20 m (65 ft) throughout the WIPP area (SAND92-0700/2, 1992). It is composed of three distinct layers consisting of a lower thick, light-to-medium-gray anhydrite bed, a middle reddish-brown silty halite or claystone unit, and an upper thick, light-to-medium-gray anhydrite bed (Snyder, 1985). Hydraulic conductivity tests at H-14, H-16, and DOE-2 yielded estimates of 5.0×10^{-9} m/s, 5.0×10^{-10} m/s, and 4.0×10^{-10} m/s, respectively for the medial claystone, (SAND92-0700/2, 1992; LaVenue et al., 1990).

4.3.2 Planned Activities and Issues

As part of the test program, two sets of activities are currently planned for the Non-Salado (as used here, the rocks that overlie the Salado host rock) portion of the natural barrier (DOE/WIPP 89-011 Revision 1, 1993). These two activities are outlined from Table 5.1 of DOE/WIPP 89-011 Revision 1 (1993) below.

- The Non-Salado Hydrologic Properties Activity includes
  - Core studies of rock properties (plan in preparation)
  - Regional-scale transport and sensitivity studies
  - Model development
  - Field testing and data interpretation for hydrology (planned)
  - Regional geochemical studies
  - Data base for field studies
  - Validation and international collaboration for model
  - Verification of performance-assessment model
  - Identification of potential underground sources of drinking water (in progress)
- The Non-Salado Transport Activity includes:
  - Adsorption studies
  - Radionuclide Solubility and Speciation
  - Brine mixing and radionuclide coprecipitation for the Non-Salado
  - Empirical sorption studies
  - Column experiments
  - Long-core tracer tests (plan in preparation)
  - Colloid characterization and transport
  - Test design and interpretation
  - Data base for performance assessment
  - Sorbing/retarding tracer tests
  - Data base laboratory studies

- Non-sorbing tracer tests

Before discussing these activities and their relevance, it is important to review the current Culebra PA model assumptions, outline the basis and issues these activities were designed to address, and examine the issues identified by the PART.

4.3.2.1 Current Culebra PA Model Assumptions

The current Culebra PA model (summarized from SAND92-0700/2-3, 1992) assumes perfectly confined two-dimensional horizontal flow with no recharge from above or loss to units below. *Note that this implies it is isolated hydrologically and geochemically and thus unaffected by any of its surrounding units in the Rustler Formation.* Recharge is assumed to occur only to the northwest and north at presumed outcrop recharge areas. Climate change is accounted for by a transient variation in the Dirichlet boundary condition along these northwest and northeast boundaries. "The Culebra Dolomite Member is imagined to be a sheet-like mass of rock having lateral dimensions of the order of tens of kilometers and uniform thickness of 8 meters" (Figure 4-1, the box labeled 10). This sheet-like rock mass is envisioned as containing planar fractures that are all parallel to the plane of bedding and run continuously throughout the rock mass (**Figure 4-18**). The fractures are partially lined with clay in half of the realizations and are unlined in the other half. Advective transport is only accounted for in the open fracture space (i.e., no advective flow in the matrix or clay fracture filling). However, one-dimensional diffusive interaction with the fracture filling and the rock matrix is assumed. Material properties are assumed to be heterogeneous or vary from one material region to another, but within a given material region the material properties are assumed constant. While the system is envisioned as fracture flow, it is modeled as an equivalent porous medium. Hydrodynamic dispersion can be quantified by a Fick's law term. Adsorption of solutes in the solid phases obeys a linear isotherm, and there is always local chemical equilibrium between solutes and solid phases.

4.3.2.2 Test Phase Activities Basis and Issues to Be Addressed

The test phase plan (DOE/WIPP 89-011 Revision 1, 1993) indicates that from a compliance perspective the ability of rocks above the Salado (in particular the Culebra dolomite) to control, minimize, or eliminate waste release to the accessible environment must be demonstrated. The uncertainties in the current long-term performance predictions of the Culebra that need to be addressed are identified in the test phase plan and they are outlined below.

- Conceptual flow model uncertainty related to the appropriateness of the current conceptual model assumptions over the long term include:
  - the applicability of two-dimensional flow,
  - whether groundwater flow is in equilibrium with the boundary conditions,
  - whether vertical flow with other units of the Rustler Formation can be neglected, and
  - the applicability of pump test data over the long-term.
- Pump test data are not fully analyzed.
- The effect of climate change on model boundary conditions are not yet determined.

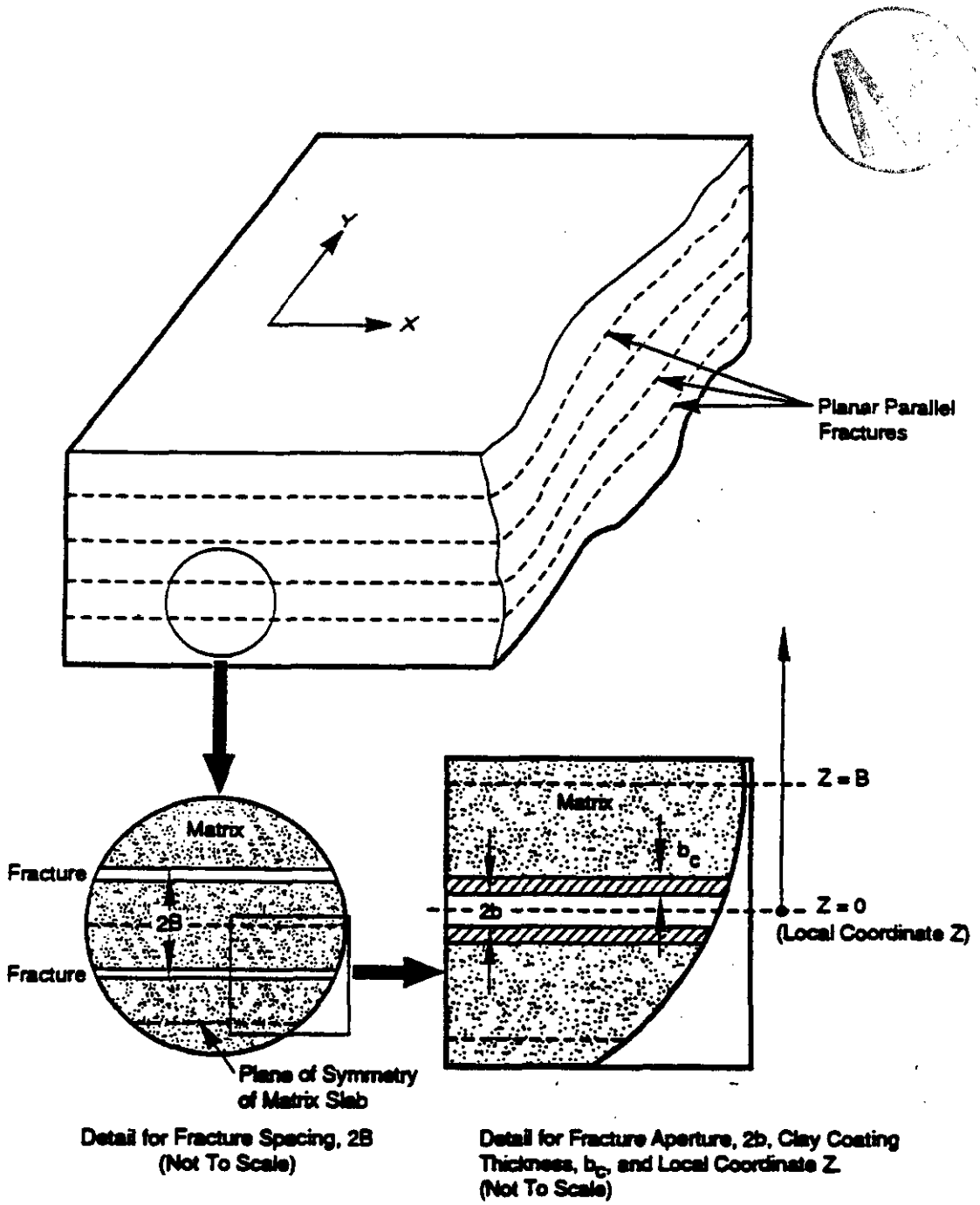

Figure 4-18. **Conceptual Hydrologic Model of the Culebra Dolomite Member (reproduced from SAND92-0700/2, 1992).**

- The confined aquifer model is not consistent with geologic, geochemical, and isotopic information.
- The effects of gas entry into Culebra have not been evaluated.
- Heterogeneity in flow properties and the associated scale-up uncertainty are not yet assessed.
- Conceptual transport model uncertainty exists, related to the appropriateness of a double porosity transport model (thought best to describe transport in the Culebra) that accounts for both
  - physical retardation by diffusion of radionuclides into the 16% mean porosity dolomite matrix of the Culebra, and
  - chemical retardation.

The test phase plan also indicates that there is a need to address the uncertainty related to whether "colloids containing radionuclides, if shown to occur, could inhibit both physical and chemical retardation."

The issues to be addressed by the activities outlined above are summarized here as a series of questions from the test phase plan.

1) Is the groundwater system in steady state or in a transient response from the last pluvial period?
2) Will groundwater flow rates change in the future?
3) Are the effects of vertical leakage and variations in groundwater flow negligible?
4) Can and do boreholes outside WIPP affect groundwater flow at WIPP (Figure 1-11)?
5) Are current conceptual flow models consistent with the site characterization data (particularly geochemical data)?
6) How would projected waste-gas releases associated with various scenarios affect flow in the Culebra?
7) What uncertainty would arise in the flow predictions from severe heterogeneity or hidden features?
8) Are there potential sources of drinking water in the regulated area of WIPP ?
9) Over what scale is a double porosity model relevant?
10) If a double porosity model is not relevant, what model should be included and what are the long-term transport implications of the other possible models?
11) If a double porosity model is relevant, how good is the case for this conceptual model?
12) What physical retardation can be expected without chemical retardation?
13) What chemical retardation can be expected with and without physical retardation for each brine and rock type along the probable flow path?
14) Can colloids exist in Culebra brines?
15) How would colloid formation and transport affect retardation?
16) How would waste-generated gas affect radionuclide retardation in the Culebra?

4.3.2.3 Issues Identified by PART

In order to achieve the quality of "reasonable expectation of compliance" there must be consistency in the way information is used to make interpretations to prove points and justify assumptions. Based on the PART's limited review of the information presented in the 1992 PA and some small fragment of the supportive literature on the WIPP site natural system, there appear to be many apparent inconsistencies that are not fully explained and many questions that arise about how conclusions were reached. Consider the following examples.

- In an attempt to explain the $^{234}U/^{238}U$ activity ratios (Figure 4-16) Siegel et al. (1991), postulated a paleoflow system flowing from the outcrop recharge areas in Nash Draw from the west-northwest potentially up the topographic gradient, which is usually the driver in a wet environment, while Bachman (1985) postulates surface streams during Gatuna time flowing from the northeast, (Figure 3-26) which are consistent with the topographic gradient.
- There are discussions of slumping related to halite removal in underlying units that are expected to cause vertical movement, and thus vertical fracturing of the Culebra dolomite and swelling related to gypsification of underlying and overlying anhydrites. However, the modeling only conceptualizes bedding plane fractures (Figure 4-18) without addressing the vertical fractures, both of which are expected and are evident in the outcrop shown in Figure 4-9.
- Two new "water producing" units have been identified since Mercer (1983), and yet, as discussed above (Subsection 4.3.1.4), undisturbed heads have never been successfully measured in one of these units, and attempts to measure the permeability were abandoned because its permeability is too low.
- Interpretations of tracer tests (Subsection 4.3.1.2) indicate that double-porosity-fracture-matrix at H-3, H-6, and H-11 is an adequate model under the interpretation of a heterogeneous system or as a horizontally anisotropic system; a homogeneous single-porosity-fracture-only model is most representative at H-2; and finally a single-porosity-fracture-only model through a vertically heterogeneous system is most representative at H-4. However, the 1992 PA states that a dual-porosity transport model provides the most realistic estimate. The visual examination of the cores from the waste shaft (Figure 4-10) would seem to support the tracer test interpretations; (i.e., possibly each of the proposed models applies somewhere).
- The undisturbed potential map for the Culebra has a drop in head of 18 m (58.5 ft) within the 6.4 km by 6.4 km (3.84 mi by 3.84 mi) land withdrawal boundary (Figure 3-24), yet in the same area a 7 km (4.2 mi) drawdown cone (see Subsection 4.3.2.2 and the hydrographs in Figure 4-14) is projected to be 33 m deep at the shafts in the Culebra and 12.2 m and 7.1 m (40 ft and 23 ft) at H-1 and H-2, respectively. These somewhat inconsistent results make determination of groundwater flow direction tenuous.
- The totally confined no-vertical flux concept for the Culebra modeling is inconsistent with studies by Davies (1989) and Haug et al. (1987) that support the vertical flux concept.

Based on this limited review and evaluation, there appears to be a basic interpretational issue that needs to be resolved. For example, the middle unit of the Tamarisk Member of the Rustler Formation (mudstone/halite) is interpreted to be continuous and is described as a "water producing unit." However, all four attempts to measure the head and permeability of this unit have failed. Does this difficulty arise simply because of insufficient resources available for permeability measurements or only standard

geohydrologic interpretations and extrapolation techniques are being applied to interpret a system that has been affected by a dissolutioning process that varies spatially? Is this an attempt to "cling faithfully ... to normal interpretations" (page 5 of LeGrand's March 13, 1985, letter to Robert H. Neill of EEG in Chaturvedi and Channell, 1985)? In the context of a system that may be cyclically exposed to dissolutioning, there may be no simple classification of an aquifer and aquitard, as the nature of these units can change related to their location in space and the particular stage of evolution in the "stop and go" flow driven dissolutioning process described by LeGrand.

Neither the 1992 PA (volumes 1-3) nor the supporting literature reviewed contains an overall integrated picture of the supra-Salado hydrologic system that weaves the available information, understanding, and efforts together in a way that supports the current Culebra modeling in a manner that the PART believes is necessary to demonstrate that there is a "reasonable expectation of compliance" to the decision makers, the regulators, and the public, should the results of the final quantitative comparisons so indicate. This does not mean or imply that much of the information (data, observations, and supporting experimental evidence) is not available nor that all outstanding potential issues need to be addressed. It simply means that there has not been, and there needs to be, a multidisciplinary effort to take available information, competing interpretations, competing conceptual models, and any supportive experiments and/or modeling and combine them to explain what is currently known (e.g., regarding current head distributions and flow directions relative to past conditions, geochemistry, recharge, dissolutioning). The team could also identify what is known well enough and why, what is not now known well enough, and, for these areas, what probably cannot be determined and what needs to be determined.

4.3.2.4 Discussion of Planned Activities

As has been discussed, planned experiments and activities should be compliance-based. Therefore, the emphasis on planned experiments and other activities should be on those activities that are likely to resolve or significantly reduce the uncertainty surrounding important issues or on those activities that make a significant contribution toward achieving that qualitative goal of reasonable expectation.

In reviewing the test phase plan (DOE/WIPP 89-011 Revision 1, 1993) and the 1992 PA (SAND92-0700/1-3, 1992), and as discussed in the previous section, there is no integrated picture of the supra-Salado hydrologic system presented in either document or in any of the other documents reviewed. Most of the puzzle parts are there, but they have not been assembled in a way that makes it clearly evident what pieces are missing (i.e., what remains to be done). In this regard, the PART's examination of the list of non-Salado hydrologic properties and transport activities outlined at the start of this subsection gave rise to many questions. Consider the following:

- Why is it that colloids and colloid transport are mentioned as an important transport issue for Culebra only in the test phase plan? Where did this issue first surface? What is the basis (e.g., were there observations during tracer tests?), rationale, and justification for believing it to be important at all?
- Where was the compliance-based importance of Culebra gas flow modeling raised other than in the test phase plan (Section 5.1.1.3 page 5-8 of DOE/WIPP 89-011 Revision 1, 1993) and how is this relevant when it is not yet clear what the appropriate compliance model should be for water and solute? How is this more important than a modeling effort that considers density driven flow and communication between units of the Rustler?

For most of the non-Salado hydrologic properties and transport activities outlined at the beginning of this subsection, there is only the brief general description and justification found in chapter 5 of the test phase plan (DOE/WIPP 89-011 Revision 1, 1993). Of these activities, only the four indicated in this outline are in the actual planning stages. The 1992 PA (SAND92-0700/1-3, 1992) discusses just three of these activities: the batch and column radionuclide sorption studies and the seven-spot multiple well tracer tests being planned by Beauheim and Davies (SAND92-0700/1-3, 1992).

None of the draft planning documents were available for the PART review; however, the PART was briefed on the column retardation experiments being planned by Fred Gelbard (SNL) during one of the PART interviews, and the PART was able to visit the laboratory and examine the apparatus that will be used in these column experiments. The only other discussion regarding planned non-Salado experiments arose in the PART's discussion with EEG. Lokesh Chaturvedi expressed concern over the possibility that DOE might abandon the seven spot multiple well tracer tests for a series of five single well tracer tests, especially considering the extensive review that the seven spot experiments had received by the technical community outside WIPP.

The PART is not able to make detailed comments on any of the proposed experiments since it did not review them in detail. However, on the basis of the description of the planned column radionuclide sorption studies outlined by Fred Gelbard and the PART's discussion with EEG on the need to replace expert judgment data on Kd's with real laboratory information, these experiments appear to be compliance based and critical.

4.4 DEWEY LAKE REDBEDS

The Dewey Lake Redbeds do not represent a pathway for the migration of radionuclides, but control the flow of recharge to the underlying units of the Rustler Formation (SAND92-0700/2).

As described by Mercer (1983) and Snyder (1985), the Dewey Lake Redbeds conformably overlie the Rustler Formation. They are the youngest Permian age rocks in southeastern New Mexico and they mark an abrupt change in the depositional environment of the area from the dominantly evaporitic Rustler deposits to a deltaic sequence representative of a tidal flat or very shallow water deposits. These deposits consist of alternating, laminated to thin, even beds of reddish-brown siltstones interbedded with minor claystones and containing lenticular interbeds of fine-grained sandstone. Nearly all siltstones and claystones contain veins of secondary selenite gypsum, except near the top. While most of the veins are parallel to the horizontal bedding, many veins cut the formation at various angles as noted by occasional vertical veins observed in cores. The formation thins from east to west as a result of post-Permian erosion and varies in thickness from 167 m (543 ft) a few miles southeast of the site to 148 m (481 ft) near the center to 30 m (97.5 ft) a few miles to the southwest. The formation outcrops in low bluffs along the north and east of Nash Draw, where it is nearly completely absent except in sinks and collapse features.

Drilling for areal geohydrologic evaluation indicated local zones of permeability but did not indicate the existence of any continuous zones of saturation, although local minor zones of saturation were observed at wells H-1, H-2, and H-3 associated with the interbeds of fine-grained sandstone (SAND92-0700/2, 1992; Mercer, 1983). Mercer (1983) believes that sand units near the top of this formation become localized perched or semiperched saturated zones dependent on the existence of favorable local recharge conditions. Several wells at the J.C. Mills Ranch (formerly the James Ranch) south of the site (T. 23 S., R. 31 E., section 6 and 7) drilled to depth of 94 to 212 ft produce water from

the Dewey Lake Redbeds (SAND92-0700/2, 1992; Mercer, 1983). Mercer (1983) postulates that ranch wells are completed in one of these lenticular sand units and, further, that the extensive region of active sand dunes to the east of this area could be the recharge source for the perched water bearing units.

Mercer (1983) hypothesizes that the Dewey Lake Redbeds act as a protective cover that retards the dissolution of evaporites of the Rustler by restricting groundwater movement within the Rustler as a result of the perched character of the water in the lenticular sands. However, he offers no explanation of just how continuous recharge would not eventually bypass these lenticular units by running off in very localized areas near a low end of these saturated lenticular units on their way to a continuously saturated unit like the Rustler in order to proceed to a regional discharge area. He does offer support for his hypothesis by arguing that groundwater percolating through the Dewey Lake Redbeds and penetrating to the upper anhydrite of the Rustler at WIPP should cause it to be altered to gypsum but that existing cores and geophysical logs do not indicate any alteration except where the Dewey Lake is thin or absent.

Hydrologic properties of all the supra-Rustler rocks are poorly understood because of the difficulty of making measurements and, as a result, have only been estimated based on the description of fine grained-sandstone and siltstone (SAND92-0700/2, 1992). Saturated hydraulic conductivity is estimated as 10^{-8} m/s and porosity is estimated as 0.2 (SAND92-0700/2, 1992).

5.0 IMPACT OF REPOSITORY AND WASTE EMPLACEMENT

In this section, the impact of repository excavation and waste emplacement on the long-term performance of the disposal system is considered. At first glance, the impact might be considered to be minimal because of the depth of the repository and the presence of only four man-made pathways (the shafts). However, the mechanical, hydrogeological, chemical and thermal fields will be disturbed by repository excavation and the introduction of waste, and changes in one field may cause changes in another, i.e., coupling. Assessment of the impact of these changes is complicated by questions of scale, both temporal and geometric. The time scale required by regulation (10,000 years) is too long for the usual iterative approaches, and the geometric scale is too large for experimental validation of repository response models. Natural heterogeneity of the rock mass and the influence of brine and gas generation are additional complicating factors.

The processes expected to occur in the repository following closure, and the PA efforts to understand and predict these processes are examined in this section. Subsection 5.1 provides background information on excavation effects and room closure. In Subsection 5.2 the permeability, pore pressure, and brine inflow in the disturbed rock zone are discussed. Subsections 5.3 and 5.4 examine gas generation and gas flow, and Subsection 5.5 considers the coupled effects of closure and fluid flow on repository behavior.

5.1 EXCAVATION EFFECTS AND ROOM CLOSURE

5.1.1 Introduction

Before considering the effects on the repository of excavation and emplacement of waste, this subsection will briefly review the undisturbed state of the Delaware Basin. There are four primary fields of interest: mechanical (stress-strain-displacement), hydrogeologic (pressure, regional pressure gradient, and velocity), chemical (species, concentration gradients, reactions), and thermal (temperature, temperature gradient, heat flow).

Prior to excavation, the stress field in the Salado is expected to be lithostatic and isotropic, because of the age of the basin and the observation that halite cannot sustain a stress difference without flowing to alleviate it. The hydrogeologic field is expected to have pore pressures close to lithostatic (because of the ductile nature of the salt), relatively low horizontal gradients (because of the location of the WIPP site relative to the edge of the basin), and very low velocity (because of the small gradients and the permeability of the halite). Because of the age of the basin and the small amount of mass transfer into the basin, one would expect that the chemical field would be near equilibrium with concentration gradients occurring only near the clay seams, anhydrite stringers, etc. Therefore, chemical reactions would not appear to be likely in this environment. The thermal field is expected to have a temperature of about 27° C and relatively low thermal gradient and high heat flow because of the relatively high thermal conductivity of rock salt.

All four of these fields will be disturbed by the excavation of a repository and the introduction of waste. The mechanical field will be altered by the excavation of the openings with attendant stress concentration around the openings, resulting in higher strain rates and displacements that tend to close the openings. A rather large sink is created in the fluid pressure field which is suddenly

dropped to approximately one atmosphere at the periphery of the openings. This results in a rapid change in the pore-pressure gradient field, with an accompanying change in the velocity field and flow into the openings. The excavation process and emplacement of waste introduces new chemical species into the formation, which produces concentration gradients and the potential for reactions, particularly in the presence of brine. As the excavation develops, a ventilation system is installed which transports vapor from incoming brine to the surface. The accompanying temperature changes near the room surfaces results in a change in the stress field, but it is unlikely that the thermally-induced strain will be large enough to induce surface fractures in the halite because of the relatively low initial surface temperature of the rock.

The discussion above implies the coupling of phenomena, i.e., changes in one field may cause changes in another. For example, the excavation-induced disturbed rock zone (DRZ) is likely to have both higher porosity and permeability than the far-field rock. Modeling of coupled phenomena is difficult due to the lack of complete understanding of the coupling and appropriate data. In PA it is desirable to make bounding calculations using relatively simple, uncoupled models. However, it appears to be prudent to understand coupled phenomena that may invalidate assumed bounding models. WIPP PA generally avoids making bounding calculations and promotes the probabilistic approach as required to capture and evaluate uncertainty, Beauheim et al (1993).

5.1.2 Questions of Scale

Some of the most difficult and challenging aspects of designing, licensing, and constructing nuclear waste repositories revolve around questions of scale. The time scale required by regulation, 10,000 years, is too long for the usual iterative approach of "build and test and redesign" used in developing common engineered systems. It is not possible to develop a pilot plant and observe its performance through its life cycle in order to improve future designs. The remaining options include conservative design, in which driving forces are overestimated and the ability of the repository to contain waste is underestimated. Even this conservative approach cannot guarantee adequate performance of the repository because the failure of engineered systems is sometimes caused by unanticipated loading conditions, for example, the dramatic failure of the Tacoma Narrows Bridge caused by dynamic wind-structure interactions that were not accounted for in the design. In the case of repositories, the possibility of overlooking a potentially important failure scenario or interaction is minimized by careful design and analysis, PA, and the licensing or certification process.

Complementary to the conservative approach outlined above, is the development of computerized models to simulate the future performance of the repository system. Given the circumstances, this is the best that can be done. It is necessary, but not sufficient, that these models reliably simulate observations made during various laboratory field tests at WIPP. Finally the judgment of experts and probabilistic modeling can be used to assess the performance of the system relative to the regulations. These approaches appear to be the best possible, given the time scale and uncertainty of the problem.

In addition to the time scale, there are geometric scale problems. The geometric scale is too large for experimental validation of repository response models. **Figure 5-1 A and B** illustrates observations made of trough subsidence over mined excavations. In part A, the width of the excavation is less than the depth, and there is an arching effect present that transfers part of the load

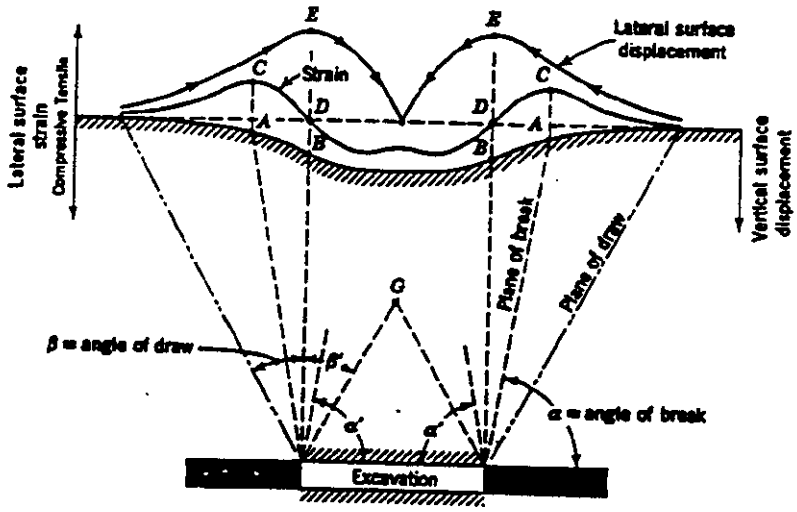

Fig. 18.2.2. Idealized representation of trough subsidence. (After Rellensmann[1]).

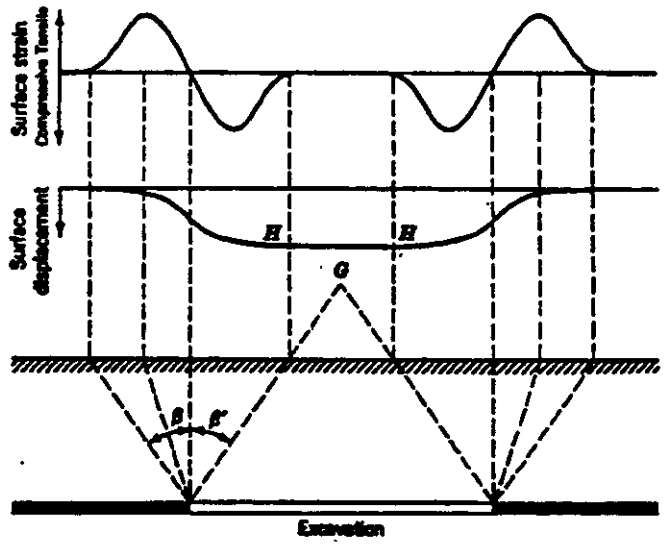

Fig. 18.2.4. Supercritical subsidence. (After Denkhaus.[5])

Figure 5-1. **(A) Idealized Representation of Trough Subsidence (after Rellensman, 1957) (B) Supercritical Subsidence (after Denkhaus, 1964).**

from the overburden to the undisturbed rock on both sides of the excavation. In this case mine pillars, which are located in the region marked "excavation" on the figure, do not need to carry the entire load of the overburden. This situation is termed subcritical subsidence. Part B illustrates supercritical subsidence where pillars near the center of the excavation must carry their share of the overburden load. Field experiments performed at the WIPP site are necessarily in a subcritical state because of the geometric scale problem, whereas the fully-developed repository will be approximately at the critical point. Large scale subsidence is not expected at the WIPP due to low extraction. Rather, this figure is shown to illustrate the problem of scale. Being able to predict room closure in the experimental area, using the elastic-steady state creep constitutive model with reduced elastic modulus in the code SANCHO as has been done in PA, may not ensure successful calculation of room closure in the full repository where the stress field will be different. This topic is further developed later in this section.

Again, it is necessary to rely on the ability to calculate and predict the future performance of the pillars and the rooms. The validity of these calculations cannot be directly checked because of the time and geometric scales. However, it is possible to validate the models over the period of observation and demonstrate that deformation (i.e., the change in size and/or shape of a region of the continuum) mechanisms in the near field around the rooms are consistent with those observed in salt naturally deformed over a much longer time. This procedure builds a higher degree of confidence in the simulated results, provided that the predicted loading conditions are approximately correct and a more complete constitutive model (described below) is used.

Work on a constitutive model for WIPP salt creep and room closure has gone on continuously since the late 1970s (Munson and Dawson, SAND79-1853, 1979; Munson et al., SAND88-2948, 1989; and Chan et al., 1992). This work is well respected in the rock mechanics community internationally and is representative of the state of the art. The Munson-Dawson (M-D) model has not yet been incorporated into PA calculations, SAND92-0700/3 DEC92 DRAFT, although plans exist to incorporate this work in the near future.

5.1.3 Heterogeneity: Natural and Repository Induced

One of the factors that makes modeling of observed phenomena in underground openings difficult is natural heterogeneity of the rock mass. Many roof falls and floor heaves seen in underground salt mines can be traced to a plane of weakness such as a clay stringer, anhydrite layer, or marker bed. These features sometimes exhibit spatial variability in properties and are frequently discontinuous in nature. **Figure 5-2** shows artists' conceptions of possible interactions between the closed disposal room and these heterogeneous features. These illustrations indicate interaction between natural heterogeneous features and the DRZ, which is a repository induced heterogeneity.

The rock bolts shown in Figure 5-2 help to maintain the structural integrity of the roof and, provided the bolts are tensioned, reduce the effects of the DRZ in the roof. Rock bolts are sometimes used in the ribs and in the floor to maintain the integrity and longevity of the opening, but not at WIPP. The effects of rock bolts are difficult to model when using two-dimensional models and are another example of repository induced heterogeneity.

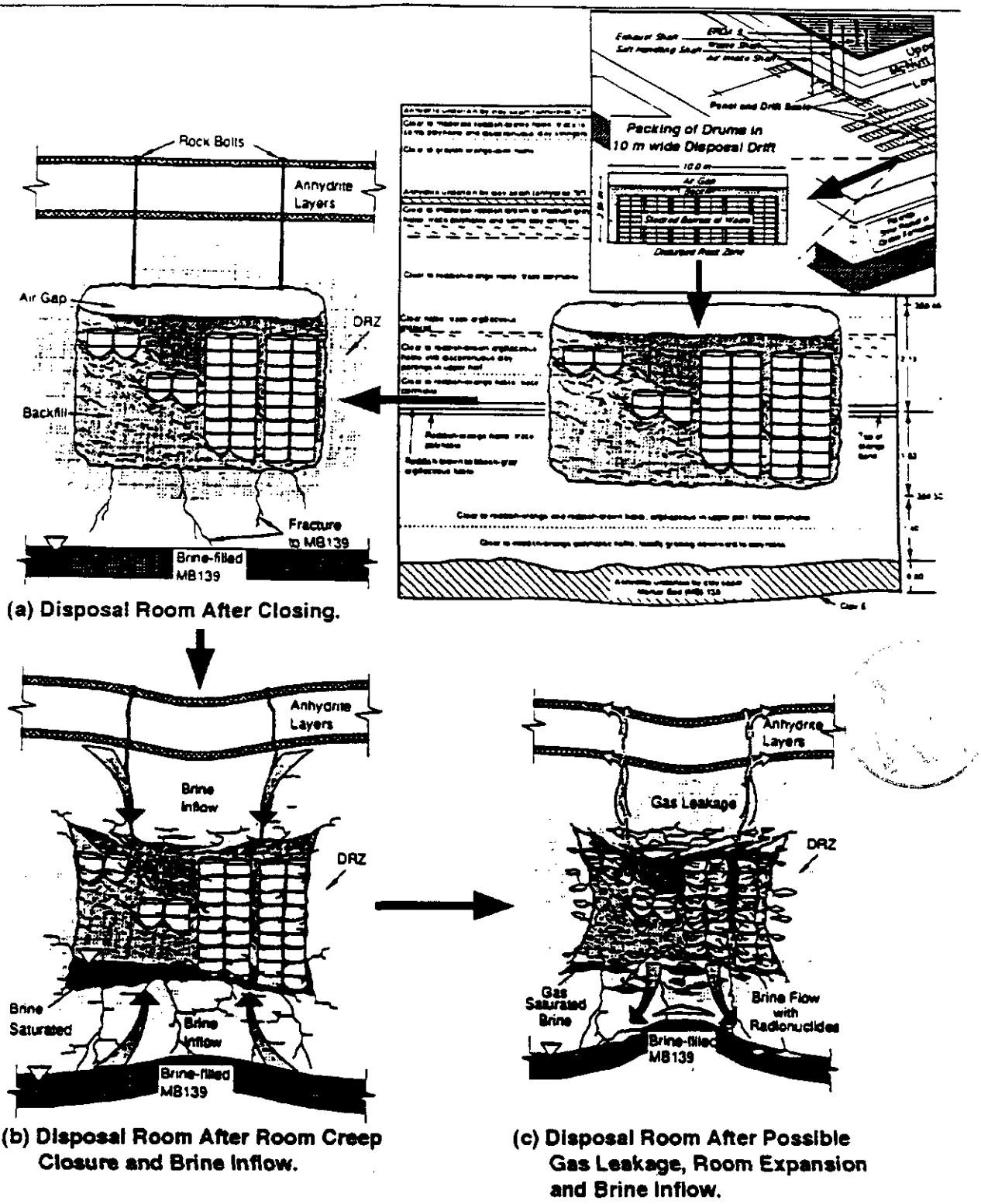

Figure 5-2. **Diagram Illustrating the Conceptual Evolution of a Disposal Room Within a WIPP Waste Panel. Illustrated in the upper left is the setting for a typical disposal room relative to the stratigraphy at depth and the progression of states, starting with (a) an idealized depiction of the disposal room after closure; (b) the disposal room after creep closure and brine inflow, and (c) the disposal room after possible gas leakage, room expansion and brine inflow. (Reference 1991 PA)**

Another example of heterogeneity is the high pressure brine pockets in the Castile formation below the repository level. These brine reservoirs represent a potential source of brine that could affect salt deformation (Section 5.3), gas generation, and radionuclide releases, but are likely only if tapped by boreholes generated by inadvertent human intrusion. Heterogeneity is of crucial importance in compliance and is receiving needed attention (see DOE/WIPP 89-011, Rev. 1, Test Phase Plan for the Waste Isolation Pilot Plant, March, 1993).

5.1.4 Repository Environment

The repository environment will affect its subsequent behavior. Significant brine migration into disposal rooms would, for example, enhance salt flow (i.e., deformation that changes with time, Section 5.2). Temperature increases due to heat-generating waste are expected to be rather small, but salt flow is very sensitive to temperature. Gas generation and its timing relative to the creep closure of the room and the effectiveness of the man-made seals, particularly in the DRZ, could alter the expected response of the repository. Gas flowing into microfractures in the DRZ could promote more brittle behavior in the salt mass by reducing the effective confining pressure. **Figure 5-3** from Chan et al., 1992 shows the influence of confining pressure on creep rate for a range of stress differences.

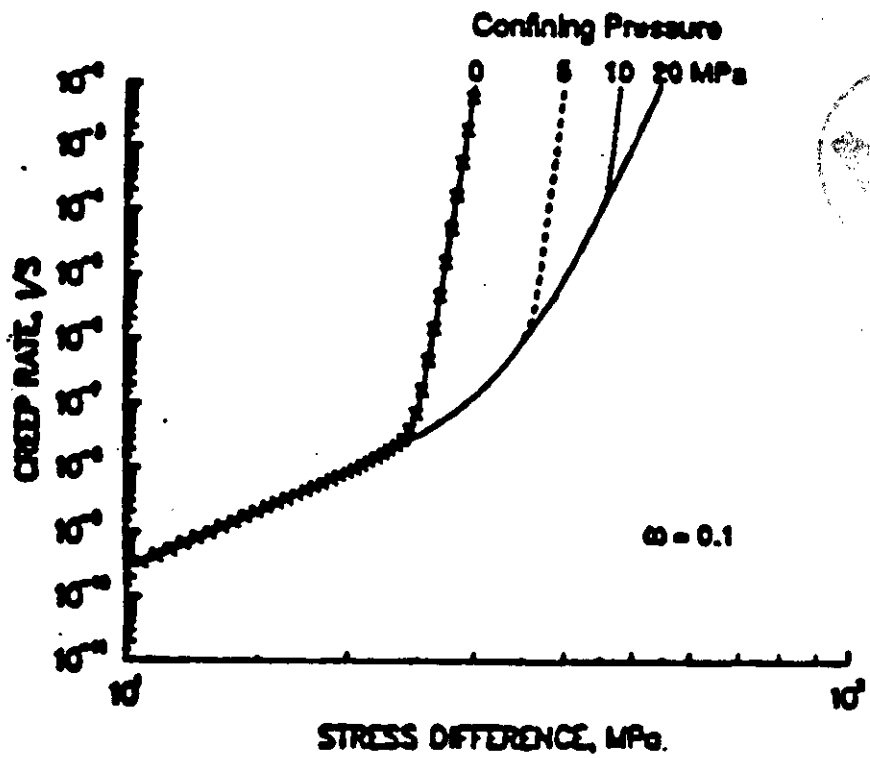

Figure 5-3. Calculated Steady State Creep Rates as a Function of Stress Difference for Various Levels of Confining Pressure Showing a Reduction of Creep Rate with an Increasing Level of Confining Pressure (Chan et al., 1992).

5.1.5 Current State of PA Relative to Creep and Room Closure

Creep and room closure PA process modeling is ongoing (**Figure 5-4 and Figure 5-5.**) Sandia National Laboratories will soon incorporate the M-D model in PA calculations. Currently PA is using an elastic-steady state constitutive model for salt in a code called SANCHO (Stone et al., 1985), that is simpler to incorporate and faster to calculate in SANCHO than the preferred M-D model. The Test Phase Plan for WIPP, March 1993 indicates that the M-D will be used in future calculations.

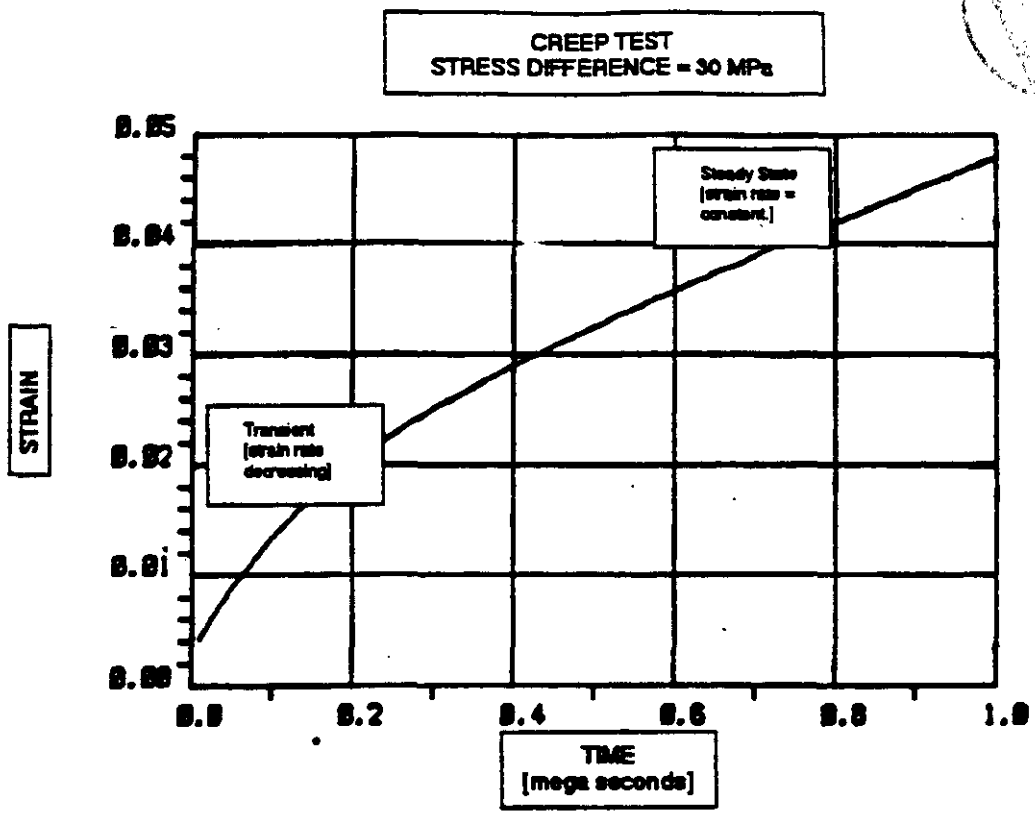

Figure 5-4 Typical Creep Test Showing Transient and Apparent Steady State Response.

The use of the M-D model in the calculations is important because decisions relative to the importance of certain events depends on when room closure and consolidation of the backfill and waste occur. Davies et al., 1991 present an overview of strongly coupled chemical, hydrologic, and simplified structural processes. **Figure 5-6** shows the dramatic reduction in cumulative brine inflow, the rate of brine inflow, and the slope of the curve (which actually reverses sign, indicating that brine is being displaced out of the room) when the coupling of gas generation and brine inflow to a disposal room is considered in the absence of room closure.

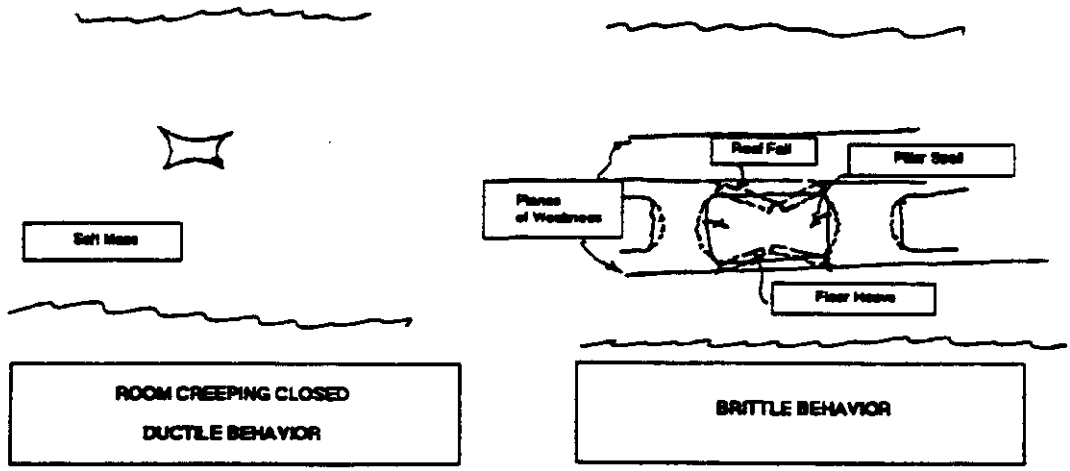

Figure 5-5. **Schematic Diagram Illustrating Creep Closure by Ductile and Brittle Processes.**

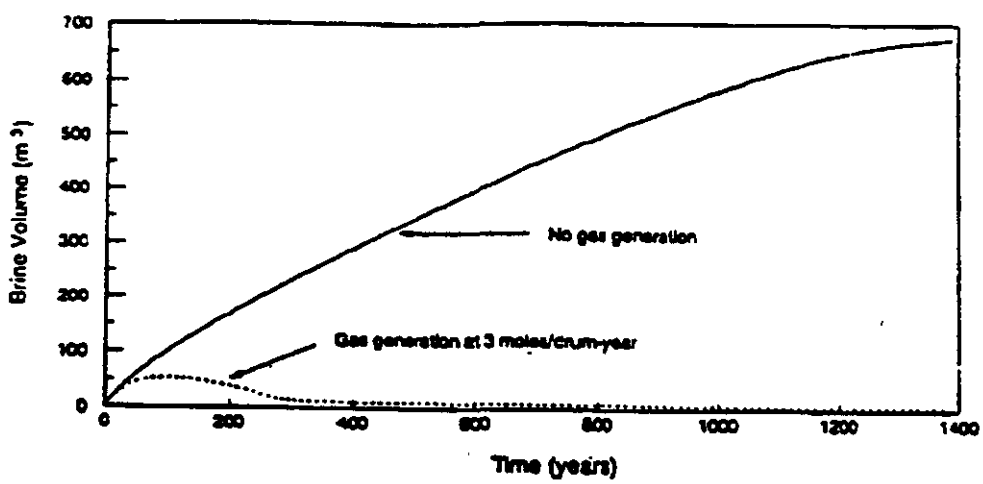

Figure 5-6. **Plot Comparing Cumulative Brine Inflow to a Disposal Room in the Absence of Gas and Brine Inflow with a Fixed Gas-Generation Rate of 3 Moles per Drum Per Year. These simulations are based on the model configuration and parameters illustrated in Figure 7. (Davies et al., 1991).**

If creep closure is considered without gas generation, average initial porosity of a backfilled room of 0.65 drops to 0.3 in 100 years and to about 0.16 in 750 years. **Figure 5-7** shows the porosity history for this case (Davies et al., 1991, Fig. 11). However, if constant gas generation rate exists in a perfectly sealed room, the decrease in porosity leads to higher pressure, which in this model leads to a reversal in room closure and an expansion of the room, as shown on **Figure 5-8.**

The results shown by Davies et al., 1991 are from two-dimensional calculations using the SANCHO code and the elastic-steady-state constitutive model. The elastic modulus in this simplified constitutive model was reduced in magnitude until computed room-closures agreed with measured values. Because the elastic modulus is a fundamental physical property of the salt, it has a measured value. When the value is changed to enhance agreement with measured results, it becomes a fitting parameter, and the constitutive equation has no fundamental basis. If the deformation in the repository is very similar to that of the measured results, such a model may be adequate to predict performance. However, it is difficult to have much confidence in the results of calculations using this model until it is shown that the simplified model produces results in agreement with the more realistic model.

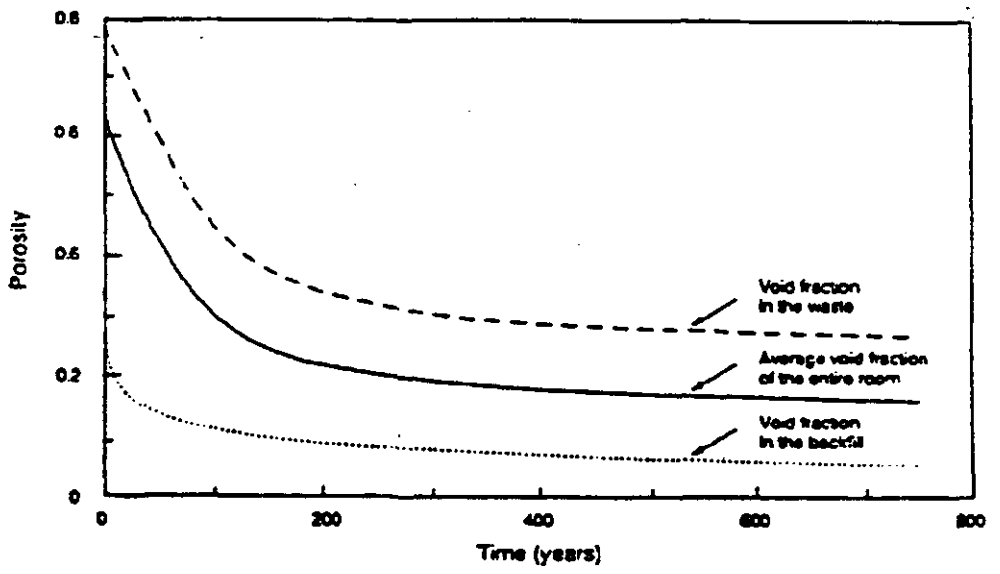

Figure 5-7. Simulation of Average Porosity History of a Disposal Room Filled with TRU Waste and 70% Salt/30% Bentonite Backfill and no Gas Generation, Adapted from Butcher et al. in Press A (Davies et al., 1991).

The finite-element mesh used is shown in **Figure 5-9** and has several limitations that may affect the results. For example, the model used is two-dimensional and represents one quarter of the room and pillar system; i.e., two planes of symmetry have been assumed, one vertical and one horizontal in a homogeneous salt mass. The horizontal symmetry plane forces the model to assume that the room is filled with waste surrounded by crushed salt backfill with no air-gap at the top. Further, the assumed horizontal symmetry plane makes it impossible to include some heterogeneity. No inter beds are included in the model.

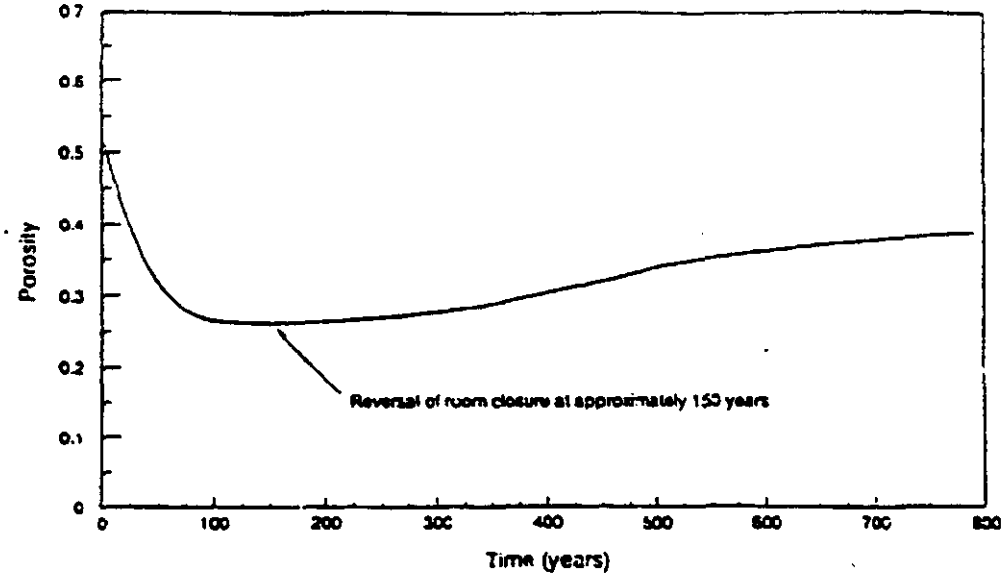

Figure 5-8. **Simulated Changes in Average Room Porosity for a Perfectly Sealed Room with a Gas Generation Rate of 2.60 Moles per Drum per Year (Davies et al., 1991).**

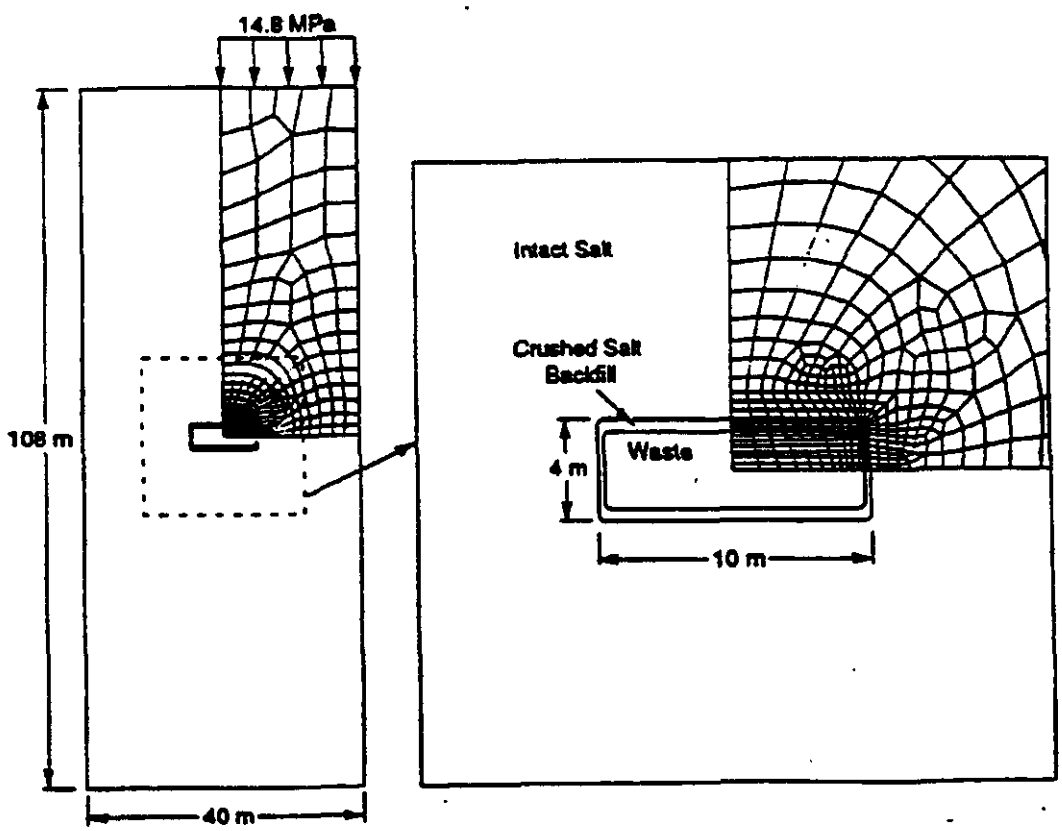

Figure 5-9. **Modeling Mesh and Boundary Conditions for Calculation of Porosity Surface with SANCHO (adapted from Mendenhall et al., 1991, Figure 3-2).**

This model is valid only if there is a continuing sequence of identical rooms in both horizontal directions, which there is not. In a repository with a width greater than critical width, see Figure 5-1, the model represents pillars near the center of the total width of the excavation.

With respect to loading on the room-pillar model, the overburden is represented as a fluid that only applies pressure to the top of the model; i.e., the model neglects the stiffness of the overburden and its potential effect on room performance. For rooms away from the central area of a repository of supercritical width, and for repositories of less than critical width, arching may occur in the overburden and the assumed boundary conditions may not be adequate. The model used also assumes that the rooms are all excavated and filled simultaneously, which is not the case. The time sequence of excavation, filling with waste, and backfilling with crushed salt may be important in the development of the DRZ and the response of the repository rooms.

The salt has been assumed to be homogenous and at a constant temperature; in other words, the natural thermal gradient, heat generated by the waste, heat removed by ventilation during the operating period, etc. have all been neglected. Given the known sensitivity of salt deformation rate to temperature, temperature calculations and thermal effects should receive careful consideration in PA.

SNL investigators are aware of the limitations of the model, as currently used. The coupled system is complicated and increasing the detail in the model will require significant effort; however the details of the system may be important to PA. It is apparent that further work in this area is needed for better understanding of the performance of the coupled system.

If chemical (gas generation), hydraulic, and structural effects are all considered simultaneously, increased gas pressure is expected to decrease brine inflow, which would limit the gas pressure generated, and decrease the possibility that the rooms would expand rather than close. If the gas pressure becomes too high, new fractures will be created that will lower the gas pressure. These fractures may occur in the DRZ if the gas-generation rate is high. It is apparent that the timing of each of these phenomena is important in the coupling. Also, the question remains of whether a disposal room can effectively seal the gas generated. The rate at which the DRZ fractures heal, relative to the gas pressure generated, appears to be important.

The M-D model and most other models are based on the results of laboratory scale tests in a dry environment. This may or may not be important, depending on how well the laboratory results scale up to the repository scale and how much brine actually enters the repository. Salt deformation may be affected by micro-cracking and gas pressure in the pores (Chan et al., 1992, report on work in progress to incorporate brittle phenomena into the M-D model). Finally, the M-D model has been developed using primarily the results of triaxial compression creep tests at various temperatures in the range expected in the repository. It is questionable whether any model based on simple stress paths will be able to accurately predict the response of the rock to the potentially more complicated stress path (possibly including a change from contraction to extension) that may occur in the repository. This is not a criticism of the M-D model; it is the best currently available and should be used. Ideally, the M-D model, as modified to include brittle behavior, will account for all of the deformation and will be adequate for coupled analysis. The Test Phase Plan for WIPP, March 1993, p. 3-27, notes that in referring to coupled multiphase studies, "these models describe the physical behavior of the disposal room in greater detail than necessary for the performance assessment. . . . The three-phase

model may allow the Project to better understand and represent the relationship of room dynamics and fluid flow for the performance assessment."

5.2 THE DISTURBED ROCK ZONE

Brine inflow rates into the waste-filled rooms and other repository-level hydraulic properties of the Salado Formation are being characterized carefully, because brine

- is the principal means by which radionuclides may be transported out of the repository;
- strongly influences gas-generation rates and pressures within the repository; and
- generally affects mechanical properties of salt and salt seals.

Hydraulic conductivity (permeability) and specific storage (porosity, storativity) all increase, while fluid pore pressure decreases within 1 to 3 meters from the walls of the excavations (Beauheim et al., 1991). These changes are to be expected because in the course of mine closure, a large stress gradient is generated from lithostatic pressure within the salt to atmospheric pressure at the excavation boundary. This leads to rapid transient creep processes, including cracking at grain boundaries in the salt and faulting in MB 139 (**Figure 5-10 A**).

Munson et al. (1989) and Chan et al. (1992) have incorporated a creep damage model into the multi-mechanism deformation model proposed by Munson and Dawson (1984) in order to account for the transient response. Ratigan et al. (1992) have developed a criterion, based upon 45 tests on WIPP salt and 39 tests on Avery Island salt, whereby, at high strain rate and at critical ratios of shear stress to mean pressure in the salt, $\sqrt{J_2} / I_1 > 0.27$ positive volumetric strains occur by dilatancy. Damage due to dilatancy increases as the ratio $\sqrt{J_2} / 0.27 I_1$ increases above unity and for values less than unity, zero or negative volumetric strains are accompanied by crack healing. R.L. Thoms (personal communication, December, 1992), for his model of a solution-mined cavern within N. Dayton dome, found that the critical value of $\sqrt{J_2} / I_1$ was exceeded only within 3 meters of the wall at 850 meters depth. At WIPP, Borns and Stormont (1988) found that dilation within the DRZ, resulting from microcrack porosity, increases with time and is accompanied by increases in gas flow rate (by 10^4, **Figure 5-10 B**), apparent resistivity (by 900 ohm-m) and by decreases in compressional wave velocities (by 10%). This dilatant volume increase at least partly accounts for closure rates observed that are three times higher than those calculated prior to excavation; (see also Munson et al., 1989).

5.2.1 Permeability and Pore Pressure

Each year, as a result of new understanding and improving technology, the hydrologic properties of various members of the Salado have been refined (Beauheim et al., 1991; Howarth et al., 1991; Jensen et al., 1993a,b; PA, 1992). More specifically, estimates of far-field permeability have consistently decreased, while those of intrinsic formation pore pressure have increased as it has become clear that disturbances resulting from the excavation have strongly influenced diffusivities and hence the results. For far-field hydraulic properties, the most reliable data have come from fifteen boreholes drilled 23 meters deep in the vicinity of what was to become a 110 m-long by 3 m-diameter (309 ft-long by 11 ft-diameter) experimental tunnel termed Q. Jensen et al. (1993 a, b)

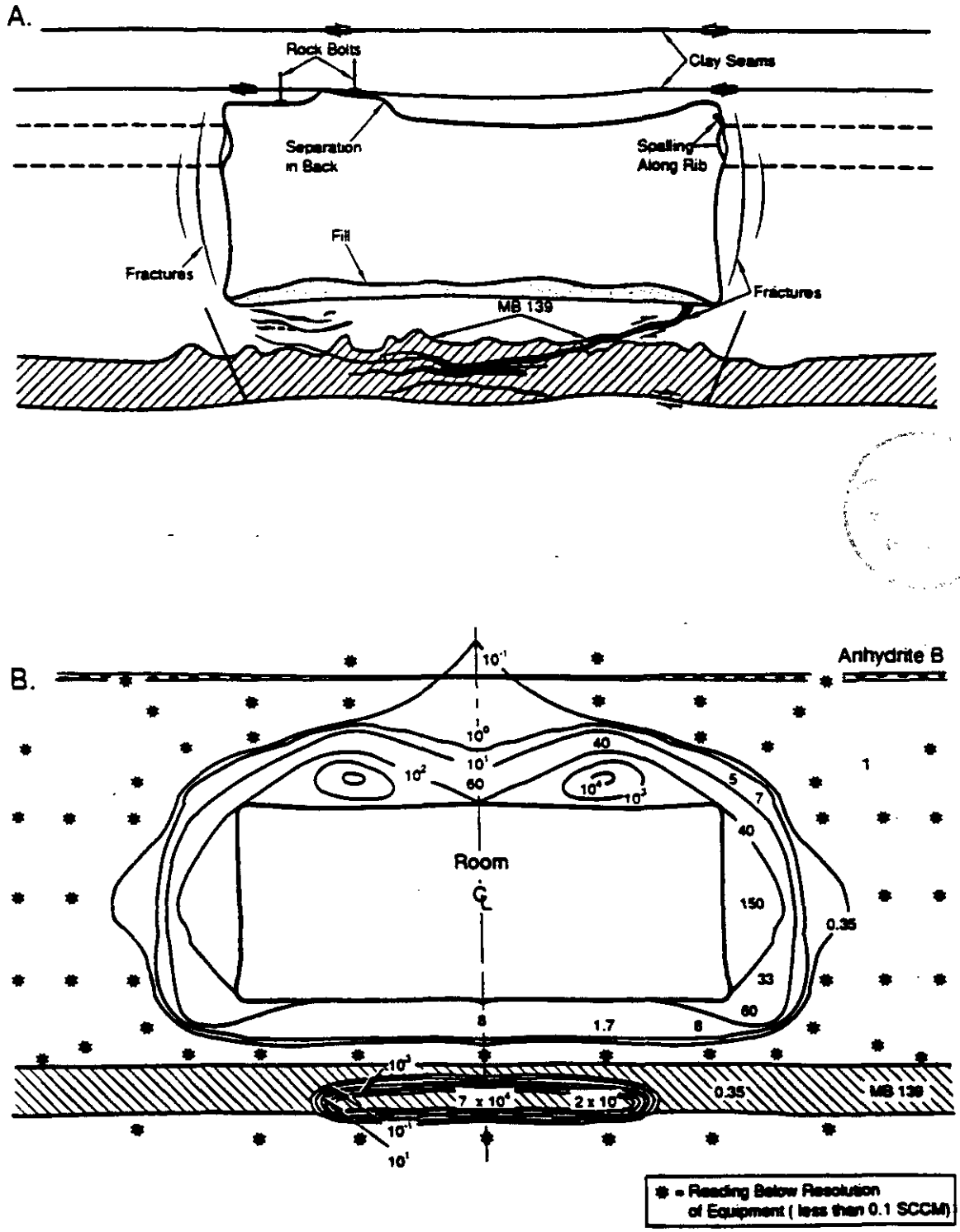

Figure 5-10. **Disturbed Rock Zone Adjacent to Underground Excavations at the Waste Isolation Pilot Plant. (A) Fracture Patterns. (B) Contours of Gas Flow Rate for Gas Injected at Less than 1 MPa (Davies et al., 1991).**

describe schedules, procedures and data acquisition in detail, and interpretations of pre-excavation data are given by Howarth et al. (1991) and Gorham et al. (1992). Howarth et al. (1991) used somewhat different data reduction, fitting, and interpretation procedures than did Beauheim in 1991 and Gorham in 1992, and, in some instances, permeability estimates differ.

Beauheim et al. (1991) discuss details of permeability tests in rooms C2, D, L4, 7, S0P01 and SCP01 (Figure 2-8) and conclude that since all tests except three were within 5.6 meters of the excavation walls, estimated hydraulic properties are likely to represent values from zones that have been disturbed or depressurized. Formation pore pressures within 3 meters of the wall range from 0.1 to 0.5 MPa. Pore pressure beyond 3 meters is variable, in the range 2.7 to 9.3 MPa and, beyond 6 meters, apparently is greater in the anhydrite (12.5 MPa) than in the halite; little change in permeability occurs in this depressurized zone (Beauheim et al., 1991; Gorham et al., 1992). Hydraulic conductivities within 3 meters of the wall are higher by two to three orders of magnitude for both halite and anhydrite layers. Peach (1991) also observed a thousand-fold decrease in permeability of Asse, Germany, salt from the gallery wall to 3 meters into the salt body in a mine room at the 800 m (2,600 ft) level.

Stormont et al. (1991) document significant increases in both brine and gas permeability in salt near a 3-foot-diameter "mine-by excavation" drilled into the floor of the WIPP mine. Prior to excavation, formation pressures and permeabilities were determined using an array of 4.8 cm (1.9-in) test holes drilled at distances of from 1.24 to 4 radii (r) from the center of the .45 m (1.5-ft) radius hole to be excavated. During and after excavation, the low pressure and high deviatoric stress near the wall induced major damage to the pore structure by cracking and dilation; large, transient pressure drops and increases in permeability were recorded in test holes placed at 1.25 and 1.5 r. These changes were much less pronounced in test holes at 2, 3, and 4 r, where little to no pore structure damage occurred (Stormont et al., 1991).

5.2.2 Brine Inflow

Mechanically, the limited brine in the DRZ may increase transient creep rates by enhancing crack growth rates at the low confining pressures (Brodsky and Munson, 1991). There is no evidence to suggest that dislocation processes (microplasticity) are enhanced by hydrolytic weakening in alkali halides, and pressure solution (grain boundary dissolution-diffusion-precipitation) kinetics at 27°C are such that these processes are not expected to contribute greatly to the creep strain during closure (Borns, 1987; Carter et al., 1993). However, the presence of water does enhance crack healing rates (Hickman and Evans, 1991; Brodsky, 1990; Costin et al., 1980) and hence the dilatant state of the DRZ during creep closure will depend on the balance between crack opening, and healing. Possible brine sources other than Salado include leaks through shaft seals of Rustler Formation brines (Section 7) and injections from boreholes in Castile Formation pressurized brine pockets; however, the Castile sources relate only to relatively late time frame behavior.

Brine inflow rates at WIPP have been monitored extensively in the Brine Sampling and Evaluation Program (BSEP) (Deal and Case, 1987; Deal et al., 1989; Deal and Roggenthen, 1992) and for rooms D, L4 and the Q access drift (Finley et al., 1992). **Figure 5-11** shows the size and orientations of 17 small-scale brine inflow boreholes relative to the stratigraphy of the waste facility horizon. Subhorizontal holes DBT 16 and DBT 17, were drilled into a single stratigraphic unit, clean

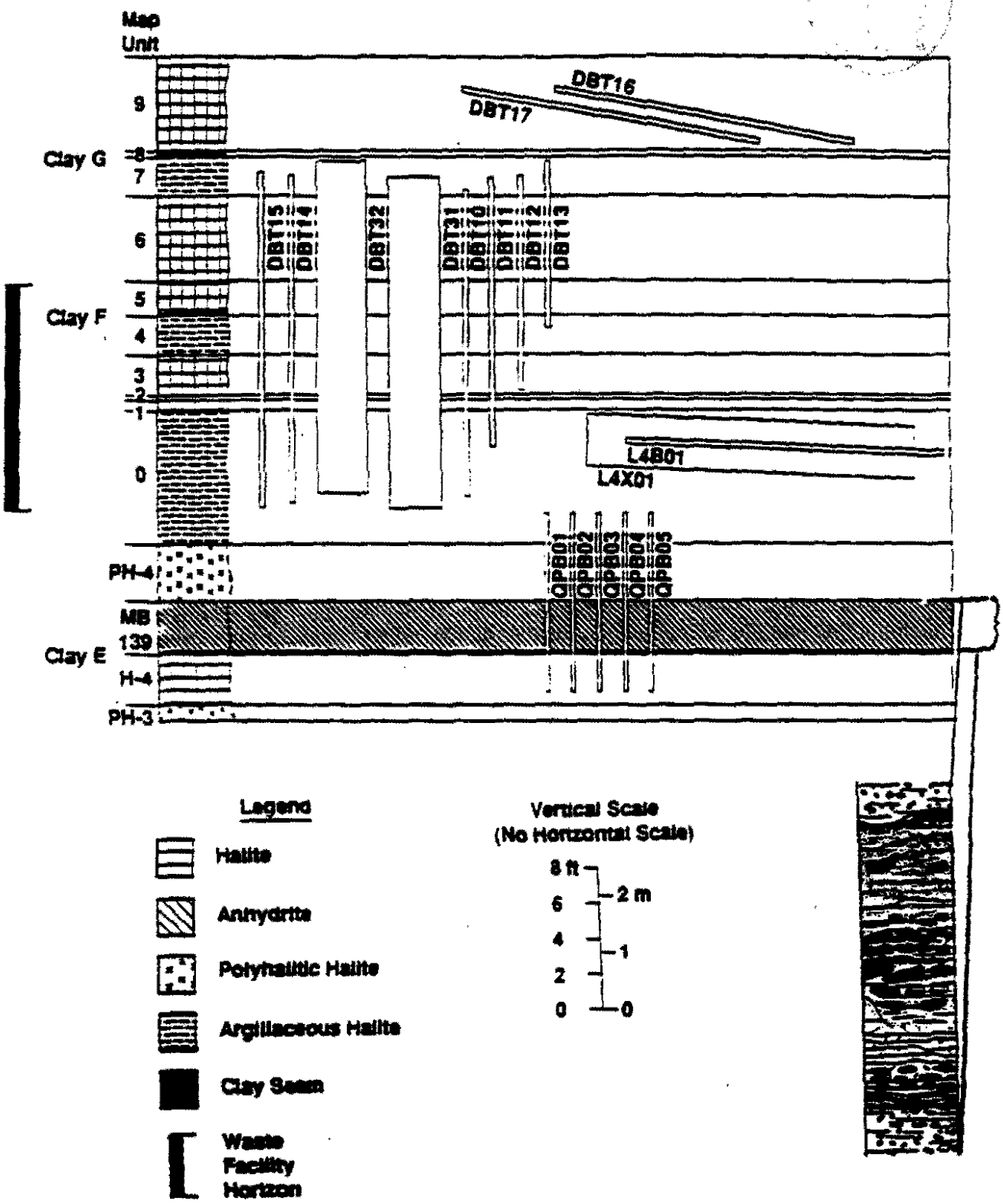

Figure 5-11. Schematic Diagram Showing Small-Scale Brine Inflow Boreholes and the Stratigraphy Tested in Each (Finley et al., 1991; MB 139 stratigraphy from Borns, 1985).

halite map unit 9, in the rib of room D and have shown no brine inflow in 1,350 days. The other two subhorizontal holes, L4X01 and L4B01 were drilled into map unit 0, a 2-m (6.6 ft) thick layer of argillaceous halite comprising the lower half of the waste facility horizon; these two holes have produced small amounts of brine over the monitoring period (**Figure 5-12**). Clay content, which is directly related to bulk water content (wt % H_2O=wt % insol. res./3; Stein and Krumhansl, 1989) is believed to be one of the controlling factors influencing the brine inflow. Deal et al. (1989) also find small inflow rates for horizontal holes of the BSEP program and note that such holes older than 2.5 years are not producing brine.

Brine inflow rates for vertical holes through the repository horizon are generally higher than for the subhorizontal holes. Rate of inflow for DBT 15 is shown in Figure 5-12 but these values differ appreciably from those recorded for hole DBT 14, a like-sized (10-cm-diameter) hole, 9 meters away, bored through the same stratigraphy. The cumulative brine mass for the eight boreholes in the floor of room D ranges from 4 to 17 kg as compared to the 1.5 to 2 kg for the two subhorizontal holes in room L4 (Finley et al., 1992). In accord with the results of Finley et al. (1992), from 5 to 15 grams/day of brine were collected from the eighteen BSEP holes near the repository horizon (Deal and Case, 1987).

The five equally-spaced boreholes in the Q access drift were designed to test stratigraphic units immediately below the waste facility horizon, especially MB 139 (Figure 5-11, lower right columnar section). Inflow rates from these boreholes have been both the greatest and the most variable of the three areas sampled, with an average of 14 kg/hole/yr. However, borehole QPB02, which is located in center of the drift, has produced more than half (63.9 kg) of the 113.4 kg of cumulative brine inflow (Figure 5-12) in two years and QPB05 has produced nearly one-third. A fracture was identified in QPB02 and a salt encrustation—or clay-covered perturbation—was found in QPB05; excavation-induced fracturing in MB 139 may explain these variable results and brine influx histories (Finley et al., 1992, Figure 12; Table 2).

Increasing, decreasing, and fairly steady inflow rates have all been observed in 15 of the 17 boreholes; all three types of behavior frequently occur in the same borehole. Most of the boreholes showed a high initial mass flux followed by a monotonic decrease in flux with time. Eleven of the 15 brine-producing boreholes have shown increasing flow rates during the last year (Finley et al., 1992) a response also noted for BSEP holes (Deal et al., 1989). Steady or increasing inflow rates are most probably the result of ongoing fracture development because, in a confined reservoir, flow rates would decrease with time, as is observed in the early history of nine of the boreholes.

Nowak et al. (1988) present a WIPP brine flow model that assumes transient Darcy flow in a porous medium and predicts brine inflow rates for comparison with those observed in the BSEP program (Deal and Case, 1987). Combined with conservative values for the fluid diffusivity, viscosity, and the borehole radius, the apparent permeability (k) at hydrostatic fluid pressure for long times was estimated to be 3.5×10^{-21} m^2. This estimate falls within the range 10^{-20} to 10^{-21} m^2, a range then believed to be representative of far-field permeabilities on the basis of in situ tests (Petersen, 1987).

Expected brine accumulations, using this permeability range and pore pressures from hydrostatic to lithostatic, were calculated for a WIPP reference disposal room (4 m x 10 m x 91 m; Total Surface Area = 2548 m^2; Volume = 3645 m^3) by means of two-dimensional numerical analyses. For a room in a panel, expected accumulations after a 100-year post-closure period range from 4 m^3

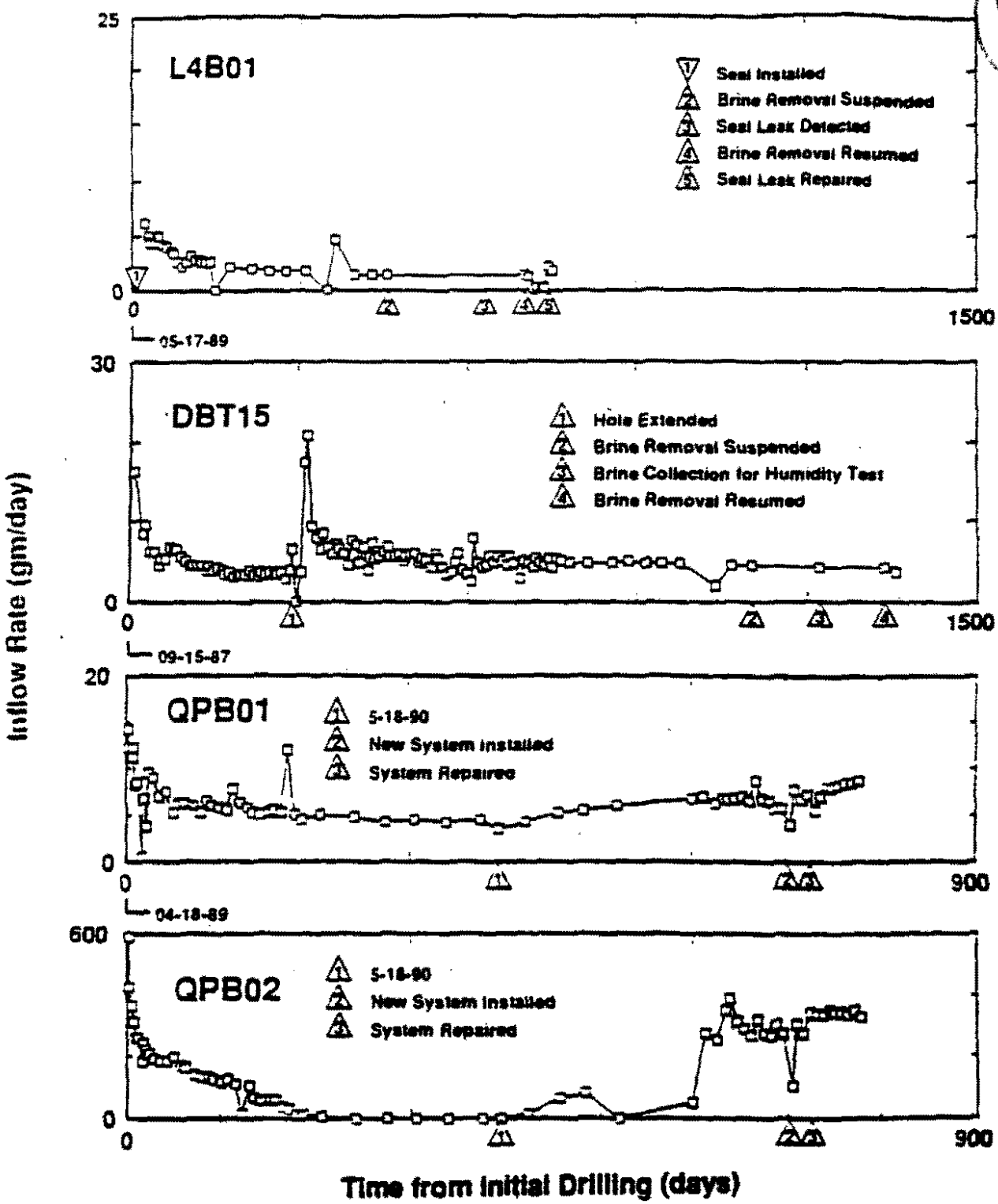

Figure 5-12. **Brine Inflow Rates From Boreholes Whose Locations Relative to Repository Stratigraphy are Shown in Figure 5-2 (Finley et al., 1991).**

for hydrostatic fluid pressure, P_0 = 6 MPa and k = 10^{-21} m^2 to 43 m^3 for lithostatic fluid pressure, P_l = 15 MPa and k = 10^{-20} m^2 (**Figure 5-13**). The increase in fluid pressure at constant permeability increases cumulative inflow by a factor of two to three whereas a ten-fold increase in permeability at constant fluid pressure increases inflow by a factor of four to five. Nowak et al. (1988) regard 43 m^3 (1.2% of the room volume) as an upper bound on brine flow into disposal rooms. Lappin et al. (1989, p. 3-14) note also that the estimates of Nowak et al. may be inherently high because of flow model assumptions and system characterization uncertainties. Bredehoeft (1988) obtained similar results for this permeability range in his numerical analysis of brine inflow.

5.3 GAS GENERATION

Preliminary analyses of post-closure evolution of disposal rooms indicate that significant quantities of gas may be generated by anoxic corrosion of steel containers and iron-based alloys in the waste and by microbial degradation of cellulosics (Lappin et al., 1989). Brine quantity and chemistry are important in considerations both of radionuclide solubility and of gas generation rate (Davies et al., 1992). Gas-generation rates are reduced if the environment is humid rather than inundated and are reduced still further if conditions are oxidizing (Brush, 1992). Under aerobic conditions, gas is not generated by metal corrosion, and microbial activity produces only CO_2 and H_2O (DOE/WPIO, 1992, p. 2-21). However, for the long-term time frame, following creep closure of the repository, anaerobic conditions should prevail, and sufficient gas may be produced to become a factor in repository behavior.

Pores in the waste, through time, will be filled with brine and/or gas generated by corrosion and biodegradation. After interaction with room contents, brine chemistry and availability are expected to affect gas generation rates during anoxic corrosion by defining the thermodynamic activity of water in the liquid and vapor states. The absolute humidity of the repository atmosphere in equilibrium with Salado brines, as a function of variations in chemistry and temperature, may range from 18 to 27 g/m^3 (DOE/WPIO, 1992). On the basis of preliminary experiments (Brush, 1991), inundated gas generation rates from anoxic corrosion are estimated at 1 mole/drum/year, about the same as those due to microbial activity; radiolysis of brine is expected to produce only 1 x 10^{-4} moles/drum/year. Inasmuch as 6,804 drums are placed in each waste disposal room, the annual amount ~~volume~~ of gas generated ~~at atmospheric pressure~~ is estimated to be about 1.4 x 10^4 moles. If conditions are humid rather than inundated, the rates and annual gas production volumes will be lower by a factor of approximately ten (Brush, 1991). The total gas production potential per drum is about 1,600 moles (1,050 - anoxic corrosion, 550 - microbial activity) for a total (equivalent disposal room) volume of 1.1 x 10^7 moles (Beraun and Davies, 1991). Depending on room environmental conditions and the microstructural state of the surrounding rock, this total production potential could be realized sometime between a few hundred and greater than 10,000 years.

The gas generated must be stored in the available void space in the waste, the backfill and the air gap within each disposal room. This storage volume decreases with time during creep closure until the pore pressure exceeds the hydrostatic pressure. Initially, the air gap volume per room is 649 m^3 and the waste volume is 1,663 m^3 (Beraun and Davies, 1991). Variations in porosity of the

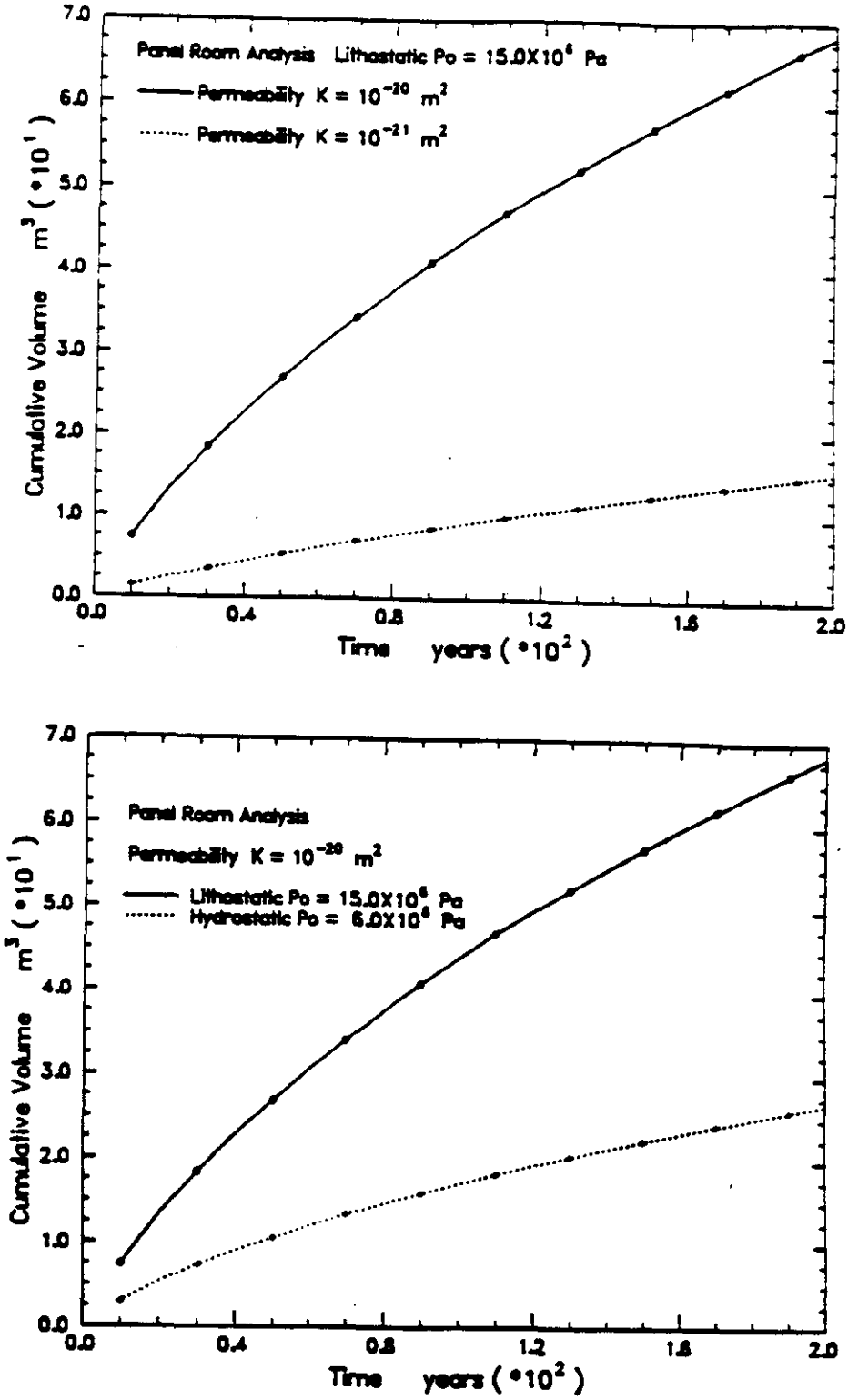

Figure 5-13. **Cumulative Brine Volumes in a Disposal Room as a Function of Time for Salado Formation Permeabilities of 10^{-20} and 10^{-21} m^2 and Pore Pressures of 6 and 15 MPa. The values were calculated from a brine transport model using BSEP data and assuming Darcy transient flow in a porous medium (Nowak et al., 1988).**

compacting waste as a function of pressure are shown in **Figure 5-14** (Butcher, 1990; 1992; Davies et al., 1991; Beraun and Davies, 1991). Properties of the crushed salt backfill are reasonably well-established by means of laboratory-scale compaction experiments (e.g. Holcomb and Shields, 1987; Holcomb and Zeuch, 1990; Pfeiffle and Senseny, 1985; Case et al., 1987): The backfill occupies a volume of 1,328 m^3 and has an initial porosity of about 0.4 (Beraun and Davies, 1991). Thus, the initial void space will be 649 m^3 (gap) plus 1,300 m^3 (waste) plus 530 m^3 (backfill) or 2,479 m^3. The "final" void volume available following closure will be about 425 m^3 (26% of 1,663; Davies et al., 1991) in the waste, since the air gap disappears and void space in the backfill will be isolated as the crushed salt becomes relatively impermeable, (Lappin et al., 1989) (Italcomb and Shield, 1987). At the maximum gas generation rate (1.4 x 10^4 moles/yr), assuming no leakage, 50 m^3 of brine, and ideal gas behavior, 375 m^3 of void space would be occupied at 27°C (300 K) and 15 MPa pressure (lithostatic) in 160 years. Lappin et al. (1989) estimate a minimum final void volume of about 109 m^3 (0.03 of initial volume) so that only about sixty years of maximum gas generation are required to produce a gas pore pressure equal to the lithostatic pressure.

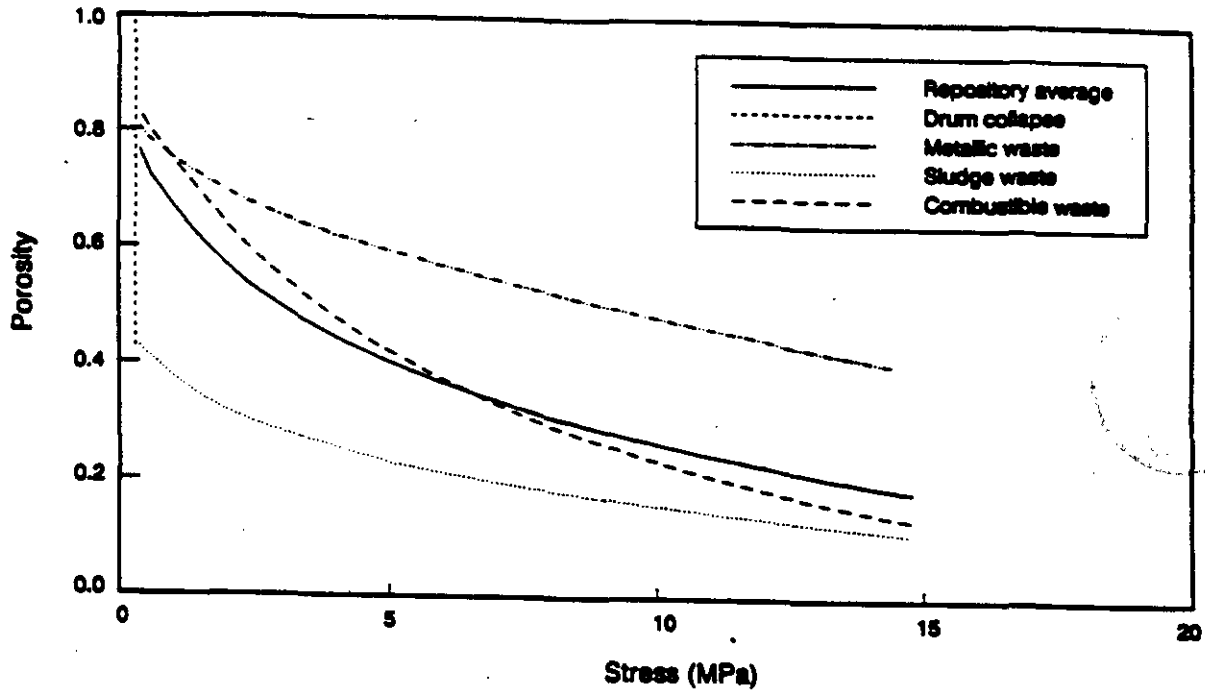

Figure 5-14. Variation in Porosity (f) of Waste as a Function of Pressure (Davies et al., 1991).

5.4 GAS FLOW

Maximum gas pressures calculated above assume, among other simplifications, that gas is entirely contained within the room. If the surrounding rock is fully saturated with brine, as is assumed for Salado members in the far-field, then the relative permeability to gas is zero. In order for gas to flow outward, it must establish interconnected pathways after exceeding resistive capillary forces (threshold pressure) and existing brine pore pressure in the rock (Davies, 1991). Davies' threshold

pressure estimates of Salado Formation members are (1) for relatively pure, undeformed halite, 25 to greater than 50 MPa; (2) for impure halite, mildly deformed halite and some interbeds, 5 to 25 MPa; and (3) for interbed units containing pre-existing, partially healed fractures, 0.5 to 2 MPa (**Figure 5-15**). Therefore, if the far-field pore pressure in halite is 9.5 MPa and the gas pressure within the reservoir builds to lithostatic (15 MPa), then lithologic units beyond the depressurized zone with a threshold pressure of less than 5.5 MPa may permit gas penetration.

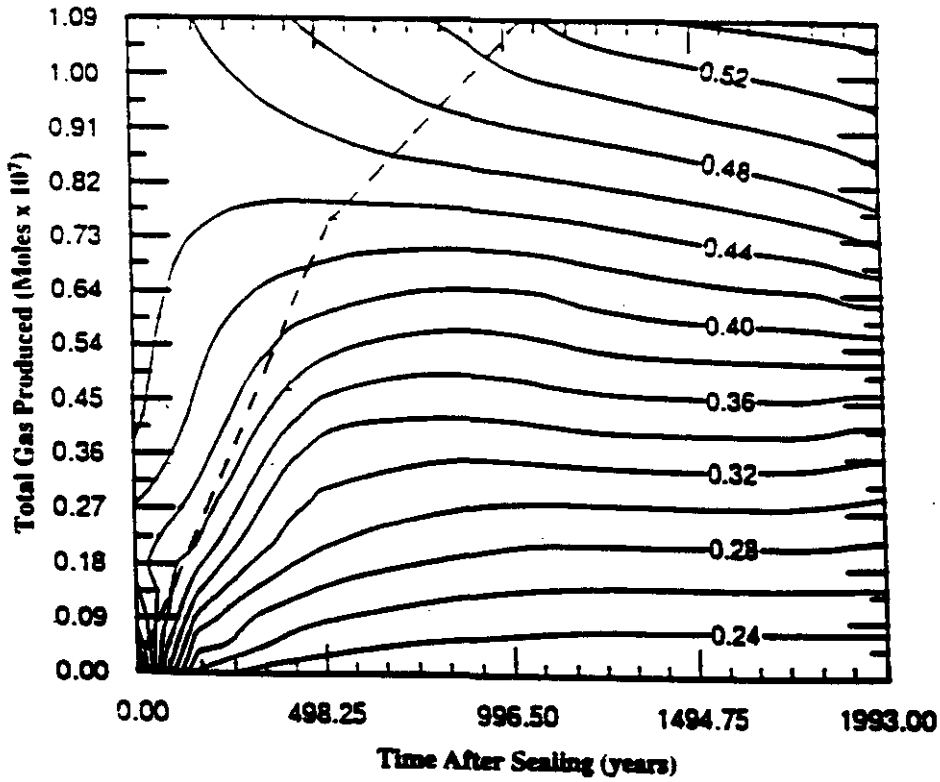

Figure 5-15. Relative Permeabilities and Threshold Pressures of Salado Formation Units in the Far-Field and Near-Field (Davies et al., 1991)

Only nonhalite interbeds and, perhaps, some impure halite members are likely to permit gas outflow under these conditions. For the near-field, several processes involved in creating the disturbed and depressurized regions will interact to provide a zone of low threshold and pore pressure. This near-field zone, which may have significant gas storage potential, is likely to provide partially desaturated pathways for gas to flow to nonhalite interbeds that have relatively high permeabilities and low threshold pressures (Davies, 1991). Possible hydraulic fracturing of MB 139 would also serve to relieve gas pressure and provide gas storage volume.

5.5 COUPLED EFFECTS OF CLOSURE AND FLUID FLOW ON REPOSITORY BEHAVIOR

On the basis of the foregoing summary of processes expected to occur in the repository following closure, it is clear that the overall behavior will depend primarily on strongly coupled rates of creep closure, brine inflow, and gas generation. Davies et al. (1991; 1992) give examples of

possible effects of coupled brine flow and gas generation on disposal room pressures and volumes through time. Their two-dimensional model assumes an isolated room in salt ($k = 10^{-20}$ m^2) in hydraulic communication with higher-permeability ($k = 10^{-19}$ m^2) interbeds, an initial pore pressure of 11 MPa and an intermediate closure state with 1,000 m^3 void volume. Brine inflow rate (initially at 0.48 m^3/year) is reduced by increasing gas pressure, so that further gas generation takes place under partially humid (.003 mole/drum/year) rather than fully inundated (3 moles/drum/year) conditions. Effects of variable gas generation rates on room pressure to 1,400 years are shown in **Figure 5-16**. In this model, gas pressure does not exceed lithostatic pressure (15 MPa) in the first 1,000 years.

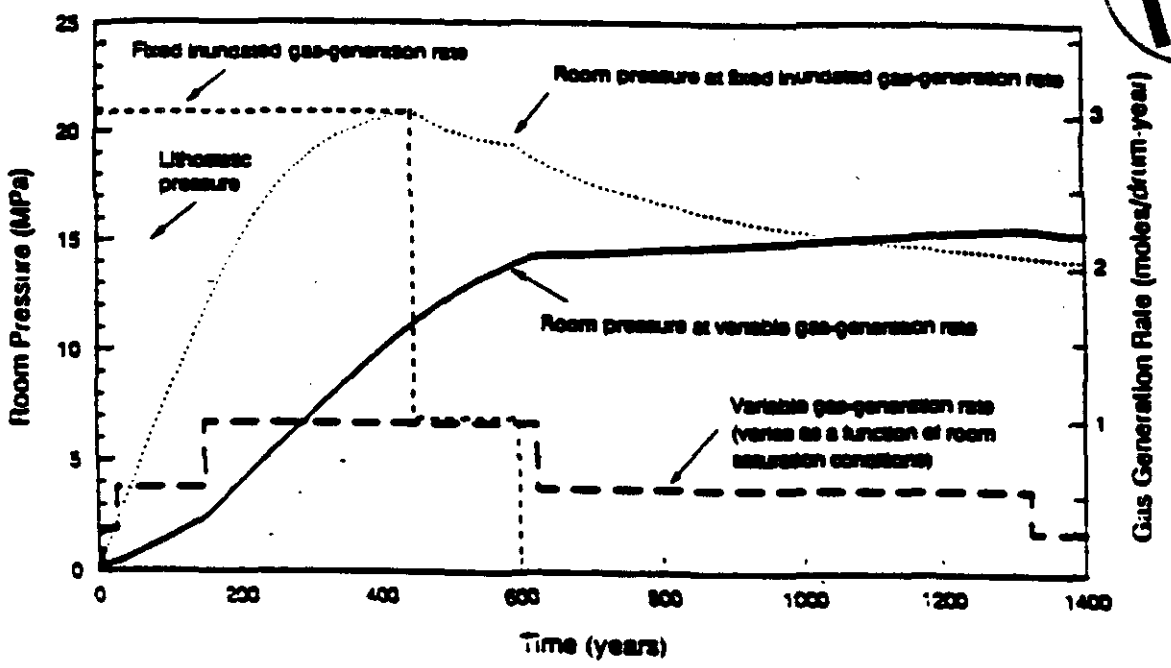

Figure 5-16. Room Pressure Calculated for Inundated (dotted curve) and Variable (solid curve) Gas-Generation Rates (Davies et al., 1992; Figure 10).

Waste and backfill consolidation during creep closure of the rooms causes a significant reduction in void volume available to store waste-generated gas. Therefore, gas pressure rises in the room, which, in turn, resists further consolidation and closure. Modeling salt flow as that of a highly viscous fluid, Davies et al. (1992) coupled brine and gas flow between a disposal room and surrounding rocks in a three-phase (salt, brine, gas), fully-coupled system. The resulting room pressure as a function of time is shown by the solid curve in **Figure 5-17**, in comparison with results obtained for two-phase (gas and brine) flow in a room of fixed geometry. Results from simulations shown all assume a gas generation rate of three moles/drum/year and do not allow for coupling with brine availability. As seen in Figure 5-16, pressure buildup will occur at a much lower rate for variable gas generation rates.

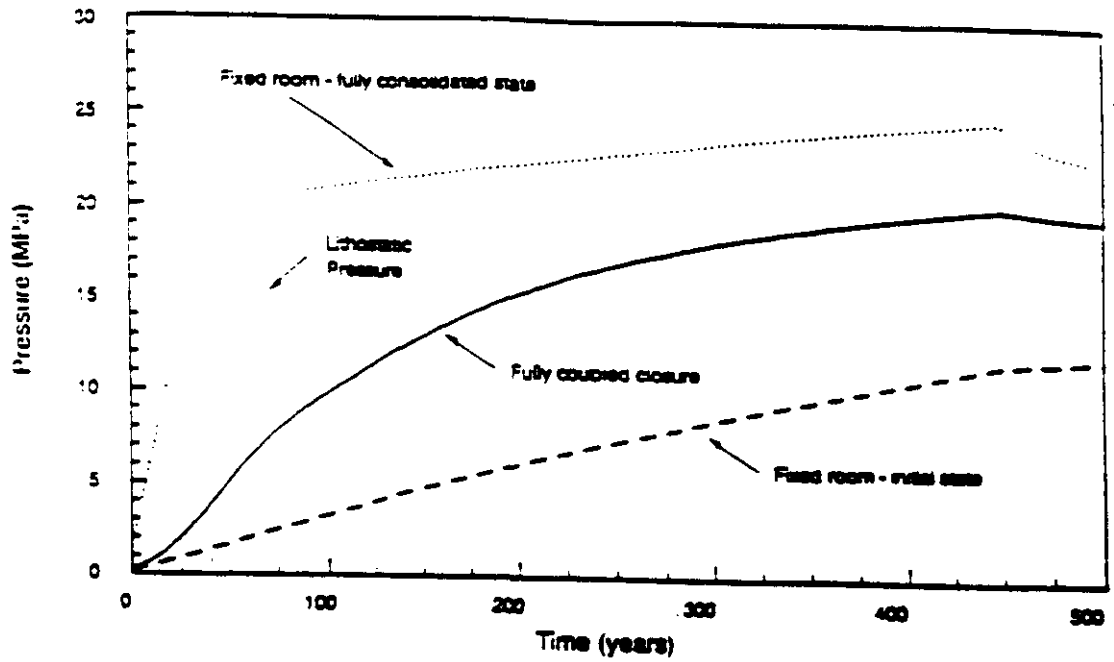

Figure 5-17. Room Pressure as a Function of Time for a Fully-Coupled (solid curve), Three-Phase System (Davies et al., 1993; Figure 16).

The microstructural state of salt, which comprises greater than 90% of the DRZ around waste disposal rooms, is also critical to repository response and must be accounted for in the coupled approximations. The volume occupied by the DRZ, approximated by assuming that it extends 3 meters into the salt, is from three to four times that of the disposal room, in the initial and fully-closed state, respectively, and hence its time-dependent physical properties are of paramount importance. If creep closure to the fully compacted state takes place within 100 years, unimpeded by brine inflow and gas pressure (Lappin et al., 1989; Marietta et al., 1989; PA, 1992; Davies et al., 1992), then the DRZ would self-heal to nearly intrinsic far-field permeability. This possibly healed condition is not accounted for in current PA calculations, Beauheim (1993). Gas generation during this period is estimated to be 1.4 x 10^5 moles per room from both microbial decay and anoxic corrosion in a humid environment (0.2 moles/drum/yr) since only about 50 m^3 of brine is available for the process. Assuming that no gas leakage occurs, the gas would occupy about 350 m^3 pore space in fully compacted waste, giving rise to a gas pressure of 1.0 MPa. Under these conditions, ideally the DRZ would self-seal, providing an impervious shield greater than 1 m (3.3 ft) thick around the waste whose only pathway to the accessible environment is migration along thin clay interbeds and gas venting along rock bolts in the roof to anhydrite layer B. Swift (Beauheim et al., 1993) reports that mining in some portions of the repository involves excavation to MB 139 followed by backfilling to the specified grade. He suggests that it is more realistic to assume that MB 139 will always be in contact with backfill and waste.

6.0 ENGINEERED BARRIERS

This section discusses issues related to the engineered barrier system for a WIPP repository. The discussion is based on a review of a large number of WIPP documents covering a range of topics that are directly or indirectly related to engineered barriers. In general, the review attempted to address the following questions:

- What quantitative and qualitative analyses have been performed relevant to the engineered barriers for the repository?
- What laboratory and field experiments have been performed?
- What is the expert opinion concerning engineered barriers for a salt repository?
- How are the potential pathways and seals being considered in the PA analysis?
- What data are available concerning geochemical compatibility?
- What criteria have been established to determine the requirements of the barrier system?
- What are the remaining issues related to engineered barriers and how are they (or are they not) being addressed?

The performance of engineered barriers at WIPP will depend on several related and often coupled mechanisms and processes. Seal performance will be determined by the creep closure of the underground openings, consolidation of crushed salt, the volume of brine inflow during consolidation, gas-generation rates in the disposal rooms, the extent and healing of the disturbed zone, the permeability of interbeds, and the ability to seal fracture zones. The following discussion touches on many of these aspects. More complete coverage of some of these topics is contained in other sections of this report and the reader is encouraged to refer to them for a more comprehensive treatment.

Subsection 6.1 provides background information concerning the purpose of engineered barriers, applicable parts of the regulatory standards, and a description of the current design concepts. This is followed by a review of the analyses (Subsection 6.2) and tests (Subsection 6.3) that have been performed to assess the viability and performance of repository seals. A summary of the issues associated with the sealing of a repository and planned tests and analyses to address them is presented in Subsection 6.4.

6.1 BACKGROUND

Engineered barriers are crucial to the successful isolation of TRU and hazardous waste from the accessible environment. Engineered barriers include repository design features and engineered components that contribute to the capability of the repository system to meet the radionuclide and hazardous materials release limits set by applicable regulations. The fundamental role of the engineered barriers is to act in conjunction with the natural system to minimize the release of radioactive and hazardous waste from the WIPP repository. Engineered barriers may include

- drift seals,
- shaft seals,
- borehole plugs,

- disturbed rock zone (DRZ) seals,
- interbed seals,
- panel seals,
- backfill,
- waste form, and
- waste packages.

This discussion and those that follow are restricted to sealing aspects of the engineered barrier system and do not directly address waste form and waste packaging components. The review assumes that the current concept for waste form and waste packaging will be employed at WIPP. Obviously, the requirements for the engineered barrier system, particularly the sealing components, would change if alternative waste forms and waste packages were employed, and the importance of performance issues may shift. For example, the volume and rate of gas generated in the disposal panels from corrosion and microbial processes depends on the containers (currently steel) and waste form (unprocessed waste including large quantities of cellulosic materials). If gas generation was no longer a concern, the performance requirements of the sealing components would likely be different.

The regulatory framework for WIPP requires assessment of cumulative release of radionuclides to the accessible environment under standards promulgated by the US Environmental Protection Agency (EPA) in 40 CFR 191 and assessment of migration of hazardous chemical constituents under standards set forth in the RCRA. There is only one reference to engineered barriers in 40 CFR 191 other than the definitions in 40 CFR 191.12. Requirement 191.14(d) states that "the disposal systems shall use different types of barriers to isolate the waste from the accessible environment. Both engineered and natural barriers shall be included." Other references to engineered barriers are contained in Appendix B, Guidance for Implementation of Subpart B, Consideration of Total Disposal System:

> When predicting disposal system performance, the Agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. Portions of the disposal system should not be disregarded, even if projected performance is uncertain, except for portions of the system that make negligible contributions to the overall isolation provided by the disposal system.

Among the standards set forth in RCRA, the Land Disposal Restrictions (40 CFR 268) regulate disposal of specified non-radioactive hazardous wastes. The standards are applicable to WIPP because the transuranic wastes include nonradioactive components, such as heavy metals, as well as volatile organic compounds (VOCs) and other contaminants covered under 40 CFR 268. The regulations prohibit the disposal of these wastes unless the owner or operator of the facility petitions for a variance and demonstrates that there will be no migration of the hazardous constituents (above health-based levels, EPA, 1992) as long as the waste remains hazardous.

In their response to a DOE no-migration variance petition, the EPA has stated that the DOE must address uncertainties about long-term WIPP performance before the DOE may proceed with full-scale operations. Among the uncertainties identified by EPA were the extent and effects of gas generation, effects of brine inflow into the repository, and the influence of the disturbed zone surrounding the mined repository (US EPA, 1990). Each of these uncertainties will play some role in

determining the requirements for and the performance of engineered barriers. Gas from the repository could transport VOCs either horizontally from the repository in the interbeds or vertically up the shafts. The transport pathways and concentration of the VOCs will be determined, in part, by the type and performance of engineered barriers used. Similarly, pressurized brine may transport heavy metals and dissolved VOCs (as well as radionuclides) through the same potential pathways.

The information required to support a demonstration of no-migration in compliance with 268.6(b) includes the results of numerical flow and transport analyses of overall system performance. Additional data from laboratory and field tests will be required to verify that the engineered barrier components of the system will perform as designed.

6.1.1. Current Design Concepts

In the reference design, multicomponent seals will be located in each of the four shafts, in the entrances to the waste disposal panels, and in selected access drifts. The locations of the various seals in the WIPP repository are shown in **Figure 6-1**. The design includes multiple shaft seals and drift seals at strategic locations within the repository. Because the purpose and function of the seals vary with their location, the shaft seals and drift seals will be discussed separately.

The four shafts are the most likely pathways for the transport of mixed waste to the accessible environment under undisturbed conditions (no human intrusion). The strategy for sealing the shafts is to maximize the amount of consolidated, low permeability salt in the shaft between the top of the Salado Formation and the repository level (Stormont, 1988a). The current design for shaft seals includes two types of seals: long-term seals consisting of segments of consolidated crushed salt (**Figure 6-2**); and short-term, composite seals (**Figure 6-3**) intended to prevent brine from contacting the crushed salt seals before it can be consolidated to a density close to intact halite.

Creep closure of the shaft opening is expected to consolidate the crushed salt in the lower portion of the shafts to near-intact (95%) density within 100 years after emplacement (Nowak and Stormont, 1987; Arguello, 1988; Lappin et al., 1989). To facilitate the consolidation phase, composite seals will be located above and below the crushed salt seals to prevent brine from saturating the crushed salt and inhibiting consolidation. Composite seals will be placed at three locations: above the upper salt seal, below the lower shaft seal, and in between the upper and lower salt seals (see **Figure 6-4**). Because the concrete bulkheads in the composite seals straddle the long-term seal intervals, they will also serve as reaction frames to restrict vertical movement of the salt during consolidation.

Fractures in the DRZ surrounding the shafts are expected to heal once the crushed salt reaches 95% density and resists further creep closure and the field stresses return to hydrostatic conditions. The permeability of the DRZ adjacent to the concrete bulkheads in the composite seals is expected to return to near in situ levels shortly after emplacement because they will resist creep closure.

The use of crushed salt as the primary, long-term sealing material for openings in the Salado Formation obviates any concern about seal longevity. The material is, for all practical purposes, identical to the surrounding halite and should have similar chemical and hydrologic properties once the material has consolidated. The concrete bulkheads are expected to degrade with time but remain functional during the near-term when the crushed salt seal is consolidating.

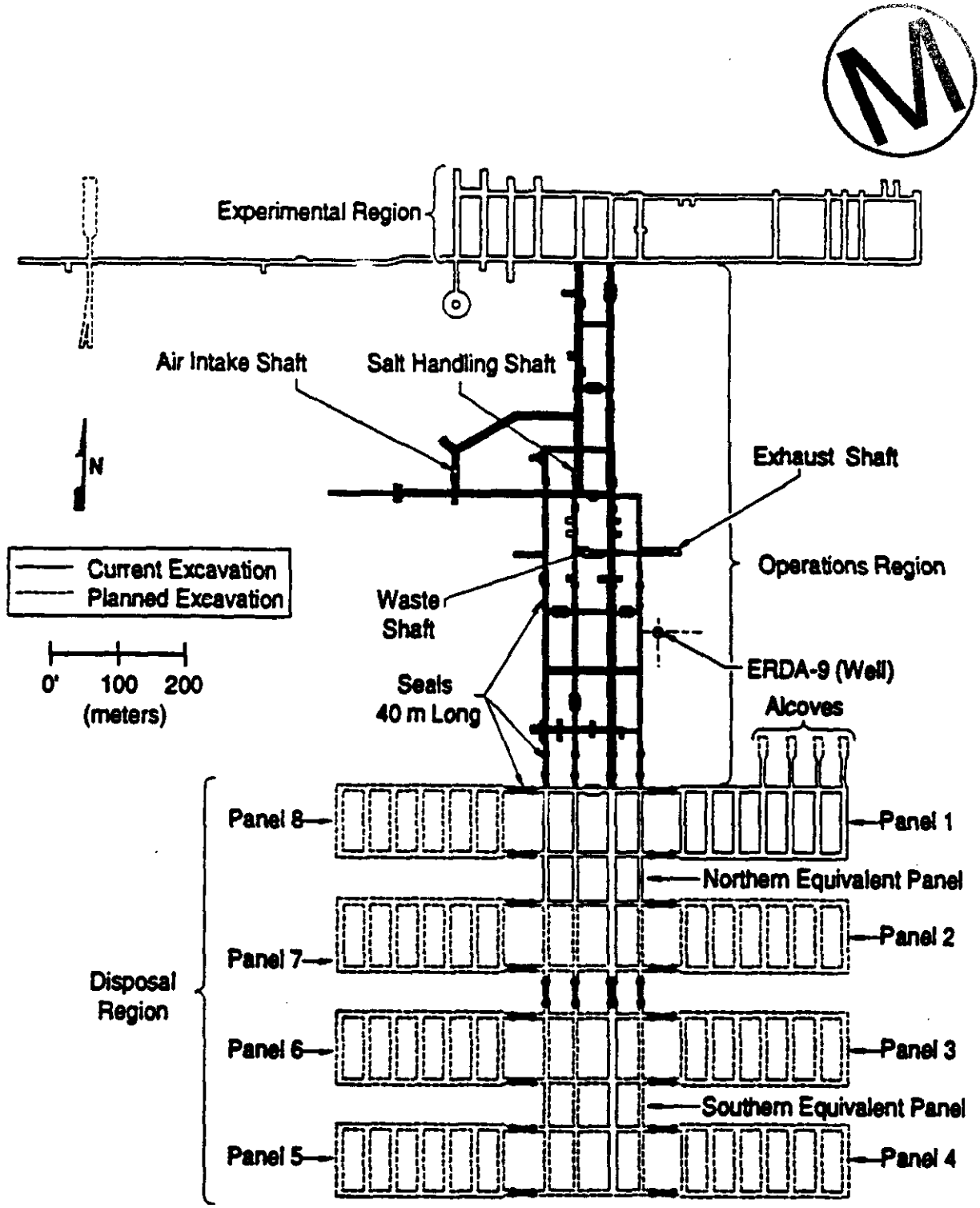

Figure 6-1. Location of Panel Seals

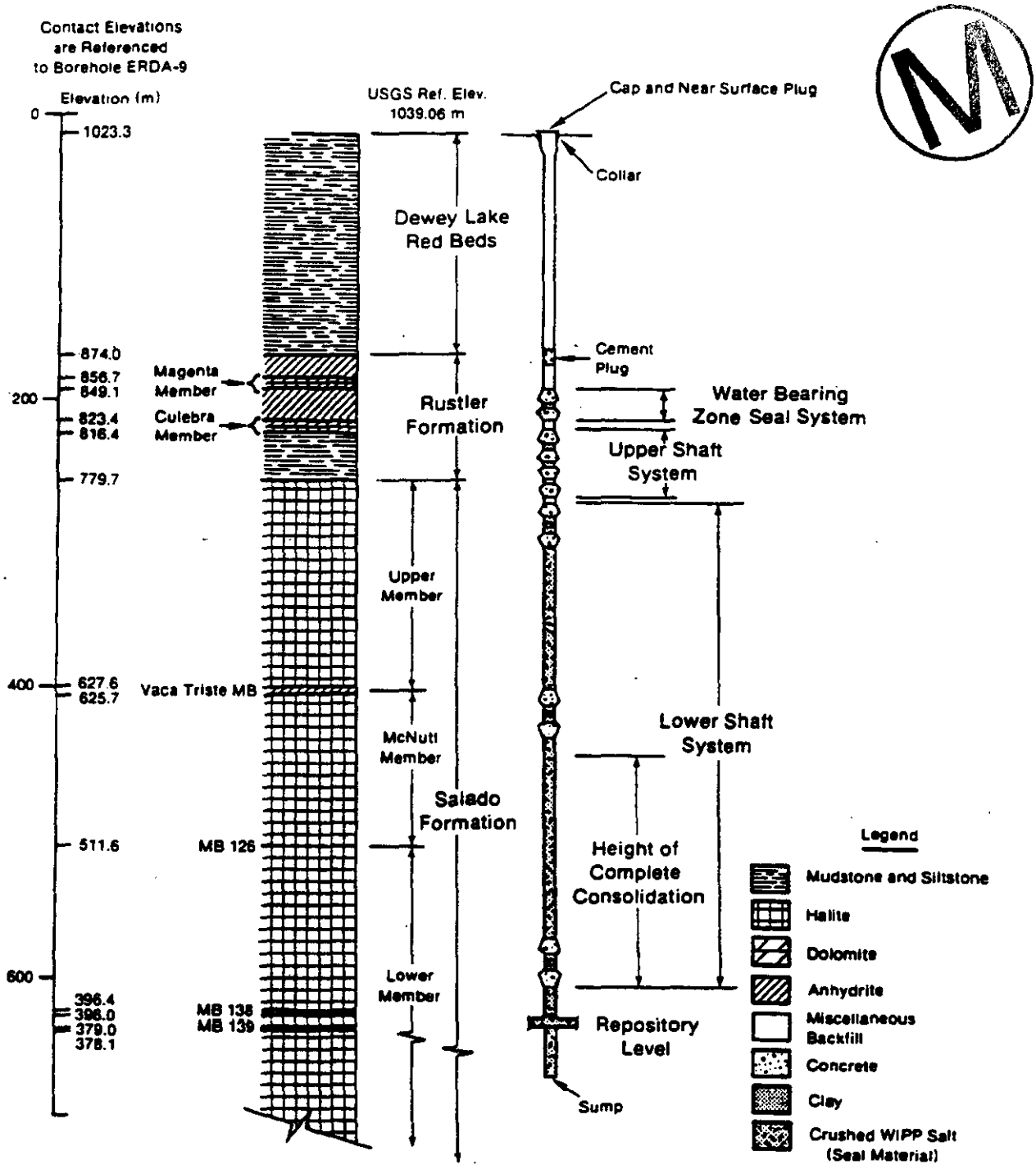

Figure 6-2. **Diagram of Typical Sealed and Backfilled Access Shaft (after Nowak et al., 1990).**

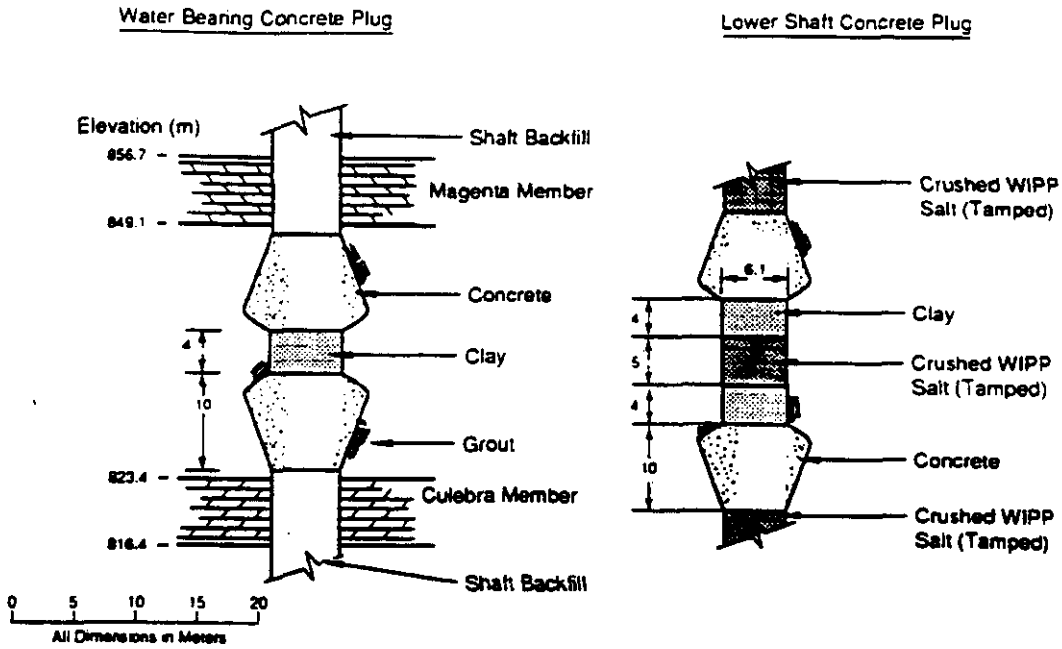

Figure 6-3. **Diagram of Typical Concrete Plugs in Backfilled Shafts Showing Combination of Different Materials Depending on Location Within the Shaft (after Nowak et al., 1990).**

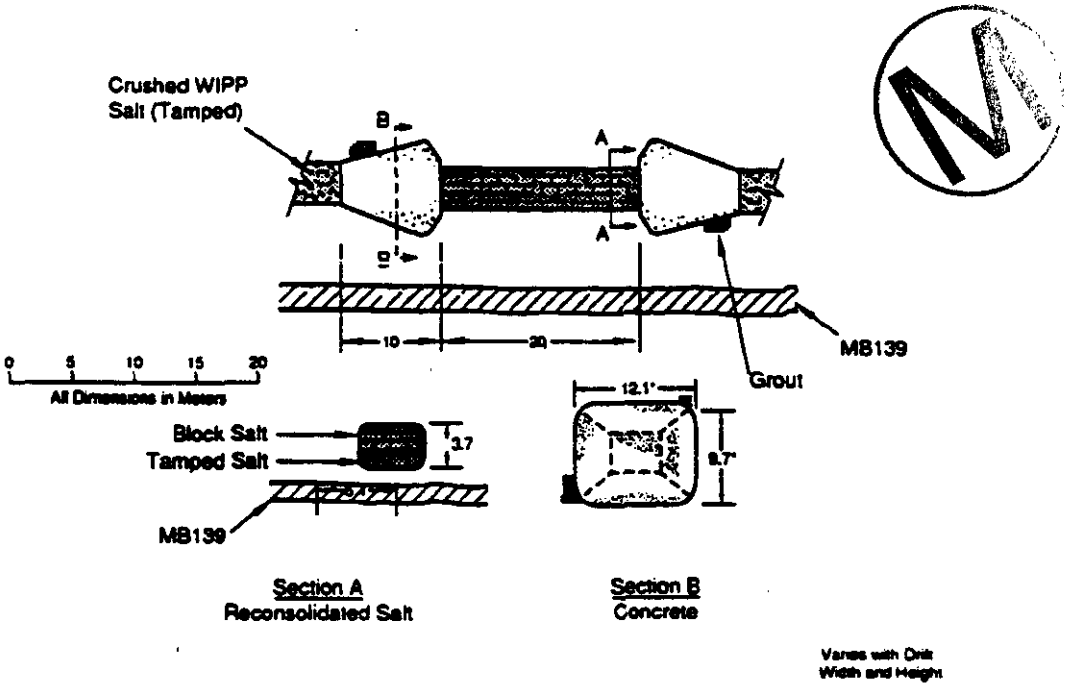

Figure 6-4. **Diagram of Preliminary Design for Concrete and Preconsolidated Crushed Salt Seal for Drifts and Panels (after Nowak et al.). (Vertical dimensions are exaggerated.)**

The upper shaft seal system in the Rustler Formation will comprise of a sequence of seals made up of bentonite clay segments (4 m in length {13 ft}) confined by adjacent concrete bulkheads. The purpose of the seals is to limit groundwater flow from the formation into the lower portions of the shaft during the consolidation phase of the crushed salt seals. The bentonite will be emplaced at an initial density tailored to allow water uptake and swelling pressures that will prevent groundwater flow down the shaft but within the limits imposed by the strength of the host rock and concrete bulkheads. The shaft liners will be removed prior to constructing the seals, to allow direct contact between the bentonite and Rustler Formation. The DRZ surrounding the shafts may be removed or sealed with grout to prevent groundwater from flowing around the plugs and into the underlying crushed salt seals.

The panel and drift seals are designed to inhibit long-term migration of radionuclide-contaminated brine through the drifts to the base of the shafts and isolate the panels during the operational phase of the repository (Sandia National Laboratories, 1992). The seals are similar to the shaft seals and comprise both long-term and short-term seals.

The current design for panel seals is shown in Figure 6-4. The seal consists of 20 m (65 ft) of pre-consolidated crushed salt confined between two 10-m (33 ft) concrete barriers (Nowak, Tillerson, and Torres, 1992). The panel entryway seals are intended to return intervals within the repository to hydraulic properties similar to the intrinsic conditions in the undisturbed host rock salt. In this way, the seals are expected to provide substantial resistance to flow through the repository as well as separating volumes of waste from one another and from the shafts. The concrete bulkheads serve to confine the crushed salt during consolidation and provide resistance to gas flow during this period. The time for consolidation is similar to that for the lower shaft seals, i.e., approximately 100 years after installation.

The DRZ in the salt surrounding the seal locations is expected to heal eventually after the crushed salt reaches 95% fractional density and resists further creep closure of the opening. The disturbed zone around the concrete bulkheads is expected to heal much earlier, due to the back stresses that will be generated. Marker Bed (MB) 139 and the other interbeds adjacent to the repository may need to be sealed above and below each panel and drift seal by grouting, with crushed-salt-based grout, cementitious material, or bitumen. The DRZ and the interbeds represent pathways for bypassing the panel seals.

The performance criteria for the seal components must be defined before the seal design can be finalized. The criteria will be determined, to a large extent, by the results of performance assessments of the WIPP repository system. The preliminary performance assessment analyses of the entire repository system have not included all aspects of the natural and engineered barriers that may influence system performance; therefore, the seal designs and design concepts are preliminary. Stormont (1988a) has identified the following predominant processes which may impact the performance seals and the repository system:

- Closure of the excavations in the Salado Formation and the consolidation of the crushed salt in the long-term seal components;
- Brine inflow into the excavations in the Salado Formation which may inhibit crushed salt consolidation, accelerate corrosion of waste packages, and, if present in discrete pockets, result in pressurized brine;
- Corrosion of the waste package and metallic waste and the generation of gases;

- Water inflow from the Rustler Formation and possible dissolution of salt seals, inhibition of crushed salt consolidation, and creation of pressured brine pockets;
- Creation and long-term behavior of the DRZ around excavations as potential pathways for the transport of contaminants in brines or gases.

These issues are being addressed in a variety of laboratory and field studies, as well as in numerical analyses. The programs are discussed in the following Subsections, and their adequacy to resolve these issues is assessed.

6.2 TESTING ACTIVITIES

The sealing strategy and reference design are supported by numerous laboratory and field tests. These include testing to demonstrate the relatively rapid consolidation of crushed salt under a wide range of pressures, in situ emplacement of crushed salt and bentonite blocks in small-scale seal environments, characterization of the DRZ and interbeds, and in situ testing of prototype grouts and injection technology. The following discussion provides a summary of these tests and their results.

6.2.1 Consolidation of Crushed Salt

When crushed salt is subjected to sufficient confining pressures, it consolidates and eventually achieves porosity and permeability values comparable to intact salt (IT Corporation, 1984). The crushed salt in the shaft, panel, and drift seals will be consolidated as a result of the creep closure of the adjacent host rock which is a function of depth, the properties of the rock salt formation, the size and shape of the excavation, and the resistance presented by the crushed salt.

At a given stress, the consolidation behavior of crushed salt is strongly influenced by the addition of small amounts of water, several percent by weight (Holcomb and Shields, 1987; IT Corporation, 1984). Stormont (1988a) compared the results of a dry consolidation test by Holcomb and Hannum (1982) with those of Holcomb and Shields (1987) in which a small amount of water was added (less than 3% wt), and found that under similar test conditions (stresses) the time required for the dry crushed salt to experience the same strain as the wet material was five to ten orders of magnitude greater. The exact mechanism responsible for this dramatic difference is not understood, although pressure solution is the preferred hypothesis. Because it is desirable for the crushed salt seal components to reach near-intact properties as soon as possible, the reference design includes the addition of small amounts of water to be added to the crushed salt in the shaft, drift, and panel seals (Nowak et al., 1992).

As the crushed salt consolidates, the porosity and permeability will decrease. **Figure-6-5** shows the results of permeability versus density tests performed by Holcomb and Shields (1987) and IT Corp (1987). In general, the permeability of the crushed salt drops rapidly between fractional densities of 85% and 95% (fractional density is defined as the percentage of the intact salt density). At 95% fractional density, the permeability is expected to be between 3×10^{-20} and 3×10^{-21} m^2 (Nowak and Stormont, 1987) compared to a permeability range of 10^{-19} to 10^{-24} m^2 for intact, undisturbed halite in the Salado Formation (Sandia National Laboratories, 1992c). Therefore, if the crushed salt portions of the shaft, drift and panel seals are consolidated to 95% relative density, the excavation will be returned to its undisturbed state. This assumes the DRZ surrounding the excavations also returns to intrinsic conditions. Interactions between the consolidation of the crushed salt and the creep closure of the excavations and the expected time for consolidation to occur is discussed in Subsection 6.3.

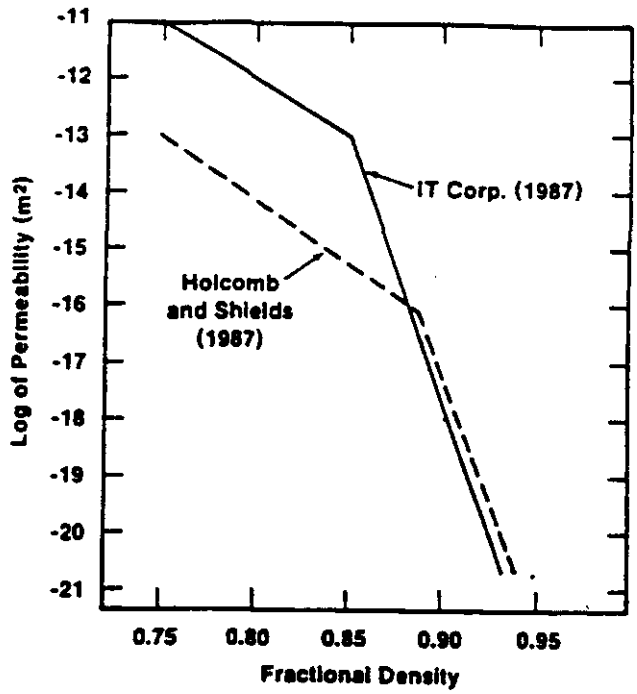

Figure 6-5. **Permeability Versus Fractional Density for Two Consolidation Tests Using Wetted Crushed Salt (Stormont, 1988)**

6.2.2 Other Seal Materials

In addition to crushed salt or quarried blocks of salt, there are a number of other seal materials being considered for use in the WIPP facility: bentonite clay, cementitious materials, and asphalt (Stormont, 1988a). Sandia National Laboratories has performed a series of in situ experiments designed to evaluate the performance of the various candidate seal materials. The tests were performed in vertical and horizontal boreholes ranging in size from 15 cm to 0.9 m (6 in to 3 ft). Test Series A and B experiments evaluated the performance of salt-based concrete in vertical and horizontal boreholes, while Test Series C evaluated salt block and salt/bentonite block-type barriers.

Bentonite has been used for creating fluid barriers in numerous civil and mining applications such as dams, liners for municipal and hazardous landfills, and groundwater control in mines. Bentonite is also an important component in the engineered barrier system for proposed nuclear waste repositories in crystalline rock (Pusch and Borgesson, 1989). A principal component of bentonite is montmorillonite, which swells when hydrated, resulting in good contact between the emplaced material and the surrounding rock. As mentioned in Subsection 6.1, bentonite plugs are being considered as part of the sealing system for the shafts to prevent groundwater from entering the shaft and contacting the crushed salt portion of the system. In the Rustler Formation, the bentonite-based seals will be used to reestablish the natural low permeability of certain portions of the formation (Stormont, 1988a). Within the Salado, bentonite-based seals are planned 15 m (49 ft) into the formation, at an interbed layer around 500 m (1,640 ft) depth, and at the base of the shafts to protect the crushed salt portion of the shaft seal during consolidation.

Test Series C of the Small-Scale Seal Performance Tests included the investigation of salt/bentonite as sealing material. Ninety-two cm-long test seals were constructed in four boreholes, 92 cm in diameter, using a 50/50 mixture of crushed salt and bentonite. The seals were exposed to brine and allowed to hydrate, eventually swelling and effectively sealing the boreholes to further brine movement (Stormont and Howard, 1987). After the seals were emplaced, permeability tests were performed by pressurizing the borehole interval beneath the seal. The permeability of the seal was approximately 1×10^{-21} m^2.

Concrete is often used as a seal and shaft or tunnel liner material in underground excavations due to its availability, relatively low cost, and favorable properties. However, there are few data concerning the performance of concrete seals over time frames or situations relevant to the proposed applications at WIPP (Stormont, 1988a). Available historical evidence suggests that leakage of concrete seals tends to occur at the rock interface or the disturbed zone in the surrounding rock and not within the concrete seal itself. This is not likely to be the case at the repository depth at WIPP, due to creep closure and fracture healing properties in salt.

A salt-saturated expansive concrete developed by Wakeley and Walley (1986) was used to assess the performance of concrete seals in salt in Test Series A and B of the Small Scale Seal Performance Test. The concrete has a unconfined compressive strength of 48.3 MPa and a permeability of 0.8×10^{-18} m^2. Results from the tests have been very favorable (Stormont, 1988a). The seal permeability calculated from gas and brine flow tests was around 1×10^{-18} m^2 (Peterson, Lagus and Lie, 1987), suggesting that the salt/concrete interface was tight and would be capable of limiting brine movement through or around the seal. A potential problem for the concrete seals is mechanical failure and loss of seal performance due to the high stress (compressive and tensile) that may develop as a result of creep closure in the salt. Predicted stress levels are discussed in Subsection 6.3. The strength of the concrete could be increased by adding fiber reinforcement or chemical additives, but these would have to be compatible with the local environment. There is significant uncertainty concerning the longevity of concrete in salt. Concrete shaft liners in nearby potash mines have deteriorated from sulfate attack (Stormont, 1988a) over a twenty-year period. However, the relatively large size of the concrete bulkheads in the shaft and panel seals (10 m (33 ft)) and the tight interface between the concrete and the salt host rock make it unlikely that significant portions of the concrete plugs would degrade prior to consolidation of the crushed salt portions of the seal system.

6.2.3 Disturbed Rock Zone

The performance of the shaft, drift, and panel seals will depend not only on the properties of the seal material (e.g., consolidated crushed salt) but also on the hydraulic properties of the surrounding rock mass and seal/rock interface. The construction of underground openings causes fracturing in the surrounding rock mass due to the redistribution of stress in the immediate vicinity of the excavation. The fractures could provide a pathway for fluid flow around the seals and compromise the performance of the repository. At the repository level at WIPP, the DRZ could extend into existing fractures (pre-excavation) in the relatively brittle anhydrite of Marker Bed 139 and other interbeds (Davies, 1991).

Excavation-related fractures have been documented by visual observation, in drill holes from excavations, by geophysical measurements, and by gas injection (Borns and Stormont, 1988). This fracturing includes vertical separations along nonhalite interbeds in the floor and back, curved fractures in the floor and back that crosscut a variety of stratigraphic units, and vertical fractures associated with spalling within the ribs. Gas permeability measurements by Stormont, Peterson, and Lagus (1987) in the first panel entries provide some insight into how the disturbed zone develops. Initial measurements were performed approximately one month after the drifts were excavated. The span of the drifts varied between 3.9 (13 ft) and 6.0 m (20 ft) which provided preliminary information on whether the extent of the disturbed zone depended on the size of the opening.

The results are summarized in Figures 6-6 to 6-8. **Figure 6-6** shows the flow rate in the halite rock as a function of distance from the excavation. In general, the region within 1 m (3.3 ft) of the excavation has much higher permeability than the undisturbed halite, with the flow rates varying by several orders of magnitude. Beyond 1 m (3.3 ft) the flow rates are consistently low. Relatively high flow rates were observed in the interbeds (MB 139 and Seam B) within 2 m (6.5 ft) of the excavation (**Figure 6-7**). The disturbance was greatest near the center of the drift. As shown in **Figure 6-8**, the degree of disturbance appears to be related to the span of the excavation with increasing flow rates in the wider drifts.

Additional gas flow measurements were made in a four-year-old drift similar to the panel entry drift (Borns and Stormont, 1988). Tests were performed in an array of boreholes drilled radially to a depth of 10 m (33 ft). The results are illustrated in **Figure 6-9** that contains contours of gas flow rate around the drift. The measurements indicate increased flow rates in the immediate vicinity of the excavation decreasing radially outward. The effect is present in the back and floor as well as in the pillars. Peterson (1987) conducted gas tracer studies in the same drift by injecting diluted tracer gas into packed-off regions of a borehole and monitoring its arrival in the surrounding boreholes. The gas was injected into two vertical boreholes (one in the back and one in the invert) and one horizontal (in the rib) borehole within 1 m (3.3 ft) of the excavation. The tests in the vertical boreholes indicated that the flow path direction for the gas was predominantly vertical, while the horizontal test indicated that the predominant flow path direction was parallel to the drift face. The effective aperture of the flow paths calculated from the tests was small (approximately 1×10^{-6} m). Stormont et al. (1987) performed additional tracer experiments to study the fracture continuity and effective aperture of the flow paths in MB 139. Tracer gas arrival times and locations suggest that the aperture of the flow path increases with increasing excavation spans. The calculated aperture was approximately one order of magnitude greater at the intersection of two drifts than under a single drift (0.04 cm versus 0.002 cm). The predominant flow direction was vertical from MB 139 to the excavation, consistent with the observations made by Peterson (1987).

Borns and Stormont (1988) visually examined the fractures in the disturbed zone, using boreholes in the rock surrounding the excavation. Fractures with apertures greater than 2 mm were common. Their observations are summarized in **Figure 6-10**, which represents an idealized cross-section of a storage room. The localized fracturing of the rock mass is elliptical and predominantly concave towards the opening. The fractures in the invert and back tend to crosscut the stratigraphy (interbeds), which is consistent with the results of the tracer experiments. Similarly, the

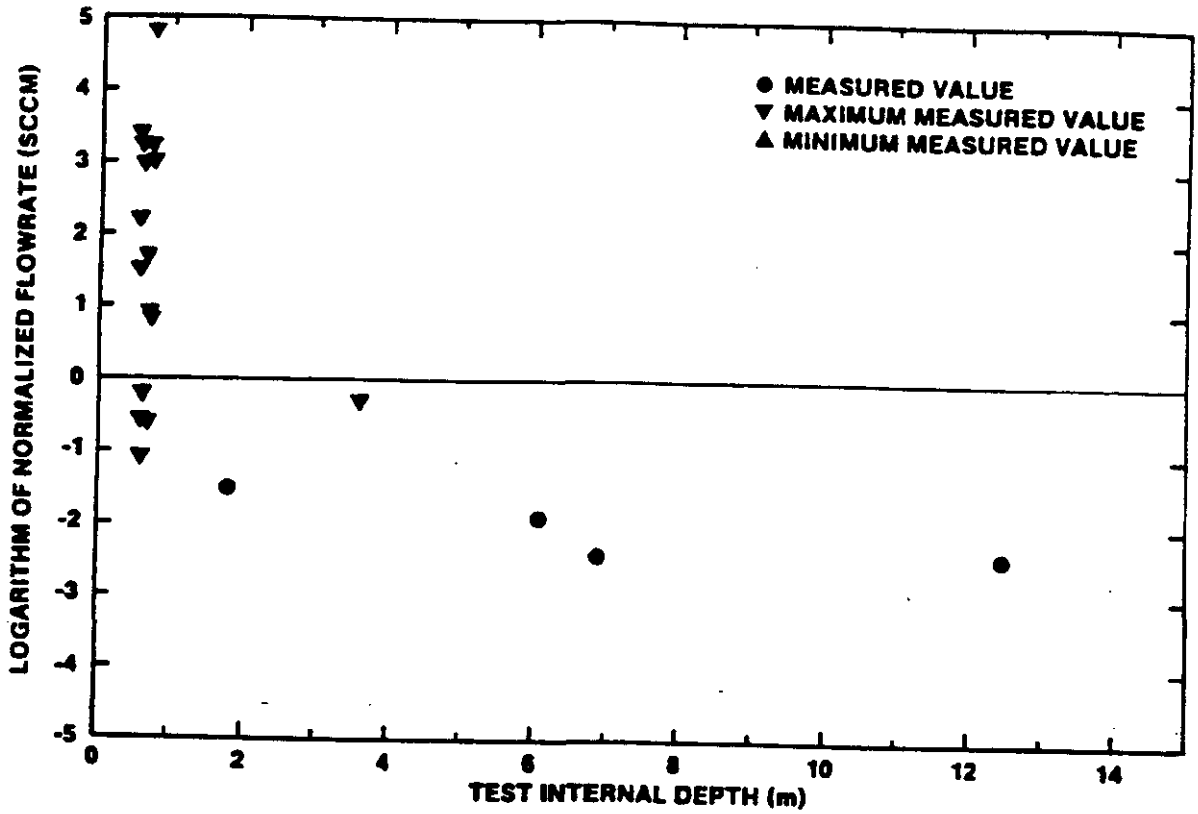

Figure 6-6. Gas Flow Rates in Halite Test Interval (Borns and Stormont, 1988).

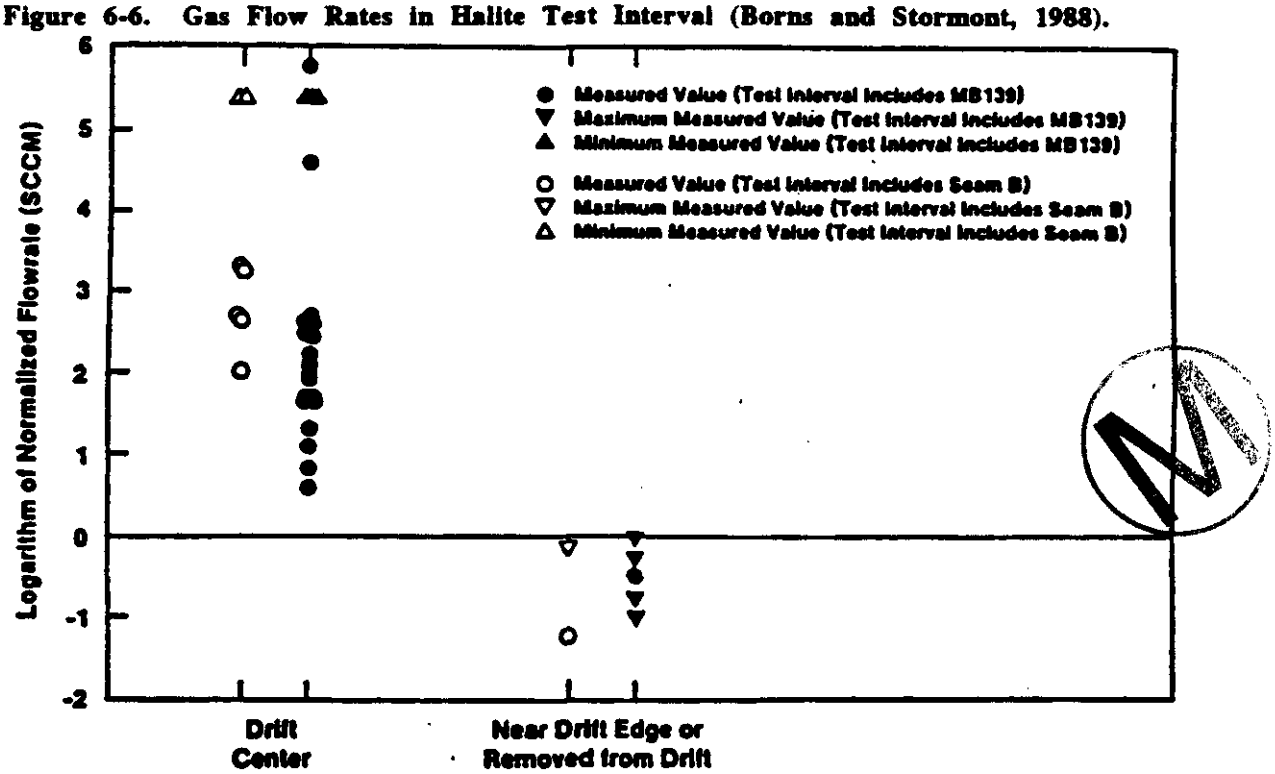

Figure 6-7. Flow Rates in Interbed Layers Within 2 m of Drifts (Borns and Stormont, 1988).

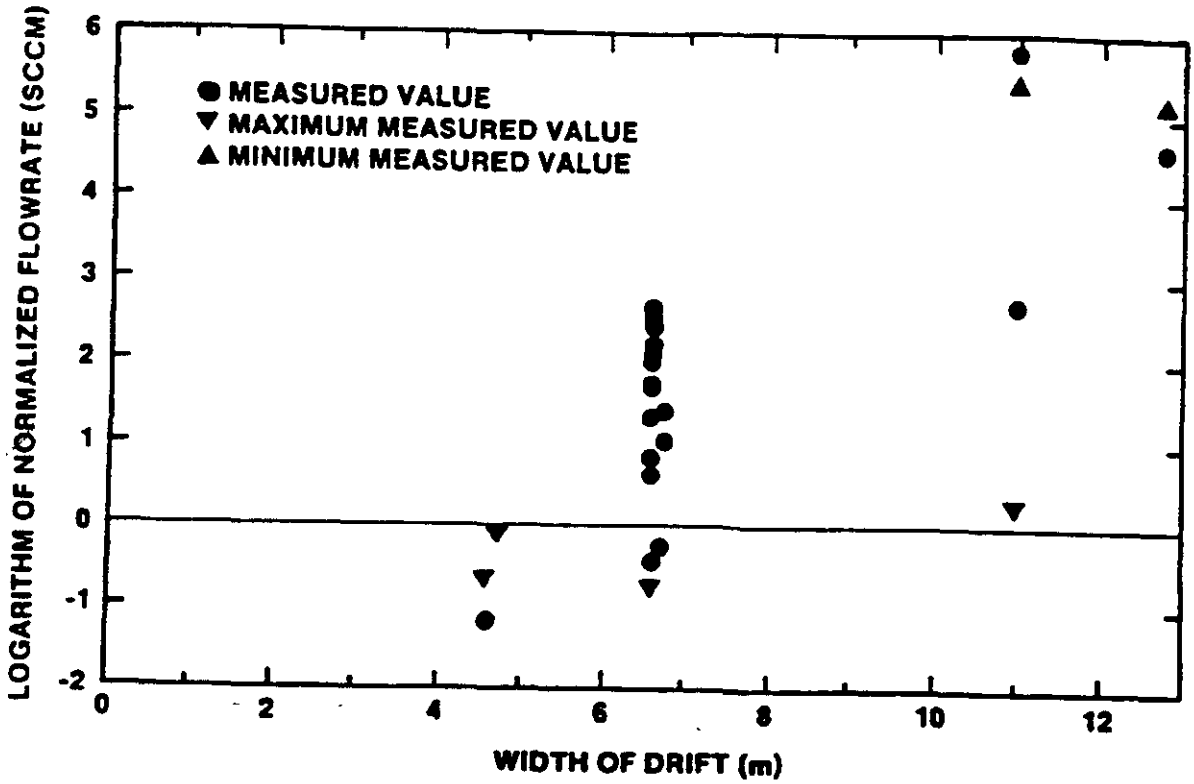

Figure 6-8. Width of Drift Versus Gas Flow Rate in MB139 (Borns and Stormont, 1988).

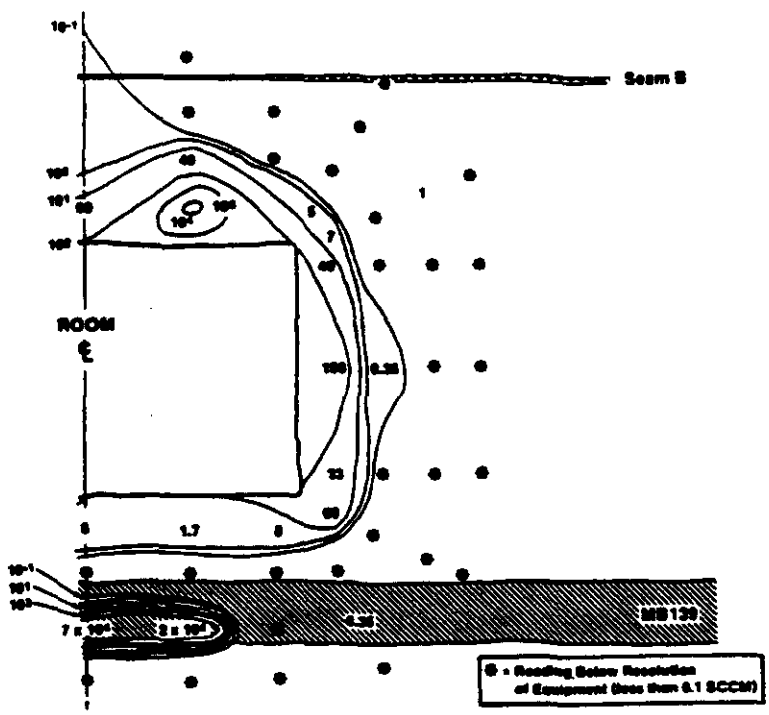

Figure 6-9. N1100 Drift Flow Rate (SCCM) Contours (Stormont, 1988).

observed fractures in the ribs are typically vertical. Separations along stratigraphic features such as interbeds were also observed. Franke (1987) reexamined the fracturing in boreholes over a one-year period and concluded that the rock mass surrounding the excavation continued to fracture over this period. Observed fractures in boreholes increased from 48% of the boreholes in 1986 to 73% of the boreholes in 1987. In older test rooms with larger spans (11 m (36 ft)), 100% of the boreholes had fractures with fracture apertures 2 mm or greater.

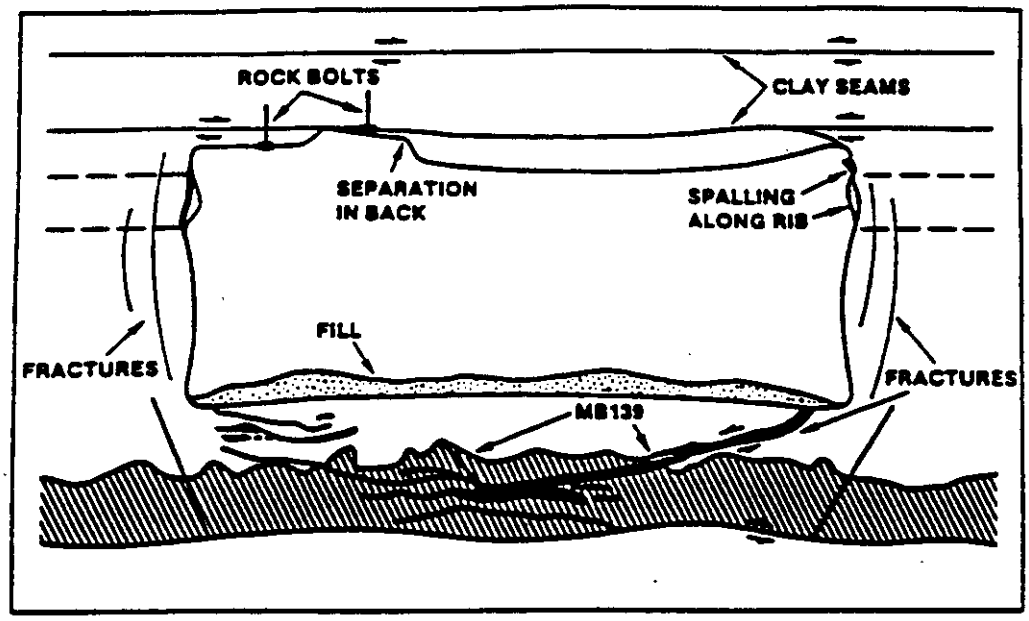

Figure 6-10. Idealized Excavation Effects in a 4 m x 10 m Room (Stormont, 1988).

The fracturing of the rock mass around the excavation results in partially saturated conditions in the rock as a result of drying, exsolution of dissolved gases, and brine inflow. The increased permeability, decreased pore-fluid pressure, and partially saturated conditions all enhance the potential for gas flow pathways between the disposal rooms and nearby higher permeability interbed units (Davies, 1991). Thus, localized regions of increased permeability may exist throughout the repository, supplying potential pathways for contaminant transport. The significance of these pathways relative to repository performance will depend on the ability of the fractures to "heal."

It is anticipated that the fractures in the disturbed zone within the halite interval will eventually close and their permeability approach that of the intact salt (Tyler et al., 1988; Lappin et al., 1989; Sandia National Laboratories, 1993b). Once an excavation is backfilled (with waste, backfill material, or sealing components) and the material is capable of resisting mechanical loading, it is theoretically impossible for the halite to maintain open, interconnected fractures due to salt's plastic deformation behavior and low yield strength. Because of the relatively large porosity in the emplaced waste (0.79) and the crushed salt backfill (0.4), there will be a delay in the closure of the disturbed zone fractures until the final density of the backfilled material is reached, and it resists further creep closure of the disposal room. As the fractures close and the confining stress acting on the fracture increases to lithostatic, the salt is expected to "heal." This process will occur earlier in those sections of the

excavation that contain the concrete bulkheads and the crushed salt seal components installed at relatively higher density.

The process of fracture healing or "disturbance reversal" has been demonstrated in the laboratory and in the field. Sutherland and Cave (1979) performed permeability tests with core samples of halite from the WIPP site. The permeability of the samples was relatively high initially, as a result of the mechanical damage that often occurs during collection and transport to the laboratory. After applying a confining stress similar to the lithostatic loads at the repository level at WIPP (14.8 MPa), the permeability of the sample decreased by an order of magnitude. When a confining pressure of 34.5 MPa was applied, the same drop in permeability was observed in six hours. Costin and Wawersik (1980) conducted fracture healing tests using rod specimens of intact salt. The specimens were loaded in tension until failure occurred by compressive loading (up to 35 MPa) at elevated temperatures (up to 100°C) in an attempt to determine whether the fracture would heal. The fractures in tests at the lowest temperature (22°C) and pressure (10 MPa) recovered from twenty to thirty percent of the intact fracture toughness after several days of loading; recovery increases with increasing temperature.

Healing of the DRZ in salt has also been observed in field experiments at WIPP. Test Series B of the Small-Scale Seal Performance Tests used of a 1-m-long concrete plug in a 1-m-diameter borehole (**Figure 6-11**). Gas flow injection and tracer tests were performed thirty days after emplacement to measure the initial permeability of the seal and the types of flow paths present. Very fast travel times (less than twenty minutes) were measured, and flow paths along the rock/seal interface or the adjacent rock mass were observed. Follow-up measurements a year later indicated that the flow paths had been eliminated; there was no tracer movement through any of the seals over a twelve-hour period with a pressure gradient of 2 MPa. (Peterson, Lagus, and Lie, 1987). The reduced permeability is assumed to result from increasing confining stresses around the emplacement hole due to creep closure. Pressure measurements within the concrete seals verified that high radial stresses were generated over the course of the year (Labreche and Van Sambeek, 1988).

6.2.4 Interbeds

The Salado Formation contains a number of interbeds at the proposed depth for the WIPP repository. The design basis assumes that the disposal panels will be excavated within a 7.3-m (24 ft) thick section of halite and polyhalite between anhydrite MB138 and 139. Two of the interbeds, anhydrite B and MB 139, will be within 3 m (10 ft) of the excavation and are likely to be intersected by the fractures in the DRZ. Thus, these features represent potential pathways for the transport of contaminants away from the disposal rooms that could bypass the panel seals. The fracture system in MB 139 below the excavations appears to be extensive and possibly interconnected. Unlike the disturbed zone in the halite rock mass, the fractures in the interbeds are not expected to heal (Stormont, 1988a). Borns (1985) studied the structure of MB 139 from several drillholes in the experimental area of the WIPP underground facility and concluded that many of the fractures existed prior to excavation. The existence of pre-excavation fractures suggests that even if the fractures are closed as the local stresses return to lithostatic conditions, they are unlikely to "heal" and are therefore likely pathways for pressurized gas and brine transport. One option under consideration is the use of cement or crushed salt grouts to seal the interbeds, particularly around the panel seal locations

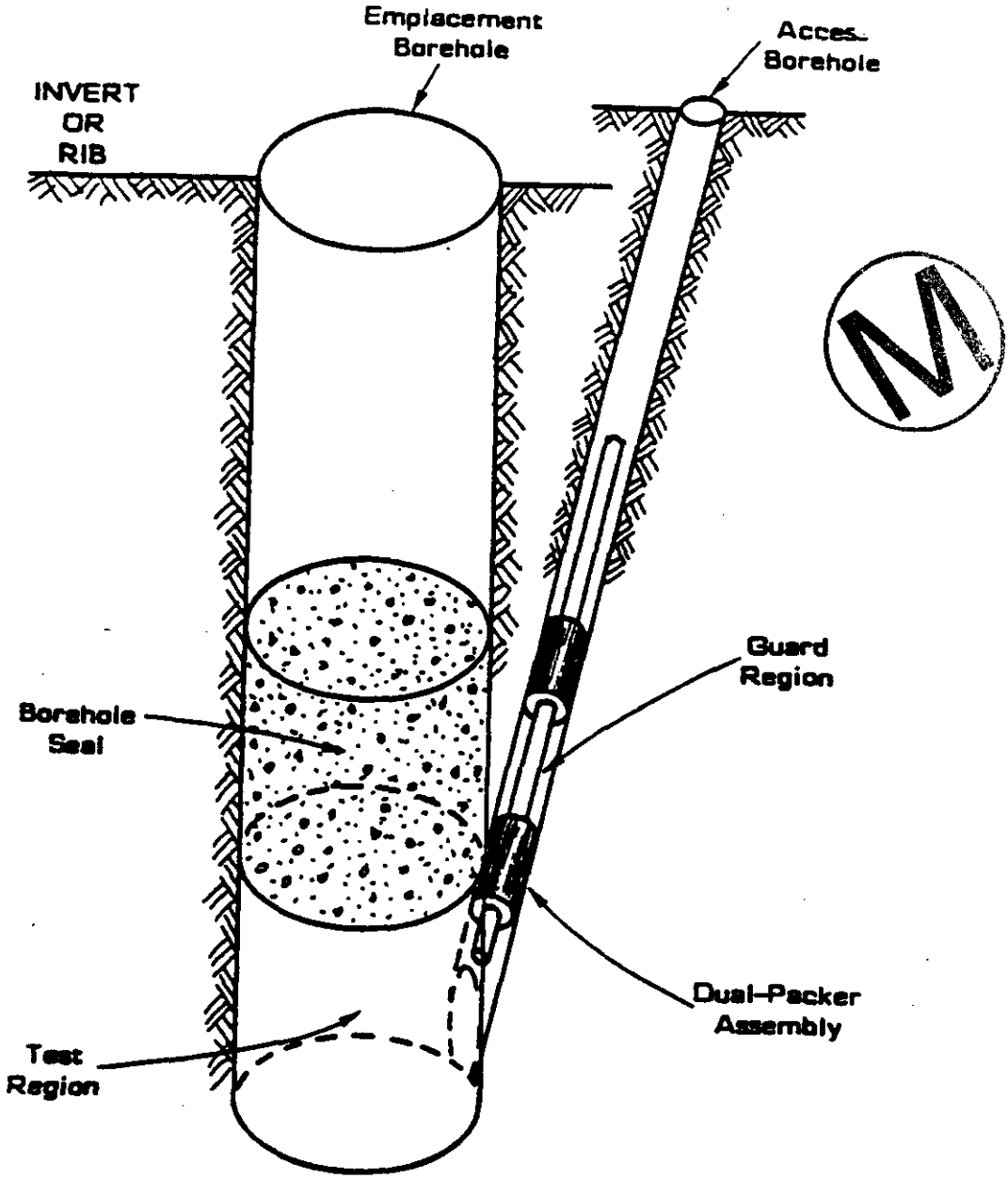

Figure 6-11. Illustration of Test Configuration for the Small-Scale Performance Tests (Peterson et al. 1987).

Effective grouting may be difficult because of difficulties in delivering the grout to the fracture system and the possibility of deformation of the interbed as the rooms close and the surrounding rock mass dilates.

The available pathways for contaminant transport will be a function of time and the processes involved. Immediately after waste disposal, the most likely pathways are through the disturbed zone into the fracture system within the interbeds (MB 139 and anhydrite B) and possibly up the shafts, either through the unconsolidated crushed salt or in the disturbed zone. Brine will tend to flow into

MB 139 and gas into anhydrite B. The consequence of contaminants moving in the interbeds depends on the effectiveness of the shaft plugs and seals and whether the interbeds are intersected by a borehole (human intrusion). Without an additional pathway from the interbeds to the biosphere, the presence of contaminants in the anhydrites is of no real consequence. Assuming the gas pressure in the rooms is less than the sum of the capillary pressure and brine pore pressure in the anhydrites, the fractures in the halite will eventually heal and the pathways to MB 139 will no longer exist. The fractures interconnecting the room to anhydrite B will also heal but rock bolt holes are presumed to provide transmissive pathways to the interbed.

The proposed support system for WIPP consists of 3-m-long (10 ft) rock bolts with mechanical anchors in a 1.5 x 1.5 m (5 x 5 ft) offset pattern. The rock bolts will be left in place after disposal and will eventually corrode, but the remaining material may prevent the halite from forming a complete, low-permeability layer between the room and Anhydrite B. If this conceptual model is correct, the panel seals will be bypassed, first by transport via the disturbed zone to MB 139 and anhydrite B and later through the rock bolt holes to anhydrite B.

It should be noted that Figure 2-1 from Rechard et. al. (1990) (and used in various other WIPP documents including the Test Phase Plan) which is utilized by the PART throughout this document (first used in Figure 4-32) shows rock bolts penetrating two anhydrite layers, creating gas release pathways through both interbeds. Assuming 3-m (10 ft) rock bolts will be used throughout the waste panels, these rock bolts could only penetrate anhydrite B (located approximately 2.5 m (8.2 ft) above the roof) and not anhydrite A (located approximately 5 m (16 ft) above the roof).

The significance of these pathways depends on many related and coupled processes (such as brine inflow, gas-generation rates, threshold pressures in the interbeds, the persistence and interconnectedness of the fractures, human intrusion scenarios, etc.). The question can only be resolved through performance assessment analysis, to determine whether the repository will comply with the performance regulations, or whether changes in the repository design, e.g., eliminating the pathways or the driving forces for contaminant transport will be required.

6.3 SUPPORTING ANALYSES

Engineered barrier performance at WIPP will depend on several related and often coupled mechanisms and processes. SNL has performed a series of analyses to understand the significance of and relationship between some of these factors and to assess the adequacy of the current design for the repository seals. The analyses have focused on the expected creep closure of the underground openings, consolidation of the crushed salt seal components, stresses in the concrete bulkheads, the influence brine inflow may have on consolidation, and the potential for gas and brine migration through the DRZ and interbeds. Summaries of three of these analyses are provided below. Additional analyses are underway to address some of these issues in greater detail. The most important mechanism and processes will be incorporated in the performance assessment models.

6.3.1. Consolidation of Crushed Salt

Sjaardema and Krieg (1977) developed a constitutive model for crushed salt compaction based on the results of small-scale laboratory experiments by Holcomb and Shield (1987) (see Subsection 6.2). The expression was integrated into the finite element code SANCHO and used to

investigate the interaction between crushed salt in shaft and drift seals and the surrounding rock mass. The models were then used to investigate whether the consolidation of the crushed salt would retard the rate of creep closure of the shafts and drifts.

The SANCHO model assumed an elastic-secondary creep model with reduced elastic constants for the intact salt. The creep model was calibrated on the basis of the observed closure rates in some of the drifts in WIPP. The results of the analyses indicate that the crushed salt seal will provide little resistance to shaft closure until the density of the crushed salt approaches intact density. The time required for the crushed salt to consolidate to 95% relative density depends on the initial emplacement density. With an initial backfill density of 80%, the calculated time for the backfill to consolidate to 95% relative density is around forty years. This time is reduced to approximately half if the initial density of the backfill material is increased to 85%.

Sjaardema and Krieg also analyzed the interaction between crushed salt backfill and the emplacement drifts. Assuming an initial relative density of 85% (i.e. compacted bricks), the crushed salt seal achieves 95% relative density in approximately twenty years after emplacement, similar to the shaft. Sjaardema and Krieg acknowledge that the analyses have several limitations. The deviatoric model for crushed salt backfill used in the analyses is *ad hoc*. The laboratory tests used to develop the constitutive model for crushed salt compaction did not examine the deviatoric or shear behavior, and the elastic-plastic deviatoric model used in the analyses was chosen for convenience; (i.e., the material parameters for the other deviatoric models were not available). Secondly, the constitutive model for crushed salt compaction is based on laboratory experiments in which the pressures applied to the sample (1.72 MPa to 3.44 MPa) are significantly higher than the calculated backfill stresses (0.5 MPa). Consolidation behavior at the lower pressures was extrapolated and the actual behavior may vary.

Arguello (1988) performed a series of analyses to evaluate the structural interaction between the proposed panel entry seals and the surrounding formation as a function of time. The conceptual design for the panel seals (see Subsection 6.1) consists of a 20 m (6.6 ft) interval of crushed salt between two concrete bulkheads or caps that provide lateral resistance during consolidation of the crushed salt and protect the region from brine inflow. The panel was modeled as a two-dimensional axisymmetric opening using the SANCHO finite element code developed at SNL. The model was used to assess whether the concrete bulkheads will have a significant influence on the consolidation of the crushed salt and to estimate the stress levels that the bulkheads will have to withstand.

The crushed salt portion of the seal was not included in the finite element model because the precompacted crushed salt provides negligible resistance to creep closure until it consolidates to approximately 95% relative density. The change in a density of the crushed salt during room closure was calculated indirectly by using the change in cross-sectional area of the panel opening to calculate the corresponding change in the volume, and hence the density, of the crushed salt. This assumes that the density of the crushed salt is uniform throughout the circular cross-section. The concrete bulkheads were explicitly modeled as linear elastic materials. Properties for the Expansive Salt-Saturated Concrete (Gulick and Wakeley, 1987) were assumed for the analysis. Because of the axisymmetric simplifying assumption, it was not possible to incorporate the stratigraphy at the repository horizon or the opening geometry.

The results of the analysis suggest that effective consolidation (95% fractional density) of the crushed salt is not achievable in the first 100 years over significant portions of the seal if the initial fractional density is less than or equal to 70%. If the initial fractional density is increased to 75%, the salt in the central portion of the seal will reach 95% fractional density in 100 years. For most of the core to achieve 95% density in this time period, the initial fractional density of the crushed 80% is required. Regardless of the initial density or time, the salt in the central portion is more highly consolidated than that adjacent to the caps. The influence of the caps is significantly diminished within one radius into the core and insignificant at 1 diameter into the core.

Based on these results, Arguello (1988) concludes that the end members of the drift seal are unlikely to affect the consolidation of the crushed salt adversely. However, the bulkheads do significantly increase the expected time necessary for the crushed salt core to consolidate to 95% fractional density. A comparison of the results with those of Sjaardema and Krieg (1987) discussed earlier, indicated that the concrete bulkheads approximately double the time required for the crushed salt to consolidate to 95% fractional density. Whether or not this is significant depends on other factors such as the gas pressure in the repository during the first 100 years after seal emplacement, brine inflow rates, etc. The possible impact of high brine inflow rates is discussed below.

The analysis by Arguello also examines the stresses in the concrete bulkheads during closure. The results indicate that the strength of unreinforced concrete may be exceeded. The maximum stresses occur within the first five years after installation of the seal. The maximum radial compressive stress occurs near the ends of the bulkhead and approaches 45 MPa, very close to the unconfined compressive strength for concrete (47.5 MPa). The calculated tensile stresses reach 19 MPa, significantly higher than the assumed tensile strength of 7.1 MPa (15% of the unconfined compressive strength), with tangential stresses (maximum stress of 39 MPa) similar to the radial stresses. On the basis of these results, it appears the bulkheads will require some type of reinforcement to accommodate the tensile and compressive stresses generated during the compaction period. A positive effect of the high compressive stresses in the region of the bulkheads is the potential for the fractures in the disturbed zone to close, reducing the permeability of the annular region in the vicinity of the bulkheads. This will be necessary in order for the bulkheads to protect the crushed salt core from brine during compaction (if it is present in sufficient volumes to be a problem).

The results of the analysis are inconclusive because of the simplifying assumptions contained in the model. The conceptual model of the seal system is assumed to have an axisymmetric geometry (circular), although the drift dimensions are expected to be rectangular (3.7 m by 6.1 m {12 ft by 20 ft}). The axisymmetric assumption also precluded the stratigraphy in the repository horizon from being included in the model of the panel seal. As a result of these assumptions, the stresses around the opening and, therefore, the room closure rates, could vary significantly.

A companion study by Arguello and Torres (1987) investigated the consolidation of a crushed salt panel seal based on a geomechanical analysis using a two-dimensional plane strain model. The drift was modeled as a 3.7-m-wide by 6.1-m-high (12-ft-wide by 20-ft-high) opening containing an infinitely long seal (a result of the plane strain simplifying assumption). The model incorporated reference stratigraphy and material property data for the site and followed a similar procedure used by Arguello (1988) for calculating crushed salt consolidation (i.e., an assumption

that the crushed salt provides minimal resistance to room closure until 95% relative density and could be indirectly modeled as an open drift).

The results of the analysis are similar to axisymmetric model; i.e., the time required to reach 0.95 fractional density decreases with increasing initial fractional density. Another finding was that time of seal emplacement (after drift excavation) influenced the time for the crushed salt seal to reach 95% fractional density. The longer the excavation remained open before seal emplacement, the longer the time required for the seal to reach 95% fractional density (assuming the same initial density of the crushed salt seal). For an opening 10 years old or less, an initial fractional density of 80% or higher is required to achieve 95% density in 100 years. While the two-dimensional models discussed above are useful and provide preliminary information concerning the expected behavior of the shaft and drift seals, more realistic three-dimensional models are needed to account for the geometry of the underground excavations and further understanding of the panel seal performance.

Nowak and Stormont (1987) performed scoping calculations of the consolidation of crushed salt shaft seals including brine inflow from the host rock and overlying water-bearing zones in the Rustler Formation. The analysis took into account the potential for brine inflow to retard consolidation of the crushed salt by predicting the decrease in the porosity of crushed salt as a function of time and tracking the percent saturation of the pore space with brine. Closure rate, brine inflow, initial density of crushed salt, and time of emplacement after excavation were varied. The consolidation of the crushed salt was assumed to stop when the salt became saturated with brine.

The results indicate that leakage of brine past the upper seal system (see Subsection 6.1) or from the Salado host rock or interbeds into the shaft seal during the consolidation period could significantly reduce the length of the seal which reaches the reference density of 95% of intact salt. The model assumes that once the brine enters the crushed salt it is prevented from flowing back up the shaft as consolidation proceeds. In order for the lower 100 m (328 ft) of the shaft seal to reach 95% relative density in 100 years, the brine inflow needed to be reduced to 1 m^3/yr and the initial density of the salt seal had to be relatively high (similar to quarried salt blocks). Therefore, the upper seal system in the Rustler Formation and Salado unit must be effective and relatively long-lived (i.e., 200 yr) to protect consolidation of the lower seal. This implies that the current inflow to the lined WIPP shafts (1000 m^3/yr) would need to be reduced by three orders of magnitude. The validity of this deduction depends on the assumption that the brine will be prevented from flowing back up the shaft (i.e., consolidation stops once the salt is saturated with brine), and additional studies may be justified to determine the reasonableness of the hypothesis.

Stormont and Arguello (1988) developed a simple model to predict the volume of water entering the Salado through the upper seal system in the Rustler Formation. The model incorporated shaft seal components (concrete and bentonite), the seal/rock interface, and the DRZ to track the amount of water passing through each element under different conditions. The properties of the seals, interface, and DRZ were varied to determine the sensitivity of the inflow to different conditions.

The results suggest that even when the shafts seals perform perfectly (i.e., achieve design permeability and good seal/rock interface), sufficient amounts of water can enter the salt-filled portions of the shaft if a DRZ is present that allows the groundwater to bypass the seals. The flow rate into the Salado portion of the shaft will depend on the water available from the Rustler and the lowest permeable layer of rock (DRZ) or seal/rock interface it must pass. Therefore, a single layer of low-

permeable rock in conjunction with a low-permeable shaft seal (and good seal/rock interface) will severely limit the flow rate through the seal system in the Rustler.

6.3.2. Disturbed Rock Zone and Interbeds

Several other models have been developed by SNL to investigate the potential for gas and brine migration through the DRZ and interbeds as well as shaft and drift seals (WIPP Performance Assessment Department, 1992). The purpose of the modeling was to provide an assessment of the most sensitive parameters affecting gas and brine migration and to help point out significant processes not yet modeled that have the potential to affect regulatory compliance. The two-phase flow code BRAGFLO was used in the analyses.

Three analyses were performed that incorporated different levels of detail about the repository system. The first model examined the potential for lateral migration of gas and brine into the Salado Formation from a representative waste disposal panel. The model did not include repository shafts or access ways (i.e., the shaft-fill material was assumed to have been consolidated to the host-rock porosity and permeability), so that the gas could only migrate laterally toward the subsurface boundary of the land-withdrawal area.

The second model employed a two-dimensional rectangular geometry to provide a more realistic geometric representation of the waste and the underground excavations. The repository system was modeled as a series of waste, panel seals, backfill, and shaft regions, with possible vertical and horizontal (via the excavations) flow paths. The objective of the model was to determine threshold seal permeability and gas-generation parameters for gas flow through the repository and up the equivalent shaft. The repository shafts were modeled as a single "equivalent" shaft containing a seal whose permeability decreases with depth. The rock surrounding the shaft was assumed to be undisturbed; for example, a DRZ was not included around the shaft.

The third model was similar to the second, except that it included an additional interbed and a modified seal design. Instead of a long shaft seal consisting of compacted crushed salt, a shorter (10 m {33 ft}) high-quality seal with a very low permeability was assumed. The remainder of the shaft was assumed to be filled with backfill.

The DRZ around the underground openings (excluding the shafts) was included in the models and was represented as an area of increased permeability and porosity. The properties of the DRZ and interbeds were held constant; i.e., possible healing of the DRZ due to salt creep and pressure-dependent fracture propagation in the anhydrite interbeds was not included. The importance of these and other modeling assumptions was not quantified.

Of the sixty Monte Carlo realizations of the sampled parameters for the first model, 13 resulted in the migration of gas through the interbeds toward the far-field boundary. Only one realization resulted in gas migrating into the element in the model grid containing the 2.4 km (1.5 mi) disposal-unit boundary. The results were most sensitive to the anhydrite rock properties (porosity, permeability, and capillary threshold pressure), the rate and amount of gas generated, the two-phase flow properties of a brine/gas system, and the far-field boundary pressure. Gas migration in the anhydrite was inhibited because of the low anhydrite permeability and associated high values

of capillary threshold pressure assumed in the model. The permeability determines the resistance to gas flow once the capillary forces necessary to displace the brine are exceeded.

Because the second model assumed relatively low permeability for the halite in the DRZ around the disposal rooms and drifts, gas flow was limited to a path through the waste and seal components in the rooms and shaft. The shaft was modeled as four sections representing regions having different permeabilities and porosities. Of the twenty-two Monte Carlo realizations analyzed, sixteen resulted in gas migrating out of the shaft and into the Culebra. In those where there was little or no gas flow, the permeability of the lowest portion of the shaft was less than 10^{-19} m^2.

In the third model, gas could migrate through the shaft and the interbeds. A total of 60 realizations was performed. Gas was predicted to penetrate the shaft seal in 15 of the realizations, resulting from cases having very high values for parameters that encourage gas production, such as high gas-generation rates, and for the parameters controlling brine inflow. The realizations in which there was no gas released from the shaft generally represented situations where the gas-generation rates were low or the amount of brine available for corrosion reactions was limited. Gas flow in the interbeds exceeded the 2.5 km (1.5 mi) boundary in only one of the realizations although the volume of gas reaching the boundary was very small. Gas flow into the interbeds occurred in only six of the realizations. These cases corresponded to simulations with high panel pressures and low threshold displacement pressures. Thus, in most of the realizations, the panel pressure was below the lithostatic pressure due to the large storage volume within the repository. However, the model did not include creep closure, which could greatly reduce the available storage volume and result in significantly higher panel pressures. The model also did not include enhancement of the interbed permeability from pressure-related fracturing.

Brine migration was also examined in the third model. The maximum quantity of brine driven out of the waste was 3,880 m^3. None of the brine entered the interbeds because the storage capacity of the DRZ was sufficiently large. These results are questionable for the same reason as the gas migration results: the absence of creep closure in the model provides unrealistic pore space in the waste panel for a majority of the time being modeled; (creep closure of the waste panels is expected to be largely complete in approximately 100 years after disposal).

In general, the longer shaft seal was more effective in preventing gas migration up the shaft. While the shorter seal had a lower permeability than the long seal, the remainder of the shaft was assumed to offer little resistance to flow (i.e., a high permeability). Therefore, the long seal provided a much longer flow path through low permeability materials.

On the basis of these analyses, the following parameters were found to be the most important:

- far-field pore pressure in the interbeds,
- gas production rate (from corrosion and microbial degradation),
- initial brine saturation in the waste,
- permeability of the shafts,
- intrinsic permeability of the interbeds.

The authors recognized the limitations of the models used in the analyses and recommended several activities to improve confidence in their ability to predict the behavior of the repository system. These involve making more realistic conceptual models of repository seals and the

surrounding rock mass, including pressure-dependent fracturing of the interbeds and the time dependent behavior of the DRZ (healing), as well as additional research to better understand the parameters controlling gas generation.

None of the conceptual models describing shaft and drift seal behavior have been incorporated into the performance assessment analyses for preliminary comparison with 40 CFR 191 or 40 CFR 268.6. The existing models used for performance assessment analyses do not include a representation of the shaft, borehole, or drift seals. The primary reason for not including engineered barriers is related to budget constraints and the need to address other aspects of the repository system that were assigned a higher priority (Anderson., 1993).

However, the importance of engineered barriers is recognized by the scientific and management staff supporting WIPP and these features will be incorporated in subsequent performance assessment analyses. Sandia National Laboratories has identified a number of issues that need to be resolved to provide a high degree of confidence in the shaft, drift, and panel seal performance (Tyler et al., 1988). The issues define the areas where additional testing or technology development and demonstration may be needed.

- Water inflow from the overlying formations must be controlled for the initial period after installing the shaft seal until the crushed salt component has been compacted to the design density.
- The DRZ around the shafts and drifts must be characterized to determine whether it represents a potential flow path around the seals and whether remedial work is necessary.
- The creep rate of salt around the shafts and drifts must be measured to determine when the crushed salt will be consolidated and form an effective seal.
- Brine inflow from the Salado Formation must be characterized to determine its likely effect on seal formation.

The significance of the above issues is difficult to assess until the seal systems are incorporated in the system model for WIPP. While the subsystem models (discussed in Subsection 6.3) provide useful insight into the sensitivity of the seal performance to local conditions it is not possible to identify and prioritize additional studies without knowing the contribution of the various features and processes to system performance.

6.4 SUMMARY

The performance of engineered barriers (seals) is difficult to predict in a performance assessment analysis because they rely heavily on other poorly understood mechanisms and processes in the natural system. Barrier performance is determined by a combination of closure of the underground openings by creep of the salt, compaction of crushed salt, the presence of brine during compaction, gas-generation rates, the extent and healing of the disturbed zone, and the permeability of interbeds. While the laboratory and analytical studies performed by the WIPP Project and Sandia National Laboratories in particular are impressive and represent significant progress in the understanding of these processes, additional work is needed before a defensible compliance application can be completed.

In the current design for the engineered barrier system, the primary component for sealing the shafts and panel entryways is crushed salt. The material has several desirable properties such as

chemical compatibility with the host rock, plastic behavior with the ability to flow under stress, and low permeability when it is compacted sufficiently under high enough stresses. The above properties make crushed salt an excellent candidate for use in the engineered barriers for WIPP. However, several issues may need to be resolved to reduce the uncertainty in the long-term performance of the WIPP repository and the ability of the system to meet the performance requirements in 40 CFR 191 and 40 CFR 268. These include the capacity of crushed salt to achieve a relative density of 95% in brine saturated conditions, the time and conditions necessary for the DRZ in the halite and polyhalite portions around the excavations to heal and approach intact conditions, and the hydrogeologic properties of the interbeds, particularly anhydrite B and MB 139.

The results of the scoping calculations by Nowak and Stormont (1987) on the consolidation of crushed salt shaft seals in the presence of brine inflow indicate that leakage of brine past the upper seal system into the shaft seal during the consolidation period could significantly reduce the length of the crushed salt seal that reaches the reference density of 95% intact salt. In order for the lower 100 m (33 ft) of the shaft seal to reach 95% relative density in 100 years, the brine inflow rate must be reduced to one m^3/yr. Therefore, the upper seal system in the Rustler Formation and Salado unit must be relatively long-lived (i.e., 200 yr) and capable of reducing the current inflow rate in the lined WIPP shafts (1000 m^3/yr) by three orders of magnitude. The validity of the above conclusion depends on the assumption that the brine will be prevented from flowing back up the shaft. Additional in situ experiments, perhaps similar to the Series C studies, are recommended to test this hypothesis. If consolidation is effectively halted once the pore volume of crushed salt is saturated, additional seals testing in the Rustler Formation may be warranted.

The DRZ will provide a pathway for brine and gas migration from the disposal rooms to nearby interbeds (MB 139 and anhydrite B). In the halite and polyhalite portions of the rock surrounding the excavations, the DRZ is expected to heal with time and eventually prevent further transport through this pathway. However, an additional pathway to anhydrite B is expected through the rock bolts holes that intersect the overlying interbed. Therefore, the pathways for contaminant migration are likely to change during the first several hundred years after disposal. Immediately after closure, gas and brine will be able to flow through the DRZ into MB 139 and anhydrite B. As the DRZ heals, gas and brine movement will be limited to anhydrite B. Because the storage and thickness of MB 139 are expected to be significantly greater than those of Seam B, the extent and pressure of any gas or brine in the interbeds will depend in part on the time MB 139 is hydraulically connected to the waste panels.

In situ tests are planned to measure the characteristics and behavior of the fractured anhydrites (US Department of Energy, 1992) and should improve the understanding of the potential for and extent of contaminant transport. In addition to the studies already planned, a large-scale field test is recommended to provide empirical information on the healing of the DRZ in the halite and polyhalite host rock. This might involve a rigid bulkhead in the experimental area of the WIPP facility. After characterizing the DRZ in the salt and interbeds, a bulkhead would be installed and changes in the DRZ properties monitored. The bulkhead would simulate DRZ healing after room closure is complete and the stress state returns to lithostatic conditions.

As mentioned earlier, it is difficult to reach firm conclusions about the adequacy of the seal system until the performance assessment analysis incorporates the most important aspects of these

components. Discussions with project staff indicate this effort will be given a high priority beginning in FY 94. At a minimum, simplified representations of the shaft and panel entryway seals, DRZ, and interbeds should be incorporated in the system model in the next performance assessment iteration to determine the sensitivity of the repository performance to the parameters and processes involved.

7.0 REPOSITORY SCENARIOS

This section outlines the approach used for performance assessment (PA) of the post-closure repository behavior of the waste disposal system, considering both undisturbed and disturbed repository scenarios. Subsection 7.1 discusses the base-case, or undisturbed, scenario, in which only naturally occurring events and processes are assumed to take place. Three cases of migration in the repository are examined in two-dimensional simulations. Fully coupled, three-phase (salt, brine, gas) models have not been implemented in the PA, nor has the time-dependent behavior of the disturbed rock zone (DRZ). Subsection 7.2 discusses PA's approach to addressing the probabilities and consequences of inadvertent human intrusion during the 10,000 year period mandated by the regulations (i.e., disturbed repository scenarios). Three inadvertent drilling scenarios are examined. Intrusion probability models are discussed, and direct releases to the surface considered.

7.1 SUMMARY OF UNDISTURBED SCENARIO AND PERFORMANCE ASSESSMENT

The base-case or undisturbed summary scenario, with which this subsection is concerned, describes the waste disposal system from the time of decommissioning and incorporates all expected changes and uncertainties in the system for 10,000 years. Because of the stability of the natural system, all naturally-occurring events and processes are nondisruptive (Marietta et al., 1989; PA, 1992a). After the repository is filled with waste, the disposal rooms are backfilled and seals are emplaced in the shafts and access drifts. Because of the high lithostatic pressure at repository depth, closure due to salt creep is expected to consolidate crushed salt seals to the nearly impervious behavior of intact salt. Simultaneously, drums housing the as-received waste will collapse and their contents will compact to materials of reduced porosity and permeability. Closure will occur in less than 100 years, unimpeded by brine inflow or gas generation, although these characteristics may affect subsequent repository behavior.

The Performance Assessment Department of the Sandia National Laboratories has considered gas and brine migration from the repository in preliminary sensitivity analyses related primarily to the no-migration requirements of 40 CFR 268.6(a). Three cases of migration in the undisturbed repository (Subsection 6.3.2) were addressed in the two-dimensional simulations (PA [RCRA], 1992). Using a probabilistic approach for analyzing uncertainty in the performance and the BRAGFLO two-phase flow code (PA, 1992, 2, App. A), Case 1 permitted only lateral gas and brine migration along MB 139 and anhydrite layers A and B by omitting shaft seals; vertical migration through the overlying halite does not occur. Cases 2 and 3 investigate gas and brine flow up the shaft as well as laterally. Case 2 analyzes migration from waste separated from the shaft by a varying number of panel seals and then up a shaft sealed by four sections of crushed salt whose permeabilities decrease to that of the intact salt. Case 3 investigates the effect of a single 10-m-thick (33-ft-thick), high quality shaft seal, and ineffective panel seals, and expands gas storage area, by adding MB 138, the experimental area and the transition (depressurized) zone between the DRZ and intact halite. However, void volume of the DRZ is not included in estimates of the final waste porosity, and possible gas pressure-dependent fracturing of anhydrite is not considered. Room porosities calculated are based on sampled volume fractions of corrodible metal and biodegradables, and they are the ones required to store all gases generated at lithostatic pressure in a brine-free repository.

Simulations predict high relative gas saturations in the waste so that, although gas generation takes place dominantly under humid rather than inundated conditions, all metal was corroded within 10,000 years. Lateral migration of the gas was generally very limited in all three cases because the room gas pressure did not rise high enough to force the gas-brine interface out through the interbeds. Gas flow up the shaft, driven by the pressure gradient between the disposal room and the Culebra Dolomite Member of the Rustler Formation, proved to be the principal migration pathway. For Case 2, gas release to the Culebra was unlikely for a lower shaft seal with a permeability less than 10^{-19} m^2, and for Case 3, a permeability of less than 5×10^{-21} m^2 is required; both estimates ignore leakage around the seals. Finally, selected simulations show that brine which has been in contact with the waste has not migrated beyond the DRZ in 10,000 years (PA [RCRA], 1992, p. 1-6).

The most recent model (PA, 1992, 1) accounts for creep closure of the waste disposal rooms by using results from the geomechanical code SANCHO (PA, 1992, App. B) to estimate waste porosity as a function of pressure. Fully-coupled, three-phase (salt, brine, gas) models have not yet been implemented in the performance assessment nor has the time-dependent behavior of the DRZ. As regards the latter, it was suggested in Subsection 5.5 that the DRZ might self-seal in 100 years, encapsulating the waste in each room at a gas pressure near 1 MPa. For this humid-environment, gas-generation model, gas pressure would build up until vented along rock bolts to anhydrite B. If permeabilities and pore and threshold pressures permit sufficiently rapid migration of the gas along these layers, and along thin clay layers exposed in the disposal rooms, then gas releases might be sufficient to maintain gas pressure in the room at or below the equilibrium lithostatic pressure. So long as the VOC and radionuclide content of gas that might escape to the accessible environment remains below 40 CFR 268 and 40 CFR 191 limits, the repository poses no threat; certainly, contaminated brine would not migrate beyond the DRZ.

This humid model assumes, with considerable experimental basis, that the moistened crushed salt backfill will reconsolidate to a fractional density greater than 95% of intact salt. Much of the 50 m^3 of brine flowing into the room in the 100-year period could thus be isolated in pores of the backfill, lowering the gas pressure in the waste and disposal room still further (Nowak et al., 1988). The model is in keeping with the statement by Mendenhall et al. (1991, p. 3-14): "As we learn more about the host rock hydrologic properties and about coupling geomechanical and fluid flow behavior, the trend seems to indicate that very low permeability host rock, deforming room boundaries, and gas pressurization will inhibit brine flow into the repository and thus limit gas generation."

7.2 SUMMARY OF DISTURBED REPOSITORY SCENARIOS AND PERFORMANCE ASSESSMENT

7.2.1 Human Intrusion Scenarios

The 40 CFR 191 Appendix B states that "... *inadvertent and intermittent human intrusion* by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies." Performance assessments for 40 CFR 191 currently concentrate on inadvertent human intrusion by exploratory drilling (for fossil fuels, water, injection disposal), which has been demonstrated to be the only event likely to lead to radionuclide releases near, or in excess of, regulatory limits (WIPP PA, 1992, 1, ch. 4). If the waste-disposal panels are penetrated by a borehole, then radionuclides may reach the accessible environment either directly as

particulate matter (e.g. cuttings) and brine in the circulating drilling fluid or indirectly through transport by groundwater flowing through overlying transmissive strata.

Figure 7-1 shows the logic diagram for WIPP performance assessment; no temporal relationships between events and processes are implied by their sequence across the top of the diagram. To date, only the base case and inadvertent drilling scenarios E1, E2 and their series combination scenario, E1E2, have been analyzed.

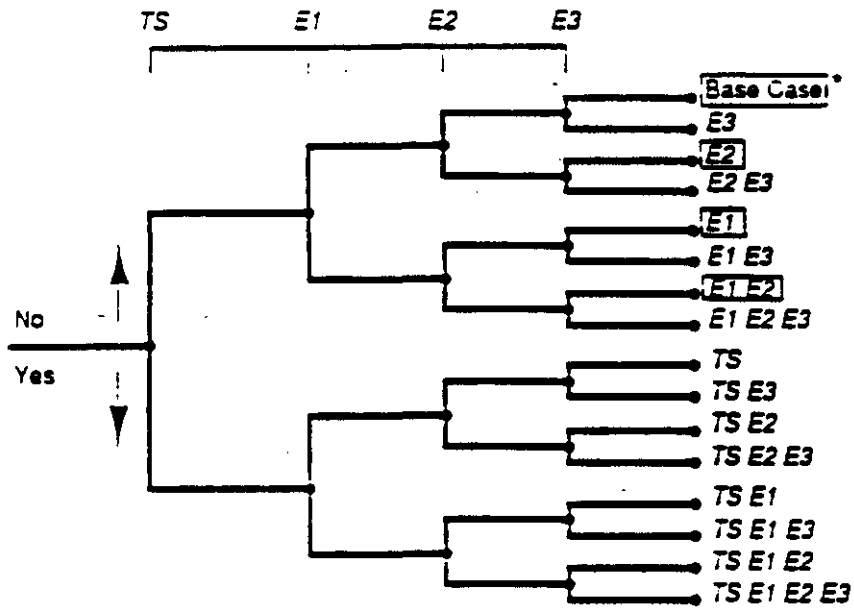

Summary Scenarios
TS - Potash mining
E1 - Intermittent exploratory drilling into room and pressurized brine pocket in Castile Formation
E2 - Intermittent exploratory drilling into room
E3 - Withdrawal wells for usable water

Figure 7-1. Potential Scenarios for the WIPP Disposal System (PA, 1992, 2).

The summary scenario E1 describes one or more exploratory boreholes that penetrate a waste-filled panel and a pressurized brine reservoir in the underlying Castile Formation (**Figure 7-2**). Scenario E2 describes events whereby one or more boreholes penetrate a waste-filled panel but do not penetrate pressurized brine below the repository horizon (**Figure 7-3**). For both E1 and E2 events, initial radionuclide releases result directly from the drill bit intersecting waste (cuttings, cavings, spalling). After drilling is complete, the holes are assumed to be plugged and abandoned, with drilling mud and plugs that degrade (except those above the Culebra) remaining in the borehole. The boreholes are assumed to remain propped open by fill, and a single plug above the Culebra is assumed to remain intact, diverting any flow up the borehole into that transmissive pathway to the accessible environment. Rate of flow depends on the hydraulic properties of the borehole fill and head difference between the Culebra and injected brine (E1) and that between the Culebra and repository (E2).

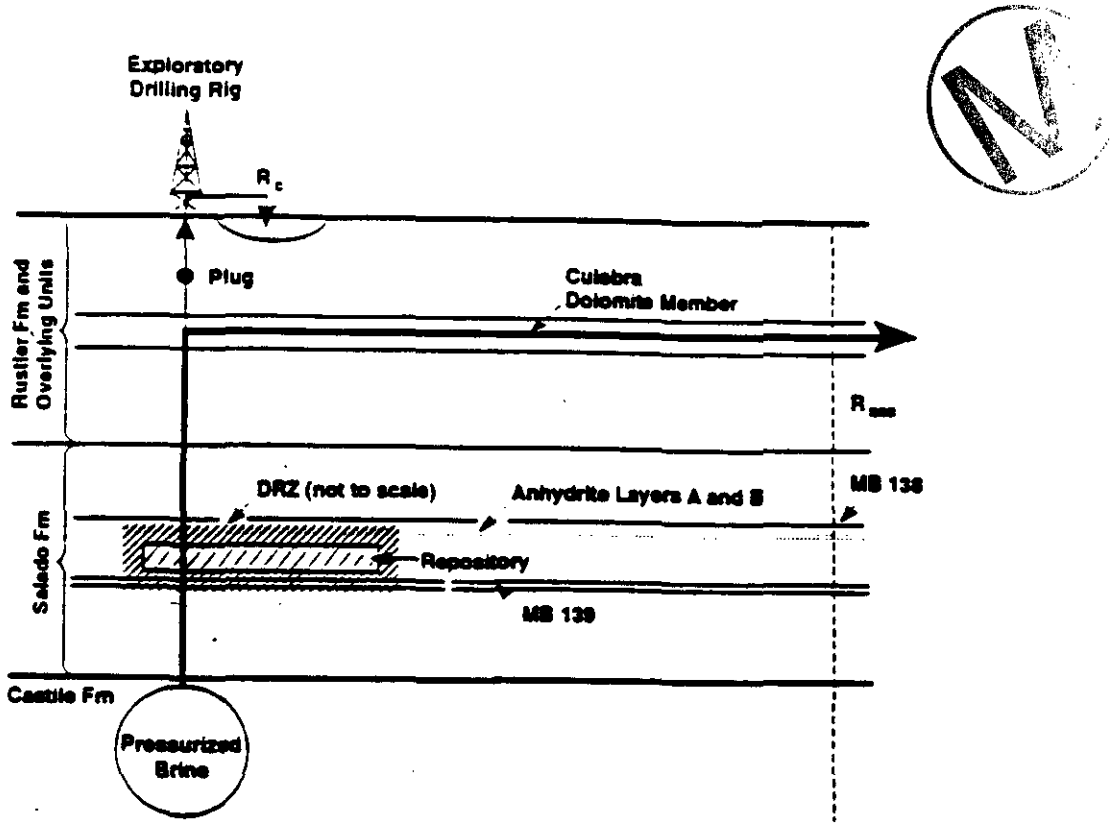

Figure 7-2. **Conceptual Model for the E1 Scenario. R_c is Release of Cuttings and R_{acc} is Release to the Accessible Environment. Plug shown is assumed to remain intact for 10,000 years (PA, 1992, 2, Figure 4-2).**

Scenario E1E2 consists of two boreholes that have penetrated waste-filled rooms or drifts in the same panel, one having also penetrated pressurized brine below (Figure 7-4). However, the intact plug for E1 (left-hand well in Figure 7-4) has been placed below the Salado-Rustler contact so as to maximize flow from the Castile pressurized brine through the waste into the borehole to the Culebra. For this scenario, intact plug placement is critical. Sequence of placement is not, however, and therefore analyses of scenario E1E2 assume that both boreholes are drilled nearly simultaneously. Scenario E1E2 reverts essentially to E2 when the driving pressure of the underlying brine is depleted. However, brine pressure depletion is not considered in current PA analyses. (Beauheim et al., 1993)

7.2.2 Subsurface Brine Transport Simulations

E2-type intrusions are simulated explicitly using the BRAGFLO, SANCHO and PANEL computer codes (Table 2-1). E1-type scenarios are not simulated explicitly. Consequences for E1 are assumed to be the same as for E2 intrusions but the probability of the E2-type is greater for most

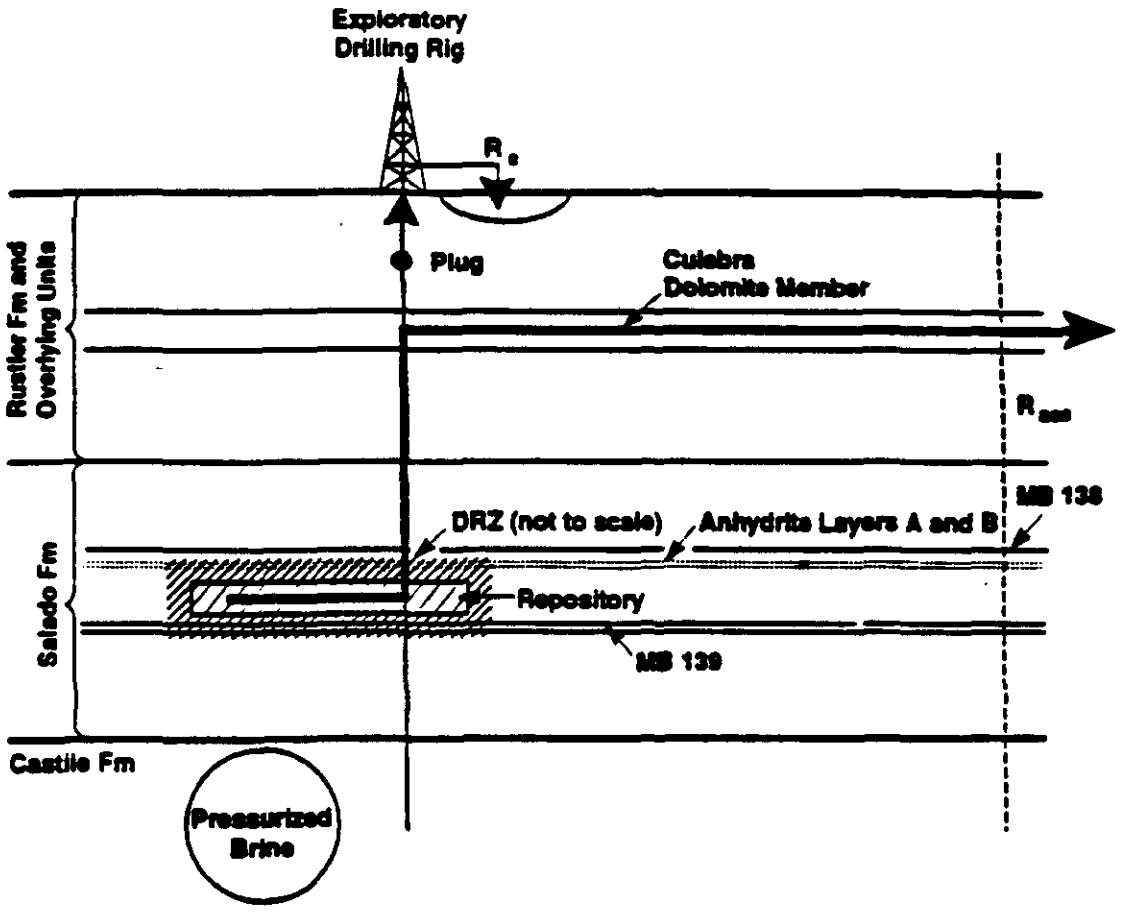

Figure 7-3. Conceptual Model of Scenario E2

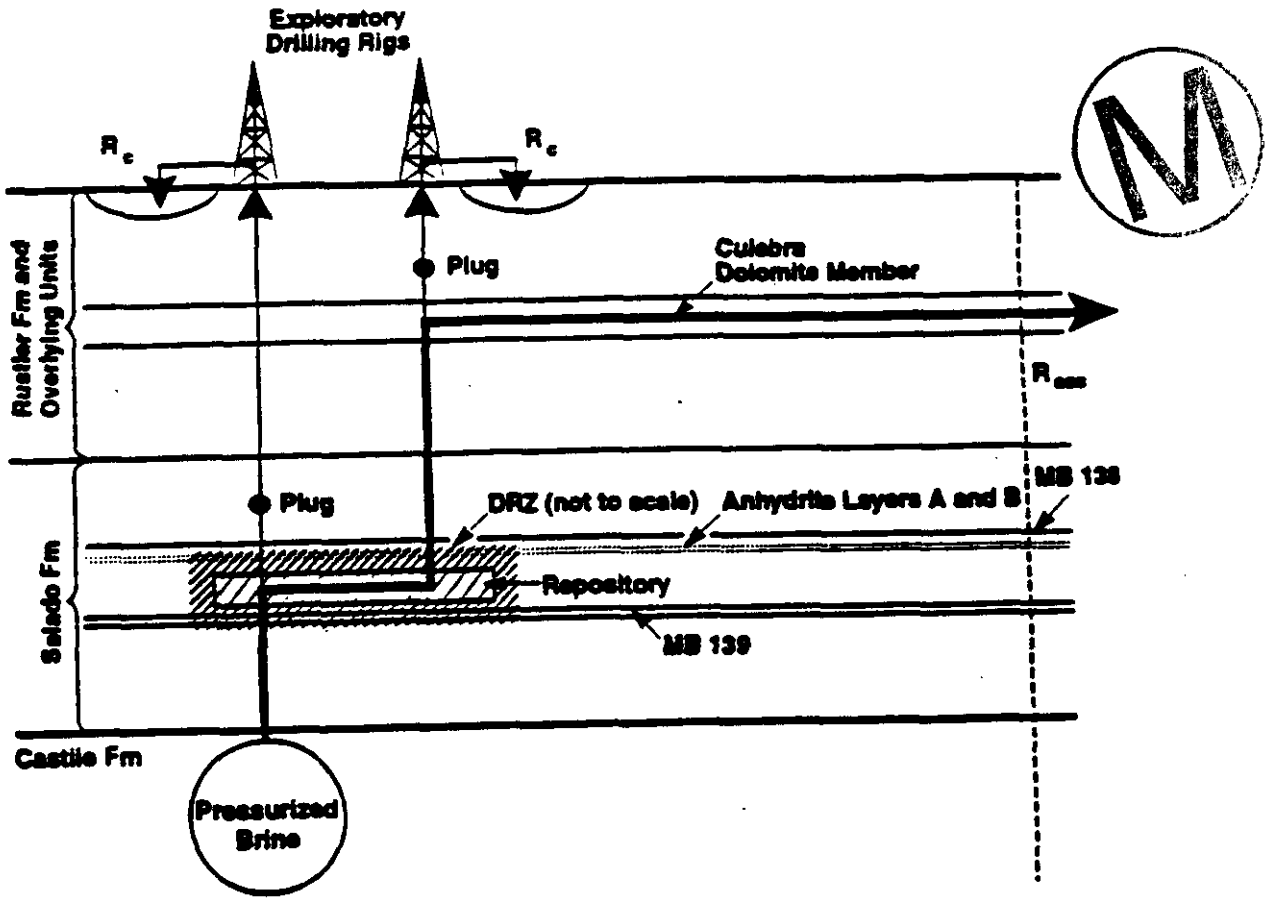

Figure 7-4. Conceptual Model of Scenario E1E2.

realizations. E1E2-type intrusions are not simulated explicitly because the axisymmetric cylindrical geometry used for BRAGFLO cannot readily accommodate two intrusion boreholes. This scenario is simulated using a single borehole and the assumption that all brine in the waste-filled panel mixes with all Castile brine flowing up the borehole. Because the flow path between the two boreholes is omitted, this simplification overestimates both the amount of waste dissolved and the rate of flow (WIPP PA, 1992, 2, ch. 4).

Following the occurrence of an E2 or E1E2 inadvertent intrusion scenario, flow of brine through a collapsed WIPP panel and up an intrusion borehole may result in transport of dissolved radionuclides through transmissive members of the Rustler Formation. Radionuclide transport in the Culebra dolomite, identified as the most highly transmissive member, has been described by three alternative conceptual models (Subsection 4.3). The fracture-only (single porosity) model—transport through unlined fractures only, with no physical or chemical retardation—is regarded as unrealistic. The dual-porosity, $K_d = 0$,

model (**Figure 7-5**) treats the Culebra as a dual-porosity medium with transport occurring along clay-lined fractures and diffusion occurring into the clay and dolomite matrix causing physical retardation; distribution coefficients, K_ds, are assumed to be zero, and no chemical retardation occurs. Available data from well tests support this model. The dual-porosity, $K_d \neq 0$ conceptual model is identical, except that chemical retardation does take place both in the clay linings and the dolomite matrix. This model is preferred by the WIPP PA department but it is not yet fully supported by available data.

7.2.3 Intrusion Probability, Release Modes, and Consequences

Intrusion probability models are based on the assumption that intrusion events will follow either a time-independent (λ_o) or a time-dependent (λ_t) Poisson process. On the basis of the λ_o model and the intrusion density that must be considered for 10,000 years, 30/km^2 (U.S. EPA, 1985, p. 38089), the largest number of intrusions for seventy realizations used in the 1992 analyses is ten.

This number is reduced to four for the λ_t model primarily because of the predicted efficacy of passive markers and because resource exploration and exploitation (especially for hydrocarbons) is likely to diminish and then end within 500 years as the resource potential is evaluated and the energy economy ends its reliance on hydrocarbons (Hora, 1992). The λ_t model, scaled to reflect the fractional area of overlap of waste panels and underlying brine pockets, is the preferred PA model for 1992 PA calculations (WIPP PA, 1992, 2, ch. 5).

The 1992 PA considers direct releases to the surface by cuttings, cavings and borehole fluids associated with the drilling process and indirect releases to the accessible environment by subsurface transport up the borehole and through the Culebra dolomite. Because of the radioactive decay history of the inventory, direct releases are more sensitive to the time of intrusion during the first 1000 years than are indirect releases (because of long periods of subsurface transport). Therefore, direct releases to the surface have been considered for intrusions at six different times after decommissioning (100, 175, 350, 1,000, 3,000 and 7,200 years), whereas a single time (1,000 years) is considered for subsurface releases. For comparison with EPA Containment Requirement 40 CFR 191.13(a), releases are plotted as Summed Normalized Releases (SNR) against the Probability of Release (POR) on mean Complementary Cumulative Distribution Function (CCDF) diagrams (§ 2).

Uncertainties introduced into cuttings releases by choices of single or multiple intrusions and choice of intrusion probability model are illustrated in **Figure 7-6**. The larger number of intrusions for the time-independent (λ_o) case leads to much higher probabilities of release than for the time-dependent λ_t) model. A single intrusion at 1,000 years for the λ_o model also results in appreciably higher release probabilities than for λ_t but only slightly lower probabilities than for the multiple-intrusion λ_o model. For all three cuttings release models, the CCDF curves show that expected releases fall two orders of magnitude or more below the EPA limit. (1992 PA, Volume 1, pg. 5-6)

Subsurface releases resulting from an E1E2-type intrusion at 1000 years, with contaminated brine transport up the borehole and through the Culebra by means of the three conceptual flow mechanisms, are as shown by the CCDF curves of Figures 7-7 and 7-8. For the single-porosity, fracture-only flow model (**Figure 7-7**), subsurface releases clearly dominate cuttings releases (Figure 7-6, one intrusion) and, for the time-independent (λ_o) model, they are less than one order of magnitude below the EPA limit at a probability of 10^{-3}. Changing to a dual porosity, $K_d = 0$ (physical but no chemical retardation) transport model for λ_o intrusion reduces the CCDF to more than one order of magnitude below the limit at all

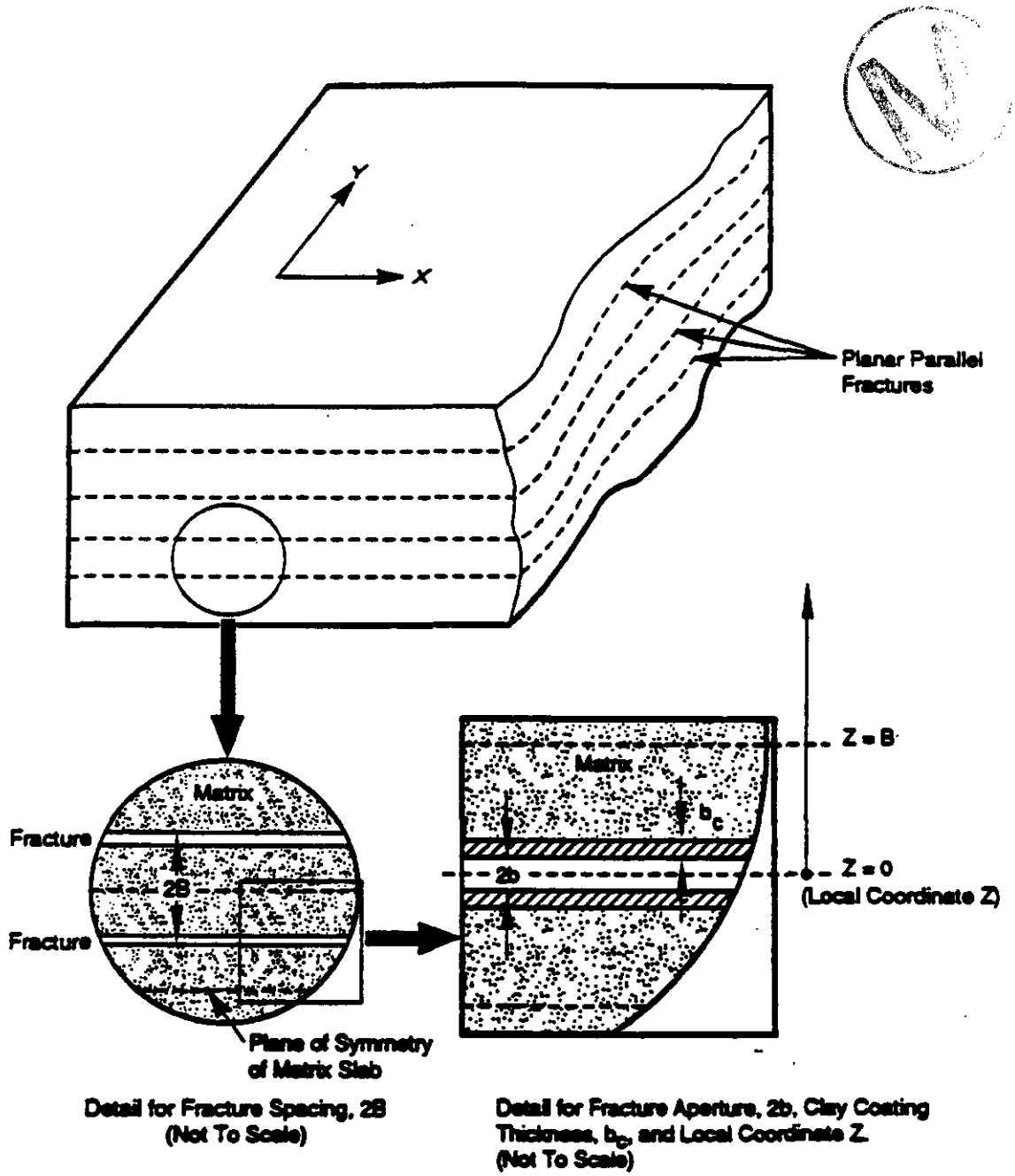

Figure 7-5. Conceptual Hydrologic Model of the Culebra Dolomite (PA, 1992, 2, Figure 7-4).

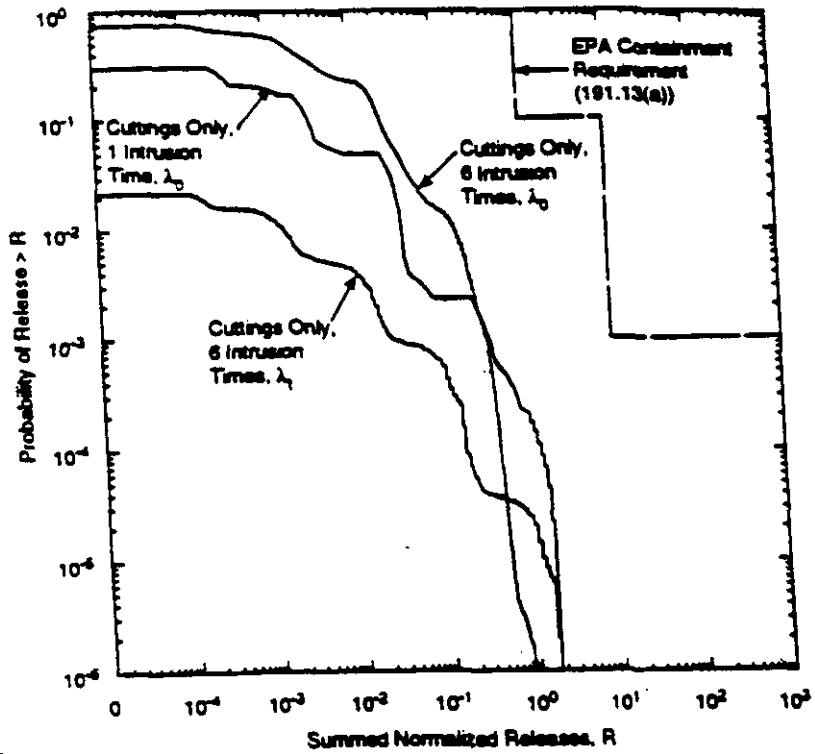

Figure 7-6. **Mean CCDFs for Cuttings Releases Assuming Single and Multiple Intrusions for a Time-Independent (λ_o) Poisson Model and Multiple Intrusions for a Time-Dependent Model (PA, 1992, 1, Figures 5.1, 5.2).**

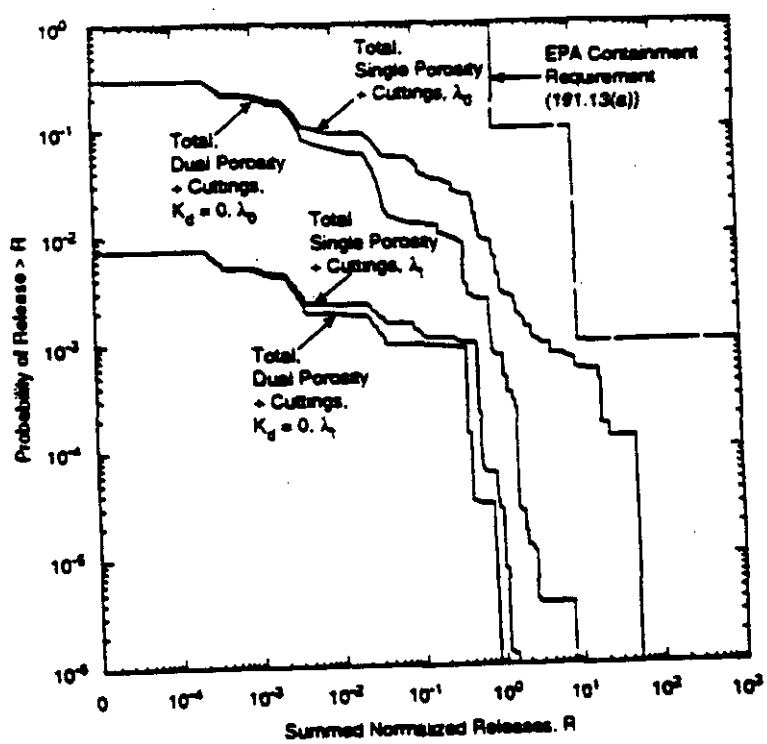

Figure 7-7. **Comparison of Mean CCDFs for Total Releases from Intrusions Occurring at 1000 Years for Single Porosity and Dual Porosity Culebra Transport Models (PA, 1992, 1, Figure 5-4).**

probabilities. Introduction of a time-dependent intrusion (λ_o) model has a profound effect on release reduction, nearly independent of type of the Culebra flow model. The addition of chemical retardation ($K_d \neq 0$) results in summed releases nearly three or more orders of magnitude below the EPA limit (**Figure 7-8**), lowermost CCDF); this conceptual model is believed to be the most realistic by the WIPP Performance Assessment Department (PA, 1992, 1, ch. 5). For the $K_d \neq 0$ model brine transport through the Culebra results in subsurface releases sufficiently lower than those at the surface so that the CCDF location is determined entirely by direct releases to the surface.

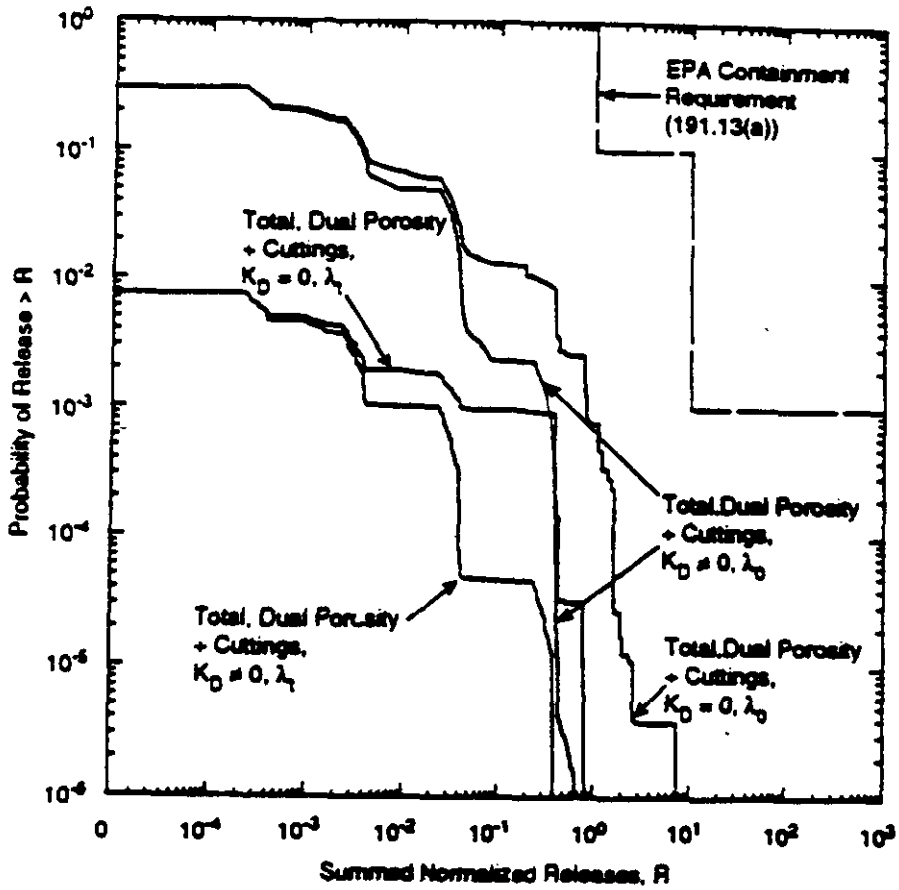

Figure 7-8. Comparison of Mean CCDFs for Total Releases from Intrusions Occurring at 1000 Years for $K_d = 0$ and $K_d \neq 0$ Dual Porosity Culebra Transport Models (PA, 1992, 1, Figure 5-5).

One final comment concerns borehole intrusion into a waste disposal panel in which a humid environment has dominated throughout its history and each room has encapsulated its waste contents, connected only by anhydrite layer B. For this model, the only releases to the accessible environment of any consequence would be through cuttings alone. The E1E2 scenario is eliminated, room contents rather than panel or repository contents form the source term, and subsurface flow pertains to scenario E1 alone. This conceptual model has not been considered by PA (Beauheim et al., 1993).

8.0 ISSUES AND RECOMMENDATIONS

In order to evaluate the technical adequacy of the WIPP Performance Assessment Program, identify any needed program changes, and make recommendations for carrying out these changes, the Performance Assessment Review Team performed a limited review of relevant PA and PA-related literature and the on-going performance assessment efforts. This review included discussions with appropriate WIPP Program staff and contractors. In performing its review, the PART has attempted to elucidate the specific issues associated with

- integrating the various types of information needed to justify and carry out the performance assessments that will provide the predicted quantitative results for comparison with the numerical compliance criteria of the regulations, and
- developing the reasonable expectation (or degree of certainty) through a process of documentation that provides the required assurance that this integration and these performance assessments are reliable and realistic and provide the right type of information on which to judge the efficacy of disposal.

Demonstrating that there is a "reasonable expectation of compliance" as required by the draft RCD (DOE, 1992) is one of the most difficult issues for the DOE, since, as implied by the various statements in the regulations, sole reliance on numerical predictions may not be appropriate because of the substantial uncertainties. These numerical predictions, as a result, require support based on the record of evidence, and they also require supplementation with qualitative professional judgments.

The difficulty in providing reasonable assurance has been recognized for some time. The Performance Assessment National Review Group (PANRG), in their review of performance assessments for high level radioactive waste disposal (Lieberman et al., 1985), observed that scientists, regulators, and decision makers have been thrust into unfamiliar territory because of the long time frame and large scale of the integrated, interdisciplinary effort. Such an effort is needed to select a site, develop a design, and conduct the experiments to identify and evaluate issues so that the disposal system protects the environmental quality and the health and safety of future generations. Also, as PANRG observed, the public now requires a level of professional documentation that has never been required before because of the magnitude of the real and perceived problems associated with nuclear waste disposal. As indicated by Ruckelshaus (1985), the major and controversial issues must be brought into the public and technical arena for open inspection, resolution, and consensus because "Risk management is not merely a set of techniques for arriving at correct answers. It must include communication to the public about how we arrive at environmental protection decisions. The values and assumptions that underlie all such decisions must be manifest. Transparency is the object of the whole process and public trust is the ultimate goal."

Early in the review effort, the PART realized that, because of the small number of review team members and their restricted technical breadth (e.g., no gas generation and geochemistry experts), it was not appropriate to perform only the limited technical review afforded by the time and budget. Various standing technical oversight groups are already in place (Subsection 1.2.7) and, through their continuing involvement with the WIPP effort, can provide a better in-depth evaluation of detailed technical issues. The PART believes that it is important to evaluate the process for developing (1) the base of supporting data and experimental evidence needed to perform the

required compliance calculations, and (2) the adequate trail of documentation to provide the required "reasonable expectation of compliance."

This section presents a summary of the various issues identified by the PART review and the recommendations for addressing them. Subsection 8.1 discusses the overall issues and recommendations for improvements associated with the performance assessment process (e.g., identification and resolution of issues) and the development of an appropriate documentation trail to provide the required degree of certainty in PA results. Subsection 8.2 presents the major technical issues and uncertainties: first, those related to the natural system (Salado Formation, Rustler Formation, and Castile Formation); then, those that arise because the system is disturbed as a result of the waste and repository emplacement; and finally, those related to the engineered barrier systems that are important to the repository design. Subsection 8.3 discusses the scenario-related issues and recommended changes identified and developed by PART, and, finally, Subsection 8.4 summarizes the major PART findings and recommendations.

8.1 PERFORMANCE ASSESSMENT PROCESSES AND DOCUMENTATION

As discussed, the issues, assumptions, controversies, resolutions, and any other basis for judgments and decisions associated with siting and licensing must be well documented, since clarity and openness in this documentation trail are needed to build the required confidence in the PA on the part of decision makers. Since the actual PA document is the primary integrating document in this total PA documentation trail, the PART, in this subsection, examines and makes specific recommendations regarding PA documentation and the integration issue and also provides more general comments and recommendations regarding the total documentation trail.

In this subsection, the PA process is viewed very broadly and includes more than just the computer calculations required for comparison with the regulatory standards. The PA includes the various processes for determining what the issues are and how to resolve them: What calculations? What supporting, compliance-based, experimental evidence is required and how should it be obtained? What are the appropriate param measurements? What are the technical issues and which ones need to be resolved? What is the best method for resolving issues that are resolvable? The PART recognized that, because of the time frame of the test phase and the PA program at WIPP, it was just as important to examine the PA process for developing the required evidence as it was to sift through the existing trail of evidence in search of specific technical areas that need improvement. This realization was based on the reasoning that if the right process for developing the PA and preparing the associated documentation trail is in place, then the appropriate PA and documentation trail will be developed; whereas, if the process is wrong, then the PART recommendations will only be another set of review team mid-course correction recommendations for the WIPP PA team. As a result, this subsection also examines and makes recommendations regarding the PA processes for

- identifying and bringing major issues to the attention of the public and the scientific community,
- identifying unresolved issues and the needed compliance-based approach for resolving them, and
- documenting which issues have been resolved and how they were resolved.

8.1.1 Integration and Documentation

In the course of the PART's interviews with SNL and WID staff and during the PART's limited review of both the base level documentation (Subsection 1.4.3) and parts of the nearly twenty years of supporting technical record for WIPP, the team encountered cooperative and dedicated staff and generally solid, well documented technical work. However, there was no adequate framework for organizing and integrating all these very diverse details regarding various issues, assumptions, data, experiments, and preliminary calculations (which have been gathered and performed throughout the many years of investigation) into a logical, coherent, and digestible form. PART is not alone in this observation. EEG's second comment on the 1991 WIPP PA states: "We have mixed feelings about the organization of the Sandia reports (4 volumes of SAND 91-0893). The report appears quite logical, but it still requires much effort to gather all the information . . . ". As discussed in Subsection 3.2.1.1, the current PA (SAND92-0700/1-3, 1992) does not provide enough information on the assumptions, controversial issues, and the evolution of understanding that PART believes will be required for licensing. The current PA, for example, provides no coherent presentation of the plausible conceptual models for the supra-Salado hydrologic system, yet a coherent discussion of these plausible models is required in order to address the major interpretational issues discussed in Subsection 3.2.1.1 and to properly discuss and document the Culebra conceptual model and justify the various associated assumptions. Clear identification and documentation of conceptual model issues and assumptions, as well as the way that they were resolved and justified through laboratory and field measurements, other experimental evidence, expert panel findings, or numerical studies, is critical to the attainment of that quality of a reasonable expectation (or degree of certainty) required for compliance models. As a very minimum, the line of reasoning that integrates the available information and understanding in support of the current conceptual model needs to be outlined in the PA document.

During the PART review (Subsection 3.2.1.1) a variety of important past issues were identified (e.g., syndepositional versus post-depositional dissolution, rate of advance of dissolutioning and karst topography), which according to the chronology of the literature, had been resolved. However, the status and resolution of these issues were never discovered, and many of these important past issues are never alluded to in the current PA documents. The issue is not that these past issues have not been adequately resolved, but that there is less credibility when both the issue and its resolution or lack of resolution are not transparent. The PA documentation, being the primary vehicle for conveying the record of evidence to the decision makers, the regulators, and the public, must clearly identify and integrate a hierarchy of known issues, provide a brief synopsis of them, and briefly discuss their addressment status. The PA documentation must attempt to integrate these various issues by indicating, in an unbiased way, each issue's relative importance from a compliance-based perspective and provide a road map to the important literature (both favorable and unfavorable to the project's position). Discovery of this important knowledge should not be left to chance, since it detracts from the reader's confidence in the reported results. Furthermore, regulators and other decision makers should not be expected to perform the technical detective work (which the PART found necessary in many cases) to locate the appropriate supplementary material containing the detailed discussions needed to clarify these issues and assumptions, as well as to elucidate the controversies and the methods used to resolve them.

A related information integration issue identified by the PART during the course of their review, i.e., "corporate memory loss," was discussed with Dr. Wendell Weart, the SNL WIPP Project Manager. The "corporate memory loss" that occurs on long-lived projects like WIPP is the loss of the integrative knowledge, due to employee attrition, that relates all the specific investigations undertaken through time by the various principal investigators (PIs). While specific investigations may be well documented and the planning documents that have identified the needs for these specific investigations may exist, the knowledge that integrates this relationship and ties the results of these efforts to the problem or issue addressed, commonly is recorded only in the minds of project staff. W. Weart, who has been with the project since its inception, indicated that SNL is aware of this problem and is currently in the process of preparing a document to address the "corporate memory loss" issue. This document may provide the basis for developing an issue and assumption section that the PART believes should be an integral part of the WIPP PA.

The basic documentation issue identified here is nearly the same as the one that prompted WPIO's ongoing evaluation of the performance assessment params used in the WIPP PA: i.e., the data and params used in the WIPP PA must be of the appropriate quality and the requisite pedigree in order to avoid difficulties during regulatory review. For these very same reasons, it is important that the various issues (including any controversies) and assumptions important to WIPP be identified and the validity of their resolution be documented and tracked by a change control process to assure the same level of quality as is required for the params. This is because these issues and assumptions are as fundamental and controversial, and can have as great an impact on both predicted PA results and the demonstration of a "reasonable expectation of compliance." Some of the concerns and issues identified during the WPIO review of the PA params list may have become moot since the quality assurance procedures (QAP 2-3 for Param Selection) were put into place in November, 1992 (Rechard, Trauth, and Guzowski, 1992). Perhaps a similar approach (i.e., development of a QA procedure) would also be appropriate for the documentation and tracking of important issues and their resolution and the development of the associated pedigree for this important information (i.e., tracking issue origin and the continuing refinement in definition and the method of addressment through time).

A more specific documentation issue identified by the PART is related to the way that confidence in the actual compliance models and the assumptions needed to support these compliance models is developed. The PART, for example, performed many hand calculations in order to check the reasonableness of assumptions and believes that they provide a simple means for establishing confidence and should be presented in the PA when appropriate. The PART observed that, in general, the PA documents present only a brief description of the actual compliance models and that there is no confidence-building description of the progression of simple deterministic or stochastic modeling that is typically investigated as part of the process of examining and justifying the various conceptual model assumptions. There is no description of the progression of modeling analysis that must have been performed to demonstrate that the appropriate level of modeling had been selected for compliance analysis. This last step is especially important when it appears to leave out important processes (see Subsection 5.1.5). The PART believes that this progression needs to be clearly documented in the PA.

Another specific documentation issue relates to compliance-based assessment. Since every outstanding issue cannot and need not be resolved to demonstrate compliance, it is important for the PA document to indicate clearly what must be known and resolved in order to reach compliance and at least to outline the reasoning (and/or present calculations or experimental evidence) that supports this assessment.

PART Recommendations: PA documentation must be considered to be the primary integrating document and, as such, the PA document should contain an evolutionary summary (e.g., similar to the type found in SAND89-0462, 1989) of the major resolved and unresolved issues, discuss their relevance to compliance analysis, and provide a guide to the literature (e.g., issue resolution documents, as discussed below) that describes each issue in detail. Perhaps the document discussed by Weart, see above, could serve as a basis for this section.

The PA must provide a clearer documentation of the line of reasoning that integrates available information and understanding in support of the current compliance conceptual models and indicate why only a certain level of (compliance-based) knowledge is needed. Interpretational and param scale (i.e., both spatial and temporal) issues need to be specifically addressed.

The PA document should present hand calculations, when appropriate, and at least a brief documentation of the progression from the simpler modeling efforts used to justify assumptions and to help achieve those qualities of "reasonable degree of certainty" and "reasonable expectation." It is also important for the PA to justify and document the analyses that led to the model selected for compliance.

As will be discussed in the next subsection, there is a need for a specific PA process for issue identification, resolution, and documentation. A format and style for these issue resolution documents needs to be prepared, and the past issues that have been identified in the "corporate memory loss" must be documented in this format. These issue resolution documents need to identify and define each issue; identify and summarize the chronology of literature, workshops, and important meetings; summarize the method of resolution; and document the consensus and any dissent. These documents should probably be prepared under strict QA with appropriate documented external review by qualified experts.

8.1.2 Performance Assessment Process

As discussed earlier, the "PA process" in the context of these discussions should be viewed very broadly and includes, for example, the various processes for determining and resolving issues and deciding what to measure and calculate. The PART has determined that there is no formal PA process or mechanism for dealing with issues (i.e., their identification, evaluation, resolution, and documentation) within the WIPP PA program. In this regard an important area of concern identified by the PART is related to the flow of information among the DOE, the PA staff, the PIs, and other participants, in order to identify problems and issues and to develop means for their resolution. From the PART review it is not clear how DOE management, PA personnel, and PIs work together to determine and fund the modeling and experimental approaches and to insure that these efforts are compliance-based, so that the experiments will lead to data of the appropriate spatial and temporal scales for compliance PA. Questions of concern include the following:

- How does the ongoing PI modeling eventually integrate with PA modeling and how is this planned?
- Is the information flow between PIs and the PA team, especially across contractors, as smooth as it could be?
- What is the process for, and who is involved in, identifying where there is sufficient scientific understanding and data and where there is not?
- How is it determined which scientific issues are resolvable by further data gathering or experimentation and which ones cannot be so resolved?
- What is the process for reevaluating the repository design to determine if difficult or unresolvable critical issues can be resolved by design changes that avoid the need for addressing them?
- Are estimates for compliance-driven data gathering and experimentation realistic in terms of what can actually be achieved (i.e., Can science actually deliver and are the time frame and costs realistic?) and how is this determined?
- Is there a process for evaluating proposed programs to determine if they are realistic and likely to lead to the desired closure of issues relative to data and understanding?
- How are decisions made about what gets modeled and when, and what gets measured and when?
- Is there a process for weighing the various programs for resolving technical issues against each other to determine what gets funded and when?

The PART believes that the WIPP PA program needs a formal documented method for dealing with the identification/tracking/resolution of WIPP PA issues. One example that illustrates this point arose during the PART discussions with EEG regarding the issue of the cuttings scenarios (Subsection 3.2.1). The PART was unable to determine whether the scenario identification and selection process would ever be revisited or what parties and types of concerns would cause it to be revisited. Another example that illustrates the need for a formal issues identification and resolution process (Subsection 3.2.1.2) relates to the oil and gas resource potential in the WIPP area and concerns raised by EEG regarding potash mining and drilling frequencies. The PART believes that there is a need to re-examine the natural resource issue as raised in §191.14 (e) in order for DOE to determine and clearly state its position regarding the oil/gas and potash resources in the vicinity of WIPP. The PART can make a recommendation, but what process is in place to allow the concerns of other parties to be raised and subsequently evaluated, addressed and documented?

The formal documented method for dealing with WIPP PA issues must provide ways for identifying issues, evaluating them, making a decision on the approach for their resolution, tracking their eventual resolution, and documenting the whole process. The approach must provide a method in which to present issues for subsequent evaluation and consideration for addressment. An approach and decision methodology to guide this evaluation will be needed so that newly identified issues can be evaluated and either (1) the issue is closed, once the reasoning for closure is formally identified and documented, or (2) the issue is moved forward and given a refined definition to serve as the basis for development of an approach for addressment.

Once an issue has been identified and moved forward for addressment, the issue identification/tracking/resolution process must provide a number of things.

- A means for the issues to be clearly identified and defined.
- A mechanism for each issue to be evaluated in terms of its relative importance to compliance analysis (including an evaluation of the effects of not resolving the issue).
- A mechanism for determining whether an issue can be resolved and, if it can, how it can be resolved. All the plausible alternatives (including engineering approaches to alternative design that avoids the issue) should be identified, along with complete time, cost, and probability of success estimates. This mechanism should first determine if the addressment of the issue is what Weinberg (1985) would describe as *"trans-scientific"* or beyond the power of science to answer. It is important to realize that not every issue need or can be addressed. It is also important to separate the questions that are beyond our current ability to address and those that are beyond our means in terms of time or cost.
- A means to classify and rank the various issues so they can all be put into the proper perspective for the decision makers for prioritization and allocation of resources.
- A means to track the issue and its eventual resolution.

PART Recommendation: In order to achieve those qualitative qualities of "reasonable degree of certainty" and "reasonable expectation," there is a need to document these issues and their status of resolution through a series of issue resolution documents to aid both the licensing reviewers and any other interested parties (Subsection 4.2.1.1). The PA should contain a brief summary of the major resolved and unresolved issues and provide a reference to these issue resolution documents, and these documents should be prepared under strict QA with appropriate documented external review by qualified experts.

8.1.3 Repository Design/Facility Configuration Control

Another important area identified by the PART is related to repository design. The original WIPP repository design and repository level were established before the current regulations were promulgated and before much of the in situ testing and measurements were completed. In their cursory review of the design, the PART identified the following issues and concerns:

- Are the repository design and repository level fixed and why?
- If the repository design is not fixed, how has the repository design changed in response to information from the site characterization and PA activities?
- Who is in charge of design configuration control to insure that design changes are compatible with other components of repository operation and performance?
- Is there a formal process and procedure for revisiting the design to determine if it must be updated in response to improved understanding of the subsurface and the waste disposal system?

PART Recommendations: Prepare a document containing the history of the design process and record (or develop) the procedures that govern the design change control concerns discussed above.

8.2 REPOSITORY SYSTEM UNCERTAINTIES

In addition to the general issues of process and information referenced above, PART has identified other important technical and management issues to be resolved. The significance of these issues cannot be properly assessed until a complete system model of WIPP is available. The issues associated with the natural system are presented first, followed by a discussion of repository-related issues, and finally, those related to future events and processes.

8.2.1 Salado Formation

Uncertainty appears to center around far-field pore pressure and permeability of impure salt, relatively pure salt, and interbeds in this heterogeneous unit. Particularly unsettling are questions concerning hydraulic (and possibly chemical) equilibrium of the system. Pore pressures in the very low permeability salt are expected to be near lithostatic (15 MPa) and in equilibrium with those of the interbeds (12.5 MPa), but the highest pore pressure measured in the halite is 9.5 MPa. Careful investigations of the physical properties and chemical equilibria of pressurized core from "representative" halite members of the Salado Formation obtained from the repository horizon may provide fundamental information toward a solution to this problem and to that of whether or not Darcy flow occurs in the undisturbed salt. More important, however, is a thorough characterization of flow properties of the heterogeneous interbeds.

PART Recommendation: Obtain pressurized core from representative pure and impure halite and interbeds of the Salado Formation at the repository horizon in the far-field for laboratory assessments of flow properties and processes.

8.2.2 Rustler Formation

Most recent work on the Rustler Formation has focused on mechanisms of contaminated brine transport through the Culebra dolomite following inadvertent borehole intrusion into and through waste panels. Apparently, these important investigations are being carried out to the exclusion of considerations of flow along other potential transmissive pathways in the Rustler, such as the Rustler-Salado contact. Three specific models for brine flow through the Culebra have been employed in consequence modeling to date. However, as shown by studies of cores obtained near walls of a shaft, the Culebra is so heterogeneous, on the scale of ms, that results of the models may well be misleading. Field tracer tests are essential for understanding flow and transport through this unit, and perhaps others in the Rustler Formation, unless they can be excluded on other grounds as potential migration pathways. A better understanding of potentiometric surfaces associated with various units of the Rustler Formation may be important. Finally, there is a need to carry out the column radionuclide sorption test on the cores removed from the air intake shaft (Subsection 4.3.3.4 and Figure 4-9).

PART Recommendation: Continue column radionuclide sorption testing and conduct field tracer tests to determine large-scale flow properties of the Culebra dolomite.

8.2.3 Castile Formation

Continuing characterization of the nature and physical properties of the Castile anhydrites and potential oil-bearing strata below is important only for purposes of inadvertent human intrusion scenarios. It appears now as if the Castile pressurized brine pockets, conservatively estimated to underlie approximately 40% of the WIPP repository, have been isolated from each other and from recharge for a very long time. If so, restricted volumes of brine are available for contaminant transport to the surface and through the subsurface, should one or more of these pockets be penetrated.

PART Recommendation: Continue geophysical studies, using remote sensing methods, in an effort to define better the extent of the pockets and volumes of brine associated with them.

8.2.4 Impact of the Repository and Waste Emplacement

Excavation of the repository perturbs the thermal, chemical, hydrologic and mechanical fields of the Salado Formation. The most profound effects are to be found in the immediate vicinity of the opening and are manifested by formation of the disturbed rock zone (DRZ). Microfracturing and faulting associated with high stresses and rapid transient creep closure lead to reduced pore pressure and greatly enhanced permeabilities. Brine inflow rates are high initially, falling off to steady-state rates as intergranular water is drained from the DRZ. Although it is not yet fully characterized, the DRZ is pervasive from excavation surfaces to about 3 ms (9.8 feet) into the salt, where it grades into a zone of diminished pore pressure but low permeability. Apparently, new DRZ may be created with time during creep closure. Eventually, closure slows and ceases and the DRZ is expected to self-heal when stress gradients are reduced by back-pressure.

Strongly coupled with closure rates, the nature and extent of the DRZ, and the rates of brine inflow, are rates of generation of gas from biodegradation, corrosion, and radiolysis of the emplaced transuranic waste. The quantity of gas generated depends markedly on the quantity of brine available, and gas pressures depend on the volume of pore space available for storage. Within waste disposal rooms, the pore space available for gas storage diminishes with time during closure so that gas pressure increases at a rate determined by gas-generating mechanisms, permeabilities to gas, and gas storage space available beyond disposal room walls. The DRZ not only provides some of the storage space required but, more important, provides the primary link between the waste disposal room and the remainder of the repository. It appears now, from preliminary analysis of fully coupled three-phase (salt, brine, gas) models, that variable gas-generation rates (dominantly humid environment) are most reasonable and that disposal room volume-pressure history may depend primarily on gas storage and transport in adjacent interbeds. With ongoing improvement in critical param characterization, fully-coupled three-phase fluid modeling will surely provide the best representations of disposal room dynamics and fluid flow for performance assessment.

Gas generation studies are ongoing; laboratory studies are expected to be augmented by the bin and alcove tests within the repository upon implementation of the Test Phase Plan. Brine inflow rates continue to be monitored with improved measurement techniques. One key area that requires more intensive investigation is the microstructural nature and extent of the DRZ, its physical and mechanical properties, and its time-dependent behavior. Detailed microstructural studies of cores

through the DRZ combined with field and laboratory tests would characterize the micromechanical processes responsible for pore and grain boundary damage. Simultaneously, experimental investigations of micromechanical processes giving rise to the transient mechanical response (in the dilatant field) could be carried out under simulated repository conditions (e.g., humid, gas-pressurized). Together, these investigations would surely lead to a much more thorough characterization of the DRZ, its transition into the depressurized zone, and its time-dependent behavior, including conditions required for self-healing.

Finally, implementation of the Munson-Dawson model, modified to include a damage factor, is essential for realistic approximation of disposal room closure that includes transient creep and associated pore and grain boundary damage. The current elastic-steady state model, that matches measured closure rates by reducing elastic moduli, fails to account for flow in the transient creep regime during which the DRZ is created. The premise upon which the current model is based is physically unreasonable; the PA department is fully aware of this and is in the process of incorporating the much more complex modified M-D model.

PART Recommendation: Conduct detailed studies of the nature and extent of the DRZ by means of microstructural analyses and by laboratory and field measurements of physical properties. Carry out a systematic experimental and micromechanical study of the time-dependent behavior of Salado salt deforming in the transient creep regime, in the dilatant field, under simulated repository conditions. Complete incorporation of the M-D model and use the model in coupled three-phase studies.

8.2.5 Engineered Barriers

The four shafts are the most likely pathways for the transport of mixed waste to the accessible environment under undisturbed (no human intrusion) conditions. The strategy for sealing the shafts is to maximize the amount of consolidated, low permeable salt in the shaft between the top of the Salado Formation and the repository level. Creep closure of the shaft opening is expected to consolidate the crushed salt in the lower portion of the shafts to near-intact (95%) density within 100 years after emplacement. Composite seals will be located above and below the crushed salt seals to prevent brine from saturating the crushed salt and inhibiting consolidation.

The upper shaft seal system in the Rustler Formation will be comprised of a sequence of water bearing seals made up of bentonite clay segments confined by adjacent concrete bulkheads. The purpose of the seals is to limit groundwater flow from the formation into the lower portions of the shaft during the consolidation phase of the crushed salt seals. The brine inflow rate must be reduced from 1000 m^3/year to 1 m^3/year in order for the lower 100 m (328 feet) of the shaft seal to reach 95% fractional density in 100 years. The DRZ in the rock surrounding the shafts may be removed or sealed with grout to prevent groundwater from flowing around the plugs and into the underlying crushed salt seals.

The panel and drift seals are designed to inhibit long-term migration of radionuclide-contaminated brine through the drifts to the base of the shafts and to isolate radionuclides during the operational phase of the repository. The seals are similar to the shaft seals and comprise both long-term and short-term seals. The panel entryway seals are intended to return intervals within the

repository to hydraulic properties similar to the intrinsic conditions in the undisturbed host rock salt and provide substantial resistance to flow through the repository, as well as to separate volumes of waste from one another and from the shafts. The time for consolidation of the crushed salt portion of the seals is similar to that for the lower shaft seals, approximately 100 years after installation.

The DRZ in the salt surrounding the seal locations is expected to heal eventually after the crushed salt reaches 95% fractional density and resists further creep closure of the opening. The damage zone around the concrete bulkheads is expected to heal much earlier, due to the back stresses that will be generated. The fracture system in MB 139 below the excavations appears to be extensive and possibly interconnected. Unlike the disturbed zone in the halite rock mass, the fractures in the interbeds are not expected to heal. Many of the fractures are thought to have existed prior to excavation. The existence of pre-excavation fractures suggests that, even if the fractures close as the local stresses return to lithostatic conditions, they are unlikely to "heal" and are therefore likely pathways for pressurized gas and brine transport. One option under consideration is the use of cement or crushed salt grouts to seal the interbeds, particularly around the panel seal locations. Effective grouting may be difficult to achieve because of difficulties in delivering the grout to the fracture system and the possibility of deformation of the interbed as the rooms close and the surrounding rock mass dilates.

An additional pathway to anhydrite layer B is expected through the rock bolt holes that intersect the overlying interbeds. Therefore, the pathways for contaminant migration are likely to change during the first several hundred years after disposal. Immediately after closure, gas and brine will be able to flow through the DRZ into MB 139 and anhydrite B. As the DRZ heals, gas and brine movement will be limited to anhydrite B. Because the storage and thickness of MB 139 are expected to be significantly greater than those of anhydrite B, the extent and pressure of any gas or brine in the interbeds will depend in part on the time MB 139 is hydraulically (pneumatically) connected to the waste panels.

None of the conceptual models describing shaft and drift seal behavior has been incorporated into the performance assessment analyses for preliminary comparison with 40 CFR 191 or 40 CFR 268.6. This is one of the most serious deficiencies in the performance assessment program identified by this review. The primary reason given by SNL for not including engineered barriers is related to budget constraints and the need to address other aspects of the repository system that were assigned a higher priority. The importance of engineered barriers is now recognized by the scientific and management staff supporting WIPP, and these features will be incorporated in subsequent performance assessment analyses.

PART Recommendation: In situ tests are planned to measure the characteristics and behavior of the fractured interbeds, which should improve understanding of the potential for and extent of contaminant transport. In addition to these studies, a large-scale field test should be considered to provide empirical information on the healing of the DRZ in the halite and polyhalite host rock. This might involve a rigid bulkhead in the experimental area of the WIPP facility. After characterizing the DRZ in the salt and interbeds, a bulkhead would be installed in the opening and changes in the DRZ properties monitored. The bulkhead would simulate DRZ healing after the room closure is complete and the stress state returns to lithostatic conditions. The empirical data from such an experiment would likely improve the confidence in our understanding of the short-term behavior of the DRZ and

its effect on other components and processes (e.g., brine inflow). Experiments should continue on crushed salt reconsolidation behavior under low pressure and pore fluid conditions up to saturation.

The significance of the above issues and the adequacy of the tests planned are difficult to assess until the seal systems are incorporated in the system model for WIPP. While the subsystem models provide useful insight into the sensitivity of the seal performance to local conditions it is not possible to identify and prioritize additional studies without knowing the contribution of the various features and processes to system performance. At a minimum, simplified representations of the shaft and panel entryway seals, DRZ, and interbeds should be incorporated in the system model in the next performance assessment iteration to determine the sensitivity of the repository performance to the params and processes involved. Until this is done, it is not possible to assess whether the WIPP is likely to meet the regulatory compliance standards.

8.3 SCENARIOS

8.3.1 Undisturbed Repository Scenarios

Numerical two-dimensional modeling of the base-case (undisturbed) scenario has concentrated on providing evaluations of the most sensitive params affecting repository behavior with no attempt to demonstrate compliance with the regulations. Gas and brine migration laterally through interbeds and vertically through shaft seals has been the primary focus of the simplified models to date. Three of the models do not permit adjustment of void volume; the fourth simulates closure by estimating the reduction, with closure pressure and time, of void space in a disposal room. In the models including the DRZ, fixed porosity and permeability are assigned; no provision is made for time-dependent healing or additional fracturing of interbeds that may result from increased gas pressure. These models do not include representation of proposed engineered barriers but rather evaluate lengths and permeabilities required of the barriers (ignoring the DRZ) to become effective seals. The principal results are (1) lateral gas release is very limited and vertical release, to the Culebra, is unlikely provided that the lower shaft seal has a permeability less than $10^{-19}m^2$; and (2) brine that has been in contact with waste has not migrated beyond the DRZ in 10,000 years.

PART Recommendation: Replace the current elastic-steady-state model for excavation closure with the modified M-D model to obtain more realistic closure models that include transient creep and associated pore and grain boundary damage. Implement fully-coupled, three-phase (gas, brine, salt) flow in base-case scenario using brine and gas properties, reasonable inflow and generation rates, and nonlinear equivalent viscosities estimated from the M-D model of Salado salt flow. Incorporate in these models time-dependent behavior of the DRZ and of engineered barriers.

8.3.2 Disturbed Repository Scenarios

Inadvertent and intermittent human intrusion by exploratory drilling for resources has been demonstrated to be the only event likely to release radionuclides in concentrations near regulatory limits. Of the fifteen possible combinations of four types of intrusion events, only three have been modeled to date along with the base-case (undisturbed) scenario. These three summary scenarios include (1) drilling through a waste-filled panel and into a pressurized brine pocket below (E1); (2)

drilling into a waste panel (E2); and (3) both types of drilling events occurring in the same panel (E1E2). From four to ten such inadvertent intrusion events may occur at WIPP in 10,000 years. For each type of event, contaminated particulate matter and brine reach the wellhead in the drilling fluid (direct), whereupon the hole is plugged and further flow (indirect) of contaminated brine to the accessible environment is assumed to be through the Culebra dolomite.

Probabilities and consequences of total direct and indirect releases to the accessible environment for intrusions taking place at 1,000 years have been calculated for comparison with the EPA containment requirement. Probability-consequence curves, whose locations are shown relative to the EPA limit, depend primarily upon the number and type of intrusions and direct releases and the type of brine transport through the Culebra dolomite. For the most conservative combination of those processes modeled, releases still fall below the EPA limit. Some of the assumptions employed in this E1E2 scenario, in which indirect releases dominate, are physically unreasonable; certainly in this category are plug placement contrived to maximize releases and the 10,000-year integrity of intact borehole plugs. Of the conceptual models considered to date, those regarded as most realistic by the Performance Assessment Department yield releases more than two orders of magnitude below the EPA limit. This model, also E1E2, assumes time-dependent intrusions, direct releases, and indirect releases by subsurface flow through the Culebra with $K_d \neq 0$. Still smaller releases may be realized from the humid, isolated-room scenario (E1E2 is eliminated) which requires no artificial restraints; this scenario has not yet been modeled.

PART Recommendation: Replace the E1E2 scenario currently modeled with a similar one that permits variable placement and normal degradation of plugs. Both time and sequence of borehole penetrations will then become important factors in consequence modeling and releases estimated will be much more realistic.

8.4 PERFORMANCE ASSESSMENT INDICATORS

The WIPP Performance Assessment Department at SNL has developed a comprehensive and technically sound PA methodology. The underlying philosophy of the SNL approach appears to be the development of increasingly more realistic (complex) models which require increasingly more specialized and precise data. Because of the level of modeling involved, this complex system has not been fully developed and implemented. For example, this modeling effort does not take into account coupled responses which will certainly occur in the repository.

Although SNL has expended considerable effort in the development of these detailed models, they have not demonstrated or documented why this approach is necessary to reach a compliance decision. In short, the approach being utilized by SNL may not be compatible with compliance-based performance assessments.

Considerable effort has been focused on modeling of natural barriers, significantly less effort has been concentrated on engineered barriers. Since compliance with the regulations cannot be achieved solely on the basis of the use of natural barriers, a complete program needs to be undertaken to develop models that include the performance of engineered barriers. In addition, seal performance will be an important consideration for compliance with 40 CFR 268.6.

Finally, component sensitivity analyses utilizing these complex, yet incomplete models may lead to incorrect conclusions that affect programmatic decisions and compliance activities.

PART Recommendation: In order to develop a compliance-based approach to performance assessment, it is essential that WIPP develop a system model for the repository which includes engineered as well as natural barriers. In addition, consideration should be given to the development of simplified models to provide direction for a compliance-based performance assessment program. These simplified models reduce the complexities in dealing with coupled effects and are generally very reliable when the params fall within a limited range.

8.4 CONCLUSION

All individuals contacted by the PART, recognized as experts in their respective disciplines, displayed the highest level of professionalism in this state-of-the-science WIPP effort. Although the review teams has made suggestions on means of improving selected areas of the performance assessment activities, the overall program clearly has a solid foundation.

In recapping major recommendations, technical issues requiring further investigation and incorporation into system models include: far-field hydraulic properties of Salado formation interbeds and halite and those of Rustler formation transmissive members; the transient creep behavior of the Salado salt and character, extent and behavior of the DRZ during creep closure; performance of engineered barriers together with the natural system in limiting fluid migration from the fully coupled disposal system; and implementation of complete system models simulating releases for both undisturbed scenarios and physically reasonable disturbed scenarios that have resulted from inadvertent human intrusion. Programmatic decisions based on incomplete system analyses can lead to incorrect decisions and allocation of resources.

Documentation of PA activities, while comprehensive for short periods, must be related summarily to the evolution of the entire WIPP project in order to make it easier for individuals, teams and agencies to track issue resolution status. The success of all integrated test programs and the entire performance assessment effort for WIPP will be determined by the final product — a compliance determination.

APPENDIX A

Applicable Review Criteria

The Performance Assessment Review Team (PART) identified a subset of the criteria contained in the *Regulatory Criteria Document for the Disposal of Defense Transuranic Mixed Waste in a Geologic Repository*, Rev. 0 (RCD), as a partial basis for the evaluation of the WIPP performance assessment (PA). Listed below are the generic criteria from the RCD and specific criteria developed by the PART for application to the WIPP PA program. Tables A-1 through A–4 contain the PART comments on each criterion.

1.0 GENERAL COMPLIANCE CRITERIA

RC1.001 RCD CRITERION:

The DOE shall apply the following criteria in determining compliance with applicable portions of 191,. 264, and 268 that apply to the disposal of defense-generated TRU radioactive waste, during the disposal, closure, and post-closure phases of the repository.

PC1.001 PART CRITERION:

The PART reviewed the following criteria to establish if WIPP will comply with the applicable portions of 40 CFR 191, 264, and 268 with regard to performance assessment.

RC1.002 RCD CRITERION:

Releases of concentrations of hazardous constituents and cumulative releases of radionuclides shall be demonstrated not to exceed the quantitative limits in 40 CFR 191.13(a), 191.15, 191.16, and the health-based limits or other acceptable criteria, established pursuant to 264.601 and 268.6(a), with a reasonable expectation of compliance.

PC1.002(A) PART CRITERION:

The PA modeling activities utilize the quantitative radionuclide release limits of 40 CFR 191.13(a), 191.15, and 191.16 for the determination of compliance to 40 CFR 191.

PC1.002(B) PART CRITERION:

The PA activities utilize the health-based limits, established pursuant to 264.601 and 268.6(a) for the determination of compliance with RCRA.

RC1.003 RCD CRITERION:

The demonstration shall predict releases from all pathways, including groundwater, surface water, soil, and air, at the boundary of the controlled area of the repository, which shall be equivalent to the boundary of the lateral extent of the unit boundary established for the RCRA.

PC1.003(A) PART CRITERION:

The PA modeling addresses releases from all pathways, including groundwater, surface water, soil, and air, at the boundary of the control area of the repository.

PC1.003(B) PART CRITERION:

The boundary of the control area of the repository is equivalent to the lateral extent of the unit boundary established for RCRA.

RC1.004 RCD CRITERION:

Compliance of the disposal system performance with 191.13, 264.601, and 268.6 shall be evaluated by performing predictions of contaminant migration (using quantitative computational models and qualitative analysis) that are supported by laboratory and field investigations as well as by expert judgment.

PC1.004 PART CRITERION:

The qualitative computational model and the quantitative analysis for disposal system performance are supported by laboratory and field studies, as well as expert judgments.

RC1.005 RCD CRITERION:

The basis for demonstrating that the geologic disposal system complies with 191.13, 264.601, and 268.6 shall be documented.

PC1.005 PART CRITERION:

The SNL PA and the WID compliance staffs are documenting the basis for demonstrating that the geologic disposal system complies with 191.13, 264.601, and 268.6.

RC1.006 RCD CRITERION:

The record(s) shall include the quantitative and qualitative evidence that was used to develop the performance assessment models as well as supplementary information (e.g., natural analogues, evidence that supports the process models, parameter ranges, geometric conceptual model(s), hypotheses, and simplifying assumptions used).

PC1.006 PART CRITERION:

The records include the quantitative and qualitative evidence that was used to develop the performance assessment models as well as supplementary information (e.g., natural analogues, evidence that supports the process models, parameter ranges, geometric conceptual model(s), hypotheses, and simplifying assumptions used).

RC1.007 RCD CRITERION:

New information relevant to the performance of the disposal system shall be incorporated in the compliance analysis and the assessment of compliance will be reevaluated until the repository is closed.

PC1.007 PART CRITERION:

The SNL PA and WID compliance staffs are incorporating new information relevant to the performance of the disposal system in the compliance analysis.

RC1.008 RCD CRITERION:

Performance of the disposal system shall be evaluated based on the projected contributions of both natural and engineered barriers. It shall be demonstrated that the system controls, minimizes, or eliminates releases.

PC1.008(A) PART CRITERION:

Performance of the disposal system is being evaluated based on the projected contributions of both natural and engineered barriers.

PC1.008(B) PART CRITERION:

It is being demonstrated that the barrier system controls, minimizes, or eliminates releases.

RC1.009 RCD CRITERION:

All components of the geologic disposal system, including the characteristics and radionuclide content of the emplaced waste, shall be considered when predicting the system performance unless it can be demonstrated that a component makes a negligible contribution to the overall system performance.

PC1.009(A) PART CRITERION:

All components of the geologic disposal system, including the characteristics and radionuclide content of the emplaced waste, are considered when predicting the system performance.

PC1.009(B) PART CRITERION:

Components which make a negligible contribution to the overall system performance are not considered.

Pathways for Migration

RC1.010 RCD CRITERION:

In demonstrating compliance with the environmental performance standards, potential pathways for the migration of radionuclides and hazardous constituents shall be identified and evaluated. All potential pathways shall be considered, including groundwater, surface water, soil, and air.

PC1.003(A) PART CRITERION:

The PA modeling addresses releases from all pathways, including groundwater, surface water, soil, and air, at the boundary of the control area of the repository.

RC1.011 RCD CRITERION:

The pathways evaluated shall be consistent for analyses performed to demonstrate compliance with the environmental performance standard of 264.601, the no-migration standard of 268.6, the containment requirements of 191.13, and the individual protection requirements of 191.15.

PC1.011 PART CRITERION:

The pathways evaluated by SNL for the analysis to the containment requirements of 191.13 and the individual protection requirements of 191.15 are consistent with the pathways evaluated by WID for demonstrating compliance with the environmental performance standard of 264.601 and the no-migration standard of 268.6.

RC1.012 RCD CRITERION:

The compliance analyses shall consider the likelihood and consequences of events and processes that may disturb the disposal system (specifically including earthquakes, floods, severe storm events, droughts, or other natural phenomena).

PC1.012 PART CRITERION:

The compliance analyses consider the likelihood and consequences of events and processes that may disturb the disposal system, including earthquakes, floods, severe storm events, droughts, and other natural phenomena.

RC1.013 RCD CRITERION:

The compliance analyses need not consider processes and events that are estimated to have less than 1 chance in 10,000 of occurring over 10,000 years. For events and processes with a probability of greater than 1 chance in 10,000 over 10,000 years, an evaluation shall be made of the potential impacts and consequences together with an evaluation of the ability of the disposal system to isolate wastes if the event or process occurs.

PC1.013(A) PART CRITERION:

The PA staff developed a process to consider many potential processes and events.

PC1.013(B) PART CRITERION:

A process assigns a probability to each process or event.

PC1.013(C) PART CRITERION:

Processes or events with likelihood of less than 1 chance in 10,000 over 10,000 years are removed from further consideration.

PC1.013(D) PART CRITERION:

For remaining processes or events, an evaluation of the ability of the disposal system to isolated wastes if the event or process occurs is being conducted.

PC1.013(E) PART CRITERION:

The consequences of the occurrence of the process or event are evaluated.

RC1.014 RCD CRITERION:

A reasonable expectation that natural processes and events shall not result in a release of radionuclides or hazardous constituents in excess of applicable standards shall be demonstrated.

PC1.014(A) RCD CRITERION:

Natural processes and events are being analyzed as part of the performance assessment.

PC1.014(B) PART CRITERION:

It is being demonstrated with reasonable expectation that natural processes and events do not result in a release of radionuclides or hazardous constituents in excess of applicable standards.

RC1.015 RCD CRITERION:

The likelihood of inadvertent human intrusion shall be evaluated, considering that controls will be imposed to make such intrusions unlikely. The judgment of the likelihood of human intrusion shall be based primarily on an evaluation of the expected effectiveness of permanent markers.

PC1.015(A) PART CRITERION:

Consideration is given to controls that will be imposed to make human intrusion unlikely.

PC1.015(B) PART CRITERION:

An evaluation of the effectiveness of permanent markers is being conducted.

PC1.015(C) PART CRITERION:

The judgment of the likelihood of human intrusion is based primarily on the evaluation stated in PC1-015(b).

PC1.015(D) PART CRITERION:

The likelihood of human intrusion is being evaluated.

RC1.016 RCD CRITERION:

The consequences of human intrusion events shall be evaluated and included in the record. Human intrusion events shall be no more severe than inadvertent and intermittent intrusion by exploratory drilling for resources (other than any resources provided by the disposal system itself). Each intrusion will be assumed to be an isolated occurrence, such that a particular intruder will inadvertently intrude only once. The assessments shall assume that systematic or persistent exploitation within the controlled area will not occur.

PC1.016(A) PART CRITERION:

Human intrusion events are considered to be no more severe than inadvertent and intermittent intrusion by exploratory drilling for resources (other than any resources provided by the disposal system itself).

PC1.016(B) PART CRITERION:

Each intrusion is assumed to be an isolated occurrence, such that a particular intruder intrudes only once.

PC1.016(C) PART CRITERION:

The assessments assumed that systematic or persistent exploitation within the controlled area do not occur.

PC1.016(D) PART CRITERION:

The consequences of human intrusion events are evaluated and included in the record.

RC1.017 RCD CRITERION:

Human intrusion events shall not be included in the quantitative modeling of total system performance of the repository.

PC1.017 PART CRITERION:

Human intrusion events are not included in the quantitative modeling of total system performance of the repository.

RC1.018 RCD CRITERION:

The compliance models for 191 and 268 shall simulate the expected behavior (processes and events) of the repository, including the potential for migration of radionuclides and hazardous constituents from the time of emplacement to 10,000 years after closure.

PC1.018 PART CRITERION:

The compliance models for 191 and 268 simulate the expected behavior (processes and events) of the repository, including the potential for migration of radionuclides and hazardous constituents from the time of emplacement to 10,000 years after closure.

RC1.019 RCD CRITERION:

The physical descriptions of the system for all models shall be identical.

PC1.019 PART CRITERION:

The physical descriptions of the system for all models for both 40 CFR 191 and RCRA are identical.

RC1.020 RCD CRITERION:

The conceptual models for the repository system, on which the mathematical and computational models are based, shall be comparable for all compliance analyses.

PC1.020 PART CRITERION:

The conceptual models for the repository system, on which the mathematical and computational models are based, are comparable for all compliance analyses.

RC1.021 RCD CRITERION:

The quantitative compliance models shall predict expected releases from a repository and shall demonstrate that the expected cumulative releases of radionuclides or concentrations of hazardous constituents will not exceed applicable standards.

PC1.021(A) PART CRITERION:

The quantitative compliance models predict expected releases from the repository

PC1.021(B) PART CRITERION:

The quantitative compliance models demonstrate that the expected cumulative releases of radionuclides does not exceed applicable standards.

PC1.021(C) PART CRITERION:

The quantitative compliance models demonstrate that the expected concentrations of hazardous constituents do not exceed applicable standards.

RC1.022 RCD CRITERION:

To demonstrate compliance with 191, the results of performance assessments shall be presented in a single CCDF that indicates the probability of exceeding various levels of cumulative release.

PC1.022(A) PART CRITERION:

For 40 CFR 191 compliance, the results of performance assessments are presented in a single CCDF.

PC1.022(B) PART CRITERION:

The CCDF in PC1.022(a) indicates the probability of exceeding various levels of cumulative release.

RC1.023 RCD CRITERION:

The justification for the selection or generation of the single CCDF shall be documented.

PC1.023 PART CRITERION:

Justification for the selection or generation of the single CCDF are documented.

RC1.024 RCD CRITERION:

The performance assessment model(s) for 191.15 shall be used to estimate the annual dose equivalent from the disposal system to any member of the public in the accessible environment for the first 1,000 years after disposal. The assessments shall consider only undisturbed performance and shall not consider water wells within the boundary of the controlled area.

PC1.024(A) PART CRITERION:

The performance assessment model(s) for 191.15 are used to estimate the annual dose equivalent from the disposal system to any member of the public in the accessible environment for the first 1,000 years after disposal.

PC1.024(B) PART CRITERION:

The assessments in PC1.024(a) consider only undisturbed performance

PC1.024(C) PART CRITERION:

The assessment in PC1.024(a) does not consider water wells within the boundary of the controlled area.

RC1.025 RCD CRITERION

Compliance models for the 191 performance assessment and the 264 and 268 environmental performance standards shall be evaluated and documented.

PC1.025 PART CRITERION

Compliance models for the 191 performance assessment and the 264 and 268 environmental performance standards are documented.

RC1.026 RCD CRITERION:

The evaluation and documentation of the model results shall include

(1) the simplifying assumptions in the conceptual, mathematical, and computational models;

(2) the rationale for the selection of the hazardous constituents and radionuclides included in the model;

(3) information demonstrating that the predictions of waste migration were calibrated for the specific site conditions, physical features, and waste emplaced at the repository;

(4) a demonstration that the modeling results are consistent with actual field measurements and that the modeling results are representative of the actual physical system; and

(5) a comparison of the model results and an explanation of any differences.

PC1.026 PART CRITERION:

The evaluation and documentation of the model results include:

(a) the simplifying assumptions in the conceptual, mathematical, and computational models;

(b) the rationale for the selection of the hazardous constituents and radionuclides included in the model;

(c) information demonstrating that the predictions of waste migration were calibrated for the specific site conditions, physical features, and waste emplaced at the repository;

(d) a demonstration that the modeling results are consistent with actual field measurements and that the modeling results are representative of the actual physical system; and

(e) a comparison of the model results and an explanation of any differences.

RC1.027 RCD CRITERION:

Sensitivity and uncertainty analyses of the compliance modeling shall be conducted. The evaluation, shall include

(1) the uncertainty in events and processes;

(2) the likelihood and consequences of alternative conceptual models;

(3) the representation of model parameters;

(4) sensitivity studies of the models; and

(5) an assessment of the accuracy of the model, including model verification results.

PC1.027 PART CRITERION:

Sensitivity and uncertainty analyses of the compliance modeling are being conducted. The evaluation include

(a) the uncertainty in events and processes;

(b) the likelihood and consequences of alternative conceptual models;

(c) the representation of model parameters;

(d) sensitivity studies of the models; and

(e) an assessment of the accuracy of the model, including model verification results.

2.0 REPOSITORY SITE CRITERIA

RC2.001 RCD CRITERION:

For geologic repositories, the boundaries of the controlled area, defined for 191, and the unit boundary, defined for 264, Subpart X, shall be coincident and shall be described in the documentation accompanying the compliance analyses.

PC2.001(A) PART CRITERION:

The boundaries of the controlled area, defined for 191, and the unit boundary, defined for 264, Subpart X, are coincident.

PC2.001(B) PART CRITERION:

The boundaries are described in the documentation accompanying the compliance analyses.

RC2.002 RCD CRITERION:

The controlled area and unit boundary shall not extend more than 5 kilometers from the outermost extent of emplaced waste and shall not exceed a total surface area of 100 square kilometers. The controlled area and unit boundary shall extend downward from the surface to a depth and configuration that is appropriate to the repository site.

PC2.002(A) PART CRITERION:

The controlled area and the unit boundary are defined.

PC2.002(B) PART CRITERION:

The controlled area and unit boundary are utilized as the point of compliance for 40 CFR 191 and RCRA.

PC2.002(C) PART CRITERION:

The controlled area and unit boundary do not extend more than 5 kilometers from the outermost extent of the emplaced waste.

PC2.002(D) PART CRITERION:

The controlled area and the unit boundary do not exceed a total area on the surface of 100 square kilometers.

PC2.002(E) PART CRITERION:

The controlled area and unit boundary extend downward from the surface to a depth and configuration that is appropriate at the repository site.

3.0 REPOSITORY OPERATIONS CRITERIA

Since the scope of the review was limited to performance assessment activities for post-closure RCRA and 40 CFR 191 Subpart B (disposal), the Repository Operation criteria were not reviewed.

4.0 NATURAL SYSTEM CRITERIA

RC4.001 RCD CRITERION:

A comprehensive, detailed description of the geology and surface and groundwater hydrology of the repository site and setting shall be provided. The description shall include an analysis of the geochemistry of the system relevant to radionuclide or contaminant migration, including a characterization of rock, soil, air and water chemistry.

PC4.001(A) PART CRITERION:

An analysis of the geochemistry of the system relevant to radionuclide or contaminant migration, including a characterization of rock, soil, air and water chemistry are being conducted.

PC4.001(B) PART CRITERION:

A comprehensive, detailed description of the geology and surface and groundwater hydrology of the repository site and setting is provided.

SPECIAL SOURCES OF GROUNDWATER

RC4.002 RCD CRITERION:

An evaluation to determine whether special sources of groundwater exist within the controlled area or less than five kilometers beyond the controlled area shall be conducted.

PC4.002(A) PART CRITERION:

An evaluation has been completed, has started, or is being planned to determine whether special sources of groundwater exist within the controlled area or less than five kilometers beyond the controlled area.

PC4.002(B) PART CRITERION:

If the evaluation has been completed, special sources of groundwater have not been found to exist within the controlled area or less than five kilometers beyond the controlled area.

5.0 WASTE CHARACTERIZATION CRITERIA

Since the scope of the review was limited to performance assessment activities for post-closure RCRA and 40 CFR 191 Subpart B (disposal), the Waste Characterization criteria were not reviewed.

6.0 ENGINEERED BARRIER SYSTEM CRITERIA

RC6.001 RCD CRITERION

The engineered barrier system shall be designed to be physically and geochemically compatible with the natural barrier system so that interactions with the natural system do not compromise the ability of the repository to meet applicable release limits.

PC6.001(A) PART CRITERION:

Proposed engineered barrier systems are designed to be physically compatible with the natural barrier system.

PC6.001(B) PART CRITERION:

Proposed engineered barrier systems are designed to be geochemically compatible with the natural barrier system.

RC6.002 RCD CRITERION:

The analyses of engineered barriers shall be supported by analytical data developed to assess their adequacy.

PC6.002(A) PART CRITERION:

Analytical data are being collected to evaluate the engineered barriers.

PC6.002(B) PART CRITERION:

Criteria are established to determine the requirements of the barrier system.

PC6.002(C) PART CRITERION:

Requirements are established to assure that the engineered system will be adequate to allow the repository to meet the release limits.

7.0 INSTITUTIONAL BARRIERS

Since the scope of the review was limited to performance assessment activities for post-closure RCRA and 40 CFR 191 Subpart B (disposal), the Institutional Barrier criteria were not reviewed.

8.0 ADMINISTRATIVE OPERATIONS

Since the scope of the review was limited to performance assessment activities for post-closure RCRA and 40 CFR 191 Subpart B (disposal), the Administrative Operations criteria were not reviewed. Although 40 CFR Part 191 does not require quality control of the computer codes, it appears necessary for a certification of compliance.

Table A-1

1.0 GENERAL COMPLIANCE CRITERIA

Criterion Number	PART Criterion	Comment
PC1.001	The PART reviewed the following criteria to establish if WIPP will comply with the applicable portions of 40 CFR 191, 264, and 268 with regard to performance assessment.	Since the performance assessment activities for compliance with 40 CFR 268.6 have not been developed as completely as those for 40 CFR 191 compliance, comments in this section are not appropriate for 40 CFR 268.6 activities unless specifically stated.
PC1.002(a)	The PA modeling activities utilize the quantitative radionuclide release limits of 40 CFR 191.13(a), 191.15, and 191.16 for the determination of compliance to 40 CFR 191.	The current PA modeling does use the quantitative release limits in §191.13(a). However, §191.15 and §191.16 require predictions based on undisturbed performance of the repository. For the undisturbed repository, SNL predicts no releases.
PC1.002(b)	The PA activities utilize the health-based limits, established pursuant to 264.601 and 268.6(a) for the determination of compliance with RCRA.	The information provided to the PART was not sufficient for the PART to draw a conclusion.
PC1.003(a)	The PA modeling addresses releases from all pathways, including groundwater, surface water, soil, and air, at the boundary of the control area of the repository.	Within the scope of the PART review, documented evidence was not found as to why some scenarios were not considered and why others were not further investigated. If some scenarios were reviewed and later dismissed, these activities were not substantiated in the documentation reviewed by the PART.
PC1.003(b)	The boundary of the control area of the repository is equivalent to the lateral extent of the unit boundary established for RCRA.	Currently, the Unit Boundary defined in the WIPP No-Migration Determination for the Test Phase is defined differently than the controlled area. DOE and the Environmental Protection Agency are discussing the possibility of re-defining the unit boundary for the disposal, closure and post-closure phases.
PC1.004	The quantitative computational model and the qualitative analysis for disposal system performance are supported by laboratory and field studies, as well as expert judgements.	Yes, conceptual models and qualitative analysis are supported by some amount of laboratory and field studies and expert judgement, but in many cases the studies are still incomplete.
PC1.005	The SNL PA and the WID compliance staffs are documenting the basis for demonstrating that the geologic disposal system complies with 191.13, 264.601, and 268.6.	Yes, but the documentation needs to be improved, especially the history of scenario development.
PC1.006	The records include the quantitative and qualitative evidence that was used to develop the performance assessment models as well as supplementary information (e.g., natural analogues, evidence that supports the process models, parameter ranges, geometric conceptual model(s), hypotheses, and simplifying assumptions used).	Yes, but this documentation needs to be improved.
PC1.007	The SNL PA and WID compliance staffs are incorporating new information relevant to the performance of the disposal system in the compliance analysis.	Yes.

Table A-1

1.0 GENERAL COMPLIANCE CRITERIA

Criterion Number	PART Criterion	Comment
PC1.008(a)	Performance of the disposal system is being evaluated based on the projected contributions of both natural and engineered barriers.	None of the conceptual models describing shaft and drift seal behavior have been incorporated into the performance assessment analyses for preliminary comparison with 40 CFR 191 or 40 CFR 268.6. The existing models used for performance assessment analyses do not include a representation of the shaft, borehole or drift seals. The importance of engineered barriers is recognized by the scientific and management staff supporting WIPP and these features will reportedly be incorporated in subsequent (FY 94) performance assessment analyses.
PC1.008(b)	It is being demonstrated that the barrier system controls, minimizes, or eliminates releases.	Similar to the response for criterion PC1.008(a), it is not possible to demonstrate the contribution of the barrier system at this time because the system model does not include all of the engineered barrier and natural system components.
PC1.009(a)	All components of the geologic disposal system, including the characteristics and radionuclide content of the emplaced waste, are considered when predicting the system performance.	No. Some components of the repository system have not been included in PA analysis to date.
PC1.009(b)	Components which make a negligible contribution to the overall system performance are not considered.	Not enough information was available to the PART to draw a conclusion.
PC1.011	The pathways evaluated by SNL for the analysis to the containment requirements of 191.13 and the individual protection requirements of 191.15 are consistent with the pathways evaluated by WID for demonstrating compliance with the environmental performance standard of 264.601 and the no-migration standard of 268.6.	Not enough information was available from WID to draw a conclusion.
PC1.012	The compliance analyses consider the likelihood and consequences of events and processes that may disturb the disposal system, including earthquakes, floods, severe storm events, droughts, and other natural phenomena.	The analysis may have considered these events, but they were not substantiated in the documentation reviewed by the PART.
PC1.013(a)	The PA staff developed a process to consider many potential processes and events.	Yes.
PC1.013(b)	A process assigns a probability to each process or event.	Yes, but the scenarios used for construction of the CCDFs are defined differently than the scenarios in the scenario selection process. SNL uses a mathematical construction through sampling to define scenarios, which, in some scenarios, leads to a probability equal to the reciprocal of the number of cases.
PC1.013(c)	Processes or events with likelihood of less than 1 chance in 10,000 over 10,000 years are removed from further consideration.	Documentation was not adequate to draw a conclusion.

Table A-1

1.0 GENERAL COMPLIANCE CRITERIA

Criterion Number	PART Criterion	Comment
PC1.013(d)	For remaining processes or events, an evaluation of the ability of the disposal system to isolated wastes if the event or process occurs is being conducted.	Documentation was not adequate to draw a conclusion.
PC1.013(e)	The consequences of the occurrence of the process or event are evaluated.	Yes.
PC1.014(a)	Natural processes and events are being analyzed as part of the performance assessment.	Yes.
PC1.014(b)	It is being demonstrated with reasonable expectation that natural processes and events do not result in a release of radionuclides or hazardous constituents in excess of applicable standards.	This determination of "reasonable expectation" of compliance is outside the scope of the PART.
PC1.015(a)	Consideration is given to controls that will be imposed to make human intrusion unlikely.	Yes.
PC1.015(b)	An evaluation of the effectiveness of permanent markers is being conducted.	Yes.
PC1.015(c)	The judgement of the likelihood of human intrusion is based primarily on the evaluation stated in PC1-015(b).	Yes.
PC1.015(d)	The likelihood of human intrusion is being evaluated.	Yes.
PC1.016(a)	Human intrusion events are considered to be no more severe than inadvertent and intermittent intrusion by exploratory drilling for resources (other than any resources provided by the disposal system itself).	Yes.
PC1.016(b)	Each intrusion is assumed to be an isolated occurrence, such that a particular intruder intrudes only once.	Yes.
PC1.017(c)	The assessments assumed that systematic or persistent exploitation within the controlled area do not occur.	Yes.
PC1.016(d)	The consequences of human intrusion events are evaluated and included in the record.	Yes.
PC1.017	Human intrusion events are not included in the quantitative modeling of total system performance of the repository.	This criterion has been eliminated from the RCD.

Table A-1

1.0 GENERAL COMPLIANCE CRITERIA

Criterion Number	PART Criterion	Comment
PC1.018	The compliance models for 191 and 268 simulate the expected behavior (processes and events) of the repository, including the potential for migration of radionuclides and hazardous constituents from the time of emplacement to 10,000 years after closure.	No. The expected behavior of the repository was not simulated due to inadequate information on shaft and panel seals, unknown gas generation potential and rate, incomplete retardation experiments, lack of verification of Culebra modeling, incomplete information on coupled response and on time dependent behavior of the DRZ and engineered barriers. No information was available on compliance models for 40 CFR 268.
PC1.019	The physical descriptions of the system for all models for both 40 CFR 191 and RCRA are identical.	Insufficient information on 40 CFR 268 activities to draw a conclusion.
PC1.020	The conceptual models for the repository system, on which the mathematical and computational models are based, are comparable for all compliance analyses.	Insufficient information on 40 CFR 268 activities to draw a conclusion.
PC1.021(a)	The quantitative compliance models predict expected releases from the repository.	See PC1.008
PC1.021(b)	The quantitative compliance models demonstrate that the expected cumulative releases of radionuclides does not exceed applicable standards.	The intent of the PA effort is to lead to this conclusion. Insufficient evidence is available at this time to make this determination.
PC1.021(c)	The quantitative compliance models demonstrate that the expected concentrations of hazardous constituents do not exceed applicable standards.	The intent of the PA effort is to lead to this conclusion. Insufficient evidence is available at this time to make this determination.
PC1.022(a)	For 40 CFR 191 compliance, the results of performance assessments are presented in a single CCDF.	Yes.
PC1.022(b)	The CCDF in PC1.022(a) indicates the probability of exceeding various levels of cumulative release.	Yes.
PC1.023	Justification for the selection or generation of the single CCDF are documented.	Yes.
PC1.024(a)	The performance assessment model(s) for 191.15 are used to estimate the annual dose equivalent from the disposal system to any member of the public in the accessible environment for the first 1,000 years after disposal.	Current SNL analysis predicted no releases from the undisturbed repository. However, no documentation was provided to the PART.
PC1.024(b)	The assessments in PC1.024(a) consider only undisturbed performance.	Insufficient information was available to draw a conclusion.

Table A-1

1.0 GENERAL COMPLIANCE CRITERIA

Criterion Number	PART Criterion	Comment
PC1.024(c)	The assessment in PC1.024(a) does not consider water wells within the boundary of the controlled area.	Insufficient information was available to draw a conclusion.
PC1.025	Compliance models for the 191 performance assessment and the 264 and 268 environmental performance standards are documented.	No. Few if any of the compliance models have been documented at the "Class A" level. Since most, if not all, of the SNL models have been developed in-house, these models must be subjected to a rigorous review process to be classified as "Class A".
PC1.026	The evaluation and documentation of the model results include: (a) the simplifying assumptions in the conceptual, mathematical, and computational models; (b) the rationale for the selection of the hazardous constituents and radionuclides included in the model; (c) information demonstrating that the predictions of waste migration were calibrated for the specific site conditions, physical features, and waste emplaced at the repository; (d) a demonstration that the modeling results are consistent with actual field measurements and that the modeling results are representative of the actual physical system; and (e) a comparison of the model results and an explanation of any differences.	This aspect of the program is still being developed. Although there is evidence that this criterion will eventually be satisfied, these activities currently are not well documented.
PC1.027	Sensitivity and uncertainty analyses of the compliance modeling are being conducted. The evaluation include (a) the uncertainty in events and processes; (b) the likelihood and consequences of alternative conceptual models; (c) the representation of model parameters; (d) sensitivity studies of the models; and (e) an assessment of the accuracy of the model, including model verification results.	The sensitivity analysis conducted to date have been utilized to investigate parameter uncertainties, not conceptual model uncertainties. The use of sensitivity studies for the conceptual models would lead to increased confidence in the models. One area in particular where additional sensitivity analyses would be useful is in connecting the detailed deterministic models developed by the principal investigators to the simplified probabilistic models used by performance assessment. The sensitivity and uncertainty analysis would be very useful is specify the limited range in which the simplified models are valid.

Table A-2

2.0 REPOSITORY SITE CRITERIA

Criterion Number	PART Criterion	Comment
PC2.001(a)	The boundaries of the controlled area, defined for 191, and the unit boundary, defined for 264, Subpart X, are coincident.	See comments on PC1.003(b)
PC2.001(b)	The boundaries are described in the documentation accompanying the compliance analyses.	Yes
PC2.002(a)	The controlled area and the unit boundary are defined.	The controlled area for 40 CFR 191 is defined by the WIPP boundary in the WIPP Land Withdrawal Act (P.L. 102-579). The RCRA unit boundary has been defined for the WIPP Test Phase in the No-Migration Determination.
PC2.002(b)	The controlled area and unit boundary are utilized as the point of compliance for 40 CFR 191 and RCRA.	Yes
PC2.002(c)	The controlled area and unit boundary do not extend more than 5 kilometers from the outermost extent of the emplaced waste.	Yes
PC2.002(d)	The controlled area and the unit boundary do not exceed a total area on the surface of 100 square kilometers.	Yes
PC2.002(e)	The controlled area and unit boundary extend downward from the surface to a depth and configuration that is appropriate at the repository site.	No, currently the unit boundary defined by the WIPP No-Migration Determination

Table A-3

NATURAL SYSTEM CRITERIA

Criterion Number	PART Criterion	Comment
PC4.001(a)	An analysis of the geochemistry of the system relevant to radionuclide or contaminant migration, including a characterization of rock, soil, air and water chemistry are being conducted.	An analysis is being done, but the current modeling does not permit SNL to address chemistry. This aspect of the analysis is just commencing.
PC4.001(b)	A comprehensive, detailed description of the geology and surface and groundwater hydrology of the repository site and setting is provided.	SNL has developed a detailed description of the local geology and hydrology for the large scale. On a small scale, this work is very difficult. The groundwater hydrology has the least detailed description.
PC4.002(a)	An evaluation has been completed, has started, or is being planned to determine whether special sources of groundwater exist within the controlled area or less than five kilometers beyond the controlled area.	[THIS CRITERION WAS NOT EVALUATED]
PC4.002(b)	If the evaluation has been completed, special sources of groundwater have not been found to exist within the controlled area or less than five kilometers beyond the controlled area.	This evaluation has not been completed.

Table A-4

ENGINEERED BARRIER SYSTEM CRITERIA

Criterion Number	PART Criterion	Comment
PC6.001(a)	Proposed engineered barrier systems are designed to be physically compatible with the natural barrier system.	An analysis by Arguello indicates that the stresses in the unreinforced concrete bulkheads in the panel and lower shaft seals may exceed the strength of the concrete. The maximum stresses occur within the first 5 years after installation of the seal. Based on these results, it appears the bulkheads will require some type of reinforcement to accommodate the tensile and compressive stresses generated during the compaction period.
PC6.001(b)	Proposed engineered barrier systems are designed to be geochemically compatible with the natural barrier system.	The only long-term component in the panel and shaft seals is crushed salt which is chemically compatible (stable) in the Salado Formation. The other components of the seals (bentonite and concrete) are unlikely to be significantly affected by the chemical conditions present over the time period they must function (hundreds of years). A salt water based concrete has been developed by SNL to minimize the chemical disequilibrium present. Cementitious grout is being considered as a sealant for MB 139 below the panel seal areas to reduce the likelihood that the interbed will serve as a bypass around the seals. The performance requirements associated with the material would presumably be relevant for long time periods and the issue of longevity and chemical compatibility becomes important. This issue has not been resolved.
PC6.002(a)	Analytical data are being collected to evaluated the engineered barriers.	SNL has performed a series of analyses to investigate the significance and relationship between the processes and events that are likely to be present in the WIPP repository system and the engineered barrier system. The analyses have focused on the expected creep closure of the underground openings, consolidation of the crushed salt seal components, stresses in the concrete bulkheads, the influence brine inflow may have on consolidation, and the potential for gas and brine migration through the DRZ and anhydrite interbeds. Additional analyses are underway to address some of these issues in greater detail and incorporate the most important ones in the performance assessment models.
PC6.002(b)	Criteria are established to determine the requirements of the barrier system.	The required performance of the engineered barrier system and its components can only be developed after they have been incorporated in the performance assessment system model. Because the seals have not been incorporated in existing performance assessment analyses, quantitative performance criteria cannot be assigned.
PC6.002(c)	Requirements are established to assure that the engineered system will be adequate to allow the repository to meet the release limits.	See PC1.008(a) and (b)

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

BSEP	Brine Sampling and Evaluation Program
CCDF	Complementary cumulative distribution function
CDF	Cumulative distribution function
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CH	Contact-handled
DAM	Design Analysis Model
DNFSB	Defense Nuclear Facility Safety Board
DOE	Department of Energy
DRZ	Disturbed rock zone
EEG	New Mexico's Environmental Evaluation Group
EM-342	The Environmental Restoration and Waste Management WIPP Project Management Division (of DOE)
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
FEIS	Final Environmental Impact Statement
FSAR	Final Safety Analysis Report
FSEIS	Final Supplemental Environmental Impact Statement
HSWA	Hazardous and Solid Waste Amendments
LWA	Land Withdrawal Act
MB	Marker Bed
NAS	National Academy of Science
NEPA	National Environmental Policy Act
NIOSH	National Institute of Occupational Safety and Health
NMD	No-migration determination
NMED	New Mexico Environmental Department
NMVP	No-migration variance petition
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
PA	Performance Assessment
PANRG	Performance Assessment National Review Group
PART	Performance Assessment Review Team
PDF	Probability density function
PI	Principal Investigator
POR	Probability of Release
QA	Quality Assurance
RCD	Regulatory Criteria Document
RCRA	Resource Conservation and Recovery Act
RH	Remote-handled
RIP	Repository Integration Program
SAR	Safety Analysis Report
SNL	Sandia National Laboratories
SNR	Summed Normalized Releases
SPDV	Site and Preliminary Design Validation
SWB	Standard waste box
SWDA	Solid Waste Disposal Act
TDEM	Time domain electromagnetic methods
TDS	Total dissolved solid
TPPW	Test Phase Plan for WIPP
TRU	Transuranic
TSG	Technical Support Group
TSI	Thermal/structural interactions
USGS	United States Geological Survey
VOC	Volatile organic carbons
WID	Westinghouse Waste Isolation Division
WIPP	Waste Isolation Pilot Plant
WPIO	WIPP Project Integration Office
WPSO	WIPP Project Site Office

Reference List

Anderson, R.Y. 1978. "Deep Dissolution of Salt, Northern Delaware Basin, New Mexico." University of New Mexico, prepared for Sansia National Laboratories, Albuquerque, NM

Anderson, R.Y. 1981. "Deep-Seated Dissolution in the Delaware Basin, Texas and New Mexico." *Environmental Geology and Hydrology in New Mexico*. Eds. S.G. Wells, and W. Lambert, New Mexico Geological Society. Special Publication No. 10

Anderson, D.R. 1993. Personal Communication. May 27, 1993. Albuquerque, NM.

Arguello, J.G. 1988. "WIPP Panel Seal - Numerical Simulation of Seal Composite Interaction for Preliminary Design Evaluation." SAND87-2804. Albuquerque, NM: Sandia National Laboratories

Arguello, J.G., and T.M. Torres. 1987. "WIPP Panel Entryway Seal - Numerical Simulation of Seal Component/Formation Interaction for Preliminary Design Evaluation." SAND87-2591. Albuquerque, NM: Sandia National Laboratories

Bachman, G.O. 1973. "Surficial Features and Late Cenozoic History in Southeastern New Mexico." USGS-4339-8. Denver, CO: U.S. Geologic Survey

Bachman, G.O. 1976. "Cenozoic Deposits of Southeastern New Mexico and an OUtline of the History of Evaporite Dissolution." *Journal of Research, U.S. Geological Survey*. Vol. 4, no. 2, 135-149

Bachman, G.O. 1980. "Regional Geology and Cenozoic History of the Pecos Region, South-Eastern New Mexico." Open-File Report 80-1099. Denver, CO: U.S. Geologic Survey

Bachman, G.O. 1985. "Assessment of Near-Surface Dissolution At and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico." SAND84-7178. Albuquerque, NM: Sandia National Laboratories

Baumgardner, R. W., Jr., Hoadley, A. D., and Goldstein, A. G., 1982, "Formation of the Wink Sink, a Salt Dissolution and Collapse Feature, Winkler County, Texas," R.I. No. 114, Bureau of Economic Geology, The University of Texas at Austin, 38 pp.

Beauheim, R.L. 1987. "Interpretation of the Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987." SAND87-0039. Albuquerque, NM: Sandia National Laboratories

Beauheim, R.L., T.F. Corbet, P.D. Davies, and J.F. Pickens. 1991. Appendix A: "Recommendations for the 1991 Performance Assessment Calculations on Parameter Uncertainty and Model Implementation for Culebra transport Under Undesturbed and Brine-Reservoir-Breach Conditions," *Preliminary Comparison with 40 CFR Part 191, Subpart B fot the WAste Isolation Pilot Plant, December 1991, Volume 3: Reference Data*. WIPP Performace Assessment Division. Eds. R.P. Rechard, A.C. Peterson, J.D. Schreiber, H.J. Iuzzolino, M.S. Tierney, and J.S. Sandha. SAND91-0893/3. Albuquerque, NM: Sandia National Laboratories. A-7 through A-18

Beauheim, R.L., and R.M. Holt. 1990. "Hydrogeology of the WIPP Site," *Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico*. SAND90-2035J. Dallas, TX: Geologic Society of America

Beraun, R., and P.B. Davies. 1991. "Baseline Design Input Data to be Used in Determining the Mechanical Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt." SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories. A-7 to A-13

Bertram-Howery, S.G., M.G. Marietta, D.R. Anderson, K.F. Brinster, L.S. Gomez, R.V. Guzowski, and R.P. Rechard. 1989. "Draft Forecast of the Final Report for the Comparison to 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant." SAND88-1452. Albuquerque, NM: Sandia National Laboratories.

Bertram-Howery, S.G., M.G. Marietta, R.P. Rechard, P.N. Swift, D.R. Anderson, B.L. Baker, J.E.Bean, Jr., W. Beyeler, K.F. Brinster, R.V. Guzowski, J.C. Helton, R.D. McCurley, D.K. Rudeen, J.D. Schreiber, and P. Vaughn. 1990. "Preliminary Comparison with 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant, December 1990." SAND90-2347. Albuquerque, NM: Sandia National Laboratories.

Borns, D.J. 1985. "Marker Bed 139: A Study of Drillcore from a Systematic Array." SAND85-0023. Albuquerque, NM: Sandia National Laboratories

Borns, D.J. 1987. "Rates of Evaporite Deformation: The Role of Pressure Solution." SAND85-1599. Albuquerque, NM: Sandia National Laboratories

Borns, D.J., and J.C. Stormont. 1988. "Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone." SAND87-1375. Albuquerque, NM: Sandia National Laboratories

Bredehoeft, J.D. 1988. "Will Salt Repositories be Dry?" EOS 69, 121-125

Brinster, K.F. 1991. "Preliminary Geohydrolic Conceptual Model of the Los Mendanos Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment." SAND89-7147. Albuquerque, NM: Sandia National Laboratories

Brodsky, N.S. 1990. "Crack Closure and Healing Studies in WIPP Salt Using Compressional Wave Velocity and Attenuation Measurements: Test Methods and Results." Sand90-7076. Albuquerque, NM: Sandia National Laboratories

Brodsky, N.S., and D.E. Munson. 1991. "Effect of Brine on the Creep of WIPP Salt in Laboratory Tests." SAND90-7076. Albuquerque, NM: Sandia National Laboratories

Brokaw, A.L., C.L. Jones, M.E. Colley, and W.H. Hays. 1972. "Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico." USGS-4339-1. Denver, CO: U.S. Geologic Survey

Brush, H.R. 1991. "Current Estimates of Gas Production Rates and Potentials Relevant to Radionuclide Chemistry for the Long-Term WIPP Performance Assessment." SAND91-0893/3. Albuquerque, NM: Sandia National Laboratories. A-27 to A-36

Brush, L.H. 1992. "Laboratory Studies of Gas Generation for the Waste Isloation Pilot Plant." SAND92-2160C. Albuquerque, NM: Sandia National Laboratories

Butcher, B.M. 1990. "Preliminary Evaluation of Potential Engineered Modifications for the Waste Isolation Pilot Plant (WIPP)." SAND89-3095. Albuquerque, NM: Sandia National Laboratories

Butcher, B.M. 1992. "Waste Compaction Properties for the Baseline Closure Surface." SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories. A-17 to A-19

Carter, N.L., S.T. Horseman, J.E. Russell, and J. Handin. 1993. "Rheology of Rocksalt." *Journal of Structural Geology*. Vol. 15, no. 9/10, 1257-1271

Case, J.B., P.C. Kelsall, and J.L. Withiam. 1987. "Laboratory Investigation of Crushed Salt Consolidation," *Rock Mechanics: Proceedings of the 28th US Symposium, University of Arizona, Tucson, AZ, June 29-July 1, 1987*. Eds I.W. Farmer, J.J.K. Daemen, C.S. Desai, C.E. Glass, and S.P. Neuman. Boston, MA: A.A. Balkema. 189-196

Cauffman, T.L., A.M. LaVenue, and J.P. McCord. 1990. "Ground-Water Flow Modeling of the Culebra Dolomite. Volume II: Data Base." SAND89-7068/2. Albuquerque, NM: Sandia National Laboratories

Chan, K.S., S.R. Budner, A.F. Fossum, and D.E. Munson. 1992. "A Constitutive Model for Inelastic Flow and Damage Evolution in Solids Under Triaxial Compression." Mechanics of Material, Vol. 14. 1-14

Chaturvedi, L. and J.K. Channell. 1985. "The Rustler Formation as a Transport Medium for Contaminated Groundwater." EEG-32. Santa Fe, NM: Environmental Evaluation Group

Conover, W.J. 1980. "Practical Nonparametric Statistics," 2nd Edition. John Wiley and Sons, New York

Costin, L.S., and W.R. Wawersik, 1980. "Creep Healing of Fractures in Rock Salt." SAND80-0392. Albuquerque, NM: Sandia National Laboratories

Cranwell, R.M., R.V. Guzowski, and J.E. Campbell. 1982, reissued 1990. "Risk Methodology for Geologic Disposal Of Radioactive Waste: Scenario Selection Procedure." SAND80-1429. Albuquerque, NM: Sandia National Laboratories

Davies, P.B., L.H. Brush, and F.T. Mendenhall. 1991. "Assessing the Impact of Waste Generated Gas from the Degradation of Transuranic Waste at the Waste Isolation Pilot Plant: An Overview of Strongly Coupled Chemical, Hydrological, and Structural Process," *Waste-Generated Gas at the Waste Isolation Pilot Plant. Paper presented at the Nuclear Energy Agency Workshop on Gas Generation and Release from Radioactive Waste Repositories, Aix-en-Provence, France, September 23-26, 1991*. Eds. P.B. Davies, L.H. Brush, M.A. Molecke, F.T. Mendenhall, and S.W. Webb. SAND91-2378. Albuquerque, NM: Sandia National Laboratories. 1-1 through 1-24

Davies, P.B. 1989. "Variable-Density Ground-Water Flow and Paleohydrology in the Waste Isolation Pilot Plant (WIPP) Region, Southeastern New Mexico." Open-File Report 88-490. Albuquerque, NM: U.S. Geological Survey

Davies, P.B. 1991. "Evaluation of the Role of Threshold Pressure in Controlling Flow of Waste-Generated Gases into Bedded Salt at the Waste Isolation Pilot Plant." SAND90-3246. Albuquerque, NM: Sandia National Laboratories

Davies, P.B., M.A. Molecke, F.T. Mendenall, and S.W. Webb, Eds. 1992. "Waste-Generated Gas at the Waste Isolation Pilot Plant": *Paper presented at the Nuclear Energy Agency WOrkshop of Gas Generation and Releases from Radioactive Waste Repositories*. SAND91-2378. Albuquerque, NM: Sandia National Laboratories

Deal, D.E., and J.B. Case. 1987. "Brine Sampling and Evaluation Program Phase I Report." DOE-WIPP 87-008. Carlsbad, NM: Westinghouse Electric Corporation

Deal, D.E., R.J. Abitz, D.S. Belski. 1989. "Brine Sampling and Evaluation Program; 1988 Report." DEO/WIPP 89-015. Carlsbad, NM: U.S. Department of Energy

Deal, D.E., and W.M. Roggenthen. 1991. "Evolution of Hydrologic System and Brine Chemistry in a Deforming Salt Medium": *Data from WIPP Brine Seeps*. Process Waste Management,. Tucson, AZ

Denkhaus, H. G., 1964, "Critical Review of Strata Movement Theories and Their Application to Practical Mining Problems," J. So. Africa Min. and Metallurgy,vol. 64.

Earth Technology Corporation. 1988. "Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site." SAND87-7144. Albuquerque, NM: Sandia National Laboratories

Finley, S.J., and D.F. McTigue. 1991. "ParameteEstimates from the Small-Scale Brine Inflow Experiments." SAND91-0893/3. Albuquerque, NM: Sandia National Laboratories. A-55 to A-58

Finley, S.J., D.J. Hanson, and R. Parsons. 1992. "Small-Scale Brine Inflow to a Borehole in a Disturbed Rock Zone." SAND91-1303. Albuquerque, NM: Sandia National Laboratories

Franke, C. 1987. "Excavation Effects and Fracture Mapping, Input to 1987 GFDAR." Memorandum to R. Mckinney. August 18, 1987. IT Corporation, WIPP Site, Carlsbad, NM [pg 6-14]

Gorham, E., R. Beauheim, P. Davies, S. Howarth, and S. Webb. 1992. "Recommendations to P.A. on Salado FOrmation Intrinsic Permeability and Pore Pressure for $) CFR 191 Subpart B Calculations." SAND-0700/3. Albuquerque, NM: Sandia National Laboratories. A-49 to A-65

Gulick, C.W., and L.D. Wakely. 1987. "Reference Properties of Cement-Based Plugging and Sealing Materials for the Waste Isolation Pilot Plant (WIPP)." Technical Report SL-89-17:SAND87-2817. Vicksburg, MS: Department of the Army, Waterways Experiment Station, Corps of Engineers

Guzowski, R.V. 1990. "Preliminary Identification of Scenarios That May Affect the Escape and Transport of Radionuclides from the Waste Isolation Pilot Plant, Southeastern New Mexico," SAND89-7149. Albuquerque, NM: Sandia National Laboratories

Guzowski, R.V., and J.C. Helton. 1991. "Scenarios for Compliance Assessment," in WIPP PA (Performance Assessment) Division, 1991, *Preliminary Comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant, December 1991*, Volume 1: Methodology and Results. SAND91-0893/1. Albuquerque, NM: Sandia National Laboratories. p. 4-61

Haug. A., V.A. Kelley, A.M. LaVenue, and J.F. Pickens. 1987. "Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report." SAND86-7167. Albuquerque, NM: Sandia National Laboratories

Helton, J.C., J.W. Garner, R.D. McCurley, and D.K. Rudeen. 1991. "Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste isolation Pilot plant." Contractor Report SAND90-7103. Albuquerque, NM: Sandia National Laboratories

Hickman, S.H., and B. Evans. 1991. "Experimental Pressure Solution in Halite: The Effect of Grain/Interphase Structure." *Journal of Geol. Soc. London*. Vol. 148, 549-560

Hiss, W.L. 1975. "Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer, Southeastern New Mexico and West Texas." Ph.D. dissertation. Boulder, CO: University of Colorado, Hydrology Department

Holcomb, D.J., and D.W. Hannum. 1982. "Consolidation of Crushed Salt Backfill Under Conditions Appropriate to the WIPP Facility." SAND82-0630. Albuquerque, NM: Sandia National Laboratories

Holcomb D.J., And M. Shields. 1987. "Hydrostatic Creep Consolidation of Crushed Salt With Added Water." SAND87-1990. Albuquerque, NM: Sandia National Laboratories

Holcomb, D.J., and D.H. Zeuch. 1990. "Modeling the Consolidation of Porous Aggregate of Dry Salt as Isostatic Hot Pressing." *Journal of Geophysical Research*. Vol. 15, 611-615, 622

Holt, R.M. and D.W. Powers. 1988. "Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico." DOE/WIPP 88-004. Carlsbad, NM: U.S. Department of Energy

Holt, R.M, D.W. Powers, R.L. Beauheim, and M.E. Crawley. 1989. "Conceptual Hydrogeological Model of the Rustler Formationin the Vicinity of the Waste Isolation Pilot Plant Site, Southeastern New Mexico." SAND89-0862. Albuquerque, NM: Sandia National Laboratories

Hora, S.C. 1992. "Probalilities of Human Intrusion into the WIPP Methodology for the 1992 Preliminary Comparison." SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories. A-71 to A-99

Howarth , S.M., E.W. Peterson, P.L. Lagus, K. Lie, S.J. FInley, and E.J. Nowak. 1991. "Interpretation if In-Situ Pressure and Flow Measurements of the Solado Formation at the Waste Isolation Pilot Plant," *Society of Petroleum Engineers Rocky Mountain Regional Meeting and Low-Permeability Reservoir Symposium, Denver, CO, April 15-17, 1991*. SPE-21840. Richardson, TX: Society of Petroleum Engineers

Hydro Geo Chem, Inc. 1986. "Two-Well Recirculation Tracer Tests at the H-2 Hydropad, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico." SAND86-7092, Albuquerque, NM: Sandia National Laboratories

Iman, R.L., and W.J. Conover. 1982. "A Distribution-Free Approach to Reducing Rank Correlation Among Input Variables." *Communication in Statistics*. B11(3):311-334

IT Corporation. 1984. "Assessment of Crushed Salt Consolidation and Fracture Healing Processes in a Nuclear Waste Repository in Salt." BMI/ONWI-546, prepared for the Office of Nuclear Waste Isolation, Columbus, OH.

IT Corporation. 1987. "Laboratory Investigation of Crushed Salt Consolidation and Fracture Healing." BMI/ONWI-631. Office of Nuclear Waste Isolation, Columbus, OH.[pg 6-8]

Jensen, A.L., R.L. Jones, and E.N. Lorusso. 1993. "Large-Scale Brine Inflow Data Report for Room Q Prior to November 25, 1991." SAND92-1173. Albuquerque, NM: Sandia National Laboratories

Jensen, A.L., C.L. Howard, and R.L. Jones. 1993. "Room Q Data Report: Test Borehole Data From April 1989 Through November 1991." SAND92-1172. Albuquerque, NM: Sandia National Laboratories

Jones, C.L. 1973. "Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico,with selection on Ground-water Hydrology by M.E. Cooley, and Surficial Geology by G.O. Bachman." Open-File Report 73-135. Denver, CO: U.S. Geological Survey 67

Jones, C.L. 1975. "Potash Resources in Part of Los Medanos Area of Eddy and Lea Counties, New Mexico." Open-File Report 75-407. Denver, CO: U.S. Geological Survey

Jones, C.L., M.E. Cooley, and G.O. Bachman. 1973. "Salt Deposits of Los Medanos Area, Eddy and Lea Counties, New Mexico." USGS-4339-7. Denver, CO: U.S. Geologic Survey

Jones, T.L., V.A. Kelley, and J.F. Pickens. 1992. "Integration of Interpretations Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site." SAND92-1579. Albuquerque, NM: Sandia National Laboratories

Kaplan, S., and B.J. Garrick. 1981. "On the Quantitative Definition of Risk." *Risk Analysis*. 1: 11-27

Kelly, V.A., and J.F. Pickens. 1986. "Interpretation of the Convergent-Flow Tracer Tests Conducted in the Culebra Dolomite at the H-3 and H-4 Hydropads at the Waste Isolation pilot Plant (WIPP) SIte." SAND86-7161. Albuquerque, NM: Sandia National Laboratories

Knauth, L.P., and M.A. Beeunas. 1986. "Isotope Geochemistry of Fluid Inclusions in Permian Halite with Implications for the Historyof Ocean Waster and the Origin of Saline Formation Waters." Geochim. Cosmochim. Acta, Vol. 50. 419-433

Labreche, D.A, and L.L. Van Sambeek. 1988. "Analysis of Data from Expansive Salt-Water Concrete Seals in Series B Small Seal Performance Tests. SAND87-7155. Albuquerque, NM: Sandia National Laboratories

Lambert, S.J., 1982. "Shallow_Seated Dissolution of Bedded Evaporites in the Northern Delaware Basin (Southeastern New Mexico)," *Bulletin of the American Association of Petroleum Geologist*. SAND&(-2475A. Vol. 65, no. 4, 764

Lappin, A.R. 1988. "Summary of Site-Characterization Studies Conducted from 1983 through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico." SAND88-0157. Albuquerque, NM: Sandia National Laboratories

Lappin, A.R., R.L. Hunter, D.P. Garber, and P.B. Davies , eds. 1989. "System Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant(WIPP), Southeastern New Mexico; March 1989." SAND89-0462. Albuquerque, NM: Sandia National Laboratories

Lappin, A.R., R.L. Hunter, P.B. Davies, D.J. Borns, M. Reeves, J. Pickens, and H.J. Iuzzolino. 1990. "System Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant(WIPP), Southeastern New Mexico; September 1989." SAND89-1996. Albuquerque, NM: Sandia National Laboratories

LaVenue, A.M., T.L. Cauffman and J.F. Pickens. 1990. "Ground-Water Flow Modeling of the Culebra Dolomite. Volume I: Model Calibration." SAND89-7068/1. Albuquerque, NM: Sandia National Laboratories

LaVenue, A.M., M. Reeves, and B.S. Rama Rao. 1989. "AN application of Coupled Adjoint-Sensitivity and Kriging Techniques to Calibrate a Groundwater Flow Model in the Vicinity of a Nuclear Waste Repository." 28th International Geological Congress, Abstracts, Washington, DC, July 9-19, 1989. SAND88-7150A. Vol 28, 2-250 through 2-251

LaVenue, A.M., and B.S. Rama Rao. 1992. "Modeling Approach to Address Spatial VAriability Within the Culebra Dolomite Transmissivity Field." SAND92-7306. Albuquerque, NM: Sandia National Laboratories

Lieberman, J.A., S.N. Davis, D.R.F. Harleman et al. 1985. "Performance Assessment National Review Group." pp 1-83. Weston Rep RFW-CRWM-85-01. Rockville, Maryland.

Lowenstein, T.K. 1987. "Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico: Textural, Stratigraphic and Chemical Evidence." EEG-36. Sante Fe, NM: Environmental Evaluation Group

Maley, V.C., and R.M. Huffington. 1953. "Cenozoic Fill abd Evaporite Solution in Delaware Basin, Texas and New Mexico." Geological Society of America Bulletin, v.64, no. 5, 539-546

Marietta, M.G., S.G. Betram-Howery, D.R. Anderson, K.F. Brinster, R.V. Guzowski, H. Iuzzolino, and R.P. Rechard. 1989. "Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance with 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant." SAND89-2027. Albuquerque, NM; Sandia National Laboratories

McKay, M.D., W.J. Conover, and R.J. Beckman. 1979. "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code." Technometrics 21(2):239-245

McTigue, B.F., S.J. Finley and E.J. Nowak. 1989. "Brine Transport in Polycrystalline Salt: Field Measurements and Model Considerations." EOS Transactions of AEU, 70, 1111.

Mendenhall, F.T., B. M. Butcher, and P.B. Davies. 1991. "Investigations into the Coupled Fluid Flow and Mechanical Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt," *Waste-Generated Gas at the Waste Isolation Pilot Plant. Paper presented at the Nuclear Energy Agency Workshop on Gas Generation and Release from Radioactive Waste Repositories, Aix-en-Provence, France, September 23-26, 1991*. Eds. P.B. Davies, L.H. Brush, M.A. Molecke, F.T. Mendenhall, and S.W. Webb. SAND91-2378. Albuquerque, NM: Sandia National Laboratories. Chapter 3

Mendenhall, F.T., and R.C. Lincoln. 1992. "Single Room Porosity History Baseline Waste Form and Gas Generation Rates." SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories. A-103 to A-1-5

Mercer, J.W. 1983. "Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeast New Mexico." Water Resource Investigation Report 83-4016. Albuquerque, NM: U.S. Geological Survey.

Mercer, J.W., and B.R. Orr. 1977. "Review and Analysis of Hydrogeologic Conditions Near the Site of a Potential Nuclear-Waste Repository, Eddy and Lea Counties, New Mexico." Open-File Report 77-123. Albuquerque, NM: U.S. Geologic Survey

Mercer, J.W., and B.R. Orr. 1979. "Interim Data Report on the Geohydrology of the Proposed Waste Isolation pilot Plant Site, Southeastern, New Mexico." Water-Resources Investigation 79-98. Albuquerque, NM: U.S. Geologic Survey

Mercer, J.W., and D.D. Gonzales. 1981. "Geohydrology of the Proposed Waste Isolation Pilot Plant Site in Southeastern New Mexico," *Environmental Geology and Hydrology in New Mexico.* Eds. S.G. Wells, W. Lambert, and J.F. Callender. New Mexico Geological Society Special Publication No. 10. SAND81-0197C. Roswell, NM: New Mexico Geological Society. 123-131.

Miller, E. H. and Pierson, F. L., 1958, "Underground Movement and Subsidence Over United States Potash Company Mine," Preprint No. 5819P9, Society of Mining Engineers of AIME, New York, presented at the Annual Meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, Feb. 16-20, 1958, 7 pp.

Munson, D.E., and P.R. Dawson. 1979. "Constitutive Model for the Low Temperature Creep of Salt (with Application to WIPP." SAND79-1853. Albuquerque, NM: Sandia National Laboratories

Munson, D.E., and P.R. Dawson. 1984. "Salt Constitutive Modeling Using Mechanism Maps," *The Mechanical Behavior of Salt: Proceedings of the First Conference, Pennsylvania State University, University Park, PA, November 9-11, 1981.* Eds. H.R. Hardy, Jr. and M. Langer. SAND81-2196C. Clausthal-Zellerfeld, Federal Republic of Germany: Trans Tech Publications. 717-737

Munson, D.E., A.F. Fossum, and P.E. Senseny. 1989. " Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures." SAND88-2948. Albuquerque, NM: Sandia National Laboratories

Nicholson, A., Jr., and A. Clebsch, Jr. 1961. "Geology and Ground-water Conditions in Southern Lea County, New Mexico." New Mexico Bureau of Mines and Mineral Resources Ground-water Report 6, 120 p.

Nowak, E.J. and J.C. Stormont. 1987. "Scoping Model Calculations of the Reconsolidation of Crushed Salt in WIPP Shafts." SAND87-0879. Albuquerque, NM: Sandia National Laboratories

Nowak, E.J., D.F. McTigue, and R. Beraun. 1988. "Brine Inflow to WIPP Disposal Rooms: Data, Modeling, and Assessment." SAND88-0112. Albuquerque, NM; Sandia National Laboratories

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1990. "Initial Reference Seal System Design, Waste Isolation Pilot Plant." SAND90-0355. Albuquerque, NM: Sandia National Laboratories

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1992. "Initial Reference Seal System Design, Waste Isolation Pilot Plant." SAND90-0355 UC-721. Prepared by Sandia National Laboratories, Albuquerque, NM and Livermore, CA. April 1992

Obert, L. and Duvall, W. I., 1967, "Rock Mechanics and the Design of Structures in Rock," John Wiley & Sons, Inc., New York, p. 558.

Peach, C.J. 1991. Influence of Deformation on the Fluid Transport Properties of Salt Rock." UN02365

Peterson, E.W. 1987. "Summary of N1100 Drift Tracer Gas Travel Time Tests." SSS-LR-88-9078, prepared for Sandia National laboratories, Albuquerque, NM

Peterson, E.W., P.L. Lagus, and K. Lie. 1987. "Fluid Flow Measurements of Test Series A and B for the Small Scale Seal Performance Tests." SAND87-7041. Albuquerque, NM: Sandia National Laboratories

Pfeifle, T.W., and P.E. Senseny. 1985. "Permeability and Consolidation of Crushed Salt from the WIPP Site." Topical Report RSI-0278. Rapid City, SD: RE/SPEC, Inc.

Popielak, R.S., R.L. Beauheim, S.R. Black, W.E. Coons, C.T. Ellingson, and R.L. Olsen. 1983. "Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico." WTSD-TME-3153. Albuquerque, NM: U.S. Department of Energy

Pusch, R., and L. Borgesson. 1989. "Interim Report on the Settlement Test in STRIPA." ST-171

Ratigan, J.L., and T.J. Vogt. 1993. "LPG Storage at Mont Belvieu, Texas: A CAse History." Society of Petroleum Engineers, Formation Evaluation. Society of Petroleum Engineers Avdanced Technology. Ser., 1, 304

Rechard, R.P. 1989. "Review and Discussion of Code Linkage and Data Flow in Nuclear Waste Compliance Assessments." SAND87-2833. Albuquerque, NM: Sandia National Laboratories

Rechard, R.P. ed. 1992. "User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller, Version 3.0." SAND90-1983. Albuquerque, NM: Sandia National Laboratories

Rechard, R.P., H. Iozzolino, and J.S. Sandha. 1990. "Data Used in Preliminary Performance Assessment of the Waste Isolation Pilot Plant." SAND 89-2408. Albuquerque, NM: Sandia National Laboratories

Rechard, R.P, K.M. Trauth, and R.V. Guzowski. 1992. "Quality Assurance Procedures for Parameter Selection and Use of Expert Judgement Panels Supporting Performance Assessment of the Waste Isolation Pilot Plant." SAND91-0429. Albuquerque, NM: Sandia National Laboratories

Rellensmann, O., 1957, "Rock Mechanics in Regard to Static Loading Caused by Mining Excavation," Second Sym. on Rock Mech., Quart., Colo. Sch. of Mines, vol. 52.

Richardson, G.B. 1904. "Report of a Reconnaissance in Trans-Pecos Texas, North of Texas and Pacific Railways." Texas University Mineralogical Survey Bulletin 9, and Texas University Bulletin 23

Robinson, T.W., and W.G. Lang. 1938. "Geology and Groundwater Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal. New Mexico, with Special Reference to the Salt Content of River Water." 12th and 13th Biennial Reports. New Mexico State Engineer. pp. 77-100

Ruckelshaus, W.D. 1985. "Risk, Science, and Democracy."In Issues in Science and Technology, 1(3):19-38. National Academy of Sciences, Washington, D.C.

Sandia National Laboratories. 1988. "In SItu Testing at the Waste Isolation Pilot Plant." SAND87-2382. Albuquerque, NM: Sandia National Laboratories

Sandia National Laboratories. 1991. "Preliminary Comparison with 40 CFR 191, SubpartB for the Waste Isolation Pilot Plant, December 1991," Volumes 1-5. SAND91-0893/1-5. Albuquerque, NM: Sandia National Laboratories

Sandia National Laboratoies. 1992. "Long-Term Gas and Brine Migration at the Waste Isolation Pilot Plant: Preliminary Sensitivity Analysis for Post-Closure 40 CFR 268 (RCRA)." SAND92-1933. Albuquerque, NM: Sandia National Laboratories

Sandia National Laboratories. 1993. "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992," Volumes 1-3. SAND92-0700/1-3. Albuquerque, NM: Sandia National Laboratories

Siegal. M.D., S.J. Lambert, K.L. Robinson. 1991. "Hydrogeochemical Studies of the Rustler Formation and Related Rock in the Waste Isolation Pilot Plant Area, Southeastern New Mexico. SAND88-0196. Albuquerque, NM: Sandia National Laboratories

Siegal, M.D., and S.J. Lambert. 1991. "Summary of Hydrogeochemical Constraints on Groundwater Flow and Evolution in the Rustler Formation." Chapter I in *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste IsolationPilot Plant Area, Southeastern New Mexico.* Eds. M.D. Siegel, S.J. Lambert, and K.L. Robinson. SAND88-0196. Albuquerque, NM: Sandia National Laboratories

Simmons, C.S. and C.R. Cole, 1985. "Guideline Approach." In Volume 1 of *Guidelines for Selecting Codes for Ground-Water Transport Modeling of the Low-Level Waste Burial Sites.* PNL-4980 Vol. 1, Pacific Northwest Laboratory. Richland, Washington

Sjaardema, G.D., and R.D. Kreig. 1987. A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analyses of Backfilled Shaft and Drift Configurations." SAND87-1977. Albuquerque, NM: Sandia National Laboratories

Snyder, R.P. 1985. "Dissolution of Halite and Gypsum, and Hydration of Anhydrite to Gypsum, Rustler Formation in the Vicinity of the Proposed Waste Isolation pilot Plant, South-Eastern New Mexico." Open-File Report 85-229. Denver, CO: U.S. Geological Survey

Stein, C.S. and J.L. Krumhansl. 1988. "A Model for the Evolution of Brines from the Lower Salado Formation, Southeastern New Mexico." Geochimica et Cosmochimica Acta, 52, 121-129

Stone, C.M., R.D. Krieg, and Z.E. Beisinger. 1985. "SANCHO: A Finite Element Computer Program for the Quasistatic, Large Deformation, Inelastic Response of Two-Dimensional Solids." SAND84-2618. Albuquerque, NM: Sandia National Laboratories

Stormont, J.C. 1988. "Preliminary Seal Design Evaluation for the Waste Isolation Pilot Plant." SAND87-3083. Albuquerque, NM: Sandia National Laboratories

Stormont, J.C., and J.G. Arguello. 1988. "Model Calculations of Flow Through Shaft Seals in the Rustler Formation." SAND87-2859. Albuquerque, NM: Sandia National Laboratories

Stormont, J.C., and C.L. Howard. 1987. "Development, Implementation and Early Results: Test Series C of Small Scall Seal Performance Tests." SAND87-2203. Albuquerque, NM: Sandia National Laboratories

Stormont, J.C., E.W. Peterson, and P.L. Lagus. 1987. "Summary of Observations About WIPP Facility Horizon Flow Measurements Through 1986." SAND87-0176. Albuquerque, NM: Sandia National Laboratories

Stormont, J.C., C.L. Howard, and J.J.K. Daemen. 1991. "Changes in Salt Permeability Due to Nearby Excavation." Proceedings 32nd Syposium Rock Mechanics as a Multidisciplinary Science. J.C. ROgers (ed.). Balkema, Rotterdam. 899-907

Sutherland, H.J., and S.P. Cave, 1979. "Gas Permeability of SENM Rock Salt." SAND78-2287. Albuquerque, NM: Sandia National Laboratories

Tyler, L.D., R.V. Matalucci, M.A. Molecke, D.E. Munson, E.J. Nowak, and J.C. Stormont. 1988. "Summary Report for the WIPP Technology Development Program for Isolation of Radioactive Waste." SAND88-0844. Albuquerque, NM: Sandia National Laboratories

U.S. Environmental Protection Agency. 1985. "40 CFR 191: Environmental Protections Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Waste," *Federal Register*. Vol. 50, no. 182, 38066-38089

U.S. Environmental Protection Agency. 1985. "40 CFR 268. Environmental Protections Standards," *Federal Register*. Vol. 50, no. 182, 38066-38089

U.S. Environmetal Protection Agency. 1990; Federal Register Vol 55 No. 220, 47,470-47,721

U.S. Environmetal Protection Agency, 1992;EPA 530-R-92-023

U.S. Environmental Protection Agency. 1992. " No-Migration Variances to the Hazardous Waste Land Disposal Prohibition: A Guidance Manual for Petioners." Draft July 1992, U.S. EPA, Office of Solid Waste, Washington, DC

U.S. Department of Energy. 1990a. "Final Supplemental Environmental Impact Statement, Waste Isolation Pilot Plant." DOE/EIS-0026-FS, Washington, DC: U.S. Department of Energy, Office of Environmental Restoration and Waste Management

U.S. Department of Energy. 1990b. "Final Safety Analysis Report, Waste Isolation Pilot Plant, Carlsbad, New Mexico." WP 02-9, Rev.0. Carlsbad, NM: U.S. Department of Energy

U.S. Department of Energy. 1991. "Waste Isolation Pilot Plant No-Migration Determination Annual Report for the Period November 1990 Through September 1991." DOE/WIPP 91-059. Carlsbad, NM; U.S. Department of Energy

U.S. Department of Energy. 1991. "Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force." DOE/WIPP 91-007. Carlsbad, NM: U.S. Department of Energy

U.S. Department of Energy. 1991. "Waste Characterization Program Plan for WIPP Experimental Waste." DOE/WIPP 89-025, Revision 1. Carlsbad, NM: U.S. Department of Energy

U.S. Department of Energy. 1992. "Gas-Generation and Source-Term Programs: Technical Needs Assessment for the Waste Isolation Pilot Plant Test Phase." DOE/WPIO/001-92. Albuquerque, NM: U.S.Department of Energy

U.S. Department of Energy. 1992. "Regulatory Criteria Document for the Disposal of Defense Transuranic Mixed Waste in a Geologic Repository." Draft Washington, DC: U.S. Department of Energy

U.S. Department of Energy. 1993. "Test Phase Plan for the Waste Isolation Pilot Plant." DOE/WIPP 89-011, Rev 1. Albuquerque, NM: U.S. Department of Energy

U.S. Department of Energy. Undated. "No-Migration Determination Annual Report for the Period October 1991 Through August 1992." DOE/WIPP 92-057. Carlsbad, NM: U.S. Department of Energy.

U.S. Department of Energy and State of New Mexico. 1984. U.S. Department of Energy and State of New Mexico, 1981, First Modification to the July 1, 1981 "Agreement for Consultation and Cooperation" on WIPP by the State of New Mexico and the U.S. Department of Energy, November 30, 1984

Wakeley, L.D., and D.M. Walley. 1986. "Development and Field Placement of an Expansive Salt-Saturated Concrete (ESC) for the Waste Isolation Pilot Plant (WIPP)." Technical Report SL-86-36. Vicksburg, MS: Waterways Experimental Station, Corps of Engineers

Webb, S.W. 1991. "Sensitivity Studies for Gas Release from the Waste Isolation Pilot Plant." SAND91-2378, Albuquerque, NM: Sandia National Laboratories

Weinburg, A.M. 1985. "Science and Its Limits: The Regulators Dilemma" *Issues in Science and Technology*. 2(1):59-72. Washington, DC: National Academy of Science

Westinghouse Electric Corporation. 1991. "Waste Acceptance Criteria for the Waste Isolation Pilot Plant." WIPP-DOE-069, Rev.4. Prepared for U.S. Department of Energy. Carlsbad, NM: Westinghouse Electric Corporation

Westinghouse Electric Corporation. 1990. "Waste Isolation Pilot Plant No-Migration Variance Petition." DOE/WIPP 89-003. Rev 1. Prepared for U.S. Department of Energy. Carlsbad, NM: Westinghouse Electric Corporation

PEER 17 - INTRAVAL (Progress Reports 5 - 10)

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PROGRESS REPORT

5

November 1989 – April 1990

INTRAVAL – An International Project to Study
Validation of Geosphere Transport Models

INTRAVAL Progress Report No. 5, 1990

The international INTRAVAL project started in October 1987 in Stockholm as an international effort towards validation of geosphere models for transport of radionuclides. The project was initiated by the Swedish Nuclear Inspectorate, SKI, and was prepared by an ad-hoc group with representatives from eight organisations.

Twentytwo organisations (Parties) from twelve countries participate in INTRAVAL. The project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat in which also Her Majesty's Inspectorate of Pollution HMIP/DoE, U.K. and the OECD/NEA take part. Project organisation, the objectives of the study and rules for the publication of results are defined by an Agreement between the Parties.

The INTRAVAL philosophy is to use results from laboratory and field experiments as well as from natural analogue studies in a systematic study of the model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
Progress Report No. 5

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was initiated in October 1987. A first phase of the study will be finalised in the autumn 1990. SKI has initiated discussions among the participating organisations about the possible contents of a second three year period. A decision about the continuation will be taken at the INTRAVAL Coordinating Group meeting in October 1990.

The purpose of the study is to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for the radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process.

Seventeen test cases have so far been included in the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project the Alligator Rivers Project, and the Poços de Caldas Project.

A Pilot Group has been appointed for each of the test cases. The responsibilities of the Pilot Groups are to compile data and propose formulations of the test cases in such a way that it is possible to simulate the experiments with model calculations.

A pronounced policy of the INTRAVAL study is to support interaction between modelers and experimentalists in order to gain reassurance that experimental data are properly understood and that experiences of the modelers regarding the type of data needed from the experimentalists are accounted for. In order to support this interaction and to develop of a strategy for the systematic application of the experiences and knowledge gained from the test cases, a special committee, the Validation Overview and Integration Committee (VOIC), has been set up within the study.

Since the issue of the previous Progress Report, the fourth INTRAVAL workshop and the fifth Coordinating Group meeting were held during the week February 5th to 10th, 1990 in Las Vegas, United States of America. During the workshop a number of oral presentations were given about work performed with the test cases. The final documentation of the first phase was also initialised and six working groups responsible for the technical content in technical reports foreseen to be published were appointed. The time scale for the final documentation of the first phase of INTRAVAL were agreed upon. VOIC had two meetings and some other working groups used the opportunity to arrange meetings.

The Fourth INTRAVAL Workshop and the Fifth Coordinating Group Meeting

The fourth INTRAVAL Workshop and the fifth Coordinating Group meeting were held in Las Vegas, Nevada, USA, on the 5th through 10th of February 1990 with the U.S. Department of Energy acting as host. In conjunction with the meetings an excursion to the Nevada Test Site was organised. The discussions at the workshop focussed on new modelling results achieved since the last workshop. Quite some time was also spent to organise the finalisation and documentation of the first Phase of INTRAVAL. In addition, the initialisation of a second Phase of INTRAVAL was discussed and proposed test cases for the second Phase were presented.

The Coordinating Group meeting was held on the 10th of February 1990. The Coordinating Group recommended a second Phase of INTRAVAL. The final decision on this matter will be taken at the next meeting in October 1990. The Swedish Nuclear Power Inspectorate will send out an invitation for participation in the INTRAVAL Phase 2 to the Organisations before the summer. The next INTRAVAL workshop and Coordinating Group meeting will be held in Cologne, The Federal Republic of Germany, in October 1990.

Validation Overview and Integration Committee (VOIC)

A Validation Overview and Integration Committee (VOIC) for the development of a strategy for the systematic application of experiences and knowledge gained from the various INTRAVAL test cases has been set up by the Coordinating Group.

The members of VOIC are: Thomas Nicholson, U.S. NRC (Chairman), Jesus Carrera, Universidad Politéchnica de Cataluña, Neil Chapman, British Geological Survey (now Intera-Exploration Consultants Ltd), Peter Glasbergen, National Institute of Public Health and Environmental Protection, David Hodgkinson, Intera-Exploration Consultants Ltd, Ivars Neretnieks, The Royal Institute of Technology, Shlomo Neuman, University of Arizona, and Chin-Fu Tsang, Lawrence Berkeley Laboratories.

The charter for VOIC states that the purpose of the committee is to provide a means for the INTRAVAL Project to investigate the broad issues related to demonstrating the validity of concepts, theories and models used in the performance assessment of repositories, and to provide for a continuing technical overview which will allow for adjustments and improvements to the selected test cases. The work within VOIC has been focussed on formulating how the term validation could be interpreted in the INTRAVAL context and what processes of relevance to radionuclide transport modelling in the performance assessment of radioactive waste repositories could be addressed by the different test cases. VOIC also specified the goals of INTRAVAL as 'ensuring that models are available and validated to each of the set of crucial processes that control the flow and transport in the geosphere'.

VOIC has suggested that the process of validation may be described as follows:

1. *Understanding and Research*
Without proper understanding of the processes and system structures involved, there could be no validation. On the other hand, one can say that a thorough understanding represents the major part of validation.

2. *Comparison of Theory and Modelling Calculations with Experiments*
This is to study how well we are able to predict or simulate experimental results quantitatively. Any discrepancy may be due to parameter uncertainties, statistical nature of the system or lack of understanding. The last case requires further effort in item 1. Care should be taken to avoid curve fitting without the proper understanding and confirmatory results.

3. *Peer Review and Public Scrutiny*
It is important to have our work published in the open literature, both to receive the benefits of anonymous technical review and to open it to public scrutiny. A study

whose results are in the open literature, examined by and maybe used by the general scientific community over long periods of time has a much better chance of being correct.

Almost by definition one can never validate a computer code without complementing the statement with further qualifying phrases. Thus, in VOIC's view, a certified code means that the code is properly verified and properly documented. It is then mathematically correct in its formulation and solution and properly documented with respect to function, accuracy, guidelines about the required discretisation, and ranges of applicability. A model, including the conceptualisation and the computer code, can be validated either with respect to (a) a process or (b) a site-specific system. For (a), a process is first identified (e.g. buoyancy driven flow) and the conceptualised (e.g. as temperature-dependent density and viscosity) and coding is performed on this conceptualisation. The model is then applied to an appropriate experiment and its results compared with measurements. If the calculations compare well with the experiment with due consideration given to parameter uncertainties etc., we can say that the model is validated with respect to this specific process. For (b), a site-specific system may be composed of a number of processes and structures, which form the building blocks of the system. Once the building blocks are identified, a model or group of models may be used to simulate and compare with field observations. If successful, the group of models is said to be validated with respect to this particular site, within a range of applications determined by the range of field observations studied.

Hence, there is no such thing as a validated model in the generic sense. However, we can say that 'a model is validated with respect to a given process', or that 'a model or group of models are validated with respect to a given site'. Ranges of applicability should always be included in such statements. The decision if a model is valid is not made only by those using the model. The model is valid in a given case if the user has applied it correctly and can convince another knowledgeable person or group of persons of this. In the end the scientific community will decide the validity of models and whether they are correctly used in the right context.

In the process of defining INTRAVAL Phase 2, VOIC has given assistance and advice to the INTRAVAL Secretariat and the Coordinating Group concerning the outline of the continuation. Phase 2 should be based on on-going and well documented field experiments. The study should be more directed to validation strategy and performance assessment considering the accomplishments of Phase 1. It is also suggested that various key issues, such as scale dependence, heterogeneity, and coupled processes, are highlighted.

Present Status of the Test Cases

TEST CASE 1a

Radionuclide migration through clay samples by diffusion and advection, based on laboratory experiments performed at Harwell Laboratory, U.K. (Pilot Group Leader: D. Lever, Harwell Laboratory)

Experimental Setup and Scales

Experiments to study solute (iodide, deuterium and tritium) migration through intact samples of clay, from one borehole at a depth 28–34 meters below ground level, have been performed at Harwell Laboratory in U.K. A set of transient and steady-state tracer experiments have been performed, both parallel and perpendicular to the bedding of clay samples (vertical through-diffusion, horizontal through-diffusion, in-diffusion, and dispersion experiment). The length scale, of the experiments are up to a few centimeters and their durations are up to a few months. The data available are breakthrough curves from the through-diffusion and from the hydrodynamic dispersion experiments, as well as the amount of tracer that have diffused into the samples in the in-diffusion experi-

ments. In addition, results are available from complementary experiments such as moisture content and porosity, size and distribution of the porosity, and hydraulic conductivity as a function of stress.

Analyses by the Project Teams

The Project Team from SNL has defined a validation strategy which has been tested on this case. The method could briefly be described in terms of a number of steps including choice of conceptual model, identification of validation issues and design of experiments to assess these. It also contained a proposed scheme for invalidation of the model by comparing the "best fit" model breakthrough curve. The model is not acceptable if a systematic error of correlation in the residual is observed. Two models of diffusion in clay has been tested on this test case, one two-dimensional single porosity model and one two-dimensional dual porosity model. The single porosity model was tested earlier and was found to be invalid. Probability distribution function representing the uncertainty in parameters were obtained, mainly by reviewing available literature, and a number of Monte Carlo simulations were undertaken.

The transport equation was solved with the finite difference code SWIFT-II. The model structure was then tested by comparing the 'best fit' model breakthrough curve with the experimental breakthrough curve in terms of residual in time values for different levels of concentration. The residual plot was judged to be acceptable if a semivariogram did not show a trend but nugget.

The method was applied on through-diffusion experiments with iodide on two different samples. The test showed a trend in the semivariogram for one of the samples (INT8I), implying that the model structure was invalid, whereas for the other sample (INT9I) the model was acceptable as the semivariogram showed nugget. During the discussion it was concluded that the applied test did not filter out constant errors.

The Project Team from RIVM used both an analytical model and the finite element code METROPOL to simulate the experiments. The results from the analytical model was checked against results obtained from METROPOL and gave equal results. The total porosity was evaluated analytically from equilibrium results of the in-diffusion experiments. The total porosity for deuterium varied between 0.47 and 0.48 in different samples, whereas the variation for iodide was between 0.14 and 0.24. The evaluated porosity for deuterium was in good agreement with porosity values obtained from oven-drying. The difference in porosity for iodide and deuterium could probably be explained by the existence of micropores accessible to deuterium but not to iodide. The effective diffusivity determined analytically from the steady state part of the through-diffusion breakthrough curves was found to vary between $7.2 \cdot 10^{-11}$ and $8.6 \cdot 10^{-11}$ $m^2 \cdot s^{-1}$ for deuterium in different samples. For iodide the effective diffusivity varies between $2.8 \cdot 10^{-11}$ and $3.9 \cdot 10^{-11}$ $m^2 \cdot s^{-1}$. Using these values to predict the transient part of the in-diffusion and through-diffusion experiments with METROPOL no good agreement between calculated and experimental results was obtained. In the case of through-diffusion, there is no agreement between experimental and calculated results even at extended times, i.e. at equilibrium where the porosity and diffusion coefficients were evaluated. A curve-fitting exercise evolved in such a way that different values of the porosity and diffusion coefficients had to be selected for the in-diffusion and the through-diffusion experiments. For iodide different values had to be selected for the different samples. The introduction of matrix diffusion in the conceptual model gave a better agreement between calculated and experimental results. A preliminary unique set of parameters for the two tracers was selected. The total porosity was estimated at 0.474 from oven-drying and in-diffusion experiment with deuterium, and the macro porosity was estimated at 0.14. The effective diffusivity and the matrix diffusivity were estimated at $7.7 \cdot 10^{-11}$ and $1.1 \cdot 10^{-5}$ $m^2 \cdot s^{-1}$ for deuterium and at $6.5 \cdot 10^{-11}$ and $2.0 \cdot 10^{-7}$ $m^2 \cdot s^{-1}$ for iodide from in-diffusion experiments. The through-diffusion experiments could be simulated with satisfac-

tory agreement with the experimental results if the above presented parameter values were employed. The permeation experiments has not yet been simulated but will be.

The Project Team from UPC previously presented an analysis where three different advection-dispersion models were used to simulate the experiments: a single porosity model, a double porosity model (including matrix diffusion, and a triple porosity model (including matrix diffusion and molecular diffusion in immobile water). The main conclusion from this evaluation was, however, that all data could be explained with a simple model. More complex models could be used but their parameters could not be estimated reliably. This indicates that the validity of the simple model or the need for more complex ones requires calibration under different conditions.

As an approach to designing experiments that can distinguish between different models, the following methodology was adopted: A suitable experiment is proposed. The proposed experiment is simulated with one model, then the other model is attempted to fit both the experimental data and the simulated data. If this can be done, then the proposed experiment cannot be used to distinguish between the two models, whereas if it cannot be done adequately then the proposed experiment is a candidate for differentiating between the models. This is then checked further by interchanging the roles of the models in the above analysis.

The experiment is a good discriminator between the models only if it satisfies both tests. A number of possible permeation experiments with pulse injection have been tested and found to fail to distinguish between the two models according to the above described methodology.

The parameters that have been varied in these experiments are:

- the pulse duration (10 000 and 5 000 s),
- the size of the downstream reservoir (1 cm and 10 cm, which is a reduction of 50 respectively 5 times compared to the reservoir used in the experiments),
- the water flow rate (5 and 2.5 times the flow rate used in the experiments),
- the weight of the pulse experiment,
- the retardation factor.

The conclusions drawn from these tests are that it is of no value to use dual or triple porosity models to evaluate the transport of conservative (non-sorbed) tracers. For sorbed tracers (retardation factor of 10), it was possible to reproduce model data, especially if reduced weight was given to the pulse experiment. The evaluation approach is based on the assumption that all samples can be characterised by one set of parameters, although there is significant variability between different samples.

The Project Team from PNC evaluated the in-diffusion and the through-diffusion experiments with a one-dimensional model. Both separate and joint analysis of the in-diffusion and through-diffusion experiments indicates that the experiments cannot be described with a single set of porosity and diffusion coefficient values. A statistical test (least squares method) shows that the population mean values of porosity and diffusion coefficient from the through-diffusion experiment are larger than those from the in-diffusion experiments both for iodide and deuterium, with 95% significance level. Data from joint analysis (porosity from in-diffusion experiments and diffusion coefficient from through-diffusion experiments) show that all experimental points of the in-diffusion experiments for iodide fit within the estimated interval of the population mean of porosity and diffusion coefficient values, whereas, for deuterium some points fall out of the estimated region (99% confidence interval). It was also concluded that the estimations of both the porosity and the diffusion coefficients are sensitive to the method applied to evaluate them, especially with regard to the applied boundary conditions. Preliminary results from evaluation of the permeation experiments with a one-dimensional advection-dispersion model show good agreement between calculated and measured breakthrough curves, except for one experiment. Further evaluation of the permeation experiments is needed before these results can be assessed in the conclusions of this modelling exercise.

TEST CASE 1b

Uranium migration in crystalline bore cores based on experiments performed at PSI, Switzerland. (Pilot Group Leader: J. Hadermann, PSI)

Experimental Setup and Scales

In this experiment, performed at the Paul Scherrer Institute (PSI) in Switzerland, tracer migration in crystalline bore cores were studied. Water at high pressure was forced to flow through rock cores of granite or gneiss with a diameter of 4.6 cm and a length between 0.8 cm and 5.0 cm. The high pressure was intended to simulate the rock overburden. Tracer (uranium-233) was added to the infiltration water and the tracer concentration was measured in the water sampled at the core outlet. After the experiments the samples were sliced and the surfaces of the slices were auto-radiographed to yield information of flow paths and sorption sites. Complementary results on hydraulic conductivity versus confining pressure, and dynamic porosities of the samples are also available, as well as results from uranium adsorption/desorption experiments.

Analyses by the Project Teams

The Project Team from HARWELL has analysed the breakthrough curves from four different bore cores, three granite and one gneiss core. They compared three different one-dimensional advection-dispersion transport models, one with linear equilibrium sorption only, one considering also matrix diffusion, and one with kinetic sorption. The approach adopted was to calibrate each of the models using the first few data points on the breakthrough curve for a core, and then compare the predictions of the model with the remaining data points for that core. In each case, the number of data points was chosen so that the model was calibrated to the data points giving the initial rise and falling back to approximately half the peak output concentration. The models were calibrated automatically using a non-linear least-squares method to evaluate the parameters that gave the best fit for the selected model.

The results from the evaluation showed with considerable evidence that the model incorporating matrix diffusion was the most appropriate model to describe the transport. The model with only linear sorption tended to underestimate the initial peak of the tracer concentration curve and to overestimate the concentration. The model with kinetic sorption also overestimated the concentration, although it gave a better estimate of the peak.

The results from the model with matrix-diffusion can be used to evaluate the retardation and the dispersion length. The retardation is approximately 20 for the gneiss sample and for two of the granite samples, whereas the retardation for the third granite sample is an order of magnitude higher. The higher value for the last sample is consistent with the broader peak in the output tracer concentration curve for this sample. The dispersion length evaluated for two of the cores was in the range of $3\text{-}8 \cdot 10^{-3}$ m, which seems reasonable. The dispersion length for the two other cores were $2 \cdot 10^{-4}$ and $3 \cdot 10^{-6}$ m respectively. These values appear to be small. To investigate the role of the model parameters for the model with matrix-diffusion a sensitivity study was carried out. For each experiment, each of the parameters was varied to half and to twice its best fit value while the other parameters were kept at their best fit. From this sensitivity analysis it was shown that the model was not very sensitive to changes in the parameter describing the dispersion length, for samples showing very low values of the dispersion length. The discrepancies between the measured data and the model predictions were also examined and there appears to be some structural tendency.

The study of the test case shows that the experiments provide considerable support for the concept of rock matrix diffusion. It would, however, be desirable to have supporting evidence for the model on larger spatial and time scales. It might also be preferable to perform experiments for temperature and groundwater chemistry

within ranges of direct interest for a repository.

The Project Team from ECL presented plans for complementary work on this test case to the work performed by HARWELL where non-linear sorption of uranium-233 is introduced instead of linear sorption in a one-dimensional advection-diffusion model. A number of sorption isotherms are identified in the literature, relating the density of sorbed tracer within the rock sample to the concentration of tracer dissolved in the surrounding water. Throughout this study the Project Team selected to use the Langmuir isotherm ($s = a \cdot c/(1+b \cdot c)$, where s is the density of sorbed tracer, c the concentration of tracer dissolved in groundwater, and a and b positive constants). The first aim with the study is to demonstrate that the specified equations can be solved robustly and efficiently before parameter estimations are started. The next step will be to analyse the test case.

TEST CASE 2

Radionuclide migration in single natural fissures in granite, based on laboratory experiments performed at KTH, Sweden. (Pilot Group Leader: T. Eriksen, KTH)

Experimental Setup and Scales

This test case is based on laboratory experiments, performed at the Royal Institute of Technology, Sweden, on radionuclide migration of non-sorbed, moderately sorbed, and strongly sorbed tracers in single natural fissures in granite drill cores (0.02 – 0.04 m in diameter and 0.08 – 0.3 m in length). Synthetic groundwater was fed to the fissure inlet and tracers were either added by continuous feeding or as a pulse of suitable duration. The effluent was continuously sampled and analysed with respect to the tracer concentration.

Analysis by the Project Teams

The Project Team from OWTD presented results of their analysis of the test case using FRACFLO-VAL. This is a package including non-linear least squares techniques for parameter estimation and analytical solutions for one-dimensional advection-dispersion equation with and without matrix diffusion. The models and the estimation procedure were tested against analytical solutions with known parameter values. Reasonable fits to all experimental data were obtained.

TEST CASE 3

Tracer tests in a deep basalt flow top performed at the Hanford Reservation, Washington, USA. (Pilot Group Leader: C. Cole, PNL)

Experimental Setup and Scales

This test case involves recirculating tracer tests in two boreholes about 17 m apart in a deep basalt flow top, about 1000 m below ground level. The data base available is very large and includes flow rates, breakthrough curves (iodine and potassium thiocyanate), pump test data, geometry of the site, water chemistry, core data, temperature versus depth, etc. The basalt flow top is expected to be rubbly rather than fractured. The path length in the rock is relatively short compared to the depth as well as to the dispersion length as derived from the breakthrough curves.

General Comments on Test Case 3

Test case 3 was formulated at a time when disposal in basalt was an option in the U.S. waste disposal programme. One valuable aspect of this test case then was a possibility to go back to the site and perform complementary measurements. Because of the discontinuation of the U.S. basalt programme the experimental site has subsequently been decommissioned and the possibility of complementary measurements no longer exists. Due to these reasons the interest among the INTRAVAL participants to perform further simulations of this test case is rather limited.

TEST CASE 4

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment performed within the International Stripa Project. (Pilot Group Leader: I. Neretnieks, KTH)

Experimental Setup and Scales

This test case is based on three-dimensional tracer tests performed in the Stripa mine in Sweden. The experiment forms part of the international Stripa Project.

An experimental drift was excavated in the old iron-ore mine in Stripa, Sweden. The whole ceiling and upper part of the walls have been covered with about 350 plastic sheets (2 m^2 each) with the purpose to collect water seeping in from the rock and to collect injected tracers. Three vertical boreholes for tracer injections were drilled and tracers were injected at nine locations, 10–55 m above the test site.

The data registered or obtained from the experiments are water flow rates, tracer concentrations in the water entering the drift, rock characteristics and fracture data, water chemistry, tracer injection pressure and flow rates, and hydrostatic pressure. Diffusivity and sorption data are available from complementary laboratory and field experiments.

The results of the water flow measurements demonstrated extreme spatial variability. Thus, 2/3 of the drift was dry, one sheet carried 10% of the water and twelve sheets carried 50%. The flow rate into the drift did not correlate well with the fracture density. However, there is a correlation between the flow rate and the local number of fracture intersections. The longest breakthrough time was 26 months from the farthest injection point. After completion of the experiment, it was noted that one of the tracers had moved about 150 m parallel to the drift over a three year period.

Analysis by the Project Teams

The Project Team from SKI/KTH has analysed the water flow and the tracer transport in the Stripa 3D experiment with a discrete fracture network model. The computer code, DISCFRAC, generates the fracture network and solves the equations. The fractures were modelled as planar circular discs with a radius, orientation and transmissivity randomly and independently placed. The model parameters were estimated from geometric estimate based on mapped fractures and the observed flow distribution in the ceiling of the drift. The cumulative tracer breakthrough times were calculated assuming pipe flow in single fractures using particle tracking. The breakthrough curves from the discrete model were then fitted to the advection-dispersion model by the method of least squares to determine a Peclet number and a water residence time.

By plotting the Peclet number as a function of cumulative fractions of realisations for different transport distances it was found that at zero variance of the channel transmissivity the Peclet number increased linearly with distance. This means that the dispersion coefficient is constant which implies a Fickian dispersion behavior. As the variance of the channel transmissivity was increased, the Peclet number tended to be smaller and more constant, which implies a non-Fickian dispersion behavior. The tracer breakthrough in different defined small squares (windows) gave different Peclet numbers in the different squares due to fracture passing. At this stage, the Project Team thinks that the discrete fracture network model can explain the experiment. Parameter uncertainty may scale up to orderly advection-dispersion and extreme channeling.

TEST CASE 5

Tracer experiments in a fracture zone at the Finnsjön research area, Sweden. (Pilot Group Leader: P. Andersson, Swedish Geological Co.)

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the

Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometers.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to be 10^{-4} $m^2 \cdot s^{-1}$, the middle 10^{-7}–10^{-6} $m^2 \cdot s^{-1}$ and the lower 10^{-4} $m^2 \cdot s^{-1}$. The middle layer is not continuous. A fresh water salt water interface exists in the fracture zone relatively close to the upper previous layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated at 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several core drilled (and some percussion drilled) boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated in 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed: a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting 11 different non-sorbed tracers at 9 different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analysis by the Project Teams

The Project Team from VTT presented their interpretation of the radially converging experiment. They used a channel model, characterised by the number of channels and the channel properties. Each channel had a transmissivity and a width, related to the channel dispersivity. The total transmissivity of Zone 2 was assumed to be the average of the sums of transmissivities measured in individual boreholes. In the present modelling, one single transport route between the injection borehole section and the pumping borehole was considered. This transport route represents the fastest connection between the injection and collection sites. It was assumed that the route was a flat channel having an aperture of about 1 mm or less and a width of 10 cm, and that the velocity in the channel varies over the width from zero to a maximum velocity over 5 cm. The analysis was performed assuming constant groundwater flow but time dependent tracer injection rates. It can be concluded that the applied simple model seems to predict the majority of the breakthrough curves rather well and also to reproduce dispersion effects over a wide range of transport routes and times by one value.

The Project Team from Intera-ECL has analysed the radially convergent tracer tests. They utilised two-dimensional flow models considering advection-dispersion. Data were available from nine continuous injection tests and three pulse injection tests. The evaluation concentrated on the pulse injection tests as they were likely to be more sensitive to the assumed fracture geometry, since both a wave-front and a wave-back had to be considered. The pulse injection tests (from borehole KFI11) showed a double pulse breakthrough which seems to be a consequence of flow path geometry. The best fit to the breakthrough curves was sought by minimising the sums of squares of the residuals over the time

frame of the experiment. The breakthrough curves received, if a single fracture plane was assumed, did not agree very well with the observed breakthrough curves. The single fracture plane was then replaced by two parallel fractures connecting the packed-off sections of the boreholes. The pressure gradient was the same in both fractures, depending only on the distance between the injection and pumping hole. The two fractures, however, had different values for the dispersivity and flow. The fitted breakthrough curves took the form of two pulses but the fitted curves gave no good agreement with the experimental breakthrough curves. These results show, however, that just one or two parallel fractures are inadequate to model radially convergent tests with pulse injection. It might be worthwhile to investigate the effect of including the following components in the model: molecular diffusion, matrix diffusion, or non-integer dimensional flow paths.

The Project Team from JAERI modelled the radially convergent tracer pulse injection experiments with a variable channel aperture model. The two-dimensional steady state channel flow in single fractures of zone 2 was evaluated and the transport of non-sorbed solutes was simulated by a particle tracking technique considering local dispersion within each channel. The probability distribution of channel aperture was assumed to be lognormal. The effects of diffusion and sorption was not considered. In the groundwater flow calculations the fracture was divided by a rectangular grid into nodes with different apertures. The model domain was a quarter part of the area. In the solute transport simulations, the fracture plane was modelled as a rectangular network system. The travel time of particles in each channel was given by one-dimensional solutions, and particles coming to an intersection of the network were distributed in the outlet branches with a probability proportional to the flow rates. A preliminary comparison between calculated and experimental breakthrough curves showed that the tailing of the calculated curves were much smaller than for the experimental curves, this could be due to diffusion into dead-ends. The effects of local dispersion was not considered in the calculations. Best fit values of the mean channel aperture and the variance of the aperture density distribution were quite different for different flow paths. From these circumstances, and from the shape of the experimental breakthrough curves, it was concluded that a macroscopic anisotropy existed for the transmissivity in the fracture zone.

The Project Team from Hazama-Gumi analysed the radially convergent tracer test. The groundwater flow in the area was modelled to pass through a fracture network. The network was generated based on observed information on orientation and fracture density from vertical drill cores as well as on fracture lengths examined at the outcrops. Zone 2 was divided into three regions; upper (12 m thick), middle (40 m thick), and lower part (33 m thick). The fracture density is higher in the upper ($0.004\ m^{-2}$) and lower ($0.002\ m^{-2}$) parts than in the middle ($0.001\ m^{-2}$) part. The fracture length was set to 50 m and the water was assumed to flow symmetrically towards the pumping borehole.

A parallel plate model was used for the water flow in each fracture element. The transport analysis was carried out using the velocity field obtained from the groundwater flow analysis. The solute transport was simulated with a particle tracking method considering advection and matrix diffusion. The residence time for each particle within the fractures was determined by a probability density function. The water flow rate at the injection boreholes was varied between $1.7 \cdot 10^{-3}$ and $2.3 \cdot 10^{-2}\ m^3 \cdot s^{-1}$ and the fracture aperture was varied between $4 \cdot 10^{-4}$ and $5 \cdot 10^{-4}$ m. When matrix diffusion was considered the matrix diffusion coefficient was assumed to be $1 \cdot 10^{-9}\ m^2 \cdot s^{-1}$ and the rock porosity ranged from 0.015 to 0.03.

The results showed that multi-peak breakthrough curves are produced if matrix diffusion was not taken into account. Some of the calculated breakthrough curves considering matrix diffusion seem to agree quantitatively with the measured ones, although the total flow rates obtained in the calculations were smaller than those observed in the field. It was concluded that

matrix diffusion seems to have significant influence on the solute transport.

TEST CASE 6

Synthetic data base, based on single fracture migration experiments in Grimsel Rock Laboratory in Switzerland. (Pilot Group Leader: R. Codell US NRC)

This test case is patterned after a tracer migration experiment in a single fracture plane at the Grimsel Rock Laboratory in Switzerland. A highly detailed two-dimensional synthetic data set of hydraulic conductivities and other properties conditioned on the actual data from the Grimsel site has been generated. In addition, results from a number of simulated hydraulic and tracer migration experiments with the synthetic model are available. Based on these data sets, the task for the Project Teams was firstly to predict the breakthrough of a non-sorbed tracer at several simulated boreholes and tunnels (Phase I of this test case), and secondly, to include also diffusion and chemical retardation in the geosphere (Phase II of the test case).

Analysis by the Project Teams

The Project Team from USNRC presented results for a simple potential flow model with uniform properties. The model was calibrated to the 'observed data' (actually obtained from very fine grid simulations of a heterogeneous medium). Comparison between predicted breakthrough curves and 'observed' breakthrough curves showed considerable differences in arrival times. A finite difference model was also applied using transmissivities inferred from 'borehole tests' from a few boreholes. A linear variogram appeared to fit these hydraulic data best. The finite-difference model gave better results than the simple potential flow model, but the conclusion was that more data in some areas are needed.

TEST CASE 7a

Redox-front and radionuclide movements in an open pit uranium mine. Natural analogue studies at Poços de Caldas, Brazil. (Pilot Group Leader: I. Neretnieks, KTH)

This test case is based on one of two subprojects in a natural analogue study performed at Poços de Caldas, Minas Gerais, Brazil. It is concerned with evaluation of the transport and speciation of natural radionuclides and rare earth elements in a fissured flow system in crystalline rock under both oxidising and reducing conditions. The deeper parts of the rock are found to be strongly reducing while the upper parts have become oxidised by oxygen carried by infiltrating rainwater. A redox front can be clearly seen because the colors of ferrous and ferric minerals are different. Secondary uranium mineralisation is found around the fractures and at the moving redox fronts.

Analysis by the Project Teams

The Project Team from SKB/KTH has studied the redox-front movements at Poços de Caldas. The redox-front movement was modelled with the coupled transport and chemical code CHEQMATE, that models the transport through a series of equilibrium boxes. The phenomena modelled were: the redox-front movement, feldspar to clay reactions, hydrolysis front movement, formation of uranium ore, and aqueous phase complex formation. The modelled water chemistry, mineral composition and front movements rate were then compared with field observations. Assumptions have been made concerning the water infiltration rate which is an important parameter for the rate of redox front movements, the chemistry of the infiltrating water, the dispersion length and the rock composition. Modelling the infiltration of rainwater through a one-meter column during 38 000 years resulted in a sharp drop in pe at 0.8 m and precipitation of uranium at this redox-front. In field observations it

can be seen that the front is not sharp but follows fractures and fracture zones, which have higher permeability than the rock matrix itself, deeper down. Oxygen from the water in the fracture diffuses into the rock and the uranium in the rock is dissolved and diffuses out to the water in the fracture, where the concentration is lower, and is swept down the fracture and precipitates at the redox-front.

TEST CASE 7b

Morro do Ferro colloid migration studies. Natural analogue studies at Poços de Caldas, Brazil. (Pilot Group leader: N. Chapman, BGS)

This test case is based on the second subproject of the natural analogue study at Poços de Caldas, Minas Gerais, Brazil. It is concerned with colloid formation and mobility in natural groundwater and the role of colloids in element transport.

The main aims are to study the content and characteristics of colloids in groundwater and to determine their role in transporting thorium, radium and rare earth elements. The Pilot Group has pointed out that the field work has given little, if any, evidence of colloid transport of the natural tracers studied. At present it is therefore deemed unlikely that the data set can be developed for a meaningful test case for INTRAVAL.

TEST CASE 8

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia. (Pilot Group leader: P. Duerden, ANSTO)

This test case deals with the natural analogue studies at the Koongarra site in the Alligator Rivers region of the Northern Territory, Australia. A comprehensive experimental and modelling programme has been set up and the main objective is to contribute to the production of reliable and realistic models of radionuclide migration within geological environments relevant to the assessment of the safety of radioactive waste repositories.

Uranium mineralisation at Koongarra occurs in two distinct but related ore bodies separated by about 100 m of barren schists. Both ore bodies strike and dip broadly parallel to the Koongarra Reverse Fault, which is the footwall to the ore zone. Primary mineralisation is largely confined to quartz-chlorite schists immediately above the fault zone. A graphitic quartz-chlorite schists forms a distinctive hanging wall unit. The more south-westerly of the two ore bodies (No. 1 ore body) has a strike length of 450 m and persists to a depth of about 100 m. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m to the east.

Analysis by the Project Teams

The Project Team from RIVM presented their proposed modelling approach for this test case. The data base will firstly be evaluated followed by three-dimensional groundwater flow modelling of No. 1 ore body and one-dimensional radionuclide migration calculations. Geochemical models is also foreseen to be used for e.g. speciation calculations.

The Project Team from ANSTO presented an approach to investigate the time signatures that might be encoded the present day shape of the secondary uranium deposit. The top 30 meters of the weathered rock, in which the major uranium mobilisation occurs, contains two distinct layers. The specific uranium distribution pattern between these layers may contain some information important for the evaluation of the time scale. The model used is a quasi-two dimensional model describing the transport in a two-dimensional vertical cross-section as transport in two one-dimensional pipes separated by an intermediate zone where no horizontal transport is considered. This zone provides transfer of material from the bottom pipe to the

upper pipe, reflecting transport due to seasonal fluctuations in water table. Two approaches were applied, one based on advection-diffusion in the pipes and a second based on open-systems model. Preliminary findings are that the distribution coefficient (K_d) is 10^4 ml/g and the time scale seems to be less than 2 million years.

TEST CASE 9

Radionuclide migration in a block of crystalline rock performed at AECL, Canada. (Pilot Group Leader: B. Gureghian, OWTD)

Experimental Setup and Scales

This test case is based on laboratory experiments on migration of tracers in a single natural fracture in a large block of granite. The size of the block is 91.5 cm × 86.5 cm × 49.0 cm (length × width × height). The block was positioned so that the fracture was approximately horizontal and an inlet reservoir was designed to produce an as uniform hydraulic gradient and inlet tracer concentration as possible across the entire fracture width. The outlet reservoir was divided into five compartments, which were sampled in sequence to give breakthrough curves for each compartment. After the experiments were performed the fracture was opened and the flow paths were investigated with alpha-autography.

Analyses by the Project Teams

The Project Team from VTT has analysed the experimental data assuming five parallel isolated channels with equal width and considering advection-dispersion, matrix diffusion and sorption (depending on tracer) both on fracture walls and in the rock matrix. The number of channels corresponds to the number of sample ports. The interpretations were made with the finite element code FTRANS. The approach was to calibrate channel specific parameters from uranine (non-sorbed tracer) breakthrough curves. Tracer specific sorption and matrix diffusion coefficients have been calibrated from caesium (sorbed tracer) breakthrough curves. The performed simulations agree reasonably well with the uranine experiments. For caesium the agreement is reasonable for all channels except one. The longitudinal dispersivity in the five channels were estimated to vary between $4.0 \cdot 10^{-3}$ and $2.2 \cdot 10^{-2}$ m and the fracture aperture was estimated to vary between $4.1 \cdot 10^{-4}$ and $6.3 \cdot 10^{-4}$ m.

TEST CASE 10

Evaluation of unsaturated flow and transport in porous media using an experiment with migration of a wetting front in a superficial desert soil, performed within a U.S. NRC trench study at Las Cruces, New Mexico. (Pilot Group Leader: T. Nicholson, U.S. NRC)

Experimental Setup and Scales

The Las Cruces Trench experiment is setup in order to study flow and transport in unsaturated soil. A trench 16.5 m long, 4.8 m wide and 6 m deep has been dug in the undisturbed soil. Two irrigated areas measuring 4 m × 9 m (first experiment) and 1 m × 12 m (second experiment) have been arranged adjacent to the trench. Water and tracers (tritium and bromide) have been applied at a rate of 1.76 $cm \cdot day^{-1}$ to the first irrigated area and at a rate of 0.5 $cm \cdot day^{-1}$ to the second irrigated area.

The movement of the wetted zone is observed on the trench walls and by neutron tubes arranged as a grid in three cross sections parallel to the trench. In addition, permeameter tests and laboratory analyses of a set of soil samples from the test area should allow for an evaluation of the statistical distribution of the saturated hydraulic conductivity as well as the characteristic curves. The solute samplers are tensiometer cups that are connected to a vacuum line (suction lysimeter).

Analyses by the Project Teams

University of Arizona presented results from an analysis of the tritium breakthrough curves. A one-dimensional advection-dispersion model assuming steady-state flow was applied. Dispersion and retardation parameters were estimated by a fitting procedure using experimental breakthrough curves from different depths.

New Mexico State University presented a comparison of observations from the second experiment and predictions of water contents, tritium and bromide concentrations using a deterministic finite-difference code. A uniform soil model was used with a dispersion coefficient, $D = 1 + 5V\ cm^{-2} \cdot day^{-1}$, and retardation $R = 1.0$, for tritium and $R = 0.84$ for bromide. The fact that retardation was smaller than 1 for bromide was explained as due to anion exclusion. The experimental data show a large scatter both in water content and tracer concentration. This scatter is due to local heterogeneities which are not encountered for in the deterministic models where smooth profiles are obtained. The calculations performed for the tracer transport give generally too high spreading of the concentration plume and also too low peak concentrations. Apparently even lower dispersion coefficients must be used in the calculations.

The Project Team from SNL set up a homogeneous deterministic model for the system in order to explore whether such a model is valid for a truly heterogeneous system. Uncertainties in data were handled using Latin-Hypercube Sampling (LHS). The performance of the model was measured by the moisture content at a depth of 1.5 m as a function of time. They found that the physical behavior at early times was outside the range of the LHS runs, whereas at later times the physical behavior was within the range. It was commented that average performance criteria should be applied rather than pointwise ones.

Hydro Geologic Inc. presented results of simulations of the second experiment using the finite element code VAM2D. Three flow scenarios and their impact on transport predictions were evaluated. Scenario 1 corresponds to a case where no data exist and representative values from the literature have to be used. Scenario 2 illustrates a case where sufficient data are available to define average soil parameters. Scenario 3 utilises all available soil core and neutron probe data to fully define heterogeneous soil properties and initial conditions. Dispersivities and diffusion coefficient for tritium transport were taken to be 5 cm and 1 $cm^2 \cdot day^{-1}$, respectively, for all three scenarios. The results indicate that the heterogeneous model reproduces the observed lateral spreading and irregular shape of the water content contours but overpredicts the movement and spread of the tritium tracer.

Kemakta Consultants Co./SKI presented flow and transport modelling using the integrated finite-difference codes TRUST and TRUMP. Three cases were considered: a uniform soil, an initially dry uniform soil and a nine-layer model. It was noted that the field data imply that the soil is initially dryer than the supposed residual moisture content. This was acknowledged by extrapolating the permeability and capillary pressure curves to lower saturations. The results demonstrated that a better moisture content agreement with experimental data was obtained using dryer initial conditions and that the layered description of the soil better predicts the lateral spreading of water. The calculations performed for tracer transport give too high spreading of the concentration plume indicating that lower dispersivities must be used.

PNL have performed Monte Carlo simulations of the infiltration experiments using a version of PORFLO with the objective to incorporate uncertainty in the prediction of the wetting front position. Using a nine-layer one-dimensional model all parameters were taken to have log-normal distributions truncated at the maximum and minimum observed values. It was pointed out that a low permeability layer could act as a barrier in a one-dimensional stochastic calculation, whereas in two-dimensions it was less likely to do so.

The group from MIT showed results from their effort to stochastically model the first trench experiment. Simulations with the highly non-linear effective mass

balance equation, in which the moisture content depends on gradients of the potential in space and time, were compared with a deterministic model with anisotropy. They found the stochastic model to better reproduce the experimental results, especially for extended times.

The Center for Nuclear Waste Regulatory Analysis presented results from three-dimensional stochastic simulations using the BIGFLO code. This code utilises the Turning Band Method to generate realisations and an efficient implicit finite-difference numerical scheme for solving the non-linear flow equations. A model comprising a strip-source in a random stratified soil similar to the Las Cruces Trench was solved on a Cray 2 using 300 000 nodes.

TEST CASE 11

Evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap tuff site near Superior, Arizona. (Pilot Group Leader: T. Nicholson, U.S. NRC)

Experimental Setup and Scales

This test case is in fact three sets of experiments on flow and transport in unsaturated welded tuff. The experiments are supported by the US NRC. The first set of experiments are field experiments at the Apache Leap Tuff Site, the second is a set of laboratory block experiments and the third is a set of laboratory core experiments. All experiments have up to date been performed by the University of Arizona.

The dimension of the field experiment is in the order of 30 m × 30 m × 30 m. Nine inclined boreholes have been installed in three rows of three boreholes per row. This general setup will allow for a set of different experiments. At one experiment performed at the site so far, the rock adjacent to one borehole was saturated and the propagation of the wetted front was to be evaluated by measuring the moisture content in the other boreholes. However, the introduction of the moisture could not be detected in the other boreholes.

The dimension of the blocks is 20 cm × 20 cm × 50 cm (block 1) and 21 cm × 20 cm × 66 cm (block 2). Each block has a single fracture located through the center of the block. The vertical sides of the blocks are insulated whereas the top and bottom are attached to porous plates which should allow for controlled unsaturated flow through the block and the fracture. The flow rate between the upper and lower plates will be used to calculate the unsaturated transmissivity, and the water content of the fracture will be monitored using mass balance calculations.

The dimension of the core is 6.4 cm in diameter and 12.7 cm in length and it does not contain any (observable) fractures. The core was oven dried and then partially wetted with a solution of potassium iodine. The core was then coated to prevent moisture or air from leaving the core. The core ends were held at two different temperatures (70°C and 5°C) whereas the sides of the core were thermally insulated (no heat flow). The temperature and moisture distribution were measured after different times, as well as the final solute concentration (after 32 days).

The present status of the experimental programme was presented by the pilot group from the University of Arizona. Additional experiments have been performed, and further experimental work is planned.

TEST CASE 12

Experiments with changing near-field hydrologic conditions in partially saturated tuffaceous rocks performed in the G-Tunnel Underground Facility at the Nevada Test Site, performed by the Nevada Nuclear Waste Storage Investigation Project of the U.S. DOE. (Pilot Group Leader: D. Hoxie, USGS)

Experimental Setup

This test case deals with near-field effects, produced by propagating transient disturbances in partially saturated Tuffaceous

rocks. The basic experimental design consists of continuously cored pairs of horizontal boreholes into both non-welded and fractured welded tuff. The boreholes are about 10 m in length and 10 cm in diameter with a separation of about 6 m. The core, diameter around 6 cm, is cased in plastic as the coring proceeds in order to minimise the contact between the drilling fluid and the core. One of each pair of boreholes is drilled using air as drilling fluid and the other is drilled using water. Gas phase tracers are injected into the drilling fluids to test for cross-hole hydrologic connections. Monitored values are drilling fluid losses, inflow and outflow temperatures, as well as inflow and outflow tracer concentrations. The physical and hydrological properties of the rock matrix are measured in laboratory.

The results were presented from the laboratory experiment, i.e. porosities and sorptivities, as well as the results from the field imbibition experiment.

TEST CASE 13

Experimental study of brine transport in porous media performed at RIVM, the Netherlands. (Pilot Group Leader: M. Hassanizadeh, RIVM.)

Experimental Setup

This test case deals with flow and transport at high salt concentrations. The experimental setup is a two-dimensional column with the dimensions 0.6 m × 1.25 m × 0.01 m, filled with glass beads. Fresh water and salt water is circulated through the column and the pressure head and salt concentration are measured at different locations in the column. The duration of a displacement experiment is from 2 to 5 hours.

Two sets of experiments have been carried out, one at low salt concentrations to estimate the porosity, permeability and dispersivity of the porous medium, and another at high concentrations to provide data about the concentration and pressure distribution along the column.

Analyses by the Project Teams

The Project Team from GSF has restricted their work to one-dimensional advection-dispersion modelling of the experiment. The dispersion length was determined to be 0.8 mm and the porosity in different regions of the column seemed to vary between 0.35 and 0.47. They used a one-dimensional finite difference code CHET, that had been checked against the SUTRA code. The CHET code was used mainly because the calculation times were far less than for similar calculations with other available codes (SUTRA, SWIFT, CFEST). For the low concentration experiments the steepness of the breakthrough curves were predicted quite well, in contrast to the breakthrough times which gave wrong results. For the high concentration experiments both the steepness and the breakthrough times were predicted badly. The dispersion length seemed to become smaller with increasing concentration. For the time being, the dispersion length had been considered as a property of the porous medium. At rather high salt concentrations, however, an additional possible dependence on fluid properties might help to more correctly simulate the experimental breakthrough curves more correctly.

The Project Team from BGR had made two-dimensional advection-dispersion calculations. The dispersivity was estimated at $1 \cdot 10^{-3}$ m, the porosity varied between 0.40 and 0.44, and the permeability was fixed to $1.7 \cdot 10^{-10}$ m^2. The slopes of the numerically approximated breakthrough curves for the low concentration experiments agreed closely with the measured curves. For the high concentration experiments the measured curves turned out to be much steeper than the calculated curves. In the calculations, the viscosity had been constant and the density had been a linear function of mass fraction. As a parameter variation the employed finite element code SUTRA was modified to include non-linear functions of mass fraction for both the viscosity and density. However, this had only minor influence on the breakthrough curves in the lower part of the column and no influence higher up in the column. Nor did the effect of varying the

transversal dispersivity between the value of the longitudinal dispersivity and zero influence the behaviour of the breakthrough curves. On the other hand, a decrease in time-step strongly affected the slopes of the breakthrough curves. The need to use smaller time-steps led to the decision to shift to one-dimensional calculations, mainly to decrease the CPU times needed. The one-dimensional calculations gave good agreement between measured and calculated breakthrough curves for the low concentration experiments. For the first 0.4 m of the column, the simulations of the high concentration experiments gave good agreement with the measured breakthrough curves only if the dispersivity were decreased to 10^{-4} m.

The Pilot Group from RIVM had earlier performed calculations with the finite element code METROPOL and obtained reasonable agreement between measured and calculated breakthrough curves in the bottom part of the column (inflow side) for low concentration experiments with the following parameter setup: porosity 0.38–0.42, permeability $1.7 \cdot 10^{-10}$ m^2, and dispersivity $5 \cdot 10^{-4}$ m. The simulations of the high concentration experiments showed much more dispersion than observed in the experiments. In parameter variations the dependence of dispersivity on concentration was investigated in advection-dispersion calculations performed with the one-dimensional computer code SPRINT. It was concluded that the linear Fickian-type relation is unable to simulate the high concentration experiments. Applying a non-linear dispersion theory, where the concentration gradient is a quadratic expression in the flux of salt, made it possible to successfully simulate all experiments.

TEST CASE 14a and b

Groundwater flow in the vicinity of the Gorleben Salt Dome, the Federal Republic of Germany. (Pilot Group Leader: K. Schelkes, BGR)

Experimental Setup and Scales

This test case is based on two experiments performed in similar geological environment in sediments above the Gorleben salt dome but on different time and space scales, a pumping test in highly saline groundwater (Test Case 14a) and movement of highly saline groundwater under natural gradient conditions in an erosional channel crossing a salt dome (Test Case 14b).

The Gorleben salt dome is located in the northern part of Lower Saxony in the Federal Republic of Germany. Hydrological investigations have been conducted in an area of about 300 km around the dome to study the aquifer system in the sediments above the dome. Sub-glacial erosion channels cross the dome at some places. The groundwater gets more saline with depth, especially above the dome. During the geological and hydrological survey programmes large quantities of data have been acquired and stored.

For Test Case 14a a part of the area has been selected where a long term pumping test was carried out. The duration of the pumping test was three weeks with six additional weeks of observation. In addition, data from a short term pump test with the duration of 24 hours, performed prior to the long term test, are available. The parameters observed continuously during the tests were e.g. electrical conductivity in observation wells and amount of water pumped.

Test Case 14b, concerns flow in one of the sub-glacial erosion channels crossing the salt dome. The area to be modelled is about 2–3 km × 15 km. The possible validation aspects are firstly to describe the present regional groundwater flow situation, and after that either to simulate the next thousand years or to start with fresh water and try to extrapolate the present

situation regarding salinity variations. At a later stage of the INTRAVAL Project, transport calculations based on a density dependent flow system could be included, using information regarding carbon-14 concentrations in water samples.

The data sets for these Test Cases are planned to be available in spring 1990. Due to delay of disseminating data, very few or no Project Teams will have the time to perform any modelling within INTRAVAL Phase I. It has therefore been proposed to transfer this test case to the anticipated next Phase of the INTRAVAL project.

Finalisation of INTRAVAL Phase 1

In the agreement for the INTRAVAL project, a time period of three years was foreseen for the project. The possibility of an extension of the project to cover an additional three year period was however indicated.

INTRAVAL Phase 1 started in October 1987 and the first phase of the project is now close to finalisation. The last workshop and Coordinating group meeting will be held during autumn 1990.

Most of the work with the analysis of the test cases is now finalised or is in draft form. However, since some of the definitions of the cases have been completed rather late, there are some test cases that have not yet been analysed by other Team than the Pilot Group. Also, because of constraints in terms of man-power limitations, the analyses of the test cases dealing with laboratory scale experiments are more complete than the analyses of the field experiments. In particular, the natural analogue studies have not been fully utilised. During the second Phase of INTRAVAL which is now being considered, the Teams would get the opportunity and time to analyse these remaining test cases.

The achievements from the first three-period of INTRAVAL will be documented in a summary report as well as in a series of technical reports, one report for each or possibly a few closely connected test cases. In addition, a report will be prepared that describes the experiments behind the test cases in detail.

The technical reports will be prepared by six Working Groups, which were set up at the Las Vegas workshop (Table 1). An editor has been appointed for each test case. The editors will have the responsibility to compile the test case analyses provided by the Project Teams, which have worked with the test case. The report describing the experiments will be prepared by the Secretariat in cooperation with the Pilot Groups. The technical reports are planned to be published in the spring 1991. The summary report will be prepared by the Secretariat in cooperation with the Working Groups and VOIC. The summary report is planned to be published late 1991.

Table 1. Working groups for finalisation of the technical reports.

Working group	Test cases[1)]
1	1a, 1b, 2, 9
2	4, 5
3	7, 8
4	10, 11, 12
5	13
6	6

1) Too few analyses have been performed to prepare a technical report for Test Cases 3 and 14.

INTRAVAL Phase 2

Since it has been decided to start planning for the optional three year period of the INTRAVAL Project, the INTRAVAL Secretariat has began to compile background material for a decision on this matter in the INTRAVAL Coordinating Group.

The overall objectives of a Phase 2 will be similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose

and to study the model validation process. This process includes several steps which can be described e.g. as follows:

1. *Identification of validation aspects of relevance for the performance assessment.*

2. *Understanding and research.* Without proper understanding of the processes and system structures involved, there could be no validation. A thorough understanding represents the major part of the validation.

3. *Comparison of theory and model calculations with experiments.* This is to study how well we are able to predict or simulate experimental results quantitatively. Any discrepancy may be due to parameter uncertainties, statistical nature of the system or lack of understanding. The agreement between the model results and the experiments should be consistent with the understanding of the parameter uncertainties and other statistical properties of the system.

4. *Peer review and public scrutiny.* It is important to have the work published in the open literature, both to receive the benefits of anonymous technical review and to open it to public scrutiny.

A model, including the conceptualisation and the computer code, can be validated either with respect to a process or a site-specific system. For a process, a process is first identified and conceptualised and coding is performed based on this conceptualisation. The model is then applied to an appropriate experiment and its results compared with measurements. If the calculations compare well with the experiment with due consideration given to parameter uncertainties etc., we can state that the model is validated with respect to this specific process. A site-specific system, on the other hand, may be composed of a number of processes and structures, that the building blocks of the system. Once the building blocks are identified, a model or group of models may be used to simulate and make comparisons with field observations. If successful, the group of models is said to be validated with respect to this particular site, within a range of applications determined by the range of field observations studied.

Although INTRAVAL has the ambition to cover both processes and site specific systems, the emphasis of the work in Phase 1 has been on the process identification part of the model validation process, based on the laboratory experiment test cases. Since the work in Phase 1 has been comparatively successful in covering the process identification issue, it appears to be a natural development to shift the focus in Phase 2 towards structure identification. This issue is more complicated than the process identification, because the number of degrees of freedom in the interpretation of the experiment increases and because the analysis should be based on field scale experiments. The experience from Phase 1 shows that the amount of manpower needed to analyse a field experiment is much greater than that needed for a laboratory experiment.

The selection of test cases for Phase 2 has been discussed in two ad-hoc meetings with VOIC and the Project Secretariat during the autumn of 1989. One conclusion of these meetings was that as a consequence of the shift of emphasis towards the structure identification issue, Phase 2 should deal mainly with field experiments and natural analogue studies. Information from laboratory experiments should be regarded primarily as supporting data and should not form the principal basis for autonomous test cases. Another conclusion of the meetings was that the number of test cases should be much reduced compared to Phase 1 in order to reduce the risk for dilution of effort. Test Cases proposed for Phase 2 were presented at the Workshop in Las Vegas and it was decided by the Coordinating Group that detailed write-ups should be prepared for nine experiments until the next Coordinating Group meeting, in the autumn of 1990, when decisions about Phase 2 will be taken.

Test cases proposed for INTRAVAL Phase 2

Here follows a short introduction of the test cases proposed for INTRAVAL Phase 2. Many of the proposed test cases are continuations of test cases from Phase 1, but there are also three completely new experiments.

Flow and tracer experiments in crystalline rock base on the Stripa 3D experiment, Sweden

The Stripa 3D experiment is included in Phase 1 as Test Case 4. The intention for Phase 2 is to further analyse the Stripa 3D experiment. An extended set of complementary data will become available since much additional information has been gathered on fracture statistics, hydraulic testing data as well as on water chemistry in what is called the 'site characterisation and validation' program. A new drift has been excavated near the old 3D drift and instrumented with plastic sheets and other water collection devices. Furthermore, channeling experiments in individual fractures are being performed providing data on the variability of hydraulic transmissivities and fracture apertures over 2 m lengths along 5 fractures. Tracer tests between two holes in the same fracture plane are also being performed.

Finnsjön tracer experiments, Sweden

This experiment is included in Phase 1 as Test Case 5. Of the three experiments performed so far, interference tests, radially converging tracer experiment and dipole experiment, only data from the radially converging test have been used during INTRAVAL Phase 1. For Phase 2 the coupling of all three experiments performed should be investigated. This would mean an increase in geometrical scales to distances between 150 and 1500 meters. Other objectives for INTRAVAL Phase 2 may be incorporation of existing laboratory data from core samples of the fracture zone. The data can also be used for predictions of a proposed natural gradient experiment.

Groundwater flow in the vicinity of the Gorleben Salt Dome, the Federal Republic of Germany

This experiment is included in INTRAVAL Phase 1 as Test Case 14. Unfortunately experimental data has not yet been made available and it is therefore proposed to transfer this test case into Phase 2.

Radionuclide migration in the weathered zone of the Koongarra uranium deposit, Australia

This natural analogue is included in Phase 1 as Test Case 8. The analyses of the data base from the Alligator Rivers Analogue are still in a preliminary stage and the number of project teams that have tackled this test case during Phase 1 is limited since a broad and innovative approach is needed for the analysis.

Poços de Caldas

The Poços de Caldas analogue is included in Phase 1 as Test Cases 7a (redox-front movement) and 7b (colloid transport). Since the data have not yet been made available to the Project Teams it is proposed to transfer the part concerning the redox-front movement and uranium movement to Phase 2. The part concerning colloid transport will not be continued since no evidence of colloid movement has been found in Poços de Caldas.

Las Cruces trench, USA

This experiment is included in INTRAVAL Phase 1 as Test Case 10. Since additional experiments will be performed at the site, it is proposed to include the experiments at Las Cruces Trench as a Test Case in INTRAVAL Phase 2. In Phase 2, models calibrated against data from the already performed experiments can be used to pre-

dict water flux and solute transport in the experiments to be carried out.

Apache Leap Tuff site, USA

This experiment is included in Phase 1 as Test Case 11. The Phase 2 exercise will be a continuation. Data from experiments performed at different scales, i.e core, block and field, are already available, and additional experiments of similar type will be performed.

Migration of tritium in clay at Mol, Belgium.

A piezometer nest is emplaced in a single bore hole drilled horizontally from the gallery of the Hades underground research facility at Mol, Belgium. The nest is equipped with several filters at 1 m intervals through which tritiated water is injected. An additional five piezometer nests have been installed for radionuclide injection, but these have not yet been loaded. Two of these are intended for determination of anisotropy in the clay (perpendicular and parallel to the bedding of the clay). The data from these additional tests will be made available to INTRAVAL as they arrive.

The experiment was originally designed to make in situ determinations of migration parameters for comparison with parameter values determined in the laboratory. The spatial scale of the experiments is in the order of 2 m migration distance involving about 30 m^3 of clay. The time required for an experiment is in the range of 1–4 years. The first tritium injection was carried out two years ago. The spatial scale of the complementary laboratory experiments is in the order of a few centimeters and the time scale in the order of weeks. The validation aspects of the experiments are coupled to radionuclide migration in clay and the scale dependence of the migration parameters.

Tracer experiments at the Twin Lake aquifer, Canada

The proposed test case comprises 20, 40, and 260 m natural gradient radio-tracer experiments performed in a sandy to gravel aquifer at the Twin Lake site. The experiments were performed in 1982, 1983 and 1987–1988. The longest experiment ran for about a year. The spatial separation of the measuring points are about 5 m in the flow direction and 0.5-1 m in the direction perpendicular to the flow. As a result of the 1982–1983 experiments there exists approximately half-a-million data points on the spread of iodine. A very large amount of hydrogeological and geophysical data have also been collected. New experiments are planned for the autumn 1990.

Sand and gravel aquifers will not be considered for radioactive waste disposal. In that sense, this test case is of limited relevance for validation with regard to radioactive waste disposal. However, the test case could potentially provide a set of detailed data, which could be used for validating the necessary conditions generally assumed in transport models, i.e. to answer the question whether a general transport model can predict the results of any field experiment, where there is little uncertainty in the data.

Brine Flow through bedded evaporities at the Waste Isolation Pilot Plant (WIPP) Site, New Mexico, USA

Field experiments are conducted in the underground facility at the Waste Isolation Pilot Plant (WIPP) site in the southeastern New Mexico. The underground facility lies 655 m below ground surface within bedded evaporites, primary halite, of Permian Salado Formation. The WIPP, currently scheduled to open late 1990, is to be a permanent repository for low-level and transuranic wastes generated by the United States' defense programmes.

This test case is based on experiments performed to determine the nature of brine flow through bedded evaporites of the Salado Formation. The experiments are designed to provide different types of data

with which to evaluate whether Darcy's law correctly describes the flow of brine through evaporites, or whether a different type of model, perhaps one involving creep-driven flow, is more appropriate. Three principal types of measurements are being made: brine-inflow rates, pore-pressures, and permeabilities, at a number of scales ranging from 4.5 cm diameter boreholes to 3 m diameter rooms. The test case is concerned with the validation of conceptualisation and models used in test interpretation and in the modelling of brine inflow to the repository. The objectives are to integrate the results of all the experiments in a comprehensive and consistent model of brine flow through evaporites.

The experimental programme is currently scheduled to continue through May 1992. In late 1990 or early 1991, the programme may expand to include gas threshold-pressure testing and tracer testing through a fractured anhydrite bed.

OECD/NEA Brochure

OECD/NEA and the Secretariat are preparing a brochure describing the INTRAVAL Project. The brochure will be printed before the upcoming autumn.

Appendix 1

INTRAVAL Organisation

The organisation of the INTRAVAL study is regulated by an agreement which has been signed by all participating organisations (Parties). The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Managing Participant sets up a Project Secretariat in cooperation with Her Majesty's Inspectorate of Pollution (HMIP/DoE), U.K. and the Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA). KEMAKTA Consultants Co. is contracted by SKI to act as Principal Investigator within the Project Secretariat.

The Parties organise Project Teams for the actual project work. Each Party covers the costs for its participation in the study and is responsible for the funding of its Project Team or Teams, including computer cost, travelling expenses, etc.

A Pilot Group has been appointed for each Test Case in order to secure the necessary information transfer from the experimental work to the Project Secretariat and the Project Teams. The Project Secretariat coordinates this information transfer.

At suitable time intervals, depending upon the progress of the study, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group. During the workshops, Test Case definitions and achieved results are discussed as a preparation for decisions in the Coordinating Group.

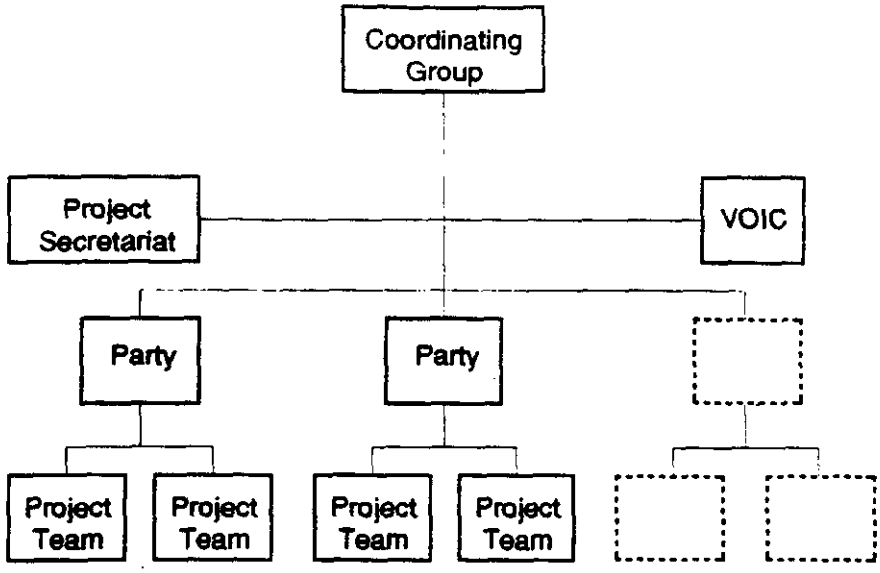

Figure 1. INTRAVAL Organisational Chart

Managing Participant:	SKI
Coordinating Group	
Chairman:	A. Larsson, SKI
Vice Chairman:	T. Nicholson, U.S. NRC
Secretary:	K. Andersson, SKI
Principal Investigator:	KEMAKTA Consultants Co.
Project Secretariat:	K. Andersson, SKI
	J. Andersson, SKI
	L. Dagerholt, KEMAKTA
	M. Ericsson, KEMAKTA
	B. Grundfelt, KEMAKTA
	D. Lever, HMIP/DoE, Harwell
	K. Pers, KEMAKTA
	K. Skagius, KEMAKTA
	C. Thegerström, OECD/NEA

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Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
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Gesellschaft für Strahlen- und Umweltsforschung, Federal Republic of Germany R. Storch	(GSF)	Gesellschaft für Strahlen- und Umweltsforschung G. Arens	(GSF)
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		Office of Waste Technology Development B. Gureghian	(OWTD)
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U.S. Nuclear Regulatory Commission, United States of America T. Nicholson	(US NRC)	U.S. Nuclear Regulatory Commission . McCartin	(US NRC)
		Massachusetts Institute of Technology L. Gelhar	(MIT)
		Pacific Northwest Laboratories G. Gee	(PNL)
		Sandia National Laboratories P. Davis	(SNL)
		Texas Bureau of Economic Geology TBEG, Dept of Hydrology and Water Resources B. Scanlon	(TBEG)
		TBEG, Soil and Water Science Dept P. Wierenga	(TBEG)

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Organisation for Economic (OECD/NEA) Cooperation and Development/ Nuclear Energy Agency Member of Secretariat: C. Thegerström	
International Atomic Energy Agency (IAEA) S. Hossain (observer)	
State of Nevada L. Lehman (observer)	

Appendix 2

Intraval Test Cases

TEST CASE 1a

Radionuclide migration through clay samples by diffusion and advection based on laboratory experiments performed at Harwell, U.K.

Introduction

This test case is concerned with the validation of models that describe the permeation, diffusion and dispersion of radionuclides through clay samples. The behaviour of the tracers in the pore water and the adjacent solid phase is to be described. The experiments are performed at Harwell.

General Description

Three sets of experiments have been carried out with iodine, deuterium and tritium as tracers. The experiments are in-diffusion, through-diffusion (vertical and horizontal) and hydrodynamic dispersion (vertical and horizontal). The transport direction vertical or horizontal refer to the 'in-situ' location of the sample. The length scales of the experiments are up to a few centimetres and the duration is up to a few months.

In the in-diffusion experiments, the tracer was allowed to diffuse axially into the sample from two sides. Six or seven replicate clay samples were loaded into diffusion cells (Figure 1) and both measurement cell and reservoir for each cell were filled with simulated clay water containing NaI and deuterated water.

The cells were dismantled in turn, and the amount of tracer that had diffused into each sample was determined. These data give an indication of the porosity accessed by the tracer at different times, and the diffusivity.

The vertical through-diffusion experiments were performed in the same type of cell as used in the in-diffusion experiment (Figure 1). The sample was loaded into the cell, and the reservoir was filled a simulated clay groundwater containing the tracers. The measurement cell was filled with simulated clay groundwater only. The increase in tracer concentration in the measurement cell was monitored. The breakthrough curve gives information about the porosity and the vertical diffusion coefficient.

In the horizontal diffusion experiment the sample was sealed into a large diffusion cell (Figure 2). A solution containing the tracers was circulated against one face of the sample. The other face of the sample was in contact with a solution initially free from the tracers. The increase in concentration of tracer in the encasement cell was monitored as a function of time. Information on the porosity and the horizontal diffusion coefficient is obtained from the breakthrough curves in these experiments.

For measurement of the vertical component of the hydrodynamic dispersion a high pressure stainless steel cell was used (Figure 3), and the large diffusion cell (Figure 2) was used for horizontal measurements. The experiments were carried out in a way similar to the through-diffusion experiments except that a pressure gradient was maintained over the sample. The breakthrough curve into the measurement cell gives in these experiments information on the permeability, porosity and dispersivity.

In addition to the tracer experiments hydraulic conductivity experiments have been performed. Results from these experi-

ments are given as hydraulic conductivity as a function of effective consolidation stress. Other complementary experiments performed are:

— determination of porosity and moisture content by an oven drying technique,
— determination of size and distribution of the porosity, and of the accessibility of the pore space to deuterated water by a small angle neutron scattering (SANS) technique,
— determination of the pore size distribution by the mercury intrusion porosimetry technique,
— determination of the mineralogical content of the clay samples and of the size fractions of individual mineral phases by X-ray Diffraction analysis.

Summary of Available Data:

— breakthrough curves from through-diffusion experiments and from the hydrodynamic dispersion experiments
— porosity of the sample accessed by the tracer after different times in the in-diffusion experiments
— results from complementary experiments such as moisture content and porosity, size and distribution of the porosity, pore size distribution, hydraulic conductivity as a function of stress etc.
— experimental conditions such as sample dimensions, initial concentrations, volumes, flow rates etc.

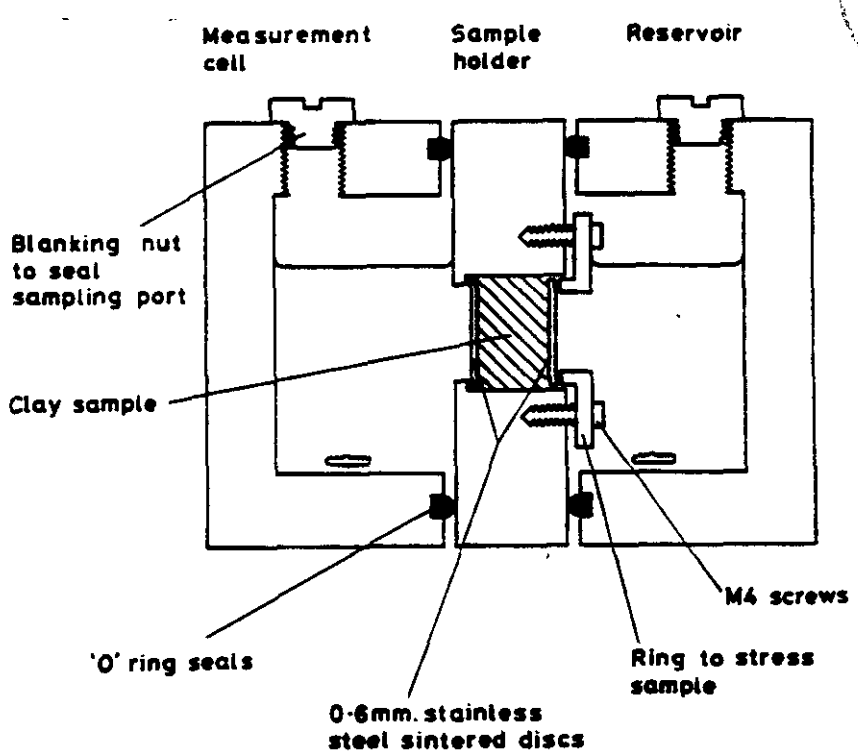

Figure 1. Diffusion cell used in the in-diffusion experiments and in the vertical through-diffusion experiments (Test Case 1a).

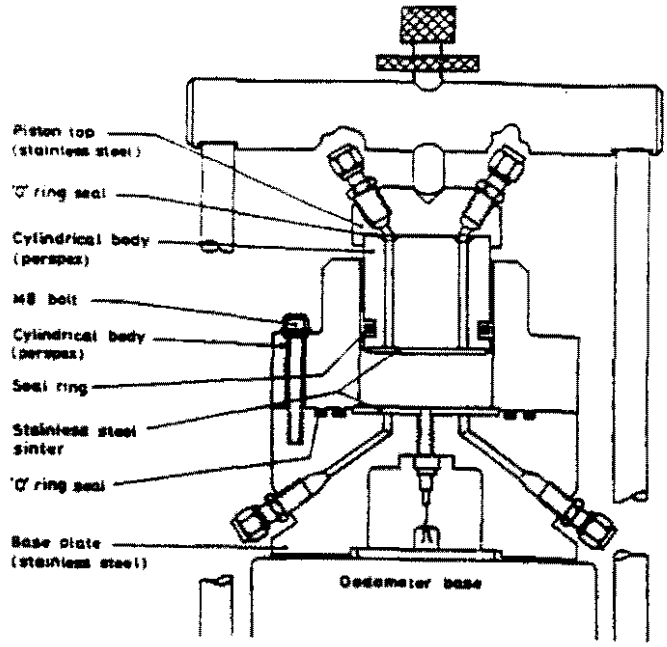

Figure 2. Large diffusion cell used in the horizontal through-diffusion experiments (Test Case 1a).

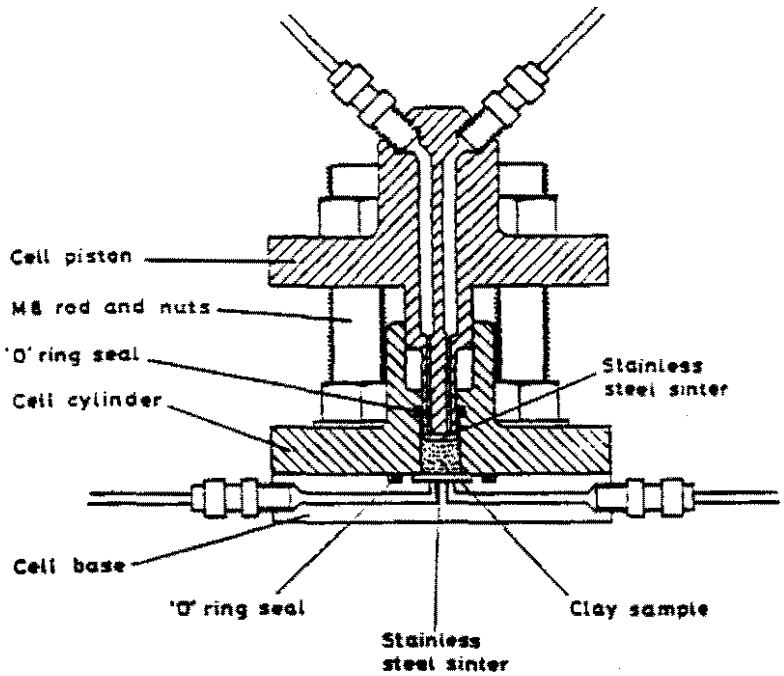

Figure 3. Cell used in the vertical permeation experiments (Test Case 1a).

TEST CASE 1b

Uranium migration in crystalline bore cores based on experiments performed at PSI, Switzerland.

Introduction

The aim of this test case is to characterise hydraulic and tracer transport properties of small samples of crystalline rock. The experiments were performed at PSI, Switzerland.

General Description

Samples of crystalline rock (granite, gneiss) originating from various depths were taken from the deep NAGRA drillings in northern Switzerland. They differ in mineralogical characterisation, especially the extent of alteration. The cores had a diameter of 4.6 cm and were between 0.8 cm and 5.0 cm long. The cylindrical rock samples were placed in a pressure apparatus. A schematic description of the equipment is shown in Figure 4. Hydraulic pumps were used to build up an isostatic confining pressure for simulation of the lithostatic pressure. A variable axial hydraulic pressure gradient over the sample allowed for infiltration of tracer solution.

As infiltration fluid a natural granitic groundwater from Bad Säckingen was used, and as tracer distilled water and ^{233}U. The tracer was injected and sampled during a period that for different runs varied between 180 and 350 hours. At the outlet the bulk water flow, the electrical conductivity and the uranium concentration was measured.

After terminating the uranium infiltration experiments the sample was taken out of the autoclave and cut into slices of about 1 mm thickness. The resulting surfaces

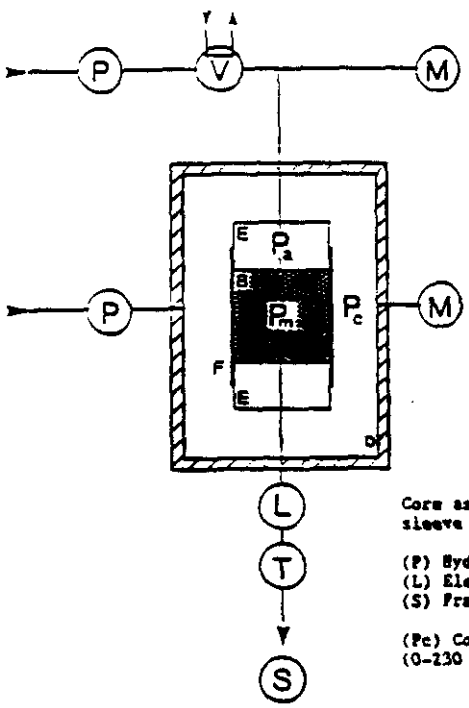

Core assembly with (B) core sample, (E) end pieces, (F) flexible sleeve

(P) Hydraulic pumps, (M) Manometers, (V) Injection valve, (L) Electrical conductivity probe, (T) Droplet counter, (S) Fraction/droplet sampler, (D) Pressure vessel

(Pc) Confining pressure (0-60 MPa), (Pa) Infiltration pressure (0-230 MPa), (Pm) Pore pressure

Figure 4. Schematic diagram of the pressure infiltration apparatus (Test Case 1b).

were then autoradiographed to yield information on flow paths and sorption sites.

Summary of Available Data:

- chemical composition of infiltrating liquid,
- mineral composition of cores,
- hydraulic conductivities as a function of pressure,
- porosities,
- uranium(VI)-breakthrough curves,
- uranium(VI) sorption data on crushed material,
- results from alpha-autoradiography of surfaces of slices.

TEST CASE 2

Radionuclide migration in single natural fissures in granite based on laboratory experiments performed at KTH, Sweden.

Introduction

This test case describes radionuclide migration in single fissures in granite. The experiments have been performed at the Department of Nuclear Chemistry, Royal Institute of Technology, Stockholm, Sweden. The experiments address important phenomena in radionuclide transport in the geosphere such as retardation, matrix diffusion, dispersion, channelling, channel structure and fracture properties.

General Description

Granite drill cores, taken from the Stripa mine were used in the experiments. Each had a natural fissure running parallel to its axis. The cylindrical surfaces of the drill cores were sealed with a coat of urethane lacquer to prevent any water leaving the rock except through the outlet end of the fissure. The granite cylinder was thereafter mounted between two plexiglass end plates containing shallow inlet and outlet channels slightly wider than the fissure. The experimental setup is shown in Figure 5.

Non-sorbed and moderately sorbed tracers

Tests with the non-sorbed tracers tritiated water and lignosulphonate ions and the moderately sorbed ions strontium and caesium were performed in a 30 cm long drill core with a diameter of 20 cm. Tests with the non-sorbed tracers tritiated water, iodine, bromide and lignosulphonate ions and the moderately sorbed tracers strontium and caesium were performed in two cores with a diameter of 10 cm and a length of 18.5 and 27 cm, respectively.

Artificial groundwater with a tracer was fed to the inlet channel. At low flow rates, flushing water was simultaneously fed through the outlet channel to reduce the time delay due to the channel volume of the end piece. The effluent was continuously fed to a fractional collector for analysis of the tracer concentrations. The tracers were introduced either as a step up or as a step up followed by a step down, after a suitable amount of tracers had been introduced (normally about 15 minutes duration).

Summary of Available Data

- flow rates and breakthrough curves,
- distribution coefficients for ^{85}Sr and ^{134}Cs on crushed granite,
- porosity of the Stripa granite,
- diffusivity of iodine and tritiated water in granite.

Actinides

The diameter of the drill cores used in these experiments was 40 mm and the lengths 80-105 mm. Before each experiment artificial groundwater was pumped for 2 to 3 days through the drill core to equilibrate the fissure surface. The water flow was characterised by feeding a solution of non-

sorbed NaLS in artificial ground water to the inlet channel. Flushing water was simultaneously fed through the outlet channel to reduce the time delay due to the channel volume. The tracer was added as a pulse of suitable duration (normally 15 minutes), and synthetic groundwater was then pumped through the fissure. The effluent was continuously fed to a fraction collector for analysis of the tracer concentration.

The radionuclides studied (^{152}Eu(III), ^{235}Np(V), ^{237}Pu(IV), ^{241}Am(III), ^{99}Tc(VII) and ^{99}Tc(IV)) were fed to the fissure by the same technique as described previously. After several hundred fissure volumes of water had been pumped through the fissure, the drill core was cracked open and the tracer distribution on the fissure surfaces measured. Each experiment generated effluent concentration versus time curves for the lignosulphonate ion and the radionuclides as well as the radionuclide distribution on the fissure surfaces.

When performing the tracer tests it was found that a small fraction (less than a few percent) of the total activity of ^{152}Eu, ^{235}Np, ^{241}Am and ^{99}Tc(IV) was transported through the fissure with nearly the same velocity as water. Inserting a 0.21 µm filter between the tracer solution reservoir and the inlet channel greatly reduced the fast moving fraction, indicating that the activity was carried by particulate matter.

Summary of Available Data:

- breakthrough curves for LS and the radionuclides,
- radionuclide distribution on the fissure surfaces,
- flow rates,
- distribution coefficients.

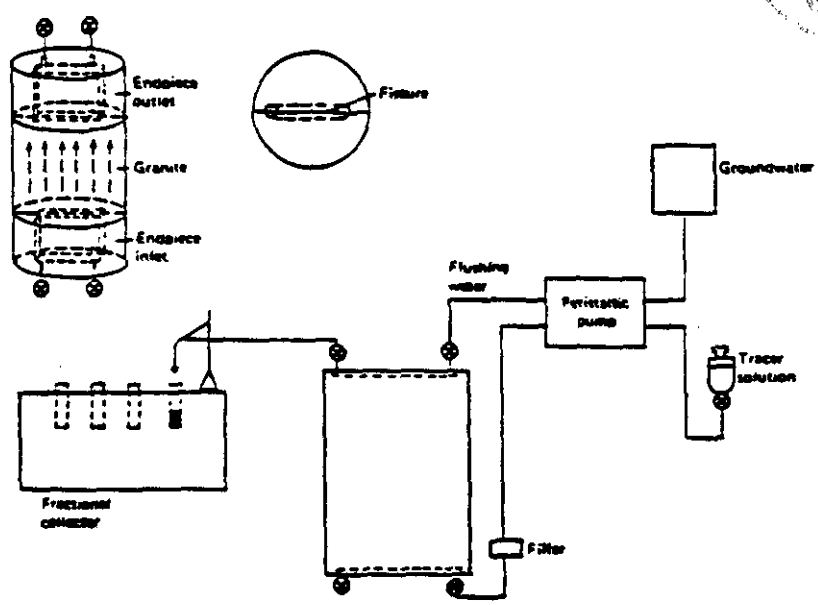

Figure 5. Experimental setup (Test Case 2).

TEST CASE 3

Tracer tests in a deep basalt flow top performed at the Hanford reservation, Washington, USA.

Introduction

This test case is concerned with the validation of important conceptual model issues such as homogeneous or heterogeneous porous media flow, fracture flow and dispersion. Data from two-well (injection/withdrawal) tracer experiments performed in the McCoy Canyon basalt flow top at the Hanford Site will be used to address these issues.

General Description

Two recirculating nonreactive, pulse-injection, ground water tracer experiments have been performed at the DC-7/8 site on the Hanford reservation, Figure 6, to determine effective thickness (i.e., effective porosity times aquifer thickness) and longitudinal dispersivity. The wells (DC-7 and DC-8) are 55 ft (16.7 m) apart and the horizon selected for the tracer testing is in the McCoy Canyon flow top between 3422 and 3459 ft (1043 and 1055 m) below land surface.

The first test was performed with an ^{131}I tracer by Science Applications, Inc., (SAI) in December 1979. It was initially analysed by a two-point match based on time-to-peak and time-to-half-peak concentrations and it was reanalysed by L. W. Gelhar utilising type-curves based on the general theory for longitudinal dispersion in non-uniform flow along streamlines. The two different techniques produced results for effective thickness and longitudinal dispersivity that were less than 1/2 an order of magnitude different. The type-curve analysis is considered to be more accurate.

The second test utilised KSCN and was performed by Rockwell in January 1982. The major differences between the two tests were the tracers and the details regarding the recirculation. In the first test by SAI the flow rate varied between 2.0-3.5 $gal \cdot min^{-1}$ (7.5-13.0 $l \cdot min^{-1}$) and only about 2/3 of the water pumped from DC-7 was reinjected into DC-8. In the second test a constant rate of 1 $gal \cdot min^{-1}$ (3.8 $l \cdot min^{-1}$) was maintained and all of the water produced at DC-7 was reinjected at DC-8.

Summary of Available Data:

- flow rates,
- breakthrough curves (I, KSCN),
- geometry of the site,
- pump test data,
- steady state pressure and hydraulic head,
- core data,
- geologic and geophysical logs.

TEST CASE 4

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment performed within the International Stripa Project.

Introduction

This test case is based on the three dimensional tracer test performed in the Stripa mine in Sweden. The experiment was performed within the OECD/NEA International Stripa Project. The main purpose of this experiment was to investigate the spatial distribution of water flow paths in a larger block of rock. This experiment gives an opportunity to validate geosphere transport models in terms of dispersion, channelling and geometrical factors when water is flowing in a fractured crystalline rock over distances up to 50 m.

General Description

In the Stripa mine at 360 m below the ground, a drift was excavated. The drift is 75 m long and has two side arms with a length of 12.5 m each. Three vertical holes

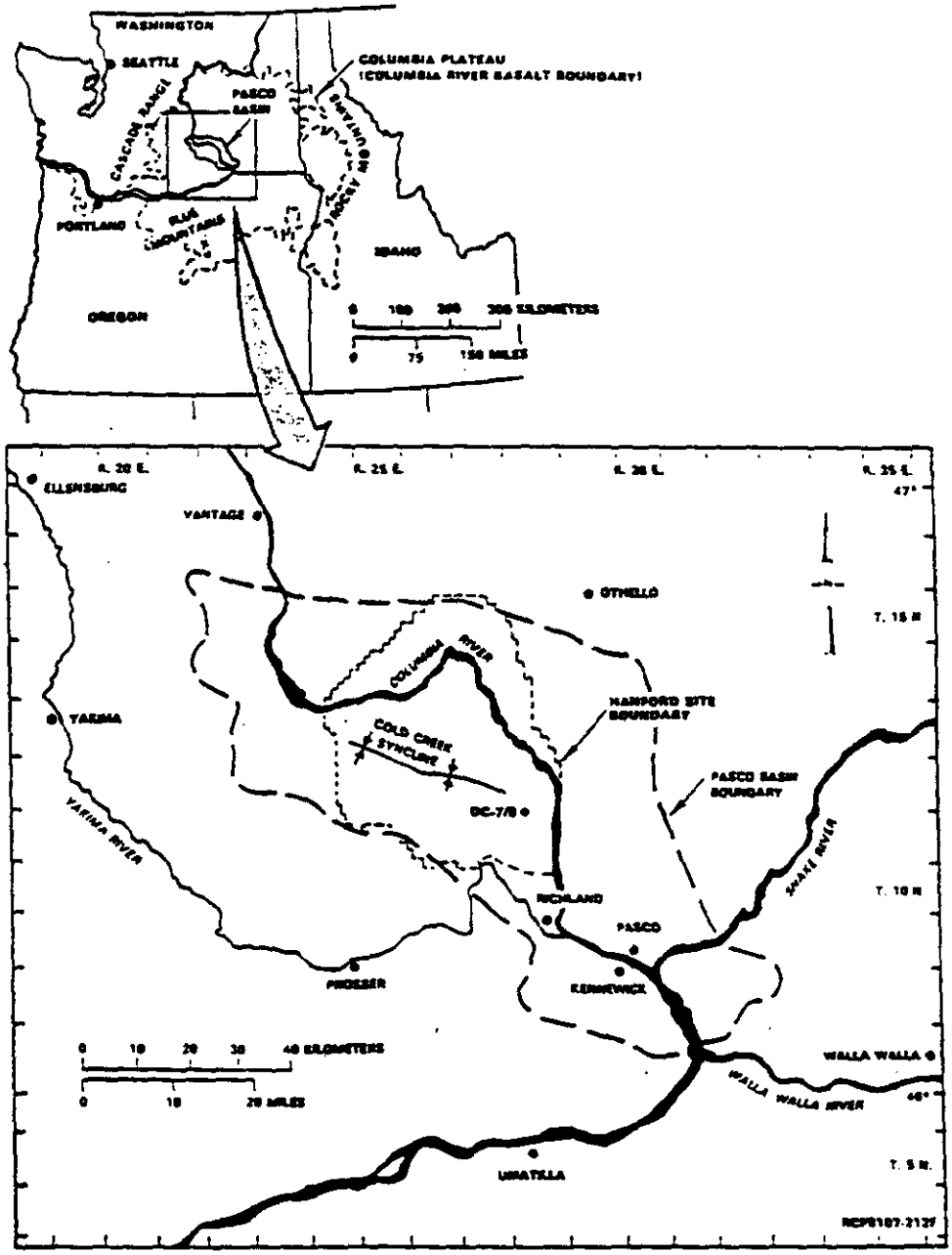

Figure 6. Location of the Columbia Plateau, Hanford Site, and the DC-7/8 Test Site (Test Case 3).

for injection of tracers have been drilled upwards with lengths of 70 m (Figure 7).

The ceiling and large parts of the walls in the drift were covered with plastic sheets, each sheet with an area of about 2 m^2. A total number of about 350 sheets served as sampling areas for water emerging into the upper part of the test drift. The sampling arrangements completely covered a surface area of 700 m^2. The spatial distribution of water flow path ways could thus be obtained.

Injection of conservative tracers were carried out from a total number of 9 separate high permeability zones within the three vertical holes, each zone about 2.5 m in length. The injection zones were located between 10 and 55 m above the test site. The tracers were injected continuously for nearly two years. The injections were carried out with a 'constant' over pressure, approximately 10-15 % above the natural pressure. The concentrations of the injected tracers were between 1000 and 2000 ppm, and the different flow rates varied from 1 to 20 $ml \cdot h^{-1}$. The following tracers were injected: Uranine, Eosin blueish, Eosin yellowish, Phloxine B, Rose Bengal, Elbenyl Brilliant Flavine, Duasyn Acid Green, Bromide and Iodide.

Results

The natural inflow of water to the drift was measured before drilling the injection holes. The results from the water monitoring shows that water does not flow uniformly in the rock over the scale considered (700 m^2), but seems to be localised to wet areas with large dry areas in between. Measurable amounts of water emerged into 113 of the 350 sampling

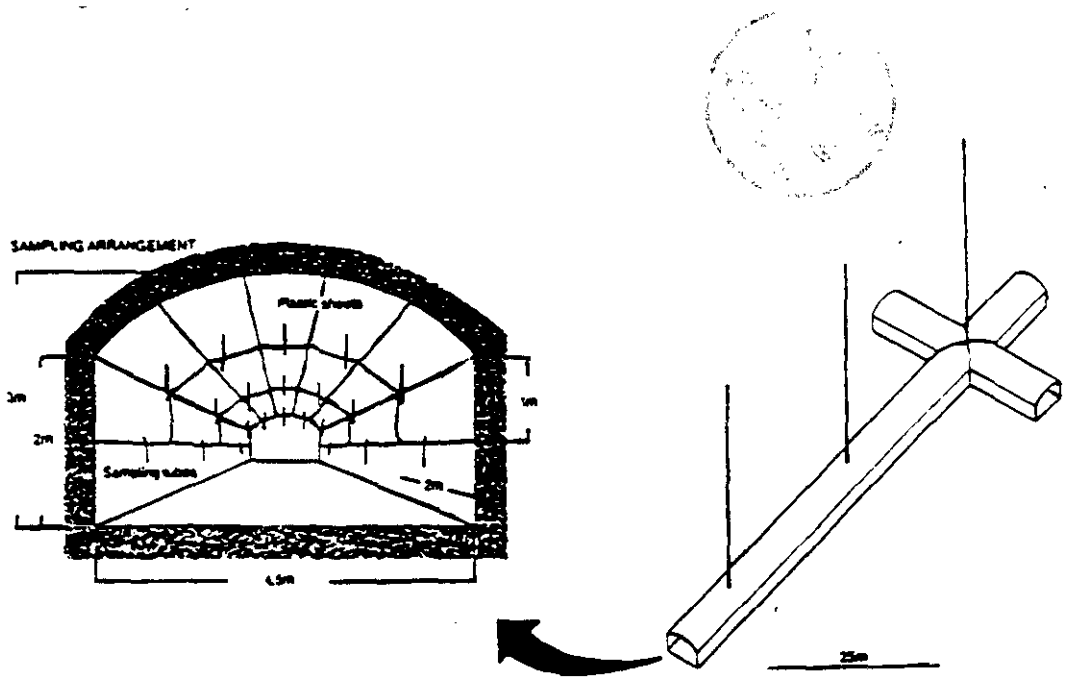

Figure 7. The experimental drift. The location of the tracer injection holes is indicated (Test Case 4).

areas. Out of these 'wet' sampling areas 10 % gave more than 50 % of the total water inflow.

After 6 months of injection, tracers from at least 5 injection zones could be found in about 35 sampling areas. After almost two years of injection, about 200 different tracer breakthrough curves have been obtained. Each curve is based on typically more than 1 000 individual measurements.

Summary of Available Data:

— water flow rates,
— tracer concentration in water to test site,
— rock characteristics and fracture data,
— water chemistry,
— injection pressures and injection flow rates,
— hydrostatic pressures,
— diffusivity and sorption data
— daily logs.

TEST CASE 5

Tracer experiments in a fracture zone at the Finnsjön research area, Sweden.

Introduction

This test case is based on tracer tests in a fracture zone at the Finnsjön research area in Sweden. The aim of the tracer tests is to investigate the transport properties in a highly conductive rock over distances up to about 400 m. In a validation sense, results from this experiment will be valuable because of the long migration distances involved. Other validation aspects are: retardation, matrix diffusion, dispersion and geometrical factors.

So far two tests in different geometries have been performed in the major subhorizontal fracture zone (zone 2) at the Brändan area (Figures 8 and 9). The fracture zone is about 100 m wide, but most of the flow appears to take place in three subzones. The first tracer test was carried out with a radially converging flow geometry and the second with a dipole flow.

Radially Converging Test

In the radially converging test tracer injections were made in three peripheral boreholes, BFI01, KFI06 and KFI11 which are situated in different directions from the withdrawal borehole BFI02 (Figure 8).

Totally 11 tracers were injected in three packed-off intervals in each injection hole, 8 of them continuously for 5-7 weeks and 3 as pulses. The tracers used were DTPA and EDTA complexes with rare earth metals, fluorescent dyes (Uranine and Amino G Acid) and two anions (I^- and ReO_4^-).

Tracer breakthrough was registered from all nine injection intervals, with first arrivals ranging between 24-3500 hours. A detailed sampling in the withdrawal borehole indicated good hydraulic interconnections between different parts of the zone.

Summary of Available Data

A lot of background information such as geological, hydrological, geochemical and geophysical data from investigations of the Brändan area are available.

Data available from the radially converging test are:

— tracer breakthrough curves,
— withdrawal and hydraulic head data,
— tracer concentrations in injection intervals,
— groundwater flow rates during tracer injection,
— log of events during the experiment,
— results from detailed sampling in the withdrawal hole.

In addition to this porosities and diffusivities from laboratory measurements on drill core samples are available.

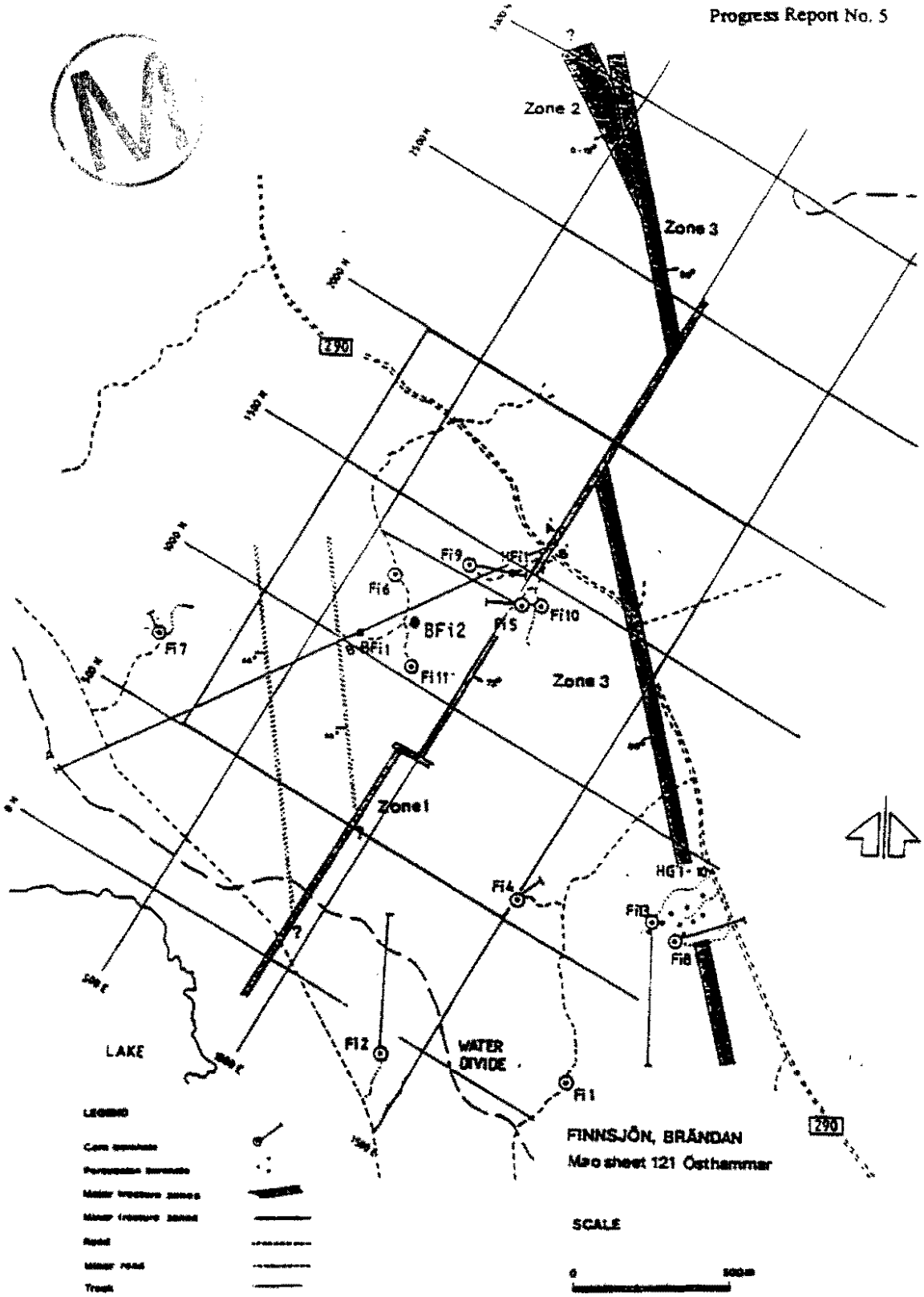

Figure 8. Borehole location in the Brändan area (Test Case 5).

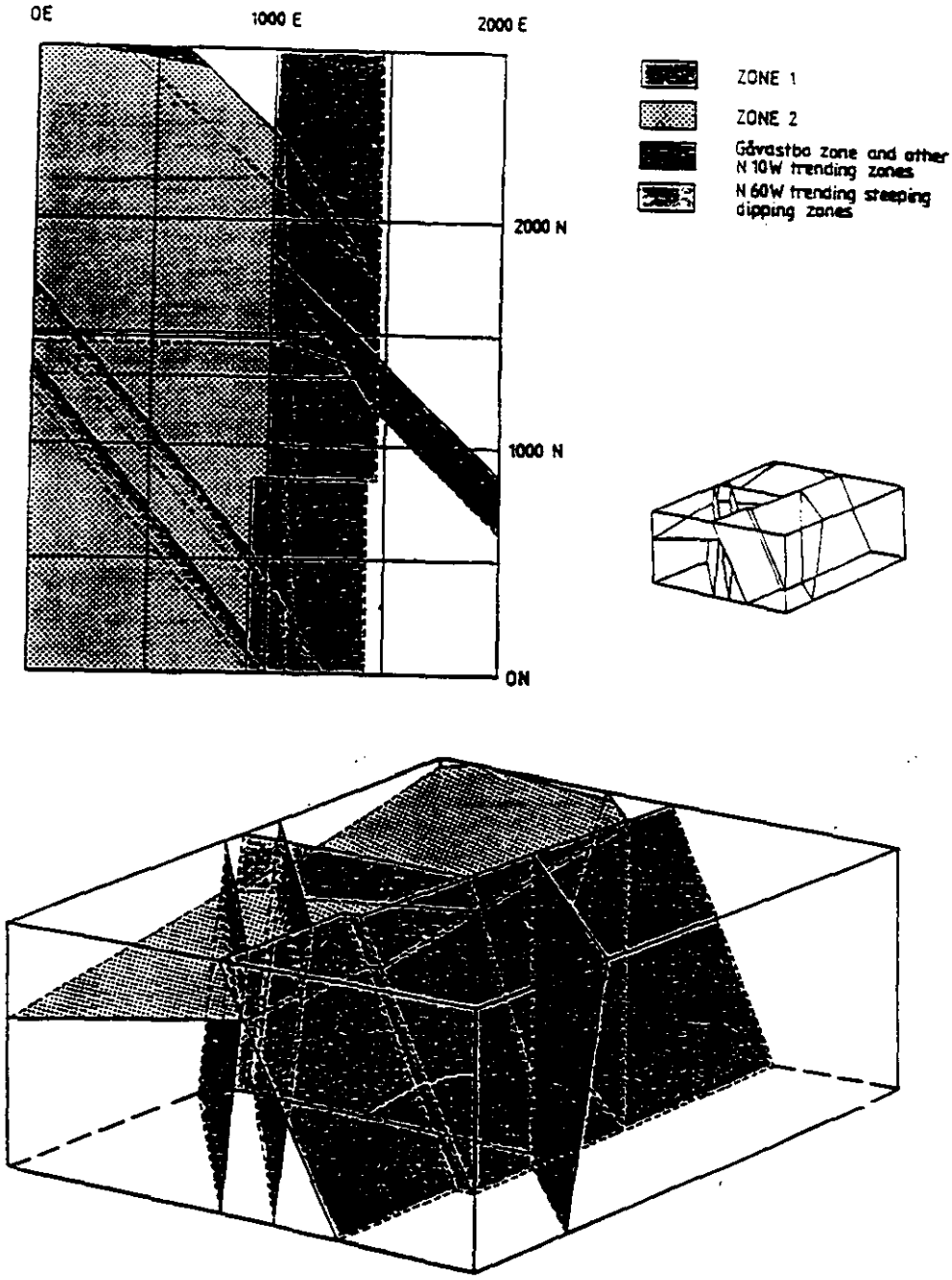

Figure 9. Cross section through the Brändan area showing Zone 2. The location of the profile is shown in Figure 8 (Test Case 5).

Dipole Experiment

The dipole experiment was performed in a recirculating flow field between the boreholes BFI01 (injection) and BFI02 (withdrawal). Only the upper highly conductive interval of zone 2 was used with injection in the same interval as in the radially converging test. Water withdrawn from BFI02 was injected again into BFI01.

Totally 20 different tracers were used, and they were injected into the system as pulses with a duration of 4-8 minutes. The tracers are non-sorbed or sorbed radioactive ons and complexes, and non-active complexes and dyes. In order to study the possible effects of matrix diffusion a macromolecular compound was also injected.

The evaluation of the dipole experiment is presently in progress. Data will be available late 1989.

TEST CASE 6

Synthetic data base, based on single fracture migration experiments in Grimsel Rock Laboratory in Switzerland.

Introduction

This test case is based on a synthetic site. Geologic and hydrologic boundaries, and the mean, variance and spatial correlation scales of the model parameters are conditioned with real-world data from the Grimsel Rock Laboratory in Switzerland. The synthetic migration experiment will test the ability of groundwater flow and transport modelling strategies to interpret and characterise transport of tracers, through a large fracture zone on the bases of a sparse number of borehole hydraulic tests, dipole tracer tests and other observations. The test will also include an assessment of the uncertainty in the interpretation and ability to predict based on this uncertain interpretation.

General Description

The site is positioned in the mountainside on a scale of kilometres. Two water bodies bound the site on either side of the mountain. The plane to be studied is an essentially vertical two dimensional fracture. It has been assumed that the tunnels in the area are open to the atmosphere and the potential at their surface is therefore equal to their elevation. Simulated experimental measurements will cover a few tens of meters, and time scales of seconds to weeks.

The generation of the synthetic geosphere has been made in four steps:

— The hydraulic head on the scale of the distance between the water bodies (about 5000 m) has been generated with a finite difference computer program using a 107×47 uniform grid with spacing of 45.5 meters (coarse scale modelling). The effect of the tunnels is taken into account, and the transmissivity is assumed to be uniform throughout the grid. The hydraulic head is considered to be equal to the land or water surface elevation along the top boundaries and no-flow on the other three boundaries.

— The second scale modelling deals with an intermediate scale problem. The domain is 182 x 182 m divided into a regular finite difference grid 513 x 513. The transmissivity field is taken from a 4096 x 4096 fractal data set, based on observed data at the Grimsel site, by arithmetic averaging. Boundary conditions of the hydraulic head on the boundary of the domain are taken from the coarse scale model.

— The finest scale model is represented by a 29.9 × 22.75 m area discretised into 673×513 grid. Bore holes are modelled separately in a radial coordinate system and matched to the rectangular grid. The boundary conditions on the edges of the rectangular domain are specified

by the output of the intermediate scale model. The finest level solution is used to simulate the dipole test and to calculate the steady state inflows to the experimental tunnel and boreholes.

— Borehole tests are simulated with a transient model. For the sake of computer run times, the transient hydraulic tests are performed in a grid twice as coarse 337 × 257, giving only minor differences from the finer grid results.

The Parameters Generated are:

— Steady state hydraulic head at closed bore holes.
— Transient and steady state outflow to or from open bore holes and tunnels.
— Response to transient pressure tests in all bore holes resulting from a pressure stress in one bore hole
— Dipole tracer tests between two pairs of boreholes
— Response in tunnels to bore hole tests (increased of diminished flow or appearance of tracer).

Models to include diffusion and geochemical retardation are being developed for a later stage of this test case.

TEST CASE 7a and 7b

Natural analogue studies at Poços de Caldas, Minas Gerais, Brazil.

Introduction

Test case 7 is a natural analogue study based on an investigation performed at Poços de Caldas, Minas Gerais, Brazil. The project involves two subprojects:

1. Evaluation of the transport and speciation of natural radionuclides and rare-earth elements in a fissure flow system in crystalline rock under both oxidising and reducing conditions

2. Colloid formation and mobility in natural groundwaters and the role of colloids in element transport.

The Poços de Caldas region consists principally of alkalic intrusive rocks and is generally anomalous with respect to uranium, thorium and the rare-earth elements. These elements show pronounced chemical similarities to neptunium, plutonium and americium/curium respectively.

Subproject 1 has been located at the Osamu Utsumi Mine (C-09 Uranium Mine; U with subordinate Th and rare earth elements) and subproject 2 at Morro do Ferro (U, Th, rare-earth elements).

For the INTRAVAL study two test cases have been defined. Test Case 7a concerns the redox front and radionuclide movement in the open pit uranium mine and Test Case 7b is based on the movement of colloids.

TEST CASE 7a

Redox front and radionuclide movement in an open pit uranium mine.

The open pit uranium mine (Osamu Utsumi) is at present several hundreds of meters wide, nearly 1 km long and more than hundred meters deep in places. The bedrock is crystalline and consists mainly of phonolites and nepheline syenites. The rock matrix is porous with a porosity of 4–20%. The hydraulic conductivity of the matrix is an order of magnitude lower than that of the overall rock including fractures. The deeper portions of the rock are strongly reducing while the upper portions has become oxidised by oxygen carried by infiltrating rain water. The redox front is very sharp. In association with fractures and fracture zones, which have higher permeability than the rock matrix itself, 'fingers' of oxidised rock are extending

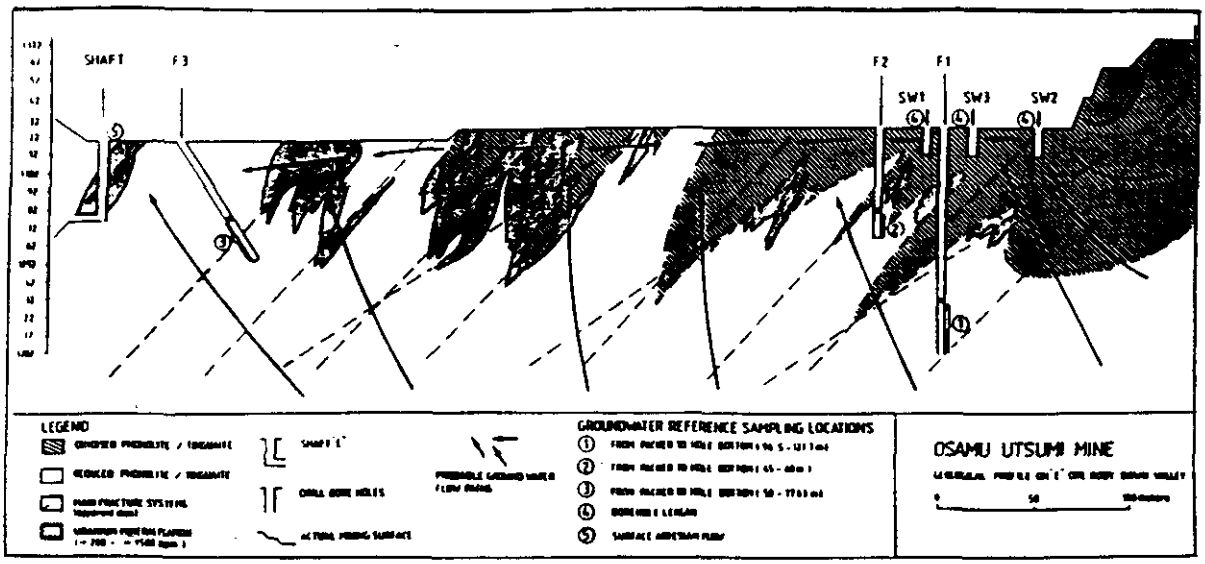

Figure 10. An example of a cross section from the Osamu Utsumi Mine, Poços de Caldas (Test Case 7a).

much further downward than the average depth of the front (Figure 10). Pitchblende modules with typical sizes between 0.5–1 cm and nearly spherical in shape, are found in many places just below the redox front in the reduced rock.

A very large amount of data has been collected from the open pit uranium mine. A complete dataset will, however, not be available until early 1990. At present the dataset includes:

- detailed maps of the vertical walls showing the location of the redox front and the concentration profiles of uranium,
- substantial information on rock chemistry, mineralogy, petrography, physical properties, uranium series disequilibria,
- the chemistry of waters at different depths in the boreholes,
- hydraulic conductivities measured in the boreholes and in the rock matrix,
- porosities and diffusivities in the rock matrix,
- content of colloids and their composition,
- information on microbiological activity,
- infiltration rates,

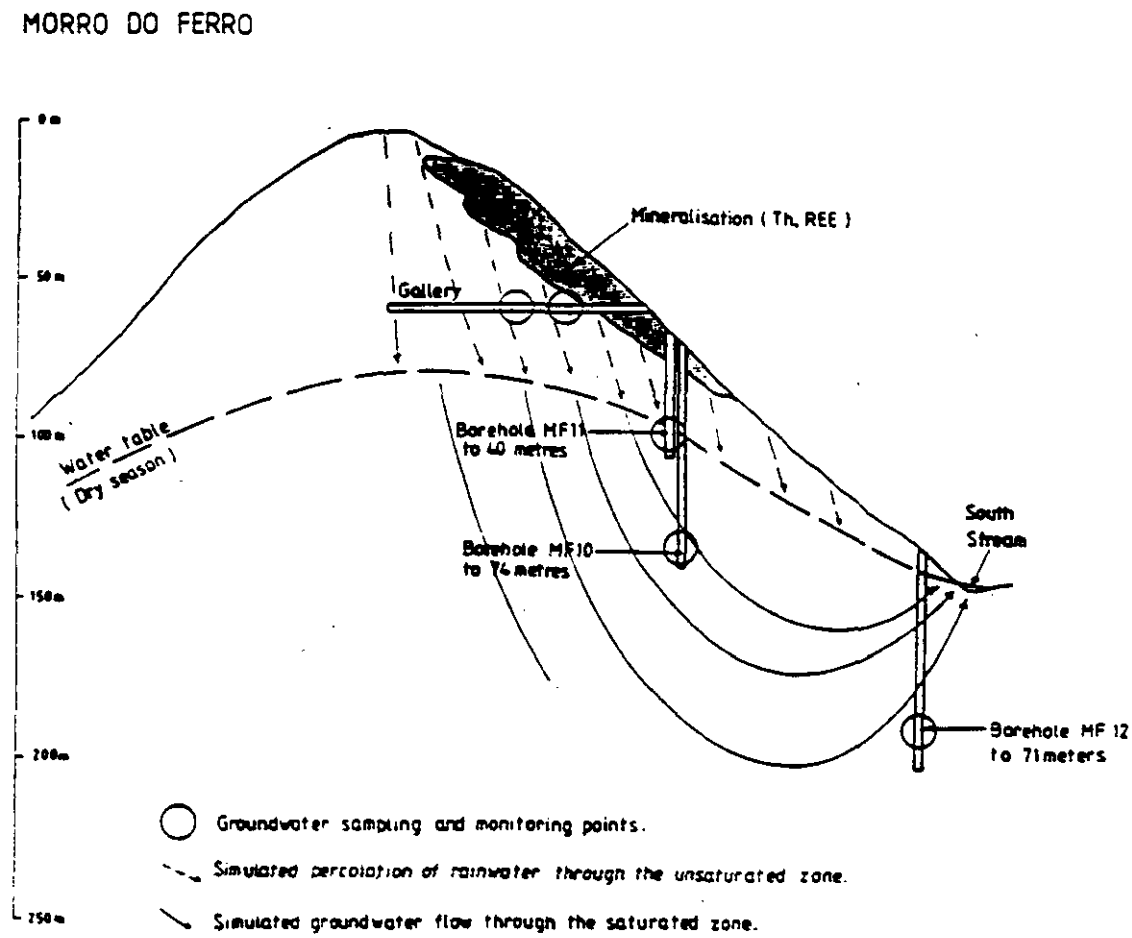

Figure 11. A schematic illustration of the Morro de Ferro site (Test Case 7b).

— results from some geochemical modelling and from hydraulic modelling of groundwater flow patterns and velocities in the area of the mine prior to excavation as well as with the mine in its present state.

TEST CASE 7b

Morro do Ferro colloid migration studies.

The basic geology of Morro do Ferro is a fractured volcanic complex containing a massive magnetite dyke system with surrounding magnetite-rich breccia. The whole system has been extensively altered both by hydrothermal activity and weathering processes. The upper tens of metres are a lateritic soil composed of kaolinite, illite, gibbsite, and accessory minerals including jarosite and magnetite. The rock is extensively oxidised, but in one borehole a redox front occurs at 35 m, with pyrite occurring in the un-oxidised phonolite below it.

The water table is a subdued reflection of the topography. At the top of the hill the water table is at least 80 m below the surface fluctuating by at least 20 m between the wet and dry seasons (Figure 11). In the valley bottom the water table is at or near the surface, coinciding with seepages or discrete springs.

High concentrations of Th and REE (rare earth-elements) can be observed in organic-rich surface and unsaturated zone waters. Humic compounds seems to be the predominant complexants in these waters; Th, REE's, Fe and Mn are present mostly as colloids. Interaction of these species with the rocks are responsible for low concentrations of Th/REE and DOC (dissolved organic carbon) in the groundwaters.

The chemistry of the groundwater in four reference zones has been monitored to establish a basic data set and any seasonal variability. The groundwater has been characterised regarding major and trace element content, natural series content, rare earth elements, organic chemistry, electrochemistry, etc. Colloidal material has been extracted from these reference waters and characterised for composition, size and Th/REE content. Simple hydraulic testing has been performed to establish the properties of the rock. A complete dataset will be available in the beginning of 1990.

TEST CASE 8

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia.

Introduction

This test case deals with the analogue studies in the Alligator Rivers region of the Northern Territory of Australia commenced in 1981. The work that has been carried out can be divided into four broad categories:

— radionuclide distribution in rock samples and rock fractures,
— the role of groundwater and colloids in radionuclide transport,
— the production and dispersion of the fission products ^{129}I and ^{99}Tc, and transuranics ^{239}Pu,
— development of modelling codes and evaluation of the Koongarra site for modelling studies.

A comprehensive experimental and modelling program has been agreed to by the participants (ANSTO, JAERI, PNC, SKI, HMIP/DoE and U.S. NRC) of the NEA/OECD co-ordinated project which will continue the earlier work carried out in the US NRC funded project. The work will be aimed of supporting modelling studies. An initial task of the project will be the establishment of a comprehensive data base and the provision of sectional contour representations of the data.

General Description

The uranium deposits of the Alligator Rivers region occur near the base of Lower Proterozoic (Cahill Formation) schists. They are located in zones of chloritisation within the schists and are adjacent to lenses of massive dolomite.

The Koongarra uranium mineralization occurs in two distinct ore bodies separated by a barren gap. Both bodies consist of primary zones containing uraninite veins within a zone of steeply-dipping, sheared quartz-chlorite schists of the lower member of the Cahill Formation, which is adjacent to a steeply-dipping reverse fault that brings the schists into contact with the Kombolgie sandstone. In the No 1 ore body, which is the subject of this study, secondary mineralisation is present in the weathered schists from near the surface down to the base of weathering at a depth of 25-30 m, and forms a tongue-like fan of ore grade material extending down-slope for about 80 m (Figure 12). There is little indication of secondary mineralisation in the No 2 ore body where the primary zone is intersected in unweathered rock from 50 m to at least 250 m below the surface.

The study region, in common with much of northern Australia, has a monsoonal climate with almost all the rainfall occurring in a wet season between November and March.

General migration of groundwater is from the north, at the foot of a prominent south facing escarpment, towards the south through the ore deposit with natural groundwater discharge taking place by evapotranspiration and direct discharge into a stream in the southern part of the site during the wet season. Rainfall records have been kept for the last 17 years and water levels in 61 wells have been monitored for various periods up to 7 years in duration since 1971.

The Koongarra ore zone has been extensively explored, but as yet Australian Government policy has restricted its development as a uranium mine.

Data Collection Activities

The geological data available is based on the mineralogical and uranium assay logs of 140 percussion holes and 107 drill cores in the immediate vicinity of the uranium deposit, together with data on over 300 backhoe pits and auger holes, geophysical surveys and geologic maps of surface exposures. The drill core material and pulp from the percussion holes is stored at the site and is available for examination. This material has been the subject of an extensive measurement program which studied the distribution of uranium and thorium series radionuclides in the region of the ore body. A computer data base is presently being established.

Hydrogeologic characterisation of the bedrock has been obtained from 24 drawdown and recovery tests and 50 water pressure tests. Five aquifer tests have also been made to help characterise the flow system in the bedrock.

Further hydrogeologic work is in progress to help determine possible trajectories and travel times. This work is aimed at investigating whether the groundwater flow is primarily along fractures even in the highly weathered zone, and what is the general depth of transition between matrix flow and fracture flow. Connections, if any, between groundwater in the bedrock and groundwater in the surficial deposits will also be investigated. These new data would generally be of a higher quality than much of the previous data that was obtained under other conditions and primarily for other purposes (potential for mining).

A base body of general hydrochemical data exists. Analyses for various radionuclides have been made. These radionuclides include ^{238}U, ^{234}U, ^{226}Ra, ^{222}Rn, ^{232}Th, ^{230}Th, ^{129}I, ^{99}Tc, ^{36}Cl, ^{14}C and ^{3}H. A number of stable nuclides have also been determined. Further work in isotope hydrochemistry and additional complete chemical analyses of water within and around the ore deposit are in progress.

A study of the geomorphology of the area is being made to try to obtain a general idea of the geological and hydrogeological history of the site. Important components to understand are formation of the escarpment, onset of the weathering, influences of erosion/deposition of loose materials, effects of glaciation i.e., changes in sea-level and in climate and precipitation.

TEST CASE 9

Radionuclide migration in a block of crystalline rock based on laboratory experiments performed at AECL, Canada.

Introduction

This test case is based on laboratory experiments on migration of tracers in a single fracture in a large block of granite. The experiments were performed at AECL, Canada, and the aim was to calibrate relevant fracture transport parameters and transport model(s). The experiments ad-

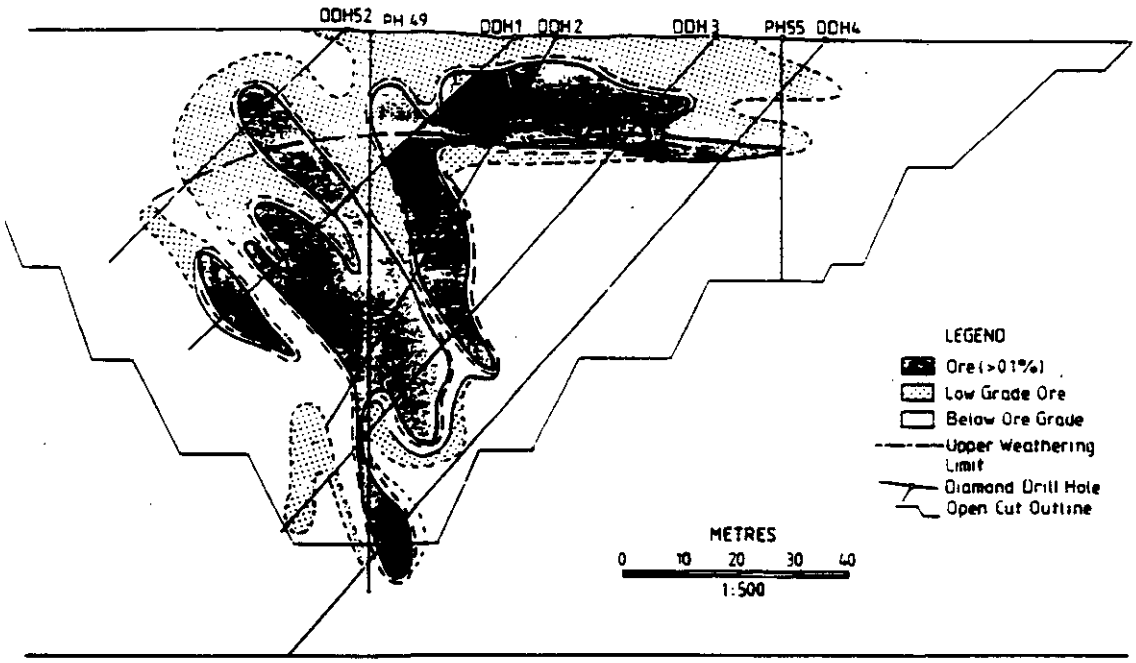

Figure 12. Cross section showing the dispersed zone at the Kongarra deposit (Test Case 8).

dress important phenomena in radionuclide transport in the geosphere such as sorption, dispersion, channelling, matrix diffusion and fracture properties.

General Description

The granite block (length 91.5 cm, width 86.5 cm, height 49.0 cm) contains a single natural fracture. The fracture aperture was estimated from the volume of water required to completely fill the fracture to be approximately 800 µm. The block was positioned so that the fracture was approximately horizontal. The outside surface of the block, as well as the edges of the fracture on the long sides, were coated with a silicone-based rubber to avoid evaporation of the transport solution through the porous matrix. Inlet and outlet reservoirs were attached to the short sides of the block covering the fracture where it intersects these surfaces of the block. This way a uniform gradient was created across the entire width of the fracture. The outlet reservoir was divided into five compartments which were sampled in sequence by solenoid valves, see Figure 13.

To determine the longitudinal dispersivity experiments with the non-sorbed tracer uranine were performed. After that, runs with the tracers iodine and caesium were made. To determine the sorption of caesium on the rock, independent, static, batch-type experiments were also performed. The fracture was then opened and the flow paths were investigated with alfa-autoradiography. The fracture surface has also been examined with gamma scan.

Summary of Available Data:

- flow rates in the experiments,
- rock porosity and density,
- rock and groundwater composition,
- caesium sorption data,
- breakthrough curves for non-sorbed uranine,
- breakthrough curves for caesium and iodine.

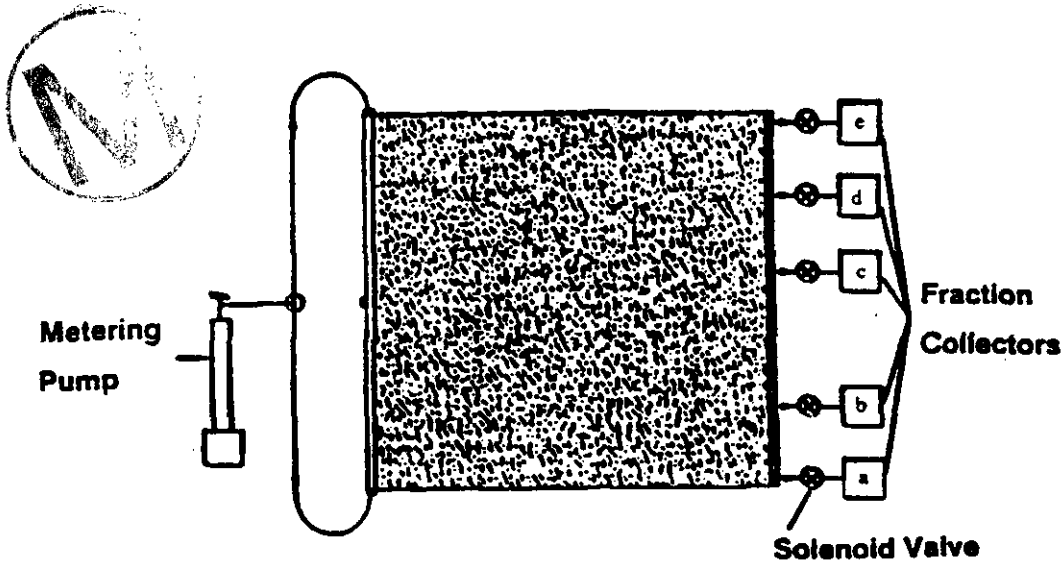

Figure 13. Schematic plan view of the arrangement of the inlet and outlet reservoirs on the large block (Test Case 9).

TEST CASE 10

Evaluation of unsaturated flow and transport in porous media using an experiment with migration of a wetting front in a superficial desert soil performed within a U.S. NRC trench study at Las Cruces, New Mexico.

Introduction

This test case are foreseen to give the opportunity to validate parameters and models relevant for radionuclide transport in unsaturated soils. The experimental location is the New Mexico State University College Ranch, 40 km north-east of Las Cruces, New Mexico, USA.

General Description

The field site is on a basin slope of a mountain. The geologic features, geomorphic surfaces, soil series and vegetation types found in the area around the field test are typical of many areas of southern New Mexico and are similar to arid and semiarid areas of the southwestern United States.

The climate in the region is characterized by an abundance of sunshine and low relative humidity. Average annual precipitation is 23 cm with about 50 % of the rainfall occurring between July 1st and September 30th.

A trench 16.5 m long, 48 m wide and 6.0 m deep has been dug in the undisturbed soil. Two irrigated areas measuring 4x9 m and 1x12 m respectively are adjacent to the trench (Figure 14). In the first test water containing a conservative tracer, tritium, has been applied at a controlled rate of 1.76 cm·day-1 on the surface of one side of the trench. The movement of water below the soil surface has been monitored with neutron probes and tensiometers as well as by visual observations of the water movement on the trench wall. In a second test, water containing tritium and bromide has been applied at a controlled rate of 0.5 cm·day^{-1} on the surface at the other side of

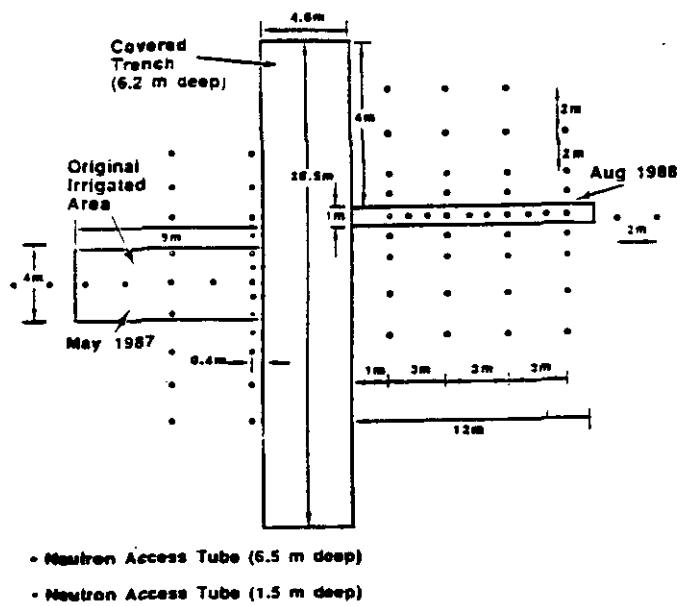

Figure 14. Top view of the trench with irrigated areas (Test Case 10).

the trench. The irrigated area in the second test is only 1 m wide, this test will therefore be used to study the lateral spreading of the wetting front.

Parameters Evaluated

The parameters measured or evaluated are hydraulic conductivity values, characteristic curves for the range of saturation to field water contents, specific water capacity, soil property parameters, moisture content or moisture profiles as a function of time, tension data and visual observation of wetting front advances.

In addition to the field experiment, laboratory column tests can be used to define transport parameters, such as Peclet number and dispersion coefficients.

TEST CASE 11

Evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap Tuff Site near Superior, Arizona.

Introduction

This test case deals with transport in unsaturated fractured rock. It includes both field and laboratory experiments. The field experiment is located at the Apache Leap Tuff Experimental Area in non-welded to welded tuff near Superior, Arizona, USA. The laboratory experiments are carried out on larger blocks and on cores from the site. The purpose with the test case is to validate parameters and models relevant for radionuclide transport in fractured unsaturated media against data sets.

Field Experiment

Nine inclined boreholes have been installed in three rows of three boreholes per row. The boreholes within a row are echelon at 10 m intervals. The rows are 5 m apart (Figure 15). The surface of the site has been covered with a plastic sheet to reduce natural infiltration and evaporation. The experiments in the boreholes include interval testing for temperature, water content and saturated hydraulic conductivity. Also, pneumatic properties are tested on intervals.

The parameters measured or evaluated are hydraulic diffusivity, moisture characteristic, hydraulic conductivity, specific water capacity, soil property parameters, saturated hydraulic conductivity, physical properties, borehole temperatures, borehole water contents and borehole air flow rates.

Many of the borehole analyses are repetitively measured during different seasons. All the moisture-dependent hydraulic parameters are measured at three meter intervals.

Additional experiments in an abandoned road tunnel and in a mine haulage tunnel located nearby will also provide important data. Comparison of parameters between sites should allow models developed at one site to be verified at another.

Block Experiment

Several laboratory experiments have been conducted on blocks containing a single fracture. The blocks were removed from outcrops located near the Apache Leap Tuff Site and subsequently shaped so that the fracture is located through the center of the block (Figure 16).

Preliminary saturated steady-state flow and transport experiments were performed on a block with the dimensions 20 cm x 20 cm x 49.5 cm (block 1). The main purpose was to test and refine the experimental setup as well as test and calibrate the instrumentation.

A transient imbibition experiment was performed on a block with the dimensions 21 cm x 20 cm x 66 cm (block 2). A constant suction was applied at the top of the block and the bottom of the block was left open to the atmosphere. Visual wetting

front locations were measured through time.

A series of steady-state flow and transport experiments are currently being performed on block 2. The matrix is held under constant suction at the top and bottom of the block. The fracture has a constant suction applied at the top, and it is open in the bottom, allowing flow to leave the block. Once steady-state flow occurs in the fracture, a pulse of non-sorbed tracer will be applied to the fracture only and the concentration monitored along the fracture and in the fracture outflow.

Core Experiment

A non-welded tuff core measuring 12.72 cm in length and 6.4 cm in diameter was oven dried and then partially wetted to a saturation of 48% with a solution of potassium iodide. The core was then coated with a sealment to prevent moisture or air from leaving the core. The core was also thermally sealed with foam insulation along its length, while a constant temperature (5 and 70°C) was maintained at both ends for a period of 32 days (Figure 17).

During the course of the experiment, temperature and saturation were measured at 1 cm intervals away from the cold end of the core. The final solute concentration along the core was obtained by sawing the core into eight sections and analysing water collected from each section.

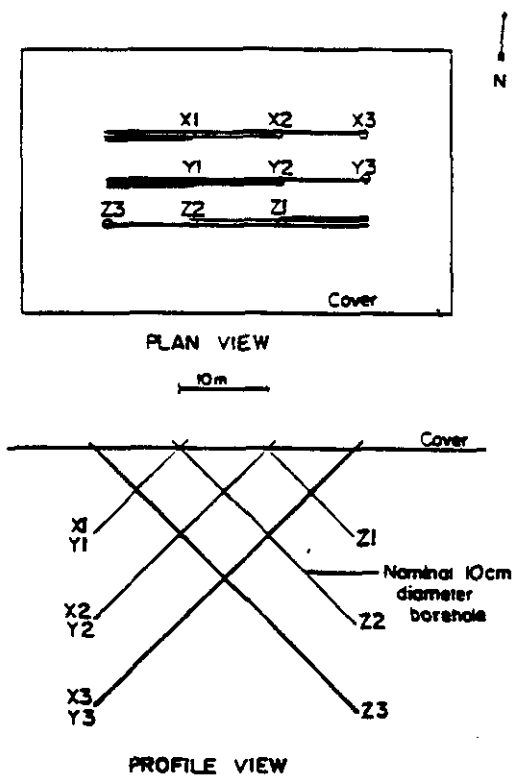

Figure 15. Borehole configuration at Apache Leap Tuff Site (Test Case 11).

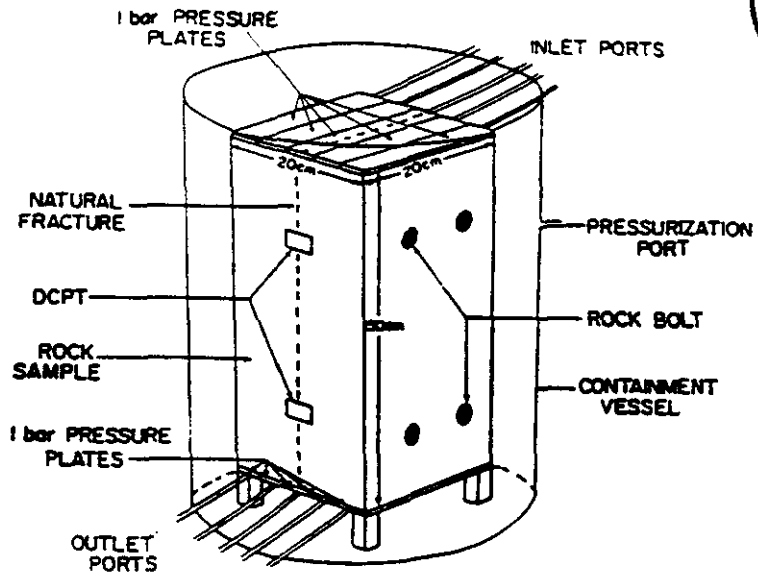

Figure 16. Experimental set-up for unsaturated fracture-matrix flow studies (Test Case 11).

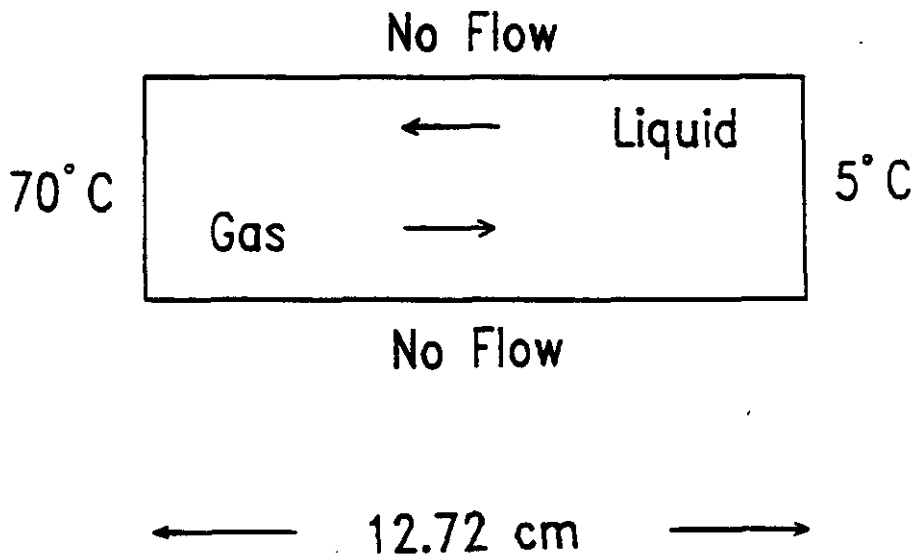

Figure 17. Schematic view of the core experiment (Test Case 11).

TEST CASE 12

Experiments with changing near-field hydrologic conditions in partially saturated tuffaceous rocks performed in the G-Tunnel Underground Facility at the Nevada Test Site performed by the Nevada Nuclear Waste Investigation Project of the U.S. DOE.

Introduction

This test case deals with near-field effects in partially saturated Tuffaceous rocks produced by propagating transient disturbances. The experimental location, the G-Tunnel Underground Facility, Nevada Test Site, is located about 110 km north of Las Vegas, Nevada, USA.

General Description

The objectives with the tests are to:

- Obtain rock-matrix and fracture-system calibration data for partially saturated welded and non-welded tuffaceous rocks,
- Predict hydrologic system flux and velocity fields in response to imposed time and spatially variable disturbances,
- Predict system long-term recovery and reequilibration following disturbance termination,
- Compare model predictions with experimental field data collected during both the short-term transient and long-term recovery periods.

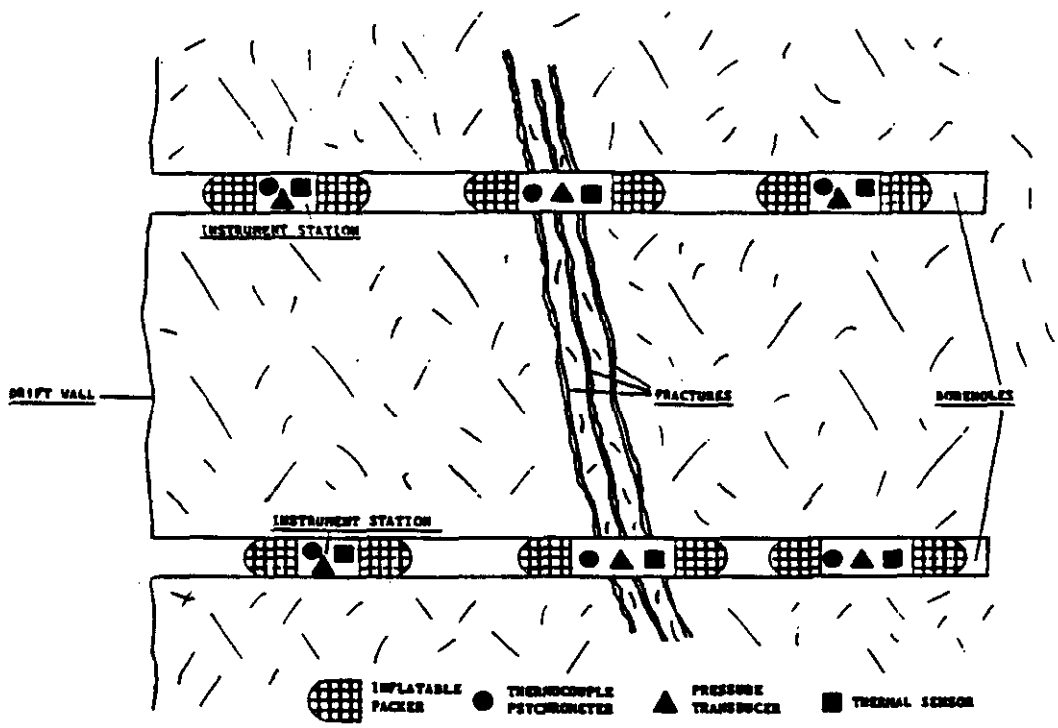

Figure 18. Schematic plan of borehole pair instrumented for long-term monitoring (Test Case 12).

The field-experimental design consists of continuously coring pairs of horizontal boreholes into both non-welded tuff and into fractured, welded tuff. The boreholes will be about 10 m in length and 10 cm in diameter with a separation of about 6 m (Figure 18). The core with a diameter of about 6 cm will be encased in plastic as coring proceeds in order to minimize drilling-fluid contact with the core. One of each pair of boreholes will be drilled and cored using air as drilling fluid and the other will be drilled and cored using water.

Data to be Measured

The borehole logging consists of caliper logs, TV camera logs and neutron moisture meter logs. At the completion of the logging each borehole is instrumented. The dry-cored boreholes are instrumented first in order to monitor any crosshole effects caused by the drilling of the wet-cored boreholes. Instrument stations are placed in all four boreholes and will remain in place until the isolated areas of the boreholes have reached equilibration. Each instrument station consists of pressure transducer, thermal sensor and thermocouple psychrometer. Gas-phase tracers are injected into the water and air drilling fluids in order to test for cross-hole hydrologic connections. Fracture zones and unfractured matrix will be isolated and instrumented. Interconnecting fractures will be instrumented if they are encountered.

Laboratory techniques are used to determine the effects of drilling fluids on the hydrologic condition of the core samples. Laboratory experiments are used to measure or evaluate bulk density, grain density, porosity, water content, water potential, water characteristic curves, saturated and unsaturated hydraulic conductivity, imbibition, heat capacity and thermal conductivity.

The effects of capillary hysteresis are investigated in a suite of complementary imbibition and moisture-release experiments. These also provide an independent set of transient data set.

TEST CASE 13

Experimental study of brine transport in porous media performed at RIVM, the Netherlands.

Introduction

This test case describes flow and mass transport in high-concentration situations. This is of importance for studies related to radioactive waste disposal in deep geological formations where high concentrations of dissolved salts are encountered in the host rock or in overlaying aquifers.

General Description

The experimental setup is a column; 0.6 m long, 0.01 m wide and 1.25 m high, filled with glass beads, see Figure 19. Fluid can be circulated through the bed. The pressure head along the bed is monitored by nine sets of manometers and three electric pressure transducers. The salt concentration of the fluid can be measured at sixteen points by electrodes. Two sets of experiments have been performed: one set at low salt concentrations to evaluate porosity, permeability and dispersivity of the porous media and another set at high salt concentrations to record the salt mass fraction and pressure along the bed.

Data Available:

- mass fraction profiles (breakthrough curves) for the electrodes
- temperature of the fluid during the experiment
- salt mass fraction in fluid entering the column
- pressure distribution in the column
- total flow rate during the experiment

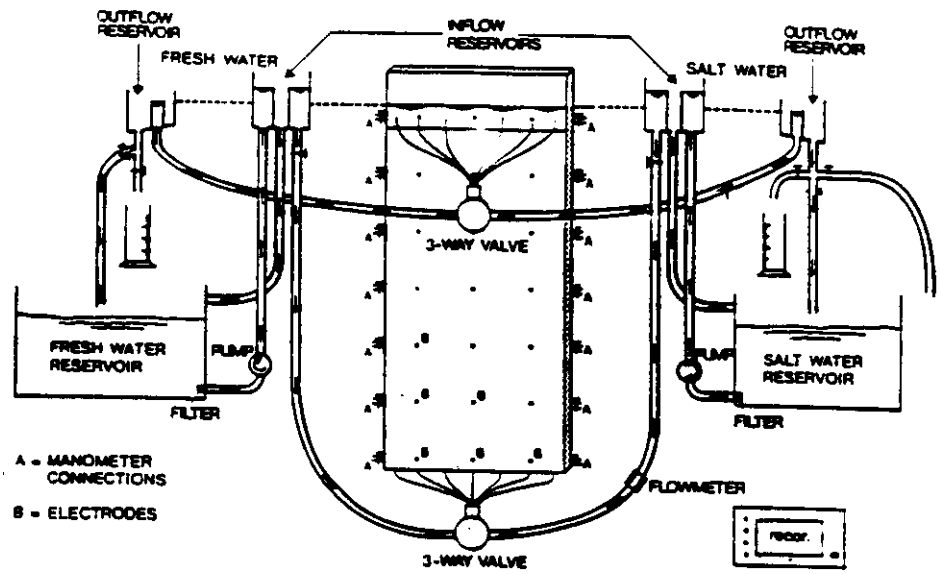

Figure 19. Experimental set-up (Test Case 13).

TEST CASE 14a and 14b

Groundwater flow in the vicinity of the Gorleben Salt Dome, the Federal Republic of Germany.

Introduction

The Gorleben Salt Dome is located in the northeastern part of Lower Saxony in the Federal Republic of Germany. An erosional channel crosses the salt dome from south to north. Test case 14a is based on a pumping test carried out in a section of this channel. Test case 14b is concerned with saline groundwater movement in the same channel.

General Description

The channel crossing the Gorleben salt dome is more than 10 km long and its widths varies between 1-2 km. In this erosional channel a fairly thick sequence of coarse to medium-grained (glaciofluvial) sands has been deposited with intercalations of till. The channel is overlain by silt and clay up to 110 m thick.

The fresh water body is underlain by rather saline groundwater. The salt content usually increases with depth and, especially above the salt dome, reaches saturation at depths greater than 220 m below sea level.

TEST CASE 14a

Pumping test in highly saline groundwater.

This test case provide the opportunity to observe the behaviour of a groundwater system filled with high saline water under simplified conditions (i.e. a system where the conductive flow is predominant).

The deeper aquifer in the erosional channel with saline water was pumped

during 3 weeks (Figure 20). The pump test was carried out with a pumping rate of 30 m^3 per hour. About twenty observation wells were monitored more than once a day for five weeks and even more often thereafter. The water level in the closest observation wells were monitored with an ultrasonic apparatus with a precision better than 1mm. Electrical conductivity logs were made in the observation wells before and after the pump test to give information on changes in the salinity distribution in the wells. The electrical conductivity and the amount of water pumped were recorded continuously during the test.

In addition to the pump test selected as an INTRAVAL test case, three other pump tests at higher pumping rates have been performed in the area. The geological and hydrogelogic situation in the aquifer system in the sediments above the dome have been investigated extensively providing large amounts of background information such as, porosity, permeability, chemical compositions etc.

TEST CASE 14b

Saline groundwater movement in an erosional channel crossing a salt dome.

This test case is based on the extensive experimental programme briefly mentioned in test case 14a. The test case concerns the description of the regional complex groundwater flow system in the Gorleben area, including variable density of the groundwater due to salinity.

The first step of this test case could be to describe the present flow situation in the erosional channel crossing the salt dome. This could then be followed up by simulations of behaviour of the salt/fresh water system as a whole during the next thousand years to check whether the modelling of the present situation was sufficient as no significant short term changes in the flow system of salt transport is expected.

Another approach could be to begin the simulations with fresh water and an appropriate source term for the rate of salt dissolution. The calculations could be made for non-steady state conditions until the model correspond to the present situation. If ^{14}C values from water samples is included in the database, transport calculations based on a density-dependent flow system can also be performed.

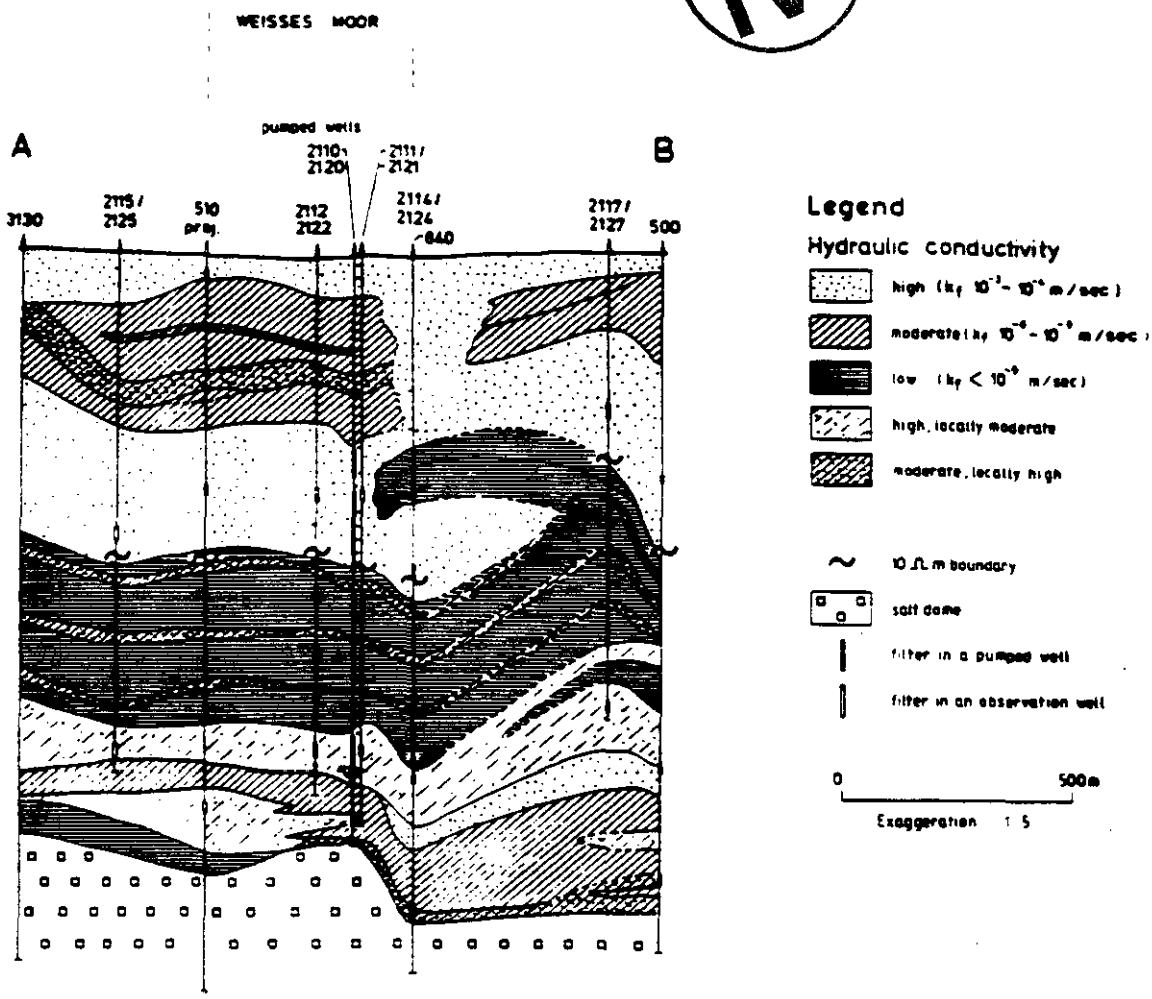

Figure 20. Hydrogeological cross section (Test Case 14).

Appendix 3

List of Test Case Related Presentations at INTRAVAL Workshops

TEST CASE 1a

Bogorinski P., Larue J. and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overwiew of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R. and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A. and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G. and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G. and Medina A., Application of Experiment Design Methods to Test Case 1a. INTRAVAL., INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A. and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P. and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J. and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K. and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K. (CSD) and Ikeda Y. (MAPI), PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R. and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R. and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 1b

Bischoff K., Hadermann J. and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J. and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J. and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E. and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., A Note on the Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Grindrod P. and Hodgkinson D., The Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A., Preliminary VTT Results on Test Case 1b, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Channels as Migration Routes in Crystalline Rock Samples, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Preece T.E. and Sumner P.J., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Sumner P.J. and Preece T.E., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Jakob A., Hadermann J. and Zingg A., PSI New Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Kjellbom K., Moreno L. and Neretnieks I., Preliminary Evaluation of Some Uranium Migration Tests, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 2

Aimo N.J., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Cole C.R. and Aimo N.J., Investigating a Parameter Estimation Approach to Design of Validation Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Gureghian B., Radionuclide Migration in Single Natural Fissures in Granite, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., Preliminary Results of Test Case 2 Study, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Previous Modelling of Test Case 2 Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 2, INTRAVAL Workshop, Tucson, November 1988.

Skagius K., Presentation of Test Case 2, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 3

Cole C., INTRAVAL Test Case 3, Experiments and Model Calculation, INTRAVAL Workshop, Barcelona, April 1988.

Cole C. and Aimo N.J., Presentation of Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Andersson J., Comments on INTRAVAL Test Case 3, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K. and Umeki H., Calculation of the Concentration of a Dispersive Tracer Solute by Means of Numerical Solution of the Balance Equation, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., Modelling of Test Case 3 by Using a Numerical Method, INTRAVAL Workshop, Tucson, November 1988.

Kimura H. and Yamashita R., Preliminary JAERI Results on Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 4

Andersson J., Discrete Network Analysis of Tracer Experiments in Stripa 3D, INTRAVAL Workshop, Las Vegas 1990.

Dverstorp B., Application of the Discrete Fracture Network Concept on Field Data: Possibilities of Model Calibration and Validation, INTRAVAL Workshop, Barcelona, April 1988.

Dverstorp B. and Nordqvist W., Flow and Transport Simulations with a Discrete Fracture Network Model, INTRAVAL Workshop, Helsinki, June 1989.

Hodgkinson D., Shaw W. and Barker J., Modelling by Flows in Continuous Dimension, INTRAVAL Workshop, Tucson, November 1988.

Hodgkinson D., Shaw W. and Grindrod P., Preliminary Fractal Analysis of the Stripa 3D Migration Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Presentation of Test Case 4: 3D Migration Experiment at Stripa, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 4, INTRAVAL Workshop, Tucson, November 1988.

Tsang Y.W. and Tsang C.F., Understanding Stripa 3-D Tracer Migration Data, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 5

Andersson P., Experimental Results and Further Plans, INTRAVAL Workshop, Tucson, November 1988.

Andersson P., Recent Experimental Results, INTRAVAL Workshop, Helsinki, June 1989.

Andersson P., Proposal for Simulation of Hydraulic Interference Tests, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P. and Worth D., Do the Pulse Injection Experiments Exhibit Radially Convergent Fracture Flow?, INTRAVAL Workshop, Las Vegas, February 1990.

Gustafsson E., Andersson P. and Wikberg P., Recent Achievements in the Performance and Evaluation of the Finnsjön Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A. and Taivassalo V., Generalised Taylor Dispersion Analysis for Tracer Breakthrough in the Radially Converging Experiment of Finnsjön (test case 5), INTRAVAL Workshop, Barcelona, April 1988.

Hautojärvi A. and Taivassalo V., Pre-Test Calculations of VTT-Team for Radially Converging Test, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Taivassalo V. and Vuori S., Interpretation of Results of the Radially Converging Test, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V. and Vuori S., Preliminary Predictive Modelling of the Dipole Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V. and Vuori S.,Interpretation of Test Case 5, Radially Converging Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H. and Katsuragi T., Predictive Modelling of the Dipole Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Helsinki, June 1989.

Kimura H., Kasturagi T. and Yamashita R., Preliminary Results of the Radially Converging Tracer Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Las Vegas, February 1990.

Moreno L. and Neretnieks I., Preliminary Evaluation of Tracer Test in Finnsjön. Radial Converging Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Introduction to Test Case 5, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Preliminary Predictions of Finnsjön Tracer Tests, INTRAVAL Workshop, Barcelona, April 1988.

Nordquist R., Numerical Predictions of a Dipole Tracer Test in a Fracture Zone in the Brändan Area, Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Winberg A., Geostatistical Analysis of Hydraulic Conductivity Data at Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Yamashita R. and Kobayashi A., Preliminary Calculations Using Fracture Network Approach for Tracer Test in Finnsjön Site, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 6

Codell R., Cole C. and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem VI, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Cole C. and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem 6, INTRAVAL Workshop, Helsinki, June 1989.

Codell R. and Trösch J., Calculation of Synthetic Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Vomvoris S., On the Synthetic Experiment, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 7a

Neretnieks I., Presentation of Test Case 7a: Redox Front and Uranium Movement at Pocos de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 7a: Redox Front Movement, INTRAVAL Workshop, Tucson, November 1988.

Neretnieks I., Redox Front Studies at Pocos de Caldas, INTRAVAL Workshop, Las Vegas, February 1990.

Romero L., Moreno L. and Neretnieks I., Poços de Caldas. The Location of the Redox Front, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 7b

Chapman N., Presentation of Test Case 7b: Colloid Transport, INTRAVAL Workshop, Tucson, November 1988.

Noy D., Presentation of Test Case 7b: Colloid Mobility at Poços de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 8

Davis S., Hydrology Sub-Project, INTRAVAL Workshop, Tucson, November 1988.

Duerden P. and Golian C., Presentation of Koongarra and Draft Test Case, INTRAVAL Workshop, Barcelona, April 1988.

Duerden P., Presentation of Test Case 8, INTRAVAL Workshop, Tucson, November 1988.

Duerden P., Update of Recent Field Work, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., Koongarra Test Case: Modelling Progress, INTRAVAL Workshop, Tucson, November 1988.

Golian C., Hydrodynamic Transport through Porous Media which Contain Two Iron Mineral Phases, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., A Quasi Two Dimension Open Sytem/Transport Model to Describe the Mobility of the Bulk Uranium, INTRAVAL Workshop, Las Vegas, February 1990.

Lever D., Koongarra Transport Modelling, INTRAVAL Workshop, Barcelona, April 1988.

Nijhoff-Pan I., Discussion on Test Case 8: Alligator Rivers (Koongarra) Ore Deposit, INTRAVAL Workshop, Helsinki, June 1989.

Slot A.F.M., Proposed Modelling Approach for the INTRAVAL Test Case 8, Alligator Rivers, Koongarra Ore Deposits, INTRAVAL Workshop, Las Vegas, February 1990.

Sverjensky D., Geochemical Aspects of the Alligator River Analogue Project, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 9

Hautojärvi A., Preliminary Calculations of Migration in the Fracture Channels, INTRAVAL Workshop, Helsinki, June 1989.

Kobayashi A. and Yamashita R., Preliminary Results on Test Case 9 by Using the Non-Uniform Velocity Distribution, INTRAVAL Workshop, Helsinki, June 1989.

Noronha C.J. and Gureghian A.B., Description of Granite Block Experiment for Test Case 9, INTRAVAL Workshop, Barcelona, April 1988.

Noronha C.J. and Gureghian A.B., Large Block Migration Experiments, INTRAVAL Workshop, Tucson, November 1988.

Rasilainen K., Hautojärvi A and Vuori S., Preliminary Interpretation of Test Case 9 using FTRANS-code, INTRAVAL Workshop, Las Vegas, February 1990.

Vandergraaf T.T., Grondin D.M. and Drew D.J., Contaminant Transport Laboratory Studies in a Single, Natural Fracture in a Quarries Granite Block at a Scale of 1 Metre, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 10

Ababou R., High-resolution Modeling of 3D Flow Fields, INTRAVAL Workshop, Las Vegas, February 1990.

Bensabat J., Stochastic Modelling of the First Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Gee G., Deterministic Modeling and Considerations for Transport Analysis of the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Gelhar L., Applications of the Stochastic Model to the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., Updegraff C.D. and Davis P.A., A 2-D Deterministic Model of the Las Cruces Trench Infiltration Experiment, Preliminary Results, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T. and Davis P.A., A Statistical Analysis of the Las Cruces Trench Hydraulic Data, INTRAVAL Workshop, Helsinki, June 1989.

Goodrich M.T. and Gribble A.R., Data Analysis and Modelling of the Las Cruces Trench Second Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Hills R.G., Hudson, D.B., Porro I. and Wierenga P.J., Modelling the Layered Soil Lysimeter Study at Las Cruces, INTRAVAL Workshop, Tucson, November 1988.

Hills R. and Wierenga P., Water Flow and Solute Transport at the Las Cruces Trench Site, INTRAVAL Workshop, Las Vegas, February 1990.

Kool J.B., Simulations of Water Flow and Tritium Transport at the Las Cruces Trench, INTRAVAL Workshop, Las Vegas, February 1990.

McLaughlin D., Model Validation Issues for Unsaturated Flow Systems, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Presentation of Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Introduction, Test Case 10, INTRAVAL Workshop, Helsinki, June 1989.

Rasmuson A., Lindgren M. and Collin M., Flow and Transport Simulations of the Second Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Smoot J.L., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Smyth J.D., Infiltration Simulations of the Jornada Trench with a Multidimensional Monte Carlo Code, INTRAVAL Workshop, Las Vegas, February 1990.

Updegraff D., 1-D Analytical Solutions on Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Field and Laboratory Experimental Results with Emphasis on Transport, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Hills R. and Hudson D., Flow and Transport Data Analyses of the Las Cruces Trench Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 11

Bradbury J., Evaporation in Unsaturated Fractured Rock - an Alternative Conceptual Model, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Transport in Two-Phase Flow in Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Evans D., Field and Laboratory Experimental Results, INTRAVAL Workshop, Tucson, November 1988.

Evans D., Rasmussen T. and Sully M., Rock Matrix Characterization in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T. and Sully M., Non Isothermal Core Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T. and Sully M., Crosshole Pneumatic Testing at the Apache Leap Tuff Site, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T. and Sully M., Laboratory Fracture Flow Experiments in Apache Leap Tuff. INTRAVAL Workshop, Las Vegas, February 1990.

McCartin T., Simulation of the Apache Leap Tuff Site Borehole Experiment, INTRAVAL Workshop, Tucson, November 1988.

McCartin T., Two-Phase Flow Simulations in a Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Nicholson T., Presentation of Test Case 11, INTRAVAL Workshop, Tucson, November 1988.

Parsons A.M. and Davis P.A., Modeling Strategy and Data Analysis for the Apache Leap Tuff Block Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Rasmussen T., Modelling of Field and Laboratory Experiments, INTRAVAL Workshop, Tucson, November 1988.

University of Arizona, Field and Laboratory Experiments in Unsaturated Fractured Tuff, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 12

Hoxie D.T., Empirical Validation of Hydrologic Model Simulations of Changing Near-Field Hydrologic Conditions, INTRAVAL Workshop, Barcelona, April 1988.

Hoxie D.T., Flint A.L. and Chornack M.P., Model Validation with Respect to Short-Term Dynamic Effects and Long-Term Transient Effects, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 13

Arens G., Preliminary Results on Test Case 13, INTRAVAL Workshop, Helsinki, June 1989.

Arens G. and Fein E., One-dimensional Brine Transport in Porous Media, INTRAVAL Workshop, Las Vegas, February 1990.

Hassanizadeh S.M., Presentation of Experimental Results from Brine Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Hassanizadeh S.M., Experimental Study of Brine Transport in Porous Media, INTRAVAL Workshop, Tucson, November 1988.

Hassanizadeh S.M. and Leijnse T., Simulation of the Brine Transport Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Hassanizadeh S.M., Latest Results on Simulation of Brine Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Schelkes K., Preliminary BGR Results, INTRAVAL Workshop, Helsinki, June 1989.

Schelkes K. and Knoop R.-M., Results of Modelling the Salt Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 14

Glasbergen P., Proposals for Test Cases Related to Rock Salt, INTRAVAL Workshop, Barcelona, April 1988.

Schelkes K., Pumping Test in Highly Saline Groundwater - a Proposed Test Case, INTRAVAL Workshop, Tucson, November 1988.

Schelkes K., Saline Groundwater Movement in an Erosional Channel Crossing a Salt Dome - Working Program for a Test Case, INTRAVAL Workshop, Tucson, November 1988.

INTRAVAL Parties:

Agence Nationale pour le Gestion des Déchets Radioactifs (France), Atomic Energy of Canada Ltd. (Canada), Australian Nuclear Science and Technology Organisation (Australia), Bundesanstalt für Geowissenschaften und Rohstoffe/Bundesamt für Strahlenschutz (Federal Republic of Germany), Commissariat à l'Energie Atomique/Institut de Protection et de Sûreté Nucléaire (France), Empresa Nacional de Residuos Radioactivos S.A. (Spain), Gesellschaft für Reaktorsicherheit (Federal Republic of Germany), Gesellschaft für Strahlen- und Umweltforschung (Federal Republic of Germany), Her Majesty's Inspectorate of Pollution (United Kingdom), Industrial Power Company Ltd. (Finland), Japan Atomic Energy Research Institute (Japan), Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (Switzerland), National Institute of Public Health and Environmental Hygiene (The Netherlands), National Radiological Protection Board (United Kingdom), Nuclear Safety Inspectorate (Switzerland), Power Reactor and Nuclear Fuel Development Corporation (Japan), Swedish Nuclear Fuel and Waste Management Co. (Sweden), Swedish Nuclear Power Inspectorate (Sweden), U.K. Nirex Ltd. (United Kingdom), U.S. Department of Energy (United States), U.S. Environmental Protection Agency (United States), U.S. Nuclear Regulatory Commission (United States).

Project Secretariat: Swedish Nuclear Power Inspectorate, Her Majesty's Inspectorate of Pollution/Harwell Laboratories, Kemakta Consultants Co., Organisation for Economic Co-operation and Development/Nuclear Energy Agency.

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intraval

PROGRESS REPORT

6

May 1990 – October 1990

INTRAVAL – An International Project to Study
Validation of Geosphere Transport Models

ERRATA

INTRAVAL PROGRESS
REPORT 6
May 1990-October 1990
pp. 16-18

General INTRAVAL Discussion

A time of three years was decided upon for the INTRAVAL project, with the option of an additional three year period.

Phase 1 started in October 1987 and has now come to an end with the launch of Phase 2.

Most of the work with the analysis of the test cases is now finalised. However, validation is a difficult process and plenty of work remains to increase the understanding of geosphere transport. Phase 2 will provide the opportunity and time to further analyse the test cases of Phase 1 as well as new test cases.

The meeting agreed that great strides toward validation have been achieved but also that validation is a difficult task. The "full problem" needs to be addressed, i.e. models, codes, data, performance assessment, and experimental techniques. Areas of uncertainty have been highlighted, for example matrix diffusion.

A systematic analysis of the validation process has been initiated. Data has been assessed, and models as well as codes have been developed, some of which have gained the confidence of the Project Teams of INTRAVAL. It was found that validation is a very different issue to different people.

The project has also provided a forum for peer review, education, and discussions regarding radionuclide transport in general.

The achievements from the first phase of INTRAVAL will be documented in a summary report and in a series of technical reports. In addition reports describing the experiments on which the test cases are based will be prepared.

The technical reports will be prepared by six Working Groups, which were set up at the Las Vegas workshop (Table 2a). An editor for each test case has been appointed. The responsibility of the editors is to compile the test case analyses provided by the Project Teams that have worked with the test case. A report describing the experiments will be prepared by the Secretariat in cooperation with the Pilot Groups. A summary report will be prepared by the Secretariat in cooperation with the Working Groups and VOIC. The summary report and the technical reports are planned to be published in spring 1992.

Phase 2 Objectives and Organisation

The overall objectives of Phase 2 are similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process.

Although INTRAVAL has the ambition to cover both validation of models in regard to the processes and site-specific systems, the emphasis of the work in Phase 1 has been on the Process Identification part of the model validation process, based on the laboratory experiment test cases. Since the work in Phase 1 has been comparatively successful in covering the Process Identification issue, it appears to be a natural development to shift the focus in Phase 2 towards Structure Identification. This issue is more complicated than the Process Identification because the number of degrees of freedom in the interpretation of the experiment increases and because the analysis should be based on field scale experiments. The experience from Phase 1 shows that the amount of manpower needed to analyse a field experiment is much greater than that needed for the analysis of a laboratory experiment.

The organisation of INTRAVAL Phase 2 will be similar to Phase 1. Four Working Groups will address the four main types of test cases (Table 2b). Each Working Group will have one leader, possibly aided by another person, and the intention is to meet at least once between each INTRAVAL meeting. To give the Working Groups ample time to do this, INTRAVAL meetings will be held about once a year. The Working Groups (leaders) are responsible for writing a working group report which will form a part of the final reporting.

Table 2a **Working Groups for INTRAVAL Phase 1**

			Editors:
Working Group 1 *Laboratory experiments*	Test Cases	1a 1b 2 9	P. Jackson J. Hadermann K. Skagius P. Jackson
Working Group 2 *Field experiments*	Test Cases	4 5	D. Hodgkinson C-F. Tsang
Working Group 3 *Natural analogues*	Test Cases	7 8	N. Chapman P. Duerden
Working Group 4 *Unsaturated media*	Test Cases	10, 11, 12	T. Nicholson
Working Group 5 *Salt*	Test Case	13	P. Glasbergen
Working Group 6 *Synthetic Experiment*	Test Case	6	R. Codell

Table 2b **Tentative Working Groups for INTRAVAL Phase 2**

Working Group 1:	Las Cruces Trench Apache Leap Tuff Site Twin Lake	leader: T. Nicholson
Working Group 2:	Finnsjön Stripa WIPP II	leaders: C-F. Tsang S. Neuman
	"Plans and Schedules" for this group has been compiled by Chin-Fu Tsang. This document can be received from the secretariat.	
Working Group 3:	Gorleben Salt Dome WIPP I Mol	leader: P. Glasbergen
Working Group 4:	Alligator Rivers Analogue Poços de Caldas	leader: N. Chapman

INTRAVAL Progress Report Number 6, 1991

The international INTRAVAL project started in October 1987 in Stockholm as an international effort towards validation of geosphere models for transport of radionuclides. The project was initiated by the Swedish Nuclear Inspectorate, SKI, and was prepared by an ad-hoc group with representatives from eight organisations.

Twentytwo organisations (Parties) from twelve countries participate in INTRAVAL. The project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat in which also Her Majesty's Inspectorate of Pollution, HMIP/DoE, U.K. and the OECD/NEA take part. Project organisation, the objectives of the study and rules for the publication of results are defined by an Agreement between the Parties.

The INTRAVAL philosophy is to use results from laboratory and field experiments as well as from natural analogue studies in a systematic study of the model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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Appendix 2: List of Test Case related Presentations at INTRAVAL Workshops

INTRAVAL
Progress Report Number 6

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was started in October 1987. Phase 1 of the study is in the process of being finalised and a second three year period, Phase 2, has just been initiated.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process.

Seventeen test cases have so far been included in Phase 1 of the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project, the Alligator Rivers Analogue Project, and the Poços de Caldas Project.

A Pilot Group has been appointed for each of the test cases. The responsibility of the Pilot Group is to compile data and propose formulations of the test cases in such a way that it is possible to simulate the experiments with model calculations.

It is a pronounced policy of the INTRAVAL study to support interaction between modellers and experimentalists in order to gain reassurance that the experimental data are properly understood and that the experiences of the modellers regarding the type of data needed from the experimentalists are accounted for. In order to support this interaction and for the development of a strategy for the systematic application of the experiences and knowledge gained from the test cases, a special committee, the Validation Overview and Integration Committee (VOIC), has been established within the study.

Contact between the participants is maintained by the arrangement of workshops followed by Coordinating Group meetings. Between these conferences, also Working Group meetings take place.

Since the issue of the previous Progress Report, the fifth INTRAVAL workshop and the sixth Coordinating Group meeting was held in Cologne, Germany. During this week the final presentations of Phase 1 modelling results were given, and Working Groups held meetings for preparation of their final reports. The second phase of INTRAVAL was launched and four Phase 2 Working Groups were appointed. Also VOIC assembled for the last meeting of Phase 1.

The Fifth INTRAVAL Workshop and the Sixth Coordinating Group Meeting

The Fifth INTRAVAL Workshop and the Sixth Coordinating Group Meeting were held in Cologne, the Federal Republic of Germany, on the 15th through 19th of October, 1990 with the Gesellschaft für Reaktorsicherheit acting as host. During the week preceding the week of meetings in Cologne, excursions to the ASSE salt mine and the Konrad iron-ore mine, close to Braunschweig in Niedersachsen (Lower Saxony) were organized. Another excursion, to the Hambach open-pit lignite mine, was arranged during the week of the meeting.

The last presentations of new modelling results of Phase 1 were held, but the greater part of the meeting was dedicated to concluding the work performed in Phase 1, and the launching of Phase 2.

As of these meetings, Phase 1 of INTRAVAL has been completed, apart from the report, and Phase 2 is in progress.

The Coordinating Group meeting was held on the 19th of October, 1990. The meeting decided that the Phase 2 of INTRAVAL would be initiated. All proposed test cases (except the Poços de Caldas test case) were agreed upon and four working groups were established to approach the different types of test cases. A final decision regarding the inclusion of the Poços de Caldas test case will be made at the next Coordination Group meeting. At the meeting, Kjell Andersson (SKI) assumed the chairmanship of INTRAVAL in the place of Alf Larsson.

The next INTRAVAL workshop and Coordinating Group meeting will be held in Seattle, Washington, U.S.A., April 22 to 26, 1991.

Validation Overview and Integration Committee (VOIC)

The Validation Overview and Integration Committee (VOIC) in the INTRAVAL organisation, acts for the development of the strategy for systematic application of experiences and knowledge gained from the various INTRAVAL test cases.

In the process of defining INTRAVAL Phase 2, VOIC has given assistance and advice to the INTRAVAL Secretariat and Coordinating Group concerning the outline of the continuation. VOIC has held the view that Phase 2 should be based on ongoing and well documented field experiments. The study should be more directed to validation strategy and performance assessment considering the accomplishments of Phase 1. It was also suggested that various key issues such as scale dependence, heterogeneity, coupled processes, etc. should be highlighted.

VOIC was specially created for Phase 1 of INTRAVAL, its function has been greatly appreciated. As this phase is now being concluded, the work of VOIC is also coming to an end. If VOIC, or a similar committee will be appointed for Phase 2 has not yet been decided.

Presentation of Additional Results from the Project Teams

The Fifth INTRAVAL workshop in Cologne was the final opportunity to present results of Phase 1 work. The test cases will be fully reported in upcoming technical reports.

TEST CASE 1B:

Uranium migration in crystalline bore cores based on experiments performed at PSI, Switzerland. (Pilot Group Leader: J. Hadermann, PSI)

Experimental Set-up and Scales:

In this experiment, performed at the Paul Scherrer Institute (PSI) in Switzerland, tracer migration in crystalline bore cores were studied. Water at high pressure was forced to flow through rock cores of granite or gneiss with a diameter of 4.6 cm and a length between 0.8 cm and 5.0 cm. The high pressure was intended to simu-

late the rock overburden. Tracer (^{233}U) was added to the infiltration water and the tracer concentration was measured in the water sampled at the core outlet. After the experiments the samples were sliced and the surfaces of the slices were auto-radiographed to yield information of flow paths and sorption sites. Complementary results on hydraulic conductivity versus confining pressure, and dynamic porosities of the samples are also available, as well as results from uranium adsorption/desorption experiments.

Analysis by the Project Teams

The Project Team from PSI has analysed all four infiltration experiments with eight different transport models. The curve fitting was achieved "by eye" as well as by least squares fit.

The models take into consideration advection, dispersion, matrix diffusion, sorption (linear and non-linear, both at the flow surface and in the matrix), fracture flow, vein flow, and several flow paths. The number of free parameters varied from five to three for the different models.

The main questions addressed were to identify the dominant transport mechanisms, identify the geometrical factors that affect transport, whether a distinction can be made between various mechanisms and geometries. The Project Team also intended to suggest additional experiments that should be performed in order to support distinction between mechanisms.

It was concluded that a model considering several flowpaths has a sufficient number of parameters to fit all breakthrough curves. The models that did not include matrix diffusion could not give a satisfactory explanation to the breakthrough curves. Linear and non-linear sorption models gave similar fits, but non-linear sorption gave a slightly better result.

It was found difficult to discriminate between fracture and vein flow from the fits. Dispersivities could be extracted reliably for vein flow only, although this is irrelevant from a safety assessment point of view.

The overall conclusions were that insufficient information exist to extract all important parameters from the data. Models with non-linear sorption produce slightly better results than models with only linear sorption. The geometry of the water flow path could not be determined.

In order to obtain better understanding of the mechanisms and geometries, experiments with clearly defined flow geometry should be added. Other experiments that were suggested were multitracer experiments with one non-sorbing tracer, experiments where conditions (flow velocity, input duration, sample size) are varied, and experiments performed on several cores from the same location. To obtain a satisfactory curve-fitting, additional data points around the peak of the breakthrough curve should be collected.

The Project Team from PNC have applied two types of fracture models, a discrete fracture (single continuum) model, and a dual porosity (double continuum) model. The main objective was to identify the dominant parameters that control the transport of tracers and to estimate their values.

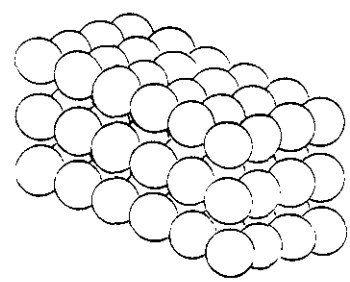

Figure. 1: Spherical block dual porosity model.

The results of the calculations with the two models were also compared. The code used was FTRANS, a finite element code developed by INTERA Inc. The fitting was done by eye as well as automatically (Powell's method).

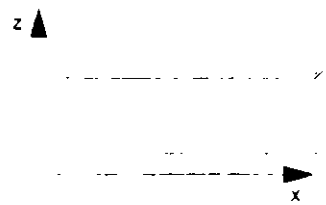

Figure 2: Discrete fracture model.

Best fit values were determined for the longitudinal dispersivity in the fracture, ε_L^F as well as the adsorption coefficient K_a for both models. The distribution coefficient K_d was estimated for the dual porosity model.

	Model Discrete fract.	Dual porosity	
ε_L^F	$7.00 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$	(m)
K_a	$3.65 \cdot 10^{-4}$*	$4.0 \cdot 10^{-3}$	(m)
K_d		$2.0 \cdot 10^{-2}$	(m^3/kg)

* insufficient

Table 1: Results from modelling of Test Case 1.

It was concluded that the best fit was reached with the dual porosity model. Even better results may be reached with a dual porosity model where the matrix is represented by spherical blocks. Calculations applying the single fracture model did not result in a satisfactory fit to the experimental data. Effects of matrix diffusion were not considered in this work, however it was recognized that matrix diffusion may be a key term in this context.

TEST CASE 5:

Tracer experiments in a fracture zone at the Finnsjön research area, Sweden. (Pilot Group Leader: P. Andersson, Swedish Geological Co.)

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometres.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated at 10^{-4} m^2/s, the middle 10^{-7} - 10^{-6} m^2/s and the lower 10^{-4} m^2/s. The middle layer is not continuous. A fresh water/ salt water interface exists in the fracture zone relatively close to the upper previous layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated at 1/300 in the horizontal direction in the zone.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several core- and a few percussion drilled boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated in 0.11 m intervals. A regional pumping test was conducted by pumping water from the full length of one borehole and observing the draw-down in 11 wells totalling 40 packed off intervals.

Tracer Tests

Two sets of tracer tests were completed: a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting 11 different non-sorbing tracers at 9 different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was performed by pumping in one well and injecting in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analysis by the Project Teams

The Project Team from VTT presented their results of modelling the dipole experiment.

The conceptual model consisted of three flow routes having different flow rates. The flow routes were calculated to pass through or very near the observation boreholes. Only a small fraction of the modelled flows are actually sampled in the observation boreholes.

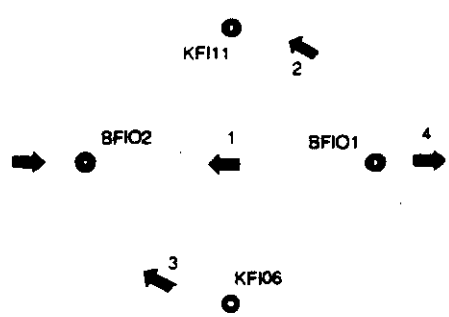

Figure 3: Main field lines and boreholes of dipole experiment.

The Project Team performed a curve-fit of the calculated data to the available experimental data.

It was observed that the flow from the injection hole to the pumping hole was not horizontally uniform. Selective pathways had been established between the two boreholes. A difference of flow was observed between boreholes KFI11 and KFI06 but the tracer concentration profile was very similar between the two boreholes. It was also seen that the actual boreholes will disturb the transmissivity of the system. When the vertical groundwater loss to a nearby fracture plane was considered in the calculations, an improvement of the fit was achieved.

TEST CASE 6:

Synthetic data base, based on single fracture migration experiments in Grimsel Rock Laboratory in Switzerland. (Pilot Group Leader: R. Codell US NRC)

This test case is patterned after a tracer migration experiment in a single fracture plane at the Grimsel Rock Laboratory in Switzerland. A highly detailed two-dimensional synthetic data set of hydraulic conductivities and other properties conditioned on the actual data from the Grimsel site has been generated. In addition, results from a number of simulated hydraulic and tracer migration experiments with the synthetic model are available. Based on these data sets the task for the Project Teams was firstly to predict the breakthrough of a non-sorbing tracer at several simulated boreholes and tunnels (Phase 1 of this test case), and secondly, to include also diffusion and chemical retardation in the geosphere (Phase 2 of the test case).

Analysis by the Project Teams

A group of ETH/NAGRA applied a finite element code to the data. The code being tested is still in a development stage, one feature not yet implemented is error analysis. The aim of the exercise has been to estimate the physical parameters of the synthetic geosphere using the hydraulic data of the experiments. The transport data will be used as a check for the transmissivity field estimated by the analysis of hydrological tests.

The direct problem is solved by the finite element method under steady state and/or transient conditions involving one-, two-, and three-dimensional quadratic elements.

The methodology has been implemented to deal with the hydrological data. Interpretation of the hydraulic data of the synthetic system has begun. The flow rate into the drift was predicted with an error margin of 1% .

TEST CASE 8:

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia. (Pilot Group leader: P. Duerden, ANSTO)

This test case deals with the natural analogue studies at the Koongarra site in the Alligator Rivers region of the Northern Territory, Australia. A comprehensive experimental and modelling programme has been set up and the main objective is to contribute to the production of reliable and realistic models of radionuclide migration within geological environments relevant to the assessment of the safety of radioactive waste repositories.

Uranium mineralisation at Koongarra occurs in two distinct but related ore-bodies separated by about 100 m of barren schists. Both ore-bodies strike and dip broadly parallel to the Koongarra Reverse Fault, which is the footwall to the ore zone. Primary mineralisation is largely confined to quartz-chlorite schist immediately above the fault zone. A graphitic quartz-chlorite schist forms a distinctive hanging wall unit. The more southwesterly of the two ore-bodies (No. 1 ore-body) has a strike length of 450 m and persists to a depth of about 100 m. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m to the east.

Analysis by the Project Teams

The Project Team from ANSTO presented results from the investigation of time characteristics in the formation of the uranium dispersion zone. The general concept has been to use the Koongarra system heterogeneity and seasonal hydrology changes for the investigation.

The model used is a quasi-two dimensional model describing the transport in a two-dimensional vertical cross-section as transport in two one-dimensional pipes separated by an intermediate zone where no horizontal transport is considered. This zone provides transfer of material from the bottom pipe to the upper pipe, reflecting transport due to seasonal fluctuations in water table. Two approaches were applied, one based on advection-diffusion in the pipes and a second based on open-systems modelling.The rock is considered to contain mineral phases that are accessible to the groundwater as well as those that are inaccessible (see adjoining figure). The adsorbed material is transferred during phase change (eg. crystallisation).

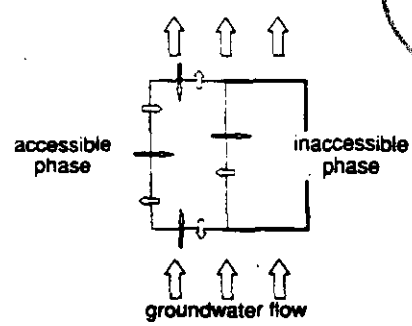

Figure 4: The accessible/inaccessible phase of the rock matrix at the Koongarra site.

The results of modelling to date support the experimentally determined distribution coefficient, K_d, as being between 0.35 and $1.5 \cdot 10^{-4}$ ml/g, the flow rate in the weathered schist being in the order of up to a few metres per year.

The mineral phase exchange rate is such that the rate at which uranium is accumulated in the accessible phase is in the order of the ^{234}U decay-constant. Most of the modelling fittings performed indicate that the mobilisation timescale is in the range of one to two million years. The calculated concentrations of uranium in the accessible/inaccessible phase of the rock are similar to the values observed from core data.

The next step is to improve the applied modelling procedure.

TEST CASE 9:

Radionuclide migration in a block of crystalline rock performed at AECL, Canada. (Pilot Group Leader: B. Gureghian, OWTD)

Experimental Set-up and Scales

This test case is based on laboratory experiments on migration of tracers in a single natural fracture in a large block of granite. The size of the block is 91.5 × 86.5 × 49.0 cm (length × width × height). The block was positioned so that the fracture is approximately horizontal and an inlet reservoir was designed to produce an as uniform hydraulic gradient and inlet tracer concentration as possible across the entire fracture width. The outlet reservoir was divided into five compartments, which were sampled in sequence to give breakthrough curves for each compartment. After the experiments were performed the fracture was opened and the flow paths were investigated with alpha-autoradiography.

Analysis by the Project Teams

Two-dimensional radionuclide migration analysis has been performed by CRIEPI. The analysis was performed with the finite element code RMF.

The following models were used :

- Porous Media, two-dimensional anisotropic porous media model (isoparametric element with 4 to 8 nodes);
- Rectangular Block Element, rectangular block model of matrix in dual porosity element;
- Circular Block Element, circular block model of matrix in dual porosity element;
- Fracture, model of discrete fracture.

The sorption was calculated both as linear and non-linear sorption.

Calculations resulted in good agreement with experimental data. It was also noted that the choice of dispersion length, α_L had a strong influence on the breakthrough curve.

TEST CASE 11:

Evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap Tuff Site near Superior, Arizona. (Pilot Group Leader: T. Nicholson, U.S. NRC)

Experimental Set-up and Scales

This test case is in fact three sets of experiments on flow and transport in unsaturated welded tuff. The experiments are supported by the U.S. NRC. The first set of experiments are field experiments at the Apache Leap Tuff Site, the second is a set of laboratory experiments performed on blocks of fractured rock, and the third a set of laboratory experiments performed on bore cores from the site. All experiments have to date been performed by the University of Arizona.

The dimension of the field experiment is in the order of 30 × 30 × 30 m. Nine inclined boreholes have been drilled in three rows, each row with three boreholes. This general set-up will allow for a set of different experiments. In one experiment performed at the site so far, the rock adjacent to one borehole was saturated and the propagation of the wetted front was evaluated by measuring the moisture content in the other boreholes. However, the introduction of the moisture could not be detected in the other boreholes.

Figure 5: Rock block with a single fracture.

The laboratory experiment was performed on Rock blocks of the dimensions 20 × 20 × 50 cm (block 1) and 21 × 20 × 66 cm (block 2). The blocks were chosen so that each block had a single fracture forming a centre plane through the rock (figure 5). The vertical sides of the blocks were hydraulically insulated whereas the top and bottom were attached to porous plates which allowed for controlled unsaturated flow through the block and the fracture. The flow rate between the upper and lower plates was to be used to calculate the unsaturated transmissivity, and the water content of the fracture was monitored using mass balance calculations.

The dimension of the core was 6.4 cm in diameter and 12.99 cm in length. It did not contain any observable fractures. The core was oven dried and then partially wetted with a solution of potassium iodine. The core was then coated to prevent moisture or air from leaving the core. The core ends were held at two different temperatures (70°C and 5°C) whereas the sides of the core were thermally insulated (no heat flow). The temperature and moisture distribution were measured at different intervals of time, as well as the final solute concentration (after 32 days).

Analysis by the Project Teams

The Kemakta/SKI Project Team presented their results of TOUGH and TRUMP modelling (integrated finite difference codes) of multiphase flow in a heated tuff drillcore.

The calculations of moisture distribution, temperature distribution, and relative tracer content were within the expected range of error compared to the experimental data. Differences between the experimental and calculated values may be attributed to heterogeneities, poor material data, and measurement errors.

It was concluded that modelling of transport mechanisms was more successful than the modelling of moisture content.

TEST CASE 13:

Experimental study of brine transport in porous media performed at RIVM, the Netherlands. (Pilot Group Leader: M. Hassanizadeh, RIVM.)

Experimental Set-up

This test case deals with flow and transport at high salt concentrations. The experimental set-up is a two-dimensional column with the dimensions 0.6 × 1.25 × 0.01 m, filled with glass beads. Fresh water and salt water was alternately circulated through the column. Head and salt concentration are measured at different locations in the column. The duration of a displacement experiment is from two to five hours.

Two sets of experiments have been carried out, one with low salt concentration to estimate the porosity, permeability and dispersivity of the porous medium, and another with high concentration to provide data about the concentration and pressure distribution along the column.

Analysis by the Project Teams

The Project Team from GRS, in cooperation with Harwell Laboratories, presented results of calculations where a new approach to the transport problem had been applied.

The new model regards the experimental set-up as a regular hexagonal network of one-dimensional tubes with advective flow. No dispersive/diffusive transport is taken into account by the model. Each tube is allocated a random permeability within a defined variance. The low concentration experiment was used to calculate this variance. The result was local density variations due to concentration changes in each tube. Simultaneous calculations of transient pressure and brine transport were made.

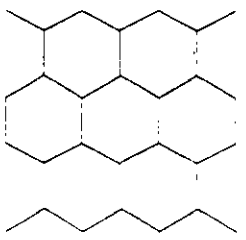

Figure 6: "network of tubes"-model

The recently developed computer code NEWFLOT was used for the calculations. The model used had 50 cells in the flow direction and 15 cells laterally, a total of 4535 connecting "tubes". The density of the salt water was specified as 1200 g/l. The dimensions were not designed to exactly represent the experiment.

It was concluded that dispersion of a low concentration brine could be reproduced by advective flow in a pipe network with random permeabilities. When simulating the high concentration experiment, the results indicate that dispersivity may be a function of the density gradient.

Results of modelling performed at TUB (Technische Universität Berlin) were presented based on one and two-dimensional calculations based on the code FAST C, and made with a Cray-XMP computer.

Modelling was performed based on the data of the low concentration experiment. The results of the propagation of the salt-front with time suggested that the flow of water/brine does not influence the flow directions of the brine. The results were not in accordance with the experimental data, but work still in progress. The question was raised if the porous-medium approach is the correct one for this experiment.

Current Status and Conclusions of Phase 1 Working Groups

WORKING GROUP 1:

(Laboratory Experiments, Test Cases 1a, 1b, 2, 9)

Working Group 1 is in the midst of the reporting stage of Phase 1. Some of the draft reports from Project Teams have been received by the Working Group. Comments were to be received until December 14. The last chance for submission of draft versions of Test Case reports was December 14. The final reports were to be completed by February 14, 1991.

The work has resulted in calibration of standard models, but few have yet considered spatial variability. No work other than to "simulate experiments" has been performed to this date.

A number of general conclusions have been drawn based on the current Project Team work. Consensus was reached as to the processes involved in nuclide transport in fractured rock, matrix diffusion, dispersion, etc. Agreement has been reached on the general methodology of the work, assessing quality of experiments, and implications for repositories, as well as suggestions of additional experiments for better understanding of the actual processes. It was also concluded that the number of parameters in the models need to be constrained to be able to use the models for prediction.

For future work, it was commented that not enough testcases addressed different scales and that experiments did not give enough data for a complete characterisation of the experiment.

WORKING GROUP 2:

(Tracer Experiments in Crystalline Rock, Test Case 4, 5)

Three different Project Teams have used different approaches to the Stripa experiment, test case 4.

The approach to test case 4 of LBL/USDOE has been one of "pseudo-independent" pathways. The Project Team from KTH/SKI has calibrated a fracture network model with Stripa data and the INTERA/NIREX team has performed a fractal analysis of the tracer travel times. The different approaches seem to fit together, not contradicting each other. One of the conclusions of the work of all Project Teams involved with test case 4 has been the recognition of the concept of channelling.

Difficulties have existed in the form of poor injection flow-rates and background flow patterns (all tracers did not arrive to the point of detection).

Seven Project Teams have modelled the Finnsjön experiment, test case 5. However, substantial amounts of data still remain unprocessed.

Most modelling teams did not consider the injection conditions. It was concluded that it is important to perform hydrologic and tracer tests simultaneously.

For the dipole experiment, the teams have chosen different models but all have found that advection and dispersion were important parameters. Differences of opinion exist regarding the existence or not of matrix diffusion. A difficulty that has been identified is the determination the geometry of the site.

At this time, there is a lack of complementary data, i.e. laboratory data, etc. Also, validation strategies have not yet been discussed, this needs to be approached in the continuation of the work based on these test cases.

A general conclusion of the achievements of the Working Group was that very good interaction between the modelling groups had been achieved.

For Phase 2, the intention is to analyze all data available. For example core samples (porosities, diffusivities, and geo chemistry), salinity data and single hole radar measurements remain to be examined from the Finnsjön experiment.

Concerning the Stripa test case, data from additional experiments performed in the Stripa mine will be made available.

In Phase 2, work will also be initiated on data from the WIPP 2 experiments.

WORKING GROUP 3:

(Natural Analogs, Test cases 7 and 8)

A Project Summary Report has been completed for the Alligator Rivers Analogue Project. A summary of this will be presented as the INTRAVAL Phase 1 report for Test Case 8. The report includes the baseline information on the work performed at KTH.

Work on Test Case 8, the Alligator Rivers Analogue Project, is still in the initial stages. Because the lack of processed information, the report which is being prepared will not be an INTRAVAL Phase 1 final report but a report of the initial approaches performed as a part of the INTRAVAL study. An elaborate test case description will be presented, and also a presentation of the data available.

For Phase 2 of INTRAVAL, the focus of test case 7, Poços de Caldas, will be on redox front processes. The aim is to model geochemical transport across a moving front. Phase 2 will also provide a good opportunity to test diffusion transport and chemical equilibrium/kinetic models.

For test case 8, the Alligator Rivers Project, three Phase 2 test cases have been prepared. The first is a hydrogeological approach, a scenario for 2-D and 3-D fluxes across the site. The second concerns geochemistry, formation of the secondary ore-zone and recent movement of the dispersion fan. The third test case will address the transport within the ore-zones. These are developed versions of the Phase 1 test case.

Phase 2 of INTRAVAL provides the study of the natural analogues with the opportunity to give more consideration to geochemical aspects of a natural analogue.

WORKING GROUP 4:

(Experiments in the Unsaturated Zone, Test cases 10, 11, and 12)

The Working Group 4 is well under way preparing the Working Group report on the unsaturated test cases.

Measurements in the unsaturated zone is still very much dependent on the development of new experimental methods. This is one explanation why high-quality data is difficult to procure. Despite the experimental difficulties, three test cases have been modelled.

Important knowledge has been gathered to address the validation issue of the unsaturated test cases, however little or no validation attempts have yet been made. The validation issue is mainly left to be addressed in Phase 2 of INTRAVAL.

It was stressed that the knowledge and experience gained from work performed in the saturated zone is valuable also for performing experiments in the unsaturated zone.

The results of the modelling exercises have been a greater comprehension of the involved processes as well as developed laboratory and field techniques.

A number of recommendations have been identified in preparation for INTRAVAL Phase 2. Conceptual models, experimental methods, and numerical solution techniques will be investigated more closely in Phase 2.

WORKING GROUP 5:

(Salt and Brine Related Experiments, Test Cases 13, and 14)

Working Group 5 is in the midst of preparing the test case report. The report will address the brine transport experiment, Test Case 13. The experiments at the Gorleben Salt Dome, Test Case 14a and 14b, will be approached in Phase 2.

A workshop in Gorleben, Germany, was held in May 1990 where the results of Test Case 13 were discussed in detail. A writing workshop was held in Bilthoven, the Netherlands, in January, 1991, to compile the reports.

A number of objectives were defined for the salt related test cases at the beginning of the first phase of INTRAVAL. These objectives were to use data for calibration of transport models developed for brine environments, to compare model predictions with experimental data, to draw conclusions on the validity of the classical Darcy's/Fick's laws at high brine concentrations, and to identify the numerical structure of the model applied. At the conclusion of the Phase 1 work, the objectives for Phase 1 have been met except the validity of Darcy's/Fick's laws.

A conclusion that has been reached is that the experimental set-up may vary with porosities, location of measurement, and may be dependent on time.Simulation of high-concentration experiment using porosities and dispersivities from the low-concentration experiment did not provide satisfactory results. To improve the simulation of the slope of the break through curves, lower values of dispersion required. No consensus was reached on explaining the observed discrepancies between the laboratory results of brine front migration and model simulations at high concentrations. The influence of the laboratory set-up was discussed.

It was observed that Fick's law was not valid for the conditions at the experiment. A reformulation of the adsorption constant in Fick's' law provided satisfactory agreement with experimental data. This may be reached by substituting the constant, as defined by classical theory, with a nonlinear function. No attempt to formulate this function has yet been made.

WORKING GROUP 6:

(Synthetic Test Case, Test Case 6)

The Grimsel Rock Laboratory Synthetic Experiment has involved a true validation attempt. Even though the experiment is based on synthetic data, no backfitting has been made.

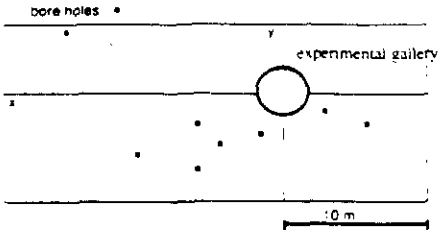

Figure 7: The small scale description of the synthetic migration experiment.

The following methods were applied by the project teams:
- Potential Flow (NRC, Team 1)
- Kriged T and H (NRC, Team 1)
- Conditional Simulation (NRC, Team 1)
- T Zonation with Manual Adjust (NRC, Team 2)
- Inverse Model (CNWRA, ETH/NAGRA)

The project team at ETH have applied an inverse methodology (with pilot points). The steady state base case and one of the transient tests have been analysed with encouraging results related to head and flux comparisons.

Conditional Simulation-runs were performed by NRC with the original data as well as runs using data from three additional boreholes. The results were compared. The additional data resulted in lower correlation to the measured data. This behaviour has not yet been explained. Problems exist in the form of shortage of computer time, lack of data, and the difficulties when alternative phenomena led to the same observations.

Presentation of CEC Program Directory

The Commission of European Communities (CEC) directory of computer programs for assessment of radioactive waste disposal in geologic formations was presented. The objectives of the directory are to gain an overview of current development and use of computer programs and to list such programs along with reviews of selected programs.

More than 300 programs are listed under a wide range of topics. Many program descriptions also include a review of the program.

The participants of INTRAVAL were asked to be generous with contributions of information to make it possible to make an informative directory with well specified information regarding the computer codes in use today. It was pointed out that more information, in addition to the name of the code, result in higher probability for a review in the directory.

General INTRAVAL Discussion

A time of three years was decided upon for the INTRAVAL project, with the option of an additional three year period.

Phase 1 started in October 1987 and has now come to an end with the launch of Phase 2.

Most of the work with the analysis of the test cases is now finalised. However, validation is a difficult process and plenty of work remains to increase the understanding of geosphere transport. Phase 2 will provide the opportunity and time to further analyse the test cases of Phase 1 as well as new test cases.

The meeting agreed that great strides toward validation have been achieved but also that validation is a difficult task. The "full problem" needs to be addressed, i.e. models, codes, data, performance assessment, and experimental techniques. Areas of uncertainty have been highlighted, for example matrix diffusion.

A systematic analysis of the validation process has been initiated. Data has been assessed, and models as well as codes have been developed, some of which have gained the confidence of the project teams of INTRAVAL. It was found that validation is a very different issue to different people.

The project has also provided a forum for peer review, education, and discussions regarding radionuclide transport in general.

The achievements from the first phase of INTRAVAL will be documented in a summary report and in a series of technical

reports. In addition reports describing the experiments on which the test cases are based will be prepared.

The technical reports will be prepared by six Working Groups, which were set up at the Las Vegas workshop (Table 2). An editor for each test case has been appointed. The responsibility of the editors is to compile the test case analyses provided by the Project Teams that have worked with the test case. The report describing the experiments will be prepared by the Secretariat in cooperation with the Pilot Groups. The technical reports are planned to be published in spring 1991. The summary report will be prepared by the Secretariat in cooperation with the Working Groups and VOIC. The summary report is planned to be published late 1991.

Phase 2 Objectives and Organisation

The overall objectives of Phase 2 are similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process.

Although INTRAVAL has the ambition to cover both validation of models in regard to the processes and site-specific systems, the emphasis of the work in Phase 1 has been on the Process Identification part of the model validation process, based on the laboratory experiment test cases. Since the work in Phase 1 has been comparatively successful in covering the Process Identification issue, it appears to be a natural development to shift the focus in Phase 2 towards Structure Identification. This issue is more complicated than the Process Identification because the number of degrees of freedom in the interpretation of the experiment increases and because the analysis should be based on field scale experiments. The experience from Phase 1 shows that the amount of manpower needed to analyse a field experiment is much greater than that needed for the analysis of a laboratory experiment.

The organisation of INTRAVAL Phase 2 will be similar to Phase 1. Four Working Groups will address the four main types of test cases (see table 2). Each Working Group will have two leaders (all have not yet been appointed), and the intention is to meet at least once between each

Table 2: Working Groups for Phase 2

Working Group 1:	Las Cruces Trench	leaders:
	Apache Leap Tuff Site	Tom Nicholson
	Twin Lake	–
Working Group 2:	Finnsjön	leaders:
	Stripa	Chin-Fu Tsang
	WIPP II	Shlomo Neuman
	"Plans and Schedules" for this group has been compiled by Chin-Fu Tsang. This document can be received from the secretariat.	
Working Group 3:	Gorleben Salt Dome	leaders:
	WIPP I	Peter Glasbergen
	Mol	–
Working Group 4:	Alligator Rivers Analogue	leaders:
	Poços de Caldas	Neil Chapman
		–

INTRAVAL meeting. To give the Working Groups ample time to do this, INTRAVAL meetings will be held about once a year. Working Groups should write a technical report to summarise experiences of the different test cases.

Phase 2 Test cases

Based on the interest of the participants of the Cologne meeting, the following test cases were decided to be included in INTRAVAL Phase 2. Inclusion of the Poços de Caldas test case will be decided at the next Coordinating Group meeting.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment, Sweden

The Stripa 3D experiment is included in Phase 1 as Test Case 4. The intention is now to further analyse the Stripa 3D experiment. An extended set of complementary data will become available since much information has been gathered on fracture statistics, hydraulic testing data as well as on water chemistry in the 'site characterization and validation' program. A new drift has been excavated near the old 3D drift and instrumented with plastic sheets and other water collection devices. In addition, channeling experiments in individual fractures have been performed and will provide data on the variability of hydraulic transmissivities and fracture apertures over 2 m lengths along five fractures. Results from tracer tests performed between two holes in the same fracture plane are also available.

FINNSJÖN

Finnsjön tracer experiments, Sweden

This experiment is included in Phase 1 as Test Case 5. Three types of experiments have been performed, hydraulic interference tests, a radially converging tracer experiment and a dipole tracer experiment. The emphasis of the work in Phase 1 has been on the radially converging tracer test. For Phase 2, all three experiments will be used as well as the coupling between them. This would mean an increase in geometrical scales to distances between 150 and 1500 metres. Another objective for INTRAVAL Phase 2 is to incorporate existing laboratory data from core samples of the fracture zone.

GORLEBEN SALT DOME

Groundwater flow in the vicinity of the Gorleben Salt Dome, the Federal Republic of Germany

This experiment is included in INTRAVAL Phase 1 as Test Case 14. As experimental data was not available in time for inclusion, the test case has been transfered to Phase 2.

The Test Case is based on a hydrogeological investigation programme in the area of the Gorleben salt dome, situated in the northeastern part of Lower Saxony. The principal aim has been to understand and determine the groundwater movement in the strata surrounding a salt dome. Freshwater in the uppermost parts of the aquifer system is in such situations commonly underlain by highly saline groundwater. The groundwater movement in such a system depends to a large degree on its salinity. Special experiments have been performed to obtain information on hydrogeological structure, hydraulic parameters and groundwater movement.

ALLIGATOR RIVERS

Radionuclide migration in the weathered zone of the Koongarra uranium deposit, Northern Territories, Australia

This natural analogue study is included in Phase 1 as Test Case 8. The analysis of the data base from the Alligator Rivers Analogue is still in progress. The number of Project Teams that have tackled this test case during Phase 1 is limited since a broad and innovative approach is needed for the analysis. This fits well with the focus of Phase 2.

The Koongarra uranium ore deposit is found in the Alligator Rivers region of the Northern Territories. Uranium mineralisation occurs at Koongarra in two distinct but related orebodies, which strike and dip broadly parallel to the Koongarra Reverse

Fault. Primary mineralisation is largely confined to quartz-chlorite schists; secondary mineralisation is present from the surface down to the base of weathering at about 25 meters depth and forms a tongue-like body of ore dispersing downslope for about 80 meters. The objective of the study is to deduce the timescale and the rate of the uranium mobilisation which resulted in the redistribution of the ore-body along the general groundwater flow direction.

POÇOS DE CALDAS

Poços de Caldas, Minais Gerais, Brazil

The Poços de Caldas Natural Analogue study is included in Phase 1 as Test Cases 7a (redox-front movement) and 7b (colloid transport). Since the data have not yet been available to the Project Teams it has been proposed to transfer the part concerning the redox-front movement and uranium movement to Phase 2. The part concerning colloid transport will not be continued since no evidence of colloid movement has been found in Poços de Caldas.

At the Cologne meeting the interest among the participants was too low to motivate Poços de Caldas as a Phase 2 test case. It was however decided to keep it within the project at least until the next meeting which will be in Seattle, April 1991.

LAS CRUCES TRENCH

Las Cruces trench, Nevada, USA

This experiment is included in INTRAVAL Phase 1 as Test Case 10. The experimental site is located at the New Mexico State University College Ranch, northeast of Las Cruces. Water and tracers are applied in a carefully controlled fashion to the surface of an experimental plot. The motion of water and the transport of various tracers through the vadose zone are monitored. The purpose of the experiments is to test deterministic and stochastic flow theories by comparing model predictions with observed measured flow and transport parameters. Additional experiments will be performed at the site and it was proposed to include the experiments at Las Cruces Trench as a Test Case in INTRAVAL Phase 2. Models calibrated against data from the already performed experiments can be used to predict water flux and solute transport in the experiments.

APACHE LEAP TUFF

Apache Leap Tuff site, Arizona, USA

This experiment is included in Phase 1 as Test Case 11. The Phase 2 exercise will be an extension of the efforts already performed. At the experimental site, the tuff formation is approximately 600 meters thick. The unsaturated zone extends to great depth due to topography and to pumping associated with nearby mining activities. The objective is to learn how to predict water flow and solute transport through unsaturated fractured rock under field conditions. Data from experiments made at different scales, i.e core, block and field, are already available, and additional experiments of similar types will be performed.

MOL

Migration of tritium in clay at Mol, Belgium.

A piezometer nest is placed in a single bore hole drilled horizontally from the gallery of the Hades underground research facility at Mol, Belgium. The nest is equipped with several filters at 1 m intervals through which tritiated water is injected. An additional five piezometer nests have been installed for radionuclide injection, but these have not yet been loaded. Two of these nests are intended for determination of anisotropy in the clay (perpendicular and parallel to the bedding of the clay). The data from these additional tests will be made available to INTRAVAL as they arrive.

The experiment was originally designed to make in situ determinations of migration for comparison with values determined in the laboratory. The spatial scale of the experiments is in the order of 2 m migration distance involving about 30 m^3 of clay. The time required for an experiment is in the range of 1-4 years. The first tritium injection was carried out two years ago. The spatial scale of the complementary laboratory experiments is in the order

of a few centimetres, and the time scale is in the order of weeks. The validation aspects of the experiments are coupled to radionuclide migration in clay and the scale dependence of the migration parameters.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada

The test case comprises 20, 40, and 260 m natural gradient radio-tracer experiments performed in a sandy to gravel aquifer at the Twin Lake site. The experiments were performed in 1982, 1983 and 1987–1988. The longest experiment ran for about a year. The spatial separation of the measuring points are about 5 m in the flow direction and 0.5–1 m in the direction perpendicular to the flow. For the 1982–1983 experiments approximately five hundred thousand data points exists on the spread of iodine. A very large amount of hydrogeological and geophysical data has also been collected. New experiments are planned for the autumn 1990.

Sand and gravel aquifers could hardly be considered for radioactive waste disposal. In that sense, this test case has a limited relevance for the validation with regard to radioactive waste disposal. However, the test case could potentially provide a set of detailed data that could be used for validating the necessary conditions generally assumed in transport models, i.e. to answer the question whether a general transport model can predict the results of any field experiment where there is little uncertainty in the data.

WIPP 1

Brine Flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) Site, New Mexico, USA

Field experiments are conducted in the underground facility at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The underground facility is located 655 m below ground surface within bedded evaporites, primary halite, of the Permian Salado Formation. The WIPP, currently scheduled to be commissioned in late 1990, is intended to be a permanent repository for low-level and transuranic wastes generated by the United States' defense programmes.

WIPP1 is a Test Case based on experiments performed to determine the nature of brine flow through bedded evaporites of the Salado Formation. The experiments are designed to provide different types of data with the purpose to evaluate whether Darcy's law correctly describes the flow of brine through evaporites, or whether a different type of model, perhaps one involving creep-driven flow, is more appropriate. Three principal types of measurements are being made: brine-inflow rates, pore-pressures and permeabilities, at a number of scales ranging from 4.5 cm diameter boreholes to 3 m diameter rooms. The test case is concerned with the validation of conceptualization's and models used in interpretation of experiments and in modelling of brine inflow to the repository. The objectives are to integrate the results of all the experiments within a comprehensive and consistent model of brine flow through evaporites.

WIPP 2

Groundwater flow at the Waste Isolation Pilot Plant (WIPP) Site, New Mexico, USA

WIPP 2 is based on extensive geologic and hydrologic investigations at the WIPP. The experiments were originally performed to provide data to be used in developing a regional groundwater - flow model and subsequent performance assessment calculations. The database available for this test case is very large, and thus suitable for further study by the INTRAVAL project. Geologic studies have taken place at the WIPP, beginning 1975. These include detailed investigation of numerous surface features for the purpose of delineating subsurface features or irregularities that could affect flow in and around the Culebra. A transient electromagnetic survey is planned for 1991 - 2 in order to better delineate a hypothesized fractured region. Sixty wells have been completed to the Culebra dolomite at 41 locations to provide information on the hydraulic properties of the Culebra. Variation in Transmissivity is related to fracturing. Where present, fracturing

causes the culebra to behave as a double porosity medium with respect to both hydraulic responses and solute transport. Pumping tests, tracer tests, geochemical and isotope studies have also been performed at the site.

The experimental programme is currently scheduled to continue through May 1992. In late 1990 or early 1991, the programme may be expanded to include gas threshold-pressure testing, and tracer testing through a fractured anhydrite bed.

Appendix 1

Progress Report Number 6

The organisation of the INTRAVAL study is regulated by an agreement which has been signed by all participating organisations (Parties). The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Power Inspectorate (SKI) acts as Managing Participant. The Managing Participant appoints a Project Secretariat in cooperation with Her Majesty's Inspectorate of Pollution (HMIP/DoE), U.K., and the Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA). KEMAKTA Consultants Co. is contracted by SKI to act as Principal Investigator within the Project Secretariat.

The Parties organise Project Teams for the actual project work. Each Party covers the costs for its participation in the study and is responsible for the funding of its Project Team or Teams, including computer costs, travelling expenses, etc.

A Pilot Group has been appointed for each Test Case in order to secure the necessary information transfer from the experimental work to the Project Secretariat and the Project Teams. The Project Secretariat coordinates this information transfer.

At suitable intervals of time, depending upon the progress of the study, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group. During the workshops, Test Case definitions and achieved results are discussed as a preparation for decisions in the Coordinating Group.

List of INTRAVAL Participants

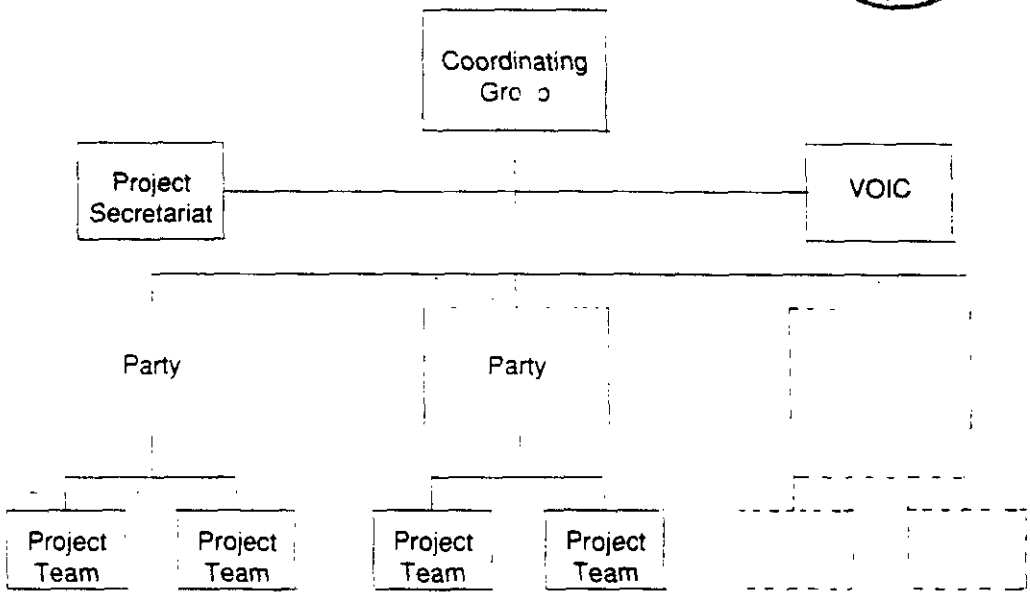

Figure 1: INTRAVAL Organisational Chart

Managing Participant:	SKI
Coordinating Group:	
Chairman:	A. Larsson, SKI
Vice Chairman:	T. Nicholson, U.S. NRC
Secretary:	K. Andersson, SKI
Principal Investigator:	KEMAKTA Consultants Co.
Project Secretariat:	K. Andersson, SKI J. Andersson, SKI L. Dagerholt, KEMAKTA M. Ericsson, KEMAKTA B. Grundfelt,KEMAKTA D. Lever, HMIP/DoE, Harwell K. Pers, KEMAKTA K. Skagius, KEMAKTA C. Thegerström, OECD/NEA

List of INTRAVAL Participants

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List of INTRAVAL Participants (cont.)

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Nuclear Safety Inspectorate, Switzerland J. Vigfusson	(HSK)	Nuclear Safety Inspectorate, J. Vigfusson	(HSK)
Power Reactor and Nuclear Fuel Development Corporation, Japan H. Umeki	(PNC)	Power Reactor and Nuclear Fuel Development Corporation H. Umeki	(PNC)
Swedish Nuclear Fuel and Waste Management Co., Sweden F. Karlsson	(SKB)	The Royal Inst. of Technology I. Neretnieks	(SKB/KTH)
Swedish Nuclear Power Inspectorate, Sweden K. Andersson	(SKI)	The Royal Inst. of Technology J. Andersson	(SKI/KTH)

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member	Project Team(s) and Team Leader(s)
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International Atomic Energy Agency (IAEA) S. Hossain (observer)	
State of Nevada L. Lehman (observer)	

Appendix 2

List of Test Case Related Presentations at INTRAVAL Workshops

TEST CASE 1a

Bogorinski P., Larue J. and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overwiew of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R. and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A. and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G. and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G. and Medina A., Application of Experiment Design Methods to Test Case 1a, INTRAVAL., INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A. and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P. and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J. and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K. and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K. (CSD) and Ikeda Y. (MAPI), PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R. and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R. and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 1b

Bischoff K., Hadermann J. and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J. and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J. and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E. and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., A Note on the Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Grindrod P. and Hodgkinson D., The Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Hadermann J., Jakob A., Modelling Test Case 1b with Various Mechanisms and Geometries.INTRAVAL Workshop, Cologne 1990.

Hara K., Nakahara Y., Neyama A., Shiga A., and Ikeda Y., Modelling Study of Test Case 1b, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A., Preliminary VTT Results on Test Case 1b, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Channels as Migration Routes in Crystalline Rock Samples, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Preece T.E. and Sumner P.J., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Sumner P.J. and Preece T.E., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Jakob A., Hadermann J. and Zingg A., PSI New Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Kjellbom K., Moreno L. and Neretnieks I., Preliminary Evaluation of Some Uranium Migration Tests, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 2

Aimo N.J., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Cole C.R. and Aimo N.J., Investigating a Parameter Estimation Approach to Design of Validation Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Gureghian B.. Radionuclide Migration in Single Natural Fissures in Granite, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H.. Preliminary Results of Test Case 2 Study, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I.. Previous Modelling of Test Case 2 Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 2, INTRAVAL Workshop, Tucson, November 1988.

Skagius K., Presentation of Test Case 2, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 3

Cole C.. INTRAVAL Test Case 3, Experiments and Model Calculations, INTRAVAL Workshop, Barcelona, April 1988.

Cole C. and Aimo N.J., Presentation of Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Andersson J.. Comments on INTRAVAL Test Case 3, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K. and Umeki H.. Calculation of the Concentration of a Dispersive Tracer Solute by Means of Numerical Solution of the Balance Equation, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K.. Modelling of Test Case 3 by Using a Numerical Method, INTRAVAL Workshop, Tucson, November 1988.

Kimura H. and Yamashita R.. Preliminary JAERI Results on Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 4

Andersson J., Discrete Network Analysis of Tracer Experiments in Stripa 3D, INTRAVAL Workshop, Las Vegas 1990.

Dverstorp B., Application of the Discrete Fracture Network Concept on Field Data: Possibilities of Model Calibration and Validation, INTRAVAL Workshop, Barcelona, April 1988.

Dverstorp B. and Nordqvist W.. Flow and Transport Simulations with a Discrete Fracture Network Model, INTRAVAL Workshop, Helsinki, June 1989.

Hodgkinson D., Shaw W. and Barker J.. Modelling by Flows in Continuous Dimension, INTRAVAL Workshop, Tucson, November 1988.

Hodgkinson D., Shaw W. and Grindrod P., Preliminary Fractal Analysis of the Stripa 3D Migration Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Presentation of Test Case 4: 3D Migration Experiment at Stripa, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 4, INTRAVAL Workshop, Tucson, November 1988.

Tsang Y.W. and Tsang C.F., Understanding Stripa 3-D Tracer Migration Data, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 5

Andersson P., Experimental Results and Further Plans, INTRAVAL Workshop, Tucson, November 1988.

Andersson P., Recent Experimental Results, INTRAVAL Workshop, Helsinki, June 1989.

Andersson P., Proposal for Simulation of Hydraulic Interference Tests, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P. and Worth D., Do the Pulse Injection Experiments Exhibit Radially Convergent Fracture Flow?, INTRAVAL Workshop, Las Vegas, February 1990.

Gustafsson E., Andersson P. and Wikberg P., Recent Achievements in the Performance and Evaluation of the Finnsjön Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A., Dipole Results, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A. and Taivassalo V., Generalised Taylor Dispersion Analysis for Tracer Breakthrough in the Radially Converging Experiment of Finnsjön (test case 5), INTRAVAL Workshop, Barcelona, April 1988.

Hautojärvi A. and Taivassalo V., Pre-Test Calculations of VTT-Team for Radially Converging Test, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Taivassalo V. and Vuori S., Interpretation of Results of the Radially Converging Test, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V. and Vuori S., Preliminary Predictive Modelling of the Dipole Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V. and Vuori S., Interpretation of Test Case 5, Radially Converging Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H. and Katsuragi T., Predictive Modelling of the Dipole Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Helsinki, June 1989.

Kimura H., Kasturagi T. and Yamashita R., Preliminary Results of the Radially Converging Tracer Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Las Vegas, February 1990.

Moreno L. and Neretnieks I., Preliminary Evaluation of Tracer Test in Finnsjön, Radial Converging Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Introduction to Test Case 5, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Preliminary Predictions of Finnsjön Tracer Tests, INTRAVAL Workshop, Barcelona, April 1988.

Nordquist R., Numerical Predictions of a Dipole Tracer Test in a Fracture Zone in the Br ndan Area, Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Winberg A., Geostatistical Analysis of Hydraulic Conductivity Data at Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Yamashita R. and Kobayashi A., Preliminary Calculations Using Fracture Network Approach for Tracer Test in Finnsjön Site, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 6

Codell R., Cole C. and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem VI, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Cole C. and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem 6, INTRAVAL Workshop, Helsinki, June 1989.

Codell R. and Trösch J., Calculation of Synthetic Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kuhlmann U. and Vomvoris S. ,Interpretation of INTRAVAL Test Case 6, Synthetic Experiment, INTRAVAL Workshop, Cologne, October 1990.

Vomvoris S., On the Synthetic Experiment, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 7a

Neretnieks I., Presentation of Test Case 7a: Redox Front and Uranium Movement at Poços de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 7a: Redox Front Movement, INTRAVAL Workshop, Tucson, November 1988.

Neretnieks I., Redox Front Studies at Poços de Caldas, INTRAVAL Workshop, Las Vegas, February 1990.

Romero L., Moreno L. and Neretnieks I., Poços de Caldas. The Location of the Redox Front, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 7b

Chapman N., Presentation of Test Case 7b: Colloid Transport, INTRAVAL Workshop, Tucson, November 1988.

Noy D., Presentation of Test Case 7b: Colloid Mobility at Po(os de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

TEST CASE 8

Davis S., Hydrology Sub-Project, INTRAVAL Workshop, Tucson, November 1988.

Duerden P. and Golian C., Presentation of Koongarra and Draft Test Case, INTRAVAL Workshop, Barcelona, April 1988.

Duerden P., Presentation of Test Case 8, INTRAVAL Workshop, Tucson, November 1988.

Duerden P., Update of Recent Field Work, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., Koongarra Test Case: Modelling Progress, INTRAVAL Workshop, Tucson, November 1988.

Golian C., Hydrodynamic Transport through Porous Media which Contain Two Iron Mineral Phases, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., A Quasi Two Dimension Open Sytem/Transport Model to Describe the Mobility of the Bulk Uranium, INTRAVAL Workshop, Las Vegas, February 1990.

Golian C., Test Results of the Simplified 2D Modelling of the Koongarra System Describing the Preferential Uranium Pathways, INTRAVAL Workshop, Cologne, October 1990.

Lever D., Koongarra Transport Modelling, INTRAVAL Workshop, Barcelona, April 1988.

Nijhoff-Pan I., Discussion on Test Case 8: Alligator Rivers (Koongarra) Ore Deposit, INTRAVAL Workshop, Helsinki, June 1989.

Slot A.F.M., Proposed Modelling Approach for the INTRAVAL Test Case 8, Alligator Rivers, Koongarra Ore Deposits, INTRAVAL Workshop, Las Vegas, February 1990.

Sverjensky D., Geochemical Aspects of the Alligator River Analogue Project, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 9

Hautojärvi A., Preliminary Calculations of Migration in the Fracture Channels, INTRAVAL Workshop, Helsinki, June 1989.

Kawanishi M., Preliminary Results on Test Case 9 by Using Dual-Porosity Simulation Code, INTRAVAL Workshop, Cologne, October 1990.

Kobayashi A. and Yamashita R., Preliminary Results on Test Case 9 by Using the Non-Uniform Velocity Distribution, INTRAVAL Workshop, Helsinki, June 1989.

Noronha C.J. and Gureghian A.B., Description of Granite Block Experiment for Test Case 9, INTRAVAL Workshop, Barcelona, April 1988.

Noronha C.J. and Gureghian A.B., Large Block Migration Experiments, INTRAVAL Workshop, Tucson, November 1988.

Rasilainen K., Hautojärvi A and Vuori S., Preliminary Interpretation of Test Case 9 using FTRANS-code, INTRAVAL Workshop, Las Vegas, February 1990.

Vandergraaf T.T., Grondin D.M. and Drew D.J., Contaminant Transport Laboratory Studies in a Single, Natural Fracture in a Quarries Granite Block at a Scale of 1 Metre, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 10

Ababou R., High-resolution Modeling of 3D Flow Fields, INTRAVAL Workshop, Las Vegas, February 1990.

Bensabat J., Stochastic Modelling of the First Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Gee G., Deterministic Modeling and Considerations for Transport Analysis of the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Gelhar L., Applications of the Stochastic Model to the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., Updegraff C.D. and Davis P.A., A 2-D Deterministic Model of the Las Cruces Trench Infiltration Experiment, Preliminary Results, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T. and Davis P.A., A Statistical Analysis of the Las Cruces Trench Hydraulic Data, INTRAVAL Workshop, Helsinki, June 1989.

Goodrich M.T. and Gribble A.R., Data Analysis and Modelling of the Las Cruces Trench Second Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Hills R.G., Hudson, D.B., Porro I. and Wierenga P.J., Modelling the Layered Soil Lysimeter Study at Las Cruces, INTRAVAL Workshop, Tucson, November 1988.

Hills R. and Wierenga P., Water Flow and Solute Transport at the Las Cruces Trench Site, INTRAVAL Workshop, Las Vegas, February 1990.

Kool J.B., Simulations of Water Flow and Tritium Transport at the Las Cruces Trench, INTRAVAL Workshop, Las Vegas, February 1990.

McLaughlin D., Model Validation Issues for Unsaturated Flow Systems, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Presentation of Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Introduction, Test Case 10, INTRAVAL Workshop, Helsinki, June 1989.

Rasmuson A., Lindgren M. and Collin M., Flow and Transport Simulations of the Second Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Smoot J.L., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Smyth J.D., Infiltration Simulations of the Jornada Trench with a Multidimensional Monte Carlo Code, INTRAVAL Workshop, Las Vegas, February 1990.

Updegraff D., 1-D Analytical Solutions on Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Field and Laboratory Experimental Results with Emphasis on Transport, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Hills R. and Hudson D., Flow and Transport Data Analyses of the Las Cruces Trench Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 11

Bradbury J., Evaporation in Unsaturated Fractured Rock - an Alternative Conceptual Model, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Transport in Two-Phase Flow in Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Evans D., Field and Laboratory Experimental Results, INTRAVAL Workshop, Tucson, November 1988.

Evans D., Rasmussen T. and Sully M., Rock Matrix Characterization in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T. and Sully M., Non Isothermal Core Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T. and Sully M., Crosshole Pneumatic Testing at the Apache Leap Tuff Site, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T. and Sully M., Laboratory Fracture Flow Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Lindgren M., Rasmusson A.,Two-Phase Flow Simulations in a Heated Tuff Drillcore, INTRAVAL Workshop, Cologne, 1990

McCartin T., Simulation of the Apache Leap Tuff Site Borehole Experiment, INTRAVAL Workshop, Tucson, November 1988.

McCartin T., Two-Phase Flow Simulations in a Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Nicholson T., Presentation of Test Case 11, INTRAVAL Workshop, Tucson, November 1988.

Parsons A.M. and Davis P.A., Modeling Strategy and Data Analysis for the Apache Leap Tuff Block Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Rasmussen T., Modelling of Field and Laboratory Experiments, INTRAVAL Workshop, Tucson, November 1988.

University of Arizona, Field and Laboratory Experiments in Unsaturated Fractured Tuff, INTRAVAL Workshop, Helsinki, June 1989.

TEST CASE 12

Hoxie D.T., Empirical Validation of Hydrologic Model Simulations of Changing Near-Field Hydrologic Conditions, INTRAVAL Workshop, Barcelona, April 1988.

Hoxie D.T., Flint A.L. and Chornack M.P., Model Validation with Respect to Short-Term Dynamic Effects and Long-Term Transient Effects, INTRAVAL Workshop, Tucson, November 1988.

TEST CASE 13

Arens G., Preliminary Results on Test Case 13, INTRAVAL Workshop, Helsinki, June 1989.

Arens G. and Fein E., One-dimensional Brine Transport in Porous Media, INTRAVAL Workshop, Las Vegas, February 1990.

Bogorinski P., Jackson P., Porter J., A New Approach to the SIVM Experiment, INTRAVAL Workshop, Cologne 1990.

Hassanizadeh S.M., Presentation of Experimental Results from Brine Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Hassanizadeh S.M., Experimental Study of Brine Transport in Porous Media, INTRAVAL Workshop, Tucson, November 1988.

Hassanizadeh S.M. and Leijnse T., Simulation of the Brine Transport Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Hassanizadeh S.M., Latest Results on Simulation of Brine Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Schelkes K., Preliminary BGR Results, INTRAVAL Workshop, Helsinki, June 1989.

Schelkes K. and Knoop R.-M., Results of Modelling the Salt Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

TEST CASE 14

Glasbergen P., Proposals for Test Cases Related to Rock Salt, INTRAVAL Workshop, Barcelona, April 1988.

Schelkes K., Pumping Test in Highly Saline Groundwater - a Proposed Test Case., INTRAVAL Workshop, Tucson, November 1988.

Schelkes K., Saline Groundwater Movement in an Erosional Channel Crossing a Salt Dome - Working Program for Test Case, INTRAVAL Workshop, Tucson, November 1988.

INTRAVAL Parties:

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intraval

PROGRESS REPORT

7

November 1990–April 1991

INTRAVAL – An International Project to Study
Validation of Geosphere Transport Models

INTRAVAL
Progress Report No. 7, 1991

The international INTRAVAL project started in October 1987 in Stockholm as an international effort towards validation of geosphere models for transport of radionuclides. The project was initiated by the Swedish Nuclear Inspectorate, SKI, and was prepared by an ad-hoc group with representatives from eight organisations.

Twentyfour organisations 'Parties' from thirteen countries participate in INTRAVAL. The Project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat in which also Her Majesty's Inspectorate of Pollution HMIP/DoE, U.K. and the OECD/NEA take part. Project organisation, the objectives of the study and rules for the publication of results are defined by an Agreement between the Parties.

The INTRAVAL philosophy is to use results from laboratory and field experiments as well as from natural analogue studies in a systematic study of the model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
Progress Report Number 7

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was started in October 1987. The first three years of the study, Phase 1, is in the process of being documented and finalised and a second three year period. Phase 2, was initiated and started in October 1990.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process. INTRAVAL has the ambition to cover both validation of models in regard to the processes and site-specific systems.

Ten test cases are included in Phase 2 of the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project and the Alligator Rivers Analogue Project.

A Pilot Group has been appointed for each of the test cases. The responsibility of the Pilot Group is to compile data and propose formulations of the test cases in such a way that it is possible to simulate the experiments with model calculations.

It is a pronounced policy of the INTRAVAL study to support interaction between modellers and experimentalists in order to gain reassurance that the experimental data are properly understood and that the experiences of the modellers regarding the type of data needed from the experimentalists are accounted for.

Contact between the participants is maintained by the arrangement of Workshops followed by Coordinating Group meetings. Between these conferences, also Working Group meetings take place.

Since the issue of the previous Progress Report, the sixth INTRAVAL workshop and the second Phase 2 Coordinating Group meeting has been held in Seattle, Washington, U.S.A. During the workshop participants described initial work performed on the Phase 2 as well as modelling results achieved so far. This was followed up by group discussions on further steps of the analyses and planning of intermediate working group meetings. The progress of the INTRAVAL Phase 1 Final Reports and the Executive Summary report was discussed both in plenary meetings and within working groups set up for finalisation of the documentation of Phase 1.

INTRAVAL Phase 2 Objectives and Organisation

The overall objectives of Phase 2 are similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process.

The organisation of INTRAVAL Phase 2 is similar to Phase 1. The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Parties organise Project Teams for the actual project work. A Pilot Group has been appointed for each test case in order to secure information transfer from the experimen-

talists to the Project Secretariat and Project Teams. At suitable intervals, about once a year, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group. Four Working Groups have been set up addressing different types of test cases (Table 1). Each Working Group will have one leader, possibly aided by another person, and the intention is to meet at least once between each INTRAVAL meeting. The Working Groups (leaders) are responsible for writing a working group report which will form part of the final reporting of INTRAVAL Phase 2.

Table 1. Tentative Working Groups for INTRAVAL Phase 2.

Working Group	Test Cases	Leader(s)
1	Las Cruces Apache Leap	T. Nicholson
2	Finnsjön Stripa WIPP 2	C.F. Tsang
3	Gorleben WIPP 1 Mol	P. Glasbergen
4	Alligator Rivers Twin Lake	P. Duerden

The Sixth INTRAVAL Workshop and the Second Phase 2 Coordinating Group Meeting

The sixth INTRAVAL Workshop and the second Phase 2 Coordinating Group Meeting were held in Seattle, Washington, USA, on the 18th through 22th of April, 1991 with the U.S. Department of Energy acting as host. In connection to the meeting a tour was arranged to the Hanford site near Richland, Washington.

At the workshop a number of technical presentations of Phase 2 modelling work were given. The modelling work of the Phase 2 test cases are in an initial stage. Much time was spent on the finalisation of the Phase 1 reports. All final reports are now available in draft form and in most cases they were sent out to the participants prior to the workshop. An outline for the Executive Summary report was presented and the content of the report was discussed.

The Coordinating Group meeting was held on the 24th of April, 1991. The Coordinating Group decided not to include Poços de Caldas as an test case in INTRAVAL Phase 2 since no Project Teams have indicated their interest in modelling the experiment. Due to the deletion of the Poços de Caldas experiment a rearrangement of the structure of the Phase 2 Working Groups were proposed, moving the Twin Lake case from Working Group 1 to Working Group 4 (see Table 1). The Coordinating Group also decided to dissolve the VOIC (Validation Overview and Integration Committee) as Phase 1 of INTRAVAL is ended. It was decided to form a new group for Phase 2 with the major objective to support the secretariat in writing the final reports.

The next INTRAVAL meeting will be held in Sydney, Australia on the 10th through 14th of February, 1992. The tentative plans for remaining INTRAVAL Workshops are: November 1992, October 1993 (last workshop) and May 1994 (Final meeting). Prior to the next INTRAVAL workshop separate Working Group meetings are planned, see Table 2.

Table 2. Planned Working Group meetings.

Working Group	Date	Location
1	June 27, 1991	Washington
2	Oct. 9–12, 1991	New Mexico
3	Oct. 14–16, 1991	New Mexico
4	June 12–15, 1991	Sydney
	Sept. 9–11, 1991	Chalk River

INTRAVAL Phase 1 Reporting

The achievements from the first phase of INTRAVAL will be documented in an Executive Summary Report and a series of Technical Reports. The Technical Reports will cover the descriptions, evaluations and conclusions from the modelling work performed for the different test cases. One of the technical reports will describe in detail the experiments on which the test cases are based. The technical reports are being prepared by six Working Groups. An editor for each test case has been appointed and the responsibility of the

editors are to compile the test case analysis provided by the Project Teams that have worked with the test case.

A draft version of most of the technical reports were available to the participants prior to the workshop in Seattle. The draft versions were discussed during the workshop and the responsible editors will as a next step include given comments and prepare a new version.

The technical report describing the experiments on which the test cases are based has been circulated for approval among the Pilot Groups, and given comments have been included. The summary report will be prepared by the Secretariat in cooperation with the Working Groups and VOIC (Validation Overview and Integration Committee).

The Summary Report and the Technical Reports are planned to be published in the spring 1992.

Current Status of INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media preformed at Las Cruces, New Mexico.

Experimental Set-up

The experimental site is located at the New Mexico State University College Ranch, 40 km northeast of Las Cruces in New Mexico, USA. Water and tracers are applied in a controlled fashion to the surface of an experimental plot. A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4×9 m and 1×12 m, respectively, are adjacent to the trench. Water and tracers were applied at controlled rates on these areas.

In the first experiment (Plot 1) water containing the conservative tracer tritium was applied at a rate of 1.76 cm/day on the area measuring 4×9 m. In the second experiment (Plot 2a), water containing tritium and bromide was applied at a rate of 0.43 cm/day on the other area (1×12 m) on the opposite side of the trench and in the third experiment tritium, bromide, boron, chromium and two organic compounds (pentafluorobenzoic acid and 2,6-difluorobenzoic acid) were applied at a rate of 1.82 cm/day on the same area. The movement of the water below the soil surface was monitored with neutron probes and tensiometers. Tracer concentrations were sampled on a regular basis through solute samplers installed in a two dimensional grid through the trench wall. In addition, laboratory experiments on cores have been performed to determine the physical properties of the soil. The Plot 1 and Plot 2a experiments were included in INTRAVAL Phase 1 and was used for model calibration. The calibrated models will be used in INTRAVAL Phase 2 to predict the Plot 2b experiment before the experimental data will be made available to the Project Teams.

Analyses by the Project Teams

The Project Team from PNL/USNRC has performed two dimensional simulations of the Plot 2b experiment with the integrated finite difference code PORFLO-3. The model domain is 12×6 m. Semivariograms were used to estimate the covariance of the saturated hydraulic conductivity. The saturated hydraulic conductivity measured in the laboratory does not show a lognormal distribution, whereas the field measurements of the saturated hydraulic conductivities show more of a lognormal distribution. The water content distribution from neutron probes and the tritium concentration from core samples were used as initial conditions. A flux of 1.8 cm/day and a normalised tritium concentration of 1.0 was applied over an area corresponding to a strip source. Zero-flux boundaries were applied at the remainder of the top boundary and at the sides. The lower boundary was set to be unit gradient. The results showed some correlation between the simulations and the experiments. Further research will include Monte Carlo simulations.

The Project Team from SNL/USNRC presented their work performed for INTRAVAL Phase 1 together with their plans for Phase 2. They will identify a performance measure closely related to the regulations for low level waste. The simulations planned to be performed are Monte Carlo simulations using a two-dimensional heterogeneous field and Richards equation model.

The Project Team from CNWRA/USNRC presented a preliminary study of the Plot 2a experiment. They used a modified version of the integrated finite difference code PORFLO-3. The hydraulic properties of 180 soil sample locations were used, which means that each sample repre-

sents a subzone with individual properties in the two-dimensional grid used to represent the trench wall. It is planned to perform a series of calculations with different solute concentration boundary conditions, i.e. prescribed concentration or prescribed mass flux during the infiltration of tracers and zero concentration or zero mass flux when the supply of tracer is cut-off. The future plans is to assess the worth of soil hydraulic data, initial water content and solute sampler density. The Plot 2a experiment will be used for calibration and the Plot 2b experiment will be predicted based on this calibration.

The Project Team from CNWRA/USNRC discussed validation and refutation of models by testing procedures for unsaturated flow models. Spatially distributed models differ by their degrees of freedom, which are determined by the product of the number of heterogeneities, number of effective flow domains and effective dimensionality. A black box model has no degree of freedom, whereas, a homogeneous column has one degree of freedom. A deterministic three-dimensional strip source infiltration model with 300 000 material heterogeneities has 10^6 degrees of freedom. The numerics of a code can be tested by truncation error analysis, stability analysis, and mass balance analysis. Other internal and comparative tests are comparisons with analytical solutions, comparisons between coarse and fine mesh predictions, and inter-code comparisons.

Other topics to look at are uncertainties due to sparse sampling and incomplete knowledge of spatially distributed and non-linear properties of unsaturated medium in situ. The degree of validation has to be quantified via a performance measure. Probabilistic decision making could be performed by comparison of models differing only in the value of some adjustment parameters. Another test is to correlate a single model to observations and evaluate the probability of error and compare with actual prediction errors. Tests of consistency and numerical occurrence are an integral part of validation. However, only refutation and not validation is possible by logical inference.

APACHE LEAP TUFF

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, U.S.A

Experimental Set-up and Scales

The test case is based on field experiments performed at the Apache Leap Tuff Site in tuffaceous rock near Superior, Arizona, USA, with the aim to predict water flow and solute transport through unsaturated fractured rock under field conditions. A multistage experimental plan is used to estimate parameters related to hydraulic, pneumatic, thermal and solute transport in unsaturated tuff. Laboratory experiment have been performed on drill cores and on rock blocks to determine important parameters for solute transport, fracture flow, thermal induced flow, etc. These experiments were included also in INTRAVAL Phase 1. Fifteen boreholes have been installed and used for the in situ site characterisation. The INTRAVAL Phase 2 study is focused on two related field experiments, one with and one without imposed temperature gradients. Data for the first experiment are available or underway and the field heating experiment will begin at the end of 1991. The INTRAVAL participants are invited to perform predictive modelling. Water and gas injection recovery tests are currently underway to determine temporal and spatial responses as well as other flow characteristics.

Analyses by Project Teams

The US NRC Project Team presented some modelling results for the large block experiment included also in INTRAVAL Phase 1. They had examined two different blocks (0.2×0.2×0.5 m and 0.2×0.2×0.7 m) containing a natural fracture oriented vertically near the centre. The blocks were mounted on a support frame and enclosed within a chamber to prevent evaporation. Water was then supplied at a constant head on the top and the water potential was measured with microtensiometers. The two-dimensional finite element code VAM2D was used in the performed simulations. The aim was to test the fracture matrix flow concepts. Both the matrix and the fracture (0.1 cm wide) were treated as equivalent porous media. The effective porosity of the fracture was set to 97% and the van

Gneuchten characteristic curve data were taken from the literature. The major conclusions were that the fracture acts as a barrier and that the code overpredicts the wetting front movement.

The Project Team from UAZ/US NRC presented their research work concerning the use of pneumatic testing to determine hydraulic properties of rocks. The major advantage with pneumatic tests are that they can be performed faster than hydraulic tests. The techniques to be used are adapted from gas and oil industry.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

This test case deals with detailed characterisation of a fractured zone including a large-scale interference test and two large-scale tracer tests, one radially converging test and one dipole experiment. This test case was included also in INTRAVAL Phase 1, but the database for the dipole experiment was never used for modelling since it became available too late. The modelling of the dipole experiment will therefore be the focus of Phase 2.

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometres.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to 10^{-4} m^2/s, the middle layer to 10^{-7} - 10^{-6} m^2/s and the lower layer to 10^{-4} m^2/s. The middle layer is not continuous. A fresh water - salt water interface exists in the fracture zone relatively close to the upper sub-layer. The salt content of the groundwater is higher below than above the zone. The natural hydraulic head gradient is estimated to 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock is penetrated by several core-drilled and some percussion-drilled boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes at 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated in 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells, totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed, a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting 11 different non-sorbed tracers at 9 different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting tracers in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analysis by the Project Teams

The Project Team from CEA/IPSN presented their plans for this test case. They contributed to this test case also during INTRAVAL Phase 1 but will now use an improved synthetic model for their simulations. The flow parameters will be interpreted from the interference test using an inverse model. Thereafter a global model will be set-up for all boreholes and the tracer tests will be simulated.

The Project Team from VTT/TVO discussed their modelling results and also phenomena, geometries and source terms in field experiments in fractured rock. The first phenomena to be studied is the hydrodynamic dispersion because it is unavoidably encountered in any experiment. Dispersion cannot be controlled just by one experiment as it is both time and length dependent. Actually

the dispersion as such is not of primary interest for nuclear waste repository performance assessment as the waterflow rates in the repository conditions means that matrix diffusion will disperse pulses much more than the hydrodynamic dispersion.

To study the matrix diffusion the water flow rates in the experiments should be as small as practically possible. Retardation due to sorption should be studied not only in batch type experiments but also in transport experiments by injection of both non-sorbing and sorbing tracers at identical conditions. It should be confirmed that the potential field used during the experiment is stable against small variations. The transport paths should be studied one by one, as superposition of the different curves is easier than to identify the contributions from different flow paths from a composite curve. The duration of injection of tracers shall be as short as possible and the concentration should not be so high that the properties of the injected solution deviates too much from the properties of the carrier flow.

The Project Team has modelled both the radial and the dipole experiments during Phase 1 using a concept of channelled flow in two dimensions and also tracer transport in two dimensions in channels with varying aperture with a linear velocity profile. The transport times were calculated from measured transmissivities in boreholes. A fixed value of 5 cm were used for the characteristic width over which the velocity varies from zero to its maximum value. The measured breakthrough curves were very sensitive to the length of the injections, which were not measured very accurately. However, an overall agreement between the calculated and measured breakthrough curves was obtained in both experiments.

Conterra/SKB presented some modelling work performed for Finnsjön related to their internal project SKB-91. They have performed stochastic continuum modelling of mass arrival at Finnsjön with both unconditional parametric and conditional non-parametric approaches. A vertical section of Finnsjön, 1 km long, has been looked at. Data were collected from five boreholes in Zone 2. 50 realisations were run to get the hydraulic conductivity field for each method. It was difficult to compare the two methods and the effects of conditioning could be seen. The non-parametric conductivities were generally lower than the parametric. Both groundwater simulations, mass arrival and particle tracking analyses were performed. It was concluded that Zone 2 acts as a barrier for transport.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiments, Sweden.

Experimental Set-up

This test case is based on three dimensional tracer tests performed in the Stripa mine in Sweden. The experiment forms part of the International Stripa Project.

An experimental drift was excavated in the old iron-ore mine in Stripa. The ceiling and upper part of the walls were covered with about 350 plastic sheets (2 m^2 each) with the purpose to collect water seeping in from the rock and to collect injected tracers. Three vertical boreholes for tracer injections were drilled and tracers were injected at nine locations, 10–55 m above the test site.

The data registered or obtained from the experiments are water flow rates, tracer concentrations in the water entering the drift, rock characteristics and fracture data, water chemistry, tracer injection pressure and flow rates, and hydrostatic pressure. Diffusivity and sorption data are available from complementary laboratory and field experiments. The experiment was a test case also during INTRAVAL Phase 1.

In addition to the 3D tracer experiments data from two other experiments performed in the Stripa mine, the 'Channelling experiment' and the 'Site Characterisation and Validation Program', will be made available to the INTRAVAL Participants during Phase 2. The channelling experiment consists of two kinds of experiments. In the single hole experiments, holes with a diameter of 29 cm were drilled about 2.5 m into the rock in the plane of a fracture. Specially designed packers were used to inject water into the fracture in 5 cm intervals. The variation of the injection flow rates along the fracture were used to determine the transmissivity variations in the fracture plane. Detailed photographs were taken from inside the holes and the visual fracture aperture was compared with the injection flow rates. Five holes were measured in detail and seven holes were scanned by simple packer systems. A double hole experiment was also performed, for which two parallel holes were drilled in the same fracture plane at nearly 2 m distance. Pressure pulse tests were made between the holes in both directions. Tracers were injected at five locations in one hole and monitored at many locations in the other hole. The 'Site Charac-

terisation and Validation Program' includes a number of investigation steps to characterise an unexplored rock volume starting with a few long boreholes, and finally a new drift was excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

Analysis by the Project Teams

The Project Team from BRGM/ANDRA is working with the 3D tracer experiment. They use a classical approach and have finalised the geometrical model and are working with the flow model. Thereafter the transport model will be tackled. The geometric model is based, i.a., on statistics of fractures and fissures. The model contains three main sets of fractures, one sub-horizontal and two sub-vertical. The fractures are simulated as circular discs in a three dimensional network. Very small fractures have been eliminated as their importance for flow and transport has been found to be of minor importance. The elimination of small fractures has, however, an impact on the connectivity. The flow simulations are made with the code TRINET. The flow model is smaller than the network model in size. Simulations have been performed both with constant conductivities and lognormal distribution of the conductivities.

The Project Team from VTT/TVO presented some results for this test case. They have used the same model as presented earlier for the Finnsjön experiment, i.e. a generalised Taylor dispersion model. In this case they used two to four channels and the properties of the channels were adopted from Chin-Fu Tsang, LBL, who has used a deconvolution technique, in which long and varying injection rates are taken into account when studying the transport properties of channels. The characteristic width of the velocity profile in the channels varied between 2 and 15 cm, which would indicate that hydraulic dispersion dominates over matrix diffusion for this experiment. Actually, the breakthrough curves could be explained entirely by hydrodynamic dispersion alone. Some preliminary sensitivity studies have been initiated.

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental set-up

The WIPP, located near Carlsbad in southeastern New Mexico, USA, is an underground research and development facility. The WIPP is located in the Delaware Basin, of which the northern part is filled with 8000 m of sedimentary Phanerozoic rocks containing evaporites. Water bearing zones within the rocks that underlie, host, and overlie the WIPP repository have low permeabilities and storativities, are generally confined, and contain waters with high salinities and long residence times. The repository lies 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation. Overlying the Salado Formation is the Rustler Formation. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is an 8 m thick vuggy dolomite layer.

Geologic, hydrologic, geochemical and isotope data have been obtained to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involves the travel time within the Culebra from a location above the repository to the WIPP site boundary. 60 wells to the Culebra dolomite at 41 locations have been completed to provide information on the hydraulic properties. Two pumping tests each of two months duration, and two convergent-flow tracer tests have been performed. Geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra.

Analyses by the Project Teams

The Pilot Group has evaluated the experimental data. The transmissivity in the Culebra varies in the range from $< 10^{-9}$ to $> 10^{-3}$ m^2/s, due to fracturing. The evaluation of fracture properties and distribution is necessarily qualitative, relying on interferences drawn from pumping tests, as the cores are too broken to allow statistical studies where the fractures are located. The hydraulic tests, performed at a variety of scales, ranging from

single-well drillstem tests to long-term pumping tests, have been interpreted using an analytical solution for homogeneous single- and double porosity systems. The interpreted transmissivities change as the scale of test changes reflecting a heterogeneous distribution of fractures. Double-porosity simulations gave good fit to the pumping test drawdown response. Simulations of the transient responses with a transient-calibrated transmissivity field gave also rather good fit to observed head values within the uncertainty of the measurements. The models used assumed homogeneity and one question is on what spatial scale, or over what range of hydraulic properties a homogeneous model can provide representative properties.

The convergent tracer tests have been analysed using a one-dimensional radial-flow, double-porosity model, SWIFT II. Three orthogonal fracture sets were simulated and anisotrophy were incorporated by making flow rate a function of direction. Dispersivity was approximated as 10% of the flow-path length, matrix porosity (0.16) and tortuosity were derived from core tests. The fracture spacings were set within the range 0.15–0.48 m and anisotropies (K_x/K_y) between 3 and 7 were needed to match the breakthrough curves (example in Figure 1).

The Pilot Group has also performed two-dimensional calculations of the flow field and the fastest travel paths in the Culebra dolomite. The system consists of a borehole penetrating both the repository and an underlying pressurised brine pocket, with contaminant release and offsite transport in the overlying Culebra. The transmissivity distribution in the Culebra has a variance of 6–7 orders of magnitude. To get a good fit of the transmissivity distribution, both real points and added data point were needed. The model used for contaminant transport is a double porosity model with variable density flow. The maximum breakthrough for a conservative nonretarded solute is reached after about 10 000 years at a boundary 5 km away.

The Project Team from INTERA/NIREX has looked at how the transition from field data to a realistic full flow and tracer model simulation can be facilitated. What does the field data tell about spatial variability on scales from the inter-well distances downwards? They have used the measured transmissivities in order to address the inverse problems for flow and transport. The analysis uses a conceptual rock-property model based on the statistical self-affinity of fractals, which yields realisations of measured fields, conditioned by the data points. The Project Team uses one by themselves developed code AFFINITY. The transmissivities from 39 wells within the WIPP model region were used to obtain a variogram. The AFFINITY code generated the realisation of the transmissivity field matching the structure of the variogram, interpolating all 39 measurements. As a check 151 random samples from the realised field were used in order to generate a synthetic variogram which compared well with the original, see Figure 2. The pressure field and associated Darcy velocity field calculated from the realised transmissivity field indicates a highly channelled flow. A similar calculation including a single borehole pump test shows that the flow is concentrated into a few discrete channels. A borehole injection test was also simulated by tracking particles through the flow field after being initially placed at a single location.

The Project Team from AEA/NIREX presented their proposed approach to the test case as well as some preliminary results. The Culebra database is very large. This offers the opportunity to build models based on a subset of data and then to use these models to make predictions which can be tested against already known data. The methods intended to be applied are primarily of geostatistical nature and the feeling is that this is the best scientific approach to problems of spatial variation and uncertainty. There are two basic types of geostatistical methods. In the first type, statistical methods, such as kriging, are used to estimate hydrogeological parameters which are then fed into purely deterministic flow and transport calculations.

The second method, which is intended to be used by the team, is a stochastic approach. The groundwater flow and transport problems are treated as stochastic differential equations solved by simulations or Monte Carlo methods. In the first phase of the work a very simple stochastic model will be used and a set of Monte Carlo simulations will be performed. The Turning Bands method will be used to generate a set of realisations of the transmissivity, which will have a multivariate log-normal distribution and an exponential variogram with the parameters obtained from the available experimental transmissivity data. These unconditional simulations will be conditioned on the known transmissivities. Particle paths and transit times will be calculated from the computed pressure or head fields. So far an experimental variogram for the logarithm of the transmissivity based on some of the measurements has been calculated. Attempts have also been made to fit four different

model variograms to the data, namely spherical, exponential, gaussian and cubic. The best fits were achieved with spherical and exponential variograms, and in these cases no nugget effects were required. The parameters calculated for the exponential variogram were used in a conditional simulation of the transmissivity field. Finally, particle paths were calculated. The calculations will be developed and refined and detailed comparisons with the experimental data as well as with the results of other groups will be made in the future.

The Project Team from VTT/TVO have performed preliminary analyses of three tracer breakthrough curves from one of the tracer test (H-11). They used the same model as was used for both the Finnsjön and Stripa test cases. The breakthrough curves are very asymmetric and the first part of the tracers arrives very fast. The explanation to this could be that many channels could be involved and there might be a very large matrix diffusion, similar to diffusion into stagnant water in areas with porosity of the order of 1. There might also be a time dependent source term, releasing tracer over several hundreds of hours, which might give the observed long tail. Only one channel was included in the model but the injection procedure resulted in a spreading of the tracer out in the surrounding followed by a slow recovery and further transport in the channel. The model seems to reproduce the observed breakthrough curves rather well, see Figure 3.

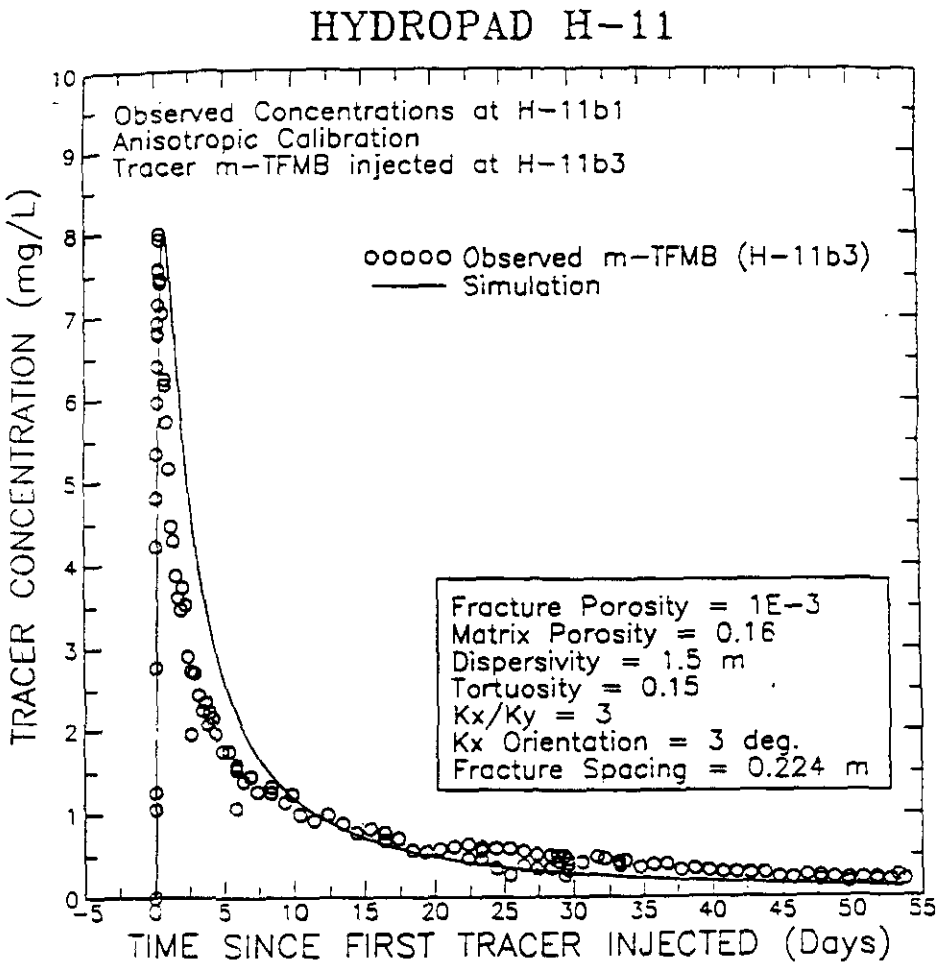

Figure 1. Tracer concentration versus time. The figure shows both observed values and the results of a simulation. (WIPP 2)

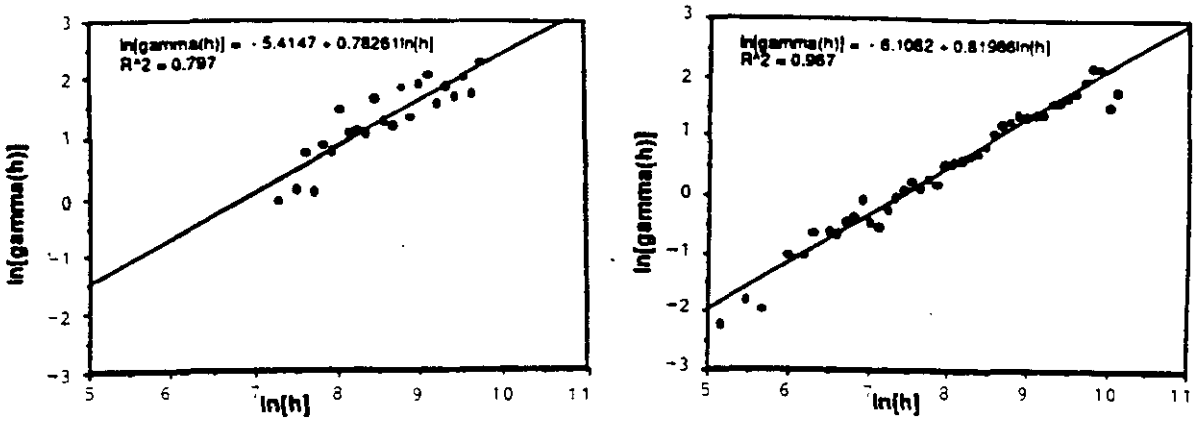

Figure 2. (a) Variogram fitted from transmissivity data of 39 wells. (b) Synthetic variogram fitted from 151 random samples from final realisation. (WIPP 2)

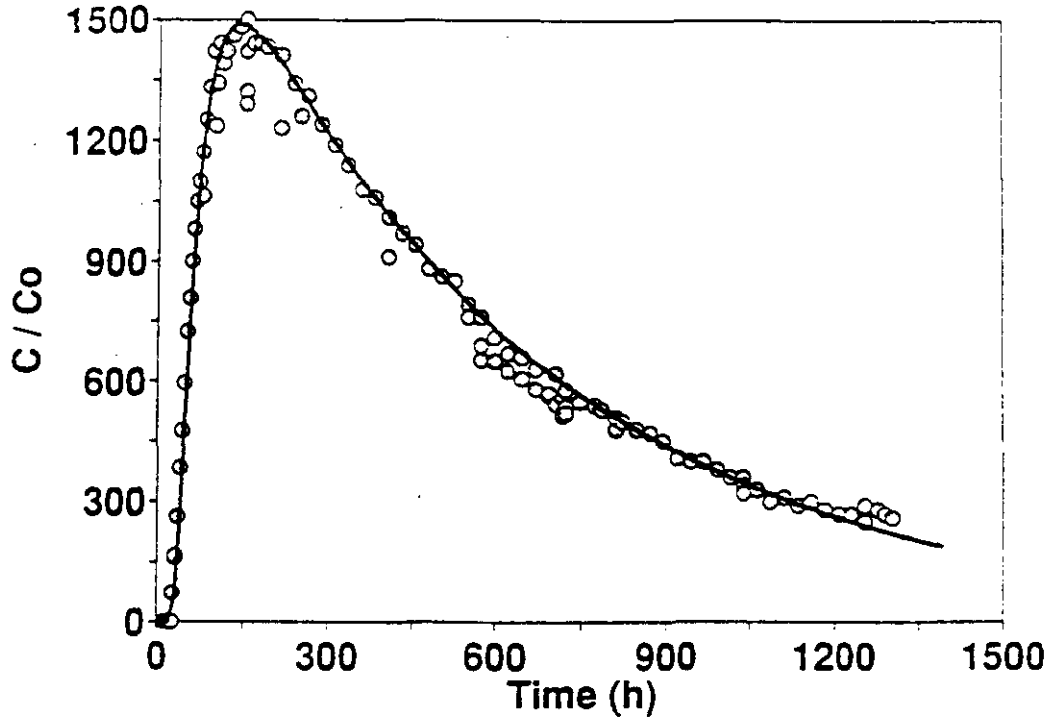

Figure 3. Breakthrough curve. Figure shows observed values (dots) and results of a simulation (line). (WIPP 2)

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Experimental set-up

The Gorleben salt dome is located in the north-eastern part of Lower Saxony in the Federal Republic of Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel the 'Gorleben Channel' more than 10 km long and 1 - 2 km wide crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel is the topic for this test case.

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out: one in the fresh water and three in the saline water. One of the pumping tests, where the pumped well penetrates the entire deeper aquifer in the erosional channel, will form the bases for the first part of this INTRAVAL test case. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of 3 weeks. The second part of the test case is an extension in both time and length scales and comprises regional groundwater flow modelling and salt dissolution as well as the interaction between the two.

Analysis by the Project Teams

No presentations were given by the Project Teams during the INTRAVAL workshop, but contributions are expected from a number of teams in the future.

WIPP 1

Brine flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental set-up

The WIPP, located in Carlsbad, New Mexico is an underground research and development repository lying 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation. This test case is based on experiments performed with the aim to determine the rate of brine flow through the Salado formation. The experiments are designed to provide a variety of data with the aim to determine whether Darcy's law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Data from three types of experiments will form the bases for this test case:

— small scale brine-inflow experiments
— pore pressure and permeability testing
— integrated, large scale experiment.

Brine inflow rates are measured at three scales: in 10 cm and 1 m diameter boreholes and in a 2.9 m diameter cylindrical room. Pore pressure measurements are made in 10 cm diameter boreholes, 2 to 27 m long, drilled at a variety of orientations. The large scale experiments are brine inflow rates to a horizontal cylindrical room, 107 m long with a diameter of 2.9 m.

Analysis by the Project Teams

The Pilot Group has made interpretations of data. The model used to analyse the small-scale experiments is one-dimensional, radial, Darcy flow assuming a homogenous isotropic medium and a uniform initial pore pressure. The apparent diffusivities are on the order of 10^{-10}–10^{-7} m^2/s determined from the rate of decay of the brine inflow rate. The permeability is determined from the magnitude of the brine inflow rate, and are on the order of 10^{-10}–10^{-7} m^2/s, if the brine viscosity is assumed to be $1.6 \cdot 10^{-3}$ Pa·s and the pore pressure is

10 MPa. A lot of activities are underway both concerning the experiments and the interpretation of data, i.e. determination of parameter uncertainties for the data set, statistical evaluation of the data, modification of the used model to include more complex processes, redesign of the measurement equipment and procedures as well as planning for additional measurements and experiments.

The Pilot Group has also interpreted some of the permeability tests (S0P01 and L4P51). They have used the code GTFM, a one-dimensional radial-flow model. Fully confined porous medium with uniform permeability and pressure throughout the tested layer was assumed. The fitted parameters were the hydraulic conductivity, the formation pore pressure and the distance to a boundary. The specific storage and the test-zone compressibility were assumed parameters. The classical groundwater definition for the specific storage, assuming negligible grain compressibility, gives a specific storage about a factor four lower than the complete definition as the porosity in the deformable halite is very low, 0.1–3%. Compressional-wave velocity of halite is observed to decrease by up to 50% in the disturbed rock zone around the repository which can be translated to a 400 % increase in specific storage. The conclusion is that the specific storage is important. The interpretations of the two tests show that the hydraulic behaviour appears to be that of a porous medium with a hydraulic conductivity of about $4 \cdot 10^{-14}$–$6 \cdot 10^{-14}$ m/s and a formation pore pressure of about 2–4 MPa and no indications of boundaries out to at least 8 m in the first test (S0P01) and a no-flow boundary 2 m from the borehole in the second test (L4P51).

MOL

Migration experiment in Boom Clay Formation at the MOL Site, Belgium.

Experimental set-up

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The purpose of the experiment is to determine migration related parameters and to confirm parameters determined earlier in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

A group of piezometers, called piezometernest, has been installed in the Boom Clay formation at a depth of 220 m. The stainless steel system contains 9 piezometers, interspaced by 0.9 m long tubes. A horizontal hole with a diameter of 50 mm and a depth of 10 m was drilled in the clay formation by rotary drilling. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. The steady state pressure distribution as a function of the depth into the clay was measured by manometers.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 (in the centre) and thereafter the system was left alone allowing migration of HTO in three dimensions.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters. The first breakthrough was obtained in filters 4 and 6, located adjacent to the injection filter 5, at a distance of 1 m.

The experiment will continue 10 years after finalisation of INTRAVAL Phase 2 and the number of measured points are at the time being limited.

Analyses by the Project Teams

The Pilot Group presented results from performed modelling. The Boom clay has been modelled as a homogeneous anisotropic medium as clay is a stratified medium and the governing transport mechanisms considered were advection–dispersion. A number of measured concentrations at filter 4 and 6 are available and the modelled results for these points gave rather good fits, see Figure 4, for the following parameter values; hydraulic conductivity $3.2 \cdot 10^{-12}$ m/s, hydraulic gradient –18.9 m/m, Darcy velocity $6.0 \cdot 10^{-11}$ m/s, dispersion length 0.002 m. The tracer HTO has a retardation factor of 1. The diffusion accessible porosity was set to 0.35, horizontal dispersion to $4.1 \cdot 10^{-10}$ m^2/s and vertical dispersion to $2.0 \cdot 10^{-10}$ m^2/s. The sensitivity to the diffusion accessible porosity (0.30–0.40) and the hydraulic conductivity ($3 \cdot 10^{-12}$–$1 \cdot 10^{-10}$ m/s) was studied before the values of the parameters were selected.

The Project Team from SNL/USNRC has applied a special validation strategy developed during INTRAVAL Phase 1 to Mol site data. A quantitative evaluation of fit between theory and experiments for suggested parameter values was made. An analytical solution of the convective

dispersion equation was used to calculate the breakthrough of HTO in filters 4 and 6. Three cases were studied. A base case using bench-scale variables with convective dispersion, a diffusion only analysis with fitted parameters, and a convective-dispersive case with fitted parameters. Three different methods of comparisons between measured data and calculated data were used; eyeball, linear regression of measured vs calculated data and residual analysis (both eyeball and runs analysis). A fourth method for comparisons, variogram of residuals, is planned for but the database does not include enough data yet. The outcome of the analyses are presented in Table 3 below. The base case could be rejected according to the outcome of all tests except for the residual runs analysis. The pure diffusive case and the convective-dispersive case with fitted parameters could only be rejected in the residual runs analysis. The conclusions are that the performed analysis could not differentiate between the tested conceptual models and that the data base is too limited.

Table 3. Summary of comparisons (MOL).

Test	Base case	Diffusion	Convection–dispersion
Eyeball	reject	not reject	not reject
Linear regression	reject	not reject	not reject
Residual analysis, eyeball	reject		
Residual analysis, runs	not reject	reject	reject

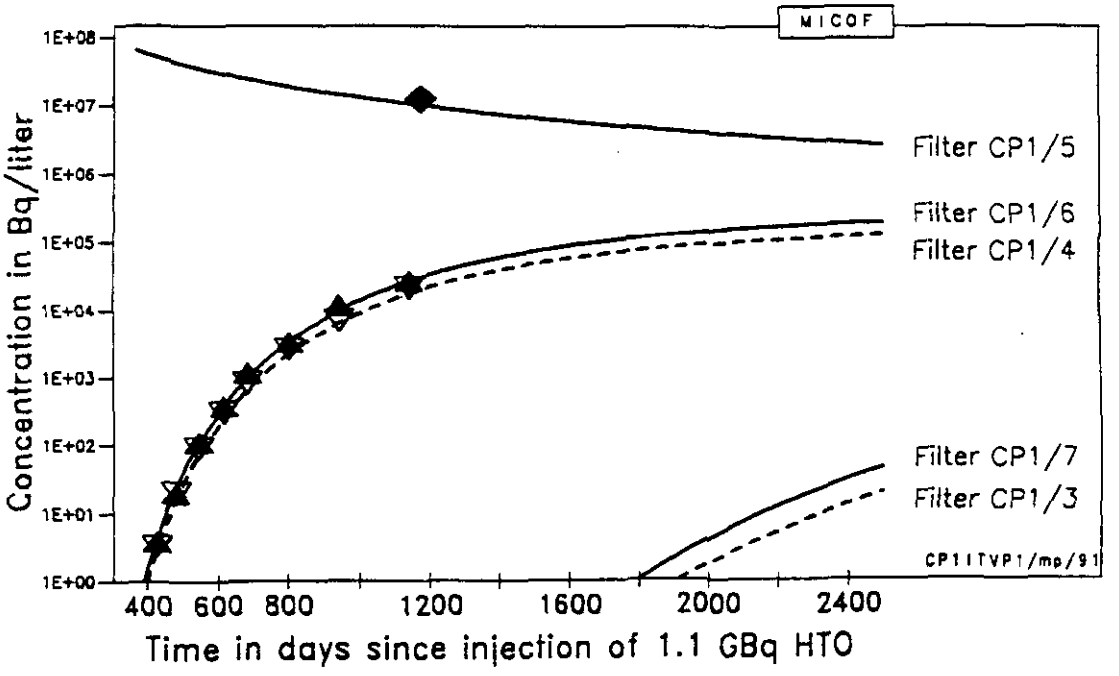

Figure 4. Breakthrough curves. The figure shows both observed values and results of simulations. (MOL)

ALLIGATOR RIVERS

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

Experimental Set-up

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator Rivers Region is located about 200 km east of Darwin.

Uranium mineralisation occurs at Koongarra in two distinct but related orebodies, which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists, secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m. The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

An extensive experimental program including both field and laboratory investigations have resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs of 140 percussion holes and 107 drill cores. Groundwater chemical data has been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The distribution of uranium and thorium between different mineral phases in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from drill cores. Distribution coefficients have also been measured on natural particles in Koongarra groundwater.

Analyses by the Project Teams

The Project Team from CISRO/ANSTO has performed both two- and three-dimensional modelling of the groundwater flow through the Koongarra uranium orebody. Earlier modelling studies of the area has shown a considerable uncertainty not only in hydraulic conductivities but also in the locations and types of model boundaries. Therefore this group decided to investigate flow in vertical sections at a much larger regional scale than has been done before with the aim to identify the real boundaries of the local flow system near the orebody. They simulated the flow in a cross-section oriented from northwest to southeast which passes through the Koongarra orebody.

The finite element grid used was rectangular with a length of 26 km and depth in the range of 1 to 3 km. The results of the two dimensional large scale modelling gave some confidence that three-dimensional modelling of the smaller region near the orebody may be relatively insensitive to the thickness of the Kombolgie sandstone and the depth of the impermeable bedrock. The two-dimensional modelling in vertical section showed the likelihood of a creek to act as a discharge boundary for the groundwater system, and the break in slope and the change in hydraulic conductivity between the Kombolgie sandstone and Cahill schist being the other major discharge region. In addition to the two-dimensional modelling, aerial photographs showed several distinct vegetation boundaries. Based on this information the appropriate domain for modelling the local groundwater system would be almost triangular. A finite difference model, BIGFLO, was used for the local simulations. The studied region was 3×3 km and 1 km deep. Groundwater surface elevations were defined at all nodes along the creek and along several other lines. In the top layer high flow rates were seen in the weathered zone and in the Koongarra Fault. It was observed that the flow is from northwest to southeast at the right side of the domain and much more towards the south at the left side.

The Pilot Group has also been studying the uranium activity ratios in different iron mineral phases to look for time indication keys in the system. The activity ratio of ^{234}U to ^{238}U and ^{230}Th to ^{234}U in both amorphous (accessible) and crystalline (inaccessible) iron phases has been modelled and compared with experimental data. The model assumes one dimensional advection dispersion in porous medium and the rock stratum is presented as a series of one dimensional boxes. The interaction between rock and water is modelled as two general processes, leaching and deposition, i.e. the K_d concept. The radionuclide

transfer between the two rock mineral phases are nucleus recoil. The processes of crystallisation considered is structural rearrangement of ferrihydrite to hematite or crystallisation of ferrihydrite to goethite (through ferric(III) ions). The K_d-values and porosities used were experimentally determined and the water flow velocity was from hydrology findings. Phase transition rates and estimates of recoil transfer were fitted parameters. The model was fitted to the activity ratios vs distance in both accessible and inaccessible rock, as well as to the concentration ratio between accessible and to inaccessible rock vs distance, and the total uranium concentration in the selected region. The very initial curves presented were found to be quite sensitive to all parameters.

The Project Team from US NRC presented results from geochemical modelling of the formation of secondary uranium minerals at the Koongarra site. Two phases of secondary uranium mineralisation can be distinguished: in situ alteration of pitchblende to uranyl silicates (sklodowskite, uranophane) and formation of uranyl phosphates (saleeite, torbernite) from mobilised uranium in the dispersion fan. These latter processes have been simulated by making reaction path calculations with the code EQ3/6 using data from the site on water chemistry and minerals.

Regarding the formation of uranyl silicates, it was concluded that the model results are consistent with modern formation of the uranyl silicate zone from reaction of silica-rich water with uraninite, but present uranium levels in the water are generally too low to form uranyl silicates. Furthermore, the uranyl silicate minerals formed in the calculations are not the same as those formed at the site. This was concluded to be mainly a result of lack of data in the uranyl silicate data base.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Experimental set-up

Aquifer testing ranging from large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of AECL research facilities, the Chalk River Nuclear Laboratories. The laboratories are located 200 km northwest of Ottawa, Canada, in the Valley of Ottawa river. The water table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

The large experimental programme includes natural gradient tracer (^{131}I and HTO) experiments over distances 20, 40 and 260 m. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation and gamma scanning is performed through the full aquifer.

The database contribute hydrogeologic data (stratigraphic information, hydraulic conductivity, porosity, groundwater flow velocity), tracer concentrations etc.

Analysis by the Project Teams

The Project Team from SNL/USNRC has made some initial analyses of the Twin Lake data. After evaluation of the experiment they applied a validation strategy developed during INTRAVAL Phase 1. It was pointed out that when model and experiment do not agree the reason can either be problems with the used model or problems with the experiments. It is therefore important to determine whether an experiment is adequate for model validation before starting the modelling. The adequacy of the Twin Lake data are based on the consistency of flow and transport and the mass balance. Part of the validation strategy developed consists of testing model structures and comparison of model results and experimental results. Three different techniques for comparisons were used, experimentally determined concentrations versus modelled concentrations, concentration residual versus time, and variogram analysis of residuals. Statistical tests, such as linear regression and residual analysis are needed to translate graphs into quantitative measures. The tests discussed so far only give probabilities of rejecting a good model and no information about acceptance of a bad model. Previous modelling by the Pilot Group with a one dimensional advective–dispersive model, and the experimental breakthrough curves at a preselected position as performance measure, indicates a model structure error with all the different comparison techniques.

The Project Team from CEA/IPSN presented their view on this test case. The main points of interest are that the dataset contains a great number of measured points at different time and spacial scales. In their modelling work they will use the finite element code METSIS.

The Project Team from CEA/DEMT/ANDRA plans to perform stochastic modelling using the finite element integration code TRIO. The problem at the time being is high Peclet numbers in the used mesh and lack of permeability data.

Distribution of Background Information and Databases

Background information and databases will be distributed to the INTRAVAL Participants either by the Secretariat or by the Pilot Groups according to Table 4. The information is distributed only on request from the Project Teams.

Table 4. Distribution of Background information and databases.

Test case	Distributor	
Las Cruces Trench	Pilot Group	T. Nicholson, NRC[1)]
Apache Leap Tuff	Pilot Group	T. Nicholson NRC[1)] T. Rasmussen, UAZ[1)]
WIPP 2	Pilot Group	E. Gorham, SNL[1)]
Gorleben	Pilot Group	K. Schelkes, BGR[1)]
Alligator Rivers	Pilot Group	P. Duerden, ANSTO[1)]
Twin Lake	Secretariat[2)]	
Finnsjön	Secretariat[2)]	
Stripa	Secretariat[2)]	
WIPP 1	Secretariat[2)]	
Mol	Secretariat[2)]	

1) Full organisation name, see List of INTRAVAL Participants in Appendix 1
2) Kemakta Consultants Co., Pipersgatan 27, S-112 28 Stockholm, Sweden

Other Information

S. Hossain, IAEA, presented an ongoing International Project (NSARS) where the application of geospheric models in an integrated safety assessment of near-surface radioactive waste disposal facilities are studied. 17 organisations from 17 different countries participate in the project. The objectives of the project are to:

- improve confidence in the results of safety assessments through model intercomparison and validation
- help in establishing international consensus on the approaches to safety assessment
- facilitate exchange of information, its documentation and wider dissemination.

Appendix 1

INTRAVAL Organisation

The organisation of the INTRAVAL study is regulated by an agreement which has been signed by all participating organisations (Parties). The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Managing Participant sets up a Project Secretariat in cooperation with Her Majesty's Inspectorate of Pollution (HMIP/DoE), U.K. and the Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA). KEMAKTA Consultants Co. is contracted by SKI to act as Principal Investigator within the Project Secretariat.

The Parties organise Project Teams for the actual project work. Each Party covers the costs for its participation in the study and is responsible for the funding of its Project Team or Teams, including computer cost, travelling expenses, etc.

A Pilot Group has been appointed for each Test Case in order to secure the necessary information transfer from the experimental work to the Project Secretariat and the Project Teams. The Project Secretariat coordinates this information transfer.

At suitable time intervals, depending upon the progress of the study, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group. During the workshops, Test Case definitions and achieved results are discussed as a preparation for decisions in the Coordinating Group.

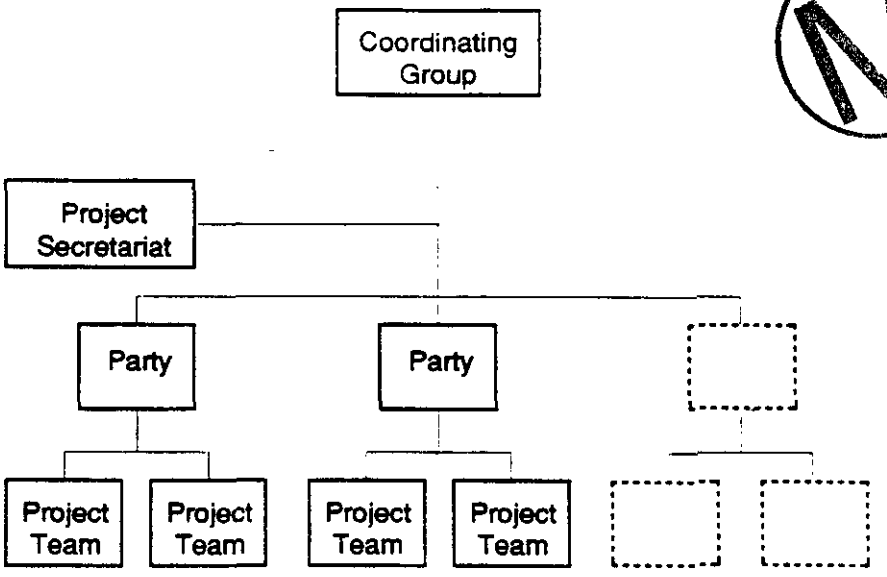

Figure 5. INTRAVAL Organisational Chart.

Managing Participant:	SKI
Coordinating Group	
Chairman:	K. Andersson, SKI
Vice Chairman:	T. Nicholson, U.S. NRC
Secretary:	J. Andersson, SKI
Principal Investigator:	KEMAKTA Consultants Co.
Project Secretariat:	K. Andersson, SKI
	J. Andersson, SKI
	M. Ericsson, KEMAKTA
	B. Grundfelt, KEMAKTA
	P. Jackson, AEA Technology
	A. Larsson, KEMAKTA
	K. Pers, KEMAKTA
	K. Skagius, KEMAKTA
	C. Thegerström, OECD/NEA

List of INTRAVAL Participants

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
Agence Nationale pour le Gestion des Déchets Radioactifs, France L. Dewiere	(ANDRA)	Commissariat à l'Energie Atomique M. Durin	(CEA/DMT)
		Bureau de Recherches Geologiques et Minières J.P. Sauty	(BRGM/STO)
Atomic Energy of Canada Ltd., Canada T. Chan	(AECL)	Atomic Energy of Canada Ltd. T. Chan (AECL-WR) G. Moltyaner (AECL-CRL)	(AECL)
Atomic Energy Control Board, Canada D. Metcalfe	(AECB)	Atomic Energy Control Board, D. Metcalfe	(AECB)
Australian Nuclear Science and Technology Organisation, Australia P. Duerden	(ANSTO)	Australian Nuclear Science and Technology Organisation C. Golian	(ANSTO)
Bundesanstalt für Geowissenschaften und Rohstoffe/ Bundesamt für Strahlenschutz, Federal Republic of Germany K. Schelkes (H. Illi)	(BGR/BfS)	Bundesanstalt für Geowissenschaften und Rohstoffe K. Schelkes	(BGR)
		Bundesamt für Strahlenschutz	(BfS)
Commissariat à l'Energie Atomique/Institut de Protection et de Sûreté Nucléaire, France J. Gomit	(CEA/IPSN)	Ecole Nationale Supérieure des Mines de Paris P. Goblet	(EDM)
Empresa Nacional de Residuos Radioactivos, S.A., Spain J.C. Mayor	(ENRESA)	Universidad Politécnica de Valencia J. Gomez-Hernández A. Sahuquillo	(UPV)
Gesellschaft für Reaktorsicherheit mbH, Federal Republic of Germany P. Bogorinski	(GRS)	Gesellschaft für Reaktorsicherheit mbH P. Bogorinski	(GRS)
Forschungszentrum für Umwelt und Gesundheit, Federal Republic of Germany R. Storck	(GSF)	Forschungszentrum für Umwelt und Gesundheit E. Fein	(GSF)

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
Her Majesty's Inspectorate of Pollution, United Kingdom K. Butter	(HMIP/DoE)	Atkins Engineering Sciences T. Broyd	(AES)
Industrial Power Company Ltd., Finland J. Vira	(TVO)	Technical Research Centre of Finland S. Vuori	(VTT)
Japan Atomic Energy Research Institute, Japan H. Matuzuru	(JAERI)	Japan Atomic Energy Research Institute H. Kimura	(JAERI)
		Central Research Institute for the Electric Power Industry M. Kawanishi	(CRIEPI)
		Hazama-gumi A. Kobayashi	(HAZAMA)
Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, Switzerland P. Zuidema	(NAGRA)	Paul Scherrer Institute J. Hadermann	(PSI)
National Institute of Public Health and Environmental Protection, The Netherlands P. Glasbergen	(RIVM)	National Institute of Public Health and Environmental Protection P. Glasbergen	(RIVM)
		State University of Utrecht M. Hassanizadeh	(RIVM/UofU)
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Power Reactor and Nuclear Fuel Development Corporation, Japan H. Umeki	(PNC)	Power Reactor and Nuclear Fuel Development Corporation, H. Umeki	(PNC)
Studiecentrum voor Kernenergie, Belgium M. Put	(SCK/CEN)	Studiecentrum voor Kernenergie. M. Put	(SCK/CEN)
Swedish Nuclear Fuel and Waste Management Co., Sweden F. Karlsson	(SKB)	The Royal Institute of Technology I. Neretnieks	(SKB/KTH)
Swedish Nuclear Power Inspectorate, Sweden K. Andersson (Chairman) J. Andersson (Secretary)	(SKI)	The Royal Institute of Technology B. Dverstorp	(SKI/KTH)

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
U.K. Nirex Ltd., United Kingdom D. George	(NIREX)	AEA Technology P. Jackson	(AEA)
		Intera–Sciences Consultants Ltd D. Hodgkinson	(INTERA)
U.S. Department of Energy–OCRWM, United States of America C. Voss	(US DOE)	Pacific Northwest Laboratories C. Kincaid	(PNL)
		U.S. Geological Survey A. Flint	(US GS)
U.S. Department of Energy–WIPP, United States of America J. Carr	(US DOE)	Sandia National Laboratories E. Gorham	(SNL)
U.S. Environmental Protection Agency, United States of America W. Gunter	(US EPA)	U.S. Environmental Protection Agency C. Hung	(US EPA)
U.S. Nuclear Regulatory Commission, United States of America T. Nicholson	(US NRC)	U.S. Nuclear Regulatory Commission T. McCartin	(US NRC)
		Center for Nuclar Waste Regulatory Analyses B. Sagar	(CNWRA)
		Massachusetts Institute of Technology L. Gelhar	(MIT)
		Pacific Northwest Laboratories G. Gee	(PNL)
		Sandia National Laboratories E.J. Bonano	(SNL)
		University of Arizona T. Rasmussen (UAZ-HWR) P. Wierenga (UAZ-SWS)	(UAZ)
Organisation for Economic Cooperation and Development/Nuclear Energy Agency Member of Secretariat: C. Thegerström	(OECD/NEA)		

List of INTRAVAL Participants (cont.)

Party and Coordinating Group Member	Project Team(s) and Team Leader(s)
Her Majesty's Inspectorate of Pollution, United Kingdom Member of Secretariat: P. Jackson	
International Atomic Energy Agency (IAEA) S. Hossain (observer)	
Environmental Evaluation Group, United states of America L. Chaturvedi (observer)	
State of Nevada L. Lehman (observer)	

Appendix 2

Intraval Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media performed at Las Cruces, New Mexico, USA.

Overview

This test case is based on experiments performed at the New Mexico State University College Ranch, 40 km northeast of Las Cruces, New Mexico, U.S.A. Water and tracers are applied at a carefully controlled rate to the surface of an experimental plot. The motion of water and the transport of various tracers through the unsaturated vadose zone is monitored. This test case was included also in INTRAVAL Phase 1. During Phase 1, data for site characterisation and model calibration were collected. In a new experiment (Plot 2b)during phase 2 the models calibrated during Phase 1 will be used to predict water flow and solute transport.

Experimental Design

A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4× 9 m and 1×12 m respectively are adjacent to the trench (Figure 6). In the first experiment (Plot 1) water containing tritium has been applied at a controlled rate of 1.8 cm/day on the area sized 4× 9 m. The movement of water below the soil surface was monitored with neutron probes and tensiometers. Soil solution samples were taken to determine the movement of tracer below the surface of the soil. The movement of the water front was also observed visually on the trench. In the second experiment (Plot 2a) water containing tritium and bromide was applied at a rate of 0.43 cm/day on the area sized 1×12 m. These two experiments were used during INTRAVAL Phase 1. In the third experiment (Plot 2b) tritium, bromide, boron, chromium and the organic compounds pentafluorobenzoic acid (PFBA) and 2,6-difluorobenzoic acid (DFBA) will be added with the water on the area sized 1×12 m.

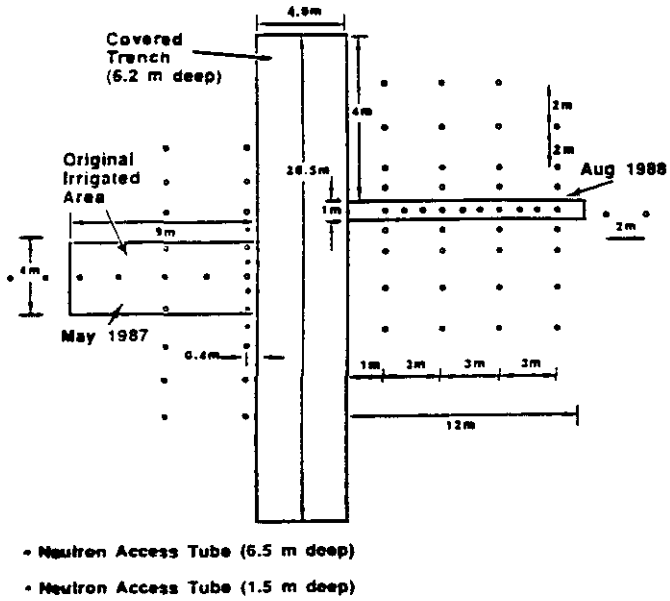

Figure 6.Top view of the trench with irrigated areas.

Available data

— water retention data
— density profiles
— particle-size analysis data
— saturated hydraulic conductivities (laboratory and in situ)
— water content
— tensiometer data
— solute concentration

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Overview

Field experiments are conducted at the Apache Leap Tuff Site in tuffaceous rock near Superior, Arizona, USA (Figure 7). The tuff formation is approximately 600 m thick and grades from a densely welded unit near its base to a slightly welded tuff which has a total porosity of 17%. The unsaturated zone extends to great depth due to topography and to pumping associated with a nearby underground mine. Laboratory experiments are conducted using cores obtained during borehole drilling at the field site and using shaped blocks removed from the field site. Relevant processes include hydraulic, pneumatic, thermal, and solute transport components which will be investigated using experiments over several length and time scales, on cores (6–10 cm, minutes), rock blocks (50 cm, month), in situ (1–30 m, years). This test case was included also in INTRAVAL Phase 1, where the main efforts were spent modelling the laboratory core and block experiments. The ultimate objectives of this case in Phase 2 will be to water flow and solute transport both with and without imposed temperature gradient under field conditions. In addition, laboratory core heater measurements are performed estimate important parameters.

Field experiments

The experimental site with an undisturbed thermal regime has been under study for three years. Fifteen boreholes were installed (twelve inclined and three horizontal) and used for the in situ site characterisation, while the obtained cores are used for logging the fractures and characterizing the rock matrix. A plastic cover was placed over the rock surface (30× 50 m) to prevent evaporation as well as precipitation from infiltrating into the rock. These experiments included testing for temperature, water conctnet and saturated hydraulic conductivities.

Water and gas injection-recovery tests are currently underway to determine temporal and spatial responses as well as other flow characteristics. The experiments should be completed by the end of 1991.

The purpose of the field heating experiment is to evaluate the magnitude and distribution of induced fluid flow around a heat source in unsaturated fractured tuff. The experimental plane for this experiment will consider preliminary experiment conducted in a road tunnel for which some data sets are available. The experiments will begin end of 1991.

Available data

Laboratory core measurements:

— rock matrix physical and hydraulic properties (porosity, bulk density, moisture characteristic curves)
— pneumatic and thermal conductivities as a function of water content.

Laboratory block experiments:

— rock matrix physical and hydraulic properties (porosity, bulk density, moisture characteristic curves)
— unsaturated hydraulic conductivity of rock matrix
— solute concentrations
— fracture properties
— etc.

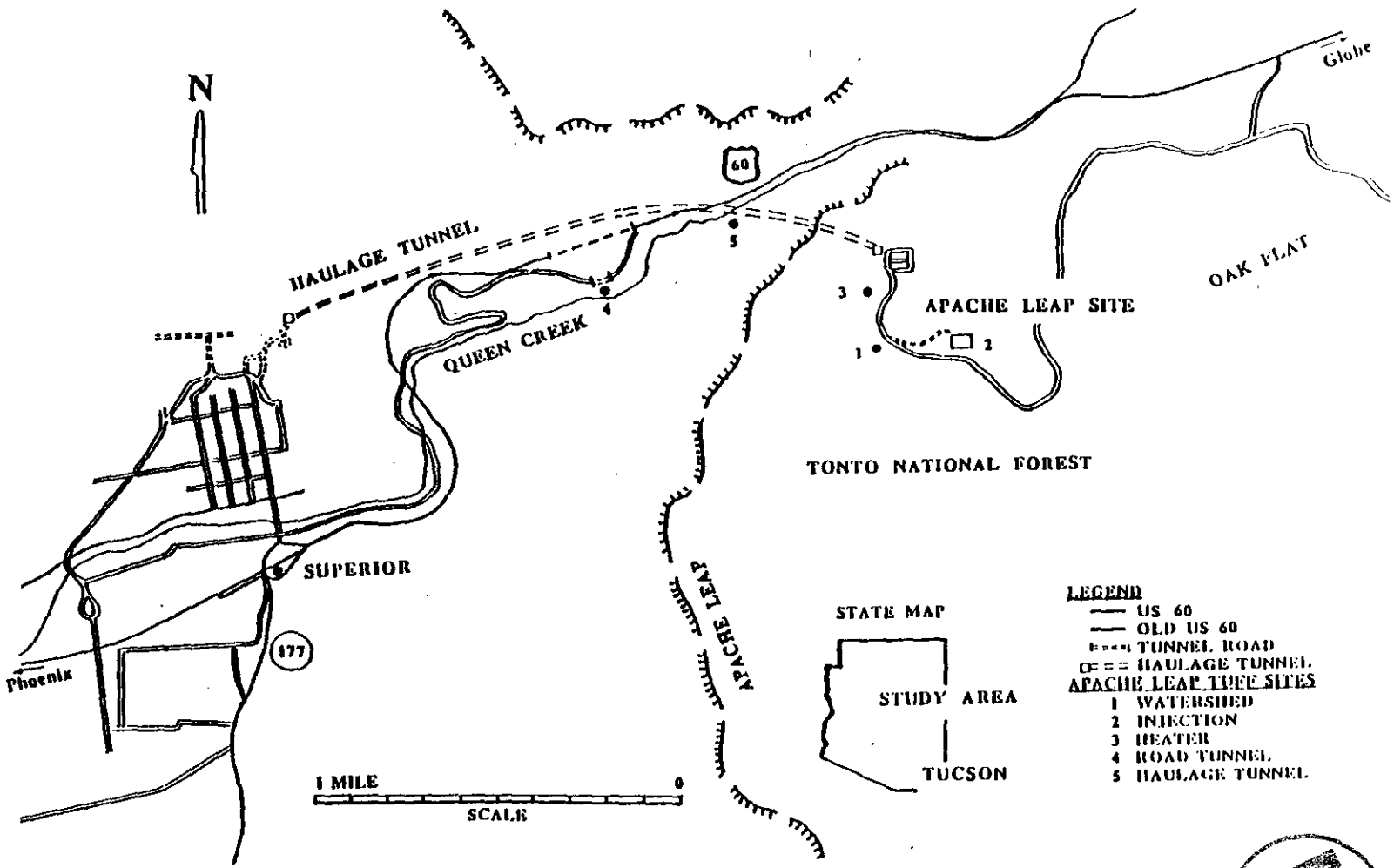

Figure 7. Location of testing facilities at Apache Leap Tuff site.

Field imbibition/redistribution experiment:

— water injection volumes in four boreholes
— rock matrix and fracture hydraulic properties (at 3 m intervals)

Laboratory core heating experiment:

— physical, hydraulic, pneumatic and thermal properties of the rock matrix
— solute concentration
— temperatures
— water contents

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

Overview

The Finnsjön research area is located approximately 130 km north of Stockholm and 15 km from the Baltic sea. The bed rock within the site is crystalline rock of Svecokarelian age (about 1800 –2100 Ma). The experiments have been performed in a major low angle fracture zone, Zone 2, located in the Brändan area (1 km^2), a sub-area within the Finnsjön research area. The Finnsjön tracer experiments are part of the Fracture Zone Project, initiated and supported by the Swedish Nuclear Fuel and Waste Management Company (SKB).

The project involve detailed characterisation of Zone 2, including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole test. The interference test and the radially converging test were used for modelling during INTRAVAL Phase I. During INTRAVAL Phase 2 the modelling of this test case will continue to include also the dipole experiment.

Experimental Design

Zone 2 is penetrated at depth ranging between 100–350 m by six diamond core drilled boreholes and three precussion drilled boreholes (Figure 8).

Two tracer experiments were carried out, one in a radially converging flow geometry and one in a dipole flow geometry. In the radially converging experiment tracer injections were made in three peripheral boreholes situated in different directions from a withdrawal hole. The distance from the injection holes to the withdrawal hole is in the order of 150 to 190 m. In each injection hole three sections were packed off, one in the upper highly conductive part of Zone 2, one at the lower boundary, and one at the most highly conductive part inbetween. Nonsorbing tracers were injected in 9 different intervals of the zone. Totally 11 different tracers were injected, 8 of them continuously for 5–7 weeks and three as pulses. First arrivals in the withdrawal hole ranged from 22 to 3500 hours.

The dipole experiment was performed after the radially converging experiment using the same hole for withdrawal and one of the other holes for injection. The two other holes used for injection in the radially converging test were used as observation holes in the dipole experiment. Only the upper highly conductive part of Zone 2 was used for tracer injection in this experiment. Totally 15 injections of tracers were made during 7 weeks. Pulse injection of both sorbing and nonsorbing tracers were made. The water pumped from the withdrawal hole was recirculated to the injection hole.

Prior to the start of the radially converging test a series of hydraulic interference tests was performed in order to determine the hydraulic properties of Zone 2. Pressure responses were registered in packed-off sections in all bore holes in the Brändan area during pumping of the hole later used as withdrawal hole in the tracer experiments. In conjunction with the interference test a preliminary tracer test was performed in order to optimise the design and performance of the planned radially converging tracer experiment.

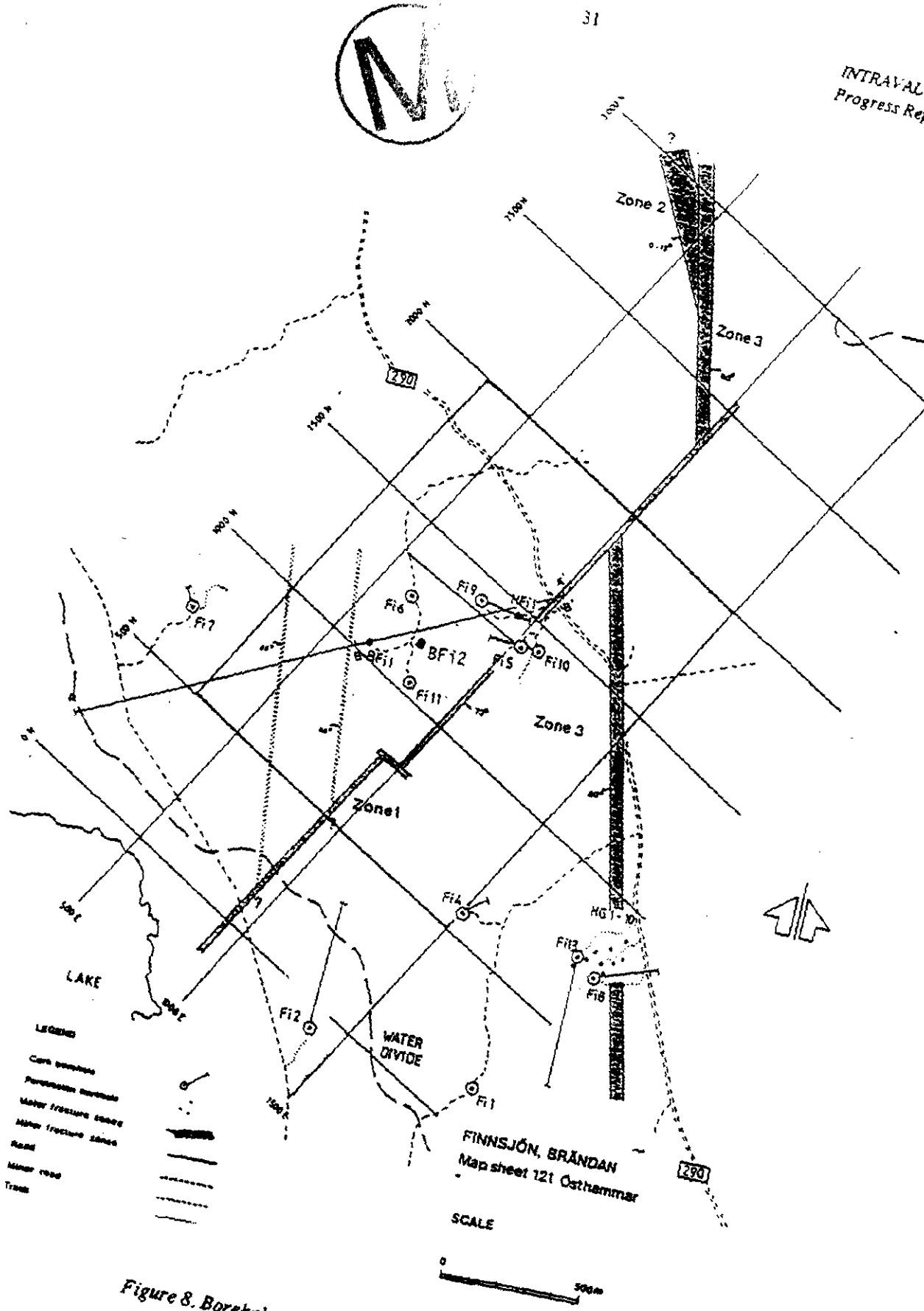

Figure 8. Borehole location in the Brändan area.

Available data

Interference tests:

— primary drawdown responses
— graphs of the recovery of groundwater head after pumping stops
— tracer injection information
— tracer breakthrough curves

Radially converging experiment:

— tracer breakthrough curves
— tracer injection information
— groundwater levels
— relative hydraulic head differences
— temperature and electrical conductivity of pumped water

Dipole experiment:

— tracer breakthrough curves,
— tracer injection information,
— hydraulic heads and groundwater levels
— temperature, electrical conductivity and redox potential of the pumped water.

In addition, geological data are available from surface survey of the Brändan area as well as from borehole investigations. Hydraulic data are available from hydraulic testings. Data on porosities and diffusivities have been determined in the laboratory.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment, Sweden.

Introduction

This test case is based on the three dimensional tracer test performed in the Stripa mine in Sweden. This experiment was also part of INTRAVAL Phase 1. In addition to the 3D experiment, data from two other experimental programmes performed in the Stripa mine, the 'Site characterisation and Validation Programme' and the 'Channelling Experiments' are or will be made available during INTRAVAL Phase 2. The experiments were performed within the OECD/NEA International Stripa Project.

In the 3D experiment water and tracers were collected in a number of plastic sheets. The main purpose of the 3D experiment was to investigate the spatial distribution of water flow paths in a larger block of rock.

The 'Site Characterisation and Validation Programme' includes a number of investigation steps to characterise an unexplored rock volume starting with a few long boreholes, and ending with a new drift being excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

The 'Channelling Experiments' comprise information about channelling in individual natural fractures on a length scale of 2 m.

General Description

3D experiment

A drift has been excavated in the Stripa mine at 360 m below the ground. The drift is 75 m long and has two side arms with a length of 12.5 m each. Three vertical holes for injection of tracers have been drilled upwards with lengths of 70 m (Figure 9).

The ceiling and large parts of the walls in the drift were covered with plastic sheets, each sheet with an area of about 2 m^2. A total number of about 350 sheets served as sampling areas for water emerging into the upper part of the test drift. The sampling arrangements completely covered a surface area of 700 m^2. The spatial distribution of water flow path ways could thus be obtained.

Injection of conservative tracers were carried out from a total number of nine separate sections with increased permeability within the three vertical holes, each zone about 2.5 m in length. The injection zones were located between 10 and 55 m above the test site. The tracers were injected continuously for nearly two years. The injections were carried out with a 'constant' over-pressure, approximately 10–15 % above the natural pressure.

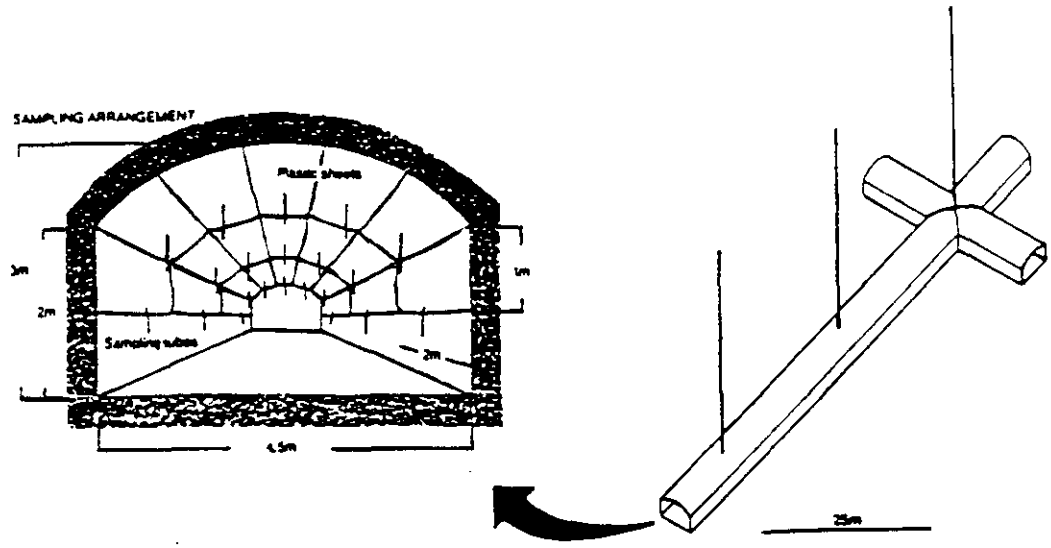

Figure 9. Layout of experimental 3D drift at Stripa and sampling arrangement.

The concentrations of the injected tracers were between 1000 and 2000 ppm, and the different flow rates varied from 1 to 20 ml/h. The following tracers were injected: Uranine, Eosin Blueish, Eosin Yellowish, Phloxine B, Rose Bengal, Elbenyl Brilliant Flavine, Duasyn Acid Green, Bromide and Iodide.

The natural inflow of water to the drift was measured before drilling the injection holes. The results from the water monitoring show that water does not flow uniformly in the rock over the scale considered (700 m^2), but seems to be localised to wet areas with large dry areas in between. Measurable amounts of water emerged into 113 of the 350 sampling areas. Out of these 'wet' sampling areas 10 % gave more than 50 % of the total water inflow.

After six months of injection, tracers from at least five injection zones could be found in about 35 sampling areas. After almost two years of injection, about 200 different tracer breakthrough curves have been obtained. Each curve is based on several hundred individual measurements. Smoothed curves consisting of approximately 40 points are available as computer files.

Site Characterisation and Validation programme (SCV)

The original aim of the project is to predict groundwater flow and tracer transport in a previously unexplored volume of the Stripa granite. The rock volume selected for detailed characterisation is about 125×125× 50 m and is located at 360 to 410 m below ground. The investigations of the rock volume have been performed in a number of steps, including modelling predictions between the different experimental steps. In the first investigation five 150–220 m long boreholes and one 50 m long were drilled. These holes were used to characterise the rock volume by core logging, hydraulic tests (down to 1 m sections), radar and seismics. Thereafter three new holes were drilled, 100–150 m long. Information from these holes were compared with made predictions, based on information from already investigated holes, concerning water bearing sections, fractures etc. Next, six boreholes, 100 m long, were drilled in the same direction as the new drift should be excavated. The water flow and its distribution were measured in these holes. These holes were also used for a tracer (salt) experiment. Finally a new drift, 50 m long and 2.4–2.9 m in diameter, was excavated. The new drift was equipped with plastic sheets (1–2 m^2) and other water collection devices. The drift cut

through one major fracture zone, 5-10 m wide, which gave more than 99% of the total water inflow. Tracer experiments were performed in this fracture zone from 7 spots located in four boreholes 10–25 m away from the drift (Figure 10). For this purpose two new boreholes had to be drilled. In each spot two nonsorbing tracers were injected. The tracers were sampled in the plastic sheets and in the other water collecting devices covering the lower parts of the walls and the floor of the drift.

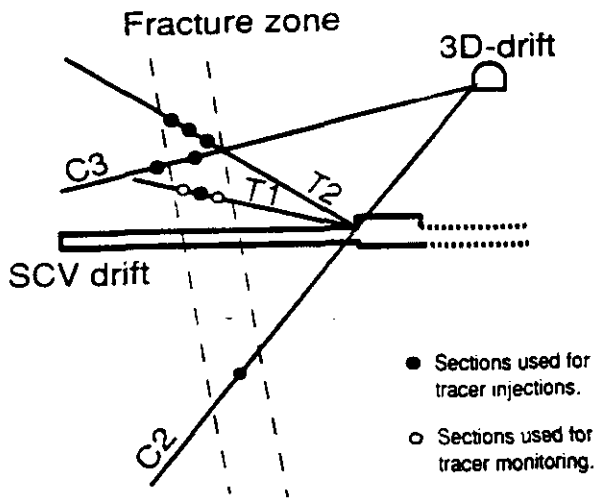

Figure 10. Layout of tracer experiment (SCV).

Channelling experiment

The channelling experiments consists of three different types of test: the 'single hole experiment', 'the double hole experiment'. and the 'tracer test'.

To be able to investigate the fracture characteristics along a fracture plane, a large diameter (200 mm) hole, was drilled along a planar fracture plane to a depth of about 2.5 m. A multi-pede packer (see Figure 11) was used to inject water all along the fracture plane. The injection flow rates were monitored separately for the left and right side of the hole over 80 short sections. The fracture intersections were scrutinised to obtain data on fracture properties such as open fracture area, number of intersections, and thickness of infilling. Before the multi-pede was used, the boreholes were tested with coarser tests. The multi-pede was used in 5 boreholes, whereas, in total 12 holes were drilled.

The double hole experiment was performed in a fracture where the single hole test has shown that channels exist. A second hole was drilled in the same fracture plane at a distance of 1.95 m from the first hole. Prior to the injection of water for detailed pressure tests more coarse tests were performed. In the detailed pressure pulse tests water was injected in one of the holes at a section of 50× 50 mm and monitored in the other hole in twenty sections along the fracture intersection. This experiment was repeated with the injection sections at different positions. The test was than reversed,

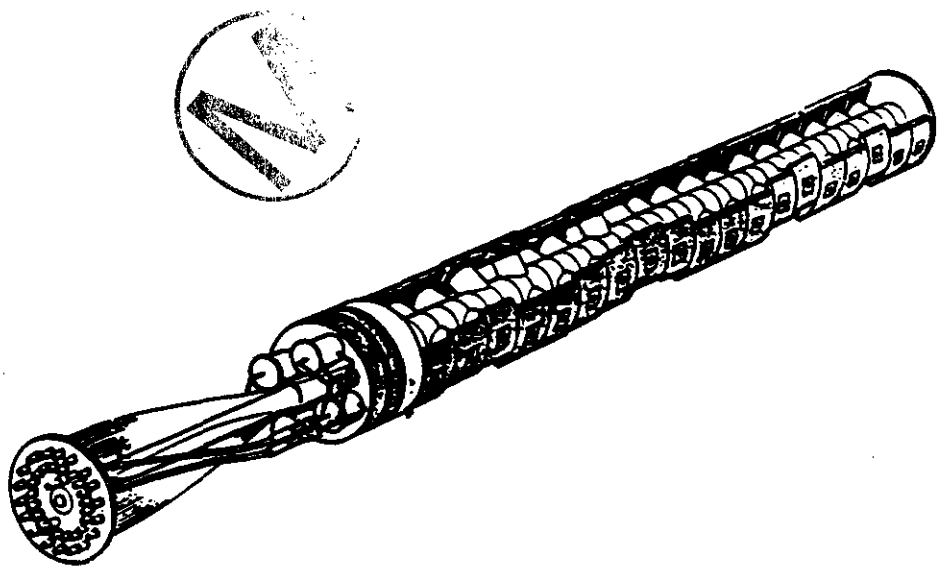

Figure 11. Design of the Multiped packer (Channelling Experiment).

i.e. injection from the second hole and monitoring in the first hole.

In the tracer test five nonsorbing tracers were injected from five 50 mm sections, that had been found to be the most conductive in one borehole, and were monitored in the other hole (see the double hole experiment). To obtain a linear flow for the tracers, water was injected with the same pressure as used for the tracers from the remaining 15 sections. The tracers, Uranin, Eosin yellowish, Ebenyl brilliant flavin, Duasyn acid green V and Phloxine B were injected continuously during 4 weeks.

Summary of Available Data:

3D Experiment

— water flow rates
— tracer concentration in water to test site
— rock characteristics and fracture data
— water chemistry
— injection pressures and injection flow rates
— hydrostatic pressures
— diffusivity and sorption data
— daily logs

Site Characterisation and Validation (SCV)

— core logging and fracture mapping in drifts
— geophysical single hole logging
— rock stress measurements
— borehole radar
— borehole seismics
— hydraulic investigations
— hydrochemisty
— water flow rates
— tracer breakthrough curves

Channelling Experiment

— number of fractures
— number of intersections
— information about infilling
— fracture lengths
— opening area of fractures
— pressure response
— tracer breakthrough

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on experiments performed in Culebra Dolomite, at the WIPP site. The WIPP, located in Carlsbad, New Mexico, U.S.A., is an underground research and development repository lying 655 m below ground surface within bedded evaporites, primarily halite, of the Salado Formation. Overlying the Salado Formation is the Rustler Formation, Figure 12. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is a 8 m thick vuggy dolomite layer. The hydrology of this zone is to be focussed on in this test case. A central issue is the travel time within the Culebra from a location above the repository to the WIPP site boundary.

Description of the Experiments

Extensive investigations of the Culebra Dolomite have taken place. These include detailed investigation of numerous surface features for the purpose of delineating subsurface features of irregularities that could affect flow in and around the Culebra. A transient electromagnetic survey is planned for 1991–92, in order to better delineate a hypothesised fractured region, a high transmissivity zone in the southeast corner of the site.

Sixty wells have been completed to the Culebra dolomite at 41 locations to provide information on the hydraulic properties (Figure 13). Large variation in transmissivity related to fracturing has been identified.

Well test data from three wells in the southeastern part of the site (DOE-1, H-3, H-11) indicate the presence of a zone of relatively high transmissivity within an area of otherwise low transmissivity.

Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed in the vicinity of the above described high transmissivity zone. One pumping test and one tracer test were performed near the

center of the WIPP site near what is believed to be the northwestern edge of the high transmissivity zone. The other pumping test and tracer test were performed in the high transmissivity zone near the southern site boundary.

In addition, geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behavior of the Culebra. In general these data have been used to demonstrate that the age of the Culebra waters is of the order of 10 000 years, and that the waters originated during a known pluvial period.

System	Series	Group	Formation	Member
Recent	Recent		Surfic. Deposits	
Quarternary	Pleistocene		Mescalero Caliche	
			Gatuna	
Triassic		Dockum	Undivided	
Permian	Ocholan		Dewey Lake Red Beds	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				Unnamed
			Salado	
			Castile	
	Guadalupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

Figure 12. WIPP area stratigraphic column.

Objectives of the Test Case

A number of different objectives can be identified. One possible objective could be to determine if the hydrologic data support the derived transmissivity distribution and/or the model boundary conditions. Related to this objective could be an evaluation of the uniqueness of the derived transmissivity distribution. A third related objective could be to determine the uncertainty in the transmissivity distribution.

An additional important objective could be to determine the resolution in transmissivity needed for long time (10 000 years) predictions of radionuclide travel time. Related to this objective could be an evaluation of the uncertainty in predictions of radionuclide travel time. Other objectives could be to detemine if the paleoflow directions inferred from the geochemical/isotopic data could be reproduced using the current transmissivity distribution and boundary conditions altered to simulate increased rainfall; to determine if halite gypsum dissolution will take place in the next 10 000 years in the Culebra, resulting in an alteration in the transmissivity distribution; to determine if the hydrologic evidence is sufficient to rule out a significant effect on transport of karst features.

Available data

The data base for this test case is very large and contains:

- UTM coordinates and surveyed elevations for all wells
- core logs and/or geophysical logs from all well locations
- geochemical and isotope data (major ion concentrations, density, etc.) from all well locations
- raw and interpreted hydraulic-test data from all well locations
- raw and interpreted tracer-test data
- core porosity and permeability data from tracer-test and other locations
- water-level data (hydrographs) from time of well construction to present for all wells
- estimated steady-state hydraulic heads at all well locations
- calibrated steady-state regional groundwater-flow model
- calibrated transient regional groundwater-flow model

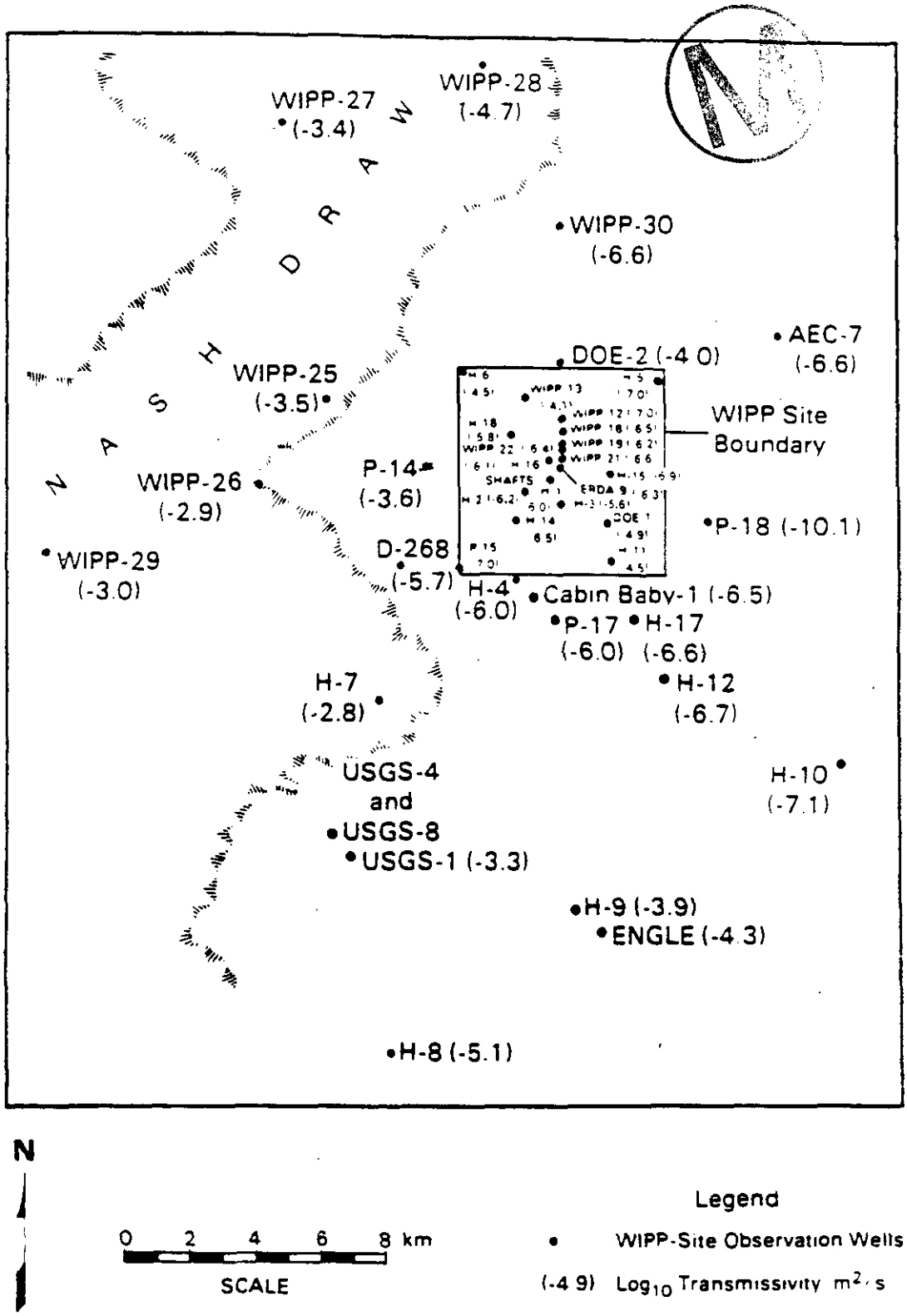

Figure 13. Culebra Wells and measured transmissivity near the WIPP Site.

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Overview

The Gorleben salt dome is located in the north-eastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the 'Gorleben Channel', more than 10 km long and 1–2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock (a residue of the dissolution process of salt in groundwater) and in some places down to the salt. In the channel, fairly thick sandy sediments with interbedded lenses of till are overlain by a complex of silt and clay up to 100 m thick. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel is the topic for this test case. The groundwater movements in such an aquifer system depend to a large degree on the salinity, which influences the water density.

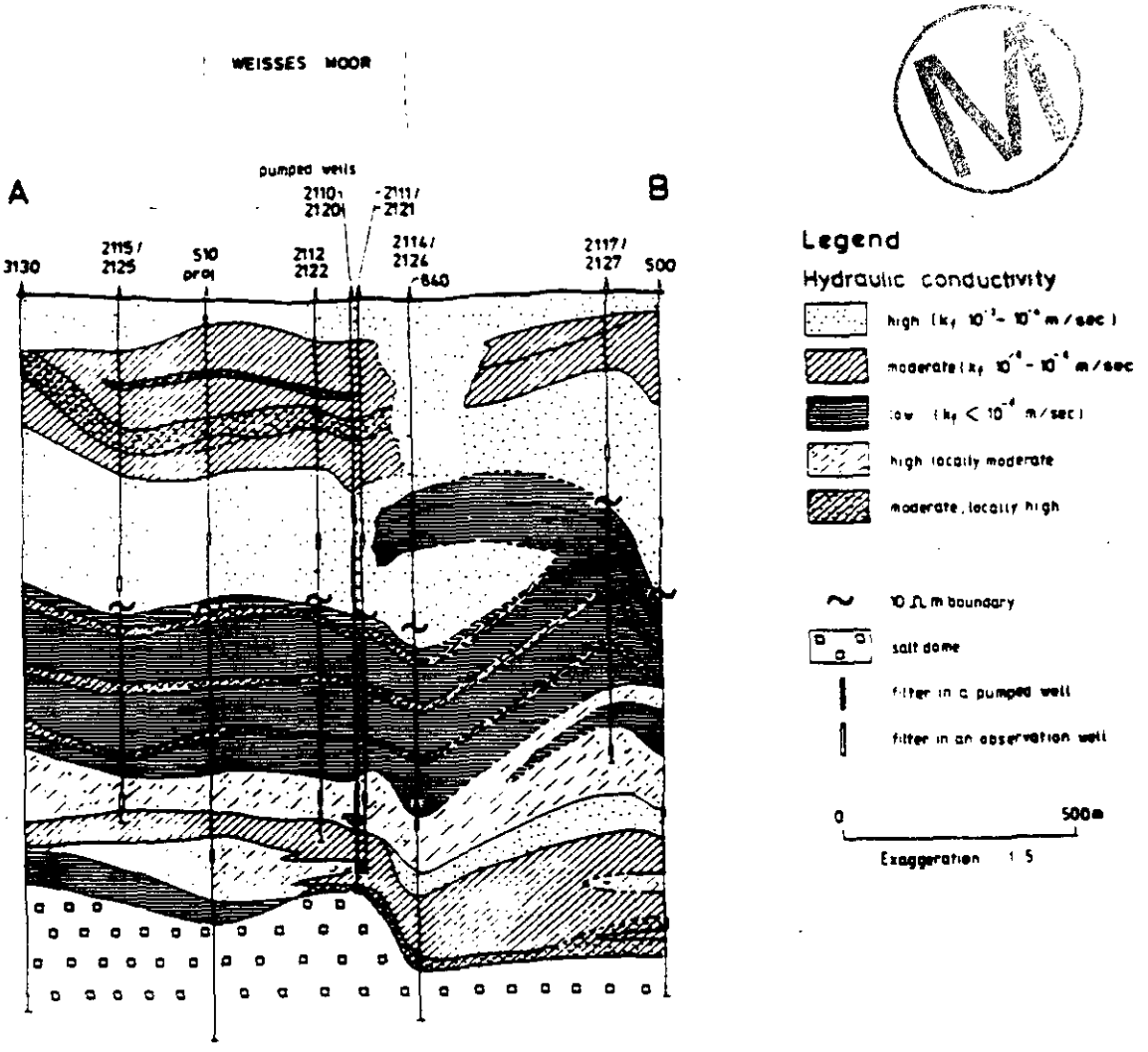

Figure 14. Hydrogeological cross section of the Gorleben salt dome.

Experimental design

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out: one in fresh water and three in saline water. Information obtained during these tests were information on boundaries, the hydrogeological structure, connections between different aquifers, hydraulic parameters (permeabilities, storage and leakage coefficients). In one of the pumping tests the pumped well penetrates the entire deeper aquifer in the erosional channel, Figure 14. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of 3 weeks. The density of the water ranges from 1010 to 1200 kg/m^3. This pump test will form the bases for the first part of this INTRAVAL test case. The second part is to model the regional groundwater flow, the salt dissolution and their interaction.

Available data

The data available from the selected pumping test:

— borehole locations (maps)
— hydrogeological data (groundwater levels etc.)
— pumping test data (hydrographs, salinometer logs, pumping rates, electric conductivities, temperatures, densities, etc.)

Large amounts of data are also available from other tests performed.

WIPP 1

Brine flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on one experiments performed with the aim to determine the rate of brine flow through WIPP bedded evaporites. The WIPP located in Carlsbad, New Mexico is an underground research and development repository (see Figure 15) lying 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation. Three geologic formations are important to the expected performance of the WIPP: the Salado formation, in which the repository is located; the Rustler formation, which contains an aquifer overlying the Salado formation; and the Castile Formation, which underlies the repository and contains pockets of pressurised brine. The hydraulic behaviour of the Salado Formation is the focus of the present test case. The experiments are designed to provide a variety of data with which to determine whether Darcy's Law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Experimental Design

Data from three types of experiments will form the bases for this test case:

— small scale brine-inflow experiments
— pore pressure and permeability testing
— integrated, large scale experiment

Small scale brine-inflow experiments

Brine-inflow rates are being measured at three scales: in 10 cm and 1 m diameter boreholes and in a cylindrical room with 2.9 m diameter (see large scale experiment). The boreholes are orientated vertically downward or horizontally and extend from 3 to 6 m. The boreholes are monitored for brine inflow (see example in Figure 16), and relative humidity. The humidity measurements aid in quantifying the total moisture entering a borehole. Chemical analyses of brine collected are also available. The brine-inflow measurements in the 10 cm in diameter boreholes generally show rapidly declining flow rates for the first few months, followed by steady but slow declining flow rates over long periods (2 years).

Pore-pressure and permeability testing

Pore-pressure measurements are made in boreholes with a diameter of 10 cm and of 2 to 27 m length, drilled at a variety of orientations. Pore-pressure are measured in brine filled, packer isolated intervals in the boreholes. Factors other than

the formation pore-pressure that could contribute to pressures observed in a borehole, e.g. temperature changes and borehole closure, are monitored. The boreholes are also used for permeability experiments, both pressure-pulse tests and constant-pressure flow tests. During the pressure-pulse tests, gas tends to accumulate in the boreholes. The gas is thought to evolve from Salado Formation brine in response to the lower pressure around the borehole relative to the pressure in the far field. The gas volumes are measured and the compositions are analysed.

Integrated, large-scale experiments

A horizontal cy drical room, with a diameter of 2.9 m and a length of 107 m, has been mined for the purpose of measuring brine inflow to a room-sized excavation. The room slopes slightly upward from front to back to follow the natural dip of bedding. The room was mined in July 1989 and sealed in October 1989. The humidity within the room is now being measured, as will the brine inflow in the room when it appears. Salt efflorescences resulting from brine evaporation on the surface of the room are regularly mapped. Pore-pressure measurements were made continuously before, during and after mining of the room and permeability experiments were performed before and after the mining in a number of boreholes placed around the room. A series of boreholes, 4 and 10 cm in diameter, will be drilled in various directions from the room. These boreholes will also be instrumented to allow permeability experiments, pore-pressure measurements, and measurements of borehole deformation and brine inflow. Brine inflow, humidity and room closure will continue to be measured past January 1992.

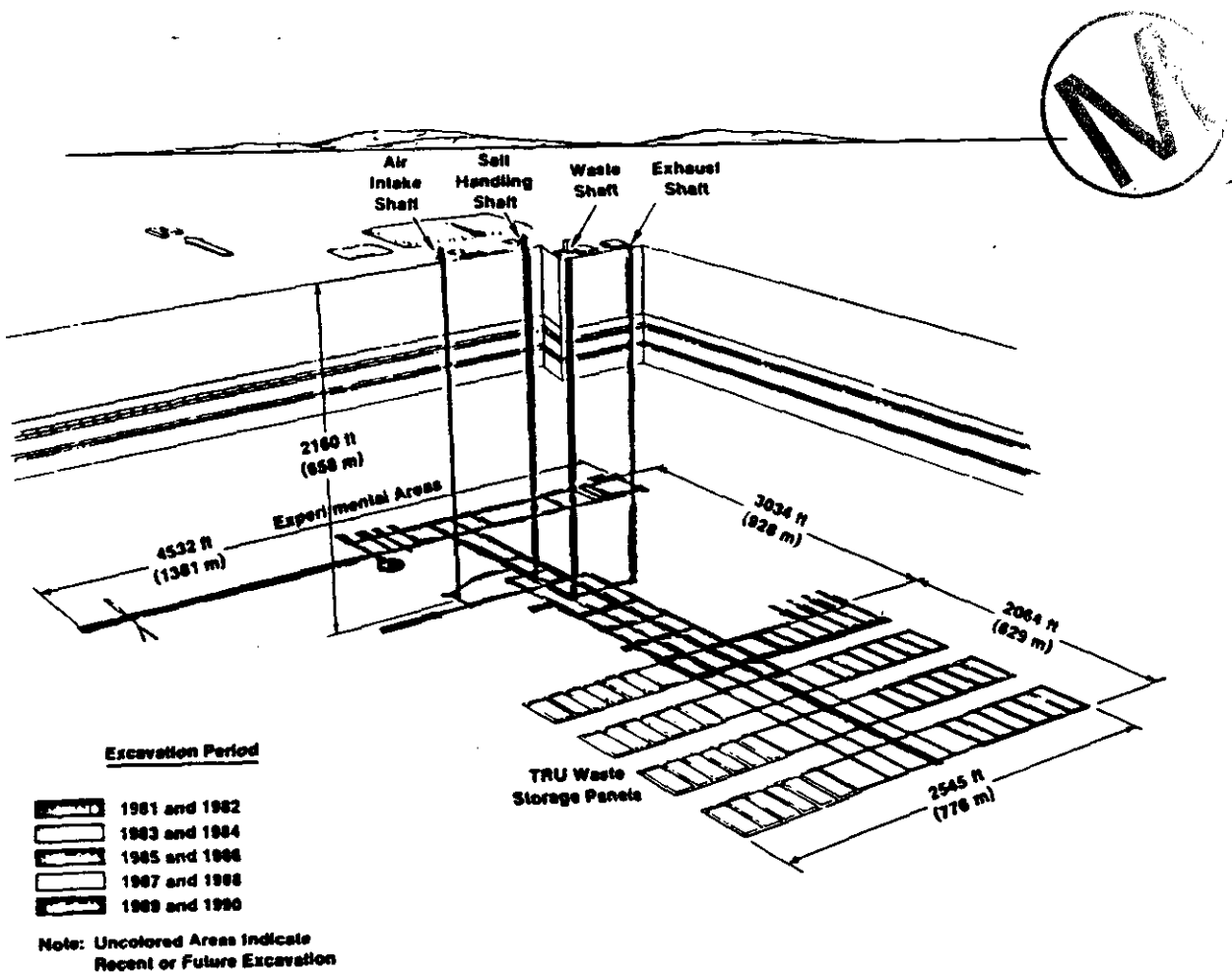

Figure 15. Schematic view of the WIPP site.

Available data

Data available from boreholes of different diameters and locations and from a mined cylindrical room are:

— brine inflow rates
— humidity
— room closure, borehole deformation
— pore-pressure
— data from permeability-tests
— rock property data
— general stratigraphic information
— core logs

Supporting information

A number of technical issues that are important to the WIPP's performance are tackled, and a large number of different types of tests are or have been performed within the pilot plant.

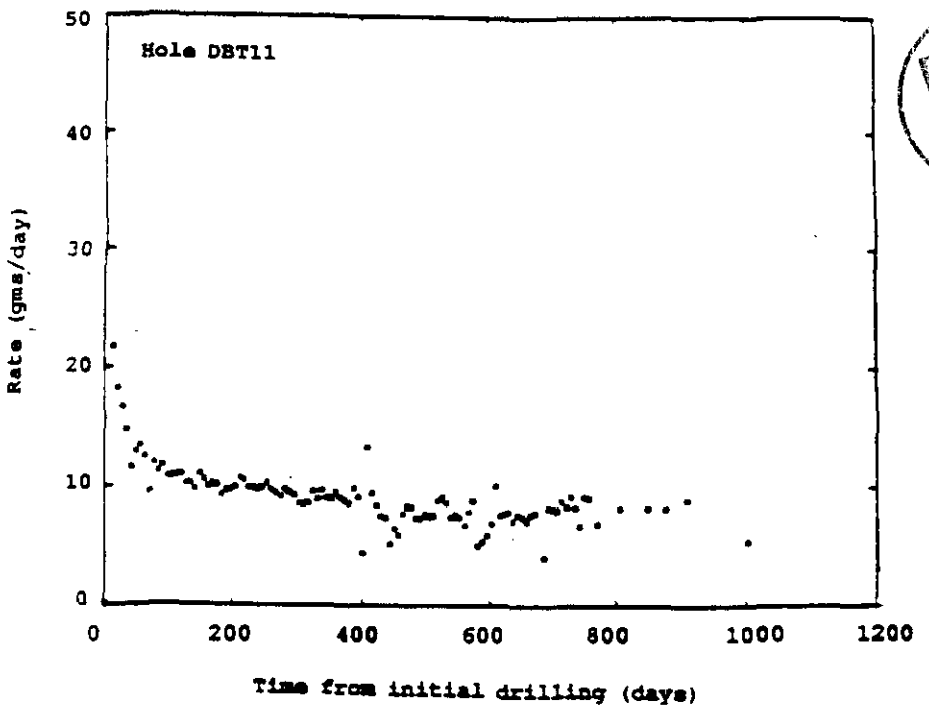

Figure 16. Brine inflow rate vs time in a borehole (Hole DBT11).

MOL

Migration Experiment in Boom Clay Formation at the Mol Site, Belgium.

Overview

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The original purpose of the in situ test is the in situ determination of migration related parameters and confirmation of these parameters determined in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

Experimental Design

In an underground research laboratory (Figure 17) in the Boom Clay formation at a depth of 220 m a number of piezometers, a so called piezometer-nest, has been installed (Figure 18). The stainless steel system contains 9 piezometers, interspaced by 0.9 m long tubes. Each piezometer consists of two concentric tubes, the outer one being made of sintered stainless steel. A stand pipe with an internal diameter of 2 mm is connected to the space separating the concentric tubes. The stand pipe

makes up the connection between the filter and the laboratory. A horizontal hole with a diameter of 50 mm and a depth of 10 m was drilled in the clay formation by rotary drilling. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. An inert gas was flushed through the filters to prevent oxidation of the clay. After about two days the small gap separating the tubing and the wall of the hole was completely sealed by convergence creep of the clay, and the gas flow was stopped. The presence of a vertical experimental shaft at the end of the underground laboratory (Figure 17) at atmospheric pressure and lined with concrete bricks creates a hydraulic pressure gradient in the neighborhood of the nest. The steady state pressure distribution as a function of the depth into the clay was measured.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 and thereafter the system is left alone allowing migration of HTO in three dimensions. The injection rate of the tracer solution was 5.6 ml/day with a duration of about one and a half month.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters in the nest. The space between the different filters is 1 m. So far tracers have been monitored only in the filter closest to the injection filter, i.e. filters 4 and 6. The sampling was started 3 months after the start of the injection and continues at a two months interval. To avoid disturbance of the HTO concentration distribution in the clay formation due to sampling, the sampling frequency and the total amount of liquid is kept as low as possible.

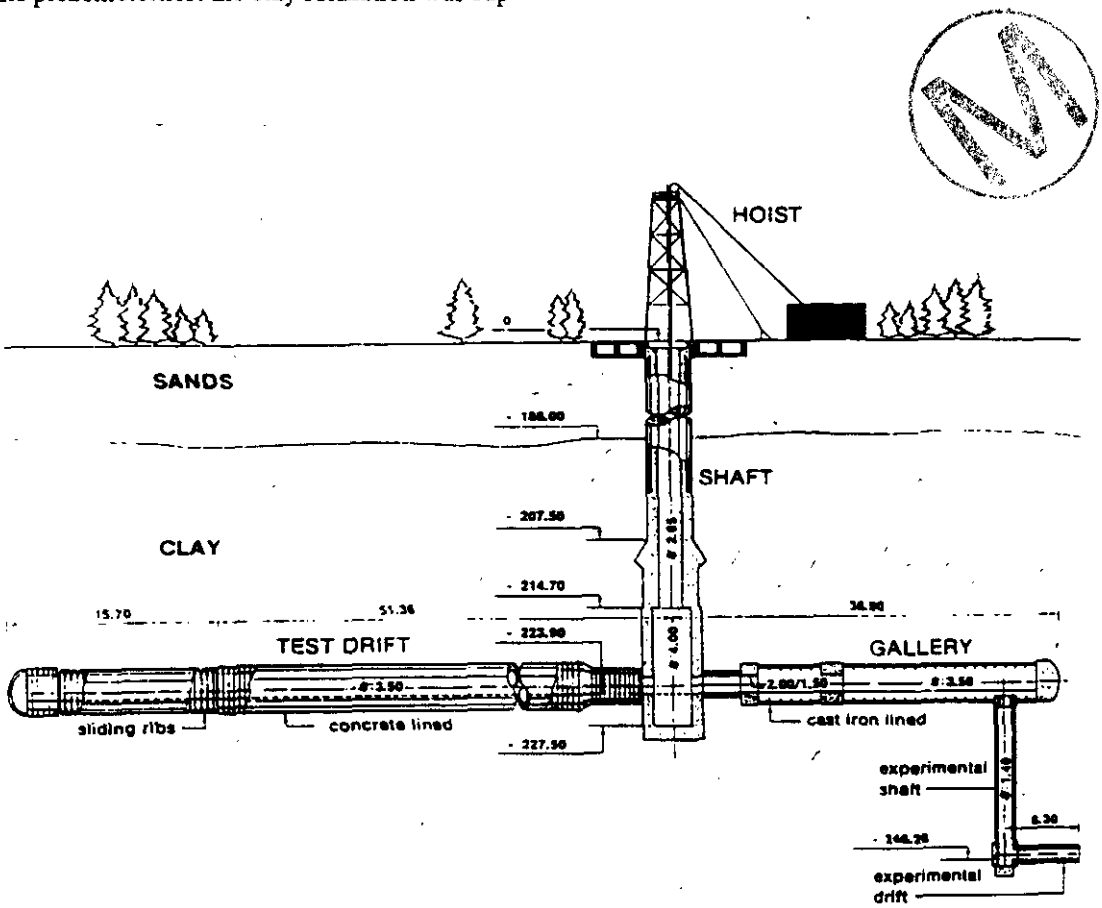

Figure 17. Scheme of the underground facility at Mol.

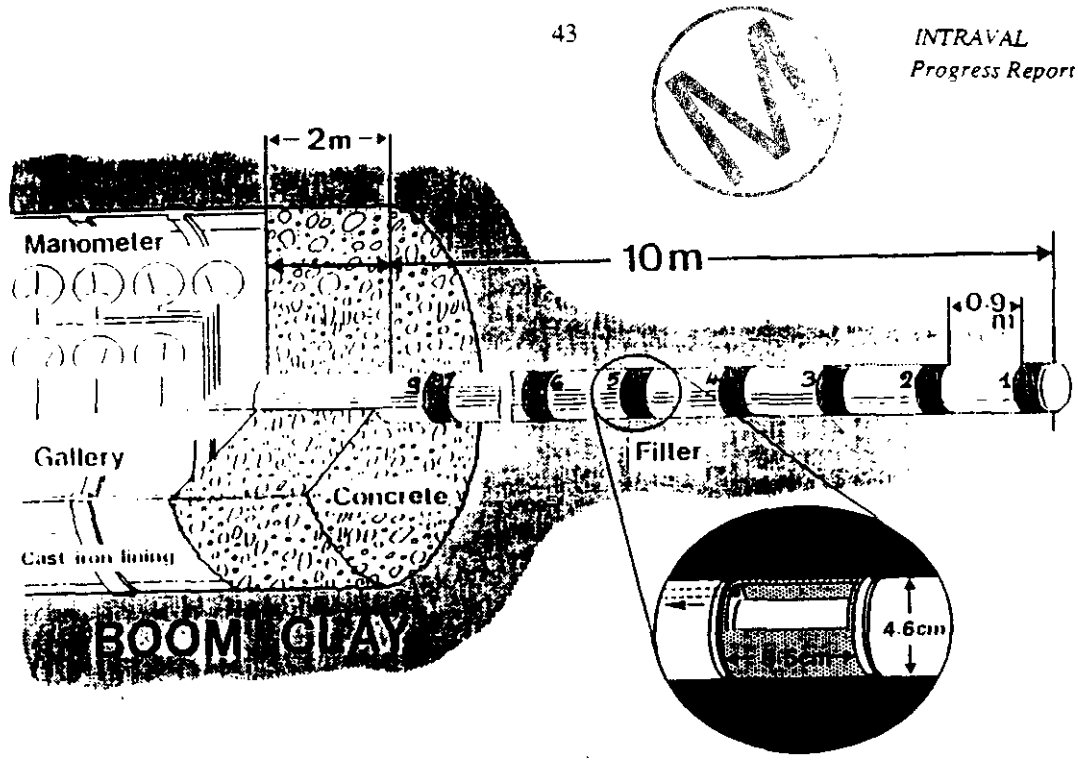

Figure 18. Conceptual view of the piezometernest.

Available Data

— steady state pressure distribution in the clay
— HTO concentration as a function time
— tracer injection data

Supporting information

Supporting data is available from laboratory experiments and other in situ experiments. Transport parameters such as the product of effective porosity and retardation factor, apparent dispersion constant, diffusivity, etc., have been estimated. A number of laboratory experiments have been performed, such as through diffusion, percolation experiments with clay cores. The Boom clay is rich in organic matter, with a large part linked to the mineral components. The remainder (humic and fulvic acids) can be regarded as dissolved. Attempts have been made to determine the diffusion parameters of the smallest humic molecules.

ALLIGATOR RIVERS

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

Overview

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator River Region is located about 200 km east of Darwin. The international Alligator Rivers Natural Analogue Project (ARAP) was set up in 1987 and was sponsored by the OECD Nuclear Energy Agency. Participation organisations are: The Australian Nuclear Science and Technology Organisation, the Japan Atomic Energy Research Institute, the Power Reactor and Nuclear Fuel Development Corporation of Japan, the Swedish Nuclear Power Inspectorate, the UK Department of Environment, and the US Nuclear Regulatory Commission.

Uranium mineralisation occurs at Koongarra in two distinct but related orebodies which strike and

dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists, secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m (Figure 19). The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

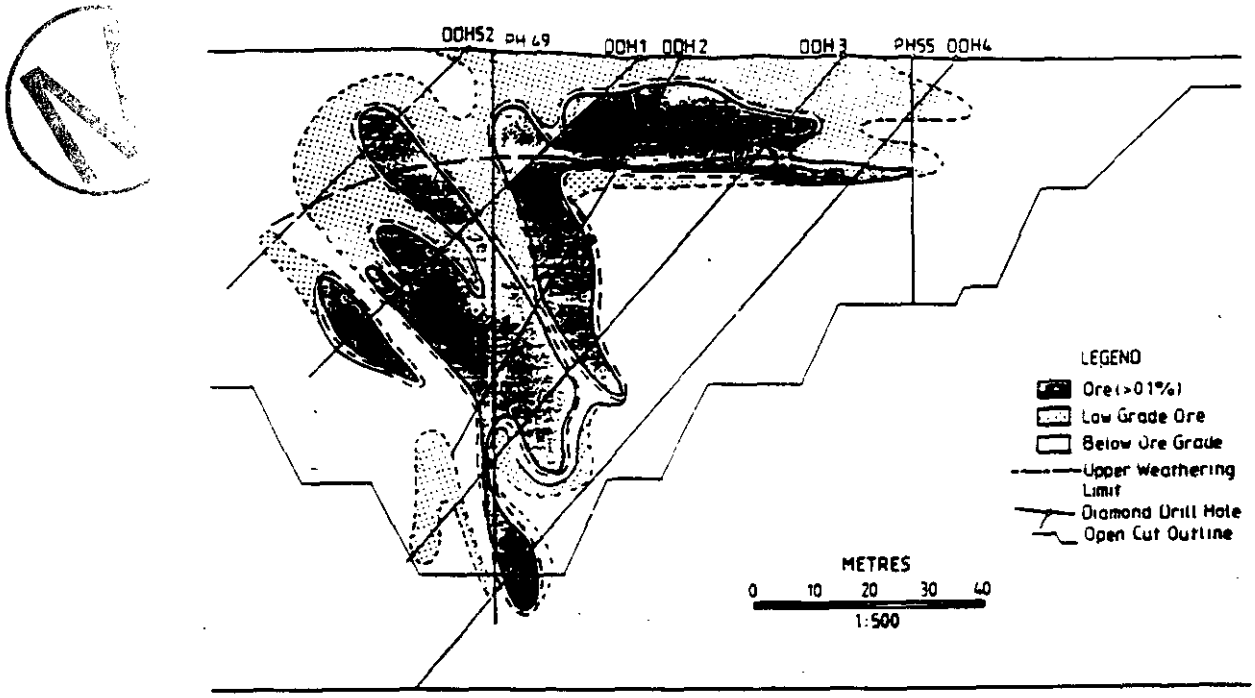

Figure 19. Cross section showing the dispersed zone at the Koongarra deposit.

Experimental Investigations

An extensive experimental programme including both field and laboratory investigations have resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs of 140 percussion holes and 107 drill cores. Groundwater chemical data have been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The phase distribution of uranium and thorium in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from bore cores. Distribution coefficients have also been measured on natural particles in Koongarra groundwater.

Available Data

Hydrogeology

- climatologic data, including rainfall and temperature
- surface water measurements, including stream flow
- location, elevation, geologic logs, casing and perforation details of all test holes and wells
- map, showing test holes and wells, as well as land-surface contours
- aquifer test results including water-level drawdowns, discharge measurements, and water quality of discharge
- periodic water level measurements which show seasonal fluctuations and regional gradients
- results of geophysical surveys and back-hoe pits which show thickness of upper deposits
- results of packer tests in upper part of the bedrock, and resistivity traverses

— results from porosity and permeability measurements on drill core samples

Hydrochemistry

— pH, Eh, D.O., conductivity and temperature in groundwaters
— groundwater concentrations of cations and trace metals
— groundwater concentrations of uranium series nuclides and isotopes

Geology, mineralogy, radiochemical

— uranium concentration distribution assay (247 drilling locations) in core pulp and soil samples
— uranium series radioisotope activity ratios data for selected samples in the ore zone
— results from chemical analyses of core samples
— mineralogical composition of samples
— concentrations and activity ratios of uranium and thorium in different mineral phases
— concentrations of ^{129}I, ^{36}Cl, ^{99}Tc, and ^{239}Pu in rock samples

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Overview

A large number of aquifer tests ranging from large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The 37 km^2 property lies on the Canadian shield, with Precambrian bedrock consisting primarily of granitic gneiss. Over 10% of the site contains bedrock that is exposed or buried beneath less than 1 m of overburden. The remainder of the property is covered by unconsolidated sediments.

The water table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

Experimental Design

The large experimental programme includes 20- 40- and 260-metres natural gradient tracer experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and at present there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation, and gamma scanning is performed through the full aquifer. The groundwater discharge area, a wetland at the toe of the dune ridge, currently contains 36 of the monitoring installations (Figure 20). The tracers used are ^{131}I, which can be mapped by gamma scanning, and HTO which is used to verify that no retardation of the iodine takes place.

In addition, laboratory measurements on cores from the aquifer have been performed. The hydraulic conductivity was determined from grain-size analysis and the hydrodynamic dispersion and longitudinal dispersivity was determined from column tracer tests.

Data Available

A large database containing data both from field and laboratory experiments is available, containing:

— permeameter test data
— small-scale dispersion
— porosities
— grain size composition
— hydrogeological data
— geophysical data
— mapping of tracer migration (Figure 21)

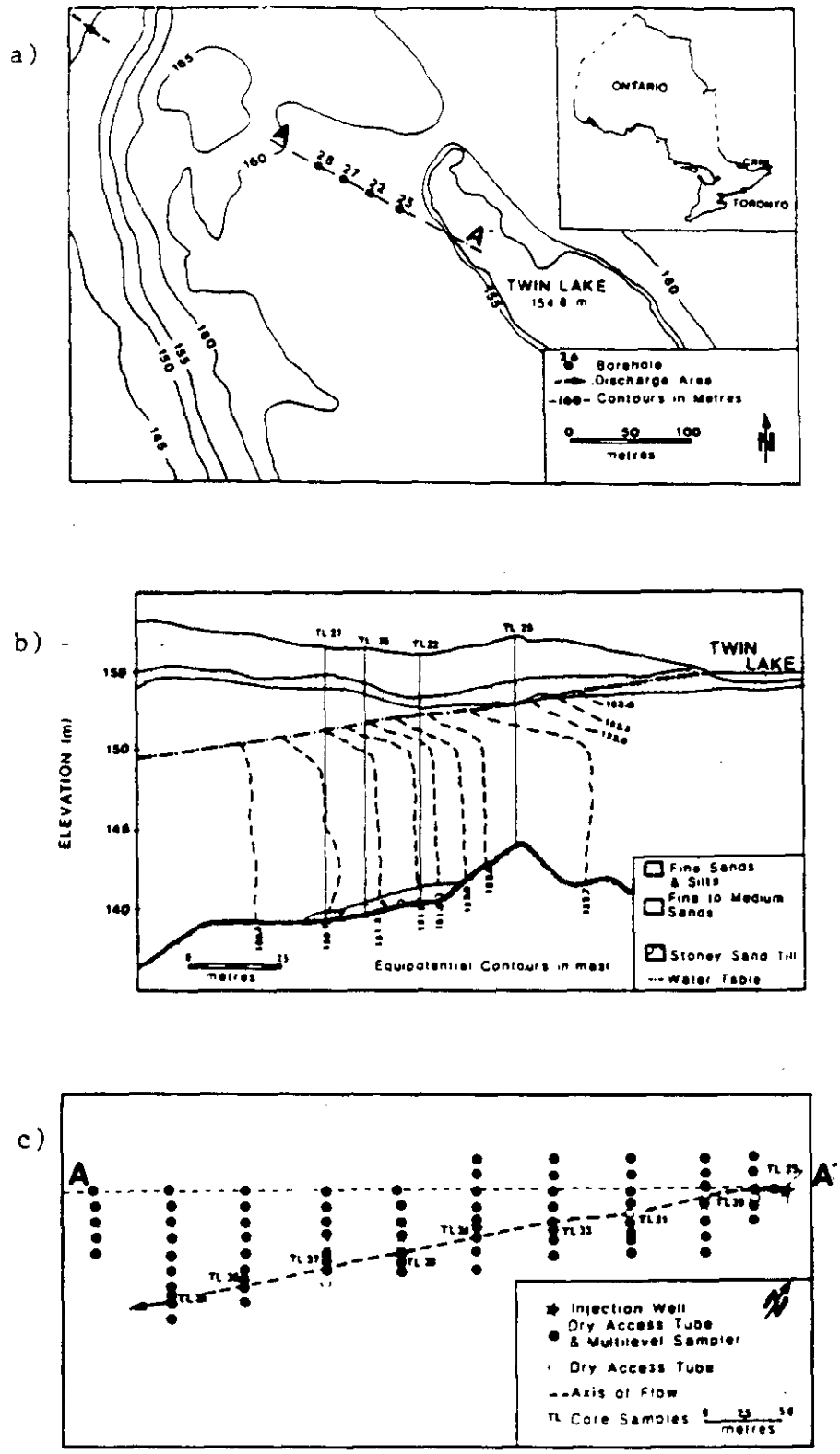

Figure 20. (a) Twin Lake Site map. (b) Geological cross section through the Twin Lake site (section A–A'). (c) Plan of field site showing instrumentation and tracer flow line.

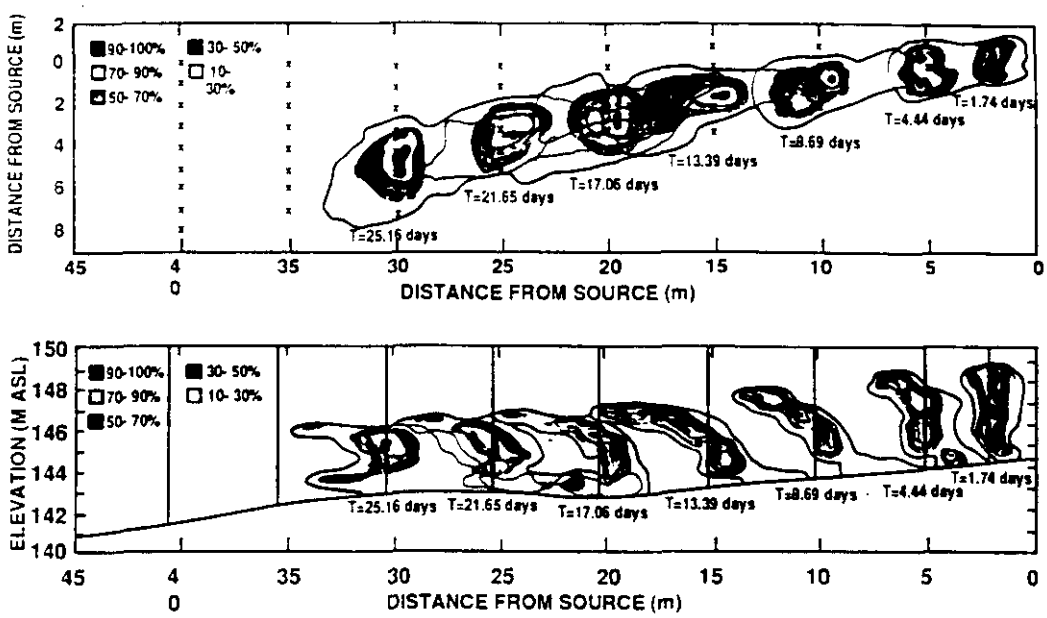

Figure 21. Example of the type of data available through the data base. Tracer migration in the sandy aquifer (percent of injection concentration).

Appendix 3

List of Test Case Related Presentations at INTRAVAL Workshops

INTRAVAL Phase 1 Test Cases

Radionuclide migration through clay samples by diffusion and advection (TEST CASE 1a)

Bogorinski P., Larue J., and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overview of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R., and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A., and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Application of Experiment Design Methods to Test Case 1a. INTRAVAL., INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A., and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P., and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J., and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K., and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K., and Ikeda Y., PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R., and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R., and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

Uranium Migration in Crystalline Bore Cores (TEST CASE 1b)

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J., and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E., and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., A Note on the Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Grindrod P., and Hodgkinson D., The Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Hadermann J., and Jakob A., Modelling Test Case 1b with Various Mechanisms and Geometries, INTRAVAL Workshop, Cologne 1990.

Hara K., Nakahara Y., Neyama A., Shiga A., and Ikeda Y., Modelling Study of Test Case 1b, INTRAVAL Workshop, Cologne 1990.

Hautojärvi A., Preliminary VTT Results on Test Case 1b, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Channels as Migration Routes in Crystalline Rock Samples, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Preece T.E., and Sumner P.J., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Sumner P.J., and Preece T.E., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Jakob A., Hadermann J., and Zingg A., PSI New Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Kjellbom K., Moreno L., and Neretnieks I., Preliminary Evaluation of Some Uranium Migration Tests, INTRAVAL Workshop, Helsinki, June 1989.

Radionuclide Migration in Single Natural Fissures in Granite (TEST CASE 2)

Aimo N.J., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Cole C.R., and Aimo N.J., Investigating a Parameter Estimation Approach to Design of Validation Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Gureghian B., Radionuclide Migration in Single Natural Fissures in Granite, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., Preliminary Results of Test Case 2 Study, INTRAVAL Workshop, Barcelona, April 1988.

Neretnicks I., Previous Modelling of Test Case 2 Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 2, INTRAVAL Workshop, Tucson, November 1988.

Skagius K., Presentation of Test Case 2, INTRAVAL Workshop, Barcelona, April 1988.

Tracer Tests in a Deep Basalt Flow Top (TEST CASE 3)

Cole C., INTRAVAL Test Case 3, Experiments and Model Calculation, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., and Aimo N.J., Presentation of Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Andersson J., Comments on INTRAVAL Test Case 3, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., and Umeki H., Calculation of the Concentration of a Dispersive Tracer Solute by Means of Numerical Solution of the Balance Equation, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., Modelling of Test Case 3 by Using a Numerical Method, INTRAVAL Workshop, Tucson, November 1988.

Kimura H., and Yamashita R., Preliminary JAERI Results on Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Flow and Tracer Experiments in Crystalline Rock Based on Stripa 3D Experiments (TEST CASE 4)

Andersson J., Discrete Network Analysis of Tracer Experiments in Stripa 3D, INTRAVAL Workshop, Las Vegas 1990.

Dverstorp B., Application of the Discrete Fracture Network Concept on Field Data: Possibilities of Model Calibration and Validation, INTRAVAL Workshop, Barcelona, April 1988.

Dverstorp B., and Nordqvist W., Flow and Transport Simulations with a Discrete Fracture Network Model, INTRAVAL Workshop, Helsinki, June 1989.

Hodgkinson D., Shaw W., and Barker J., Modelling by Flows in Continuous Dimension, INTRAVAL Workshop, Tucson, November 1988.

Hodgkinson D., Shaw W., and Grindrod P., Preliminary Fractal Analysis of the Stripa 3D Migration Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neremieks I., Presentation of Test Case 4: 3D Migration Experiment at Stripa, INTRAVAL Workshop, Barcelona, April 1988.

Neremieks I., Presentation of Test Case 4, INTRAVAL Workshop, Tucson, November 1988.

Tsang Y.W., and Tsang C.F., Understanding Stripa 3-D Tracer Migration Data, INTRAVAL Workshop, Helsinki, June 1989.

Tracer Experiments in a Fracture Zone at the Finnsjön Research Area (TEST CASE 5)

Andersson P., Experimental Results and Further Plans, INTRAVAL Workshop, Tucson, November 1988.

Andersson P., Recent Experimental Results, INTRAVAL Workshop, Helsinki, June 1989.

Andersson P., Proposal for Simulation of Hydraulic Interference Tests, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., and Worth D., Do the Pulse Injection Experiments Exhibit Radially Convergent Fracture Flow?, INTRAVAL Workshop, Las Vegas, February 1990.

Gustafsson E., Andersson P., and Wikberg P., Recent Achievements in the Performance and Evaluation of the Finnsjön Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A., Dipole Results, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A., and Taivassalo V., Generalised Taylor Dispersion Analysis for Tracer Breakthrough in the Radially Converging Experiment of Finnsjön (test case 5), INTRAVAL Workshop, Barcelona, April 1988.

Hautojärvi A., and Taivassalo V., Pre-Test Calculations of VTT-Team for Radially Converging Test, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Results of the Radially Converging Test, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Preliminary Predictive Modelling of the Dipole Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Test Case 5, Radially Converging Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., and Katsuragi T., Predictive Modelling of the Dipole Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Helsinki, June 1989.

Kimura H., Katsuragi T., and Yamashita R., Preliminary Results of the Radially Converging Tracer Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Las Vegas, February 1990.

Moreno L., and Neretnieks I., Preliminary Evaluation of Tracer Test in Finnsjön. Radial Converging Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Introduction to Test Case 5, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Preliminary Predictions of Finnsjön Tracer Tests, INTRAVAL Workshop, Barcelona, April 1988.

Nordquist R., Numerical Predictions of a Dipole Tracer Test in a Fracture Zone in the Brändan Area, Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Winberg A., Geostatistical Analysis of Hydraulic Conductivity Data at Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Yamashita R., and Kobayashi A., Preliminary Calculations Using Fracture Network Approach for Tracer Test in Finnsjön Site, INTRAVAL Workshop, Las Vegas, February 1990.

Synthetic Data Base, Based on Single Fracture Migration Experiments in Grimsel (TEST CASE 6)

Codell R., Cole C., and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem VI, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Cole C., and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem 6, INTRAVAL Workshop, Helsinki, June 1989.

Codell R., and Trösch J., Calculation of Synthetic Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kuhlmann U., and Vomvoris S., Interpretation of INTRAVAL Test Case 6, Synthetic Experiment, INTRAVAL Workshop, Cologne, October 1990.

Vomvoris S., On the Synthetic Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Redox-front and radionuclide movements in an open Pit Uranium Mine, Pocos de Caldas (TEST CASE 7a)

Neretnieks I., Presentation of Test Case 7a: Redox Front and Uranium Movement at Pocos de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 7a: Redox Front Movement, INTRAVAL Workshop, Tucson, November 1988.

Neretnieks I., Redox Front Studies at Poços de Caldas, INTRAVAL Workshop, Las Vegas, February 1990.

Romero L., Moreno L., and Neretnieks I., Poços de Caldas. The Location of the Redox Front, INTRAVAL Workshop, Helsinki, June 1989.

Morro do Ferro Colloid Migration Studies (TEST CASE 7b)

Chapman N., Presentation of Test Case 7b: Colloid Transport, INTRAVAL Workshop, Tucson, November 1988.

Noy D., Presentation of Test Case 7b: Colloid Mobility at Poços de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Natural Analogue Studies at the Koongarra Site in the Alligator Rivers Area (TEST CASE 8)

Davis S., Hydrology Sub-Project. INTRAVAL Workshop, Tucson, November 1988.

Duerden P., and Golian C., Presentation of Koongarra and Draft Test Case, INTRAVAL Workshop, Barcelona, April 1988.

Duerden P., Presentation of Test Case 8, INTRAVAL Workshop, Tucson, November 1988.

Duerden P., Update of Recent Field Work, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., Koongarra Test Case: Modelling Progress, INTRAVAL Workshop, Tucson, November 1988.

Golian C., Hydrodynamic Transport through Porous Media which Contain Two Iron Mineral Phases, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., A Quasi Two Dimension Open System/Transport Model to Describe the Mobility of the Bulk Uranium, INTRAVAL Workshop, Las Vegas, February 1990.

Golian C., Test Results of the Simplified 2D Modelling of th Koongarra System Describing the Preferential Uranium Pathways, INTRAVAL Workshop, Cologne, October 1990.

Lever D., Koongarra Transport Modelling, INTRAVAL Workshop, Barcelona, April 1988.

Nijhoff-Pan I., Discussion on Test Case 8: Alligator Rivers (Koongarra) Ore Deposit, INTRAVAL Workshop, Helsinki, June 1989.

Slot A.F.M., Proposed Modelling Approach for the INTRAVAL Test Case 8, Alligator Rivers, Koongarra Ore Deposits, INTRAVAL Workshop, Las Vegas, February 1990.

Sverjensky D., Geochemical Aspects of the Alligator River Analogue Project, INTRAVAL Workshop, Tucson, November 1988.

Radionuclide Migration in a Block of Crystalline Rock (TEST CASE 9)

Hautojärvi A., Preliminary Calculations of Migration in the Fracture Channels, INTRAVAL Workshop, Helsinki, June 1989.

Kawanishi M., Preliminary Results on Test Case 9 by using Dual-Porosity Simulation Code, INTRAVAL Workshop, Cologne, October 1990.

Kobayashi A., and Yamashita R., Preliminary Results on Test Case 9 by Using the Non-Uniform Velocity Distribution, INTRAVAL Workshop, Helsinki, June 1989.

Noronha C.J., and Gureghian A.B., Description of Granite Block Experiment for Test Case 9, INTRAVAL Workshop, Barcelona, April 1988.

Noronha C.J., and Gureghian A.B., Large Block Migration Experiments, INTRAVAL Workshop, Tucson, November 1988.

Rasilainen K., Hautojärvi A., and Vuori S., Preliminary Interpretation of Test Case 9 using FTRANS-code, INTRAVAL Workshop, Las Vegas, February 1990.

Vandergraaf T.T., Grondin D.M., and Drew D.J., Contaminant Transport Laboratory Studies in a Single, Natural Fracture in a Quarries Granite Block at a Scale of 1 Metre, INTRAVAL Workshop, Tucson, November 1988.

Evaluation of Unsaturated Flow and Transport in Porous media Using an Experimental with Migration of a Wetting front in a Superficial Desert Soil, Las Cruces Trench (TEST CASE 10)

Ababou R., High-resolution Modeling of 3D Flow Fields, INTRAVAL Workshop, Las Vegas, February 1990.

Bensabat J., Stochastic Modelling of the First Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Gee G., Deterministic Modeling and Considerations for Transport Analysis of the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Gelhar L., Applications of the Stochastic Model to the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., Updegraff C.D., and Davis P.A., A 2-D Deterministic Model of the Las Cruces Trench Infiltration Experiment, Preliminary Results, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., and Davis P.A., A Statistical Analysis of the Las Cruces Trench Hydraulic Data, INTRAVAL Workshop, Helsinki, June 1989.

Goodrich M.T., and Gribble A.R., Data Analysis and Modelling of the Las Cruces Trench Second Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Hills R.G., Hudson, D.B., Porro I., and Wierenga P.J., Modelling the Layered Soil Lysimeter Study at Las Cruces, INTRAVAL Workshop, Tucson, November 1988.

Hills R., and Wierenga P., Water Flow and Solute Transport at the Las Cruces Trench Site, INTRAVAL Workshop, Las Vegas, February 1990.

Kool J.B., Simulations of Water Flow and Tritium Transport at the Las Cruces Trench, INTRAVAL Workshop, Las Vegas, February 1990.

McLaughlin D., Model Validation Issues for Unsaturated Flow Systems. INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Presentation of Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Introduction, Test Case 10, INTRAVAL Workshop, Helsinki, June 1989.

Rasmuson A., Lindgren M., and Collin M., Flow and Transport Simulations of the Second Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Smoot J.L., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Smyth J.D., Infiltration Simulations of the Jornada Trench with a Multidimensional Monte Carlo Code, INTRAVAL Workshop, Las Vegas, February 1990.

Updegraff D., 1-D Analytical Solutions on Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Field and Laboratory Experimental Results with Emphasis on Transport, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Hills R., and Hudson D., Flow and Transport Data Analyses of the Las Cruces Trench Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Evaluation of Flow and Transport in Unsaturated fractured Rock Using Studies at Apache Leap Tuff Site (TEST CASE 11)

Bradbury J., Evaporation in Unsaturated Fractured Rock - an Alternative Conceptual Model, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Transport in Two-Phase Flow in Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Evans D., Field and Laboratory Experimental Results, INTRAVAL Workshop, Tucson. November 1988.

Evans D., Rasmussen T., and Sully M., Rock Matrix Characterization in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Non-isothermal Core Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Cross-hole Pneumatic Testing at the Apache Leap Tuff Site, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Laboratory Fracture Flow Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Lindgren M., and Rasmuson A., Two-Phase Flow Simulations in a Heated Tuff Drillcore, INTRAVAL Workshop, Cologne, October 1990.

McCartin T., Simulation of the Apache Leap Tuff Site Borehole Experiment, INTRAVAL Workshop, Tucson, November 1988.

McCartin T., Two-Phase Flow Simulations in a Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Nicholson T., Presentation of Test Case 11, INTRAVAL Workshop, Tucson, November 1988.

Parsons A.M., and Davis P.A., Modeling Strategy and Data Analysis for the Apache Leap Tuff Block Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Rasmussen T., Modelling of Field and Laboratory Experiments, INTRAVAL Workshop, Tucson, November 1988.

University of Arizona, Field and Laboratory Experiments in Unsaturated Fractured Tuff, INTRAVAL Workshop, Helsinki, June 1989.

Experiments with changing Near-Field Hydrologic Conditions in Partially Saturated Tuffaceous Rocks, G-Tunnel (TEST CASE 12)

Hoxie D.T., Empirical Validation of Hydrologic Model Simulations of Changing Near-Field Hydrologic Conditions, INTRAVAL Workshop, Barcelona, April 1988.

Hoxie D.T., Flint A.L., and Chornack M.P., Model Validation with Respect to Short-Term Dynamic Effects and Long-Term Transient Effects, INTRAVAL Workshop, Tucson, November 1988.

Experimental study of Brine Transport in Porous Media (TEST CASE 13)

Arens G., Preliminary Results on Test Case 13, INTRAVAL Workshop, Helsinki, June 1989.

Arens G., and Fein E., One-dimensional Brine Transport in Porous Media, INTRAVAL Workshop, Las Vegas, February 1990.

Bogorinski P., Jackson P., and Porter J.A., New Approach to the RIVM Experiment, INTRAVAL Workshop, Cologne, October 1990.

Hassanizadeh S.M., Presentation of Experimental Results from Brine Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Hassanizadeh S.M., Experimental Study of Brine Transport in Porous Media, INTRAVAL Workshop, Tucson, November 1988.

Hassanizadeh S.M., and Leijnse T., Simulation of the Brine Transport Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Hassanizadeh S.M., Latest Results on Simulation of Brine Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Schelkes K., Preliminary BGR Results, INTRAVAL Workshop, Helsinki, June 1989.

Schelkes K., and Knoop R.-M., Results of Modelling the Salt Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Groundwater Flow in the Vicinity of the Gorleben Salt Dome (TEST CASE 14)

Glasbergen P., Proposals for Test Cases Related to Rock Salt, INTRAVAL Workshop, Barcelona, April 1988.

Schelkes K., Pumping Test in Highly Saline Groundwater - a Proposed Test Case., INTRAVAL Workshop, Tucson, November 1988.

Schelkes K., Saline Groundwater Movement in an Erosional Channel Crossing a Salt Dome - Working Program for a Test Case, INTRAVAL Workshop, Tucson, November 1988.

INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Hills R., and Wierenga P., Las Cruces Trench Experiments Phase 2, and Validation Strategy, INTRAVAL Workshop, Seattle, April 1991.

Olague N., Kozak M., and McCord J., Las Cruces, Summary of Post Analysis. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Rockhold M., Conceptual Approach and Initial Numerical Modelling of the Plot 2b Experiment Using PORFLO-3, INTRAVAL Workshop, Seattle, April 1991.

Wittmeyer G., and Sagar B., Flow and Transport Modelling of Test Case, INTRAVAL Workshop, Seattle, April 1991.

APACHE LEAP TUFF

Ford W., Pole J., Codell R., and McCartin T., Simulations of Hypothetical Flow Experiments in Fractured Rock Blocks, INTRAVAL Workshop, Seattle, April 1991.

Guzman A., Sully M., and Neuman S.P., Three Dimensional Characterization of Pneumatic Permeabilities in Unsaturated Fractured Tuff at the ALT Site, INTRAVAL Workshop, Seattle, April 1991.

Rasmussen T.C., and Anderson I., Unsaturated Apache Leap Tuff Experiments: Fracture Imbibition Tests and Non-Isothermal Core Tests, INTRAVAL Workshop, Seattle, April 1991.

Rasmussen T.C., and Evans D., The Apache Leap Tuff Site Proposed Field Heater Experimental Plan, INTRAVAL Workshop, Seattle, April 1991.

Sully M., Guzman A., and Neuman S.P., In Situ Pneumatic Permeability, INTRAVAL Workshop, Seattle, April 1991.

FINNSJÖN

Gomit J.M., Finnsjön Test Case, INTRAVAL Workshop, Seattle, April 1991.

Vuori S., Evaluation of Migration Processes and Geometries Using Tracer Break-through Curves of INTRAVAL Test Cases (Finnsjön, Stripa, WIPP 2), INTRAVAL Workshop, Seattle, April 1991.

STRIPA

Guerin F., Billaux D., Chiles J.P., and Sauty J.P., Stripa: First Attempt at Tracer Experiments. Simulations by a Set of Interconnected Channelized Fractures, INTRAVAL Workshop, Seattle, April 1991.

WIPP 2

Beauheim R., Overview of Tests Conducted on the (WIPP 2) Culebra Formation at the WIPP, INTRAVAL Workshop, Seattle, April 1991.

Corbet T.F., Overview of Modeling Studies of the (WIPP 2) Culebra Formation at the WIPP, INTRAVAL Workshop, Seattle, April 1991.

Grindrod P., Flow Through Fractal Rock: What does the WIPP 2 Field Data Reveal?, INTRAVAL Workshop, Seattle, April 1991.

Jackson P.C., Preliminary Discussion on WIPP 2, INTRAVAL Workshop, Seattle, April 1991.

GORLEBEN

Schelkes K., Gorleben Test Case, INTRAVAL Workshop, Seattle, April 1991.

WIPP 1

Beauheim R., Interpretation of Permeability Tests (WIPP 1) S0P01 and L4P51, INTRAVAL Workshop, Seattle, April 1991.

Finley S.J., Small Scale Brine Inflow Experiments (WIPP 1): Data and Interpretation, INTRAVAL Workshop, Seattle, April 1991.

MOL

Olague N., Kozak M., and McCord J., Mol: Preliminary Analyses. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Put M., Mol: Case Description and Modelling Methodology with Results, INTRAVAL Workshop, Seattle, April 1991.

ALLIGATOR RIVERS

Birchard G., and Murphy W., Koongarra Analogue of the Near Field of an HLW Repository, INTRAVAL Workshop, Seattle, April 1991.

Golian C., Uranium Series Radionuclide Mobility in the Koongarra Weathered Zone, INTRAVAL Workshop, Seattle, April 1991.

Townley L., Hydrology of the Koongarra Site, Including Predictions of 3D Groundwater Flow Patterns, INTRAVAL Workshop, Seattle, April 1991.

TWIN LAKE

Durin M. and Mouche E., Comments to Twin Lake Test Case, INTRAVAL Workshop, Seattle, April 1991.

Gomit J-M., Twin Lake Test Case, INTRAVAL Workshop, Seattle, April 1991.

Olague N., Kozak M. and McCord J., Twin Lake: Preliminary analyses. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

INTRAVAL Parties:

Agence Nationale pour le Gestion des Déchets Radioactifs (France), Atomic Energy of Canada Ltd. (Canada), Atomic Energy Control Board (Canada), Australian Nuclear Science and Technology Organisation (Australia), Bundesanstalt für Geowissenschaften und Rohstoffe/Bundesamt für Strahlenschutz (Federal Republic of Germany), Commissariat à l'Energie Atomique/Institut de Protection et de Sûreté Nucléaire (France), Empresa Nacional de Residuos Radioactivos, S.A. (Spain), Gesellschaft für Reaktorsicherheit mbH (Federal Republic of Germany), Forschungszentrum für Umwelt und Gesundheit (Federal Republic of Germany), Her Majesty's Inspectorate of Pollution (United Kingdom), Industrial Power Company Ltd. (Finland), Japan Atomic Energy Research Institute (Japan), Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (Switzerland), National Institute of Public Health and Environmental Protection (The Netherlands), National Radiological Protection Board (United Kingdom), Power Reactor and Nuclear Fuel Development Corporation (Japan), Studiecentrum voor Kernenergie (Belgium), Swedish Nuclear Fuel and Waste Management Co. (Sweden), Swedish Nuclear Power Inspectorate (Sweden), U.K. Nirex Ltd. (United Kingdom), U.S. Department of Energy–OCRWM (United States of America), U.S. Department of Energy–WIPP (United States of America), U.S. Environmental Protection Agency (United States of America), U.S. Nuclear Regulatory Commission (United States of America).

Project Secretariat:

Swedish Nuclear Power Inspectorate, Her Majesty's Inspectorate of Pollution/AEA Technology, KEMAKTA Consultants Co., Organisation for Economic Cooperation and Development/Nuclear Energy Agency.

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PROGRESS REPORT

8

May 1991 – February 1992

INTRAVAL – An International Project to Study
Validation of Geosphere Transport Models

INTRAVAL
Progress Report Number 8, 1992

The international INTRAVAL project started in October 1987 in Stockholm as an international effort towards validation of geosphere models for transport of radionuclides. The project was initiated by the Swedish Nuclear Inspectorate, SKI, and was prepared by an ad-hoc group with representatives from eight organisations.

24 organisations 'Parties' from fourteen countries participate in INTRAVAL. The project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat in which also Her Majesty's Inspectorate of Pollution HMIP/DoE, U.K. and the OECD/NEA take part. Project organisation, the objectives of the study and rules for the publication of results are defined by an Agreement between the Parties.

The INTRAVAL philosophy is to use results from laboratory and field experiments as well as from natural analogue studies in a systematic study of the model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
Progress Report Number 8

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was started in October 1987. The first three year study, Phase 1, is finalised. The second three year period, Phase 2, started in October 1990. The last workshop will be held in the autumn 1993 followed by a final meeting mid- 1994.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process. In INTRAVAL the ambition is to cover validation of models both in regard to the processes and site-specific systems.

Ten test cases are included in Phase 2 of the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project and the Alligator Rivers Analogue Project.

Pilot Groups have been appointed for each of the test cases. The responsibility of the Pilot Group is to compile data and propose formulations of the test cases in such a way that it is possible to simulate the experiments with model calculations. It is a pronounced policy of the INTRAVAL study to support interaction between modellers and experimentalists in order to gain reassurance that the experimental data are properly understood and that the experiences of the modellers regarding the type of data needed from the experimentalists are accounted for.

Contact between the participants is maintained by arranging workshops which are followed by Coordinating Group meetings. Working Group meetings take place between the workshops.

Since the issue of the previous Progress Report, the seventh INTRAVAL workshop and the third Phase 2 Coordinating Group meeting were held in Sydney, Australia. During the workshop the participants described the modelling work performed and discussed the results achieved so far. Additional background information has been made available for some of the test cases, and an additional experiment in unsaturated media was included.

A tentative schedule for the final reporting of the project was discussed and it was concluded that extended outlines of the reports have to be available in November 1992. The finalisation of the Phase 1 final reports proceeds according to plan. All test case reports are scheduled for printing in May 1992 and the Executive Summary report is scheduled for printing in the autumn 1992.

The Seventh INTRAVAL Workshop and the Third Phase 2 Coordinating Group Meeting

The seventh INTRAVAL workshop and the third Phase 2 Coordinating Group Meeting were held in Sydney, Australia, on the 10th through 14th of February, 1992, with the Australian Nuclear

Science and Technology Organisation (ANSTO) acting as host. At the workshop technical presentations of the modelling results achieved by the Project Teams were given. Many of the teams discussed validation issues. The final reporting of INTRAVAL phase 2 was initiated and it was decided that extended outlines of the Working Group reports should be available in November 1992.

The Coordinating Group meeting was held on the 14th of February, 1992. At this meeting Mr. Johan Andersson, SKI, the former secretary, was elected as new Chairman of the INTRAVAL Coordinating Group replacing Mr. Kjell Andersson who has resigned from the SKI. Mr. Björn Dverstorp was elected the new secretary. The time schedule for the finalisation of the INTRAVAL project was agreed upon (see section about Working Groups). An INTRAVAL Subcommittee for Integration (ISI) was formed and the proposed charter was adopted. It was decided to arrange a topical session (full day) on validation issues at the next workshop. The validation session will be divided into a morning session reserved for invited speakers and an afternoon session with discussions.

The next INTRAVAL workshop will be held in San Antonio, Texas, USA, on the 9th through the 13th of November, 1992. A field trip to the WIPP site will be arranged the week before the workshop. The tentative time schedule for the remaining INTRAVAL activities are: the fourth and last workshop in September 1993, and a final meeting in autumn 1994. Separate Working Group meetings are scheduled prior to the next INTRAVAL workshop.

INTRAVAL Sub-Committee for Integration (ISI)

At the first Phase 2 INTRAVAL Coordinating Group Meeting, the Coordinating Group approved the establishing of a subcommittee to the INTRAVAL Coordinating Group. The purpose of the INTRAVAL Subcommittee for Integration (ISI) is to assist the INTRAVAL Secretariat by integrating the activities of the Working Groups, the validation approaches and the lessons learned for the INTRAVAL Project. The activities include preparation of an integration report to become part of the INTRAVAL Phase 2 final reports. The Committee members shouldtake part in workshops and related activities and give suggestions for future activities.

The Committee consists of the Chairs of the four INTRAVAL Working Groups and additional members elected by the Coordinating Group and members of the Secretariat.

INTRAVAL Phase 1 Reporting

The achievements from the first phase of INTRAVAL will be documented in an Executive Summary Report and a series of technical reports. The technical reports cover descriptions, evaluations and conclusions from the modelling work performed for the different test cases. One of the technical reports is a compilation of descriptions of the experiments on which the test cases are based. The technical reports have been prepared by six Working Groups. An editor for each test case has been appointed with the responsibility to compile the test case analysis provided by the Project Teams that have worked with the test case.

The reporting proceeds according to plan. All test case reports are scheduled for printing in May 1992 and the Executive Summary Report is scheduled for printing autumn 1992.

Information from the Phase 2 Working Groups

Four Working Groups have been set up addressing different types of test cases (Table 1).

Table 1. Working Groups for INTRAVAL Phase 2.

Working Group	Test Cases	Chairman
1	Las Cruces Trench Apache Leap	T. Nicholson
2	Finnsjön Stripa WIPP 2	C-F. Tsang S. Neuman
3	Gorleben WIPP 1 Mol	P. Bogorinski
4	Alligator Rivers Twin Lake	P. Duerden

A chairman has been elected for each Working Group, sometimes aided by another person. The chairs of the Working Groups are responsible for

the preparation of Working Group reports, which will form part of the final reporting of INTRAVAL Phase 2.

Since the last workshop in Seattle, USA, in April 1991, all Working Groups have arranged meetings. Minutes from most of these meetings are available on request from the Project Secretariat. The meetings held are presented in Table 2. During the workshop in Sydney one and a half day was dedicated to Working Group meetings.

Table 2. Working Group meetings held between May 1991 and April 1992.

Working Group	Date	Location	Test Case
1	June 1991	Rockville, USA	Apache Leap Tuff
1	November 1991	Rockville, USA	Las Cruces Trench
1	December 1991	Berkeley, USA	Apache Leap Tuff
2	October 1991	Santa Fe, USA	
3	October 1991	Santa Fe, USA	
4	July 1991	Sydney, Australia	Alligator Rivers
4	September 1991	Twin Lake, Canada	Twin Lake

Prior to the next INTRAVAL workshop a number of Working Group meetings are scheduled (Table 3).

Table 3. Scheduled Working Group meetings.

Working Group	Date	Location	Test Case
1	March 1992	Yucca Mountain	Yucca Mountain matrix infiltration*
1	May 1992	Las Cruces, USA	Las Cruces Trench
1	July 1992	Berkeley, USA	Apache Leap Tuff
2	June 1992	Forsmark, Sweden	
3	June 1992	Traben-Trarbach, Germany	
4	Summer 1992	Canada	Twin Lake

*USA experiment (new experiment in INTRAVAL study).

INTRAVAL Phase 2 Reporting

The final documentation of INTRAVAL Phase 2 study will comprise Working Group reports from the four Working Groups and a Phase 2 Executive Summary report. In addition, a special report on integrated conclusions from the INTRAVAL Project will be prepared by the INTRAVAL Subcommittee for Integration. The tentative schedule for the printing and publishing of these reports are by the end of 1994.

Current Status of INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media preformed at Las Cruces, New Mexico.

Experimental set-up

The experimental site is located at the New Mexico State University Collage Ranch, 40 km northeast of Las Cruces in New Mexico, USA. A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4 × 9 m and 1 × 12 m, respectively, are adjacent to the trench. Water and tracers were applied at controlled rates on these areas. In the first experiment (Plot 1) water containing the conservative tracer tritium was applied at a rate of 1.76 cm/day on the area measuring 4 × 9 m. In the second experiment (Plot 2a), water containing tritium and bromide was applied at a rate of 0.43 cm/day on the other area (1 × 12 m) on the opposite side of the trench, and in the third experiment (Plot 2b) tritium, bromide, boron, chromium and two organic compounds (pentafluorobenzoic acid and 2,6-difluorobenzoic acid) were applied at a rate of 1.82 cm/day on the same area (1 × 12 m). The movement of the water below the soil surface was monitored with neutron probes and tensiometers. Tracer concentrations were sampled on a regular basis through solute samplers installed in a two dimensional grid through the trench wall. In addition laboratory experiments on cores were performed to determine the physical properties of the

soil. The Plot 1 and Plot 2a experiments were included in INTRAVAL Phase 1 and was used for model calibration. The calibrated models will be used in INTRAVAL Phase 2 to predict the Plot 2b experiment before the experimental data will be made available to the Project Teams.

Analyses by the Project Teams

The Project Team from CNWRA/USNRC has modelled the Plot 2a experiment with the finite difference code PORFLOW-3, which handles variably saturated fluid flow, heat and mass transfer. The presented results are based on comparisons of model predictions and measurements of first and second moments and point concentrations. The calculations were carried out with five different models with different spatial resolution of soil-hydraulic properties and initial conditions. The simplest model assumes one uniform material zone while the most complex model includes 180 zones. The initial conditions are based either on measurements with thermocouple psychrometers and tensiometers or on measured water contents. The complex models all overpredicted the vertical spreading of the tracer bromide, whereas the more simple models gave better predictions of the bromide concentrations. None of the models correctly predicted the depth of movement of the tracer plume at later times. It was pointed out that the limited spatial resolution of the concentration sampling could be one explanation to the fact that the simpler models appeared to perform better.

The Pilot Group from University of New Mexico/USNRC presented their initial look at a validation methodology with application to the Las Cruces experiments. The results of performed blind model predictions have been provided to the Pilot Group for comparison with observed data using simple statistical tests. The quantities to be compared are point values of water contents, solute concentrations, first detection times at specific horizons as well as some integrated values (0th, 1st, and 2nd moments versus time and flux through specific horizons versus time). The performance measure used is scatter plots of observed quantity versus the predicted quantity. This performance measure estimates the ability of the used model to predict observed mean behaviour for this special experiment over the temporal and spatial scales of this experiment. So far, the Pilot Group has looked at performed predictions of the water content. The predictions made are based on five different conceptual models for the soil properties; two for a uniform and isotropic soil, one for a heterogeneous but isotropic soil, and two where the soil properties have stochastic distributions. Linear regression, with a confidence interval of 99%, used on the experimental water content versus predictions with the different models would reject all predictions of the situation on day 70 (Figure 1), all model predictions except one (with uniform isotropic soil) would be rejected for day 310.

Regression used on normalised change in water volume will reject all models tested. There are a number of limitations in the test used as the error bounds are based on uncertainty in estimating the parameters due to scatter in observed data. The error bounds decrease with an increased number of measurements and less scatter in data. The test used may lead to rejection even though the difference between integrated observation and predicted mean behaviour is as small as less than 10%. It was concluded that the statistical method applied may not be appropriate to model validation because models can be rejected even though the maximum predictive error is small. Furthermore, if the model is rejected, it is not possible to know whether the reason is due to error in the conceptual or mathematical model, a parameter estimation error, an experimental error, or invalid statistical assumptions.

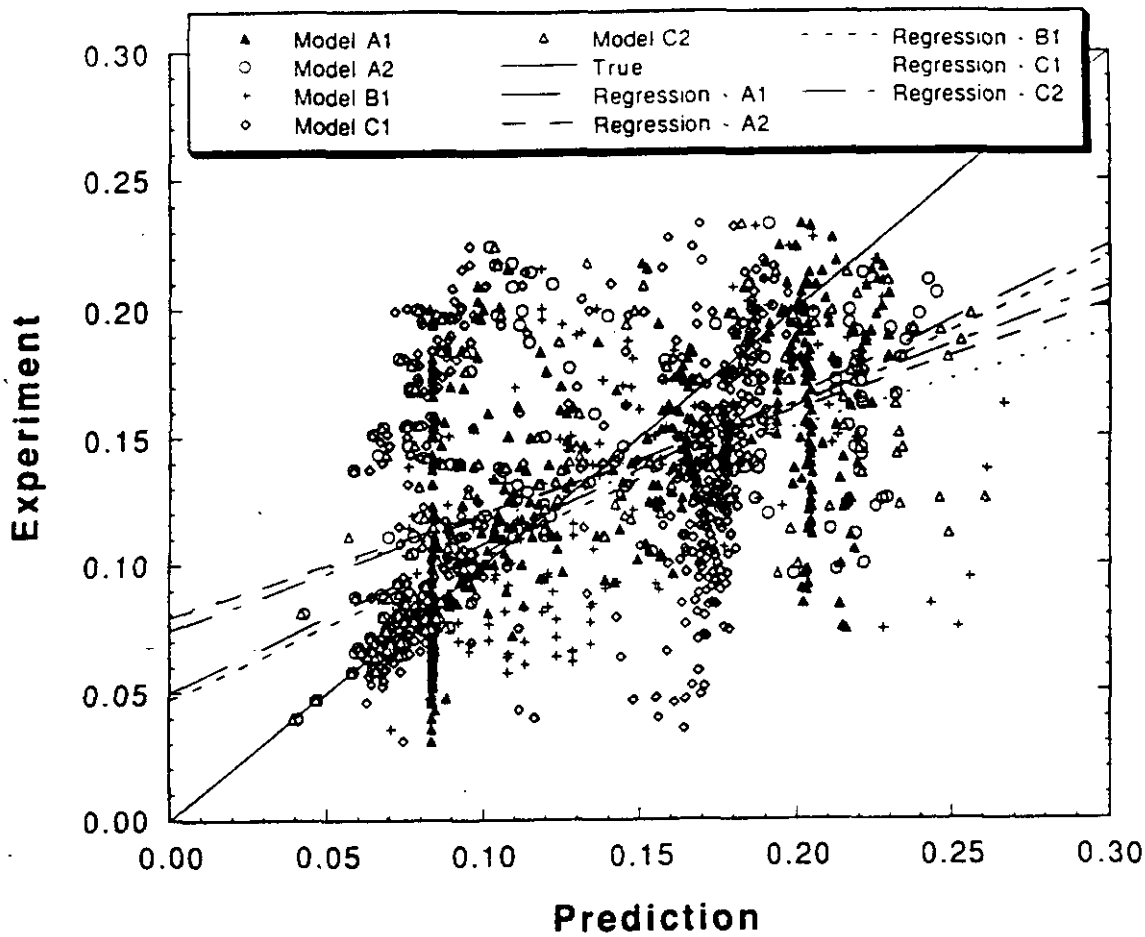

Figure 1. Scatter plots of observed versus predicted voulmetric water content day 70. Also presented are linear regression lines for five conceptual models.

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Experimental Set-up and Scales

The Apache Leap Test Case in INTRAVAL Phase 2 concentrates mainly on two topics: how a thermal source will affect air, vapour, water and solute movement in geologic media, especiallyunsaturated fractured rock, and the water and air transport properites of fractures and rock matrix in unsaturated rock.

The effects of a thermal source were studied with laboratory nonisothermal core measurements. A cylindrically shaped core, approximately 12 cm long and 10 cm in diameter, was extracted from a block of Apache Leap Tuff. The core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses from all surfaces, and to minimize heat loss along the sides of the core. During the experiment, a horizontal temperature gradient is established along the long axis of the core. The data available from the core measurements are rock matrix porosities, initial water contents, and temperatures.

The behaviour of unsaturated fractured rock, was studied in a series of tests being performed to

characterise water and air transport properites from fractures and rock matrix for a range of matrix suction. The measurements were conducted on a block of Apache Leap Tuff which is 92.5 cm long, 21.0 cm high and 20.2 cm wide and contains a single discrete fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent. The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The position of the wetting front in the fracture over time and the position of the wetting front in the matrix over time was studied. Available data are rock matrix sorptivity coefficient, rock matrix porosity, rock fracture aperture, and cumulative inflow volume over time.

In addition to these laboratory experiments there are plans to perform field investigations. However, most of the data from the planned field experiments cannot be expected until after the end of INTRAVAL Phase 2.

Analyses by Project Teams

The observer from the State of Nevada presented some initial benchmark calculations with the code VTOUGH (a vectorised version of TOUGH) of an one-dimensional infiltration experiment. The code will later on be used for simulations of the Apache Leap Site experiments.

The Project Team from USNRC has looked at vapor phase flow and transport in unsaturated fractured rock. The mechanisms of importance for gas transport in unsaturated rock are moisture and temperature difference between air in rock and atmosphere, binary diffusion, barometric pressure variation, wind, repository heat, and possibly volcanic heat. In dry climates there may be a substantial loss of water to the atmosphere due to flow in the gas phase in the rock which is important for the hydrology. Not only water may be transported in the gas phase, but also carbon-14, iodine-129, and volatile compounds of other elements, i.e., technetium and selenium. Modelling of the transport of C-14 has been performed both with a transport model and with a geochemical model. No calculations has been performed for Apache Leap, but the approach is of interest for the Test Case. The first step in the calculations with the transport model is to calculate a steady state gas flow in two dimensions for a number of times. Thereafter particles, in this case C-14, are traced in a gas flow field interpolated from the steady state calculations. This model has been used for simulations of the release of carbon-14 from an underground repository to the atmosphere. The retardation coefficient used for carbon-14 was 100, based on the carbonate geochemistry. A geochemical model for simulations of the transport of carbon-14 in one dimension has also been used. The carbon transport model in this case is based on the chemical equilibria for the carbonate system in gas, liquid and the solid phase and the transport is controlled by transport and transfer between gas, liquid and solid phases. It was concluded that a significant amount of calcite rapidly will precipitate around the repository and then redissolve slowly. Carbon-14 released early will be partially incorporated in this calcite and trapped for thousands of years. Carbon-14 released late will be unretarded by calcite precipitation until the migration wave reaches a point, where the temperature still is increasing and calcite is precipitating. An overall conclusion from this study, based on data inadequate for the Apache Leap site, is that vapor phase considerations are potentially important to a repository in unsaturated fractured rock. Apache Leap research could then support the validation of vapor phase transport models for repository performance assessment.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

This test case deals with detailed characterisation of a fractured zone including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole experiment. This test case was also included in INTRAVAL Phase 1, but the database for the dipole experiment were never used for modelling, since it became available too late. The modelling of the dipole experiment therefore is the focus of Phase 2.

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometres.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to be 10^{-4} m^2/s, the middle 10^{-7}-10^{-6} m^2/s and the lower 10^{-4} m^2/s. The middle layer is not continuous. A fresh water-salt water interface exists in the fracture zone relatively close to the upper sub-layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated to 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several core drilled (and some percussion drilled) boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated at 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed, a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting eleven different non-sorbed tracers at nine different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting tracers in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analyses by the Project Teams

The Project Team from PNC presented preliminary analyses of the Finnsjön experiments using a stream tube approach. The rock was modelled as two layers of an equivalent porous medium, a high conductive layer (2 m thick) and a low conductive layer (10 m thick). The mass transport parameters, dispersivity and porosity, were estimated from the radially converging tracer tests. Location of stream lines, equipotential curves and velocity along the streamlines were generated from the results of the dipole tests. This information together with the estimated transport parameters were used to simulate the tracer breakthrough curves at the pumping borehole in the dipole tests.

The mass transport in both the high conductive zone and the low conductive zone was expressed by one dimensional advection-dispersion equations for each stream line. The hydraulic conductivity in the high conductive layer was assumed to be 10^3 times higher than in the low conductive layer, but the dispersivity in both layers was assumed to be equal. Calculated and measured breakthrough curves of the tracers In-EDTA, Gd-DTPA and I^- in the pumping hole in the radially converging test showed satisfactorily agreement (Figure 2). The dipole test was fairly well simulated with best-fit values of dispersivity and porosity from the tracer breakthrough between the same boreholes in the radially converging test. With best-fit parameter values from tracer breakthrough between the other boreholes in the radially converging test, the calculated peak concentrations in the dipole test were 0.4–3 times the observed. A sensitivity analysis of the influence of the porosity of the low conductive layer shows that the mass transport in this layer cannot be neglected.

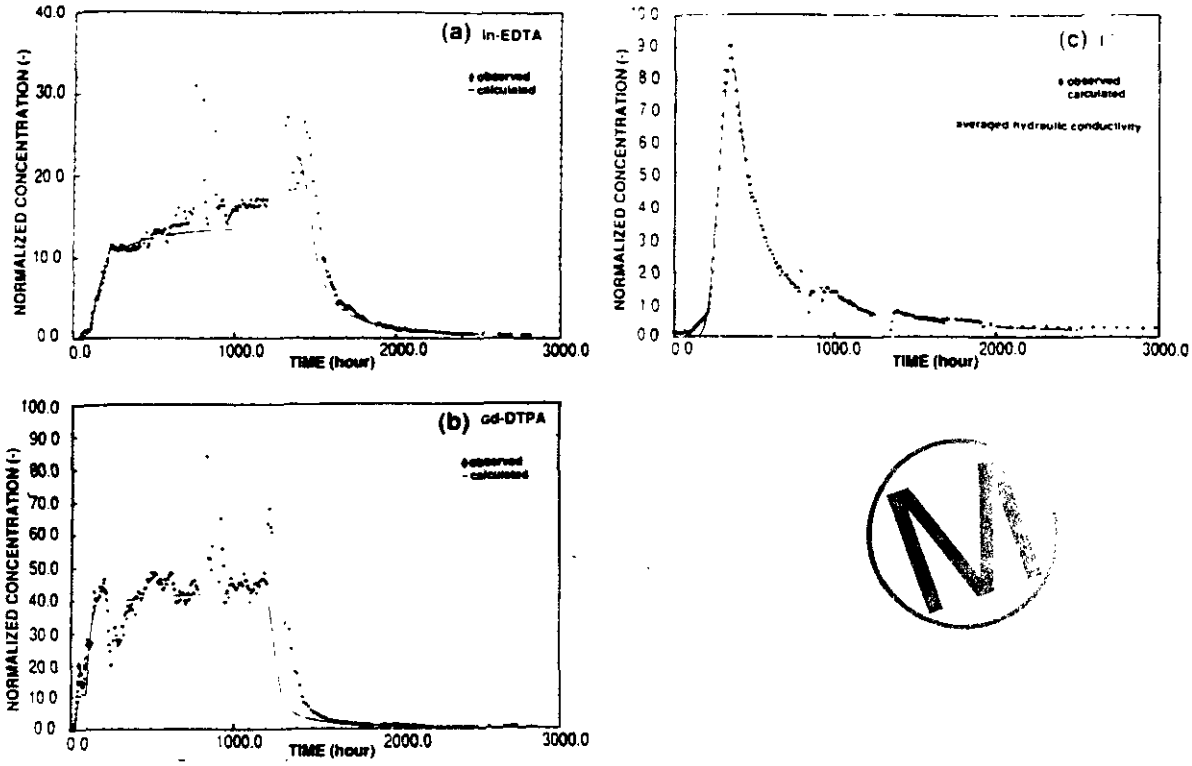

Figure 2. Breakthrough curves of (a) In-EDTA, (b) Gd-DTPA, and (c) I for radially converging tests at the pumping borehole.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiments, Sweden.

Experimental Set-up

This test case is based on three dimensional tracer tests performed in the Stripa mine in Sweden. The experiments are part of the International Stripa Project.

An experimental drift was excavated in the old iron ore mine in Stripa. The whole ceiling and upper part of the walls were covered with about 350 plastic sheets (2 m^2 each) with the purpose to collect water seeping in from the rock and to collect injected tracers. Three vertical boreholes for tracer injections were drilled and tracers were injected at nine locations, 10–55 m above the test site.

The data registered or obtained from the experiments are water flow rates, tracer concentrations in the water entering the drift, rock characteristics and fracture data, water chemistry, tracer injection pressures and flow rates, and hydrostatic pressure. Diffusivity and sorption data are available from complementary laboratory and field experiments. The experiment was a test case also during Phase 1 of INTRAVAL.

In addition to the results from the 3D experiment, data from two other experiments performed in the Stripa mine, the 'Channeling Experiment' 'and the 'Site Characterisation and Validation program', are available to the INTRAVAL Participants during Phase 2. The 'Channeling Experiment' consists of two kinds of experiments. In a single hole experiment, holes with a diameter of 20 cm were drilled about 2.5 m into the rock in the plane of a fracture. Specially designed packers were used to inject water into the fracture at 5 cm intervals. The variation of the injection flow rates along the fracture were used to determine the transmissivity variations in the fracture plane. Detailed photographs were taken from inside the holes and the visual fracture aperture was compared with the injection flow rates. Five holes were measured in detail and seven holes were scanned by simpler

packer systems. In a double hole experiment, two parallel holes were drilled in the same fracture plane at nearly 2 m distance. Pressure pulse tests were carried out between the holes in both directions. Tracers were injected at five locations in one hole and monitored in several locations in the other hole. The 'Site Characterisation and Validation program', with the aim to predict groundwater flow and tracer transport in a previously unexplored rock volume, includes a number of investigation steps with modelling predictions in between. The first investigation includes a few long boreholes used to characterise the rock volume. Additional boreholes were drilled and used for investigations of water bearing sections, fractures, tracer tests etc. All investigations were compared to already performed model predictions. Finally, a new drift, the 'Validation Drift', was excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

Analyses by the Project Teams

Geosigma/SKB has performed radar and saline tracer test to provide data on the geometry of flow-paths in the fractured rock and possible changes in flow-paths caused by excavation of the new 'Validation Drift'. The experiment includes two tests, one before and one after the excavation of the drift. The results of the tests indicate that the drift cut through one major fracture zone. The excavation of the drift caused 3–4 times longer tracer travel times and the tracer occupied a larger volume of the rock in the second experiment, i.e. after the excavation of the drift. The possible cause of delayed tracer inflow could be due to stress redistribution, two-phase flow conditions, blast damage or chemical precipitations. Geosigma/SKB has also performed some modelling. A two-path advection-dispersion model with different mean velocity and dispersivity in the two paths gave a good fit with measured breakthrough curves, whereas assuming only one-path did not give as good a fit (Figure 3).

The Project Team from VTT/TVO has applied a deconvolution procedure to the long and varying injection flow rates and the corresponding tracer breakthrough curves to obtain equivalent breakthrough curves for a delta function puls injection. It can be suspected that peaks in the deconvoluted data are artifacts and they should therefore be considered having large error bars or small probabilities to present a real system behaviour. The analysis of experimental data in order to find the system behaviour should be carried out by taking error estimations into account. The idea is that there does not exist 'the solution' for the problem but a 'region' of acceptable solutions. The Stripa 3D data seems to be 'explained' by matrix-diffusion-like phenomena with very narrow channels and diffusion from the channels into stagnant areas, but other conceptual models may also apply.

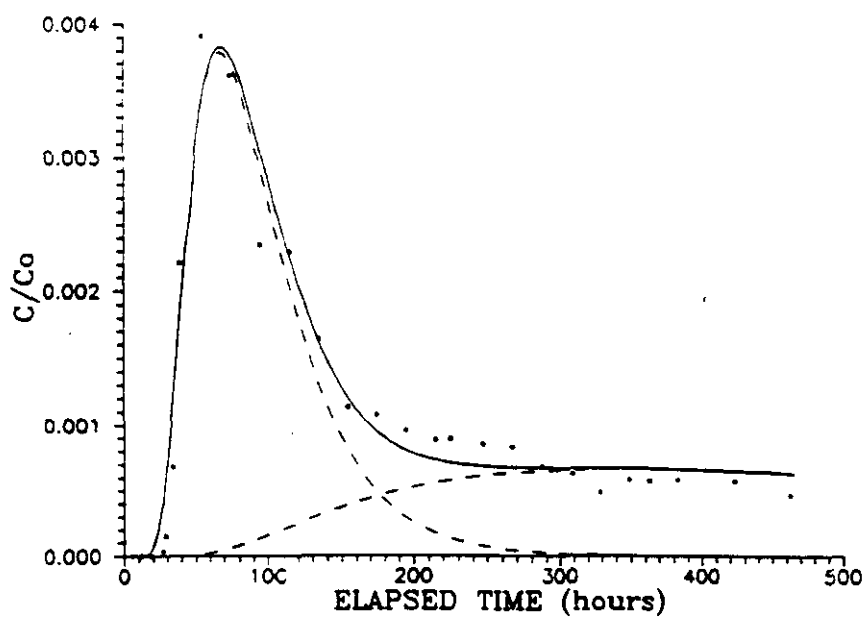

Figure 3. Breakthrough curve for Amino G in grid element 265. The solid line represents the regression estimate with a two-path model.

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located near Carlsbad in southeastern New Mexico, USA, is an underground research and development repository. It is located in the Delaware Basin, the northern part of which is filled with 8000 m of sedimentary Phanerozoic rocks containing evaporities. Water bearing zones within the rocks that underlie host and overlie the WIPP repository have low permeabilities and storativities. They are generally confined and contain waters with high salinities and long residence times. The repository lies 655 m below groundsurface within bedded evaporities, primarily halite, of the Permian Salado Formation. Overlying the Salado Formation is the Rustler Formation. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is an 8 m thick vuggy dolomite layer.

Geologic, hydrologic, geochemical and isotope data have been collected to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involves the travel time within the Culebra from a location above the repository to the WIPP site boundary. Sixty wells into the Culebra dolomite at 41 locations have been completed to provide information on the hydraulic properties. Two pumping tests, each of two month duration, and two convergent-flow tracer tests have been performed. Geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra.

Analyses by the Project Teams

The Pilot Group gave an overview of their work with the development of a new conceptual model for regional groundwater flow in the strata above the Salado Formation. The model, a basin model, is a three-dimensional closed hydrologic unit bounded on the bottom by an 'impermeable' rock unit, on the top by the ground surface, and on the sides by groundwater divides. All recharge to the basin is by infiltration of precipitation and all discharge is by flow across the groundwater table to the land surface. Differences in elevation of the groundwater table across the basin are assumed to be the driving force for groundwater flow. The stratigraphic interval modelled extends from the top of the Salado Formation to the land surface. The conductivity in the six different homogeneous and isotropic layers identified are either 10^{-11} or 10^{-8} m/s.

Several important simplifications have been introduced in the model, each stratigraphic layer is homogeneous and the hydraulic conductivities used to represent strata containing evaporities is probably much higher than the actual hydraulic conductivity of these units. The higher conductivity was used to emphasize the possible role of vertical flow.

The initial conditions for the simulation was intended to represent flow in a wet climate assumed to exist 20 000 years ago (time = 0). The initial condition was generated by providing a surface infiltration rate sufficient to raise the groundwater table to land surface and allowing a steady-state flow field to develop. To simulate a change in climate the infiltration was then set to zero for 20 000 years (time = 20 000 years). Thereafter the maximum infiltration rate was increased to 1 mm/yr for 15 000 years (time = 35 000 years).

Initially (at time = 0) the groundwater table looks very similar to the specified surface topography. The rate of vertical flow in the Culebra is extremely slow, because two model layers with low permeability ($K = 10^{-11}$ m/s) are located between the groundwater table and the Culebra, and the difference in head between the groundwater table and the Culebra is small. There is a slow downward flow into the Culebra over a large area in which the groundwater table is high and a slow upward flow out of the Culebra over a large area in which the groundwater table is low during the wet periods. The groundwater table drops 40 m at the most during this period. The infiltration of 1.0 mm/yr for 15 000 years raised the groundwater table to the land surface again.

An important aspect of the basin model that is demonstrated by these simulations is the similarity of potentiometric surface of confined aquifers and the water table. The identification of such a correlation in measured heads is on the way to confirm that the relief of the water table drives flow in deep aquifers. The calculations also demonstrate that changes in the position of the water table tend to occur in regions where it is elevated. That is the

case in the region in which the vertical component of the flow is downward and the Culebra receives leakage from above. With the basin model it cannot be shown that vertical flow does occur. However, the calculations demonstrate that a hydrologic system, for which vertical leakage is an important component, the basin model is a possible conceptual model. The vertical flow rate received in the calculations is very small but its quantity could be large over time.

The Project Team from UPV/ENRESA presented a probabilistic modelling approach of particle movement simulations in the Culebra dolomite. They used a krieged transmissivity field into which 21 fictitious points were added to create enough heterogeneity to reproduce the field measurements. The transmissivities varied between 10^{-10} and 10^{-3} m/s. The team performed Monte Carlo simulations to calculate particle arrival times and locations. The transmissivity field was calculated with the code GCOSIM3D, the groundwater flow was modelled with the MODFLOW code and particle tracking was calculated by the MODPATH code. All three models were used in 200 realizations and a probabilistic assessment of arrival times and arrival locations was performed. The piezometric maps from the different realisations varied greatly. They concluded that stochastic models contain a confidence interval which a deterministic model does not include. However, the reality is still unique and permeabilities are not random. The Project Team also introduced some thoughts about the theory of further conditioning of the transmissivity fields. They proposed that the hydraulic heads should be calculated from each realisation of the transmissivity field and compared with observed heads. The transmissivity field and boundary conditions would then have to be modified so that the agreement between calculated and observed heads would become acceptable.

The Project Team from AEA/NIREX had performed their modelling work on the WIPP data with stochastic models. They started up with a preliminary study with 300 conditioned realisations of the transmissivity fields and continued with a second study with 1000 conditioned realisations. Most of the calculations were performed with exponential variograms but power-law (fractal) variograms were also used. The flow was calculated using the finite element code NAMMU with 40×60 nine-node quadrilateral elements and biquadratic interpolation. The results from the transport calculations were particle pathlines, transport times and exit points. From the preliminary calculations it was concluded that conditioning of the transmissivity field was important, possibly more important than parameter uncertainty. Calculations with 300 and 1000 realisations gave very similar results for the release from well H-1. Applying power-law variograms gave nearly the same results as the first preliminary calculations with exponential variograms, although the results from the calculations with power-law variograms gave less confident results. The models used were checked in various ways. The trend and variogram parameters were estimated by least-squares fitting, maximum-likelihood, and chi-squared minimisation/Kolmogorov-Smirnoff minimisation. The first two tests both gave low confidence in variogram fits, whereas the chi-squared minimisation failed. A model with a trend and an exponential variogram gave no large difference compared to the preliminary calculation (exponential variogram), except that the standard deviation for the particle exit position increased. The WIPP 2 test case provides a large data set which gives the opportunity to build models on a subset of data and make tests with the remainder of the data.

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Experimental set-up

The Gorleben salt dome is located in the northeastern part of Lower Saxony in the Federal Republic of Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the 'Gorleben Channel', more than 10 km long and 1 – 2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel are the topic for this test case.

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out, one in the freshwater and three in the saline water. One of the pumping tests, in which the pumped well penetrated the entire

deeper aquifer in the erosional channel, will form the basis for the first part of this INTRAVAL test case. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The second part of the test case is an extension in time and length scales and comprises modelling of regional groundwater flow and salt dissolution as well as interaction between the two.

Analyses by the Project Teams

The Pilot Group (BGR) has performed numerical studies using the SUTRA code to investigate the density dependent groundwater movement in the Gorleben Channel. The objective was to investigate whether steady-state conditions exist in the system today, and also to check the influence of hydrogeological and hydraulic parameters in the model calculations. A two dimensional, 15 km wide and 250 m deep cross-section was selected. The boundary conditions used were, no flow at the bottom, no-flow and no-flux at the sides, linear prescribed pressure at the top with free outflow, and fresh water infiltration. The permeability distribution was developed from a very simplified case in the first calculations to a more realistic description of the hydraulic system by introducing more and more heterogeneities in the system.

A number of long-term (up to several hundred thousand years) simulations to predict the present day density distribution were conducted, starting with different initial conditions for the density distribution. So far the calculations indicate that steady-state conditions have not yet been reached in the groundwater system in the erosional channel. It was also concluded that a realistic picture of the geological setting is essential to be able to predict the present day density distribution. The results of the calculations are dependent on the time-scale of the simulation as well as on the selected initial density distribution, which indicate that additional paleoclimatic information is necessary. It was also concluded that the calculated density distribution is strongly dependent on the transverse dispersivity.

The Project Team from BFS performed calculations for the first part of the test case, the pumping tests. The specific permeability ($3.5 \cdot 10^{-12}$ m^2), storage coefficient ($5 \cdot 10^{-4}$), and aquifer thickness (44.6 m) were estimated with an analytical model using regression technique to minimise the residuals in draw-down in the observation wells. The fitted drawdown curve corresponded well to that observed. The determined parameters were then used in a numerical model to test the influence of well screen location and density distribution on the calculated draw-down values. A two-dimensional mesh corresponding to a 4.8 km wide and 45 m deep rock was generated. The numerical codes used were SUTRA and ROCKFLOW. Calculations were performed both for constant density of the water and for density dependent flow, i.e an increased density with depth. The boundary conditions in the pumped well was either constant withdrawal along the whole well or constant withdrawal only at the well screen. No large differences in drawdown could be seen between the different calculations except for a small influence of the well screen location at early times. Consequently, the influence of density dependent flow is less than the influence of the well screen location. It was also concluded that other types of experiments have to be created to allow for validation of density dependent flow.

The Project Team from GRS presented some results from two-dimensional calculations of the groundwater flow in the Gorleben Channel. They used the finite element code NAMMU5C, which includes an extension for transient saline flow. The boundary conditions were, no-flow at the bottom and fixed head on the sides and at the top. The first calculations were carried out for freshwater and the groundwater velocity in the lower aquifer was calculated to be around 1 m/yr, whereas the velocity in the upper part of the aquifer was some orders of magnitude higher. The future plans are to reconsider the selected boundary conditions before brine transport is introduced in the two dimensional model. A three dimensional model of the channel will then be built and used for freshwater simulations before introducing brine transport also in this model.

WIPP 1

Brine flow through bedded evaporities at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository lying 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado

formation. This test case is based on experiments performed with the aim to determine the rate of brine flow through the Salado formation. The experiments are designed to provide a variety of data with the aim to determine whether Darcy's law for a porous, elastic medium correctly describes the flow of brine through evaporities, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Data from three types of experiments form the bases for this test case:

- small scale brine-inflow experiments
- pore pressure and permeability testings
- integrated, large scale experiment.

Brine inflow rates are measured at three scales, in 10 cm and 1 m diameter boreholes and in a 2.9 m diameter cylindrical room. Pore-pressure measurements are made in 10 cm diameter boreholes, 2 to 27 m long, drilled at a variety of orientations. The large scale experiments are brine inflow rates to a horizontal, 107 m long, cylindrical room, with a diameter of 2.9 m.

Analyses by the Project Teams

The Pilot Group (SNL/WIPP) has modelled the hydraulic testing in the test zone including the anhydrite Marker Bed 138, a 17 cm thick zone containing subhorizontal fractures. The test zone is about 11 m above the ceiling of Room 7. The performed test sequence included an initial pressure build-up period, two pulse withdrawal tests, a 10-day constant pressure flow test and a final pressure build-up period. Pulse tests cannot uniquely quantify permeability independently of specific storage, but provide a good estimate of initial pore pressure. Constant pressure flow tests provide estimates of permeability and are required to quantify specific storage. Pressure build-up tests can quantify permeability independently of specific storage, they provide a good estimate of initial pore-pressure, and also a check on measured test zone compressibilities. An analytical and a numerical interpretation of the pulse withdrawal tests gave similar results. The permeability was determined to be $2.9 \cdot 10^{-19}$ m^2. The test zone compressibility determined from the simulations is a factor 2 lower than the measured value. This parameter affects the simulations most at early times when compliance effects are occurring. The analytical and numerical interpretation of the permeability from the constant pressure flow test differs with a factor of 3 ($1 \cdot 10^{-19}$ m^2 with the analytical model and $2.9 \cdot 10^{-19}$ m^2 with the numerical model). The observed high flow rates over the first days could not be matched by any of the two models. These flow rates are probably artificially high because of tool compliance and borehole squeeze.

The interpretation of the pressure-buildup tests gave the same estimate of the permeability ($2.9 \cdot 10^{-19}$ m^2) both with the analytical and the numerical method. Both methods also showed a high test-zone compressibility. The integration of analytical and numerical interpretation techniques of different types of test provides a high degree of confidence in the interpreted results.

MOL

Migration experiment in Boom Clay Formation at the MOL Site, Belgium.

Experimental set-up

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The purpose of the experiment is to determine migration related parameters and to confirm parameters determined earlier in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

A group of piezometers, a piezometernest, has been installed in the Boom Clay formation at a depth of 220 m. The stainless steel system contains nine piezometers, interspaced by 0.9 m long tubes. A horizontal hole with a diameter of 50 mm and a depth of 10 m has been drilled in the clay formation. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. The steady-state pressure distribution as a function of the depth into the clay is measured by means of manometers.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 (in the center) and thereafter the system was left alone allowing migration of HTO in three dimensions.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters. The first breakthrough was obtained in filters 4 and 6 located adjacent to the injection filter 5, at a distance of 1 m.

The experiment will continue 10 years after finalisation of INTRAVAL Phase 2 and the number of measured points are limited at the time being.

Analyses by the Project Teams

The Pilot Group (SCK/CEN) presented their modelling of the migration of the HTO tracer. The Boom clay was modelled as a homogeneous anisotropic saturated porous medium. The governing transport mechanisms considered were either advection–diffusion or diffusion only, as one question is whether advective transport is apparent from the existing data. One important parameter in the modelling is the porosity accessible for diffusion which was set to 0.34 to get the best fits of the two models. Concerning other parameters, the best fit of the diffusion only model was obtained with a diffusivity of $4.05 \cdot 10^{-10}$ m^2/s, and an almost identical value $4.03 \cdot 10^{-10}$ m^2/s, was obtained for the advection–diffusion model. Other fitted parameters were also identical or almost identical and it was concluded that advective transport is not apparent from this analysis of existing data.

The Project Team from SNL/USNRC presented an initial analysis of the effect of anion exclusion on transport in the Boom clay at Mol. The concern was enhanced transport velocities or flux due to this phenomena and as pure Darcy flow behaviour is usually assumed as the governing transport mechanism, the anion exclusion represents a conceptual model uncertainty. Their anion exclusion model has not yet been applied to the data, since more information concerning ionic strengths, zeta potential and pore size distribution are needed.

ALLIGATOR RIVERS

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

Experimental Set-up

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator Rivers Region is located about 200 km east of Darwin.

Uranium mineralisation occurs at Koongarra in two distinct but related ore bodies, which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium minerals are present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m. The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

An extensive experimental programme including both field and laboratory investigations has resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs from 140 precussion holes and 107 drill cores. Groundwater chemical data has been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The distribution of uranium and thorium between different mineral phases in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from drill cores. In addition, distribution coefficients have been measured on natural particles in Koongarra groundwaters.

Analyses by the Project Teams

The Project Team from CSIRO/ANSTO gave a short summary of the ARAP Hydrology workshop held in October 1991. The discussions at this workshop resulted in consensus on a number of important issues. Firstly, there is general agreement that most of the horizontal groundwater flow occurs at or below the bottom of the weathered zone and that the system can be viewed as a confined aquifer with essentially horizontal flow below the base of weathering. Secondly, there is little evidence for significant flow across the Koongarra Fault. Thirdly, there appears to be a highly conductive zone to the southeast (mine

grid) of the No. 1 ore body. Fourthly, it appears that directions of flow are influenced by the orientation of planes of schistosity, or by fractures sub-parallel to these planes. Fifthly, there is evidence from standing water level measurements that the gradient in hydraulic head sometimes reverses towards the fault near the ore body.

The Project Team from CSIRO/ANSTO also gave a presentation of their new groundwater flow modelling attempts, in which most of the above described features are taken into account. They used the finite element groundwater flow model AQUIFEM-N to model a two-dimensional aquifer 1 km×3 km located near or below the transition zone. The model domain is bounded by the Koongarra Fault to the west (mine grid), the Koongarra Creek to the east, the Nourlangie gauging station and a small non-perennial creek to the south and a small non-perennial creek to the north of the No.2 ore body. Koongarra Fault is assumed to act as a non-flow boundary. Koongarra Creek and most of the other creeks are assumed to act as mixed boundaries. At a mixed boundary neither the head at the boundary nor the flux across the boundary is prescribed, but a relationship between the two. The model parameters required are (i) either the hydraulic conductivity and aquifer thickness or the aquifer transmissivity, (ii) the aquifer storage coefficient, and (iii) time averaged recharge of the land surface. The aquifer is assumed to be homogeneous but not isotropic. The time averaged recharge of the land-surface varies sinusoidally in time. In the base case calculation the hydraulic conductivity ratio in the modelled aquifer is 10 (K_{11}/K_{22}, $K_{11} = 1$ md^{-1}) and the anisotropy orientation varies almost continuously throughout the region. Each simulation was performed for a two-year period to allow the effects of initial transient effects to dimininish. During the wet season the calculated flow patterns are intuitively reasonable with flows oriented to the southeast (mine grid), the calculated velocity is 1-2 m/yr. The overall flow orientation of the dry season is not entirely pleasing and the flow rates are very low.

The Project Team from CRIEPI investigated the distribution of fractures and the attitude of schistosity in the Cahill Formation in and around the western part of the No. 1 ore body using a Borehole TV. The obtained schistosity attitudes clearly explains the contour maps of the measured drawdowns in aquifer tests, which showed an asymmetric pattern. Schistosity in fractured rocks could be considered as a main factor for the hydraulic anisotropy, and the permeability in the direction parallel to the schistosity plane is generally larger than in the direction normal to the plane. The team also made three-dimensional simulations of the present groundwater flow during the rainy season around the No. 1 ore body. They used the finite element code GMF for a mesh corresponding to an area 700 m×400 m large with a depth of 200 m (from the ground surface). The modelled hydrogeologic unit was divided into three units, the weathered zone, the transitional zone, and the unweathered zone. Only the unweathered zone was assumed to be hydraulically anisotropic with respect to permeability, while the other two zones were assumed to be isotropic. For the unweathered zone a hydraulic tensor for each element was determined. The lower boundary and the boundary corresponding to the Koongarra Fault were given as no flow boundaries, the upper boundary was given as a constant head boundary (groundwater level was assumed to be at the ground surface), the other boundaries were given as constant heads. The choosen hydraulic conductivity for the weathered zone was $5 \cdot 10^{-4}$ m/d, for the transition zone $1 \cdot 10^{-2}$ m/d, and for the unweathered zone $6 \cdot 10^{-1}$ m/d. The calculated flow is from the northeast in the southwestern part of the No. 1 ore body and in the region to the south of the ore body, while the flow is from the north in the region to the northeast of the ore body. The flow velocities are extremely small in the region to the westsouthwest of the ore body.

The Pilot Group (ANSTO) gave a presentation about the approaches and finding in the transport modelling performed for the natural analogue. The major aims with the transport modelling performed has been to

- determine the extent of uranium transfer,
- assign the time scale,
- identify and classify transport and retardation processes, and
- determine the relevance of using the Koongarra analogue for the purpose of the assessment of a specific repository site.

The Koongarra ore body is located rather shallow, and has direct interaction with rain, climate effects, weathering and erosion. There are two different time scales, one very long as the climate has changed between desert and tropical during the years, and the present time scale with its seasonal variations between a very wet and a very dry climate. The modelling work performed includes many different processes, such as one dimensional advection and molecular diffusion. Matrix dif-

fusion has not been considered. The K_d-concept has been adopted for sorption as well as surface sorption. Other processes looked at are secondary mineralisation, accessible and inaccessible mineral phases, nuclear recoil, and the occurrence of colloids. It has been found that transport with colloids are of minor importance although thorium and actinium have been observed on colloids. The time scale for development of the secondary uranium dispersion fan has been estimated to 1-2.5 Myr with a number of different models. It has also been concluded that during a time scale of about 0.5 Myr, 40% of the uranium in the weathered zone has moved 150 m, 20% moved 350 m and the remaining 40 % has not moved. The mobility of uranium is minimal in the unweathered zone.

Kemakta/SKI presented some modelling work performed with the aim to test the applicability of simple transport models used in the performance assessment of repositories. The migration of uranium and daughter nuclides in the weathered zone located below the water table of the No. 1 ore body has been simulated with a one dimensional advection-dispersion model with linear sorption (K_d-concept). The rock was assumed to be a saturated homogeneous and porous medium. Material properties (defined by present day conditions), water flux, and source concentration of uranium do not change with time. The codes used for the migration calculations were the finite difference codes TRUMP and TRUCHN, where the latter is an extended version of TRUMP including radionuclide chain decay. Scoping calculations show that a water flux less than 0.01 m/yr is required to match the observed migration distance, and a source concentration of uranium in the water of ~10 mg/l is needed to match the observed concentration of uranium in solid phase, assuming a K_d-value of 0.1 m^3/kg for uranium and a migration time of 2 Myr. To match the observed migration distance and solid uranium concentration, assuming a 100 times higher K_d-value for uranium, requires a water flux between 0.1 and 1 m/yr and a source concentration of uranium in the water of ~0.1 mg/l.

Calculations have also been performed to estimate the activity ratios $^{234}U/^{238}U$ and $^{230}Th/^{234}U$ in solid phase as a function of distance from the source. The calculations were performed both for constant and varying water fluxes over a time period of 2 Myr. The calculations of the activity ratios support the assumption of a migration time of the order of million years. Altering periods of flow and no flow during the last 200 000 years (2 periods with 75 000 years of no flow and 25 000 years of flow) seems to be of importance for the decrease in $^{230}Th/^{234}U$ activity ratio with distance. In addition to these calculations a very simple mass balance calculation has been performed to estimate the water flux needed to dissolve the uranium dispersed in the weathered zone. The mass of uranium in different depth intervals in the weathered zone was estimated from observed data. With a uranium solubility of 1 mg/l and a dissolution time of 1 Myr the water flux was calculated to be of the order of 0.1-0.3 m/yr.

The Project Team from JAERI presented their modelling of the uranium migration, considering the weathering, i.e. alteration of chlorite. Because of the weathering of chlorite, the mineral composition of the rock changes, which results in an increase of distribution coefficients and rock porosities with time. The retardation of the radionuclides increases with time, whereas the groundwater velocity decreases. The model used was a one dimensional advection-dispersion model with time dependent rock porosities and retardation. The water flux in the rock is kept constant and the uranium is released at a constant concentration from the source (the primary ore body) until the end of weathering. The domain modelled was a 300 m long section across the No. 1 ore body (between borehole DDH52 and DDH4). The results from the modelling are the uranium concentration and the $^{230}Th/^{234}U$ ratio in the bulk rock. A number of calculations have been performed, where the Darcy velocity was varied between 0.5 and 10 m/yr, and the dispersion length between 0.5 and 10 m. The simulations represent trends of observed data and it was concluded that the weathering of chlorite is important for the uranium migration. In future work two dimensional simulations are foreseen to be performed.

The Pilot Group (ANSTO) presented their work on the development of sorption models. The goal has been to develop a mechanistic description of U(VI) adsorption on typical minerals present in the weathered zone. Experiments indicate the presence of multiple types of sorption sites, some which are strong and some which are weak. A simple surface complexation model has been used to simulate the experimental results from batch experiments of the sorption on ferrihydrite of U(VI) at different concentrations as a function of pH. The concentration of strong and weak sorption sites was varied until good fits were obtained. It was concluded that this simple surface complexation model, involving two site types and one major

surface species, satisfactorily describes U(VI) adsorption to ferrihydrite and quartz over a wide range of solution conditions.

The Project Team from USNRC presented their modelling of the chemical evolution of the present-day groundwaters. Aqueous speciation, saturation state and chemical mass transfer calculations were carried out using the codes EQ3NR and EQ6. The magnesium and aluminium contents of the soil and weathered rocks support the division of the site into different depth zones dependent on the degree of weathering. Close to the surface the schist is weathered which is reflected by a low Mg content and a high Al content. The transition at larger depths to unweathered rock is correlated with an increase in Mg content and a decrease in Al content of the bulk rock. This weathering profile is also supported by trends in the water chemistry, such as a sharp increase in pH in the top 25 m, followed by a more gradually increase with greater depths, and an overall trend of increasing Mg and HCO_3 concentration with depth. Speciation and state of saturation calculations suggest that the waters are part of a continuous spectrum of reaction progress extending from acidic relatively unreacted waters to slightly basic water near equilibrium with chlorite and kaolinite. Furthermore, it was concluded that the very strong dependence of all major chemical trends leads to a picture of essentially vertical recharge by rainwater that progressively evolves chemically by reaction with the chlorite schists.

The Project Team from RIVM presented their geochemical modelling work with the aim to study the formation of uranium phosphate in the weathered zone and uranium silicate in the unweathered zone just beneath the weathered zone. They used the codes EQ3NR and EQ6 to carry out observed system reaction paths calculations. The initial water was assumed to have a composition similar to the water sampled in borehole KD1, and the reactant minerals were chlorite, muscowite, quartz, pyrite, graphite, fluorapatite and U_3O_8. The output from the calculations shows that the most abundant uranyl phosphate mineral at Koongarra, saleeite, is formed, but under conditions which do not occur at Koongarra. The database used has, therefore, to be checked and data of relative abundance of minerals have to be included before further calculations will be performed.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Experimental Set-up

Aquifer testing ranging from a large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The groundwater table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

The large experimental programme includes 20-40- and 260-metres natural gradient tracer (^{131}I and HTO) experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation and gamma scanning is performed through the full aquifer.

The database contribute hydrogeologic data (stratigraphic information, hydraulic conductivity, porosity, groundwater flow velocity), tracer concentrations etc.

Analyses by the Project Teams

The Project Team from SNL/USNRC discussed the validation aspects for the Twin Lake study and presented data analysis of the tracer tests. The task for SNL as a contractor for USNRC is to develop both a validation strategy to address process model validation as well as site-specific model validation. The use of Twin Lake data could provide insight into the site-specific model validation process, specifically to determine the conservativeness of analyses relative to different models, different assumptions about existing data and the existence of data as well as the treatment of uncertainty. In the analyses of the Twin Lake data base the Project Team has applied a one dimensional advection-dispersion model. The input parameters are hydraulic conductivity, porosity, dispersivity, and

hydraulic gradient. The dispersivity has been assumed to have an uniform distribution and is set to 10% of the travel distance. The hydraulic conductivity is evaluated from different tests, such as single well response tests, grain size analysis, and permeameter tests and is assumed to have a log-normal distribution. The gradient is determined from groundwater table levels and bedrock levels. The porosity which is assumed to have a normal distribution is evaluated from gravimetric analyses on core samples.

The analyses showed that the probability of obtaining a concentration larger than the maximum concentration steeply decreases at a certain value of the maximum concentration, but that this value of the maximum concentration always was larger than the measured maximum concentration (Figure 4). Furthermore, the calculated maximum concentration was insensitive to the choice of hydraulic conductivity. The probability of calculating a time at which the maximum concentration occurs which is larger than the corresponding time observed in the experiment changed from about 0.2 to about 0.85 depending on the characteristics of the log-normal distribution of hydraulic conductivity. Based on the results it was concluded that there is a very low probability of accepting a 'bad' site, but a high probability of rejecting a 'good' site based on the uses of conservative models combined with complete ranges of data.

The Pilot Group (AECL) informed about a new technique and methodology for characterisation of geologic heterogeneities. High energy emitting tracers are used to detect inhomogeneities and the dispersivity characteristics of a geologic structure. A gamma radiation detector which detects tracers within a circle with a radius of 0.1 m are used to get a vertical activity profile of the tracers. A local-scale dispersion model was used to simulate tracer tests, and it was concluded that this model is of universal nature and applicable to solving one-, two-, and three-dimensional problems. Furthermore, it was concluded that the most reliable approach to account for local heterogeneities is to measure velocities rather than conductivities.

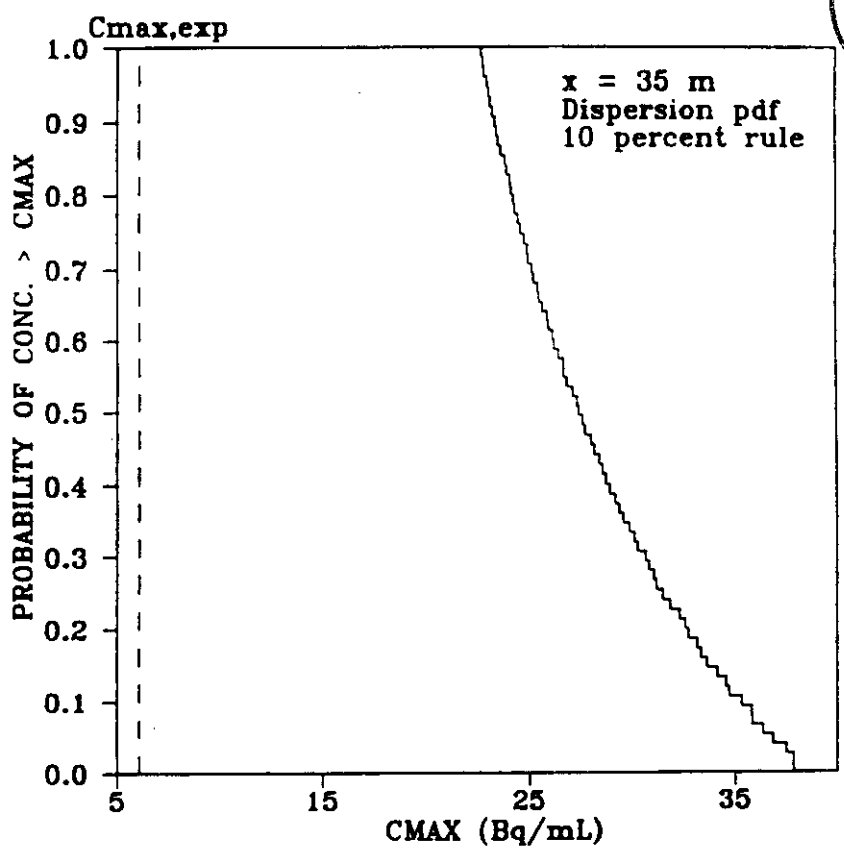

Figure 4. Probability of obtaining a modelled concentration larger than the measured maximum concentration.

Distribution of Background Information and Databases

Background information and databases are distributed to the INTRAVAL Participants either by the Secretariat or directly from the Pilot Groups according to Table 4. The information is distributed only on request from the Project Teams.

Table 4. Distribution of background information and databases.

Test Case	Distributor
Las Cruces Trench	Pilot Group, T. Nicholson, NRC[1)]
Apache Leap	Pilot Group, T. Nicholson, NRC[1)] and T. Rasmussen, UAZ[1)]
WIPP 2	Pilot Group, E. Gorham, SNL[1)]
Finnsjön	Secretariat[2)]
Stripa	Secretariat[2)]
Gorleben	Pilot Group, K. Schelkes, BGR[1)]
WIPP 1	Secretariat[2)]
Mol	Secretariat[2)]
Alligator Rivers	Pilot Group, P. Duerden, ANSTO[1)]
Twin Lake	Secretariat[2)]

1) Full organisation name, see List of Intraval Participants in Appendix 1

2) Kemakta Consultants Co., P.O. Box 12655, S-112 93 Stockholm, SWEDEN

The overall objectives of Phase 2 are similar to those of Phase 1, i.e. to increase the understanding of how various geophysical, geohydrological and geochemical phenomena of importance for radionuclide transport from a repository to the biosphere can be described by mathematical models developed for this purpose and to study the model validation process.

The organisation of INTRAVAL Phase 2 is similar to Phase 1. The study is directed by a Coordination Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Parties organise Project Teams for the actual project work. A Pilot Group has been appointed for each test case in order to secure the information transfer from the experimentalists to the Project Secretariat and Project Teams. At suitable intervals, about once a year, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group.

Appendix 1

INTRAVAL Organisation

The organisation of the INTRAVAL study is regulated by an agreement which has been signed by all participating organisations (Parties). The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Managing Participant sets up a Project Secretariat in cooperation with Her Majesty's Inspectorate of Pollution (HMIP/DoE), U.K. and the Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA). KEMAKTA Consultants Co. is contracted by SKI to act as Principal Investigator within the Project Secretariat.

The Parties organise Project Teams for the actual project work. Each Party covers the costs for its participation in the study and is responsible for the funding of its Project Team or Teams, including computer cost, travelling expenses, etc.

A Pilot Group has been appointed for each Test Case in order to secure the necessary information transfer from the experimental work to the Project Secretariat and the Project Teams. The Project Secretariat coordinates this information transfer.

At suitable time intervals, depending upon the progress of the study, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group. During the workshops, Test Case definitions and achieved results are discussed as a preparation for decisions in the Coordinating Group.

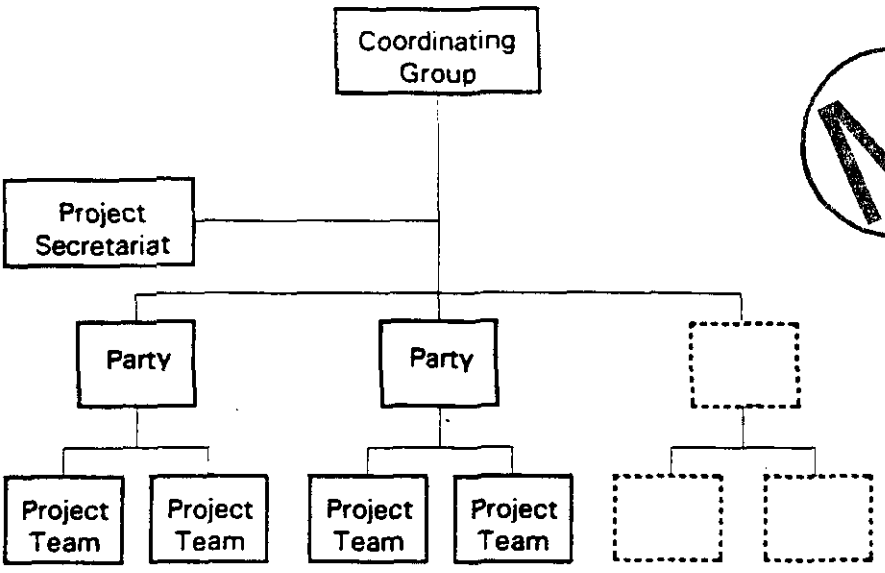

Figure 5. INTRAVAL Organisational Chart.

Managing Participant:	SKI
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Vice Chairman	T. Nicholson, U.S. NRC
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	B. Dverstorp, SKI
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International Atomic Energy Agency S. Hossain (observer)	(IAEA)		
Environmental Evaluation Group, United States of America L. Chaturvedi (observer)	(EEG)		
State of Nevada L. Lehman (observer)			

Appendix 2

Intraval Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media performed at Las Cruces, New Mexico, USA.

Overview

This test case is based on experiments performed at the New Mexico State University College Ranch, 40 km northeast of Las Cruces, New Mexico, U.S.A. Water and tracers were applied at a carefully controlled rate to the surface of an experimental plot. The motion of water and the transport of various tracers through the unsaturated vadose zone was monitored. This test case was also included in INTRAVAL Phase 1. During Phase 1 data for site characterisation and model calibration were collected. In phase 2 the models calibrated during Phase 1 will be used to predict water flow and solute transport in a new experiment (Plot 2b).

Experimental Design

A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4 × 9 m and 1 × 12 m respectively are adjacent to the trench (Figure 6). In the first experiment (Plot 1) water containing tritium was applied at a controlled rate of 1.8 cm/day on the area sized 4 × 9 m. The movement of water below the soil surface was monitored with neutron probes and tensiometers. Soil solution samples were taken to determine the movement of tracers below the surface of the soil. The movement of the water front was also observed visually on the trench wall. In the second experiment (Plot 2a) water containing tritium and bromide was applied at a rate of 0.43 cm/day on the area sized 1 × 12 m. These two experiments were used during INTRAVAL Phase 1. In the third experiment (Plot 2b) tritium, bromide, boron, chromium and the organic compounds pentafluorobenzoic acid (PFBA) and 2,6-difluorobenzoic acid (DFBA) were added with the water on the area sized 1 × 12 m.

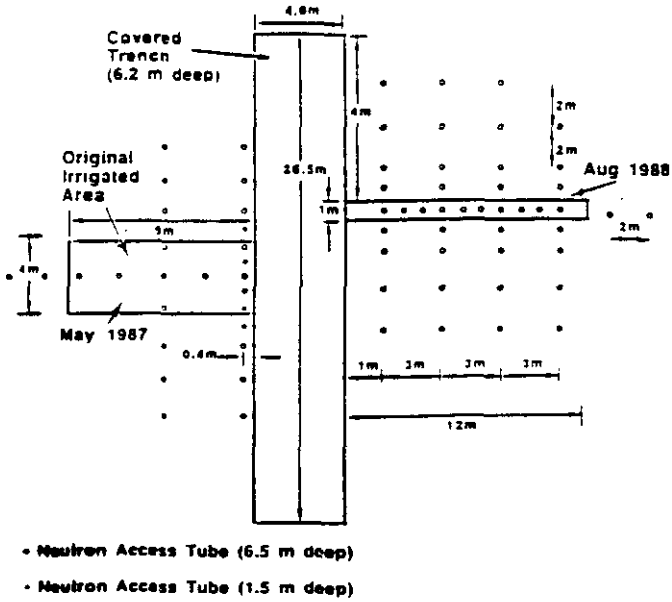

Figure 6. Top view of the trench with irrigated areas.

Available data

- water retention data
- density profiles
- particle-size analysis data
- saturated hydraulic conductivities (laboratory and in situ)
- water content
- tensiometer data
- solute concentration

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Overview

The Apache Leap Tuff Site in tuffaceous rock is situated near Superior, Arizona, USA (Figure 7). The tuff formation is approximately 600 m thick and grades from a densely welded unit near its base to a slightly welded tuff which has a total porosity of 17%. The unsaturated zone extends to great depths due to topography and to pumping associated with a nearby underground mine. The Apache Leap Test Case in INTRAVAL Phase 2 concentrates mainly on two topics, how a thermal source dramatically affect air, vapour, water and solute movement in geologic media, in particular unsaturated fractured rock , and to investigate the water and air transport properites of fractures and rock matrix of unsaturated rock.

The effects of a thermal source are studied wit laboratory nonisothermal core measurements, whereas the behaviour of fractures and other macropores are investigated in a series of laboratory measurements conducted on a block of Apache Leap Tuff having a single discrete fracture. In addition to these laboratory experiments there are plans to perform field investigations that will provide multiscale estimates of permeability at Apache Leap Site, information regarding mechanisms affecting the flow of fluids in fractured rock, and data for validation of flow models. The field experiment programme outline contributes to the characterisation of permeability distribution of a selected portion of the site using single-borehole pneumatic tests, pneumatic cross-borehole tests, gas tracer tests, and hydraulic tests. Most of the data from the planned field experiments cannot be expected until after the end of INTRAVAL Phase 2.

Laboratory Nonisothermal Core Measurements

A cylindrically shaped core approximately 12 cm long and 10 cm in diameter was extracted from a block of Apache Leap Tuff (white unit). The large core, termed the 'mother' core, is used for the experiment, while smaller, 'daughter' cores were also extracted from the block for characterisation purposes. The mother core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses on all surfaces, and to minimise heat loss along the sides of the core.

During the experiment, a horizontal temperature gradient was established along the long axis of the core. Thirteen thermistors were situated along the core at approximately 1 cm intervals to record temperature over time (about twice weekly). A dual-gamma source was used to determine the water and solute content along the core over time.

The daughter cores were used to provide characterization data regarding porosity, moisture characteristic curves (including hysterisis effects), saturated and unsaturated hydraulic conductivity, and saturated and unsaturated air permeabilities. Similar data from 105 core segments at the Apache Leap Tuff Borehole Site were also available.

The simulation objective is to reproduce the core water content and solute concentration profiles using characterisation data and observed temperatures. The simulation output will consist of mean water contents and solute concentrations along 1 cm slices at 0.5 cm increments along the length of the core for selected times. The output will also consist of predicted temperatures at 1 cm intervals. The temperature measurement should be considered a point measurement.

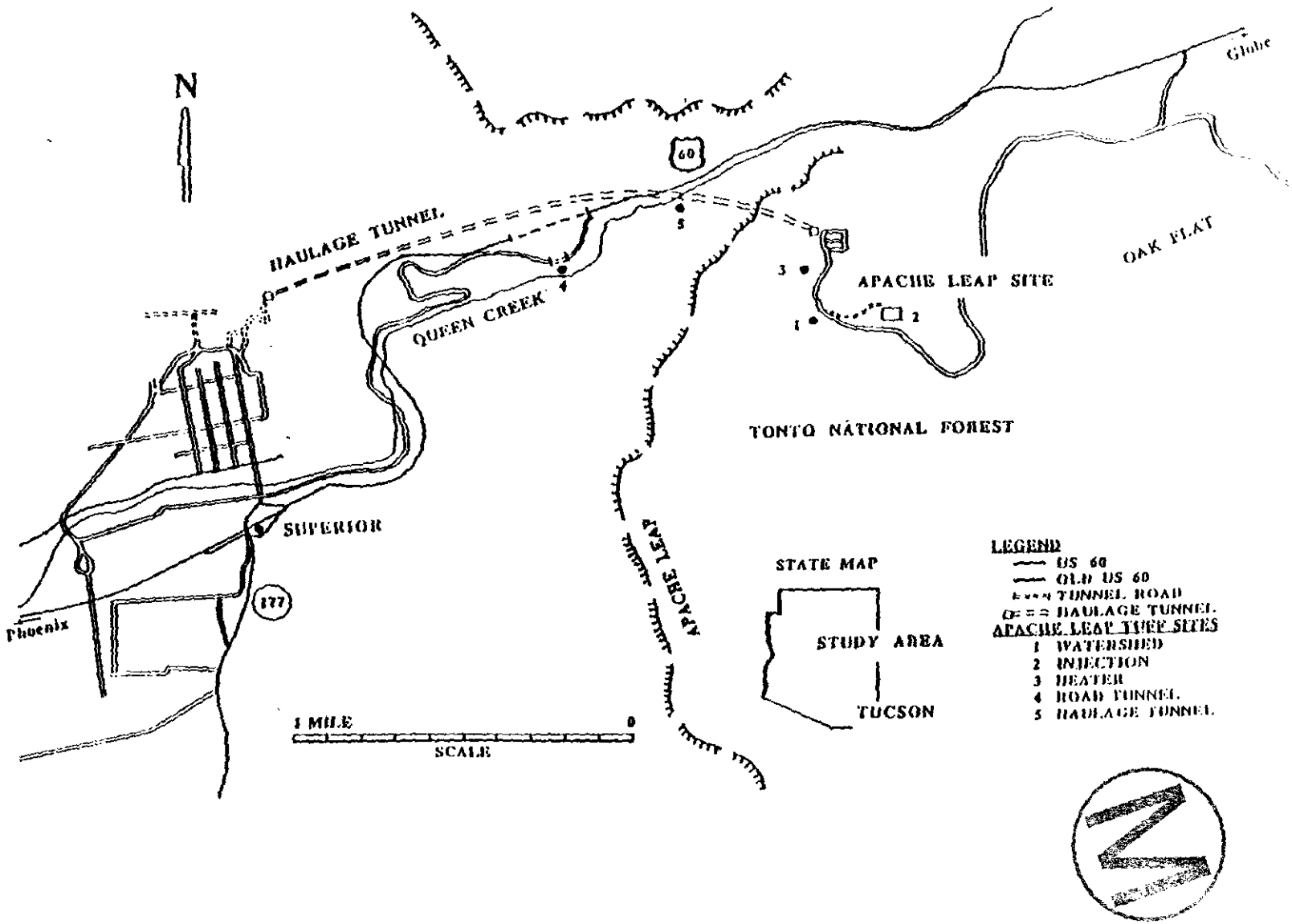

Figure 7. Location of testing facilities at Apache Leap Tuff site.

Laboratory Isothermal Fractured Block Measurements

A block of Apache Leap Tuff (white unit) measuring 92.5 cm in length, 21.0 cm in height and 20.2 cm in width contains a fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent (~150 MPa). The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The positions of the wetting front in the fracture over time and the positions of the wetting front in the matrix over time were recorded.

The simulation objective of this problem is to reproduce the movement of a wetting front of water in a fractured, unsaturated rock using characterisation data and observed fracture inflow volumes over time. The simulation output should be wetting front positions in the fracture and rock matrix over time. Observed characterisation data can be used to calibrate the model, together with inflow data collected during the experiment.

Available data

Core Measurements

- rock matrix porosities
- initial water contents
- temperatures

A set of data collected prior to the heater experiment may also be useful for calibration purposes. Before the thermal experiments were conducted, the circumference of the mother core was sealed, while the two ends were left open. The core was fully saturated and then one end ot the core was placed on a pressure plate and a 5 bar (500 kPa) pressure was applied. The total weight of the core was measured on various dates, and used to develop a time series of core saturations. Additional data are also available from tests performed on daughter cores collected near the core used in the nonisothermal experiment.

Block Measurements

- rock matrix sorptivity coefficient
- rock matrix porosity
- rock fracture aperture
- cumulative inflow volume over time

Data from the Apache Leap Tuff Borehole Site related to rock matrix physical and hydraulic properties, including porosity, bulk density, rock matrix moisture characteristic curves and unsaturated hydraulic conductivity, are also available.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

Overview

The Finnsjön research area is located approximately 130 km north of Stockholm and 15 km from the Baltic sea. The bed rock within the site is crystalline rock of Svecokarelian age (about 1800 - 2100 Ma). The experiments have been performed in a major low angle fracture zone, Zone 2, located in the Brändan area (1 km^2), a sub-area within the Finnsjön research area. The Finnsjön tracer experiments are part of the Fracture Zone Project, initiated and supported by the Swedish Nuclear Fuel and Waste Management Company (SKB).

The project involves detailed characterisation of Zone 2, including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole test. The interference test and the radially converging test were used in modelling during INTRAVAL Phase 1. During INTRAVAL Phase 2 the modelling of this test case will continue to include also the dipole experiment.

Experimental Design

Zone 2 is penetrated by six diamond core drilled boreholes and three precussion drilled boreholes (Figure 8) at depths ranging between 100–350 m.

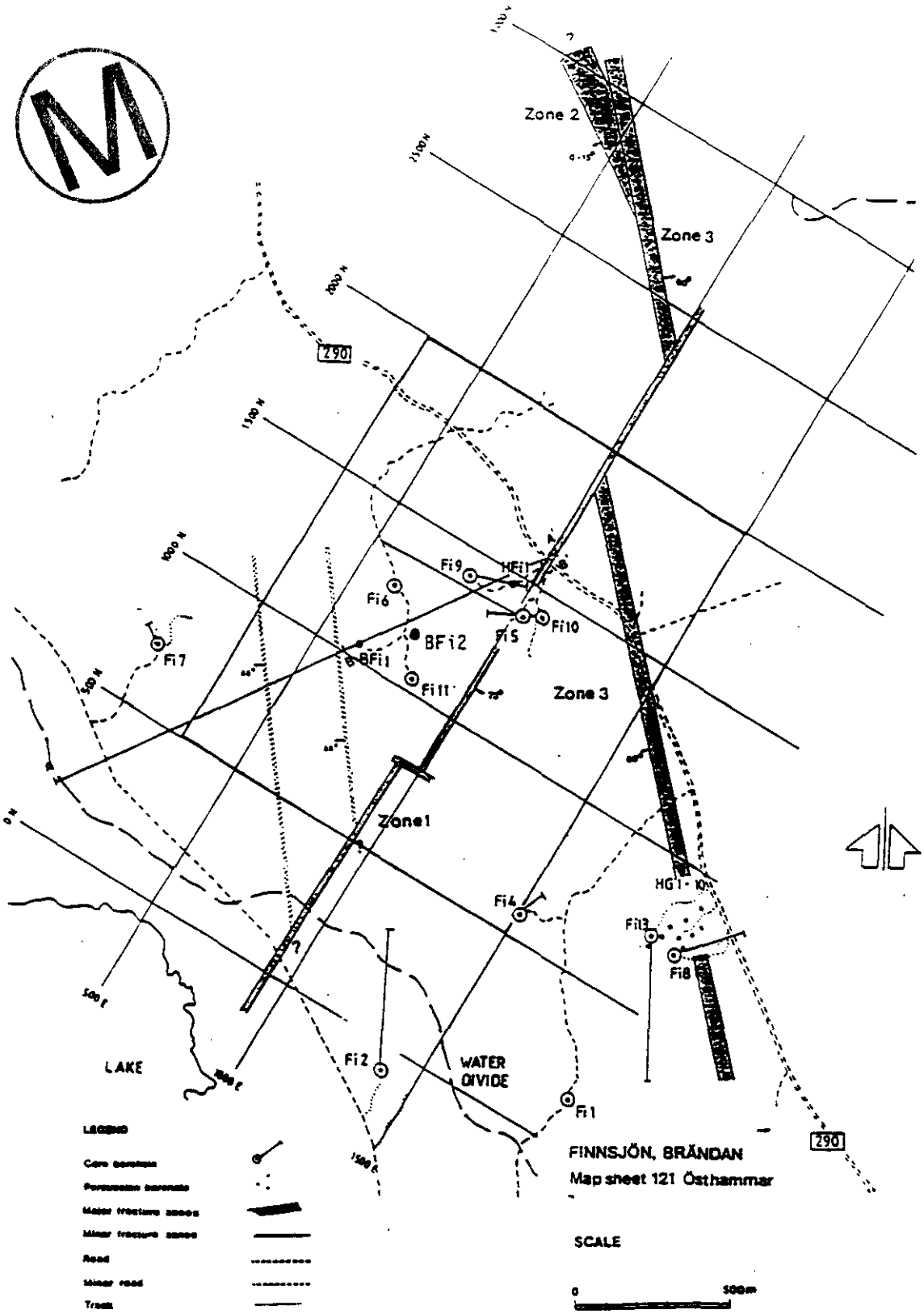

Figure 8. Borehole location in the Brändan area.

Two tracer experiments were carried out, one in a radially converging flow geometry and one in a dipole flow geometry. In the radially converging experiment, tracer injections were made in three peripheral boreholes situated in different directions from a withdrawal hole. The distance from the injection holes to the withdrawal hole is in the order of 150 to 190 m. Three sections were packed off in each injection hole, one in the upper highly conductive part of Zone 2, one at the lower boundary, and one at the most highly conductive part in between. Non-sorbing tracers were injected in nine different intervals of the zone. Totally eleven different tracers were injected, eight of them continuously for 5–7 weeks and three as pulses. First arrivals in the withdrawal hole ranged from 22 to 3500 hours.

The dipole experiment was performed after the radially converging experiment using the same hole for withdrawal and one of the other holes for injection. The two other holes used for injection in the radially converging test were used as observation holes in the dipole experiment. Only the upper highly conductive part of Zone 2 was used for tracer injection in this experiment. Totally 15 injections of tracers were made during 7 weeks. Pulse injection of both sorbing and nonsorbing tracers were made. The water pumped from the withdrawal hole was recirculated to the injection hole.

Prior to the start of the radially converging test, a series of hydraulic interference tests was performed in order to determine the hydraulic properties of Zone 2. Pressure responses were registered in packed-off sections in all bore holes in the Brändan area during pumping of the hole later used as withdrawal hole in the tracer experiments. In conjunction with the interference test, a preliminary tracer test was performed in order to optimise the design and performance of the planned radially converging tracer experiment.

Available data

Interference Tests

- primary drawdown responses
- graphs of the recovery of groundwater head after pumping stops
- tracer injection information
- tracer breakthrough curves

Radially Converging Experiment

- tracer breakthrough curves
- tracer injection information
- groundwater levels
- relative hydraulic head differences
- temperature and electrical conductivity of pumped water

Dipole Experiment

- tracer breakthrough curves
- tracer injection information
- hydraulic heads and groundwater levels
- temperature, electrical conductivity and redox potential of the pumped water

In addition, geological data are available from a surface survey of the Brändan area as well as from borehole investigations. Hydraulic data are available from hydraulic testings. Data on porosities and diffusivities have been determined in the laboratory.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3D experiment, Sweden.

Introduction

This test case is based on the three dimensional tracer test performed in the Stripa mine in Sweden. This experiment was also part of INTRAVAL Phase 1. In addition to the 3D experiment, data from two other experimental programmes performed in the Stripa mine, the 'Site characterisation and Validation Programme' and the 'Channelling Experiments' are or will be made available during INTRAVAL Phase 2. The experiments were performed within the OECD/NEA International Stripa Project.

In the 3D experiment water and tracers were collected in a number of plastic sheets. The main purpose of the 3D experiment was to investigate the spatial distribution of water flow paths in a larger block of rock.

The 'Site Characterisation and Validation Programme' includes a number of investigation steps to characterise an unexplored rock volume starting

with a few long boreholes and ending with a new drift being excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

The 'Channelling Experiments' comprise information about channelling in individual natural fractures on a length scale of 2 m.

General Description

3D Experiment

A drift has been excavated in the Stripa mine at 360 m below the ground. The drift is 75 m long and has two side arms with a length of 12.5 m each. Three vertical holes for injection of tracers have been drilled upwards with lengths of 70 m (Figure 9).

The ceiling and large parts of the walls in the drift were covered with plastic sheets, each sheet with an area of about 2 m^2. A total number of about 350 sheets served as sampling areas for water emerging into the upper part of the test drift. The sampling arrangements completely covered a surface area of 700 m^2. The spatial distribution of water flow pathways could thus be obtained.

Injections of conservative tracers were carried out from a total number of nine separate sections with increased permeability within the three vertical holes, each zone about 2.5 m in length. The injection zones were located between 10 and 55 m above the test site. The tracers were injected continuously for nearly two years. The injections were carried out with a 'constant' over-pressure, approximately 10–15 % above the natural pressure.

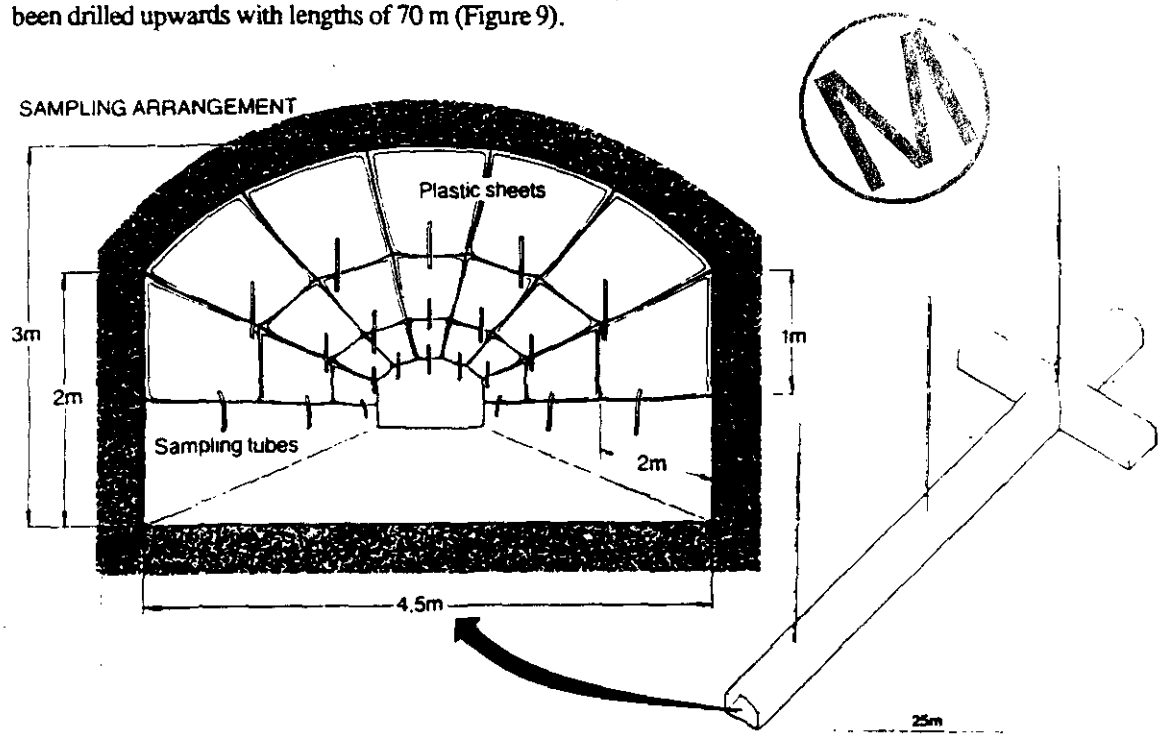

Figure 9. Layout of experimental 3D drift at Stripa and sampling arrangement.

The concentrations of the injected tracers were between 1000 and 2000 ppm and the different flow rates varied from 1 to 20 ml/h. The following tracers were injected: Uranine, Eosin Blueish, Eosin Yellowish, Phloxine B, Rose Bengal, Elbenyl Brilliant Flavine, Duasyn Acid Green, bromide and iodide.

The natural inflow of water to the drift was measured before drilling the injection holes. The results from the water monitoring show that water does not flow uniformly in the rock over the scale considered (700 m^2), but seems to be localised to wet areas with large dry areas in between. Measurable amounts of water emerged into 113 of the 350 sampling areas. Out of these 'wet' sampling areas 10 % gave more than 50 % of the total water inflow.

After six months of injection, tracers from at least five injection zones could be found in about 35 sampling areas. After almost two years of injection, about 200 different tracer breakthrough curves were obtained. Each curve is based on

several hundred individual measurements. Smoothed curves consisting of approximately 40 points are available as computer files.

Site Characterisation and Validation Programme (SCV)

The original aim of the project is to predict groundwater flow and tracer transport in a previously unexplored volume of the Stripa granite. The rock volume selected for detailed characterisation is about 125×125×50 m and is located at 360 to 410 m below ground. The investigations of the rock volume have been performed in a number of steps, including modelling predictions between the different experimental steps. In the first investigation five 150–220 m long boreholes and one 50 m long were drilled. These holes were used to characterise the rock volume by core logging, hydraulic tests (down to 1 m sections), radar and seismics.

Thereafter three new 100–150 m long holes were drilled. Information from these holes were compared with made predictions, based on information from already investigated holes, concerning water bearing sections, fractures etc. Next six 100 m long boreholes, were drilled in the same direction as the new drift would be excavated. The water flow and its distribution were measured in these holes. The holes were also used for a tracer (salt) experiment.

Finally a new drift, 50 m long and 2.4–2.9 m in diameter, was excavated. The new drift was equipped with plastic sheets (1–2 m^2) and other water collection devices. The drift cut through one 5-10 m wide major fracture zone, which gave more than 99% of the total water inflow. Tracer experiments were performed in this fracture zone from seven spots located in four boreholes 10–25 m away from the drift (Figure 10). For this purpose two new boreholes had to be drilled. In each spot two non-sorbing tracers were injected. The tracers were sampled in the plastic sheets and in the other water collecting devices covering the lower parts of the walls and the floor of the drift.

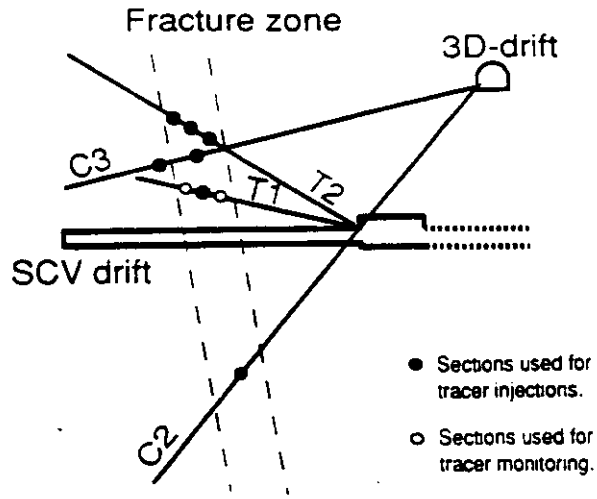

Figure 10. Layout of tracer experiment (SCV).

Channelling Experiment

The channelling experiments consist of three different types of test: the 'single hole experiment', 'the double hole experiment', and the 'tracer test'.

To be able to investigate the fracture characteristics along a fracture plane, a large diameter (200 mm) hole, was drilled along a planar fracture plane to a depth of about 2.5 m. A multi-pede packer (Figure 11) was used to inject water all along the fracture plane.

The injection flow rates were monitored separately for the left and right side of the hole over 80 short sections. The fracture intersections were scrutinised to obtain data on fracture properties such as open fracture area, number of intersections, and thickness of infilling. Before the multi-pede was used, the boreholes were tested with coarser tests. The multi-pede was used in 5 boreholes, whereas in total 12 holes were drilled.

The double hole experiment was performed in a fracture, where the single hole test has shown that channels existed. A second hole was drilled in the same fracture plane at a distance of 1.95 m from the first hole. Prior to the injection of water for detailed pressure tests, more coarse tests were performed. In the detailed pressure pulse tests, water was injected in one of the holes at a section of 50×50 mm and monitored in the other hole in twenty sections along the fracture intersection. This experiment was repeated with the injection sections at different positions. The test was then

reversed, i.e. injection was performed in the second hole and monitoring in the first hole.

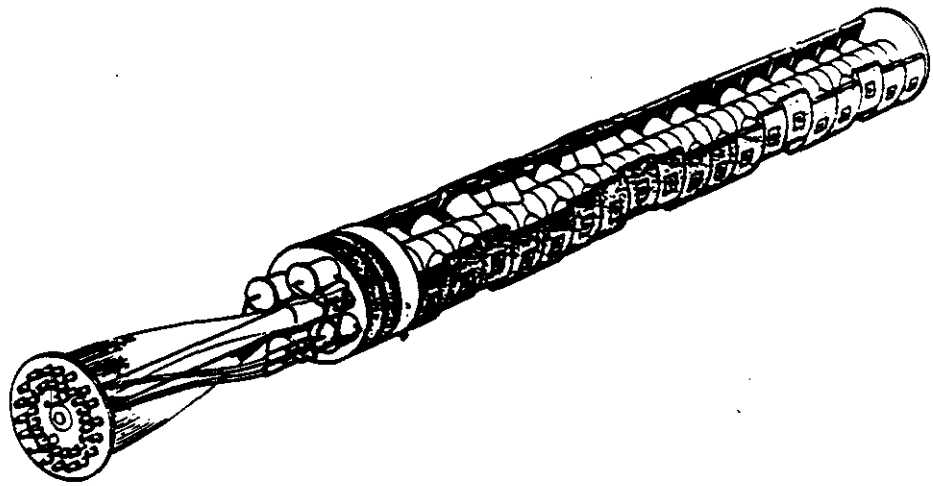

Figure 11. Design of the multiped packer (Channelling Experiment).

In the tracer test five non-sorbing tracers were injected from five 50 mm sections, that had been found to be the most conductive in one borehole, and were monitored in the other hole (see the double hole experiment). To obtain a linear flow for the tracers, water was injected with the same pressure as used for the tracers from the remaining 15 sections. The tracers, Uranine, Eosin Yellowish, Ebenyl Brilliant Flavin, Duasyn Acid Green V and Phloxine B were injected continuously during four weeks.

Summary of Available Data

3D Experiment

- water flow rates
- tracer concentration in water to test site
- rock characteristics and fracture data
- water chemistry
- injection pressures and injection flow rates
- hydrostatic pressures
- diffusivity and sorption data
- daily logs

Site Characterisation and Validation (SCV)

- core logging and fracture mapping in drifts
- geophysical single hole logging
- rock stress measurements
- borehole radar
- borehole seismics
- hydraulic investigations
- hydrochemisty
- water flow rates
- tracer breakthrough curves

Channelling Experiment

- number of fractures
- number of intersections
- information about infilling
- fracture lengths
- opening area of fractures
- pressure response
- tracer breakthrough

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on experiments performed in Culebra Dolomite at the WIPP site. The WIPP, located in Carlsbad, New Mexico, U.S.A., is an underground research and development repository lying 655 m below ground surface within bedded evaporites, primarily halite, of the Salado Formation. Overlying the Salado Formation is the Rustler Formation (Figure 12).

System	Series	Group	Formation	Member
Recent	Recent		Surficial Deposits	
Quarternary	Pleistocene		Mescalero Caliche	
			Gatuna	
Triassic		Dockum	Undivided	
Permian	Ochoian		Dewey Lake Red Beds	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				Unnamed
			Salado	
			Castile	
	Guadalupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

Figure 12. WIPP area stratigraphic column.

The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is a 8 m thick vuggy dolomite layer. The test case will be focussed on the hydrology of this zone. A central issue is the travel time within the Culebra from a location above the repository to the WIPP site boundary.

Description of the Experiments

Extensive investigations of the Culebra Dolomite have been made including detailed investigation of numerous surface features for the purpose of delineating subsurface features of irregularities that could affect flow in and around the Culebra. A transient electromagnetic survey is planned for 1991-92 in order to get a better delineation of a hypothesised fractured region, a high transmissivity zone in the southeast corner of the site.

Sixty wells drilled to the Culebra dolomite at 41 locations provide information on the hydraulic properties (Figure 13). Large variations in transmissivity related to fracturing have been identified.

Test data from three wells in the southeastern part of the site (DOE-1, H-3, H-11) indicate the presence of a zone of relatively high transmissivity within an area of otherwise low transmissivity.

Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed in the vicinity of the above described high transmissivity zone. One pumping test and one tracer test were performed near the center of the WIPP site near what is believed to be the northwestern edge of the high transmissivity zone. The other pumping test and tracer test were performed in the high transmissivity zone near the southern site boundary.

In addition, geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra. These data have been used to demonstrate that the age of the Culebra waters is of the order of 10 000 years, and that the waters originated during a known pluvial period.

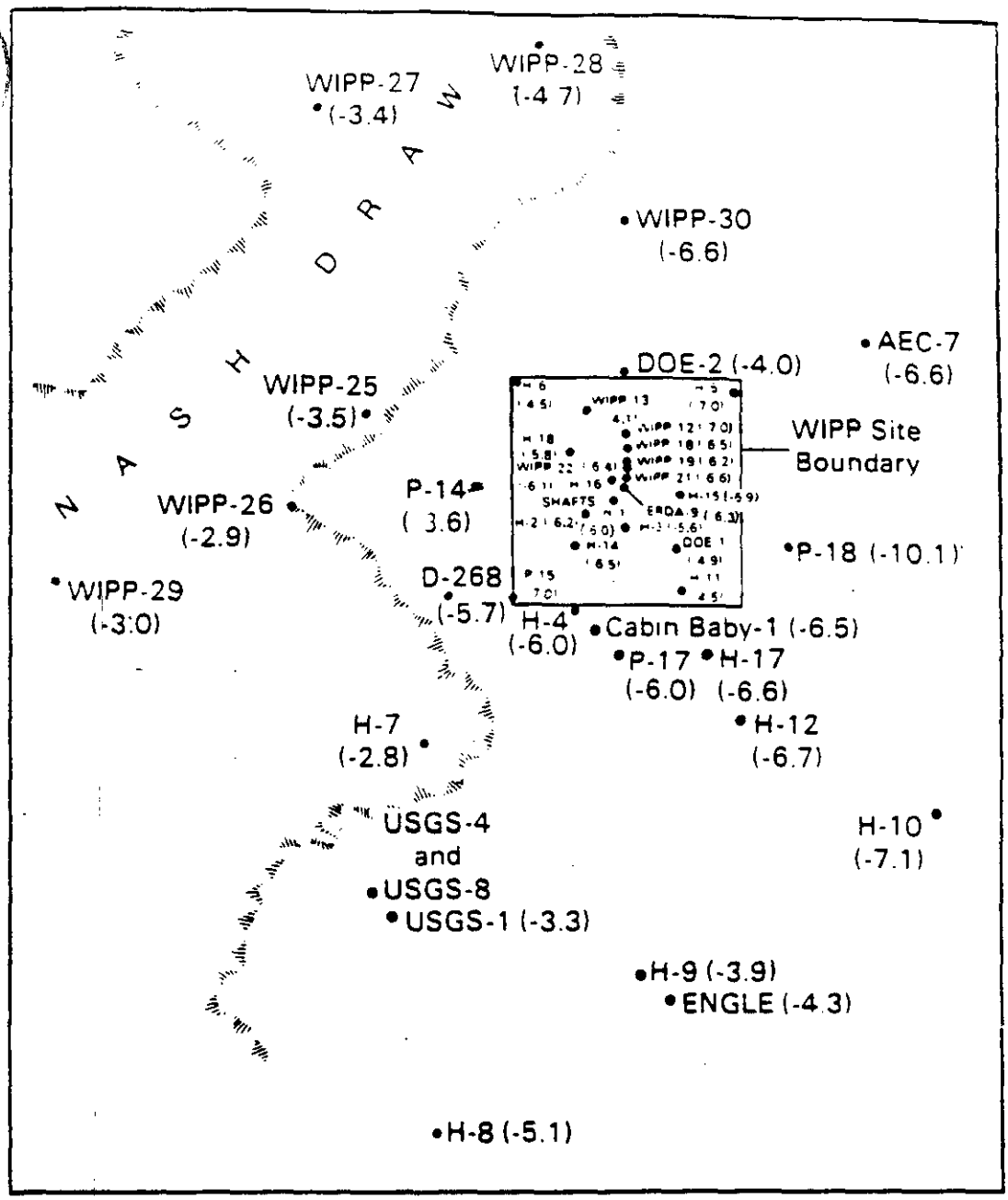

Figure 13. Culebra Wells and measured transmissivity near the WIPP site.

Objectives of the Test Case

A number of different objectives are identified:

- to determine if the hydraulic data support the derived transmissivity distribution and/or the model boundary conditions
- to evaluate the consequences of and the uncertainty in the derived transmissivity
- to determine the resolution in transmissivity needed for long time (10 000 years) predictions of radionuclide travel time
- to calculate the uncertainty in predictions of radionuclear travel time
- to determine if the paleoflow directions inferred from the geochemical/isotropic data could be reproduced using current transmissivity distribution and boundary conditions altered to simulate increased rainfall
- to determine if halite and gypsum dissolution will take place in the next 10 000 years in the Culebra, resulting in an alteration of the transmissivity distribution
- to determine if the hydrologic evidence is sufficient to rule out a significant effect on transport of karst features

Available Data

The data base for this test case is very large and contains:

- UTM coordinates and surveyed elevations for all wells
- core logs and/or geophysical logs from all well locations
- geochemical and isotope data (major ion concentrations, density, etc.) from all well locations
- raw and interpreted hydraulic test data from all well locations
- raw and interpreted tracer test data
- core porosity and permeability data from tracer-test and other locations
- water-level data (hydrographs) from time of well construction to present for all wells
- estimated steady-state hydraulic heads at all well locations
- calibrated steady-state regional groundwater flow model
- calibrated transient regional groundwater-flow model

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Overview

The Gorleben salt dome is located in the northeastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the 'Gorleben Channel', more than 10 km long and 1-2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock (a residue of the dissolution process of salt in groundwater) and in some places down to the salt. In the channel, fairly thick sandy sediments with interbedded lenses of till are overlain by a complex of silt and clay up to 100 m thick. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel is the topic for this test case. The groundwater movements in such an aquifer system depend to a large degree on the salinity, which influences the water density.

Experimental Design

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out: one in fresh water and three in saline water. During these tests information were obtained on boundaries, hydrogeological structure, connections between different aquifers, and hydraulic parameters (permeabilities, storage and leakage coefficients). In one of the pumping tests the pumped well penetrated the entire deeper aquifer in the erosional channel (Figure 14).

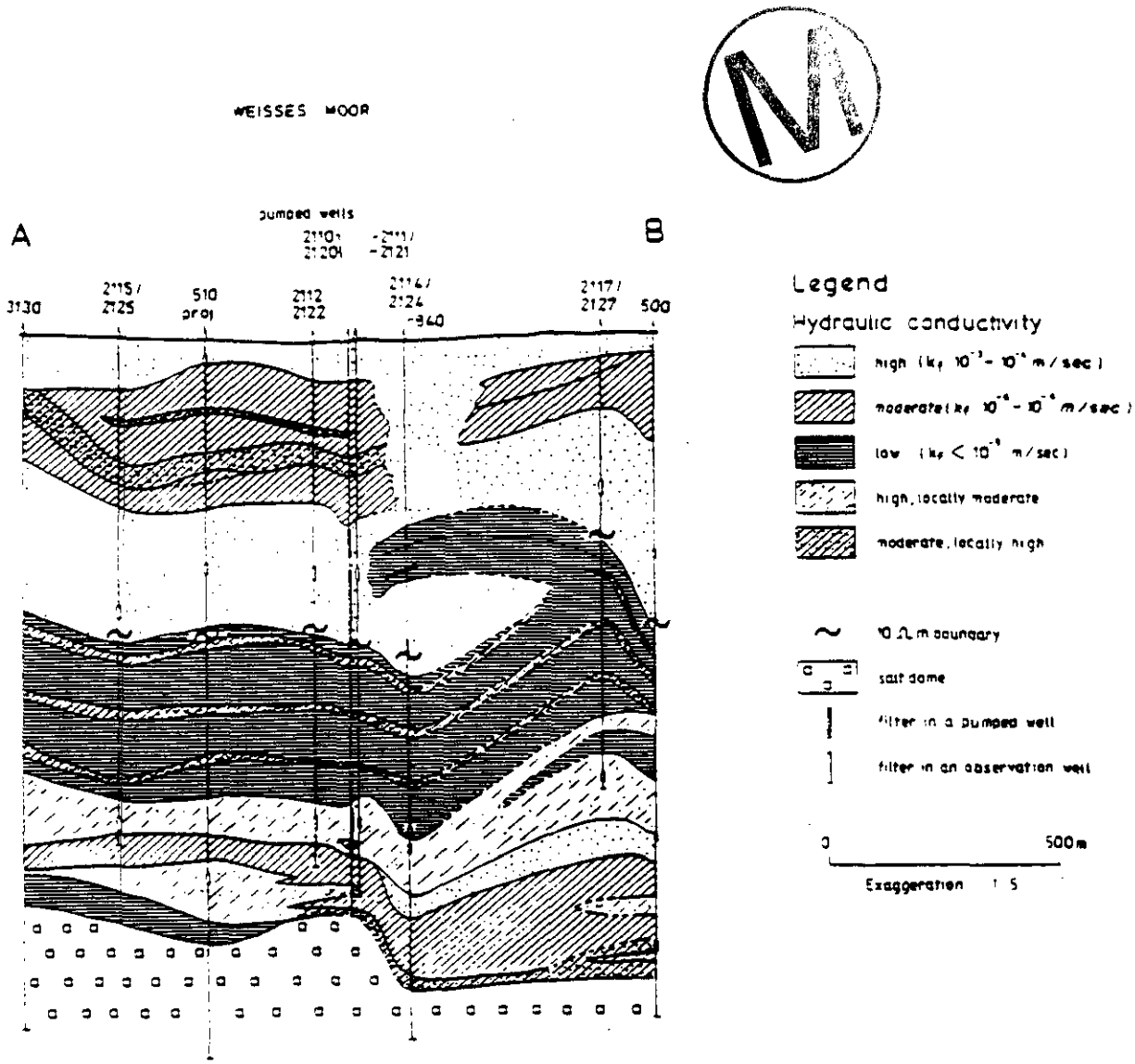

Figure 14. Hydrogeological cross section of the Gorleben salt dome.

The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The density of the water ranges from 1010 to 1200 kg/m^3. This pump test will form the basis for the first part of this INTRAVAL test case. The second part is to model the regional groundwater flow, the salt dissolution and their interaction.

Available Data

The data available from the selected pumping tests are:

- borehole locations (maps)
- hydrogeological data (groundwater levels etc.)
- pumping test data (hydrographs, salinometer logs, pumping rates, electric conductivities, temperatures, densities, etc.)

Large amounts of data are also available from other tests performed in the area.

WIPP 1

Brine flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on one experiments performed with the aim to determine the rate of brine flow through WIPP bedded evaporites. The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository (Figure 15) lying 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation.

Three geologic formations are important to the expected performance of the WIPP: the Salado formation, in which the repository is located; the Rustler formation, which contains an aquifer overlying the Salado formation; and the Castile Formation, which underlies the repository and contains pockets of pressurised brine. The hydraulic behaviour of the Salado Formation is the focus of the present test case. The experiments are designed to provide a variety of data with which to determine whether Darcy's Law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

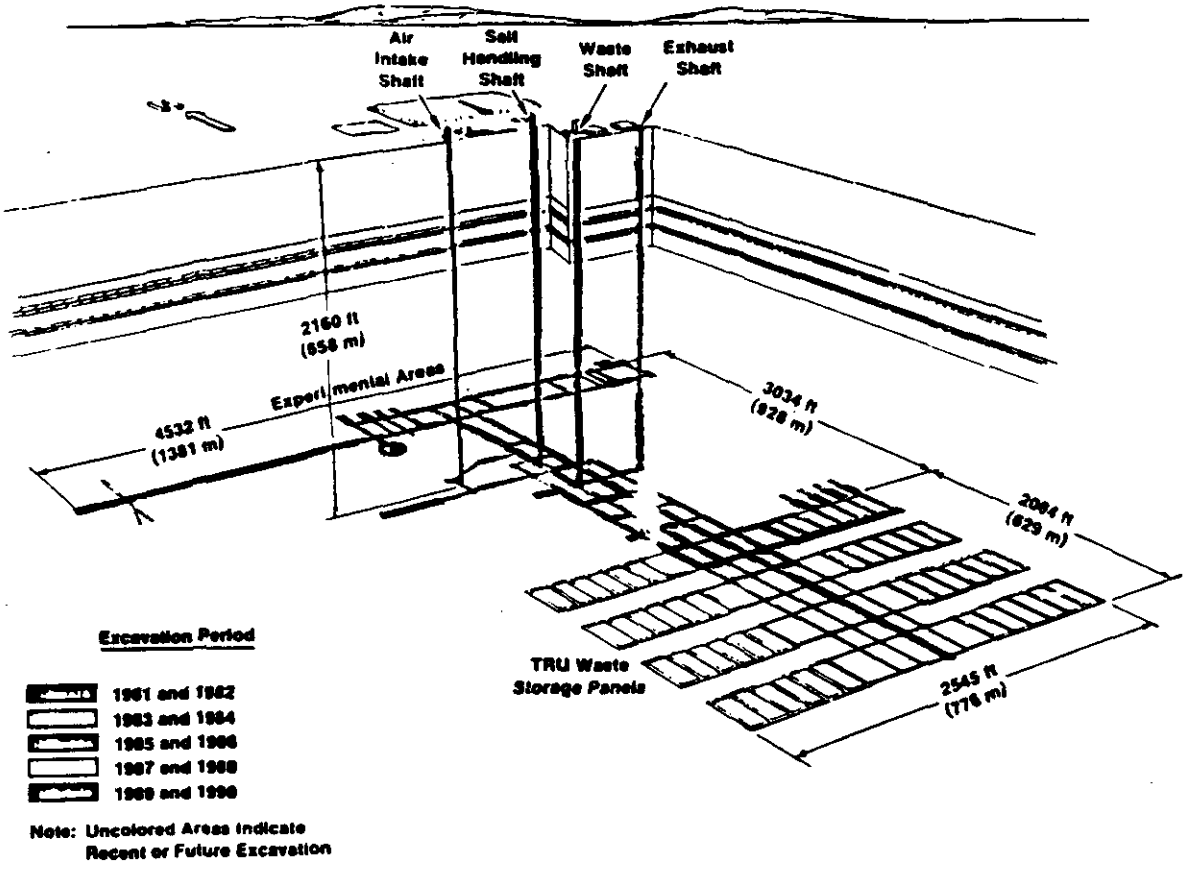

Figure 15. Schematic view of the WIPP site.

Experimental Design

Data from three types of experiments will form the bases for this test case:

- small scale brine-inflow experiments
- pore-pressure and permeability testing
- integrated, large scale experiment

Small Scale Brine-inflow Experiments

Brine-inflow rates are being measured at three scales: in 10 cm and 1 m diameter boreholes and in a cylindrical room with 2.9 m diameter (see large scale experiment). The boreholes are orientated vertically downward or horizontally and extend from 3 to 6 m. The boreholes are monitored for brine inflow (Figure 16) and relative humidity. The humidity measurements aid in quantifying the total moisture entering a borehole.

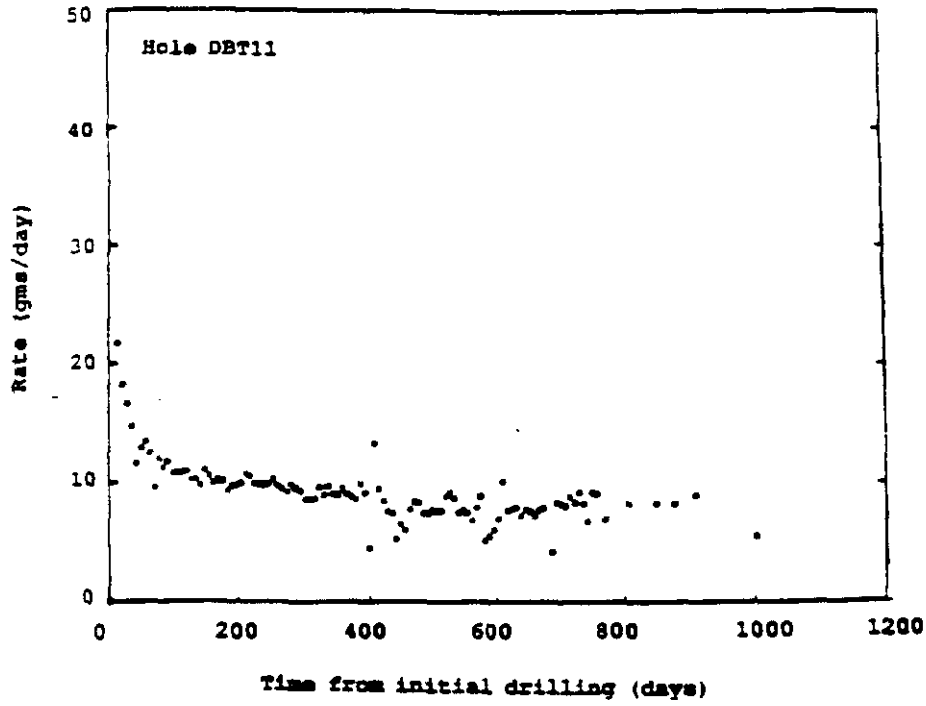

Figure 16. Brine inflow rate vs time in a borehole (Hole DBT11).

Chemical analyses of brine collected are also available. The brine-inflow measurements in the 10 cm diameter boreholes generally show rapidly declining flow rates for the first few months, followed by steady but slow declining flow rates over long periods (2 years).

Pore-pressure and Permeability Testing

Pore-pressure measurements are made in boreholes with a diameter of 10 cm and 2 to 27 m in length, drilled at a variety of orientations. Pore-pressure is measured in brine-filled, packer isolated intervals in the boreholes. Factors other than the formation pore-pressure that could contribute to pressures observed in a borehole, e.g. temperature changes and borehole closure, are also monitored. The boreholes are furthermore used for permeability experiments, both pressure-pulse tests and constant-pressure flow tests. During the pressure-pulse tests, gas tends to accumulate in the boreholes. The gas is thought to evolve from Salado Formation brine in response to the lower pressure around the borehole relative to the pressure in the far field. The gas volumes are measured and the compositions are analysed.

Integrated, Large-scale Experiments

A horizontal cylindrical room, with a diameter of 2.9 m and a length of 107 m, has been mined for the purpose of measuring brine inflow to a room-sized excavation. The room slopes slightly upward from front to back to follow the natural dip of bedding. The room was mined in July 1989 and sealed in October 1989. The humidity within the

room as well as the brine inflow into the room are now being measured. Salt efflorescences resulting from brine evaporation on the surface of the room are regularly mapped. Pore-pressure measurements were made continuously before, during and after mining of the room and permeability experiments were performed before and after the mining in a number of boreholes placed around the room. A series of boreholes, 4 and 10 cm in diameter, will be drilled in various directions from the room. These boreholes will also be instrumented to allow permeability experiments, pore-pressure measurements, and measurements of borehole deformation and brine inflow.

Available Data

Data available from boreholes of different diameters and locations and from a mined cylindrical room are:

- brine inflow rates
- humidity
- room closure, borehole deformation
- pore-pressure
- data from permeability tests
- rock property data
- general stratigraphic information
- core logs

Supporting Information

A number of technical issues that are important to the WIPP's performance are tackled, and a large number of different types of tests are or have been performed within the pilot plant.

MOL

Migration experiment in Boom clay formation at the Mol site, Belgium.

Overview

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The original purpose of the test is the in situ determination of migration related parameters and confirmation of these parameters determined in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

Experimental Design

A number of piezometers, a so called piezometer-nest, have been installed in an underground research laboratory in the Boom Clay formation at a depth of 220 m (Figures 17 and 18). The stainless steel system contains 9 piezometers, interspaced by 0.9 m long tubes. Each piezometer consists of two concentric tubes, the outer one being made of sintered stainless steel. A stand-pipe with an internal diameter of 2 mm is connected to the space separating the concentric tubes. The stand-pipe makes up the connection between the filter and the laboratory. A horizontal hole with a diameter of 50 mm and a depth of 10 m was drilled in the clay formation by rotary drilling. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. An inert gas was flushed through the filters to prevent oxidation of the clay. After about two days the small gap separating the tubing and the wall of the hole was completely sealed by convergence creep of the clay, and the gas flow was stopped. The presence of a vertical experimental shaft at the end of the underground laboratory (Figure 17) at atmospheric pressure and lined with concrete bricks creates a hydraulic pressure gradient in the neighborhood of the nest. The steady state pressure distribution as a function of the depth into the clay was measured.

About two and a half years after the installation of the piezometer-nest the clay formation was supposed to be settled. HTO was injected to filter number 5 and thereafter the system was left alone allowing migration of HTO in three dimensions. The injection rate of the tracer solution was 5.6 ml/day during about one and a half month.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters in the nest. The space between the different filters is 1 m. The sampling was started 3 months after the start of the injection and continues at a two months' interval. To avoid disturbance of the HTO concentration, distribution in the clay formation due to sampling, the sampling frequency and the total amount of liquid is kept as low as possible.

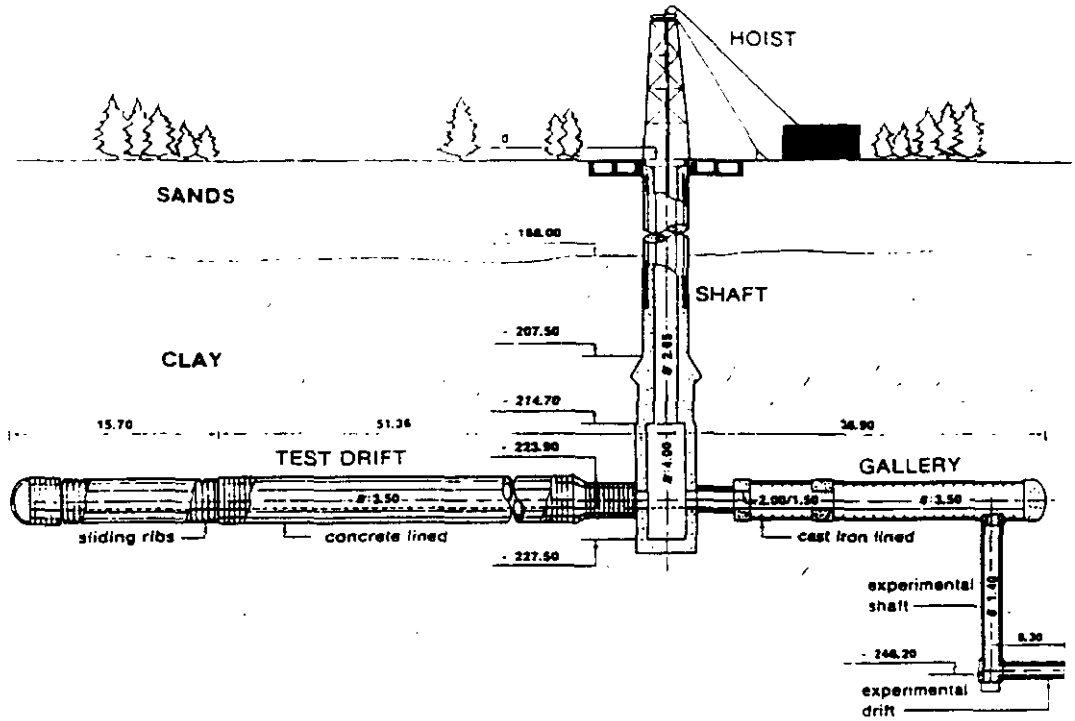

Figure 17. Scheme of the underground facility at Mol.

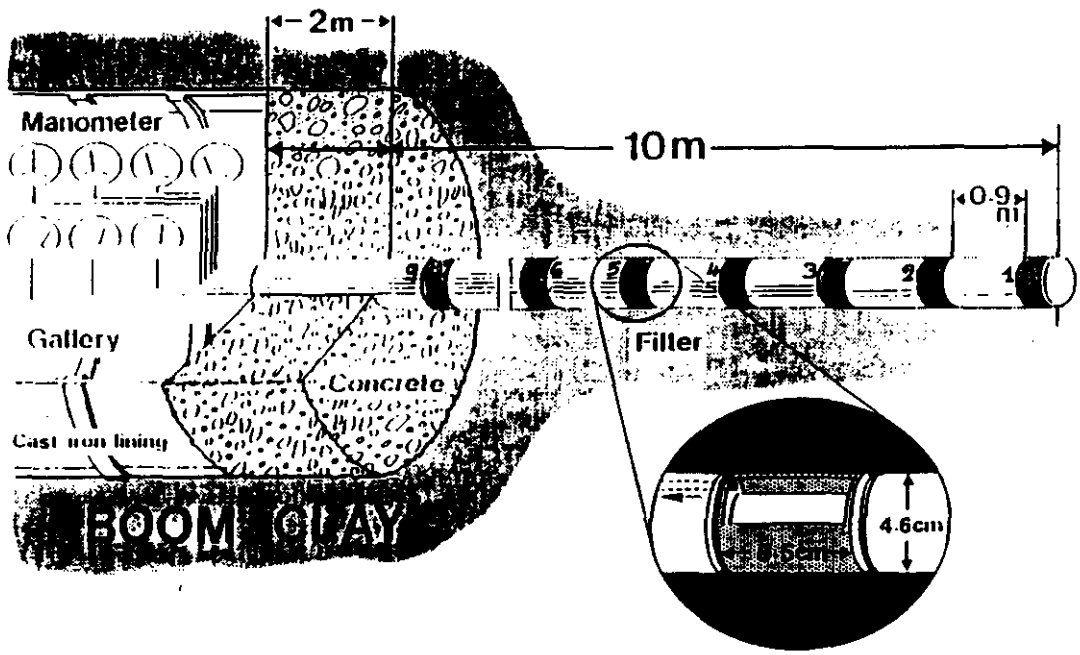

Figure 18. Conceptual view of the piezometernest.

Available Data

- steady state pressure distribution in the clay
- HTO concentration as a function time
- tracer injection data

Supporting Information

Supporting data are available from laboratory experiments and other in situ experiments. Transport parameters, e.g., the product of effective porosity and retardation factor, apparent dispersion constant, and diffusivity, have been estimated. A number of laboratory experiments have been performed, such as through-diffusion and percolation experiments with clay cores. The Boom clay is rich in organic matter which to a large part is linked to the mineral components. The remainder (humic and fulvic acids) can be regarded as dissolved. Attempts have been made to determine the diffusion parameters of the smallest humic molecules.

ALLIGATOR RIVERS

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

Overview

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region in the Northern Territory in Australia. The Alligator River Region is located about 200 km east of Darwin. The international Alligator Rivers Natural Analogue Project (ARAP) was set up in 1987 and was sponsored by the OECD Nuclear Energy Agency. Participating organisations are the Australian Nuclear Science and Technology Organisation, the Japan Atomic Energy Research Institute, the Power Reactor and Nuclear Fuel Development Corporation of Japan, the Swedish Nuclear Power Inspectorate, the UK Department of Environment, and the US Nuclear Regulatory Commission.

Uranium mineralisation occurs at Koongarra in two distinct but related orebodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m (Figure 19). The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

Experimental Investigations

An extensive experimental programme including both field and laboratory investigations have resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs of 140 percussion holes and 107 drill cores. Groundwater chemical data have been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The phase distribution of uranium and thorium in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from bore cores. Distribution coefficients have also been measured on natural particles in Koongarra groundwater.

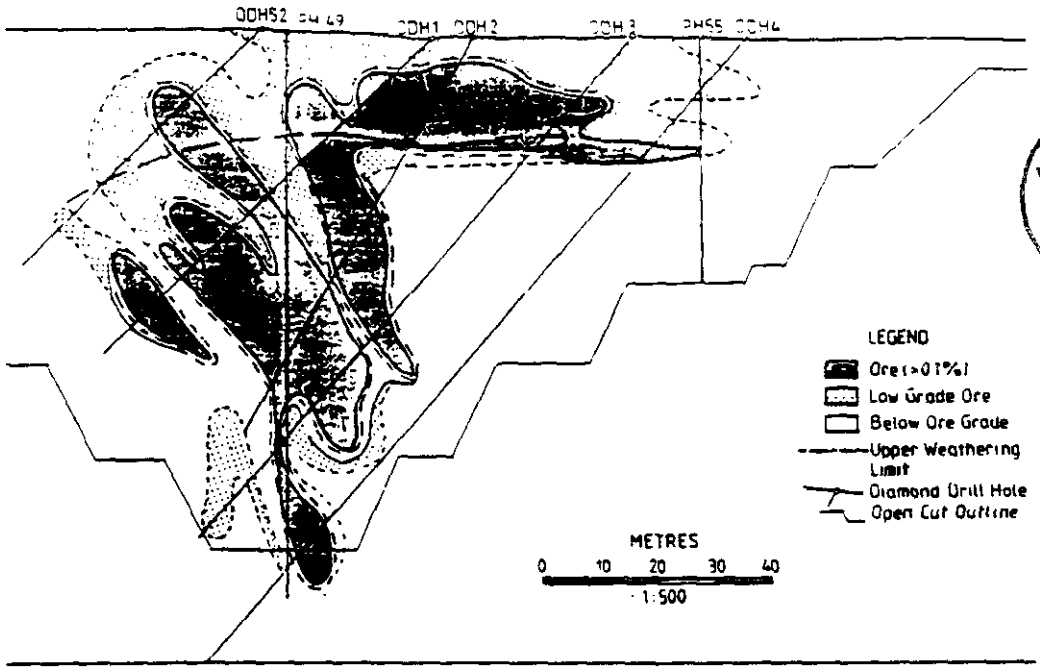

Figure 19. Cross section showing the dispersed zone at the Koongarra deposit.

Available Data

Hydrogeology

- climatologic data, including rainfall and temperature
- surface water measurements, including stream flow
- location, elevation, geologic logs, casing and perforation details of all test holes and wells
- map, showing test holes and wells, as well as land-surface contours
- aquifer test results including water-level drawdowns, discharge measurements, and water quality of discharge
- periodic water level measurements which show seasonal fluctuations and regional gradients
- results of geophysical surveys and back-hoe pits which show thickness of upper deposits
- results of packer tests in upper part of the bedrock, and resistivity traverses
- results from porosity and permeability measurements on drill core samples

Hydrochemistry

- pH, Eh, D.O., conductivity and temperature in groundwaters
- groundwater concentrations of cations and trace metals
- groundwater concentrations of uranium series nuclides and isotopes

Geology, Mineralogy, Radiochemical

- uranium concentration distribution assay (247 drilling locations) in core pulp and soil samples
- uranium series radioisotope activity ratios data for selected samples in the ore zone
- results from chemical analyses of core samples
- mineralogical composition of samples
- concentrations and activity ratios of uranium and thorium in different mineral phases
- concentrations of ^{129}I, ^{36}Cl, ^{99}Tc, and ^{239}Pu in rock samples

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Overview

A large number of aquifer tests ranging from small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The 37 km^2 property lies on the Canadian shield, with Precambrian bedrock consisting primarily of granitic gneiss. Over 10% of the site contains bedrock that is exposed or buried beneath less than 1 m of overburden. The remainder of the property is covered by unconsolidated sediments.

The water table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

Experimental Design

The large experimental programme includes 20- 40- and 260-metres natural gradient tracer experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and at present there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation, and gamma scanning is performed through the full aquifer. The groundwater discharge area, a wetland at the toe of the dune ridge, currently contains 36 of the monitoring installations (Figure 20). The tracers used are ^{131}I, which can be mapped by gamma scanning, and HTO which is used to verify that no retardation of the iodine takes place.

In addition, laboratory measurements on cores from the aquifer have been performed. The hydraulic conductivity was determined from grain-size analysis and the hydrodynamic dispersion and longitudinal dispersivity was determined from column tracer tests.

Available Data

A large database is available, containing data both from field and laboratory experiments, such as:

- permeameter test data
- small-scale dispersion
- porosities
- grain size composition
- hydrogeological data
- geophysical data
- mapping of tracer migration (Figure 21)

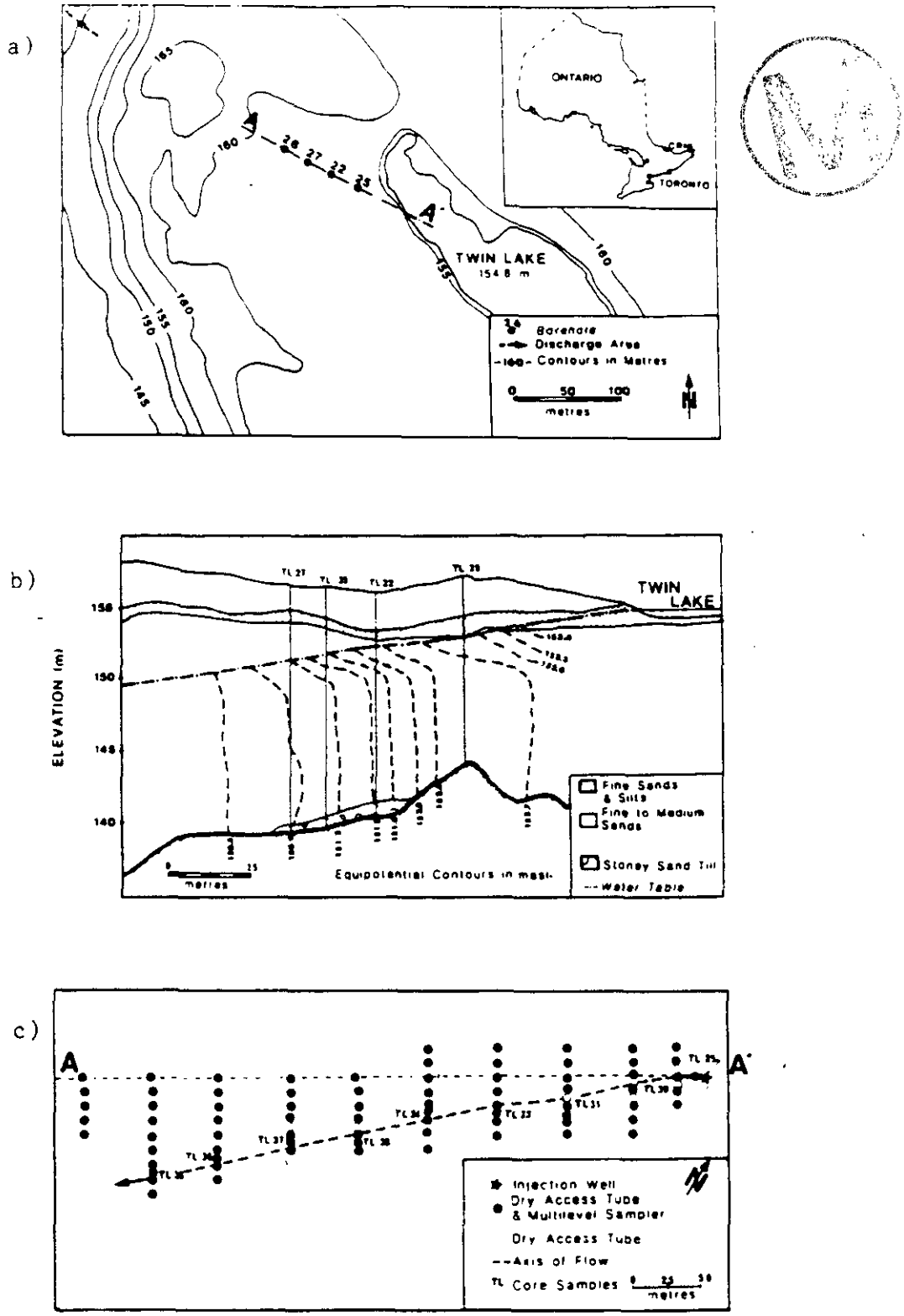

Figure 20. (a) Twin Lake Site map. (b) Geological cross section through the Twin Lake site (section A–A'). (c) Plan of field site showing instrumentation and tracer flow line.

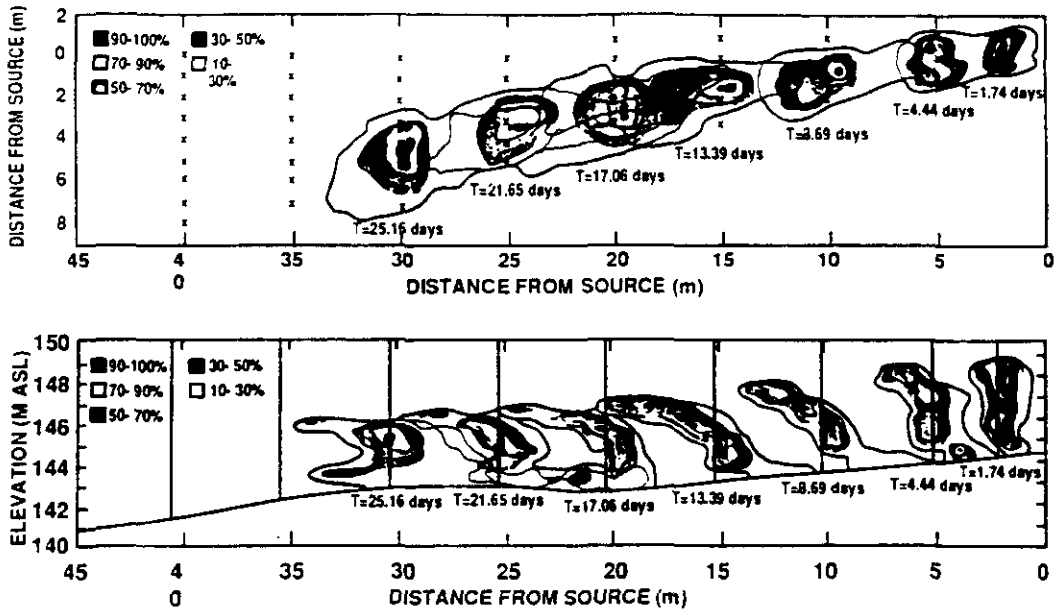

Figure 21. Example of the type of data available through the data base. Tracer migration in the sandy aquifer (percent of injection concentration).

Appendix 3

List of Test Case Related Presentations at INTRAVAL Workshops

INTRAVAL Phase 1 Test Cases

Radionuclide migration through clay samples by diffusion and advection (TEST CASE 1a)

Bogorinski P., Larue J., and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overview of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R., and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A., and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Application of Experiment Design Methods to Test Case 1a. INTRAVAL., INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A., and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P., and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J., and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K., and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K., and Ikeda Y., PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R., and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R., and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

Uranium Migration in Crystalline Bore Cores (TEST CASE 1b)

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J., and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E., and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., A Note on the Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Grindrod P., and Hodgkinson D., The Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Hadermann J., and Jakob A., Modelling Test Case 1b with Various Mechanisms and Geometries, INTRAVAL Workshop, Cologne 1990.

Hara K., Nakahara Y., Neyama A., Shiga A., and Ikeda Y., Modelling Study of Test Case 1b, INTRAVAL Workshop, Cologne 1990.

Hautojärvi A., Preliminary VTT Results on Test Case 1b, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Channels as Migration Routes in Crystalline Rock Samples, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Preece T.E., and Sumner P.J., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Sumner P.J., and Preece T.E., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Jakob A., Hadermann J., and Zingg A., PSI New Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Kjellbom K., Moreno L., and Neretnieks I., Preliminary Evaluation of Some Uranium Migration Tests, INTRAVAL Workshop, Helsinki, June 1989.

Radionuclide Migration in Single Natural Fissures in Granite (TEST CASE 2)

Aimo N.J., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Cole C.R., and Aimo N.J., Investigating a Parameter Estimation Approach to Design of Validation Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Gureghian B., Radionuclide Migration in Single Natural Fissures in Granite, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., Preliminary Results of Test Case 2 Study, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Previous Modelling of Test Case 2 Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 2, INTRAVAL Workshop, Tucson, November 1988.

Skagius K., Presentation of Test Case 2, INTRAVAL Workshop, Barcelona, April 1988.

Tracer Tests in a Deep Basalt Flow Top (TEST CASE 3)

Cole C., INTRAVAL Test Case 3, Experiments and Model Calculation, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., and Aimo N.J., Presentation of Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Andersson J., Comments on INTRAVAL Test Case 3, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., and Umeki H., Calculation of the Concentration of a Dispersive Tracer Solute by Means of Numerical Solution of the Balance Equation, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., Modelling of Test Case 3 by Using a Numerical Method, INTRAVAL Workshop, Tucson, November 1988.

Kimura H., and Yamashita R., Preliminary JAERI Results on Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Flow and Tracer Experiments in Crystalline Rock Based on Stripa 3D Experiments (TEST CASE 4)

Andersson J., Discrete Network Analysis of Tracer Experiments in Stripa 3D, INTRAVAL Workshop, Las Vegas 1990.

Dverstorp B., Application of the Discrete Fracture Network Concept on Field Data: Possibilities of Model Calibration and Validation, INTRAVAL Workshop, Barcelona, April 1988.

Dverstorp B., and Nordqvist W., Flow and Transport Simulations with a Discrete Fracture Network Model, INTRAVAL Workshop, Helsinki, June 1989.

Hodgkinson D., Shaw W., and Barker J., Modelling by Flows in Continuous Dimension, INTRAVAL Workshop, Tucson, November 1988.

Hodgkinson D., Shaw W., and Grindrod P., Preliminary Fractal Analysis of the Stripa 3D Migration Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Presentation of Test Case 4: 3D Migration Experiment at Stripa, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 4, INTRAVAL Workshop, Tucson, November 1988.

Tsang Y.W., and Tsang C.F., Understanding Stripa 3-D Tracer Migration Data, INTRAVAL Workshop, Helsinki, June 1989.

Tracer Experiments in a Fracture Zone at the Finnsjön Research Area (TEST CASE 5)

Andersson P., Experimental Results and Further Plans, INTRAVAL Workshop, Tucson, November 1988.

Andersson P., Recent Experimental Results, INTRAVAL Workshop, Helsinki, June 1989.

Andersson P., Proposal for Simulation of Hydraulic Interference Tests, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., and Worth D., Do the Pulse Injection Experiments Exhibit Radially Convergent Fracture Flow?, INTRAVAL Workshop, Las Vegas, February 1990.

Gustafsson E., Andersson P., and Wikberg P., Recent Achievements in the Performance and Evaluation of the Finnsjön Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A., Dipole Results, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A., and Taivassalo V., Generalised Taylor Dispersion Analysis for Tracer Breakthrough in the Radially Converging Experiment of Finnsjön (test case 5), INTRAVAL Workshop, Barcelona, April 1988.

Hautojärvi A., and Taivassalo V., Pre-Test Calculations of VTT-Team for Radially Converging Test, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Results of the Radially Converging Test, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Preliminary Predictive Modelling of the Dipole Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Test Case 5, Radially Converging Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., and Katsuragi T., Predictive Modelling of the Dipole Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Helsinki, June 1989.

Kimura H., Katsuragi T., and Yamashita R., Preliminary Results of the Radially Converging Tracer Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Las Vegas, February 1990.

Moreno L., and Neretnieks I., Preliminary Evaluation of Tracer Test in Finnsjön. Radial Converging Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Introduction to Test Case 5, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Preliminary Predictions of Finnsjön Tracer Tests, INTRAVAL Workshop, Barcelona, April 1988.

Nordquist R., Numerical Predictions of a Dipole Tracer Test in a Fracture Zone in the Brändan Area, Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Winberg A., Geostatistical Analysis of Hydraulic Conductivity Data at Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Yamashita R., and Kobayashi A., Preliminary Calculations Using Fracture Network Approach for Tracer Test in Finnsjön Site, INTRAVAL Workshop, Las Vegas, February 1990.

Synthetic Data Base, Based on Single Fracture Migration Experiments in Grimsel (TEST CASE 6)

Codell R., Cole C., and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem VI, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Cole C., and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem 6, INTRAVAL Workshop, Helsinki, June 1989.

Codell R., and Trösch J., Calculation of Synthetic Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kuhlmann U., and Vomvoris S., Interpretation of INTRAVAL Test Case 6, Synthetic Experiment, INTRAVAL Workshop, Cologne, October 1990

Vomvoris S., On the Synthetic Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Redox-front and radionuclide movements in an open Pit Uranium Mine, Pocos de Caldas (TEST CASE 7a)

Neretnieks I., Presentation of Test Case 7a: Redox Front and Uranium Movement at Pocos de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 7a: Redox Front Movement, INTRAVAL Workshop, Tucson, November 1988.

Neretnieks I., Redox Front Studies at Poços de Caldas, INTRAVAL Workshop, Las Vegas, February 1990.

Romero L., Moreno L., and Neretnieks I., Poços de Caldas. The Location of the Redox Front, INTRAVAL Workshop, Helsinki, June 1989.

Morro do Ferro Colloid Migration Studies (TEST CASE 7b)

Chapman N., Presentation of Test Case 7b: Colloid Transport, INTRAVAL Workshop, Tucson, November 1988.

Noy D., Presentation of Test Case 7b: Colloid Mobility at Poços de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Natural Analogue Studies at the Koongarra Site in the Alligator Rivers Area (TEST CASE 8)

Davis S., Hydrology Sub-Project, INTRAVAL Workshop, Tucson, November 1988.

Duerden P., and Golian C., Presentation of Koongarra and Draft Test Case, INTRAVAL Workshop, Barcelona, April 1988.

Duerden P., Presentation of Test Case 8, INTRAVAL Workshop, Tucson, November 1988.

Duerden P., Update of Recent Field Work, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., Koongarra Test Case: Modelling Progress, INTRAVAL Workshop, Tucson, November 1988.

Golian C., Hydrodynamic Transport through Porous Media which Contain Two Iron Mineral Phases, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., A Quasi Two Dimension Open System/Transport Model to Describe the Mobility of the Bulk Uranium, INTRAVAL Workshop, Las Vegas, February 1990.

Golian C., Test Results of the Simplified 2D Modelling of th Koongarra System Describing the Preferential Uranium Pathways, INTRAVAL Workshop, Cologne, October 1990.

Lever D., Koongarra Transport Modelling, INTRAVAL Workshop, Barcelona, April 1988.

Nijhoff-Pan I., Discussion on Test Case 8: Alligator Rivers (Koongarra) Ore Deposit, INTRAVAL Workshop, Helsinki, June 1989.

Slot A.F.M., Proposed Modelling Approach for the INTRAVAL Test Case 8, Alligator Rivers, Koongarra Ore Deposits, INTRAVAL Workshop, Las Vegas, February 1990.

Sverjensky D., Geochemical Aspects of the Alligator River Analogue Project, INTRAVAL Workshop, Tucson, November 1988.

Radionuclide Migration in a Block of Crystalline Rock (TEST CASE 9)

Hautojärvi A., Preliminary Calculations of Migration in the Fracture Channels, INTRAVAL Workshop, Helsinki, June 1989.

Kawanishi M., Preliminary Results on Test Case 9 by using Dual-Porosity Simulation Code, INTRAVAL Workshop, Cologne, October 1990.

Kobayashi A., and Yamashita R., Preliminary Results on Test Case 9 by Using the Non-Uniform Velocity Distribution, INTRAVAL Workshop, Helsinki, June 1989.

Noronha C.J., and Gureghian A.B., Description of Granite Block Experiment for Test Case 9, INTRAVAL Workshop, Barcelona, April 1988.

Noronha C.J., and Gureghian A.B., Large Block Migration Experiments, INTRAVAL Workshop, Tucson, November 1988.

Rasilainen K., Hautojärvi A., and Vuori S., Preliminary Interpretation of Test Case 9 using FTRANS-code, INTRAVAL Workshop, Las Vegas, February 1990.

Vandergraaf T.T., Grondin D.M., and Drew D.J., Contaminant Transport Laboratory Studies in a Single, Natural Fracture in a Quarries Granite Block at a Scale of 1 Metre, INTRAVAL Workshop, Tucson, November 1988.

Evaluation of Unsaturated Flow and Transport in Porous media Using an Experimental with Migration of a Wetting front in a Superficial Desert Soil, Las Cruces Trench (TEST CASE 10)

Ababou R., High-resolution Modeling of 3D Flow Fields, INTRAVAL Workshop, Las Vegas, February 1990.

Bensabat J., Stochastic Modelling of the First Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Gee G., Deterministic Modeling and Considerations for Transport Analysis of the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Gelhar L., Applications of the Stochastic Model to the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., Updegraff C.D., and Davis P.A., A 2-D Deterministic Model of the Las Cruces Trench Infiltration Experiment, Preliminary Results, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., and Davis P.A., A Statistical Analysis of the Las Cruces Trench Hydraulic Data, INTRAVAL Workshop, Helsinki, June 1989.

Goodrich M.T., and Gribble A.R., Data Analysis and Modelling of the Las Cruces Trench Second Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Hills R.G., Hudson, D.B., Porro I., and Wierenga P.J., Modelling the Layered Soil Lysimeter Study at Las Cruces, INTRAVAL Workshop, Tucson, November 1988.

Hills R., and Wierenga P., Water Flow and Solute Transport at the Las Cruces Trench Site, INTRAVAL Workshop, Las Vegas, February 1990.

Kool J.B., Simulations of Water Flow and Tritium Transport at the Las Cruces Trench, INTRAVAL Workshop, Las Vegas, February 1990.

McLaughlin D., Model Validation Issues for Unsaturated Flow Systems, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Presentation of Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Introduction, Test Case 10, INTRAVAL Workshop, Helsinki, June 1989.

Rasmuson A., Lindgren M., and Collin M., Flow and Transport Simulations of the Second Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Smoot J.L., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Smyth J.D., Infiltration Simulations of the Jornada Trench with a Multidimensional Monte Carlo Code, INTRAVAL Workshop, Las Vegas, February 1990.

Updegraff D., 1-D Analytical Solutions on Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Field and Laboratory Experimental Results with Emphasis on Transport, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Hills R., and Hudson D., Flow and Transport Data Analyses of the Las Cruces Trench Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Evaluation of Flow and Transport in Unsaturated Fractured Rock using Studies at Apache Leap Tuff Site (TEST CASE 11)

Bradbury J., Evaporation in Unsaturated Fractured Rock - an Alternative Conceptual Model, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Transport in Two-Phase Flow in Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Evans D., Field and Laboratory Experimental Results, INTRAVAL Workshop, Tucson, November 1988.

Evans D., Rasmussen T., and Sully M., Rock M trix Characterization in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Nonisothermal Core Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Crosshole Pneumatic Testing at the Apache Leap Tuff Site, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Laboratory Fracture Flow Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Lindgren M., and Rasmuson A., Two-Phase Flow Simulations in a Heated Tuff Drillcore, INTRAVAL Workshop, Cologne, October 1990.

McCartin T., Simulation of the Apache Leap Tuff Site Borehole Experiment, INTRAVAL Workshop, Tucson, November 1988.

McCartin T., Two-Phase Flow Simulations in a Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Nicholson T., Presentation of Test Case 11, INTRAVAL Workshop, Tucson, November 1988.

Parsons A.M., and Davis P.A., Modeling Strategy and Data Analysis for the Apache Leap Tuff Block Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Rasmussen T., Modelling of Field and Laboratory Experiments, INTRAVAL Workshop, Tucson, November 1988.

University of Arizona, Field and Laboratory Experiments in Unsaturated Fractured Tuff, INTRAVAL Workshop, Helsinki, June 1989.

Experiments with changing Near-Field Hydrologic Conditions in Partially Saturated Tuffaceous Rocks, G-Tunnel (TEST CASE 12)

Hoxie D.T., Empirical Validation of Hydrologic Model Simulations of Changing Near-Field Hydrologic Conditions, INTRAVAL Workshop, Barcelona, April 1988.

Hoxie D.T., Flint A.L., and Chornack M.P., Model Validation with Respect to Short-Term Dynamic Effects and Long-Term Transient Effects, INTRAVAL Workshop, Tucson, November 1988.

Experimental study of Brine Transport in Porous Media (TEST CASE 13)

Arens G., Preliminary Results on Test Case 13, INTRAVAL Workshop, Helsinki, June 1989.

Arens G., and Fein E., One-dimensional Brine Transport in Porous Media, INTRAVAL Workshop, Las Vegas, February 1990.

Bogorinski P., Jackson P., and Porter J.A., New Approach to the RIVM Experiment, INTRAVAL Workshop, Cologne, October 1990.

Hassanizadeh S.M., Presentation of Experimental Results from Brine Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Hassanizadeh S.M., Experimental Study of Brine Transport in Porous Media, INTRAVAL Workshop, Tucson, November 1988.

Hassanizadeh S.M., and Leijnse T., Simulation of the Brine Transport Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Hassanizadeh S.M., Latest Results on Simulation of Brine Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Schelkes K., Preliminary BGR Results, INTRAVAL Workshop, Helsinki, June 1989.

Schelkes K., and Knoop R.-M., Results of Modelling the Salt Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Groundwater Flow in the Vicinity of the Gorleben Salt Dome (TEST CASE 14)

Glasbergen P., Proposals for Test Cases Related to Rock Salt, INTRAVAL Workshop, Barcelona, April 1988.

Schelkes K., Pumping Test in Highly Saline Groundwater - a Proposed Test Case., INTRAVAL Workshop, Tucson, November 1988.

Schelkes K., Saline Groundwater Movement in an Erosional Channel Crossing a Salt Dome - Working Program for a Test Case, INTRAVAL Workshop, Tucson, November 1988.

INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Hills R., and Wierenga P., Las Cruces Trench Experiments Phase 2, and Validation Strategy, INTRAVAL Workshop, Seattle, April 1991.

Hills R., and Wierenga P., A Quantitative Model Validation Methodology with Application to the Las Cruces Trench Experiments. INTRAVAL Workshop, Sydney, February 1992.

Olague N., Kozak M., and McCord J., Las Cruces, Summary of Post Analysis. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Rockhold M., Conceptual Approach and Initial Numerical Modelling of the Plot 2b Experiment Using PORFLO-3, INTRAVAL Workshop, Seattle, April 1991.

Sagar B., and Wittmeyer G., Las Cruces Trench Experiment, Plot 2a, Model Valic tion Methods, INTRAVAL Workshop, Sydney, February 1992.

Wittmeyer G., and Sagar B., Flow and Transport Modelling of Test Case, INTRAVAL Workshop, Seattle, April 1991.

APACHE LEAP TUFF

Codell R., Performance Assessment Considerations for the Vapor Phase in Unsaturated Fractured Rock - Applications to the Apache Leap Tuff Studies, INTRAVAL Workshop, Sydney, February 1992.

Ford W., Pole J., Codell R., and McCartin T., Simulations of Hypothetical Flow Experiments in Fractured Rock Blocks, INTRAVAL Workshop, Seattle, April 1991.

Guzman A., Sully M., and Neuman S.P., Three Dimensional Characterization of Pneumatic Permeabilities in Unsaturated Fractured Tuff at the ALT Site, INTRAVAL Workshop, Seattle, April 1991.

Lehman L.L., Apache Leap - Benchmarking of the Beta Mode Code V-TOUGH on the UNLV Cray, INTRAVAL Workshop, Sydney, February 1992.

Rasmussen T.C., and Anderson I., Unsaturated Apache Leap Tuff Experiments: Fracture Imbibition Tests and Non-Isothermal Core Tests, INTRAVAL Workshop, Seattle, April 1991.

Rasmussen T.C., and Evans D., The Apache Leap Tuff Site Proposed Field Heater Experimental Plan, INTRAVAL Workshop, Seattle, April 1991.

Sully M., Guzman A., and Neuman S.P., In Situ Pneumatic Permeability, INTRAVAL Workshop, Seattle, April 1991.

Sully M.J., Guzman A.G., Neuman S.P., and Lohrstorfer C. Validation Studies for Assessing Unsaturated Flow and Transport through Fractured Rock at the Apache Leap Site, INTRAVAL Workshop, Sydney, February 1992.

FINNSJÖN

Andersson P., Brief Summary of New Data From Finnsjön, INTRAVAL Workshop, Sydney, April 1992.

Gomit J.M., Finnsjön Test Case, INTRAVAL Workshop, Seattle, April 1991.

Hatanaka K., Umeki H., Sasaki N., Mukai S., and Doi, H., Preliminary Analysis on Tracer Transport Test at Finnsjön Site, INTRAVAL Workshop, Sydney, February 1992.

Vuori S., Evaluation of Migration Processes and Geometries Using Tracer Break-through Curves of INTRAVAL Test Cases (Finnsjön, Stripa, WIPP 2), INTRAVAL Workshop, Seattle, April 1991.

STRIPA

Andersson P., Monitoring of Saline Tracer Transport by Radar Measurements and Model Simulations, INTRAVAL Workshop, Sydney, February 1992.

Guerin F., Billaux D., Chiles J.P., and Sauty J.P., Stripa: First Attempt at Tracer Experiments. Simulations by a Set of Interconnected Channelized Fractures, INTRAVAL Workshop, Seattle, April 1991.

Guerin F., Billaux D., Chiles J.P., and Saury J.P., Stripa: First Attempt at Tracer Experiments. Simulations by a Set of Interconnected Channelized Fractures, INTRAVAL Workshop, Seattle, April 1991.

Hautojärvi A., Analysis of Stripa 3D Data Employing EVE (Extreme Value Estimation) deconvolution Method, INTRAVAL Workshop, Sydney, February 1992.

WIPP 2

Beauheim R., Overview of Tests Conducted on the (WIPP 2) Culebra Formation at the WIPP, INTRAVAL Workshop, Seattle, April 1991.

Cliffe K.A., Jackson C.P., and Impey M.D., Summary of Results of a Preliminary Geostatistical Analysis of WIPP 2: Uncertainty and Validation, INTRAVAL Workshop, Sydney, February 1992.

Cliffe K.A., Jackson C.P., and Impey M.D., Further Results on WIPP 2, INTRAVAL Workshop, Sydney, February 1992.

Corbet T.F., Overview of Modeling Studies of the (WIPP 2) Culebra Formation at the WIPP, INTRAVAL Workshop, Seattle, April 1991.

Corbet T.F., Overview of Recent Progress on Geostatistical Estimates of the Culebra Transmissivity Field, Interpretation of Tracer Tests, and Alternative Conceptual Models of Regional Groundwater Flow, INTRAVAL Workshop, Sydney, February 1992.

Gomez-Hernandez J., and Capilla J., Application, INTRAVAL Workshop, Sydney, February 1992.

Grindrod P., Flow Through Fractal Rock: What does the WIPP 2 Field Data Reveal?, INTRAVAL Workshop, Seattle, April 1991.

Jackson P.C., Preliminary Discussion on WIPP 2, INTRAVAL Workshop, Seattle, April 1991.

Sahuquillo Herraiz A., Further Conditioning of Transmissivity Fields: Honoring Piezometric Data Theory, INTRAVAL Workshop, Sydney, February 1992.

GORLEBEN

Arens G., and Wollrath J., BfS - Calculations on Pumping Test 'Weisses Moor', INTRAVAL Workshop, Sydney, February 1992.

Bogorinski P., and Pöttl B., Modeling the Gorleben Channel, INTRAVAL Workshop, Sydney, February 1992.

Schelkes K., Gorleben Test Case, INTRAVAL Workshop, Seattle, April 1991.

Schelkes K., Status of Test Case and Validation Issues, INTRAVAL Workshop, Sydney, February 1992.

Vogel P., and Schelkes K., 2D-Studies on Salt Water Movement in the Gorleben Channel - First Results, INTRAVAL Workshop, Sydney, February 1992.

WIPP 1

Beauheim R., Interpretation of Permeability Tests (WIPP 1) S0P01 and L4P51, INTRAVAL Workshop, Seattle, April 1991.

Beauheim R.L., and Roberts R.A., Integrated Numerical/Analytical Interpretation of S1P73-B Hydraulic Tests, INTRAVAL Workshop, Sydney, February 1992.

Finley S.J., Small Scale Brine Inflow Experiments (WIPP 1): Data and Interpretation, INTRAVAL Workshop, Seattle, April 1991.

Gorham E., et. al., Status of WIPP 1 Test Case and Current Validation Strategy, INTRAVAL Workshop, Sydney, February 1992.

MOL

Kozak M., Initial Analyses of Anion Exclusion as Applied to the Mol Site, INTRAVAL Workshop, Sydney, February 1992.

Olague N., Kozak M., and McCord J., Mol: Preliminary Analyses. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Put M., Mol: Case Description and Modelling Methodology with Results, INTRAVAL Workshop, Seattle, April 1991.

Put M., Theoretical Validation Considerations for the Mol Test Case (with Results), INTRAVAL Workshop, Sydney, February 1992.

ALLIGATOR RIVERS

Birchard G., and Murphy W., Koongarra Analogue of the Near Field of an HLW Repository, INTRAVAL Workshop, Seattle, April 1991.

Birchard G., Groundwater Geochemical Speciation Modelling, INTRAVAL Workshop, Sydney, February 1992.

Emerson D., Site Characterization, INTRAVAL Workshop, Sydney, February 1992.

Golian C., Uranium Series Radionuclide Mobility in the Koongarra Weathered Zone, INTRAVAL Workshop, Seattle, April 1991.

Golian C., Transport Modelling of Natural Analogue - Approach and Findings, INTRAVAL Workshop, Sydney, February 1992.

Kimura H., and Murakami T., Uranium Migration Considering Alternation of Chlorite at Koongarra Site, INTRAVAL Workshop, Sydney, February 1992.

Skagius K., Modelling of Uranium and Thorium Migration in the Weathered Zone at Koongarra, INTRAVAL Workshop, Sydney, February 1992.

Tanaka Y., Miyakawa K., and Kawanishi M., Three-Dimensional Groundwater Flow Analysis on the Basis of Schistosity at the Koongarra Site, INTRAVAL Workshop, Sydney, February 1992.

Townley L., Hydrology of the Koongarra Site, Including Predictions of 3D Groundwater Flow Patterns, INTRAVAL Workshop, Seattle, April 1991.

Townley L., Summary of Hydrology Workshop, INTRAVAL Workshop, Sydney, February 1992.

Waite D., Implications of Sorption in Retardation, INTRAVAL Workshop, Sydney, February 1992.

van de Weerd R., Geochemical Modeling of the Koongarra Uranium Deposit, INTRAVAL Workshop, Sydney, February 1992.

TWIN LAKE

Durin M. and Mouche E., Comments to Twin Lake Test Case, INTRAVAL Workshop, Seattle, April 1991.

Gomit J-M., Twin Lake Test Case, INTRAVAL Workshop, Seattle, April 1991.

Moltyaner G., A Novel Methodology for Characterizing Geologic Heterogeneities, INTRAVAL Workshop, Sydney, February 1992.

Olague N., Kozak M. and McCord J., Twin Lake: Preliminary analyses. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Olague N., and Davis P., Validation Aspects for the Twin Lake Studies and Data Analysis of Twin Lake 1983 Tracer Tests, INTRAVAL Workshop, Sydney, February 1992.

INTRAVAL Parties:

Agence Nationale pour la Gestion des Déchets Radioactifs (France), Atomic Energy of Canada Ltd. (Canada), Atomic Energy Control Board (Canada), Australian Nuclear Science and Technology Organisation (Australia), Bundesanstalt für Geowissenschaften und Rohstoffe/Bundesamt für Strahlenschutz (Federal Republic of Germany), Commissariat à l'Energie Atomique/Institut de Protection et de Sûreté Nucléaire (France), Empresa Nacional de Residuos Radioactivos, S.A. (Spain), Gesellschaft für Reaktorsicherheit mbH (Federal Republic of Germany), Forschungszentrum für Umwelt und Gesundheit (Federal Republic of Germany), Her Majesty's Inspectorate of Pollution (United Kingdom), Industrial Power Company Ltd. (Finland), Japan Atomic Energy Research Institute (Japan), Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (Switzerland), National Institute of Public Health and Environmental Protection (The Netherlands), National Radiological Protection Board (United Kingdom), Power Reactor and Nuclear Fuel Development Corporation (Japan), Studiecentrum voor Kernenergie (Belgium), Swedish Nuclear Fuel and Waste Management Co. (Sweden), Swedish Nuclear Power Inspectorate (Sweden), U.K. Nirex Ltd. (United Kingdom), U.S. Department of Energy–OCRWM (United States of America), U.S. Department of Energy–WIPP (United States of America), U.S. Environmental Protection Agency (United States of America), U.S. Nuclear Regulatory Commission (United States of America).

Project Secretariat:

Swedish Nuclear Power Inspectorate, Her Majesty's Inspectorate of Pollution/AEA Technology, KEMAKTA Consultants Co., Organisation for Economic Cooperation and Development/Nuclear Energy Agency.

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intraval

PROGRESS REPORT

9

March 1992 – November 1992

INTRAVAL – An International Project to Study
Validation of Geosphere Transport Models

INTRAVAL
Progress Report Number 9, 1992

The international INTRAVAL project started in October 1987 in Stockholm as an international effort towards validation of geosphere models for transport of radionuclides. The project was initiated by the Swedish Nuclear Inspectorate, SKI, and was prepared by an ad-hoc group with representatives from eight organisations.

24 organisations 'Parties' from fourteen countries participate in INTRAVAL. The project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat in which also Her Majesty's Inspectorate of Pollution HMIP/DoE, U.K. and the OECD/NEA take part. Project organisation, the objectives of the study and rules for the publication of results are defined by an Agreement between the Parties.

The INTRAVAL philosophy is to use results from laboratory and field experiments as well as from natural analogue studies in a systematic study of the model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
Progress Report Number 9

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The INTRAVAL study was started in October 1987. The first three year study, Phase 1, is finalised. The second three year period, Phase 2, started in October 1990. The last workshop will be held in the autumn 1993.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process. In INTRAVAL the ambition is to cover validation of models both with regard to the processes and site-specific systems.

Eleven test cases are included in Phase 2 of the study. The test cases are based on experimental programmes performed within different national and international projects. Several of the cases are based on international experimental programmes, such as the Stripa Project and the Alligator Rivers Analogue Project.

Pilot Groups have been appointed for each of the test cases. The responsibility of the Pilot Group is to compile data and propose formulations of the test cases in such a way that it is possible to simulate the experiments with model calculations. It is a pronounced policy of the INTRAVAL study to support interaction between modellers and experimentalists in order to gain reassurance that the experimental data are properly understood and that the experiences of the modellers regarding the type of data needed from the experimentalists are accounted for.

Contact between the participants is maintained by arranging workshops which are followed by Coordinating Group meetings. Working Group meetings take place between the workshops.

Since the issue of the previous Progress Report, the eighth INTRAVAL workshop and the fourth Phase 2 Coordinating Group meeting have been held in San Antonio, USA. During the workshop the participants described the modelling work performed and discussed the results achieved so far. A full day session was dedicated to a general discussion of validation issues.

Most of the Phase 1 reports have been finalised, printed and distributed to the Coordinate Group members. Two of the reports are in print and some minor editorial changes remain in another report. The Phase 1 Summary report is scheduled for printing in the spring 1993. The schedule for the Phase 2 reporting was discussed and it was concluded that draft versions of the Working Group reports have to be available in the summer of 1993 and final versions in December 1993.

The Eighth INTRAVAL Workshop and the Fourth Phase 2 Coordinating Group Meeting

The eighth INTRAVAL workshop and the fourth Phase 2 Coordinating Group Meeting were held in San Antonio, Texas, USA, on the 9th through 13th of November, 1992, with the Center for Nuclear Waste Regulatory Analysis (CNWRA) acting as host. At the workshop technical presentations of the modelling results achieved by the Project Teams were given. A full day session was dedicated to a general discussion of validation issues. The session was divided into a morning session with presentations from invited speakers and an afternoon session with discussions. The schedule for the final reporting of the project was discussed and it was concluded that draft versions of the Working Group reports have to be available in the summer of 1993 and final versions in December 1993. Extended outlines of the reports to be written were presented.

The Coordinating Group meeting was held on the 13th of November, 1992. The time schedule for the finalisation of the INTRAVAL project was agreed upon (see section about Phase 2 reporting). Because

the leader of Working Group 4 was no longer available, it was decided to dissolve Working Group 4. A summary of the Alligator Rivers Test Case will be prepared by the Secretariat. The Twin Lake test case will be incorporated with Working Group 1 for the remaining part of INTRAVAL Phase 2.

The next, and final, INTRAVAL workshop will be held in Stockholm, Sweden, August 30 - September 3, 1993. It was suggested that each Working Group, together with the Secretariat, should organise a one-day plenary session that should follow the outline of the Working Group report. The next Coordinating Group meeting will be held in connection with the workshop in Stockholm. It was also decided to have an additional, and final, Coordinating Group meeting after the Stockholm meeting. Separate Working Group meetings are scheduled prior to the next INTRAVAL workshop.

The chairman informed that SKI will not be able to organise a third phase of INTRAVAL. However, SKI would be interested in the formation of a "Forum for flow and transport in rock in relation to performance assessment needs", but SKI would not take any specific initiative for its creation.

INTRAVAL Sub-Committee for Integration (ISI)

The second meeting of the INTRAVAL Sub-committee for Integration (ISI) was held on the 11th of November, 1992. A draft outline of the INTRAVAL integration and validation (summary) report was reviewed. A draft version of this report is to be completed by summer 1993, a second draft version by December 1993 and the final report in 1994. The aim is to get the ISI summary report published in a scientific journal.

INTRAVAL Phase 1 Reporting

The achievements from the first phase of INTRAVAL will be documented in a Summary Report and a series of technical reports. The technical reports cover descriptions, evaluations and conclusions from the modelling work performed for the different test cases. One of the technical reports is a compilation of descriptions of the experiments on which the test cases are based. The technical reports have been prepared by six Working Groups. An editor was appointed for each test case with the responsibility to compile the test case analysis provided by the Project Teams.

All except four of the Phase 1 reports have been finalised, printed and distributed to the Coordinate Group members. Two of the reports are in print and some minor editorial changes remain in one report. A draft version of the Phase 1 Summary report has been distributed to the Working Group leaders and the members of the Sub-committee for Integration for review. The final version of the Phase 1 Summary report is scheduled for printing in the spring of 1993.

Information from the Phase 2 Working Groups

Originally four Working Groups were set up addressing different types of test cases. Because of Mr. P. Duerdens, leader of Working Group 4, withdrawal from INTRAVAL, it was decided to dissolve Working Group 4. Two test cases were included in Working Group 4; Alligator Rivers and Twin Lake. A summary of the work on the Alligator Rivers Test Case will be prepared by the Secretariat. The Twin Lake test case will be incorporated in Working Group 1 for the remaining part of INTRAVAL Phase 2. Table 1 gives the test cases included in the three remaining Working Groups.

Table 1. Working Groups for INTRAVAL Phase 2.

Working Group	Test Cases	Chairman
1	Las Cruces Trench Apache Leap Twin Lake	T. Nicholson
2	Finnsjön Stripa WIPP 2	C-F. Tsang S. Neuman
3	Gorleben WIPP 1 Mol	P. Bogorinski

A chairman has been elected for each Working Group, sometimes aided by another person. The chairs of the Working Groups are responsible for the preparation of Working Group reports, which will form part of the final reporting of INTRAVAL Phase 2.

Since the previous workshop in Sydney, Australia, in February 1992, all Working Groups have arranged meetings. Minutes from most of these meetings are available on request from the Project Secretariat. Except for the meetings presented in Table 2, half a day was dedicated to Working Group meetings during the workshop in San Antonio.

Table 2. Working Group meetings held between March 1992 and November 1992.

Working Group	Date	Location	Test Case
1	June 1992	Las Cruces, USA	Las Cruces Trench
2	June 1992	Forsmark, Sweden	
3	June 1992	Traben-Trarbach, Germany	
4	October 1992	Toledo, Spain	Alligator Rivers

Prior to the next INTRAVAL workshop a number of Working Group meetings are scheduled (Table 3).

Table 3. Scheduled Working Group meetings.

Working Group	Date	Location	Test Case
1	December 1992	USA	Yucca Mountain
1	January 1993	Tucson, USA	Apache Leap
1	June 1993	USA	Yucca Mountain
2	March 1993	Berkeley, USA	
3	December 1992	SNL, USA	
3	March/April 1993	Bilthoven, Netherlands	
3	June 1993	Germany	Gorleben
4	No more meetings, Working Group has been dissolved		

INTRAVAL Phase 2 Reporting

The Secretariat will not take responsibility for publishing INTRAVAL Phase 2 Working Group reports. It is suggested that the technical work should be published in existing report series, journals etc. However, the Secretariat need a summary of the work within each Working Group to be included in the INTRAVAL Phase 2 Summary Report. In addition, a special report on integrated conclusions from the INTRAVAL Project will be prepared by the INTRAVAL Sub-committee for Integration (ISI).

Tentative schedule for the Phase 2 reporting:

Working Group reports:

- Extended outline, November 1992
- Draft, summer 1993
- Final draft, December 1993

Summary Report, INTRAVAL Phase 2:

- First draft, December 1993
- Final report, December 1994

Integrated conclusions (ISI) report for INTRAVAL Phase 1 and 2:

- Extended outline, November 1992
- First draft, summer 1993
- Second draft, December 1993
- Final Report, 1994

Current Status of INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media preformed at Las Cruces, New Mexico.

Experimental Set-up

The experimental site is located at the New Mexico State University Collage Ranch, 40 km northeast of Las Cruces in New Mexico, USA. A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4 m × 9 m and 1 m × 12 m, respectively, are adjacent to the trench. Water and tracers were applied at controlled rates on these areas. In the first experiment (Plot 1) water containing the conservative tracer tritium was applied at a rate of 1.76 cm/day on the area measuring 4 m × 9 m. In the second experiment (Plot 2a), water containing tritium and bromide was applied at a rate of 0.43 cm/day on the other area (1 m × 12 m) on the opposite side of the trench, and in the third experiment (Plot 2b) tritium, bromide, boron, chromium and two organic compounds (pentafluorobenzoic acid and 2,6-difluorobenzoic acid) were applied at a rate of 1.82 cm/day on the same area (1 m × 12 m). The movement of the water below the soil surface was monitored with neutron probes and tensiometers. Tracer concentrations were sampled on a regular basis through solute samplers installed in a two dimensional grid through the trench wall. In addition laboratory experiments on cores were performed to determine the physical properties of the soil. The Plot 1 and Plot 2a experiments were included in INTRAVAL Phase 1 and was used for model calibration. The calibrated models will be used in

INTRAVAL Phase 2 to predict the Plot 2b experiment before the experimental data will be made available to the Project Teams.

Analyses by the Project Teams

The Project Team from PNL/USNRC has used the Plot 2b experimental data for testing deterministic and stochastic models of water flow and solute transport through heterogeneous, unsaturated porous media. When evaluating the Plot 2b experiment it was found that the effects of spatial variations in hydraulic properties on solute transport during transient unsaturated flow are significant. The Plot 2b experiment was modelled using four scenarios: 1) isotropic conductivities and modified van Genuchten water retention function, 2) anisotropic conductivities ($K_x = 2K_z$) with constrained residual water content, 3) isotropic conductivities with water retention parameters determined using 1-D inverse solution and data from Las Cruces trench experiment 1, and 4) a single stochastic realisation of conductivities conditioned on data from the trench. It was found that simple uniform models predicted water flow better than the single stochastic realisation conditioned on data from the trench. Future work will investigate the use of generalised scaling analysis for describing the spatial variability of flow and transport properties.

The Project Team from CNWRA/USNRC have used the Plot 2b experiment to study the effect of model complexity on the accuracy of model predictions. The technical approach includes re-estimation of the van Genuchten model parameters from water retention data to ensure that initial suctions are consistent with measured initial water contents, kriging of the van Genuchten model parameters to quadrilateral zones, modelling of the movement of the moisture plume along three 2-D transects using the code PORFLOW, and finally, comparison of model predictions of water content to measured water content at different times up to 310 days by momentum analysis and point-to-point comparisons. All data available from the Plot 2b experiment were used in three models with different complexity regarding the discretisation. It was found that the most complex model provides the most accurate predictions, based on the sum of squared differences between computed and measured water contents. Analysis of the moments of the water content distribution does not aid in determining which of the three models is best. Analysis of the second moments indicates that there is less variation among the three models than between the models and the experimental results.

The Project Team from University of New Mexico/USNRC discussed the use of statistical inference to quantify the validity of different models applied to the Las Cruces experiments. Observations and, in most cases, blind predictions performed by different groups concerning water contents, first arrivals, fluxes and moments have been compared. The predictions made are based on 13 different conceptual models for the soil properties; five for a uniform isotropic soil, two for a heterogeneous isotropic soil, and six where the soil properties have stochastic distributions. The results varied, some models performing well for some measures and others performing well for other measures. For example, it was found that the models consistently predicted longer times for the first arrival than observed, implying that the models cannot be regarded as conservative. The applied stochastical models showed more preferential flow than observed in the experiment. It was pointed out that quantifying the uncertainty in the applied models requires models for probability distributions and correlation structure of the uncertainty. This suggests that stochastic models for uncertainty may be required to quantitatively validate deterministic models.

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Experimental Set-up and Scales

The Apache Leap Test Case in INTRAVAL Phase 2 concentrates mainly on two topics, how a thermal source will affect air, vapour, water and solute movement in geologic media, especially unsaturated fractured rock, and the water and air transport properites of fractures and rock matrix in unsaturated rock.

The effects of a thermal source were studied with laboratory non-isothermal core measurements. A cylindrically shaped core, approximately 12 cm long and 10 cm in diameter, was extracted from a block of Apache Leap Tuff. The core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses from all surfaces, and to minimise heat loss along the sides of the core. During the experiment, a horizontal temperature gradient was established along the long axis of the core. The data available from the core measurements are rock matrix porosities, initial water contents, and temperatures.

The behaviour of unsaturated fractured rock, was studied in a series of tests being performed to characterise water and air transport properites from fractures and rock matrix for a range of matrix suction. The measurements were conducted on a block of Apache Leap Tuff which was 92.5 cm long, 21.0 cm high and 20.2 cm wide and contained a single discrete fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent. The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irri-

gated with water. The position of the wetting front in the fracture over time and the position of the wetting front in the matrix over time was studied. Available data are rock matrix sorptivity coefficient, rock matrix porosity, rock fracture aperture, and cumulative inflow volume over time.

In addition to these laboratory experiments there are plans to perform field investigations. However, most of the data from the planned field experiments cannot be expected until after the end of INTRAVAL Phase 2.

Analyses by Project Teams

The Project Team from the University of Georgia/USNRC presented laboratory experiments where water and gas flow behavior in unsaturated fractured rock were studied. A block of Apache Leap Tuff with a single discrete fracture was used to perform a series of tests to characterise the water and air transport properties of fractures and the rock matrix for a range of matric suctions. Fracture flow experiments were carried out to investigate the behavior of water and three gas mixtures: air, air plus a helium gas tracer, and air plus an argon gas tracer. In addition, coupled fracture-matrix fluid flow was addressed by studying the imbibition of water into the fracture and subsequent uptake and migration of water into the rock matrix bounding the fracture in an initially dry rock block. The rock fracture transmissivity was determined before and after the imbibition test using air flow, tracer and water injection experiments. Similar transmissivities were obtained in the different types of experiments even when using different pressure head gradients.

Equivalent fracture apertures were evaluated from six types of experiments. Three volumetric fracture aperture values were obtained using a pycnometer, tracer breakthrough volumes, and the ratio of fracture transmissivity to fracture hydraulic conductivity. Two Poiseuille apertures were calculated using a cubic aperture equation applied to gas and water flow rates, and using a quadratic aperture equation for the gas tracer breakthrough. A final estimate of fracture aperture was obtained using the air-entry potential of the saturated fracture.

The volumetric apertures, estimated using the pycnometer and the tracer breakthrough volumes, were found to be very close. The volumetric aperture determined using the ratio of fracture transmissivity to hydraulic conductivity gave smaller apertures, followed by the apertures determined using the cubic and quadratic equations, respectively. The smallest aperture observed was the capillary aperture. This progression is consistent with the hypothesis that fracture roughness will decrease the effective flow area for the Poiseuille flow and induce an ink bottle effect at fracture constrictions. The difference between apertures obtained using these six different methods was almost one order of magnitude.

The water imbibition rate was predicted using a model for a single horizontal fracture bounded by porous rock. The applied model include three stages in the fracture imbibition process. The first stage consists of rapid water imbibition into the dry fracture, the second stage of a lower imbibition rate into the fracture and rock matrix, and the final stage corresponds to an imbibtion rate where nearby fractures or rock matrix boundaries interfere and limit the lateral migration of flow away from the fracture. The model was found to provide a good fit of the shape of the observed data, but the model overestimated the fracture imbibition volume by a factor of twenty and the fracture wetting front advance by almost a factor of ten. The noted reduction in water inflow may be due to phenomena neglected in the theoretical model, such as fracture surface coatings or enhanced surface wetting and the inability to accurately determine fracture physical properties a priori, such as the fracture water diffusivity.

It was shown that fracture saturation behind the wetting front initially is very low, perhaps ten percent, but increases to complete saturation during the course of the experiment. This may indicate that fingers of saturation exist within the fracture during early times which expand laterally and dissipate over time. It seems that the fingering (channeling) is at least as pronounced in unsaturated fractures as in saturated.

Scale effects in air permeability determinations were studied by the Project Team from University of Arizona/USNRC. One borehole, Y2, has been tested at three different scales: 0.5, 1, and 3 m. Two other boreholes, X2 and V2, are currently being tested at a 1 m scale and another three boreholes, W2, Z2 and V2, will be tested at a 1 m scale. This will give a total borehole length of 180 m tested at a 1 m scale. High permeability intervals in these six boreholes will be retested at a 0.25 m scale to better define major fractures. The data obtained so far have been used for a preliminary geostatistical analysis to study the scale effect on the permeability determinations. The permeability based on the 0.5 m measurements has been found to vary over 11 orders of magnitude. The variability of the 1 and 3 m scale data is smaller, as expected, inferring that the measured permeability is a strong function of scale. The average permeability increased with increasing scale. Despite the large spatial variability of the permeability measurements, the underlying spatial structure has been found to be represented by a classical semivariogram model. Thus, flow through the fractured porous material may be amenable to the theory of stochastic hydrology.

YUCCA MOUNTAIN

Yucca Mountain experiments.

Experimental Set-up

The objective of the Yucca Mountain test case is to compare predicted and observed moisture content as a function of depth in a borehole currently being drilled. The data set for the test case consists of composite transects of hydrologic properties at the site, detailed geohydrological data and moisture content data from boreholes UZN-53, UZN-54 and UZN-55, and topographic and structural geology information for the site. Data from the three UZN-boreholes will be used for prediction of the moisture content in a new borehole, UZ-16, that will be drilled to a depth of about 500 m at a distance of about 100 m from the UZN-boreholes. The drilling of this borehole is scheduled to be completed in March 1993 and the comparison between measured and predicted data is scheduled to be completed until next INTRAVAL meeting, in the autumn 1993.

Analyses by the Project Teams

The observer from the State of Nevada has studied the effects of variability in selected model inputs on modelled unsaturated water content profiles. 1-D, 2-D as well as fracture models were applied for simulations of the water content in the rock to a depth of almost 500 m. Some of the data used originate from boreholes at the Yucca Mountain site not included in the test case. The rock was modelled as consisting of seven hydrologic layers except for the 1-D case where the number of layers varied from 4 to 11. The results from the 1-D models showed a poor fit to measured data even though the number of layers as well as the infiltration rate were varied. The wet conditions within the upper high conductivity unit, co-existing with the unsaturated conditions in the low conductivity units, could not be modelled with 1-D geometry and infiltration. Like the 1-D simulations, the 2-D simulations were found to underestimate the measured water content in the upper unit. The fracture flow model showed considerably better match to observed data. In this model, water was recharged into a vertical fracture intersecting all seven hydrologic layers. The recharge rate was estimated based on ground surface material, topography, and climate data. The fracture density in the rock was set to about three fractures per metre. In this case, the very wet conditions in the upper permeable unit as well as the unsaturated conditions below are much better represented than either the 1-D or 2-D representations.

The Project Team from SNL/USNRC presented their initial work with geostatistics applied to the Yucca Mountain test case. The porosity between boreholes was simulated using a geostatistical simulator that can be used for 2-D as well as 3-D simulations and where each simulation is equally consistent with observed data. Observed correlations with porosity are used to generate other properties in a stochastic fashion. In this way, the saturated conductivity is generated from the porosity and the average pore size from the square root of the saturated conductivity divided by the porosity. Each simulation produces porosities on a local scale which are upscaled to the size of the element used in the grid followed by calculations of velocities and fluxes in the studied section.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

This test case deals with detailed characterisation of a fractured zone including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole experiment. The modelling is focussed on the dipole experiment. This test case was also included in INTRAVAL Phase 1, but the database for the dipole experiment was never used for modelling, since it became available too late.

Geological Structures

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometres.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to be 10^{-4} m^2/s; the middle 10^{-7}–10^{-6} m^2/s and the lower 10^{-4} m^2/s. The middle layer is not continuous. A fresh water–salt water interface exists in the fracture zone relatively close to the upper sub-layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated to 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated at 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed, a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting eleven different non-sorbing tracers at nine different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting tracers in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analyses by the Project Teams

The Project Team from VTT/TVO discussed if breakthrough curves obtained from field tests using non-sorbing tracers reveal matrix diffusion. In tracer tests, like those performed in Finnsjön where a tracer is injected in one borehole and collected in another borehole, the breakthrough will be affected by hydrodynamic dispersion as well as matrix diffusion. When studying the Finnsjön tracer experiments it was found that the observed dispersion in the breakthrough curves was dominated by hydrodynamic dispersion rather than matrix diffusion because of the relatively high flow rates. Furthermore, if the flowpaths and velocity fields between the boreholes are unknown, which is the normal case, then transport in a number of individual channels can produce breakthrough curves similar to those that would be obtained for transport in a single path where the tracers interact with the rock matrix. Another effect that also might be misinterpreted as matrix diffusion is diffusion into stagnant volumes of water. The conclusion from the presentation was that matrix diffusion parameters cannot be determined from breakthrough curves obtained in field experiments. Instead, laboratory experiments and possibly also in in-situ experiments without any flow or with extremely low flow rates should be used for this purpose. Field tracer experiments, like the Finnsjön tests, should aim at studying flow and channeling concepts.

The Project Team from PNC has used a stream tube approach to study the effect of heterogeneity on tracer transport at the Finnsjön site. The rock was modelled as a high conductive layer with low conductive layers above and below. The mass transport in the high and low conductive zones were expressed by 1-D and 2-D advection-dispersion equations, respectively, for each streamtube. A hydraulic conductivity distribution was generated by using data from hydraulic tests at each borehole and the radially converging test. This hydraulic conductivity distribution was then used to simulate the dipole tests and to estimate the tracer transport parameters, dispersivity and porosity. Finally, the validity of the estimated parameters was confirmed by simulating breakthrough curves at the pumping hole in the radially converging test. These simulated breakthrough curves showed good agreement with measured curves, except for the tracer iodide which was explained with experimental problems during the iodide experiment causing disturbances in the breakthrough curves.

The Project Team from Conterra/SKB presented work regarding calibration and validation of a stochastic continuum model using data from the Finnsjön dipole tracer test. The main aim with this work was to investigate whether the stochastic continuum approach can successfully be used to describe tracer transport in fractured crystalline bedrock and specifically to explore whether a model calibrated on a local scale can be validated on a larger scale.

In the case of the Finnsjön tracer tests, only one scale of testing has been done and in view of the lack of a second measurement scale, a realistic generic case was created to test the ideas on calibration and validation of a stochastic continuum model. The problem was tackled by creating a reference transmissivity field represented by a 0.5 m thick 2-D confined aquifer with a size of 1200 m × 1200 m, corresponding to the upper highly conductive part of zone 2. All measured transmissivity data were used to construct a synthetic reference field as close as possible to the real situation. Dipole tracer tests, similar to the Finnsjön test, and a far-field (natural gradient) test were performed in this synthetic reference field for calibration and validation.

Eight boreholes penetrating fracture zone 2 have been hydraulically tested and several realisations were generated and conditioned on the data from these boreholes. One of the generated realisations was randomly chosen as the reference field. Two dipole experiments were simulated in the synthetic reference field, BFI01 to BFI02 and KFI11 to BFI02. In both experiments a total number of 900 particles, which were assumed to be conservative, were released. The movement of particles was analyzed using particle tracking techniques assuming no local dispersion, i.e. only advection was taken into account. These results were considered to be the real system response of the reference field and was used for calibration. The far field simulation in the synthetic reality was performed under natural gradient conditions. The tracer particles were instantaneously injected at a 20 m × 200 m area along the upstream boundary and the breakthrough at the downstream boundary of the model, more than 1000 m away, was recorded. The results from this far field simulation were used to validate the overall model, i.e. the validity of extrapolating a model calibrated and partially validated on a local scale to a larger, far field scale.

The team used the Monte-Carlo approach to generate 100 equally probable realisations having the same statistical structure as the observed data. The generated realisations are inherently unconditional since only the statistical parameters are the same as

the measured data, whereas the actual transmissivity data at the boreholes are not honored. Comparing the breakthroughs in the dipole experiments it was found that individual realisations could be very different to the reference field due to uncertainty in transmissivity values, while the mean (assemble) breakthrough curve was very close to that of the reference field, especially for the BFI01 test. Based on a quantified measure of the deviation of the simulated breakthrough curve from that of the reference field, 3 of the 100 fields were chosen that captured the reference field quite well. The far field simulations were calculated under natural gradient conditions using the same transmissivity fields as for the local scale dipole test. The results from the three simulations show very different mean arrival times and dispersion patterns, indicating that calibration of the model on the local scale and subsequent prediction of far field transport phenomena can result in high uncertainty. To investigate the effect of the number of conditioning data on uncertainty, 28 new points were randomly selected from the reference field as new measurement data. Thus, a total of 36 measurement points were used for new conditional simulations. The calculation results on the local scale (dipole test) are similar to the results obtained when using only eight conditional points. In this situation, adding more measurement points on a larger scale does not improve the simulations on a local scale. However, the far field simulations were improved by adding these conditional points. It was thus concluded that calibration on a local scale is insufficient to validate a model for a larger transport scale and the model that gives the best fit on the local scale may not be the best model for far field predictions due to pronounced heterogeneity.

The Project Team from BRGM/ANDRA presented an analysis of the Finnsjön interference tests that accounted for boundary effects. The interference tests were performed by pumping in borehole BFI02, which intersects fracture zone 2, while the drawdown was monitored in the other boreholes at the site. Analysis of the interference tests was performed in two phases, with interpretations applying analytical solutions in the first phase and using a 3-D finite difference model in the second phase. In the first phase, the team evaluated transmissivities, storativities and distance to boundaries from the drawdown curves obtained from boreholes KFI05, KFI06, KFI09, KFI10 and KFI11. The transmissivities were found to be almost one order of magnitude larger when evaluating the drawdowns for early times compared to the whole test duration due to boundary effects. It was also observed that there are difficulties in correlating the estimated boundaries to the interpreted geometry of the main structural/geological features at the site.

In the second phase of the work the team calibrated a 3-D finite difference model on interference tests 1 and 2, performed in the lower and upper highly conductive subzones of fracture zone 2. The model was subsequently "validated" on test 3, performed in the entire fracture zone 2. It was found that the performed calibration on tests 1 and 2 gave a good representation of the data from test 3. The team will continue with tracer test interpretations using the calibrated hydrology.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiments, Sweden.

Experimental Set-up

This test case is based on three-dimensional tracer tests performed in the Stripa mine in Sweden. The experiments are part of the International Stripa Project.

In an experimental drift, excavated in the old iron ore mine in Stripa, the whole ceiling and upper part of the walls was covered with about 350 plastic sheets (2 m^2 each) with the purpose to collect water seeping in from the rock and to collect injected tracers. Three vertical boreholes for tracer injections were drilled and tracers were injected at nine locations 10 – 55 m above the test site.

The data registered or obtained from the experiments are water flow rates, tracer concentrations in the water entering the drift, rock characteristics and fracture data, water chemistry, tracer injection pressures and flow rates, and hydrostatic pressure. Diffusivity and sorption data are available from supporting laboratory and field experiments. The experiment was a test case also during Phase 1 of INTRAVAL.

In addition to the results from the 3-D experiment, data from two other experiments performed in the Stripa mine, the "Channeling Experiments" and the "Site Characterisation and Validation program", are available to the INTRAVAL Participants during Phase 2. The Channeling Experiments consisted of two kinds of tests, single hole and double hole experiments. In the single hole experiments, holes with a diameter of 20 cm were drilled about 2.5 m into the rock in the plane of a fracture. Specially designed packers were used to inject water into the fracture at 5 cm intervals. The variation of the injection flow rates along the fracture were used to determine the transmissivity variations in the fracture plane. Detailed photographs were taken from inside the holes and the visual fracture aperture was compared with the injection flow rates. Five holes were measured in detail and seven holes were scanned by simple packer systems. In the double hole experiment, two parallel holes were drilled in the same fracture plane at nearly 2 m distance. Pressure pulse tests were carried out between the holes in both directions. Tracers were injected at five locations in one hole and monitored in several locations in the other hole. The Site Characterisation and Validation program, with the aim to predict groundwater flow and tracer transport in a previously unexplored rock volume, involved a number of investigation steps with modelling predictions. A few long boreholes were used to characterise the rock volume. Additional boreholes were drilled and

used for investigations of water bearing sections, fractures, tracer tests etc. All investigations were compared to already performed model predictions. Finally, a new drift, the "Validation Drift", was excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

Analyses by the Project Teams

The Project Team from BRGM/ANDRA analysed flow and tracer transport in the Stripa 3-D experiment and especially studied the influence of connectivity. The modelling was performed in steps, starting with building and conditioning of the stochastic fracture network model, followed by calibration of two types of channelling models, and finally simulation of the tracer breakthrough in these channel networks to check the physical meaning of the two tested models. The model contains the three main sets of fractures that were found at the 3-D site. The orientation of the fractures was assumed to be identical for fractures belonging to the same fracture set and was set to the peak density value. The disc diameter distribution was estimated from the observed trace length distribution. One of the main results obtained from a parameter study of the simulated fracture network was that the medium connectivity was not basically affected if fractures with a radius less than 2 m were excluded. This significantly reduces the number of fractures that have to be generated. The next step in the study was to reproduce the actual location of the fractures. This was achieved by conditioning the simulated fracture field to the observed fracture traces.

The flow through the generated fracture networks was calculated assuming that the flow takes place in a secondary network of one-dimensional hydraulic channels. Two models were calibrated to observed data in such a way that the global properties and the observed heterogeneities of the medium were described. Hence, the two models give by construction the same hydraulic response since calibrated to the same data. The Simplified Random Disk (SRD) model assumes that the nodes of the network are the centers of the fractures and flow occurs through "bonds" joining the center of each disk to the center of any intersecting disk. The Random Channel (RC) model assigns one or more sets of channels to each set of fractures. Inside the plane of a given fracture, each channel is defined by an orientation, a length, and a center. The channel centers are randomly located on the fracture planes. The flow simulations were performed in a 190×160×150 m volume, completely covering the 3-D drift. A zero constant head was imposed in the 3-D drift and a constant head derived from borehole measurements was imposed at the top of the studied volume. All the vertical box faces as well as the bottom of the flow domain were no-flow boundaries.

The calibrated flow models were used for transport modelling. The aim of the transport modelling was to reproduce the global transport properties rather than the exact location of each restitution point or the detailed breakthrough curves corresponding to these points. The breakthrough curve for one of the injected tracers, Eosin B, was chosen for calibration of the transport models. The usual advection-dispersion equation was solved within the channel network using a particle tracking method and the code TRIPAR.

There were only two transport parameters included in the transport models, the dispersivity and a shape factor defined as the ratio between the length and the width of each hydraulic channel. Although the two models by construction give the same hydraulic response, the SRD model is macroscopically less dispersive and transport solutes faster than the RC model. It therefore needs higher dispersivities and lower shape factors to conform to a given curve. In order to simulate correct arrival times with the SRD model, shape factors were needed which imply a generalised flow in the plane of the fractures and therefore basically no channelling effect. The shape factors obtained with the RC model are more compatible with the channel-like arrivals observed in the drift. The parameters calibrated from the Eosin B experiment were used to simulate the breakthrough for another tracer, Uranine. With the SRD model the predicted first arrival time of Uranine into the drift was too short and with the RC model the predicted concentrations were too low (Figure 1). Hence, the parameters determined from the breakthrough curve of one tracer could not be used directly to simulate the breakthrough curve of another tracer. It was suggested that the used parameter values may not be reliable estimates of global rock mass properties because of the no-flow boundary conditions used in the modelling and because of the low recovery of the tracer Uranine in the field experiment.

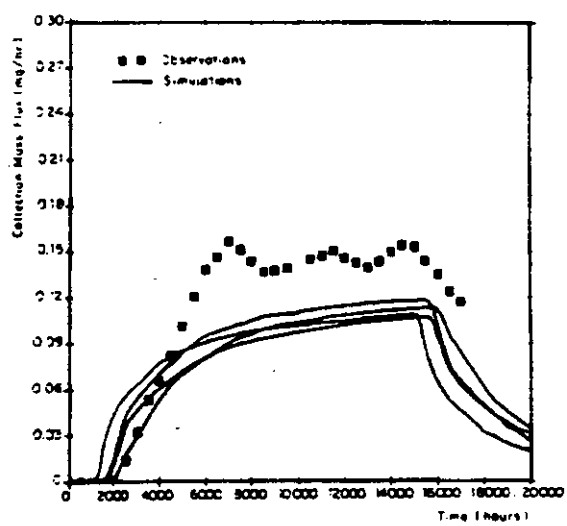

Figure 1. Stripa, BTGM/ANDRA. Observed and simulated mass flux curves for Uranine, Random Channel Model.

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located near Carlsbad in southeastern New Mexico, USA, is an underground research and development repository. It is located in the Delaware Basin, the northern part of which is filled with 8000 m of sedimentary Phanerozoic rocks containing evaporities. Water bearing zones within the rocks that underlie host and overlie the WIPP repository have low permeabilities and storativities. They are generally confined and contain waters with high salinities and long residence times. The repository lies 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado Formation. Overlying the Salado Formation is the Rustler Formation. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is an 8 m thick vuggy dolomite layer.

Geologic, hydrologic, geochemical and isotope data have been collected to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involves the travel time within the Culebra from a location above the repository to the WIPP site boundary. 60 wells into the Culebra dolomite at 41 locations have been completed to provide information on the hydraulic properties. Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed. Geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra.

Analyses by the Project Teams

The Project Team from BGR/BFS has performed some initial modelling regarding regional density dependent flow at the WIPP site. There are not many results or conclusions available so far, since the work has mainly been concentrated on the problem definition and the conceptual model. A vertical regional 2-D section extending almost east-west and intersecting the WIPP site has been chosen for the modelling of flow velocities and salt distribution. The first attempt of the modelling exercise was a simple system considered to be homogeneous. The next step in the work included the high conductive halite formation within the modelled plane. It was then found that the flow velocities within the halite formation were considerably higher than those in the surrounding formations. The latest modelling efforts involve a realistic permeability distribution based on available data and assumptions. The halite formation has not yet been included in the modelling using a realistic permeability distribution.

The Project Team from UPV/ENRESA used stochastic analysis for modelling of the groundwater flow and travel times at the WIPP site. A general problem with kriged fields is that they will become unrealistically smooth, since the variability of the original data will be lost to a large extent. Such smoothing may yield biased responses, particularly for transport problems. By adding perturbations determined at selected locations and interpolated to the remaining points, the spatial structure of the transmissivity field will be preserved. The team applied Monte Carlo methods to generate equiprobable maps of hydraulic conductivity that reflect the variability observed in the field. These conductivity fields are used in flow and transport modelling to obtain different equiprobable output responses. Instead of the turning band method, the common algorithm for stochastic conditional simulations, the team used their own developed conditional sequential simulation method (CSSM). When flow models are run for a series of conditional simulations, the obtained piezometric heads are in most cases found to compare very badly with the observed heads. It is therefore a need and advisable to honor the observed piezometric heads in the stochastical simulations. The following steps were performed to generate stochastic conditioned transmissivity fields honoring piezometric data: 1) application of CSSM to realise conditioning the transmissivity, 2) calculation of the head vector and compare this with the observed piezometric head and, 3) modification of the transmissivity field and boundary conditions within confidence limits, albeit preserving the measured transmissivity values and variability. An objective function was defined as the weighted square difference between observed and computed heads to optimise the solution to this problem. When comparing the heads it was found that the values were somewhat closer, but still quite far from the observed after optimisation (Figure 2). This remaining difference between observed and calculated heads represents the errors due to the applied linear optimisation, indicating that the linear optimisation fails. A more complex objective function will be introduced in future work.

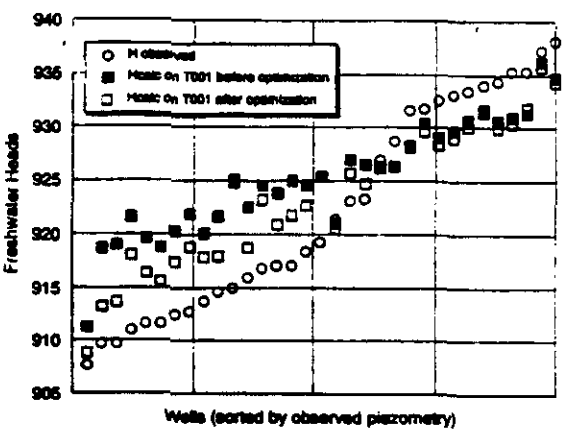

Figure 2. WIPP 2, UPV/ENRESA. Observed and calculated piezometric heads.

The Project Team from Intera presented an automated pilot point inverse technique to generate calibrated conditionally-simulated transmissivity fields. The present model for the Culebra formation uses kriged transmissivity fields to account for the spatial variability and can be calibrated to steady-state and transient pressure fields using the pilot point methodology. Conditional simulations are used to resolve the residual uncertainty not addressed by kriging and the travel time statistics are produced via Monte Carlo simulations. A total of 70 fields have been generated and used for transport calculations. The heads for all these fields were found to be close to those observed. Transport calculations, using the flow model SWIFT II, for these 70 fields indicate travel times between 10000 and 30000 years from the central part of the site to the southern boundary. Although different travel times, there does not seem to be any correlation between goodness of fit for the different fields and the predicted travel time.

The Project Team from SNL presented results from retardation experiments using cores from the Culebra formation. The formation has been found to be very heterogeneous. Different rock types and water chemistry has been found in boreholes separated by just a few meters. However, the team has successfully obtained samples on the Culebra formation water and intact horizontal cores that have been used in column experiments with sorbing and non-sorbing tracers. Core samples with a length of about 10 cm and a diameter of almost 15 cm were used in the column experiments. The samples were fragile and had to be coated with a polyurethane rubber prior to the repressurisation. The experiments started with brine injection until stable conditions were achieved followed by a simultaneous injection of non-sorbing and sorbing tracers. Due to practical considerations, the flow velocity in the laboratory samples were as large as 128 m/year compared to about 0.3 m/year for field conditions. The sorbing nuclides tested so far are: Pb, Eu, and Nd. Tests with U, Pu, Np, Th, Am, Pb, and Ra are being prepared. The experiments performed so far have shown an almost immediate response to the injected tracer, indicating that the primary flow through the Culebra samples is through fractures. Future experiments will be performed using lower flowrates in order to study effects, such as diffusion into the matrix.

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Experimental Set-up

The Gorleben salt dome is located in the northeastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the "Gorleben Channel", more than 10 km long and 1 – 2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel are the topic for this test case.

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out, one in the freshwater and three in the saline water. One of the pumping tests, in which the pumped well penetrated the entire deeper aquifer in the erosional channel, forms the basis for the first part of this INTRAVAL test case. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The second part of the test case is an extension in time and length scales and comprises modelling of regional groundwater flow and salt dissolution as well as interaction between the two.

Analyses by the Project Teams

The Project Team from BFS presented calculations performed on the Weisses Moor pumping test. The specific permeability (3.5×10^{-12} m^2), storage coefficient (5×10^{-4}), and aquifer thickness (44.6 m) have been estimated with an analytical model (Theis solution) using regression technique to minimise the draw-down residuals in the observation wells. The fitted drawdown curve was found to correspond well to that observed. The determined parameters were used in a numerical model to test the influence of well screen location and density distribution on the calculated draw-down values. A two-dimensional mesh corresponding to a 4.8 km wide and 45 m deep rock was generated. The numerical codes used were SUTRA and ROCKFLOW. Calculations were performed for both constant density of the water and a density increase with depth. The boundary conditions in the pumped well was either constant withdrawal along the entire well or constant withdrawal at one or both well screens. Almost identical drawdowns were obtained in the different calculations except for a small influence of the well screen location at early times. A conclusion is therefore that the effect of the well screen location is greater than the influence of taking density dependent flow into account. The density effect would probably have been larger if the duration of the pumping test had been longer than the actual three weeks.

The Project Team from RIVM has analysed the Weisses Moor pumping test. When comparing simulated and observed data on drawdown as function of time it was noted that there could in some cases be large discrepancies. Simulated and observed drawdowns were mostly quite close in the vicinity of the pumping well, but was found to be more deviating some distance away from the well. A few wells located close to the edge of the aquifer did not show any response to the pumping test. No pattern has, so far, been found between smaller/larger interpreted

drawdowns compared to the observed. When studying the thickness of the aquifer it was found that it varies from 0 m up to about 90 m. Furthermore, samples taken in different parts of the aquifer indicate that the composition could be quite different at different locations. It was therefore suggested that one should carefully study the available geological data of the area and include observed heterogeneities when further analysing the pumping test.

The Project Team from SNL presented an evaluation of the hydraulic anisotropy from the Weisses Moor pumping test. Individual well responses were analysed to evaluate the validity of the distance-drawdown approach. This was done with the code INTERPRET/2 which provides an automatic fitting to Theis and other analytical solutions. Fitting of the transmissivity and storativity to the draw-down data generally gives very good fits to the entire draw-down period, but poor fits to the recovery period. The model generally underpredicts the pressure build up in the well during the recovery period, given that lower transmissivities and storativities are obtained if the recovery period is considered (Figure 3).

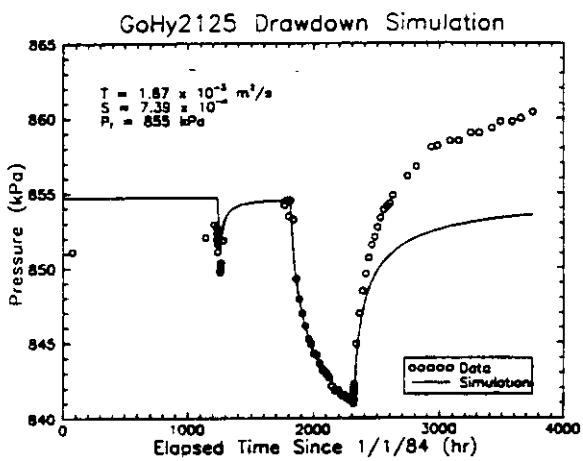

Figure 3. Gorleben, SNL. Fit of transmissivity and storativity to the drawdown data.

The anisotropy in the Gorleben channel was calculated for two groups each consisting of three wells. The horizontal anisotropy of the aquifer was found to be between three and nine, where the larger values were obtained when analyzing the recovery period. It was concluded that an undiscriminating application of the distance-drawdown approach to data from all observation wells does not provide a good indication of the validity of a Theis analysis of the Weisses Moor pumping test.

The Project Team from AEA/NIREX has applied indicator methods to the Gorleben data set. This modelling work include a binary indicator method and uses variograms and kriging for stratigraphic interpolations. The binary indicator approach uses data from boreholes and assigns a number 1 for conductive sections and a 0 for more or less impervious sections, such as clay. Using available data from boreholes in this way and interpolating the indicator function between boreholes by kriging gives estimates of the distribution and variability of the clay formation at the Gorleben site that significantly influences flow and transport predictions. Five boreholes in a vertical section almost perpendicular to the Gorleben channel were selected for comparison between kriged and geological interpretations. It was noted that the long connected features originating from the geological interpretation was not seen when the indicator kriging was applied. Future work with the indicator method will include conditioning by taking known geological structures into account in the model.

The Pilot Group (BGR) has performed numerical studies using the SUTRA code to investigate the density dependent groundwater movement in the Gorleben channel. The objective was to investigate whether steady-state conditions exist in the system today, and also to check the influence of hydrogeological and hydraulic parameters in the model calculations. A two dimensional, 15 km wide and 250 m deep cross-section was selected. The boundary conditions used were no-flow at the bottom, no-flow and no-flux at the sides, linear prescribed pressure at the top with free outflow, and fresh water infiltration. The permeability distribution was developed from a very simplified case in the first calculations to a more realistic description of the hydraulic system by introducing more and more of the observed heterogeneities in the system. A number of long-term (up to several hundred thousand years) simulations to predict the present day density distribution were conducted, starting with different initial conditions for the density distribution. So far the calculations indicate that steady-state conditions have not been reached in the groundwater system in the erosional channel even after a considerably long time. It was also concluded that a realistic picture of the geological setting is essential to be able to predict the present day density distribution. The results of the calculations are dependent on the time-scale of the simulation as well as on the selected initial density distribution, which indicate that additional paleoclimatic information is necessary. It was also concluded that the calculated density distribution is strongly dependent on the transverse dispersivity while an anisotropic longitudinal dispersivity is of secondary importance. The results from the travel time calculations were found to agree well with measured ^{3}H and ^{14}C data. Diffusion has been included in the calculations, but was found to have a negligible effect on the density distribution compared to advection. The work will continue with calculations in a new cross-section, but there are no plans to perform any 3-D calculations.

WIPP 1

Brine flow through bedded evaporities at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository lying 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado formation. This test case is based on experiments performed with the aim to determine the rate of brine flow through the Salado formation. The experiments are designed to provide a variety of data with the aim to determine whether Darcy's law for a porous, elastic medium correctly describes the flow of brine through evaporities, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Data from three types of experiments form the bases for this test case:

- small scale brine-inflow experiments
- pore pressure and permeability testings
- integrated, large scale experiment.

Brine inflow rates are measured at three scales, in 10 cm and 1 m diameter boreholes and in a 2.9 m diameter cylindrical room. Pore-pressure measurements are made in 10 cm diameter boreholes, 2 to 27 m long, drilled at a variety of orientations. The large scale experiments are brine inflow rates to a horizontal, 107 m long, cylindrical room, with a diameter of 2.9 m.

Analyses by the Project Teams

The Pilot Group (SNL/WIPP) presented the latest results concerning the small scale brine inflow experiments. The brine inflow is measured as function of time in a number of 3 to 5 m deep boreholes located in room D, room L4, and the Q access drift. It has been found that the inflow rates increase with time due to improved sealing and the quite heavy ongoing fracturing. The experiments have been going on for about five years and the brine inflow rate has in many of the observation holes more than doubled during the last year (Figure 4). Seismic tomography has been applied to determine the location and extent of fractures.

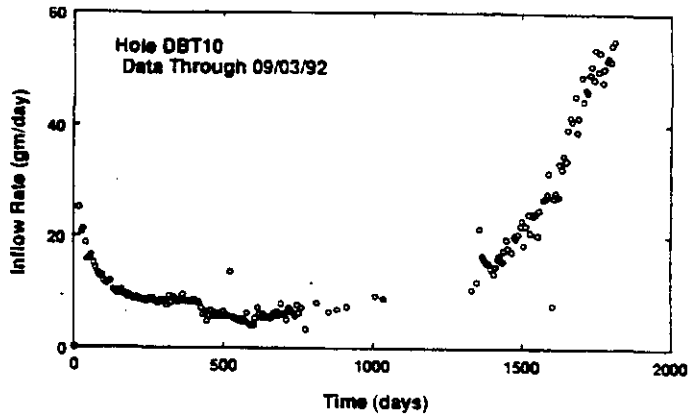

Figure 4. WIPP 1, SNL/WIPP. Brine inflow rate into borehole DBT10.

MOL

Migration experiment in Boom clay formation at the MOL Site, Belgium.

Experimental Set-up

This test case is based on an in situ migration experiment set-up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The purpose of the experiment is to determine migration related parameters and to confirm parameters determined earlier in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

A group of piezometers, a piezometernest, has been installed in the Boom Clay formation at a depth of 220 m. The stainless steel system contains nine piezometers, interspaced by 0.9 m long tubes. A horizontal hole with a diameter of 50 mm and a depth of 10 m has been drilled in the clay formation. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. The steady-state pressure distribution as a function of the depth into the clay is measured by means of manometers.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 (in the center) and thereafter the system was left alone allowing migration of HTO in three dimensions.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters.

The first breakthrough was obtained in filters 4 and 6 located adjacent to the injection filter 5, at a distance of 1 m.

The experiment will continue 10 years after finalisation of INTRAVAL Phase 2 and the number of measured points are limited at the time being.

Analyses by the Project Teams

The Pilot Group (SCK/CEN) presented their modelling of the HTO tracer experiment that now has been running for about 5 years. The Boom clay has been modelled as a homogeneous anisotropic saturated porous medium. The considered governing transport mechanisms has been either advection-diffusion or diffusion only, as one question is whether advective transport is apparent from the existing data due to the very low hydraulic conductivity in the clay. The tracer transport is therefore almost entirely determined by diffusion. The best fit of the diffusion-only-model was obtained with a diffusivity of 4.05×10^{-10} m^2/s, and an almost identical value 4.03×10^{-10} m^2/s was obtained with the advection-diffusion model. Furthermore, almost identical values on diffusivity, conductivity and porosity has been evaluated from this in-situ experiment as found in supporting laboratory experiments. It was pointed out that the observed concentrations in filters 4 and 6 agree very well to those precalculated, giving confidence to the transport model used for prediction of the experimental outcome. The conclusion so far is therefore that the applied conceptual model is valid for prediction of field-scale concentrations and that laboratory scale parameters are valid for field-scale predictions. However, a drawback with the present experiment is that it is one-dimensional and can therefore not be used to study the expected anisotropy in the clay. A new type of experiment has recently been started with the aim to study the 3-D migration of the tracer $^{125}I^-$. As the distance between the filters is only 35 cm in this experiment, the first data point has already been achieved and was found to correspond well with the precalculated concentration at this location. The diffusion accessible porosity is assumed to be about half for I^- compared to HTO due to ion exclusion effects.

The Project Team from CEA-DMT/ANDRA presented modelling efforts and a sensitivity study of the Mol test case. A 3-D transport model that takes advection, dispersion, diffusion and radioactive decay into account was used. The influence of the piezometer pipe on the obtained concentrations was studied by comparing results using an analytical solution for a point injection with results from the 3-D transport model including the actual piezometer pipe. Using the same diffusivities in these two approaches resulted in a concentration difference of about a factor 2, which equals the error introduced when the experiment is evaluated with an analytical solution not taking the piezometer pipe into account.

The data from the HTO experiment have been fitted using linear as well as logarithmic concentrations. The best fits, based on the least square method, for these two approaches gave almost the same horizontal diffusivity (0.375 and 0.35 cm^2/d respectively), but a large difference in the vertical diffusivity (0.35 and 0.225 cm^2/d respectively). A sensitivity analysis including both logarithmic and linear concentrations showed that the experimental layout makes the determination of the horizontal (parallel with the piezometer pipe) diffusivity accurate, which was found not to be the case for the vertical diffusivity or the flow velocity.

ALLIGATOR RIVERS

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

Experimental Set-up

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator Rivers Region is located about 200 km east of Darwin.

Uranium mineralisation occurs at Koongarra in two distinct but related ore bodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium minerals are present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m. The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

An extensive experimental programme including both field and laboratory investigations has resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs from 140 precussion holes and 107 drill cores. Groundwater chemical data has been accumulated from more than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The distribution of uranium and thorium between different mineral phases in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from drill cores. In addition, distribution coefficients have been measured on natural particles present in Koongarra groundwaters.

Analyses by the Project Teams

The Project Team from RIVM presented some preliminary results of nuclide transport modelling at Koongarra. The aim with the work is to reproduce the shape of the dispersion fan in the unweathered zone. Contour plots of observed uranium concentrations in a horizontal plane are similar in shape at different depths in the weathered zone. Based on this it was suggested that uranium dispersion would mainly take place in the transition zone just above the weathering front. In the upper part of the weathered zone the rock is more heavily weathered and the weathering products, clays, reduces the water flow and increases the sorption in this part. The dispersion fan observed at higher levels should then be a more or less "frozen picture" except for any influences of diffusion processes. The similarity in shape of the dispersion fan at different depths also suggests that the groundwater pattern has not changed considerably in the past. The dispersion of uranium was simulated with a simple 2-D advection-dispersion-sorption model. With typical values of flow velocity, dispersivity and retardation factor it was possible to obtain a qualitatively acceptable dispersion fan. A model which takes into account the downward movement of the weathering front and transition zone is currently being developed and will be applied in future modelling work.

The Project Team from KEMAKTA/SKI used uranium and thorium data from the weathered zone at Koongarra to test the applicability of simple transport models generally used in performance assessment. In earlier work, the team simulated the migration of uranium and daughter nuclides using a 1-D advection-dispersion model with linear sorption (K_d-concept). The results showed a fair agreement between calculated and observed migration distance and concentration level of uranium in the solid phase. This model has now been extended to include phase transfer of radionuclides due to weathering and α-recoil. It is assumed that uranium and daughter nuclides in the groundwater are reversibly sorbed onto amorphous iron minerals and clays. By α-recoil and transformation of amorphous minerals to crystalline minerals, sorbed radionuclides are transferred from the accessible phase of the rock to the inaccessible phase of the rock. With parameter values from independent analyses carried out within the Alligator Rivers Analogue Project (ARAP), calculations were performed with two different values of the rate of transfer of radionuclides from accessible to inaccessible phase caused by weathering. The results were compared with observed uranium concentrations and activity ratios in the total rock as well as in the accessible and inaccessible phases of the rock. No significant improvement of the simulation of uranium concentration and activity ratios was obtained with the extended model and the assumed values of the phase transfer rate compared to the results of the simple model. However, it cannot be excluded that other combinations of phase transfer rate and sorption coefficient would give a better agreement between calculated and observed data.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer. Canada.

Experimental Set-up

Aquifer testing ranging from a large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The groundwater table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

The large experimental programme includes 20, 40 and 260 m natural gradient tracer (^{131}I and HTO) experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation and gamma scanning is performed through the full aquifer.

The database contains hydrogeologic data (stratigraphic information, hydraulic conductivity, porosity, groundwater flow velocity), tracer concentrations, etc.

Analyses by the Project Teams

The Pilot Group (AECL) has critically evaluated the usefulness of hydraulic conductivity data, determined on the basis of head measurements or empirical relationships, for heterogeneity characterisation and contaminant transport predictions. The conventional approach of quantifying aquifer heterogeneities is based on characterisation of the spatial pattern of hydraulic conductivity and it has been found that the inherent variability to a large extent is lost, since measured hydraulic conductivities are based on mean values for the medium. Furthermore, estimation of conductivity heterogeneities by calibrating a flow model against measured head data is deemed to be inappropriate, because heads are not particularly sensitive to conductivity variations. It was therefore suggested that the most reliable approach to account for local heterogeneities is to measure velocities and velocity variations rather than conductivities. The drawback is, however, that the velocities are usually very low implying measurement problems. A parameter set based on local scale dispersion was found to give good agreement to observed concentrations in a tracer test compared to another parameter set based on hydraulic conductivity values obtained from grain size analysis which gave rather poor agreement to the same data.

The Project Team from EDM/CEA/IPSN has used data from the Twin Lake tracer experiments to study mass transport with high Peclet numbers. Sharp fronts implying high Peclet numbers usually indicate modelling problems due to the small spatial and time steps that have to be used. The team presented a new numerical code that can be used for flow and mass transport in 2-D, where advection and dispersion are separated giving no Peclet number constraints. Unknowns, such as concentration and/or head, are approximated using arbitrary order Lagrange polynomials. The advective term is treated by backtracking along characteristic lines of flow. The advantage with this code using "spectral elements" compared to classical codes is that stable solutions are achieved even if large timesteps are used when the Peclet number is large. However, too long time steps will increase the time needed for the backtracking. The code can so far be used for 2-D simulations, but a 3-D extension is underway.

The Project Team from CEA/ANDRA raised the question whether stochastic modelling applied to the Twin Lake site can be performed. The team has analyzed the data from the 40 m tracer experiment and concluded that the experiment cannot be used to evaluate important parameters like the horizontal covariance of the hydraulic conductivity and the horizontal correlation length.

The Project Team from JAERI presented some preliminary modelling results of the Twin Lake tracer test. A 2-D vertical section has been modelled using an advection-dispersion model. The code MIGINT was used to generate hydraulic conductivities, porosities, retardation factors, as well as various statistical distributions and correlation lengths among these parameters. The data generated by MIGINT was used to calculate groundwater flow and nuclide transport with the finite element code MIG2DF. When conditioning the model to measured hydraulic conductivities, it was found that the observed tracer plume could not be reproduced which might be explained by heterogeneities in the system. The small dispersion length caused large computational problems, why the mesh size will be reduced in future calculations and a new numerical method will be applied.

Distribution of Background Information

Background information and databases are distributed to the INTRAVAL Participants either by the Secretariat or directly from the Pilot Groups according to Table 4.

Table 4. Distribution of background information.

Test Case	Distributor
Las Cruces Trench	Pilot Group, T. Nicholson, NRC[1)]
Apache Leap	Pilot Group, T. Nicholson, NRC[1)] and T. Rasmussen, UoG[1)]
WIPP 2	Pilot Group, E. Gorham, SNL[1)]
Finnsjön	Secretariat[2)]
Stripa	Secretariat[2)]
Gorleben	Pilot Group, K. Schelkes, BGR[1)]
WIPP 1	Secretariat[2)]
Mol	Secretariat[2)]
Alligator Rivers	Secretariat[2)]
Twin Lake	Secretariat[2)]
Yucca Mountain	Pilot Group, C. Voss, USDOE[1)]

1) Full organisation name, see List of Intraval Participants in Appendix 1

2) Kemakta Consultants Co., P.O. Box 12655, S-112 93 Stockholm, Sweden

Appendix 1

INTRAVAL Organisation

The organisation of the INTRAVAL study is regulated by an agreement which has been signed by all participating organisations (Parties). The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Managing Participant sets up a Project Secretariat in cooperation with Her Majesty's Inspectorate of Pollution (HMIP/DoE), U.K. and the Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA). KEMAKTA Consultants Co. is contracted by SKI to act as Principal Investigator within the Project Secretariat.

The Parties organise Project Teams for the actual project work. Each Party covers the costs for its participation in the study and is responsible for the funding of its Project Team or Teams, including computer cost, travelling expenses, etc.

A Pilot Group has been appointed for each Test Case in order to secure the necessary information transfer from the experimental work to the Project Secretariat and the Project Teams. The Project Secretariat coordinates this information transfer.

At suitable time intervals, depending upon the progress of the study, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group. During the workshops, Test Case definitions and achieved results are discussed as a preparation for decisions in the Coordinating Group.

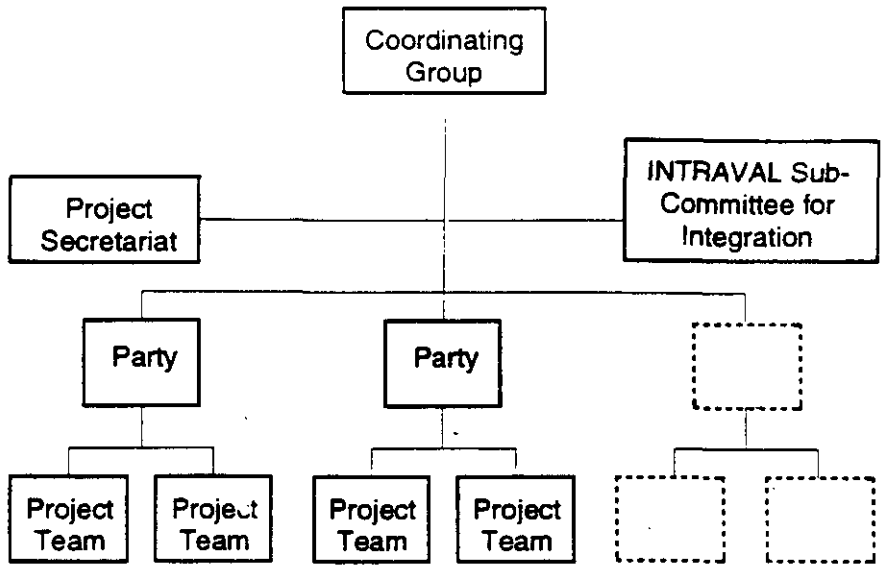

Figure 5. INTRAVAL Organisational Chart.

Managing Participant: SKI

Coordinating Group:

Chairman	J. Andersson, SKI
Vice Chairman	T. Nicholson, U.S. NRC
Secretary	B. Dverstorp, SKI

Principal Investigator: KEMAKTA Consultants Co.

Project Secretariat:

J. Andersson, SKI
L. Birgersson, KEMAKTA
B. Dverstorp, SKI
M. Ericsson, KEMAKTA
P. Jackson, AEA Technology
Å. Larsson, KEMAKTA
J.P. Olivier, OECD/NEA
K. Pers, KEMAKTA
K. Skagius, KEMAKTA

List of INTRAVAL Participants

Party and Coordinating Group Member		Project Team(s) and Team Leader(s)	
Agence Nationale pour la Gestion des Déchets Radioactifs, France L. Dewiere	(ANDRA)	Commissariat à l'Energie Atomique M. Durin	(CEA/DMT)
		Bureau de Recherches Géologiques et Minières J.P. Sauty	(BRGM/STO)
Atomic Energy of Canada Ltd., Canada T. Chan	(AECL)	Atomic Energy of Canada Ltd. T. Chan (AECL-WR) G. Moltyaner (AECL-CRL)	(AECL)
Atomic Energy Control Board, Canada D. Metcalfe	(AECB)	Atomic Energy Control Board, D. Metcalfe	(AECB)
Australian Nuclear Science and Technology Organisation, Australia	(ANSTO)	Australian Nuclear Science and Technology Organisation	(ANSTO)
Bundesanstalt für Geowissenschaften und Rohstoffe/Bundesamt für Strahlenschutz, Federal Republic of Germany K. Schelkes	(BGR/BfS)	Bundesanstalt für Geowissenschaften und Rohstoffe K. Schelkes	(BGR)
		Bundesamt für Strahlenschutz H. Illi	(BfS)
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Appendix 2

Intraval Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media performed at Las Cruces, New Mexico, USA.

Overview

This test case is based on experiments performed at the New Mexico State University College Ranch, 40 km northeast of Las Cruces, New Mexico, USA. Water and tracers were applied at a carefully controlled rate to the surface of an experimental plot. The motion of water and the transport of various tracers through the unsaturated vadose zone was monitored. This test case was also included in INTRAVAL Phase 1. During Phase 1 data for site characterisation and model calibration were collected. In Phase 2 the models calibrated during Phase 1 will be used to predict water flow and solute transport in a new experiment (Plot 2b).

Experimental Design

A trench 16.5 m long, 4.8 m wide and 6.0 m deep has been dug in undisturbed soil. Two irrigated areas measuring 4 m × 9 m and 1 m × 12 m respectively are adjacent to the trench (Figure 6). In the first experiment (Plot 1) water containing tritium was applied at a controlled rate of 1.8 cm/day on the area sized 4 m × 9 m. The movement of water below the soil surface was monitored with neutron probes and tensiometers. Soil solution samples were taken to determine the movement of tracers below the surface of the soil. The movement of the water front was also observed visually on the trench wall. In the second experiment (Plot 2a) water containing tritium and bromide was applied at a rate of 0.43 cm/day on the area sized 1 m × 12 m. These two experiments were used during INTRAVAL Phase 1. In the third experiment (Plot 2b) tritium, bromide, boron, chromium and the organic compounds pentafluorobenzoic acid (PFBA) and 2,6-difluorobenzoic acid (DFBA) were added with the water on the area sized 1 m × 12 m.

Available data

- water retention data
- density profiles
- particle-size analysis data
- saturated hydraulic conductivities (laboratory and in situ)
- water content
- tensiometer data
- solute concentration

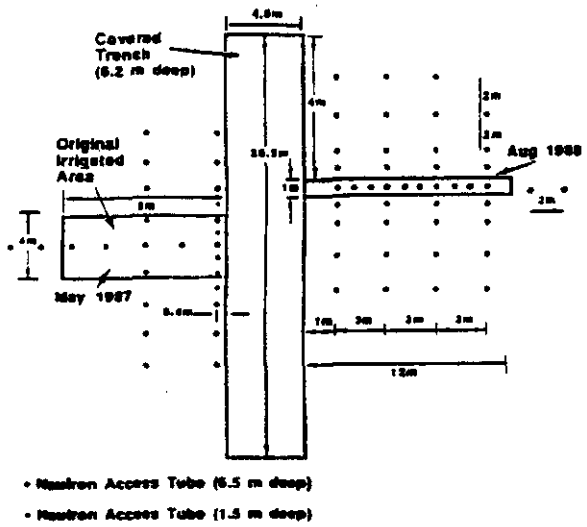

Figure 6. Las Cruces. Top view of the trench with irrigated areas.

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Overview

The Apache Leap Tuff Site in tuffaceous rock is situated near Superior, Arizona, USA (Figure 7). The tuff formation is approximately 600 m thick and grades from a densely welded unit near its base to a slightly welded tuff which has a total porosity of 17%. The unsaturated zone extends to great depths due to topography and to pumping associated with a nearby underground mine. The Apache Leap Test Case in INTRAVAL Phase 2 concentrates mainly on two topics, how a thermal source dramatically affect air, vapour, water and solute movement in geologic media, in particular unsaturated fractured rock, and to investigate the water and air transport properites of fractures and rock matrix of unsaturated rock.

The effects of a thermal source are studied with laboratory nonisothermal core measurements, whereas the behaviour of fractures and other macropores are investigated in a series of laboratory measurements conducted on a block of Apache Leap Tuff having a single discrete fracture. In addition to these laboratory experiments there are plans to perform field investigations that will provide multiscale estimates of permeability at Apache Leap Site, information regarding mechanisms affecting the flow of fluids in fractured rock, and data for validation of flow models. The field experiment programme outline contributes to the characterisation of permeability distribution of a selected portion of the site using single-borehole pneumatic tests, pneumatic cross-borehole tests, gas tracer tests, and hydraulic tests. Most of the data from the planned field experiments cannot be expected until after the end of INTRAVAL Phase 2.

Laboratory Nonisothermal Core Measurements

A cylindrically shaped core approximately 12 cm long and 10 cm in diameter was extracted from a block of Apache Leap Tuff (white unit). The large core, termed the "mother" core, is used for the experiment, while smaller, "daughter" cores were also extracted from the block for characterisation purposes. The mother core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses on all surfaces, and to minimise heat loss along the sides of the core.

During the experiment, a horizontal temperature gradient was established along the long axis of the core. Thirteen thermistors were situated along the core at approximately 1 cm intervals to record temperature over time (about twice weekly). A dual-gamma source was used to determine the water and solute content along the core over time.

The daughter cores were used to provide characterization data regarding porosity, moisture characteristic curves (including hysterisis effects), saturated and unsaturated hydraulic conductivity, and saturated and unsaturated air permeabilities. Similar data from 105 core segments at the Apache Leap Tuff Borehole Site were also available.

The simulation objective is to reproduce the core water content and solute concentration profiles using characterisation data and observed temperatures. The simulation output will consist of mean water contents and solute concentrations along 1 cm slices at 0.5 cm increments along the length of the core for selected times. The output will also consist of predicted temperatures at 1 cm intervals. The temperature measurement should be considered a point measurement.

Laboratory Isothermal Fractured Block Measurements

A block of Apache Leap Tuff (white unit) measuring 92.5 cm in length, 21.0 cm in height and 20.2 cm in width contains a fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent (~ 150 MPa). The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The positions of the wetting front in the fracture over time and the positions of the wetting front in the matrix over time were recorded.

The simulation objective of this problem is to reproduce the movement of a wetting front of water in a fractured, unsaturated rock using characterisation data and observed fracture inflow volumes over time. The simulation output should be wetting front positions in the fracture and rock matrix over time. Observed characterisation data can be used to calibrate the model, together with inflow data collected during the experiment.

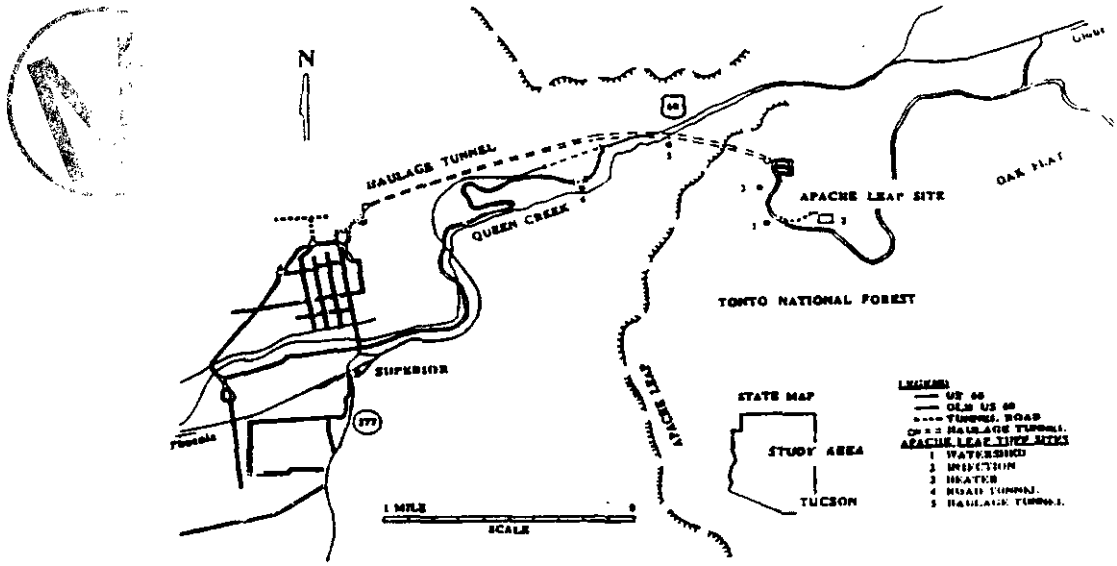

Figure 7. Location of testing facilities at Apache Leap Tuff site.

Available data

Core Measurements

- rock matrix porosities
- initial water contents
- temperatures

A set of data collected prior to the heater experiment may also be useful for calibration purposes. Before the thermal experiments were conducted, the circumference of the mother core was sealed, while the two ends were left open. The core was fully saturated and then one end of the core was placed on a pressure plate and a 5 bar (500 kPa) pressure was applied. The total weight of the core was measured on various dates, and used to develop a time series of core saturations. Additional data are also available from tests performed on daughter cores collected near the core used in the nonisothermal experiment.

Block Measurements

- rock matrix sorptivity coefficient
- rock matrix porosity
- rock fracture aperture
- cumulative inflow volume over time

Data from the Apache Leap Tuff Borehole Site related to rock matrix physical and hydraulic properties, including porosity, bulk density, rock matrix moisture characteristic curves and unsaturated hydraulic conductivity, are also available.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

Overview

The Finnsjön research area is located approximately 130 km north of Stockholm and 15 km from the Baltic sea. The bed rock within the site is crystalline rock of Svecokarelian age (about 1800 – 2100 Ma). The experiments have been performed in a major low angle fracture zone, Zone 2, located in the Brändan area (1 km^2), a sub-area within the Finnsjön research area. The Finnsjön tracer experiments are part of the Fracture Zone Project, initiated and supported by the Swedish Nuclear Fuel and Waste Management Company (SKB).

The project involves detailed characterisation of Zone 2, including a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole test. The interference test and the radially converging test were used in modelling during INTRAVAL Phase 1. During INTRAVAL Phase 2 the modelling of this test case will continue to include also the dipole experiment.

Experimental Design

Zone 2 is penetrated by six diamond core drilled boreholes and three precussion drilled boreholes (Figure 8) at depths ranging between 100–350 m.

Two tracer experiments were carried out, one in a radially converging flow geometry and one in a dipole flow geometry. In the radially converging experiment, tracer injections were made in three peripheral boreholes situated in different directions from a withdrawal hole. The distance from the injection holes to the withdrawal hole is in the order of 150 to 190 m. Three sections were packed off in each injection hole, one in the upper highly conductive part of Zone 2, one at the lower boundary, and one at the most highly conductive part in between. Non-sorbing tracers were injected in nine different intervals of the zone. Totally eleven different tracers were injected, eight of them continuously for 5–7 weeks and three as pulses. First arrivals in the withdrawal hole ranged from 22 to 3500 hours.

The dipole experiment was performed after the radially converging experiment using the same hole for withdrawal and one of the other holes for injection. The two other holes used for injection in the radially converging test were used as observation holes in the dipole experiment. Only the upper highly conductive part of Zone 2 was used for tracer injection in this experiment. Totally 15 injections of tracers were made during 7 weeks. Pulse injection of both sorbing and nonsorbing tracers were made. The water pumped from the withdrawal hole was recirculated to the injection hole.

Prior to the start of the radially converging test, a series of hydraulic interference tests was performed in order to determine the hydraulic properties of Zone 2. Pressure responses were registered in packed-off sections in all bore holes in the Brändan area during pumping of the hole later used as withdrawal hole in the tracer experiments. In conjunction with the interference test, a preliminary tracer test was performed in order to optimise the design and performance of the planned radially converging tracer experiment.

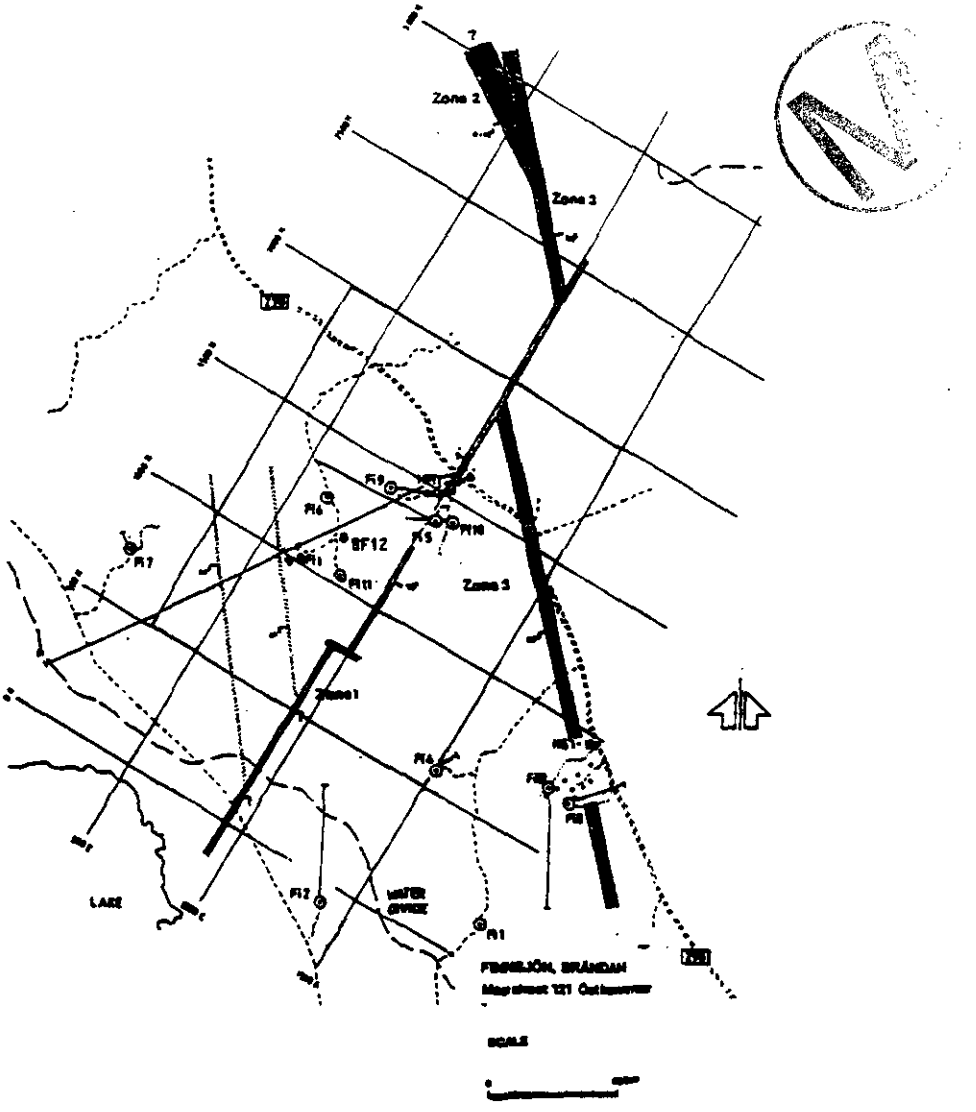

Figure 8. Finnsjön. Borehole location in the Brändan area.

Available data

Interference Tests

- primary drawdown responses
- graphs of the recovery of groundwater head after pumping stops
- tracer injection information
- tracer breakthrough curves

Radially Converging Experiment

- tracer breakthrough curves
- tracer injection information
- groundwater levels
- relative hydraulic head differences
- temperature and electrical conductivity of pumped water

Dipole Experiment

- tracer breakthrough curves
- tracer injection information
- hydraulic heads and groundwater levels
- temperature, electrical conductivity and redox potential of the pumped water

In addition, geological data are available from a surface survey of the Brändan area as well as from borehole investigations. Hydraulic data are available from hydraulic testings. Data on porosities and diffusivities have been determined in the laboratory.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiment, Sweden.

Introduction

This test case is based on the three dimensional tracer test performed in the Stripa mine in Sweden. This experiment was also part of INTRAVAL Phase 1. In addition to the 3-D experiment, data from two other experimental programmes performed in the Stripa mine, the "Site characterisation and Validation Programme (SCV)" and the "Channelling Experiments" are available during INTRAVAL Phase 2. The experiments were performed within the OECD/NEA International Stripa Project.

In the 3-D experiment water and tracers were collected in a number of plastic sheets. The main purpose of the 3-D experiment was to investigate the spatial distribution of water flow paths in a larger block of rock.

The Site Characterisation and Validation Programme includes a number of investigation steps to characterise an unexplored rock volume starting with a few long boreholes and ending with a new drift being excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

The Channelling Experiments comprise information about channelling in individual natural fractures on a length scale of 2 m.

General Description

3-D Experiment

A drift has been excavated in the Stripa mine at 360 m below the ground. The drift is 75 m long and has two side arms with a length of 12.5 m each. Three vertical holes for injection of tracers have been drilled upwards with lengths of 70 m (Figure 9).

The ceiling and large parts of the walls in the drift were covered with plastic sheets, each sheet with an area of about 2 m^2. A total number of about 350 sheets served as sampling areas for water emerging into the upper part of the test drift. The sampling arrangements completely covered a surface area of 700 m^2. The spatial distribution of water flow pathways could thus be obtained.

Injections of conservative tracers were carried out from a total number of nine separate sections with increased permeability within the three vertical holes, each zone about 2.5 m in length. The injection zones were located between 10 and 55 m above the test site. The tracers were injected continuously for nearly two years. The injections were carried out with a "constant" over-pressure, approximately 10–15 % above the natural pressure.

The concentrations of the injected tracers were between 1000 and 2000 ppm and the different flow rates varied from 1 to 20 ml/h. The following tracers were injected: Uranine, Eosin Blueish, Eosin Yellowish, Phloxine B, Rose Bengal, Elbenyl Brilliant Flavine, Duasyn Acid Green, bromide and iodide.

The natural inflow of water to the drift was measured before drilling the injection holes. The results from the water monitoring show that water does not flow uniformly in the rock over the scale considered (700 m^2), but seems to be localised to wet areas with large dry areas in between. Measurable amounts of water emerged into 113 of the 350 sampling areas. Out of these "wet" sampling areas 10 % gave more than 50 % of the total water inflow.

After six months of injection, tracers from at least five injection zones could be found in about 35 sampling areas. After almost two years of injection, about 200 different tracer breakthrough curves were obtained. Each curve is based on several hundred individual measurements. Smoothed curves consisting of approximately 40 points are available as computer files.

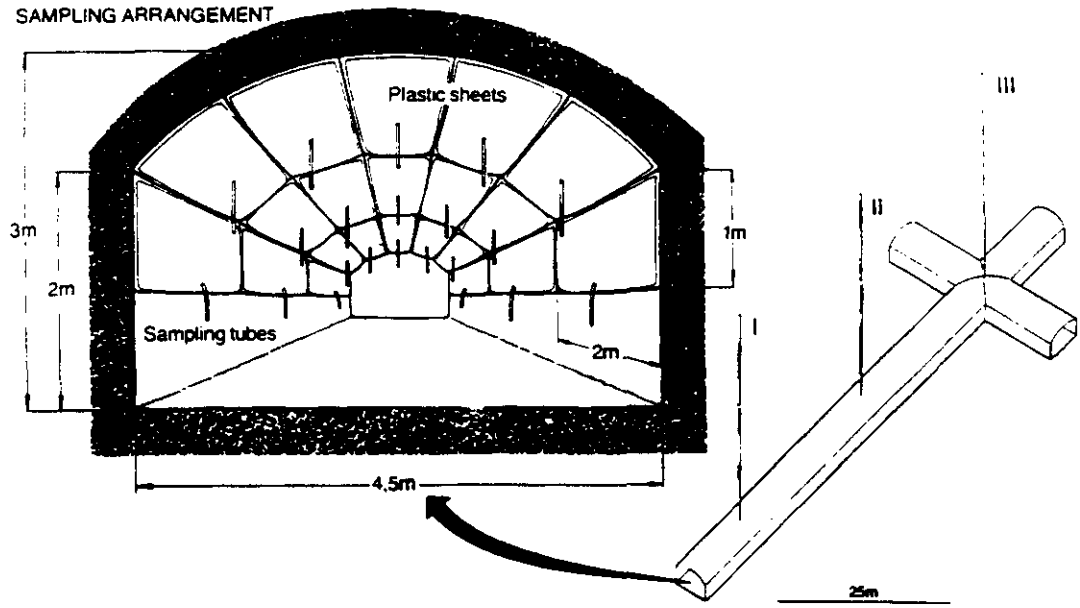

Figure 9. Layout of experimental 3-D drift at Stripa and sampling arrangement.

Site Characterisation and Validation Programme

The original aim of the project is to predict groundwater flow and tracer transport in a previously unexplored volume of the Stripa granite. The rock volume selected for detailed characterisation is about 125× 125× 50 m and is located at 360 to 410 m below ground. The investigations of the rock volume have been performed in a number of steps, including modelling predictions between the different experimental steps. In the first investigation five 150–220 m long boreholes and one 50 m long were drilled. These holes were used to characterise the rock volume by core logging, hydraulic tests (down to 1 m sections), radar and seismics.

Thereafter three new 100–150 m long holes were drilled. Information from these holes were compared with made predictions, based on information from already investigated holes, concerning water bearing sections, fractures etc. Next six 100 m long boreholes, were drilled in the same direction as the new drift would be excavated. The water flow and its distribution were measured in these holes. The holes were also used for a tracer (salt) experiment.

Finally a new drift, 50 m long and 2.4–2.9 m in diameter, was excavated. The new drift was equipped with plastic sheets (1–2 m^2) and other water collection devices. The drift cut through one 5-10 m wide major fracture zone, which gave more than 99% of the total water inflow. Tracer experiments were performed in this fracture zone from seven spots located in four boreholes 10–25 m away from the drift (Figure 10). For this purpose two new boreholes had to be drilled. In each spot two non-sorbing tracers were injected. The tracers were sampled in the plastic sheets and in the other water collecting devices covering the lower parts of the walls and the floor of the drift.

Channelling Experiments

The channelling experiments consist of three different types of test: the "single hole experiments", the "double hole experiment", and the "tracer test".

To be able to investigate the fracture characteristics along a fracture plane, a large diameter (200 mm) hole, was drilled along a planar fracture plane to a depth of about 2.5 m. A multi-pede packer (Figure 11) was used to inject water all along the fracture plane.

The injection flow rates were monitored separately for the left and right side of the hole over 80 short sections. The fracture intersections were scrutinised to obtain data on fracture properties such as open fracture area, number of intersections, and thickness of infilling. Before the multi-pede was used, the boreholes were tested with coarser tests. The multi-pede was used in 5 boreholes, whereas in total 12 holes were drilled.

The double hole experiment was performed in a fracture, where the single hole test has shown that channels existed. A second hole was drilled in the same fracture plane at a distance of 1.95 m from the first hole. Prior to the injection of water for detailed pressure tests, more coarse tests were performed. In the detailed pressure pulse tests, water was injected in one of the holes at a section of 50 mm × 50 mm and monitored in the other hole in twenty sections along the fracture intersection. This experiment was repeated with the injection sections at different positions. The test was then reversed, i.e. injection was performed in the second hole and monitoring in the first hole.

In the tracer test five non-sorbing tracers were injected from five 50 mm sections, that had been found to be the most conductive in one borehole, and

were monitored in the other hole (see the double hole experiment). To obtain a linear flow for the tracers, water was injected with the same pressure as used for the tracers from the remaining 15 sections. The tracers, Uranine, Eosin Yellowish, Ebenyl Brilliant Flavin, Duasyn Acid Green V and Phloxine B were injected continuously during four weeks.

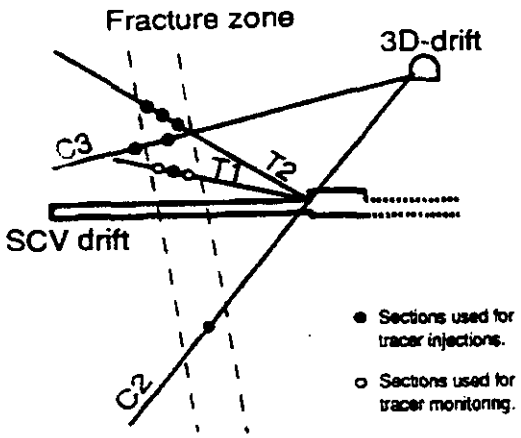

Figure 10. Stripa. Layout of tracer experiment (SCV).

Summary of Available Data

3-D Experiment

- water flow rates
- tracer concentration in water to test site
- rock characteristics and fracture data
- water chemistry
- injection pressures and injection flow rates
- hydrostatic pressures
- diffusivity and sorption data
- daily logs

Site Characterisation and Validation

- core logging and fracture mapping in drifts
- geophysical single hole logging
- rock stress measurements
- borehole radar
- borehole seismics
- hydraulic investigations
- hydrochemisty
- water flow rates
- tracer breakthrough curves

Channelling Experiments

- number of fractures
- number of intersections
- information about infilling
- fracture lengths
- opening area of fractures
- pressure response
- tracer breakthrough

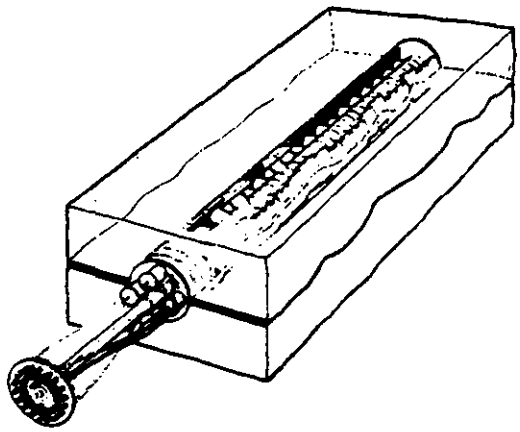

Figure 11. Stripa. Design of the multiped packer (Channelling Experiments).

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on experiments performed in Culebra Dolomite at the WIPP site. The WIPP, located in Carlsbad, New Mexico, USA., is an underground research and development repository lying 655 m below ground surface within bedded evaporites, primarily halite, of the Salado Formation. Overlying the Salado Formation is the Rustler Formation (Figure 12).

System	Series	Group	Formation	Member
Recent	Recent		Surficial Deposits	
Quarter-nary	Pleisto-cene		Mescalero Caliche	
			Gatuna	
Triassic		Dockum	Undivided	
Permian	Ochoian		Dewey Lake Red Beds	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				Unnamed
			Salado	
			Castile	
	Guada-lupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

Figure 12. WIPP area stratigraphic column.

The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is a 8 m thick vuggy dolomite layer. The test case will be focussed on the hydrology of this zone. A central issue is the travel time within the Culebra from a location above the repository to the WIPP site boundary.

Description of the Experiments

Extensive investigations of the Culebra Dolomite have been made including detailed investigation of numerous surface features for the purpose of delineating subsurface features of irregularities that could affect flow in and around the Culebra.

Sixty wells drilled to the Culebra dolomite at 41 locations provide information on the hydraulic properties (Figure 13). Large variations in transmissivity related to fracturing have been identified.

Test data from three wells in the southeastern part of the site (DOE-1, H-3, H-11) indicate the presence of a zone of relatively high transmissivity within an area of otherwise low transmissivity.

Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed in the vicinity of the above described high transmissivity zone. One pumping test and one tracer test were performed near the center of the WIPP site near what is believed to be the northwestern edge of the high transmissivity zone. The other pumping test and tracer test were performed in the high transmissivity zone near the southern site boundary.

In addition, geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra. These data have been used to demonstrate that the age of the Culebra waters is of the order of 10 000 years, and that the waters originated during a known pluvial period.

Objectives of the Test Case

A number of different objectives are identified:

- to determine if the hydraulic data support the derived transmissivity distribution and/or the model boundary conditions
- to evaluate the consequences of and the uncertainty in the derived transmissivity
- to determine the resolution in transmissivity needed for long time (10 000 years) predictions of radionuclide travel time
- to calculate the uncertainty in predictions of radionuclear travel time
- to determine if the paleoflow directions inferred from the geochemical/isotropic data could be reproduced using current transmissivity distribution and boundary conditions altered to simulate increased rainfall
- to determine if halite and gypsum dissolution will take place in the next 10 000 years in the Culebra, resulting in an alteration of the transmissivity distribution
- to determine if the hydrologic evidence is sufficient to rule out a significant effect on transport of karst features

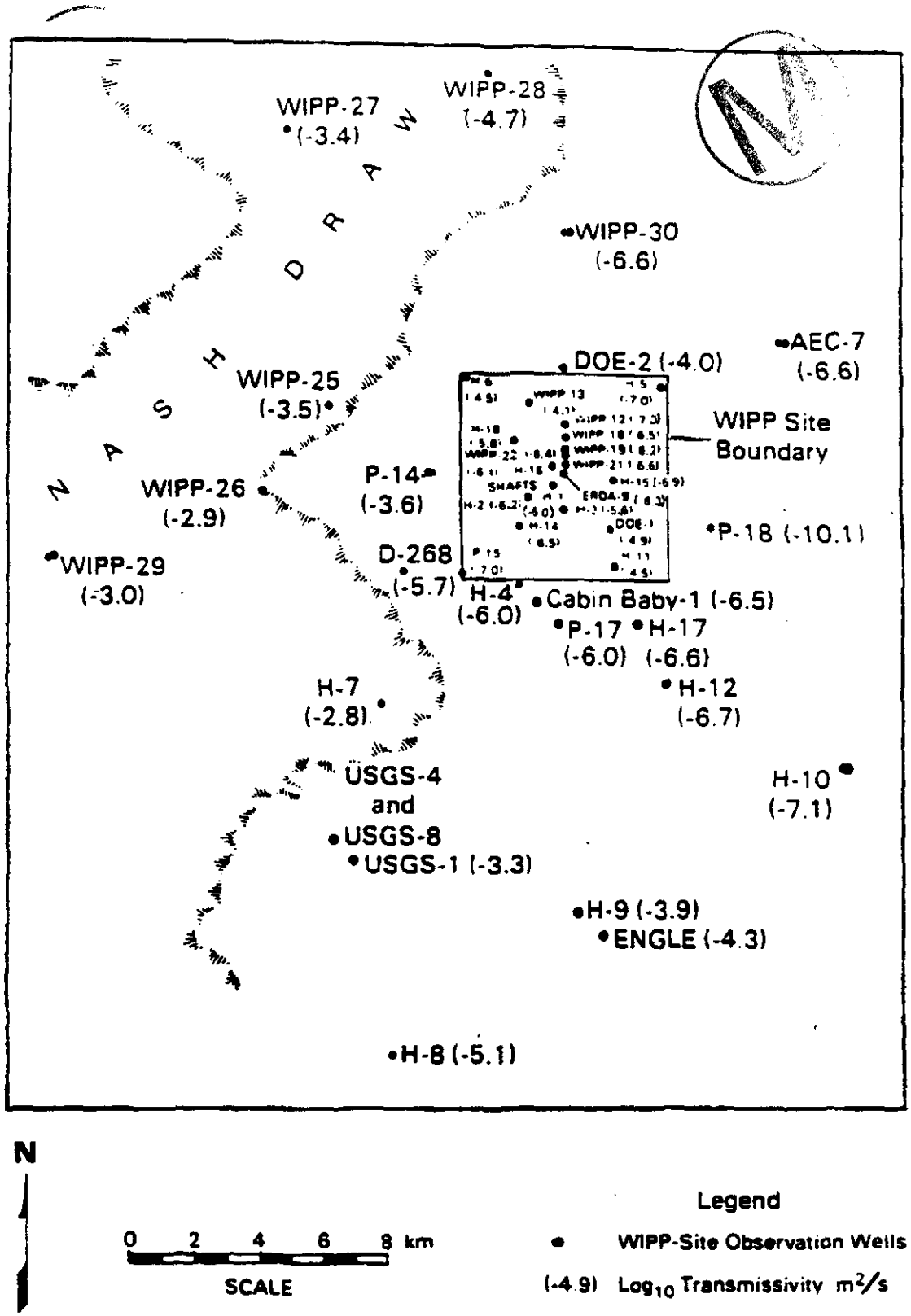

Figure 13. WIPP 2. Culebra Wells and measured transmissivity near the WIPP site.

Available Data

The data base for this test case is very large and contains:

- UTM coordinates and surveyed elevations for all wells
- core logs and/or geophysical logs from all well locations
- geochemical and isotope data (major ion concentrations, density, etc.) from all well locations
- raw and interpreted hydraulic test data from all well locations
- raw and interpreted tracer test data
- core porosity and permeability data from tracer-test and other locations
- water-level data (hydrographs) from time of well construction to present for all wells
- estimated steady-state hydraulic heads at all well locations
- calibrated steady-state regional groundwater flow model
- calibrated transient regional groundwater-flow model

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Overview

The Gorleben salt dome is located in the northeastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the "Gorleben Channel", more than 10 km long and 1–2 km wide, crosses the salt dome from south to north. Erosion along the channel tends down to the cap rock (a result of the dissolution process of salt in groundwater) and in some places down to the salt. In the channel, fairly thick sandy sediments with interbedded lenses of till are overlain by a complex of silt and clay up to 100 m thick. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel is the topic for this test case. The groundwater movements in such an aquifer system depend to a large degree on the salinity, which influences the water density.

Experimental Design

Hydrogeological investigations have been conducted in an area of about 300 km² around the salt dome. During these investigations four pumping tests were carried out: one in fresh water and three in saline water. During these tests information were obtained on boundaries, hydrogeological structure, connections between different aquifers, and hydraulic parameters (permeabilities, storage and leakage coefficients). In one of the pumping tests the pumped well penetrated the entire deeper aquifer in the erosional channel (Figure 14).

The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The density of the water ranges from 1010 to 1200 kg/m^3. This pump test will form the basis for the first part of this INTRAVAL test case. The second part is to model the regional groundwater flow, the salt dissolution and their interaction.

Available Data

The data available from the selected pumping tests are:

- borehole locations (maps)
- hydrogeological data (groundwater levels etc.)
- pumping test data (hydrographs, salinometer logs, pumping rates, electric conductivities, temperatures, densities, etc.)

Large amounts of data are also available from other tests performed in the area.

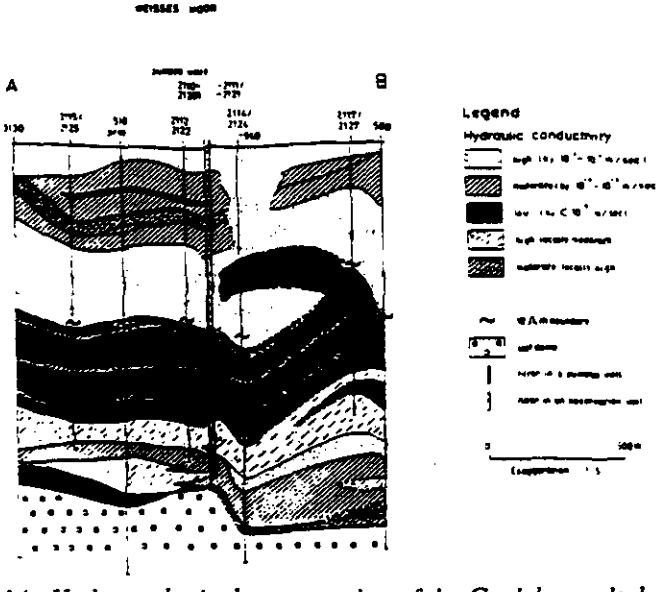

Figure 14. Hydrogeological cross section of the Gorleben salt dome.

WIPP 1

Brine flow through bedded evaporites at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Overview

This test case is based on one experiments performed with the aim to determine the rate of brine flow through WIPP bedded evaporites. The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository (Figure 15) lying 655 m below ground surface within bedded evaporites, primarily halite, of the Permian Salado Formation.

Three geologic formations are important to the expected performance of the WIPP: the Salado formation, in which the repository is located; the Rustler formation, which contains an aquifer overlying the Salado formation; and the Castile Formation, which underlies the repository and contains pockets of pressurised brine. The hydraulic behaviour of the Salado Formation is the focus of the present test case. The experiments are designed to provide a variety of data with which to determine whether Darcy's Law for a porous, elastic medium correctly describes the flow of brine through evaporites, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Experimental Design

Data from three types of experiments will form the bases for this test case:

- small scale brine inflow experiments
- pore pressure and permeability testing
- integrated, large scale experiment

Small Scale Brine Inflow Experiments

Brine inflow rates are being measured at three scales: in 10 cm and 1 m diameter boreholes and in a cylindrical room with 2.9 m diameter (see large scale experiment). The boreholes are orientated vertically downward or horizontally and extend from 3 to 6 m. The boreholes are monitored for brine inflow (Figure 16) and relative humidity. The humidity measurements aid in quantifying the total moisture entering a borehole.

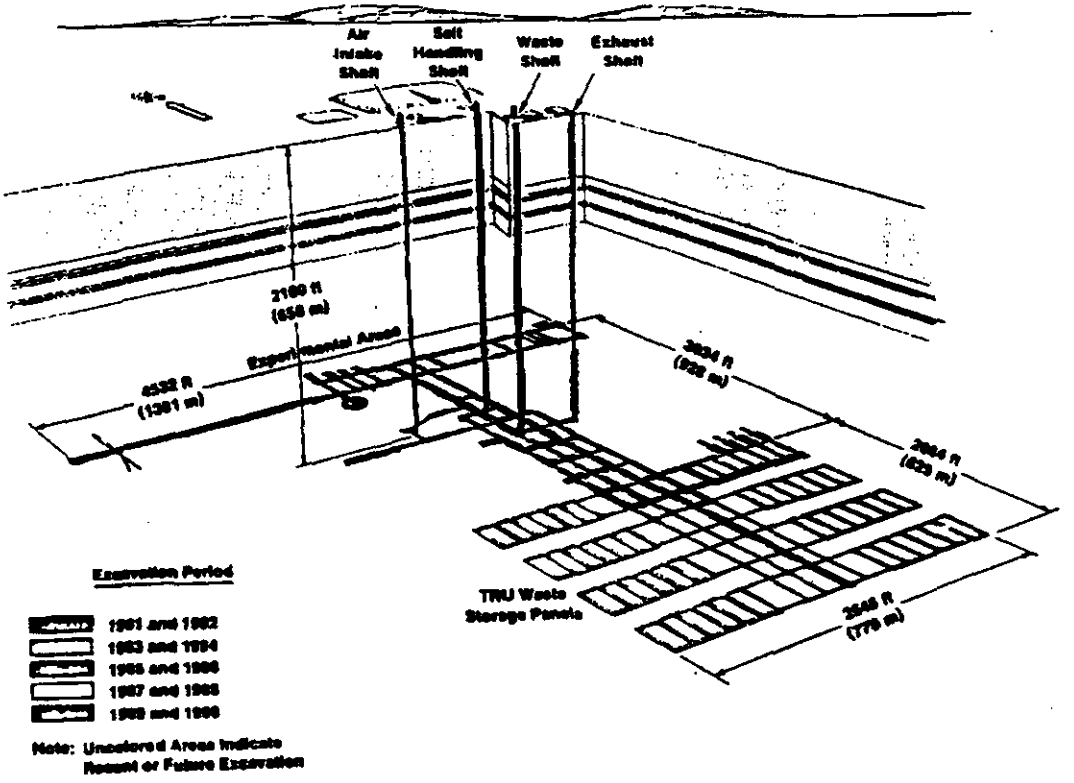

Figure 15. WIPP 1. Schematic view of the WIPP site.

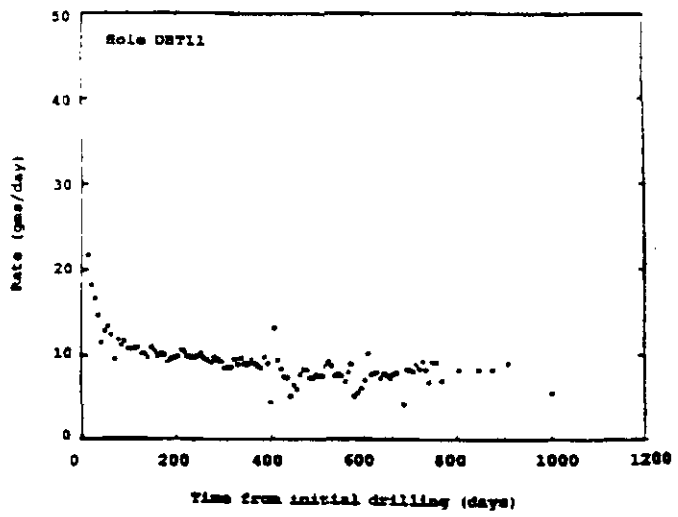

Figure 16. WIPP 1. Brine inflow rate vs time in a borehole (Hole DBT11).

Chemical analyses of brine collected are also available. The brine inflow measurements in the 10 cm diameter boreholes generally show rapidly declining flow rates for the first few months, followed by steady but slow declining flow rates over long periods (2 years).

Pore Pressure and Permeability Testing

Pore pressure measurements are made in boreholes with a diameter of 10 cm and 2 to 27 m in length, drilled at a variety of orientations. Pore pressure is measured in brine-filled, packer isolated intervals in the boreholes. Factors other than the formation pore pressure that could contribute to pressures observed in a borehole, e.g. temperature changes and borehole closure, are also monitored. The boreholes are furthermore used for permeability experiments, both pressure-pulse tests and constant-pressure flow tests. During the pressure-pulse tests, gas tends to accumulate in the boreholes. The gas is thought to evolve from Salado Formation brine in response to the lower pressure around the borehole relative to the pressure in the far field. The gas volumes are measured and the compositions are analysed.

Integrated, Large-scale Experiments

A horizontal cylindrical room, with a diameter of 2.9 m and a length of 107 m, has been mined for the purpose of measuring brine inflow to a room-sized excavation. The room slopes slightly upward from front to back to follow the natural dip of bedding. The room was mined in July 1989 and sealed in October 1989. The humidity within the room as well as the brine inflow into the room are now being measured. Salt efflorescences resulting from brine evaporation on the surface of the room are regularly mapped. Pore pressure measurements were made continuously before, during and after mining of the room and permeability experiments were performed before and after the mining in a number of boreholes placed around the room. A series of boreholes, 4 and 10 cm in diameter, will be drilled in various directions from the room. These boreholes will also be instrumented to allow permeability experiments, pore pressure measurements, and measurements of borehole deformation and brine inflow.

Available Data

Data available from boreholes of different diameters and locations and from a mined cylindrical room are:

- brine inflow rates
- humidity
- room closure, borehole deformation
- pore pressure
- data from permeability tests
- rock property data
- general stratigraphic information
- core logs

Supporting Information

A number of technical issues that are important to the performance of WIPP are tackled, and a large number of different types of tests are or have been performed within the pilot plant.

MOL

Migration experiment in Boom clay formation at the Mol site, Belgium.

Overview

This test case is based on an in situ migration experiment set up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The original purpose of the test is the in situ determination of migration related parameters and confirmation of these parameters determined in the laboratory. The

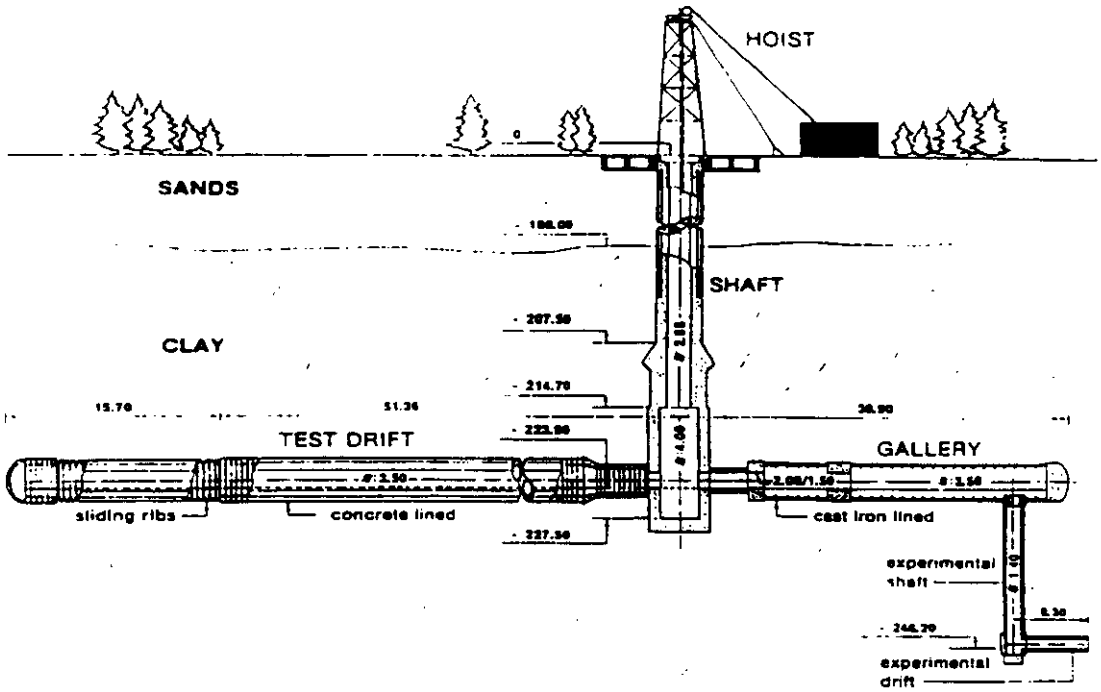

Figure 17. Scheme of the underground facility at Mol.

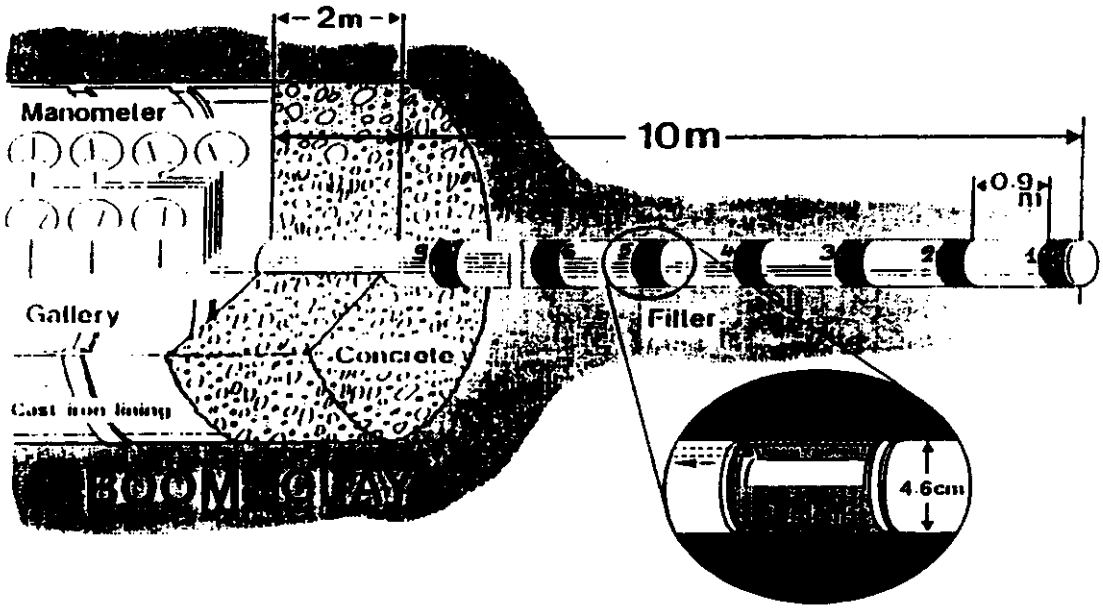

Figure 18. Mol. Conceptual view of the piezometernest.

experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

Experimental Design

A number of piezometers, a so called piezometernest, have been installed in an underground research laboratory in the Boom Clay formation at a depth of 220 m (Figures 17 and 18). The stainless steel system contains 9 piezometers, interspaced by 0.9 m long tubes. Each piezometer consists of two concentric tubes, the outer one being made of sintered stainless steel. A stand-pipe with an internal diameter of 2 mm is connected to the space separating the concentric tubes. The stand-pipe makes up the connection between the filter and the laboratory. A horizontal hole with a diameter of 50 mm and a depth of 10 m was drilled in the clay formation by rotary drilling. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. An inert gas was flushed through the filters to prevent oxidation of the clay. After about two days the small gap separating the tubing and the wall of the hole was completely sealed by convergence creep of the clay, and the gas flow was stopped. The presence of a vertical experimental shaft at the end of the underground laboratory (Figure 17) at atmospheric pressure and lined with concrete bricks creates a hydraulic pressure gradient in the neighborhood of the nest. The steady state pressure distribution as a function of the depth into the clay was measured.

About two and a half years after the installation of the piezometer-nest the clay formation was supposed to be settled. HTO was injected to filter number 5 and thereafter the system was left alone allowing migration of HTO in three dimensions. The injection rate of the tracer solution was 5.6 ml/day during about one and a half month.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters in the nest. The space between the different filters is 1 m. The sampling was started 3 months after the start of the injection and continues at a two months' interval. To avoid disturbance of the HTO concentration, distribution in the clay formation due to sampling, the sampling frequency and the total amount of liquid is kept as low as possible.

Available Data

- steady state pressure distribution in the clay
- HTO concentration as a function time
- tracer injection data

Supporting Information

Supporting data are available from laboratory experiments and other in situ experiments. Transport parameters, e.g., the product of effective porosity and retardation factor, apparent dispersion constant, and diffusivity, have been estimated. A number of laboratory experiments have been performed, such as through-diffusion and percolation experiments with clay cores. The Boom clay is rich in organic matter which to a large part is linked to the mineral components. The remainder (humic and fulvic acids) can be regarded as dissolved. Attempts have been made to determine the diffusion parameters of the smallest humic molecules.

ALLIGATOR RIVERS

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

Overview

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator River Region is located about 200 km east of Darwin. The international Alligator Rivers Natural Analogue Project (ARAP) was set up in 1987 and was sponsored by the OECD Nuclear Energy Agency. Participating organisations are the Australian Nuclear Science and Technology Organisation, the Japan Atomic Energy Research Institute, the Power Reactor and Nuclear Fuel Development Corporation of Japan, the Swedish Nuclear Power Inspectorate, the UK Department of Environment, and the US Nuclear Regulatory Commission.

Uranium mineralisation occurs at Koongarra in two distinct but related orebodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium mineralisation is present from the surface down to the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m (Figure 19). The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the transport in the weathered zone and the time scale over which they have operated.

Experimental Investigations

An extensive experimental programme including both field and laboratory investigations have resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs of 140 percussion holes and 107 drill cores. Groundwater chemical data have been accumulated from more

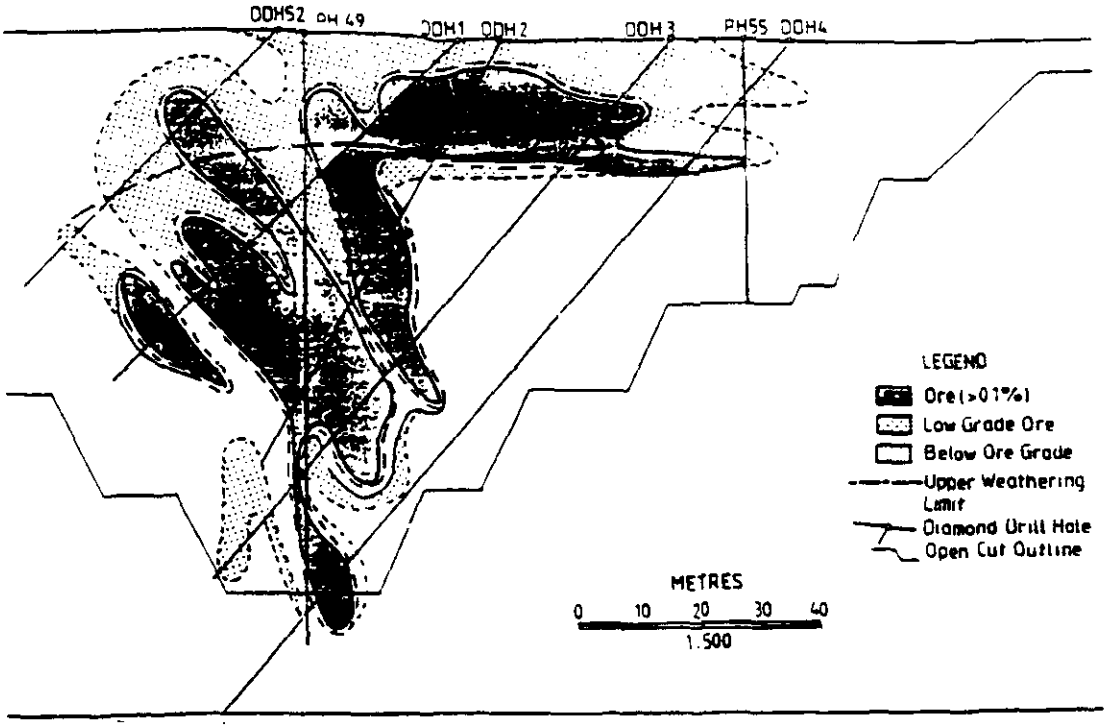

Figure 19. Alligator Rivers. Cross section showing the dispersed zone at the Koongarra deposit.

than 70 boreholes. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The phase distribution of uranium and thorium in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from bore cores. Distribution coefficients have also been measured on natural particles in Koongarra groundwater.

Available Data

Hydrogeology

- climatologic data, including rainfall and temperature
- surface water measurements, including stream flow
- location, elevation, geologic logs, casing and perforation details of all test holes and wells
- map, showing test holes and wells, as well as land-surface contours
- aquifer test results including water-level drawdowns, discharge measurements, and water quality of discharge
- periodic water level measurements which show seasonal fluctuations and regional gradients
- results of geophysical surveys and back-hoe pits which show thickness of upper deposits
- results of packer tests in upper part of the bedrock, and resistivity traverses
- results from porosity and permeability measurements on drill core samples

Hydrochemistry

- pH, Eh, D.O., conductivity and temperature in groundwaters
- groundwater concentrations of cations and trace metals
- groundwater concentrations of uranium series nuclides and isotopes

Geology, Mineralogy, Radiochemical

- uranium concentration distribution assay (247 drilling locations) in core pulp and soil samples
- uranium series radioisotope activity ratios data for selected samples in the ore zone
- results from chemical analyses of core samples
- mineralogical composition of samples
- concentrations and activity ratios of uranium and thorium in different mineral phases
- concentrations of ^{129}I, ^{36}Cl, ^{99}Tc, and ^{239}Pu in rock samples

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Overview

A large number of aquifer tests ranging from small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The 37 km^2 property lies on the Canadian shield, with Precambrian bedrock consisting primarily of granitic gneiss. Over 10% of the site contains bedrock that is exposed or buried beneath less than 1 m of overburden. The remainder of the property is covered by unconsolidated sediments.

The water table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

Experimental Design

The large experimental programme includes 20, 40 and 260 m natural gradient tracer experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and at present there are 170 monitoring installations in the aquifer around the downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation, and gamma scanning is performed through the full aquifer. The groundwater discharge area, a wetland at the toe of the dune ridge, currently contains 36 of the monitoring installations (Figure 20). The tracers used are ^{131}I, which can be mapped by gamma scanning, and HTO which is used to verify that no retardation of the iodine takes place.

In addition, laboratory measurements on cores from the aquifer have been performed. The hydraulic conductivity was determined from grain-size analysis and the hydrodynamic dispersion and longitudinal dispersivity was determined from column tracer tests.

Available Data

A large database is available, containing data both from field and laboratory experiments, such as:

- permeameter test data
- small-scale dispersion
- porosities
- grain size composition
- hydrogeological data
- geophysical data
- mapping of tracer migration (Figure 21)

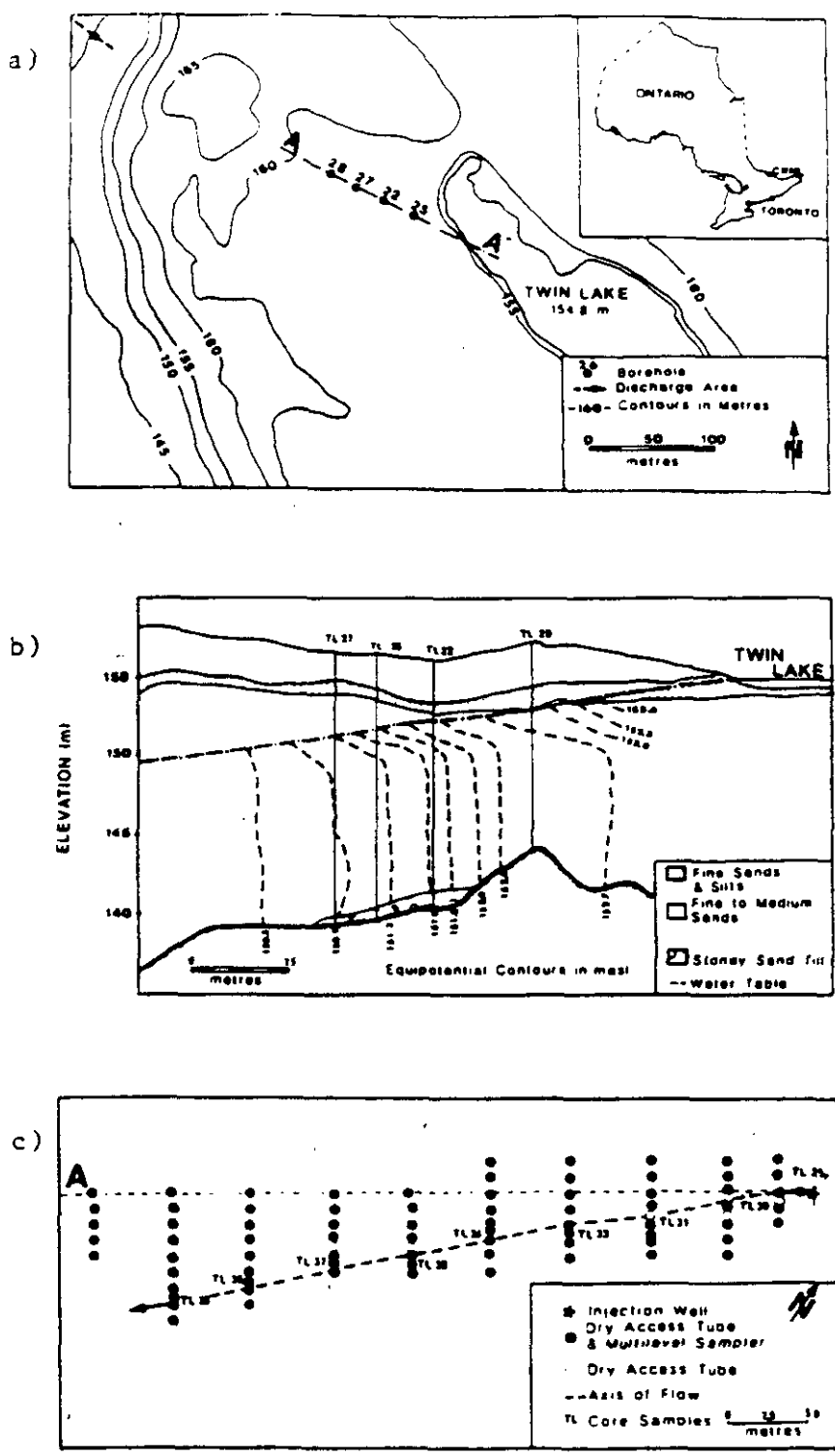

Figure 20. (a) Twin Lake Site map. (b) Geological cross section through the Twin Lake site (section A–A'). (c) Plan of field site showing instrumentation and tracer flow line.

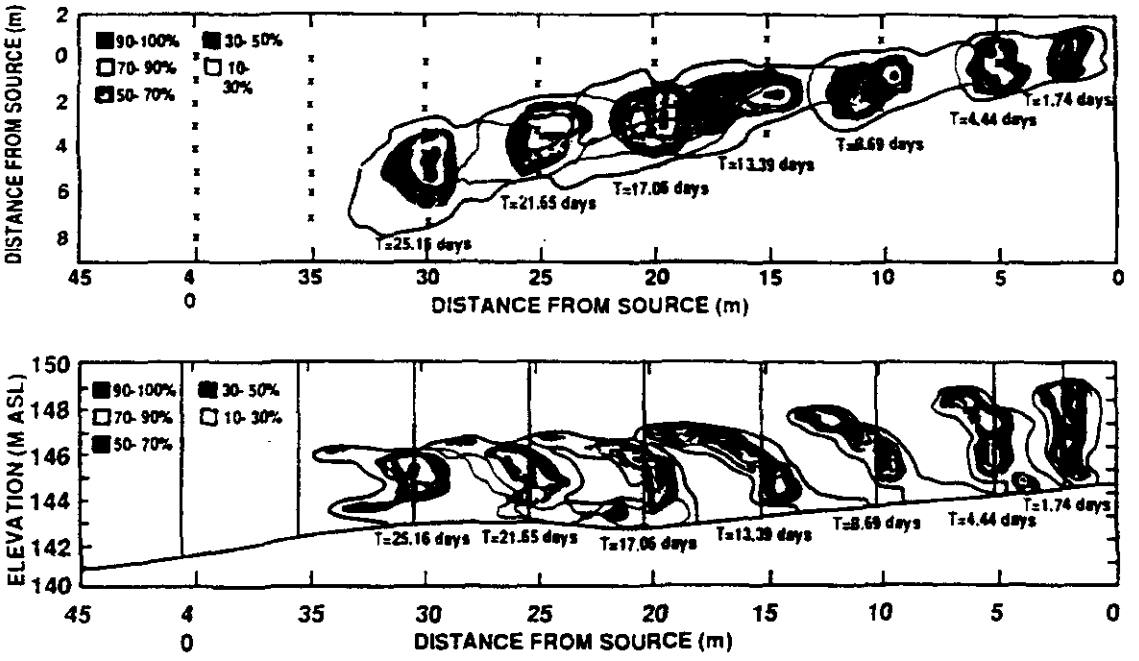

Figure 21. Twin Lake. Example of the type of data available through the data base. Tracer migration in the sandy aquifer (percent of injection concentration)

Appendix 3

List of Test Case Related Presentations at INTRAVAL Workshops

INTRAVAL Phase 1 Test Cases

Radionuclide migration through clay samples by diffusion and advection (TEST CASE 1a)

Bogorinski P., Larue J., and von Maravic H., Comments on Modelling the Harwell Migration Experiments, INTRAVAL Workshop, Barcelona, April 1988.

Bogorinski P., Overview of Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lineham T.R., and Lever D.A., Radionuclide Migration in Clay Samples at Harwell Laboratory, INTRAVAL Workshop, Barcelona, April 1988.

Bourke P.J., Gilling D., Jefferies N.L., Lever D.A., and Lineham T.R., Mass Transfer Through Clay by Diffusion and Advection: Description of INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Interpretation of Test Case 1a: Old Data, INTRAVAL Workshop, Helsinki, June 1989.

Carrera J., Samper J., Galarza G., and Medina A., Application of Experiment Design Methods to Test Case 1a, INTRAVAL, INTRAVAL Workshop, Las Vegas, February 1990.

Hossain S., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Olague N.E., Davis P.A., and Gribble R.A., Modeling Strategy, Data Analysis and Initial Simulations: INTRAVAL Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Olague N., Davis P., and Gribble R., Dual-porosity Simulations of the Through-diffusion Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Samper J., and Carrera J., Preliminary UPC Results on Test Case 1a, INTRAVAL Workshop, Tucson, November 1988.

Umeki H., Idemitsu K., and Ikeda Y., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Umeki H., Neyama A., Furuichi K., and Ikeda Y., PNC Analysis of Test Case 1a, INTRAVAL Workshop, Las Vegas, February 1990.

Wijland R., and Hassanizadeh S.M., Preliminary Results on Test Case 1a, INTRAVAL Workshop, Helsinki, June 1989.

Wijland R., and Hassanizadeh M., Simulation of Nuclide Migration in Clay, including Matrix Diffusion, INTRAVAL Workshop, Las Vegas, February 1990.

Uranium Migration in Crystalline Bore Cores (TEST CASE 1b)

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores, INTRAVAL Workshop, Barcelona, April 1988.

Bischoff K., Hadermann J., and Jakob A., INTRAVAL Test Case 1b, Uranium Migration in Crystalline Bore Cores - Small Scale Pressure Infiltration experiments, INTRAVAL Workshop, Tucson, November 1988.

Carrera J., and Samper J., Identifiability Problems with Data on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., Preliminary Results on Test Case 1b, INTRAVAL Workshop, Barcelona, April 1988.

Cordier E., and Goblet P., INTRAVAL Project - Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., A Note on the Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Grindrod P., and Hodgkinson D., The Role of Nonlinear Sorption in INTRAVAL Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Hadermann J., and Jakob A., Modelling Test Case 1b with Various Mechanisms and Geometries, INTRAVAL Workshop, Cologne 1990.

Hara K., Nakahara Y., Neyama A., Shiga A., and Ikeda Y., Modelling Study of Test Case 1b, INTRAVAL Workshop, Cologne 1990.

Hautojärvi A., Preliminary VTT Results on Test Case 1b, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Channels as Migration Routes in Crystalline Rock Samples, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Preece T.E., and Sumner P.J., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Helsinki, June 1989.

Jackson C.P., Sumner P.J., and Preece T.E., A Study of INTRAVAL Test Case 1b, INTRAVAL Workshop, Las Vegas, February 1990.

Jakob A., Hadermann J., and Zingg A., PSI New Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Kjellbom K., Moreno L., and Neretnieks I., Preliminary Evaluation of Some Uranium Migration Tests, INTRAVAL Workshop, Helsinki, June 1989.

Radionuclide Migration in Single Natural Fissures in Granite (TEST CASE 2)

Aimo N.J., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Cole C.R., and Aimo N.J., Investigating a Parameter Estimation Approach to Design of Validation Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Gureghian B., Radionuclide Migration in Single Natural Fissures in Granite, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., Preliminary Results of Test Case 2 Study, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Previous Modelling of Test Case 2 Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 2, INTRAVAL Workshop, Tucson, November 1988.

Skagius K., Presentation of Test Case 2, INTRAVAL Workshop, Barcelona, April 1988.

Tracer Tests in a Deep Basalt Flow Top (TEST CASE 3)

Andersson J., Comments on INTRAVAL Test Case 3, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., INTRAVAL Test Case 3, Experiments and Model Calculation, INTRAVAL Workshop, Barcelona, April 1988.

Cole C., and Aimo N.J., Presentation of Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Idemitsu K., and Umeki H., Calculation of the Concentration of a Dispersive Tracer Solute by Means of Numerical Solution of the Balance Equation, INTRAVAL Workshop, Barcelona, April 1988.

Idemitsu K., Modelling of Test Case 3 by Using a Numerical Method, INTRAVAL Workshop, Tucson, November 1988.

Kimura H., and Yamashita R., Preliminary JAERI Results on Test Case 3, INTRAVAL Workshop, Tucson, November 1988.

Flow and Tracer Experiments in Crystalline Rock Based on Stripa 3D Experiments (TEST CASE 4)

Andersson J., Discrete Network Analysis of Tracer Experiments in Stripa 3D, INTRAVAL Workshop, Las Vegas 1990.

Dverstorp B., Application of the Discrete Fracture Network Concept on Field Data: Possibilities of Model Calibration and Validation, INTRAVAL Workshop, Barcelona, April 1988.

Dverstorp B., and Nordqvist W., Flow and Transport Simulations with a Discrete Fracture Network Model, INTRAVAL Workshop, Helsinki, June 1989.

Hodgkinson D., Shaw W., and Barker J., Modelling by Flows in Continuous Dimension, INTRAVAL Workshop, Tucson, November 1988.

Hodgkinson D., Shaw W., and Grindrod P., Preliminary Fractal Analysis of the Stripa 3D Migration Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Presentation of Test Case 4: 3D Migration Experiment at Stripa, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 4, INTRAVAL Workshop, Tucson, November 1988.

Tsang Y.W., and Tsang C.F., Understanding Stripa 3-D Tracer Migration Data, INTRAVAL Workshop, Helsinki, June 1989.

Tracer Experiments in a Fracture Zone at the Finnsjön Research Area (TEST CASE 5)

Andersson P., Experimental Results and Further Plans, INTRAVAL Workshop, Tucson, November 1988.

Andersson P., Recent Experimental Results, INTRAVAL Workshop, Helsinki, June 1989.

Andersson P., Proposal for Simulation of Hydraulic Interference Tests, INTRAVAL Workshop, Helsinki, June 1989.

Grindrod P., and Worth D., Do the Pulse Injection Experiments Exhibit Radially Convergent Fracture Flow?, INTRAVAL Workshop, Las Vegas, February 1990.

Gustafsson E., Andersson P., and Wikberg P., Recent Achievements in the Performance and Evaluation of the Finnsjön Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Hautojärvi A., Dipole Results, INTRAVAL Workshop, Cologne, October 1990.

Hautojärvi A., and Taivassalo V., Generalised Taylor Dispersion Analysis for Tracer Breakthrough in the Radially Converging Experiment of Finnsjön (test case 5), INTRAVAL Workshop, Barcelona, April 1988.

Hautojärvi A., and Taivassalo V., Pre-Test Calculations of VTT-Team for Radially Converging Test, INTRAVAL Workshop, Tucson, November 1988.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Results of the Radially Converging Test, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Preliminary Predictive Modelling of the Dipole Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Hautojärvi A., Taivassalo V., and Vuori S., Interpretation of Test Case 5, Radially Converging Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kimura H., and Katsuragi T., Predictive Modelling of the Dipole Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Helsinki, June 1989.

Kimura H., Katsuragi T., and Yamashita R., Preliminary Results of the Radially Converging Tracer Experiment at the Finnsjön Research Area, INTRAVAL Workshop, Las Vegas, February 1990.

Moreno L., and Neretnieks I., Preliminary Evaluation of Tracer Test in Finnsjön. Radial Converging Experiment, INTRAVAL Workshop, Helsinki, June 1989.

Neretnieks I., Introduction to Test Case 5, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Preliminary Predictions of Finnsjön Tracer Tests, INTRAVAL Workshop, Barcelona, April 1988.

Nordquist R., Numerical Predictions of a Dipole Tracer Test in a Fracture Zone in the Brändan Area, Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Winberg A., Geostatistical Analysis of Hydraulic Conductivity Data at Finnsjön, INTRAVAL Workshop, Helsinki, June 1989.

Yamashita R., and Kobayashi A., Preliminary Calculations Using Fracture Network Approach for Tracer Test in Finnsjön Site, INTRAVAL Workshop, Las Vegas, February 1990.

Synthetic Data Base, Based on Single Fracture Migration Experiments in Grimsel (TEST CASE 6)

Codell R., Cole C., and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem VI, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Cole C., and Vomvoris S., Synthetic Migration Experiment - INTRAVAL Problem 6, INTRAVAL Workshop, Helsinki, June 1989.

Codell R., and Trösch J., Calculation of Synthetic Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Kuhlmann U., and Vomvoris S., Interpretation of INTRAVAL Test Case 6, Synthetic Experiment, INTRAVAL Workshop, Cologne, October 1990.

Vomvoris S., On the Synthetic Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Redox-front and radionuclide movements in an open Pit Uranium Mine, Pocos de Caldas (TEST CASE 7a)

Neretnieks I., Presentation of Test Case 7a: Redox Front and Uranium Movement at Pocos de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Neretnieks I., Presentation of Test Case 7a: Redox Front Movement, INTRAVAL Workshop, Tucson, November 1988.

Neretnieks I., Redox Front Studies at Poços de Caldas, INTRAVAL Workshop, Las Vegas, February 1990.

Romero L., Moreno L., and Neretnieks I., Poços de Caldas. The Location of the Redox Front, INTRAVAL Workshop, Helsinki, June 1989.

Morro do Ferro Colloid Migration Studies (TEST CASE 7b)

Chapman N., Presentation of Test Case 7b: Colloid Transport, INTRAVAL Workshop, Tucson, November 1988.

Noy D., Presentation of Test Case 7b: Colloid Mobility at Poços de Caldas, INTRAVAL Workshop, Barcelona, April 1988.

Natural Analogue Studies at the Koongarra Site in the Alligator Rivers Area (TEST CASE 8)

Davis S., Hydrology Sub-Project, INTRAVAL Workshop, Tucson, November 1988.

Duerden P., and Golian C., Presentation of Koongarra and Draft Test Case, INTRAVAL Workshop, Barcelona, April 1988.

Duerden P., Presentation of Test Case 8, INTRAVAL Workshop, Tucson, November 1988.

Duerden P., Update of Recent Field Work, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., Koongarra Test Case: Modelling Progress, INTRAVAL Workshop, Tucson, November 1988.

Golian C., Hydrodynamic Transport through Porous Media which Contain Two Iron Mineral Phases, INTRAVAL Workshop, Helsinki, June 1989.

Golian C., A Quasi Two Dimension Open System/Transport Model to Describe the Mobility of the Bulk Uranium, INTRAVAL Workshop, Las Vegas, February 1990.

Golian C., Test Results of the Simplified 2D Modelling of the Koongarra System Describing the Preferential Uranium Pathways, INTRAVAL Workshop, Cologne, October 1990.

Lever D., Koongarra Transport Modelling, INTRAVAL Workshop, Barcelona, April 1988.

Nijhoff-Pan I., Discussion on Test Case 8: Alligator Rivers (Koongarra) Ore Deposit, INTRAVAL Workshop, Helsinki, June 1989.

Slot A.F.M., Proposed Modelling Approach for the INTRAVAL Test Case 8, Alligator Rivers, Koongarra Ore Deposits, INTRAVAL Workshop, Las Vegas, February 1990.

Sverjensky D., Geochemical Aspects of the Alligator River Analogue Project, INTRAVAL Workshop, Tucson, November 1988.

Radionuclide Migration in a Block of Crystalline Rock (TEST CASE 9)

Hautojärvi A., Preliminary Calculations of Migration in the Fracture Channels, INTRAVAL Workshop, Helsinki, June 1989.

Kawanishi M., Preliminary Results on Test Case 9 by using Dual-Porosity Simulation Code, INTRAVAL Workshop, Cologne, October 1990.

Kobayashi A., and Yamashita R., Preliminary Results on Test Case 9 by Using the Non-Uniform Velocity Distribution, INTRAVAL Workshop, Helsinki, June 1989.

Noronha C.J., and Gureghian A.B., Description of Granite Block Experiment for Test Case 9, INTRAVAL Workshop, Barcelona, April 1988.

Noronha C.J., and Gureghian A.B., Large Block Migration Experiments, INTRAVAL Workshop, Tucson, November 1988.

Rasilainen K., Hautojärvi A., and Vuori S., Preliminary Interpretation of Test Case 9 using FTRANS-code, INTRAVAL Workshop, Las Vegas, February 1990.

Vandergraaf T.T., Grondin D.M., and Drew D.J., Contaminant Transport Laboratory Studies in a Single, Natural Fracture in a Quarries Granite Block at a Scale of 1 m, INTRAVAL Workshop, Tucson, November 1988.

Evaluation of Unsaturated Flow and Transport in Porous media Using an Experimental with Migration of a Wetting front in a Superficial Desert Soil, Las Cruces Trench (TEST CASE 10)

Ababou R., High-resolution Modeling of 3D Flow Fields, INTRAVAL Workshop, Las Vegas, February 1990.

Bensabat J., Stochastic Modelling of the First Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Gee G., Deterministic Modeling and Considerations for Transport Analysis of the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Gelhar L., Applications of the Stochastic Model to the Las Cruces Data Base, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., Updegraff C.D., and Davis P.A., A 2-D Deterministic Model of the Las Cruces Trench Infiltration Experiment, Preliminary Results, INTRAVAL Workshop, Tucson, November 1988.

Goodrich M.T., and Davis P.A., A Statistical Analysis of the Las Cruces Trench Hydraulic Data, INTRAVAL Workshop, Helsinki, June 1989.

Goodrich M.T., and Gribble A.R., Data Analysis and Modelling of the Las Cruces Trench Second Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Hills R.G., Hudson, D.B., Porro I., and Wierenga P.J., Modelling the Layered Soil Lysimeter Study at Las Cruces, INTRAVAL Workshop, Tucson, November 1988.

Hills R., and Wierenga P., Water Flow and Solute Transport at the Las Cruces Trench Site, INTRAVAL Workshop, Las Vegas, February 1990.

Kool J.B., Simulations of Water Flow and Tritium Transport at the Las Cruces Trench, INTRAVAL Workshop, Las Vegas, February 1990.

McLaughlin D., Model Validation Issues for Unsaturated Flow Systems, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Presentation of Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Nicholson T., Introduction, Test Case 10, INTRAVAL Workshop, Helsinki, June 1989.

Rasmuson A., Lindgren M., and Collin M., Flow and Transport Simulations of the Second Las Cruces Trench Experiment, INTRAVAL Workshop, Las Vegas, February 1990.

Smoot J.L., Battelle PNL Modelling Results, INTRAVAL Workshop, Tucson, November 1988.

Smyth J.D., Infiltration Simulations of the Jornada Trench with a Multidimensional Monte Carlo Code, INTRAVAL Workshop, Las Vegas, February 1990.

Updegraff D., 1-D Analytical Solutions on Test Case 10, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Field and Laboratory Experimental Results with Emphasis on Transport, INTRAVAL Workshop, Tucson, November 1988.

Wierenga P., Hills R., and Hudson D., Flow and Transport Data Analyses of the Las Cruces Trench Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Evaluation of Flow and Transport in Unsaturated fractured Rock Using Studies at Apache Leap Tuff Site (TEST CASE 11)

Bradbury J., Evaporation in Unsaturated Fractured Rock - an Alternative Conceptual Model, INTRAVAL Workshop, Tucson, November 1988.

Codell R., Transport in Two-Phase Flow in Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Evans D., Field and Laboratory Experimental Results, INTRAVAL Workshop, Tucson, November 1988.

Evans D., Rasmussen T., and Sully M., Rock Matrix Characterization in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Nonisothermal Core Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Crosshole Pneumatic Testing at the Apache Leap Tuff Site, INTRAVAL Workshop, Las Vegas, February 1990.

Evans D., Rasmussen T., and Sully M., Laboratory Fracture Flow Experiments in Apache Leap Tuff, INTRAVAL Workshop, Las Vegas, February 1990.

Lindgren M., and Rasmuson A., Two-Phase Flow Simulations in a Heated Tuff Drillcore, INTRAVAL Workshop, Cologne, October 1990.

McCartin T., Simulation of the Apache Leap Tuff Site Borehole Experiment, INTRAVAL Workshop, Tucson, November 1988.

McCartin T., Two-Phase Flow Simulations in a Tuff Drillcore, INTRAVAL Workshop, Helsinki, June 1989.

Nicholson T., Presentation of Test Case 11, INTRAVAL Workshop, Tucson, November 1988.

Parsons A.M., and Davis P.A., Modeling Strategy and Data Analysis for the Apache Leap Tuff Block Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Rasmussen T., Modelling of Field and Laboratory Experiments, INTRAVAL Workshop, Tucson, November 1988.

University of Arizona, Field and Laboratory Experiments in Unsaturated Fractured Tuff, INTRAVAL Workshop, Helsinki, June 1989.

Experiments with changing Near-Field Hydrologic Conditions in Partially Saturated Tuffaceous Rocks, G-Tunnel (TEST CASE 12)

Hoxie D.T., Empirical Validation of Hydrologic Model Simulations of Changing Near-Field Hydrologic Conditions, INTRAVAL Workshop, Barcelona, April 1988.

Hoxie D.T., Flint A.L., and Chornack M.P., Model Validation with Respect to Short-Term Dynamic Effects and Long-Term Transient Effects, INTRAVAL Workshop, Tucson, November 1988.

Experimental study of Brine Transport in Porous Media (TEST CASE 13)

Arens G., Preliminary Results on Test Case 13, INTRAVAL Workshop, Helsinki, June 1989.

Arens G., and Fein E., One-dimensional Brine Transport in Porous Media, INTRAVAL Workshop, Las Vegas, February 1990.

Bogorinski P., Jackson P., and Porter J.A., New Approach to the RIVM Experiment, INTRAVAL Workshop, Cologne, October 1990.

Hassanizadeh S.M., Presentation of Experimental Results from Brine Experiment, INTRAVAL Workshop, Barcelona, April 1988.

Hassanizadeh S.M., Experimental Study of Brine Transport in Porous Media, INTRAVAL Workshop, Tucson, November 1988.

Hassanizadeh S.M., and Leijnse T., Simulation of the Brine Transport Experiments, INTRAVAL Workshop, Helsinki, June 1989.

Hassanizadeh S.M., Latest Results on Simulation of Brine Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Schelkes K., Preliminary BGR Results, INTRAVAL Workshop, Helsinki, June 1989.

Schelkes K., and Knoop R.-M., Results of Modelling the Salt Transport Experiments, INTRAVAL Workshop, Las Vegas, February 1990.

Groundwater Flow in the Vicinity of the Gorleben Salt Dome (TEST CASE 14)

Glasbergen P., Proposals for Test Cases Related to Rock Salt, INTRAVAL Workshop, Barcelona, April 1988.

Schelkes K., Pumping Test in Highly Saline Groundwater - a Proposed Test Case, INTRAVAL Workshop, Tucson, November 1988.

Schelkes K., Saline Groundwater Movement in an Erosional Channel Crossing a Salt Dome - Working Program for a Test Case, INTRAVAL Workshop, Tucson, November 1988.

INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Hills R., and Wierenga P., Las Cruces Trench Experiments Phase 2, and Validation Strategy, INTRAVAL Workshop, Seattle, April 1991.

Hills R., and Wierenga P., A Quantitative Model Validation Methodology with Application to the Las Cruces Trench Experiments, INTRAVAL Workshop, Sydney, February 1992.

Hills R.G., and Wierenga P.J., Validation Results from the Las Cruces Trench Experiment, INTRAVAL Workshop, San Antonio, November 1992.

Olague N., Kozak M., and McCord J., Las Cruces, Summary of Post Analysis. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Rockhold M., Conceptual Approach and Initial Numerical Modelling of the Plot 2b Experiment Using PORFLO-3, INTRAVAL Workshop, Seattle, April 1991.

Rockhold M.L., Gee G.W., and Kincaid C.T., Simulations of Las Cruces Trench Experiment 2b, INTRAVAL Workshop, San Antonio, November 1992.

Sagar B., and Wittmeyer G., Las Cruces Trench Experiment, Plot 2a, Model Validation Methods, INTRAVAL Workshop, Sydney, February 1992.

Wittmeyer G., and Sagar B., Flow and Transport Modelling of Test Case, INTRAVAL Workshop, Seattle, April 1991.

Wittmeyer G., Las Cruces Trench Experiment Plot 2b. Model complexity and Predictive Capability, INTRAVAL Workshop, San Antonio, November 1992.

APACHE LEAP TUFF

Codell R., Performance Assessment Considerations for the Vapor Phase in Unsaturated Fractured Rock - Applications to the Apache Leap Tuff Studies, INTRAVAL Workshop, Sydney, February 1992.

Ford W., Pole J., Codell R., and McCartin T., Simulations of Hypothetical Flow Experiments in Fractured Rock Blocks, INTRAVAL Workshop, Seattle, April 1991.

Guzman A., Sully M., and Neuman S.P., Three Dimensional Characterization of Pneumatic Permeabilities in Unsaturated Fractured Tuff at the ALT Site, INTRAVAL Workshop, Seattle, April 1991.

Guzman A., Neuman S.P., Lohrstorfer C., and Basset R., Air Permeability Determinations. Scale Effects, INTRAVAL Workshop, San Antonio, November 1992.

Lehman L.L., Apache Leap - Benchmarking of the Beta Mode Code V-TOUGH on the UNLV Cray, INTRAVAL Workshop, Sydney, February 1992.

Rasmussen T.C., and Anderson I., Unsaturated Apache Leap Tuff Experiments: Fracture Imbibition Tests and Non-Isothermal Core Tests, INTRAVAL Workshop, Seattle, April 1991.

Rasmussen T.C., and Evans D., The Apache Leap Tuff Site Proposed Field Heater Experimental Plan, INTRAVAL Workshop, Seattle, April 1991.

Rasmussen T.C., Isothermal Coupled Fracture-Matrix Flow and Coupled Thermal-Solute-Water Matrix Flow through Apache Leap Tuff, INTRAVAL Workshop, San Antonio, November 1992.

Sully M., Guzman A., and Neuman S.P., In Situ Pneumatic Permeability, INTRAVAL Workshop, Seattle, April 1991.

Sully M.J. , Guzman A.G., Neuman S.P., and Lohrstorfer C., Validation Studies for Assessing Unsaturated Flow and Transport through Fractured Rock at the Apache Leap Site, INTRAVAL Workshop, Sydney, February 1992.

YUCCA MOUNTAIN

Lehman L., The Effects of Variability in Selected Model Inputs on Modeled Unsaturated Water Content Profiles at Yucca Mountain, Nevada, INTRAVAL Workshop, San Antonio, November 1992.

Robey T., Rautman C., and Kaplan P., Unsaturated Flow and Geostatistics Applied to the Yucca Mountain Test Case, INTRAVAL Workshop, San Antonio, November 1992.

Voss C., Yucca Mountain Test Case. Status report, INTRAVAL Workshop, San Antonio, November 1992.

FINNSJÖN

Andersson P., Brief Summary of New Data From Finnsjön, INTRAVAL Workshop, Sydney, April 1992.

Fillion E., and Schwartz J., Interpretation of Interference Tests at Finnsjön Site, INTRAVAL Workshop, San Antonio, November 1992.

Gomit J.M., Finnsjön Test Case, INTRAVAL Workshop, Seattle, April 1991.

Hatanaka K., Umeki H., Sasaki N., Mukai S., and Doi, H., Preliminary Analysis on Tracer Transport Test at Finnsjön Site, INTRAVAL Workshop, Sydney, February 1992.

Hatanaka K., Preliminary Modelling of the Effect of Heterogeneity on Tracer Transport at Finnsjön Site, INTRAVAL Workshop, San Antonio, November 1992.

Hautojärvi A., Do Break-through Curves in Field Tests Reveal Matrix Diffusion?, INTRAVAL Workshop, San Antonio, November 1992.

Kung C.S., Cvetkovic V., and Winberg A., Calibration and Validation of a Stochastic Continuum Model using the Finnsjön Dipole Tracer Test, INTRAVAL Workshop, San Antonio, November 1992.

Vuori S., Evaluation of Migration Processes and Geometries Using Tracer Break-through Curves of INTRAVAL Test Cases (Finnsjön, Stripa, WIPP 2), INTRAVAL Workshop, Seattle, April 1991.

STRIPA

Andersson P., Monitoring of Saline Tracer Transport by Radar Measurements and Model Simulations, INTRAVAL Workshop, Sydney, February 1992.

Guerin F., Billaux D., Chiles J.P., and Sauty J.P., Stripa: First Attempt at Tracer Experiments. Simulations by a Set of Interconnected Channelized Fractures, INTRAVAL Workshop, Seattle, April 1991.

Guerin F., and Billaux D., Analyzing Flow and Transport in the Stripa 3-D Site; Influence of Connectivity, INTRAVAL Workshop, San Antonio, November 1992.

Hautojärvi A., Analysis of Stripa 3D Data Employing EVE (Extreme Value Estimation) deconvolution Method, INTRAVAL Workshop, Sydney, February 1992.

Neretnieks I., The Stripa Site Characterization and Validation (SCV) Experiment and Review of Earlier Work, INTRAVAL Workshop, Sydney, February 1992.

WIPP 2

Beauheim R., Overview of Tests Conducted on the (WIPP 2) Culebra Formation at the WIPP, INTRAVAL Workshop, Seattle, April 1991.

Capilla J.E., Gómez-Hernández J.J., and Sahuquillo A., Stochastic Analysis of Groundwater Flow at the WIPP Site, INTRAVAL Workshop, San Antonio, November 1992.

Cliffe K.A., Jackson C.P., and Impey M.D., Summary of Results of a Preliminary Geostatistical Analysis of WIPP 2: Uncertainty and Validation, INTRAVAL Workshop, Sydney, February 1992.

Cliffe K.A., Jackson C.P., and Impey M.D., Further Results on WIPP 2, INTRAVAL Workshop, Sydney, February 1992.

Corbet T.F., Overview of Modeling Studies of the (WIPP 2) Culebra Formation at the WIPP, INTRAVAL Workshop, Seattle, April 1991.

Corbet T.F., Overview of Recent Progress on Geostatistical Estimates of the Culebra Transmissivity Field, Interpretation of Tracer Tests, and Alternative Conceptual Models of Regional Groundwater Flow, INTRAVAL Workshop, Sydney, February 1992.

Gomez-Hernandez J., and Capilla J., Application, INTRAVAL Workshop, Sydney, February 1992.

Grindrod P., Flow Through Fractal Rock: What does the WIPP 2 Field Data Reveal?, INTRAVAL Workshop, Seattle, April 1991.

Jackson P.C., Preliminary Discussion on WIPP 2, INTRAVAL Workshop, Seattle, April 1991.

Kröhn K-P., Modelling of Regional Variable-Density Flow at the WIPP-Site. Initial Results for a Vertical Section, INTRAVAL Workshop, San Antonio, November 1992.

LaVenue M., Application of an Automated Pilot-Point Inverse Technique to Generate Calibrated Conditionally-Simulated Transmissivity Fields, INTRAVAL Workshop, San Antonio, November 1992.

Sahuquillo Herraiz A., Further Conditioning of Transmissivity Fields: Honoring Piezometric Data Theory, INTRAVAL Workshop, Sydney, February 1992.

GORLEBEN

Arens G., and Wollrath J., BfS - Calculations on Pumping Test 'Weisses Moor', INTRAVAL Workshop, Sydney, February 1992.

Beauheim R.L., Evaluation of Hydraulic Anisotropy from Weisses Moor Pumping Test, INTRAVAL Workshop, San Antonio, November 1992.

Bogorinski P., and Pöttl B., Modeling the Gorleben Channel, INTRAVAL Workshop, Sydney, February 1992.

Porter J., Application of Indicator Methods to the Gorleben Data Set, INTRAVAL Workshop, San Antonio, November 1992.

Schelkes K., Gorleben Test Case, INTRAVAL Workshop, Seattle, April 1991.

Schelkes K., Status of Test Case and Validation Issues, INTRAVAL Workshop, Sydney, February 1992.

Schelkes K., and Vogel P., Salt Water Movement in the Gorleben Channel. Studies on Dispersion and Geometry Effects, INTRAVAL Workshop, San Antonio, November 1992.

Vogel P., and Schelkes K., 2D-Studies on Salt Water Movement in the Gorleben Channel - First Results, INTRAVAL Workshop, Sydney, February 1992.

Wollrath J., and Arens G., BfS-Calculations on INTRAVAL Test Case Pumping Test Weisses Moor", INTRAVAL Workshop, San Antonio, November 1992.

WIPP 1

Beauheim R., Interpretation of Permeability Tests (WIPP 1) S0P01 and L4P51, INTRAVAL Workshop, Seattle, April 1991.

Beauheim R.L., and Roberts R.A., Integrated Numerical/Analytical Interpretation of S1P73-B Hydraulic Tests, INTRAVAL Workshop, Sydney, February 1992.

Finley S.J., Small Scale Brine Inflow Experiments (WIPP 1): Data and Interpretation, INTRAVAL Workshop, Seattle, April 1991.

Foesch J.A., Small-scale Brine Inflow, INTRAVAL Workshop, San Antonio, November 1992.

Gorham E., et. al., Status of WIPP 1 Test Case and Current Validation Strategy, INTRAVAL Workshop, Sydney, February 1992.

MOL

Kozak M., Initial Analyses of Anion Exclusion as Applied to the Mol Site, INTRAVAL Workshop, Sydney, February 1992.

Mouche E., and Rouzier P., Tracer Experiment at the Mol Site: Modeling and Sensitivity Analysis, INTRAVAL Workshop, San Antonio, November 1992.

Olague N., Kozak M., and McCord J., Mol: Preliminary Analyses. Proposed Strategy for Phase 2, INTRAVAL Workshop, Seattle, April 1991.

Put M., Mol: Case Description and Modelling Methodology with Results, INTRAVAL Workshop, Seattle, April 1991.

Put M., Theoretical Validation Considerations for the Mol Test Case (with Results), INTRAVAL Workshop, Sydney, February 1992.

Put M., Mol Test Case. Validation of used model, INTRAVAL Workshop, San Antonio, November 1992.

ALLIGATOR RIVERS

Birchard G., and Murphy W., Koongarra Analogue of the Near Field of an HLW Repository, INTRAVAL Workshop, Seattle, April 1991.

Birchard G., Groundwater Geochemical Speciation Modelling, INTRAVAL Workshop, Sydney, February 1992.

Emerson D., Site Characterization, INTRAVAL Workshop, Sydney, February 1992.

Golian C., Uranium Series Radionuclide Mobility in the Koongarra Weathered Zone, INTRAVAL Workshop, Seattle, April 1991.

Golian C., Transport Modelling of Natural Analogue - Approach and Findings, INTRAVAL Workshop, Sydney, February 1992.

Kimura H., and Murakami T., Uranium Migration Considering Alternation of Chlorite at Koongarra Site, INTRAVAL Workshop, Sydney, February 1992.

Skagius K., Modelling of Uranium and Thorium Migration in the Weathered Zone at Koongarra, INTRAVAL Workshop, Sydney, February 1992.

Skagius K., Modelling of Uranium and Thorium Migration in the Weathered zone at Koongarra, INTRAVAL Workshop, San Antonio, November 1992.

Tanaka Y., Miyakawa K., and Kawanishi M., Three-Dimensional Groundwater Flow Analysis on the Basis of Schistosity at the Koongarra Site, INTRAVAL Workshop, Sydney, February 1992.

Townley L., Hydrology of the Koongarra Site, Including Predictions of 3D Groundwater Flow Patterns, INTRAVAL Workshop, Seattle, April 1991.

Townley L., Summary of Hydrology Workshop, INTRAVAL Workshop, Sydney, February 1992.

Waite D., Implications of Sorption in Retardation, INTRAVAL Workshop, Sydney, February 1992.

van de Weerd R., Geochemical Modeling of the Koongarra Uranium Deposit, INTRAVAL Workshop, Sydney, February 1992.

van de Weerd R., Richardson-van der Poel M., and Hassanizadeh S.M., Preliminary Results of Modelling of Nuclide Transport at Koongarra, INTRAVAL Workshop, San Antonio, November 1992.

TWIN LAKE

Durin M. and Mouche E., Comments to Twin Lake Test Case, INTRAVAL Workshop, Seattle, April 1991.

Goblet P., Modelling of Mass Transport with a High Peclet Number. Application to the Twin-Lake Tracer Experiments, INTRAVAL Workshop, San Antonio, November 1992.

Gomit J-M., Twin Lake Test Case, INTRAVAL Workshop, Seattle, April 1991.

Moltyaner G., A Novel Methodology for Characterizing Geologic Heterogeneities, INTRAVAL Workshop, Sydney, February 1992.

Moltyaner G., Indirect Testing of a Constitutive Law. INTRAVAL Workshop, San Antonio, November 1992.

Mouche E., Twin Lake Tracer Experiments: Can a Stochastic Modeling be performed?, INTRAVAL Workshop, San Antonio, November 1992.

Munakata M., and Kimura H., Preliminary Results of Twin-Lake Tracer Test (1983), INTRAVAL Workshop, San Antonio, November 1992.

Olague N., Kozak M. and McCord J., Twin Lake: Preliminary analyses. Proposed Strategy for Phase 2. INTRAVAL Workshop, Seattle, April 1991.

Olague N., and Davis P., Validation Aspects for th Twin Lake Studies and Data Analysis of Twin Lake 1983 Tracer Tests, INTRAVAL Workshop, Sydney, February 1992.

INTRAVAL Parties:

Agence Nationale pour la Gestion des Déchets Radioactifs (France), Atomic Energy of Canada Ltd. (Canada), Atomic Energy Control Board (Canada), Australian Nuclear Science and Technology Organisation (Australia), Bundesanstalt für Geowissenschaften und Rohstoffe/ Bundesamt für Strahlenschutz (Federal Republic of Germany), Commissariat à l'Energie Atomique/Institut de Protection et de Sûreté Nucléaire (France), Empresa Nacional de Residuos Radioactivos, S.A. (Spain), Gesellschaft für Reaktorsicherheit mbH (Federal Republic of Germany), Forschungszentrum für Umwelt und Gesundheit (Federal Republic of Germany), Her Majesty's Inspectorate of Pollution (United Kingdom), Industrial Power Company Ltd. (Finland), Japan Atomic Energy Research Institute (Japan), Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (Switzerland), National Institute of Public Health and Environmental Protection (The Netherlands), National Radiological Protection Board (United Kingdom), Power Reactor and Nuclear Fuel Development Corporation (Japan), Studiecentrum voor Kernenergie (Belgium), Swedish Nuclear Fuel and Waste Management Co. (Sweden), Swedish Nuclear Power Inspectorate (Sweden), U.K. Nirex Ltd. (United Kingdom), U.S. Department of Energy–OCRWM (United States of America), U.S. Department of Energy–WIPP (United States of America), U.S. Environmental Protection Agency (United States of America), U.S. Nuclear Regulatory Commission (United States of America).

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Swedish Nuclear Power Inspectorate, Her Majesty's Inspectorate of Pollution/AEA Technology, KEMAKTA Consultants Co., Organisation for Economic Cooperation and Development/Nuclear Energy Agency.

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intraval

PROGRESS REPORT

10

December 1992 – August 1993

INTRAVAL–An International Project to Study
Validation of Geosphere Transport Models

INTRAVAL
Progress Report Number 10, 1993

The international INTRAVAL project started in October 1987 in Stockholm as an international effort towards validation of geosphere models for transport of radionuclides. The project was initiated by the Swedish Nuclear Inspectorate, SKI, and was prepared by an ad-hoc group with representatives from eight organisations.

24 organisations 'Parties' from fourteen countries participate in INTRAVAL. The project is governed by a Coordinating Group with one representative from each Party. The SKI acts as Managing Participant and has set up a Project Secretariat in which also Her Majesty's Inspectorate of Pollution HMIP/DoE, U.K. and the OECD/NEA take part. Project organisation, the objectives of the study and rules for the publication of results are defined by an Agreement between the Parties.

The INTRAVAL philosophy is to use results from laboratory and field experiments as well as from natural analogue studies in a systematic study of the model validation process. It is also part of the INTRAVAL project strategy to interact closely with ongoing experimental programmes.

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INTRAVAL
Progress Report Number 10

Introduction

INTRAVAL is the third project in a series of three international cooperation studies aimed at evaluating conceptual and mathematical models for groundwater flow and radionuclide transport in the context of performance assessment of repositories for radioactive waste. In the two previous studies, INTRACOIN (1981-1986) and HYDROCOIN (1984-1990), the numerical accuracy of computer codes, the validity of the underlying conceptual models and different techniques for sensitivity/uncertainty analysis have been tested. In INTRAVAL the focus is on the validity of model concepts.

The purpose of the INTRAVAL study is to increase the understanding of how mathematical models can describe various geophysical, geohydrological and geochemical phenomena. The phenomena studied are those that may be of importance to radionuclide transport from a repository to the biosphere. This is being done by systematically using information from laboratory and field experiments as well as from natural analogue studies as input to mathematical models in an attempt to validate the underlying conceptual models and to study the model validation process. In INTRAVAL the ambition is to cover validation of models both with regard to the processes and site-specific systems.

The INTRAVAL study was started in October 1987. The first three year study, Phase 1, is finalised. The second three year period, Phase 2, started in October 1990.

Eleven test cases are included in Phase 2. Several of the cases are based on international experimental programmes, such as the Stripa Project and the Alligator Rivers Analogue Project.

Pilot Groups have been appointed for each of the test cases. The responsibility of the Pilot Group is to compile data and propose formulations of the test cases in such a way that it is possible to simulate the experiments with model calculations. It is a pronounced policy of the INTRAVAL study to support interaction between modellers and experimentalists in order to gain reassurance that the experimental data are properly understood and that the experiences of the modellers regarding the type of data needed from the experimentalists are accounted for.

Contact between the participants has been maintained by arranging workshops which were followed by Coordinating Group meetings. Working Group meetings have taken place between the workshops.

Since the issue of the previous Progress Report, the ninth and last INTRAVAL workshop and the fifth and last Phase 2 Coordinating Group meeting were held in Stockholm, Sweden. During the workshop the participants described the modelling work performed and discussed the achieved results. Since this was the last workshop, the presentations were focussed on summarising the results from each Working Group.

The Phase 1 reports have been finalised, printed and distributed to the Coordinate Group members except the Phase 1 Summary report which is scheduled for printing late 1993. The schedule for the Phase 2 reporting was discussed and it was concluded that draft versions of the Working Group reports have to be available in the spring of 1994 and final versions in June 1994.

The Ninth INTRAVAL Workshop and the Fifth Phase 2 Coordinating Group Meeting

The ninth INTRAVAL workshop and the fifth Phase 2 Coordinating Group Meeting were held in Stockholm, Sweden, on the 30th of August through the 3rd of September, 1993, with the Swedish Nuclear Inspectorate (SKI) acting as host. The objective of the workshop was to summarise and conclude the INTRAVAL Project. All Working Groups had plenary sessions with a summary of the work performed within the group followed by technical presentations of recent work.

The Coordinating Group meeting was held on the 3rd of September, 1993. The plan for reporting (see section about INTRAVAL Reporting) was agreed upon. INTRAVAL will be formally concluded as the INTRAVAL Phase 2 Summary report has been approved by the Parties.

INTRAVAL Sub-Committee for Integration (ISI)

The purpose of the INTRAVAL Sub-committee for integration (ISI) is to assist the Secretariat by integrating the activities of the Working Groups, the validation approaches and the lessons learned. The

ISI had their third meeting on August, 31 in connection with the INTRAVAL workshop in Stockholm. A revised outline of the ISI INTRAVAL Phase 1 and 2 integrated conclusions report was developed during the meeting. A first draft of the report will be available by May, 1994 and the final report will be published early 1995.

Information from the Phase 2 Working Groups

Four Working Groups have been set up addressing different types of test cases, see Table 1. Each Working Group has a chairman, possibly aided by another person. The chairs of the Working Groups are responsible for the preparation of Working Group reports, which will constitute the base for the final reporting of INTRAVAL Phase 2.

Table 1. INTRAVAL Phase 2 Working Groups.

Working Group	Test Cases	Chairman
1	Las Cruces Trench Apache Leap Twin Lake Yucca Mountain	T. Nicholson
2	Finnsjön Stripa WIPP 2	C-F. Tsang S. Neuman
3	Gorleben WIPP 1 Mol	P. Bogorinski
	Alligator Rivers	Secretariat (K. Skagius)

INTRAVAL Reporting

All INTRAVAL Phase 1 technical reports have been printed and distributed. The final draft of the Phase 1 Summary report was distributed in June, 1993 to the INTRAVAL Parties for formal approval and is scheduled for publication at the end of 1993.

The Secretariat will take responsibility for publishing INTRAVAL Phase 2 Working Group reports prepared by the Working Group leaders with help from appointed editors. In addition, the Secretariat will prepare an INTRAVAL Phase 2 Summary report based on test case summaries from each of the Working Groups.

The time schedule for the INTRAVAL Phase 2 reporting is according to Table 2. Final reports from all Working Groups will be available in June 1994. A first draft of the INTRAVAL Phase 2 Summary report is scheduled for October, 1994 and a final report for spring 1995. The INTRAVAL Sub-committee for integration (ISI) will publish a report concerning Integrated Conclusions in early 1995. In addition, there are plans for publication in scientific journals during 1995.

Table 2. Schedule for INTRAVAL Phase 2 Reporting.

Report	First Draft	Final Draft	Final Report
Working Group 1	Jan. 1994	April 1994	June 1994
Working Group 2	Jan. 1994	April 1994	June 1994
Working Group 3	Feb. 1994	April 1994	June 1994
Alligator Rivers	Jan. 1994	March 1994	June 1994
Phase 2 Summary	Oct. 1994		Spring 1995
ISI Report	May 1994	Oct. 1994	Early 1995

Status of INTRAVAL Phase 2 Test Cases

LAS CRUCES TRENCH

Flow and transport experiments in unsaturated porous media performed at Las Cruces, New Mexico.

Experimental Set-up

The experimental site is located at the New Mexico State University Collage Ranch, 40 km northeast of Las Cruces in New Mexico, USA. A trench 16.5 m long, 4.8 m wide and 6.0 m deep was dug in undisturbed soil. Two irrigated areas measuring 4 m × 9 m and 1 m × 12 m, respectively, are adjacent to the trench. Water and tracers were applied at controlled rates on these areas. In the first experiment (Plot 1) water containing the conservative tracer tritium was applied at a rate of 1.76 cm/day on the area measuring 4 m × 9 m. In the second experiment (Plot 2a), water containing tritium and bromide was applied at a rate of 0.43 cm/day on the other area (1 m × 12 m) on the opposite side of the trench, and in the third experiment (Plot 2b) tritium, bromide, boron, chromium and two organic compounds (pentafluorobenzoic acid and 2,6-difluorobenzoic acid) were applied at a rate of 1.82 cm/day on the same area (1 m × 12 m). The movement of the water below the soil surface was monitored with neutron probes and tensiometers. Tracer concentrations were sampled on a regular basis through solute samplers installed in a two dimensional grid through the trench wall. In addition laboratory experiments on cores were performed to

determine the physical properties of the soil. The Plot 1 and Plot 2a experiments were included in INTRAVAL Phase 1 and was used for model calibration. The calibrated models were used in INTRAVAL Phase 2 to predict the Plot 2b experiment before the experimental data were made available to the Project Teams.

Analyses by the Project Teams

The following Project Teams have been working with the Las Cruces trench test case during INTRAVAL Phase 2:

- New Mexico State University (NMSU)/USNRC
- CNWRA/USNRC
- PNL/USNRC
- MIT/USNRC
- Bureau for Economic Geology, Univ. of Texas (BEG)/USNRC

During Phase 2 of INTRAVAL some teams modelling the second experiment (Plot 2b) have done blind predictive modelling of water content and solute concentrations at various points using data from previous laboratory and field experiments, and some teams have done predictions based on data from the second experiment. The Pilot Group has then gathered all results and performed comparative analyses. They have used a series of comparative plots, tables and simple non-parametric tests to assess model performance, see Figure 1 where populations of tritium prediction errors for the different models are illustrated. No rigorous statistical model testing were performed.

The models used for predictions of water flow and solute transport in the Plot 2b experiment are summarised in Table 3. Different types of 2-D models have been used ranging from simple models assuming homogeneous isotropic soil profiles to complex models considering heterogeneous anisotropic soil profiles.

Table 3. Summary of 2-D models used by the Project Teams for the Las Cruces Trench test case.

Project Team	Approach	Predicted value(s)	Soil properties
BEG1	not blind	water flow	uniform, isotropic
CNWRA1	blind	water flow	9 layers, isotropic
CNWRA2-3	blind	water flow	heterogeneous, isotropic
MIT1	blind	water flow	homogeneous, anisotropic
NMSU1	not blind	water flow, tritium migration	homogeneous, isotropic
NMSU2-5	not blind	water flow, tritium migration	heterogeneous, isotropic
PNL1-4	blind	water flow, tritium migration	uniform, isotropic

All model predictions of first arrival times of the water plume were non-conservative at latter times, whereas several of the models with heterogeneous soil profiles provided predictions of first arrival times of the tritium plume that were conservative at latter times. The results of the model predictions show that models that assumed heterogeneous soil profiles did not necessarily perform better than those that assumed homogeneous soil profiles. Furthermore, it was shown that models with anisotropic property fields did not perform better than those that assumed isotropic property fields.

When comparing the results from the different Project Teams it was found that models that performed best by one measure were out performed by other models using other measures. As a result of the comparisons it could be concluded that simple models seems to predict the measured values with as good result as the more complicated models. A number of

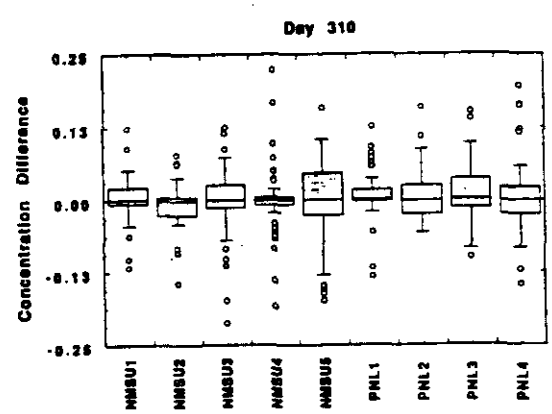

Figure 1. Las Cruces Trench. Populations of tritium prediction errors.

topics were identified that has to be developed: better techniques to condition soil property models on local observation, techniques to scale local observations to larger scales, better understanding of the relative importance of various physical processes. Concerning the model testing it has been identified that the models must be tested at different sites on larger scales and that more rigorous mathematical/numerical model testing techniques using field data have to be developed.

What concerns performance assessment, the work with the Las Cruces test case has illustrated the need of a test site characterisation methodology as well as a better understanding of when simple models are truly conservative compared to more complex models.

APACHE LEAP

Flow and transport experiments in unsaturated fractured rock performed at Apache Leap Tuff Site, Arizona, USA.

Experimental Set-up and Scales

The Apache Leap test case in INTRAVAL Phase 2 concentrates mainly on two topics, how a thermal source will affect air, vapor, water and solute movement in geologic media, especially unsaturated fractured rock, and the water and air transport properties of fractures and rock matrix in unsaturated rock.

The effects of a thermal source were studied with laboratory non-isothermal core measurements. A cylindrical shaped core, approximately 12 cm long and 10 cm in diameter, was extracted from a block of Apache Leap Tuff. The core with a prescribed initial matrix suction and solute concentration was sealed and insulated to prevent water, air and solute gains or losses from all surfaces, and to minimise heat loss along the sides of the core. During the experiment, a horizontal temperature gradient was established along the long axis of the core. The data available from the core measurements are rock matrix porosities, initial water contents, and temperatures.

The behaviour of unsaturated fractured rock, was studied in a series of tests being performed to characterise water and air transport properties of fractures and rock matrix for a range of matrix suction. The measurements were conducted on a block of Apache Leap Tuff which was 92.5 cm long, 21.0 cm high and 20.2 cm wide and contained a single discrete fracture oriented along the 92.5 cm by 20.2 cm plane. The rock was initially air-dried at a relative humidity of approximately 30 percent. The fracture traces along both ends of the block were connected to manifolds, while the fracture traces exposed along the sides of the block were sealed with putty. All external surfaces of the rock except those covered by the manifold were then sealed with adhesive vinyl. One of the fracture surfaces covered by the manifold was open to the atmosphere and the other was irrigated with water. The position of the wetting front in the fracture and in the matrix over time was studied. Available data are rock matrix sorptivity coefficient, rock matrix porosity, rock fracture aperture, and cumulative inflow volume over time.

In addition to these laboratory experiments there are some results available from field investigations. However, much of the data from the field experiments will not be available during the course of INTRAVAL Phase 2.

Analyses by Project Teams

The following Project Team has been working with Apache Leap Tuff site test case during INTRAVAL Phase 2:

– UAZ/USNRC

The Pilot Group (UAZ) gave some comments on the Apache Leap test case which includes five hierarchical scale experiments, from core characterisation to field air permeability tests. The validation strategy has been to use field characterisation data to provide model predictions with confidence intervals. Each experiment should be conducted in such a way that the observed behaviour is known with sufficient confidence and to ensure that it is not artifacts one is studying. If models based on alternative concepts show identical behaviour then the experiment is not properly designed. The strategy used for comparison of model predictions and observed data has been to propagate parameter uncertainties to forecast uncertainties in predicted values. If the predicted values lie outside the forecasted confidence interval the model is found to be inadequate. It was also pointed out that experimental uncertainties should be used to evaluate the degree of significance between model prediction and experimental observations. The core characterization studies showed that hysteresis significantly altered the drying and wetting curves. Therefore, the wetting history at the site must be known if matric suctions are estimated from field measurements of water content. The fracture imbibition experiment indicated that fingers of saturation existed within the fracture during early times and that those fingers expanded laterally and dissipated with time. Furthermore, it seems that the fingering (channeling) is at least as pronounced in unsaturated fractures as in saturated.

The Project Team from UAZ has studied scale effects in air permeability determinations. Three boreholes, Y2, V2, and X2 have been completely tested at a 1 meter scale. The borehole Y2 has as well been tested at 0.5 and 3 m scales. Two other boreholes, W2A and Z2, are currently being tested at a 1 m scale. When the testing program is completed, a total borehole length of 180 meters will have been tested at a 1 m scale. An important conclusion from the analysis performed so far is that air permeability is a strong function of applied pressure. Values quoted without such pressures are therefore ambiguous. The average permeability has been found to increase with increas-

ing scale. Another major finding is that the data indicate that flow through the fractured porous material may be amenable to the theory of stochastic hydrology.

YUCCA MOUNTAIN

Yucca Mountain experiments.

Experimental Set-up

The objective of the Yucca Mountain test case is to compare predicted and observed moisture content as a function of depth in a borehole currently being drilled. The data set for the test case consists of composite transects of hydrologic properties at the site, detailed geohydrological data and moisture content data from boreholes UZN-53, UZN-54 and UZN-55, and topographic and structural geology information for the site. Data from the three UZN-boreholes have been used to predict the moisture content in another borehole, UZ-16, that will be drilled to a depth of about 500 m at a distance of about 100 m from the UZN-boreholes.

Analyses by the Project Teams

The following Project Teams have been working with the Yucca Mountain test case during INTRAVAL Phase 2:

- Golder/USDOE
- USGS/USDOE
- CNWRA/USNRC
- State of Nevada
- SNL/USNRC
- USNRC

The Project Team from USGS has used a 1-D finite difference matrix model (TOUGH) to predict the water content in the core from borehole UZ-16. The model parameters were calibrated using data from nearby shallow boreholes. The parameters were particle density, porosity, permeability and van Genuchten parameters for unsaturated hydraulic conductivity from filled moisture retention curves for different microstratigraphic units at different depth. The problem with this modelling was that the applied rock properties were from another location than UZ-16 and no fracture or fault properties were available. The team has used past climate conditions to estimate earlier infiltration and noted that the saturation measured today is not sensitive to earlier climatic changes.

The Project Teams from CNWRA and USNRC applied a 1-D steady state, composite porosity model and a dual continuum fracture-matrix model for 1-D steady-state infiltration to predict the water saturation in the core from borehole UZ-16. The predictions were based on hydraulic characteristics of rocks from transects and other boreholes, neutron logs from other boreholes and porosity and lithologies from the borehole to be predicted (UZ-16). The first model (composite porosity) predicted the water content profiles rather well except in a few geological units. The predicted saturation appear to be less accurate than the predicted water content. The second model (dual-continuum) which represents fractures and matrix as two continua interconnected trough a transfer term gave a proper description of the saturation behaviour of the fracture continuum. The effect of fracture coatings may be seen in flow regimes where there is a transition between fracture and matrix flow.

The observer from the State of Nevada has studied the effects of variability in selected model inputs on modelled unsaturated water content profiles. 1-D, 2-D as well as fracture models have been applied for simulations of the water content in the rock to a depth of almost 500 m. Some of the data used originate from boreholes at the Yucca Mountain site not included in the test case. The rock has been modelled as consisting of seven hydrologic layers except for the 1-D case where the number of layers were varied from 4 to 11. The results from the 1-D models showed a poor fit to measured data even though the number of layers as well as the infiltration rate were varied. The wet conditions within the upper high conductivity unit, co-existing with the unsaturated conditions in the low conductivity units, could not be modelled with 1-D geometry and infiltration. Like the 1-D simulations, the 2-D simulations were found to underestimate the measured water content in the upper unit. The fracture flow model showed considerably better match to observed data. In this model, water was recharged into a vertical fracture intersecting all seven hydrologic layers. The recharge rate was estimated based on ground surface material, topography, and climate data. The fracture density in the rock was set to about 3 fractures/meter. In this case, the very wet conditions in the upper permeable unit as well as the unsaturated conditions below are much better represented than the 1-D and 2-D representations.

Different Project Teams applied different modelling approaches to predict the water saturation in the core from borehole UZ-16. The test case provided insufficient data to discriminate between the models used but it seems that the stratigraphy is the most important aspect in modelling unsaturated flow at Yucca Mountain. It was not possible to reach any conclusions concerning fracture vs. matrix flow models because of the large differences in model geometries and boundary conditions. Another aspect that makes model comparison dubious is the difference in applied initial conditions. No conclusions concerning infiltration from the saturation profile could be drawn because of the fractured nature of the tuffs.

FINNSJÖN

Tracer experiments in a fractured zone at the Finnsjön research area, Sweden.

This test case is based on a set of tracer tests in a fracture zone in crystalline rock at the Finnsjön research area in Sweden. The main experiments carried out are a large-scale interference test and two large scale tracer tests, one radially converging test and one dipole experiment. The modelling is focused on the dipole experiment. This test case was also included in INTRAVAL Phase 1, but the database for the dipole experiment was never used for modelling, since it became available too late.

Geological Structures

The experiments are confined to a sub-horizontal fracture zone at approximately 300 m depth. The thickness of the zone is approximately 100 m and its horizontal extent is in the order of kilometers.

It appears that the zone contains three highly permeable sub-layers. The transmissivity of the upper layer is estimated to be 10^{-4} m^2/s, the middle 10^{-7}–10^{-6} m^2/s and the lower 10^{-4} m^2/s. The middle layer is not continuous. A fresh water–salt water interface is located in the fracture zone relatively close to the upper sub-layer. The salt content of the groundwater is higher below the zone than above. The natural hydraulic head gradient is estimated to 1/300 in the horizontal direction.

Hydraulic Tests

The fracture zone and the surrounding rock are penetrated by several boreholes. Packer tests for hydraulic conductivity (Lugeon tests) have been performed in all boreholes in 2 m and 20 m section intervals. In addition, a part of one borehole has been investigated at 0.11 m intervals. A regional pumping test has been conducted by pumping water from the full length of one borehole and observing the drawdown in 11 wells totalling 40 intervals.

Tracer Tests

Two sets of tracer test have been completed, a radially convergent test and a dipole test. The radially convergent test was conducted by pumping one well from a packer interval covering the full width of the fracture zone and injecting eleven different non-sorbing tracers at nine different intervals in three wells surrounding the production well, i.e. more than one tracer was injected at some points.

The dipole test was conducted by pumping in one well and injecting tracers in another. A total of 20 different tracers were introduced at the upper layer of the injection well. The tracer discharge points at the discharge well were estimated by sampling the tracers in different layers. Both the radially convergent and the dipole test showed that tracers could move between the layers in the fracture zone.

Analyses by the Project Teams

The Finnsjön experiments has been studied by the following Project Teams:

- Geosigma/SKB
- VTT/TVO
- PNC
- PSI/NAGRA
- New Mexico State University (NMSU)/SNL/US-DOE
- Hazama/JAERI
- Conterra/KTH/SKB
- BRGM/ANDRA
- UPV/ENRESA

These Project Teams applied different approaches for the analysis of the experiments.

The Geosigma team performed a porous media advection-dispersion analysis applying the same concept for the whole sequence of flow and transport experiments. The team also studied the effects of the natural gradient and anisotropy. 1-D as well as 2-D models were applied and the classification of model simulations was based on regression statistics.

The VTT team applied a channel concept for the whole sequence of tests. The main objectives were to obtain a model which was as realistic as possible for the description of groundwater flow and tracer transport and to test if the same concept could be applied to all three tracer tests in zone 2. The modelling approach was to consider flow in a 2-D network of channels and transport in just one or two routes. The channels were assumed to be non-interacting and having variable apertures. The team concluded that all experiments could be described with the same concept. Furthermore, 50–100 % of the transport could be explained by just considering one channel. The team found that the effect of hydrodynamic dispersion was clearly noted in the experiments contrary to the effect of matrix diffusion.

The PNC team performed a porous media analysis with the main objective to study the effect of heterogeneity on the tracer transport. The system was assumed to be a dual porosity porous medium and the modelling approach included generation of hydraulic conductivity distributions by trial and error as well as applying a geostatistical approach. Stream tube and 2-D finite difference models were used. The procedure was to fit the transport parameters from the dipole test and to check the validity by simulating the radially converging test. The objectives were to statistically estimate transmissivities in the high conductive zone in the upper part of zone 2 and to identify transport parameters by considering least square errors. The validity of the model was examined by comparing calculated and observed data. The team concluded that the tail part of the breakthrough

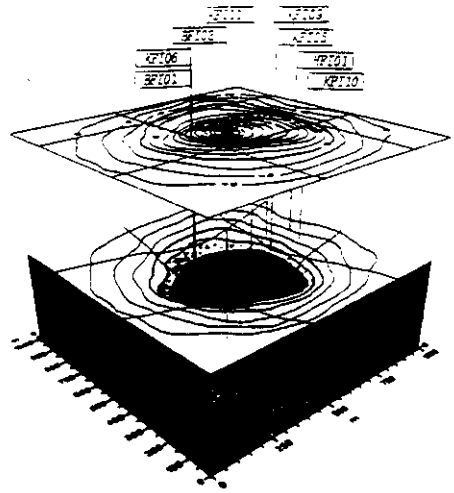

Figure 2. Finnsjön, PNC. Calculated hydraulic heads in the radially convergent test.

curve of each tracer could be explained by considering the mixing between the low conductive and the high conductive zone. Furthermore, the parameters identified from the dipole tracer test simulation could explain the general characteristics of the breakthrough curve obtained from the radially converging tracer test. Figure 2 illustrates the calculated hydraulic heads in the radially convergent test.

The PSI team did not use the same data as the other teams, but performed a porous media analysis of a radially converging tracer test from another part of the Finnsjön site. The main modelling objectives were to determine the geometrical assumptions needed to reproduce the breakthrough curves and to determine the dominant transport processes in the Finnsjön experiments. The modelling approach was to assume a 2-D dual porosity homogeneous system. The team concluded that the concept of the dual

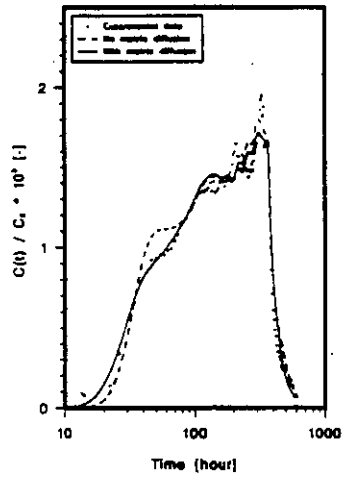

Figure 3. Finnsjön, PSI. Experimental data and calculated breakthrough curves with and without matrix diffusion.

porosity medium has proven to be a versatile, efficient and highly appropriate "tool" for analysing the Finnsjön migration experiments. Furthermore, no serious limitation of the model was identified, i.e. no indication for further mechanisms that ought to be included could be recognized. One of the main goals of the investigations was to find an answer to the question of the minimum number of independent flow paths that had to be included in the calculations. It was found that models with a single flow path reproduced the break-through curves in a grossly averaged way. Introducing a second flow path improved the fits. Furthermore, the concept with a further flow path complies with in-situ observations. An inspection of the measured data showed that the signature of matrix diffusion could not be identified in the tailing part of the breakthrough curves. However, calculations for both concepts (one/two flow path systems) demonstrated that this mechanism cannot be neglected. It effectively influences the shape of the breakthrough curves and strongly improves the fits (Figure 3).

The NMSU team used a layered porous media model and a double porosity model to analyse the radially converging test and the dipole test. The modelling approach included a description of a vertical cross-section representing the flow paths. The thickness and hydraulic conductivity distribution was interpreted from individual borehole data. The results showed a reasonable agreement with most breakthrough curves for both single and double porosity models. It was therefore not possible to judge which model that best represented the fracture zone.

The Hazama team performed a flow and transport analysis of the radially converging and the dipole tracer tests. The modelling approach included the use of a REV from the Crack Tensor Theory. Values of the apparent aperture were assigned using conditional simulation followed by a transport analysis in a continuum model by means of a particle tracking method. The modelling included particle releases from simulated test sections and calculation of ensemble breakthrough curves. These calculated breakthroughs were found to give good as well as bad fits to the measured breakthrough curves.

The Conterra/KTH team applied a stochastic continuum model to analyse the dipole test and a conceived far-field natural gradient test. The main objective in this modelling exercise was to determine if a stochastic continuum model calibrated on a local test scale also is valid on a larger, far-field scale.

The team tackled this problem by creating a reference transmissivity field represented by a 0.5 m thick 2-D confined aquifer with a size of 1200 m × 1200 m, corresponding to the upper permeable part of zone 2. All measured transmissivity data were used to construct a synthetic reference field as close as possible to the real situation. Dipole tracer tests, similar to the Finnsjön test, and a far-field (natural gradient) test were performed in this synthetic reference field for calibration and validation.

Eight boreholes penetrating fracture zone 2 have been hydraulically tested and several realisations were generated and conditioned on the data from these boreholes. One of the generated realisations was randomly chosen as the reference field. The results from "tracer tests" using a particle tracking technique were considered to be the real system response of the reference field. The far field simulation in the synthetic reality was performed under natural conditions.

The team used the Monte-Carlo approach to generate 100 equally probable realisations having the same statistical structure as the observed data. Comparing the breakthroughs in the dipole experiments it was found that individual realisations could be very different to the reference field due to uncertainty in transmissivity values, while the mean(assemble) breakthrough curve was very close to that of the reference field. Based on a quantified measure of the deviation of the simulated breakthrough curve from that of the reference field, 3 of the 100 fields were chosen that captured the reference field quite well. The far field simulations were calculated under natural gradient conditions using the same transmissivity fields as for the local scale dipole test. The results from the three simulations show very different mean arrival times and dispersion patterns, indicating that calibration of the model on the local scale and subsequent prediction of far field transport phenomena can result in high uncertainty. This indicates that there are not enough conditioning points on the far-field scale to recapture the characteristics of the far-field reference case transport response. Therefore, calibration of a model on a local scale is insufficient to also validate the model on a larger transport scale. This conclusion implies that measurement data should be collected on scales relevant to the studied transport problem.

The BRGM team performed an analytical and numerical porous media analysis of the interference tests and the radially converging tracer test. The boundary effects as well as the multi-layering of zone 2 were taken into account in the modelling. The model was calibrated using data from two of the tests and subsequently validated on a third test. A 3-D analysis showed a good fit between measured and calculated drawdown during the complete test sequence. Furthermore, it was possible to simulate the behavior of the five high-recovery tracers. Another finding was that a homogeneous porosity could not be employed.

The UPV team analysed the implications of selecting a multiGaussian model based on the parsimony principle. The modelling approach included a demonstration of the impact of extreme values on travel times by applying two stochastic models, multiGaussian and non-multiGaussian, in a stochastic continuum study. The team concluded that a Gaussian histogram does not imply that the only multivariate model must be multiGaussian. Furthermore, it was pointed out that a multiGaussian model implies a very low connectivity of extreme values and might therefore be too optimistic from a regulatory point of view.

The analysis of the Finnsjön experiments includes a variety of different approaches including stochastic modelling even though the porous medium concepts seems to dominate. An important conclusion is that the dimensionality of the applied model was not decisive for the ability to reproduce the field responses. It was furthermore noted that a relatively simple model could reproduce the experimentally obtained breakthrough curves. The effect of matrix diffusion seems to have been very small in the experiments mainly due to the high induced flow velocities. The tracer migration has therefore been governed by advection and it was noted that hydrodynamic dispersion was needed to explain the breakthrough curves measured in field.

STRIPA

Flow and tracer experiments in crystalline rock based on the Stripa 3-D experiments, Sweden.

Experimental Set-up

This test case is based on three-dimensional tracer tests performed in the Stripa mine in Sweden. The experiments are part of the International Stripa Project.

In an experimental drift, excavated in the old iron ore mine in Stripa, the whole ceiling and upper part of the walls was covered with about 350 plastic sheets (2 m^2 each) with the purpose to collect water seeping in from the rock and to collect injected tracers. Three vertical boreholes for tracer injections were drilled and tracers were injected at nine locations 10 – 55 m above the test site.

The data registered or obtained from the experiments are water flow rates, tracer concentrations in the water entering the drift, rock characteristics and fracture data, water chemistry, tracer injection pressures and flow rates, and hydrostatic pressure. Diffusivity and sorption data are available from supporting laboratory and field experiments. This so called 3-D experiment was as well a test case during Phase 1 of INTRAVAL.

In addition to the results from the 3-D experiment, data from two other experiments performed in the Stripa mine, the "Channeling Experiments" and the "Site Characterisation and Validation program", were available to the INTRAVAL Participants during Phase 2. The Channeling Experiments consisted of two kinds of tests, single hole and double hole experiments. In the single hole experiments, holes with a diameter of 20 cm were drilled about 2.5 m into the rock in the plane of a fracture. Specially designed packers were used to inject water into the fracture at 5 cm intervals. The variation of the injection flow rates along the fracture were used to determine the transmissivity variations in the fracture plane. Detailed photographs were taken from inside the holes and the visual fracture aperture was compared with the injection flow rates. Five holes were measured

in detail and seven holes were scanned by simple packer systems. In the double hole experiment, two parallel holes were drilled in the same fracture plane at nearly 2 m distance. Pressure pulse tests were carried out between the holes in both directions. Tracers were injected at five locations in one hole and monitored in several locations in the other hole.

The Site Characterisation and Validation program, with the aim to predict groundwater flow and tracer transport in a previously unexplored rock volume, involved a number of investigation steps with modelling predictions. A few long boreholes were used to characterise the rock volume. Additional boreholes were drilled and used for investigations of water bearing sections, fractures, tracer tests etc. All investigations were compared to already performed model predictions. Finally, a new drift, the "Validation Drift", was excavated in the rock block. The new drift was instrumented with plastic sheets and other water collection devices.

Analyses by the Project Teams

The data set from the Stripa 3-D migration experiment has been studied in INTRAVAL Phase 1 and 2. Four Project Teams studied the test case in Phase 1:

- KTH/SKB
- Lawrence Berkely Laboratory (LBL)/USDOE
- KTH/SKI
- INTERA/AEA/NIREX

Two other Project Teams have analysed the Stripa 3-D data as part of Phase 2:

- VTT/TVO
- BRGM/ANDRA

The experimental findings from the Stripa 3-D experiment clearly indicated that:

- the water flow into the drift was very unevenly distributed
- there seems to be a correlation between fracture intersections and high water flow rates
- also the tracer migration properties were unevenly distributed since experimental breakthrough curves in adjacent sheets for the same tracer were in many cases quite dissimilar.

To reproduce such observations, most Project Teams based their analysis upon the assumption of flow and transport within one-dimensional channels. The channeling concepts considered by the different Project Teams were:

- one-dimensional models assuming no mixing of tracer between the channels over the migration domain
- models of interconnected one-dimensional channels assuming a perfect mixing at each channel intersection
- and finally, one team did not assume any mixing and flow dimension a priori, but considered the flow dimension as the main unknown.

Different teams considered different transport properties in the individual channels. The KTH/SKB team considered channels that only had advective transport as well as channels having transport properties based on a combination of advection-dispersion-matrix diffusion. The Project Teams from KTH/SKB, KTH/SKI, BRGM and LBL considered channels having transport properties due to advection and dispersion.

Different channel arrangements were as well considered by the Project Teams. All teams analysed transport in a single channel. The LBL team assumed an arrangement consisting of several discrete parallel channels. Each channel had a variable aperture along its length, and the hydraulic conductivity in the channel was controlled by constrictions. Such channels does not represent physical pipes, but rather channels that arise naturally as paths of low resistance through the fracture planes. The LBL team used this arrangement coupled with the advection-dispersion model.

The KTH/SKB team also considered an arrangement consisting of a large number of parallel channels that conduct the flow from the inlet to the outlet without mixing between the channels. Thus, this arrangement is very close to the one used by the LBL team, but the KTH/SKB team assumed that dispersion in the direction of flow was caused by channeling, so that the "advection only" single channel property was applied. A further assumption was that the channel properties obeyed a lognormal distribution function. The flow rate through each channel was calculated using the cubic law.

The Project Teams from KTH/SKI and BRGM considered a network of one-dimensional channels located in a three-dimensional network of interconnected disc-shaped fractures. Both teams considered a channel geometry where flow was assumed to occur through "bonds" joining the center of each disc to the center of the adjacent disc. In addition to this concept, the BRGM team also used a "Random Channel Model" where one-dimensional channels were randomly located on the fracture discs and where fracture intersections may or may not be considered as channels.

The LBL and VTT teams used deconvolution techniques to analyse the experimental breakthrough curves. The impulse responses obtained by LBL were composed of distinct peaks. These peaks were considered as the result of solute transport in independent channels and the solution of the one-dimensional advection-diffusion equation, for a delta pulse injection, was fitted to each peak. The VTT team focused on the detailed analysis of the impulse responses given by deconvolution of the experimental breakthrough curves and injection pulses, taking into account the effects of measurement errors and other disturbances on the deconvolution results. The impulse responses obtained by the VTT team were also composed of various peaks. These peaks did not

necessarily correspond to those previously identified by the LBL team. The LBL team used the Toeplitz method and the VTT team the Extreme Value Estimation method (EVE) to perform the deconvolution. The EVE method estimates the lower and upper bounds of the unknown or any user-defined linear expression formed from them. The analysis by the VTT team indicated that the experimental breakthrough data could be explained by hydrodynamic dispersion.

The geometry of the system was estimated in the approach employed by the INTERA/AEA team. The team calculated fractional dimensions of the flow paths and noted that the slopes of the fitted lines were generally close to unity suggesting that the basic premise of transport through a simple geometric structure is appropriate and that the dominant structure is pipelike.

The Project Teams, except for KTH/SKI, used the tracer breakthrough curves to fit the transport parameters. However, a problem was that the tracer injections had been time-varying. Because of this, the teams had to use either the real data and compute what the response would have been if a simple (pulse) injection had been performed or compute the responses of the system to the time-varying injection. The first approach which involves a deconvolution technique was used by the LBL and VTT Project Teams and the second approach which involves a convolution technique was used by the KTH/SKB and BRGM teams. Two other approaches were as well used. The LBL team studied the first peak early arrival data and modelled the time-varying injection flow rates by an exponential decay curve followed by a period of stabilization. The KTH/SKI team generated synthetic breakthrough curves with the channel network model using a pulse injection and integrated the simulated curves over time in order to simulate a constant step injection of tracer.

One of the more important experimental observation from the 3-D experiment was that the flow and tracer transport seemed to be localized to a few preferential flowpaths, channels. The definition and incorporation of channels and channel properties has therefore been a common theme for the Project Teams. Although the Project Teams applied quite different assumptions, the various channel models were able to reproduce most of the trends observed in the experiment. Such a finding therefore points out that the experimental data could not be used to validate or invalidate any of the various channel models. Furthermore, several mechanisms were probably unmodelled. Indeed, it is true that these models have allowed to reproduce some of the field observations, nevertheless it can hardly be seen how they could have predicted them. Mechanisms such as diffusion into stagnant pools of water, matrix diffusion, mixing between channels, flow channel geometry and disturbances, as two-phase flow, due to the drift will have to be studied further.

WIPP 2

Flow and transport experiments in heterogeneous fractured media performed at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located near Carlsbad in southeastern New Mexico, USA, is an underground research and development repository. It is located in the Delaware Basin, the northern part of which is filled with 8000 m of sedimentary Phanerozoic rocks containing evaporities. Water bearing zones within the rocks that underlie host and overlie the WIPP repository have low permeabilities and storativities. They are generally confined and contain waters with high salinities and long residence times. The repository lies 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado Formation. Overlying the Salado Formation is the Rustler Formation. The Culebra Dolomite Member of the Rustler Formation is the most transmissive water-bearing unit found at the WIPP site. It is an 8 m thick vuggy dolomite layer.

Geologic, hydrologic, geochemical and isotope data have been collected to resolve several issues concerning the hydrology of the Culebra dolomite. A central issue involves the travel time within the Culebra from a location above the repository to the WIPP site boundary. 60 wells into the Culebra dolomite at 41 locations have been completed to provide information on the hydraulic properties. Two pumping tests, each of two months' duration, and two convergent-flow tracer tests have been performed. Geochemical and isotope studies have been conducted in order to obtain additional insight into the hydrologic behaviour of the Culebra.

Analyses by the Project Teams

The test case has been studied by the Project Teams from:

- AEA/NIREX
- UPV/ENRESA
- AECB
- BGR
- SNL/USDOE

The main data used in the studies undertaken within INTRAVAL were the hydrogeological properties of the Culebra dolomite. The Culebra dolomite is quite thin, approx 8 m, but extends for many kilometers and is highly fractured. A large number of hydraulic tests have been performed in the dolomite including transmissivity measurements, steady-state measurements of heads and cross-hole tests. The modelling has mainly addressed the issues involved in treating the heterogeneity of the transmissivity of the Culebra dolomite. The effects of the varying

salinity of the groundwater in the Culebra dolomite has also been analysed. There are large variations in the transmissivities of the Culebra leading to uncertainties in quantities of importance in a repository performance assessment such as travel times. Therefore, there seems to be a generally-agreed approach to use stochastic models. The conceptual models include two as well as three dimensional descriptions of the Culebra dolomite. Furthermore, continuum porous media as well as fracture network models have been studied.

The teams from AEA and UPV tackled this test case by using stochastic models. The AEA team applied the Turning Band algorithm for generation of realizations. The finite element groundwater and transport code NAMMU was used to solve the problem. The team examined the uncertainties in the pathlines, travel time, head and Darcy velocity that resulted from the uncertainties in the parameters. Furthermore, the statistical behavior of the variogram estimators was studied using Monte-Carlo simulations. The team considered four different stochastic models, all isotropic, and concluded that if the correlation length was comparable to, or greater than, the size of the domain investigated it was not possible to determine the correlation length from the measured data. However, this did not have a significant impact on the uncertainties in quantities such as the travel time, provided that the model was conditioned on a reasonable number of transmissivity measurements. The team applied three different approaches to condition the head data. None of these approaches were found to be entirely satisfactory. Furthermore, the performed work gave some evidence that conditioning on head data is not as strong constraint as conditioning on transmissivity data.

The UPV team used a sequential Gaussian simulation for the generation of realizations. The finite difference codes MODFLOW and MODPATH were used to compute the flow and particle paths. An optimization method was used to condition the head data. The team found that the anisotropic variogram gave best fits. The conditioning on the heads implied some significant improvement, but some discrepancies were still remaining. Gaussian models imply lack of connectivity of regions with higher (or lower) than average transmissivity. Therefore, they might not take into account fast flow paths from the repository which are responsible for the main radiological consequences. Furthermore, the modelling performed by the team indicated that variable density has a large impact on the results and should therefore be included.

The AECB team studied the effects of salinity on the groundwater flow. This was done by comparing the groundwater flow and head data using three different salinity distributions. The problem was solved using the finite difference code SWIFT. The results indicated that there was not any strong evidence for a trend, the variations were consistent with the correlated spatial process. The match to the heads were not good even with conditioning. The calculations with different salinity indicated that the flow paths in the Culebra from the center of the site are relatively insensitive to the uncertainties in the salinity distribution.

The BGR team addressed issues relating to the choice of conceptual model. The AEA, UPV and AECB teams all considered two-dimensional areal models of the Culebra dolomite and assumed that the permeabilities of the units above and below are sufficiently small so that vertical flow can be neglected. The BGR team examined this assumption by including different approaches for the density variations due to variations in salinity and the effect of permeability differences.

The SNL team has applied different conceptual models to study the importance of vertical flow between the Culebra dolomite and the overlying units. Calculations using the preliminary conceptual model indicate that leakage from the Culebra may be of importance.

This test case provided a very valuable focus for the development and study of stochastic models for the treatment of heterogeneity in hydrogeological properties. The applied stochastic models have proven to be valuable tools in assessing the effect of uncertainty due to heterogeneity on the performance of a repository.

GORLEBEN

Saline groundwater movements in the vicinity of the Gorleben salt dome, Germany.

Experimental Set-up

The Gorleben salt dome is located in the northeastern part of Lower Saxony in Germany. The salt dome is approximately 14 km long, up to 4 km wide and its base is more than 3000 m below surface. An erosional channel, the "Gorleben Channel", more than 10 km long and 1 – 2 km wide, crosses the salt dome from south to north. Erosion along the channel extends down to the cap rock. Freshwater in the upper part of the aquifer system is underlain by saline groundwater. The groundwater movements in the erosional channel are the topic for this test case.

Hydrogeological investigations have been conducted in an area of about 300 km^2 around the salt dome. During these investigations four pumping tests were carried out, one in the freshwater and three in the saline water. One of the pumping tests, in which the pumped well penetrated the entire deeper aquifer in the erosional channel, forms the basis for the first part of this INTRAVAL test case. The pumping test was carried out with a pumping rate of 30 m^3/h over a period of three weeks. The second part of the test case is an extension in time and length scales and comprises modelling of regional groundwater flow and salt dissolution as well as interaction between the two.

Analyses by the Project Teams

The following Project Teams have been working with the Gorleben test case during INTRAVAL Phase 2:

- BGR
- AEA/NIREX
- BfS
- GRS
- RIVM
- SNL/USDOE

The different teams have worked with a number of different tasks. The Project Team from AEA have applied geostatistics on the Gorleben data set and the quantity of interest has been the distribution of clay at the site. The pumping test has been evaluated by BfS, SNL and RIVM and the regional flow situation has been studied by GRS and BGR.

The Project Team from AEA has applied an indicator kriging method to study the Gorleben data set. The modelling work include indicator methods and the use of variograms and kriging for stratigraphic interpolations. Qualitative data from boreholes logs were used in a statistical framework to estimate the distribution and variability of the clay formation at the site. The analysis was conditioned by taking stratigraphic information into account. Information from five boreholes in a vertical section perpendicular to the Gorleben channel were selected for comparison between kriged and geological interpretation and a reasonable degree of agreement was observed.

The Project Team from RIVM made an interpretation of the Weisses Moor pumping test. The drawdown during the pumping period was analytically evaluated with the THEIS model, but the team concluded that the analytical solution could not be used. The drawdown in the boreholes during pumping but also during recovery were then calculated numerically. The varying density of the water observed in different boreholes were not included in the calculations as the density effect was judged to have minor influence on the flow during the short time period for which the calculations were performed (500-2000 hr). A reasonable estimate of the hydraulic conductivity and storage coefficient could be obtained with a 2-D constant density mode, taking into account anisotropy and global heterogeneities. The fit for boreholes located close to the pumping well is usually good, whereas, the fit is usually less good for boreholes further away. The issue of validation has not been addressed yet since the work has been concentrated on data evaluation and parameter fitting.

The Project Team from BfS presented calculations on the Weisses Moor pumping test. The specific permeability, storage coefficient, and aquifer thickness were estimated with an analytical model, THEIS, using regression technique to minimise the residuals in draw-down in the observation wells. The so fitted drawdown curve corresponded well to that observed. The determined parameters were then used in a numerical model to test the influence of well screen location and density distribution on the calculated draw-down values. A two-dimensional mesh corresponding to a 4.8 km wide and 45 m deep crossection was generated. The numerical codes used were SUTRA and ROCKFLOW. Calculations were performed for both constant density of the water and density dependent flow, i.e an increased density with depth. The boundary conditions in the pumped well were either constant withdrawal at one or at both well screens. Almost identical drawdowns were observed in the different calculations except for a small influence of the well screen location at early times. A conclusion is therefore that the effect of the well screen location is greater than taking the influence of density dependent flow into account.

The Pilot Group (BGR) performed numerical transient calculations with the code SUTRA to study density dependent groundwater movements in the erosional channel above the salt dome. The aim was to reproduce the density distribution and to check if the flow situation in the channel today is in a steady-state situation. Calculations were performed for a cross-section intersecting the channel. The modelled 2-D cross-section is 15 km wide and 250 m deep. Three different initial conditions were applied for the density distribution: linear density distribution, density distribution from measured data, and a narrow density transition zone (between 220 and 240 m depth). The conclusion from these calculations were that steady-state conditions have not been reached in the system yet. The sensitivity to the channel outlet has also been studied by performing calculations of the density distribution after 10 000 years. The calculations differ mainly in the hydraulic properties at the northern channel outlet. The outlet was modelled in three different ways: a closed outlet, an open outlet, and a very small outlet. These calculations gave almost identical results.

The Project Team from GRS presented simulation of the salt transport in the Gorleben channel with the finite element code NAMMU. They started to perform 3-D fresh water simulations followed by 2-D salt transport calculations for a cross section of the channel. They presented salt concentration profiles and pressure contours at different times. The calculations are very time consuming and advanced numerical solvers are required for the problem. One concluding remark was that more information about the initial conditions, boundary conditions as well as the time evolution of the site would have been appreciated.

WIPP 1

Brine flow through bedded evaporities at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA.

Experimental Set-up

The WIPP, located in Carlsbad, New Mexico, is an underground research and development repository lying 655 m below ground surface within bedded evaporities, primarily halite, of the Permian Salado formation. This test case is based on experiments performed with the aim to determine the rate of brine flow through the Salado formation. The experiments are designed to provide a variety of data with the aim to determine whether Darcy's law for a porous, elastic medium correctly describes the flow of brine through evaporities, or whether a different model is more appropriate. The test case is also related to another important issue, the ability of waste-generated gas to flow from the repository into the formation.

Data from three types of experiments form the bases for this test case:

- small scale brine-inflow experiments
- pore pressure and permeability testings
- integrated, large scale experiment.

Brine inflow rates are measured at three scales, in 10 cm and 1 m diameter boreholes and in a 2.9 m diameter cylindrical room. Pore-pressure measurements are made in 10 cm diameter boreholes, 2 to 27 m long, drilled at a variety of orientations. In the large scale experiments, brine inflow rates to a horizontal, 107 m long, cylindrical room, with a diameter of 2.9 m are measured.

Analyses by the Project Teams

The following Project Teams have been working with the WIPP 1 test case during INTRAVAL Phase 2:

- SNL/USDOE
- EDM/CEA/IPSN
- RIVM

The Pilot Group (SNL) presented their conclusions and unresolved issues regarding brine inflow through evaporities. The permeability testing on halite and anhydrite interbeds gave the following permeabilites: for pure halite less than 10^{-23} m^2 (no response observed), impure halite ranges from $2 \cdot 10^{-21}$ to $5 \cdot 10^{-20}$ m^2, permeability of anhydrite interbeds is controlled by sub-horisontal bedding-plane fractures and ranges from $2 \cdot 10^{-20}$ to $6 \cdot 10^{-18}$ m^2. The transmissivities of anhydrite interbeds (8 to 96 cm thick) ranges from $5 \cdot 10^{-14}$ to $7 \cdot 10^{-12}$ m^2/s. Pore pressure in halite are generally lower than in anhydrite at the same distance from an excavation, possibly due to combined effects of stress relief and pore dilation caused by creep. The small-scale brine inflow tests showed: no inflow from pure halite, inflow rates consistent with permeabilites for impure halite and heterogeneous fracturing cause large variations for anhydrite (inflow rate varies two order of magnitude between boreholes 1 to 2 metres apart). The inflow of brine to boreholes through multiple layers of impure halite decreased for the first two years and increased thereafter (the increase may be caused by creep and other forms of deformation). The brine inflow rates to bore holes in anhydrite increase with time, possibly due to shear deformation and creation of new storage volumes beneath the excavations. The large-scale brine inflow testing (Room Q) showed an up to 25% increased permeability in boreholes in anhydrite interbeds after mining of the room. The stress relief from mining caused pore pressure in anhydrite interbeds to decrease by up to 5.5 MPa. Halite with no measurable permeability or distinct pore pressure prior to mining showed clear permeability and pore pressure after mining. A total of 150 litres of brine has been collected in the room over 2 years. Future plans for the permeability experiments are one additional test of an anhydrite interbed to evaluate the pressure dependence of permeability, and two additional tests of argillaceous halite (one in the far field). It was concluded that Darcy's flow model has not been validated for evaporites. It may be valid for anhydrites under natural low-gradient conditions, but is probably invalid for fractured anhydrites under large hydraulic gradients because permeability will change as pressure changes. Darcy's flow model is probably also invalid in a medium such as halite in which plastic deformation of pores occurs over long time scales.

The Project Team from EDM presented their evaluation and modelling of the small scale brine inflow experiment. They used the law of conservation and Darcy's law to describe the flow of brine through the salt. The salt was assumed to be a homogeneous and isotropic material, and the team excluded the impact of mechanical and thermal effects. Brine inflow data from bore holes DBT10, 11, 12, and 13 were used to estimate the storativity and the permeabilities. The conclusion from these simulations were that good agreement with the inflow experiments was observed and that the permeability in argillaceous halite is about 50 times larger than in pure halite.

It can be concluded from the WIPP 1 experiments and evaluations that the pressurisation of a repository due to gas generation depends on the amount of available brine. However, the validation of brine flow in salt under natural gradients is still an open issue, since the tests were carried out with order of magnitude higher gradients. The question was raised whether it is possible to use coupled hydro-mechanical models for this purpose.

MOL

Migration experiment in Boom clay formation at the MOL Site, Belgium.

Experimental Set-up

This test case is based on an in situ migration experiment set-up in the underground facility built in the Boom clay formation at the Mol site in Belgium. The purpose of the experiment is to determine migration related parameters and to confirm parameters determined earlier in the laboratory. The experiment is a joint effort between SCK/CEN, NIRAS/ONDRAF and PNC.

A group of piezometers, a piezometernest, has been installed in the Boom Clay formation at a depth of 220 m. The stainless steel system contains nine piezometers, interspaced by 0.9 m long tubes. A horizontal hole with a diameter of 50 mm and a depth of 10 m has been drilled in the clay formation. Immediately after drilling, the complete assembled piezometernest was pushed into the hole. The steady-state pressure distribution as a function of the depth into the clay is measured by means of manometers.

About two and a half years after the installation of the piezometernest the clay formation was supposed to be settled. HTO was injected to filter number 5 (in the center) and thereafter the system was left alone allowing migration of HTO.

The HTO concentration in the clay is measured by collection of liquid samples from the other filters. The first breakthrough was obtained in filters 4 and 6 located adjacent to the injection filter 5, at a distance of 1 m.

The experiment will continue 10 years after finalisation of INTRAVAL Phase 2.

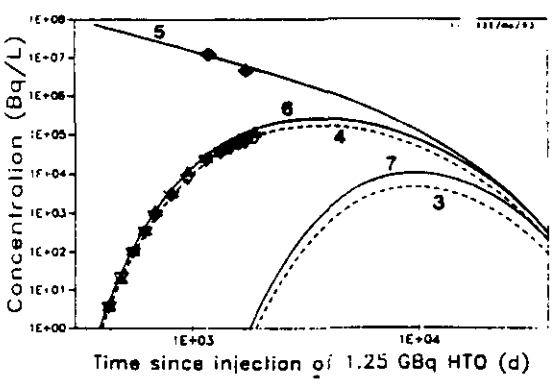

Figure 4. Mol, SCK/CEN. Measured tracer concentration points and the precalculated lines in the HTO experiment.

Analyses by the Project Teams

The following Project Teams have been working with the MOL test case during INTRAVAL Phase 2:

- SCK/CEN
- BRGM
- EDM/CEA/IPSN
- RIVM
- SNL/USDOE

The Pilot Group (SCK/CEN) presented some new concentration values obtained from filters 4 and 6 in the HTO experiment, which now has been running for more than 5 years (Figure 4). These new concentration values were found to be close to precalculated values. The pressure gradient in the system is slightly lower today compared to when the experiment was started about five years ago. The Pilot Group has modelled the Boom Clay as a homogeneous anisotropic saturated porous medium. The governing transport mechanism has then been diffusion-advection or diffusion only, since it is doubtful whether advective transport can be evaluated from the existing data due to very low hydraulic conductivity in the clay. The tracer transport is almost entirely determined by diffusion. Almost identical values on diffusivity, conductivity and porosity has been evaluated from the in-situ experiments as found in supporting laboratory experiments. It was concluded that the conceptual model is valid for predictions of field-scale concentrations and that the parameters determined in the laboratory are valid for field-scale predictions. The anisotropy of the clay cannot be studied with this one-dimensional tracer monitoring and a new type of experiment has therefore been started with the aim to study 3-D migration of the tracer $^{125}I^-$. The distance between the filters in this new experiment is only 0.35 m and the first data points achieved was found to agree with those precalculated.

ALLIGATOR RIVERS

Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia

Experimental Set-up

This test case is based on work conducted at the Koongarra site in the Alligator Rivers Region of the Northern Territory in Australia. The Alligator Rivers Region is located about 200 km east of Darwin.

Uranium mineralisation occurs at Koongarra in two distinct but related ore bodies which strike and dip broadly parallel to a fault, the Koongarra Reverse Fault. The main ore body (No. 1), which is the subject of this study, has a strike length of 450 m and persists to 100 m depth. Primary mineralisation is largely confined to quartz-chlorite schists. Secondary uranium minerals are present from the surface down to

the base of weathering at about 25 m depth and forms a tongue-like body of ore dispersing downslope for about 80 m. The objective of the ARAP test case in INTRAVAL is to develop a consistent picture of the processes that have controlled the mobilisation and transport of uranium in the weathered zone and the time scale over which they have operated.

An extensive experimental programme including both field and laboratory investigations has resulted in a large number of data characterising the site. Hydrogeologic data are from drawdown and recovery tests and water pressure tests. Geologic data are based on the mineralogic and uranium assay logs from 140 precussion holes and 107 drill cores. Groundwater chemical data from more than 70 boreholes have been collected. Distribution of uranium, thorium and radium isotopes has been determined in the different mineralisation zones. The distribution of uranium and thorium between different mineral phases in the weathered zone has also been studied. Laboratory sorption experiments have been performed, using samples from drill cores. In addition, distribution coefficients have been measured on natural particles present in Koongarra groundwaters.

Analyses by the Project Teams

The following Project Teams have been working with the Alligator Rivers test case during INTRAVAL Phase 2:

- RIVM
- KEMAKTA

The primary orebody at Koongarra is estimated to be $1 \cdot 10^9$ yr old. Geomorfological information indicate that weathering started some $1 \cdot 10^6$ to $6 \cdot 10^6$ years ago. The base of weathering is at present at a depth of 25–30 m below the surface and a dispersed fan of uranyl phosphates as well as dispersed uranium is found in the weathered zone. A partly weathered transition zone with higher permeability than in both the unweathered zone and the weathered zone is located just above the base of weathering. The groundwater flow direction in the area is at present towards the south.

The Secretariat (KEMAKTA) summarised the analyses performed within INTRAVAL and the Alligator Rivers Analogue Project (ARAP) by the Project Team from RIVM and KEMAKTA. Both teams started with an analyse of data from the field and laboratory experiments. The solid phase uranium concentrations and the uranium concentration in the water indicate an extension of the dispersed fan of about 350 m towards the south and about 100 m towards southeast from the fault. A similar dispersion pattern is obseved at all depths in the weathered zone. This is an interesting observation, since if the rate of weathering is assumed to have been constant with time, then the shape of the dispersion pattern could be explained by the assumption that the transport of uranium is mainly located to the transition zone whereas the uranium transport has ceased in the highly weathered rock. Data also support the theory that there has been only minor changes in magnitude and direction of the average groundwater flow with time. Furthermore, the analyses of the data indicate that uranium in crystalline phases of the weathering zone is not in isotopic equilibrium with the groundwater whereas uranium in other phases of the weathering products is in isotopic equilibrium with the groundwater. This suggests that the crystalline phases are inaccessible to the water, but there might be a transfer of uranium from the accessible phase to the inaccessible crystalline phase. The theory of a linear sorption equilibrium is supported by data as the relationship between uranium concentrations in groundwater and in the accessible solid phase is linear. The activity ratios between ^{234}U and ^{238}U in the inaccessible phase is larger than 1 which might support that transfer of ^{234}U from the accessible to the inaccessible phase is by recoil.

The migration of uranium in the transition zone has been modelled as advection-dispersion in a homogeneous porous medium in 1-D and 2-D assuming linear sorption. The calculated migration distance agreed fairly well with observed migration distances for migration times of $0.2 \cdot 10^6$ - $2 \cdot 10^6$ yr. Other mechanisms such as chain-decay, recoil and phase transfer were also included in the modelling with reasonable success. The applied methodology has showed the importance of joint interpretation of different types of data as well as the importance of an iterative procedure for data collection, data interpretation and modelling. The evaluation of this test case has shown that sorption is an important retardation mechanism, that uranium fixation in crystalline phases is a potentially important retardation mechanism in geologic media where significant alteration of the rock is expected, that recoil may have an impact on the distribution of uranium isotopes in the water, and that geochemistry is an important part of radionuclide transport.

The Project Team from RIVM presented their recent modelling of the uranium transport considering the downward movement ($1.4 \cdot 10^{-5}$ m/yr or 25 m/$1.8 \cdot 10^6$ yr) of the transition zone. The thickness of the transition zone is assumed to be 5 m. The uranium transport mechanism considered is advection-dispersion with linear sorption, and the water flux was assumed to be 1.3 m to the south. Compared to similar calculations without downward movement of the transition zone the migration distance is shorter. The team concluded that geological processes like weathering may be important for transport of radionuclides over long time periods.

TWIN LAKE

Tracer experiments at the Twin Lake aquifer, Canada.

Experimental Set-up

Aquifer testing ranging from a large number of small scale field experiments to very large scale tracer migration tests have been performed in a sandy aquifer at one of the AECL research facilities, the Chalk River Nuclear Laboratories. The site is located 200 km northwest of Ottawa, Canada, in the valley of the Ottawa river. The groundwater table in the sandy Twin Lake aquifer lies 6 to 20 m below grade and the saturated thickness of this unconfined aquifer ranges from 6 to 10 m.

The large experimental programme includes 20, 40 and 260 m natural gradient tracer (^{131}I and HTO) experiments. The total groundwater flow path length from the tracer injection well to the groundwater discharge area is 270 m and there are 170 monitoring installations in the aquifer downgradient of the injection well. Each installation consists of piezometers with short screens located at 1 m depth increments through the zones of saturation and gamma scanning is performed through the full aquifer.

The database contains hydrogeologic data (stratigraphic information, hydraulic conductivity, porosity, groundwater flow velocity), tracer concentrations, etc.

Analyses by the Project Teams

The following teams have worked with the Twin Lake test case:

- AECL-CRL
- AECL-WR
- JAERI
- CEA/IPSN
- SNL/USNRC

The main model validation objectives for the AECL-WR team was to identify the quantitative (physical) measure of aquifer performance. Another aim was to identify the best aquifer and transport simulation model with regard to the measure. The team applied a 2-D steady-state flow model and a 2-D transient transport model to solve this problem. The transport model was based on a moving mesh having a fine resolution around the tracer plume. Some discrepancies were noted between the field data and the model results, but the general pattern of the concentration contours agree with field data. One major lesson that was learned from this exercise was that there seems to be a fine layering of the aquifer on the scale of a few centimeters. This layering could have caused a velocity variation which resulted in an increased dispersivity.

The Pilot Group (AECL-CRL) has critically evaluated the usefulness of hydraulic conductivity data, determined on the basis of head measurements or empirical relationships, for heterogeneity characterisation and contaminant transport predictions. The conventional approach of quantifying aquifer heterogeneities is based on characterisation of the spatial pattern of hydraulic conductivity and it has been found that the inherent variability to a large extent is lost, since measured hydraulic conductivities are based on mean values for the medium. Furthermore, estimation of conductivity heterogeneities by calibrating a flow model against measured head data is deemed to be inappropriate, because heads are not particularly sensitive to conductivity variations. It was therefore suggested that the most reliable approach to account for local heterogeneities is to measure velocities and velocity variations rather than conductivities. Estimates of hydraulic conductivities based on grain size analysis are directionless and thus improve the velocity calculation only when they are used in conjunction with tracer test data. The heterogeneities observed from grain size analysis are smoothed if hydraulic conductivities are used.

An important finding that the Pilot Group pointed out was that grain size analysis and the applicability of an empirical formula to relate an "effective" grain diameter to hydraulic conductivity have allowed for a detailed resolution of aquifer heterogeneity at the Twin Lake site.

The work performed by the SNL team was limited to identification of models which produced conservative results with regard to the observed concentration distributions.

The JAERI team applied a three step procedure for the 2-D concentration calculations. The first step was a generation of hydraulic conductivities followed by flow calculations and finally a random walk concentration calculation. The code MIGINT was used for generation of the hydraulic conductivities in 2-D. The code MIG2DF, which is a 2-D finite element code, was used for the groundwater flow calculations. The transport part of the problem was solved applying a random walk model including advection and dispersion. The team concluded that the applied model seemed to explain the results qualitatively, but that more data of geostatistics and experimental conditions are needed in order to validate the model.

Appendix 1

INTRAVAL Organisation

The organisation of the INTRAVAL study is regulated by an agreement which has been signed by all participating organisations (Parties). The study is directed by a Coordinating Group with one member from each Party. The Swedish Nuclear Inspectorate (SKI) acts as Managing Participant. The Managing Participant sets up a Project Secretariat in cooperation with Her Majesty's Inspectorate of Pollution (HMIP/DoE), U.K. and the Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA). KEMAKTA Consultants Co. is contracted by SKI to act as Principal Investigator within the Project Secretariat.

The Parties organise Project Teams for the actual project work. Each Party covers the costs for its participation in the study and is responsible for the funding of its Project Team or Teams, including computer cost, travelling expenses, etc.

A Pilot Group has been appointed for each Test Case in order to secure the necessary information transfer from the experimental work to the Project Secretariat and the Project Teams. The Project Secretariat coordinates this information transfer.

At suitable time intervals, depending upon the progress of the study, workshops are arranged. Normally, the workshops are held in conjunction with meetings of the Coordinating Group. During the workshops, Test Case definitions and achieved results are discussed as a preparation for decisions in the Coordinating Group.

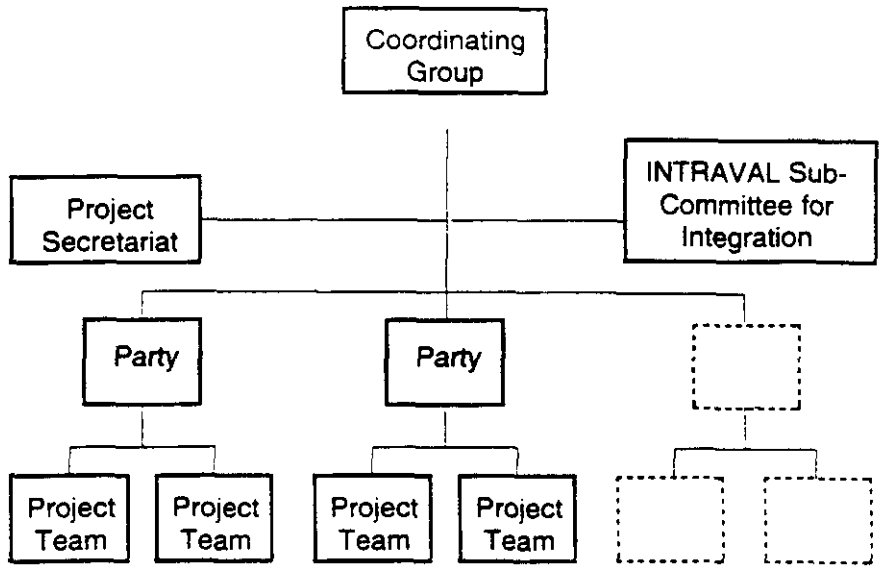

Figure 5. INTRAVAL Organisational Chart.

Managing Participant: SKI

Coordinating Group:

Chairman	J. Andersson, SKI
Vice Chairman	T. Nicholson, U.S. NRC
Secretary	B. Dverstorp, SKI

Principal Investigator: KEMAKTA Consu .ants Co.

Project Secretariat:

J. Andersson, SKI
L. Birgersson, KEMAKTA
B. Dverstorp, SKI
M. Ericsson, KEMAKTA
P. Jackson, AEA Technology
A. Larsson, KEMAKTA
J.P. Olivier, OECD/NEA
K. Pers, KEMAKTA
K. Skagius, KEMAKTA

PEER 18 - WIPP conceptual Model Uncertainty Group Review

WIPP PERFORMANCE ASSESSMENT CONCEPTUAL MODEL UNCERTAINTY GROUP

Report on Meeting of 22–25 March, 1993
Albuquerque, New Mexico

Prepared by
Dennis McLaughlin, CMUG Chairman
27 September, 1993

1. INTRODUCTION AND BACKGROUND

The WIPP Conceptual Model Uncertainty Group (CMUG) is an advisory group which was formed to provide guidance to Sandia's WIPP performance assessment (PA) effort. The group includes expertise in hydrology, geology, geochemistry, risk assessment, and environmental modeling. All committee members are consultants drawn from outside the Sandia community (a list of CMUG members is provided in Appendix A). This report summarizes conclusions and recommendations developed by the CMUG during its first meeting, which was held in Albuquerque on 22–25 March, 1993. The first CMUG meeting was held concurrently with meetings of the Geostatistical Expert Group (GXG) and the Fracture Expert Group (FXG), two other WIPP PA advisory groups. The common goal of all three expert groups is to help Sandia produce an accurate and scientifically defensible performance assessment for WIPP.

The motivation for the Conceptual Modeling Uncertainty Group can be traced to concerns expressed by advisory groups, reviewers, and other interested parties about the conceptual basis for WIPP's performance assessment modeling effort. Sandia's approach to PA relies heavily on computer simulations of 'release scenarios' which could conceivably result in the transport of waste from the WIPP repository to the accessible environment. The WIPP PA simulations make many assumptions about the nature of future releases and about the engineered and natural systems that may be affected by such releases. These assumptions have a significant impact on PA predictions and will undoubtedly be focal points for future debates over the validity of the PA.

The WIPP PA procedure relies on a 'conceptual model' of waste transport which assumes that the most likely release scenario is for radionuclides to move through an intrusion borehole upward into the Culebra dolomite portion of the Rustler formation (the E1/E2 scenario). The conceptual model further assumes that wastes entering the Culebra are carried by groundwater moving in response to a regional hydraulic gradient. Exposures at the WIPP compliance boundary depend, in part, on the geohydrologic and geochemical properties assumed for the Culebra. The critical reviews which led to the formation of the CMUG suggested that the PA screening process failed to include a number of plausible alternative conceptual models. Moreover, these reviews argued that the screening process failed to consider a number of physical and chemical processes which could affect waste migration from the repository. Such deficiencies could jeopardize the scientific credibility of the PA process, even if the overall conclusions of the PA are correct.

The charter of the CMUG states:

> "The conceptual model uncertainty ... group is being formed to provide guidance to the WIPP PA program on how to account for uncertainty associated with conceptual models for the groundwater flow and radionuclide transport systems in the Rustler and other non-Salado formations"

The group is also asked to:

> ... help ... on the development of alternative conceptual models and treatment of conceptual model uncertainty ....

It seems neither feasible nor particularly desirable at this point to attempt to quantify conceptual model uncertainty in the way that the GXG is attempting to quantify uncertainty in the travel time predictions obtained from a particular conceptual model. Instead, the conceptual modeling group will try to help Sandia develop a more rigorous scientific justification of the assumptions made in its PA effort. The CMUG may eventually suggest that Sandia carry out new investigations to clarify ambiguities in the existing conceptual model. The CMUG may also suggest that Sandia review and modify assumptions made in the past. Finally, the CMUG may suggest changes in the way that Sandia carries out and documents its PA activities. These items constitute a sort of "working charter" that could change over time.

The next section of this report lists specific topics which the CMUG believes need to examined more carefully in the WIPP PA. The list was compiled from oral and written comments provided by each of the CMUG members after the first group meeting. The final section provides programmatic recommendations which deal with the way the PA effort is organized. It is likely that future meetings of the CMUG will continue to consider programmatic as well as technical questions. CMUG members will be available to help Sandia staff carry out recommendations whenever this is feasible.

2. CONCEPTUAL MODELING TOPICS

During its first meeting the CMUG focused on gaps, ambiguities, questionable assumptions, and simplifications which need to be resolved before a final PA is submitted. The CMUG's initial reaction is that the WIPP PA has concentrated too much on simulation exercises and too little on identifying potential pathways and processes. The PA needs to devote more effort to understanding the origins and evolution of the non-Salado environment, particularly its geology, geochemistry, and hydrology. The PA will rise or fall on its ability to justify the conceptual model used to generate performance statistics.

Specific topics which need more study and/or more careful discussion in the PA report are described in the next four subsections. The first three topics deal primarily with the structure and behavior of the WIPP environment while the fourth topic deals with the selection of transport pathways for PA evaluation.

2.1 Regional Hydrology, Recharge, and the Effects of Climate Change

The WIPP PA effort does not appear to have taken a thorough look at regional hydrology. Basic questions about the sources and magnitude of recharge (if any), the location of the water table, the importance of vertical leakage, and the role of

non-Culebra formations (such as the Dewey Lake Red Beds, the Magenta, and the Tamarisk) remain unanswered. The PA reports prepared to date do not even attempt to give an aggregate water balance for the region. It will be hard to prove that we understand how radionuclides move below the WIPP site if we cannot construct a convincing description of the regional water cycle.

The PA effort should attempt to identify the origin of groundwater flowing beneath the WIPP site. It remains to be seen whether groundwater flow in the Culebra is the result of recharge upgradient of WIPP or is the long term response to a paleoclimatic transient. A paleoclimatic history of the WIPP area should be developed and alternative explanations of regional groundwater flow patterns should be examined in light of this history.

The hydrologic portion of the WIPP PA would probably benefit from a careful analysis of natural geochemical tracers. One of the goals of such an analysis should be to reconcile apparent inconsistencies between available hydrologic and geochemical data. There are large variations in Culebra groundwater chemistry (as evidenced, for example, by TDS measurements) over relatively small distances. These are not discussed in the PA. It seems unlikely that such effects are limited to the Culebra. Future investigations of natural tracers should also include other units above the Salado. An expanded set of geochemical surveys would probably provide useful information about connections between geological units which are now considered to be isolated and independent (see Section 2.3).

It will be very difficult to develop a convincing analysis of the effects of climate change at WIPP until we have a better understanding of groundwater recharge. Recharge depends on vegetation patterns and the hydrogeologic properties of the unsaturated zone as well as rainfall. Moreover, it is likely that recharge in the vicinity of the WIPP site is localized in space and episodic in time. These factors need to be considered as part of a larger study of regional hydrology. It should be noted that recharge at the WIPP site could be comparable to the total flux of groundwater moving through Culebra, depending on the assumptions made. The importance of recharge could increase under the influence of climate change, both as a result of greater total rainfall and as a result of an increase in the intensity and frequency of extreme events which contribute disproportionately to deep infiltration.

Many of the hydrologic questions raised by the CMUG could be addressed with the three-dimensional regional groundwater flow modeling effort currently underway, if this effort were given sufficient support. Unfortunately, the existing 3D modeling effort is not likely to have much impact on the WIPP PA so long as it remains understaffed and underfunded. The 3D modeling work needs to be expanded and a concentrated effort needs to be devoted to the estimation of inputs for the regional hydrologic model. The 3D model should be used to investigate regional flow patterns, including vertical leakage. The model should also be used to assess the significance of transport pathways other than the E1/E2/Culebra pathway which has been the focus of past PA simulations (see Section 2.4).

2.2 Geological History, Evolution, and Structure over a Range of Scales

The CMUG believes that the PA needs to be based on a better picture of the WIPP geological environment. This environment is influenced by a number of interacting factors, including fracturing, dissolution, and regional tectonics. WIPP needs to develop evolutionary (as opposed to purely descriptive) models of Rustler

geology. WIPP should rely on a number of different tools (geological observations, geophysical measurements, geochemical techniques, and hydrologic tests) in its search for scientifically credible models. The WIPP PA does not appear to have used modern geophysical and geochemical techniques to best advantage. This has hindered the development of a credible conceptual model of regional geology.

The WIPP site characterization effort needs to consider the various geological structures or processes that control groundwater flow over the scales of interest for PA. Particular attention needs to be given to the sources and types of fractures present in the Rustler, with an eye to identifying the likelihood that open or highly permeable fractures could be interconnected over significant distances. Horizontal fractures could act as preferred pathways for migrating wastes and vertical fractures could influence recharge and leakage between different units. Although fracture properties provide clues about the processes responsible for fracture formation WIPP does not appear to have made any effort to compile or interpret quantitative data on fracture orientation, density, spacing, or aperture. This makes it difficult to know how fracturing should be accounted for in the PA.

WIPP needs to determine whether connected fracture porosity will induce one, two, or three-dimensional flow and whether this flow contacts a large surface area or is concentrated into preferred pathways. Local variations in fracture structure will have an important effect on transmissivity. Surface area will influence both physical and chemical retardation. There is little or no discussion of such issues in the existing PA. The PA does not justify the use of its "equivalent porous medium" (or continuum) flow and transport models and does not relate the effective properties of these models to the small-scale geological structure of the Culebra. No attempt is made to compare the continuum models to plausible alternatives which may be able to provide just as good a fit to available data.

WIPP geologists appear convinced that dissolution will not be a major issue over the PA time scale. Although this may be true, it would be helpful to see dissolution addressed more seriously (and quantitatively) in the PA. When viewed from a regional perspective the WIPP site is quite close to known dissolution boundaries. It seems conceivable that dissolution could contribute to the enhancement of preferred flow paths in the Culebra, the Salado-Rustler contact zone, and other units lying above the repository horizon. Perhaps dissolution processes could be accelerated by increased recharge rates and/or modifications in brine chemistry resulting from climate change. The presence of Breccia chimneys off-site is an additional cause for concern, even though there is no evidence of such structures in the study area. It seems that the PA should at least consider the possibility that chimneys and other pathways opened by dissolution could serve as transport pathways (see Section 2.4).

2.3 Geochemical Evolution and Composition of Groundwater

The consensus of the CMUG is that the WIPP PA has not given sufficient attention to geochemistry. The project does not presently have either the staff or the data base needed to properly address the complex geochemical processes which have shaped the WIPP environment. The focus in the PA has been primarily on chemical retardation rather than on the geochemical evolution of groundwater at the site. WIPP geochemistry involves much more than "taking credit" for chemical retardation. Improved geochemical understanding could shed light on WIPP geohydrology, providing useful information about regional flow patterns, the effects of recharge, the impact of dissolution, and the importance of preferred

pathways.

Geochemical issues at WIPP can be loosely divided into questions relating to the natural evolution of the site and questions relating to the behavior of radionuclides released into the WIPP environment. The PA should be able to construct, from both geological and hydrochemical data, a coherent description of the composition and history of groundwater in the Rustler and Dewey Lake Red Beds. At present, only the hydrochemical zonation of the Culebra is being addressed and this information has not been convincingly related to flow within the formation (see comments in Section 3.1, above). WIPP should investigate the possibility of combining environmental isotope data (e.g. ^{3}H, D, ^{14}C, ^{36}Cl, oxygen isotopes, etc.) with major and trace element data in order to get a more complete picture of both flow and geochemistry in the units lying above the Salado. Geochemical data from the Magenta, Tamarisk, Dewey Lake Red Beds, and various 'aquitard' units should be included in this investigation.

Considerable uncertainty remains about the composition and properties of radioactive wastes considered in the PA transport studies. WIPP needs to devote more effort to understanding the solubility and speciation of radionuclides in room brines and in the brines naturally present in geological formations lying above the Salado. Organic complexants and chelating agents produced by waste degradation could have a significant influence on the solubility and mobility of radionuclides. The WIPP PA needs to consider the stability of such organics as well as their interactions with the surrounding geologic medium. Engineered barrier corrosion products (such as ferrihydrites) could act as sources of colloidal material which could facilitate transport. The PA needs to consider the production, stability, and sorption properties of colloids in the repository environment and in the Rustler and Dewey Lake formations. Special attention should be given to transport in the vicinity of geochemical discontinuities where radionuclide speciation may change and colloids may be generated or destroyed.

The PA needs to consider the possibility that changes in brine chemistry due to a waste release could have effects on the hydraulic properties of fractures and other pathways in the Rustler and Dewey Lake Red Beds. These changes could result in dissolution in some areas and in fracture "healing" (due to precipitation of supersaturated salts) in other areas. There is also the possibility of anion exclusion or other geochemical processes that could enhance transport by reducing the porosity available for flow. The PA should examine some of the possibilities with exploratory calculations which could demonstrate whether or not a given effect is important enough to be included in the PA simulations.

One of the major questions confronting the WIPP PA is the role of matrix diffusion in radionuclide transport. The critical features are the extent to which the matrix porosity of the rock is available as a diffusion reservoir and the nature of sorbing surfaces within that reservoir. The matrix diffusion model presently used in the WIPP PA does not seem well constrained in these respects since it can produce almost any degree of retardation. The model's parameters need to be related more directly to physical properties such as fracture spacing, matrix porosity, and brine diffusivity (as revealed by paleoprofiles of substances such as chloride, taken across fractures and into the rock). The model should also consider natural decay series radionuclide disposition in rocks and groundwaters as well as the thickness and persistence of clay fracture linings. Pore-filling minerals such as clays will undoubtedly influence the sorption of radionuclides along preferred

transport pathways.

The above discussion indicates that there are many geochemical processes which could be relevant in the complex WIPP environment. It will not be feasible to carry out detailed field or laboratory studies of most of these processes. But the PA should attempt to identify and rank potentially important processes with respect to their possible effect on compliance. Effort can then be concentrated on a few key geochemical issues.

It should be noted that CMUG members differ as to the advisability of 'taking credit' for chemical retardation in the PA. Some members feel that it would be better to avoid debates about geochemistry by making conservative assumptions which ignore sorption. Other members feel that this approach is risky, both because it tends to deemphasize the importance of geochemical effects and because it increases the chance that compliance targets might be violated if new scenarios are included in the PA process. This issue will be discussed further in future CMUG meetings.

2.4 Alternative Transport Pathways

The WIPP PA has, for reasons not completely clear to the CMUG, only identified a single transport pathway for wastes released from the repository — the E1/E2 intrusion borehole Culebra pathway. A preliminary review by the CMUG suggests that a number of other possible pathways deserve further investigation. These alternatives can be summarized as follows:

1. Transport through All or Part of the Rustler Formation — WIPP should consider the possibility that wastes carried upward through an intrusion borehole could travel through a number of different Rustler units, particularly the Magenta dolomite and the Salado–Rustler contact zone. The CMUG recognizes that WIPP's transmissivity estimates suggest that these units are much less conductive than the Culebra. These estimates, which are based on very limited data, should be backed up by geological arguments which identify the reasons why other Rustler units can be ignored, despite the existence of extensive fracturing. Investigations of Rustler transport should consider various intrusion borehole plug options, included no plug (see discussion in Section 3.2 below)

2. Transport through the Dewey Lake Red Beds — Rising water levels caused by climate could saturate significant portions of the Dewey Lake Red Beds, which could then serve as transport pathways for wastes carried upward through intrusion boreholes. It is possible that wastes moving in saturated Dewey Lake units could be accessible to water supply wells drilled in the future. Given ambiguities about the location of the regional water table and existence of perched water it seems that a more careful look at the Dewey Lake pathway is warranted.

3. Multiple Borehole Pathways — It is possible that waste released from the repository could move vertically between various Rustler and Dewey Lake units, following abandoned boreholes (either from hydrologic or oil and gas exploration). Increased vertical communication would enable wastes to travel along least resistance

pathways winding through several different units. Variants on this theme would account for enhanced vertical transport through past and future potash mine shafts.

4. Direct Release of Brine to the Surface — Historical evidence indicates that an unplugged borehole encountering a pressurized reservoir below the repository could carry contaminated brine directly to the surface, at least for a limited time period. Although such surface releases will be transient they could contribute significantly to the cumulative exposures of interest for compliance.

5. Vapor-borne Surface Releases — Radionuclides entrained in a pressurized two-phase gas-brine mixture could conceivably move upward through vertical fractures and abandoned boreholes directly to the surface, bypassing the slower, more tortuous groundwater pathway. It does not appear that the PA has given any serious thought to this escape route.

6. Enhanced Culebra Transport — Preliminary calculations suggest that the flux of brine released by an intrusion borehole penetrating a brine reservoir below the repository could be much larger than the natural groundwater flux through the Culebra, at least for a relatively short time following intrusion. If this hypothesis is correct, it is possible that liquid wastes could be pushed through the Culebra under pressure, irreversibly opening up fractures and shortening travel times to the accessible environment. The brine transient could also be expected to change the density of the natural groundwater, with accompanying effects on groundwater flow, and to induce major changes in Culebra geochemistry.

7. Pathways Created by Intrusion-induced Subsidence — It seems possible that future intrusions, particularly potash mining, could have effects similar to dissolution, in that they could induce localized collapse such as observed at Breccia chimney locations near the WIPP site. Collapse could open new pathways or enhance transport in existing pathways between the Culebra and the accessible environment.

We wish to emphasize that the CMUG does not necessarily believe that any or all of the transport pathways identified above are more important than the E1/E2/Culebra pathway investigated in the PA. But it is reasonable to expect some justification for the omission of such alternatives from a screening analysis which is supposed to be comprehensive. The assumption that the Culebra is confined is not justified in the PA, which also does not mention that the location of the water table is unknown over most of the study area. The PA should clearly explain why the Culebra pathway is the only one worth considering or, alternatively, it should be expanded to include consideration of other pathways.

3. PROGRAMMATIC RECOMMENDATIONS

The following recommendations address programmatic issues which the CMUG believes are relevant to Sandia's ability to produce a scientifically defensible PA. The recommendations are grouped into three broad categories which deal, respectively, with the formation of an in-house conceptual modeling group, the scenario screening process, and the scope of the PA effort.

3.1 In-house Conceptual Modeling Group

WIPP should start an in-house conceptual modeling group which brings together representatives from both the PA and test plan sides of the project. This group should meet periodically in open-ended workshops and brainstorming sessions. Questions raised in the in-house group should be similar to those raised by the CMUG. In fact, if the WIPP group is truly successful it should be able to take over most of the functions of the CMUG. The in-house conceptual modeling group should take maximum advantage of available WIPP literature in documenting responses to conceptual modeling questions raised both inside and outside the group. Representatives of this group should include long-term staff members who can provide corporate (or project) 'memory'. The in-house conceptual modeling group may be able to provide most of the staff resources needed to produce the 'issue papers' mentioned in Section 3.3 below.

3.2 Scenario Selection and Screening

The WIPP PA formalism reserves the word 'scenario' for uncertain events that may happen in the future. These include discrete natural events such as earthquakes, prolonged natural events such as dissolution or climate change, and discrete human intrusion events. The PA has devoted considerable effort to consideration of an extensive list of possible events which have been eliminated, one by one, from consideration. The result of this screening process is essentially two 'scenarios', an undisturbed (or 'base') case and a borehole intrusion scenario which has a few variants (the E1/E2 scenario).

The CMUG believes that the assumptions and methods used in the scenario screening process need to be reviewed. The difficulties of the present approach to screening are illustrated by the way the E1/E2 scenario was developed. The final intrusion scenario was assumed, without any real justification, to include an impermeable borehole plug placed just above the Culebra. This has the effect of forcing released waste through the Culebra and diverting it from the Dewey Lake Red Beds and other potential pathways mentioned in Section 2.4. The borehole plug assumption was made despite the fact that pressurized brine has already escaped from unplugged exploratory boreholes drilled at the site.

It appears that the WIPP PA has relaxed the questionable borehole plug assumption since publication of the last PA report. But the fact remains that a scenario screening process that could come up with such an assumption should be viewed with some skepticism. Scenario screening and conceptual model formulation are not objective processes. They depend on the creativity and judgment of the analyst. For this reason the process of identifying scenarios and conceptual models should provide for input from many sources and should be sufficiently open-ended to include new alternatives as they arise. Particular attention should be given to coupled scenarios, which combine one or more intrusion events with various natural events (such as tectonic activity, enhanced dissolution, and/or increased recharge). Coupled scenarios that have low probability but give high cumulative exposures may have an important impact on compliance and cannot be dismissed out of hand.

The WIPP PA should seriously consider ways to better relate the scenario screening process to site characterization and test plan activities. The process of eliminating plausible events, such as a rising Dewey Lake water table or opening up of fractures due to a low-probability tectonic event, should be made more

rigorous and the arguments should be more carefully documented.

3.3 Scope and Structure of the PA Effort

The CMUG has raised and will continue to raise many difficult questions, both about conceptual models of the WIPP environment and about selection of scenarios for PA evaluation. It is likely that similar questions will be raised by the in-house modeling group proposed above as well as by regulators, interveners, and other interested parties. The present PA effort cannot respond to all of these questions, partly because of staff and time constraints and partly because WIPP's PA process is designed primarily to demonstrate compliance in a narrow probabilistic sense. It is possible that this emphasis on probabilistic compliance, as demonstrated by simulation-based probability distributions (CCDF's), is short-sighted. EPA's regulations make it clear that actual compliance depends on the scientific credibility of the performance assessment as well as the results of probabilistic scenario evaluations. The difficult questions raised by the CMUG and others will probably need to be addressed in some form before the approval process is completed. Consequently, WIPP should begin to consider how it can deal with conceptual modeling issues which do not fit neatly into the existing PA framework.

The most obvious way to address the conceptual modeling issues raised by the CMUG is to incorporate previous and on-going site characterization (or 'test plan') studies into the PA. The existing PA reports could be accompanied by a set of issue papers or reports which deal (in some depth) with the four basic conceptual modeling topics considered by the CMUG. These reports could be prepared by teams of WIPP investigators drawn from the test plan or research groups most closely involved with each topic.

Given time and resource limitations, the conceptual modeling reports would have to rely heavily on existing WIPP technical literature. Conversations with WIPP personnel indicate that many of the topics considered by the CMUG have been investigated in the past. The results of these investigations have, for various reasons, not found their way into PA documents and have often not had much influence on PA simulations. This situation needs to be corrected as soon as possible. Otherwise, WIPP may find that it has no formal way to reply to regulators, interveners, and others who question the basic premises of the PA simulations.

It is time for the WIPP PA to step back from its simulations and to consider the scientific justification for its overall approach. The PA is attempting to base an analysis of a very complex physical system on a very limited data base. It seems unreasonable to expect the uncertainties in such an analysis to be handled exclusively by a set of Monte Carlo simulations. It also seems unlikely that planned refinements in the PA simulations will have a major impact on PA conclusions. WIPP should deemphasize its simulation efforts and concentrate instead on producing more thoughtful discussions of relevant hydrologic, geologic, and geochemical issues. The resources to do this are available within WIPP if they are properly mobilized.

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SANDIA WIPP PROJECT MATRIX DIAGRAM

date: 09/09/93

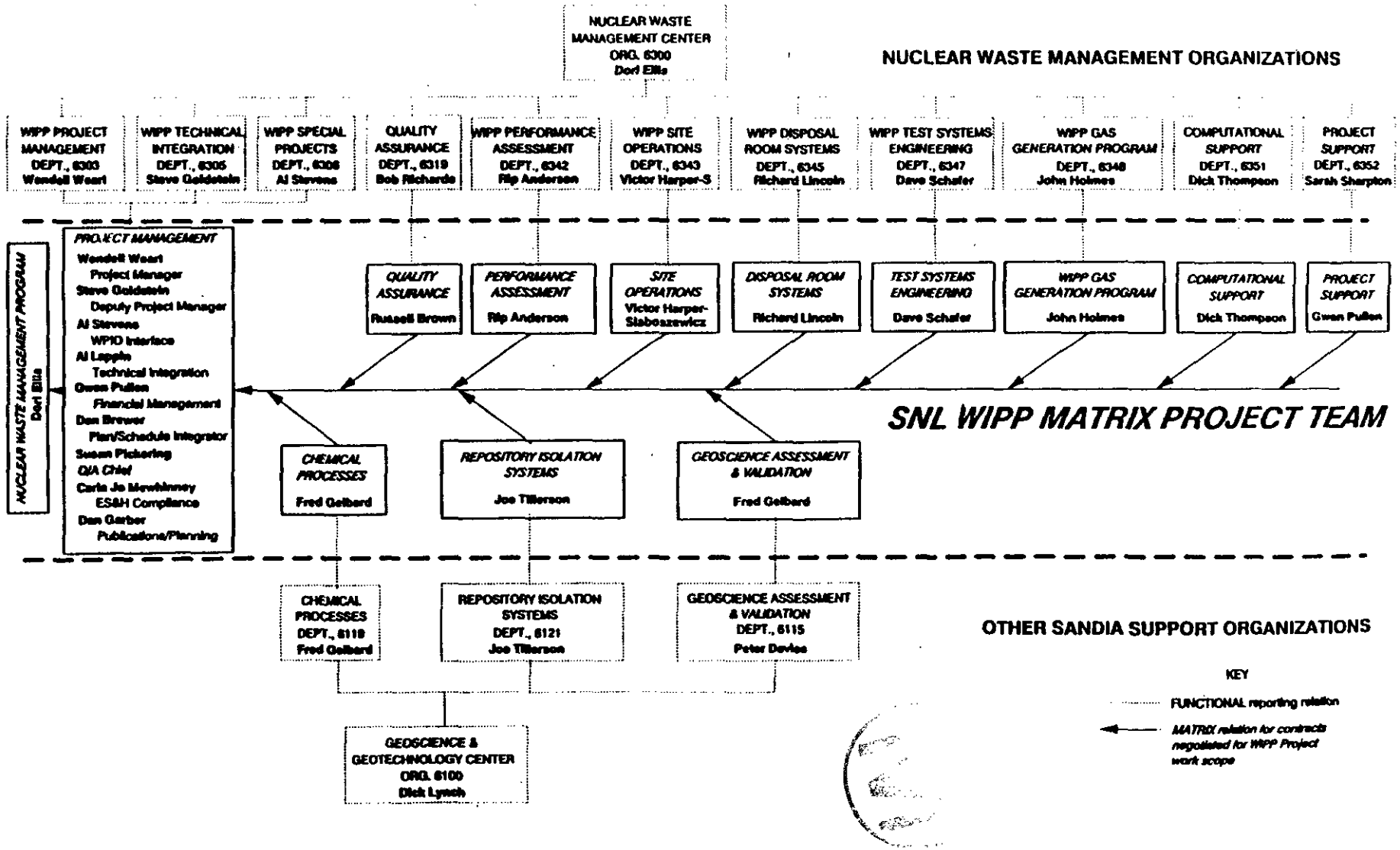

PEER 19 - Environmental Evaluation Group Review Reports

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-3

(NOTE: REPORT NUMBER EEG-2 IS ATTACHMENT III)

EEG-3

NEW MEXICO
HEALTH AND ENVIRONMENT
DEPARTMENT

RADIOLOGICAL HEALTH REVIEW OF THE DRAFT ENVIRONMENTAL IMPACT STATEMENT (DOE/EIS-0026-D) WASTE ISOLATION PILOT PLANT, U. S. DEPARTMENT OF ENERGY

Robert H. Neill, James K. Channell, Carla Wofsy,
Moses A. Greenfield, Editors

Environmental Evaluation Group
Environmental Improvement Division
Health and Environment Department
State of New Mexico

August 1979

ENVIRONMENTAL EVALUATION GROUP

LIST OF REPORTS

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979.

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

Radiological Health Review
of the Draft Environmental Impact Statement (DOE/EIS-0026-D)
Waste Isolation Pilot Plant, U. S. Department of Energy

Robert H. Neill, James K. Channell, Carla Wofsy,
Moses A. Greenfield, Editors

Environmental Evaluation Group
Environmental Improvement Division
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*The notation (5) refers to Chapter 5 in the DEIS.

APPENDIX

RADIOACTIVITY INVENTORY CALCULATIONS. I

TRANSPORTATION CALCULATIONS II

GEOLOGICAL CHARACTERIZATION REPORT REVIEW (EEG-2) III

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is no environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department – the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies and other organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U.S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.

Robert H Neill

Robert H. Neill
Director

INTRODUCTION

These comments are limited to the radiological health and safety and environmentally related aspects of the Draft Environmental Impact Statement (DEIS), Waste Isolation Pilot Plant (DOE/EIS-0026-D) and the background material used by DOE, with the primary focus of the comments on those aspects that have potential effects on the State of New Mexico.

While the Environmental Evaluation Group (EEG) recognizes that some later data have become available and that there may be significant changes in the mission of the WIPP, the review has been confined to the DEIS WIPP Reference Case (1-2; 6).* In those cases where options on WIPP are still open or data was not provided, final evaluation will await that information.

This evaluation includes:

(1) checking the calculations in the DEIS with the assumptions and methods used;

(2) checking computations by alternate (usually simplified) approaches;

(3) evaluating the assumptions and methodology used;

(4) considering possible omissions;

(5) evaluating conclusions reached; and

(6) recommending additional actions to be taken.

Alternative locations to the proposed WIPP site have not been evaluated since they are beyond the scope of EEG's mission.

Several meetings were held with the DOE and it's contractors to clarify some of the assumptions, input parameters, and numerical procedures used in various analyses.

*The notation (1-2; 6) refers to Chapter 1, page 2, paragraph 6 of the DEIS.

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SUMMARY

General

The Department of Energy is to be commended for making a major effort to determine the environmental impact of WIPP.

This review of radiological health considerations contains a number of concerns, questions and recommendations that should be addressed by the Department of Energy in the final Environmental Impact Statement (EIS).

Using the assumptions contained in the Draft Environmental Impact Statement (DEIS), the EEG calculated a number of radiation doses and the results were found to be in general agreement with those presented in the DEIS. The doses resulting from the operational and long-range releases from WIPP to the general population are no more than a fraction of existing radiation doses to the public. However, there are a number of technical considerations in the assessment of radiation exposure that were not adequately evaluated in the DEIS. They are discussed in this review.

A number of additional dosage estimates have been identified that need to be calculated by both DOE and EEG.

As the DEIS did not contain estimates of the amounts of radioactivity to be permanently located in the repository, it was necessary to calculate these amounts.

Estimated Plutonium Inventory in TRU Wastes*

Radionuclide	Activity (Curies)
Pu-238	35,000
Pu-239	480,000
Pu-240	120,000
Pu-241	1,200,000

*after 30 years of repository operation

It is apparent from our analyses that additional information and evaluations will be necessary in the future if the WIPP project proceeds. Consequently, the DEIS and its review are only the beginning of the health and safety evaluations that need to be performed.

The DOE stated in the DEIS that the WIPP repository should be licensed by the Nuclear Regulatory Commission (NRC). Recent developments suggest that the WIPP may not be licensed by that organization. EEG recommends that the proposed facility be subjected to the full scrutiny of health and safety considerations afforded by the licensing procedures of the NRC.

Health Effects

The DEIS did not estimate health effects to people from either the expected or potential radiation exposure but used dose as a presumptive index of hazard. Although not as informative as health effects, it has been a common practice in radiation protection work. Various radiation standards-setting organizations such as the International Commission on Radiological Protection (ICRP), United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) and the Biological Effects of Ionizing Radiation Committee (BEIR) of the National Academy of Sciences have developed models for mortality risk coefficients from ionizing radiation. In order to do expected mortality calculations, it is necessary to know not only the magnitude of the radiation exposure but the size of the population exposed as well as the probability of such an occurrence. DOE should address the issue of health effects in the final EIS. EEG will generate those estimates when the required information has been developed for the various population groups from both normal and accidental exposures.

Transportation

The equations used in the DEIS calculations of radiation dose from the normal transportation of the radioactive wastes were derived by the EEG and the calculated doses were found to be in agreement with those presented in the DEIS. These exposures to the general population are small additions to those from natural background and other man-made radiation sources. However, a critical evaluation of the assumptions used on potential accidents in the DEIS raises the following issues.

Radiation exposures from deliberate acts of sabotage in the transportation of radioactive materials could be considerably higher than those from traffic and rail accidents but the DEIS assumed there would not be a difference.

Some of the DEIS assumptions for accidents may not be conservative. Examples are:

1) A fire occurring during a rail accident involving contact-handled transuranic wastes (CH-TRU).

2) Leakages of remote-handled transuranic wastes (RH-TRU) from a container following a rail accident.

3) Ingestion of radioactive material following an airborne release.

Consideration should be given to shipping all the radioactive waste by rail wherever the calculations show that the actual and potential radiation exposures to people will be reduced. This is consistent with the concept in radiological health that all unnecessary radiation exposure be avoided and exposures kept as low as reasonably achievable (ALARA). Consideration should also be given to restricting shipments in icy weather.

Waste Acceptance Criteria

A full evaluation of the radiological consequences of operations and accidents cannot be completed until the waste acceptance criteria are developed by the DOE Waste Acceptance Criteria Steering Committee. DOE has been furnishing that material to EEG for review as it becomes available. There are a number of criteria that must be specified such as the degree of combustibility of the wastes, the amount of gas that can be generated through decomposition of organic materials, the amount of pyrophoric material, and the amount and type of non-radioactive hazardous material to be stored.

Site Characterization

There are uncertainties regarding several geologic and hydrologic aspects of the area surrounding the WIPP site. DOE is continuing to gather and analyze data relevant to these features and processes. The final EIS should include a more detailed analysis of the following:

1) Brine reservoirs, apparently large and under high pressure, which have been encountered in at least 7 wells within 9 miles of the periphery of the WIPP site.

2) Deep dissolution; i.e. dissolution of lower and intermediate levels of the salt beds.

3) Breccia pipes, which may be localized deep dissolution features, starting in the lower portion of the salt beds and migrating upward.

4) Variations and uncertainties in ground water flow rates and flow paths.

5) The effect of the presence of impurities (e.g. clay, anhydrite, and polyhalite) on the physical, hydrological, thermal and strength characteristics of rock salt from the repository horizons.

Site Selection Criteria

In the absence of regulatory standards by the Nuclear Regulatory Commission and the Environmental Protection Agency for the permanent disposal of radioactive wastes, reliance has been placed by the Department of Energy on establishing criteria that a repository should meet.

In light of this fact, we recommend that the Department of Energy formally request the involved federal agencies and other bodies of technical expertise to comment on the reasonableness and adequacy of the site selection criteria so that a consensus can be achieved. In this manner, any allegation that the criteria were unilaterally established by DOE can be avoided.

A failure of the proposed repository to meet a given design criterion does not in itself mean there is a hazard. It does identify or flag those areas that need to be thoroughly analyzed to determine whether or not the consequences of failure could result in radiation exposure to people.

Operational Exposure

The information on occupational radiation exposure is incomplete in the DEIS and presumably will be covered in more detail in the Preliminary Safety Analysis Report (PSAR).

The operational accident scenarios evaluated in the DEIS appear to be fairly complete in scope and the EEG calculations agreed with the DEIS when the same assumptions were used. Some of the assumptions may underestimate the amount of radioactivity released from damaged containers.

It is also unclear whether the exhaust air from the underground waste handling facility will pass through the HEPA filters before being released to the environment.

From the information in the DEIS, there is a question whether the non-radiological Ambient Air Quality Standards of New Mexico will be met in Zones II, III and IV. A more detailed analysis is necessary to determine the control measures that will be required.

Experimental Waste Program

It is recognized that the experimental high level radioactive waste program will provide empirical evidence for many of the theoretically derived geological parameters. However, in order to evaluate the potential radiation exposure to workers and the public it will be necessary to know the radionuclides involved, the amounts of radioactivity, the waste form, the details of the experiments and the plans for retrieval of the radioactive material. The experimental waste program could contain 9 to 90 million curies of radioactivity if the full-sized commercial high level waste canisters are used.

Long Term Radiation Releases

The DEIS considers a number of scenarios which could lead to release of radioactivity after the repository has been sealed. Based on the assumptions used in the DEIS analyses of long-term release scenarios, EEG's results are in reasonable agreement with dose rates and radionuclide migration times presented in the text. Except for the drilling scenario, the dose rates are small. However, the scenarios considered were limited and the EEG has identified additional scenarios and calculations which should be considered such as the potential contamination of well water or the role of pressurized gas in bringing radioactive material to the surface. EEG has considered the ranges over which some of the parameters

relevant to the movement of radioactivity in ground water can vary and the effects of these variations on the DEIS results. Therefore, EEG recommends that the detailed sensitivity analysis currently being conducted by DOE should be included in the final EIS.

Retrievability

It is essential that the ability to retrieve the radioactive wastes be examined in detail as to criteria, procedures, logistics, canister integrity, hazards to workers and hazards to the general population.

Decommissioning

Decommissioning options are discussed in satisfactory detail in the DEIS. However, the related issue of the degree and longevity of site control after decommissioning must be addressed. This is important since an uncontrolled site would be subject to various human actions, especially drilling, that could violate site integrity. The advantage and feasibility of site control for periods greater than 100 years should be evaluated.

HEALTH EFFECTS

The DEIS neither estimated nor discussed health effects from the potential radiation exposure to the population but used doses instead as an index of hazard. In the definition of risk in the glossary, the DEIS defined "consequence" of exposure as "population dose" and not "health effects". Although this is not as informative as health effects, it has been a common practice in radiation protection work.

Estimated health effects from WIPP should be included in the final EIS. It is recognized that there are uncertainties associated with such estimates that include the anticipated size of the future population at risk from WIPP, the probability of accidents and the frequency distribution of those accidents, the magnitude of the population dose for various conditions and indeed the basic applicability of a linear correlation of health effects with doses at such low dose rates. EEG plans to undertake these calculations in the future and to also include comparisons with presumed deaths from natural background and other radiation sources in the environment.

EEG intends to use the following approach. ICRP (Publications 26, 27) has developed a set of risk coefficients for various somatic biological end points and tissues that are based on currently available data (Ref. 1, 2). For a uniform whole-body irradiation (averaged over both sexes and all ages) their report indicates a mortality risk coefficient of approximately 10^{-4} rem^{-1} (a probability of 1 death per 10,000 person-rem). In 1977 UNSCEAR gave more detailed information on the basis for this numerical value and pointed out that such coefficients are obtained for mortalities induced at doses in excess of 100 rads (Ref. 3, p. 414). There is disagreement over the numerical values of the risk coefficients and their applicability for different types of radiation and for different population groups and the results should be considered as approximations. Table 1 indicates the steps in developing risk estimates.

As indicated in the first column, populations at risk of 10^4 (10,000) and 10^6 (1,000,000) are assumed. In column 2, the uniform whole-body equivalent dose received by each member of that population is indicated to be either 10^{-6} (0.000001), 10^{-4} (0.0001), or 10^{-2} (0.01) rems. These ranges of values generally cover the estimated average dose equivalents received and the population sizes according to the calculations contained in the DEIS. It is assumed for purposes of this table that these dose equivalents are received throughout the body of each of the persons in the populations. The products of a value in column 1 and the value in column 2, for a given line, gives the population dose equivalent in person rems indicated in the third column. If the risk coefficient is assumed to be 10^{-4} deaths/rem, the product of a numerical value in the third column and 10^{-4} gives the number of deaths that are presumed to occur as a result of the irradiation. One needs to remember that these are the number of deaths throughout the lifetime of the individuals involved. It is seen that for a population of 1 million persons, uniformly exposed to a dose equivalent of 0.01 rem, one would estimate 1 death from radiation induced cancer during the entire lifetime of all members of that population.

Table 1

Illustration of Method to Calculate Radiation Induced Deaths*

If Population is	and Dose Equivalent is (rem)	Population Dose Equivalent (person-rem)	Presumed Deaths
10,000	0.000001	0.01	0.000001
10,000	0.0001	1	0.0001
10,000	0.01	100	0.01
1,000,000	0.0001	100	0.01
1,000,000	0.01	10,000	1

*The numbers used for this example are for illustrative purposes only and are not directly applicable to WIPP.

Comparison with Natural Background

In the absence of information on health effects, it is customary to compare man-made radiation exposure to that which occurs from natural background and the DEIS has done this. Dose commitments from ionizing radiation are presented in the DEIS for time periods ranging from a few days to one year and fifty years. These dose commitments are compared to the dose equivalent from natural background over a few hours, one year, fifty years and seventy years. In some cases, the DEIS inappropriately used dissimilar time periods.

Doses in which the radiation is absorbed over one year should only be compared to natural background radiation over a similar time period. Similarly, doses from radiation that occur over fifty years can be compared to fifty years cumulative total from natural background radiation exposure. Examples where this has not been done include Tables 9-18, 9-19, 9-25 and in the discussion of Table 6-13.

References

1. International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection (ICRP Publication 26), 1977.

2. International Commission on Radiological Protection. Problems Involved in Developing an Index of Harm (ICRP Publication 27), 1977.

3. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation, 1977.

INVENTORY OF RADIOACTIVITY

(DEIS Chapters 2, 6, 9, E)

TRU Waste Inventory

The DEIS stated that: "The quantities of waste stored at various storage locations are not precisely known; that is, the estimations of these quantities...have large uncertainties associated with them. In addition, it has not yet been decided which locations will actually be shipping waste to the WIPP reference repository" (6-11;3). EEG recognizes DOE's difficulty in obtaining an accurate inventory of TRU waste to be stored at the WIPP. The calculated inventories used by EEG are based on information in the DEIS. If this information is incomplete or incorrect on the quantity or isotopic composition, then the dose and concentration estimates will also be in error.

Activity Estimates

Since the DEIS did not include estimates of the total volume or activity of transuranic (TRU) waste, EEG has prepared estimates of the amounts to be located in the repository (see Tables 2, 3 and 5) and the inventories for truck and rail shipments (see Tables 3 and 4) and recommends that such information be included in the final EIS.

EEG's estimates are based on information in the DEIS, particularly waste volume and shipment projections in Chapter 6 and radionuclide concentrations in Appendix E. The period of repository operation was taken to be thirty years, because of the DEIS statement that "...the plant is designed for a useful life of at least 30 years" (1-4;8). Details of the calculations appear in Appendix 1.

Radionuclide Concentrations

It is recognized that the amounts of radionuclides present in containers of a given type differ greatly, making it difficult to get an accurate inventory. However, there are inconsistencies in

the DEIS. The average plutonium content listed in Appendix E is 8 grams per box and 13 grams per drum for CH-TRU waste (Tables E-1, E-2, pp. E-2,3), whereas Table 9-43 (9-103) in the DEIS leads to higher estimates. This table gives projected CH-TRU waste isotopic concentrations (in Ci/liter and g/liter) 100 and 1000 years after burial. The DEIS notes that "the inventory listed in these tables is not precisely the same as that shown in Appendix E" and states that "actual assay data from the Idaho National Engineering Laboratory" were used (9-102). The data in Table 9-43 appear consistent with results of an INEL assay reported by Bingham and Barr (SAND 78-1730).

Table 6 summarizes the differing actinide concentrations obtained from Tables E-1, E-2 and 9-43. Box concentrations obtained from Table E-2 are an order of magnitude lower than drum concentrations obtained from Table E-1. The INEL assay concentrations are slightly higher than the Table E-1 drum concentrations. Does this mean that new data suggest higher box and drum concentrations than those given in Tables E-1 and E-2?

Spent Fuel Inventory

The spent fuel inventory in the DEIS agrees with other published inventories (references 1, 2, 3). The computer program used to derive these inventories was ORIGEN (ref.4). ORIGEN has been evaluated, tested and distributed by the U. S. Department of Energy, Radiation Shielding Information Center (ref. 5) and is being used worldwide as an accepted inventory code by the nuclear field. Correlation between measurements and calculations has generally been good (ref. 6).

EEG notes that the activation product Carbon-14 was not included in the spent fuel inventory. It will be present in greater quantities than I-129 (ref. 7), has a half-life of 5730 years, and is very mobile in the environment. It has been projected to cause the major part of the population dose from nuclear reactors (ref. 8). This omission should be explained.

Table 2

Estimated 30-year Repository TRU Waste Inventory*

Isotope	Activity (Ci)
Plutonium-238	3.5×10^4
Plutonium-239	4.8×10^5
Plutonium-240	1.2×10^5
Plutonium-241**	1.2×10^6
Americium-241**	5.5×10^4

*These estimates include the effects of decay and ingrowth.

**Plutonium-241 (half-life = 13 years) is a beta emitter which decays to Americium-241 (half-life = 460 years).

Table 3

Inventory of Radioactivity*

CH-TRU

Isotope	Repository Total (Ci)
Pu-238	4.0×10^4
Pu-239	4.7×10^5
Pu-240	1.2×10^5
Pu-241**	2.8×10^6
Am-241	7.7×10^3
Total	3.4×10^6

RH-TRU

Isotope	Repository Total (Ci)	Activity in a rail shipment (Ci)	Activity in a truck shipment (Ci)
Sr-90/Y-90	2.8×10^6	2100.	420.
Co-60	1.7×10^4	13.	2.6
Ru-106/Rh-106	2.5×10^4	18.5	3.7
Cs-137/Ba-137m	1.4×10^4	10.5	2.1
Eu-152	3.6×10^3	2.7	.53
Eu-154	1.4×10^4	10.5	2.1
Th-232	8.0	.006	.001
U-234	6.5×10^{-2}	(4.9×10^{-5})	(9.7×10^{-6})
U-235	2.7	.002	(4.1×10^{-4})
U-238	6.0×10	.044	.009
Pu-238	7.4×10^2	.55	.11
Pu-239	8.7×10^3	6.5	1.3
Pu-240	2.0×10^3	1.5	.3
Pu-241**	5.2×10^4	39.	7.8
Am-241	1.4×10^2	.11	.02
Cm-244	3.6×10^4	27.	5.3
Total	3.0×10^6	2.2×10^3	4.5×10^2

*30 years of new production are added to the backlog (see DEIS Tables 6-2, 6-6). The effects of decay and ingrowth are not included in these estimates.

**Beta emitter with a 13 year half-life.

Table 4

CH-TRU Shipment Inventories

Isotope	Ci/drum (Table E-1)	Ci/box (Table E-2)	Ci/rail shipment of drums	Ci/truck shipment of drums	Ci/rail shipment of boxes	Ci/truck shipment of boxes
Pu-238	4.1×10^{-2}	6.5×10^{-2}	4.9	1.7	1.6	.52
Pu-239	4.8×10^{-1}	7.5×10^{-1}	58.	20.2	18.	6.0
Pu-240	1.2×10^{-1}	1.8×10^{-1}	14.	5.0	4.3	1.4
Pu-241	2.9	4.6	350.	120.0	110.	37.
Am-241	7.8×10^{-3}	1.2×10^{-2}	0.94	0.33	.29	.10

CH-TRU Shipment Volumes*

Mode	Container	Volume of container (ft^3)	Containers per shipment	Waste volume per shipment (ft^3)
Rail[a]	Box	112	24	2700
Rail	Drum	7.4	120	930
Truck[b]	Box	112	8	900
Truck	Drum	7.4	42	310

[a]ATMX railcar assumed for rail shipment.
[b]Type B container for truck shipment assumed to hold 8 boxes.

*DEIS, Table 6-3(6-12).

Table 5

TRU Waste Volumes (ft.^{3}): 30 Year Repository Totals

Type of Waste	Containers	Backlog*	New waste production per year*	New waste production in 30 years	Backlog + 30 year production
CH	Boxes	7.0×10^5	9.0×10^4	2.7×10^6	3.4×10^6
CH	Drums	2.4×10^6	1.5×10^5	4.5×10^6	6.9×10^6
RH	Canisters	7.7×10^4	6.9×10^3	2.1×10^5	2.8×10^5

* DEIS, Tables 6-2, 6-6 (6-12,6-14).

Table 6

CH TRU Radionuclide Concentrations

Isotope	Half-life (yrs.)	Radionuclide concentrations (μCi/l) From Table E-1,* in drums	From Table E-2,* in boxes	From INEL assay SAND 78-1730 (p. 87)	From Table 9-43 at 100 years
Pu-238	8.8 x 10	2.0×10^2	2.0 x 10	2.4×10^2	1.1×10^2
Pu-239	2.4×10^4	2.3×10^3	2.3×10^2	2.8×10^3	2.8×10^3
Pu-240	6.5×10^3	5.8×10^2	5.6 x 10	6.8×10^2	6.7×10^2
Pu-241	1.3 x 10	1.4×10^4	1.4×10^3	1.7×10^4	---
Am-241	4.6×10^2	3.8 x 10	3.8	4.6 x 10	4.7×10^2

*Calculated by dividing the expected activities (Ci/drum and Ci/box) in Tables E-1 and E-2 by the container volumes (208 liters for a drum and 3.2×10^3 liters for a box), and multiplying by 10^6 μCi/Ci.

References

1. U.S. Nuclear Regulatory Commission. Draft Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel (NUREG-0404), March 1978.

2. U.S. Energy Research and Development Administration. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle (ERDA-76-43), May 1976.

3. U.S. Environmental Protection Agency. Significant Actinide Activities in the LWR and LMFBR Nuclear Fuel Cycles (EPA-520/3-75-006), 1974.

4. Bell, M.J. ORIGEN - The ORNL Isotope Generation and Depletion Code (ORNL-4628), 1973.

5. Oak Ridge National Laboratory. Radiation Shielding Information Center. ORIGEN. Isotope Generation and Depletion Code - Matrix Exponential Method (CCC-127), October 1978.

6. Industridepartment Energikommissionen. Disposal of High Active Nuclear Fuel Waste. A Critical Review of the Nuclear Fuel Safety (KBS) Project on Final Disposal of Vitrified High Active Fuel Wastes.

7. U.S. Department of Energy. Management of Commerically Generated Radioactive Waste (DOE/EIS-0046D), Draft Environmental Impact Statement, April 1979.

8. U.S. Nuclear Regulatory Commission. Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors (NUREG-0002), 1976.

WASTE ACCEPTANCE CRITERIA
(DEIS Chapter 5)

Major Conclusions

1) Since the waste acceptance criteria are under active development by the DOE, they are not in the DEIS. However, DOE has been furnishing EEG with material on the criteria as they are being developed by the Waste Acceptance Criteria Steering Committee for review.

   Until such time as waste acceptance criteria are defined, the radiological consequences of operations and accidents cannot be fully analyzed. Three major concerns of both the DOE and the EEG are the presence in the TRU waste of:

   a) gas from organic decomposition

   b) combustible materials; and

   c) respirable particles.

2) Some interim criteria on RH-TRU waste in Table 5-1 are less stringent than criteria for CH-TRU waste.

3) It is essential that the retrievability of the radioactive wastes be examined in detail as to criteria, logistics, procedures, integrity of containers, hazards to workers, and hazards to the general population.

CH and RH-TRU Criteria

The review of the interim waste acceptance criteria for CH and RH-TRU waste (5-4, 5-5) led to several concerns:

1) Combustibility. A limit has not been placed on the amount of combustible materials which may be placed in individual containe or collectively in the underground storage rooms. EEG is

concerned since fire is listed among the possible accidents.

2) Gas Generation. Gas-generating materials in CH-TRU waste are limited to 10% by weight in any single storage room. No limit is given for RH-TRU waste. The 10% limit shown would not provide meaningful guidance to the individuals packing the containers. How much gas-generating waste will be accepted? How much gas and what type can be generated? What will be the long term effects of gas generation? On pp. 9-133 to 9-136, gas generation and its possible effects on the repository are discussed. These problems are being investigated by the DOE. Calculations have been carried out which indicate that gas pressures in the repository "might exceed lithostatic pressures at the repository depths" (9-136; details are not given).

The statement is made that "To insure that evolved gases will not fracture the rock overlying the reference repository, the waste acceptance criteria will limit the amount of gas-producing material in the waste accepted for burial" (9-136;3). Gas generation criteria should be very specific and should be supported by evidence of their adequacy. Detailed guidance should be provided to waste-generating facilities in order to help them meet the criteria. It is not clear how waste-generating facilities will determine the content of gas-producing materials in previously stored wastes.

3) Pyrophorics. EEG believes criteria should specify the amounts of pyrophoric material permitted in both CH and RH-TRU waste.

4) Hazardous Material. What non-radioactive hazardous materials must WIPP be prepared to handle, and in what total quantity? What criteria will the WIPP operator use in authorizing such material? (See the reference to "Hazardous materials" in Table 5.1). What calculations have been done on the potential reentry of these materials to the biosphere? Some of them could be hazardous for periods longer than the radioactive wastes.

5) Thermal Power. A criterion of 0.1 W/ft^3 is given for color coding and identification for the CH-TRU waste. A criterion should be given for RH-TRU as well.

The explanation given for not restricting combustibility, gas generation or thermal power for RH-TRU waste is that "quantities [of RH-TRU waste] are insignificant, and processing will probably not be available" (5-4). The DEIS refers to RH-TRU waste as constituting "a small fraction (about 2% by volume) of the TRU waste generated by the DOE complex" (5-6;1), and goes on to state that "Even if all the RH-TRU waste were gas-producing or combustible, there would probably not be enough to cause significant problems at the WIPP reference repository" (5-6;2). EEG's estimates of total respository TRU wastes volumes (see Table 5, p. 20) are 1.0×10^7 cubic feet of CH-TRU and 2.8×10^5 cubic feet of RH-TRU. If this amount of RH-TRU material is to be considered insignificant, calculations in the final EIS should support this conclusion. Furthermore, EEG estimates the average level of radioactivity of material in a shipment of RH-TRU waste to be 2.2×10^3 Ci/rail shipment and 4.5×10^2 Ci/truck shipment (see Table 3, p. 18). The degree of mobility and combustibility of wastes will be a factor in determining the consequences of a transportation accident.

Previously Stored TRU Wastes

To what extent will previously stored TRU waste be re-examined, treated as may be necessary (incineration, immobilization of ash, etc.) and repackaged prior to shipment to WIPP? Some of the wastes proposed for WIPP may have been in storage as long as 20 years. The characteristics of the wastes and the containers could have changed substantially in that time, rendering either the wastes, the containers, or both unsuitable for storage at the WIPP. According to reference 16, it is doubtful that 17C drums would meet the leak test requirements of the ANSI standard 14.5, particularly after a decade of storage. The integrity of the drums without polyethylene liners is particularly suspect. Is the no-leak requirement of ANSI 14.5 or the requirements of 10

CFR 71.42 (b) applicable to the packages to be shipped to the WIPP?

Information in reference 11 indicated that there was non-uniformity among the various suppliers of the TRU wastes in the way in which wastes were stored and data recorded. The waste acceptance criteria should clearly establish uniform practices which are consistent with the needs of WIPP. For example, reference 22 indicated that all Pu-238 contaminated waste in drums which have been previously stored for significant time periods should be considered potentially explosive until individual drum analyses are conducted. This would imply that such drums would not meet a criterion prohibiting explosive material in CH and RH-TRU waste containers.

Impacts of Processing

Processing of CH-TRU waste by slagging pyrolysis was presented in the DEIS as a strong possibility (5-9). This raises certain questions. Would slagging pyrolysis facilities be set up at all sites from which waste would be sent? Would pyrolysis take place only at INEL? In this case, would waste from other locations be sent to Idaho for processing or would the waste acceptance criteria be relaxed for waste from other locations? Will some of the waste be processed at the repository site? This would have implications in the area of transportation and operational exposures.

The statement on page 5-7;3 that "the waste-acceptance criteria finally selected will produce smaller impacts than the impacts calculated from the assumed criteria" seems premature.

Detailed Comments

5-3, 5-4 What is the rationale behind "Large suppliers must observe another limit: the surface-dose rate of their shipment averaged over 3 months, must be no higher than 10 mrem/hr" (5-3:7)? What is the limit for small suppliers? Also, what are the surface contamination limits (Ref. 49 CFR 143.398)?

5-4 Have criteria been developed for spent fuel and High Level Waste?

5-5 Surface Contamination Criteria reference should be 49 CFR 173.398 instead of 49 CFR 73.398 in Table 5-1.

5-4,5-7;4 Table 5-1 stated that small quantities of pyrophoric material will be acceptable. Page 5-7 stated that environmental impacts were assessed under the assumption that no pyrophoric material would be accepted.

M

References

1. Sandia Laboratories, "WIPP Acceptance Criteria for Defense Low-Level TRU Waste," July 1, 1977.

2. Molecke, Martin A., WIPP Transuranic Wastes Experimental Characterization Program (SAND 78-1356 Draft), July 1977.

3. "Previous ERDA Commitments Concerning the Removal of Waste from Idaho," a memorandum from Colin A. Heath to Del Davis, July 28, 1977.

4. "Final Report of Task Group on WIPP Criteria Interrelationship," a letter from C. Wayne Bills to R. Glenn Bradley, August 30, 1977.

5. "WIPP Acceptance Criteria for Defense Intermediate-Level TRU Waste," September 1, 1977.

6. "Assessment of R & D in Support of Finalizing WIPP Acceptance Criteria," a memorandum and report from P.Y. Lowry to R. Glenn Bradley, September 8, 1977.

7. "Draft Revised Acceptance Criteria for Defense Low-Level TRU Wastes," a letter and comments of C.D. Zerby to J.J. Schreiber, September 22, 1977.

8. "Minutes of Meeting of Waste Acceptance Criteria Steering Committee," March 7, 1978.

9. "NRC Analysis of Repository Loadings," a memorandum and report from J.E. Vath to J.E. Russell, March 29, 1978.

10. "Response to the Waste Acceptance Criteria Steering Committee Regarding Leachability Concern for Transuranic Wastes," a memorandum and report from M.A. Molecke, May 23, 1978.

11. "Waste Acceptance Criteria Steering Committee, Minutes of Meeting, June 14-15, 1978," with 17 attachments.

12. "Transuranic Waste Acceptance Criteria for Geologic Disposal," a memorandum from M.L. Kram to Waste Acceptance Criteria Steering Committee.

13. "Contact-Handled TRU Waste Packages," a memorandum and report from L.W. Scully to Waste Acceptance Criteria Steering Committee, September 19, 1978.

14. Los Alamos Technical Associates, Inc. Preliminary Report on the WIPP Operator Dose Calculations, September 1978.

15. "The Effect of Waste Leachability on Radionuclide Mobility," a memorandum and report from P.D. O'Brien to Waste Acceptance Criteria Steering Committee, September 22, 1978.

16. Shefelbine, Henry C. Preliminary Evaluation of the Characteristics of Defense Transuranic Wastes (SAND 78-1850 Draft), undated.

17. "Comments Received on TRU Packaging in WIPP Conceptual Design Report," an undated and unsigned report.

18. "Minutes of Waste Acceptance Criteria Steering Committee Meeting," September 25, 1978.

19. "Comments on Revision 1 (Oct. 5, 1978) of Proposed Interim Acceptance Criteria for Contact-Handled TRU Wastes," a memorandum and report from M.L. Kram to H.H. Irby.

20. "Comments on Proposed Interim Waste Acceptance Criteria for Contact-Handled TRU Waste," a letter from D.E. Large to H.H. Irby, October 5, 1978.

21. "WIPP Fire Test Program," a memorandum from T.O. Hunter to Waste Acceptance Criteria Steering Committee, September 22, 1978.

22. "An Interim Summary of Experimental Programs for the WIPP TRU Waste Acceptance Criteria," (Draft), January 1979.

23. U.S. Department of Energy. Project Overview. Waste Isolation Pilot Plant (WIPP-DOE-21), January 10, 1979.

TRANSPORTATION
(DEIS Chapter 6)

Major Conclusions

1) The equations used in the calculations of radiation doses from the normal transportation of the radioactive wastes have been derived by the EEG and the calculated doses were found to be in agreement with those presented in the DEIS. EEG has made a critical evaluation of the assumptions used in order to determine the validity of these dose estimates. These doses would represent small additions to the general population radiation exposure in comparison to other man-made radiation sources and natural background.

2) EEG has identified a number of additional dosage calculations to be performed and these are listed on pages 90-92.

3) Radiation exposures from deliberate acts of sabotage in the transportation of radioactive materials could be considerably higher than those from conventional traffic and rail accidents. The DEIS assumed there would not be a difference.

4) Some of the assumptions for accidents may not be sufficiently conservative. The following possibilities were not included in the DEIS calculations.

   a) A fire occurring during a rail accident involving contact handled transuranic wastes (CH-TRU).

   b) Leakage of remote handled transuranic wastes (RH-TRU) from a container following a rail accident.

   c) Ingestion of radioactive material following an airborne release.

5) Consideration should be given to shipping all the radioactive waste by rail wherever the calculations show that the potential radiation exposures to people would be reduced. This is consistent with the concept in radiological health that all unnecessary radiation exposure be avoided and exposures kept as low as reasonably achievable (ALARA). Consideration should also be given to restricting shipments in icy weather.

6) The maximum dose to people from atmospheric dispersion can be closer than the 0.5 miles calculated in the DEIS if the plume does not rise to a height of 20 meters at the time of release or if more unstable atmospheric conditions occur.

Radiation Doses from the Normal Transportation of Radioactive Wastes

The radionuclide inventories for truck and rail shipments of both CH-TRU and RH-TRU wastes were calculated by EEG and are shown in Tables 3 and 4. Derivations of the equations used in the calculation of radiation exposure from the normal transportation of radioactive wastes are shown in Appendix II.

Comparison of calculated doses in Table 7 and 8 show substantial agreement between the annual doses in the DEIS and those calculated by the EEG using NUREG-0170. These exposures represent small additions to normal background radiation and man-made radiation exposure.

The doses given in the DEIS are population doses. No information was presented on potential doses to individuals. Projections of maximum individual doses during normal transport should be provided.

TABLE 7

Calculated Radiation Doses from Normal Transportation of CH-TRU Waste

Origin and Mode	Annual Population Dose (man-rem)											
	Population surrounding route while moving			Passing Motorists			Population surrounding route while stopped			Crew		
	EIS	EEG	EIS/EEG*	EIS	EEG	EIS/EEG*	EIS	EEG	EIS/EEG*	EIS	EEG	EIS/EEG*
INEL(box) Truck	.096	.14	.68	.049	.044	1.1	.16	.16	1.0	2.4	2.6	.92
Rail	.34	.21	1.6				.007	.007	1.0	.01	.009	1.1
INEL(drum) Truck	.59	.88	.68	.31	.27	1.1	.99	.99	1.0	15	16	.93
Rail	2.1	1.3	1.7				.04	.04	1.0	.08	.05	1.6
Hanford Truck	.52	.75	.69	.27	.24	1.1				13	14	.92
Rail	1.6	1.0	1.6							.06	.04	1.5
LASL Truck	.15	.22	.68									
SRP Truck	.06	.09	.67									
Rail	.16	.10	1.6									

*Ratio of EIS Dose to EEG Dose.

TABLE 8

Calculated Radiation Doses from Normal Transportation of RH-TRU Waste

Origin and Mode	Annual Population Dose (man-rem) Population surrounding route while moving EIS	EEG	EIS/EEG*
INEL			
Truck	.29	.44	.66
Rail	.26	.37	.70
Hanford			
Truck	.16	.25	.67
Rail	.13	.19	.68

*Ratio of EIS Dose to EEG Dose.

Radiation Doses from Transportation Accidents

According to the DEIS, the barriers limiting the release of radioactivity to the environment following an accident result in only 0.004% of the radioactive material being respirable following a rail accident with CH-TRU wastes (6-23) and 0.015% following a truck accident (6-24). The only radioactive material that would be released in a rail accident involving RH-TRU waste would be 0.1% of the Cs-137 activity (6-25). The references from which the values of these barriers were selected in many instances do not show the basis on which they were derived. Empirical evidence needs to be developed under experimental conditions to confirm the reasonableness of many of these values.

Consolidated calculations for atmospheric dispersion coefficients (χ/Q) are to be found in Appendix V and are in reasonable agreement with those presented in the DEIS when the same assumptions are used.

If the plume in an airborne release does not rise to a height of 20 meters, then larger χ/Q values can be obtained and the maximum dose can occur at distances closer than 0.5 miles.

The following calculations were performed for a rail accident with spent fuel, using the assumptions shown in the DEIS. The results obtained were in substantive agreement with those in the DEIS.

Table 9

Dose to an Individual[a]

	Dose Commitment, (rem)		
Organ	DEIS	EEG	DEIS/EEG
Bone	1.2	1.2	1.0
Lung	0.3	0.2	1.5
Whole Body	1.1	0.9	1.2

[a]Maximum dose to an individual one-half mile from the accident. Details are shown in Appendix II.

Although the CH and RH-TRU doses to the general population from normal transportation are not considered to be of public health significance in comparison to other radiation sources in the environment, serious consideration should be given to shipping all the radioactive waste by rail, wherever the calculations show that the actual and potential radiation exposures will be reduced. This is consistent with the concept in radiological health that all unnecessary radiation exposure be avoided and exposures kept as low as reasonably achievable (ALARA).

The approximate total distance to be driven by the trucks will be: (600 shipments/year) x (1000 miles/shipment) x (30 years) = 18 million truck-miles. Calculations of injuries and accidents unrelated to radiation should be performed for rail and truck shipments. Consideration should also be given to restricting shipments in icy weather.

The following need to be clarified:

1) Who is responsible for accident response?

2) What response capability exists now and is planned for the future?

3) What state and local assistance is required?

4) Who equips, trains and funds the people?

5) Who pays for deployment, if required?

6) Who assumes financial risk for accidents?

Additional Dosage Estimates

There are a number of additional dosage estimates that need to be calculated:

1) Radiation exposure from acts of sabotage in the transportation of radioactive waste materials. The amounts of radioactivity released could be greater than those released in accidents. Are there any sabotage scenarios that could produce criticality? (Occupational, General Population)

2) Radiation exposure to emergency workers such as police and firemen following a transportation accident. (Occupational)

3) Exposure to a person stopped in an automobile next to a radioactive waste truck at a red light or in a traffic jam. (General Population)

4) Exposure from shipments of retrieved radioactive waste following the completion of the high level waste experiments. Containers could be bent, damaged or under pressure from gas generated by decomposed organic material. (Occupational, General Population)

5) Ingestion from contamination of a water supply or crops following an airborne release. (General Population)

6) Material resulting from decommissioning and dismantling of weapons production facilities in Hanford. While the DEIS assumes that none of the 5 to 95 million cubic feet of material will be shipped to WIPP, it notes that the WIPP will have the capacity to receive some of this TRU waste (2-22;2). (Occupational, General Population)

7) Consideration of a diffuse source of radioactivity rather than a point source in transportation calculations.

8) Population dose estimates were provided in man-rems. They do not identify the maximum dose to an individual.

Detailed Comments

6-4 Consideration should be given to limiting truck shipments during icy weather from sites such as LASL.

6-7;5 According to the DEIS (5-7), the shipping containers will not contain pyrophoric material. Can depleted uranium be pyrophoric under certain circumstances?

6-8 The interaction of the pyrophoric material permitted on page 5-4 and the hydrogenous material layered in the cask construction is not addressed in the transportation fire scenarios.

6-9 Will DOE or the carrier select the routes to be taken? Are there always two drivers or could the shipment be left unattended during stops?

6-12, 6-14 No information is provided on waste used in HLW experiments such as:

- radionuclides
- amount of radioactivity
- type of container
- form of material

What quantity, types, configuration of non-radioactive wastes are expected to be shipped as a contaminant in the radioactive waste?

6-17;2 The last line should read "from natural background" and the time period should be one year.

6-18;1 The numerical value (1.0 person-rem) does not agree with the value shown in Table 6-10, and unit "person-rem dose" is inappropriate. We are not able to confirm the figure of 0.02%.

6-18 Tables of doses include values for occupational and general population. They should be separated since different criteria apply to them.

6-23 What is the basis for assuming no ingestion of radioactivity from an airborne release following a transportation accident? Also, a body of water could be contaminated.

The assumptions for meteorology coupled with a release height of 20 meters for the aerosol result in a maximum dose occurring 0.5 miles downwind. Other assumptions can produce larger exposures at closer distances.

6-23;4 What is the basis for the assumption that contaminated food would immediately be taken out of distribution? Such administrative action has not always been possible or necessary.

6-23;5 The hypothetical rail accident involving CH-TRU waste calculates that only 0.004% of the radioactive material in the shipment would be airborne and respirable in a release. What is the basis for each of the factors in the calculation?

6-24;2 The 1978 Shefelbine reference is not adequate to justify the assumption that 10% of the waste is in powder form.

6-25, 6-26 Would radionuclides other than Kr-85 and Cs be volatilized in the fuel element accidents involving fire?

6-25;3 The hypothetical rail accident of a violent wreck with a fire for one hour involving RH-TRU waste assumes that only 0.1% of the Cs-137 would be released. No other radionuclide listed in Table E-3 on page E-4 would be released to the environment. What is the basis and rationale for these numerical values?

6-25;5 The hypothetical rail accident of a violent wreck with a fire for one hour involving spent fuel waste assumes that only 30% of Kr-85 and 0.1% of Cs-134/137 would be released. No other radionuclide listed in Table E-3 on page E-4 would be released to the environment. What is the basis for these statements?

6-26 The hypothetical accident involving the shipment of spent fuel only considers cesium and krypton being released; but the operational accident for spent fuel on 9-37;1 otes that tritium, Krypton-85, and Iodine-129 are easily released.

6-26, 6-23 It was assumed that there was no route of exposure except inhalation for the accident. Administrative control cannot be relied upon in this type of incident and other routes of exposure must be considered.

6-26 The assumptions that many nuclides including tritium, Iodine-129 (and others) are released from a damaged spent-fuel assembly in the WIPP above ground facility, are different than the assumptions discussed on 6-26 for a rail accident. These differences should be resolved.

6-26, Tables 6-14,6-15 We were able to reproduce the spent fuel bone dose of 4200 man-rem shown in Table 6-14. We were unable to reproduce the population dose commitments in Table 6-15.

6-27 Drums were considered in the scenarios involving transportation accidents but boxes were not. An explanation is needed.

Surface contamination tests upon arrival at the repository are needed.

6-27, Table 6-3 Using the assumptions of the spent fuel transportation accident outlined in the DEIS, calculations by EEG were in general agreement with the dose to individuals given in Table 6-3.

6-27, 6-18 The various radiation exposures from the shipment by truck are greater than by rail (annual man-rem doses from transportation of CH-TRU, RH-TRU and spent fuel, pp. 6-18 and 6-19). The same is true for accidents (p. 6-28). Consideration should be given to transporting all the

radioactive wastes by rail which would reduce the expected and potential radiation exposure in accordance with the ALARA (as low as reasonably achievable) concept.

References

1. U.S. Department of Energy. Draft Environmental Impact Statement, Waste Isolation Pilot Plant (DOE/EIS-0026-D), Vol. 1, April 1979.

2. U.S. Department of Energy. Draft Environmental Impact Statement, Waste Isolation Pilot Plant (DOE/EIS-0026-D), Vol. 2: Appendices, April, 1979.

3. Taylor, John M., RADTRAN: A Computer Code to Analyze Transportation of Radioactive Material, (SAND76-0243), April 1977.

4. U.S. Nuclear Regulatory Commission. Office of Standards Development. Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes (NUREG-0170), Vol. 1, December 1977.

5. U.S. Nuclear Regulatory Commission. Office of Standards Development. Final Environmental Statement of the Transportation of Radioactive Material by Air and Other Modes (NUREG-0170), Vol. 2, December 1977.

6. U.S. Nuclear Regulatory Commission. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants (WASH-1400), Sec. 1, October 1975.

7. U. S. General Accounting Office. Federal Actions Are Needed to Improve Safety and Security of Nuclear Materials Transportation (EMD-79-18), May 7, 1979.

8. U.S. Nuclear Regulatory Commission. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants (WASH-1400), October 1975.

9. Moore, R. E. The AIRDOS-II Computer Code for Estimating Radiation Dose to Man from Airborne Radionuclides in Areas Surrounding Nuclear Facilities (ORNL-5245), April 1977.

10. U.S. Nuclear Regulatory Commission. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Appendix VI. Calculation of Reactor Accident Consequences, (WASH-1400), October 1975.

11. U.S. Atomic Energy Commission. Environmental Survey of Transportation of Radioactive Materials to and From Nuclear Power Plants (WASH-1238), December 1972.

12. Killough, G.G., and McKay, L.R. A Methodology for Calculating Radiation Doses from Radioactivity Released to the Environment (ORNL-4992), March 1976.

13. Killough, GG., et al. INREM - A FORTRAN Code Which Implements ICRP 2 Models of Internal Radiation Dose to Man (ORNL-5003), February 1975.

14. Trubey, D.K., and Kaye, S.V. The EXREM III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases (ORNL-TM-4322), December 1973.

15. Cohen, J.J., et al. Determination of Performance Criteria for High-Level Solidified Nuclear Waste (NUREG-0279), 1977.

SITE CHARACTERIZATION

(DEIS Chapter 7)

VI

Major Conclusions

The EEG has evaluated the Geological Characterization Report (GCR) Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico (SAND 78-1596), December, 1978, which is the source of most of the geological and hydrological data in the DEIS; the complete review is in Appendix III. Conclusions and summary statements in the DEIS, as well as in the GCR, did not take into account certain important problems related to geologic and hydrologic factors. The following is a summary of EEG's major concerns:

1) Seven wells within nine miles of the periphery of the WIPP site have encountered brine reservoirs under artesian pressure. The origin, evolution, frequency of occurrence and size of these high pressure brine reservoirs were not adequately addressed in either the DEIS or the GCR.

2) There is at least one confirmed occurrence of a "chimney... with clay cemented brecciated rock", commonly called a breccia pipe, approximately seven miles from the WIPP site (Mississippi Chemical Corporation potash mine). Several other possible breccia pipes are under various stages of investigation. The origin, evolution and frequency of occurrence of these features must be better understood. They may be localized deep dissolution features which originate in the lower portion of the evaporites and migrate upward. Such localized dissolution features could now exist or develop later beneath the proposed site.

3) The DEIS and the GCR assumed that surface or shallow dissolution is the dominant process of salt removal from the evaporite beds. However, deep dissolution may be causing a preferential removal of the salt horizon which is proposed for the repository.

4) The lithology of the repository horizons is described on page 7-24 of the DEIS and parts of the lithologic log of the ERDA-9 hole are shown in Figures 1 and 2 of this section (from Fig. 4.3-3B of the GCR). These sections of the logs describe the lithology of the repository horizons for CH and RH zones as shown on Figure 4.3-3A of the GCR. The logs show the presence of clay, anhydrite and polyhalite in addition to halite, as the constituents of both repository horizons. The presence of these impurities should be taken into account in evaluating physical, hydrological, thermal and strength characteristics of "rock salt" from the repository horizons.

5) The values of hydrologic parameters (e.g. hydraulic conductivity, distribution coefficients, and effective porosity) can vary over a large range and the DEIS provides such information. In addition, potentiometric surface maps, hydraulic gradients and flow paths have been constructed on the basis of limited data. In some cases (e.g. hydraulic conductivity) the DEIS gives a range of measured values. Ranges should be assessed in all cases, particularly for distribution coefficients. The distribution coefficient (K_d), which affects the speed with which a given radionuclide is transported in groundwater, can be affected by rock type, extent of fracture permeability, water quality characteristics, competing ion effects, and the chemical form of the radionuclide of interest. Values obtained for a given nuclide in a given rock formation have been observed to vary by several orders of magnitude.

6) More information should be given in the final EIS on surface water hydrology in the region surrounding the WIPP site.

Items 1, 2 and 3 have been discussed in detail in Appendix III (EEG's Review Comments on the GCR). No new information on these items is presented in the DEIS. The DEIS concluded that there was no evidence of brine reservoirs or ongoing deep dissolution at the WIPP site. EEG questions the basis of these conclusions in the Review of the GCR.

Lithology of Proposed Emplacement Horizons

According to the DEIS (7-21;4), the repository horizons were selected due to the presence of relatively pure salt layers. When the NAS-NRC Committee (Ref. 2) recommended salt as the most likely geologic medium for radioactive waste disposal, it placed strong emphasis on the "purity" of a bedded salt formation so that its thermal and physical properties could be predicted. The presence of impurities can affect the properties of bedded salt. Examples are:

1) Argillaceous (clayey) layers in bedded salt may provide conduits for the migration of water to and from the repository. While some of the impurities found in bedded salt have lower permeabilities than halite, a path for migration of water may be created along the contact between two layers of differing lithology.

2) A subgroup of the Interagency Review Group on Nuclear Waste Management commented on salt formations: "The hydrologic regimes in which anhydrite occurs are characterized by flows along bedded planes, but locally channeling (cavern formation) occurs in anhydrite similar to that in limestone and gypsum" (Ref. 1).

3) The chemical reactions which may take place in the vicinity of high level waste, accelerated by elevated temperatures and high pressures become more complex and unpredictable when the host rock is heterogeneous.

4) Because thermal conductivities of clays and polyhalite are very different from that of halite, the dissipation of heat resulting from the high level wastes will not be uniform around the waste. This may result in cracking, parting of seams and uneven concentration of moisture.

These potential problems are not discussed in the DEIS, although the lithology of the repository horizons is presented as follows: "The basic mineral of both repository horizons is halite. Also present are anhydrite, polyhalite, quartz and a suite of clay minerals (illite, chlorite, talc, serpentine, and expendable clays). Halite beds within the emplacement horizons are about 97% halite. Most of the remainder is anhydrite" (7-24;5). Note that the last line quoted refers to 97% halite in halite beds and not in the total repository horizon. The lithologic log for the CH repository horizons (Figure 1) shows anhydrite beds which are 0.2, 0.7 and 0.9 feet thick and most halite layers are "argillic and polyhalitic". The RH repository rocks are mostly "anhydritic and argillic halite" (Figure 2). The bottom 20 feet of the RH zone is primarily "dense anhydrite".

Unidentified Structures

A lamprophyre dike or a series of en-echelon dikes were reported within six miles of the periphery of the WIPP site. If associated igneous bodies underlie the WIPP site, they could affect the integrity of the salt beds. The cross-section on Figure 4.4-5 in the GCR shows faults in the Castile directly below the WIPP site and the contour map on Figure 4.4-6 shows confined faults on top of the Castile. These should be explained.

Surface Water Hydrology

There is not enough information given on surface water hydrology in the region around the site to enable one to adequately evaluate the effect of the site on local water resources. Since surface runoff is a potential pathway to spread contamination, it needs to be evaluated in much more detail. This evaluation should include runoff from floods with a 100-year and 1,000-year return period. The fate of this runoff water after it reaches Nash Draw (or elsewhere) needs to be evaluated. A description of

existing and planned water resource development in the area (including irrigation withdrawal, canals, irrigated lands, and return flows) would make it possible to evaluate the effect of the project on present and future surface water resources. Also, it will be necessary to describe water use downstream from Malaga Bend into Texas in order to evaluate the transport and concentration of radionuclides released to the Pecos River from the long term breach scenarios.

Ground Water Hydrology

The ground water data was largely obtained on the Rustler and deeper aquifers and was used to evalute the role of these aquifers in transporting radionuclides away from the site. Another pathway of exposure would be from wells drilled into the Rustler, Santa Rosa Sandstone or other shallow lenses near the site, and used for individual water supplies, gardens or stock watering. More information is needed on present and potential well water use, quantities of water available, effect of surface recharge, and potential for the well water to be contaminated by the Bell Canyon or Rustler aquifers.

Climatic Changes

Based on the evidence presented on page H-62 and H-63 of the DEIS, the present interglacial period may last another 4,000-5,000 years followed by a cooling trend culminating in another glacial age. In that case, the climate near the WIPP site may be significantly cooler and wetter in 10,000-15,000 years. EEG recommends that long range modeling take into account plausible future climatic changes in hydrological regime.

Figure 1

From GCR, Figure 4.3-3B

CH repository horizon from 2074 to 2176 feet

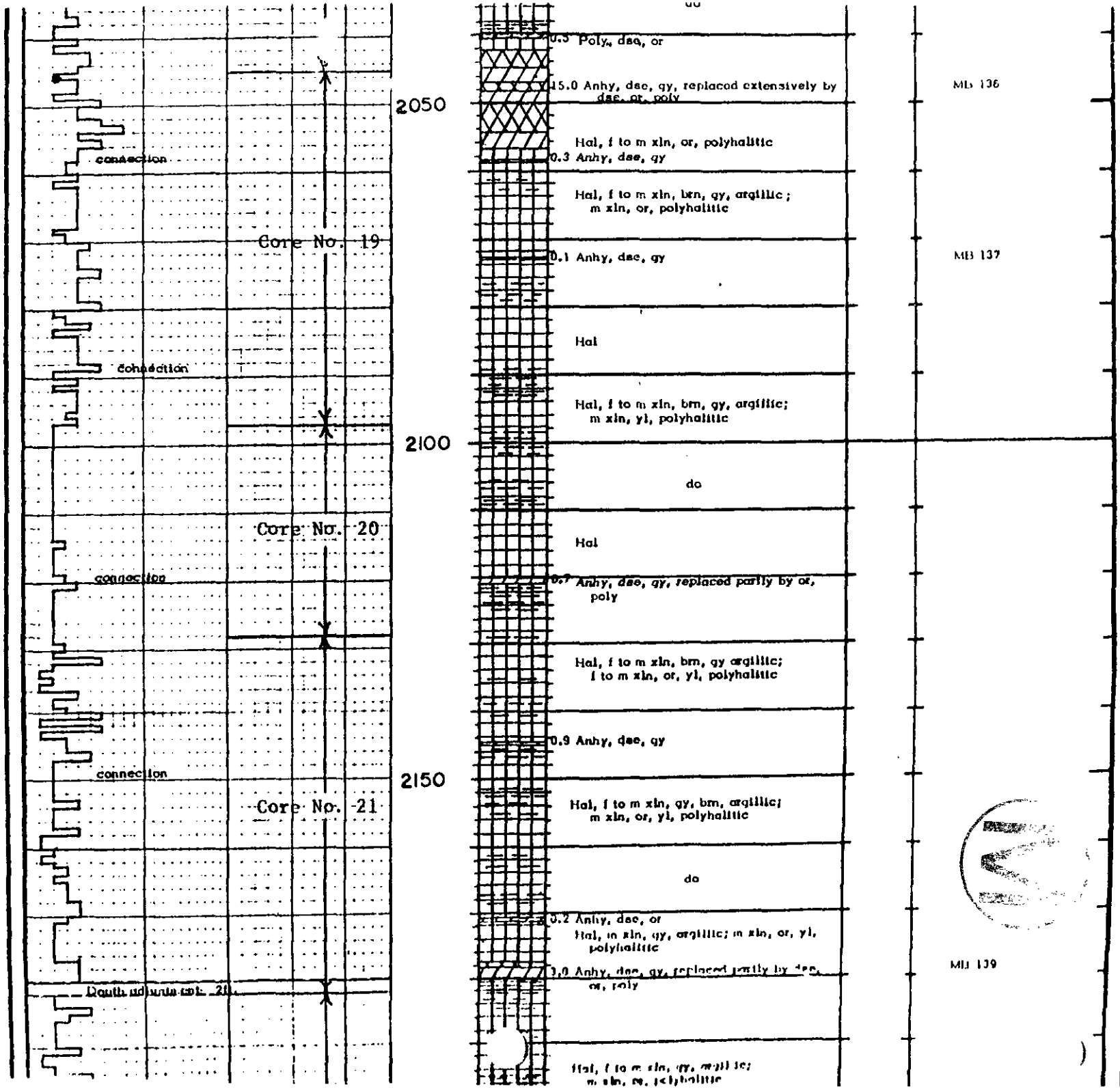

Figure 2

From GCR, Figure 4.3-3B
RH repository horizon from 2620 to 2730 feet

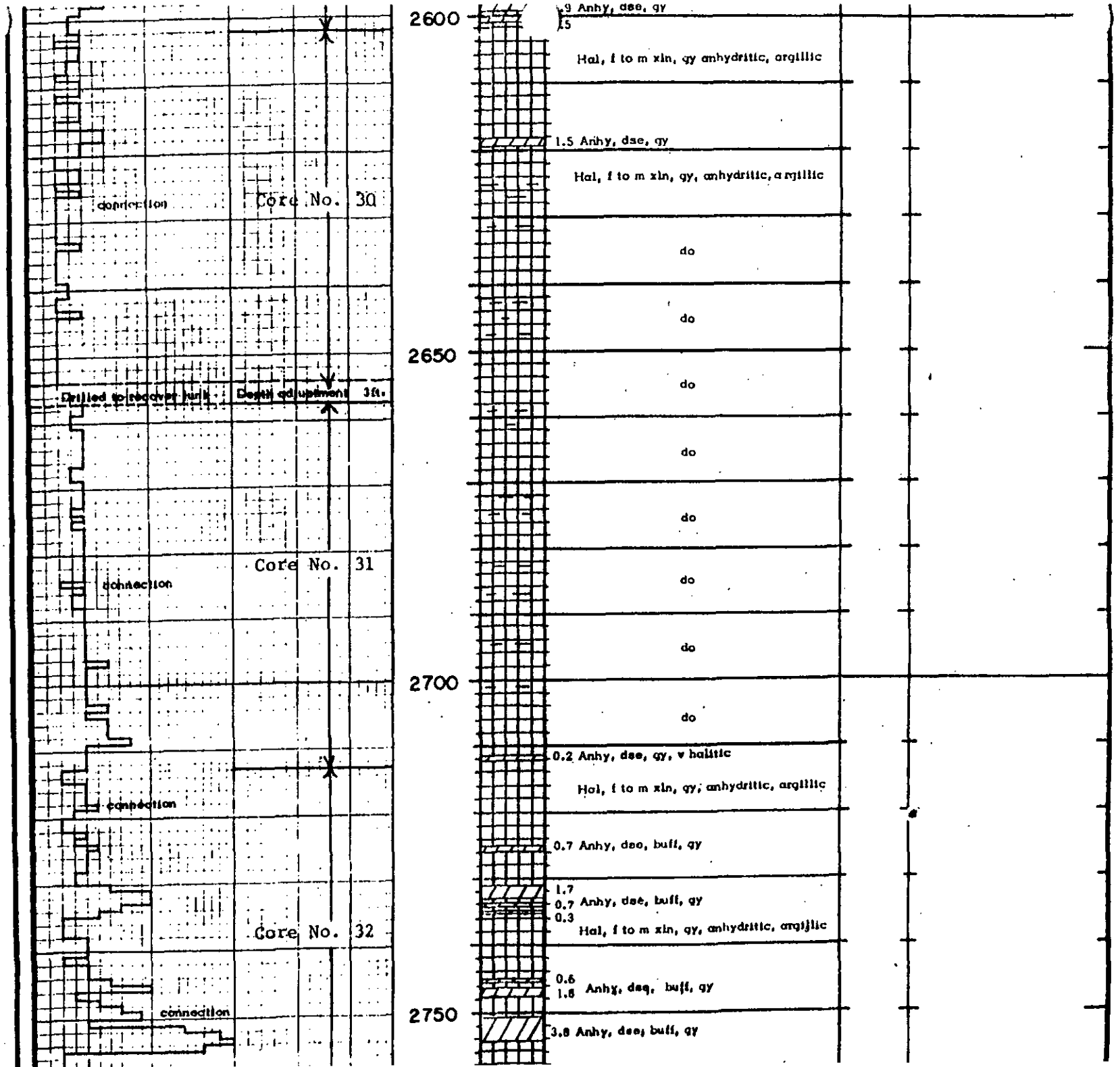

Detailed Comments

7-17;2 Section 17, T22S, R31E is in control Zone III.

7-26;7 What is a "depositional-growth fault" and what is its significance?

7-30;9 What is the status of the investigation of these faults?

7-47;3 It should be "approximately 3300 square miles" instead of "1 million sq. mi." (See Fig. 7-17).

7-65;1 A map and a cross-section showing locations of brine pockets encountered and their stratigraphic locations should be included in the final EIS.

7-65;4 Why has the model assumed a flow path in the Rustler directly to Malaga Bend to the Pecos River. (See Fig. K-5). Couldn't the water seep out in Nash Draw since the top of the Salado is exposed in Nash Draw?

7-69;1 Why is it assumed that the water will come out at Malaga Bend? Why not Laguna Grande de la Sal? What is the origin of the water in Laguna Grande de la Sal?

7-72;6 What is the basis for the assumption of the origin of water for Laguna Plata and Laguna Gatuna?

7-74;1 "Weaver Pipe" could be an example of a breccia pipe which has no surface expression. Could there be such breccia pipes at the WIPP site which have no surface expression?

7-75;3 Late Pleistocene (Wisconsin) was from 40,000 years to 15,000 years B.P. Such climate changes can occur in the future as well.

7-75;7 The GCR (August 1978) referred to current and future studies to evaluate deep dissolution (6-46;1). The EIS (April 1979) concluded "In any case, deep dissolution does not occur near the site". Have these studies been conclud.

References

1. Interagency Review Group on Nuclear Waste Management, Subgroup for Alternative Technology Strategies. "Isolation of Radioactive Waste in Geologic Repositories: Status of Scientific and Technological Knowledge," Subgroup Report on Alternative Technology Strategies for the Isolation of Nuclear Waste (TID-28818 Draft), Appendix A, October 1978.

2. National Academy of Sciences-National Research Council. Committee on Waste Disposal. The Disposal of Radioactive Waste on Land (Publication 519), April 1957.

OPERATION OF THE REPOSITORY
(DEIS Chapter 8)

Major Conclusions

1) Present plans would permit public access to Zones II, III and IV during operations. Also, there is private land 2.8 miles downwind (northwest) of the center of the site where building could occur. Consideration should be given to the radiological air quality and noise environments at these locations in addition to those at the James Ranch.

2) Calculations of radionuclide releases from routine operations agree with those in the DEIS when the same assumptions are used. However, several assumptions used in estimating the amount of radioactivity released are unverified.

3) Radon emissions from natural radioactivity in the repository have not been measured in soil, mined rock, and the proposed waste horizons. Radon should be measured to see if levels might be high enough to be a problem for underground workers and a source of radiation exposure to the public from the excavated salt.

4) Other than radon, the present radiological monitoring program appears satisfactory for the next several years.

5) From the limited information provided in the DEIS on the high level waste experimental program, 9-90 million curies of radioactivity may be involved in the experiments with full-size canisters. In this case, the experimental waste could be the most significant factor in the analysis of potential radiation exposures during the operational phase of the repository. This was not considered in the DEIS calculation of radiation doses.

6) All high level waste used in experiments is scheduled to be retrieved and all TRU waste and spent fuel elements are to be in a

retrievable condition. The DEIS does not address such important items as the criteria for retrieval, the hazards to workers, and hazards to the public. More information is needed before the feasibility of retrievability can be evaluated.

7) The options of decommissioning are adequately covered for the present. The advantage and feasibility of control for periods greater than 100 years should be included in this evaluation.

8) From the material presented in the DEIS, one could conclude that Ambient Air Quality Standards may be violated in Zones II, III, and IV, unless certain measures are taken to insure that the standards are met.

9) There will be some degradation of the noise environment due to repository operations and the traffic related to it. More attention needs to be given to mitigating noise.

10) Due to WIPP-induced population growth in surrounding communities, there will be some impact on water quality, water supply, and solid and hazardous waste conditions. The EEG agrees with the DEIS conclusion that, with proper planning, the existing systems are adequate to absorb the increase.

The Site and Its Environs

The entire area of the site and much of the land immediately outside of Zone IV are owned by the Federal or State government. The James Ranch, located 3 miles south-southwest of the site center, is privately owned and occupied and was used to calculate the maximum individual exposures to radioactivity and noise in the DEIS.

However, it may not be conservative to assume that this is the location of the maximum exposed individual, for the following reasons:

1) Private land is located just outside the northwest boundary, 2.8 miles downwind from the site center. From the atmospheric

dispersion coefficients given in Table H-36, calculations of concentrations of airborne effluents would be about 5 times higher than at James Ranch.

2) Plans indicate public access to parts of the site for ranching, recreation and resource extraction. Consequently, people may be as close as one-half mile from the site center.

Analysis of the effects of repository operation on individuals in the population should consider these locations where people will be permitted to live or visit as well as where they live now.

Normal Radiation Releases

Radon Emissions

Radon, a naturally occurring radioactive noble gas is contained in air exhausted from underground mines. Because radon concentrations could be high enough to be a hazard to some underground workers and could result in measurable off-site exposures, the concentrations should be measured.

The DEIS recognized that radon will be present in exhaust air but did not consider the radon from the mined rock storage pile on the surface. Radon concentrations in the DEIS were based on concentrations reported in the Nuclear Regulatory Commission's Final Generic Impact Statement on Mixed Oxide Fuels (GESMO).

Appendix IV contains a more detailed discussion of the possible radon exposure and calculates dosages to the bronchial epithelium as well as the pulmonary lung dose at 0.5 miles, 2.8 miles (NW) and 3.0 miles (SSW). These calculated doses (which are average, rather than upper-bound limits) suggest that potential radon exposures are high enough to require direct measurement at the site to determine actual concentrations.

Operational Releases of Radioactivity

Starting with the assumptions used in Chapter 8, the radiation releases to the environment were calculated by EEG and they agreed with the

results listed in the DEIS (Table 8-6). Agreement was also obtained with the quantity of radioactivity collected on HEPA filters reported in Table 8-7.

However, one area of potential disagreement relates to the calculation of releases of radioactivity from underground storage of contaminated containers. The EEG calculations assumed a 4-year accumulation of boxes and drums that were releasing 1% per year of their remaining surface contamination. The EEG calculated release was approximately four times the quantity of released TRU wastes listed in Table 8-6. Was the calculation in the DEIS based on one year's accumulation of containers?

It is not clear from the description in the DEIS what becomes of spilled material from damaged drums and boxes. The DEIS, assumed that 1.47 curies of TRU waste would be spilled per year and 0.1% would become airborne. The remainder is unaccounted for. The quantity of TRU wastes on ion exchange resins reported in Table 8-7 was only 0.04 curies per year.

Assumptions for Release

A number of factors are involved in the chain of events that must occur before radioactivity is released at the site. Most of the factors that are used to calculate the release of the CH-TRU waste are assumed (surface contamination, non-fixed surface contamination, number of boxes and drums damaged, percent of the surface area that is cracked). Is there a data base for the surface contaminated or damaged drums and boxes that have been packaged, shipped and stored over the years? It is difficult to determine if the assumptions are conservative based on the following information presented in the DEIS:

1) The DEIS assumed that one spent fuel assembly and its canister are damaged in a four-year period (8-32:1) as described in the NRC's Reactor Safety Study, 1975. A more recent report reviewing the history of spent fuel assembly accidents by Johnson (Ref. 1), presented data which suggest that one or more accidents per year might be more realistic.

2) All calculations assumed an average percentage of powder and average radionuclide concentration in each drum. Calculations should also be made using boxes, which contain more waste than drums and have higher levels of radioactivity.

3) Specific data are absent on design, testing and experience with remote handled TRU waste casks and canisters.

Due to the ranges of possible values of factors involved in a potential release of radioactivity, a sensitivity analyses should be performed to determine their effect on potential doses.

High Level Waste Experiments

The DEIS did not state the amount and types of radionuclides that will be brought into the repository for these experiments. Twenty to 200 bare waste experiments are to be conducted (8-47). The number of full sized canisters emplaced was estimated to be between 20 and 200 (8-48), but "...these numbers, like the estimates of bare waste reaction chambers may change by as much as a factor of 2" (8-48;2). "The source of the waste to be used in these experiments is not as yet defined" (2-24;3). The possibilities of using laboratory produced commercial reactor wastes, aged defense HLW or wastes fortified with Strontium-90 or Cesium-137 are then discussed.

Even with these few details it is apparent that the quantities of radioactivity brought into the repository in the experimental program could be large if one assumes that the full sized canisters described on page 8-48 are the same as the high level waste canisters described for commercial high level waste in Table E-4 on page E-5. The estimated amount of radioactivity in a high level waste canister is about 460,000 curies (Table E-4) which would give a total of 9-92 million curies from the canisters alone.

Retrievability

Present plans are to retrieve all high level wastes (HLW) experiments after completion and to have the ability to retrieve contact-handled and remote-handled TRU wastes and spent fuel. The periods of retrievability are apparently 10 years for TRU wastes and 20 years for spent fuel (the times are reversed in the statements on 2-18;7 and 2-19;1). Container life for TRU wastes is designed for 10 years so it can be retrieved (5-4). A possible need for repackaging retrieved containers is recognized (9-52;5) and apparently it is planned to do this underground. Another reference (9-49;2) stated that accidents during retrieval are expected to be no worse than could occur during emplacement.

The DEIS did not provide guidance on the criteria for retrieval of TRU and spent fuel wastes. Details were not provided on how retrieval would be conducted and on the contamination and exposure problems that are expected. The retrieved containers could be damaged during emplacement, storage, and retrieval. Also, chemical action of the salt environment for periods of 10 or 20 years could produce deterioration in the integrity of the canisters. Retrieval of high level waste experiments will be further complicated by bare wastes and contaminated salt.

While retrieval is possible, the removal of radioactive waste from the repository will involve more problems than emplacement. The extent of this difference has not been adequately addressed in the DEIS and should be expanded upon in either the final EIS or PSAR (Preliminary Safety Analysis Report).

EEG believes that retrieval will be a complex operation with the potential for significant radiation exposure to workers and for possible releases to the environment. It is necessary for retrievability to be evaluated in detail for procedures, logistics, and criteria before conclusions can be drawn about its feasibility.

Decommissioning

The discussion on decommissioning of the WIPP site repository (8-53 to 8-57) covers various alternatives and contains adequate detail at this time. Any of the alternatives listed on page 8-54 should be acceptable if carried out properly. There are two issues that have the potential to increase the probability of long-term problems:

1) administrative control over the site; and

2) borehole plugging.

Possible industrial use of the site is indicated (8-53;3). The land area is expected to be returned to its natural state in several decades unless the mothballing option is taken (11-1). Also, Scenario 5 (9-124) assumes administrative control is lost after 100 years and unregulated drilling can occur. This scenario results in a high dose to well drillers. A detailed evaluation should be made of the degree of control needed at the site after decommissioning and should include:

1) the possibility of control for periods longer than 100 years;

2) the long-term controls over shallow-well drilling in Zone III and resource extraction in Zone IV; and

3) details of the long-term radiological monitoring program.

Radiological Monitoring Program

Pages J-24 to J-41 of Appendix J of the DEIS describe the present radiological monitoring program, the tentative pre-operational monitoring program, the proposed operational monitoring program, and the post-operational monitoring program.

While it is realized that these future programs are necessarily tentative, the following comments are offered.

Present Program

This program appears adequate for several years, with one exception. Measurements of radon and its short-lived daughter product concentrations are needed from the soil, from mined rock, and in the underground mine.

Radon monitoring should be done as soon as possible because the presence of high levels could influence the design of underground ventilation.

It will be necessary to obtain sufficient samples and analyses before operation to insure that the variations in the background (naturally occuring and from weapons testing fallout) levels of actinides, tritium, Carbon-14 and fission products are adequately known. These values are needed in order to be able to detect contamination from site operations.

Pre-operational Program

It is noted that no air particulate station is planned for Hobbs. Since it is a major population center, with a calculated long-term χ/Q only 10% lower than at Eunice, this omission should be reconsidered. Also, the three days per week of sampling should be randomized in order to measure levels on work days, and non-work days.

Consideration should also be given to monitoring radioactivity in rainfall and runoff (when it occurs) at the site as well as surface water and biota in Nash Draw. Several additional shallow wells, whether presently used for human consumption or not, should also be sampled on an annual or biennial basis.

In several cases in Table J-4 (Appendix J), the types of analyses are not specific enough. Gross analysis is useful as a screening mechanism for detecting significant contamination. However, it usually will not detect trace migration of radionuclides. All media being sampled should have periodic analyses of the actinides, tritium, Carbon-14 and long-lived fission products. Consideration should be given to developing and maintaining a capability of measuring Iodine-129 in case of accidents (J-27;2).

Operational Monitoring Program

The same considerations expressed for the pre-operational program are applicable for the operational program. No further comments are offered at this time.

Post-operational Program.

The outline of a post-operational program presented in Table J-7 appears reasonable. However, the borehole radionuclide analyses should be for specific radionuclides rather than gross alpha and beta for the reasons discussed above.

Non-Radiological Hazards

Air Quality

The EEG analyzed the data presented in the DEIS to determine if a potential exists to exceed the Ambient Air Quality Standards at the Reference Site. It was concluded that standards for several of the criteria pollutants could be violated during construction and operation of the WIPP. This conclusion, which differs from that implied in the DEIS, is due to the following factors:

1) When calculating ambient concentrations, it is appropriate to consider locations where the public has access rather than county-wide averages. The distance from the WIPP site may be less than 0.5 miles.

2) Appropriate allowance must be made for the number of shifts that will operate at the site. There is a discrepancy in the DEIS. Table 8-9 assumes only one shift operation, whereas page 2-19 and 8-27 mention three-shift operation to calculate radiation releases.

3) For three shift, five-day per week operation, the nitrogen oxide and sulfur dioxide concentrations at 0.5 miles were calculated to exceed the annual average concentrations permitted by the State of New Mexico if the χ/Q values in Table H-36 are used. The annual nitrogen dioxide Standard would also be exceeded during construction.

4) During construction, the fugitive dust emissions shown on page 9-8 would exceed the permissible 24-hour level at a distance of two miles when the background concentration of approximately 30 $\mu g/m^3$ is added.

5) Particulate emissions during the operating phase are dominated by releases from the salt pile and from the salt drying unit. The magnitude of salt pile emissions has a range of uncertainty. Experience with the potash industry suggests that the pile emissions will be negligible except for the periods when salt is being reclaimed for drying and use as backfill. Emissions from the salt drying unit (other than from combustion) were not estimated in the DEIS. This source has been found to be significant in the potash industry.

Although the EEG analysis concludes that construction and operation of the site will violate the New Mexico Ambient Air Quality Standards, experience with the potash industry suggests that it should be possible to meet these standards with proper engineering controls, elevated releases, and other mitigating measures.

A more detailed analysis of the air quality aspects needs to be performed. This analysis should include one-hour and three-hour analyses as well as 24-hour and annual values. A more precise estimate of emissions from the salt pile and dryer is needed. The analysis should consider such factors as elevated releases, non-point source emissions, cloud depletion, control technology, and other mitigating measures that will be taken. The final EIS should contain the results of this re-evaluation and indicate the measures that will be provided to insure that Ambient Air Quality Standards are not exceeded.

Noise

The DEIS makes predictions on the noise levels from construction and operation at the WIPP site. For the most part these projections appear reasonable. However, the conclusions emphasize the fact that ambient levels will still be well below various standards and suggest there is no problem. Actually, the noise environment will be degraded both during the construction and operating phase and some residents, off-site and near transportation arteries, and users of Zones II, III and IV will be exposed to more noise than at present. Furthermore, while the DEIS makes reference to measures that could minimize noise exposure, no commitments are made to implement specific measures.

Several items in the DEIS requiring clarifications are:

1) Traffic noise impact from WIPP-related commuter and truck traffic cannot be estimated without knowing the projected traffic volume (of both trucks and autos) with and without the project. This needs to include the effect of night-time traffic which will be present during three-shift operation and construction.

2) The assumption of a peak dBA of 84 at 50 feet from diesel trucks is optimistic since the Federal standard for Inter-State trucks permits 90 dBA and many intrastate trucks cannot meet this standard.

3) References on pages 9-4 and 9-27 imply that noise levels of about 45 dBA will be inaudible at the James Ranch. Actually, if the ambient is 26-28 dBA, sound pressure levels of less than 35 dBA will be clearly audible.

4) It is unclear from the description of the mined-rock storage just what noise sources are included and how they might vary with time.

5) Operational noise near the site would be expected to alter the present mix of wildlife species. The conclusion that this would be minor and insignificant should be documented.

The final EIS should include more precise analysis of just how much the noise level is expected to rise from site construction and operation. Also, consideration should be given to mitigating measures such as:

1) busing of workers to drastically reduce auto traffic;

2) muffling of construction equipment and use of low noise products where available;

3) a requirement that all trucks meet the Federal noise regulations required for Inter-State Commerce; and

4) housing of various equipment and operations.

Water Quality

Several aspects of the WIPP site operation may have an effect on water quality. Primary impacts (on site) could occur from:

1) the sewage plant effluent and sludge;

2) reclaimed water use on-site;

3) runoff and leaching from the salt pile; and

4) general site runoff.

Secondary impacts could occur from the WIPP induced population growth in Eddy and Lea counties. The most likely problem is from septic tank contamination in unsewered areas and is recognized in the DEIS (9-91;2). Both primary and secondary impacts appear to be manageable with proper planning.

Solid and Hazardous Waste Control

Construction, operation and decommissioning of the WIPP site will result in the generation of substantial quantities of solid waste and unestimated amounts of non-radiological hazardous wastes. There will also be some secondary impacts in Carlsbad and Hobbs due to the WIPP induced population growth.

It is not possible to evaluate the hazardous waste situation from the limited information in the DEIS. Under present New Mexico regulations, it is permissible to dispose of hazardous wastes on the site without a permit where they are generated. However, Federal regulations are expected to be in effect prior to the beginning of site construction and they will probably require regulation whether disposal is on or off-site. The types and quantities of hazardous waste expected to be generated on-site need to be determined more precisely.

Metals and discarded equipment are scheduled to be recycled with a commercial salvage company (8-35;6). An appropriate control system should be established to insure that this recycling does not lead to off-site radiological contamination.

Water Supply

Since the WIPP plant operators propose to purchase its water supply from the City of Carlsbad, the State of New Mexico would be involved in regulatory procedures only indirectly. In addition, the project could be exempted from State regulations under Part I., Section 102, Water Supply Regulations.

A portion of the population growth could take place outside of incorporated city limits. Water supplies for these families would probably come from individual wells. Local and regional governmental agencies should be aware of potential water quality problems related to the increased number of wells and their proximity to septic systems since the State Environmental Improvement Division does not regulate individual water supply systems.

Detailed Comments

8-15;3 No mention is made in the DEIS of the management or organization of the health physics program. EEG assumes this will be covered in the PSAR.

8-17;5 A contamination check should be made on empty CH waste containers before they are "reloaded onto vehicles leaving the plant".

8-23 Consideration should be given to isolating the High Level Waste experimental area from the remainder of the mine in case of accident. It is unclear how the isolation of the air flow will be accomplished from the description on pages 8-20, 8-22 and 8-23.

8-28;1 The DEIS stated that 10% of surface activity is released and becomes airborne. What data is this based on?

8-28;2 The DEIS states that 30 drums and five boxes per year may be received in a damaged condition. This is .019% of the drums and 0.21% of the boxes. Are these numbers predicated on actual experience?

8-28;3 The DEIS states that cracks generated by dropping a 55-gallon drum will be less than 1% of the total area of the drum surface. Is there a reference for this assumption?

8-28;4 The assumptions of an airborne fraction of 0.00023 per hour and a decontamination factor of 10^6 are referenced and the airborne fraction is taken from an experiment utilizing a road-like surface. Both larger and smaller fractions were observed from other experiments by the authors (Mishima and Schwendiman, 1973).

8-31;4 The DEIS assumed that one canister per year will be cracked, the crack is 1% of the area, and that the release is proportional to the crack. Is there a reference for these assumptions? Mishima and Schwendiman in BNWL-1732, 1973 do not cover these items.

8-32;1 It is assumed that one spent fuel assembly and its canister are damaged in a four-year period. From the data presented in a review of the history of spent fuel assembly accidents (ref. 1) it appears the assumed rate of one accident per 1000 assemblies handled might be too low.

The NRC's Draft Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel (ref. 2) stated that both NFS (Nuclear Fuel Service) and AGNS (Allied-General Nuclear Services) included in their safety analysis reports on underwater fuel drop accidents in which it is assumed that all of the fuel pins in a fuel assembly were ruptured. It appears that when the DEIS assumptions on released fractions from fuel assemblies are compared to other references (ref. 1 and 2) the DEIS assumptions might be too low.

8-31;5 Since experiments with high level waste are planned with bare sources, this paragraph should be clarified.

8-32;1 The assumptions that many nuclides including H-3, Kr-85, I-129, tellurium and selenium are released from the damaged spent fuel are much different from the assumptions discussed on page 6-26 for a rail accident. These differences should be resolved or the rationale explained.

In addition, C-14 has been consistently omitted from all inventories, releases and dose calculations pertaining to spent fuel. The DOE in its Draft Environmental Impact Statement Management of Commercially Generated

Radioactive Waste (Ref. 3), consistently lists C-14 in its inventory (as on page 2.1.16) and outlines the calculations for C-14 (in Appendix D).

8-34;1,3 The DEIS stated that there are 200 HEPA filters in "parallel". This differs with statements made in 8-26;4 where it says there are two stages of filters in series. If the statement on page 8-34 is correct, then there is only a decontamination factor of 10^3 rather than the 10^6 used throughout the report.

8-34 Table 8-7 The total radioactivity per drum in Table 8-7 totals 6.7-4 Ci, not 5.7-4.

8-36;3 How effective will the protective action of spraying the salt pile with water be in containing the contents?

8-37;2 265 $\mu g/m^3$.

8-38 Table 8-9 While the table shows the total emissions of pollutants at the site, it would be helpful to show the maximum expected emission rates and when they occur.

8-43;3 Laboratory decontamination agents with EDTA may be present in the TRU waste. If EDTA is present, it may drastically alter the migration of actinides through the soil and effectively alter the K_d values in the long range release scenarios.

8-47;4 Are the "reaction chambers" merely drilled holes in the salt of the mine? If so, how does one collect "gaseous samples" without having such samples contaminated by the ambient air?

8-49;7 If the canistered spent fuel assembly is placed inside a sleeved hole, can this assembly do anything more than produce a temperature gradient outside the sleeve? If not, why use a spent fuel assembly?

8-49;5 There is no reference or backup information given to substantiate the statement "Sufficient air quantities will be provided to support the mining and storage operations as well as to remove fission gases that might escape from unsealed storage rooms". Uranium mining experience indicated adequate ventilation can be difficult to provide.

8-51 The plans for retrieval have not addressed the problem of radiation protection.

8-52;2 Have the contamination limits been established, and what is "an acceptable level"? The potential contamination problem for "retrieval after backfilling" could be extremely troublesome. More information on personnel exposure control and contamination limits should be provided. Where will the radioactive waste and contaminated salt be taken?

8-55;3 The DEIS stated that the site might be used after decommissioning as an industrial site. No scenarios cover this possibility of future use.

8-57;1 The DEIS stated that the results obtained so far give the DOE confidence that newly developed plugging methods will be available in decommissioning the repository. What are the references?

References

1. Johnson, A.B., Jr. Behavior of Spent Nuclear Fuel in Water Pool Storage (BNWL-2256), 1977.

2. U.S. Nuclear Regulatory Commission. Draft Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel (NUREG-0404), March 1978.

3. U.S. Department of Energy. Management of Commer ally Generated Radioactive Waste (DOE/EIS-0046D), Draft Environmental Impact Statement, April 1979.

4. U.S. Energy Research and Development Administration. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle (ERDA-76-43), May 1976.

5. Bell, M.J. ORIGEN - The ORNL Isotope Generation and Depletion Code (ORNL-4628), 1973.

6. Oak Ridge National Laboratory. Radiation Shielding Information Center. ORIGEN. Isotope Generation and Depletion Code - Matrix Exponential Method (CCC-127), October 1978.

7. Industridepartment Energikommissionen. Disposal of High Active Nuclear Fuel Waste. A Critical Review of the Nuclear Fuel Safety (KBS) Project on Final Disposal of Vitrified High Active Fuel Wastes.

RADIOLOGICAL IMPACTS OF THE REPOSITORY
(DEIS Chapter 9)

Major Conclusions

Operational Releases

1) Atmospheric dispersion coefficients were calculated by EEG, checked with those listed in the DEIS and found to be in agreement. However, the DEIS did not use a consistent approach in calculating those coefficients for operational releases of radioactivity, air quality emissions and transportation accidents.

2) EEG obtained close agreement with the DEIS inhalation dose calculations from both normal and accidental releases to an individual at the James Ranch. Consideration should be given to inhalation doses received by transient people in Zones II, III and IV and to potential residents near the northwest site boundary.

3) The detailed assumptions used in evaluating accident scenarios may underestimate the amounts of radioactivity that could be released.

4) An accident scenario involving a methane gas pocket should be considered.

5) The assumption that contaminated food will be taken out of distribution has not always been possible or necessary.

6) The Chapter 9 assumption that exhaust air from underground waste handling and storage areas passes through HEPA filters is inconsistent with statements in Chapter 8. Since the absence of filters can result in a substantial increase in doses from particulate radioactivity, it is important to clarify this point.

7) Occupational radiation exposure has not been evaluated by EEG because of lack of necessary data in the DEIS. More information is needed on waste operations, the environmental control systems, and the health physics program. It is anticipated that this information will be provided in the Preliminary Safety Analysis Report.

Long Term Releases

1) EEG has identified a number of repository breach scenarios which also should be considered and evaluated in the final DEIS:

   a) well water becomes contaminated and is used for irrigation or stock watering;

   b) gas, generated by organic decomposition of the waste, acts as a driving mechanism in bringing waste to the surface;

   c) a connection develops between the repository, a high pressure brine reservoir and the surface;

   d) solution mining for salt takes place.

2) EEG has checked many of the DEIS dose calculations for the long term release scenarios considered, and the EEG and DEIS results are in agreement. Since the hydrologic parameters on which these dose estimates are based can vary by several orders of magnitude, the effect of parameter variation on dose estimates should be evaluated.

3) Unacceptably high radiation doses could occur to well drillers from a scenario 5 type incident. Control measures should be considered to prevent such an event.

Operational Releases

Atmospheric Dispersion Coefficients

Several key χ/Q values were calculated by a simplified hand calculation (see Appendix V for details) and compared with those used in the DEIS. The EEG model differed somewhat from the MESODIF Code used in the DEIS in not allowing the plume to be blown back over the source to contribute on a "second pass". The values calculated for the long term average χ/Q were lower than those used in the DEIS by factors of 3.3 to 4.4 (Table H-36). Lower values would be expected in the prevailing downwind direction from the model difference, although the magnitude of the difference cannot be estimated from the data available. Values calculated for the one-hour frequency $(\chi/Q)_{5\%}$ and $(\chi/Q)_{50\%}$ (H-Annex 1, Table 21) varied from 1.0-4.1 times those in the DEIS with agreement being best at 0.5 miles. EEG concluded that the short-term and long-term χ/Q values used for the site are reasonable.

The DEIS analysis did not use atmospheric dispersion coefficients to compute annual concentrations for non-radiological air pollutants other than a 24-hour value for particulates. In this case, another equation was used and an effective $(\chi/Q)_{24\ hrs.}$ of 2.1×10^{-6} s/m^3 was obtained. This is to be compared to a $(\chi/Q)_{50\%}$ of about 15×10^{-6} s/m^3 (H-Annex 1, Table 21) and an annual average of 5.9×10^{-6} s/m^3 (in downwind maximum sector from Table H-36). This calculation is inconsistent with that for site radionuclide releases.

Slightly different dispersion coefficients were used in the DEIS to compute doses from transportation accidents and an elevated release was assumed. This assumption produces lower dose estimates and is consequently less conservative than assuming a surface release. The DEIS did not explain its procedures for determining

that 0.5 miles from an accident was the maximum concentration. EEG made this calculation and was in general agreement when the same assumptions were used. However, it was noted that concentrations were not negligible closer to the site and that if other atmospheric stability categories were assumed the highest values occurred closer than 0.5 miles.

Any inconsistencies in the use of atmospheric dispersion coefficients and assumptions (especially the rationale for assuming an elevated release in transportation accidents that do not involve fires, while assuming surface releases from the site) should be explained in the final EIS.

Radiological Doses to the Public

The calculated doses (Table 9-18) received by an individual at the James Ranch were checked using the releases from Table 8-6 (see Appendix VII). In all cases, the results agreed with the DEIS within 20%. The doses are small and well below existing standards that apply to other types of nuclear facilities. However, there are some uncertainties in the release fractions assumed (see Chapter 8 discussion) and in the source term.

There is a question whether the maximum exposed individual would necessarily be a resident of the James Ranch. If he were to reside on private land 2.8 miles northwest of the center of the site, he would receive an inhalation dose five times as great as at the James Ranch. Also, individuals spending some time in Zones II, III and IV would be exposed to higher concentrations while on the site. For example, average concentrations at 0.5 miles from the site center would be 16-145 times those at the James Ranch.

The assumptions on living patterns in Table 9-17 appear reasonable for the average person residing in each subsector. The calculation of a maximum dose to an individual should consider a person with a

family cow that provides over 1% of his milk, or a garden that provides over 10% of his vegetables, or cattle that provide over 50% of his meat. Additionally, there may be game killed on the site and consumed by area residents. The final EIS should state the assumptions and calculate the maximum ingestion dose to an individual at both the James Ranch and at the northwest boundary. The inhalation doses should be listed separately from the ingestion doses.

Environmental Effects of Accidents During Operations

The operational accident scenarios evaluated in the DEIS (Table 9-21, pp. 9-45 to 9-48) appear to be fairly complete. However, it appears that the DEIS may underestimate the duration of fires, the number of containers involved and the clean-up time involved. An operational scenario not addressed was that of encountering a methane gas pocket during the mining operations resulting in an underground explosion involving multiple drums and/or boxes or spent fuel canisters. EEG recommends that such a severe operational accident be investigated by DOE in the final EIS.

Where referenced, estimates of release fractions (pp. 9-49 and 9-50) have been reviewed and in some cases the values used in the DEIS may be questioned. For example, it is stated (9-49;5) that Shefelbine supports a conservative assumption that 10% of the waste is in powder form and that 25% of the waste is combustible (Ref. 1). In reviewing the Shefelbine report, no mention of powder was found. The 10% powder figure might be deduced from the data indirectly. Shefelbine does reference Dieckhoner (1978) as the source of the information that 25% of the waste is combustible. In fact, Shefelbine states that "this data should be used with caution because there seems to be a consensus that, in spite of regulations, considerable mixing of combustibles and non-combustibles occurred in the past" (Ref. 1, p. 25). The presence of combustibles directly affects the severity of a postulated fire.

A second example concerns the percentage of activity which is released and respirable during accidents. It was stated that 1% was used as an intermediate value based on Mishima and Schwendiman (Ref. 2, 3). Mishima and Schwendiman described that as much as 1% of the plutonium was airborne during the combustion of flammable contaminated materials (Ref. 2, p.6). They also found that 10-40% of uranium oxide became airborne after being mixed with combustible material and ignited. Uranium oxide was used to simulate plutonium in these experiments.

In the spent fuel accident, a gap activity of 30% of the gaseous activity (H-3, Kr-85, I-129) was chosen. Although there is little information in the literature on the gap activity of fuel assemblies older than 10 years, gap activities as high as 45% have been observed (Ref. 4). Also, the quantity of Carbon-14 released was ignored.

The computer code AIRDOS-II was used in the DEIS to calculate resulting doses and dose commitments. It traces each nuclide from the point of release through the biosphere to man. AIRDOS-II is listed with the U.S. Department of Energy Radiation Shielding Information Center and has been tested and evaluated by this group prior to distribution for general use. Hand calculations by EEG using the DEIS assumptions and standard formulas gave results which generally agreed with those reported in the DEIS.

The assumed distribution of radionuclides released to the environment during operational accidents is sometimes different than the assumed releases from transportation accidents. For example, the RH-TRU waste railroad accident involving impact and fire considers only the release of cesium-137. The surface fire at the facility (Accident R-11) has cesium-137 as less than 1% of the total release. It is recommended that a consistent release fraction be used in calculations throughout the final EIS.

AIRDOS-II considers only the inhalation and external pathways of exposure. In some situations (such as surface runoff) the water pathway could be significant and should be considered. The assumption that contaminated food will be taken out of distribution has not always been possible or necessary. Existing Federal Protective Action Guides do not recommend removal of food or milk from commerce unless the projected dose commitment is 5 rem to the whole body or 15 rem to the thyroid.

Using the releases and the atmospheric dispersion coefficients (χ/Q) for accident scenario C-7 described in the DEIS, EEG calculated doses for a person living at the James Ranch. The results agreed with those given in Table 9-25 of the DEIS and are shown on the following Table 10.

Table 10

Dose Estimates at the James Ranch from Accident C7

Reference	χ/Q Type	χ/Q (s/m^3)	50 yr. Bone Dose Commitment (re	
			EEG	EIS
Table 21 p. 26	50% one-hour frequency	0.58×10^{-5}	7.4×10^{-9}	5.5×10^{-9}
Table H-36 p. H-59	Annual	0.62×10^{-6}	7.9×10^{-10}	
Table 21 p. 26	5%	0.568×10^{-4}	7.2×10^{-8}	

EEG also calculated doses from the spent fuel hoist drop accident scenario (R15) using the assumptions of the DEIS. The results, presented in Table 11, are in agreement with the DEIS calculations. The only question raised concerned the assumptions of release fractions for various accidents. The margin of error in the assumptions is not well known and EEG recommends that the basis of the assumptions be discussed in the final EIS.

The Chapter 9 assumption that exhaust air from underground waste handling and storage areas passes through HEPA filters is inconsistent with statements in Chapter 8.

Occupational Radiation Exposure

Occupational radiation exposure at WIPP is scheduled to be covered in the Preliminary Safety Analysis Report (PSAR). Therefore, no attempt will be made to evaluate it here. The following are examples of the kind of information needed to adequately evaluate occupational exposure:

1) The analysis should consider estimates of maximum individual doses, the expected distribution of doses among workers, and the population dose to the entire work force. An evaluation should be made of whether these doses are as low as reasonably achievable (ALARA).

2) Additional information will be needed on the environmental control systems, other physical facilities, and pertinent equipment, both above and below ground, so that the reasonableness of projected doses can be evaluated. More data are needed on the actual radiation levels (average and range) that workers will be exposed to from remote handled TRU waste, spent fuel assemblies and on the high level waste

Table 11

Operational Accident Scenario R-15
Hoist Drop - Spent Fuel - 6 hr. Release

Nuclide	50 year Dose Committment (rem)				
	Bone	Lung	Whole Body	Skin	Thyroid
H-3		9.54×10^{-6}	7.66×10^{-6}		0.77×10^{-5}
Kr-85		2.52×10^{-6}		7.04×10^{-5}	
Sr-90	7.43×10^{-6}	2.78×10^{-8}	0.46×10^{-6}		
Ru-106		5.97×10^{-12}			
I-129	0.02×10^{-6}		0.06×10^{-6}		4.82×10^{-5}
Cs-134		2.14×10^{-10}			
Cs-137		3.96×10^{-10}			
Pm-147	7.65×10^{-12}	2.4×10^{-13}			
Eu-154	8.22×10^{-11}	1.4×10^{-12}			
Np-237	5.89×10^{-12}	1.0×10^{-14}			
Pu-238	8.53×10^{-8}	1.0×10^{-10}			
Pu-239	1.04×10^{-8}	5.5×10^{-11}			
Pu-240	1.66×10^{-8}	8.75×10^{-11}			
Pu-241	1.49×10^{-10}	1.06×10^{-11}			
Pu-242		2.48×10^{-13}			
Am-241	1.59×10^{-8}	2.87×10^{-11}			
Am-242m					
Am-243	2.2×10^{-10}				
Cm-243	3.11×10^{-11}				
Cm-244	1.29×10^{-9}				
EEG Totals	7.58×10^{-6}	1.2×10^{-5}	8.28×10^{-6}	7.04×10^{-5}	5.59×10^{-5}
DEIS Totals*					
R-15 Spent Fuel	8.7×10^{-6}	1×10^{-5}	8.3×10^{-6}	2.2×10^{-4}	3.2×10^{-5}

*Table 9-25, page 9-56

experiments (including retrieval operations). Also, it will be necessary to describe the management organization (including health physics activities) that will be used to operate the facility and provide health and safety control.

Long-Term Releases

Five repository breach "scenarios" were analyzed in the DEIS (section 9.5.1). Scenarios 1-4 all resulted in dissolution of the waste, passage of the waste into the Rustler aquifer, and passage through the aquifer into the Pecos River. Scenario 5 involved direct access by drilling.

Dose Calculation Methodology

The radionuclide concentrations and resultant radiation doses reported in the DEIS were obtained by using large computer codes. EEG was able to check many of these computer calculations by hand. To check results of the hydrologic model used to describe nuclide transport in the liquid breach scenarios 1-4, EEG used a simpler model. To check dose calculations, EEG used standard formulas and conversion factors. The calculations are discussed in Appendices VI and VII, and the results compared with those in the DEIS. In its calculations, EEG used the hydrologic parameters, radionuclide inventory, and scenario descriptions in the DEIS. The EEG and DEIS results agree closely.

While these calculation checks tend to support the validity of the methods employed in the DEIS to calculate nuclide concentrations, ingestion doses and external gamma radiation doses, they do not provide checks on the validity of the assumptions used or the appropriateness of the situations analyzed.

Parameter Values

One must consider the key parameters that lead to the nuclide concentrations and ingestion doses calculated. They include the distribution coefficients (K_d) values which are responsible for holding back such nuclides as plutonium, neptunium and thorium, as well as the basic driving parameter, $\bar{v}$, the assumed groundwater flow velocity. The last quantity depends on hydraulic conductivity, porosity and hydraulic gradient. All of these parameters have large uncertainties associated with them because of natural variation and difficulties in measurement. Both K_d values and hydraulic conductivities can vary by several orders of magnitude. A thorough review of these uncertainties and of their impact on radiation doses must be made, and should be included in the final EIS.

EEG has done some calculations relevant to the effect of variations in K_d and hydraulic conductivity values and they appear in Appendix VII.

Flow Paths

All of the hydrologic breach scenarios assumed a flow along the Rustler aquifer and release at the Malaga Bend of the Pecos River. However, the interface between the Rustler and Salado formations is exposed at Nash Draw. A spring at the north edge of Laguna Grande de la Sal is fed by water from the Rustler aquifers. The calculated hydraulic potentials for the Rustler formation (Figure K-5, p. k-13) indicate that the shortest release path is 15 miles from WIPP to Malaga Bend. However, the measured hydraulic potential contours in the Rustler formation (Figure K-3, p. K-12) indicate that the shortest flow path is 9 miles to Laguna Grande de la Sal. The dosage calculations should take this shorter path into consideration.

Scenario 5

Dose estimates in the DEIS for both external radiation to a drill crew member (Table 9-47) and inhalation to a resident (Tables 9-48 and 9-49) were checked using the assumptions in the DEIS (see Appendix VII). EEG calculated a dose of 71 rem to a drill crew-member, compared to ∿90 rem in the DEIS. In either case the dose is high enough to warrant serious consideration of control measures to prevent such an occurrence.

Alternate Scenarios

It is not clear that the scenarios used in the DEIS are indeed upper limits or bounding cases. EEG has identified a number of scenarios which also should be considered in the final EIS:

1) well water becomes contaminated and is used for irrigation or stock watering;

2) gas, generated by organic decomposition of the waste, acts as a driving mechanism in bringing waste to the surface;

3) a connection develops between the repository, a high pressure brine reservoir and the surface; and

4) solution mining for salt takes place.

The April 1979 Draft Environmental Impact Statement, Management of Commercially Generated Radioactive Waste (DOE/EIS-0046D) discussed solution mining for salt as the most likely of several repository breach scenarios. The main pathway of exposure was considered to be ingestion of contaminated salt. The presence of salt contaminated with radioactive materials was not expected to go undetected for long, due to quality control checks. The DOE assumed the contamination went undetected for one year, and obtained radiation doses orders of magnitude higher than those obtained for the scenarios considered in the WIPP DEIS.

Detailed Comments

9-4 Table 9-2	The construction equipment noise levels given in Table 9-2 are achievable but will require proper equipment and noise control procedures to obtain.
9-26 Table 9-13	The Department of Housing and Urban Development Criteria for Noise Assessment given in Table 9-13 were revised in 1979 and those should be listed in the final EIS.
9-33 Fig. 9-3	The schematic diagram (Fig. 9-3) shows only the air pathway of exposure. Surface runoff from contaminated surface areas, wildlife contamination from surface lagoon, and ingestion of drinking water are not discussed. Although these pathways may not be the primary ones, they should be considered.
9-33;4	Each wedge of the study area was divided into 10 subsectors, not 14 as stated.
9-34 Fig. 9-4	According to page H-6, Figure H-1 and page H-8, Table H-4, the population size of 50 would not be within the 5 mile or 10 mile radius. There also appears to be some discrepancy with some of the other numbers. For example, the population of 230 given within the 10 mile radius in the WNW direction does not agree with the numbers given in Appendix H. Do the numbers include workers at potash mills?
9-37;2-4	The DOE Draft Environmental Impact Statement, Management of Commercially Generated Radioactive Waste (Ref. 6) consistently used a 70 year dose commitment instead of the 50 year dose commitment used in the WIPP DEIS. The 70 year dose commitment seems most appropriate when discussing population dose commitments.

9-37;6 Would one expect the dose from krypton to be about 25% of the total from spent fuel when one considers the whole body, lungs and bone? The krypton irradiation involves primarily submersion in the gas because little of the krypton will circulate in the blood and therefore irradiate bone.

9-38 Tables 9-18, 9-19 It should be indicated whether the tritium that seems to be included in the spent fuel group is a gaseous molecule or incorporated in a water molecule. If the tritium is a diatomic molecule, then the dose is received only from immersion, but if it is a part of a water molecule, then it has an effective half life of about 12 days (indicated in ICRP II, or in ICRP Publication 10). Since the values indicate similar doses for bone, lungs and whole body, one must assume that the calculations were for tritium incorporated in a water molecule. In this case, the values given are for dose equivalent and not dose equivalent commitment.

It is not clear what nuclides are contained within "structural materials, fission products, actinides, and spent-fuel". One can assume that the actinides are specified in Table 8-6, page 8-30; however, it is not clear how one separates the structural material, fission products and spent-fuel.

EEG questions the comparison of dose commitment and 50 year dose equivalent from natural background in assessing the acceptability of such releases.

9-38 A dose calculation was made from the actinides (largest dose contributor) using Pu-239 as the primary isotope and agreement with Table 9-18 was obtained when the information in Table 8-6, page 8-30, was used as the source term.

9-40
Table 9-20 The surface dose rate should be 10mrem/hour not per year. The 1900 mrem/year should be subjected to the "as low as reasonable achievable" (ALARA) principle.

9-40;1 The statement was made that the radiation dose to workers on the RH waste portion has not been computed. This type of waste is perhaps the source of highest individual exposures and should be carefully monitored.

9-42;5 The information for the environmental control for the rock pile is inadequate.

9-51;7 The use of filters on exhaust air from the underground storage areas to the atmosphere can reduce the radioactive concentration of particulates by a factor of 10^6. It is unclear from the following two statements whether the storage room air is actually filtered:

(1) page 8-29, Table 8-5, footnote a - "Except for underground operations, effluent treatment is provided by filters in the ventillation system (decontamination factor = 10^6)".

(2) page 8-33;4 - "Airborne surface activity in the underground storage area will be released to the atmosphere unfiltered".

Operational Accident Scenarios C13 and C22 both use 10^6 decontamination factor for the HEPA filters.

9-53
Table 9-24

The DEIS used different distributions of radionuclides released to the environment in transportation accidents and operational accidents involving RH-TRU canisters.

9-54;3

The DEIS assumed 30% of the Kr-85, H-3 and I-129 present in the fuel cladding gap were available for release. NUREG-0404 assumed that 10% of the Kr-85 and 1% of the I-129 present is in the fuel cladding gap and available for release (ref. 9, p. 4-19). A General Electric document (ref. 4) predicted that fission gas release fractions range from 20 to 45%. This report further quotes studies which report 3% of iodine found in the gas plenum and is available for release. The 45% for Krypton is somewhat higher than the 30% predicted by the Reactor Safety Study (ref. 8) used in the DEIS. The General Electric figures of 20 - 45% are also higher than ref. 2 results of 10% release of Kr-85 and 1% of I-129. The doses and dose commitments are directly proportional to the release fractions chosen for the calculations, and the DEIS value of 30% appears reasonable.

Why is the 50 percentile χ/Q used for the accidents? Would the 5 percentile value be more reasonable? The (χ/Q) 5% in NW downwind sector is approximately 16 times the (χ/Q) 50% in SSW sector used in the DEIS.

9-56;1

All calculated doses appear to be adult doses. Were the doses to infants, children and teenagers considered in the computer programs used?

9-56
9-57

One should not compare the radiation received from natural background over 50 years with doses that occur over shorter times (e.g. tritium and I-129).

9-107;3

How was the pressure difference of 7.5 psi obtained? How reliable is that pressure difference? See EEG's question in the GCR review (Appendix III) on the reliability of the head data in the Delaware Mountain Group aquifer.

9-108

In the flow calculations for scenario 1, what value of transmissivity was used for the DMG? Was it 50 ft.^{2}/day? How reliable is the value?

In the flow calculations for scenario 2, what was the basis for the assumption that the wellbore has a hydraulic conductivity K = 50 ft./day?

9-112;5

Should this reference be to figure K-5 rather than K-6?

9-114,
9-115

Table 9-45 is inconsistent with Table 9-46. The transport rates given for I-129, Ra-226, and U-235 in scenario 2 (with the upper transmissivity assumption), do not agree.

	Table 9-45	Table 9-46
I-129, g/yr	2.6×10	3.3×10^{-1}
I-129, Ci/yr	4.5×10^{-3}	5.8×10^{-5}
Ra-226, g/yr	2.0×10^{-14}	2.9×10^{-7}
Ra-226, Ci/yr	2.0×10^{-14}	2.9×10^{-7}
U-235, g/yr	2.9×10	2.2×10
U-235, Ci/yr	6.2×10^{-5}	4.8×10^{-5}

9-116
9-117

The graphs appear to be incorrectly plotted. For example, in Figure 9-15 the maximum concentration of 3.1×10^{-6} should be plotted at between .5 and .6 of the distance from 1 towards 10^{-10}. Tables would provide a more accurate presentation.

9-117

The graphs terminate while the dose rate is still rising in Figure 9-16 a, d, and f. The final EIS should show the maximum dose rates and when they will occur.

9-133,
9-134

EEG agrees that the generation of gas from organic material in the radioactive waste can be important for both transportation accident and long-term storage, and the question posed in the DEIS of the gas generation effects upon the repository must be resolved. Large amounts of gas could be generated. Pressures exceed lithostatic pressure (9-136), i.e. 2000 psi.

These large pressures could cause fracturing of the overlying rocks and would possibly release gas with radioactive contaminants directly to the atmosphere through fractures or through a well drilled into the repository.

9-136;4

Will the brine migration induced by heat-emitting radionuclides cause difficulty in retrieval of sources?

9-153
Table 9-53

The probability of fire is assumed to be 10^{-3} and of a dropped container, 10^{-2}. The reasoning behind these numbers should be in the EIS.

9-154 What is the expected distribution of annual dose equivalents received by the radiation workers retrieving stored waste?

9-157 The ratio of population doses to maximally exposed persons is constant in Table 9-55, except for the whole body dose. Why?

References

1. Shefelbine, Henry C. Preliminary Evaluation of the Characteristics of Defense Transuranic Wastes (SAND 78-1850), November 1978.

2. Mishima, J., and Schwendiman, L.C. The Amount and Characteristics of Plutonium Made Airborne Under Thermal Stress (BNWL-SA-3379), October 1970.

3. _____. Some Experimental Measurements of Airborne Uranium (Representing Plutonium) in Transportation Accidents (BNWL-1732), August 1973.

4. General Electric Company. Safety Evaluation Report for Morris Operation Fuel Storage Expansion. Phase I (NEDO-20825), March 1975.

5. Oak Ridge National Laboratory, Radiation Shielding Information Center. AIRDOS-II, Estimation of Radiation Doses Caused by Airborne Radionuclides in Areas Surrounding Nuclear Facilities (CCC-304), 1977.

6. U.S. Department of Energy. Draft Environmental Impact Statement, Management of Commercially Generated Radioactive Waste (DOE/EIS-0046D), April 1979.

7. U.S. Nuclear Regulatory Commission. Draft Generic Environmental Impact Statement, Uranium Milling (NUREG-0511), April 1979.

8. U.S. Nuclear Regulatory Commission. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants (WASH-1400), 1975.

9. U.S. Nuclear Regulatory Commission. Draft Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel (NUREG-0404), March 1978.

ADDITIONAL DOSE ESTIMATES

The following lists additional dosage estimates that should be considered in the final EIS.

Long Term

1) Build-up in the environment from radionuclides in water removed from the Pecos River for irrigation, incorporated into soil and plants, and cycled in food and man over long periods of time.
(General Population)

2) Generate dosage estimates using the DOE generic Waste Isolation Safety Assessment Program (WISAP) model currently under development by the Battelle Northwest Laboratories.
(General Population)

3) A connection is made between the Delaware Mountain Group aquifer, the repository and the surface.
(General Population)

4) A connection is made between the repository, a high pressure brine reservoir and the surface.

5) Effects of high pressure gas formation on the release of radionuclides to the environment.
(General Population)

Transportation

1) Radiation exposure from acts of sabotage in the transportation of radioactive waste materials. The amounts of radioactive material released could be greater than those released in accidents.
(General Population, Occupational)

2) Radiation exposure to emergency workers such as police and firemen following a transportation accident.
(Occupational)

3) Exposure to a person in an automobile stopped next to a radioactive waste truck at a red light or in a highway traffic jam. (General Population)

4) Exposures from shipments of retrieved radioactive wastes following the completion of high level waste experiments. Containers could be bent, damaged or under pressure from gas generated by decomposed organic material. (Occupational, General Population)

5) Contamination of a water supply or crops following an airborne release. (General Population)

6) Potential radiation exposure from transportation of material resulting from decommissioning and dismantling of weapons production facilities. While the DEIS assumes that none of the 5 to 95 million cubic feet of material will be shipped to WIPP, it notes that the WIPP will have the capacity to receive some of the TRU waste (2-22;2). (Occupational, General Population)

7) Calculation of individual doses as well as population doses. (Occupational, General Population)

8) Consideration of a diffuse source of radioactivity rather than a point source.

<u>Construction and Operation</u>

1) Radon-222 from the mined salt and from the walls of the underground repository. (Occupational, General Population)

2) Radiation exposure from decommissioning and dismantling of the above ground facility. (Occupational)

3) Pressurized brine breaches the mine, damages containers and flows up the shaft to the surface.
(Occupational, General Population)

4) A methane gas pocket leaks into mine and explodes.

5) Acts of sabotage at surface processing facility.
(Occupational, General Population)

6) On-site exposure.
(General Population)

7) Ingestion doses from operational releases at the site.
(General Population)

Mineral Extraction

1) Radiation exposure to workers who may bring minerals to the surface (oil drilling, solution mining) and to the public using the products.
(Occupational, General Population)

2) Exposure from burning natural gas obtained from formations below the site. Radioactive waste material could move downward as pressure is decreased with the removal of gas.
(General Population)

3) Exposure to people who may use well water from the Culebra, Magenta, or Santa Rosa sandstone aquifers contaminated with radionuclides.
(General Population)

APPENDICES

IV

APPENDIX I

Radioactivity Inventory Calculations

Tables 2-5 in the Inventory of Radioactivity section were prepared as follows:

Volume estimates (cu. ft.), Table 5, were calculated to equal:

$$\begin{pmatrix}\text{backlog} \\ \text{of waste,} \\ \text{cu.ft.}\end{pmatrix} + \begin{pmatrix}30 \times \text{new waste} \\ \text{yr.} \quad \text{production,} \\ \quad\quad \text{cu. ft./yr.}\end{pmatrix}$$

where backlog and new production volumes were taken from Table 6-2 for CH waste and Table 6-6 for RH waste.

Total repository CH and RH-TRU activities (Curies), Table 3, were obtained by adding total box, drum and RH-TRU canister activities, without considering decay or ingrowth. The total activity of a given nuclide in a given type of container was calculated as:

$$\frac{\text{(curies per container)} \times \text{(total cu. ft. of waste in containers}}{\text{(cu. ft. per container)}}$$

where the container activities were taken from Table E-1 (drums), E-2 (boxes) and E-3 (RH canisters); single container volumes were taken from Table 6-3 and 6-5; and total waste volumes in given types of containers were taken from Table 5 of this review.

Shipment activities (Curies), Tables 3 and 4, were obtained by multiplying activities per container (Tables E-1, E-2, E-3) by the number of containers in a shipment (Tables 6-3, 6-5).

The total repository actinide inventory (Curies), Table 2, which includes the effects of decay and ingrowth, after 30 years of repository operation, was calculated as follows. The Plutonium-239 and 240 inventories are not affected by decay over a 30 year period,

and these activities are found by adding the CH and RH-TRU activities given in Table 3. Plutonium-238 and 241 have half-lives of 88 and 13 years, respectively, and so these inventories decay significantly in 30 years. The activity after 30 years, A(30), is found from:

$$A(30) = A(0)e^{-\lambda(30)} + \frac{C}{\lambda}\left(1 - e^{-\lambda(30)}\right)$$

where λ is the nuclide decay constant, A(0) is the nuclide activity in the waste backlog, and C is the activity in the new waste produced each year.

Americium-241 is affected by both decay and ingrowth (from Plutonium-241) in a 30 year period. The final inventory was estimated by adding the total Table 3 Americium-241 inventory to the ingrowth term:

$$\frac{13}{460}\left[\begin{array}{l}\text{Pu-241 activity in Table 3 (without decay)} \\ \quad - \text{Pu-241 activity in Table 2 (with decay)}\end{array}\right]$$

where 13/460 is the ratio of the Pu-241 and Am-241 half-lives. Then this undecayed total was multiplied by a 30-year Am-241 decay factor of .96. This method underestimates slightly the amount of Am-241, since it assumes that all of the Am-241 (from the 30 year repository inventory and from the decay of Pu-241) has been present for the full 30 years.

A more complete discussion of decay and ingrowth estimates is included in Appendix VI.

APPENDIX II

TRANSPORTATION CALCULATIONS
(Chapter 6)

To Develop An Expression For Dose To A Person At Point P From A Moving Source

(1) Dose at Point P $= \int D_r \, dt$

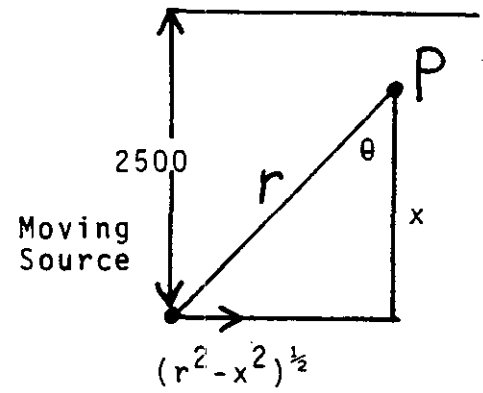

where D = dose (rads)

D_r = dose rate (rads/h)

t = time (h)

(2) $D = \int D_{r6} \frac{6^2}{r^2} e^{-\mu r} \, dt$

where D_{r6} = dose rate at 6 feet

r = distance (feet)

μ = linear absorption coefficient ($feet^{-1}$)

Now $s = (r^2 - x^2)^{\frac{1}{2}}$. Thus:

(3) $v = \frac{ds}{dt} = \frac{1}{2} (r^2 - x^2)^{-\frac{1}{2}} \, 2r\frac{dr}{dt}$;

substituting (3) for dt into (2):

$$D = \int D_{r6} \frac{6^2}{r^2} e^{-\mu r} \frac{r\,dr}{v(r^2 - x^2)^{\frac{1}{2}}}$$

To evaluate the integral

$$\int \frac{dr}{r(r^2-x^2)^{\frac{1}{2}}} ,$$

The following change of variable is made:

$$\frac{r}{x} = \sec\theta$$

$$r = x\sec\theta$$

$$dr = x\sec\theta\tan\theta\, d\theta$$

$$\tan\theta = \frac{(r^2 - x^2)^{\frac{1}{2}}}{x}$$

$$(5)\ \int \frac{x\sec\theta\tan\theta\, d\theta}{x\sec\theta\ x\ \tan\theta} = \int_{\theta=\pi/2}^{\theta=0} \frac{d\theta}{x} = \frac{\pi}{2x}\ .$$

Therefore,

$$D = \frac{D_{r6}\ 36\ \pi 2}{v\ 2x}$$

for both sides of 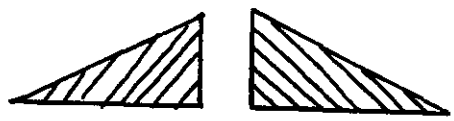

$$\text{Dose to a Person at Point P} = \frac{D_{r6}\ 36\pi}{v\ x}$$

To Calculate Total Man Rem Dose to People

$$\underset{\text{(Man-Rem)}}{\text{Dose}} = 2\ (\text{P.D.})L \int_{\text{Min}}^{d} \frac{D_{r6}\ 36\pi\ dx}{v\ \ x}$$

$$\text{Dose} = \frac{2\ (\text{P.D.})L\ \ D_{r6}\ 36\Pi}{v}\ \ \ln\ (d/\text{min})$$

where

P.D. = population density (people/mi^2)
L = length of shipment path (miles)
v = velocity (mile/hour)
d = distance to people (miles)
min = minimum distance (miles)

correcting for different population densities in urban (u), suburban (s) and rural (r) and velocities and using format of NUREG 0170, p. D-6, Ref. 4 and RADTRAN P. 19, Ref. 3.

$$\frac{\text{pop. dens.}}{V} = \left[\frac{f_r PD_r}{V_r} + \frac{f_s PD_s}{V_s} + \frac{f_u\ PD_u}{V_u} \quad (f_o + 1.636 f_1) \right]$$

incorporating PPS = Packages per shipment
SPY = Shipments per year
L = Distance of Shipment (miles)
TI = Transport Index (mr/h)
K = Dose Rate at Distance d
k = Ko (TI)

$$\text{Dose} = (TI)(Ko)(PPS)(SPY)(L)\pi \ \ln(d/min) \ x$$

$$x \left[\frac{f_r PD_r}{V_r} + \frac{f_s PD_s}{V_s} + \frac{f_u PD_u}{V_u} \quad (f_o + 1.636 f_1) \right]$$

<u>To Develop An Expression For Dose To a Population During Shipment Stops</u>.

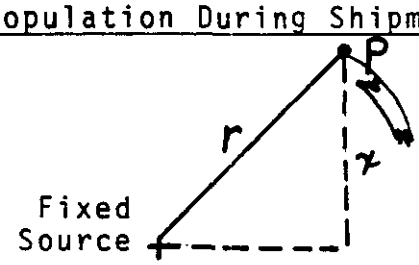

Annulus=2Πrdr

$$\text{Dose} = \int D_r \, dt$$

$$= Ko(TI)\Delta T(\text{Pop. Dens.}) \int \frac{2\Pi r dr \ e^{-\mu r} \ B(r)}{r^2}$$

$$= Ko(TI)\Delta T(\text{Pop.Dens}) \int_x^d \frac{2\Pi e^{-\mu r} \ B(r) \ dr}{R}$$

Evaluating the integral

$$\int_{r=x}^{r=d} \frac{e^{-\mu r}\ B(r)\ dr}{r^2} = \ln\ (d/x) - \ln(d-x) - \frac{(\mu t)^2}{22!} - \frac{(\mu r)^3}{33!} + \frac{(\mu r)^4}{44!}$$

$$= 3.845$$

$$= (Q_1)Ko(TI)(Shipments/y)\left[\Delta T_r(PD)_r + \Delta T_s\ PD_s + \Delta T_u\ PD_u\right]$$

<u>To Develop An Expression for Dose To Crew</u>

$$Dose = D_r\ \Delta t$$

$$= Ko(TI)S\ N_c\ \frac{e^{-\mu d}\ B(d)}{d^2}\ \Delta t_{shipment}$$

where N_c = Number in crew
d = Average distance to crew (feet)
FM = Distance/shipment (miles
Δt = Average time for shipment (hours)
S = Shipments/year

$$\Delta t = \left[\frac{f_r}{V_r} + \frac{f_s}{V_s} + \frac{f_u}{V_u}\right] FM$$

$$Dose = Ko(TI)S\ N_c\ e^{-\mu d}\ B(d)\left[\frac{f_r}{V_r} + \frac{f_s}{V_s} + \frac{f_u}{V_u}\right] FM,$$

Accident Calculations

Inhalation Dose

$$D_{INH} = K_{INH} \times C_{INH} \quad \text{(rem/}\mu\text{Ci inhaled)}$$

$$\left(\frac{pCi}{cm^3}\right)$$

EIS App. G-5

External γ Dose

$$D_{IMM} = K_{IMM} \times C_{imm}$$

$$\left(\frac{pCi}{cm^3}\right) \text{(rem-cm}^3\text{/}\mu\text{Ci-hr)}$$

EIS App. G-5

Immersion Dose

$$D_{wimm} = K_{wimm} \frac{R_t}{d}\left(\frac{1 - e^{-\lambda Tt}}{\lambda t}\right) C_{wimm}$$

(rem cm^3/μCi-hr.)

R_t = surface dep. pCi/cm^2-sec

EIS App. 6-6

D_{wimm} = water immersion dose

d = depth of water

λt = effective λ

t = build up in water

Atmospheric Dispersion

Using Gaussian Plume Dispersion for Ground Level Concentrations, EIS G-1 Equation of Pasquill Reduces to

$$x = \frac{Q}{\Pi \sigma_y \sigma_z \mu} e^{\left[-\frac{1}{2}\left(\frac{H}{T_z}\right)^2\right]}$$

EIS p. G-3

X = pCi/m^3

T_y = horiz. dispersion coef. (m)

T_z = vert. dispersion coef. (m)

H = effective ht. of plume

Q = emission rate (pCi/sec)

AIRDOS-II

(FORTRAN on CDC 6600)

<u>To Calculate Curies (Release)</u>

NUREG 0170 Vol. 1 G-1

$Q^1 = (n_i)\ (RF)\ (AER)\ (RESP)\ (E)\ (DF)$

(Ci/shipment)

(Fraction Released)

(Fraction as Aerosol)

(Fraction Respirable in Aerosol)

(Particle Size Dust Factor)

(Dilution Factor)

Radioactivity Released in Transportation Accidents

Type of Accident	Common Assumptions	Source	Fraction Released From Drum	Fraction Released to Environment	Fraction in Air	Fraction Entrained in Air	Fraction Respirable	Amt of Radioactivity
Rail CH-TRU	Pasquill Stability Factor=F	1 Flat Bed Car 3 Type B Packages 42 Drums/Package 126 Drums	50% in Drums Released to Packages 63	10% 6.3	10% .64 Drum	1.4% .0090	62% .0055 Drum	See Inventory of Radioactivity
Truck CH-TRU	Wind Speed = 1 m/sec	1 truck 42 Drums 42 Drums	50% 21	10% 2.1	25% .5	----------	---1%-------- .0065 Drum	See Inventory of Radioactivity
Rail RH-TRU	Inversion Layer = 1000 m Release Height = 20 m	1 Flat Bed Car 5 Canisters	1% (Only Volatile fission products)	10%				.01 Ci Cs-137
Rail Spent Fuel		1 Cask 10 Canister/cask	30% Kr-85 1% Cs	100% Kr-85 10% Cs				7800 Ci Kr-85 440 Ci volatile f/p

Transportation X/Q Factors

at 0.5 mi, F condition
μ= 1 m/sec, H = 20

p. G-3 $$\frac{X}{Q} = \frac{1}{\Pi \sigma_Y \sigma_Z \mu} e^{\left[-1/2\left(\frac{H}{z}\right)^2\right]}$$

$$\sigma_z = .016d(1 + .003d)^{-1} = .016(805)[1 + (3-4)(8+2)] = 10.39$$

$$\sigma_y = .04d(1 + .001d)^{-1/2} = 32.2[1 + .08]^{-1/2} = 31.0$$

$$\frac{X}{Q} = \frac{1}{\Pi(10.4)(31.0)(1)} e^{-1/2\left(\frac{20}{10.4}\right)^2} = 9.9\text{-}4(.158) = \underline{\underline{1.6\ \text{-}4}}$$

As comparison:

Worst annual at 0.5 mi = 9.0 - 5 (Table H-36) 10 x lower
(X/Q)5% for 1 hour, 0.5 mi = 4.3 - 4 (Table 21, App. H)
3 x higher (X/Q) max for 1 hour, 0.5 mi = 1.1 - 3

The X/Q for gound level release is between 5% and max one-hour X/Q so is conservative enough. Justification for using effective height of 20m is not obvious.

Also, can't check whether X max at 1/2 mile is correct.
See additional comments on χ/Q in Chapter 8.

APPENDIX III

EEG-2

Review Comments on
Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico
SAND 78-1596, Volumes I and II, December 1978

Environmental Evaluation Group
Environmental Improvement Division
Health and Environment Department
State of New Mexico

August, 1979

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10/79

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is no environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department - the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies and other organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U.S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.

Robert H. Neill
Director

INTRODUCTION

The purpose of this document is to review and evaluate the scientific information contained in the Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, SAND 78-1596, Volume I and II, December, 1978, (herein referred to as the GCR), and its supporting references, as it pertains to the environmental, health and safety aspects of the radioactive waste repository proposed near Carlsbad, New Mexico.

These evaluations and interpretations are based on reviews by the Environmental Evaluation Group (EEG) staff and several consultants with expertise on geological aspects of the site. EEG also convened two technical meetings to explore some topics of particular concern.

The review focused on some major concerns regarding areas in which more data or more detailed analysis appeared necessary and did not comment on those areas with which EEG agrees such as Seismology, or on areas which fall outside the scope of EEG's mission such as Resources. In this sense, the review may appear negative in tone and does not acknowledge those areas that have been thoroughly investigated by Sandia, and the U.S. Geological Survey and other contractors of the U.S. Department of Energy. It is recognized that additional data have been obtained since August, 1978, which may answer some of the questions raised.

The review describes in detail the important geotechnical issues on which there are questions or differences in interpretation and comments on the technical basis for certain conclusions presented in the GCR.

ACKNOWLEDGEMENTS

This document reflects the efforts of a number of individuals. The review is a synthesis of comment by the EEG staff consisting of

Robert H. Neill, Director
James K. Channell, Environmental Engineer
Lynn W. Gelhar, Hydrologist*
Carla Wofsy, Mathematician

and the following consultants who have reviewed and commented on portions of the GCR:

Mary Anderson, Assistant Professor of Geology, University of Wisconsin
Roger Anderson, Professor of Geology, University of New Mexico
Lokesh Chaturvedi, Associate Professor of Geological Engineering, New Mexico State University
Stanley Davis, Professor of Hydrology and Water Resources, University of Arizona
George Griswold, President, Tecolote Corporation
Gerardo P. Gross, Professor Geophysics, New Mexico Institute of Mining & Technology
William Hiss, Geologist, U.S. Geological Survey
Gary Landis, Assistant Professor of Geology, University of New Mexico

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*Dr. Lynn Gelhar served as a part-time member of the EEG staff from February 15 to July 1, 1979, during which time he reviewed aspects of the Geological Characterization Report (GCR) and prepared an early draft of the EEG comments on that report. He was not involved in any way in the preparation of the final version of EEG's comments on the GCR.

Donald Langmuir, Professor of Geochemistry, Colorado School of Mines

Allan Sanford, Professor of Geophysics, New Mexico Institute of Mining & Technology.

Each of the consultants had an opportunity to review and comment on an early draft of this document. In the process of the evaluation there were informal contacts and a meeting on March 22 and August 20, 1979 with personnel from Sandia Laboratories and the U.S. Geological Survey who are associated with the WIPP project. Their assistance in clarifying interpretations in the GCR and providing reference materials is acknowledged. They also indicated that a considerable amount of data has been obtained by the Department of Energy since the GCR was prepared over a year ago that will be published shortly.

PRINCIPAL CONCERNS

The following geotechnical questions, each of which bears on the short-term or long-term integrity of the site, are not resolved by the August 1978 information in the GCR and its references. DOE is continuing to gather and analyze data relevant to these features and processes.

1. What is the origin, evolution and occurrence of the high-pressure brine-reservoirs which were encountered in the upper part of the Castile formation in ERDA No. 6 and in at least 6 wells within 9 miles of the site? (See Section 2).

2. What is the origin, evolution and occurrence of the "breccia pipes" which have been encountered in the area? They may be localized deep dissolution features which originate in the lower portion of the evaporites and migrate upward. Such localized dissolution features could now exist or develop later beneath the proposed site (see Section 3).

3. What are the processes and rates of deep dissolution of salt near the site? There may be a preferential removal of the salt horizon which is proposed for the repository (see Section 3).

4. What are the regional and site hydrologic conditions for the aquifers above and below the evaporites? The hydrologic information is necessary to assess any possible long-term release of radioactive material from the repository (see Section 5).

Additional information on geological phenomena will be required by EEG in order to assess their significance in any potential release of radioactive materials to the surface and any effect on the health and safety of people and on the environment.

REVIEW OF GEOTECHNICAL ISSUES

1. Site Selection Procedures and Criteria

The following references suggested endorsement by different agencies in the selection of sites for an underground radioactive waste repository. Were they official recommendations by those agencies or were they made by individual staff members?

a) "...the USGS and ORNL selected the Permian Basin in New Mexico as best satisfying their site selection guidelines." (2-5.1)*?

b) "In the opinion of both ORNL and USGS, the two core holes, AEC 7 and 8, indicated acceptable subsurface geology at the ORNL site." (2-5.4)

c) "On November 14, 1975, the USGS recommended an area about seven miles southwest of the ORNL site for further examination"? (2-7.1)

There are several instances in which criteria appear to have been developed or altered to satisfy the condition of the WIPP site. A failure of the proposed repository to meet a given design criterion does not in itself mean there is a hazard. It does identify or flag those areas that need to be thoroughly analyzed to determine whether or not the consequences of failure could result in radiation exposure to people. The requirement (2-12.3) that the site be located at least one mile from a borehole penetrating the Salado formation was changed from two miles to one mile after the site at the ERDA No. 6 borehole was discovered to be unacceptable.

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*The notation (2-5.1) refers to Chapter 2, page 5, paragraph 1 of the GCR.

a) The GCR states that the studies of Snow and Chang (1975) and Walters (1975) allowed a more quantitative judgment on the question (2-6.2).

1) What specific results of these studies justify the statement that "This buffer would assure more than a quarter of a million years of isolation using very conservative flow assumptions"?

2) How are the conditions of those studies pertinent to the WIPP situation?

b) A report by Fader (1973) is also cited (2-12.3) as justification of the one mile criterion. However, this study was based on field observations of surface subsidence near abandoned wells in a Kansas salt bed and indicated that borehole dissolution can develop very rapidly in terms of geologic time. The area of surface subsidence was found to be approximately 1000 feet in diameter after about 31 years and subsidence of over 10 feet was observed. In view of these other studies, are there any analyses to substantiate the "quarter million years of isolation" and justify the one-mile criterion?

c) Griswold (1977, p. 12) is also cited (2-12.3) as providing justification for the one-mile criterion but Griswold's report only had a general statement that "This change, which resulted from studies performed for ORNL on the dissolutioning effects in boreholes, was made desirable by the extensive deep gas-exploration drilling in the Delaware Basin."

The ORNL criterion "no active mining within 5 miles (2-10.3) was also changed to "minimize existing potash lease rights in Zones I and II" (2-22.1).

The criterion that the site should be located one mile from a dissolution front (2-21) appears to be arbitrary in view of the uncertainty of the mechanism and rates of dissolution. According to Fig. 2-9, the dissolution front at the top of the Salado is located slightly inside the western boundary of Zone IV of the site. This would be about 1.8 miles west of the boundary of Zone II, the limits of underground storage in the proposed WIPP repository (4-39.1). How accurately is the location of the dissolution front and the rate of 6-8 miles per million years known?

2. Brine Reservoirs in the Evaporites

As noted on (2-11.2), an artesian brine flow was encountered at the original site at ERDA No. 6. Aspects of this brine occurrence are discussed in several locations in the report (e.g. 1-16.3, 1-31.4, 2-11.2, 4-67.3, 4-69.3, 6-19.4, 7-75.2, 7-90.1, 7-99.3, 7-102.4, 8-5.1). This approach together with some omissions has made it difficult to assess. The ERDA No. 6 brine, accompanied by concentrations of H_2S exceeding OSHA's standards for occupational exposure, was encountered on the flank of an extreme localized upthrusting structure from the middle of the Castile; dips as high as 70° were seen in the core and the middle anhydrite unit (A-11) has been displaced vertically by as much as 950 feet (Anderson and Powers, 1978, p. 79). According to a report to Sandia Laboratories [Tiab, 1977, p. 1]*, the well flowed at 662 barrels/day, but this data is not in the GCR. Tiab [1977, p. 6] also reported that the volume of the reservoir at ERDA No. 6 could be as large as 2 million barrels of water. The GCR reports Griswold's estimate of 100,000 to 1 million barrels in the discussion of lithium resources (8-5.1).

Seven wells have encountered brine reservoirs within a distance of 9 miles from the site. Griswold's (1977, page 42) Table XII (see below) gave data on four nearby oil wells

*References in brackets are listed in the end of this document; all other references are given in the GCR.

which have also encountered artesian brine reservoirs; these flows are typically an order to magnitude larger than that of ERDA No. 6. Griswold (personal communication to Lynn Gelhar, April 6, 1979) confirmed that two additional wells (Masco No. 1 & 2, Sec. 20, T22S, R33E) encountered artesian brine in the Castile. The GCR gives only sketchy information on these additional brine flows. Locations of "artesian brine flows" are shown in Figure 2-5 but the text (2-13.3) that describes the figure simply refers to "..., brine flow anticlines,..." without discussion. A more comprehensive discussion of these brine reservoirs should have been included in Chapter 6 on hydrology.

Griswold (1977)

TABLE XII

Brine Flows From Nearby Wells

Well Name	Location	Flow Rate (bbl/day)	Depth of Flow (ft.)
ERDA No. 6	Sec. 35, T21S, R31E	600	2709
Hudson Federal	Sec. 1, T23S, R30E	12,000	2802
Culbertson-Erwin	Sec. 26, T22S, R32E	Strong	3515
Bootlegger Ridge	Sec. 36, T22S, R32E	20,000	3671
Gulf 1-A	Sec. 25, T22S, R32E	36,000	3600

The Castile brine reservoir encountered about 1/4 mile from the southwest corner of the outer boundary of the site at the Belco Hudson Federal well is discussed briefly (4-68.1). This occurrence, with an estimated flow of 12,000 barrels/day (Griswold, 1977), demonstrated that such brine flows are not always associated with the highly deformed region near the

Capitan reef. Griswold's Figure 6 (see Figure 1) graphically demonstrated the stratigraphic position of these brine flows in relationship to the proposed repository.

Several statements are made in the report implying that Castile brine flows are generally associated with anticlinal structures; these include: use of the term "...brine flow anticline..." (2-13.3), the criterion on anticlinal structures (2-22.1), the discussion of structure of the 124 marker bed on (4-69.3) and discussion of lithium resources (8-5.1). The structure of the top of the Castile (Figure 4.4-6) indicates anticlinal features within the immediate site area (e.g. at the north edge of Zone II) which are as severe as that associated with the Belco Hudson Federal brine flow. In view of the common association of the brine flows and anticlinal structures there appears to be little justification for the statement on (4-73.1); "There is no suggestion here of deformation of the type associated with artesian brine reservoirs."

The GCR makes no attempt to evaluate the possibility that geopressurized brine with H_2S may occur within the evaporites in places without anticlinal structures. Anderson (1976, p. 21-22) described such an occurrence at the UNM-Pokorney No. 1 location and noted that dissolution effects were similar to those observed at ERDA No. 6.

Brine reservoirs occur in the Castile formation which is directly below the Salado formation where the repository would be located and the brine reservoir at the ERDA No. 6 location has intruded locally up to the level of the lower part of the Infracowden salt. The origin, occurrence and configuration of these brine reservoirs are not adequately addressed in the GCR. For example, the geochemical analyses of the ERDA No. 6 brine are generally inconclusive with regard to the origin and period of isolation of the brine (see Section 6). It is conceivable that stress changes due to repository con-

struction and/or heat generating wastes in combination with the high pressure in an underlying brine reservoir could induce deformation and fracturing which would release brine into the repository. In view of the large flows and volumes, high pressures, and accompanying H_2S of these reservoirs, they need to be characterized in detail in order to assess their role as a potential threat to health, safety and environment. Finally, future resource exploration could conceivably penetrate an underlying brine reservoir and bring pressurized brine to the surface.

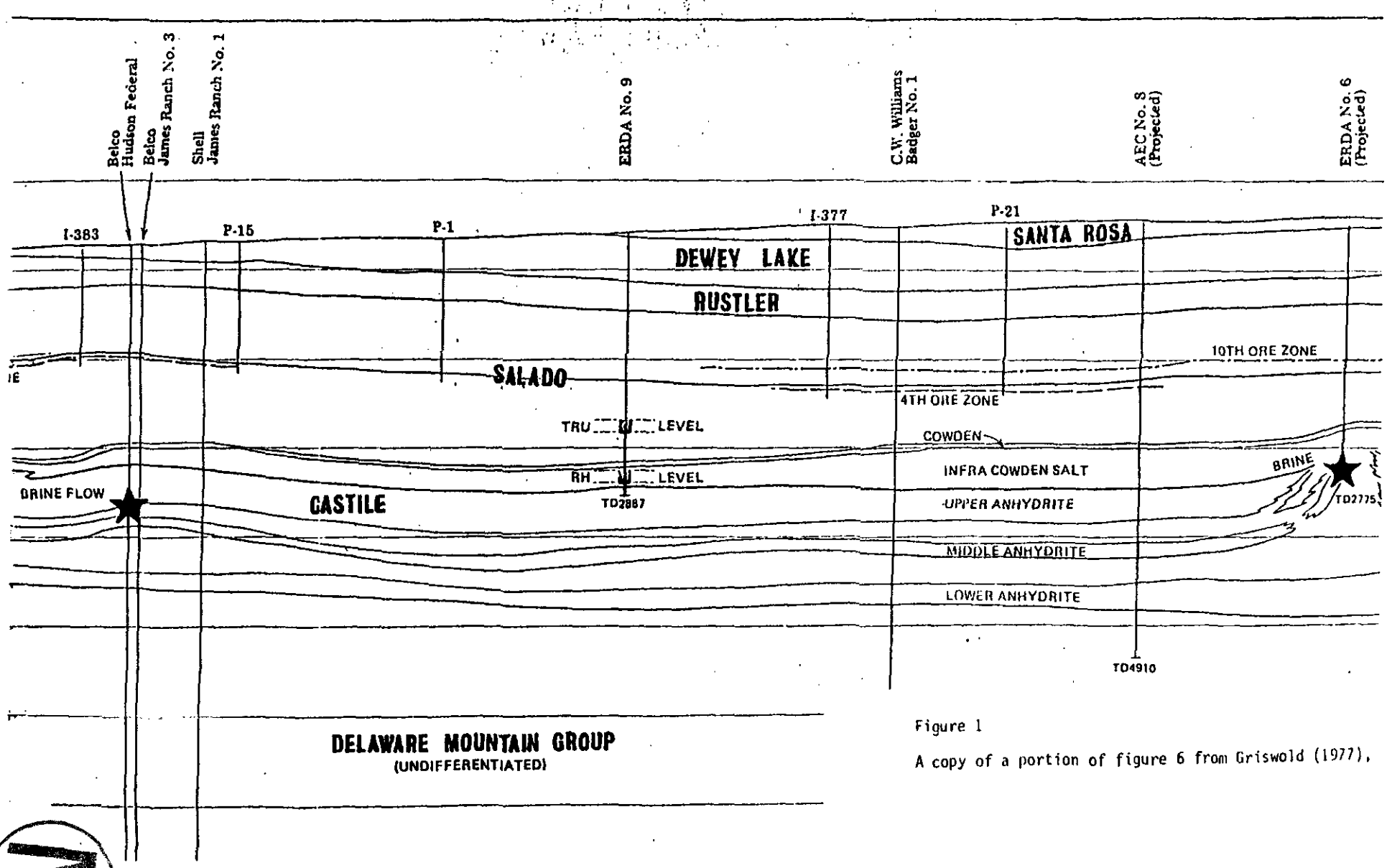

Figure 1

A copy of a portion of figure 6 from Griswold (1977).

3. Dissolution Processes and Rates

Salt dissolution can occur at different depths in the salt beds. The GCR presumes that the dissolution at the top surface of the Salado (shallow dissolution) is the most significant (1-26.2, 6-38). However, the presence of on-going deep dissolution, near the levels of the repository, has been suggested as a possible threat to the site. Both types of dissolution are discussed separately below.

Shallow Dissolution.

The GCR adopts the estimate by Bachman and Johnson (1973) that the lateral shallow dissolution front located 2 miles west of the site is approaching the site at 6 to 8 miles per million years and would take 225,000 years to reach a point 1,500 feet above the repository. However, the dissolution is probably not advancing eastward at a uniform rate. The front is envisioned as a "feather edge" (4-37.2) and certain tongues of the edge may move faster than others. Vertical dissolution is estimated at 0.33 to 0.5 feet per 1,000 years which would require 3 million years to remove the 1,500 feet of evaporites above the repository. Much of the salt in the Rustler formation directly above the repository has already been removed (4-41.3 and Figure 6.3-7) by dissolution along this front. How accurately is the location of the dissolution front and the rate of dissolution known?

Deep Dissolution.

The question arises whether deep dissolution is an on-going process in or near the horizons proposed for the repository and may play a role in helping to bring radioactive waste to the surface. EEG is presenting the following discussion in an attempt to help resolve the issue.

The GCR stated that exploratory holes, including ERDA 10 and ERDA 11 (6-2.1) as well as other data, indicate that deep dissolution is not taking place near the site. Anderson (letter to EEG, 4/24/79) has provided a photograph of a portion of the ERDA 10 core which shows a possible dissolution breccia in the lower anhydrite of the Salado formation. Anderson (letter to EEG, 5/14/79) also provided a photograph of core from WIPP 11 at a depth of 3100 feet showing clear replacement halite indicative of solution activity. The photographs are not included in this review since they do not reproduce clearly. EEG is sending them to the DOE for their interpretation. Why is ERDA 10 considered to be "...the nearest probable location of regional deep dissolution..." (6-42.1)?

According to Anderson (1978) deep dissolution within or below the salt has occurred extensively in the Delaware Basin. The GCR quoted Anderson's (1978) estimate that 50 percent of the original salt of the Delaware Basin evaporites has been removed (6-37.14) and that the salt from that unit will be gone from the basin in about another million years (6-45.3) but does not include his estimate that 73 percent of the lower Salado salt has been removed. Anderson's data indicate that the lower Salado salt beds, in which the disposal horizons are located, have been the most active zone of dissolution in the basin.

The GCR (6-45.2) appears to question Anderson's (1978) conclusion that dissolution is mainly a Cenozoic process and that it could remove the entire lower Salado salt in another million years, hypothesizing that deep dissolution may have been important in the Jurassic period. Anderson (1978) concluded that "The advancing effects of lateral dissolution can be expected to reach the disposal site before removal of the overlying salt beds." Are there any recent data to resolve this difference between Anderson and the GCR?

The GCR stated that "The proposed site is in an area of the Delaware Basin that is free of regional deep dissolution, but localized features are present in the vicinity" (6-41.3). What are these localized features?

The following geological phenomena may be related to deep dissolution.

Feature 5 mi. SE of site. The GCR discussed a map of Anderson on deep-seated dissolution features in the northern Delaware Basin and stated "The nearest of these deep mid-basin features to the proposed WIPP site...occurs about 5 miles southeast of the site..." (4-64.2). The sonic log of the Perry Federal #1-31 well in that area (Sec. 31, T22S, R32E, Fed-1, Figure 4.1-2) indicated that 200 feet of Infracowden salt was missing (R. Anderson, personal communication to Lynn Gelhar, 4/24/79). Furthermore, a major structural depression appeared in the 124 marker bed in that same location (see Figure 4.4-7). A similar depression in the 124 marker bed was found in the northern part of the WIPP site (see Figure 4.4-7, Sec. 9, T22S, R31E). The GCR suggests that this feature "...is not significant to the WIPP site" (4-70.1), citing isopach maps of Anderson (1978), and seismic reflection data. However, none of this information resolves the question of whether this depression is a deep-dissolution feature. The isopach maps (Figs. 4.3-4 through 4.3-7) do not cover the lower portion of the Salado or the Castile where the deep dissolution would be expected.

Anderson's regional isopach maps obviously are not going to resolve this feature because they are based on deep well data which are sparse in the site area. Seismic reflection data for the next horizon below the 124 marker bed (top of the Castile, Fig. 4.4-6) are inclusive in that area which is identified as "highly disturbed area".

Thinning of salt. Anderson's (1978) Figure 16 also showed a possible dissolution feature at the southwest edge of the site. The Infracowden salt (the high level waste horizon)

thins rapidly toward the southwest and disappears completely about three miles from ERDA No. 9 in the area of this feature (Anderson 1978, Figure 7). The GCR (4-35.1) presents Jones' and Anderson's different interpretations of this thinning. Griswold (1977, p. 42) has suggested that brine pockets may be left behind a dissolution (suberosion) front. Might some of this thinning of Infracowden salt be associated with dissolution and brine flows in the area of the Belco Hudson Federal well?

The GCR (4-35.1) indicates that the lower member of the Salado is 1,195 feet thick at ERDA No. 9 and "...thins to 430 feet near the northeast corner of the area,..., due to beds missing at corrosion surfaces...". Where was the 430 foot thickness measured? "Corrosion" surfaces in ERDA No. 6 core samples are associated with dissolution (Anderson and Powers 1978). Is this thinning primarily due to faulting or is dissolution also a factor?

Origin of San Simon Sink. In discussing the origin of San Simon Sink, the GCR indicates that "shallow dissolution is a factor in the development of this sink" (6-40.3). In view of the depth of collapse, the scale of the feature, and its location along the reef margin, why is deeper dissolution not considered an equally good possibility?

Breccia pipes. Breccia pipes or "domal karst features" (Vine, 1960) are thought to be a result of localized removal of salt and are discussed on pages 2-17.2, 3-18, 4-7.1, 4-41.2 and 10-12.1. The second paragraph of the section on page 3-17 discussed Anderson's hypothesis that breccia pipes are caused by localized deep dissolution and brine density flow through fractures connected to an underlying aquifer. Anderson (1978) suggested that breccia pipes are formed by dissolution from below followed by collapse of the overlying units. Breccia pipes would then migrate upward and might eventually penetrate the surface. The deep dissolution theory of breccia pipe formation is consistent with conclusions reached in investigating the Michigan Basin [Landes, Ehlers, Stanley 1954] and collapse structures of the Prairie Formation Saskatchewan

[DeMille et al, 1964]. Anderson suggested that these processes are ongoing and that breccia pipes are presently being formed or could be activated in the basin. If Anderson's ideas are correct, and in view of the presence of dissolution features near the site, it is not inconceivable that breccia pipes may exist or may develop beneath the proposed repository.

The GCR indicated that recent drilling (WIPP 13) of a suspected breccia pipe has shown that the resistivity anamoly is not caused by dissolutioning (4-7). What data formed the basis for this interpretation? Also, what additional studies are planned to resolve the origin, occurrence and significance of breccia pipes? Anderson's (1978) concept, as well as others, of the origin of dissolution features in the salt beds in the Delaware Basin should be treated in detail.

The nature and occurrence of deep dissolution has not been resolved by the information in the GCR. Anderson (1978) has presented evidence indicating that deep dissolution can play a significant role in the removal of salt and concluded "Extensive regional and localized dissolution in the Delaware Basin and the random distribution and on-going nature of localized dissolution suggests that this particular basin may have already progressed to a stage of dissolution where geological estimates of site integrity may not be obtained with the required degree of certainty" (page IV). How will the mechanism and rate of deep dissolution be determined?

Future course of the Pecos River. Another aspect of salt dissolution is its possible effect on the future course of the Pecos River. The thickness of the salt section decreases on the order of 1000 feet from the WIPP site to a point at the Pecos River directly west of the site and the corresponding difference in surface elevation is around 400 feet. If dissolution causes subsidence east of the Pecos River, it could cause the river to migrate eastward toward the site. If the course of the Pecos River is so altered, this could lead to accelerated dissolution near the site.

The GCR does note briefly that the course of the Pecos River may be affected by solution features (3-10), but does not consider possible eastward migration of the river or its role in ongoing and future dissolution. What is being done to evaluate this possibility?

4. Site Structure and Geophysical Exploration

Information on structural features within the evaporites in and around the WIPP site is needed to evaluate potential hazards such as brine reservoirs or breccia pipes which may be associated with deformation or dissolution in the evaporites. Potash exploration holes provide some detail on shallow features but the only direct information on the disposal levels in the lower Salado is from a single well, ERDA No. 9. All information in the GCR on the underlying Castile formation in the site area appears to be based on seismic reflection surveys.

The GCR identified several anomalous features which may be of concern including:

a) A resistivity anomaly in the northern portion of Zone II bearing some resemblance to the patterns associated with breccia pipes (4-7.1). The GCR said it is a shallow surficial feature with no disturbance of underlying beds, based on drilling WIPP 13.

b) A 70-foot depression at the top of the Salado formation, two miles NE of the site (4-7.1).

c) A depression in the 124-marker bed in the Salado formation on the northern edge of the site, one mile west of feature b) (Figure 4.4-7). According to Anderson (1978,

p. 78), this feature could be associated with faulting in the Bell Canyon formation. If so, this would suggest that the depression was formed by deep dissolution, possibly caused by movement of water upward from the Bell Canyon formation.

d) A missing section of Infracowden salt (base of the Salado formation) 5 miles southeast of the site which also shows up higher in the Salado formation as a depression in the 124-marker bed.

e) A salt anticline located on the northern boundary of the site originating in the Castile formation. WIPP 11 was drilled through this structure to the lower anhydrite of the Castile and did not encounter brine (4-68.3, 4-69).

f) Seismic reflection data suggested the presence of faults at the top of the Salado formation north of ERDA No. 9 but data from WIPP 18, 19, 21 and 22 showed no apparent faulting (4-72).

Several wells were drilled to evaluate some of these features (WIPP 11, 13, 18, 19, 21, 22) and in each case the interpretation was that the anomaly was not significant. No information is given in the GCR on the type of data that was collected from the wells or the depth of the wells. What data are available for these wells?

The configuration of the top of the Castile (Figure 4.4-6) is important because that horizon may reflect deformation related to brine reservoirs or deep dissolution. Figure 4.4-6 indicated several faults with vertical displacement up to 300 feet, a possible anticline northeast of the site, and a "highly disturbed area" extending to the northeast. The significance of these structures is recognized in the GCR (4-73.1). "Among aspects needing further investigation,

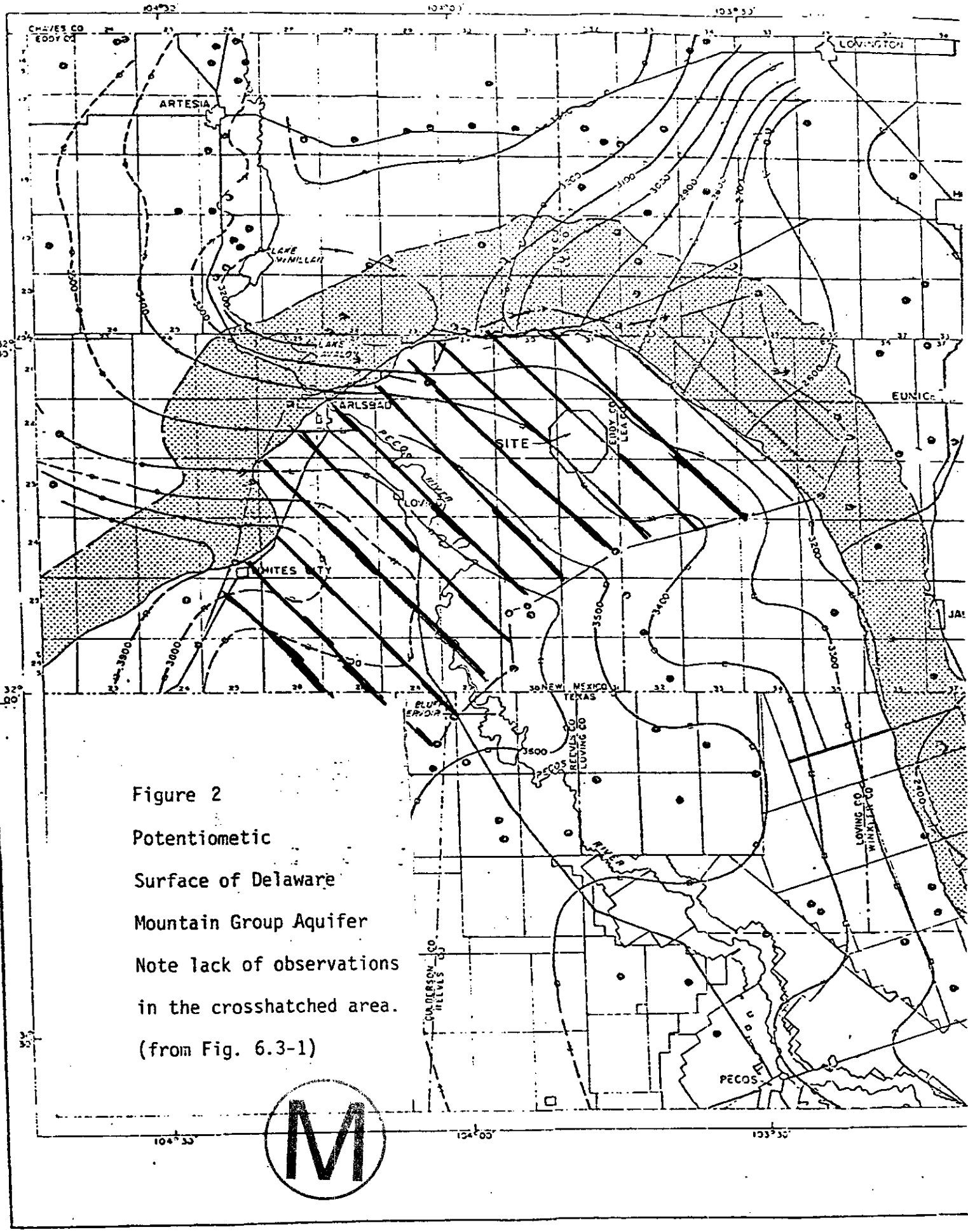

Figure 2

Potentiometic

Surface of Delaware

Mountain Group Aquifer

Note lack of observations

in the crosshatched area.

(from Fig. 6.3-1)

perhaps the most significant is a determination of the extent to which the upper levels of the Castile closest to the repository levels have been deformed by any salt deformation that may have taken place in the lower halite units of the Castile." Because of these uncertainties, the following statements in paragraph (4-73.1), (1) "There is no suggestion here of deformation of the type associated with brine reservoirs..." and (2) "This knowledge will permit a more detailed assessment relative to the location, design and construction of the storage facility but is not believed necessary for a general qualification of the site." do not appear warranted on the basis of information in the GCR or its references. In view of the complex structural feature indicated by Figure 4.4-6, what detailed justification is available?

Because of the possibility of localized deep-dissolution features (breccia pipes) in the site area, there is a need to define the ability of the seismic reflection method to detect such features. What information is available on the ability of the seismic reflection method or other geophysical techniques to detect breccia pipes or brine reservoirs?

5. Hydrology

Aquifers exist above, below and adjacent to the evaporite beds which are proposed for the repository. Therefore, subsurface hydrology at the site and in the region is a major concern because ground water flow controls the process of salt dissolution and is a primary transport mechanism for the release of radioactive material from the repository.

The underlying aquifer (Delaware Mountain Group) is discussed on (6-14); the potentiometric map for this aquifer (Fig. 6.3-1) is based on Hiss (1975). As shown in Figure 3, there is a large area around the site in which no well data were available. Are there additional data which could be included in

this map? What about AEC 8? Also, would it be more useful to map the potentiometric surface of Delaware Mountain Group aquifers using a density near that of the aquifer waters?

The GCR (6-16.1) indicates that recharge to the Delaware Mountain Group occurs via precipitation on the outcrops and downward leakage through the younger rocks where the evaporites have been removed. If there is to be any assessment of the effects of climate change on this aquifer, it is necessary to know more specifically the locations and conditions in the recharge area(s) of the Delaware Mountain Group aquifer.

Data on the overlying aquifers are more extensive but the regional potentiometric map for the Rustler aquifers (Figure 6.3-2) contains no data from east of the site. The degree of connection between the brine aquifer and the Rustler aquifers east of the site should be clarified. Do the two aquifers have the same potentiometric surface (Figure 6.3-2)? The GCR contains no specific information on the nature of recharge to the Rustler aquifer; on (6-9.4) it states "...is presumed to be from precipitation in outcrop areas or from overlying formations." How much recharge occurs and what fraction of this enters the aquifer from the outcrop areas, and what fraction from the overlying formations? How will the recharge and flow in the Rustler aquifer be affected by climatic change? The summary of the Mercer and Orr (1978) report in the GCR (6-30.2) noted that head distributions in the Culebra Dolomite indicate fluid movement to the southeast across the site. This observation is not consistent with the regional potentiometric map (Figure 6.3-2) which indicated flow toward the southwest. How are these differences reconciled?

The summary stated "...measurements of the effective porosity...are very difficult to obtain". Have ranges been established of the effective porosity in the site area? This parameter is important in the hydrologic transport modeling of the long-term release of radioactive material from the repository. Aquifers adjacent to the evaporite beds are also of importance especially in relation to possible deep-dissolution in the evaporites. The discussion of the Capitan aquifer (6-17) does not consider the possibility of some lateral connection between the reef aquifer and the salt beds with the resulting development of deep-dissolution wedges and reef-margin dissolution features (Anderson, 1978).

The statement on (6-10) referring to the Castile formation "...as an aquiclude separating the Salado from the underlying sandstones of the Delaware Mountain Group" does not consider the possibility of fracture permeability which may be associated with deformation in the Castile, as suggested by Anderson (1978) in relation to deep dissolution.

The question of the effect of climate change on the hydrologic regime is not addressed.

Generally the hydrologic data for the region and the site is not adequate to characterize the long-term hydrologic transport of radioactive materials or to define the mechanism and rates of salt dissolution.

6. Geochemical Analyses

The analyses of waters from ERDA No. 6 (Sections 7.7 and 7.9) are intended to resolve questions about the nature and origin of this brine reservoir; the appropriate questions are stated on (7-90). On (7-102.4) the GCR concludes, on the basis of the uranium disequilibrium model, that the ERDA No. 6 reservoir "...has no connection with any other known ground water, and has been in its present environment for at least 880,000 years." This conclusion is unjustified. A more qualified statement is found on (7-99.1) that assumes an original connection to the Capitan reef and an original activity ratio equal to that of the Capitan reef water at "Carlsbad 7", $\alpha_0 = 5.14$.

One could assume as an initial value the results for the Middleton (α_0 = 1.81) or Hackberry (α_0 = 1.22) waters (Table 7.27) which also come from the Capitan aquifer and are geographically closer to ERDA No. 6 (see Fig. 7.18). From Figure 7.20 these values of α_0 yield much smaller ages; about 300,000 years for Middletone and a "negative" age for Hackberry. The results of the uranium-disequilibrium dating are stongly dependent on an assumed α_0 and do not provide any definitive information about the age or degree of isolation of the ERDA No. 6 reservoir.

On (7-99.1) it is indicated that the solid, liquid and gaseous phases are not in chemical equilibrium in the ERDA No. 6 brine reservoir. A static body of water would be expected to come to chemical equilibrium with surrounding rocks within a relatively short time frame. (Opinions expressed to EEG ranged from weeks to decades). Yet this presumably very old water was not found to be in chemical equilibrium with the host rock. One or more of the following is implied:

a) The laboratory analyses of brine, gas and stable isotopes are in error.

b) The ERDA No. 6 water is not "old", i.e., the interpretation of the uranium-disequilibrium method in the GCR (7-99) is invalid.

c) Water which has been in contact with other types of rocks is mixing with the brine reservoir fluids and preventing equilibrium.

d) Biogenic reactions which prevent equilibrium are occurring.

e) The surrounding rocks are not halite or anhydrite, contrary to core data.

As stated on (7-78) "The isotopic composition of ERDA No. 6 brine is consistent with an approach to isotopic equilibrium between water and clay minerals, not necessarily in the Castile." This observation is an additional indication that the ERDA No. 6 brine may not be indigenous to the Castile; this possibility is further supported by the following:

a) Gas analyses from ERDA No. 6 (7-76) predict a calculated P_{O_2} of 8.8×10^{-83} using CO_2-CH_4 redox equilibria. This value is not compatible with sulfate evaporite mineral assemblages.

b) Results of the synthesis of ERDA No. 6 water chemistry (Sample 14, Table 7.20) using the U.S. Geological Survey computer program WATEQF indicate that the water is undersaturated with halite, anhydrite and gypsum, but is saturated with calcite and dolomite.

c) WATEQF calculates a P_{CO_2} of $10^{-2.09}$; P_{CO_2} calculated from the basis of calcite saturation is $10^{-1.98}$ indicating that ERDA No. 6 water is in equilibrium with calcite.

These points suggest the possibility that ERDA No. 6 water has recently been in contact with dolomite and calcite, e.g. the Capitan limestone and associated dolomites (Figure 3.3-2) or the Bell Canyon formation which "contains considerable limestone interbeds and lime rich intervals" and whose top unit consists of limestone (Figure 4.3-2). Two possible routes for water movement from the Capitan reef were suggested by Anderson (1978, pp. 69, 72): along the contact between the Castile and Salado formation, or moving upward from the Bell Canyon formation through fractures in the Castile formation.

The stable isotope data for ERDA No. 6 water (Figure 7.12) indicated isotopic composition which is distinct from modern meteoric waters. However, these data do not give a positive indication of the origin of the water in the brine reservoir.

Regional water chemistry information is important because it can help to understand salt dissolution conditions and clarify the interpretation of the regional hydrology. However, the data are limited and are not systematically related to the possible flow system. There are two water samples from the Bell Canyon aquifer listed in the GCR (AEC 8 on Table 6-3.3 and Sample No. 9 on Table 7.20) and they have different chemical compositions. The composition diagram of Figure 3 was prepared from concentrations of 3 of the 8 ions listed on Table 7.20. Only one Bell Canyon water sample is included (No. 9). Figure 3 suggests that this Bell Canyon water sample has a composition similar to the three water samples from the Salado. This is consistent with the observation in the GCR that "this brine probably did not originate in the Bell Canyon, but its solutes probably came from nearby evaporites" (7-74.3). A possible interpretation of these observations is that solutes in the Bell Canyon aquifer have originated in the overlying evaporites. While this is not conclusive, it supports the Anderson (1978) hypothesis of deep dissolution through connection with the underlying aquifer.

None of the questions posed on (7-90) concerning the ERDA No. 6 reservoir are resolved with any degree of certainty by the geochemical information in Chapter 7; all that can be said is that the origin and evolution of such brine reservoirs in the evaporites remains a mystery.

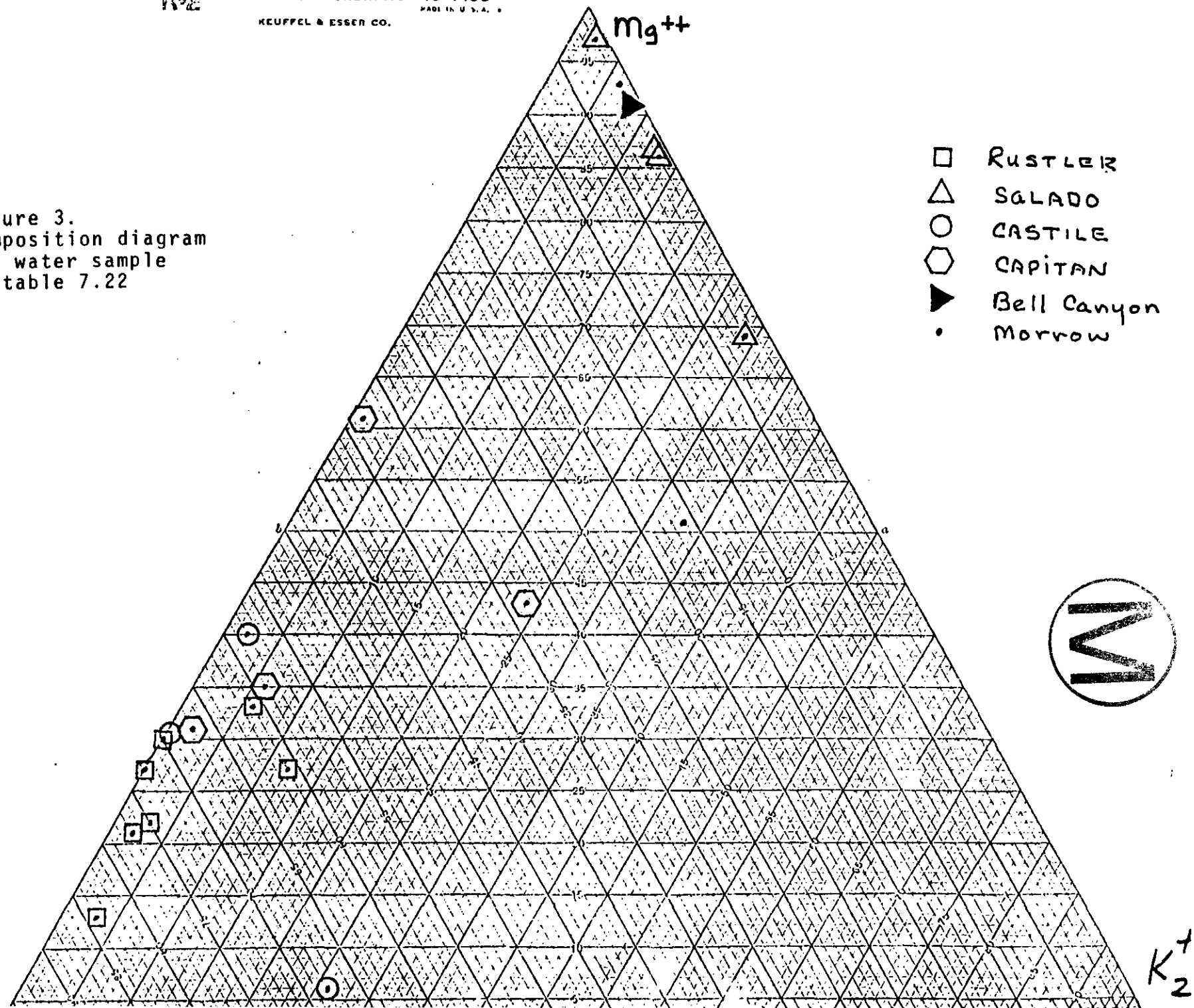

Figure 3.
Composition diagram
for water sample
of table 7.22

K_2^+

7. Rock Properties and Special Studies

The special studies of Chapter 9 are not being reviewed at this time. These studies are very important for the evaluation of the long-term integrity of a proposed repository, but Chapter 9 generally covers ongoing work which has not come to definitive conclusions. The following are some general concerns which will have to be resolved before the long-term integrity of the site can be evaluated.

a) The thermo-mechanical properties of salt and other adjacent rock are very complex especially when one is concerned with the regional-scale deformation induced by a proposed repository. The *in situ* properties of rocks at this scale can be strongly affected by impurities, heterogeniety and fracturing which is not accounted for in laboratory experiments of the kind described in Chapter 9. This problem is recognized on (9-2.3).

b) The radionuclide sorption properties of rocks are important in the hydrologic transport modeling of the long-term radioactive releases from a proposed repository. The static experiments with powdered rock samples (9-26) may not be relevant to the flow in fractured rock that would be involved in the Rustler aquifer (6-30.4).

   Additional laboratory and field work will be required to realistically describe the *in situ* sorptive properties of rocks at the site.

c) Migration of brine inclusions within the salt under the influence of waste induced thermal gradients could lead to undesirable accumulations of water in the repository. On (7-68.2) "Accurate predictions of the behavior of *in situ* inclusions in the thermal gradient around a canister in salt cannot be obtained at this time...". More information is required on this phenomenon.

8. General Comments

"The purpose of the GCR is to provide an account of the known geotechnical information considered relevant to site selection (see Section 2-3) for the proposed WIPP site" (2-2.2). Further discussion on (2-2.2) states "...for the most part, specific judgments regarding the suitability of the site are not made." A conclusion is presented on (2-7.1) that "Sufficient information has now been developed to allow the site to be adequately characterized for site selection purposes," and on (2-23.6) the statement is made that "...much basic information has been gathered indicating no major technical problems with the site as it is now understood."

Based on our review of the GCR and its references, additional data collection and analyses will be required in order for EEG to conduct its assessment of any potential release of radioactive materials to the surface and any subsequent effect on the health and safety of people and on the environment. Critical analyses of the role of localized geological perturbations such as breccia pipes, brine pockets and varying rates of dissolution are required for hydrologic transport modeling.

References

Landes, K.K., et al. "Geology of the Mackinac Straits Region and Sub-Surface Geology of Northern Southern Penisula," The Mackinac Breccia, Michigan Geological Survey Publication 44, Geological Series 37 (1954), pp. 123-254.

De Mille, G., et al. "Collapse Structures Related to Evaporites of the Prairie Formation, Saskatchwan," Geological Society of America, v. 75, (1964), pp. 307-316.

Tiab, D. Perform Reservoir Calculations on Brine Accumulation at ERDA No. 6 and Other Locations in the Vicinity of the Los Medanos Site in S.E. New Mexico, March 2, 1977.

APPENDIX IV

RADON RELEASES FROM WIPP

Summary

The quantities of radon expected to be released from operation of the WIPP site were calculated without any local measurements. The situation is discussed in greater detail below.

WIPP DEIS Radon Emanation Estimates

The DEIS uses a value of 0.9 curies/year of Radon-222 and 0.04 curies/year for Radon-220 obtained from the Nuclear Regulatory Commission's Final Generic Impact Statement on Mixed Oxide Fuels (GESMO). The DEIS also uses a typical concentration of 1×10^{-9} curies/cubic meter in exhaust air. These values are apparently estimates since they are unreferenced in the GESMO document.

There are no data in the DEIS on either uranium levels or radon at the surface or in the Salado formation where extensive mining would occur. In general, the Carlsbad area has a slightly lower than average terrestrial radiation, which suggests low uranium concentrations in the soil. While salt beds are usually low in uranium content, there are significant variations in different areas or geological formations and averages cannot be presumed. It is interesting to note that Carlsbad Caverns has high enough radon levels (up to 0.25 Working Levels) for the National Park Service to be concerned about exposure to their employees. (Ref. 1).

Since concentrations of radon from mines can vary over two to three orders of magnitude, it is necessary to obtain uranium, radium and radon data underground and at the surface. Three areas of environmental concern include:

(1) the amount of radon exhausted from the repository;

(2) the quantity of radon that emanates from the salt stored above ground; and

(3) the radon naturally emanating from the salt storage area (so that it can be estimated whether salt storage increases or reduces net emanation).

The possible doses from radon, while low, could be significant compared to other releases from the repository. See the attached calculations.

Radon Dose Estimates

DEIS Estimates

p. 8-33 $Q = 0.90\ Ci/y\ {}^{222}Rn,\ 0.04\ Ci/y\ {}^{220}Rn$

p. H-59 $\frac{\chi}{Q} = 6.2 \times 10^{-7}\ \frac{s}{m^3}$ at James Ranch (3 miles SSW of site)

$$\frac{pCi}{m^3} = \frac{9 \times 10^{11}\ pCi/y}{3.15 \times 10^{7}\ \frac{s}{y}} \cdot \left(6.2 \times 10^{-7}\ \frac{s}{m^3}\right) = \underline{\underline{0.18\ pCi/m^3}}$$

$$\text{Dose, mrem/y} = 0.18\ \frac{pCi}{m^3}\ \frac{(0.625\ mrem/y)}{\frac{pCi}{m^3}} = \underline{\underline{0.011\ mrem/y}}$$

Bronchial Epithelium

[conversion factor is from G-44 in GEIS Uranium Mills and is the average dose a resident indoors would get from an outside concentration of 1 pCi/m^3 of ${}^{222}Rn$. This dose is to bronchial epithelium. Dose to pulmonary lung is only 4-11% of this (pages 6-39 and 6-67 of GEIS)]

p. 9-39 The DEIS uses a dose of 2.5×10^{-4} mrem/y to lung. This can be checked by the above information and the Dose Committment Factor from NUREG-0172, Table 8.

$$\text{Dose} = \frac{pCi}{m^3}\left(\frac{m^3}{y}\ \text{inhalation}\right)\left(\text{DCF}\ \frac{mrem}{pCi\ \text{inhaled}}\right)$$

$$= 0.18\ (7300)\ (2.05 \times 10^{-6}) = 2.6 \times 10^{-4}\ \frac{mrem}{y}$$

Reasonableness of DEIS Estimate

Assume an emanation rate from the mine equal to the average rate (1 pCi/sec-m^2) and that there may be as much as 5×10^5 m^2 exposed area in the tunnels and storage rooms (this could be high by factor of 2-3, depending on the plan for opening and closing rooms in the repository).

Then:

$$Ci/y = 5 \times 10^5 \ m^2 \left(10^{-12} \frac{Ci}{m^2\text{-}s}\right) \ 3.15 \times 10^7 \ \frac{s}{y} = \underline{\underline{15.7}} \ Ci/y$$

From Mine

No estimate has been made from possible salt pile radon. If radon emanation is even 1 pCi/m^2 - s above background, then for a 30 acre pile:

$$Ci/y = 30 \ Ac. \ (4.05 \times 10^3 \ \frac{m^2}{AC}) \ 3.15 \times 10^7 \ \frac{s}{y} \ (10^{-12} \frac{Ci}{s\text{-}m^2})$$

$$Ci/y = \underline{\underline{3.8}} \ Ci/y \quad \text{from pile (per 1 pCi/}m^2\text{ - s)}$$

These values may be higher than exist at the site but they are by no means an upper bound, e.g. a variety of metal mines have been observed to have radon concentrations 2-40 times those assumed here. Evaporite deposits are typically an order of magnitude lower, yet in some cases they contain commercial ore deposits. Also, there is poor correlation between radon levels and ore geochemistry.

Possible Radon Doses

Assume 20 Ci/yr. radon release and check doses at two closest privately owned areas (James Ranch, use 3.0 mile SSW; and 2.8 mile NW) where residences are possible. Also check dosage at maximum 0.5 mile sector, because these areas are open to people.

Inhalation Dose

$$\text{millirem/yr.} = \frac{PCi}{s} \left(\frac{\chi}{Q} \frac{s}{m^3}\right) \frac{0.625 \text{ mrem/y}}{PCi/m^3}$$

$$= \frac{20 \times 10^{12} \frac{PCi}{y}}{3.15 \times 10^{7} \frac{s}{y}} (6.2 \times 10^{-7})\ 0.625 = \underline{\underline{0.25}} \text{ mr/yr.} \quad 3.0 \text{ mi}$$

$$= 6.34 \times 10^{5} \ (2.9 \times 10^{-6})\ .625 = 1.1 \text{ mr/yr.} \quad 2.8 \text{ mi}$$

$$= 6.34 \times 10^{5} \ (9 \times 10^{-5})\ .625 = \underline{\underline{35.7}} \text{ mr/yr.} \quad 0.5 \text{ mi}$$

Regional Annual Radon Dose Committment

A crude estimate of the total dose to the regional population from all pathways can be obtained by prorating the doses shown on Table 6-15 (attached) from the Generic Environmental Impact Statement on Uranium Milling (NUREG-0511). Adjustments need to be made for the difference in regional population (94,050 for WIPP versus the 57,300 used in Table 6-15) and for the curies of radon released (7,000 versus 20 curies/year).

Adjustment Factor = $\frac{94,050}{57,300} \frac{20}{7000} = .00469$

Bronchial Epithehium Dose = 138 man-rem (.0047) = $\underline{\underline{0.65}}$ man-rem

Bone Dose = 53.3 (.33) (.0047) = $\underline{\underline{0.08}}$ man-rem

Whole Body Dose = 6.47 (.35) (.0047) = $\underline{\underline{0.01}}$ man-rem

Lung Dose = 12.8 (.50) (.0047) = $\underline{\underline{0.03}}$ man-rem

Dose Comment

The regional doses from a 20 curie/year radon release are small. They are, however, similar in magnitude to the total doses presented in Table 9-19, not trivial as suggested on page 9-39.

It is also noted that the individual doses calculated in Table 9-18 are for James Ranch. Areas outside the security fence have χ/Q values as large as 9×10^{-5} s/m^3 (WNW at 0.5 mile) which is 145 times as large as used here. This needs further consideration.

Table 6.15 Annual Population and Environmental Dose Commitments Resulting from Operation of the Model Mill

Exposure Pathway	Annual Population Dose Commitments, person-rem/yr[a]							
	Total Dose Commitments				Doses Received by the Regional Population[b]			
	Whole Body	Bone	Lung	Bronchial Epithelium[c]	Whole Body	Bone	Lung	Bronchial Epithelium[c]
External from ground	0.511	0.511	0.511	-	0.511	0.511	0.511	-
External from cloud	2.36	2.36	2.36	-	2.36	2.36	2.36	-
Inhalation	0.170	4.61	6.48	138.	0.170	4.61	6.50	138.
Vegetable Ingestion	3.58	50.0	3.58	-	2.74	38.3	2.74	-
Meat Ingestion	2.94	30.24	2.94	-	0.437	4.49	0.437	-
Milk Ingestion	0.458	5.5	0.458	-	0.253	3.04	0.253	-
TOTALS	10.0	93.2	16.3	138.	6.47	53.3	12.8	138.

Exposure Pathway	Annual Environmental Dose Commitments, person-rem/yr							
	Total Dose Commitments				Doses Received by the Regional Population[b]			
	Whole Body	Bone	Lung	Bronchial Epithelium[c]	Whole Body	Bone	Lung	Bronchial Epithelium[c]
External from ground	1.97	1.97	1.97	-	1.97	1.97	1.97	-
External from cloud	2.36	2.36	2.36	-	2.36	2.36	2.36	-
Inhalation	0.170	4.61	6.50	138.	0.170	4.61	6.50	138.
Vegetable Ingestion	4.52	59.6	4.52	-	3.46	45.6	3.46	-
Meat Ingestion	4.78	48.7	4.78	-	0.710	7.24	0.710	-
Milk Ingestion	0.725	8.45	0.725	-	0.400	4.66	0.400	-
TOTALS[d]	14.6	125.7	20.9	138.	9.07	66.4	15.4	138.

[a]Based on exposure during the final year of mill operation.

[b]Doses received by the regional population are less than total doses for ingestion pathways because the regional population consumes only 76.5%, 14.9% and 55.2% of regionally produced vegetables, meat, and milk, respectively.

[c]Doses presented for the bronchial epithelium are those resulting from inhalation of short-lived Rn-222 daughters.

[d]The following percentages of annual dose commitments received by the region are due to annual radon releases (7.0 kCi): whole body, 35%; bone, 33%; pulmonary lung, 50%; and bronchial epithelium, 100%.

References - Appendix IV

1. U.S. Environmental Protection Agency. Radiation Protection Activities (EPA-520/4-77-005), 1976.

2. U.S. Nuclear Regulatory Commission. Draft Generic Environmental Impact Statement on Uranium Milling (NUREG-0511), April 1979.

3. U.S. Environmental Protection Agency. Radioactivity in Selected Mineral Extraction Industries, A Literature Review (ORP/LVF-79-1), November 1978.

APPENDIX V

ATMOSPHERIC DISPERSION COEFFICIENTS

I Long Term Averages

Procedure Used. Several key χ/Q values were calculated by EEG by a separate hand calculation to determine if the values from Table H-36 in the Draft EIS were reasonable. The procedure used differed in several ways from the MESODIF Code:

(1) It did not account for a plume being blown back over the source to contribute on the "second pass".

(2) It did not include the effect of releases during the 0.7% of the time that winds are below 0.3 meters per second ("calm conditions").

(3) The horizontal and vertical dispersion coefficients (σy, σz) for Category F were used for Category G conditions.

All of these differences would tend to make the calculated values of χ/Q less than those obtained from MESODIF.

The basic expression used was:[1]

$$\frac{\bar{\chi}}{Q}_{\text{long-term}} = \Sigma_i = A,B,C,D,E,F \; \frac{\left(\frac{2}{\pi}\right)^{\frac{1}{2}} fFi}{\sigma z_i \mu_i \frac{2\pi x}{n}} e^{-\frac{h^2}{2\sigma z^2}}$$

where

$\bar{\chi}$ = annual average downwind concentration in the sector of interest at distance x downwind, $\mu Ci/m^3$

Q = annual average discharge rate, $\mu Ci/s$

---

(1) From: Fowler, Ted W., "Air Submersion Skin Surface Dose Rate from Noble Gases", EPA Radiological Review Guidelines No. 3, May 1973.

f = frequency of the time that wind blows in a given sector

$\frac{2\pi x}{n}$ = sector width where x is the downwind distance and n is number of sectors

F_i = annual stability persistence frequency for the f_i th meterological conditions (A,B,C,D,E, and F)

σ_{z_i} = vertical stability parameter for the i th meteorological condition at distance x downwind, m

$\bar{\mu}_i$ = wind speed at ground level for the i th meteorological condition, m/s

h = effective stack height, m

if elevated releases are ignored and 16 sectors are used this reduces to:

$$\frac{\bar{\chi}}{Q} = \Sigma_i = A,B,C,D,E,F \quad \frac{2.032fFi}{\sigma_{z_i}\mu_i x}$$

The normal use of this equation would be where only the frequency of stability categories (in Table H-35 for the WIPP site) and the annual distribution of wind direction (Table 20, Annex 1, of Appendix H) is known. Average values of wind speed ($\bar{\mu}_i$) are used for each stability category (from Fowler). A sample calculation is shown below for the northwest downwind sector at 2.8 miles from the site.

Stability Category	F_i	$\bar{\mu}_i$ $\left(\frac{m}{s}\right)$	σ_z (m)	$\frac{F_i}{\sigma_{z_i}\bar{\mu}_i}\left(\frac{s}{m^2}\right)$
A	.255	2.46	2600	4.00 - 5
B	.033	2.69	570	2.11 - 5
C	.031	3.98	240	3.34 - 5
D	.136	5.86	83	2.77 - 4
E	.105	3.68	53	5.28 - 4
F	.119	2.00	33	5.07 - 3
G	.216			
			=	5.97 - 3

For NW downwind sector (f = 0.182)

$$\frac{\chi}{Q} = \frac{2.032\ (.182)(5.97\text{-}3)}{4.5 + 3} = \underline{\underline{(4.9 - 7)\ \frac{s}{m^3}}}$$

DEIS value from H-36, by interpolation = $(3.3 - 6)\frac{s}{m^3}$

A similar calculation at 3.0 miles SSW of the site gives a value of $(7.8 - 8)\frac{s}{m^3}$ compared to the DEIS value of $(6.2 - 7)\frac{s}{m^3}$

The DEIS contains more meteorological data than needed for the above simplified calculation. Use can be made of these data by using actual data for wind speed and stability category frequency in each downwind sector. An example is shown below for 2.8 miles northwest of the site. Wind speed frequency for each stability category is obtained from Tables 13-20 in Annex 1, Appendix H for the southeast wind direction.

Stability Category	μ_i (m/s)	fF_i	σ_z (m)	$\frac{fF_i}{\sigma_z \mu_i} \left(\frac{s}{m^2}\right)$	
G & F	0.85	.033	33	1.28 - 3	
	2.25	.038	.	0.51 - 3	
	4.05	.002		0.02 -3	1.81 - 3
E	0.85	.003	53	0.67 - 4	
	2.25	.028		2.34 - 4	
	4.05	.022		1.02 - 4	
	6.55	.005		0.14 - 4	0.42 - 3
D	0.85	.001	83	0.14 - 4	
	2.25	.009		0.48 - 4	
	4.05	.005		0.15 - 4	0.08 - 3
C	2.25	.001	240	0.02 - 4	
	4.05	.001		0.01 - 4	0.00 - 3
B & A	Negligible by inspection				
				Σ =	2.31 - 3

$$\left(\frac{\chi}{Q}\right)_{2.8\ \text{mi NW}} = \frac{2.032\ (2.31 - 3)}{4.5 + 3} = (1.0 - 6)\frac{s}{m^3}$$

DEIS value from H-36, by interpolation $= (3.3 - 6)\frac{s}{m^3}$

A similar calculation at 3.0 mi SSW of the site gives a value of $(1.4 - 7)\frac{s}{m^3}$ compared to the DEIS value of $(6.2 - 7)\frac{s}{m^3}$.

Also, a calculation for 0.5 mi NW downwind sector was $(1.6 - 5)\frac{s}{m^3}$ compared to $(6.2 - 5)\frac{s}{m^3}$ in DEIS.

II Short Term Averages

The $(\frac{\chi}{Q})_{5\%}$ and $(\frac{\chi}{Q})_{50\%}$ one hour frequencies were calculated from inspection of Tables 16-19, in Annex 1, Appendix H. The key factor in determining each value is to find the $\sigma_{z_i}\mu_i$ value that is minimum at a given distance. This is done in the tabulation below at 800 m.

Stability Category	σ_{z_i} (m)	μ_i $(\frac{m}{s})$	$\sigma_{z_i}\mu_i$ m^2/s	Inverse Ranking
G & F	12	0.85	10	1
		2.25	27	4
		4.05	49	7
		6.55	79	
E	18	0.85	15	2
		2.25	41	5
		4.05	73	
		6.55	117	
D	27	0.8	23	3
		2.25	61	8
C	50	0.8	42	6

A SE wind direction (NW downwind sector) occurs 18.2% of the time. Consequently, the 5% frequency is 0.91% of the total time; the 50% frequency is 9.1%.

Percent occurrence: $G_{.85} = 2.6$; $F_{.85} = 0.7$; $D_{.85} = 0.1$; $E_{.85} = 0.3$; $G_{2.25} = 1.8$; $F_{2.25} = 2.0$; $E_{2.25} = 2.8$.

$\therefore \left(\frac{X}{Q}\right)_{5\%}$ = G stability, 0.85 $\frac{m}{s}$ speed.

$$= \frac{2.032\ (1)}{10(805)} = (2.5 - 4)\frac{s}{m^3}$$

DEIS has $(2.8 - 4)\frac{s}{m^3}$

$\left(\frac{X}{Q}\right)_{50\%}$ = E stability, 2.25 $\frac{m}{s}$

$$= \frac{2.032\ (1)}{41(805)} = (5.2 - 5)\frac{s}{m^3}$$

DEIS has $(6.3 - 5)\frac{s}{m^3}$

III Summary of Results

ATMOSPHERIC DISPERSION COEFFICIENTS
(Comparison of EEG and DEIS values)

Downwind Sector	Long-Term Values DEIS s/m^3		EEG s/m^3	RATIO DEIS/EEG		One-hour Values DEIS s/m^3	EEG s/m^3	RATIO DEIS/EE
SSW, 3.0 mi	6.2-7	(a)	7.8-8	7.9	(c)	5.6-5	1.5-5	3.7
		(b)	1.4-7	4.4	(d)	5.8-6	2.1-6	2.8
NW, 2.8 mi	3.3-6	(a)	4.9-7	6.7	(c)	6.5-5	1.6-5	4.1
		(b)	1.0-6	3.3	(d)	8.3-6	3.8-6	2.2
NW, 0.5 mi	6.2-5	(b)	1.6-5	3.9	(c)	2.9-4	2.5-4	1.2
					(d)	6.3-5	6.2-5	1.0

(a) Short method, using average stability category frequencies from H-35 and wind speed.

(b) Procedure using specific meteorological data in Annex 1, Appendix H.

(c) 5% occurrence, one hour frequency (Table 21, Annex 1, Appendix H).

(d) 50% occurrence, one hour frequency (Table 21, Annex 1, Appendix H).

The agreement is not too close in most cases with the values in the DEIS being consistently higher. Higher values in the DEIS are to be expected from the differences in models. The use of stability Category G parameters and the incorporating of calm winds into the model might reasonably increase the calculations by more than two-fold. Including the plume being blown back on the source would tend to increase the values some also. This is considered satisfactory agreement and it is concluded that the values used in the DEIS are reasonable.

Figure 1 - Vertical dispersion coefficient as a function of downwind distance from the source (2)

3.9

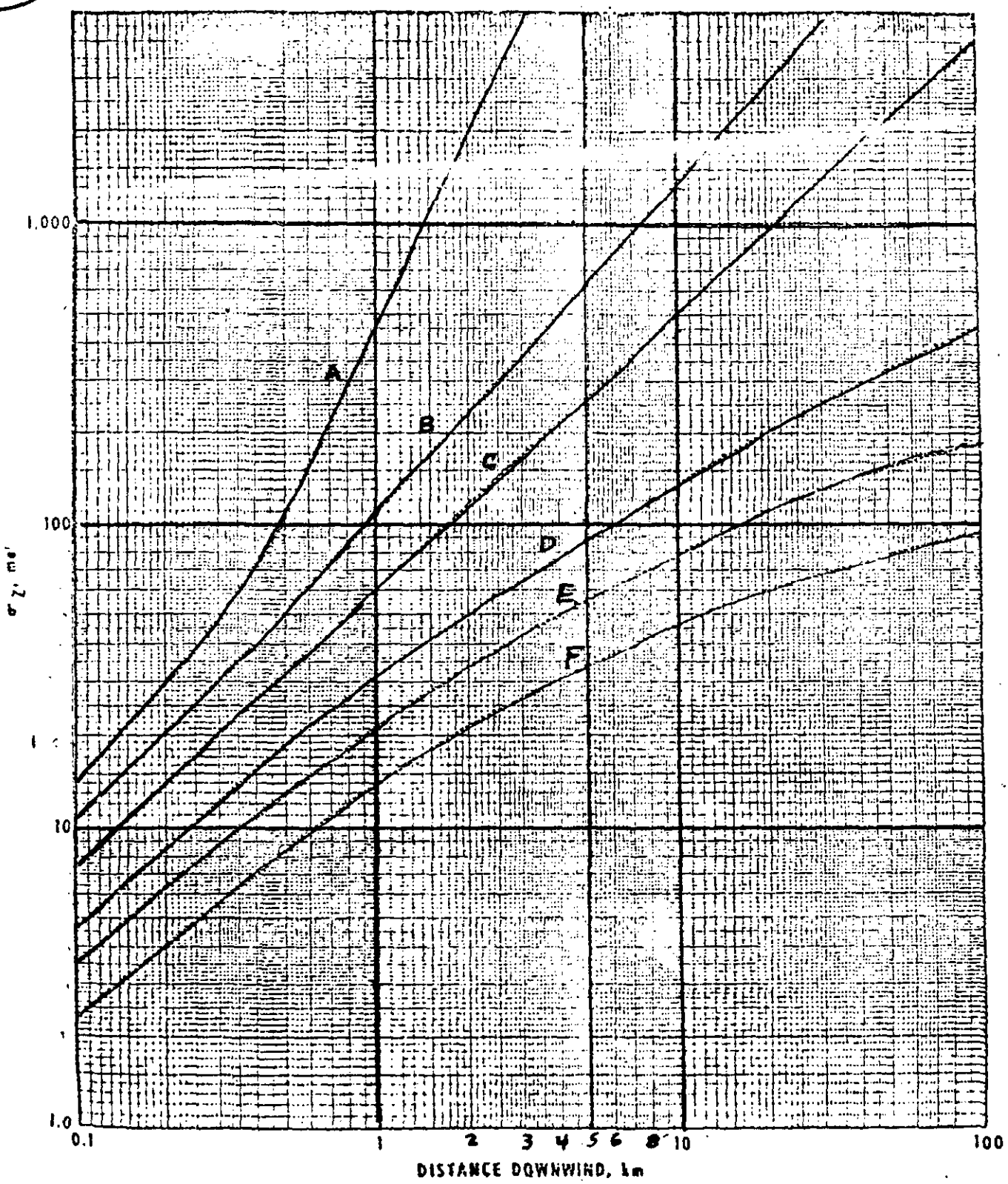

(2) Turner, D. Bruce, "Workbook of Atmospheric Dispersion Estimates", U.S. Department of Health, Education, and Welfare, Public Health Service, 1967.

IV Air Quality χ/Q

For calculation of the 24-hour ground-level concentration of particulates, the DEIS (p. 9-8) used the following equations (from Turner, 1969; PEDCo, 1973):

$$= \frac{0.360}{\pi\mu\sigma_y\sigma_z}$$

and assumed "restrictive dispersion conditions" that gave $(\sigma_y\sigma_z) = 17{,}000\ m^2$ at 2 miles. This is equivalent to category D conditions as computed by the formulas in Table G-1. This gives an "effective χ/Q" of:

$$\frac{\chi}{Q} = \frac{0.36}{\pi\mu(17{,}000)} = \frac{0.36}{\pi(3.14)17{,}000} = (2.1 - 6)\frac{s}{m^3}$$

This value can be compared to the χ/Q values calculated in Appendix H for long term and one-hour frequency.

$$\left(\frac{\chi}{Q}\right)_{50\%} = (15 - 6)\frac{s}{m^3} \quad \text{(SW downwind sector)}$$

$$\left(\frac{\chi}{Q}\right)_{\text{long term}} = (5.9 - 6)\frac{s}{m^3} \quad \text{(NW downwind sector)}$$

Since the 24-hour χ/Q by this calculation is only about one-third of the annual χ/Q calculated in Appendix H, it is concluded that the two methods are inconsistent.

V Transportation X/Q Factors

From page G-3:

$$\frac{X}{Q} = \frac{1}{\pi \sigma_y \sigma_z u} e^{\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]}$$

Assumptions: distance = 0.5 mi, F stability conditions,
μ = 1 m/s, h = 20m

$$\sigma_z = .016d(1 + .0003d)^{-1} = .016(805)[1 + (3-4)(8+2)]^{-1} = 10.39$$

$$\sigma_y = .04d(1 + .0001d)^{-\frac{1}{2}} = 32.2[1+ .08]^{-\frac{1}{2}} = 31.0$$

$$\frac{X}{Q} = \frac{1}{\pi(10.4)(31.0)(1)} e^{-\frac{1}{2}\left(\frac{20}{10.4}\right)} = 9.9\text{-}4(.158) = \underline{\underline{(1.6 - 4)}}\frac{s}{m^3}$$

As comparison:

Worst annual (X/Q) at 0.5 mi = $(9.0 - 5)\frac{s}{m^3}$ (Table H-36).
9% of above.

$(\frac{X}{Q})_{5\%}$ for 1 hour, 0.5 mi = $(4.3 - 4)\frac{s}{m^3}$ (Table 21, App. H).
44% of above.

$(\frac{X}{Q})_{max}$ for 1 hour, 0.5 mi = $(1.1 - 3)\frac{s}{m^3}$. 111% of above.

The $(\frac{X}{Q})$ for ground level release is between 5% and max one-hour $\frac{X}{Q}$ so is conservative compared to values used elsewhere in the DEIS.

Since the assumption of an elevated release significantly reduces the calculated doses, there should be more of a justification

for its use, especially in an accident where no fire is assumed. Furthermore, the assumption of stability F conditions is not especially conservative since less stable conditions can result in similar concentrations occurring closer than 0.5 miles from the source. This analysis should consider other distances and stability categories and also the case of a ground level or other elevated release height.

APPENDIX VI

Simple Model for Estimating Maximum Radionuclide Concentrations in the Pecos River, and Associated Ingestion Doses, due to the Release of Radioactivity from the WIPP Repository

by Moses A. Greenfield

A. The Square Wave Model

The model used in the Draft Environmental Impact Statement (DEIS, 1979) is based on a system of "three coupled partial differential equations describing the behavior of a liquid phase injected into an aquifer system" (INTERA, Sept. 1977). The equations are based on conservation of liquid mass, energy and the mass of a contaminant dissolved in the fluid. Additionally there are equations for each radioactive nuclide which conserve mass for each species and take account of radioactive decay.

Solutions for this complex system of coupled non-linear partial differential equations are obtained by developing finite-difference approximations in a three-diminsional grid (INTERA, Sept. 1977). There is also interest in developing relatively simpler solutions based on a one-dimensional approximation. The authors of the INTERA report checked the adequacy of their programmed trace component equations by comparison with known one-dimensional analytical solutions for radioactive chains (Lester et al, 1975). One-dimensional transport models have been developed by a number of writers and used to test parameter dependence and to compare different nuclide behaviors (Holly et al, 1971; Borg et al, 1976; Barr, 1979). It is helpful to give an elementary derivation to gain insight into the importance of the various terms that appear.

In Holly's treatment (loc. cit.) account is taken of nuclide transport due to water flow in a homogeneous, isotropic, porous aquifer with hydrodynamic dispersion, adsorption and desorption, and radioactive decay, with a one-dimensional spatial coordinate.

Figure I depicts a homogeneous, isotropic aquifer with groundwater flow rate $\bar{v}$, porosity Θ, single spatial coordinate x, and L and S representing the liquid and solid phases respectively. C_L, C_S represent the concentrations of a radionuclide in the two phases. An equation representing material balance in the element Δx after a time passage, Δt, may be written as follows:

I. $\theta \cdot \Delta x \cdot \Delta C_L + (1 - \theta) \cdot \Delta x \cdot \Delta C_S = C_L \cdot \theta \cdot \bar{v} \cdot \Delta t$

(expresses change in quantity of nuclide after a time passage, Δt, in volume element Δx.)

(flow in)

$$-\left(C_L + \frac{\partial C_L}{\partial x} \Delta x\right) \cdot \theta \cdot \bar{v} \cdot \Delta t$$

$\cdot$(flow out)

$$- \lambda \Delta t \left[\theta \cdot \Delta x \cdot C_L + (1 - \theta) \cdot \Delta x \, C_S\right]$$

(decay Fraction) (inventory in L,S.)

$$-D_L \frac{\partial C_L}{\partial x} \cdot \theta \Delta t + D_L \left[\frac{\partial C_L}{\partial x} + \frac{\partial^2 C_L}{\partial x^2} \Delta x\right] \theta \Delta t$$

(flow associated with dispersion at entrance, exit of element; D_L assumed independent of x.)

Equation I represents the material balance for any nuclide; λ is the decay constant and D_L is the coefficient of hydrodynamic dispersion.

Combining terms and dividing by $\theta \cdot \Delta x \cdot \Delta t$, gives:

$$\text{II.} \quad \frac{\partial C_L}{\partial t} + \frac{1 - \theta}{\theta} \frac{\partial Cs}{\partial t} = - \bar{v} \frac{\partial C_L}{\partial x} + D_L \frac{\partial^2 C_L}{\partial x^2} - \lambda \left[C_L + \frac{1 - \theta}{\theta} Cs\right]$$

Adsorption may be introduced by assuming instantaneous equilibrium and reversibility between liquid and solid phases. with:

$$C_s = K_d' C_L \quad (K_d' \text{ dimensionless})$$

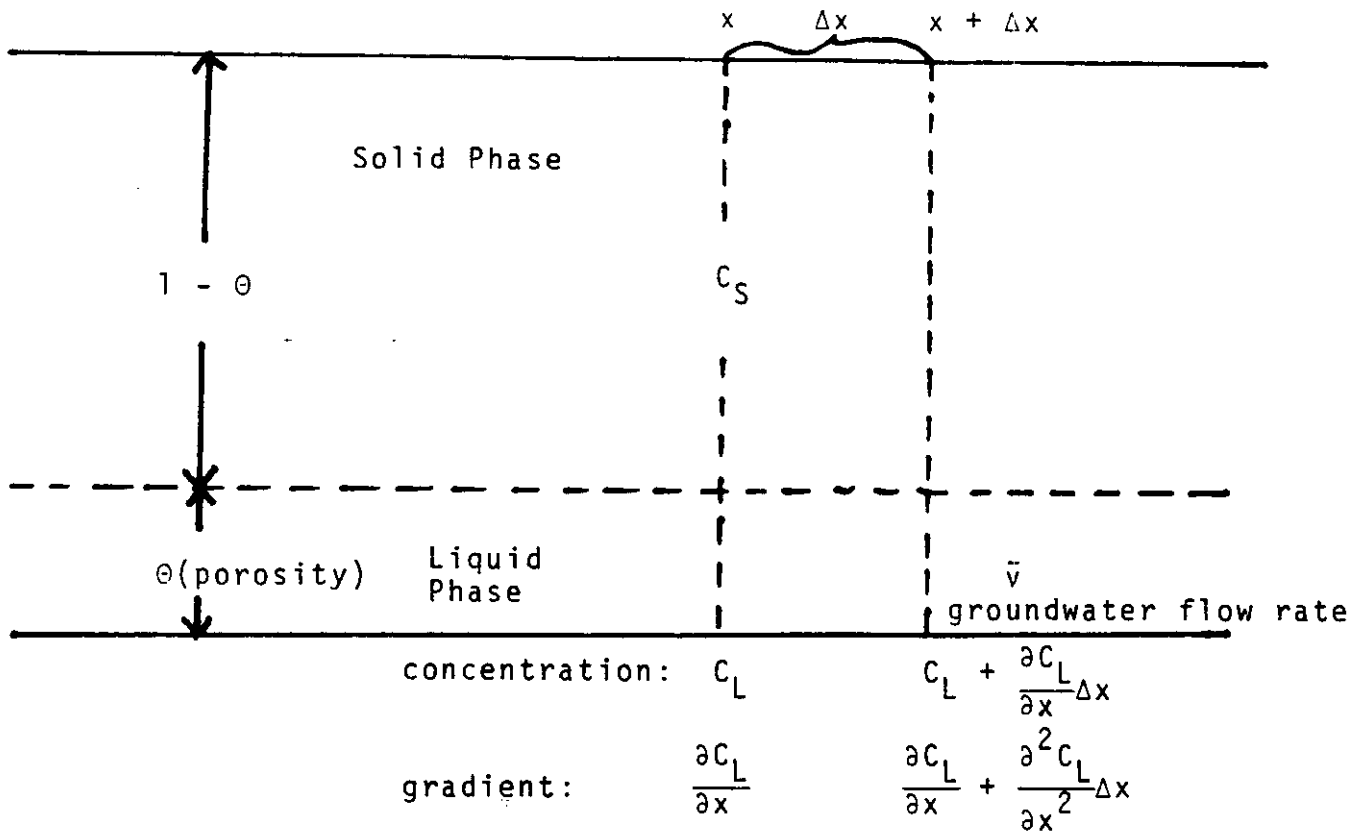

Volume Elements:

Liquid $\Theta\Delta x$

Solid $(1-\Theta)\Delta x$

C_L, C_S in $\frac{\mu Ci}{ml}$ or similar units

Figure 1

Also, let $K_d' = \rho_B K_d$, with ρ_B(g/ml) = bulk density of aquifer.

Then $\frac{Cs}{\rho_B} = K_d C_L$; ($\frac{Cs}{\rho_B}$ in uCi/g, K_d in ml/g).

K_d is called the distribution coefficient, and is a measure of the extent to which the solid adsorbs the nuclide. Values for K_d are listed in the DEIS, Volume II, Table K-3, page K-20, and were used as input parameters for the calculations made in the report.

Replace C_s in II by $\rho_B K_d C_L$. Then

$$\text{III.} \quad \left(\frac{\partial C_L}{\partial t} + \lambda C_L\right)\left(1 + \frac{1-\Theta}{\Theta} \rho_B K_d\right) = -\bar{v}\frac{\partial C_L}{\partial x} + D_L \frac{\partial^2 C_L}{\partial x^2}.$$

IV. Let $B = 1 + \frac{1-\Theta}{\Theta}\rho_B K_d$; $K_L = e^{\lambda t} C_L$.

Then:

$$\text{V.} \quad B\frac{\partial K_L}{\partial t} = -\bar{v}\frac{\partial K_L}{\partial x} + D_L \frac{\partial^2 K_L}{\partial x^2}$$

Let $t' = t/B$.

Then:

$$\text{VI.} \quad \frac{\partial K_L}{\partial t'} = -\bar{v}\frac{\partial K_L}{\partial x} + D_L \frac{\partial^2 K_L}{\partial x^2}.$$

Values for $D_L = 185\ m^2/yr$ (P. Brannen, personal communication to M. Greenfield, 1979) and $\bar{v} = 4.45$ m/yr (=0.04 ft/day) (DEIS, II, K-14; also DEIS, I, 9-112) have been used in the report calculations.

Note that $\frac{D_L}{\bar{v}} = 41$ m = 136 ft.

If the concentration gradient changes are small in ~40 meters, perhaps $D_L \frac{\partial^2 K_L}{\partial x^2}$ can be neglected in some approximation compared to $\bar{v}\frac{\partial K_L}{\partial x}$.

VII $$\frac{\partial K_L}{\partial t'} + \bar{v}\,\frac{\partial K_L}{\partial x} = 0$$

Any function of the form $f\,(x - \bar{v}t')$ or $f[x - (\frac{\bar{v}}{B})\,t]$ will satisfy this partial differential equation; it represents a traveling wave form, f, moving with the speed $\frac{x}{t} = \frac{\bar{v}}{B}$ from repository site towards the river. Thus if B>>1, then the consequences will be a retarded nuclide movement. The actual concentration C_L is of the form $e^{-\lambda t}f$. For a collection of nuclides, indexed by i, each will move with its own velocity, $\bar{v}/Bi$, and will be modified by its own decay factor, $e^{-\lambda_i t}$, and the appropriate inventory activity, A_i.

If one assumes a common dissolution time, T_d, then $\frac{A_i}{T_d}$ is the time rate of release from the repository, acting as a source term. Figure 2 depicts the "spectral" composition of nuclides traveling from the repository to the Pecos River.

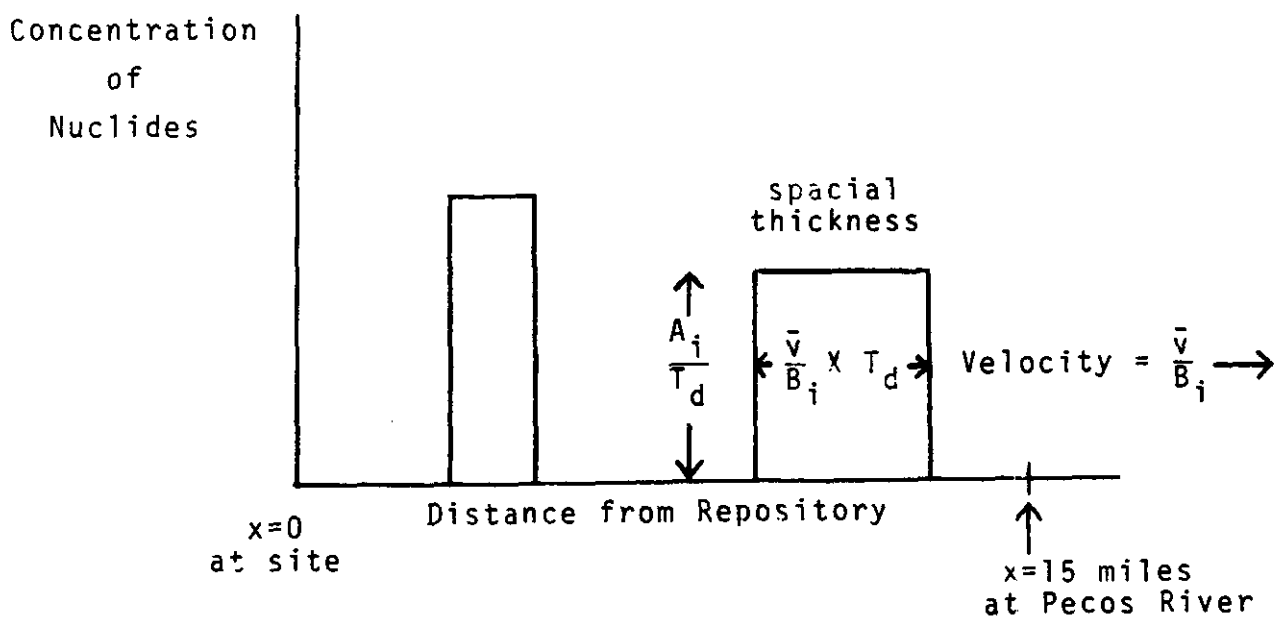

Figure 2.

Arrival time $(AT)_i$ to Pecos River is $\frac{15 \text{ miles}}{\bar{v}/B_i}$.

Release Rate from Repository (RRR) is $\frac{Ai}{T_d}$.

Discharge Rate at Pecos River (DR_{PR}) is $\frac{Ai}{T_d} e^{-\lambda_i (AT)_i}$

If the flow rate of the Pecos River is F, then the concentration of nuclides at the Pecos River, (C_{PR}), is $\frac{Ai}{T_d} \cdot \frac{1}{F} \cdot e^{-\lambda_i (AT)_i}$, at the arrival time $(AT)_i$.

The purpose of constructing this rather crude and simple "square wave" model is to use a zero order approximation approach for comparison with the calculations in the DEIS reports. Since the model is one-dimensional and dispersivity is neglected, one may reasonably expect concentrations and doses to be greater than those based on a more elaborate 3 dimensional approach. Clearly this comparison is intended only as a rough check on the validity of the methodology used in the DEIS calculations. If there is an approximate agreement, then attention may be turned to the assumed values for the input parameters, notably $\bar{v}$ the groundwater flow velocity and the K_d values.

B. Parent-Daughter Decay Chain

The preceeding analysis assumes that repository inventory accounts for all the nuclides that potentially may travel towards the Pecos River. Actually one must consider daughter decay products as additional sources. In some instances the production of the nuclide via decay may be much greater than the source from the repository. Another reason for the importance of decay products stems from the retardation values, B, for some nuclides. For example, the K_d value for Thorium is given as 2200 $(\frac{ml}{g})$ (DEIS, II, Table K-3, p. K-20). This leads to a B value of the order of 10^4, which precludes the travel of Thorium from the repository (Th-230 and Th-229). However,

Th-229 is the daughter decay product of U-233 which is present in the repository inventory. The listed value of K_d for uranium is 1 (ml/g) (DEIS, II, Table K-3, p. K-20) which leads to a B value for uranium of about 19. Thus U-233 travels from the repository to the Pecos River in a time interval of approximately $(AT)_{U-233}$ = 19(15 mi./.04 ft./day) = 10^5 years. The Th-229 in effect gets a "piggy-back" ride and makes the journey in the same time interval. The following analysis develops the relations needed to compute release rates into the Pecos River and consequent concentrations.

Assume a single daughter, D, from a parent, P, with decay constants λ_D, λ_P. The initial parent activity (in the repository) is $A_{P,0} = \lambda_P N_{P,0}$ ($N_{P,0}$ is the number of parent atoms initially in the repository). Assume the daughter activity initially is $A_{D,0} = 0$.

In general.

I.
$$\frac{dN_D}{dt} = \lambda_P N_P - \lambda_D N_D = A_P - A_D$$

$$N_P = N_{P,0} e^{-\lambda_P t}$$

Thus, at t=0:

II.
$$\left.\frac{dN_D}{dt}\right|_0 = \lambda_P N_{P,0} = A_{P,0}$$

Thus, the initial rate of production of daughter activity is:

III.
$$\lambda_D \left.\frac{dN_D}{dt}\right|_0 = \left.\frac{dA_D}{dt}\right|_0 = \lambda_D A_{P,0}.$$

For a very long lived parent, III is a convenient approximation for computing the rate of production of a daughter.

The general solution for I is:

IV.
$$N_D = \frac{A_{P,0}}{\lambda_D - \lambda_P} \left[e^{-\lambda_P t} - e^{-\lambda_D t}\right]$$

The general form for $\frac{dA_D}{dt} = \lambda_D \frac{dN_D}{dt}$ can be stated as:

V. $$\frac{dA_D}{dt} = \lambda_D A_{P,0} \left[\frac{\lambda_D e^{-\lambda_D t} - \lambda_P e^{-\lambda_P t}}{\lambda_D - \lambda_P} \right]$$

One may also compute the ratio (A_D/A_P):

VI. $$\frac{A_D}{A_P} = \frac{\lambda_D}{\lambda_D - \lambda_P} \left[1 - e^{-(\lambda_D - \lambda_P)t} \right]$$

For sufficiently long times (with $\lambda_D t >> 1$), VI becomes:

VII. $$\frac{A_D}{A_P} = \frac{\lambda_D}{\lambda_D - \lambda_P}$$

An approximation for the daughter discharge rate into the Pecos River can be derived. Assume that $B_D >> B_P$. One may picture the "square wave" concentration of the parent making its journey to the Pecos River, dropping or leaving behind the daughter product distributed along the pathway from repository to the Pecos River. Compute the total activity of the daughter at the arrival time, AT_P, of the parent $\left(AT_P = \frac{15 \text{ miles}}{\bar{v}/Bp}\right)$, distributed spatially along the 15 miles.

From VI:

VIII. $$A_D = \frac{\lambda_D}{\lambda_D - \lambda_P} \left[1 - e^{-(\lambda_D - \lambda_P)(AT)_P} \right] \times A_{P,0} e^{-\lambda_P (AT)_P}$$

If one makes the approximation that this activity of the daughter is uniformly spread over the 15 miles (actually there is a small gradient which is computed later in this report for an actual case), then the spatial distribution at the time AT_P is:

$$\frac{\Delta A_D}{\Delta x} = \frac{A_D}{15} \Bigg|_{t = AT_P}$$

Now one may compute the linear velocity of this distributed activity as:

$$V_D = \frac{\bar{v}}{B_D}$$

Combining the spatial distribution with the velocity yields the discharge rate into the Pecos River (DR_{PR}):

IX. $$DR_{PR} = \frac{A_D}{15} \times \frac{\bar{v}}{B_D}\Bigg|_{t=AT_p}$$

C. Computation of Discharge Rates into the Pecos River and of Concentrations; Comparison of Peak Values (and Times) With Intera Calculations

Scenario 4 mandates the full flow of Rustler aquifer through the repository, and assumes the complete dissolution of the spent fuel assemblies along with the bedded salt. The DEIS states that this proposed event is a bounding case, and for this reason it was chosen for calculation using the linear, square-wave model.

Column 1 of Table 1 lists the nuclide and Column 2 lists the inventory activity, A, in curies contained in the 1000 spent fuel assemblies in the repository. These numbers are based on the tabulated values of Ci/liter for each nuclide, 10 years after discharge from the reactor, (DEIS, I, Table 9-44, p. 9-104), and the computed volume per assembly (or canister) of 485 liters. This number is based on the stated dimensions of the assembly as 14 inch diameter by 16 foot length.

$$Vol_{can} = \frac{\pi D^2 H}{4} = \frac{\pi}{4}\left(\frac{14}{12}\right)^2 \; 16 \text{ ft.}^3$$

$$= 17.1 \text{ ft.}^3 = 485 \text{ l.}$$

Thus the inventory listing for Tc-99 is obtained as:

$$1.4 \times 10^{-2} \text{ Ci/l} \times 485 \text{ l/can} \times 10^3 \text{ can}$$

$$= 6.8 \times 10^3 \text{ Ci.}$$

Th-232 is omitted in column I because the inventory is very small, a factor of 10^4 less than the next larger amount (Th-229).

Column 3 lists the release rate from the repository (RRR) in (μCi/sec), obtained by dividing the activity in column 2 by the dissolution time T_d = 4650 yrs. = 1.47×10^{11} sec.

This value for T_d is based on a dissolution rate of 21.4 $ft.^3$/day (salt plus radioactive material), and a repository volume of (930 x 930 x 42)$ft.^3$ = 3.63×10^7 $ft.^3$. Thus $T_d = \frac{3.63 \times 10^7}{21.4}$ days = 1.70×10^6 days = 4,650 yrs. = 1.47×10^{22} sec.

(DEIS, I, p. 9-112; II, p. K-14.)

Column 4 lists the values for the retardation factor, $B = 1 + \frac{1-\theta}{\theta}\rho_B K_d$ (equation IV, section A). The porosity, Θ, for the Rustler aquifer is taken as 0.1 (DEIS, II, K-18): ρ_B is assumed to be $2 g/m^3$. Values for K_d are taken from DEIS, II, Table K-3, p. K-20.

Column 5 lists arrival times, AT, at the Pecos River computed as:

$$(AT)_i = B_i \ (5280) \text{ years.}$$

Since $(AT)_i$ = 15 mi./($\bar{v}/B_i$) and $\bar{v}$ = .04 ft./day or 15 ft./yr.

Column 6 lists half- lives (DEIS, I, Table 9-44, 9-104).

Column 7 lists computed discharge rates into the Pecos River (DR_{PR}) in units of (μCi/sec), based on the release rate from repository with an appropriate decay factor: $(DR_{PR}) = (RRR)e^{-\lambda(AT)}$.

Column 8 lists the concentration in the Pecos River computed by dividing the discharge rate by the volume flow rate of the river, 515 l/s (DEIS I, 9-116).

Column 9 lists peak values for concentrations in the Pecos River as computed by INTERA and listed in BDM/TAC 79-156-TR, Appendix B, P. B-4 through B-27.

D. Discharge Rates into Pecos River, Concentrations for Daughter Products

Discharge rates for a number of nuclides were not computed (column 7) either because of relatively short half-lives, or rather large B (K_d) values or both (Ra-226, Th-229, Th-230, Np-237, Pu-239, Pu-240, Pu-242, Am-243). However a number of these are produced as daughter products of "traveling" parents and computations are then made on that basis. For example:

U-234 (P) $\rightarrow\rightarrow\rightarrow$ Th-230 (D);
Th-239 (P) $\rightarrow\rightarrow\rightarrow$ Ra-226 (D);

Thus both Ra-226 and Th-230 will piggy-back on the U-234.

In the case of U-233, the repository is a source. Np-237 in the repository doesn't travel because of a large B(K_d) value. However Np-237 does produce U-233, which constitutes a second (and larger) source for that nuclide. Additionally:

U-233 (P) $\rightarrow\rightarrow\rightarrow$ Th-229(D).

In this case the Th-229 will piggy-back on a traveling parent, U-233.

D.1. Consider this series:

U-238 (4.8×10^9 yrs.)
$\downarrow$
U-234 (2.4×10^5 yrs.)
$\downarrow$
Th-230 (0.77×10^5 yrs.)
$\downarrow$
Ra-226 (1.6×10^3 yrs.)

For the first pair (U-238, U-234):

$A_{U\text{-}238}$ (repository) = 146Ci
RRR U-234 = 5.9×10^{-3} (μCi/sec)

(from Table 1, column 2 and 3). From section B, equation III,

$$\lambda_{U-234} \frac{dN_U}{dt} = \frac{0.693}{2.4 \times 10^5 \text{ yr.}} \times 146 \text{ Ci} \times 10^6 \ \mu\text{Ci/Ci}$$

$$\times \frac{\text{yr.}}{0.315 \times 10^8 \text{ sec.}}$$

$$= 1.3 \times 10^{-5} \ \mu\text{Ci/sec.}$$

This is <1/4% of RRR U-234, and is unimportant as a source term.

D.2. Now consider U-234→ Th-230; A_{U-234} = 870 Ci.

Compare the initial rate of growth of Th-230 activity with the repository source, RRR_{Th-230}. From section B, equation III,

$$\lambda_{Th-230} \frac{dN_{Th-230}}{dt} = \frac{0.693}{0.77 \times 10^5 \text{ yr.}} \times 8.7 \times 10^2 \text{ Ci}$$

$$\times 10^6 \ \mu\text{Ci/Ci} \times \frac{\text{yr.}}{0.315 \times 10^8 \text{ sec}}$$

$$= 2.5 \times 10^{-4} \ \mu\text{Ci/sec.}$$

This is about 5 x RRR_{Th-230} (= 4.6×10^{-5} µCi/sec).

Thus not only is the radioactive decay of U-234 a larger source term to produce Th-230 (compared to repository), but the uranium also acts as a carrier.

The method outlined in section B is now used to compute the discharge rate into the Pecos River.

First compute the total activity of the Th-230, distributed along the 15 miles. The time of interest is the arrival time, AT, for the parent of U-234, which is 1.0×10^5 yrs. (Table 1, column 5). At t = 10^5 yrs., the activity of U-234 is:

$$A_{U-234(t=o)}\ e^{-\lambda_{U-234}(AT)}$$

$$= 870\ \text{Ci} \times \exp\left\{\frac{-0.693 \times 10^5}{2.4 \times 10^5}\right\}$$

$$= 870 \times 0.75$$

$$= 652\ \text{Ci}.$$

The activity of daughter Th-230 is given by (section B, equation VIII):

$$\frac{A_{Th-230}}{A_{U-234}} = \frac{0.693/0.77}{(0.693/0.77) - (0.693/2.4)} \times \left[1 - e^{-\left(\frac{0.693}{0.77} - \frac{0.693}{2.4}\right)}\right]$$

$$= 0.67.$$

Thus, $A_{Th-230} = 652 \times 0.67 = 437$ Ci at $5=10^5$ yrs.

The distribution of this activity spatially over the 15 miles is not uniform, but the gradient is not large. It can be estimated by computing the rate of formation in (Ci/Kyr) at the Pecos River ($t=10^5$ yrs.) vs. the rate of formation at the repository with an allowance for a time interval of 10^5 hrs. to elapse.

Using section B, equation III, at the repository, at t=0:

$$\frac{dA_{Th-230}}{dt} = \frac{0.693}{0.77 \times 10^2\ \text{Kyr}}\ (870\text{Ci}) = 7.8\ \text{Ci/Kyr}$$

Thus at the repository, at $t=10^5$ yrs., this would in effect be diminished by the decay factor:

$$\exp\left\{\frac{-.693 \times 10^5}{0.77 \times 10^5}\right\} = 0.407$$

or $\frac{dA_{Th-230}}{dt} = 7.8(.407) = 3.2$ Ci/Kyr at the repository at $t=10^5$ yrs.

However at the Pecos River, at $t=10^5$ yrs, from section B, equation V:

$$\frac{dA_{Th-230}}{dt} = \left(7.8\ \frac{Ci}{yr}\right)\left[\frac{\frac{0.407}{0.77} - \frac{0.749}{2.4}}{\frac{1}{0.77} - \frac{1}{2.4}}\right] = 1.9\ Ci/Kyr$$

Thus an inventory of 437 Ci of Th-230 is distributed along the path from the repository to the Pecos River, with a spatial gradient such that the relative concentration (Ci/mile) at the repository is just $\frac{3.2}{1.9} = 1.7$ x the value at the Pecos River. If the variation is assumed to be linear with distance it can be shown that the spatial gradient varies from 36.7 $\frac{Ci}{mile}$ at the repository to 21.7 Ci/mile at the Pecos River. (If uniformity had been assumed, the value would be $\frac{437\ Ci}{15\ miles} = 29.1\ \frac{Ci}{mile}$). The linear speed of this activity is computed as:

$$V_{Th-230} = \frac{\bar{v}}{B_{Th-230}} = \frac{0.04\ ft/day}{0.396 \times 10^5}\left[\frac{1}{0.528 \times 10^4\ ft./mile}\right] \times \left[\frac{1}{0.864 \times 10^5\ sec/day}\right]$$

$$= 0.221 \times 10^{-14}\ miles/sec.$$

Combining the speed with spatial gradient one computes the discharge rate:

$$DR_{Th-230} = 21.7\ \frac{Ci}{mile}\left(10^6\ \frac{\mu Ci}{Ci}\right) 0.221 \times 10^{-14}\ \frac{miles}{sec}$$

$$= 4.80 \times 10^{-8}\ \frac{\mu Ci}{sec.}$$

Dividing by the flow rate of the Pecos River, $F = 515\ \frac{\ell}{sec}$:

$$C_{PR,\ Th\text{-}230} = \frac{4.80 \times 10^{-8}\ \frac{\mu Ci}{sec}}{5.15 \times 10^{2}\ \frac{\ell}{sec}}$$

$$= 0.93 \times 10^{-10}\ \mu Ci/\ell.$$

The comparison value (Intera) listed in BDM-TAC 79-156-TR, Appendix B, B-12 is:

$$1.01 \times 10^{-10}\ \frac{\mu Ci}{\ell} \quad \text{at} \quad t = 10^{5}\ \text{years.}$$

D.3. The calculation for radium-226, the last daughter of interest in the U-238 chain can only be approximated with the crude model being used, in part because of its relatively short half-life. However an upper limit can be estimated.

Since Ra-226 is so short-lived, it may be assumed to be in secular equilibrium with its parent, Th-230. At or close to the time $t = 10^5$ years, the parent activity is $A_{Th\text{-}230} = 437$ Ci (see D.2.). In this case, use section B equation VII, to compute the daughter activity:

$$A_{Ra\text{-}226} = 437\ (1.02) = 446\ \text{Ci.}$$

The spatial distribution will be the same, virtually, as for the Th-230. Thus at or near the Pecos River the spatial gradient will be $21.7 \times 1.02 = 22.1\ \frac{Ci}{mile}$. If one assumes that the Th-230 distribution has advanced to or near the Pecos River, then the Ra-226 would move with greater speed, since its B value is much lower (~ 450) than that for Th-230 (39,600). The potential discharge rate into the Pecos River would be the product of the spatial gradient and the speed of advance. Thus:

$$DR_{Ra\text{-}226} = 22.1 \times 10^{+6}\ \frac{\mu Ci}{mile} \times \frac{0.04\ \frac{ft.}{day}}{450} \times \frac{1}{5.28 \times 10^{3}\ ft./mile}$$

$$\times \frac{1}{8.64 \times 10^{4}\ sec./day} = 4.31 \times 10^{-6}\ \mu Ci/sec.$$

This must be considered an upper limit, since it is clear that prior to the arrival of Th-230 to the Pecos River, the production of the Ra-226 from the leading edge of the Th-230 would "race" ahead of the thorium column, but would also undergo relatively rapid decay (radium has a short half-life in this context of 1600 yrs.). Thus there would actually be some build-up of Ra-226 at or near the Pecos River over some period of time.

The discharge rate computed above must be compared with the total production rate of Ra-226 from Th-230, to ascertain whether that would constitute a rate-limiting process. Using section B, equation III:

$$\frac{dA_{\text{Ra-226}}}{dt} = \frac{0.693}{1600 \text{ yrs.}} (437 \text{ Ci}) \left(10^{+6} \frac{\mu\text{Ci}}{\text{Ci}}\right) \frac{1}{0.315 \times 10^{8} \frac{\text{sec}}{\text{yr.}}}$$

$$= 0.60 \times 10^{-2} \ \mu\text{Ci/sec.}$$

Thus Th-230 is producing Ra-226 at a rate which is orders of magnitude greater than the rate at which Ra-226 is leaving Th-230 as a discharge into the Pecos River.

An upper limit value for the concentration in the Pecos River is computed by dividing the discharge rate by the river's flow rate, F:

$$C_{\text{PR, Ra-226}} = \frac{0.431 \times 10^{-5} (\mu\text{Ci/sec})}{0.515 \times 10^{3} \ (1/\text{s})}$$

$$= 0.84 \times 10^{-8} \ (\mu\text{Ci/l})$$

$$= 8.4 \times 10^{-9} \ (\mu\text{Ci/l}).$$

The listed concentrations in BDM/TAC 79-156-TR, Appendix B, B-13, show increasing values up to the last tabulation for $t=10^5$ yrs. of 7.5×10^{-10} (μCi/l).

D.4. Consider Np-237 $\rightarrow\rightarrow\rightarrow$ U-233 as a source term for the U-233. The repository produces a release rate for U-233 of 0.99×10^{-5} μCi/sec, and continues this for a dissolution time DT = 4650 yrs. For this same time interval one may compute the activity of U-233 produced by decay from the Np-237 inventory of 440 Ci.

From Section B, equation VI:

$$\frac{A_D}{A_P} = \frac{\lambda_D}{\lambda_D - \lambda_P} \quad [1 - e^{-(\lambda_D - \lambda_P)t}].$$

In this case t (=4650 yrs.) is sufficiently small that $(\lambda_D - \lambda_P)t \ll 1$. Thus one may rewrite the above as:

$$\frac{A_D}{A_P} = \lambda_D \cdot t,$$

(by expanding the exponential).

Thus: $$A_{U-233} = A_{Np-237} \times \frac{0.693 \times 4560}{1.6 \times 10^5}$$

$$= 440 \text{ Ci} \times 0.020$$

$$= 8.86 \text{ Ci at } t = 4650 \text{ yrs.}$$

This is in effect to be added to the repository inventory of 1.46 Ci for U-233. Thus the correction to the previously computed concentration in the Pecos River of 1.2×10^{-8} μCi/l is:

$$1.2 \times 10^{-8} \times \frac{8.86 + 1.46}{1.46} = 8.5 \times 10^{-8} \left(\frac{\mu Ci}{l}\right).$$

See the entry in column 8, Table 1 for U-233. Compare with the BDM, Appendix B, B-25 value of 6.2×10^{-8} $\left(\frac{\mu Ci}{l}\right)$.

D.5. Consider Th-229 as the daughter of U-233. As the U-233 moves to the Pecos River, it produces Th-229 which is then distributed over the 15 miles from the repository to the river (because of the large B value for Thorium). To obtain the total activity of Th-229 produced by decay, it is first necessary to compute the total activity of U-233 produced in $t = 10^5$ years by decay from Np-237. From section B, equation VI:

$$\frac{A_{U-233}}{A_{Np-237}} = \frac{\lambda_{U-233}}{\lambda_{U-233} - \lambda_{Np-237}} \times \left[1 - e^{-(\lambda_{U-233} - \lambda_{Np-237})t}\right]$$

at $t = 10^5$ yrs., with appropriate values for the λ's:

$$\frac{A_{U-233}}{A_{Np-237}} = 0.356;$$

at $t = 10^5$ yrs., $A_{Np-237} = 440 \times \exp\left\{\frac{-0.693}{21}\right\}$

$$= 426 \text{ Ci.}$$

Thus $A_{U-233} = 151$ Ci at $t = 10^5$ yrs. Since Th-229 is a short lived daughter, it will be in transient equilibrium with U-233 and have virtually the same activity of 151 Ci.

Thus the spatial distribution of the Th-229 is $\frac{151}{15} \frac{\text{Ci}}{\text{mile}} = 10.0 \frac{\text{Ci}}{\text{mile}}$

$$= 10 \times 10^6 \frac{\mu\text{Ci}}{\text{mile}} .$$

The linear speed of the Th-229 is $0.221 \times 10^{-14} \frac{\text{miles}}{\text{sec}}$ (see similar calculations for Th-230).

Therefore: $DR_{PR} = 10.0 \times 0.221 \times 10^{-14} \times 10^{+6}$

$= 2.21 \times 10^{-8}$ µCi/sec

and $C_{PR,\ Th\text{-}229} = \dfrac{2.21 \times 10^{-8}}{0.515 \times 10^{+3}} \quad \dfrac{\mu Ci}{l}$

$= 4.3 \times 10^{-11} \ \dfrac{\mu Ci}{l}$.

Compare with BDM, Appendix B, B-26 value of 1.5×10^{-11} (µCi/l).

E. Comparison of I-129 and TC-99 with DEIS, I, for Discharge Rate and Maximum Concentrations

The computed value for the discharge rate into the Pecos River for I-129 is $1.0 \times 10^{-4} \ \dfrac{\mu Ci}{sec} \times 0.864 \times 10^{5} \ \dfrac{sec}{day}$ = (µCi/day).

The value given as a maximum in DEIS, I, Fig. 9-14(b), 9-113 is 12.2 (µCi/day).

One may picture the time sequence for the square-wave calculation and for the DEIS computation as follows:

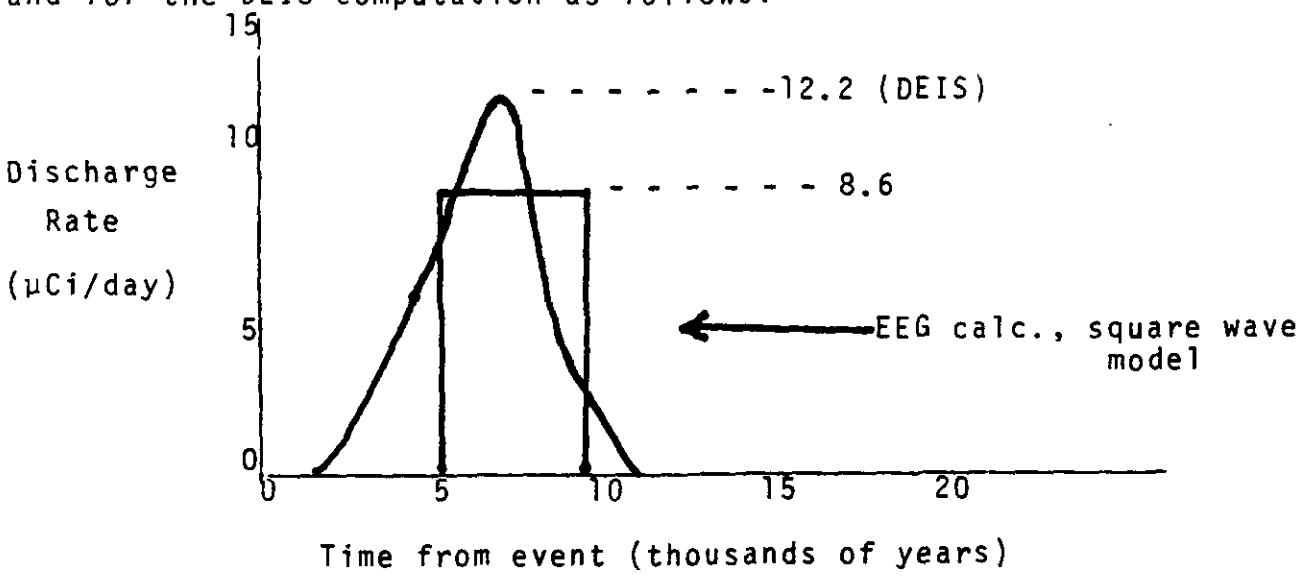

Figure 3

For the concentration at the Pecos River, one may picture the time sequence as follows:

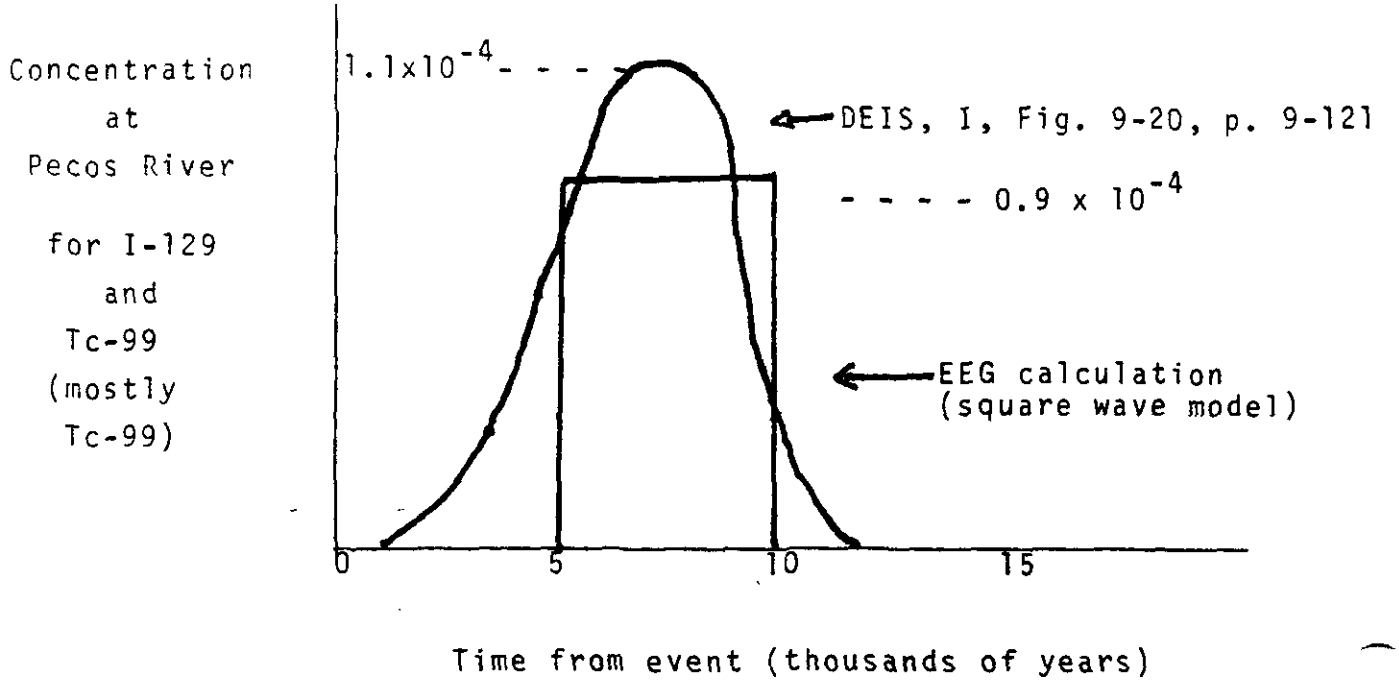

Figure 4

F. Use of "Square Wave" Model to Calculate Dosages to Whole Body and Organs

Scenario 4, Spent Fuel Assemblies at Malaga Bend

One may test the square wave model by combining Pecos River concentrations (μCi/l) with the assumed ingestion rate of 730 (l/yr.) to obtain μCi ingested. The mrem dose will be spread over a time interval depending on the t_{eff} (effective half-life) for the nuclide in the whole body (or organ of interest). Conventionally a 50 year commitment period is utilized. For nuclides like Tc-99 with rapid elimination (t_{eff} ~ 5 to 30 days), the dosage interval virtually coincides with the ingestion time. For radium and thorium with very slow elimination, the body (organ) content diminishes slowly, and the dosage is spread over the 50 years. Thus, the final computed dose is equivalent to mrem/yr. only for rapidly equilibrated nuclides (Tc-99). For others, the designation is the unavoidably awkward: mrem/per 50 yr. per μCi ingested. If the ingestion is assumed to re-occur a second year, a third year, etc., then the mrem/50 yr. will increase approximately linearly with the total ingested number of μCi's, for radium and thorium but not for Tc-99 (see Figure 5).

Note the temporal relation between uptake rate I (μCi/yr.) and body or organ content q (μCi) for various nuclides.

Note that the DEIS, pages 9-122 and 9-123, uses the notation "Dose rate (rem/yr.)" which is inappropriate. To be consistent with its own source material it should read: "Dose Commitment/ one year intake" or equivalent.

Nuclide	T_{eff}	I (uptake rate, μCi/yr.)	q(body or organ content, μCi
Tc-99	5-30 d.		
I-129	7-100d (thyroid)		
U	15-300d (bone)		
Th	55 yrs. (kidney) 190 yrs. (bone)		
Ra-226	44 yrs. (bone)		

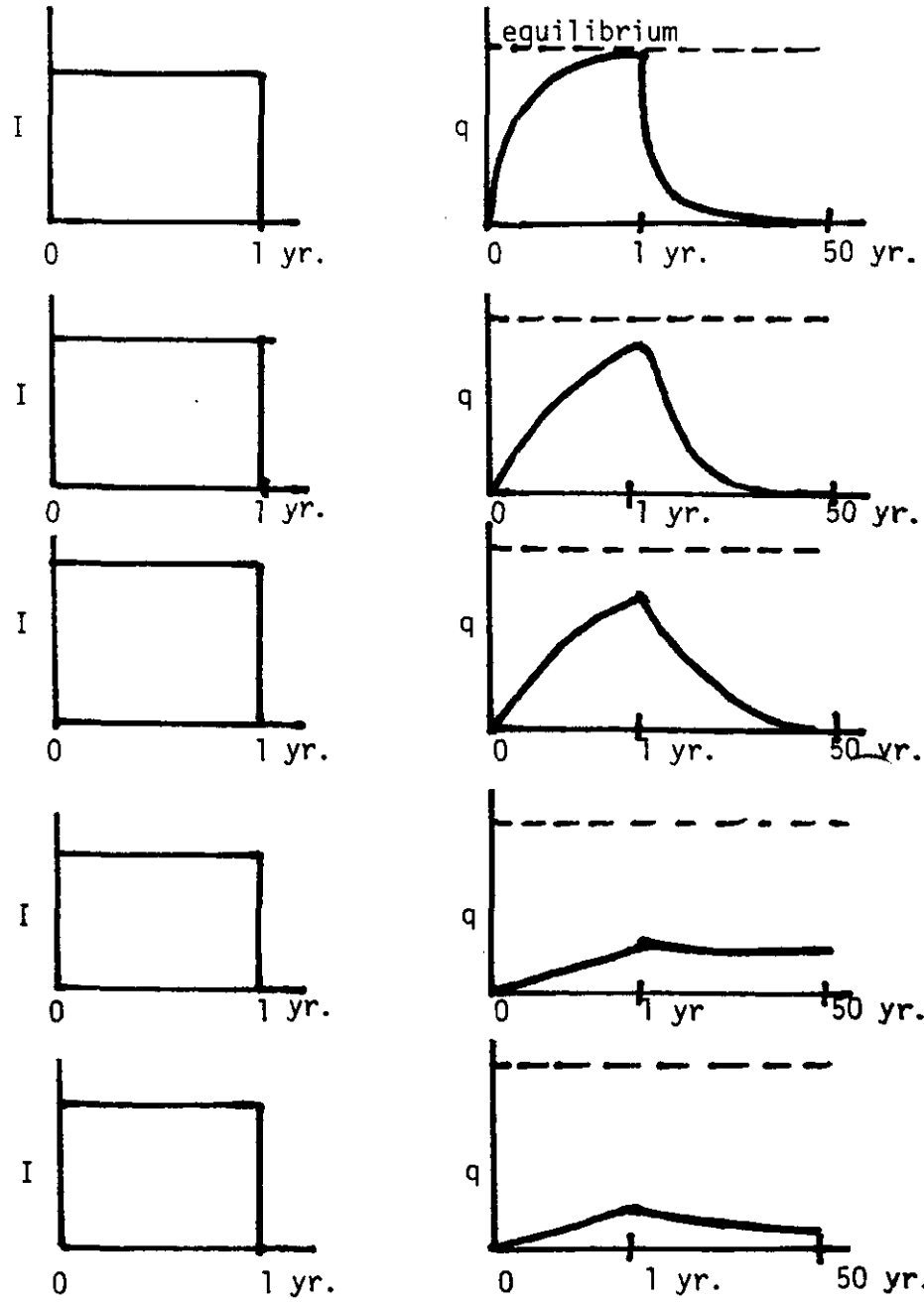

Figure 5

Tables 2-8 include the following, column by column:

column 1: nuclide

column 2: concentration at the Pecos River in (μCi/l), as computed by square wave model

column 3: mrem/μCi ingested, as tabulated in NUREG 0172 for whole body (or organ); based on ICRP Reports 2 (1959), 6 (1962) and 10 (1967).

column 4: col. (2) x col. (3) x 730 ℓ/yr = mrem/one year intake

column 5: compare with BDM/TAC 79-156-TR, Appendix B listings, pages designated

bottom of page : compare with EIS-I; 9-122, 123, maximum dose, upper transmissivity assumption.

The tables give comparisons for 10 nuclides and for 8 organ systems, where appropriate (e.g. of the 10 nuclides only I-129 contributes to thyroid dose). The nature of the concordance between columns (4) and (5) follows that obtained previously between Pecos River concentrations, "square wave" model vs. computer listings in BDM, Appendix B print-outs. The <u>ratios</u> of "square wave" to computer listings for doses vary from a minimum of 1.2 to a maximum of 5.0 with a mean value of 4.0.

Comparisons (for internal consistency) between DEIS maximum values and BDM sums are generally good, with one exception: for Lower Large Intestine [LLI], the sum of BDM listings is 0.124 $\frac{\text{mrem}}{\text{1 yr. intake}}$ vs. 0.158 for the DEIS maximum value, a difference of 24%.

G. Comments

The square wave model yields results which differ from INTERA - BDM listings (e.g. for maximum concentrations in Pecos River) by factors ranging from 1.1 to 11.2 (for Radium-226) with a mean value of 4.2 (see Table 1). Considering the crudity of the one-dimensional square wave model, this may be considered fair agreement. The same degree of variation is present in the comparisons of total body and organ doses (see Tables 2-8). Usually the square wave model leads to a higher estimate, as expected.

Perhaps the most useful outcome of the calculations made is that it permits one to put as a lower priority the question of the validity of the methodology employed in the DEIS calculations of nuclide concentrations and doses by ingestion. Instead one may consider the key parameters that lead to the final results. This would include the K_d values which are responsible for holding-back such nuclides as Pu, N_p, and Thorium. Also, one would include the basic driving parameter, $\bar{v}$, the assumed ground water flow velocity. A thorough review appears to be appropriate to permit an assessment to be made of the validity of the values actually employed in the DEIS. Additionally, it is probably useful to examine the scenarios used in the DEIS to consider whether indeed 'bounding cases' have been included, as stated in the report.

TABLE 1

MOVEMENT OF NUCLIDES FROM REPOSITORY TO PECOS RIVER (15 mi.)

Comparison of Peak Values with Intera (BDM** listings)

NUCLIDES	ACTIVITY Ci	RELEASE RATE FROM REPOSITORY RRR (μci/s)	RETARDATION FACTOR B	ARRIVAL TIME AT PECOS RIVER AT (YRS.)	HALF-LIFE (YRS.)	DISCHARGE RATE INTO PECOS RIVER DR_{pr} (μci/s)	CONCENTRATION IN PECOS RIVER C_{pr} (μci/l)	BDM PEAK VALUE (time, yrs)
Tc-99	6.8×10^{3}	4.6×10^{-2}	1	5.4×10^{3}	2.1×10^{5}	4.5×10^{-2}	0.87×10^{-4}	1.2×10^{-4} (7000)
I-129	15	1.02×10^{-4}	1	5.4×10^{3}	1.6×10^{7}	1.0×10^{-4}	1.9×10^{-7}	2.7×10^{-7} (7000)
Cs-135	1.5×10^{2}	1.02×10^{-3}	270	1.5×10^{6}	2.3×10^{-6}	0.65×10^{-3}	1.3×10^{-6}	
Ra-226	1.26	0.86×10^{-5}	450	2.4×10^{6}	1.6×10^{3}			
Ra-226*				1×10^{5}		4.3×10^{-6}	8.4×10^{-9}	0.75×10^{-9} (10^{5})
Th-229	0.06	0.4×10^{-6}	39,600	2.1×10^{8}	7.2×10^{3}			
Th-229*				1×10^{5}		2.2×10^{-8}	4.3×10^{-11}	1.5×10^{-11} (10^{5})
U-233	1.46	0.99×10^{-5}	19	1.0×10^{5}	1.6×10^{5}	0.64×10^{-5}	1.2×10^{-8}	
U-233*'			19	1×10^{5}			8.5×10^{-8}	6.2×10^{-8} (10^{5})
U-234	8.7×10^{2}	5.9×10^{-3}	19	1×10^{5}	2.4×10^{5}	4.4×10^{-3}	8.5×10^{-6}	1.8×10^{-6} (10^{5})
U-235	7.8	5.3×10^{-5}	19	1×10^{5}	7×10^{8}	5.3×10^{-5}	1.0×10^{-7}	0.24×10^{-7} (10^{5})
U-236	1.4×10^{2}	0.95×10^{-3}	19	1×10^{5}	2.3×10^{7}	0.95×10^{-3}	1.8×10^{-6}	0.47×10^{-6} (10^{5})
U-238	1.46×10^{2}	0.99×10^{-3}	19	1.0×10^{5}	4.8×10^{9}	0.99×10^{-3}	1.9×10^{-6}	0.37×10^{-6} (10^{5})
Th-230*			39,600	1.0×10^{5}	0.77×10^{5}	4.8×10^{-8}	0.93×10^{-10}	1.01×10^{-10} (10^{5})

*as a daughter product 'repository plus parent **BDM-TAC-79-156-TR, Appendix B, B-4 to B-27

TABLE 2

Whole Body - Adult - Drinking 730 l/yr

NUCLIDE	C_{pr} (µci/l)	NUREG 1072 m rem/50y per µci/yr		(1)(2)x730(l/yr) m rem/1 yr intake	BDM 79-156-TR App. B m rem/1 yr intake		
I-129	1.9×10^{-7}	9.21	p. 21	1.28×10^{-3}	2.5×10^{-3}	p. B-100	t=6,000 to 8,000 yrs.
Tc-99	0.87×10^{-4}	5.02×10^{-2}	21	3.19×10^{-3}	5.5×10^{-3}	B-108	
Cs-135	1.3×10^{-6}	7.99	22	7.58×10^{-3} 1.5×10^{6} yrs			
U-238	1.9×10^{-6}	4.54x10 +D*	23	6.30×10^{-2}	1.27×10^{-2}	B-124	t ($.0^{5}$ yrs.
U-234	8.5×10^{-6}	5.17x10	23	$32.\times10^{-2}$	7.0×10^{-2}	B-132	
Th-230	0.89×10^{-10}	5.70x10	23	3.7×10^{-6}	7.9×10^{-6}	B-140	
Ra-226	0.84×10^{-08}	2.2×10^{5}	23	1.35	0.29	B-148	
U-236	1.8×10^{-6}	4.96x10	23	6.52×10^{-2}	1.8×10^{-2}	B-172	
U-235	1.0×10^{-7}	4.86x10 +D	23	3.55×10^{-3}	0.98×10^{-3}	B-204	
U-233	8.5×10^{-8}	5.28x10	23	3.28×10^{-3}	2.65×10^{-3}	B-228	
Th-229	0.88×10^{-10}	3.91×10^{2}	23	2.51×10^{-5}	0.81×10^{-5}	B-236	
				COMPARE			
Sum				1.80 m rem / 1 yr int	0.394 m rem / 1 yr int		

Also compare EIS, 9-122(a): 0.399 m rem / 1 yr int

Note: Ra-226 accounts for 75% of total!!

*Includes effect of daughters

TABLE 3

Bone - Adult - Drinking 730 l/yr.

NUCLIDE	C_{pr} (μci/l)	NUREG 0172 m rem/μci intake	p.	(1)(2)x730(l/yr) m rem/l yr intake	BDM 79-156-TR App. B.	p.	
I-129	1.9×10^{-7}	3.27	21	4.54×10^{-4}	9.45×10^{-4}	B-98	t=8,000 to 8,000 yrs.
Tc-99	0.87×10^{-4}	1.25×10^{-1}	21	0.79×10^{-2}	1.38×10^{-2}	B-106	
U-233	8.5×10^{-8}	8.71×10^{2}	23	5.40×10^{-2}	4.16×10^{-1}	B-226	t = 10^{6} yrs.
U-234	8.5×10^{-6}	8.36×10^{2}	23	5.19	1.13	B-130	
U-235	1.0×10^{-7}	8.01×10^{2}	23	5.85×10^{-2}	1.50×10^{-2}	B-202	
U-236	1.8×10^{-6}	8.01×10^{2}	23	1.05	0.289	B-170	
U-238	1.9×10^{-6}	7.67×10^{2}	23	1.06	0.214	B-122	
Th-229	0.88×10^{-10}	7.98×10^{3}	23	5.13×10^{-4}	1.66×10^{-4}	B-234	
Th-230	0.89×10^{-10}	2.06×10^{3}	23	1.83×10^{-4}	2.84×10^{-4}	B-138	
$Ra\text{-}226_D$	0.84×10^{-8}	3.02×10^{5}	23	1.85	0.403	B-146	
				COMPARE			
Sum				9.26 $\frac{\text{m rem}}{\text{1 yr int}}$	2.09 $\frac{\text{m rem}}{\text{1 yr int}}$		

DEIS-I, 9-122(d): 2.09 $\frac{\text{m rem}}{\text{1 yr int}}$

U-234 accounts for 55% of total.

TABLE 4

Thyroid - Adult - Drinking 730 l/yr.

NUCLIDE	C_{pr} (μci/l)	NUREG 0172 m rem/μci intake	(1)(2)x730(l/yr) m rem/l yr intake	BDM 79-156-TR App. B	
		p.		p.	
I-129	1.9×10^{-7}	7.23×10^{3} 21	1.00	1.86 B-101	t=6,000 to 8,000 yrs.
			COMPARE		
EIS-I, 9-122(b):				1.88 $\frac{\text{m rem}}{\text{yr}}$	

TABLE 5

Liver - Adult - Drinking 730 l/yr.

NUCLIDE	C_{pr} (μci/l)	NUREG 0172 m rem/μci intake	(1)(2)x730(l/yr) m rem/1 yr intake	BDM 79-156-TR App. B m rem / 1 yr intake	
I-129	1.9×10^{-7}	2.81	3.90×10^{-4}	8.26×10^{-4}	p. B-99
Tc-99	0.87×10^{-4}	1.86×10^{-1}	1.18×10^{-2}	2.05×10^{-2}	B-107
Th-229	0.88×10^{-10}	1.19×10^{2}	0.76×10^{-5}	0.25×10^{-5}	B-235
Th-230	0.89×10^{-10}	1.17×10^{2}	0.76×10^{-5}	1.61×10^{-5}	B-139
Ra-226	0.84×10^{-8}	5.74	3.52×10^{-5}	1.66×10^{-5}	B-147
U-238*	1.9×10^{-6}			3.68×10^{-5}	
U-234*	8.5×10^{-6}			1.19×10^{-6}	
U-236*	1.8×10^{-6}			9.0×10^{-9}	
U-235*	1.0×10^{-7}			7.08×10^{-5}	
U-233*	1.2×10^{-8}			1.31×10^{-4}	
			COMPARE		
Sum				2.58×10^{-4}	at $t=10^5$ yrs.
EIS-I, 9-123(a):				2.72×10^{-4}	

t=6,000 to 8,000 yrs.

$t = 10^5$ yrs.

*No values for liver for U are listed in NUREG 0172.

TABLE 6

Kidney - Adult - Drinking 730 l/yr.

NUCLIDE	C_{pr} (μci/l)	NUREG 0172 m rem/μci intake	p.	(1)(2)x730(l/yr) m rem/ 1 yr intake	BDM 79-156-TR App. B m rem/1 yr intake	p.	
I-129	1.9×10^{-7}	6.04	21	8.4×10^{-4}	16.5×10^{-4}	B-102	t=6,000 to 8,000 yrs.
Tc-99	0.87×10^{-4}	2.34	21	1.49×10^{-1}	2.58×10^{-1}	B-110	
U-233	8.5×10^{-8}	2.03×10^{2}	23	1.26×10^{-2}	0.98×10^{-2}	B-230	t = 10^{9} yrs.
U-234	8.5×10^{-6}	1.99×10^{2}	23	1.23	0.27	B-134	
U-235	1.0×10^{-7}	1.87×10^{2}	23	1.36×10^{-2}	0.36×10^{-2}	B-206	
U-236	1.8×10^{-6}	1.91×10^{2}	23	2.51×10^{-1}	0.69×10^{-1}	B-174	
U-238	1.9×10^{-6}	1.75×10^{2}	23	2.43×10^{-1}	0.49×10^{-1}	B-126	
Th-229	0.88×10^{-10}	5.75×10^{2}	23	3.69×10^{-5}	1.20×10^{-5}	B-238	
Th-230	0.89×10^{-10}	5.65×10^{2}	23	3.67×10^{-5}	7.78×10^{-5}	B-142	
Ra-226	0.84×10^{-8}	1.63×10^{2}	23	1.00×10^{-3}	0.23×10^{-3}	B-150	
				COMPARE			
Sum				1.75 ⟷	0.402		
					↕		
EIS-I, 9-123(b):					0.408		

U-234 accounts for 67 to 70% of total.

TABLE 7

Lung - Adult - Drinking 730 l/yr

NUCLIDE	C_{pr} (µci/l)	NUREG 0172 m rem/µci intake	(1)(2)x730(l/yr) m rem/l yr intake	BDM 79-156-TR App. B 1 yr intake	
I-129	1.9×10^{-7}	*	*	1.01×10^{-4}	p. B-103
Tc-99	0.87×10^{-4}	1.58×10^{-2} 21	1.00×10^{-3}	1.74×10^{-3}	p. B-111
			COMPARE		

t=6000 to 8000 yrs.

*No value listed for I-129/Lung in NUREG 0172.

EIS-I, 9-123(c) 2.45×10^{-4} at $t=10^5$ yrs.

U-238	1.9×10^{-6}	3.68×10^{-5}	p. B-127
U-234	8.5×10^{-6}	1.19×10^{-6}	B-135
Th-230	0.89×10^{-10}	7.3×10^{-10}	B-143
Ra-226	0.84×10^{-8}	8.99×10^{-6}	B-151
U-235	1.0×10^{-7}	7.08×10^{-5}	B-207
U-233	8.5×10^{-8}	1.31×10^{-4}	B-231
Th-229	0.88×10^{-10}	3.11×10^{-8}	B-239
U-236	1.8×10^{-6}	9.0×10^{-9}	B-176
Sum		2.49×10^{-4}	

No values of m rem/µci intake for Lung are listed for U in NUREG 0172.

TABLE 8

Lower Large Intestine (LLI) - Adult - Drinking 730 l/yr.

NUCLIDE	C_{pr} (μci/l)	NUREG 0172 m rem/μci intake	(1)(2)x730(l/yr) m rem/l yr intake	BDM 79-156-TR m rem/l yr intake		
I-129	1.9×10^{-7}	4.44×10^{-1}	6.16×10^{-5}	21.5×10^{-5}	p. B-104	t=6000 to 8000 yrs.
Tc-99	0.87×10^{-4}	6.08	3.86×10^{-1}	6.71×10^{-1}	B-112	
U-233	8.5×10^{-8}	6.27×10^{1}	3.89×10^{-3}	3.12×10^{-3}	B-232	$t=10^5$ yrs.
U-234	8.5×10^{-6}	6.14×10^{1}	3.81×10^{-1}	0.83×10^{-1}	B-136	
U-235	1.0×10^{-7}	7.81×10^{1}	5.70×10^{-3}	1.53×10^{-3}	B-208	
U-236	1.8×10^{-6}	5.76×10^{1}	7.57×10^{-2}	2.08×10^{-2}	B-175	
U-238	1.9×10^{-6}	5.50×10^{1}	7.63×10^{-2}	1.54×10^{-2}	B-128	
Th-229	0.88×10^{-10}	5.12×10^{2}	3.29×10^{-5}	1.06×10^{-5}	B-240	
Th-230	0.89×10^{-10}	6.02×10^{1}	3.91×10^{-6}	8.30×10^{-6}	B-144	
Ra-226	0.84×10^{-8}	3.32×10^{2}	2.04×10^{-3}	0.452×10^{-3}	B-152	
			COMPARE			
Sum			0.545	0.124		

EIS-I, 9-123(d): 0.158 $\frac{\text{m rem}}{\text{yr}}$

References

1. Barr, G. (Sandia Laboratory). Personal communication, 1979.

2. Borg, I.Y., et al. Information Pertinent to the Migration of Radionuclides in Ground Water at the Nevada Test Site (UCRL-52078). Part 1. May 1976

3. BDM Corporation. WIPP Safety Assessment Biosphere Transport and Dosimetry Model Documentation (BDM/TAC-79-156-TR). Appendix B: Sample Runs. April 1979.

4. Brannen, P. (Sandia Laboratory). Personal communication, 1979.

5. U.S. Department of Energy. Draft Environmental Impact Statement, Waste Isolation Pilot Plant (DOE/EIS-0026-D). April 1979.

6. Holly, D.E., et al. Hydrodynamic Transport of Radionuclides: One-Dimensional Case with Two-Dimensional Approximation (NVO-1229-179). September 1971.

7. International Commission on Radiological Protection. Report of Committee II on Permissible Dose for Internal Radiation (ICRP Publication 2). 1959.

8. International Commission on Radiological Protection. (ICRP Publication 6). 1962.

9. International Commission on Radiological Protection. Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposure (ICRP Publication 10). 1967.

10. INTERA, Environmental Consultants, Inc. Development of Radioactive Waste Migration Model. September 1977.

11. Lester, D.H., et al. "Migration of Radionuclide Chains through an Adsorbing medium," A.I.Ch.E. Symposium Series, v. 71, no. 152 (1975), pp. 202-214.

12. Hoenes, G.R. Age-Specific Radiation Dose Commitment Factors for a One-Year Chronic Intake (NUREG-0172). November 1977.

APPENDIX VII

OPERATIONAL AND LONG TERM RELEASE CALCULATIONS

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APPENDIX VII

OPERATIONAL AND LONG TERM RELEASE CALCULATIONS

Item VII-A

Annual Dose Commitment at James Ranch
from Routine Operation Releases

The Draft EIS uses the Releases to the Environment tabulated in Table 8-6 to calculate doses at James Ranch (3.0 miles south-southwest of the center of the site) in Table 9-18. The following calculation is based on Table 8-6 and the extrapolated χ/Q value from Table H-36.

$$\text{Dose} = \left(\frac{\chi}{Q}\right) Q \text{ (inhalation per year) (Dose Commitment Factor)}$$

adjusting for units

$$\text{Dose} = \left(\frac{\chi}{Q}\,\frac{s}{m^3}\right)\left(\frac{m^3}{y}\text{ intake}\right)\frac{pCi}{Ci}\,\frac{1}{\frac{s}{y}}\left[Q\,\frac{Ci}{y}\left(\frac{mrem}{pCi\text{ intake}}\right)\right]$$

$$\text{Dose} = \frac{(6.2-7)(7.3+3)(1+12)}{(3.14+7)}\,\frac{pCi}{Ci}\,\left[(Q \times DCF)\,\frac{Ci\ mrem}{pCi\ y}\right]$$

$$\text{Dose} = (1.44\ +2)\,(Q \times DCF)\,\frac{mrem}{y}$$

Dose commitment factors are from NUREG-0172, Table 8.

Values of Q x DCF are tabulated on the following page for significant radionuclides from Table 8-6.

TABLE VII-A

Organ Dose Commitments at James Ranch from Routine Releases

Nuclide	Q (Ci/y)	Bone DCF (mrem/pCi)	Bone Q(DCF) (Ci/pCi mrem/y)	Lungs DCF (mrem/pCi)	Lungs Q(DCF) (Ci/pCi mrem/y)	Whole Body DCF (Ci/pCi)	Whole Body Q(DCF) (Ci/pCi mrem/y)
^{3}H	0.45	-	-	1.58-7	7.1-8	1.58-7	7.1-8
^{85}Kr	7.8	-	-	2.41-9	1.9-8	-	-
^{238}Pu	2.3-5	2.74	6.3-5	.182	4.3-6	6.92-2	1.6-6
^{239}Pu	2.6-4	3.19	8.3-4	.172	4.5-5	7.75-2	2.0-5
^{240}Pu	6.4-5	3.18	2.0-4	.172	1.1-6	7.73-2	4.9-6
^{241}Pu	3.5-3	6.41-2	2.2-4	1.52-4	5.2-7	1.29-3	4.5-6
^{241}Am	4.3-6	1.01	4.3-6	6.06-2	2.6-7	6.71-2	2.9-7
^{244}Cm	9.5-7	5.90-1	5.6-7	6.06-2	5.8-8	3.51-2	3.4-8
Σ(DCF)Q			1.31-3		5.12-5		3.13-5
50 year dose commitment = (1.44+2)(QxDCF) =			0.19 mrem		7.4-3 mrem		4.5-3 mrem
			= 1.9-4 rem		7.4-6 rem		4.5-6 rem
DEIS values (Table 9-18) =			1.5-4 rem		7.1-6 rem		3.8-6 rem
Ratio DEIS value / EEG value			0.8		0.96		0.84

Item VII- B

Operation Accidents - CH-TRU Waste
Scenario C-7

The activity released and the resulting doses due to operational accident Scenario C-7, Surface Fire (1 hr.), have been evaluated.

The basic assumptions or model of the scenario are given on page 9-50, DEIS and summarized below.

Assumptions

1) It takes one hour to put out the fire.

2) 25% of a typical drum is combustible.

3) 1% of the activity in the combustible waste is released in respirable form per hour.

4) One drum burns, the two adjacent drums burst exposing contents which do not burn, only 10% of spilled contents is powder.

5) A total of 0.0014% of each of the two adjacent drums is respirable and released.

6) The double HEPA filter bank has a decontamination factor of 10^6.

Based on the CH-TRU inventory given on page E-2, DEIS, the following analysis may be made:

Table VII-B

Amount of Radioactivity Released in C-7 Surface Fire

Isotope	Ci/drum (Pg. E-2)	Respirable Release Fraction [0.25%	+	Adjacent 2 Drums 2(0.0014%)]	x	Decon Factor 10^{-6}	=	Ci Released
Pu-238	4.1×10^{-2}	1×10^{-4}		1.148×10^{-6}		10^{-6}		1×10^{-10}
Pu-239	4.8×10^{-1}	1.2×10^{-3}		1.34×10^{-5}		10^{-6}		1.2×10^{-9}
Pu-240	1.2×10^{-1}	3.0×10^{-4}		3.36×10^{-6}		10^{-6}		3.0×10^{-10}
Pu-241	2.9	7.25×10^{-3}		8.12×10^{-5}		10^{-6}		7.3×10^{-9}
Am-241	7.8×10^{-3}	1.95×10^{-5}		2.18×10^{-7}		10^{-6}		1.97×10^{-11}
Total	3.5							8.9×10^{-9}
				DEIS (Table 9-23, Page 9-51)				8.8×10^{-9}

The curies released due to the accident scenario C-7, Surface Fire calculated above is the product of the curies per drum times the sum of the fraction released from the burned drum and two adjacent damaged drums times the decontamination factor.

The curies released to the environment are then dispersed and diluted by using AIRDOS-II in the DOE analysis (page 9-54, DEIS). In order to evaluate the doses due to the releases given in Table 9-25, page 9-56, DEIS, an independent calculation was made using the same procedure as in Item VII-1, with dose commitment factors from NUREG-0172. For a $(\chi/Q)_{50\%}$ of $(5.8\text{-}6)\frac{s}{m^3}$ the dose is:

$$\text{Dose: } \frac{(5.8\text{-}6)(0.83)(1+12)}{(3.6+3)} [Q(DCF)] = (1.34 + 3) [Q(DCF)]$$

Doses are calculated on Table VII - 3 for the James Ranch. The maximum dose at 0.5 miles is also calculated $(\frac{\chi}{Q})_{max}$ because the public could be at this location.

Table VII-C

Dose Received at James Ranch From
Radioactivity Releases in C-7 Surface Fire

Nuclide	Q Ci	Bone Dose		Lung		Whole Body	
		DCF	Q(DCF)	DCF	Q(DCF)	DCF	Q(DCF)
^{238}Pu	1.0-10	2.74	2.74-10	.182	1.82-11	6.92-2	6.92-12
^{239}Pu	1.2-9	3.19	3.83-9	.172	2.06-10	7.75-2	9.30-11
^{240}Pu	3.0-10	3.18	9.54-10	.172	5.16-11	7.73-2	2.32-11
^{241}Pu	7.3-9	0.064	4.68-10	1.52-4	1.11-12	1.29-3	9.42-12
^{241}Am	1.9-11	1.01	1.92-11	6.06-2	1.15-12	6.71-2	1.27-12
		$\Sigma Q(DCF)$ =	5.54-9		2.78-10		1.34-10
50 year dose commitment		=	7.4-6 mrem		3.7-7 mrem		1.8-7 mrem
		=	7.4-9 rem		3.7-10 rem		1.8-10 rem
DEIS value (Table 9-25)		=	5.5-9 rem		2.7-10 rem		1.3-10 rem
Ratio $\frac{\text{DEIS value}}{\text{EEG value}}$		=	0.74		0.73		0.72
Dose at 0.5 mile		=	1.4-6 rem		7.1-8 rem		3.4-8 rem

Item VII-C

Operational Accidents
Underground Container Failure (hoist drop - R15)

One of the potentially more serious operational accidents with WIPP is described in the DOE DEIS is the hoist drop accident involving a spent fuel canister. The assumptions made are:

1) 0.1% of contents crushed into particles 10 microns or less;

2) Duration of accident - 6 hours;

3) Multiplying 0.84% (6 x 0.14%/h) by the powder inventory will give the airborne and respirable release of all isotopes except H-3, Kr-85, I-129;

4) 30% of H-3, Kr-85, I-129 released during first hour.

5) Gases not retained by filters; and

6) Double HEPA filter bank gives a decontamination factor of 10^6.

Table VII-D, entitled "Hoist Drop Accident", details the calculations going from the spent fuel isotopic inventory to curies released. The results agree with those presented in the DEIS (Table 9-24) for the hoist-drop - spent fuel accident.

The dose that would be received by an individual at the James Ranch was then calculated using the assumptions in the DEIS. The equations used in this calculation are given below. The resulting doses are shown in Table 11 of the main report.

Intake and Dose Equivalent or Dose Commitment
Equations for R-15 Accident

Intake

Io = intake in uCi

$$Io = Q\left(\frac{Ci}{s}\right) \chi/Q \left(\frac{s}{m^3}\right) B \left(\frac{20\ m^3}{d} \times \frac{6}{24}\right) \times 10^6\left(\frac{uCi}{Ci}\right) fa$$

Where Q = quantity in curies released divided by the sec of release.

$X/Q = 0.58 \times 10^{-5}\ s/m^3$ given in Table 21, page 26 of Appendix H, Annex 1 DEIS.

B = air intake, breathing rate 20 m^3/d release of 6 hours = (6/24). 20 = $5m^3$

fa = fraction inhaled which reaches critical organ.

Dose Commitment

DE = 50 year dose commitment from short term intake.

$$DE = \frac{74\ Io\ T\ \Sigma E(RBE)n}{m} \left(1-e^{\frac{-0.693\ t}{T}}\right)$$

Where DE = rem (50 year)

$$74 = \left(\frac{51}{0.693}\ \frac{rem.dis.g}{MeV.d.uCi}\right)$$

T = effective half life, days.

$\Sigma E(RBE)n$ = effective energy

t = time of exposure 50 years, (50 x 365 days)

m = mass of critical organ.

Table VII-D

Hoist Drop Accident R-15

Isotope	Table E-5 Ci/Canister	Respirable Dust 0.001 (Ci)	Respirable air-borne Dust 0.0084 (Ci)	gas fraction 0.3	10^{-6} decon*	Ci released
H-3	150	-	-	-		45
Kr-85	2600	-	-	-		780
Sr-90/Y-90	$3x10^{4}$	$3x10^{1}$	$2.52x10^{-1}$		-	$2.5x10^{-7}$
Ru-106/Rh-106	$2.3x10^{2}$	$2.3x10^{-1}$	$1.93x10^{-3}$		-	$1.9x10^{-9}$
I-129	$1.5x10^{-2}$	-	-	-	-	$4.5x10^{-3}$
Cs-134	$4.3x10^{3}$	$4.3x10^{0}$	$3.6x10^{-2}$		-	$3.6x10^{-8}$
Cs-137/Ba-137m	$4.0x10^{4}$	$4.0x10^{1}$	$3.36x10^{-1}$		-	$3.36x10^{-7}$
Pm-147	$3.6x10^{3}$	$3.6x10^{0}$	$3.02x10^{-2}$		-	$3.0x10^{-8}$
Eu-154	$2.4x10^{3}$	$2.4x10^{0}$	$2x10^{-2}$		-	$2.0x10^{-8}$
Np-237	$1.6x10^{-1}$	$1.6x10^{-4}$	$1.34x10^{-6}$		-	$1.3x10^{-12}$
Pu-238	$1.3x10^{3}$	$1.3x10^{0}$	$1.09x10^{-2}$		-	$1.1x10^{-8}$
Pu-239	$1.5x10^{2}$	$1.5x10^{-1}$	$1.26x10^{-3}$		-	$1.26x10^{-9}$
Pu-240	$2.2x10^{2}$	$2.2x10^{-1}$	$1.84x10^{-3}$		-	$1.8x10^{-9}$
Pu-241	$3.1x10^{4}$	$3.1x10^{1}$	$2.6x10^{-1}$		-	$2.6x10^{-7}$
Pu-242	$6.7x10^{-1}$	$6.7x10^{-4}$	$5.6x10^{-6}$		-	$5.6x10^{-12}$
Am-241	$6.7x10^{2}$	$6.7x10^{-1}$	$5.6x10^{-3}$		-	$5.6x10^{-9}$
Am-242m	4.0	$4.0x10^{-3}$	$3.36x10^{-5}$		-	$3.36x10^{-11}$
Am-243	9.1	$9.1x10^{-3}$	$7.6x10^{-5}$		-	$7.6x10^{-11}$
Cm-243	1.5	$1.5x10^{-3}$	$1.3x10^{-5}$		-	$1.3x10^{-11}$
Cm-244	$8.8x10^{2}$	$8.8x10^{-1}$	$7.39x10^{-3}$		-	$7.4x10^{-9}$

Compares to table 9-24 Spent Fuel Hoist drop.

*Particulate Decontamination (10^{-6})

Item VII-D

Scenario 5 - Indirect Pathways Calculation

The DEIS calculated the doses from inhalation and ingestion pathways to an individual living 500 meters downwind from a drilling mud pit that was contaminated with CH-TRU or spent fuel. A procedure is presented on page K-22, K-23 for this calculation. However, the following calculation will attempt to check this result by an alternate procedure, using χ/Q values from H-36.

For the CH-TRU waste case with a 10-inch drill hole, the following assumptions are used:

ρ, do, K, A: same as on K-23

μ : 2.25 m/s

χ/Q : (2.3-4)s/m^3 extrapolation from 800m to 500m assuming $\left(\frac{d_2}{d_1}\right)^2$ relationship

Ci/g sample: average concentration from Table E-1 times a sample size of 142ℓ (9.12 inch diameter hole drilling through 11 feet of drums).

Quantity of mud: 100 tons (p. 9-124).

Curies/gram of Pu-239: $\dfrac{\frac{0.48\text{Ci}}{208\ell}(142\ell)}{100 \text{ tons } (2000 \frac{\text{lb}}{\text{ton}})454\frac{\text{g}}{\text{lb}}}$

Ci Pu-239 in top cm of mud: $66.9\text{m}^2 \left(10^4 \frac{\text{cm}^2}{\text{m}^2}\right)(1 \text{ cm depth})^2 \frac{\text{g}}{\text{cm}^3}(3.61\text{-}9\frac{\text{Ci}}{\text{g}})$

$= (4.83\text{-}3)\text{Ci}$

Source Term, Pu-239 $\frac{\text{Ci}}{\text{s}} = (4.83\text{-}3)\text{Ci}\ (10^{-13})\frac{1}{\text{s}}\left(\frac{2.25}{1.0}\right)^3 = (5.51\text{-}15)\frac{\text{Ci}}{\text{s}}$

$$\text{Dose} = \frac{\chi}{Q}(Q)(\text{inhalation})\text{DCF}$$

$$= (2.3\text{-}4\frac{s}{m^3})(5.51\text{-}3\frac{pCi}{s})(7.3\text{+}3\frac{m^3}{y})(3.19\frac{mrem}{pCi}) = (2.95\text{-}2)\frac{mrem}{y}$$

$$\underline{(3.05\text{-}5)}\frac{rem}{y}$$

Dose from other actinides, besides Pu-239, are tabulated below:

Table VII-E

Indirect Pathways Doses - Scenario 5

Nuclide	Ci/drum t = 0	Ci/drum t = +100y	Ci/142ℓ	(DCF)	Q(DCF)
Pu-238	.041	.018	.012	2.74	3.29-2
Pu-240	.12	.12	.082	3.18	2.61-1
Pu-241	2.9	.015	.010	.064	6.4-4
Am-241	.0078	.078	.053	1.01	5.3-2
				ΣQ(DCF) =	3.47-1
Pu-239	.48	.48	.327	3.19	1.04

Total Bone Dose: $(2.95\text{-}5)\frac{rem}{y}\left(\frac{1.39}{1.04}\right) = (3.93\text{-}5) = (3.9\text{-}5)\frac{rem}{y}$ Bone Dose.

This value is close to the value of (3.6-5) rem/y used in Table 9-48 of the DEIS.

It is noted that the χ_1 factors listed on the bottom of page K-23 cannot be obtained from the equation and assumptions at the top of the page without choosing a value for μ, the mean wind speed. The value of 2.25 m/s used in the above calculation is reasonable based on the data in Appendix H (although perhaps lower than the site average) and gives agreement within 10-15%.

Item VII-E

Scenario 5 - Drill Back Accident
Occupational Dose Evaluation

The accident scenario described on pages 9-124 to 9-126 was evaluated to check the reasonableness of the calculations. Data, and source inventories from the DEIS are used and referenced.

Mineral Exploration Case - Spent Fuel

1) The volume of waste in a geological core with a 14 foot fuel rod is:

$$V = \frac{\Pi}{4}\left(\frac{2.12}{12}\right)^2 \text{ ft}^2 \text{ [14 ft] } 28.3 \frac{\ell}{\text{ft}^3} = 9.84 \text{ liters}$$

which agrees with the 10 liters used in 9-124.

2) The drill recovers only a fraction of the fuel in an assembly. If the dimensions of an assembly are 8.5 inches square (NUREG-0116, p. 3-8) then

$$F = \frac{\frac{\Pi}{4}(2.12)^2}{(8.5)^2} = 0.049 \text{ of contents in one assembly.}$$

3) The dose rate was established by using the inventory in Table E-5, page E-6 of the DEIS and calculating the amount present at 100 years after emplacement (i.e. t + 110 years after removal from reactor). Exposures at 1 meter per curie per hour were obtained from the Radiological Health Handbook, 1979 edition, page 130 or the relationship:

(1) R_{hr} at 1 foot ≈ 6 Ci (mev/γ)(No. of γ/disintegration)

4) Bremsstrahlung was also calculated for Sr-90, Y-90 and Cs-137 and considered for other Beta emitters. The expression:

(2) $f = 3.5 \times 10^{-4}\ ZE$ where f = fraction energy to photons
Z = atomic number absorber
E = maximum Beta energy

gives the amount of γ energy from the beta decay. This value is used in expression (1) to calculate the dose rate at 1 meter. Uranium Oxide, with a Z = 82.2 was used for Z.

5) Ingrowth of ^{241}Am from decay of ^{241}Pu was also calculated using the expression:

$$(3)\ A_2 = \frac{\lambda_2 A_i}{\lambda_2 - \lambda_1}(e^{-\lambda_1 t} - e^{-\lambda_2 t}) + A_2^{\circ}\, e^{-\lambda_2 t}$$

for ^{241}Pu, $A_1^{\circ} = 3.1 \times 10^4$ Ci; for ^{241}Am, $A_2^{\circ} = 6.7 \times 10^2$ Ci

at + 100 years:

$$A_2 = \frac{0.00151}{-.0510}(3.1 \times 10^4)[.005 - .860] + 6.7 \times 10^2(.86) =$$

$$\underline{\underline{1350}}\ \text{Ci of } ^{241}Am$$

6) Most radionuclides in Table E-5 were eliminated by inspection, because of short half-lives and concentrations that appeared to make the contribution to the does rate negligible.

The above procedure gives an external radiation dose of about 71 rem to the maximum exposed individual with the assumption given in Scenario 5. This is about 20% below the value given in Table 9-47 as an approximation. The reason for being this far below is not known; there appear to be no other nuclides in the inventory that would make much difference.

It is noted that if the time were taken as 100 years after removal from the reactor (rather than 110 years as used here) then the total would be 90 rem.

Conclusion. Agreement on the maximum dose to a drilling crew member is sufficiently close so that the conclusions drawn about the seriousness of such an accident remain valid.

Table VII-F

External Dose Rate From Fuel Assembly Radionuclides

Nuclide	$Ci_{(R+10)}$	$T_{\frac{1}{2}}(y)$	$Ci_{(R+110y)}$	Exp. Factor R/h-Ci	Dose Rates - R/h Assembly	Sample
^{135}Cs	-	-	1.5 - 4	-	-	-
^{137}Cs	4.0 + 4	30.1	4.0 + 3	0.33	1320.	64.6
^{154}Eu	2.4 + 3	16	3.1 + 1	0.62	19.2	0.9
^{85}Kr	2.6 + 3	10.8	4.2 + 0	0.013	.05	-
^{241}Am	6.7 + 2	458	1.35 + 3	0.012	16.3	0.8
^{244}Cm	8.8 + 2	17.6	1.7 + 1	0.00001	-	-
^{234}U	3.9 - 1	2.5 + 5	3.9 - 1	0.010	.004	-
Bremsstrahlung Radiation						
^{90}Sr	3.0 + 4	28.1	2.55 + 3	0.0016	4.2	0.2
^{90}Y	3.0 + 4	(28.1)	2.55 + 3	0.034	85.8	4.2
^{137}Cs	4.0 + 4	30.1	4.0 + 3	0.0034	7.0	0.4
					Dose =	71.1 rem

Mineral Exploration Core - CH-TRU Waste

1) Check volumes used on 9-124 (8 liters in sample.
Assume drill through either 4 levels of drums or 3 of boxes.

$$V_{drum} = [\frac{\Pi}{4}(\frac{2.12}{12})^2 \text{ ft}^2 \text{ core}][2.75 \frac{\text{ft}}{\text{drum}} (4 \text{ drums})]28.3\frac{\ell}{\text{ft}^3} = 7.64\ell$$

$$V_{box} = 7.64\ell[\frac{3.8 \text{ ft of box (3 boxes)}}{11.0 \text{ ft drums}}] = 7.94\ell$$

So the use of an 8 liter sample is reasonable.

2) Since the average drum (p. E-2) has a higher concentration of plutonium than the average box, the drum case will be used. From p. E-6 the only external dose would come from the Am-241 that is present or which ingrows from Pu-241.

$$A_{241_{Am}} = \frac{0.00151}{-.0510} (Ci_{241_{Pu}})[.005 - .860] + (7.8 - 3) .86 \; Ci_{241_{Am}}$$

$$Ci \; 241_{Pu} \text{ in waste} = \frac{2.9Ci}{208\ell} (8\ell) = 0.112$$

$$Ci \; 241_{Am} \text{ in waste} = \frac{0.0078}{209} (8) = 0.0003$$

at t+100 yrs $A_{241_{Am}} = .00284 + .00026 = \underline{.0030}$ Ci

Dose: $\frac{(3.0 - 3)}{(1.35 + 3)} (16.3) = (35.6 -6) = (0.036 - 3)$ Rem from 241_{Am}

(Table 9-47 uses 1.0 - 3).
Note (from SAND 78-1850 pp. 21-23) a drum could have ≤200 gm Pu or 25 times the average. If one of those were struck +3 average drums the dose would be:

$(3.6-5)(\frac{224}{32}) = (2.5 - 4)$ Rem from 241_{Am}.

An inspection of nuclides distribution on pages E-36 and E-37 indicates that the only non TRU gamma emitter of possible significance is ^{137}Cs. 6.08 Ci of ^{137}Cs are distributed in 467,323 cubic feet.

$$^{137}Cs \text{ per } 8\ell = \frac{6.08 \text{ Ci } (8\ell)}{(4.67 + 5 \text{ ft}^3)(2.83+1\frac{\ell}{\text{ft}^3})} = (3.68\text{-}6)\text{Ci } ^{137}Cs \text{ in sample}$$

at +100 years =(3.7-7)Ci in sample.

Dose = (3.7-7)0.33 =(1.2-7)Rem from ^{137}Cs

If concentration is $(\frac{224}{32})$ average; $^{137}Cs = (8.6\text{-}7)\frac{s}{m^3}$

So ^{137}Cs dose is negligible compared to 241Am.

Conclusion. The calculated dose in Table 9-47 for CH waste appears to be accurate and perhaps slightly conservative.

Item VII-F

Scenarios 1-4 (Hydrologic Breach)

Scenarios 1-4 (section 9.5.1) are similar in that all involve the formation of a hydrologic connection between the repository and the Rustler aquifer, after the repository is sealed. In each case, the breach results in dissolution of the waste, passage of the waste into the Rustler aquifer, and passage through the Rustler into the Pecos River.

The three-dimensional model used in the DEIS analysis of nuclide transport in the Rustler was developed by Intera Environmental Consultants. EEG used a simple "square wave" model, described in Appendix VI, to gain a better understanding of the key features of the Intera model and to check some of the DEIS results. Appendix VI includes an application of the square wave model to scenario 4. In this section, the square wave model is outlined briefly and its application to scenarios 1-4 is discussed.

The model assumes that the waste dissolves at a constant rate and enters the Rustler at this rate. Each nuclide then moves toward the Pecos River at a rate equal to the Rustler velocity $\bar{v}$, divided by a retardation factor:

$$B = \frac{1 - \theta}{\theta} \rho K_d$$

where θ is the porosity of the Rustler aquifer, ρ is the bulk density of the Rustler aquifer and K_d is the distribution coefficient associated with adsorption of the given nuclide onto Rustler rocks. The values used for θ and ρ are $\theta = 0.1$ and $\rho = 2$ (g/ml).

Distribution coefficients used in the DEIS are listed in Table K-3, p. K-20. (The large uncertainties associated with these parameters are discussed briefly in Item VII-I of this Appendix.)

Thus each radionuclide has an arrival time (AT) at the Pecos River, 15 miles from the repository:

$$AT = 15 \text{ mi}/(\bar{v}/B).$$

(Earlier arrival times for nuclides produced by radioactive decay of other nuclides are discussed in Appendix VI.)

Each radionuclide has a release rate from the repository (RRR):

$$RRR = \frac{\text{repository inventory activity (Ci)}}{\text{Total dissolution time (sec)}}$$

where the dissolution time (DT) is given by:

$$DT = \frac{\text{repository volume}}{\text{dissolution rate}} .$$

The repository volumes from the CH and RH levels are:

CH volume = 9,000 x 1,200 x 16.5 ft (K-22)
RH volume = 930 x 930 x 42 ft (K-21).

Radionuclide concentrations in the Pecos River (C_{PR}) at the nuclide's arrival time (AT) are found from:

$$C_{PR} = \frac{RRR \times e^{-\lambda(AT)}}{515 \text{ liters/second}}$$

where λ is the nuclide's decay constant and 515 l/sec is the flow rate of the Pecos River (9-116).

Table VII-G summarizes the Rustler velocities and dissolution rates characteristic of the different scenarios. Table VII-H lists dissolution times and selected arrival times for scenarios 1 and 4.

Table VII-G

Rustler Velocities and Dissolution Rates

Scenario	Fluid Velocity $\bar{v}$ in Rustler (ft/yr)*	Dissolution Rates (ft^3/day)** CH	RH
1	17.5	.33	.84
2	15	.15	.39
3	15	.057	.012
4	15	81	21.4

*"Fluid velocity through the Rustler aquifer for the upper-transmissivity bound is roughly 0.04 ft./day" (p. 9-112); that is 15 ft./year. "In scenario 1, some fluid from the Bell Canyon aquifer is added to the Rustler aquifer; after this addition the fluid velocity in the Rustler aquifer increases slightly -- roughly by a factor of 1/6 (p.9-109). Thus the Rustler fluid velocity in scenario 1 becomes (15 ft/yr) x (7/6) = 17.5 ft/yr.

**In scenario 1, a borehole through the repository connects the Rustler (upper) and Delaware Mountain Group (lower) aquifers. Water flows from the lower to the upper aquifer, dissolving 54 ft^3/day of the salt and waste bordering the borehole (9-111). The fraction of dissolved material which is from the CH repository level is the ratio of the CH level height (16.5 ft.) to the borehole length (2,700 ft.); i.e. 54 x (16.5/2700) ft^3/day or 0.33 ft^3/day of material from the CH level is dissolved. Similarly, 54 x (42/2700) ft^3/day or .84 ft^3/day of material from the RH level is dissolved. For scenario 2, the DEIS states that "The waste-dissolution rate for Scenario 2 was calculated to be less than that for Scenario 1 by a factor of 2.17" (9-109). This was used to calculate the scenario 2 dissolution rates given in Table VII-G. However, these rates add up to 0.54 rather than the total 0.64 ft^3/day given in (9-112; 2). In scenario 3, the rates at which diffusion brings waste and salt into the Rustler are given as 0.057 ft^3/day for the CH repository level and .012 ft^3/day for the RH level (9-112). Scenario 4 is discussed in Appendix V

Table VII - H

Migration and Dissolution Times

Scenario	Arrival time (AT) at Pecos River, (yrs.) if: $K_d=0$	$K_d=1$	$K_d=10$	Dissolution time (yrs.) CH	RH
1	4.5×10^3	8.6×10^4	8.2×10^5	1.5×10^6	1.2×10^5
4	5.3×10^3	1.0×10^5	9.6×10^5	6.0×10^3	4.7×10^3

Item VII- G

Hydraulic Conductivity, Interstitial Velocity in the Rustler Aquifer

Notation: $\bar{v}$ = interstitial velocity [ft/day]

K = hydraulic conductivity [ft/day]

θ = porosity

Δh = change in head (difference between heights of potential lines) [ft]

$\Delta \ell$ = distance over which Δh is calculated. [ft]

Formula for interstitial velocity:

$$\bar{v} = \frac{K}{\theta} \cdot \frac{\Delta h}{\Delta \ell}$$

(see, for example, Mercer and Orr, 1977, p. 17).

Calculation of $\bar{v}$, from DEIS information:

Let K = 1 ft/day (Fig. K-7, vicinity of WIPP)

θ = 0.1 (Table K-2)

$$\left.\begin{aligned} \Delta h &= 3200\text{-}2900\text{ft} \\ &= 300 \text{ ft} \\ \Delta \ell &= 15 \text{ mi} \\ &= 79{,}200\text{ft.} \end{aligned}\right\} \text{(Fig. K-3, Fig. K-5)}$$

$$\text{Then } \bar{v} = \frac{1}{0.1} \times \frac{300}{79{,}200} \text{ ft/day}$$

$$= 0.038 \text{ ft/day.}$$

Compare with the DEIS value of 0.04 ft/day (9-112).

This calculation suggests that the interstitial Rustler aquifer velocity of .04 ft/day, taken as an upper bound in the DEIS, is not conservative.

1) Figure K-7 gives hydraulic conductivity values in the Rustler which are lowest (1 ft/day) at the WIPP site and increase after that.

2) A 1977 Mercer and Orr report used in the DEIS transport modeling, gives the average hydraulic conductivity in the rustler as 16 ft/day and the average interstitial velocity as 0.5 ft/day.

3) Transmissivities reported in a later Mercer and Orr report (1979) range from 10^{-4} to 140 ft^2/day and translate to a hydraulic conductivity range of 5×10^{-6} to 7 ft/day. The highest conductivity value measured in a well near WIPP is 2 ft/day (for hydrologic hole H-3 in WIPP Zone II).

Item VII-I

Variability in K_d Values; Effect on Radiation Exposure

The low radiation doses calculated for the hydrologic breach scenarios result in part from the fact that the K_d value assumed for plutonium retards the rate at which plutonium travels in groundwater by a factor of 37,800.* Thus, by the time it reaches the Pecos River, the large initial inventory of plutonium (in spent fuel or transuranic waste) has decayed to an insignificant quantity. In fact, the only significant nuclides that are not retarded by adsorption are iodine and technetium, and the smallest retardation factor for other nuclides is B = 19 (when K_d = 1) for uranium.

However, much smaller K_d values than those used in the DEIS have been measured using rocks from the Rustler formation (ref. 1, 2). More importantly, laboratory measurements of K_d values probably do not reflect field conditions. For example, small amounts of plutonium or other elements with the capacity of the rocks to adsorb more plutonium; thus a "loading effect" can reduce K_d values. Chelating agents like EDTA can also reduce K_d values, as can temperature, pH and other physical and chemical factors. Finally the equilibrium model in which K_d's make sense may be inappropriate for flow in a fractured medium.

Table VII-I summarizes K_d information for different nuclides and Table VII-J indicates the maximum nuclide concentrations in the Pecos River in scenarios 1 and 4 when low K_d values (K_d = 0 or 1) are assumed.

---

*The retardation factor B is: 1 + 18 K_d (see Appendix VI).

Note that essentially the same effect on nuclide speed can be obtained by lowering the K_d value by a given factor or raising the hydraulic conductivity or interstitial velocity by the same factor. (See Item VII-H for a discussion of variations in hydraulic conductivity and interstitial velocity.)

Table VII-I

K_d Information

Nuclide	K_d used in DEIS	K_d range in refs. 1, 2
Tc-99	0	0.15-6.7
I-129	0	1
Cs-135	15	1 to 6,540
Ra-226	25	-
Thorium	2200	-
Uranium	1	-0.9 to 6.7
Np-237	700	8-23
Plutonium	2100	17.6 to 5400

Table VII-J

Effect of K_d's on Plutonium Concentration in Pecos River, Scenarios 1 and 4, Spent Fuel

Nuclide	Inventory (Ci) at 1000 yrs.	Half-Life Years	Scenario	Release Rate[1] from Repository (μCi/sec)	Decay factor[2] at arrival time, if $K_d=0$	$K_d=1$	$K_d=18$	Maximum concentration[3] in Pecos River (μCi/l), if $K_d=0$	$K_d=1$	$K_d=18$
Pu-239	1.5×10^5	2.4×10^4	1	3.8×10^2	.88	.08	0	6.5×10^{-5}	1.2×10^{-6}	0
			4	9.7×10^{-1}	.86	.06	0	1.6×10^{-3}	1.1×10^{-4}	0
Pu-240	2.0×10^5	6.5×10^3	1	5.3×10^{-2}	.62	1.0×10^{-9}	0	6.2×10^{-5}	1.0×10^{-8}	0
			4	1.3	.57	2.3×10^{-5}	0	1.4×10^{-3}	5.8×10^{-8}	0

[1] $\frac{\text{Inventory (Ci)} \times 10^6\ \mu\text{Ci/Ci}}{\text{Dissolution time (sec)}}$ (see Item VII-F, Table VII-H , for dissolution times)

[2] $e^{-(\ln 2/\text{half-life}) \times (\text{arrival time})}$ (see Item VII-F, Table VII-H , for arrival times).

[3] $\frac{\text{Release rate from repository (μCi/sec)} \times \text{decay factor}}{\text{515 l/sec flow of Pecos River}}$

References

1. Dorsh, R. G. and A. W. Lynch. Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) Site in New Mexico (SAND 78-0297), 1978.

2. Serne, R. J., D. Rai and M. J. Mason. Batch K_d Measurements of Nuclides to Estimate Migration Potential at the Proposed Waste Isolation Pilot Plant in New Mexico (PNL-2448), 1977.

Environmental Evaluation Group
Reports

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentrations of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

Environmental Evaluation Group
Reports

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures, and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (edi), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kenney, Jim W., A Critical Assessment of Continuous Air Monitoring Systems At The Waste Isolatioon Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-8

EEG-8

NEW MEXICO
HEALTH AND ENVIRONMENT
DEPARTMENT

THE SIGNIFICANCE OF CERTAIN RUSTLER AQUIFER PARAMETERS FOR PREDICTING LONG-TERM RADIATION DOSES FROM WIPP

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September 1980

Environmental Evaluation Group
Reports

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

(Continued on Back Cover)

NOTICE TO THE READER

The Environmental Evaluation Group (EEG) was assigned to the New Mexico Institute of Mining and Technology in October 1988 by the National Defense Authorization Act, Fiscal Year 1989, Public Law 100-456, Section 1433, and is no longer a part of the New Mexico Health and Environment Department, Environmental Improvement Division. Continued funding is being provided by the Department of Energy through Contract DE-AC04-79AL10752.

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The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses From WIPP

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the Waste Isolation Pilot Plant (WIPP), a Federal radioactive waste repository proposed for construction underground in an area near Carlsbad, New Mexico. The objective of the EEG evaluation is to protect the public health and safety and ensure that there is no environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP. Analyses are conducted by EEG of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies, and other organizations as they relate to the potential health, safety, and environmental impacts of WIPP. These analyses may involve public meetings, site visits, and consultations with agencies, professional associations, and scientific experts.

The project is funded entirely by the U.S. Department of Energy through Contract #DE-AC-04-79AL10752 with the New Mexico Health and Environment Department.

Robert H. Neill
Director

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SUMMARY

This report considers some aspects of the radionuclide transport modeling presented in documents published by the U. S. Department of Energy (DOE) regarding the Waste Isolation Pilot Plant (WIPP) nuclear waste repository proposed for development in Southeastern New Mexico. The radionuclide transport modeling is used to predict worst possible consequences of a WIPP repository breach event in which waste enters groundwater. The aim of this report is to determine whether plausible changes in the parameters used by DOE to describe the flow of groundwater near the WIPP site could result in: a) significantly faster radionuclide movement in groundwater; and b) significantly higher concentrations of radionuclides in Pecos River water and correspondingly higher radiation doses than predicted by DOE. The conclusion reached is that while plausible changes in hydrologic conditions and waste-rock interactions might result in a significant reduction in the time it takes for radionuclides to reach the Pecos River, the shorter travel times do not result in significant increases in the estimated concentrations of radionuclides in the Pecos River nor in the radiation doses associated with the use of such water. Other ways in which parameter changes might affect these concentrations and doses are mentioned in the Conclusions section of the report, but are not the subject of this analysis.

The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Exposures from WIPP

I. Introduction

To estimate worst possible radiation doses which might result from a hydrologic breach of the proposed WIPP repository, the U. S. Department of Energy (DOE) has considered situations in which:

1. groundwater passes through the repository, dissolves some waste and brings the dissolved radionuclides into the Rustler aquifer;
2. the radionuclides are carried by the Rustler water to the Pecos River at Malaga Bend, fifteen miles from the WIPP site.

(See, for example, the WIPP Safety Analysis Report, Ref. 1 and the Draft Environmental Impact Statement for WIPP, Ref. 2). Figure 1 illustrates two of the breach events which have been analyzed.

The aim of this report is to assess the assumptions made in modeling step 2, nuclide transport in the Rustler. The question is: has a worst (plausible) case really been considered?

In its report of a January, 1980 meeting of geologists and hydrologists to discuss conditions in the vicinity of the WIPP site, the Environmental Evaluation Group has summarized information presented concerning the status of hydrologic testing and questions raised concerning the adequacy of the available data for predicting consequences of a repository breach(Ref. 3). It is clear that there are uncertainties in the hydrologic parameters used for modeling flow in the Rustler aquifer,

and that there are even greater uncertainties involved in predicting changes in hydrologic conditions that might occur over thousands or millions of years. However, it is not clear that these uncertainties introduce equivalent uncertainties into the projected consequences of a worst case WIPP repository breach. This report will address the question of whether or not a worst plausible case has been considered in the WIPP Safety Analysis Report (SAR) nuclide transport modeling by asking:

Can plausible changes in the nuclide transport modeling assumptions and Rustler aquifer parameters result in significantly higher estimates of peak radionuclide concentrations in Pecos River water? (By "peak concentration" is meant the radionuclide concentration in Pecos River water at Malaga Bend, measured in picocuries per liter, at the time when that concentration is highest.)

In order to limit attention to step 2 of the breach event modeling, nuclide transport in the Rustler aquifer, it is assumed that radionuclides enter the Rustler at a given rate and move along a flow path to Malaga Bend. Then the calculated radionuclide concentrations in Pecos River water and the resulting radiation doses depend primarily on the transit times of the radionuclides in the Rustler, between the WIPP site and the Pecos River. For radionuclides in the initial repository inventory, the longer it takes the nuclide to reach the Pecos River, the smaller its concentration will be in the river, because of radioactive decay of the nuclide. For radioactive decay products, the situation is more complex, because ingrowth causes an increase in activity over a period of time, followed by a decrease.

This paper is organized as follows:

Section II outlines the models used in the WIPP SAR (Ref. 1) and in this report to describe radionuclide transport in the Rustler aquifer. The next two sections explore the relation

between peak radionuclide concentrations in the Pecos River and key hydrologic parameters. First, Section III considers the relation between the hydrologic parameters and the radionuclide travel times. Then, Section IV considers the relation between radionuclide travel times and peak radionuclide concentrations in the Pecos River. Sections V and VI examine the plausibility of various changes in parameter values and modeling assumptions used to assess consequences of a WIPP repository breach. In Section VII, radiation dose commitments which could result from drinking Pecos River water are calculated, under a variety of assumptions. Conclusions are summarized in Section VIII.

Although this analysis investigates only a portion of the breach consequence assessment which has to do with nuclide transport in the aquifer, it is necessary to have some source term to use for radionuclide concentration and dose calculations. That is, one must start with a rate at which radionuclides are introduced into the aquifer. For illustrative purposes, this analysis will focus on a single radionuclide, Plutonium-239 (Pu-239). This choice is made for the following reasons: The waste proposed for permanent disposal at WIPP is transuranic waste, primarily that classified as contact handled.* The radionuclide content includes plutonium and americium isotopes. Pu-239 is the dominant radionuclide in contact handled transuranic waste, in the sense that it has a long half-life (2.4×10^4 years) and a higher initial inventory than any of

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* Transuranic waste (i.e., waste contaminated with plutonium, americium and other radionuclides with atomic number greater than that of uranium) is classified as contact handled if its container has a surface dose rate of 200 mrem/hr or less.

the other alpha-emitting radionuclides present. However, under the hydrologic modeling assumptions used in the WIPP SAR, Pu-239 travels so slowly in the Rustler aquifer that it decays before it reaches the Pecos River. While its decay product Uranium-235 does contribute significantly to dose estimates, Plutonium-239 itself does not. This analysis will explore the possibility that plausible changes in the hydrologic modeling assumptions can result in a substantial portion of the Pu-239 inventory reaching the Pecos River.

In the WIPP SAR, the hydrologic breach event which would result in the largest amount of waste entering the Rustler aquifer is Communication Event 1, in which water flows from the Bell Canyon aquifer below the repository, through the repository and up into the Rustler aquifer (see Figure 1). Thus, peak radionuclide concentrations and dose commitments will be calculated based on the rate at which Plutonium-239 would be released into the Rustler aquifer under the SAR assumptions for Communication Event 1.

II. Nuclide Transport Model

The Sandia Waste Isolation Flow and Transport model (SWIFT), developed by Intera Environmental Consultants, Inc., has been used by the Department of Energy for calculations involving nuclide transport in the Rustler aquifer (Ref. 4). For the purposes of calculating the nuclide concentrations in Rustler brine entering the Pecos River, a simplified version of the model is used by DOE (Ref. 1, Section 8.2.1.3.3). The basic assumptions made for this application can be outlined as follows:

Assumption 1. Water Flow in the Rustler Aquifer

Water moves along a one-dimensional flow path with average velocity $\bar{v}$ given by Darcy's Law:

$$\bar{v} = \frac{K}{\theta} \cdot \frac{\Delta h}{\Delta \ell} \quad \text{ft/yr} \qquad (1)$$

where:

θ = aquifer porosity

K = hydraulic conductivity or permeability (ft/yr)

$\frac{\Delta h}{\Delta \ell}$ = hydraulic gradient (change in hydraulic head per unit distance).

To account for the fact that at any time and position, some water particles are moving more rapidly than the average while some are moving more slowly, the differential equation describing flow includes a term which reflects this "longitudinal dispersivity."

Assumption 2. Equilibrium Adsorption of Nuclides

At any point in the aquifer and at any time, the activity concentration of a given radionuclide is distributed between the aquifer rock and the aquifer water as follows:

$$C_s = K_d \, C_L \qquad (2)$$

where:

C_s = activity concentration in/on rock (pCi/g)

C_L = activity concentration in water (pCi/mℓ)

K_d = distribution coefficient for the nuclide in question (mℓ/g).

Assumption 3. Radioactive Decay and Ingrowth

Nuclide concentrations change with time because of radioactive decay. These changes are built into the SWIFT model.

In order to study the effects of parameter changes on nuclide concentration and dose estimates, it is useful to simplify Assumption 1 still further and neglect longitudinal dispersivity. This can be justified only if the simplification does not change the model predictions significantly, for the nuclides under consideration. In Appendix VI of Ref. 5, Greenfield has shown that for long-lived radionuclides and their decay products this is indeed the case; that is, the peak concentration and dose estimates obtained using the SWIFT model, including longitudinal dispersivity, are close to those obtained using the analogous model with zero dispersivity. Results of the two models differ by less than a factor of 2 in the case of long-lived initial inventory radionuclides. When additional approximations are made in connection with the simple model to accommodate a decay chain in which different members move with different velocities, the concentration and dose estimates obtained from the two models still differ by less than a factor of 5. Peak concentration and dose estimates obtained using the simpler model tend to be larger than those obtained taking dispersivity into account.

Thus, for the remainder of this analysis, the following assumption will be made.

Assumption 4. Zero Dispersivity

Longitudinal dispersivity is zero. All water particles move with the average velocity $\bar{v}$ given by equation (1).

Under these assumptions, it can be shown (Ref. 5, Appendix VI) that a nuclide with a distribution coefficient K_d (mℓ/g) will move in the aquifer with velocity:

$$r = \frac{\bar{v}}{B} \quad \text{ft/yr} \qquad (3)$$

where B, the retardation factor, is given by:

$$B = 1 + \frac{\rho}{\theta} K_d \qquad (4)$$

ρ = aquifer density (g/mℓ).

III. Hydrologic Parameters and Nuclide Travel Times

Suppose the aquifer parameters defined in Section II are constant over a portion of the flow path which is d feet long. Then the time T that it takes for a nuclide to travel through that part of the flow path is given by:

$$T = \frac{d}{r} = \quad yr \qquad (5)$$

where r is the nuclide velocity, given in ft/yr.

Combining equations (1), (3), (4) and (5) gives:

$$T = \frac{d(\theta + \rho K_d)}{K\ (\Delta h/\Delta \ell)} \quad yr \qquad (6)$$

for the time T that it takes for a radionuclide with distribution coefficient K_d to traverse a segment of the aquifer having length d, porosity θ, density ρ, hydraulic conductivity K and hydraulic gradiant $\Delta h/\Delta \ell$.

To illustrate the effects of the various parameters on T, consider Plutonium-239 traversing the first 5 miles of the flow path from the repository to the Pecos River. The parameter values for this interval, based on information in the SAR*, are:

$$d = (5\ mi)\ (5280\ ft/mi) = 2.6 \times 10^4\ ft$$

$$\theta = 0.1$$

$$\rho = 2\ g/m\ell$$

$$K_d = 2.4 \times 10^3\ m\ell/g$$

$$K = 1\ ft/day \text{ or } 365\ ft/yr$$

$$\frac{\Delta h}{\Delta \ell} = \frac{100\ ft}{(5\ mi)\ (5280\ ft/mi)} = 3.8 \times 10^{-3}.$$

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* Table 3.3-1 gives $\theta = 0.1$; Table 2.5-12 gives 2.4×10^3 mℓ/g as the lowest K_d value measured with plutonium, groundwater and Rustler formation rock; Figure 8A-4 gives K=1 ft/day at the WIPP site (Ref. 1).

The hydraulic gradient $\Delta h/\Delta \ell$ is computed on the basis of the potential lines shown in Figure 2. Over the first 5 miles of the flow path from the repository, the calculated hydraulic potentials in the Rustler aquifer drop 100 feet, from about 3150 to 3050 feet.

Substituting these parameter values into equation (6) one finds that the time T that it would take for Pu-239 to migrate over this 5 mile stretch is:

$$T = 9.0 \times 10^7 \text{ yr.}$$

The question is: What changes in parameter values could reduce the travel time T significantly? To make the example more specific, what changes in parameter values could result in an order of magnitude decrease in T?

If the distribution coefficient K_d decreases by an order of magnitude, the travel time T decreases by an order of magnitude. The same decrease in T would result from an order of magnitude increase in hydraulic conductivity K or hydraulic gradient $\Delta h/\Delta \ell$. Changes in the aquifer porosity θ have virtually no effect on the travel time T, provided that the distribution coefficient K_d remains high (say, above 10).

IV. Plutonium-239 Travel Time and Its Peak Concentration in the Pecos River

If Pu-239 enters the Rustler aquifer at a rate of q pCi/sec at the WIPP site, moves in the Rustler according to the assumptions in Section II, and begins to enter the Pecos River at an arrival time T_A years after waste emplacement, then the peak concentration C of Pu-239 in Pecos River water is given by:

$$C = \frac{q\, e^{-(\ln 2)(T_A)/(2.4 \times 10^4)}}{F} \quad p\ Ci/\ell \qquad (7)$$

where 2.4×10^4 years is the half-life of Pu-239 and F ℓ/sec is the Pecos River flow at Malaga Bend. The minimum value for F is given in the SAR as 18 ft^3/sec (Ref. 1, 8.2-9). That is:

$$F = 5.1 \times 10^2\ \ell/sec.$$

As discussed in Section I, the breach event under consideration in this analysis involved a hydrologic connection between aquifers above and below the repository. The SAR describes such a breach event: Communication Event 1. Under the SAR assumptions* for Communication Event 1, the rate q at which Pu-239 in contact handled transuranic waste enters the Rustler is:

$$q = 2.1 \times 10^4\ \ pCi/sec.$$

Thus, from equation (7), the peak concentration C of Pu-239 in Pecos River water is:

$$C = 41 \times e^{-(\ln 2)T_A/2.4 \times 10^4}\ pCi/\ell \qquad (8)$$

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* The steady state repository dissolution rate is given as 0.25 ft^3/day (p. 8.3-5); the fraction of the repository volume which is waste is 0.115 (p. 8.3-3); and the specific activity of Pu-239 in the waste is 2.21×10^{-3} Ci/ℓ (Table 3.1-2). Then q = (0.25 ft^3/day) x (0.115) x (28.32 ℓ/ft^3) x (2.21×10^{-3} Ci/ℓ) x 10^{12} pCi/Ci) ÷ (8.64×10^4 sec/day), (Ref.1).

where the arrival time T_A is the sum of the breach time (i.e. the number of years between waste emplacement and the repository breach event) and the Pu-239 travel time (i.e. the time it takes for Pu-239 to travel in the Rustler aquifer from the WIPP site to the Pecos River).

Using the information in the SAR concerning Rustler aquifer hydrology and distribution coefficients*, the time between a breach event and the arrival time of Pu-239 at the Pecos River would be about 1.4×10^8 years.**

The Pu-239 in the repository inventory would decay in this time, since Pu-239 has a half-life of 2.4×10^4 years. However, this analysis considers whether plausible changes in parameters can lead to significantly shorter travel times and significantly higher radiation doses than those derived from the parameters used in the SAR analysis. For the moment, equation (8) will be used to study the dependence of the peak Pu-239 concentration C on the arrival time T_A, without regard to the plausibility of different T_A values. The plausibility of different arrival time values will be discussed in Section V.

Figure 3 illustrates the relation between the peak Pu-239 concentration C in Pecos River water and the Pu-239 arrival time T_A. Using equation (8), C is plotted against the logarithm of T_A. This semi-log plot makes it easy to see how order-of-magnitude changes in T_A affect C. Table 1 summarized key values of C.

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* Table 2.5-12, Table 8.3-1, Figure 8A-2 and Figure 8A-4, (Ref. 1).

** The sum of the travel times for the first 5 miles, where K=1 ft/day and the last 10 miles, where K=4 ft/day (Ref. 1, Figure 8A-4). The other parameters are as given in Section III.

It can be seen from Figure 3 and Table 1, that arrival times between 0 and 10,000 years all result in roughly the same peak Pu-239 concentrations in the Pecos River. If the Pu-239 starts to enter the Pecos River 100,000 years after waste emplacement, then the peak concentration is less than a tenth of what it would be if the arrival time were 10,000 years. An arrival time of 500,000 years results in a further reduction of the peak Pu-239 concentration by a factor of 10^{-5}.

This suggests a way of making the basic question more precise:

1. Can plausible changes in the modeling assumptions or hydrologic parameters used in the WIPP SAR analysis result in a Pu-239 Pecos River arrival time of less than 100,000 years?
2. Can the Pu-239 arrival time be less than 10,000 years?

V. The Validity of Using Average Parameter Values

As discussed in Section III, an order of magnitude decrease in distribution coefficient (K_d) or increase in hydraulic conductivity (K) or hydraulic gradient ($\Delta h/\Delta \ell$) would result in an order of magnitude decrease in the travel time (T). Parameter changes amounting to more than three or four orders of magnitude would be necessary to reduce the travel time from 14,000,000 years to 100,000 or 10,000 years. The next step, then, in this analysis, is to evaluate the potential for large changes in the three key parameters.

The hydraulic gradient $\Delta h/\Delta \ell$ appears to be the least variable of these parameters. In order for the average hydraulic gradient to increase by a factor of 10, the difference between potentiometric levels of the Rustler at the WIPP site and at the Pecos River would have to go from 300 to 3000 feet. Such a change does not appear credible.

The hydraulic conductivities K for different portions of the flow path are more likely to deviate from the assumed values, either because of difficulties in measurement, non-uniformity of the aquifer or future changes (e.g. fracturing of the aquifer rock or dissolution of salt in the Rustler at the WIPP site). The SAR calculations of hydraulic conductivities in the Rustler show an increase from 1 ft/day near the WIPP site to 64 ft/day at the Pecos River. It does not appear likely that hydrologic conditions in the vicinity of the site would change so drastically in 10,000 or even 100,000 years that they would match present conditions in the Rustler near the Pecos River. Perhaps an increase by one order of magnitude in hydraulic conductivity values can be taken as a worst plausible case.

The most unpredictable of the parameters is the distribution coefficient (K_d). Laboratory K_d measurements using apparently identical rocks, solutions and precedures can differ by an order of magnitude. Changing the rock or solution slightly can result in greater discrepancies. Different laboratories report widely different results (e.g. plutonium K_d values between 16 and 20 mℓ/g for Culebra dolomite and "prepared water" in Ref. 6 and values of 2,100 mℓ/g for Culebra dolomite and brine and 7,300 mℓ/g for Culebra dolomite and groundwater in Ref. 7). In addition to the problems just discussed involving reproducibility of laboratory measurements, there are problems involved with predicting and studying in-situ conditions. Many factors influence the relative amounts of a nuclide in the solid and liquid phases of an aquifer. For example, the concentration of the nuclide in question or of other elements, can affect the capacity of the rock to absorb more of the radionuclide; thus a "loading effect" can reduce K values. Chelating agents like EDTA can also reduce K_d values, as can temperature, pH and other physical and chemical properties of the rock, the water and the nuclide. Table 21 in Ref. 7 shows a reduction of one to two orders of magnitude in K_d (for Gd-153, Eu-152 and Ce-144) when a plywood extract is added to the solution.

Therefore, it is conceivable that average K_d values for nuclides in a waste and brine mixture, moving through fifteen miles of the Rustler aquifer, would turn out to be two or even three orders of magnitude smaller (or larger) than the value used in the WIPP SAR nuclide transport modeling. However, statements in the SAR indicate that the K_d values chosen already reflect a worst case (i.e. lowest plausible average values).

The plutonium K_d value used in the SAR modeling is the lower of two K_d values reported in WIPP site-specific tests using simulated groundwater and Rustler formation rock from just outside the WIPP boundary (Ref. 1, Table 2.5-12). Further, the measurements are made using a highly oxidized species of plutonium, which is thought to be more mobile than species with lower oxidation states but less likely to be present following a repository breach (Ref. 1, p.2.5-43).

VI. Heterogeneity of Aquifer and Nuclide Properties

The preceding section considered the extent to which the average values of key parameters could differ, now or in the future, from those used in the WIPP safety assessment. This section will discuss the extent to which it is appropriate to look at average behavior. The answer proposed is in two parts.

1. In this application, it is appropriate to use average hydrologic parameters to describe water movement in the aquifer.
2. The use of a single average distribution coefficient for each nuclide may mask significant effects resulting from the migration of a subpopulation of the nuclide particles.

Point 1, regarding water movement in the aquifer, requires some qualification. The claim is that it is appropriate to use average parameter values over intervals where there are no large scale changes in hydrologic conditions. For example, one should not lump mile-long stretches where the hydraulic conductivity is measured as 1 ft/yr with mile-long stretches where the hydraulic conductivity is measured as 50 ft/yr. However, small scale variations should not add up to gross effects on water movement over a 15 mile flow path. In its travel from the WIPP site to the Pecos River, each water drop will pass through 1 inch or 10 foot fractures where it moves relatively quickly and through small portions of the aquifer which are less permeable than the average. The hydraulic gradient may be steep over a small interval, but will be less steep than the average somewhere else. This type of variation over short intervals would not result in significant changes in the nuclide concentrations and doses calculated on the basis of average values of hydrologic parameters over several mile intervals.

What is the difference, then, between the use of average aquifer parameters and the use of average distribution coefficients? The difference, as suggested in point 2, is that there may be subpopulations of nuclide particles which migrate through the whole 15 mile flow path in a way that differs significantly from the predicted norm.

Consider the case of plutonium. Under the equilibrium adsorption assumption stated in Section II, using a K_d value of 2400 mℓ/g, each plutonium particle spends a large amount of time associated with the aquifer rock and not moving with the water. This is what slows the plutonium down in its migration through the aquifer. Since there is a single K_d value governing the behavior of all of the particles, all are slowed down equally.

It is more likely, especially given the heterogeneity of the contact handled transuranic waste to be stored in the WIPP repository, that plutonium and other radionuclides will be in various physical and chemical states and complexes and will be heterogeneous in their affinity for aquifer rock and their solubility in water.

Two lines of experimental evidence suggest that if a repository breach occurred, a fraction of the plutonium particles entering the Rustler would move with an effective distribution coefficient of zero. In the plywood extract experiment discussed in Section V, there is an apparently lowering of K_d when the organic material is added to the brine-rock-nuclide mixture used to measure K_d. One interpretation suggested in Ref. 7 is that some of the nuclide particles are in organic complexes. The reason this would lower the apparent K_d is that the particles in organic complexes would remain in solution (i.e. behave as if their K_d were zero) while the other particles would not change their behavior.

In these batch experiments, movement is not observed and the chemical forms of nuclides and nuclide complexes are not determined, so any heterogeneity in form or behavior of the nuclide in question would not be observed directly.

Column infiltration experiments reported in Ref. 6 provide direct evidence of transuranic nuclide fractions which move in water through porous rock columns at the speed of water (i.e. with $K_d = 0$).* Additional amounts of the nuclide are observed to travel more slowly than water in the columns but much more rapidly than would be predicted on the basis of average K_d values measured in either batch or column experiments.**

It is not clear how to apply the results of these column infiltration experiments to nuclide migration modeling in the case of a repository breach event. The experiments discussed in Ref. 6 were not done with Rustler formation rocks. In addition, the nuclides were not in solution with organic material or minerals which would be present in the event of a WIPP repository breach. Finally, nuclide migration behavior over a distance of several centimeters in a column may not mimic nuclide behavior over a fifteen mile path. However, until WIPP-specific experiments or theoretical analyses are performed which rule out the presence of a mobile plutonium (or transuranic) fraction under WIPP conditions, this possibility should be included in the

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* The fractions listed are 7×10^{-5} for Pu^{4+} in limestone; 3×10^{-4} for Np^{5+} in limestone; and 1.3×10^{-2} for Np^{5+} in sandstone (Ref. 6, p. 15).

** For example, in one experiment, 1/1000th of the plutonium used was observed to pass through limestone at a velocity at least equal to ½ the water velocity. A neptunium fraction of 0.12 was observed to move through sandstone at a velocity at least equal to 0.1 times the water velocity (Ref. 6, p. 15).

breach consequence assessment for WIPP. Based on the evidence available so far, it is possible that a portion of the transuranic inventory injected into the Rustler aquifer in the event of a WIPP repository breach would be in a chemical form which would allow it to move through the aquifer unretarded.

The fraction chosen to represent a plausible worst case for the remainder of this analysis is 0.01. That is, this analysis will investigate the consequences of assuming that one percent of the Pu-239 entering the Rustler aquifer in the case of a repository breach moves throughout the fifteen mile flow path at the velocity of the aquifer water. The one percent value is much higher than that observed in the Ref. 6 plutonium/limestone experiment and slightly lower than that observed in the neptunium/sandstone experiment. It is considered to be a plausible worst case value because of the conflicting influences of the presence of organic material (which might create a mobile subpopulation) and the length of the flow path (which allows time for the alteration of chemical form, breaking down subpopulations).

VII. Potential Doses from Drinking Pecos River Water

The WIPP SAR includes calculations of radiation doses which people could receive if Pecos River water were to be contaminated following a repository breach event. The doses calculated are from the ingestion of fish and water and from external exposure during swimming, boating and other activities (Ref. 1, p. 8.2-9). The largest doses are from the ingestion of water, except in the case of Radium-226 where the ingestion of fish leads to slightly greater doses than the ingestion of water. Thus dose projections based on drinking Pecos River water can give a good idea of the overall radiation dose which might be received from the various water uses.

The doses calculated in this section will be whole body fifty year dose commitments received by maximally exposed adults from one year's ingestion of Pu-239 in Pecos River water. These are the doses most easily compared with doses listed in the SAR. The dose commitment D (mrem) resulting from one year's ingestion of water with a Pu-239 concentration of C (pCi/ℓ) is given by:

$$D = (C\ \text{pCi}/\ell)(730\ell)(1.9 \times 10^{-5}\ \text{mrem/pCi}) \qquad (9)$$

where 730 liters is the value recommended in NUREG 1.109 (Ref. 8, Table E-5) as the annual water uptake value to assume for maximally exposed adults and 1.9×10^{-5} mrem is given in NUREG 0172 (Ref. 9, Table 4) as the fifty year total body dose commitment an adult receives from ingesting 1 pCi of Pu-239 in the first year.

Table 2 lists peak Pu-239 concentrations C in Pecos River water and corresponding fifty year total body dose commitments D received by adults drinking 730 liters of the water in a year, for a variety of modifications of the SAR hydrologic modeling assumptions. Figure 4 shows how the dose commitment depends on the average K_d value used, if other parameters and assumptions are as in the SAR. The breach event is assumed to occur 1000 years after waste emplacement.

VIII. Conclusions

Based on the discussion of average parameter values in Section V, it is possible but unlikely that in the event of a hydrologic breach of the WIPP repository, the average values of the key hydrologic transport parameters would differ by more than three orders of magnitude from those used in the SAR modeling, all in a direction which would reduce the Pu-239 travel time to 100,000 years and raise the peak Pu-239 concentration in Pecos River water to 2.3 pCi/ℓ. It is very unlikely that the average Pu-239 travel time would actually be as low as 10,000 years, raising the peak Pecos River concentration to 31 pCi/ℓ.

It is possible, as discussed in Section VI, that a portion of the transuranic nuclide inventory, including Pu-239, will be in a chemical form which allows it to stay in solution and move at the velocity of the aquifer water. If one percent of the Pu-239 entering the Rustler aquifer under the conditions discussed in this analysis were to move throughout the fifteen mile flow path unretarded, this would result in a peak Pu-239 concentration in Pecos River water of 0.37 pCi/ℓ.

The fifty year total body dose commitments which adults drinking 730 liters of Pecos River water in a year would receive from the Pu-239 in the water are:

1. 3.2×10^{-2} mrem, if the Pu-239 travel time in the Rustler aquifer is 100,000 years;
2. 5.1×10^{-3} mrem, if 1% of the Pu-239 in the aquifer has a distribution coefficient (K_d) of zero.

These doses are comparable to the Radium-226 drinking water dose of 3.8×10^{-3} mrem from one year's intake, reported in

SAR Table 8.3-2. Thus, plausible variations in the SAR assumptions governing nuclide transport in the Rustler aquifer do not result in Pu-239 doses which are significantly greater than the Ra-226 doses already projected on the basis of the SAR assumptions. It can also be shown, using the methods of Greenfield in Appendix VI of Ref. 5 that the peak Ra-226 concentrations and doses do not change significantly* under plausible variations in the SAR assumptions.

This analysis addressed a limited question, and the conclusions are limited accordingly. Only part of the breach consequence analysis was considered: the modeling of nuclide transport in the Rustler aquifer. The question asked was essentially: if radionuclides were to enter the Rustler aquifer as described in the SAR breach event modeling, could plausible changes in the SAR nuclide transport modeling lead to predictions of shorter nuclide travel times and greater concentrations of radionuclides in Pecos River water than would be calculated on the basis of the SAR assumptions? The answer is that while plausible changes in hydrologic conditions and waste-rock interactions might result in significantly shortened nuclide travel time in the Rustler aquifer, the shorter times do not result in significant increases in the estimated concentrations of radionuclides in the Pecos River or in the radiation doses received by people drinking the water.

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* Doses based on faster water flow in the aquifer, lower K_d's or a portion of the Ra-226 and its parent nuclides traveling with a $K_d = 0$, within limits judged in this paper as plausible, are at most 20 percent higher than those doses calculated based on SAR assumptions. If all of the Ra-226 and its parent nuclides move with a $K_d = 0$, a situation considered unlikely, then the peak Ra-226 concentration in Pecos River water would be about 7×10^{-4} pCi/ℓ and the resulting drinking water dose would be 0.1 mrem (50 year whole body commitment to a maximally exposed adult).

However, aquifer parameters also affect the initial stage of breach consequence analysis, which was not a part of this evaluation. For the breach event considered, in which water flows from the Bell Canyon aquifer below the repository, through the repository and into the Rustler aquifer above the repository the aquifer parameters determine the amount of water flowing through the repository and hence determine the amount of waste dissolved. If the Rustler flow increases, so will the amount of waste entering the Rustler. The relation between the hydrologic parameters and the waste dissolution rate is a subject for further study.

The radiation doses calculated in this study are a function, of course, of the repository inventory. They are low in part because the waste proposed for permanent disposal at WIPP is primarily contact handled transuranic waste. If the repository inventory is changed to include high-level waste, new dose calculations will obviously have to be performed. The methods in this paper can be used to estimate doses from any long-lived radionuclide but because of the zero dispersivity assumption, these methods might be inappropriate for estimating doses from short-lived nuclides.

For short-lived radionuclides, doses would be received primarily from the portion of the inventory moving faster than the average in groundwater.

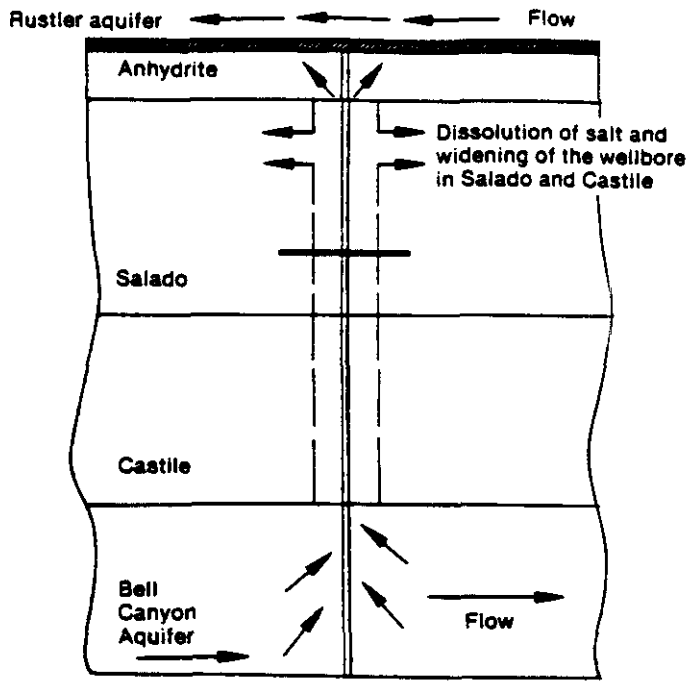

Communication Event 1

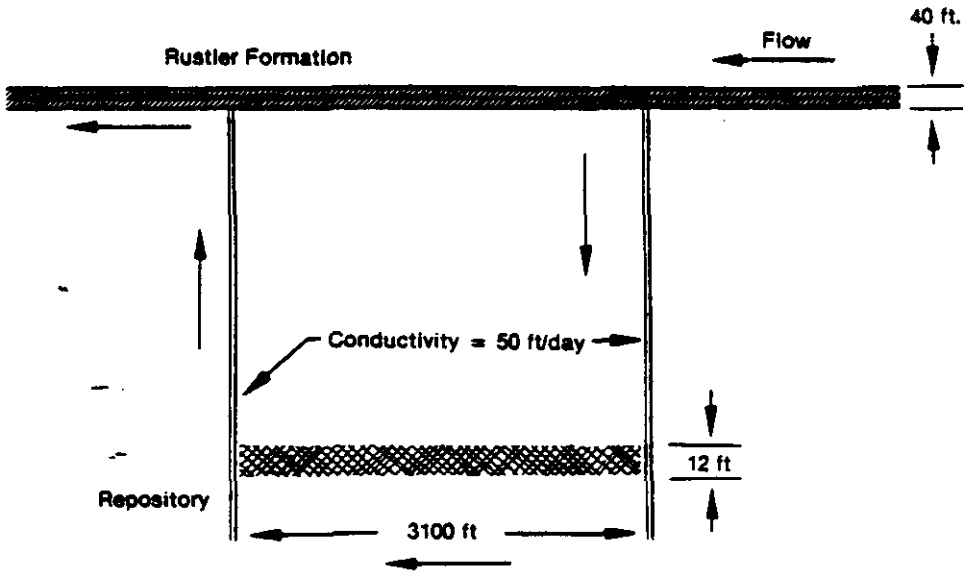

Communication Event 2

Figure 1. Schematic Diagram of Two Breach Events, Modified From WIPP DEIS Figures 9-10 and 9-11 (Ref. 2).

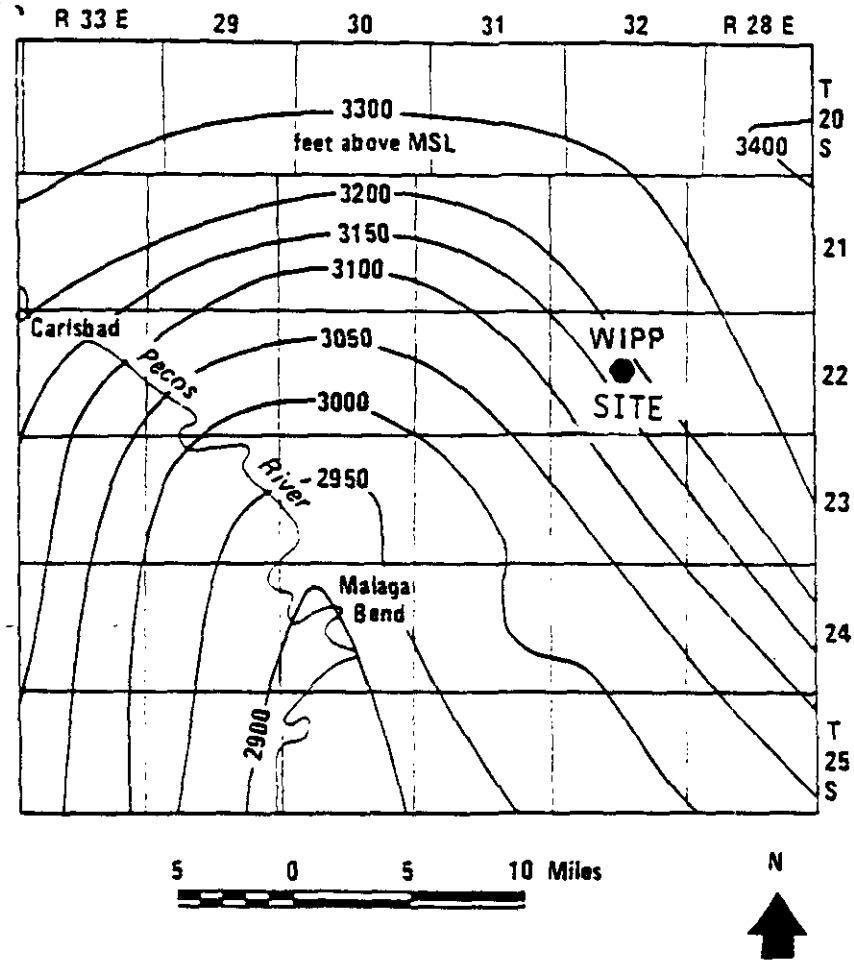

NOTES:
1. DATUM IS MEAN SEA LEVEL: VALUES GIVEN IN FEET — FRESH WATER (EQUIVALENT).
2. "RUSTLER AQUIFER" REFERS TO COMBINED CULEBRA AND MAGENTA AQUIFERS.

Figure 2. Reproduced from Figure 8A-2, SAR: Calculated Hydrologic Potentials in the Rustler Aquifer (Ref. 1).

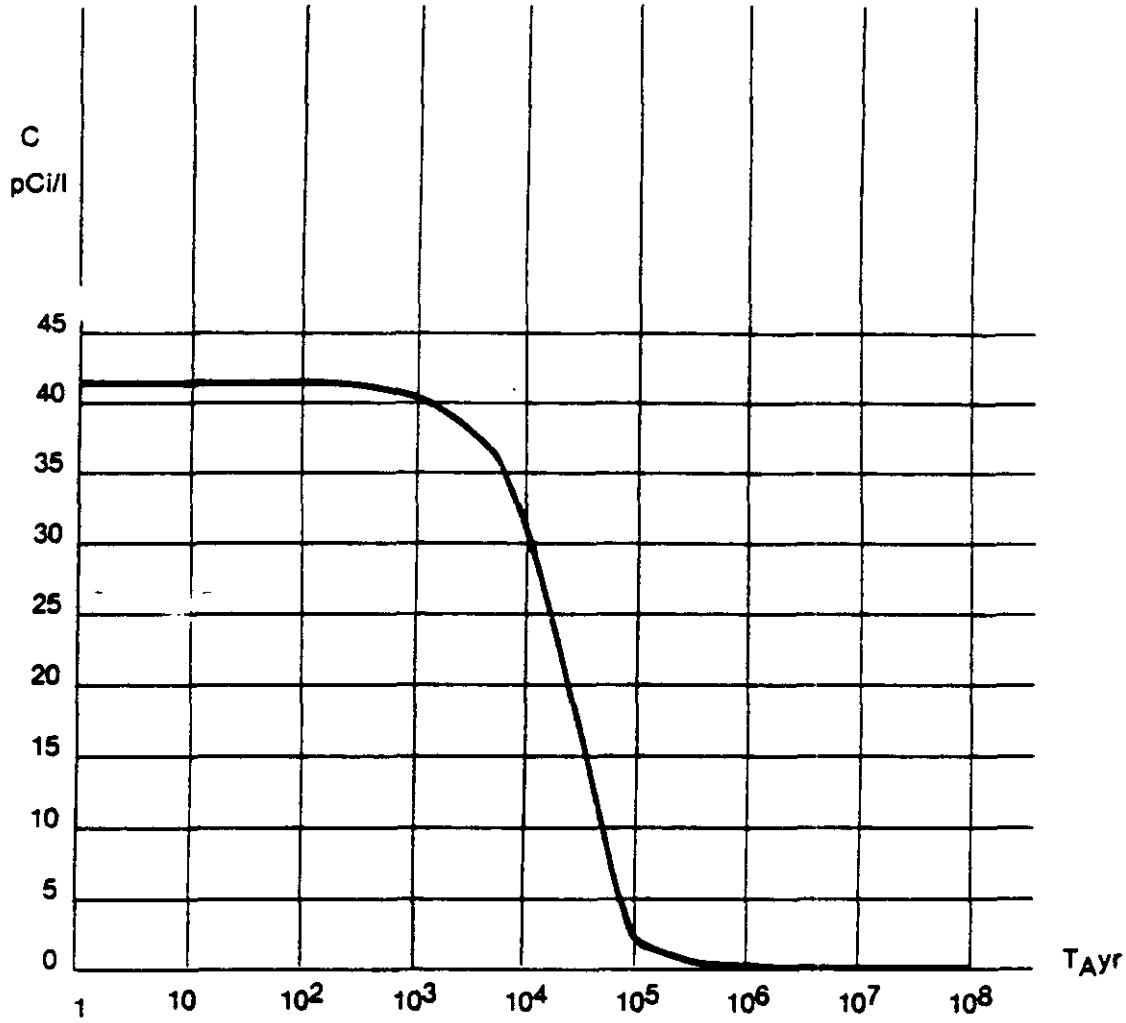

Figure 3. Peak Concentration of Pu-239 in the Pecos River as a Function of Arrival Time T_A.

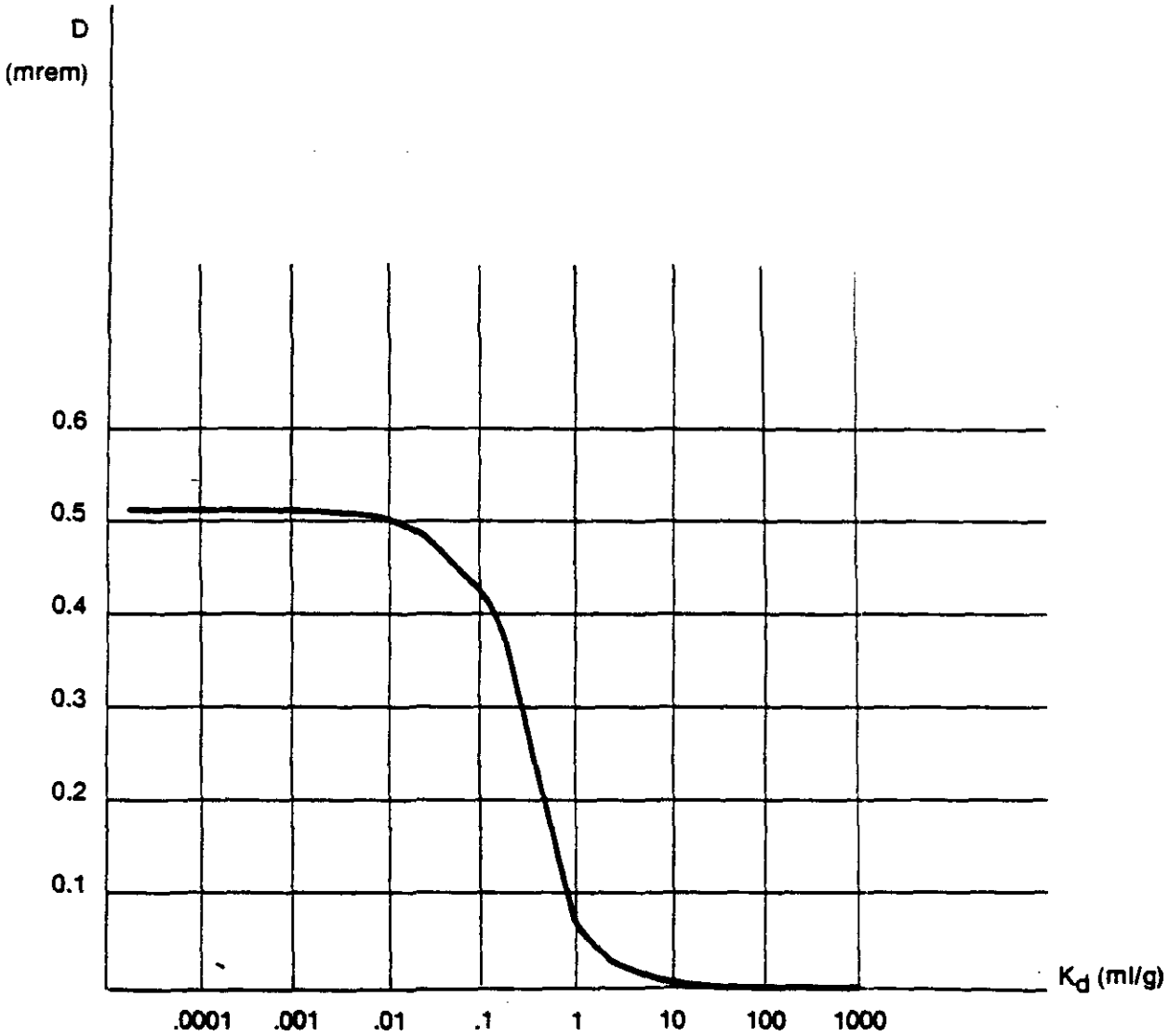

Figure 4. Fifty Year Total Body Dose Commitment D from Drinking 730 Liters of Pecos River Water in First Year, as a Function of Distribution Coefficient K_d.
(Breach time = 1000 yr.).

Table 1. Peak Pu-239 Concentration

As a Function of Arrival Time

T_A (yr)		C (pCi/ℓ)	
0		41	
1		41	
10		41	
1	+2[1]	41	
1	+3	40	
5	+3	35	
1	+4	31	
2.4	+4[2]	20.5	
3.5	+4[3]	15	
5	+4	9.7	
1	+5	2.3	
5	+5	2.2	-5
1	+6	1.2	-11
1	+7	< 1	-99
1	+8	< 1	-99

[1] 1 +2 means 10^2.

[2] Pu-239 half-life.

[3] Pu-239 mean life.

Table 2. Peak Pu-239 Concentrations and Dose Commitments

Modification of SAR Assumptions[1]	Peak Pu-239 Concentration in Pecos River Water[2] (pCi/l)	Adult Total Body 50-Year Dose Commitment from Drinking Water[3] (mrem)
1. None	0[4]	0
2. Porosity $\theta = 0.01$	0	0
3. Hydraulic conductivity K = 10 ft/day throughout flow path	0	0
4. K = 50 ft/day throughout flow path (*)	0	0
5. Distribution coefficient K_d = 100 mℓ/g throughout flow path	0	0
6. K = 10 ft/day and K_d = 100 mℓ/g throughout flow path	1.9 -13	2.7 -15
7. K_d = 10 mℓ/g throughout flow path	2.6 -6	3.6 -8
8. K = 10 ft/day and K_d = 10 mℓ/g throughout flow path	1.7	2.4 -2
9. K_d = 1 mℓ/g throughout flow path (*)	7.0	9.8 -2
10. K_d = 0 mℓ/g throughout flow path (*)	37.	5.1 -1
11. 1% of the Pu-239 moves at the velocity of water	0.37	5.1 -3
12. 10% of the Pu-239 moves at 0.1 times the velocity of water	1.7	2.4 -2
13. 10% of the Pu-239 moves at the velocity of water (*)	3.7	5.1 -2

---

(1) All modifications lead to faster nuclide movement.

(2) Based on equations (6) and (8).

(3) Based on equation (9).

(4) 0 means $< 10^{-50}$.

(*) Starred modifications are not considered plausible.

REFERENCES

1. U.S. Department of Energy. Waste Isolation Pilot Plant Safety Analysis Report. 1980.

2. U.S. Department of Energy. Draft Environmental Impact Statement, Waste Isolation Pilot Plant (DOE/EIS-0026-D) April 1979.

3. Environmental Evaluation Group. Geotechnical Considerations for Radiological Hazard Assessment of WIPP: A Report of a Meeting Held on January 17-18, 1980 (EEG-6), April 1980.

4. Dillon, R.T., R.B. Lantz, and S.B. Pahwa. Risk Methodology for Geologic Disposal of Radioactive Waste: The Sandia Waste Isolation Flow and Transport (SWIFT) Model (SAND-78-1267), October 1978.

5. Environmental Evaluation Group. Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U.S. Department of Energy (EEG-3), August 1980.

6. Seitz, M.G., et al. Studies of Nuclear Waste Migration in Geologic Media, Annual Report. November 1976-October 1977 (ANL-78-8), March 1978.

7. Dosch, R.G., and A.W. Lynch. Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) Site in New Mexico (SAND-78-0297), June 1978.

8. U.S. Nuclear Regulatory Commission. Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I. (NUREG 1.109, Revision 1), October 1977.

REFERENCES

Continued

9. U.S. Nuclear Regulatory Commission. Age-Specific Radiation Dose Commitment Factors for a One-Year Chronic Intake (NUREG-0172), November 1977.

Environmental Evaluation Group
Reports

(Continued from Front Cover)

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

Environmental Evaluation Group
Reports

(Continued from Front Cover)

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (edi), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

Environmental Evaluation Group
Reports

(Continued from Front Cover)

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kenney, James W., A Critical Assessment of Continuous Air Monitoring Systems At The Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

EEG-40 Review of the Final Safety Analysis Report (Draft), DOE Waste Isolation Pilot Plant, May 1989.

EEG-41 Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, July 1989.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-9

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EEG-9

An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach

[redacted]

Peter Spiegler, Ph.D.
Environmental Evaluation Group
Environmental Improvement Division
Health and Environment Department
State of New Mexico

September 1981

Environmental Evaluation Group

Reports

EEG-1 A Compilation of Site Selection Criteria, Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, Donna Goad, June 1979.

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Plant, U. S. Department of Energy
Robert H. Neill, James K. Channell, Carla Wofsy, Moses A. Greenfield, Editors; August 1979.

(EEG-3 and EEG-2 published together in same report)

EEG-4 Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, Marshall S. Little, February 1980.

EEG-5 Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, James K. Channell, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A report of a meeting held on January 17-18, 1980, Environmental Evaluation Group, April 1980.

EEG-7 WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, Lokesh Chaturvedi, November 1980.

EEG-8 The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, Carla Wofsy, September 1980.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach

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September 1981

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the Waste Isolation Pilot Plant (WIPP), a Federal radioactive waste repository proposed for construction underground in an area near Carlsbad, New Mexico. The objective of the EEG evaluation is to protect the public health and safety and ensure that there is no environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP. Analyses are conducted by EEG as well as reviews of reports issued by the U. S. Department of Energy (DOE) and its contractors, other Federal agencies and other organizations as they relate to the potential health, safety and environmental impacts of WIPP.

The project is funded entirely by the U. S. Department of Energy through Contract #DE-AC-04-79AL10752 with the New Mexico Health and Environment Department.

Robert H. Neill
Director

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SUMMARY

As part of the assessment of the potential radiological consequences of the proposed Waste Isolation Pilot Plant (WIPP), this report evaluates the post-closure radiation dose commitments associated with a possible breach event which involves dissolution of the repository by groundwaters and subsequent transport of the nuclear waste through an aquifer to a well assumed to exist at a point 3 miles downstream from the repository.

The concentrations of uranium and plutonium isotopes at the well are based on the nuclear waste inventory presently proposed for WIPP and basic assumptions concerning the transport of waste as well as treatment to reduce the salinity of the water. The concentrations of U-233, Pu-239, and Pu-240, all radionuclides originally emplaced as waste in the repository, would exceed current EPA drinking water limits. The concentrations of U-234, U-235, and U-236, all decay products of plutonium isotopes originally emplaced as waste, would be well below current EPA drinking water limits. The 50-year dose commitments from one year of drinking treated water contaminated with U-233 or Pu-239 and Pu-240 were found to be comparable to a one year dose from natural background. The 50-year dose commitments from one year of drinking milk would be no more than about 1/5 the dose obtained from ingestion of treated water.

These doses are considered upper bounds because of several very conservative assumptions which are discussed in the report.

I. Introduction

As part of the assessment of radiation risk associated with the proposed Waste Isolation Pilot Plant (WIPP), the Department of Energy (DOE) has considered ways in which the repository might be breached long after it is sealed. Four representative scenarios chosen for analysis (Refs. 1, 2) have the following assumptions:

1) A hydrologic breach event occurs.
2) Radioactivity is leached from the waste at the same rate as salt is dissolved into water. The contaminated water is transported to the Rustler aquifer formation through a connection.
3) The contaminated water enters the Rustler aquifer and moves with the aquifer water toward Malaga Bend, where it enters the Pecos River.

The transport of radioactive waste in the Rustler aquifer is considered by DOE to be the principal pathway which would result in radioactivity entering usable water in the shortest time and in the highest concentration.

II. Statement of Problem

This report considers the following scenario:

1) Saturated brine containing leached radioactivity from the repository enters the Rustler aquifer formation.
2) Radioactive brine is transported to a well assumed to exist at a point 3 miles downstream from the repository.
3) As the brine plume moves toward the well, it is diluted such that when the water reaches the well it is assumed to be usable for agriculture, without treatment, and for drinking, after treatment to remove most of the salts.

The dose commitment to average members of the public are based on the consumption of treated well water and of milk from cows drinking untreated well water. The quantity of well water was considered insufficient for use on crops, or for other agriculture; therefore, meat and vegetable pathways were not considered. The vegetable and meat pathways would probably result in only a small fraction of the water and milk pathway.

III. Method of Calculation

The calculations are based on the model illustrated in Figure 1. The repository is separated from the biosphere by a number of barriers which must be breached sequentially if radioactivity is to reach the biosphere. The penetration of a barrier can be achieved only at a cost that is expressed quantitatively in terms of a dilution factor, i.e., radioactive water can only be carried across a barrier by mechanisms which bring about a dilution of the radioactive concentration. Under the assumption that all barriers are breached, the concentration of radioactivity of water reaching the biosphere is given by

$$C_{b,i} = (1.0E+12)(D_n \; . \; . \; . \; . \; . \; D_2 \; D_1) \, C_{r,i} \qquad (1)$$

where:

$C_{b,i}$ = Concentration of radionuclide i in water that reaches the biosphere, pCi/ℓ

$C_{r,i}$ = Concentration of radionuclide i in the repository Ci/ℓ

D_j = Dilution factor associated with the breaching of barrier j

1.0E+12* = Conversion factor, Ci to pCi

The dose commitment is then calculated by

$$H_{50,i} = C_{b,i} \; U \; DCF_i \qquad (2)$$

*1.0E+12 + 1×10^{12}

$H_{50,i}$ = 50 year dose commitment for a one year intake of isotope i, mrem

U = the usage; the usage rate or consumption rate of contaminated water or milk, ℓ/yr

DCF_i = the 50 year dose commitment factor (Ref. 3), mrem/pCi

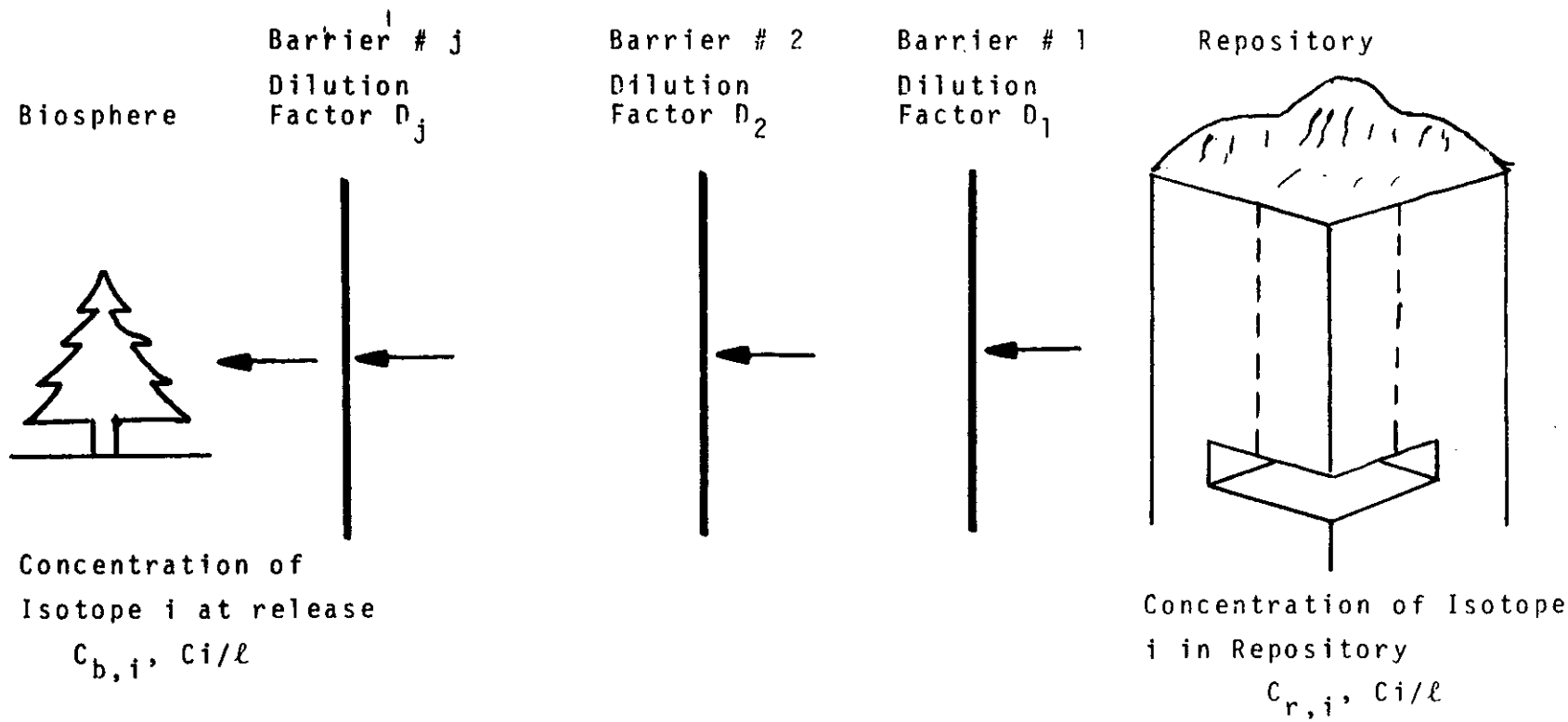

Figure 1. Schemetic of waste movement following a repository breach.

IV. Dilution Factors

1) Leaching of radioactivity from the repository by brine, D_1.

The hydrologic breach event considered is described as communication event 2 by DOE (Ref. 1, 2). Two wellbore connections are made between the Rustler formation and the repository as illustrated in Figure 2. The breach occurs 1,000 years after waste emplacement and decommissioning. Water from the Rustler aquifer flows down the upstream wellbore, through the repository, and then back to the Rustler via the downstream wellbore. Salt is continuously dissolved along the path of flow until the water becomes saturated brine. It is assumed that water leaves the Rustler with a total-dissolved-solids (TDS) concentration of 3000 milligrams per liter and reenters as saturated brine containing 410,000 milligrams per liter of TDS.* Since the density of salt is about 2, one liter of water will dissolve about 0.2 liter of salt when becoming saturated brine. It is further assumed that salt dissolution occurs uniformly along the 5500 foot flow path through the salt bed (see Figure 2) and that the leach rate of waste is equal to the leach rate of salt. The dilution factor to leach the salt/waste is then given by

$$D_1 = f_1 \; f_2 \; f_3 = 1.3E\text{-}02^* \qquad (3)$$

where:

f_1 = Volume of Salado formation dissolved per unit volume of Rustler water = 0.20

f_2 = fraction of breach path through repository = 3100/5500

f_3 = fraction of repository volume which is CH-TRU waste = 0.115

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*The TDS concentration of 3000 is based upon a similar value in a well found at the James Ranch, about 3 miles from the center of the WIPP site (Reference 1, Table 7-19).

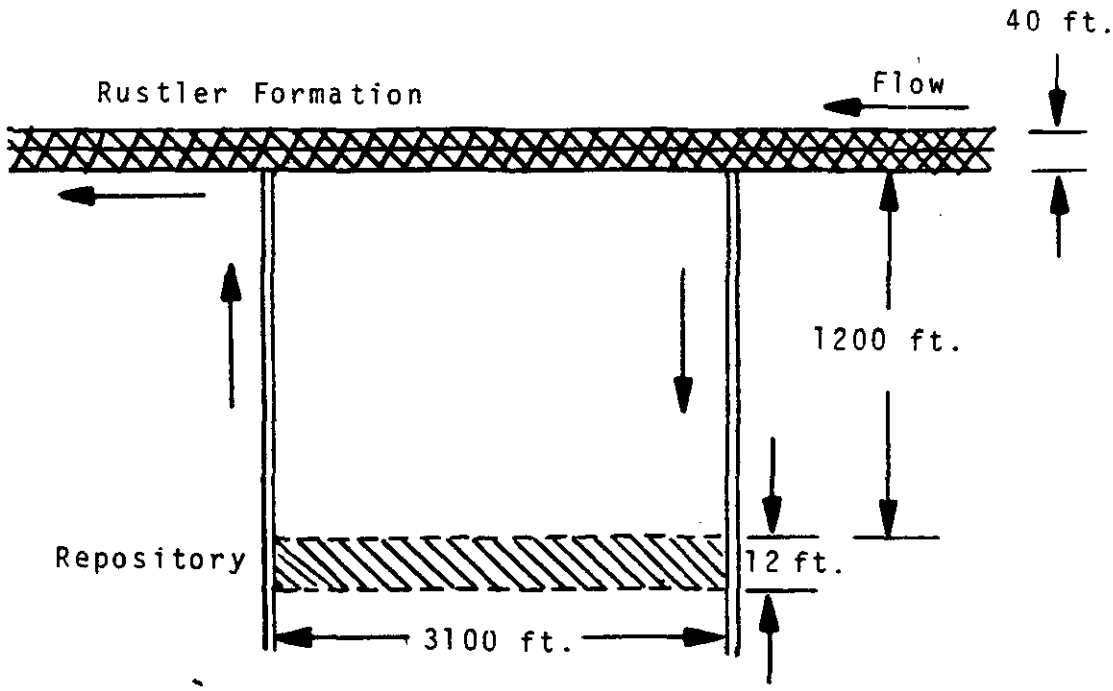

Figure 2. Schematic Diagram of Communication Event 2
Modified From WIPP FEIS Figure 9-11 (Ref. 2)

2) Dilution factor due to movement between repository and well, D_2:

Because of the adsorption and desorption of nuclides as they pass through the rock, the movement of nuclides in the aquifer is slower than the velocity of water.

The nuclide velocity is given by the water velocity divided by the retardation factor B

$$V_n = V_w/B \qquad (4)$$

$$B = 1 + \frac{\rho}{\theta} K_d \qquad (5)$$

where:

V_n = nuclide velocity
V_w = water velocity, 15 ft/yr.
θ = formation porosity = 0.1
ρ = formation density = 2 gm/cc
K_d = distribution coefficient = 1 mℓ/gm for all uranium isotopes and 2.4E+03 mℓ/gm for all plutonium isotopes (Reference 2, Table 2.5-12)

The values of the above parameters are from references 1 and 2. The time of travel between the repository breach and the well is then calculated from

$$T = \frac{dB}{V_w} \qquad (6)$$

where

d = distance between repository breach and well = 3 miles or 15840 ft.

If a repository breach occurs one thousand years after waste emplacement, all uranium isotopes and all plutonium isotopes will reach the well in about twenty thousand and fifty million years respectively (There are other radionuclides in the waste but their radiological impact is not significant compared to the plutonium and uranium isotopes).

Because of radioactive decay, the activity decreases as the nuclides travel in the direction of the well. The decrease in activity is given by the following dilution factor

$$D_2 = \exp(-\lambda T) \qquad (7)$$

where

λ = decay constant of isotope, $yrs.^{-1}$

T = time of travel between breach and well, yrs.

For Pu, the retardation factor is so large that all the isotopes decay before reaching the well. The dilution factor D_2 is zero. However, there is evidence that the transport model and the distribution coefficients do not account fully for certain observed phenomena. Thus, Seitz et al (Reference 4) observed in their studies of radionuclide migration in geologic media that 2.6% of the plutonium traveled at a relative migration rate (Vn/Vw) greater than 0.001. Dosch and Lynch (Reference 5) also observed that the K_d values for rare earth radionuclides decreased when plywood extract was added to the brine. This was attributed to the formation of more soluble complexes between radionuclides and organic molecules.

In this report, it will be assumed that 1% of the Pu-239 and Pu-240 in CH-TRU waste is in a chemical form which allows it to move with a Rustler water velocity of 15 ft/yr (K_d = 0). On the bases of the Seitz studies, this is highly conservative. Since the distance between the breach and the well is 3 miles, the travel time is thus 1,000 years. The dilution factors D_2 (including the assumption that 1% of Pu moves with water velocity of 15 ft/yr) for Pu-239 and Pu-240 are therefore 9.7E-03 and 8.9E-03 respectively.

The dominant uranium isotopes in CH-TRU waste after 21,000 years time of breach plus time of travel to the well for

uranium nuclides are U-233 (from the initial inventory) U-234 (derived mainly from Pu-238) and U-235 (derived from Pu-239), and U-236 (derived from Pu-240).

Because of the long half-lives of U-233, U-234, U-235, and U-236, the dilution factors D_2 are 0.91, 0.94, 1.0 and 1.0 respectively.

3) Dilution factor to make brine potable, D_3.

The brine coming out of the repository and entering the Rustler aquifer is so saline that it cannot be used for irrigation or for drinking. It is assumed that the brine will be diluted in the aquifer as it travels toward the well. Several dilution mechanisms can be postulated but they will not be discussed in detail in this report.

Regional data on the quality of Rustler well water are sparse. However, a Rustler well at James Ranch, about three miles southwest of the center of the WIPP site is reported to have a TDS content of 3240 mg/ℓ (Ref. 1). In this report it will be assumed that saturated brine is diluted with water having a TDS content of 3000 mg/ℓ to form water with a TDS of 5000 mg/ℓ at the well.

Let w denote the number of units of water with a TDS content of 3000 mg/ℓ which must be added to one unit of saturated brine (at 410,000 mg/ℓ) to yield water with a TDS content of 5000 mg/ℓ. w is then found by solving the equation

$$\frac{(1 \times 410{,}000) + (w \times 3000)}{1 + w} = 5000 \text{ mg/}\ell$$

Rounded to two significant figures, w = 200 units. The dilution factor to make brine potable, D_3, is then 5E-03.

4) Treated water used for drinking, D_4.

Because of the relatively high salt content, it is assumed that water is treated before being used as drinking water for people. Such a treatment system could be reverse osmosis. In addition to the halite, treatment is assumed to remove 90% of any radium, thorium, uranium and plutonium in the water. The dilution factor for treatment of water, D_4, is thus 1.0E-01. The sludge resulting from reverse osmosis treatment will have a higher radioactive concentration than the aquifer water. The path of the sludge in the biosphere will not be studied in this report.

5) Dilution factor for water-cow-milk pathway, D_5.

In this case, it is assumed that the untreated well water is used as drinking water for a cow. The members of the farm family who own the cow drink the cow's milk.

It is assumed that the cow drinks 60 liters of water per day (Ref. 6, Table E-3) and the transfer coefficient used is 5E-04 and 1.5E-06 Ci/ℓ milk per Ci/day ingested for U and Pu respectively (Ref. 7, Table 3). The dilution factors for the water-cow-milk pathway, D_5, are thus 3.0E-02 and 9.0E-05 for uranium and plutonium respectively.

V. Isotope Inventory

The values for the activity concentrations in the repository at the time of the breach and the half-life of the nuclides are presented in Table I.

Table I

Radionuclide Concentrations at Time of Breach

Radionuclide	Half-life	Activity in Waste
	yrs	Ci/ℓ
U-233	1.6E+05	8.4E-06
U-234	2.4E+05	7.2E-08
U-235	7.0E+08	3.8E-08
U-236	2.3E+07	1.5E-07
Pu-239	2.4E+04	2.3E-03
Pu-240	6.5E+03	5.3E-04

The U-233 activity is based on 1500 Ci that originated from the light water breeder reactor core program. It is assumed that this activity is uniformly distributed in the repository. The U-234 activity is obtained by complete conversion of all the originally emplaced Pu-238 (concentration is 2.0E-04 Ci/ℓ at time of emplacement). The U-235 activity is based on the assumption that 45 per cent of the initially emplaced Pu-239 has been converted to U-235 (amount of Pu-239 converted in 21,000 years) and that this activity is available for travel to the well following the breach. This simplified source term is conservative and yields higher concentration at the well than the more rigorous source term resulting from the transport model of Lester et al (Reference 8). Similarly, the U-236 activity is based on the assumption that 89 per cent of the initially emplaced Pu-240 has been converted to U-236. The Pu-239 and Pu-240 activities are the concentrations in the repository 1,000 years after closure of the repository. As discussed on Page 8, it is assumed that 1% of this concentration moves with the speed of the Rustler.

VI. Summary of Dilution Mechanisms for Different Pathways

The dilution factors for the pathway of interest and the activity concentrations of water and milk prior to consumption are presented in Table II.

Table II

Summary of Dilution Factor Calculations

Path	Dilution Factor Formula	Dilution Factor	Activity Concentration in water or Milk pCi/ℓ	NRC limits * pCi/ℓ
Treated water used for drinking	D_1 D_2 D_3 D_4			
U-233		5.9E-06	5.0E+01	3E+04
U-234		6.1E-06	4.4E-01	3E+04
U-235		6.5E-06	2.5E-01	3E+04
U-236		6.5E-06	9.8E-01	3E+04
Pu-239		6.3E-08	1.4E+02	5E+03
Pu-240		5.8E-08	3.1E+01	5E+03
Water-cow-milk	D_1 D_2 D_3 D_5			
U-233		1.8E-06	1.5E+01	see above
U-234		1.8E-06	1.3E-01	
U-235		2.0E-06	7.6E-02	
U-236		2.0E-06	3.0E-01	
Pu-239		5.7E-11	1.3E-01	
Pu-240		5.2E-11	2.8E-02	

In studying Table II, it should be remembered that the concentrations for the Pu-nuclides appear 1,000 year after the breach while the concentrations for the U-nuclides appear 20,000 years after the breach.

*Reference 9

The EPA national interim primary drinking water regulations limit the gross alpha particle activity (including radium-226 but excluding radon and uranium) to 15 pCi/ℓ (Ref. 10). The EPA environmental protection standards for disposal of residual radioactive material from inactive uranium processing site limit the concentration in water of all uranium radionuclides to 10 pCi/ℓ. The water concentrations of U-233 exceed the limits of Ref. 11 while the water concentration of Pu-239 and Pu-240 exceed the limits of Ref. 10.

VII. 50-year Dose Commitments

The water and milk consumption values, and the dose commitment factors used in the calculations are presented in Tables III, IV and V.

Table III

Water and Milk Consumptions Values (6)

Exposed Individual	Annual Water Consumption ℓ/yr	Annual Milk Consumption ℓ/yr
Infant	330	330
Child	510	330
Teenager	510	400
Adult	730	310

Table IV

50-Year Ingestion Dose Commitment Factors for Bone from a one year intake (3), mrem/pCi

Exposed Individual	U-233 and U-234	U-235 and U-236	Pu-239 and Pu-240
Infant	5.1E-03	4.7E-03	1.5E-03
Child	3.7E-03	3.4E-03	1.4E-03
Teenager	1.2E-03	1.1E-03	8.3E-04
Adult	8.7E-04	8.0E-04	7.9E-04

Table V

50-Year Ingestion Dose Commitment Factors
for Total Body from a one year intake (Ref. 3), mrem/pCi

Exposed Individual	U-233 and U-234	U-235 and U-236	Pu-239 and Pu-240
Infant	3.9E-04	3.6E-04	3.5E-05
Child	2.3E-04	2.1E-04	3.3E-05
Teenager	7.5E-05	7.1E-05	2.0E-05
Adult	5.3E-05	5.0E-05	1.9E-05

The 50-year dose commitments were calculated using equation (2) and are presented in Tables VI, VII, and VIII.

Table VI

50-Year Dose Commitments Due to U-233
from Drinking Treated Water or Milk for one year (mrem)

Exposed Individual	Drinking of Treated Water		Drinking of Milk	
	Bone	Total Body	Bone	Total Body
Infant	8.4E+01	6.4	2.5E+01	1.9
Child	9.4E+01	5.9	1.8E+01	1.1
Teenager	3.1E+01	1.9	7.2	4.5E-01
Adult	3.2E+01	1.9	4.0	2.5E-01

Table VII

50-Year Dose Commitments Due to U-234, U-235, and U-236
from Drinking Treated Water on Milk for one year (mrem)

Exposed Individual	Drinking of Treated Water		Drinking of Milk	
	Bone	Total Body	Bone	Total Body
Infant	2.6	2.0E-01	8.0E-01	6.1E-02
Child	3.0	1.8E-01	5.8E-01	3.6E-02
Teenager	9.6E-01	6.1E-02	2.3E-01	1.5E-02
Adult	1.0	6.2E-02	1.3E-01	8.0E-03

Table VIII

50-Year Dose Commitments Due to Pu-239 and Pu-240
from Drinking Treated Water or Milk for one year (mrem)

Exposed Individual	Drinking of Treated Water		Drinking of Milk	
	Bone	Total Body	Bone	Total Body
Infant	8.5E+01	2.0	7.8E-02	1.8E-03
Child	1.2E+02	2.9	7.3E-02	1.7E-03
Teenager	7.2E+01	1.7	5.2E-02	1.3E-03
Adult	9.9E+01	2.4	3.9E-02	9.3E-04

VIII. Discussion

A simple model is used to calculate the dose commitments to individuals resulting from the use of well water contaminated by a breach of the WIPP repository. The safety factors of the barriers are quantified in terms of dilution factors. The calculations are kept simple but conservative. For example, it is assumed that a U-shaped connection can occur between the Rustler aquifer and the repository even though a recent hydrological study found this connection as unrealistic when the density of the brine is taken into account (Ref. 12). Also, it is assumed that the leach rate of waste is equal to the leach rate of salt, and that 1% of the Plutonium moves with the speed of the water. For plutonium these ultra-conservative assumptions may be partialy offset by the use of the EPA dose conversion factors for transuranic elements (Table A 3-5, Reference 13). These EPA factors for the mobile fraction of plutonium would result in doses 33 to 165 times higher than those based on NUREG-0172.

The concentrations of all radionuclides at the well are less than the NRC release limits to the uncontrolled environment (9). The concentrations in the treated well water of U-233, Pu-239, and Pu-240,

all radionuclides originally emplaced with the waste, exceed the EPA drinking water limits. The concentration of U-233 in treated water exceeds the EPA limits by a factor of 3 while the combined concentration of Pu-239 and Pu-240 in treated well water exceeds the EPA limit by a factor of 11. The Pu concentration exceeds the EPA limit because it has been assumed that 1 percent of the plutonium inventory moves with the speed of groundwater. The combined concentration of U-234, U-235, and U-236 in treated well water, all decay products of Pu isotopes, is a factor of nine less than the EPA limit.

Other barriers, that could lower the release of radionuclides, can be imagined in addition to the ones discussed. For example, the salt surrounding the WIPP repository contains significant amounts of clay which is known to selectively bind uranium and plutonium (Ref. 14). Two clay seams are reported at a depth of 2124 to 2134 feet which is 20 to 30 feet above the floor of the repository. The clay could thus act as a barrier with a significant dilution factor. Data from the planned WIPP experiment may help quantify this dilution factor.

Based on the conservative assumptions used, the planned inventory of radionuclides in the waste would not present a significant risk to health from a well three miles from the site, even if a breach and transport of the waste to the well is assumed. For this to be true, however, it is particulary important that the major fraction of the plutonium be retarded by adsorption on the rock during its passage from the repository to the well.

REFERENCES

1. U.S. Department of Energy, Final Environmental Impact Statement, Waste Isolation Pilot Plant, (DOE/EIS-0026-D), October 1980, 2 volumes.

2. U.S. Department of Energy, Waste Isolation Pilot Plant, Safety Analysis Report, 1980, 5 volumes.

3. Homes, G.R., and Soldat, J.K., Age Specific Radiation Dose Commitment Factors for a One-Year Chronic Intake, (NUREG 0172), November 1977.

4. Seitz, M.G., et al, Studies of Nuclear Waste Migration in Geologic Media, Annual Report, November 1976-October 1977, (ANL 78-8), March 1978.

5. Dosch, R.G., and A.W. Lynch, Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) Site in New Mexico, (SAND-78-0297), June 1978.

6. U.S. Nuclear Regulatory Commission, Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I, (Regulatory Guide 1.109), October 1977.

7. Ng, Y.C. et al., Prediction of the Maximum Dosage to Man from the Fallout of Nuclear Devices. Handbook for Estimating the Maximum Internal Dose from Radionuclides Released to the Biosphere, (USAEC Report UCRL-50163), Part IV, 1968.

8. Lester, D.H., Jansen, G., and Burkholder, H.C., Migration of Radionuclide Chains through an Adsorbing Medium, A.I.Ch.E. Symposium Series, v. 71, 1975.

9. Code of Federal Regulations Title 10 part 20, Appendix A, Table II, Concentration in air and water above Natural Background.

10. Code of Federal Regulations Title 40, part 141.15, Maximum contaminant level for radium-226, radium-228, and gross alpha particle radioactivity in community water systems.

11. Code of Federal Regulations Title 40 part 192. Environmental Protection Standards for Uranium Mill Tailings. Section 03 Standards.

12. D'Appolonia, Modeling Verification Studies Long Term Waste Isolation Assessment. Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico, (Project No. NM78-648-701), January 1981.

13. U.S. Environmental Protection Agency, Proposed Guidance on Transuranic Elements (EPA 520/4-77-016), 1977.

14. U.S. Environmental Protection Agency, Technical Support of Standards for High-Level Radioactive Waste Management. Task C Report. Assessment of Migration Pathways, (EPA 520/4-79-007C), 1979.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-10

EEG-10

NEW MEXICO
HEALTH AND ENVIRONMENT
DEPARTMENT

RADIOLOGICAL HEALTH REVIEW OF THE FINAL ENVIRONMENTAL IMPACT STATEMENT (DOE/EIS-0026) WASTE ISOLATION PILOT PLANT, U.S. DEPARTMENT OF ENERGY

Environmental Evaluation Group
Environmental Improvement Division
Health and Environment Department
State of New Mexico

January 1981

Environmental Evaluation Group
Reports

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

(Continued on Back Cover)

NOTICE TO THE READER

The Environmental Evaluation Group (EEG) was assigned to the New Mexico Institute of Mining and Technology in October 1988 by the National Defense Authorization Act, Fiscal Year 1989, Public Law 100-456, Section 1433, and is no longer a part of the New Mexico Health and Environment Department, Environmental Improvement Division. Continued funding is being provided by the Department of Energy through Contract DE-AC04-79AL10752.

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Radiological Health Review of the Final Environmental Impact Statement

Waste Isolation Pilot Plant

Volumes 1 and 2

DOE/EIS-0026

Environmental Evaluation Group
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Health and Environment Department
State of New Mexico

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is minimal environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of reports issued by the U. S. Department of Energy (DOE) and its contractors, other Federal agencies and other organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U. S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.

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INTRODUCTION

The Environmental Evaluation Group has reviewed the Final Environmental Impact Statement on WIPP (DOE/EIS 0026) and has submitted written comments to the U.S. Department of Energy. Due to the length and complexity of the documents, the EEG was not able to complete, to its satisfaction, a comprehensive review in sufficient time to meet the deadline of December 8, 1980. Thus, preliminary comments were transmitted on December 8th and supported Governor King's November 4, 1980 request for a 45 day extension.

On January 15, 1981 the final and more detailed supplemental comments were submitted. Both of these transmittals are incorporated in this report.

RADIOLOGICAL HEALTH REVIEW OF FINAL ENVIRONMENTAL IMPACT STATEMENT ON WASTE ISOLATION PILOT PLANT, DOE/EIS-0026, VOL. I AND II, OCTOBER, 1980.

SUMMARY

Pursuant to the requirements of the National Environmental Policy Act of 1969, the Department of Energy has provided in the Final Environmental Impact State (FEIS) a comprehensive review of the potential radiological impact of the proposed Waste Isolation Pilot Plant, referred to in the FEIS as, "the authorized alternative." The EEG has reviewed this document to determine (a) the changes made in comparison with the Draft Environmental Impact Statement (DEIS); (b) the adequacy of the DOE's evaluation of the potential radiological impact; (c) the thoroughness of the DOE's response to the comments of the EEG on the DEIS; and (d) other issues which should be addressed by DOE more fully prior to beginning construction of the WIPP.

Based on our review of the FEIS, the Department of Energy has incorporated and addressed the majority of the concerns, questions and recommendations that the EEG provided to them in our August 1979 review (Reference 2) of the Draft Environmental Impact Statement on WIPP and the FEIS provides a generally satisfactory evaluation of the potential radiological impact. There are, however, a number of areas that have yet to be adequately treated by DOE and should be acted upon and resolved prior to beginning construction of the WIPP. The more important issues are listed below, and are discussed in more detail in our December 8, 1980 and January 15, 1981 comments on the FEIS.

1) EEG has referred to various statements and data in the FEIS, Geological Characterization Report on WIPP (Reference 12), and the Safety Analysis Report (Reference 8) which indicate possible instability in the area just north (1.2 to 3 miles) and southwest (less than 1 mile) of ERDA-9, and at depths near the repository horizon. EEG continues to have concern as to how this zone of anomalous seismic reflection data will

Preliminary

Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy

Environmental Evaluation Group
Environmental Improvement Division
Health and Environment Department
State of New Mexico

December 8, 1980

RADIOLOGICAL HEALTH REVIEW OF FINAL ENVIRONMENTAL IMPACT STATEMENT ON WASTE ISOLATION PILOT PLANT DOE/EIS-0026, Vol. I and II, October, 1980

INTRODUCTION

The Department of Energy appears to have incorporated and addressed the majority of the concerns, questions and recommendations that the EEG provided to them in our August 1979 review (Reference 2) of the Draft Environmental Impact Statement on WIPP.

There are, however, a number of areas that do not appear to have been adequately addressed. These and other areas are discussed in the following sections. The limited time available for this review does not permit us to determine with certainty the adequacy of either the FEIS or these preliminary comments.

INVENTORY OF RADIOACTIVE MATERIAL

EEG recommended in September 1979 that the Final EIS contain estimates of the radioactivity to be present in the repository and the uncertainty associated with the estimates. That was not done, although page 9-127 of the FEIS does show 539,000 curies of transuranic activity at 1000 years.

While the following table presents our estimates of the radioactivity, the information did not permit estimates of the uncertainties.

Radioactive Inventory of WIPP at the Time of Closure

	Radioactivity (Curies)	Emplacement	Volume (ft^3)
CH-TRU	2,800,000	Permanent	6,200,000
RH-TRU	5,100,000	Permanent	250,000
HLW	17,000,000	Temporary	150

RESOURCE EXTRACTION

There has been a slight shift in language in the Final EIS on the degree of mineral extraction that may be permitted in the various zones. Exact comparisons are not possible because various sections in both Draft and Final give different impressions of what may be permitted. The wording in the Final EIS appears to be predicting a greater degree of extraction, especially in the inner zones. These statements are paraphrased below.

Draft EIS - On page 3-6 it is stated that Zone IV will eventually be released for resource exploitation (no mention of other zones). On page 8-1 it is said that only DOE drilling would be permitted in Zones I & II; possible resource extraction would be allowed in Zone III pending outcome of studies; potash mining (no solution mining) and hydrocarbon extraction (no secondary recovery) may be permitted by DOE. On page 9-21 it is stated that mining and drilling may be permitted in Zone IV but hydrocarbons could be extracted from under Zone IV by deviated drilling from outside Zone IV. There is no mention of possible recovery from under Zones I, II, or III. On page 11-1 the statement is made that it may eventually be possible to recover hydrocarbons from beneath all zones by deviated drilling from outside Zone III.

Final EIS - The Executive Summary (page 6-14) says that hydrocarbon resources can be exploited by deviated drilling from outside zone IV or by vertical and deviated drilling within Zone IV. Potash reserves in Zone IV may be mined; the consequences of mining in Zones I, II, III are currently being evaluated. Page 4-5 says that mining for hydrocarbons and potash in Zone IV is expected and that all the natural gas could be recovered by deviated drilling from Zone IV. On page 9-27 the words "may" and "would" are both used in reference to potash and hydrocarbon extraction in Zone IV. Statements on page 11-1 say that potash and hydrocarbon extraction from Zone IV will not affect site integrity but it is not clear what the consequences would be of mining langbeinite from the inner control zones.

Our concerns with the issues are:

1. It is uncertain just what restrictions DOE presently plans to put on extraction from Zone IV and for deviated drilling beneath the inner zones.

2. The possibility of potash extraction in the inner zones of the site directly above or near the storage rooms is of particular interest. Mining activity, with possible blasting, 400 feet above the waste horizon could significantly reduce the safety factors that would be expected from storage at a depth of 2150 feet below the surface in a formation that is 2,000 feet thick.

3. We have not seen the evaluations that led to the language in the Draft nor the subsequent evaluations that apparently give DOE a greater confidence in the ability to extract minerals without threatening site integrity. It will be necessary to review these reports in order to be assured that DOE's conclusions are valid.

4. The time table for making these decisions and the procedure for doing so needs to be known so that EEG can have input into this process.

DENIAL OF MINERAL RESOURCES

Section 9.2.3.1 and related sections of the FEIS clearly describe the mineral and hydrocarbon reserves at the site, their relative economic importance, and attractiveness for potential extraction in the future. EEG still has concerns about this possible future attractiveness and the methodologies for mineral and hydrocarbon extraction currently proposed by DOE. These concerns are clearly stated in this FEIS review under sections entitled "Decommissioning" and "Resource Extraction."

EEG's comilation of references on "People-Made Penetrations" and "Conflict with Natural Resources" contained in EEG-1 (Reference # 10) inventoried in detail recommendations regarding repository sites with mineral and hydrocarbon resources. This and subsequent work in this major issue area has led EEG to emphasize the necessity to quantitate potential radiation risks associated with resource extraction at the site as currently proposed by DOE and the long-term risks with future extraction after site decommissioning.

WASTE ACCEPTANCE CRITERIA

Except for one change (the criterion for restricting toxic materials), Chapter 5 on Waste Acceptance Criteria is unresponsive to the comments of EEG. (See Reference 4 and pp. 4, and 20-24, Reference 2.) Because the SAR (Reference 8) makes it clear that the contents of the waste shipments will not be analyzed at WIPP to determine compliance with the criteria limiting toxic and corrosive material, sludges, pyrophorics, powders, and fissile material, the FEIS should have indicated how compliance will be assured, or evaluated the environmental impact assuming no compliance.

Page 15-36 of the FEIS states that the quality assurance system to insure compliance by the shippers with the WAC will be developed before the start of the WIPP operations. However, these procedures are germane to the hazard evaluation and environmental impact of the WIPP operations and therefore should have been included in the FEIS.

The FEIS discusses the possibility of processing the waste before shipment, and there is a strong implication that the waste will be processed by slag pyrolysis. If so, the WAC would be met. If the waste is not processed how will compliance be assured? What methods and what audit procedures will be used?

On page 9-176 of the FEIS, it is recognized that overpacking of the waste containers at INEL would not provide compliance with Waste Acceptance Criteria. Yet the overpacking procedures described in Section 9.8 indicate transfer of the packages to the rail car and then to the WIPP with no plans indicated for evaluation of the waste to assure compliance with WAC. There are also no plans to evaluate the waste at WIPP.

On page 8-26 of the FEIS, we note, also, that waste packages which would not meet the WAC may be shipped from WIPP to other sites for processing. Criteria are needed for such shipments, and DOE should evaluate the possible hazards associated with such shipments.

It was noted that the wording of the criteria in Chapter 5 remains ambiguous

or misleading. There is clear implication that WIPP will analyze the waste to determine if it will be accepted, and have it returned if it is unacceptable. EEG objects to such wording, and urges that it be revised to clearly indicate that the shipper--not WIPP--is responsible if the criteria are not met. Furthermore ambiguities resulting from the phrase "will be accepted" or "will not be accepted" should not be used. The DOE legal staff should also review the criteria to be certain that the wording is construed as legally mandatory on the part of the shipper, and that vague statements will be revised as previously recommended by EEG (References 2 and 4).

We also note small inconsistancies between the FEIS Waste Acceptance Criteria and the criteria published in WIPP-DOE-069, Reference 5. For example, the criterion in the FEIS limiting gas generation states the total gas produced from contact-handled waste by all mechanism may not exceed 10 moles per cubic meter of disposal room in the WIPP. The WIPP-DOE-069 limits the gas to 10 moles per cubic meter of disposal room per year in the WIPP. Is this an inadvertent deviation or has the criterion been changed? Also the FEIS criterion for "immobilization" indicates that no dry powders "will be accepted," whereas WIPP-DOE-069 limits the dry powders to 1% of the waste matrix weight.

Neither the FEIS nor any other DOE report has provided criteria for the high level waste. These criteria also are needed for the evaluation of the environmental impact of WIPP.

Another concern which has not been addressed in the FEIS is how the WIPP facility will assure that the drums do not contain explosive gas mixtures at the time of retrieval, should retrieval prove necessary. (See p. 3-15, Reference 3.)

TRANSPORTATION

We recommended that a number of dosage estimates be performed including acts of sabotage, doses to emergency workers, exposures to people in cars stopped next to a truck with radioactive waste. These estimates are included in the FEIS.

DOE did not include our recommendation to estimate doses from the ingestion of contaminated food following a transportation accident with a release of radioactive material based on their belief that corrective action measures including the condemnation of food and decontamination of farmland would be promptly taken. EEG believes that an assessment of possible radiation doses by these pathways is important for two reasons:

1) to indicate if radiation doses could be high enough to require short-term protective measures or long-term land use controls;
2) to estimate the amount of low-level, long-term dose that may be unavoidable if such a release occurs.

We have published such an analysis entitled Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, by Dr. James K. Channell, EEG-5 (Reference 6).

More detailed comments concerning information contained in Chapter 6 of the FEIS are provided below:

6-4* The Regulatory responsibilities of the New Mexico State Government and the Federal Government affecting the transportation of radioactive waste to WIPP need to be clarified. EEG will bring this matter up to the appropriate agencies.

6-12 According to the FEIS, CH-TRU waste shipped from Hanford, LASL and SRL will not be directly considered in the impact analysis. The following analysis indicates that 1/3 of the CH-TRU waste to be shipped by volume is not being considered in the impact statement for dosage estimates in transportation.

*These numbers refer to the chapter and page number of the FEIS.

CH TRU TO BE SHIPPED TO WIPP (10/1/86)

Source	Considered in FEIS	10^3 Cu ft	Dose Calculations in FEIS
INEL	yes	2376[a]	yes
Rocky Flats Plant	yes	100[b]	yes
Hanford	no	855[a]	no
LASL	no	249[a]	no
SRL	no	109[a]	no

[a]page 2-17
[b]page 6-17

6-13 The truck routing concept used by DOE for transuranic and high level waste appears different from NRC guides relating to the shipment of spent fuel. Both use interstate highways but NRC bypasses large cities such as Albuquerque whereas Figure 6-3 on page 6-15 appears to have the trucks pass through the cities.

6-15 According to the FEIS the transportation analysis will not include RH-TRU from ORNL, LASL and Hanford. From the following analysis, 78% (69/89) of the RH-TRU waste by volume to be shipped to WIPP is not being considered in the FEIS.

RH TRU (1986)

Source	Considered in FEIS	10^3 cu ft[a]	Dosage Calculation in FEIS
INEL	yes	20	yes
ORNL	no	52	no
Hanford	no	8	no
LASL	no	9	no
	Total	89	

[a]page 2-17

6-17 The FEIS calculations of the radiological impacts of waste transport under normal condition assume that 370,000 ft^3 of CH waste and 4,200 ft^3 or RH waste will be transported annually from INEL and RFP to WIPP (page 6-17). The breakdown of the data is given in tables 6-2, 6-6, 6-7, and 6-8 of the FEIS.

The calculations may not be conservative for the following reasons: The WIPP design criteria report, WIPP DOE 7L, states that for a three-shift-per-day operation, the annual design capacity will be 1,200,000ft^3 of CH-waste and 10,000 ft^3 of RH-waste; for a one-shift-per-day, the annual design capacity will be 500,000 ft^3 of CH waste and 4,000 ft^3 of RH-waste (the last number is estimated by EEG; it is not mentioned in the design criteria). The design criteria also state that the estimated rate of shipment for CH-waste for 9 years (year 4 to year 13) will be 500,000 ft^3/y. Further, most of the RH-waste is stored at ORNL which is considerably further away from WIPP than INEL and RFP (Table 2-3, page 2-17).

It is possible that waste will be shipped to WIPP at rates greater than 370,000 ft^3/y because of the large backlog.

The title of Table 6-2 "Volume of Waste Shipped per Year" is misleading since it identifies only 2 of the 8 sites shipping waste to WIPP.

6-18 According to the FEIS, very small quantities of HLW will be shipped to WIPP for experiments." This is not so. Our calculations show this to be 17 million curies which is more than twice as large as the combined CH and RH TRU waste to be permanently emplaced.

6-19 The waste volume being shipped from INEL by truck in Table 6-4 should be 1,100 ft^3 RH-TRU, not 110,000 ft^3.

6-19;1 Clarification is needed to evaluate the impact of high-level waste for experiment. Section 6.5.3 of the FEIS estimates the equivalent of 40 canisters of high-level waste. The SAR mentions 60 canisters. Section 8.9.5 (p.8-48) of the FEIS mentions 20 canisters per waste form. Clarification is needed between the FEIS and the SAR.

6-24 & 6-25 The collective doses for INEL and RFP in tables 6-6, 6-7, and 6-8 are the same as those shown in table 6-9 and 6-10 of the DEIS. The collective doses for shipments from Hanford, LASL, and SRP have been omitted even though in the DEIS they amount to about 50% of the total collective dose. One might conclude that the radiological impact has been underestimated in the FEIS. This should be clarified.

6-26 The statement that the most-exposed person receives an annual dose of 0.15 mrem from the normal transport of radioactive waste requires clarification. In fact, in the same paragraph a dose of 1.[illegible] mrem is quoted for a person waiting 2 hours behind a stopped truck. EEG has obtained doses greater than 0.[illegible] mrem for the following four plausible scenarios:

Case	mrem/yr	Assumptions
I	0.26	Individual is exposed to 20% of all trucks stopped for 1 minute at a distance of 25'
IIa	1.2	Individual is exposed to all trucks stopped for 1 hour at a distance of 100'
IIb	2.9	Individual is exposed to 25% of all trucks stopped for 1 hour at a distance of 50'
III	32.	Service station attendant gassing up 25% of all trucks at a distance of 5 feet for a time interval of 2 min/truck

6-18 It appears that the radiological impact for high level waste is based on a one-way scenario of 40 canisters distributed in 6 shipments over the lifetime of the repository. It should include an equal number of shipments leaving the repository after the experimental phase is over. Furthermore, the description of the high level waste experiment (in Chapter 8, pages 8-48,49) suggest that more than 40 canisters might be necessary.

6-31 & 6-34 In the accidents analyzed in the FEIS, it is assumed that inhalation of radionuclides is the primary pathway to people. It is assumed that administrative procedures used in the clean up procedure will prevent radionuclides from reaching the food chain. EEG disagrees with this assumption and has pointed out in the report EEG-5--Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, by J. K. Channell --that doses through food pathways are greater than zero even after protective measures are taken.

6-41 The emergency procedure section does not address itself to the following questions: If an accident occurs and the shipment is damaged, will the damaged shipment be forwarded to WIPP or will it be returned to shipper? If forwarded to WIPP, is the design of the waste handling building adequate to handle large damaged shipments?

A number of additional dosage calculations had been identified by EEG in report EEG-3. The status of these calculations is as follows:

1. Sabotage	Included in FEIS
2. Emergency Workers	Included
3. Stopped Automobile	Included
4. Retrieved wastes	Not Included
5. Contamination of Food Supply	Not Included
6. D & D of Hanford	Not Included
7. Individual doses as well as population	Included
8. Diffuse sources	Not Included in FEIS (We agree)

GEOLOGY, HYDROLOGY AND SITE CHARACTERIZATION

Our preliminary review of the geology, hydrology and site characterization information as contained in the FEIS indicates that several sections have been expanded and better explained than that presented in the DEIS. However, there is still insufficient treatment of potential problem areas as discussed in more detail below:

1) Disturbed Zone or Zone of Anomalous Seismic Reflection

This topic is briefly mentioned in the Geology Summary on pages 7-16 to 7-19 as "an anticline...on the upper Castile is located at the northern edge of Control Zone II." Although more details concerning this zone is provided on page 7-42, the FEIS should have more clearly reflected the uncertainty, controversy and concern regarding the potential implications of this zone to the future integrity of the repository. The EEG has provided discussion of this issue in commenting on the DEIS (See EEG-2 published as Appendix III, EEG-3, Reference 2). The FEIS has not adequately addressed these comments. For example, on page 7-29, the FEIS discusses various suspected dissolution features present in sections 9 and 17 of T22S, R31E, but fails to point out that these features coincide with the zone of anomolous reflection, the depression in MB 124, and is close to the apparent anticline in the Castile. Also, on page 7-42, the FEIS explains the anomolous seismic reflections as "relatively tight folding or a discontinuity in the upper Castile." This does not adequately explain the phenomena and EEG believes that a more definitive explanation based on additional data is necessary before the site is judged acceptable for the repository.

2) Brine Reservoirs

This subject is discussed in the FEIS on pages 7-33 to 7-4[illegible], particularly section 7.3.5. Although this topic has been treated more extensively in the FEIS, it should have contained more data on the location of known artesian brine flows, and the differing views as to their origin and significance to the adequacy of the WIPP site. (Further discussion of this issue is contained in EEG Reports, References 7 and 9).

3) Dissolution Processes

The FEIS provided a clearer discussion of this issue than did the DEIS, but did not provide new data, nor were the various contrasting views

adequately presented. For example, the discussion on page 7-29 failed to mention the Bell Lake Sink and Slick Sink, and the views of Anderson as to their possible deep-seated origin. Also on page 7-100, the last paragraph is misleading with respect to the Anderson citation. His 1978 paper indicated that the active dissolution front in the Salado could reach the WIPP site in 50,000 years, but he believes the advance effects of deep dissolution may already have affected the repository area and vicinity. Page 7-27, paragraph 4 refers to the lamprophyre dike which is shown in Figure 7-13. Is it not possible that offshoots of the dike and perhaps sills may exist in the Salado near the site? Would this provide a preferential path for fluids in the event of a breach? The zone of anomolous seismic reflection may be evidence of deep dissolution. (For further discussion by EEG of this issue see References 7 and 9).

4) Effect of Impurities in Salt

Page 7-35, paragraph 5, indicates that the halite beds at the repository horizon are 97% halite, however there are also present many clay seams. What is the fraction of halite in the repository mass? The effect of these clay minerals on the repository should be based on in situ studies and should be known before a final decision is made on the adequacy of the site.

5) Site and Preliminary Design Validation Program (SPDV)

Under section 8.9, the FEIS provides very useful information on the research and development program for the proposed repository, including the in situ validation program. We recognize the need for the SPDV program, and note that it will obtain valuable data for site validation which cannot be obtained by other means. We hope that more details will be made available on the experiments in order that other groups might provide comments on these anticipated experiments. We note that one of the objectives will be to explore the undeveloped portion of the planned repository by horizontal core holes. Our preliminary evaluation of these plans indicate that the horizontal core will not extend into the zone of anomolous reflection discussed in section 1 above, and therefore definitive data concerning the significance of this zone to the repository integrity will still be needed. How will this issue be resolved? We note that the underground area covered by the SPDV program will be located within about 14 acres or about 10% of the total repository. At what point and on what bases will a final decision be made on construction of the complete repository?

THE WIPP AND ITS OPERATION

The following comments address the more important operational uncertainties that have been noted in our review of the information in Chapter 8.

Shaft

8-11* The 12' shaft will be bored to a depth of 2300 feet. This is inconsistent with 8-14 paragraph 2 which makes the following statement: "Starting at the bottom of the 12-foot-diameter shaft, horizontal excavation in the Salado salt will produce a network of underground cavities." The repository is at a depth of 2150 feet. Also, the hoist drop accident assumes that there is only 40' between the repository level and the bottom of the shaft.

Since the repository will be located at 2150 feet, why drill the SPDV shaft to 2300 feet? This additional depth may decrease the factor of safety of a vertical connection if a brine reservoir is located in the upper Castile similar to ERDA-6.

Facility Layout

8-17 The FEIS indicates that the underground development of the repository will be due north from the shafts (page 8-17, Figure 8-2). In the DEIS the direction is due west (page 8-16, Figure 8-11). Is there a final decision on the orientation to the north? If so, why? If no decision has been made, what criteria will be used to determine the direction of development?

8-19 Figure 8-10 of FEIS shows a significantly different layout in the eastern area of the waste-handling building different from the drawings of Section WBE-41 of the Title I study. Which is more up to date?

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*These numbers refer to the page numbers of Chapter 8 of the FEIS.

Ventilation

8-21 The paragraph states the following: "To confine radioactive material, the air-cleaning system will pass the air through banks of high-efficiency particulate air (HEPA) filters." This statement is too general since the disposal exhaust filtration building is a surface facility in which the air will pass through HEPA filtration only if radioactivity is detected by monitors. More information is needed on the delay time for conversion from an unfiltered system to a filtered system. How much unfiltered air would be released during this transition?

8-32 "The first stage of the filtration system in the waste-handling building will consist of 200 HEPA filters in parallel." The Title I study reveals that the filtration system of the waste-handling building consists of 17 customized two stage HEPA filters. Each unit will also have a prefilter. the units will be customized and their drawings do not exist at this time. The conclusion that 200 HEPA filters are required appears incorrect.

Rad-Waste and Gaseous Releases

8-25 The paragraph at the top of the page states the following: "These systems have sufficient surge capacity to handle waste produced during postulated accidents..." This is contradicted by the paragraph at the bottom of the page which states the following: "In the unlikely event of a fire...., contaminated water will be processed by a portable liquid-radwaste-processing system brought onto the site after the fire." The portable system is not mentioned again. Its availability and possible location of use should be clarified.

8-28 The FEIS discusses possible pathways for the release of CH and RH TRU waste but does not address HLW. ("Surface contamination of HLW canisters are available for release," page 8-31). Information is needed on the possible pathways for HLW.

8-30 Table 8-5 estimates that the curies of radon gas released from the repository will be much greater than that due to man-made radiation.

EEG pointed out in commenting on the DEIS that these estimates were not obtained from site-specific data and recommended that radon measurements be taken at the site before and after construction to evaluate the amount of radon present. DOE did not respond to this comment. We still believe that radon should be measured to see if levels might be high enough to be a problem for underground workers and to estimate radiation doses to the public.

8-36 While the FEIS estimates the amount of gas produced from the underground waste experiments of 150 ft^3/y, it does not present the estimate of 6,000,000 ft^3/y from decomposition of the CH and RH TRU waste.

Waste Experiments

8-50 The paragraph suggests that the retrieval process will be a difficult task since the "volume of contaminated salt is expected to equal the volume of waste removed." Large volumes of salt might be involved.

If necessary to retrieve wastes, where will they be sent? Will DOE establish criteria for retrieval of CH and RH, and when will these be available? This information is necessary to evaluate the radiological impact of the retrieval process.

8-51 We are pleased to see the expanded section of 8.10.3 on the retrieval of HLW. The section does not state the destination of the waste. We believe that this should be included in the experimental plan.

HIGH LEVEL WASTES

We were pleased to note that the information on the Defense High Level Waste (HLW) experiments has been expanded in Chapter 8. The purpose and justification of these experiments is well stated in sections 8.9.3 and 8.9.4. However, the methods described in section 8.9.5, do not allow a clear evaluation of the radiological impact. Two classes of experiments are described but it is not clear if there will be more than one waste form per class. Therefore, it is difficut to estimate the total amount of radioactivity involved. It is emphasized that the HLW will be retrieved after the conclusion of the experiments, but since the waste handling building has only overpacking capability, it is difficult to envision how the HLW will be repackaged so that it can leave the plant in compliance with transportation regulations and DOE criteria.

The radiological impact of shipping these wastes from the repository at the end of the experiments has not been evaluated and it should be. Also, there is a need for shipping criteria for the HLW, both to the site and after retrieval.

More information is needed on the fate of the HLW at the end of the experiments. The impression given in the FEIS (page 15-45) that DOE has no idea where the waste will go is troubling. What laboratories might receive these wastes shipments for analysis? Where would any full-sized canisters that did not need laboratory evaluation be sent? Might some of these canisters remain at the WIPP site if a radiological evaluation at the end of the experiment indicated this would result in the lowest radiation doses to workers and the public?

EEG believes the HLW experiments have more potential for significant occupational doses and site contamination than the other operations and we plan to thoroughly review the detailed plans for individual experiments as they become available.

EFFECTS OF PLANT OPERATION, ACCIDENTS, AND LONG TERM EXPOSURE

We are pleased that the FEIS has addressed a number of our suggestions for expanding the potential scenarios necessary to better assess the potential radiological risks both during the operational phase and over the long-term.

One of our primary concerns centers around the potential for eventual human intrusion. We believe this is a credible scenario particularly because of the mineral and hydrocarbon resources in the region.

In addition to the intrusion scenarios addressed in the FEIS we repeat our recommendations made in the DEIS review for the following scenarios:

1) A connection is made between the repository, a high pressure brine reservoir and the surface.

2) Effects of high pressure gas formation, generated by organic decomposition of the waste, acts as a driving mechanism in bringing waste to the surface. (General Population)

3) Generate dosage estimates using the DOE generic Waste Isolation Safety Assessment Program (WISAP) model currently under development by the Battelle Northwest Laboratories. (General Population)

4) Solution mining for sylvite or langbeinite takes place leading to breach of the decommissioned repository and release of radionuclides.

These comments and others relating to the information contained in Chapter 9 of the FEIS are discussed below:

I. Operational Exposures

9-40 Routine occupational radiation exposures (man-rem) expected during normal operations are given in Table 9-26. In order to evaluate these estimates we will need the assumptions upon which these were based.

9-107 Doses and dose commitments from accident scenarios were calculated to an individual living at James Ranch (Table 9-52). The EEG recommendation in the DEIS review that doses be computed at the NW site boundary and for transients in Zones II, III, and IV was ignored. We still believe these should be made.

9-117 The Chapter 9 assumption that exhaust air from underground waste handling and storage areas passes through HEPA filters is inconsistent with statements in Chapter 8. Since the absence of filters can result in a substantial increase in doses from particulates, it is important to clarify this point. In addition, more detailed information is needed on the response sensitivity levels which activates the switching of the ventilation air stream through the HEPA filters, including response times, for both fires and increased radioactive particulates in the mine atmosphere.

The following areas of concern were raised on the DEIS (EEG-3) but were not addressed in the FEIS report by DOE and we request that they be addressed:

1) Is there a possiblity that Radon-222 and daughters could pose an occupational problem?

2) Is there any possibility of encountering a methane gas pocket in bedded salt which could cause an explosion?

II. Long-Term Exposures

In evaluating the long-term radiological consequences of the WIPP repository, the FEIS has considered the same 5 scenarios for release of radionuclides as considered in the DEIS. In commenting on the DEIS, EEG had recommended the following additional scenarios be considered (Reference 2, pages 81,90):

1) Build-up in the environment from radionuclides in water removed from the Pecos River for irrigation, incorporated into soil and plants, and cycled in food and man over long periods of time.
(General Population)

2) Generate dosage estimates using the DOE generic Waste Isolation Safety Assessment Program (WISAP) model currently under development by the Battelle Northwest Laboratories.
(General Population)

3) A connection is made between the Delaware Mountain Group aquifer, the repository and the surface.
(General Population)

4) A connection is made between the repository, a high pressure brine reservoir and the surface.

5) Effects of high pressure gas formation, generated by organic decomposition of the waste, acts as a driving mechanism in bringing waste to the surface.
(General Population)

6) Well water becomes contaminated and is used for irrigation or stock watering.

7) Solution mining for salt takes place.

Scenario Recommendation 1

The FEIS indicates on page 15-30 that the consequences of using contaminated water below Malaga Bend for irrigation purposes as recommended is being studied, and the results will be included in the WIPP Safety Analysis Report SAR. The DOE should provide an estimate as to when the results will be available.

Scenario Recommendation 3

Our recommendation # 3 is discussed on p. 15-29. DOE concludes that a connection between the delaware Mountain Group aquifer, the repository and the surface is not realistic, because the hydraulic head of the aquifer is too small to allow direct releases of brine to the surface. We will review this conclusion.

Scenario Recommendation 4

Page 15-29 also rejects the brine-pocket scenario in recommendation #4 as being highly unlikely. We disagree with this conclusion for two reasons: (1) the well at ERDA-6 involved the "accidental" contact with a pressurized brine pocket that did flow to the surface; and (2) there have been several other encounters with brine reservoirs in the Castile in the Delaware Basin, which have involved surface flow, and at least one of these encounters (the Hudson-Belco) was not associated with the "deformation zone." (See additional discussion under "Geology and Site Characterization.") Therefore, we remain convinced that there is insufficient information on the origin and location of brine reservoirs to conclude that a connection at some future date between a brine-pocket, the decommissioned repository, and the surface (through a well) is not a plausible means for radionuclide release.

Scenario Recommendation 6

We were pleased to note on page 15-30 of the FEIS that our recommendation #6 concerning the radiation dose incurred by the use of well water taken downstream from a breached repository is to be analyzed by DOE. The EEG is also evaluating this scenario. Target dates for completion of studies in progres or to be initiated by DOE should be provided.

Scenario Recommendation 7

Page 9-145 (Section 9.7.1.6) of the FEIS provided a helpful discussion of the potential for solution mining in the vicinity of the decommissioned repository. We agree that such a scenario in our recommendation # 7 for halite has a very low probability. Nonetheless, the difficulty of predicting the conditions far into the future, and the availability of minerals sylvite and langbeinite warrant evaluation of this scenario for these minerals. No reasons were given in the FEIS for rejecting scenarios 2 and 5. We continue to believe that these scenarios should be considered.

III. Additional Comments

9-127 We are pleased that DOE has followed our suggestion to show the inventory of radioactive waste. At 1000 years it is 539,000 curies. DOE should also have indicated the activity at the time of closure which we estimate to be 7,800,000 curies. Also helpful would be an estimate of the error bounds associated with the inventory.

9-107 Table 9-52

The source terms in Table 9-50 and 9-51 of FEIS are considerably higher than those in Table 9-23 and 9-24 of the DEIS. The dose commitments in Table 9-52 of FEIS are also substantially higher than those in Table 9-25 of DEIS. However, for the CH-area accidents, the ratios of the source terms (FEIS/DEIS) do not equal the ratios of the dose commitments (FEIS/DEIS). This is questionable since the quantity of activity has changed, not the isotope spectra.

RADIOACTIVE WASTE VOLUMES

The FEIS states the repository would receive over a 25-year period 6.2 million cubic feet of CH-TRU wastes. This would include all wastes presently stored at INEL, two-thirds of all waste generated at DOE facilities from the present until 1990, and all DOE wastes generated from 1990 to 2003. Similar (though not exact) statements are made on pages 2-17,18. The transportation analyses assume wastes will come only from INEL and RFP and would be shipped at a rate of 370,000 (Table 6-2, page 6-17) or 390,000 (Table 6-4, page 6-19) cubic feet per year. The amounts of new waste produced per year and the length of time it takes to fill the repository do not agree completely between these references but the differences are probably not important.

These statements lead to the following specific questions:

1) Why design a waste handling capacity of 500,000 cubic feet per year for a one-shift operation and 1,200,000 for a 3 shift operation (SAR Table 3.1-5) when plans are to ship less than 400,000 cubic feet per year?

2) Why is an operating life of 25 years assumed, when the 6.2 million cubic foot capacity would be filled in 16 or 17 years at the planned shipping rate?

3) Why are only 2/3 of the retrievable wastes generated at DOE facilities between the present and 1990 assumed to be shipped to WIPP? What plans are there to dispose of the other 1/3 of the waste?

4) Why are the presently stored retrievable wastes at DOE facilities other than INEL not going to be shipped to WIPP? Where will these wastes be disposed?

5) Why does the transportation analysis assume that wastes will come only from INEL and RFP?

As presently defined the WIPP project would be unable to dispose of TRU wastes that are presently stored at DOE facilities other than INEL, stored after the year 2003, buried, and generated by decontamination and decommissioning activities.

Since the above facts suggest that a larger repository is possible, the following questions should be answered:

1) What is the probability that this volume will be increased substantially? What might the maximum volume be?

2) What effect would an increased waste storage volume have on the environmental and radiological health aspects of waste transportation, facility operation, and a repository breach?

3) What procedural requirements under the NEPA process would be necessary before the radioactive waste storage capacity could be substantially increased?

DECOMMISSIONING

The Final EIS expanded the discussion of controls after decommissioning and this considerably strengthened the section and satisfactorily addressed some of our concerns. Our requests for more information on long-term controls over shallow well drilling and resource extraction were not answered. Neither was a commitment made to our recommendation for long term monitoring.

We believe that drilling into the repository could occur from a variety of activities (e.g. for hydrocarbon recovery at greater depths, from exploration of the repository for possible recovery of gas or other minerals, and from potash extraction) and this may be the most likely way that a repository breach would occur. Furthermore, well drilling into the Rustler aquifer could also be a problem if breaching has previously occurred. The plans for written records, markers, and monuments are an important aspect of control since they minimize the likelihood that drillers would have no knowledge of the repository. However, we are not fully convinced (page 15-46) that knowledge of a repository would be an adequate deterrent to man-made intrusion. Consequently, we believe there should be further evaluation of the need for positive control of drilling at the site.

An effective control period of up to 400 years (as suggested on page 15-46) might be optimum. The initial hazard from the estimated repository inventory is dominated by Strontium-90 until about 300 years and thereafter decreases slowly because Plutonium-239 is dominant.

HEALTH EFFECTS

The issues involving health effects appear to have been adequately addressed in the FEIS.

Radiological Health Review

of the Final Environmental Impact Statement (DOE/EIS-0026)

Waste Isolation Pilot Plant, U. S. Department of Energy

Supplementary Comments

to

Review of Dec. 8, 1980

Environmental Evaluation Group

Environmental Improvement Division

Health and Environment Department

State of New Mexico

January 15, 1981

FEIS EXECUTIVE SUMMARY

The Executive Summary of the FEIS was checked for consistency with Volumes I and II and for any misleading statements. The following items were noted.

3-3*

The security and sabotage statement about experimental HLW fails to mention there will also be a similar number of shipments leaving the site at the end of the experiments.

3-6

The one chance in 40,000 per year probability used here and in Chapter 6 gives a misleading impression of the expected rarity of a severe accident. The probability of this severe an accident occurring is actually about 1 in 140 per year. The 1 in 40,000 number comes from multiplying the 1 in 140 probability by probability factors for occurrence in: (1) an urban area (0.3); (2) with restrictive meterology (0.2); and (3) with proper wind direction (0.06) to obtain maximum population doses. The accidents occurring with probabilities between 1 and 140 and 1 in 40,000 per year would be expected to result in the release of radioactive material and some radiation dose to people.

4-5 to 4-8

The section on geology is brief, and does not include any reference to pressurized brine reservoirs or to the zone of anomalous reflection (mentioned on p. 7-29, Volume I).

4-8

We do not believe the statement on this page "It is believed that deep dissolution will not affect the site for the next million years (Anderson, 1978)" accurately portrays Dr. Anderson's concerns about deep dissolution at the WIPP site. A more thorough review of his 1978 paper (Reference 13), as well

* This numerical designation refers to the page number in the FEIS.

as his more recent publications, indicate his view that the site may be breached at the repository horizon before the overlying salt is removed by surface water and groundwater flow. Hence, estimates of site stability based upon the rate of movement of a surface dissolution front may not be pertinent.

6-1

While the sanitary waste discharge is estimated as 25,000 gallons per day, the same volume used in the DEIS, page 8-33 of the FEIS uses 45,000 gallons per day.

M

1-4; 6. Hydrology

The conclusion that there is no deep dissolution active within 10 miles of the site should not be made until the zone of anomalous reflection, near the edge of Zone II, has been adequately explained.

1-5; 4. Alternative 2. The authorized WIPP facility.

The statement is made that "the SPDV program has been planned to confirm the geologic adequacy of the site and to verify the engineering properties of the salt at the depth of the WIPP repository." We agree that the SPDV program will provide valuable information as to the engineering properties of the salt at the repository horizon. However, our review of the available information on the SPDV does not indicate how the program will resolve all of the questions relative to the geologic adequacy. For example, the zones of anomalous reflection needs further investigation to clarify this phenomenon. These questions should be resolved, since these zones could be interpreted as potential artesian brine pockets or advanced stages of deep dissolution in proximity to the repository horizon.

1-7; 2

This paragraph fails to point out that the maximum occupational 50 year dose commitment calculated (p. 9-108) was 130 rem to the bone. This is about 20 times the 50 year background dose.

1-8; 5

The statement is made that the characteristics of the Los Medanos site do not appear to conflict with the draft criteria of the National Waste Terminal Storage (NWTS) program for qualifying sites for the disposal of commercially generated high-level waste (Reference 14). As indicated in our comments on Appendix D, there are several questions raised concerning whether the site meets certain of the criteria.

CHAPTER 2

References for Chapter 2.

Several reference citations in the text are not listed in the reference list for Chapter 2. For example, Griswold 1977; Snow and Chang 1975; Jones. 1974a; Jones, 1974b, Jones et al, 1973; ORNL, 1972; and others. It appears that all references with a first letter beyond "D" in the alphabet were omitted. This makes it difficult to evaluate the information and data cited in the Chapter.

CHAPTER 4

4-12;2

This paragraph states that a solution mining release scenario was not considered conceivable in the bedded salt at WIPP, "because of the relationship of the repository to geologic features (i.e., the presence of numerous thin layers of relatively impermeable anhydrite and polyhalite in the Salado) lack of economic incentive as compared to other salt deposits, and lack of large quantities of water." The FEIS contains no data to support the contention that the thin layers of anhydrite would be totally impermeable during solution mining. There are presently economic incentives to mine potash in the area, and if at some future date, a source of water becomes available, solution mining would become more likely.

The FEIS contains additional information on site surface water and groundwater hydrology. This information included responses to specific comments by EEG (Reference 2) on surface water use and on site storm water runoff. The additions are very helpful. Also, the planned hydrologic studies (p. 7-96) will address two items mentioned in a later report of EEG (Reference 7) as needing additional information (recharge areas and hydrologic systems and transit times.)

We have two additional concerns that may not be addressed by currently planned studies and evaluations. One is the need to quantify as much as possible the uncertainties that exist in such key parameters as K_d, hydraulic conductivity, and porosity. There may be enough data presently available to do this in approximate form. The uncertainty analysis would give a range of possible values that would be much more meaningful than the single numbers used in various scenarios involving radionuclide transport. The second concern is whether the effects of future climatic changes on the current hydrologic regimen may be significant. One aspect of climate change could be a change in hydraulic head relationships in the various aquifers. Planned future studies may provide an answer for this part of the problem. The second aspect is the possible increase in fracture permeability that might occur from further dissolution within the Rustler aquifers. The statement was made at EEG's January 1980 Geotechnical Meeting that it may be possible to estimate the rates that permeability will increase (Reference 7, page 9).

The following specific questions and comments are offered:

7-82.

The description of Pecos River water use below Carlsbad and below Red Bluff reservoirs is helpful. However the use of water in Pecos County, Texas and downstream lacks detail. Also, it is stated that the water, with a discharge-weighted TDS exceeding 15,000 mg/ℓ is used for irrigation and stock watering. Is this high TDS water used only after blending with better quality water?

7-88.

If stormwater runoff drains into Nash Draw, might it also be a source of recharge to the Pecos River as the potash-refinery effluents are said to be (page 7-93)? Consideration should be given to estimating the quantities of radionuclides that might be carried offsite by stormwater runoff. Also the possibility that the nuclides might be concentrated in sediment at some point offsite should be investigated.

7-89.

This statement (lines 5 and 6) "Groundwater movement in the Rustler near the site is westward toward Nash Draw and then southward toward the Pecos River," is inconsistent with the sentence on pages 7-87, 88 "...the average groundwater gradient of the Magenta Dolomite and the Rustler-Salado contact is to the southwest and that of the Culebra Dolomite is to the southeast and then to the southwest."

7-89.

Several questions arise from the description of the Santa Rosa Sandstone aquifer:

(1) Is groundwater flow to the south (first paragraph and conclusion 8 on page 7-96) or "into the Pecos River rather than to the south into Texas" (second paragraph)?

(2) Where is the recharge area for the portion of the Santa Rosa aquifer overlying the WIPP site? What is the possibility that a wet hydrologic cycle would increase the saturated thickness of this formation? If this occurred it could place an aquifer with good quality water immediately over horizons containing wastes.

7-96.

When might information concerning hydrologic studies 1 and 2 be available?

CHAPTER 8

8-4: Section 8.1.2

From Figures 9-1, and 9-2, one can calculate that a shift in the site of 0.5 miles to the southwest would still meet the one mile borehole criterion and would reduce the area of langbeinite mineralization inside of Zone IV by more than one square mile while increasing the amount of lease grade sylvite inside of Zone IV by less than one quarter square miles. Also this would be moving away from the zone of anomalous reflection. What considerations are being given to shifting the location or underground orientation of the repository as more data become available?

General Comments

If the dose rates and dose commitment detailed in the FEIS are reasonable estimates for the scenarios considered it appears that there are few radiological problems of concern. In a number of instances, however, we need more definitive information concerning the fact that the kinetics and parameters used in arriving at these dose estimates indeed reflect actual environmental conditions at the site.

The following examples illustrate the lack of supportive data needed to perform independent analyses to confirm dose calculations.

9-105

Following the narrative of accident R15, one obtains a release of 2×10^{-3} curie. Is there an assumption omitted that 1% of the waste released is suspended in the air? A factor of 10^{-2} is not explained.

9-107 Table 9-52

The source term in Table 9-50 and 9-51 of FEIS are considerably higher than those in Table 9-23 and 9-24 of the DEIS. The dose commitments in Table 9-52 of FEIS are also substantially higher than those in table 9-25 of DEIS. However, for the CH-area accidents, the ratios of the source terms (FEIS/DEIS). This is questionable since the quantity of activity has changed, not the isotope spectra. Also, the natural background dose in Table 9-52 is a 50-year dose.

9-112;1

The last line of the paragraph states that all the radioactivity is released instantaneously. Table 9-55 lists a release rate in pCi/sec. We have not been able to arrive at the numerical values in Table 9-55 from the information provided.

9-130 (flow rates through wellbore)

It appears that the data in Figure K-11 applies to scenarios 1, 2, and 3. Presumably, the data was obtained with the SWIFT code although it appears to be a combination of Darcy's law and Poiseuille's formula. The flow numbers in the three scenarios in section 9.7.1.3 cannot be obtained from Figure K-11. Some further explanation might be helpful.

Specific Comments

9-6

In designing the size of the diked area to contain fluid runoff was the interception of a geopressurized brine reservoir considered? What is the total containment volume?

9-100: 4

The last line mentions a total release of 6.9×10^{-8} curie for accident C 10. The correct number should be 2.2×10^{-9} as given in Table 9-50.

9-101: 2

The paragraph mentions a total activity of 376 curies. Calculations suggest that the correct value should be 326.

9-104: Table 9-51

What is the numerical value of the air volume of the cask, transporter, and waste cage that is displaced from the pit? This value is needed in verification of the C-13 consequences.

9-127

The curies of U-235 in Table 9-59 should be 0.36 rather than 36.

9-137 Nuclide Transport

The FEIS states. "The highly sorbed plutonium nuclides do not contribute to the discharge even at 3 million years; these species are retained in the aquifer near the repository, while their much less sorbed uranium daughters are transported at about one-tenth the aquifer flow speed." This statement does not reflect the uncertainty associated with the distribution coefficients for many of the radionuclides. A member of the EEG has recently evaluated the significance of certain Rustler aquifer parameters for predicting long-term radiation doses from WIPP (Reference 15). This report has considered the uncertainty associated with plutonium distribution coefficients (K_d). If a portion of the plutonium moves with a lower K_d, the radiological consequences in all of the liquid breach scenarios may be significant.

APPENDIX D

SELECTION CRITERIA FOR THE WIPP SITE

D-2; 4.5 Lateral extent

The discussion in the FEIS of this criterion implies that there are no questionable structures or dissolution features near the repository horizon. As indicated in previous comments, the areas about 1 to 3 miles north and 1 mile southwest of ERDA-9 at the level of the Castile, and below, has yielded anomalous seismic reflection data, and possible structural faults in the Castile. This data raise questions about the integrity of the structure in these areas. The repository will extend almost to the northern boundary of Zone II which would be within ½ mile of the northern zone of anomalous reflection. Therefore there is insufficient data at this time to be certain that this criterion is met.

D-2; .10 Structure.

WIPP-12 is at the edge of a possible anticlinal structure in the Castile, and the hole is also located at the southern edge of one of the zones of anomalous reflection discussed above. Seismic reflection data also suggest faults in the area north of Zone II and southwest and south of ERDA-9. The seismic data has insufficient resolution to know if geologic faults extend into the Salado. Until more information is available, one cannot conclude that the WIPP site meets the structure criterion.

D-3; 5 Dissolution.

We agree that the edge of regional dissolution in the basin is in the vicinity of Nash Draw, and therefore would not pose a problem for the proposed repository. However the seismic reflection data, as discussed in the preceding paragraphs may be indicative of dissolution features in proximity to the repository horizons.

D-5; 9 Faulting and Fracturing.

This paragraph states that there are no known faults in post Permian rocks at the site area. As discussed above, the seismic reflection data do indicate the possibilit of faults in the Castile. Therefore, it is not yet possible to know whether this criterion is met.

D-6; Salt-Flow Anticline.

As discussed in the preceding paragraphs, there could be a major anticline in the Castile beginning at the northern edge of Zone II and extending north. There is a definite steepening and the seismic data do not permit an adequate resolution of the extent of this steepening toward the north. Such structure is indicative of possible effect on long-term safety of the repository.

D-8: 7 Natural Resources.

The statement is made that "very little potash exists above the repository (Zone II) itself." This statement conflicts with the information in Figure 2.7-6 of the SAR (Reference 13) which states that the McNutt member at ERDA-9, "contains potassic rock rich in sylvite, langbeinite and other hydrous minerals." Also Figure 9-1 would suggest that at least 1/3 of Zone II contains lease grade sylvite.

D-9; 2 Man-made Penetrations.

As indicated in other EEG comments on the FEIS, the possibility of human intrusion is of considerable concern, and therefore additional information is needed as to how-control will be maintained.

APPENDIX E

DESCRIPTIONS OF WASTE TYPES

The activity curve for U-234 and Ra-226 in Figure E-2 can only be explained if there is a substantial amount of U-238 in the waste; this is not apparent in table E-3. The total activity curve in the time interval between 10^5 and 10^6 years seems to include Th-230 and all the radioactive daughters of Ra-226 that are in secular equilibrium. Some clarification might help.

APPENDIX J

EFFLUENT AND ENVIRONMENTAL MEASUREMENTS PROGRAMS

The FEIS did not acknowledge or respond to EEG's comments concerning radiation monitoring programs. We believe these comments are still applicable and need to be addressed. The more important ones are:

Present Program

(1) "Radon emissions from natural radioactivity in the repository have not been measured in soil, mined rock, and the proposed waste horizon. Radon should be measured to see if levels might be high enough to be a problem for underground workers and a source of radiation exposure to the public...." (page 53, Reference 2).

(2) "It will be necessary to obtain sufficient samples and analyses before operation to ensure that the variations in the background (naturally occurring and from weapons testing fallout) levels of actinides,....and fission products are adequately known. These values are needed in order to be able to detect contamination from site operations." (page 60, Reference 2)

Pre-Operational and Operational Programs

(3) "It is noted that no air particulate station is planned for Hobbs. Since it is a major population center, with a calculated long-term X/Q only 10% lower than at Eunice, this omission should be reconsidered. Also, the three days per week of sampling should be randomized in order to measure levels on work days, and nonwork days." (page 60, Reference 2).

(4) "Consideration should also be given to monitoring radioactivity in rainfall and runoff (when it occurs) at the site as well as surface water and biota in Nash Draw." (page 57, Reference 2)

(5) "In several cases...the types of analyses are not specific enough. Gross analysis is useful as a screening mechanism for detecting significant contamination. However, it usually will not detect trace migration of radionuclides. All media being sampled should have periodic

analyses of the actinides...and long-lived fission products." (page 58. Reference 2)

Post-operational Program

(6) "The outline of a post-operational program...appears reasonable. However, the borehole radionuclide analyses should be for specific radionuclides rather than gross alpha and beta analyses for the reasons discussed above." (page 61, Reference 2)

Several changes have been made in Appendix J between the Draft and FEIS. One of these is substantive. In the DEIS (page J-30 and Tables J-5, J-6) it is stated that "In general, state-of-the-art techniques and instruments will be used." In the FEIS (page J-32) it is stated "The equipment used for measurement during operation will meet or exceed the sensitivities required to detect radiation levels below the limits described in 10CFR 20, Appendix B." The 10CFR 20 criteria would permit minimum detection levels that are one to three orders of magnitude less sensitive than would occur from state-of-the-art techniques. We believe that use of the 10CFR 20 criteria is unacceptable for environmental samples since it could result in some trace radionuclide releases not being detected. This position is consistent with the Nuclear Regulatory Commission Regulatory Guide 4-1 which states "the detection sensitivity of environmental measurements should be the most sensitive that is practically achievable for measuring plant contributed radionuclides in the environment."

All the TLDs stations are along a line going N-E from the center of the WIPP facility. Some data points near the James Ranch might be desirable since it is the reference location for accident analysis.

Water Quality

p. 8-33

The estimated rate of sewage discharge is 45,000 gallons per day. This disagrees with the DEIS and the Executive Summary, both of which use 25,000 gpd. Which is correct? Also, the statement in the DEIS that all treated waste water would be used for landscape irrigation or evaporated has been deleted. Has there been a change in the earlier plan to evaporate all excess water?

p. 14-7

The term Water Quality Division used twice in section 14.2.5 should be Water Pollution Control Bureau. The Water Pollution Control Bureau notified DOE on October 7, 1980 that a ground water discharge plan was not needed for the SPDV program.

Air Quality

p. 14-8

The appropriate New Mexico Air Quality Regulation for new sources is 702, not 100. A permit was granted by the New Mexico Air Quality Bureau of June 6, 1980 for the SPDV phase of the WIPP project.

Noise

The FEIS was largely unresponsive to EEG comments on noise aspects in the DEIS. Of the 5 items we pointed out as needing clarification only one was partially responded to. None were acknowledged. The 4 possible mitigation measures suggested were ignored. We still believe these mitigation measures have the potential for reducing noise exposure of workers and those living along right-of-way and should be considered.

1) busing of workers to drastically reduce auto traffic;

2) muffling of construction equipment and use of low noise products where available;

3) a requirement that all trucks meet the Federal noise regulations required for inter-state commerce; and

4) housing of various fixed noisy equipment and operations.

REFERENCES

1. Environmental Evaluation Group. Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND 78-1596, Volumes I and II, December 1978 (EEG-2), August 1979.

2. Neill, Robert H., et al. Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U.S. Department of Energy (EEG-3), August 1979.

3. Sandia National Laboratories. Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP, (SAND 79-1305), November 1979.

4. Little, Marshall S. Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant (EEG-4), February 1980.

5. Irby, H.H., ed. Report of the Steering Committee on TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant (WIPP-DOE-069), May 1980.

6. Channell, James K. Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes (EEG-5), October 1980.

7. Environmental Evaluation Group. Geotechnical Considerations for Radiological Hazard Assessment of WIPP: A Report of a Meeting Held on January 17-18, 1980 (EEG-6), April 1980.

8. U. S. Department of Energy. Waste Isolation Pilot Plant, Safety Analysis Report, 5 vols., 1980.

9. Chaturvedi, Lokesh. WIPP Site and Vicinity Geological Field Trip: A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980 (EEG-7 , October 1980.

10. Goad, Donna. A Compilation of Site Selection Criteria, Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes (EEG-1), June 1979.

11. U.S. Department of Energy. Draft Environmental Impact Statement, Waste Isolation Pilot Plant (DOE/EIS 0026-D), 2 vols., April 1979.

12. Sandia National Laboratories. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site Southeastern New Mexico (SAND 78-1596), 2 vols., December 1978.

13. Anderson, Roger Y. Deep Dissolution of Salt, Northern Delaware Basin, New Mexico (prepared for Sandia Laboratories), revised April 1978.

14. Office of Nuclear Waste Isolation. NWTS Criteria for the Geologic Disposal of Nuclear Wastes: Site Qualification Criteria (ONWI-33 (2)), January 1980.

15. Wofsy, Carla. The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP (EEG-8), September 1980.

Environmental Evaluation Group
Reports

(Continued from Front Cover)

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP, A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

Environmental Evaluation Group
Reports

(Continued from Front Cover)

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (edi), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

Environmental Evaluation Group
Reports

(Continued from Front Cover)

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kenney, James W., A Critical Assessment of Continuous Air Monitoring Systems At The Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

EEG-40 Review of the Final Safety Analysis Report (Draft), DOE Waste Isolation Pilot Plant, May 1989.

EEG-41 Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, July 1989.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-11

M

EEG-11

NEW MEXICO
HEALTH AND ENVIRONMENT
DEPARTMENT

CALCULATED RADIATION DOSES FROM RADIONUCLIDES BROUGHT TO THE SURFACE IF FUTURE DRILLING INTERCEPTS THE WIPP REPOSITORY AND PRESSURIZED BRINE

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January 1982

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Reports

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP, A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip, A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

Calculated Radiation Doses from Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is minimal environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of available data concerning the proposed site, the design of the repository, its planned operation, and its long-term stability. These analyses include assessments of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U.S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.

Robert H. Neill
Director

INTRODUCTION

If brine filled the void space in the waste storage areas of the proposed WIPP repository sometime after closing, it could initiate leaching and exchange actions between the brine, the waste, and the salt used for backfilling. This action would result in a radionuclide contaminated brine. A subsequent penetration of the repository, could bring contaminated brine to the surface if there was adequate pressure.

Several pressurized brine reservoirs have been encountered by drilling in the vicinity of the WIPP site and significant discharges have occurred at the surface. At the time this report was written in draft form all except one of the known brine reservoirs were associated with the Capitan Reef and its deformation front, rather than the Delaware Basin (where the proposed WIPP repository is located). However, this report was written because of the belief that the location and occurrence of these reservoirs is not well enough understood to completely rule out their existence under the site.

On November 22, 1981 a pressurized brine reservoir was encountered at the WIPP-12 borehole. The point where this brine reservoir was intercepted was only 558 feet horizontally and 786 feet vertically from the proposed location of the northernmost waste storage room. Since more definitive information on this brine reservoir will not be available for several weeks or months, it was decided to proceed with this report using the original assumptions and to prepare a new report in the future if the data from WIPP-12 suggest that significant changes in the assumptions are appropriate.*

---

*Preliminary information indicates that the WIPP-12 brine reservoir will affect at least the following two assumptions:

(1) The probability per borehole of hitting a brine resevoir beneath the site will be greater than the value of 0.04 used in this analysis.

(2) Greater than 75,000 cubic feet of brine may be brought to the surface during normal drilling operations.

This report describes a scenario in which an exploratory borehole connects an underlying brine reservoir with the repository and results in saturation of the waste storage area. A subsequent borehole brings portions of this radionuclide contaminated brine to the surface. Radiation doses are calculated for time periods of 125, 400, and 1,000 years after repository closing for the following:

(1) external radiation doses for workers at the borehole location
(2) inhalation doses for workers at the borehole location,
(3) external and inhalation doses for a resident located 360 meters downwind,
(4) ingestion doses for the downwind resident from locally grown produce, milk, and meat, and
(5) Population doses from inhalation within a 50-mile radius.

The probability of the various calculated doses occurring was estimated. Probability was included in the report because of a belief that probability considerations are useful in evaluating the acceptability of unlikely events and to encourage others to provide a more detailed evaluation using more sophisticated methodology. Since the probabilities presented in this report were calculated using a simple methodology, with some parameter values chosen arbitrarily, they should be considered as approximate examples, not accurate numbers.

The reasonableness of the scenario and the significance of the results are also discussed.

SUMMARY AND CONCLUSIONS

1. Calculated radiation doses from radionuclides brought to the surface from a postulated interaction between a pressurized brine reservoir, the repository, and an exploratory borehole are summarized below.

Radiation Doses From Brine Reservoir Scenario
(50-year Dose Commitment from One Year's Intake)

	tc+125y*		tc+400y		tc+1000y ***	
	w.b**	Bone	w.b.	Bone	w.b.	Bone
			Rem			
Drilling crew						
inhalation	0.049	1.3	0.30	12.	0.78	32.
external	0.045	-	0.084	-	0.084	-
Downwind Resident						
inhalation	0.049	1.3	0.30	12.	0.80	32.
external	<.001	-	<.001	-	-	-
produce	0.47	1.9	0.001	0.026	-	-
milk	0.032	0.13	-	-	-	-
meat	0.009	0.035	-	-	-	-
			Person - rem			
Area population	1.0	24.	5.9	220.	15.	600

*tc+125y = 125 years after closure of the repository

**w.b. = whole body

***The tc+1000y doses are not considered plausible

2. Inhalation and external radiation doses increase with time after the repository is flooded due to the continued leaching of long-lived actinides. Ingestion doses are dominated by the 29-year half-life of ^{90}Sr and become negligible in less than 300 years after closure of the repository (tc+300y).
3. Preliminary estimates were made of the cumulative probabilities of doses equal to or greater than the tc+125y doses occurring during the lifetime of the repository. The estimated probabilities were 5×10^{-7} for the inhalation pathway and 5×10^{-8} for the ingestion pathway. The estimated probability of some radionuclides being brought to the surface and resulting in doses between zero and those summarized above is much greater, about one part in 4,000.
4. A preliminary estimate indicated a probability of 3×10^{-5} that 175 Ci of ^{239}Pu (or equivalent) would be brought to the surface by this scenario. Since the draft EPA HLW standards would be violated only if the probability of bringing this quantity of radionuclides to the surface in 10,000 years is $> 10^{-4}$--the estimate indicates the standard would be met. However, since the values are only a factor of 3 apart a more refined analysis would be worthwhile.
5. The ingestion dose estimates are not great enough to be of particular concern after tc+125y because they: (a) have a low probability of occurrence; (b) are below recommended guidelines for accidental releases; and (c) decrease rapidly (2.4%/y) with time.
6. Calculated inhalation doses to workers about the site and to residents 360m downwind are undesirably high at tc+400y. The bone dose exceeds that permitted for the general population either for routine exposure or accidental conditions. However, the dose from one year's inhalation is well below that which would result in noticeable health effects to an individual.
7. Inhalation doses calculated for tc+1000y years are even higher than those at tc+400y. However, because of pressurization and solubility limitations these doses would not be expected to occur. Consequently, the tc+400y calculated doses are considered to be the highest that would occur.
8. Radiation doses to the population residing within 50 miles of the WIPP site due to inhalation are low on an annual basis but, in the absence

of remedial measures, would be expected to continue for hundreds of years as resuspension continues. The total cumulative dose over 1500 years might result in 1 or 2 cancer fatalities (compared to an estimated 500,000 cancer fatalities from all other causes).

9. The calculated amounts of surface contamination and resuspended radionuclide concentrations are great enough to warrant a more detailed evaluation of the probability of this scenario occurring.
10. The maintaining of sufficient active institutional controls over the site to be able to detect surface contamination for up to about 600 years after closure should be considered unless the probability of occurrence can be shown to be less than estimated here.

PROCEDURE

Scenario Description

An exploratory borehole is drilled through the repository at a future time when institutional control has been lost. This borehole strikes a pressurized brine reservoir in the Castile formation and portions of this brine reach the surface. The well is capped to stop the brine flow, subsequently plugged, and then abandoned. Geopressurized brine infiltrates into the void space in the repository before the reservoir is plugged because the backfilled material is much more permeable than surrounding formations. The brine remains in contact with the salt and the waste for an extended period of time (25 years or more). During this time exchange occurs between brine, salt and waste.

A second exploratory bore hole at least 25 years later, penetrates backfilled portions of the repository. Some of this brine, which is still pressurized from the brine reservoir, from gases generated in the repository, or from salt creep is carried to the surface before the borehole can be capped. This brine is unrecognized or ignored as a possible radiological problem and is ponded with subsequent evaporation of the liquid.

The residue of this brine, which contains radionuclides from the repository, remains in the pond after evaporation and is available for resuspension. A largely self-sufficient farm family resides downwind and produces most of its produce, milk, and meat from the surrounding land. Annual radiation doses received by an adult from inhalation, ingestion and external radiation are calculated. Radiation doses received by drilling crew workers in the brine pond area from inhalation and external radiation are also calculated. Doses received by the population within a 50-mile radius from inhalation of resuspended radionuclides were estimated.

Assumptions

General

Several institutional assumptions must be made in order for the calculated doses to occur:

1) There must be a loss of institutional control so that drilling can occur without any requirements for determining the existence of a radiological hazard.
2) Drilling must occur and the drillers, either through ignorance of the repository or complacency about radiation dangers, do not determine if a radiological problem exists or take any protective measures.
3) Residence must be occurring on the land. The residence must be in the maximum downwind direction for the calculated doses to occur. Conditions (especially the availability of adequate water) must exist where subsistence farming is possible in order for calculated ingestion doses to occur.

Specific

The key physical and technical assumptions that must occur are:

1) A geopressurized brine reservoir must exist below the repository, be intercepted by a borehole and enter the repository. This event occurs 100 years or more after repository closure.
2) The exchange that occurs between waste and brine in a 25 year period results in all of the ^{90}Sr going into solution. The fraction going into solution is 0.01%/y for the actinides and 0.12%/y for cesium. These leaching values come from data reported in Reference 2.
3) A second borehole intersects the repository at least 25 years after the first borehole brings brine into the repository. For the maximum ^{90}Sr dose this event is assumed to occur 25 years after the first event (tc+125y).
4) Seventy-five thousand cubic feet of brine escapes to the surface before the well is sealed, the brine is diverted to a 20,000 m^2 pond and evaporated, leaving a residue of solids that is ≈3 cm thick. This volume of brine represents 0.93% of that in the repository and carries with it 0.93% of the ^{90}Sr. The fraction of the actinide inventory in the brine brought to the surface is .0023% after 25 years of leaching and 0.028% after 300 years.

5) The amount of this residue that is resuspended and carried downwind to the residence is assumed to be 0.2% per year of the total residue. Radionuclides are evenly mixed in the residue and are resuspended at the same rate. This value is more conservative than the value of 0.07% found at Rocky Flats (Ref. 3) but is less than the 0.7% expected to be lost from the top 3 cm of the WIPP salt pile (Ref. 7).

6) The downwind residence and farm is located 360m from the center of the 2 hectare evaporation pond. Since the source term is modeled as a virtual point source it is appropriate to use an annual $\frac{\chi}{Q}$ value for 804m. The value used (from the Final EIS) is $(5.0 \times 10^{-5})\ \frac{s}{m^3}$

7) Radionuclide transit, adult intake, and dose conversion factors are taken from Regulatory Guide 1-109 and NUREG-0172 (References 4 and 5).

FINDINGS

Source Term. The total curies of each significant radionuclide reaching the surface 125, 400 and 1000 years after closure are shown in Table I.

Table I
Quantity of Radionuclides Brought to Surface
(Curies)

Radionuclides	Radionuclide Quantities - Ci			
	Repository Total, t_c	t_c+125y	t_c+400y	t_c+1000y
^{90}Sr	2.5 + 6*	1,200.	1.5	-
^{137}Cs	1.3 + 4	0.21	-	-
^{238}Pu	3.5 + 4	0.34	0.51	
^{239}Pu	3.9 + 5	9.0	110.	310.
^{240}Pu	9.3 + 4	2.1	27.	79.
^{241}Am**	4.5 + 3	1.7	14.	14.

*2.5 + 6 = 2.5×10^6
**^{241}Am ingrows from decay of ^{241}Pu, inventory at t_c+125y = 7.5 + 4

Concentration in Air. The assumption is made that 0.2% of the radionuclides brought to the surface are resuspended and carried downwind per year. The amount of atmospheric dilution occurring at 360m in the maximum downwind direction is assumed to have an annual average of $(5.0 \times 10^{-5}) \frac{s}{m^3}$
Resulting concentrations are shown in Table II.

Table II
Atmospheric Concentrations of Radionuclides
at Downwind Residence

Radionuclide	t_c+125y		t_c+400y		t_c+1000y	
	Ci/y resuspended	$\frac{pCi^*}{m^3}$	Ci/y resuspended	$\frac{pCi}{m^3}$	Ci/y resuspended	$\frac{pCi}{m^3}$
^{90}Sr	2.4	3.8	.0032	0.0051	-	-
^{137}Cs	0.0004	0.0007	-	-	-	-
^{238}Pu	.0007	.0011	.0010	.0016	-	-
^{239}Pu	.018	.029	0.22	0.35	0.62	0.99
^{240}Pu	.0043	.0068	.054	0.086	0.16	0.26
^{241}Am	.0034	.0054	.028	0.045	0.024	0.045

*pCi/m^3 = 1.6 (Ci/y resuspended)

Inhalation Dose. The inhalation dose that the maximum individual would receive for 100% occupancy at the nearest residence is shown in Table III. An annual intake of 8000 m^3 of air is assumed. The calculated whole body and bone doses use dose conversion factors from Reference 5 and are expressed as the 50 year dose commitment in rems resulting from one year's inhalation. Since the residence time for actinides in the body is very long the dose actually delivered in the maximum year from a one-year intake is only about 2.2% of the dose commitment.

The inhalation dose that would be received by drill crew operators working in the brine pond area is shown in Table IV. This calculation assumes 200 hours per year of presence on site, a breathing rate of 1.25 m^3/hr, and a resuspension factor of 6×10^{-9}/m of the radionuclides in the top centimeter of the brine pond.

Table III

50-Year Dose Commitment From One Year's Inhalation

at Downwind Residence

(Rem)

Radionuclide	Dose Conversion F. mrem/pCi*		t_c+125y			t_c+400y			t_c+1000y		
			Intake pCi/y	Dose		Intake pCi/y	Dose		Intake pCi/y	Dose	
	w.b.	Bone		w.b.	Bone		w.b.	Bone		w.b.	Bone
^{90}Sr	7.6 - 4	1.2 - 2	3.0 + 4	0.023	0.36	4.1+1	-	-	-	-	-
^{137}Cs	5.4 - 5	6.0 - 5	5.3 + 0	-	-	-	-	-	-	-	-
^{238}Pu	6.9 - 2	2.7 + 0	8.8 + 0	.0006	.002	1.3+1	0.001	0.035	-	-	-
^{239}Pu	7.8 - 2	3.2 + 0	2.3 + 2	.018	0.74	2.8+3	0.22	9.0	7.9+3	0.62	25.
^{240}Pu	7.7 - 2	3.2 + 0	5.5 + 1	0.004	0.18	6.9+2	.053	2.2	2.1+3	0.16	6.6
^{241}Am	6.7 - 2	1.0 + 0	4.3 + 1	.003	0.043	3.6+2	.024	.36	3.6+2	0.024	0.36
		TOTALS		0.049	1.3		0.30	12.		0.80	32.

*From Reference 5, Table 8.

Table IV

50-Year Dose Commitment From One Year's Inhalation for Workers at the Brine Pond

(Rem)

Radionuclide	t_c+125y			t_c+400y			t_c+1000y		
	Intake pCi/y	Dose w.b.	Dose Bone	Intake pCi/y	Dose w.b.	Dose Bone	Intake pCi/y	Dose w.b.	Dose Bone
^{90}Sr	3.0 + 4	.023	.36	4.0+1	.0001	.0005	-	-	-
^{238}Pu	8.5 + 0	.0006	.023	1.3+1	.0009	.035	-	-	-
^{239}Pu	2.3 + 2	.018	.74	2.8+3	.22	9.0	7.8+3	.61	25.
^{240}Pu	5.3 + 1	.0041	.17	6.8+2	.052	2.2	2.0+3	.15	6.4
^{241}Am	4.3 + 1	.0029	.043	3.5+2	.023	.35	3.5+2	.023	.35
	TOTALS	.049	1.3		.30	12.		.78	32.

Ingestion Doses. Ingestion doses are calculated assuming the downwind resident obtains 76% of his fruits, vegetables, and grain; 100% of his milk; and 100% of his meat from the surrounding land which is contaminated by deposition of the resuspended radionuclides. A deposition rate of (8.0×10^{-5}) per meter of plume length is assumed (Ref. 6). Stable element transfer data, annual consumption rates, maximum individual intake rates, and other parameters are taken from Tables E-1, E-3, E-9, and E-15 of Reference 4.

Table V

Radionuclide Intake From One Year's Ingestion of Fruits, Vegetables, and Grain (Picocuries)

Radionuclides	t_c+125 years			t_c+400y		
	$Q(\frac{pCi}{s})$	$C(\frac{pCi}{kg})$	Intake (pCi)	$Q(\frac{pCi}{s})$	$C(\frac{pCi}{kg})$	Intake (pCi)
^{90}Sr	7.7 + 4	5.9 + 2	2.5 + 5	1.1 + 2	8.4 - 1	3.3 + 2
^{137}Cs	1.3 + 1	1.0 - 1	4.3 + 1	-	-	-
^{238}Pu	2.1 + 1	1.6 - 1	6.6 + 1	3.2 + 1	2.5 - 1	1.0 + 2
^{239}Pu	5.7 + 2	4.4 + 0	1.8 + 3	6.8 + 3	5.2 + 1	2.1 + 4
^{240}Pu	1.4 + 2	1.1 + 0	4.4 + 2	1.8 + 3	1.4 + 1	5.6 + 3
^{241}Am	1.1 + 2	8.5 - 1	3.4 + 2	9.0 + 2	6.9 + 0	2.8 + 3

$$Ccrops = .0077\frac{s}{kg}\ Q\ \frac{pCi}{s}$$

$$Q\ \frac{pCi}{s} = (3.17 + 4)\ \frac{pCi - y}{Ci - s}\ \left[\frac{Ci}{y}\ \text{resuspended}\right]$$

Table VI

50-Year Dose Commitment From One Year's Ingestion of Fruits, Vegetables, & Grain

Radionuclide	Dose Conversion* Factors (mrem/pCi)		Dose in millirem			
			t_c+125y		t_c+400y	
	w.b.	Bone	w.b.	Bone	w.b.	Bone
^{90}Sr	1.9 - 3	7.6-3	4.7 + 2	1.9+3	6.3 - 1	2.5+0
^{137}Cs	7.1 - 5	8.0-5	3.0 - 3	3.4-3	-	-
^{238}Pu	1.7 - 5	6.8-4	1.1 - 3	4.5-2	1.7 - 3	6.8-2
^{239}Pu	1.9 - 5	7.9-4	3.4 - 2	1.4+0	4.0 - 1	1.7+1
^{240}Pu	1.9 - 5	7.9-4	8.4 - 3	3.5-1	1.1 - 1	4.4+0
^{241}Am	5.4 - 5	8.2-4	1.8 - 2	2.8-1	1.5 - 1	2.3+0
Totals, mrem			4.7 + 2	1.9+3	1.3 + 0	2.6+1
Rem			0.47	1.9	0.001	0.026

*From Reference 5, Table 4.

Table VII

Radionuclide Intake From One Year's

Ingestion of Milk

(Picocuries)

Radionuclide	Fm (d/ℓ)	t_c+125y			t_c+400y		
		Cpast $(\frac{pCi}{kg})$	Cmilk $(\frac{pCi}{\ell})$	Annual Intake (pCi)	Cpast $(\frac{pCi}{kg})$	Cm$(\frac{pCi}{\ell})$	Annual Intake(pCi)
^{90}Sr	8.0 - 4	1.4 + 3	5.5 + 1	1.7 + 4	1.9 + 0	7.3 - 2	2.3 + 1
^{137}Cs	1.2 - 2	2.3 - 1	1.3 - 1	4.1 + 1	-	-	-
^{238}Pu	1.5 - 6	3.7 - 1	2.8 - 5	8.7 - 3	5.8 - 1	4.3 - 5	1.3 - 2
^{239}Pu	1.5 - 6	1.0 + 1	7.5 - 4	2.3 - 1	1.2 + 2	9.0 - 3	2.8 + 0
^{240}Pu	1.5 - 6	2.6 + 0	1.9 - 4	5.9 - 2	3.3 + 1	2.5 - 3	7.8 - 1
^{241}Am	5.0 - 6	2.0 + 0	5.0 - 4	1.6 - 1	1.6 + 1	4.0 - 3	1.2 + 0

Fm = pCi/ℓ in milk per pCi/day ingested by the animal

Cpasture = .018 $\frac{s}{kg}$ (Q $\frac{pCi}{s}$)

Cmilk = 50 Cp Fm

Intake = 310 ℓ/y

Table VIII
50-Year Dose Commitment From One Year's Ingestion of Milk
(millirem)

Radionuclide	t_c+125y		t_c+400y	
	w.b.	Bone	w.b.	Bone
^{90}Sr	3.2 + 1	1.3 + 2	4.4 - 2	1.7 - 1
^{137}Cs	3.0 - 3	3.4 - 3	-	-
^{238}Pu	1.5 - 7	5.9 - 6	2.2 - 7	8.8 - 6
^{239}Pu	4.4 - 6	1.8 - 4	5.3 - 5	2.2 - 3
^{240}Pu	1.1 - 6	4.7 - 5	1.5 - 5	6.2 - 4
^{241}Am	8.6 - 6	1.3 - 4	6.5 - 5	9.8 - 4
Total Doses (mrem)	32.	130.	0.044	0.17

Table IX
Radionuclide Intake From One Year's
Ingestion of Meat
(Picocuries)

Radionuclide	Ff (d/kg)	t_c+125y		t_c+400y	
		Cmeat $(\frac{pCi}{Kg})$	Annual Intake (pCi/y)	Cmeat $(\frac{pCi}{kg})$	Annual Intake (pCi/y)
^{90}Sr	6.0 - 4	4.2 + 1	4.6 + 3	5.7 - 2	6.3 + 0
^{137}Cs	4.0 - 3	4.6 - 2	4.9 + 0	-	-
^{238}Pu	3.0 - 6	5.6 - 5	6.2 - 3	8.7 - 5	9.6 - 3
^{239}Pu	3.0 - 6	1.5 - 3	1.7 - 1	1.8 - 2	2.0 + 0
^{240}Pu	3.0 - 6	3.9 - 4	4.3 - 2	5.0 - 3	5.5 - 1
^{241}Am	3.0 - 6	3.0 - 4	3.3 - 2	2.4 - 3	2.6 - 1

Ff = pCi/kg in meat per pCi/d ingested by the animal

Cmeat = 50 (Cpast) Ff

Intake = 110 kg/y

Table X

50-Year Dose Commitment From One Year's Ingestion of Meat

(millirem)

Radionuclide	t_c+125y		t_c+400y	
	w.b.	Bone	w.b.	Bone
^{90}Sr	8.7 + 0	3.5 + 1	1.2 - 2	4.8 - 2
^{137}Cs	3.4 - 4	3.9 - 4	-	-
^{238}Pu	1.1 - 7	4.2 - 6	1.6 - 7	6.5 - 6
^{239}Pu	3.3 - 6	1.3 - 4	3.9 - 5	1.6 - 3
^{240}Pu	8.3 - 7	3.3 - 5	1.1 - 5	4.4 - 4
^{241}Am	1.8 - 6	2.7 - 5	1.4 - 5	2.1 - 4
Totals	8.7	35.	0.012	0.050

External Radiation

External radiation can occur at two locations: (1) the brine pond area where the radionuclide will be deposited once the brine has evaporated; and (2) the residence located 360m downwind. The maximum dose at the pond would occur during the first year following the release. The year when the maximum concentration would appear in the brine is a function of leaching rate and half-life and will vary for each nuclide. The maximum soil concentrations at the downwind residence would occur many years later since resuspension from the pond and deposition downwind is an on-going process. In this case the half-life of the nuclide is a factor, with the maximum concentration occurring when the decay of the deposited radionuclides equals the rate of deposition. Key assumptions are: (1) the 0.2%/y resuspension and transport rate will continue indefinitly; (2) 20% of the amount deposited each year will attach to foliage and be removed from the site; (3) the remaining radionuclides at the residence will be evenly mixed in the top 15 cm of soil and appropriate soil attenuation factors will be used for the various energy gamma radiations; and (4) occupancy factors are .023 for the pond area (based on 200 hours per year for an occupational worker) and 0.7 for the residence area.

Table XI

Maximum External Radiation Doses

Nuclide	Brine Pond Area		Downwind Residence	
	Max dose mrem/y	Time of ocurrence	Max dose mrem/y	Time of Occurrence
$^{90}Sr/^{90}Y$	26.	t_c+125y	0.014	t_c+165y
^{137}Cs	6.6	t_c+140y	0.005	t_c+180y
^{154}Eu	.056	t_c+125y	-	-
^{241}Am	97.	t_c+700y	0.70	t_c+1100y

Population Dose

The population about the WIPP site would receive some radiation dose if the scenario described in this report were to occur. The inhalation dose is expected to be much greater than the other pathways because:

(1) It is the dominant pathway near the site where the ingestion and external pathways are assumed to be plausible;

(2) The mechanism (i.e. winds and atmospheric dispersion) exists for the inhalation pathway whereas an ingestion pathway is not expected to impact the population as a whole since food crops are not extensively grown in the area. Also a logical water supply pathway does not exist for the population.

Table XII shows an estimated population dose (50-year dose commitment from one year's inhalation) within a 50-mile radius of the site for the tc+400y release. Annual χ/Q values are taken from Table H-49 of Reference 7. Plume depletion was taken from Figure 3 in Reference 6. The projected 2010 population values from Table M-6 in Reference 7 are assumed to be applicable at tc+400y. Population doses for tc+125y and tc+1000y can be obtained by ratio of actinide activities brought to the surface (Table 1).

Although Table XII shows the dose commitment for only one year and uses the quantities calculated for a tc+400y breach it should be recognized that the release could occur anytime after about tc+125y. This projected tc+400y dose is expected to be the maximum that could occur (because of repository pressurization and radionuclide solubility considerations) although the assumption used in the calculation suggest greater doses for several thousand years. Resuspension and transport of the contaminated material would continue for many years. If the depletion rate of 0.002 per year continued indefinitely this would eventually lead to an integrated dose commitment to a stable population at about 500 times the annual calculated dose. About 95% of this dose would be delivered in the first 1500 years. However, it is more likely that the depletion rate would decrease with time and that significant amounts of the radionuclides would never be resuspended because of fixation or migration into the soil.

Table XII

Population Doses within a 50-mile Radius of the WIPP Site
from Inhalation of Resuspended Contamination
(50-year Dose Commitment From One Year's Inhalation)

Location*	χ/Q s/m^3	Fraction Remaining in Plume	Max Adult whole body dose (mrem)	Projected** 2010 Population	Population Dose (person-rem)***	
					w.b.	Bone
Carlsbad	(1.7-8)	.57	0.056	49,465	2.7	100.
Loving	(3.5-8)	.66	0.14	2,645	.35	13.
Artesia	(3.2-8)	.48	0.088	15,770	1.4	53.
Hobbs	(8.6-10)	.48	0.0024	52,850	.12	4.8
Lovington	(2.0-8)	.48	0.055	21,800	1.2	46.
Other Locations		.53	-	11,825	.16	6.4
			Totals	154,355	5.9	220.

* includes populations in the vicinity. In some cases χ/Q values are averages of more than one section.

** projected 2010 population from Appendix M of Reference 7.

*** population dose assumed to be 0.95 (adult dose) (population) from Reference 4 population mix and inhalation rate assumptions.

PROBABILITY CONSIDERATIONS

There are a chain of events that must occur before the doses calculated above would be incurred. Each of these events has a probability of occurring that may be near zero or approach one. The probability of all the necessary events occurring is:

$$P\ total = (P_1)\ (P_2)\ (P_3)\ (P_{n-1})\ P_n$$

The following events are the key ones that must all occur for the doses to materialize:

(1) Institutional control of the repository is lost 100 years after closure.

(2) A geopressurized brine reservoir of sufficient size must exist under the Site.

(3) The brine reservoir and the repository must both be intersected by an exploratory borehole which is capped shortly after discovery.

(4) This brine reservoir must saturate the pore space in the repository where it is in intimate contact with salt and waste.

(5) The assumed amount of leaching and exchange between the waste and salt occurs.

(6) A second borehole must intercept the repository.

(7) There must be sufficient pressure in the reservoir to drive 75,000 cubic feet of brine to the surface.

(8) The drilling crew must require approximately 16 hours before capping the well in order for 75,000 cubic feet to flow to the surface (assuming a flow rate of 20,000 barrels/d).

(9) The possibility of a radiological hazard is not recognized by the drillers and no radiological analyses are made of the brine. (This requires either loss of knowledge of the repository or a complacency about potential hazards).

(10) There is a home located 360m in the maximum downwind direction from the center of the evaporation pond.

(11) This home is inhabited by a largely self-sufficient farm family.

The absence of some of these assumptions (e.g. 1, 2, 3, 4, 6, and 7) would prevent any radiation dose from occurring. The other conditions could be less critical than estimated here and still lead to some radiation exposure (less than calculated above).

The values assigned to each event are given below with an explanation of why they were chosen.

(1) 1.0 DOE assumes this may occur in their evaluations. Also, EPA's draft HLW standard would require that credit cannot be taken for longer periods of control.

(2) 0.04 per drill hole. This value was chosen from the map on page 146 of Reference 8 which shows that 1 out of 27 holes drilled into the Castile formation in the Delaware Basin (not including those on the reef or deformation belt) struck a brine reservoir.

(3) 0.049 bore holes penetrate the backfilled area of the repository in each century. This estimate is taken from an EPA suggested value of 2.0 boreholes per century for an 8 km^2 area (Ref. 9). The effective cross-sectional area of the repository is the sum of the backfilled rooms, subentries, and main entry areas in the waste storage portion of the repository and is about 0.19 km^2. Because of pressurization and closure phenomena in the repository the time period when this borehole would be effective is 100 to 500 years after closure (see Appendix A).

(4) 0.5 There is a possibility the brine would go into other permeable zones.

(5) 0.5 The 25 year period may be too-short a time for all of the ^{90}Sr to go into the brine solution. Longer time periods would reduce the probability and dose but not eliminate the pathway. Also, the assumed degree of equilibration may be less. The value of this event is taken as 1.0 for the transuranic elements since an annual leach rate is used in that calculation.

(6) Same assumptions as in (3) except that the effective period is 125-600 years after closure of the repository.

(7) 0.5 There is a possibility that much of the pressure would be lost during the first borehole penetration and movement of brine to the repository. However, this could be offset by pressure from gases generated within the repository from organic decomposition or by the pressure generated from salt creep (see Appendix A).

(8) 0.4 It should be possible to cap the borehole in a period shorter than 16 hours. A shorter capping time would reduce the consequences, but not eliminate the scenario.

(9) 0.5 Either lack of knowledge of the repository or a lack of appreciation for possible radiological problems could cause the contamination to go unrecognized. However, it is possible that the unusual occurrence will result in recognition of the problem. Recognition of the problem would drastically reduce, but not eliminate radiation doses.

(10) 0.01 There is only a 6% probability that a nearby house would be located in the maximum downwind direction. The probability that any housing will occur within one-half mile of the repository is certainly less than one. Lesser doses would occur to residents located in any direction and greater distances away. Also, agricultural use of the land, without residency, would lead to lesser doses.

(11) 0.2 The area is more conducive to ranching and not self-sufficient farming. This factor would effect the ingestion dose only.

Probability Calculation Examples

The overall probability can be determined by combining the above probabilities. The calculation of events (2), (3), and (6) (which gives the probability that a borehole will hit a brine reservoir and the repository followed by a second borehole hitting the repository later) varies depending on the time frame chosen for the first hit and that chosen for the second hit. For example, to calculate the cumulative probability that a dose equal to or greater than the tc+125y inhalation dose would occur during the lifetime of the repository, it is necessary to determine the summation of:

$$\sum \; .04 \; (P_i/y)t_i \; P_2/y \; [600-(t_i+25)]$$

for each year i between tc+100y and tc+500y. This cumulative probability is about 0.001.

The overall probability of this minimum tc+125y inhalation dose occurring after closure is then:

$$P_{(tc+125y\ dose)} = (1.0)\,[0.001]\,(0.5)\,(1.0)\,(0.5)\,(0.4)\,(0.5)\,(0.01)$$
$$= 5\times10^{-7} \text{ for inhalation}$$

The probability that both the inhalation and ingestion dose would occur in 5×10^{-8}. The probability that there will be some dose delivered is somewhat

greater than this because several of the events [(5), (8), (9), (10), and (11)] are ones that are non-critical, i.e. they affect the magnitude of the doses assumed, not the existence of any dose. The possibility there will be some dose to either drillers, clean-up personnel, or to nearby residents or agricultural users can be estimated by setting the non-critical event probabilities to 1.0.

$$P \text{ some dose} = (1.0)\ [0.001]\ (0.5)\ (0.5) = \underline{0.00025}$$

An example of a dose that may be plausible is for an individual to reside 1/2 time at a distance of 800m in any direction from the brine pond. This would raise assumption (10) by a factor of 16 but the value would still be only 0.16 rather than 1.0. This would give a probability of 8×10^{-6} that an inhalation dose $\geq$ 0.07 or the maximum dose would occur.

Draft High Level Waste Standard

Another use of the probabilistic approach is to determine whether the release would meet the Draft EPA High Level Waste Standard for quantities of radionuclides released to the environment in a 10,000 year period. The draft standards would permit 100 Ci of ^{239}Pu, 10 Ci of ^{241}Am, and 80 Ci of ^{90}Sr to be released per 3 million curies of alpha emitting TRU wastes initially in the repository for a "reasonably foreseeable release" ($p \geq .01$ during 10,000 year period) and 10 times these amounts for a "very unlikely release" ($.01 > p > .0001$).

Since the WIPP repository is projected to have an initial inventory of 0.52 million curies of alpha emitting TRU waste, a total of 175 Ci of $^{239+240}Pu$, 17.5 Ci of ^{241}Am, or 140 Ci of ^{90}Sr would be permitted for a "very unlikely release". Combinations of these nuclides must meet the following relationship:

$$\frac{\text{Ci Pu}}{175} + \frac{\text{Ci Am}}{17.5} + \frac{\text{Ci Sr}}{140} \leq 1.0$$

When the assumed leaching rate of 10^{-4}/y for the actinides is factored into this expression it is found that the minimum leaching time necessary to exceed the standard is about 225 years. The probability that a second borehole would hit the repository 225 or more years after the first hit is about .0003. When this probability is combined with those parameters necessary to bring waste to the surface one gets.

$$P = 1.0\ (.0003)\ (0.5)\ (1.0)\ (0.5)\ (0.4) = \underline{\underline{3 \times 10^{-5}}}$$

This calculated probability is one-third of that allowed in the draft standards and (considering the crudeness of the approximation) suggests that a more refined analysis would be worthwhile.

Discussion

This probabilistic approach is a simplified one and the values chosen for some of the parameters are arbitrary (although they are considered plausible). Consequently, undue value should not be placed on the probabilities calculated in the above examples.

This approach is presented here for several reasons:

(1) A probabilistic approach is considered preferable to a consequence analysis because it gives some basis for estimating whether a scenario is reasonable or incredible.

(2) It is time to begin applying this approach to analyses of long-term releases from repositories. Hopefully, reaction to this approach will lead to a more sophisticated methodology and a sounder basis for values chosen.

(3) The approach can be useful in pointing out key parameters that need to be better quantified in order to assess the probability. For example, in this case a greater understanding of brine reservoir occurrence might change the value chosen for this probability by an order-of-magnitude or more. Or, the implementation of a positive institutional control program could reduce that probability by 1 to 2 orders-of-magnitude.

DISCUSSION

Reasonableness of Assumptions

The existence of a brine reservoir beneath the site is considered unlikely but possible. Further investigations of the brine reservoir phenomena and the structure beneath the site may significantly change the estimated probability of 4% per borehole used in this report.

In the absence of institutional control over drilling after time of closing plus 100 years, it must be assumed some exploratory drilling will occur. The values chosen for the frequency of drilling were taken from Reference 9.

The probability that a plugged borehole connecting repository and brine reservoir would result in flooding of the more permeable void space in waste storage rooms throughout the repository was assumed to be 0.5. This phenomena is reasonable, unless the repository is backfilled so that the waste storage rooms are hydraulically isolated from each other. Also, other highly permeable zones along the borehole could receive the brine before it entered the repository.

The presence of sufficient pressure to bring repository brine to the surface is another uncertainty because much pressure may be lost due to the venting of the first borehole. However, another possible source of pressure is the generation of gases in the repository from decomposition of the organic wastes. The possibility of near lithostatic gas pressures developing within a few hundred years has been estimated (Ref. 10). Also, salt creep of the backfilled area over a period of perhaps 200 years will cause pressurization of any brine present. This probability was taken as 0.5.

It should be noted that, if repository generated gas pressures develop, this scenario could occur without the presence of a pressurized brine reservoir. All that would be needed would be for water to enter the repository (from whatever sources) to be followed some years later by a single borehole into

the repository. The probability of a scenario developing in this manner was not estimated.

Leaching rates of the actinides and cesium were taken from experimental work carried out on fuel fragments and borosilicate glass in various waters, including WIPP "B" brine (Ref. 2 and 11). It was assumed that CH-TRU wastes would leach at the same rate as these materials, which may or may not be conservative. Solubility considerations would probably limit the concentrations of actinides in brine to less than the tc+400y values. (Experimental solutions were typically <0.02 mg/ℓ which would have been reached in less than ten years at the assumed leaching site. However, these experiments were not carried to saturation).

The assumption that all strontium would go into solution was taken from Reference 12. The choice of a 25-year period for the reaction to occur was arbitrary.

There is a possibility that some of the leached radionuclides would become sorbed onto the 1-2% of clay present in the salt backfill, settle out of solution, and not be brought to the surface along with the brine. The percentage of radionuclides that might be removed from solution by this mechanism was not estimated.

The presence of administrative control over the site longer than 100 years after closing has not been assumed by DOE for the WIPP site. Also, both the NRC and the EPA policies are currently using the philosophy that controls after 100 years should not be relied upon.

It seems probable that knowledge of the repository would not be lost. Plans to have an extensive marker system and maintenance of records should give a high probability that drillers would know there is a repository in the vicinity. However, knowledge of the repository does not assure that drillers will forego the drilling or take the necessary precautions to minimize radiation exposure. Recent history shows numerous cases where persons who should have had knowledge of the presence and dangers of radiation acted foolishly. For example: (1) use of uranium mill tailings for household

construction purposes; (2) diversion of radioactive material from a low-level waste disposal site; and (3) careless use of industrial radiography sources.

The quantity of brine (and radionuclides) reaching the surface is dependent on how long it takes to control the brine flow. At a flow rate of 20,000 barrels per day (which has been observed in nearby brine reservoirs) the assumed volume of brine would be released in 16 hours. The probability that it would take longer than 16 hours to stop the flow was taken as 0.4. This is probably conservative but is certainly not an upper limit.

No separate probability was calculated for the presence of occupational workers about the brine pond. However, if a well is developed, there will be some occupancy at the site, perhaps for several years. Also reuse of the site many years later could still result in a significant dose due to the presence of long-lived radionuclides and relatively slow removal by wind erosion.

The presence of a residence 370m away in the maximum downwind sector is of low probability. The low probability is partially because there is only a 1 in 16 probability that the residence would be located in the maximum downwind sector. However, the presence of a residence in some direction within about 1 mile of the brine pond is not considered unlikely. Inhalation doses at 1 mile would vary from 0.02 - 0.19 times those calculated here.

The existence of a full-pledged family farm at this location is considered unlikely because of the absence of economically recoverable water of good quality. However, the meat pathway exists at the site now and could be expected to continue.

Significance of Calculated Radiation Doses

General Background

At present the consensus in the health physics profession is that any radiation dose received probably has the potential to harm an individual. The possibility of harm, however, becomes very small as the annual dose received becomes less than the dose that man has always received from natural background radiation.

The relation between health effects (H.E.) and dose received (D) can be expressed by:

$$H.E. = CD^n$$

where C is a constant. If the value of $n=1$, the relationship is linear; if $n<1$ the resulting health effects are greater than for the linear condition (super linear); if $n>1$ the health effects are sub-linear. Most mandatory or advisory standards assume the relation is linear although many professionals believe the relationship is actually sub-linear and that the linear assumption is conservative.

Regardless of the actual shape of the response curves at low radiation doses, the following philosophies are pertinent:

(1) Radiation doses should be maintained as low as reasonably achievable because the possibility of damage even at very low levels cannot be ruled out.

(2) Annual doses received by non-radiation workers from routine (or expected) releases should be a fraction of that received from natural background radiation. Thus EPA's Uranium Fuel Cycle (40 CFR 190) and Drinking Water (40 CFR 141) Standards allow maximums of 25 and 4 mrem/y (to the whole body or any organ except the thyroid) to the population (compared to a natural background average of about 100 mrem/y.

(3) Allowable doses to nonradiation workers from accidents can be set much higher than this because an individual is not expected to receive such a dose more than once in a lifetime. Typically, guidance limits the dose to less than the lifetime dose a person would receive from natural background (e.g. 1 to 5 rem might be permitted, compared to lifetime natural background doses of 5-10 rem).

(4) Contamination of the accessible environment with long-lived radionuclides is in itself undesirable because there are many ways these nuclides can eventually get back to man. Also, contamination from multiple sources could result in a radionuclide buildup in the environment. This is the reason that limits are set on the quantities of long-lived radionuclides released in both EPA's Uranium Fuel Cycle Standard and in their draft High Level Waste Disposal Standard (40 CFR 191).

The radiation doses calculated in this report are more appropriately considered to be accidental doses because the events are not expected to happen. However, if the event were to occur and these long-lived radionuclides were brought to the surface, they could be a potential source of radiation exposure for decades or centuries. Consequently, the potential exists for a few individuals or a larger population to receive radiation doses over a number of years. For this reason, it should be recognized that these doses may not really be a one-shot event and to treat them as such is non-conservative.

Ingestion Doses

The 50-year dose commitments from one year's intake total only 0.51 rem to the whole body and 2.0 rem to the bone at 125 years after closure. While the whole body doses are high compared to those permitted from continuous exposure to routine planned releases (25 mrem/y) they are an order-of-magnitude below the suggested guidelines for a once-in-a-lifetime accident. Furthermore, since the calculated doses would decrease with the 29-year half-life of ^{90}Sr a whole body dose greater than 25 mrem/y would not occur after tc+250y. The calculated probability of this event occurring before tc+250y would be about ($4x10^{-9}$). Note that with shorter time before breach the ^{90}Sr could become more of a problem, e.g. at tc+75y the whole body 50-year dose commitment would be 1.7 rem, and for tc+50y it would be 3.1 rem.

The calculated bone dose is about 4 times the whole body dose and would not fall below the 25 mrem/y limit until about tc+310y. Also, the dose at tc+125y is within the 1-5 rem range suggested by EPA as a protective action guide for accidential releases. However, it is not reasonable to equate bone dose to whole body doses since the relative health effect ratio (H.E. whole body/H.E. bone) has been estimated to be as high as 20 (Ref. 13).

Because of the above considerations of a relatively low dose commitment and unlikely occurrence it is concluded that after tc+100y plausible doses via the ingestion pathway are not significant enough to require protective measures.

Inhalation Doses

Inhalation doses are somewhat greater than ingestion doses and have a higher probability of occurrence. Consequently, they are of greater concern than ingestion doses.

The dose to occupational workers about the brine pond at tc+400y is significant (a 50-year dose commitment of 0.30 rem to the whole body and 12 rem to the bone from one year's exposure). Since approximately 2.2% of the 50-year dose commitment from these radionuclides would be delivered in the maximum year, the maximum annual dose resulting from a tc+400y breach would be .0066 rem to the whole body and 0.26 rem to the bone. The bone dose is below permissible standards for radiation workers (5 rem/y) but is above the lower dose limits applicable to the general population and to non-radiation workers (which the drillers would be). Even though these calculated doses are undesirably high they should not be considered as hazardous, since they represent only an estimated one in 6,000 probability of inducing a fatal cancer (compared to a natural incidence of about one in 6 from all causes). Also, it is unlikely that one individual would spend more than 200 hours about the site.

The downwind 50-year dose commitment from one years inhalation at tc+400y is 0.3 rem whole body and 12 rem to the bone. If the resident was exposed for only one year the maximum annual dose delivered would be 7 mrem to the whole body and 260 mrem to the bone. The annual bone dose would remain well above any permissible standard or guideline for non-radiation workers as long as the recipient lives. Clearly this is an undesirable situation. However, the probability that the dose commitment from one year's inhalation would result in a fatal cancer to an individual is slight, only about one in 6,000.

Population dose estimates for the population within a 50-mile radius total 5.9 and 220 person-rem to the whole body and the bone at tc+400y. These doses represent a negligible hazard to any of the 154,000 individuals (projected 2010 population) in the affected population. However, if this resuspension rate continued for a period of 1500 years it would deliver a cumulative dose to a stable population about 480 times the first year dose. This would result in cumulative doses of about 110,000 person-rem to the bone and 2,800 to the whole body and might result in 1 or 2 fatal

cancers. However, it is unlikely that all of the material would be resuspended; most studies show that significant amounts of material become fixed or migrate into the soil.

These consequences are small when one considers the large number of persons involved and the number of generations over which any health effect would occur. For example, a stable population of 154,000 persons would be expected to incur over 500,000 cancer deaths in 1500 years if present cancer mortality rates continue. Obviously, any health effect that actually did occur would not be visible among the much more prevelant effects from other causes.

Nonetheless, the presence of significant undetected contamination remaining on the surface for long periods of time must be considered as undesirable and precautions should be taken to minimize its occurrence. This concern comes from the realization that over a period of several hundred years large numbers of persons could come and go about the site and within the 50-mile radius. Prediction of all the human activity that might be impacted by the contamination would be very speculative. For these reasons steps should be taken to avoid situations where significant surface contamination could exist for decades without detection and remedial action.

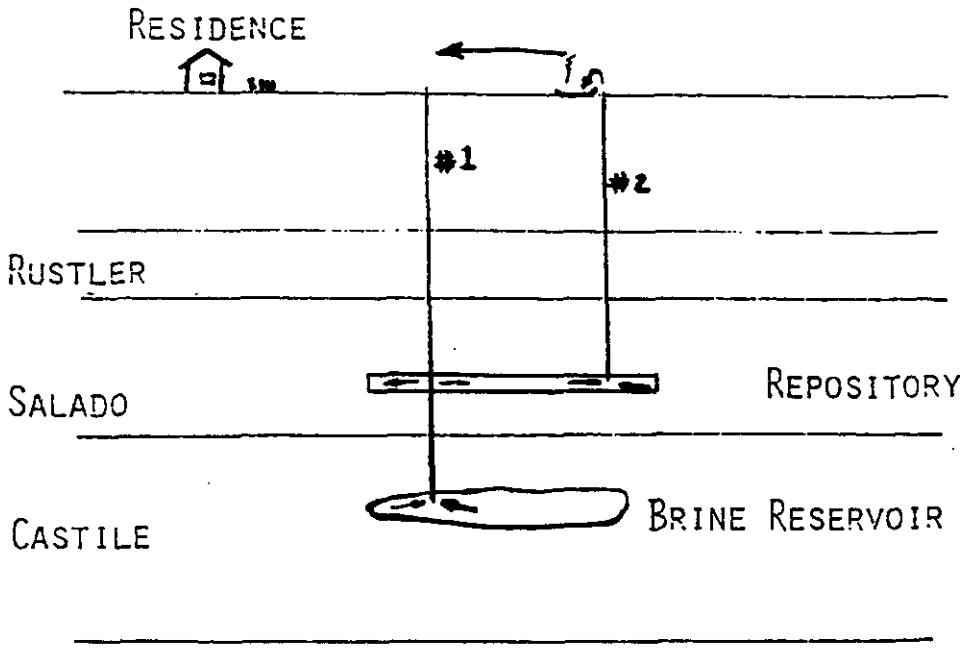

FIG. 1. SCHEMATIC OF SCENARIO

REFERENCES

1. Selected Provisions of EPA's Disposal Standards for High-Level and Transuranic Radioactive Wastes. A draft paper for discussion during NRC/ORNL symposium at Gatlinburg, TN, March 1981.

2. Katayama, Y.B., and Bradley, D. J. "Long-Term Leaching of Irradiated Spent Fuel," Scientific Basis for Nuclear Waste Management, Vol. 2, 1980, p. 323.

3. Michels, D.E. Diagnosis of Plutonium Reintrained in Air, (FRP-1927), 1973.

4. U.S. Nuclear Regulatory Commission. Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I, (Regulatory Guide 1.109, Revision 1), October 1977.

5. Hoenes, G. R. and Soldat, J. K. Age-Specific Radiation Dose Commitment Factors For a One-Year Chronic Intake (NUREG-0172), November 1977.

6. U. S. Nuclear Regulatory Commission. Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases From Light-Water-Cooled Reactors (Regulatory Guide 1.111, Revision 1), July 1977.

7. U. S. Department of Energy. Final Environmental Impact Statement, Waste Isolation Pilot Plant (DOE/EIS-0026), October 1980.

8. Chaturvedi, Lokesh. WIPP Site and Vicinity Geological Field Trip (EEG-7), October 1980.

9. Smith, C. Bruce, et al. Population Risks From Disposal of High-Level Radioactive Wastes in Geologic Repositories (EPA 520/3-80-006 Draft), July 1981.

10. Sandia Laboratories. Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP (SAND 79-1305), November 1979.

11. Bradley, D. J., Harvey, C. O., and Turcotte, R. P. Leaching of Actinides and Technetium From Simulated High-Level Glass (PNL-3152), August 1979.

12. Clynne, M.A., Chou, I-Ming, and Haas, J. L., Jr. "$SrC\ell_2$ Solubility in Complex Brines," Scientific Basis for Nuclear Waste Management, Vol. 3, 1981, p. 499.

13. International Commission on Radiological Protection. "Recommendations of the International Commission on Radiological Protection," Annals of the ICRP 26, January 1977.

APPENDIX A
REPOSITORY PRESSURIZATION CONSIDERATIONS

Key assumptions in this scenario are that brine would be able to flow into the repository and would be under sufficient pressure to enable it to flow to the surface in the event a borehole penetrated the backfilled area. This appendix examines several mechanisms that affect this assumption.

Initial Brine Reservoir Pressure

If the initial borehole through the repository struck a brine reservoir that was under near-lithostatic pressure (which have been observed in nearby brine reservoirs) there would be sufficient pressure to infiltrate the repository (after the well was capped) if the pore space were not under greater pressure at the time. Since it is presumed the borehole will be sealed down to the brine reservoir level within a few weeks, any infiltration would have to occur during this interval.

The brine would not occupy all pore space even if the inflow from the brine reservoir were completed before sealing the well. This is true for several reasons:

(1) The initial gas in the repository, even if at atmospheric pressure, would become pressurized as it was being reduced in volume and would eventually equal the pressure of the inflowing brine.

(2) A portion of the inflow would be dissolved gases rather than brine.

(3) The pressure in the brine reservoir would drop significantly as the reservoir expands into the repository. Also, the size of the brine reservoir may be limiting.

(4) Prior pressurization may exist in portions of the repository either from salt creep or from organic decomposition of the wastes (see discussion below).

From the above considerations it is concluded that while some brine inflow to the repository is reasonable, it will not be sufficient to fill the entire pore space of the repository. However, it is difficult to relate this conclusion to the degree of conservatism in the scenario since none of the dose assumptions directly address the effect of brine-to-waste ratios, fraction of repository saturated, etc.

Pressurization by Salt Creep

Arthur D. Little, Inc. estimated that in a site with favorable salt creep characteristics the pore space of backfilled material would decrease linearly with time to approximately zero in about 200 years. A site with unfavorable salt creep characteristics might require 1000 years to decrease to zero (Ref. 9).

Assume that: (1) salt creep is the only pressurization mechanism; (2) the time for closure is 200 years and the rate is linear; (3) initial gas pressure in the pore space is 1.0 atmospheres; (4) pressurization of the gas is inversely proportional to original volume; and (5) the brine reservoir inflow pressure is 80% of lithostatic (.8 x 140 = 112 atmospheres). Brine inflow to the repository would continue until the final pore volume was 1/112 (0.0089) of the original. This inflow would have to occur before about tc+190y in order for a significant portion of the voids to be filled with brine. Therefore if salt creep is the dominant pressurization mechanism, the first borehole must strike the brine reservoir and bring brine into the repository during the period 100-190 years after repository closure. Pressurization above the 0.5 (lithostatic pressure) level (which is required to bring saturated brine to the surface) might persist for 100-200 years, depending on the gas permeability of the surrounding salt.

Pressurization From Organic Decomposition

The possibility of significant gas buildup in the WIPP repository due to decomposition of organic materials in the waste has been predicted (Ref. 10). Assumptions were made that gas generation would occur for 400 years, then cease abruptly. The generation of gas will slow down or stop the closure of the repository due to salt creep during the time of operation. The pressure in the repository at equilibrium depends on the permeability of the salt formations. In the more feasible ranges of 0.5 - 5.0 μdarcy (the only 2 measured values being 11 and 21 μdarcy) the pressure during the period from about 100 to 400 years varied from about 2/3 to 1/4 lithostatic pressure. After 400 years the pressure drops off exponentially with a half-life of about 100 years (see Figure A-1).

If gas generation is the dominant mechanism, it appears that the pressure in the repository during the period from 100 to about 500 years could be both low

enough to permit brine to flow into the repository and high enough to bring brine to the surface. Salt creep between tc+500 years and tc+600 years would probably maintain sufficient pressure to bring brine to the surface.

Conclusions About Repository Pressures

1. It is reasonable to assume that void space in the repository could be present during the period of 100 to 500 years with low enough gas pressure to permit at least partial flooding by a brine reservoir.
2. It is reasonable to assume that sufficient gas pressure may exist in the repository from the period 100 to 600 years to bring some brine to the surface in the event the flooded repository is struck by a second borehole.
3. The probability that brine under sufficient pressure to reach the surface will exist in the repository becomes less likely as post-closure times increase past 600 years.
4. The limited "time window" in which the necessary pressures might exist, decreases the probability of such an event occurring at all and makes the occurrence of this scenario at 1000 years after closure highly improbable.

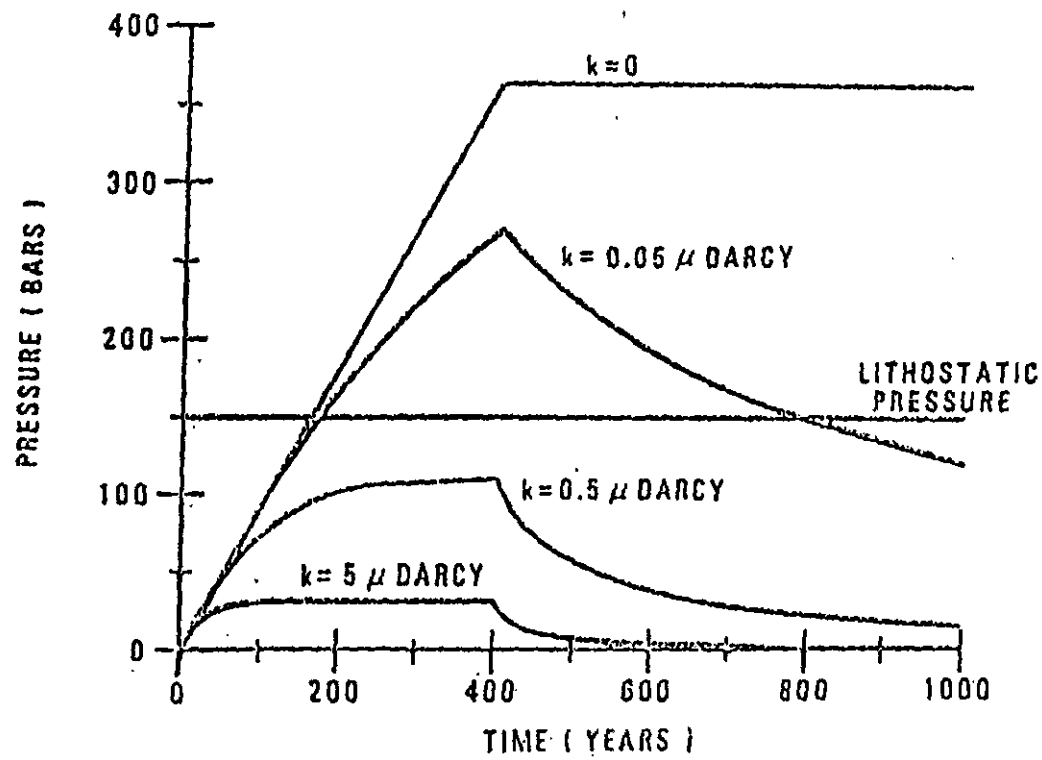

FIGURE A-1 ONE DIMENSIONAL DRIFT GAS PRESSURE FOR FOUR PERMEABILITIES

(Figure 3-13 from Reference 10)

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP, A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado

Formation, March 1984.

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (edi), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kenney, James W., A Critical Assessment of Continuous Air Monitoring Systems At The Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-12

EEG-12

NEW MEXICO
HEALTH AND ENVIRONMENT
DEPARTMENT

POTENTIAL RELEASE SCENARIO AND RADIOLOGICAL CONSEQUENCE EVALUATION OF MINERAL RESOURCES AT WIPP

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State of New Mexico

May 1982

Environmental Evaluation Group
Reports

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP, A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip, A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP

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May, 1982

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is minimal environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of available data concerning the proposed site, the design of the repository, its planned operation, and its long-term stability. These analyses include assessments of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U.S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.

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INTRODUCTION

In providing a technical evaluation of the potential radiation doses and health effects resulting from the nuclear waste repository (Waste Isolation Pilot Plant) being considered for southeastern New Mexico, the Environmental Evaluation Group attempts to consider all credible pathways of exposure of the population to the waste, including those events which might occur long after the repository is sealed, controls over the site are abandoned and records are lost. Some of these potential long-term breach events were considered by the U.S. Department of Energy in its Final Environmental Impact Statement and in other reports (Refs. 1, 2, and 3), and it was pointed out that these events might be associated with exploration or mining of the important resources located at the site. EEG evaluates the radiological health consequences of these and other scenarios which may reasonably be expected to lead to release of the waste to the biosphere. The DOE has considered the following long-term breach scenarios, all of which might arise as a result of exploration or mining of the resources at the site, or from certain natural geologic events:

Scenario 1: A hydraulic communication connects the Rustler aquifers above the repository, the Bell Canyon aquifer of the Delaware Mountain Group below the repository, and the repository.

Scenario 2: A hydraulic communication allows water to flow from the Rustler, through the repository, and back to the Rustler.

Scenario 3: A stagnant pool connects the Rustler aquifers with the repository. In contrast to scenarios 2 and 3, which involve flowing water, this communication permits radionuclide migration to the Rustler only by molecular diffusion.

Scenario 4: A hydraulic communication connects the Rustler aquifers with the repository; all the Rustler water normally moving above the repository flows through the repository and back to the Rustler. In contrast, scenarios 1 and 2 establish only a limited hydraulic connection.

Scenario 5: A drill shaft penetrates the repository and intercepts a radioactive waste container; the radioactive material is brought directly to the surface.

This report discusses the implications of the above scenarios which might arise as a result of exploration or mining of resources. The first four of the foregoing scenarios involve a liquid breach of the repository and transport of the dissolved waste through the Rustler aquifer, above the repository, to the Pecos River at Malaga Bend. Only Scenario 5 brings a fraction of the waste to the surface at the WIPP site. The DOE has concluded that scenario 5 provides a worst-case consideration of transport of the waste to the surface, and does not consider a breach of the repository from the mining of halite as credible.

EEG agrees that (1) the shortage of water and processing facilities for salt in the area, (2) impurities present in the salt of the Salado, and (3) vast amounts of salt available in other areas of the U. S. lead one to conclude that the salt at the WIPP site could not be economically extracted in the foreseeable future. However, EEG believes that significant climatic and social changes could make such mining more plausible. Therefore this report analyzes the potential radiological consequences of solution mining of halite 250 years after decommissioning. The report also discusses the reasons why solution mining of potash or drilling for natural gas are believed to be bounded by other scenarios considered by DOE in the Final Environmental Impact Statement (Ref. 2).

SUMMARY

This report has reviewed certain of the natural resources which may be found at the site of the nuclear waste repository being considered for southeastern New Mexico, and discussed the scenarios which have been used to estimate the radiological consequences from the mining of these resources several hundred years after the radioactive waste has been emplaced.

It has been concluded that the radiological consequences of the mining of potash or hydrocarbons (mostly natural gas) are probably bounded by the consequences of hydrologic breach scenarios already considered by the U. S. Department of Energy, (Ref. 2), and by reports of EEG (Refs. 4, 5). These studies conclude that the resultant doses would not constitute a significant threat to public health.

This report also evaluates the radiological consequences of solution mining of halite at the WIPP site. Although such mining in the Delaware Basin and particularly at the WIPP site, is not likely at the present time, significant economic, social or climatic changes a few hundred years after emplacement may make these resources more attractive. The DOE did not consider such mining at the site credible (Ref. 2, p. 9-145).

The fifty-year individual dose commitment from the ingestion of the average adult consumption of salt (contaminated with the radioactive waste from the repository) was 72 millirems for one year. This might be compared to an average lifetime dose from natural background radiation of 7500 millirem. Assuming that 0.2% of the radioactive inventory was mined and contaminated the salt during the solution mining event, and that about 2.5% of the total salt was consumed in food products, the total whole body dose to a population at risk of 300 million would be 0.9 million person-rems. This represents about 0.06% of the 50 year dose commitment from natural background. Although this population dose may not be considered insignificant, the small probability of such an event, and the very conservative assumptions used would lead one to conclude that the risk of such an event is small.

It is unlikely that the small doses resulting from this solution mining breach event would produce any detectable biological effects. It is possible that the long term consequences would be an increase in the normal incidence of cancer in the population, but such an increase would be within the range of statistical variation. Based on the recent conclusions of the National Academy of Sciences BIER Committee (Ref. 6, Table V-3) the total risk of such cancers would be about 0.32 fatal cancers per million population over the 50 years. This can be compared with the current incidence of 167,000 cancers per year per million population, or 8.35 million cancers over 50 years.

NATURE OF RESOURCES AT WIPP SITE

Mineral resources at the site include potash in the form of the potassium salts, sylvite and langbeinite; hydrocarbon resources, which, if present, may include crude oil, but mostly natural gas and distillate (liquid associated with natural gas). The potassium salts are found in strata 400 to 700 feet above the repository which is 1400 to 1700 feet below the surface; the hydrocarbons most likely would be found 8,000 to 12,000 feet below the repository which is 10,000 to 15,000 feet below the surface. Although other minerals such as salt, caliche, and gypsum are also in this area in quantity, there are enormous quantities in many other areas. Of these only halite is in close enough proximity to the repository to warrant considertion of a breach scenario. The size and economic value of potash, halite and hydrocarbons which may exist at the WIPP site are summarized below:

(a) Potash

Potash resources were estimated by the U.S. Geological Survey (USGS), the U.S. Bureau of Mines (USBM), and Agricultural and Industrial Minerals, Inc. (AIM) (Refs. 7, 8, and 9). In reference to potash, the terms "resources," and "reserves" as used here are defined as follows:

> Resources are considered minerals that are currently or potentially of economic value; this includes seams that are thicker than 4 feet and contain sylvite or langbeinite with a potassium oxide richness greater than 8% or 4% respectively.
>
> Reserves are the portion of the resources that are economically recoverable at today's market prices and removable with existing technology; this includes seams that are thicker than 4 feet and contain sylvite or langbeinite with potassium oxide richness greater than 13% or 9% respectively. The current estimates of resources and reserves under the four zones of the WIPP site are shown in Table 1.

TABLE 1

POTASH WITHIN WIPP SITE*

Deposit	Resources (million tons)	Reserves (million tons)	% of Resources recoverable in Zone IV	% of Reserves recoverable in Zone IV
Sylvite	133	27.4	71	100
Langbeinite	351	48.5	65	73

Since the surface value of mined potash ore at the present time is about $15/ton, the total surface value of the reserves is about $1.14 billion. The in-place value of the ore is much less, but more difficult to estimate. The U.S. Department of Energy has estimated in-place value of the potash ore as 14 cents per ton for sylvite and 5 cents per ton for langbeinite (Ref. 2, Table 9-16). The DOE has stated that mining in Zone IV of the WIPP site is possible without adverse impact on the proposed repository (Ref. 2, p. 9-118), and such recovery may be allowed before decommissioning. If this is the case, then 83% of the potash reserves (100% of 27.4 million tons of sylvite and 73% of 48.5 million tons of langbeinite) would be authorized for removal.

The Department of Energy has considered the impact of several mechanisms of liquid breach of the repository and transport of the radionuclides to the Pecos River at Malaga Bend (Refs. 1, 2, 3 and 10), or to a well in the Rustler, located about three miles downstream from the repository (Ref. 10). The EEG has independently calculated doses resulting from the transport of the radionuclides to Malaga Bend or to a well following a liquid breach and agrees that the doses would represent only a small fraction of the natural radiation background, even if very conservative (designed to increase severity) hydrologic parameters are assumed (Refs. 4, 5). Therefore, if the mining of potash leads to a liquid breach with transport of radionuclides to the Rustler at the WIPP site, the results would be bounded by the long-term scenarios

*This table is adapted from Table 9-19 of the FEIS (Ref. 2).

already considered. Because the potash ore is located at least 400 feet above the repository horizon, it is likely that the ore could be removed by conventional techniques without disturbing the repository; however EEG has requested that DOE provide a detailed plan and consequence evaluation if the decision is made to allow such removal.

Solution mining of the potash is not economical in the area because of the limitation of suitable water, absence of processing facilities and thinness of the ore beds. However, if water and facilities did become available, and solution mining were attempted, it is likely that the potash could be successfully solution-mined without breach of the repository during the operation. Nonetheless, such techniques near a nuclear repository might constitute a risk because the liquid-filled caverns may weaken the formations leading to breach after thousands of years, possibly resulting in transport of the radionuclides to one of the underground aquifers (Ref. 11).

To remove the potash ore by solutioning or brining techniques involves drilling two or more large diameter wells to the ore zone, establishing a circulation between the wells through hydrofracturing or hydrocarbon padding and recovering the dissolved brine. Because these ores are found in quantity considerably above the repository horizon, it is not plausible to believe that the hydrofracturing and brining would accidently extend 400 feet down into the repository horizon, unless some pathway already existed. The presence of horizontal clay seams in the salt would tend to move the hydrofractures up or horizontally along the clay seams, and current techniques permit shaping of the cavern to follow closely the ore horizon (Refs. 12, 13, 14, 15). If abandoned drill holes were present in the area and extended down into the repository, the effect of such a communication would be readily detected because of the retarding effect of such undesirable hydraulic communication on the solutioning of the potash ore. (The returning solution generally is monitored for potassium content.) For these reasons, a breach associated with potash mining resulting in transport of the radioactive material to the surface is not considered credible.

(b) Solution Mining of Halite and Consequence Analysis

Dickinson estimates that halite (sodium chloride) production in the U.S. for a variety of applications is over 40 million tons per year, valued at $300 million. Another 20% or more of salt is being imported from Canada, Mexico, and to a lesser extent, from other countries (Ref. 16).

There are extensive deposits of bedded halite in many areas of the Delaware Basin. The thickest and purest salt beds at the site are found in the Castile, although the Salado contains from 80 to 90% halite. The New Mexico Bureau of Mines and Mineral Resources has estimated that there are 118 billion tons of salt in the Salado within the WIPP boundary (Ref. 17). The Castile formation would add approximately 80 billion tons of additional salt resource. Along with gypsum and caliche, the halite deposit was not considered by the DOE to have any economic significance, because of the prevalence of salt deposits throughout the Permian Basin and other areas within the United States (Ref. 18). Because of the purity, domed salt usually is preferred to bedded salt. Approximately 56% of the halite produced in the United States is derived from the salt domes of Louisiana and Texas (Ref. 14). Within the Permian Basin, salt is being recovered by mechanical or solution-mining techniques at locations in Kansas, Texas and southwestern Oklahoma. No mining of halite has occurred in the Delaware Basin, and commercial mining is not considered economical in the WIPP area in the near future, because of the shortage of water, the remote location of the site from processing facilities and the presence of anhydrite and polyhalite beds intermingled with the bedded halite formations. It is conceivable, however, that in the long-term, climatic and social changes may render these deposits more attractive. For example, in the United States during the Pleistocene epoch, 1 to 2 million years ago, several lakes were formed or expanded during periods of increased precipitation, especially in the western United States in areas that are now deserts (Ref. 10, Sec. 2.3.4.1).The climate of New Mexico during such periods was characterized by more precipitation (about 60% more than at present), less evaporation (only about 70% of present) and a mean June - September temperature about 18°F lower than at present. Flooding was probably more frequent. Given greater access to water, there would be increased probability that industry supportive of solutioning techniques would

be available to the area. Therefore, although mining of halite at the WIPP site is considered highly unlikely, it is sufficiently plausible to warrant evaluation of the potential radiological consequences of a breach resulting from this activity.

This is considered in the following way. It is assumed that a commercial brining operation is initiated 250 years after decommissioning, directly over the 100 acres which house the abandoned repository. Initial exploratory and drilling operations fail to detect the repository, and two or more wells are drilled to produce hydraulic fracturing and to establish solutioning of salt. A cavern in the Salado is produced of approximately one million cubic feet, and the dissolved brine is routed to a nearby chemical processing plant for removal of the salt and recycling of the reconstituted unsaturated water. It is assumed that the radionuclides dissolve at the same rate as the salt, and that 0.2% of the 100 acre column of the Salado salt is removed by brining. Any more than this fraction might lead to some collapse of the overlying formations. It also would be reasonable to assume that detection of radioactive impurities occurred after 1 year. The scenario is illustrated by a typical cavern as shown in Figure 1. The radionuclide inventory at 250 years after storage is shown in Table 3.* Table 4 provides the resultant whole body dose from ingestion of the contaminated salt for a period of 1 year (1800 gms).

The 50-year individual dose commitment provided in Table 4 is considered conservative for at least two reasons: (1) It assumes the ingestion of 1800 gms of the unrefined salt extracted entirely from the solution mining breach event described. In other words, the salt is undiluted with other salt obtained from uncontaminated sites. (2) It neglects the potential reduction of plutonium contamination which is likely to occur as a result of adsorption to the clay constituents of the Salado, as follows:

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*This inventory is calculated from the initial inventories of TRU waste provided in Tables 3.1-2, and 3.1-4 of the SAR (Ref. 10).

To a rough approximation, the distribution of radioactivity between brine and suspended solids is given by

$$C_s = K_d \, C_\ell \qquad (1)$$

C_s = concentration per unit mass of a given nuclide sorbed on solids, Ci/gm

C_ℓ = concentration per unit volume in the liquid phase, Ci/mℓ

K_d = distribution coefficient, mℓ/gm

As the water dissolves the repository, conservation of activity also is maintained. This is expressed by the following equation

$$m_s \, C_s + C_\ell = A \qquad (2)$$

m_s = mass of solid in volume of repository suspended by a unit volume of H_2O (gm/ml)

A = activity in volume of repository dissolved or suspended by a unit volume of H_2O. C_s and C_ℓ are as previously defined. Combining equations (1) and (2) one obtains

$$C_\ell = \frac{A}{m_s \, K_d + 1} \qquad (3)$$

$$C_s = \frac{A \, K_d}{m_s \, K_d + 1}$$

Equation (3) can be interpreted as follows:

Of the activity, A, leached by a unit volume of water (assuming the saturated brine contains total dissolved solids of 0.4 gm/ml), a fraction

$$\frac{1}{m_s \, K_d + 1}$$

remains in the water and a fraction

$$\frac{m_s \, K_d}{(m_s \, K_d + 1)}$$

is resorbed on the suspended clay freed by the brining of the water. If 5% of the Salado is material other than salt, and 1% of this material is clay for which K_d for Plutonium can range from 40,000 to 180,000 mℓ/gm (Ref. 10, Table 2.5-12); then m_s is 2×10^{-4} gm/mℓ and between 90 to 97 percent of the Plutonium is resorbed on the clay. The clay in the Salado is thus an effective barrier against bringing plutonium to the biosphere.

An important question that must be resolved is what fraction of the insoluble material is brought to the surface as suspended particulates and what fraction remains in the subsurface cavity.

In summary, therefore, the 72 millirem individual fifty-year dose commitment might be compared with normal background radiation of about 100 millirem each year, or a lifetime dose of about 7,500 millirem. The total population dose may be conservatively estimated by assuming that each member of a population of 300 million consumes 1800 gms of salt per year. It also is assumed that 1/24 of this salt for food is derived from this solution mining event. (If the annual production in the nation is 48 million tons, only about 1/50 of a year's production is consumed as food.)

Based on one year's production of the contaminated salt, the total population 50-year dose commitment would be 0.9 million person-rems. This might be compared to a background 50-year dose commitment of about 1.5 billion person-rems. Therefore, there would result from this breach event a 0.06% increase over background.

It might be of interest to compare these results to those obtained from a halite solution mining scenario involving a salt dome (Ref. 19). That scenario assumed a breach 1000 years after emplacement and a total of 2.6 million tons mined from nine wells over a period of one year. It was assumed that three percent of this salt was consumed as food (1800 gms/individual). The resulting 70-year whole-body dose commitment, for spent fuel nuclear waste, was 390 millirems, and for reprocessed high-level waste the dose was 100 millirems. This was converted into a 70-year total population dose commitment of 16 million person-rems from spent fuel, or four million person-rems from reprocessed waste.

It is unrealistic to assume a production rate at the WIPP site in excess of one million tons/year, because of the water limitations in the area - even if much more favorable climatic conditions occurred. Assuming an average flow of the Pecos of 2000 liters/second, the fresh water required for mining of one million tons/year is about equal to four percent of the total annual Pecos flow.

If solution mining of halite should occur in the WIPP site area at some time after termination of controls, it is likely that the scenario considered in this report provides the upper limit of dose consequences from solution mining at WIPP for the following reasons:

1. Most of the transuranic nuclides would probably be bound to the clay impurities in the salt formation and would not be contained in the processed and purified salt.
2. The limitation of fresh water in the area, even under conditions of favorable climatic change, is likely to discourage solution mining of salt because of the large reserves in other areas more accessible to water.
3. Because the salt is located at considerable depth, solution mining would require high technology to achieve economic return, and such technology would be expected to include the ability to recognize and remove radioactive impurities, if present.

Health Effects of Radiation Consequences

It is unlikely that any adverse health effects would occur from small doses resulting from the present scenario. If the 900,000 person-rems are assumed to be uniformly spread over the population of 300 million. The average 50 year dose would be only 3 millirems. Such doses are far too low to produce detectable effects. Using the data provided in the most recent report of the National Academy of Sciences BIER Committee (Ref. 6, Table V-3) and using a linear extrapolation from dose-effect curves provided by high doses, there would be about 96 fatal cancers resulting from this population dose over the 50 years, or 0.32 per million population. These values should be compared to the current cancer risk of 167,000 per million population per year, or 8.35 million cancers over 50 years.

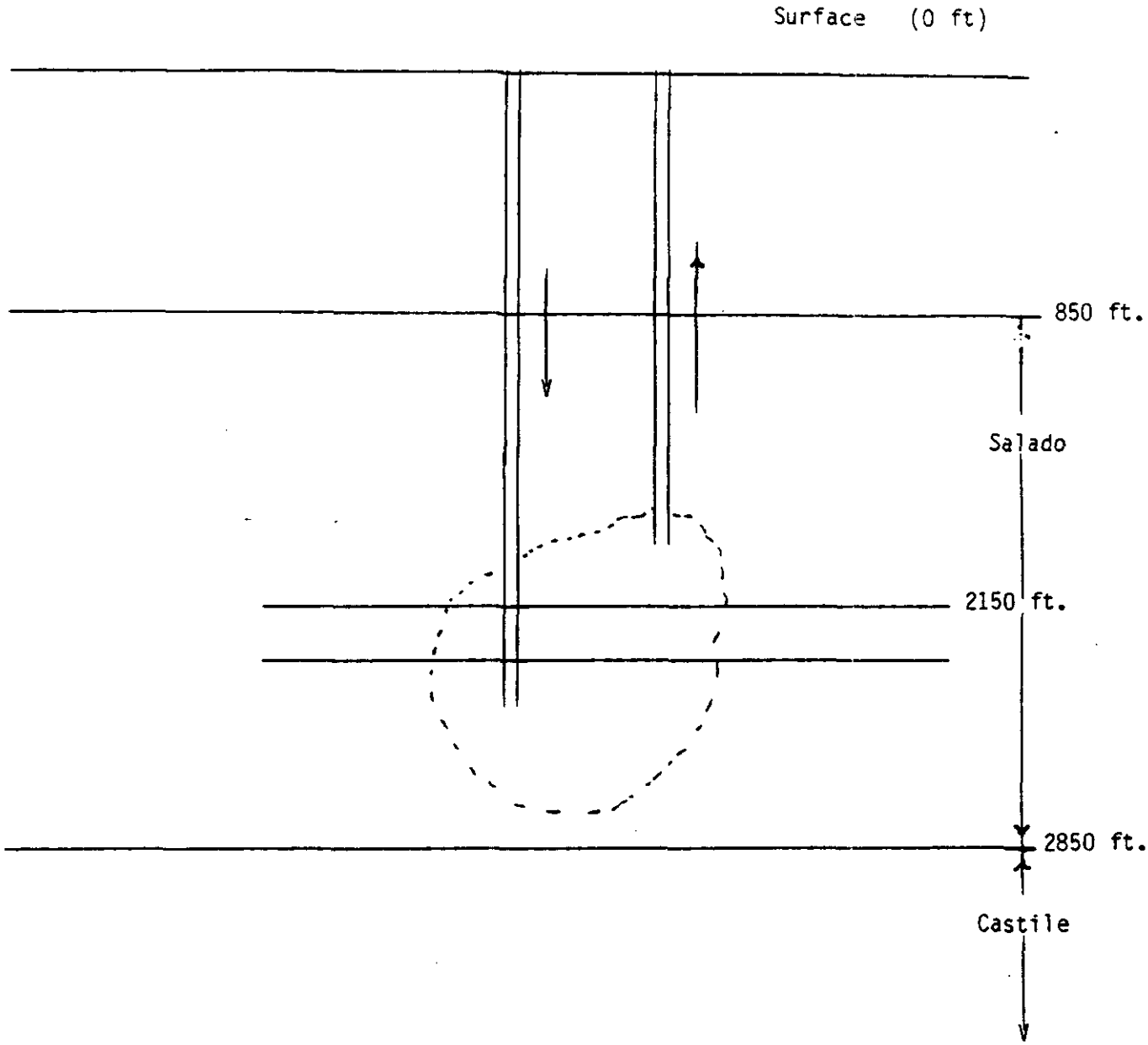

Figure 1. Breach of repository from solution mining of halite.

TABLE 2

PARAMETERS FOR SOLUTION MINING (BRINING)
OF HALITE SCENARIO

1. Area of Repository Site: 100 acres
2. Thickness of Salado Salt at Site: 2000 ft. (600 m)
3. Volume of Salt ore under 100 acres of the Salado at site: 8.7×10^9 ft^3 (2.5×10^{11} ℓ)
4. Volume of CH waste: 1.7×10^8 liters
5. Volume of RH waste: 7.1×10^6 liters
6. Volume of repository: 5.2×10^7 ft^3 (1.5×10^9 ℓ)
7. Fraction of salt which is repository: 6×10^{-3}
8. Fraction of repository which is CH waste: .113
9. Fraction of repository which is RH waste: .0047
10. Production rate: or 1×10^6 metric tons of solid salt/year (1.6×10^7 ft^3)
11. Fraction of total Salado at WIPP site removed by brining in 1 year: 0.002
12. Volume of salt in the Salado under entire area of WIPP site (Zones 1, 2, 3, 4): 4.6×10^{13}ℓ (1.6×10^{12} ft^3)
13. Density of recovered and dried salt: 2.2 gm/ml
14. Annual Adult Consumption of salt: 1800 gms
15. Total population at risk: 300 million

TABLE 3

NUCLIDE INVENTORIES OF TRU WASTE AT 250 YEARS

Nuclide A	CH TRU (Ci/ℓ) B*	CH TRU Total (Ci) C*	RH TRU Ci/ℓ D*	RH TRU Total (Ci) E*	Final Total (Ci) F*
Pu-238	2.9 - 5**	4.9 + 3	1.2 - 5	8.5 + 1	5.0 + 3
Pu-239	2.2 - 3	3.7 + 5	1.1 - 3	7.8 + 3	3.8 + 5
Pu-240	5.2 - 4	8.8 + 4	2.4 - 4	1.7 + 3	9.0 + 4
Am-241	3.3 - 4	5.6 + 4	2.0 - 4	1.4 + 3	5.7 + 4
Sr^{90} + d			1.4 - 3	1.0 + 4	1.0 + 4
Cs^{137} + d			1.1 - 5	80.	80.
				Total	5.4 + 5

*Explanation of columns:

B = Average inventories from SAR at 250 years

C = (B) (1.7×10^8 liters)

D = Average inventories from SAR at 250 years

E = (D) (7.1×10^6 liters)

F = C + E

**2.9 - 5 = 2.9×10^{-5}

TABLE 4

FIFTY-YEAR DOSE COMMITMENT FROM ONE YEAR'S INGESTION OF SALT

Nuclide G	Concentration PCi/gm of salt H*	Dose (50 yr.) Commitment (mrem per Pci) I*	Whole Body Dose/ (mrem) J*
Pu-238	8.9	1.7 - 5	.27
Pu-239	7.0 + 2	1.9 - 5	24.0
Pu-240	1.7 - 2	1.9 - 5	5.8
Am-241	1.0 + 2	5.4 - 5	10
Sr^{90} + d***	1.9 + 1	9.3 - 4	32.
Cs^{137} + d	1.4 - 1	3.6 - 5	.009
		Total:	72

*Explanation of columns:

$$H = \frac{(F)\ (10^{12})\text{pCi/Ci liter}}{2.5 \times 10^{11}\ \text{liters} \times 2200\ \text{gm}}$$

I = NUREG 0172 dose conversion factors (Ref. 20)

J = (H) (I) (1800)

**7.0 + 2 = 7.0×10^2

***d = including daughters

(c) Hydrocarbons

The New Mexico Bureau of Mines and Mineral Resources (BMMR) evaluated the hydrocarbon resources at the earlier WIPP site, about five miles northeast of the current site (Ref. 17). This evaluation was based upon known reserves of crude oil and natural gas, and on the probability of discovering new reservoirs. The estimate of natural gas was 16.5 billion cubic feet per 640 acres, which amounts to a total of 490 billion cubic feet for the present site. Since the hydrocarbon estimate relies on statistical probabilities, this value would not be as accurate as the potash values. This volume also assumes that the quantity of hydrocarbon resources at the current WIPP site are about the same as at the old site, five miles away. A later evaluation of hydrocarbon resources of the present site was made by Sipes, Williamson and Aycock, Inc. (Ref. 21), in which they relied on information gained from nearby exploration. To protect the site no hydrocarbon drilling has occurred in Zones I, II, and III of WIPP. The area evaluated was 400 square miles centered on the present site. They concluded that a single zone, between 14,000 and 15,000 feet below the surface is worthy of exploratory risk, based on current economic considerations. Only natural gas is estimated to be present in quantities that are economical. The potential resources and reserves of natural gas are summarized in Table 5.

TABLE 5

POTENTIAL NATURAL GAS WITHIN WIPP SITE

	Total BCF*	In Zones I, II III BCF*	In Zone IV BCF*
Resources 100%	490 (100%)	211 (43%)	279 (57%)
Reserves	44.6	21 (47%)	23.6 (53%)

*BCF = billion cubic feet

At a value of $4.40/1000 cubic feet, the total surface value of the natural gas reserves is about $200 million.

Sipes, Williamson, and Aycock, Inc. have also evaluated the extra cost of extracting the natural gas through directional drilling. If drilling is allowed in Zone IV, 23 directional boreholes from the boundary of Zone III would be necessary to extract the natural gas from Zone I, II, and III (Ref. 22).

The DOE has considered the radiological consequences of drilling for hydrocarbons and drilling directly through a canister containing either contact-handled or remote-handled TRU waste (Ref. 2, p.9-143). Since the hydrocarbons, if present, are located 8,000 to 12,000 feet below the repository, a breach of the repository as a result of extraction of these resources would be bounded by either the liquid breach or direct drilling scenarios already considered in the FEIS.

REFERENCES

1. U. S. Department of Energy. Draft Environmental Impact Statement, Waste Isolation Pilot Plant, 2 vols. (DOE/EIS-0026-D), 1979.

2. U. S. Department of Energy. Final Environmental Impact Statement, Waste Isolation Pilot Plant, 2 vols. (DOE/EIS-0026), 1980.

3. D'Appolonia Consulting Engineers, Inc. Modeling Verification Studies, Long-Term Waste Isolation Assessment, Waste Isolation Pilot Plant WIPP Project, Southeastern New Mexico, (Westinghouse Electric Corp. Project No. NM 78-648-701, 1981.

4. Wofsy, Carla. The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses From WIPP, (EEG-8), 1980.

5. Spiegler, P. An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach (EEG-9), September 1981.

6. Committee on The Biological Effects of Ionizing Radiation National Academy of Sciences, The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, July, 1980.

7. John, C. B., et al. Potash Ore Reserves in the Proposed Waste Isolation Pilot Plant Area, Eddy County, Southeastern New Mexico (U.S. Geological Survey File Report 78-828). 1978.

8. U. S. Bureau of Mines. Valuation of Potash Occurrences Within the Waste Isolation Pilot Plant Site in Southeastern New Mexico (ALO-18), 1977.

9. Agricultural and Industrial Minerals, Inc. Resource Study for the Waste Isolation Pilot Plant Site, Eddy County, New Mexico, San Carlos, California.

10. U. S. Department of Energy. Waste Isolation Pilot Plant Safety Analysis Report, 5 vol., 1980.

11. Ege, J.R. Surface Subsidence Related to Solution Extraction of Salt, Presented at meeting of Solution Mining Research Institute, Albuquerque, N.M., April 18-20, 1982.

12. Davis, J. G. and Shock, D. A. "Solution Mining of Thin Bedded Potash, "Mining Engineering, (July 1970), pp. 106-109.

13. Shock, D. A. "Use of Hydraulic Fracturing to Make a Horizontal Storage Cavity in Salt,", pp. 406-411, 1969.

14. Griswold, G. B. Solution Mining in Salt Domes of the Gulf Coast Embayment, (PNL-3190), 1981.

15. Ozsahim, S. and Husband, H.W. "Some Engineering Aspects of Solution Mining of Potash in Saskatchewan," Canadian Mining Journal, v. 88 (1967), pp. 45-48.

16. Dickinson, W. E. "The Salt Industry to 1980," Fourth Symposium on Salt, v. 1 (1974), p. 7.

17. Foster, R. W. Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste, (Oak Ridge National Laboratory Contract No. AF (40-1)-4423), 1974.

18. Powers, D. W., et al. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, 2 vols. (SAND 78-1596), 1978.

19. U. S. Department of Energy, Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste, DOE/EIS-0046F, October, 1980.

20. Battelle Pacific Northwest Laboratories for U.S. Nuclear Regulatory Commission, Age-Specific Radiation Dose Commitment Factors for a one-year chronic Intake, NUREG 0172, November 1977.

21. Sipes, Williamson & Aycock, Inc. Hydrocarbon Evaluation, Proposed Southeastern New Mexico, 2 vols. (SAND 77-7033), 1976.

22. Sipes, Williamson & Associates. Evaluation of Directional Drilling for Oil and Gas Reserves Underlying the Waste Isolation Pilot Plant Site Area, Eddy County, New Mexico, 1979.

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado

Formation, March 1984.

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (edi), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kenney, James W., A Critical Assessment of Continuous Air Monitoring Systems At The Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

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REPORT NUMBER EEG-22

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EEG-22

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HEALTH AND ENVIRONMENT
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EEG REVIEW COMMENTS ON THE GEOTECHNICAL REPORTS PROVIDED BY DOE TO EEG UNDER THE STIPULATED AGREEMENT THROUGH MARCH 1, 1983

Environmental Evaluation Group
Environmental Improvement Division
Health and Environment Department
State of New Mexico

April 1983

Environmental Evaluation Group
Reports

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP, A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip, A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983

Environmental Evaluation Group
Environmental Improvement Division
Health and Environment Department
P.O. Box 968
Santa Fe, New Mexico

April 1983

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is minimal environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of available data concerning the proposed site, the design of the repository, its planned operation, and its long-term stability. These analyses include assessments of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U.S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.

Robert H. Neill

Robert H. Neill
Director

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([1]) Certified, American Board of Health Physics
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INTRODUCTION

As part of the Stipulated Agreement signed on July 1, 1981 between the Department of Energy (DOE) and the State of New Mexico, the DOE agreed to provide the following reports to the State of New Mexico to help in the State's evaluation of the suitability of the WIPP site.

- Deep Dissolution
- Disturbed Zone
- Breccia Pipes
- DMG Hydrology
- Regional Hydrology
- Natural Resources
- Results of SPDV Site Validation Experiments
- Plans for SPDV Design Validation
- Results of SPDV Design Validation Experiments
- Plans for Simulated Wastes Experiments
- Brine Reservoir Report
- Horizontal Exploration of the Disturbed Zone
- Fracture Flow in the Rustler Aquifers
- Study of Aquifer Characteristics

The Environmental Evaluation Group had received the following reports in draft form by March 1, 1983:

- Deep Dissolution
- Breccia Pipes
- DMG Hydrology
- Natural Resources
- Plans for SPDV Design Validation
- Plans for Simulated Waste
- Brine Reservoir Report
- Disturbed Zone Exploration
- Fracture Flow in the Rustler Aquifers

This publication is a compilation of the written comments on each of these reports provided by EEG to DOE. Where DOE responded to EEG comments in writing,

they are included here. On others, meetings were held between the appropriate EEG staff and the author(s) of the reports and the authors agreed to make changes in the final version of the reports, based on EEG comments. Only in the case of Breccia Pipe report prepared by the U.S. Geological Survey for DOE, no changes were made in the final version of the report.

EEG's conclusions on each of these issues will be provided in a forthcoming EEG report to be published in May, 1983.

NATURAL RESOURCES

TME-3156

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

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Dr. George S. Goldstein
Chairman
Governor's Task Force on WIPP
P. O. Box 968
Santa Fe, NM 87503

Dear Dr. Goldstein:

Interim Policy Statement on Resource Recovery at the WIPP Site

Enclosed for your information is the Department of Energy's Interim Policy Statement on Resource Recovery at the Waste Isolation Pilot Plant (WIPP) Site. The interim policy will be used as the basis for the performance of dose consequence analyses related to resource recovery at the site as required by Item 6 of Appendix "B" of the Stipulated Agreement. This interim policy may be amended based upon the results of the analyses currently being performed and expected to be available in December, 1981.

Should you have any questions, please contact us.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 81-5046

Enclosure

cc w/enclosure:
See Page 2

INTERIM POLICY STATEMENT

By

U.S. Department of Energy

Resource Recovery at the Waste Isolation Pilot Plant Site

The primary concern of the U.S. Department of Energy (DOE) in the development of the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico is both the short and long-term protection of public health and safety. As a major element of this policy, the DOE has delineated buffer zones around the WIPP Site in which resource recovery will be strictly controlled or prohibited (Figure 1). The incorporation of multiple buffer zones in the present design is a conservative approach to maintaining the integrity of the site and ensuring that emplaced wastes remain isolated from the environment. The DOE recognizes, however, that the state of New Mexico relies upon the royalties generated from resource recovery as a significant source of revenue and that other adverse economic and social impact may result if access to the resources at the WIPP Site is permanently denied.

Accordingly, the DOE is issuing this Interim Policy Statement on resource recovery at the WIPP Site to clarify its present position relative to those resource extraction activities that the DOE believes may eventually be allowable within various portions of the WIPP Site. This interim position is based on the previously conducted long-term waste isolation assessment that utilized all available site geologic, hydrologic, and other pertinent data.

It is the policy of the DOE to maximize the opportunity for resource recovery at the WIPP Site, consistent with the requirements to isolate the emplaced radioactive wastes from the biosphere. The interim policy is temporary denial of all resource extraction within the four control zones of the WIPP Site until the decision is made relative to which, if any, of the emplaced waste will be retrieved. Within five years after the first emplacement of each type of waste (i.e., contact and remotely handled), separate decisions will be made about the retrieval of each kind of waste. Should DOE decide that all waste is to be retrieved, the site will be available for complete resource recovery. As an additional part of the interim policy, the DOE is currently undertaking analyses to identify the potential for possible radiation dose consequences of resource development within Control Zone IV of the WIPP Site. The interim and final Statements of Policy will be revised to include additional detail if the results of these studies indicate that the allowable extraction activities could cause an unacceptable hazard to the public health and safety.

The criteria for the final DOE policy is that permanent denial of resources should be limited to those areas in which extraction activities could potentially lead to radiation dose consequences or which are necessary to satisfy institutional requirements; with the exception of those areas required by insitutional considerations, all extraction activities that would not lead to unacceptable effects with the waste permanently emplaced will be defined as "allowable" under the anticipated final DOE policy. From a radiation dose consequence point of view, the timing of resource extraction activities is not critical; the radioactive wastes decay very slowly so that

minor differences in waste age do not affect the potential radiation dose consequences of exposure.

Potash (i.e., sylvite and langbeinite) and hydrocarbons (i.e., natural gas and distillate) comprise the resources present at the WIPP Site that are of interest, considering the technology and market conditions in the foreseeable future. These resources and the methods available to recover them are described in detail in the WIPP Final Environmental Impact Statement (Sections 7.3.7, 9.2.3, and 9.6.5).

The DOE anticipates that extraction of potash within Control Zone IV will be "allowable" if traditional underground mining methods are employed. Traditional methods include drill-and-blast, continuous mining, shortwall, and longwall techniques. If mining of potash is allowed, it is not reasonable to prohibit those mining techniques that make such an activity economically viable. To limit potash ore extraction ratios to low values is, in effect, to preclude such mining. Accordingly, it is anticipated that extraction ratios can be maximized in any mines developed within Control Zone IV of the WIPP Site consistent with mine safety considerations and other state and federal requirements. Solution mining is not now and will not be "allowable" within the limits of the WIPP Site. This restriction does not affect langbeinite recovery because langbeinite is less soluble than the surrounding minerals (i.e., halite, sylvite) so that solution mining for this material would be ineffective. The lack of existing solution mining for sylvite in the Carlsbad potash district confirms that this restriction does not place a significant economic hardship on the producers or significantly affect state revenues.

The DOE anticipates that recovery of hydrocarbon resources from Control Zone IV will be "allowable" following a final decision on waste retrival. This activity includes drilling, production stimulation, and, possibly, secondary recovery. Resources located beneath Zone IV may be accessed by vertical drilling; resources located beneath the inner three control zones may be accessed by drilling vertically in Zone IV to a depth of 6,000 feet and then deviating from vertical at the angle required to reach the target resource zone. It is not realistic to allow drilling for hydrocarbon resources and, if oil or gas is found, to prohibit those techniques available to the producer that maximize recovery. It is the anticipated postion of the DOE that analyses will confirm the acceptability of enhancing production from drilled wells by hydraulically fracturing the reservoir rock, acidizing the formation, or other applicable techniques. These types of production stimulation are used primarily to increase the permeability of the rock that contains the hydrocarbons. Secondary recovery methods (i.e., techniques used to enhance or replace the natural driving force that "pushes" the oil to the production well) may also be employed, but because the resources present are primarily natural gas and not oil, such techniques are not expected to be useful.

DOE intends to amend the present interim policy following completion of the impact analyses. This amendment will expand upon the present policy by identifying the extent to which resource recovery is anticipated to be "allowable"

if radioactive waste is permanently emplaced. The amendment will not affect the interim policy that no resource recovery will be allowed until all retrieval decisions are made.

The final DOE policy on resource recovery will be based upon the interim policy, institutional requirements in effect at that time, and data obtained during development and operation of the facility.

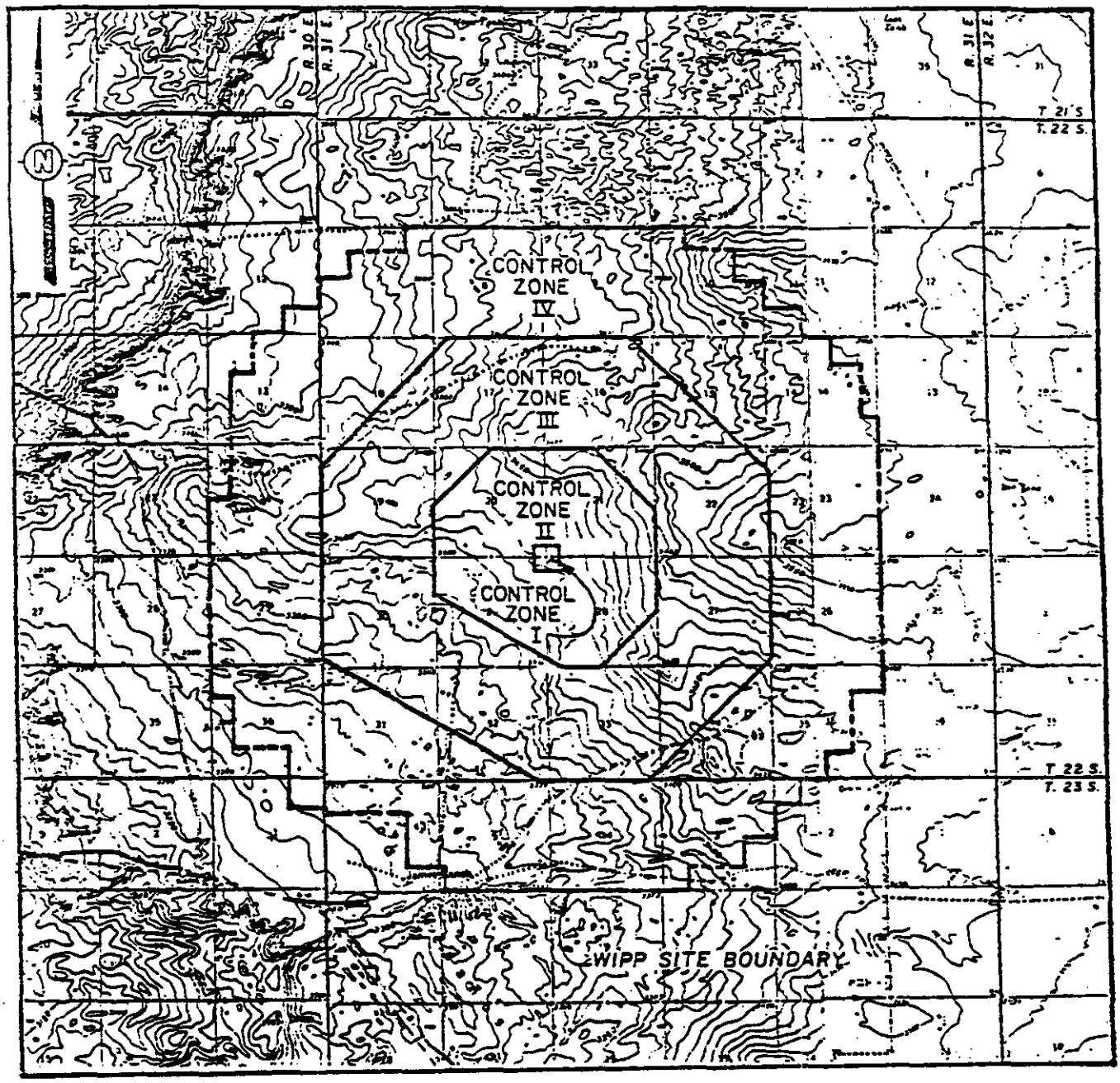

REFERENCE:

USGS 15 MINUTE TOPOGRAPHIC QUADRANGLES: NASH DRAW, NEW MEXICO (1965) AND HAT MESA, NEW MEXICO (1972). SCALE 1:62,500.

FIGURE 1

WIPP SITE CONTROL ZONES

2-19-1-1 6

STATE OF NEW MEXICO
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SANTA FE
87503

BRUCE KING
GOVERNOR

GEORGE S. GOLDSTEIN, PH.D.
SECRETARY FOR HEALTH & ENVIRONMENT

November 17, 1981

Mr. D. T. Schueler
Assistant Manager for Project
and Energy Programs
U. S. Department of Energy-ALO
P. O. Box 5400
Albuquerque, NM 87115

Dear Mr. Schueler:

This is in response to Mr. Joseph McGough's November 3, 1981 letter containing DOE's Interim Policy Statement on Resource Recovery at the WIPP Site to be used as the basis of dose consequence analyses as required by item 6 of Appendix B of the Stipulated Agreement.

The State is very interested in this Interim Policy as well as with other land withdrawal and land use aspects at the WIPP site. Since we believe that a resource recovery policy should only be adopted after a thorough consequence analysis, we will not comment in detail on your Interim Policy until we have had the opportunity to review your analysis scheduled for release in December, 1981. We have the following observations on the Interim Policy:

1. The policy statement implies that Zone IV will be withdrawn and under the control of DOE. It is our understanding that at the present time the Department of the Interior is not transferring Zone IV to DOE but only Zones I - III. The question of who will have control over activities in Zone IV needs to be answered.

2. The statement is silent on what resource recovery may be permitted in Zones I, II, and III and implies that the current analyses will not consider this. From a radiological health standpoint, resource recovery activity in these zones is more important than in Zone IV and should be evaluated in detail. At some date in the future, DOE will relinquish administrative control over Zones I-III and the consequences of resource recovery should be published.

3. The policy states that resource recovery will be controlled or prohibited in the buffer zones. How long a period is DOE using for planning purposes?

4. The statement that secondary recovery of hydrocarbons may be permitted in Zone IV is more permissive than the statement on page 9-27 of the FEIS: "Hydrocarbon exploration in control Zone IV would be permitted by DOE, but no

water flood recovery methods or extensive hydrofracture stimulation would be allowed."

5. The terms "unacceptable hazard" and "unacceptable effects" need to be defined. Is it based on exceeding a predetermined limit of exposure or on the presence of radiation effects in people?

Thank you for sending the Interim Policy Statement. While we look forward to the receipt of your analyses next month, we would appreciate your comments at this time.

Sincerely,

George S. Goldstein, Ph.D.
Secretary

GSG:teb

cc: Joseph M. McGough, Project Manager on WIPP, DOE
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Albuquerque Operations Office
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DEC 29 1981

Dr. George S. Goldstein
Secretary
Health and Environmental Department
P.O. Box 968
Santa Fe, NM 87503

Dear Dr. Goldstein:

Interim Policy Statement on Resource Recovery at the WIPP Site

This is in response to your November 17, 1981 letter providing observations on and requesting clarification of some of the points made by the subject document.

We are in complete agreement that a resource recovery policy should be adopted only after a thorough consequence analysis has been performed. The Interim Policy was not, and is not intended as, a DOE position on resource recovery that would allow resource extraction companies to begin planning for future mineral recovery at the WIPP Site. Instead, the Interim Policy provides a basis from which pertinent breach scenarios can be developed and analyzed; it will be modified before publication as a final Interim Policy, if necessary, to reflect the results of consequence studies presently underway.

Specific issues raised in your recent letter are addressed below:

1. At present, we have pending, an application for temporary withdrawal of lands in Zones I, II and III. This application was filed so that land could be withdrawn, thus, protected for the duration of the Site and Preliminary Design Validation (SPDV) Program. Zone IV is not included in this application but will be protected from some nonDOE activities (e.g., deep drilling) by a Cooperative Agreement between DOE and DOI. We have also filed a permanent land withdrawal application with the intent of obtaining DOE administrative control over the lands within all four zones of the WIPP Site.

2. Allowing resource recovery from Zones I, II and III is not currently planned and consequently was not addressed in the Interim Policy. The report, presently in preparation, discussing the effects of resource extraction activities in Zone IV will not provide analyses of short-term consequences of extraction activities in the other zones. The report will, however, address indirectly the potential long-term consequences of resource extraction at any location within the Zone IV boundary. No discussion of potential short-term consequences of extraction in Zones I, II and III was felt necessary because it is unlikely that DOE will allow such activities while it retains administrative control over the lands.

If DOE does desire, in the future, to allow some types of resource extraction in Zones I, II and III, the potential consequences will be evaluated prior to a final decision on whether to allow or disallow specific activities at the site. In any case, denial of resource extraction from Zones I, II and III would cause only a small percentage of the natural resources at the site to be lost. As reported in the FEIS, more than half the hydrocarbon resources and more than two-thirds of potash resources are located in Zone IV. Additionally, it is believed that deviated drilling from Zone IV would allow extraction of all hydrocarbon resources at the WIPP Site.

3. DOE plans to maintain its resource recovery policy at the WIPP Site for the duration of its administrative control over the site lands. In the FEIS, it was assumed to be reasonable that administrative control would exist for a minimum of 100 years.

4. At the time of publication of the FEIS, studies necessary to evaluate the effects of primary production stimulation and secondary recovery of hydrocarbons had not been conducted. Thus, to maintain the consistently conservative posture of the WIPP Project, DOE elected to preclude these hydrocarbon recovery methods until further study could be undertaken. As noted in the second paragraph of this letter, the Interim Policy was intended to provide direction relative to the types of breach scenarios that should be considered and analyzed. In development of the statement, it was felt unreasonable to allow an extraction company to complete an exploration well (at great cost) and to then not allow the operator to perform whatever techniques he deemed useful to regain his investment. Thus, it was felt essential that the potential consequences of all types of production enhancement be evaluated before general distribution of a policy on resource extraction.

5. Presently, the potential dose consequences of resource extraction at the WIPP Site are deemed unacceptable if the potential hazards to public health and safety exceed those of the breach events considered in the FEIS and SAR.

We are currently on schedule in the preparation of the report on the potential consequences of resource recovery at the WIPP Site and plan to submit a draft to the State in December. If you have further questions or comments on this matter, please contact me.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 81-5135/5190

cc:
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STATE OF NEW MEXICO

ENVIRONMENT department

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February 23, 1982

Mr. Joseph McGough
Project Manager on WIPP
WIPP Project Office
U. S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, NM 87115

Dear Mr. McGough:-

The Environmental Evaluation Group has reviewed D'Appolonia's Draft Report, "Natural Resources Study" which you transmitted to us on January 29, 1982. There is attached a summary of our comments. We would appreciate your response to these comments and will be pleased to discuss them if you have any questions.

Sincerely,

Robert H. Neill
Director

RHN:MSL:lgr

cc: George S. Goldstein, Ph.D., Secretary, Health & Environment Department
Larry Kehoe, Secretary, Energy and Minerals Department
Joe Hewett, Secretary, Highway Department
Thomas E. Baca, Director, Environmental Improvement Division
Joe Canepa, Attorney at Law
Wendell Weart, Manager, Sandia Laboratories
Chuck Little, Westinghouse Electric Corporation
TSC, IEA

REVIEW COMMENTS

CONCERNING

Draft Report on Natural Resources Study.

Waste Isolation Pilot Plat (WIPP) Project

Southeastern New Mexico

Comments by

Environmental Evaluation Group

Environmental Improvement Division

Health and Environment Department

P. O. box 968

Santa Fe, New Mexico

87503

February 22, 1982

General Comments

1. The report fails to comprehensively address the question of new exploration. Neither the DOE Interim Policy statement (Section 1.4) nor the balance of the report indicate that any restrictions will be imposed on new exploration for natural resources, only extraction. Since certain exploratory techniques may seriously affect the integrity of the repository, the Interim Policy Statement should impose restrictions similar to those for removal.

2. It is recognized that the construction of solution cavities for storage of hydrocarbons does not constitute exploration or mining for natural resources; however, it is an extraction technology; it is very relevant to gas and oil resources; it is becoming an increasingly popular practice; and it has not previously been examined by DOE. Therefore, EEG recommends that it be included and the impact analyzed in the Final Policy Statement and Report on Natural Resouces.

3. It is noted that this report addresses the extraction in Zone IV only, which is consistent with the present Interim Policy. It should be noted that if at some future date, DOE proposes to modify that Policy to allow extractions from Zones II or III, it would be necessary to make a new analysis of the impact of such change.

Specific Comments

1. Section 1.4, DOE Interim, Policy Statement -- In a letter dated November 17, 1981, Dr. George Goldstein, Secretary for Health and Environment of New

Mexico, submitted several comments with respect to the DOE Interim Policy Statement. Although a letter from J. M. McGough of the DOE Albuquerque Operations Office responded to Dr. Goldstein's comments, the Interim Policy Statement was not modified and the report failed to either clarify or amend the ambiguous passages of the Policy Statement. For example, the phrases "unacceptable effects" (p. 1-6) and "allowable effects" (p. 1-8) remain undefined. EEG recommends that the statement be revised to reflect Dr. Goldstein's previous comments and the comments contained herein.

2. Section 2.1.1. Page 2-2, second paragraph -- The report is inconsistent in statements about the depth at which potash may be found. This section states that it is not within 400 feet of the repository horizon. Table 1 indicates langbeinite as low as 1800 feet (350 feet above the repository horizon). However, Table 5 indicates depths as low as 2300 feet (150 feet below the horizon). It would be helpful if the report indicated where the potash mines listed in Table 5 are located, and what are the actual depths to potash within the site.

3. Section 3.1.1.1, Page 3-1, last paragraph -- It is emphasized that empirical data for the pressure arch theory is based on coal mining experience. The appropriateness and applicability for mines in salt needs to be addressed.

4. Section 3.1.1.2, Page 3-3, last paragraph -- The author should also include data from studies performed by Sandia using elaborate rock mechanics codes, as contained in the following reference:

Morgan, H. S., Krieg, R. D., Matalucci, R. V., "Comparative Analyses of Nine Structural Codes Used in the Second WIPP Benchmark Problem," Sand-81-1839, Sandia National Laboratories, Albuquerque, N.M.

5. Section 3.1.1.2, Page 3-5, first line -- This sentence assumes that the stress-relaxation process which occurs prior to establishing steady-state conditions, cannot be studied. This assumption seems to be incorrect since the problem of transient creep is treated in great detail in report ECN-89. (See reference provided in comment 4 above.) The report also contains a program for the HP-41C pocket calculator.

6. Section 3.1.1.2, Page 3-5 3rd paragraph -- This paragraph addresses the zone of influence of a potential potash mine when superimposed by the influence of the WIPP repository and concludes that a separation of 2,100 feet assures that interaction will not occur. This conclusion seems to be based on the assumption that the existing rock between the WIPP and the potential potash mine is reasonably stable. However, in Zone III, north of the repository, there is a zone of "anomalous seismic reflection" where the structure is presently unknown. Also the presence of brine at WIPP-12 suggests that fracturing within the Castile may be extensive. Further information is needed on this anomalous zone before it can be concluded that 2,100 feet is sufficient.

7. Section 3.1.1.2, Page 3-5, 3rd paragraph -- The conclusion that the effects of mining the WIPP repository will only extend to 200 feet beyond the perimeter of the repository, the effect of a single panel, is not convincing. A potash mining activity approaching the WIPP repository from the north faces

a 2560' x 33' room running east-west and crossed by 18 rooms running north-south. It may be better to model the WIPP facility by some effective cavity. Also, since potash mining may extend to depths from the McNutt zone to 2300 feet (see comment 2 above), it may be preferable to approximate the extent of WIPP influence on the potash mine by the extent of possible subsidence area over the WIPP.

8. Section 4.1, page 4-2, 3rd paragraph -- The assumption that plutonium would dissolve at the same rate as the Salado formation is undoubtedly conservative if the salt is actually all dissolved (this would give a concentration of ≈ 1.6 mg/ℓ Pu in the brine). However, leaching of Pu from the waste can occur in the absence of net salt dissolution. Studies at PNL* have shown that about 10^{-4} per year of plutonium oxide fuel pellets would leach into "WIPP-B" brine. At this leach rate it would take 500 years to get a concentration of 1.6 mg/ℓ and solubility limits would probably prevent this high a concentration from ever occurring. It is recommended that the final report recognize that some waste leaching will occur if brine is in contact with the waste. Also, leaching by brine is more plausible than scenarios that require large volumes of the Salado formation to be dissolved.

---

*Bradley, D.J., Harvey, C.O., and Turcotte, R.P. Leaching of Actinides and Technetium from Simulated High-Level Glass (PNL-3152), August 1979.

RESPONSES TO NATURAL RESOURCES STUDY COMMENTS

GENERAL COMMENTS

1. Comment:

"The report fails to comprehensively address the question of new exploration. Neither the DOE Interim Policy Statement (Section 1.4) nor the balance of the report indicate that any restrictions will be imposed on new exploration for natural resources, only extraction. Since certain exploratory techniques may seriously affect the integrity of the repository, the Interim Policy Statement should impose restrictions similar to those for removal."

Response:

The report indicates that exploration activities are an integral part of resource development for both potash and hydrocarbons. As exploration is an essential portion of resource development, it is implied that restrictions placed on extraction activities would also apply to new exploration. Additionally, it is highly unlikely that resource companies would spend money to explore areas that are closed to resource extraction; however, a phrase will be added to the introduction to address exploration activities.

2. Comment:

"It is recognized that the construction of solution cavities for storage of hydrocarbons does not constitute exploration or mining for natural resources; however, it is an extraction technology; it is very relevant to gas and oil resources; it is becoming an increasingly popular practice; and it has not previously been examined by DOE. Therefore, EEG recommends that it be included and the impact analyzed in the Final Policy Statement and Report on Natural Resources."

Response:

A statement will be added to the report prohibiting any extraction activities at the WIPP site other than those discussed in the report, without prior approval of the DOE. It is unlikely, however, that DOE would allow construction of storage cavities at the site because there are many other suitable locations in the Delaware Basin for construction of these cavities.

3. Comment:

"It is noted that this report addresses the extraction in Zone IV only, which is consistent with the present Interim Policy. It should be noted that if at some future date, DOE proposes to modify the Policy to allow extractions from Zones II and III, it would be necessary to make a new analysis of the impact of such change."

Response:

Substantial modification of portions of the report would likely be necessary should DOE choose to examine the impacts of resource recovery from Zone II or Zone III.

SPECIFIC COMMENTS

1. Comment:

"Section 1.4, DOE Interim, Policy Statement -- In a letter dated November 17, 1981, Dr. George Goldstein, Secretary for Health and Environment of New Mexico, submitted several comments with respect to the DOE Interim Policy Statement. Although a letter from J. M. McGough of the DOE Albuquerque Operations Office responded to Dr. Goldstein's comments, the Interim Policy Statement was not modified and the report failed to either clarify or amend the ambiguous passages of the Policy Statement. For example, the phrases "unacceptable effects" (p. 1-6) and "allowable effects" (p. 1-8) remain undefined. EEG recommends that the Statement be revised to reflect Dr. Goldstein's previous comments and the comments contained herein."

Response:

The DOE Interim Policy Statement was included in the report for historical perspective and to indicate that certain extraction activities would not be allowed at the site and thus would not be evaluated relative to their impact. The precise definitions of "unacceptable effects" and "allowable effects" are not germane to the technical content of the report, because no effects are expected to result from resource recovery in Zone IV.

It should be realized that the Interim Policy Statement was developed not as a legal document but to provide a basis with which the potential effects of resource recovery could be studied.

2. Comment:

"Section 2.1.1 Page 2-2, second paragraph -- The report is inconsistent in statements about the depth at which potash may be found. This section states that it is not within 400 feet of the repository horizon. Table 1 indicates langebinite as low as 1800 feet (350 feet above the repository horizon). However, Table 5 indicates depths as low as 2300 feet (150 feet below the horizon). It would be helpful if the report indicated where the potash mines listed in Table 5 are located, and what are the actual depths to potash within the site."

Response:

The depth to the base of the McNutt potash member of the Salado Formation is about 1740 feet at ERDA-9, or approximately 400 feet above the storage horizon. The depth at which potash is found in the

basin varies as the depth to the McNutt potash member varies, which is dependent on the occurrence of strata dip, structural features and changes in topography. The base of the McNutt is at a depth of aproximately 1600 feet in the northern part of Zone IV; at a depth of about 1500 feet in the western part of Zone IV; at a depth of about 1550 feet in the southern part and at a depth of about 2000 feet in the eastern part. The depths to potash mineralization were included in the report primarily to indicate the depths at which potash mining experience exists. The location of the drillholes or mines from which depth measurements were obtained are available from the reference given in the tables or from maps prepared for WIPP or for other purposes and included in published project documents.

3. Comment:

"Section 3.1.1.1, Page 3-1, last paragraph -- It is emphasized that empirical data for the pressure arch theory is based on coal mining experience. The appropriateness and applicability for mines in salt needs to be addressed."

Response:

The pressure arch theory is a sound, proven concept and should be applicable to nearly any underground opening. As noted in the report, limited data exist for mines in salt compared to the extensive data base developed from coal mining experience. Further attempts, however, are underway to obtain more data on potash mining to strengthen the conclusions reached relative to mining effects. In any case, the report will be modified to demonstrate the appropriateness of the methodology used relative to the pressure arch theory.

4. Comment:

"Section 3.1.1.2, Page 3-3, last paragraph -- The author should also include data from studies performed by Sandia using elaborate rock mechanics codes, as contained in the following reference:

Morgan, H. S., Krieg, R. D., Matalucci, R. V., "Comparative Analyses of Nine Structural Codes Used in the Second WIPP Benchmark Problem." SAND-81-1839, Sandia National Laboratories, Albuquerque, N.M."

Response:

The Benchmark studies were directed at determining predicted stress-strain behavior of the WIPP underground workings in the near field. The effects that potash mining in Zone IV might produce on the WIPP facility are certainly not near-field. Thus, the applicability of the Benchmark analyses relative to this problem is not apparent.

In any case, more sophisticated techniques, such as geomechanical modeling using finite element techniques are not necessary. This is primarily because the results of first approximations as described in the report, using very conservative assumptions, demonstrate the integrity of a significant buffer zone between potash mines developed in Zone IV and the WIPP facility.

5. Comment:

"Section 3.1.1.2, Page 3-5, first line -- This sentence assumes that the stress-relaxation process which occurs prior to establishing steady-state conditions, cannot be studied. This assumption seems to be incorrect since the problem of transient creep is treated in great detail in report ECN-89. (See reference provided in comment 4 above.) The report also contains a program for the HP-41C pocket calculator."

Response:

The sentence referenced in the comment will be modified to indicate that the model used to determine zone of influence around underground openings cannot be used to address transient creep phenomena. The determination of the transient creep characteristics are unimportant in this instance because the cummulative effects of stress-relaxation on the surrounding strata, produced by a potash mine or the WIPP facility, are of primary concern.

6. Comment:

"Section 3.1.1.2, Page 3-5 3rd paragraph -- This paragraph addresses the zone of influence of a potential potash mine when superimposed by the influence of the WIPP repository and concludes that a separation of 2,100 feet assures that interaction will not occur. This conclusion seems to be based on the assumption that the existing rock between the WIPP and the potential potash mine is reasonably stable. However, in Zone III, north of the repository, there is a zone of "anomalous seismic reflection" where the structure is presently unknown. Also the presence of brine at WIPP-12 suggests that fracturing within the Castile may be extensive. Further information is needed on this anomalous zone before it can be concluded that 2,100 feet is sufficient."

Response:

The "zone of anomalous seismic reflection data" extends less than half a mile into Zone III at the Cowden Anhydrite horizon. No disturbance has been noted at WIPP storage horizon; in fact, there is very little steepening of strata at the storage horizon. At the McNutt potash zone horizon, the strata in the northern part of Zone IV are nearly horizontal and unaffected by the steepening of the

Castile Formation. Additionally, core obtained from boreholes located in the Salado Formation in the northern part of the Zones III and IV has not shown evidence of fracturing or deformation. Further, it is highly unlikely that any fracture created in the Salado Formation would remain open and permeable, due to the geomechnical properties of salt rock. It should be remembered that the fracture networks that are brine-containing in the Castile Formation are confined to thick anhydrite layers. Even in areas where fractures in Castile anhydrites are present, these fractures generally terminate at anhydrite-halite contacts. Thus, it is highly improbable that the "zone of anomalous seismic reflection data" represents any geologic condition that would impact the determination of the zones of influence of a potash mine or the WIPP underground workings.

7. Comment:

"Section 3.1.1.2, Page 3-5, 3rd paragraph -- The conclusion that the effects of mining the WIPP repository will only extend to 200 feet beyond the perimeter of the repository, the effect of a single panel, is not convincing. A potash mining activity approaching the WIPP repository from the north faces a 2560' x 33' room running east-west and crossed by 18 rooms running north-south. It may be better to model the WIPP facility by some effective cavity. Also, since potash mining may extend to depths from the McNutt zone to 2300 feet (see Comment 2 above), it may be preferable to approximate the extent of WIPP influence on the potash mine by the extent of possible subsidence area over the WIPP."

Response:

The statements that describe the independence of individual rooms within the WIPP underground facility will be better substantiated in the final report. It should be noted, however, that the length of the cavity is irrelevant as a cylinder of infinite length was assumed in the analysis. Relative to the expected depths of potash mining in Zone IV, see the Response to Comment 2 of the Specific Comments.

8. Comment:

"Section 4.1, page 4-2, 3rd paragraph -- The assumption that plutonium would dissolve at the same rate as the Salado Formation is undoubtedly conservative if the salt is actually all dissolved (this would give a concentration of 1.6 mg/l Pu in the brine). However, leaching of Pu from the waste can occur in the absence of net salt dissolution. Studies at PNL* have shown that about 10^{-4} per year of plutonium oxide fuel pellets would leach into "WIPP-B" brine. At this leach rate it would take 500 years to get a concentration of 1.6 mg/l and solubility limits would probably prevent this high a concentration from ever occurring. It is recommended that the final report recognize that some waste leaching will occur if brine is in

*Bradley, D. J., Harvey, C. O., and Turcotte, R. P. Leaching of Actinides and Technetium from Simulated High-Level Glass (PNL-3152), August 1979.

contact with the waste. Also, leaching by brine is more plausible than scenarios that require large volumes of the Salado formation to be dissolved."

Response:

The report simply restates the assumptions that were used in development of the WIPP long-term waste isolation assessment. The assumption that the waste is as soluble as the encapsulating salt is basic to the scenario analyses performed for this assessment. Although some leaching of plutonium oxide might occur under flowing conditions, some driving force must be present to cause brine to enter and leave the facility and pathways for brine to enter and leave must be established. The analyses and discussion in the report indicate that resource extraction activities in Zone IV would not significantly contribute to the creation of necessary pathways or driving forces.

9. Comment:

"Section 4.2, page 4-2 -- As previously discussed, the zone of influence in the northern sector of Zone III as a result of potash mining cannot be determined with reliability because the structure over the disturbed zone is unknown. It may contain significant fractures and be in direct communications with Zone II. See Comment 17 for recommended action."

Response:

See Response to Comment 6 of Specific Comments.

10. Comment:

"Section 4.2, page 4.2 -- It would seem that fresh water would not be required to move through a more permeable formation around the repository. Brine with some driving force should be able to flow through a permeable salt formation."

Response:

The permeability of undisturbed Salado salt is quite low and would allow very little fluid flow through the formation. The areal extent of mining-caused elevated permeability is very limited around both a hypothetical potash mine and the WIPP facility. No overlap of the zones of increased permeability would be expected, thus, a preferential flowpath for fluid travel would not be created.

If brine were to saturate the zone of increased permeability, no additional dissolution could occur. Additionally, the fracture network representing the zone would not be expected to remain open for any significant time interval based on the creep-closure properties of salt.

11. Comment:

"Section 4.2.1, page 4-3 -- The Interim Policy Statement does not appear to impose any restrictions on exploratory drilling in Zones II or III. If such restrictions were intended, it should be stated more clearly."

Response:

See Response to Comment 1 of General Comments

12. Comment:

"Section 4.2.1.1, page 4-3, first paragraph -- See Comment 2 above concerning the separation between the potash ore and the repository horizon. Also see Comment 11 above."

Response:

See Response to Comment 2 of Specific Comments and Comment 1 of General Comments.

13. Comment:

"Section 4.2.1.1. -- Why is it necessary to dissolve the (entire) one-mile-wide buffer strip to get to the repository? Could not fresh water follows fractures, (dissolving salt along the way) between potash mine and repository? The probability of dissolving in a straight line between the repository and mine may be low but subsidence (page 3-8) and zone of influence (page 3-3) effects could provide a preferential pathway for part of the distance between Zone II and III."

Response:

This section will be modified to clarify its intended meaning. It was not meant to imply that the entire one-mile-wide buffer must be dissolved for fluids to reach the WIPP facility. It is understood that fluids would seek preferential pathways (if such pathways exist). The primary purpose of Chapter 3 is to describe the expected extent of any preferential pathways created by resource extraction activities or by WIPP facility construction. As shown in this chapter, the effects on surrounding strata created by mining for potash in Zone IV and by construction of the WIPP facility do not overlap. Given the expected extent of effects from construction of these underground openings, millions of years would be required for fluids to dissolve a sufficient amount of halite to create a pathway from a mine in Zone IV to the WIPP storage facility.

14. Comment:

"Section 4.2.2., page 4-4 -- As previously indicated, mining of potash in the northern sector of Zone IV indeed may establish communications with Zone II at the repository horizon. The zone of anomalous seismic reflections encompasses virtually all of Zone III and portions of Zone II; there is a large brine reservoir at WIPP-12; thus there is considerable disturbance in Zone III which may extend to the repository horizon. Additional information is needed on this disturbed area before it can be known with confidence that potash mining in Zone IV can be allowed. See also Comment 13 above."

Response:

The analyses performed to evalute the effects of potash mining indicate that mining in Zone IV will not establish communications with Zone II.

Also, see Response to Comment 6 and Comment 13 of Specific Comments.

15. Comment:

"Section 4.3.1 -- There is a question concerning deviated drilling into the Ramsey sand. Since this formation is less than 6,000 feet deep zones I, II, III, it could not be developed under the policy stated on page 1-9. The question is whether this formation would not be developed under the inner zones or whether a variance would be permitted."

Response:

Deviated drilling into the Ramsey sand under Zones I, II and III will not be allowed. Disallowing this action will maintain the conservative approach taken by DOE on WIPP development. Additionally, denial of drilling into the Ramsey sand under the inner three Control Zones should not cause a substantial volume of hydrocarbons to remain untapped because the Ramsey sand is not an attractive exploration target in the site area.

16. Comment:

"Section 4.3.2, Page 4-8, paragraph 2 -- What is the basis for the statement (on page 4-8) that the Capitan aquifer potentiometric gradient is high enough to reach the surface at the WIPP site? Hiss' data show the potentiometric surface to the north of the site as 2900-3200 feet (fresh water equivalent), compared to a surface elevation of 3400 feet at the site."

Response:

The sentence should have stated that the potentiometric gradient of the Capitan and the ground surface in the WIPP site area is insufficient to drive fresh water to the surface.

17. Comment:

"Section 5.0, page 5.1, last paragraph -- It is the conclusion of EEG that the mining of potash in Zone IV should not be allowed until after the completion of the analysis of the zone of anomalous seismic reflection in Zone III and of WIPP-12. Therefore, the decision on allowing extraction of natural resources within Zone IV should be delayed until after the State has commented on the DOE reports on Brine Reservoirs and the Disturbed Zone."

Response:

See Response to Comment 6 of Specific Comments

EDITORIAL COMMENTS

The report is in final editing and these as well as other editorial items will be corrected in the final report.

"Equal Opportunity Employer"

STATE OF NEW MEXICO

ENVIRONMENTAL EVALUATION GROUP
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October 26, 1982

Joseph M. McGough
WIPP Project Manager
U. S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, NM 87115

Dear Mr. McGough:

Pursuant to our conversations over the past several weeks, I wanted to confirm the EEG's concern relative to DOE's issuance of a "Policy on Resource Recovery" without giving the State ample opportunity for review. We have a number of questions about the relinquishment of Zone IV control, a few of which are contained below. I request that you involve us at the earliest practical stage in the review process to assure that we can work together constructively on the resource recovery issues.

A few of our questions about the DOE policy follow:

1. Will solution mining be allowed in Zone IV?
2. If so, how will it be controlled?
3. Will storage cavities be allowed?
4. Will there be any restrictions on extraction or storage cavities in any of the evaporite formations in Zone IV?
5. Will directional drilling be allowed in Zone III?
6. Will extraction of brine reservoirs in the Castile from Zone IV permit drainage of brine from underneath the inner zones?
7. What will the Interim Policy Statement say regarding restrictons in zones?
8. Will the MOW between BLM and/or MMS allw DOE to have any input concerning future requests for activities in Zone IV? Or will it be completely out of DOE's hands?
9. What has become of the interim DOE policy to permit no exploration or extraction before 1993?
10. How will Zone IV be controlled if it is not under direct DOE control?
11. Will extraction of brine be authorized? Who will decide?

Please advise how we may best work together on resolution of not just these questions but others as well.

Sincerely,

Robert H. Neill
Director

2-081AG2-19-1

RHN:JM:eg

cc: TSC, IEA

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

RECEIVED
NOV 29 1982
ENVIRONMENTAL
EVALUATION GROUP

NOV 24 1982

Mr. Robert H. Neill
Director
State of New Mexico
Environmental Evaluation Group
320 Mary Street
P. O. Box 968
Santa Fe, NM 87504

Dear Mr. Neill:

DOE Policy on Resource Recovery at the WIPP Site

As you know, the DOE Interim Policy Statement on Resource Recovery at the WIPP Site, which was transmitted to the State of New Mexico on November 3, 1981, was developed to serve as the basis for performing the Natural Resources Study. And, as you also are aware, the study concludes that activities related to potash and hydrocarbon resource extraction and solution mining outside the Control Zone III boundary, using currently available and applicable technology, will not compromise the integrity of the WIPP waste emplacement facility.

It was my understanding that your concerns regarding the draft and final Natural Resources Study reports were discussed with representatives of our Technical Support Contractor and resolved to your satisfaction. The DOE is now considering the issuance of a revised interim policy statement on resource recovery which would reflect the conclusions of the Natural Resources Study and, possibly, permit access to potash and hydrocarbons that many believe are critical resources.

Although the revised interim policy statement is still undergoing DOE review, responses to your questions have been developed based on our

current position and are included in the enclosure. The revised interim policy statement will be based on the results of the Natural Resources Study and will be transmitted to the State of New Mexico as soon as our internal review is completed.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 82-0801/6252A

Enclosure

cc w/o enclosure:
R. K. Brown, TSC
G. L. Hohmann, TSC
C. C. Little, TSC

cc w/enclosure:
C&C File, IEA, TSC

Question -- Will solution mining be allowed in Zone IV?

Response -- Unsuccessful experiences in solution mining of potash by the Potash Company of America and Continental Potash and the lack of suitable water supplies in the Carlsbad area suggest that the potential for application of currently available solution mining technology for the extraction of sylvite is remote; however, solution mining will be allowed in Control Zone IV.

Question -- If so, how will it be controlled?

Response -- The DOE will impose no controls over solution mining in Control Zone IV. The U.S. Department of the Interior Minerals Management Service and the New Mexico Energy and Minerals Department are responsible for reviewing proposed mining operations to assure compliance with regulations and prevent violation of adjacent leases.

Question -- Will storage cavities be allowed?

Response -- Although the development of storage cavities in the WIPP site area is considered unlikely, the DOE will exercise no controls over the development of such cavities outside Control Zone III provided that the WIPP site boundary is not violated.

Question -- Will there be any restrictions on extraction or storage cavities in any of the evaporite formations in Zone IV?

Response -- No, provided that the WIPP site boundary is not violated.

Question -- Will directional drilling be allowed in Zone III?

Response -- No drilling will be allowed from Control Zone III. However, drilling from outside Control Zone III to gain access to hydrocarbons beneath Control Zones I, II and III at depths greater than 6000 feet will be allowed if the planes formed by the downward vertical projections of the Control Zone III boundaries are not penetrated above a depth of 6000 feet.

Question -- Will extraction of brine reservoirs in the Castile from Zone IV permit drainage of brine from underneath the inner zones?

Response -- In general, the geographical extent of brine reservoirs in the Castile Formation has not been determined; however, it is possible that a brine reservoir encountered in Control Zone IV could extend beneath the inner zones. Consequently, extraction of brine from a reservoir beneath Control Zone IV could result in removal of brine from beneath the inner zones. Because of the characteristics of brine reservoirs found in the Castile Formation, extraction of brine will not result in subsidence of sufficient magnitude to fracture overlying strata. Thus, no effect on the underground facility is expected.

Question -- What will the Interim Policy Statement say regarding restrictions in zones?

Response -- The revised interim policy statement is expected to indicate the following:

- No potash or other commercial mining will be allowed in Control Zones I, II and III.
- No commercial drilling (hydrocarbon or other) will be allowed from Control Zones I, II and III.
- Drilling from outside Control Zone III to access locations beneath Control Zones I, II and III at depths greater than 6000 feet will be allowed.

Question -- Will the MOU between BLM and/or MMS allow DOE to have any input concerning future requests for activities in Zone IV? Or will it be completely out of DOE's hands?

Response -- The DOE does not expect to exercise any control over activities in Control Zone IV except that no permanent residences will be allowed by BLM in Zone IV. The DOE will, however, arrange with BLM and MMS to be kept apprised of all such activities in Zone 4 and provide recommendation or other assistance to Federal and State regulatory agencies upon request.

Question -- What has become of the interim DOE policy to permit no exploration or extraction before 1993?

Response -- The interim DOE policy which was transmitted to the State of New Mexico in November 1981, was developed to serve as the basis for performance of the Natural Resource Study. The results of this study demonstrate that activities related to potash and hydrocarbon resource extraction and solution mining from within (and outside of) Control Zone IV, using currently available technology, would not compromise the integrity of the WIPP waste emplacement facility. Because of these findings, the DOE is evaluating the desirability of revising the interim policy statement as indicated above.

Question -- How will Zone IV be controlled if it is not under direct DOE control?

Response -- The lands in Control Zone IV will be managed by the Bureau of Land Management in the same manner as other public lands. Commercial mining and hydrocarbon extraction activities will be controlled by the Minerals Management Service and the New Mexico Energy and Minerals Department in accordance with Federal and State regulations governing such activities.

Question -- Will extraction of brine be authorized? Who will decide?

Response -- As indicated above, no commercial mining or drilling (hydrocarbon or other) will be allowed in Control Zones I, II and III, however, no controls will be imposed on such activities outside the Zone III boundary. Although requests for approval of brine extraction activities in the WIPP site area are considered unlikely, such requests will be reviewed by the Minerals Management Service, New Mexico Energy and Minerals Department (for State lands) and the Bureau of Land Management to assure compliance with Federal and State regulations. The DOE will provide assistance to these agencies if requested.

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STATE OF NEW MEXICO

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December 6, 1982

Mr. Joseph M. McGough
Project Manager of WIPP
WIPP Project Office
U.S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, New Mexico 87115

Dear Mr. McGough:

Thank you for your letter of November 24, 1982 (WIPP:JMM82-0801/6252A) enclosing a response to our questions concerning the DOE plans for the "Policy on Resource Recovery."

There is attached a summary of EEG's comments concerning the recent draft of the DOE "Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site."

Sincerely,

-for-

Robert H. Neill
Director

RHN:MSL:eg

2-92-AG2-19-1-1

cc: TSC, IEA

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

REVIEW COMMENTS
on
DOE REVISED INTERIM POLICY STATEMENT ON NATURAL RESOURCES RECOVERY AT WIPP SITE

by

Environmental Evaluation Group
Environmental Improvement Division
N. M. Health and Environment Department
P. O. Box 968
Santa Fe, NM 87503

December, 1982

A. GENERAL COMMENTS

1. The Statement implies that DOE plans to relinquish all control over Zone IV of the present WIPP site, and that DOE plans to rely on the New Mexico Energy and Minerals Department and the Minerals Management Service of the U. S. Dept. of Interior for reviewing plans in this zone in the future. Because of the remote possibility that activities in this zone may have an adverse impact on the long-term stability of the repository horizon, it is recommended that DOE maintain, in a memorandum of understanding with DOI, a provision for DOI to notify DOE of any proposal for solution mining, solution storage cavities, and mining of Castile brine in Zone IV prior to a decision on that proposal, and that DOE in cooperation with the appropriate State agencies will review these plans and submit comments to DOI for their consideration.

2. The Policy Statement applies only during facility construction and operation of the WIPP facility. The Policy should be expanded to reflect the post-operation controls, since the integrity of the repository and the consequence analyses are dependent upon some controls being maintained.

B. SPECIFIC COMMENTS

1. Page 1, line 6:

The phrase "commercial drilling" should be defined so that it clearly excludes any drilling as well as mining not related to WIPP in Zones I, II, and III.

2. Page 1, line 14:

As reflected in the preceding "General Comments," EEG recommends that the MOU between DOE and DOI request that DOE (and the appropriate State agencies) be notified of any proposal in Zone IV envolving solution mining, construction of solution storage cavities or mining of brine from brine reservoirs in the Castile.

3. Page 1, line 25:

As recommended in the "General Comments," we believe that the controls which are to be maintained after decommissioning should be addressed. This would necessitate deletion of the sentence at line 25.

4. Page 2, line 6:

The phrase "measurable effects" is ambiguous and may lead to misunderstandings. It should be deleted or more precisely defined.

5. Page 2, paragraph 2:

This paragraph does not adequately state the potential for resources at the site. It should recognize that technology and market conditions are not predictable and some materials, such as may be found in Castile

brine, or Salado salt could become of economic value if technology and market conditions are substantially modified.

6. <u>Page 3, paragraph 4, line 7:</u>

The D'Appolonia draft report "Natural Resources Study" indicates that "resource grade oil" is under the site.

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

DEC 23 1982

Dr. George S. Goldstein
Chairman, Radioactive Task Force
Health and Environment Department
P.O. Box 968
Santa Fe, NM 87503

Dear Dr. Goldstein:

DOE Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site

Enclosed for your use and information is the DOE Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site. Under the terms of this policy statement no potash or other commercial mining in, or commercial drilling from, Control Zones I, II and III will be allowed; however, the DOE will exercise no control over mining or drilling outside Control Zone III. (Control Zone III is being redefined as the area withdrawn for SPDV which is a square containing 16 sections (10,240 acres) surrounding the center of the site.) Additionally, BLM will prohibit permanent inhabitation of Zone IV while the facility is in operation. Hydrocarbon resources below 6000 ft. beneath Control Zones I, II and III can be accessed by deviated drilling from outside the Control Zone III boundary. The DOE will rely on the review of State and Federal regulatory agencies, including the New Mexico Energy and Minerals Department and the U.S. Department of the Interior, Minerals Management Service, to protect the integrity of the WIPP Site boundaries from commercial exploration, mining or other extractive activities. So that the DOE can maintain information on resource recovery near the WIPP Site, the Bureau of Land Management will notify the DOE of any requests for resource recovery permits within one mile of the WIPP Site boundary.

The final DOE policy will be issued when the decision is made regarding retrieval of the waste. Should the DOE decide to retrieve all the radioactive waste, the WIPP Site will become available for complete resource recovery after retrieval and decommissioning are complete.

The initial Interim Policy Statement, which was transmitted to the State of New Mexico on November 3, 1981, was developed to serve as the basis for the performance of the Natural Resources Study. The initial DOE

Interim Policy, as indicated therein, was "temporary denial of all resource extraction within the four control zones of the WIPP Site until the decision is made relative to which, if any, of the emplaced waste will be retrieved." Based on the conclusions of the Natural Resources Study, which was transmitted to the State of New Mexico on October 5, 1982, we have determined that the initial Interim Policy can be revised as indicated above.

Not only does the DOE Revised Policy Statement reflect the conclusions of the Natural Resources Study but it also addresses comments provided by the New Mexico Environmental Evaluation Group on the Policy Statement.

If you require additional information or have questions on this matter, please contact me.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

Enclosure

WIPP:JMM 82-0885/6366A

cc: w/encl:
J. K. Otts, Chairman, Radioactive Waste Consultation Committee, Santa Fe, NM
J. Bingaman, Attorney General, Santa Fe, NM
D. T. Schueler, AMPEP, AL
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R. H. Neill, Director, EEG, Santa Fe, NM
C. W. Luscher, State Director, BLM, Santa Fe, NM
M. Wilson, OCC, AL

DOE REVISED INTERIM POLICY STATEMENT ON RESOURCE RECOVERY AT THE WIPP SITE

The policy of the Department of Energy (DOE) concerning resource recovery at the Waste Isolation Pilot Plant (WIPP) site during facility construction and operation is as follows:

- No potash or other mining excluding that conducted for the WIPP Project will be allowed in WIPP Control Zones I, II, and III.

- No drilling excluding that conducted for the WIPP Project will be allowed from Control Zones I, II, and III.

- Drilling from outside Control Zone III to access locations beneath Control Zones I, II, and III at depths greater than 6,000 feet will be allowed if the planes formed by the downward vertical projections of the Control Zone III boundaries are not penetrated above a depth of 6,000 feet.

- DOE will rely on the review of State and Federal regulatory agencies, including the New Mexico Energy and Minerals Department and the Minerals Management Service, U.S. Department of the Interior, to protect the integrity of the WIPP site boundaries from commercial exploration, mining, and other extractive activities.

- If the DOE decides that all radioactive waste is to be retrieved, the WIPP site will become available for complete resource recovery once retrieval and facility decommissioning is accomplished.

This policy may be re-evaluated after facility decommissioning. The following paragraphs provide a measure of clarification of the rationale used to develop the resource recovery policy.

It is the policy of the DOE to maximize the opportunity for resource recovery at the WIPP site, consistent with the requirements to isolate the emplaced radioactive wastes from the biosphere. Within five years after the first emplacement of each type of TRU waste (i.e., contact and remotely handled), separate decisions will be made about the retrieval of each kind of waste. If the DOE decides that all waste is to be retrieved, the WIPP site will become available for complete resource recovery once retrieval and facility decommissioning are accomplished.

The criterion for the DOE policy is that permanent denial of resources should be limited to those areas in which extraction activities could potentially lead to measurable effects[1] on the WIPP facilities or whose protection is needed to satisfy institutional considerations, all extraction activities that would not lead to measurable effects on the WIPP site are defined as "allowable" under the DOE policy.

Potash (sylvite and langbeinite) and hydrocarbons (natural gas and distillate) comprise the resources present at the WIPP site that are of interest considering the technology and market conditions in the foreseeable future. These resources and the methods available to recover them are described in detail in the FEIS (U.S. Department of Energy, 1980).

---

1 Measureable effects are those influences from extraction activities that could cause the assumptions made in the breach scenario consequence analyses (U.S. Department of Energy, 1980) to be unconservative.

Due primarily to institutional considerations, no potash mining in or commercial exploratory drilling (hydrocarbon or other) from Control Zones I, II, and III will be permitted. A study was conducted to investigate the possible effects of resource recovery within Control Zone IV on the WIPP facility (Natural Resources Study, Brausch et al., 1982). The following paragraphs provide a brief summary of the results and conclusions of that study.

The extraction of potash outside Control Zone III is allowable. Potential methods of mining potash include drill-and-blast, continuous mining, solution mining, shortwall, and longwall techniques. Since mining of potash is allowable, it is not reasonable to prohibit those mining techniques that make such an activity economically viable. To prohibit such activities is, in effect, to preclude mining. Accordingly, extraction ratios can be maximized in any mines developed outside Control Zone III of the WIPP site, consistent with mine safety considerations and other state and federal requirements. Solution mining will be allowable outside Control Zone III. Resource extraction by solution mining may be applied to recovery of sylvite. Solution mining for recovery of langbeinite would be ineffective because langbeinite is less soluble than the surrounding minerals (e.g., halite, sylvite). However, the lack of existing solution mining for sylvite in the Carlsbad potash mining district suggests that solution mining for potash within Control Zone IV may not be feasible.

The recovery of hydrocarbon resources outside Control Zone III is allowable. This activity includes drilling, production stimulation, and, possibly, secondary recovery. Resources located outside Control Zone III may be accessed by vertical drilling; resources located beneath the inner three control zones at depths greater than 6,000 feet may be accessed by drilling vertically outside Control Zone III to a depth of 6,000 feet and then deviating from vertical at the angle required to reach the target resource zone.

If oil or gas is found, it is not reasonable to prohibit those techniques available to the producer that maximize recovery. Enhancing the production from drilled wells by hydraulically fracturing the reservoir rock, acidizing the formation, or other applicable techniques would not be expected to affect the WIPP facility.

These types of production stimulation are used primarily to increase the permeability of the rock that contains the hydrocarbons. Secondary recovery methods (techniques used to enhance or replace the natural driving force that "pushes" the oil to the production well) and tertiary methods (techniques used primarily to decrease the viscosity of heavy crude oils) may also be employed but, because the crude oil resources at the site are not reasonably or economically extractable, these techniques are not expected to be useful unless significant technological advances and adaptations are made.

State and federal regulatory agencies, including the New Mexico Energy and Minerals Department and the Minerals Management Service of the U.S. Department of Interior, are responsible for reviewing proposed mining and hydrocarbon exploration plans to prevent injury to adjacent leases or properties. The DOE will rely on this regulatory review process to protect the integrity of the WIPP site boundary from potash mining and hydrocarbon exploration on adjacent properties. The DOE will provide assistance to these agencies during the review process upon request. In addition, the BLM will notify the DOE of any requests for permits for resource recovery activities within one mile of the WIPP site boundary.

This policy will be modified if changes in institutional requirements occur or if significant new data relevant to the policy are obtained during development and operation of the WIPP facility.

References Cited

Brausch, L. M., Kuhn, A. K., Register, J. K., 1982, Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, TME 3156, Prepared for U.S. Department of Energy.

U.S. Department of Energy, 1980, Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026, Assistant Secretary for Defense Programs, Washington, D.C.

Department of Energy
Albuquerque Operations Office
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RECEIVED

JAN 12 1983

ENVIRON.
EVALUATION GROUP

JAN 6 1983

Mr. Robert H. Neill
Director
State of New Mexico
Environmental Evaluation Group
P. O. Box 968
Santa Fe, NM 87503

Dear Mr. Neill:

DOE Responses to EEG Comments on DOE Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site (Letter, Neill/McGough, dated December 6, 1982)

This is a response to your review comments on our Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site. Enclosed is our response to your comments and a revised Interim Policy Statement which incorporates changes resulting from your comments.

Based on the conclusions of the Natural Resource Study and the DOE's desire to mitigate any adverse effect of the WIPP Project, we believe that this policy provides the maximum opportunity for resource recovery without any degradation of public health and safety or facility integrity.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 82-0899/6363A

2 Enclosures

cc w/o enclosures:
G. L. Hohmann, TSC, AL
C. C. Little, TSC, AL

cc w/enclosures:
C&C File, IEA, TSC, AL

General Comment No. 1

"The Statement implies that DOE plans to relinquish all control over Zone IV of the present WIPP Site, and that DOE plans to rely on the New Mexico Energy and Minerals Department and the Minerals Management Service of the U.S. Department of Interior for reviewing plans in this zone in the future. Because of the remote possibility that activities in this zone may have an adverse impact on the long-term stability of the repository horizon, it is recommended that DOE maintain, in a Memorandum of Understanding with DOI, a provision for DOI to notify DOE of any proposal for solution mining, solution storage cavities, and mining of Castile brine in Zone IV prior to a decision on that proposal, and that DOE in cooperation with the appropriate State agencies will review these plans and submit comments to DOI for their consideration."

Response:

The WIPP Site is now defined as the lands withdrawn by Public Land Order 6232, March 30, 1982, for the purpose of performing the Site and Preliminary Design Validation (SPDV) Program and protecting the integrity of the Site. The administrative land withdrawal application for full WIPP facility construction and the legislation land withdrawal, which is being requested by DOE, will encompass these same lands, i.e., 8960 acres of public lands and 1280 acres of State land which will be subject to the withdrawal if they pass to Federal ownership.

The lands withdrawn will be managed in accordance with a DOE/BLM Memorandum of Understanding which will, among other things, withdraw DOE objection to leasing, drilling and mining outside this withdrawal area; require BLM to notify DOE of any requests for resource recovery permits within one mile of the site boundary; and prohibit habitation within one mile of the site boundary. While the DOE does not plan to exercise any control over resource extraction activities outside the WIPP Site boundary, if required, the DOE will take any actions necessary based upon our review of resource recovery permits which may include State involvement if adverse impacts could result from the proposed resource recovery permits.

This position is consistent with the conclusions of the Natural Resources Study (Brausch, et al., 1982) which indicates that resource exploration and extraction activities more than one mile from the limits of the underground facility will not compromise the integrity of the facility.

General Comment No. 2

The Policy Statement applies only during facility construction and operation of the WIPP facility. The Policy Statement should be expanded to reflect the post-operation controls, since the integrity of the repository and the consequence analyses are dependent upon some controls being maintained.

Response:

The Policy Statement does apply only during WIPP construction and initial operation, a period of about 10 to 15 years. During that period, advances in drilling and mining technology and other pertinent information can be evaluated to determine whether more or less stringent resource recovery restrictions are required to protect the facility. Early (5-10 years) in the operating life of the facility, DOE will decide whether to retrieve all emplaced waste and return the land to BLM for releasing or to finalize the present interim policy. At this time, no revisions to the interim policy are planned if WIPP becomes a permanent disposal facility.

Specific Comment No. 1

The phrase "commercial drilling" should be defined so that it clearly excludes any drilling as well as mining not related to WIPP in Zones I, II, and III.

Response

The sentence has been changed to read: "No drilling excluding that conducted for the WIPP Project will be allowed from Control Zones I, II and II."

Specific Comment No. 2

As reflected in the preceding "General Comments," EEG recommends that the MOU between DOE and DOI request that DOE (and the appropriate State agencies) be notified of any proposal in Zone IV involving solution mining, construction of solution storage cavities or mining of brine from brine reservoirs in the Castile.

Response

As indicated in our response to your first general comment above, the DOE/BLM Memorandum of Understanding, under which the lands will be managed, will require the BLM to notify the DOE of any requests for permits for resource recovery activities within one mile of the site boundary. The following sentence has been added to the third paragraph on page 4: "In addition, the BLM will notify the DOE of any requests for permits for resource recovery activities within one mile of the WIPP Site boundary."

Specific Comment No. 3

As recommended in the "General Comments" we believe that the controls which are to be maintained after decommissioning should be addressed. This would necessitate deletion of the sentence at line 25.

Response

As indicated in our response to your second general comment, the 10 to 15 year duration of remaining construction and initial operation allows adequate time to review and assess changes in technology and develop detailed plans for controls following decommissioning.

Specific Comment No. 4

The phrase "measurable effects" is ambiguous and may lead to misunderstandings. It should be deleted or more precisely defined.

Response

A footnote has been added to clarify the phrase. The footnote reads as follows: "Measurable effects are those influences from extraction activities that could cause the assumptions made in the breach scenario consequence analyses (U.S. Department of Energy, 1980) to be unconservative."

Specific Comment No. 5

This paragraph does not adequately state the potential for resources at the site. It should recognize that technology and market conditions are not predictable and some materials, such as may be found in Castile brine, or Salado salt could become of economic value if technology and market conditions are substantially modified.

Response

The brief paragraph on resources present at the site is not intended to describe all possible resources which could become of economic value. It does indicate the two resources that are of current interest and whose recovery could potentially affect the underground facility. In the event that other resources at the WIPP Site become of economic value in the future, exploration and extraction technology for such resources will be evaluated and, if required, appropriate changes will be made in the Policy Statement.

Specific Comment No. 6

The D'Appolonia draft report "Natural Resource Study" indicates that "resource grade oil" is under the site.

Response

The hydrocarbon resource evaluations of the WIPP Site are based on known resources of natural gas and crude oil in the region and the probability of discovering new reservoirs. The fundamental assumption is, therefore,

that the WIPP Site has the same potential for containing hydrocarbons as the much larger area for which exploration data are available. Although the New Mexico Bureau of Mines and Mineral Resources (NMBM & MR) study shows that minor deposits of crude oil are statistically probable at the WIPP Site, later studies have discounted the existence of economically attractive quantities of crude oil at the site.

HEALTH & ENVIRONMENT department

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STATE OF NEW MEXICO

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January 21, 1983

Mr. Joseph M. McGough
Project Manager on WIPP
WIPP Project Office
U.S. Department of Energy
P.O. Box 5400
Albuquerque, New Mexico 87115

Dear Mr. McGough:

This is in reply to your letter (WIPP:JMM 82-0899/6363A) and enclosures of January 6, 1983 concerning the DOE Revised Interim Policy Statement on Natural Resource Recovery at the WIPP Site. While we are generally satisfied with the revised Policy Statement, as provided in your recent letter, there remains one concern which needs to be resolved.

The Policy Statement and the DOE/BLM Memorandum of Understanding include the requirement that BLM notify DOE of any requests for resource recovery permits within one mile of the new site boundary. While the DOE does not plan to exercise control over resource extraction activities outside the new WIPP site boundary, we note that, "if required, the DOE will take actions necessary... which may include State involvement if adverse impacts could result from the resource recovery permits." So that the State may continue to make its own independent analysis of potential adverse impacts, we would like DOE's assurance that EEG will be notified of any request for resource recovery permits within one mile outside of the site boundary. And further, we would like to be advised of the planned Federal action on such requests prior to the initiation of the resource recovery.

The statements accompanying the Policy Statement implying no possibility of objection to solution mining of potash and secondary recovery for hydrocarbons outside the Control Zone III should be revised to indicate that any proposals for fluid injection underground within one mile of the WIPP site will be evaluated by DOE and EEG to determine if such proposals will adversely affect the integrity of the repository.

Sincerely,

Robert H. Neill
Director

RHN:jdc

2-100AG2-19-1-2

cc: TSC,IEA

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

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FEB 28 1983
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EVALUATION GROUP

FEB 24 1983

Mr. Robert H. Neill
Director
State of New Mexico
Environmental Evaluation Group
P. O. Box 968
Santa Fe, NM 87503

Dear Mr. Neill:

As you know, the DOE Revised Interim Policy Statement on Resource Recovery at the WIPP Site is based on the Natural Resources Study which concludes that resource recovery outside the Site boundary (Zone III) using current technology, will not compromise the integrity of the WIPP underground facility. Accordingly, the DOE does not plan to exercise any control over resource recovery activities outside the Site boundary and will rely, primarily, on other Federal and State regulatory agencies to assure that the WIPP boundaries are not violated. As an additional protection measure, the BLM will notify the DOE of any requests for resource recovery permits within one mile of the WIPP Site boundary so that the DOE will be aware of resource recovery activities near the Site.

We do not expect to perform a comprehensive review of resource recovery plans utilizing conventional technology; however, any plans which employ unusual methods or advanced technology will be evaluated to determine possible effects on the underground facility. Upon receipt of notification of unusual or advanced technology planned resource recovery activities from the BLM, we will forward the information to the EEG.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 83-0171

cc:
G. L. Hohmann, TSC, AL
C. C. Little, TSC, AL
C&C File, IEA, TSC, AL
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DEEP DISSOLUTION

SAND 82-0461

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August 13, 1982

Joseph M. McGough
WIPP Project Manager
U. S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, NM 87115

Dear Mr. McGough:

Enclosed is a summary of our comments on the Draft "Interim Report: Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas," by Stephen J. Lambert.

We would appreciate your consideration of these comments in the preparation of the final report. As with the other formal reports required by the Stipulated Agreement, we would like to have our staff and yours meet to discuss the final version of the document before its publication.

Sincerely,

Jack M. Mobley
for

Robert H. Neill
Director

RHN:eg
2-047AG2-15-1-1
Enclosure

cc with attachment:
George S. Goldstein, Ph.D., Secretary, Health & Environment Department
Joe Hewitt, Secretary, Highway Department
Charles Turpen, Secretary, Energy and Minerals
Jeff Bingaman, District Attorney
Russell F. Rhoades, Director, Environmental Improvement Division
Joe Canepa, Attorney at Law
James K. Otts, Chairman, Rad-Waste Consultation Committee
D. T. Schueler, Assistant Manager for Project of Energy Programs
Wendell Weart, Sandia Laboratories
TSC, IEA

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

REVIEW COMMENTS

CONCERNING

Interim Report: Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas, by Stephen J. Lambert

Sandia National Laboratories

Printed February, 1982

Comments by

Environmental Evaluation Group

Environmental Improvement Division

Health and Environment Department

P. O. Box 968

Santa Fe, New Mexico 87504-0968

August 12, 1982

INTRODUCTION

These comments are based upon a critical reading of the report and many of the references cited in the report. A meeting with the author of the report, Steven Lambert, was held on July 21, 1982 to clarify the important points discussed in the report. Since a major part of the report deals with the ideas of salt dissolution at depth as postulated by Roger Anderson, he was also invited to attend this meeting. Some of the following comments resulted from this and subsequent discussions with Lambert and Anderson.

The report is a major effort to include in one document the various components of the theory, experimental and field work bearing on the partial removal of evaporite beds in the Delaware Basin. The work and scholarship displayed in the report is most commendable.

GENERAL COMMENTS

The purpose of the State's request for this document was to get DOE's most current thinking on the matter of the dissolution of evaporites in the Delaware Basin. The main area of concern in this matter is the possibility of removal of salt from the repository horizon in lower Salado by circulating waters, in the recent geologic past and the possibility of such dissolution being ongoing. Roger Anderson has published several papers during the past 10 years developing this hypothesis. This report was expected to provide DOE's views on the feasibility of such dissolution having taken place and the consequences and threat, if any, to the integrity of the proposed waste repository.

Although the report has presented data on the geologic, geomorphic, geohydrologic and geochemical aspects of the question of dissolution and removal of salt and has presented a review of various models of dissolution, it has not addressed the possibility of "deep dissolution" in sufficient depth. It is hoped that the document in its final form will either accept or reject the idea of active dissolution of salt beds in the lower Salado formation in the vicinity of WIPP site. Of course, detailed reinterpretation of the existing data and argumentation will have to be provided for a conclusion.

To help the author accomplish the objective of a more definitive conclusion of the deep dissolution controversy, the following is a discussion of the important aspects of this question, with reference to their treatment in the draft report.

Non-existence of Lower Salado Salt

Anderson has shown that a large amount of salt from the lower part of Salado formation is missing from the Delaware Basin and has attributed this to the removal by dissolution at depth in geologically recent times. A number of acoustic logs from oil and gas wells have been used by Anderson as hard data to advance his hypothesis. The report has acknowledged that the salt is missing from the Lower Salado, but does not acknowledge that it is missing due to dissolution. Other ideas advanced are non-deposition or erosion shortly after deposition (p. 98). No arguments are advanced, however, for statements such as, "...removal of some halite (if originally deposited) near the basin margin must have occurred during Castile time (not Pleistoene)" -p. 90.

The argument of non-deposition could easily be settled with a statistical study of regional thickness trends in acoustic logs. However, according to Anderson, (written communication) there is no reason to do this because lateral changes into depressions are dramatic and associated with collapse and therefore not the result of original deposition (or non-deposition). Also, according to Anderson, the argument of dissolution at some earlier than late Cenozoic time is not tenable because of the age of the fill in the collapse.

According to Lambert, "A complete review of raw geophysical log data, and possible interpretations of them, will be undertaken, together with an independent determination of thickness variations in the Castile and Salado formations" (p. 98). EEG looks forward to the results of such a review. In fact, this should have been completed before issuing the draft report.

An important point raised in the report with regard to the use of acoustic logs for dissolution studies is that "the sections of anhydrite which are postulated to be dissolution residue by virtue of no interlayered halite, show no log signature of chaotic dissolution residue, but are nearly pure anhydrite" (p. 97). Also such zones "bear the signatures of anhydrite,

not gypsum as would be present in abundance if large quantities of fresh water were circulating in subsurface open space" (p. 98). It appears that the best way to resolve whether there is a distinct signature for the dissolution residue would be to run an acoustic log in one of the WIPP holes in Nash Draw (WIPP-25 to WIPP-30) where dissolution residue is known to occur and compare the signatures thus obtained with those used by Anderson where salt sections have changed to Anhydrite.

Other specific instances of "errors" (p. 91) in Anderson's data and interpretations are addressed under Specific Comments (for pages 88-100).

Connection of Evaporite Beds and the Basin Aquifer

In his deep-dissolution model, Anderson (1978, 80, 81) invoked the Delaware Mountain Group aquifer as a pathway for supply (i.e., source) of unsaturated water to the evaporite beds for salt dissolution as well as for removal (i.e., sink) of saturated brines. Contrary to the findings of Hiss (1975) and Anderson, the report rules out the DMG aquifer as a potential supplier of water for dissolution in the evaporite beds, for the following reasons.

a. "The entire Delaware Mountain Group is probably not a single, vertically interconnected hydrostratigraphic unit" (p. 37).
b. In the Bell Canyon formation, as encountered in AEC No. 8 "Static water levels were 615 and 560 feet below land surface as supported by the lower and upper sands, respectively. This conspicuous difference (in levels of water of similar density) attests to the strata-bound, vertically-isolated nature of water occurrences in the Bell Canyon formation." (p. 38)
c. "The deposition-controlled porosity containing natural gas in isolated lens-shaped sandstone reservoirs is also an indication of but small degrees of vertical and horizontal connected porosity in the Bell Canyon formation. Thus, in the upper 700 feet of the Bell Canyon formation, the total saturated thickness is less than 30 feet."
d. "Much of the Bell Canyon water is highly saline, but not completely saturated with sodium chloride under the evaporites" (p. 39).
e. "The salinity does not abruptly rise from west to east as evaporites appear in the overlying section" (p. 39).

f. "The water contains solutes in combinations not found in the evaporites" (p. 39). "Bell Canyon waters from AEC-7, AEC-8 and ERDA-10 have Na/Cl ratios of 0.50, 0.46 and 0.56 respectively" (p. 150). "Na/Cl (weight) ratio of brines formed by dissolution of salt in western Oklahoma is remarkably close to 0.64, regardless of whether the water is a low-salinity or a saturated brine" (p. 150). "Oil-field brines consistently have Na/Cl ratios of 0.55 or less, and the ratio decreases well below 0.50 as the salinity increases" (p. 150). "Thus we see that the Bell Canyon waters clearly have closer affinity with oil-field brines than with dissolution brines (and therefore) it has not been a sink for dissolution brines" (p. 150).

The reasons cited above can be disputed individually, but together they do present a formidable challenge to the idea of an active interconnection of the DMG aquifer with Castile and Salado beds.

In addition, the report also rules out any interconnection of the Bell Canyon aquifer with the Capitan aquifer on the basis of the Bell Canyon potentiometric heads being higher than the juxtaposed Capitan, "at all locations along the Basin margin....even after corrections are made for salinities" (p. 44). This, by itself, does not eliminate the possibility of the Bell Canyon water moving into the Capitan aquifer in the eastern part of the basin.

Replacement Limestone as Basis for Past DMG-Evaporite Bed Connection

Anderson (1980) has cited replacement limestone masses - "Castiles" and "limestone dikes" as evidence for past movement of water from the DMG aquifer to the evaporite beds. Konrad B. Krauskopf (EEG-7, p. 85) commented on these features as follows:

> "The fact that Bell Canyon water has invaded the overlying evaporite sequence at places other than the immediate vicinity of the Capitan reef seems clearly demonstrated by the replacement of Castile Anhydrite by biogenic limestone, locally accompanied by sulfur, in the western part of the Delaware Basin. The reduction of sulfate and its replacement by porous carbonate with a high carbon 12/13 ratio is clearly the work of bacteria, and the organic matter needed for bacteria to flourish could have come only from the Bell Canyon."

Lambert (in the report under review) suggests that "A more likely source for the water to supply the formational process for Castiles is in the nearby solution-subsidence troughs of the type described by Olive (1957), which are both near-surface and recently have contained water" (p. 74). There are two serious errors in this suggestion. Firstly, it does not take into account the brecciation seen in the Castiles, and more importantly, it is contrary to conclusions reached by all the serious investigators (Kirkland and Evans, 1976; Smith, 1978) of these features, without presenting any analysis or reasons.

Castile Formation Brine and Bell Canyon Aquifer

The report rules out the possibility of interconnection between the Bell Canyon waters and the brine encountered at several locations in the Castile Formation. "The (ERDA-6) water's unique stable isotope relationships isolate it from any active source in the Capitan or Bell Canyon. The solutes in the Castile water also make it incompatible with the Bell Canyon; a high sulfate (Castile) water and a high calcium water (Bell Canyon) cannot be in connection lest gypsum precipitate (p. 120)." The proposed deepening of ERDA-6 through the upper Bell Canyon formation should help in answering this question.

Continuity of Strata in Castile

The report (pp. 91-92) criticizes Anderson (1978) for implying that thickening and thinning of Halite Units in Castile are related to deep dissolution and, by comparing the Halite-I "sinks" of Anderson with the isopach map of Anhydrite-I (Snider, 1966) (Fig. VII-2), concludes that "several of these thinings actually represent non-deposition, due to a local elevation of substrate above base level" (p. 92). According to Anderson (personal communication, 1982), the mounds shown on Snider's (1966) map (Fig. VII-2 of Lambert's report) probably resulted from salt tectonics and are not due to non-deposition.

Clearly, there are possible errors in Anderson's estimate of the amount of salt removal through dissolution at depth, due to the apparent assumptions (p. 89) made by him in calculating the percentage of removal. On the other hand, non-deposition or pre-Cenozoic subaerial erosion does not satisfactorily explain the amount and pattern of salt missing.

Geomorphic Evidence against Deep Dissolution

The report cites (p. 82) Bachman's interpretation of the Gatuna stream deposits as evidence of the westward migration of the Pecos river; and also that this is "contrary to a monotonically-eastward progression of postulated evaporite dissolution, if the river is said to keep pace with the dissolution front". Possibly this argument is in reference to the possibility of eastward migration of the Pecos which was suggested in an early EEG report (EEG-2 pp. 16-17). However that possibility was based upon the subsidence which has occurred east of the Pecos, and such subsidence may continue to move eastward if dissolution is occurring at depth. In spite of the assertion made in the report that, "Scarp formation appears to be insensitive to depth of halite removal and appears to keep pace with halite removal" (p. 139), slow removal of salt at depths of approximately 2000 ft. below the surface may not result in the formation of a scarp prominent enough for the river to follow. Erosion by water or by wind would most likely "keep pace to obliterate scarps as they form" (p. 140), if they are formed by lateral sapping of salt at depth.

The Timing of Deep Dissolution

Chapter IX of the report presents the evidence for dissolution in Triassic, Jurassic and Tertiary times. Anderson (1981) presented detailed arguments against Bachman's (1980) interpretation of the Cretaceous outcrops resting on the Castile formation as signifying a profound episode of dissolution down into the Castile during the Jurassic period. Anderson (1981) has referred to several published instances of Cretaceous rocks resting ("implaced by collapse") on rocks of various other ages. The main evidence cited by Anderson (1981) in favor of the more recent age of much of the deep dissolution is the age of the fill in Maley and Huffington's (1953) depressions; the depressions and the fill are clearly post-tilting and the Salado salt is absent in the center of these depressions.

The report acknowledges that, "San Simon Sink, at least, is a collapse feature" (p. 75) but has not commented on Anderson's postulation that the collapse has resulted from the dissolution of lower Salado Salt by waters derived from the Capitan reef aquifer (Anderson, 1981). The question has been left open with remarks such as, "Subsidence in San Simon Sink might (also) be attributable to collapse into a phreatic cavity in the Capitan" (p. 148), "It

is likely that these depressions (as well as such features as San Simon Swale) are in part erosional features" (p. 152-153), "The Cenozoic-filled depressions could simply be pre-Gatuna deeply-developed equivalents of Nash Draw" (p. 154) and "The ultimate nature of San Simon Sink, however, remains unresolved." (p. 76).

Stratabound Dissolution

A model of deep-dissolution called "Stratabound Dissolution" has been presented in the report as an alternate hypothesis to that of Anderson's. The essential features of this model are outlined on pages 153-154 and in Figure X-2.

According to the report, "The fatal weakness of the Anderson (1981) model of dissolution is the identification of the Bell Canyon formation as a sink" (p. 150). On the other hand, "One limiting factor in the stratabound dissolution model is as yet the inability to identify an efficient sink for the disposal of saturated brine of dissolution origin" (p. 161). One might say that this is a fatal weakness of the stratabound model also. The other weakness of this model is its ambiguity with respect to the geologic horizons involved and the time of occurrence.

SPECIFIC COMMENTS

Page 24, paragraph 1 - Jones et al. (1960) refers to drill hole logging in potash deposits which are in the Salado formation. This comment is therefore applicable to the Salado marker beds, which at any rate, "are traceable in the subsurface over horizontal distances of several kilometers to tens of kilometers" (p. 26, 4-6 lines). Anderson et al. (1978) have shown that Castile units can be correlated in wells as much as 113 km. apart.

Page 44 (last 2 lines) - The water from Bell Canyon could flow into Capitan?

Page 83 (First 2 lines) - But the line of cross-section in Figure x-1 does not pass through San Simon Swale!

Page 90 (Bottom) - "... removal of some halite (if originally deposited) near the basin margin must have occurred during Castile time (not Pleistocene)." What is the basis for this statement?

Page 100 - With regard to the quotation from Bachman (1980), Anderson points out that the correct interpretation is that of Castile-Salado unconformity and not "pan" deposition. At any rate, it does not address dissolution and collapse in lower Salado. With respect to the quotation from Jones (1972), Anderson points out that there are lateral variations in Salado, but not enough to explain the correlatable salt zones and missing salt as seen in logs.

Page 103, Fig. VII - 1-B - According to Anderson (personal communication), his interpretation of these logs was wrong. Cowden Anhydrite should be at the top of UNM Phillips No. 1 and higher in all other logs. The discussion of this figure on p. 97 is therefore irrelevant.

Page 144 - There should be detailed discussion of Maley and Huffington's depressions and Pleistocene dissolution and fill exhibited by them in this section.

Page 160 (3rd para) - Anderson's (1980) Brine Density Flow works laterally as well as vertically, driven by density gradient.

Page 161 (Mid Para) - Maley and Huffington's Cenozoic filled depressions provides the evidence that much of the salt removal at depth occurred in late Cenozoic, according to Anderson (1981).

SUMMARY AND RECOMMENDATIONS

Looking at Figure X-2 and the discussion of the Stratabound Dissolution concept, one gets the impression that the author of this report accepts the central basis for the idea of deep dissolution i.e., the preferential removal of salt at depth in the lower Salado beneath the Maley and Huffington depressions. The stratabound explanation is a fairly strong commitment to the idea of removal of salt by dissolution. The admission to the lack of a "sink" for the brine makes the concept difficult to accept. Not completing a thorough review of the geophysical logs and cores from wells to examine the causes for the absence of salt in the lower Salado horizon is a serious omission on the part of DOE which should be corrected as soon as possible.

It appears that one could skirt the issue of deep dissolution in the Delaware Basin altogether Vis-a-Vis the safety and integrity of the WIPP site, if an area of stable platform into which dissolution at depth has not made a dent, could be established around the WIPP site. This would, of course, require a fairly accurate estimate of the rate of advance of the "dissolution front", which could then be used to estimate a minimum period of safety. However, such an effort cannot be undertaken unless the mechanism for salt removal at depth is fairly clearly understood. The lower Salado salt is seen to be missing on accoustic log of Perry Federal #1 well, which is less than 2 miles east of the Zone IV boundary of WIPP. And of course, the encounter of brine at WIPP-12 has opened the entire question of the relationship of brine in Castile and the mechanism of salt removal in lower Salado formation. These questions must be answered in the best possible manner if confidence is to be placed on the geological integrity of the WIPP site.

EDITORIAL COMMENTS

1. Page 3, line 4 - delete "as."
2. Page 5, line 7 - "dendritic" is misspelled.
3. Page 9, equation in middle of page - The formula for polyhalite is incorrect. It should be

   $$Ca_2K_2Mg\ (So_4)_4.H_2O$$

4. Page 22, line 2 - The word "with" or "to" should be inserted between "proximity" and "the Ochoan."
5. Page 36, line 5 - The word "water" should be "salt" or "evaporites."
6. Page 49, 2nd paragraph, line 1 - The word "Rustler" is misspelled.
7. Page 72, line 1 - The word "completion" should be "completeness."
8. Page 94 - The first sentence on this page needs rewording....something like, "Anderson (1978) did not entertain the possibility that infra-Cowden thinning over the reef was due to reef-controlled non-deposition rather than reef related dissolution from below."
9. Page 163, 3rd line - "Origin" should be "original".
10. Page 164, para 4, line 4 - "features" is misspelled.

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
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ENVIRONMENTAL
EVALUATION GROUP

NOV 0 5 1982

Mr. Robert H. Neill
Director
State of New Mexico
Environmental Evaluation Group
P. O. Box 968
Santa Fe, NM 87503

Dear Mr. Neill:

Reply to Review Comments by EEG on Deep Dissolution Report (Neill to McGough, August 13, 1982)

Your comments on the draft Deep Dissolution Report have been taken into consideration, and the enclosed response has been prepared by the authoring organization.

It is necessary to keep in mind that it was the intent of this work to show that:

(1) there is no direct evidence of present or past preferential removal of lower Salado halite;

(2) previous (Anderson's) hypotheses have been tested and found wanting;

(3) a potentially efficient mechanism for stratabound dissolution (more efficient than "brine density flow" involving Bell Canyon, Capitan or Castile) had been identified;

(4) there is little evidence for stratabound dissolution anywhere save in the Rustler;

(5) if an efficient sink for brine disposal cannot be identified, there is no active dissolution, regardless of the postulated mechanism, and;

(6) if greater confidence in these conclusions is required, specific tests of the stratabound hypothesis could be made, for it is a testable hypothesis.

If after reviewing these responses you feel that further discussion of your comments is warranted, please contact my office to arrange for a meeting with the authors prior to printing of the final report.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 82-0759/6217

Enclosure

cc w/o enclosure:
R. K. Brown, TSC
G. L. Hohmann, TSC
C. C. Little, TSC
W. Weart, Sandia
C&C File, TC

ATTACHMENT TO MCGOUGH LETTER
NUMBER 0759/6217 DATED 11/5/82

Non-existence of Lower Salado Salt

Anderson's "hard data" for absence of salt are really his interpretations of acoustic logs, not the logs themselves. We disagree in numerous instances with his stratigraphic picks. A rereading of p. 90 will reveal that the page is replete with arguments for the statement about some halite removal (if any) being Permian and not Pleistocene.

Use of the word "missing" forces specific conclusions not appropriate with a sense of healthy skepticism toward any hypothesis. Non-deposition, for example, means "not missing." The whole discussion on p. 92 says the thickness of anhydrite near the basin margin is strong evidence that no halite was deposited, or if originally deposited, "removal . . . must have occurred during Castile time."

Despite your assurance from Prof. Anderson that thickness trends are not worth reanalyzing, we shall continue our re-interpretation as we have proposed and you have urged. As to the age of fill, Maley and Huffington called it Cenozoic. There is no evidence that we are aware of that assures us that broad definition (Cenozoic) has any precision greater than 65 my to present. No faunal or radiometric data are known on which to base any maximum age. Gatuna age deposits are known as part of the fill, but that does not demonstrate anything other than a minimum age. The age of the fill in the collapse areas is not well documented as all Pleistocene; therefore, Anderson's speculation of constraint of all dissolution to the Pleistocene on this basis alone is not tenable.

SNL proposed log correlations early in this process, but the preparation of the dissolution and deformation reports is what convinced us of the necessity. Activity was deferred until the specific goals of such a reinterpretation could be defined, and additional resources could be allocated, since the activity will serve many endeavors (structure, deformation, dissolution, etc.).

The acoustic logs have been run in Nash Draw holes (WIPP 25 through 30) and compared with Anderson's logs. That comparison was the basis for saying that the Anderson logs showed no signature of either gypsum or dissolution residue. Specific examples will be included to demonstrate the point.

Connection of Evaporite Beds and the Basin Aquifer

The potentiometric (static) differences between Bell Canyon and Capitan do not eliminate the possibility of interconnection. A re-reading of p. 45 will uncover a further, more powerful, argument against interconnection in the immense difference in osmotic potentials. The

report says "there is no tendency" for water movement across the Capitan/Bell Canyon interface, and also explains the basis for this statement. Page 45 explains the high osmotic gradient between Capitan and Bell Canyon waters, which must be taken into account as well as the static potentiometric gradient in predicting degree of water movement. The discussion will be augmented to clarify that in view of these opposing conditions, flow in either direction is considered unlikely.

Replacement Limestone as Basis for Past DMG-Evaporite Bed Connection

It was stated that the hypothesis of Kirkland and Evans was not the primary point of review; perhaps a more orderly discussion in the text is necessary so that the point about castiles not necessarily indicating deep dissolution will be considered "serious."

There are several serious flaws in the Kirkland and Evans suggestions and the Anderson speculation; chief among these is the innate (thermodynamic) incompatibility between (oxygenated) meteoric water (postulated to have moved freely in the Bell Canyon) and highly reduced hydrocarbons in the Bell Canyon.

By "errors," it is assumed that you mean the discussion is incomplete. It isn't what might normally be considered an "error" to suggest explanations, no matter how "serious" the investigation. We fail to comprehend how brecciation in the castiles is inconsistent with a deeper development of Olive's solution - subsidence troughs in the Gypsum Plain.

Castile Formation Brine and Bell Canyon Aquifer

There remains no "question" in our minds of Castile/Bell Canyon isolation in view of fundamental thermodynamics. Deepening ERDA-6 just to "answer" the "question" (which we consider non-existent) is not expected to help much. We feel that this comment recommends no useful change to the original text.

Continuity of Strata in Castile

It is Lambert's opinion expressed in the report that thinned halite overlying thickened anhydrite represents a syndepositional phenomenon. Apparently, Anderson considers it deformation. It is difficult to imagine how salt tectonics can give rise to anhydrite mounds, long after sedimentary consolidation. Anhydrite does not flow. The deformation report (Barrows et al., in preparation) considers that compensating variations in thicknesses of Castile anhydrite and halite beds are due to deformation (rather than late Cenozoic dissolution), despite cursory geological reasoning for such a situation.

It can be agreed that non-deposition or pre-Cenozoic subaerial erosion does not explain all things concerning the amount and pattern of salt "missing." The professional opinion is expressed that these are very

important factors which can explain the basic amount and pattern. Certainly a very strong case is made that a pronouncement of "deep dissolution" through the last few million years has very serious shortcomings whether the Anderson or Lambert models are applied. We are unable to make specific revisions based on the comment.

Geomophic Evidence Against Deep Dissolution (sic)

The results of serious investigations of dissolution in the Permian Basin of west (and northern) Texas shows the presence of scarps and dissolution as a front (Gustavson et al., 1980). If erosion destroys such a scarp or prevents it from forming, the dissolution rate is reasonably slow. If scarp formation due to "deep dissolution" is so slow that erosion obliterates scarps, (and the river keeps pace), the dissolution is so slow as to be inconsequential on the time scale appropriate to WIPP. Simultaneous blanket dissolution to prevent scarp formation is a difficult process to envision as "fresh" water has to be distributed over large areas before dissolving salt. There is no revision apparent for responding to the comment.

The Timing of Deep Dissolution

Rereading of p. 142 will reveal that Bachman's Cretaceous occurrences were not used as timers, and the report considers some of Anderson's objections to them valid. The absence of Jurassic rocks (Bachman, 1980) still stands as evidence of Jurassic or post-Jurassic exposure, since no Jurassic has been found associated with the Cretaceous collapsed rock.

The comment has been made (p. 141) that not all of these times when the area was above (and below) sea level are separable. However, there is consistent evidence for dissolution during earlier times, no matter how the Cretaceous rocks are interpreted. We have to disagree over the precision of the age of fill in the troughs -- see comment above, same subject.

No comment was intended to be made on Anderson's postulation of lower Salado dissolution by Capitan water under San Simon Sink. Overnight collapse occurs, however, only in brittle rock, and that is strong evidence for collapse into a phreatic cavity in the Capitan. A large natural open cavity in halite at 2000 ft depth has not been found: such cavities are not preserved so as to collapse catastrophically. See p. 147 (quote from Brokaw, et al, 1972). It was intended that the question of San Simon Sink be left open. The origins of Capitan-associated features (such as San Simon Sink, Carlsbad Caverns, and "breccia pipes") were not intended to be ultimately resolved by this report, unless they are shown by consequence analysis to be worthy of consideration as direct threats to the integrity of the WIPP horizon. This will be made explicit in the revision.

Stratabound Dissolution

The identification of the Bell Canyon Formation as a sink in Anderson's (1981) model is a fatal flaw. The lack of a demonstrated sink for stratabound dissolution is a problem, but not fatal in the same sense. This lack of a good candidate is a major reason why all schemes for dissolution at depth that are postulated to be very active now must be considered suspect. The parenthetical remark on p. 152 will be made more explicit in this regard.

Discussion of the stratabound model will be clarified to indicate that the only evidence of its occurrence is in the lower Rustler/upper Salado of Nash Draw.

Specific Comments

p. 24, para. 1: It is recognized that C. L. Jones can correlate the Salado marker beds as well and as far as R. Y. Anderson can correlate the Castile anhydrites.

p. 44 (last 2 lines): Yes. No tendency for Capitan water to flow into the Bell Canyon. See p. 45, middle. No tendency is indicated for flow in the other direction, either.

p. 83 (first 2 lines): Indeed the cross-section does not pass through San Simone Swale. A transition phrase will be added to make the reasoning smoother. The discussion concerns a general category of depressions to which San Simon Swale may belong. It is not necessary that Figure X-1 show San Simone Swale, since the relationship is clear along the line of Section A-A.

p. 90 (bottom): The basis for the statement is that the total thickness of Castile halite/anhydrite paired units remains the same. The only time that anhydrite could have formed "mounds" over which halite was thinned was the Permian, not the Pleistocene. Words will be added to that effect.

p. 100: The quotation is accurate and it does concern the evolution of evaporites within the basin. An unconformity at the Castile/Salado boundary would be an acceptable way of having Castile halite beds in the western part of the basin disappear, but we doubt this is the inference Anderson means to have drawn. The known Salado variations are evidence that beds may have disappeared during Salado times. No claim is made that it accounts for all "missing" halite.

Anderson has totally ignored the greatly thickened anhydrite sections that occur in the same boreholes with the thinned halite sections. This neglect makes his interpretations suspect. Thus, variations in the Salado can be explained by processes other than Pleistocene dissolution. This statement will be made explicit.

p. 103: The discussion is not irrelevant just because Anderson found an error in his interpretation. The interval nomenclature will need to be annotated or clarified. Final revision will probably await reinterpretation of the log data. This is an example of why the interpretation should be redone.

p. 144: It is not the intent of this work to reproduce all the source works within it. It will be clarified that the "Cenozoic" age of all the fill is not well established, and therefore cannot be used as a strong argument in favor of dominantly Pleistocene dissolution.

The basis of ages (e.g., lack thereof) for fill in the depressions will be more explicitly stated. The chapters on recommendations will be more explicit concerning some followup investigations of information on the fill.

p. 160 (3rd para.): There is geological evidence that Brine Density Flow does not work at all in this geologic setting. There is no salinity stratification observed in any subevaporite aquifer in the basin (excluding the Capitan). See p. 161, 1st para.

p. 161 (mid-para.): There is no evidence that all the Maley and Huffington fill is "late Cenozoic." Anderson's speculation is unwarranted solely on this basis. Again, it will be re-emphasized that the age of the fill is largely unknown.

SUMMARY AND RECOMMENDATIONS

The comments do not recognize that the Figure X-2 is diagrammatic and hypothetical. Looking at the text, we find it difficult to get the impression that the report accepts "deep dissolution." In addition, to our knowledge this report is the first instance of the detailed examination of the immense difficulty of brine disposal in any proposed dissolution mechanism, given the geohydrologic conditions of the Delaware Basin. If the concept of dissolution is made difficult to accept for want of a sink, there can be no active dissolution.

Stratabound dissolution is a hypothesis to explain how dissolution is occurring (Nash Draw); the lack of sink makes any hypothesis regarding active dissolution at great depths suspect. See similar earlier comment.

The review of geophysical logs had been previously done by Anderson under contract. The drafting of dissolution and deformation reports demonstrated the necessity of re-examining and updating the interpretation.

The problems with an operating, active method of "deep dissolution" will have to be more explicitly summarized. No estimate of rate of advance is germane without an operating mechanism. A revision to express the threat from stratabound dissolution (vis a vis Nash Draw) will be included.

M

There is no relationship apparent between brine reservoirs and salt removal.

The example of Perry Federal #1-31 cannot be used to illustrate preferential (active?) dissolution in the lower Salado. Note the greatly thickened section of Castile Anydrite III underlying the "thinned" halite between "Cowden"(?) and MB136. The total thickness of this section does not differ markedly from regional thickness, thus supporting depositional thinning of halite over an anhydrite "mound."

At the risk of repetition, we say that it has been scientifically established that WIPP-12 brine is not active dissolution brine. We do not consider the "relationship of brine in Castile and the mechanism of salt removal in the lower Salado Formation" an "open question." Such an issue has been addressed in detail on pages 114 through 121.

"Equal Opportunity Employer"

STATE OF NEW MEXICO

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January 3, 1983

Mr. Joseph M. McGough
Project Manager on WIPP
WIPP Project Office
U. S. Department of Energy
P. O. Box 5400
Albuquerque, NM 87115

Dear Mr. McGough:

RE: Deep Dissolution Report (SAND 82-0461)

Your reply to EEG's comments on the subject report (McGough to Neill, 11/5/82) and the attachment to your letter, indicate that the author of this report has accepted a number of EEG suggestions for improvement of the report. We understand that the final version of the report will include the following major changes.

a. A reinterpretation of geophysical logs of Salado and Castile strata in the northern part of the Delaware Basin will be completed and the results clearly presented to prove your assertion that the absence of halite in Salado is due to non-deposition or erosion shortly after deposition.

b. Specific examples of accoustic logs from WIPP 25 through 30 will be used to show that the zones of missing salt in Salado, as interpreted from accoustic logs of deeper boreholes do not show signature of either gypsum or dissolution residue.

c. Clear examples and explanations will be provided to justify the contention that the total thickness of Castile halite/anhydrite paired units remain essentially the same in the basin. Figure VII-2 (p. 105) and the discussion on page 92 show some examples of errors in Anderson's argument but do not bring out the point being made convincingly.

M

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

There are other points in your reply to our comments which could be argued from an academic point of view. However, the changes listed above will satisfy our major concerns in this area.

Sincerely,

Robert H. Neill
Director

RHN:eg

2-096-AG2-15-1-1

cc: TSC, IEA

DMG HYDROLOGY

TME-3166

"Equal Opportunity Employer"

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August 25, 1982

Mr. Joseph McGough
Project Manager of WIPP
U.S. Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87115

Dear Mr. McGough:

Enclosed are our review comments regarding the draft of "Delaware Mountain Group (DMG) Hydrology - Salt Removal Potential NM78-648-813B. April 1982" by D'Appolonia Consulting Engineers. We shall be looking forward to hearing your response.

Sincerely,

Robert H. Neill
Director
2-050AG2-18-3
RHN:du:lgr

cc: TSC, IEA

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

Comments on Draft DMG Hydrology Report

INTRODUCTION

These comments are based upon a critical reading of the report and many of the references cited in the report. The calculations, assumptions and data in the report were checked for accuracy and reasonableness. Most of the calculations are correct - a few specific errors or discrepancies are noted under Specific Comments. Construction of some of the graphs presented in Chapter 5 is unclear - these are also discussed under Specific Comments. The section on General Comments contain our suggestions for improvement of the report on a thematic basis.

EXPECTATIONS FROM THE REPORT

The "Cost and Merits Evaluation for Stipulated Agreement Activities" attached to the 8.31.81 letter from Schueler to Goldstein contained details of the proposed work and expected results. In our judgement, the following two items have not been included in the draft report.

a. "Possible communication (of DMG) with other aquifers e.g. reef aquifer, San Andres limestone aquifer and shallow aquifers" has not been treated in this report. Although the details on this theme are expected in the regional hydrology report, a brief treatment of this subject will be desirable in this report for completeness. We recommend adding a subsection under section 2.2 of the report for such discussion.

b. The "Expected Results" section of the Costs and Merits document for DMG Hydrology states, "Additionally, the relative merits of various dissolution theories will be discussed." We understand that the primary document for such a discussion is the Deep Dissolution report, but the DMG Hydrology report should at least discuss the possibility of proposed mechanisms, other than Anderson's deep dissolution, explaining the observed features of DMG and Reef

hydrology and hydrogeochemistry. A discussion of Bachman's "Solution and fill," subaerial erosion during Jurassic time and Lambert's "Stratabound Dissolution" in this context would be very appropriate and useful.

GENERAL COMMENTS

Acceptance of Deep Dissolution

On the basis of geological and geochemical evidence and observed rates of mass transport, the report has accepted the possibility of deep-seated dissolution at the margins of the Capitan reef and above it. The following quotations from the report indicate such acceptance.

> "Based on observed mass transport rates in the Capitan Reef and existing deep-seated dissolution features (breccia pipes), convective mechanisms such as brine density flow may be occurring at the reef margin." (p. 4-16, para 3)

> "...there is evidence to suggest that active convective dissolution of the overlying Salado Formation together with the diffusion from halite zones can result in the observed mass transport rate in the Capitan Reef aquifer". (p. 4-9, para 2)

> "....dissolution at the Capitan Reef margin in the Castile and Salado may be associated with the convective mechanism and is consistent with observed deep dissolution features which suggest a more vigorous dissolution process than diffusion." (p. 5-4, 3rd para)

In addition, the report has accepted the possibility of some deep-seated dissolution <u>throughout the basin</u>.

"Additionally, the presence of saline waters to the Bell Canyon and Capitan Reef aquifers which underlie or are adjacent halite units suggests that some form of deep-seated dissolution may be present throughout the basin." (p. 3-3, 4th para).

Omission of Salado Salt Removal

Having accepted the possibility of the mechanism of salt removal through convective flow at depth, the report has not addressed a major contention of Anderson (1981), i.e., the removal of salt from the Salado formation. All the analytical models considered in the report deal with the "salt dissolution in the Castile Formation and mass transfer to the Bell Canyon Aquifer" (p. 6-1, para 2).

The reasons for this omission are not clear, since according to the report, "it seems likely that the groundwaters have dissolved some salt from the Salado and Castile formations" (p. 3-2, 2nd line). In fact, task no. 3 (p. 1-4) for the study is to, "Assess the potential for dissolution in the Castile and Salado formations." It is hoped that the final version of this report will correct this omission.

DMG Aquifer Parameters

The conclusion that the rate of dissolution of salt is so slow that, "this would have an insignificant effect on the integrity of the facility" (p. 1-7) is based upon the salt transporting capacity of the DMG aquifer. The report accepts that, "Removal rates from the Castile Formation based on convective transport mechanisms are estimated to be significantly greater than the salt transport capacity of the Bell Canyon aquifer" (p 4-11, line 3 to 6). Therefore, it becomes critically important to examine the raw data which has been used to estimate the salt transporting capacity of the DMG aquifer.

The input parameters for numerical computations are listed in Table 4-1 of the report. These parameters are identified from the hydrogeological characteristics of the Bell Canyon formation listed in Table 2-1. The data for Bell Canyon hydrogeology are taken from Hiss (1975a). The only other source of data is Lynes Inc. (1979) which reports on a drill-stem test in AEC-7 drillhole.

The most important input parameter is the hydraulic conductivity of Bell Canyon aquifer. Hiss (1975a) compiled laboratory determinations of

permeability and porosity, made by oil companies on cores collected from the lower Bell Canyon and Upper Cherry Canyon formations. The cores were collected from sections most promising for hydrocarbon production. On the basis of these compiled values, Hiss (1975a) computed an "average" permeability for the DMG formation as 6.70 millidarcies which is equal to about 0.005 m/day of hydraulic conductivity. The hydraulic conductivity of 1.8 m/yr. listed in Table 4-1 is simply this value computed by Hiss (1975) from reported laboratory values (0.005 m/day x 365 = 1.8 m/yr.). Similarly, the effective porosity value of 0.16 is also the "average" porosity value reported by Hiss (1975a) from his compilation of oil companies data. Hiss (1975a) did not report any aquifer performance tests for Bell Canyon. In fact, the only aquifer data are that collected from a drill stem test in AEC-7 (Lynes, Inc. 1979).

While the report treats several mechanisms for flow in the Castile formation, it only treats porous media flow in the DMG aquifer. The hydrologic data available for porous media flow in the DMG indicates that the DMG is not capable of transmitting significant amounts of salt. This in turn keeps dissolution of salt to a minimum even when considering the "implausible worst case scenarios" described in the report (Sec. 5.2).

In view of a possible fault connecting Bell Canyon with Castile formation (U.S. DOE, 1980b, Figs. 2.7-20 and 2.7-21) and the existence of a joint system (p. 2-7, para. 2), it is surprising that no consideration is given to salt transport through fractures which may exist in DMG aquifer. It is recommended that the final version of the report includes calculations based on assumptions of joints in DMG and at least one fault connecting DMG and Castile formations.

Capitan Aquifer as a Deep Dissolution Sink

The report states that the, "Geochemical evidence of salt dissolution is provided by the composition of groundwater from the Bell Canyon and Capitan aquifers" (p. 3-1, 3rd para) and that "it seems likely that the groundwaters have dissolved some salt from the Salado and Castile formations" (p. 3-2, first para). While the report rules out DMG as a carrier of the dissolved

salt, it suggests that the Capitan aquifer may directly participate in the salt dissolution at depth. The Chapter on "Conclusions" (Chapter 6) states,

> "As is evident from this study, brine density flow or convective dissolution is a potential mechanism for removal of halite and its occurrence in the Delaware Basin is possible in areas overlying and at the Capitan Reef aquifer margin." (p. 6-3)

This is an important statement and raises several questions concerning the mechanism of salt removal without DMG aquifer participation, directly to the Capitan aquifer. The existence of decreasing chloride concentration down gradient in the Capitan Reef aquifer is one example of the problems to be resolved and understood. The report, in its final form, should try to present a mechanism of salt removal from Castile and Salado into the Capitan Reef aquifer without involving the DMG aquifer.

Brine in Castile

The report has disregarded the importance of pressurized brine in the Castile formation vis-a-vis the question of salt removal from Castile and Salado (p. 2-12). Even though these brine occurrences do not seem to be connected to the DMG aquifer, they may not be completely isolated. Also, the brine is found in large volumes. The most recent estimate of the volume of the brine reservoir encountered by WIPP-12 is 30 million barrels (Popielak, NAS-WIPP panel presentation, Aug. 1982) which would occupy 170 million cu. ft of space. The significance of such large volumes of pressurized brine to the question of removal of salt through dissolution in the same formation should be discussed more thoroughly in the report.

Use of Mathematical Models and Equations

The report has quantified the rates of dissolution for mechanisms of diffusion and density induced convection by using the equations for density induced flow effects, Rayleigh numbers and Nusselt numbers; use of a steady state analytical mass balance model; and the use of a numerical mass transport model.

Many of these approaches and assumptions appear to have possibilities of errors. Thus, for example it seems possible that brine density flow could occur in fractures much smaller than the 0.5 and 1.5 mm calculated in the report; the value of Rs used for the equation $N_S=0.1\ R_S^{1/3}$ may not exceed $5x10^{10}$ whereas the report uses $R_S=1.2 \times 10^{21}$; and the comparison of the dispersion coefficients calculated from the Knapp and Podio (1979) experiments to the diffusion coefficient could be erroneous. All these points are discussed in detail under Specific Comments.

SPECIFIC COMMENTS

page 1-3, 8th and 9th line from top and page 2-7, 2nd paragraph:
The WIPP Safety Analysis Report (page 2.7-33, Figures 2.7-20 and 2.7-21) indicates that a northwest-southeast trending fault may exist on the interface between the Delaware Mountain Group and the Castile Formation. The fault is located approximately 9 km northeast of ERDA-9 and would be within 1 km of the repository as presently planned. The potential existence of a fault and its consequent hydrologic effects on the repository should be addressed in this report.

page 1-4, 1st paragraph:
The statement, "When placed in salt beds which have remained generally stable since deposition in the Permian time (more than 230 million years ago), the waste buried in the WIPP facility may reasonably be expected to remain isolated from the biosphere for thousands of years" ignores everything that has happened to the salt beds since their deposition, viz. uplift, tilting, folding, salt tectonics, intrusion by a dike, collapse along breccia chimneys, dissolution, formation of cavities filled with huge reservoirs of brine, erosion, etc. It is clearly misleading, detracts from a satisfactory resolution of the question of future stability and isolation of the WIPP repository, and should therefore be removed from this report.

Similarly the sentence following the above mentioned one states that radioactive decay will reduce the hazard to "negligible levels" in a few thousand years. The Pu-239 inventory will be essentially the same as at closure and the statement as incorrect.

page 1-7 3rd, and 4th bulletted conclusions:
The terms "insignificant", "no significance," and "not greatly increase" are qualitative. They should be either replaced by or appear with the respective quantifiable number from Chapter 5 or Appendix B.

page 2-7, section on "Fracturing":
In which formations are the two sets of joints located?

Does the joint set extend into or is it located within the transmitting sandstones of the DMG? These joints may be capable of transmitting water and thus have a high dissolution potential. The dissolution effects of convection along a joint or fracture in the DMG should be addressed in the report.

page 2-8, 19th through 29th line from top:
The values of permeability presented here appear to be taken from Table 6 of Hiss's (1975a) report and are average permeabilities on a county by county basis. Figure 21 of Hiss's (1975a) report indicates that permeabilities near the WIPP site range from less than 1 md to 59 md (<0.3 m/year to 18 m/year for pure water at 20°C).

page 2-11, last paragraph
The report should indicate that the hydraulic conductivity of the Castile anhydrites is not limited to porous flow. At WIPP-12 a fracture in Anhydrite III-IV of the Castile is capable of producing over 300 gallons per minute of brine (D'Appolonia Consulting Engineers, Inc., "Data File Report, ERDA-6 and WIPP-12 Testing," Volume IV A, Activity WIPP-12.2, Feb., 1982). At ERDA-6 a fractured zone in Anhydrite II of the Castile is capable of producing over 20 gallons per minute of brine (D'Appolonia Consulting Engineers, Inc., "Data File Report, ERDA-6 and WIPP-12 Testing, Volume II A, Activity ERDA-6.7, Feb., 1982) Preliminary calculations by EEG staff members indicate hydraulic conductivities of 2000 m/day for the fractured zone at WIPP-12 and 5 m/day for the fractured zone at ERDA-6. These values of hydraulic conductivity are at least six orders of magnitude greater than the values presented here.

page 2-12, 2nd paragraph:
Does the source of salt in the Castile brines come from dissolution of halite overlying or underlying the anhydrite layers?

page 2-12, 2nd paragraph:
The statement is made that Castile brine "pockets exhibit different (mostly higher) potentiometric surfaces than the Bell Canyon". It appears that all the potentiometric surfaces for the brine pockets are higher than those for the Bell Canyon.

page 2-13, 2nd paragraph:
Are the contours on Figure 2-7 "averaged" over the various water bearing units of the Rustler Formation or are they the contours for the Culebra only? They look like they represent water levels in the Culebra. A recent draft report (Gonzalez, D.D., "Fracture Flow in the rustler Formation: Waste Isolation Pilot Plant (WIPP) Southeast New Mexico (Draft Interim Report)," SAND 82-1012, May, 1982) has changed the Culebra contours from those presented in previous reference works (Mercer, J. W., and B. W. Orr, 1977; Mercer, J. W. and B.R. Orr, 1979; Mercer, J. W. and D. D. Gonzalez, 1981). Figure 1 through Figure 4 indicate how conceptions of the head in the Rustler Formation and the Culebra Dolomite have changed with time.

page 3-4, section 3.2.1
This section deals with possible mechanisms for salt dissolution. This section appears to put forth only the ideas developed by Anderson (1978) and Anderson and Kirtland (1980). If any other ideas exist, they are not presented. No additional ideas for potential deep dissolution mechanisms are put forth. The possibility of dissolution from flow in joints or fractures in the Delaware Mountain Group and Castile anhydrite rocks should be addressed.

page 3-5, section 3.2.2
This section quantifies the amount of salt that can be diffused through the lower anhydrite of the Castile Formation by means of either a fracture or a porous medium. The results indicate that the fracture will propagate upward at a rate of $3x10^{-5}$ meters per year and that, in the porous medium case, a dissolution front would propagate upward at a rate of $3x10^{-6}$ meter per year.

The analysis is based on the assumption that steady state is reached. This approach is probably correct for the porous medium approach because the porous medium has been in place for more than 200,000,000 years. On the other hand,

fractures can form at any time. In a fracture the initial unsteady state rates of dissolution and diffusion of salt should be very large compared to those of the steady state because of the steep concentration gradient which forms at the top of the fracture. The amount of salt that can be dissolved at unsteady state by a fracture should be quantified here.

Both the fracture and porous medium rate of diffusion calculations should include the range of Delaware Mountain Group NaCl concentrations because the amount and rate of dissolution are dependent on this. These calculations should show that dissolution of halite will occur faster at the up gradient parts of the Delaware Mountain Group than at the down-gradient parts.

page 3-8 to 3-10, "Threshold of Convection in Fractures and Porous Media"

This section is used to estimate the width of a fracture required to initiate brine density flow. This is done by approximating the width of a fracture with the radius of a tube. A study performed by Wooding (Wooding, R. A., "Instability of a Viscous Fluid of Variable Density in a Vertical Hele-Shaw Cell," Journal of Fluid Mechanics, vol. 7, Jan. - Apr., 1960, pp. 501-515) tends to indicate that this is not the correct approach. Using a mathematical model of water and mass transport between two parallel plates, he found that the width required to initiate density flow was dependent on the length of the parallel plates. Wooding (1960) verified his results with a Hele-Shaw analog model. The results of his study indicated that brine density flow could occur in fractures much smaller than the 0.5 and 1.5 millimeters indicated in this report. If a fracture is assumed to have smooth parallel sides, then a fracture with a width of 1 mm has a high hydraulic conductivity (0.7 m/s) and is capable of transmitting significant amounts of salt.

page 3-10, 2nd paragraph:
A basis or reference for the statement "It is doubtful whether single fractures of one millimeter or more in aperture could remain open and continuous in Anhydrite I" should be provided. While the drilling in the Castile Formation has not indicated any significant fluid producing fractures in Anhydrite I, they have been observed in the higher anhydrites of the Castile. The most notable example of a fracture occurs at WIPP-12 about 3010

feet below land surface. This fracture is capable of producing several hundred gallons per minute of flow and it could be classed as open and continuous.

page 3-10, last line:
The validity of the equation $Ns \approx 0.1\ R_s^{1/3}$ should be examined. It appears that this relationship was originally derived by Elder (1967) although this report attributes it to Golitsyn (1979). Elder (1967) presented data which indicates that the above equation is valid for $\approx 5x10^8 < R_s < \approx 5x10^{10}$. Elder (1967) has other relationships for $R_s < \approx 5x10^8$, but none for $R_s > \approx 5x10^{10}$. The value of R_s used in the calculation involving the above equation is $1.2x10^{21}$, which is many orders of magnitude higher than the known range of valid R_s values for that equation ($\approx 5x10^8 < R_s < \approx 5x10^{10}$).

page 3-11, 2nd paragraph:
The comparison of the dispersion coefficients calculated from the Knapp and Podio (1979) experiments to the diffusion coefficient could be erroneous. This comparison is made on page 3-11 of the report as support for the contention that convective mass flux is 10^6 times higher than diffusive mass flux. Knapp and Podio (1979) treated the salt transport as a purely dispersive process. Wooding (1959), who studied the same phenomenon, included both a convection term and a diffusive term in his analysis. The large value of the Knapp and Podio (1979) dispersivity estimates tend to indicate that convection is occurring. Essentially the dispersion coefficient determined by Knapp and Podio (1979) approximates the convection of brine as a dispersive process.

Knapp and Podio (1979) performed four experiments in their study of salt transport in boreholes. Three tests were run in a bore tube with a diameter of four inches. Two of these tests were run with an induced velocity in the borehole; one was run with no induced velocity. The fourth test was run in a two inch diameter borehole and had no induced velocity. The calculated dispersivities ranged from 45 cm^2/sec to 48 cm^2/sec for experiments run in the four inch bore tube and was 12 cm^2/sec in the two inch bore tube. Knapp and Podio (1979) concluded that the dispersivity depends on the cross-sectional area of the bore tubes. If these dispersivities are corrected for the "radius

of a fracture" of 0.001 meter, the dispersivity would be very small, say on the order of 10^{-6} m^2/sec. This would yield a Nusselt number of about 10^3 instead of 10^6 and would dispute the contention that convective mass transport is 10^6 times higher than diffusive mass transport.

page 3-12, 5th line from top:
The reason for believing that fracture of 1mm or more are unlikely to exist should be given. Wooding's (1960) results indicate that convection in a fracture of less than 1mm width can exist.

page 3-14, 3rd paragraph:
If a fracture were to propogate itself, (i.e. dissolve only the salt directly above it) it would reach the repository in less than 20 years at a rate of 28 cubic meters per square meter per year.

It seems very unlikely for a front to propogate as a square tunnel. Does any literature exist or has any been reviewed to indicate what shape forms when salt dissolves?

page 3-15, 1st line to 6th line from top:
This calculation assumes that there is no flow or dispersive flux through the DMG. What is the effect of flow and dispersion through the DMG on the time for salinity buildup to saturation? It is possible that a fracture extending into the DMG could transport the salt away toward the reef at a high rate and saturation would never be reached. It is highly probable that, due to the sparse drilling activity in the DMG, vertical fractures were missed during drilling.

page 4-4, "Hydraulic Conductivity" section:
The range of hydraulic conductivity should be extended from 1 md to 59 md (0.3 m/year to 18 m/year). See comment regarding page 2-8.

page 4-5, "Chloride Concentrations" section
The chloride data on Hiss's (1975a) Figure 26 tends to confirm the existence of the 100 kg/m^3 contour on the upgradient end of the Bell Canyon aquifer.

page 4-6, section 4.3.1

This is a good approach to use as a first approximation because the method is insensitive to whether the source of salt is by diffusion from above, convection from above or from some other source. In essence, the amount of calculated salt input by this method can be assumed to be from dissolution of overlying halite. Thus the amount of halite dissolved is probably overestimated. However the basic assumption in this model as applied to the DMG is porous media flow in the DMG aquifer. In addition the model presented here does not include longitudinal dispersion, which would tend to increase the amount of salt dissolved. Is dispersion insignificant in this case?

page 4-7, 8th line from top:

The mass of salt dissolved per year or 10,000 years should be presented here. Also the mass flux and rate of salt being dissolved from underneath the WIPP site should be presented for comparison purposes. An EEG calculation indicates these values are 4.1×10^{-4} kg/yr/m^2 and 0.31 cm/10,000 years, respectively.

page 4-9, 2nd paragraph:

It would be interesting to see the amount of salt that can be dissolved by the mechanism described in this paragraph. Would it be large enough to dissolve Salado salt laterally from the reef to the repository? Would it also be large enough to account for the amount of salt being transported by the Capitan Reef aquifer? However, the decreasing concentration of chloride downgradient along the eastern side of the Capitan Reef (see page 4-5) tends to indicate that convective dissolution of the overlying Salado is not occurring in this part of the aquifer. Active convective dissolution would tend to increase the chloride.

Could salt transport through fractures in either the DMG or Castile be enough to account for the estimated salt transport in the Capitan Reef aquifer?

page 4-10, 2nd and 3rd paragraphs:

The mass balance model described here should have a longitudinal dispersive term included.

page 4-13, 8th line from bottom:
The average value of vertical removal of 0.34 cm per 10,000 years obtained from the numerical approach agrees very well with the 0.31 cm per 10,000 years obtained from the analytical approach. What is the range of vertical salt removal over the 16,500 m long line underneath the repository?

page 4-14, section 4.4.3
The sensitivity analysis with respect to hydraulic conductivity should be extended to 18 m/yr. See comment regarding page 2-8.

page 4-16, 3rd to 6th line from top:
One of the reasons the numerical approach concluded diffusion as the source of salt to the DMG is that the model assumed diffusion as the source to start with. The model was then calibrated to determine the diffusion coefficient, which happened to be in the range of acceptable values. It can only be concluded that diffusion is a possible explanation but by no means the only one.

page 4-16, last paragraph:
Has an estimate of the rate of salt dissolution from the reef toward the repository been obtained? Page 4-9 indicates that the reef transports 20×10^6 to 440×10^6 kg/year of chloride, of which only about 3×10^6 kg/year is accounted for. If the remainder of the chloride transported by the reef comes from the brine density flow indicated here, how large a cavity would form in the Salado? What is the structural integrity of such a cavity? How fast would a cavity advance toward the repository? No sound basis is provided for the argument that the salt removal potential of the reef will not affect the repository.

page 5-2, 6th line from bottom:
"0.34 centimeter" should read "0.31 centimeter".
It appears that this paragraph is discussing the rates of dissolution determined from the analytical model. Page 4-7, third paragraph, indicates that the amount of salt dissolved is 0.3 centimeters in 10,000 years.

page 5-3, 1st line:
"0.7" should be "0.6". The dissolution process described on page 5-2 has a linear relationship between flow thickness and dissolution height. If the aquifer thickness is doubled, the dissolution height should double.

page 5-4, 5th line from top, ref. Figure 5-2:
The "dissolution controlled by diffusion" curve on Figure 5-2 does not pass through the point defined by flow rate= .135 m^3/yr/m and height = 0.34 cm. The results of the numerical modelling as presented on page 4-13 indicate that flow rate= .135 m^3/yr/m and height = 0.34 cm is the solution to the numerical modelling problem. Is the "dissolution" curve on Figure 5-2 correct?

page 5-6:
Going back to the analytical model; for an aquifer flow rate of .135 m^3/yr/m and a chloride concentration change of 50 kg/m^3 in 16,500m, underneath the repository, the amount of salt dissolved over the 16,500 m line is 4.1×10^{-4} kg/yr/m.[2] If this amount of chloride all dissolved from one fracture, the amount of chloride passing through this fracture is 6.8 kg/yr/m, which is slightly less than the 10 kg/yr/m being used here. Therefore the results presented in Figure 5-2 may be slightly higher than what can actually occur,subject to any sensitivity analysis and the assumption of porous flow in the DMG. An approach to maximize salt dissolution would be to use a chloride concentration change of 150 kg/m^3, which is the change from one end of the DMG to the other. Using this approach, one gets about 20 kg/yr/m of slat dissolution through a fracture.

page 5-6 5th line from bottom:
As mentioned earlier, work by Wooding (1960) indicates that convection can occur in fractures smaller than 1.5 mm.

page 5-6, 2nd para.:
The calculation of fracture width is not quite clear. If a fracture is capable of transporting 6×10^4 kg/m^2/yr (page 3-11) of salt, it is capable of transporting 3.64×10^4 kg/m^2/yr of chloride. If fracture width is calculated by $Q\Delta C/3.64 \times 10^4$ kg/m^2/year, then the fracture width curve on Figure 5-4B

should be lowered. Again, Wooding (1960) indicates convection can occur in fractures with an aperture smaller than 1.5 mm.

page 5.12, bottom paragraph:
The simple statement that 400 m thickness over a 1 m cavity with a 94 m diameter should be enough structural support is weak and not convincing. Some more justification of this idea should be provided.

Table 4-1
What is the basis for the dispersivity of 3.048 meters shown on Table 4-1?

TYPOGRAPHIC ERRORS

page 2-2, 6th line from bottom, page 2-12, bottom line and "Bibliography," page 6:
"Gonzales" should be "Gonzalez"

page 3-6, bottom line and "Bibliography," page 3:
"Bear, (1975)" should be "Bear (1972)." This typographic error occurs several places in the report.

Table 3-1, footnote 5:
"Figure 3-8" should be "Figure 3-7"

Figure 3-7:
An "H" should be placed after "Dissolution Cavity Width" at the top of the figure.

Figure 5-1:
"Cayon" should be "Canyon" in footnote 2.

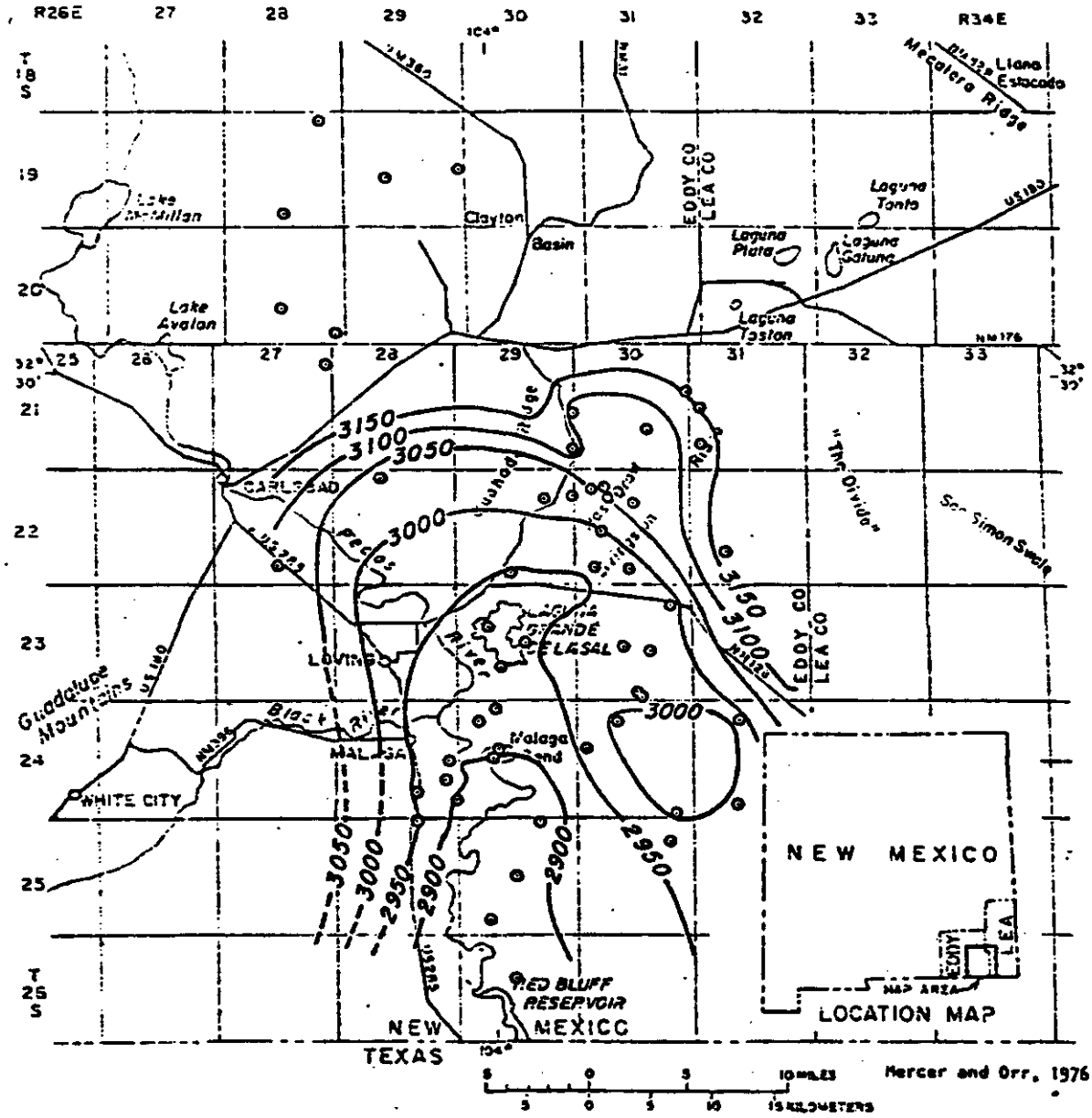

EXPLANATION

● Well producing water from Rustler Formation

3000 — Potentiometric contour showing altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 50 feet. Datum is mean sea level.

Sources of data:
Hendrickson and Jones, 1952; Hale and others, 1954;
Cooper, J. B., 1962; Jones and others, 1973

Figure 1.--Potentiometric surface of the Rustler Formation, 1952 through 1973.

From: Mercer, J. W. and B. R. Orr, 1977

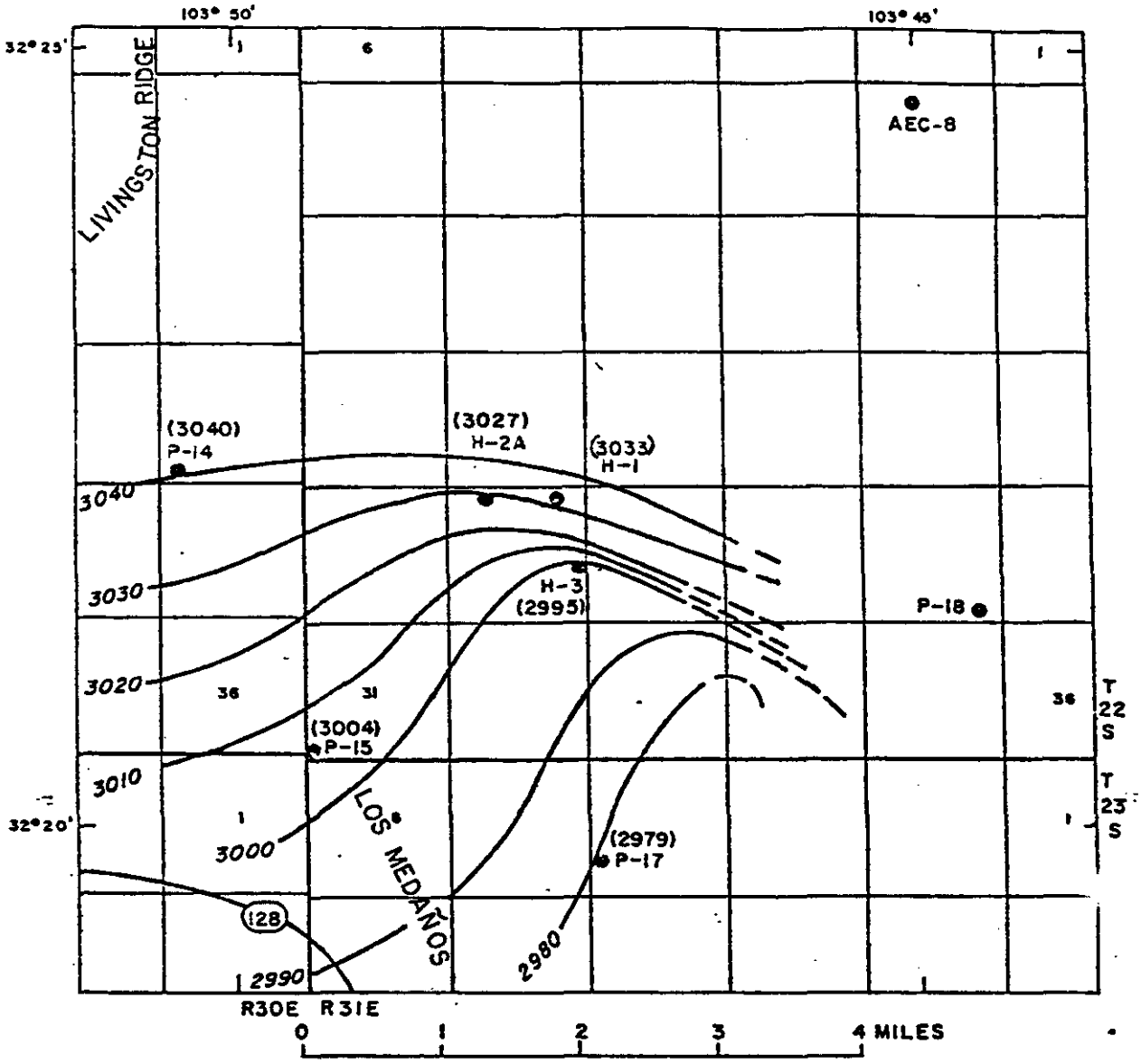

EXPLANATION

● P-17 (2979) WELL--P-17 is well identification. (2979) is altitude of water level, in feet (expressed as freshwater with a density of 1.00 gram per centimeter). Datum is mean sea level

—— 2990 —— POTENTIOMETRIC CONTOUR--Shows altitude at which fresh water having a density of 1.00 gram per centimeter would have stood in a tightly cased well, October 1977. Dashed where approximately located. Contour interval 10 feet. Datum is mean sea level

Figure 2. --Potentiometric surface of the Culebra Dolomite Member of Rustler Formation.

From: Mercer J. W. and B. R. Orr, 1979

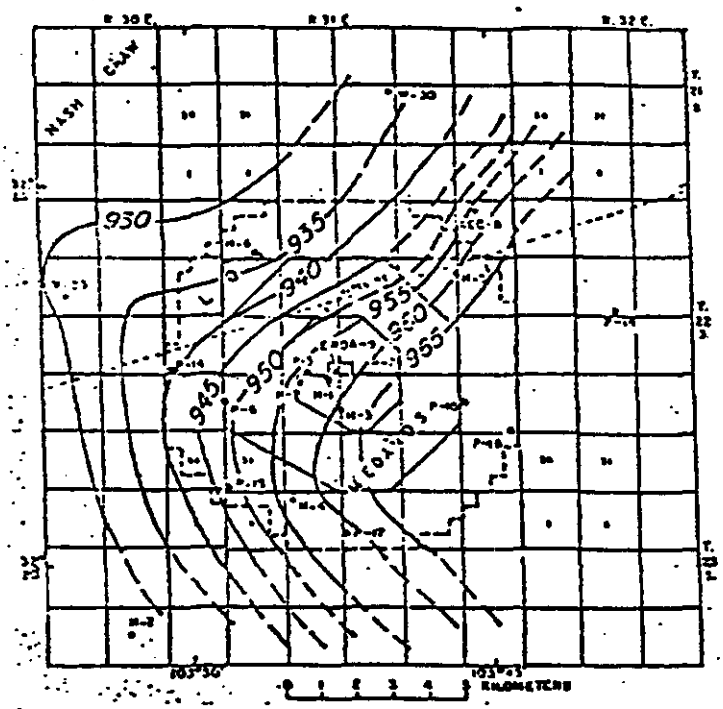

MAGENTA DOLOMITE MEMBER
OF THE RUSTLER FORMATION

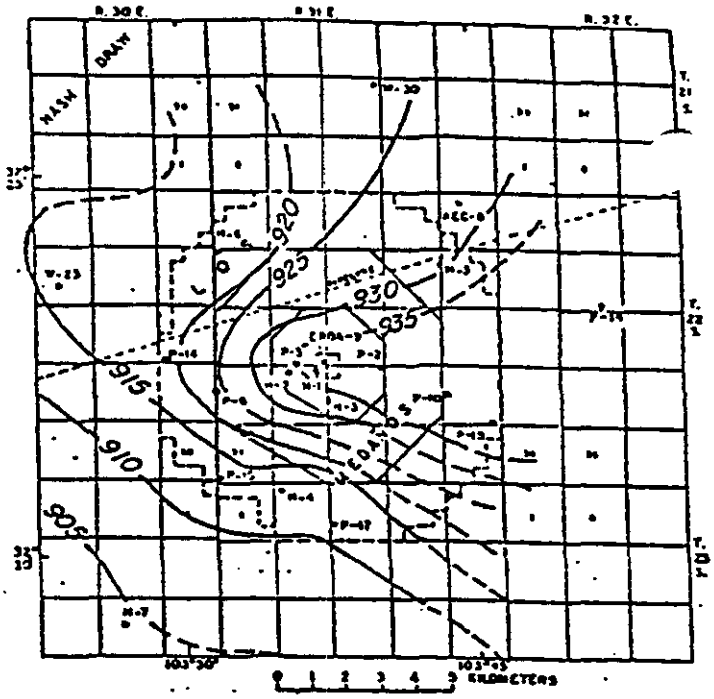

RUSTLER SALADO CONTACT

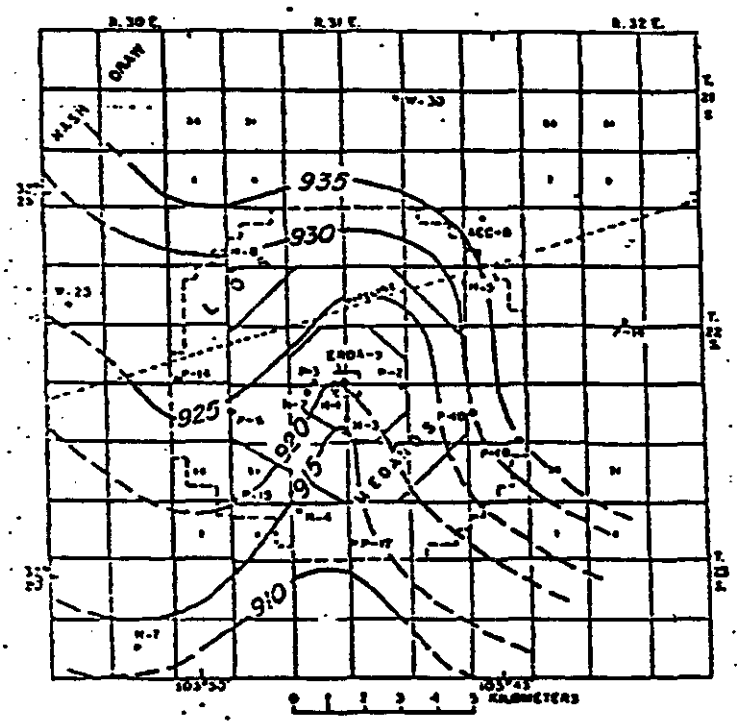

CULEBRA DOLOMITE MEMBER
OF THE RUSTLER FORMATION

EXPLANATION

—925— POTENTIOMETRIC CONTOUR--Shows altitude at which freshwater having a density of 1.00 gram per cubic centimetr would stand in a tightly cased well. Dashed where approximately located. Contour interval 5 meters. National Geodetic Vertical Datum of 1929

P-17 WELL AND NUMBER

Figure 3.--Preliminary potentiometric surface maps of water-bearing zones at WIPP in fresh-water equivalent head.

From: Mercer, J. W. and D. D. Gonzalez, 1981

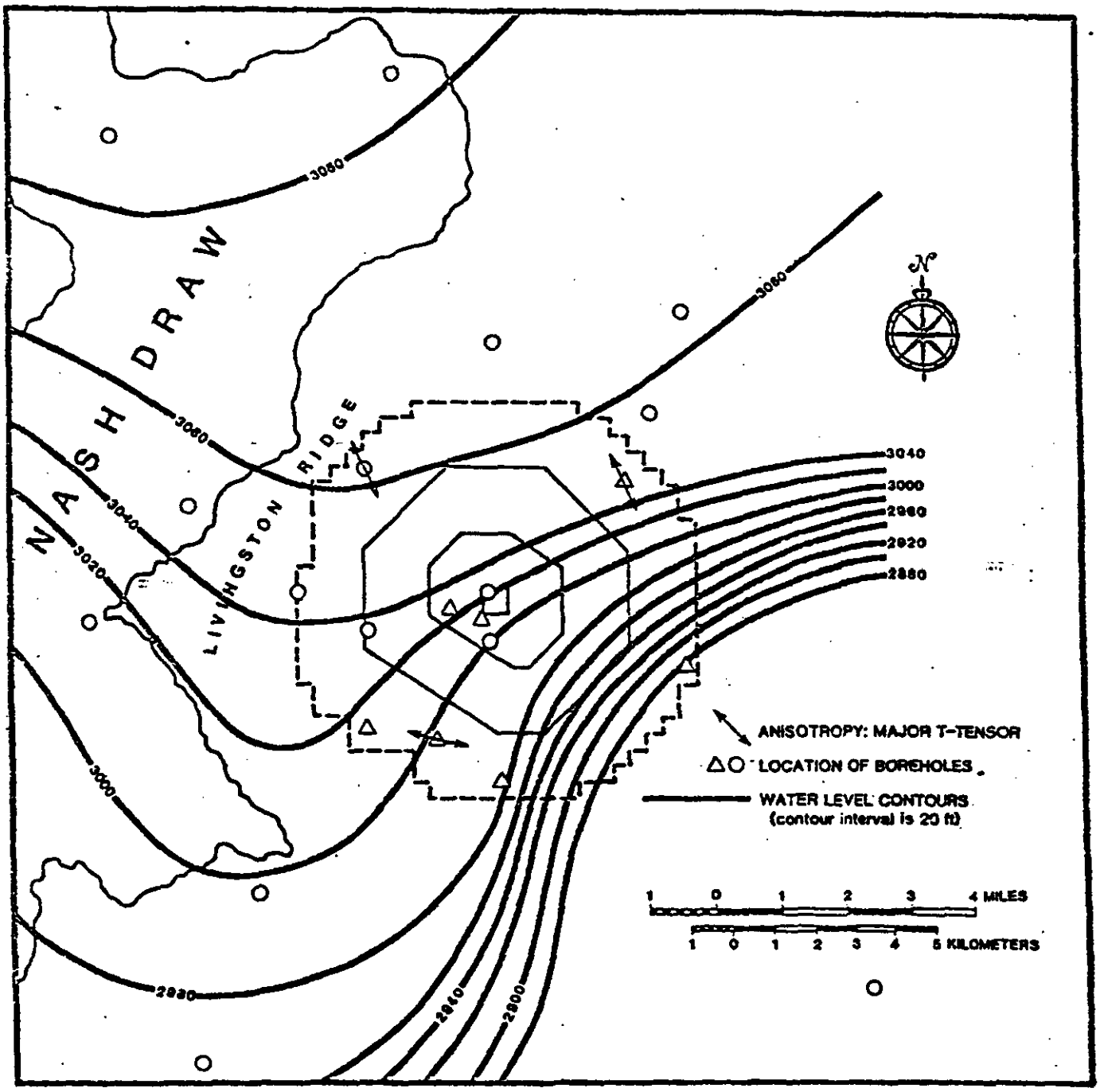

Figure 4. Water Level Contour Map of the Culebra Dolomite in Fresh Water Head

From: Gonzalez, 1982

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

RECEIVED
NOV 30 1982
ENVIRONMENTAL
EVALUATION GROUP

NOV 24 1982

Mr. Robert H. Neill
Director
State of New Mexico
Environmental Evaluation Group
P. O. Box 968
Santa Fe, NM 87504

Dear Mr. Neill:

Reply to EEG Comments on Draft Report, "Delaware Mountain Group (DMG) Hydrology - Salt Removal Potential"

Responses to your comments on the subject document have been prepared by the authoring organization. Your comments have led the authors to propose changes in the report which are given with the enclosed responses. It should be noted that the primary purpose of the report is to determine the solute-transport capacity of the Delaware Mountain Group (DMG), specifically, the Bell Canyon Formation. An understanding of the solute-transport capacity of the DMG is essential to any proposed model for dissolution that invokes the DMG as a source of unsaturated fluids or a sink for saturated fluids. Regardless of the specific model proposed for dissolution, transport in the Bell Canyon is the rate-determining mechanism.

After you have had an opportunity to review the responses to your comments, if you feel that a meeting with the authors of the report is necessary, please contact us as soon as possible so that arrangements can be made.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 82-0829

Enclosure

cc w/o enclosure:
G. L. Hohmann, TSC
C. C. Little, TSC
C&C File, IEA, TSC

General Comment No. I

"a. Possible communication (of DMG) with other aquifers e.g. reef aquifer, San Andres limestone aquifer and shallow aquifers" has not been treated in this report. Although the details on this theme are expected in the regional hydrology report, a brief treatment of this subject will be desirable in this report for completeness. We recommend adding a subsection under section 2.2 of the report for such discussion."

Response:

The USGS regional hydrology report currently in preparation includes an assessment of the aquifers of the Delaware Basin and surrounding areas and possible communication between aquifers. As part of the subject study for the draft report, "DMG Hydrology-Salt Removal Potential," the regional hydrogeology, and specifically communication of aquifers, has been reviewed. Chapter 2.0 provides the necessary hydrogeologic background for the study and indicates the communication of ground water between the Bell Canyon and Capitan Reef. To elaborate further on the communication of the DMG with other aquifers, the following discussion summarizing hydraulic communication characteristics of the DMG with the Capitan, San Andres, and shallow aquifers will be added in Section 2.2 after the third paragraph on Page 2-10:

> "Communication between the DMG and the Capitan, San Andres, and shallow aquifers is determined by hydrogeologic parameters. Hiss (1975a) has compiled stratigraphic cross sections, potentiometric surface maps, and hydraulic characteristics of the DMG and Guadalupian age rocks in the Delaware Basin. Hiss' work indicates that the Capitan is immediately underlain by members of the DMG and that the potentiometric surface in the DMG is greater than the Capitan Reef aquifer and some discharge from the DMG to the Capitan is expected.
>
> Stratigraphic cross sections in Hiss' work show that sandstone tongues of the Cherry Canyon Formation interfinger the San Andres limestone. Thus, hydraulic communication between the two units is likely. Hiss, however, reports that the average hydraulic conductivity of the shelf aquifers, including the San Andres, is about 4.8 meters per year compared with the DMG average hydraulic conductivity of 1.8 meters per year. The low conductivity of both units restricts the transfer of large quantities of ground water. The head differential between the DMG and San Andres is difficult to determine from literature sources, but it appears to be similar or less than the differential at the Capitan-DMG interface.

A relatively small amount of literature information is available on the degree of hydraulic communication between shallow aquifers and the DMG. Major dissolution or fracture zones are the most probable areas where hydraulic communication between shallow aquifers and the DMG could occur."

General Comment No. II

"b. The "Expected Results" section of the Costs and Merits document for DMG Hydrology states, "Additionally, the relative merits of various dissolution theories will be discussed." We understand that the primary document for such a discussion is the Deep Dissolution report, but the DMG Hydrology report should at least discuss the possibility of proposed mechanisms, other than Anderson's deep dissolution, explaining the observed features of DMG and Reef hydrology and hydrogeochemistry. A discussion of Bachman's "Solution and fill," subaerial erosion during Jurassic time and Lambert's "Stratabound Dissolution" in this context would be very appropriate and useful."

Response:

This subject report focuses on the DMG and addresses dissolution data and hypotheses only as far as they relate to salt removal associated with the DMG aquifer. Sandia National Laboratories is preparing a report on deep dissolution which sufficiently addresses the dissolution hypotheses which have been referenced with respect to the DMG. The major hypothesis which involves the DMG is Anderson and Kirkland's (1980) brine density flow model which uses the Bell Canyon Formation as the source of unsaturated ground water and as the sink for saturated brine. Section 3.2 of the report addresses the Anderson and Kirkland hypothesis as the primary model for salt removal associated with the DMG aquifer and discusses the mechanisms (diffusion and convection) for salt removal by ground water. Additional hypotheses which could involve the Bell Canyon as a sink for dissolved halite include downward percolation of meteoric water and Lambert's "stratabound dissolution" hypothesis. Both of these hypotheses employ the mechanisms of diffusion and/or convection for salt removal by ground water which have been studied in the report. Additionally, the results of such dissolution hypotheses have already been implicitly discussed in the report for it was shown that under most circumstances the maximum amount of salt which can be removed is controlled by the mass transport rate of the Bell Canyon aquifer. Further discussion of alternative dissolution hypotheses is given in the response to Comment No. 11.

General Comment No. III

"Omission of Salado Salt Removal

Having accepted the possibility of the mechanism of salt removal through convective flow at depth, the report has not addressed a major contention of Anderson (1981), i.e., the removal of salt from the Salado formation. All the analytical models considered in the report deal with the "salt dissolution in the Castile Formation and mass transfer to the Bell Canyon Aquifer." (page 6-1, paragraph two)

The reasons for this omission are not clear, since according to the report, "it seems likely that the groundwaters have dissolved some salt from the Salado and Castile formations" (page 3-2, second line). In fact, Task No. 3 (page 1-4) for the study is to "assess the potential for dissolution in the Castile and Salado formations." It is hoped that the final version of this report will correct this omission."

Response:

The analytical and numerical modeling which was performed focused on the potential of dissolution of halite immediately overlying the DMG because the mechanisms for salt removal are dependent on the distance of the dissolving media from the aquifer. As a result, dissolution of the lowest halite unit in the Castile Formation was specifically addressed in the report. The potential for dissolution by ground water from the DMG would be less for the upper halite zone and Salado Formation. This is a conservative approach for determining potential dissolution in both Castile and Salado halite deposits because it maximizes the concentration gradient between saturated brine at the dissolution front and unsaturated Bell Canyon ground water. The calculation overestimates the rate of salt removal from the Salado Formation, which is located approximately 300 meters above the lowermost halite unit of the Castile. Thus, the dissolution rates calculated for the lowermost Castile are conservative estimates of salt removal from the Salado Formation.

The report will be clarified at several locations to emphasize that the calculated dissolution rates can be applied to both the Castile and Salado formations.

The last sentence of the first paragraph on Page 1-4 will be reworded as follows:

> "Review of the geologic and hydrogeologic evidence and potential salt dissolution mechanisms has been undertaken to assess the possible extent of the dissolution in the Castile and Salado formations and evaluate the potential impact of such processes on the facility integrity."

The fourth bullet on Page 1-4 will be revised to read:

- "Establish hydrogeologic models for evaluation of the potential for salt removal from the Castile and Salado formations by fluids in the underlying DMG units."

The first sentence on Page 1-6 will be reworded:

> "In addition, their application for salt removal from the Castile and Salado formations by the DMG for site hydrogeologic and geologic conditions was investigated."

The last sentence of the second paragraph on Page 3-4 will be changed to:

> "It is the purpose of this section to review the physical and chemical mechanisms by which salt may be removed from the Castile and Salado formations by solution from below and to estimate the relative efficiency of these processes in removing salt from halite units within the Delaware Basin. In order to simplify the discussion in the remainder of this chapter, salt dissolution only in the Castile Formation will be used to illustrate the mechanisms. Salt dissolution in the Salado Formation could occur due to similar mechanisms but, as will be shown, the dissolution rates would be smaller because of the larger distance between a dissolution front and the Bell Canyon aquifer."

The following sentence will be added at the end of the first paragraph on Page 4-1:

> "As discussed in Section 3.2.1, calculated dissolution rates in the Castile Formation provide conservative estimates of Salado salt removal."

The second sentence on Page 5-1 will be revised to read:

> "An assessment of the impact of salt dissolution on the site integrity must include consideration of the potential solution cavity that may form in the Castile or Salado formations due to the anticipated dissolution rates."

The last sentence on Page 6-3 will be reworded as follows:

> "Furthermore, the very low flow rate of the Bell Canyon aquifer and the associated salt transport rate indicate that significant convective dissolu-

tion of halite in the overlying Castile and Salado formations would be prevented due to the inability of the aquifer to maintain the density gradient for any significant time period."

General Comment No. IV

"In view of a possible fault connecting Bell Canyon with Castile formation (U.S. DOE, 1980b, Figs. 2.7-20 and 2.7-21) and the existence of a joint system (p. 2-7, para. 2), it is surprising that no consideration is given to salt transport through fractures which may exist in DMG aquifer. It is recommended that the final version of the report includes calculations based on assumptions of joints in DMG and at least one fault connecting DMG and Castile formations."

Response:

As discussed in the response to Comment No. 1 (Specific Comments), the existence of the fault cited above, which was based on seismic reflection data, has been recently reevaluated. The existence of a joint system has been identified by Anderson (1978) although no other investigations have identified fracturing and jointing in the central basin area. The joint system identified by Anderson (1978) is exposed near Carlsbad Caverns and has reportedly fractured the lower anhydrite of the Castile Formation along the western basin margin, more than 40 kilometers from the WIPP facility. Available permeability measurements and drill stem tests throughout the site area indicate very low permeabilities and the potentiometric surface in the DMG dips gently northeastward with no apparent discontinuities or steep gradients. These data all strongly suggest that large-scale fracture flow is absent in the DMG aquifer. If localized fracturing of the aquifer was present, the net ground water flow and salt transport rates upgradient and downgradient of the fracture zone would control the flow. As a result, the report calculations have been based on measured permeabilities of the aquifer with the assumption of porous media flow. Because of the importance of the parameters governing flow in the Bell Canyon aquifer, a sensitivity analysis was performed to determine the potential dissolution for a range of aquifer flow rates varying over more than one order of magnitude.

General Comment No. V

"Brine Aquifer as a Deep Dissolution Sink

The report states that the, "Geochemical evidence of salt dissolution is provided by the composition of groundwater from the Bell Canyon and Capitan aquifers" (p. 3-1, 3rd para) and that "it seems likely that the groundwaters have dissolved some salt from the Salado and Castile formations" (p. 3-2, first para). While the report rules out a DMG as a carrier of the dissolved salt, it suggests that the Capitan aquifer may directly participate in the salt dissolution at depth. The Chapter on

"Conclusions" (Chapter 6) states, "As is evident from this study, brine density flow or convective dissolution is a potential mechanism for removal of halite and its occurrence in the Delaware Basin is possible in areas overlying and at the Capitan reef aquifer margin." (p. 6-3)

This is an important statement and raises questions concerning the mechanism of salt removal without DMG aquifer participation, directly to the Capitan aquifer. The existence of decreasing chloride concentration down gradient in the Capitan reef aquifer is one example of the problems to be resolved and understood. The report, in its final form, should try to present a mechanism of salt removal from Castile and Salado into the Capitan reef aquifer without involving the DMG aquifer."

Response:

The purpose of the study on salt dissolution was to evaluate the salt removal potential of the DMG and the associated effects on the WIPP facility. The Capitan reef is not a part of the DMG and is located more than 16 kilometers from the WIPP facility. Nevertheless, a preliminary analysis is presented herein to assess the possible rates and hypothetical cavity sizes associated with dissolution from the Capitan reef. Based on the relative isolation of the WIPP facility from the reef aquifer and the brief analysis presented herein, it is believed that dissolution associated with the Capitan reef will not affect the structural integrity of the WIPP facility in 10,000 years and that the last paragraph on Page 4-16 of the report sufficiently addresses this concern.

Section 4.3.2 addressed potential chloride transport rates in the Capitan aquifer and the possible origins of the dissolved salt. A general decrease in chloride concentration is identified downgradient based on recent data (Hiss, 1975a). Evidence of flow reversal in the Capitan due to pumping associated with the petroleum industry has also been reported by Hiss (1975a).

Based on the observed range of chloride concentrations in the Capitan aquifer and the estimated flow rate, the mass transport capacity of the reef has been estimated (Page 4-8 of the report). If dissolution is assumed uniform over the interface of the Castile-Capitan contact throughout the basin (a distance of approximately 110 kilometers), the average dissolution rate is approximately one millimeter per year, or an estimated 4 to 30 meters in 10,000 years, based on the range of aquifer parameters and chloride concentrations. This estimate conservatively assumes that the observed chloride concentration in the reef is due only to dissolution at the Castile-Capitan interface and that the dissolution rate remains constant for the 10,000-year period.

The location of the reef with respect to the WIPP site, more than 16 kilometers away, suggests that the dissolution mechanism as discussed in the report would not impact the facility in 10,000 years. As discussed in the report, the mass transport capacity of the reef is much greater than that of the Bell Canyon aquifer such that convective dissolution

may be responsible for some of the observed chloride concentration in the reef. Convective dissolution can be generated by a circulation cell in which lower density (lower concentration) fluid ascends pores or fractures, becomes higher in density (and concentration) due to dissolving of halite, and subsequently descends due to its higher density. A density convection cell resulting in fluid movement can develop in a horizontal direction in addition to a vertical direction. However, development of a horizontal convection cell is hindered as the width of the cell increases (the distance between the discharge point of saturated brine water and the dissolution front). Since the length to width ratio of a fracture extending from the reef toward the WIPP facility would be very large, the horizontal advance of dissolution from the Capitan aquifer into the Castile is not anticipated to be very aggressive.

As a very conservative estimate of the mass flux through a fracture capable of supporting convective dissolution in a horizontal direction, studies by Warner and Arpaci (1968) and Cheesewright (1968) concerning natural convection at a vertical face were reviewed. These investigations did not consider the full circulation effect with reversal of flow. The circulation pattern in a fracture extending from the Capitan into the Castile Formation would involve horizontal flow of unsaturated brine from the reef toward the dissolution front, downward flow during salt dissolution at the front, and flow of saturated brine back toward the reef (flow reversal). Applying the results reported in the above reference is believed to be conservative because the reversal of flow would tend to reduce the horizontal density gradient which drives the circulation cell.

Warner and Arpaci (1968) and Cheesewright (1968) identified the following relationship for the Nusselt number (N_s) for natural convection at a vertical face for Rayleigh numbers (R_s) up to 10^{12}:

$$N_s = 0.1\ R_s^{1/3}$$

This is identical to Equation (3-6) of the report which was utilized in the assessment of potential convective dissolution through a vertical fracture. Based on this relationship and the relationship for the Rayleigh number [Equation (3-5)], an estimate of the total mass flux associated with convective flow in a horizontally propagating fracture can be determined. Substitution of Equation (3-5) for the Rayleigh number into the previous expression for the Nusselt number results in an equation for the convective mass transport through the fracture.

The potential dissolution cavity resulting from convective mass flux through a horizontal fracture was assumed to take the form of either a cylinder with a vertical axis or a rectangular tunnel with equal depth and width. For an assumed one-millimeter fracture, the hypothetical mass flux is 93 kg/yr per meter of fracture height. The hypothetical dissolution cylinder would have a diameter of 24 meters in 10,000 years, or a hypothetical rectangular tunnel would have a depth and width of 21 meters.

Considering a one-centimeter fracture and convective mass transport from the Capitan aquifer, the hypothetical mass flux is 930 kg/yr per meter of fracture height. The dissolution diameter for a cylindrical cavity would be about 100 meters in 10,000 years. The dissolution depth and width of a rectangular tunnel would be 66 meters in 10,000 years.

This analysis is conservative in that there is no consideration of return of saturated brine through the fracture to the Capitan and the associated reduction of the density gradient which drives the circulation cell. Due to the difficulty in sustaining a convection cell over a distance of several kilometers, it is reasonable to assume that the location of a hypothetical cavity would be near the reef where halite units are adjacent the aquifer. While it is clear that the potential convective dissolution rate from a hypothetical fracture could be transported by the Capitan aquifer, it is believed that development of a cavity over the period of study will not impact the WIPP facility, which is more than 16 kilometers from the reef.

General Comment No. VI

"Brine in Castile

The report has disregarded the importance of pressurized brine in the Castile formation vis-a-vis the question of salt removal from Castile and Salado (p. 2-12). Even though these brine occurrences do not seem to be connected to the DMG aquifer, they may not be completely isolated. Also, the brine is found in large volumes. The most recent estimate of the volume of the brine reservoir encountered by WIPP-12 is 30 million barrels (Popielak, NAS-WIPP panel presentation, Aug. 1982) which would occupy 170 million cu. ft of space. The significance of such large volumes of pressurized brine to the question of removal of salt through dissolution in the same formation should be discussed more thoroughly in the report."

Response:

Observations made in the WIPP-12 and ERDA-6 boreholes indicate storage of brine in fractures and flow through fractures of up to five millimeters aperture, with the majority of storage appearing to be in microcracks as discussed further in the brine reservoir report (in preparation). The brine pressures are well above that of the Bell Canyon aquifer, which indicates that they are not hydraulically connected. The brine reservoirs have formed in response to deformation and are isolated from one another by zones of Castile anhydrite of very low permeability. In addition, the brine pockets and wide (up to five millimeters) fractures are typically associated with the uppermost anhydrite unit in the sequence rather than with the lowermost unit overlying the Bell Canyon aquifer. Therefore, although the presence of fractures cannot be ruled out, it is believed that the low Castile Formation permeabilities discussed in Section 2.2 are representative of most of the lower anhydrite unit overlying the DMG.

These observations indicate that the presence of pressurized brine in the Castile Formation does not affect the salt dissolution calculations and discussions given in the report. However, a discussion of this subject will be added to the report as indicated in the response to Comment No. 7.

Comment No. 1

"Page 1-3, 8th and 9th line from top and Page 2-7, 2nd paragraph: The WIPP Safety Analysis Report (Page 2.7-33, Figures 2.7-20 and 2.7-21) indicates that a northwest-southeast trending fault may exist on the interface between the Delaware Mountain Group and the Castile Formation. The fault is located approximately 9 km northeast of ERDA-9 and would be within 1 km of the repository as presently planned. The potential existence of a fault and its consequent hydrologic effects on the repository should be addressed in this report."

Response:

The WIPP Safety Analysis Report (SAR) states that "on the Delaware sandstone, roughly 9,500 feet above the Morrow horizon, a possible fault (interpreted from seismic reflection data,[31]) trends in a northwest direction for about nine miles (Figure 2.7-20), with about 200 feet of indicated displacement." Figures 2.7-20 and 2.7-21 of the WIPP SAR suggest that this potential fault is located within one kilometer of the site and at the Bell Canyon-Castile interface. The existence of this fault was based on connecting a series of "features" seen on the seismic reflection processed sections. A subsequent interpretation of the reflection data indicates that the existence of this fault is highly unlikely (Powers, 1982). Amendments to the SAR which are published subsequent to issuance of the Sandia National Laboratories site deformation report (currently in preparation) will no longer indicate a fault. Available permeability measurements and drill stem test data indicate very low values of permeability and we have incorporated these available measurements into our investigation. Even if localized fracturing of the Bell Canyon aquifer was present, the net ground water flow and salt transport rates would not be affected because aquifer zones without fracturing upgradient and downgradient of the fracture zone would control the flow.

The last sentence of the first paragraph on Page 1-3 will be deleted. The last sentence of the first paragraph on Page 2-7 will be revised to read:

> "Continuous post-Wolfcampian strata indicate that major faulting had ceased before the middle Permian and hence is not believed to affect the Bell Canyon, Castile, or Salado formations."

Comment No. 2

"Page 1-4, 1st paragraph: The statement, "When placed in salt beds which have remained generally stable since deposition in the Permian time (more than 230 million years ago), the waste buried in the WIPP facility may reasonably be expected to remain isolated from the biosphere for thousands of years" ignores everything that has happened to the salt beds since their deposition, viz. uplift, tilting, folding,

salt tectonics, intrusion by a dike, collapse along breccia chimneys, dissolution, formation of cavities filled with huge reservoirs of brine, erosion, etc. It is clearly misleading, detracts from a satisfactory resolution of the question of future stability and isolation of the WIPP repository, and should therefore be removed from this report."

Response:

A discussion of the geologic history of the Delaware Basin is presented in Section 2.1.1. The first sentence of Page 1-4 will be revised as follows:

> "It has been proposed to locate the WIPP facility in Permian age salt beds (formed more than 230 million years ago) in order to isolate the radioactive waste from the biosphere for a period of at least several thousand years."

Comment No. 3

"Page 1-4, 1st paragraph: Similarly, the sentence following the above mentioned one states that radioactive decay will reduce the hazard to "negligible levels" in a few thousand years. The Pu-239 inventory will be essentially the same as at closure and the statement is incorrect."

Response:

A time period of a few thousand years is sufficient to allow complete decay of the highest activity fission products, Cs-137 and Sr-90, but not for some of the lower activity species such as Pu-239. However, we agree that the statement might be misleading. The sentence beginning on the fourth line of Page 1-4 will therefore be reworded to read:

> "This period is sufficient to allow virtually complete decay of the short-lived high activity nuclides such as Cs-137 and Sr-90 and thus to substantially reduce the hazard posed by the waste."

Comment No. 4

"Page 1-7, 3rd and 4th bulletted conclusions: The terms "insignificant," "no significance," and "not greatly increase" are qualitative. They should be either replaced by or appear with the respective quantifiable number from Chapter 5 or Appendix B."

Response:

The actual values of potential dissolution and flow rate which are referenced in Section 1.4, "Summary and Conclusions," are presented and discussed in more detail in the appropriate sections of the report. The last two bullets on Page 1-7 will be revised as follows:

- "Based on an analysis of potential changes in the hydrologic characteristics (e.g., hydraulic gradient and associated flow rate) of the Bell Canyon aquifer, an increase in flow rate of even one order of magnitude (from an estimated rate of 0.135 cubic meter per year per meter of width to 1.35 cubic meter per year per meter) would not increase the salt removal from the Castile Formation by more than 17 percent (from a calculated rate of approximately 0.3 centimeter in 10,000 years to less than 0.4 centimeter in 10,000 years). The unlikely occurrence of a change in hydrogeologic characteristics and the associated potential dissolution are not anticipated to have any effect on the facility integrity.

- An analysis of implausible "worst-case" dissolution rates associated with both diffusive and convective dissolution at the Bell Canyon aquifer-Castile Formation interface suggests that the structural integrity of the WIPP facility located more than 400 meters above would not be affected. In this analysis, it was determined that the theoretical maximum cavity radius would be seven meters over a fracture and one meter above a circular porous zone in a period of 10,000 years."

Comment No. 5

"Page 2-7, section on "Fracturing": In which formations are the two sets of joints located? Does the joint set extend into or is it located within the transmitting sandstones of the DMG? These joints may be capable of transmitting water and thus have a high dissolution potential. The dissolution effects of convection along a joint or fracture in the DMG should be addressed in the report."

Response:

The WIPP SAR (Page 2.6-35) indicates that "two sets of joints, striking northwest and northeast" have been identified in the Delaware Basin rocks. The joints, believed to be pre-Cenozoic in age, are exposed near Carlsbad Caverns and filled with early Cretaceous sandstone and conglomerate.

The potentiometric surface for the DMG aquifer in the Carlsbad area implies northerly flow with no evidence of large scale fracturing. For example, there are no indications of the radical changes in flow field which might be expected in an extremely fractured area. Similarly, 40 kilometers to the east of the outcrop of the joint, the potentiometric surface in the DMG dips gently northeastward with no apparent discontinuities or steep gradients (Figure 2-5). These data all strongly suggest that large scale fracture flow is absent from the DMG aquifer. If localized fracturing of the aquifer was present, the net ground water flow and salt transport rates would not be affected because the aquifer zones without fracturing upgradient and downgradient of the fracture zone would control the flow. As a result, the report calculations have been based on the measured permeabilities of the aquifer with the assumption of porous media flow.

The second paragraph of Page 2-7 will be reworded as follows:

> "Although no major faults are known to exist at the WIPP site, data from boreholes drilled at the site indicate that jointing has occurred. Data concerning joint frequency and orientations are extremely sparse. Joint orientations are described as 'two sets of joints striking northwest and northeast' (U.S. Department of Energy, 1980b). The joints are exposed near Carlsbad Caverns, more than 40 kilometers from the WIPP site. These joints have been identified in Delaware Basin rocks and may extend into the water bearing sandstone."

Comment No. 6

"Page 2-8, 19th through 29th line from top: The values of permeability presented here appear to be taken from Table 6 of Hiss's (1975a) report and are average permeabilities on a county by county basis. Figure 21 of Hiss's (1975a) report indicates that permeabilities near the WIPP site range from less than 1 md to 59 md (<0.3 m/year to 18 m/year for pure water at 20°C)."

Response:

The permeabilities of the Bell Canyon aquifer near the WIPP site, as indicated in Figure 21 of Hiss's (1975a) report, are generally in the range of 1 to 25 millidarcys (md) (less than 0.3 to 8 meters per year). The 59 md (18 meters per year) measurement is isolated and does not appear to be representative of the site area permeability. The range of permeabilities used in the salt dissolution sensitivity analysis (Appendix B) was from approximately 1.7 to 15 md (0.5 to 4.5 meters per year), with an average value of 6 md (1.8 meters per year). The average Bell Canyon permeability on a county by county basis ranges from approximately 3 to 10 md (1.1 to 2.9 meters per year). These permeabilities

are average values for all areas around the WIPP site and were utilized because the potentiometric surface for the Bell Canyon aquifer is relatively uniform. Specifically, the available data do not indicate a significantly variable flow field which would be observed with large variations in the aquifer permeability. However, the sensitivity analysis presented in Appendix B has been modified to include a permeability of 18 meters per year and this result will be incorporated in the report.

The fourth sentence of the last paragraph on Page 2-8 of the report will be clarified as follows:

> "The hydraulic conductivity of the Bell Canyon aquifer [based on core sample measurements (Hiss, 1975a)] ranges from 1.1 to 2.9 meters per year and averages approximately 1.8 meters per year. One measurement of hydraulic conductivity of 18 meters per year has also been reported; however, it does not appear representative of the basin."

The sentence beginning on the twentieth line of Page B-2 will be reworded as follows:

> "As shown in Figure B-1(A), an increase in Bell Canyon aquifer hydraulic conductivity from 1.8 to 18.0 meters per year would result in a 17 percent increase in dissolution height (H/H_{ref}, dimensionless dissolution rate, increases from 1.0 to 1.17)."

The seventh and eighth lines of Table B-1 will read:

"Hydraulic Conductivity of Bell Canyon Aquifer, K	0.5 to 18.0	Meters per year (m/yr)"

In Table B-2, the seventh, eighth, and ninth lines will read:

"Hydraulic conductivity of Bell Canyon aquifer, K	0.5	Meters per year (m/yr)	-72	0.14	-57
	1.8*		-	0.34*	-
	18.0		+900	0.40	+17"

In addition, a fourth point will be added to Figure B-1(A) representing K = 18.0 meters per year and H/H_{ref} = 1.17.

The sensitivity of the average dissolution rate when assumed to be controlled only by the Bell Canyon aquifer flow rate is presented in Figure B-2 of the report. As is evident from the figure, an order of magnitude increase in the flow rate of the Bell Canyon aquifer from 0.135 to 1.35 m^3/yr-m (based on a permeability increase from 1.8 to 18.0 meters per year) would result in an average dissolution of less than 4 centimeters in 10,000 years.

Comment No. 7

"Page 2-11, last paragraph: The report should indicate that the hydraulic conductivity of the Castile anhydrites is not limited to porous flow. At WIPP-12 a fracture in Anhydrite III-IV of the Castile is capable of producing over 300 gallons per minute of brine (D'Appolonia Consulting Engineers, Inc., "Data File Report, ERDA-6 and WIPP-12 Testing," Volume IV A, Activity WIPP-12.2, Feb., 1982). At ERDA-6 a fractured zone in Anhydrite II of the Castile is capable of producing over 20 gallons per minute of brine (D'Appolonia Consulting Engineers, Inc., "Data File Report, ERDA-6 and WIPP-12 Testing, Volume II A, Activity ERDA-6.7, Feb., 1982). Preliminary calculations by EEG staff members indicate hydraulic conductivities of 2000 m/day for the fractured zone at WIPP-12 and 5 m/day for the fractured zone at ERDA-6. These values of hydraulic conductivity are at least six orders of magnitude greater than the values presented here."

Response:

Observations made in the WIPP-12 and ERDA-6 boreholes indicate storage and flow of brine in fractures with apertures of up to 5 millimeters. The majority of storage appears to be in microcracks which have formed in response to deformation and which are isolated from one another by zones of Castile anhydrite of very low permeability. In addition, the brine pockets and wide (up to 5 millimeters) fractures are typically associated with the uppermost anhydrite unit in the sequence rather than with the lowermost unit overlying the Bell Canyon aquifer. In general, Anhydrite I of the Castile Formation appears not to be affected by the deformations and associated fractures identified in the upper anhydrites. Thus, it is not likely that the lower anhydrite would be fractured.

It is therefore concluded that the low permeabilities discussed on Page 2-11 are appropriate for most of the lower anhydrite units overlying the DMG. The report will, however, be reworded to include a description of the occurrence of fractures associated with brine pockets and to state that the occurrence of such fractures in Anhydrite I cannot be ruled out.

The last sentence of the first paragraph on Page 2-12 will be deleted and the following will be added at the end of the paragraph:

> "Observations made in the WIPP-12 and ERDA-6 boreholes indicate storage and flow of brine in fractures of up to 5 millimeters aperture, with the majority of storage appearing to be in microcracks. The brine reservoirs have formed in response to deformation and are isolated from one another by zones of Castile anhydrite of very low permeability. In addition, the brine pockets and wide (up to 5 millimeters) fractures are typically

associated with the uppermost anhydrite unit in the sequence rather than with the lowermost unit overlying the Bell Canyon aquifer. Although the presence of fractures cannot be ruled out, it is believed that the low permeabilities discussed in the previous paragraph are representative of most of the lower anhydrite unit overlying the DMG."

Comment No. 8

"Page 2-12, 2nd paragraph: Does the source of salt in the Castile brines come from dissolution of halite overlying or underlying the anhydrite layers?"

Response:

D'Appolonia has performed an extensive series of hydrologic and geochemical tests on the brine reservoirs occurring in WIPP-12 and ERDA-6 since the draft DMG hydrology report was prepared. The geochemical evidence strongly suggests that the brines were not produced by the dissolution of evaporite units either by ground or meteoric waters. The very high content of bromide (up to 990 milligrams per liter) and the ratios of Na, K, Cl, SO_4, and Ca to bromide all correspond very well to the expected values for evaporated seawater. This evidence suggests that the most likely origin of the brines is original residue from seawater evaporation. They therefore appear to be original evaporated Permian seawaters that may have dissolved very small amounts of evaporite minerals during transport to the anhydrite fracture system.

Comment No. 9

"Page 2-12, 2nd paragraph: The statement is made that Castile brine "pockets exhibit different (mostly higher) potentiometric surfaces than the Bell Canyon". It appears that all the potentiometric surfaces for the brine pockets are higher than those for the Bell Canyon."

Response:

The second sentence of the first paragraph on Page 2-12 will be reworded to read:

> "These 'reservoirs' have higher potentiometric surfaces than the Bell Canyon aquifer and do not appear to be connected with the DMG."

Comment No. 10

"Page 2-13, 2nd paragraph: Are the contours on Figure 2-7 "averaged" over the various water bearing units of the Rustler Formation or are they the contours for the Culebra only? They look like they represent water levels in the Culebra. A recent draft report (Gonzalez, D. D., "Fracture Flow in the Rustler Formation: Waste Isolation Pilot Plant (WIPP) Southeast New Mexico (Draft Interim Report)," SAND 82-1012, May 1982) has changed the Culebra contours from those presented in previous reference works (Mercer, J. W. and B. W. Orr, 1977; Mercer, J. W. and B. R. Orr, 1979; Mercer, J. W. and D. D. Gonzalez, 1981). Figure 1 through Figure 4 indicate how conceptions of the head in the Rustler Formation and the Culebra Dolomite have changed with time."

Response:

The origin of the potentiometric surface and extent of brine aquifer presented in Figure 2-7 for the Rustler Formation are based on the USGS Open-File Report 77-123, 1977 (Mercer and Orr, 1977), as reproduced in the WIPP SAR. These data do not differentiate between Culebra and Magenta dolomites or other zones. Based on the reference cited in the comment, it appears that the potentiometric surface has been redefined although its level when converted to fresh water with a specific gravity of 1.0 is below the observed potentiometric surface for the Bell Canyon aquifer. The second paragraph of Page 2-13 will be revised as follows:

> "The potentiometric surface of the Rustler Formation is generally lower than the potentiometric surface in the DMG. The brine aquifer and the potentiometric surface identified in the Rustler Formation are shown in Figure 2-7. These representations are based on data compiled from wells during the period 1962 through 1973 (Mercer and Orr, 1977). Recently, some revision to the potentiometric surface has been suggested (Gonzalez, in preparation) but the estimated level is below that of the Bell Canyon aquifer."

Comment No. 11

"Page 3-4, Section 3.2.1: This section deals with possible mechanisms for salt dissolution. This section appears to put forth only the ideas developed by Anderson (1978) and Anderson and Kirkland (1980). If any other ideas exist, they are not presented. No additional ideas for potential deep dissolution mechanisms are put forth. The possibility of dissolution from flow in joints or fractures in the Delaware Mountain Group and Castile anhydrite rocks should be addressed."

Response:

Two basic mechanisms or processes for the removal of salt from the halite regions are discussed in the report. These are molecular diffusion and convection associated with ground water flow induced by a density gradient. The major hypothesis for deep dissolution which involves the Bell Canyon Formation as the source of water and the sink for saturated brine is that put forward by Anderson (1978) and Anderson and Kirkland (1980). This hypothesis invokes the mechanisms of diffusion and convection for salt removal and is specifically addressed in Section 3.2.1.

Other hypotheses which involve the DMG as the sink for saturated brines are downward percolation of meteoric water and Lambert's (in preparation) "strata-bound dissolution" mechanism. These may be regarded as subsets of the hypotheses treated in the report since the total mass of salt that can be removed is controlled by the flow and mass transport rate in the underlying aquifer, regardless of the dissolution mechanism believed to occur in the basin. Removal rates calculated in Chapters 3.0, 4.0, and 5.0 which are limited by the Bell Canyon flow rate apply to all possible mechanisms which use the Bell Canyon as a sink.

To clarify the report with respect to these points, the following changes will be made. The last sentence of the first paragraph on Page 3-5 will be deleted. On Page 3-5 after the first paragraph, the following paragraph will be added:

> "Other hypotheses which include the DMG as the sink for saturated brines are downward percolation of meteoric water and Lambert's (in preparation) hypothesis of "strata-bound dissolution." In the latter, water dissolves salt while migrating approximately horizontally along soluble strata. The Bell Canyon aquifer could potentially provide a sink for saturated brines produced by this mechanism. In the context of this report, both these mechanisms may be regarded as subsets of the Anderson (1978) hypothesis since they require flow through Castile anhydrites in order to reach the Bell Canyon Formation. Thus, the calculated maximum rates of salt removal above a fracture or through a porous zone discussed in Chapters 3.0, 4.0, and 5.0 apply approximately to all hypotheses. Since the physical processes described by Anderson (1978) and Anderson and Kirkland (1980) are readily analyzed, their hypothesis is used in subsequent sections to illustrate the mechanisms for salt removal."

Comment No. 12

"Page 3-5, Section 3.2.2: This section quantifies the amount of salt that can be diffused through the lower anhydrite of the Castile Formation by means of either a fracture or a porous medium. The results indicate that the fracture will propagate upward at a rate of 3×10^{-5} meter per year and that, in the porous medium case, a dissolution front would propagate upward at a rate of 3×10^{-6} meter per year.

The analysis is based on the assumption that steady state is reached. This approach is probably correct for the porous medium approach because the porous medium has been in place for more than 200,000,000 years. On the other hand, fractures can form at any time. In a fracture the initial unsteady state rates of dissolution and diffusion of salt should be very large compared to those of the steady state because of the steep concentration gradient which forms at the top of the fracture. The amount of salt that can be dissolved at unsteady state by a fracture should be quantified here.

Both the fracture and porous medium rate of diffusion calculations should include the range of Delaware Mountain Group NaCl concentrations beause the amount and rate of dissolution are dependent on this. These calculations should show that dissolution of halite will occur faster at the upgradient parts of the Delaware Mountain Group than at the downgradient parts."

Response:

In the steady state calculation of diffusion through a fracture, a constant chloride concentration gradient of 1.2 kg/m^3 per meter was assumed based on a 100 meter fracture height above the Bell Canyon aquifer, existing chloride concentration in the aquifer of 70 kg/m^3 (actual range is generally 100 to 150 kg/m^3), and a concentration of 190 kg/m^3 (saturation) at the top of the fracture. Under such conditions, the fracture propagates upward at a rate of 3×10^{-5} meter per year. These calculations were presented as an approximate illustration of the propagation rate of a fracture which originates at a distance of less than 100 meters above the Bell Canyon aquifer. It was assumed that by the time the fracture reaches the 100 meter level, a gradually varying concentration gradient would have developed from 70 to 190 kg/m^3.

For the case of instantaneous formation of a 100 meter fracture, the initial gradient at the top of fracture is very steep, thereby resulting in a high initial propagation rate. The transient propagation rate and the time to reach steady state were calculated for such a fracture and the results will be documented in the final report.

Section 3.2.2 will document the results of the transient analysis of diffusion through a fracture and the calculated fracture propagation rate as a function of time. The following paragraph will be inserted after the second paragraph on Page 3-6:

"In the above discussion of dissolution by diffusion through a fracture, it was assumed that a uniformly varying steady state concentration gradient had developed. For the case of instantaneous formation of a 100 meter fracture, the initial gradient at the top of fracture is very steep, thereby resulting in a high initial propagation rate. As salt dissolution and fracture propagation continue, the variation in salt concentration becomes more gradual due to diffusion in the fracture and the propagation rate declines. To evaluate the rates at which a fracture moves under these conditions, a transient form of the one-dimensional diffusion equation (Crank, 1975) was solved. The parameter values are identical to the ones used in the steady state calculation except that the initial chloride concentration in the fracture is assumed to be constant at 70 kg/m^3 instead of uniformly varying at a 1.2 kg/m^3 per meter gradient. The analytical solution of the diffusion equation gives the chloride concentrations at different locations within the fracture as a function of time. From this information, the concentration gradient at the top of the fracture, which determines the salt dissolution and propagation rates, is determined.

The calculated propagation rates for different times beyond initial fracture formation are as follows:

TIME (years)	PROPAGATION RATE (meters per year)
1	290×10^{-5}
10	230×10^{-5}
100	89×10^{-5}
1,000	29×10^{-5}
10,000	9×10^{-5}
100,000	3×10^{-5}

This analysis indicates that on the order of 100,000 years is required for the upward fracture movement to decline to the assumed steady state rate of 3×10^{-5} meter per year. The initial rate (e.g., time = 1 year) is almost 100 times greater; but after 1,000 years, the rate is less than 10 times the assumed steady state value. Integration of the above results for the first 10,000 years after fracture formation yields a total propagation distance of approximately 2.0 meters. These transient results indicate that fracture propagation due to diffusion is a relatively slow process, even immediately after fracture formation."

The first sentence of the third paragraph on Page 3-7 will be revised as follows:

> "The above discussion demonstrates that diffusion-controlled dissolution is an extremely slow process. The steady state propagation of a single fracture is approximately 3×10^{-5} meter per year and the steady state movement of a dissolution front above a porous zone is on the order of 3×10^{-6} meter per year. For instantaneous formation of a fracture, the initial propagation rate is approximately 3×10^{-3} meter per year, decreasing to 2.9×10^{-4} meter per year in 1,000 years, and reaches steady state conditions (3×10^{-5} meter per year) in 100,000 years."

Comment No. 13

"Pages 3-8 to 3-10, "Threshold of Convection in Fractures and Porous Media": This section is used to estimate the width of a fracture required to initiate brine density flow. This is done by approximating the width of a fracture with the radius of a tube. A study performed by Wooding (Wooding, R. A., "Instability of a Viscous Fluid of Variable Density in a Vertical Hele-Shaw Cell," Journal of Fluid Mechanics, Vol. 7, Jan. through Apr. 1960, pp. 501-515) tends to indicate that this is not the correct approach. Using a mathematical model of water and mass transport between two parallel plates, he found that the width required to initiate density flow was dependent on the length of the parallel plates. Wooding (1960) verified his results with a Hele-Shaw analog model. The results of his study indicated that brine density flow could occur in fractures much smaller than the 0.5 and 1.5 millimeters indicated in this report. If a fracture is assumed to have smooth parallel sides, then a fracture with a width of 1 mm has a high hydraulic conductivity (0.7 m/s) and is capable of transmitting significant amounts of salt."

Response:

The conditions necessary for the onset of convection in a fracture must depend on the geometry of the aperture as was recognized on Page 3-9 of the draft report. The rationale for using cylindrical geometry is that it gives an approximate order of magnitude of the fracture width required for the onset of convection without the need to specify a hypothetical aspect ratio. The results were shown on Page 3-10 to confirm the approximate magnitude of critical fracture width deduced by Anderson and Kirkland (1980). Wooding's (1960) results may be used to deduce that for an aspect ratio (length/width) of 20, the critical fracture width for solute-driven convection would be about 0.4 millimeter, whereas an aspect ratio of 100 would yield a critical width of about 0.2 millimeter.

The choice of an appropriate aspect ratio is complicated by the general roughness of geologic fracture surfaces which would hinder convection in long, thin fractures but, even with a high aspect ratio (100), the result is not substantially different from that (0.5 to 1.5 millimeter) given in the draft report.

Given the variability in critical width, the important conclusion of Section 3.2 is that, if convection occurs, the Nusselt number is so high that the fracture rapidly saturates with salt. Removal rates therefore are controlled by the properties of the aquifer rather than by the critical width of potential fractures as discussed in Section 5.2.1.

The report will be modified by adding the following comments after the first paragraph on Page 3-10:

> "The above calculations of critical fracture width are based on the simplifying assumption of cylindrical geometry. If the fracture is to be elongated, then the minimum width for convection is reduced, although the results are of similar order to those given above. Wooding's (1960) study may be used to estimate a minimum fracture width of approximately 0.4 millimeter for an aspect ratio (length/width of the fracture) of 20 and approximately 0.2 millimeter for an aspect ratio of 100. As aspect ratio increases, the irregularity of fracture surfaces and occasional fill materials will tend to interfere progressively with the convective process so that modeling as long, thin, parallel-sided fractures is inappropriate. It is likely, therefore, that the cylindrical model gives a reasonable and conservative order of magnitude calculation of the critical fracture width for solute-driven convection."

Comment No. 14

"Page 3-10, 2nd paragraph: A basis or reference for the statement "It is doubtful whether single fractures of one millimeter or more in aperture could remain open and continuous in Anhydrite I" should be provided. While the drilling in the Castile Formation has not indicated any significant fluid producing fractures in Anhydrite I, they have been observed in the higher anhydrites of the Castile. The most notable example of a fracture occurs at WIPP-12 about 3,010 feet below land surface. This fracture is capable of producing several hundred gallons per minute of flow and it could be classed as open and continuous."

Response:

Fluid pressures in the brine reservoir intercepted by WIPP-12 and ERDA-6 are substantially greater than those in the Bell Canyon aquifer, extending up to about 70 percent of the calculated lithostatic value. As a result, fluid pressure may be expected to keep fractures open within a brine reservoir even if there is a general tendency for plastic deformation to close them. In the case of a fracture connecting the lowermost Castile anhydrite to the DMG, however, the fluid pressure would be less able to keep the fracture open because the aquifer cannot be pressurized by deformation in the same way as a small localized reservoir can. Thus, it is to be expected that fractures connected to the Bell Canyon aquifer will be mechanically much less stable than those within limited pressurized reservoirs.

The first sentence of the second paragraph on Page 3-10 will be modified to read:

> "There is some doubt as to the long-term stability of a one millimeter fracture in a deformable medium such as the Anhydrite I unit of the Castile Formation."

Comment No. 15

"Page 3-10, last line: The validity of the equation $Ns = 0.1\ R_s^{1/3}$ should be examined. It appears that this relationship was originally derived by Elder (1967) although this report attributes it to Golitsyn (1979). Elder (1967) presented data which indicate that the above equation is valid for $\approx 5 \times 10^8 < R_s < \approx 5 \times 10^{10}$. Elder (1967) has other relationships for $R_s < \approx 5 \times 10^8$, but none for $R_s > \approx 5 \times 10^{10}$. The value of R_s used in the calculation involving the above equation is 1.2×10^{21}, which is many orders of magnitude higher than the known range of valid R_s values for that equation ($\approx 5 \times 10^8 < R_s < \approx 5 \times 10^{10}$)."

Response:

From a review of the literature discussed by Golitsyn (1979), Warner and Arpaci (1968), and their references, it appears that the relationship $Ns = 0.1\ R_s^{1/3}$ is both a theoretically predicted and experimentally observed limit for very high Rayleigh numbers ($R_s \gg 10^6$, Warner and Arpaci, 1968). While experiments only appear to have been performed to Rayleigh numbers on the order of 10^{10} (Golitsyn, 1979), no substantial deviations from this relationship have been observed experimentally. The data of Knapp and Podio (1979) provide a check on the validity of this Nusselt-Rayleigh relationship at a very high Rayleigh number (10^{19}). At this Rayleigh number, the predicted Nusselt number is within an order of magnitude of that obtained from Knapp and Podio's empirical

dispersion coefficients. This tends to confirm the general applicability of the above equation in the approximate manner employed by the report.

Comment No. 16

"Page 3-11, 2nd paragraph: The comparison of the dispersion coefficients calculated from the Knapp and Podio (1979) experiments to the diffusion coefficient could be erroneous. This comparison is made on Page 3-11 of the report as support for the contention that convection mass flux is 10^6 times higher than diffusive mass flux. Knapp and Podio (1979) treated the salt transport as a purely dispersive process. Wooding (1959), who studied the same phenomenon, included both a convection term and a diffusive term in his analysis. The large value of the Knapp and Podio (1979) dispersivity estimates tend to indicate that convection is occurring. Essentially, the dispersion coefficient determined by Knapp and Podio (1979) approximates the convection of brine as a dispersive process.

Knapp and Podio (1979) performed four experiments in their study of salt transport in boreholes. Three tests were run in a bore tube with a diameter of four inches. Two of these tests were run with an induced velocity in the borehole; one was run with no induced velocity. The fourth test was run in a two-inch-diameter borehole and had no induced velocity. The calculated dispersivities ranged from 45 cm^2/sec to 48 cm^2/sec for experiments run in the four-inch bore tube and was 12 cm^2/sec in the two-inch bore tube. Knapp and Podio (1979) concluded that the dispersivity depends on the cross-sectional area of the bore tubes. If these dispersivities are corrected for the "radius of a fracture" of 0.001 meter, the dispersivity would be very small, say on the order of 10^{-6} m^2/sec. This would yield a Nusselt number of about 10^3 instead of 10^6 and would dispute the contention that convection mass transport is 10^6 times higher than diffusive mass transport."

Response:

The discussion in the draft report is aimed at deducing the convective mass transport from Knapp and Podio's dispersivity estimate and comparing it with predictions based on the relationship N_s Z 0.1 $R_s^{1/3}$. The fact that Knapp and Podio obtained empirical dispersivities which are six orders of magnitude greater than the diffusion coefficient implies that convective transport in their experiments is six orders of magnitude greater than diffusive transport, i.e., N_s Z 10^6. This observation is in reasonably good agreement with convection theory which predicts an N_s of about 3 x 10^5 (Page 3-11 of the draft report). Thus, the experiments confirm the general validity of the Nusselt-Rayleigh relationship at a very high Rayleigh number (approximately 10^{19}).

Knapp and Podio observed some dependence of dispersivity on tube diameter. They also found a dependence of dispersivity-salinity relationships on tube diameter. Although such effects are not predicted in the

simple convection theory used in the report, they may be quantitatively understood by considering the nature of the experiments and the fitting procedures used. First, Knapp and Podio's experiments started with a concentration discontinuity in their simulated well bore which is expected to lead to short-term transient transport effects. The initiation of rapid convection in such a system could depend on tube diameter although in the long-term, as steady state is approached, tube diameter is expected to be relatively unimportant. Secondly, by forcing actual convective transport data to fit a diffusion (or dispersion) equation, Knapp and Podio introduced empirical parameters which cannot readily be justified. Although their data are of considerable interest, their theoretical treatment is very limited and impossible to extrapolate with confidence. Thus, the complex dispersivity composition and dispersivity tube width relationships they obtained cannot be put into a good theoretical framework because they apply to a physical process different from the one actually observed. In such a case, a relationship between dispersivity and tube diameter may appear to be present but simply be an artifact of the fitting procedures used. There is certainly no justification for a linear extrapolation of Knapp and Podio's apparent dispersivity-width relationship in the manner suggested by the comment.

In conclusion, Knapp and Podio's experiments provide a reasonable test of the Nusselt-Rayleigh number relationship at high values of R_g, but their data cannot be extrapolated using dispersion theory. Paragraph 2 of Page 3-11 will be modified to clarify the discussion. The first sentence will be revised to read:

> "Some recent experiments on salt transport in wide bore tubes (Knapp and Podio, 1979) tend to confirm the approximate convective mass transport relations derived and discussed here."

The third sentence will be reworded as follows:

> "They found that the data, although produced by a vigorous convective process, could be modeled by using a semiempirical equation of the same form as the diffusion equation (Fick's second law):"

Comment No. 17

"Page 3-12, 5th line from top: The reason for believing that fractures of one millimeter or more are unlikely to exist should be given. Wooding's (1960) results indicate that convection in a fracture of less than one millimeter width can exist."

Response:

Discussions of the long-term stability of fractures and critical fracture widths for convection are presented in the responses to Comment

Nos. 13 and 14. In response to this comment, the first two sentences of the second paragraph on Page 3-12 will be changed as follows:

> "Although the long-term stability of large fractures in Anhydrite I is open to doubt, it is conceivable that zones of small fractures, 0.01 millimeter or less in width, could remain stable for extended time periods. Although they would be below the critical radius for convection (approximately 0.2 to 1.5 millimeters), convection could occur in multiple fracture zones where inflow takes place in some fractures and descent in others, similar to the method discussed by Anderson and Kirkland (1980)."

Comment No. 18

"Page 3-14, 3rd paragraph: If a fracture were to propagate itself, (i.e., dissolve only the salt directly above it) it would reach the repository in less than 20 years at a rate of 28 cubic meters per square meter per year.

It seems very unlikely for a front to propagate as a square tunnel. Does any literature exist or has any been reviewed to indicate what shape forms when salt dissolves?"

Response:

D'Appolonia has reviewed the available literature on cavity shapes resulting from salt dissolution. Very little information is applicable to the problem addressed by the DMG report. The most comprehensive work that has been found (Jessen, 1973) is for solution mining where the principal dissolution mechanism is injection of large volumes of fresh water. The principal dissolution mechanism for the Castile halite is natural solute-driven convection due to the vertical density gradient in a fracture or porous zone resulting from the variation in salt concentration.

Salt dissolution within a cavity is a very complex mechanism depending on many variables, including concentration (degree of saturation) and chemical composition of the solute fluid, temperature, viscosity, pressure, size and shape of the dissolution cavity, effects of surface irregularities and insoluble inclusions as well as lamination of layers of different mineralogical composition (solubility), and the angle of contact between the salt and fluid. A discussion of this very complex mechanism in full detail is beyond the scope of the report. The shape of a dissolution cavity formed by this process cannot be analytically predicted in terms of the relative rates of vertical and horizontal spreading as the cavity enlarges. This would be a complex function of the flow patterns within the cavity and the material characteristics of

the halite formation. However, certain simplifications and assumptions allow an estimate of the size and shape of the dissolution cavity to be made.

D'Appolonia has evaluated data on solutioning presented by Jessen (1973) and has used it to evaluate the potential dissolution of the Castile halite. The shape of the dissolution cavity would be affected mainly by:

- Impurity (laminae layers) content in the halite.
- Chemical and physical properties of these impurities, mainly their solubility ratio (impurity versus pure salt).
- Effect of the angle of contact between the salt and solution fluid. The maximum rate of salt removal occurs when the contact surface is inclined about 70 degrees from vertical and the fluid is below it.

After applying various simplifications and assumptions, it was determined that the dissolution cavities would resemble a rounded trapezoid with the base slightly shorter than the top and a general width to height ratio of approximately 1:1 for pure halite. WIPP-12 analysis results indicate that the 2 to 5 percent range of anhydrite impurities is representative of the Halite I Formation. Considering the inclusion of anhydrite impurities in the Castile and Salado formations, the theoretical cavity ratio (width to height) could be as large as 10:1 (assuming a dissolution ratio of halite to anhydrite of 157:1). These results show that assuming a rectangular tunnel geometry (1:1 width to height ratio), or a cylindrical shape (2:1 width to height ratio) as for the worst case analysis, is conservative in terms of upward movement of a dissolution cavity.

The first sentence of the last paragraph on Page 3-14 will be modified as follows:

> "The potential dissolution front would probably take the form of a cavity whose shape is governed by a very complex mechanism depending on many variables. Using the available information from the literature (Jessen, 1973) and adapting it for the Castile and Salado halite dissolution problem, it was determined that the cross-section of the cavity may resemble a rounded trapezoid with the base slightly shorter than the top. The width to height ratio is estimated to be about 1:1 for pure halite and, considering the influence of anhydrite impurities, the ratio may be as high as 10:1. To simplify further calculations, a conservative rectangular tunnel shape

(width to height ratio of 1:1) was used. If the dissolution front were to propagate as such (Figure 3-7), then for a 1.5 millimeter wide fracture it would have advanced less than 0.2 meter in one year and less than 20 meters in 10,000 years."

Comment No. 19:

"Page 3-15, 1st line to 6th line from top: This calculation assumes that there is no flow or dispersive flux through the DMG. What is the effect of flow and dispersion through the DMG on the time for salinity buildup to saturation? It is possible that a fracture extending into the DMG could transport the salt away toward the reef at a high rate and saturation would never be reached. It is highly probable that, due to the sparse drilling activity in the DMG, vertical fractures were missed during drilling."

Response:

The calculation on Page 3-15 dealing with time to reach saturation for the case of a large fracture connecting Castile halite and Bell Canyon Formation is not significantly affected by dispersion and ground water flow. The latter parameters are only important if the fracture density becomes extremely small such that the dissolution rate approaches that expected for diffusive flux. Since the calculated salt transport rate of 6×10^4 kg/m^2 is many orders of magnitude greater than the rate at which the Bell Canyon aquifer can remove salt from a fracture, it is reasonable to ignore the effects of flow and dispersion for the purposes of the illustration.

The remainder of Comment No. 19 involves a speculation that transport within fractures in the DMG could be more important than porous media flow. If there were any indication in the current data base that fracture permeability is important over a significant portion of the basin, then it could be addressed. Available permeability measurements and drill stems test data indicate very low values of permeability and we have incorporated these available measurements into our modeling study. Further discussion of the effects of fractures in the DMG is given in the response to Comment No. 5.

Comment No. 20

"Page 4-4, "Hydraulic Conductivity" section: The range of hydraulic conductivity should be extended from 1 md to 59 md (0.3 m/year to 18 m/year). See comment regarding Page 2-8."

Response:

Consistent with the response to Comment No. 6, the fifth sentence of the last paragraph on Page 2-8 will be revised to read:

"The hydraulic conductivity of the Bell Canyon aquifer [based on core sample measurements (Hiss, 1975a)] ranges from 1.1 to 2.9 meters per year and averages approximately 1.8 meters per year. One measurement of hydraulic conductivity of 18 meters per year has also been reported; however, it does not appear representative of the basin."

The first sentence of the third paragraph on Page 4-4 will be reworded as follows:

"Based on laboratory measurements of the core samples (Hiss, 1975a) and analysis of drill stem tests in Borehole AEC-7 as discussed in Section 2.2, the representative hydraulic conductivity of the Bell Canyon aquifer ranges from 1.1 to 2.9 meters per year with a weighted average value of 1.8 meters per year.

Comment No. 21

"Page 4-5, "Chloride Concentrations" section: The chloride data in Hiss's (1975a) Figure 26 tend to confirm the existence of the 100 kg/m^3 contour on the upgradient end of the Bell Canyon aquifer."

Response:

The Bell Canyon aquifer flow direction near Whites City is toward the north which is not the direction of flow observed through the section (Figure 4-1) used for the salt dissolution analyses (northeastward). Chloride concentrations in this section generally increase in the direction of flow and no chloride concentration measurements were available at the upgradient end of the section which is approximately 20 kilometers southeast of Whites City. As a result, it is believed that there is little evidence for the existence of the 100 kg/m^3 contour in this particular area.

The potential dissolution associated with the Bell Canyon aquifer mass transport capacity was evaluated through average dissolution calculations and two implausible worst case analyses. These analyses are not sensitive to the existing chloride concentration identified near Whites City. The upgradient chloride concentration of 100 kg/m^3 in the 16,500 meter section (Figure 4-1) used for the average and worst case dissolution analyses is well defined by existing data (Hiss, 1975a).

Comment No. 22

"Page 4-6, Section 4.3.1: This is a good approach to use as a first approximation because the method is insensitive to whether the source of salt is by diffusion from above, convection from above or from some

other source. In essence, the amount of calculated salt input by this method can be assumed to be from dissolution of overlying halite. Thus the amount of halite dissolved is probably overestimated. However, the basic assumption in this model as applied to the DMG is porous media flow in the DMG aquifer. In addition, the model presented here does not include longitudinal dispersion, which would tend to increase the amount of salt dissolved. Is dispersion insignificant in this case?"

Response:

The discussion in Section 4.3.1 describes the average rate of salt dissolution from the Castile and Salado formations assuming that the Bell Canyon aquifer controls the rate at which salt can be removed from the dissolution zone. For this approach, the mechanism by which salt dissolves is not important; the aquifer mass transport capacity is the key parameter. The product of aquifer flow rate and salt concentration increase in the direction of flow beneath the dissolution area yields the average dissolution rate. An illustration of this process, including dispersion, is provided in Figure 4-4 which shows the numerical model results.

Consideration of the dissolved salt transport in the Bell Canyon aquifer based on porous media flow theory is justified based on the available data on the DMG. (See response to Comment No. 5 for further discussion of the possibilities and effects of fractures in the DMG.) Section 5.1 of the report presents a discussion of the dissolution rate as computed by this technique with respect to possible parameter variations. Fracture flow would have to be significant and widespread to impact the calculations presented in the report.

As part of the sensitivity analysis described in Appendix B, the effect of longitudinal dispersion in the Bell Canyon aquifer on salt dissolution was investigated. The results of the analysis are presented in Figures B-1(F) and B-1(G) and show that salt dissolution is insensitive to the magnitude of longitudinal, as well as transverse, dispersion. Similarly, the effect of longitudinal dispersion on the hand calculation results in Section 4.3.1 is insignificant.

Comment No. 23

"Page 4-7, 8th line from top: The mass of salt dissolved per year or 10,000 years should be presented here. Also, the mass flux and rate of salt being dissolved from underneath the WIPP site should be presented for comparison purposes. An EEG calculation indicates these values are 4.1×10^{-4} kg/yr/m^2 and 0.31 cm/10,000 years, respectively."

Response:

The variation of salt dissolution along the 16,500 meter section beneath the WIPP facility is shown by the dimensionless mass flux curve in Figure 4-4. The hand calculations presented in Section 4.3.1 are intended only to give approximate ranges of average salt dissolution. More detailed results are given in Section 4.4.2. The mass flux curve shows that the mass flux directly beneath the WIPP facility (Zone II) ranges from 80 to 70 percent of the average mass flux rate (Note 5 in Figure 4-4). Accordingly, the mass dissolution rate of salt varies from 6.6×10^{-4} to 5.8×10^{-4} kg/yr-m^2. For a salt density of 2,160 kg/m^3, the mass rates correspond to vertical movements of 0.31 and 0.27 centimeter per 10,000 years, respectively.The third sentence on Page 4-7 of the report will be clarified as follows:

> "Based on a flow rate of 0.135 m^3/yr-m and the observed chloride concentration profiles, the average thickness of salt removal in the basin was calculated to range between 0.07 and 0.62 centimeter in 10,000 years. This corresponds to a chloride concentration difference (ΔC) between upgradient and downgradient ends of the aquifer varying from 10 to 100 kg/m^3 across the basin, resulting in a salt removal rate ranging from 2.2 to 22.2 kg/yr-m, respectively."

The following statement will be added after the last sentence of the first paragraph on Page 4-7:

> "The calculated variation of salt dissolution along a 16,500 meter section beneath the WIPP facility is presented in Section 4.4.2 which describes numerical model results."

Comment No. 24

"Page 4-9, 2nd paragraph: It would be interesting to see the amount of salt that can be dissolved by the mechanism described in this paragraph. Would it be large enough to dissolve Salado salt laterally from the reef to the repository? Would it also be large enough to account for the amount of salt being transported by the Capitan Reef aquifer? However, the decreasing concentration of chloride downgradient along the eastern side of the Capitan Reef (see Page 4-5) tends to indicate that convective dissolution of the overlying Salado is not occurring in this part of the aquifer. Active convective dissolution would tend to increase the chloride."

Response:

See discussion on General Comment V regarding the potential dissolution associated with the Capitan Reef.

Comment No. 25

"Page 4-10, 2nd and 3rd paragraphs: The mass balance model described here should have a longitudinal dispersive term included."

Response:

The discussion on Page 4-10 refers to the numerical modeling of salt dissolution and subsequent transport in the Bell Canyon aquifer. In the modeling analysis, both longitudinal and transverse dispersion were included. A detailed presentation of the equations of flow and mass transport, which are solved in the numerical model and include longitudinal and transverse dispersion, is presented in Appendix A. The sensitivity analysis, which includes these terms, is discussed in Section 4.4.3 and Appendix B of the report. It demonstrates that the dispersivity of the Bell Canyon aquifer has negligible effect on the salt dissolution rate.

Comment No. 26

"Page 4-13, 8th line from bottom: The average value of vertical removal of 0.34 cm per 10,000 years obtained from the numerical approach agrees very well with the 0.31 cm per 10,000 years obtained from the analytical approach. What is the range of vertical salt removal over the 16,500 m long line underneath the repository?"

Response:

Figure 4-4 shows that along the 16,500 meter length the vertical salt removal varies from approximately 60 percent greater than to 40 percent less than the average salt removal rate for the entire section. Taking the average rate as 0.31 centimeter per 10,000 years, the range of vertical salt removal is 0.50 to 0.19 centimeter per 10,000 years.

Comment No. 27

"Page 4-14, Section 4.4.3: The sensitivity analysis with respect to hydraulic conductivity should be extended to 18 m/yr. See comment regarding page 2-8."

Response:

See response to Comment No. 6.

Comment No. 28

"Page 4-16, 3rd to 6th line from top: One of the reasons the numerical approach concluded diffusion as the source of salt to the DMG is that the model assumed diffusion as the source to start with. The model was then calibrated to determine the diffusion coefficent, which happened to be in the range of acceptable values. It can only be concluded that diffusion is a possible explanation but by no means the only one."

Response:

The purpose of the numerical analysis was to illustrate, using an accurate representation of the geology and transport processes in the DMG, that salt dissolution by continuous diffusion along the 16,500 meter section beneath the WIPP facility could produce the observed chloride concentrations in the Bell Canyon aquifer. Although localized convective dissolution could be present, it is unlikely that convection occurs over a widespread area because the associated large mass dissolution rate would far exceed the capacity of the aquifer to remove the dissolved salt. The potential dissolution cavity sizes and shapes that could result from localized convective mechanisms are discussed in the worst case analyses of Chapter 5.0. For both an average and localized basis, convection and diffusion are presented only as examples of dissolution mechanisms that could exist in the Castile and Salado formations considering the available hydrogeologic data. The Bell Canyon aquifer salt transport capacity, which is independent of the dissolution mechanisms, is concluded to be the primary parameter controlling dissolution rates.

In the final report, the third, fourth, and fifth sentences of the paragraph beginning at the bottom of Page 4-15 will be restated as follows:

> "Both analytical and numerical calculations indicate that salt dissolution by continuous diffusion along the 16,500 meter section beneath the WIPP facility could produce the observed chloride concentrations in the Bell Canyon aquifer. Although localized convective dissolution may be present, it is unlikely that convection occurs over a widespread area because the associated large mass dissolution rate would far exceed the capacity of the aquifer to remove the dissolved salt."

Comment No. 29

"Page 4-16, last paragraph: Has an estimate of the rate of salt dissolution from the reef toward the repository been obtained? Page 4-9 indicates that the reef transports 20 x 10^6 to 440 x 10^6 kg/year of chloride, of which only about 3 x 10^6 kg/year is accounted for. If the

remainder of the chloride transported by the reef comes from the brine density flow indicated here, how large a cavity would form in the Salado? What is the structural integrity of such a cavity? How fast would a cavity advance toward the repository? No sound basis is provided for the argument that the salt removal potential of the reef will not affect the repository."

Response:

See discussion on General Comment V concerning potential dissolution associated with the Capitan Reef.

Comment No. 30

"Page 5-2, 6th line from bottom: "0.34 centimeter" should read "0.31 centimeter." It appears that this paragraph is discussing the rates of dissolution determined from the analytical model. Page 4-7, third paragraph, indicates that the amount of salt dissolved is 0.3 centimeter in 10,000 years."

Response:

In the analytical evaluation of salt dissolution, a chloride concentration increase of 50 kg/m^3 (100 to 150 kg/m^3) based on field data was used to represent the salt dissolution along the Bell Canyon aquifer. This increase corresponds to an average dissolution rate of 0.31 centimeter per 10,000 years. The model predicted an increase of approximately 55 kg/m^3 chloride or 0.34 centimeter salt removal per 10,000 years. Due to the relatively small amount of concentration data available and the assumptions required to perform some of the calculations, the difference between 0.31 and 0.34 centimeter per 10,000 years as the average dissolution rate is insignificant. Solely for comparison purposes, the model result of 0.34 centimeter was adopted in Section 5.1.

Comment No. 31

"Page 5-3, 1st line: "0.7" should be "0.6." The dissolution process described on Page 5-2 has a linear relationship between flow thickness and dissolution height. If the aquifer thickness is doubled, the dissolution height should double."

Response:

As discussed in the response to Comment No. 30, the average salt removal rate of 0.34 centimeter per 10,000 years, as determined from the model results, was used for comparative purposes in Section 5.1. Given the same 55 kg/m^3 chloride concentration increase in the Bell Canyon aquifer, doubling the aquifer thickness to 60 meters would increase the salt removal rate to 0.68 centimeter, or approximately 0.7 centimeter per

10,000 years. The difference between using a 0.31 to 0.62 centimeter increase or a 0.34 to 0.68 centimeter increase is insignificant for the purposes of the illustration.

To clarify the discussion, the second paragraph on Page 5-2 will be reworded. The ninth sentence in the second paragraph will be revised to read:

> "For a Bell Canyon aquifer flow rate of 0.135 m^3/yr-m and a chloride concentration increase of 55 kg/m^3 (numerical model results), the average dissolution cavity height in 10,000 years would be 0.34 centimeter."

The eleventh sentence will read:

> "If the aquifer thickness is assumed to be 60 meters rather than 30 meters, the average salt removal corresponding to a 55-kg/m^3 chloride increase would be 0.68 centimeter per 10,000 years and 17 centimeters in 250,000 years."

Comment No. 32

"Page 5-4, 5th line from top, ref. Figure 5-2: The "dissolution controlled by diffusion" curve on Figure 5-2 does not pass through the point defined by flow rate = 0.135 m^3/yr/m and height = 0.34 cm. The results of the numerical modeling as presented on Page 4-13 indicate that flow rate = 0.135 m^3/yr/m and height = 0.34 cm is the solution to the numerical modeling problem. Is the "dissolution" curve in Figure 5-2 correct?"

Response:

The straight-line curve in Figure 5-2, representing dissolution controlled by the Bell Canyon aquifer, is based on a constant increase in chloride concentration of 50 kg/m^3 (Note 1 in the figure) over an aquifer length of 16,500 meters. The curve defining dissolution controlled by diffusion is derived from the numerical model predictions of dissolution-induced concentration increases for varying aquifer flow rates. The diffusion-controlled dissolution curve shown in Figure 5-2 of the April 1982 draft report was constructed for illustrative purposes using a smaller diffusion coefficient than was determined by the calibration. The sensitivity analysis described in Appendix B shows the effect of the diffusion coefficient on the salt dissolution rate. The dissolution curve using the calibrated diffusion coefficient value of 8.7×10^{-3} m^2/yr (Table B-2) increases from 0.14 centimeter at 0.038 m^3/yr-m, to 0.34 centimeter at 0.135 m^3/yr-m, and remains approximately horizontal at 0.40 centimeter from 0.2 to 0.5 m^3/yr-m. Figure 5-2 of

the final report has been redrafted to show the results obtained from the calibrated diffusion model.

Comment No. 33

"Page 5-6: Going back to the analytical model; for an aquifer flow rate of 0.135 $m^3/yr/m$ and a chloride concentration change of 50 kg/m^3 in 16,500 m, underneath the repository, the amount of salt dissolved over the 16,500 m line is 4.1×10^{-4} $kg/yr/m^2$. If this amount of chloride all dissolved from one fracture, the amount of chloride passing through this fracture is 6.8 kg/yr/m, which is slightly less than the 10 kg/yr/m being used here. Therefore, the results presented in Figure 5-2 may be slightly higher than what can actually occur, subject to any sensitivity analysis and the assumption of porous flow in the DMG. An approach to maximize salt dissolution would be to use a chloride concentration change of 150 kg/m^3, which is the change from one end of the DMG to the other. Using this approach, one gets about 20 kg/yr/m of salt dissolution through a fracture."

Response:

The discussion beginning at the bottom of Page 5-6 and continuing through the first paragraph on Page 5-7 refers to the "worst case" dissolution of salt through a fracture as controlled by the Bell Canyon aquifer. The steady state diffusion case referred to in Comment No. 33 is discussed in Section 4.4. In a fashion similar to the procedure used to estimate average salt dissolution, the rate at which salt can be removed from a fracture (i.e., the dissolution rate) is assumed to equal the product of the aquifer flow rate and the downgradient increase in salt concentration over the concentration already existing directly below the fracture. The chloride concentration beneath the fracture was assumed to be 120 kg/m^3, which is low compared to the observed concentration below the WIPP facility, and the downgradient concentration was set equal to the maximum or saturation level of 190 kg/m^3 chloride. For a flow rate of 0.135 $m^3/yr-m$, the potential chloride removal rate from the fracture is approximately 10 kg/yr-m (product of 0.135 $m^3/yr-m$ and 70 kg/m^3) which corresponds to salt removal at a 16 kg/yr-m rate. Clarification of this and other items regarding the worst case analysis in the report is presented following Comment No. 35.

Comment No. 34

"Page 5-6, 5th line from bottom: As mentioned earlier, work by Wooding (1960) indicates that convection can occur in fractures smaller than 1.5 millimeter."

Response:

This comment is addressed in the responses to Comment Nos. 13 and 35.

Comment No. 35

"Page 5-6, 2nd paragraph: The calculation of fracture width is not quite clear. If a fracture is capable of transporting 6 x 10^4 kg/m^2/yr (Page 3-11) of salt, it is capable of transporting 3.64 x 10^4 kg/m^2/yr of chloride. If fracture width is calculated by QWC/3.64 x 10^4 kg/m^2/year, then the fracture width curve in Figure 5-4B should be lowered. Again, Wooding (1960) indicates convection can occur in fractures with an aperture smaller than 1.5 mm."

Response:

The salt transport rate of 6 x 10^4 kg/yr-m^2 through a fracture, referred to on Page 3-11, is the rate that could develop due to convective mass transport in a fracture. However, since 6 x 10^4 kg/yr-m^2 is four orders of magnitude greater than the Bell Canyon aquifer's capacity to remove the salt from the fracture, this dissolution rate is unrealistic. As discussed in the response to Comment No. 33, a conservative estimate of the Bell Canyon aquifer's capacity to remove chloride from a fracture is 10 kg/yr-m (16 kg/yr-m salt removal). Potential cavity sizes above a fracture were estimated for a range of chloride removal rates (0 to 30 kg/yr-m) as shown in Figure 5-4. For a given removal rate, the fracture width is the minimum width that could transport the indicated amount of chloride from the dissolution zone down to the Bell Canyon aquifer (100 meters) by a combination of convective and diffusive mechanisms. The magnitudes of convective and diffusive transport that could develop were determined by combining Equations (3-1), (3-5), and (3-6) to give an analytical expression for total salt transport through a fracture as a function of the diffusion coefficient, fracture height, fluid viscosity, concentration difference between the top and bottom of the fracture, and the fracture width. By holding the chloride concentration difference constant at 70 kg/m^3 (190 to 120 kg/m^3 variation) and equating salt transported through the fracture with salt removed by the aquifer, the fracture width becomes a linear function of the Bell Canyon salt removal rate. For a particular salt removal rate, a larger fracture than indicated on the curve of Figure 5-4 could produce the same dissolution rate.

To better explain the fracture width calculation, a revision in the text of Section 5.2.1 will be made. The two sentences beginning on the ninth and twelfth lines of Page 5-6 will be rephrased as follows:

> "Similar to the procedure used to estimate average salt dissolution, the rate at which salt can be removed from the fracture (i.e., the dissolution rate) is assumed to equal the product of the aquifer flow rate and the downgradient increase in salt concentration above the concentration existing directly below the fracture. For the worst case analysis, the downgradient chloride concentration is the maximum or saturation value, 190 kg/m^3 (315 kg/m^3 salt concentration)."

The second paragraph on Page 5-6 will be revised to read:

> "Figure 5-4(A) illustrates the rate of development of a cylindrical cavity for a chloride removal rate of 10 kg/yr-m (16 kg/yr-m salt removal rate). The dissolution rate is based on an aquifer flow rate of 0.135 m^3/yr-m and a chloride concentration increase from 120 kg/m^3 beneath the fracture to 190 kg/m^3 downgradient of the fracture. Figure 5-4(B) illustrates the potential cavity sizes in 10,000 years for a range of chloride removal rates. Also shown are the minimum fracture widths required to transport the indicated chloride removal rates. For a given removal rate, the fracture width is the minimum width that could transport the indicated amount of chloride from the dissolution zone down to the Bell Canyon (100 meters) by a combination of convective and diffusive mechanisms. The magnitudes of convective and diffusive transport that could develop were determined by combining Equations (3-1), (3-5), and (3-6) to give an analytical expression for total salt transport through a fracture as a function of the diffusion coefficient, fracture height, fluid viscosity, concentration difference between the top and bottom of the fracture, and the fracture width. By holding the chloride concentration difference constant at 70 kg/m^3 (190 to 120 kg/m^3 variation) and equating salt transported through the fracture with salt removed by the aquifer, the fracture width becomes a linear function of the Bell Canyon aquifer salt removal rate. For a particular salt removal rate, a larger fracture than indicated on the curve of Figure 5-4 would produce the same dissolution rate.

The paragraph beginning at the bottom of Page 5-6 will be reworded as follows:

> "A chloride removal rate of 10 kg/yr-m (equivalent to a halite dissolution rate of about 16 kg/yr-m) requires a minimum fracture width on the order of 0.3 millimeter and may result in a dissolution cavity, based on the geometry shown in Figure 5-3, with a radius of approximately 7 meters in 10,000 years for the implausible worst case. Figure 5-6 illustrates the computed hypothetical cavity relative to the stratigraphy beneath the WIPP facility. The computed width of fracture is a minimum value required to sustain the indicated chloride transport rate. If the fracture width were greater than the minimum value, the rate of salt removal would be

unchanged. This is because the dissolution rate is limited to 16 kg/yr-m due to the Bell Canyon aquifer salt removal capacity."

Comment No. 36

"Page 5-12, bottom paragraph: The simple statement that 400 m thickness over a 1 m cavity with a 94 m diameter should be enough structural support is weak and not convincing. Some more justification of this idea should be provided."

Response:

The size of the potential cavity (either the seven meter radius or one meter height with 93 meter diameter) in comparison with the overburden strata thickness of more than 400 meters between the WIPP facility floor and the potential cavity is negligible. The very slow propagation of the dissolution front would be even slower than the closure due to salt creep, which means that the potential cavity could never reach the theoretical dimensions used in the discussion. Also, the overall deformation of the overburden would have only limited upward propagation and would most likely occur only within the lower portions of Halite I.

The third and fourth sentences of the last paragraph on Page 5-12 will be reworded as follows:

"As is evident in Figure 5-6, more than 400 meters of overburden exist between the implausible worst case potential cavities and the floor of the WIPP underground facility. As a result, the propagation of the dissolution front would cause a creep deformation of the overburden salt prompting closure of the cavities. Considering the extremely small volume of salt removed in comparison with the total strata thickness, the vertical propagation of this deformation would probably be limited to the lower section of the Halite I Formation."

Comment 37

"Table 4-1: What is the basis for the dispersivity of 3.048 meters shown in Table 4-1?"

Response:

Values of longitudinal dispersivity ranging between 0.01 and 100 meters and transverse dispersivity values of between 0.001 and 50 meters have been used in mass transport evaluations (Freeze and Cherry, 1979). The

dispersivity is a function of grain size distribution, anisotropic characteristics of the porous medium, and the tortuosity of the medium. In the simulation of salt dissolution in the DMG, a value of 3.048 meters (10 feet) was used for both longitudinal and transverse dispersivity. This value was selected based on literature data for similar materials (Freeze and Cherry, 1979 and Bear, 1975); but, due to the inherent variability of this parameter, a range of dispersivities (0.3048 to 30.48 meters) was investigated in the sensitivity analysis. Figure B-1 shows that the salt dissolution rate is very insensitive to the dispersivity of the Bell Canyon aquifer, indicating that the use of 3.048 meters in the salt dissolution simulation has little impact on the conclusions of the study.

REFERENCES

The following references are used in the responses to Comment Nos. 1 through 37 and General Comment Nos. I through VI. Each reference appears in the format that will be used in the final report:

Anderson, R. Y., 1978, "Deep Dissolution of Salt, Northern Delaware Basin, New Mexico," Report to Sandia Laboratories, Albuquerque, New Mexico, 106 pp.

Anderson, R. Y. and D. W. Kirkland, 1980, "Dissolution of Salt Deposits by Brine Density Flow," Geology, Vol. 8, pp. 66-69.

Bear, J., 1975, Dynamics of Fluids in Porous Media, American Elseveir Publishing Company, Inc., New York, 764 pp.

Cheesewright, R., 1968, "Turbulent Natural Convection from a Vertical Plane Surface," J. Heat Transfer, ASME, pp. 1-7.

Crank, J., 1975, The Mathematics of Diffusion, 2nd ed., Oxford University Press, 44 pp.

Elder, J. W., 1967, "Steady Free Convection in a Porous Medium Heated From Below," J. Fluid Mech., Vol. 27, pp 29-48.

Freeze, R. A. and J. A. Cherry, 1979, Groundwater, Prentice-Hall, Inc., New Jersey, 604 pp.

Golitsyn, G. S., 1979, "Simple Theoretical and Experimental Study of Convection with Some Geophysical Applications and Analogies," J. Fluid Mech., Vol. 95, Part 3, pp. 567-608.

Gonzalez, D. D., In Preparation, "Fracture Flow in the Rustler Formation, Waste Isolation Pilot Plant (WIPP), Southeast New Mexico," SAND 82-1012, Sandia Laboratories, Albuquerque, New Mexico.

Hiss, W. L., 1975a, "Stratigraphy and Groundwater Hydrology of the Capitan Aquifer, Southeastern New Mexico and Western Texas," Ph.D. Dissertation, University of Colorado, Boulder, Colorado, 374 pp.

Jessen, F. W., 1973, "Dissolution Processes," SME Mining Engineering Handbook, Vol. 2, A. B. Cummins, ed., SME of AIMMPE, New York, New York, pp. 21-1 to 21-15.

Knapp, R. M. and A. L. Podio, 1979, "Investigation of Salt Transport in Vertical Boreholes and Brine Invasion to Freshwater Aquifers," Technical Report, ONWI-77, Battelle Office of Nuclear Waste Isolation, 80 pp.

Lambert, S. J., In Preparation, "Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas," Sand 82-0461, Sandia Laboratories, Albuquerque, New Mexico.

Mercer, J. W. and B. R. Orr, 1977, "Review and Analysis of Hydrogeologic Conditions Near the Site of a Potential Nuclear Waste Repository, Eddy and Lea Counties, New Mexico," Open File Report 77-123, U.S. Department of Interior, Geological Survey, 35 pp.

Mercer, J. W. and B. R. Orr, 1979, "Interim Data Report on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site Southeast New Mexico," U.S. Geol. Surv. Water Resource Investigations, 79-98, U.S. Geological Survey Water Resources, Albuquerque, New Mexico, 178 pp.

Mercer, J. W. and Gonzales, D. D., 1981, "Geohydrology of the Proposed Waste Isolation Pilot Plant Site in Southeastern New Mexico," Special Publication No. 10, New Mexico Geological Society, pp. 123-131.

Powers, D. W., 1982, Sandia National Laboratories, Albuquerque, New Mexico, Personal Communication.

U.S. Department of Energy, 1980b, Waste Isolation Pilot Plant Safety Analysis Report (SAR), Vol. 1 and Vol. 2, U.S. Department of Energy, Washington, D.C.

Warner, C. Y. and V. S.Arpaci, 1968, "An Experimental Investigation of Turbulent Natural Convection in Air at Low Pressure Along a Vertical Heated Plate," Int. J. Heat Mass Transfer, Vol. 11, pp. 397-406.

Wooding, R. A., 1960, "Instability of a Viscous Fluid of Variable Density in a Vertical Hele-Shaw Cell," J. Fluid Mech., Vol. 7, pp. 501-515.

FRACTURE FLOW IN THE RUSTLER FORMATION

SAND 82-1012

"Equal Opportunity Employer"

STATE OF NEW MEXICO

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September 8, 1982

Mr. Joseph M. McCough
Project Manager of WIPP
WIPP Project Office
U.S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, New Mexico 87115

Dear Mr. McGough:

Enclosed are our review comments regarding the draft report "Fracture Flow in the Rustler Formation: Waste Isolation Pilot Plant (WIPP), Southeast New Mexico (Draft Interim Report)", SAND82-1012, May, 1982, Sandia National Laboratories.

We are looking forward to hearing your comments regarding our review.

Sincerely,

Robert H. Neill
Director

RHN:eg

2-058AG2-18-2-1-1

Enclosure

cc: TSC, IEA
W. Weart, Sandia

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

REVIEW COMMENTS
CONCERNING

FRACTURE FLOW IN THE RUSTLER FORMATION: WASTE ISOLATION PILOT PLANT (WIPP) SOUTHEAST NEW MEXICO (DRAFT INTERIM REPORT)

Comments by

Environmental Evaluation Group
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P. O. Box 968
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September 8, 1982

REVIEW OF "FRACTURE FLOW IN THE RUSTLER FORMATION: WASTE ISOLATION PILOT PLANT (WIPP), SOUTHEAST NEW MEXICO (DRAFT INTERIM REPORT)"

INTRODUCTION

A detailed review of the draft interim report entitled "Fracture Flow in the Rustler Formation: Waste Isolation Pilot Plant (WIPP), Southeast New Mexico" has been made by staff members of the Environmental Evaluation Group. The draft report presents some new information and ideas regarding the hydrology of the Rustler aquifer, most notably the direction of flow and the transport capabilities of the aquifers. The following comments are intended to get more clarification of some of the data interpretations presented in the report and to present some additional concerns the Environmental Evaluation Group has regarding flow in the Rustler Formation.

The "Costs and Merits Evaluation for Stipulated Agreement Activities" (pages 37 and 38) attached to the August 31, 1981 letter from Schueler to Goldstein does not clearly state the items that are to be addressed in the interim report. However, the comments represent the concerns of the Environmental Evaluation Group at this time and should be addressed in the final report regarding fracture flow in the Rustler, which is due during February, 1983.

DISCUSSION

The following items were referred to in the "Cost and Merits Evaluation for the Stipulated Agreement Activities," and subsequent correspondence between Schueler and Goldstein. We believe they were not adequately addressed in the Interim Report.

Proposed Work

- The best model to represent the flow path and aquifer characteristics in the Rustler will be developed.

Expected Results

- If the results are such that additional consequence analyses should be run, they will be incorporated into the study.

Schueler Letter

Item 10 in the October 30, 1981 letter from Schueler to Goldstein reads: "If results of tracer studies warrant, a model for multiple fracture flow will be developed. Discrete fracture flow (a one fracture flow path) is not considered to be a credible mechanism; this will be indicated and discussed in the report(s) on the Rustler aquifers."

It is recognized that some of these omissions would logically be presented in the final, rather than the interim report. However, it appears the fracture flow study is being conducted on two premises that have not yet been justified:

1. That the Culebra aquifer is critical and thus it is not necessary to study the Magenta aquifer. The conclusions that initial flow in the Culebra is to the southeast away from Nash Draw raises the question of whether flow in the Magenta may reach the more permeable Nash Draw area in shorter time. (see our comments regarding page 43). It is noted that the Cost and Merit Evaluation refers to Rustler aquifers and makes no mention of restricting investigations and evaluations to the Culebra aquifer.

2. That discrete fracture flow (a one fracture flow path) is not credible. A justification of this conclusion was promised in the October 30, 1981 letter and is necessary before one can dismiss the need to model discrete fracture flow.

GENERAL COMMENTS

Portions of the report summarize the transmissivity, storage coefficient, porosity and dispersivity of the various field test data. It appears that the details of these tests are presented in Bentley et. al. (1981, in

preparation), Ward and Gonzalez (1981, in preparation) and Gonzalez et. al. (in preparation), which are not yet available. It would have been very useful if these reports were available for the Environmental Evaluation Group to consult while reviewing the draft fracture flow report. In addition, Walter (1981, in preparation) would have been useful to review in order to evaluate the three-well technique for anisotropy. These reports should be made available to the Environmental Evaluation Group prior to issuance of the final report on fracture flow.

The report summary could address several additional items. At present it concludes the following:

- Culebra flow through the WIPP site is to the southeast
- the direction of the major component of the transmissivity tensor is from northwest to southeast
- depth averaged hydraulic conductivities decrease eastward from Livingston Ridge.

It also summarizes the transmissivities storage coefficients and porosities determined from the various tests. An additional item that needs to be addressed in the summary section concerns the nature of the fracture hydraulic conductivity. The report mentions double porosity flow (page 23) and discrete flow (page 35 and 44) but uses methods of analyses developed by Papadopulos (1965), Grove and Beetem (1971) and Sauty (1980), which are based on porous media flow. The report appears to conclude (page 35 and 44) that the dominant mode of transport in the Culebra is through discrete fractures. If this is true, the data may have to be reevaluated with models of flow through discrete fractures. A conclusion concerning the nature of fracture flow should be made before the regional transport model is developed.

The physical meaning of the values of the transmissivity storage coefficient, anisotropy, porosity and dispersivity in terms of fracture flow should be addressed.

For instance, is the anisotropy due to alternating vertical bands of highly transmissive rock and low transmissive rock that trend norhtwest to southeast or due to karst channels recharging the aquifers.

The porosity of 18% determined from the H-2 nest of wells appears high for a fractured rock. At the H-6 nest of wells the porosity appears to exhibit some directional characteristics, when it should not.

In addition, the data presented in the report indicate that Culebra flow in the repository area is to the southeast. Previous studies have indicated that flow is to the south and southwest. This data may indicate other discharge areas for the Culebra. An increased flow path that might result from the gradient presented in this report indicates that the Magenta may provide faster releases of radionuclides to the biosphere than the Culebra.

SPECIFIC COMMENTS

"ABSTRACT", 13th to 18th lines

The term "principal to minor transmissivity tensor" should be changed to "major to minor components of the transmissivity tensor." The term "principal transmissivity component" should be changed to "the principal direction of the major component of the transmissivity tensor" or "The orientation of the principal axes of the transmissivity tensor is northwest by southeast for the major component and northeast by southwest for the minor component." A statement about the variability of the transmissivity with respect to distance from the outcrop should also be included in the "abstract."

page 4, 2nd paragraph

Mercer and Gonzalez (1981) indicate a strong westward gradient from WIPP to Nash Draw in the Magenta dolomite. Have any calculations of travel time from WIPP to Nash Draw been made for the Magenta and compared to travel times for the Culebra?

The Culebra's southeast gradient through the repository, as indicated on Figure 16, shows that contamination from a repository breach may either never reach Nash Draw or may take longer than the 40,000 years previously estimated. If the Culebra travel times are significantly increased, the Magenta may provide quicker radioactive releases to the biosphere than the Culebra. Estimates of travel time from the repository to Nash Draw through the Magenta should be provided in this paragraph.

What are the data and assumptions that went into the calculation of the 40,000 year travel time from ERDA-9 to Malaga Bend? Is this number taken from some other work?

page 7, 1st and 2nd lines

The sentence should be changed to read something like "the major and minor components and principal directions of the transmissivity tensor."

page 8, bottom paragraph

Figure 15 indicates that the hydraulic gradient is to the southeast through the facility. Why does this paragraph say south and then southwest toward Malaga Bend? The statement appears to be referring to the previously assumed flow path shown in Figure 3, but it certainly is not clear.

page 9

Table 1 should be checked for errors. The "Fresh Water Altitude" for P-18 on the table and the altitude used for construction of Figure 16 appear to differ by 100 feet. Other "Fresh Water Altitudes" that appear to need checking belong to wells H-5, H-8, H-9, H-10, W-28 and W-30. In addition, the surface altitude of H-9 is 100' higher than that presented in Seward ("Abridged Borehole Histories for the Waste Isolation Pilot Plant (WIPP) Studies," SAND 82-0080). This may lower the fresh water altitude to 2976 at H-9. It is probable that the fractured nature of the dolomite may be causing the anomalous water levels. The water level at H-5 appears to be associated with a structural anomaly of the Culebra Dolomite (see attached Figures 1 and 2 and comment regarding page 44 and 45).

page 11, 1st paragraph

References for transmissivity values should be provided.

page 14, 10th line

Line should read "minor components and principal directions of the transmissivity tensor."

page 14, 2 bottom lines

It would be nice if the reference were already published to check the theory and to see the report contents.

page 15, 1st paragraph

The description of test procedures indicate that the "a" well at each pad was pumped. However, the anisotropy results of Table 2, Table 3 and Table 4 provide no results from pumping the "a" well. Why are the results from pumping the "a" well not presented? Was the "a" well pumped at all?

page 15, last paragraph

If the tracer curves are insensitive to dispersion (dispersivity), how can it be estimated?

page 18, lines 6, 15 and 17

Change "principal" to "major."

page 19, Table 2

According to the theory of anisotropic aquifers developed by Papadopulos (1965), the response of well H-4C from pumping H-4B should produce the same T and S values as the response of well H-4B from pumping well H-4C. The T estimates for these wells differ by a factor of two for tests one and two. The range of T (not including pumping wells) for all three tests is 0.8 feet squared per day to 1.7 feet squared per day. What is the cause of this discrepancy?

page 23, 1st paragraph

Were any methods such as images, tried to locate any of the barrier boundaries? What could these boundaries be attributed to? For instance, could the boundaries be due to vertical fractures filled with an impermeable material or to a less fractured nearby region of dolomite?

The shape of the curve on Figure 7 is interesting. The early part of the curve (prior to the formation of the straight line) may be a result of no storage of water in the fractured part of the aquifer or possibly a horizontal fracture overlain by a porous block (see "Well Hydraulics in Heterogeneous Aquifer Formations" by T. D. Streltsova-Adams in Advances in Hydroscience, Vol. 11, Academic Press, 1978). In addition,it appears questionable that the flat part of the curve is attributable to flow from the blocks to the fractures. According to Streltsova-Adams (see Proceedings, Second

Invitational Well-Testing Symposium held by Earth Sciences Division, Lawrence Berkeley Laboratory, on October 25-27, 1978) the flat part of the data should not show if the ratio $(S_f + S_m)/S_p$ (S_f and S_m are storage coefficients of the fractures and the porous matrix, respectively) is less than about 5 to 11. In other words, if the straight lines on Figure 7 are less than about 0.7 to 1.0 log cycles apart, which they are on Figure 7, then the flat part of the curve should not show. This brings several questions to mind:

1. Is it possible that the straight line shows up between 200 minutes and 2000 minutes on Figure 7? If this is the case, then the data after 2000 minutes including the flat part may be attributable to the transition period between flow in fractures and "induced response."
2. If the straight line is correct and there is no double porosity system, is the flat part of the data and the "induced response" caused by a highly permeable fracture or karst channel near the well test?
3. Is the anistotropy observed in these tests due to recharge into the rocks from a highly permeable fracture or karst channel? Such a response would cause the lines of equal drawdown to have oval shapes rather than the elliptical ones caused by anisotropy. Unless there are data from more than three observation wells it may be very difficult to tell the difference between an anisotropic aquifer and an aquifer with a recharge boundary.

Figure 7 of the report shows the response of the H-4a and H-4b wells due to pumping the H-4c well. Was the response of H-4a and H-4c due to pumping H-4b similar to the data shown on Figure 7 such that a double porosity system was indicated?

page 23, last paragraph

It appears questionable that chloride is the ideal tracer to use to determine if leakage is occurring between Rustler aquifers at the H-4 site. Table 4 of Mercer et. al. indicates that the chloride concentration of both the Magenta and Culebra is 7500 mg/ℓ (Mercer J.W., Paul Davis, Kevin F. Dennehy, and Carole L. Goetz, "Results of Hydrologic Tests and Chemistry Analyses, Wells H-4A, H-4B, and H-4C at the Proposed Waste Isolation Pilot Plant Site,

Southeastern New Mexico", Water-Resources Investigations 81-36, U.S. Geological Survey, May, 1981).

page 25, 2nd paragraph

The transmissivities as presented here are extremely small for a fractured rock and would tend to indicate that fracture flow is not that significant, at least in the areas that were tested. Any radionuclide transport in the Culebra would tend to be very slow because of the low transmissivities. Do fractures or karst channels capable of transmitting water exist near the WIPP site?

Table 9.2 of Walton (Walton, William C., Groundwater Resource Evaluation, McGraw-Hill, 1970) indicates the values of specific storage presented here are those for "sound rock." This would tend to indicate that any fractures in the Culebra, at least in the areas tested, are well cemented or that clean, open fractures are far apart. This suggests that fracture flow is not extensive over much of the Culebra but may be confined to long channels or fractures outside the area of influence of the pump tests. Does flow in open fractures exist in areas not tested by the pump or tracer tests?

page 27, 3rd paragraph

Was the aquifer pumped clear prior to tracer injection for the second test? If not, did the non-completion of the first tracer test affect the results of the second test? Is it possible that Segments I and II of Fig. 12 are due to the first test and Segments III and IV to the second test? If so, some type of deconvolution would be necessary to interpret the results.

page 28, 3rd paragraph

The Grove and Beetem (1971) model needs to be corrected for anisotropy. Was this done?

What were the ranges of porosities and dispersivities used in the Grove and Beetem (1971) analyses and how did they compare with the data?

page 32, 3rd paragraph

The significance of the porosities of 0.17 and 0.18 should be discussed here. These values are extremely high for a fractured rock. A fractured rock

typically has a fracture porosity of 0.01 - 0.02 and less (Streltsova, 1976). The porosity values presented here are typical for a porous media. If it is assumed that a fractured system operates at the H-2 well sites, then tracer diffusion from the fracture into the porous matrix could account for the high porosity. The effect of this diffusive process has been shown to increase travel times from one point to another when compared to a process without diffusion into the matrix. (See Grisak and Pickens, "Solute Transport Through Fractured Media I: The Effect of Matrix Diffusion, Water Resources Research, vol. 16, no. 4, Aug., 1980, pp. 719-730 and Grisak et al., "Solute Transport through Fractured Media 2: Column Study of Fractured Till," Water Resources Research vol. 16, no. 4, Aug., 1980, pp 731-739). The net effect of increasing the travel time would be a high porosity. Grisak and Pickens also indicated that the diffusion of solute into the matrix would be more significant for low velocities of fluid flow in the fracture than for high velocities. With the hydraulic conductivity of the Culebra at about 0.032 feet per day, fluid velocities are probably small.

The causes of the various segments on Figure 12 should be explained. For instance, were they caused by diffusion into the matrix at one time and out of the matrix at another time? Are they caused by a convolution of the two tracer tests?

page 35, 2nd paragraph

Sauty's (1980) method should be modified for the anisotropy determined from the pump tests at the H-6 site. Since the principal axes of the transmissivity tensor are known for this site, the modification is:

$$n = \frac{Qt}{\pi b\left(\sqrt{\frac{Tyy}{Txx}}\,x^2 + \sqrt{\frac{Txx}{Tyy}}\,y^2\right)}$$

where Q = pumping rate

b = aquifer thickness

t = time of match point

x,y= coordinates of well slugged with tracer

Txx= major transmissivity component

Tyy= minor transmissivity component

n = porosity.

In the above equation, the pumping well is at the origin and the major component of the transmissivity tensor runs between wells H-6b and H-6c as indicated from the well test data. The corrected porosities are 9.1% for the H-6b to H-6c test and 0.97% for the H-6a to H-6c test.

The 0.97% porosity appears reasonable for a fractured rock and occurs along the major axis of the transmissivity tensor. The 9.1% appears reasonable for a porous media. There is, however, almost an order of magnitude difference between the two. Since porosity is not anisotropic the disparity is probably caused by a heterogeneity in the Culebra. The suggestion of a discrete zone of flow i.e. a long highly permeable fracture, a set of parallel fractures or a karst channel, appears reasonable. Whether or not this discrete flow can be modelled adequately appears questionable. The problem lies in determining the number of discrete fractures and their locations.

page 38, 1st paragraph

The Safety Analysis Report (page 2.6-35) indicates that two sets of joint exist in the Delaware Basin. One of these sets strikes NW to SE, in the same direction as the major component of the transmissivity tensor. Does this joint set have some relationship to the principal axes of the transmissivity tensor? What is the possibility that vertical or near vertical fractures formed by the joint set could be missed by the drilling activities and subsequently untested by the pump testing program?

page 38, 2nd paragraph to page 39, 1st paragraph

The physical significance of the range of porosities to the following parameters should be discussed in more detail:

- travel times
- fracture flow or porous media flow
- the directional characteristics of the porosity.

The hydraulic conductivities should also be discussed in terms of fracture flow and porous media flow. The hydraulic conductivity values quoted in this report are averaged over the thickness of the Culebra i.e. the hydraulic conductivity is assumed to be uniform throughout the thickness of the Culebra. In a fractured media, the hydraulic conductivity is not uniform. It is peaked in a fracture and near zero outside a fracture. How would the hydraulic conductivity vary throughout the thickness of the Culebra? What effect would this variation have on travel times?

page 39, 1st paragraph

Figure 16 indicates that flow through the H-6 site is initially SSE. However the flow path appears to curve to the southeast away from Nash Draw. What is the basis for concluding that flow through H-6 reaches Nash Draw? In addition, a flow to the south-southeast would eventually have to turn toward the southwest in order to reach Nash Draw.

It further appears that Figure 16 may need some refinement. The figure does not appear to have contours based on the fresh water altitudes at H-8, H-9 and H-10. In addition, the fresh water elevation at P-18 is extremely low compared to the elevations at the other wells. The validity of the fresh water altitude is questionable because of the low hydraulic conductivity at that well. How does the fresh water altitude map change if fresh water altitudes at H-8, H-9 and H-10 are included in the map construction and P-18 is eliminated?

page 41, bottom paragraph

What is the basis for assuming 10 miles to the southeast? The data are all within 5 miles of the WIPP site. Most of the "path which would exceed 10 miles" is located in an area of very low hydraulic conductivity and in an area of unknown hydraulic gradient. In view of the southeast gradient over the study area, (Figure 16 of the draft report) how can the radionuclides discharge at Malaga Bend? The direction of the hydraulic gradient would have to turn southwest in order for a radionuclide to discharge at Malaga Bend. At

present there are no data to support this. Are there other discharge areas for the Culebra?

page 43, 1st paragraph

If travel time for a non-absorbing radionuclide in the Culebra becomes greater than 40,000 years, is it possible that the Magenta's westward flow from the WIPP to Nash Draw would provide a quicker radioactive release to the biosphere than flow in the Culebra? If so perhaps future studies should concentrate on flow in the Magenta rather than on the Culebra.

page 44 ad 45, Continuing Investigations

The following are suggestions that should be useful in the continuing study of fracture flow in the Rustler:

1. A review of aerial photographs through the area defined by WIPP-29, WIPP-25, WIPP-33, H-6 and H-5 should be made to see if any geomorphic features associated with either karst hydrology or fracture hydrology exist there. Thermal infrared photographs may be useful in locating springs or shallow ground water flowing in subsurface channels. This suggestion is made for several reasons:
   a. Larry Barrows, in a presentation to EEG, indicated that an elevated gravity anomaly existed in this area. He attributes it to a possible karst channel in the Culebra.
   b. A structure contour map (see Figure 1) on top of the Culebra was generated from Table 1 of the report. It indicates a depression extending through the WIPP-25, H-6, H-5 area. This depression may be associated with a karst channel.
   c. A fresh water altitude map (see Figure 2) for the Culebra was constructed from the data presented in Table 1 of the report. The figure indicates that a ground water high is associated with the depression. The ground water high indicates a potential for some flow to the west.

   If possible the review of the aerial photographs should extend from the northern part of Nash Draw to Malaga Bend.

2. The application of inverse techniques to flow in the Rustler should be interesting. For the most part inverse techniques are in their infancy and are designed for porous media flow, not discrete flow. If it is decided

that fracture flow can be modeled as a porous media, then the inverse technique developed by Neuman and Yakowitz ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 1: Theory," Water Resources Research, vol. 15, no. 4, pp 845-860, 1979), Neuman et al. ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 2: Case Study," Water Resources Research, vol. 16, no. 1, pp. 33-58, 1980) and Neuman ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 3: Improved Solution Method and Added Perspective, "Water Resources Research, vol. 16, no. 2, pp 331-346, 1980) should be tried. It appears that, at present, this is the only technique that has been published with an application to a real problem. Before the inverse techniques are applied to the Rustler, it should be decided whether flow in the Culebra is discrete or porous.

3. It appears that any contamination from a repository breach in Zone II would flow to the southeast. This is based on the flow paths as determined from Figure 15 and Figure 16 of the report. The area southeast of the WIPP should be studied further in terms of piezometric head, flow direction and discharge areas.

4. The tracer test at H-7 should be run similarly to the one at H-6. This should provide some more insight into the directional characteristics of the porosity and the areal extent of this phenomenum. Because the hydraulic conductivities at H-6 and H-7 are almost the same, the time required to run a test at H-7 should be about the same as at H-6.

   If possible, two two-well tracer tests should be run at H-4 in order to determine the porosity along the major and minor components of the transmissivity tensor.

5. If it has not been done, the Grove and Beetem (1971) model, the Sauty (1980) model and the SWIFT model, if it is used, should be modified to account for the anisotropy of the Rustler Formation.

TYPOGRAPHIC ERRORS

page 11, 2nd line

"definied" should be "defined"

page 25, bottom 3 lines

Either "yields" or "obtains" should be eliminated.

page 26

"(C)" should be "(°C)."

"(mhos)" should be "(μmhos)."

page 28, 2nd line from bottom

"Increases in displace" should read "Increases in ∝ displace."

page 36

"H-6b-c" should be "H-6a-c."

page 37

H-6a-c" should be "H-6b-c."

page 43, 3rd line

"members" should be "numbers."

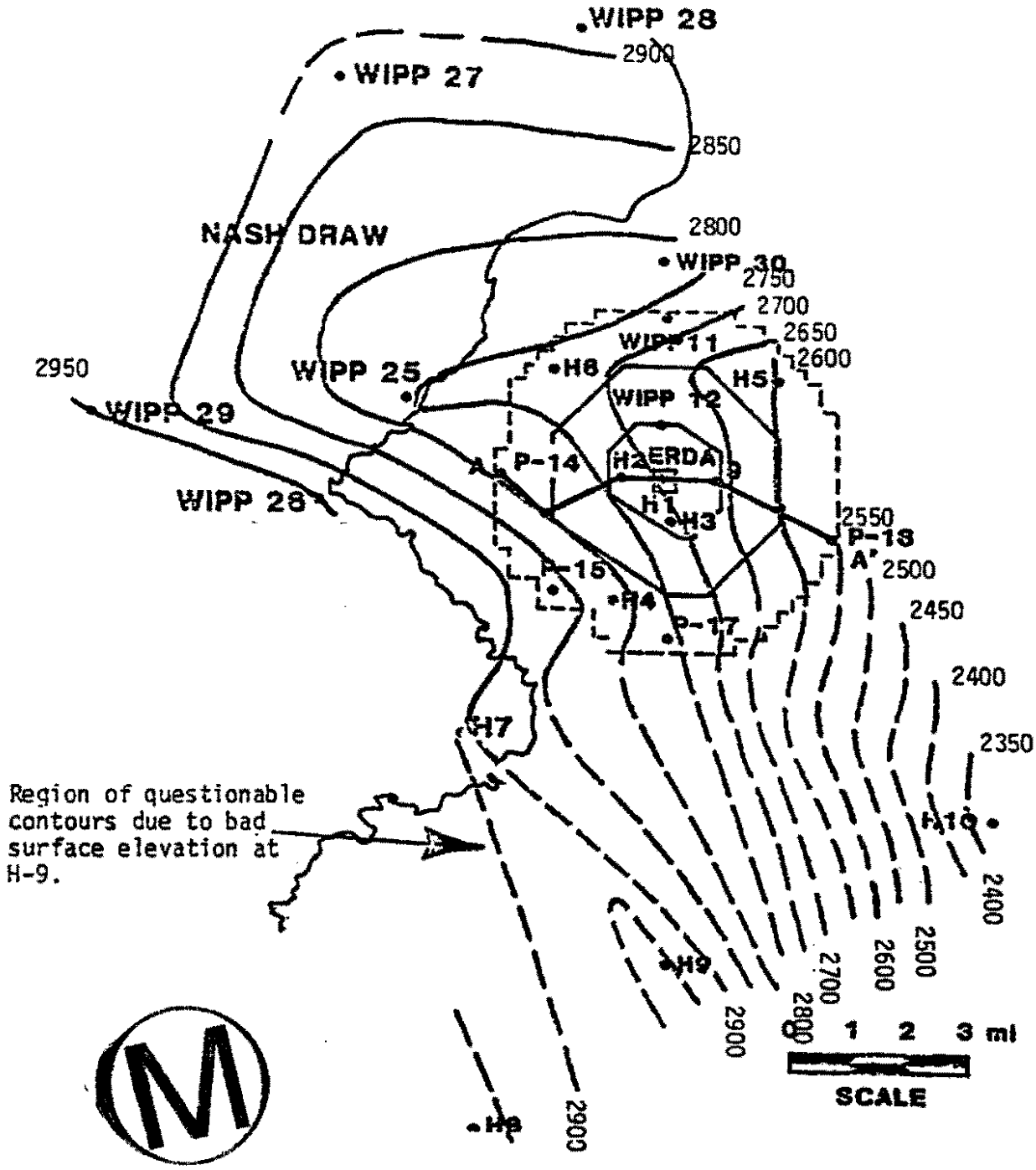

Figure 1. Structure Contours on Top of Culebra

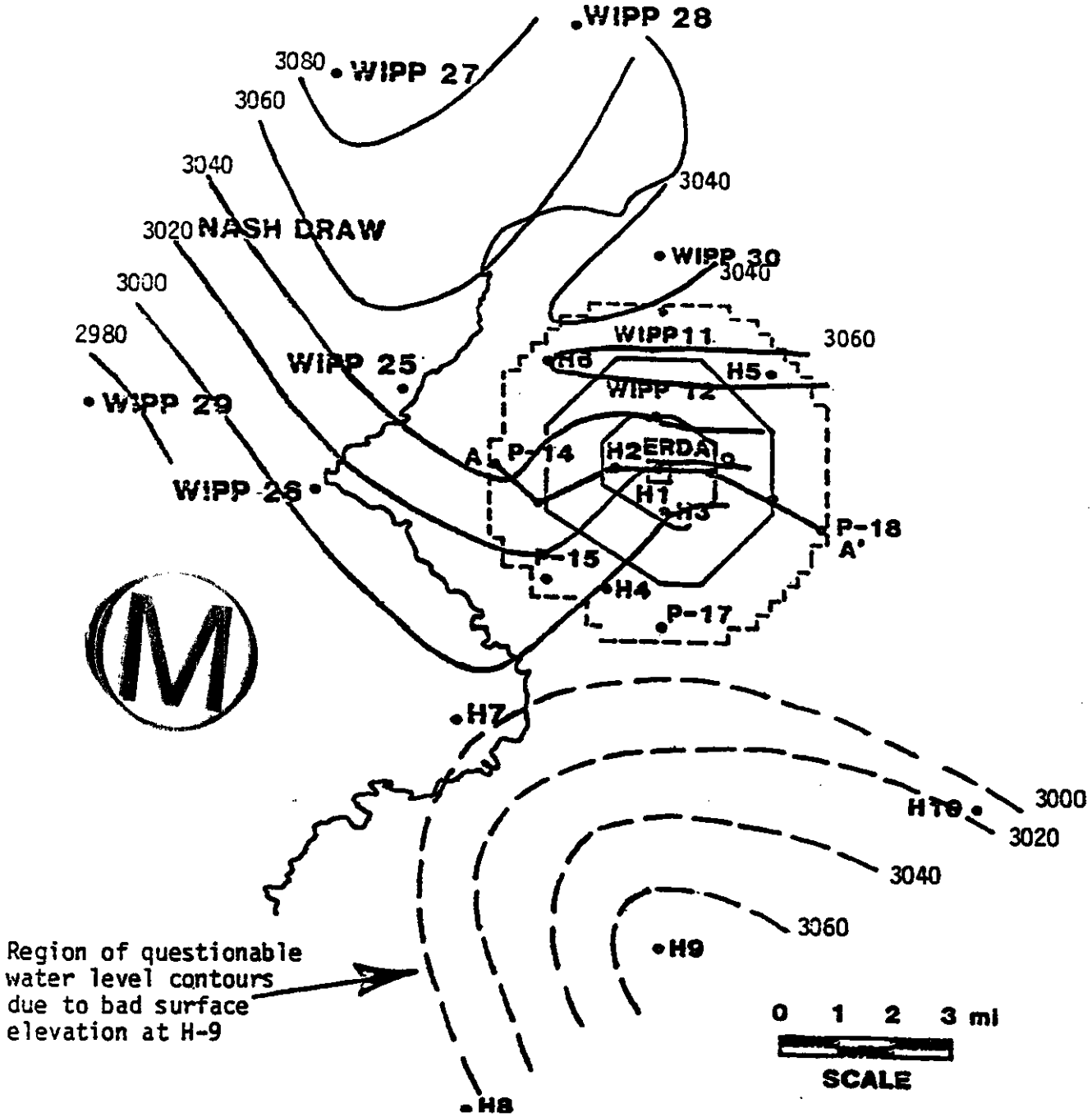

Figure 2. Fresh Water Altitude Contours for Culebra

RESPONSE TO EEG COMMENTS ON
"DRAFT INTERIM REPORT ON FRACTURE FLOW IN THE RUSTLER FORMATION"

EEG Comment: (Proposed Work - p. 1)

In the "Cost and Merits Evaluation for the Stipulated Agreement Activities," the following proposed work was identified: "The best model to represent the flow path and aquifer characteristics in the Rustler will be developed." This item was not adequately addressed in the interim report.

DOE Response:

The interim report does not address specifically the best model for flow path and aquifer characteristics of the Rustler. This "best model" will be formulated when the tracer/pump tests are completed.

EEG Comment: (Expected Results - p. 2)

In the "Cost and Merits Evaluation for the Stipulated Agreement Activities" the following expected results were identified: "If the results are such that additional consequence analyses should be run, they will be incorporated into the study." This item was not adequately addressed in the interim report.

DOE Response:

The consequence analyses, if warranted, will be performed by TSC for DOE. Though they are part of the study, the EEG should not expect consequence analyses as part of the interim or final reports on fracture flow in the Rustler.

EEG Comment: (Schueler letter, premise 1, p. 2)

The premise that the Culebra aquifer is critical and thus, it is not necessary to study the Magenta aquifer has not yet been justified.

DOE Response:

The premise that the Culebra is the critical aquifer has been justified for years on the basis of fluid volume, transport times, and discharge point. If the additional data and analysis indicate this premise is no longer justified, additional consequence analysis for the Magenta may be appropriate.

The evaluation of fracture flow in the Rustler Formation has been restricted to the Culebra aquifer on the basis of available hydrologic evaluation of the three fluid-bearing zones of the Rustler and their relationship to release scenarios developed in the EIS. In

short, the Culebra Dolomite exhibits the most potential to contain fluids and to be capable of solute transport over a large distance. The Rustler-Salado contact is practically devoid of transmissive property (10^{-4} ft^2/day) and the Magenta Dolomite varies from 10^{-1} to 10^{-4} under the site. Many holes show the Magenta devoid of fluids especially along the east flank of Nash Draw where it appears the Magenta is draining downward across fractured anhydrite and the ensuing gypsum (W-26, 28 and H-7a) and into the underlying Culebra aquifer.

EEG Comment: (Schueler letter, premise 2, p. 2)

The premise that discrete fracture flow is not credible has not yet been justified.

DOE Response:

Discrete fracture flow (one fracture flow path) is certainly inappropriate in view of the discussions on p. 23, for example. On pp. 35 and 38, discrete flow is described as appropriate for H-6, but this is not as one fracture flow path which might describe the system. Discrete fracture flow is not a credible mechanism for solute transport across the WIPP to a discharge area near Malaga Bend. As mentioned in the interim report, we have definite plans to model for multiple fracture block flow (double media). Furthermore, it is geologically unreasonable to conceive that one fracture exists across the WIPP towards the discharge area. The revision of the interim report will add statements summarizing the justification for this idea.

EEG Comments: (General comments, para. 1, p. 3)

The reports currently in preparation which contain details of the various field tests would be useful to the EEG to consult while reviewing the report.

DOE Response:

Yes, the reports in preparation which were cited would be useful to the EEG. The reports are being readied as Contractor Reports (SAND documents) with the intent of publishing and distributing each at or before the time of publication of the revised interim report on fracture flow.

EEG Comment: (General comments, para. 3, p. 3)

A conclusion concerning the nature of fracture flow should be made before the regional transport model is developed.

DOE Response:

The nature of the fracture flow is the point of the work being conducted. Porous media (continuous) methods were used; however, as a first approximation in analyzing the results of the hydraulic and tracer tests. This use is justified because they are not subject to the conceptual uncertainties that cloud the use of discrete fracture models and which make the results based on discrete fracture models subject to controversy. Certainly, a conclusion regarding fracture flow should be made before the regional transport model is completed.

EEG Comment: (General comments, para. 4, p. 3)

The physical meaning of the values of the transmissivity storage coefficient, anisotropy, porosity and dispersivity in terms of fracture flow should be addressed.

DOE Response:

The final report shall include a glossary of terms commonly used in the hydro-world, i.e, fracture conductivity, double porosity, porous media flow, discrete fractures, matrix permeability, transmissivity, anisotropy, porosity, dispersivity and storage. Again, the point of continuing the investigations is to determine the contribution (physical meaning?) of fracture flow. The site specific meaning of various hydraulic properties is the focus of the program.

EEG Comment: (General comment, para. 5, p. 3)

Is the anisotropy due to alternating vertical bands of highly transmissive rock and low transmissive rock that trend northwest to southeast or due to karst channels recharging the aquifers?

DOE Response:

The comment about anisotropy seems related to paragraph 4 in some way. At present, there is no hydraulic test which, unsupported by independent information, can show the cause of anisotropy. The fact that anisotropy tests at three sites were in relative agreement with each other have allowed some inferences to be drawn regarding the regional nature of the flow system. Anisotropy is explained in the report as due to fracturing, which is evidently caused by dissolution and subsidence. There is a possibility that the principal tensor orientation reflects a fracture trend due to tectonic forces. Additional testing for anisotropy will show if the direction for the principal tensor remains the same as in a broader tectonic process. A note regarding the uncertainty here will be added to the text.

There is no fundamental geohydrological process that seems appropriate to this site for developing "alternating vertical bands

of highly transmissive rock and low transmissive rock." The higher transmissivities correlate with areas subjected to more apparent Rustler/top Salado salt dissolution. Here, that is interpreted as resulting in fracturing which complements the natural porosity of fluid-bearing zones in the Rustler. These holes do not indicate any direct penetration of cavernous karst features.

We strongly disagree with the use of the word karst to describe the flow system in the Rustler Formation. At the present time data are insufficient to draw such a conclusion. Furthermore, the word karst can and has been used to describe the most disparate observations, from submicroscopic solution enlargements along a fracture, to man-size caverns and house-swallowing sinkholes, such as those that occur in Florida. Unfortunately, it is often times the more lurid definition that sticks in people's minds when the word is brought up. We do not attribute the results of the anisotropy and tracer tests to karst; neither do we preclude its possible existence at the WIPP. We merely state that the use of the word is premature and therefore, inappropriate. It causes emotional responses due to its several definitions, and it puts the investigator in the almost indefensible position of proving that every break in slope of a drawdown curve is not due to a karst feature.

EEG Comment: (General comment, para. 6 & 7, p. 4)

The porosity of 18% determined from the H-2 nest of wells appears high for a fractured rock. At the H-6 nest of wells the porosity appears to exhibit some directional characteristics, when it should not. In addition, the data presented in the report indicate that Culebra flow in the repository area is to the southeast. Previous studies have indicated that flow is to the south and southwest. This data may indicate other discharge areas for the Culebra. An increased flow path that might result from the gradient presented in this report indicates that the Magenta may provide faster releases of radionuclides to the biosphere than the Culebra.

DOE Response:

Thin-section porosity at H-2 is as high as 10 percent. A matrix porosity of 18 percent for the Culebra at H-2 does not seem unreasonable. because there have not been any tests for anisotropy at the H-2 site (the reviewer may believe there have been), we do not draw any specific conclusions about the nature of flow at that site. At H-6 porosities were determined along the major (1%) and minor (11%) components of flow. Keeping in mind the concept of double-porosity medium (fracture-block concept), it is reasonable to find directional characteristics in this type of matrix. Although we presently interpret flow southeast across the site, we have no supporting data to alter our beliefs that the ground water discharges near Malaga Bend. The increased flow path does not discredit the

Culebra as the major vehicle for transport because of the previous discussion on the Magenta.

EEG Comment: (Abstract, 13th to 18th line, p. 4)

The term "principal" to minor transmissivity tensor" should be changed to "major to minor components of the transmissivity tensor." The term "principal transmissivity component" should be changed to "the principal direction of the major component of the transmissivity tensor" or "The orientation of the principal axes of the transmissivity tensor is northwest by southeast for the major component and northeast by southwest for the minor component." A statement about the variability of the transmissivity with respect to distance from the outcrop should also be included in the "abstract."

DOE Responses:

The terminology regarding transmissivity tensors is in need of change. Tensors shall be described in terms of major and minor components and to a principal direction of either a major or minor component. The reference made to distance from the outcrop is confusing. Does the reviewer mean Nash Draw? We do refer to the variation in transmissivity relative to the east flank of Nash Draw. The comment may imply inferences about recharge areas being the Nash Draw "outcrop" areas which were not ready to draw yet.

EEG Comment: (2nd para., p. 4)

Mercer and Gonzalez (1981) indicate a strong westward gradient from WIPP to Nash Draw in the Magenta dolomite. Have any calculations of travel time from WIPP to Nash Draw been made for the Magenta and compared to travel times for the Culebra?

The Culebra's southeast gradient through the repository, as indicated on Figure 16, shows that contamination from a repository breach may either never reach Nash Draw or may take longer than the 40,000 years previously estimated. If the Culebra travel times are significantly increased, the Magenta may provide quicker radioactive releases to the biosphere than the Culebra. Estimates of travel time from the repository to Nash Draw through the Magenta should be provided in this paragraph.

What are the data and assumptions that went into the calculation of the 40,000 year travel time from ERDA-9 to Malaga Bend? Is this number taken from some other work?

DOE Response:

The comment about Magenta travel times seems to be leading to an inference that Nash Draw is where the Magenta discharges. Instead,

the travel time to the probable common discharge point is appropriate. Travel time is tempered by flux. The additional consequence analysis, if necessary, is the appropriate comparison.

The calculation of the 40,000 year travel time resulted from a request by D. D. Gonzalez to Intera Groundwater Consultants. The date of the request was January 1979 and was based on a very limited set of hydrologic parameters, including transmissivity, storativity and hydraulic head at four locations and only estimates in areas near Laguna Grande de La Sal and towards Malaga Bend. The assumed thickness and porosities for the Culebra Dolomite were 30 feet and 10% respectively. The particle tracking model (SWIFT) determining the streamline and travel time for a non-absorbing tracer particle released at the WIPP site calculated a streamline proceeding due south from the center of the WIPP for about five miles, then west south-westward towards Laguna Grande de La Sal, then south towards Malaga Bend. Over 80% of this travel time is attributed to flow in the five-mile long reach south of the site where our understanding of the hydraulic characteristics have not changed appreciably since 1979, except for porosities being calculated at 18% at H-2. Further discussion will be included in the final report as well as a reference to the Intera work, dated 5-22-79.

EEG Comment: (Page 8, bottom para., p. 5)

Figure 16 indicates that the hydraulic gradient is to the southeast through the facility. Why does this paragraph say south and then southwest toward Malaga Bend? The statement appears to be referring to the previously assumed flow path shown in figure 3, but it certainly is not clear.

DOE Response:

The southeast flow across much of the site still appears correct. The flow is expected to swing to the southwest based on H-8, 9, and 10. The contours of Figure 16 will be revised for the interim version, and we expect to perform additional testing in the southeast portion of the site to verify contours and hydraulic properties. The interim report will be clarified.

EEG Comment: (Page 9, p. 5)

Table 1 should be checked for errors. The "Fresh Water Altitude" for P-18 on the table and the altitude used for construction of Figure 16 appear to differ by 100 feet. Other "Fresh Water Altitudes" that appear to need checking belong to wells H-5, H-8, H-9, H-10, W-28 and W-30. In addition, the surface altitude of H-9 is 100' higher than that presented in Seward ("Abridged Borehole Histories for the Waste Isolation Pilot Plant (WIPP) Studies," SAND82-0080). This may lower the fresh water altitude to 2976 at H-9. It is probable that the fractured nature of the dolomite may be causing the anomalous water

levels. The water level at H-5 appears to be associated with a structural anomaly of the Culebra Dolomite (see attached Figures 1 and 2 and comment regarding page 44 and 45).

DOE Response:

P-18 and W-30 seem anomalously low, and both wells have very low transmissivity. They will be monitored to see if they have truly regained static equilibrium. If they have not, then the use of these nonrecovered water levels makes the water level at H-5 seem anomalously high and may lead to erroneous conclusions about the formation around H-5. in addition, we are in the process of double checking those elevations at all H- and W- sites where hydro-data have been collected.

EEG Comment: (Page 11, 1st para., p. 5)

References for transmissivity values should be provided.

DOE Response:

References will be given as appropriate.

EEG Comment: (Page 14, 2 bottom lines, p. 5)

It would be nice if the reference were already published to check the theory and to see the report contents.

DOE Response:

Agreed. See previous comment.

EEG Comment: (Page 15, 1st para., p. 6)

The description of test procedures indicates that the "a" well at each pad was pumped. However, the anisotropy results of Table 2, Table 3 and Table 4 provide no results from pumping the "a" well. Why are the results from pumping the "a" well not presented? Was the "a" well pumped at all?

DOE Response:

The "a" wells could not be pumped, though the report implied they were. The tests for anisotropy require only two wells be pumped within a three-well array; however, at each pad the "a" wells developed downhole or pump complications which prohibited their pumping. Clarification will be made in the interim report.

EEG Comment: (Page 15, last para., p. 6)

If the tracer curves as insensitive to dispersion (dispersivity), how can it be estimated?

DOE Response:

The fact that the Grove and Beetem breakthrough curves are relatively insensitive to dispersivity means only that they do not give precise values of dispersivity. Single well "pump-back" and two-well convergent flow tests are the best method to determine dispersivity and these tests are being pursued.

EEG Comment: (Page 19, Table 2, p. 6)

According to the theory of anisotropic aquifers developed by Papadopulos (1965), the response of well H-4C from pumping H-4B should produce the same T and S values as the response of well H-4B from pumping well H-4C. The T estimates for these wells differ by a factor of two for tests one and two. The range of T (not including pumping wells) for all three tests is 0.8 feet squared per day to 1.7 feet squared per day. What is the cause of this discrepancy?

DOE Response

In theory, the same effective transmissivity should be observed in the observation wells in an anisotropic aquifer, but not the storage coefficient. Obviously if the observation well data yield the same T and S and if the wells are the same distance from the pumped well, then the aquifer is isotropic. Also, only in an ideal aquifer will the same values be obtained from observation wells. However, the sensitivity of the anisotropy results to errors in the drawdown interpretation should be investigated, and sensitivity tests are included in our final product.

EEG Comment: (Page 23, 1st para., pp. 6-7)

Were any methods, such as images, tried in order to locate any of the barrier boundaries? What could these boundaries be attributed to? For instance, could the boundaries be due to vertical fractures filled with an impermeable material or to a less fractured nearby region of dolomite?

The shape of the curve on Figure 7 is interesting. The early part of the curve (prior to the formation of the straight line) may be a result of no storage of water in the fractured part of the aquifer or possibly a horizontal fracture overlain by a porous block (see "Well Hydraulics in Heterogeneous Aquifer Formations" by T. D. Streltsova-Adams in Advances in Hydroscience, Vol. 11, Academic Press, 1978). In addition, it appears questionable that the flat

part of the curve is attributable to flow from the blocks to the fractures. According to Streltsova-Adams (see Proceedings, Second Invitational Well-Testing Symposium held by Earth Sciences Division, Lawrence Berkeley Laboratory, on October 25-27, 1978) the flat part of the data should not show if the ratio $(S_f + S_m)/Sp$ (S_f and S_m are storage coefficients of the fractures and the porous matrix, respectively) is less than about 5 to 11. In other words, if the straight lines on Figure 7 are less than about 0.7 to 1.0 log cycles apart, which they are on Figure 7, then the flat part of the curve should not show. This brings several questions to mind:

1. It is possible that the straight line shows up between 200 minutes and 2000 minutes on Figure 7? If this is the case, then the data after 2000 minutes including the flat part may be attributable to the transition period between flow in fractures and "induced response."

2. If the straight line is correct and there is no double porosity system, is the flat part of the data and the "induced response" caused by a highly permeable fracture or karst channel near the well test?

3. Is the anisotropy observed in these tests due to recharge into the rocks from a highly permeable fracture or karst channel? Such a response would cause the lines of equal drawdown to have oval shapes rather than the elliptical ones caused by anisotropy. Unless there are data from more than three observation wells, it may be very difficult to tell the difference between an anisotropic aquifer and an aquifer with a recharge boundary.

Figure 7 of the report shows the response of the H-4a and H-4b wells due to pumping the H-4c well. Was the response of H-4a an H-4c due to pumping H-4b similar to the data shown on Figure 7 such that a double porosity system was indicated?

DOE Response:

Image-well theory was applied to drawdown data in an effort to locate groundwater "barriers," which could be attributed to skin effects, wellbore storage, pumping variations, elastic deformation, and formation barriers. A formation barrier may consist of abrupt changes in aquifer properties, such as porosity, conductivity, fracture density or orientation, recharge and discharge zones, transient or steady-state flow, vertical/horizontal permeability. Barriers may be the result of one or a combination of geologic or hydrologic parameters. Vertical communication with known overlying and underlying aquifers is practically negligible throughout the WIPP facility on the basis of observed differences in hydraulic potential and conductivities and general chemistry. We believe that the

reviewer means that the slope of the transitional curve should not be zero, not that it should not show. Also, Streltsova-Adams assumes in her report that the matrix has zero permeability. If, in our case, the matrix has some permeability, then the shape of the drawdown curve may be different from her examples.

In regards to the three questions raised by the reviewer:

1. We think that the curvature of the early-time data on Figure 7 is pronounced. On log-log paper this portion of the curve is straight with nearly unit slope indicating full fracture flow or well-bore storage (probably the latter). It is entirely possible that the data after 2000 minutes is in a transitional period, but we think it is more consistent to treat the data between 2000 and 5000 minutes as a good straight-line (Jacob approx.) solution, and between 5000 and 8000 minutes as transitional (or induced response). Past 8000 minutes the line becomes approximately parallel to the earlier data. (The "INDUCED RESPONSE" arrow on Figure 7 points to the wrong part of the curve and will be corrected in the interim report.)

2. If the first break in the drawdown curve is attributed to hitting a recharge boundary, then it follows that the second break must be due to a barrier boundary. Furthermore, the shapes and permeabilities of both boundaries must be such that the effect of the second boundary must completely negate the first so drawdown may continue as if neither existed. We agree that several interpretations are possible, given that little is known about the system, but we do not believe that the drawdown data alone support the existence of a recharge boundary. In regards to "karst channel near the well," please refer to earlier discussion about so-called karst.

3. According to our dictionary, the definitions of "oval" and "elliptical" are the same. The drawdown data we used for anisotropy determinations was early-time, hopefully taken before any breaks, boundaries, or possible induced response affected the results. The anisotropy results should be free from these effects.

Some of this discussion will be included in the revision of the draft.

Well H-4a could not be pumped and the H-4b test was not run for a sufficient length of time to see the second break in the drawdown curve.

EEG Comment: (Page 23, last para., p. 7)

It appears questionable that chloride is the ideal tracer to use to determine if leakage is occurring between Rustler aquifers at the H-4

site. Table 4 of Mercer et. al. indicates that the chloride concentration of both the Magenta and Culebra is 7500 mg/l (Mercer, J. W., Paul Davis, Kevin F. Dennehy, and Carole L. Goetz, "Results of Hydrologic Tests and Chemistry Analyses, Wells H-4A, H-4B, and H-4C at the Proposed Waste Isolation Pilot Plant Site, Southeastern New Mexico," Water-Resources Investigations 81-36, U.S. Geological Survey, May, 1981).

DOE Response:

The objective was to determine if leakage did occur during the tests; we had few other tools at out disposal (such as piezometers in confining zones or adjacent water-bearing units) to assess leakage, so water chemistry (temperature, ph, conductivity, chloride) was looked at during these tests as an alternative means. The results are not conclusive, but indicate that no leakage occurred. The text will be revised to indicate the uncertainty at H-4.

EEG Comment: (Page 25, 2nd para., p. 8) --

The transmissivities as presented here are extremely small for a fractured rock and would tend to indicate that fracture flow is not that significant, at least in the areas that were tested. Any radionuclide transport in the Culebra would tend to be very slow because of the low transmissivities. Do fractures or karst channels capable of transmitting water exist near the WIPP site?

Table 9.2 of Walton (Walton, William C., Groundwater Resource Evaluation, McGraw-Hill, 1970) indicates the values of specific storage presented here are those for "sound rock." This would tend to indicate that any fractures in the Culebra, at least in the areas tested, are well cemented or that clean, open fractures are far apart. This suggests that fracture flow is not extensive over much of the Culebra but may be confined to long channels or fractures outside the area of influence of the pump tests. Does flow in open fractures exist in areas not tested by the pump or tracer tests?

DOE Response:

The hydraulic conductivities observed at the WIPP are actually large compared to fractured crystalline rock. For example, the lowest transmissivity measured in our tests was at the H-5 site (0.04 feet squared per day), and corresponds to a hydraulic conductivity of 2×10^{-3} feet per day, which is an average for fractured crystalline rocks (Stripa Mine Project Report, 1980). It cannot be concluded that fluid movement will be slow because transmissivities are small. Solute transport may be quite rapid in a fracture flow situation. Determining solute transport capability is, of course, a major reason to perform tracer tests, which will yield indications of fluid velocities in the natural flow system.

The values of specific storage measured at the WIPP are of the order of 10^{-6}/ft, which, using Walter (Table 9.2) is reasonable for fissured and jointed rock. Lohman (Ground-Water Hydraulics, USGS Prof. Paper 708) uses a value of 10^{-6}/ft as a way to estimate storage coefficients for confined aquifers in general. A rock, such as a fairly rigid dolomite, could have a very low specific storage and still have measurable matrix and fracture porosity. Low specific storage does not mean that fracture flow is not extensive; it may only mean that there is a lack of significant compressibility in the system, both from fractures and matrix. For the reviewer to carry his suggestion one step further and imply that low specific storage within the area of pumping influence is evidence that open fracture or channel (karst?) flow exists outside the area of pumping influence, is, of course, unanswerable.

EEG Comment: (Page 27, 3rd para., p. 8)

Was the aquifer pumped clear prior to tracer injection for the second test? If not, did the non-completion of the first tracer test affect the results of the second test? Is it possible that Segments I and II of Figure 12 are due to the first test and Segments III and IV to the second test? If so, some type of deconvolution would be necessary to interpret the results.

DOE Response:

Different tracers were used in each test; thus, no interference existed.

EEG Comments (Page 28, 3rd paragraph, p. 8)

The Grove and Beetem (1971) model needs to be corrected for anisotropy. Was this done? What were the ranges of porosities and dispersivities used in the Grove and Beetem (1971) analyses and how did they compare with the data?

(Page 32, 3rd paragraph, pp. 8-9)

The significance of the porosities of 0.17 and 0.18 should be discussed here. These values are extremely high for a fractured rock. A fractured rock typically has a fracture porosity of 0.01 - 0.02 and less (Streltsova, 1976). The porosity values presented here are typical for a porous media. If it is assumed that a fractured system operates at the H-2 well sites, then tracer diffusion from the fracture into the porous matrix could account for the high porosity. The effect of this diffusive process has been shown to increase travel times from one point to another when compared to a process without diffusion into the matrix. (See Grisak and Pickens, "Solute Transport Through Fractured Media I: The Effect of Matrix Diffusion,

Water Resources Research, vol. 16, no. 4, Aug., 1980, pp. 719-730 and Grisak et al., "Solute Transport through Fractured Media 2: Column Study of Fractured Till," Water Resources Research vol. 16, no. 4, Aug., 1980, pp. 731-739). The net effect of increasing the travel time would be a high porosity. Grisak and Pickens also indicated that the diffusion of solute into the matrix would be more significant for low velocities of fluid flow in the fracture than for high velocities. With the hydraulic conductivity of the Culebra at about 0.032 feet per day, fluid velocities are probably small.

The causes of the various segments on Figure 12 should be explained. For instance, were they caused by diffusion into the matrix at one time and out of the matrix at another time? Are they caused by a convolution of the two tracer tests?

(Page 35, 2nd paragraph, pp. 9-10)

Sauty's (1980) method should be modified for the anisotropy determined from the pump tests at the H-6 site. Since the principal axes of the transmissivity tensor are known for this site, the modification is:

$$n = \frac{Qt}{b\left(\frac{Tyy}{Txx}x^2 + \frac{Txx}{Tyy}y^2\right)}$$

where Q = pumping rate
b = aquifer thickness
t = time of match point
x,y = coordinates of well slugged with tracer
Txx = major transmissivity component
Tyy = minor transmissivity component
n = porosity.

In the above equation, the pumping well is at the origin and the major component of the transmissivity tensor runs between wells H-6b and H-6c as indicated from the well test data. The corrected porosities are 9.1% for the H-6b to H-6c test and 0.97% for the H-6a to H-6c test.

The 0.97% porosity appears reasonable for a fractured rock and occurs along the major axis of the transmissivity tensor. The 9.1% appears reasonable for a porous media. There is, however, almost an order of magnitude difference between the two. Since porosity is not anisotropic, the disparity is probably caused by a heterogeneity in the Culebra. The suggestion of a discrete zone of flow, i.e., a long highly permeable fracture, a set of parallel fractures or a karst

channel, appears reasonable. Whether or not this discrete flow can be modelled adequately appears questionable. The problem lies in determining the number of discrete fractures and their locations.

DOE Responses:

Several good points are brought out here. We do not yet believe that we can define the flow system at the H-2 site. A double porosity system is appealing, but anisotropy needs to be determined and further tracer tests along different flow paths need to be conducted at the site to define the flow system. Again, we do not believe that the hydraulic conductivity at the H-2 site precludes the possibility or rapid fluid movement. The final report will include the results of additional tracer and anisotropy tests and respective modification to the code developed by Grove and Beetum.

Much discussion can be related to what value of porosity is typical of fractured rock vs. porous media. A minimum of effort has been spent on acquiring field data through extended tracer and anisotropy tests to evaluate and determine what these values are and what they mean. We hope to solidify our thoughts on double porosity media after the conclusion of our tests at H-6 and 7. At this point, the number of discrete fractures and their locations are not the problem -- neither is the notion of karst channel domination. A macroscopic point of view is the solution.

The H-6 tracer results certainly imply the existence of both fracture and matrix flow, at least under the flow regime set up by the test itself. There is not necessarily a disparity in the porosity determinations, nor need the difference be caused by local heterogenities.

EEG Comment: (Page 38, 1st para., p. 10)

The Safety Analysis Report (page 2.6-35) indicates that two sets of joint exist in the Delaware Basin. One of these sets strikes NW to SE, in the same direction as the major component of the transmissivity tensor. Does this joint set have some relationship to the principal axes of the transmissivity tensor? What is the possibility that vertical or near vertical fractures formed by the joint set could be missed by the drilling activities and subsequently untested by the pump testing program?

DOE Response:

See previous discussion of principal tensor and fracture trends. The testing program would not test a set of non-intersecting or non-interconnected fractures by definition. The fact that dipping fractures are intersected requires interconnection of even vertical fractures with the borehole though the zone of influence has limits.

EEG Comments:

(Page 38, 2nd para. to Page 39, 1st para., pp. 10-11)

The physical significance of the range of porosities to the following parameters should be discussed in more detail:

- o travel times
- o fracture flow or porous media flow
- o the directional characteristics of the porosity.

The hydraulic conductivities should also be discussed in terms of fracture flow and porous media flow. The hydraulic conductivity values quoted in this report are averaged over the thickness of the Culebra, i.e., the hydraulic conductivity is assumed to be uniform throughout the thickness of the Culebra. In a fractured media, the hydraulic conductivity is not uniform. It is peaked in a fracture and near zero ouside a fracture. How would the hydraulic conductivity vary throughout the thickness of the Culebra? What effect would this variation have on travel times?

(Page 39, 1st para., p. 10)

Figure 16 indicates that flow through the H-6 site is initially SSE. However, the flow path appears to curve to the southeast away from Nash Draw. What is the basis for concluding that flow through H-6 reaches Nash Draw? In addition, a flow to the south-southeast would eventually have to turn toward the southwest in order to reach Nash Draw.

It further appears that Figure 16 may need some refinement. The figure does not appear to have contours based on the fresh water altitudes at H-8, H-9 and H-10. In addition, the fresh water elevation at P-18 is extremely low compared to the elevations at the other wells. The validity of the fresh water altitude is questionable because of the low hydraulic conductivity at that well. How does the fresh water altitude map change if fresh water altitudes at H-8, H-9 and H-10 are included in the map construction and P-18 is eliminated?

DOE Response:

How hydraulic conductivity varies within the Culebra, both vertically and horizontally, will be a very difficult study. Cores taken from and measurements taken within the new ventilation shaft will help us. In our final analysis, a variation of parameters shall be input to the final regional model to simulate a variation of travel times under differing conditions.

The potentiometric surface as shown on Figure 16 typifies a very transmissive system approaching the WIPP from the north-east but encountering, in effect, a leaky boundary defined by the decrease in hydraulic conductivity from west to east and probably influenced by the presence of "salt" within the Rustler and lower transmissivities in the Culebra Dolomite. As the flux of groundwater encounters a less permeable portion of the aquifer, it resists flow and takes the more plausible avenue - down Nash Draw where we find transmissivities much greater in a number of wells. Figure 16 exemplifies the site specific information collected on and within the boundaries of the facility. The final report will include a refinement of the data, which will include tracer and anisotropy tests at locations south-east and south of the site. The validity of the use of fresh water altitudes based on fluid density influenced by low conductivity is also our concern. A final suite of W.L. measurements and density determinations will be taken and evaluated for inclusion in the final report. There are no better estimates for discharge areas other than near Malaga Bend or south of Laguna Grande de la Sal.

EEG Comment: (Page 41, bottom para., pp. 11-12)

What is the basis for assuming 10 miles to the southeast? The data are all within 5 miles of the WIPP site. Most of the "path which would exceed 10 miles" is located in an area of very low hydraulic conductivity and in an area of unknown hydraulic gradient. In view of the southeast gradient over the study area (Figure 16 of the draft report), how can the radionuclides discharge at Malaga Bend? The direction of the hydraulic gradient would have to turn southwest in order for a radionuclide to discharge at Malaga Bend. At present there are no data to support this. Are there other discharge areas for the Culebra?

DOE Response:

See previous comments.

EEG Comment: (Page 43, 1st para., p. 12)

If travel time for a non-absorbing radionuclide in the Culebra becomes greater than 40,000 years, it is possible that the Magenta's westward flow from the WIPP to Nash Draw would provide a quicker radioactive release to the biosphere than flow in the Culebra? If so, perhaps future studies should concentrate on flow in the Magenta rather than on the Culebra.

DOE Response:

See previous comments on Magenta.

EEG Comment: (Pages 44 and 45, Continuing Investigations, pp. 12-13)

The following are suggestions that should be useful in the continuing study of fracture flow in the Rustler:

1. A review of aerial photographs through the area defined by WIPP-29, WIPP-25, WIPP-33, H-6 and H-5 should be made to see if any geomorphic features associated with either karst hydrology or fracture hydrology exist there. Thermal infrared photographs may be useful in locating springs or shallow ground water flowing in subsurface channels. This suggestion is made for several reasons:

   a. Larry Barrows, in a presentation to EEG, indicated that an elevated gravity anomaly existed in this area. He attributes it to a possible karst channel in the Culebra.

   b. A structure contour map (see Figure 1) on top of the Culebra was generated from Table 1 of the report. It indicates a depression extending through the WIPP-25, H-6, H-5 area. This depression may be associated with a karst channel.

   c. A fresh water altitude map (see Figure 2) for the Culebra was constructed from the data presented in Table 1 of the report. The figure indicates that a ground water high is associated with the depression. The ground water high indicates a potential for some flow to the west.

   If possible, the reviw of the aerial photographs shoud extend from the northern part of Nash Draw to Malaga Bend.

2. The application of inverse techniques to flow in the Rustler should be interesting. For the most part, inverse techniques are in their infancy and are designed for porous media flow, not discrete flow. If it is decided that fracture flow can be modeled as a porous media, then the inverse technique developed by Neuman and Yakowitz ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 1: Theory," Water Resources Research, vol. 15, no. 4, pp. 845-860, 1979), Neuman et al. ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 2: Case Study," Water Resources Research, vol. 16, no. 1, pp. 33-58, 1980) and Neuman ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 3: Improved Solution Method and Added Perspective, "Water Resources Research, vol. 16, no. 2, pp. 331-346, 1980) should be tried. It appears that, at present, this is the only technique that has been published with an application to a real problem. Before the inverse techniques are applied to the Rustler, it should be decided whether flow in the Culebra is discrete or porous.

3. It appears that any contamination from a repository breach in Zone II would flow to the southeast. This is based on the flow paths as determined from Figure 15 and Figure 16 of the report. The area southeast of the WIPP should be studied further in terms of piezometric head, flow direction and discharge areas.

4. The tracer test at H-7 should be run similarly to the one at H-6. This should provide some more insight into the directional characteristics of the porosity and the areal extent of this phenomenon. Because the hydraulic conductivities at H-6 and H-7 are almost the same time, the time required to run a test at H-7 should be about the same as at H-6.

   If possible, two two-well tracer tests should be run at H-4 in order to determine the porosity along the major and minor components of the transmissivity tensor.

5. If it has not been done, the Grove and Beetem (1971) model, the Sauty (1980) model and the SWIFT model, if it is used, should be modified to account for the anisotropy of the Rustler Formation.

DOE Response:

Item 1.a. Bachman (1980, 1981) examined karst features extensively through Nash Draw, along the Pecos, and in the site area. He attributed the fill and depression at WIPP 33 to a karst-type process by which Nash Draw expands. In his field work and review of aerial photos, he does not attribute geomorphic features at the site to karst processes. Barrows found anomalously low gravity indicating which he infers as due to removal of mass by dissolution (= karst). Barrows does not restrict karst to the Culebra - it is more likely in the gypsum units by his log correlations.

Item 1.b. Whether the gravity anomaly and structure contour maps show karst channels or not is still speculation. Perhaps comparing these maps with similar ones in regions of known karst will help somewhat. If the structure contour map does delineate a west-east karst channel, it cuts through some of the highest transmissivities tested at the WIPP (WIPP 25 and H-6), as well as the lowest (WIPP 30 and H-5). It also trends parallel to the minor component direction of the transmissivity tensor determined at H-6 and H-5; that is, the transmissivity is least in the direction of the channel.

Item 1.c. Figure 16 will be revised as previously stated. WIPP 30 is still being monitored, and all potentiometric data will be revised to be current for the interim report.

Item 2. Those suggestions are well taken and shall be considered. Inverse techniques are subject to criticism; however, significant strides are being made towards utilizing these techniques and

determining whether fracture media can be treated as porous media (Neuman, U of Arizona); C. Wilson, and J. B. Long, LBL). We do have the insight to perform these evaluations in determining whether we are dealing with fracture or porous - the objective of our site specific studies.

Item 3. Locations for testing in the southeastern part of the site have been of some interest. DOE 1 was considered, but the operations may have been unsuitable for the conversion of the hole to hydro testing. However, that pad and borehole continue to be candidates for further testing. Anisotropy tests at H-9 and H-10 are also being considered.

Item 4. See report, p. 7, last line; also p. 45.

Item 5. See p. 44.

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February 18, 1983

Mr. Joseph M. McGough
Project Manager
WIPP Project Office
U.S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, New Mexico 87115

Dear Mr. McGough:

Subject: DOE response to EEG comments on "Draft Interim Report on Fracture Flow in the Rustler Formation"

We have evaluated the DOE response to EEG comments on the above cited document. For the most part, the responses were adequate. In some cases, additional text descriptions are suggested in our evaluation. One point, however, will require additional investigation and discussion.

We question the premise that only the Culebra aquifer is critical for contaminant transport scenarios. The Magenta should also be considered a migration pathway. Although the transmissivity of the Magenta is nearly a factor of 10 smaller than that of the Culebra, the flux through each aquifer is also dependent on the hydraulic gradient. Based on the limited data available to EEG at this time, the hydraulic gradient to the northwest in the Magenta (Mercer and Gonzalez, 1981) is steeper than the gradient to the south or southeast in the Culebra. Therefore, the flux through each aquifer may not be as different as the transmissivity difference would suggest. If the Magenta discharges into the Culebra near Nash Draw, as is suggested by the DOE response to the EEG comment regarding the Schueler letter dated Oct. 30, 1981, premise 1, (see page 2 of the enclosure), then a repository breach could send contaminants south--southeast through the Culebra as DOE has suggested and northwest through the Magenta and eventually into the Culebra at Nash Draw. The contaminant in the Culebra at Nash Draw would move toward Malaga Bend as has been suggested for a contaminant in the Culebra moving southeast from the WIPP. Although the discharge point may be the same, the travel times may differ greatly. However, present data are inadequate to precisely define the discharge points. Therefore until such time as the flow direction in the Culebra is accurately known, two migration paths should be considered.

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

Enclosed are our detailed evaluations of DOE responses to EEG comments.

Sincerely,

Robert H. Neill
Director

RHN:KR:eg

cc: TSC, IEA

EEG EVALUATION OF
THE DOE RESPONSE TO EEG COMMENTS ON
"DRAFT INTERIM REPORT ON FRACTURE FLOW IN THE RUSTLER FORMATION"

EEG Comment: (Proposed Work - p. 1)

In the "Cost and Merits Evaluation for the Stipulated Agreement Activities", the following proposed work was identified: "The best model to represent the flow path and aquifer characteristics in the Rustler will be developed." This item was not adequately addressed in the interim report.

DOE Response:

The interim report does not address specifically the best model for flow path and aquifer characteristics of the Rustler. This "best model" will be formulated when the tracer/pump tests are completed.

EEG Evaluation:

The response is adequate at this time. It was hoped that the draft preliminary report would contain some initial ideas regarding the best model to use.

EEG Comment: (Expected Results - p. 2)

In the "Cost and Merits Evaluation for the Stipulated Agreement Activities" the following expected results were identified: "If the results are such that additional consequence analyses should be run, they will be incorporated into the study." This item was not adequately addressed in the interim report.

DOE Response:

The consequence analyses, if warranted, will be performed by TSC for DOE. Though they are part of the study, the EEG should not expect consequence analyses as part of the interim or final reports on fracture flow in the Rustler.

EEG Evaluation:

The response is adequate at this time. However, it is EEG's understanding that an additional report regarding a consequence analysis of fracture flow in the Rustler Formation may be prepared by the TSC. It should be pointed out that this additional report is part of the stipulated agreement and should be prepared prior to the site validation declaration.

EEG Comment: (Schueler letter, premise 1, p. 2)

The premise that the Culebra aquifer is critical and thus, it is not necessary to study the Magenta aquifer has not yet been justified.

DOE Response:

The premise that the Culebra is the critical aquifer has been justified for years on the basis of fluid volume, transport times, and discharge point. If the additional data and analysis indicate this premise is no longer justified, additional consequence analysis for the Magenta may be appropriate.

The evaluation of fracture flow in the Rustler Formation has been restricted to the Culebra aquifer on the basis of available hydrologic evaluation of the three fluid-bearing zones of the Rustler and their relationship to release scenarios developed in the EIS. In short, the Culebra Dolomite exhibits the most potential to contain fluids and to be capable of solute transport over a large distance. The Rustler-Salado contact is practically devoid of transmissive property (10^{-4} ft^2/day) and the Magenta Dolomite varies from 10^{-1} to 10^{-4} under the site. Many holes show the Magenta devoid of fluids especially along the east flank of Nash Draw where it appears the Magenta is draining downward across fractured anhydrite and the ensuing gypsum (W-26, 28 and H-7a) and into the underlying Culebra aquifer.

EEG Evaluation:

The premise that the Culebra is the critical aquifer seems to be based on old data. Piezometric head maps for the Culebra Dolomite as presented in the interim report and Mercer and Gonzalez (1981) are different from maps published earlier (see "Final Environmental Impact Statement, Waste

Isolation Pilot Plant." DOE/EIS-0026, Oct., 1980; or "Review and Analysis of Hydrogeologic Conditions near the site of a Potential Nuclear-Waste Repository, Eddy and Lea Counties, New Mexico," USGS, OFR 77-123, February, 1977). The earlier maps treated the Culebra Dolomite and Magenta Dolomite as one hydrologic unit. The Culebra Dolomite and Magenta Dolomite have been treated as two distinct hydrologic units only since 1979. Since then, data have shown a westward dipping hydraulic gradient in the Magenta Dolomite. The data in the interim report even changes some of the conceptions regarding the distribution of hydraulic conductivity than that presented in the "Final Environmental Impact Statement."

The EEG concern regarding this matter is the potential contamination of the Culebra Dolomite in Nash Draw caused by a repository breach into the Magenta Dolomite. See addition evaluation of EEG comment regarding 2nd paragraph, page 4 (pages 9 and 10 of this evaluation).

EEG Comment: (Schueler letter, premis 2, p. 2)

The premise that discrete fracture flow is not credible has not yet been justified.

DOE Response:

Discrete fracture flow (one fracture flow path) is certainly inappropriate in view of the discussions on p. 23, for example. On pp. 35 and 38, discrete flow is described as appropriate for H-6, but this is not as one fracture flow path which might describe the system. Discrete fracture flow is not a credible mechanism for solute transport across the WIPP to a discharge area near Malaga Bend. As mentioned in the interim report, we have definite plans to model for multiple fracture block flow (double media). Furthermore, it is geologically unreasonable to conceive that one fracture exists across the WIPP towards the discharge area. The revision of the interim report will add statements summarizing the justification for this idea.

EEG Evaluation:

The response is adequate.

EEG Comments: (General comments, para. 1, p. 3)

The reports currently in preparation which contain details of the various field tests would be useful to the EEG to consult while reviewing the report.

DOE Response:

Yes, the reports in preparation which were cited would be useful to the EEG. The reports are being readied as Contractor Reports (SAND documents) with the intent of publishing and distributing each at or before the time of publication of the revised interim report on fracture flow.

EEG Evaluation:

The response is adequate.

EEG Comment: (General comments, para. 3, p. 3)

A conclusion concerning the nature of fracture flow should be made before the regional transport model is developed.

DOE Response:

The nature of the fracture flow is the point of the work being conducted. Porous media (continuous) methods were used; however, as a first approximation in analyzing the results of the hydraulic and tracer tests. This use is justified because they are not subject to the conceptual uncertainties that cloud the use of discrete fracture models and which make the results based on discrete fracture models subject to controversy. Certainly, a conclusion regarding fracture flow should be made before the regional transport model is completed.

EEG Evaluation:

The response is adequate. The intent of the comment was to make sure that the flow system was well understood before any computer modeling was started. It sometimes happens that modeling is started before the flow system is understood.

EEG Comment: (General comments, para. 4, p. 3)

The physical meaning of the values of the transmissivity, storage

coefficient, anisotropy, porosity and dispersivity in terms of fracture flow should be addressed.

DOE Response:

The final report shall include a glossary of terms commonly used in the hydro-world, i.e., fracture conductivity, double porosity, porous media flow, discrete fractures, matrix permeability, transmissivity, anisotropy, porosity, dispersivity and storage. Again, the point of continuing the investigations is to determine the contribution (physical meaning?) of fracture flow. The site specific meaning of various hydraulic properties is the focus of the program.

EEG Evaluation:

The intent of the comment was to get a feel if the transmissivities, storage coefficients, porosities, etc., were typical, high, or low for a fractured rock. Perhaps they could be related to data from other sites or rock types. After talking with other hydrologists regarding some of the above terms, the EEG feels that a glossary is a good idea.

EEG Comment: (General comment, para.. 5, p.3)

Is the anisotropy due to alternating vertical bands of highly transmissive rock and low transmissive rock that trend northwest to southeast or due to karst channels recharging the aquifers?

DOE Response:

The comment about anisotropy seems related to paragraph 4 in some way. At present, there is no hydraulic test which, unsupported by independent information, can show the cause of anisotropy. The fact that anisotropy tests at three sites were in relative agreement with each other have allowed some inferences to be drawn regarding the regional nature of the flow system. Anisotropy is explained in the report as due to fracturing, which is evidently caused by dissolution and subsidence. There is a possibility that the principal tensor orientation reflects a fracture trend due to tectonic forces. Additional testing for anisotropy will show if the direction for the principal tensor remains the same as in a broader tectonic process. A note regarding the uncertainty here will be added to the text.

There is no fundamental geohydrological process that seems appropriate to this site for developing "alternating vertical bands of highly transmissive rock and low transmissive rock." The higher transmissivities correlate with areas subjected to more apparent Rustler/top Salado salt dissolution. Here, that is interpreted as resulting in fracturing which complements the natural porosity of fluid-bearing zones in the Rustler. These holes do not indicate any direct penetration of cavernous karst fractures.

We strongly disagree with the use of the word karst to describe the flow system in the Rustler Formation. At the present time, data are insufficient to draw such a conclusion. Furthermore, the word karst can and has been used to describe the most disparate observations, from submicroscopic solution enlargements along a fracture, to man-size caverns and house-swallowing sinkholes, such as those that occur in Florida. Unfortunately, it is often times the more lurid definition that sticks in people's minds when the word is brought up. We do not attribute the results of the anisotropy and tracer tests to karst; neither do we preclude its possible existence at the WIPP. We merely state that the use of the word is premature and therefore, inappropriate. It causes emotional responses due to its several definitions, and it puts the investigator in the almost indefensible position of proving that every break in slope of a drawdown curve is not due to a karst feature.

EEG Evaluation:

The EEG comment responded to here was related to the previous comment and nothing specific was intended by it. A note or paragraph relating the anisotropy to tectonic forces or other geologic factors is a good idea.

We understand your concern regarding karst hydrology. Our consultant in karst hydrology believes that dissolution prongs along fractures are advancing eastward from Nash Draw. The rate of advance is very slow and the prongs should not affect the WIPP site for many tens of thousands of years. However, enlargement of fractures is a major concern and we will continue to pursue it.

EEG Comment: (General comment, para. 6 & 7, P. 4)

The porosity of 18% determined from the H-2 nest of wells appears high for a fractured rock. At the H-6 nest of wells the porosity appears to exhibit some directional characteristics, when it should not. In addition, the data presented in the report indicate that Culebra flow in the repository area is to the southeast. Previous studies have indicated that flow is to the south and southwest. This data may indicate other discharge areas for the Culebra. An increased flow path that might result from the gradient presented in this report indicates that the Magenta may provide faster releases of radionuclides to the biosphere than the Culebra.

DOE Response:

Thin-section porosity at H-2 is as high as 10 percent. A matrix porosity of 18 percent for the Culebra at H-2 does not seem unreasonable. Because there have not been any tests for anisotropy at the H-2 site (the reviewer may believe there have been), we do not draw any specific conclusions about the nature of flow at that site. At H-6 porosities were determined along the major (1%) and minor (11%) components of flow. Keeping in mind the concept of double-porosity medium (fracture-block concept), it is reasonable to find directional characteristics in this type of matrix. Although we presently interpret flow southeast across the site, we have no supporting data to alter our beliefs that the ground water discharges near Malaga Bend. The increased flow path does not discredit the Culebra as the major vehicle for transport because of the previous discussion on the Magenta.

EEG Evaluation;

The response to the high porosity at H-2 is adequate.

The response to the direction characteristics is not quite clear. Are you implying that flow between H-6b and H-6c is through discrete fractures and flow between H-6a and H-6b is through pores? The exact implication should be brought out better in the report.

The response regarding the discharge area of the Culebra Dolomite is adequate. It is hoped that the revision of Figure 16 will indicate better discharge areas of the Culebra Dolomite.

Responses regarding the Magenta Dolomite are presented elsewhere in this evaluation.

EEG Comment: (Abstract, 13th to 18th line, p. 4)

The term "principal to minor transmissivity tensor" should be changed to "major to minor components of the transmissivity tensor." The term "principal transmissivity component" should be changed to "the principal direction of the major component of the transmissivity tensor" or "The orientation of the principal axes of the transmissivity tensor is northwest by southeast for the major component and northeast by southwest for the minor component." A statement about the variability of the transmissivity with respect to distance from the outcrop should also be included in the "abstract."

DOE Responses:

The terminology regarding transmissivity tensors is in need of change. Tensors shall be described in terms of major and minor components and to a principal direction of either a major or minor component. The reference made to distance from the outcrop is confusing. Does the reviewer mean Nash Draw? We do refer to the variation in transmissivity relative to the east flank of Nash Draw. The comment may imply inferences about recharge areas being the Nash Draw "outcrop" areas which were not ready to draw yet.

EEG Evaluation:

The response regarding the transmissivity tensor terminology is adequate. The "Review Comments" also indicated that terminology regarding the transmissivity tensor on page 7, 1st and 2nd lines; page 14, 10th line; and page 18, 6th, 15th, and 17th lines also need correcting and should be changed accordingly.

It appears that the decrease of the transmissivity with respect to increasing distance from the east flank of Nash Draw is an important

result of the present work. We believe the result should be included in the abstract. It was not included in the abstract of the reviewed report.

The comments regarding the abstract were intended to improve the abstract. No other inferences should have been drawn from the comments.

EEG Comment: (2nd para., p.4)

Mercer and Gonzalez (1981) indicate a strong westward gradient from WIPP to Nash Draw in the Magenta dolomite. Have any calculations of travel time from WIPP to Nash Draw been made for the Magenta and compared to travel times for the Culebra?

The Culebra's southeast gradient through the repository, as indicated on Figure 16, shows that contamination from a repository breach may either never reach Nash Draw or may take longer than the 40,000 years previously estimated. If the Culebra travel times are significantly increased, the Magenta may provide quicker radioactive releases to the biosphere than the Culebra. Estimates of travel time from the repository to Nash Draw through the Magenta should be provided in this paragraph.

What are the data and assumptions that went into the calculation of the 40,000 year travel time from ERDA-9 to Malaga Bend? Is this number taken from some other work?

DOE Response:

The comment about Magenta travel times seems to be leading to an inference that Nash Draw is where the Magenta discharges. Instead, the travel time to the probable common discharge point is appropriate. Travel time is tempered by flux. The additional consequence analysis, if necessary, is the appropriate comparison.

The calculation of the 40,000 year travel time resulted from a request by D.D. Gonzalez to Intera Groundwater Consultants. The date of the request was January 1979 and was based on a very limited set of hydrologic

parameters, including transmissivity, storativity and hydraulic head at four locations and only estimates in areas near Laguna Grande de La Sal and towards Malaga Bend. The assumed thickness and porosities for the Culebra Dolomite were 30 feet and 10% respectively. The particle tracking model (SWIFT) determining the streamline and travel time for a non-absorbing tracer particle released at the WIPP site calculated a streamline proceeding due south from the center of the WIPP for about five miles, then west south-westward towards Laguna Grande de La Sal, then south towards Malaga Bend. Over 80% of this travel time is attributed to flow in the five-mile long reach south of the site where our understanding of the hydraulic characteristics have not changed appreciably since 1979, except for porosities being calculated at 18% at H-2. Further discussion will be included in the final report as well as a reference to the Intera work, dated 5-22-79.

EEG Evaluation:

The comment regarding travel time in the Magenta Dolomite is leading to an inference that the Magenta discharges there. The DOE response to the EEG comment regarding the Schueler letter, premise 1, seems to indicate that this is the case.

We disagree with the statement that "travel time to the probable common discharge point is appropriate." It is probable that the Culebra Dolomite is a usable aquifer in Nash Draw. It is productive and contains relatively good quality water. The Culebra Dolomite water quality could be deteriorated by a repository breach into the Magenta Dolomite and subsequent transport into the Culebra Dolomite. Such contamination may make the Culebra Dolomite an unusable aquifer in Nash Draw. This is the EEG concern regarding transport in the Magenta Dolomite.

The Culebra Dolomite south of the WIPP site has a low transmissivity and poor quality water. It is unlikely that it would be a usable aquifer. Therefore, for a breach into the Culebra, a travel time through the Culebra from the WIPP to Malaga Bend is appropriate.

The response regarding the calculation of the 40,000 year travel time is adequate.

EEG Comment: (Page 8, bottom para., p.5.)

Figure 16 indicates that the hydraulic gradient is to the southeast through the facility. Why does this paragraph say south and then southwest toward Malaga Bend? The statement appears to be referring to the previously assumed flow path shown in figure 3, but it certainly is not clear.

DOE Response:

The southeast flow across much of the site still appears correct. The flow is expected to swing to the southwest based on H-8, 9, and 10. The contours of Figure 16 will be revised for the interim version, and we expect to perform additional testing in the southeast portion of the site to verify contours and hydraulic properties. The interim report will be clarified.

EEG Evaluation:

In addition, it should be clearly indicated which wells were used and not used to construct Figure 16 of the draft interim report. The figure, as presented in the report, leads to confusion with regard to travel paths.

EEG Comment: (Page 9, p.5)

Table 1 should be checked for errors. The "Fresh Water Altitude" for P-18 on the table and the altitude used for construction of Figure 16 appear to differ by 100 feet. Other "Fresh Water Altitudes" that appear to need checking belong to wells H-5, H-8, H-9, H-10, W-28 and W-30. In addition, the surface altitude of H-9 is 100' higher than that presented in Seward ("Abridged Borehole Histories for the Waste Isolation Pilot Plant (WIPP) Studies," SAND82-0080). This may lower the fresh water altitude to 2976 at H-9. It is probable that the fractured nature of the dolomite may be causing the anomalous water levels. The water level at H-5 appears to be associated with a structural anomaly of the Culebra Dolomite (see attached Figures 1 and 2 and comment regarding page 44 and 45).

DOE Response:

P-18 and W-30 seem anomalously low, and both wells have very low transmissivity. They will be monitored to see if they have truly

regained static equilibrium. If they have not, then the use of these nonrecovered water levels makes the water leval at H-5 seem anomalously high and may lead to erroneous conclusions about the formation around H-5. In addition, we are in the process of double checking those elevations at all H- and W- sites where hydro-data have been collected.

EEG Evaluation:

The response is adequate.

EEG Comment: (Page 11, 1st para., p.5)

References for transmissivity value should be provided.

DOE Response:

References will be given as appropriate.

EEG Evaluation:

The response is adequate.

EEG Comment: (Page 14, 2 bottom lines, p. 5)

It would be nice if the reference were already published to check the theory and to see the report contents.

DOE Response:

Agreed. See previous comment.

EEG Evaluation:

The response is adequate.

EEG Comment: (Page 15, 1st para., p. 6)

The description of test procedures indicates that the "a" well at each pad was pumped. However, the anisotropy results of Table 2, Table 3 and Table 4 provide no results from pumping the "a" well. Why are the results from pumping the "a" well not presented? Was the "a" well pumped at all?

DOE Response:

The "a" wells could not be pumped, though the report implied they were. The tests for anisotropy require only two wells be pumped within a

three-well array; however, at each pad the "a" wells developed downhole or pump complications which prohibited their pumping. Clarification will be made in the interim report.

EEG Evaluation:

The response is adequate.

EEG Comment: (Page 15, last para., p. 6)

If the tracer curves are insensitive to dispersion (dispersivity), how can it be estimated?

DOE Response:

The fact that the Grove and Beetum breakthrough curves are relatively insensitive to dispersivity means only that they do not give precise values of dispersivity. Single well "pump-back" and two-well convergent flow tests are the best method to determine dispersivity and these tests are being pursued.

EEG Evaluation:

The response is adequate. Clarification regarding the statement should be made in the text.

EEG Comment: (Page 19, Table 2, p. 6)

According to the theory of anisotropic aquifers developed by Papadopulos (1965), the response of well H-4C from pumping H-4B should produce the same T and S values as the response of well H-4B from pumping well H-4C. The T estimates for these wells differ by a factor of two for tests one and two. The range of T (not including pumping wells) for all three tests is 0.8 feet squared per day to 1.7 feet squared per day. What is the cause of this discrepancy?

DOE Response:

In theory, the same effective transmissivity should be observed in the observation wells in an anisotropic aquifer, but not the storage coefficient. Obviously if the observation well data yield the same T and S and if the wells are the same distance from the pumped well then the

aquifer is isotropic. Also, only in an ideal aquifer will the same values be obtained from observation wells. However, the sensitivity of the anisotropy results to errors in the drawdown interpretation should be investigated, and sensitivity tests are included in our final product.

EEG Evaluation:

It appears that the transmissivity presented in Table 2 (and Table 3 and Table 4) is the effective transmissivity as used in the draft report and is the determinate of the transmissivity tensor. It further appears that the storage coefficient presented in Table 2 is really the quantity:

$$S(\text{table}) = \frac{S}{r^2} \; \frac{Txx\ y^2 - 2Txy\ xy + Tyy\ x^2}{Txx\ Tyy - Txy^2}$$

where S is the aquifer storage coefficient; Txx, Txy, and Tyy are the various components of the transmissivity tensor; x and y are the coordinates of the observation well if the pumping well is at the origin of the axes; and r is the distance between the pumping well and the observation well ($r^2 = x^2 + y^2$).

If the aquifer is homogeneous but not isotropic, then the drawdown response at H-4C caused by pumping H-4B should be the same as the drawdown response at H-4B caused by pumping H-4C. The observation well drawdown in a homogeneous anisotropic aquifer is

$$\$ = \frac{Q}{4\pi(Txx\ Tyy - Txy^2)}\ W\ (Uxy)$$

where

$$Uxy = \frac{S}{4t} \; \frac{Txy\ x^2 - 2T_{xy}\ xy + T_{xx}y^2}{(Txx\ Tyy - Txy^2)}$$

and $ is the observation well drawdown, Q is the pumping rate, S is the aquifer storage coefficient, W (Uxy) is the well function with the

argument Uxy and x and y are the coordinates of the observation well if the pumping well is at the origin of the axes. If the H-4B well is the pumping well as in Test 1, then the observation well H-4C has the coordinates x and y. If the role of each well is reversed as in Test 2 the coordinates of the H-4C well, now the observation well, are now -x and -y, which, when entered into the above Uxy equation, produce the same Uxy values as positive x and y. Therefore, the drawdown response at the H-4B well caused by pumping the H-4C well is the same as the drawdown at the H-4C well caused by pumping the H-4B well. This is the only well pair where this is true. The respective effective transmissivity and storage coefficient (table) for the two wells should be equal. However, the effective transmissivity differs by a factor of 2 and the storage coefficient (table) differs by a factor of 1.5. These are large differences and should be explained.

The sensitivity analyses proposed are a good idea.

EEG Comment: (Page 23, 1st para., pp. 6-7)

Were any methods, such as images, tried in order to locate any of the barrier boundaries? What could these boundaries be attributed to? For instance, could the boundaries be due to vertical fractures filled with an impermeable material or to a less fractured nearby region of dolomite?

The shape of the curve on Figure 7 is interesting. The early part of the curve (prior to the formation of the straight line) may be a result of no storage of water in the fractured part of the aquifer or possibly a horizontal fracture overlain by a porous block (see "Well Hydraulics in Heterogeneous Aquifer Formations" by T.D. Streltsova-Adams in Advances in Hydroscience, Vol. 11, Academic Press, 1978. In addition, it appears questionable that the flat part of the curve is attributable to flow from the blocks to the fractures. According to Streltsova-Adams (see Proceedings, Second Invitational Well-Testing Symposium held by Earth Sciences Division, Lawrence Berkeley Laboratory, on October 25-27, 1978) the flat part of the data should not show if the ratio $(S_f + S_m)/Sp$ (S_f and S_m are storage coefficients of the fractures and the porous matrix, respectively) is less than about 5 to 11. In other words, if the

straight lines on Figure 7 are less than about 0.7 to 1.0 log cycles apart, which they are on Figure 7, then the flat part of the curve should not show. This brings several questions to mind:

1. Is it possible that the straight line shows up between 200 minutes and 2000 minutes on Figure 7? If this is the case, then the data after 2000 minutes including the flat part may be attributable to the transition period between flow in fractures and "induced response."

2. If the straight line is correct and there is no double porosity system, is the flat part of the data and the "induced response" caused by a highly permeable fracture or karst channel near the well test?

3. Is the anisotropy observed in these tests due to recharge into the rocks from a highly permeable fracture or karst channel? Such a response would cause the lines of equal drawdown to have oval shapes rather than the elliptical ones caused by anisotropy. Unless there are data from more than three observation wells, it may be very difficult to tell the difference between an anisotropic aquifer and an aquifer with a recharge boundary.

Figure 7 of the report shows the response of the H-4a and H-4b wells due to pumping the H-4c well. Was the response of H-4a and H-4c due to pumping H-4b similar to the data shown o Figure 7 such that a double porosity system was indicated?

DOE Response:

Image-well theory was applied to drawdown data in an effort to locate groundwater "barriers," which could be attributed to skin effects, wellbore storage, pumping variations, elastic deformation, and formation barriers. A formation barrier may consist of abrupt changes in aquifer properties, such as porosity, conductivity, fracture density or orientation, recharge and discharge zones, transient or steady-state flow, vertical/horizontal permeability. Barriers may be the result of one or a combination of geologic or hydrologic parameters. Vertical communication with known overlying and underlying aquifers is practically negligible throughout the WIPP facility on the basis of observed

differences in hydraulic potential and conductivities and general chemistry.

We believe that the reviewer means that the slope of the transitional curve should not be zero, not that it should not show. Also, Streltsova-Adams assumes in her report that the matrix has zero permeability. If, in our case, the matrix has some permeability, then the shape of the drawdown curve may be different from her examples.

In regards to the three questions raised by the reviewer:

1. We think that the curvature of the early-time data on Figure 7 is pronounced. On log-log paper, this portion of the curve is straight with nearly unit slope indicating full fracture flow or well-bore storage (probably the latter). It is entirely possible that the data after 2000 minutes is in a transitional period, but we think it is more consistent to treat the data between 2000 and 5000 minutes as a good straight-line (Jacob approx.) solution, and between 5000 and 8000 minutes as transitional (or induced response). Past 8000 minutes the line becomes approximately parallel to the earlier data. (The "INDUCED RESPONSE" arrow on Figure 7 points to the wrong part of the curve and will be corrected in the interim report.)

2. If the first break in the drawdown curve is attributed to hitting a recharge boundary, then it follows that the second break must be due to a barrier boundary. Furthermore, the shapes and permeabilities of both boundaries must be such that the effect of the second boundary must completely negate the first so drawdown may continue as if neither existed. We agree that several interpretations are possible, given that little is known about the system, but we do not believe that the drawdown data alone support the existence of a recharge boundary. In regards to "karst channel near the well," please refer to earlier discussion about so-called karst.

3. According to our dictionary, the definitions of "oval" and "elliptical" are the same. The drawdown data we used for anisotropy determinations was early-time, hopefully taken before any breaks,

boundaries, or possible induced response affected the results. The anisotropy results should be free from these effects.

Some of this discussion will be included in the revision of the draft.

Well H-4a could not be pumped and the H-4b test was not run for a sufficient length of time to see the second break in the drawdown curve.

EEG Evaluation:

If possible, distances and directions to barriers, estimated from the method of images should be provided. A description of possible barriers mentioned here should also be included in the text.

Streltsova-Adams does not assume that the matrix has zero hydraulic conductivity; she assumes that the transmissivity of the porous blocks is so small compared to the transmissivity of the fractures that the transmissivity of the blocks can be neglected. If the blocks had zero hydraulic conductivity, then a mechanism to transport fluid from the blocks to the fractures would not exist and there would be no transition curve.

The response to question 1 is adequate for the most part. The log-log plot that shows the unit slope should be included and described in the report. In addition, a USGS publication (Reed, J.E., "Type Curves for Selected Problems of Flow to Wells in Confined Aquifers," Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter B3, 1980) indicates that the drawdown response at an observation well far from a pumping well of finite diameter is much steeper than unit slope. Therefore, the unit slope is not likely to be caused by wellbore storage effects, but more likely the full fracture flow mentioned in the DOE response.

The response to question 2 is adequate.

The response to question 3 is adequate. However, the EEG dictionary defines oval as an egg shape. Perhaps "egg shaped" instead of "oval" would have been a better term.

The response to the comment concerning the H-4 pumping is adequate.

EEG Comment: (Page 23, last para., p. 7)

It appears questionable that chloride is the ideal tracer to use to determine if leakage is occurring between Rustler aquifers at the H-4 site. Table 4 of Mercer, et. al., indicates that the chloride concentration of both the Magenta and Culebra is 7500 mg/l (Mercer, J.W., Paul Davis, Kevin F. Dennehy, and Carole L. Goetz, "Results of Hydrologic Tests and Chemistry Analyses, Wells, H-4A, H-4B, and H-4C at the Proposed Waste Isolation Pilot Plant Site, Southeastern New Mexico," Water-Resources Investigations 81-36, U.S. Geological Survey, May, 1981.

DOE Response:

The objective was to determine if leakage did occur during the tests; we had few other tools at our disposal (such as piezometers in confining zones or adjacent water-bearing units) to assess leakage, so water chemistry (temperature, ph, conductivity, chloride) was looked at during these tests as an alternative means. The results are not conclusive, but indicate that no leakage occurred. The test will be revised to indicate the uncertainty at H-4.

EEG Evaluation:

The response is adequate.

EEG Comment: (Page 25, 2nd para., p. 8)

The transmissivities as presented here are extremely small for a fractured rock and would tend to indicate that fracture flow is not that significant, at least in the areas that were tested. Any radionuclide transport in the Culebra would tend to be very slow because of the low transmissivities. Do fractures or karst channels capable of transmitting water exist near the WIPP site?

Table 9.2 of Walton (Walton, William C., Groundwater Resource Evaluation, McGraw-Hill, 1970) indicates the values of specific storage presented here are those for "sound rock." This would tend to indicate that any

fractures in the Culebra, at least in the areas tested, are well cemented or that clean, open fractures are far apart. This suggests that fracture flow is not extensive over much of the Culebra but may be confined to long channels or fractures outside the area of influence of the pump tests. Does flow in open fractures exist in areas not tested by the pump or tracer tests?

DOE Response:

The hydraulic conductivities observed at the WIPP are actually large compared to fractured crystalline rock. For example, the lowest transmissivity measured in our tests was at the H-5 site (0.04 feet squared per day), and corresponds to a hydraulic conductivity of $2x10^{-3}$ feet per day), which is an average for fractured crystalline rocks (Stripa Mine Project Report, 1980). It cannot be concluded that fluid movement will be slow because transmissivities are small. Solute transport may be quite rapid in a fracture flow situation. Determining solute transport capability is, of course, a major reason to perform tracer tests, which will yield indications of fluid velocities in the natural flow system.

The values of specific storage measured at the WIPP are of the order of 10^{-6}/ft, which, using Walton (Table 9.2) is reasonable for fissured and jointed rock. Lohman (Ground-Water Hydraulics, USGS Prof. Paper 708) uses a value of 10^{-6}/ft as a way to estimate storage coefficients for confined aquifers in general. A rock, such as a fairly rigid dolomite, could have a very low specific storage and still have measurable matrix and fracture porosity. Low specific storage does not mean that fracture flow is not extensive; it may only mean that there is a lack of significant compressibility in the system, both from fractures and matrix. For the reviewer to carry his suggestion one step further and imply that low specific storage within the area of pumping influence is evidence that open fracture or channel (karst?) flow exists outside the area of pumping influence is, of course, unanswerable.

EEG Evaluation:

Comparisons of the transmissivity and/or hydraulic conductivities with other fractured rocks should be made in the report. The comparison should be made to other dolomitic rocks not just fractured crystalline rocks.

The values of specific storage presented in the interim report range from 3.5×10^{-7}/ft to 8.3×10^{-7}. The higher values seem to occur at H-5 and H-6 and the low value at H-4. Perhaps fissures and joints could exist at H-5 and H-6. However, the specific storages calculated at these wells are at the upper limit of the "sound rock" values and slightly below the lower limit for "fissured and jointed rock." The specific storage calculated at H-4 is in the "sound rock" range.

EEG Comment: (Page 27, 3rd para., p.8)

Was the aquifer pumped clear prior to tracer injection for the second test? If not, did the non-completion of the first tracer test affect the results of the second test? Is it possible that Segments I and II of Figure 12 are due to the first test and Segments III and IV to the second test? If so, some type of deconvolution would be necessary to interpret the restults.

DOE Response:

Different tracers were used in each test; thus, no interference existed.

EEG Evaluation:

The response is adequate. Perhaps this should be brought out in the report.

EEG Comments: (Page 28, 3rd paragraph, p. 8)

The Grove and Beetem (1971) model needs to be corrected for anisotropy. Was this done? What were the ranges of porosities and dispersivities used in the Grove and Beetem (1971) analysis and how did they compare with the data?

(Page 32, 3rd paragraph, pp. 8-9):
The significance of the porosities of 0.17 and 0.18 should be discussed here. These values are extremely high for a fractured rock. A fractured rock typically has a fracture porosity of 0.01 - 0.02 and less (Streltsova, 1976). The porosity values presented here are typical for a porous media. If it is assumed that a fractured system operates at the H-2 well sites, then tracer diffusion from the fracture into the porous matrix could account for the high porosity. The effect of this diffusive process has been shown to increase travel times from one point to another when compared to a process without diffusion into the matrix. (See Grisak and Pickens, "Solute Transport Through Fractured Media I: The Effect of Matrix Diffusion, Water Resources Research, vol. 6, no. 4, Aug., 1980, pp. 719-730 and Grisak, et al. "Solute Transport through Fractured Media 2: Column Study of Fractured Till,"Water Resources Research, vol. 16, no. 4, Aug., 1980,, pp. 731-739). The net effect of increasing the travel time would be a high porosity. Grisak and Pickens also indicated that the diffusion of solute into the matrix would be more significant for low velocities of fluid flow in the fracture than for high velocities. With the hydraulic conductivity of the Culebra at about 0.032 feet per day, fluid velocities are probably small.

The causes of the various segments on Figure 12 should be explained. For instance, were they caused by diffusion into the matrix at one time and out of the matrix at another time? Are they caused by a convolution of the two tracer tests?

Page 35, 2nd paragraph, pp. 9-10:
Sauty's (1980) method should be modified for the anisotropy determined from the pump tests at the H-6 site. Since the principal axes of the transmissivity tensor are known for this site, the modification is:

$$n = \frac{Qt}{b\left(\frac{Tyy}{Txx}x^2 + \frac{Txx}{Tyy}y^2\right)}$$

where Q = pumping rate
b = aquifer thickness
t = time of match point
x,y = coordinates of well slugged with tracer
Txx = major transmissivity component
Tyy = minor transmissivity component
n = porosity

In the above equation, the pumping well is at the origin and the major component of the transmissivity tensor runs between wells H-6b and H-6c as indicated from the well test data. The corrected porosities are 9.1% for the H-6b to H-6c test and 0.97% for the H-6a to H-6c test.

The 0.97% porosity appears reasonable for a fractured rock and occurs along the major axis of the transmissivity tensor. The 9.1% appears reasonable for a porous media. There is, however, almost an order of magnitude difference between the two. Since porosity is not anistropic, the disparity is probably caused by a heterogeneity in the Culebra. The suggestion of a discrete zone of flow, i.e., a long highly permeable fracture, a set of parallel fractures or a karst channel appears reasonable. Whether or not this discrete flow can be modelled adequately appears questionable. The problem lies in determining the number of discrete fractures and their locations.

DOE Responses:

Several good points are brought out here. We do not yet believe that we can define the flow system at the H-2 site. A double porosity system is appealing, but anisotropy needs to be determined and further tracer tests along different flow paths need to be conducted at the site to define the

flow system. Again, we do not believe that the hydraulic conductivity at the H-2 site precludes the possibility or rapid fluid movement. The final report will include the results of additional tracer and anisotropy tests and respective modification to the code developed by Grove and Beetem.

Much discussion can be related to what value of porosity is typical of fractured rock vs. porous media. A minimum of effort has been spent on acquiring field data through extended tracer and anisotropy tests to evaluate and determine what these values are and what they mean. We hope to solidify our thoughts on double porosity media after the conclusion of our tests at H-6 and H-7. At this point, the number of discrete fractures and their locations are not the problem - neither is the notion of karst channel domination. A macroscopic point of view is the solution.

The H-6 tracer results certainly imply the existence of both fracture and matrix flow, at least under the flow regime set up by the test itself. There is not necessarly a disparity in the porosity determinations, nor need the difference be caused by local heterogenities.

EEG Evaluation:

The response to the anisotropy correction to the Grove and Beetem model is adequate. The comment regarding the ranges of porosity and dispersivity was not responded to. We were concerned about the apparent emphasis on the late time data for the curve match and the humps in the data.

The response regarding the tracer test at the H-2 pad is adequate. Anisotropy and tracer tests should be run at the H-2 pad. The EEG will be waiting for results from these tests.

The response to the H-6 comment is adequate. However, it should be pointed out that zones of discrete flow in a porous media is a heterogenity.

EEG Comment: (Page 38, 1st para., p. 10)

The Safety Analysis Report (page 2.6-35) indicated that two sets of

joints exist in the Delaware Basin. One of these sets strikes NW to SE, in the same direction as the major component of the transmissivity tensor. Does this joint set have some relationship to the principal axes of the transmissivity tensor? What is the possibility that vertical or near vertical fractures formed by the joint set could be missed by the drilling activities and subsequently untested by the pump testing program?

DOE Response:

See previous discussion of principal tensor and fracture trends. The testing program would not test a set of non-intersecting or non-interconnected fractures by definition. The fact that dipping fractures are intersected requires interconnection of even vertical fractures with the borehole though the zone of influence has limits.

EEG Evaluation:

The fact that the boreholes intersect dipping fractures should be brought out better in the report.

EEG Comments:

(Page 38, 2nd para. to Page 39, 1st para., pp. 10-11)

The physical significance of the range of porosities to the following parameters should be discussed in more detail:

- o travel times
- o fracture flow or porous media flow
- o the directional characteristics of the porosity

The hydraulic conductivities should also be discussed in terms of fracture flow and porous media flow. The hydraulic conductivity values quoted in this report are averaged over the thickness of the Culebra, i.e., the hydraulic conductivity is assumed to be uniform throughout the thickness of the Culebra. In a fractured media, the hydraulic conductivity is not uniform. It is peaked in a fracture and near zero outside a fracture. How would the hydraulic conductivity vary throughout the thickness of the Culebra? What effect would this variation have on travel times?

(Page 39, 1st para., p. 10)
Figure 16 indicates that flow through the H-6 site is initially SSE. However, the flow path appears to curve to the southeast away from Nash Draw. What is the basis for concluding that flow through H-6 reaches Nash Draw? In addition, a flow to the south-southeast would eventually have to turn toward the southwest in order to reach Nash Draw.

It further appears that Figure 16 may need some refinement. The figure does not appear to have contours based on the fresh water altitudes at H-8, H-9 and H-10. In addition, the fresh water elevation at P-18 is extremely low compared to the elevations at the other wells. The validity of the fresh water altitude is questionable because of the low hydraulic conductivity at that well. How does the fresh water altitude map change if fresh water altitudes at H-8, H-9 and H-10 are included in the map construction at P-18 is eliminated?

DOE Response:

How hydraulic conductivity varies within the Culebra, both vertically and horizontally, will be a very difficult study. Cores taken from and measurements taken within the new ventilation shaft will help us. In our final analysis, a variation of parameters shall be input to the final regional model to simulate a variation of travel times under differing conditions.

The potentiometric surface as shown on Figure 16 typifies a very transmissive system approaching the WIPP from the north-east but encountering, in effect, a leaky boundary defined by the decrease in hydraulic conductivity from west to east and probably influenced by the presence of "salt" within the Rustler and lower transmissivities in the Culebra Dolomite. As the flux of groundwater encounters a less permeable portion of the aquifer, it resists flow and takes the more plausible avenue - down Nash Draw where we find transmissivities much greater in a number of wells. Figure 16 exemplifies the site specific information collected on and within the boundaries of the facility. The final report will include a refinement of the data, which will include tracer and anisotropy tests at locations south-east and south of the site. The validity of the use of fresh water altitudes based on fluid density influenced by low conductivity is also our concern. A final suite of

W.L. measurements and density determinations will be taken and evaluated for inclusion in the final report. There are no better estimates for discharge areas other than near Malaga Bend or south of Lagune Grande de la Sal.

EEG Evaluation:

Changing the values of parameters in the final regional transport model is good. However, the purpose of the comment was to get some feel if the reported values of hydraulic conductivity and porosity are typical or atypical of fractured rock. This does not appear to have been addressed in the response.

Until the vertical variation in hydraulic conductivity can be answered, the EEG suggests that references to hydraulic conductivity in the report be deleted. The hydraulic conductivities in the report are calculated by dividing the transmissivity by the aquifer thickness. This implies that the transmissivity is uniform over the aquifer thickness, when, in fact, the transmissivity may be concentrated in one or two fractures. In addition, it may be better to use the prosity-thickness product, which is the number really estimated from the tracer tests, rather than the calculated porosity.

The responses to the Figure 16 and the H-6 flow path comments are adequate.

EEG Comment: (Page 41, bottom para., pp. 11-12)

What is the basis for assuming 10 miles to the southeast? The data are all within 5 miles of the WIPP site. Most of the "path which would exceed 10 miles" is located in an area of very low hydraulic conductivity and in an area of unknown hydraulic gradient. In view of the southeast gradient over the study area (Figure 16 of the draft report), how can the radionuclides discharge at Malaga Bend? The direction of the hydraulic gradient would have to turn southwest in order for a radionuclide to discharge at Malaga Bend. At present, there are no data to support this. Are there other discharge areas for the Culebra?

DOE Response:

See previous comments.

EEG Evaluation:

It is hoped that the refinement of the data used to construct Figure 16 will support the previous responses.

EEG Comment: (Page 43, 1st para., p.12)

If travel time for a non-absorbing radionuclide in the Culebra becomes greater than 40,000 years, it is possible that the Magenta's westward flow from the WIPP to Nash Draw would provide a quicker radioactive release to the biosphere than flow in the Culebra? If so, perhaps future studies should concentrate on flow in the Magenta rather than on the Culebra.

DOE Response:

See previous comments on Magenta.

EEG Evaluation:

See our evaluation of your previous response to Magenta comments.

EEG Comment: (Pages 44 and 45, Continuing Investigations, pp. 12-13)

The following are suggestions that should be useful in the continuing study of fracture flow in the Rustler:

1. A review of aerial photographs through the area defined by WIPP-29, WIPP-25, WIPP-33, H-6 and H-5 should be made to see if any geomorphic features associated with either karst hydrology or fracture hydrology exist there. Thermal infrared photographs may be useful in locating springs or shallow ground water flowing in subsurface channels. This suggestion is made for several reasons:
   a. Larry Barrows, in a presentation to EEG, indicated that an elevated gravity anomaly existed in this area. He attributes it to a possible karst channel in the Culebra.
   b. A structure contour map (see Figure 1) on top of the Culebra was generated from Table 1 of the report. It indicates a depression

extending through the WIPP-25, H-6, H-5 area. This depression may be associated with a karst channel.

c. A fresh water altitude map (see Figure 2) for the Culebra was constructed from the data presented in Table 1 of the report. The figure indicates that a ground water high is associated with the depression. The ground water high indicates a potential for some flow to the west.

If possible, the review of the aerial photographs should extend from the northern part of Nash Draw to Malaga Bend.

2. The application of inverse techniques to flow in the Rustler should be interesting. For the most part, inverse techniques are in their infancy and are designed for porous media flow, not discrete flow. If it is decided that fracture flow can be modeled as a porous media, then the inverse technique developed by Neuman and Yakowitz ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 1: Theory," Water resources research, vol. 15, no. 4, pp. 845-850, 1979), Neuman et al. ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 2: Cast Study, "Water Resources Research, vol. 16, no. 1, pp. 33-58, 1980) and Neuman ("A Statistical Approach to the Inverse Problem of Aquifer Hydrology, 3: Improved Solution Method and Added Perspective, "Water Resources Research, vol. 16, no. 2, pp. 331-346, 1980) should be tried. It appears that, at present, this is the only technique that has been published with an application to a real problem. Before the inverse techniques are applied to the Rustler, it should be decided whether flow in the Culebra is discrete or porous.

3. It appears that any contamination from a repository breach in Zone II would flow to the southeast. This is based on the flow paths as determined from Figure 15 and Figure 16 of the report. The area southeast of the WIPP should be studied further in terms of piezometric head, flow direction and discharge areas.

4. The tracer test at H-7 should be run similarly to the one at H-6. This should provide some more insight into the directional characteristics of the porosity and the areal extent of this

phenomenon. Because the hydraulic conductivities at H-6 and H-7 are almost the same, the time required to run a tst at H-7 should be about the same as at H-6.

If possible, two two-well tracer tests should be run at H-4 in order to determine the porosity along the major and minor components of the transmissivity tensor.

5. If it has not been done, the Groe and Beetem (1971) model, the Sauty (1980) model and the SWIFT model, if it is used, should be modified to account for the anisotropy of the Rustler Formation.

DOE Response:

Item 1.a. Bachman (1980, 1981) examined karst features extensively through Nash draw, along the pecos, and in the site area. He attributed the fill and depression at WIPP 33 to a karst-type process by which Nash Draw expands. In his field work and review of aerial photos, he does not attribute geomorphic features at the site to karst processes. Barrows found anomalously low gravity which he infers as due to removal of mass by dissolution (=karst). Barrows does not restrict karst to the Culebra - it is more likely in the gypsum units by his log correlations.

Item 1.b. Whether the gravity anomaly and structure contour maps show karst channels or not is still speculation. Perhaps comparing these maps with similar ones in regions of known karst will help somewhat. If the structure contour map does delineate a west-east karst channel, it cuts through some of the highest transmissivities tested at the WIPP (WIPP 25 and H-6), as well as the lowest (WIPP 30 and H-5). It also trends parallel to the minor component direction of the transmissivity tensor determined at H-6 and H-5; that is, the transmissivity is least in the direction of the channel.

Item 1.c. Figure 16 will be revised as previously stated. WIPP 30 is still being monitored, and all potentiometric data will be revised to be curent for the interim report.

Item 2. Those suggestions are well taken and shall be considered. Inverse techniques are subject to criticism; however, significant strides are being made towards utilizing these techniques and determining whether fracture media can be treated as porous media (Neuman, U of Arizona); C. Wilson, and J.B. Long, LBL). We do have the insight to perform these evaluations in determining whether we are dealing with fracture or porous - the objective of our site specific studies.

Item 3. Locations for testing in the southeastern part of the site have been of some interest. DOE 1 was considered, but the operations may have been unsuitable for the conversion of the hole to hydro testing. However, that pad and borehole continue to be candidates for further testing. Anisotropy tests at H-9 and H-10 are also being considered.

Item 4. See report, p. 7, last line; also p. 45.

Item 5. See p. 44.

EEG Evaluation:

The responses to Items 1b, 1c, 2, 3 and 5 are adequate. The response to 1a indicates that perhaps the Rustler Formation gypsum units should be studied in more detail to determine if karst channels exist in those units. Channels in the gypsum could be a pathway for radionuclide transport. The response to Item 4 indicates only that tests will be run, but gives no information on how they will be run.

BRECCIA PIPES

USGS 82-0968

"Equal Opportunity Employer"

STATE OF NEW MEXICO

ENVIRONMENTAL EVALUATION GROUP
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P.O. Box 968
Santa Fe, NM 87504-0968
(505) 827-5481

September 21, 1982

Joseph M. McGough
WIPP Project Manager
U. S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, NM 87115

Dear Mr. McGough:

Enclosed is a summary of our comments on the Draft "Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the WIPP Site," by R. P. Snyder and L. M. Gard, Jr., USGS.

We would appreciate your consideration of these comments in the preparation of the final report. As with the other formal reports required by the Stipulated Agreement, we would like to have our staff and yours meet to discuss the final version of the document before its publication.

Sincerely,

Robert H. Neill
Director

RHN:LC:eg
2-062-AG2-17-1-1
Enclosure

cc with attachment:
George S. Goldstein, Ph.D., Secretary, Health & Environment Department
Joe Hewett, Secretary, Highway Department
Charles Turpen, Secretary, Energy and Minerals
Jeff Bingaman, Attorney General
Russell F. Rhoades, Director, Environmental Improvement Division
Joe Canepa, Attorney at Law
James K. Otts, Chairman, Rad-Waste Consultation Committee
D. T. Schueler, Assistant Manager for Project of Energy Programs
Wendell Weart, Sandia Laboratories
TSC, IEA

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

EEG Comments on the USGS Draft Open File Report: Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the WIPP Site. by R. P. Snyder and L. M. Gard, Jr., USGS

INTRODUCTION

These comments are based upon a critical reading of the report and many of the references cited in it. The report has achieved in most respects, the purpose of presenting "all available pertinent up-to-date data and analyses concerning the existence of breccia pipes in the basin and the reef, potential for future breccia pipe development, and their significance to WIPP," as required by the Stipulated Agreement between the State of N. M. and DOE. In fact, the report has exceeded the requirements and expectations in many respects. A few recommendations to improve the quality of the report are given below.

GENERAL COMMENTS

Mechanics and Age of Formation of Breccia Pipes Over the Reef:
The authors of this report have done an excellent job in studying and reporting the characteristics of the known breccia pipes viz. at Hills A and C. Their conclusions on the mechanics and age of formation of breccia pipes (pp. 93-104) are primarily based on these detailed studies.

The authors have hypothesized that the initial collapse took place in a cavity in the Capitan limestone with the Tansill and Yates formations dropping into the cavity until the thick beam of the Fletcher Anhydrite was reached. In the second stage, the Fletcher beam failed, resulting in a catastrophic collapse of all the overlying formations in this cavity. Subsequent removal of salt from the Rustler and Salado formations around the margins of the pipe resulted in the outward-dipping beds at the surface.

Basically, this appears to be a sound hypothesis. However, a few difficulties with it are listed below.

a. Neither of the two exploratory boreholes (WIPP-31 and WIPP-16) drilled in the breccia pipe Hills A and C was drilled deep enough to encounter the Capitan Reef limestone. In fact, WIPP-16 was drilled only to the middle of Salado and the anhydrite cored at the bottom (1903 to 1981 feet) of WIPP-31, "is tentatively assigned to the Fletcher Anhydrite" (p. 42).

b. The probability of right conditions existing for the proposed mechanism appear to be very high all over the reef. Why then do the four known breccia pipes (Hills A, B, C and Wills-Weaver) lie within a five mile radius? Such localization indicates additional restrictive conditions which are not included in this hypothesis.

c. The outward dip of the Mescalero Caliche beds from the known pipes (e.g. at Hill A) has been interpreted to indicate "removal of halite from around the pipe" (p. 100). This removal of halite has been ascribed to a dissolution front which is very briefly described on p. 31. In the pipes too, halite is missing from the Rustler formation. At WIPP-31 drilled at Hill A, the cores show a chaotic collapse involving the Rustler formation, whereas WIPP-16 (at Hill C) encountered nearly intact Rustler formation in the pipe. And yet, the halite is missing from the Forty-niner and Tamarisk members of Rustler as found inside the pipe in WIPP-16. Did the collapse at Hill C occurred <u>after</u> the regional removal of salt from Rustler formation at this point? If so, how does one explain the outward dipping of the Triassic and younger strata at Hill C?

d. The mechanism of removal of halite and other soluble minerals from the fragments of Salado and Rustler formations found in the breccia pipe at Hill A (WIPP-31) is hypothesized on p. 98. It states that, following the collapse of Fletcher Anhydrite "beam", the unsaturated water filling the cavity would be forced upwards. Later, "much of the halite would be dissolved by this water and eventually the now saturated water would move downward and out through the existing paths in the reef." It is not clear how this would have occurred since the standing water implies either an impermeable base or a high hydraulic head and what would cause either of the two conditions to change for dissolution of salt and removal of the resulting brine?

Possibility of Breccia Pipes in the Basin

The report has concluded that, "known locations where deep dissolution occurs and forms structures called breccia pipes are limited to areas over the buried Capitan Reef." In support of this conclusion, the report has presented the results of investigation of suspected breccia pipes in the Delaware Basin and has shown why those features are not breccia pipes. However, the description of "Karst domes" (p. 14) needs to be improved to clearly show how "the formation of these domes is related to dissolution of the soluble portions of the units." Similarly, the idea of "blanket dissolution" (p. 84) to explain the features such as at WIPP-32 needs to be described more fully.

The report has not considered the possibility of a breccia pipe forming at depth in the basin. A description of Anderson's "brine density flow" (e.g. Anderson, 1980) and a discussion of why this mechanism is not expected to be forming a breccia pipe at depth through upward stopping, at the WIPP site, should be included in this report. The question of occurrence of breccia pipes in the Delaware Basin should be addressed from a genetic point of view, using the information from other evaporite basins and specific stratigraphic and hydrologic information from the Delaware Basin. Not having found one is not an argument against the potential presence of one.

SPECIFIC COMMENTS

Page 1, last sentence: This sentence, obviously added as an afterthought, does not belong in an otherwise excellent and scholarly report, and should therefore be deleted.

Page 3, first paragraph: Questions 3, 4, 5 and 7 need more detailed treatment in the report.

Table 1, p. 6: The table should include the basin facies of the Guadalupian series viz. the Delaware Mountain Group formation.

Page 7: A description of the Delaware Mountain Group formation should be included here.

Page 9, line 5: The "dissolution" should be described in some detail and a figure showing the dissolution fronts in Rustler and Salado should be included in the report.

Page 11, line 4: Add "and northeast" between "southwest" and "of".

Page 12, last sentence: Change to, " ...showed that two of them (Hills A and C) are definitely breccia pipes. Geophysical and geological studies show that two others (Hill B and Wills-Weaver) are also most likely breccia pipes, although they have not been cored. On the basis of geophysical work (gravity and resistivity), Hill D is not thought to be a breccia pipe."

Page 21: A line or two describing the interpretation with the captions would be helpful. For example, add to the caption of Fig. 4 "the resistivity profile indicates that this is not a breccia pipe."

Fig. 9, Page 29(a): A legend and a few cross-sections will make this figure more useful.

Fig. 10, Page 30(a): The bottom of the breccia pipe should be drawn with dotted lines and question marks.

Page 31, last sentence: The dissolution fronts and their leading edges should be shown on a map.

Page 42, last sentence: Reasons for not drilling through at least the Fletcher should be outlined.

Page 43, lines 12-14: The statement regarding the increase in weight and the stress exceeding the rock strength needs elaboration with assumptions for unit weight and strength (Shear? Tensile?) for the anhydrite.

Page 44, last sentence: The mechanism of removal of salt from Salado needs to be discussed here.

Fig. 31, p. 90, 2nd line of caption: Add before (A), "in the Saline basins of western Canada".

Fig. 32, p. 91(a): Provide a stratigraphic legend for this figure.

Page 54, last sentence: The sentence states that the pipes at Hills A and C occurred at widely spaced times. On page 103, line 11, the statement is made that the two pipes formed at nearly the same time. Some clarification is desirable.

Page 92, last sentence: Why is it assumed that the pipes go down only to Zechstein formation and not even lower? Is there other evidence of preferential, deep-seated dissolution of salt from the Zechstein formation?

Page 93, line 15: The title of this section includes the age of the breccia pipes. The section, however, is a summary of earlier work and avoids assigning an age to the pipes. The section on page 105, which deals with possible effect on the WIPP site, mentions an age of 400,000 - 500,000 years ago.

Page 105: The possibility of occurrence of a breccia pipe in the Basin should be discussed here.

Page 105. Possible Effect on WIPP Site: The paragraphs summarizes observations while the heading of the section demands explanations.

EDITORIAL COMMENTS

Page 2, line 15: "respositories" should be "repositories."

Page 2, last line: It is not clear to whom "to them" and "their" refers to.

Page 80, line 6: "does increase" should be changed to "increases".

EEG Comments on Draft USGS report by Snyder & Gard entitled
"Evaluation of Breccia Pipes in Southeastern New Mexico
and their Relation to the WIPP Site"

Comments Reflecting Alternate Interpretations

General comment c.--"The outward dip of the Mescalero Caliche beds from the known pipes (e.g. at Hill A) has been interpreted to indicate "removal of halite from around the pipe" (p. 100). This removal of halite has been ascribed to a dissolution front which is very briefly described on p. 31. In the pipes too, halite is missing from the Rustler formation. At WIPP-31 drilled at Hill A, the cores show a chaotic collapse involving the Rustler formation, whereas WIPP-16 (at Hill C) encountered nearly intact Rustler formation in the pipe. And yet, the halite is missing from the Forty-niner and Tamarisk members of Rustler as found inside the pipe in WIPP-16. Did the collapse at Hill C occur after the regional removal of salt from Rustler formation at this point? If so, how does one explain the outward dipping of the Triassic and younger strata at Hill C?"

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RESPONSE.--The USGS has considered a wide range of interpretations, perhaps including the above, within their peer review and approval system. The interpretations presented are the ones they feel best explain the mechanisms involved. They suggest that alternates may be presented in technical journals with wide scientific forums, if sufficient reasons exist.

Comments which deal with previous work

"Possibility of Breccia Pipes in the Basin

The report has concluded that, "known locations where deep dissolution occurs and forms structures called breccia pipes are limited to areas over the buried Capitan Reef." In support of this conclusion, the report has presented the results of investigation of suspected breccia pipes in the Delaware Basin and has shown why those features are not breccia pipes. However, the description of "Karst domes" (p. 14) needs to be improved to clearly show how "the formation of these domes is related to dissolution of the soluble portions of the units." Similarly, the idea of "blanket dissolution" (p. 84) to explain the features such as at WIPP-32 needs to be described more fully."

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RESPONSE.--The comments are directed toward questions on previous work which is accepted and credited for this report. This is not the proper forum for their discussion.

Comments which would require additional studies

General comment b.--"The probability of right conditions existing for the proposed mechanism appear to be very high all over the reef. Why then do the four known breccia pipes (Hills A, B, C and Wills-Weaver) lie within a five mile radius? Such localization indicates additional restrictive conditions which are not included in this hypothesis."

"Page 42, last sentence: Reasons for not drilling through at least the Fletcher should be outlined."

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RESPONSE.--The above comments are not central to the question of facility integrity, nor to the intent of the report. Perhaps other agencies or entities would be interested in funding their pursuit.

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Comments to be considered in later USGS Publications

Specific Comments

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"Page 54, last sentence: The sentence states that the pipes at Hills A and C occurred at widely spaced times. On page 103, line 11, the statement is made that the two pipes formed at nearly the same time. Some clarification is desirable."

RESPONSE.--All of these comments deal with a request for more information, or, additional thoughts to consider which are not central to the purpose of determining the importance of breccia pipes to the integrity of the facility. These more properly belong in the realm of scientific inquiry and we understand the USGS is preparing a report in their Circular series which will treat these questions.

Comments which are primarily editorial in nature

General comment a.--"Neither of the two exploratory boreholes (WIPP-31 and WIPP-16) drilled in the breccia pipe Hills A and C was drilled deep enough to encounter the Capitan limestone. In fact, WIPP-16 was drilled only to the middle of Salado and the anydrite cored at the bottom (1903 to 1981 feet) of WIPP-31, "is tentatively assigned to the Fletcher Anhydrite" (p. 42)."

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"Page 80, line 6: "does increase" should be changed to "increases"."

RESPONSE.--We believe you will find that most of these were cleared up in the final, approved version of the report. Those which were not are principally a matter of editorial style of the USGS. Incidentally WIPP-16 was bottomed in the Rustler, not the Salado.

BRINE RESERVOIR REPORT

TME-3153

HEALTH & ENVIRONMENT department

"Equal Opportunity Employer"

STATE OF NEW MEXICO

ENVIRONMENTAL EVALUATION GROUP
320 Marcy Street
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February 24, 1983

Mr. Joseph M. McGough
Project Manager
WIPP Project Office
U.S. Department of Energy
P.O. Box 5400
Albuquerque, New Mexico 87115

Dear Mr. McGough:

Enclosed are our review comments on the draft of "Brine Reservoirs in the Castile Formation, Southeastern New Mexico" (TME-3153). Appropriate personnel from EEG would be happy to meet again with the authors of this report, if further clarifications of our comments are desired. We will look forward to hearing your response to these comments.

Sincerely,

Robert H. Neill
Director

RHN:LC:eg

2-112AG2-21-10-1

cc: TSC, IEA

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

REVIEW COMMENTS
ON
THE DRAFT OF "BRINE RESERVOIRS
IN THE CASTILE FORMATION, SOUTHEASTERN NEW MEXICO"

(TME-3153, December 1982)

by

Environmental Evaluation Group
Environmental Improvement Division
N. M. Health and Environment Department
P. O. Box 968
Santa Fe, NM 87503

February, 1983

EEG Review Comments on the draft of "Brine Reservoirs in the Castile Formation, Southeastern New Mexico" (TME-3153)

INTRODUCTION

These review comments are based upon a critical reading of the report and many of the references cited in the report. The report was evaluated to see whether it has achieved its stated purpose of determining "the characteristics and origin of these reservoirs and evaluate their potential impact on the integrity and stability of the WIPP site" (Executive Summary, p. 2, TME-3153), and whether the conclusions are supported by observed facts, experiments and analyses.

The comments are divided under the categories of Geology, Hydrology and Chemistry, following the organization of the subject report.

GENERAL COMMENTS

1. GEOLOGY

Location of the Brine

It should be realized at the outset that each borehole which encountered brine in the Castile formation did not necessarily encounter a separate "reservoir," unless it can be so proven on the basis of geology, geohydrology or geochemistry.

It is accepted that there are thirteen reported encounters of pressurized brine in the Castile formation in the northern Delaware Basin (12 shown on Fig. G-11 plus "H and W Danford Well No. 1" in Sec. 9, T 225, R 29E- see EEG-7, p. 66). In addition, there are "numerous reports of small brine occurrences with sub-artesian heads in other parts of the basin" which suggests " a fairly uniform distribution of fluid throughout the Castile" (subject Report, p. G-41).

Previous DOE documents (e.g. TME-3080) stated that brine is restricted in a 6 mile wide "deformation front" which borders the buried Capitan Reef to the south. The subject document has extended this zone to "six to twelve miles" (p. G-37), presumably to include the Belco-Hudson and WIPP-12 encounters. There doesn't appear to be any scientific reason for drawing these boundaries, because if a future well encounters brine, say, 15 miles away from the reef, the boundary would have to be extended further. In any case, the twelve mile zone covers the entire WIPP site and therefore it is difficult to see any significance in this arbitrary exclusion.

Concerning the brine encounters that did not flow to the surface, the report states that, "none are located in the area covered by Figure G-11" (p. G-37). It is impossible to make a statement like this, since most rotary drilling operators for deep hydrocarbon wells would not report brine encounter in Castile unless it created a problem for them.

Stratigraphic and Structural Control of Brine Encounters

Pressurized brine has been found in Anhydrite-III unit of Castile in every reported case. There is some question about ERDA-6 where R. Y. Anderson and C. L. Jones interpreted the upper Anhydrite layer where brine was found as A-II on the basis of visual charcteristics. It is however, very likely, that this anhydrite was A-III also (Powers, personal communication).

While it is probably true that most pressurized brine encounters are related to at least some structural disturbance, Figure G-11 does not show it. Brine occurrence numbers 1, 2, 3, 4, 5, 6 and 9 (Fig. G-11) do not seem to be related to any structure at all. According to Snyder (personal communication) the structure contour map of Fig. G-11 was prepared by C. L. Jones as a very preliminary map. EEG recommends that the final version of this report should have a map prepared by using the up-to-date borehole information as well as the seismic data such as shown in Barrows' map (Fig. G-12).

The statement, "Examination of structures in Fig. G-6 reveals that deformation is mainly confined to the Castile formation...the underlying Delaware Mountain Group does not appear to be widely involved in the structures under discussion" (p. G-39) is based on a misleading drawing of WIPP-12, ERDA-6 and ERDA-9 boreholes in Fig. G-6. How can one use a borehole to correlate horizons below its total depth? Only WIPP-12, ERDA-6 and AEC-7 show structures in Castile. WIPP-12 and ERDA-6 stopped short of the Bell Canyon and AEC-7 did not penetrate deep enough to show the structure in Bell Canyon.

The Age of Deformation

"Between late Permian and Pleistocene" (p. G-2) is indeed the widest possible "bracket" for the age of deformation. Anderson and Powers (1978) concluded that "the salt structure (in ERDA-6) is inferred as post-microfolding." Kirkland and Anderson (1970) showed that microfolding in the basin follows Cenozoic structural trends, which resulted from the uplift and tilting of the basin in early to mid-Cenozoic time (King, 1948), or in late Cenozoic (Pliocene) according to TME-3153 (p. G-9).

The subject report concludes, "The most likely mechanism is formation during or immediately after deposition as a result of slumping and flow, although tectonic stresses cannot be ruled out." (p. G-23). The only reference cited in support of this conclusion is a paper by Riley and Byrne (1961)-p. G-22. Enclosed is a copy of two figures from this paper showing photographs of structures created by piling three layers of different density materials (Fig. 1). Of course some flowage and some deformation is seen, resulting from density contrasts. Ramberg (1963, 1967, 1968) has developed an elaborate theory of gravity--controlled tectonics based on such experiments. However, the Castile microstructures have resulted from tectonic stresses during late Cenozoic, because they are basin-wide, show close relationship with megafolds and the microfold axes generally parallel the trend of Cenozoic tectonism in the area (Kirkland and Anderson, 1970). The report almost correctly summarizes the discussion on the age of deformation, "by concluding that the deformation is probably Cenozoic,

and could have occurred between 25 to 1 million years ago" (p. G-43). this implies that the postulation, "the salt structures developed in response to the latest stage of basinal tilting in late Pliocene to early Pleistocene time" (p. G-43) is accepted. Since the Pliocene began 7 million years ago, the "bracket" should be 7 to 1 million years.

In this connection, Kirkland and Anderson (1970) is wrongly cited on p. G-48--this paper rejects "syndepositional movement" as the cause of microfolds.

Brine Reservoir Formation

A mechanism for the formation of brine reservoirs is discussed on page G-44 to G-47 of the subject report. Conceptually, the postulated model of producing fractures in anhydrite by the upward movement of the underlying salt, appears acceptable. However, the discussion should be expanded to explain the following points.

1. How this would happen mechanically by using average reported values for the tensile strength of anhydrite and the expected values of tensile stresses generated by underlying salt flow.
2. How were the "typical average elongations for the structures around WIPP-12 and ERDA-6" calculated (p. G-44).
3. The postulated mechanism would open the fractures in an anhydrite at the upper surface. Almost all the brine filled fractures have been encountered in the lower part of anhydrite-III layer. The explanation that these holes are probably on the flanks of structures (p. G-46) does not satisfactorily explain this contradiction since both WIPP-12 (Fig. G-12) and ERDA-6 (Fig. G-11) appear to be in the crest area of the domal structures.

Pressurization of Brine Reservoirs

The theory of dilatancy (p. G-47) does not appear to provide a reasonable explanation for the differences in reservoir pressures in ERDA-6 and WIPP-12. Using the tidal efficiency (T.E.) from groundwater hydrology (see Walton, 1970), the theoretical reservoir pressures due to a thickness of overburden can be calculated. The

tidal efficiency, in general terms, is a measure of the ability of the reservoir rock to transfer a pressure change outside the reservoir to the reservoir fluid. The tidal efficiency can be defined by

$$T.\ E. = \frac{\alpha}{\alpha + \phi\beta}$$

where α = compressibility of the reservoir rock

β = compressibility of water

ϕ = porosity

β is 4.4×10^{-10} pa^{-1} and the range of α given in TME 3153 is

$2.9 \times 10^{-9}\ pa^{-1} \leq \alpha \leq 1.45 \times 10^{-7}\ pa^{-1}$.

For a range of porosity of 0.1 to 10 percent, the tidal efficiency varies from 1.000 to 0.985. The calculated reservoir pressures in a particular reservoir differ by less than 50 psi for the range of porosity above. This indicates that increased porosity due to fracturing will have little effect on the reservoir pressure. W. Weart, at the February 15, 1983 Quarterly Meeting between DOE and EEG mentioned some preliminary model studies at Sandia National Labs that indicate rock movement and fracture closure as a possible repressurization mechanism.

The dilatancy theory works well in the fractured metamorphic rocks cited in McNaughton (1953). If the rock compressibility is 1×10^{-10} pa^{-1} (within the range of sound rock and jointed rock as given in Freeze and Cherry, 1979) the calculated pressure difference at WIPP-12, for example, is 850 psi for a porosity variation of 0.1 to 10 percent.

The anhydrite compressibility is not in the range necessary to invoke the dilatancy theory. A much more likely explanation for the pressure differences is brine migration. The above comments are presented in

greater detail in an upcoming EEG report.

Geologic Evidence of Brine Origin

The discussion under this heading in the subject report (pp. G-48, 49) can be summarized as follows.

1. Small quantities of fluids which may have been present in the rock matrix may be trapped interstitially or within grains. (No quantitative values of assumed original amount of fluids and loss during compaction and diagenesis have been presented to reach this conclusion).
2. Gypsum dehydration would explain the origin of water in the brine, but "the evidence for primary gypsum is not compelling, although dehydration waters cannot be ruled out as a minor source of brine reservoir fluid" (p. G-49).
3. "Groundwater or meteoric water does not appear to be a plausible fluid source at WIPP-12, based on the lack of evidence of dissolution features and the tight contacts observed" (p. G-49). This line of reasoning does not take into account the possibility of brine migration to its present location after its formation elsewhere.

The "evidence" presented under this section is mostly negative. What is the geologic evidence of brine origin?

2. HYDROLOGY

Reservoir Pressure

The subject report uses the "fact" of the reservoir pressures being different from each other as a strong argument favoring the lack of interconnection between different encounters of brine in the Castile formation (pp. H-1, H-36, H-55, H-56). Table H-1 lists 12 pressurized brine encounters with measured or estimated "formation pressure." Only 4 of the 12 pressures (ERDA-6, WIPP-12, Belco and Gulf Covington) were measured; the rest were estimated by using the pressure of the drilling mud necessary to stop the brine flow in the well. There are so many possibilities of errors in the estimated pressures that these

should be completely ignored. Among the 4 measured pressures, the differences are not significant--ERDA-6 and Belco had 2060 psig and 2075 psig respectively, Gulf Covington reported 1972 psig with conflicting data for the initial flow rate and WIPP-12 measured 1828 psig pressure. Using this data, it is difficult to see how one can reach to conclusions like, "The persistence of high and different hydraulic heads in the Castile brine reservoirs over millions of years is the principal evidence for their isolation." (p. H-1).

The maximum pressures for wells ERDA-6 and WIPP-12 are given in terms of wellhead pressure and reservoir pressure. Using the two pressures for each well and the depth to the reservoir, (p. H-44, H-51) the fluid pressure gradient is calculated to be 0.537 psi/ft. for each well (p. H-39). The average fluid pressure gradient from the D'Appolonia Data File Report is 0.533 psi/ft for ERDA-6 and 0.538 psi/ft for WIPP-12. Why are the pressure gradients used in the analyses different from the measured data?

In ERDA-6, the different hydraulic pressure gradients affect an 11 psi difference in the maximum wellhead pressure from 615 psig at 0.533 psi/ft to 604 psig at 0.537 psi/ft.

The total reservoir volume estimates are dependent on the total pressure depletion and as such are highly suspect. For example, the wellhead pressure in ERDA-6 as of 1/5/83 was 552.5 psig and is still rising. A Horner plot extrapolation (Fig. 3 attached) indicates the pressure could go as high as 615 psig. If the fluid pressure gradient were 0.533 psi/ft, then the maximum wellhead pressure would be 615 psig. The total pressure depletion would then be zero and the total reservoir volume infinite!

The use of the maximum reservoir pressure of 604 psig versus 615 psig could make a large difference in the total reservoir volume calculation especially as the pressure in ERDA-6 continues to increase.

What is the basis for the statement that the Castile brine reservoirs have maintained their hydraulic heads over millions of years (p. H-1, H-38, H-39)? The elevation of the reservoir relative to sea level has changed over "millions of years" and so has the hydrology of the area.

Volume and Interconnection

The volume of brine reservoir encountered by WIPP-12 has been calculated to be 20 million barrels (p. H-52). Even if the reservoir is assumed to extend through one-half of the 317 feet thickness of Anhydrite-III, the brine would be found underlying an area of 140 million square feet or more than 5 square mile. The actual extent of the brine is probably several times this area, since it is unrealistic to assume that the brine fills the entire lower-half of the anhydrite layer at a uniform porosity of 0.5%.

The volume of ERDA-6 brine has been calculated to be at least 440,000 bbl. (p. H-46). Since this calculation was based on a pressure depletion of 75 psi and the pressure recovery through January 5, 1983 reached 553 psig (which is equal to 51 psi pressure depletion), the volume of the brine reservoir intercepted by ERDA-6 is most likely much larger.

The attempts to correlate the volume calculated from flow tests with the "antiforms" presume the localization of brine within such structures. This attempt is meaningless since the structures are not well defined. In the case of ERDA-6, the structure based on a very sparse borehole data (Fig. G-11) is used (p. H-47). In the case of WIPP-12 the structure interpreted from a seismic time structure map is used (Fig. G-12, p. H-53). The ERDA-6 structure is too large for the calculated brine volume (p. H-47) and the WIPP-12 structure is too small (p. H-53).

The results of interference testing (p. H-37) are inconclusive because the time of testing and observation was not sufficient for the distance between wells. ERDA-6 is about 23,000 feet away from WIPP-12 and the pressure response in the former due to pumping from the latter

would take much longer than three weeks (Fig. H-13). Both ERDA-6 and WIPP-12 showed sustained recovery after one year of shut-in, and this recovery is probably generated from within a radius of influence of less than 5000 ft.

Similarly, AEC-7 is 10,000 ft. from ERDA-6 and the pressure response in that well was monitored for less than two months. Even if the tests and the monitoring had continued for a long time, the response due to interference would be extremely small considering the large distances.

Analysis of Flow Tests

All the known methods of analysis of flow test data are listed on pp. H-18 and H-19, yet only the Horner straight line method is actually used. The explanation of why the other methods were unsuitable has been provided in 10 pages (H-19 to H-28). The general explanation is that one or more of the theoretical assumptions were violated. The assumptions are no less violated in Horner's method than in others. All the results should be presented anyway--even in an appendix.

If all the data is not used, there is a possibility of biasing the results. The expression "highest quality data" is used on pages H-41, H-42 and H-43. It seems more apropriate to use all the data and present the results. If the data is poor, the results could be labeled as questionable. A range of values is more useful than a single, carefully chosen, value.

Migration of Brine

The conclusion (p. H-59) that present reservoir pressures are less than lithostatic because of brine flow into fractures, appears to be incorrect. Calculations of the lithostatic pressure by EEG indicate a minimum depressurization of the ERDA-6 brine of 500 psi and of the WIPP-12 brine of 1000 psi. These estimates are considered minimum because the present overburden thickness was used and not a pre-erosional value. In addition, the overburden was assumed to be pure halite. Within the range of formation compressibilities measured

for the anhydrite, the variation of porosity of 0.1 to 10 percent caused only a 50 psi difference in the calculated lithostatic pressure.

Therefore it appears unlikely that the reduction of ancient reservoir pressure to the present level is due to increased porosity from fracturing. A more reasonable explanation is that some fluid has migrated to an area of lower potential. As the calculated lithostatic pressure in WIPP-12 is greater than ERDA-6, the WIPP-12 may be more mobile. This would appear to be supported by the observation that WIPP-12 encountered brine in clean, smooth fractures while a recrystallized, brecciated zone held the brine in ERDA-6 (p. G-35). Other brine occurrences of much lower pressure (p. G-37) may represent areas where the brine migration is at a more advanced stage.

3. CHEMISTRY

Samples (Page C-8, Sec. 3.1)

D'Appolonia describes the rationale and techniques for brine sampling very adequately and thoroughly. However, with the excetion of some data reporting tables and figures (Table C-2, C-5, C-6, C-7 and ancillary Figures) which indicate averages, and variation, there is a distinct absence of more rigorous statistical evaluations. Analysis of variance (F-test) and student's t-tests would provide a clearer indication of the reliance which may be placed on certain sample population sets (e.g., Flow Test-3 versus Flow Test-2, etc.) and their respective subsets (downhole versus flowed sample). Such additional tests would appear to be easily performed, given the detail with which D'Appolonia has assembled their basic data.

Evaluation of Mineral Saturation (§Page C-12/13; Sec. 3.3.2)

The use of saturation indices as a means of predicting the degree to which a solution is at (or near) thermodynamic equilibrium with its host rock solid phase is a useful tool. Tables C.3 and C.4 provide a summary of log Ksp and log IAP values for five mineral phases. The discussion on page C-12 and C-13 point out that if the IAP is equal

or greater than the Ksp, then the solution is saturated with the phase. The data in Table C.3 and C.4 suggest that calcite as well as halite may not be saturated in ERDA-6 and WIPP-12. The more detailed data in Table C.2 were analyzed by an EEG consultant (Langmuir, 1983) and he concluded that there is undersaturation with respect to sylvite and polyhalite as well. We do agree, however, that the brines appear to be at or very near equilibrium with their surroundings.

Janecke Diagram (Page C-13; Section 3.3.2; Figure C-3)

Further details are needed concerning the Janecke diagram beginning in the last paragraph on p. C-13. This figure appears to be identical to the figure on page 993 of the paper by Harvie and Weare (1980), and shows zones which are saturated with respect to halite. It is not clear how this figure provides information relevant to ERDA-6 and WIPP-12.

Isotope Chemistry (Page C-20, C-39 and C-40, Sections 3.3.4 and 5.1.3)

The linear regression lines shown in Figures C-20 and C-21 using δD versus TDS and $\delta^{18}O$ versus TDS are interesting, but with only two points, the conclusions are not convincing. It is recommended that data on Union also be plotted with that of ERDA-6 and WIPP-12.

Sulfates (Page C-21; Section 3.3.4 , last paragraph)

This paragraph seems to suggest that the sulfate (^{34}S) of the brines is not in equilibrium with the ^{34}S of the rock. If so, this is inconsistent with the statement on p. C-22, 4th paragraph, which states that the $\delta^{34}S$ in sulfate is equal to values characteristsic of sulfates in permian evaporites. Then on p C-41, the last sentence of the first paragraph concludes that the $\delta^{34}S$ values for sulfate in brine are consistently less than the $\delta^{34}S$ values of the rock, which therefore precludes dissolution. Based on Tables C.5 and C.6, this latter statement seems to be correct.

Summary of Findings (Page C-31, Section 4.4)

Since the H_2S, methane and heavier hydrocarbons in WIPP-12 brine appear to have a thermogenic origin, and since the ^{34}S of the brine and anhydrite suggest that the WIPP-12 brines at their present location have not been exposed to high temperatures, one might conclude that the WIPP-12 brine

may have originated at depths much greater than their present location. This would also point toward a closer association with the DMG. The data also suggest an origin for ERDA-6 brine which is different from that of WIPP-12. Other possible origins of the thermogenic H_2S and hydrocarbons are discussed in Section 5.1..4, page C-48.

Seawater Evaporation Model (Page C-36, Section 5.1.2)

The 2nd paragraph on p. C-36 states that WIPP-12 brine is "probably saturated" with glauberite, whereas ERDA-6 brine is not. The results in Table C-3 suggest that ERDA-6 brine is more clearly saturated with glauberite than is WIPP-12. This would tend to refute the discussion in this paragraph, and the "Summary" on page C-38.

Seawater Evaporation Model (Pages C-44-45, Section 5.1.3)

Although the data in general seem to support a seawater evaporation model, some of the arguments used are not technically consistent with the literature. For example, suggesting on p. C-45 that reaction with marine clays will increase the δD and $\delta^{18}O$ is contrary to the literature (Savin 1980; Faure, 1977). As indicated in the Table below, the water would be depleted in ^{18}O and enriched in deuterium.

Table 1 Isotope Fractionation Factors for Clay-Water Systems at Earth-Surface Temperatures

MINERAL	OXYGEN	HYDROGEN	REFERENCE
Montomorillonite	1.027	0.94	1
Kaolinite	1.027	0.97	1
Glauconite	1.026	0.93	1
Gibbsite	1.018	0.984	2
Illite	1.0234	-	3

1. Savin and Epstein (1970)
2. Lawrence and Taylor (1972).
3. James and Baker (1976).

SPECIFIC COMMENTS

P. G-9, 2nd para.: The age of the dike has been measured as 30±1.5 m.y. (Urry, 1936) and 34.8±0.8 m.y. (GCR, p. 3-80). Therefore, the first episode of tilting did not occur in "very early Tertiary time" but in "mid-Tertiary time".

P. G-10, 2nd para.: The apparent dip observed in the drifts at the site is approximately 2° to the south (Geotechnical Field Data Report no. 5, p. 3-3).

P. G-17, 1st para.: It is possible that the top Castile anhydrite encountered in ERDA-6 may be A-III rather than A-II. In DOE-1 core, A-III showed thin bedding laminations similar to A-II.

P. G-29, First sentence: What is the correspondence between the fracture orientations (Fig G-10) and the structure contour map of Halite II (Fig. G-11) and the seismic isochron map (Fig. G-12)?

P. G-32, 3rd para.: The equation for compressibility is given as $C_p = \frac{1}{\phi K}$ where ϕ is the effective porosity and K is the bulk modulus of the rock mass.

In this equation, if $\phi \longrightarrow 0$, $Cp \longrightarrow \infty$
and if $\phi \longrightarrow 1$, $Cp \longrightarrow Cp$ of rock mass, instead of brine.
Clearly, this equation is incorrect or correct over a limited porosity interval only.

P. G-37, 2nd para: Fig. G-11 should include the borehole "H and W Danford well no. 1" in Section 9, township 22 South, Range 29 East which encountered pressurized brine in Castile (see EEG-7, p. 66)

P. G-43, 4th para.: The conclusion about the deformation having occurred between 25 to 1 million years ago does not match with the conclusion about the most likely mechanism for deformation being "slumping and flow

immediately after deposition" (p. G-23, first sentence), since the deposition occurred 225 million years ago.

P. H-1, 2nd para.: Only two brine occurrences were tested, yet here and at other places in the report reference is made to "other Castile brine reservoirs" and conclusions are drawn concerning all the brine occurrences. How are brine reservoirs identified? Does each well that encounters brine represent a separate reservoir?

P. H-1, 3rd para.: Throughout the report, ages are suggested (million years, millions of years) without any supporting evidence. Where do the ages come from?

P. H-4 section 2.2.2 Why doesn't the drainable volume have a direct bearing on the integrity of the WIPP site repository?

What is meant by drainable volume? Does it include only the large fractures or is the microfracture volume also included?

P. H-10, H-11, section 3.2.1, 2nd para.: How sensitive were the measured flow rates to these affects?

P. H-11, 1st para.: Do the gas/liquid separators restrict flow?

P. H-22, 1st para.: The correction to Horners method for fractures is empirical and based on drainage area. The drainage area is very poorly known. So how can this be justified over another method?

P. H-35, 3rd para.: As the heads in the different brine occurrences differ, lateral flow between brine occurrences is also possible.

P. H-36, 2nd para., last sentence: Substantial volumes of brine will be produced only if larger fractures are intersected. Brine in microfractures or in intact anhydrite would not enter a borehole in large enough volumes to cause a problem in normal drilling. Unless the brine caused a problem (flowing at the surface) the oil and gas drillers would not be interested in it.

Granted that no evidence exists to suggest a regional, homogeneous aquifer in the Castile Formation. However, a regional heterogeneous aquifer may exist. This aquifer would be characterized by zones of fracturing and high permeability (known brine occurrences) and zones of intact anhydrite or microfractures and low permeability. Upon fracturing, a high permeability brine reservoir could form as brine from the low permeability zone entered the fractures.

P. H-37, line 17: "fracture-enhanced" should be "large fracture enhanced." From Fig. H-8, H-9 there is no evidence that any kind of a boundary for the micro-fractures was encountered.

P. H-37, last para.: Granted that the fractures are not uniformly distributed. However if one assumes microfracture or porous media flow between the large-fracture zones of WIPP-12 and ERDA-6, a radial flow, or even a 1-D linear flow model could be used.

All the Horner tests, in fact, assume radial flow and all your results are based on Horner's method. Once you leave the large fractures, the radial flow may not be a bad assumption.

P. H-38, 1st para.: Calculations by EEG indicate that the transducer would need to raise the water level in AEC-7 by almost four feet to cause the 2 psi increase in pressure. Is that reasonable?

Page H-38, last para.: The existing hydraulic gradient may not be indicative of the geologic past. Where do you get "millions of years"?

Page H-39, line 10: It is stated that the disposal facility will be open for a few tens of years, after which it will be sealed and the pressure will return to its present state.

There is no reliable calculation on how fast the creep of salt will encapsulate and compact the repository. TME-3153 suggests 300 years.

Page H-41, bottom of page: The quantity F = correction fator when calculating permeability for a vertically fractured well is presented. An accurate estimate of this correction factor requires a knowledge of x_f/x_c, the fracture penetration. See Figure 11.12, p. 153 of Advances in Well Test Analysis, R.C. Earlougher, SPE, 1977.

Page H-43, last paragraph: Why wasn't a log-log analysis attempted for this early time data?

Page H-43, paragraph 3 and H-44, paragaph 1: Why do you expect the permeability of annydrite (core test) to be similar to that of halite (DST-2472-1/S8U).

Pages H-45 and H-46: Three volume estimates are presented.

In using the equation $V = \Delta V/(\Delta p c_t)$, it must be remembered that $\Delta p = pi - \bar{p}$ where pi = reservoir pressure prior to any brine flow and $\bar{p}$ is the average reservoir pressure after a known amount of brine flow.

The downhole pressure prior to any testing is a measure of pi. The downhole pressure following flow test 1 is not a good measure of $\bar{p}$. The surface shut-in pressure as of 10/18/82 is a measure of $\bar{p}$ if it can be demonstrated that there is no gas bubble at the head of the well. At best, only the second calculation on page H-46 is trustworthy.

Page H-46, bottom: If the largest volume figure, 2.2×10^6 bbl, is used, the circle radius is 2,646 ft. Although 2.2×10^6 bbl was an upper bound using a reservoir pressure of 1985 psig on October 18, 1982, it would not be an upper bound when ERDA-6 finally reaches equilibrium (which, because k is so small, may take years).

Page H-52: Two volume estimates for WIPP-12 are presented.
The downhole pressure following flow test 2 is not a good measure of $\bar{p}$. The surface shut-in pressure of 168 psig on 10/18/82 is a good measure of $\bar{p}$ if it can be shown that the well does not have a gas cap.

H-54, lines 17-19: Already 80,000 barrels of brine have been produced from WIPP-12 with less than a 40 psi reduction in pressure. 100,000 barrels may be a reasonable volume for a single event, but multiple events could produce much, much more.

Page H-55, bullet one: Measurement in 4 wells out of 12 does not constitute most.

Page 55, Observations 1) and 2): If this means that each encounter of brine represents a different reservoir, then the observation is clearly incorrect.

Page H-56, line 18: Is $K<5 \times 10^{-5}$ md obtained from a Salado sample at the WIPP site? Sandia (SAND 81-7073) obtained an in situ permeability of the Salado salt of about 1.0×10^{-3} md.

Page H-56, 3rd and 4th para.: The data is inconclusive about the interconnection between ERDA-6 and WIPP-12. Extending the conclusion derived from such data to other brine encounters is unscientific.

Page H-57: The permeabilities estimated are dependent on the fractures encountered. The high k at ERDA-6 is less than the low k at WIPP-12. Does that indicate two distinct zones of hydraulic characteristics or simply chance fracture encounters?

Page H-58, 2nd para.: Storage capacity and permeability are hydraulically unrelated parameters. The relationship in ERDA-6 and WIPP-12 is coincidental.

Figures 2 (Exec. Summ.), G-6, H-14: Show the boreholes only down to the total depths. Do not correlate below T.D. Also, the key map scale (in the upper right hand corner) is incorrect.

Figure H-12: Gonzales (in SAND 82-1012) gave the fresh water head of well H-1 as 3012.5 ft.

EDITORIAL COMMENTS

P. G-43, line 14: The word "probably" is misspelled.

P. G-44, line 10: "Figure G-12" should be "Figure G-13".

P. G-45, line 7: "Figure G-11" should be "Figure G-13".

P. C-8, Section 3.0, third line: The word "preceded" is misspelled.

P. C-22, Section 4.0, third line: The word "preceded" is misspelled.

P. C-26s, Section 4.3.2, first line: The word "preceding" is misspelled.

P. C-34, Section 5.1.2, 15th line: "Figure C-29" should be "Figure C-28".

REFERENCES

Anderson, R. Y. and D. Powers, 1978, Salt Anticlines in Castile--Salado evaporite sequence, Norhern Delaware Basin, New Mexico, N. M. Bureau of Mines and Mineral Resources, Circular 159, pp. 79-83.

Faure, G., 1977, Oxygen and hydrogen in the lithosphere, in Principles of Isotope Geology, Chapter 19, John Wiley and Sons (publishers).

Freeze, R. A. and J. A. Cherry, 1979, Groundwater, Prentice Hall, Inc., 604 p.

Harvie, C. E. and J. H. Weare, 1980, The production of mineral solubilities in natural waters: The Na-K-Mg-Ca-cl-SO_4-H_2O system from zero to high concentrtion at 25°C, Geochimica et Cosmochimica Acta, v. 44, p. 981-997.

King, P. B., 1948, Geology of the Southern Guadalupe Mountains, Texas, U.S.G.S. Professional Paper 215.

Kirkland, D. W. and R. Y. Anderson, 1970, Microfolding in the Castile and Todilto evaporites, Texas and New Mexico, Geol. Soc. of America Bull., v. 81, pp. 3259-3282.

Langmuir, D., 1983, Age and evolutionary history of WIPP-12 and ERDA-6 groundwaters and their comparison with other groundwaters in the Delaware Basin, Report to EEG, 10 p.

McNaughton, D. A., 1953, Dilatancy in migration and accumulation of oil in metamorphic rocks, Amer. Assoc. of Pet. Geol. Bull., v. 37, pp. 217-231.

Ramberg, H., 1963, Experimental study of gravity tectonics by means of centrifuged models, Bull. Geol. Inst. Univ. Uppsala, v. 42, p. 1-97.

_____, 1967, Gravity, deformation and the Earth's crust, London, Academic Press, 214 p.

_____, 1968, Instability of layered systems in the field of gravity, I and II, Phys. Earth Planet. Inst., v. 1, pp. 427-474.

Riley, C. M. and J. V. Byrue, 1961, Genesis of primary structures in anhydrite, Jour. of Sed. Petrology, v. 31, no. 4, pp. 553-559.

Savin, S. M., 1980, Oxygen and hydrogen isotope effects in low temperature mineral water interactions, Chap. 8, in Handbook of Environmental Isotope Geochemistry, Elsevier Scientific Publishing Co., pp. 282-327.

Urry, W. E., 1936, Post Keweenawan time scale, National Res. council Report, Comm. on Measurement of Geologic Time 1935-36, Exh. 2, pp. 35-40.

Walton, W. C., 1970, Groundwater Resource Evaluation, McGraw Hill.

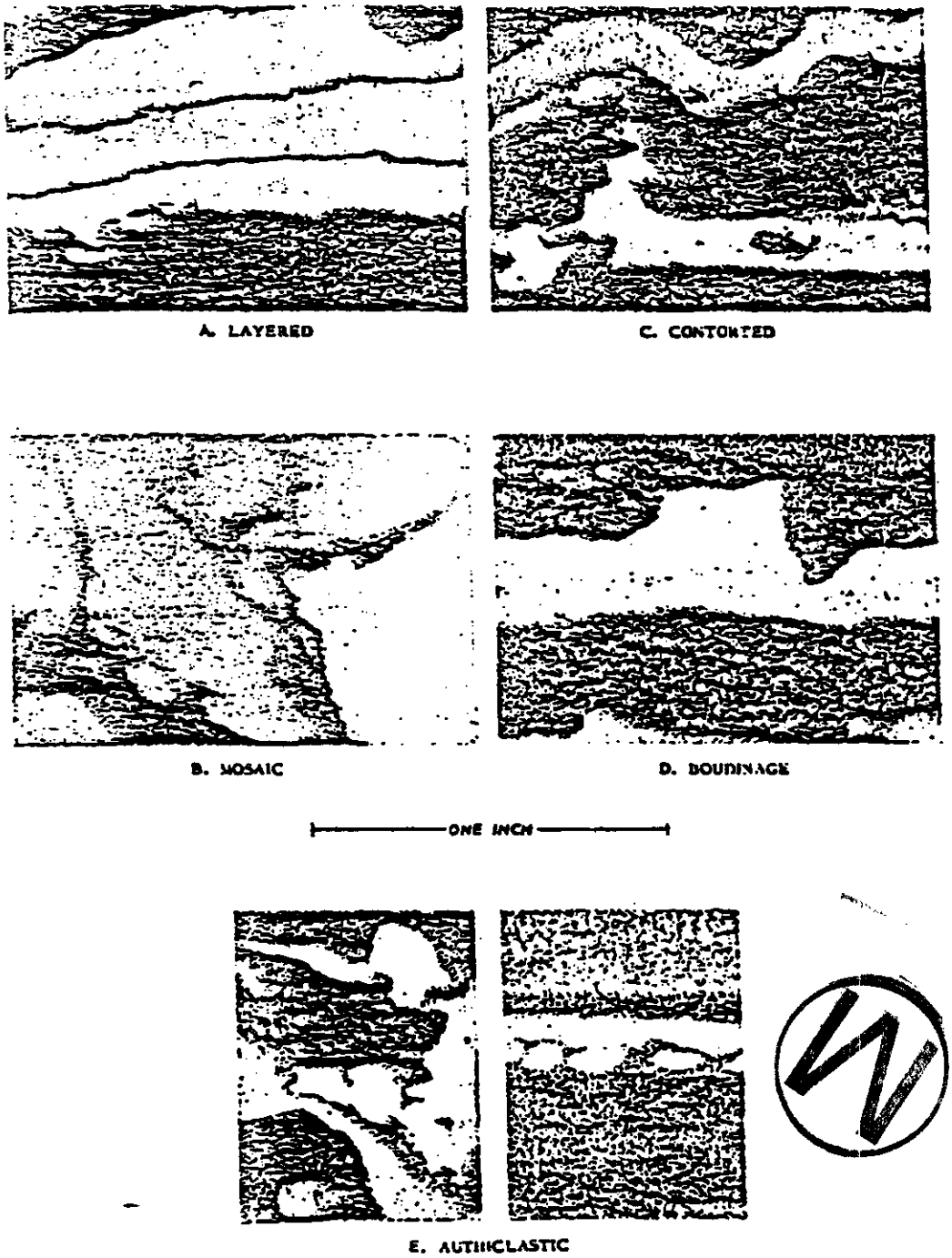

FIG. 4.—Anhydrite structures formed in model experiments.

From Riley and Byrne (1961)

FIGURE 1

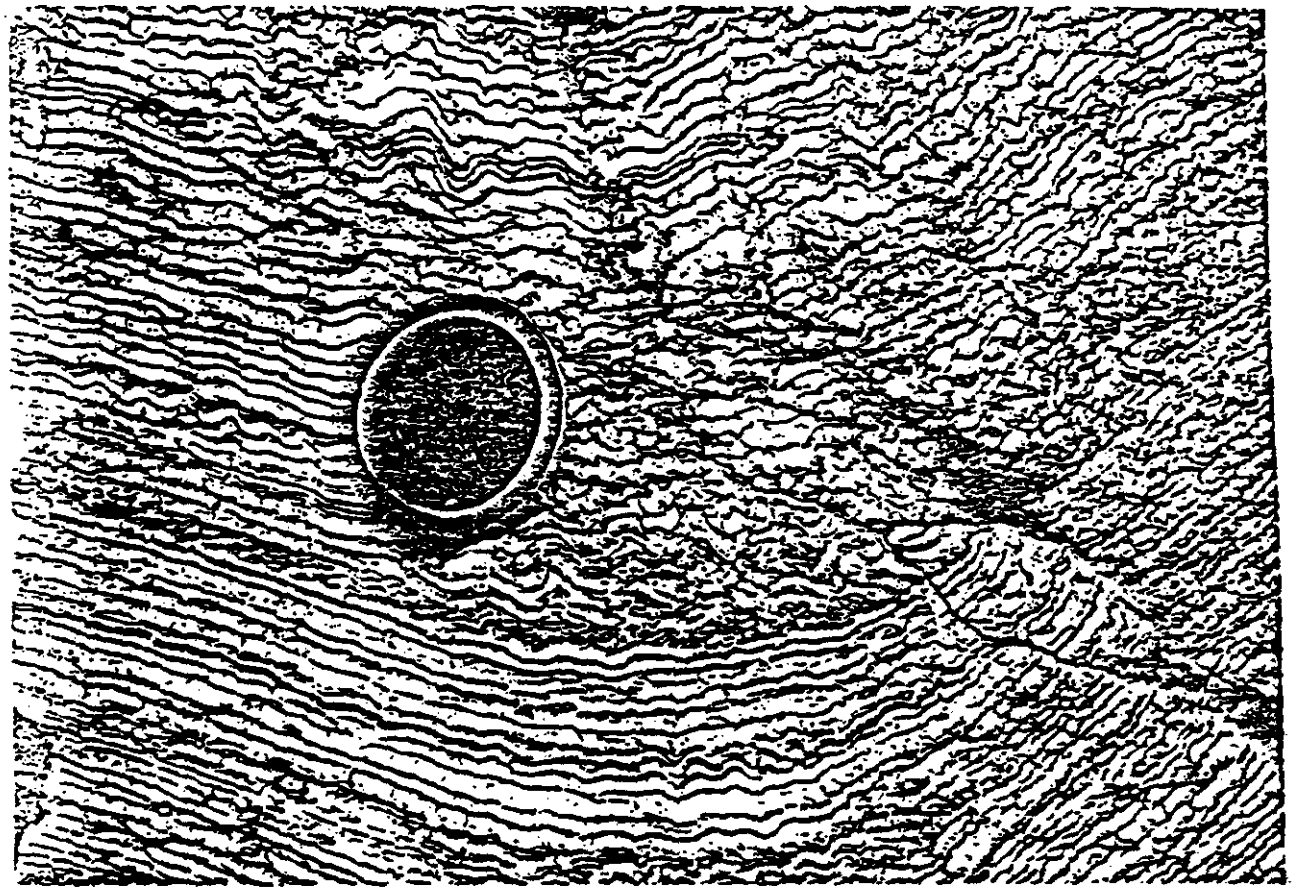

Fig. 12 Microfolding in Castile at the Stateline outcrop, Stop 3-5. Camera lens-cap is for scale.

(photo: Lokesh Chaturvedi)

From EEG-7

FIGURE 2

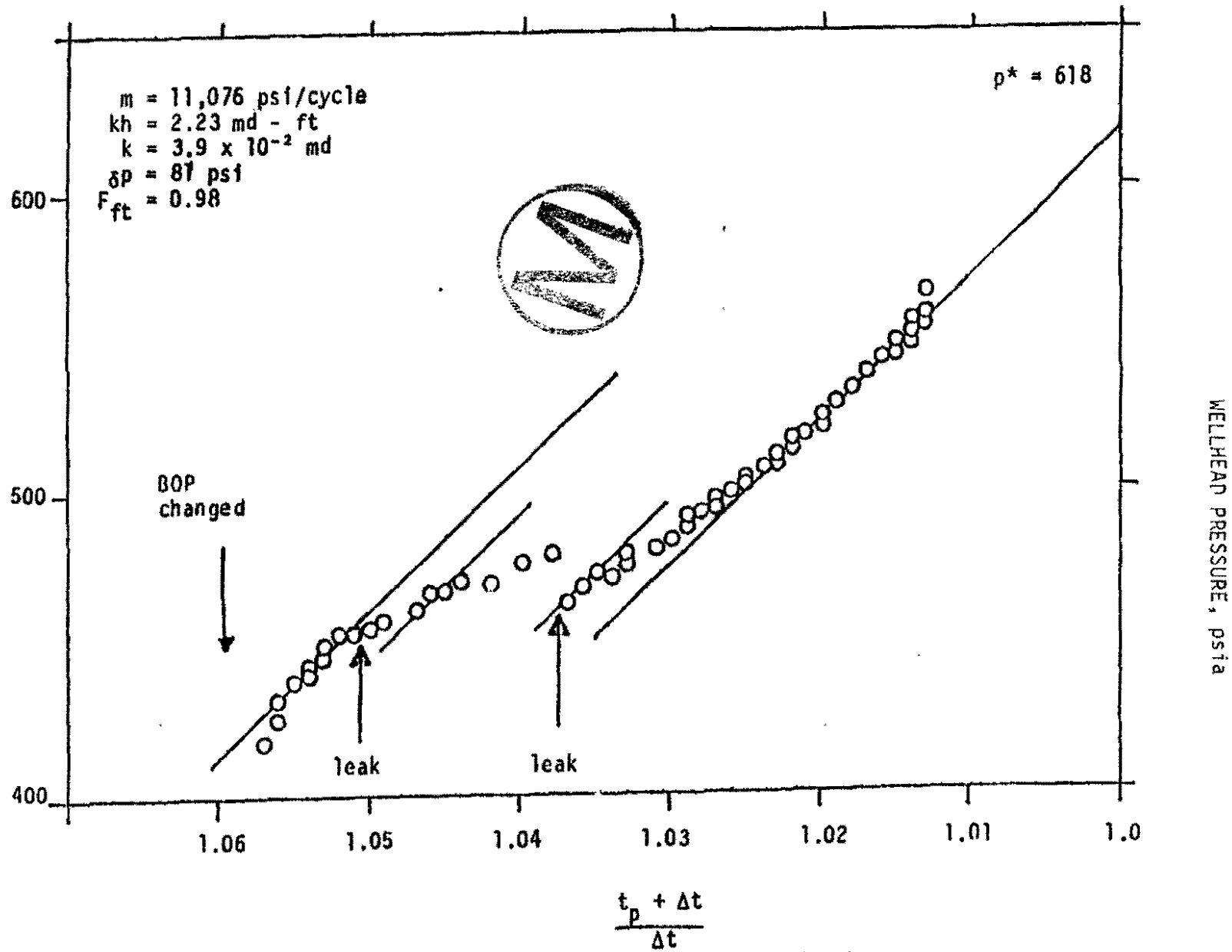

FIGURE 3. Horner plot of pressure buildup following the BOP change.

PLANS FOR SIMULATED WASTE EXPERIMENTS

SAND 82-0547

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May 27, 1982

Joseph M. McGough
WIPP Project Manager
U. S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, NM 87115

Dear Mr. McGough:

There is attached a summary of our comments and recommendations concerning the Draft of "Simulated Waste Experiments Planned for the Waste Isolation Pilot Plant (WIPP), printed March, 1982.

We would appreciate knowing your response to these views.

Sincerely,

Robert H. Neill
Director

RHN:eg

2-031-AG2-20-2
cc: TSC, IEA
Enclosure

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

REVIEW COMMENTS

CONCERNING

SIMULATED-WASTE EXPERIMENTS PLANNED FOR THE WASTE ISOLATION PILOT PLANT

DRAFT FOR REVIEW

Printed March, 1982

Comments by

Environmental Evaluation Group

Environmental Improvement Division

Health and Environment Department

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May, 1982

General Comment

The description of the experiments often is too brief to permit a satisfactory technical review. We would appreciate receiving a copy of the Test Plan for each experiment when that becomes available in draft so that we may have an opportunity to comment prior to its final preparation.

Specific Comments

1. Section 2.2.2 (a), page 8. EEG agrees that waste form stability and leachability can be evaluated by in situ tests; however, there appears to be very little attention given in the SWE plan to the in situ evaluation of the TRU waste form stability and leachability. There is a need for information at an early stage to validate the TRU waste acceptance criteria, to assure safe waste handling procedures, and to plan for retrieval if deemed necessary. Therefore the SWE should include experiments designed to provide in situ investigations of TRU waste form interactions. Of particular concern is the radiolytic production of explosive gas mixtures in 210ℓ drums within three months to five years (Reference 4). It is recognized that such in situ studies would require drums containing actual TRU wastes, however, because the results are essential to an assessment of retrievability, the experiments should be considered under the SWE program schedule.

2. Section 3.3, pages 20-24 - The "Overtest for Simulated DHLW" experiment has two phases with the second phase being addressed to the elucidation of the mechanics of reestablishing a stable, impermeable backfill in DHLW repository rooms. It is recommended that a similar experiment be planned for the TRU waste repository room. The experiment should be addressed to the consolidation of backfill and TRU-containing drums into a stable, impermeable layer. It would provide data on the time span following closure over which a liquid breach scenario has validity.

3. Section 4.2, page 32-36 - This section does not indicate plans for verification of permeability studies for gases produced in untreated wastes. Earlier laboratory and borehole studies by Sandia (Reference 3) have shown that gas pressures on the order of lithostatic could be produced over a several hundred year period. There is question concerning the validity of these data under repository conditions, since the earlier tests were conducted either under controlled laboratory conditions or at only two depths in one borehole (Reference 4). The studies proposed by BNL on page 190 of Reference 4 should be considered.

4. Section 4.1.2(d), page 32 - Although there is considerable data available on the thermal near-field effects on rock salt, consideration should be given to the thermal effect on plastic flow under actual repository conditions.

5. Section 4.2, pages 32-36
   a) Tests should be included to demonstrate ability to handle explosions or fires involving wastes. Such tests should be scheduled prior to the handling of radioactive wastes.
   b) Experiments designed to verify the radionuclide leach and sorption assumptions used in the long-term consequence modeling of Reference 5 should be initiated at the earliest possible time, since meaningful data would not be available for several years.

c) This section does not indicate whether investigations of the durability of "TRU waste-drums" will include studies of the TRU waste "boxes," such as the DOT-7A FRP coated plywood box, and the RH steel drums. It is suggested that studies of the durability of these additional waste containers be included.

REFERENCES

1. Molecke, Martin A., "Gas Generation From Transuranic Waste Degradation: Data Summary and Interpretation," Sandia Laboratories, SAND79-1245, Printed December 1979.

2. Westinghouse Electric Corporation, "TRU Waste Acceptance Criteria For The Waste Isolation Pilot Plant," WIPP-DOE-069, Rev. 1., September, 1981.

3. Sandia Laboratories, "Summary of Research and Development Activities in Support of Waste Acceptance Criteria for WIPP," SAND79-1305, December 1979.

4. Brookhaven National Laboratory, "Nuclear Waste Management Technical Support in the Development of Nuclear Waste Form Criteria for the NRC," Task 2, Alternative TRU Technologies, NUREG/CR-2333, February 1982.

5. U. S. Department of Energy, "Final Environmental Impact Statement, Waste Isolation Pilot Plant," vol. 1 and 2, October 1980.

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

RECEIVED
AUG 2 1 1982
ENVIRONMENTAL
EVALUATION GROUP

AUG 2 4 1982

Mr. Robert H. Neill
Director
State of New Mexico
Environmental Evaluation Group
P. O. Box 968
Santa Fe, NM 87503

Dear Mr. Neill:

EEG Comments on Simulated Waste Experiments

Enclosed for your use are responses to the comments and recommendations in your letter dated May 27, 1982, concerning the Draft of "Simulated Waste Experiments Planned for the Waste Isolation Pilot Plant (WIPP)."

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 82-0539/5985A

Enclosure

cc w/enclosure:
C. C. Little, TSC
C&C File, IEA, TSC
T. Hunter, Org. 9732, SNLA

General Comment

Our response to the EEG review comments corresponds to the EEG specific comments number. The general comment by EEG suggested that the description of experiments was too brief for satisfactory technical review. The descriptions of the Simulated Waste Experiments (SWEs) were intentionally summarized in the document. More emphasis was given to objectives and technical issues. The descriptions provided, however, are more than adequate to determine the purpose, scope, and physical configuration of the experiments. Further details will be developed prior to initiation of each experiment and the test plan for each experiment will be continually revised as the experiment progresses.

Specific Comments

1. Section 2.2.2 (a), page 8: The EEG comment concerned the requirement for in situ evaluation of the TRU waste form stability and leachability.

   Based on the considerations which follow we consider in situ tests to evaluate degradation further as unjustified and not necessary.

   Previous laboratory and field studies conducted by SNL on the TRU waste form defined the limits of waste degradation, by-products and potential consequences on environmental safety of the WIPP (SAND79-1305). These studies were conducted under accelerated conditions (higher levels of actinides, higher temperatures, etc.) to observe by-products of the degradation process. The generation of gas mixtures was well characterized and its impact on long-term storage was assessed.

   Drums of CH TRU wastes that meet the WIPP waste acceptance criteria on gas generation will not generate explosive gas mixtures from radiolytic degradation. Their rate of hydrogen production is too low (reference: SAND79-1245, Chapter 2). Actual drums of such waste have been in semi-enclosed temporary storage for years without significant operational problems associated with gas generation. TRU wastes are, however, in existence which could potentially generate explosible concentrations of gases (reference: SAND79-1245, p. 16-17); these wastes, containing large concentrations of ^{238}PU, would not meet WIPP waste acceptance criteria.

   Storage rooms in the WIPP will be ventilated and monitored, thereby preventing accumulation of hazardous concentrations of gases. Gas monitoring is generally a routine procedure and not an experiment. As such, it was not described in the SWE document, particularly since actual (TRU-contaminated) wastes are not in place during this stage of the WIPP.

2. Section 3.3, pages 20-24: The EEG comment suggested additional testing of backfills for TRU wastes. Response of candidate backfill will be examined not only in the DHLW Overtest Experiment but also in the Plugging and Sealing Tests documented in SAND81-2628. The current R&D program is structured to address the sealing potential of backfills. It includes not only the tests outlined in SAND81-2628, but also corresponding modeling and laboratory tests. Backfill for the TRU waste demonstration rooms is planned primarily for fire protection purposes and not for sealing. Sealing for the TRU waste rooms will be accomplished in access drifts using techniques evaluated in the other planned tests described in Section 4.2, Plugging and Sealing, SAND81-2628.

3. Section 4.2, pages 32-36: EEG comment concerned gas pressure buildup over a period of several hundred years. We believe that for the expected gas generation rate and range of salt permeabilities that gas pressurization will be well within acceptable limits. A study of this subject ("Potential for Salt Fracturing Due to Gas Generation" (DRAFT), 1979, D'Appolonia), in addition to the references cited by EEG, leads to this belief. The references show that significant fractures could only occur at very low permeabilities, lower than anticipated at WIPP, and at gas generation rates higher than expected for the WIPP storage horizon.

   Gas permeability in situ tests, as addressed in Section 4.2.2.1 of SAND81-2628 where a plan for permeability measurements is described for the salt formation at the WIPP facility horizon, will be performed for verification. The results of these tests will be utilized, if needed, to support previous studies on this subject.

4. Section 4.1.2 (d), page 32: EEG comment pertained to the thermal effect on salt creep rate under actual conditions. The effect of temperature on salt creep rate will be evaluted in situ as planned in the heater tests described in Sections 3.2 (12-W/m^2 mockup) and 3.3 (Overtest for Simulated DHLW). Thermal "very" near-field effects on rock salt will be examined by measuring the mock DHLW canister borehole deformation throughout the duration of the test. Detailed plans for obtaining near-field (room) and "very" near-field (around-the-canister) response data will be considered during preparation of the Test Plans.

5. Section 4.2, pages 32-36:

   a) EEG comment related to demonstrating the ability to handle explosions or fires involving storage of waste. The WIPP design has attempted to minimize fire and explosion hazards and planned operating procedures are expected to minimize these hazards both before and after placement of radioactive waste. Code of Federal Regulation (30 CFR Part 57.4-58) prohibits building of fires underground. Therefore, no underground tests to demonstrate ability to handle explosions or fires involving waste are being planned as part of the SWE or any other experimental program.

b) EEG comment suggests initiating early tests designed to verify the radionuclide leach and sorption assumption used in long-term consequence assessments for WIPP are best addressed by laboratory experiments and hydrologic tests of the Rustler aquifer. The additional benefits of local backfills and the limited release rate and solubility of radionuclides will be addressed by experiments with radioactivity described in SAND81-2628. These will address primarily defense high level waste as the effects on TRU wastes are clearly bounded by the assumptions in the SAR.

c) EEG comment suggests studies of the durability of TRU waste "boxes" such as the DOT-7A FRP coated plywood box and the RH canisters be included in the SWE TRU drum durability tests. The planned SWE TRU drum durability tests are essentially demonstrations of adequacy as established from previous studies (SAND79-1305, Chapter 7). This reference also provides adequate justification for the durability of the RH waste canisters. The TRU waste box containers will be overpacked in all cases, hence tests of bare boxes are unwarranted.

TRIP/CONFERENCE REPORT

TECHNICAL SUPPORT CONTRACTOR
WIPP PROJECT
ALBUQUERQUE, NEW MEXICO

REPORT NO. EA:82:0390

DATE OF REPORT August 30, 1982

TRIP DESTINATION or LOCATION of CONFERENCE and DATES

- **Organization visited** EEG visited TSC offices
- **Dates of Trip/Conference** August 26, 1982

SUBJECT of TRIP/CONFERENCE

Discuss Final EEG Comments On Two Stipulated Agreement Reports

ATTENDEES (Name and Organization)

R. H. Neill, NM EEG
M. Little, NM EEG
C. C. Little, TSC-W
J. S. Treadwell, DOE*
T. Hunter, SNLA*
R. Matalucci, SNLA*
K. R. Porter, TSC-D'Appolonia*

* = Part Time

DISTRIBUTION (Name and Organization)

R. K. Brown, TSC
G. L. Hohmann, TSC
W. Baer, TSC
V. F. Likar, TSC
D. K. Shukla, TSC
W. D. Weart, SNLA
T. Hunter, SNLA
J. M. McGough, DOE
J. S. Treadwell, DOE
R. L. Dintaman, DOE

- **SUMMARY of TRIP/CONFERENCE**

DOE, EEG, TSC and SNLA met to discuss the reports entitled Simulated Waste Experiments Planned for the WIPP (SAND82-0547) and Natural Resources Study, WIPP (TME-3156). Both reports have gone to the printer with only minor change to the resource study resulting from the State's final review.

- **DISCUSSION OF TRIP/CONFERENCE TRANSACTIONS (Use Trip/Conference Continuation Sheet)**

Prior to the morning meeting, the State was presented with copies of both reports-Simulated Waste Experiments (SWE) and Natural Resources. Resolution of the State's comments and incorporation of changes felt to be necessary by the reports authors had occurred earlier and the State was provided with the documents as they were to be printed. Although EEG reviewed the Natural Resources Report, they declined the opportunity to review the SWE report.

The final meeting concerned the SWE report and the DOE response to EEG's comments. After some discussion between all parties, it became obvious that there were three areas of concern by the State which were not addressed by SNLA in the SWE report but which are or will be addressed inother WIPP documents. These three areas include:

1. items relating to the WAC and waste certification,

Report Prepared by C. C. Little C.C. Little

Report Approved by 9/2/82

Organization Institutional and Environmental Assessments

2. items requiring details of specific tests which will not be available until specific plans are developed for each test, and

3. items not related to simulating waste but which will be covered in the overall R&D In-Situ Test Program presently undergoing final review by DOE.

EEG concerns relating to item 1 will be addressed as part of the State's review of other project documents. As such, no revision to the SWE is required. EEG concerns relating to item 2 will be addressed in the detailed SNLA test plans which will be provided to DOE prior to each test. DOE (Treadwell) observed that these plans may be provided to the State if the DOE Project Manager agrees with the State's need to review each plan -- and further observed that there was no apparent reason not to release the plans to the State. TSC (Little) pointed out that the ERDA-6, WIPP-12 and DOE-1 plans had not been released by DOE although the State had participated in a detailed review (through numerous meetings) and that most of their comments had been incorporated in the final plan for each test. EEG (Neill) reiterated the State's request to review each detailed plan. This request has not been resolved pending further consideration by the Project Office. No change will be made in the final SWE report for the second item. Relative to the third item, EEG was informed that SAND81-2628 should be issued in September or October and that no changes in this area were planned for the SWE report. Except as noted relative to EEG review of the detailed test plans, EEG concurred with the DOE/SNLA plan to not modify the SWE report.

During the detailed SWE discussion, EEG requested two documents which TSC agreed to check for availability for release. These are:

"Potential for Salt Fracturing Due to Gas Generation"
(Draft D'Appolonia - 1979)

and

"Long-Range Master Plan for Defense Transuranic Waste Management"
(DOE-TRU 8201 Draft 1982)

Finally, during the SWE discussion, EEG pointed out a potential error in the SAR Table 3.1-1 in that the overpack described does not fit over the FRP box it appears to be intended to protect from fires. TSC (Little) agreed to review the Table for a possible error. Subsequent review indicates that there is not an error, but that the Table depicts containers and overpacks which currently exist in the waste management industry. Prior to shipment of FRP boxes to WIPP, new overpacks will be constructed and placed over the FRP box.

The afternoon meeting consisted of a very brief discussion between EEG and TSC relative to the Natural Resources Study. Two editorial problems were discussed and resolved. The only remaining EEG comments will be discussed further when the revised "Interim" DOE Policy Statement is ready for issuance. Only minor changes have been made to the final Natural Resources Study, and it has been forwarded to the printer for final printing.

Both reports should be issued in final form during September, 1982.

DESIGN VALIDATION PLAN

WIPP-DOE-160

HEALTH & ENVIRONMENT department

"Equal Opportunity Employer"

STATE OF NEW MEXICO

ENVIRONMENTAL EVALUATION GROUP
320 Marcy Street
P.O. Box 968
Santa Fe, NM 87504-0968
(505) 827-5481

August 24, 1982

Mr. Joseph M. McGough
Project Manager of WIPP
WIPP Project Office
U.S. Department of Energy
Albuquerque Operations Office
P. O. Box 5400
Albuquerque, New Mexico 87115

Subject: Letter from J. M. McGough to R. H. Neill, Draft Design Validation Plan, JMM 82-0496, 8/3/82

Dear Mr. McGough:

Enclosed are EEG's comments on the report "Preliminary Design Validation Plan Waste Isolation Pilot Plant (WIPP)", which was submitted by you as item 8 of Appendix B of the Stipulated Agreement between the State of New Mexico and the Department of Energy. Should you have any questions regarding these comments, please contact Dr. P. Spiegler.

Sincerely,

Robert H. Neill
Director
AG-046AG2-14-3

RHN:eg

cc: TSC, IEA

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

Comments on draft

"Preliminary Design Validation Plan Waste Isolation Pilot Plant (WIPP)

by

Environmental Evaluation Group
Environmental Improvement Division
N. M. Health and Environment Department
P. O. Box 968
Santa Fe, NM 87503

August 24, 1982

General Comments

1. The report is considered to be much too general to comply with requirements of the Stipulated Agreement Appendix B, between the State and DOE, and the statement of work described by DOE in the letter from D.T. Schueler to G. S. Goldstein, "Costs and Merits Evaluation for Stipulatd Agreement Activities," August 31, 1981. It is recommended that the report be extensively revised to include a detailed plan with appropriate technical rationale, to construct the test panel and to carry out the tests, and to indicate how the results will validate the key assumptions for design regarding rock mass behavior. It should include (a) establishment of priorities and schedule for various components of the test; (b) preparation of the steps in design, analysis, monitoring and review of the test program; (c) and review of the consistency of the proposed plan with the objectives an rationale for the test.

2. The report relies on references that are partially out of date. See further discussion of references below under "Specific Comments."

Specific Comments

Section 1.1

This section should include a reference to the Stipulated Agreement and a restatement of the work proposed by DOE in the letter from D. T. Schueler to G. S. Goldstein, "Cost and Merit Evaluation for Stipulated Agreement Activities," 8/31/1981.

Section 1.4

The SPDV underground facilities also include an exploratory drift into the area of the repository. This drift was recommended by DOE in lieu of the horizontal coring activities.

Section 1.6

The layout and configuration of the underground openings are not based on experience gained in existing potash mines in the Carlsbad area. In fact, the first underground design was by Serata Geomechanics. The design was rejected

when the room closure rates could not be verified. The present design has a slow room closure rate that permits retrieval of waste 5 to 10 years following emplacement. Retrieval of waste and modular design of the repository are important criteria in the present underground design. The criteria require that substantial barriers of undisturbed salt be left between modules to ensure isolation of each module from other modules.

Section 2.1

The objectives of the preliminary design validation plan are to enhance the level of confidence and credibility of the current design of haulageways and storage rooms. To do this, it is necessary to have some preliminary data that will show that the haulageways and storage rooms will remain stable during the waste emplacement and retrieval period. The objectives of the preliminary design validation plan have been succinctly stated in report SAND 81-25/628* as follows:

- To validate the design for the WIPP access shafts and TRU waste disposal demonstration rooms.
- To evaluate the amount and rate of shaft convergence and room creep deformation and to correlate these data with model predictions.
- To perform a preliminary evaluation of creep in salt and of the steady-state creep model.
- To evaluate instrumentation systems for accuracy and the reliability of measurements made with them in rock salt and to document the suitability of the system for future measurements.
- To evaluate the response of in situ formations such as clay seams and other material layers in addition to the salt.
- To collect large numbers of samples of rock salt and other materials and to conduct laboratory and bench-scale tests to determine the mechanical properties of these samples.

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*R. V. Matalucci, C. L. Christensen, T. O. Hunter, M. A. Molecke, D. E. Munson, Waste Isolation Pilot Plant (WIPP) Research and Development Program: In Situ Testing Plan. Draft report SAND 81-2628.

3.0 plan

This section does not describe a plan, rather, it describes a preliminary proposal for a plan. An excellent description of the plan can be found in report SAND 81-2628,* section 4.1.2.1, preliminary Design Validation, contains much more specific information than is included in this draft and should be incorporated, at least in summary, if it is still current.

4.0 Documentation

Section 4.2

The section should mention that as part of the Stipulated Agreement, a document entitled "Results of SPDV Site Validation Experiment" will be issued in March 1983 (latest revised date from DOE).

5.0 WIPP Design Development

Section 5.1

A statement should be made that indicates that Ref. 5 is outdated due to numerous recent design changes. This reference contains the early underground design by Serata Geomechanics. It was never revised because it was decided to include all the updating in the Title II design. The layout and configuration is not based largely on the experience gained from potash mining in the Carlsbad area (see comments for Section 1.6).

The last sentence which states that the extraction ratio for WIPP is more conservative than the extraction ratio in commercial salt and potash mines is misleading since the two cases have opposite goals. In commercial potash mining the aim is to extract as much ore as possible and to have the rooms close as fast as possible thereafter. (No need for empty drifts in which workers could get lost.) In WIPP the aim is to have haulageways and storage rooms that will remain stable during the waste emplacement and retrieval periods.

---

*R. V. Matalucci, C. L. Christensen, T. O. Hunter, M. A. Molecke, D. E. Munson, Waste Isolation Pilot Plant (WIPP) Research and Development Program: In Situ Testing Plan. Draft report SAND 81-2628.

Section 5.5

The last sentence, "the modeling techniques mentioned in para. 5.3 will attempt to define long term creep behavior" is incorrect. The techniques have only been used to evaluate creep for the first ten years following room construction. Long term creep requires terms that describe the inertia of the backfilling and the waste cans to the creep. The Thermal/Structural Interactions experiments of the WIPP Research and Development Program will provide data on long term creep.

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

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EVALUATION GROUP

NOV 24 1982

Mr. R. H. Neill
Director
State of New Mexico
Environmental Evaluation Group
P. O. Box 968
Santa Fe, NM 87504

Dear Mr. Neill:

Design Validation Plan

Enclosed for your review is the final draft of the Design Validation Plan required by Item 8 of Appendix B of the Stipulated Agreement. This revision incorporates the results of our discussions of September 21, 1982 on this document. Because of the extensive changes to the document resulting from your comments, we are reissuing the report for your final review. We would appreciate your comments before December 10 since we would like to go to the printer on December 17. This schedule will allow us to issue the final printed report before the end of 1982.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 82-0823

Enclosure

cc w/o enclosure:
J. Treadwell, WIPP/PO, AL
J. Smrha, B, AL
C. C. Little, TSC, AL

cc w/enclosure:
C&C File, IEA, TSC

"Equal Opportunity Employer"

STATE OF NEW MEXICO

ENVIRONMENTAL EVALUATION GROUP
320 Marcy Street
P.O. Box 968
Santa Fe, NM 87504-0968
(505) 827-8280

December 15, 1982

Mr. Joseph M. McGough
Project Manager on WIPP
WIPP Project Office
U. S. Department of Energy
P. O. Box 5400
Albuquerque, NM 87115

Dear Mr. McGough:

Subject: Design Validation Plan, Rev. 4, 11/15/82. Letter WIPP: JNM 82-0823, dated 11/24/82.

We have reviewed the above cited document and are pleased to note that it has been revised to address EEG's comments in my letter of August 24, 1982 as well as those items discussed at our meeting on September 21, 1982. The document provides a good description of the tests to be performed to demonstrate the soundness of the design of WIPP. Aside from a few detailed comments, we have no further comments concerning this document. However, we have one suggestion for the preliminary design validation report.

The design validation plan provides a description of the geological observations that will be made and of the data that will be accumulated during the SPDV phase of the WIPP. It does not convey the impression that data analysis will play an important role in the final design of the WIPP repository. For example, unlike the description of the tests in the document SAND 81-2628, there is no discussion of expected results. Also, there is no mention of possible design alterations. The section, "Drawings, Figures, Logs" of Appendix B, does not indicate any preliminary calculations. We believe that data analysis is important to the validity of the design validation report and the preliminary design validation report should reflect this by having two subsections on expected results; one in section 8 "Geological Behaviour--Shafts", and the other in section 9 "Geological Behaviour--Horizontal Openings."

Detailed comments on the design validation plan are enclosed.

Sincerely,

Robert H. Neill
Director

RHN:PS:eg

2-93-A02-14-3-1

Enclosure

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

Detailed Comments on Design Validation Plan

1. Page 6, last line.

   The paragraph should point out that the exploratory drift is to be excavated to the south.

2. Page 7, Figure 1-2.

   The figure should have an arrow indicating the north-south direction.

3. Page 15, 2nd paragraph or line 12.

   The term "through SPDV" appears to be meaningless. SPDV will go on until September '83, which is past March '83.

4. Page 16, item 2a.

   Is there a typing error in the date 4/31?

5. Page 17, 1st paragraph.

   There is no commitment in the paragraph to furnish the data as available after the final design validation report to the EEG.

6. Page 20, item f).

   A statement indicating the locations of drillholes or other plans to monitor Marker Bed 139 and height of clay seams above roof should be added.

7. Page 20, bottom of Page.

   The following item should be added:
   k) Geophysical measurements to determine possible anomalies above or below the drift.

8. Page 22, section 4.1.

   Most of the documents to be furnished under the Stipulated Agreement can be viewed as part of the site characterization program. They should be referenced in this section.

9. Page 23, Figure 4.1.

   This figure should be replaced by the latest design which shows the repository in the southern region of the site.

10. Page 25, Figure 4.2.

    The direction of this cross-section should be indicated.

11. Page 31, 3rd paragraph or line 25.

The sentence "After a retrieval period of five years, the rooms with waste emplaced will have been completely backfilled with salt." is unclear.

12. Page 36, last line.

The sentence is incomplete. It should be as follow: A schedule of activities included in the performance of the Design Validation Plan is presented on p. 16.

13. Page 47, item 13.

The item should point out that the correlation goes from WIPP-12 to DOE-1.

Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, New Mexico 87115

FEB 11 1983

FEB 15 1983
EVALUATION GROUP

Mr. Robert H. Neill
Director
State of New Mexico
Environmental Evaluation Group
P.O. Box 968
Santa Fe, NM 87503

Dear Mr. Neill:

Conference Report for DOE/EEG Meeting, January 26, 1983

Enclosed for your information, is a conference report for the subject meeting on the validation process and forthcoming reports. I believe, based on my observations at the meeting, that we are in agreement on the planned activities and reports leading to DOE's pending decision relative to our proceeding with full facility construction.

At the present time, we are making arrangements for an EEG tour of the underground facility including the complete south drift on February 16, 1983. This will be the earliest opportunity under our present schedule during which all mine conditions will be suitable for such a tour. We also plan to conduct the seventh quarterly review in our Albuquerque office on February 15, 1983. We have arranged for a Ross flight to Carlsbad the morning of February 16. The flight will return late that afternoon.

If there are any questions on our plans, please contact me at your convenience.

Sincerely,

J. M. McGough
Project Manager
WIPP Project Office

WIPP:JMM 83-0111

Enclosure

cc:
See Page 2

TECHNICAL SUPPORT CONTRACTOR
WIPP PROJECT
ALBUQUERQUE, NEW MEXICO

REPORT NO. EA:83:0037
DATE OF REPORT January 28, 1983

TRIP DESTINATION or LOCATION of CONFERENCE and DATES

- Organization visited EEG/DOE/TSC/B/SNLA Meeting

- Dates of Trip/Conference January 26, 1983

SUBJECT of TRIP/CONFERENCE

See Attachment I

ATTENDEES (Name and Organization)

DISTRIBUTION (Name and Organization)

R. K. Brown, TSC
G. L. Hohmann, TSC
D. K. Shukla, TSC
H. Taylor, B
J. Smrha, B
W. Weart, SNLA
T. Hunter, SNLA
J. M. McGough, DOE
J. S. Treadwell, DOE
T. Shea, DOE
R. Dintaman, DOE

- SUMMARY of TRIP/CONFERENCE

The parties met to discuss DOE's response to EEG comments on the Design Validation Plan and to discuss documentation being prepared to support the April 1, 1983 DOE decision relative to the initiation of full facility construction. EEG agreed with the resolution of comments and DOE's planned documentation to support their decisions.

- DISCUSSION OF TRIP/CONFERENCE TRANSACTIONS (Use Trip/Conference Continuation Sheet)

The subject meeting was conducted in accordance with the attached agenda (Attachment II). After a brief opening by DOE during which it was explained that the Project Office had reassigned certain functional responsibilities, TSC presented (Attachment III) a summary of the hierarchy of reports which have been and are being prepared to support the suitability of the site and preliminary design. The relationship of documentation to the Stipulated Agreement was discussed to ensure a mutual understanding of required submittals. The greater significance of documentation supporting site suitability was also discussed, and all parties agreed that preliminary design validation will be less important in the decision to proceed because the design is continually evolving over the life of the facility. It was pointed out that all supporting documents will be provided to EEG and the State reading rooms, but that DOE will print a larger number of the documents responding to item 2 of the Stipulated Agreement to respond to public requests for information. At the conclusion of these discussions, all parties were in agreement concerning the planned documentation and schedules for review. EEG did feel that,

Report Prepared by C. C. Little C.C. Little
Organization TSC - WIPP Project

Report Approved by

although there was no requirement to do so at this time, DOE should address the draft EPA standard on site suitability -- no commitment was made to do this until the regulations are promulgated and DOE has reviewed the final rules.

The next agenda item, discussion of EEG comments on the Design Validation Program Plan, was led by Bechtel. EEG's comment had been provided earlier in a letter to the Project Office and the discussion concerned revisions to the document by Bechtel. EEG was pleased with the revisions to the Design Validation Program Plan. Bechtel indicated they would finalize the report for issuance as a DOE document. Bechtel also pointed out that the Preliminary Design Validation Report presently scheduled for March 31, 1983 would not include a comparison of predictive calculations versus actual results in the mine since earlier predictions were not directly applicable to the final horizon. During the discussions, EEG questioned whether or not the project was continuing to use radar to preview conditions ahead of the continuous minor. DOE indicated that, as had been observed in potash mines, the use of radar was less efficient than periodic probe hole drilling and that the use of radar had been discontinued. EEG also requested further details relative to the northernmost location of TRU waste relative to WIPP-12 under the present design. It was pointed out that this was related to the final decommissioning plan which had not been developed, but that if no TRU waste was permanently disposed of in the experimental area that the northernmost waste would be more than 6000 feet horizontally from WIPP-12. If during decommissioning TRU waste was placed in the experimental area, this waste would be slightly less than one mile horizontally from WIPP-12.

The next agenda item, site suitability report contents, was directed by SNLA. During this discussion, it was pointed out that the summary would include a discussion of the 21 site qualification criteria delineated in WIPP-DOE-116. The summary report would not address the issues in detail, but would instead rely on the other documentation developed in support of this final decision on site suitability.

The final agenda item, contents of the report on results of SPDV site validation experiments, was directed by TSC. A draft table of contents (Attachment IV) was provided and discussed. EEG felt that the report should contain information on the petrography of the inner bedded materials and characterization of the individual aquifers in the shaft mapping report. TSC pointed out that neither of these items were required by WIPP-DOE-116 and that the last item would be very difficult (maybe impossible) to obtain at this time. TSC/DOE agreed to evaluate the possibility of providing the requested petrographic information.

"Equal Opportunity Employer"

STATE OF NEW MEXICO

ENVIRONMENTAL EVALUATION GROUP
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April 5, 1983

Mr. Joseph McGough
Project Manager on WIPP
WIPP Project Office
U.S. Department of Energy
P.O. Box 5400
Albuquerque, New Mexico 87115

Subject: Design Validation Plan

Dear Mr. McGough:

The document Design Validation Plan (WIPP-DOE-160) Reference 9 attached to your letter of 3/24/83 is sufficiently responsive to issues on questions raised in both correspondence and meetings on the attached reference list. The document fulfills item 8 of the Stipulated Agreement.

Sincerely,

Robert H. Neill
Director

RHN:ps

Attachment

2-123AG-2-14-3-1

cc: TSC, IEA

Providing an independent analysis for the New Mexico Health and Environment Department of the proposed Waste Isolation Pilot Plant (WIPP), a federal nuclear waste repository.

References

1. WIPP:JMM 82-0496, Transmittal of Draft Design Validation Plan, J.M. McGough to R.H. Neill, 8/9/82.

2. AG-046 AG2-14-2, Comments on Draft Preliminary Design Validation Plan Waste Isolation Pilot Plant (WIPP), R.H. Neill to J.M. McGough, 8/24/82.

3. EEG Conference Report 49, 9/28/82.

4. WIPP:JMM 82-0823, Design Validation Plan, J. McGough to R.H. Neill, 11/29/82.

5. 2-93-AG2-14-3-1, Comments on Design Validation Plan, Rev. 4, R.H. Neill to J. McGough, 12/15/82.

6. EEG Conference Report 58, 1/27/83.

7. WIPP:JMM 83-0111, Conference Report for DOE/EEG Meeting, January 28, 1983, J.M. McGough to R.H. Neill, 2/15/83.

8. WIPP:JMM 83-0118, Advance Copy of Design Validation Plan, J.M. McGough to R.H. Neill, 2/9/83.

9. WIPP:JMM 83-0211/6552A, Transmittal of WIPP-DOE-160, Design Validation Plan, January 1983, J.M. McGough to R.H. Neill, 3/24/83.

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP, A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado

Formation, March 1984.

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (edi), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kenney, James W., A Critical Assessment of Continuous Air Monitoring Systems At The Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-23

EEG-23

EVALUATION OF THE SUITABILITY OF THE WIPP SITE

Robert H. Neill
James K. Channell
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Marshall S. Little
Kenneth Rehfeldt
Peter Spiegler

Environmental Evaluation Group
Environmental Improvement Division
Health and Environment Department
State of New Mexico

May 1983

Environmental Evaluation Group
Reports

EEG-1 Goad, Donna. A Compilation of Site Selection Criteria, Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979.

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, eds. Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S. Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K. Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla. The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses From WIPP, September 1980.

EEG-9 Spiegler, Peter. An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

(Continued on back cover)

EVALUATION OF THE SUITABILITY OF THE WIPP SITE

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May 1983

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is minimal environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of available data concerning the proposed site, the design of the repository, its planned operation, and its long-term stability. These analyses include assessments of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U.S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.

Robert H. Neill

Robert H. Neill
Director

EXECUTIVE SUMMARY

The determination of the suitability of the site for WIPP is only the first major phase in the evaluation of the radiological impact of the repository on the public health and safety. The Environmental Evaluation Group (EEG) will continue to independently review the design of the facility, the operational procedures (including safety criteria and quality assurance), the criteria for packaging and shipment of the waste, the plans, procedures and results of the WIPP experiments, emergency preparedness, adherence to EPA and pertinent NRC regulations, and other important features of the project.

EEG has concluded from existing evidence that the Los Medanos site for the WIPP project has been characterized in sufficient detail to warrant confidence in the validation of the site for the permanent emplacement of approximately 6 million cubic feet of defense trasuranic waste. This conclusion is based on the assumption that the maximum surface dose rate for the unshielded remote-handled transuranic waste (RH-TRU) canisters will be 100 rem per hour with a maximum radionuclide concentration of 23 curies per liter as indicated in Table E-3 of the Final Environmental Impact Statement for WIPP. The Site and Preliminary Design Validation (SPDV) program, through the drilling of two shafts to the selected repository level at 2160 feet below the surface and excavation of about 9000 feet of tunnels, has confirmed the interpretations made about the subsurface geological conditions at the site.

For an assessment of the potential radiation effects of the nuclear waste repository on the public health and safety, it is necessary to understand the regional geological and hydrological setting. A large amount of work has been done to understand these conditions and to address several specific issues which have arisen as a result of such studies. However, in an assessment effort of this magnitude, it is almost inevitable that some questions remain unanswered at a given time in the decision-making process. EEG has identified work which still needs to be done at the Los Medanos site in order to improve confidence in the worst case scenario models of possible breaches of the repository. Also, it is anticipated that some of the additional information will be necessary to assure compliance with the EPA standard when it is promulgated.

EEG strongly recommends that the following important commitments be obtained from DOE prior to beginning the full facility construction.

Recommended Commitments from DOE Prior to Beginning the Construction

1. The WIPP will comply fully with the U.S. Environmental Protection Agency standard for the disposal of transuranic wastes, when it is promulgated. WIPP does not appear to meet some parts of the proposed standard.

2. The maximum surface-dose rate for the unshielded Remote Handled Transuranic Waste (RH-TRU) canisters will be 100 rem per hour with a maximum radionuclide concentration of 23 curies per liter as indicated in Table E-3 of the Final Environmental Impact Statement for WIPP.

3. No potash mining will be allowed in Zones I, II and III of the WIPP site. Deviated drilling for oil and gas from outside the WIPP site to reach under the WIPP site at depths greater than 6000 feet may be allowed. The federal government shall exercise active institutional control at the site for this purpose for at least 100 years after repository decommissioning.

4. DOE shall provide to the State certified data and final reports as appropriate for the studies and investigations listed herein by July 1, 1985, and allow for a 60 day review and comment period by the State and general public. DOE shall consider and respond to such comment within 30 days.

The following lists certain investigations currently in process or planned by DOE and additional work which EEG recommends that the State should demand if the construction is allowed to proceed.

Studies Recommended by EEG

1. Investigate the depression of the marker beds in the lower part of the Salado formation, centered two miles north of the WIPP shafts.

2. Perform computer modeling of groundwater flow in the Rustler aquifers.

3. Conduct the following hydrology tests:
   a) A long duration pumping test at the well H-3.
   b) Measure the anisotropy of the hydraulic conductivity at test pads H-1, H-2, and H-3.
   c) Perform convergence tracer tests at wells H-1, H-3 and H-4.
   d) Perform convergence tracer tests at well H-6 using sorbing tracers.

Continuing or Planned DOE Studies

1. Evaluate and field test non-invasive geophysical methods to identify possible occurrence of brine under the repository.

2. Analyze the drawdown data in test holes H-1, H-2 and H-3 caused by the excavation of WIPP shafts.

3. Publish the results of solute transport modeling in the Rustler aquifers.

4. Analyze the Rustler aquifer waters for environmental isotopes (Carbon-14, Chlorine-36, Uranium-234, Uranium-238) to aid in understanding the groundwater flow direction and relative velocity.

5. Drill the planned additional wells for hydrologic testing, viz. H-11 and H-12. Obtain the cores while drilling these wells to determine the extent of fracturing and solution residues throughout the Rustler formation.

6. Conduct a water balance study for the WIPP site.

7. Study the mechanics of removal of salt from the Rustler formation at and near the site.

8. Drill a shallow auger-hole in the depression in the SW corner of Sec. 30, T225, R 31E in Zone III to address the suspicion of this depression being a doline.

9. Further study marker bed 139 (MB139) underlying the repository horizon to determine its origin and its effect on the repository.

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INTRODUCTION

On March 31, 1983, the Department of Energy issued the "Summary of the Results of the Evaluation of the WIPP Site and Preliminary Design Validation Program" (WIPP-DOE-161). This publication contains a "Summary of the Evaluation of the WIPP Site Suitability" by W. D. Weart of Sandia National Laboratories and an Executive Summary of the Preliminary Design Validation Report by Bechtel National, Inc. The report concludes that the Los Medanos site fulfills the intent of all the site qualification factors and should, therefore, be used for the Waste Isolation Pilot Plant project. It also concludes that "the major WIPP design elements and design bases have been validated by observation or measurement."

The Environmental Evaluation Group (EEG) is charged with the responsibility of evaluating the suitability of the site for carrying out the mission of WIPP by analyzing all the reports and other information which form the background to the DOE evaluation of the site. The results of this evaluation are being conveyed to the appropriate State authorities to help them formulate the State's position on whether to oppose the beginning of construction of the Waste Isolation Pilot Plant project.

A summary of EEG's involvement since November 1978 is provided in the Appendix to indicate the extent of evaluation process for the past 4 1/2 years. During the past year alone, EEG has received approximately 40 major and numerous supporting reports from DOE concerning various aspects of the evaluation of the site.

The "Summary of the evaluation of the WIPP Site Suitability" by W. D. Weart of Sandia National Laboratories, contained in the U. S. Department of Energy document (WIPP-DOE-161, March, 1983) is based on the 21 site qualification factors formulated in the Site Validation Program (WIPP-DOE-116, October 1982). The specific issues on which EEG has expressed its concerns in the past (EEG-3, EEG-6, EEG-7, EEG-10, DOE/State Stipulated Agreement, 1981) are included in the 21 site qualification factors. Rather than comment on the adequacy of the WIPP site with respect to each of the 21 factors, the discussion in this report is arranged according to issues which EEG considers

important in evaluating both the operational and the long-term integrity of the site. The section on Conclusions and Recommendations provides a summary of EEG analyses of the issues of site suitability.

The Environmental Evaluation Group organized a meeting on "Evaluation of WIPP Site Suitability" at Carlsbad on May 12 and 13, 1983. The purpose of the meeting was to present EEG's tentative conclusions on the issues of WIPP site suitability to a group of 40 invited scientists and engineers which included scientists from State agencies, members of the National Academy of Sciences Panel on WIPP; several University professors from New Mexico and from Stanford, University of Arizona and Pennsylvania State; U. S. Geological Survey scientists; scientific personnel from DOE and its contractors e.g. Sandia, and D'Appolonia. While the discussions, comments and recommendations made at this meeting were considered in the preparation of this report, the conclusions reflect the views of the Environmental Evaluation Group and do not necessarily reflect the views of others.

As the title of this report suggests, only the issues directly related to the suitability of the site are addressed here. Other issues including transportation, waste acceptance criteria, the absence of engineered barriers, and adherance to EPA and NRC regulations will be dealt with separately.

RESOLUTION OF SPECIFIC ISSUES

DISSOLUTION

1.0 Blanket Dissolution

Geologists who have studied the Delaware Basin generally agree that the Ochoan evaporite deposits of upper Permian age have undergone erosion and shallow dissolution in the Basin. This regional dissolution must have been initiated with the tilting of the basin and injection of water from the Capitan aquifer downdip to the east into the evaporite deposits. Since halite is the most soluble of the ochoan evaporites, it has been dissolved where the unsaturated waters have managed to attack it. The sequence from the oldest to the youngest of the Delaware Basin evaporites is Castile, Salado and Rustler formations, respectively. Figure 1 shows the western edges of the Castile and Salado halite. The edge of the salt in the youngest, i.e., the Rustler formation, is farther east and it criss-crosses the WIPP site in a general north-south direction (Fig. 2).

The effects of the regional dissolution nearest the WIPP site can be observed in Nash Draw, a dog bone shaped depression immediately west of the WIPP site. Nash Draw is approximately 15 miles long in the north-south direction and its width ranges from approximately 5 miles to as much as 12 miles. Bachman (1980, 1981) studied and mapped this depression in detail and concluded that it has been formed by a process of "solution and fill," which is active today. Based upon the dating of a volcanic ash layer associated with the Gatuna formation which is exposed at the ridge on the eastern margin of Nash Draw and using the marker beds in Salado, Bachman (1980) concluded that about 200 feet of subsidence has occurred in this depression during the past 600,000 years. Using this observation, Bachman (1974) calculated an average rate of 330 feet per million years for the vertical dissolution. Assuming that the edge of the Salado salt has moved from the Capitan Reef front to its present location during the past 7 to 8 million years (since the Ogallala time), Bachman and Johnson (1973) concluded that the horizontal rate of movement of the blanket dissolution front is about 6 to 8 miles per million years. It should, of course, be recognized that these are very rough average rates of movement of the dissolution front. The front itself may be expected to move faster under less arid climatic conditions. Also, an advancing "tongue" of the front may reach a point faster than the front itself.

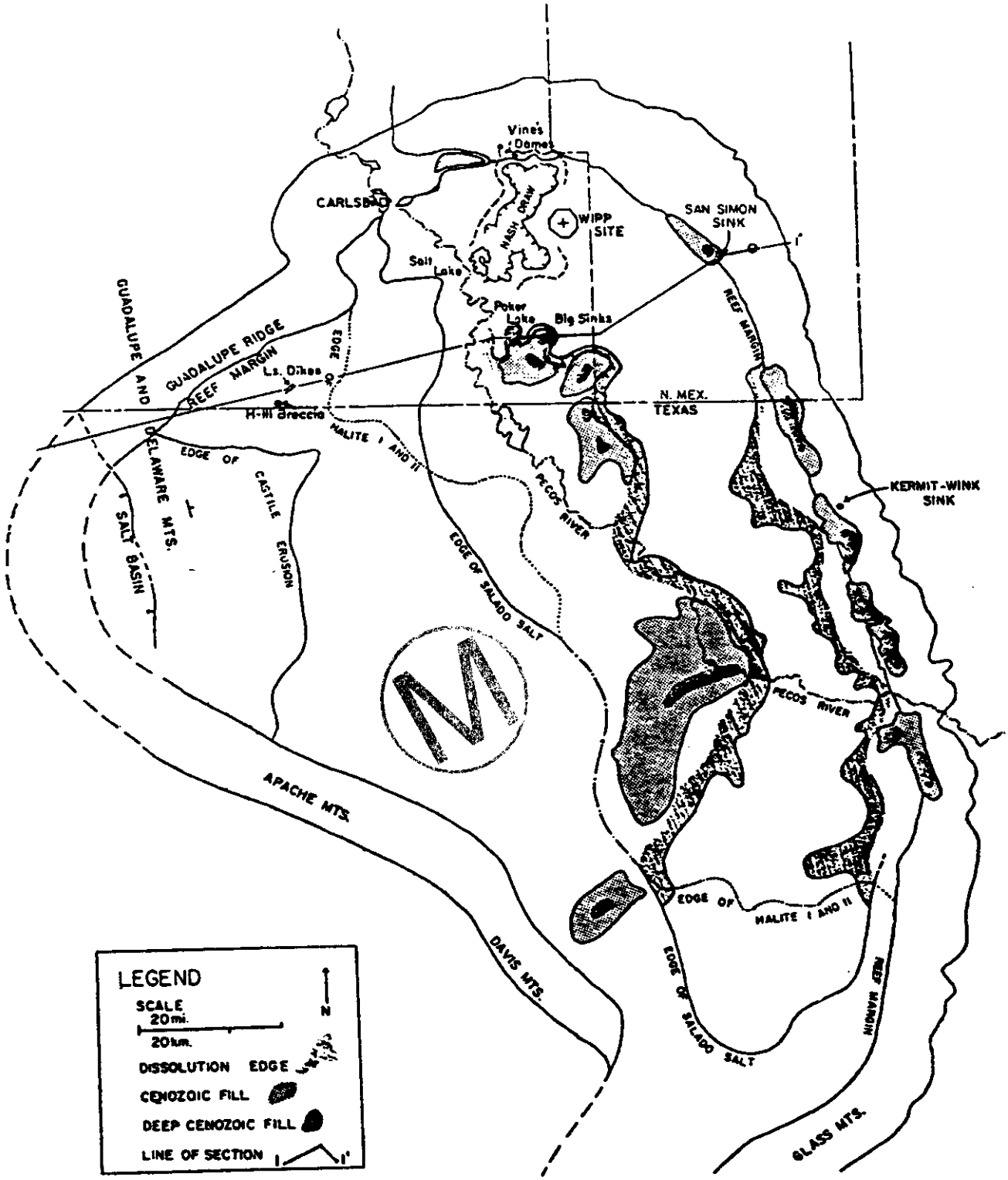

Figure 1. Map of Delaware Basin showing location of Capitan reef, major dissolution depressions, and western dissolution of evaporites and of major salt units (from Anderson, 1981)

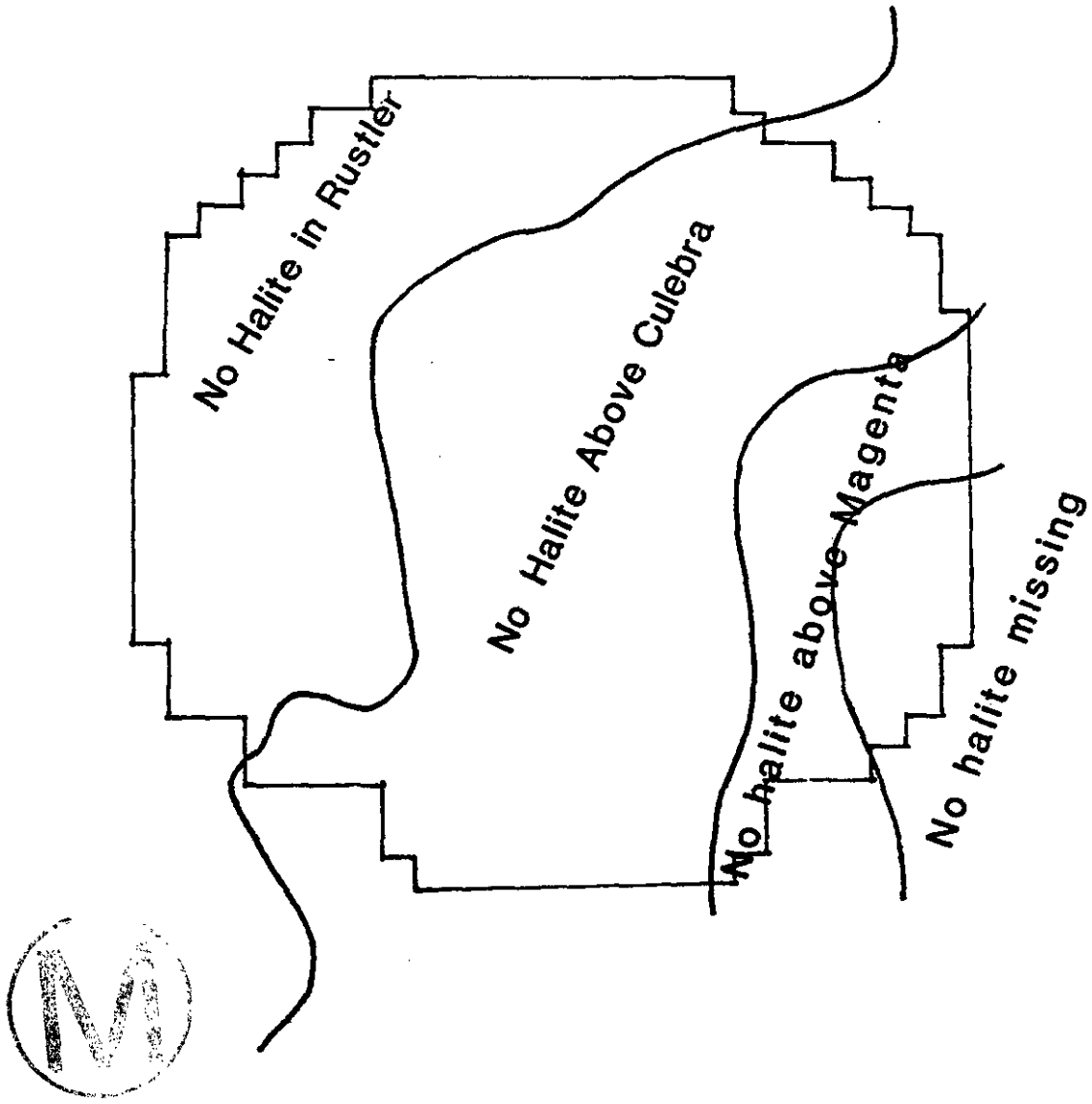

Figure 2. Extent of removal of salt from the Rustler formation at the WIPP site (Modified from Snyder, 1983)

Using the above rates for horizontal and vertical dissolution, it can be shown that it would take approximately 225,000 years for the front to travel approximately two miles to reach the western edge of the WIPP repository and would start dissolving salt from upper Salado, about 1500 feet above the repository horizon. It would then require at least 2 to 3 million years for the removal of 1500 feet of salt by dissolution, at the rate of 330 to 500 feet per million years. In spite of the very approximate nature of the estimated rates of advance of the dissolution front, and the possibility of a more rapid advance of a segment of the front, these calculated rates provide sufficient safety from an advancing front of blanket shallow dissolution of salt towards the WIPP site.

2.0 Deep Dissolution

The hypothesis of preferential removal of salt from the lower Salado and Castile formations has been called "Deep" dissolution. In attempting to correlate the varved evaporite sequence of the Castile formation and the overlying Salado, Anderson et al.(1972) concluded that large quantities of bedded salt were missing from the middle of the evaporite sequence near the center of the basin. Using the correlation of acoustic logs across several lines in the Delaware Basin, Anderson et al. (1978) concluded that (a) the preferred dissolution horizons from which salt has been removed by dissolution occur between the Halite III salt of the Castile formation and the 136 marker bed of the Salado formation, and (b) the large depressions in the basin, first identified by Malley and Huffington (1953), were the result of selective dissolution of lower Salado salt beds. Anderson (1981) further developed the idea of deep-seated dissolution and concluded that deep-seated dissolution has occurred around the margin of the basin where the Capitan aquifer is in contact with the Permian evaporites and within the basin where selective dissolution in the lower Salado has undercut the overlying salt beds. He calculated that more than 70% of the original salt has already been removed from the lower Salado horizon in the basin.

For the mechanics salt removal salt through the process of deep dissolution, Anderson (1981) invoked the "brine density flow" which had been proposed earlier (Anderson and Kirkland, 1980) for the formation of breccia pipes. This mechanism requires a connection between the lower Salado and the

underlying Delaware Mountain Group aquifer. It was hypothesized that this aquifer supplies unsaturated water to the overlying evaporites through a fracture system and the brine produced after dissolution of the salt is also removed through this aquifer. Using the reported (Hiss, 1975) values of hydraulic conductivity of 0.0049 m/day and a chlorinity of 150 g/ℓ for the DMG aquifer, Anderson (1981) calculated that this aquifer, where it is in contact with the reef, can remove the volume of salt missing from the Salado in 1.5 million years.*

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*There appears to be a discrepency in Anderson's calculation here.

According to Anderson (1981), Figure 3, $[(10 - 49) + (13.9 - 3.8)] \times 10^{11}\ m^3 = 7.11 \times 10^{12}\ m^3$ of salt has been removed from lower Salado.

For hydraulic conductivity, K = 0.173 m/day (maximum measured value)
hydraulic gradient, i = 0.0025 m/m
Cl = 150 gms/liter = 247 g/ℓ of NaCl
= 247 kg/m^3 of NaCl

NaCl density ≈ 2.2 g/ml
= 2200 kg/m^3

Salt removal is $\frac{247\ kg/m^3}{2200\ kg/m^3} = 0.112\ m^3$ salt/m^3 water

If the thickness of the DMG aquifer is 100 m, the volumetric flux of water per one meter width of aquifer is

$Q = K.i.100$
$= 4.33 \times 10^{-2}\ m^3/d\text{-}m$
$= 15.8\ m^3/yr\text{-}m$

In 1.5×10^6 years, the flow is,
$15.8 \times 1.5 \times 10^6 = 2.37 \times 10^7\ m^3/m\text{-width}$

And the amount of salt removed is
$0.112 \times 2.37 \times 10^7 = 2.65 \times 10^6\ m^3$ salt/m - width

In 1.5×10^6 years

Width of Flow	Volume of Salt Removed
50 km	$1.33 \times 10^{11}\ m^3$
100 km	$2.65 \times 10^{11}\ m^3$
150 km	$3.98 \times 10^{11}\ m^3$

Even with conservative assumptions, the volume of salt removed as calculated by EEG is 20 to 50 times less than that calculated by Anderson.

Wood et al (1982) conducted a detailed study of the potential of the DMG aquifer to remove the dissolved salt as hypothesized by Anderson (1981). They studied the potential dissolution mechanisms of diffusion and convection from the halite zones of Castile and Salado to the Bell Canyon (DMG) and the Capitan Reef aquifers, and reached the following conclusions.

- The diffusion and possibly very weak convection result in removal of halite from the Castile. Convection may be significant at locations adjacent to the Capitan Reef aquifer.

- Salt removal by the diffusion process would produce an advancement of the dissolution front of only 0.3 centimeter in 10,000 years.

EEG (1983, pp. 75-93) has questioned several assumptions and analyses contained in this study but has accepted the conclusion that the known properties of the DMG aquifer make it an unlikely pathway for supply and removal of water needed to carry out the dissolution at a massive scale as asserted by Anderson (1981).

Anderson (1982) countered that the interpretation of geophysical logs from hundreds of wells in the basin clearly shows that the upper Castile and lower Salado salt is missing under a large part of the basin and that it has been removed by dissolution during the Pleistocene time. If the DMG aquifer was not the pathway for the brine movement, then an alternate pathway must account for the missing salt. Anderson (1982) developed a case for the upper Anhydrite layer in the Castile formation as the conduit for the movement of unsaturated waters from west to east. The brine produced by such dissolution would escape through the Capitan Reef to the east. This mechanism is illustrated in Figure 3.

There are several unresolved questions in this postulated mechanism. Besides a very few isolated reports of minor quantities of water in the upper Castile, mainly near the Pecos river southwest of the WIPP site, the only liquid found in the Castile anhydrite is in the pressurized brine reservoirs. In spite of a large number of boreholes which have been drilled through the Castile, there is no indication of the existence of unsaturated water flowing through this zone. Therefore, the upper Castile is not an aquifer. Also, the two

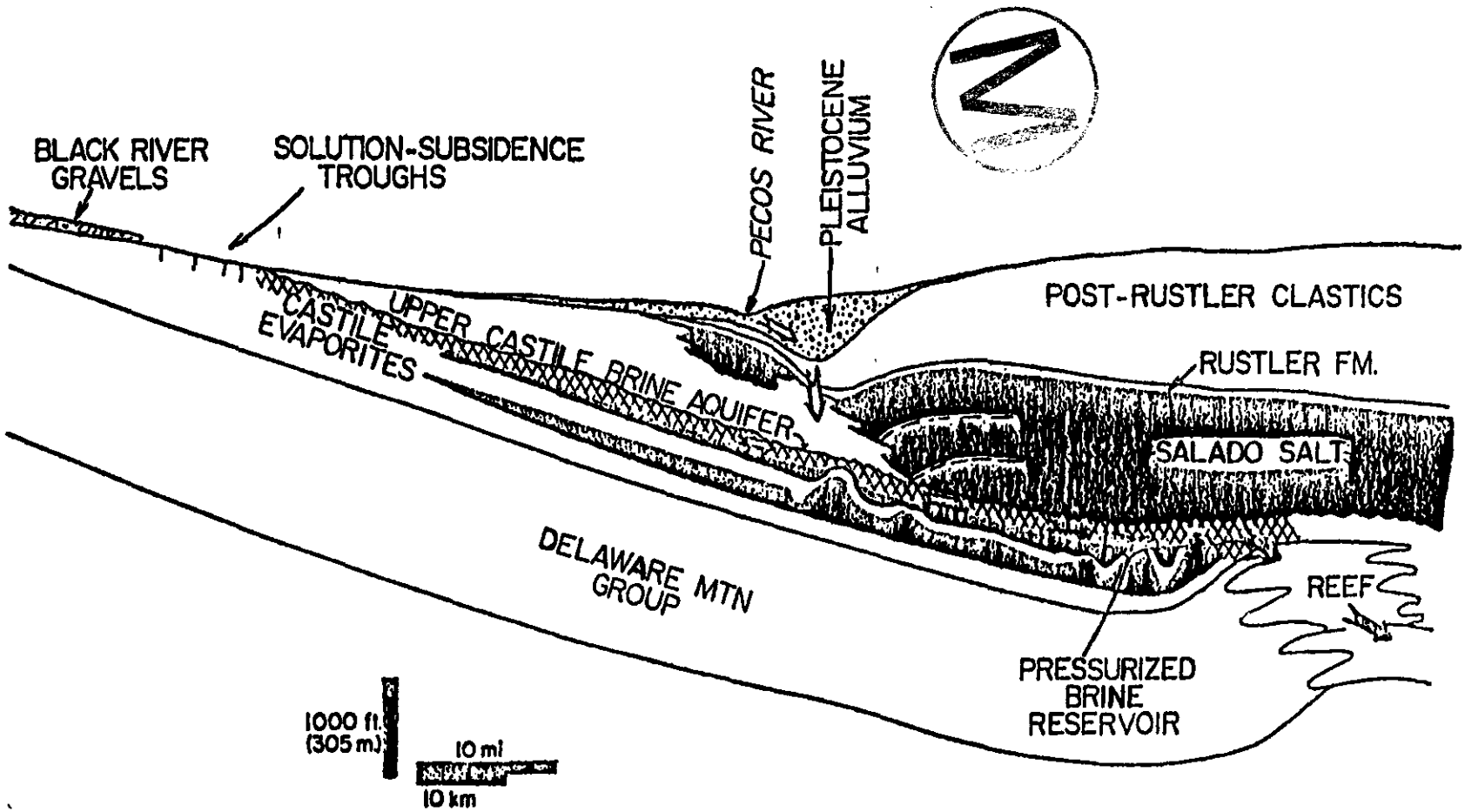

Figure 3. Diagrammatic cross section through the northern Delaware Basin, New Mexico, showing possible pathways of movement of water and brine drainage into and through upper Castile brine acquifer (from Anderson, 1982).

pressurized brine encounters which have been tested, display varied chemistry and pressures which suggests that the two encounters are not connected. Finally, the salinity of the Capitan Reef to the east is low indicating that if brines are being discharged into the Reef aquifer, the volume must be very small in comparison to the total volume of flowing water in the Reef.

It appeared in 1982 that the only way to address the question of deep dissolution was to reexamine the geophysical logs in the basin and provide alternate explanations, if any, for the missing salt. At EEG's suggestion, this work was done by Sandia National Laboratories. Lambert (1983) has drawn two isopach maps, one for the composite thickness of Anhydrite I, Halite I, Anhydrite II and Halite II of the Castile formation and another for the composite thickness of the Castile formation and the Salado formation beneath marker bed 136. These isopach maps are included here as Figures 4 and 5. Lambert (1983) has used these maps to argue that the total thickness of Castile anhydrite/halite paired units tend to remain the same throughout much of the Delaware Basin regardless of variations in thicknesses of individual halite or anhydrite beds; the observed variations in the individual beds are thus syndepositional or deformational, not dissolutional. Lambert (1983) finally concludes that there is no preferential removal of any salt horizon in the post-Permian time, aside from the dissolution in the Rustler and upper Salado.

EEG requested Anderson to comment on the Lambert (1983) work and its conclusions. In a report submitted to EEG in April 1983, Anderson (1983, a) claims that "(Lambert's) conclusions related to lower Salado dissolution are almost completely wrong." The main reason for the confusion, according to Anderson, is the lack of understanding of the nature of the boundary between the Castile and Salado formations. If one does not recognize the unconformity between the Castile and the Salado formations and thus ignores the episode of dissolution during the post-Castile/pre-Salado time, one is assuming the lower Salado and upper Castile to be a single unit. When this is done, the lateral thickness changes are compensated and evidence for later salt removal through dissolution disappears. Further, according to Anderson (1983, a), if the truncated relationships at the unconformity are recognized and used to establish a datum, the original facies variation is easily discriminated from later dissolution.

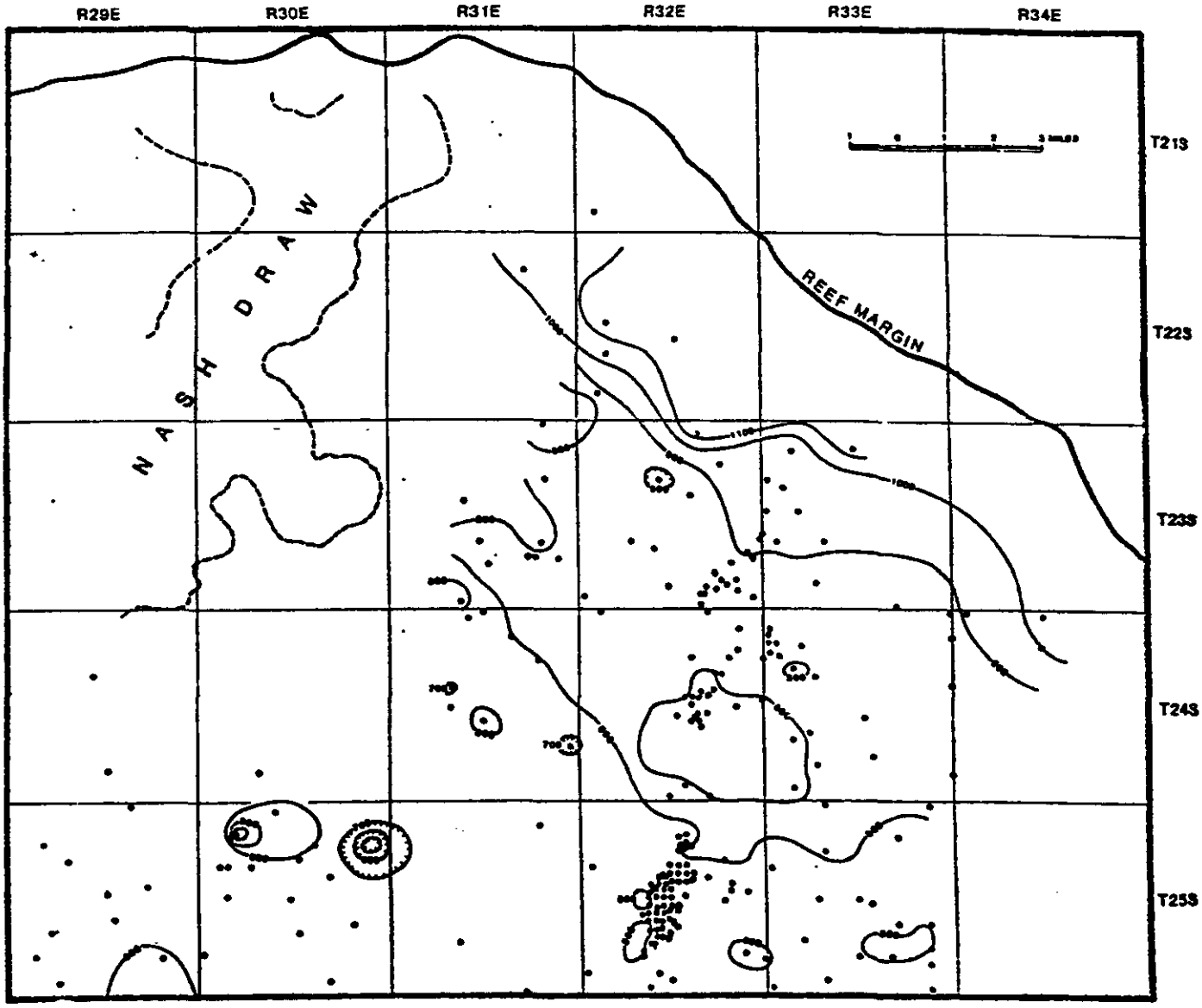

Figure 4. Isopach map of Anhydrite I, Halite I, Anhydrite II, and Halite II in the Castile Formation in the northern Delaware Basin (from Lambert, 1983)

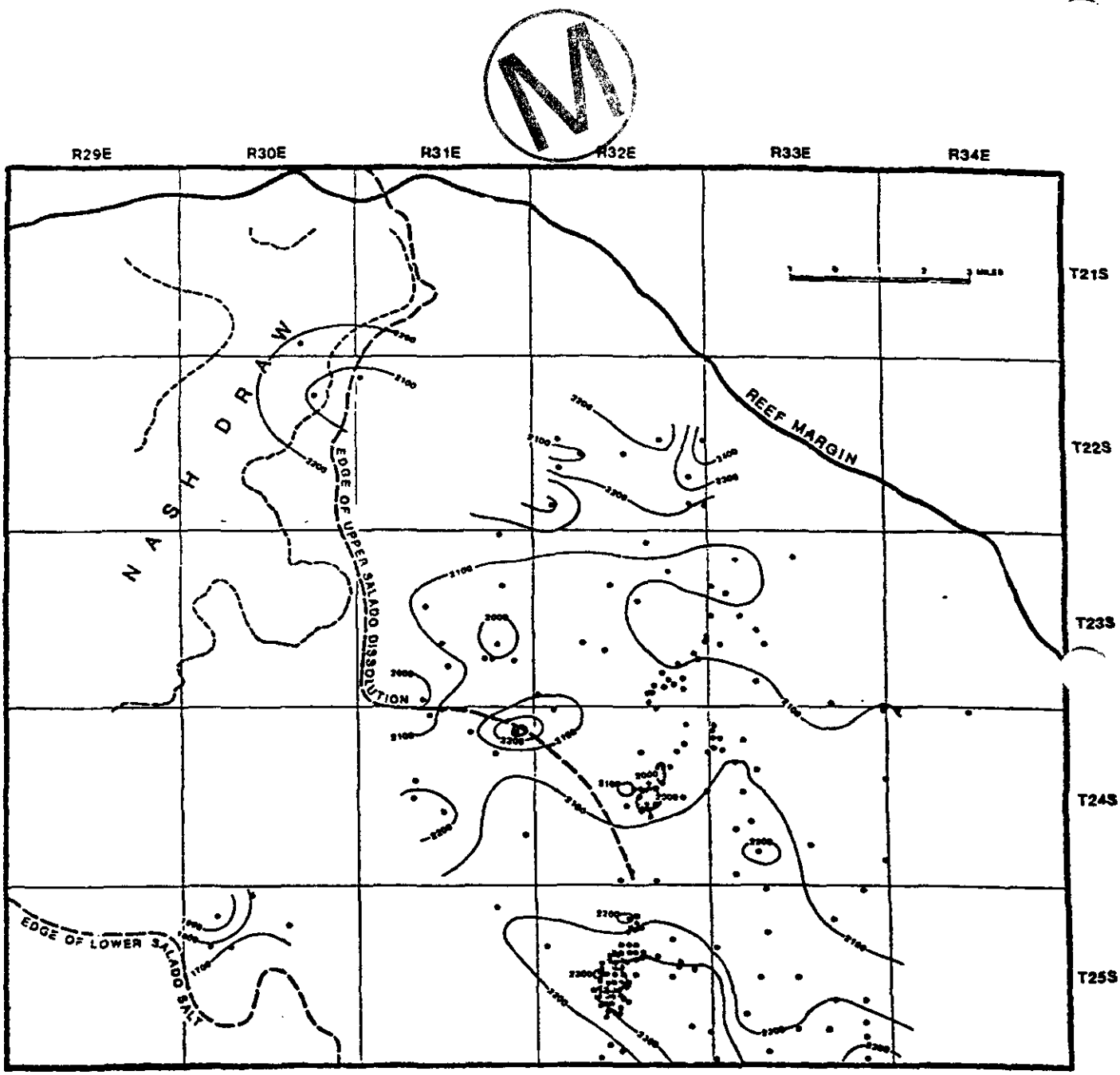

Figure 5. Isopach map of the Castile and lower Salado formation in the northern Delaware Basin (from Lambert, 1983)

In another report, Anderson (1983, b) has used a north-south cross-section in the eastern part of the basin to illustrate a one by one truncation of the salt beds in the upper Castile as one moves to the north. This line of truncation is the unconformity between the Castile and the Salado. Anderson (1983, b) has used this unconformity as an evidence for erosion and dissolution during the post-Castile/pre-Salado time. By using two other cross-sections, Anderson shows his evidence that the missing salt is in lower Salado and that the effects of facies change are separable from the effects of preferential removal of salt. By correlating the area of the bulk of the missing salt with the Malley and Huffington (1953) depressions, Anderson concludes that the dissolution occurred during the Pleistocene time since the fill in the upper part of the depressions is Gatuna, i.e. Pleistocene in age.

3.0 *Conclusions*

Roger Anderson has studied the Ochoan evaporite sequence in the Delaware Basin in great detail over a period of almost 20 years. He has advanced some very compelling evidence that a large amount of salt from the upper Castile and lower Salado units is missing, that the absence of salt follows a pattern which distinguishes it from facies changes within individual units and that the removal of salt is preferential, stratawise. The weakest argument in the Anderson hypothesis is the timing of deep dissolution. Since the assumption of timing of predominant dissolution as late Cenozoic is based on an assumed age of the Malley and Huffington (1953) depressions and the age of the basin uplift and tilting, there is room for different interpretations of the timing of deep dissolution.

On the other hand, the argument against the removal of salt, by assuming that any absence of salt is due to facies change, is not convincing. It is true that there does not seem to be a viable mechanism for preferential removal of salt at depth during geologically recent time or for this to be an active process. However, the lack of understanding of a mechanism should not be a reason to ignore the evidence for a phenomenon. EEG, therefore, accepts the existence of deep-seated dissolution as a strong hypothesis to explain the missing salt at depth.

Figure 1 shows the deep dissolution edges for the salt units, as interpreted by Anderson (1981). It should be noted that the WIPP site is situated in the northern part of the basin, away from the dissolution fronts, in a region where deep dissolution has not yet reached. The nearest point of the dissolution edge from the WIPP site is about 15 miles away. It would seem ironic to worry about the "deep dissolution" front when the front of shallow "blanket dissolution" lies only 2-3 miles west of the site and is known to be moving towards the WIPP site. The reason for this ironic concern is, of course, the lack of understanding of the deep dissolution process. According to Anderson, the basin has reached an advanced stage of dissolution and should, therefore, be rejected for nuclear waste disposal, as a whole. The EEG does not subscribe to this point of view.

There are five boreholes at the WIPP site (WIPP-9, 11, 12, 13 and DOE-1) which have penetrated the lowermost anhydrite bed (Anhydrite-I) in the Castile formation. These holes have been cored at selected intervals and geophysical logs for the entire depths have been obtained. In addition three holes outside the WIPP boundary, AEC-7 and 8 to the northeast and ERDA-10 to the southwest were drilled, cored and logged through the Castile formation. None of these seven boreholes (Fig. 6), not to mention several industry boreholes around the WIPP site, show any evidence of extensive dissolution. This points to the fact that at least the immediate area surrounding the WIPP site has not been affected by deep dissolution and is not expected to be affected in the immediate geologic future.

Anderson (1983) has pointed out two features, one on and the other near the WIPP site, which may indicate the possibility of point source dissolution. One of these is the encounter of the lower Salado marker beds e.g. MB 124, 75 feet below their expected level in an industry potash hole (F-92) 2 miles north of the center of the site. According to Davies (1983), this anomaly extends to the well WIPP-34. WIPP-14 was drilled to explore this area but was located 0.6 mile to the east of F-92 on the basis of a marked low in the gravity data which coincided with a seismic anomaly as well as a topographic low. WIPP-14 found the beds in Rustler and upper Salado essentially at the expected depths and did not find any evidence of brecciation or dissolution. However, it was drilled only 50 feet into the Salado and did not encounter any marker beds in the Salado. The other feature is five miles southeast of the center of the WIPP site. The acoustic log of

the Perry Federal # 1-31 well in that area (Sec. 31, T225, R32E) shows, according to Anderson, that 200 feet of infracowden salt is missing.

In EEG's view, a single hole anomaly out of hundreds of wells drilled through the Salado horizon in the northern Delaware Basin, especially when it is *outside the WIPP repository area, may not be very significant. The safety of* the WIPP site from deep dissolution can be assured on the basis of the deep dissolution fronts (Fig. 1) being a safe distance away from WIPP and on the results of excavations at the repository horizon already completed under the SPDV program. The 9000 ft. of drifts already completed include a one-mile north-south drift (12 feet high and 25 ft. wide), another north-south drift (1840 ft. long, 8 ft. high and 25 ft. wide), six east-west drifts (each 140 ft. lo: ;, 8 ft. high and 25 ft. wide) and four rooms (each 13 ft. high, 33 ft. wide and 300 ft. long). The thickness and continuity of strata displayed in all this excavation is dramatically uniform, and there is no evidence for dissolution at the repository horizon as seen in SPDV excavations.

The only remaining anomaly within the WIPP site is the depression of lower Salado marker beds in the well F-92. Anderson (1983) and Davies (1983) propose that this feature may have resulted from point source dissolution at depth.

4.0 Recommendations

The Department of Energy should evaluate the depression exhibited by the stucture contours on lower Salado marker beds, centered two miles north of the center of the site and should first attempt to provide a reasonable explanation for this feature. If the possibility of lower Salado dissolution causing this feature cannot be eliminated, then a drill hole should be drilled through the entire Salado and selected horizons cored to investigate the cause for this anomaly. *The feature appears to be confined to F-92 and WIPP-34 area* and WIPP-14 is outside of it. Therefore, a deepening of WIPP-14 will not answer the question.

R. Y. Anderson made four other recommendations at the May 12 and 13 meeting in Carlsbad, viz., core Slick Sink, core one of the Maley and Huffington depression, core a deep dissolution margin and investigate the regional hydrology of deep dissolution. EEG has examined these suggestions carefully

and has determined that in view of our acceptance of the possibility of deep dissolution in the Basin, away from the WIPP site, it is not necessary to further prove or disprove the hypothesis. Only the feature, close to the repository, which may indicate a point source deep dissolution, should be investigated.

5.0 References Cited

Anderson, R. Y., Dean, W. E., Jr., Kirkland, D. W. and Snider, H. I., 1972, Permian Castile varved evaporite sequence, west Texas and New Mexico, Geological Society of America Bulletin, v. 83, p. 59-86.

Anderson, R. Y., 1978, Deep dissolution of salt, northern Delaware Basin, New Mexico, Report to Sandia Laboratories, Albuquerque, New Mexico, 106 p.

Anderson, R. Y. and Kirkland, D. W., 1980, Dissolution of salt deposits by brine density flow, Geology, v. 8, p. 66-69.

Anderson, R. Y., 1981, Deep-seated salt dissolution in the Delaware Basin, Texas and New Mexico, N.M. Geol. Soc., Spec. Publ. no. 18, pp. 133-145

Anderson, R. Y., 1982, Upper Castile brine aquifer, Northern Delaware Basin, N.M., Unpublished manuscript, 11 p.

Anderson, R. Y., 1983 a, Review comments related to dissolution of evaporites in the Delaware Basin, Prepared for E.E.G., 13 p.

Anderson, R. Y., 1983 b, Evidence for deep dissolution in the Delaware Basin, Prepared for E. E. G., 7 p. + illustrations.

Bachman, G. O., and R. B. Johnson, 1973, Stability of salt in the Permian salt basin of Kansas, Oklahoma, Texas, and New Mexico (with a section on "Dissolved Salts in Surface Water" by F. A. Swenson), USGS Open-File Rpt 4339-4.

Bachman, G. O., 1974, Geologic processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U.S. Geological Survey Open-File Report 74-194, 81 p.

Bachman, G. O., 1980, Regional geology and Cenozoic history of Pecos region, southeastern New Mexico, U.S. Geological Survey Open-File Report 80-1099, 116 p.

Bachman, G. O., 1981, Geology of Nash Draw, Eddy County, New Mexico, USGS Open-File Rpt 81-31

Davies, Peter, 1983, Presentation at the EEG Carlsbad Meeting, May 12, 1983.

Environmental Evaluation Group, 1983, EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement, EEG-22, 268 p.

Hiss, W. L., 1975, Stratigraphy and ground-water hydrology of the Capitan aquifer, southeastern New Mexico and western Texas, University of Colorado, Boulder, unpublished Ph.D. dissertation, 396 p.

Lambert, S. J., 1983, Dissolution of Evaporites in and Around the Delaware Basin, Southeastern N. M. and West Texas, SAND 82-0461.

Maley, V. C. and Huffington, R. M., 1953, Cenozoic fill and evaporite solution in Delaware Basin, Texas and New Mexico, Geological Society of America Bulletin, v. 64, p. 539-546.

Snyder, R. P., 1983, General site geology, Chap. 2 in Deformation of evaporite near the WIPP site, by Borns, D. T., et al., SAND 82-1069 (Draft).

Wood, B. J., R. E. Snow, D. J. Cosler, and S. Haji-Djufari, 1982, Delaware Mountain Group (DMG) Hydrology - Salt Removal Potential, TME-3166.

BRECCIA PIPES

1.0 Definition

Breccia pipes are vertical chimneys of brecciated rock which extend through several layers of intact rock strata to root in a collapsed cavity. These features are found in many evaporite basins of the world. The diameter of a breccia pipe is generally less than 1000 feet.

2.0 Confirmed Breccia Pipes

Vine (1960) identified several domal structures in the Delaware Basin which have been explored during the investigations for WIPP, as possible breccia pipes. After extensive investigation, the existence of only two pipes (Hills A and C) has been confirmed. Geophysical and geological studies show that two others (Hills B and Wills-Weaver) are also most likely breccia pipes, although they have not been cored. All four of these features appear to be situated over the Capitan Reef limestone, which is a prolific aquifer in the area. These four features as well as other features, previously suspected to be breccia pipes in the Basin, are shown in Fig. 6. Davies (1983) has pointed out that the Hill 'C' breccia pipe is located at the southern edge of the buried Capitan Reef and since the borehole (WIPP-16), drilled to explore this pipe, was drilled only to the level of the McNutt Potash Zone of the Salado formation, it is not clear whether the Hill 'C' breccia pipe roots in the Capitan aquifer. This is a valid argument, but although it is true that the borehole WIPP-16 was not drilled deep enough to answer this question unequivocally, the feature being at the edge of the reef is sufficient cause to believe that the Capitan Reef aquifer is responsible in the creation of this feature.

3.0 Suspected Breccia Pipes

Besides boreholes WIPP-31 and WIPP-16 which were drilled at hills A and C respectively to investigate the breccia pipes, three other boreholes were drilled at suspected breccia pipe locations in the Basin. Borehole

WIPP-32, 12 miles west of the center of the WIPP site, was drilled in a small topographic high which had been described by Vine (1963) as a domal karst feature. These features (domal karst) have been extensively studied by Bachman (1982). The boreholes WIPP-13 and WIPP-33 were also drilled to explore the presence of possible breccia pipes. There was a marked electrical resistivity anomaly at WIPP-13 and a prominent topographic depression exists at the location where WIPP-33 was drilled. Collapsed breccia was not found at either of the wells.

Anderson and Kirkland (1980) have described the occurrence of collapse breccia in a borehole in Culberson County, Texas, about 55 miles south of the WIPP site (see Fig. 6). Anderson (in Chaturvedi, 1980) has described occurrences of "Castiles" which are mounds of brecciated rock that outcrop a few miles south of the New Mexico-Texas border, south of the WIPP site. Both these occurrences are in the exhumed western part of the Delaware Basin which has already undergone extensive dissolution. These are not "active" features.

4.0 Mechanics and Time of Formation

Snyder and Gard (1982) have studied the known occurrences of breccia pipes. The one studied in most detail is the Hill 'C' breccia pipe which is also encountered at the McNutt Potash Zone of the Salado formation in the Mississippi Chemical Company potash mine, 1200 feet below the surface. From the study of this exposure, the core of WIPP-16 drilled in this pipe and the core of WIPP-31 drilled in the Hill 'A' breccia pipe, Snyder and Gard (1982) have concluded that the breccia pipes are formed due to the collapse of overlying rocks in solution cavities in the Capitan Reef aquifer. This appears to be a reasonable explanation. Bachman (1980) has hypothesized that the location of all the known breccia pipes in a small area over the reef is due to the presence of an old submarine canyon in the reef in this area. On the basis of the presence of Mescalero Caliche over the breccia pipes, Bachman (1980) also concluded that the collapse occurred prior to the deposition of this caliche layer, i.e., more than 500,000 years ago.

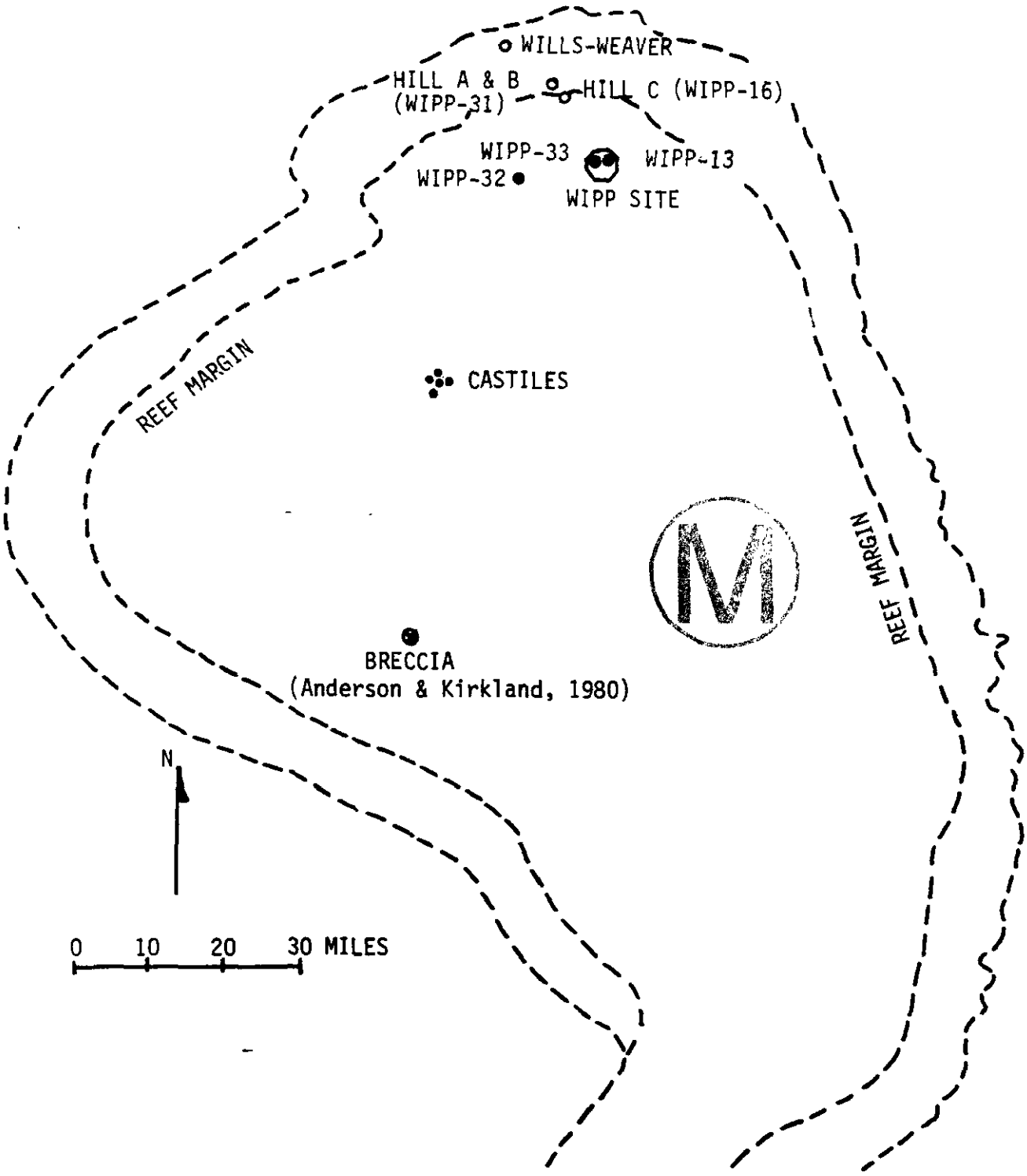

Figure 6. Map of the Delaware Basin showing features related to the Breccia Pipe issue.

5.0 EEG Conclusions

After considering all the available evidence on this question, EEG has concluded that the breccia pipes, by themselves, do not pose a threat to the WIPP repository. This conclusion is based on the following observations.

After extensive investigation in the Delaware Basin area, the existence of only two pipes (Hills A and C) has been confirmed. Geophysical and geological studies show that two others (Hill B and Wills-Weaver) are also most likely breccia pipes, although they have not been cored. All these pipes are located over the Capitan Reef limestone, which is a prolific aquifer in the area. The exhumed breccia pipes in the basin, e.g. the Castiles, are not actively developing.

Extensive potash mining operations in the Delaware Basin have encountered only one breccia pipe (Hill C) in the subsurface, and it also is most likely located over the Reef; although due to the lack of sufficient borehole control around Hill C, its location over the reef is not confirmed.

Several features in the Delaware Basin (Vine's Domes--Vine, 1960) are clearly the result of either near-surface dissolution or surficial erosion (Karst domes or mounds--Bachman, 1980).

Three holes (WIPP-13 and 32 and 33) were specifically drilled to explore suspected breccia pipes in the basin but did not encounter brecciated strata in the subsurface.

The explanation (Bachman, 1980) that the known breccia pipes were formed in the area near an old submarine canyon in the Capitan Reef, about 500,000 years ago, seems to be a reasonable explanation for the formation of breccia pipes.

- EEG has calculated the effect of a hypothetical breccia pipe developing under the repository and has concluded that the radiological impact of such a feature returning radioactive materials to the biosphere would be insignificant (Spiegler, 1982).

The question of breccia pipe formation representing deep dissolution through brine density flow (Anderson and Kirkland, 1980) is discussed in the section on Deep Dissolution.

6.0 References Cited

Anderson, R. Y. and Kirkland, D. W., 1980, Dissolution of salt deposits by brine density flow, Geology, v. 8, no. 2, p. 66-69.

Bachman, G. O., 1980, Regional geology and Cenozoic history of Pecos region, Southeastern N.M., U.S. Geological Survey Open-File Report 80-1099, 116 p., 20 figs.

Chaturvedi, L., 1980, WIPP Site and vicinity geological field trip, EEG-7, 148 p.

Davies, P. B., 1983, A review of the USGS Open File Report 82-968, "Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the WIPP Site" by R. P. Snyder and L. M. Gard, Jr., prepared for EEG, 7 p.

Environmental Evaluation Group, 1980, Geotechnical considerations for radiological hazard assessment of WIPP, EEG-6, 69 p.

Spiegler, P., 1982, Analysis of the potential formation of a breccia chimney beneath the WIPP repository, EEG-13, 25 p.

Snyder, R. P. and L. M. Gard, Jr., 1982, Evaluation of breccia pipes in Southeastern New Mexico and their relation to the WIPP site, U.S. Geological Survey Open-File Report 82-968, 73 p.

Vine, J. D., 1960, Recent domal structures in Southeastern New Mexico, American Assoc. of Petro. Geologists, Bull, v. 44, no. 12, pp. 190

BRINE RESERVOIRS

1.0 Introduction

Within a few miles of the WIPP site there have been thirteen reported brine encounters during drilling in the upper anhydrite layer of the Castile Formation with sufficient pressure to produce significant flow at the land surface (Figures 7 and 8). Additionally, Snyder (1983) documents brine occurrences in the upper anhydrite layer of the Castile formation without sufficient pressure to produce a significant surface brine flow. These nonflowing artesian brines (labeled as sub-artesian on Figure 7) are generally concentrated along and west of the Pecos River; however, a few scattered occurrences are reported east of the Pecos River. The flowing artesian brines are of most concern and will be discussed in detail.

During the characterization of the WIPP site, two wells encountered pressurized artesian brine which flowed to the surface at test holes ERDA-6 and WIPP-12 (Figure 8). At EEG's insistence, DOE has tested both encounters to obtain hydrological and geochemical data (D'Appolonia, 1982). Both DOE and EEG have independently analyzed these data. DOE has reported its findings in Popielak, et al. (1983) while EEG has reported its findings in Spiegler (1982), Spiegler (1983) and Faith et al. (1983). Although the studies of these two encounters undoubtedly have improved the scientific understanding of such phenomenon, conclusions drawn from the ERDA-6 and WIPP-12 testing are applicable to only those two encounters.

2.0 Occurrence

From Figure 7, it appears that the brine encounters in boreholes do not occur randomly. Two large groups of encounters are observed northeast and east of the WIPP site. The location of these two groups appears to indicate a relationship between the pressurized brines and the Capitan Reef. The WIPP-12, Belco, and Danford encounters are isolated and away from the Reef. Although non-random, the occurrences do not follow a consistent pattern.

In each borehole that encountered pressurized brine, the brine was located in the upper anhydrite of the Castile Formation, generally anhydrite III. The

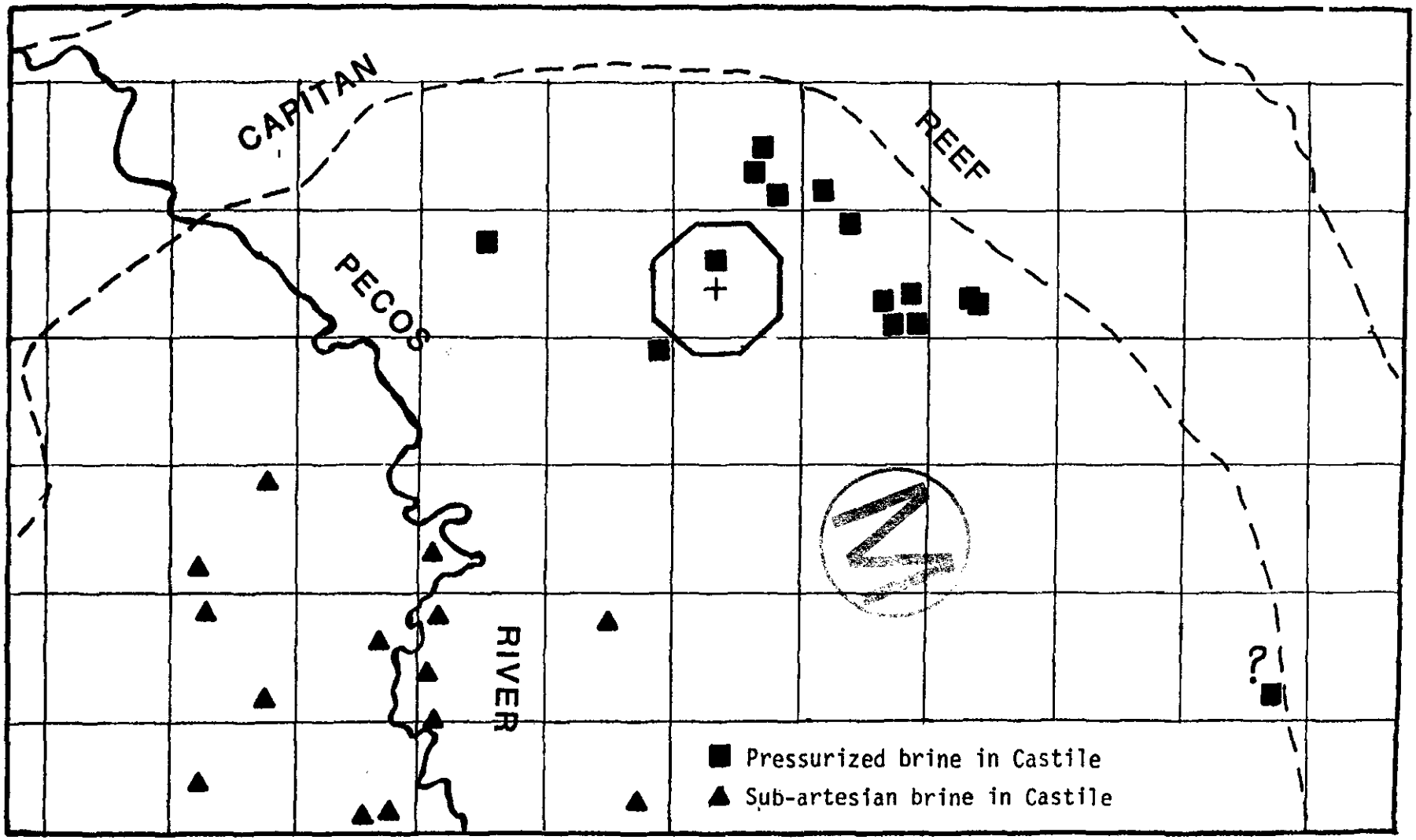
CAPITAN
REEF
PECOS
RIVER
?
Pressurized brine in Castile
Sub-artesian brine in Castile

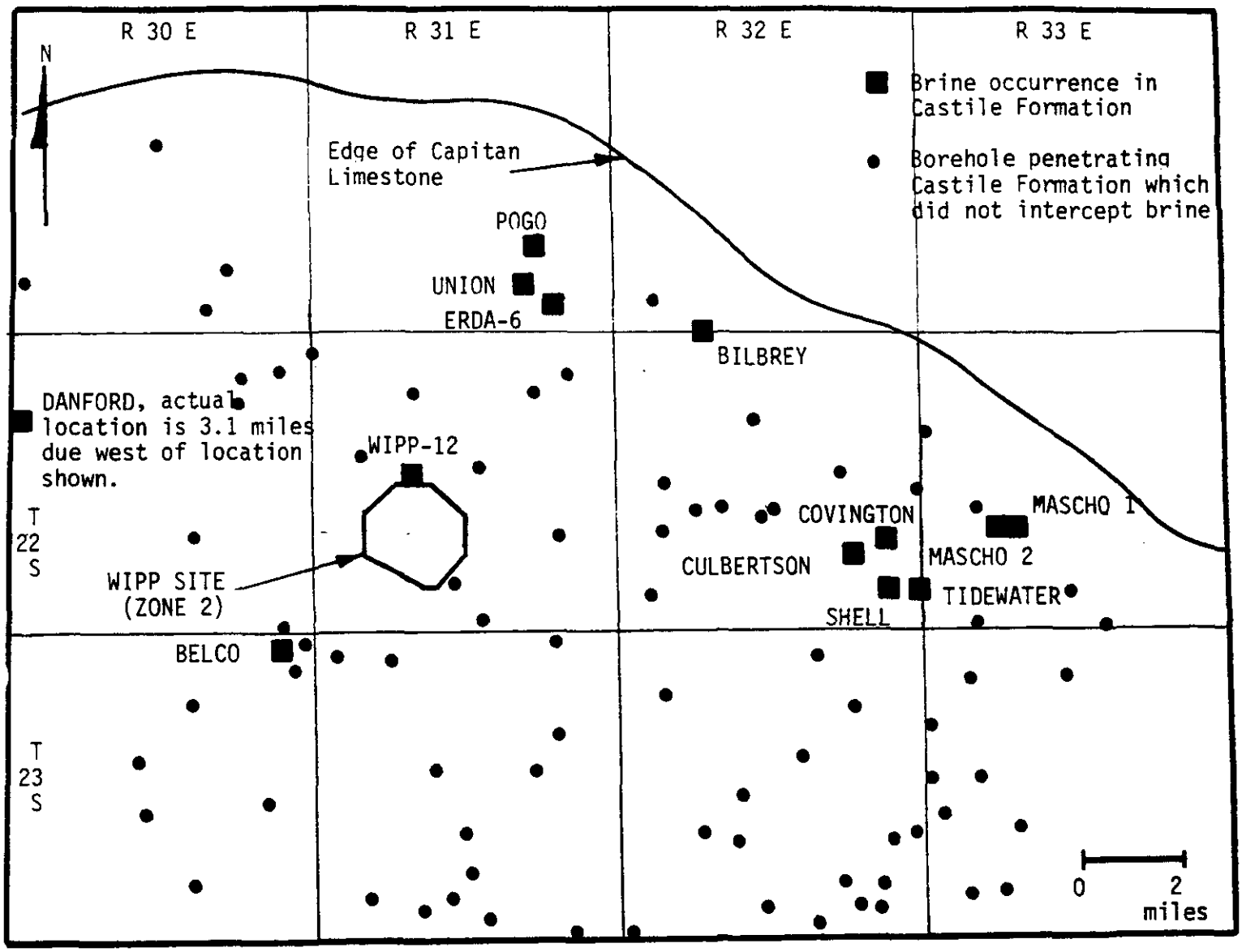

Figure 8. Location of brine encounters and deep boreholes penetrating the Castile Formation. Figure obtained from reference 1.

occurrence appears to be associated with structural features in the Castile. However, every drill hole into a structure has not encountered brine. The general consensus is that the brines occur within the fractured upper Castile anhydrite in areas of structural deformation.

3.0 Hydraulics

Extensive drill stem and flow testing of both ERDA-6 and WIPP-12 have yielded data on the permeability of the two reservoirs. In both wells heterogeneity of permeability was observed. Short tests produced high flows of brine and associated high permeabilities. The longer flow tests were characterized by smaller flows and smaller permeabilities.

The representative calculated permeabilities (Popielak et al, 1983; Spiegler, 1982) for the short and long tests in ERDA-6 and WIPP-12 are listed below.

	Long tests	Short tests
ERDA-6	1 - 3 md	10 - 13 md
WIPP-12	6 - 17 md	2000 - 5000 md

In each well, the brine was produced from fractures. Therefore, the calculated permeabilities based on porous media radial flow theory are rough approximations. In addition, the permeabilities were calculated from the permeability - thickness product, where the thickness was not the length of a fracture encountered, but rather the interval isolated by the packers. Although approximate, the data clearly indicate the greater permeability associated with the WIPP-12 encounter.

The hydraulic testing showed that the high initial flows from the two tested reservoirs are sustained for only a short time.

The wellhead pressures on March 19, 1983, at ERDA-6 and WIPP-12 were 552 and 162 psig, respectively. These pressures correspond to a column of brine extending above the wellhead for 1047 ft. and 307 ft., for ERDA-6 and WIPP-12, respectively.

4.0 Size

DOE (Popielak, et al., 1983) estimates the representative volumes of the ERDA-6 and WIPP-12 brines as 630,000 bbl and 17 x 10^6 bbl, respectively. Based on preliminary data EEG estimated the volumes to be between 60,000 bbl and 120,000 bbl for ERDA-6 and between 5 x 10^6 bbl and 10 x 10^6 bbl for WIPP-12 (Spiegler, 1982). Using the most recent data provided by DOE, EEG calculates the ERDA-6 brine volume to be between 170,000 bbl and 340,000 bbl. The WIPP-12 volume remains unchanged.

The volume is calculated by

$$V = \frac{\Delta V}{\Delta P \; C_t} = \frac{\Delta V}{\Delta P \; (\phi K)^{-1}}$$

where ΔV = volume of fluid discharged

ΔP = reservoir pressure depletion

C_t = total system compressibility which in most situations can be approximated by the pore-volume compressibility

$(\phi K)^{-1}$ = inverse porosity-rock bulk modulus product; used by DOE to calculate the pore-volume compressibility

The smaller EEG estimate for the ERDA-6 volume is due to the assumption of a larger compressibility. Compressibility will be discussed later. The smaller EEG estimate of the WIPP-12 volume is due to EEG's utilization of a subset of the WIPP-12 data and a larger compressibility. The volume discharged and pressure depletion used by EEG were those as of January, 1982 whereas DOE uses the data through March, 1983. Since the WIPP-12 brine encounter is closer to the site, larger in volume, and has a larger permeability than the ERDA-6 encounter, subsequent discussion will concentrate on WIPP-12.

The compressibilities used by both EEG and DOE are largely crude estimates. Figure 9 depicts the variation in DOE's calculated reservoir volume as a function of porosity (ϕ) and rock bulk modulus (K), where $C_t \approx (\phi K)^{-1}$. The representative volume presented by DOE falls near the center of the regions.

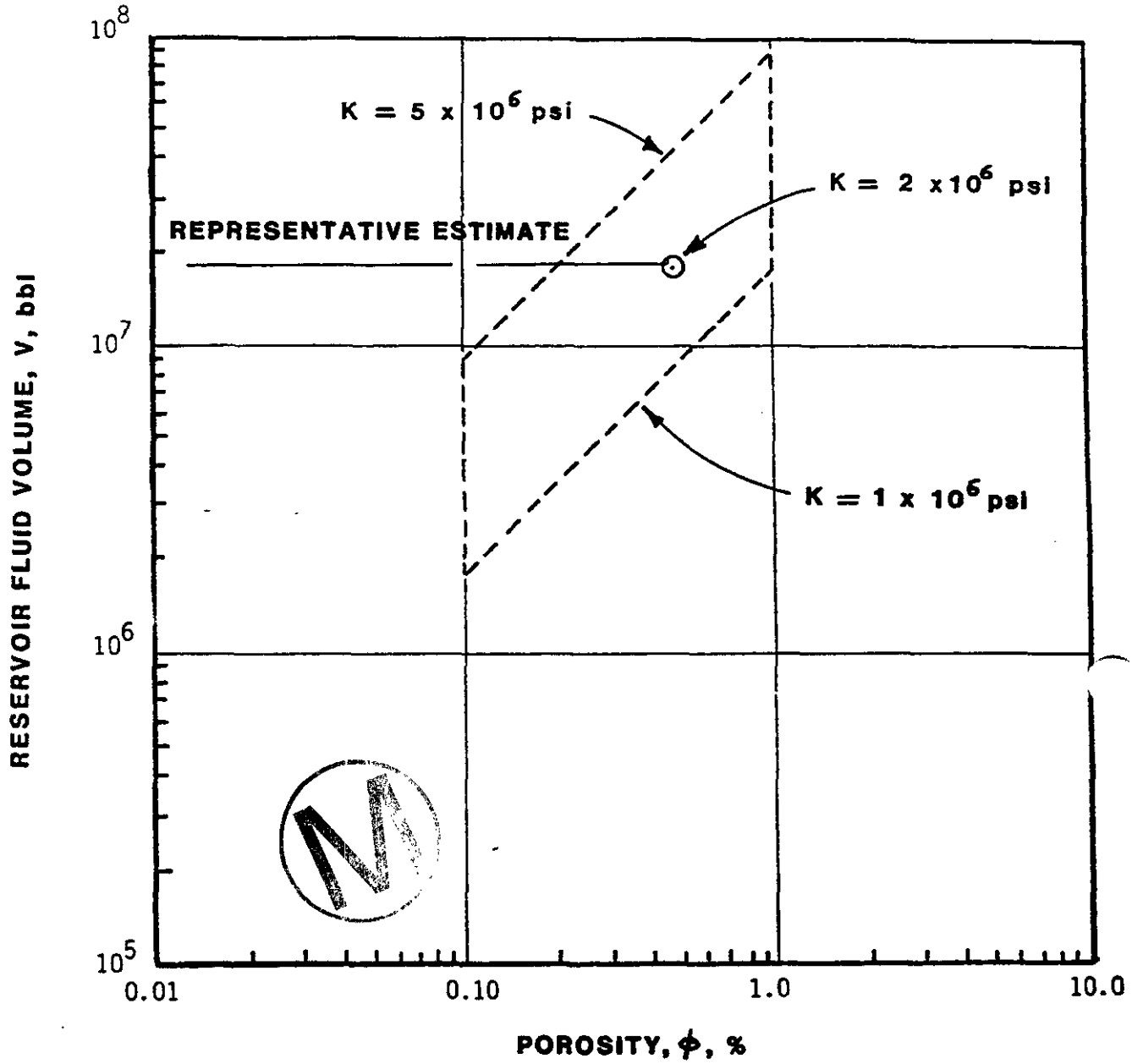

Figure 9. Total reservoir fluid volume WIPP-12
(from Popielak et al., 1983)

EEG has adopted the larger DOE estimates as reasonable, recognizing the approximate nature of the volume estimates.

Given an estimate of the brine volume, albeit a rough one, the next logical step is to estimate an area over which the brine is contained. The area is obtained from Popielak, et al. (1983), as,

$$A = \frac{V}{H\phi} = \frac{\Delta V \phi K}{\Delta P H \phi}$$

where A = area

V = volume of brine

H = thickness of anhydrite that contains brine

ϕ = porosity

It is interesting to note that because the total compressibility (C_t) is calculated as the porosity - rock bulk modulus product, the calculated area is independent of porosity. The only variable in the area calculation is the thickness of anhydrite that contains brine. The area of the WIPP-12 brine as a function of thickness and rock bulk modulus is presented in Figures 10.

Figure 11 is a map of the WIPP site showing the area of the WIPP-12 brine assuming the bulk modulus $K = 2 \times 10^6$ psi for various reservoir thicknesses. Also included on Figure 11 is the seismic time structure on the middle of the Castile. The calculated areas for WIPP-12 all extend well beyond the limits of the apparent domal structure.

In summary it is apparent that any volume or areal extent estimate for the brine encounters is of limited accuracy. However, these estimates indicate that the WIPP-12 brine could extend beneath the repository.

5.0 Geochemical Data

Extensive chemical analyses (D'Appolonia, 1982) have produced a wealth of data. In addition to major and minor element chemical determinations, trace and isotopic chemical analyses were performed.

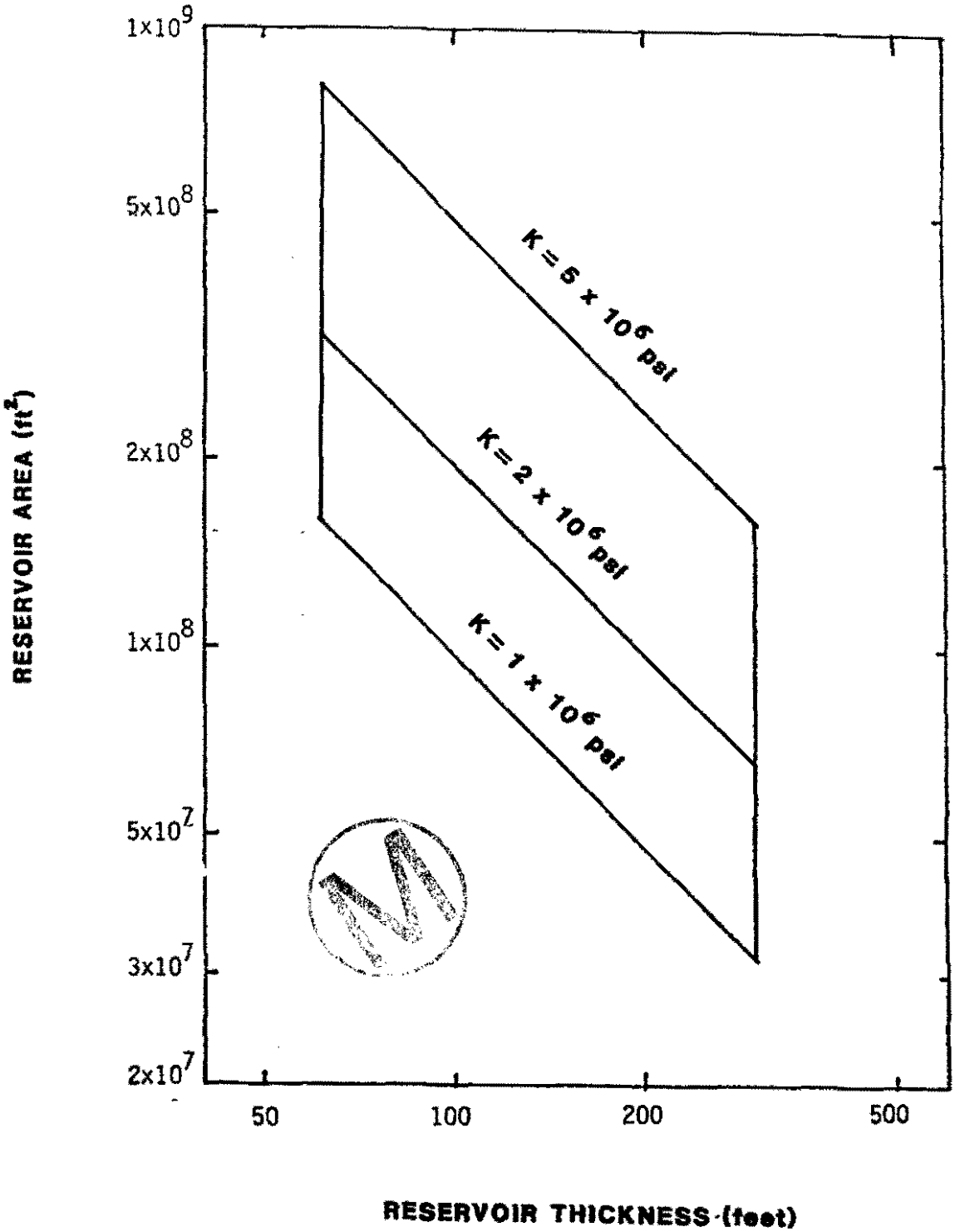

Figure 10. Reservoir area for the WIPP-12 brine as a function of reservoir thickness and rock bulk modulus.

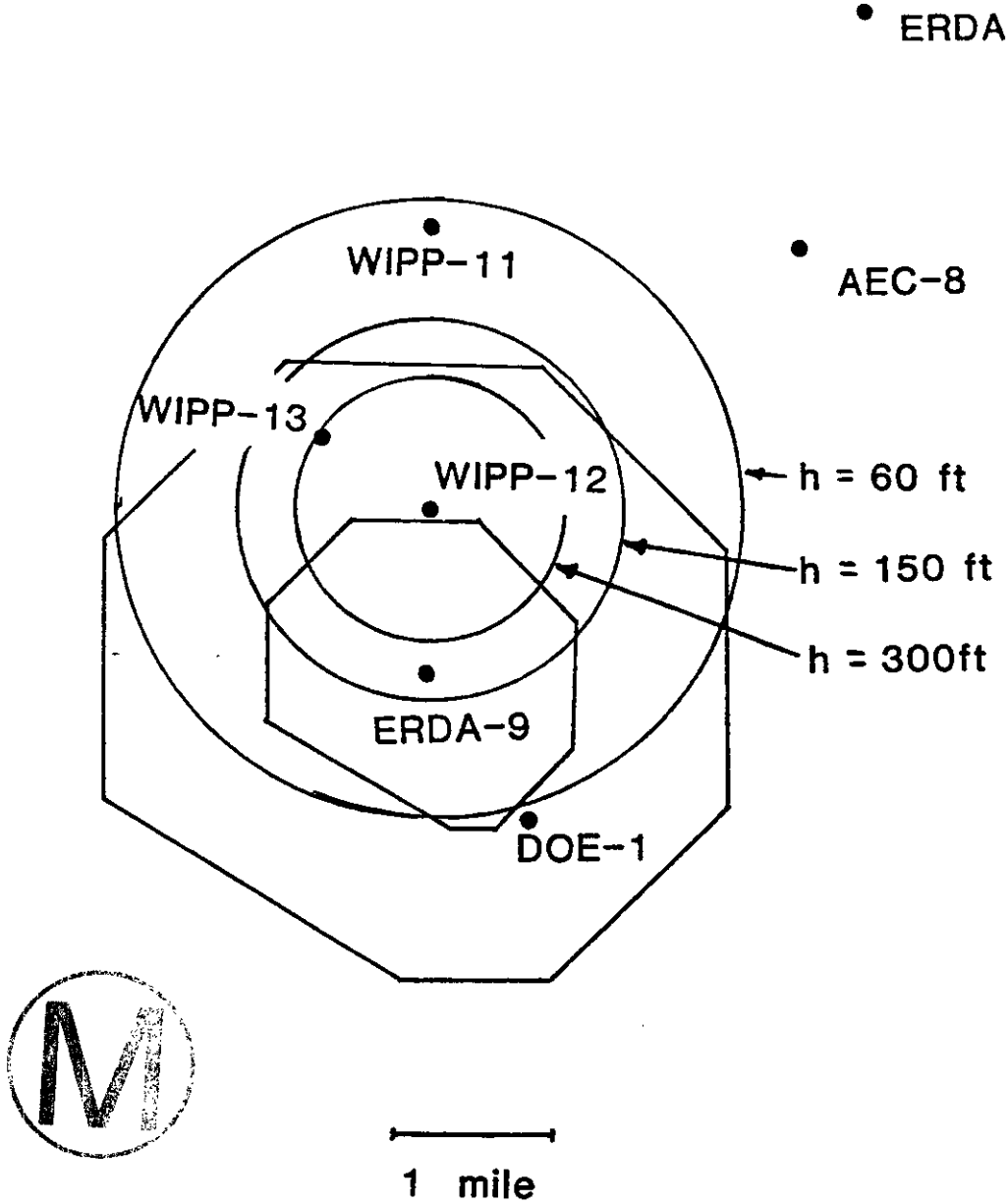

Figure 11. Aereal extent of the brines assuming a circle centered at the borehole for various reservoir thicknesses, K = $2x10^6$ psi.

Interpretation of the major and minor element chemical data by EEG (Faith, et al., 1983) has led to the following conclusions.

- Small, yet statistically significant differences in the chemistry of the ERDA-6 and WIPP-12 brines are evident.

- Within the accuracy of thermodynamic equilibrium modeling, the ERDA-6 and WIPP-12 brines are saturated with calcite, anhydrite, glauberite and dolomite. The ERDA-6 brine is slightly undersaturated with halite and the WIPP-12 brine is nearly saturated with halite. The potential for dissolving additional halite or anhydrite is considered to be minimal.

- The relationship between the bromide content and the total dissolved solids in the brines indicates the brines are attributable to seawater evaporation and additional halite dissolution. The source of water for the halite dissolution is unclear.

The ERDA-6 and WIPP-12 brines appear to be nearly saturated with halite, therefore, the need to determine the original mechanism of halite dissolution may be of academic interest only. Suggested mechanisms for additional halite dissolution include: (1) dehydration of gypsum at depth, (2) introduction of meteorically derived water during Permian exposure, (3) mixing of groundwater from the underlying Bell Canyon aquifer with subsequent isolation by recrystallization or healing of fracture pathways, and (4) combinations of the above.

Interpretation of the isotopic data by EEG (Spiegler and Updegraff, 1983; Faith, et al., 1983) suggests the following conclusions:

- Many of the stable isotope fractionations indicate equilibrium. However, the calcite water fractionation, which does not indicate equilibrium, suggests that the water was not enriched in 18-oxygen by exchange with carbonates of the Castile formation. The fractionation of carbon between dolomite and calcite for WIPP-12 suggests that the dolomite and calcite are not cogenetic in the sense of having been precipitated from the same solution under the same conditions.

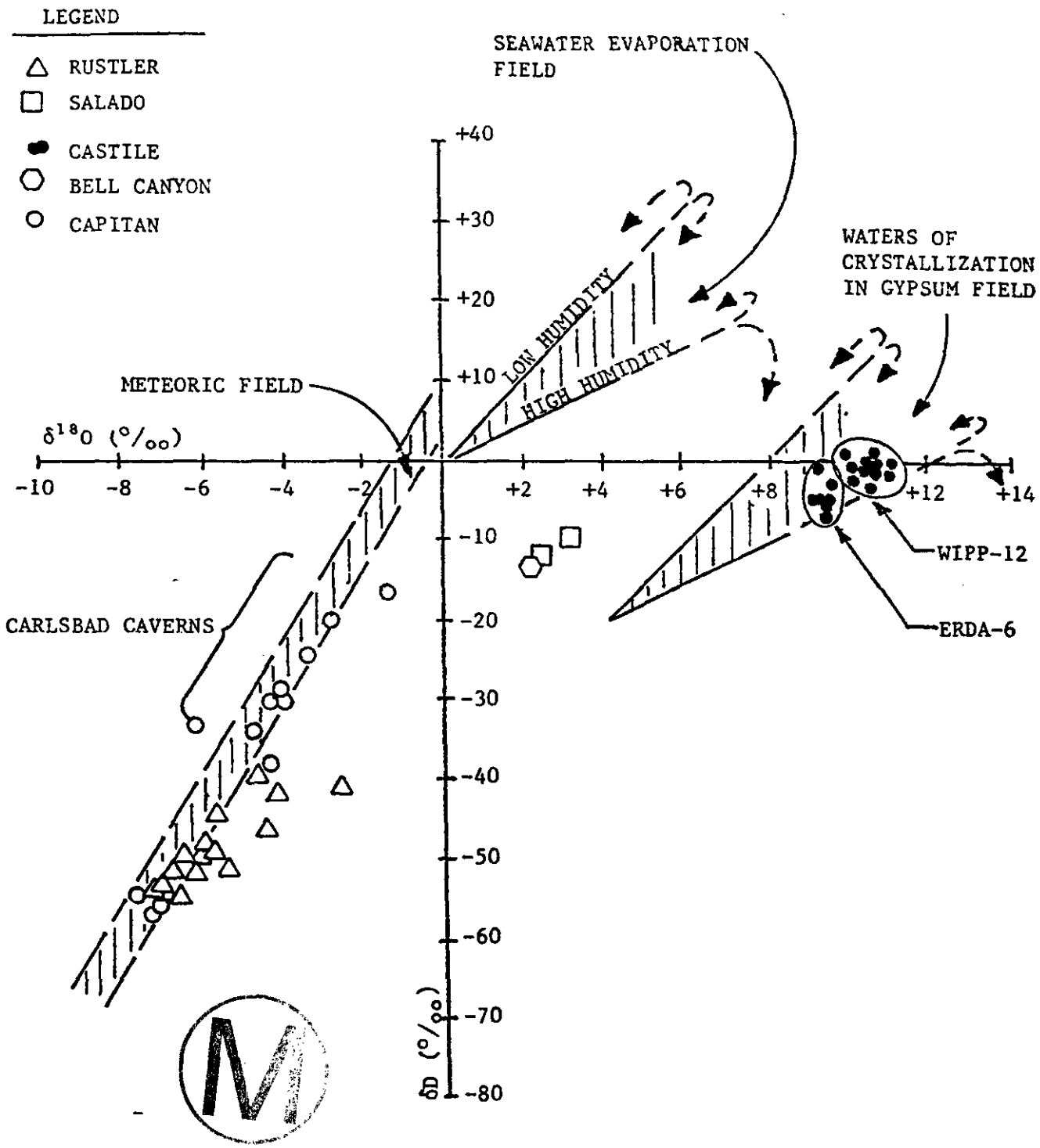

Figure 12. Isotopic compositions of the water/brine from the Delaware Basin (Spiegler and Updegraff, 1983)

- The oxygen-18 and deuterium concentration of the brines is unique compared to water in other nearby aquifers (Figure 12). A variety of source waters and isotope alteration pathways were considered. The hypotheses that the brines could have originated from waters of the Bell Canyon Formation or Capitan Reef in recent geologic time did not seem plausible. The ERDA-6 and WIPP-12 brines were probably derived from ancient ocean waters that have been isotopically enriched in oxygen-18 by exchange interaction with rock. The dehydration of gypsum as a process of brine origin cannot be ruled out.

- Analyses of uranium disequilibrium data yield only general conclusions. The ^{234}U in the ERDA-6 and WIPP-12 brines is not in secular equilibrium with ^{238}U. The disequilibrium probably results from the preferential leaching of ^{234}U from fractures in anhydrite. This leaching may be an ongoing process. Neither the true age of the brine, nor the age of fracturing is determinable with any degree of confidence.

6.0 Interconnection of Brine Occurrences

Based on the following evidence, the WIPP-12 and ERDA-6 brine occurrences are not likely to be connected to each other.

- The pressure potentials of the two encounters are significantly different. However, this in itself does not constitute proof of separation as pressure potential differences within reservoirs is an indication of fluid movement.

- The calculated areas, albeit approximate, for WIPP-12 and ERDA-6 do not overlap.

- The geochemical data suggest a lack of communication between the ERDA-6 and WIPP-12 reservoirs.

The lack of communication between the ERDA-6 and WIPP-12 brines does not imply that all brine encounters represent isolated brine pockets.

7.0 Origin of Brine

The tests performed on the brines of ERDA-6 and WIPP-12, which include hydrological tests, major and minor element chemistry analyses, isotope geochemical analyses, uranium disequilibrium measurements, and helium concentration in gases of brines, have yielded data which allow a discussion of the following possibilities of the origin.

Ancient seawater. Major and minor element geochemical data and stable isotope data favor this hypothesis.

Delaware Mountain Group aquifer water. Not likely because of geochemical and stable isotope data.

Capitan Reef water. Still implicated when estimating the age of brines using uranium disequilibrium data. Also implicated by proximity to a majority of brine encounters. Less likely based on geochemical and stable isotope data.

Water from dehydration of gypsum to anhydrite. Stable isotope composition of water in brines favors this hypothesis.

Meteoric water. Not likely because of geochemical and stable isotope data.

7.1 Age of Brine

There is no consensus on estimates of the age of the brine. The major and minor element chemistry data and the stable isotope data indicate ancient seawater. This hypothesis indicates that the water has been separated from the biosphere for tens of millions of years. The uranium disequilibrium age dating is very speculative since it requires numerous assumptions. With a range of parameters and initial conditions, The calculated brine "age" range from a negative age to 2 million years (Faith, et al, 1983).

8.0 Brine Reservoirs as a Threat to the Proposed Repository

The southern part of Zone II of the WIPP site appears to be more geologically predictable based on seismic and core hole data than the disturbed zone to the north. As no structure other than the WIPP-12 anticline is seen in the seismic profiles in zone II, the probability of the presence of brine in the southern part of Zone II appears to be low. Estimates of the area of brine include the zone beneath the proposed repository. Because there is no currently available method to prove a brine reservoir does not exist beneath the repository, other than by drilling boreholes into the Castile formation, EEG has taken the position of assuming a brine reservoir does exist beneath the repository and quantifying the consequences (Bard, 1982; Channell, 1982).

Human intrusion scenarios are believed to be the limiting cases because no plausible natural causes that will allow brine to bring wastes to the biosphere are envisioned. From its scenario analyses, EEG concludes that plausible radiation doses to the public (Bard, 1982; Channell, 1982) are below the limits that Protective Action Guides recommends for low probability accidents. DOE (Woolfolk, 1982) has reached similar conclusions.

9.0 Recommendations

In order to achieve more confidence and understanding of the subsurface below the repository, at least from an operational viewpoint, EEG recommends further evaluation and testing of the geophysical methods such as controlled source audio Magneto-Telluric (CSAMT) for the detection of brine in Zone II.

10.0 References cited

Bard, S. T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon - A Single Hole Scenario, Report EEG-15, February 1982.

Borns, D. J., Barrows, L. J., Powers, D. W., and Snyder, R. P., Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site, Report SAND 82-1069, March 1983.

Channell, J. K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, Report EEG-11, January 1982.

D'Appolonia Consulting Engineers, Inc., Data File Report. ERDA-6 and WIPP-12 Testing. Waste Isolation Pilot Plant, Westinghouse Electric Corp. Project No. NM 78-648-811A/812B, 7 vols., February 1982.

Faith, S., Spiegler, P., Rehfeldt, K. R., The Geochemistry of Two Pressurized Brine from the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, Report EEG-21, April 1983.

Popielak, R. S., Beauheim, R. L., Black, S.R., Coons, W. E. Ellington, C. T., and Olsen, R. L., Brine Reservoirs in the Castile Formation, Southeastern New Mexico, Report TME 3153, January 1983.

Snyder, R. P., private communication, 1983.

Spiegler, P., Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, Report EEG-17, December 1982.

Spiegler, P., and Updegraff, D., Origin of the Brines from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentrations of Hydrogen and Oxygen, Report EEG-18, March 1983.

Woolfolk, S. W., Radiological Consequences of Brine Release by Human Intrusion into WIPP, Report TME-3151, July 1982

REGIONAL HYDROLOGY

1.0 Introduction

Knowledge of the regional hydrology near the WIPP is crucial because groundwater is the most likely path for radionuclide migration to the biosphere. In particular, modeling the solute transport characteristics of the water-bearing formations requires accurate determination of the direction and velocity of the groundwater flow.

The nearest perennial water course is the Pecos River, which at its nearest point is about 14 miles from the proposed repository. The only well developed ephemeral drainage is located about 4 miles west of the site at Nash Draw. The nearest surface water body, Laguna Grande de la Sal, is located within Nash Draw, about 10 miles southwest of the center of the site. The lake is fed by groundwater dicharging through springs, by local surface runoff following intense rainfall, and by discharge water from nearby mining operations (Geohydrology Associates, 1978).

Six water-bearing units have been identified near the proposed repository (Figures 13 and 14). Although defined as aquifers in this report, the units do not qualify as aquifers by strict definition. The three aquifers above the proposed repository (Figure 14) are contained in the Rustler-Salado contact, the Rustler Culebra Dolomite, and the Rustler Magenta Dolomite. Water is observed in two units underlying the level of the proposed repository; (Figure 13) as isolated brine occurrences in the upper anhydrite of the Castile Formation, probably anhydrite III, and in the Bell Canyon formation of the Delaware Mountain Group. The Capitan Reef aquifer which surrounds nearly the entire Delaware Basin, lies about 10 miles northeast of the site at its closest point.

2.0 Surface Water Hydrology

The nearest surface water body, Laguna Grande de la Sal, is located about 10 miles southwest of the center of the site (Figure 15). The lake is perennial and receives its water from precipitation, local surface runoff and from the

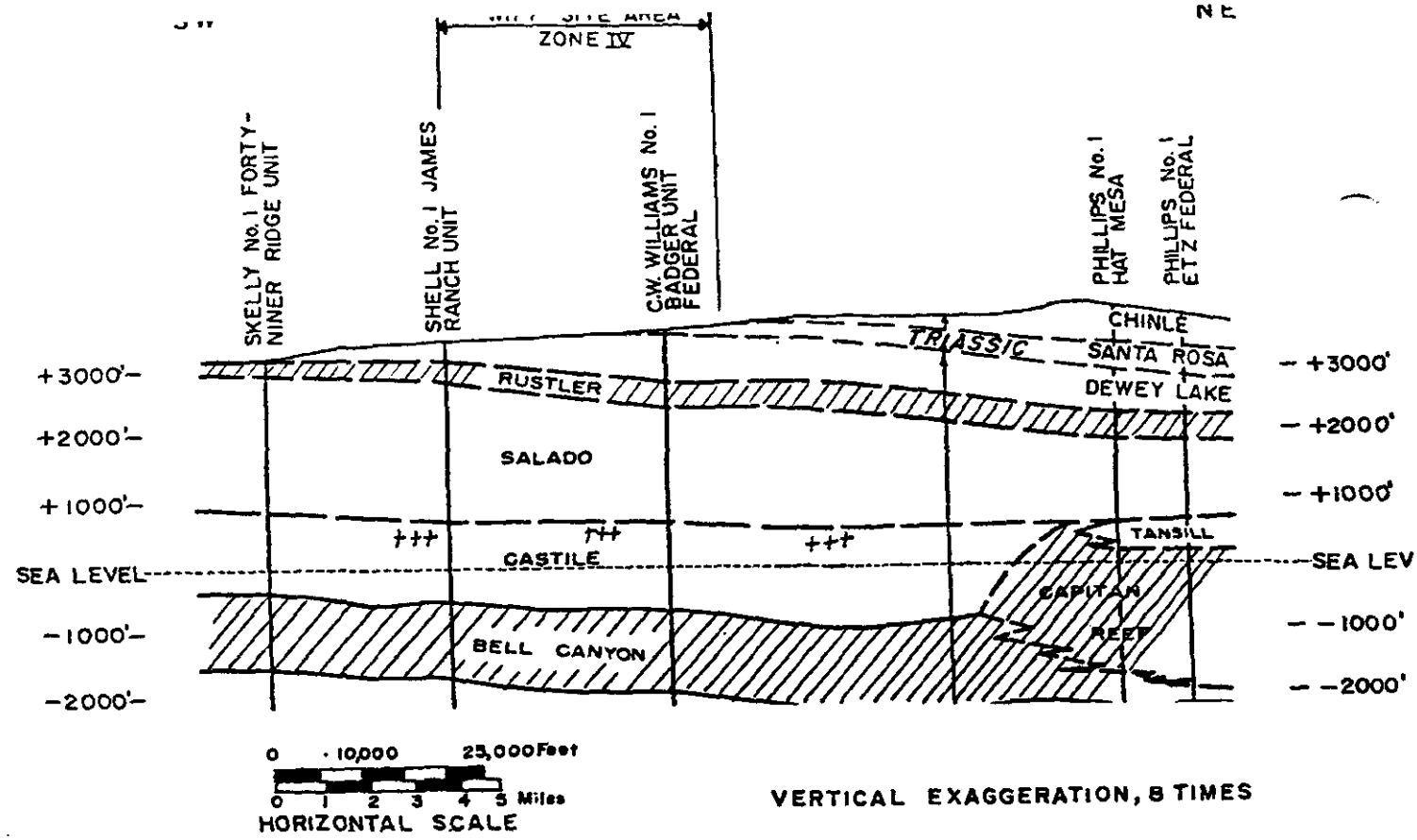

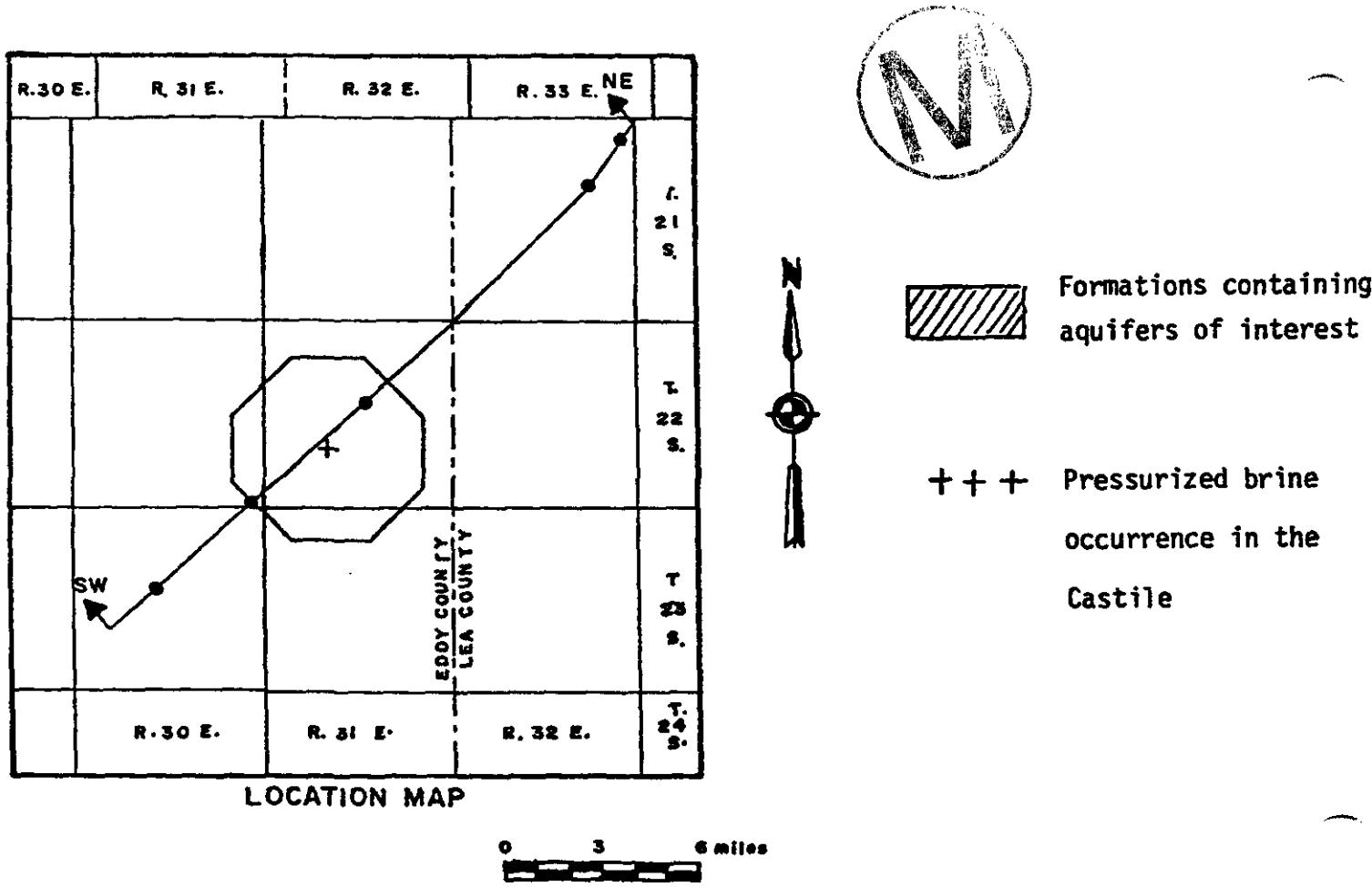

LOCATION MAP

Figure 13. Generalized Site Stratigraphic Section (from the Geological characterization Report, 1978)

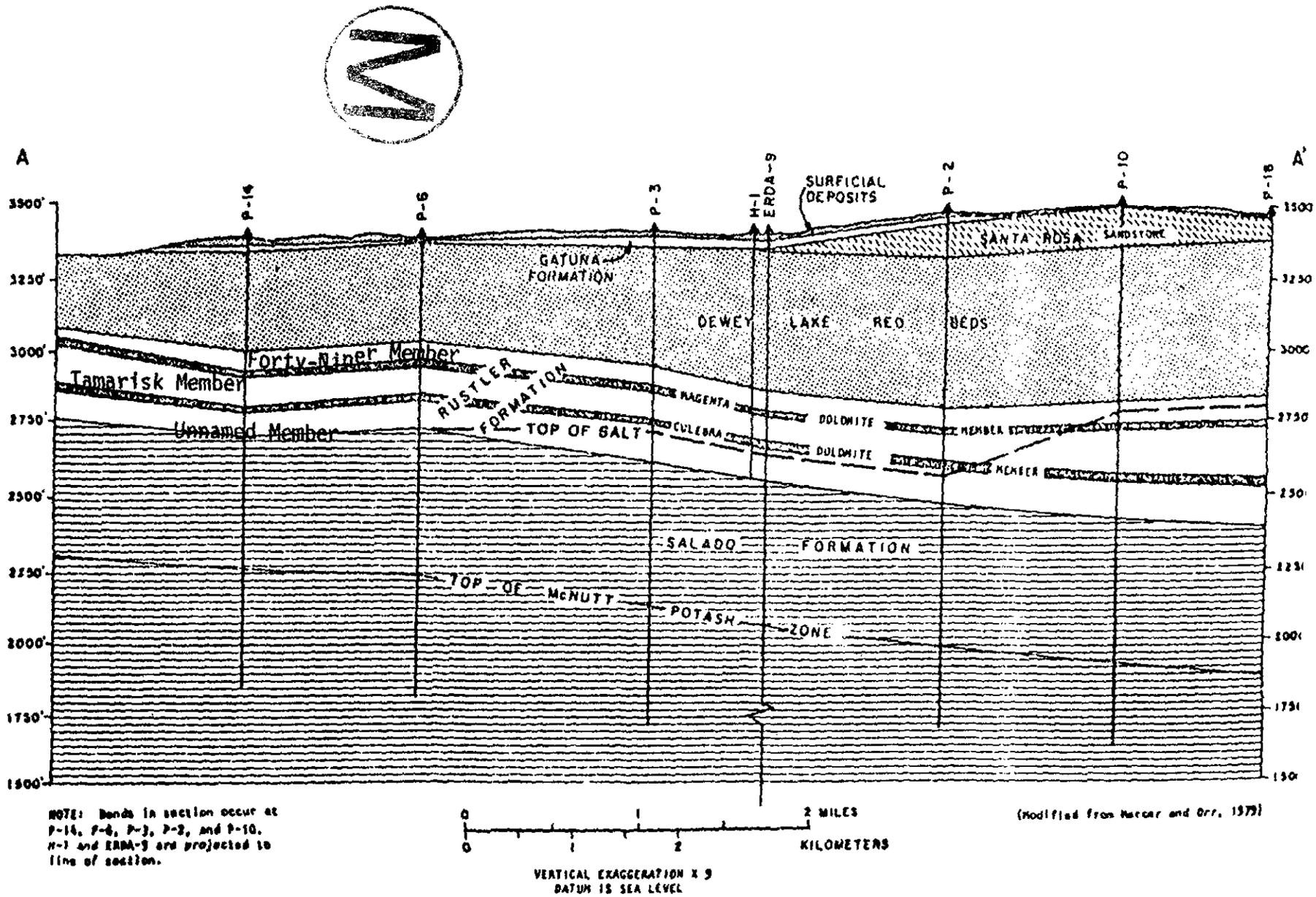

Figure 14. Geologic section across the proposed WIPP site (from Mercer, 1983)

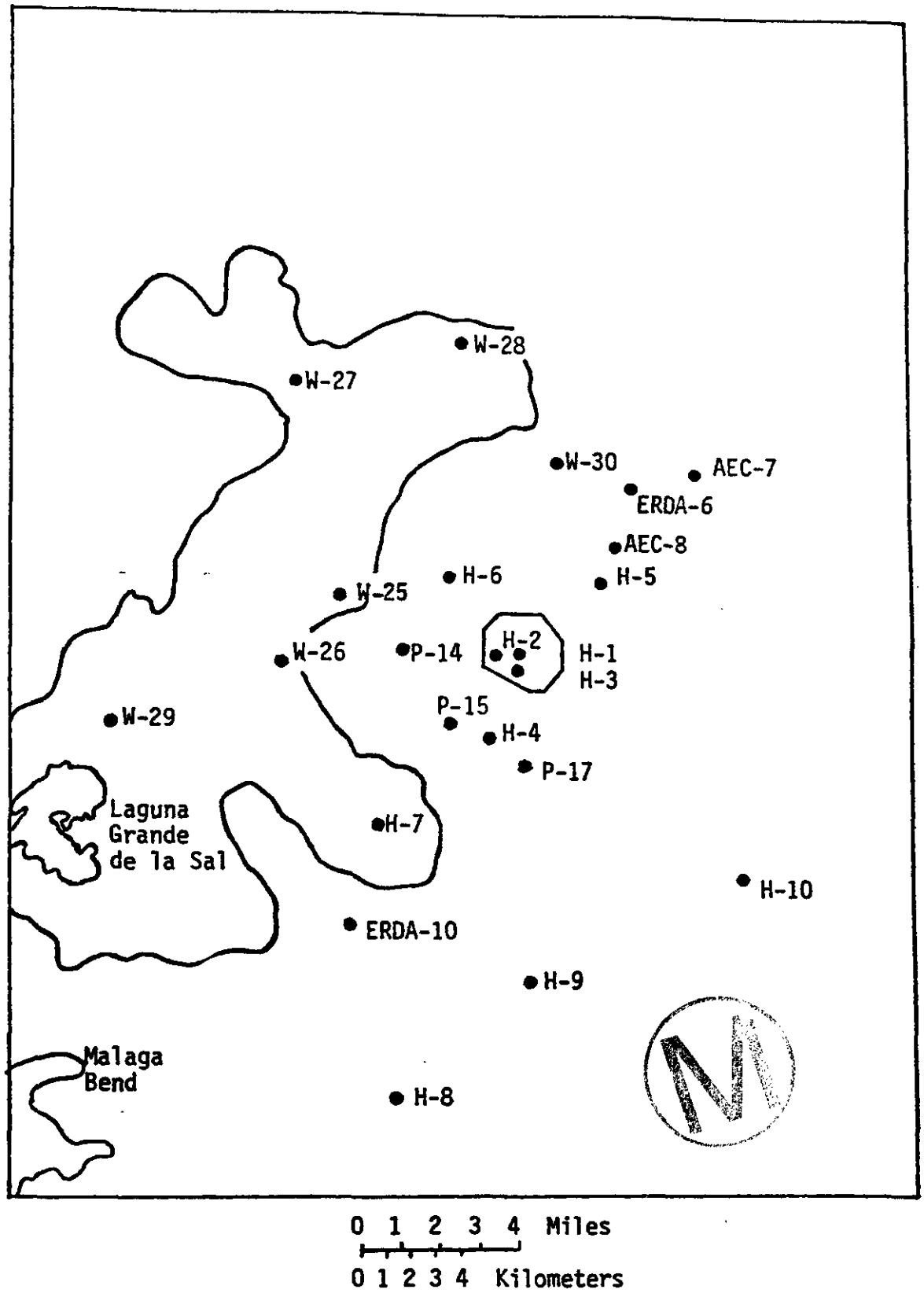

Figure 15. Location of test holes at and near the proposed WIPP site (from Mercer, 1983)

underlying Rustler formation, which may include discharge water from mining operations. The groundwater source is either the Culebra Dolomite, or an overlying anhydrite unit. The source is indeterminate at this time based on the limited chemical data available. However, on a piper diagram (Figure 16) two separate chemical analyses of water attributed to Surprise Spring are compared to Culebra water from selected surrounding wells (Mercer, 1983). One analysis (Geohydrology Associates, 1978) is similar to Culebra wells WIPP-27, WIPP 28, WIPP-29, WIPP-30, and P-17 while the second analysis (Lambert, 1983) is similar to wells P-14, WIPP-25, and WIPP-26.

The first chemical analysis of Surprise Spring (Geohydrology Associates, 1978) had a total dissolved solids content higher than any Culebra water sample. This may indicate that the sample was really from the lake and was not a representative sample of Surprise Spring. The second chemical analysis (Lambert, 1983), although similar to the Culebra waters, is dissimilar enough to make a postulated connection between the Culebra and Surprise Spring tenuous without further study. Surprise Spring is obviously not the only source of water to Laguna Grande de la Sal, but other specific locations of inflow to the lake are not identified.

Mercer (1983) states that at a drill hole in Laguna Grande de la Sal, the hydraulic head in the Culebra was 21 feet above the lake level. The Culebra was overlain by 40 feet of gypsum mud at that location. These data are an indication that some leakage of Culebra water into the Laguna Grande de la Sal is occurring, but the leakage rates are unknown. In any event, the lake is a potential discharge point of the Culebra Dolomite.

The other currently recognized surface discharge point for the Culebra, or Rustler water in general, is the Pecos River. The large brine springs near Malaga Bend are the likely Pecos discharge locations nearest the WIPP site.

3.0 Groundwater Flow in the Bell Canyon Aquifer

The Bell Canyon Formation is of interest in relation to deep dissolution and as a transport mode for bringing radioactive waste to the biosphere.

Figure 16. Modified Piper Trilinear Diagram showing 2 samples from Surprise Spring and selected Culebra wells

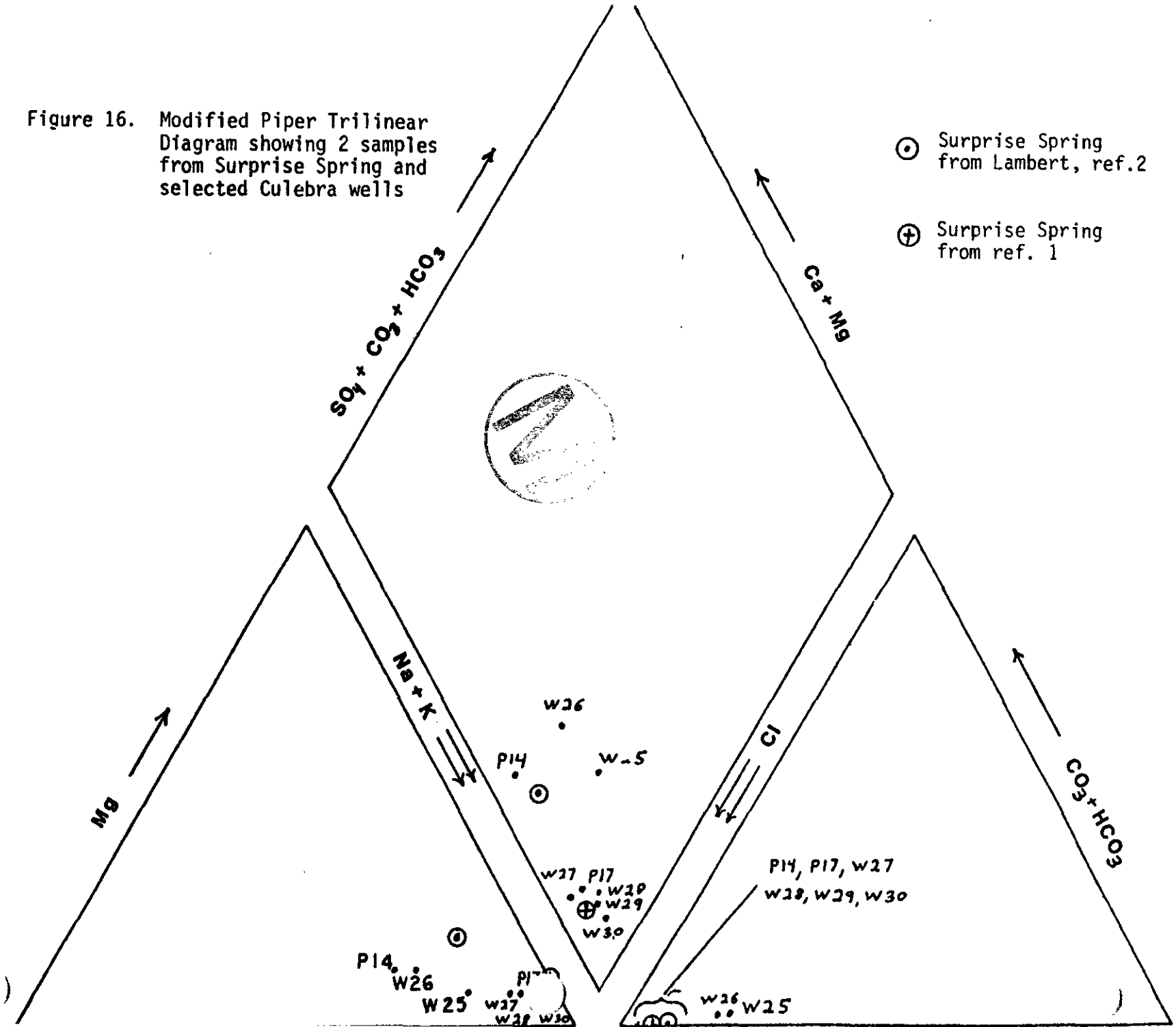

The question of dissolution has been addressed elsewhere in this report. Studies by EEG and Wood et al. (1982) indicate that groundwater flow in the Bell-Canyon is insufficient to remove enough salt to pose a threat to the repository. In the unlikely event that a local dissolution feature (such as a breccia pipe) rooted in the Bell Canyon below the site were to form, Spiegler (1982) has shown the radiological consequences to not be significant. Additional analyses by EEG indicate that the representative solute transport characteristics of the Bell Canyon are such that water transport times to the accessible environment, assumed to be the Capitan Reef, are in excess of 165,000 years. If the most conservative parameters (Williamson, 1979) are used, then travel time could be as low as 9000 years. Solute transport times would likely be much longer due to solute retardation.

A significant point is the hydraulic head (uncorrected for salinity) of the Bell Canyon. Mercer (1983) and Gonzalez (1983) present extrapolated static bottom hole pressures and fluid densities for petroleum drill tests conducted over various intervals in three test holes (Table 1). Mercer (1983) and Weart (1983) state that the head of the Bell Canyon is insufficient to cause an upward flow of water into the overlying Culebra Dolomite aquifer, should such a connection occured, based primarily on the data of the three deep test holes (AEC-7, AEC-8, ERDA-10). EEG questions the contention of insufficient head in the Bell Canyon based on the limited borehole test data for the following six reasons.

1. Measured hydraulic head is only available for test hole AEC-8. For test holes AEC-7 and ERDA-10 only downhole pressure and fluid density are available from which hydraulic head can be calculated.

2. When calculating the hydraulic head based on bottom hole pressure and fluid density, the resulting heads are very sensitive to changes in density or pressure. At test hole ERDA-10, test number 10, a change in fluid specific gravity from 1.165 to 1.164 results in a 3 foot calculated head increase. A change in static downhole pressure from 1820 psig to 1821 psig yields an increase in calculated head of two feet. Therefore, if the measured fluid densities and pressures are not an accurate representation of the in-situ conditions, substantial errors in calculated hydraulic head may result.

Table 1. Summary of drill-stem tests at test holes AEC-7, AEC-8, and ERDA-10, upper Bell Canyon Formation, in the vicinity of the WIPP site (from Mercer, 1983).

Test number	Date of test	Tested interval, in feet below	Type of test	Hydrostatic pressure, in pounds per square inch (gage) Initial	Hydrostatic pressure, in pounds per square inch (gage) Final	Flow period in minutes	Bottom hole flowing pressure, in pounds per square inch (gage) Initial	Bottom hole flowing pressure, in pounds per square inch (gage) Final	Shut-in period, in minutes	Bottom hole shut-in pressure, in pounds per square inch (gage) Initial	Bottom hole shut-in pressure, in pounds per square inch (gage) Final	Calculated hydraulic conductivity, in feet per day	Static bottom hole pressure (extrapolated), in pounds per square inch (gage)	Fluid density, in grams per cubic centimeter
Test Hole AEC-7														
1	4-23-79	4520-4583 (Lamar)	Standard	2,841	2,462	30 120 360	30 23 25	23 23 21	60 360 480	23 23 21	23 25 23	Insufficient Data to Make Calculation	-	-
2	4-27-79	4609-4714 (Ramsey)	Standard	2,547	2,531	25 60 120	127 460 861	395 804 1,270	60 120 335	395 804 1,270	1,814 1,808 1,839	4×10^{-2}	1,883	1.130
3	4-28-79	4493-4714 (Upper Bell Canyon)	Standard	2,479	2,466	10 60 120	120 352 770	314 717 1,188	60 120 350	314 717 1,188	1,764 1,737 1,768	4×10^{-2}	1,811	1.130
Test Hole AEC-8														
1	8-15-77	4844-4800 (pre Ramsey lower sand)	Modified	-	-	-	-	-	-	-	-	2×10^{-2}	2,037	1.147
2	9-27-77	4821-4827 (upper sand)	Modified	-	-	-	-	-	-	-	-	7×10^{-3}	2,044	1.060
7	7-24-76	4304-4405 (Lamar)	Standard	2,445	-	30 58	13 24	18 32	121 748	18 32	1,761 1,788	2×10^{-6}	1,813	-
Test Hole ERDA-10														
9	9-19-77	3860-3927 (Lamar)	Standard	2,083	2,054	30 120 480	51 --	58 106 215	120 360 240	58 106 215	1,708 1,684 1,511	4×10^{-4}	1,783	-
											-	6×10^{-2}	1,820	1.165

3. Large variations in reported fluid densities are observed. For test hole AEC-8, test number 1, two different fluid densities are reported; 1.147 g/cm^3 (Mercer, 1983) and 1.11 g/cm^3 (Mercer and Orr, 1979). For test number 2, the densities are 1.060 g/cm^3 (Mercer, 1983) and 1.12 g/cm^3(Mercer and Orr, 1979). The measured hydraulic head for test number 1 is 2979 feet (Mercer, 1983); the calculated heads are 2807 feet and 2944 feet., for densities 1.147 g/cm^3 and 1.11 g/cm^3, respectively. For test number 2 the measured head is 2964 feet (Mercer, 1983). The calculated heads are 3186 feet and 2948 feet for densities 1.060 g/cm^3 and 1.12 g/cm^3, respectively.

4. There are large variations reported for static bottom hole pressure. For test hole AEC-8, test number 7, extrapolated static bottom hole pressures of 1813 psig and 1962 psig are presented in the Basic Data Report for AEC-8 (SAND 79-0269). For test hole ERDA-10, test number 9 extrapolated static bottom hole pressures of 1783 psig and 1816 psig are recorded in the Basic Data Report for ERDA-10 (SAND 79-0271). For both test holes, only the lower pressure is presented by Mercer (1983) and Gonzalez (1983). Fluid densities are not available, so hydraulic heads cannot be calculated.

5. The calculated freshwater head in ERDA-10 is not consistent with previous studies (Hiss, 1976; McNeal, 1965). The freshwater head relative to mean sea level is defined by

$$h_f = \frac{P \cdot 144}{\gamma_f} + sg\ (e_s)$$

where h_f = freshwater head (feet above sea level datum)

e_s = elevation of the pressure measurement (feet)

sg = fluid specific gravity; assumed numerically equal to fluid density

P = measured pressure (lb/in^2)

γ_w = the weight density of the water (lb/ft^3)

γ_f = 62.4 lb/ft^3 for fresh water

The calculated fresh water hydraulic head, pressure measurement elevation, pressure, and specific gravity for well tests in the Bell Canyon sandstones in the three test holes are presented in Table 2.

Table 2. Calculated Fresh Water Hydraulic Head in the Bell Canyon Sandstones at Test Wells AEC-7, AEC-8 and ERDA-10 Using Published Static Bottom Hole Pressures and Densities.

Test Hole	Test Number	Pressure Measurement Elevation (msl datum) (feet)	Static bottom hole pressure (psig)	Fluid specific gravity	Fresh water head (feet above msl) Calculated	Ref. 11
AEC-7	2	-941.6*	1883	1.130	3281	3280
AEC-7	3	-827.6*	1811	1.130	3244	
AEC-8	1	-1291.3[1]	2037	1.147[3]	3220	
AEC-8	2	-1264.0[1]	2044	1.060[2]	3377	3310
AEC-8	1	-1291.3[1]	2037	1.11[1]	3267	
AEC-8	2	-1264.0[1]	2044	1.12[1]	3301	
ERDA-10	10	-742.8*	1820	1.165	3335	3490

*Pressure measurement elevation is assumed to be the top of the tested interva given in Table 1.

[1]from Mercer and Orr (1979)

[2]from Table 1

[3]interpolated from Figure 22 of Hiss (1976)

The calculated fresh water heads for AEC-7 and AEC-8 are generally consistent with the work of Hiss (1976). The calculated fresh water head for test hole ERDA-10 appears to be too low compared to Hiss (1976). Errors in fluid density or bottom hole pressure of the magnitude observed in reasons 3 and 4 could easily account for the unusually low freshwater head in test hole ERDA-10.

6. The intervals tested in test hole AEC-8 appear to completely bypass the Ramsey sandstone member. Geophysical logs of the upper Bell Canyon including the 2 tested intervals are presented in Figure 17. The two sand units were chosen for testing because "The natural gamma log indicated that the two units were predominantly sandstone and the porosity log indicated that they

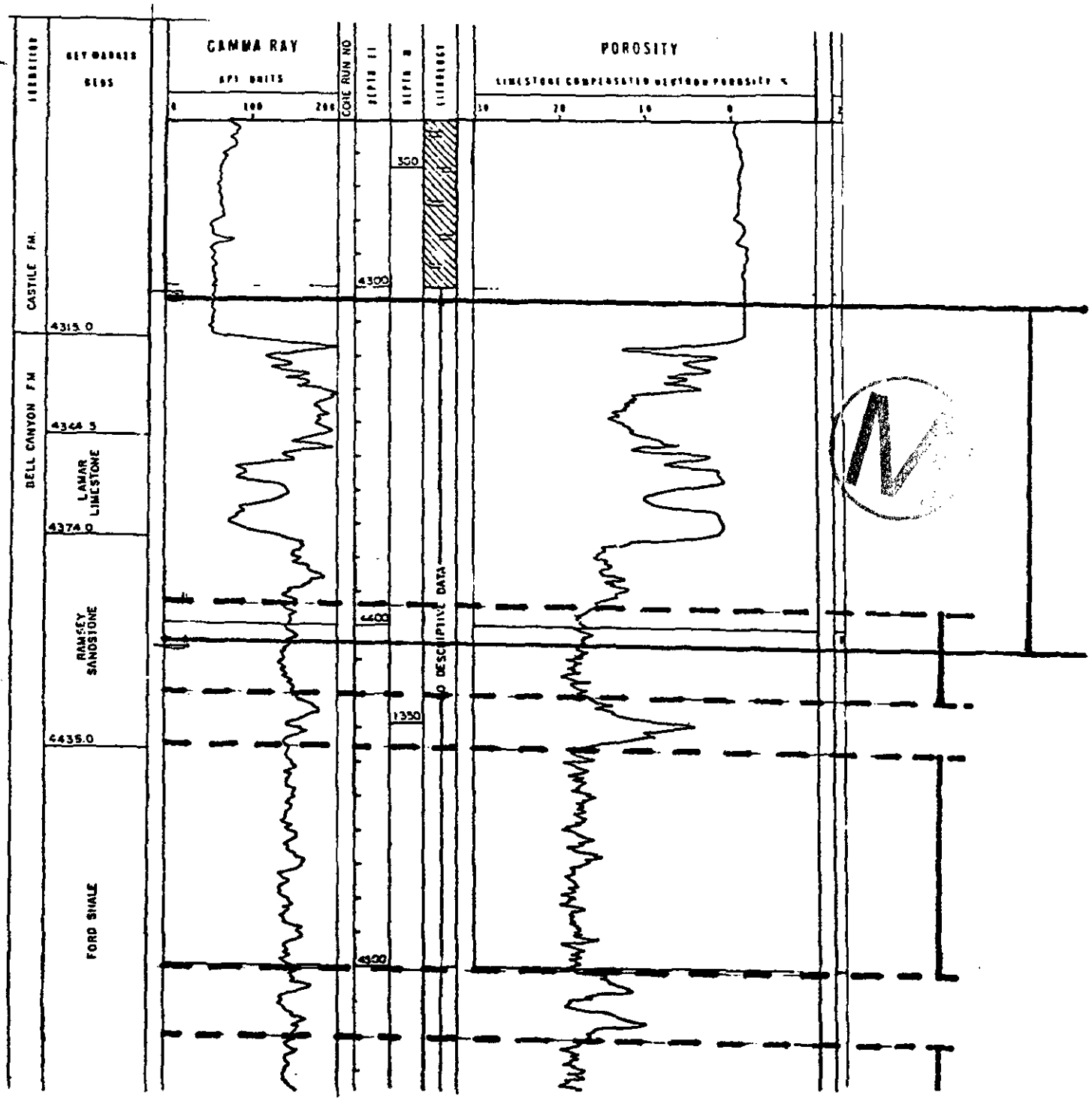

Figure 17a. Geophysical logs of borehole AEC-8 and intervals that EEG contends should have been tested (logs adapted from SAND79-0269, 1983)

intervals tested by DOE

intervals EEG contends should been tested

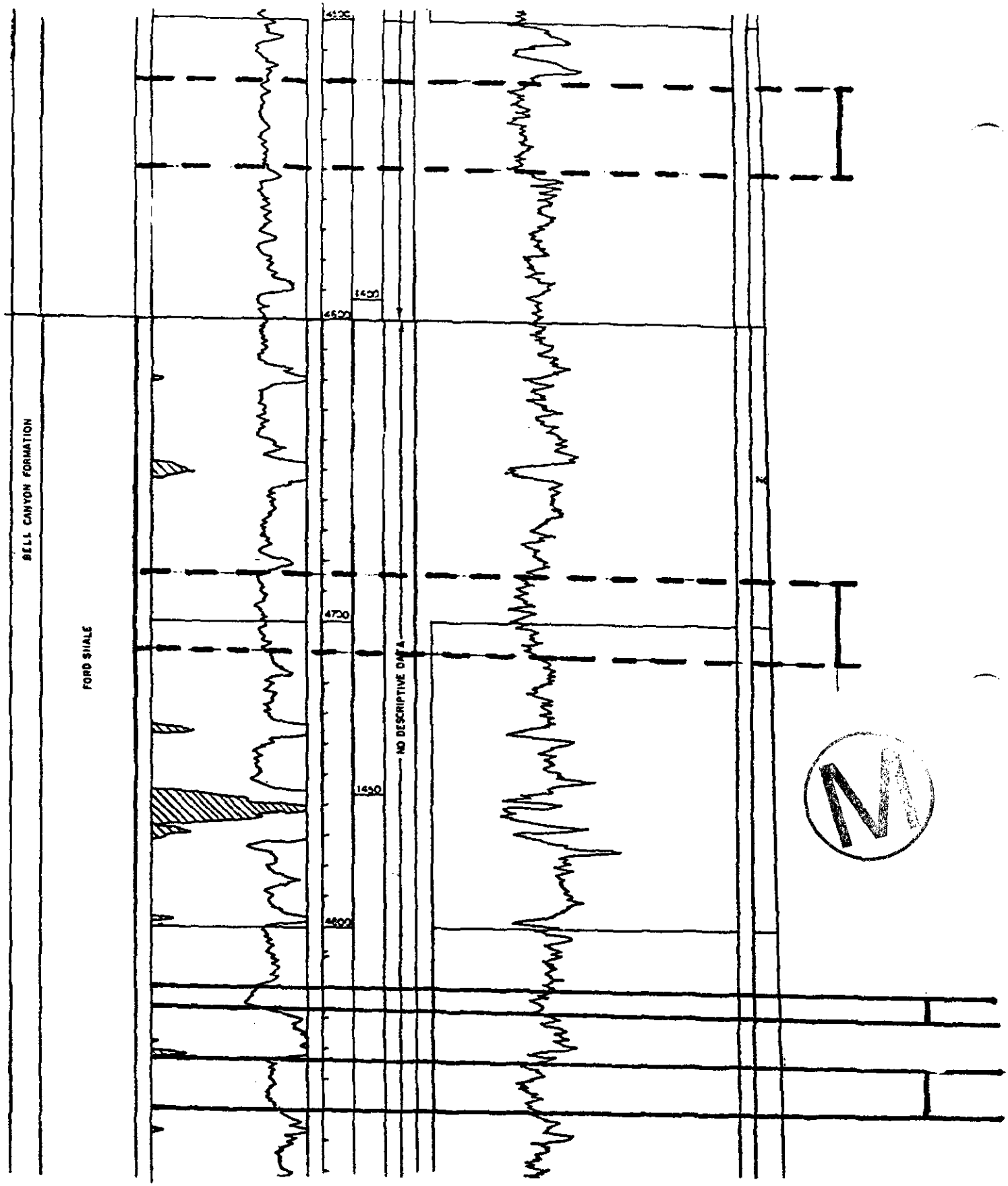

Figure 17b. Geophysical logs of borehole AEC-8 and intervals that EEG contends should have been tested (logs adapted from SAND79-0269, 1983)

intervals tested by DOE

intervals EEG contends should have been tested

had greater porosities than other Bell Canyon sand units." (Mercer and Orr, 1979, p. 127). Four other sand units, not tested, which possess very similar geophysical log signatures as the intervals tested are indicated on Figure 17. These other untested sand units with a combined thickness of 150 feet, are stratigraphically closer to the repository and would have been logical intervals to test.

The calculated hydraulic head data for AEC-7 and ERDA-10 appear unreliable. From reason 2, a 5 foot error in hydraulic head results from a 1 psig error in pressure and a 0.001 g/cm^3 error in fluid density. From reasons 3 and 4, inconsistencies in both fluid density and pressure can be quite large. In addition, the intervals tested in AEC-8 do not appear to be representative of the upper Bell Canyon because from reason 5 it appears that 150 ft. of stratigraphically higher sands should have been tested.

In summary although EEG disagrees with some details presented by DOE concerning the salt removal and transport characteristics of the Bell Canyon, it does not appear to pose a threat to the repository either through the dissolution of salt or as a medium of radionuclide transport to the accessible environment.

Knowledge of the true hydraulic head in the Bell Canyon is essential to determining the direction of groundwater flow between the Culebra Dolomite and the Bell Canyon should such a connection occur in the future. If the flow is downward into the Bell Canyon, the radiological consequences of a repository breach would probably be much less than if the flow is upward into the Culebra.

The most conservative scenario modeling of a connection between the Bell Canyon and Culebra aquifers assumes the flow to be from the Bell Canyon to the Culebra. If DOE insists on establishing a downward flow from the Culebra to the Bell Canyon, the water level in at least one other well in addition to AEC-8 should be monitored. The well could be any borehole of opportunity located southwest, south, or southeast of the proposed repository. In addition, AEC-8 should be perforated in sandstones above the currently monitored intervals.

4.0 Castile Formation

Scattered occurrences of artesian and flowing artesian brines in the upper anhydrite layer of the Castile formation are recorded in the Northern Delaware Basin (see the section on Brine Reservoirs for more detail). To date, there is no evidence to suggest that a brine aquifer exists in the Castile Formation east of the Pecos River. In fact, the existence of highly pressurized brines provides evidence that an aquifer does not exist because the hydraulic head associated with such an aquifer should be consistent with the hydraulic head in the other aquifers, namely the Bell Canyon and the Capitan Reef. The observed hydraulic heads of the highly pressurized brines are much above the hydraulic heads in either the Capitan Reef or the Bell Canyon. Also, the geochemical data of the ERDA-6 and WIPP-12 brines indicate that the brines are immobile and not part of an aquifer system.

In the outcrop area west of the Pecos River, localized flow systems containing relatively fresh water are observed in the Castile Formation. The eastern extension of these fresh water systems is unknown, but it is assumed to be limited to the area west of the Pecos River.

Aquifers have not been observed near the WIPP site in the Castile Formation and consequently it is not considered a viable mode of radionuclide transport. The observation of only brines in the Castile near the WIPP would indicate that salt dissolution by the water in the Castile is not likely.

5.0 Groundwater Flow in the Rustler Formation

Groundwater in the Rustler Formation is observed in 3 distinct units: the Rustler Salado contact, the Culebra Dolomite, and the Magenta Dolomite (Figure 14). At the site the three aquifers are distinct and separate, but in Nash Draw, the distinction is less apparent to the southwest toward the Pecos River. Table 3 contains measured transmissivities for the Rustler aquifers.

5.1 Rustler-Salado Contact

The Rustler-Salado contact aquifer exists in solution residuum at the top of the Salado formation. From the site, the groundwater in the Rustler-Salado residuum

Table 3. Values of transmissivity and storage coefficient for water-bearing zones in the Rustler Formation penetrated by selected test holes at and near the WIPP site (from Mercer, 1983)

(Tansmissivity is expressed in feet squared per day)

Test hole	Magenta Dolomite Member		Culebra Dolomite Member		Rustler-Salado Contact	
	Transmissivity	Storage	Transmissivity	Storage	Transmissivity	Storage
H-1	0.05	–	0.07	10^{-4}	0.0003	–
H-2a	.01	10^{-4}				
H-2b			0.4	10^{-9}		
H-2c					0.0001	–
H-3	.1	10^{-5}	19.0	–	0.0003	10^{-4}
H-4a	.06	10^{-6}				
H-4b			0.9	10^{-9}		
H-4c					0.0006	10^{-4}
H-5a	.1	10^{-5}				
H-5b			0.2	10^{-5}		
H-5c					.00003	10^{-3}
H-6a	.3	10^{-5}				
H-6b			73.0	–		
H-6c					.003	10^{-6}
H-7a	Dry	–				
H-7b			1000+	–		
H-7c					0.73	–
H-8a	.006	10^{-5}				
H-8b			16.0	–		
H-8c					0.003	–
H-9a	1.0	10^{-9}				
H-9b			231	–		
H-9c					0.0002	–
H-10a	0.01	10^{-3}				
H-10b			0.07	10^{-4}		
H-10c					0.00009	–
P-14			140	–	0.05	–
P-15			0.07	10^{-4}	0.0004	–
P-17			1.0	10^{-6}	0.0002	10^{-4}
P-18			0.001	–	0.00003	10^{-5}
W-25	375	–	270	–	5.0	10^{-3}
W-26	Dry	–	1250	–	0.4	–
W-27	53	–	650	–	0.0002	–
W-28	Dry	–	18	–	0.87	–
W-29	Not present		1000	–	8	–
W-30	0.004	–	0.3	10^{-4}	0.2	10^{-4}

flows generally southwest with a possible discharge at Laguna Grande de la Sal, but the major discharge point nearest the WIPP site is the Pecos River near Malaga Bend. In Nash Draw, the Rustler-Salado contact is an aquifer with a transmissivity as high as 8000 ft^2/day. The transmissivity of the aquifer is very small (less than $3 \times 10^{-4} ft^2$/day) within 2 miles of the center of the site.

The water in the aquifer is characterized by extremely high total dissolved solids, the lowest being around 70,000 mg/l. In, and near Nash Draw the TDS is dominated by NaCl indicating flowing groundwater and active dissolution. Within zone II and most of zone III, the Rustler-Salado aquifer is very thin, has an extremely high TDS concentration and a disproportionately high potassium and magnesium concentration (Mercer, 1983). The extremely small transmissivity east of the western edge of zone II, in conjunction with the high magnesium and potassium concentration indicates a very restricted flow system at the Rustler-Salado contact at the site. Therefore, the Rustler-Salado contact residuum aquifer does not appear to be an important consideration for waste transport following a repository breach.

5.2 Culebra Dolomite Aquifer

The Culebra Dolomite aquifer is the most hydraulically conductive of the Rustler-water bearing units. As such, the Culebra may represent the bounding transport mode for contaminated water following a repository breach and subsequent water movement upward into the Rustler. In this section, the general hydrogeological characteristics of the Culebra are presented. Maps of the Culebra potentiometric surface and major chemical constituents are presented in Figures 18 and 19. The inferred direction of flow from the center of the site is from north to south and then west to Malaga Bend passing somewhere near to the Project Gnome site. Determinations of anisotropy of hydraulic conductivity at H-4, H-5, and H-6 by Gonzalez (1983), when incorporated into the flow analysis, indicate an initial southeasterly direction of flow from the WIPP site center before turning west to Malaga Bend. No data on anisotropy are available at the center of the site or to the southeast. In any event, the discharge point of Culebra water at the site would appear to be Malaga Bend.

The above picture of flow from the site passing in the vicinity of the Project Gnome site and discharging into the Pecos River is inconsistent with the observed

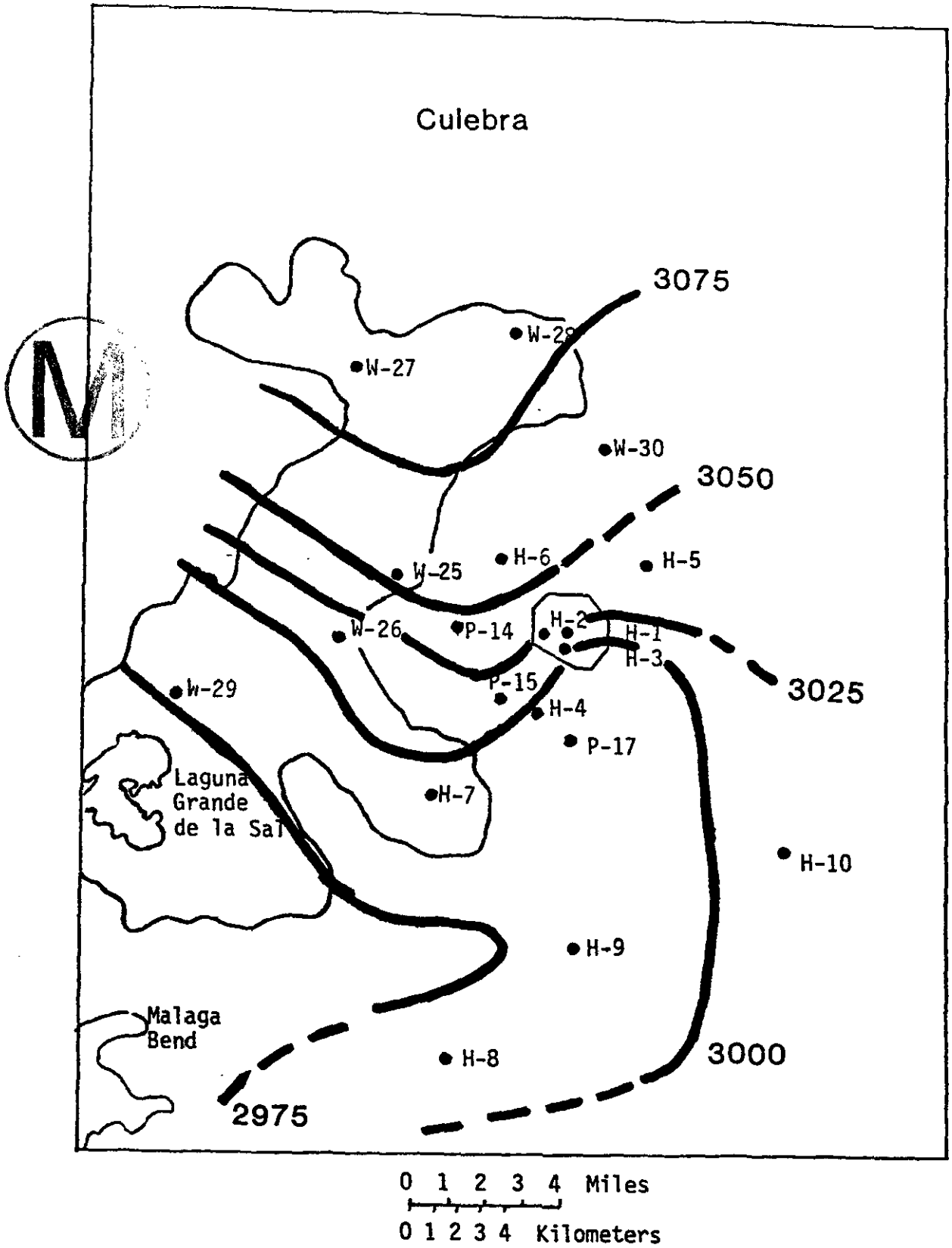

Figure 18. Adjusted potentiometric surface of the Culebra Dolomite Member of the Rustler Formation (1982) at and near the proposed WIPP site (from Mercer, 1983)

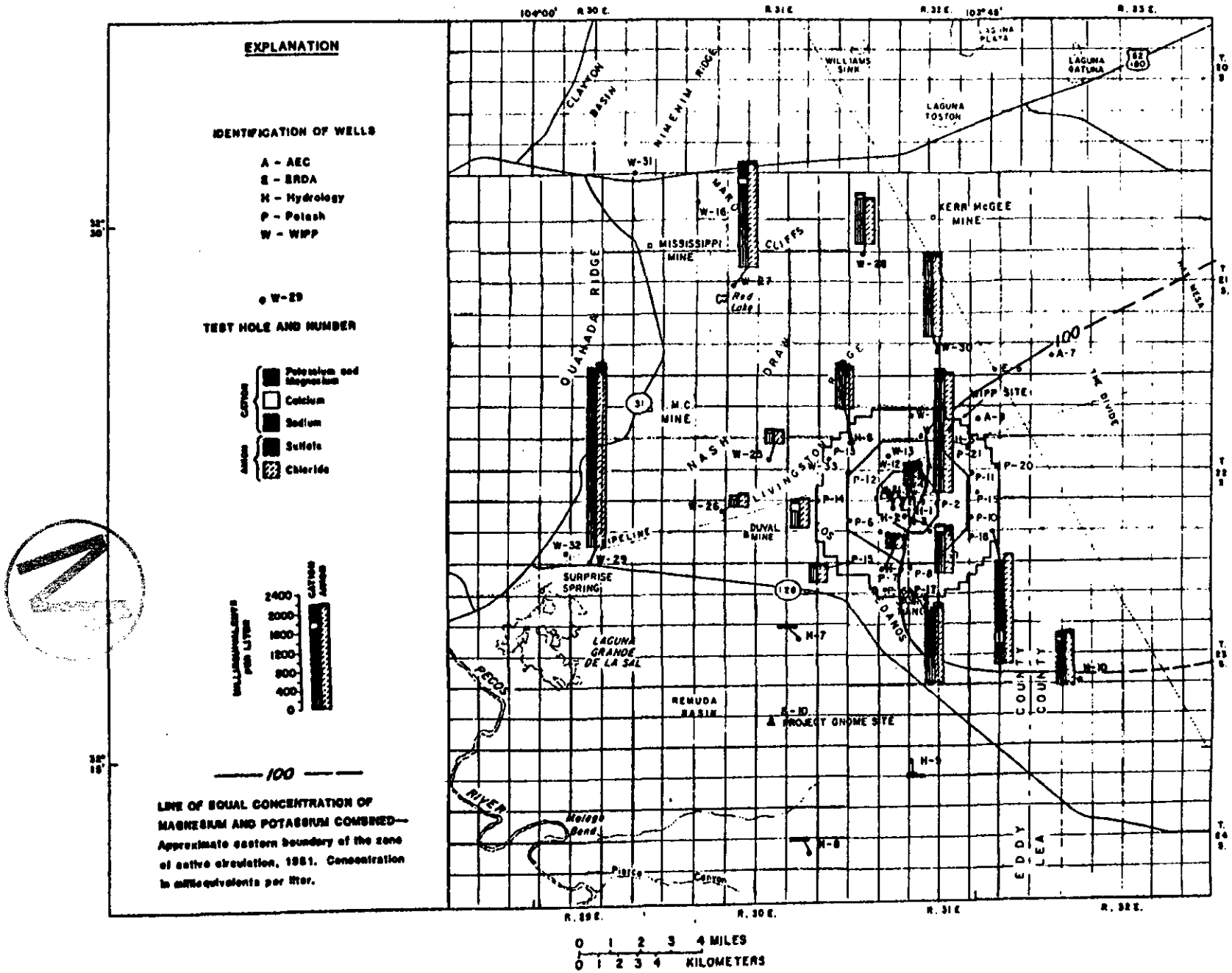

Figure 19. Concentration of major chemical constituents in water from the Culebra Dolomite Member of the Rustler Formation at and near the proposed WIPP site (from Mercer, 1983)

water chemistry in the Culebra. Figure 20 is a modified Piper Trilinear plot of all the Culebra water chemistry data. From the plot, the chemical constituents of wells at the center of the site H-1, H-2, H-3 are predominantly Na and Cl and have total dissolved solids concentrations (TDS) of 30,100 mg/l, 9700 mg/l and 62,000 mg/l respectively. The chemical constituents of wells down flow, H-7, H-8, H-9 are predominantly Ca, Mg and SO and have total dissolved solids concentrations of 3610 mg/l, 3200 mg/l and 3590 mg/l respectively. There is no credible mechanism, other than mixing, to account for a decrease in TDS and a change in chemical constituents from Na and Cl to Mg, Ca and SO in the direction of apparent flow. Mixing with the overlying Magenta aquifer appears unlikely because the TDS in the Magenta is everywhere greater than the TDS in H-7, H-8 and H-9 of the Culebra. Continued investigation into the hydrology of the Culebra Dolomite by Sandia National Laboratories will hopefully clarify the current inconsistency between the apparent water flow direction and water chemistry.

EEG's tentative conclusion is that there is insufficient well data south and southeast of the site to accurately estimate the direction of groundwater flow from the site. As additional information is made available, EEG will modify its conclusions accordingly.

5.3 Magenta Dolomite Aquifer

The Magenta Dolomite aquifer lies stratigraphically above the Culebra Dolomite. Figures 21 and 22 show the potentiometric surface and major chemical constituents for the Magenta. In general, water in the Magenta at the center of the WIPP site will flow westward to Nash Draw where it likely discharges into underlying units. The Magenta has been largely ignored by DOE for solute transport scenarios because of the small transmissivities associated with that aquifer. However, due to the uncertainty associated with the direction of flow in the Culebra, the possible transport of contaminants in the Magenta should be given consideration. This will be discussed in detail in the section on "Hydrologic Transport Characteristics in the Rustler Formation."

6.0 Capitan Reef Aquifer

The Capitan reef aquifer, one of the most productive freshwater aquifers in southeastern SE New Mexico, extends in an arcuate band around most of the

Figure 20. Modified Piper Diagram of Culebra Water Chemistry

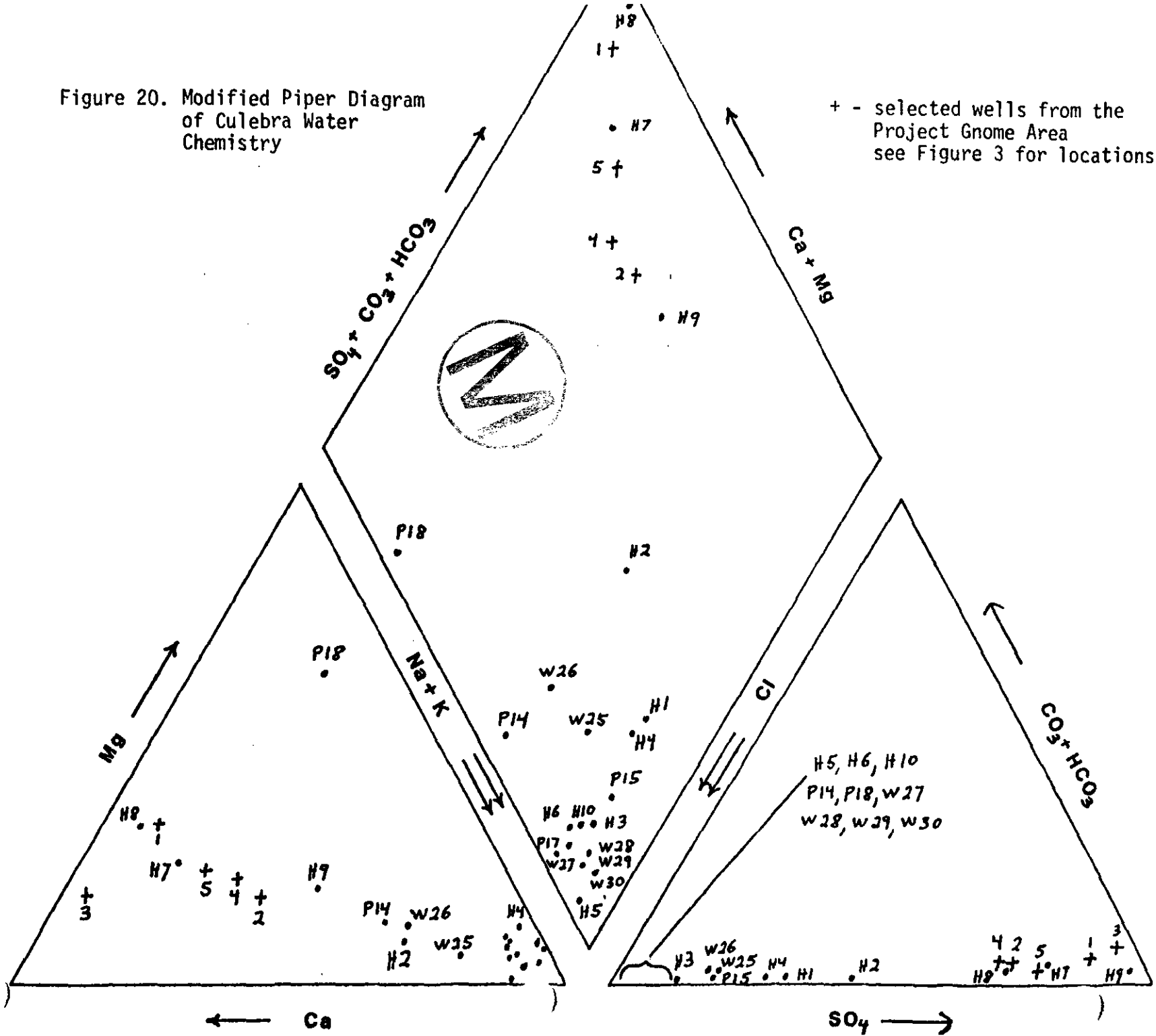

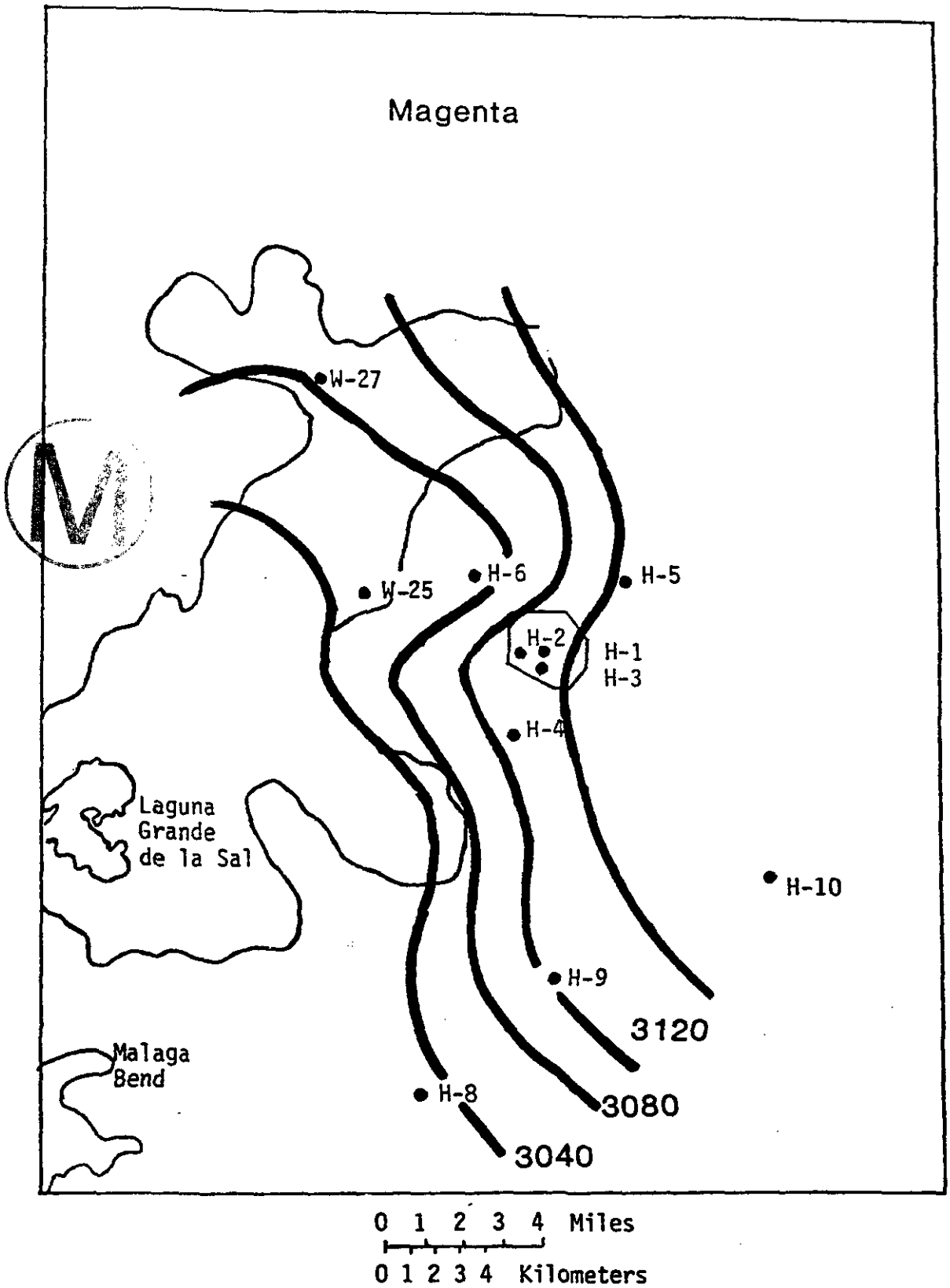

Figure 21. Adjusted potentionmetric surface of the Magenta Dolomite Member of the Rustler Formation (1982), at and near the proposed Waste Isolation Pilot Plant (WIPP) site (from Mercer, 1983)

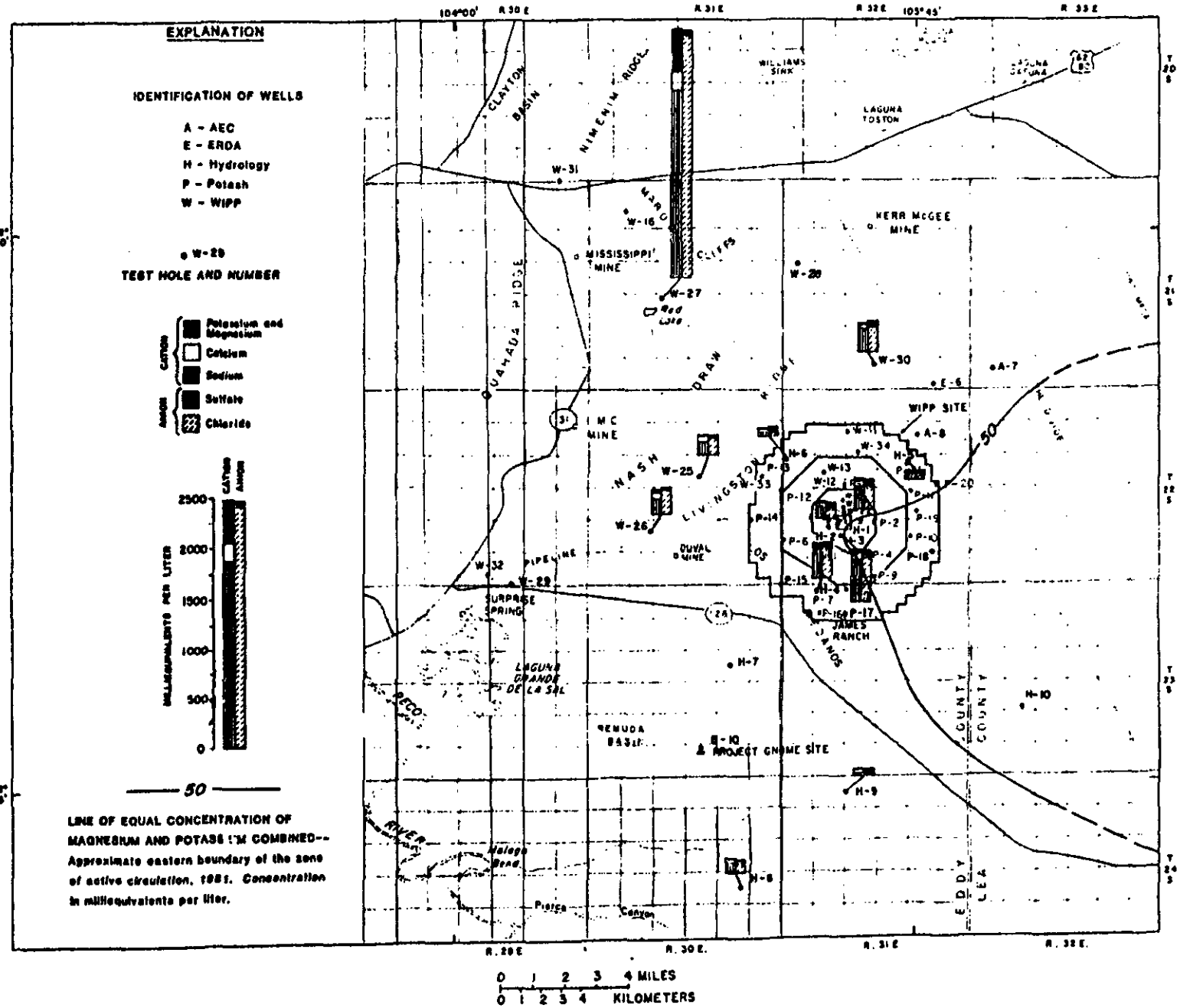

Figure 22. Concentrations of major chemical constituents in water from the Magenta Dolomite Member of the Rustler Formation near the proposed site (from Mercer, 1983)

Delaware Basin and lies at its closest point about 10 miles north of the WIPP. The hydraulic head in the Capitan Reef aquifer is less than that in the Bell Canyon (Hiss, 1976) indicating a flow into the reef if the two aquifers are connected. The relatively impermeable anhydrites of the Castile Formation restrict the lateral movement of freshwater away from the reef (Mercer, 1983). Numerous collapse phenomena are associated with the Capitan Reef and some near reef salt dissolution is probably attributable to the Capitan Reef aquifer (see the section on Dissolution). However, salt dissolution associated with the reef does not appear to pose a threat to the repository. The solute transport characteristics of the Bell Canyon are such that a minimal radiological hazard would result from a repository breach and subsequent transport of radionuclides to the Capitan Reef by the Bell Canyon aquifer.

7.0 Summary of Conclusions

The degree of understanding of the regional hydrology, although far from complete, is sufficient to reach some general conclusions.

7.1 Waters in the Bell Canyon formation and the Castile formation do not pose a significant threat to the repository. The salt removal potential is too low and the radionuclide transport time is too long.
However, both formations may be a source of water for some breach scenarios that result in the injection of radionuclides into the Rustler.

7.2 The Capitan Reef Aquifer is at its nearest point about 10 miles from the site. Water in the aquifer is largely prevented from moving laterally into the basin. Although there is some localized dissolution associated with the reef, the basinward dissolution north of the site appears small. Therefore, the Capitan Reef Aquifer poses a minimal threat to the repository.

7.3 The groundwater in the Rustler Formation is the likely bounding conduit following a repository breach for radionuclides to reach the accessible environment. Within the Rustler, the Culebra aquifer is of most concern, because of higher transmissivities. However, there are insufficient data to characterize the flow system in the Culebra south of the site and hence

additional experiments are needed. EEG hopes the solution will come from ongoing hydrologic studies concentrated in the Culebra.

7.4 The various nuclear waste repository criteria that relate to groundwater generally are directed toward solute transport characteristics of the aquifers. How well WIPP meets these criteria is discussed in the section on hydrologic transport in the Rustler.

8.0 References Cited

Geohydrology Associates, Inc., Ground-Water Study Related to Proposed Expansion of Potash Mining near Carlsbad, New Mexico, June, 1978.

Gonzalez, D. D., Hydrogeochemical Parameters of Fluid-Bearing Zones in the Rustler and Bell Canyon Formations: Waste Isolation Pilot Plant (WIPP), Southeast New Mexico (SENM), Sandia National Laboratories, Report SAND 83-0210, March, 1983.

Gonzalez, D. D., Groundwater Flow in the Rustler Formation, Waste Isolation Pilot Plant (WIPP), Southeast New Mexico (SENM): Interim Report, Sandia National Laboratories, Report SAND 82-1012, March 1983.

Hiss, W. L., Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer, Southeastern New Mexico and West Texas, University of Colorado, Boulder, Ph.D. dissertation, 1976.

Lambert, S. J., Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas, Sandia National Laboratories, Report SAND 82-0461, March, 1983.

McNeal, R. P., Hydrodynamics of the Permian Basin in Fluids in Subsurface Environments -- A Symposium, American Association of Petroleum Geologists Memoir 4, p. 308-326, 1965.

Mercer, J. W., and Orr, B. R., Interim Data Report on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site Southeast New Mexico, U.S. Geological Survey, Water - Resources Investigations Report 79-98, July, 1979.

Mercer, J. W., Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico, U.S. Geological Survey, Water Resources Investigations Report 83-4016, 1983.

Sandia National Laboratories, Basic Data Report for Drillhole AEC-8 (Waste Isolation Pilot Plant - WIPP), SAND 79-0269, January 1983.

Sandia National Laboratories, Basic Data Report for Drillhole ERDA-10 (Waste Isolation Pilot Plant - WIPP), SAND 79-0271, February 1983.

Spiegler, P., Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository, Environmental Evaluation Group, Report EEG-13, May, 1982.

Weart, W. D., Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability, Sandia National Laboratories, Report SAND 83-0450, March 1983.

Williamson, C. R., 1979, Deep-sea sedimentation and stratigraphic traps, Bell Canyon Formation (Permian), Delaware Basin, in Sullivan, N. M., ed., Guadalupian Delaware Mountain Group of west Texas and southeast New Mexico: Society of Economic Paleontologists and Mineralogists (Permian Basin Section), Publication 79-18, p. 39-74.

Wood, B. J., Snow, R. E., Cosler, D. J., and Haji-Djafari, S., Delaware Mountain Group (DMG) Hydrology - Salt Removal Potential, U.S. Department of Energy, Report TME 3166, prepared by D'Appolonia Consulting Engineers, December, 1982.

THE DISTURBED ZONE

1.0 Definition

The northern part of the WIPP site is an area of poor seismic reflections. The first direct evidence of the structural complexity of this area was obtained in 1975 when ERDA-6 encountered very high dips of the upper Castile anhydrite beds and pressurized brine. On the basis of seismic reflection data then available, Long and Associates (1977), showed a "highly disturbed area (Castile)" in the northern part of the WIPP site (Fig. 23). Several more seismic reflection surveys were conducted in 1978 and 1979 and the boundary of the disturbed zone was broadened to include the northern part of Zone III in a "zone of Anomalous Seismic Reflection Data" (SAR, 1980, Fig. 2.7-23). The same figure (Fig. 23) also shows a "Line indicating steepening of dip of Castile strata to the north" More recently, Borns et al, (1983) have delineated the "Disturbed Zone" (DZ) on the "combined basis of structure exhibited in boreholes and by the chaotic seismic reflection data in the northern part of the site" (p. 10). This figure, reproduced here as Fig. 24, shows a band of DZ bordering the Capitan Reef and passing through the northern part of the WIPP site. Since the zone of WIPP is not identified in this figure and there is no scale, it is difficult to estimate the part of WIPP covered by this band of DZ. The text of Borns et al., (1983, p. 11) however, explains that the southern boundary of DZ approximately coincides with the "line indicating steepening of dip of Castile strata to the north," which is about 2/3 mile north of ERDA-9. Of more interest are the two other areas identified as DZ in this figure. The circular area to the southwest appears to be based on the structure observed in the Belco-Hudson Well. The other oblong area, south of the highway, appears to include the Poker Lake anticline. The report (Borns et al 1983) does not contain an explanation for the inclusion of these two areas in the "Disturbed Zone."

Other than being an area of poor seismic reflections, the Disturbed Zone has never been properly defined. Borns et al (1983) have variously defined it

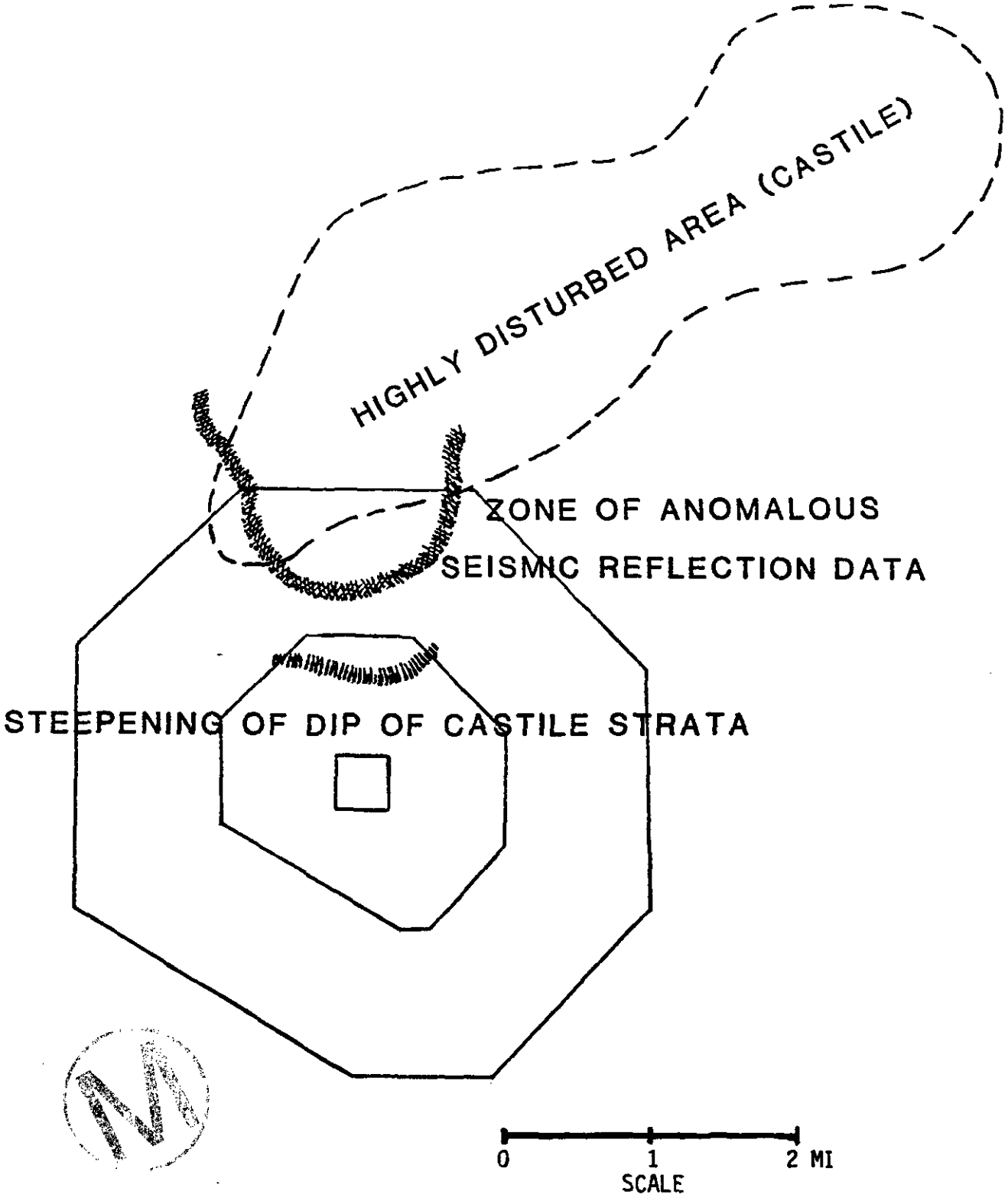

Figure 23. WIPP Site and the southern limits of the "Highly Disturbed Area" (GCR), the "Zone of Anomalous Seismic Reflection Data" and the "Steepening of Dip of Castile Strata" (SAR).

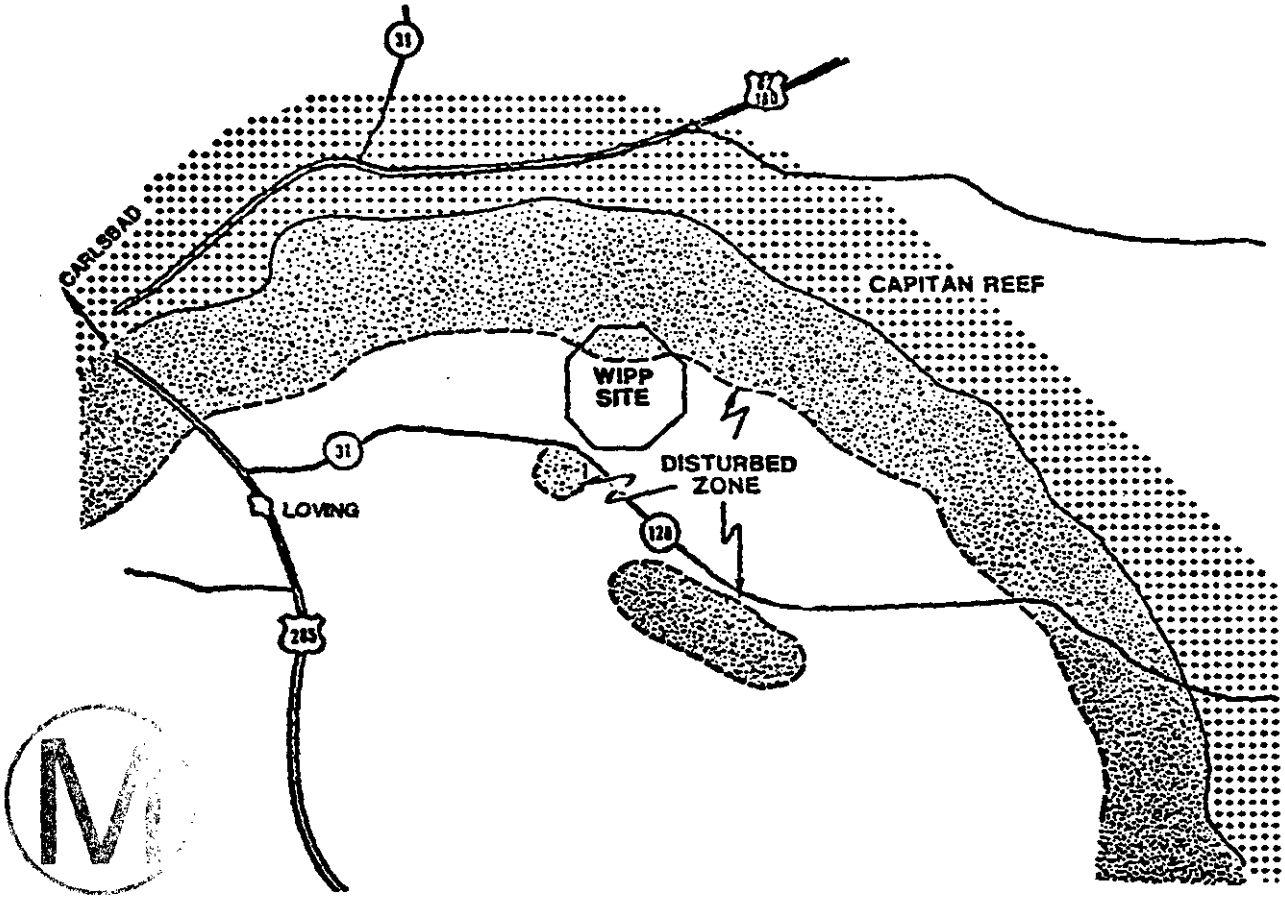

Figure 24. Aereal extent of the disturbed zone, northern Delaware Basin (from Borns et al., 1983)

as, "the area where the Castile/lower Salado departs from generally parallel beds with slight dip" (p. 11) and "The outer edge of the mapped flow structures is here taken as the limit of the DZ. This definition is necessarily ambiguous. It includes the anticline at WIPP-12, and may or may not include the anticline in Sec. 19" (p. 69).

2.0 Areal Extent

In earlier DOE publications, e.g. Powers et al (1978) and Register (1981)*, the disturbed zone was presented as a zone bordering the Capitan Reef. Borns et al (1983) have widened this zone to include the WIPP-12 structure where brine was encountered. In addition, they have shown two more areas, to the southwest and south of the WIPP site (Fig. 23), as part of DZ. No rational explanation has been provided for separating these two areas from the band bordering the reef. The seismic profiles do show structures between WIPP-12 and Belco-Hudson well, but there are no wells penetrating the Castile formation between these two and, therefore, the boundary of the circular DZ shown southwest of the site in Figure 23 is arbitrary.

Concerning the explanation for the limited areal distribution of the disturbed zone, Borns et al (1983) state, "no hypothesis adequately answers why the deformation has a limited areal distribution" (p. 4). However, a hypothesis has been offered by them (on p. 87-88) to explain this phenomenon. It concerns the difference in the yield strength of the rock due to anomalously high water content which would facilitate grain boundary pressure solution.

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*Register (1981) showed the DZ as a 6 mile wide "Deformation Front" bordering the reef. Popielak et al (1983) simply refer to it as, "this band or belt extends underneath the WIPP site" (p. G-38) and avoid assigning a southern limit to it.

Because of the absence of identifiable boundaries of DZ and the lack of an adequate explanation for a limited areal extent, it seems logical to conclude that some structural complexity in the Castile formation may exist to varying degrees anywhere in the northern Delaware Basin including the WIPP site.

3.0 Geophysical Data

3.1 Seismic Reflection

The disturbed zone has been delineated primarily on the basis of seismic reflection data. The seismic data indicate a "blocky structure with abrupt dip changes and offsets (faults) between units" and "the seismic character (wiggle shape) changes, which indicates variations in thicknesses and/or acoustic properties." (Borns, et al, 1983, p. 69). The seismic data at the disturbed zone shows that the geologic structures within the Castile formation are too complex to map with the seismic technique. It is this complexity of geologic structures within the Castile that identifies the DZ from the "undisturbed" strata. The interpretations from the seismic profile are supported by "the steep lamination dips, variable stratigraphic thicknesses and petrographic features (e.g. recumbent folds, shear zones) exhibited by core" (Borns, et al 1983).

Since most of the deformation in the disturbed zone is restricted to the Castile formation and involves a redistribution of the massive anhydrite and halite beds within this formation, it was thought that the gravity survey should pick out the lateral density variations resulting from the deformation. The interpretation of the gravity survey is described in Chapter 3 of Borns, et al (1983). According to this interpretation, "the (gravity) anomalies are much too sharp (shorter double half-width) to originate within the Castile formation. They extend into areas that are indicated by the seismic profiles as undeformed. The negative gravity anomalies were established by drilling to originate from lateral density variations within relatively flat strata." (p.73).

The only explanation of lateral density variations within a shallow zone as interpreted from the gravity survey, provided by Borns et al (1983) is that the negative anomalies represent, "decreased rock densities near karst channels, primarily in the Rustler formation" (p. 73). The question of karst hydrology in the Rustler formation is discussed in the section on "Rustler Hydrology".

4.0 The Origin of the Disturbed Zone

Borns et al (1983) discusses the following hypotheses of origin for the disturbed zone:

Gravity Foundering
Dissolution
Gravity Slides
Gypsum Dehydration
Depositional Processes

Out of these, they appear to favor the gravity foundering and, to a lesser extent, gravity sliding, as the mechanisms which are most consistent with the available observations. As far as the movement of salt within the Castile formation is concerned, gravity foundering appears to be a reasonable hypothesis to explain the phenomenon. The difficulty with this hypothesis is, of course, in explaining the areas which remained undeformed, adjacent to the deformed or "disturbed" areas.

5.0 The Age of Deformation

The geological time during which the deformation in the DZ occurred has been a question of debate in the literature. The following account provides a summary of various approaches to answer this question.

Kirkland and Anderson (1970) studied the microfolding in the Castile strata exposed in the western part of the basin. By noticing the relationship between the orientation of microfolds and the larger folds, which in turn correspond with the basic Cenozoic structural grain of the basin, they concluded that the Castile microfolds postdate the late Cenozoic regional tilting. Anderson (in

Chaturvedi, 1980) showed that the ERDA-6 core has a similar stretching of microfolds as seen at the stateline Castile outcrop, and inferred from this, that the deformation in the DZ would also be post Cenozoic-tilting of the basin.

Borns et al (1983) have examined the possibility of dating the deformation by applying the axiom that the deformation must predate deposition of the oldest underformed strata. However, this axiom cannot be applied to a situation where the deformation is clearly stratabound in Castile and becomes dampened upward and downward in the section.

Consideration of the mechanism of gravity foundering, the preferred hypothesis for the deformation in the DZ, led Barrows (1983) to the conclusion that the deformation would remain active until all the anhydrite has settled beneath the halite. Since this has not yet happened in the DZ, the implication is that the deformation in the DZ is an active, ongoing process.

6.0 The Rate of Deformation

Barrows (1983) has calculated that the time required for the deformation in the Castile through the process of isostatic movement of salt would range from 10^4 to 10^7 years. Borns et al (1983) have calculated that, by this mechanism, a structure of the size of WIPP-12 anticline could develop at the WIPP site in a time frame of approximately 10,000 years to 250,000 years. Such a structure, developing in the Castile anhydrite, would produce fractures and may result in the development of a brine reservoir. Although theoretically possible, Borns et al (1983) argue that the development of a structure directly under the site would be a random event and given that the conditions for such an event have existed for the past several millions of years, it would be very unlikely for a structure to develop directly under the site during the next 250,000 years.

Borns et al (1983) have calculated the effect of the "deformation front" progressing toward the site. By assuming an average width of 10 km of the DZ adjacent to the reef and 30 m.y. as the time since basin tilted and the deformation began, they calculate that the belt has grown at a rate of 0.3 mm/yr and "At this rate 4.6 m.y. would be required for the deformation front to progress over the site."

The assumptions made in this calculation may not be valid. Fig. 1 of Borns et al shows the width of DZ bordering the reef, near the WIPP site, to be about 16 km (≈10 miles). The main phase of the uplift occurred in late Pliocene to early Pleistocene time (King, 1948; Hayes, 1964) or about 2 to 6 m.y. ago. Therefore, a more realistic assumption would be that the deformation has progressed 16 km in 2 to 6 m.y., or 2.7 to 8 Km per million years. The edge of the WIPP-12 structure is about 1 Km north of the center of the site. Using these assumptions, the deformation front would reach the center of the site in 125,000 years to 375,000 years.

7.0 Conclusions

It is clear that the structural deformation is most pronounced within the Castile formation and near the Capitan Reef. However, there is no rational basis to assume a 10 km band of deformation bordering the Capitan Reef. The WIPP-12 structure clearly shows that the "front" extends to at least the northern part of the WIPP Zone II. A more conservative approach would be to assume that the entire WIPP site is within the zone where the Castile beds have been deformed to varying degrees and include the Belco-Hudson structure within this zone. Further, the interpretation of the structure at WIPP-11 shows that the involvement of the Delaware Mountain Group formation with the deformation in Castile, at least locally, is possible, and at this drill hole the Castile structural deformations appear to extend into the lower Salado as well.

The gravity foundering hypothesis provides a reasonable explanation for the style of deformation present in the Castile formation in the northern Delaware Basin. By using this hypothesis, Borns et al (1983) have calculated that if the deformation is progressing towards the WIPP repository area, it would take 4.6 m.y. for the deformation front to reach the area directly under the WIPP repository. EEG's calculations show that this may happen in 125,000 to 375,000 years. The progression of a structure such as that located at WIPP-12, however, requires conditions which facilitate the gravity foundering mechanism and these conditions (e.g. high trapped fluid in rock, low yield strength, etc.) may not exist under the southern part of Zone II of the WIPP site. The borehole DOE-1 drilled just outside the Zone II, to the southeast, certainly does not exhibit the Castile deformation structures except some minor lateral

flow textures in the Castile halites. Further, with the reorientation of the WIPP repository to the south within Zone II, the repository would now be in a relatively undeformed region as interpreted from the seismic reflection data. EEG, therefore, concludes that the proposed WIPP repository in the southern part of Zone II is located in a relatively undeformed area.

8.0 References Cited

Barrows, L., 1983, Halokinetic development of the Disturbed Zone, Appendix, in Borns, et al Deformation of Evaporites Near the WIPP Site, SAND 82-1069 (Draft)

Borns, D. J., L.J. Barrows, D. W. Powers, R. P. Snyder, 1983, Deformation of Evaporites Near the WIPP Site, Report SAND 82-1069 (Draft)

Chaturvedi, L., 1980, WIPP Site and Vicinity Geological Field Trip, EEG-7

Hayes, P. T., 1964, Geology of the Guadalupe Mountains, N.M., USGS Prof. Paper 446

King, P. B., 1948, Geology of the Southern Guadalupe Mountains, Texas, USGS Prof. Paper 214

Kirkland, D. W. and R. Y. Anderson, 1970, Microfolding in the Castile and Todilto evaporites, Texas and New Mexico, GSA Bull 81, pp. 3259-3282

Long, G. J. and Associates, 1977, Interpretation of geophysical data, Los Medanos and vicinity, Lea and Eddy Counties, N.M., Report to Sandia Laboratories

Popielak, R. S., R. L. Beauheim, S. R. Black, W. E. Coons, C. T. Ellingson and R. L. Olsen, 1983, Brine reservoirs in the Castile formation, S.E. New Mexico, TME 3153, D'Appolonia Counsulting Engineers

Powers, D. J., S. J. Lambert, S-E. Shaffer, L. R. Hill and W. D. Weart (Ed.), 1978, Geological Characterization Report, WIPP site, S.E. New Mexico, SAND 78-1596, Vols. I and II.

Register, J. K., 1981, Brine Pocket Occurrences in the Castile Formation, S.E. New Mexico, TME 3080, U.S. Department of Energy

HYDROLOGIC TRANSPORT CHARACTERISTICS OF THE RUSTLER AQUIFERS

The site validation report (DOE, 1983) concluded that the Culebra and Magenta Dolomite aquifers of the Rustler Formation are the only aquifers of significance at the WIPP site. Of the two, the Culebra is considered the most important and is the target of DOE's detailed hydrologic transport studies. Recent modeling studies (Barr et al., 1983), cited by Weart (1983) indicate that water will move less than 2 miles in 1000 years in the region near the site but the document (Barr et al, 1983) was unavailable for review by EEG on May 25, 1983.

While the general hydrogeology of the Rustler aquifers has been presented in the section on Regional Hydrology, specific aspects relating to a repository breach and the transport of radionuclides to the biosphere are discussed in this section. Neither the breach mechanism nor the mechanism to move radioactive material 1400 feet from the repository to the Rustler are addressed in the following discussion.

Figure 25 shows the WIPP site, the pertinent test holes, the location of Laguna Grande de la Sal, the Pecos River at Malaga Bend, and the approximate boundaries of Nash Draw. The three Rustler aquifers in ascending order are the Rustler-Salado interface residuum, the Culebra Dolomite, and the Magenta Dolomite.

1.0 Rustler-Salado Residuum

Groundwater in the Rustler-Salado residuum flows southwest from the site with a possible discharge at Laguna Grande de la Sal, but the major discharge point is the Pecos River near Malaga Bend. In Nash Draw the transmissivity is as high as 8000 ft /day (Hale et al, 1958), but it is less than 3 x 10^{-} ft /day within 2 miles of the center of the site. In addition, the high magnesium and potassium concentration of the water (Mercer, 1983) in zone II would indicate a very restricted flow system. Therefore, the Rustler-Salado contact residuum is not considered to be a major avenue for the transport of radionuclides to the accessible environment.

2.0 Culebra Dolomite

Where hydraulic conductivity has been measured in the Rustler, the Culebra has been the most conductive layer. Hence DOE has concluded that the Culebra is the limiting aquifer for modeling studies.

The potentiometric surface map of the Culebra is presented in Figure 18. From these data one might conclude that the direction of flow from the site is due south to about the center of T 23S, R. 31E, and then southwest to a discharge point at Malaga Bend. Recent work by Gonzalez (1983) to define the anisotropy of hydraulic conductivity (Figure 25) has led to the conclusion by DOE that the flow from the site will be southeast and then westerly to Malaga Bend. The decrease in TDS and the change in water chemistry from sodium and chloride to calcium, magnesium and sulfate south of the site has been discussed in the Regional Hydrology section. Until the chemical inconsistencies are explained, the hydraulic head distribution shown in Figure 18 does not definitively show that the direction of groundwater flow is other than along a straight line to Malaga Bend. To date, the anisotropy of conductivity has been determined at only three locations; H-4, H-5, and H-6. The direction of the principal component of the transmissivity tensor is nearly identical at test pads H-5 and H-6. At H-4, the direction of the principal component of the transmissivity tensor is rotated about 50° counterclockwise in relation to H-5 and H-6. No data on anisotropy are available at the center of the site or to the southeast. Additional anisotropy tests are needed to accurately predict the direction of groundwater flow in the fractured Culebra Dolomite.

When the direction of groundwater flow and specific discharge are firmly established, the speed at which the solutes will travel is dependent on the effective porosity and the distribution coefficient. Gonzalez (1983) has performed a number of tracer tests to estimate effective porosity. The results of two tracer tests, at test pads H-2 and H-6 yield different results.

The recirculating tracer test at test pad H-2 yielded an effective porosity of 18 percent. The convergent tracer test at test pad H-6 yields effective porosities of 0.7 and 11 percent. These results point out some very interesting aspects of solute transport in the Culebra.

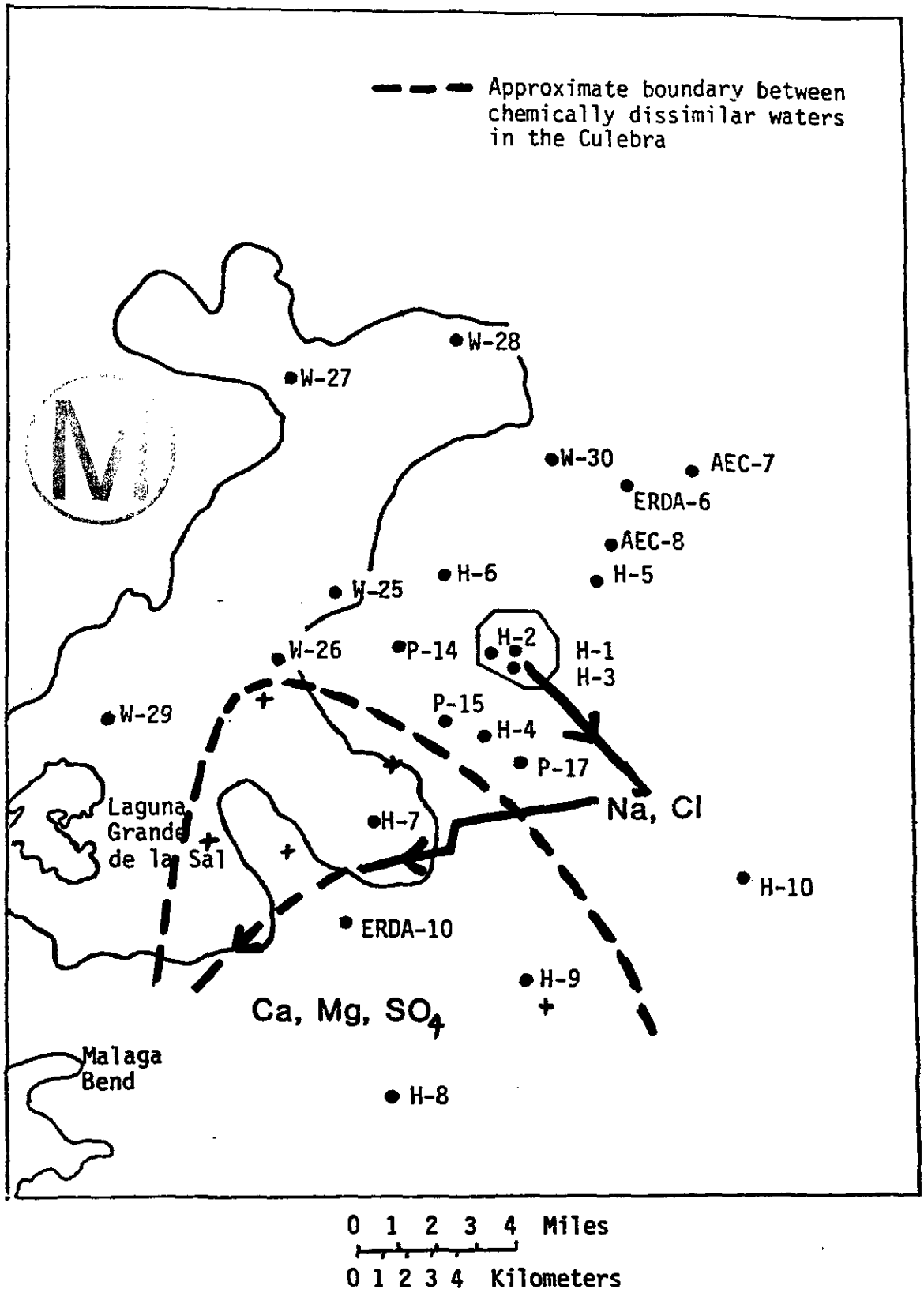

Figure 25. Particle flow path estimates 1983 in the vicinity of the WIPP site. Major chemical constituents of the Culebra water are indicated (based on Gonzalez, 1983)

Groundwater flow in the Culebra through fractures (Gonzalez, 1983; Weart, 1983; Mercer, 1983) is dramatically displayed by the H-6 tracer test. The three well configuration (labeled a, b and c) was an equilateral triangle, 100 feet on each side, with pumping from well "c" and tracer injection into the other two. The peak concentration in the b-c direction was 10 times greater and arrived 30 times faster than the peak concentration in the a-c direction. As the hydraulic conductivity in the b-c direction is at most 2.1 times greater than the hydraulic conductivity in the a-c direction, the travel time differences were attributed to differences in effective porosity. This assumption implies an equal flow path length, but this may be a poor assumption in fractured media.

While the b-c well pair may have intersected the same fracture, the a-c well pair may not. The b-c flow path would have been nearly a straight line whereas the a-c path could have been extremely tortuous thereby causing a long flow path. This interpretation would not be inconsistent with the hydraulic conductivity data. The water level response in well "a" due to pumping in "c" is a pressure response in the confined Culebra aquifer and does not signify the movement of large amounts of water.

Because the tracer tests force the groundwater and tracer to flow in a specific direction, the flow may or may not coincide with the preferred natural flow direction. Parameters derived from an artificial flow test may not be the appropriate parameters to use in a natural flow situation. The apparent variability of effective porosity in the H-6 tracer experiments is significant because effective porosity exhibits such a strong influence on calculated water velocities.

Although water transit times in Nash Draw are rapid, the controlling times are associated with the relatively small permeabilities observed near the center of the site. If the hydraulic conductivity at H-1 (0.003 ft/d) and an effective porosity of 0.18 (from the H-2 tracer test) are representative of the site, then transit times are long. If the hydraulic conductivity at H-3 (0.86 ft/d) and an effective porosity of 0.007 (from the H-6 tracer test) are representative, transit times are short.

The lack of anisotropy data at the site severely limits the confidence one can place in any model results. In fractured media, such as the Culebra, the hydraulic gradient does not necessarily indicate the direction of groundwater flow. In fact, the flow direction could be nearly parallel to the hydraulic head contours. The unexplained decrease in TDS and a change in the general chemical nature of the Culebra water from sodium and chloride at the site to magnesium, calcium, and sulfate south of the site indicates that insufficient data are presently available to adequately characterize the flow system south of the site. The anisotropy of hydraulic conductivity at the site must be determined before the flow direction can be postulated. The tracer tests provide information on the transport of conservative solutes, but these tests generate artificial flow systems. In fractured media, these tracer tests may not provide the proper data to use in modeling the transport of water and solutes in a natural flow system. However, the tracer tests are the only means currently available to estimate the solute transport parameters in a reasonable amount of time.

The hydologic testing program conducted by Sandia National Laboratories is ongoing. Future testing is planned at the site and to the south and southeast. These additional tests will hopefully provide adequate data to confidently model the groundwater flow direction and velocity at the site.

Until the Culebra groundwater flow system is adequately understood, consequence analysis scenarios that assume essentially a straight line connection between the site and the nearest probable discharge point, Malaga Bend are valid. EEG has modeled the consequences of 3 scenarios in which a repository breach injects radioactivity into the Culebra aquifer (Greenfield, 1979; Wofsy, 1980; Spiegler, 1981). In two scenarios transport is assumed to be straight from the site to Malaga Bend with discharge into the Pecos River. Both analyses are conservative, but may not be bounding. The largest calculated one year exposure for an adult drinking Pecos River water containing radionuclides is less than 10 mrem to the bone (Greenfield, 1979). This scenario is conservative in that a large rate of waste dissolution was assumed, but it is not conservative in terms of groundwater velocity. The second scenario (Wofsy, 1980) is a sensitivity analysis which examined the consequences of plutonium transport only. The maximum exposure for the adult whole body 50-year dose commitment from drinking Pecos River water is

less than 1 mrem. Neither scenario uses concentration (pCi/ℓ) as an input initial condition, but rather uses rates (pCi/sec). Concentration scenarios m be more appropriate for some scenario analyses.

The third scenario examined the consequences of using contaminated water from a well located three miles from the site. Accounting for desalinization, radioactive decay, secondary water treatment, and solute retardation in the aquifer, the 50-year bone dose commitments from one year of drinking treated water contaminated with U-233 or Pu-239 and Pu-240 were found to be 132 mrem for an adult and 217 mrem for a child.

These doses are not significant when one considers that doses from natural background radiation are between 60 and 100 mrem per year. The dose calculated from scenario 1 (Greenfield, 1979) could be slightly higher than 10 mrem if faster travel times are used. In any event, precise knowledge of the groundwater flow regime in the Culebra Dolomite is needed to insure that the scenarios are bounding. If the flow from the site is to the southeast then the consequences at a Pecos River discharge point should be less than those obtained from the above scenarios. If, however, the fracture network at the site directs flow t the southwest into Nash Draw, rapid transport times could result in larger doses than indicated by the scenarios.

3.0 Magenta Dolomite

The potentiometric surface map for the Magenta is presented in Figure 21. This aquifer has not been considered as a major vehicle for solute transport by DOE largely because of its relatively low hydraulic conductivity (Gonzalez, 1983).

There are no data for the Magenta on effective porosity, anisotropy of hydraulic conductivity, or dispersivity near the site. It appears that fracture flow in the Magenta is less prominant than in the Culebra (Mercer, 1983). Therefore, the Magenta may be best represented by porous media flow analyses. Magenta water at the site appears to discharge into underlying units near Nash Draw (Mercer, 1983), however, there are no direct observations of such discharge.

The Magenta is not the major avenue for radionuclide transport in the Rustler based on the currently available data. However, if ongoing studies of the Culebra lead to extremely long radionuclide travel times to the accessible environment then hydrologic transport in the Magenta should be considered.

4.0 Solute Retardation

Many radionuclides do not travel at the same velocity as the water, but move at a slower, retarded velocity. The low radiation doses calculated for the hydrologic breach scenarios (ref. Greenfield, 1979; Spiegler, 1981) result in part from the fact that the K_d value greatly retards the rate at which plutonium travels. A sensitivity analysis (Wofsy, 1980) showed that if K_d of plutonium were greater than 10, the effective porosity had little effect on the radiation doses at the Pecos River.

The laboratory measurements are generally performed on powdered rock samples thereby greatly inceasing the rock surface area (Dosch and Lynch, 1978; Dosch, 1980; Lynch and Dosch, 1980)). K_d is generally reported as the mass of solute on the solid phase per unit mass of solid phase divided by the concentration of solute in solution. In fractured media it is better to report the distribution coefficient on a per-unit-surface-area basis (Freeze and Cherry, 1979). Porous secondary material filling some fractures in the Culebra may justify the use of K_d on a per-unit-mass-basis. Laboratory measurements of K_d values may not reflect field conditions. For example, small amounts of plutonium or other elements will decrease the capacity of the rocks to adsorb more plutonium; thus a "loading effect" can reduce K_d values. Chelating agents like EDTA can also reduce K_d values, as can temperature, pH and other physical and chemical factors. The appropriate K_d to use for scenario analyses is not established. Therefore, until in-situ K_d data are available, the smallest reported K_d value should be used to have truly conservative scenarios.

5.0 Possibility of Karst Hydrology in Rustler

A gravity survey was carried out at the WIPP site by Sandia National Laboratories, during 1981-82, with a primary purpose of delineating the "Disturbed Zone" structures within the Castile formation. The field parameters

for this study were selected to resolve low-amplitude, broad-wavelength anomalies originating from structures within the Castile formation, more than 3000 ft. below the surface at WIPP (Barrows, 1982). Instead of the anticipated signals, the survey revealed a complex pattern of high-amplitude and short-wavelength negative anomalies. Barrows (1982) interpreted these anomalies as resulting from density (and acoustic velocity) alterations in the vicinity of karst channels. Borns et al. (1983) have presented this as the only interpretation of the gravity data with a disclaimer that the other authors of that report do not necessarily agree with it and it also does not imply endorsement by Sandia National Laboratories. The discussion presented in Borns et al. (1983, p. 3-9) rules out the possibility that the lateral density variations interpreted from the gravity data are caused by facies variations. Weart (1983) states that the negative gravity anomalies might be caused by low-density channel fillings in the Dewey Lake Redbeds.

5.1 Observations Supporting the Presence of Karst

Barrows (1983) compiled other observations besides the negative gravity anomalies to support his conclusion that karst channels exist in the Rustler formation. His observations are summarized below.

5.1.1 Rustler Thinning: The Rustler formation is about 475 feet thick in the southeast corner and about 300 feet thick in the northwest corner of the WIPP site (GCR, Fig. 4.3-8 and Snyder 1983, Fig. 2.25). Barrows cites this "thinning" of Rustler as an example of, "a complex interstratal blanket karst involving halite, anhydrite-gypsum, and, to a lesser extent, dolomite." According to him, if the thinning were caused by dissolution by confined water, it should have proceeded in the direction of flow of the aquifers, which is to the southwest. Therefore, he argues, that "a more likely process involves easterly progressing karst development with downward infiltration of fresh water through feeders in the overlying Dewey Lake formation to karst channels in the Rustler formation.

5.1.2 Closed Depressions: There are a large number of depressions at the WIPP site. The smaller ones may be due to wind deflation but the larger ones can only be reasonably attributed to alluvial dolines, which form when loose surficial material is washed into solution cavities in the underlying rocks. The WIPP-3 depression is a good example of such a doline.

5.1.3 The WIPP 33 Cavities: The borehole WIPP 33, located in Zone IV in the northwest part of the WIPP site, encountered four cavities totaling slightly over 20 feet in the forty-niner and Magenta Dolomite members of the Rustler formation. According to Barrows, these cavities are direct evidence of karst and they demonstrate the relation between alluvial dolines, negative gravity anomalies and karst channels in the Rustler formation.

5.1.4 Lack of Surface Runoff and the Water Balance: Barrows points out that there are about 12 inches of annual rainfall at the WIPP site, most of which falls between May and October. Since the WIPP site has almost no visible surface runoff, Barrows claims that the precipitation collects in the small topographic depressions and rapidly soaks into the ground.

5.2 Observations Doubting the Presence of Karst

Weart (1983, p.20) gives several reasons to doubt the existence of karst conditions over the WIPP site. These are briefly discussed below.

5.2.1 Lateral Movement of Water: The alteration in the Rustler formation is carried out by lateral movement of water along beds of fractured (permeable) anhydrite and should not be ascribed to vertically downward moving waters.

5.2.2 The WIPP-33 Cavities: Features such as WIPP-33 sink is a manifestation of the eastward growth of dissolution along fingers extending from Nash Draw.

5.2.3 Closed Depressions: The depressions interpreted as dolines by Barrows (1982) may have resulted by wind deflation.

5.2.4 Hydrologic Tests: The data from pump tests shows no indication of karst channels underlying the site.

5.2.5 Water Table: There is no free water-table at WIPP and karst development usually requires this condition.

5.2.6 Gravity Anomalies: The negative gravity anomalies might be caused by low-density channel fillings in the Dewey Lake Redbeds.

5.3 Implications of Karst Hydrology

Calculations based on the hydrologic parameters measured in boreholes and tracer tests yield extremely long (5000 years to 40,000 years) travel times of water through the Rustler formation at the WIPP site to the Pecos River at Malaga Bend (Gonzalez, 1983). If karst channels exist in the Rustler formation, the travel time for the tranport of radionuclides in the Rustler formation might be drastically reduced if a breach occurred that would bring radioactive material up into the Rustler.

5.4 Discussion

EEG organized a field trip on May 11, 1983 to afford Larry Barrows an opportunity to point out the field evidence for the presence of karst at the WIPP site. The field trip was attended by 20 geologists and geohydrologists including some of the well known experts in this area. In addition, Harry Legrand has written two brief reports for EEG on this question. The following discussion is based on the views expressed by LeGrand and others in writing, during the field trip on May 11 and during the discussions at the meeting in Carlsbad on May 12 and 13, 1983.

The most direct evidence for karst features near the WIPP site is the sink hole at WIPP-33, approximately 3 miles northwest of the center of the site. The few closed depressions near the site seem to be too conspicuous to have been caused by wind deflation, yet do not show features of typical sinkholes. The hydrologic tests may not detect the presence of fine karst. Even though the Rustler aquifers are under artesian conditions, there are examples at several locations worldwide where karst can develop under such conditions. The gravity anomalies at the site can be interpreted in more than one way. There is sufficient sand and vegetation at the site that very little, if any, water may percolate down into the fractured rock, although careful water balance studies have not yet been conducted. The unconsolidated sand deposits at the surface of the site would facilitate rapid infiltration of precipitation. The depth of infiltration will determine whether the water returns to the atmosphere by evaporation or recharges the groundwater. Most of the hydrologic testing in Zones III and IV of the WIPP site shows the Rustler aquifers to be extremely

tight with very low hydraulic conductivities, but the Well H-3, in Zone II shows an anomalously high hydraulic conductivity compared to H-1 and H-2. However, preliminary flow net analyses by EEG indicate that the H-3 hydraulic conductivity is consistent with the potentiometric surface and that the H-1 and H-2 data are anomalous. Finally, the mechanics of removal of halite from the Rustler formation, without invoking vertical infiltration of water at the WIPP site, should be understood.

EEG concludes that although there is very little evidence for the presence of karst conditions east of the western margin of Zone III of the WIPP site, some additional work should be done to completely settle this issue. Recommendations for the additional work include the water balance study, the understanding of the mechanics of salt removal from the Rustler formation, exploration of at least one depression e.g. in Sec. 30, about two miles SW of the center of the site and continued evaluation of the Rustler aquifer hydrology. These recommendations are outlined in more detail at the end of this chapter.

6.0 Dispersion

Dispersion in groundwater flow is a spreading phenomenon that leads to a dilution of the solute. This generally leads to reduction of the peak concentration in comparison to models where dispersion is ignored. An additional phenomenon of dispersion is that a portion of the solute travels faster than the mean velocity. This may be important in situations where first arrivals, rather than peak concentrations, are of paramount concern.

Dispersion is generally ignored in scenario analyses as a means of making the analyses more conservative. If more realistic results are desired, the dispersivity is required. It is not clear, however, that dispersivities obtained from tracer tests which create an artificial flow system are accurate estimates of the parameters applicable to natural flow systems.

7.0 Site Qualification Criteria

It is important for EEG to evaluate how well the WIPP satisfies proposed criteria for nuclear waste repositories. Of concern in this discussion are the criteria that specifically relate to groundwater.

7.1 DOE WIPP Site Qualification Factors (Criteria)

Weart (1982) lists four Site Qualifiction Criteria pertaining to groundwater. The criteria and EEG's determination of how well the WIPP satisfied the criteria are presented below.

Criterion 11.1:

> "Facility and related shafts must not adversely affect existing aquifers which are, or could be, sources of water supply for humans or animals."

Only two aquifers could be affected by the shafts; the Culebra and the Magenta. Perched groundwater, although present in scattered locations near the site, was not encountered during the sinking of either shaft. At the site, neither the Culebra nor the Magenta are likely to be sources of water to humans or animals. Irrespective of that, the sealing of the Rustler in the 12 foot exploratory shaft suggests that in the short term the aquifers will be unaffected. The WIPP appears to satisfy criterion 11.1.

Criterion 11.2:

> "The underground facility must be able to be isolated from waterbearing strata and must not, itself, be located in a water-bearing stratum (stratum which will yield water to a drillhole under the influence of gravity alone)."

The repository level is separated by about 1300 ft. of bedded halite from the overlying Rustler Formation. There is about 1900 feet of interbedded halite and anhydrite between the repository horizon and the top of the Bell Canyon Formation. If the borehole and shaft plugging programs are successful, the respository will be isolated from the water-bearing strata.

Potash mining operations have encountered relatively small pockets of brine in the Salado formation approximately 400 ft. above the level of the repository. These pockets would yield water to a drill hole under the influence of gravity, but to date no brine pockets are observed at the repository level. In any event, a small brine pocket or two would not define the repository horizon as water-bearing. The WIPP appears to satisfy criterion 11.2.

Criterion 11.3:

> "The hydraulic conductivity of the facility stratum must be sufficiently low (10^{-6} cm/sec or less) to prevent the flow of water through that stratum from any source which could develop after facility construction."

Some of the layers in the repository horizon exhibit hydraulic conductivities of near 10^{-6} cm/sec under light loading (Black et al., 1983). Under loadings consistent with in situ conditions, the hydraulic conductivities were much less than 10^{-6} cm/sec. The WIPP appears to satisfy Criterion 11.3.

Criterion 11.4:

> "Calculated hydrologic transport of radionuclides through the waste disposal facility and overlying strata must be slow enough that a significant hazard to humans would not exist even if the disposal stratum were breached."

Under some repository-breach scenarios, the transport of waste from the repository to the Rustler is rapid. Therefore, radionuclide transport in the Rustler aquifers is the critical factor to consider in determining whether a significant hazard to humans would exist if the disposal stratum were breached.

To adequately predict the radiological hazard to humans following a breach and transport of radionuclides in the Rustler, knowledge of the groundwater flow direction, anisotropy of hydraulic conductivity, effective porosity, and solute distribution coefficients are required.

There are no data on the anisotropy of hydraulic conductivity within 2 miles of the center of the site. These data are critical to determining the direction of groundwater flow in the fractured Culebra Dolomite. At present, the nearest

observation well southeast of the site (H-10) is 8 miles away. Additional observation wells are planned. The proposed flow path in the Culebra southeast of the site and then west to Malaga Bend (Gonzalez, 1983) is based on insufficient data. Therefore, the WIPP has not yet been shown to satisfy criterion 11.4.

7.2 NRC Criterion on Travel Time to the Accessible Environment

The NRC is proposing criteria for the Disposal of High-Level Radioactive Wastes in Geological Repositories (10 CFR Part 60). One of their requirements concerns water travel time from a repository to the accessible environment. The proposed wording in a late draft (December 1982) of this regulation is:

> "The geologic repository shall be located so that pre-waste emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such travel time as may be approved or specified by the Commission."

Definitions pertinent to an understanding of the above requirement are:

1) The "disturbed zone means that portion of the controlled area whose physical or chemical properties have changed as a result of underground facility construction or heat generated by the emplaced radioactive wastes...."

2) "Accessible environment means (1) the atmosphere, (2) the land surface, surface water, (4) oceans, and (5) the portion of the lithosphere that is outside the controlled area."

3) "Controlled area means a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure."

The intent of this requirement is to have groundwater flow time as one of the multiple barriers to "act independent of overall repository performance to provide confidence that the wastes will be isolated at least for as long as they are most hazardous" (preamble to proposed rule, July 8, 1981). It is recognzied there are uncertainties concerning this proposed NRC requirement. For example: (1) it may be changed before promulgation of 10CFR60; (2) the manner in which dispersion should be included in the travel time; (3) the interpretation of the requirement that should be applied to a bedded salt repository where circulating groundwater is not expected in the host rock; and (4) to what extent it should be applicable to a transuranic waste repository. However, it is worthwhile considering whether aquifers at the WIPP site would meet this criteria.

First it is apparent from the definition that travel time from the repository to the Rustler aquifer would be included in the 1,000 year transport time unless it is interpreted that the disturbed zone includes shafts that penetrate the aquifer. The travel time from breach to arrival at the Rustler aquifer would be greater than 1,000 years itself in several of the scenarios that have been considered. However, with a direct hydraulic connection such as Scenario #2 in the FEIS, the travel time to the Rustler aquifer would be minimal.

Weart (1983) states that recent modeling results indicate that water will move less than 2 miles in 1000 years. The minimal distance from waste emplacement to the edge of Zone III is now estimated to be about 6900 feet due south or 9700 feet in a southeasterly direction. WIPP may not meet the proposed NRC criteria.

8.0 Conclusions

The regional hydrology appears to be adequately understood except for the Rustler Formation aquifers. Of the three aquifers recognized in the Rustler formation, the Culebra represents the bounding transport mode to the accessible environment should the repository be breached and radioactive material brought into the Rustler aquifers.

The work done so far indicates a lack of a clear understanding concerning the direction of flow and the velocity of groundwater in the Culebra aquifer at

the site. Additional work is recommended to better define groundwater flow in the Culebra Dolomite aquifer. The question of karst is embodied in the need to better define the groundwater system. The karst phenomenon of concern is the development of open channels in the Culebra aquifer. The channels would greatly increase the groundwater velocity and hence reduce the groundwater travel time. Groundwater travel time refers to the time required for water to flow from the site to a discharge point at Malaga Bend. The time following emplacement that waste enters the groundwater system is the breach time.

The question of breach and radionuclide travel time is important because of the presence of short-lived radionuclides in the WIPP repository. The relative radiological ingestion toxicity hazard of the inventory decreases from approximately 1.00 at 100 years to 0.023 at 1000 years, and to 0.014 at 10,000 years. Therefore if breach and travel times to the accessible environment were only a few hundred years there would be a need to calculate the effect of the short-lived radionuclides on the dose received in the water transport scenarios.

The probability of human intrusion within 250 years after closure is low. In addition, groundwater travel times are currently estimated to be greater than 5000 years. However, the existence of karst channels could reduce groundwater travel times to less than 500 years. The probability of channeling at the WIPP site is also low, but there is still enough doubt to warrant additional testing as outlined below. The expected result of this testing will be to provide greater assurance that channeling does not exist in Zone II and, thereby, improve the confidence that the present scenarios are conservative.

9.0 RECOMMENDATIONS

9.1 Analysis of drawdown data in test holes H-1, H-2, H-3 caused by the open vent shaft. These data can be interpreted as a large scale pumping test and may yield estimates of average aquifer parameters. In addition, the presence of large karst channels should be detectable from the data. Small channels, however, will likely not be detected.

9.2 Computer modeling of groundwater flow in the Rustler Aquifers. This will help determine if the measured aquifer parameters through well testing

represent the larger area. In addition, the model will help identify recharge to and discharge from aquifers, and leakage between aquifers.

9.3 Publish the results of transport modeling using concentration as an input.

9.4 Long duration pumping at test well H-3, in conjunction with careful monitoring of groundwater levels in H-3 and surrounding wells. This will indicate whether the relatively high hydraulic conductivity at H-3 is of limited areal extent or whether it represents a zone of high hydraulic conductivity extending over a large area.

9.5 Measure the anisotropy of the hydraulic conductivity at test pads H-1, H-2 and H-3.

9.6 Perform convergence tracer tests at H-1, H-3 and H-4. Items 9.4 and 9.5 will yield valuable data for the radionuclide transport modeling. In the March, 1983, Project progress Report (WIPP-DOE-156), DOE states that a tracer test at H-4 is in progress, but no data are yet available.

9.7 Perform tracer test (convergence) at H-6 using sorbing tracers. The K_d of such tracers from the H-6 field test will then be compared to laborator derived K_d using the same tracer and Culebra rock to determine if laboratory derived values are applicable to the field situation.

9.8 Analyze for environmental isotopes (Carbon-14, Chlorine-36, Uranium-234, and Uranium-238) to aid in understanding the groundwater flow direction an relative velocity.

9.9 Drill the planned additional hydrologic testing wells, viz. H-11 and H-12. Obtain the cores while drilling these wells and examine the cores to determine the extent of fracturing and solution residues, which may indicate possible movement of water through zones other than the two dolomite aquifers.

9.10 Conduct a water balance study for the WIPP site.

9.11 Study the mechanics of removal of salt from the Rustler formation at and near the site.

9.12 Drill a shallow hole in the depression in Sec. 30 (SW 1/4) using an auger to determine the depth of soil and the presence of the caliche layer. This would help answer whether it is a sink hole or a wind deflation feature.

10.0 References Cited

Barr, G. E., Miller, W. B., and Gonzalez, D. D., 1983, Interim Report on the Modeling of the Regional Hydraulics of the Rustler Formation, Sandia NationalLaboratories, Report SAND 83-0391.

Barrows, L., 1982, WIPP Geohydrology - The Implications of Karst, unpublished manuscript, May 1982, 21 p.

Black, S., Newton, R., and Shukla, D., eds., 1983, Results of SPDV Site Validation Experiments, Waste isolation Pilot Plant, TME-3177.

Borns, et al., 1983, Deformation of Evaporites Near the WIPP Site, SAND 82-1069.

DOE, 1983, Summary of the Results of the Evaluationof the WIPP Site and Preliminary Design Validation Program, Report WIPP-DOE-161.

Dosch, R. G., 1980, Assessment of Potential Radionuclide Transport in Site-SpecificGeologic Formations, Sandia National Laboratories, Report SAND 79-2468.

Dosch, R. G., and Lynch, A. W., 1978, Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) Site in New Mexico, Sandia National Laboratories, Report SAND 78 - 0297.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater, Prentice Hall.

Greenfield, M. A., 1979, Simple Model for Estimating Maximum Radionuclide Concentrations in the Pecos River, and Associated Ingestion Doses, due to

the Release of Radioactivity from the WIPP Repository, Appendix VI in Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, ed. by Neill, R. H., Channell, J.K., Wofsy, C., and Greenfield, M. A., EEG publication EEG-3.

Gonzalez, D. D., 1983, Groundwater Flow in the Rustler Formation, Waste Isolation Pilot Plant (WIPP), Southeast New Mexico (SENM): Interim Report, Sandia National Laboratories, Report SAND 82-1012.

Hale, W. E., Hughes, L. S., and Cox, E. R., 1958, Possible Improvement of the Quality of Water of the Pecos River by Diversion of Brine at Malaga Bend, Eddy County, New Mexico; Pecos River Commission, New Mexico and Texas, and U. S. Geological Survey.

Lynch, A. W., and Dosch, R. G., 1980, Sorption Coefficients for Radionuclides on Samples from the Water-Bearing Magenta and Culebra Members of the Rustler Formation, Sandia National Laboratories, Report SAND 80-1064.

Mercer, J. W., 1983, Geohydrology of the Proposed Waste Isolation Pilot Plant Site,Los Medanos Area, Southeastern New Mexico, U. S. Geological Survey, Water Resources Investigations Report 83-4016.

Spiegler, P., 1981, An approach to Calculating Upper Bounds on Maximum Individual Doses from the Use of Contaminated Well water Following a WIPP Repository Breach, EEG report EEG-9.

Snyder, R. P., 1983, General Site Geology, Chapter 2 in Deformation of Evaporites Near the WIPP Site, by Borns, D. T. et al., SAND 82-1069 (Draft).

Weart, W. D., 1983, Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability, Sandia National Laboratories, Report SAND 83 - 0450.

Wofsy, C., 1980, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, EEG report EEG-8.

NATURAL RESOURCES AT WIPP

1.0 Introduction

This review discusses the extent of natural resources at the WIPP site, and the results of EEG's analysis of the potential effect of removal of certain of these resources on the integrity of the repository. To ensure consideration of all important aspects of the question of resources, the subject will be divided as follows:

- The nature and extent of resources at WIPP;
- Provisions of important criteria and standards which relate to resources;
- The U.S. Department of Energy's (DOE) Interim Policy on Resource Recovery at WIPP;
- The potential effect of exploration for or removal of resources on the integrity of the repository;
- Summary and conclusions.

The presence of scarce or easily accessible resources at a site under consideration for a nuclear waste repository is undesirable for two reasons: a) efforts at exploration or removal of the resources could lead to structural alterations of the site which over the long term would increase the potential for breach and release of the radioactive nuclides to the biosphere; or b) there is a possibility that it would be necessary to permanently prohibit access through institutional controls and therefore they represent an additional cost consideration. The question of resources is fraught with uncertainty because of the difficulty of assigning values to the resources and degree of technical sophistication to populations thousands of years into the future. Indeed, it may well be that the waste itself will prove to be a resource of the future. For this reason, it is not reasonable to conclude that any site is without resources or is free from the potential for human intrusion or damage.

2.0 Nature and Extent of Resources at WIPP

The known resources at WIPP include caliche, gypsum, halite, potash, possibly lithium, and hydrocarbons. (Most of the hydrocarbons are natural gas and distillate). Several contractors, both private and government, were involved in the evaluation of resources at the site. These are listed in Table 4, and the reports are further described in the references. Table 5 provides a summary of the known resources and the estimated quantities.

2.1 Caliche

Large quantities of caliche are used in New Mexico for road surfacing, however because of extensive deposits in the region, and since it is near the surface and about 2000 feet from the repository horizon, it is not considered to be of potential consequence to the repository.

2.2 Gypsum

Gypsum is found mostly in the Rustler formation, but the quality and bed thickness is inferior to those deposits found west of the site, where it is readily mined by open pit methods. Very large deposits of gypsum are also found in California, Michigan, Iowa, and Oklahoma. These sources account for 62% of the U.S. production. Most of New Mexico's gypsum production is from mines located in Sandoval and Santa Fe counties (about 250,000 tons/yr.). Therefore, it is not likely that gypsum from the WIPP area will ever be of commercial interest, and because of its location in the Rustler, it could be removed without imposing a threat to the repository horizon.

2.3 Halite

Halite in the Salado underlies the entire area of the WIPP site from about 170 meters down to 870 meters below the surface. It is from 90 to 98% pure sodium chloride, but an even purer grade is found in portions of the Castile formation. The Salado salt is interbedded with anhydrite, polyhalite, sandstone and claystone in a regular succession, and in

discrete layers that range from 2 cm. to several meters in thickness. The Salado at the WIPP site also includes a zone of potassium minerals, sylvite and langbeinite as discussed below. The total thickness of the Castile salt is about 170 meters at the WIPP site. The leading producers of salt are in Louisiana, Texas, New York, Ohio, and Indiana. About 80% of the annual production is used in chemical manufacturing, and from 12 to 25% for highway deicing. It has been estimated that as much as 61 trillion tons (Klingman, 1975) exist underground in the U.S. as rock salt or as brine. Also, sea water represents an almost inexhaustible source of salt. The U.S., therefore, has unlimited salt resources. There is some salt production in southeastern New Mexico, mostly from the Salt Lake Mine (about 108,000 tons/yr.). Salt is also produced from the Zuni Salt Lake in west central New Mexico. It is likely that brine lakes and potash tailing piles could meet New Mexico's salt needs indefinitely, and that bedded salt at the WIPP site probably will not become economically attractive for several reasons:

- These resources are more than 165 meters below the surface;
- There are plentiful surface supplies of salt in New Mexico;
- At the regional and national level there are virtually unlimited salt reserves which are more economically attractive;
- Water supplies for processing the rock salt are not readily available in the area.

2.4 Potash

The potash resources within the WIPP site are summarized in Table 6 and Fig. 26. Reserves are those resources which are economically recoverable at current prices and removable with existing technology. Most of the potassium ore at the WIPP site lies between 420 and 550 meters below the surface. The estimates of these resources have been reported by John, et al, (1978) of the U.S. Geological Survey (USGS) and are based on a total of 61 holes drilled by industry and 21 by DOE in the vicinity of the site. The U.S. Bureau of Mines (1977) evaluated the extent to which the resources defined by USGS could be classified as reserves.

Resources were considered to be ore zones of at least 4 feet and with sylvite (KCL) and langbeinite ($K_2Mg_2(SO_4)_3$) of at least 8% and 3% richness respectively in K_2O equivalent. Reserves are those deposits having at least 14 and 8% richness in K_2O equivalent. On this basis, the total potash resources within the four zones of WIPP was estimated to be 484 million tons. Of these resources, 132 million tons were considered reserves. Sixty-seven percent of the potash resources are within Zone IV. Sixty-eight percent of the langbeinite and 82% of the sylvite reserves are recoverable from Zone IV. Because of limited water in the area, and solubility considerations, the more likely method of removal would be by underground (room and pillar) mining.

In summary, the nonretrievable potash resources within Zones I, II and III is estimated as 38 million tons of sylvite and 122 million tons of langbeinite. The non-retrievable langbeinite represents 7% of the known U.S. resources of this mineral.

2.5. Lithium

Powers, et al, (1978), in the WIPP Geological Characterization Report (GCR), recognized the existence of brine reservoirs containing potentially economic concentrations of lithium (at that time thought to be 140 mg/l at ERDA-6 well, 6 miles northeast of the center of the site). Brine reservoirs have been encountered in the Castile formation on several occasions around the WIPP site (DOE, 1983). The DOE in the GCR concluded on the basis of seismic data that no brine pockets existed within the WIPP site, and therefore stated that lithium is not a potential resource at WIPP. In 1981, however, a brine reservoir was encountered at the northern boundary of Zone II and following extensive studies of the reservoir, it was estimated to contain 17 million barrels of saturated brine having a lithium content of 280 mg/l. ERDA-6 brine pocket was reassayed and found to contain 240 mg/l, and the brine pocket at Union Well (about 3/4 mile northwest of ERDA-6) contained 360 mg/l (DOE, 1983). On this basis, one might conclude that lithium is a potential resource and considering only the WIPP-12 reservoir, the extent of the lithium resources may be as high as 800 tons. It is also of

interest to note that the lithium contents of the brine are not nearly as high as in Searles Lake and other non-marine evaporite areas. The United States has reserves in excess of 400 times the amount consumed (as of 1975), much of this Li is from brines in which the average Li content is well over 0.1 percent (as compared to the 0.03% in Delaware Basin brines). The U.S. also supplies about 60% of the World Common Market lithium as well. It is unlikely that the Li content of the Delaware Basin brines will be able to compete with other reserves. It also is likely that removal of the brine at WIPP-12 would not lead to a breach of the WIPP repository with transport of the waste to the accessible environment at a substantially accelerated rate. Therefore, the consequences of this resource recovery are bounded by scenarios already considered.

Because of restrictions on deep drill holes within the site to preserve a buffer zone around the repository, the evaluation of the potential hydrocarbon resources was based on a statistical area survey around the site (Foster, 1974). The economic evaluation of these potential resources was then conducted by Keesy (1976). He concluded that there is a high potential for natural gas in the Morrow unit, but too much of an economic risk for other hydrocarbons. These results are summarized in Table 7. Of course, since Foster's study used a regional statistical approach, there may be considerably more or less than the average quantity of hydrocarbons if the site were actually drilled. Therefore, it is possible that significant reserves of oil also exist within the site.

3.0 Criteria and Standards

Although there are numerous criteria, regulations and guidelines which bear on the subject of site suitability, this report will examine only those which relate to the question of natural resources at a site under consideration for high-level or transuranic waste.

3.1 EPA Proposed Standards

On December 29, 1982, the Environmental Protection Agency (EPA) published proposed "Environmental Standards for the Management and Disposal of Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" (47 FR 58196). These standards apply "to radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel, high-level, or transuranic radioactive wastes to the extent that these operations are not subject to the provision of Part 190 of Title 40." (Part 190 of Title 40 applies to environmental protection for nuclear power operations.) Section 191.14(f) of these standards states that.

> "Disposal systems shall not be located where there has been mining for resources or where there is a reasonable expectation of exploration for scarce or easily accessible resources in the future. Furthermore, disposal systems shall not be located where there is a significant concentration of any material which is not widely available from other sources."

Furthermore, there is no provision for a variance from this subpart of the proposed regulation. The above provision also is not as explicit as one might like, certain passages from the published preamble add to the uncertainty of the intended meaning:

> "This requirement (section 191.14(f)) would discourage the use of geologic formations which are often associated with resources or mining activity. For example, the frequent mining of salt domes either for their relatively pure salt or for use as storage caverns would argue against locating a repository in this type of structure. However, this same concern would generally not apply to bedded salt deposits because they are much more common." (Certain words are underlined for emphasis.)

Thus, one would conclude that EPA did not intend to prohibit use of geologic formations which are associated with resources, but only discourage such use. Also, the EPA either was not aware of the resources frequently associated with bedded salt (potash, hydrocarbons, etc.) or did not consider these resources to be as threatening to a repository as the commercial activities associated with salt domes.

3.2 NRC Proposed HLW Regulations.

The Nuclear Regulatory Commission (NRC) published on July 8, 1981 its proposed regulations for "Disposal of High-Level Radioactive Wastes in Geologic Repositories" (48 FR 35280). Subsection 60.122 (c)(18) of Siting Criteria of a draft of the final NRC regulation defines as one of several "potentially adverse conditions":

> "(18) The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such form that: (i) economic extraction is currently feasible or potentially feasible during the foreseeable future; or (ii) such materials have greater gross value, or net value, than the average for other areas of similar size that are representative of and located in the geologic setting."

Although WIPP is exempt from NRC licensure and the NRC regulations, if the site were evaluated against these criteria, one would conclude that the WIPP site has adverse conditions as described with respect to natural resources and when adverse conditions exist, the NRC regulations would require additional analysis, specific site characterization or identification of compensating or mitigating factors before qualifying the site.

A comparison of the WIPP site to the two standards discussed above is summarized in Table 8. In conclusion, the WIPP site appears to have adverse conditions by virtue of the of the natural resources. It was on this basis that EEG recommended that DOE indicate its plans for control of exploration and recovery of the resources, and analyze the consequences of such exploration and recovery.

4.0 DOE Interim Policy on Resource Recovery at WIPP

By letter of January 6, 1983, from the Project Manager, WIPP Project Office, DOE provided EEG its revised Interim Policy Statement. This policy authorizes resource recovery from Zone IV (see Figure 26), but would prohibit mining or drilling within Zones I, II, or III. The policy also allows hydrocarbon recovery from Zone I, II, or III by deviated drilling from Zone IV provided the planes formed by the downward vertical projections of the Control Zone III boundary are not penetrated above 6000 feet.

The policy would also allow solution mining for potash in Zone IV, but is silent on whether castile brine reservoirs under Zone I, II, or III could be accessed from outside of Zone III (eg. to obtain brine for extraction of lithium). One would infer that the 6000 foot restriction would prohibit removal of brine from Zones I, II or III, but if the brine extends into Zone IV, it may be accessible without violating that restriction.

The EEG asked DOE to notify EEG of any requests for mining within one mile of the zone III boundary, but DOE replied that they would notify EEG of any unusual or advance technology planned resource recovery activities which are made known to them by Bureau of Land Management, Department of Interior (BLM).

For this reason, the State intends to negotiate with BLM to obtain notification from BLM of any applications for mining activity within 1 mile of the Zone III boundary. Upon notification, EEG plans to evaluate such proposals and provide appropriate comments, if any, to BLM and DOE, concerning the potential effects on the repository horizon.

5.0 The potential effects of exploration for or removal of resources on the integrity of the repository.

The DOE has considered the consequences of several breach and release events including some which may occur long after the repository is sealed and controls are discontinued and records lost (DOE, 1980, Woolfolk, 1982). Several of these scenarios could occur as a result of drilling activities associated with exploration or mining of resources. In all cases, it was concluded that the resultant radiation doses would be only a small fraction of that from natural

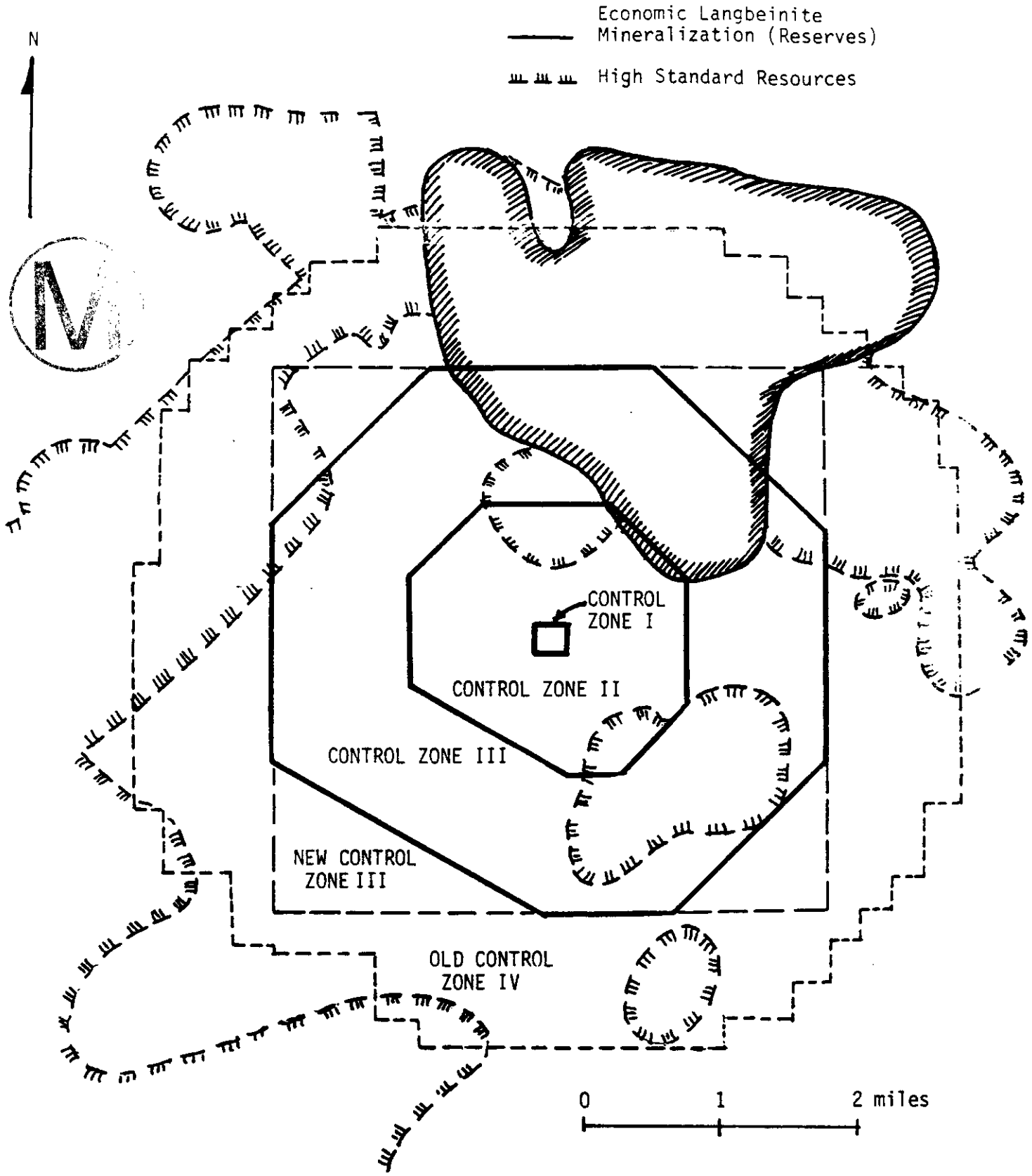

Figure 26. Potash deposits at the WIPP site.

background radiation. The proposed permanent TRU waste inventory (with no high level waste) was used for all such calculations. The EEG has evaluated certain of the models used in these scenarios (EEG-3), and independently considered several other hypothetical breach events associated with human intrusion (EEG-11, 12, 15, and 16). All of these involve low probability events, each associated with considerable uncertainty. Because of the differing assumptions used, the doses are not comparable, but they do suggest that even with conservative assumptions the associated long-term radiation risks of releases associated with natural resource recovery are generally only a small fraction of normal background radiation.

In compliance with one of the terms of the Stipulated Agreement between the DOE and New Mexico (Civil Action of the U. S. District Court for the District of New Mexico, 81-0363, July 1, 1981), the DOE has provided an analysis of the effects of resource recovery if carried out in accordance with the DOE Interim Policy (DOE, 1982). An earlier draft of this report was reviewed by EEG and the revised report (DOE, 1982) was responsive to the EEG comments and recommended changes. The report did not address the effects of brine removal from the WIPP-12 reservoir because at the time of this report, lithium was not recognized as a potential resource. It is likely, however, that such resource recovery is bounded by events already considered. The report also failed to consider bedded salt as a resource. Although EEG agrees that the probability of solution mining of halite from the WIPP site is unlikely, for reasons previously discussed, the potential consequences of such a conservative scenario were considered (EEG-12), and it was concluded that the associated risk is quite small.

Table 4*

Organizations Responsible for Resource Evaluation and Key Reports Concerning Resources

Organization	Responsibility	Reports
U.S. Geol Surv.	Potash Resources as related to ore grade and volume	John et al. (1978) Jones (1978)
U.S. Bur. of Mines	Determination as to what extent the potash resources reported by U.S.G.S. could be economically mined and refined under today's technology and market	USBM (1977)
N.M. Bur. of Mines	Definition of resources and economics for caliche, salt, gypsum, brine, sulfur and uranium	Siemers et al. (1978)
N.M. Bur. of Mines	Oil and gas resources of a four township area which includes the WIPP site	Foster (1974)
Sipes, Williams and Aycock, Inc.	Determination of the economic viability of hydrocarbons under the WIPP site	Keesey (1976)
G.J. Long & Assoc. Inc., Permain Exploration Co.	Interpretation of structure of Paleozoic sediments beneath Ochoan evaporites. These studies were useful in evaluation of hydrocarbons	Long (1976), McMillan (1976)

*From Powers, D. W., et al, 1978.

Table 5. Total Mineral Resources at the WIPP Site*

Resource	Quantity	Depth (ft)	Richness
Caliche[a]	185 million tons	At surface	21-69% insoluble
Gypsum[a]	1.3 billion tons	300-1500	Pure to mixed
Salt[a]	198 billion tons	500-4000	Pure to mixed
Sylvite ore[b]	133.2 million tons	1600	8% K_2O, 4-ft thickness
Langbeinite ore[b]	351.0 million tons	1800	3% K_2O, 4-ft thickness
Lithium[e]	800 tons	3050	240 mg/ℓ brine
Crude oil[c]	37.50 million bbl	4000-20,000	31-46° API[d]
Natural gas[c]	490.12 billion ft^3	4000-20,000	1100 Btu/ft^3
Distillate[c]	5.72 million bbl	4000-20,000	53° API[d]

[a]Data from Siemers et al. (1978).

[b]Low-grade resource and better. Data from John et al. (1978).

[c]Data from Foster (1974).

[d]The degrees API unit has been adopted by the American Petroleum Institute as a measure of the specific gravity of hydrocarbons.

[e]This resource is based on DOE (1983).

*DOE, 1980.

Table 6. Potash Within WIPP Site*

Deposit	Resources (million tons)	Reserves (million tons)	of Resources recoverable in Zone IV	% of Reserves recoverable in zone IV
Sylvite	133	54	71	82
Langbeinite	351	78	65	68

*This table was prepared from data in Johns (1978)

Table 7.* Potential Natural Gas Within WIPP Site

	Total BCF**	In Zones I,II,III BCF**	In Zone IV BCF**
Resources 100%	490 (100%)	211 (43%)	279 (57%)
Reserves	44.6	21 (47%)	23.6 (53%)

* Based on data from U. S. DOE (1980)

**BCF = billion cubic feet

At a value of $4.40/1000 cubic feet, the total surface value of the natural gas reserves is about $200 million.

Table 8
The WIPP Site Natural Resources and
Federal Standards and Criteria

Standard	DOE Conclusion	EEG Conclusion	Remaining Question
DOE			
a) Site criteria	Site meets.	Natural resources at site create adverse condition.	Lithium not considered.
b) NRC proposed regulations (10CFR60)	No opinion expressed.	Natural resources at site create adverse condition.	Lithium not considered.
c) EPA proposed standard (40CFR191)	No opinion expressed.	Natural resources would render site unqualified.	Language of standard not consistent with preamble. Clarification needed.

6.0 References Cited

Foster, R.W., 1974, Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste: Open-file report, New Mexico Bureau of Mines and Mineral Resources (work done under Contract No. AF(40-1)-4423 to ORNL).

John, C.B., Cheeseman, R.J., Lorenz, J.C. and Millgate, M.L., 1978, Potash Ore Reserves in the Proposed Waste Isolation Pilot Plant Area, Eddy County, New Mexico: U.S. Geol. Surv. Open-file report 78-828.

Jones, C.L., 1978, Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico: U.S. Geol. Surv. Open-file report 78-592.

Keesey, J.J., 1976, Hydrocarbon Evaluation Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico: Sipes, Williamson and Aycock, Inc., Vols. I and II.

Klingman, C.L., 1975, Salt: U.S. Bureau of Mines Mineral Facts and Problems, 12 pp.

U.S. Department of Energy, 1980, Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/0026, 2 volumes.

U.S. Department of Energy, 1982, Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, TME 3156.

G.J. Long and Associates, Inc., 1976, Interpretation of Geophysical Data, Los Medanos and Vicinity: Report to Sandia Laboratories.

McMillan, C., 1976, Los Medanos Area: Permian Exploration Co., Report to Sandia Laboratories.

Powers, D.W., Lambert, S.J., Shaffer, Sue-Ellen, Hill, L.R., and Weart, W.D., 1978, Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, Sandia Laboratories, SAND78-1596 (2 volumes).

U.S. Department of Energy, 1983, Brine Reservoirs in The Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, TME 3153.

Woolfolk, S.W., 1982, Radiological Consequences of Brine Release by Human Intrusion Into WIPP, TME 3151.

Siemers, W.T., Hawley, J.W., Rautman, C., and Austin, G., 1978, Evaluation of the Mineral Potential (excluding hydrocarbons, potash and water) of the Waste Isolation Pilot Plant Site, Eddy County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Report to Sandia Laboratories.

U.S. Bureau of Mines, 1977, Valuation of Potash Occurrences Within the Waste Isolation Pilot Plant Site in Southeastern New Mexico: Prepared for the ERDA.

SPDV RESULTS

1.0 Introduction

The Site and Preliminary Design Validation (SPDV) program consists of two phases: Site Validation and preliminary design validation.

The results of the site validation phase were released on 3/31/83 in TME 3177, Results of Site Validation Experiments (ref. 1) which has been reviewed by the Environmental Evaluation Group (EEG) since it comprises item 7 of Appendix B of the Stipulated Agreement. The objectives and activities of the site validation phase are summarized in Table 9 and were intended by DOE to raise the level of satisfaction from "partially" or "adequately" to "complete" of nine WIPP site qualification criteria. The WIPP site qualification criteria are described in WIPP-DOE-116 Rev. 1 (ref. 2).

The results of the preliminary design validation phase were also released on 3/31/83 in a report entitled Preliminary Design Validation Report. Waste Isolation Pilot Plant (WIPP) (ref. 3). The document has been reviewed by EEG since it comprises item 9 of Appendix B of the Stipulated Agreement. The objectives of the preliminary design validation phase are summarized in Table 10. They are intended to demonstrate that the WIPP can be operated safely over its projected lifetime of 25 years and to insure that the waste can be retrieved should such a step be necessary.

2.0 Background of SPDV Program

The first justification for the SPDV program is contained in WIPP-DOE-049 (ref. 4) as follows:

"During the Title I design efforts on WIPP (1979), it has become increasingly obvious that the earlier research and development activities performed primarily by Sandia Laboratories, which were limited by the prohibition of penetrating the salt with drill holes, must be extended to include additional site verification studies and studies to support critical design assumptions

Table 9 SPDV Site Validation Activities

Objective (To Determine:)	Activity
Thickness of Facility Horizon	Map and Log Shafts, Excavations, Horizontal and Vertical Drillholes
Lateral Extent, Continuity, Inclination of Facility	992-m Exploratory Drift to the South Visual and Geophysical Logs, Map Excavations, High-Resolution Gravity Surveys, Correlation With Drillhole Logs
Brine and Gas Content	TGA, Miscellaneous Analysis of Samples Fluid Probe
Mineralogical Content	X-Ray Fluorescence and Diffraction and Microprobe Analysis of Samples
Interbed Characterization	Constituent Analysis, Mechanical Tests, Permeability
Aquifer Characterization	Fluid Inflow to Shaft, Piezometers in Shaft, Water Samples
Fluid Potential of Facility Level	Inflow of Excavation, Solution Composition
Permeability of Facility Level	Tests on Laboratory Samples

Table 10 Preliminary Design Validation Objectives

- To validate the design for the WIPP access shafts and TRU waste disposal demonstration rooms.
- To evaluate the amount and rate of shaft convergence and room creep deformation and to correlate these data with model predictions.
- To perform a preliminary evaluation of creep in salt and of the steady-state creep model.
- To evaluate instrumentation systems for accuracy and the reliability of measurements made with them in rock salt and to document the suitability of the system for future measurements.
- To evaluate the response of in situ formations such as clay seams and other material layers in addition to the salt.
- To collect large numbers of samples of rock salt and other materials and to conduct laboratory and bench-scale tests to determine the mechanical properties of these samples.

associated with the stability of the underground openings. The rationale and support for the proposed DOE actions has come from three primary sources:

The Nuclear Regulatory Commission, in testimony before the Runnels Oversight Committee, stated that their new proposed licensing process for HLW repositories will include the necessity of any repository applicant for license to have conducted early, detailed site exploration and evaluation at depth (i.e., exploratory shaft).

The Panel on the WIPP of the Committee on Radioactive Waste Management of the National Academy of Science advised that continuing efforts to acquire the necessary additional information solely by means of surface exploration, including boreholes, have reached the point of diminishing returns and recommended that:

a. An exploratory shaft be sunk at the site of one of the proposed shafts as soon as practicable, to the depth of the proposed repository horizon,

and that

b. Drilling be done, and tunnels developed in the salt as necessary to conduct the measurements and observations needed to resolve remaining site-specific geotechnical uncertainties and to ascertain the degree to which the site is suitable for the excavation of a repository.

The USGS, in testimony before the Runnels Oversight Committee, stated that their position on the suitability of the proposed site for WIPP could not be provided until observations taken during shaft sinking, and the results of in situ tests at the candidate horizon, were available."

The SPDV program was designed by Sandia National Laboratories (SNL) to satisfy the above demands. It was categorized into three general areas with the following headings: 1) Site Acceptability Program; 2) Measurement for Design Verification and Repository Boundary Determination; 3) Early Non-Waste Experimental Program. Although there have been changes in the experiments, the

three categories have remained and are known today as: 1) Site Validation Program; 2) Preliminary Design Validation Program, and 3) WIPP Research and Development Program (R & D). However, only items 1 and 2 have been retained the current SPDV program; the WIPP R & D program has become a separate program. An environmental assessment (ref. 5) and a terse description of the SPDV program (ref. 6) were published in October 1980. The WIPP R & D program, which had already become a separate program was not included in the description.

A detailed description of the Site Validation Program, TME 2975, was published in April 1981 (ref. 7). It linked the experiments of the SPDV program with the WIPP site qualification criteria drafted by SNL and published in the Geological Characterization Report (GCR) (ref. 8). TME 2975 cross-referenced the WIPP site qualification criteria with the Office of Nuclear Waste (ONWI)'s criteria for high level waste (HLW) repositories (ref. 9). EEG commented on TME 2975, and these comments led to the issuance of a revised document (ref. 10). Another revision was published in October 1982 (ref. 2). This revision included the studies required under the Stipulated Agreement and the replacement of five proposed horizontal core holes at the repository horizon by an exploratory drift. EEG had taken the position that the horizontal core holes should be replaced by drifts in order to obtain more information than could be obtained from coreholes. The suggestion had first been made in the Golder Associates Report (ref. 11), an independent review of WIPP-DOE-049 commissioned by the Nuclear Regulatory Commission.

A detailed description of the Preliminary Design Validation Program first became available with the publishing of the draft report SAND 81-2628 (ref. 12) in March 1982. A report entitled Preliminary Design Validation Plan (ref. 13) was issued in January 1983; it was required as item 8 of the Stipulated Agreement. EEG commented on the drafts of this report.

3.0 SPDV Configuration and Instrumentation

Two shafts have been drilled and an underground experimental area has been mined. The layout of the experimental facility and the boundaries of zone 2 are shown in Figure 27. The 3.66-m in diameter shaft, the exploratory shaft, which was drilled to a depth of 702-m (2300 ft.), was outfitted to provide the

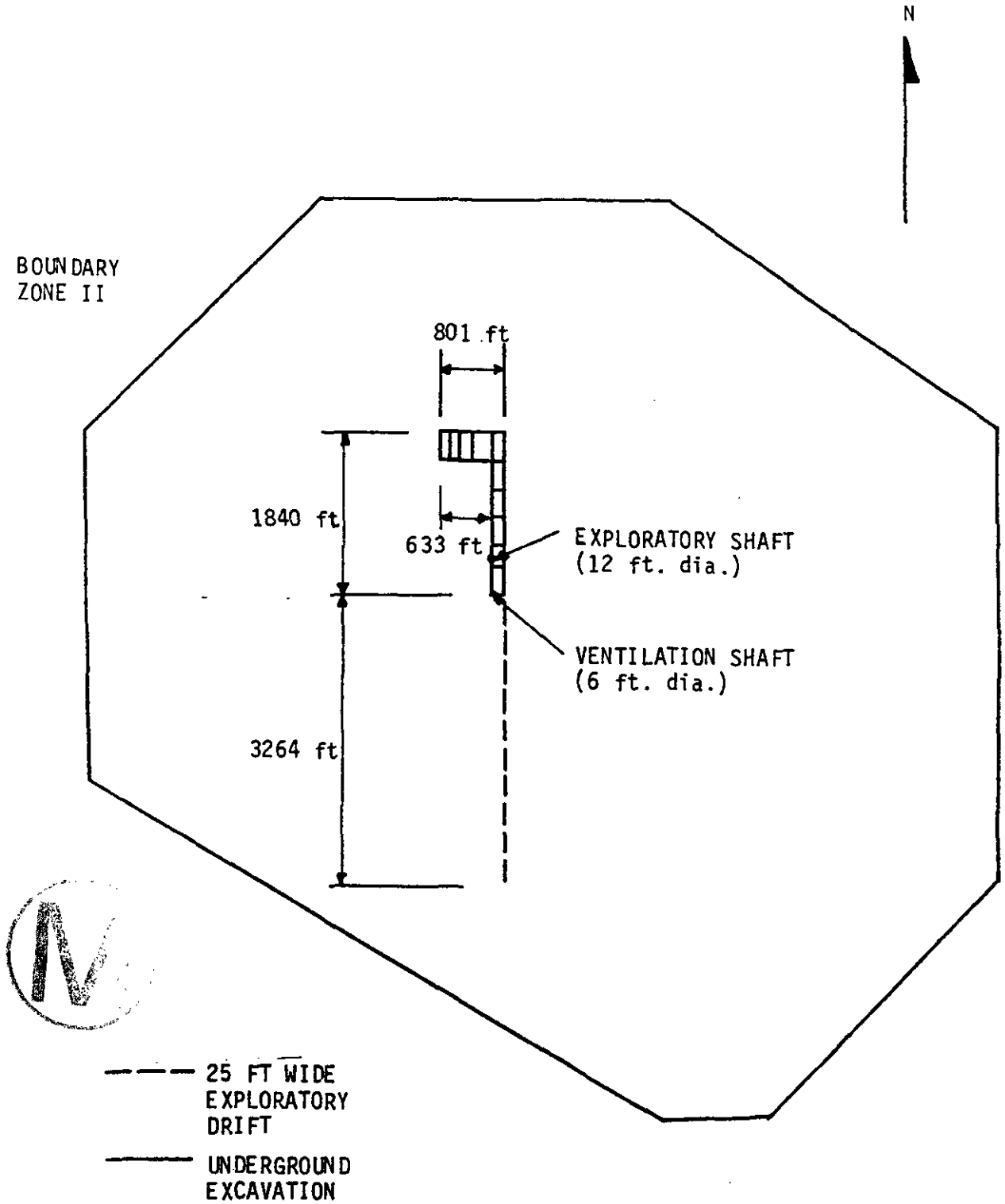

Figure 27. The SPDV layout.

main access to the underground and to bring the mined salt to the surface . The exploratory shaft has three testing areas: the upper part, which has a grouted steel liner from the surface down to the Salado formation (247-m, 850 ft.) is instrumented with piezometers for gathering hydrological data from the Rustlerformation, and with strain gages for gathering data on liner deformation; the shaft liner key, which seals the liner bottom from seapage, is instrumented with piezometers for obtaining hydrological data and with strain gages for obtaining strain data; the unlined portion of the shaft is instrumented for obtaining data on shaft closure and salt deformation. Figure 28 shows the instrumentation locations in the exploratory shaft. The 1.83-m diameter ventilation shaft is unlined except for about 100 ft. of surface conductor. It provides an outlet for the ventilation system and an escape way. It will be transformed into the 20 ft-diameter waste shaft later. The two shafts also provided mappings of the strata from the surface down to the repository horizon.

The underground facility consists of a 995-m (3264 ft.) drift to the south and a network of drifts to a design validation test panel in the north. The drift to the south was excavated to obtain data on the salt and to map the geology in the area of the repository. The design validation test panel consists of four 10 x 3.96-m rooms separated by 30.48-m pillars. The drifts and the test panel are instrumented to obtain data on room stability and room closure. Figure 29 shows the instrumentation of the underground facility.

For completeness, Figure 30 shows the entire WIPP underground layout.

4.0 Results of Site Validation Program

The results of the Site Validation Program are summarized below.

The host rock interval exhibits acceptable thickness and lithologic characteristics as projected from surface-based studies. All principal marker beds and intervening strata are consistent in thickness within the host rock interval throughout the extent of potential underground workings. The average apparent dip of rock strata is less than one degree. These statements are based on geologic profiles from deep boreholes, in-drift coreholes, geologic

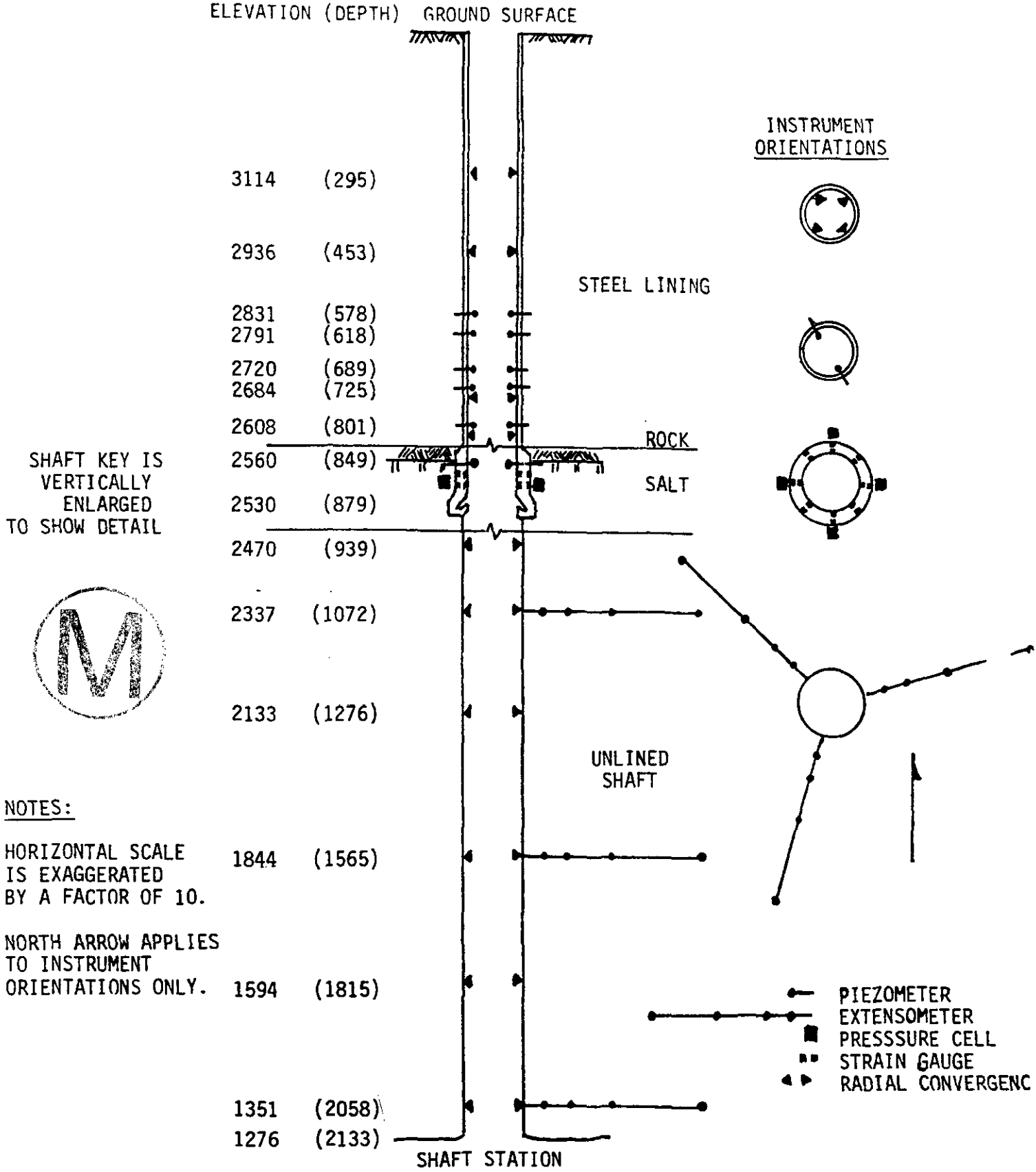

Figure 28. Instrumentation in the exploratory shaft.

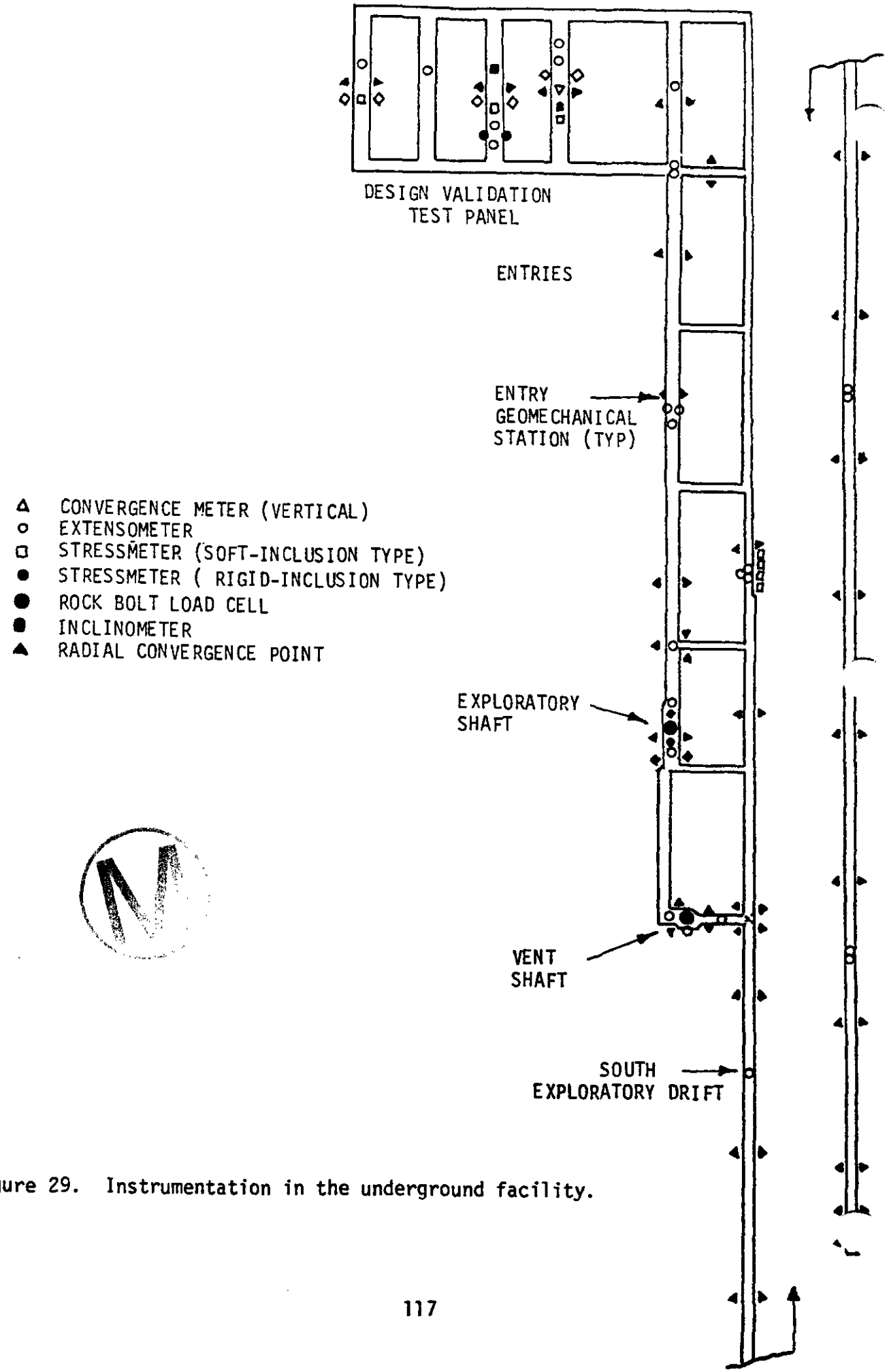

Figure 29. Instrumentation in the underground facility.

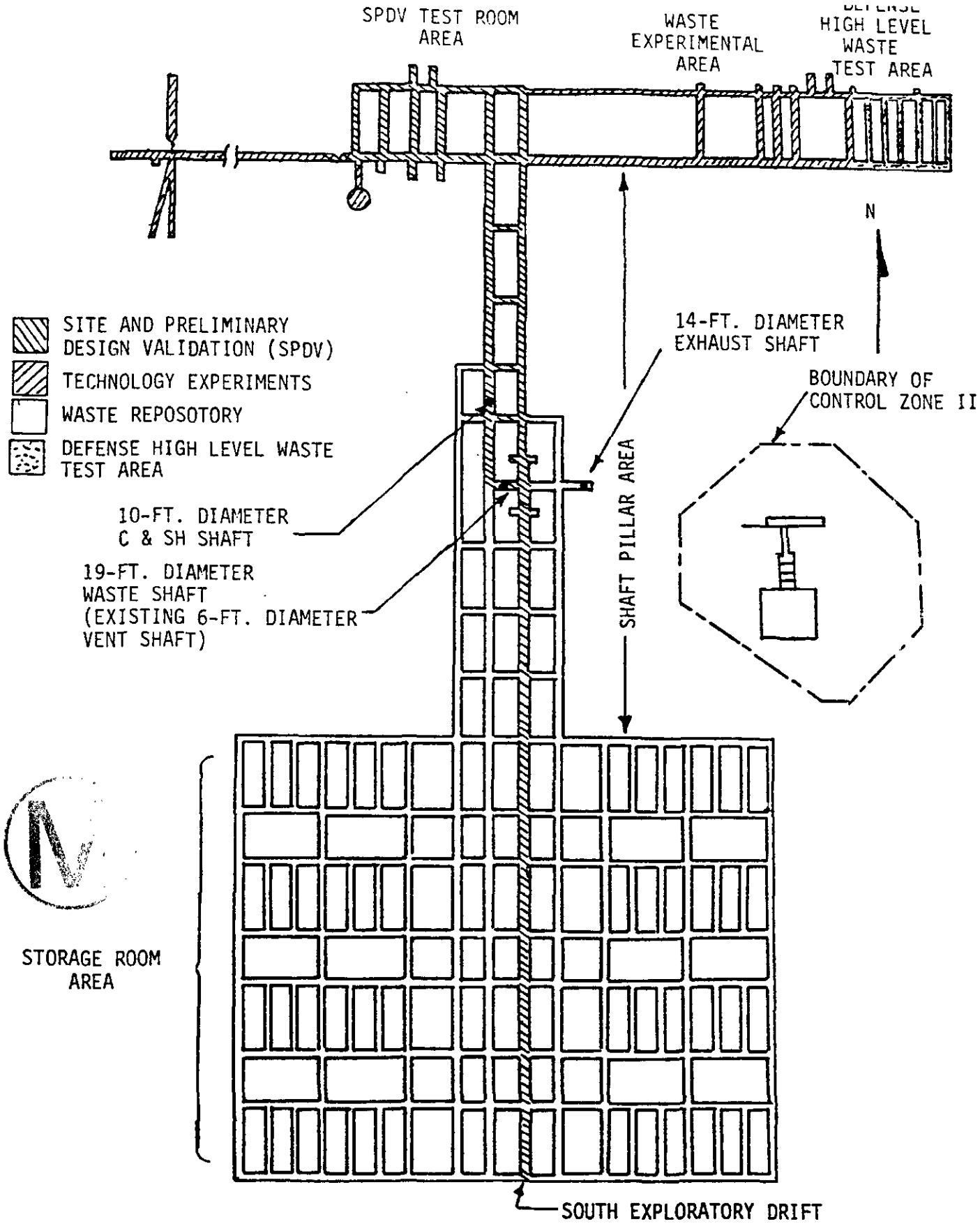

Figure 30. Layout of WIPP underground facility.

mapping of the shafts and of the drifts. Figures 31 and 32 summarize the geologic profile of the WIPP site.

The mean fluid content of the facility interval strata is 0.59% by weight. The principal mineral of the facility interval is halite with minor impurities consisting of polyhalite, quartz, magnesite, clay, anhydrite and gypsum. This statement is based on the analysis of 20 grab samples and 6 core samples. The locations from where the samples were obtained are shown in Figure 33.

The interbeds of the host rock interval are anhydrite and thin clay seams. Their physical properties do not pose an unmanageable problem on stability of the excavation. Based on laboratory testing, permeabilities of the interbeds measured under approximate lithostatic pressure were less than seven microdarcies. Test included Atterberg limits, direct shear, indirect tension, x-ray diffraction, and permeability. The sampling locations of interbedded materials is shown in Figure 34.

The observed inflow from the Rustler was approximately 1.5 gpm in the exploratory shaft and approximately 1 gpm in the ventilation shaft. The actual inflow may be larger, since all the water could not be collected during the inflow tests (ref. 14, p. 5-3).

No water inflows were encountered during excavations of the facility interval.

Permeability of facility interval samples tested under confining pressures approximating in situ conditions was less than 0.01 microdarcy. This statement is based on laboratory tests of 6 samples.

5.0 Resuωt{ of Preliminary Design Validation Program

5.1 Preliminary Analysis

Sandia National Laboratory has performed calculations to predict the mechanical response of the shafts, the passageways, and the TRU demonstration rooms.

Figure 35 shows nominal calculated closures in the unlined shaft at three depths(ref. 15). These calculations are subject to considerable uncertainty and will have to be refined as more data are accumulated.

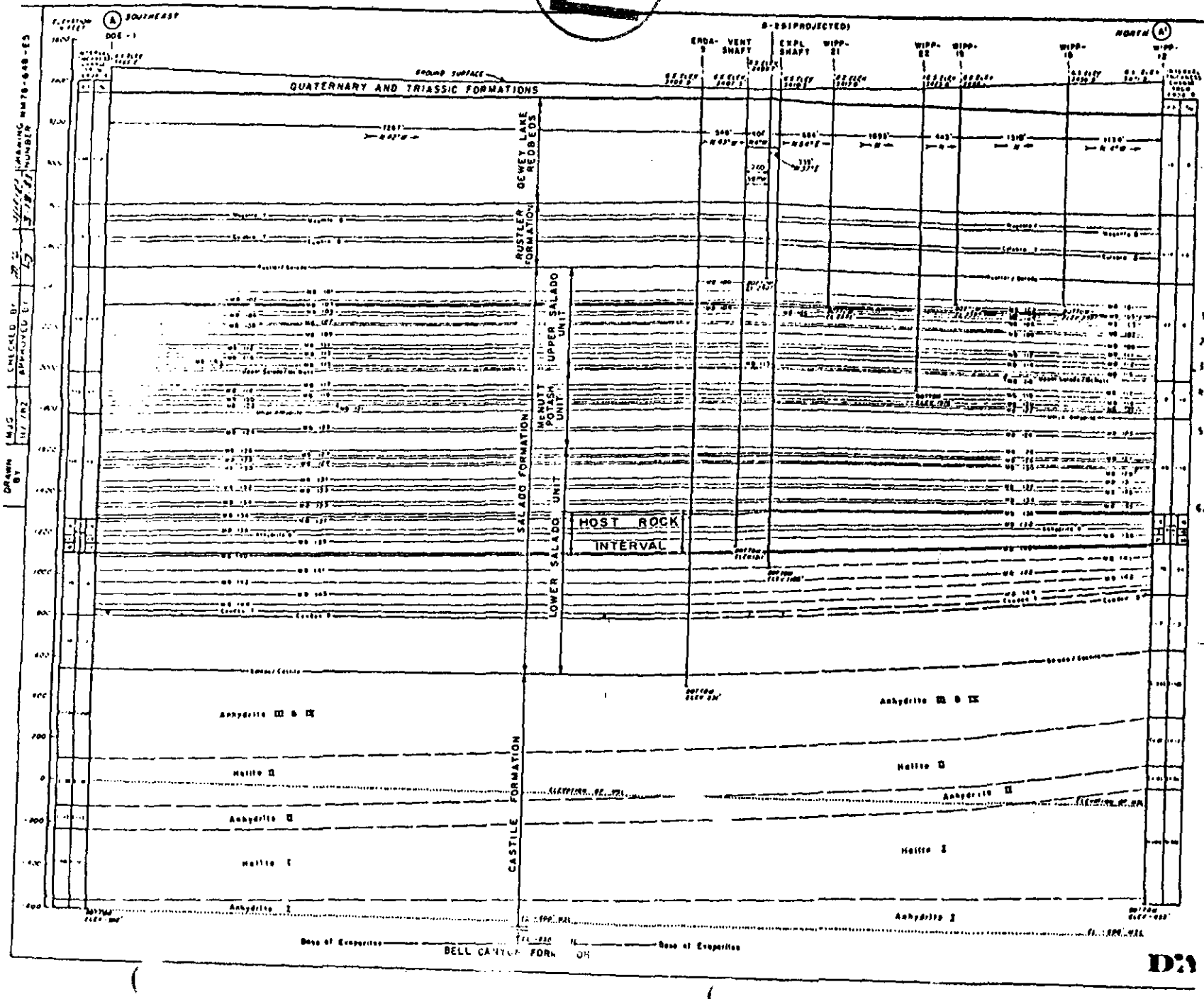

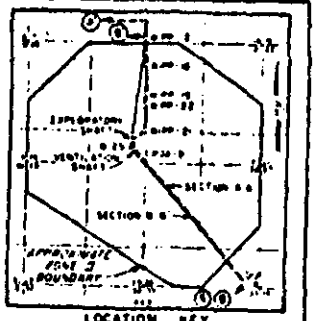

NOTES

1. ONLY DATES SHOWN FOR THEIR PARTICIPATED PERS.
2. SELECTED INTERVALS SHOWN FOR CLARITY.
3. DASHED LINES INDICATE POSSIBLE CONTACTS.
4. MORE DETAILED BORING DATA ARE PRESENTED IN APPENDICES A AND B.
5. DETAILED DATA ON (1) THICKNESSES OF INDIVIDUAL INTERVALS ARE PRESENTED IN TABLE 6, AND (2) APPARENT DIPS OF INDIVIDUAL CONTACTS ARE PRESENTED IN TABLE 5.
6. INTERVAL THICKNESS CHANGES IN CASTILE FORMATION (SHOWN IN PARENTHESIS) ARE BASED ON ASSUMED THICKNESSES BELOW THE BOTTOM OF ERDA-9.

HORIZONTAL SCALE

Figure 31
North to south geological cross section of the WIPP site

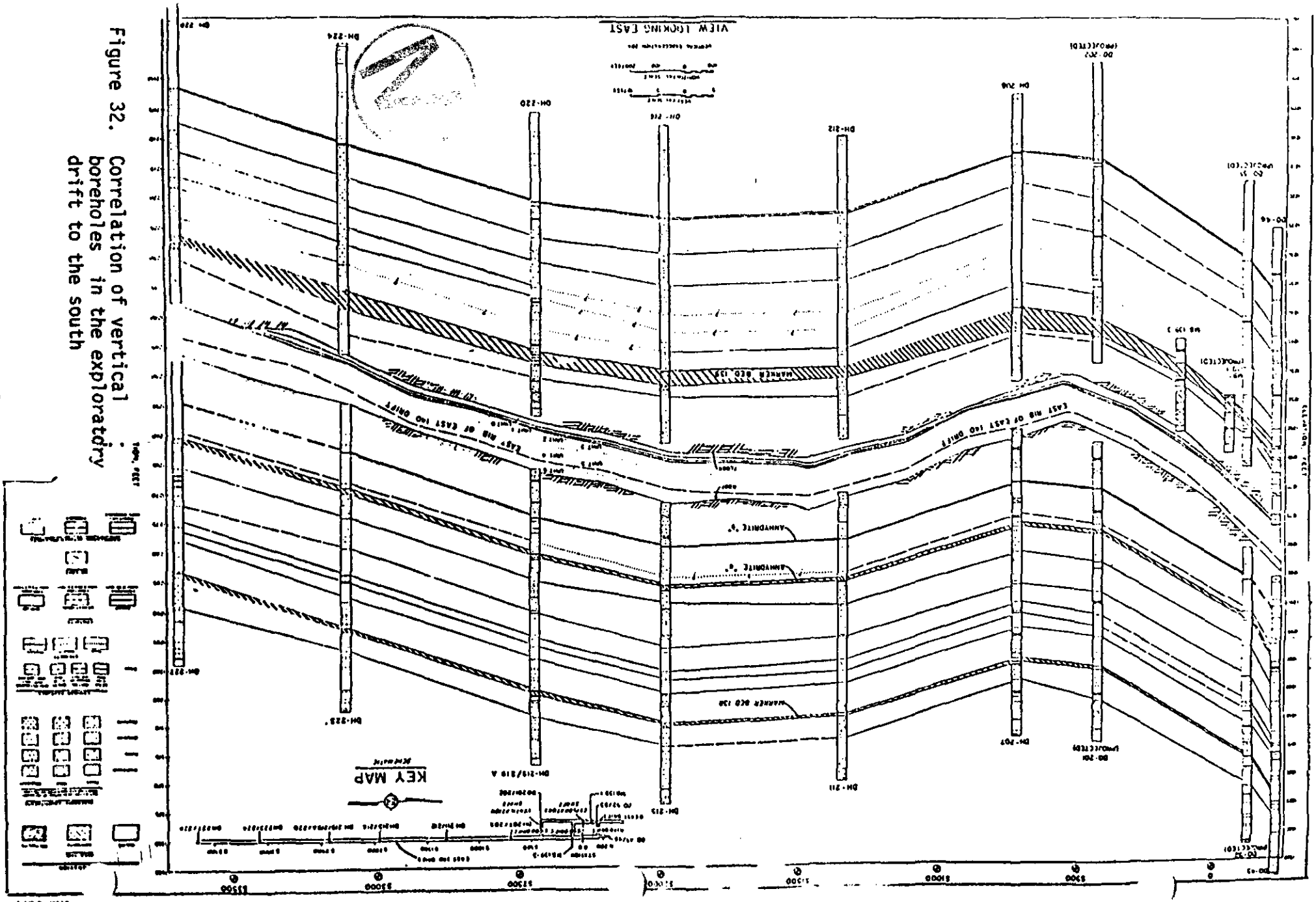
VIEW LOOKING EAST
KEY MAP
DH-224
DH-220
DH-216
DH-212
DH-206
DH-207
DH-211
DH-213
DH-219/219 A
DH-225
DH-227
ANHYDRITE "B"
ANHYDRITE "C"
MARKER BED 139
MARKER BED 138
EAST MIN OF EAST 140 DRIFT
55000
55500
56000
56500
57000
57500
58000
58500
59000
59500
60000
60500
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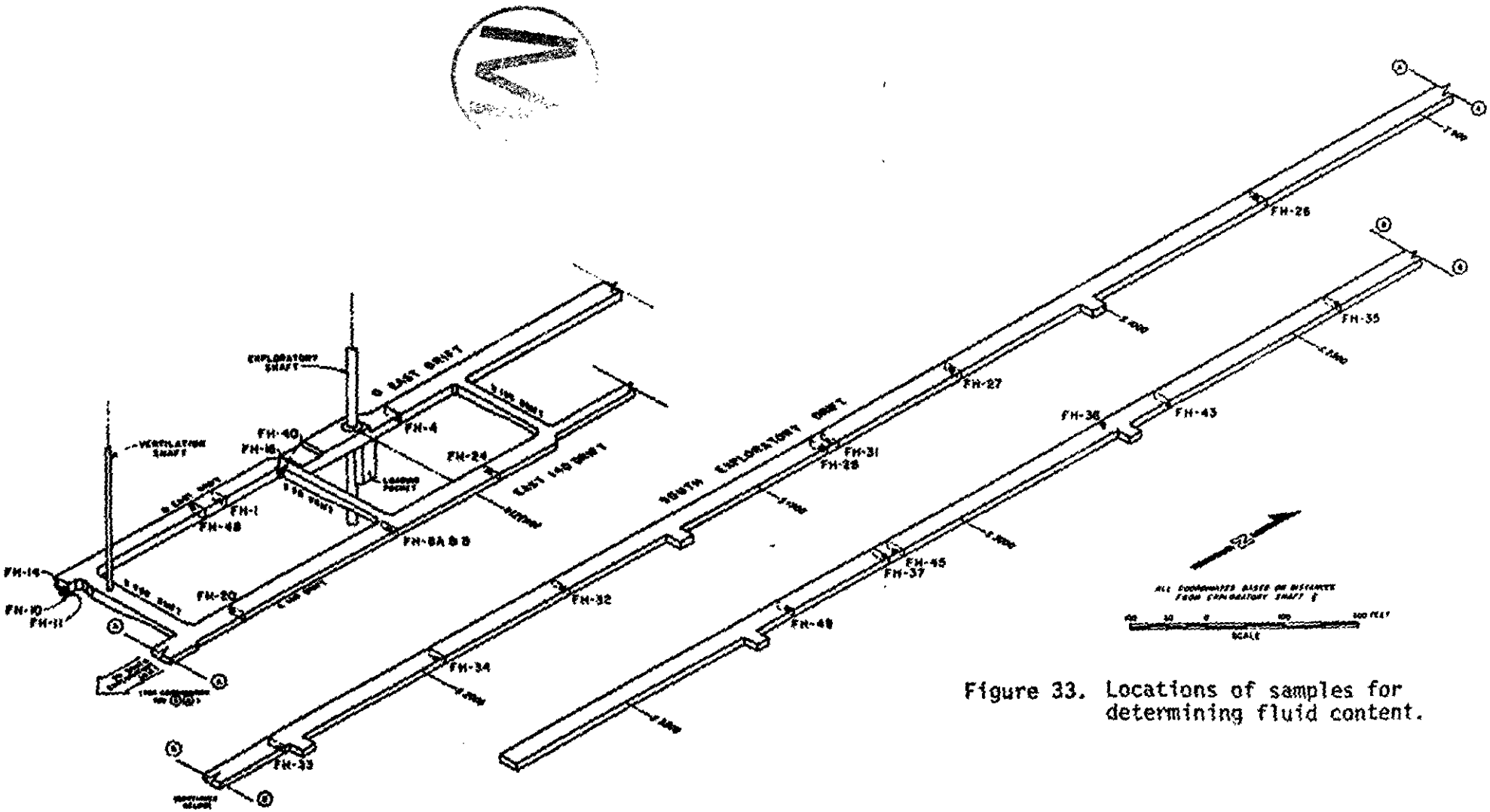

Figure 33. Locations of samples for determining fluid content.

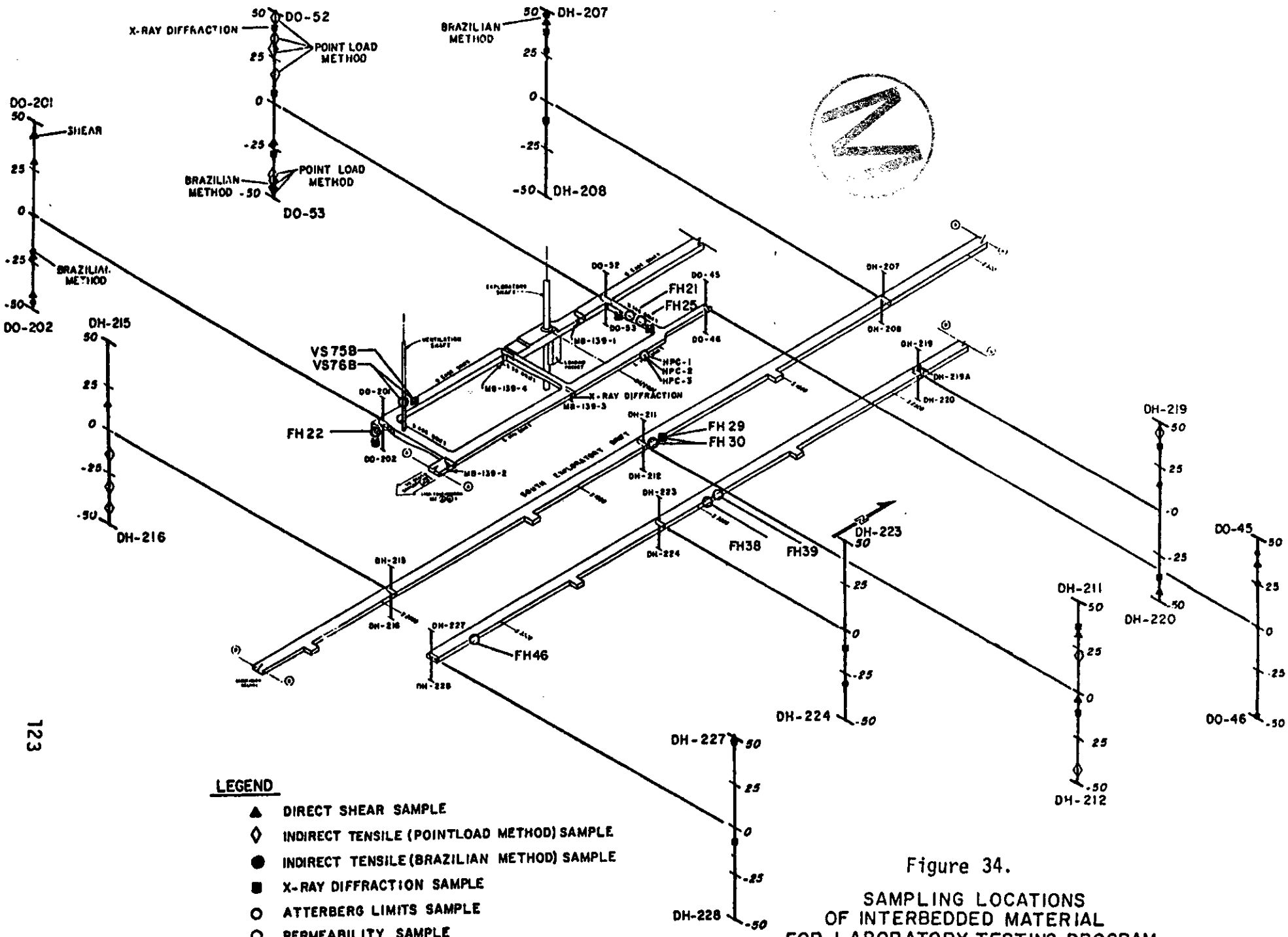

Figure 34.

SAMPLING LOCATIONS
OF INTERBEDDED MATERIAL
FOR LABORATORY TESTING PROGRAM
WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

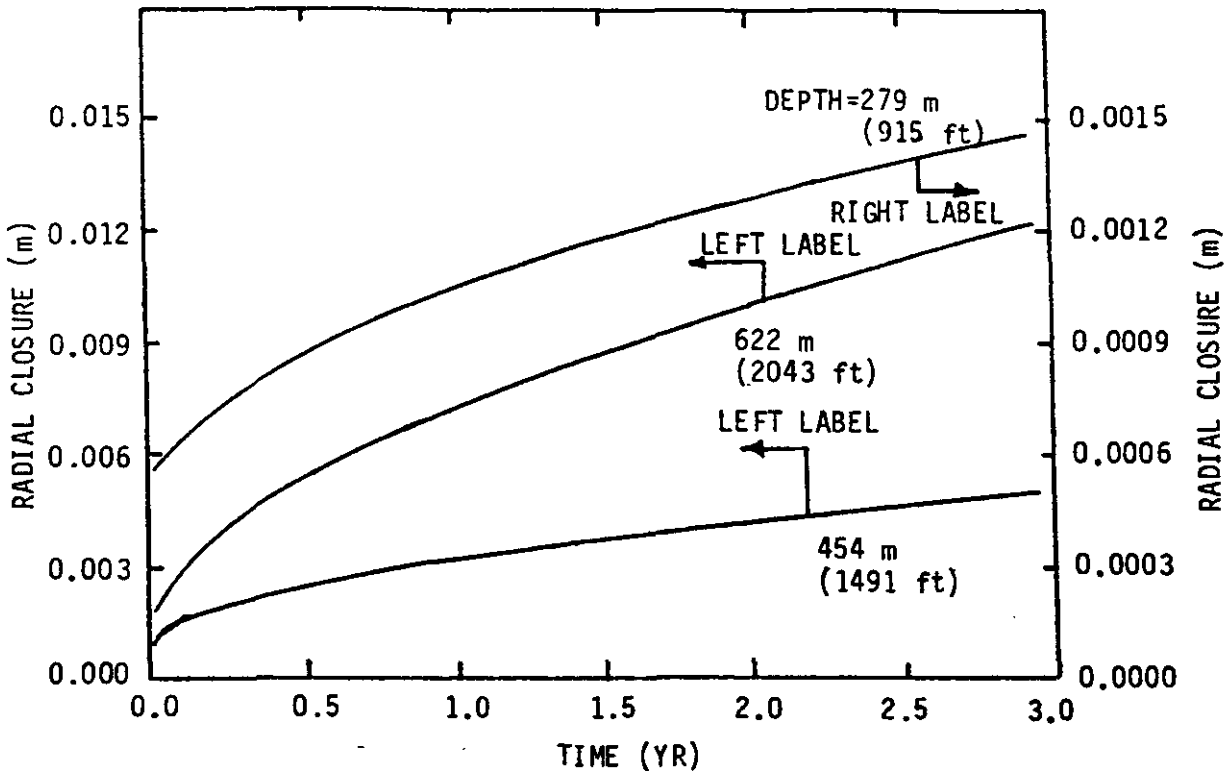

Figure 35. Calculated shaft radial closure at three extensometer locations for the SPDV (ref. 15).

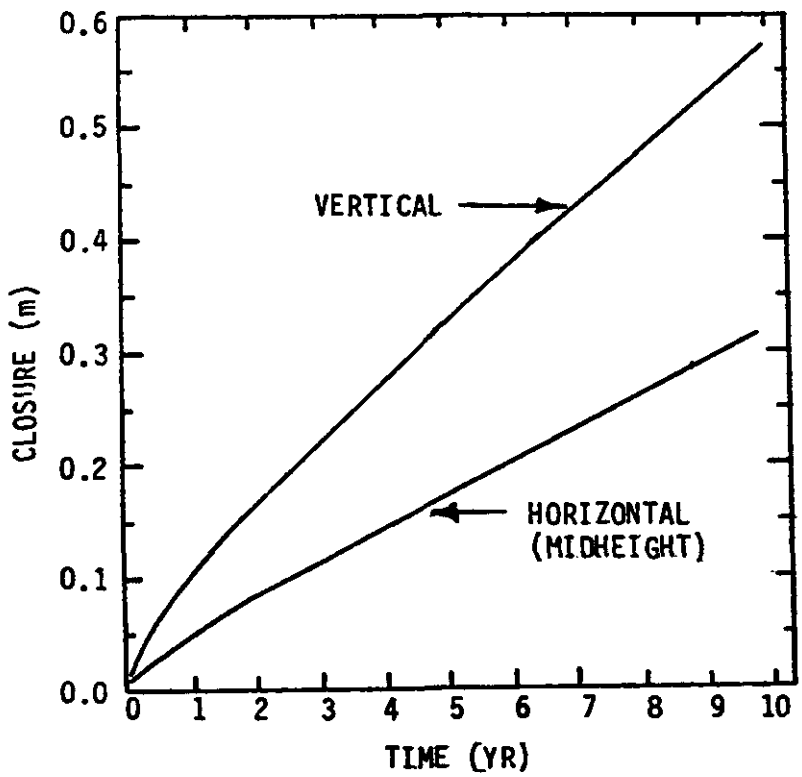

Figure 36. Preliminary calculations of storage room closure for design validation test panel of SPDV. (ref. 15).

Figure 36 shows typical calculation results for vertical and horizontal room closures. Figure 37 shows a two dimensional closure pattern. The calculations were made using sophisticated rock mechanics codes, the reference WIPP stratigraphy, and current steady-state constitutive models (ref. 16, 17). Again, the calculations will have to be refined as data are accumulated.

5.2 Early Design Validation Data

Most of the instrumentation, in particular that in the drift and in the test panel, has been only recently installed. A data gathering period of one year will probably be required before attempting any correlation between measurements and prediction. This is especially true of room and drift convergence. Hence only the sampling data is presented below and no attempt is made to correlate the observations with the calculated predictions.

Figure 38 shows the stabilized readings from the piezometers installed behind the steel lining in the exploratory shaft. Also shown is the design hydrostatic pressure. There is no correlation of pressure with depth; hence, more data will be necessary before drawing any conclusions on these pressure readings.

The piezometers installed in the salt formation behind the shaft key so far have shown a nominal reading of 6 psi. This indicates that there is no water pressure buildup behind the key.

Four earth pressure cells installed behind the shaft key do not indicate any pressure buildup between the salt formation and the concrete key. This confirms the prediction that the initial shrinkage rate of concrete is greater than the radial creep rate of the salt. An interactive pressure is not expected for two years. The strain gages in the concrete do not indicate significant strains.

Limited water leakage observed through telltales in the shaft key indicate that the chemical seal ring placed near the top of the shaft key is fairly effective in preventing the migration of water from the upper aquifers down to the shaft key and the salt formation.

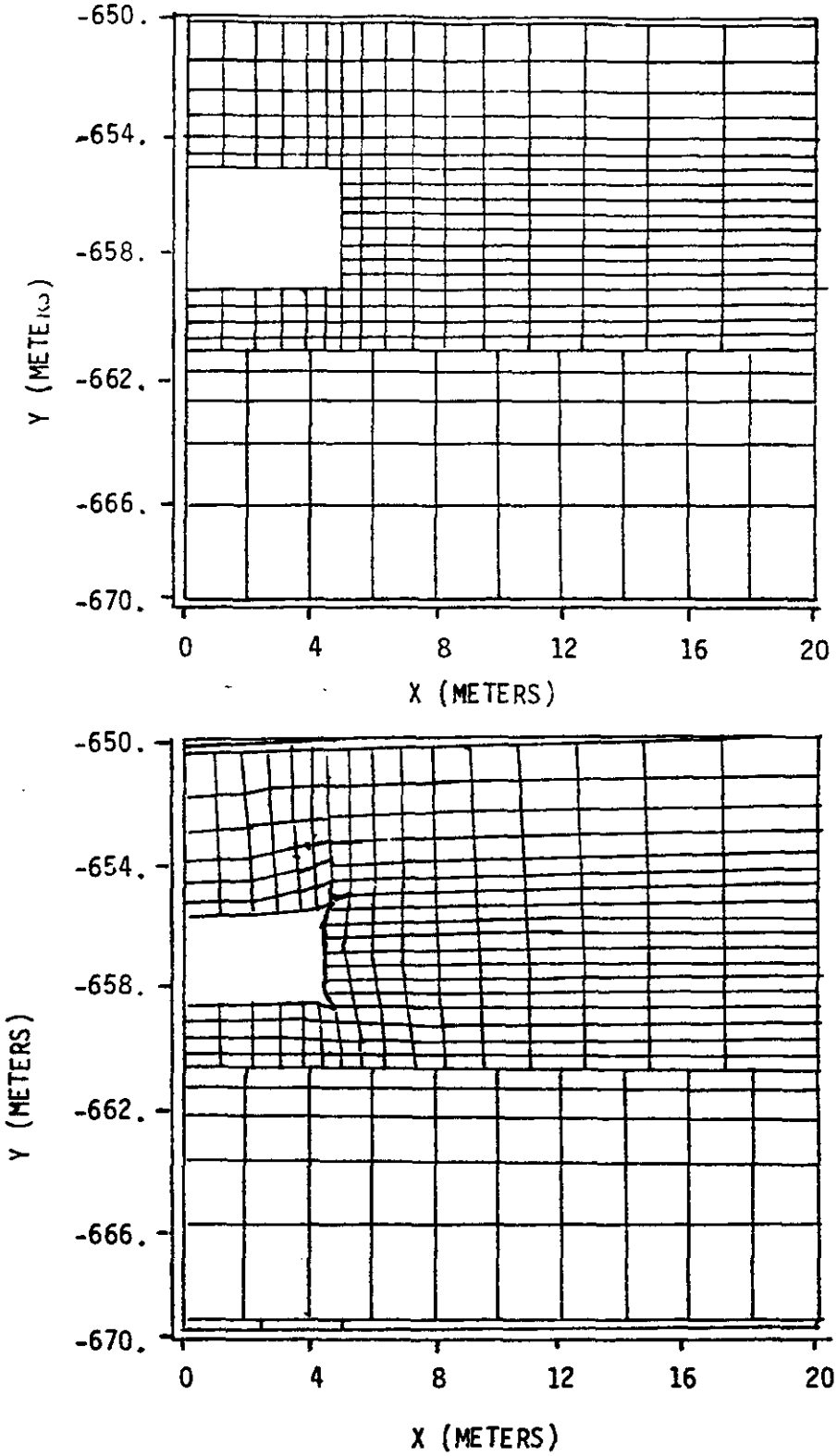

Figure 37. Two dimensional room closure calculations. Comparison of undeformed room and deformed room after 10 years (ref. 16).

PIEZOMETER READING ON
FEBRUARY 21, 1983

LEVEL	PIEZOMETER	PSI	FT
578	PE-00201, 00202	95	219
618	PE-00203, 00204	94	217
689	PE-00205, 00206	85	196
725	PE-00208	108	249
801	PE-00209, 00210	144	332

△ PIEZOMETER READING

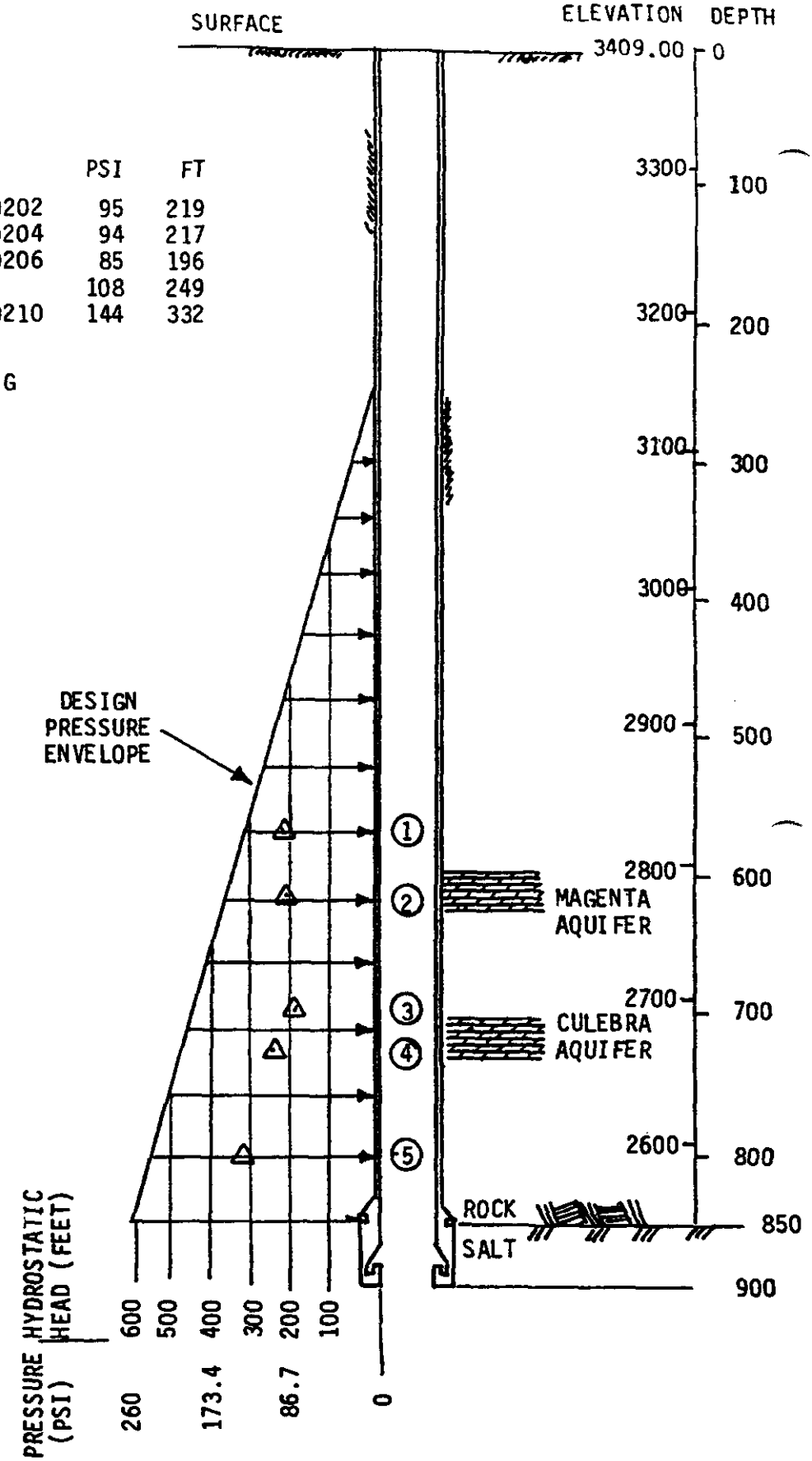

Figure 38. Stabilized piezometer readings and design pressure envelope of liner for exploratory shaft. (ref. 2).

Radial convergence of the unlined shaft has been monitored since July 1982. For the three extensometers at the level of 2057 ft., the seven month average radial convergence is 0.081 in. The calculated value is 0.087 in. For the three extensometers at the level of 1564 ft., the average radial convergence is 0.030 in. The calculated value is 0.027 in. For the three extensometers at the level of 1073 ft., the average reading is 0.002 in. The calculated value is 0.008 in.

The extensometer data thus indicate shaft closure rates ranging from 0.001 in./year at the top of the Salado formation to 0.10 in./year at the level of the repository horizon.

Six rock bolt load cells were installed in the exploratory shaft station in May 1982. Some showed a large increase in rock bolt load in the months following their installation. However, two cells indicate a significant decrease in rock bolt load since January 1983. Based on seven extensometers in the exploratory shaft station that were installed in July, September, and October, the total roof movement has been estimated at 1 1/2 to 2 1/2 in. up to the end of February. The roof movement appears to be decreasing. Figures 39 and 40 are samples of data obtained by extensometers in the exploratory shaft station. The figures suggest that the extensometers will provide data necessary to verify two dimensional room closure calculations.

Three extensometers installed since mid November in the ventilation shaft indicate that roof and wall movement is occurring at a decreasing rate.

Accumulated roof movement shown by the extensometers is less than 2 in.

Only minimal measurements are available for the 3256 ft. drift south, the instrumentation having been installed after January 1, 1983. However, all the room closure rate data show a gradual decrease.

6.0 Assessment of SPDV Program

General criteria for nuclear waste emplacement in geological repositories are in the process of being finalized. The Environmental Protection Agency (EPA) has published standards for comments under 40 CFR 191 (ref. 19) and the DOE has published general guidelines for comments under 10 CFR 960 (ref. 20). These criteria are similar to those published in NWTS-33 (ref. 9). For WIPP, criteria were first published in the GCR (ref. 8) and later in documents entitled Site Validation Program (refs. 7, 10, 2). In the site validation documents, the WIPP site criteria are cross-referenced with the NWTS-33 criteria. EEG also gave consideration to site criteria in its first report (ref. 21).

EEG concludes that the detailed geologic mapping at the repository horizons and a limited number of rock mechanics experiments conducted in the drifts and the shafts show no adverse conditions at the proposed repository level. However, the marker bed 139 (MB 139), which lies less than 10 feet below the repository horizon and consists of "mounds caused by growth of gypsum crystal clusters which were later slightly crushed by overburden pressure" (p. 6-4, ref. 22) may not satisfy DOE Criterion 13.2 (p. 12, ref. 22). EEG has recommended a detailed study of this layer to DOE.

No comprehensive set of criteria pertaining to the verification of design validation exists at present since an NRC licensed mined geological repository will not be built before 1990.

The excavations to date, the shaft and the underground facilities, clearly verify the first objective in Table 10. The piezometer readings in the Rustler formation (Fig. 38) show high hydrostatic pressures away from the Magenta and Culebra aquifers. Assuming that the Piezometers are functioning properly, this raises questions concerning the Rustler hydrology, which are raised in the Regional Hydrology section. Several years of data gathering will be necessary to verify the remaining objectives. EEG will evaluate this data as it becomes available and will make appropriate recommendations applicable to the design of the facility.

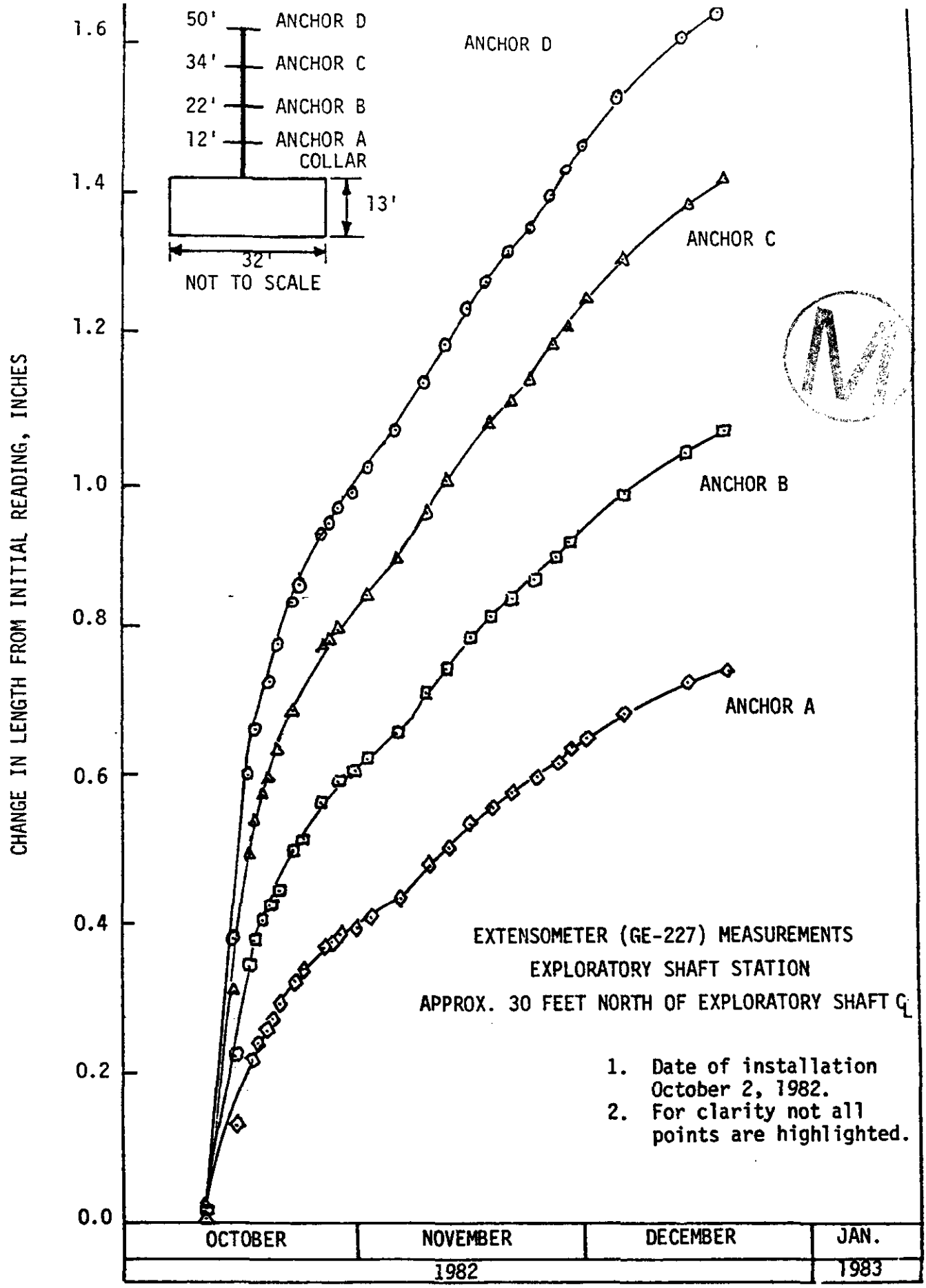

Figure 39. Closure data from an extensometer in the exploratory shaft station (ref. 18)

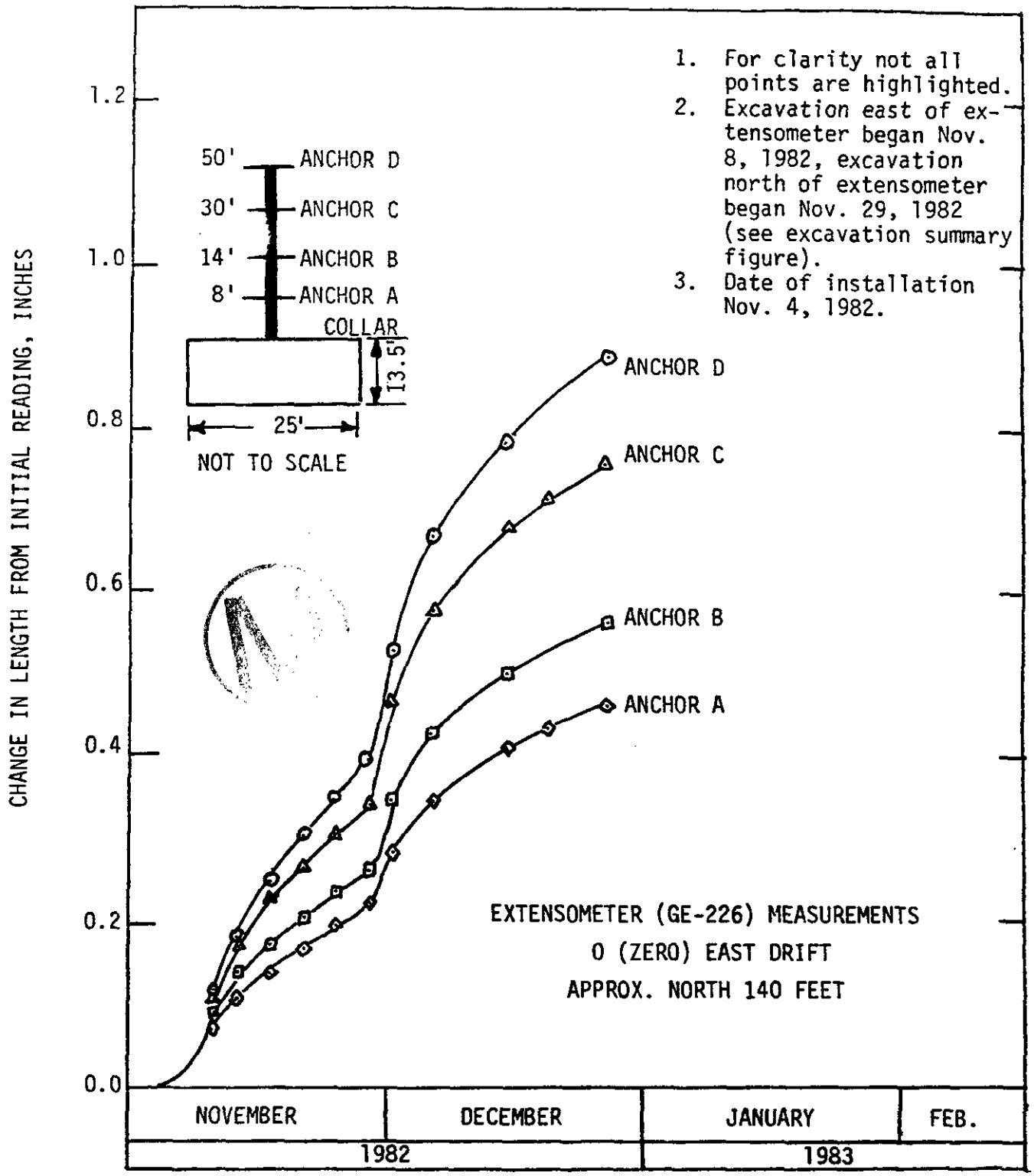

Figure 40. Closure data from an extensometer in the 0 drift 140 feet north of exploratory shaft.(ref. 18).

Additionally, EEG must also keep abreast of the WIPP R and D program because many of the experiments, notably the plugging and sealing of boreholes and shafts, and demonstration of waste emplacement, will provide important data applicable to design and operation of the facility.

7.0 References Cited

U.S. Department of Energy, Results of Site Validation Experiments Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico, 2 Volume, TME 3177, March 1983.

U.S. Department of Energy, Site Validation Program, WIPP-DOE-116, Rev. 1. October 1982.

U.S. Department of Energy, Waste Isolation Pilot Plant. Preliminary Design Validation Report, Job 12484 performed by Bechtel National, Inc., March 30, 1983.

U.S. Department of Energy, SPDV (Site Preliminary Design Verification) Project Plan Summary, WIPP-DOE-49, November 1979.

U.S. Department of Energy, Technical and Environmental Analyses Development of the Site and Preliminary Design Validation Program Los Medanos Site, Southeastern New Mexico, Report TME-3058, October 1980.

U.S. Department of Energy, A Description of the Site and Preliminary Design Validation Program for the WIPP Site, Report TME-3063, October 1980.

U.S. Department of Energy, Site Validation Program, April 1981, Report TME-2975, April 1981.

Powers, D.W., Lambert, S.J., Shaffer, S.E., Hill, L.R., Weart, D.W., Geological Characterization Report Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, Volume I, SAND 78-1596, August 1978.

NWTS Program Office U.S. Department of Energy, NWTS Program Criteria for Mined Geologic Disposal of Nuclear Waste, DOE/NWTS-33(2), February 1981.

U.S. Department of Energy, Site Validation Program, Report WIPP-DOE-116, January 1982.

Golder Associates, Final Report. Review of Site Preliminary Design Verification Project Plan, August 1980.

Matalucci, R. V., Christensen, C.L., Hunter, T.O., Molecke, M. A., Munson, D. E., Waste Isolation Pilot Plant (WIPP) Research and Development Program: In Situ Testing Plan, Draft Report SAND 81-2628, March 1982.

U.S. Department of Energy, Design Validation Plan, WIPP-DOE-160, January 1983.

WIPP-SPDV, Geotechnical Field Data Report No. 4, Geologic Mapping and Water Inflow Testing on the SPDV Ventilation Shaft, 1983.

Matalucci, R.V., Christensen, C.L., Hunter, T.O., Molecke, M.A., and Munson, D.E., Waste Isolation Pilot Plant (WIPP) Research and Development Program: In Situ Testing Plan, March 1982, SAND 81-2628 (December 1982)

Brandstetter, L.J., Stone, C.M., and Krieg, R.D., WIPP Benchmark II results Using SANCHO, SAND 81-0853 (Albuquerque, NM, November 1981).

Morgan, H.S., Krieg, R.D., and Matalucci, R.V., Comparative Analysis of Nine Structural Codes Used In the Second WIPP Benchmark Problem, SAND 81-1389 (November 1981).

WIPP-SPDV, Geotechnical Field Data Report No. 6, Underground Excavation Field Instrumentation Data, January 17, 1983.

40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes, Federal Register, Vol. 47, No 250, December 29, 1982, Proposed Rule, p. 58196.

10 CFR 960 - General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories, Federal Register, Vol. 48, No 26, February 7, 1983, Proposed Rules, p. 5676.

Goad, D., A Compilation of Site Selection Criteria, Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, Report EEG-1, June 1979.

U. S. DOE, Correlation of Drill hole and Shaft Logs, WIPP, S. E. New Mexico, TME-3179, March 1983.

CONCLUSIONS AND RECOMMENDATIONS

The Environmental Evaluation Group (EEG) has concluded that the Los Medanos site for the WIPP project has been characterized in sufficient detail to warrant confidence in the safety of the site for the permanent emplacement of approximately 6 million cubic feet of defense transuranic waste. This conclusion is based on the assumption that the maximum surface dose rate for the unshielded remote-handled transuranic waste (RH-TRU) canisters will be 100 rem per hour with a maximum radionuclide concentration of 23 curies per liter as indicated in Table E-3 of the Final Environmental Impact Statement for WIPP. The Site and Preliminary Design Validation (SPDV) program, through the drilling of two shafts to the selected repository level at 2160 feet below the surface and excavation of about 9000 feet of tunnels, has confirmed the interpretations made about the subsurface geological conditions at the center of the site.

For an assessment of the potential radiation effects of the nuclear waste repository on the public health and safety, it is necessary to understand the regional geological and hydrological setting. A large amount of work has been done to understand these conditions and to address several specific issues which have arisen as a result of such studies. However, in an assessment effort of this magnitude, it is almost inevitable that some questions remain unanswered at a given time in the decision-making process. EEG has identified work which still needs to be done at the Los Medanos site in order to improve confidence in the worst case scenario models of possible breaches of the repository. Also, it is anticipated that some of the additional information will be necessary to assure compliance with the EPA standard when it is promulgated.

The following is a summary of EEG conclusions on each of the major issues of suitability of the WIPP site and a list of recommendations for additional work for further characterization of the site.

CONCLUSIONS

Dissolution

There is no doubt that a large amount of salt has been removed from the Rustler and Salado formations in the Delaware Basin through the process of shallow blanket dissolution. This process has removed the salt from these two formations in the western part of the basin and only the collapsed insoluble residue of the Rustler and Salado remain in that area. The two dolomite aquifers in the Rustler formation provide the unsaturated water necessary for this shallow dissolution. The exit point for the brines produced by such dissolution near the WIPP site at the present time is the Pecos River at Malaga Bend and several points downstream. Piper (1973) calculated that the salts discharged into the Pecos River at Malaga Bend amount to 310,000 tons of NaCl and 170 tons of $CaSo_4$ each year. On the basis of an estimate of 955 tons per square mile per year of salt discharged by the springs and streams into the Pecos River, Bachman and Johnson (1973) calculated a present vertical-dissolution rate of about 500 feet of salt per million years. Using two different approaches for calculating the rate of advance of the "shallow" dissolution front towards the WIPP site, it has been shown that it would take at least 2 to 3 million years for such dissolution to be a threat to the repository.

The question of deep-seated dissolution, which has been postulated to be responsible for removing up to 70% of the lower Salado salt (Anderson, 1981) is of more concern to EEG. This concern arises from the fact that the stratigraphic level from which the salt is postulated to have been removed is that of the proposed repository. EEG has examined the evidence for and against "deep dissolution" and concludes that there is sufficient evidence to accept the existence of deep-seated dissolution as a strong hypothesis to explain the missing salt from the lower Salado and Castile formations. The mechanism for such a dissolution process, i.e., the source and the sink for the unsaturated water and the saturated brine respectively, still remains unexplained.

Anderson (1983) has argued that the lack of understanding of the mechanics of deep dissolution throws suspicion on the integrity of the Delaware Basin as a

whole. However, a detailed examination of hundreds of logs in the Basin has resulted in the drawing of "dissolution edges" by Anderson (1981). These dissolution edges are at least 15 miles to the south and farther to the east of the WIPP site. Therefore, EEG views the WIPP site to be situated in an area which is safe from the effects of any deep-seated dissolution process, now or during the isolation time of the proposed repository. This conclusion is strengthened by the study of cores from deep boreholes at and around the WIPP site and the results of the excavation at the repository level under the SPDV program.

There is one area, two miles north of the center of the site, where the lower Salado marker beds show a depression. EEG recommends that the logs of boreholes in this area be reexamined and a modeling of the anomaly be conducted. After this work, a decision can be made whether to drill a new borehole to test the possibility of this anomaly having been caused by the process of point source deep dissolution.

Breccia Pipes

A chimney of brecciated rock represents collapse of the overlying rock into a cavity formed at some location at depth. Vine (1960) identified several domal structures in the Delaware Basin which have been explored during the investigations for WIPP, as possible breccia pipes. Anderson and Kirkland (1980) proposed the mechanism of brine density flow for the formation of breccia pipes. This mechanism requires an active participation of the DMG aquifer in supplying the unsaturated water and in removing the saturated brine. The characteristics of the DMG aquifer (Wood et al., 1982) do not appear to support this role.

Detailed investigations and analyses of the breccia pipes in the Delaware Basin have shown that the breccia pipes appear to form only over the buried Capitan Reef which borders the Delaware Basin. The domes in the basin show characteristics which identify them as having resulted from near surface phenomena. The "Castile" domes which are commonly found in the west-central part of the basin may have resulted from an interconnection between the DMG aquifer (which is at a shallow depth in the western part of the Basin) and the

overlying evaporites. However, these are not "active" features. On the basis of a drill hole core, Anderson (personal communication) has identified a breccia pipe in the Basin, about 60 miles south of the WIPP site. Several miles of mining activity for potash in the upper Salado formation has not found a breccia pipe near the WIPP site. EEG, therefore, concludes that breccia pipes are not present at the WIPP site, and therefore do not pose a threat to the WIPP.

Spiegler, 1982 calculated the effect of a hypothetical breccia pipe developing under the repository and concluded that the radiological impact of such a feature returning radioactive materials to the biosphere would be insignificant.

Brine Reservoirs

Pressurized brine, at pressures between hydrostatic and lithostatic, have been encountered in the upper anhydrite layer of the Castile formation. Thirteen such encounters have been reported within eight miles of the proposed repository site. All except two of these were encounters in commercial oil and gas exploratory holes. ERDA-6 and WIPP-12 were WIPP project boreholes. WIPP-12 is situated at the northern edge of Zone II of WIPP. In addition to the pressurized encounters, brines at sub-artesian heads have also been found in the Castile formation, mainly along the Pecos River (Snyder, 1983, Personal Communication).

It should be realized that only the encounters at WIPP-12 and ERDA-6 were studied in detail. Varying degrees of detail are available on the other encounters.

Based on a study of all the data available, EEG has reached the following tentative conclusions.

- The Castile brine is not confined to a zone bordering the Capitan Reef. If one wishes to draw a zone, it would include the entire WIPP site.

- Each encounter of brine may not represent a distinct brine reservoir.

- Most of the brine encounters appear to be related to a structure in the Castile.

- Hydrologic testing and geochemical analyses of WIPP-12 and ERDA-6 brines indicate that the two are not connected.

- Geochemical data indicate that the brines may have been produced from water trapped in the rock at the time of deposition and later squeezed out at the time of structural deformation. However, the Capitan aquifer cannot be ruled out as a source.

- The brine, at least in WIPP-12 and ERDA-6, is not connected to any active aquifer at present.

- The presence of brine in the Castile formation underlying the WIPP site cannot be ruled out.

To provide an estimate of risk associated with a possible presence of brine under the repository, EEG modeled the case of a man-made future drilling intrusion 125 years hence. The results of EEG's two analyses (Channell, 1982; Bard, 1982) produce a maximum radiation dose to the bone of a nearby resident of 3.4 rem, less than the 5 rem permitted for a low probability accident. The man-made intrusion has been assumed to be a limiting case since a plausible scenario in which natural causes will allow brine to be brought to the biosphere more rapidly has not been identified. A recent EEG consultant's report (Logan, 1983) concludes that an unexpected communication between the brine reservoir in the Castile and the repository level, during excavation, will have serious consequences. DOE takes precautions for such a possibility although the chances of this occurrence are remote. To provide additional assurance and knowledge, EEG recommends further evaluation and field testing of geophysical methods such as CSAMT to identify possible occurrence of brine under the repository level.

Regional Hydrology

- The only perennial surface water in the vicinity of the WIPP is located at least 10 miles from the center of the site. The surface water bodies are

discharge points for local groundwaters beneath the site. There is no direct threat to the repository from these surface water bodies.

- The groundwater in the Bell Canyon aquifer does not appear to pose a significant threat to the repository based on previous EEG scenario consequence calculations. Some recent data indicates that some parameters in the previous calculations were not conservative. Evaluation of the previous calculations is under way, but the results are not expected to yield significantly different consequences than the previous calculations.

- The Castile formation contains pressurized brines near the WIPP site. These brines are discussed in detail in the section on Brine Reservoirs.

- The Capitan Reef Aquifer is at its nearest point about 10 miles from the site. Since the basinward dissolution from the north has not progressed towards the site, the Capitan Reef Aquifer does not pose a threat to the repository.

- The characteristics of the Rustler aquifers are discussed in a separate section.

Disturbed Zone

The Disturbed Zone was initially defined (e.g. in Powers, et al., 1978) as the area where seismic reflection signals were uninterpretable. The cause for this was later determined to be the structural complexity within the Castile formation (Borns et al., 1983). Since the Castile formation shows extensive thinning and thickening of the salt layers, even within the WIPP site boundary, a conservative approach would be to assume that the so-called "Disturbed Zone" extends underneath the WIPP site.

The gravity foundering hypothesis provides a reasonable explanation for the deformation present in the Castile formation in the northern Delaware Basin. By using this hypothesis, DOE has calculated that if the deformation is progressing towards the WIPP repository area, it would take 4.6 m.y. for the deformation front to reach the area directly under the WIPP repository. EEG's calculations show that this may happen in 125,000 to 375,000 years. The

progression of a structure such as that located at WIPP-12, however, requires conditions which facilitate the gravity foundering mechanism and these conditions (e.g., more trapped fluid in rock, low yield strength, etc.) may not exist under the southern part of Zone II of the WIPP site. The borehole DOE-1 drilled just outside the Zone II, to the southeast, certainly does not exhibit the Castile deformation structures except some minor lateral flow textures in the Castile halites. Further, with the reorientation of the WIPP repository to the south within Zone II, EEG concludes that the new location of the WIPP repository is in a relatively undeformed area.

Hydrologic Transport Characteristics of the Rustler Aquifers

There are three discreet zones in the Rustler formation through which the water moves. The quality and flow characteristics of these aquifers vary significantly but at the WIPP site, the waters are of poor quality and the flow rates are low. These aquifers are (a) the Rustler-Salado Interface Residuum (b) the Culebra dolomite, and (c) the Magenta dolomite. The water exists primarily in interconnected fractures in all three zones. In addition, there is some evidence that a very small quantity of water may exist in zones other than these three distinct aquifers. There is a possibility that features of karst hydrology may exist in the Rustler formation. However, all the information available at this time suggest that, if present, the karst solution channels would be very small in aperture.

The aquifers at the Rustler-Salado interface and the Magenta appear to carry a very limited volume of water at a very low velocity. The Culebra is the primary aquifer at the site and in case of a breach of the WIPP repository, it would be the most rapid pathway for radionuclides to reach the accessible environment. At the present time, the Culebra aquifer is not sufficiently characterized to model the hydrologic transport through it with confidence. Additional study of the Culebra aquifer is therefore recommended by EEG. These recommendations are outlined in the section of this title as well as at the end of this chapter.

Natural Resources

Extensive potash (sylvite, KCl and langbeinite $K_2Mg_2(SO_4)_3$) mining has occurred several miles to the north (in the McNutt Potash Zone) at a horizon 500 feet above the repository horizon. There are 38 million tons of sylvite and 122 million tons of langbeinite of varying economic grades in Zones I, II and III and DOE has banned any potash mining in these zones during the next 25 years - the operational lifetime of the repository. Seven percent of the known langbeinite resources in the U. S. are in these zones. To minimize possible future risk to the repository, we believe that mining of these potassium salts should be banned indefinitely.

If hydrocarbon resources exist at depths greater than 10,000' below the site, it is not clear their extraction is economically feasible via off-set slant drilling outside Zone III. The removal of natural gas does not present any radiological problems.

The presence of such resources appears to violate the provisions of the EPA proposed standard 40 CFR 191, Section 191.14(f).

SPDV Results

DOE has provided two reports entitled "Results of SPDV Site Validation Experiments" and "Results of SPDV Design Validation Experiments." Concerning site validation experiments, EEG concludes that the detailed mapping at the repository horizons and a limited number of rock mechanics experiments conducted to date in the drifts and the shafts, show no adverse conditions at the proposed repository level. However, in order to satisfy Section 13.2 of the DOE's Site Criteria and Qualification Factors, EEG recommends further stud on a bed (MB 139) underlying the repository level.

With respect to the design validation experiments, EEG concludes that several years of data gathering will be necessary to predict the closure and stability of the facility over its project lifetime of 25 years. EEG has not identified any additional experiments for design validation that should be conducted prio to the decision to construct.

RECOMMENDATIONS

The following is a list of certain investigations currently in progress or planned by DOE and additional work which EEG recommends that the State should demand if the construction is allowed to proceed.

Continuing or Planned DOE Studies

1. Evaluate and field test non-invasive geophysical methods to identify possible occurrence of brine under the repository.

2. Analyze the drawdown data in test holes H-1, H-2 and H-3 caused by the excavation of WIPP shafts.

3. Publish the results of solute transport modeling in the Rustler aquifers.

4. Analyze the Rustler aquifer waters for environmental isotopes (Carbon-14, Chlorine-36, Uranium-234, Uranium-238) to aid in understanding the groundwater flow direction and relative velocity.

5. Drill the planned additional wells for hydrologic testing, viz. H-11 and H-12. Obtain the cores while drilling these wells to determine the extent of fracturing and solution residues throughout the Rustler formation.

6. Conduct a water balance study for the WIPP site.

7. Study the mechanics of removal of salt from the Rustler formation at and near the site.

8. Drill a shallow auger-hole in the depression in the SW corner of Sec. 30, T225, R 31E in Zone III to address the suspicion of this depression being a doline.

9. Further study marker bed 139 (MB139) underlying the repository horizon to determine its origin and its effect on the repository and to confirm that it does not violate Section 13.2 of the DOE's site criteria and qualification factors.

Studies Recommended by EEG

1. Investigate the depression of the marker beds in the lower part of the Salado formation, centered two miles north of the WIPP shafts.

2. Perform computer modeling of groundwater flow in the Rustler aquifers.

3. Conduct the following hydrology tests:
   a) A long duration pumping test at the well H-3.
   b) Measure the anisotropy of the hydraulic conductivity at test pads H-1, H-2 and H-3.
   c) Perform convergence tracer tests at wells H-1, H-3 and H-4.
   d) Perform convergence tracer tests at well H-6 using sorbing tracers.

APPENDIX

SUMMARY OF EEG INVOLVEMENT WITH SITE SUITABILITY DETERMINATION FOR WIPP

SUMMARY OF EEG INVOLVEMENT WITH SITE SUITABILITY DETERMINATION FOR WIPP

APPENDIX

1.0 Review of GCR and DEIS (1979)

After an exhaustive review of available criteria for site characterization and selection (EEG-1), one of the first documents that the Environmental Evaluation Group reviewed upon its formation in 1978 was the Geological Characterization Report (GCR) by Powers, et al (1978). EEG's comments on this detailed compilation of up-to-date knowledge on the geologic and hydrologic characteristics were published in a report (EEG-2), which was included as Appendix III in EEG-3. The principal concerns expressed in that review were as follows:

What is the origin, evolution and occurrence of the high-pressure brine-reservoirs which were encountered in the upper part of the Castile formation in ERDA No. 6 and in at least 6 wells within 9 miles of the site?

What is the origin, evolution and occurrence of the "breccia pipes" which have been encountered in the area? They may be localized deep dissolution features which originate in the lower portion of the evaporites and migrate upward. Such localized dissolution features could now exist or develop later beneath the proposed site.

What are the processes and rates of deep dissolution of salt near the site? There may be a preferential removal of the salt horizon which is proposed for the repository.

What are the regional and site hydrologic conditions for the aquifers above and below the evaporites? The hydrologic information is necessary to assess any possible long-term release of radioactive material from the repository.

The Draft Environmental Impact Statement (DEIS) on WIPP was issued in April, 1979. This document contained very little additional information in the areas of geology and hydrology. In its review of the DEIS, EEG repeated the concerns expressed in EEG-2 and made additional recommendations as follows in EEG-3:

- The values of hydrologic parameters for WIPP site aquifers vary over a wide range. This data base should be improved and the subsurface hydrology should be better understood.

- The effect of impurities in salt at the proposed repository horizon should be taken into account in evaluating the physical, hydrological, thermal and strength characteristics of rock salt from the repository horizons.

- More information is needed on the regional hydrology of the WIPP site. Items such as surface runoff, existing and planned water resource development in the area, water use downstream of Malaga Bend and the present and potential well water use from aquifers in the area, need to be better understood.

- The long range modeling for potential breach of the site should take into account plausible future climatic changes in the hydrologic regime.

The correspondence between DOE and EEG following these comments reflects a consideration of most of these concerns and recommendations by DOE. In general, DOE conveyed to EEG that the continuing studies for site characterization would answer most of these concerns.

2.0 Geotechnical Meeting - January, 1980

EEG organized a two-day meeting of experts representing a wide spectrum of earth sciences, on January 17 and 18, 1980, to address the geotechnical questions concerning the WIPP site. The meeting, titled "Geotechnical Considerations for Radiological Hazard Assessment of WIPP", was attended by 66 persons, 35 of whom were geological scientists. The participants

included members of State and Federal agencies, the National Academy of Sciences WIPP panel, the Governor's Advisory Committee on WIPP, several universities in the State, the mining industry and the state and national environmental groups.

The report of this meeting (EEG-6), published in April, 1980, contained the following recommendations in various geotechnical areas:

2.1 Geohydrology

- Better define the regional geohydrology through more field tests.
- Provide a clearer definition of recharge areas for the Rustler and DMG aquifers.
- Further refine Hiss' map of potentiometric surfaces in the Bell Canyon aquifer and its connection with the Capitan and/or San Andres aquifers.
- Evaluate the hydrologic transit times from the WIPP site to man from existing or potential water well development in all aquifers near the site.

2.2 Deep Dissolution

- Provide the arguments against active deep dissolution in a reviewable scientific paper format.
- Thoroughly investigate several anomalous features near the WIPP site, which have been pointed out by proponents of the deep dissolution idea. The results of such investigation should be presented to the scientific community in a reviewable paper.
- Assess potential consequences of deep dissolution and make the calculations available.

2.3 Brine Reservoirs

At the time of the meeting in early January, 1980, EEG was performing the hazard analyses described below and recommended that DOE do the same. EEG further recommended that DOE provide detailed documentation.

2.3.1 Salado Brine: The likelihood and potential extent of water movement into a waste-filled portion of the repository, both during and after the operating lifetime of the repository should be evaluated. If it is determined that a sealed repository might contain large amounts of brine, then hydrologic breach and drilling scenarios should be evaluated under the assumption that some waste is mixed or dissolved in brine at the time of the breach. In the hydrologic breach scenarios, the waste/salt dissolution rate is an important determinant of nuclide concentrations in the Rustler aquifer and in the Pecos River. The assumption that a portion of the waste is already in solution at the time of the breach might alter the scenario consequences significantly.

2.3.2 Castile Brine: Possible consequences of a connection between a brine reservoir, the repository, and the surface should be assessed and the plausibility of different sequences of events which might lead to such a connection should be evaluated. Consequences of a connection between a brine reservoir and the repository extending only as far as the Rustler aquifers are discussed in a draft of the final WIPP Environmental Impact Statement. At the time, EEG was reviewing this analysis.

2.4 Human Intrusion

- The DOE should publish detailed plans and restrictions on drilling for hydrocarbon resources at the site. The description should include:

  a) plans for regulating drilling and production outside of Zone IV;
  b) permissible drilling and production practices in and under Zone IV.
  c) whether secondary and tertiary recovery methods are being considered for Zone IV;
  d) possible use of slant drilling to recover natural gas or oil from beneath Zones I, II and III;
  e) the length of time over which drilling controls would be imposed.

The DOE should publish detailed plans and restrictions on mining of potash at the site. This description should include:

a) whether solution mining would ever be permitted;
b) whether any recovery inside of Zone IV would be permitted;
c) whether shafts will be sealed when potash mines are decommissioned;
d) the length of time over which mining controls would be imposed;
e) whether any controls are to be imposed on mining outside of Zone IV.

- Scenarios need to be evaluated for the following situations:

a) a repository breach involving an abandoned potash mine in Zone IV, either as a source of water into the repository or as a pathway for migration away from it;
b) drilling into a repository containing highly pressurized gas that has developed from decomposition of organic material in the wastes;
c) an exploratory well striking a brine pocket below the repository. The brine ascends to the surface (being under pressure) and brings contaminants with it.
d) appropriate breach scenarios for any additional exploration or mining activity that may be proposed (e.g., solution mining, secondary and tertiary air recovery methods, and exploitation of Zones I, II and III).

2.5 Additional Scenarios

The following scenarios had been proposed by EEG, its consultants, or other groups commenting on the WIPP DEIS. EEG suggested that DOE analyze the hydrologic or geologic events described in these scenarios, determine their plausibility, and whether other events should be considered in designing meaningful radiological hazard scenarios.

2.5.1 Event: Breaching of the excavation workings by pressurized brine after installation of substantial quantities of waste.

Causes: a) Penetration of a brine reservoir during excavation for WIPP.
b) Structural overburden adjustments.
c) Heat source effects.
d) Collapse of underlying beds from previous or renewed dissolution.

Result: A large flow of brine into the repository, rising to the surface and entering the local or Pecos River drainage and/or the Rustler aquifer.

2.5.2. Event: Hydraulic communication between the excavation for WIPP and the dissolution conduits connected to the Capitan Reef aquifer.

Causes: a) Existing conduits NE and E of site already in communication with the Capitan Reef aquifer.
b) Development of communication between the excavation and existing conduits from collapse of subjacent or underlying beds.
c) Development of communication from renewal of dissolution.

Result: Movement of brines into lower part of Capitan aquifer, transfer to San Andres limestone and escape from the basin (with possible effects on petroleum and gas exploration in Texas).

2.5.3. Event: Communication between excavation for WIPP and surface drainage, Rustler aquifer and Delaware Mountain Group aquifer.

Causes: a) Collapse of existing dissolution pocket beneath site.
b) Climatically induced renewal or development of a dissolution chamber beneath site.
c) Collapse due to retrieval of hydrocarbons beneath site.
d) Seismic activity, possibly induced by operation of repository or nearby mines.

Result: Movement of this fluid under artesian pressure to surface or down into Delaware Mountain Group aquifer with ultimate escape from the basin.

Note: This scenario is a variation on DEIS scenario 1, where water flows vertically from the Delaware Mountain Group to the Rustler horizon before moving laterally to Malaga Bend.

2.5.4 Event: Communication between the repository, a source of water, and reserves of potash, oil or natural gas.

Causes: a) Communications between aquifers and repository, as in items 2, 3.

b) Communication between brine reservoir and repository, as in item 1.

c) Solution mining for potash after site control is lost.

d) Injection of water for secondary oil recovery.

Result: Dissolution of a fraction of the waste and contamination of retrievable resources.

3.0 Geological Field Trip, June, 1980

A consensus which emerged from the geotechnical meeting of January, 1980 was that a geological field trip to the site and vicinity would further clarify the different views on the geological processes active at the site. A three-day field conference to the site was organized by EEG on June 16 to 18, 1980 for this purpose. Twenty-three participants in this field conference included seventeen geoscientists from State and Federal agencies, universities and the private sector. There were extensive discussions on many aspects of the geology of the site at each field stop. In addition, there was a 1-2 hour post-field trip meeting each day and a 1/2 day discussion session on the third day. Participants were also requested to send written comments on the geological issues debated during this field conference.

Based on the discussions and the written comments, EEG formulated and submitted to DOE the following recommendations for further work by DOE (EEG-7, pp. 105-106):

3.1 Review Papers. Prepare detailed review papers on the following topics:

a) Deep dissolution - Specifically addressing Roger Anderson's hypothesis about extensive deep dissolution in the lower part of the Ochoan evaporite deposits in the Delaware Basin.

b) Structural anomalies at and near the WIPP site - This should include the anomalies interpreted from geophysical data and from drill cores. The discussion should include the details of geological interpretation of the anomalies and the work being planned or conducted to resolve the seismic data discrepancies, as stated in the Safety Analysis Report, pp. 1.7-65 and 1.7-66.

c) Occurrence of brine reservoirs/pockets in the evaporite beds of Delaware Basin - This should include available information on location, quantity, pressures, quality, ideas on origin, methods of handling it in mines, etc.

d) Details of DOE plans to allow recovery of potash and hydrocarbon resources without disturbing the sealed repository.

e) Basic data and interpretations of boreholes WIPP-31 and WIPP-16 - drilled at hills A and C respectively to obtain more information on the origin of these breccia pipes.

3.2 Exploratory Program. DOE should perform and submit detailed reports on the following explorations:

a) Run a seismic reflection profile across the San Simon Swale to pass over WIPP-15 (sink) from the Antelope Ridge to San Simon Ridge. This should answer the question regarding the postulated fault between the sink and the ridge.

b) Drill 4 or 5 shallow holes across Bell Lake Sink or Slick Sink to reach the Red Soil horizon and drill one deep exploratory hole to the evaporites, if Red Soil is not missing. Even though it is far from the WIPP site, this testing program will answer an important question about the presence of deep dissolution in the Basin itself.

c) Drill one core-hole to the lower Castile in Section 9, northern part of the WIPP site.

d) Reopen one of the brine reservoir wells: AEC-7, Pogo or ERDA-6; allow it to flow for 10 days; measure the depletion of pressure and levels in all three and test the brine at regular intervals.

4.0 Scenario Modeling by EEG

In 1979, EEG published a "Simple Model for Estimating Maximum Radionuclide Concentrations in the Pecos River, and Associated Ingestion Doses, due to the Release of Radioactivity from the WIPP Repository" by Moses A. Greenfield in EEG-2. The results generally agreed within a factor of 2 with the calculated doses shown in the DEIS.

During the latter part of 1980 and the first part of 1981, EEG published two reports (EEG-8 & 9) on a sensitivity analysis and a well scenario and their impact on the hazard assessment for WIPP. This effort of radiological hazard assessments is continuing with the publication of 9 more reports (EEG-11, 12, 13, 15, 17, 18, 19, 20 and 21) to date.

5.0 Stipulated Agreement

As a result of a Stipulated Agreement between DOE and the State signed in July 1981 after the State filed a lawsuit against DOE, the DOE agreed to produce a number of reports addressing specific geologic issues and also agreed to perform additional experiments and field work at the site. The list of these reports and experiments is contained in Appendices B and C of the Stipulated Agreement. These appendices are reproduced below.

5.1 "Appendix B: Comprehensive Topical Reports to be Made Available to Environmental Evaluation Group Before the Decision to Construct the Permanent Repository

1. Deep Dissolution: Including all available pertinent up-to-date data and arguments for and against the hypothesis of deep dissolution in the Delaware Basin and its potential effect on WIPP.

2. Disturbed Zone: Including all available pertinent up-to-date data and analyses of the nature, extent and potential significance to the repository.

   Breccia Pipes: Including all available pertinent up-to-date data and analyses concerning the existence of breccia pipes in the basin and the reef, potential for future breccia pipe development, and their significance to WIPP.

4. DMG Hydrology: Including all available pertinent up-to-date data and analyses of the hydrologic characteristic, geochemistry, potential and rates for salt removal, and directions of flow and possible communication with other aquifers e.g., reef aquifer, San Andres Limestone aquifer and shallow aquifers.

5. Regional Hydrology: Including all available pertinent up-to-date data and analyses of the recharge and discharge area, flow times and interconnections of aquifers near the site.

6. Natural Resources: Including detailed plans to control recovery of potash and hydrocarbons without disturbing the repository, and the evaluation of potential consequences of these plans.

7. Results of SPDV Site Validation Experiments: Including all pertinent results and analyses of experiments as listed in WIPP-TME-2975, pp. 15-16.

8. Plans for SPDV Design Validation: Updated, detailed plans and rationale for the proposed design validation experiments as outlined in TME-3058 and TME-3063.

9. Results of SPDV Design Validation Experiments: Including all pertinent results and analyses of experiments as agreed by DOE and EEG. (Further results to be later provided per *note below.

10. Plans for Stimulated Wastes Experiments: Updated, detailed plans and rationale for the proposed experiments.

11. Results of Simulated Waste Experiments: Including all pertinent results and analyses of experiments as agreed by DOE and EEG.*

5.2 Appendix C: Additional Investigations, the Results of Which to be Made Available to Environmental Evaluation Group Before the Decision to construct the Permanent Repository.

1. Test Brine Reservoir in Deformation Zone: Reopen ERDA-6 and allow it to flow for at least 10 days to measure the depletion of pressure at regular intervals in this well, and if access can be obtained, in Pogo #1 federal well. Perform other necessasry tests to determine the size, age, origin, and possfible association with aquifers or other brine pockets.

2. Report on Brine Reservoirs: Provide a comprehensive topical report on available information concerning brine reservoirs in evaporite beds found in the Delawre Basin including the results of tests on ERDA-6. This should include available information on the location, sizes, quantity, pressures, quality, ideas on origin and methods of handling in mines.

3. Horizontal Exploration of the Disturbed Zone: At the earliest possible stage of facility construction and before emplacement of any waste at the WIPP repository, provide for an additional 3000 feet of drift north of presently planned station #2, which is approximately 2500 feet North of ERDA #9, and drill 3000 feet horizontal cores to the north from this new location.

4. Fracture Flow in Rustler Aquifers: Evaluate the extent of fracture flow in the Rustler aquifers and provide a report on the effect of fracture flow on the resultant release pathways considered in the FEIS.

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*Note: To be completed prior to the 45 day review period and prior to the decision to proceed as set forth in Paragraph 5 of the Order.

5. Study of Aquifer Characteristics: Using in-situ methods, assess quantitatively and qualitiatively the lithology, porosity, permeability, bulk density and distribution coefficients of the Rustler aquifers."

6.0 Costs and Merits Evaluation for Stipulated Agreement Activities

As required in the Stipulated Agreement, the DOE provided a document titled, "Report Assessing the Merits and Costs of Experiments and Studies Set Forth in Appendix B and Appendix C of the Stipulated Agreement Between the State of New Mexico and the U. S. Department of Energy and Others," August 31, 1981. This report provided a detailed review of the items to be covered in the reports and experiments to be conducted by DOE. There was further correspondence between the State and the DOE to clarify some of these items.

After a careful study of all the reports received under the Stipulated Agreement, the EEG finds that the following items which are contained in the "Costs and Merits Evaluation" or in subsequent clarifying letters, are not contained in the reports and have not been transmitted separately.

6.1 Fracture Flow in the Rustler Formation

The proposed work for this report is contained on p. 37 of the "Costs and Merits" report. The following items have not been completed do date.

- Tracer tests in Well number H-5 has not been conducted. The H-4 test is in process, but no useful data has been generated to date.
- A model to represent the flow path and aquifer characteristics in the Rustler has not been released.

It is recommended that this work be completed.

6.2 Study of Aquifer Characteristics

The proposed work under this item is outlined on p. 39 of the "Costs and Merits" report. The following proposed work has not been completed.

- The water inflow tests in the shafts were not conducted for each aquifer. The total inflow down the shaft was measured but not very accurately. EEG concurs with the evaluation by D'Appolonia Consulting Engineers that it is extremely difficult to do this work.

6.3 Marker Bed 124 Depression at the Northern Edge of Zone III

In a letter (Goldstein toSchueler, 10/5/81) following the submission of the "Costs and Merits" proposal, the State suggested that the DOE should reexamine all available data on the MB 124 depression centered at well # F-92 and should determine if the evidence warrants a new borehole at that location. DOE agreed to evaluate this feature in the Disturbed Zone report. However, this report (SAND 82-1069) does not contain such an evaluation. It is recommended that this work be done.

7.0 Review of Stipulated Agreement Reports

During the period from November 1981 to April 1983, EEG received the Appendix B Stipulated Agreement reports as well as the certified data from the Appendix C experiments from DOE. Generally, the reports were first sent to EEG in draft forms, upon which EEG made detailed comments to DOE. Meetings of EEG and DOE technical personnel were then held to resolve any differences concerning the content and scope of the reports. The DOE subsequently issued each report with modifications that they deemed fit to make. EEG-22 contains the EEG comments and DOE replies for all the reports which had been received by EEG through March 1, 1983.

EEG-11 Channell, James K. Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

EEG-12 Little, Marshall S. Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter. Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository, May 1982.

EEG-14 Zand, Siavosh M. Dissolution of Evaporites and Its Possible Impact on the Integrity of the Waste Isolation Pilot Plant (WIPP) Repository (Draft).

EEG-15 Bard, Stephen T. Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon - A Single Hole Scenario, February 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter. Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter and Dave Updegraff. Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentrations of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K. Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E. An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, Peter Spiegler, Kenneth R. Rehfeldt. The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-29

EEG-29

EVALUATION OF THE SAFETY ANALYSIS REPORT FOR THE WASTE ISOLATION PILOT PLANT PROJECT

Marshall S. Little

Environmental Evaluation Group

Environmental Improvement Division

Health and Environment Department

State of New Mexico

May, 1985

Environmental Evaluation Group
Reports

EEG-1 Goad, Donna. A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979.

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, eds. Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Deparatment of Energy. August 1979.

EEG-4 Little, Marshall S. Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K. Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980. April 1980.

EEG-7 Chaturvedi, Lokesh WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP September 1980.

EEG-9 Spiegler, Peter An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K. Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine. January 1982.

EEG-12 Little, Marshall S. Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

(Continued on back cover)

EVALUATION OF THE SAFETY ANALYSIS REPORT

FOR THE WASTE ISOLATION PILOT PLANT PROJECT

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May, 1985

FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is minimal environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of available data concerning the proposed site, the design of the repository, its planned operation, and its long-term stability. These analyses include assessments of reports issued by the U. S. Department of Energy (DOE) and its contractors, other Federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U. S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.

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SUMMARY

The Safety Analysis Report [1] (SAR) for the Waste Isolation Pilot Plant (WIPP) Project was first published by the U. S. Department of Energy (DOE), WIPP Project Office (WPO) in 1980. Since that time a total of eight amendments to this Report have been published. As part of its independent evaluation of the WIPP Project for the State of New Mexico, the Environmental Evaluation Group (EEG) maintains a continuing technical assessment of the information in this Report and its amendments.

Beginning with the initial publication, and following the amendments, the EEG prepares detailed written comments and recommendations which are submitted to the WPO for consideration in future amendments.

The WPO has made many substantial changes to the SAR in response to the EEG's comments. On frequent occasions, meetings between the two groups have been held in an effort to reach an accord on some of the more controversial issues. These meetings generally have been very constructive, but several important areas of conflict remain. In many instances, these areas represent changes which are to be considered by the WPO at some future date, rather than irreconcilable issues.

The most important issues remaining to be resolved are included in the discussions of this report, and could be summarized as follows:

1. An amendment of the topical content to be more in accord with the DOE Order 5481.1A and AL 5481.1A.
2. Substantial revisions of the classification of components, structures and systems, and related quality assurance.
3. Revisions to the site geological and hydrologic data based on studies agreed to between DOE and the State.

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1. INTRODUCTION

The U. S. Department of Energy (DOE) published the Safety Analysis Report (SAR) for the Waste Isolation Pilot Plant Project (WIPP) in 1980.[1] Although the WIPP is not subject to licensure by the U. S. Nuclear Regulatory Commission (NRC), DOE order 5481.1A suggests that the SAR be patterned after the Safety Analysis Report required for licensure under the regulations of the NRC for nuclear reactors (10 CFR 50). It is a five volume report which, according to the NRC regulations, should include (1) the description and safety assessment of the site; (2) a description and discussion of the facility with special attention to design and operating characteristics; (3) the current design of the facility; (4) an analysis and evaluation of the design and performance of structures, systems and components to reflect their risk to health and safety; (5) the technical safety specifications for the facility and the bases for these specifications; (6) the plan for training and operation of the facility; the quality assurance program to be applied to the design, construction, and testing of components, structures and systems to confirm their adequacy; and (7) those plans and procedures which would apply in the event of emergencies.

In September, 1982 the Albuquerque Operations Office of DOE issued the current Order, AL 5481.1A for nuclear operations of the Albuquerque Operations Office of DOE. Chapter 1, section 3.b. lists the Table of Contents for SARs[a] as follows:

"b. Table of Contents for SARs.

Chapter	Title
1	Introduction
2	Summary
3	Description and Safety Assessment of Site[b]
4	Description of Facility
5	Description of Operations
6	Accident Analysis
7	ES&H Systems Critical to the Safety of the Facility
8	Air and Water Pollution Control System
9	Environmental Monitoring Program
10	Waste Management
11	Quality Assurance and Acceptance Programs
12	Facility Expansion Decontamination and Decommissioning
13	ES&H Safety Management Program
14	Summary of Emergency Response Plan
15	Summary Plan for Employee Training
16	Summary Plan for Operating Procedures
17	Operations Safety Requirements
18	Conclusions
19	Glossary"

(a) Chapters 1 through 12 and 18 constitute the Preliminary Safety Analysis Report (PSAR). Additional sections shall be included in the Final Safety Analysis Report (FSAR).

(b) When a formal site study has already been prepared, the study can be referenced in Chapter 3. Pertinent data specific to the facility can then be extracted and placed in Chapter 3.

As stated in Appendix B of the Consultation and Cooperation Agreement between the State of New Mexico and DOE.[2]

> "The Safety Analysis Report (SAR), as amended from time to time, constitutes the most comprehensive document concerning WIPP both in general and specifically as related to public health and safety as well as other matters. The SAR is a dynamic document describing all aspects of the WIPP design and shall be amended by way of revision and additions throughout the entire WIPP project."

The SAR has been rather extensively amended by DOE a total of eight times. These amendments were made in response to comments of the State Environmental Evaluation Group (EEG), as a result of changes in design of structures, systems and components, or because of new information considered by DOE to be more reliable. The EEG has reviewed each of these amendments and has forwarded detailed written comments and recommendations to DOE. This report represents a summary of the more significant EEG comments and associated DOE responses. In most instances, following the submission by EEG of written comments, appropriate DOE staff, and contractor representatives meet with EEG to discuss the DOE's interpretations and planned response to the EEG comments. Any controversial issues may be further debated in an effort to reach a resolution. This report includes a listing at the end of the discussion of each Chapter of those issues which remain unresolved.

The comments and DOE responses as presented below do not include all topics addressed in the original documents nor are they intended to be verbatim quotations from those originals. Instead, an effort has been made to provide only a summary of the more substantive issues raised. Copies of the original submittals, and the written response from DOE are available from EEG upon request. The comments are presented according to the organization of the SAR rather than in relation to their importance to health and safety. However, the more significant health issues are highlighted as appropriate following the discussion of each chapter.

II. EEG COMMENTS AND RECOMMENDATIONS

A. Chapter 1, Introduction and General Description

This Chapter of the SAR provides an introduction and very general description of the facilities, the types of wastes, and the DOE Contractors involved in either design, construction, or operation of WIPP. EEG has suggested additional information to be added to this Chapter, and recommended deleting conclusions not fully substantiated by the data. For example, in the original versions, the statement was made that there are "no major technical problems with the site as it is now understood." In the early stages of the site evaluation, discussed further with respect to Chapter 2 below, EEG urged that more information be provided on the Site and Preliminary Design Validation Program (SPDV) and that several geological issues relative to the suitability of the site be resolved through additional studies. EEG also recommended that the SAR provide details on procedures for verification and enforcement of the Waste Acceptance Criteria.

In general, the DOE responded favorably to these recommendations for additional geotechnical information by including the information in several chapters of the SAR, rather than Chapter 1. The DOE also agreed to perform additional geotechnical studies to resolve the questions concerning site suitability. This agreement, however, was made as a result of a lawsuit filed by the State against DOE. The DOE has continued to maintain in the SAR that there are no significant

geotechnical problems with the site. The State/DOE litigation resulted in a Stipulated Agreement [2] signed July 1, 1981, requiring the execution of a Consultation and Cooperation Agreement between the parties. Appendices B and C of this Agreement provided for the completion of several topical reports and five additional studies designed to improve the understanding of the geology at or near the site and the hydrology of the water-bearing zones at the site. The following final or interim reports were to be completed before the decision to construct the repository:

"1. Deep Dissolution: Including all available pertinent up-to-date data and arguments for and against the hypothesis of deep dissolution in the Delaware Basin and its potential effect on WIPP.

2. Disturbed Zone: Including all available pertinent up-to-date data and analyses of the nature, extent and potential significance to the repository.

3. Breccia Pipes: Including all available pertinent up-to-date data and analyses concerning the existence of breccia pipes in the basin and the reef, potential for future breccia pipe development, and their significance to WIPP.

4. DMG Hydrology: Including all available pertinent up-to-date data and analyses of the hydrologic characteristic, geochemistry, potential and rates for salt removal, and directions of flow and

possible communication with other aquifers e.g., reef aquifer, San Andres Limestone aquifer and shallow aquifers.

5. Regional Hydrology: Including all available pertinent up-to date data and analyses of the recharge and discharge area, flow times and interconnections of aquifers near the site.

6. Natural Resources: Including detailed plans to control recovery of potash and hydrocarbons without disturbing the repository, and the evaluation of potential consequences of these plans.

7. Results of SPDV Site Validation Experiments: Including all pertinent results and analyses of experiments as listed in WIPP-TME-2975, pp. 15-16.

8. Plans for SPDV Design Validation: Updated, detailed plans and rationale for the proposed design validation experiments as outlined in TME-0358 and TME-3063."

The additional studies of the geology and hydrology at the site included the following:

"1. Test a (known) brine reservoir in the deformation zone (ERDA-6).

2. Present an up-to-date report of all data on other known brine reservoirs in the area.

3. Carry out horizontal exploration of the disturbed zone from the depth of the repository. (By mutual agreement between the State and DOE, this plan was deleted and instead the drill hole WIPP-12, located just north of Zone II and in the disturbed area, was deepened to the Delaware Mountain Group. In the process of deepening, another pressurized brine reservoir was encountered.)

4. Evaluate the extent of fracture flow in the Rustler aquifers.

5. Study the characteristics of other aquifers in the area."

In commenting on planned or ongoing studies referred to in Chapter 1 and other Chapters of the SAR, EEG has urged that target dates for completion of these studies also be included in the summary tables of Chapter 1. In some cases, DOE has preferred to delete reference to such studies. As an illustration, section 2.6.63 was deleted in that it referred to "Ongoing Studies" to determine the timing and magnitude of past climatic changes in the site region, and their impact on geologic events over the past ten thousand years. These studies were to include examination of cores, and radiometric dating of organic and ash fall materials. It was to be completed in Mid-1981. DOE stated in 1982 that "These studies have been temporarily suspended due to the magnitude of effort being expended to satisfy the requirements of the DOE State Stipulated Agreement. A schedule for completion of these studies will be established in a future amendment." This new schedule

has not been included in any revision through Amendment 8. EEG recommended that provisions be added to this Chapter to reflect the fact that some wastes which do not meet all of the Waste Acceptance Criteria may be accepted at WIPP with prior approval of the WIPP Project Office. DOE had previously agreed that the State will be notified in advance of such shipments and be permitted to review these proposals before the decision is made to ship the waste. DOE responded to this comment by proposing that such provisions related to DOE/State agreements be added to the Consultation and Cooperation Agreement (C. & C.) and the WIPP Operational Procedures instead of the SAR. DOE stated on December 29, 1983, that draft provisions of such an amendment would be submitted to EEG. To date, no such amendment of the C. & C. agreement nor the WIPP Operational Procedures has been submitted.

Unresolved Comments

1. Although the First Modification to the C & C Agreement will provide for a description and anticipated schedule of reports on geotechnical studies, revisions should be added to the SAR to reflect all studies underway or planned by DOE and its contractors. Such revisions should include the anticipated completion date for each study.

2. The C & C agreement and the WIPP Operational Procedures should be amended to indicate that the EEG will be notified in advance and be given an opportunity to review any proposal to ship waste to WIPP which does not meet the WIPP Waste Acceptance Criteria.

B. Chapter 2. Site Characteristics

This Chapter provides details on the geography and demography of the site, nearby facilities, meteorology, seismicity, hydrology, and regional and site geology. Although DOE concluded in Chapter 1 that there were "no major problems" with the site, the data in Chapter 2 of the original SAR seemed to EEG to be inconsistent with this conclusion. For example, although the seismic reflection profile data were conflicting and inconclusive, they did suggest that faults may exist in the northern part of Zone III and IV from the DMG to the Salado formation, extending through the Castile. This zone of instability appeared to begin only about 3/4 mile north of Zone II, which originally represented the northern-most boundary of the repository. In early comments, EEG also called attention to the depression in Marker Bed 124 about two miles north of ERDA-9 (center of the repository). This collapse feature was considered possible evidence of deep dissolution such as a breccia pipe. Also an anticline in the Castile exists at WIPP-12 borehole, at the northern edge of Zone II, and the northern boundary of the proposed repository. Figure 2.7-25 illustrates three known depressions in MB 124, and since the depression two miles north of ERDA 9 is not reflected in the Salado and higher formations, the possibility was considered that it is a collapse feature due to deep dissolution.

EEG stated that the SAR had inadequately evaluated the extent of deep dissolution within or near the site. It was noted that several studies were being planned or in progress by DOE and its contractors

which would help to resolve the questions on deep dissolution, and these were completed prior to the decision on the suitability of the site.

EEG called attention to the inaccuracies of the SAR's data and discussion with respect to numerous brine reservoirs in the Castile formation and their location and possible interconnection.

Certain of the reservoirs may be interconnected and cover a broad area including the WIPP site, however the data on the reservoirs at ERDA-6 and WIPP-12 suggest that these reservoirs are not connected. There remains the possibility that the WIPP-12 brine extends beneath the WIPP repository.

EEG also expressed concern over the natural resources present at the site and believed that this provided further evidence that the SAR should not conclude that no major problems exist at the site.

DOE responded by deleting Figures 2.7-23, 2.7-24, and 2.7-25, on the basis of Westinghouse "reinterpreting" the seismic profile data. The "disturbed zone" was considered a misnomer, and instead the zone was referred to as an "anomalous zone." The fact that the disturbed area did not extend into the Salado was considered by DOE to be evidence that it was not active "instability" and therefore would present no threat to WIPP. The MB-124 depression and the WIPP-12 anticline also were not considered problems for WIPP but rather reflect slow geologic processes of general interest. As a result of the State/DOE

Stipulated Agreement[2]. DOE carried out several additional studies to try and improve the understanding of possible deep dissolution, brine reservoirs and the nature of the anomalous zone and its potential impact on the proposed repository. The agreement provided that a final or interim report on these studies would be completed prior to a decision to construct the repository. For example, DOE agreed to drill an additional hole in the area 2 miles north of ERDA-9 to determine the cause of the depression of MB-124. This is being planned for the Summer of 1985. Horizontal drill holes at the level of the repository were to be drilled 3000 feet north of the northernmost drift in the repository, to obtain further data on the "Zone of Anomalous Reflection." This decision was subsequently rescinded by mutual agreement between the State and DOE and instead the Drill Hole WIPP-12 was deepened into the Castile to determine the cause of the anticline at this location. This well encountered a large pressurized brine reservoir at 3016 feet below the surface within fractures in the Castile formation, about 900 feet below the repository horizon.

More detail on the issues addressed above by EEG may be obtained from the EEG reports 2, 3, 6-18, 21, 22, 23, 25 and 27.

The original WIPP design put the underground 100 acre repository in the northern part of Zone II, which would have located a part of it directly above the deformed beds of the Castile Formation. From the seismic and borehole data, this area was thought to contain the potential problems of deformed salt at the repository horizon as well as the long-term uncertainties associated with regional deformation.

EEG proposed to DOE in the Spring, 1982 to reorient the WIPP repository to the southern part of Zone II in order to take advantage of an area with apparently more predictable structure and much less deformation. This decision received a strong impetus when pressurized brine was encountered in the borehole WIPP-12, one mile north of the center of the site, in late November, 1981. The DOE announced the decision to reorient the site to the south in Summer, 1982. To confirm the predictions of the geologic structure in the southern part, the DOE drilled a well, DOE-1, just outside Zone II. The data from this well showed a lack of deformation in the geologic units in this area.

There continues to be disagreement between DOE and EEG in the interpretation of the WIPP site characteristics in Chapter 2 of the SAR. EEG interprets the descriptions to be inaccurate or incomplete in many respects and omits references to potential problems which are not yet resolved. EEG maintains that the SAR should accurately reflect the current status of understanding of these issues and should describe the efforts being made to resolve them. The DOE agreed to address these concerns in SAR Amendment 9. Although additional information is needed to improve understanding of the geologic processes, EEG concluded in EEG-23 that the site has been characterized sufficiently to warrant site validation for the present WIPP project.

In commenting on section 2.1.1.2 concerning the boundaries for establishing effluent release limits, EEG argued against use of the

Zone IV boundary for purposes of accident releases. In the published interagency agreement between DOE and the Bureau of Land Management of the Department of Interior (BLM), it was clearly stated that BLM would have control of Zones II, III and IV and that only Zone I was under DOE control. In meeting with DOE[19], their representatives stated to EEG that they would seek an amendment to the Interagency Agreement to reflect DOE control of access to all four zones. This amendment has not been issued to date. In a recent communication from the WIPP Project Office, it was pointed out that the present Department of the Interior Administrative Land Withdrawl for the development of WIPP specifically prohibits bringing radioactive waste on site. Therefore no change is needed for radiological accidents under the current withdrawal authority. Legislation for permanent withdrawal of the WIPP area is being drafted and will provide for appropriate DOE control.

Unresolved Comments

1. Revisions are needed to the discussions of site characterization to reflect data as it becomes available from studies in progress or planned. Particular effort should be made to see that statements accurately reflect the current status.

2. Either the Department of Interior Withdrawal Legislation or the Interagency Agreement between DOE and the Bureau of Land Management should be revised to provide for DOE control of Zones I, II, III and IV for purposes of accidental release of radionuclides. This change is needed prior to shipment of the wastes to WIPP.

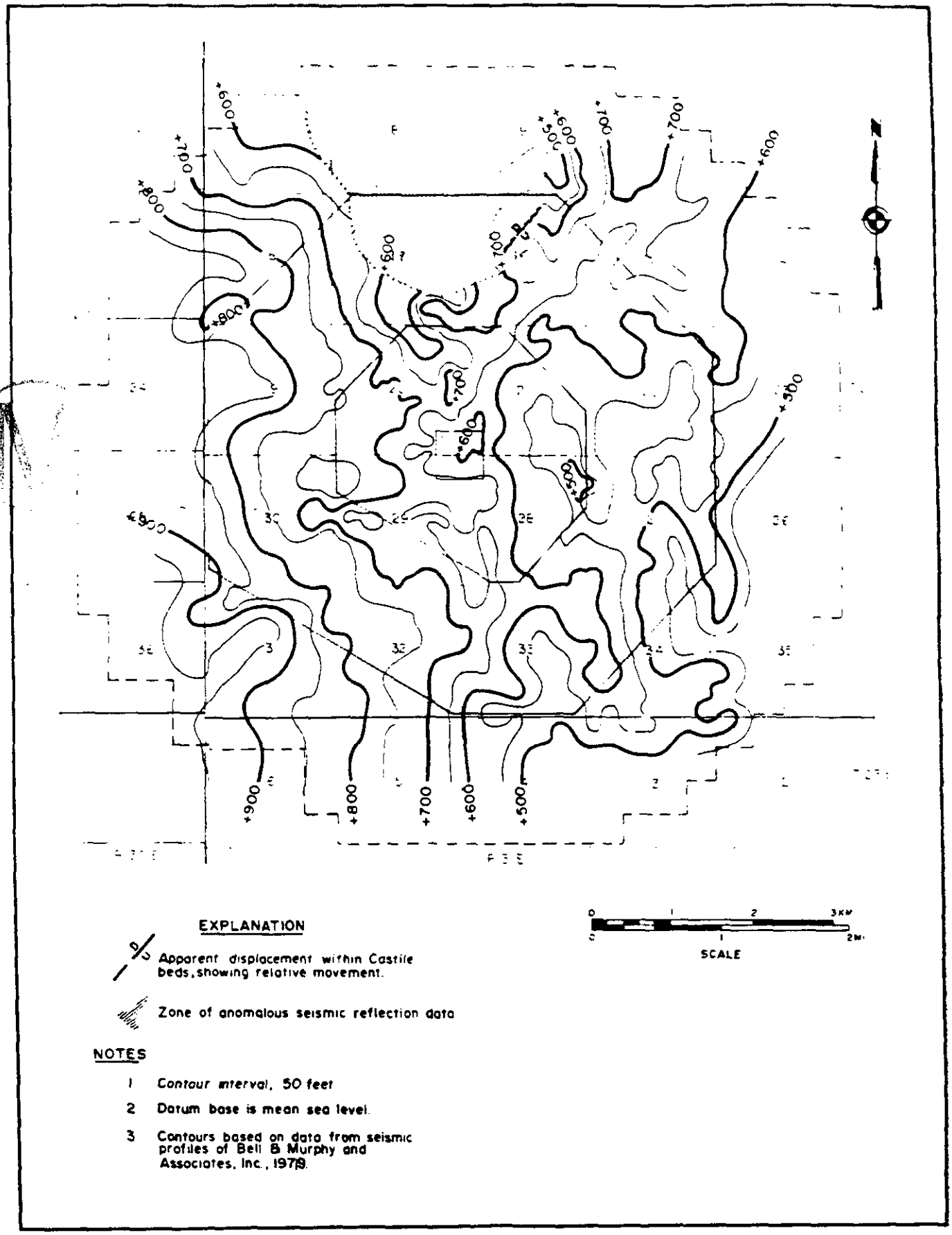

Figure 2.7-23 Structure Contours on Top of Castile Formation

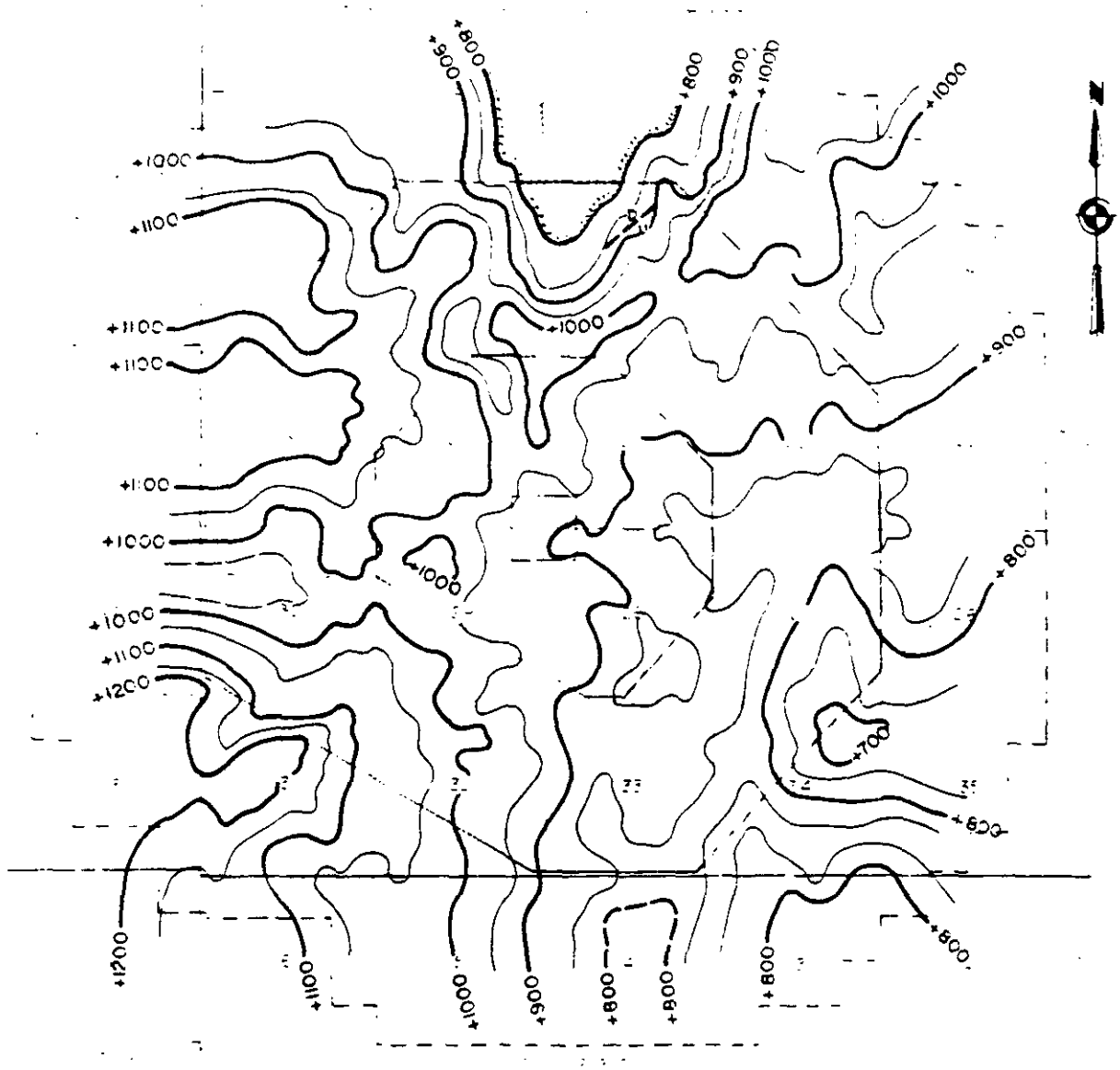

EXPLANATION

Apparent displacement within Cowden Anhydrite, showing relative movement

Zone of anomalous seismic reflection data

0 1 2 3 KM
0 1 2 MI
SCALE

NOTES

1. Contour interval, 50 feet.
2. Datum base is mean sea level.
3. Contours based on data from seismic profiles of Bell & Murphy and Associates, Inc., 1979.

Figure 2.7-24 Structure Contours near the Cowden Anhydrite

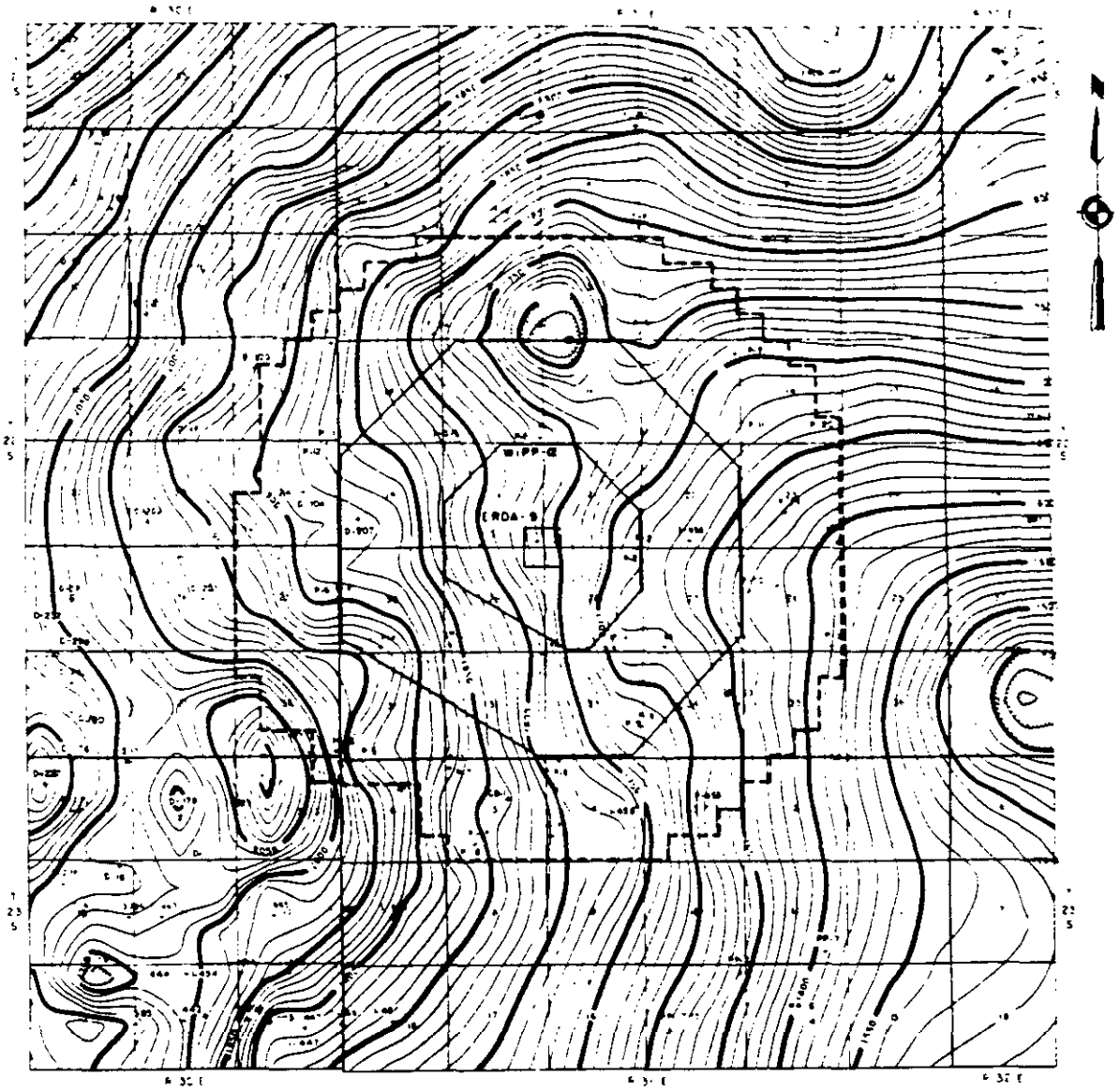

NOTES

1. Contour interval: 10 feet
2. Datum base is mean sea level
3. Contours based on data from geophysical logs of WIPP and industry potash exploration holes

REFERENCE

Griswold, 1977, Figure 13

Figure 2.7-25 Structure Contours on Base of MB124

C. Chapter 3, Principal Design Criteria

This Chapter describes the principal design criteria for the WIPP project. This includes the characteristics of the waste, waste handling and storage capacities, structural and mechanical design criteria, safety protection criteria, classification of structures, systems and components for purposes of quality assurance, and a few statements on decommissioning.

The EEG has pointed out some discrepancies between the wastes inventory in the SAR and the inventory as reported in the FEIS and other DOE publications. Also the characteristics of the wastes as described in the narrative (e.g. subsection 3.1.1.1) are not consistent with the tabulated characteristics in the SAR (e.g. Table 3.1-1A). DOE agreed that these inconsistencies exist and stated in November 1983 that a study was underway to obtain more accurate data, and on completion of this study, the SAR will be revised. Although subsequent amendments have been issued (Amendments 7 and 8), this data has not been revised. For example, subsection 3.1.1.1 states that the average density of the CH-Waste is 2 gm/cc, or approximately 930 lbs/55 gal drum. However, Table 3.1-1A indicates an average weight of 330 lbs/drum. The SAR indicated in Table 3.1-2 a maximum alpha TRU/55 gal drum of CH-Wastes of about 15 Ci, whereas on pages 3.1-4, a maximum of 85 Ci was indicated. This was changed in amendment 8 to indicate that a maximum ^{239}Pu equivalent limit would be provided at a later date.

Concerning the experimental Defense High-Level Waste (DHLW), the FEIS stated that the equivalent of 40 canisters would be emplaced, whereas the SAR indicated 60. The SAR since has been amended to be consistent with the FEIS on the number of equivalent canisters (40), but also stating that about 60 experiments may be carried out. Additionally, subsection 3.1.1.3.2 and Table 3.1-3 stated a volume of 23 ft^3/ canister DHLW, an increase over the previous volume of 520%. When EEG commented on this increase,DOE responded that the Ci/l for many nuclides will be sharply reduced in a future amendment, resulting in the same total curies/canister. Amendment 8 reported the nuclides of DHLW as 54.2 Ci/Lb. Based on a density of 2.8 gm/cc for the glassified waste, the total curies/canister of DHLW has been reduced from 444,000 to about half that number. However, a recent draft of the "Interim Bounding Criteria for Defense High-Level Waste for Receipt at the WIPP"[33] establishes a maximum of 430,000 curies/canisters. The SAR needs to be revised to reflect the authorized maximum.

EEG commented in 1983 that although the SAR discussed the possible retrieval of wastes, no information was given on the criteria to be used to determine the necessity for retrieval. EEG urged that this criteria be included in the SAR at an early date, so that it is clear that the decision process is based upon public health considerations, and there will be an opportunity for public input into the development of the criteria. In a letter of October 1, 1984,the DOE Albuquerque Operations Office stated that the retrieval criteria would be provided to the State by the end of 1985. In the reply from the State, this date was accepted.

In 1980 EEG objected to certain provisions of the classification system for structures, components and systems to be used in the construction and operation of WIPP. This classification system originally was based on Title 10, Parts 20, 21, 71, 100 of the Code of Federal Regulations. A design Class I item was regarded in the SAR as a basic component as defined in Title 10, Part 21, and applied to items essential to the prevention or mitigation of the consequences of an accident that could result in an annual radiation dose beyond the exclusion area boundary to the whole body, bone marrow, and gonads of 0.5 rem, or 1.5 rem to all other organs. "Exclusion Area" is defined in Title 10, Part 100. 3(a), and was interpreted by DOE as the area within Zones I, II, III and IV. The SAR concluded that no design Class I items have been identified at WIPP. EEG's original objections were based on the DOE conclusion that no items fell into Class I. For example, EEG urged that the shipping containers for the three types of waste be considered Class I, EEG contended that it was meaningless to define a Class such that no items were included. The purpose of the classification system is to designate the extent of quality assurance and design requirements for each item in relation to their potential hazard. The response from DOE was that the quality of the shipping container will be assured through the Waste Acceptance Criteria.

In January 1981, the definition of Design Class I was amended to apply to items essential to the prevention or mitigation of the consequences of an accident that could result in a 50 year dose commitment to the whole body, bone marrow and gonads of 25 rem, or

75 rem to all other organs beyond the protective area boundary. "Protective Area" was defined on p.4.1-2 as "controlled Zone I." But subsequent statements indicated that DOE interpreted the "Protective Area" as the four zones of WIPP. The conclusion that no items fell into Design Class 1 remained unchanged. In October, 1982 EEG pointed out that the classification system was inconsistent with the proposed final rule of the Nuclear Regulatory Commission (NRC) for "Disposal of High-Level Radioactive Waste in Geologic Repositories", 10 CFR 60. For example, 10 CFR 60 defined the phrase "important to safety" with reference to structures, systems, and components, or "Those structures, systems and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure." The preamble to this final NRC rule indicated that this value of 0.5 rem is equal to the annual dose to the whole body in an unrestricted area that would be permitted under 10 CFR 20 for normal operations. However under the SAR interpretation, a Class I component would be one which upon failure would allow a 50 year dose commitment of 25 rem, which could be delivered in a single incident. This would imply a higher radionuclide release limit for WIPP than for a high level waste repository. Although WIPP is not subject to NRC regulations, it certainly should not be a greater public health risk than a high level waste repository.

In further comments on the classification system in November, 1983, EEG noted that the Class assigned to various components, structures and systems did not seem consistent with the definition of the Class as stated in Chapter 3, and in some cases the assigned class was downgraded for no apparent basis. Also, the definition of Class II was changed. For example, items used to process waste, the Central Monitoring System (CMS), certain contamination alarms, and the auxiliary generator, were all downgraded from Class II to Class III. The word "permanent" was added to the Class II definition leaving the impression that items for occasional or emergency use only would not be assigned Class II, but would fall into Class III. Also the relationship between the quality assurance and the various classes was not clearly defined in the SAR.

The SAR indicated that the quality assurance requirements are applied on "a selective basis" to Design Class II and III items, and the methods used in the selection process are described in manuals and procedures developed by DOE and the major project participants. In reviewing these manuals and procedures, EEG has been unable to find reference to the classification system except in references 28, 29, 30. These describe a classification somewhat different from that used in the SAR. As further illustration of the inconsistency in the classification system EEG compared the WIPP classification as shown in Table 3.4-2 of the SAR with the office of Nuclear Waste Isolation (ONWI) classification of similar structures and components for an exploratory shaft for a HLW repository in the Permian Basin.[14] In the

ONWI classification several components of the Exploratory Shaft are identified as Class I and II, and there is a direct correlation between the design and QA requirements and the assigned Class. For the WIPP project, all shaft components are Class III. It is also interesting to note that the DOE Albuquerque Operations Office Order AL5481.1A on "Safety Analysis and Review System For AL Operations"[15] provided the following directive for new DOE facilities containing large quantities of radioactive material:

> "The postulated exposures to the general public (from credible accidents) shall be compared to 10 CFR 100 limits as maximal allowable dose commitments. More desirable upper limit accidental dose commitments are 5 rem whole body and 15 rem to an internal organ including the thyroid and 30 rem to the bone (limits in Draft of 10 CFR 101). These are 50 year dose commitments to be applied for each individual accident situation analyzed."

In reference to the DOE (ALO) Order, it was further noted that this Order presented a suggested Table of Contents for a SAR. This also was found to be significantly different from the WIPP SAR. For example, unlike the SAR the Table of Contents in the DOE (ALO) Order included Chapters covering "Summary of Emergency Response Plan", "Waste Management," "Summary Plan for Employee Training," and a "Glossary". EEG has repeatedly recommended that the SAR be revised to be more in accord with this Order, but the WIPP Project Office has

replied that this Order is only a guide and the information on these topics is available in other published reports.

It is obvious that some inconsistency exists between the quality assurance criteria for WIPP, the more restrictive criteria of a HLW repository, and the directives of DOE (ALO) for new nuclear facilities.

In August, 1984, the EEG retained the Tenera Corporation to further examine the adequacy of the WIPP classification system, design requirements and quality assurance. A report of their findings has been prepared and will be distributed as an EEG report [31]. In general, this report concludes that the health or hazard implications of the classification system, as defined by Bechtel, is not substantially different from that used for a civilian nuclear reactor. However, they also noted inconsistencies between the classification as described in the SAR and that of Bechtel. Tenera's report recommended that the 0.5 rem dose in 10 CFR 60 be established as a WIPP criterion for determining whether components must comply with the quality assurance program. The report recommended that the EEG review the implementation of the quality assurance program during the construction of the WIPP facilities and the underground repository. At the present time, the EEG has a full-time radiological physicist and a part-time engineer on site. Their responsibilities include evaluation of the WIPP quality assurance program.

Unresolved Comments

1. Revisions should be added to the information in the SAR on the characteristics of the wastes and waste containers so that this information accurately reflects the waste packages coming to WIPP. It is understood that this information will be included in Amendment 9.

2. Extensive revisions are needed in the SAR to the definitions, data and discussions of the classification system for structures, systems and components. These revisions should show more clearly the relationship between the class, the design requirements, and the required quality assurance. The classification system should provide for the protection of the public at least to the same extent as that required for a high level waste repository licensed by NRC, and should conform more rigorously to applicable orders of DOE and the Albuquerque Operations Office. According to the WIPP Project Office of DOE, some of these revisions will be included in Amendment 9.

3. The SAR should be amended to include the criteria to be used to determine the necessity for retrieval of the wastes. DOE has indicated that these criteria will not be available until December, 1985.

D. Chapter 4, Plant Design

The principal features of the Plant are described in this Chapter, including surface and subsurface facilities. There is also provided a description of the service and utility systems, the waste handling, emplacement and retrieval equipment, and the underground excavation equipment.

The comments of EEG on this Chapter have previously focused on the need for more detailed information covering the various subjects. For example, EEG has noted the need for more details on the emplacement procedures and equipment for the RH waste. Additional information was also needed on the fire protection systems, components and procedures. In responding to the EEG comments on RH emplacement, the DOE indicated that this information would not be available until Title II plans were completed. Concerning the EEG comments on fire suppression, DOE responded by the addition of considerably more information in the SAR on fire protection facilities and consequence assessment.

In section 7B.2.17, the SAR recognizes that a fire could occur in the sample preparation room, because of the chemicals to be used there. After analysis of this event, the DOE concluded that such a fire is bounded by the fire considered in the underground facilities, but this conclusion was based on the assumption that the fumes and radioactive effluents would be removed by the fume scrubber and HEPA filters, and

the fire would be extinguished by the automatic sprinkler system. As indicated in DOE Order 6430,[17] these assumptions may not be valid unless the fire protection systems are considered "critical", or Class I or II components.

Unresolved Comments

1. More detail is needed in either Chapter 4 or 5 on the waste emplacement procedures.

Chapter 5. Process Description

A description of the waste handling system for each type of waste is included in this Chapter. The Chapter also discusses process interruption modes, underground excavation operations, and procedures for the retrieval of each type of waste, when retrieval is decided upon.

The early comments of EEG requested additional information on how the WIPP facility intends to verify compliance of the waste shipments with the waste acceptance criteria and what action would be taken if a shipment fails to meet the criteria. Subsequent additions to this Chapter and Chapter 9 (section 9.5) have revealed that aside from routine visual inspection the only waste acceptance criteria to be verified at WIPP are the containment configuration, labeling, surface contamination, external dose limits, and documentation. In discussion with the Westinghouse staff, the EEG also was informed that the other waste acceptance criteria would be verified at the waste generator sites by means of DOE audits. Limited information has been provided to EEG on the frequency and the nature of these audits. Also, the WPO has agreed to have an EEG representative on each of these audits, so that EEG may verify their adequacy in protecting the public health of New Mexico.

The EEG also recommended that additional information be added on procedures for solidification of radioactive liquid waste generated at the site. The DOE response stated that solidification would be

carried out on site by a local contractor, but no procedures were added to the SAR to provide sufficient information to make a radiation safety evaluation. The EEG also objected to the logging procedure for waste shipments illustrated in Table 5.5.1. This Table listed the type of information which would be recorded on each shipment of waste. It was satisfactorily revised in Amendment 4 as shown below to add logging information on all of the Waste Acceptance Criteria.

The SAR (Chapter 4) has indicated that RH-TRU is to be emplaced in rooms or entries where CH waste also is to be emplaced. However EEG requested additional information in Chapter 5 on the procedures for retrieval of CH waste when RH waste is emplaced in the walls. Additionally, more information is needed to evaluate shielding in the underground storage area. The DOE responded by clarifying in both Chapters 4 and 5 that CH and RH Waste would not be combined in a storage room until after the retrieval decision. Therefore it now appears that both wastes will be emplaced prior to the retrieval decision, but such emplacement will be in separate rooms or entries until after the retrieval decision. Concerning underground shielding, DOE indicated that results of their evaluation would not be available until after completion of Title II design.

Unresolved Comments

Additional information is needed in the SAR to provide evaluation of shielding in the underground facilities.

F. Chapter 6. Radiation Protection

This chapter reviews the measures designed to ensure that radiation doses to workers at WIPP and the general public are "as low as reasonably achievable" (ALARA). It discusses the types of radiation sources, the design features of the facility intended to prevent undue exposure, or radiation risks, the radiation protection instrumentation and the estimated on-site and off-site dose assessments to workers and the general population as a result of normal releases. The WPO has established the operational dose limit to workers at 1 rem/year, approximately 20% of the allowable occupational limit.

EEG's initial comments urged that more information be added to allow evaluation of the radiation shielding in the underground areas. Also the dose assessments did not address potential internal doses to workers using respiratory equipment. DOE subsequently expanded the dose assessment information to include doses to workers with respirators, but indicated that the underground shielding could not be completely evaluated until the Title II designs are complete. The SAR also contained inadequate information on the environmental sampling planned. Additional information was added, but this did not include location or frequency of sampling. In early 1985, the WPO provided for review by EEG a draft report on "Preoperational Environmental Monitoring Program for the Waste Isolation Pilot Plant".

This chapter refers to the DOE Order 6430 (Draft)[16] as a basis for the design criteria for WIPP. As reflected in our comments on Chapter 3,

the EEG has repeatedly called attention to the fact that the design criteria should be upgraded to the DOE (ALO) Order 5481.1A or 10 CFR 60. We note that the draft document [16] referred to in Chapter 6 has been superceded by a revised DOE Order.[17] In Chapter XXI of this more recent Order, it defines "critical items" as "those structures, systems, and components whose continued integrity and/or operability are essential to assure confinement or measure the release of radioactive materials in the event of the DBA (Design Basis Accident)..." DOE has maintained that there are no critical items at WIPP. We also noted that the definition of the "Design Basis Fire" is consistent with EEG's recommendation for consideration of fires in the surface facilities at WIPP. EEG has pointed out to DOE that their failure to consider the fire suppression and manual fire protection equipment as "critical items" (either Class I or II) means that they must assume failure of this equipment in evaluating the design basis fire.

The recent DOE Order (6430.1)[17] defines the DBF as "That fire which is the most severe DBA of this type. In postulating such a fire, failure of the automatic and manual fire suppression provisions <u>shall be assumed except for those systems considered critical items.</u>" (Emphasis added.) This point is discussed further under Chapter 7. The response from the WIPP Project Office on this point was that Chapter XXI of the DOE Order refers only to Plutonium Processing Facilities and WIPP is not such a facility. This does not appear

consistent with the language of Chapter XXI. As stated in the first paragraph:

> "This Chapter supplements these other sources and provides, specific direction and guidance on particular requirements <u>which must be met</u> in the design and construction of facilities for processing <u>and handling</u> of substantial quantities of plutonium. These particular requirements are necessary because of specific toxicological problems associated with plutonium."

Certainly WIPP is a facility for handling large quantities of plutonium contaminated wastes, therefore it would appear to be subject to Chapter XXI. Furthermore in the third paragraph of this chapter, it states that:

> "Questions on the application of these design criteria in the planning and design of new DOE facilities should be addressed to the Director, Office of Project and Facilities Management and to the Deputy Assistant Secretary for Environment, Safety, and Health, EP-30, at DOE Headquarters, for resolution."

Therefore EEG believes that the question of the application of Chapter XXI should be referred to the offices indicated above for resolution.

EEG has also opposed the definition of Class I items on the basis that the radiation limits referred to are not consistent with current

national criteria. This EEG argument, also, is supported by the more recent DOE Order[17], Chapter XXI, and DOE Order 5480.1A,[18] Chapter XI. The radiation limits for members of the public are prescribed as 0.5 rem/year and in DOE Order 6430.1, XXI-6, it states that "in no case shall the applicable exposure regulation be exceeded, either with respect to the operating personnel, or to the public at the boundary or nearest point of public access".

More recently, EEG has questioned the assumptions used for certain of the dose assessment calculations. For example, it is not clear why the RH-TRU gamma spectrum was used for CH-TRU. This would tend to ignore the neutron and ^{241}Am radiation. Also, further information is needed to support the assumptions used to calculate resuspended radionuclides (Section 6.2.2.1). DOE responded by pointing out that this assumption (RH-TRU spectrum) provided conservatism with respect to shielding calculations, and the Am-241 was ignored because it would cause no significant change in the shielding design. Also, the neutron dose will be monitored during operations, and appropriate action taken if neutrons are detected. This response was acceptable to EEG.

Unresolved Comments

1. Additional information is needed in the SAR on the environmental monitoring program for WIPP.

2. As recommended under comments on Chapter 5, more information is needed to permit evaluation of the adequacy of underground shielding.

3. As recommended for Chapter 3, revisions are needed to the definitions, and data on classification and quality assurance for structures, systems and components.

Chapter 7. Accident Analysis

This Chapter provides analyses of the radiological consequences of accidents which might occur during handling of the radioactive wastes at WIPP. These accident scenarios were based on studies of the effect of the misuse or breakdown of handling equipment on waste containers. It has not been revised since the 4th amendment to the SAR which was issued by DOE in September 1982. Therefore, it has not addressed certain changes in the design of components, facilities and source terms. For example, the cost reduction changes of 1983 led to several substantive changes in design, which might effect the Design Basis Accident (DBA). Also there have been changes in the characteristics of the wastes to be shipped to WIPP.

In commenting on Chapter 7, EEG noted that no consideration was given to the buildup of radioactive contamination during the operational life of WIPP. Because of the long-lives of some of the transuranics, and perhaps contribution of Sr^{90}, the total buildup could exceed the EPA limits of 0.2 uCi/m^2 in the top centimeter of soil. DOE responded adequately by extensive revision of Chapter 6 to include the total releases.

EEG recommended to DOE that additional surface accident scenarios be considered. For example, EEG considers a major surface fire credible if one assumes that fire suppression equipment fails. (See comments on Chapter 5.) Also transportation accidents in Zones II, III or IV

should be considered. The DOE rejected those comments in that DOE does not agree that a major surface fire is credible, and transportation accidents will be addressed in the Safety Analysis Report on Packaging (SARP). (The draft SARP was transmitted to the EEG in December, 1984, and is currently under review.) EEG also urged that the SAR consider radiation doses to individuals within Zones II, and III because the general public will have temporary access to these areas. DOE agreed and included consideration of a person located between Zones I and IV at the point of maximum deposition from an airborne release. Concerning surface fires of serious proportions at WIPP in section 7B.2.17, the SAR recognizes that a fire could occur in the sample preparation room, because of the chemicals to be used there. After analysis of this event, the DOE concluded that such a fire is bounded by the fire considered below ground. This analysis was not included in the SAR, but it was based on the assumption that the fumes and radioactive effluents would be recovered by the fume scrubber and HEPA filters, and the fire would be extinguished by the automatic sprinkler system. As previously indicated, these assumptions may not be valid unless the fire protection systems are considered "critical", or Class I or II components, as required by DOE 6430.1[17]. Furthermore, it would seem reasonable to include the analysis of this event in the SAR, even if the consequences are bounded.

Unresolved Comments

1. This chapter needs extensive revisions to reflect changes in design and waste characteristics.

2. The analyses should be consistent with DOE Order 6430.1.

3. The analyses of potential surface fires should be included.

H. Chapter 8. Long Term Waste Isolation Assessment

This chapter assesses the long-term consequences to the public health and safety of hypothetical sequences of events leading to breach of the salt formation and repository by aqueous solution and movement of the radioactive material to the biosphere. It includes a description of the communication modes, the criteria for the selection of the modes, and the assumptions and methods of analyses used.

EEG offered some suggestions in 1980 and 1981 for clarifying some of the assumptions made in the communication modes considered, and also urged consideration of other plausible modes. The DOE responded by adding additional clarification, and also added a detailed analysis of some of the additional modes recommended. For example, DOE has indicated that the high salt content of the Rustler water ruled out the likelihood of a well into the Rustler between the WIPP repository and Malaga Bend, which could shorten the time needed for transport of the breached waste to the biosphere. However in response to EEG's comments, the DOE added a well scenario to Section 8.3.1.4. The results were acceptable and comparable to a similar study by EEG.[20] Also, DOE revised one of the earlier Communication Events (#1) on page 8.3-7 to consider the effect of buildup of radionuclides in the environment of Malaga Bend following a breach and leach scenario. The results demonstrated that accumulation of radionuclides over thousands of years at the maximum release rate would not lead to significant annual doses to the affected population. EEG also suggested that the

scenario analyses include, or discuss, potential doses to infants and children. DOE agreed and included the results in a revision to the SAR. This analysis was acceptable to EEG.

Another area addressed in 1981 by EEG was the need for evaluating the effect of uncertainties in the distribution coefficients used by DOE to estimate the travel time from the repository to Malaga Bend. DOE agreed that there was considerable uncertainty in the Kd coefficients but did not revise the SAR. EEG subsequently published a report which included a sensitivity analysis for changes in several parameters including the absorption coefficient. This report[21] concluded that assuming wide variations in absorption coefficient (down to 0 ml/gm) did greatly affect the rate of transport of the radionuclides released from a breached repository, but did not substantially increase the resultant doses associated with use of the water at Malaga Bend.

In 1981, EEG suggested that additional detail is needed in section 8.3 to describe the communication events and methods of analysis, particularly the specific equations used. DOE agreed with this comment and stated that the detail would be provided "in a future amendment." It was added to an appendix to Chapter 8. EEG published several reports containing EEG's analyses of potential breach of the repository including transport, release and consequences. On September 16, 1981, these analyses [22-26] also were discussed by EEG at an open meeting with experts in several disciplines to further resolve whether all reasonable analytical approaches and potential breach and transport mechanisms had been adequately examined.[27] Although it was

agreed that considerable uncertainty remains concerning the hydrology parameters used in the scenarios presented in the Final Environmental Impact Statement (FEIS) on WIPP[28], there were no new scenarios recommended at this public forum. Also there were no major objections to the EEG proposals or the approaches taken in the EEG analyses.

Additionally, in 1981, EEG urged DOE to consider scenarios in which human intrusion leads to the transport of the waste directly from the repository to the surface, such as possible communication with a brine reservoir below the repository. DOE believed that such a release would be bounded by scenarios already considered in the FEIS, and therefore did not agree to add such a scenario to the SAR. This type of release was considered by EEG in 1982 [23,26], and DOE in 1983 (amendment 6 to the SAR). The results showed that if the communication events occurred at least 400 years after decommissioning, the resultant doses would be less that what might be associated with normal background. The highest 50 year dose commitment to an individual was found to occur at 100 years post-closure and was 590 mrem from the inhalation of contaminated dust resuspended into the atmosphere.

In 1983, in commenting on amendments 4, 5, and 6 of the SAR, EEG noted that the assumed maximum CH-TRU/drum of 85 Ci is no longer consistent with the 140 Ci/drum of Pu-239 equivalent which is being considered by DOE as an amendment to the Waste Acceptance Criteria (WAC). DOE

agreed to evaluate the effect of this change in a future amendment, but to date the change to the WAC has not been finalized, so no such evaluation has been made.

EEG called attention to the need to revise Chapter 8 scenarios as new hydrology data for the Rustler becomes available. DOE agreed to make such changes, if needed.

Unresolved Comments

1. An early decision is needed by DOE on the maximum TRU to be authorized for waste packages to be shipped to WIPP. This level must be sufficiently low so that long-term consequences will not exceed those published in the Final Environmental Impact Statement for the WIPP project [34] Chapter 8 will need to be revised to reflect this new limit.

2. An amendment may be needed to reflect the final results of hydrology studies currently in progress .

I. Chapter 9, Conduct of Operations

This chapter provides general information on the organization and administration of the WIPP project. It includes an overview of simulation preoperational tests, training programs, security and emergency plans.

In EEG's early comments on this chapter, in 1980, it was brought out that the organization of the WIPP project, as reported in Chapter 9, was not consistent with information reported in Chapter 6. Also the references to regulations applicable to WIPP should have included the environmental health regulations of the State Health and Environment Department. A subsequent revision corrected these deficiencies.

In EEG's comments on amendments 4, 5, and 6, in December 1983, it was noted that section 9.2 stated that all equipment and systems designed for the WIPP are tested prior to operation. No detail was provided on the nature of these tests or who is responsible. The section also indicated that administrative procedures are established to ensure that test procedures are prepared, reviewed and approved. Such a testing program is commendable, and is of considerable interest to EEG to ensure that it is carried out. However, when it was recommended to DOE that these administrative procedures be added to the SAR, DOE stated that "these procedures are beyond the scope of the document" (the SAR). In commenting on amendments 7 and 8, in April 1984, EEG requested a copy of these procedures because of their potential importance to health and safety. DOE responded in September, 1984.

that they were being transmitted under separate cover. To date, no such procedures have been received. EEG also noted that WIPP does not have an Emergency Plan to cover the construction phase. The SAR makes several references to an emergency plan, but no such plan has been prepared since the Site Preliminary Design Validation phase. DOE replied that a plan has been drafted, and a copy was transmitted to EEG in November, 1984. Shortly thereafter, EEG transmitted to WPO detailed comments on the plan.

Unresolved Comments

1. *This chapter should be revised to provide more detail on the* nature of the tests carried out on equipment and systems designed for WIPP, and what group or groups are responsible.

2. The WPO provided in November, 1984 to EEG for review a draft Emergency Plan for WIPP. EEG submitted comments on this plan in December, 1984. The plan should be completed without further delay, and referenced in this Chapter of the SAR.

J. Chapter 10, Operations Safety Requirements

This chapter was intended to provide operational limits to maintain compliance with the basic design assumptions used in Chapters 7 and 8, and to meet the operational objectives of WIPP. This information was intended to parallel the technical specifications for a commercial nuclear power reactor, as specified in 10 CFR 50.36. It subsequently was amended to delete reference to regulations of the Nuclear Regulatory Commission, and instead, references as a basis the DOE Order 5481.1A, pages I-3, and II-2. This does not appear to be a substantive change, since these provisions of the DOE Order closely parallel the NRC requirements pertaining to a Safety Analysis Report.

EEG concluded in its initial review of this chapter that the information was not useful, because so much of the detailed data were not available (to be included in a later amendment). Also many of the terms and administrative positions referenced in the chapter were not consistent with other chapters. For example, the description of RH-Waste in Section 10.1.9 was not correct, and the design limits in Section 10.2 referred to only some, but not all of the Waste Acceptance Criteria (WAC). Also no criteria were provided as a basis for rejecting a waste shipment. Some of the WAC were incorrectly described.

In Amendments 1 and 2, this chapter was extensively revised in response to the EEG comments. The consistency of the terms and position titles was expanded to be more in accord with the established

criteria. Also additional information was added to more clearly reflect action if a waste shipment is received which is not in accord with the criteria. It was noted, however, that the certification papers of the waste shipments would be checked for compliance with the WAC, but other than containment configuration, contamination, surface dose rate, labeling and documentation, no other verification would be made. Also there was no provision for notifying the State if a shipment is received which is not in compliance with the WAC. In discussions with the WPO on this point, at a meeting on December 9, 1983, it was agreed that the Consultation and Cooperation Agreement would be amended to indicate that the State EEG would be notified in advance of an approved shipment which is not in accord with the WAC. Also, the WIPP operational procedures would reflect this point. The WPO did not believe that such an agreement should be stated in the SAR. To date, this amendment to the C & C Agreement has not been made; also, the WIPP Operational Procedures should be revised to verify that the procedures require notification of EEG if a nonconforming shipment is received at the site. Such a notification is needed so that the State can evaluate the possible health implications to the public of New Mexico during transportation of the shipment.

It has been pointed out to the WPO through several letters from EEG during 1984 that the SAR is not in complete accord with DOE Order 5481.1A or the supplement to this Order issued by the Albuquerque Operations Office, AL 5481.1A. Specifically in reference to Chapter 10, the SAR is not in accord with certain of the provisions on page I-

3, I-4, and I-5 of AL 5481.1A. For example, this order indicates that desirable upper limits for accidental 50 year dose commitments would be 5 rem whole body and 15 Rem to any internal organ. The WIPP SAR has a 25 rem 50 year dose commitment upper limit. Additionally, it has been repeatedly called to the attention of the WPO by EEG, that the content of the SAR does not include all of the topics referred to on page I-5 of AL 5481.1A, such as a Summary, Environmental Safety and Health Systems Critical to the Safety of the Facility, Environmental Monitoring Program, Conclusions and a Glossary. The WPO indicated that these sections may be added at a later date, however, more recent correspondence states that they have no plans to add the information referred to above, and in AL 5481.1A.

Unresolved Comments

1. It was also stated in a previous chapter that DOE needs to revise the DOE/State agreement and the WIPP Operational Procedures to document DOE's commitment to notify EEG in advance of a proposed shipment which is not in compliance with the WAC.

2. The SAR should be revised to be more fully in accord with the Orders of DOE and Albuquerque Operations Office.

K. Chapter 11, Quality Assurance

This chapter describes the Quality Assurance (QA) Program to be implemented by the WIPP Project Office and the major project participants -- the architect-engineer, the construction manager, the scientific advisor, and the technical support contractor. It is applicable to the site evaluation, design and construction phases of the WIPP Project.

Sections 11A and 11B are blank. Section 11C of Chapter 11 contained a summary of the comments of the EEG on the SAR and the DOE (WIPP Project Office) responses covering all eleven chapters. Section 11C was deleted in Amendment 4.

As stated on page 11.1-1, it is the intent of DOE that each of the QA Programs of the Project Participants be based upon the American National Standard ANSI/ASME NQA-1-1979 and selected supplements. However, that document has been updated and is now ANSI/ASME NQA-1 1983.[33]

In the early comments on this chapter (1981)' EEG called attention to lack of clarity and consistency with other chapters in the description of the organizations as they relate to QA. Amendment 4 extensively revised this chapter to more clearly describe the organization and to define responsibilities for QA. However, the descriptive information of the QA program for each of the Project Participants was provided by

reference to their individual operational manuals. Therefore the QA procedures for the WIPP project could only be reviewed by reviewing the procedural manuals of each of the Project Participants, which is neither practical nor consistent with the established format for a SAR. The only documents which provided detailed procedures for QA were references 28, 29 and 30, however, these procedures were not entirely consistent with various chapters in the SAR.

EEG has requested that the WPO extensively revise the SAR with respect to Quality Assurance to include more details on the relationship between the classification of structures, systems and components and the quality assurance assigned to each class. In section 11.1.2.3 it is stated that such a design classification document is in preparation. However, Chapter 11 has not been revised since Amendment 4, so perhaps the information from this document will be added to the SAR in a future amendment.

<u>Unresolved Comments</u>

As discussed extensively under Chapter 3, the SAR does not adequately provide information on the relationship of the classifiction system to quality assurance. This information should also be provided in Chapter 11. Information referred to in section 11.1.2.3 should be provided without delay, because it is applicable to the construction activities now in progress.

III. References

1. U. S. Department of Energy, "Waste Isolation Pilot Plant Safety Analysis Report," 5 volumes, 1980.

2. U. S. Department of Energy and the State of New Mexico, civil action No. 81-0363, U. S. District Court for the District of New Mexico, July 1, 1981.

3. Environmental Evaluation Group, "Evaluation of the Suitability of The WIPP Site," EEG-23, May 1983.

4. Borns, D. J., L. J. Barrows, D. W. Powers, R. P. Snyder, "Deformation of Evaporities Near the WIPP Site," SAND 82-1069, March 1983.

5. Chaturvedi, L., "WIPP Site and Vicinity Geological Field Trip," EEG-7, 1980.

6. Powers, D. J., S. J. Lambert, S. E. Shaffer, L. R. Hill, and W. D. Weart, "Geological Characterization Report, WIPP Site, S. E. New Mexico, "SAND 78-1596, V. I, II, 1978.

7. Spiegler, P., "Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site," EEG-17 December 1982.

8. Spiegler, P., and Updegraff, D., "Origin of the Brines Near WIPP From the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentrations of Hydrogen and Oxygen," EEG-18, March 1983.

9. Faith, S., Spiegler, P. Rehfeldt, K. R., "The Geochemistry of Two Pressurized Brines from the Castile Formation in the Vicinity of the WIPP Site," EEG-21, April 1983.

10. Bard, Stephen T. "Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below The WIPP Repository Horizon," EEG-15, March 1982.

11. Channell, James K. "Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine," EEG-11, January 1982.

12. Spiegler, P., "Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository," EEG-13, May 1982.

13. Sandia National Laboratories, "Basic Data Report for Drillhole WIPP-14 (Waste Isolation Pilot Plant-WIPP)," SAND 82-1783, August 1982.

14. Office of Nuclear Waste Isolation, Batelle Memorial Institute, "Exploratory Shaft Facility Preliminary Design-Permian Basin," ONWI-498, September 1983.

15. U. S. Department of Energy, Albuquerque Operations Office, "Safety Analysis and Review System for AL Operations," AL 5481.1A, September 15, 1982.

16. U. S. Department of Energy, DOE Order 6430 (Draft), "General Design Criteria Manual," June 10, 1981.

17. U. S. Department of Energy, DOE Order 6430.1, "General Design Criteria Manual," December 12, 1983.

18. U. S. Department of Energy, DOE Order 5480.1A, "Environmental Protection Program for DOE Operations," August 13, 1981.

19. Letter and enclosures of December 15, 1983, from R. H. Neill Director, Environmental Evaluation Group, to Joseph M. McGough, Project Manager on WIPP (3-156AG2-7-10).

20. Spiegler, Peter "An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach," EEG-9, September 1981.

21. Wofsy, Carla "The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP," EEG-8, September, 1980.

22. Environmental Evaluation Group. "Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico (SAND 78-1596, Vol. 1 and II)" EEG-2, August 1979.

23. Channell, James K. "Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine" EEG-11 January 1982.

24. Little, Marshall S. "Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP," EEG-12, May 1982.

25. Spiegler, Peter. "Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository", EEG-13, May, 1982.

26. Bard, Stephen T. "Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon", EEG-15 March 1982.

27. Environmental Evaluation Group, "Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981," EEG-16 February 1982.

28. Bechtel National, Inc., "Quality Assurance Manual, Waste Isolation Pilot Plant," Bechtel Job No. 12484, 3/16/83.

29. Bechtel National, Inc., "Waste Isolation Pilot Plant, Title I Design Report Supplement", VL.1-A, Bechtel Job 12484, January 1980.

30. Westinghouse Electric Corporation, Technical Support Contractor, "Design Criteria Waste Isolation Pilot Plant," WIPP-DOE 71, Revision 4, February, 1984.

31. Tenera Corporation, "Evaluation of Waste Isolation Pilot Plant Classification of Systems, Structures and Components," November, 1984. (Unpublished)

32. Letter and enclosure of December 27, 1984, from W. R. Cooper, Project Manager of WIPP Project Office, to R. H. Neill, Director EEG (WIPP:AEH 84-121).

33. American Society of Mechanical Engineers, "Quality Assurance Program Requirements for Nuclear Facilities," ANSI/ASME NQA-1-1983 (and supplements), An American National Standard.

34. U. S. Department of Energy, "Final Environmental Impact Statement, Waste Isolation Pilot Plant, " DOE/EIS 0026, two volumes, October 1980.

35. U. S. Department of Energy WIPP Project Office and U. S. Department of Interior, N. M. State Office, Bureau of Land Management, Memorandum of Understanding, June 29, 1983.

Environmental Evaluation Group

Reports

(Continued)

EEG-13 Spiegler, Peter. Analysis of the Potential Formation of a Breccia Chimney beneath the WIPP Repository, May, 1982.

EEG-14 Zand, Siavosh M. Dissolution of Evaporites and Its Possible Impact on the Integrity of the Waste Isolation Pilot Plant (WIPP) Repository (Draft).

EEG-15 Bard, Stephen T. Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon. March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981. February 1982.

EEG-17 Spiegler, Peter Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site . December 1982.

EEG-18 Spiegler, Peter Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentrations of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K. Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982. November 1982.

EEG-20 Baca, Thomas E. An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP. February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983. April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site. May 1983.

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP. August 1983.

EEG-25 Chaturvedi, Lokesh Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B. Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S. Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-40

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REVIEW OF THE FINAL SAFETY ANALYSIS REPORT (DRAFT), DOE WASTE ISOLATION PILOT PLANT, DECEMBER 1988

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EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

(Continued on Back Cover)

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REVIEW OF THE FINAL SAFETY ANALYSIS REPORT (DRAFT), DOE WASTE ISOLATION PILOT PLANT, DECEMBER 1988

Environmental Evaluation Group
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May 1989

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a respoitory for permanent disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U. S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and provided for continued funding from DOE through Contract DE-AC04-79AL10752.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. EEG also performs environmental monitoring for background radioactivity in air, water, and soil, both on-site and in surrounding communities.

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SUMMARY

These are the Environmental Evaluation Group's comments on the December 1988 Draft of the DOE Final Safety Analysis Report (FSAR) on WIPP which was received by EEG on February 13, 1989. Previously we commented (October 14, 1988 letter from the Director of EEG to the DOE WIPP Project Manager) on the earlier Draft FSAR, the initial 1980 Safety Analysis Report (SAR), and all nine subsequent amendments to the SAR. EEG's comments on the SAR and its amendments are summarized in EEG-29, Marshall S. Little, "Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project," May 1985.

EEG's October 1988 comments were extensive and indicated there was much we believed needed to be corrected, amplified, and included in the FSAR. The current comments are equally extensive and we believe a significant amount of work still needs to be done by DOE to produce an acceptable FSAR. Many comments are repeated from our October 1988 review because the December 1988 Draft either failed to respond to all of our comments, or responded inadequately. Additional comments on the current draft involve the hazardous wastes analyses in Chapter 6 and 7 which are in the Draft FSAR for the first time. A few of the comments address issues not covered in our October 1988 review but which may have been raised previously in EEG's comments on the various SAR amendments or in other WIPP Project Office (WPO) Reports.

Another point needs to be made. The FSAR does not contain all of the detailed information and procedures necessary to determine operational readiness of the WIPP facility. In fact, it is apparent from the detailed description in the Working Agreement to the July 1, 1989, Consultation and Cooperation Agreement (see Appendix B,

Working Agreement, Revision 1, March 23, 1983, Article IV, K. Operations) that the review of the FSAR is intended to be only one of the milestones under the Operations Key Event and not the sole criteria for determining operational readiness. EEG has concluded, from participation in the DOE Preoperational Readiness Appraisal in March 1989, that there are a significant number of outstanding items. We have made no attempt to address all of these concerns in our FSAR comments because they don't appear to be pertinent to the document and because we intend to make our operational readiness decision separate from the FSAR.

Our more important comments are summarized below in the order the items are addressed in the Draft FSAR. The significance we attach to each should be apparent from our discussion. More detail is provided on these issues under individual chapter comments.

1. Since the FSAR does not include the long-term risk assessment required by EPA in their disposal standards for TRU waste (40 CFR 191, Part B Performance Assessment), the Safety Analysis Report only applies to the five-year demonstration phase of the project. This should be clearly stated in Chapter 1 of the FSAR. There must then be a supplement to the FSAR prior to a disposal phase of the WIPP Project. Also, the supplement would need to contain the operational safety requirements for handling RH-TRU waste.

2. The Second Modification to the July 1, 1981, "Agreement for Consultation and Cooperation" on WIPP by the State of New Mexico and the U.S. Department of Energy requires the FSAR to "document DOE's ability to comply with the provisions of Subpart A of...(40 CFR 191)." This Draft FSAR does not explicitly address Subpart A compliance. Explicit documentation must be provided.

3. EEG strongly objects to the exclusion of calculations for the hoist drop scenario (C8) on the grounds that it is not a credible event. We have never believed that failure mode analysis can be relied on to prove that low probability accidents will not occur. The history of evaluations on the waste hoist system support this skepticism. The DOE WIPP Project Office published a report in 1985 showing the probability of a catastrophic accident was less than 1E-07 per year. Then in 1987, as part of the Operational Readiness Review, a DOE study indicated the probability to be 1E-03 per year. But we are assured (on page 1A.4-5) that this will be corrected and the event will still be incredible. Implicit in this assurance is the belief that every possible failure sequence has now been recognized and correctly evaluated. EEG does not share this conclusion and believes calculations for this scenario should be included in the FSAR.

4. We consider the assumed low failure rate (1E-04) of the exhaust filtration system claimed on page 1A.4-6 to be unproven. For one thing, the system did not work properly during a scheduled drill during the March 1989 Preoperational Appraisal Audit. Secondly, even if this portion of the system performed perfectly, the Continuous Air Monitors (CAMs) would also have to perform adequately with the required sensitivity in order to signal the switch to the filtration mode. As mentioned below, we also consider the CAM system to be unproven. We believe a great deal of effort needs to go into proving the capability and insuring the reliability of both systems.

5. The FSAR should specify in as much detail as possible the volumes, curies, and distribution within both CH-TRU and RH-TRU containers and the totals. Also, possible

ranges and uncertainties in these estimates should be discussed directly. All of these parameters have a bearing on evaluating different aspects of safety at WIPP and are required (by Article VI of the Consultation and Cooperation Agreement) to be included. (See comment in Chapter 3.)

6. Appendix 6A, which contains the methodology necessary for evaluating airborne radionuclide concentrations from routine operations, contains serious flaws. The corresponding radionuclide concentrations and doses in Chapter 6 are incorrect. Appendix 6A and related portions of Chapter 6 need to be completely redone.

7. The CAMs located in the Waste Handling Building, underground, and in the Exhaust Filtration Building are vital to the protection of workers and to the warning of environmental releases. The ability of these instruments to detect airborne radionuclide concentrations with the required degree of sensitivity has not yet been proven. The adequacy of the CAMs must be established by the WPO and verified by an outside peer review group, including EEG, before wastes can be brought to WIPP. (See Chapter 6 comments.)

8. Several of our comments on Chapter 6 refer to concerns about the WIPP Operational Health Physics Program. Since the FSAR does not address this Program in a comprehensive manner, these comments will not respond in detail. However, EEG's serious reservations about the present status of this Program were provided to DOE in our April 7, 1989, comments on the WIPP Phase II Preoperational Appraisal.

9. Analytical samples for both high- and low-level counting rooms should not be prepared in the same preparation room. Also, routine (as well as incident) bioassays must be carried out on radiation workers. (See Chapter 6 comments.)

10. The use of a 1000 PE-Ci upper limit for individual waste containers at WIPP is unacceptable to EEG. Even with a somewhat lower limit it may still be necessary to impose operational restrictions on high-curie drums. (See our comments under Chapter 7.)

11. The potential doses calculated in Chapter 7 to radiation workers from accidents involving CH-TRU waste handling are unreasonably low because the assumptions include only an average PE-Ci quantity in a drum and because (in the C2 and C3 scenarios) the forklift operator is not considered to be exposed. It should be recognized that very high occupational doses are possible and that operational restrictions need to be employed to minimize them.

12. It is appropriate to include the safety aspects of the non-radiological hazardous waste component coming to WIPP. There are some numerical inconsistencies or ambiguities in this draft (see our comments on Chapters 6 and 7) which should be corrected in the next draft. Our principal observations on the methodology and assumptions are:

(a) the exclusion of all chemicals that represent less than 1% of the hazardous waste constituents (by weight) may not be conservative, because toxicities can vary over several orders of magnitude, and should be reconsidered;

(b) the assumption that average concentrations of Rocky Flats Plant waste are conservative averages for the entire system has not been adequately explained;

(c) the atmospheric dispersion models used give drastically different results than the ones used for radionuclides; and

(d) assumptions about zero mobility of lead and any other hazardous chemical (except VOC's in head space gas)

following accidents is non-conservative and inconsistent with assumptions and observations about loss of transuranics (which should be as immobile as virtually all chemicals) from damaged containers.

Because of the extensive re-writing needed on the hazardous waste sections in Chapters 6 and 7 we will not try to reach a conclusion at this time about the potential hazard.

13. The FSAR takes credit in Chapter 8 for a Peer Review Panel providing assurance on suitability of WIPP as a repository. Since the Department has never involved EEG with any of the Peer Review Panels, nor provided us with the agenda, minutes, or recommendations, we believe that the committees do not provide credibility as stated in the FSAR, but in actuality detract from it. In order to take credit, EEG must be involved.

14. It is noted that all references to backfilling the waste storage rooms have been deleted from the FSAR. The FSAR should clearly state whether backfilling will be done during the experimental phase, when the decision on backfill will be made, and the probable final backfill design during operation. (See Chapter 1 comments.)

15. The Operational Safety Review (Chapter 10) lacks sufficient detail to permit us to evaluate the operational safety of WIPP. EEG's specific comments describe the areas in which extensive expansion and revision are needed.

16. A Design Basis Accident (DBA) assessment addressing the requirements of DOE Order 6430.1 and the guidelines to "A Guide to Radiological Accident Consideration for Siting and Design of DOE Non-Reactor Nuclear Facilities," LA-10294-AC,

should be performed and summarized in Chapter 7.

17. This draft of the FSAR evaluates only the proposed disposal mode waste emplacement procedure. Yet, the FSAR is fully applicable to only the (approximately) Five-Year Performance Assessment and Operational Demonstration Test Phase which is not evaluated in any manner. The FSAR should contain analyses of the operations required during the Test Phase. The analysis should include the period at the end of the Test Phase when the wastes at WIPP must be either permanently emplaced or retrieved and shipped elsewhere. (See our comments in Chapters 6 and 12.)

CHAPTER 1
Introduction and General Description

A. General Comments

1. This chapter, including Appendix 1A, has several significant improvements, including a more comprehensive list of pertinent references and an updating of general scientific, technical and physical descriptions. The WPO has made significant responses to EEG's previous comments and recommendations. The chapter provides a good introduction to the FSAR, and there are only a few areas where further changes are recommended. These are discussed in the detailed comments below.

2. After reviewing the entire FSAR, it was noted that it does not contain the performance assessments required by 40 CFR 191 Part B. Therefore, the safety analyses appear to be limited to the five-year pilot plant phase of the WIPP operations. This fact should be clearly stated in Chapter 1.

3. Chapter 1 should include a brief discussion of the status of the potash leases which cover part of the WIPP site, and indicate how and when DOE plans to address this problem.

4. The decision to dispose of the wastes at WIPP or retrieve them will not be based on the results of the Five-Year Pilot Phase as described in the text, but should be based on the ability to meet the EPA Standards for disposal.

B. Detailed Comments

1. Section 1.1, Introduction, Page 1.1-2. The second paragraph on this page refers to the WIPP facility as a "low hazard facility," namely, one "which presents minor onsite and negligible offsite impacts to people of the environment." This conclusion is contrary to DOE/AL Order 5481.1B. According to this Order, a low hazard facility involves only "hazards of a type and magnitude routinely encountered and accepted by the public." As pointed out in the FSAR, the WIPP is a first-of-a-kind facility and, pursuant to DOE Order 5480.5, it is a nuclear facility. Therefore, the hazards of a nuclear facility should not be considered as a type "routinely encountered and accepted by the public." DOE/AL Order 5481.1B also states that all nuclear facilities shall be supported by a SAR. The second paragraph on page 1.1-2 also states that this classification of WIPP as a low hazard facility is in accord with Chapter II of DOE/AL Order 5481.1B. Chapter II discusses "Operational Safety Requirements" and provides no guidance whatsoever for classification of nuclear facilities.

On page 1.1-4, the third paragraph discusses experiments and operational demonstrations needed to reach a decision regarding the permanent isolation of wastes at WIPP. Such experiments and demonstrations are not described in the FSAR, therefore it does not seem appropriate to refer to them in Chapter 1 until such time as they become a part of the FSAR. Also, the latter part of this paragraph discusses the EPA Standard, 40 CFR 191, and leaves the impression that WIPP compliance with the standard is delayed because the standards were vacated and remanded by the courts back to EPA for reconsideration. It should be added that DOE and the State of New Mexico have formally agreed that DOE will proceed to demonstrate compliance with the vacated standard.

On page 1.1-7, there is a statement that technical data, unless it directly supports the Safety Analysis of recent facility modifications, is current through December 1986. Please clarify why technical data on site characterization collected in 1987 and 1988 is not included.

At the bottom of page 1.1-7 and top of page 1.1-8, there is a discussion of the plans to prepare a Supplemental Environmental Impact Statement. Among the reasons which should be added for the need for the SEIS is to summarize the considerable amount of information acquired between 1980 and 1989. This information may change the assessment of the site for the mission of WIPP. For example, concerning the Castile brine reservoirs, FEIS (p. 9-134) stated, "...brine pockets of the size assumed in this example are extremely unlikely near the repository..." In 1981, WIPP-12 borehole, located at the edge of the repository, was deepened and a brine reservoir was encountered which was estimated to contain 17 million barrels of brine, 2 million barrels more than the amount assumed in the FEIS example. After the location of the repository was moved 1.25 miles to the south geophysical surveys performed over the new location showed, "...brine appears to be present 250 meters below portions of the waste panel horizon..." (DOE letter to EEG, 12/29/87). Many such examples of new facts, revised concepts and updated data will need to be addressed in the SEIS.

2. Section 1.1.2, Mission, Page 1.1-11. The Mission Statement emphasizes the research and development aspect of WIPP and mentions the possibility that wastes will not be permanently disposed of at the site. Because of this possibility, the FSAR should indicate where retrieved waste would be sent for storage or disposal.

3. Section 1.1.2, Mission, Page 1.1-11. The Mission of WIPP includes permanent disposal of TRU waste and not simply "to demonstrate many technical and operational principles." The FSAR should clearly state this.

The statement in this section that "the studies and experiments using simulated wastes...are discussed in numerous publications by Sandia National Laboratories and other project participants" is wrong. We are not aware of any published report that lists, describes, or discusses experiments with simulated or real TRU wastes. Room J experiments to evaluate the corrosion effects of brine on the 55 gallon drums cannot be considered to be a "simulated wastes" experiment. The heater experiments were designed to simulate the high level waste and not the TRU waste.

As we have stated before (EEG comments on Draft FSAR, October 1988, Chapter 1, #3, P. 7), the decision to use WIPP for permanently disposing of the waste should be based on demonstration of compliance with the EPA Standards 40 CFR 191, Subpart B, and not "until sufficient operating and scientific data have been accumulated." The Standards do not require operating experience.

4. Section 1.1.3, Design Capabilities, Page 1.1-12. Please delete all references to experiments which are not described and made a part of the FSAR.

5. Section 1.1.4, Schedule, Page 1.1-13. This section should indicate when experimental data and other information will be provided which support the need for the pilot plant phase of WIPP, i.e., emplacing CH-TRU waste at WIPP.

6. Section 1.3, Page 1.3-1. "The shipments are surveyed for external contamination prior to their movement

into the WHB..." During the preoperational audit this was done at the gate. What is planned? EEG believes the check should not be done at the main entrance gate (see our comments on the Phase II Preoperational Appraisal).

7. Section 1.3.1. It is noted that references to backfilling the waste storage rooms that were in Amendment 9 of the SAR have been deleted from the FSAR. We know that the Department has decided to emplace the experimental CH-TRU waste without backfill to avoid crushing the drums during the retrieval period. The FSAR should clearly state this decision and the reason for it and should state that when the waste is emplaced for disposal, a properly selected, tailored backfill will be used to fill the space between the drums, above the drums, and between the walls of the drums. The FSAR should also state that only the amount of waste expressly needed for conducting experiments to help in performance assessment (to show compliance with the EPA Standards 40 CFR 191, Subpart B) will be emplaced in a temporary mode without backfill.

8. Section 1.5.2.1, Repository Plugging and Sealing Studies, Page 1.5-4. It would be helpful to include in this discussion an indication of when the final decision on plug and seal design will be made. Such a decision is important to the Final Safety Analysis.

9. Section 1.5.3, Site and Design Validation Activities, Page 1.5-9. The last paragraph should be revised to delete the indication that there is no recognized function for crushed-salt backfill. There is a well recognized value for such backfill as was discussed in the paper by Chaturvedi, Channell, and Chapman (1988) published in the Waste Management 1988 Conference Proceedings.

10. Section 1.5.3.1, Site Validation Program, Page 1.5-11. In the discussion of Hydrologic Tests, it should be pointed out that the piezometers in the C&SH shaft have not performed well. The groundwater pressures measured in the water-bearing zones of the Rustler were approximately the same as pressures measured at levels where no groundwater is supposed to exist. Also, please clarify the statement that "pressure changes could be diagnostic of changing conditions in the rock or deterioration of seal materials."

11. References for Section 1.5, Page 1.5-15. This reference list includes several unpublished documents which are not available for evaluation. Yet, the discussion in Section 1.5 failed to recognize many of the published works of EEG which are quite relevant to the topics discussed.

CHAPTER 1A
Summary Safety Analysis

A. General Comments

This Summary Safety Analysis Chapter reflects items and conclusions covered in somewhat greater detail elsewhere in the FSAR. Our reaction to the presentation and conclusions of the individual items is expressed elsewhere in comments on the other chapters and is usually not repeated below.

1. This draft responded reasonably well to our October 1988 comments on Chapter 1A. Responses were made to 7 of our 11 comments, with partial responses to two others. However, all responses were not completely satisfactory.

Our first comment asked for a summary of the criteria used to determine that the facility could be operated safely. This was partially answered by mentioning original site design criteria. However, there are other safety-related EPA regulations and DOE Orders the facility will be required to meet. What are they? Have you shown that you met them?

2. This draft of the FSAR appropriately includes an assessment of occupational and public exposures to the hazardous waste component of TRU waste; yet, this is not mentioned in Chapter 1A. It should be.

3. Section 1A.1.1.2, Wind, Page 1A.1-5. The exhaust filter building is mentioned elsewhere as a Design Class II Structure (not III). Also, since it is Design Class II, why is it not designed for a 110 mi/hr wind?

4. Table 1A.3-1, Page 1A.3-3. The title and column

heading in this table are confusing. What is being reported is the average dose for six CH-TRU workers (four waste handlers and two radiation control) and three RH-TRU workers (two waste handlers and one radiation control). See Table 6.1-9.

5. Section 1A.4.5, Waste Hoist Hydraulic Brake System, Page 1A.4-5. The discussion on hopefully reducing the estimated waste hoist brake system annual failure rate from 2.7E-02 is not convincing. All that is expressed is a feeling of faith that the total system failure rate will be shown to be less than 1E-06 per year. See our comments under Section 7.3.2.

6. Section 1A.4.5, HVAC Waste Handling and Exhaust Filter Building, Page 1A.4-6. The estimation that the unavailability of the Exhaust Filter Building would be only 1.4E-04 per release event is unproven. It is understood that this system did not perform properly during the March 1989 Preoperational Appraisal Audit. Furthermore, no allowance is made for the failure of the CAMs to deliver a proper signal in the event of a release. The ability of the CAMs to perform with the required sensitivity in the underground environment has yet to be proven. Also, EEG would appreciate receiving information on the relay test circuits "being considered." How can the problem be considered solved when the specific correction is still being considered?

CHAPTER 2
Site Characteristics

A. General Comments

1. This Chapter has been greatly improved, and we were gratified to note that many of the improvements were in response to comments and recommendations of EEG.

B. Detailed Comments

1. Section 2.1.2.1.2, Potash Leases, Page 2.1-7. This section does not provide adequate discussion of the potash leases. Because there is indication that these private leases may involve large sums of money, it is important that they be resolved before the first shipment of wastes to WIPP. Please add information on when a resolution is anticipated. Also, add a description by section numbers of the 1600 acres referred to.

2. Section 2.2.3.1, Fort Bliss/Biggs AAF, Texas, Page 2.2-2. We understand that there have been 14 flights per year of UH-1H aircraft from the Biggs Air Force Base which fly 500 ft. above the ground directly over the WIPP site. These flights pose a threat to the safety of the WIPP facility, and DOE should take steps to insure they will not occur in the future.

CHAPTER 3
Principal Design Criteria

A. General Comments

1. Although Chapter 3 was extensively revised since the earlier version of the FSAR, and there were many editorial corrections, there was little substantive response to EEG's previous comments and recommendations. We continue to be opposed to the Design Classification definition of Class I items, and believe that the definition should be consistent with that contained in 10 CFR 60.

2. EEG would appreciate the opportunity of reviewing the design classification evaluations for all Design Class II items prepared in accordance with WIPP PROCEDURE WP-300, CHAPTER 4. Please provide information on where this documentation may be obtained.

3. Additional sections should be added to describe the application of the Quality Codes 1, 2, and 3 that are assigned to on-site work requests, to design documents, and to purchase requisitions and for certain analytical or laboratory services for Design Class I, II, and IIIA facility SSC's. Also, the Quality Codes should be described as they apply to certain services associated with the design validation, environmental monitoring, radiological monitoring and geological programs. An additional section should also be added, either here or in Chapter 11 to describe the implementation of the Quality Assurance Surveillance Program.

4. The total expected inventory of CH-TRU and RH-TRU wastes is never stated directly in Chapter 3 or elsewhere in the FSAR. One can make estimates from various sources,

including: (1) Tables in Section 3.1; (2) Table 6.1-4; and (3) statements about design volumes, operating lifetime, and maximums permitted (for RH-TRU). But none of these calculations are as likely to lead to as good an estimate as that determined by those in the WPO who are most knowledgeable about waste characteristics, generation rates, and treatment and emplacement plans. Inventory data affect several aspects of safety analysis: (1) estimates of the number of transportation and operational accidents; (2) probabilities of given concentrations of radionuclides being involved in accidents; and (3) the amounts of radionuclides available for release in post closure scenarios. The FSAR should summarize as much detail as is available on quantities, curies, and distribution in containers for both CH-TRU and RH-TRU. Possible ranges and uncertainties should be discussed in all these values.

B. Detailed Comments

1. Section 3.1.1.1, Container Configuration. Pages 3.1-3,30,31. The text on page 3.1-3 and the Tables 3.1-1 and 3.1-2 on pages 3.1-30,31 do not give a complete picture of the CH-TRU containers since the TRUPACT Efficient Box (Standard Waste Container) is not mentioned on any of these pages. Also, several of the approved CH-TRU waste containers (Table 3.1-2) cannot be shipped in TRUPACT II and it is unclear how the waste in these containers will be transported to WIPP. These pages should be updated and adequately describe the present situation.

2. Section 3.1.1.2.4, Thermal Power, Page 3.1-6. It is unreasonable to assume an average thermal power of 60w for RH-TRU if the average concentration is really similar to that shown in Table 3.1-5. The watts from the Table 3.1-5 inventory would be about 0.6/canister. Furthermore, a

maximum canister subject to the constraints of 1000 PE-Ci, 23 Ci/l and 200 gm fissile material would produce only about 86 watts (assuming the same fission and activation product mixture as in Table 3.1-5). A 1000 PE-Ci CH-TRU drum would generate about 36 watts with no MAP or MFP radioactivity.

3. Table 3.1-5, Page 3.1-35. The average curies per canister of RH-TRU waste has been reduced from 1000 in the previous draft FSAR to 37 (47 if daughter radionuclides are included). This drastic change is not discussed in the FSAR. The current Table is closer to the values reported in the latest Integrated Data Base and in DOE/WIPP 88-005 but there are a lot of internal inconsistencies within these documents. It can only be concluded from the various reports that the volume of RH-TRU coming to WIPP may be as little as 2500 m^3 or it may be over 5000 m^3. The number of curies may be from less than 50,000 to over a million. There are other uncertainties; for example, some of the waste reported in DOE/WIPP 88-005 do not appear to be TRU (less than 100 nCi/gm).

The FSAR should explicitly discuss what is known as well as the uncertainties of the total RH-TRU inventory expected to come to WIPP. This discussion should include estimated ranges of volumes and curies expected to come to WIPP during its lifetime.

4. Table 3.3-2, CMS Vital Information Processing, Pages 3.3-31 through 3.3-34. This table should be revised to tabulate the CMS functions for each of the systems described in Section 3.3.2 Air Handling, i.e., Section 3.3.2.1 Surface Ventilation Systems for the Radioactive Materials Area, Section 3.3.2.2 Surface Support Facilities Ventilation System, Section 3.3.2.3 Subsurface Facilities Ventilation System, Section 3.3.2.4 Interactions Between Air Handling

Systems. The present table appears to incorporate all of the air handling functions in the one designation, HVAC, which could be interpreted to be only the surface air systems with air conditioning. The CMS functions for the Subsurface Facilities Ventilation System, Section 3.3.2.3 are detailed on pages 3.3-12 through 3.3-16 and should be tabulated in Table 3.3-2.

On page 3.3-32, Table 3.3-2 should be revised to tabulate the CMS functions for each of the four Shaft & Hoist Systems identified in Table 3.1-8, i.e., Waste Hoist, Construction & Salt Handling Hoist, Exhaust Shaft, and Air Intake Shaft. For the Waste Hoist, the CMS functions should indicate when TRU waste is being transported, when there is hoist or shaft maintenance, shaft inspection, and personnel transportation.

5. Section 3.4, Decommissioning and Decontamination Design Criteria, Pages 3.4-1 through 3.4-3. The Decommissioning and Decontamination Design Criteria section should discuss and reference the design criteria and programmatic requirements of DOE Order 5820A, "Radioactive Waste Management, Chapter V, Decommissioning of Radioactively Contaminated Facilities." The current reference to Chapter 12, which references DOE 5820.2A, is considered to be inadequate for the purposes of the FSAR since neither Section 3.4 nor Chapter 12 address each of the major design and programmatic requirements (5.1 through 5.e) of DOE 5820.2A.

The reference to the ALARA program should reference DOE Order 5480.11, "Radiation Protection for Occupational Workers," which references (paragraph 9.a) PNL-6577, "Health Physics Manual of Practices for Reducing Radiation Exposure to Levels that are As Low as Reasonably Achievable (ALARA)."

CHAPTER 4
Plant Design

A. General Comments

1. This chapter has been expanded to include significantly improved descriptions of ventilation, fire protection, electrical and water distribution. This information was quite helpful to EEG's review.

2. Inspections and testing of important equipment and mechanical systems is discussed throughout this chapter, but only occasionally is the frequency given for such inspections and tests. This additional information should be added for all of the important systems, or a reference cited where such information is specified.

B. Detailed Comments

1. Figure 4.1-2, WIPP Surface Structures, Page 4.1-8. Buildings 364 and 365 are not identified on the Explanation page.

2. Section 4.2.1.1, Inventory and Preparation Area, Page 4.2-4. The description of this area refers to a waste surge storage area, a battery recharge area, and office space for waste handling personnel. These areas should be identified in Figure 4.2-1 or reference made to other figures where the areas are identified.

3. Section 4.2.1.2, RH Waste Handling Area, Page 4.2-6 to 4.2-10. Figures 4.2-1 and 4.2-3 should be changed to label and identify the cask preparation area, the cask maintenance station, and the cask transfer cell.

4. Section 4.2.1.5, Fire Protection, Page 4.2-14. The last paragraph of this section discusses solidification of contaminated liquid wastes. As previously requested, the FSAR should provide further details of this processing - either here or elsewhere in the FSAR. It should address radiation protection and include the processing procedure, where such processing will take place, and how separation will be maintained of contaminated RH-waste water from CH-waste water.

5. Section 4.2.1.6, Effluent Monitoring System, Page 4.2-15. The air that exhausts the WHB is filtered by a prefilter and two HEPA filters, not "...3 multiple stages of HEPA filters..."

6. Section 4.2.2.2, Construction and Salt Handling Shaft Headframe and Hoist House, Page 4.2-17. Please provide further clarification of the "placement of the emergency escape hoist over the C&SH shaft." Is the emergency escape hoist not part of the existing/in-place mucking hoist, or will there be a requirement to change cages prior to evacuating the mine through the C&SH shaft?

7. Figure 4.2-7, Support Building, Page 4.2-34. Rooms 124 and 125 are mislabeled. The High- and Low-Level Counting Labs are not located here. The walls that remodeled rooms 107 and 139 into offices are not shown.

8. Figure 4.2-8, Support Building, Page 4.2-35. The floor plan for rooms 250 through 253 are incorrect.

9. Section 4.3.2.1.2, Electrical Utility Services, Page 4.3-9. The description of the Electrical Utility Services should be revised to state that one diesel generator can be remotely started and brought on line from the Central

Monitoring Room, as stated in Section 4.4.2.1.2. As shown on the legend to Table 4.4-6, DG No. 25P-E504 is able to be synchronized and brought on line automatically.

10. Section 4.3.2.1.3, Subsurface Structural Features, Page 4.3-10. The third paragraph on this page suggests that vapors from diesel fuel constitute the principal risk of an underground explosion. Of possible greater risk is an explosion from hydrogen formation around the battery recharge areas. Battery recharge in the WHB is shown in Figure 4.4-2 and discussed in Section 4.4.3.1.2, but no mention is made of subsurface battery charging. This should be addressed here and in other sections of the FSAR. This deficiency was mentioned in previous EEG comments. Also, it was previously brought out that the wastes may contain small amounts of pyrophoric materials, or materials which may produce explosive mixtures. Since backfill will not be used during the first five years, some consideration of this potential problem should be discussed.

11. Section 4.3.2.3, RH-TRU Waste Storage Area, Page 4.3-13. EEG requests that up-to-date reference design documentation be cited on pages 4.3-13 and 4.3-15, and that EEG be supplied with drawings of the current design of the shield plug and documentation that supports the 3 - 5 mrem/hour statement.

12. Section 4.4.1, Ventilation Systems, Page 4.4-1. The last paragraph on this page refers to WP 04-1, "Facility Operation Manual." This is an important document which EEG needs to complete review of the FSAR. As of this date, it has not been made available.

13. Section 4.4.1.2.1, CMR and Instrument Shop, Page 4.4-10. The last paragraph should be revised to reflect the

fact that the CAMs located at stations B and C do not monitor ambient air, but monitor only HEPA-filtered "clean" air and therefore do not necessarily represent ambient air.

14. Section 4.4.1.3.2, System Description, Page 4.4-18, 4.4-19, 4.4-20. On page 4.4-18, the statement, "Alarm of any two CAMs can activate HEPA filtration" is misleading. According to J.P. Harvill, at the 28th Quarterly Meeting between DOE and EEG, an alarm by any two underground alpha or any two underground beta/gamma CAMs will initiate HEPA filtration.

On page 4.4-19, please clarify how the reversal of air flow will impact the emergency traffic flow underground pursuant to the escape markings.

The last two paragraphs on page 4.4-20 refer to "periodic" leak and operational tests. Please indicate the frequency of testing, and appropriate action levels.

15. Section 4.4.2.1.5, Backup Loads, Page 4.4-25. This discussion of the backup loads should be revised on page 4.4-25 and in Table 4.4-8 on page 4.4-126. The electrical power needs of the Exhaust Fans, items 28 and 29 on the Legend to Table 4.4-5, page 4.4-105, should be identified rather than the backup electrical load for ventilation for the Air Intake Shaft Hoist on page 4.4-25 and the Air Intake Shaft Hoist Fans on Table 4.4-8. Also, the discussion of the minimum load for backup should be consistent with the above revision.

16. Section 4.4.3.1.2, Fire Characteristics, page 4.4-32. The discussion of <u>spontaneous ignition</u> includes mention of hydrogen formation and venting through a separate exhaust system. It is presumed that this "separate exhaust" venting of hydrogen applies only to the battery recharge area of the

WHB. Please also indicate what safety design features are available in the subsurface battery recharge areas.

17. Section 4.4.6, Radioactive Waste Systems, Pages 4.4-49 and 4.4-50. This section refers to section 5.4 for a description of decontamination procedures, process operation, and radwaste properties. Section 5.4 anticipates radioactive waste will be generated above and below ground at WIPP, however no mention is made of how water mixed with waste and salt in the underground will be collected, assayed or solidified, nor how the underground tunnels will be decontaminated.

The last paragraph of this section on page 4.4-50 refers to the "Waste Handling Operations Manual," WP 05-1. The EEG has not been provided a copy of this manual which is necessary to complete our review of the FSAR. The section also refers to the FMEA, Table 4.4-13. This table does not appear to address the waste water from the RH area, which is contaminated and may have to be treated separately from the CH-liquid waste. This problem should be addressed.

18. Section 4.4.6.2, Liquid Radioactive Wastes, Page 4.4-52. This section describes a trench system which holds fire water pending sampling and analysis for radioactive contamination. If contamination is confirmed, then the contaminated water is manually transferred to a collection tank. This section does not provide details of radiation protection for workers, and procedures needed to collect, mix and measure the activity of the supernatant or precipitate in the holding tank and sump.

19. Section 4.4.9.4, Air Filtering Equipment, Page 4.4-63. Please provide more information on the criteria for filter changeout - the radiation level or pressure drop.

This information should either be provided here or a reference to where such information is available should be provided. Also, it is noted that there is no airlock included in the present design of the Exhaust Filter Building HEPA filter plenum. Further details of the changeout procedure are needed.

20. Section 4.4.9.4, Air Filtering Equipment, Page 4.4-64. It seems likely that the negative pressure of the filter plenum in the Waste Handling Building would collapse the bag for the used filters.

21. Section 4.4.10.2.2, Exhaust Filter Building, Pages 4.4-69, 4.4-70. This section indicates that the compressed air requirements are met by two compressors. It was EEG's understanding that compressed air to the EFB is provided by a buried pipe to the Compressor building.

22. Table 4.4-1, FMEA for the WHB HVAC System, Page 4.4-79. Item 6 on this page describes a Failure Mode as "Permissive to supply air handling unit fails." Please clarify this failure mode.

CHAPTER 5
Process Description

A. Detailed Comments

1. Section 5.1.1.2, Inventory/Preparation Area, Page 5.1-4. Further details are needed here or elsewhere in the FSAR on the procedures for removal and assay of the HEPA filters to avoid potential contamination.

2. Table 5.1-3, CH-TRU Waste Handling Failure Mode and Effects Analysis. This table fails to consider the potential for fire or explosion resulting from hydrogen gas around the battery recharge area in the subsurface. According to Figure 4.3-5, there are five battery recharging stations in the subsurface.

3. Table 5.1-3, CH-TRU Waste Handling Failure Mode and Effects Analysis, Pages 5.1-16, 5.1-19. On page 5.1-16, accident 13 refers to use of breathing air masks for fire in a site-generated rad waste room. Only SCBA would be approved for use during a fire. Please clarify.

On page 5.1-19, Item A1 for Accident 19 is not a safety feature as stated.

4. Table 5.2-1, RH-TRU Waste Handling Failure Mode and Effects Analysis. This table also fails to consider fire or explosion in the underground battery recharge areas. See previous comment.

5. Section 5.4.2, Solid Radwaste System, Page 5.4-2. This section states that all solid radwaste is anticipated to be CH, however, if contamination is found or occurs in the

hot lab or RH-canisters, the resultant cleanup could produce RH-waste. This should be reevaluated and a procedure developed to handle RH-TRU generated wastes.

6. Table 5.5-1, Waste Package Information, Page 5.5-7. This table omits several items which are required pursuant to WIPP/DOE -157, Rev. 2. For example, the Shipment Certification Date, the name of the official who certified the TRUPACT payload, the organic materials volume present, the thermal power (if the amount exceeds the specified limit), the Pu-239 Gram Equivalent, the Waste Package Certification Date, and name of the certifying official are either required or conditionally required.

CHAPTER 6

Environmental, Safety and Health Protection

A. General Comments

1. Appendix 6A, which is necessary for the review of the radionuclide concentration and dose calculations in this chapter, was not received until April 26, 1989, after most comments for the chapter were completed. Our comments on the appendix are summarized at the end of the chapter. We consider the appendix to be seriously flawed.

2. There appears to have been a failure to address in this chapter the changes brought about by the introduction of the new ventilation shaft and the new fans. Also, there is a need for more careful consideration of the placement of monitoring equipment in the Waste Handling Building. There should be a systematic ventilation and contaminant migration study with smokes and tracer gases to arrive at more realistic decisions on placement.

3. The Draft FSAR makes only two brief references to the requirements of 40 CFR 191 Part A and does not explicitly say how compliance will be shown. Neither does the Draft FSAR compare expected doses estimated in this chapter with Part A. The Second Modification of the C&C Agreement requires that the FSAR document comply with Subpart A. Therefore, this documentation of compliance must be included in the FSAR.

4. The Draft FSAR does not fully cover the disposal phase of the project because compliance with 40 CFR 191, Part B, has not been shown, and final decisions have not been made on waste treatment, backfill, and emplacement details.

The need for a supplement to the FSAR has been recognized in the Draft FSAR and is included elsewhere in our comments. However, this Draft FSAR does not address any of the operational procedures that will take place in the proposed experimental phase of WIPP. There are important differences in the waste form that would be used for proposed bin experiments and in underground handling procedures for both experimental and proposed operational demonstration wastes. In addition, the movement and/or backfilling of wastes emplaced during the experimental phase into the final disposal mode must be evaluated. There are possibilities of increased radiation exposure and perhaps mine safety when working in rooms that will have been open for six to eight years. In addition, treatment of waste containers on-site is a possibility. Also, some emplacement rates which have been proposed during the experimental phase could lead to a three-panel operation during the first few years when experimental phase waste is being finally emplaced and new waste is being brought in for the disposal phase. The adequacy of the ventilation system to allow waste handling operations in three panels needs to be evaluated.

B. Detailed Comments

1. Section 6.1.1.2, Design Consideration, Page 6.1-2. In view of recent moves to super-compact waste and heavily load boxes, and the possibility that the existing inventory of boxes may be repacked into the smaller TRUPACT-II standard waste containers, it may be prudent to reevaluate the assumption that radiation fields from boxes will be smaller than from a 55 gallon drum.

2. Section 6.1.2.1, Direct Radiation Sources, Page 6.1-5. The third paragraph uses "mr/h" as allowed neutron dose rate. This should be "mrem/h." Also, please provide

the basis for ignoring the neutron contribution to total dose rate, particularly from high alpha content (heat source Pu-238 and enhanced Am-241) wastes.

3. Section 6.1.3.1, Plant Arrangement Designs for Keeping Exposures ALARA, Pages 6.1-8, 6.1-9. On page 6.1-8, there is a need for further information on the contamination check points. For example, describe the equipment to be used, the procedure for survey of personnel and control of potential contamination, and the procedures and facilities for handling contaminated personnel when or if found. On page 6.1-9, please include information which supports the assumption that pressure differential values created by the ventilation system correspond correctly and appropriately to the identified contamination "zones" in the WHB such that contamination spread between zones will be controlled.

4. Section 6.1.3.3, Radiological Control Zoning and Access Control, Page 6.1-12. More detail is needed here on how personnel are surveyed for contamination at the control points, equipment used, what action is taken when contaminated workers are found (where decontamination occurs), etc.

5. Section 6.1.3.4, Radiation Shielding, Page 6.1-17 to 6.1-18. It is very difficult to review input parameters for the operation of the QAD-P5A computer code from figures 6.1-6 through 6.1-8. A listing of the structural and configurational, as well as source term magnitude/location for this analysis, and those involving the execution of two other shielding codes (G3 and ANISN) is required to make an analysis of this activity with any degree of confidence.

6. Section 6.1.3.5, Ventilation, Page 6.1-20. Please clarify and revise the grammatical errors in the first

paragraph on this page.

7. Section 6.1.3.6, Radiation Monitoring Equipment, Pages 6.1-24,25. The discussion on page 6.1-24 concerning the placement of alpha CAMs and FASs is misleading and implies a lack of understanding of the purpose of these sampling systems in meeting the monitoring requirements of DOE Order 5480.11:

(a) CAMs are not designed to provide indications of concentrations of airborne radioactivity. Their role is to provide alarm in the event of accidental releases;

(b) The decision to utilize a CAM, according to DOE Orders, is not based on whether personnel occupancy is "low" or not; and

(c) FAS sampling is not an adjunct to CAM monitoring in cases of "low occupancy." FASs have their own proper function in monitoring and control of worker exposure. This should be clearly described here.

The second paragraph on page 6.1-25 states that each monitoring system is set to alarm within "acceptable levels of the limits in DOE 5480.1B, Chapter XI." Since DOE 5480.1B does not address alarm levels, please provide an indication of the criteria which will be used to establish these levels. For example, perhaps the level will be set at some designated fraction of the maximum permissible exposure range. It would be desirable to specify that fraction either in the FSAR or the Radiation Safety Manual, so that it could be verified and would not become an arbitrary value.

Also, the discussion of airborne radioactivity monitoring assumes that the monitors are "designed to operate in the expected environmental conditions." Based on recent reviews of the CAMs for both collecting and detecting transuranics in a radon daughter and salt loading environment, this assump-

tion is unproven. Also the calibration of the CAMs, while traceable to NBS and which provide instrument checking, do not calibrate for the actual environmental conditions. Proper operation of the CAMs is vital to the protection of workers at WIPP and to the warning of environmental releases. EEG's concerns about the ability of these instruments to detect radionuclide concentrations with the required sensitivity (particularly in the repository where the greatest amount of interference from salt loading and radon daughters are encountered) have been well documented elsewhere. It is mandatory that further studies be carried out to insure that an adequate monitoring system will be in place before wastes arrive.

8. Section 6.1.4.2, Normal Operation, Page 6.1-27. In the description of the input for annual exposure during normal CH-TRU and RH-TRU waste handling operations, dose rates of 14 mrem/h, 5 mrem/h, and 2 mrem/h four inches from the surface are given for CH-drum, CH-box, and RH-cask, respectively. Please provide the basis for these values. Also, please clarify whether the surface level on a drum is from an individual drum or a 7-Pack.

9. Section 6.1.5.3, Radiation Protection Instrumentation, Page 6.1-34, 6.1-38.

On page 6.1-34, it is stated that samples for both the low level laboratory and the high-level laboratory are prepared in the sample preparation room. It is unacceptable to prepare a sample for high-level counting in the same room as samples for low-level counting since cross contamination of the low-level facilities will likely occur.

Please provide a reference where further details for the calibration procedures may be found.

The first paragraph on page 6.1-38 states that bioassay services are available on a contract basis. The implication is that bioassays would be performed only following evidence of a contamination incident. The WIPP "Radiation Safety Manual," WP 12-5, Revision 1, indicates that preassignment baseline assays and annual bioassays will be routinely carried out. This would suggest that on-site capability for certain types of bioassays (urine, fecal and chest counting) should be available, and the annual bioassays for radiation workers scheduled to minimize assay work loads. This section should be revised to clarify that routine and incident assays will be carried out pursuant to the "Radiation Safety Manual." The discussion on page 6.1-41 clarifies this ambiguity to some degree, but has a typographical error in the sixth paragraph where "routing" should be "routine."

10. Section 6.1.5.5, Radiological Control Facilities, Page 6.1-43, 6.1-44. Please provide more information on the facilities and methods for personnel decontamination, and for detecting such contamination. With respect to personnel decontamination, reference is made to the transport of patients to "a hospital, which has agreed to handle injuries involving radioactive materials." Has a hospital(s) been identified for this purpose? If so, please identify it in this document.

On page 6.1-45, under equipment for the dosimetry laboratory, a statement indicates that compressed nitrogen gas is used for heating. Please clarify this statement.

11. Section 6.1.6.1, Sources of Potential Release, Page 6.1-48. The first paragraph states that the assumptions used in assessing releases are shown in Table 6.1-5. This table provides the estimated results only, but does not indicate

the basic assumptions used to obtain these values. The basic assumptions are needed in order to properly evaluate these data. Neither Table 6.1-4 or Appendix 6A provide sufficient information to arrive at the data shown in Table 6.1-5. Also the first sentence in this paragraph should be revised to state that "the design of WIPP recognizes that very small amounts of radioactivity will be released." To state that it "may" be released implies that no radioactivity may be released, which is not possible.

12. Section 6.1.6.2, Dose Calculation Models, Page 6.1-51. The use of the mean reciprocal wind speed in the atmospheric dispersion equation instead of the mean wind speed biases the equation toward the lower wind speeds. The resulting deposition would be higher than if the numerical average of the wind speeds were used in the equation. Please clarify how the average of the reciprocal wind speeds can save computer time, or other reason why these values were used.

Also on the following page (page 6.1-52), in the determination of the effective stack height for air discharges, credit is taken for the effluent air velocity in the vertical direction. It is our understanding that these stacks are not arranged to release air in the vertical direction, nor will they emit air equally well in all directions. Therefore, the angle of discharge, and the effects of shrouding to effect releases in one direction from the stacks, should be taken into consideration when utilizing the Rupp equation to determine effective stack height. Lower effective stack heights and greater momentum of air in the horizontal direction (and possibly turbulence when the airstream must change direction) after exiting would be expected. Some consideration should be given toward determination of the exiting plume as a function of wind

direction and velocity since the dry deposition rate is affected by wind speed in the horizontal direction as well as by radionuclide concentration.

On page 6.1-53, the use of a constant precipitation factor for the determination of radionuclide deposition is questionable for several reasons. The first reason is stated in the document: precipitation occurs in discrete events of varying magnitude throughout the year. At the WIPP, there are about three to nine events/month on the average (Climates of the United States, U.S. Dept. of Commerce, Washington, D.C. 1973) depending on the month of the year. However, most of the precipitation, and the greatest number of precipitation events, occur during the growing season. Hence, most of the deposition of this type occurs during livestock foraging periods and does not occur equally throughout the year. This period also marks the greatest surface contamination of forage plants which are consumed by livestock. During the spring when biomass densities are limited, livestock must forage over large areas to obtain their food requirements when compared to later in the growing season. During the growing season the deposition is affected by the leaf area index of the plant on the one hand, and lower grazing areas/animal unit as well as tissue dilution of the areal radionuclide concentration on the plants. Thus a complex set of processes involving both precipitation events and biomass densities affect livestock intake of radionuclides deposited on plant surfaces. A simplistic approach in using a constant scavenging coefficient is probably not conservative, and should be tested with a model that can take these factors into consideration in evaluating this dose pathway to man to give it validity.

This document does not mention, and presumably does not include, resuspension events which can contaminate plant

surfaces via additions to the air concentration resulting from stack emissions. They are mentioned only with respect to inhalation hazards to man. Curiously, it does mention washoff of contamination from these surfaces in estimating pathways. The document is totally silent on soil saltation-creep (erosion) events which contaminate forage and crops up to about one meter above the ground, and also rainsplash momentum which does the same thing. In a region where radionuclides accumulate on the soil surface as a result of deposition from a plume, these processes become very important to consider as pathways of radionuclides to man. It is well known that insoluble plutonium compounds are not readily eluviated from the soil surface. Hence, this pathway is ever present, particularly in an arid environment, and should be taken into account in a risk model for this purpose.

Although dose calculation equations from reference (39) were used, it is not clear what specific equations were used, and what differences in parameter input assumptions were made. This should be clarified. Also the meaning of "exponential transfer from one segment to another" is not clear. Presumably this refers to the four-segment catenary model of the GI tract developed by Eve. This should be stated. Generally, the integrated form of transport processes can be expressed as exponential equations with constant or time variant coefficients, but the actual transport processes are not of this type.

13. Section 6.1.6.3, Dose Calculation Parameters and Discussion of Results, Page 6.1-55. The assumed value for the deposition velocity at the WIPP site of 0.18 cm/sec was not found in reference (38), however, a value of 0.68 cm/sec was found for typical meteorological conditions at Oak Ridge, Tennessee. This value for the WIPP site appears to be low by

a factor of about two. A justification and an exact reference for this parameter should be added. It is generally assumed that there is a one order of magnitude difference between wet and dry deposition amounts (wet = 10 x dry).

It is not clear whether the 0.28 kg/m^2 and 1.9 kg/m^2 values on page 6.1-56 are wet or dry weight units. The value of grassland biomass density appears to be greater than expected by a factor of two for arid sites if wet weight units are assumed. Please clarify whether the reference cited specifically addresses arid sites. The value used for forage consumption for cattle is 15.6 kg/day dry weight. The value recommended by NRC is 12.5 kg/day. Why was the latter value not used? Also, it is not clear why it was assumed that the entire beef herd was consumed on an annual basis, or why a specific fractional part of the herd was assumed to be consumed per day if one assumes constant biomass density and an adequate number of beef cows are available to feed the individual(s). Because beef cows are not slaughtered until they have reached a certain stage of maturity (discrete event), and a human's beef consumption is continuous, a lag period accounting for maturation (seasonal), and another between slaughter and consumption (NRC recommends 20 days, although it is not important for transuranics) should be implemented. Please indicate how the seasonal factor was addressed in these analyses. If mean annual concentrations in beef tissue are being utilized each day to account for the maturation period, the validity of this assumption should be documented. Please also indicate the extent to which water ingestion was considered in these analyses.

14. Section 6.1.6.4, Effluent and Environmental Monitoring and Exposure Pathways, Page 6.1-57. The first paragraph of this section states that the nonradiological

monitoring is discussed in Chapter 3. We could find no such discussion in Chapter 3. There was a reference to handling non-radioactive hazardous materials, namely the "Operations Program Plan," DOE/WIPP 85-001, Rev. 3, July 1988. This document has not been provided to EEG.

On page 6.1-62, it is not proven that either of the alpha CAMs can correctly measure the release of TRU from underground in the presence of salt loading of the filters. In the case of the beta CAM, the correction for radon progeny beta emitters is not discussed, and how the salt loading on the monitor will affect the gamma correction on the opposed "nonloaded" detector. What are the lower limits of detectability for the WIPP radionuclides in environmental media for these detector systems?

On page 6.1-64, first sentence. This sentence should read: "The filters obtained from this FAS will be collected and analyzed by the New Mexico Environmental Evaluation Group, for independent verification of releases from the facility."

On page 6.1-64, please provide more information on the minimum detectable concentrations (MDC) which determine quantitatively the meaning of the phrase "significant release." Also indicate what total release and/or release rate would correspond to these levels based on calculated X/Q and deposition velocities for the predominant plume direction. It should be noted that once the HEPA filters are activated in the EFB, Station B must remain in operation continuously from that time on, because it is the sole point at which this effluent can be monitored after it passes through the HEPA filtration system.

15. Section 6.1.7.1.1, Overall Approach, Page 6.1-70.

Under item (4) it is stated that a 50-year effective committed dose equivalent is used. This concept is commonly used for radionuclides, but it should be made clear how the methodology would be applied for hazardous wastes.

On page 6.1-72, the first paragraph includes a statement that risks for hazardous wastes are being overestimated by one to three orders of magnitude by the use of conservative assumptions. The basis for this statement should be added or the statement deleted.

16. Section 6.1.7.1.2, Assumptions and Considerations of Uncertainty, Pages 6.1-71, and 6.1-72. The first sentence of this section indicates that conservative estimates are provided in Table 6.1-16. Please provide a justification for this statement. EEG agrees with the first sentence of the second paragraph on page 6.1-72 in that this statement recognizes the uncertainties in the chemical data base. Also, the assumption of 24 hours-a-day, 365 days-a-year occupancy may lead to a conservative factor of two or three, but not a factor of 10 to 1000.

17. Section 6.1.7.2.1, Migration Pathways, Page 6.1-73. We agree that for normal operations the volatile organic gases would be the predominant releases, however, it is not obvious that 100% of the lead would be in a monolithic form. Since there is so much lead in the waste, the mobility of only a few percent of it could be significant. A contrary assumption should be justified.

Also there is no indication that surface contamination has been considered. Data is needed on surface contamination so that exposure can be evaluated.

This section concludes that the ingestion pathway was

not evaluated. This conclusion is based on the assumption that the chemicals are relatively insoluble and tend to break down in the atmosphere and through biodegradation. Please provide data or references which support such assumptions.

18. Section 6.1.7.2.2, Characteristics of Potential Hazardous Contaminants, Page 6.1-74. It may not be valid to consider only those hazardous wastes present to the extent of 1% or more. It is possible that a highly toxic component present in amounts less than 1% by weight may be of greater significance in toxicity evaluations. For example, cadmium has a cancer potency factor about 425 times as great as methylene chloride and is listed in Table 6.1-17 as having an average concentration about .006 of that of methylene chloride. Therefore, perhaps cadmium should have been considered. Was the data base examined to determine the presence in low concentrations of other highly toxic waste?

The statement in the second paragraph on this page that the method of calculation leads to a "worst case" scenario is correct for some of the waste forms but not for those waste forms in which the concentration of a hazardous constituent may be greater than the "calculated" average. Also, the concentrations of hazardous waste from other generators may substantially exceed that from RFP/INEL. Therefore, more convincing evidence is needed to support the claim that this is a conservative estimate.

At the bottom of page 6.1-74, it appears to be assumed that lead is not one of the mobile constituents. With the very high quantities of lead in some of the drums, this may not be valid. Evidence should be provided to support such an assumption. Furthermore, lead can be assumed to be controlling for the other heavy metals only if the mobile fraction and/or toxicity of these other metals is substantially less

than for lead.

On page 6.1-75, a statement that volatilization of liquid organics need not be considered because the WAC does not allow liquids is inaccurate. Actually, the WAC does allow small amounts of liquid residues.

As previously indicated, the statement at the top of page 6.1-77 that using an average concentration represents a worst case assumption is not valid for all waste containers.

19. Section 6.1.7.2.3, Exposure Modeling, Page 6.1-78. Using the "nearest residence," the Mills Ranch, as the location of the maximum exposed individual from routine releases is probably not conservative. The X/Q concentrations at Crawford Ranch (5 miles NNW-NW in the prevailing downwind direction) are about 50% greater than at Mills Ranch (Table H-49, page H-93 of FEIS). For accidents, Mills Ranch has one hour X/Q values about 10% higher than Crawford Ranch.

In the second paragraph on page 6.1-78, there appears to be a typographical error in the first sentence. The volatile releases should be "from" the waste handling building and underground area rather than "to." Also please address the potential for adsorption of the VOC's to particulates. In which case, why should not the particulate form of hazardous materials be considered? Please also clarify whether the mixing heights utilized for VOC's are the same as those used for the dispersion of radioactive material. Do VOC's have a higher effective mixing layer because of diffusion?

20. Section 6.1.7.3, Routine Releases and Exposures for Hazardous Chemicals, Page 6.1-80. This section states that "before opening the TRUPACT-II, samples will be taken from the sample port to detect any accumulation of hazardous

chemicals." This monitoring procedure is not described in Chapter 5. It should be indicated whether such analyses of hazardous chemicals will be a routine procedure, and, if so, what methods of analysis will be used. If these materials will be routinely analyzed in the gases of all TRUPACT-II's, the procedure should be addressed in Chapter 5. The average flow rates in Table 6.1-19 for 14 drums sealed in TRUPACT-II for 100 hours would lead to air concentrations in the TRUPACT-II cavity that exceed threshold limit values for carbon tetrachloride and are about 15% of the TLV for 1,1,1 trichloroethane. Therefore, concentrations inside the TRUPACT-II may be significant and routine sampling should be required.

21. Section 6.1.7.3.1, Routine Releases, Page 6.1-80. The statement is made here that "backfilling is expected to effectively reduce exposure to VOCs to negligible levels." This would be true only after a storage chamber has been sealed, but not necessarily during the filling of a chamber with waste.

Also on this page, there appears to be an error in the assumed air velocity in a storage room. Since the empty room has a cross-sectional area of about 40 m^2, the velocity of 3 m/s yields a ventilation in the storage room of 120 m^3/s or 254,000 ft^3/min, which is 60% of the entire repository ventilation air. Also using the data in Table 6.1-22, one can calculate the air flow to be in the vicinity of 116 to 123 m^3/s. The WPO ventilation drawings indicate that the entire flow in a waste panel will be 122,000 ft^3/min. Thus the air flow assumption here appears to be high by at least 108% and the calculated air concentrations in Table 6.1-22 should be more than doubled. (Methylene chloride concentration appears high by a factor of 10.)

22. Section 6.1.7.4, Health Risks and Ecological Consequences of Chemical Releases, Page 6.1-83. Please clarify this paragraph and indicate whether the acceptable excess cancer risks (1 in 10,000 occupational, etc.) are per year or per lifetime.

The assumption of 65 to 70 individuals exposed does not appear consistent with information in Tables 6.1-8, and 6.1-10. Please clarify. Also the significance of the last sentence on this page is not clear.

Concerning the discussion at the top of page 6.1-84, the use of human risk standards when considering exposure risks to animals may be conservative for certain species, and/or hazardous materials, but not valid for others. For example, herbivores do not wash forage prior to consumption and are more likely to inhale resuspended contamination for longer periods of time in a contaminated area. Therefore, it may be desirable to carry out additional environmental studies of the ecological system to further support these assumptions.

On page 6.1-85, it was possible for EEG to derive the risk factor for carbon tetrachloride as stated in the second paragraph by using a cancer potency factor of 0.13 $(mg/kg/d)^{-1}$, and by assuming the values in Table 6.1-22 are in mg/kg/d. However it was not possible for us to arrive at the risk factor for methylene chloride. Please clarify these derivations. Also, the statement that 2.7E-06 is "at least two orders of magnitude less than 1E-04," is not correct.

23. Tables 6.1-16 and 6.1-17, Pages 6.1-108 and 6.1-109. By using the values in Table 3.1-6, it was possible to derive the values shown in Tables 6.1-16 and 6.1-17. It is recommended that these two tables reference Table 3.1-6.

24. Table 6.1-20, Page 6.1-112. Except for the values of Freon 113, it is not possible to correlate the values in this table with the respective emanation rates shown in Table 6.1-19. Please provide the methodology for deriving these values or information to indicate why the respective routine releases should not be the product of the number of drums times the emanation rate per drum.

25. Table 6.1-21, Page 6.1-113. The inhalation values given in this Table cannot be obtained from data in other tables when using normal inhalation rates of 12 m^3/d for occupational exposure and 22 m^3/d for the public. Possibly these tables should have been labeled as mg/kg body weight per day.

26. Table 6.1-22, Page 6.1-114. In evaluating this Table, and as indicated in comment 21 on this Chapter, the air flows appear to be high by a factor of at least two. Also if the mg/day values in Table 6.1-21 should be mg/kg/d and are multiplied by 70 for a 70 kg individual, and using an AIC value of 6.30 mg/Kg/day the risk would be 5.1E-04 for 1,1,1 trichloroethane. The risk value for carbon tetrachloride was verified but we did not agree with the methylene chloride value when using a cancer potency factor of .0143 $(mg/kg/d)^{-1}$. Also, isn't the cancer risk the excess lifetime risk from a 25-year exposure at WIPP, rather an excess annual risk as stated in the footnote?

27. Table 6.1-23, Page 6.1-115. No information is given on the EPA ISG Dispersion Model used to calculate off-site air concentrations. The values reported in Table 6.1-23 could be obtained by using an effective X/Q factor of about 5E-08 s/m^3. The X/Q factor used in the FEIS (Table H-49) is about 6E-07. Even the equivalent X/Q factor used to calculate individual radiation doses in this chapter (in

Table 6.1-13 from releases in Table 6.1-12) is over six times greater (about 3.3E-07 s/m^3). It was not possible to check the values for carcinogens. Also, as mentioned in comment 19 on this chapter, it appears that Crawford Ranch would have higher concentrations than at Mills Ranch.

The risk values were verified for all hazardous chemicals except methylene chloride by assuming the mg/d values from Table 6.1-21 should have been mg/kg/d.

28. Figure 6.1-16, Page 6.1-135. The shaded areas referred to in this figure are not shown.

29. Section 6.2, Environmental Protection, Page 6.2-2. In the discussion of the applicability of subpart B of 40 CFR 191 to the FSAR, it is not clear how WIPP can become a disposal facility without demonstration of compliance beforehand. The FSAR will be incomplete until such demonstration has been achieved, and this should be clearly stated.

30. Section 6.2.1.3, Non-Radiological Environmental Surveillance Program, Page 6.2-7. This section should be expanded to indicate the extent to which environmental studies, if any, will be made of the ecological system to support the assumptions and conclusions in the FSAR concerning RCRA requirements.

31. Section 6.3.2, Occupational Medical Program, Page 6.3-4. Please provide additional information on this program, such as how employees are informed about the program, particularly the termination medical examinations.

32. Section 6.4, Industrial Hygiene, Pages 6.4-1 through 6.4-5. While this section has been expanded from two

to five pages, there is nothing WIPP-specific in the section, neither are there any references. This section is inadequate in describing the potential industrial hygiene problems at WIPP or the program being developed to control them. More WIPP specific detail is needed to demonstrate that industrial hygiene problems have been evaluated and control is assured. Please include in this discussion an indication of how RCRA requirements will be interfaced into the industrial hygiene program. Also references to documents which support the discussion should be added.

C. Appendix 6A

EEG believes this draft of Appendix 6A is seriously flawed. There are two major errors of logic in the calculations. The values that are calculated are not reflected in appropriate tables in Chapter 6. Also, there are non-conservative changes in assumptions from the previous draft FSAR that are not justified.

One principal problem is that the procedure used to calculate the radionuclides present in the surface contamination is incorrect if one starts from the assumption (which you did, and EEG agrees with) that "the internal content of the drum would also tend to reflect the radionuclide distribution on the external surfaces of the respective container." The average drum contains 65% alpha radioactivity and 35% beta plus gamma radioactivity. Yet, the calculation method assumes that the beta plus gamma contamination limit (which is nine times the alpha limit) is reached first and depresses the maximum alpha contamination. The final result is that, from an alpha/beta plus gamma ratio of 1.86 in the drum, the calculation ends up with a ratio of 0.024 on the surface! Because of a different radionuclide distribution in boxes, the Appendix 6A methodology is only in

error by about 3%. However, because alpha radiation delivers most of the internal dose, the overall dose would be about 90% higher than calculated with the Table 6A-2 and 6A-3 values.

Furthermore, it does not appear that the values calculated with the Appendix 6A methodology are used in Chapter 6. For example, the 6A calculation indicates a normal Pu-239 concentration of 6.6E-16 $\mu Ci/cm^3$ near the drum from resuspension, while the value in Table 6.1-5 is 6.1E-14 $\mu Ci/cm^3$. Appendix 6A does not explicitly state how one goes from resuspended activity from a drum or box to the average concentration for the year. Apparently, it is assumed that the resuspended concentration endures for one hour for each contaminated drum or box. The number of workers exposed during each incident is not stated. Likewise, there is no indication of how long the resuspended concentration from damaged containers is assumed to persist. If it is assumed that all 24 workers are exposed to the "6A concentration" for 1,900 hours per year and six persons were exposed to damaged containers for 20.4 hours/year (which seems low), then the dose would still be 0.30 + 1.00 = 1.3 person-rem/year committed effective dose equivalent (CEDE). But Table 6.1-10 presents a value of 0.66 person-rem. To further confuse the issue, the concentrations in Table 6.1-5 would result in a CEDE of 0.54 rem per worker-year of exposure. It is noted that DOE/WIPP 88-012 estimates about 10.3 person-hours of handling for each trailer and this would be about 3.4 person-years/year near enough to containers to receive external radiation doses. This would result in a dose of 1.8 person-rem/year (CEDE) from Table 6.1-5. We conclude that the estimated doses in Table 6.1-10 cannot be reproduced from assumptions given in either Chapter 6 or Appendix 6A and are probably low.

Another fundamental error in methodology is the use of the resuspension factor to calculate the amount of radioactivity being discharged to the atmosphere from surface contamination. Using the assumptions in Appendix 6A, one can calculate that the total amount of radioactive contamination on containers brought on-site during a year would be about 2.8E-05 PE-Ci. Yet, Table 6.1-12 indicates that 1.2E-03 PE-Ci are released to the atmosphere in storage exhaust and about 0.3E-03 PE-Ci/y is released into the Waste Handling Building. The total in Table 6.1-12 is then almost 55 times the amount brought in! Similarly, the amount of Pu-239 reported as being released in Appendix 6A (1.9E-5 Ci/y) is about 4.7 times that calculated in Tables 6A-2 and 6A-3. The resuspension factor cannot be used to determine amounts lost from a contaminated surface over a period of time because it includes a fraction that is being continuously deposited (as well as suspended material being transported from the location).

The "Assumptions Used" table (Table 6.1-4) corresponds to Table 6.1-5 in the earlier FSAR draft. However, two key assumptions are less conservative compared to the previous draft:

1) the assumed number of contaminated containers received during a year is only 5%; and

2) the assumed number of damaged containers received per year is only 19%.

What is the basis for these reductions? Are there data from waste generation and storage facilities to justify them?

CHAPTER 7
Accident Analysis

A. General Comments

1. This chapter failed to adequately respond to several of EEG's previous comments. For example:

(a) There is still no indication that a formal Design Basis Accident (DBA) has been performed. There are requirements for such a DBA assessment in DOE Order 6430.1, Chapter 1. This assessment should be performed and summarized in Chapter 7.

(b) Contamination of the underground by releases from several accident scenarios in the CH-TRU portion of the WHB from ventilation air flow down the Waste Handling Shaft should be assumed. Of even greater probability would be the transport of contamination off-site by workers, visitors or equipment. Such incidents have occurred in nuclear facilities on several occasions over the years. Because of the difficulty of detecting alpha particles this could be of particular importance at facilities like WIPP.

(c) We had also recommended that some of the events of moderate frequency be considered for a drum loaded with the maximum PE-Ci level. This comment was ignored with no explanation or justification for retaining the "average" loading. Also see comment 2 below.

(d) Concerning Accident C2, Drum Drop from a Forklift in the Inventory and Preparation Area, we had recommended that 100% credit not be taken for safety features of the facility and equipment, and for worker training. Instead, no change was made in the assumptions, and the exposure "allowed" is to a worker located in a remote location. What if the forklift operator is injured or stunned by the falling drums, or trapped and fails to immediately leave the scene? Therefore, we still consider this scenario to be insufficiently conservative.

2. Although the WPO has assured EEG the 1000 PE-Ci upper limit value would not be adopted until we had resolved our differences, the WIPP Waste Acceptance Criteria has incorporated it and it appears to be becoming a de-facto limit. The EEG has objected to this limit since 1985, and remains opposed to such a high value. For example, significant comments have been made by EEG on September 27, 1985 (see comments on Chapter 7 of the SAR), November 1, 1985, and June 22, 1988. Most of these comments are still applicable. The basis for our objections include the following:

(a) Such a limit permits a drastic increase in the consequences of the scenarios presented in the FEIS. The need to limit accident consequences from the newer inventories to those estimated in the FEIS was the principal reason why the WPO developed the PE-Ci concept in early 1983.

(b) The occurrence of the C2, C3, C4, and C6 operational accident scenarios with a 1000 PE-Ci container would result in a committed effective dose equivalent of 400 to 700 rem to a worker. The effective dose equivalent delivered in the first year would be about 42 rem. Those are unacceptable doses. The FSAR avoids presentation of this problem by assuming that these scenarios (each assumed to occur once a year for 25 years for a total of about 100 accidents during the lifetime of WIPP) will always occur with a container with the average concentration.

(c) The results of Accident C10 indicate a committed effective dose equivalent to the maximum off-site individual of 1.7 rem. Dose commitments of 3.9 rem to the lung, 29.8 rem to endosteal surfaces, and 6.5 rem to the liver would also occur. These doses greatly exceed a maximum dose of 0.5 rem to any organ of an off-site individual. NRC regulations (10 CFR 60) for a high-level waste repository require "important to safety" structures, systems, and components to prevent or mitigate accidents that could result in a one-time off-site dose greater

than 0.5 rem. The FSAR has concluded that there are no items important to safety at the WIPP facility, consequently accident doses off-site from the WIPP facility are allowed to exceed those from a high-level waste repository. The effect of a serious accident could be greatly reduced by significantly lowering the PE-Ci limit.

(d) If a drum containing very high PE-Ci concentrations were intercepted by a human intrusion borehole, there could be more curies of TRU reaching the surface than would be permitted by the EPA standard. It would be possible to produce about 7,000 drums of newly-generated waste at SRP and LANL during the lifetime of WIPP with an average of 470 Ci/drum. The probability of hitting one of these drums would be about 0.1.

(e) Hydrogen gas generation is likely to limit the concentration of radionuclides in most waste forms that can be transported in the TRUPACT to much below 1000 PE-Ci per container.

(f) We don't believe DOE should encourage the production of newly-generated waste that may approach concentrations of 1000 PE-Ci per container and are unaware of any need to do so. If the intent is not to encourage the creation of such containers, why does DOE insist on such a high limit?

In summary, we believe that the 1000 PE-Ci limit has to be significantly lowered. Even with a somewhat lower limit it may still be necessary to address related problems in some other way, such as limiting the number of high PE-Ci drums, imposing more restrictive operational procedures for these drums, etc. We would be pleased to meet with representatives of the WPO to discuss such options.

B. Detailed Comments

1. Section 7.2.1, Source Term, Page 7.2-1. The assumption is made that for accidents expected to happen once a year the

average waste package radioactivity will be used. This is not sufficiently conservative. There should be a consideration of the dose workers could receive from high curie packages, which are likely to be involved in some of the approximately 100 accidents (once each year for C2, C3, C4, and C6 over 25 years) estimated to occur. This assumption also renders the maximum permitted PE-Ci content irrelevant for operational accidents. The FSAR should calculate doses to workers from the C2, C3, C4, and C6 accidents with high-curie containers, including the maximum PE-Ci limit that is finally established.

2. Section 7.2.2.1.2, Dose Assessment, Page 7.2-4. Please clarify whether the described use of the Rupp equation adjusts for the acute angle release of the effluent (45 deg.), and the forced exit direction. If not, the adjustment should be made.

On page 7.2-5, it is difficult to see the logic in excluding scavenging from consideration. In Chapter 6, a constant scavenging coefficient was used for estimating non-accident exposures, and although there was some question as to the validity of using this approximation, it was not specifically excluded. The discussion here should address the possibility of an accident during a precipitation event assuming that an average of about 4 such events occur per month throughout the year at WIPP (U.S. Climate Atlas), with the greatest number of events occurring during the summer. Also it should be made clear whether resuspension of deposited radionuclides and/or saltation-creep-rainsplash contamination were considered. The latter phenomenon is particularly important in affecting plant surface contamination in arid environments. As noted in an earlier comment under Chapter 6 (Comment 13), the deposition velocity assumed for the WIPP site appears to be low by a factor of two. The basis for the selected value should be more clearly documented.

3. Section 7.2.2.2, Doses to Individuals Inside the

Facilities, Page 7.2-6. Consideration should be given to doses to non-radiation workers inside the facilities. It is possible that a significant exposure could occur within the fence from a release from the exhaust stack.

4. Section 7.3.1, Incidents of Moderate Frequency Involving CH-TRU Waste, Page 7.3-1. We concur with the conclusions in the CO scenario that accidents involving the unopened TRUPACT-II in the radiological control area would be less than the hypothetical accident tests and no release would be anticipated.

On pages 7.3-2 and 7.3-3, two changes were made in the C2 Accident scenario. One clarified that only one drum was assumed to be breached. The other updated the average PE-Ci value for a drum. However, EEG's two main concerns (use of an average drum instead of maximum, and assumption of maximum exposed worker) were not addressed. It is not sufficiently conservative to assume the forklift operator has left his position in about 6 seconds and thereby receives no dose. Ten seconds of inhalation from an average drum would result in a committed effective dose equivalent of about 38 rem, whereas a 1000 PE-Ci drum would result in a dose of 2900 rem. This illustrates that very significant doses are possible from handling TRU waste, and this fact needs to be recognized when establishing a maximum PE-Ci limit and operating procedures for drums. The location of the maximum exposed worker and the assumption of the average drum also applies to the C3 scenario.

EEG comments on Amendment 9 of the SAR objected to the low assumed fractions of the damaged drum's waste contents that were assumed to be aerosolized and respirable (1.25E-05 in this case). We still believe they are non-conservative by a factor of 2 to 5. We don't want to resurrect this issue except to note that the release fraction used should not be claimed to be a conservative

assumption to offset the non-conservative assumptions of an average drum and the maximum exposed individual being 20 feet away.

5. Section 7.3.1, Accident C4, Page 7.3-5. In the second paragraph on this page, it is assumed that the depletion of the released activity is 20%. Please provide the basis for assuming that this is a conservative value.

6. Section 7.3.2, Limiting Incidents Involving CH Waste, Page 7.3-7. The C8 (hoist cage drop) scenario is still listed as "not credible" and is not evaluated. There has been a long standing difference of opinion between EEG and the WPO about the credibility of this event. In 1985, the WPO produced calculations indicating the probability was about 1.7E-08 per year ("Probability of a Catastrophic Hoist Accident at the Waste Isolation Pilot Plant," TME-063).

However, a December 1987 draft report ("Quantitative Fault Tree Analysis of the Waste Isolation Pilot Plant Waste Hoist Hydraulic Brake System"), prepared as part of the Operational Readiness Review, evaluated this same system and concluded that "the total probability of a catastrophic accident of the Waste Hoist is 1.0E-03 per year (or one failure expected in 1000 years of hoist operation)." This draft report goes on to assure the reader that the suggested modification (providing a solenoid-operated emergency dump value) reduced this probability to 5.2E-08, so failure is still a "not credible" event.

We are not sanguine about the assurance the probability is now 5.2E-08. The 1987 analysis concluded that the 1985 analysis was in error by a factor of 60,000. How can we be expected to now accept the 5.2E-08 value as reliable? EEG still insists that the C8 hoist drop accident be considered credible and the dose consequences of it be evaluated in the FSAR.

It is noted that when using the assumptions for the C8 accident in the FEIS and assuming a load of seven 7-Packs, each with the maximum thermal load permitted in TRUPACT II (40 watts for two 7-Packs), one calculates a release to the environment of 1.15 PE-Ci. By extrapolation from the C10 Accident in Table 7.3-1, this would result in a maximum off-site dose of 3.9 rem (committed effective dose equivalent).

Concerning the C9 Accident on page 7.3-8, EEG had urged in its October 1988 comments on the draft FSAR that the procedures necessary to protect against a diesel fire be incorporated into the "WIPP Standard Operating Procedure Manual," and that the FSAR reference these procedures. This comment was not responded to in the discussion of the C9 Accident. It is essential that these procedures be formally adopted and rigorously followed during the life of the facility.

7. Table 7.3-1, Page 7.3-13. The internal inconsistences in this table that were commented on by EEG in October 1988 have been corrected (except that the second footnote is no longer applicable). The doses in the table can be obtained by using X/Q factors of 2.0E-05 s/m^3 for the maximum individual, 1.7E-05 s/m^3 at the site boundary, and 1.3E-05 s/m^3 at Mills Ranch. The X/Q value at the location of the maximum individual dose is only 1/3 of the 50% frequency 1-hour value from the FEIS. The X/Q values for the other locations are 20% to 40% of the 5% frequency 1-hour values in the FEIS. Without a detailed reevaluation of both of these computations, it is not possible to judge which values are the more appropriate. However, the value for the C10 accident is high enough to be considered "important to safety" as defined in the FSAR and the NRC regulations without using the higher X/Q values.

8. Table 7.3-2, Page 7.3-15. The doses presented in this

table are correct for the assumptions described in Chapter 7, however they are misleading because they apply only to an average drum and assume the forklift operator is not exposed. Assuming a 1000 PE-Ci drum, the C2 scenario dose would be 400 rem (committed effective dose equivalent). For our assumptions discussed in comment 4 above, the forklift operator would receive 2900 rem.

9. Section 7.4, Accidental Releases and Exposure to Hazardous Wastes, Page 7.4-1, 7.4-2. These accidental releases are related to the same scenarios used for radionuclide releases, which is a reasonable approach. The assumption that all VOC head space gases would be released in an accident seems quite likely because of the properties of VOC's. However, it also seems likely that a fraction of the hazardous components of the drums which are not in gaseous (or volatile) form would be released. Therefore, it is recommended that these releases be revised to assume a fractional release of the hazardous components in a manner similar to the fractional release of the radionuclides. The SAR has always assumed that radionuclides would be released from the waste matrix following an accident and there is experimental evidence to indicate that such releases are likely. The release fraction being used in the draft of the FSAR is 1.25E-05 of the container's waste contents in an aerosolized and respirable form except for the C10 fire scenario which uses 2.5E-03 to the drift and 5.0E-04 to the environment. Therefore it seems appropriate to assume that all hazardous constituents in the containers will be released from the waste matrix in the same proportion as the radionuclides. Also, the assumed concentration of the constituents in the drums should be that in the highest waste form category rather than the average. These assumptions will increase the VOC release by 20% to 70% except for the fire scenario, where it would be increased by factors of 5 to 28. The lead release would be increased about 2.5 times for those scenarios other than the fire scenario, and 100 times for the

fire scenario.

On page 7.4-2, third paragraph, either the ground receptor concentration or the 30 minute intake value for lead is in error. A person would inhale about 0.6 m^3 of air in 30 minutes and if the air concentration was 5.46E-12 g/m^3 the intake would be about 3.3E-09 mg.

10. Table 7.4-1, Releases and Exposures from Projected Accidents During WIPP Facility Operations, Page 7.4-3.

(a) We agree with the release values for the VOC's (based on the assumptions) except for Freon. The Freon values are high by a factor of about 14, however, the amount of Freon inhaled by both the worker and off-site individual is consistent with the correct release value (assuming that the fraction of release inhaled is the same for all VOC's). It is of interest that the No-Migration Variance Petition, February 1989, DOE/WIPP 89-003, Table 5-10, has a consistent value for Freon.

(b) Based on the assumptions presented, the lead release and inhalation values cannot be reproduced. The value of "potentially vaporized lead" is not given. Also the fraction of release that is inhaled is only about 1.5% of that for the VOC's after adjusting the amount removed by filters and that plated out. Credit should not be taken for the HEPA filters being in operation and reducing a release, because credit is not taken in other accident scenarios due to the fact that the filtration system is only operative following an alarm and therefore may not engage in a timely manner. Also a lead release could occur without releasing enough radioactivity to trigger an alarm.

(c) The fraction of the release assumed to be inhaled by a worker is unusually high, about 1.3% of the total release. The fraction for radionuclide inhalation in this chapter is less than .01% of the release. Also Table 5-10 in the No-Migration Variance Petition referred to above shows a worker's intake to be only 5.3E-03% of the release. Therefore, the 1.3% inhalation

value is obviously in error and should be corrected.

(d) The effective X/Q values at the location of the maximum off-site individual for the VOC releases are 1200 times greater than the X/Q values used for the radionuclides. Please explain the basis for this difference.

CHAPTER 8
Long Term Waste Isolation Assessment

A. General Comments

1. In our October 14, 1988 review of the Draft FSAR, EEG strongly objected to the deletion of 159 pages of detailed discussion, summary, and tabulations estimating the consequences from long-term waste isolation and pointed out that this violated the 1981 DOE/State Consultation and Cooperation Agreement which specified content of the SAR. This Draft FSAR responded to our objection by reinstating 18 pages of summary statements, conclusions and tabulations heavily referencing Amendment 9 of the SAR.

This re-insertion of consequence analyses in Chapter 8 by reference to an earlier SAR could be claimed to have resolved the issue of non-compliance with the C&C Agreement. However, it is a superficial outdated effort. None of the tabulations and figures are more recent than March, 1983. There have been drastic changes in the inventory since that time and the method of calculating radiation dose has been changed. EEG considers this long-term Waste Isolation Assessment to be inadequate.

2. <u>Failure to Meet 1981 C&C Agreement</u>

The text begins with the statement "The purpose of this Chapter is to <u>discuss</u> the long term isolation assessments that <u>will apply</u> to the WIPP facility" (emphasis added). While the text does provide a minimal discussion, that is not the purpose mutually agreed upon by DOE and New Mexico in the July 1, 1981 Stipulated Agreement, Appendix B, Working Agreement that specified the contents of the Safety Analysis Report, Chapter 8, Long Term Waste Isolation Assessment. It was agreed that the

document would analyze the long term impact on public health and safety following decontamination and site control termination and would include consequence analyses. This chapter does not discuss the 1981 commitment by DOE to perform consequence analyses or even reference the Working Agreement.

3. Failure to Provide Comparable SAR to DOE HLW SAR

DOE has agreed to complete their SAR for the HLW repository in Nevada before they begin construction of the repository. That SAR will include an evaluation of the performance of the proposed geologic repository for the period after permanent closure and give the rates and quantities of releases of radionuclides to the accessible environment as a function of time and a similar evaluation which assumes the occurrence of unanticipated processes and events. Why can the Department agree to provide this detailed information in their SAR for HLW in Nevada and not provide it in the FSAR for TRU waste in New Mexico? Note that this issue is independent of whether the facility is a repository or is a research and development facility. Both are analyses of the safety of a proposal to place unwanted radioactive materials in a mine.

4. It is stated that until the decision is made regarding the use of the WIPP facility as a permanent repository, compliance with Subpart B of 40 CFR 191 is not required. The following reasons are advanced for not demonstrating compliance at this time:

- Possibility of Revision of Subpart B by EPA.

- Further experiments and analyses are needed to complete a performance assessment.

Since it is not expected that there will be any major changes in Subpart B, and an agreement with New Mexico to adhere

to the vacated standards is in effect, anticipation of a revision is not a justified reason for non-compliance. The FSAR should be more specific as to the analyses involving the collection of data. What is the specific data that must be collected to refine assumptions? What are these assumptions? If undefined assumptions have been formulated, then they should be stated in this report, as well as any supporting analyses. If experiments are to be performed, then they should be described and schedules presented.

5. The issue of demonstrating compliance with Subpart B of the EPA Standards for the disposal of transuranic waste and performing long term waste isolation assessment of consequence analyses is separate and administratively unrelated as the following chronological sequence indicates.

- 7/81 DOE agrees to conduct consequence analyses in the SAR (Ref. W.A.)

- 11/84 DOE agrees to meet any future EPA disposal standards (Ref. 1st Mod.)

- 9/85 EPA promulgates standards for disposal of TRU waste.

Since there is nothing in the C & C Agreement and subsequent modifications to relieve the Department of its obligation to conduct these SAR Analyses, on what basis does the Department contend that the obligation to demonstrate compliance with Subpart B of 40 CFR 191 relieve DOE of the 1981 SAR obligation?

B. Detailed Comments

1. Section 8.1, Summary of Initial Consequence Analyses

Performed for WIPP, Page 8.1-2. This section references Amendment 9 of the Safety Analysis Report. Since the FSAR will supersede all previous amendments to the SAR, it does not seem reasonable to adopt or take credit for passages in earlier versions by reference. As previously recommended, the long-term consequence analyses should be included in the FSAR, Chapter 8.

2. Page 8.1-2, "These standards now exist in 40 CFR 191..." - Subpart B of the standards does not now exist.

"The WIPP facility must demonstrate compliance to these new standards..." - They were promulgated in September 1985 and are not new.

3. Section 8.1-12. While the issues of compliance with the EPA standards and performing consequence analyses in the SAR are mutually unrelated events, the discussion of EPA standards contains a number of misleading and incorrect statements.

The text states that compliance with Subpart B of 40 CFR 191 is not required until the decision is made to use the WIPP facility as a permanent repository. Two reasons are provided for not demonstrating compliance at this time:

A) Possibility of Revision of Subpart B by EPA, and B) Further experiments and analyses are needed during the Pilot Plant Phase to complete the performance assessment.
Neither are correct.

With respect to A), a formal agreement exists between New Mexico and DOE to evaluate the expected performance of the proposed repository with the vacated standards. Hence, the possibility that the standards may change is not germane. Additionally, anticipation of a revision of the standard is not a justified reason for non-compliance, particularly when all parties agree that most of the standard will be salvaged. With

respect to B), to date there are no experiments nor analyses that have been identified that are needed for performance assessment.

4. Section 8.1, Tables 8.1-1-6. It is noted that all doses in these Tables are from Amendment 6 (March 1983) or earlier versions of the SAR. The inventories used have been changed significantly. Also, old dose conversion factors and the pre ICRP-26 & 30 method of dose calculation is still used.

5. References for Section 8.1. Other than a 1986 revision of the SAR, the remaining references are 1978 or earlier.

6. Section 8.2.1, Performance Assessment, Page 8.2-3. As stated in our earlier comments, DOE-WIPP 86-013 requires that sensitivity and uncertainty analysis be carried out. This section again fails to recognize the need to include uncertainty analysis in the performance assessment methodology. Also, the final scenario report has not been published as of April 1, 1989.

7. Section 8.2.1.1, Scenario Development and Screening, Page 8.2-4. As previously recommended, the discussion on human intrusion modeling should include consideration of the possibility of Castile brine reservoirs under the repository. (See EEG reports EEG-11 and EEG-15).

8. Section 8.2-3, 8.2.1.1, "A final scenario report will be published in 1988..." - It is now May 1989, the report has not yet been published, and the future tense should not be used to describe a 1988 publication date.

9. Section 8.2-2, "Activity to address each of the assurance requirements is scheduled to begin in FY88..." - FY89 is now over half over and the sentence should be rewritten as, "Activity <u>began</u>..." or <u>will begin</u> in FY89.

10. The following paragraphs "summarize the progress to date" - What progress has occurred since September 1985? Nothing but a schedule has been published.

Section 8.2-7, 8.2.1.5. Our October 14, 1988 comments on the internal Peer Review Panel have been ignored and are reprinted again.

11. The text states that DOE is the only implementing agency responsible to determine compliance with the standards and an internal Peer Review Panel will provide assurance to state officials can be assured that DOE's conclusions are credible. That philosophy virtually guarantees a loss of credibility with the New Mexico EEG if the intent is merely to ask us to review the results. The authors appear unfamiliar with the 1978 contract between DOE and the State of New Mexico.

12. Section 8.2-10. The schedule shows completion of Subpart B compliance in October 1992. No indication is provided of the amount of time between completion by DOE and review by EEG and others. Contrary to the text, the Compliance Strategy (Plan) does not provide such a schedule.

13. What does "major" and "supporting" mean in the diagram? For example, will scenario development be completed in April 1990? That is not consistent with the plan to publish scenario development before October 1988.

CHAPTER 9
Conduct of Operations

A. General Comments

1. This chapter contained several significant improvements, and evidences considerable response to previous EEG comments and recommendations.

"Although DOE is responsible for all aspects of the WIPP facility, it delegates those functions to various contractors." The chapter is silent on the responsibility to protect the workers and the general population except for identifying the Safety, Security, and Environmental Protection Department as being responsible for "health and safety related programs which satisfy the requirements of the DOE and other...agencies." The philosophy and tone of the responsibilities and authorities of the various officials do not convey a strong commitment to health and safety matters.

B. Detailed Comments

1. Section 9.1.1, Owner Organization. The text states that the functions, responsibilities, and authorities of DOE and its contractors are discussed in Section 11.1.1. They are not.

2. Section 9.1.2.2.1, Page 9.1-2, General Manager. The General Manager has overall responsibility for the operation, maintenance, and modification of the WIPP facility. Is the General Manager ultimately responsible for the health and safety of WIPP personnel or has this authority been delegated to a lower level?

3. Section 9.1.2.2.7, Page 9.1-4, Safety, Security, and

Environmental Protection Department. This paragraph assigns the responsibility of health and safety to the "department." The department should have "functions," and responsibilities should be assigned to an individual, such as the Department Manager. This comment also applies to other sections in the chapter where the "department" is assigned responsibilities.

4. Figure 9.1-1, Page 9.1-8, Management & Operating Contractor Organization Diagram. The management diagram does not reflect a communication line between the General Manager and the Radiation Safety Manager. The WIPP "Radiation Safety Manual," WP 12-5, assigns the responsibility for interpreting the radiation safety program to the Radiation Protection Manager, yet the FSAR, Section 6.1.5.2, assigns responsibility for the radiation safety program to the Safety, Security, and Environmental Protection Manager.

The radiological safety program responsibilities should be clearly defined and reflected in the formal organization structure. Please clarify the reporting and communication lines.

5. Section 9.1.3.2, Page 9.1-6, Staff Managers. Although there is reference to staff manager's qualifications, there are no requirements specified. The words "typically have" should be replaced with "as a minimum requirement shall have." The importance of qualifications should be reviewed with respect to guidance found in ANSI/ANS-3.1-1987, "American National Standard for Selection, Qualification, and Training of Personnel for Nuclear Power Plants." Although this document is not a general DOE requirement, the overall guidance should be followed at WIPP. Chapter 9 should state commitments to high level management qualifications, and specifically to appropriate technical experience of the Radiation Protection Manager. As per ANSI/ANS-3.1-1987, the collective qualifications of management and technical managers shall be reviewed and supplemented, as

necessary, with personnel with applicable qualifications.

6. Section 9.2, Acceptance Testing, Page 9.2-1. This section refers to the "WIPP Procedure Manual." Presumably this is a reference to "Standard Operating Procedures," WIPP-DOE-103. If so, this title should be correctly presented. EEG does not have a document entitled "WIPP Procedure Manual."

7. Sections 9.2.2, 9.3.5, and 9.4.1, Acceptance Tests, Administration and Records, and Plant Procedures, Pages 9.2-3, 9.3-5, and 9.4-1. These sections refer to Sections 11.1.11, 11.1.12, and 11.1.17. There are no such sections. They should refer to Sections 11.11, 11.12, and 11.17.

8. Section 9.4.4, Operational Occurrences, Page 9.4-2. The text discusses compliance with U.S. DOT regulations in the transportation of TRU wastes, but fails to discuss compliance with U.S. NRC regulations.

9. Section 9.4.4, Operational Occurrences, Page 9.4-3. This section refers to DOE Order 5484.2 which has been superceded by DOE Order 5000.3.

10. Section 9.4.4.1, Page 9.4-3. The assumption that a contaminated drum, box, or canister would not contaminate the interior of the Internal Containment Vessel on the TRUPACT may not be valid and can result in reduced worker safety.

CHAPTER 10
Operational Safety Requirements

A. General Comments

1. There have been substantial improvements in this chapter, and it has been responsive to many of EEG's comments and recommendations.

2. The introduction states that RH-TRU waste handling is not covered and that, "This document will be expanded to include those OSRs (Operational Safety Requirements) prior to receipt of RH-TRU." EEG agrees that this supplement will be necessary.

B. Detailed Comments

1. Section 10.1, Introduction, Page 10.1-1. We disagree that, "It is inconceivable that non-radioactive hazardous materials would be released from containers without the simultaneous release of radioactive materials." Our reasons include:

(a) the VOC's are much more volatile than the transuranics;

(b) in some containers there may be heavy concentrations of hazardous chemicals and low amounts of radioactivity; and

(c) the amount of radioactivity released may not be enough to trigger an alarm.

This assumption should not be made before sufficient operational experience is obtained to verify it.

2. Section 10.1.4, Definitions and Acronyms, Page 10.1-4. The following acronyms should be added: AC (Page 10.6-4,5), OSR (Page 10.6-3).

3. Section 10.3.1.1, Continuous Air Monitors, Page 10.3-2. This section implies that only two CAMs are mandatory, and therefore the CAMs used for Effluent Monitors, as discussed under Section 10.2.1.2, are not required. This is incorrect. Also, the title of this section should be amended to "Continuous Air Monitors for Waste Handling Building."

4. Section 10.3.1.2, Effluent Monitors, Page 10.3-4. The second paragraph under LCO should be amended to include activity alarm limits for the Station B CAM. Since Station B represents filtered exhaust from the storage horizon, it should have the same alarm limits as Station C from the Waste Handling Building. Such an alarm system would provide an alert to defective filtration in the event of a release followed by an alarm at Station A (also see discussion on page 10.3-11). Furthermore, there is a reference to the LCO for Station B under "Applicability" on page 10.3-5.

On page 10.3-5, it is recommended that this discussion be amended to indicate that portable equipment would only be acceptable for use at Station C if it were connected to the isokinetic probe. The use of batch sampling for monitoring of this effluent point should be used only as a last resort, and for a very short time period.

5. Section 10.3.2.1, Waste Handling Building Differential Pressures, Page 10.3-6. Normal differential pressure ranges for the four WHB areas were given in the first Draft FSAR, but deleted here. Why? Is the system in the WHB able to meet these previously mentioned differential pressures? On page 10.4-2 this draft still takes credit for listing the pressure differentials.

6. Section 10.3.2.3, Underground Exhaust Air Filtration System, Page 10.3-11. The last paragraph on this page discusses

the HEPA filtration system provided for the underground exhaust. It states that periodic verification of the efficacy of the filters is required to maintain confidence in their ability. This discussion should refer to Section 10.4 for information on how verification will be provided. Section 10.4 indicates that the filters will be verified by local examination at each shift. A local visual examination may not be sufficient to determine that a filter system is ineffective. A more definitive description of "local examination" is needed here. At the present time, there is no alarm if the exhausted air exceeds prescribed radiation limits; therefore, the filters could be defective throughout an entire shift, or longer, if the "local examination" is not adequate. See comment 3 above.

The CAM at Station A would be sampling a significant dilution of the radioactive particulates if there should be a release. Consideration should be given to initiating filtration of the underground effluent based upon alarms from CAMs located inside the RMAs of the underground. Dilution of the contaminated air would be less and the air being monitored would be comparatively free of interfering salt dust.

7. Section 10.4.1.2, Effluent Monitors, Page 10.4-2. This section also uses the ambiguous phrase "local examination." This phrase should be more definitive. For example, it could refer to a specific WIPP procedure. In Section 10.4.2.3, the requirements indicate that the filter banks will be tested only annually. Therefore, it is essential that the "local examination" can actually determine effectiveness of the effluent monitors.

8. Section 10.4.2.3, Underground Exhaust Air Filtration System, Page 10.4-4. This section requires only annual verification of the effectiveness of the HEPA filter banks. Because of their importance, it would seem desirable to increase the frequency of such verification. Please provide the basis for

such infrequent verification.

9. Section 10.5.4, Ventilation Systems, Page 10.5-3. The first paragraph on this page states that, "All effluent air streams from areas that contain radioactive materials are filtered <u>and</u> monitored for activity." It should be made clear that the normal operating mode is to exhaust unfiltered monitored air from the exhaust shaft. All air effluents at WIPP are not filtered.

10. Sections 10.6.1, 10.6.2 and 10.6.3, Training, Design and Procurement, and Document Control, Pages 10.6-2, 10.6-3 and 10.6-4. The references listed on these pages should include the "Radiation Safety Manual," WP 12-5.

11. Section 10.6.4, Audit Program, Page 10.6-4 to 10.6-6. The references listed on this page should include the "Radiation Safety Manual," WP 12-5, since there are several important limits which are set forth only in this manual.

12. Section 10.6.8.2, Area Radiation Monitors, Page 10.6-10. This section allows the ARMs to be reset to higher levels for an indefinite period if a higher radiation source is in the area. This seems to defeat the purpose of the ARMs and could allow indiscriminate violation of the established limit of 10 mr/hr. The section should be revised to more definitively establish criteria for resetting to a higher level, and limiting the time at which it may remain at the higher level. Also resetting to a higher level should be permitted only if authorized by a health physicist.

CHAPTER 11
Quality Assurance

A. Detailed Comments

1. Table 11.1, Applicable Quality Assurance Standards, Page 11.1-4. Part B of this table and associated discussions should be revised to include reference to ANSI/ASME NQA-2, Current Editions, "Quality Assurance Requirements for Nuclear Power Plants." NQA-2 is applicable to the operations phase of work at nuclear facilities and is to be used in conjunction with applicable portions of ANSI/ASME NQA-1.

2. Section 11.2.2, General Responsibilities, Page 11.2-5. Documentation should be added to describe the implementation of the Quality Code Classification work described in Guidelines for Requisitions to Determine Quality Code Classification for Purchase Requisitions and Purchase Requisitions Change Notice Attachment 2 of Westinghouse Procedure 15-009, Revision 2. Documentation should also be added to describe the Quality Surveillance work required by the Westinghouse Procedure 13-011, Revision 0, Quality Assurance Surveillance.

CHAPTER 12

Decontamination and Decommissioning of the WIPP Facility

A. General Comments

1. Chapter 12 assumes that the facility will meet the EPA Standards for disposal of TRU waste during the five-year demonstration period and that the removal of 65,000 drums will not be required. A safety analysis should reflect conservative assumptions on matters affecting the health and safety of workers and the general public. Hence, this chapter should contain plans and safety analyses of potential radiation doses to workers and the public from operations and transportation if the wastes need to be retrieved, returned to the generating sites, sent to the high-level waste repository, left indefinitely on the surface at WIPP, sent to a new site, or left in place.

B. Detailed Comments

1. Section 12.1, General, Page 12-2. In the first paragraph of page 12-1, the reference to "DOE Order 5280.2A" should be 5820.2A.

2. Section 12.2, Decontamination and Decommissioning, Page 12-3. This section lists the sequence of future planned events for decontamination and decommissioning, but does not provide meaningful information either in this section, or the chapter, to permit a safety evaluation of the processes. Additional detail is needed for a safety analysis.

3. Section 12.5, Post Closure Physical and Environmental Surveillance, Page 12-5. As previously indicated, additional detail is needed. For example, further information should be

included on how mining will be controlled. Furthermore, the plans for surface environmental surveillance do not appear to address the intent of the NRC in 10 CFR 60 which requires subsurface early warning detection. The National Academy of Science report also recommended subsurface surveillance.

APPENDIX:

OCTOBER 1988 COMMENTS

ENVIRONMENTAL EVALUATION GROUP

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

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October 14, 1988

Mr. Jack B. Tillman
Project Manager
WIPP Project Office
U. S. Department of Energy
P. O. Box 3090
Carlsbad, NM 88221-3090

Dear Mr. Tillman:

Our review, which contains 77 pages of detailed comments and recommended changes, of the draft DOE Final Safety Analysis Report (FSAR) is attached. Several of the SAR chapters reflected a conscientious response by the WIPP Project Office (WPO) to EEG's December 1986 and January 1987 comments on Amendment 9. The Final SAR, however, does not contain an adequate analysis of the safety of the WIPP project as required by the July 1, 1981 Working Agreement for Consultation and Cooperation, as well as DOE Order 5481.1B. A considerable amount of work needs to be documented and risks quantified before the SAR can be considered acceptable.

We have repeatedly requested that the SAR include a forthright statement of the purpose of the WIPP project, which is designed to serve as a repository for permanent isolation of defense transuranic waste from the environment. Also, the purpose of the SAR has been downgraded from ". . . the most comprehensive document . . . on public health and safety . . ." (DOE/NM C & C Agreement) to ". . . to support the construction and operation of the WIPP." (Draft FSAR, page 1.1-1)

The "draft final" document contains serious deficiencies, misleading information, omissions of sufficient detail, failures to respond to our previous comments, and minor errors. The more serious deficiencies involve primarily Chapter 1A, 6, 8, 10, and 12. Chapter 1A fails to address the criteria used as a basis for the summary and conclusions; Chapter 6 does not respond to our previous comments on Amendment 9 as you agreed to do in your

letter of November 19, 1987; Chapter 8 fails to provide a long-term waste isolation assessment as required by the 1981 DOE/New Mexico Consultation and Cooperation Agreement and the 1988 DOE Order DOE/AL 5481.1B; Chapter 10 needs to provide considerably more detail to permit us to evaluate the operational safety; and Chapter 12 should contain detailed plans for decommissioning and decontamination, if retrieval of nuclear waste becomes necessary.

Due to the substantive nature of our objections to the Final SAR, EEG requests reconsideration of the position taken in your September 15, 1988 letter that you will not respond to our comments prior to publishing the Final Safety Analysis Report. Your early response to this request is needed to insure that our concerns are addressed.

Sincerely,

Robert H. Neill
Director

RHN:ML:lsb

Enclosure

cc: Mr. James Bickel, Assistant Manager
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Comments and Recommendations

on

DOE Draft Final Safety Analysis Report

Waste Isolation Pilot Plant

Prepared by

Environmental Evaluation Group

New Mexico

October 1988

Providing an independent technical analysis of the Waste Isolation Pilot Plant (WIPP), a federal transuranic nuclear waste repository.

SUMMARY

The preliminary Safety Analysis Report was first published by the Department of Energy's WIPP Project Office (WPO) in 1980. The New Mexico Environmental Evaluation Group (EEG) reviewed this five volume document shortly after publication and transmitted detailed comments and recommended changes to the WPO. Following such review and comments, and on some occasions, meetings between representatives of respective agencies, the report has been revised nine times. These amendments have been based upon both DOE initiated changes in design, criteria, and planned operations, as well as EEG recommendations.

The present DOE draft Final Safety Analysis Report reflects a favorable response to many of EEG's previously recommended changes, but there remain some serious deficiencies, some misleading information, omissions of sufficient detail, failures to respond to previous comments, and minor errors. The more serious deficiencies are summarized below, with the more detailed observations and recommended changes itemized under each Chapter heading.

1. The SAR does not provide an adequate safety analysis of WIPP including the quantification of risk and documentation of calculations and analyses envisioned in the 1981 Consultation and Cooperation (C & C) Agreement between DOE and the State of New Mexico. Even the purpose of the SAR has been downgraded from "the most comprehensive document . . . on public health and safety . . ." agreed to by DOE and the State in the 1981 C & C Agreement to the present "to support the construction and operation of the WIPP."

2. The purpose of the WIPP Project is to provide a facility to permanently isolate the defense TRU waste from the environment. It should be clearly stated in the first paragraph of Chapter 1 of the FSAR. Statements such as, "The WIPP facility is designed to receive, inspect containers for damage and contamination, emplace, and store unclassified defense-generated transuranic wastes in a retrievable fashion . . ." (Chapter 1, page 1.1-1) and "The WIPP is designed as a full-scale facility to demonstrate the technical and operational principles for the permanent isolation of defense-generated transuranic waste in salt" (Chapter 3, page 3.1-1) are misleading.

3. The draft FSAR violates the 1981 DOE/State Consultation and Cooperation Agreement (Appendix B, Article III), and the requirements of the 1988 DOE Order AL 5481.1B, both of which require the FSAR to have a long-term waste isolation assessment, identifying potential communication modes, modeling methods, and consequence analyses. Earlier drafts of the SAR did attempt to evaluate long-term waste isolation (159 pages in the previous edition), but such analyses have been replaced in the Final SAR with a nine page general discussion of how performance assessment will be conducted. Consequence analyses must be included.

4. Although the Department has informally indicated that there is no intent to conduct experiments at WIPP with high level waste, there are numerous references in the SAR to high level waste experiments. They should be deleted since the SAR contains neither technical justification nor radiological risk evaluation of bringing high level waste.

5. The SAR takes credit in Chapter 8 for a Peer Review Panel providing assurance on suitability of WIPP as a repository. Since the Department has never involved EEG with any of the Peer Review Panels, nor provided us with agenda, minutes or recommendations, we believe that the committees do not provide credibility as stated in the SAR, but in actuality detract from it. In order to take credit, EEG must be involved.

6. According to the August 4, 1987 Second Modification to the C & C Agreement, DOE agreed to document compliance with Subpart A of 40 CFR 191 in the Final SAR prior to the receipt of waste. Such compliance has not been adequately shown nor specifically identified.

7. Chapter 1A is important because it is intended to provide a summary of more detailed information contained in other chapters for final conclusions on the safety of the WIPP design, criteria and plans for operations, and for long-term stability. Unfortunately, Chapter 1A fails to present the basic criteria used in coming to the conclusion that WIPP can be operated safely.

8. While the SAR invokes frequent comparisons with the NRC safety regulations for nuclear reactors, it would be far more appropriate to make comparisons with the NRC health and safety standards for high-level waste disposal (10 CFR 60).

9. It is noted that all references to backfilling the waste storage rooms have been deleted from the FSAR. We know that the Department has decided to emplace the experimental CH-TRU waste without backfill to avoid crushing the drums during the retrieval period. The FSAR should clearly state this decision and the reason for it and should state that when the waste is emplaced for disposal, a properly selected tailored backfill will be used to fill the space between the drums, above the drums and between the walls and the drums. The FSAR should also state that only the amount of waste expressly needed for conducting experiments to help in Performance Assessment (to show compliance with the EPA Standards 40 CFR 191 Subpart B) will be emplaced in a temporary mode without backfill.

10. While DOE made a conscientious response to EEG's December 16, 1986 comments on Amendment 9 of the SAR, an important exception was Chapter 6, Environmental Safety and Health Protection, in which it appeared that the authors were neither aware of our previous comments nor the commitments contained in the November 19, 1987 response by the WIPP Project Manager. Chapter 6 needs to be extensively revised by addressing our comments.

11. The Operational Safety Review (Chapter 10) lacks sufficient detail to permit us to evaluate the operational safety of WIPP. EEG's specific comments describes the areas in which extensive expansion and revision are needed.

12. Since it is not apparent that a Design Basis Accident (DBA) assessment has been performed, it is strongly recommended that such an assessment

addressing the requirements of DOE Order 6430.1 and the guidelines to "A Guide to Radiological Accident Consideration for Siting and Design of DOE Non-Reactor Nuclear Facilities," LA-10294-AC, be performed and summarized in Chapter 7.

13. Chapter 12 assumes that the facility will meet the EPA Standards for *disposal of TRU waste during the five year demonstration period and that* the removal of 125,000 drums will not be required. A safety analysis should reflect conservative assumptions on matters affecting the health and safety of workers and the general public. Hence, this chapter should contain plans and safety analyses of potential radiation doses to workers and the public from operations and transportation if the wastes need to be retrieved, returned to the generating sites, sent to the high level waste repository, left indefinitely on the surface at WIPP, sent to a new site, or left in place.

CHAPTER 1

Introduction and General Description

1. Section 1.1, Page 1.1-1. The purpose of the WIPP project to provide a facility to permanently isolate defense TRU wastes from the environment is not stated anywhere in this document. We understand that the Department's data needed for the analysis to show that the project can accomplish that purpose is not yet available, however, the purpose should be clearly stated in the document. Statements such as on page 1.1-1, "The WIPP facility is designed to receive, inspect . . . " are misleading and raise unnecessary questions as to the intent of constructing the repository.

2. The text states, "The final SAR has been prepared by DOE to support the construction and operation of the WIPP . . . ." This stated purpose appears to be considerably less comprehensive than that agreed to by DOE and New Mexico in Article III of the Working Agreement For Consultation and Cooperation (1981) which states, "The Safety Analysis Report (SAR), as amended from time to time, constitutes the most comprehensive document concerning WIPP both in general and specifically as related to public health and safety as well as other matters." Use the definition in the C & C Agreement since DOE and New Mexico devoted four pages in that Agreement to delineate the expected scope of the SAR. It would also be helpful to state in this section that the Final Safety Analysis Report (FSAR) is required by the 1981 State/DOE Consultation and Cooperation Agreement, and the 1988 DOE Order 5481.1B, and its purpose is to provide analyses of the risks associated with the location, design, and operation of the facility, a summary of applicable standards and criteria, and to

demonstrate through such documentation that it meets applicable standards and requirements for public health and safety.

3. The last line of the first paragraph of this section should be amended to indicate that the facility will not become a permanent disposal facility through "successful demonstration of the acceptability," but through successful demonstration of compliance with the EPA Standards 40 CFR 191, followed by a decision by DOE to make it a permanent disposal facility.

4. All references to the high level waste experiments at WIPP should be deleted from the SAR since DOE has not developed any plans for such experiments nor intends to do so.

5. Section 1.1.1, Page 1.1-2. A reference to the presence of "three mines are located between five and ten miles of the site" should be expanded with a description of lease holdings at the WIPP site and the distance of nearest mining activity from the edge of the site. A more recent and reliable estimate of resources at WIPP than the information contained in the FEIS is a report by the New Mexico Energy and Minerals Department, entitled "Natural Resources at the Waste Isolation Pilot Plant," January 1984.

6. Section 1.1.2, Page 1.1-2. Please enunciate the "technical and operational principles" to be demonstrated. Describe the "studies and experiments . . . to extend the understanding of the behavior of high-level waste in salt" or cite a reference where these are described. Describe the "operating and scientific data" that is expected from

temporary emplacement of waste or provide reference to a document that describes it. Finally, provide the basis(es) on which "DOE will make a decision regarding whether to dispose permanently of transuranic waste at WIPP." The role of the State of New Mexico in this decision should be indicated since the text implies that it is a unilateral decision by DOE.

7. Section 1.1.3, Page 1.1-3. The text improperly states that the CH-TRU storage capacity is 6.3×10^6 cu ft based on the assumed drum-box split. The capacity of 6.3×10^6 cu ft is specified in the 1980 WIPP FEIS.

8. While the text states, "A specific WIPP storage capacity has not been established for RH-TRU waste," the C & C Agreement (Modification 1, 11/30/84) specifies that the limit of RH-TRU waste is 5.1×10^6 curies.

9. The current concept of disposal of decommissioned, contaminated surface facilities of WIPP should be expanded to include plans for the disposition of these contaminated facilities.

10. Section 1.1.3, Page 1.1-4. "The design accommodates the time required to reach the waste and retrieve it if such a decision is made." Please provide specific time periods for the emplacement and retrieval of each waste form.

11. Section 1.1.3, Page 1.1-4. The definition of when WIPP becomes a permanent waste facility on page 1.1-4 (after decommissioning) differs from the definition on page 1.1-1 (upon successful demonstration of the acceptability). Actually, WIPP becomes a permanent facility when the

waste is emplaced with no intent of recovery (40 CFR 191.02 1). The SAR should describe plans for review and approval by EPA, EEG, and the State of New Mexico, before WIPP becomes a permanent facility.

12. Section 1.1.4, Page 1.1-4. The schedule should be amended to reflect recent changes. Also, please provide a basis for the planned schedule.

13. Section 1.2.3.3, Page 1.2-6. Please identify the location of the waste experimental area and provide a brief description of these experiments.

14. Section 1.3, 2nd Paragraph, Page 1.3-1. This paragraph discusses the possible need for allowing exception to the WIPP Waste Acceptance Criteria. The Environmental Evaluation Group (EEG) has participated extensively in reviews of the original WAC and the various revisions. We recognize the importance of the criteria to the safety of WIPP operations and to public health and safe transportation of WIPP wastes. Therefore, it is our firm conviction that the State and EEG should be informed in advance of proposed revisions or exceptions to the WIPP WAC, and that we should be provided the opportunity to make a determination of the safety impact independent of the WPO. This policy would be consistent with Amendment 1 of the DOE/State Consultation and Cooperation Agreement, which states ". . . the DOE will, prior to granting such exceptions for such waste and prior to the shipment of such waste: (1) perform analyses to ascertain the impact of such on the public health and safety, (2) consult with the State of New Mexico, including providing the State with a copy of the analyses for review and comment, and (3) provide to the State a period of forty-five (45) days to review and comment on such

analyses prior to granting any such exceptions. In no instance will such an exception to the WAC be granted if it would cause a significant increase in the impacts on public health and safety discussed in the WIPP FEIS." The EEG is not insisting that such a policy be stated in the FSAR, but it should be made a part of the Standard Operating Procedures (SOP) for amending or allowing exceptions to the WIPP WAC. The failure to include such a policy in the SOP would represent a failure to adhere to the spirit of the commitment reflected in the WIPP WAC and the C & C Agreement.

Also, it would be desirable to include in this section a reference to the need to meet the requirements of 40 CFR 191.

15. Section 1.3.1, Page 1.3-2. It is noted that all references to backfilling the waste storage rooms have been deleted from the FSAR. We know that the Department has decided to emplace the experimental CH-TRU waste without backfill to avoid crushing the drums during the retrieval period. The FSAR should clearly state this decision and the reason for it and should state that when the waste is emplaced for disposal, a properly selected tailored backfill will be used to fill the space between the drums, above the drums and between the walls and the drums. The FSAR should also state that only the amount of waste expressly needed for conducting experiments to help in Performance Assessment (to show compliance with the EPA Standards 40 CFR 191 Subpart B) will be emplaced in a temporary mode without backfill.

16. Section 1.3.4, Page 1.3-3. This section on defense high level waste experiments should be deleted since there are no plans to conduct such experiments.

17. Section 1.5.1, Page 1.5-1. The second paragraph indicates that site characterization was completed in December 1978. As indicated in the title of a Sandia Report (SAND 88-0157) published in May 1988 (received by EEG on July 1, 1988), "Summary of Site-Characterization Studies conducted from 1983 through 1987 at the WIPP Site," site characterization is ongoing. Also, Mr. Troy E. Wade II, Acting Assistant Secretary for Defense Programs, in his testimony before the Subcommittee on Procurement and Military Nuclear Systems of the Committee on Armed Services of the U. S. House of Representatives on September 8, 1988, said, "Formal WIPP site characterization activities will end in December 1988." Only the first phase of site characterization was completed in 1978. The first sentence on page 1.5-2 is a description of the site characterization studies performed since 1983, but the attempt appears to have been made to not use the phrase "site characterization" and thus the description is meaningless. We suggest using the appropriate language from the summary of SAND 88-1057 to describe this effort.

18. Section 1.5.2, Page 1.5-2, 1.5-3. It should be made clear that the experimental programs described in this section do not require emplacement of any radioactive waste. In order to avoid confusion, it would be appropriate to clearly separate the R and D that requires waste from experiments that are performed to better design the repository.

19. Section 1.5.2.1, Page 1.5-3. The discussion of the tests that have been performed for several years should include at least the preliminary results of those tests. What have the plugging and sealing studies shown to date? When is the decision on plugs and seals design expected to be made? What assumptions on plugs and seals performance will be used for showing compliance with the EPA Standards? Please indicate when room-scale seals will be evaluated.

20. Section 1.5.2.3, Page 1.5-5. This section does not describe experiments with waste and, therefore, the title is misleading. Please change the title to "CH TRU Waste Container Stability."

21. Section 1.5.2.4, Page 1.5-5. Please change the title of this section to "RH TRU Waste Container Stability."

22. Section 1.5.3, Page 1.5-8. This section refers to "the design modification alternatives." These alternatives should be listed and the one that was selected should be justified. Also, describe which of the "follow-on studies" are being performed and why, and include a summary of the results to date.

23. Section 1.5.3.1, Pages 1.5-8, 1.5-9, 1.5-10. Please provide references for the studies described in this section and at least a brief synopsis of the results.

24. Section 1.5.4, Page 1.5-12. As previously indicated, please delete references to high-level waste experiments.

25. Table 1.5-1, Pages 1.5-16, 1.5-17. New dates are needed for publishing the "Interim Sorbing Tracer Test Report", "Hydrogeochemical Facies in the Rustler Formation", "Groundwater Modeling Study of the Rustler Water-Bearing Zones", and the "Facies Variability and/or Evaporite Dissolution Within the Rustler Formation" reports.

CHAPTER 1A

Summary Safety Analysis

1. This Chapter attempts to summarize the entire FSAR in order to present the conclusion that it is a safe facility. It does in fact summarize the radiation doses to the worker and the public as a result of normal and abnormal operations and accidents. It then concludes that there is no significant impact on the public health. It fails, however, to summarize the criteria that would provide the basis for such a conclusion. These also should be summarized, either as a table or narrative. For example, the FSAR must provide reasonable assurance that the facility will meet Subpart A of 40 CFR 191, i.e., the combined annual dose equivalent to any member of the public in the general environment resulting from (1) discharges of radioactive material and direct radiation from such management and storage shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ.

2. Section 1A.1, Page 1A-1. It is recognized that Chapter 1A is a Summary Safety Analysis, however, the attempt to summarize in the first paragraph leads to some confusion and ambiguity. For example, the definition of Design Class I in the first paragraph is a serious distortion of the more detailed definition in Sections 3.1.7.1.1. To refer in the first paragraph to "a leak" from the WIPP facility, and then discuss effluents and controlling radiation doses off site in the second paragraph, will almost certainly lead to confusion for some. Please also see our comments on the definition of Class I items in Section 3.1.7.1.1.

3. Section 1.A.1.2.1.2, Page 1A.1-6. The first section describes a potential problem which would be resolved by means of an inexpensive test. It is recommended that the types of clay minerals present in the Dewey Lake Redbeds be determined to resolve the question referred to.

The finite element model mentioned in the third paragraph of this section predicted the closure rates that were 3 to 4 times slower than the actual observations. This section should include the discrepancy between the predicted and actual creep rates and what changes in the design and operations plans have been made to accommodate tne faster rates of closure.

4. Section 1.A.1.2.2, Page 1A.1-7. The first sentence of this section is incorrect. There is plenty of evidence of infiltration below the Mescalero Caliche. The second sentence should be more explicit. The water-bearing zones are at depths of approximately 608 to 632 feet, 714 to 740 feet, and 850 to 860 feet. In the third sentence, because grouting of the shafts had to be performed three times before leakage was stopped, it should be indicated that frequent checks and maintenance will be provided to ensure that the shafts remain dry. The fourth sentence, "No groundwater forces in salt are experienced because there are no connected saturated pore spaces" is incorrect. (See Bredeholft, 1988; and Beauheim, 1987, page 4, lines 1 to 4.) Finally, the last word of this section should be "important" and not "significant."

5. Section 1.A.1.3, Page 1A.1-7. Potential damage from an aircraft crash should not be indicated as "very small." While the probability of a

scheduled airliner crash may be very small, a number of small aircraft and military aircraft are seen flying very low over the site. In fact, a small private plane crash occurred at the site in 1982. Efforts should be made to safeguard the site from such incidents in the future. Also, please note our comment 5 on Chapter 2.

6. Section 1A.2.3.1, Page 1A.2-5. The last paragraph of this section states that the gamma source strength was used to calculate shielding for RH-TRU rather than neutron dose rates. Please indicate a reference for information which provided a basis for this conclusion.

7. Section 1A.2.3.2, Page 1A.2-6. The last paragraph of this section implies that the doses to the public for normal operations are developed assuming use of HEPA filters for the exhaust from underground. It should be mentioned that this is a valid assumption only for accidents.

8. Section 1A.2.4.1, Pages 1A.2-8 and 1A.2-11. The units used in Table 1A.2-1 are confusing. From Table 6.1-8, it is apparent that doses due to "direct radiation" (external radiation is preferred terminology) are average individual doses and should be labeled rem/year. The doses due to inhalation are called population doses in Table 6.1-10 (total dose received by all exposed persons), which would be 50 year dose commitment in person-rem.

9. Section 1A.5, Page 1A.5-1. This section states, "The facility operation will include in situ experiments addressing technical issues for defense waste programs and storage of defense related contact-handled (CH) and

remote-handled (RH) transuranic (TRU) waste." At least a brief description of experiments and technical issues to be resolved should be provided to support receipt of waste at WIPP for the R and D purposes. References should be provided of documents in which a detailed description of the experiments may be found.

The statement, "This section provides conclusions with regard to the adequacy of the WIPP site," is incorrect. Either remove the statement or provide the conclusions with appropriate rationale.

10. Section 1A.5.1, Pages 1A.5-1, 1A.5-2. Please provide appropriate references for the "conceptual design" and the "preliminary design."

Page 1A.5-2, first paragraph, mentions keeping a minimum clearance for five years. It should be changed to at least ten years since the retrieval would take at least as long as emplacement. The same paragraph discusses the models to predict the rate of closures without mentioning that these predicted rates were three to four times lower than the rates observed after excavation.

Before reaching the conclusions stated in the last paragraph of this section, it is necessary to discuss the changes in the plans for retrievable emplacement of waste which became necessary due to rates of closure three to four times higher than predicted. For example, it is planned to emplace the waste without backfill during the period when retrievability needs to be maintained to minimize the possibility of the drums being crushed. Also, the rooms will be cut an extra foot higher and

trimmed before emplacement of waste. The original design criteria were, therefore, not suitable. This section should discuss why these changes became necessary, what were the options available, why was an option chosen, and why the changes are not likely to affect the operations in the facility adversely.

Reference 1 cited at the end of this section is not listed at the end of the Chapter. There are no references listed.

11. Section 1A.5.2, Page 1A.5-3 to 1A.5-5. The last paragraph on page 1A.5-3 should be expanded to include the plans for disposal of excavated salt.

Before concluding (last paragraph of this section on page 1A.5-5) that, "Under no circumstances will the public health and safety be subjected to significant risks," this section should provide references to detailed information on the accident scenarios which were analyzed, and potential releases from malfunctioning or inadequate design of shafts and underground facilities. (Also, please note comment one on this Chapter.)

CHAPTER 2

Site Characteristics

In response to many EEG comments on previous versions of SAR, this chapter has been extensively revised and is much improved. A few questions that remain are listed below.

1. Section 2.1.1.2, Pages 2.1-4 through 2.1-5. This section refers to DOE Order 5480.1A which has been superseded by DOE Order 5480.1B. Also, it is noted that the dose limits on page 2.1-5 exceed the limits of the EPA Standard 40 CFR 191.03(b). Under 40 CFR 191.04(a), DOE may establish alternative standards for WIPP provided EPA has approved an application for such alternative. If DOE has made such application, please provide EEG with a copy of the application and EPA approval notice. DOE Order 5480.1B references DOE Order 5480.11 for radiation protection standards, however, this order indicates that the "Requirements for Exposure of Individuals and Population Groups in Uncontrolled Areas" is to be added at a later date. Therefore, if no alternative standard has been approved by EPA, the FSAR should adhere to the exposure standard prescribed in 40 CFR 191.03(b).

2. Section 2.1.2.1, Page 2.1-6. Please update paragraph two of this section since the land exchange of State-owned sections has been completed.

3. Section 2.1.2.1.2, Page 2.1-7. Settlement of potash leases inside the WIPP site should be completed before a permanent decision is made to store waste at WIPP.

4. Section 2.1.2.2, Pages 2.1-8 and 2.1-9. The last paragraph of this section refers to "low level of radioactive releases . . . ." Please include references to the analyses of postulated accidents which support this statement.

5. Section 2.2.3.1. EEG personnel have witnessed very low flying military aircraft directly over the WIPP site, almost on a daily basis during certain periods in summer, 1988. Either such flights should be banned or their potential impact on WIPP should be considered in Section 2.2.9, and evaluated in other Chapters of the FSAR. One crash has occurred already at the WIPP site.

6. Section 2.1.3.4, Page 2.1-14. The reference to "population centers" as defined in 10 CFR 100 is no longer appropriate. Those regulations apply to siting of nuclear reactors, not nuclear waste repositories. A more appropriate reference would be 10 CFR 60 or 40 CFR 191. With respect to exposure to members of the public off-site, it would be preferable to refer to the limits of 40 CFR 191.03(b).

7. Figure 2.1-7. The location of the potash leases of the International Minerals and Chemical Corporation are not shown on this map.

8. Section 2.5.3.5.2, Page 2.5-23 through 2.5-27. This section is very well written, but needs to be updated.

9. Section 2.5.4, Pages 2.5-29 through 2.5-34. This section needs a thorough updating in view of the recent publications by Bredeholft, Nowak, McTigue, Beauheim, etc.

10. Section 2.5.5.1, Page 2.5-37. The last paragraph of this section on page 2.5-37 refers the reader to Chapter 8, but the new Chapter 8 of FSAR is devoid of any technical evaluations.

11. Section 2.5.6, Page 2.5-46. The first sentence on page 2.5-46 is incorrect. In a karst region, such as the WIPP area, lack of a near-surface regional water table does not preclude a significant quantity of recharge. The fact is that in spite of several suggestions by EEG over the past five years, the WIPP Project Office has chosen not to perform systematic studies to determine the rate of recharge at and in the vicinity of the WIPP site. It is more correct to say that the information is not available rather than assuming it to be "negligible."

12.. Section 2.5.7.4, Page 2.5-58. In view of the discussion in this and the preceding subsections, it is recommended that Table 2.5-21 not be included in the FSAR. This table and the last paragraph on page 2.5-58 should be replaced by a discussion of the program to determine more reliable values of Kd being performed currently.

CHAPTER 3

Principal Design Criteria

1. Section 3.1, Page 3.1-1. This section refers to experiments and studies to understand the behavior of waste in salt. Please add the reference to reports or chapters in the FSAR where these experiments are described.

2. Section 3.1.1, Page 3.1-2. Experimental (high-level) waste as one of the types of waste to be emplaced should be deleted.

3. Section 3.1.1.1.1, Page 3.1-3. This section should clearly indicate that the boxes described in Table 3.1-2 are not compatible with TRUPACT-II. Therefore, there should be an indication of how these boxes will be transported, i.e., whether they will be repackaged into a TRUPACT-II compatible box, or whether another type B container, certified by NRC will be used. Also, Table 3.1-2, page 2, should be revised to indicate the type of "standard waste container" to be used.

4. Section 3.1.1.1.2, Page 3.1-3. Radionuclide composition of waste for WIPP has been calculated and presented in Table 3.1-4, based on a March 1987 report (Ref. 4). To date, the WIPP office has refused to provide us with this report. In order for EEG to conduct its evaluation, the report must be provided.

5. Section 3.1.1.1.2, Page 3.1-4. This section states that the average Pu-239 equivalent is 7 g for a drum and 110 g for the most common box.

Table 3.1-3 shows 14 g of Pu-239 in drums and 79 g in "standard waste containers." It is recommended that this section, or Table 3.1-3, be revised to reflect consistency and the basis for the values presented.

6. Section 3.1.1.1.4, Page 3.1-5. This section also should indicate that the thermal power will be limited by the PE-Ci limits and the Watt limits of TRUPACT-II. Please also add a reference to the data which reflect the fraction of heat source plutonium to be shipped to WIPP. According to EEG information, the SRP heat source wastes alone comprise about 10% of the total volume and 60% of the total alpha curies that will be coming to WIPP.

7. Section 3.1.1.2, Page 3.1-5. This section is misleading in that it implies a very small fraction of the WIPP waste is RH-TRU. State that RH-TRU waste comprises 36% of the total radioactivity.

8. Section 3.1.1.2.2, Page 3.1-6. The first paragraph of this page contains incorrect reference designations. On line 2, the reference to the current data base probably should be 6 rather than 7. Also, the reference designation in the last line should 8 rather than 9.

9. Section 3.1.1.2.3, Page 3.1-6. This section also designates 9 as reference for surface dose rate limits, and it should designate 8 (the first modification of the C & C Agreement).

10. Section 3.1.2.2, Page 3.1-7. In this section, it would be helpful to state how many TRUPACTS could be stored outside and how many drums inside

(in both surge storage and shielded CH-TRU area) and the basis for the limitation.

11. Section 3.1.3.1, Page 3.1-9. This section states that the RH throughput would be two canisters per shift, which indicates a throughput of 500 canisters per year, which is greater than 250 canisters per year. Which is the maximum?

12. Section 3.1.3.3, Page 3.1-11. In the fourth line from the bottom, the reference designation should be 9 rather than 10. Also, the designation 10 CFR (c)(ii) is incomplete and, therefore, ambiguous. It should designate which subparagraph of (c) is applicable, i.e., (c)(2)(ii) or (c)(6)(ii) or both.

13. Section 3.1.3.3, Page 3.1-12. The reference designation in the first paragraph is in error. Please see previous comment.

14. Section 3.1.3.3, Page 3.1-13. The second paragraph on this page describes movable shielding in the floor hatch which mates with the bottom of the facility cask to allow access to the cask loading room while the cask is being loaded. Is there a control or alarm provided to preclude access when the shield is not in place? If so, this should be described here.

15. Section 3.1.6.2, Page 3.1-16. This section indicates radioactive waste generated on-site will be disposed at WIPP. Compliance with the EPA disposal standards must be completed before any wastes can be disposed at

WIPP. Please provide the design for solidification of liquid wastes at WIPP. EEG has not received any information on this.

16. Section 3.1.7.1.1, Pages 3.1-17 to 3.1-18. The first paragraph defines the Design Class I items and relates these items to a "basic component" as defined in 10 CFR 21.3 (a) (2) as follows:

"'Basic Component,' when applied to other facilities (than nuclear power reactors) and when applied to other activities licensed pursuant to Parts 30, 40, 50, 60, 61, 70, 71, or 72 of this chapter, means a component, system or part thereof . . . in which a defect . . . could create a substantial safety hazard . . . ." "A 'substantial safety hazard' means a loss of safety function to the extent that there is a major reduction in the degree of protection provided to public health and safety for any facility licensed . . . pursuant to Parts 30, 40, 50, 60, 61, 70, 71, or 72 of this chapter."

The only one of the listed parts of Title 10 which would have provisions somewhat comparable to the WIPP facility would be Part 60, "Disposal of High Level Radioactive Wastes in Geologic Repositories." In that Part, Section 60.1 defines "important to safety" as follows:

"'Important to safety,' with respect to structures, systems, and components means those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion or permanent closure."

Therefore, the definition of Class I in this paragraph of the draft FSAR is not consistent with "a basic component" as defined in 10 CFR 21. As EEG has previously maintained, the Class I definition should be amended so that it is consistent, and so that it will not appear that the design criteria for WIPP provides less protection than that which will be imposed on DOE for high-level waste repository. Perhaps the reason that the WPO has resisted this change is because there would then exist some Class I items at WIPP, just as there are likely to be some Class I items at a high-level geological waste repository. If not, then there should be no reason for not making the two definitions identical.

17. Section 3.1.7.1.1, Page 3.1-18. The third paragraph on this page states that "each WIPP item was evaluated against the design classification criteria." It is presumed that such evaluations are documented, however, no reference is cited to this documentation. Please provide this reference in order that EEG and others may obtain copies.

18. Section 3.1.7.3, Page 3.1-21. This section lists several design factors which provide a basis for the design class. Among these is included the phrase "importance to safety," which is not defined. If this phrase also has the same meaning as in 10 CFR 60.1, it further substantiates the need to modify the Class I definition as discussed in comment 11 above. In any case, this phrase should be defined and if it is not the same as in the NRC regulations for high-level waste repositories, the EEG would like to know the rationale for the difference.

19. Section 3.1.7.5.1, Page 3.1-22. The cited reference 13 in this section should be changed to 11.

20. Section 3.1.7.5.2, Page 3.1-22. The cited references in this section are also in error.

21. Table 3.1-3, Page 3.1-27. This table has two errors, as follows:

a. Th-282 should be Th-232,

b. The activity for Pu-238 should be 1.0E+01

22. Table 3.1-3, Page 3.1-28. This table also has two errors, as follows:

a. The Ci/container of Pu-239 should be 4.9 E+00,

b. The total activity should be 83.

23. Table 3.1-5, Page 3.1-30. If the average canister contains 1000 curies, then the first modification to the C & C Agreement (which limits total curies in RH-TRU to 5.1 million) will limit the number of canisters to 5100 and to 162,000 cubic feet of waste, rather than 250,000 as stated in Section 3.1.1.2.3. It is also noted that the WIPP Final Environmental Impact Statement (FEIS) shows 510 Ci/canister, 170 Ci of Cs-137, 160 Ci BA-137m, and 145 Ci of Pu-241.

24. Section 3.3.1.1, Page 3.3-1. The last sentence on this page is misleading. A significant fraction of the WIPP waste may be mobile since

the Waste Acceptance Criteria (WAC) allow one percent of the particulates to be less than 10 microns in particle size.

25. Section 3.3.3, Page 3.3-17. Paragraph (1) of this section indicates some "minor exceptions" to the general rule that "all buildings and their support structures are protected by fixed, fire suppression systems . . . ." Please add to this paragraph some examples of such exceptions. Of particular interest is whether any fixed permanent structures lack such fire suppression systems.

26. Section 3.3.4, Page 3.3-19. This section discusses radiological protection design considerations. In the second paragraph, it states that the plant is designed so that under normal operating conditions, "the radiation exposure to the general public is negligible as compared to the natural background radiation." It then references section 6.1.6.4. This reference section does not clarify the meaning of "negligible," but instead merely discusses the effluent and environmental monitoring program. For the FSAR, it is necessary that the criteria forming the basis for the "negligible" conclusion be clearly stated, and that this section should reference the relationship between potential doses to the public and the design criteria. These criteria and relationship are clarified for occupational exposure, but not for the general public.

CHAPTER 4

Plant Design

1. This chapter contains many improvements and a considerable amount of additional important information. With only a few exceptions, the information also was well presented. The few exceptions concerned some of the figures which were not always legible in their newly condensed form.

2. Section 4.2.1.5, Page 4.2-15. The last paragraph of this section states the liquid waste produced at WIPP will be solidified prior to disposal at WIPP. Additional details should be added here on the plans, designs, method of processing, and radiation protection procedures, since it could be a factor in evaluating radiation safety.

3. Section 4.2.2.3, Page 4.2-19. The first paragraph erroneously refers to Figure 4.2-7 for the air intake shaft headframe. It should reference Figure 4.2-6.

4. Section 4.2.5, Page 4.2-20. This section refers to Figure 4.2-10 for a display of the pumphouse and contents. Figure 4.2-10 is a pictorial of the east and south elevations of the Support Building. There is no figure in the 4.2 series which displays the pumphouse.

5. Section 4.2.2.6, Page 4.2-20. The first paragraph refers to Figures 4.2-12 through 4.2-15. The correct references are Figures 4.2-7 through 4.2-10. There are no Figures 4.2-12 through 4.2-15.

6. Figure 4.2-4, Page 4.2-30. This figure is an unacceptable representation of the configuration and operation of the EFB for the following reasons:

   a. The effluent monitoring station locations are improperly identified. The reduction in size and extension of the duct at Station B is not represented. Station A is now to be down the exhaust shaft, not after the bend as shown.

   b. The normal operating position of the dampers of the EFB is improperly identified, e.g., the EFB isolation dampers should be normally "closed" not "open," to allow normal discharge to occur by the new main fans (which, incidentally, are not identified in the figure).

7. Section 4.3.2.1, Page 4.3-10. This section describes the subsurface facilities and refers to Figure 4.3-5. This figure does not indicate the location of the area for plug-in battery charging. The plug-in area should be indicated since it is a location of potential fires or explosion should ventilation be inadequate.

8. Section 4.3.2.1.2, Page 4.3-9. This section states that vapor from diesel fuel constitutes the principal risk of an underground explosion. Other areas warranting consideration are those for vehicle battery charging as discussed in Section 4.3.2.1, and the waste storage area when filled with waste. The latter deserves consideration unless the emplaced waste will be covered with backfill following emplacement. Audits of the

WIPP Waste Acceptance Criteria do not verify absence of pyrophoric wastes or those materials which tend to produce explosive gas mixtures.

9. Section 4.3.2.2, Page 4.3-14. Please provide a reference to the procedure to be used for retrieval of contaminated and uncontaminated waste packages. Such procedures are essential to an adequate radiation safety analysis.

10. Section 4.3.2.3, page 4.3-14. In the last paragraph on this page, there is a discussion of the dose rate from emplaced RH-TRU. It is stated that the maximum loaded canister would be 100 rem/hr. This is not correct. Pursuant to Modification 1 of the DOE/State Consultation and Cooperation Agreement, up to 5% of the RH-TRU canisters may have a surface dose of 1000 rem/hr. Also, please provide the reference or more detail in the last paragraph on this page on the calculation that concludes the highest radiation dose rate around the shield plug will be only 3 mrem/hr.

11. Section 4.4.1.2.1.2, Page 4.4-13. The first line on this page indicates that "if excessive airborne contamination is detected at the air intakes, the outside air supply is directed through HEPA filters." It is not clear in Figure 4.4-7 (the Legend page is not legible) if a separate CAM is provided for the intake, or will the air be monitored elsewhere? Please clarify.

12. Section 4.4.1.3, Page 4.4-16, third paragraph. This paragraph indicates that "a small quantity of air is drawn down the waste

shaft . . . ." What is meant by "a small quantity"? Has an analysis been performed of the potential radiological health consequences of an airborne release incident in the WHB which results in contaminants being drawn down the waste shaft and exposing workers below?

13. Section 4.4.3.1.2.3, Page 4.4-34. Please provide a reference to figures which display the location and other details of the "separate exhaust system" provided for venting hydrogen from the battery-charging process.

14. Section 4.4.3.1.6, Page 4.4-37. Please include a reference to the report of the study done to evaluate public fire fighting capability and level of mutual aid response in case of a fire emergency at WIPP.

15. Section 4.4.3.2, Page 4.4-37. This section refers to Table 4.4-10 which provides a considerable amount of new and helpful information on the fire suppression equipment throughout the plant.

16. Section 4.4.4.1, Page 4.4-47. The first paragraph of this page refers to Figure 4.2-10 for a schematic of the pumphouse. As indicated in comment 4 above, this is an incorrect reference. There is no figure showing the pumphouse.

17. Section 4.4.6, Page 4.4-51. The second paragraph of this section refers to Section 5.4 for details on process operations, however, Section 5.4 fails to provide details on the solidification process for liquid waste. As previously stated, information on this solidification process

is necessary for an adequate safety evaluation. The Failure and Affects Analysis (Table 4.4-13) does not consider this subject. Furthermore, such processing should be clearly defined prior to the receipt of WIPP wastes.

18. Section 4.4.10.4, Page 4.4-74. This section describes the breathing air supplies available for fire fighting and normal WIPP operations. More detail should be added on the equipment and procedures used for producing the Class D breathing air for SCBA cylinders. Information also is needed on the inventory of SCBA tanks. No breathing air compressor systems are indicated.

19. Section 4.5.2.5, Page 4.5-6. This section describes the canister shuttle car used to transfer waste canisters from the port in the floor of the hot cell to the floor of the cask loading room. Please add a scale drawing of the shuttle car.

20. Section 4.6.5, Page 4.6-2. More detail is needed on the criteria to be used to determine when reinforced canopies will be used to protect operators of mobile mining equipment.

CHAPTER 5

Process Description

1. Page 5.1-1. If DOE decides to ship waste by rail to WIPP, EEG requests six months prior notification in order to address education of the public and rail workers to potential doses and problems.

2. Section 5.1, Page 5.1-1. Following the sentence, "The shipping containers are DOT Type B containers certified by the NRC," please add the sentence "These containers are designed for shipments exceeding 20 curies of plutonium and are, therefore, doubly contained."

3. Table 5.1-3, Accidents 15 and 16. The stated consequences are not consistent with the information provided in Chapter 7, and the consequences as stated for Accident 18. How can an accident be bounded by another accident which is not considered credible, and therefore the consequences were not analyzed?

4. Section 5.2.1.2, Page 5.2-3. The second paragraph on this page should contain a reference to the Standard Operating Procedure to be used for this and subsequent operations. These procedures are necessary for an adequate safety analysis.

5. Section 5.5.2, Page 5.5-2. The first paragraph of this section refers to DOE Order 5480.1A, Chapter V, but references DOE Order 5480.1B, Chapter XI. Please clarify. Since DOE 5480.1B superseded 5480.1A, references to 5480.1A should be deleted.

CHAPTER 6

Environmental Safety and Health Protection

1. In general, Chapter 6 appeared to have been prepared hastily. There were few improvements, and there was no evidence of response to EEG's December, 1986 comments on Amendment 9 of the SAR. The Bibliography for Chapter 6 was poorly done, containing several duplications and inaccuracies.

2. Section 6.1.1.1, Page 6.1-1. Credit is taken for periodic ALARA reviews of design documents by nuclear and health physics specialists from the architect-engineer organization. EEG has not received any of their reports, analyses or recommendations. Please provide this information.

3. Section 6.1.1.3, Page 6.1-3. This section refers to the WIPP Radiation Safety Manual (WP 12-5) as the basis for the WIPP ALARA programs. EEG agrees that this manual will impact substantially on the radiation safety aspects of WIPP, and we recently transmitted comments and recommendations for the improvement of the policies, procedures and criteria contained in that manual. We are pleased that most of our recommendations were adopted in the July 1988 revision of the manual.

The SAR states that the WIPP ALARA program is described in Section 2.0 of the WIPP Radiation Safety Manual (WP 12-5). Section 2.0 of that document contains only generalized responsibilities of management, personnel and radiation workers. Hence, the SAR does not adequately describe the WIPP ALARA Program as claimed and should do so.

4. Section 6.1.2.1.1, Page 6.1-4. Please add a table in support of this section to show the estimated number of 55 gallon drums of waste and the number of each type of boxed waste to be shipped to WIPP.

5. Section 6.1.2.1.2, Page 6.1-5. This section refers to Table 6.1-2 for the design basis gamma source strengths for RH-TRU waste, however, this table provides only average source strengths. The description should include the maximum source strengths of 1000 rem/hr.

6. Section 6.1.2.1, Pages 6.1-4, 5. The CH-TRU and RH-TRU gamma source strengths presented in Tables 6.1-1 and 6.1-2 are not derived from the current radionuclide content of RH-TRU waste presented in Table 3.1-5. The Mev/s-canister total in Table 6.1-2 should be less than one-quarter of the value given, and the peak energy group area should be in 0.4-0.8 Mev, not 0.8-1.3 Mev and 1.3-1.7 Mev. While the values used probably give conservative results for shielding and external dose considerations, it would be desirable to directly determine the gamma spectrum on representative drums. An assumption that external radiation does not contain significant quantities of low energy radiation can lead to the selection of instruments or TLD badges that fail to detect the radiation present.

The comment was made that the allowed neutron dose rate is much smaller than the allowed gamma dose rate. A table similar to Table 6.1-1 should be provided for neutron energy group and surface flux.

7. Section 6.1.2.2, Pages 6.1-6 through 6.1-9. The procedure used to estimate resuspended radionuclide concentrations, quantities of radionuclides inhaled, and the resulting radiation doses from handling undamaged, surface contaminated containers is difficult to follow. We also question some of the assumptions and are unable to arrive at similar conclusions. Also, the reference to the August 19, 1981 version of DOE 5480.1B may not be appropriate in view of the 1988 draft version of 5480.11, if it has been approved.

The surface contamination concentrations given in Table 6.1-4 are only about 52% of the WAC limits for both drums and boxes. This will, of course, impact subsequent calculations. In our comments on this table in Amendment 9, we pointed out that the values were incorrect and were told the table would be completely revised in the FSAR. The numbers are unchanged from Amendment 9.

The expression on Page 6.1-7 used to calculate the concentration in room air is difficult to check because we are not given the volume of the room used. Using only the volume of the inventory and preparation area (that was scaled from Figures 4.2-1 and 4.2-3) of 1.80×10^{10} cm^3, we arrive at total alpha concentrations of about 1×10^{-13} $\mu Ci/cm^3$, about 0.2 of those in Table 6.1-3. Also, the concentrations in Table 6.1-3 are mislabeled; it should be $\mu Ci/cm^3$ (not mCi). Furthermore, the MPC fraction assumes the radionuclides are insoluble form. If they are soluble, the combined MPC would be about 0.17.

However, either concentration results in doses received by the work force that are somewhat greater than the values shown in Table 6.1-10. The concentrations in Table 6.1-3 lead to an annual dose to a worker in the Waste Handling Building (with 2400 m^3/y inhalation) of 0.43 to 0.54 rem, depending on solubility assumptions. Yet in Table 6.1-10, it is stated that the total dose from air contaminants to the 16 waste handlers and 7 radiation control workers in the Waste Handling Building is 0.22 person-rem. Even with an occupancy factor of 50% for these workers, there should be a dose of at least 5 person-rem. And if 100% of the WAC contamination limit had been used in Table 6.1-4, the dose would have been at least 10 person-rem. Is it intended that the doses be average individual doses? (Note our comment on Table 1A.2-1.)

Furthermore, it is questionable if use of a "resuspension fraction" to calculate airborne concentrations is the most appropriate approach. Other concepts such as the "resuspension factor" (units of Ci/m^3 per Ci/m^2) or "resuspension rate" (units of Ci/sec) have a larger data base and usage. Your reference (Sutter) gives data for these other concepts. Also, it is probable that most exposure will occur to workers near the contaminated drum, rather than other parts of the Waste Handling Building where the aerosol concentration is much more dilute. If a "resuspension factor" of 10^{-6}/m is used (commonly accepted value for PuO_2 resuspension in the work place, from page 83 Jones and Pond in "Surface Contamination," Pergamon Press, 1964), one calculates that one person-year in proximity to containers would lead to a 50-year effective dose commitment of 6 rem.

In summary, we believe that the assumptions and methodology used in calculating airborne concentrations are questionable, that the calculated doses presented are much lower than they should be for the assumptions used, and that worker exposure to airborne contaminants is probably a much greater fraction of potential occupational exposure than is concluded in Chapter 6. This entire calculation should be carefully reviewed.

8. Section 6.1.3.1.1, Page 6.1-9. Credit is taken for minimizing personnel radiation exposures by limiting access in the plant. Reference and document this claim.

9. Section 6.1.3.2.2, Page 6.1-13. This section discusses use of Respiratory Protective Equipment. The section does not provide any detailed information on the SCBA equipment to be used. There have been several recent improvements in the design of such equipment, and the WIPP should use these improved design criteria. For example, in none of the WIPP documents is there an indication that SCBA equipment to be used will be positive pressure demand type, equipment which will maintain a positive pressure in the face mask (even during high breathing rates), and provide fresh air on demand. It is only recently that the value of such positive pressure equipment has been demonstrated. (Some WIPP documents have referred to Pressure demand SCBA's but this could be a reference to the Negative-pressure respirators, which only provide air on demand.

10. Section 6.1.3.3, and Table 6.1-7. This section refers to Table 6.1-7 which indicates design contamination zones. Based on this Table, the CH waste handling area is a Contamination Zone B which has a maximum contamination of 50 pCi/100 cm^2 loose alpha, contamination which would be equal to the WAC contamination limits. It may be difficult, therefore, to detect contamination at or in excess of the WAC limits if the room in which the package is located has contamination levels equal to those limits. Also, it is noted that the Radiation Safety Manual (July 1988) calls Contamination Zones I, II, III, with Zone I having limits of 20-100 dpm/100 cm^2 (9-45 pCi/100 cm^2) removable alpha contamination. The SAR terminology should be identical to the RSM and we recommend that the Zone I limits apply to the CH waste handling area.

11. Section 6.1.3.4.2.1, Page 6.1-16. What is the "derived average source strength," and how was respiratory protection considered in the result (i.e., how was the NRC manual on respiratory protection used)? This should be clarified in the FSAR.

The use of special shielding in separate enclosed area should be based on 1 rem annual dose or 100 mrem/h contact dose rate and ALARA considerations. For example, an ALARA evaluation might consider worker dose resulting from installation of temporary shielding as compared to worker dose from moving drums to a specified location. Other ALARA considerations might be potential contamination problems, existing radioactive inventories in shielded areas, or worker activity in controlled areas. In other words, the criteria is too simplistic and could result in a greater dose to workers rather than less.

12. Section 6.1.3.4.2.4, Page 6.1-19 to 6.1-21. This section fails to provide information on the basis for the underground shielding for RH-TRU canisters. For example, in calculating the shielding provided for emplaced canisters, was consideration given to those canisters which may have dose rates up to 1000 rem/hr? Information should be added to the FSAR to indicate the criteria used for shielding of emplaced canisters.

13. Section 6.1.3.5, Page 6.1-21. "The design and operation of ventilation systems assure that doses to personnel and the general public . . . are below limits specified in the appropriate regulatory guidance." Please include the data used, an illustration of the methods and the assumptions used for calculations, and results.

14. Section 6.1.3.5.1, Page 6.1-22. Please provide more detailed information or data to support the ALARA assumptions of this section.

15. Section 6.1.3.6, Page 6.1-26. This section refers to Figure 6.1-13 which consists of 11 sheets, none of which is legible. Please provide legible copies.

16. Section 6.1.3.6, Page 6.1-26. The Continuous Air Monitor (CAM) description here no longer correctly describes the CAMs (now alpha CAMs). What is needed is a figure and detailed description which fully explains the marriage of the NRC and Eberline equipment added later. A proper description of all these instruments would involve a statement - really a commitment - to a certain DAC-hr response capability in a specified

radon/thoron daughter background. A step in this direction is provided later for the Pu CAMs, but it still is flawed. There should be an estimation of performance of the alpha and beta CAMs in above-ground applications, and another in the salt dust-laden below-ground applications. It is likely that the beta-gamma CAMs as engineered will not be adequate in either case. The Pu CAMs may be adequate in the above-ground applications. It is difficult to know how the area Radiation Monitors should be required to be specified, except in terms of the ability to detect a gamma field producing a given exposure rate at 1 meter from a remote position typical of the installation.

17. Section 6.1.3.6.2, Page 6.1-28. Reference to the "posting requirements" of 5480.1B is not an adequate way to reference CAM performance requirements. Continued reference to "alpha equivalent" detectors is probably incorrect. If not, this needs some clarification.

The concept of airborne radioactivity monitoring is simplistic and not in accordance with the intent of DOE Order 5480.11. As an example, NUREG/CR-4033 and NRC Regulatory Guide 8.21 suggest that air samples should be collected that are representative of the air in the worker's breathing zone. Sampling of radioactivity shall be in areas known to be of a greater concentration than that of the worker's breathing zone. This section should be revised to reflect this fundamental concept.

18. Section 6.1.3.6.2, Page 6.1-29. On what basis is an alarm setting at 10 MPC-hrs an acceptable performance standard for CAMs? It should not be larger than 4 MPC-hrs (as is stated later in the chapter). The

underground CAMs might have a severe problem meeting 4 MPC-hrs in a reasonable radon/thoron background and outfitted with a long transport line. The FSAR should specify exactly (based on appropriate tests) what MPC-hr performance can be expected from both types of CAMs, in both types of settings.

References to the CAMs "operating" in "expected" environmental conditions hardly seems a satisfactory specification, particularly with reference to background suppression, for both alpha and beta-gamma CAMs. Furthermore, if the internal aerosol transport system of the CAM heads has not been changed to match TAMU design specifications, then from an aerosol sampling perspective the CAMs in the WHB and below ground are substandard, and would not be expected to meet reasonable response standards under accident conditions.

"Calibration" of the CAMs with plated sources, as stated here, can really only provide an indication that detector response continues to be the same as before. With an MCA-based count collection and analysis system and microprocessor based algorithm for background suppression, a more exacting calibration should be done, and explained here. The periodic demonstration of the proper functioning of such a sophisticated system will require careful development.

19. Section 6.1.3.6.3. The SAR states that no credible criticality hazard exists. References please.

20. Section 6.1.4, Page 6.1-30. More current data for the waste forms for WIPP may be found in revision 3 of reference 22.

21. Section 6.1.4.1, Page 6.1-30. The design objective should be less than 1 rem/year/person and ALARA.

22. Section 6.1.4.2, Page 6.1-31 and Table 6.1-8. The external doses calculated for routine operations use the February 1985 report, WTSD-TME-009, as a basis for calculating external doses received by workers. This report uses older inventory data and time-motion study based on TRUPACT-I and drums being packaged as six-packs. The WPO has a July 1988 report, DOE/WIPP 88-012, which uses actual time and motion data obtained in a June 1988 Preoperational Checkout that was specific to TRUPACT-II and used the latest inventory data. The later report estimates annual external radiation doses from CH-TRU of 13.7 person-rem for normal operation and 0.64 person-rem for "off-normal" waste handling, compared to 9.19 and 0.132 person-rem in Chapter 6. Although EEG has not critically reviewed DOE/WIPP 88-012, the methodology is more specific, contains real data, and uses newer inventories. We believe it should be used in place of WTSD-TME-009.

23. Section 6.1.4.3.2, Pages 6.1-33, 6.1-34. The whole analysis of the handling of damaged drums seems to presuppose that the workers instantly recognize that drums or boxes are damaged before they could possibly be exposed, and don respirators. The experiences recently at the SWEPP facility at INEL involving a damaged drum show otherwise. Two people were exposed apparently before anyone donned respirators. Thus, it is

likely that there will be some delay in discovery of damage unless TRUPACT itself was visibly damaged.

There are several additional questions or observations on this scenario:

a. The origin of the number 66 for contaminated seven-packs is not clear. From Table 6.1-15 one would expect 34,000/7 = 4860 seven-packs/year and 1% of this would be 49 seven-packs.

b. From the information given here, the estimate of 1.0 mrem/hr seems low. A 6 mrem/hr dose rate at 4 inches would be about 1.2 mrem/hr at 2 feet, and an exposure to two drums would be about 2.4 mrem/hr during hands-on operations. Furthermore, DOE/WIPP 88-012 uses average surface dose rates of 14 mrem/hr for drums and 5 mrem/hr for boxes.

c. The fraction of the waste assumed to be aerosolized and respirable (FA&R) is 10^{-5}. If it is intended that this fraction apply to all drums in the seven-pack, then the FA&R is equivalent to 7×10^{-5} of one drum. In contrast, the accident scenarios in Chapter 7 have FA&R values for one drum of 1.25×10^{-5} (C2) and 2.23×10^{-5} (C3). Is this consistent? Should an average overpacking and decontamination operation release as high or higher FA&R as the accidents?

d. We believe the assumption of 10^{-5} release of one average drum's contents is sufficiently conservative. But this is not a negligible release and it is not clear how this could lead to a dose as low as 0.04 person-rem. Consider the following:

(1) amount released from an average drum (11.9 PE-Ci) would be 1.19 x 10^{-4} PE-Ci;

(2) this would be released in 6 volumes of Overpack and Decontamination Room air, or 1.98 x 10^{-5} PE-Ci/volume;

(3) the volume of air (from Figures 4.2-2 and 4.2-3) seems to be about 130,000 ft^3 (3.6 x 10^9 cc);

(4) thus the apparent concentration in air is 5.5 x 10^{-15} PE-Ci/cc;

(5) a worker would inhale about 6.6 x 10^{-11} PE-Ci/hr (after allowing for a decontamination factor of 10^{-2} from use of respirators);

(6) for 132 person-hours per year this would be an intake of 8.73 x 10^{-9} PE-Ci/year;

(7) for a 50 year committed effective dose equivalent (CEDE) of 430 rem/μCi, this becomes 3.8 person-rem.

This calculation needs to be carefully rechecked since the results are potentially significant.

e. We checked the doses in Table 6.1-9 for RH-TRU casks decontamination within 5% and believe the assumptions are conservative.

24. Section 6.1.5.2, Page 6.1-37. This section refers to Figure 6.1-13, which should be Figure 6.1-14.

25. Section 6.1.5.4.5, Page 6.1-49. This section refers to "pressure demand self-contaminated breathing apparatus." Please note Comment 4 above. WIPP should use only POSITIVE pressure demand SCBA's.

26. Section 6.1.5.4.4, Page 6.1-50. The last paragraph refers to WIPP 12-006, "Respiratory Protection Equipment," Reference 31. EEG has been unable to locate such a report. It probably should refer to WIPP 12-106, "Respiratory Protection Program."

27. Section 6.1.5.5.1, Page 6.1-51. The first paragraph on this page states that "Radiation contamination survey stations are indicated on Figures 6.1-1 through 6.1-6." There are no survey stations indicated on these figures, except for the underground area (Figure 6.1-5).

28. Section 6.1.5.5.8, Page 6.1-53. What is the criteria for considering clothing contaminated? The level of contamination in anti-contamination clothing is important in minimizing skin dose and as an indicator of contamination problems. The WPO Radiation Safety Manual does not provide for how contaminated anti-contamination clothing will be handled. It should be made clear whether anti-contaminated clothing will be disposable clothing or laundered. Information on the processing of anti-contaminated clothing should be added to the Radiation Safety Manual.

28. Section 6.1.6.1.1, Page 6.1-56 and Table 6.1-13. When using 100% of the WAC surface contamination limit and the other assumptions in this chapter and χ/Q value of 1×10^{-5} s/m^3 at the site boundary, there results a maximum adult dose of 6.2×10^{-7} rem/y from resuspension of surface contamination. Although this is a significant increase from the value presented in Table 6.1-13, it is still a negligible dose.

29. Section 6.1.6.3, Page 6.1-63 through 6.1-65. In our comments on Amendment 9 of the SAR, we noted that Table 6.6-5 (now Table 6.1-13) did not provide data on doses from the several ingestion pathways, nor does it compare these doses with those from pathways which directly involve the plume as claimed on (Page 6.1-66). The WPO response stated that this section is being reevaluated for the FSAR to be consistent with the previous discussion. It appears that with only one minor exception, this section is identical to the previous one, therefore there appears to have been no response to our earlier comment.

30. Section 6.1.6.4.2, Pages 6.1-68 through 6.1-70. This section contained no changes from Amendment 9 of the SAR. Therefore it was totally unresponsive to our previous comments on Amendment 9 as contained in our letter to the WPO of December 16, 1986. It also did not reflect a peer review of the plans for stack monitoring at WIPP held on November 14, 1986, in Santa Fe. The entire discussion of the effluent monitoring probe design and operation here is written with little or no resemblance to the reality of the present stack monitoring system and facility monitoring system, which was to be completely redesigned following extensive EEG review. More specifically:

a. At present it appears that the alpha CAMs in the stack systems have a vastly improved aerosol transport system of TAMU design when compared to the facility monitoring systems built around an Eberline supplied alpha detector apparently replacing the L X-ray detector in an otherwise unmodified NRC CAM head. Neither here nor in the discussion of the other probes is there any mention of aerosol transport capabilities.

b. The shrouded Texas A & M University (TAMU) stack monitoring probe is not designed to be an isokinetic probe as stated here, for example, the flow rate is kept constant, so there is no "sample flow rate controller" associated with the TAMU probes, as stated here. A more nearly correct description is found later in Chapter 6.

c. There is no discussion at all of the expected response time of the effluent monitoring system, whether triggered by a CAM underground, or in the stack. This is a significant omission of an assessment of accidental releases to the environment.

31. Section 6.1.6.4.2, Page 6.1-69. The statement that the sampling period and volume for the FAS are "maximized to provide a reasonable lower limit of detection" is unacceptably vague. There are limits on time and sample rate for each FAS setting set by the conditions of sampling and the choice of filter size, filter medium, etc. It should be stated what the lower limit of detection will be for the major TRU radionuclides from the various FAS locations.

32. Section 6.1.6.4.2, Page 6.1-70. With regard to the response characterization of the beta CAM (11 cpm after 4 hrs at 60 lpm), it is almost certainly true that this level of activity could never be seen after a relatively short sampling period (about 1 hr) in the beta-gamma noise of the radon-thoron background on the filter. As was pointed out in EEG-38, the background sensing GM tube is not sensing the appropriate background for this instrument. Based on the stated sampling rate and

MPC, using the filter activity equation, the implied efficiency of the system at the stated 11 cpm is 34%, which is reasonable for a low-background GM detector counting a Sr-90 standard source. But that is totally inappropriate as a measure of the LLD for the system with an equilibrium load of radon and thoron daughters on the filter. The FSAR should specify the LLD of both the beta-gamma and alpha CAMs under realistic background conditions.

With regard to the alpha CAM response, it is quite adequate to specify an MPC-hr response of 4 MPC-hrs for Pu-239. However, it is totally unacceptable to add the proviso: ". . . when no other radionuclides are present." There is no basis for such a provision in DOE Orders, ANSI Standards, or any other authority that is known to EEG. There will <u>always</u> be background radionuclides present on the filter during monitoring. The FSAR should state the MPC-hr response without qualification.

33. <u>Section 6.1.6.4.3, Page 6.1-74</u>. The summary of the preoperational program in Table 6.1-15 should include data collected by the EEG.

34. <u>Section 6.1.6.4.7, Page 6.1-77</u>. As is evident throughout Chapter 6, there is no response to EEG's comments on Amendment 9 of the SAR. The EEG had recommended that mention be made in this section of the agreement to conduct intercomparison and verification of environmental data with the State of New Mexico as provided in the Consultation and Cooperation Agreement. In response, the WPO committed to "Appropriate words will be included in the FSAR, referring to the arrangement outlined in the

Supplemental Stipulated Agreement through which the State and DOE Environmental Programs are coordinated and through which the State is to provide independent environmental monitoring verification services to DOE."

35. References for Section 6.1, Pages 6.1-79 through 6.1-84. This bibliography contains numerous duplications and inaccuracies. For example, it has five listings of DOE Order 5480.1B, Chapter XI; three listings of WIPP Radiation Safety Manual; it refers to a 1981 version of DOE Order 5480.1B, whereas Chapter 4 refers to a 1986 version. We believe the Chapter 4 listing is correct.

36. Table 6.1-12, Page 6.1-98. We commented on this Table when it was presented in Amendment 9 of the SAR. At that time, we were informed by the WPO that this data was based on the data in Section 3.1 of the SAR, but that new source term data will be used for the FSAR and an example calculation will be provided for clarification as to how the data in Table 6.1-12 was derived. The data in Table 6.1-12 is unchanged from the previous Table, and no example was provided.

37. Section 6.2, Page 6.2-1. The material on non-radiological surveillance programs, relevant to agreements, laws and regulations, is a new addition to the SAR. Its inclusion is desirable. However, the amount of detail is inadequate. Three omissions are noted in the Section.

38. Table 6.2-1, Page 6.2-8 through 6.2-10. The Resource Conservation and Recovery Act is appropriately noted in the Table. However, the extensive

effort and problems concerned with obtaining a RCRA permit for disposal of the hazardous waste component contained in much of the TRU waste is nowhere discussed or evaluated. This is an important effort which is necessary for the FSAR.

39. Table 6.2-2, Page 6.2-11. List the contract establishing EEG in 1978. Same for Table 6.2-3, Page 6.2-14.

40. Table 6.2-3. The Second Modification to the DOE/State Agreement for Consultation and Cooperation was signed August 4, 1987, and should be listed and summarized in this Table.

41. Section 6.3, Page 6.3-1. The last sentence of this Section refers to Figure 6.3-1. This figure was not included in EEG's copy of Chapter 6.

42. Section 6.3.1.1, Page 6.3-2, 6.3-3. This Section should provide greater detail for the various training and indoctrination programs discussed, or each program described should reference the documents which provide greater detail.

43. Section 6.3.3, Page 6.3-5. This Section also should provide more detailed descriptions of the emergency preparedness, or it should reference other sections of the FSAR or other documents where more information is available.

44. Section 6.3.3, Page 6.3-6, 2nd Paragraph. The discussion of emergency medical technicians should indicate the number of EMT's per 100 employees.

45. Section 6.3.4, Page 6.3-7. Please provide appropriate references to the Emergency Preparedness Plan.

CHAPTER 7

Accident Analysis

1. There does not appear to be a "Design Basis Accident" identified in this Chapter. The category "limiting incident" may be considered by the WIPP Project Office to be an acceptable alternative to the DBA (both have an associated probability such that they are credible, but not expected to happen over the life time of the project).

   The requirements for identification and discussion of DBAs are set forth in DOE Order 6430.1, Chapter 1. Both internal and external (e.g. earthquake) initiating events must be considered. It is not apparent from the text of this Chapter that a DBA assessment has been performed. It is strongly recommended that such an assessment be performed and summarized in Chapter 7. It should meet the requirements of 6430.1 and the guidelines of related documents such as "A Guide to Radiological Accident Consideration for Siting and Design of DOE Non-reactor Nuclear Facilities," LA-10294-AC, January 1986. The advantage of the DBA assessment is that it provides a perspective for evaluating the significance of the potential mitigators which are presently described as limiting impacts to inconsequential outcomes. Moreover, the DBA assessment would reflect conditions which might enable structures, systems and components to be evaluated with respect to their importance to safety. In a suitable DBA assessment, degraded performance of all mitigators must be considered, and a release of radioactivity described associated with the DBA which causes radiological exposure. This release event must be shown to result in doses which are not in excess of the guideline doses in DOE Order 6430.1, Chapter I, or associated guidance.

Another problem in not performing a rigorous DBA analysis is that all possible failure modes are not systematically considered. The following two scenarios were apparently not considered:

a. The contamination of the underground by releases from several accident scenarios in the CH-TRU portion of the WHB from the ventilation air flow down the Waste Handling Shaft;

b. Any scenario involving contamination of the radiation control area, or carrying contamination off-site by workers, visitors, or equipment. This is perhaps the most likely pathway for radionuclide contamination from the WIPP Site to reach surrounding communities. It has been a problem in various nuclear facilities over the years and considering the difficulty in detecting alpha contamination, is a potential problem at WIPP. There is no indication in the SAR that this threat has been adequately addressed by the WPO.

2. There are significant numerical errors and inconsistencies in this chapter, and serious questions are raised in the comments that follow, concerning the appropriations of the assumptions and methodologies used.

3. Section 7.2.1, Page 7.2-1. All of the significant CH-TRU accidents are considered moderate frequency, which is defined as accidents assumed to occur once a year or up to 25 times during the project lifetime. Yet all these accidents are assumed to occur only with an average drum (apparently 11.9 PE-Ci). We believe that occupational dose commitments

for all of these moderate frequency accidents should be calculated for the drum loading with the maximum PE-Ci level. These doses would be significant. For example, with the proposed 1000 PE-Ci limit (which EEG is objecting to in our letter of June 22, 1988) the 50 year EDE to a worker in the C2 accident would be about 420 rem and 15 rems would be delivered in the first year for W category wastes. If the waste were Y category the 50 year EDE and the 1 year EDE would be about 275 rem and 24 rem. In either case, these are very undesirable doses that are possible and should not be ignored in the Chapter 7 tabulations. Furthermore, the realization that very high occupational doses are possible should affect the choice of PE-Ci limit as well as the operational health physics procedures employed.

4. Page 7-3. Please indicate the basis for the statement that the relative radionuclide abundance per cubic foot is greater for drums than for any of the alternative containers. If this is true, is the probability of release necessarily higher for drums in the various accident contexts given the weight and presence, for example, of heavy, hard wastes in boxes? It is worth pausing to consider that the most spectacular release of TRU has occurred with an accident involving a box and not a drum.

5. Section 7.2.2.1, Page 7.2-2. The second paragraph on this page states that "three" individuals were considered in the analysis. In Section 7.2.2.1.2, second paragraph, "four" individuals were located within a single sector. Also Table 7.3-2 provides dose estimations to a worker, but fails to show the location of the worker. Was the worker also considered to be "outside the facilities?"

6. Table 7.2-1, Page 7.2-9. This table from Chapter 3 also has an error in the Ci/drum of Pu-238. The value should be 1.0E + 01 rather than 1.0E + 02. The PE-Ci should be 11.9 rather than 8. This will affect most other calculations.

7. Section 7.3.1, Page 7.3-1. This is a new scenario necessitated by the changed design for TRUPACT-II which requires unloading outside of the Waste Handling Building. Any release would be to the site and the environment from a ground level release without HEPA filtration. It is important that this scenario be completed and releases and inhalation values calculated.

8. Section 7.3.1, Page 7.3-2 through 7.3-3. This accident assumes that a bundle (7 drums) are dropped from a fork lift. Also it assumes that the drop "causes the lids of the drums to be knocked off and an inner plastic liner to tear." It is also assumed that 25% of "the drum contents (8 PE-Ci) is spilled, and 5% of the total activity is contained in the allowed one weight-percent." Therefore these assumptions imply that the total activity released is

$$(8 \times 7) \times .25 \times .05 = .7 \text{ PE-Ci}$$

If .001 is resuspended this results in 7E - 04 being released, a factor of 7 higher than indicated. Perhaps it was intended to state that the lid of only one drum fell off, releasing 25% of its contents. Regardless, this is an excellent candidate for the above-ground facility DBA if analyzed properly. Unfortunately, the opportunity is not adequately considered. First, it is assumed that all workers who could

potentially be exposed in the immediate vicinity of the accident instantaneously leave, so there is no exposure. In effect 100% credit is taken for safety features of the facility and equipment, and for worker training. This is not valid unless the circumstances and consequences of this accident are considered in more detail. The exposure "allowed" is that to a worker located in a remote location (and this cannot be evaluated since Appendix 7B is not complete). Why is it incredible (probability 10^{-6}) that a worker might <u>not</u> instantly leave the accident scene? What if he is injured or stunned by the falling drums? What if he is uncertain about whether or not a release actually happened? What if he is trapped momentarily by the equipment and drums?

Although, the scenario description did not state residency time for the nearby worker it was estimated that it would take about 25 seconds for the "cloud" to travel 20 feet and about 1½ minutes of breathing to obtain the stated inhalation quantity. The forklift operator, at about 5 feet distance, would get the "cloud" in about 6 seconds and in the next 10 seconds would inhale about 4.5×10^{-8} PE-Ci (7 times that of the worker in a 2 minute residency time). We believe the assumption is non-conservative and that a dose to the forklift operator should be calculated. Incidentally, we note that the 5/86 version of this section used a "cloud" velocity of 5 ft/min, which is only 1/10 of that listed here.

9. <u>Table 7.3-1, Page 7.3-14</u>. This table has several serious errors and inconsistencies. For example, it is noted that the numbers in both 50 year Effective Dose Commitment columns are unchanged from the May 1986

draft FSAR even though there are substantive changes in the PE-Ci values released or inhaled for most scenarios. As an illustration, the 6.5 x 10^{-9} PE-Ci inhaled in the C2 accident (using 520 rem/uCi inhaled) the 50 year Effective Whole Body Dose would be 3.4 rem. If this is further corrected by using the correct 11.9 PE-Ci average per drum (rather than 8.0) the dose would be 5.0 rem. Also, the 50 year EBD for R4 is not consistent with that for C3.

10. Table 7.3-2, Page 7.3-15. This table has errors similar to those in Table 7.3-1. Although the intake for the scenarios is significantly different in the 1986 draft, the doses in the Table have not been changed. Accident C3 uses the C2 model to relate resuspended radioactivity to inhaled radioactivity. With 1.8 times the resuspended activity the amount inhaled would be 1.2 x 10^{-8} PE-Ci. This would result in an occupational dose of 6.1 rem in Table 7.3-2. With the use of an 11.9 PE-Ci per drum the dose would be 9.0 rem.

In scenario C4 the calculations check although its not clear why 15 seconds inhalation time was used when the cloud volume would pass a point in slightly over 2 seconds. The occupational dose commitment in Table 7.3-2 would be 3.2 rem with an 8.0 PE-Ci drum and 4.8 rem with an 11.9 PE-Ci drum.

When the C6 scenario is modeled as the C4 scenario the worker would inhale 1.1 x 10^{-8} PE-Ci and the dose would be 5.6 rem for an 8.0 PE-Ci drum and 8.4 rem for an 11.9 PE-Ci drum.

There are two separate observations on the R4 scenario. One is that if the maximum canister had 1000 PE-Ci of TRU with the same relative composition shown in Table 3.1-5 there would be 17.3 Ci/l of TRU only. Thus it would not be possible to have the 17.1 Ci/l of fission and activation products in the same canister and remain under the 23 Ci/l maximum concentration permitted by agreement with the State of New Mexico. See also the preceding comment on Table 7.3-1, which relates to the R4 scenario.

11. Section 7.3.2, Page 7.3-7, Accident C7. The first paragraph of this section refers to DOE-AL Order 5484.1A. There is no such reference in Chapter 7. The only DOE Order referred to is DOE-AL Order 5481.1B, on Page 7.1-2. Perhaps this is the Order intended here. See also a reference to DOE-AL Order 5481.1A in the first paragraph on Page 7.3-8. As discussed in Comment 1 above, EEG does not agree that this accident fulfills the DBA assessment requirements of DOE Order 6430.1.

12. Section 7.3.2, Page 7.3-8, Accident C9. The requirements for diesel vehicle safety were upgraded years ago following discussions with EEG, so that this scenario could be considered incredible. Please provide the procedures to be used to insure that these upgraded requirements are followed throughout the lifetime of the project.

13. Section 7.3.2, Page 7.3-9, Accident C10. This accident has some conservative assumptions, however, the last sentence in this description assumes that no worker is located downstream of the fire. This does not seem to be conservative. What is the basis for such an assumption? Note

that Accident C4 assumes that a worker is downstream when the accident occurs. A new employee or a worker excited in the presence of smoke could conceivably violate established policy and be located downstream from the fire. Also, is there available experimental evidence to support such a large depletion in a mine environment? Reference 4 does not provide such evidence.

This accident becomes the limiting scenario for off-site releases. It is noted that the postulated release from a 1000 PE-Ci drum is calculated to deliver a 50 year effective dose commitment of 1.4 rem. This intake would also result in a one year dose of 0.51 rem if the release is in soluble form or 0.67 rem if it is insoluble. Thus the WIPP system components pertinent to this scenario would be classified as "important to safety" if this were a commercial repository to which 10 CFR 60 applied. Important to safety items require special quality assurance procedures which are not presently required of WIPP items.

Also, while the choice of a 1000 PE-Ci drum in this scenario is very conservative, the χ/Q value used is not. If maximum possible χ/Q values were used along with appropriate effective stack height correction factors one could calculate a dose greater than 0.5 rem from a 30 PE-Ci drum. So, such doses are clearly possible.

14. <u>Section 7.3.2, Page 7.3-11, Accident R4</u>. There appears to be a slight error in the calculated fission and activation products released for this accident. The result should be 7.8×10^{-9} Ci.

CHAPTER 8

Long Term Waste Isolation Assessment

The Long-Term Waste Isolation Assessment in Chapter 8, Amendment 9, contained 159 pages of text, figures, and tables. EEG was in basic agreement with the format presented in Amendment 9, although we responded with over 10 pages of questions and comments on details of the assessment. Now, in the Draft FSAR, all of these scenarios and evaluations are omitted and replaced with 9 pages of general discussion on how performance assessment will be conducted.

The deletion of the analyses presented in Amendment 9 and failure to provide consequence analyses is unacceptable to EEG. We understand that DOE is not prepared to do the Performance Assessment now and have never considered Chapter 8 to be the Performance Assessment. However, the SAR is supposed to analyze the ability of the project to be operated safely in all areas including long-term waste isolation. How can EEG and others reviewing the SAR conclude that the facility is adequate for long-term waste isolation when the SAR is completely silent on this?

The inclusion of the compliance strategy in Chapter 8 along with the long-term waste isolation assessment is desirable. However, the strategy presented is very brief and largely avoids mentioning specific dates or other details. This compliance schedule should be included in the FSAR. Also, on page 8.1-2, the last sentence refers to "data collection and development during the Pilot

Plant Phase will be required to complete the predictive models being used for the long-term performance assessment." Please describe in more detail the data and predictive models referred to. Other comments on specific sections of this Chapter are provided below.

1. Section 8.1.1, Page 8.1-3. As stated on Page 14 of DOE-WIPP 86-013, the Compliance Strategy will include Sensitivity AND UNCERTAINTY (emphasis added) analysis. The third item on this page failed to include the uncertainty aspect of the analysis. It is particularly important that the DOE analyze the parameter uncertainties, i.e., uncertainties about the numerical values in or resulting from data, and uncertainties in the conceptual model and its mathematical representation.

2. Section 8.1.1, Page 8.1-3. This section indicates that the final set of scenarios to be modeled for inclusion in the CCDF will be chosen from 73 scenarios examined during the PA. Because of lack of data on probabilities from actual experience, we urge that the DOE have a Peer Review of the scenarios and utilize the recommendations resulting from such review for the selection of the final set. EEG should participate in such Peer Review. Although the last paragraph on Page 8.1-7 indicates that a Peer Review Panel will evaluate the PA, there is no indication of the timing of such review or of what aspects will be reviewed by the Panel.

3. Section 8.1.1, Page 8.1-3. The last bullet on this page concerning human intrusion modeling should include Castile brine reservoirs. (See EEG reports EEG-11 and EEG-15.)

4. Section 8.1.3, Pages 8.1-4 to 8.1-6. This section completely ignores human intrusion scenarios that result in waste being brought to the surface (which is also the accessible environment). This is likely to be the most serious single pathway.

5. Section 8.1.6, Page 8.1-7. The last paragraph of this section states that "a Peer Review Panel will provide assurance to the DOE/WPO that the performance assessment is well conceived and being carried out with professional competence, and so that scientists and state officials can be assured that DOE's ultimate conclusions as to the suitability of WIPP as a repository are credible." In the past, the DOE/WPO has refused to include the State Environmental Evaluation Group (EEG) as a participant or observer of such Peer Review Panels. Until EEG is routinely included, and given reasonable advance notice of such reviews, with agenda and background information on proposals, the ultimate conclusions are not likely to be considered credible by state officials, nor by other scientists having no organizational ties to DOE. If the DOE/WPO plans to establish a new policy with respect to these Peer Review Panels, such that they will include full participation by EEG, it should be indicated in this section.

CHAPTER 9

Conduct of Operations

1. Section 9.2, Page 9.2-1. The first paragraph indicates that "formal test procedures are prepared for complex and critical systems as discussed in the Operations Program Plan." The FSAR should list those complex and critical systems, and should provide more detail on the test procedures.

2. Sections 9.2.1 through 9.2.2, Pages 9.2-1, 9.2-2. These sections should provide more detail on the acceptance testing programs. To what extent are equipment and systems tested at the factory? What fraction are found to be defective? What fraction of systems checked at the WIPP Site are found to be defective? Where are such testing records maintained? What documents contain the testing procedures? What documents contain the procedures for handling nonconformance? This type of additional detail should be provided or this section should reference where such detail is documented.

3. Section 9.3, Page 9.3-3. The first paragraph on page 9.3-3 refers incorrectly to "regulations numbered 48, 49, and 74 in 30 CFR 57 . . . ." The correct reference should be to "parts 48, 49, 57, and 74 in Title 30 of the CFR," however, Part 74 is applicable to coal mines only.

4. Section 9.3, Page 9.3-6. Reference 2 is also incorrect in that it refers to only one Part (i.e., 57) of Title 30, whereas it should refer to Title 30, CFR, without specifying parts.

5. Section 9.4.1, Page 9.4-1. Please provide a reference to the formal written operating procedures.

6. Section 9.4.2, Page 9.4-2. The third paragraph of this page refers to 30 CFR 57, whereas a more appropriate reference is 30 CFR 48.

7. Section 9.4.4, Page 9.4-2, 9.4-3. The last paragraph of 9.4-2 refers to "abnormal" occurrences. To be consistent with the terminology of other DOE and WIPP documents, the word "unusual" should be used instead of "abnormal." For example, see the definition of "unusual occurrence" in DOE order 5484.2. The word "unusual" should also be used in the first and last paragraphs of page 9.4-3 instead of "abnormal" and "internal."

8. Section 9.4.4.2, Page 9.4-4. The discussion in the first paragraph of this page should include a requirement that the WIPP operating contractor shall notify appropriate state authorities to assist in determining the impact of the violation on public health and safety. For example, the New Mexico/DOE C & C Agreement requires that "DOE shall keep the State currently and fully advised . . . so that the State may make independent reviews on public health and safety concerns relative to WIPP." To maintain credibility, it should be considered essential by WPO to involve the State authorities at an early stage in the public health evaluation. Furthermore, the WPO must meet the public exposure requirements of 40 CFR 191, Subpart A. These regulations should be referenced in Section 9.4.4.

CHAPTER 10

Operations Safety Requirements

1. This chapter lacks sufficient detail to permit EEG to adequately evaluate the operational safety at WIPP. It begins by defining safety limits but then states that there are no variables which require safety limits (see Sections 10.2). However, there are provided sections called "Surveillance Requirements" for the safety limits. The references in some cases are so general as to be of little value. In all instances, the references do not provide the complete title, nor do they cite the applicable section of the referenced documents. It is recommended that this Chapter be extensively revised and specific sections be revised as indicated in the following comments.

2. Section 10.1.4, Page 10.1-3 through 10.1-4. Please add and define the following ACRONYMS which are used in the Chapter, or should be cited in the Chapter:

   MOC - (See page 10.3-9)

   HVAC -

   WAC - Waste Acceptance Criteria

3. Section 10.2, Page 10.2-1, Safety Limits. This paragraph states that there are no measurable process variables which could result in an unfiltered release of radioactive material that exceed the DOE guidelines at the plant boundary. It would seem that the DOE Waste Acceptance Criteria should be construed as such a set of variables. Although unlikely, it should be considered credible that a waste shipment could be

received which has external contamination well in excess of the WAC. Furthermore, the DOE radiation exposure limits should be construed as safety limits or measurable process variables.

4. Section 10.3, Page 10.3-2. It is recommended that the word "activities" in Item 3 be amended to "activities, equipment or services".

5. Section 10.3.1.3, Page 10.3-3. In the first and second paragraph, the language should be amended to preclude, without exception, any operation with radioactive material when the CAMs and ARMs are not operating. These devices must be considered as essential to a central monitoring system. When not operational, the operations with radioactive materials should be suspended until these devices, or substitute equipment, are again operational. Therefore, in the first paragraph, please delete the words "except during calibration and change out." In the second paragraph delete "unless otherwise noted" and "(within a one hour limit)". The "Exception" on page 10.3-4 is quite reasonable and proper, however it is recommended that the words "continuously monitored by HP personnel . . . " be changed to "continuously monitored with equivalent equipment."

6. Section 10.3.1.3, Page 10.3-3, Item F. "50 ft" should be revised to "50 ft or less."

7. Section 10.3.1.4, Page 10.3-4. The language under "Basis" is so general as to be useless. It should be expanded, or replaced, to state the applicable sections of specific standards or guides.

8. Section 10.3.1.5, Page 10.3-4. To avoid confusion, please provide specific and complete references.

9. Section 10.3.2.5, Page 10.3-5. The reference "Westinghouse O and M Procedures" is inadequate. Please provide specific references.

10. Section 10.3.3.3, Page 10.3-6. Please revise the mid-page notation to state that the HVAC systems for the above ground facilities in the WHB are independent. The underground ventilation systems do not provide independent operation in the CH and RH areas.

11. Section 10.3.3.3, Page 10.3-6, Paragraph 2. Item 2 needs to clarify whether all (above ground and underground) ventilation will be shutdown, or whether it will only be shutdown in the affected work area.

12. Section 10.3.3.3, Page 10.3-6, Paragraph 3. Item 3 needs to be amended to state what minimum air flow is needed when normal operations are stopped. What air flow is required when HP surveys are being made to determine the area affected by an unplanned radiological incident or release, or when an air monitoring instrument is not operable.

13. Section 10.3.3.5, Page 10.3-7. The references should cite the applicable sections of the referenced documents. Also the referenced documents should be complete, including reference number, etc.

14. Section 10.2.3.4, Page 10.3-8. The referenced citations should be complete and should cite specific sections applicable.

15. Section 10.3.5.1, Page 10.3-8. The applicability should include portable fire suppression devices such as extinguishers, fire hose and stand pipe equipment.

16. Section 10.3.5.3, Page 10.3-8. This paragraph should be more specific to include minimal water pressure of sprinkler and hose systems.

17. Sections 10.3.5.4 and 10.3.5.5, Page 10.3-9. Cite specific sections of the referenced documents and include document numbers.

18. Section 10.4.1, Page 10.4-1. Please cite specific sections of the WIPP operating procedures and maintenance instructions.

19. Section 10.4.2, Page 10.4-1. Cite specific sections of reference documents which apply.

20. Section 10.4.2, Page 10.4-1, Paragraphs 1 and 2a, b and c. These paragraphs should be revised to assure that records of each inspection will become a part of the central records system.

21. Section 10.4.2, Page 10.4-2.

Paragraph 1 - The local monitoring should be equivalent to the CMS capability.

Paragraph 2 - Should be revised to assure that the air quality is checked frequently and to document the air quality standards.

Paragraph 4 - Should be titled "Exhaust Filter Building Equipment," and paragraphs 4a and b become subparagraphs. Paragraph 4b should require a monthly demonstration of the ability of the equipment to shift automatically to the filtration mode.

22. Sections 10.4.4 and 10.4.5, Page 10.4-3. Please include specific sections of the WIPP Safety Manual which apply to inspection and testing. Also include the requirement that the records of the testing be included in the Central Records System. Furthermore, the equipment to be tested or inspected should include portable fire extinguishers and stand pipe systems.

23. Section 10.5, Page 10.5-1 through 10.5-3. This section seems superfluous since it does not include limiting conditions of operations. It should be edited to be consistent with other sections to include specific LCO's, or it should be eliminated. Chapter 10 is not the chapter for descriptions of systems.

24. Section 10.6, Pages 10.6-1 through 10.6-16. This section should be revised to include the role of the Quality Assurance (QA) program. The QA manager's role is indirectly referenced in 10.6.5.3. Specific QA responsibilities should be stated, or referenced, relative to such items as 10.6.1 Training, 10.6.2 Design and Procurement, 10.6.3 Document Control, 10.6.4 Auditing, and 10.6.7, 10.6.8, and 10.6.9 on radiological protection. Quality Assurance is essential to operational safety.

25. Section 10.6, Page 10.6-1. The paragraph entitled "Administrative Controls for Operations" states that "Administrative Controls shall define the mechanisms and interfaces necessary (emphasis added) to insure adherence to the Safety Limits and LCO's, DOE orders and WIPP Standards Practices." If this statement is referring to the Administrative Controls of Section 10.6, these controls do not seem to meet this definition. The Administrative Controls of Section 10.6 do nothing more than refer to other documents in such general terms as to be of minimal value. Also, in some cases, the "controls" are nothing more than a restatement of previous sections of Chapter 10. As examples of the foregoing, Section 10.6.2.3 does not state a "control;" it states that a control shall be established. Similarly, Section 10.6.3.3, Paragraph 2 states that the operation manager shall establish a control. Section 10.6.7.3 is a restatement of portions of Section 10.3.1.3.

CHAPTER 11

Quality Assurance

EEG has not reviewed the quality assurance plans and procedures of various aspects of the project and is, therefore, not in a position to evaluate these adequately. Quality assurance relative to the waste acceptance criteria and waste certification at the generator sites have been performed and the comments are contained in other chapters of draft FSAR.

CHAPTER 12

Decontamination and Decommissioning

While it would be unreasonable to expect DOE to provide detailed analyses of decommissioning procedures at this time, it is reasonable to expect some indication that the Department is addressing the problems involved as shown in the following:

1. Section 12.1, Page 12.1-1. There is no commitment here to meet the D & D requirements of EPA's Standards for the disposal of TRU waste, 40 CFR 191, which should be included. This section should be expanded to include specifics on the regulations of 40 CFR 191, as they relate to the preparation for Decontamination and Decommissioning. For example, pursuant to DOE's "A Plan for the Implementation of Assurance Requirements in Compliance with the 40 CFR 191.14 at the Waste Isolation Pilot Plant," DOE/WIPP 87-016, the WIPP will become a disposal facility if the decision is made (5 years after receipt of the first waste) not to retrieve the wastes. The WPO must then begin to implement the WIPP active institutional controls program as required by 40 CFR 191, Subpart B, and DOE/WIPP 87-106. This program includes four important steps, which are listed on page 8 of DOE/WIPP 87-016, and should be listed in the FSAR, Section 12.2. These steps relate to the advance preparation for Decontamination and Decommissioning. Furthermore, this section states that Chapter 12 is written with the assumption that WIPP is shown to be acceptable as a repository and, therefore, decommissioning activities begin near the end of the operational life (25 years) of WIPP. Such an assumption reflects a bias in favor of the acceptability of the

five year pilot phase. If the five year phase is to provide a valid test, then such a bias should not be condoned. Also, if the demonstration does indicate that permanent disposal is unacceptable, there should be available, well-in-advance, a detailed plan for removal of the waste, decommissioning of the facilities, and decontaminations and environmental evaluation. This chapter does not provide this degree of detail. This degree of detail is needed to allow for sufficient budgeting, agencies and facilities, and to provide a base for post decommissioning activities such as the disposition of the land.

2. Section 12.2, Page 12.1-1. The text states that all the waste will be retrieved if the site proves to be unacceptable during the five-year demonstration period. Then the text states that this Chapter is written with the assumption that WIPP will be acceptable. Hence, it will not be necessary to retrieve the waste. Since DOE has consistently insisted that it is necessary to emplace 125,000 drums during this five-year period, specific plans and consequence analyses should be provided as to whether the 125,000 drums will be returned to the generating sites, sent to the high level waste repository, left on the surface at WIPP or be held underground before a new site is selected.

3. Section 12.2.1, 12.4, and 12.5. The term "Decommissioning Plan" in Chapter 12 includes varying adjectives of "final" and "detailed." Are they different?

4. Section 12.3, Page 12.1-2. Since the Department has requested the Congress to assign exclusive responsibility to DOE to prevent future

mining during the post-decommissioning phase, Section 12.3 should state whether the Department plans to reassign those authorities to the BLM, Department of Interior, State of New Mexico or establish a DOE organization to prevent mining rather than merely rely on records and documents.

5. Section 12.4, Page 12.1-4. While the three goals of closure are laudable, no indication is presented of how they are to be completed. The text should provide some indication of plans for active and passive controls, how long DOE will maintain a fence, employ watchmen and actively prevent mining permits in the area. Also, the various regulations and orders that must be met should be mentioned and discussed. These include DOE Order 5820.2A, 40 CFR 91, 40 CFR 265 Subpart G, and NMHWMR 206.C.2.

6. Section 12.5, Page 12.1-5. Post-closure environmental surveillance within the repository should be determined before the disposal mode begins in order to allow installation of sensors at the time of emplacement.

CHAPTER 13

Glossary

1. "Aquifer" - This definition contains a misspelled word "aquiclide", which should be "aquiclude."

2. This glossary should be expanded to include additional terms used in several chapters and other WIPP documents, such as:

   a. Radiation area

   b. High radiation area

   c. Unusual occurrence

Environmental Evaluation Group
Reports

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EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP, A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

Environmental Evaluation Group
Reports

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EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (edi), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

Environmental Evaluation Group
Reports

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EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kenney, James W., A Critical Assessment of Continuous Air Monitoring Systems At The Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

EEG-40 Review of the Final Safety Analysis Report (Draft), DOE Waste Isolation Pilot Plant, May 1989.

EEG-41 Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, July 1989.

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REVIEW OF THE DRAFT SUPPLEMENT ENVIRONMENTAL IMPACT STATEMENT, DOE WASTE ISOLATION PILOT PLANT, APRIL 1989

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EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

(Continued on Back Cover)

EEG-41
DOE/AL/10752-41

REVIEW OF THE

DRAFT SUPPLEMENT ENVIRONMENTAL IMPACT STATEMENT,

DOE/EIS-0226-DS, VOLUMES I AND II

DOE WASTE ISOLATION PILOT PLANT, APRIL 1989

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for permanent disposal of transuranic (TRU) radioactive wastes generated by the nation's defense programs. The EEG was established in 1978 with funds provided by the U. S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and provided for continued funding from DOE through Contract DE-AC04-79AL10752.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. EEG also performs environmental monitoring for background radioactivity in air, water, and soil, both on-site and in surrounding communities.

Robert H. Neill
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SUMMARY

The Draft Supplement Environmental Impact Statement (SEIS) for WIPP does not provide adequate justification to support the proposed action of shipping up to 620,000 cubic feet of transuranic (TRU) waste to WIPP before demonstrating compliance with the Environmental Protection Agency's (EPA) Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR 191). The "alternative action" of shipping no waste to WIPP prior to demonstrating compliance with the EPA Standards has been dismissed without sufficient discussion and justification. The document contains mistakes in calculations, reflects an erroneous knowledge of the history of the project, presents tables without units, and displays an indifference to the statistical precision of predictions. It also does not adequately address the environmental impacts of the potential failure to complete the demonstration of compliance with the EPA Standards by October 1993. By comparison, DOE plans to complete the demonstration of compliance with the same standards before starting construction of the high-level waste repository in Nevada. These two diametrically opposed approaches by DOE, for WIPP and for the Yucca Mountain repository, need to be addressed.

There is insufficient time for EEG to check all the calculations and to evaluate the public health and safety implications of the errors found in the calculations. EEG will pursue these when time permits, since they may be substantial. The following is a summary of our main concerns with the document.

1. Lack of Compliance with EPA Standards

The SEIS is silent on the observed lack of progress by DOE in demonstrating compliance with the Standards for safe disposal of transuranic waste which were promulgated by EPA in September 1985, and had been circulated in draft for several years prior to that.

New Mexico's position on the Standards was expressed as early as January 15, 1979, in a letter from the Secretaries of the New Mexico Health and Environment Department and the Energy and Natural Resources Department, to the U.S. Department of Energy:

> "We feel that DOE should clearly state that EPA Standards will take precedence over any interim standards established by DOE."

Unfortunately, DOE still has not published any probabilistic risk assessment studies as required by EPA, and DOE continues to issue deterministic analyses of the type used in the 1980 Final Environmental Impact Statement (FEIS) for WIPP.

The NM Secretaries' letter further stated:

> "Also, the DOE should state that they will move quickly to come into conformity with any EPA Standards developed for nuclear wastes." "...we feel that a permanent TRU repository should be conceived and designed to allow for timely compliance with new standards developed in the future." - January 15, 1979

The work has not moved quickly nor has the DOE committed to timely compliance.

Preliminary calculations of performance assessment by the DOE's scientists since 1987 have indicated that the repository may not meet the EPA Standards under human intrusion scenarios. This issue must be addressed by the SEIS directly and explicitly, and its impact on the proposed action should be evaluated.

2. Incomplete NEPA Documentation

The October 1980 FEIS stated that the necessary National Environmental Policy Act (NEPA) documentation had been completed for two of the ten waste generating sites. The April 1989 SEIS states that the necessary NEPA documentation has been completed for two more sites in the intervening 8.5 years. The SEIS states that DOE may propose that TRU wastes generated at six other facilities be shipped to WIPP, and appropriate site-specific NEPA documentation would be prepared for such a proposal. Why hasn't site-specific NEPA documentation been completed for the other six sites? An explanation of the lack of progress of documentation for each of these six sites and the proposed schedule for compliance should be included.

3. Incomplete Information

While the SEIS does address bounding calculations for the environmental impact of 10% of the waste (83,000 drum-equivalents), it does not identify the quantities of CH-TRU waste associated with the various alternatives. Since the amounts of waste are an intrinsic component of any evaluation, the document neither provides nor permits a meaningful comparison of the alternatives. The reader must rely on other documents to obtain estimates of the quantities of TRU waste. They include the April Draft Test Phase for Performance Assessment and Operational Demonstration, the June 6, 1989 Addendum to the Test Phase, and the June 7, 1989 Draft Test Phase for the Bin and Alcove Experiments, all of

which contain conflicting and inconsistent information.

4. Unexplained Changes in Radioactive Inventories

While estimates of the expected amounts of waste to be produced are continuously changing, we are concerned with the very wide differences from those shown in the FEIS. For example, the amounts of remote handled transuranic (RH-TRU) waste have changed from 250,000 cubic feet to 93,000 cubic feet. The estimated actual radioactivity in each canister dropped from 510 curies in the 1980 FEIS, to 47 curies (adjusted for daughter radionuclides) in the 1989 draft Final SAR, and has now increased to 177 curies in the 1989 draft SEIS. The total amount of RH-TRU radioactivity has been reduced from 5.1 million curies to 0.51 million curies, a ten-fold reduction without any explanation.

5. Uncertainty Estimates

EEG recommended in September 1979 (EEG-3) that DOE include estimates of the uncertainty associated with the radionuclide inventories. This has not yet been done. Instead, the document shows seven-place accuracy in the projections in which two-thirds of the CH-TRU waste has yet to be generated.

6. Incorrect Dosage Estimates

The calculations of human exposure from the stock water well to beef pathway are incorrect. The correct dose to an individual would be over two orders of magnitude greater than reported. The corrected doses (15.7 rem committed effective dose equivalent in the Case IIC scenario) are very significant and will most likely violate the EPA Standards when probabilities are assigned.

7. U.S. Department of Transportation Preferred Routes

While there is agreement in the routes to be followed

in New Mexico for the 34,000 truck shipments to WIPP, they are not "Preferred Routes" in the context of regulations issued by the U.S. Department of Transportation (49 CFR 171 and 173) and it is misleading to imply that they fulfill the DOT requirements.

8. Shortcomings in the FEIS

Of fundamental concern is whether DOE will properly and adequately address concerns expressed in this review of the SEIS. The following issues identified by EEG in January 1981 (EEG-10) in our review of the 1980 Final Environmental Impact Statement (FEIS) were then rejected by DOE (WIPP-DOE 81 and 81A). Subsequently, all the following problems identified in EEG-10 have been encountered or have yet to be resolved.

A. We recommended that DOE evaluate a scenario of a connection between the WIPP, a high-pressure brine reservoir and the surface (EEG-10, pages 20, 23). DOE refused to do so, stating it appears extremely unlikely and the only pressurized brine pocket in a deep drill hole in the Delaware Basin away from the Capitan Reef was associated with an anticlinal structure. EEG then published two scenarios (EEG-11, EEG-15). After a brine reservoir estimated to be 17 million barrels was encountered 1,000 feet from the then proposed waste location, DOE finally published an analysis and has now updated it for the SEIS.

B. In EEG-10, we repeated our August 1979 recommendation on the DEIS review (EEG-3) that a scenario evaluating the effects of high pressure gas formation, generated by organic decomposition of the waste, acts as a driving mechanism in

bringing wastes to the surface.

DOE rejected the hypothesis and did not consider the effects of human intrusion. EEG raised the issue of the retardation on room closure at a meeting with the NAS WIPP Panel in January 1988, and presented an extensive discussion in a paper at the waste management conference in March 1988. While the 1989 SEIS does not address this issue, gas generation has been recognized as a major problem associated with a human intrusion scenario.

C. EEG questioned why there was no consideration of gas generated from CH-TRU waste decomposition.

DOE stated that it would not be expected to be released to the atmosphere because of the overburden and slow rate of gas production. Today, gas is recognized as a major problem.

D. EEG raised the concern whether the CH-TRU waste drums could contain explosive gas mixtures at the time of retrieval, if retrieval proved necessary.

DOE responded "The amount of time between waste emplacement and retrieval is expected to be too short to allow significant generation of gas in the CH-TRU waste containers ("Gas Generation from Radiolytic Attack of TRU-Contaminated Hydrogenous Waste," LA-7674-MS, Los Alamos Scientific Laboratory, 1979)."

The amount of time between waste emplacement and retrieval could be 10 years. We now know that hydrogen gas generation can be a problem in the

transportation of CH-TRU wastes which involves a period of only several months (EEG-24).

E. EEG recommended that the FEIS provide an estimate of the total radioactivity expected to be emplaced in WIPP.

DOE did not do so and part of the confusion that exists today on the proper source term to be used in dosage estimates stems from that fact.

F. We recommended that an effective control period of 400 years be established.

No further progress has been reported by DOE on this request.

G. EEG stated that the information was not adequate on large brine reservoirs.

DOE stated that the information was adequate for an assessment of the WIPP site. A large reservoir was subsequently encountered at WIPP-12 on November 22, 1981.

H. EEG recommended that estimates of the uncertainties of waste quantities be included.

DOE ignored the recommendation and it has been ignored in the SEIS.

I. EEG asked what would be the ultimate disposal site if wastes had to be retrieved.

DOE responded that the specific site has yet to be

determined. Today, that is still true.

J. EEG expressed concern that DOE did not incorporate an analysis of ingesting contaminated food after a transportation accident. The SEIS still does not address this concern.

K. DOE stated that "the SPDV program has been planned to confirm the geologic adequacy of the site..."

We did not agree. DOE's response was to insist that it was adequate and subsequent events have confirmed that the SPDV program was not adequate.

L. EEG stated (EEG-10, p. 39) that WIPP-12 was at the edge of an anticlinal structure in the Castile, and was also at the southern edge of one of the zones of anomalous seismic reflection.

The response of DOE was to ignore the comment. Later, brine was encountered when the hole was deepened in November 1981.

SPECIFIC COMMENTS ON SEIS SUMMARY CHAPTER

1. Page S-2, Changes in Waste Package. The TRUPACT-I design was not a Type A package. It was a single-contained, vented, Type B package that could not have met NRC requirements for shipments of plutonium in excess of 20 curies.

2. Page S-2, Implementation of a Test Phase. The Test Phase, which is part of the proposed plan, is not presented with any detail in the Draft SEIS nor has it yet been evaluated in detail by the National Academy of Sciences (NAS) WIPP Panel, or the Environmental Evaluation Group (EEG). Nonetheless, reviewers of the SEIS are asked to accept the proposed plan rather than the Alternative Plan or the No Action Plan without being able to evaluate the efficacy of the proposed Test Plan.

3. Page S-3, New Information. The following should be included in the section titled "New Information":

A. State that there is much better understanding of the Rustler Formation hydrology, including higher transmissivities in the central and southeastern part of the site, geochemical zonations, sorption, and salt dissolution.

B. Add to the last item (salt creep), "and fracturing would make it difficult to retrieve the waste after five years, without rock-bolting in the roof of the waste rooms." Add "3 times faster."

C. Also add, "It is now assumed that a large quantity of pressurized brine exists in the upper part of the Castile Formation, approximately 800 feet below

the repository."

4. Page S-5, First Sentence. It is stated that all TRU waste emplacement would be conducted so as to maintain retrievability for a reasonable time period. This statement is not definitive enough and should discuss more specifically the effect of room closure, fracturing and other anticipated problems on the ability to retrieve and the amount of time to emplace and retrieve.

5. Page S-7, No Action Alternative. This alternative is given very little attention in the Draft SEIS and the reason(s) given for not accepting it are not persuasive. The section on Pages 5-168 to 176 does give estimated doses to persons on and off-site from very low probability events. The consequences of those events are similar to those postulated for WIPP during the transportation and operation phase and it is not known how the degree of conservation or the probability of occurrence would compare. However, there are expected consequences from the WIPP Project which are delineated in the Draft SEIS (e.g., 8.3 traffic fatalities, 106 injured in traffic, about 1.1 Latent Cancer Fatalities from transportation and operation radiation exposure to workers and the public) and none are mentioned for the No Action Alternative. There is one good reason for not choosing the No Action Alternative, but it is not invoked in the SEIS. Congress has passed laws to dispose of TRU and high-level radioactive wastes in geologic repositories and, thus, ruled against reliance on long-term storage. It appears that the Draft SEIS was written with a predetermined conclusion to accept the proposed plan and that alternatives were not seriously considered.

6. Pages S-8 to S-13, Summary Table. The inclusion of a summary table is an effective way to give the reviewer a

quick overview of projected environmental consequences. Most entries in the table will be discussed elsewhere in our comments, but the following comments are offered here:

A. The expected number of fatalities and injuries from transportation accidents are the greatest projected impacts of the project. Yet the Draft SEIS says very little about this impact and does not even attempt to explain why the plans are to ship all (or virtually all) wastes by truck and incur 5.3 (179%) more fatalities and 72 (212%) more injuries than by train. The failure to thoroughly evaluate the transportation mode is a major shortcoming in the Draft SEIS.

B. Since several effects are not listed in the table or in the SEIS, the document fails to fully reflect the consequences of WIPP. For example:

(1) The irreversible and irretrievable commitment of resources (said to be similar to the FEIS in Chapter 9, but fails to list any numbers);

(2) The numbers of deaths and injuries expected from industrial accidents, both at WIPP and the generating/storage sites;

(3) Any updating of the quantity and value of mineral resources located in the proposed 16-square-mile withdrawn area since 1980 and their impact on national markets.

C. Table 5.1 uses both per year and per project lifetime health effects and the footnotes do not

always reflect the correct units. This is confusing and should be clarified and made consistent.

7. Page S-14, Alternatives Considered but Rejected. It is not clear what synergistic mechanisms would require radioactive waste emplacement at WIPP, given the time frame of the experiments, and why these experiments cannot be performed at the generator sites. More documentation is needed to evaluate the "unreasonableness" of this alternative than has been presented.

It is stated that another alternative to conduct performance assessment without collecting any data was rejected for reasons related to the rejection of using non-radioactive simulated wastes. Why is it necessary to obtain additional data? Has performance assessment with existing data shown non-compliance? If so, then this information should be made available to evaluate the need for additional data.

8. Page S-14, Existing Environment. The Draft SEIS should explain why DOE determined that Zone IV was unnecessary (the change is mentioned on Page 2-1).

9. Page S-15, Transportation. The calculation of 34,144 truck shipments of TRU waste or 18,467 rail shipments is one that affects most calculations pertaining to transportation doses throughout this document. Unfortunately, those numbers are based on an incorrect assumption of the volumes of waste coming to WIPP.

Waste volumes listed in the Integrated Data Base (IDB) represent total volumes of various containers instead of the actual volume of waste contents. The IDB for 1987 (Table

3.9, Page 110) and the IDB for 1988 (Table 3.10, Page 97) indicates that the projected volume accumulation to move to WIPP through the year 2013 is 156,613 m^3 (5.53 x 10^6 ft^3). This is comparable to the total in SEIS Table 3.1, (5.60 x 10^6 ft^3) compiled from Tables 3.5 and 3.16 in the IDB of 1987.

The 6.2 x 10^6 ft^3 design capacity of WIPP is based upon the total volume of emplaced containers and not their contents. Attachment 1 to this review provides an informal analysis of WIPP capacity for CH and RH wastes. If the projected mix (per DOE/WIPP 88-005) of 65% by volume in drums and 35% by volume in Standard Waste Boxes (SWB) is used, and if the SWBs are emplaced three tiers high, 6.16 x 10^6 ft^3 can be accommodated. Scaling up slightly to 6.20 x 10^6 ft^3, this corresponds to 843,537 drum equivalents. Each drum represents a value of 208 L (0.21 m^3). The SEIS makes a fundamental error that permeates the entire document. The SEIS takes the 6.2 x 10^6 ft^3 waste capacity at face value, assumes this represents the volume of container <u>contents</u>, and generates a fictitious number of drums that cannot fit into the WIPP. They assume the average drum is 80% full, round off the total drum volume to 0.2 m^3, and obtain 6.2 x 10^6/(0.2 x 0.8 x 35.31) = 1.10 x 10^6 drums (where 35.31 is ft^3/m^3). This is 256,463 drums <u>more</u> than the capacity of WIPP! For the 10% of waste capacity assumed for the Test Phase, the SEIS correctly uses 6.2 x 10^5 ft^3, but because of the interpretation error, uses 110,000 drums and 22,000 drums per year instead of 84,354 and 16,870 drums per year, respectively. For the Disposal Phase, they use 990,000 drums and 49,500 drums per year instead of 759,183 drums and 37,959 drums per year. The effects of using the 0.8 "fullness" factor on results are as follows:

A. The number of required shipments are overstated by

23%.

B. The number of transportation accidents are overstated by 23%.

C. The radioactive control per shipment should also be affected. However, it does not appear to be, since Table D.3.3 (average curies per shipment) values don't agree with the total inventory (Table B.2.1) either with or without the 0.8 factor.

D. The chemical content per shipment and for the total campaign are not affected, since these calculations are done on a per drum basis, not a total inventory.

These calculated transportation consequences affect several portions of the SEIS and it is disturbing that more care was not taken in setting basic parameters at the outset.

10. Page S-15, Transportation. EEG comments on Incident-Free Conditions and Accident Conditions are included under Chapter 5 and Appendix D. We concluded that the population doses (person-rem) calculated for both routine transportation and accidental releases were conservative. However, the maximum exposures to a member of the public from routine operation and the bounding accident were non-conservative by at least an order of magnitude.

11. Page S-17, Long Term Performance. It should clearly be stated at the beginning of this section that these calculations neither provide a basis for assessment of compliance with the long-term performance part of the EPA Standards (40 CFR 191), nor do they substitute for those

calculations. The failure to include any work to date in showing compliance with these 4-year-old standards is distressing.

12. The reference to "usual guidelines" in the last paragraph on Page S-17 is sloppy. State the guidelines that apply to WIPP - EPA Standards, DOE Orders, etc. - and judge compliance with them.

13. Page S-18, Last Paragraph. The statement, "Nevertheless, the results suggest that appropriate Performance Assessment methods and likely values of parameters would show that the WIPP would comply with the Standard. They also indicate the efficiency of potential engineering modifications..." is without basis and should be deleted. The official position of DOE is that compliance with standards for safe disposal cannot be shown until October 1993. Hence, conjecture such as "likely values would show that WIPP would comply" is misleading.

14. Page S-20, Mitigation Measures. EEG believes the presentation of mitigation measures in the Draft SEIS is incomplete and preliminary and is a major shortcoming. Some of these measures will be required by the project, and the Draft SEIS implies that those that are needed will be used and they will automatically work in a satisfactory manner.

Much more careful thought and consideration needs to be given to these measures than is contained in the SEIS or other documents published by the project. Too many decisions regarding mitigation measures are yet to be made, yet credit already appears to have been taken for several of these measures.

15. Both the Proposed Action and Alternative Action reveal a

serious shortcoming concerning waste treatment mitigation measures. They indicate that construction of waste treatment facilities will be in abeyance until after the Test Phase and pursued only if a determination is made that noncompliance with EPA regulations would result if additional treatment is not done. If the Test Phase must be followed by a study of options, design facilities, a budget cycle, construction, and tests prior to start of waste shipment to WIPP, a delay of many years will be introduced. DOE may argue that commencing such work now would be interpreted that treatment must be done, while tests may indicate it is not needed. The risk is that there can be a serious interruption of WIPP operations if waste treatment is required. A counter argument may be that selected stored waste, plus certain newly-generated wastes, may be "complying" and can be shipped during the interim while facilities are constructed. If DOE had vigorously pursued waste processing as recommended by EEG, oversight committees and other organizations, instead of following a stated minimal processing policy, much of the current debate over gas generation and brine inflow may have been resolved. An up-to-date discussion of the impact on the program of possible waste processing needs should be provided in the Final SEIS.

SECTION 1

1. Page 1-1, First Paragraph. It is not correct to say that "most of the underground experimentation rooms and waste rooms for initial waste emplacement have been excavated." Excavation for the alcoves began in late June, 1989.

2. The Salado Formation is 1700 to 2000 feet thick. What is a "3000-foot-thick bedded salt and anhydrite formation?"

3. "The volumes and characteristics of TRU wastes are discussed in Subsection 2.4..." Should this be Subsection 2.3?

4. Page 1-1, Third Paragraph. There is no Subsection 10.3.1 in the Draft SEIS. Subsection 10.2.5 appears to be the appropriate reference.

5. The SEIS fails to identify the role of EEG, created in 1978, as the <u>only</u> full-time, external, review agency on WIPP subsequently mandated by Congress in the National Defense Authorization Act, Public Law 100-456, September 29, 1988, Section 1433 (a).

6. Page 1-1, Last Full Paragraph. In the list of items requiring completion prior to testing, add "an EPA Permit to receive mixed wastes at WIPP."

7. Page 1-2, First Paragraph: It is stated that, "In addition, the delay of the WIPP Project holds the potential to adversely affect the nation's production of nuclear weapons." This sentence should be amplified to explain the delay of any progress in demonstrating compliance with the EPA Standards for disposal of TRU waste, which were

promulgated by EPA almost four years ago in September 1985. The lack of progress toward showing compliance and the resulting delay is the factor that may well impact on weapons production.

8. Page 1-2, Last Paragraph. DOE's Record of Decision of January 28, 1981 was challenged in a court by the NM State Attorney General. Describe that challenge and the resulting "Stipulated Agreement" between DOE and the state here.

9. Page 1-4, NEPA Documentation Since the FEIS. In 1980, DOE completed NEPA documentation for shipment of waste from INEL and RFP. Since that time, DOE has completed NEPA documentation for transportation of radioactive wastes from only Hanford and SRP. Why? Section 1.2.2 does not contain any information on NEPA documentation since the FEIS.

10. The discussion of the 1982 cost-reduction measures that were subsequently reinstated is not included. For example, DOE maintained that the deletion of the fourth shaft would not pose problems for air circulation. In 1988, DOE acknowledged that the fourth shaft was required for adequate air circulation underground.

11. Page 1-4, Purpose and Need for Supplement. The statement that DOE <u>may</u> be proposing disposal of wastes from six additional facilities is puzzling since DOE has publicly acknowledged that the mission of WIPP is to include wastes from LANL and five other facilities.

12. Page 1-4, "The analysis in the 1980 FEIS considered only TRU wastes from INEL and Rocky Flats Plant".

The FEIS never explained why the transportation of wastes from all other sites was included in the 1979 Draft

EIS and deleted in the Final EIS. Please explain, including the impact of hydrogen gas generation from radiolysis on the unvented TRUPACT-I.

13. Page 1-4, Fourth Paragraph. Also state EEG's response to DOE (1983) and the recommendations that were accepted by DOE and implemented during 1984-89 period.

14. Page 1-5, Changes in the TRU Waste Inventory. Provide an explanation for the 10-fold reduction of RH TRU from 5.1 x 10^6 curies to 0.51 x 10^6 curies.

15. Page 1-5. In the list of new data and significant geotechnical information, include the presence of a brine reservoir in the uppermost anhydrite of the Castile Formation below the proposed repository. The significant change in the withdrawal area of the WIPP site should also be an important reason for a SEIS, as is compliance with 40 CFR 191.

16. Page 1-5. The text states that experiments would be conducted to reduce uncertainties associated with the prediction of several natural processes (e.g., gas generation, brine inflow, and salt deformation).

There are no experiments requiring the use of waste to measure brine inflow. There are no experiments requiring waste to measure salt deformation since they are mutually independent events. Gas generation is the <u>only</u> parameter proposed to be measured that requires waste.

17. Page 1-5, Proposed Action. It is stated that operations are needed to "show the ability of the TRU-waste management system to safely and efficiently certify, package, transport, and emplace waste in the WIPP." This claim is misleading for the following reasons:

A. The certification of waste for WIPP is independent of operational demonstration and is currently underway at the generating and storage sites.

B. The packaging of waste has been studied and perfected since 1970 and is independent of any operational demonstrations.

C. The transportation of these wastes has been demonstrated in the past with packages other than TRUPACT-II and experience with TRUPACT-II could be obtained (once it is certified by NRC) by shipments from RFP to INEL and from LLNL to NTS.

D. No justification has been provided for the emplacement of 83,000 drums (up to 10% of the WIPP capacity). Emplacement is occurring today at INEL.

18. Page 1-6, Line 9. It is stated that, "At the conclusion of the Test Phase, the DOE would decide...whether WIPP would comply with EPA disposal standards." No mention is made of receiving input or requiring concurrence by other organizations. Does DOE plan to make this determination unilaterally?

19. Page 1-6, Line 14. "If there is a determination of non-compliance, a number of options would be considered (e.g. waste treatment) and the required NEPA documentation would be prepared." We believe it would be prudent for DOE to begin evaluating options at this time and not rely completely on the hope that the Proposed Action will be found to be satisfactory. It is irresponsible to plan on deferring action on a potential problem for 4 years and then say that the required NEPA paperwork would deal with it.

20. Page 1-6, Alternatives Considered in the SEIS. The SEIS is not able to adequately justify the alternative chosen

because of the lack of a detailed, DOE-approved, Five-Year Test Plan to review.

21. Page 1-6, Content of the SEIS. "...it is not the purpose of this SEIS...to demonstrate compliance with regulatory requirements." Unfortunately, it is also not the purpose of the Final Safety Analysis Report to do so either, nor has any other document been prepared by DOE to demonstrate regulatory compliance. By comparison, DOE will provide that documentation in the FSAR in Nevada. Why the difference?

22. Page 1-6, Section 1.5. The first paragraph of this section gives the impression that assessment of compliance with 40 CFR 191 was not done because the Standards were vacated. This is not true and is misleading.

23. Page 1-7, Footnote. The SEIS uses numerical values and projections made in the December 1988 draft of the FSAR. EEG has extensively reviewed the Draft FSAR and believes many of these calculations are flawed (see EEG-40, May 1989).

24. Page 1-17 & 18, References. The reference list does not include the following documents referred to in the text:

A. 1978 Contract establishing EEG
B. Public Law establishing EEG
C. C&C Agreement
D. Five-Year Test Plan

SECTION 2

1. Page 2-1, Location, Fourth Paragraph. Provide the reference for the justification for DOE eliminating "the requirement to control the land identified as Zone IV in the FEIS"? This is a significant change that should be explained.

2. It is misleading to merely state the percent reduction (from the FEIS) of desirable mineral resources resulting from the reduced site area since this does not mention that the amount of these resources is so significant. For example, the FEIS stated that the (old) WIPP site contained 20.2% of the free world's langbeinite resources and reserves. If 35% of this is still within the present WIPP site boundaries, this would still be 7.1% of the free world total. The resource issue needs to be addressed directly, not by reference to the FEIS.

3. Describe the status of private leases being held.

4. Page 2-3, Exclusive Use Area. The location of the Exclusive Use Area and the proposed expanded area should be shown in Figure 2.2 or elsewhere. Also, the rationale for choosing a 640-acre or a 1,454-acre exclusive use area should be explained.

5. Page 2-5, Figure 2.3. Buildings numbered 364 and 365 are missing from this figure and from the listing of building names on the next page. These buildings are significant since they house Station A and Station B of the Effluent Monitoring System.

6. Page 2-7. Although the definition of TRU wastes

excludes actinides with half-lives less than 20 years, DOE has committed to including Cm-244, with a half-life of 18 years, and Cf-252, with a half-life of 2.6 years, in the TRU wastes coming to WIPP. DOE has also committed to include U-233 with a half-life of 150,000 years which does not have an atomic number greater than 92. This commitment by DOE to include these three radionuclides should be shown in conjunction with the definition.

7. Page 2-7, "Wastes with TRU concentrations between 10 and 100 nCi/g are expected to be reclassified as low-level wastes which would not be sent to the WIPP."

They are classified as low-level wastes. Our understanding is that waste with TRU concentrations between 10 and 100 nCi/g <u>will</u> (not may) be classified as low level wastes and not be sent to WIPP. This is an important distinction. What are the plans?

8. Page 2-9, "CH-TRU waste is packaged in sealed steel drums and boxes."

They are not and must be vented to avoid the generation of mixtures of flammable gases during shipment.

9. Page 2-9, "Approximately 3% by volume of defense TRU waste is RH TRU waste,..."

It is about 5.3% by curies (a more meaningful measure than volume) and 1.6% by volume (see Appendix B-2 and 3). The text should be specific about the volume percentage that is being quoted and should also give the radioactivity percentage. Also, the maximum dose rate limits for RH-TRU should be listed.

10. Page 2-9. The use of units of volume to characterize transuranic waste is misleading. The discussion should describe typical concentration in nanocuries/gram for both weapons grade plutonium and heat source plutonium.

11. Page 2-9, Waste Acceptance Criteria. The statement, "The DOE established the WAC in consideration of DOT and NRC regulations" is incorrect. The purpose of the WAC was to delineate the criteria that waste packages must meet in order to permit safe handling and disposal at WIPP.

12. Page 2-9, "The NRC will be asked to issue a certificate of compliance for the TRUPACT-II shipping container...".

Add "... and the yet to be built RH-TRU waste shipping cask."

13. The SEIS does not discuss the two sets of additional criteria that must be met in transporting and disposing of wastes at WIPP, including:

A. Those issued by the NRC as a condition for licensing the use of TRUPACT-II for CH-TRU waste.

B. Those issued by EPA to meet the requirements of 40 CFR 261 and 262 for hazardous waste.

The SEIS should explain how these criteria differ, how each is implemented, and if there are potential conflicts in meeting all three sets of criteria simultaneously.

14. Page 2-9, Section 2.3.1 (WAC). Although Revision 3 of the "TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant," January 1989 (WAC), reflected many improvements over Revision 2, it still contains certain serious deficiencies, some of which EEG had called to the attention of the WIPP Project Office following publication of Revision

2. (See letter to Mr. W. R. Cooper, WIPP Project Manager, from R. H. Neill, Director, EEG, January 15, 1986.) These and other comments are addressed below:

A. Does the gas generation criterion allow the waste generators to make a decision on the need for venting? There is no definition of what is considered an "overpressure," nor an "explosive mixture." The criterion also specifies that the "TRU waste shipper" must provide data on the total alpha activity, waste form, and organic content, but this language appears redundant, since such information is already required by the Data Package Certification criterion. If it is to be provided in two separate places, it should be clarified and justified. The provision of such information does not preclude the possibility of judgmental or careless errors on venting due to lack of sufficiently definitive criteria.

Also, the technical justification for the gas criteria has not been updated and fails to recognize current data on gas permeabilities and gas generation levels of concern now being expressed by Sandia. The gas criteria needs to be completely reevaluated and rewritten.

B. The immobilization criterion fails to recognize the potential for increases in particulates with time due to breakdown of cellulosic material. Packages containing such material should be subject to a lower limit.

C. The criterion applicable to radioactive mixed waste mandates that hazardous waste as defined in 40 CFR 261 be included only as co-contaminants with

transuranics (and presumably fission products). The last line of the criterion as stated in Revision 3 indicates that such hazardous materials "are to be reported," however, no further details are indicated on such reporting. It is not clear whether such reporting is in reference to the Data Certification information, or whether it is an additional reporting pursuant to 40 CFR 262. This latter RCRA regulation requires reporting to EPA and also requires that the waste shipment be accompanied by a detailed manifest on a specific EPA form. This manifest requirement is not mentioned in the WAC, Revision 3, and should be added. The entire subject of the RCRA regulations is treated in excellent detail in "Radioactive Mixed Waste Compliance Manual," 1989, WP-02-07, and could be included in the WAC by reference.

D. The EEG has been objecting to the use of a maximum Plutonium-Equivalent Curie (PE-Ci) limit of 1,000 since November, 1985, and considers it to be unacceptable. For our latest comments on the PE-Ci limit, see EEG-40 (May, 1989).

15. Page 2-10, "The WAC do not require detailed characterization of chemical constituents because waste sampling and analysis would result in increased radiological exposure of personnel."

The WAC does not and was never intended to specify how a waste generator demonstrated compliance, and suggests a lack of familiarity by the author with the intent of those criteria. By that rationale, the WAC would never have required characterization of radiological constituents.

16. References should include the review by Marshall S. Little, "Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project," May 1985, EEG-29.

17. Page 2-10. In the discussion of "plutonium-239 equivalent activity," , mention should be made of the long-standing disagreement by EEG of the 1,000 PE-Ci limit chosen by DOE.

18. Page 2-12, "Gas generation considerations for transportation have resulted in the introduction of vented waste packages at some generation facilities."

The WAC needs to be modified to require filters in all packages prior to shipment.

19. Various DOE documents describe the fraction of stored mixed waste as 60% (SEIS) to 90%. Is 60% the agreed upon value?

20. Page 2-14. Clearly state that it is planned to emplace waste during the first five years without backfill, and that backfill will be added later by moving the waste to new rooms. Also, state the reasons for not backfilling during the test phase.

21. Page 2-14. The decision on retrieval fails to specifically describe what DOE would do with 83,000 drums if it were necessary to retrieve them. This is different from DOE's commitment in Nevada to include a detailed discussion in the Final SAR. (See DOE planned Table of Contents for the HLW repository, 10 CFR 60.21, SAR Content.)

22. Page 2-15. The reasons cited for possibly not returning wastes to the generating sites due to "costs of double

handling and transportation impacts" should be addressed in evaluating the alternative of showing WIPP can meet the safety standards first.

23. Page 2-15, Third Paragraph. Serious consideration to the feasibility and problems of various engineered modifications should be given now rather than postpone it for several years. The problems are fairly well defined already.

24. Page 2-15, Fourth Paragraph. Where will the waste be shipped if the drums are to be compacted, incinerated, etc.?

Too many DOE documents have claimed the possibility of in-place installation of backfill without describing and demonstrating the process. "It could possibly be installed" is not good enough for making decisions.

This section (2.5) should also describe the changes (roof rock-bolting, for example) that have been introduced in the design due to fracturing observed in the SPDV rooms, and analyze the effect of these design changes on the assurance of retrievability and long-term performance.

26. Page 2-20, Section 2-9. This section does not describe any of the independent environmental surveillance conducted by EEG. It is suggested that this section be changed to read as follows:

> "Since 1985, DOE has funded independent environmental and effluent studies at WIPP which are conducted by the Environmental Evaluation Group. Measurements of radioactivity include atmospheric, terrestrial, hydrologic and biotic baselines. EEG will also conduct radiological analyses of particulate samples from the effluent air exhaust system which serves the underground portion of the facility."

SECTION 3

1. Page 3-1. The SEIS identifies the Proposed Action of bringing 83,000 drums (10% WIPP capacity) to WIPP prior to demonstrating compliance with the EPA Standards on the basis that it is needed to demonstrate compliance with those Standards. The authors appear unfamiliar that the quantity of wastes identified by DOE in providing information useful to assess compliance with those Standards amounts to 4,500 drums (650 for bin and 3,850 for alcove tests as described in M. Molecke test plans.) The discussion in comparing alternatives without any reference to the amounts involved is meaningless.

2. Page 3-2. Why has DOE completed the necessary NEPA documentation for only two additional sites since 1980? The SEIS should specify the status of such documentation for six other facilities, including the expected dates of completion.

3. Page 3-2, Paragraph Three. Stating that "DOE may propose that TRU waste stored and/or generated by six additional facilities should be transferred to the WIPP for permanent emplacement" after the expenditure of 3/4 billion dollars is not only surprising, but, if true, illustrates that DOE has not made any plans for alternative disposal.

4. Page 3-2. For the past 11 years, DOE has repeatedly issued estimates of RH-TRU waste of about 250,000 cubic feet at 5.1 million curies. This document shows a ten-fold reduction to 0.51 million curies. Why? What is the explanation?

In 1984, the DOE Inspector General recommended (DOE/IG-0207) that there was insufficient justification to build a

hot-cell at WIPP for RH-TRU waste only, and those unwanted residuals should be sent to the HLW repository. The reduction of RH-TRU from 36% of the WIPP radioactive inventory to 5.3% suggests that the recommendation of the IG had merit.

5. Page 3-2. The text suggests that the purpose of WIPP can be modified to accommodate up to 1.65 million cubic feet of TRU waste from new facilities ($6.45 \times 10^6 - 5.8 \times 10^6$). Is this correct? Is DOE suggesting that buried TRU wastes or unidentified stored TRU wastes could be brought to make up the difference? Also, what information is available on the Special Isotope Separation Facility?

6. Page 3-4, Table 3.2, RH-TRU Quantities. These values are reported in Chapter 3 and Appendix B. Both the expected volume and curies of RH-TRU waste continue to change drastically as shown in the following table:

	FEIS(1)	FSAR(2)	SEIS
Ci/canister	510	47(3)	177(4)
Volume, $feet^3$	250,000	88,285 - 176,570	93,000
Total, Curies	5.1×10^6	$5 \times 10^4 - 1 \times 10^6$	$.52 \times 10^6$

1 Expected Average Conditions
2 Representative Radionuclide Content (see EEG-40, p. 19)
3 Includes Daughter Radionuclides
4 Equals the Ratio of Total Curies/ft^3 x 31.8 ft^3/canister.

There is no documentation or justification for these changes. How certain are these estimates in which half the RH-TRU has yet to be generated (Table B.2.3)? Provide an explanation for these substantive differences. Also, there are internal inconsistencies within Appendix B; the average

curies per trailer load in Table B.2.7 is not consistent with that calculated from Tables B.2.1 and B.2.3.

7. Page 3-3. Only 1/3 of the total TRU waste to be shipped to WIPP now exists with 2/3 yet to be produced. Table 3.3 shows seven-place accuracy in the estimates of future waste ($1 \div 5{,}598{,}397 = 10^{-7}$). Either DOE can make astonishingly accurate predictions, or the authors are unaware of the statistical limitations of future projections. The same comment applies to Table 3.2 on Page 3-4.

8. EEG requested a discussion of uncertainties in the RH-TRU inventory in our review of the FSAR and has not had a reply. We suspect there is still considerable uncertainty in volumes, curies, and distribution of radionuclides in RH-TRU waste. We are aware that a questionnaire is now being conducted by the WPO on RH-TRU inventories, and have heard that there are wastes that are high in activation products that may have a problem meeting the 1,000 rem/hour surface dose rate limit. Although calculations in the FEIS, FSAR, and SEIS indicate that RH-TRU wastes should be less of a problem than CH-TRU wastes, we cannot conclude this because of the apparently greater uncertainty in the data base.

9. Page 3-5. "The design of the CH-TRU waste package has been changed from a Type A (TRUPACT-I) container in 1980 to Type B..."

While EEG has called the original design a lot of things, we never called it a Type A container. Change it to Type B. Also, the decision to abandon the rectangular TRUPACT-II design in favor of a right circular cylinder TRUPACT-II design was not made in 1980, but in 1987.

10. Page 3-5, Brine Inflow Studies. Although there are

plans to measure brine inflow in a cylindrical room to be mined in the WIPP repository, the study will not involve the use of radioactive waste. Hence, the statement inferring that radioactive TRU waste is needed during the Test Phase to reduce uncertainties associated with brine inflow is incorrect and should be changed.

11. Page 3-6, Last Paragraph. This paragraph states that the average Pu-238 activity content has increased from 1.2% in the FEIS (correct) to 17%. This does not agree with the tabulation in Table B.2.13, Page B-19, in Volume 2, which indicates that 42% of the total radioactivity and 81% of the alpha-emitting transuranic radioactivity is Pu-238.

12. Page 3-7, Table 3.3. Change "Curies" to "Radioactivity" to be consistent with the other entries and list all units (including curies) in the table.

The table should indicate maximum values. For example, the maximum surface dose rate of RH-TRU is 1,000,000 mrem/hour. The failure to provide units results in this confusion.

Fill in the blanks in the table on RH-TRU waste characteristics. Since the Final Safety Analysis Report (FSAR) has not been published, include the information in both documents.

13. Page 3-10, Table 3.4. EEG has expressed concern previously (see EEG-40) about the extent that concentrations of hazardous chemicals at RFP could be considered as conservative for all other sites. There is now an additional uncertainty with the RFP wastes since we understand that the FBI and EPA are currently investigating the RFP characterization of mixed wastes. Thus, it is possible that

the RFP waste constituent data are flawed.

14. Page 3-16, Transportation Modes. It is stated that the requirements of the trucking contract in all these areas are highly specific and demanding with respect to the transport of TRU waste to WIPP. Does the contract include alternate route restrictions to safeguard against arbitrary selection by the driver/company? If so, then it should be documented in the text.

15. Page 3-19, Transportation Routes. DOT regulations contained in 49 CFR, Parts 171, 174, and 177, are characterized as requiring that the interstate highway system be used whenever possible to transport highway route controlled quantities of radioactive materials to WIPP and that appropriate state agencies can require other routes if less risk can be demonstrated.

This analysis of 49 CFR, Parts 171, 174, and 177, is misleading and inaccurate. The requirements of 49 CFR, Part 177.825, are that highway route controlled quantities of radioactive materials can be transported over "preferred routes" which are selected by a state routing agency when an interstate highway system or bypass is not available. As of this date, there have been no "preferred routes" designated by the State of New Mexico as required by the DOT regulations in 49 CFR 177.825 dated May 8, 1988.

16. Page 3-25, Integrated Operations Demonstration. The emplacement of TRU waste at WIPP for operational demonstration purposes is being proposed before compliance with 40 CFR, Part 191, Subpart B. What is the advantage of initiating such a demonstration before compliance with the Standard where the possibility exists that the waste may have to be removed, treated, etc.? What are the disadvantages of

delaying this activity until compliance is demonstrated? If the reasons are political, economic, training, etc., then a justification for overriding a health and safety standard should be incorporated into the SEIS. Also, why is it not possible for some operational demonstrations external to WIPP to be conducted without actual transport and emplacement of waste at WIPP prior to compliance?

17. Page 3-26, Performance Assessment. DOE and the State did not agree to proceed with performance assessment planning as if the Standards were in effect. We agreed to proceed with the documentation. Unfortunately, nothing except a schedule has been published by DOE since those Standards were promulgated in September 1985.

18. Page 3-26, Performance Assessment. It is stated that the SEIS describes the proposed Test Phase activities that will enable DOE to ascertain whether the repository can meet the Standards (Subpart B). An alternative to the Test Phase is to proceed with performance assessment without gathering any more data (Page 3-32). It is stated that under these circumstances DOE would not have "sufficient" data for conducting a performance assesssment that would provide a basis for determining compliance with Subpart B. Yet it may be possible to perform an assessment with the available data that would be bounding, and could be compared with the Standard to justify additional data gathering in critical areas of uncertainty and sensitivity. If such assessments have already been performed, then they should be incorporated into the SEIS.

19. Page 3-27, Bin-Scale Tests. Because the bin-scale tests would involve the emplacement of TRU wastes at WIPP before compliance with Subpart B of 40 CFR, Part 191, then a justification for such action should be stated. Other

locations for these tests have been presented as an alternative with little impact on the health and safety of the public or on the environment. The preference to conduct these experiments at WIPP are guided by economics and delays expected due to permitting at other facilities. But these economics have not been demonstrated, nor has it been explained why permitting would be much easier at WIPP. In fact, due to the expected delay in obtaining a permit for mixed wastes, the date to begin starting bin-scale experiments at WIPP may be considerably delayed.

20. Page 3-28, Second Paragraph. Why are treated wastes such as incinerated, cemented, charred, asphalted, etc., not part of the experimental design since some of the alternatives to retrieval (under non-compliance) involve treatment of wastes? If treatment of some or all wastes is found to be necessary, the lack of experiments now may result in considerable delay.

21. Page 3-28, Room-Scale Tests. Room or alcove experiments are designed without consideration of possible future waste forms. Also, it is stated that four room-scale tests will be performed; whereas, the Test Plan lists six rooms for these experiments. Which plan is correct? Finally, what is the effect of the short time frame in which to conduct these experiments on the value of the results?

22. Page 3-30, Alternative Action. The discussion on waiting until DOE demonstrates compliance with the EPA Standards does not address a number of facts that should be included:

A. DOE has not objected to the NRC requirement to demonstrate compliance in Nevada before beginning construction of the repository, and DOE has published plans to do so. Why does DOE object at

WIPP?

B. DOE sees no merit in conducting an operational test phase in Nevada prior to meeting standards and has no plans to do so.

C. Unlike the Nevada repository, which has NRC licensing, DOE has been given the authority by Congress to self-determine compliance with the EPA Standards at WIPP. These Standards state in the 1985 preamble that compliance should be completed <u>during the design phase</u>. Why does the SEIS ignore that statement and present an analysis to bring up to 83,000 drums (10% of design volume) to WIPP first? This is particularly relevant since DOE has not published any progress (except a schedule) in compliance with those Standards.

D. The text invokes the mantle of performance assessment (for which DOE only identifies a need of 4,500 drums) in discussions which variously require 83,000 drums, 36,000 drums or 18,400 drums.

E. The text does not acknowledge that representative mixtures of waste may not be available for shipment until March 1990 at the earliest (projected date for EPA authorization for mixed waste). Therefore, meaningful bin experiments at the site may not begin for a year.

F. Additionally, there is no discussion of why gas measurements have not been made at the generator sites since 1985. If the measurements are useful, discuss this as well as the impact of a year's delay in starting to get data.

G. The text also does not address limits in gas pressurization in the alcoves (e.g., 1 psi extrapolated to 2,100 psi, absence of repository conditions of backfill, engineered fixes, leakages of gas from instrumentation connections).

H. Standards issued by NRC and EPA do not <u>require</u> tests. Explain why they must be done and do not imply that such tests are obligatory. The text should describe how the information derived may be useful or helpful in long-term risk assessment analyses.

SECTION 4

1. Page 4-2, Socioeconomic Environment. The nearest community to the WIPP site is Loving, whose population "decreased from an estimated 1,600 in 1980 to 1,450 in 1986..." While the presence of the proposed repository probably did not cause a negative economic impact on the community, it obviously did not result in any positive economic impact. Discuss the absence of this despite the proximity to the site, high unemployment rate, availabiity of local manpower, the railroad track to WIPP passing through the community, and the presumed naturally occurring breach surfacing at Malaga Bend in the Pecos River at Loving. Identify the number of workers from Loving of the 640 employed for WIPP.

2. Page 4-3, First Paragraph. The text should provide the distance and direction of the three ranches and three mining operations located near the site or locate them on a suitable map.

3. Page 4-3, Land Use. The SEIS should provide (either here or in Chapter 2) a summary of the natural resources, estimated to be present, beneath the 16-section WIPP site, and the extent of private mining leases still being held within the site boundaries.

4. The information contained in the last sentence of Section 4.1.4 should explain what is meant by "restricted" mining and drilling within the WIPP site. How does DOE plan to implement these "restrictions" and for how long? If the DOE obtains control in perpetuity of this real estate, currently managed by the Department of Interior, how will mining be prevented? Will DOE delegate those

responsibilities back to the Department of Interior, Bureau of Land Management?

5. Page 4-4, Background Radiation. EEG's preoperational environmental radiation surveillance program should be referenced here (as well as in Chapter 2).

6. Page 4-4. Reference EEG's work in the preoperational environmental radiation surveillance.

7. Page 4-7, Last Sentence. The sentence should be expanded to, "The WIPP horizon is in a 26-foot-thick section bounded by Marker Beds 138 and 139, that consists mostly of halite with a few thin interbeds of anhydrite, clay, and polyhalite. Detailed stratigraphy of this section between the two marker beds and the location of WIPP excavations is shown in Figure _____." (Add a figure.)

8. Page 4-13, Hydrology and Water Quality. Add "Dewey Lake Redbeds" among the geologic units of hydrologic interest of WIPP.

9. Page 4-13, Section 4.3.1.1, Third Paragraph. "Deposits" is not a synonym for brine "reservoirs."

10. Page 4-14, Brine Inflow. The stated in-flow rate of 1.6 L/day/m^2 would completely fill an empty 4 x 10^3 m^3 room with brine in three years! With waste, it would be filled to the ceiling in less than a year! The correct value from the Nowak and McTigue report is 1.6 mL/day/m^2.

11. The development of the concept of Salado salt as a saturated medium should be described and the work of Bredehoeft (1988) should be cited.

12. Page 4-18. Reference the required tests that DOE conducted for the Stipulated Agreement to the lawsuit by the New Mexico Attorney General. Ignoring those required tests ignores the true history.

13. Page 4-22, Table 4.2. The work of Stormont et al, 1987, is cited on Pages 4-22 through 4-25, but not referenced at the end of the chapter.

14. Page 4-20. The discussion of gas permeability should include estimates of the expected amounts of gas and the pressure to be reached. If a modification to the waste form is required to reduce the amount of gas produced, the environmental impacts should be discussed.

15. Page 4-25, Section 4.3.2.4. "Underground experience at the WIPP indicates that these fractures open locally in response to excavation" does not adequately describe the extensive continuous fractures up to four inches thick that have been observed in the SPDV rooms.

16. Section 4.3.2.4. This section should describe extensive fracturing observed in the roofs of the SPDV rooms that will also provide potential pathways for gas or brine migration.

17. Page 4-33, Last Sentence. Arguments counter to the hypothesis advanced by Lambert and Harvey (1987) should also be provided here. See, for example, Chapman, 1986 (EEG-35).

18. Page 4-55, Section 4.3.3.4. This section should also refer to Chapman, 1988 (EEG-39) and Ramey, 1985 (EEG-31) to describe the geochemistry of the Rustler Formation, especially since Siegel et al, 1988, has not yet been published.

19. Page 4-58, Figure 4-20. The "Disturbed Zone" boundaries have become enlarged with each new encounter of a Castile brine reservoir. There is no rational basis for the delineation of these zones and they should be abandoned.

20. Page 4-60, Last Full Paragraph. The request to relocate the repository and the report by Channell should both be attributed to the New Mexico Environmental Evaluation Group.

21. Channell's calculations (in EEG-11, 1982) were made with a lesser waste inventory and likelihood of occurrence of a brine reservoir and did not address compliance with the EPA Standards, which were not promulgated until 1985. Therefore the report cannot be used to conclude that the presence of an underlying brine reservoir would not result in exceeding the EPA Standards.

22. Page 4-60, Paragraph Beginning at Bottom of Page. "The presence of Castile brine beneath the repository is of concern only in the event of human intrusion." (Emphasis added.) Gas pressures exceeding lithostatic in the repository could cause fracturing to ERDA-9 and then to the upper anhydrite layer of the Castile where brine is located.

SECTION 5

1. Page 5-2, Biology. It is stated that the salt levels do not appear to inhibit plant species diversity or abundance. This statement should be clarified to say that "current" accumulations do not have an effect, unless soil salt concentrations are not expected to increase in the future as a result of operations. Also, the phrase "do not appear" suggests that a detailed study has not been performed. Has it?

2. Page 5-3, Last Sentence of Paragraph Two. Delete the words "modifications of."

3. Page 5-6, Land Use. A justification should be provided for the choice of the WIPP site boundaries and various control zones that have changed since the FEIS (See Chapter 2 comments).

4. Page 5-6, Air Quality. The occurrences where state and federal air quality standards have been exceeded are not adequately explained in this paragraph. For example, the text states:

> "The WIPP has not been determined to be responsible for the elevated sulfur dioxide levels."

How was this determined? Similarly, the cause of high ozone levels "has not been identified," but WIPP has been exonerated.

With respect to dust loadings exceeding the air quality standards, it is stated that the cause is attributed to heavy use of a dirt road near the air sampler. Has this cause been

verified by moving the sampler to another location, or from analysis of deposits on the filter?

There are possible explanations for the high values. They could be due to sampling or analytical errors, or could cover a wider area than the WIPP site, or could be due to WIPP-related traffic. But no explanations have been justified here. We must conclude from this paragraph that the WIPP site has not been shown to have a negligible effect on air quality standards.

5. Page 5-22, Transportation. EEG has thoroughly evaluated the calculations presented in Appendix D for transportation and our detailed comments are included in that section. Our findings on the evaluation are summarized here.

A. The methodology and assumptions used to calculate population doses to workers and the public from routine transportation were appropriate and conservative.

B. The estimated dose to the maximally exposed members of the public (1.6 mrem during 25 years) is unrealistically low by one to two orders of magnitude.

C. Assumptions used for the Total Respirable Release Fraction from the different Severity Category Accidents are more conservative than those used by EEG in EEG-33 for a doubly-contained, non-vented TRUPACT. Thus, the total radiological impact projected for transportation accidents is conservative.

D. The probabilistic method of presenting accident results completely hides the effect of accidents, especially the more severe ones, from all except the technical reviewer who digs them out of the tables himself. For example, the total number of

accidents and the number of accidents leading to a release are not presented anywhere. Neither are any route specific total accident and release values provided. If the SEIS is going to use these numbers, it should summarize them in a way that is understandable.

E. The Bounding Accident is very non-conservative because it uses the average PE-Ci trailer-load from the Rocky Flats Plant. The average PE-Ci value for the entire system is 6.5 times the RFP value and the average SRP trailer is 64 times as great.

F. EEG believes the appropriate Bounding Accident (with SRP wastes) would result in 35,800 person-rem. This would be about ten Latent Cancer Fatalities (LCF).

G. The probability of a bounding accident is not "extremely low" as stated on Page 5-24. From the tables and assumptions in Appendix D, one can calculate a probability of about 0.6% that an accident involving >0.75 LCF will occur during the WIPP operational period.

6. Page 5-24 to 5-28, Human Health Consequences of Transportation Releases. We believe the LCF/rem factors used are appropriate, and, since we judge the total doses received from transportation to be conservative, the total LCF are considered conservative. EEG has the following observations about transportation health effects:

A. Transportation causes the majority of the radiological health effects of the entire project.

B. The expected effects are about 0.96 LCF for 100% truck shipments and 0.31 LCF for maximum rail shipments.

C. Consideration should be given to maximizing rail shipments and other ALARA practices to reduce the

total health effects.

7. Page 5-29, Transportation Accidents. Although the statement that the bounding accident assumes that all drums are breached is incorrect, we agree with the assumption that all headspace gas is released in an accident.

8. Page 5-29, Trichloroethylene. We agree with the inclusion of this VOC in the waste inventory because it was commonly used prior to and during the 1970's. This point had been raised to DOE by our consultant, Dr. William Lappenbusch, some months ago, and we are pleased that it has been accepted.

9. Page 5-30, Quantities of Chemicals Released. We agree that 100% of Volatile Organic Compound (VOC) gases present in the headspace should be assumed to be released in a transportation accident. However, we also believe that a fraction of the total VOCs in the waste matrix should be assumed to be released in an accident. The SEIS assumes that .02% (2E-4) of all TRU radionuclides in a TRUPACT are released in the most severe accident. There are experimental data to support releases of this order for TRU radionuclides, which are typically in a non-mobile, non-volatile form. We believe a factor of 2E-4 would be appropriate for the VOC fraction in the waste matrix. This will increase the source term by 29% to 630%. For carbon tetrachloride, which has the most hazardous headspace gas concentration (40 times TWA-TLV), the increase would be 86%. Note also that there would still be the non-conservative assumptions of assuming average values for headspace gas concentration and concentrations in the waste.

10. Page 5-30 to 5-32, Quantities of Lead Released. The release values are unrealistically low. Starting from an

average amount of lead in an average drum of wastes of 60.3 kg, the released amount is only 0.46 mg. So the total release fraction is 7.6E-9! Again, we compare this to the average value of plutonium in these wastes of 2E-4. We don't believe plutonium is 26,000 times as mobile as lead.

The very low value resulted from the DOE assumption that no lead could possibly be released from any waste form other than sludges, which have only 10 mg/kg of lead. EEG rejects this assumption and believes the appropriate source term should be 507 grams per trailer.

11. Page 5-31, Paragraph Three. These two sentences have fires lasting for 2.0 hours and 1.5 hours.

12. Page 5-31, Paragraph Five. Why is the maximally exposed individual at 30m here and at 50m in paragraph seven?

13. Page 5-32, Second Paragraph. What is the origin of the 1300°K temperature in the bounding case accident? Assumed temperatures for the hypothetical test accident are somewhat lower (800°C or 1073°K).

14. Page 5-33, Table 5.10. It is not clear how the values in this table were calculated. Is g/m^3 the correct unit? Why would the concentration (g/m_3) in six TRUPACTs be twice as great as in three TRUPACTs? Using carbon tetrachloride as an example, the average headspace gas concentration in Table 5.26 and the average emission rate in Table 5.28, we can also calculate a concentration. There are 1.9 g/m^3 in the headspace gas. If this were also diluted in the TRUPACT cavity outside the drums (2.45 m^3), the average concentration in the entire TRUPACT void volume would be 0.87 g/m^3. This value is 50 times that reported in Table 5-10 for three TRUPACTs. The emission rate for carbon tetrachloride would

add another 0.12 g in 100 hours. Thus, we believe the amount of carbon tetrachloride in the TRUPACT void space should be assumed to be 2.0 g or 0.82 g/m^3. This value is 27 times the TWA-TLV. The 1,1,1-Trichloroethane and trichloroethylene values are 3.2 and 1.2 times TWA-TLV values.

15. Page 5-34, Table 5.11. For the quantity of lead available for release, the fraction received by the maximum receptor is very high. The intake for an individual amounts to 8.5E-5 of that released. The radiological bounding accident had only 3.1E-8 fractional intake, and EEG-33 had 5.5E-8. Should the concentration be micrograms/m^3?

This very low dilution offsets a good bit of our objection to the very low release fraction. We believe the quantity released from a CH-TRU trailer should be about 5E+5 mg, and the fraction inhaled by the maximum individual about 5E-8 for an intake of 2.5×10^{-2} mg. The air concentration (~42 μg/m^3) would be about 28 times the Clean Air Act Standard for 90 days but for a time weighted average would be well below any of the limits shown on Page G-15.

16. Summary Comment on Section 5.2.2.2. EEG has significant reservations about the quality of the data, some of the assumptions, and calculation inconsistencies in this section. Because of these concerns, we cannot yet conclude that reported concentrations, which are low compared to TLV-based limits, indicate that hazardous chemical releases from transportation accidents are negligible.

17. Section 5.2.2.3, Non-Radiological, Non-Chemical Transportation Requests. Comments on this subject are also included in comments on the Summary Chapter and Appendix D. The only additional observations are that:

A. Expected LCF from vehicle emissions are less than 20% of the LCF from radiation for truck shipments, and less than 30% for rail shipments.

B. Expected deaths from accidents are much greater than from radiation, 8.6 times for truck shipments, and 6.6 times for rail shipments.

C. Since rail transportation is predicted to be safer than truck transportation in all areas (radiation, accidents, vehicle emission), consideration should be given to maximizing rail shipments.

18. Page 5-39, Assumptions and Considerations of Uncertainty. As mentioned previously, the use of a "fullness factor" of 0.80 is incorrect and will influence many of the calculations that follow.

19. Page 5-44, Waste Retrieval. Our general comments on waste retrieval also apply to comments on Pages 5-46 and 5-49, and Table 5.18. It is difficult to believe that routine exposures from retrieval would be the same per shift as emplacement (but twice as much per drum, because of greater handling time) or that surface contamination would be present on only one-half (5%) of the drums that were brought underground contaminated (10%). Table 5.18 assumes that the 5% of drums that are contaminated can be retrieved and repackaged with a dose of only 1.7 mrem per drum. This is unrealistic. If retrieval is believed to be no more hazardous, why are there plans to HEPA filter area exhausts during retrieval, but not during emplacement?

19. Page 5-45, Routine Radiological Releases. Two fundamental errors were made in calculating releases of radionuclides to the environment in Table 5.15. First, the

number of drums was overestimated by the erroneous use of the 0.8 fullness factor. This results in increasing the annual drum equivalents handled. The values should be about 17,000 and 38,000 drums per year in the test phase and disposal phase, respectively. Secondly, the use of the 1E-5/m resuspension factor to calculate amount removed in a year is incorrect, because this factor includes amounts that settle out as well as those carried away. This error also occurred in the December 1988 Draft FSAR. In fact, the amount of alpha curies shown in Table 5.15 to be released in a year is 1.55E-3 Ci/year. The curies of alpha radiation included on all drums brought in during a year (with 10% contamination at 50 pCi/100 cm^2) is only 5E-5 Ci/year! The SEIS claims to carry off 31 times the amount of radioactivity brought in!

Both of the errors give conservative predictions, that is, they predict greater releases to the environment. However, such significant errors cause real doubts about the thoroughness and accuracy of subsequent calculations.

20. Page 5-47, Table 5.15. It is noted that the radionuclide releases in this table are about 35% higher than those in Chapter 6 of the Draft FSAR. The ratio on a per drum basis would be about 58% higher. However, the values in both tables need to be recalculated.

21. Page 5-48, Table 5.16. The values of annual radiation exposure in this table are apparently scaled up (by a factor of about 1.33) from the Draft FSAR. As stated above, we believe the source term (Table 5.15) is incorrect. Our comments on the environmental pathway analysis are substantive and are included under Appendix F.

22. Page 5-48, Table 5.17. These occupational radiation doses are apparently scaled up from the Draft FSAR. EEG

conclusions on the FSAR numbers were that the direct radiation dose was reasonable, but the inhalation dose was not reproducible from assumptions listed and was probably low. The same conclusions apply here.

23. Page 5-49, Section 5.2.3.4, Accidental Radiological Releases and Exposures. The accident scenario assumptions, releases, and doses are identical to those in the Draft FSAR. EEG's principal conclusions are summarized below. A more detailed explanation of these conclusions is included in EEG-40, Pages 50 to 52.

A. The C-8 (hoist drop) accident is not incredible and should be included in dose calculations.

B. The use of a 1,000 PE-Ci upper limit for individual waste containers is unacceptable to EEG.

C. The potential doses to radiation workers from accidents are unreasonably low, because of the assumption that all accidents occur with an average PE-Ci drum.

D. The C-2 (forklift) accident doses are unreasonably low, because the forklift operator is assumed to receive no dose.

24. Page 5-54, Table 5.2.1. The Draft FSAR calculated doses to a member of the public at the maximum location in the WIPP site where public access is allowed. The doses are 60% higher than at Mills Ranch and would be more appropriate to use.

25. Page 5-55, Third Paragraph. There are three errors in this paragraph relative to Table 5.22, and the table is correct in each case. The excess fatal cancers are per year

and not during the entire operation. The fatal cancers per year in the population from facility operations should be 7.6E-6, during the Test Phase, and 2.5E-5, during the Disposal Phase, as shown in Table 5.22. They are incorrectly described in the text on Page 5-55 as 8.4×10^{-6} and 2.7×10^{-5}, respectively.

26. Page 5-57, Table 5.23. The values given for risk of latent cancer fatalities from accidents are correct for the doses presented in this section. However, if the maximum exposed worker (in the C-6 accident) had been handling a 1,000 PE-Ci drum, the dose would have been 713 rem. This would lead to a 0.20 probability of a LCF. EEG has estimated that the dose to the C-2 forklift operator with a 1,000 PE-Ci drum would be about 2,900 rem.

27. Page 5-61, Heavy Metal Releases. The statement that WAC certification assures no radioactive contamination exists on the surface of containers is incorrect. A limited amount of radioactive contamination is allowed (50 pCi/100 cm^2 for alpha emitters and 450 pCi/100 cm^2 for beta-gamma emitters) and some containers are expected to contain measurable contamination between zero and the limit. Also, the "elaborate HEPA filtration system" will not normally be operating to filter underground exhaust, and, thus, cannot be categorized as routinely filtering exhaust air.

28. Page 5-64, Line 4. The statement that use of average concentrations represent a bounding case is misleading. In any scenario where only a few drums are involved (e.g., when unloading a TRUPACT), a conservative assumption would be at least as great as the average concentration for the maximum class of waste. This is especially pertinent because the original TRUPACT certification is not expected to permit mixing of waste types. For example, carbon tetrachloride

Waste Category 2 (cemented and uncemented organic sludges) are 10.5% of all wastes and have a concentration of 50,000 mg/kg, 9.3 times the average.

29. As mentioned in the Chapter 3 comments, EEG is not yet confident that the hazardous chemical inventory is accurate, including RFP.

30. Page 5-64, Last Paragraph. The statement that 10% of the 6.2 million cubic feet of total repository capacity is 110,000 drum-equivalents is incorrect. The 6.2 million cubic feet is based on the total volume within the containers, not the estimated volume of waste within the container. A 55-gallon drum holds about 7.34 cubic feet. There would then be 845,000 drum-equivalents in 6.2 million cubic feet.

31. Page 5-67, Table 5.28. The 1,1,1-trichloroethane emission rate (9.3E-9) is inconsistent with the other values and the assumption that the diffusion coefficient is related to the square root of the molecular weight ratios. A consistent value would be 1.7E-7, which was used in the December 1988 Draft FSAR, and is 19 times greater. Also, the value in Table 5.31 uses the higher emission value.

32. Page 5-68, Assumptions of Operational Exposure. We believe the assumptions listed on this page are all reasonable and slightly conservative.

33. Page 5-70, Air Dispersion Modeling. The EPA Industrial Source Complex (ISC) dispersion is used to predict off-site concentrations of VOC's. Is it being assumed in these analyses that hazardous wastes are not adsorbed onto particulates in the exhaust? If true, then documentation for this assumption is required in the SEIS for proper justification; otherwise, it should be considered in the

assessment.

34. Page 5-71, Exposures from Above Ground Operations. The statement is made that releases from waste containers into the TRUPACT-II may occur during transport. We believe they will surely occur. Your assumptions of average emission rates in Table 5.28 would lead to significant gas concentrations in a TRUPACT-II while it was sealed during shipment. In 100 hours, the predicted concentration would be 1.6 times the TWA-TLV for carbon tetrachloride in an average load. In a maximum load, the concentration would be 15 times the TWA-TLV for carbon tetrachloride and 1.8 times for 1,1,1-trichloroethane. It is apparent that sampling must be done before opening the TRUPACT-II units at WIPP, and that precautions may have to be taken to insure safety of those most involved in waste handling with the TRUPACT.

35. Page 5-71, Exposures from Underground Operations. The assumption of an air velocity of 3m/s is non-conservative by a factor of at least two. This assumption requires a flow rate of 120 m^3/s in either one storage room or in the panel exit drift. The total flow rate for a panel is about 58 m^3/s and for an individual room would be only a fraction of this. This discrepancy was pointed out in our Draft FSAR comments and acknowledged by Westinghouse. The values in Tables 5.31 and 5.32 check for the assumptions used.

36. Table 5.31 and 5.32, Exposures from Underground Operations. From the assumptions stated on Page 5-68, the above ground worker should be exposed to the emissions from an average of 66,000 drums during the first five years, and 6,000 drums thereafter. The estimated daily intakes in Table 5.32 reflect this 11 to 1 ratio. Also, the concentration for an above ground worker in the 20-year period is consistent. But the above ground worker concentrations for five years are

too low by a factor of about three. The effective X/Q value for the 20-years concentration is about 1.5×10^{-6}. It is about a factor of ten low compared to Table H-49 of the FEIS, but without knowing stack height assumptions we can't comment on its validity.

37. Page 5-78, Table 5.34. Units of micrograms/m^3 are missing.

38. Page 5-82, Table 5.36. Footnote "a" is missing.

39. Page 5-100, Non-radiological Risks. The LCF for CH-TRU shipping by rail would be 0.088 (See Table D.4.9).

40. Page 5-109, Third Bullet. Although the assumption used in the FEIS that TRU waste in the repository dissolves at the same rate as salt is called unrealistic, it led, because of other assumptions, to a concentration that was less than 4E-6 Molar.

41. Page 5-110, Last Sentence. Since concentrations of VOC's in some waste forms average as high as 150,000 mg/kg (see Table B.3.2), it is imprudent to call this limited or minor.

42. Page 5-111, Fourth Paragraph. The statement implies there is a definite plan and commitment to using a backfill containing bentonite. We are unaware of any such commitment, and the text should not take credit for it.

43. Page 5-113, Fourth Paragraph. EEG has been assured in the past that there was not enough brine in the Salado to fill a room before closure. We believe the current hypothesis is more reasonable.

44. Page 5-114, Third Paragraph. Although a human intrusion drill hole may be considered unlikely by the SEIS writers, its evaluation is required by 40 CFR 191.

45. Page 5-114, Last Paragraph. EEG has been told that blowout preventers do not activate unless pressures are quite high and might not be activiated by a brine reservoir. Also, since the WIPP-12 brine reservoir unavoidably permitted 27,000 barrels of brine to flow to the surface before it could be shut in for pressure testing (see Page H-9 of TME 3153), how can the claim be made that little or no brine would reach the surface?

46. Page 5-115, First Paragraph. What assurance is there that standard borehole plugs would be installed? Who inspects these?

47. Page 5-117, Cases IIC and IID. We agree with plutonium and americium solubility values of 1E-6M for average and 1E-4M for degraded conditions. An order of magnitude increase in the solubility for uranium might be more appropriate.

48. Page 5-119, Third Paragraph. Again, credit is taken for bentonite in the backfill.

49. Page 5-125, Last Paragraph. It is not obvious that gas generation by radiolysis is negligible. Waste inventories have become more concentrated and more work has been done on gas generation since 1980. The average concentration in an equivalent drum in the repository will be about 6.16 alpha curies. The Safety Analysis Report for Packaging (SARP) for TRUPACT-II uses G factors (net gas) that range from 0.6 - 8.4 atoms of gas per 100 electric volts of absorbed alpha energy for five of the six waste forms considered. A G factor of 1.0 would generate 0.64 moles/year/drum. Even though G

factors are usually assumed to decrease, in a poorly defined manner, with time it does not seem conservative to ignore radiolysis. Besides, the only reason to use real waste for experiments is the contributor by radiolysis. Neither bacterial decay nor chemical reactions require waste.

50. Page 5-129, Last Paragraph. The flow would be around as well as through the seal in MB139.

51. Page 5-135, Table 5.52. The large retardation factors, for 100% of the wastes, assumed in the Culebra should guarantee that you will have no problems, regardless of other assumptions. Since there are so many complexities to this waste and large quantities of material that are potential chelating materials, we believe that a small percentage (perhaps in the 1 - 10% range) of waste should be assumed to move with no retardation.

52. Page 5-137, Fifth Paragraph. It is stated that 12 liters of brine with a radionuclide solubility of 1E-4 molar would carry 1% of a drum's radionuclides. Our calulations show that this volume of brine at 1E-4 molar would contain about 0.288 grams each of plutonium and americium and about 0.281 grams of uranium. These quantities would be 3.2%, 100%, and 24% of the average grams in a drum (See Table B.2.14.).

53. Page 5-138, Table 5.54. We agree with the calculated dose for the assumptions used. For the average LANL wastes, which has an Am-241 concentration 7.3 times the WIPP average, the dose would be 0.6 mrem. This is still a low value.

It should be recognized that taking a cuttings sample from RH-TRU wastes could conceivably result in somewhat higher doses. For example, if an RH-TRU cylinder contained

an average of 10 Ci/L of Cs-137 at time of emplacement (this would meet the requirements of the State of New Mexico for a total concentration of less than 23 Ci/L), this would still be 1.0 Ci at 100 years. A 526 cm^3 cutting would have a dose rate at 1 meter of 175 mrem/hour, even if no compaction of the waste were assumed.

54. Section 5.4.2.6, Analysis of Scenarios: Cases IIA, IIB, IIC, and IID. EEG has not had the time to check all of the calculations in this section, so we are unable to provide a comprehensive assessment of the analysis. Most of the checking we have done is discussed in Appendix I. There was one significant finding.

The calculations of human exposure from the stock-well-beef pathway are calculated incorrectly and understate the doses that should have been calculated from the assumptions by over two orders of magnitude. The problem was caused by calculating the intake of radionuclides by the steer for <u>only one day</u>. Two hundred days of intake is typically considered to be a reasonable assumption. The 200-day feeding assumption would increase the concentration in the nuclides of interest by factors of 100 to 200, depending on the effective half-life of the specific nuclide. When calculated correctly, the 129 mrem dose in Case IIC becomes 15.7 rem Committed Effective Dose Equivalent per year of beef consumption.

This dose (using the SEIS assumptions) is significant, about two orders of magnitude above natural background doses. A great deal of explanation is needed to explain why this type of dose is acceptable, even for an event with a probability somewhat less than 1.0.

The fact that Uranium-233 turns out to be the dominant

radionuclide in a well scenario is not suprising to EEG. We came to the same conclusion in EEG-9, published in September 1981.

EEG has long maintained that a well scenario with humans drinking treated water directly is reasonable to consider. The technology to reduce high solids water is available today (with reverse osmosis being perhaps the most practical method), and is used some in water-short areas that do not have access to better quality water. The well water in Case IIC, if treated to remove 90% of the solids, and, incidentally, remove 90% of the radionuclides, would result in a dose of about 33 rem/year (CEDE). Even if 99% of the radionuclides were released, the CEDE would still be 3.5 rem/year.

SECTION 6

1. Page 6-2, Introduction. The text states, "If, for example, it were determined through the Test Phase experimentation that gas-generation is a long-term repository problem, then gas-getter materials could be selected as a mitigative measure."

Current DOE estimates clearly show that gas generation is a long-term repository problem. For gas not to be a problem, measurements would have to show a 25-fold reduction in the amounts expected of 2.4 moles/y-drum to 0.1 moles/y-drum, a most unlikely situation.

The text states that the solution is to use gas-getters. If this is the case, why do the experiments? The text further states, "Other experimental results could identify the need for other treatments." What are the kinds of results that could prompt other treatments?

2. Page 6-2. The text states, "The requirements of the Occupational Safety and Health Administration (OSHA) and Mining Safety and Health Administration (MSHA) have been closely followed." Include a discussion of violations and citations identified by those federal agencies since the FEIS was issued and how these have been corrected.

3. Page 6-2, Existing Facilities. The reader is led to believe that HEPA filters are continuously filtering underground exhaust air during normal operations. This is not the case, and the wording should be changed to indicate that air is normally discharged without passing through the HEPA filters.

4. Page 6-2. It is inferred that the remainder of the

repository has not been excavated because of premature closure due to salt creep. It should be added that those rooms which have been excavated require rock bolting and wire-mesh surfacing to insure worker safety due to fracturing in the ceiling of the drifts and rooms along with salt creep during the short term.

5. Page 6-2, Socioeconomics. The release of land in Control Zone IV for unconditional use for economic reasons, as opposed to the FEIS which did not allow this option, impacts on both health and safety, and on ecological preservation. Presumably, these were the original reasons for control of this zone. What has changed since the FEIS to account for this release? How does this release impact on slant drilling under the site for mineral exploration and extraction which is not currently permitted?

6. Page 6-5, Emplacement of Backfill. It is stated that the FEIS considered only crushed salt as a backfill for waste containers, and that various types of backfill developed since that time may speed the entombment process and the attainment of final porosities within the waste areas. A 70:30 crushed salt-bentonite mixture with yet unidentified gas getter(s) is the only option discussed in the SEIS as bulk backfill. Is the only option a selection of getters? What other backfill materials, including getters, are being considered?

7. Page 6-5. "The reason for backfilling WIPP disposal rooms and access tunnel systems...would be to shorten the estimated 'time for closure' of the disposal room." That is not the sole reason. Getters, such as bentonite, are used to retard radionuclide movement after a hydrologic breach. Additionally, EPA requires engineered barriers. Since the WIPP waste is soluble, respirable, and housed in a carbon

steel oil drum, backfill at the present time is the only engineered barrier at the WIPP.

The text states that compaction of backfill in situ would be costly and require manual labor. Thus, a loosely placed backfill is seemingly being proposed, and faster emtombment using backfill compaction is not being considered. Because brine sorption and minimized gas production through the use of getters are now being completed since the FEIS was written, what is the mechanism for more rapid entombment of waste exclusive of these two processes? It appears from this analysis that the SEIS authors favor getters rather than bulk backfill material.

8. Page 6-8, Figure 6.1, Tentative Location of Panel Seals. The impact on workers' safety after the first panel is sealed, becomes pressurized with hydrogen and other gases, and potentially blows out the bulkhead prior to closing the mine 25 years later, is not discussed in the SEIS. Estimates of the potential pressures should be included.

9. Page 6-10-19, Mitigation by Waste Treatment. The discussion of waste treatment in the SEIS appears to favor postponing any decision on waste processing on the basis that knowledge acquired during or after the Test Phase may modify the approach to take, yet all evidence points to a need for immediate consideration with respect to potential gas generation problems, brine influx, and hazardous waste components. Neither immobilization treatment nor incineration are included in the experiments. The investigation of incinerated wastes and/or immobilization may be more important because of their potential in reducing the problems and hazards associated with gas-generation and hazardous wastes, in addition to ameliorating the consequences of transportation accidents, and enhancing WAC

Certification. Why aren't these treatments being considered in the Test Phase? The lack of experience with incinerators is not the problem, as about 80 incinerators have been operated for this purpose internationally (Page 6-16), and immobilization has been employed at nine commercial reactors (Page 6-13). This experience may be compared to compactor utilization at 74 commercial power reactors (Page 6-17).

10. Page 6-17, Effects of Waste Treatment. It is stated that it is not currently possible to qualitatively estimate any long term benefit from waste treatment. How about the indirect benefits of diffusing objections, meeting Performance Assessment requirements (if otherwise not met), and, in short, allowing disposal to proceed?

SECTION 7

1. Page 7-1, Section 7.1.1. Why is DOE proposing to increase the fenced area at WIPP from 250 acres to 1,454 acres? No explanation is provided.

2. The 1980 FEIS stated, "The waste that is emplaced underground is not expected to release any radioactivity; it will, therefore, produce no long-term radiological impact." The 1989 SEIS repeated this statement that the wastes "would not be expected to release any radioactivity..." Statements like these without documentation of probabilities are inconsistent with the stated DOE position that it will be October 1993 before the DOE can complete the demonstration that the facility can meet the Standards for safe disposal issued by EPA.

3. Page 7-2, Cost Reduction Program. A discussion of the decision under the Cost Reduction Program in 1982 to eliminate the fourth shaft should be included, since subsequent events led the DOE to eventually build the fourth shaft. A number of issues were raised on the Cost Reduction Program by EEG in November 1982 (see EEG-19), and the economic and environmental impacts should be discussed.

4. Page 7-4. DOE concludes that delaying the receipt of TRU waste until compliance with the Standards (Alternative Action) would not result in any difference in unavoidable adverse impacts when compared to the alternative of bringing waste now. In that case, why not commit to full compliance first?

5. Page 7-4. The conclusion that the emplacement of 65,000 drums in WIPP before meeting the Standards would not have any

differences in potential impacts with the option of completing compliance first has not been thought through. If wastes had to be retrieved, the costs of retrieval, transportation risks, and operational risks would be substantially different for both cases. A detailed benefit/risk analysis should be included.

SECTION 8

1. The text discusses slant drilling to permit the extraction of hydrocarbon resources under the WIPP site. This is counter to previous DOE commitments to prevent the extraction of those resources.

2. In addition to the bin tests, discuss alcove tests at sites other than WIPP, since EPA indicated that the earliest date for shipment of RCRA wastes, which are representative of the various waste streams, may be March 1990.

SECTION 9

1. The discussion of conducting bin-scale tests at WIPP versus generating sites should address the potential of a one-year delay for authorization to ship RCRA type waste, which would substantially delay the availability of experimental results.

2. Page 9-4. Add the appropriate references to the list. Only one is shown.

3. The discussion on bin tests should be extended to include alcove tests and room tests.

Was there a commitment by DOE not to allow drilling in Zone IV?

SECTION 10

1. Page 10-6, "Complete waste characterization data for waste expected to be shipped to WIPP is not yet available." Reference whatever data is available.

2. The status of the variance request for a no migration petition should be updated, including an estimate on the earliest date mixed waste could be shipped to WIPP.

3. Add a commitment to the list of regulations for safe transportation to those issued by the U.S. Department of Transportation, 49 CFR, Parts 171 through 178.

4. Add a commitment in Table 10.1 to have the CH-TRU and RH-TRU shipping container certified by NRC.

5. Page 10-13. The text cites the Second Modification of Agreement 4, 1987, to the New Mexico Department of Energy C&C Agreement as the earliest date to meet NRC transportation regulations. Actually, DOE agreed to do this in the October 1980 FEIS, Page 6-1, which states, "The transportation of radioactive waste to the WIPP will comply with the regulations of the U.S. Department of Transportation (DOT) and the corresponding regulations of the U.S. Nuclear Regulatory Commission (NRC)." Unfortunately, DOE would not honor their 1980 FEIS commitment until 1987. This is discussed in EEG-33, "Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986," and should be discussed here.

6. Page 10-13. Although there are 8000 shipments of RH-TRU waste identified in the SEIS, the document is silent on the status of that shipping container. Include a drawing of the

shipping cask, the expected date of construction, schedule for testing and planned submittal of documentation to NRC and the expected date of certification.

Include an explanation on the absence of progress in this area since shipments of RH-TRU waste were planned ten years ago.

APPENDIX A

1. Page A-4, Table A.1.1. Table A.1.1 does not show a limit on the amount of RH-TRU waste that can have a maximum surface dose rate of 1,000 rem/hour. It should be 5% of the expected 93,000 cubic feet of RH-TRU or 4,650 cubic feet as agreed in the C&C Agreement as modified. The remainder has a maximum surface dose rate of 100 rem/hour.

2. Page A-5. Change the text to require all CH-TRU waste containers to have a venting feature.

APPENDIX B

1. Page B-2, Inventory. Some explanation should be provided for the enormous changes in waste concentrations and amounts shown in the SEIS in comparison to the FEIS.

2. Page B-3, Table B.2.1. The term "Newly-generated" is used to describe waste that has yet to be produced. A better term might be "to be produced."

3. Page B-4, Table B.2.2. Table B.2.2 lacks units and contains seven-place accuracy for two-thirds of waste yet to be produced.

4. Page B-5, Table B.2.3. Table B.2.3 lack units.

5. Page B-6, Table B.2.4. What is a "volume scale-up?"

6. Page B-7. EEG does not agree with the 1,000 PE-Ci limit per package established by DOE.

7. Page B-7. Additional information on the radioactive waste inventory has been drafted in a report, DOE/WIPP-88-049 (WIPP, 1989), and "constitutes the fundamental basis for analysis reported in the SEIS and in the WIPP FSAR." Since DOE has not provided the report to EEG, no conclusions can be drawn as to its value.

8. Page B-8. Table B.2.5 lacks units.

9. Page B-8, Table B.2.5. Table B.2.5 lacks units. Fill in the blanks in the table which shows major changes from the FEIS.

10. Page B-11, Paragraph Three. The equation includes the 0.80 "fullness" factor. This generates more drums than WIPP can hold and results in 23% more shipments than expected.

11. Page B-12, Table B.2.8. The table indicates 6.26×10^4 m^3 of newly-generated CH waste for Rocky Flats, and 1.29×10^5 containers. This implies a container volume of 0.485 m^3 that does not match either a drum (.208 m^3) or a SWB (1.798 m^3). The value for newly-generated waste in the table (6.24×10^4 m^3) is <u>greater than</u> the value of 5.66×10^4 m^3 (2.0×10^6 ft^3) given in Table B.2.4 (Page B-6) for <u>both</u> stored <u>and</u> new waste at Rocky Flats.

12. The equation in Table B.2.8 includes a factor of 3 m^3/TRUPACT. It is actually 2.9 m^3/TRUPACT for drums, and 3.6 m^3/TRUPACT for SWBs.

13. Page B-13, Table B.2.9. Total RH volume 1.98×10^4 probably should be 1.98×10^1, which would then be consistent with 2.20×10^1 containers. The 19.8 m^3 stored + 5.4 m^3 newly-generated waste (Page B-12) totals 25.2 m^3, somewhat less than the $1.2 \times 10^3 \times .02832 = 34.0$ m^3 indicated by Table B.2.4 (Page B-6).

14. Page B-15, Paragraph One. What is the citation for "updated by WIPP, 1989?" Is it DOE/WIPP 88-005? The citation should be given.

15. Page B-15, Paragraph Two and Table B.2.14 on Page B-20. The process used to obtain the modified inventory for long-term performance analysis, although not cited, was found in SAND 89-0462, pages 4-23 to 4-26. The "modified inventory" shown in Table B.2.14 shows a 22% increase of Am-241 adjusted for decay and ingrowth from Pu-241, whereas, all of the latter is not present in the inventory. Also, there is no

change in the Pu-238 inventory over the time period, nor does Np-237 appear to reflect its production from Am-241. Is the decay time allowed 100 years? What is the justification for this inventory?

16. Page B-15, Section B.2.2.2, Operational Analysis. The draft FSAR is referenced for operational impacts of waste handling and storage at WIPP. It should be noted in the SEIS that reference is being made to a draft, and that changes may have to be reflected in the SEIS. Only a brief mention of "updating" the SEIS for this purpose is mentioned in a footnote.

17. Section B.2.2.3, Long Term Performance Assessment. It is stated that emplacement procedures at WIPP of RH-waste will minimize degradation. In light of brine seepage, how is corrosion of canisters minimized? Also, how does the uncertainty of RH-inventory justify excluding this type of waste in performance assessment? These terms need clarification.

18. Pages B-22 and 23, CH-TRU Mixed Waste. It is not clear how RFP wastes represent a conservative upper bound for potential risks rather than just a representative sample for risk assessment involving hazardous wastes. Are all identified hazardous waste quantities in RFP waste in higher concentrations than that generated at other locations? Is there any quantitative reasoning behind this assumption?

19. Page B-15, High Curie Waste. It is gratifying to note the correction in the SEIS in identifying the heat source Pu-238 contribution is 17% of the inventory, in comparison to the 1.2% used in the FEIS. However, it is not reassuring to realize that the FEIS calculations were predicted on the more dilute weapons grade waste streams and ignored the heat

source Pu-238 wastes.

20. Page B-16, Table B.2.10. An explanation should be provided for the increases in the activities represented in the SEIS from the FSAR.

	Factor Of
Pu-238 increased	260
Pu-239 increased	2
Pu-240 increased	1.7
Pu-241 increased	2.4
Am-241 increased	300
TOTAL	6.2

21. Page B-17, Table B.2.11. Table B.2.11 describes waste in a Standard Waste Box. Hence, mass and activity should not be shown as "grams per drum" and "Ci per drum." They should be "g/box" and "Ci/box."

22. Page B-18, Table B.2.12. While the table is technically correct in telling the reader that daughter products are not included in reporting 260 Ci/container of RH-TRU waste, it is deliberately misleading to delete the contribution of Y-90 of 250 Ci and report only half of the actual radioactivity present in the container, which is 510 Ci. Besides, the Y-90 was included in the FEIS Volume II, Page E-4, which shows 5.1×10^2 Ci/canister. The deletion masks the 12-fold reduction of radioactivity in each container. Please explain the difference.

23. Page B-19, Table B.2.13. The table lists the initial CH-TRU inventory. A similar table should be provided with the initial inventory for RH-TRU, which would include fission products and activation products.

APPENDIX C

EEG has had a number of critical comments on the adequacy of the emergency response program and has transmitted these concerns to DOE in a June 21, 1989, letter from the Director of EEG to the WIPP Project Manager. Hence, those concerns will not be duplicated here with the expectation that they will be addressed in the Final SEIS.

1. Page C-7, Emergency Response Scenario. There are a number of unrealistic conditions portrayed in the emergency response scenario. It is unlikely that any state's police officer would have the expertise to verify that radiation levels were at normal background levels even if he did have the correct instrumentation. Radiochemical analyses of soil samples would be required if the goal was to return the accident area to background levels as is inferred.

APPENDIX D

1. Page D-10 and 11. The text indicates that all applicable U.S. DOT regulations, with respect to "preferred routes," have been implemented. They have not.

The definition of preferred route in the context of U.S. Department of Transportation regulations is incorrect and fails to acknowledge the May 8, 1988, revision of the U.S. Department of Transportation regulations, 49 CFR 177.825, requiring a state to formally notify DOT when it has completed the procedures. Such notification has not occurred and the text should make this clear.

The first 42 pages of this appendix cover routes to WIPP in considerable detail. This is useful information, and only a few minor discrepancies were noted.

Incident Free Transportation

1. Page D-47, Table D.3.2. Footnote B shows that the 0.80 factor, erroneously used throughout the SEIS, is used in calculating the number of shipments. See our comments in the Summary Chapter. However, we believe it would be appropriate to use a factor to allow for the likelihood that TRUPACT shipments from some generators will be weight-limited. For example, they will not be able to carry 14 drums and stay within permitted trailer weight limits. This is because the average payload of the three TRUPACTS on a trailer is now down to about 5,300 pounds per TRUPACT (380 pounds per drum), and there have been predictions that RFP wastes will average about 600 pounds/drum after the supercompactor is operational in 1990.

2. Page D-48, Table D.3.3. This table is very useful

because it gives the average radionuclide distribution and concentration for each generator. It also points out that any use of RFP wastes as a typical or average waste is incorrect and misleading. The SEIS uses an average RFP trailer-load for the "bounding" transportation accident. The average trailer-load is 183 PE-Ci, 6.5 times the RFP average. The SRP wastes, which comprise 11.9% of all shipments, average 1,787 PE-Ci, 63.8 times the RFP average. It is noted that the values in this table should be calculable from Tables 13.2.1, D.3.1, and D.3.2, but they are not consistent even with the 0.8 factor.

3. Page D-53, Table D.3.7. The stop time (hr/km) for trucks seems unreasonably high. For example, on the LANL to WIPP route, the vehicle would have 7.02 hours of driving time and 6.07 hours of stops.

4. Pages D-50 to D-57, Tables D.3.5 to D.3.10. We have spot-checked the dose values presented in Tables D.3.8 - D.3.10 by non-RADTRAN methodology and believe they are reasonable. See additional comments on Chapter 5 in the significance of these doses. However, in Table D.3.10, we note that the differences between the proposed action and alternative action apparently do not assume RFP waste will be transported to INEL with the alternative action scenario. If they were, the approximately 1,270 (or 1,590 with 0.8 factor) shipments during five years would result in about 100 - 130 additional person-rem, compared to direct shipment.

5. Page D-57 and Table D.3.14. The claim that the "...hypothetical maximum exposure to an individual from incident-free transportation during Test Phase and Disposal Phase is only 1.6 millirems over 25 years..." is unreasonably low. This value would be approximately correct for a resident at a 100-foot distance from a roadway where trucks

were stopped for 30 seconds each. However, there are locations along the route where residences are within 50 feet of the roadway, and this would lead to doses of about 6 mrem.

But the above assumptions are not reasonable for the maximum exposed individual. For example:

A. A person in the adjoining traffic lane for <u>one</u> 30-minute period during the entire lifetime of WIPP would receive a dose of 2.6 mrem from an average ORNL CH-TRU load and 3.1 mrem from a Hanford RH-TRU shipment.

B. An employee at a restaurant who is exposed to 10% of all trucks stopped for 45 minutes each from a distance of 100 feet would receive about 14 mrem. If this person were exposed to 5% of trucks at a distance of 50 feet, the 25-year dose would be about 26 mrem.

C. A service station attendant who refuels 10% of all trucks and spends two minutes each time at a distance of 10 feet from the center of the truck would receive almost 110 mrem over the 25 years.

D. A guard at the entry to the WIPP site (who is not a "member of the public") who observed one-half of all shipments being checked for contamination (the present procedure takes over 15 minutes) at a distance of 25 feet would receive about 450 mrem.

None of the above assumptions are incredible or bounding. They are likely to happen. The SEIS should not try to trivialize the maximum individual doses by presenting non-conservative dose estimates.

Transportation Accidents

1. Page D-57, Severity Categories. The claim that 99.5% of truck and 99.6% of rail accidents are less severe than regulatory criteria is not consistent with other statements and the calculations presented in this section. For example, the statement is made on Page D-68 that Severity Category III slightly exceeds the regulatory limits and Tables D.3.15 and D.3.16 (which are used in the calculations) show that 9% of truck and 20% of rail accidents are Category III or higher.

2. Page D-73, Table D.3.19. EEG believes the Total Respirable Release Fraction (TRRF) values given for the various Severity Categories are conservative. In fact, they are more conservative than the values used in EEG-33 for a doubly contained, non-vented TRUPACT, except for the Category VIII accident.

3. Page D-79, Resuspension. We do not agree with the assumption that governmental authorities will impound foodstuffs and clean up contaminated land to the level necessary to result in zero dose from ingestion. The RADTRAN III model can calculate ingestion doses, and it should be used here.

4. Pages D-79 to D-86, Accidental Risk Results. We have checked portions of the risk results and believe that the total values are reasonable and conservative. Also, we agree that the probabilistic method of calculating the "expected" radiation doses from accidents is appropriate. However, presenting the results only in a probabilistic manner hides much of the impact from a non-technical or casual technical reader.

For example, the total number of accidents expected was

not found in either Volume 1 or 2. One can calculate a value of 78 accidents with wastes and an equal number without wastes. Also, one can calculate a prediction of 7.0 accidents where radioactive material is released, and 4.8 of these would be in urban or suburban areas.

Route specific totals could also be calculated. For example, LANL shipments would lead to 1.64 accidents, 0.19 deaths, and 1.19 injuries. The expected number of release accidents would be 0.15, and about 40% of these would be in suburban areas. If 40% of the suburban accidents occurred in Santa Fe, there would be about a 2.3% probability of a release occurring.

Accident results should be presented in a form where laymen can get a feel for the number and severity of release accidents that may occur along routes where they live. Another statistic that would be informative to laymen is that in the section of the route between Vaughn and Carlsbad (which carries about 91% of all WIPP vehicles) on Highway 285, there would be about a 3.4% probability of an accident occurring along each mile of roadway. There would be about 0.3% probability of a release accident per mile.

Bounding Transportation Accident

EEG does not believe the "bounding case" transportation accident is bounding. Our reason is principally due to the choice of a typical RFP waste trailer load. The average RFP trailer would carry only 28 Plutonium Equivalent Curies (PE-Ci). The averages, concentrations, and percentages of shipments from major generating sites are:

SITE	AVERAGE TRAILER (PE-Ci)	PERCENTAGE OF CH-TRU SHIPMENTS
RFP	28.	32.8

SRP	1787.	11.9
LANL	583.	10.3
LLNL	231.	4.2
Hanford	67.	13.0
INEL	61.	23.5
ORNL	338.	1.1
CH-TRU Average	183.	100

We believe that a "bounding case" should include the average SRP waste, which comprises about 12% of the total CH-TRU shipments.

Otherwise, the values assumed for parameters are conservative. The 2E-4 fractional release rate is twice that used by EEG for a Severity Category VII accident.

Consequently, the "EEG Bounding Accident" would be a release fraction of 0.5 times the SEIS release value, and a PE-Ci load of 63.8 times. This would result in a population dose of 35,800 person-rem. The estimated latent cancer fatalities (LCF) would be 10.0.

The probability of the "EEG Bounding Accident" can be calculated from data in Appendix D. The probability is about 0.1% (1E-3), certainly not incredible.

There are other probabilities that can be determined from those data and assumptions. The total probability of having an accident that leads to greater than 1.0 LCF (>3,570 person-rem) is 2.5×10^{-3} from the SRP, LANL, LLNL, and ORNL routes. The total probability of having an accident that leads to 0.75 - 1.0 LCF is 3.7×10^{-3} from the Hanford, INEL, and ORNL (suburban) routes.

The SEIS should clearly present some of these doses and

probabilities so that the reviewer understands you are predicting a fairly high possibility of accidents leading to latent cancer fatalities.

Nonradiological and Nonchemical Consequences

There is only one basic comment on this section (and related portions of Volume 1). The differences in projected deaths from shipments by truck (8.3) vis a vis rail (3.0) is significant. Likewise, the expected injuries are 106 by truck and 34 by rail. These are the most significant health and safety impacts predicted anywhere in the SEIS. Yet, there is no discussion of why the truck mode is being chosen and why this difference of 5.3 deaths and 72 injuries is considered negligible. Also, if all RFP wastes for the first five years were shipped to INEL for storage (and then to WIPP later), this would be expected to add about 0.3 - 0.4 accidental deaths by truck (compared to the proposed plan). Yet, Table D.4.8 shows 0.11 less deaths for the alternative plan (RFP + INEL shipments) than the compared plan values in Table D.4.6. Why?

APPENDIX E

1. Page E-5. Appendix D should read "E".

2. Page E-18, Hole NG252. It is stated that hole NG252 appears to be an anomaly because of its substantially higher rate of brine flow than other comparable holes distant and nearby. How can a real observation and measurement be considered an anomaly?

3. Page E-49 to 54, WIPP Brine Flow Model. References are made to a significant number of citations ...36, 37, 25, 40, Figure 1, Appendix A, Sec 4.3.4 which are either not identified in the SEIS, or are not referred to in the discussion. This information should be included in the SEIS.

4. Page E-55 and 59, WIPP Moisture Release Data. References are made to citations, 30, 25, 26, 29, Table 1, Table 2, Figure 2, which are also not identified in the SEIS as they should be. It appears that the brine flow and moisture release information in the SEIS were taken from another publication(s) where the citations appeared. The references for these documents should also be included in the SEIS if they were not referenced in the missing citations.

5. Page E-57, Equation(8). Shouldn't the parameter listed as 10E14 be listed as 10E-14?

APPENDIX F

1. Page F-2, Stack Effluent Modeling. It should be explained how a stack which exhausts gases and particulates at an acute angle to the horizontal and shrouded to force exit in one direction can be made to fit Rupp's Equation for estimating effective stack height. The resulting effective stack height from the use of this equation is probably not valid. Since it probably affects the shape of the exhaust plume as well, the use of the equation without modification should be verified in the SEIS.

2. Page F-2, Dispersion Modeling. The use of a constant scavenging coefficient is probably not conservative. Precipitation scavenging is about 10 times more efficient than dry deposition mechanisms in removing particulates from the atmosphere and varies with the amount of precipitation. Scavenging should be coupled to precipitation pattern at the site with other parameters such as wind direction and velocity. Precipitation varies both temporally and in amount throughout the year at WIPP with most of the precipitation occurring during the growing season. Where precipitation is more evenly distributed and in larger amounts than occur at WIPP, the assumption may have more validity. If this assumption is to be used for performance assessment, then it should be verified with models which take the stochastic and temporal characteristics of precipitation events at the site into consideration. It does not appear to be a valid assumption at WIPP.

In the case of accidental releases, the occurrence of an accident during an intense precipitation event (or scavenging) should not be discounted as indicated in the SEIS. In fact the probablity of a serious accident is

increased by bad weather conditions which limit visibility and affect road conditions. A scenario of this type should be included in the SEIS as a credible event.

3. Page F-2, Terrestrial Modeling. What is the scientific basis for using 12.5 years (one-half the repository life) as the period of long-term buildup of radioactivity on the soil surface. How does the life of the facility enter into the determination of this process. Why isn't the build-up process modeled?

4. Page F-3, Dose Modeling. The terms "exponential transfer" and "decaying exponential functions" are not used properly when modeling ingestion. The transfer is governed by exponential functions, not exponential transport. Retention of nuclides in organs is represented by exponential functions with negative exponents, not decaying exponential functions.

5. Page F-4, Table F.1, Meteorological Data. It is not clear from the footnote "Categories A-D are not utilized in AIRDOS-EPA Code" how the frequencies for the individual stability classes are adjusted for in the model, unless one stability class is being used in the simulation. The adjustment of frequencies other than A-D should be explained in the SEIS.

6. Page F-8, Table F.5, Stack Information. Are the reported values actual stack heights? If so, then "effective stack heights" should also be included in the Table as estimated from the use of the Rupp equation. How is the correction made for the angular and directional release of the exhaust stack from the repository? Is it valid to apply Rupp's equation to stack(s) in question? If so, please document how this adjustment is made.

7. Page F-9, Table F.6, Terrestrial Modeling Assumptions. How was the build-up time of 4,562.5 days for surface deposition obtained? What is the scientific basis for this determination? Why is the resuspension rate of particulate matter from both soils and plants not taken into account in the model? Also, why have potential contamination pathways involving erosion events (saltation-creep, rainsplash) been ignored in the model since they are important processes in arid sites? Why is it that physical removal of particulates (weathering) from plant surfaces was considered without including these other important processes?

Were the reported biomass densities of forage crops fresh weight or dry weight? In either case, the reported value appears high by a factor of 2-3 above the forage biomass values existing at the site. These larger biomass densities would tend to decrease radionuclide intakes because of tissue dilution of surficial contamination and lower resuspension rates with increasing biomass density and crown cover.

Why is a value of 15.6 kg/day utilized as a consumption rate in lieu of the NRC-reported value of 12.5 kg/day for cattle? A lag period from slaughter of beef to consumption of meat by humans (20 days) is used in the model although it is not that important for transuranics. However, it is not clear whether a similar and more important lag between grazing and slaughter has been incorporated in the model. The build-up of radionuclides in beef tissue during this period is significant, and it is not clear whether this period of radionuclide ingrowth in these tissues has been taken into consideration in making dose calculations. If not, then the total amount of radioactivity ingested by humans from this pathway would be underestimated and incorrect. More

documentation of this process is required in the SEIS.

8. Page F-19, C2: Drum Drop From a Forklift. The use of the average radionuclide content of a drum (12.9 PE-Ci) is not conservative, even though other parameters may have been conservatively assumed. The maximum allowed content (1000 PE-Ci) would have been the most conservative approach, while a value at the 99% c.l. of the activity distribution would have been more realistic in bounding the release. Also, reference is made to the draft FSAR for more specific information concerning this scenario, yet the description is identical to the SEIS; hence no new needed information for evaluation of this scenario is available. Also, the time of exposure of the worker that is 20 feet away is not included in the SEIS (or FSAR) which does not allow straightforward verification of dose calculations in this case. It is not clear what type of exposure would be received by the forklift operator if he became immersed in the cloud. Furthermore, if the operator removed the forklift from the punctured drum before he left the scene, then the activity from the punctured drum would probably reach him before he could shut down the forklift and take flight. This scenario is not conceptually well established as it now stands and needs more study. Finally, what is the scientific basis for the contamination dispersal rate used in these calculations?

9. Page F-22, Hoist Cage Drop. The annual probability of a catastrophic accident is given as 1.7×10^{-8} and concludes that such an accident is not credible. Over a 30-year operational life of WIPP, that becomes 0.51×10^{-6}. EEG has never agreed with the assumptions and calculations used by DOE and still believes such an accident is sufficiently credible to warrant the calculation of the consequences which would require a higher QA classification system than the one used in the hoist system.

The assumption by DOE that faulty maintenance would be negligible as a contributing factor to a potential accident was found to be incorrect when workmen installed a valve backwards in the waste hoist system. Similarly, excluding human error as a contributing factor to a potential accident was found incorrect when the wrong valve was purchased and installed. The assumption that a poor design could not contribute may now be considered unreasonable based on the recent defects found in one of the three main bearings on the hoist shaft. Our position has been expressed in letters to the WIPP Project Manager dated May 15, 1985, October 8, 1985 and April 8, 1986.

EEG is aware that our request in 1980 to address the consequences of a fire in the mine was rejected by DOE on the basis that it was an incredible event. Earlier this month, there was a fire in an instrumentation panel in the mine.

10. Page F-23, Fire Within A Drum Underground. What criteria were used in estimating that 80% of the heated aerosol was deposited on the walls of the repository before leaving in the exhaust stream?

11. Page F-24, R5: Hoist Drop With a Canister of RH Waste. The premise for not including this scenario as a credible accident is the same as C8, and is submitted without proof or evidence in support of the assumption. This information should be provided in the SEIS.

APPENDIX G

1. Page G-4, Summary. The formula for methylene chloride is CH_2Cl_2, not Ch_2Cl_2.

2. Page G-4, 5, Fate and Transport. Reference is made to biodegradation of CH_2Cl_2 occurring both aerobically and anaerobically. A reference or documentation to this effect should be included in the SEIS.

3. Page G-8, Health Effects. Reference is made to an LC50 for rats of 14,000 mg/kg. It appears that LC50 has been confused with an oral LD50; otherwise what do the units refer to in terms of concentration?

4. Page G-24, Long Term Risk Estimation for Non-Carcinogens, Routine Operations. The basis for excluding non-carcinogens if they are present in amounts less than 1% by weight is not clear. Since the reference cited is not readily available (Rockwell, 1985), a summary or explanation of its contents should be included in the SEIS. Also, in equation G-4, the term "Ri" and RLi" appear to reference the same variable. What is the correct usage? If Li is a variable, then it should be defined in the SEIS.

5. Page G-24, 25, Risks Associated With Accident Scenarios. What does the phrase "...to the only occupational population" mean? Also, what is the meaning of "residential exposure," and how does the assumption of filtration validate that the latter are assumed to be excluded from exposure? Does the filtration system also "filter" out VOC's? How does dilution exclude persons from exposure?

APPENDIX H

1. Page H-6. In the section on EEG, add the sentence "EEG has published 40 major reports on their investigation and analyses." That is far more significant than the number of quarterly meetings between DOE and EEG, which appears to trivialize the 11 years of work.

APPENDIX I

In general the SEIS provides information in the form of Tables and Figures which are quite useful for verification purposes. However, in many cases involving dose calculations, some of the assumed parameters are either not present in the SEIS, or must be searched for in an unspecified location in the two volumes. Furthermore, there usually isn't any citation as to where these parameters may be located. This makes it difficult, if not impossible, to verify some of the SEIS dose estimates for a reader that is not familiar with secondary sources which provide this information. This has lead to the use of more than one value in the SEIS for a given parameter and to units for these parameters which give incorrect dimensional analysis in the document itself. Therefore, it is imperative that the assumed values for parameters be presented in the SEIS at each location where doses are being estimated. In addition, many of the parameter estimates are "assumed values" and are presented without any validation of their worth to the reader. All assumed values should be more fully justified in the SEIS to give them more credibility.

Several other problems arise with respect to pathway analyses notwithstanding those already discussed. A major problem is the reliance on established source codes to the extent that flexibility or site-specific alternative pathways or processes of importance to the WIPP site may be excluded. The rationale given in some instances is that many of these processes are not significant and, therefore, are not worthy of analysis. However, the analysis upon which these conclusions are based may be flawed, and have not been validated or proved. Investigators who utilize established codes are not exempt from using realistic input parameters

and from incorporating site-specific information if necessary. An example is the use of the Rupp equation for determining effective stack heights of the two underground exhaust stacks at WIPP: the existing configuration is probably not amenable to this type of analysis, yet it is still utilized in the SEIS for this purpose. Another example concerns the climatology of the WIPP environment: erosion events which may significantly contribute to the atmospheric transport of contaminants to man are ignored because they are not readily incorporated into the codes being used in the analyses. The SEIS is silent on these issues.

There also appears to be a generalized carelessness with respect to the assemblage of transport pathways of contaminants, particularly those involving the food chain. Some of the large discrepancies in dose estimates have been caused by the failure of the SEIS to properly estimate steady-state concentrations of contaminants in soils as a result of air deposition events, and by not accounting for ingrowth of contaminant concentrations in beef tissue beyond one day. These oversights should be addressed in the SEIS.

SPECIFIC COMMENTS

1. Page I-5, top. Arrival times at points of interest for cases 1A and 1B "were determined by the times at which the discharge rates rose to 10^{-18} Ci/day." This extremely low activity represents material discharged per day having an activity of only about <u>one</u> disintegration per <u>year</u>! This represents the extreme leading edge of a distributed nuclide and <u>effective</u> arrival times are <u>longer</u> than stated.

2. Page I-7, The Swift II Groundwater Transport Code, Influence Functions. Figure 1.1.2.1 referred to in the text

is missing, it should be Figure 1.1.1.

3. Page I-13, Table 1.1.3.1, Maximum Dose Received by a Member of the Drilling Crew. Plutonium-239 is cited twice in the Table. Does the first citation refer to Pu-238?

4. Page I-14, Table 1.1.3.2, Radionuclide Concentrations in Dried Mud Pit. Not enough information was presented in the SEIS to reproduce the values in this Table. They were reproduced by using the assumptions presented in SAND 89-0462 (p. 5-9) which was not cited for this purpose. The use of "drum equivalents" for TRU activities is nowhere mentioned in this section (we could not find it in the entire SEIS), yet it is not possible to estimate the values without it. Also, other assumptions: percent solid in mud(50%), density of dried mud (1.4 g/cc) were also found in SAND 89-0462. Curiously, the density of the mud for plume dispersion is given as 2.0 g/cc which is inconsistent. The SEIS should settle on one value for both calculations and "stick" to it.

5. Page I-15, Table 1.1.3.3, Air Concentrations And Deposition Fluxes. The values of Ci/M3 in this Table appear to be about 20+% too low based on eq.(I-37) unless drum equivalent activities are being used. Our calculation is summarized below.

Assumptions:

Mud Density = 2.0 g/cc (p)
Wind Velocity = 3.7 m/s (U)
Resuspension Rate = 5.065E-12 (1/s)
Distance Downwind = 500 M (d)
Plume Vertical Standard Deviation = 40.92 m (Tz)
Plume Lateral Standard Deviation = 57.68 m (Ty)
Depth of Resuspension Layer = 1 cm (do)
Area of Mud Surface = 46.45 m2 (A)
(taken from Pb plume, Page I-29)
Mud Activity = 1.54E-8 Ci/g (CS) for Pu-239
Source Strength = 1e04*p*do*A*K*CS, Ci/s (Q)
Air Concentration = 2*Q/2.51*3*Ty*Tz*U

= (2*2*1*46.45*5.065E-12*1.54E8*1e04)/
(2.51*3*57.68*40.92*3.7)
= 2.2E-18 Ci/m3 (X)
(reported value = 1.68E-18 Ci/m3)

Assuming a density of 1.4 g/cc yields X = 1.54 E-18 Ci/m3 for this parameter, however, recalculation of Ty and Tz:

Ty = 0.11*d/(1+1E-4*d)1/2 = 53.67 m,
Tz = 0.08*d/(1+2E-4*d)1/2 = 36.36 m, which yields a value of:
X = 1.86E-18 Ci/m3.

The FEIS reports a pit area of 66.9 m2 for resuspension of radionuclides and 46.45 m2 is reported for resuspension of Pb from the same mud pit in the SEIS, a factor of 1.4 difference for these estimates. Why do the areas vary? Which one was used in obtaining the reported values? If the higher value was used, then greater disagreement in estimates arises.

6. Page I-16, Table 1.1.3.4, Steady State Soil Concentrations. The steady state soil concentrations as reported in Table I.1.3.4 appear to be very low estimates based on steady state approximation. Our calculation used the following assumptions from SAND89-0462, Page 7-9:

Plow Layer Thickness = 0.2 m (plt)
Soil Density = 1.4e03 Kg/m3 (p)
Sink Loss Rate = 1.1E-4 /d (lr)
Deposition Rate = 1.68E-20 Ci/m2-s
= 1.452E-15 Ci/m2-day (I)
Soil Radionuclide Buildup as a Function of Time, Days, QA(t),
Ci/m2 = (I/lr)*(1-exp(-lr*t), for t=100 years and negligible radioactive decay.
= (1.45E-15/1.1E-4)*(1-exp(-1.1E-4*100*365))
= (1.32E-11)*(1-.018)
= 1.3E-11 Ci/m2
Mass of Soil = plt*1*p
= 0.2*1*1.4e03
= 280kg/m2
Pu-239 Concentration, Ci/kg Soil = 1.3E-11/280
= 4.64E-14 Ci/kg

The reported value = 5.17E-18 Ci/kg, is a factor of 8,975 too low. The details of how this estimate was derived is not included in the SEIS, therefore, it is not possible to compare analytical strategies. Since the relationship between soil concentrations and rem doses is linear, then those contributed from beef, milk, vegetables, and root crops are also underestimated by almost four orders of magnitude. However, other factors also contribute further in underestimating these pathways.

7. Page I-18, Exposure From Stock Well Water. A reference to Table 5.7 should be to Table 5.59. The former refers to annual cumulative exposures from RH-TRU waste, whereas, the latter refers to stock well water concentrations at 1,000 years.

8. Page I-19 to 21, Soil-Plant-Beef Pathway Analysis Using Pu-239 as an Example. The following assumptions were used:

Soil Specific Activity = 5.18E-18 Ci/kg (CPu)
Soil-Plant Transfer Factor = 1.4E-2 Kg-p/Kg-s (SPF)
Forage-Meat Transfer Factor = 1.0E-6 d/Kg-meat (FMF)
Forage Consumption Rate = 15 Kg-p/d (FCR)
Feeding Period to Slaughter = 200 days (FP)
Biological Half-Life = 64000 days (TB)

The concentration in beef after 1 day of feeding ,uCi/Kg-meat, (CBD) is estimated as:

CBD = CPu*SPF*FMF*FCR*1e06 uCi/Ci
= 1.0857E-18 uci/Kg-meat

The concentration in beef after 200 days, uCi/Kg-meat, (CB200D) is estimated as:

CB200D = (CBD/(.693/TB)*(1 - exp(-(.693/TB)*FP))

= (1.0E-13)*(.0022)
= 2.2E-16 uCi/Kg at

If one uses the concentration in beef after one day of feeding, then the committed dose after one-year consumption is estimated as 1.95E-15 mrem/50 year integration. The reported value (1.98E-15) agrees with this estimate quite well, however, it is a factor of 199 too low if the beef concentration at slaughter time (200 days) is used in the estimate, providing all other assumptions are correct. Previously it was determined that soil concentrations were a factor of 8,975 too low, hence an underestimate of as much as 1.82E6 are reported, and the rem dose would be 3.7E-09 mrem/50 year integration. Similarly, the dose contribution from milk, vegetables, and root crops would be a factor of 8,975 too low because of the higher soil radioactivity. The corresponding corrected values for milk, vegetables, and root crops would be 2.8E-13, 3.4E-8, and 1.4E-7 mrems/50 year integration period, respectively. These pathways would yield a total of 1.8E-7 mrems/50 years, whereas the reported dose total equals 1.96E-11 for this radionuclide or a factor of 9,183 too low. Assuming that this underestimate applies to all radionuclides, then the reported dose for these pathways (4.87E-10 mrem/50yr) would be increased to about 4.5E-07 mrem/50 years. Throughout this analysis it has been assumed that a 20cm plow layer has been used for beef cattle grazing such as on winter wheat. If cattle are grazing on open range, then the thickness of the radionuclides deposit is closer to 2cm or the Pu-239 concentration is a factor of ten higher than the corrected value or 4.64E-13 Ci/Kg. Assuming that cattle at the WIPP site consume one pound of soil/day from foraging in an arid environment, then the daily intake would be 2.1E-13 Ci/day from this source. The dose from this pathway alone would be 1.68E-8 mrem/50 year integration period or about 1.3E-8 mrem/50 year when adjusted for that present on vegetation surfaces.

Inclusion of this pathway in the total analysis would increase the dose to 4.6E-07 mrem/50 yr. These values are admittedly small when compared to doses resulting from inhalation, but are not as small as that reported. As commented earlier, the method of estimating deposition using a constant value may yield lower soil activity values than one which employs stochastic methods involving precipitation pattern and precipitation amounts. Also, the contribution of beef cow radionuclide uptake from inhalation and translocation to internal organs and tissues has been ignored in these calculations.

9. Page I-19 to 21, Inhalation Pathway for Humans. The reported dose from this pathway (5.4E-2 mrem/50 yr) compares well with our estimate (5.44E-2 mrem/50 yr).

10. Page I-20, 21, Stock Well Pathway Using Pu-239 as an Example and Case IIB. The values reported for Np-237, Pb-210, Pu-239, and Pu-240 are 1.0E06 too low (column 5); all other values for the rest of this column and for other columns are correct according to the assumptions used. The confusion comes from the use of the relationship presented in the footnote; Column H = FxGx365(days) where F is given in Ci/d, and G is given in rem/uCi, that is H must be multiplied by 1.0E06 to make the conversion to uCi/d before the terms can be multiplied. The conversions were made for all calculations except those noted.

Assumptions for Beef Cows:

Water Consumption Rate = 49 Kg/d (WCR)
Pu-239 Activity in Water = 6.66E-8 Ci/Kg (CWpu)
Water-Meat Conversion Factor = 5.0E-7 d/Kg (WMF)
Feeding Period to Slaughter = 200 days (FP)
Biological Half-Life = 64000 days (TB)

The concentration in beef after one day of drinking water, Ci/Kg-meat, (CBD) is estimated as:

CBD = CWPu*WCR*WMF*1.0e06 uCi/Ci
= 1.66E-6 uCi/Kg

The concentration in beef after 200 days, uCi/Kg-meat, (CB200D) is estimated as :

CB200D = (CBD/(.693/TB))*(1-exp(-(.693/TB)*FP))
= (1.53E-1)*(.0022)
= 3.4E-4 uCi/Kg-meat

The dose obtained when using the Pu-239 concentration in beef after one day of drinking water uptake agrees quite well with that reported (.224 mrem/50yr vs .225 mrem/50yr), however, the concentration after 200 days water consumption is 199 times greater. Therefore, the 50-year committed dose would be 46 mrem/50 yrs on this basis which alone exceeds the EPA Standard. Assuming that this analysis applies to all radionuclides in the water, then the following doses would be projected:

Case IA:	reported = 2.09E-4	corrected = .0425 mrem/50y
Case IIB:	= 72	= 14630
Case IIC:	= 129	= 26213
Case IID:	= .915	= 186

With the exception of Case IA, all cases exceed the standard on this basis.

11. Page I-22, Calculation For Chemical Exposure Pathways. It is not entirely clear why lead is selected as a representative toxic metal in lieu of others, such as cadmium, which may be more toxic, other than it is present in the

highest concentration. Some further explanation of other wastes, including organics, should be included in the SEIS to document or justify this "lead bounding" assumption further.

12. Page I-23, Modeling Assumptions For Calculating Lead Solubility in Culebra Groundwater. Why hasn't the possibility of chelation of metallic ions by organic compounds been considered in these calculations? Some of the compounds used for decontamination purposes are of this type.

13. Page I-27, Health Effects Associated With Stable Lead From Wind Dispersion. Because cattle consume significant quantities of soil, which is present on plant surfaces as a result of erosion processes (lbs/day), it may not be advisable to ignore lead consumption by animals through this pathway. Do any of the models employed incorporate this pathway? Also, why wasn't inhalation of lead contaminants taken into consideration from both ambient and resuspension pathways for these animals?

14. Page I-28, Calculation of Inhalation of Pb Containing Particulates. The variable (RV) is given in units mg/m3/day and m3/day. Dimensional analysis indicates that the latter set of units is applicable. Also, the conversion factor should probably be in mg/g rather than ug/mg for the same reason (although they are equivalent). Finally, the equation incorporating these variables should be:

$$Ir = (Cai)*(RV)*(Tai)*(A)/Wa$$

To obtain the correct units for Ir:

$$(g/m3)(m3/day)(mg/g)(1/kg) = mg/kg/day$$

The reported equation has the variable (A) incorrectly in the denominator. Were the calculations in the SEIS made with the reported equation?

15. Page I-29, Table 1.1.4.5, Calculation of the Ambient Lead Concentration at Receptor Site. The equation used for these calculations shows 2*pi rather than the square root of 2*pi as required (see equation I-37, Page I-14). However, the actual estimate does use the square root value in arriving at the average concentration estimate. This equation should be corrected.

16. Page I-32, Intake by Beef Cattle. The parameter "49.21" is assumed to be the variable (Qw) referenced in Table 1.1.4.5, however, the value reported is 49.0 l/day. Is there any significance to this inconsistency?

17. Page I-35, Waste Porosity. The void ratio, e = Vv/Vrs, is not clear. Is the term "Vrs" actually "Vs" defined as the solid volume? If not, then what is "rs"? Should not the equation be e = Vv/Vs?

18. Page I-25 to 33, Lead Pathway Analysis. The reported value for the concentration of Pb in the drilling mud (3.6E-5 g-Pb/g-mud) agrees with our estimate (3.602E-5 g/g) assuming a mud density (2g/cc), 22,000 gal (1.665E8 g), and 6 Kg of Pb in the mud overall. Two values of air concentration at the designated distance downwind (500 m) are obtained depending on the values of Ty and Tz. Using the reported values (Ty = 57.68 m, Tz = 40.92 m), a value of 5.15E-15 g/m3 is obtained which compares with the reported value (5.16E-15 g/m3) quite well. The value obtained when using the recalculated values of these parameters under the conditions specified (Ty = 53.67 m, Tz = 36.36 m) yields a slightly higher estimate (6.23E-15 g/g). The SEIS text is inaccurate because it confuses g/m3 with ug/m3 in several locations (Page I-27). Also, when radionuclides were being considered, a steady-state concentration of radionuclide

soil concentrations was used as a result of deposition at the receptor site (100 years). Why was only one year of Pb deposition utilized in these analyses assuming parallel exposure scenarios? The reported air deposition at the site after one year (1.63E-9 g/m2) compared with our estimate (1.62E-9 g/m2). However, assuming steady-state accumulation and a Pb loss rate from the plow layer equal to 1.1E-4, then a concentration of 1.45E-5 g/m2 results over a 100-year period as described earlier for radionuclides. Estimation of Pb concentration uptakes in mg/kg/day for beef cattle via this pathway is based on the following assumptions:

Soil Pb Concentration = 1.45E-5(g-Pb/m2)/280(Kg-s/m2)
= 5.2E-8 g/Kg (CPb)
Soil-Plant Transfer Factor = 0.1 Kg-p/Kg-s (SPF)
Forage-Meat Transfer Factor = 3.0E-4 d/Kg-meat (FMF)
Forage Consumption Rate = 15 Kg-p/d (FCR)
Feeding Period to Slaughter = 200 d (FP)
Biological Half-Time = 1460 d (TB)

The concentration in beef after one day of feeding, g/Kg-meat, CBD is estimated as:

CBD = CPb*SFP*FMF*FCR
CBD = CPb*SPF*FMF*FCR
= 2.3E-11 g/Kg-meat

The concentration in beef after 200 days, g/Kg-meat (CB200D) is estimated as:

CB200D = (CBD/(.693/TB)*(1 - exp(-(.693/TB)*FP))
= (4.85E-8)*(.091)
= 4.4E-09 g/Kg-meat

This analysis agrees with the statement in the SEIS that this pathway contributes an insignificant Pb burden to humans.

Pathway analysis on plant food consumption yields comparably low values as well, even after steady-state soil concentrations are reached.

The calculation involving the inhalation of Pb by humans is flawed in the following ways:

A. The relationship used is in error. The relationship requires the conversion factor 1000 mg/g to be in the numerator:

Ir = Ca(g/m3)*RV(m3/d)*Ta1*A(mg/g)/Wa(Kg)
= mg/Kg/day

B. The concentration employed is 5.16E-9 g/m3 which is 5.16E-9 ug/m3; thus, the value 5.16E-15 g/m3 is correct.

The calculation yields, (5.16E-15)(20)(.35)(1000)/70 = 5.16E-13, which yields the reported value by coincidence. In addition, there are two sets of units for RV.

19. Page I-30, Transport of Pb From Stock Water to Beef Cows. The reported concentration of Pb in stock well water (2.31 mg/l) was obtained from a 10 mg/l prediction of SWIFT-II allowing for lateral dispersion of 4.2 which gives an estimate of 2.38 mg/l from the ratio 10/4.2. The correction for dispersion was not mentioned in connection with radionuclide concentrations, and the SEIS should document that SWIFT-II does not make this correction in its operation. The following assumptions were used to predict the transport of Pb from well water to beef cattle:

Concentration of Pb in Well Water = 2.31 mg/l (CPbW)
Water Consumption Rate = 49 Kg/d (WCR)
Water-Meat Conversion Factor = 3.0E-4 d/Kg (WMF)
Feeding Period to Slaughter = 200 d (FP)

Biological Half-Life = 1460d (TB)

The concentration of Pb in beef after 1 day of drinking water, mg/Kg-meat (CBD) is estimated as:

$$CBD = CPbW*WCR*WMF$$
$$= 0.034 \text{ mg/Kg-meat}$$

The concentration in beef after 200 days, mg/Kg-meat (CB200D) is estimated as:

$$CB200D = (CBD/(.693/TB))*(1 - \exp(-(.693/TB)*FP))$$
$$= (71.6)*(0.091)$$
$$= 6.48 \text{ mg/Kg-meat}$$

The reported concentration is equal to that estimated using one day of drinking water. However, the concentration after 200 days of drinking is 191 times higher than that reported. Therefore, the daily intake of Pb by humans is 2.79E-3 mg/Kg/day instead of the reported value (1.46E-5 mg/Kg/day). The corrected hazard index (HI) is equal to 6.4 which indicates that the EPA Standard is exceeded in this scenario by this amount.

ATTACHMENT 1

Informal Analysis of WIPP Capacity for CH and RH Wastes
S. E. Logan, May 1989

Reference volumes used in calculations are as follows:

	m^3	ft^3	Drum Equivalents
55 Gallon Drum	0.208	7.35	1
Standard Waste Box	1.798	63.51	8.64
RH Canister	0.850	30.02	

WIPP "Capacity":

CH TRU	6.2E6
RH TRU	2.5E5

CH Waste

The capacity of a room is generally stated to be 6,000 drums. A review of the CH Criticality Safety Analysis report, shows that 6,750 drums can ideally be accommodated in a room if the slip sheet alignment tabs are oriented lengthwise in the room with alternate seven-packs staggered for close packing. This is essentially 15 drums wide, 150 drums long, and three tiers high. Allowing for some over packed drums and emplacement anomalies, the 6,000 value appears to be a reasonable average.

An array of Standard Waste Boxes (SWB) six boxes wide, average of 55 boxes long, and three tiers high, representing a total of 990 boxes, can be accomplished if half of the boxes are placed lengthwise and half are placed crosswise across the room width. However, if seven boxes are placed with the small dimension across the room by 50 boxes long, 1,050 boxes can be placed in a room using three tiers (700 boxes with two tiers). But, the CH Criticality Analysis is ambiguous about whether two

tiers or three tiers will be used.

The capacity of a room becomes:

	Drums	Boxes	Drum Equivalents
Drums, maximal	6,750		
nominal	6,000		6,000
SWB, 3 tiers		1,050	9,072
2 tiers		700	6,048

The CH waste storage areas are calculated to be as follows:

	m^2
One room	920
One panel	11,664
Total, 8 panels	93,308
Central zone	20,382
Total	113,690

These areas include the effect of area loss to isolation plugs, except no isolation plugs are included for division of the central zone into two halves (division is indicated in the SEIS).

The multiplier for total capacity as compared to the capacity of one room is:

$$113,690/920 = 123.6$$

This assumes that the areal efficiency is the same throughout the CH storage area, although it has not been shown that drifts as narrow as 14 feet can accommodate seven-packs and SWB's with the same packing efficiency as in the 33 foot-wide rooms. Using the above multiplier, the WIPP capacity

becomes:

	Number	Drum Equivalents	ft^3
All as drums	741,600	741,600	5.45E6
All as SWB, 2 tiers	86,520	747,533	5.49E6
3 tiers	129,780	1,121,299	8.24E6

The draft source term document (DOE, 1988) indicates that the projected division by volume between drums and the SWB is 65% in drums and 35% in the SWB (number of containers 94.2% and 5.8%, respectively).

Some calculations are needed at this point.

Let D = number of drums

D_T = total number if all drums (741,600)

B = number of boxes

B_T = total number if all boxes (129,780 in 3 tiers, 86,520 in 2 tiers)

V_d = volume of drum, ft^3 (7.35)

V_b = volume of box, ft_3 (63.51)

C = total waste volume capacity of WIPP, ft^3

Then, for 65% by volume in drums, and 35% by volume in boxes:

$$DV_d = 0.65\ C \qquad (1)$$

$$BV_b = 0.35\ C \qquad (2)$$

$$DV_d + BV_d = C \qquad (3)$$

$$D/D_T + B/B_T = 1 \qquad (4)$$

Solving equations 1 through 4 for D, B, and C, the following results are obtained for numbers of drums and boxes, and WIPP waste volume capacity:

	Number	Drum Equivalents	ft^3
Drums	546,951	546,951	4.020E6
3 Tiers of Boxes	34,076	294,417	2.164E6
Total	581,027	841,368	6.184E6
Drums	483,741	483,741	3.555E6
2 Tiers of Boxes	30,115	260,194	1.912E6
Total	513,856	743,935	5.468E6

Note that here waste volume is taken to be container volume. On this basis, the WIPP has a capacity approximately equal to the generally stated 6.2E6 ft^3, providing at least 5.8% of the containers (35% of the volume) is emplaced in SWB's, and that all SWB's are placed three tiers high. If only two tiers of SWB's are used, the WIPP capacity is less than 5.5E6 ft^3 regardless of the drum/SWB mix. Adding isolation plugs in the central zone reduces storage area by approximately 600 m^2 or 0.5% of the total. This eliminates about 3,900 drum equivalents of storage space. This decreases the drum/3-tiers-of-SWB total from 841,368 drum equivalents by 3,900 to 837,468 drum equivalents (6.155×10^6 ft^3).

If we adjust the total waste volume slightly from 6.155×10^6 ft^3 to the "design" 6.2×10^6 ft^3 (a factor of 1.0073), it corresponds to adjusting the calculation basis of 6,000 drums/room up to 6,044 drums/room. The net WIPP capacity then becomes as follows:

	Number	Drum Equivalents	ft^3
Drums	548,361	548,361	4.03E6
3 Tiers of Boxes	34,164	295,176	2.17E6
Total	582,525	843,537	6.20E6

Recently, major DOE documents have emerged, notably the SEIS, that erroneously interpret the 6.2E6 ft^3 "waste capacity"

of WIPP to be the volume of settled contents of containers instead of the volume of the containers themselves. Using an average "fullness" of 80%, this leads the SEIS to increase the number of drums by a factor of 1/0.80 = 1.25, which would increase the actual capacity of 843,537 drum equivalents (with 3-tier SWB component) to a fictitious 1.05 million drums (the SEIS uses 1.10 million). There simply is no space for the "extra" 256,463 drums!

RH Waste

The WIPP capacities for RH waste are generally stated as 250,000 ft^3 or 6,000 canisters. At 30 ft^3 per canister, the two values are not consistent. 250,000 ft^3 represents 8,300 canisters, and 6,000 canisters represents 180,000 ft^3. The planned nominal spacing is eight feet along CH storage walls. The total CH storage perimeter has been calculated to be 26,000 m, including the central zone between the two sets of panels. This would indicate a maximum number of horizontal RH storage holes, on 8-foot centers, of 10,663. Subtracting 672 to avoid interference at 336 corners and 100 for possible isolation plugs added in the central zone leaves a capacity, with full wall utilization, of 9,890, though some reports indicate the total requirement is for about 4,800. Looking at this another way, utilizing 8,300/9,890 = 84% of the available wall for RH would provide for 250,000 ft^3, 61% of the wall would provide for 6,000 canisters, and 49% of the wall would provide for an expected 4,800 canisters. If the central zone is not available for RH emplacement (can the hole boring and emplacement equipment operate in a 14-foot-wide drift?), the wall perimeter is reduced 29% to 18,439 m and the corresponding number of emplacement holes is limited to 7,562 - 416 = 7,146. This would accommodate 2.15E5 ft^3 of RH waste (will not accommodate 2.5E5 ft^3). Some of this potential RH storage wall perimeter may not be accessible after experimental emplacement of CH waste. If longer holes are bored to accept two or more RH

canisters, additional wall perimeter becomes unavailable to avoid interference, but a net increase in emplacement can be obtained.

References

(DOE, 1988) "Radionuclide Source Terms for the Waste Isolation Pilot Plant," working draft report.

(DOE, 1989) "Draft Supplement Environmental Impact Statement," SEIS.

Environmental Evaluation Group
Reports

(Continued from Front Cover)

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (ed), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kerney, Jim W., A Critical Assessment of Continuous Air Monitoring Systems At The Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

EEG-40 Review of the Final Safety Analysis Report (Draft), DOE Waste Isolation Pilot Plant, May 1989.

EEG-41 Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, July 1989.

EEG-42 Chaturvedi, Lokesh, Evaluation of the DOE Plans for Radioactive Experiments and Operational Demonstration at WIPP, September, 1989.

EEG-43 Kenney, Jim W., John C. Rodgers, Jenny B. Chapman, and Kevin J. Shenk, Preoperational Radiation Surveillance of the WIPP Project by EEG, 1985-1988, January 1990.

EEG-44 Greenfield, Moses A., Probabilities of a Catastrophic Waste Hoist Accident at the Waste Isolation Pilot Plant, January 1990.

EEG-45 Silva, Matthew K., Preliminary Investigation into the Explosion Potential of Volatile Organic Compounds in WIPP CH-TRU Waste, June 1990.

ENVIRONMENTAL EVALUATION GROUP

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EEG-50

IMPLICATIONS OF OIL AND GAS LEASES AT THE WIPP ON COMPLIANCE WITH EPA TRU WASTE DISPOSAL STANDARDS

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New Mexico

June 1992

Environmental Evaluation Group Reports

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979.

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volume I and II, December 1978.

EEG-3 Neill, Robert H., et al., (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U.S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, October 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, October 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter, Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon - A Single Hole Scenario, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter and Dave Updegraff, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals (WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-Radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell, Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter, Proposed Preoperational Environmental Monitoring Program for WIPP, November 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

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IMPLICATIONS OF OIL AND GAS LEASES AT THE WIPP ON COMPLIANCE WITH EPA TRU WASTE DISPOSAL STANDARDS

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FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health, safety, and environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for permanent disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the funding from DOE under contract DE-AC04-79AL10752 as DE-AC04-89AL58309.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and in surrounding communities.

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EXECUTIVE SUMMARY

A decision by the U.S. Department of Energy (DOE) to proceed with the disposal of transuranic waste at the Waste Isolation Pilot Plant will require the DOE to determine compliance with Standards (40 CFR 191) issued by the Environmental Protection Agency (U.S. EPA, 1985).[1] The Standards recognize that future exploration for natural resources sometime during the next 10,000 years could disrupt the integrity of the repository and release radionuclides to the biosphere and require consideration of inadvertent human intrusion. The Standards appear to allow the assumption that active institutional control will completely deter human intrusion for 100 years. At the WIPP, the DOE has assumed active control will prevent any human intrusion during this period. After 100 years, the Standards allow credit for passive institutional controls such as public records and markers to reduce the risk of human intrusion.

The U.S. Department of Energy (DOE) documentation overlooked two active oil and gas leases and a gas well within the WIPP Site Boundary in spite of lease, drilling, and production records filed by the oil company with the federal government; a condemnation suit filed in civil court by the federal government in 1977; a Consultation and Cooperation Agreement between the State of New Mexico and the federal government; a Memorandum of Understanding between agencies of the federal government recognizing the existence of these leases; technical reports funded by the federal government on area oil and gas resources; and the visible existence of a producible gas well from the south access highway to the WIPP facility.

---

[1]The DOE has sole regulatory authority to make a determination of compliance of the WIPP facility with Environmental Protection Agency (EPA) Standards and proceed with the WIPP as a repository. Legislation pending before Congress would transfer that authority to another agency.

Several important DOE documents are either incorrect, silent, or inconsistent on the existence of these leases. For example, the Final Environmental Impact Statement (FEIS, U.S. DOE, 1980, pp. 8-8—8-10) identifies the oil and gas leases held by ten companies in March 1979, yet the 1952 Conoco and 1957 Bass leases in the southwest corner of the WIPP Site on Section 31 are not mentioned. The WIPP Final Safety Analysis Report (WIPP FSAR, U.S. DOE, 1990a, Section 2.1.1.1), incorrectly states that there are no active oil and gas leases within the WIPP Site Boundary and fails to chart the intruding well on its map of producible oil and gas wells. The DOE No-Migration Variance Petition to the EPA incorrectly states that the DOE has purchased all oil and gas leases in the area of the WIPP site to prevent any exploration now and in the future (U.S. DOE, 1990b). The Secretary of Energy's Decision Plan monitored the status of an active potash lease until it was purchased by the DOE but remained silent on the active oil and gas lease issue even after an article in the Albuquerque Journal raised the issue (McCutcheon, 1990). The recently published DOE Implementation of the Resource Disincentive document, (U.S. DOE, 1991) is inconsistent on the number of active oil and gas leases within the WIPP Site Boundary and on the production status of the forgotten gas well.

The actual experience of forgotten oil and gas leases at the WIPP strongly suggests that the U.S. Environmental Protection Agency and the U.S. Department of Energy need to reexamine the assumption that active institutional control will be completely effective for 100 years after disposal and how much credit should be taken for passive institutional control between 100 and 10,000 years. The EPA Standards should require the implementing agency to publish specific plans on how the agency intends to maintain active institutional control. Even in the absence of such a requirement, the DOE should publish plans now that specify in detail how the Department intends to maintain control at the site for 100 years after decommissioning and describe how that control will completely deter human intrusion. Finally the DOE needs to describe in detail their passive institutional control system and show how it will provide a deterrence to inadvertent human intrusion after 100 years.

1.0 STATEMENT OF PROBLEM

Most analyses of the safety of a nuclear repository identify scenarios of inadvertent human intrusion for natural resource exploration as the most likely mechanism to return unwanted radioactive residuals to the biosphere. The question arises as to how long our institutions would maintain knowledge of the repository as a deterrent to an unplanned release. The U.S. Environmental Protection Agency (EPA) has issued Standards (U.S. EPA, 1985) which allow the implementing agency to take credit for active institutional control, for up to 100 years after decommissioning. Beyond 100 years, the EPA Standards allow credit only for passive institutional controls such as markers, public records and archives, government ownership and regulations regarding resource use and other methods of preserving knowledge.

On November 3, 1990, the Albuquerque Journal reported the rediscovery of a natural gas well that had been completed beneath the WIPP Site Boundary.

> [Department of Energy] Officials had previously believed that they had acquired all existing mineral leases at the site as part of their push to open WIPP for testing.... officials had known of the well years ago but rediscovered its existence only recently.... Department records indicate the well was drilled in about 1981 or 1982 after its owners obtained permission from the federal Bureau of Land Management, the current owner of WIPP's land.... After the well was first drilled, its owners decided to slant it underground, still keeping it off the site, officials said. When WIPP's geographic configurations were later remapped, the bottom of the well wound up appearing inside the underground boundary of WIPP lands.... (McCutcheon, 1990).

This report focuses on the history of two oil and gas leases and one well completed within the WIPP Site Boundary that were overlooked by the DOE for several years. The incident is important because it indicates that active institutional control and passive institutional control, such as markers and records, do not always deter

unwanted drilling activity or effectively convey necessary information to decision makers. The report addresses the question of whether the EPA and the DOE are assuming more credit for the deterrent value of institutional controls than is warranted.

The decision by the DOE to use the WIPP as a repository for defense transuranic waste will depend in part on results of performance assessment analyses required by the EPA Standards (40 CFR 191). The performance assessment analyses calculate the probability and quantities of radionuclides released into the accessible environment for different breach scenarios within the first 10,000 years after disposal. The Standards for disposal of radioactive waste were issued by EPA in November 1985. Subpart B was vacated by the First Circuit Court of Boston in June 1987. EPA is not expected to promulgate the revised Standards before mid-1993 (SNL, 1991). Until the revised Standards are available, the State of New Mexico and the U.S Department of Energy have agreed to use the 1985 Standards as a basis for performance assessment planning (U.S. DOE, 1981). At the present time, the Department of Energy has the sole authority to use the analyses to determine if the DOE WIPP facility complies with the Standards yet to be repromulgated by the EPA. The remanded Standards required the consequences of inadvertent human intrusion to be calculated because such an event could significantly disrupt the integrity of a repository.

Guidance to the Environmental Protection Agency's *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, 40 CFR 191* (U.S. EPA, 1985) allows credit to be taken for active institutional control when making assumptions about the frequency and severity of human intrusion into the repository. Specifically, the Guidance states "... the implementing agency will assume that none of the active institutional controls prevent or reduce radionuclide release for more than 100 years after disposal" (U.S. EPA, 1985, p. 38088). The statement in the latest working draft of the Guidance remains

unchanged (U.S. EPA, 1992, p. 30). This Guidance appears to allow the repository operator to assume that active institutional control will deter all inadvertent human intrusion. In the WIPP performance assessment calculations, Sandia National Laboratories (SNL) has assumed active institutional control will be maintained for 100 years and this control will be 100 percent effective in deterring human intrusion (Sandia National Laboratories, 1991, p. 2-5) even though the DOE has made no commitment to maintain active control at the WIPP for any specific length of time.

This report does not address the issue of whether the "forgotten" gas well, which is completed within the WIPP Site Boundary, is a hazard to the long-term safety of the repository. Only the implication of the effectiveness of institutional controls is being addressed.

2.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is ultimately intended to serve as a repository for the safe disposal of transuranic waste generated by the defense activities of the United States Government. The anticipated inventory includes a maximum of 176 000 cubic meters (6.2 million cubic feet or 850,000 drum equivalents) of contact-handled transuranic (CH-TRU) waste and about 7100 cubic meters (250,000 cubic feet or 8,000 canisters) of remote-handled transuranic (RH-TRU) waste. The CH-TRU waste is estimated to contain 9 million curies of activity. The activity of the RH-TRU waste is limited to 5.1 million curies.

The repository is located in the Los Medaños area in southeastern New Mexico, 17 miles (28 kilometers) east-northeast of the city of Loving and 25 miles (40 kilometers) east of the city of Carlsbad and the repository is sited at a depth of 2,150 feet (655 meters) in the lower part of a 1,970-foot (600 meters) thick salt formation.

The area of land that lies within the WIPP Site Boundary is a square four miles (6.44 kilometers) on a side. It contains 10,240 acres (4144 hectares) including Sections 15, 16, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, and 34 in T22S, R31E, NMPM in Southeastern New Mexico (U.S. DOE, 1990a, Section 2.1.1.1)

Figure 1 illustrates the WIPP boundary and the areas of Zone I and Zone II. Zone I contains the WIPP facility surface structures, is surrounded by a chain link fence, and covers about 35 acres (14 hectares) in Sections 20 and 21. Zone II defines the maximum extent of the area for underground development. The WIPP Site Boundary provides a minimum one mile (1.6 kilometers) buffer area of intact salt around Zone II (U.S. DOE, 1990a, Section 2.1.1.1).

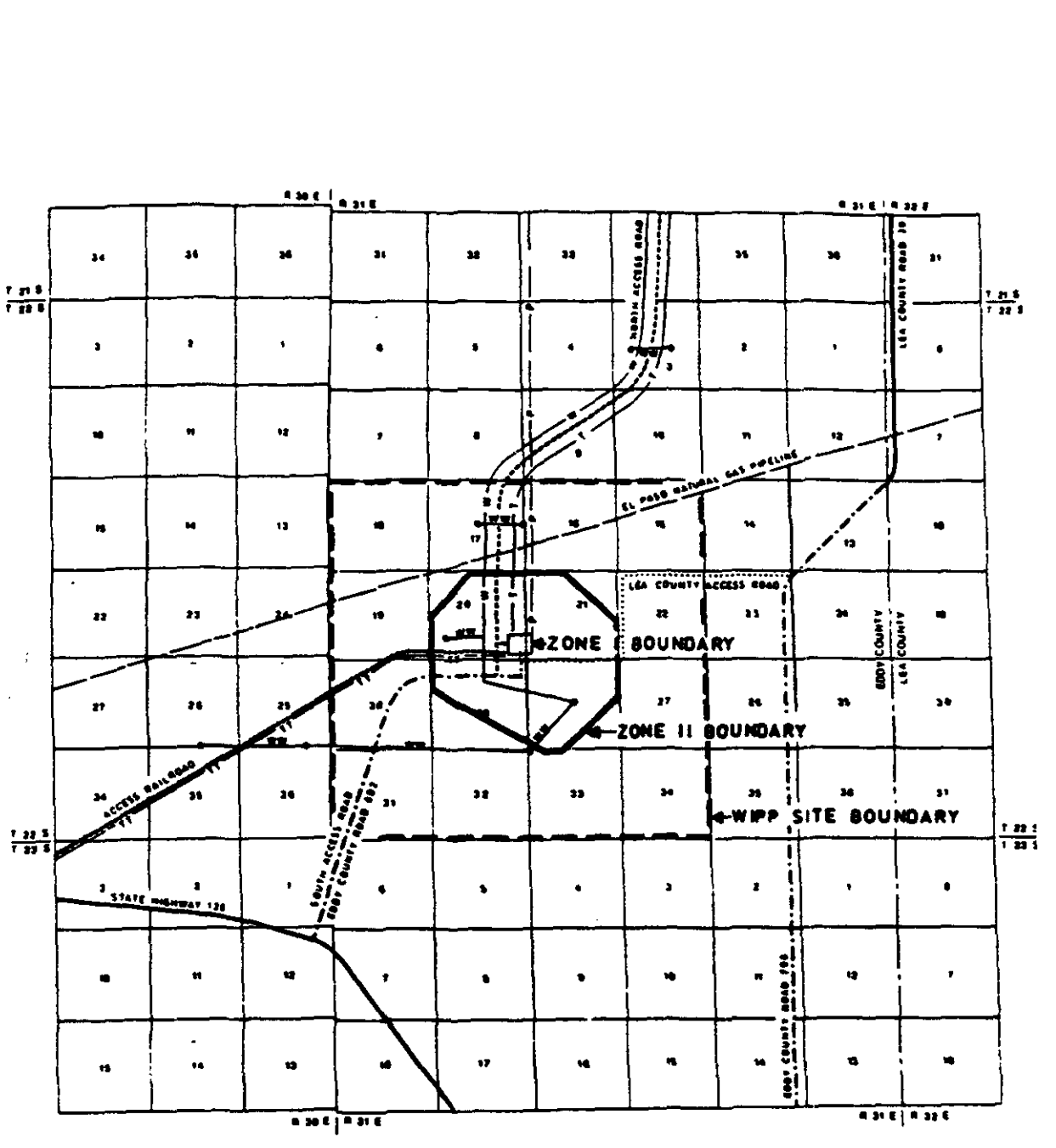

Figure 1. 1990 Zone I, Zone II, and WIPP Site Boundaries. From Figure 2.1-3, WIPP FSAR. (U.S. DOE, 1990a, reproduced with permission).

Although the designations of Zone III and Zone IV are no longer used, they merit a brief description because much of the initial WIPP documentation refers to these zones. The location of Zones III and IV are shown in Figure 2.

Zone III essentially provided a one-mile (1.6 kilometer) buffer around Zone II. In Zone III, all mining, other than for the repository, and deep drill holes penetrating through the evaporites were prohibited (U.S. DOE, 1980, p. 8-4).

Zone IV provided a one-mile (1.6 kilometer) buffer around Zone III. Within Zone IV, conventional potash mining would be permitted but solution mining was prohibited. Deep drill holes were also allowed but water flooding and massive hydrofracture for hydrocarbon recovery would not be permitted. The Final Environmental Impact Statement also noted existing oil and gas wells producing in this zone will be permitted to continue through their useful lives. To protect the repository, they will be sealed as prescribed by the DOE when abandoned. New wells for oil and gas production may be drilled in conformance with DOE standards to facilitate eventual plugging (U.S. DOE, 1980, p. 8-4).

When Zone IV was relinquished by DOE as being unnecessary, the Zone III boundary was "squared off" and the new site boundary extended into the former Zone IV at the four corners (Weart, 1990). Hence, the current four mile (6.44 kilometers) by four mile WIPP Site Boundary[2] also provides the one-mile buffer originally established as Zone III.

[2]Throughout this report, the term "WIPP Site Boundary" refers to the four mile by four mile area described above and the term "WIPP Site Area" refers to the approximately thirty-two square mile area that includes all of Zone IV.

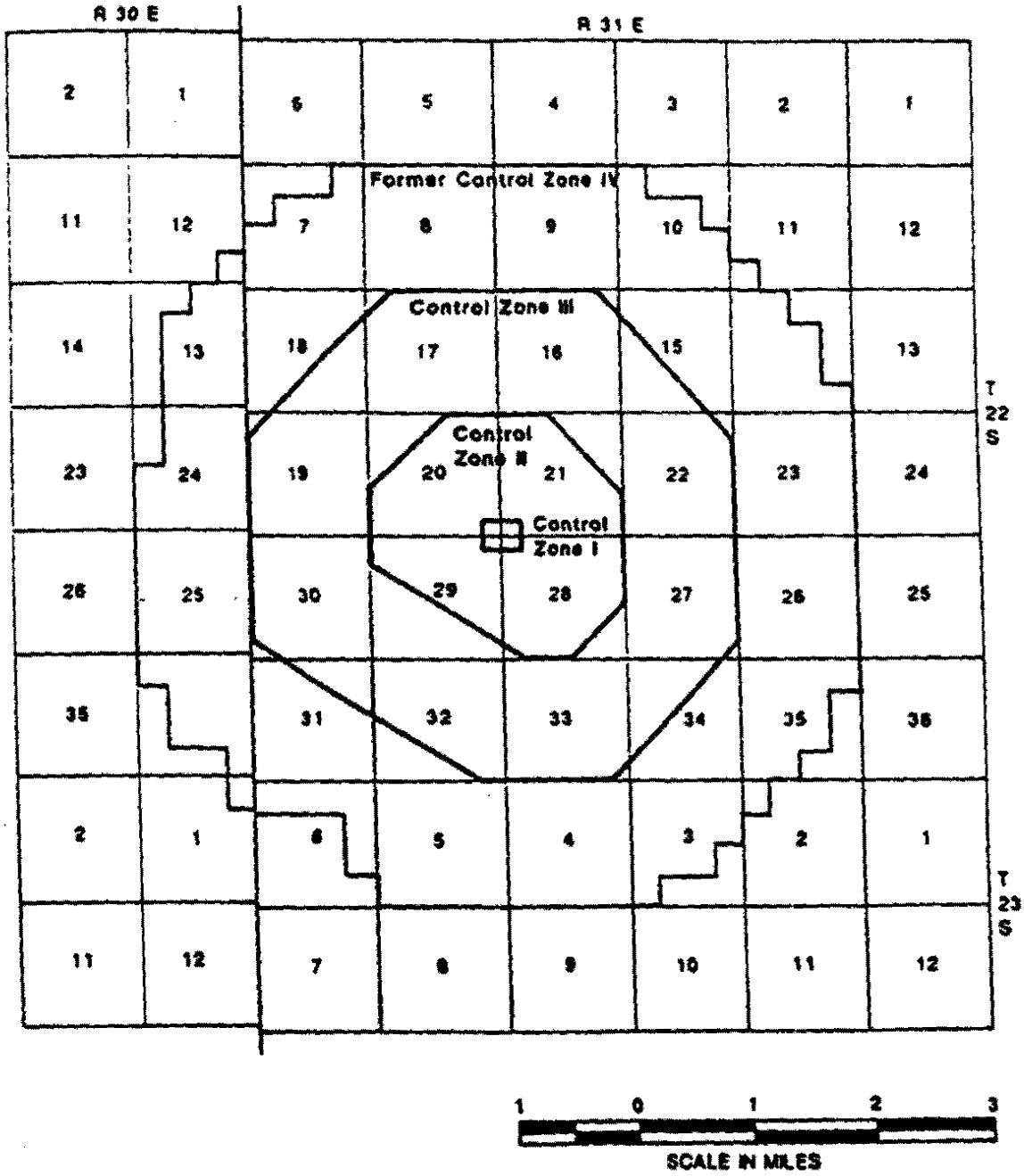

Figure 2. 1980 Control Zones at the WIPP Site. (FSEIS, U.S. DOE, 1990d, reproduced with permission).

3.0 REPORTS ON PETROLEUM RESOURCES AND LEASES

EPA's requirements for establishing a repository in a resource rich area were clearly stated in 40 CFR 191.14(e):

> Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas.... Such place shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future (U.S EPA, 1985).

From 1976 through 1980, SNL published several reports on the mineral resources in the Los Medaños area. Each discussed oil and gas resources.

A report by the petroleum consulting firm of Sipes, Williamson, and Aycock, Inc. (Keesey, 1976) focused on estimating the remaining economically recoverable oil and gas reserves underlying the proposed disposal site. The evaluation was intended to serve as a guideline to SNL in determining the acceptability of the "site area" and the potential value to the owners of the hydrocarbon rights.

Griswold's (1977) subsequent evaluation of site selection and mineral resources incorporated the information provided by Keesey (1976).

Powers, et al. (1978) prepared the geological characterization report for the WIPP citing the work of Keesey (1976) and Griswold (1977) as well as earlier work by Foster (1974).

Keesey (1977) provided a more detailed analysis of the hydrocarbon resources including those in Section 31, T22S, R31E, the section containing the active gas leases in the southwest corner of the current WIPP Site Boundary. The study was limited to surface and subsurface rights to 6,000 feet (1829 meters), which were eventually condemned and purchased by the federal government in 1979. The evaluation did not include the deeper resources.

Keesey (1979a) evaluated the feasibility of directionally drilling for oil and gas reserves under the WIPP Site Area, which, by previous definition, included Zone IV. It was technologically feasible to drill into gas and condensate reserves underlying the WIPP Site Area from outside the WIPP Site Area.

Keesey (1979b) updated the estimated potential hydrocarbon reserves and associated costs and incomes for oil and gas underlying the WIPP. The estimates were intended for use in the Environmental Impact Statement for the WIPP being prepared by Westinghouse Electric Corporation. The estimates were not intended to represent future net revenue values normally used by the petroleum industry to determine the fair market value of oil and gas producing properties. The undiscounted value of the gas and condensate reserves underlying the WIPP Site Area (including Zone IV) was determined to be $287,502,346 (Keesey, 1979b, p. 6; U.S. DOE, 1980, p. 7-72).

4.0 HISTORY OF NATURAL GAS EXPLORATION AND PRODUCTION

The WIPP site is situated in the northern portion of the Delaware Basin. While there were no oil or gas wells within the 32 square miles (8288 hectares) of Zone IV in 1976, oil and gas were being produced from 60 wells in a 368 square-mile (95 312 hectares) area surrounding the site. Although the area was considered to be potentially rich in hydrocarbon reserves, extensive deep drilling had not been ventured in the New Mexico portion of the Delaware Basin. Only 10 to 15 percent of the available acreage had been investigated. The lack of more complete drilling and development was attributed to several factors including historically restrained gas prices, a higher exploration risk due to the varying depositional environment, a lack of readily available pipelines during earlier periods, and moratoriums on drilling in the potash areas to prevent methane gas from entering potash mines (Keesey, 1976; Powers et al., 1978).

As noted by Griswold (1977), the energy crisis of the mid-1970's had driven up the price of natural gas at least fourfold in just two years, prompting a renewed interest in previously unattractive areas. In 1977, deep exploratory drilling for natural gas was underway throughout the Delaware Basin. Just prior to the publication of Griswold's report, three different companies applied for drilling permits in the Los Medaños site area.

Known petroleum production in the area extended from the Delaware Formation (mean depth 4,200 feet; 1280 meters) down to the Morrow Formation (mean depth 13,400 feet; 4084 meters). The deeper Morrow sandstones and the overlying Atoka sandstones of the Pennsylvanian series held the best promise for commercial natural gas production (Griswold, 1977).

In addition to several single well fields, there were two major producing fields in the Los Medaños area. Five wells were producing gas from the Morrow Formation in the Cabin Lake field just northwest of the WIPP site. A five-well field, the Los Medaños Field, was producing gas from both the Morrow and the Atoka Formations just southwest of the WIPP site.

4.1 Shell James Ranch Unit No. 1 - A Prolific Gas Well

A very productive gas well is located two thousand feet (610 meters) west of the WIPP site in the southwest corner of Section 36, T22S, R30E. The location is shown in Figure 3. Known as the Shell James Ranch Unit No. 1, the well was drilled, in 1957, to a total depth of 17,555 feet. The well was completed in the 12,920 to 12,929 foot (3938 to 3940 meters) interval for production of gas and oil condensate from the Los Medaños-Atoka Formation and has been producing since 1958.

The well has been prolific throughout its production history. Initial twenty-four hour production was 9,000 MCF gas and 104 BBLs condensate.[3] As of mid-1976 cumulative production exceeded 17,000,000 MCF (481 000 000 cubic meters) of gas and 200,000 barrels (32 000 cubic meters) of condensate. The gas production rate from that single well in 1976, was over 100,000 MCF (2 800 000 cubic meters) per month. Keesey (1976) calculated the James Ranch Unit No. 1 would ultimately recover 35,900,000 MCF (1 billion cubic meters) of gas and 425,000 barrels (68 000 cubic meters) of condensate.[4] The history of gas and condensate production since 1970 is shown in Figure 4.

---

[3]An MCF is equal to one thousand standard cubic feet (28.32 cubic meters) of gas. A BBL is equal to one barrel (0.159 cubic meters) of oil or condensate.

[4]As of August 1, 1991, production records filed with the U.S. BLM for the James Ranch Unit No. 1 show that cumulative gas production has exceeded 25,000,000 MCF and condensate oil production has exceeded 270,000 BBLs.

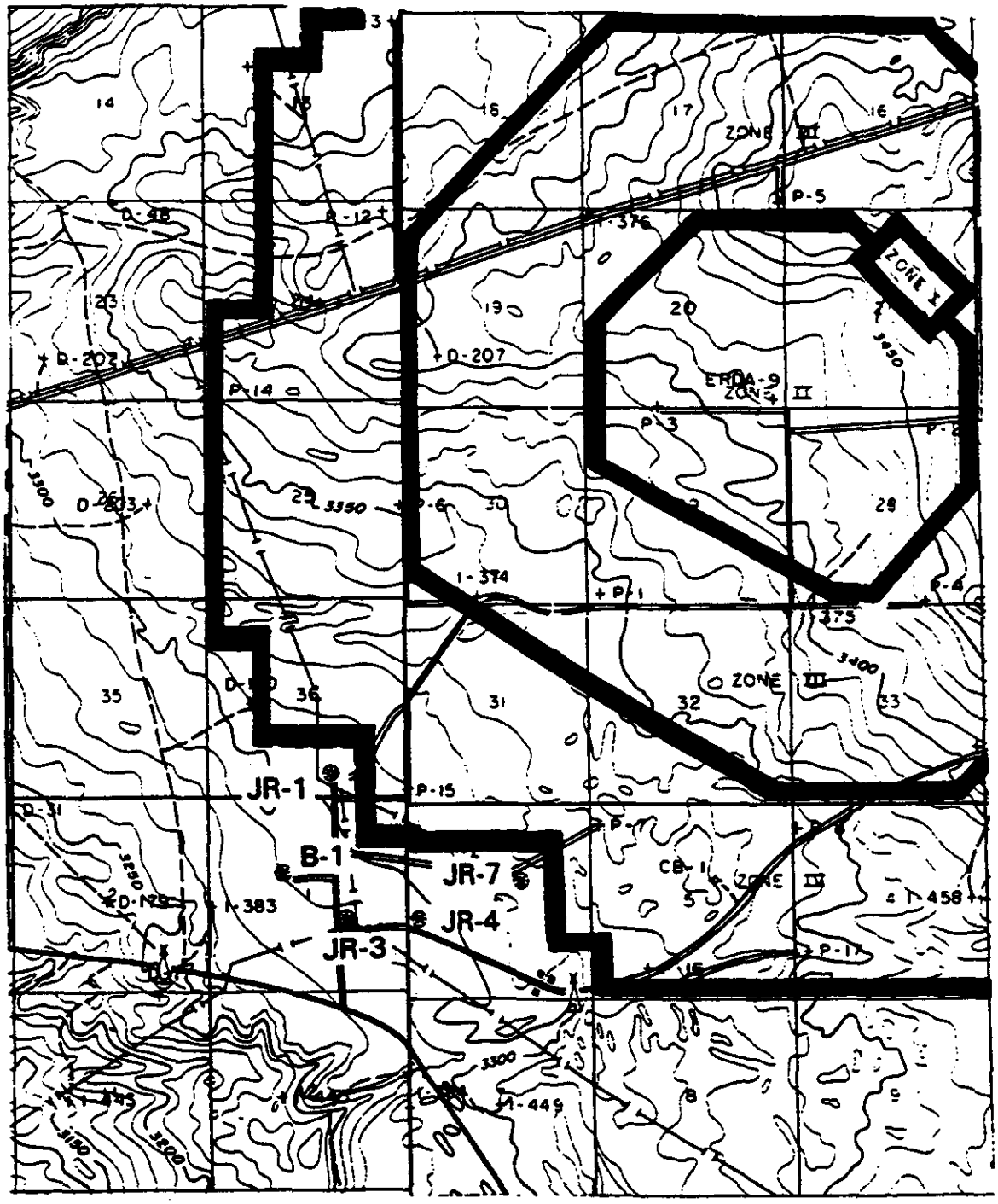

Figure 3. Five Gas Wells Outside Southwest Corner of WIPP Site in 1977. James Ranch Unit No's 1, 3, 4, 7 and Hudson Federal No. 1 (B-1). (after Griswold, 1977, Figure 4, highlighted and reproduced with permission.)

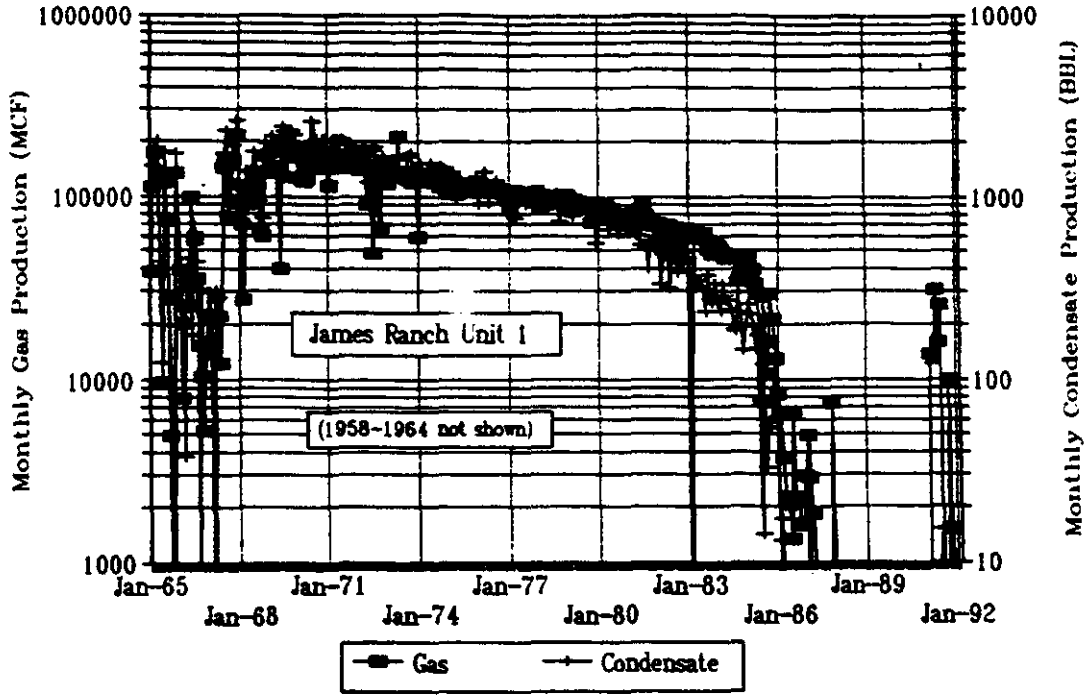

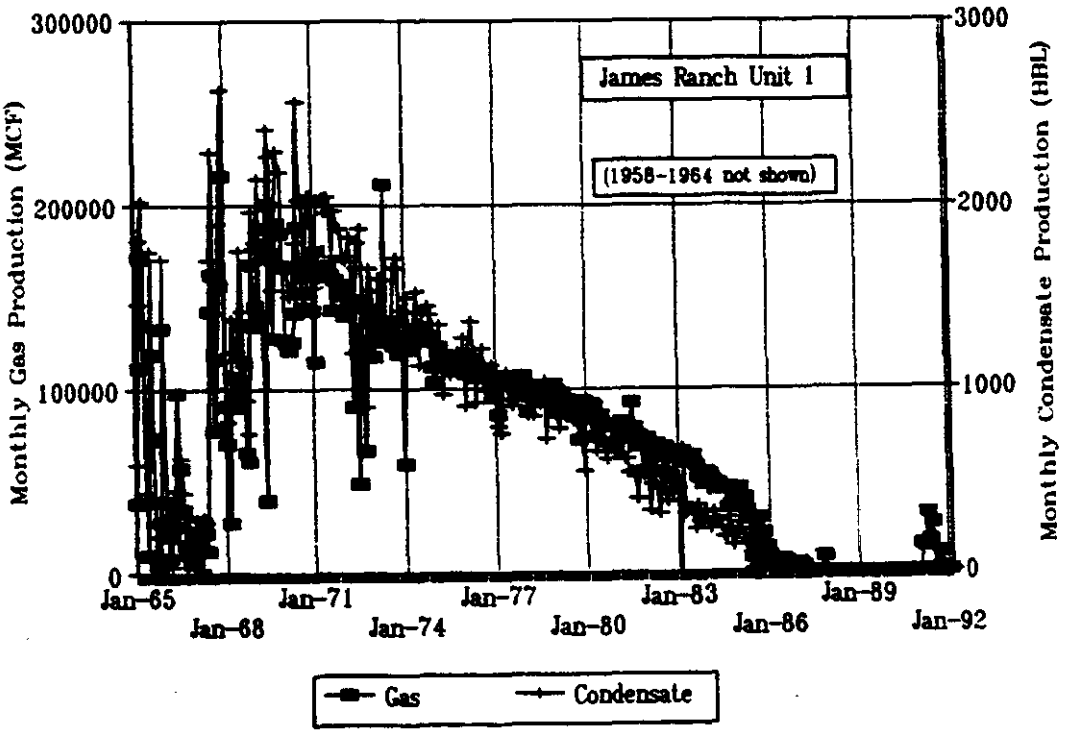

Figure 4. Gas and Oil Production from 1965 - 1991; James Ranch Unit No. 1. Data provided by Roswell District Office, U.S. BLM, 1992.

By 1977, the Shell James Ranch Unit No. 1 was flanked by an arc of four other wells on the south and west that essentially failed to tap the Atoka reservoir. The four wells were initially completed in the deeper Morrow Formation (Griswold, 1977). Figure 3 shows these wells included the Hudson Federal No. 1, Belco's James Ranch Unit No. 3, Belco's James Ranch Unit No. 4, and Conoco's James Ranch Unit No. 7.

4.2 Natural Gas Beneath the WIPP Site

A faulted anticline controls the Morrow reservoir in the Los Medaños field, southwest of the WIPP site. This same structure probably persists up into the Atoka and both reservoirs probably extend toward the northeast (Griswold, 1977).

Analysis of production decline curves through 1976 for the James Ranch No. 1 well indicated the well was probably draining at least five square miles (1300 hectares). That observation, coupled with the favorable geologic structure and the failure of wells drilled to the west and south, further suggested that wells drilled to the northeast would have a high chance of success (Keesey, 1976; Griswold, 1977; U.S. DOE, 1980).

As part of the hydrocarbon resource evaluation, potential drilling sites were selected based on the structure contours of the Morrow Formation. Depending on the geologic structure and distance from producing wells, the potential drilling sites were ranked as either 1) proved undeveloped, 2) probable, or 3) possible. Proved undeveloped reserves identified commercially recoverable hydrocarbons to be recovered from new wells on undrilled acreage or from existing wells requiring a major expenditure for recompletion or new facilities for fluid injection. (Keesey, 1976; Griswold, 1977, U.S. DOE, 1980).

The two locations ranked as "proven undeveloped" were north and east of the Shell James Ranch No. 1, as shown in Figure 5. The production data and geologic information available in 1976 indicated that much of the natural gas being produced from the Atoka Formation came from beneath the defined WIPP Site Boundary and the best place to drill a well would be in Section 31, T22S, R31E, which is precisely where the two active gas leases beneath the WIPP site are located.

Keesey (1976) noted that the drilling and completion of additional wells northeast of the Shell James Ranch No. 1 would only enhance the rate of recovery of the Atoka reservoir now being drained by the one well. Ultimate recovery would remain about the same.

4.3 Early History of Leases

In May 1952, Continental Oil Inc. (Conoco) obtained an oil and gas lease (NMPM Lease # NM 02953) that included all 640 acres (259 hectares) of Section 31, T22S, R31E. In June 1953, the area was approved by the U.S. Geological Survey (U.S.G.S.) as the James Ranch Unit. Sid Richardson and Perry R. Bass were designated Unit Operators.[5]

As discussed above, Shell Oil Company drilled the James Ranch Unit No. 1 in 1957, on Section 36 just west of the Conoco lease. Shell began prolific production of gas and condensate from the newly discovered resources in the Atoka Formation in March 1958.

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[5]Information about drilling applications, completion records, pipeline connections, production records, and official memoranda concerning these leases was obtained from U.S. Bureau of Land Management Offices in Roswell, New Mexico and Santa Fe, New Mexico.

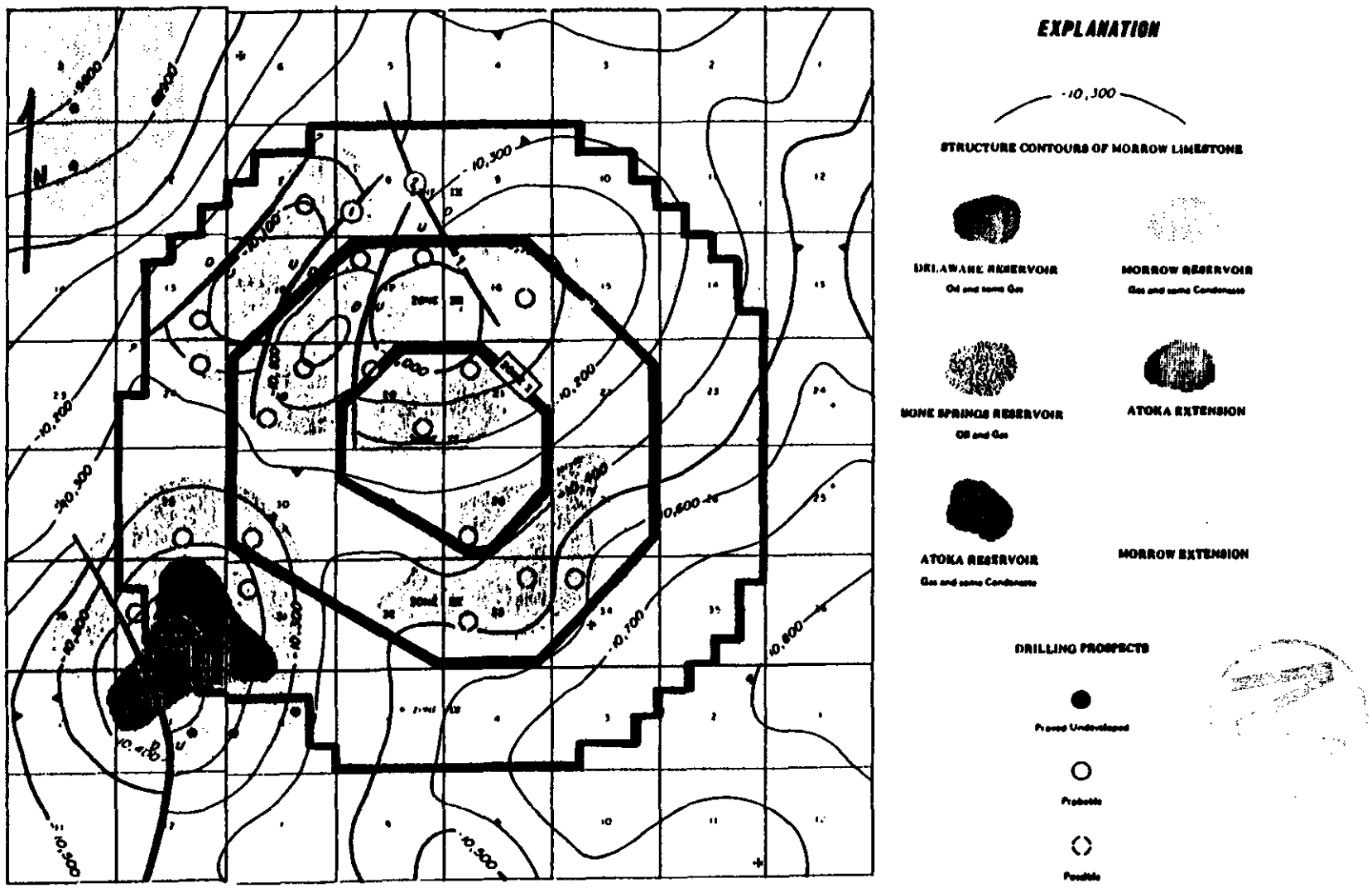

Figure 5. Hydrocarbon Resources and Possible Extensions (Griswold, 1977, Figure 32, reproduced with permission).

In February 1959 the Conoco lease on Section 31 was divided. The north half of the section remained with Conoco and the south half was assigned to Richardson and Bass under lease NM 02953-C. Perry R. Bass was designated the Unit Operator, in March 1961.

Keesey (1976) completed the analysis of hydrocarbon reserves for SNL, effective September 1, 1976, in which he concluded:

> that the Los Medaños (Atoka) reservoir extends north and northeast underneath the 'site area' in section 31-22S-31E [Conoco's and Bass's undeveloped leases] and 36-22S-30E [Shell's producing lease] (Keesey, 1976, p. 16).

4.4 <u>1976 Application to Drill For Natural Gas Beneath the WIPP Site</u>

On November 7, 1976, Bass formally filed for a permit with the U.S. Geological Survey to drill a well on Section 31. Three days later, November 10, 1976, Conoco was designated as the operator and local agent for Bass "with full authority to act in his behalf in complying with the terms of the lease and regulations...." (Bass, 1976).

On November 11, 1976, the District Engineer for the U.S.G.S., routinely notified the New Mexico Division of Lands and Minerals Program and Land Office in Santa Fe, New Mexico, of the intent of Bass Enterprises Production company to commence drilling operations.

On December 10, 1976, a withdrawal notice appeared in the *Federal Register*. The Energy Research and Development Administration (ERDA, precursor of the DOE) applied for withdrawal of 17,000 acres (6880 hectares) of public lands in New Mexico for a nuclear waste disposal site including the land containing the Bass lease.

On January 20, 1977, the U.S.G.S Area Oil and Gas Supervisor, James W. Sutherland, approved the Bass application to drill for oil and gas .

4.5 Court Condemnation of Oil and Gas Leases at the WIPP Site

On February 9, 1977, the U.S. Government, at the request of the Acting Administrator for the ERDA, filed a complaint in civil court (Case # CIV 77-071 B) against Bass Enterprises et al. condemning their oil and gas lease from the surface to a depth of 6,000 feet (1829 meters) for the southern half of section 31.

On April 4, 1977, the U.S. BLM Assistant Solicitor of Lands, John J. McHale, informed the Director of the U.S. BLM that an attorney for the U.S. ERDA in New Mexico had inquired by telephone about the impact of the Federal Land Policy and Management Act (FLPMA) on the land status because the issue had been raised in litigation. The lessee (Bass) was contending in court that the condemnation of oil and gas leases by the Government was illegal, arguing that the Government can only terminate the lease through the lease provisions. The Assistant Solicitor had advised the ERDA attorney, that in BLM's judgment, the land should never have been taken (McHale, 1977).

On December 7, 1977, an additional complaint was filed in civil court (Case # CIV 77-776 B) by the U.S. Government against Conoco Inc. condemning their oil and gas lease from the surface to a depth of 6,000 feet (1829 meters) for the northern half of Section 31.

On February 12, 1979, both cases were settled jointly. The court condemned the oil and gas lease from the surface to 6,000 feet (1829 meters) and assigned $1,350,000 to Conoco, Bass Enterprises, and other defendants as just compensation for these leases.

4.6 1981 Application to Drill Natural Gas Well Beneath the WIPP Site

On December 11, 1981, Bass Enterprises filed a formal application to drill a wildcat well, James Ranch Unit No. 13, on Section 6, T-23-S, R-31-E (#NM 02887-D) with the intent to deviate north into Section 31, T-22-S, R-31-E. This section, would fall entirely within the defined WIPP Site Boundary fourteen months later.

On December 14, 1981, James Pettengill, geologist with the U.S.G.S. Office in Roswell, filed a review of the drilling application with the U.S.G.S. District Engineer in Artesia. The review noted that the "completion location is within the boundaries of the Department of Energy's proposed Waste Isolation Pilot Project (WIPP)" (Pettengill, 1981).

On December 16, 1981, the U.S.G.S. District Supervisor in Roswell, James Gillham, issued a memo to the U.S.G.S. Deputy Conservation Manager of Oil and Gas transmitting the request to drill and commenting that the "drillsite is not considered to be in a politically sensitive area" (Gillham, 1981).

On December 18, 1981, the U.S.G.S Area Manager for the Carlsbad Resource Area notified the DOE WIPP Project Manager of Bass's application to drill and requested advice on any special stipulations or concerns by December 28, 1981 (Koski, 1981).

The DOE December 30, 1981, response noted that the Department had obtained exclusive use of the surface and uppermost 6,000 feet (1829 meters) of subsurface for the specific purpose of preventing any drilling activity in Section 6, N½,NW¼, T23S, R31E and Section 31, T22S, R31E. The letter cautioned the BLM that "the approval to drill must include the stipulation that Perry R. Bass is not permitted to drill into the areas described above" (McGough, 1981) .

Following the January 11, 1982, approval by the U.S.G.S. (Reitz, 1982) to drill, drilling started on February 6, 1982. On September 13, 1982, the well was tested and produced 141 MCF of gas for an eight hour period. On September 21, 1982, drilling was completed. On February 14, 1983, the Natural Gas Pipeline Company of America connected to the well, James Ranch Unit No. 13, for the purpose of purchasing gas. The wellhead is shown in Figure 6 with the WIPP Waste Handling Building in the background.

4.7 Zone Designation and Resource Recovery Control

On February 17, 1983, the DOE WIPP Project Manager notified the Director of the Environmental Evaluation Group (EEG) that:

> the configuration of WIPP surface control zones has changed as a result of the cost reduction program, the DOE resource management policy and Bureau of Land Management land withdrawal action.... Descriptions of the new control zones are also enclosed (McGough, 1983a).

On February 24, 1983, the DOE WIPP Project Manager further informed the EEG Director that:

> the DOE does not plan to exercise any control over resource recovery activities outside the Site boundary and will rely, primarily, on other Federal and State regulatory agencies to assure that the WIPP boundaries are not violated (McGough, 1983b).

On October 28, 1983, the EEG requested a clarification on the DOE's conflicting descriptions of the Zone III boundaries and a clarification on the interim controls on resource recovery. The EEG was puzzled by the DOE's reference to the new WIPP site boundary as Zone III. The EEG was also concerned the restriction against drilling into the first 6,000 feet (1829 meters) was not included in the BLM/DOE

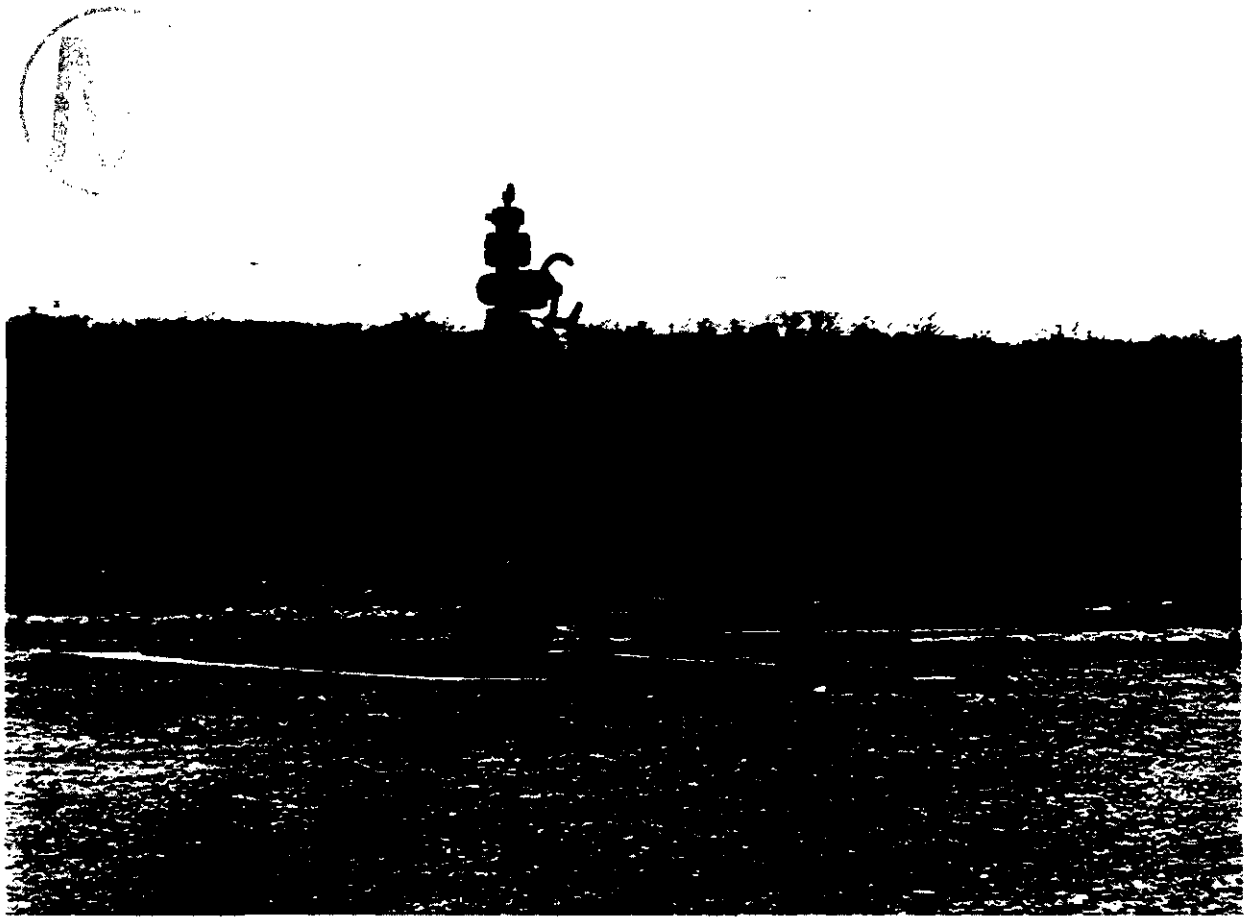

Figure 6. James Ranch Unit No. 13 with WIPP Waste Handling Building in Background.

Memorandum of Understanding or in the Resource Management Plan. Hence, EEG suggested that there was no apparent reason for the BLM to enforce the restriction (Neill, 1983a).

On December 7, 1983, the DOE WIPP Project Manager acknowledged that:

> 1. Our February 24, 1983 letter incorrectly identified the WIPP Site boundary as being the Zone III when in fact the Zone III boundary has not changed from that shown in the FEIS. The zone being controlled as regards mineral extraction, is the 16 full sections of land as shown in the sketch enclosed in our February 17, 1983 letter. These 16 sections comprise the area identified in the June 29, 1983 administrative land withdrawal.
>
> 2. All lease rights which have been purchased by the DOE within the site boundary have been purchased in their entirety or alternatively we acquired only the upper 6,000 feet of the leases to reduce the acquisition cost to the DOE and to allow access to potential hydrocarbon resources below the WIPP Site. It was not considered necessary to detail this information in the DOE/BLM Memorandum of Understanding (MOU) or Resource Management Plan because the BLM is required to enforce mineral leasing laws which prohibit violation of adjacent (in this case, DOE's) lease boundaries (McGough, 1983c).

In evaluating the suitability of the WIPP Site, the EEG (Neill et al., 1983, p. iii) recommended that

> no potash mining will be allowed in Zones I, II, and III of the WIPP site. Deviated drilling for oil and gas from outside the WIPP site to reach under the WIPP site at depths greater than 6,000 feet may be allowed. The federal government shall exercise active institutional control at the site for this purpose for at least 100 years after repository decommissioning.

The recommendation was reiterated on December 6, 1983, in a letter from the EEG Director (Neill, 1983b) to the WIPP Project Manager on the suggested wording for the First Modification to the Consultation and Cooperation (C&C) Agreement between the U.S. Department of Energy and the State of New Mexico. On November 14, 1984, the State of New Mexico and the U.S. Department of Energy agreed that:

> During facility construction and operation the DOE will not allow subsurface mining, drilling or resource exploration from within the WIPP site. The 'WIPP site' as used here means the 4 x 4 mile (10,240 acres) area consisting of sections 15, 16, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, and 34 of Township 22 South, Range 31 East, NMPM, in Southeastern New Mexico.
>
> Deviated drilling for oil and gas from outside the WIPP may be allowed so long as the subsurface of the WIPP site is not penetrated above a depth of 6,000 feet from the surface.

EEG's recommendation to include a statement that the federal government shall exercise active institutional control at the site for at least 100 years after repository decommissioning was not included in the modification. Rather, the First Modification to the C&C agreement stated that:

> the consultation process concerning the length and extent of the post-closure institutional control, shall be negotiated and resolved by the parties in the future, and at least one year prior to the start of the decontamination and decommissioning of WIPP.

5.0 THE FORGOTTEN GAS LEASES AND WELL BENEATH THE WIPP SITE

The 1984 agreement between the U.S. Department of Energy and the State of New Mexico to allow slant drilling under the WIPP Site changed on August 4, 1987, in the second modification to the C&C agreement (U.S. DOE and NM, 1987), which states:

> The DOE will not permit subsurface mining, drilling, or resource exploration unrelated to the WIPP Project on the WIPP site during facility construction, operation, or after decommissioning. This prohibition also **precludes slant drilling**[6] under the site from within or from outside the site.

Several important DOE documents are either incorrect, silent, or inconsistent on the existence of the two oil and gas leases and the gas well. For example, the Final Environmental Impact Statement (FEIS, U.S. DOE, 1980, pp. 8-8—8-10) identifies the oil and gas leases held by ten companies in March 1979, yet the 1952 Conoco and 1957 Bass leases in the southwest corner of the WIPP Site on Section 31 are not mentioned. The WIPP Final Safety Analysis Report (WIPP FSAR, U.S. DOE, 1990a, Section 2.1.1.1), incorrectly states that there are no active oil and gas leases within the WIPP Site Boundary. Moreover, the WIPP FSAR (U.S. DOE, 1990a, Figure 2.2-1) fails to chart the intruding well on its map of producible oil and gas wells. The DOE No-Migration Variance Petition to EPA incorrectly states that the DOE has purchased all oil and gas leases in the area of the WIPP site to prevent any exploration now and in the future (U.S. DOE, 1990b). Revisions 1 through 5 of the Secretary of Energy's Decision Plan were monitoring the status of an active potash lease until it was purchased by the DOE. Yet Revisions 6 through 10 remained silent on the active oil and gas lease issue even after the article in the Albuquerque Journal raised the issue (McCutcheon, 1990). The recently published DOE Implementation

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[6]Emphasis added.

of the Resource Disincentive document, (U.S. DOE, 1991) is inconsistent on the number of active oil and gas leases within the WIPP Site Boundary and on the production status of the forgotten gas well.

5.1 1980 WIPP Final Environmental Impact Statement

The WIPP Final Environmental Impact Statement (U.S. DOE, 1980) identifies the gas and oil leases held by ten companies in March 1979 at the WIPP Site. Figure 7 (reproduced from the 1980 WIPP FEIS) does not show the Bass and Conoco leases on Section 31. While those two leases were condemned in February 1979 from the surface to 6,000 feet (1829 meters), the oil and gas leases below 6,000 feet (1829 meters) did remain valid.

5.2 1990 WIPP Final Safety Analysis Report

The DOE's stated commitment to prohibit slant drilling and the loss of knowledge is also documented in the WIPP Final Safety Analysis Report (U.S. DOE, 1990a) which the DOE describes as the top level document in the hierarchy of the WIPP safety documents. The WIPP FSAR states:

> The area of land that lies within the WIPP Site Boundary and committed to the WIPP facility is a square four miles on a side. It contains 10,240 acres (16 mi^2) including Sections 15-22 and 27-34 in township T22S, R31E....
>
> The DOE will not permit subsurface mining, drilling, or resource exploration unrelated to the WIPP Project within the WIPP Site Boundary during facility operation or after decommissioning. This prohibition **precludes slant drilling**[7] under the WIPP facility from within or outside the WIPP facility. (U.S. DOE, 1990a, Section 2.1.1.1).

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[7]Emphasis added.

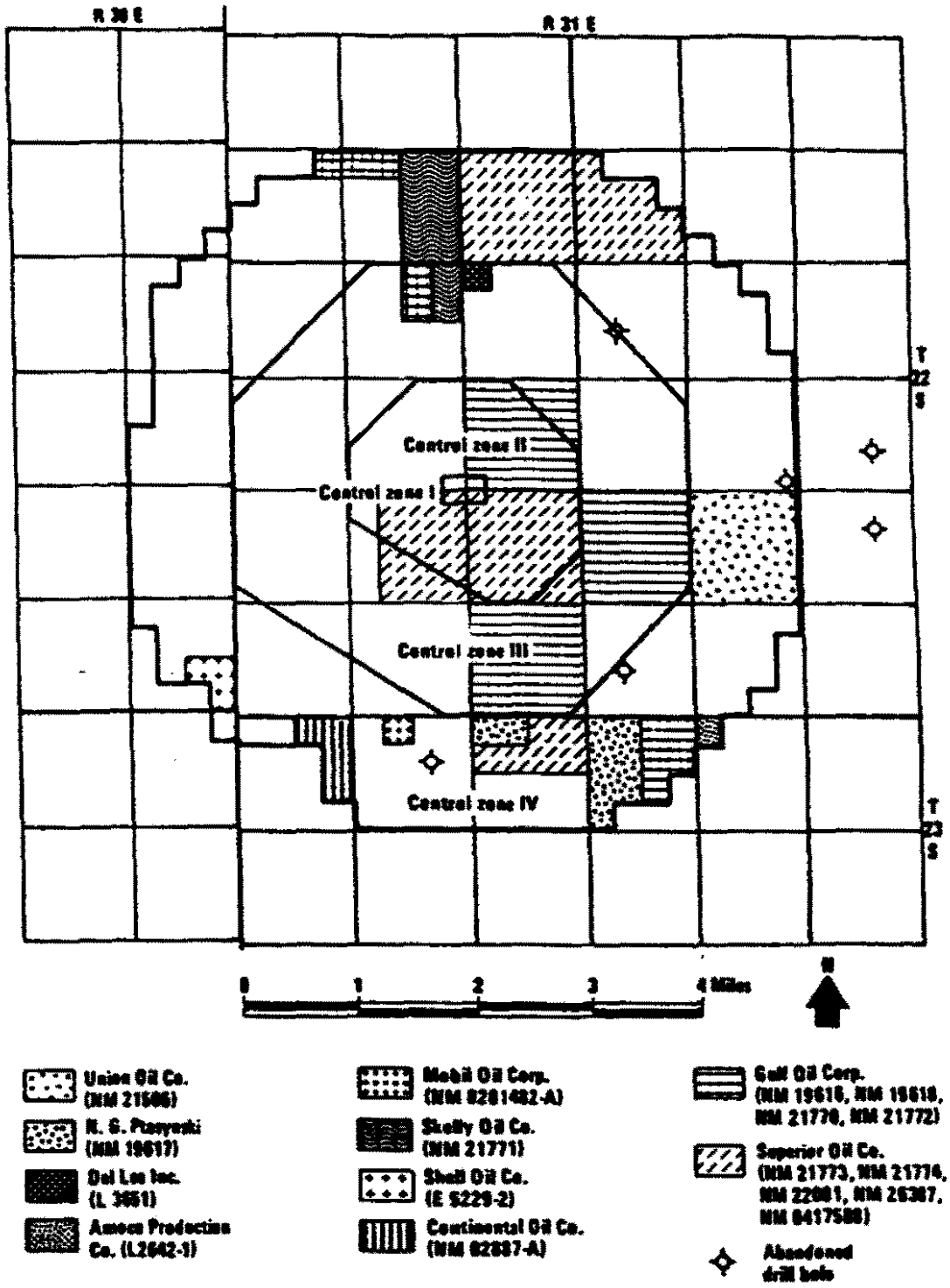

Figure 7. Oil and Gas Leases Within the WIPP Site according to the DOE FEIS, (U.S. DOE, 1980, Figure 8-6, reproduced with permission).

The WIPP Final Safety Analysis Report also incorrectly states:

> ... all oil and gas leases within the WIPP Site Boundary have expired (U.S. DOE, 1990a, Section 2.1.2.1.3).

Furthermore, Figure 2.2-1 (Figure 8 in this report) of the WIPP FSAR fails to show all of the 1986 operable natural gas and oil wells within a ten mile (16.1 kilometers) radius. This figure shows seven wells just outside the southwest corner of the site - James Ranch Unit Nos. 1, 3, 4, 7, 10, 11 and Hudson Federal No. 1. James Ranch Unit No. 3 appears to be plotted in the wrong location. At least two wells, James Ranch Unit Nos. 13 and 14 shown in Figure 9, both slant drilled wells, are not shown in the WIPP FSAR. James Ranch Unit No. 13 and James Ranch Unit No. 14 were not only operable, but each was producing through the entire year of 1986, as shown in Figures 10 and 11.

Table 1 (prepared from data provided by the Roswell District Office of the U.S. BLM) lists the gas and condensate production from the James Ranch Unit No. 13. Production was stopped for one month in July 1985 and again for three extended periods of several months beginning in April 1987. Nonetheless, gas and condensate were produced for several months in 1987, 1988, and again in 1991. To date this well has produced over 3,000,000 MCF gas. The latest available production records in the Roswell District Office of the U.S. BLM show production of 27,618 MCF gas and 164 BBLs condensate for February 1992 (U.S. BLM, 1992).

James Ranch Unit No. 14 was slant drilled in 1983. The top of the well is located in Section 6, T23S, R31E and completed in the Los Medaños-Morrow Formation in Section 7, T23S, R31E. Since production began in December 1983 records through February 1992 show this well has produced gas every month except for a two month period in 1987.

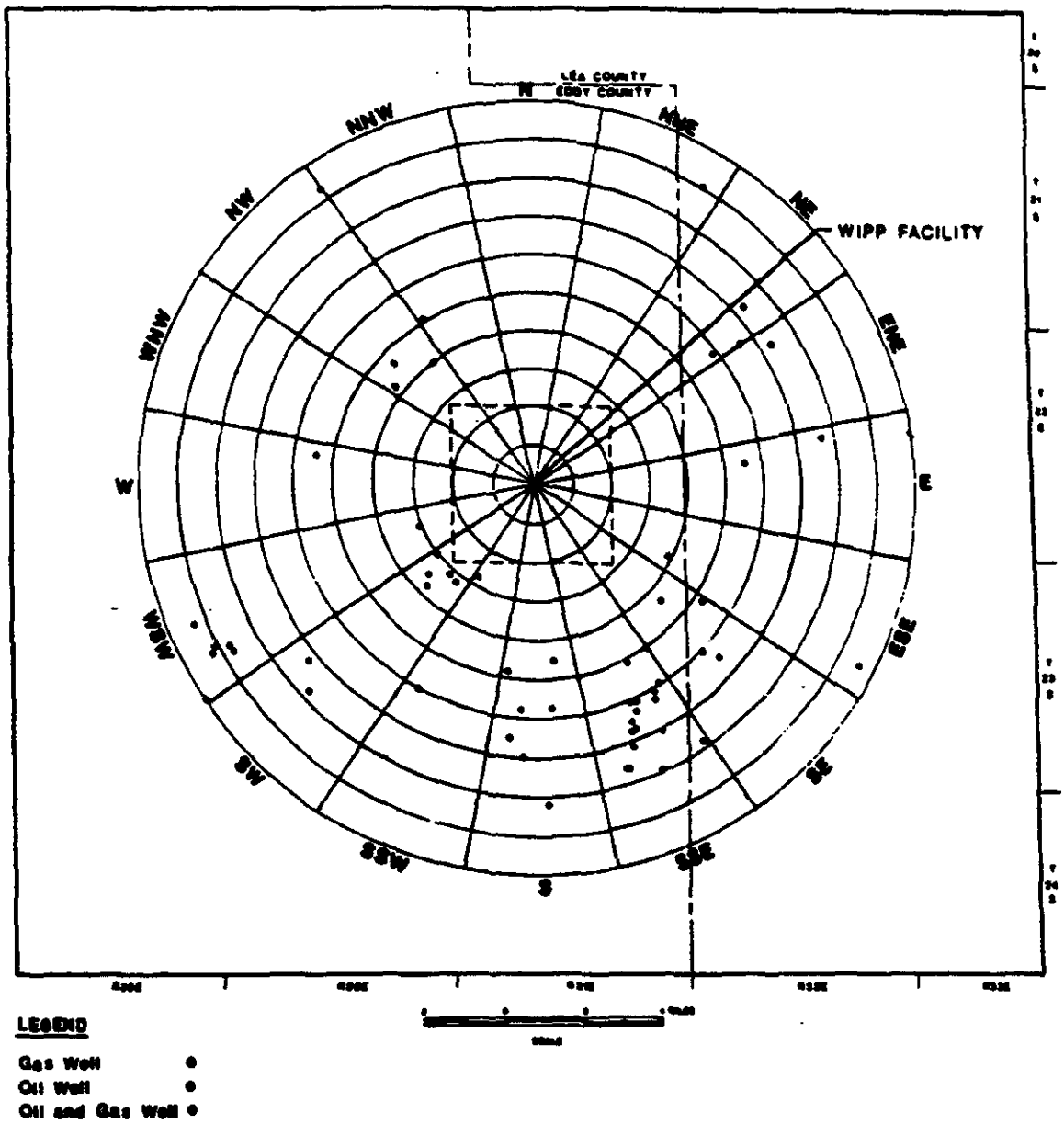

Figure 8. 1986 Operable Natural Gas and Oil Wells, within 10 Mile Radius (WIPP FSAR, U.S. DOE, 1990a, Figure 2.2-1, reproduced with permission).

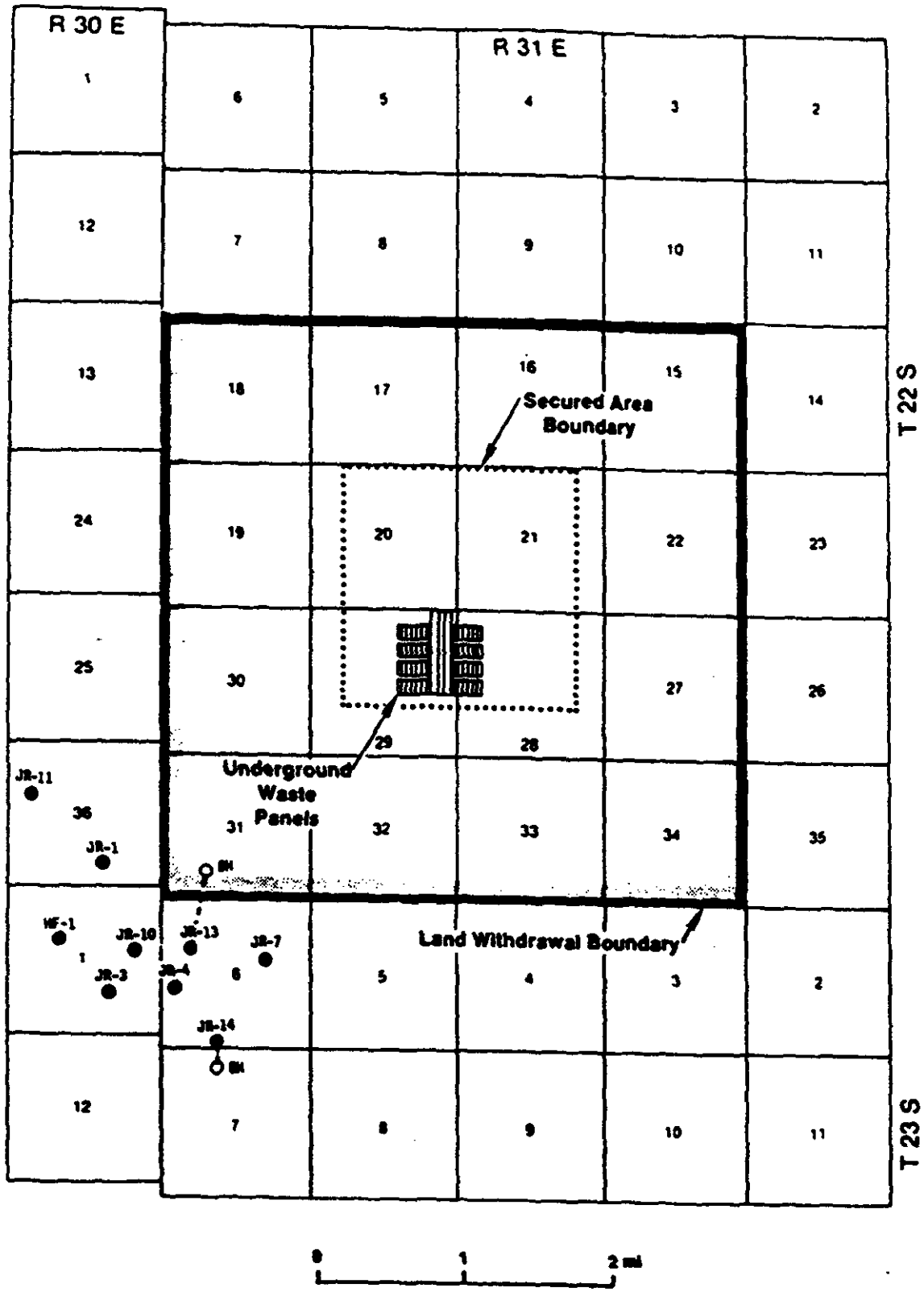

Figure 9. Gas and Condensate Wells at Southwest Corner of WIPP Site. Well locations plotted from U.S. BLM records.

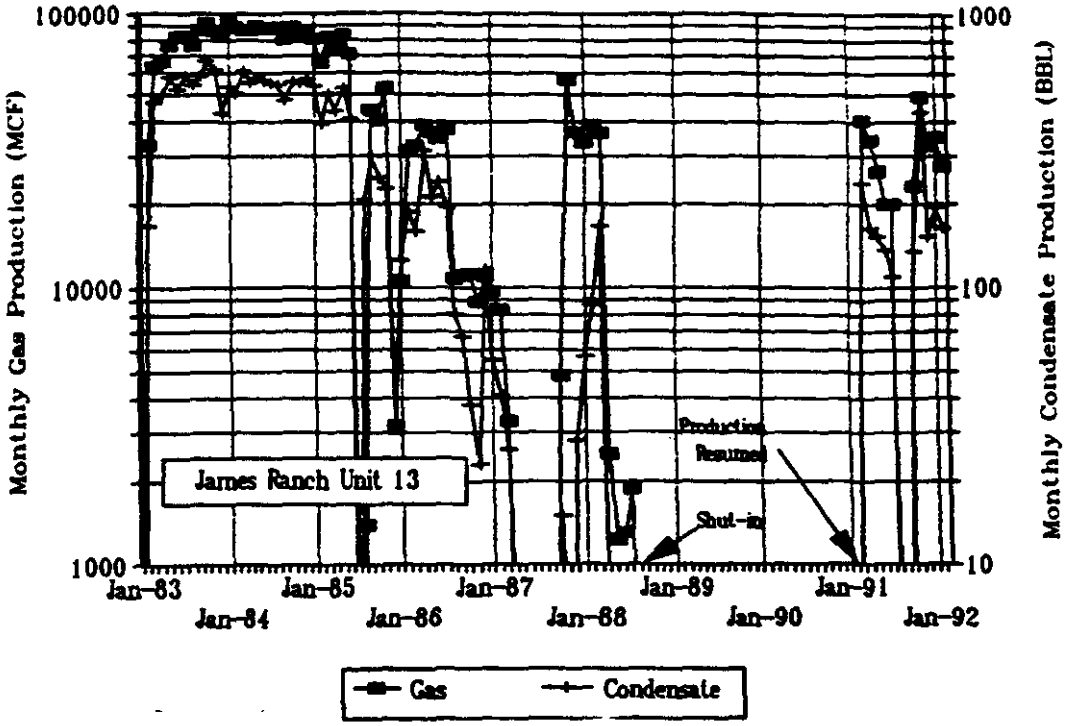

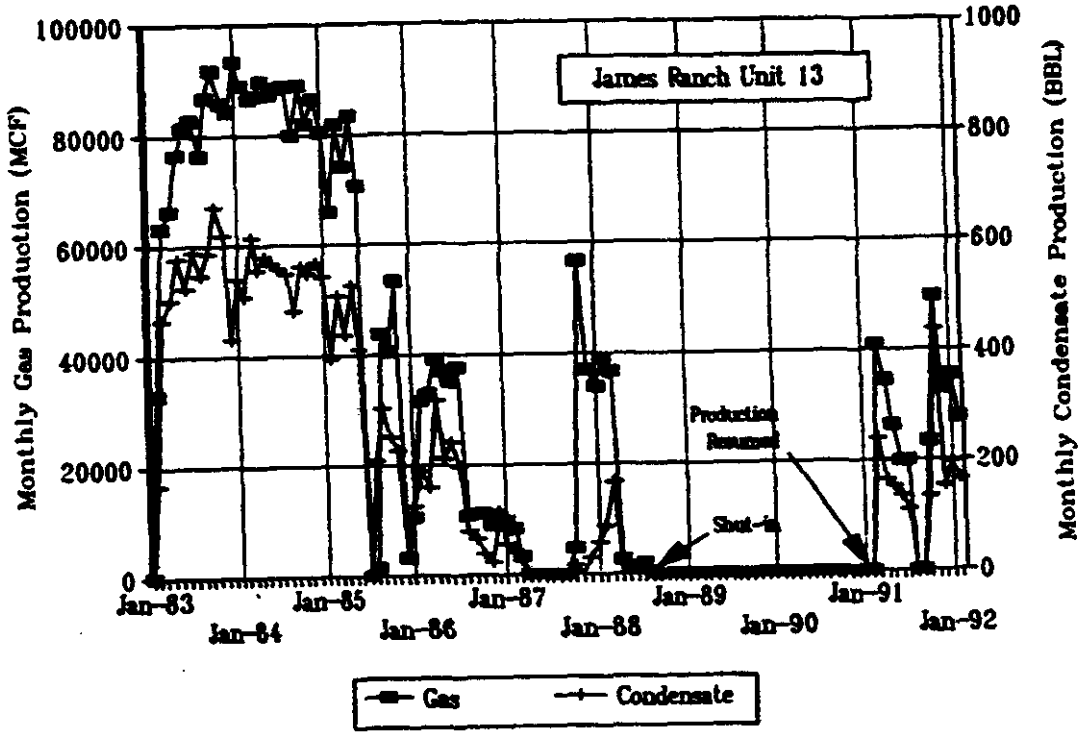

Figure 10. Production History of James Ranch Unit No. 13. Data provided by Roswell District Office, U.S. BLM, 1992.

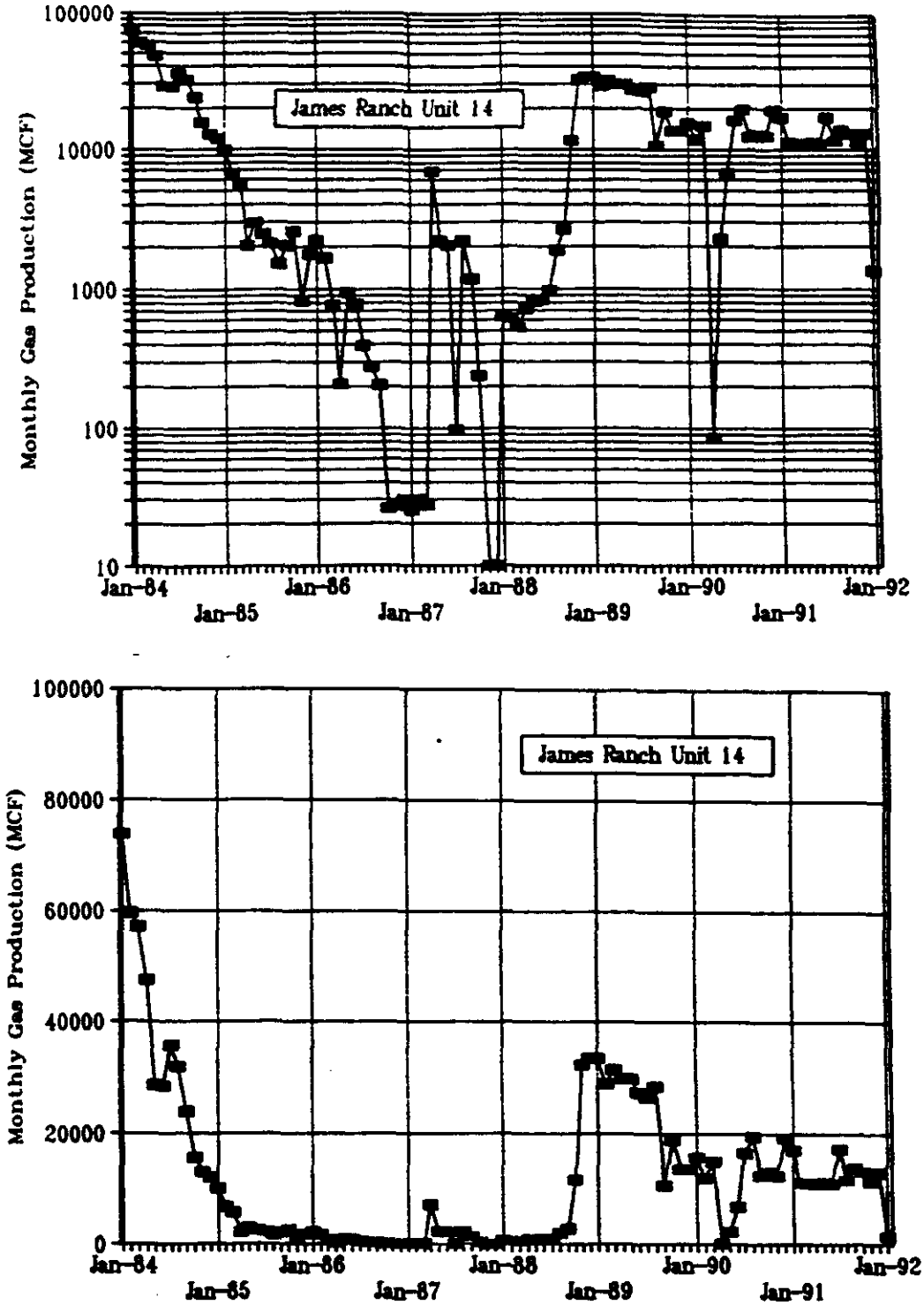

Figure 11. Production History of James Ranch Unit No. 14. Data provided by Roswell District Office, U.S. BLM, 1992.

TABLE 1: PRODUCTION HISTORY OF JAMES RANCH UNIT NO. 13

DATE	OIL (BBL)	GAS (MCF)	WATER (BBL)
01/31/83	0	0	0
02/28/83	167	32970	17
03/31/83	467	63373	31
04/30/83	501	66425	27
05/31/83	579	76613	30
06/30/83	524	81409	30
07/31/83	589	82734	31
08/31/83	546	76421	31
09/30/83	588	86647	30
10/31/83	672	91799	31
11/30/83	619	85720	30
12/31/83	431	84334	29
01/31/84	539	93266	31
02/29/84	508	88828	29
03/31/84	615	86519	30
04/30/84	555	86971	30
05/31/84	580	89612	31
06/30/84	567	87216	30
07/31/84	557	88357	31
08/31/84	548	88778	31
09/30/84	481	80027	29
10/31/84	562	89005	31
11/30/84	549	82072	30
12/31/84	569	86411	31
01/31/85	543	80505	30
02/28/85	393	65972	26
03/31/85	507	81783	31
04/30/85	437	74131	58
05/31/85	526	83292	31
06/30/85	410	70727	28
07/31/85	0	0	0
08/31/85	207	1391	16
09/30/85	302	43919	17
10/31/85	250	40550	17
11/30/85	227	53275	21
12/31/85	33	3112	14
01/31/86	126	10583	4
02/28/86	189	31505	10
03/31/86	160	32865	13
04/30/86	316	38991	17
05/31/86	212	36926	30
06/30/86	241	35085	16

TABLE 1 (continued)

07/31/86	196	37753	16
08/31/86	81	10837	5
09/30/86	67	11113	5
10/31/86	38	11235	5
11/30/86	23	8979	5
12/31/86	117	10951	6
01/31/87	55	9701	7
02/28/87	41	8374	24
03/31/87	26	3305	3
04/30/87	0	0	0
05/31/87	0	0	0
06/30/87	0	0	0
07/31/87	0	0	0
08/31/87	0	0	0
09/30/87	0	0	0
10/31/87	15	4824	4
11/30/87	0	56786	22
12/31/87	28	36952	36
01/31/88	57	33926	30
02/29/88	87	38970	32
03/31/88	167	36552	28
04/30/88		2518	4
05/31/88		1219	2
06/30/88		1297	4
07/31/88		1872	
08/31/88	0	0	0
09/30/88	0	0	0
10/31/88	0	0	0
11/30/88	0	0	0
12/31/88	0	0	0
01/31/91	0	0	0
02/28/91	0	0	0
03/31/91	240	40888	0
04/30/91	164	34513	30
05/31/91	153	26441	0
06/30/91	136	20034	26
07/31/91	110	20043	31
08/31/91	0	0	
09/30/91	0	0	
10/31/91	135	23393	
11/30/91	436	49658	29
12/31/91	153	32782	31
01/31/92	196	35364	
02/29/92	164	27618	

5.3 No-Migration Variance Petition to EPA

The DOE No-Migration Variance Petition (U.S. DOE, 1990b) to the EPA states in the section on human intrusion:

> Oil and gas exploration has been and continues to occur around the WIPP site. The target horizons for this type of exploration are below the Castile. Oil and gas exploratory drilling requires permits from the state, and it is unlikely that prospective future well drillers would not be informed about the existence of WIPP. As an additional protective measure, **the DOE has purchased all oil and gas leases in the area of the WIPP site**[8] to prevent any exploration now and in the future (U.S. DOE, 1990b, Section 6.3.2).

With respect to petroleum exploration and the human intrusion issue, the last sentence in this paragraph provided incorrect information to the EPA. The EPA subsequently granted a variance to the DOE in November 1990 (U.S. EPA, 1990).

5.4 New Mexico Energy and Minerals Department Report

The 1984 report published by the New Mexico Energy and Minerals Department (NMEMD) Task Force on Natural Resources (NMEMD, 1984) stated that the DOE had acquired several oil and gas leases at a cost of over $19.6 million dollars. The report stated that "As a result of these lease acquisitions, only one hydrocarbon lease remains within the WIPP Site Boundary... an 80-acre tract held by Skelly Oil Company...." (NMEMD, 1984, p. 27). The report did not identify the active gas and oil leases in Section 31, deeper than 6,000 feet (1829 meters).

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[8]Emphasis added.

5.5 1990 Memorandum of Understanding between BLM and DOE

The U.S. Department of Energy and the U.S. Department of Interior's BLM signed the Memorandum of Understanding on October 26, 1990, recognizing that:

> **BLM will prohibit directional drilling underneath the WIPP site boundary, except as may be required for the development of the two leases located under Section 31;**[9] drilling may be allowed below 6,000 feet of the surface.

Hence, it appears the DOE entered into an agreement in 1990 to honor these leases despite commitments to preclude slant drilling in the 1987 C&C Agreement with New Mexico and the 1990 WIPP FSAR.[10] Apparently, the DOE accepted the *fait accompli* without considering the commitments in the C&C Agreement and the WIPP FSAR.

5.6 Department of Energy Position

On November 3, 1990, the Albuquerque Journal reported the discovery of the forgotten natural gas well completed within the WIPP Site Boundary. (McCutcheon, 1990).

On November 15, 1990, the Assistant Manager for Energy and Special Programs of the Albuquerque Operations Office of the Department of Energy sent a letter to the

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[9]Emphasis added.

[10]On January 22, 1991, the Assistant Secretary of the Interior signed 43 CFR Public Lands Order 6826 (Administrative Land Withdrawal). That Administrative Land Withdrawal Order cites the October 26, 1990 Memorandum of Understanding between the U.S. Department of Energy and the U.S. Department of the Interior BLM as the guiding document regarding resource management.

Chairman of the New Mexico Radioactive Waste Consultation Task Force. The letter maintained:

> ...at the time this deviated well was drilled, the section 31 bottom hole was within what was formerly termed "zone IV" of the WIPP site. A 1980 report prepared by Sandia National Laboratories (SNL) concluded that extraction from within zone IV would have no technical impact on repository performance. The 1980 Environmental Impact Statement for the WIPP stated that the DOE would permit drilling for natural gas in zone IV. Accordingly, in 1981 when Bass Enterprises filed an application to drill the well, the DOE stated it had no objection, so long as the operator did not encroach upon the surface or the first 6,000 feet condemned by the United States. Recent review by SNL confirms that the existence of this bottom hole more than 14,000 feet below section 31 does not affect the performance of the repository.
>
> We do not believe that the existence of this 1982 well contravenes the August 4, 1987 Second Modification to our Agreement for Consultation and Cooperation in which we previously agreed to prospectively preclude "subsurface mining, drilling, or resource exploration unrelated to the WIPP Project on the WIPP site" [including "slant drilling under the site from within or from outside the site"].... (Bickel, 1990a).

The DOE response requires further explanation because it cited a "1980 report" from Sandia National Laboratories and a "recent review by SNL." The "1980 report" was a **draft** of a position paper on Zone IV. The 1980 memo of transmittal accompanying those draft pages also recommended that:

> well selected, realistic scenarios addressing the consequences of mining and drilling in Zone IV should be a part of the Zone IV position paper (Weart, 1980).

The cited "recent review by SNL" described in the November 15, 1990, DOE letter was a November 5, 1990, memo (Weart, 1990) prepared at the DOE's request. The one and one-half page memo reexamined the reasoning from the 1980 draft in light of the new dilemma and current regulatory requirements. The memo correctly stated:

> the portion of the hole that penetrates the salt is outside the site boundary and thus beyond the boundary at which compliance with the standards will be evaluated (Weart, 1990).

and concluded that:

> even though the Bass drill hole is bottomed within the site boundary, it is much more than a mile from the waste zone and therefore exceeds the technical safety requirements (Weart, 1990).[11]

The DOE Albuquerque Operations Office November 16, 1990, letter to the Coordinator of the New Mexico Radioactive Waste Task Force stated:

> there is one producing well allowed in each 320-acre production unit. The south half of Section 31 has its one well, James Ranch Unit No. 13 (Bickel, 1990b).

However, the letter failed to note current drilling practices in New Mexico would allow additional deep gas wells to be drilled into Section 31 including the south half

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[11]Initially, the selection of a site required that the repository be located at least two miles from a borehole penetrating the Salado formation. The two mile requirement was believed to be conservative but was also arbitrary (Schueler, 1980). The two mile requirement was reduced to one mile after the site at the ERDA 6 borehole was found to be unacceptable (Neill et al., 1979, Appendix III, p. 6). The Geologic Characterization Report (Powers et al., 1979, p.2-12) stated that justification for a one mile criteria was based on reports by Snow and Chang (1975), Walters (1975), Fader (1973), and Griswold (1977). However, EEG questioned the pertinence of these studies and, hence, questioned the justification for the reduction to a one mile criteria (Neill et al., 1979, Appendix III, pp. 6,7).

of that section. The lessee can request permission to drill on tighter spacing by demonstrating to the New Mexico Oil Conservation Division that the tighter spacing is required to efficiently produce the gas from the formation. For example, if a reservoir exhibits retrograde condensate behavior, the buildup of liquid around the well bore can reduce, sometimes seriously, the flow rate as the pressure declines below the dew point (Craft and Hawkins, 1959, p. 73). Hence, efficient production may require more wells on a tighter spacing.

Also, the existing well in Section 31 could be deepened. That activity would constitute exploratory drilling.

Furthermore, the lessee is still entitled to slant drill an exploratory hole into the north half of Section 31, which has yet to be developed. In summary, as long as the lessee maintains the leases, the U.S. BLM can not deny them access to their oil and gas in Section 31, the southwestern section of the WIPP Site.

5.7 SNL WIPP Performance Assessment Division

The SNL WIPP Performance Assessment Division issues an annual report on the status of the demonstration of the extent of compliance with 40 CFR Part 191. The December 1990 annual report stated:

> About 56 oil and gas wells are within a radius of 16 km (10 mi); the wells generally tap Pennsylvanian strata, about 4,200 m (14,000 ft) deep. The nearest well is about 3 km (2 mi) to the south-southwest of the waste panels (Bertram-Howery, 1990, p. I-20).

There was no discussion on the status of that well. For 1991, the SNL WIPP Performance Assessment Division added:

> The surface location of the well, which is capable of producing gas, is outside the proposed land-withdrawal boundary, but the borehole is slanted to withdraw gas from rocks within the boundary. Except for this well, resource extraction is not allowed within the proposed land-withdrawal boundary (Sandia National Laboratory, 1991, p. 1-15).

The 1991 document also stated in the discussion on natural resources:

> In order to gain control over the development of hydrocarbons at the WIPP, the DOE acquired the oil and gas leases within all the WIPP control zones. The only leases that are still intact are in Section 31. These leases only allow resource production by entry of the proposed land withdrawal area below 6000 feet. **One of these leases is currently in production.**[12] The upper 6000 feet of the leases was taken by the DOE in 1979. Current policy does not allow any further resource development inside the proposed land withdrawal boundary (Sandia National Laboratory, 1991, p. 8-7).

5.8 <u>The Secretary of Energy's Decision Plan</u>

While the Secretary of Energy's Decision Plan for the WIPP had carefully tracked an active potash lease until it was purchased, successive Revisions 6 through 10 did not document the existence of the active oil and gas leases even after the issue had been raised. The potash lease purchase was noted in Revision 5 (U.S. DOE, August 15, 1990). The failure of subsequent revisions to mention the rediscovered gas leases incorrectly suggests that there were no outstanding leases in the WIPP Site Boundary other than the one potash lease.

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[12]Emphasis added.

5.9 DOE Implementation of the Resource Disincentive Plan

The *DOE Implementation of the Resource Disincentive Plan in 40 CFR 191.14(e) at the Waste Isolation Pilot Plant* (U.S. DOE, 1991) is inconsistent in reporting the number of oil and gas leases within the WIPP Site Boundary and the production status of those leases. First it incorrectly states that:

> Only one lease currently exists within the WIPP site boundary (U.S. DOE, 1991, p.32).

However, there are two active gas and oil leases within the WIPP site boundary — the Conoco lease on the north half of Section 31 and the Bass lease on the south half of Section 31.

The Resource Disincentive Plan then states:

> This lease, **currently shut in for production of oil and gas,**[13] is being exploited by a well that was initiated outside the WIPP site boundary and was deviated to under the site only after the depth was below 6000 feet (U.S. DOE, 1991, p.32).

The document then reverses its position on the number of leases and their production status:

> In order to gain control over the development of hydrocarbons within the WIPP site area, the DOE acquired the oil and gas leases within all the WIPP control zones. These acquisitions were necessary to keep the salt beds intact. The only leases that are still intact are in section 31. These leases only allow

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[13]Emphasis added.

the production of resources by entry below 6000 feet. **One of these leases is currently in production**[14] (U.S. DOE, 1991, p.50).

The U.S. Bureau of Land Management (U.S. BLM, 1992) records show the well produced 141,919 MCF of natural gas from March 1991 through July 1991 as shown in Table 1, and was shut-in effective August 1991 - coincidently, the issue date of the Disincentive Plan. The latest available records from the Roswell District Office of the U.S. BLM indicate production resumed in October 1991.

5.10 Comments on Credit for Active and Passive Institutional Control

In terms of active institutional control, the leases were forgotten by the DOE in spite of the lease, drilling, and production records filed with the federal government, a condemnation suit filed in civil court by the federal government, agreements between the State of New Mexico and the federal government, technical reports to the federal government on area oil and gas resources, and the existence of a producible gas well visible from the south access highway into the WIPP facility.

The loss of knowledge in just a short few years is cause for concern. There were no major changes in society, government, language, culture, or technology. Yet the WIPP project lost knowledge of this gas well and the active oil and gas leases. The current wording in the EPA Standards permits the assumption that active institutional control can completely deter inadvertent human intrusion for up to 100 years.

We believe that present assumptions about the effectiveness of active institutional control needs to be reconsidered because of this experience of the forgotten oil and gas leases and a forgotten gas well. First, the EPA should reexamine whether full credit for 100 years active institutional control is reasonable given the actual experience of inaccurate record keeping. Second, the DOE should examine the basis

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[14]Emphasis added.

for assuming full credit for 100 years control and consider using a lesser value to reflect the actual experience of the WIPP project. Third, the EPA Standards should require the implementing agency to publish specific plans on how the agency intends to maintain active institutional control. Fourth, even in the absence of such a requirement, the DOE should publish plans now that specify in detail how the Department intends to maintain full control of activities in the area of the repository for 100 years after decontamination and decommissioning and how that control will completely deter human intrusion.

At this time the DOE commitment is effectively limited to a statement in the First Modification to the C&C Agreement which states:

> the post-closure institutional control, shall be negotiated and resolved by the parties in the future, and at least one year prior to the start of the decontamination and decommissioning of WIPP (U.S. DOE, 1981).

In the Second Modification to the C&C Agreement, the DOE agreed to provide a plan by February 1, 1988, which would:

> contain an estimated schedule and a description of the process DOE will use to: identify needed active institutional controls, gather data for the implementation of such controls, develop and implement a monitoring plan for passive institutional controls, determine the barriers to be used, assess the selection of the WIPP site in view of the resources at the site, and review the recoverability of the waste for a reasonable period after disposal.

However, the DOE Plan:

> merely describes the steps that the DOE will undertake to implement compliance to one portion of the Standard [40 CFR 191 Subpart B]. For most of the Assurance Requirements, the information needed to specify detailed plans and activities for implementation is not yet available.... Other

> information will not be available until close to the time that the Project has completed its mission and the WIPP is closed (U.S. DOE, 1987, p.1).

Furthermore, the remanded EPA Standards allow credit for the use of passive institutional controls to deter inadvertent human intrusion (U.S. EPA, 1985, p. 38080). However, excessive credit for passive controls, such as markers and public records, could reduce the estimated probability of inadvertent human intrusion in the performance assessment calculations and underestimate the actual risk. As discussed above, there is inaccurate information in key DOE documents which can be considered public records. There was the presence of a gas wellhead, visible from the south access highway and availability of lease and production records in the Roswell District Office of the U.S. BLM. Yet that marker and these public records were not effective in notifying the preparers of the DOE documentation of the gas and condensate production activity beneath the WIPP site and the existince of active leases with the WIPP Site Boundary.

6.0 PROPOSED CONGRESSIONAL LEGISLATION

The issue of allowing the existing oil and gas leases and a well to produce hydrocarbons from beneath the WIPP Site has been addressed by the U.S. Congress in the various bills for the WIPP land withdrawal.

The bill passed by the Senate (S. 1671) would:

- prohibit slant drilling from within or without the site
- require the Department of the Interior, in consultation with the Department of Energy, to determine the effects of the oil and gas leases on the activities at the WIPP and to recommend as to the advisability of trading or cancelling the leases.
- authorize funds to be appropriated to the Department of Energy for the cancellation of the leases.

The House Armed Services Committee Bill (H.R. 2637) is identical to S. 1671 except that it does not authorize funds to cancel the lease.

The bills passed by the House Committee on Interior and Insular Affairs (H.R. 2637) and the House Committee on Energy and Commerce (H.R. 2637) would both:

- prohibit slant drilling from outside the WIPP boundary,
- provide funds for the DOE to acquire the leases.

7.0 CONCLUSIONS

Several U.S. Department of Energy documents failed to record the existence of two active oil and gas leases and a producible gas well within the WIPP Site Boundary. In its performance assessment calculations, the WIPP project has assumed that active institutional control would deter human intrusion for 100 years after decommissioning. The EPA should reexamine whether full credit for 100 years active institutional control is reasonable given the actual experience of inaccurate record keeping. The DOE should also examine the basis for assuming full credit for 100 years control and consider using a lesser amount to reflect the actual experience of the WIPP Project. The EPA Standards should require the implementing agency to publish specific plans on how the agency intends to maintain active institutional control. Even in the absence of such a requirement, the DOE should publish plans now that specify in detail how the Department intends to maintain full control of activities in the area of the repository for 100 years after decontamination and decommissioning and describe how that control will completely deter human intrusion. Finally the DOE needs to describe in detail their passive institutional control system and describe how it will provide a deterrence to inadvertent human intrusion after 100 years.

8.0 REFERENCES

Bass, P. R, 1976. November 10 letter to U.S.G.S Supervisor of Oil and Gas Operations, Roswell Office designating Continental Oil Company as designated agent.

Bertram-Howery, S. G., et al., 1990. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990. SAND90-2347, Sandia National Laboratories.

Bickel, J. E., 1990a. November 15 letter from DOE Assistant Manager for Energy and Special Programs to Anita Lockwood, Chairman of the New Mexico Radioactive Waste Consultation Task Force.

Bickel, J. E., 1990b. November 16 letter from DOE Assistant Manager for Energy and Special Programs to Chris Wentz, Coordinator of the New Mexico Radioactive Waste Consultation Task Force.

Craft, B. C. and Hawkins, M. F., 1959. *Applied Petroleum Reservoir Engineering*. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Fader, S. W., 1973. Land subsidence caused by dissolution of salt near four Wells in central Kansas: U.S. Geological Survey Administrative Report for AEC.

Foster, R. W., 1974. Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste, Open-File Report, Contract No. Af (40-1)-4423, Oak Ridge National Laboratory.

Gillham, J. A., 1981. December 16 memorandum from the U.S.G.S. District Supervisor, Roswell to U.S.G.S. Deputy Conservation Manager of Oil and Gas.

Griswold, G. B., 1977. Site Selection and Evaluation Studies of The Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM. SAND77-0946, Sandia National Laboratories.

Keesey, J. J., 1976. Hydrocarbon Evaluation Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico. SAND77-7033, Volume I, Sandia National Laboratories.

Keesey, J. J., 1977. Appraisal Report Waste Isolation Pilot Plant, Eddy County, New Mexico, including: south half of Section 31, T22S, R31E; all of the eastern half; all of the western half excluding the south half of Section 31, T22S, R31E. Sipes, Williamson, and Aycock, Inc., Petroleum Consultants, Midland, Texas.

Keesey, J. J., 1979a. Evaluation of Directional Drilling for Oil and Gas Reserves Underlying the Waste Isolation Pilot Plant Site Area, Eddy County, New Mexico. Sipes, Williamson and Associates, Inc., Petroleum Consultants, Midland, Texas.

Keesey, J. J., 1979b. Estimation of Potential Hydrocarbon Reserves and Associated Costs and Income for Oil and Gas Reserves Underlying the Waste Isolation Pilot Plant Site Area, Eddy County, New Mexico. Sipes, Williamson, and Associates, Inc., Petroleum Consultants, Midland, Texas.

Koski, G. B., 1981. December 18 letter to J. M. McGough, WIPP Project Manager.

McCutcheon, C., 1990. WIPP Officials May Acquire Gas Lease for Dormant Well. Albuquerque Journal, November 3, 1990, p. E-3.

McGough, J. M., 1981. December 30 letter to G. B. Koski, Area Manager, U.S. Bureau of Land Management, Carlsbad Office.

McGough, J. M., 1983a. February 17 letter to R. H. Neill, Director, Environmental Evaluation Group.

McGough, J. M., 1983b. February 24 letter to R. H. Neill, Director, Environmental Evaluation Group.

McGough, J. M., 1983c. December 7 letter to R. H. Neill, Director, Environmental Evaluation Group.

McHale, J. J, 1977. April 4 memorandum from the U.S. Assistant Solicitor for Lands to the U.S. BLM Director regarding the Energy Research and Development Administration Condemnation of BLM-Administered Lands.

Neill, R. H., Channell, J. K., Wofsy, C. Greenfield, M. A., Editors, 1979. Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U.S. Department of Energy. EEG-3.

Neill, R. H., Channell, J. K., Chaturvedi, L., Little, M. S., Rehfeldt, K., and Spiegler, P., 1983. Evaluation of the Suitability of the WIPP Site. EEG-23.

Neill, R. H., 1983a. October 28 letter to J. M. McGough, WIPP Project Manager.

Neill, R. H., 1983b. December 6 letter to J. M. McGough, WIPP Project Manager.

New Mexico Energy and Minerals Department, 1984. Natural Resources at the Waste Isolation Pilot Plant Site. New Mexico Energy and Minerals Department Task Force on Natural Resources. Santa Fe, New Mexico.

Pettengill, J. G., 1981. December 14 memorandum from U.S.G.S Geologist, Roswell Office, to U.S.G.S. District Engineer, Artesia Office, regarding Review of Application for Permit to Drill Surface Lease # NM-02887-D.

Powers, D. W., Lambert, S. J., Shaffer, S. E., Hill, L. R., Weart, W. D., 1978. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND 78-1596, Sandia National Laboratories.

Reitz, M. F., 1982. January 11 letter from U.S.G.S. Deputy Conservation Manager to Perry R. Bass approving application to drill James Ranch Unit No. 13.

Sandia National Laboratories, 1991. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. SAND91-0893, Sandia National Laboratories.

Schueler, T. D., February 20, 1980 letter to R. H. Neill, Director of the Environmental Evaluation Group.

Snow, R. H. and Chang, D. S., 1975. Prediction of Cavity Growth by Solution of Salt Around Boreholes. IITRIC631314, Union Carbide Corporation.

U.S. Congress House. Waste Isolation Pilot Plant Land Withdrawal Act, H. Rept. 102 -241, Part 1-3 to accompany H.R. 2637, 102d Cong., 1st sess., 1991.

U.S. Congress. Senate. Waste Isolation Pilot Plant Land Withdrawal Act of 1991, S. Rept. 102-196, to accompany S. 1671, 102d Cong., 1st sess., 1991.

U.S. Bureau of Land Management, 1992. Production information and reports provided by the Roswell District Office, Roswell, New Mexico.

U.S. Department of Energy, 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant. DOE/EIS-0026.

U.S. Department of Energy and State of New Mexico, 1981. "Agreement for Consultation and Cooperation" on WIPP, First Modification, November 30, 1984 and Second Modification, August 4, 1987.

U.S. Department of Energy, 1987. A Plan for the Implementation of Assurance Requirements in Compliance with 40 CFR 191.14 at the Waste Isolation Pilot Plant. DOE/WIPP 87-016.

U.S. Department of Energy, 1990a. Final Safety Analysis Report, Waste Isolation Pilot Plant. WP-02-9, Rev. 0.

U.S. Department of Energy, 1990b. No-migration Variance Petition: Waste Isolation Pilot Plant. DOE/WIPP-89-003, Rev. 1.

U.S. Department of Energy, 1990c. Draft Decision Plan for WIPP, Revision 5, August 5, 1990.

U.S. Department of Energy, 1990d. Final Supplement Environmental Impact Statement: Waste Isolation Pilot Plant. DOE/EIS-0026-FS.

U.S. Department of Energy, 1991. Implementation of the Resource Disincentive in 40 CFR Part 191.14 (e) at the Waste Isolation Pilot Plant. DOE/WIPP 91-029 (August).

U.S. Environmental Protection Agency. Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-level and Transuranic Radioactive Wastes. *Federal Register* 50 no. 182, 19 September 1985, 38066-38089.

U.S. Environmental Protection Agency. Conditional no-migration determination for the U.S. Department of Energy Waste Isolation Pilot Plant. *Federal Register* 55, no. 220, 14 November 1990, 47700.

U.S. Environmental Protection Agency. Draft Notice for 40 CFR Part 191. *Federal Register* 57, no. 22, 3 February 1992.

Walters, R. F., 1975. Salt Dissolution in Oil and Gas Test Holes in Central Kansas. ORNL Contract No. 78X-38283V.

Weart, W. D., 1980. October 10 memorandum to J. M. McGough, WIPP Project Manager transmitting draft of Sandia National Laboratories input to a position paper on Zone IV.

Weart, W. D., 1990. November 5 memorandum to A. Hunt, WIPP Project Manager, consisting of a one and one-half page review of issues related to drilling on Zone IV at the WIPP Site.

9.0 LIST OF ACRONYMS

BBL	Barrels
BLM	Bureau of Land Management
C&C	Consultation and Cooperation
CFR	Code of Federal Regulations
CH-TRU	Contact-Handled TRU (waste)
DOE	U.S. Department of Energy
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
FEIS	Final Environmental Impact Statement
FSAR	Final Safety Analysis Report
MCF	Thousand standard cubic feet
MOU	Memorandum of Understanding
NMEMD	New Mexico Energy and Minerals Department
RH-TRU	Remote-Handled TRU (waste)
SNL	Sandia National Laboratories
TRU	Transuranic
U.S.G.S	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

Environmental Evaluation Group Reports
(Continued From Front Cover)

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (ed.), The Rustler Formation at the WIPP Site, February 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C. and Jim W. Kenney, A Critical Assessment of Continuous Air Monitoring Systems at the Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

EEG-40 Review of the Final Safety Analyses Report (Draft), DOE Waste Isolation Pilot Plant, December 1988, May 1989.

EEG-41 Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, July 1989.

EEG-42 Chaturvedi, Lokesh, Evaluation of the DOE Plans for Radioactive Experiments and Operational Demonstration at WIPP, September 1989.

EEG-43 Kenney, Jim W., et al., Preoperational Radiation Surveillance of the WIPP Project by EEG 1985-1988, January 1990.

EEG-44 Greenfield, Moses A., Probabilities of a Catastrophic Waste Hoist Accident at the Waste Isolation Pilot Plant, January 1990.

EEG-45 Silva, Matthew K., Preliminary Investigation Into the Explosion Potential of Volatile Organic Compounds in WIPP CH-TRU Waste, June 1990.

EEG-46 Gallegos, Anthony, and James K. Channell, Risk Analysis of the Transport of Contact Handled Transuranic (CH-TRU) Wastes to WIPP Along Selected Highway Routes in New Mexico Using RADTRAN IV, August 1990.

EEG-47 Kenney, Jim W. and Sally C. Ballard, Preoperational Radiation Surveillance of the WIPP Project by EEG During 1989, December 1990.

EEG-48 Silva, Matthew, An Assessment of the Flammability and Explosion Potential of Transuranic Waste, June 1991.

EEG-49 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1990, November 1991.

EEG-50 Silva, Matthew K. and James K. Channell, Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards, June 1992.

EEG-51 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1991, October 1992.

EEG-52 Bartlett, William T., An Evaluation of Air Effluent and Workplace Radioactivity Monitoring at the Waste Isolation Pilot Plant, February 1993.

EEG-53 Greenfield, Moses A. and Thomas J. Sargent, A Probabilistic Analysis of a Catastrophic Transuranic Waste Hoist Accident at the WIPP, June 1993.

EEG-54 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1992, February 1994.

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-57

EEG-57

AN APPRAISAL OF THE 1992 PRELIMINARY PERFORMANCE ASSESSMENT FOR THE WASTE ISOLATION PILOT PLANT

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Environmental Evaluation Group Reports

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disp of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al., (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter, Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon - A Single Hole Scenario, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter and Dave Updegraff, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell, Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter, A Proposed Preoperational Environmental Monitoring Program for WIPP, November 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dol September 1984.

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AN APPRAISAL OF THE 1992 PRELIMINARY PERFORMANCE ASSESSMENT FOR THE WASTE ISOLATION PILOT PLANT

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FOREWORD

This is the Environmental Evaluation Group's (EEG) appraisal of the 1992 performance assessment for the Waste Isolation Pilot Plant. Performance assessments have been performed by Sandia National Laboratories for the U. S. Department of Energy to predict the long-term safety of the Waste Isolation Pilot Plant. The 1992 Performance Assessment, entitled *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992,* is in five volumes:

vol. 1: Third Comparison with 40 CFR 191, Part B;

vol. 2: Technical Basis;

vol. 3: Model Parameters;

vol. 4: Uncertainty and Sensitivity Analysis for 40 CFR 191, Part B;

vol. 5: Uncertainty and Sensitivity Analysis for Gas and Brine Migration for Undisturbed Performance.

This current appraisal incorporates EEG's preliminary comments on volumes 1, 2, and 3 transmitted to the U. S. Department of Energy on September 13, 1993, and volumes 4 and 5 received October 27, 1993.

The purpose of the New Mexico Environmental Evaluation Group is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-ACO4-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include as-

sessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.

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EXECUTIVE SUMMARY

The Environmental Evaluation Group (EEG) has reviewed the WIPP *1992 Performance Assessment*. The Sandia team should be commended for both the substance of this work, and a sound theoretical foundation. Progress has been made towards assessing WIPP's compliance with the U.S. Environmental Protection Agency's Standards for high-level and transuranic waste. Our comments on the *1992 Performance Assessment* are organized into Major Issues, and Detailed Comments. Specific recommendations on major issues follow.

1. Claimed Improvements in the *1992 Performance Assessment.*
   - R-1.1 Apply available fully coupled codes to make explicit the relationship between the complex processes of gas generation, brine flow and room closure.
   - R-1.2 Abandon further statistical manipulation of transmissivity fields in the Culebra in favor of additional field and laboratory work to better define multi-well flow and transport characteristics, including flow and tracer tests (sorbing and non-sorbing) at additional locations.
   - R-1.3 Abandon claiming credit for matrix diffusion and corrensite sorption until experimental data can substantiate the claim.

2. Displaying Uncertainty in Final Results
   - R-2 Show the full uncertainty band of CCDFs when comparison with the containment requirement (40 CFR 191) is made.

3. Use of Judgment in Performance Assessment
   - R-3.1 As experimental solubility values become available (e.g. Nitsche *et al.*, 1992; 1993), use them in performance assessment.
   - R-3.2 Use only demonstrable retardation coefficients in performance assessment.
   - R-3.3 Discard the subjective probabilities for human intrusion used in the *1992 Performance Assessment* and adopt the specific suggestion in Section 3.4.

4. Computer Code Documentation
   - R-4 Establish a workable system to provide EEG with relevant documentation, so that EEG has reasonable access to perform its work.

5. The Culebra as a Natural Barrier
   - R-5 Quantify the extent of matrix diffusion and sorption through accelerated experimentation.

6. Effects of Gas Generation
   - R-6 In future analysis, the deleterious effect of gas generation should be included.

7. Correlation Among Variables
   - R-7 The performance assessment should either give reasons why physical correlations have been ignored, or show results with correlations.

8. Natural Resources Near the WIPP

R-8 Performance assessment reports should accurately reflect the status of resource development near the WIPP site.

9. Oil and Gas Production Near the WIPP

R-9 The performance assessment effort should use the latest and verifiable data on oil and gas production near the WIPP, because the extent of oil and gas resources in this area is likely to be an important determinant of inadvertent human intrusion, and oil and gas production can potentially affect the hydrogeology at the WIPP site.

10. Gas Generation

R-10a The gas generation calculations should include

(a) methane generation,

(b) radiolytically generated hydrogen.

R-10b The relationships in the gas generation model should be validated before the gas generation model is incorporated into BRAGFLO.

11. Unanalyzed Scenarios

R-11.1 The criticality issue needs to be thoroughly evaluated before it can be concluded that its effects are negligible.

R-11.2 Subsidence effects need to be evaluated in much more detail and incorporated, in some manner, into the human intrusion scenarios.

R-11.3 Provide results of the abovementioned analyses, and include contaminated brine flow to the ground surface in future versions of human intrusion scenarios.

R-11.4 Perform a complete analysis of a brine-slurry release scenario. In addition, variants of the brine-slurry scenario in undisturbed performance and in the E2 scenario need to be better understood.

R-11.5 Performance Assessment should not assume perfect plugging of abandoned oil and gas wells near the WIPP. For the human intrusion borehole, the range of degraded permeabilities should span sand and gravel.

12. Analysis of Direct Discharge to the Ground Surface

R-12 Future performance assessments need to include erosion of waste by helical turbulent flow and the effect of sediment erosion. Also needed is analysis of other relevant scenarios, such as the E1E2 with brine slurry discharge to the surface.

13. Inventory

R-13.1 Include ^{135}Cs, ^{129}I and ^{99}Tc and other fission product nuclides as appropriate in future performance assessments.

R-13.2 Show the basis for inventories used.

14. Solubilities

R-14 In future performance assessments, limit the sampling range to the error bands in experimental data.

15. Transport Modeling of Volatile Organics

R-15 Two-phase transport of volatile organic compounds through gas-fractured interbeds should be analyzed in the future.

16. Corrensite Retardation in the Culebra

R-16 Abandon claiming credit for corrensite sorption as well as additional experiments with corrensite, unless the extent of corrensite or other clay minerals can be quantified along postulated flow paths.

17. Ideal Gas Assumption in VOC Migration

R-17 Unless there is experimental evidence that VOC vapors move as ideal gases and move with the low-molecular-weight gases generated by radiolysis, corrosion, or microbial action, movement of VOC vapors should not be modeled as ideal gas flow in showing compliance with 40 CFR 268.

I. INTRODUCTION

The Environmental Evaluation Group (EEG) has reviewed the WIPP *1992 Performance Assessment* (Sandia WIPP Performance Assessment Department, 1992). Although this performance assessment was released after the October 1992 passage of the WIPP Land Withdrawal Act (PL 102-579), the work preceded the Act. For individual and ground-water protection, calculations have been done for 1000 years post closure, whereas the U.S. Environmental Protection Agency's Standards (40 CFR 191) issued in 1993 require calculations for 10000 years.

This is the third iterative performance assessment of the Waste Isolation Pilot Plant (Sandia WIPP Performance Assessment Department, 1992; 1991; Bertram-Howery *et al.*, 1990). EEG believes the Sandia team should be commended for both the substance of this work, and a sound theoretical foundation for performance assessment. The *1992 Performance Assessment* continues to assimilate improved understanding of the geology and hydrogeology of the site, and evolving conceptual models of natural barriers. Progress has been made towards assessing WIPP's compliance with the U.S. Environmental Protection Agency's Standards (40 CFR 191).

The *1992 Performance Assessment* has addressed several items of major concern to EEG, outlined in our July 1992 review of the 1991 performance assessment (Neill *et al.*, 1992). In particular, we are pleased that some key results in this performance assessment, shown in Chapter 5 of volume 1, deal with sensitivity of the calculated complementary cumulative distribution functions (CCDF) to alternate conceptual models proposed by EEG—that flow in the Culebra be treated as single-porosity fracture-flow; with no sorption retardation unless substantiated by experimental data. We look forward to results of additional analysis using scenarios and assumptions that EEG has suggested in the past and hereinafter.

Our review is organized into Major Issues, and Detailed Comments.

II. MAJOR ISSUES

1. Claimed Improvements in the *1992 Performance Assessment*

The overall conclusions of the *1992 Performance Assessment* are stated in chapter 9 of volume 4. Several improvements over previous assessments are noted, and we discuss the claimed improvements below.

1.1 While the first major improvement noted is the coupling of repository creep closure modeling to gas generation and brine flow, the coupling is not entirely satisfactory. The geomechanical closure calculated by SANTOS is passed onto BRAGFLO although the two computer codes use different conceptual models, geometries, and time scale.

Recommendation 1.1. Apply available fully coupled codes to make explicit the relationship between the complex processes of gas generation, brine flow and creep closure.

1.2 The *1992 Performance Assessment* accounts for spatial variation of transmissivity in the Culebra using improved methods. Table 8.4-1 in volume 4 shows that variation in Culebra transmissivity fields accounted for a mere 6% of the variation in total integrated releases. The respective solubilities of Am, Np, Pu, Th and U accounted for more of the variation in release rates.

Recommendation 1.2 Abandon further statistical manipulation of transmissivity fields in the Culebra in favor of additional field and laboratory work to better define flow and transport characteristics, including flow and tracer tests (sorbing and non-sorbing) at additional locations.

1.3 The *1992 Performance Assessment* accounts for radionuclide transport in the Culebra "more accurately" [sic]. To be accurate implies the existence of an unique and correct standard which does not exist in this case. The *1992 Performance Assessment* considers three radionuclide retardation mechanisms in the Culebra: equilibrium sorption, matrix diffusion and clay sorption. For equilibrium sorption, the second modification of the Consultation and Cooperation Agreement between the Department of Energy (USDOE) and the State of New Mexico specifies that retardation coefficients shall be set to zero unless there are experimental data otherwise. The *1992 Performance Assessment* offers no experimental evidence for matrix diffusion. No clear evidence is given for the extent of corrensite in the calculated

flow paths. Moreover, clay in fractures can act either as an additional sorption agent, or serve to block mass transfer between the fracture and the matrix. The *1992 Performance Assessment* has eliminated the latter role [vol. 2, p. 7-23, line 11]. This is double counting for a mechanism which may not exist. We deal with the role of corrensite in detail in 16.

Recommendation 1.3 Abandon claiming credit for matrix diffusion and corrensite sorption until experimental data can substantiate the claim.

The *1992 Performance Assessment*

> ...accounts for the effects of passive marker systems through time-varying drilling intensities within the Poisson model for calculating intrusion probabilities [vol. 4, p. 9-1].

What this means is that subjectively elicited probabilities of drilling intrusion that are orders of magnitude below the USEPA guidance (40 *CFR* 191, Appendix C) have been used. The EEG objects to the use of these probabilities as elicited. We deal with this topic in 3b below.

The *1992 Performance Assessment* states that the following improvements will be made in future performance assessments:

- modeling pressure fracturing of anhydrite interbeds,
- modeling three-dimensional flow in the Rustler, especially the effects of subsidence of potash mine excavations,
- incorporating plug degradation,
- modeling spalling in drilling intrusions,
- acquiring experimental data on actinide solubilities and retardation,
- determining the most appropriate conceptual model for radionuclide transport in the Culebra.

We have called for these improvements for several years, and welcome the commitment.

2. Displaying Uncertainty in Final Results

In previous performance assessments, the USDOE noted that the calculated CCDF's were at least an order of magnitude below the allowable limits in the USEPA Standards (Sandia WIPP Performance Assessment Department 1991). In the *1992 Performance Assessment*, for the case of total release from repository/shaft barrier only, and a [0, 30] sampled intrusion

rate, the mean CCDF comes to within a factor of two or three of the USEPA containment requirement [vol. 4, Fig. 9-1, curve 1]. This suggests several vectors of CCDF lie in the zone of violation of the containment requirement. This mean CCDF is not as conservative as it may appear because subjectively elicited solubilities are incorporated. The non-conservative basis of curve 1 in Figure 9-1 is illustrated in Figure 1. Using BRAGFLO-calculated brine flow from the repository up to the Culebra (70 vectors for both the E2 and E1E2 scenarios), all actinide solubilities at 10^{-3}, 10^{-5} and 10^{-7} M, and the human intrusion rate sampled uniformly between 0 and 30 boreholes/km^2/10,000 years, the mean CCDFs are shown in Figure 1, along with curve 1 from Figure 9-1 (vol. 4). If the extremely low subjectively elicited solubilities are **not** used, then the mean CCDF for the case of engineered barriers alone may not meet the containment requirement. See also 14 below.

The EEG has also suggested to the USEPA that for comparison with the containment requirement, that the 90% curve be used to be conservative.

Recommendation 2. Show the full uncertainty band of CCDFs when comparison with the containment requirement (40 CFR 191) is made.

3. Use of Judgment in Performance Assessment

3.1 Beginning with the *1992 Performance Assessment*, "expert judgment" is used to estimate

a. solubilities of actinides;

b. retardation coefficients of radionuclides; and

c. probabilities of inadvertent intrusion.

Experimental programs are underway to measure solubility and retardation coefficients, for conditions relevant to the WIPP.

Recommendation 3.1. As experimental solubility values become available (e.g. Nitsche *et al.*, 1992; 1993), use them in performance assessment.

3.2 The second modification of the Cooperation and Consultation Agreement between the Department of Energy and the State of New Mexico specifies that retardation coefficients be set to zero unless experimental data shows otherwise. Results using zero and nonzero retardation coefficients appear in chapter 5 of volume 1.

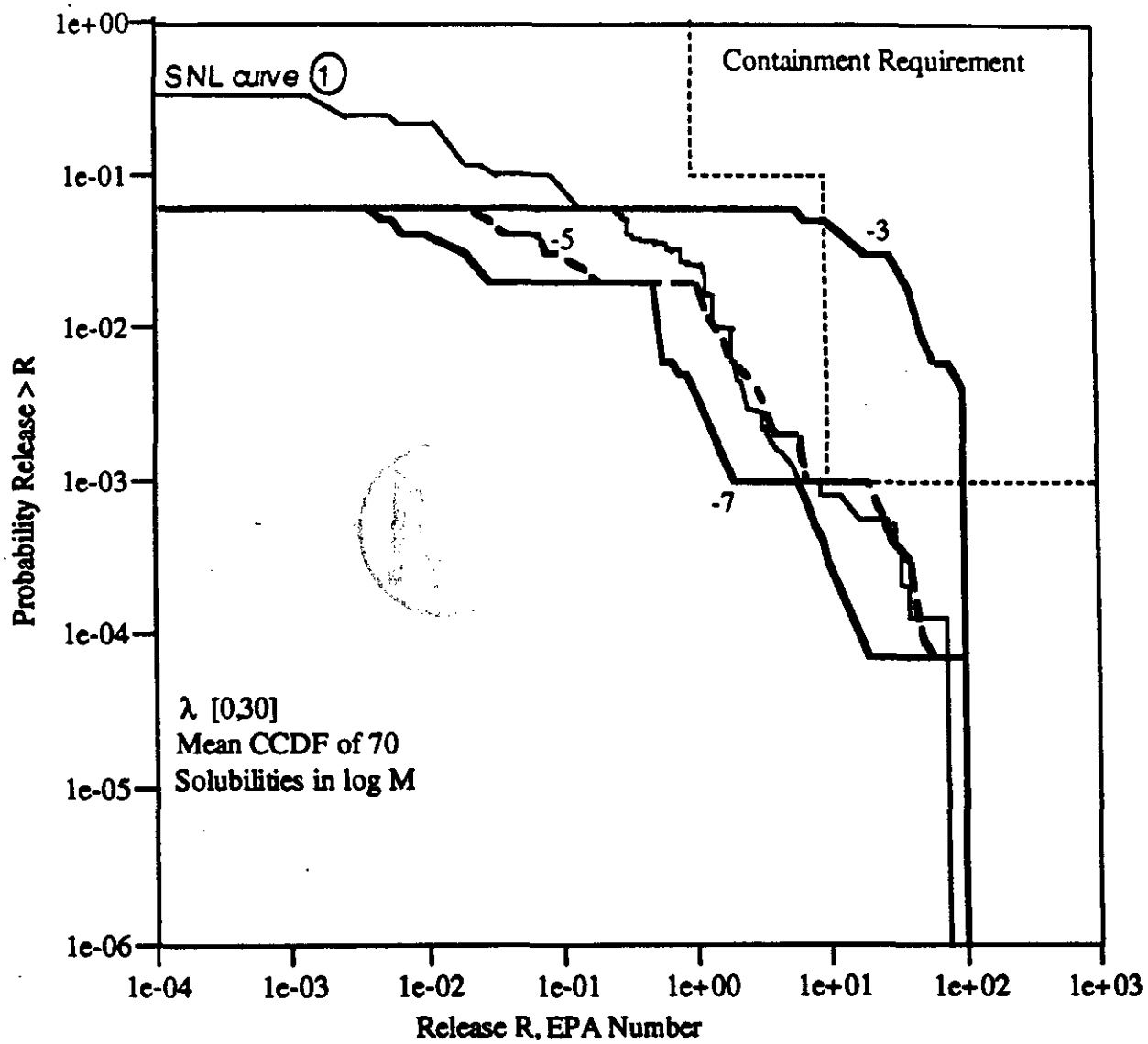

Figure 1. Comparison of mean CCDFs from the EEG scenario of direct ground discharge for all actinide solubilities set at 10^{-3}, 10^{-5}, and 10^{-7} M with Curve 1 from Figure 9-1 of SAND92-0700/4.

Recommendation 3.2. Use only experimental retardation coefficients.

3.3 EEG is concerned about the use of subjective probabilities in human intrusion analysis. While human judgment may be the only method of estimating these probabilities, we disagree with the procedure used in the *1992 Performance Assessment* to estimate human intrusion probabilities.

3.3.1 The disagreement between EEG and SNL centers around how the problem of subjective elicitation is to be formulated, whom to use as panelists and what information should be supplied to the panels. Elicitation should have been for the probability of future human intrusion by drilling for resources, the judges should have been people experienced in oil and gas and energy futures, and factual information should have been given to the judges during orientation.

Table I summaries the divergence.

Table I. Summary of Disagreement on Subjective Elicitation

Topic	SNL	EEG
Problem Formulation	Open	Focused
Required expertise	Knowledgeable in a subject	Knowledgeable in the focused subject
Briefing	Available information	Verified Information

SNL prefers to set no limits on the exercise, whereas EEG believes the problem must be well-defined. The divergence is clear from the SNL definition of an expert:

> An expert possesses exceptional knowledge about **a** subject [Hora to the Futures Panel, August 13, 1990 and to the Marker Panel, November 4, 1991].

EEG claims that the relevant definition should be

> An expert possesses exceptional knowledge about **the** subject.

3.3.2 The probabilities that have been elicited from panels for the purpose of estimating future intrusion intensity (Hora, von Winterfeldt and Trauth, 1991) are subjective probabilities. To call them "expert judgment" is to give them an aura of respectability they do not deserve. The methods for eliciting such probabilities come from statistics (Savage, 1954) and

experimental psychology (Edwards, 1954). There are futurologists, such as Alvin Toffler or John Naisbitt, but the SNL Futures Panel was not composed of these people. While the elicitation of opinions is valid, the elicitation of expert opinion on the future is gratuitous. The WIPP Performance Assessment Department undertook an "extensive and impartial process" to select the panelists, but the process alone did not ensure the appropriateness of the chosen candidates. No attempt appears to have been made to establish the qualifications of the panel members as experts on the future. If the WIPP Performance Assessment Department had defined the problem properly, then it would be much easier to establish the expertise of the panelists.

3.3.3 The WIPP Performance Assessment Department invokes the interdisciplinary nature of an expert judgment panel as a reason to use such a panel. But "interdisciplinary" is not a synonym for "good" or "appropriate" any more than "single disciplinary" is a synonym for "bad" or "inappropriate." The advantage of multidisciplinary data interpretation over interpretation by an expert in a single discipline is not at all clear. For example, the marker panel (Rechard *et al.*, 1993; Table I) lists experts in materials science, architecture, linguistics, communications, etc. How is the judgment of a linguist on materials hardness and durability relevant? Either the linguist accepts the materials scientist's judgment, in which case the interpretation is not interdisciplinary, or the two differ in interpretation, in which case the materials scientist's interpretation is clearly the more valid and that judgment should not be diluted.

3.3.4 In the attempt to find general experts in lieu of futurologists, SNL might have empaneled representatives from diverse backgrounds, but failed to do so. The panels are not representative of modern United States, not representative of the modern world, and not representative of the historical continuity of the human race. While there were historians, sociologists and anthropologists, there was only one woman on the markers panels and none on the futures panels. There are no representatives of indigenous cultures of the southwestern United States.

In the USDOE response to the preliminary comments from the EEG, SNL stated

> The EEG should note, in fairness, that the range of organizations from which the experts were selected (Natural Resources Defense Council, universities, institutions,

etc.) provides rich diversity in political and environmental organizations.

This statement is counter to the claim that panelists were selected on the basis of their individual qualifications.

3.3.5 The elicitation process used was open-ended. While it is true that what will be mined over 10,000 years is unknown, let alone where to mine it, the problem is simpler for a specific area with known minerals. For example the Outer Continental Shelf Lands Act allows oil and gas drilling in the sea beyond the three-mile limit, but includes a clause for "other minerals." When the Outer Continental Shelf Lands Act was first passed in 1953, "other minerals" referred to sulfur. By the mid-1970s the focus of other minerals became construction aggregates around coastal cities, and in the early 1990s, manganese crusts. At a specific location, with geologic information, we know what can be mined now and in the future. The minerals to be mined will change only if society's needs change dramatically. If that had been borne in mind, the problem would have been much more circumscribed, and the results more realistic and reliable.

In the USDOE response to the preliminary comments from the EEG, SNL stated

> This comment [above] proposes that the experts be directed as to what potentially intrusive activities to study. We believe that this is inappropriate and would not stand up under peer review due to extensive direction by the analytic staff.

All elicitations have to be circumscribed, if only to ensure that the problem is within the expertise of the judges. Figure 2 is a reproduction of a SNL viewgraph shown to the panelists, demonstrating how the SNL analysts defined the problem and may have biased the panelists.

3.3.6 Results of the open-ended elicitation process used by Hora (Hora, von Winterfeldt and Trauth, 1991) appear to have been used selectively. If a more circumscribed process had been used, then the methods available to combat cognitive bias (Tversky and Kahneman, 1974) could have been used. Unfortunately, the results used in the *1992 Performance Assessment* strongly reflect the intervention of the analyst. The final result used a form

$$\lambda_t = d(1 - p_1 p_2) \tag{1}$$

where λ is the intrusion intensity, number of holes per time, d is the raw drilling intensity number of holes per time, p_1 is the probability of markers surviving, and p_2 is the probability

How Will the Expert Judgments Be Used in the WIPP Performance Assessment?

- The findings of the expert teams will provide modes of intrusion. These modes will be grouped into similar types of intrusions and modeled.
- The frequencies of intrusion given by the experts will be encoded as rates and used as input to simulation studies.
- The expert judgments will be both analyzed separately and combined into a base case. The analyses will preserve the findings of the individual teams.

Figure 2. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's formulation of the problem.

that surviving markers are effective in deterring drilling, all functions of time. The paradigm was not elicited from any one panel, but the result is a mixture of results from the panelists, who may not have understood how their inputs would be used.

The USDOE response to the preliminary comments from the EEG referred to a SNL viewgraph (Figure 3) entitled "Logic Tree for Deterrence by Markers Given Time, Society, Mode of Intrusion, and Marker Criteria." If one defines each of the branches in Figure 3 as p_1, p_2, p_3 and p_4, then deterrence is

$$p_1 p_2 p_3 p_4 \tag{2}$$

and eq. (1) does not obtain. Eq. (1) does NOT appear anywhere in the hundreds of viewgraphs shown to the Futures and Markers Panels.

An example of the intervention of the analyst occurred when elicited probabilities of the Washington A and B Teams and the Southwest Team for the period 0 to 100 years after closure were ignored. Professor Hora states [vol. 3, p. A-87]

> In contrast, the two Washington teams gave assessment beginning immediately after closure and thus did not allow for the period of continuing administrative control. **The performance assessment, however, assumes that the drilling rate is effectively nil during the first 100 years after closure** [emphasis supplied].

Clearly these three teams would not have agreed with SNL's use of their opinion in meeting the USEPA Standards (USEPA 1993).

3.3.7 A flagrant and important abuse of the analyst-assessor role occurred when the WIPP Performance Assessment Department assumed that there will be no intrusions after 2000 years (vol. 4, p. 2-19, lines 4 and 20). For consequence calculations, the *1992 Performance Assessment* considered only a single intrusion at 1000 years. This is clearly counter to the spirit and letter of analyzing human intrusions for the entire 10000-year regulatory period. If one assumes that the computer program by Professor Hora [vol. 3, p. A-92ff] captures the essence of the Futures and Markers Panels (which we do not) Appendix D of vol. 3 of the *1992 Performance Assessment* contains 12 pages of realizations of drilling intensity functions. The graphs in Appendix D show the intrusion rate and cumulative number of intrusions as a function of time to 10,000 years. Showing these graphs to 10,000 years is misleading because the WIPP Performance Assessment Department discarded the Panels'

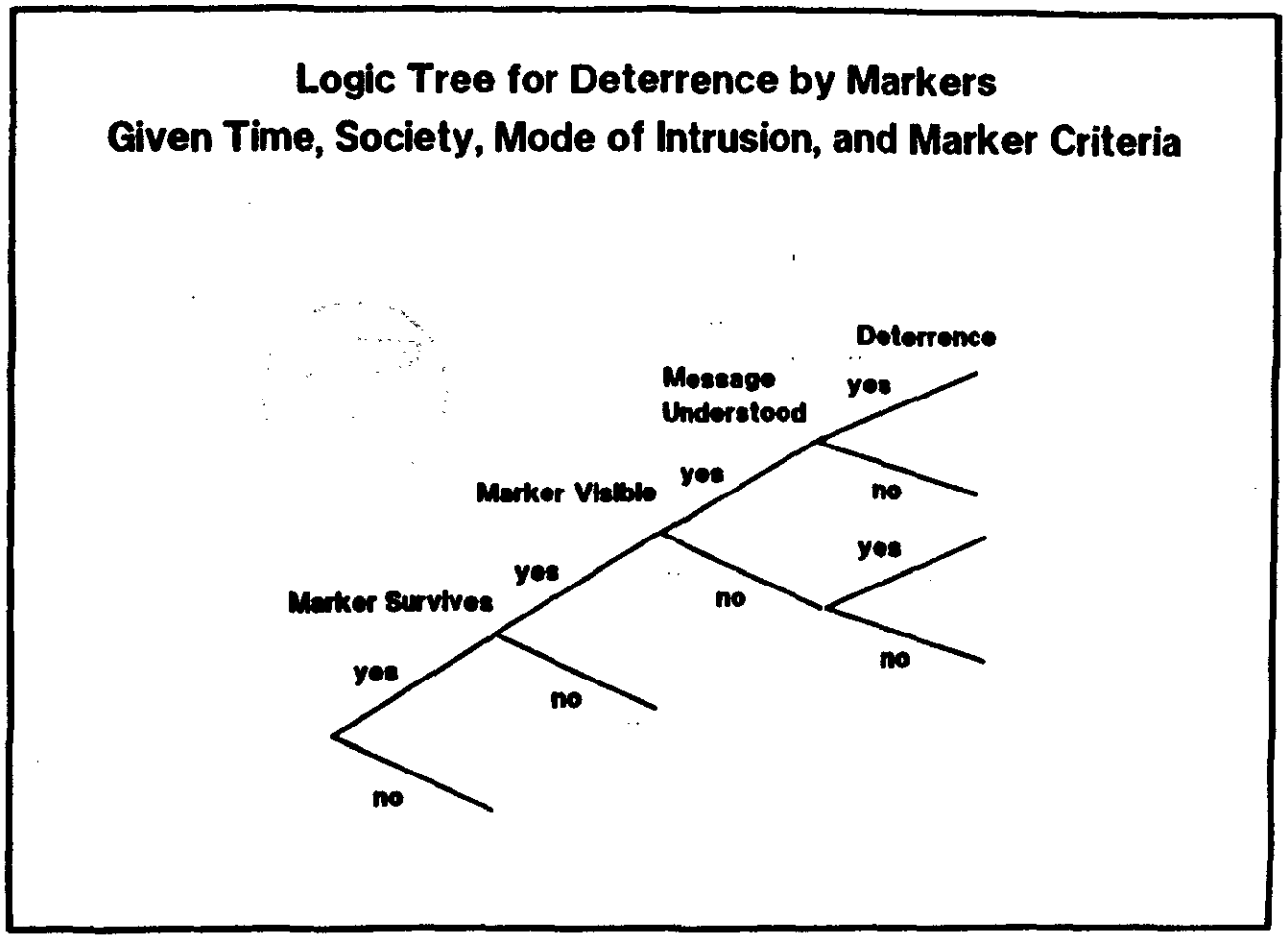

Figure 3. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's concept of the elicitation.

recommendations, assuming the intrusion rate to be zero after 2000 years.

3.3.8 The elicitation process is described in the Hora memo, vol. 3, pp. A-71 through A-99. The memo includes a FORTRAN program to sample among the panels, and produces realizations of intrusion intensities as functions of time for use in the 70 Monte Carlo runs. On page A-94, line 13, a three-dimensional array BOSTAB2 is undimensioned and undefined, thus the program cannot possibly work. In May 1993, EEG requested a working copy of this program, first from Professor Hora, then from WIPP Performance Assessment Department, and finally obtained a copy on December 31, 1993. This program creates Monte Carlo realizations of rates of human intrusion, drawn primarily from Prof. Hora's interpretation of the Futures and Markers Panels.

3.4 EEG suggests a simplified, focused and understandable alternative.

Figure 4 shows what EEG believes the exploratory drilling rate to be in any specific area, and illustrates the evolution of oil and gas drilling as a function of time.

Figure 4 shows a historical record of drilling in this area, a known rate, a holes per area per year, $a > 0$. The U.S. Environmental Protection Agency's guidance (40 *CFR* 141, Appendix C) of thirty boreholes per kilometer^2 over 10,000 years is such a rate.

Giving no credit for passive institutional control, because of recent experience (Silva 1994), we extend the historical drilling rate some time into the future, b years, $b > 0$. Geologic knowledge should be used for this extension. If there is current oil and gas drilling, then it is likely for the exploration and development to continue for some time. If there is no current drilling in this area, then there may not be any drilling until some new mineral is discovered in this area. This extension should extend beyond the period of active institutional control.

Given our present understanding of energy economics, we may postulate a decrease in oil and gas drilling, after a period of time, due to either exhaustion of the resource, or technological developments in some other fuel sources, or both. This decline can be represented by an exponential decay function, $y = y_0 \exp^{-ct}$. The rate of decrease is characterized by a single parameter, c.

For the long-term, there should be a rate of intrusion that is

(a) non-zero; and

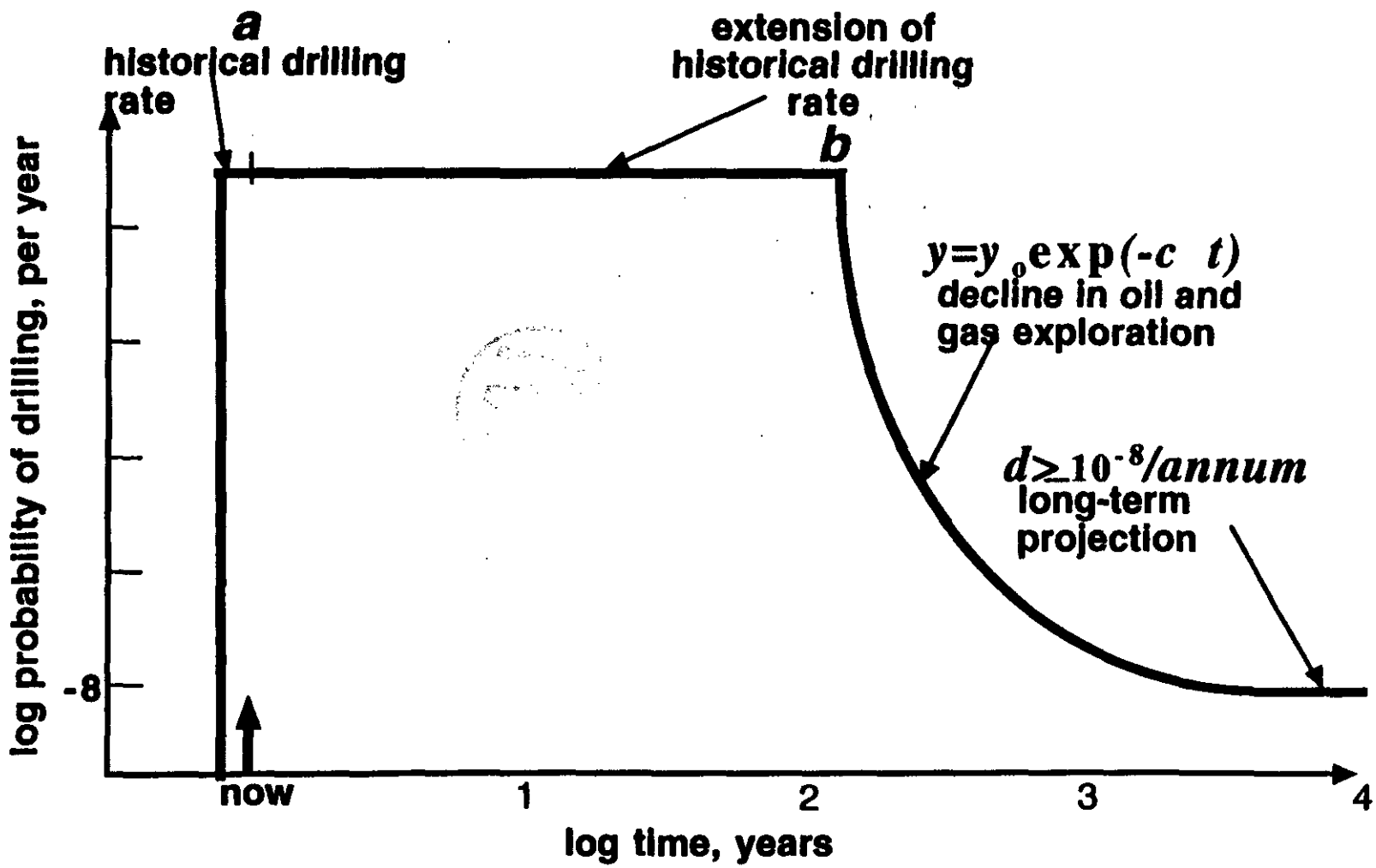

Figure 4. EEG's suggestion for a rate of human intrusion by drilling.

(b) above the USEPA threshold probability for events and scenarios to be considered, or 10^{-8} per year. Call the rate d holes per area per year, $d \geq 10^{-8}$ per year.

Because the waste will not have decayed to harmless levels after 10,000 years, and because the site may still contain resources, the intrusion rate should not be zero for any time within the regulatory period. To ignore such probabilities is to do an incomplete analysis.

The parameters a, b, c, and d completely specify the rate of inadvertent human intrusion in a readily understandable way. Subjective elicitation can now focus on these four parameters. The Department of Energy has experts in the history of oil and gas fields in the Energy Information Administration, and also experts in prospects for solar and other new energy sources.

In the USDOE response to EEG's preliminary comments, SNL stated four principles upon which to object to EEG's suggestion. In brief they are: Avoid Problem Definition, Avoid Bias, Put Rationale Before Results, and Do Elicitation Only on Physical Quantities.

A subjective elicitation requires problem definition. Figure 2 shows SNL's definition before the elicitations. Apparently SNL fitted the results of the elicitation into its preconceived structure. Although the EEG is not free of judgment, it focuses judgment on relevant parameters. SNL should heed its own advice about following USEPA's guidance and limit the elicitation to inadvertent drilling for minerals, without exploring irrelevant intrusion modes.

We will illustrate the bias that SNL imparted to the panelists on the topic of oil and gas resources at WIPP. In the orientations, SNL cited three different studies that there is no economically recoverable oil near WIPP, shown in Figures 5, 6, and 7, augmented by SNL's own conclusion that (Figure 8)

> Crude oil will not be the target for exploration unless the price is drastically higher than the present [1990].

Figure 9 shows the number of oil wells near the WIPP site in October 1993. Table II shows the recent history of wells in the same locations. Figure 9 and Table II belie the suggestion that there is no economically recoverable oil near WIPP. Actually, SNL did tell the panelists about oil and gas production near the WIPP. Figure 10 is a viewgraph shown to the panels by the speaker on cultural resources. That the panelists did not raise questions suggests that

TOTAL MINERAL AND ENERGY RESOURCES
(Brausch and others, 1982)

ESTIMATES ARE FOR ALL FOUR CONTROL ZONES

RESOURCE			
Caliche	185 MT	at surface	Not a reserve
Gypsum	1.3 BT	300-1,500 ft	Not a reserve
Salt	198 BT	500-4,000 ft	Not a reserve
Potash			
Sylvite	133.2 MT	1,600 ft	27.43 MT reserves
Langbeinite	351.0 MT	1,800 ft	48.46 MT reserves
Hydrocarbons			
Crude Oil	37.50 MB	4,000-20,000 ft	Not a reserve
Natural Gas	490 BCF	4,000-20,000 ft	44.62 BCF at 14K ft
Distillate	5.72 MB	4,000-20,000 ft	0.12 MB at 14K ft

Figure 5. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a resource study.

ESTIMATES OF UNDISCOVERED HYDROCARBON RESOURCES--PROVINCE 092 (Mast and others, 1989)

RESOURCE	Mean	F95	F5
Crude Oil			
recoverable	0.02 BB	Negl.	0.05 BB
economically recoverable	0.02 BB	Negl.	0.05 BB
Natural Gas			
recoverable	0.24 TCF	0.05 TCF	0.67 TCF
economically recoverable	0.24 TCF	0.05 TCF	0.67 TCF
Natural-Gas Liquids			
recoverable	0.00	0.00	0.00
economically recoverable	0.00	0.00	0.00

Figure 6. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a second resource study.

GEOLOGICAL CHARACTERIZATION REPORT
(Powers and others, 1978)

POTENTIAL RESOURCES EXAMINED

- Caliche
- Gypsum
- Salt
- Uranium
- Sulfur
- Lithium
- Potash
- Hydrocarbons (crude oil, natural gas)

CONCLUDED

Only potash and natural gas have potential as significant exploitable deposits.

Figure 7. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a third resource study.

CONCLUSIONS ABOUT THE POTENTIAL FOR ECONOMICALLY IMPORTANT NATURAL RESOURCES AT THE WIPP

1. Crude oil will not be the target for exploration unless the price is drastically higher than at present.
2. Natural gas in the Morrow Formation is the only hydrocarbon of potential economic importance in the area.
3. All currently recognized potash resources are confined to a zone above the waste-filled rooms and drifts.
4. Only the lowest grade of potash ore overlies part of two waste panels.
5. Other resources are present, but because of abundance and greater accessibility elsewhere, these resources at the WIPP are of no economic interest.

Figure 8. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's conclusion on oil resources near the WIPP.

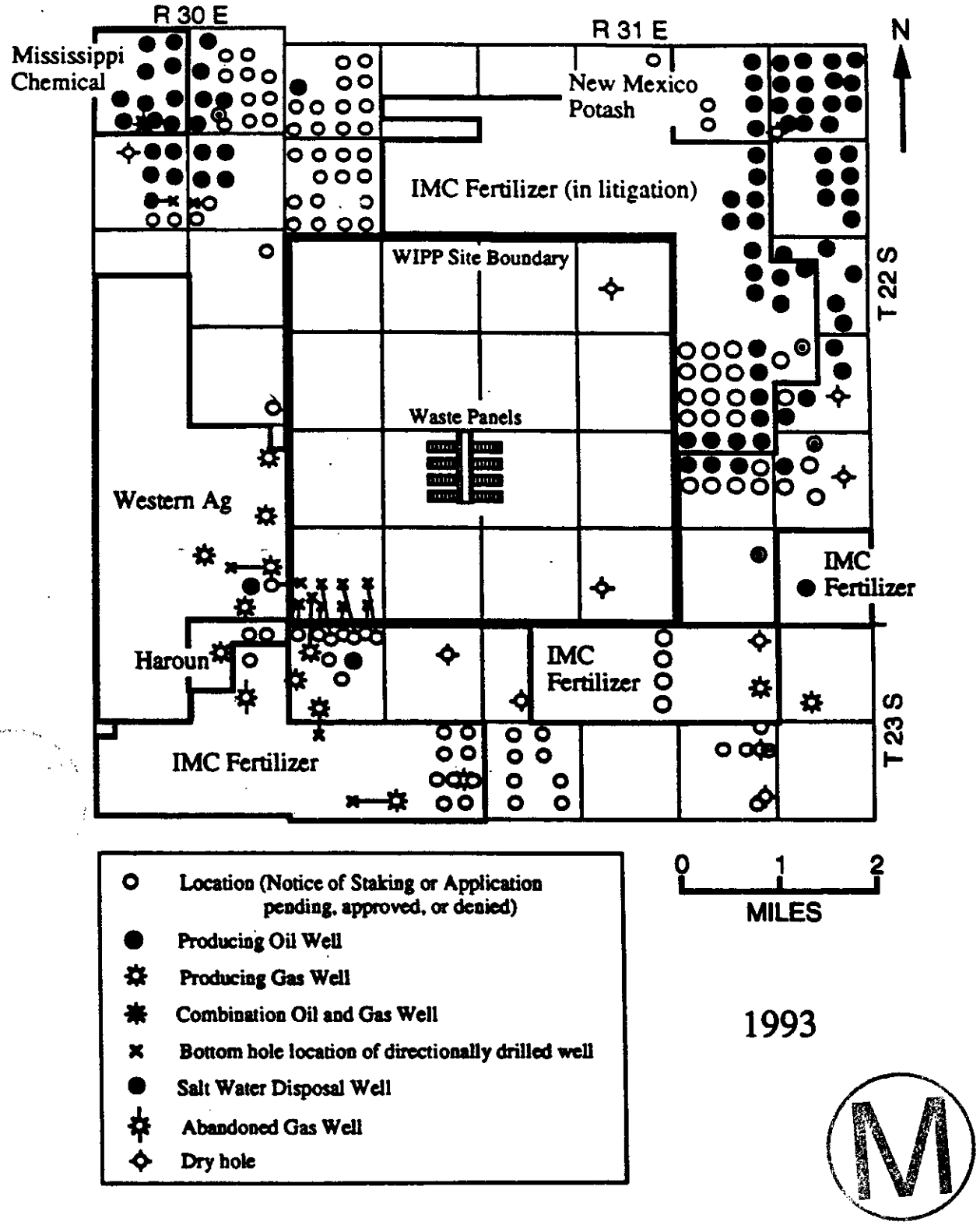

Figure 9. Oil and gas wells near the WIPP, October 1993.

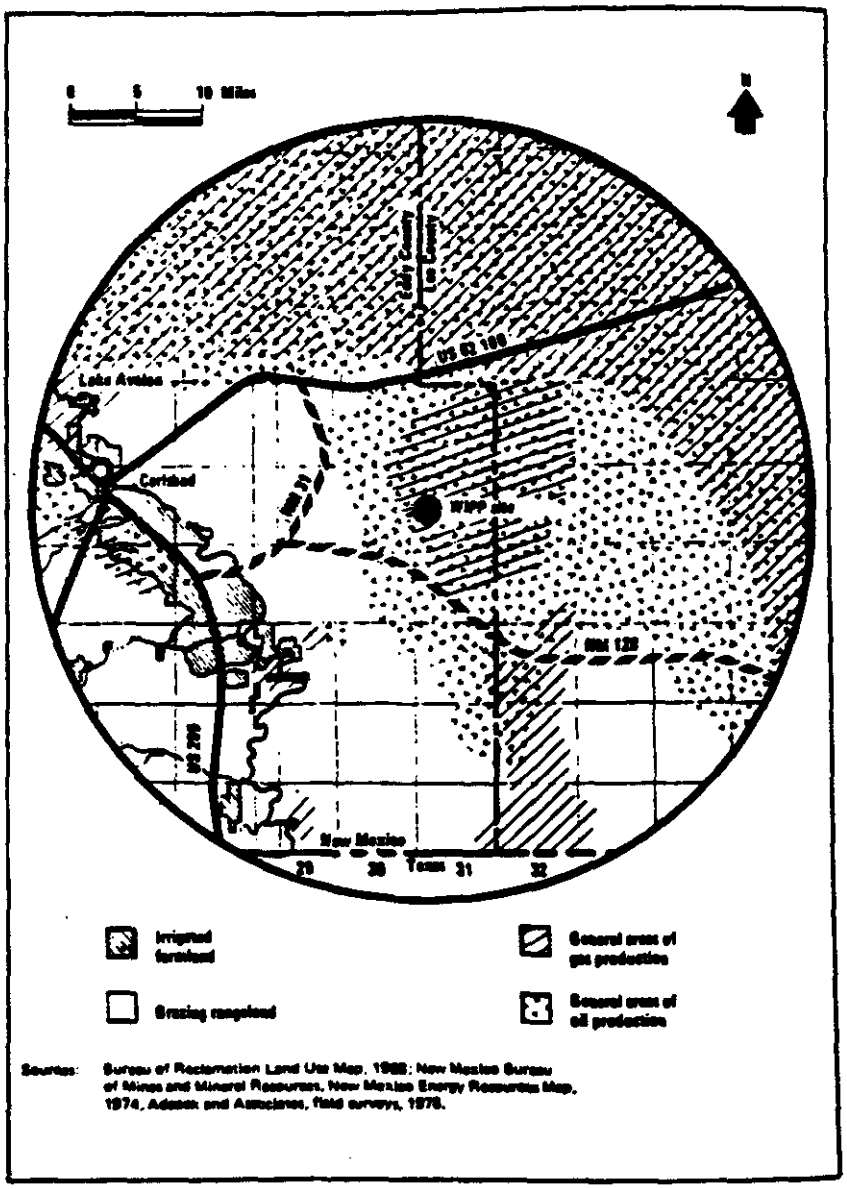

Figure 10. Reproduction of a map shown to the Future and Markers Panels by SNL, showing oil and gas resources near the WIPP.

Table II. Drilling rate for a 124 km^2 area immediately surrounding the WIPP*.

Year	Gas Wells	Oil Wells
1987	0	4
1988	0	2
1989	0	3
1990	0	13
1991	1	37
1992	1	23

*Source: Silva (1994)

SNL was successful in putting bias in the mind of the panelists.

To say that this elicitation puts rationale before numerical results belies the purpose of the effort. The emphasis on rationale may have prompted Prof. Hora to make arbitrary assumptions to obtain numerical results.

> The information for the drilling intensity from the Washington B team indicates that if minerals are extracted in the WIPP region, exploration will occur in the first 200 years or in the next 300 years, but not in both periods. **There does not seem to be adequate information from this team to model with dependence without making arbitrary assumptions**....[Sandia WIPP Performance Assessment Department 1992; vol. 3, p. A-87, emphasis supplied].

To object to elicitation for parameters without physical meaning is a surprise to us. One of the most frequently cited elicitation exercises is on perceived risk (Slovic, Fischhoff and Lichtenstein 1980), in which judges were asked to rank order risks from 40 technologies. The resulting ordinal ranking has no physical meaning. A greater surprise is that SNL would object to eliciting parameters on human intrusion when the entire Future and Markers Panels effort is attempting the same.

3.5 The Effect of Using Subjective Probabilities

We are now in a position to examine the consequences of using subjectively elicited probabilities. EEG has long maintained that a more reasonable conceptual model for intrusion would

include a degrading plug, with the contaminated brine reaching the accessible environment at the ground surface, release Path b in Figure 11. Current oilfield practice in the Delaware Basin is to case the wells down to the top of the salt deposits, preventing contaminated brine from entering the water-bearing zones above the salt. Figure 12 shows CCDFs for the following conditions:

- Brine flow calculated for flow up the borehole, from the *1992 Performance Assessment*;
- Solubilities of all actinides set at 10^{-6} M;
- Intrusion probabilities from subjective elicitation, constant 30 boreholes/km^2/10000 years, or sampled between 0 and 30 boreholes/km^2/10000 years.

Figure 12 shows that if all actinide solubilities are 10^{-6} M, the mean CCDF of 70 would be very close to violating the containment requirement, unless subjective probabilities are used.

Recommendation 3.3. Discard the subjective probabilities for human intrusion used in the *1992 Performance Assessment* and adopt EEG's specific suggestion in Section 3.4.

4. Computer Code Documentation

4.1 The EEG has been concerned about the lack of documentation of computer codes used in the *1992 Performance Assessment*. Of the major codes used in the *1992 Performance Assessment*, as shown in vol. 1, Figure 4-4, only SANCHO and GENII-S have complete documentation. Ironically, no direct results from SANCHO and GENII are shown in the *1992 Performance Assessment*. In response to an EEG inquiry, USDOE provided the following schedule for complete documentation of computer codes shown in Figure 4-4 of vol. 1 (Arthur 1993):

Complete documentation is a requirement of Sandia's own software quality assurance program. For most of the codes shown in Figure 4-4, volume 1, only brief descriptions appear in the *1992 Performance Assessment*, and such descriptions do not present sufficient details for reviewers. As shown in our discussion of human intrusion, it is necessary to review the computational tools at that level of detail. In June 1994, EEG learned that complete documentation of all codes will be available by January 3, 1995.

Technical papers are no substitute for documentation, because technical papers and documentation have different purposes. Documentation is intended to communicate effectively

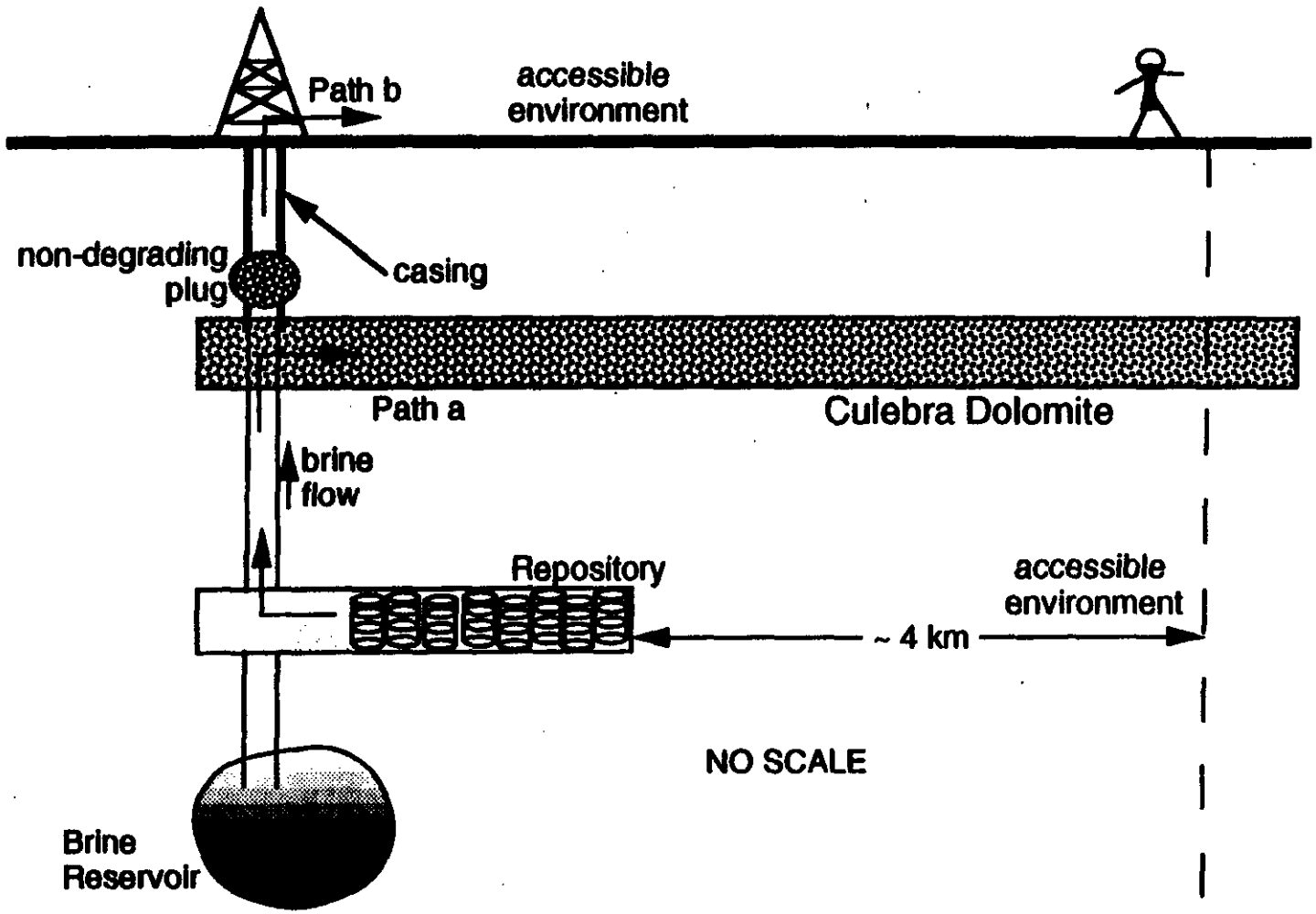

Figure 11. EEG scenario of direct discharge of contaminated brine to ground surface.

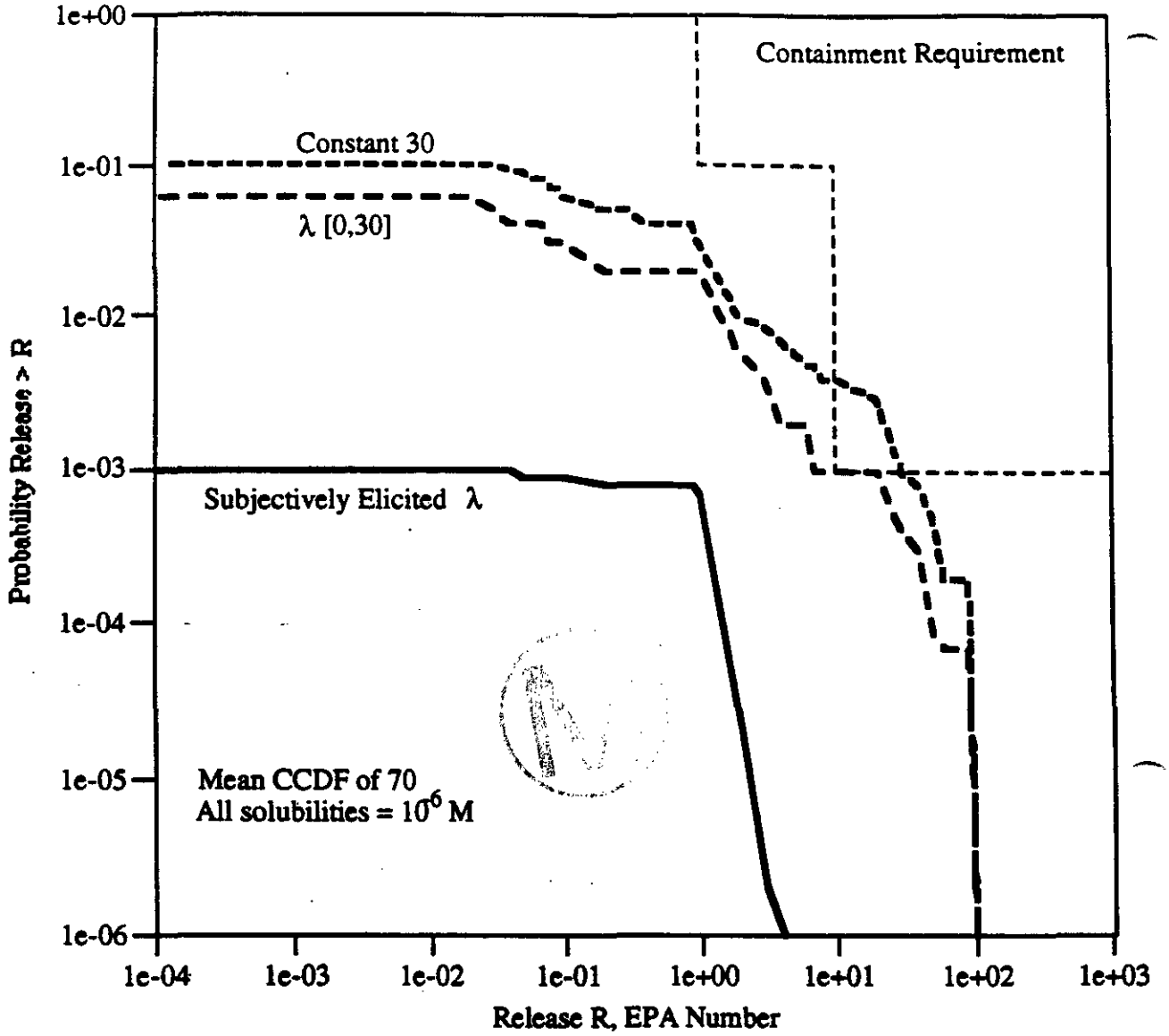

Figure 12. Mean CCDFs from the EEG scenario of direct ground discharge for all actinide solubilities set at 10^{-6} M, using 3 methods of deriving the rate of human intrusion, constant 30 boreholes/km²/10,000 years, uniform sampling between 0 and 30 boreholes/km² /10,000 years, and subjectively elicited probabilites.

Table III. Schedule for Performance Assessment Computer Code Documentation

Code	Aug 9, 93*	Jun 10, 91*
BRAGFLO	DEC 97	Sep 1, 94
CCDFPERM	DEC 94	Dec 1, 94
CUTTINGS	DEC 96	Oct 1, 94
GENII	DEC 96	Jul 1, 94
PANEL	DEC 97	Oct 1, 94
SECOFL2D	DEC 97	Jul 1, 94
SECOTP2D	DEC 97	Jul 1, 94

* Dates of USDOE promise by letter.

the details of the code design and operation so that people with different interests can be convinced of the usefulness and validity of the computer code. Documentation presents the code's logical structure, equations and methods, assumptions and limitations affecting the code's applicability, essential for an effective review.

The brief descriptions in the *1992 Performance Assessment* are inadequate as documentation for the following reasons.

4.2 According to SAND92-0700/3, p. 1-36, PANEL calculates

$$\dot{M}_i = -QC_{di} - \lambda_i M_i + \lambda_{i-1} M_{i-1} \tag{3}$$

where M_i is the mass of the ith nuclide in dissolved form,
Q is the brine flow rate, and
λ is the nuclide's decay constant.

The concentration is calculated

$$C_{di} = \frac{M_i}{\sum_j M_j} S_i, \tag{4}$$

where S_i is the concentration in saturated solution, and this equation calculates the isotopic fraction of solubility over j isotopes.

According to the February 22, 1994 USDOE presentation to USEPA, PANEL actually solves

$$C_{di}(t) = \begin{cases} S_i, & \text{if } I_i(t)/V(t) \geq S_i \\ I_i(t)/V(t), & \text{if } I_i(t)/V(t) < S_i \end{cases} \tag{4a}$$

where $I_i(t)$ is the inventory of element i at time t, and

$V(t)$ is the brine volume in the panel at t. Eq. (4a) incorporates a different concept than eq. (4). This kind of information is needed to fully understand the *1992 Performance Assessment.*

4.3 The transport code SECOTP2D offers the best examples of the need for full documentation. Roache (1993) does not explain how the following important items are handled.

- SECOTP2D is a two-dimensional code. How does it handle the conversion of the source term from zeroth dimension, the solubility, to two dimensions? The source is Qc, where Q is the well injection rate. How is Q determined? Is Qc spread uniformly vertically, uniformly laterally to infinity, making it an infinite line source?

- Two types of matrix diffusion are claimed for the Culebra, in the dolomite and in the clay layer. Is the classic Neretnieks equation for matrix diffusion used for calculating these effects?

- Over the years several codes have been used for the calculation of flow and transport in the Culebra, such as SWIFT, and STAFF2D. Are there benchmarking results?

c. To further demonstrate the inadequacies of technical papers as documentation, the following comments are offered on the Roache paper.

- The paper touts the TVD algorithm but failed to define TVD.

- The algorithm begins with a variable transformation. A key variable J in the transformation is not defined.

- No results are given for verification of the dual porosity option.

Finally, it is often claimed that because a computer code is undergoing continuous development, its documentation cannot be released. This is simply not the case. A calculation done with a computer code is made with a specific version. Subsequent calculations may use the next version. However, for the purpose of documentation, a calculation and the tool (computer code) are inextricably intertwined. For a meaningful review, the code version used and the extant documentation must be made available.

Recommendation 4. Establish a workable system to provide EEG with relevant documentation, so that EEG has reasonable access to perform its work.

5. The Culebra as a Natural Barrier

The *1992 Performance Assessment* elucidates the role of the Culebra as an isolation barrier. Figure 5-6 of vol. 1, claims that WIPP can meet the USEPA's containment requirement (USEPA 1993) without the Culebra as an isolation barrier. That is, if the USEPA containment limit is applied where brine is diverted into the Culebra, WIPP would still be in compliance. With matrix diffusion and sorption, the Culebra would contribute additional isolation.

Recommendation 5. Quantify the extent of matrix diffusion and sorption through accelerated experimentation.

6. Effects of Gas Generation

While the USDOE has analyzed the beneficial effects of gas generation, the EEG continues to be concerned that the deleterious effect of gas generation, particularly the opening of new discharge pathways, has not been analyzed.

Recommendation 6. In future analysis, the deleterious effect of gas generation should be included.

7. Correlation Among Variables

No correlation has been assumed between sampled variables using Latin Hypercube sampling. In real life, many of the variables are related. For example, there is an inverse correlation between VWOOD, the fraction of waste that is wood, and VMETAL, the fraction of waste that is metal.

Recommendation 7. The performance assessment should either give reasons why physical correlations have been ignored, or show results with correlations.

8. Natural Resources Near the WIPP

The *1992 Performance Assessment* is unclear on the extent of natural resources extraction near the WIPP site, and particularly the possible impact of human intrusion. In vol. 1,

Section 2.2 an incorrect statement is made:

> About 56 productive oil and gas wells are located within a radius of 16 km (10 mi) from the WIPP; the wells generally tap Pennsylvanian strata, about 4,200 m (14,000 ft) deep (p.2-4).

This statement is incorrect because there are many more oil and gas wells. The estimate of 56 producing oil and gas wells is based on 1986 data. EEG showed (Silva and Channell, 1992) that some of the 1986 data were incorrect. Furthermore, if the USDOE wishes to take credit for current and accurate public records, then USDOE should have used current information and not obsolete information. Given the importance of drilling for oil and gas on the performance assessment calculations, future iterations should use a more accurate representation of the drilling activity near the WIPP facility. One method of so doing is to show up-to-date and accurate locations of oil and gas wells on a map. Most of the oil and gas wells drilled in the last four years do not tap the deeper Pennsylvanian Formation, but produce from various shallow (1200 to 2400 m) zones within the Delaware Mountain Group Formation.

The statement in the *1992 Performance Assessment* continues:

> The hydrocarbon well closest to the land withdrawal boundary is about 3 km (2 mi) to the south-southwest of the waste panels, and has produced natural gas since 1982 (Silva and Channell, 1992). The surface location of the well is outside the land-withdrawal boundary, but the borehole is slanted to withdraw gas from rocks below the WIPP horizon within the boundary. Except for this well, resource extraction is not allowed within the proposed land-withdrawal boundary (vol. 1, p.2-4).

The 1992 WIPP Land Withdrawal Act recognizes the validity of two specific oil and gas leases in section 31, within the WIPP Site Boundary. The owner of one of these leases has recently filed an application for permits to drill eight directionally drilled oil wells that would be completed within the WIPP Site Boundary but at depths greater than 2,000 m (6,000 ft) to produce oil from within the WIPP Site Boundary. While there was no restriction on drilling within the WIPP Site Boundary contained in the Consultation and Cooperation Agreement between the USDOE and the State of New Mexico, the second modification restricted slant drilling.

The following statement appears in vol. 1, section 3.3.3 (p. 3-10):

> ... the DOE agreed to prohibit further subsurface mining, drilling, slant drilling under the withdrawal area, or resource exploration unrelated to the WIPP Project from the land surface to 6,000 feet (1,830 m) in the subsurface for the 16 square miles under DOE control.

The second modification to the Cooperation & Consultation Agreement has been incorrectly interpreted. The Agreement is not limited to the first 6,000 feet (2,000 m) of depth. The Agreement states "The DOE will not permit subsurface mining, drilling, ..."

Recommendation 8. Performance assessment reports should accurately reflect the status of resource development near the WIPP site.

9. Oil and Gas Production Near the WIPP

In vol. 1, section 5.3.5, the following statement is made regarding the Assurance Requirement (40 *CFR* 191.14) for natural resources:

> Future societies might attempt to exploit natural resources near the WIPP and thereby create the potential for a release of radionuclides into the accessible environment. These issues have been evaluated in several reports (USDOE, 1980, 1981b; USDOE and State of New Mexico, 1981, as modified; Brausch et al., 1982; Weart, 1983; USDOE, 1990a). A recent report summarizes these earlier reports (USDOE, 1991a), and the DOE will continue to document information about natural resources that was used in making the decision to proceed with the WIPP Project (I, p. 5-20).

A detailed reading of the references cited does not appear to support the text.

Silva and Channell (1992) showed that the *USDOE Implementation of the Resource Disincentive Plan in 40 CFR 191.14(e) at the Waste Isolation Pilot Plant* (USDOE, 1991a) is inconsistent in reporting the number of oil and gas leases within the WIPP Site Boundary and the production status of those leases.

The No-Migration Variance Petition (USDOE, 1990a) states:

> Oil and gas exploration has been and continues to occur around the WIPP site. The target horizons for this type of exploration are below the Castile. Oil and

gas exploratory drilling requires permits from the state, and it is unlikely that prospective future well drillers would not be informed about the existence of WIPP. As an additional protective measure, the DOE has purchased all oil and gas leases in the area of the WIPP site to prevent any exploration now and in the future (Section 6.3.2).

The last sentence above is incorrect. Weart (1983), Brausch *et al.* (1982) and Weart *et al.* (1991) failed to recognize the potential crude oil resources for this area. Crude oil is now being produced from the former control zone IV.

Recommendation 9. The performance assessment effort should use the latest and verifiable data on oil and gas production near the WIPP, because the extent of oil and gas resources in this area is likely to be an important determinant of inadvertent human intrusion, and oil and gas production can potentially affect the hydrogeology at and near the WIPP repository.

10. Gas Generation

10.1 BRAGFLO is one of the most important codes in the WIPP performance assessment. A brief summary of BRAGFLO is given in vol. 3, section 1.4.1. Equations 1.4.1-1 and 1.4.1-2 use rate constants and mole fractions (called "stoichiometry factors") to calculate the rate of gas generation. These factors, although not specifically referenced in this section, are referred to in the discussion on pp. 3-44 to 3-45. Median corrosion gas production rates are given as 6.3 $\times 10^{-9}$ moles H_2/m^2-s for inundated steel and 0.1 [-] for humid steel under aerobic conditions, and 0.5 [-] for inundated steel under anoxic conditions. An analogous set of rates are given for microbial gas generation, with units of moles of gas/kg cellulosics given only for inundated conditions. It should be noted that in the development of the equations on pp. 1-24 to 1-26, the rate constants and stoichiometric factors are given with acceptable units. Why aren't the dimensions the same for all these rates, if they are used for the same variable in BRAGFLO? How can a corrosion rate have the units of moles per unit area of exposed substrate in one case and no units in another? How can a dimensionless variable be used interchangeably with a variable with units?

10.2 A more serious question arises about the use of these results. The gas generation rates and stoichiometry factors cited are those calculated by a model and are thus th

result of model inputs rather than experimental data. Table IV summarizes the results of the SNL scientific investigations into gas generation, and distinguishes model calculations from experimental measurements. Model results are only as good as model inputs. Some model inputs include unsupported assumptions, such as the failure to include methane. Experimental data exist - see Table IV- but have not been used in modeling. Moreover, as the Table IV shows, models give different gas generation rates when given different inputs and assumptions, and the median of such calculated rates has little validity.

Although the assumption that radiolysis will contribute only negligible hydrogen formation at WIPP appears to have found general acceptance, the data developed by Kosiewicz (1981) show this need not be the case. In fact, the gas generation problem was first noticed in stored drums of TRU waste in which hydrogen had been generated by radiolysis. Moreover, the microbial generation model does not recognize the dependence of the microbial gas generation rate on the initial and continued presence and availability of microbes. Radiolysis can be the principal source of gas from Pu-238 heat source waste.

Recommendation 10a. The gas generation calculations should include

(a) methane generation,

(b) radiolytically generated hydrogen.

Recommendation 10b. The relationships in the gas generation model should be validated before the gas generation model is incorporated into BRAGFLO.

11. Unanalyzed Scenarios

As Helton (1993) so aptly pointed out, the formulation of scenarios is an integral part of performance assessment. There are a number of assumptions used in the human intrusion scenarios to date that EEG believes need to be reconsidered and either changed or better justified. These have all been related to USDOE in previous written comments and discussed in meetings. For completeness of the record, all significant items are mentioned below.

Some scenarios not currently analyzed in performance assessment need to be considered. See especially the lower half of Figure 4-1 (vol. 2) in the *1992 Performance Assessment.*

Table IV. Gas Generation as Modeled and Tested

	Source	Gas From	Result moles/drum/a	Gas from 1050 drums in an alcove (moles/a)	Pressure P_0 (atm)	$P = nRT/V$ per annum (atm)	Gas Pressure at end of year one $P_1 = P_0 + P$
H_2	Brush *et al.*, (1993)	anoxic corrosion	2.0	2,100	1.0	0.0568	1.06
Total gas	Brush *et al.*, (1993)	microbio. deg.	1.0	1,050	1.0	0.0284	1.03
H_2 - 3 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.97×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 6 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.72×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 12 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.23×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 24 mos.	Brush *et al.*, (1993)	anoxic corrosion	9.9×10^{-7}	0.0	1.0	0.0	1.0
Total gas	Brush *et al.*, (1993)	aerobic microbes	0.5	525	1.0	0.0142	1.01
Total gas	Brush *et al.*, (1993)	anaerobic microbes	1.21	1271	1.0	0.0343	1.03
Total gas	Bixler (1989)		0.3	315	1.0	0.0085	1.01
Total gas	Molecke & Lappin (1990)	Calculated	0.05	52.5	1.0	0.0014	1.00
			0.5	525	1.0	0.06	1.06
			5.0	5,250	1.0	0.59	1.59
Total gas	Kosiewicz (1980)	radiolysis	0.3	315	1.0	0.04	1.04
			0.11	770	1.0	0.01	1.01
			0.016	115	1.0	0.0031	1.00

11.1 A Scenario Involving Nuclear Criticality

In 1984 S. Cohen, an EEG consultant, analyzed potential nuclear criticality in the Culebra Aquifer and concluded that this needed to be thoroughly evaluated by USDOE.

The potential nuclear criticality could occur if:

(1) sufficient quantities of a fissile radionuclide such as Pu-239 or U-233 are adsorbed on a large enough volume of aquifer matrix;

(2) there is sufficient hydrogen or other moderator available in the brine or matrix;

(3) the matrix or brine does not contain sufficient quantities of stable nuclides that can "poison" the reaction.

EEG's analysis indicated that, with the expected elemental composition of the brine and the Culebra aquifer matrix, nuclear criticality could occur in a block 7 m high x 0.5 m wide x 1 m long if the product of the distribution coefficient (K_d, mL/g) and plutonium solubility (S, moles/L) was greater than about 5.6×10^{-5} moles/g.

The possibility of a K_dS product of $> 5.6 \times 10^{-5}$ moles/g is credible. For example, the probability distributions for K_d and solubility from volume 3 of SAND 91-0893 (pages 2-104 and 3-64) have approximate probabilities of occurrence given in Table V.

Table V. Probabilities of Criticality From Sorbed Fissionable Species

Species	Probability $K_dS > 5.6 \times 10^{-5}$ moles/g
Pu^{5+}	0.025
Pu^{4+}	5×10^{-6}
U^{6+}	0.25
U^{4+}	0.11

In response to EEG's comments on the *1990 Preliminary Comparison*, SNL responded that

> A performance assessment task has been initiated to examine the potential for nuclear criticality from post closure processes.

Two pages were devoted to discussing nuclear criticality in the *1991 Preliminary Comparison* (vol. 1, page 4-52). SNL recognized that sorption can also occur in the backfill and at certain components of the seal system as well as in the Culebra Aquifer. The very remote possibility

of a high-yield nuclear explosion is also discussed. We find no analysis of nuclear criticality in the *1992 Performance Assessment*. No schedule has been given for performing additional criticality evaluations.

EEG also believes the possibility of a high-yield nuclear explosion is very remote. One concern is with an instantaneous criticality excursion in which there is a brief burst of energy, neutrons, and gamma radiation. Perhaps more likely in this situation, where fissile material is being added very slowly in a solution, is a delayed criticality where the system does not become promptly critical. Such a system would behave much like a nuclear reactor and could produce fissions, perhaps in bursts, for extended periods of time. This phenomenon has occurred in several process criticality accidents in the U.S., e.g. at Hanford in 1962 one system boiled for 37 hours (Thomas 1978). The Oklo "natural reactor" in Gabon is believed to have operated in a similar fashion.

It is not obvious that a criticality accident would have a significant effect on a repository waste disposal system, even if a criticality accident occurs. Considerable heat would be produced, some brine would be vaporized, and minor amounts of fission products would be formed. It takes 8×10^{20} fissions to produce one curie of Cs-137. Also, the relatively high K_d values that would be necessary to make criticality possible are otherwise a benefit because they retard radionuclide transport.

Recommendation 11.1 The criticality issue needs to be thoroughly evaluated before it can be concluded that its effects are negligible.

11.2 Subsidence

Subsidence could occur in the area overlying the WIPP some time after repository decommissioning. Subsidence can also occur from nearby potash mining. The *1992 Performance Assessment* identifies an event **TS** which is subsidence from mining of potash, but **TS** has not been analyzed.

SNL discussed the potential for subsidence in the *1990 Preliminary Comparison*. They recognized that "subsidence could in turn conceivably affect the disposal system in three ways: by increasing hydraulic conductivity of the Salado Formation, by creating fractures through the Salado Formation, or by disturbing the surface drainage and groundwater flow in overlying units." The incorporation of the effects of subsidence into the performance

assessment is still planned. In the *1991 Preliminary Comparison* SNL presented an analysis of possible caving and subsidence over the waste storage areas from room closure.

SNL's analysis of subsidence concluded that no problems were likely to result for the waste disposal system. The maximum subsidence at the surface was calculated to be only 0.13 meter over an area of 1.54×10^6 m^2. The affected area at the surface was determined by assuming an angle of draw of 35°. It was further stated that if the Rustler-Salado contact residuum had (historically) lost about 400 meters due to dissolution without disrupting the confined water-producing Culebra and Magenta dolomite aquifers, subsidence should not be a problem.

No evaluation has yet been made of subsidence from potash mining. There are significant potash resources within the WIPP site boundary. However, the USEPA Standards requires analysis of only resource exploration drilling on site. However, it is appropriate to consider subsidence effects from potash mining offsite.

Offsite potash mining is highly probable. There are reserves on all sides of the site. Sections to the south of the site are already leased, sections to the north and east are under litigation for potash leases, and the entire western border is leased or expected to be leased. Because the areas leased or expected to be leased to the north and south include the flow path of the Culebra Aquifer across the waste storage area, a potential exists for both upstream and downstream effects on the Culebra. Catchment areas could be formed to the north from subsidence and shafts could provide access to the Culebra for recharge. To the south there could be increased transmissivity from subsidence effects. With the assumption that mining occurs up to the site boundary and the angle of draw is 35° the extent of influence at the Culebra Aquifer horizon would be about 200 meters onto the site. Another possibility is that mining activity near the South Boundary could result in vertical drainage (via shafts or boreholes) from the Culebra Aquifer into underlying mined out areas. This could significantly increase the hydraulic gradient between the injection point of contaminated brine and the site boundary.

Recommendation 11.2 Subsidence effects need to be evaluated in much more detail and incorporated, in some manner, into the human intrusion scenarios. Some scenarios currently analyzed in performance assessment should be re-formulated.

11.3 Contaminated Brine Flows to the Surface

The E1, E2 and E1E2 scenarios assume that the only material reaching the surface is drill-bit cuttings and some "cavings" from the annulus about the drill bit in the waste storage room. Brine flowing to the surface from an encounter with a pressurized Castile brine reservoir was not assumed. EEG believes that brine flows to the surface should be assumed and that the consequences could be significant for the E1E2 scenario.

Sandia and USDOE have described typical drilling practices elsewhere (Appendix C of SAND 89-0462 and in USDOE February 7, 1990 response to EEG's comments on the Draft Supplement EIS). These responses explain how it is possible to have very little flow to the surface by closing in blow-out preventers within a few minutes, determining the pressure, and then preparing drilling mud of sufficient density to stop the flow before resuming drilling. For example, USDOE stated in a February 7, 1990 letter that only 51 barrels flowed at WIPP-12 before shut in by a blow-out preventer.

The February 7, 1990 USDOE letter went on to say that at WIPP-12 an additional 49,224 barrels flowed during deepening, geophysical logging, and further deepening before it was finally shut in for subsequent hydrologic testing. This additional flow was described as resulting from a "conscious decision."

Virtually every time a pressurized Castile brine reservoir was encountered in the vicinity of WIPP, "conscious decisions" were made to allow varying amounts of brine to flow to the surface. Table VI, extracted from two WIPP reports (USDOE 1981a; 1983), describes the remedial measures taken. Although the available data are not as detailed or as quantitative as one would like, it is clear that drilling practice through 1982 included release of brine at the surface whenever pressurized Castile brine reservoirs were encountered. There has been considerable drilling activity around the WIPP Site in the last few years, and brine has been reported in seven wells. In two of these wells brine was reported to have flowed for three hours before being stopped, and in another, brine flowed for at least 12 hours. Records did not indicate how long the remaining wells flowed. It appears that, in most cases, significant amounts of brine flow to the surface before being controlled and performance assessment scenarios should assume that any intruding driller will face similar situations. Also, minor flows may not always be recorded in drilling logs, or perhaps even recognized. Furthermore, it is likely that not all Castile brine encounters have been reported.

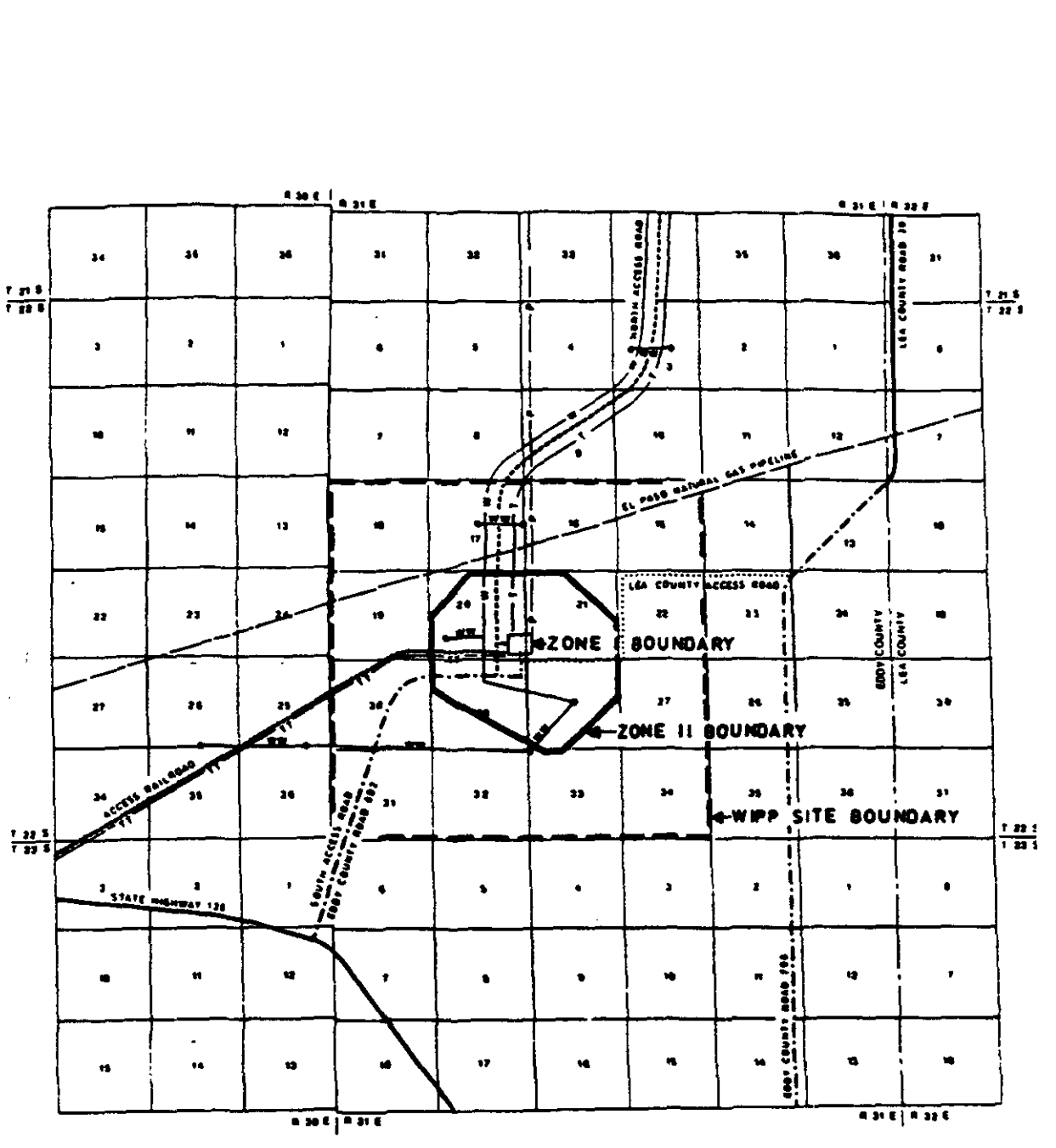

Figure 1. 1990 Zone I, Zone II, and WIPP Site Boundaries. From Figure 2.1-3, WIPP FSAR. (U.S. DOE, 1990a, reproduced with permission).

Although the designations of Zone III and Zone IV are no longer used, they merit a brief description because much of the initial WIPP documentation refers to these zones. The location of Zones III and IV are shown in Figure 2.

Zone III essentially provided a one-mile (1.6 kilometer) buffer around Zone II. In Zone III, all mining, other than for the repository, and deep drill holes penetrating through the evaporites were prohibited (U.S. DOE, 1980, p. 8-4).

Zone IV provided a one-mile (1.6 kilometer) buffer around Zone III. Within Zone IV, conventional potash mining would be permitted but solution mining was prohibited. Deep drill holes were also allowed but water flooding and massive hydrofracture for hydrocarbon recovery would not be permitted. The Final Environmental Impact Statement also noted existing oil and gas wells producing in this zone will be permitted to continue through their useful lives. To protect the repository, they will be sealed as prescribed by the DOE when abandoned. New wells for oil and gas production may be drilled in conformance with DOE standards to facilitate eventual plugging (U.S. DOE, 1980, p. 8-4).

When Zone IV was relinquished by DOE as being unnecessary, the Zone III boundary was "squared off" and the new site boundary extended into the former Zone IV at the four corners (Weart, 1990). Hence, the current four mile (6.44 kilometers) by four mile WIPP Site Boundary[2] also provides the one-mile buffer originally established as Zone III.

[2]Throughout this report, the term "WIPP Site Boundary" refers to the four mile by four mile area described above and the term "WIPP Site Area" refers to the approximately thirty-two square mile area that includes all of Zone IV.

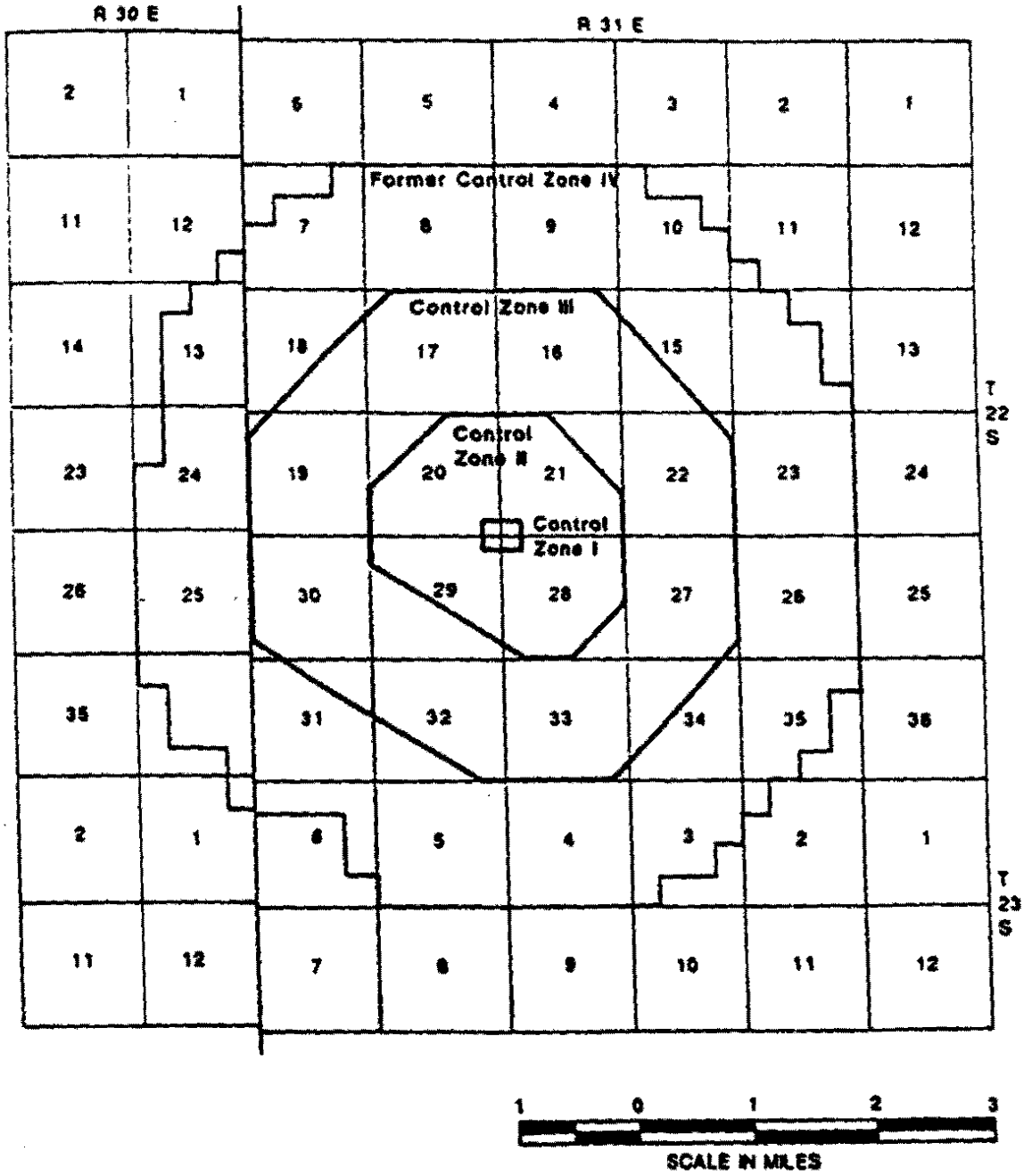

Figure 2. 1980 Control Zones at the WIPP Site. (FSEIS, U.S. DOE, 1990d, reproduced with permission).

3.0 REPORTS ON PETROLEUM RESOURCES AND LEASES

EPA's requirements for establishing a repository in a resource rich area were clearly stated in 40 CFR 191.14(e):

> Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas.... Such place shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future (U.S EPA, 1985).

From 1976 through 1980, SNL published several reports on the mineral resources in the Los Medaños area. Each discussed oil and gas resources.

A report by the petroleum consulting firm of Sipes, Williamson, and Aycock, Inc. (Keesey, 1976) focused on estimating the remaining economically recoverable oil and gas reserves underlying the proposed disposal site. The evaluation was intended to serve as a guideline to SNL in determining the acceptability of the "site area" and the potential value to the owners of the hydrocarbon rights.

Griswold's (1977) subsequent evaluation of site selection and mineral resources incorporated the information provided by Keesey (1976).

Powers, et al. (1978) prepared the geological characterization report for the WIPP citing the work of Keesey (1976) and Griswold (1977) as well as earlier work by Foster (1974).

Keesey (1977) provided a more detailed analysis of the hydrocarbon resources including those in Section 31, T22S, R31E, the section containing the active gas leases in the southwest corner of the current WIPP Site Boundary. The study was limited to surface and subsurface rights to 6,000 feet (1829 meters), which were eventually condemned and purchased by the federal government in 1979. The evaluation did not include the deeper resources.

Keesey (1979a) evaluated the feasibility of directionally drilling for oil and gas reserves under the WIPP Site Area, which, by previous definition, included Zone IV. It was technologically feasible to drill into gas and condensate reserves underlying the WIPP Site Area from outside the WIPP Site Area.

Keesey (1979b) updated the estimated potential hydrocarbon reserves and associated costs and incomes for oil and gas underlying the WIPP. The estimates were intended for use in the Environmental Impact Statement for the WIPP being prepared by Westinghouse Electric Corporation. The estimates were not intended to represent future net revenue values normally used by the petroleum industry to determine the fair market value of oil and gas producing properties. The undiscounted value of the gas and condensate reserves underlying the WIPP Site Area (including Zone IV) was determined to be $287,502,346 (Keesey, 1979b, p. 6; U.S. DOE, 1980, p. 7-72).

4.0 HISTORY OF NATURAL GAS EXPLORATION AND PRODUCTION

The WIPP site is situated in the northern portion of the Delaware Basin. While there were no oil or gas wells within the 32 square miles (8288 hectares) of Zone IV in 1976, oil and gas were being produced from 60 wells in a 368 square-mile (95 312 hectares) area surrounding the site. Although the area was considered to be potentially rich in hydrocarbon reserves, extensive deep drilling had not been ventured in the New Mexico portion of the Delaware Basin. Only 10 to 15 percent of the available acreage had been investigated. The lack of more complete drilling and development was attributed to several factors including historically restrained gas prices, a higher exploration risk due to the varying depositional environment, a lack of readily available pipelines during earlier periods, and moratoriums on drilling in the potash areas to prevent methane gas from entering potash mines (Keesey, 1976; Powers et al., 1978).

As noted by Griswold (1977), the energy crisis of the mid-1970's had driven up the price of natural gas at least fourfold in just two years, prompting a renewed interest in previously unattractive areas. In 1977, deep exploratory drilling for natural gas was underway throughout the Delaware Basin. Just prior to the publication of Griswold's report, three different companies applied for drilling permits in the Los Medaños site area.

Known petroleum production in the area extended from the Delaware Formation (mean depth 4,200 feet; 1280 meters) down to the Morrow Formation (mean depth 13,400 feet; 4084 meters). The deeper Morrow sandstones and the overlying Atoka sandstones of the Pennsylvanian series held the best promise for commercial natural gas production (Griswold, 1977).

In addition to several single well fields, there were two major producing fields in the Los Medaños area. Five wells were producing gas from the Morrow Formation in the Cabin Lake field just northwest of the WIPP site. A five-well field, the Los Medaños Field, was producing gas from both the Morrow and the Atoka Formations just southwest of the WIPP site.

4.1 Shell James Ranch Unit No. 1 - A Prolific Gas Well

A very productive gas well is located two thousand feet (610 meters) west of the WIPP site in the southwest corner of Section 36, T22S, R30E. The location is shown in Figure 3. Known as the Shell James Ranch Unit No. 1, the well was drilled, in 1957, to a total depth of 17,555 feet. The well was completed in the 12,920 to 12,929 foot (3938 to 3940 meters) interval for production of gas and oil condensate from the Los Medaños-Atoka Formation and has been producing since 1958.

The well has been prolific throughout its production history. Initial twenty-four hour production was 9,000 MCF gas and 104 BBLs condensate.[3] As of mid-1976 cumulative production exceeded 17,000,000 MCF (481 000 000 cubic meters) of gas and 200,000 barrels (32 000 cubic meters) of condensate. The gas production rate from that single well in 1976, was over 100,000 MCF (2 800 000 cubic meters) per month. Keesey (1976) calculated the James Ranch Unit No. 1 would ultimately recover 35,900,000 MCF (1 billion cubic meters) of gas and 425,000 barrels (68 000 cubic meters) of condensate.[4] The history of gas and condensate production since 1970 is shown in Figure 4.

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[3]An MCF is equal to one thousand standard cubic feet (28.32 cubic meters) of gas. A BBL is equal to one barrel (0.159 cubic meters) of oil or condensate.

[4]As of August 1, 1991, production records filed with the U.S. BLM for the James Ranch Unit No. 1 show that cumulative gas production has exceeded 25,000,000 MCF and condensate oil production has exceeded 270,000 BBLs.

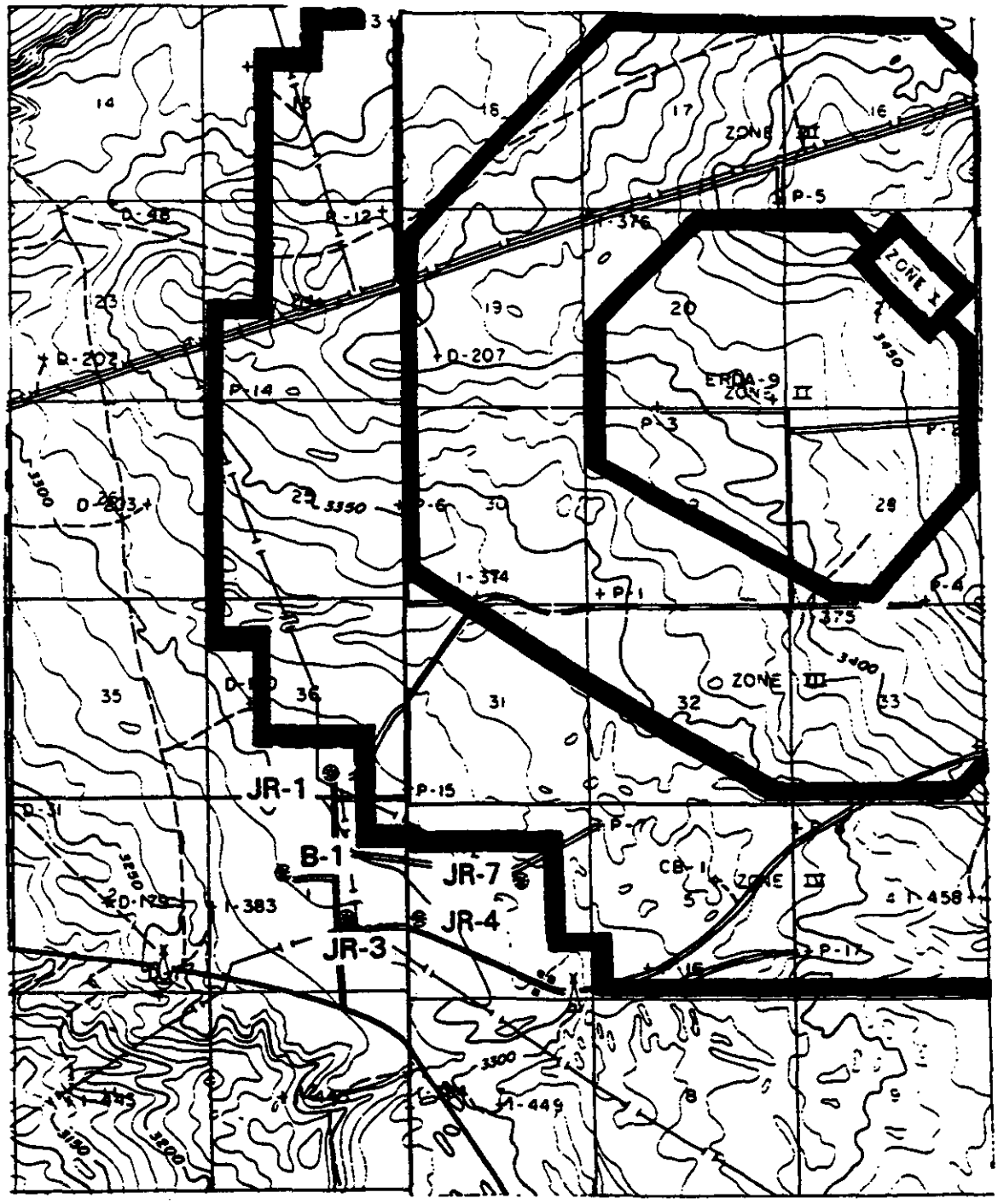

Figure 3. Five Gas Wells Outside Southwest Corner of WIPP Site in 1977. James Ranch Unit No's 1, 3, 4, 7 and Hudson Federal No. 1 (B-1). (after Griswold, 1977, Figure 4, highlighted and reproduced with permission.)

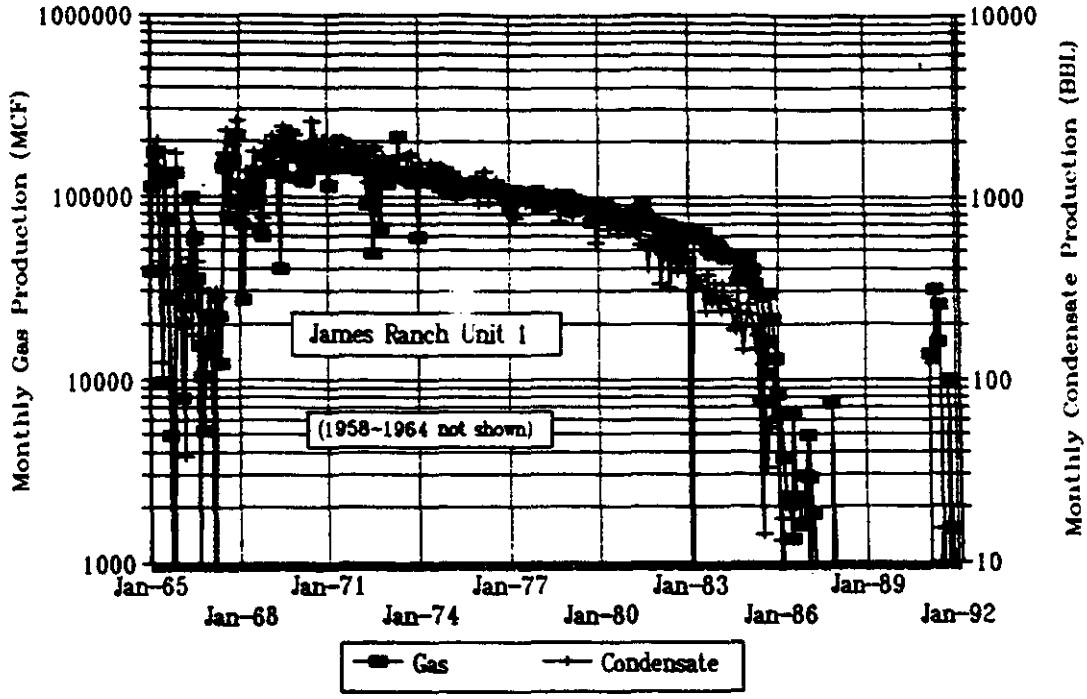

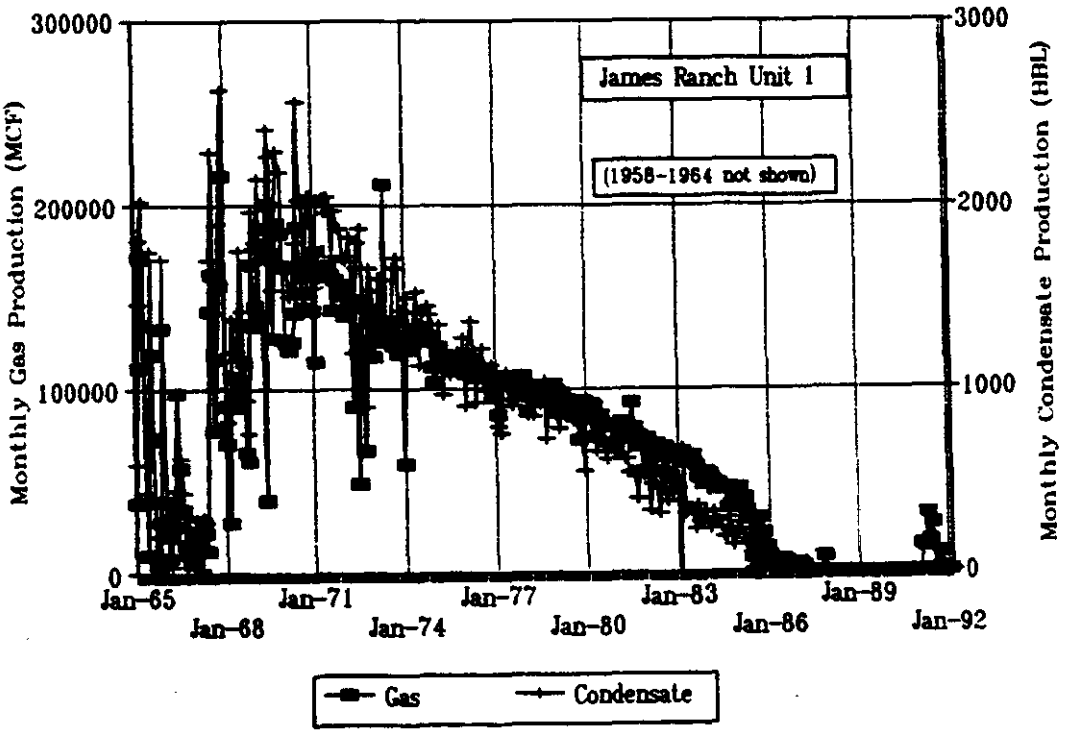

Figure 4. Gas and Oil Production from 1965 - 1991; James Ranch Unit No. 1. Data provided by Roswell District Office, U.S. BLM, 1992.

By 1977, the Shell James Ranch Unit No. 1 was flanked by an arc of four other wells on the south and west that essentially failed to tap the Atoka reservoir. The four wells were initially completed in the deeper Morrow Formation (Griswold, 1977). Figure 3 shows these wells included the Hudson Federal No. 1, Belco's James Ranch Unit No. 3, Belco's James Ranch Unit No. 4, and Conoco's James Ranch Unit No. 7.

4.2 Natural Gas Beneath the WIPP Site

A faulted anticline controls the Morrow reservoir in the Los Medaños field, southwest of the WIPP site. This same structure probably persists up into the Atoka and both reservoirs probably extend toward the northeast (Griswold, 1977).

Analysis of production decline curves through 1976 for the James Ranch No. 1 well indicated the well was probably draining at least five square miles (1300 hectares). That observation, coupled with the favorable geologic structure and the failure of wells drilled to the west and south, further suggested that wells drilled to the northeast would have a high chance of success (Keesey, 1976; Griswold, 1977; U.S. DOE, 1980).

As part of the hydrocarbon resource evaluation, potential drilling sites were selected based on the structure contours of the Morrow Formation. Depending on the geologic structure and distance from producing wells, the potential drilling sites were ranked as either 1) proved undeveloped, 2) probable, or 3) possible. Proved undeveloped reserves identified commercially recoverable hydrocarbons to be recovered from new wells on undrilled acreage or from existing wells requiring a major expenditure for recompletion or new facilities for fluid injection. (Keesey, 1976; Griswold, 1977, U.S. DOE, 1980).

The two locations ranked as "proven undeveloped" were north and east of the Shell James Ranch No. 1, as shown in Figure 5. The production data and geologic information available in 1976 indicated that much of the natural gas being produced from the Atoka Formation came from beneath the defined WIPP Site Boundary and the best place to drill a well would be in Section 31, T22S, R31E, which is precisely where the two active gas leases beneath the WIPP site are located.

Keesey (1976) noted that the drilling and completion of additional wells northeast of the Shell James Ranch No. 1 would only enhance the rate of recovery of the Atoka reservoir now being drained by the one well. Ultimate recovery would remain about the same.

4.3 Early History of Leases

In May 1952, Continental Oil Inc. (Conoco) obtained an oil and gas lease (NMPM Lease # NM 02953) that included all 640 acres (259 hectares) of Section 31, T22S, R31E. In June 1953, the area was approved by the U.S. Geological Survey (U.S.G.S.) as the James Ranch Unit. Sid Richardson and Perry R. Bass were designated Unit Operators.[5]

As discussed above, Shell Oil Company drilled the James Ranch Unit No. 1 in 1957, on Section 36 just west of the Conoco lease. Shell began prolific production of gas and condensate from the newly discovered resources in the Atoka Formation in March 1958.

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[5]Information about drilling applications, completion records, pipeline connections, production records, and official memoranda concerning these leases was obtained from U.S. Bureau of Land Management Offices in Roswell, New Mexico and Santa Fe, New Mexico.

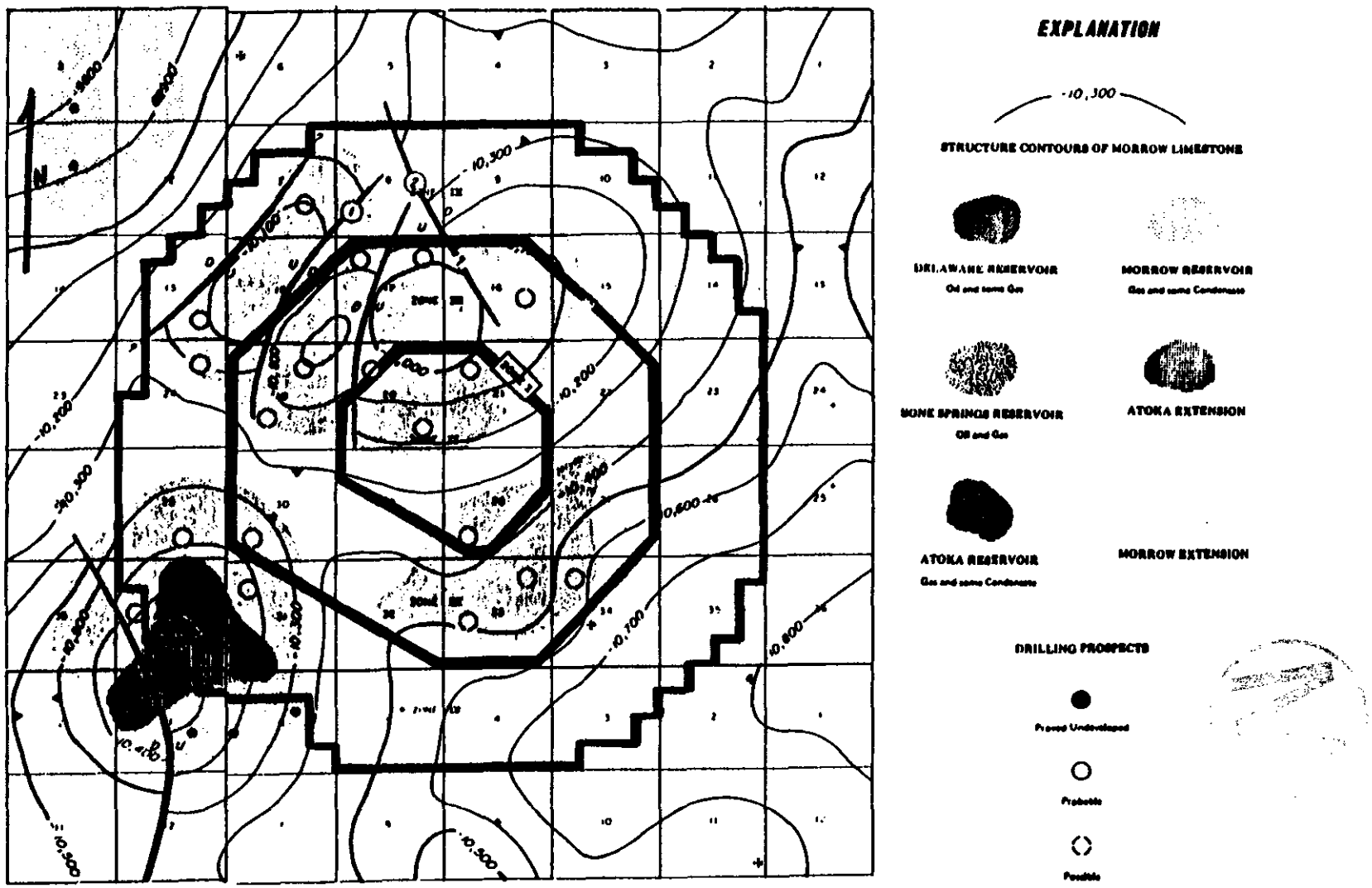

Figure 5. Hydrocarbon Resources and Possible Extensions (Griswold, 1977, Figure 32, reproduced with permission).

In February 1959 the Conoco lease on Section 31 was divided. The north half of the section remained with Conoco and the south half was assigned to Richardson and Bass under lease NM 02953-C. Perry R. Bass was designated the Unit Operator, in March 1961.

Keesey (1976) completed the analysis of hydrocarbon reserves for SNL, effective September 1, 1976, in which he concluded:

> that the Los Medaños (Atoka) reservoir extends north and northeast underneath the 'site area' in section 31-22S-31E [Conoco's and Bass's undeveloped leases] and 36-22S-30E [Shell's producing lease] (Keesey, 1976, p. 16).

4.4 <u>1976 Application to Drill For Natural Gas Beneath the WIPP Site</u>

On November 7, 1976, Bass formally filed for a permit with the U.S. Geological Survey to drill a well on Section 31. Three days later, November 10, 1976, Conoco was designated as the operator and local agent for Bass "with full authority to act in his behalf in complying with the terms of the lease and regulations...." (Bass, 1976).

On November 11, 1976, the District Engineer for the U.S.G.S., routinely notified the New Mexico Division of Lands and Minerals Program and Land Office in Santa Fe, New Mexico, of the intent of Bass Enterprises Production company to commence drilling operations.

On December 10, 1976, a withdrawal notice appeared in the *Federal Register*. The Energy Research and Development Administration (ERDA, precursor of the DOE) applied for withdrawal of 17,000 acres (6880 hectares) of public lands in New Mexico for a nuclear waste disposal site including the land containing the Bass lease.

On January 20, 1977, the U.S.G.S Area Oil and Gas Supervisor, James W. Sutherland, approved the Bass application to drill for oil and gas .

4.5 Court Condemnation of Oil and Gas Leases at the WIPP Site

On February 9, 1977, the U.S. Government, at the request of the Acting Administrator for the ERDA, filed a complaint in civil court (Case # CIV 77-071 B) against Bass Enterprises et al. condemning their oil and gas lease from the surface to a depth of 6,000 feet (1829 meters) for the southern half of section 31.

On April 4, 1977, the U.S. BLM Assistant Solicitor of Lands, John J. McHale, informed the Director of the U.S. BLM that an attorney for the U.S. ERDA in New Mexico had inquired by telephone about the impact of the Federal Land Policy and Management Act (FLPMA) on the land status because the issue had been raised in litigation. The lessee (Bass) was contending in court that the condemnation of oil and gas leases by the Government was illegal, arguing that the Government can only terminate the lease through the lease provisions. The Assistant Solicitor had advised the ERDA attorney, that in BLM's judgment, the land should never have been taken (McHale, 1977).

On December 7, 1977, an additional complaint was filed in civil court (Case # CIV 77-776 B) by the U.S. Government against Conoco Inc. condemning their oil and gas lease from the surface to a depth of 6,000 feet (1829 meters) for the northern half of Section 31.

On February 12, 1979, both cases were settled jointly. The court condemned the oil and gas lease from the surface to 6,000 feet (1829 meters) and assigned $1,350,000 to Conoco, Bass Enterprises, and other defendants as just compensation for these leases.

4.6 1981 Application to Drill Natural Gas Well Beneath the WIPP Site

On December 11, 1981, Bass Enterprises filed a formal application to drill a wildcat well, James Ranch Unit No. 13, on Section 6, T-23-S, R-31-E (#NM 02887-D) with the intent to deviate north into Section 31, T-22-S, R-31-E. This section, would fall entirely within the defined WIPP Site Boundary fourteen months later.

On December 14, 1981, James Pettengill, geologist with the U.S.G.S. Office in Roswell, filed a review of the drilling application with the U.S.G.S. District Engineer in Artesia. The review noted that the "completion location is within the boundaries of the Department of Energy's proposed Waste Isolation Pilot Project (WIPP)" (Pettengill, 1981).

On December 16, 1981, the U.S.G.S. District Supervisor in Roswell, James Gillham, issued a memo to the U.S.G.S. Deputy Conservation Manager of Oil and Gas transmitting the request to drill and commenting that the "drillsite is not considered to be in a politically sensitive area" (Gillham, 1981).

On December 18, 1981, the U.S.G.S Area Manager for the Carlsbad Resource Area notified the DOE WIPP Project Manager of Bass's application to drill and requested advice on any special stipulations or concerns by December 28, 1981 (Koski, 1981).

The DOE December 30, 1981, response noted that the Department had obtained exclusive use of the surface and uppermost 6,000 feet (1829 meters) of subsurface for the specific purpose of preventing any drilling activity in Section 6, N½,NW¼, T23S, R31E and Section 31, T22S, R31E. The letter cautioned the BLM that "the approval to drill must include the stipulation that Perry R. Bass is not permitted to drill into the areas described above" (McGough, 1981) .

Following the January 11, 1982, approval by the U.S.G.S. (Reitz, 1982) to drill, drilling started on February 6, 1982. On September 13, 1982, the well was tested and produced 141 MCF of gas for an eight hour period. On September 21, 1982, drilling was completed. On February 14, 1983, the Natural Gas Pipeline Company of America connected to the well, James Ranch Unit No. 13, for the purpose of purchasing gas. The wellhead is shown in Figure 6 with the WIPP Waste Handling Building in the background.

4.7 Zone Designation and Resource Recovery Control

On February 17, 1983, the DOE WIPP Project Manager notified the Director of the Environmental Evaluation Group (EEG) that:

> the configuration of WIPP surface control zones has changed as a result of the cost reduction program, the DOE resource management policy and Bureau of Land Management land withdrawal action.... Descriptions of the new control zones are also enclosed (McGough, 1983a).

On February 24, 1983, the DOE WIPP Project Manager further informed the EEG Director that:

> the DOE does not plan to exercise any control over resource recovery activities outside the Site boundary and will rely, primarily, on other Federal and State regulatory agencies to assure that the WIPP boundaries are not violated (McGough, 1983b).

On October 28, 1983, the EEG requested a clarification on the DOE's conflicting descriptions of the Zone III boundaries and a clarification on the interim controls on resource recovery. The EEG was puzzled by the DOE's reference to the new WIPP site boundary as Zone III. The EEG was also concerned the restriction against drilling into the first 6,000 feet (1829 meters) was not included in the BLM/DOE

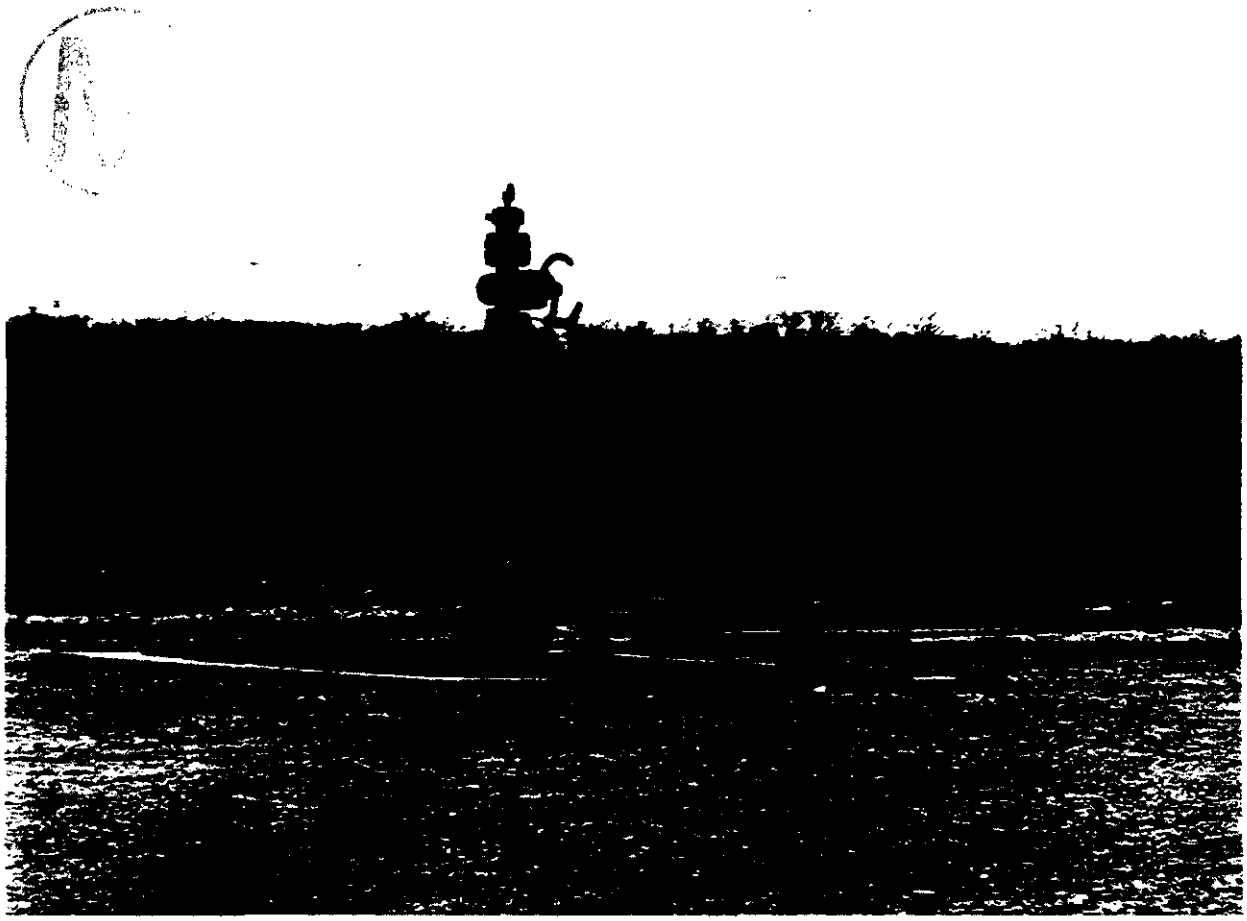

Figure 6. James Ranch Unit No. 13 with WIPP Waste Handling Building in Background.

Memorandum of Understanding or in the Resource Management Plan. Hence, EEG suggested that there was no apparent reason for the BLM to enforce the restriction (Neill, 1983a).

On December 7, 1983, the DOE WIPP Project Manager acknowledged that:

> 1. Our February 24, 1983 letter incorrectly identified the WIPP Site boundary as being the Zone III when in fact the Zone III boundary has not changed from that shown in the FEIS. The zone being controlled as regards mineral extraction, is the 16 full sections of land as shown in the sketch enclosed in our February 17, 1983 letter. These 16 sections comprise the area identified in the June 29, 1983 administrative land withdrawal.
>
> 2. All lease rights which have been purchased by the DOE within the site boundary have been purchased in their entirety or alternatively we acquired only the upper 6,000 feet of the leases to reduce the acquisition cost to the DOE and to allow access to potential hydrocarbon resources below the WIPP Site. It was not considered necessary to detail this information in the DOE/BLM Memorandum of Understanding (MOU) or Resource Management Plan because the BLM is required to enforce mineral leasing laws which prohibit violation of adjacent (in this case, DOE's) lease boundaries (McGough, 1983c).

In evaluating the suitability of the WIPP Site, the EEG (Neill et al., 1983, p. iii) recommended that

> no potash mining will be allowed in Zones I, II, and III of the WIPP site. Deviated drilling for oil and gas from outside the WIPP site to reach under the WIPP site at depths greater than 6,000 feet may be allowed. The federal government shall exercise active institutional control at the site for this purpose for at least 100 years after repository decommissioning.

The recommendation was reiterated on December 6, 1983, in a letter from the EEG Director (Neill, 1983b) to the WIPP Project Manager on the suggested wording for the First Modification to the Consultation and Cooperation (C&C) Agreement between the U.S. Department of Energy and the State of New Mexico. On November 14, 1984, the State of New Mexico and the U.S. Department of Energy agreed that:

> During facility construction and operation the DOE will not allow subsurface mining, drilling or resource exploration from within the WIPP site. The 'WIPP site' as used here means the 4 x 4 mile (10,240 acres) area consisting of sections 15, 16, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, and 34 of Township 22 South, Range 31 East, NMPM, in Southeastern New Mexico.
>
> Deviated drilling for oil and gas from outside the WIPP may be allowed so long as the subsurface of the WIPP site is not penetrated above a depth of 6,000 feet from the surface.

EEG's recommendation to include a statement that the federal government shall exercise active institutional control at the site for at least 100 years after repository decommissioning was not included in the modification. Rather, the First Modification to the C&C agreement stated that:

> the consultation process concerning the length and extent of the post-closure institutional control, shall be negotiated and resolved by the parties in the future, and at least one year prior to the start of the decontamination and decommissioning of WIPP.

5.0 THE FORGOTTEN GAS LEASES AND WELL BENEATH THE WIPP SITE

The 1984 agreement between the U.S. Department of Energy and the State of New Mexico to allow slant drilling under the WIPP Site changed on August 4, 1987, in the second modification to the C&C agreement (U.S. DOE and NM, 1987), which states:

> The DOE will not permit subsurface mining, drilling, or resource exploration unrelated to the WIPP Project on the WIPP site during facility construction, operation, or after decommissioning. This prohibition also **precludes slant drilling**[6] under the site from within or from outside the site.

Several important DOE documents are either incorrect, silent, or inconsistent on the existence of the two oil and gas leases and the gas well. For example, the Final Environmental Impact Statement (FEIS, U.S. DOE, 1980, pp. 8-8—8-10) identifies the oil and gas leases held by ten companies in March 1979, yet the 1952 Conoco and 1957 Bass leases in the southwest corner of the WIPP Site on Section 31 are not mentioned. The WIPP Final Safety Analysis Report (WIPP FSAR, U.S. DOE, 1990a, Section 2.1.1.1), incorrectly states that there are no active oil and gas leases within the WIPP Site Boundary. Moreover, the WIPP FSAR (U.S. DOE, 1990a, Figure 2.2-1) fails to chart the intruding well on its map of producible oil and gas wells. The DOE No-Migration Variance Petition to EPA incorrectly states that the DOE has purchased all oil and gas leases in the area of the WIPP site to prevent any exploration now and in the future (U.S. DOE, 1990b). Revisions 1 through 5 of the Secretary of Energy's Decision Plan were monitoring the status of an active potash lease until it was purchased by the DOE. Yet Revisions 6 through 10 remained silent on the active oil and gas lease issue even after the article in the Albuquerque Journal raised the issue (McCutcheon, 1990). The recently published DOE Implementation

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[6]Emphasis added.

of the Resource Disincentive document, (U.S. DOE, 1991) is inconsistent on the number of active oil and gas leases within the WIPP Site Boundary and on the production status of the forgotten gas well.

5.1 1980 WIPP Final Environmental Impact Statement

The WIPP Final Environmental Impact Statement (U.S. DOE, 1980) identifies the gas and oil leases held by ten companies in March 1979 at the WIPP Site. Figure 7 (reproduced from the 1980 WIPP FEIS) does not show the Bass and Conoco leases on Section 31. While those two leases were condemned in February 1979 from the surface to 6,000 feet (1829 meters), the oil and gas leases below 6,000 feet (1829 meters) did remain valid.

5.2 1990 WIPP Final Safety Analysis Report

The DOE's stated commitment to prohibit slant drilling and the loss of knowledge is also documented in the WIPP Final Safety Analysis Report (U.S. DOE, 1990a) which the DOE describes as the top level document in the hierarchy of the WIPP safety documents. The WIPP FSAR states:

> The area of land that lies within the WIPP Site Boundary and committed to the WIPP facility is a square four miles on a side. It contains 10,240 acres (16 mi^2) including Sections 15-22 and 27-34 in township T22S, R31E....
>
> The DOE will not permit subsurface mining, drilling, or resource exploration unrelated to the WIPP Project within the WIPP Site Boundary during facility operation or after decommissioning. This prohibition **precludes slant drilling**[7] under the WIPP facility from within or outside the WIPP facility. (U.S. DOE, 1990a, Section 2.1.1.1).

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[7]Emphasis added.

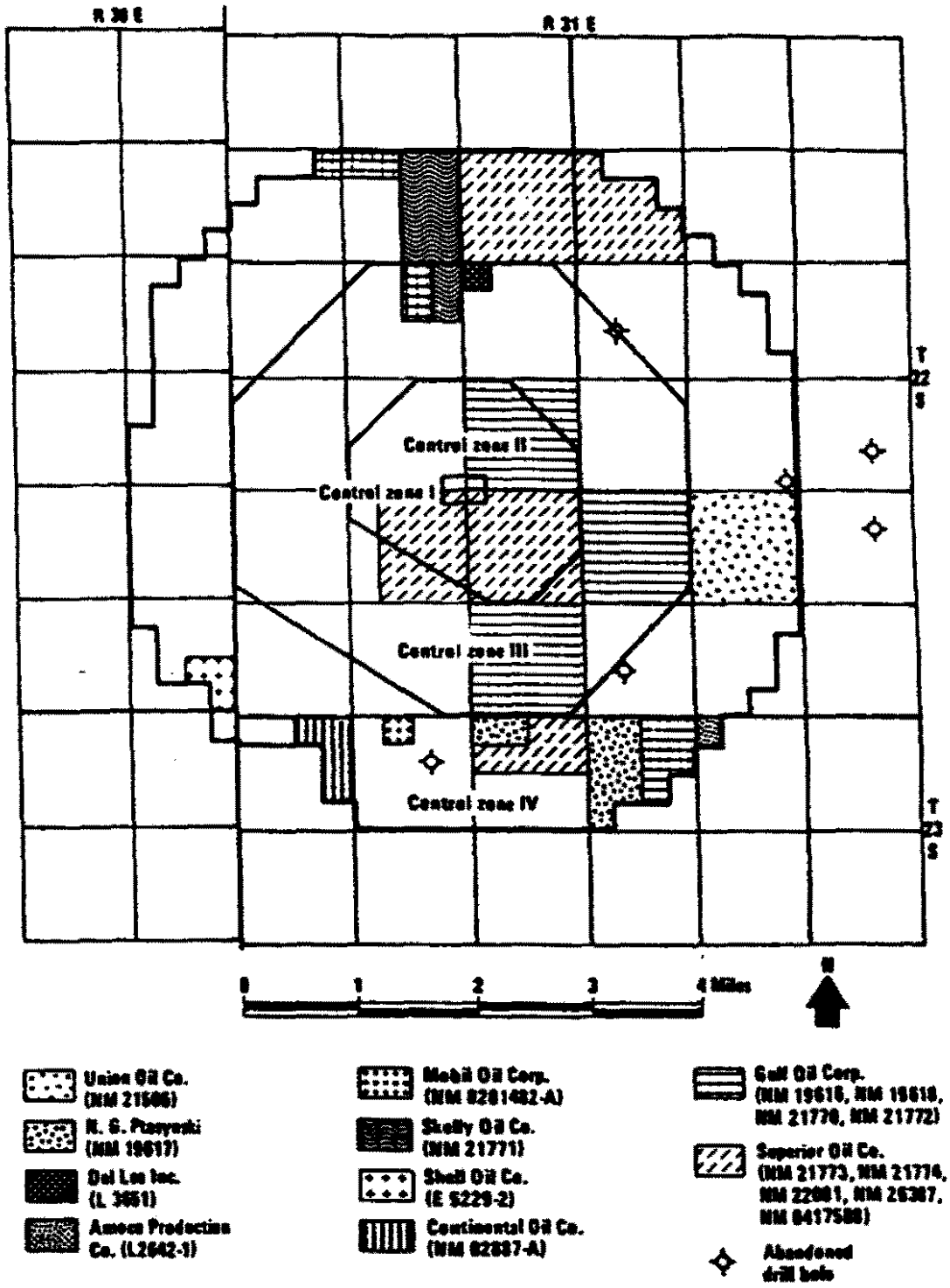

Figure 7. Oil and Gas Leases Within the WIPP Site according to the DOE FEIS, (U.S. DOE, 1980, Figure 8-6, reproduced with permission).

The WIPP Final Safety Analysis Report also incorrectly states:

> ... all oil and gas leases within the WIPP Site Boundary have expired (U.S. DOE, 1990a, Section 2.1.2.1.3).

Furthermore, Figure 2.2-1 (Figure 8 in this report) of the WIPP FSAR fails to show all of the 1986 operable natural gas and oil wells within a ten mile (16.1 kilometers) radius. This figure shows seven wells just outside the southwest corner of the site - James Ranch Unit Nos. 1, 3, 4, 7, 10, 11 and Hudson Federal No. 1. James Ranch Unit No. 3 appears to be plotted in the wrong location. At least two wells, James Ranch Unit Nos. 13 and 14 shown in Figure 9, both slant drilled wells, are not shown in the WIPP FSAR. James Ranch Unit No. 13 and James Ranch Unit No. 14 were not only operable, but each was producing through the entire year of 1986, as shown in Figures 10 and 11.

Table 1 (prepared from data provided by the Roswell District Office of the U.S. BLM) lists the gas and condensate production from the James Ranch Unit No. 13. Production was stopped for one month in July 1985 and again for three extended periods of several months beginning in April 1987. Nonetheless, gas and condensate were produced for several months in 1987, 1988, and again in 1991. To date this well has produced over 3,000,000 MCF gas. The latest available production records in the Roswell District Office of the U.S. BLM show production of 27,618 MCF gas and 164 BBLs condensate for February 1992 (U.S. BLM, 1992).

James Ranch Unit No. 14 was slant drilled in 1983. The top of the well is located in Section 6, T23S, R31E and completed in the Los Medaños-Morrow Formation in Section 7, T23S, R31E. Since production began in December 1983 records through February 1992 show this well has produced gas every month except for a two month period in 1987.

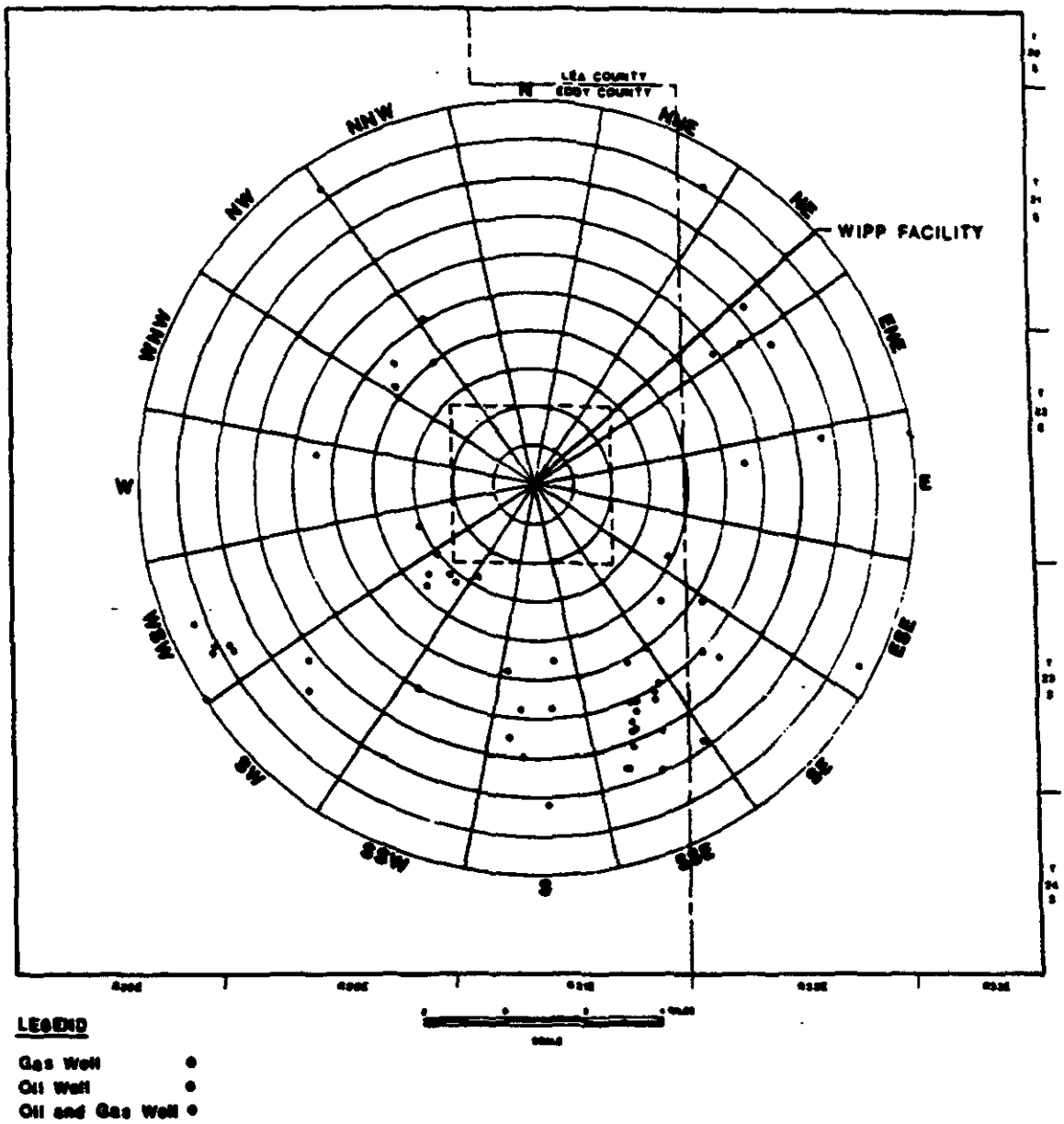

Figure 8. 1986 Operable Natural Gas and Oil Wells, within 10 Mile Radius (WIPP FSAR, U.S. DOE, 1990a, Figure 2.2-1, reproduced with permission).

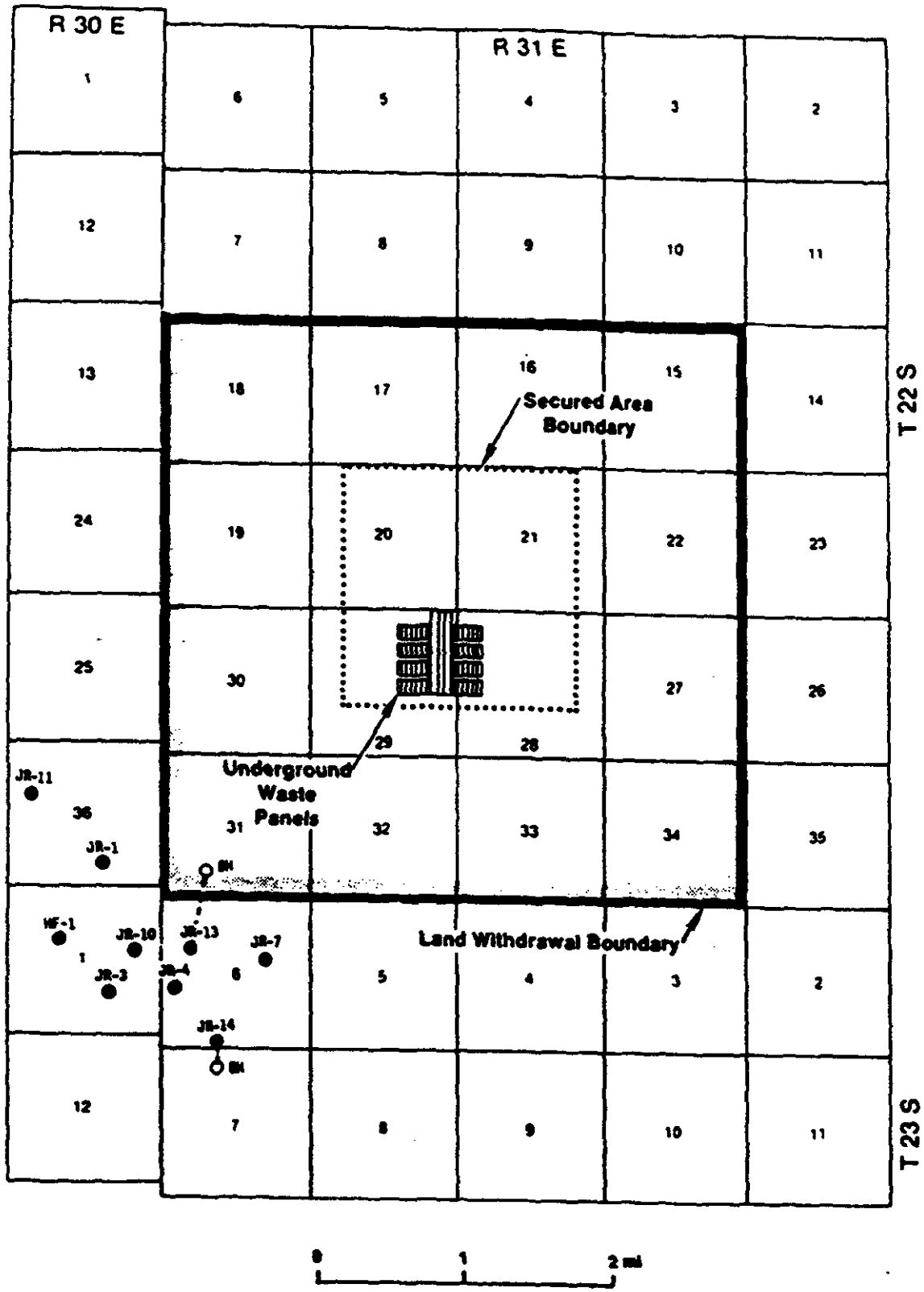

Figure 9. Gas and Condensate Wells at Southwest Corner of WIPP Site. Well locations plotted from U.S. BLM records.

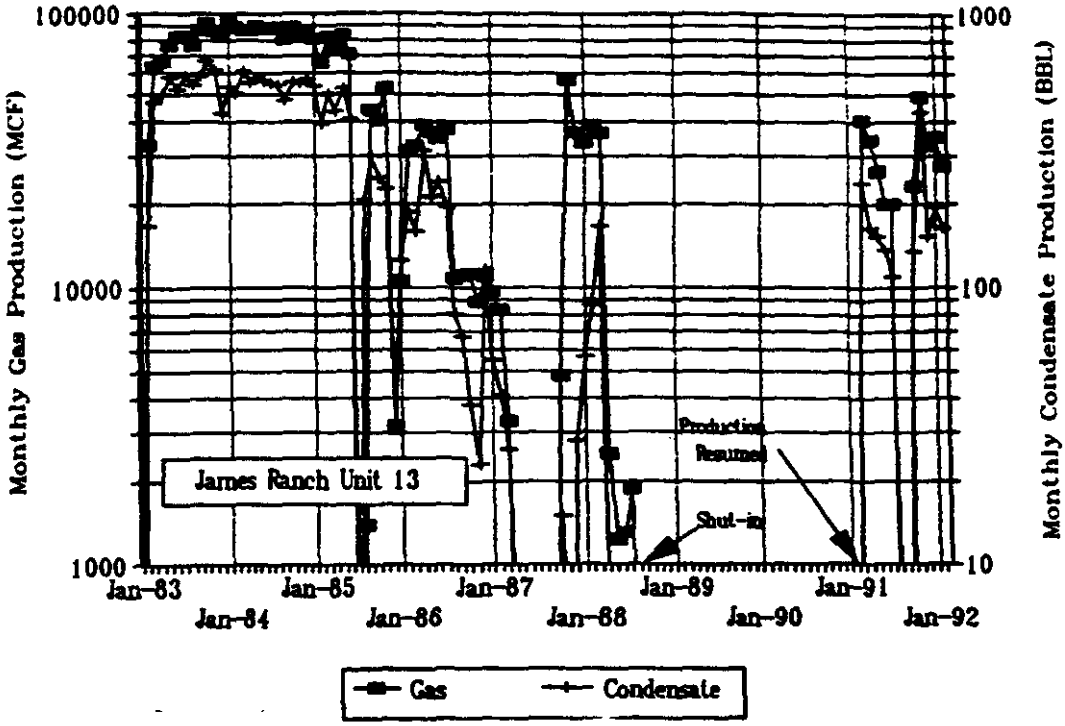

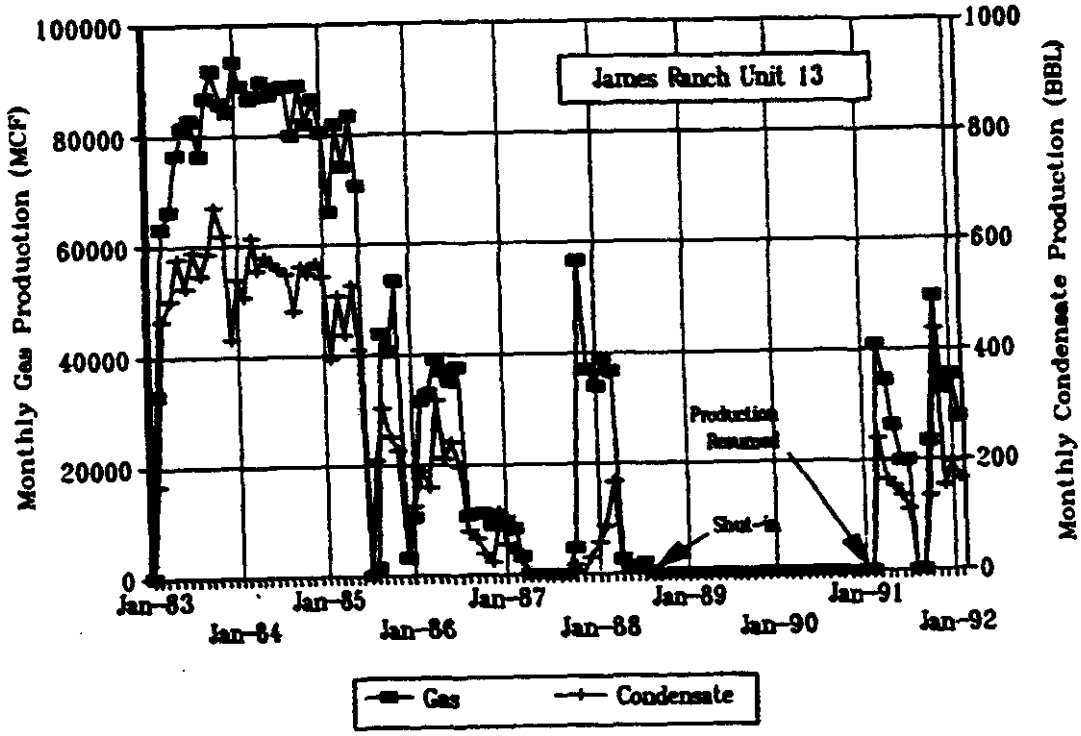

Figure 10. Production History of James Ranch Unit No. 13. Data provided by Roswell District Office, U.S. BLM, 1992.

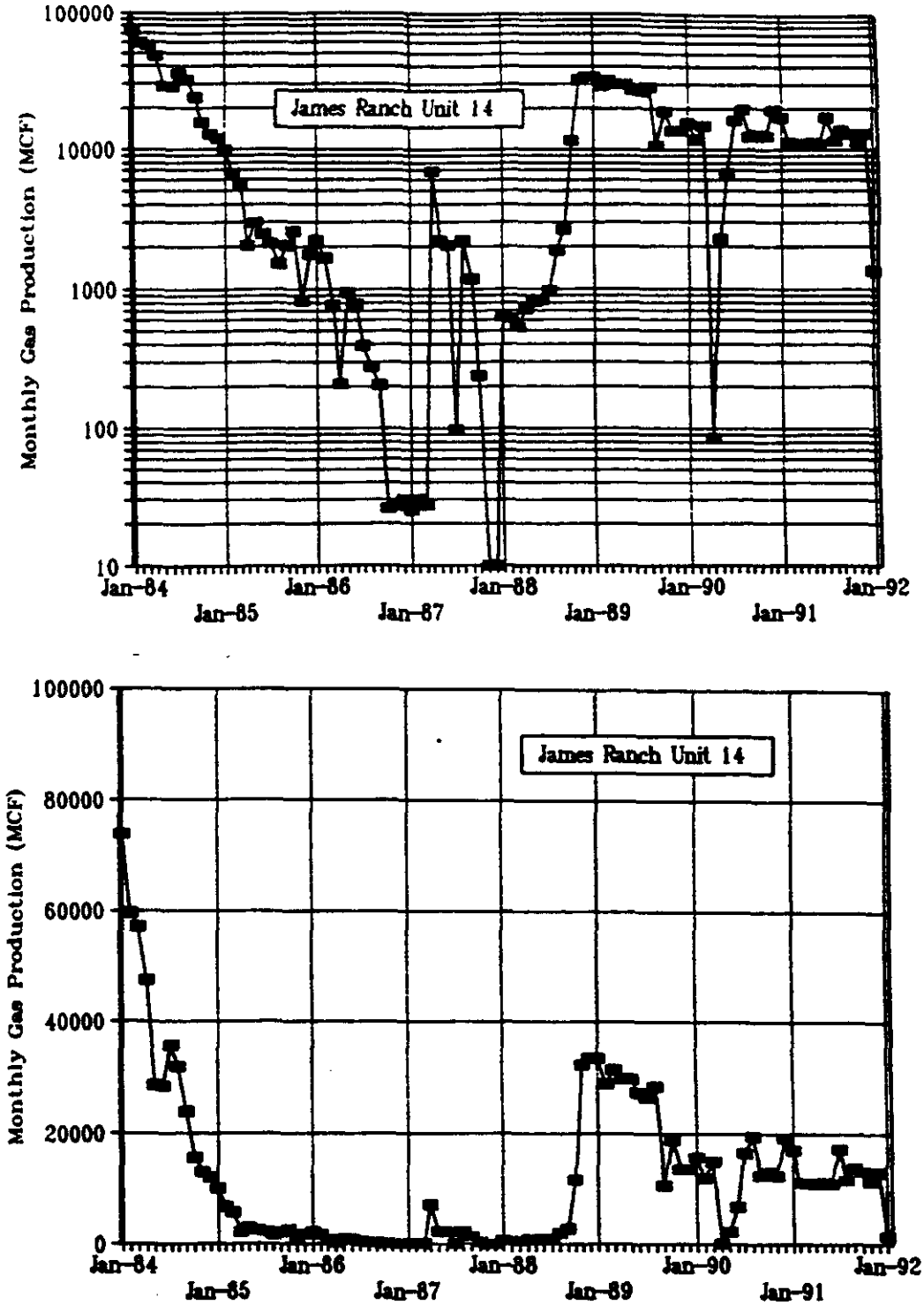

Figure 11. Production History of James Ranch Unit No. 14. Data provided by Roswell District Office, U.S. BLM, 1992.

TABLE 1: PRODUCTION HISTORY OF JAMES RANCH UNIT NO. 13

DATE	OIL (BBL)	GAS (MCF)	WATER (BBL)
01/31/83	0	0	0
02/28/83	167	32970	17
03/31/83	467	63373	31
04/30/83	501	66425	27
05/31/83	579	76613	30
06/30/83	524	81409	30
07/31/83	589	82734	31
08/31/83	546	76421	31
09/30/83	588	86647	30
10/31/83	672	91799	31
11/30/83	619	85720	30
12/31/83	431	84334	29
01/31/84	539	93266	31
02/29/84	508	88828	29
03/31/84	615	86519	30
04/30/84	555	86971	30
05/31/84	580	89612	31
06/30/84	567	87216	30
07/31/84	557	88357	31
08/31/84	548	88778	31
09/30/84	481	80027	29
10/31/84	562	89005	31
11/30/84	549	82072	30
12/31/84	569	86411	31
01/31/85	543	80505	30
02/28/85	393	65972	26
03/31/85	507	81783	31
04/30/85	437	74131	58
05/31/85	526	83292	31
06/30/85	410	70727	28
07/31/85	0	0	0
08/31/85	207	1391	16
09/30/85	302	43919	17
10/31/85	250	40550	17
11/30/85	227	53275	21
12/31/85	33	3112	14
01/31/86	126	10583	4
02/28/86	189	31505	10
03/31/86	160	32865	13
04/30/86	316	38991	17
05/31/86	212	36926	30
06/30/86	241	35085	16

TABLE 1 (continued)

07/31/86	196	37753	16
08/31/86	81	10837	5
09/30/86	67	11113	5
10/31/86	38	11235	5
11/30/86	23	8979	5
12/31/86	117	10951	6
01/31/87	55	9701	7
02/28/87	41	8374	24
03/31/87	26	3305	3
04/30/87	0	0	0
05/31/87	0	0	0
06/30/87	0	0	0
07/31/87	0	0	0
08/31/87	0	0	0
09/30/87	0	0	0
10/31/87	15	4824	4
11/30/87	0	56786	22
12/31/87	28	36952	36
01/31/88	57	33926	30
02/29/88	87	38970	32
03/31/88	167	36552	28
04/30/88		2518	4
05/31/88		1219	2
06/30/88		1297	4
07/31/88		1872	
08/31/88	0	0	0
09/30/88	0	0	0
10/31/88	0	0	0
11/30/88	0	0	0
12/31/88	0	0	0
01/31/91	0	0	0
02/28/91	0	0	0
03/31/91	240	40888	0
04/30/91	164	34513	30
05/31/91	153	26441	0
06/30/91	136	20034	26
07/31/91	110	20043	31
08/31/91	0	0	
09/30/91	0	0	
10/31/91	135	23393	
11/30/91	436	49658	29
12/31/91	153	32782	31
01/31/92	196	35364	
02/29/92	164	27618	

5.3 No-Migration Variance Petition to EPA

The DOE No-Migration Variance Petition (U.S. DOE, 1990b) to the EPA states in the section on human intrusion:

> Oil and gas exploration has been and continues to occur around the WIPP site. The target horizons for this type of exploration are below the Castile. Oil and gas exploratory drilling requires permits from the state, and it is unlikely that prospective future well drillers would not be informed about the existence of WIPP. As an additional protective measure, **the DOE has purchased all oil and gas leases in the area of the WIPP site**[8] to prevent any exploration now and in the future (U.S. DOE, 1990b, Section 6.3.2).

With respect to petroleum exploration and the human intrusion issue, the last sentence in this paragraph provided incorrect information to the EPA. The EPA subsequently granted a variance to the DOE in November 1990 (U.S. EPA, 1990).

5.4 New Mexico Energy and Minerals Department Report

The 1984 report published by the New Mexico Energy and Minerals Department (NMEMD) Task Force on Natural Resources (NMEMD, 1984) stated that the DOE had acquired several oil and gas leases at a cost of over $19.6 million dollars. The report stated that "As a result of these lease acquisitions, only one hydrocarbon lease remains within the WIPP Site Boundary... an 80-acre tract held by Skelly Oil Company...." (NMEMD, 1984, p. 27). The report did not identify the active gas and oil leases in Section 31, deeper than 6,000 feet (1829 meters).

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[8]Emphasis added.

5.5 1990 Memorandum of Understanding between BLM and DOE

The U.S. Department of Energy and the U.S. Department of Interior's BLM signed the Memorandum of Understanding on October 26, 1990, recognizing that:

> **BLM will prohibit directional drilling underneath the WIPP site boundary, except as may be required for the development of the two leases located under Section 31;**[9] drilling may be allowed below 6,000 feet of the surface.

Hence, it appears the DOE entered into an agreement in 1990 to honor these leases despite commitments to preclude slant drilling in the 1987 C&C Agreement with New Mexico and the 1990 WIPP FSAR.[10] Apparently, the DOE accepted the *fait accompli* without considering the commitments in the C&C Agreement and the WIPP FSAR.

5.6 Department of Energy Position

On November 3, 1990, the Albuquerque Journal reported the discovery of the forgotten natural gas well completed within the WIPP Site Boundary. (McCutcheon, 1990).

On November 15, 1990, the Assistant Manager for Energy and Special Programs of the Albuquerque Operations Office of the Department of Energy sent a letter to the

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[9]Emphasis added.

[10]On January 22, 1991, the Assistant Secretary of the Interior signed 43 CFR Public Lands Order 6826 (Administrative Land Withdrawal). That Administrative Land Withdrawal Order cites the October 26, 1990 Memorandum of Understanding between the U.S. Department of Energy and the U.S. Department of the Interior BLM as the guiding document regarding resource management.

Chairman of the New Mexico Radioactive Waste Consultation Task Force. The letter maintained:

> ...at the time this deviated well was drilled, the section 31 bottom hole was within what was formerly termed "zone IV" of the WIPP site. A 1980 report prepared by Sandia National Laboratories (SNL) concluded that extraction from within zone IV would have no technical impact on repository performance. The 1980 Environmental Impact Statement for the WIPP stated that the DOE would permit drilling for natural gas in zone IV. Accordingly, in 1981 when Bass Enterprises filed an application to drill the well, the DOE stated it had no objection, so long as the operator did not encroach upon the surface or the first 6,000 feet condemned by the United States. Recent review by SNL confirms that the existence of this bottom hole more than 14,000 feet below section 31 does not affect the performance of the repository.
>
> We do not believe that the existence of this 1982 well contravenes the August 4, 1987 Second Modification to our Agreement for Consultation and Cooperation in which we previously agreed to prospectively preclude "subsurface mining, drilling, or resource exploration unrelated to the WIPP Project on the WIPP site" [including "slant drilling under the site from within or from outside the site"].... (Bickel, 1990a).

The DOE response requires further explanation because it cited a "1980 report" from Sandia National Laboratories and a "recent review by SNL." The "1980 report" was a **draft** of a position paper on Zone IV. The 1980 memo of transmittal accompanying those draft pages also recommended that:

> well selected, realistic scenarios addressing the consequences of mining and drilling in Zone IV should be a part of the Zone IV position paper (Weart, 1980).

The cited "recent review by SNL" described in the November 15, 1990, DOE letter was a November 5, 1990, memo (Weart, 1990) prepared at the DOE's request. The one and one-half page memo reexamined the reasoning from the 1980 draft in light of the new dilemma and current regulatory requirements. The memo correctly stated:

> the portion of the hole that penetrates the salt is outside the site boundary and thus beyond the boundary at which compliance with the standards will be evaluated (Weart, 1990).

and concluded that:

> even though the Bass drill hole is bottomed within the site boundary, it is much more than a mile from the waste zone and therefore exceeds the technical safety requirements (Weart, 1990).[11]

The DOE Albuquerque Operations Office November 16, 1990, letter to the Coordinator of the New Mexico Radioactive Waste Task Force stated:

> there is one producing well allowed in each 320-acre production unit. The south half of Section 31 has its one well, James Ranch Unit No. 13 (Bickel, 1990b).

However, the letter failed to note current drilling practices in New Mexico would allow additional deep gas wells to be drilled into Section 31 including the south half

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[11]Initially, the selection of a site required that the repository be located at least two miles from a borehole penetrating the Salado formation. The two mile requirement was believed to be conservative but was also arbitrary (Schueler, 1980). The two mile requirement was reduced to one mile after the site at the ERDA 6 borehole was found to be unacceptable (Neill et al., 1979, Appendix III, p. 6). The Geologic Characterization Report (Powers et al., 1979, p.2-12) stated that justification for a one mile criteria was based on reports by Snow and Chang (1975), Walters (1975), Fader (1973), and Griswold (1977). However, EEG questioned the pertinence of these studies and, hence, questioned the justification for the reduction to a one mile criteria (Neill et al., 1979, Appendix III, pp. 6,7).

of that section. The lessee can request permission to drill on tighter spacing by demonstrating to the New Mexico Oil Conservation Division that the tighter spacing is required to efficiently produce the gas from the formation. For example, if a reservoir exhibits retrograde condensate behavior, the buildup of liquid around the well bore can reduce, sometimes seriously, the flow rate as the pressure declines below the dew point (Craft and Hawkins, 1959, p. 73). Hence, efficient production may require more wells on a tighter spacing.

Also, the existing well in Section 31 could be deepened. That activity would constitute exploratory drilling.

Furthermore, the lessee is still entitled to slant drill an exploratory hole into the north half of Section 31, which has yet to be developed. In summary, as long as the lessee maintains the leases, the U.S. BLM can not deny them access to their oil and gas in Section 31, the southwestern section of the WIPP Site.

5.7 SNL WIPP Performance Assessment Division

The SNL WIPP Performance Assessment Division issues an annual report on the status of the demonstration of the extent of compliance with 40 CFR Part 191. The December 1990 annual report stated:

> About 56 oil and gas wells are within a radius of 16 km (10 mi); the wells generally tap Pennsylvanian strata, about 4,200 m (14,000 ft) deep. The nearest well is about 3 km (2 mi) to the south-southwest of the waste panels (Bertram-Howery, 1990, p. I-20).

There was no discussion on the status of that well. For 1991, the SNL WIPP Performance Assessment Division added:

> The surface location of the well, which is capable of producing gas, is outside the proposed land-withdrawal boundary, but the borehole is slanted to withdraw gas from rocks within the boundary. Except for this well, resource extraction is not allowed within the proposed land-withdrawal boundary (Sandia National Laboratory, 1991, p. 1-15).

The 1991 document also stated in the discussion on natural resources:

> In order to gain control over the development of hydrocarbons at the WIPP, the DOE acquired the oil and gas leases within all the WIPP control zones. The only leases that are still intact are in Section 31. These leases only allow resource production by entry of the proposed land withdrawal area below 6000 feet. **One of these leases is currently in production.**[12] The upper 6000 feet of the leases was taken by the DOE in 1979. Current policy does not allow any further resource development inside the proposed land withdrawal boundary (Sandia National Laboratory, 1991, p. 8-7).

5.8 <u>The Secretary of Energy's Decision Plan</u>

While the Secretary of Energy's Decision Plan for the WIPP had carefully tracked an active potash lease until it was purchased, successive Revisions 6 through 10 did not document the existence of the active oil and gas leases even after the issue had been raised. The potash lease purchase was noted in Revision 5 (U.S. DOE, August 15, 1990). The failure of subsequent revisions to mention the rediscovered gas leases incorrectly suggests that there were no outstanding leases in the WIPP Site Boundary other than the one potash lease.

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[12]Emphasis added.

5.9 DOE Implementation of the Resource Disincentive Plan

The *DOE Implementation of the Resource Disincentive Plan in 40 CFR 191.14(e) at the Waste Isolation Pilot Plant* (U.S. DOE, 1991) is inconsistent in reporting the number of oil and gas leases within the WIPP Site Boundary and the production status of those leases. First it incorrectly states that:

> Only one lease currently exists within the WIPP site boundary (U.S. DOE, 1991, p.32).

However, there are two active gas and oil leases within the WIPP site boundary — the Conoco lease on the north half of Section 31 and the Bass lease on the south half of Section 31.

The Resource Disincentive Plan then states:

> This lease, **currently shut in for production of oil and gas,**[13] is being exploited by a well that was initiated outside the WIPP site boundary and was deviated to under the site only after the depth was below 6000 feet (U.S. DOE, 1991, p.32).

The document then reverses its position on the number of leases and their production status:

> In order to gain control over the development of hydrocarbons within the WIPP site area, the DOE acquired the oil and gas leases within all the WIPP control zones. These acquisitions were necessary to keep the salt beds intact. The only leases that are still intact are in section 31. These leases only allow

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[13]Emphasis added.

the production of resources by entry below 6000 feet. **One of these leases is currently in production**[14] (U.S. DOE, 1991, p.50).

The U.S. Bureau of Land Management (U.S. BLM, 1992) records show the well produced 141,919 MCF of natural gas from March 1991 through July 1991 as shown in Table 1, and was shut-in effective August 1991 - coincidently, the issue date of the Disincentive Plan. The latest available records from the Roswell District Office of the U.S. BLM indicate production resumed in October 1991.

5.10 Comments on Credit for Active and Passive Institutional Control

In terms of active institutional control, the leases were forgotten by the DOE in spite of the lease, drilling, and production records filed with the federal government, a condemnation suit filed in civil court by the federal government, agreements between the State of New Mexico and the federal government, technical reports to the federal government on area oil and gas resources, and the existence of a producible gas well visible from the south access highway into the WIPP facility.

The loss of knowledge in just a short few years is cause for concern. There were no major changes in society, government, language, culture, or technology. Yet the WIPP project lost knowledge of this gas well and the active oil and gas leases. The current wording in the EPA Standards permits the assumption that active institutional control can completely deter inadvertent human intrusion for up to 100 years.

We believe that present assumptions about the effectiveness of active institutional control needs to be reconsidered because of this experience of the forgotten oil and gas leases and a forgotten gas well. First, the EPA should reexamine whether full credit for 100 years active institutional control is reasonable given the actual experience of inaccurate record keeping. Second, the DOE should examine the basis

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[14]Emphasis added.

for assuming full credit for 100 years control and consider using a lesser value to reflect the actual experience of the WIPP project. Third, the EPA Standards should require the implementing agency to publish specific plans on how the agency intends to maintain active institutional control. Fourth, even in the absence of such a requirement, the DOE should publish plans now that specify in detail how the Department intends to maintain full control of activities in the area of the repository for 100 years after decontamination and decommissioning and how that control will completely deter human intrusion.

At this time the DOE commitment is effectively limited to a statement in the First Modification to the C&C Agreement which states:

> the post-closure institutional control, shall be negotiated and resolved by the parties in the future, and at least one year prior to the start of the decontamination and decommissioning of WIPP (U.S. DOE, 1981).

In the Second Modification to the C&C Agreement, the DOE agreed to provide a plan by February 1, 1988, which would:

> contain an estimated schedule and a description of the process DOE will use to: identify needed active institutional controls, gather data for the implementation of such controls, develop and implement a monitoring plan for passive institutional controls, determine the barriers to be used, assess the selection of the WIPP site in view of the resources at the site, and review the recoverability of the waste for a reasonable period after disposal.

However, the DOE Plan:

> merely describes the steps that the DOE will undertake to implement compliance to one portion of the Standard [40 CFR 191 Subpart B]. For most of the Assurance Requirements, the information needed to specify detailed plans and activities for implementation is not yet available.... Other

> information will not be available until close to the time that the Project has completed its mission and the WIPP is closed (U.S. DOE, 1987, p.1).

Furthermore, the remanded EPA Standards allow credit for the use of passive institutional controls to deter inadvertent human intrusion (U.S. EPA, 1985, p. 38080). However, excessive credit for passive controls, such as markers and public records, could reduce the estimated probability of inadvertent human intrusion in the performance assessment calculations and underestimate the actual risk. As discussed above, there is inaccurate information in key DOE documents which can be considered public records. There was the presence of a gas wellhead, visible from the south access highway and availability of lease and production records in the Roswell District Office of the U.S. BLM. Yet that marker and these public records were not effective in notifying the preparers of the DOE documentation of the gas and condensate production activity beneath the WIPP site and the existince of active leases with the WIPP Site Boundary.

6.0 PROPOSED CONGRESSIONAL LEGISLATION

The issue of allowing the existing oil and gas leases and a well to produce hydrocarbons from beneath the WIPP Site has been addressed by the U.S. Congress in the various bills for the WIPP land withdrawal.

The bill passed by the Senate (S. 1671) would:

- prohibit slant drilling from within or without the site
- require the Department of the Interior, in consultation with the Department of Energy, to determine the effects of the oil and gas leases on the activities at the WIPP and to recommend as to the advisability of trading or cancelling the leases.
- authorize funds to be appropriated to the Department of Energy for the cancellation of the leases.

The House Armed Services Committee Bill (H.R. 2637) is identical to S. 1671 except that it does not authorize funds to cancel the lease.

The bills passed by the House Committee on Interior and Insular Affairs (H.R. 2637) and the House Committee on Energy and Commerce (H.R. 2637) would both:

- prohibit slant drilling from outside the WIPP boundary,
- provide funds for the DOE to acquire the leases.

7.0 CONCLUSIONS

Several U.S. Department of Energy documents failed to record the existence of two active oil and gas leases and a producible gas well within the WIPP Site Boundary. In its performance assessment calculations, the WIPP project has assumed that active institutional control would deter human intrusion for 100 years after decommissioning. The EPA should reexamine whether full credit for 100 years active institutional control is reasonable given the actual experience of inaccurate record keeping. The DOE should also examine the basis for assuming full credit for 100 years control and consider using a lesser amount to reflect the actual experience of the WIPP Project. The EPA Standards should require the implementing agency to publish specific plans on how the agency intends to maintain active institutional control. Even in the absence of such a requirement, the DOE should publish plans now that specify in detail how the Department intends to maintain full control of activities in the area of the repository for 100 years after decontamination and decommissioning and describe how that control will completely deter human intrusion. Finally the DOE needs to describe in detail their passive institutional control system and describe how it will provide a deterrence to inadvertent human intrusion after 100 years.

8.0 REFERENCES

Bass, P. R, 1976. November 10 letter to U.S.G.S Supervisor of Oil and Gas Operations, Roswell Office designating Continental Oil Company as designated agent.

Bertram-Howery, S. G., et al., 1990. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990. SAND90-2347, Sandia National Laboratories.

Bickel, J. E., 1990a. November 15 letter from DOE Assistant Manager for Energy and Special Programs to Anita Lockwood, Chairman of the New Mexico Radioactive Waste Consultation Task Force.

Bickel, J. E., 1990b. November 16 letter from DOE Assistant Manager for Energy and Special Programs to Chris Wentz, Coordinator of the New Mexico Radioactive Waste Consultation Task Force.

Craft, B. C. and Hawkins, M. F., 1959. *Applied Petroleum Reservoir Engineering*. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Fader, S. W., 1973. Land subsidence caused by dissolution of salt near four Wells in central Kansas: U.S. Geological Survey Administrative Report for AEC.

Foster, R. W., 1974. Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste, Open-File Report, Contract No. Af (40-1)-4423, Oak Ridge National Laboratory.

Gillham, J. A., 1981. December 16 memorandum from the U.S.G.S. District Supervisor, Roswell to U.S.G.S. Deputy Conservation Manager of Oil and Gas.

Griswold, G. B., 1977. Site Selection and Evaluation Studies of The Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM. SAND77-0946, Sandia National Laboratories.

Keesey, J. J., 1976. Hydrocarbon Evaluation Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico. SAND77-7033, Volume I, Sandia National Laboratories.

Keesey, J. J., 1977. Appraisal Report Waste Isolation Pilot Plant, Eddy County, New Mexico, including: south half of Section 31, T22S, R31E; all of the eastern half; all of the western half excluding the south half of Section 31, T22S, R31E. Sipes, Williamson, and Aycock, Inc., Petroleum Consultants, Midland, Texas.

Keesey, J. J., 1979a. Evaluation of Directional Drilling for Oil and Gas Reserves Underlying the Waste Isolation Pilot Plant Site Area, Eddy County, New Mexico. Sipes, Williamson and Associates, Inc., Petroleum Consultants, Midland, Texas.

Keesey, J. J., 1979b. Estimation of Potential Hydrocarbon Reserves and Associated Costs and Income for Oil and Gas Reserves Underlying the Waste Isolation Pilot Plant Site Area, Eddy County, New Mexico. Sipes, Williamson, and Associates, Inc., Petroleum Consultants, Midland, Texas.

Koski, G. B., 1981. December 18 letter to J. M. McGough, WIPP Project Manager.

McCutcheon, C., 1990. WIPP Officials May Acquire Gas Lease for Dormant Well. Albuquerque Journal, November 3, 1990, p. E-3.

McGough, J. M., 1981. December 30 letter to G. B. Koski, Area Manager, U.S. Bureau of Land Management, Carlsbad Office.

McGough, J. M., 1983a. February 17 letter to R. H. Neill, Director, Environmental Evaluation Group.

McGough, J. M., 1983b. February 24 letter to R. H. Neill, Director, Environmental Evaluation Group.

McGough, J. M., 1983c. December 7 letter to R. H. Neill, Director, Environmental Evaluation Group.

McHale, J. J, 1977. April 4 memorandum from the U.S. Assistant Solicitor for Lands to the U.S. BLM Director regarding the Energy Research and Development Administration Condemnation of BLM-Administered Lands.

Neill, R. H., Channell, J. K., Wofsy, C. Greenfield, M. A., Editors, 1979. Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U.S. Department of Energy. EEG-3.

Neill, R. H., Channell, J. K., Chaturvedi, L., Little, M. S., Rehfeldt, K., and Spiegler, P., 1983. Evaluation of the Suitability of the WIPP Site. EEG-23.

Neill, R. H., 1983a. October 28 letter to J. M. McGough, WIPP Project Manager.

Neill, R. H., 1983b. December 6 letter to J. M. McGough, WIPP Project Manager.

New Mexico Energy and Minerals Department, 1984. Natural Resources at the Waste Isolation Pilot Plant Site. New Mexico Energy and Minerals Department Task Force on Natural Resources. Santa Fe, New Mexico.

Pettengill, J. G., 1981. December 14 memorandum from U.S.G.S Geologist, Roswell Office, to U.S.G.S. District Engineer, Artesia Office, regarding Review of Application for Permit to Drill Surface Lease # NM-02887-D.

Powers, D. W., Lambert, S. J., Shaffer, S. E., Hill, L. R., Weart, W. D., 1978. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND 78-1596, Sandia National Laboratories.

Reitz, M. F., 1982. January 11 letter from U.S.G.S. Deputy Conservation Manager to Perry R. Bass approving application to drill James Ranch Unit No. 13.

Sandia National Laboratories, 1991. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. SAND91-0893, Sandia National Laboratories.

Schueler, T. D., February 20, 1980 letter to R. H. Neill, Director of the Environmental Evaluation Group.

Snow, R. H. and Chang, D. S., 1975. Prediction of Cavity Growth by Solution of Salt Around Boreholes. IITRIC631314, Union Carbide Corporation.

U.S. Congress House. Waste Isolation Pilot Plant Land Withdrawal Act, H. Rept. 102 -241, Part 1-3 to accompany H.R. 2637, 102d Cong., 1st sess., 1991.

U.S. Congress. Senate. Waste Isolation Pilot Plant Land Withdrawal Act of 1991, S. Rept. 102-196, to accompany S. 1671, 102d Cong., 1st sess., 1991.

U.S. Bureau of Land Management, 1992. Production information and reports provided by the Roswell District Office, Roswell, New Mexico.

U.S. Department of Energy, 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant. DOE/EIS-0026.

U.S. Department of Energy and State of New Mexico, 1981. "Agreement for Consultation and Cooperation" on WIPP, First Modification, November 30, 1984 and Second Modification, August 4, 1987.

U.S. Department of Energy, 1987. A Plan for the Implementation of Assurance Requirements in Compliance with 40 CFR 191.14 at the Waste Isolation Pilot Plant. DOE/WIPP 87-016.

U.S. Department of Energy, 1990a. Final Safety Analysis Report, Waste Isolation Pilot Plant. WP-02-9, Rev. 0.

U.S. Department of Energy, 1990b. No-migration Variance Petition: Waste Isolation Pilot Plant. DOE/WIPP-89-003, Rev. 1.

U.S. Department of Energy, 1990c. Draft Decision Plan for WIPP, Revision 5, August 5, 1990.

U.S. Department of Energy, 1990d. Final Supplement Environmental Impact Statement: Waste Isolation Pilot Plant. DOE/EIS-0026-FS.

U.S. Department of Energy, 1991. Implementation of the Resource Disincentive in 40 CFR Part 191.14 (e) at the Waste Isolation Pilot Plant. DOE/WIPP 91-029 (August).

U.S. Environmental Protection Agency. Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-level and Transuranic Radioactive Wastes. *Federal Register* 50 no. 182, 19 September 1985, 38066-38089.

U.S. Environmental Protection Agency. Conditional no-migration determination for the U.S. Department of Energy Waste Isolation Pilot Plant. *Federal Register* 55, no. 220, 14 November 1990, 47700.

U.S. Environmental Protection Agency. Draft Notice for 40 CFR Part 191. *Federal Register* 57, no. 22, 3 February 1992.

Walters, R. F., 1975. Salt Dissolution in Oil and Gas Test Holes in Central Kansas. ORNL Contract No. 78X-38283V.

Weart, W. D., 1980. October 10 memorandum to J. M. McGough, WIPP Project Manager transmitting draft of Sandia National Laboratories input to a position paper on Zone IV.

Weart, W. D., 1990. November 5 memorandum to A. Hunt, WIPP Project Manager, consisting of a one and one-half page review of issues related to drilling on Zone IV at the WIPP Site.

9.0 LIST OF ACRONYMS

BBL	Barrels
BLM	Bureau of Land Management
C&C	Consultation and Cooperation
CFR	Code of Federal Regulations
CH-TRU	Contact-Handled TRU (waste)
DOE	U.S. Department of Energy
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
FEIS	Final Environmental Impact Statement
FSAR	Final Safety Analysis Report
MCF	Thousand standard cubic feet
MOU	Memorandum of Understanding
NMEMD	New Mexico Energy and Minerals Department
RH-TRU	Remote-Handled TRU (waste)
SNL	Sandia National Laboratories
TRU	Transuranic
U.S.G.S	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

Environmental Evaluation Group Reports
(Continued From Front Cover)

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (ed.), The Rustler Formation at the WIPP Site, February 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C. and Jim W. Kenney, A Critical Assessment of Continuous Air Monitoring Systems at the Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

EEG-40 Review of the Final Safety Analyses Report (Draft), DOE Waste Isolation Pilot Plant, December 1988, May 1989.

EEG-41 Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, July 1989.

EEG-42 Chaturvedi, Lokesh, Evaluation of the DOE Plans for Radioactive Experiments and Operational Demonstration at WIPP, September 1989.

EEG-43 Kenney, Jim W., et al., Preoperational Radiation Surveillance of the WIPP Project by EEG 1985-1988, January 1990.

EEG-44 Greenfield, Moses A., Probabilities of a Catastrophic Waste Hoist Accident at the Waste Isolation Pilot Plant, January 1990.

EEG-45 Silva, Matthew K., Preliminary Investigation Into the Explosion Potential of Volatile Organic Compounds in WIPP CH-TRU Waste, June 1990.

EEG-46 Gallegos, Anthony, and James K. Channell, Risk Analysis of the Transport of Contact Handled Transuranic (CH-TRU) Wastes to WIPP Along Selected Highway Routes in New Mexico Using RADTRAN IV, August 1990.

EEG-47 Kenney, Jim W. and Sally C. Ballard, Preoperational Radiation Surveillance of the WIPP Project by EEG During 1989, December 1990.

EEG-48 Silva, Matthew, An Assessment of the Flammability and Explosion Potential of Transuranic Waste, June 1991.

EEG-49 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1990, November 1991.

EEG-50 Silva, Matthew K. and James K. Channell, Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards, June 1992.

EEG-51 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1991, October 1992.

EEG-52 Bartlett, William T., An Evaluation of Air Effluent and Workplace Radioactivity Monitoring at the Waste Isolation Pilot Plant, February 1993.

EEG-53 Greenfield, Moses A. and Thomas J. Sargent, A Probabilistic Analysis of a Catastrophic Transuranic Waste Hoist Accident at the WIPP, June 1993.

EEG-54 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1992, February 1994.

ENVIRONMENTAL EVALUATION GROUP

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EEG-57

AN APPRAISAL OF THE 1992 PRELIMINARY PERFORMANCE ASSESSMENT FOR THE WASTE ISOLATION PILOT PLANT

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September 1994

Environmental Evaluation Group Reports

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disp of Radioactive Wastes, June 1979

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al., (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter, Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon - A Single Hole Scenario, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter and Dave Updegraff, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell, Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter, A Proposed Preoperational Environmental Monitoring Program for WIPP, November 1984.

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dol September 1984.

(Continued on Back Cover)

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AN APPRAISAL OF THE 1992 PRELIMINARY PERFORMANCE ASSESSMENT FOR THE WASTE ISOLATION PILOT PLANT

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AN APPRAISAL OF THE 1992 PRELIMINARY PERFORMANCE ASSESSMENT FOR THE WASTE ISOLATION PILOT PLANT

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FOREWORD

This is the Environmental Evaluation Group's (EEG) appraisal of the 1992 performance assessment for the Waste Isolation Pilot Plant. Performance assessments have been performed by Sandia National Laboratories for the U. S. Department of Energy to predict the long-term safety of the Waste Isolation Pilot Plant. The 1992 Performance Assessment, entitled *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992,* is in five volumes:

vol. 1: Third Comparison with 40 CFR 191, Part B;

vol. 2: Technical Basis;

vol. 3: Model Parameters;

vol. 4: Uncertainty and Sensitivity Analysis for 40 CFR 191, Part B;

vol. 5: Uncertainty and Sensitivity Analysis for Gas and Brine Migration for Undisturbed Performance.

This current appraisal incorporates EEG's preliminary comments on volumes 1, 2, and 3 transmitted to the U. S. Department of Energy on September 13, 1993, and volumes 4 and 5 received October 27, 1993.

The purpose of the New Mexico Environmental Evaluation Group is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-ACO4-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include as-

sessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.

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EXECUTIVE SUMMARY

The Environmental Evaluation Group (EEG) has reviewed the WIPP *1992 Performance Assessment*. The Sandia team should be commended for both the substance of this work, and a sound theoretical foundation. Progress has been made towards assessing WIPP's compliance with the U.S. Environmental Protection Agency's Standards for high-level and transuranic waste. Our comments on the *1992 Performance Assessment* are organized into Major Issues, and Detailed Comments. Specific recommendations on major issues follow.

1. Claimed Improvements in the *1992 Performance Assessment.*
   - R-1.1 Apply available fully coupled codes to make explicit the relationship between the complex processes of gas generation, brine flow and room closure.
   - R-1.2 Abandon further statistical manipulation of transmissivity fields in the Culebra in favor of additional field and laboratory work to better define multi-well flow and transport characteristics, including flow and tracer tests (sorbing and non-sorbing) at additional locations.
   - R-1.3 Abandon claiming credit for matrix diffusion and corrensite sorption until experimental data can substantiate the claim.

2. Displaying Uncertainty in Final Results
   - R-2 Show the full uncertainty band of CCDFs when comparison with the containment requirement (40 CFR 191) is made.

3. Use of Judgment in Performance Assessment
   - R-3.1 As experimental solubility values become available (e.g. Nitsche *et al.*, 1992; 1993), use them in performance assessment.
   - R-3.2 Use only demonstrable retardation coefficients in performance assessment.
   - R-3.3 Discard the subjective probabilities for human intrusion used in the *1992 Performance Assessment* and adopt the specific suggestion in Section 3.4.

4. Computer Code Documentation
   - R-4 Establish a workable system to provide EEG with relevant documentation, so that EEG has reasonable access to perform its work.

5. The Culebra as a Natural Barrier
   - R-5 Quantify the extent of matrix diffusion and sorption through accelerated experimentation.

6. Effects of Gas Generation
   - R-6 In future analysis, the deleterious effect of gas generation should be included.

7. Correlation Among Variables
   - R-7 The performance assessment should either give reasons why physical correlations have been ignored, or show results with correlations.

8. Natural Resources Near the WIPP

R-8 Performance assessment reports should accurately reflect the status of resource development near the WIPP site.

9. Oil and Gas Production Near the WIPP

R-9 The performance assessment effort should use the latest and verifiable data on oil and gas production near the WIPP, because the extent of oil and gas resources in this area is likely to be an important determinant of inadvertent human intrusion, and oil and gas production can potentially affect the hydrogeology at the WIPP site.

10. Gas Generation

R-10a The gas generation calculations should include

(a) methane generation,

(b) radiolytically generated hydrogen.

R-10b The relationships in the gas generation model should be validated before the gas generation model is incorporated into BRAGFLO.

11. Unanalyzed Scenarios

R-11.1 The criticality issue needs to be thoroughly evaluated before it can be concluded that its effects are negligible.

R-11.2 Subsidence effects need to be evaluated in much more detail and incorporated, in some manner, into the human intrusion scenarios.

R-11.3 Provide results of the abovementioned analyses, and include contaminated brine flow to the ground surface in future versions of human intrusion scenarios.

R-11.4 Perform a complete analysis of a brine-slurry release scenario. In addition, variants of the brine-slurry scenario in undisturbed performance and in the E2 scenario need to be better understood.

R-11.5 Performance Assessment should not assume perfect plugging of abandoned oil and gas wells near the WIPP. For the human intrusion borehole, the range of degraded permeabilities should span sand and gravel.

12. Analysis of Direct Discharge to the Ground Surface

R-12 Future performance assessments need to include erosion of waste by helical turbulent flow and the effect of sediment erosion. Also needed is analysis of other relevant scenarios, such as the E1E2 with brine slurry discharge to the surface.

13. Inventory

R-13.1 Include ^{135}Cs, ^{129}I and ^{99}Tc and other fission product nuclides as appropriate in future performance assessments.

R-13.2 Show the basis for inventories used.

14. Solubilities

R-14 In future performance assessments, limit the sampling range to the error bands in experimental data.

15. Transport Modeling of Volatile Organics

R-15 Two-phase transport of volatile organic compounds through gas-fractured interbeds should be analyzed in the future.

16. Corrensite Retardation in the Culebra

R-16 Abandon claiming credit for corrensite sorption as well as additional experiments with corrensite, unless the extent of corrensite or other clay minerals can be quantified along postulated flow paths.

17. Ideal Gas Assumption in VOC Migration

R-17 Unless there is experimental evidence that VOC vapors move as ideal gases and move with the low-molecular-weight gases generated by radiolysis, corrosion, or microbial action, movement of VOC vapors should not be modeled as ideal gas flow in showing compliance with 40 CFR 268.

I. INTRODUCTION

The Environmental Evaluation Group (EEG) has reviewed the WIPP *1992 Performance Assessment* (Sandia WIPP Performance Assessment Department, 1992). Although this performance assessment was released after the October 1992 passage of the WIPP Land Withdrawal Act (PL 102-579), the work preceded the Act. For individual and ground-water protection, calculations have been done for 1000 years post closure, whereas the U.S. Environmental Protection Agency's Standards (40 CFR 191) issued in 1993 require calculations for 10000 years.

This is the third iterative performance assessment of the Waste Isolation Pilot Plant (Sandia WIPP Performance Assessment Department, 1992; 1991; Bertram-Howery *et al.*, 1990). EEG believes the Sandia team should be commended for both the substance of this work, and a sound theoretical foundation for performance assessment. The *1992 Performance Assessment* continues to assimilate improved understanding of the geology and hydrogeology of the site, and evolving conceptual models of natural barriers. Progress has been made towards assessing WIPP's compliance with the U.S. Environmental Protection Agency's Standards (40 CFR 191).

The *1992 Performance Assessment* has addressed several items of major concern to EEG, outlined in our July 1992 review of the 1991 performance assessment (Neill *et al.*, 1992). In particular, we are pleased that some key results in this performance assessment, shown in Chapter 5 of volume 1, deal with sensitivity of the calculated complementary cumulative distribution functions (CCDF) to alternate conceptual models proposed by EEG—that flow in the Culebra be treated as single-porosity fracture-flow; with no sorption retardation unless substantiated by experimental data. We look forward to results of additional analysis using scenarios and assumptions that EEG has suggested in the past and hereinafter.

Our review is organized into Major Issues, and Detailed Comments.

II. MAJOR ISSUES

1. Claimed Improvements in the *1992 Performance Assessment*

The overall conclusions of the *1992 Performance Assessment* are stated in chapter 9 of volume 4. Several improvements over previous assessments are noted, and we discuss the claimed improvements below.

1.1 While the first major improvement noted is the coupling of repository creep closure modeling to gas generation and brine flow, the coupling is not entirely satisfactory. The geomechanical closure calculated by SANTOS is passed onto BRAGFLO although the two computer codes use different conceptual models, geometries, and time scale.

Recommendation 1.1. Apply available fully coupled codes to make explicit the relationship between the complex processes of gas generation, brine flow and creep closure.

1.2 The *1992 Performance Assessment* accounts for spatial variation of transmissivity in the Culebra using improved methods. Table 8.4-1 in volume 4 shows that variation in Culebra transmissivity fields accounted for a mere 6% of the variation in total integrated releases. The respective solubilities of Am, Np, Pu, Th and U accounted for more of the variation in release rates.

Recommendation 1.2 Abandon further statistical manipulation of transmissivity fields in the Culebra in favor of additional field and laboratory work to better define flow and transport characteristics, including flow and tracer tests (sorbing and non-sorbing) at additional locations.

1.3 The *1992 Performance Assessment* accounts for radionuclide transport in the Culebra "more accurately" [sic]. To be accurate implies the existence of an unique and correct standard which does not exist in this case. The *1992 Performance Assessment* considers three radionuclide retardation mechanisms in the Culebra: equilibrium sorption, matrix diffusion and clay sorption. For equilibrium sorption, the second modification of the Consultation and Cooperation Agreement between the Department of Energy (USDOE) and the State of New Mexico specifies that retardation coefficients shall be set to zero unless there are experimental data otherwise. The *1992 Performance Assessment* offers no experimental evidence for matrix diffusion. No clear evidence is given for the extent of corrensite in the calculated

flow paths. Moreover, clay in fractures can act either as an additional sorption agent, or serve to block mass transfer between the fracture and the matrix. The *1992 Performance Assessment* has eliminated the latter role [vol. 2, p. 7-23, line 11]. This is double counting for a mechanism which may not exist. We deal with the role of corrensite in detail in 16.

Recommendation 1.3 Abandon claiming credit for matrix diffusion and corrensite sorption until experimental data can substantiate the claim.

The *1992 Performance Assessment*

> ...accounts for the effects of passive marker systems through time-varying drilling intensities within the Poisson model for calculating intrusion probabilities [vol. 4, p. 9-1].

What this means is that subjectively elicited probabilities of drilling intrusion that are orders of magnitude below the USEPA guidance (40 *CFR* 191, Appendix C) have been used. The EEG objects to the use of these probabilities as elicited. We deal with this topic in 3b below.

The *1992 Performance Assessment* states that the following improvements will be made in future performance assessments:

- modeling pressure fracturing of anhydrite interbeds,
- modeling three-dimensional flow in the Rustler, especially the effects of subsidence of potash mine excavations,
- incorporating plug degradation,
- modeling spalling in drilling intrusions,
- acquiring experimental data on actinide solubilities and retardation,
- determining the most appropriate conceptual model for radionuclide transport in the Culebra.

We have called for these improvements for several years, and welcome the commitment.

2. Displaying Uncertainty in Final Results

In previous performance assessments, the USDOE noted that the calculated CCDF's were at least an order of magnitude below the allowable limits in the USEPA Standards (Sandia WIPP Performance Assessment Department 1991). In the *1992 Performance Assessment*, for the case of total release from repository/shaft barrier only, and a [0, 30] sampled intrusion

rate, the mean CCDF comes to within a factor of two or three of the USEPA containment requirement [vol. 4, Fig. 9-1, curve 1]. This suggests several vectors of CCDF lie in the zone of violation of the containment requirement. This mean CCDF is not as conservative as it may appear because subjectively elicited solubilities are incorporated. The non-conservative basis of curve 1 in Figure 9-1 is illustrated in Figure 1. Using BRAGFLO-calculated brine flow from the repository up to the Culebra (70 vectors for both the E2 and E1E2 scenarios), all actinide solubilities at 10^{-3}, 10^{-5} and 10^{-7} M, and the human intrusion rate sampled uniformly between 0 and 30 boreholes/km^2/10,000 years, the mean CCDFs are shown in Figure 1, along with curve 1 from Figure 9-1 (vol. 4). If the extremely low subjectively elicited solubilities are **not** used, then the mean CCDF for the case of engineered barriers alone may not meet the containment requirement. See also 14 below.

The EEG has also suggested to the USEPA that for comparison with the containment requirement, that the 90% curve be used to be conservative.

Recommendation 2. Show the full uncertainty band of CCDFs when comparison with the containment requirement (40 CFR 191) is made.

3. Use of Judgment in Performance Assessment

3.1 Beginning with the *1992 Performance Assessment*, "expert judgment" is used to estimate

a. solubilities of actinides;

b. retardation coefficients of radionuclides; and

c. probabilities of inadvertent intrusion.

Experimental programs are underway to measure solubility and retardation coefficients, for conditions relevant to the WIPP.

Recommendation 3.1. As experimental solubility values become available (e.g. Nitsche *et al.*, 1992; 1993), use them in performance assessment.

3.2 The second modification of the Cooperation and Consultation Agreement between the Department of Energy and the State of New Mexico specifies that retardation coefficients be set to zero unless experimental data shows otherwise. Results using zero and nonzero retardation coefficients appear in chapter 5 of volume 1.

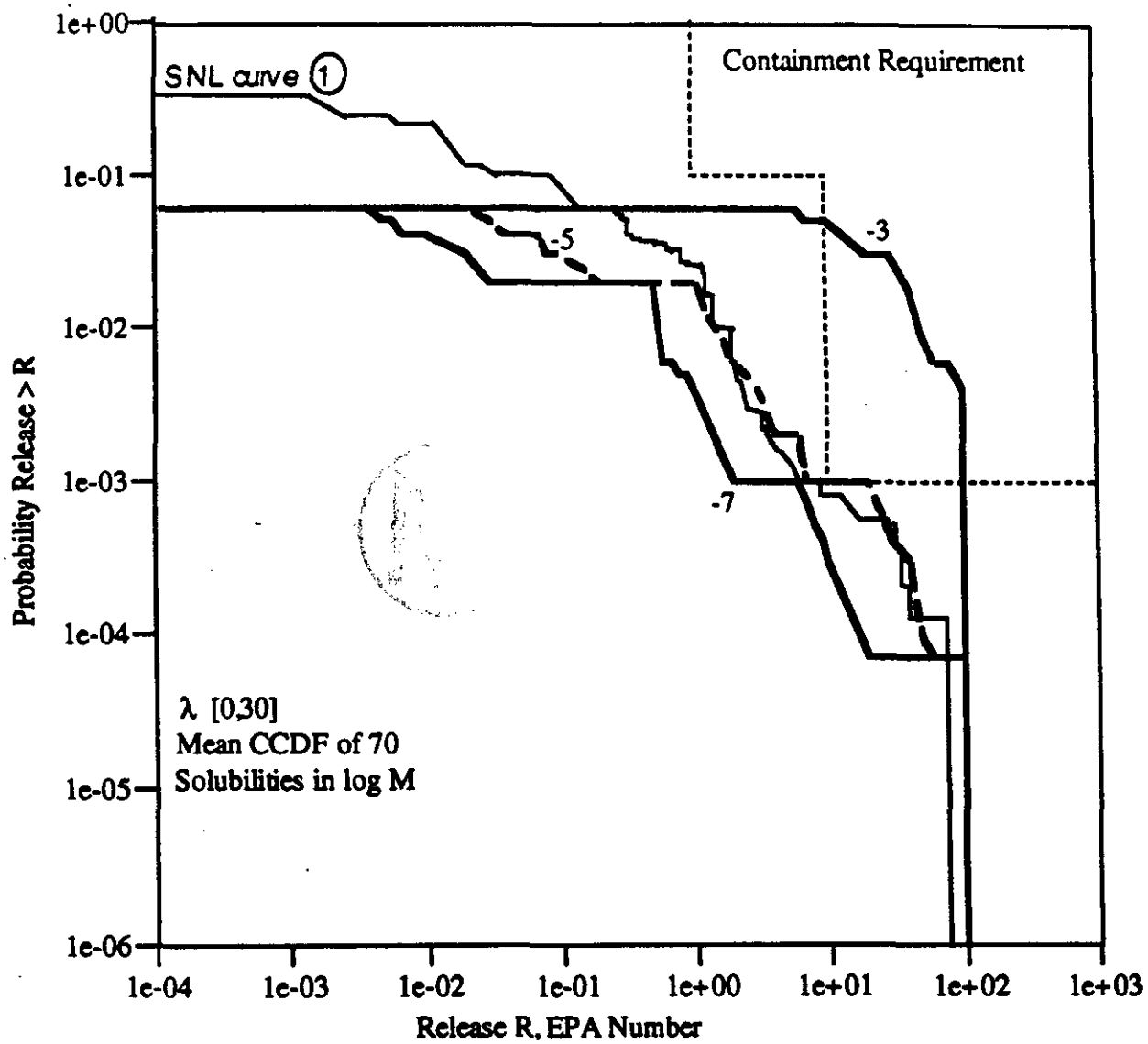

Figure 1. Comparison of mean CCDFs from the EEG scenario of direct ground discharge for all actinide solubilities set at 10^{-3}, 10^{-5}, and 10^{-7} M with Curve 1 from Figure 9-1 of SAND92-0700/4.

Recommendation 3.2. Use only experimental retardation coefficients.

3.3 EEG is concerned about the use of subjective probabilities in human intrusion analysis. While human judgment may be the only method of estimating these probabilities, we disagree with the procedure used in the *1992 Performance Assessment* to estimate human intrusion probabilities.

3.3.1 The disagreement between EEG and SNL centers around how the problem of subjective elicitation is to be formulated, whom to use as panelists and what information should be supplied to the panels. Elicitation should have been for the probability of future human intrusion by drilling for resources, the judges should have been people experienced in oil and gas and energy futures, and factual information should have been given to the judges during orientation.

Table I summaries the divergence.

Table I. Summary of Disagreement on Subjective Elicitation

Topic	SNL	EEG
Problem Formulation	Open	Focused
Required expertise	Knowledgeable in a subject	Knowledgeable in the focused subject
Briefing	Available information	Verified Information

SNL prefers to set no limits on the exercise, whereas EEG believes the problem must be well-defined. The divergence is clear from the SNL definition of an expert:

> An expert possesses exceptional knowledge about **a** subject [Hora to the Futures Panel, August 13, 1990 and to the Marker Panel, November 4, 1991].

EEG claims that the relevant definition should be

> An expert possesses exceptional knowledge about **the** subject.

3.3.2 The probabilities that have been elicited from panels for the purpose of estimating future intrusion intensity (Hora, von Winterfeldt and Trauth, 1991) are subjective probabilities. To call them "expert judgment" is to give them an aura of respectability they do not deserve. The methods for eliciting such probabilities come from statistics (Savage, 1954) and

experimental psychology (Edwards, 1954). There are futurologists, such as Alvin Toffler or John Naisbitt, but the SNL Futures Panel was not composed of these people. While the elicitation of opinions is valid, the elicitation of expert opinion on the future is gratuitous. The WIPP Performance Assessment Department undertook an "extensive and impartial process" to select the panelists, but the process alone did not ensure the appropriateness of the chosen candidates. No attempt appears to have been made to establish the qualifications of the panel members as experts on the future. If the WIPP Performance Assessment Department had defined the problem properly, then it would be much easier to establish the expertise of the panelists.

3.3.3 The WIPP Performance Assessment Department invokes the interdisciplinary nature of an expert judgment panel as a reason to use such a panel. But "interdisciplinary" is not a synonym for "good" or "appropriate" any more than "single disciplinary" is a synonym for "bad" or "inappropriate." The advantage of multidisciplinary data interpretation over interpretation by an expert in a single discipline is not at all clear. For example, the marker panel (Rechard *et al.*, 1993; Table I) lists experts in materials science, architecture, linguistics, communications, etc. How is the judgment of a linguist on materials hardness and durability relevant? Either the linguist accepts the materials scientist's judgment, in which case the interpretation is not interdisciplinary, or the two differ in interpretation, in which case the materials scientist's interpretation is clearly the more valid and that judgment should not be diluted.

3.3.4 In the attempt to find general experts in lieu of futurologists, SNL might have empaneled representatives from diverse backgrounds, but failed to do so. The panels are not representative of modern United States, not representative of the modern world, and not representative of the historical continuity of the human race. While there were historians, sociologists and anthropologists, there was only one woman on the markers panels and none on the futures panels. There are no representatives of indigenous cultures of the southwestern United States.

In the USDOE response to the preliminary comments from the EEG, SNL stated

> The EEG should note, in fairness, that the range of organizations from which the experts were selected (Natural Resources Defense Council, universities, institutions,

etc.) provides rich diversity in political and environmental organizations.

This statement is counter to the claim that panelists were selected on the basis of their individual qualifications.

3.3.5 The elicitation process used was open-ended. While it is true that what will be mined over 10,000 years is unknown, let alone where to mine it, the problem is simpler for a specific area with known minerals. For example the Outer Continental Shelf Lands Act allows oil and gas drilling in the sea beyond the three-mile limit, but includes a clause for "other minerals." When the Outer Continental Shelf Lands Act was first passed in 1953, "other minerals" referred to sulfur. By the mid-1970s the focus of other minerals became construction aggregates around coastal cities, and in the early 1990s, manganese crusts. At a specific location, with geologic information, we know what can be mined now and in the future. The minerals to be mined will change only if society's needs change dramatically. If that had been borne in mind, the problem would have been much more circumscribed, and the results more realistic and reliable.

In the USDOE response to the preliminary comments from the EEG, SNL stated

> This comment [above] proposes that the experts be directed as to what potentially intrusive activities to study. We believe that this is inappropriate and would not stand up under peer review due to extensive direction by the analytic staff.

All elicitations have to be circumscribed, if only to ensure that the problem is within the expertise of the judges. Figure 2 is a reproduction of a SNL viewgraph shown to the panelists, demonstrating how the SNL analysts defined the problem and may have biased the panelists.

3.3.6 Results of the open-ended elicitation process used by Hora (Hora, von Winterfeldt and Trauth, 1991) appear to have been used selectively. If a more circumscribed process had been used, then the methods available to combat cognitive bias (Tversky and Kahneman, 1974) could have been used. Unfortunately, the results used in the *1992 Performance Assessment* strongly reflect the intervention of the analyst. The final result used a form

$$\lambda_t = d(1 - p_1 p_2) \tag{1}$$

where λ is the intrusion intensity, number of holes per time, d is the raw drilling intensity number of holes per time, p_1 is the probability of markers surviving, and p_2 is the probability

How Will the Expert Judgments Be Used in the WIPP Performance Assessment?

- The findings of the expert teams will provide modes of intrusion. These modes will be grouped into similar types of intrusions and modeled.
- The frequencies of intrusion given by the experts will be encoded as rates and used as input to simulation studies.
- The expert judgments will be both analyzed separately and combined into a base case. The analyses will preserve the findings of the individual teams.

Figure 2. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's formulation of the problem.

that surviving markers are effective in deterring drilling, all functions of time. The paradigm was not elicited from any one panel, but the result is a mixture of results from the panelists, who may not have understood how their inputs would be used.

The USDOE response to the preliminary comments from the EEG referred to a SNL viewgraph (Figure 3) entitled "Logic Tree for Deterrence by Markers Given Time, Society, Mode of Intrusion, and Marker Criteria." If one defines each of the branches in Figure 3 as p_1, p_2, p_3 and p_4, then deterrence is

$$p_1 p_2 p_3 p_4 \tag{2}$$

and eq. (1) does not obtain. Eq. (1) does NOT appear anywhere in the hundreds of viewgraphs shown to the Futures and Markers Panels.

An example of the intervention of the analyst occurred when elicited probabilities of the Washington A and B Teams and the Southwest Team for the period 0 to 100 years after closure were ignored. Professor Hora states [vol. 3, p. A-87]

> In contrast, the two Washington teams gave assessment beginning immediately after closure and thus did not allow for the period of continuing administrative control. **The performance assessment, however, assumes that the drilling rate is effectively nil during the first 100 years after closure** [emphasis supplied].

Clearly these three teams would not have agreed with SNL's use of their opinion in meeting the USEPA Standards (USEPA 1993).

3.3.7 A flagrant and important abuse of the analyst-assessor role occurred when the WIPP Performance Assessment Department assumed that there will be no intrusions after 2000 years (vol. 4, p. 2-19, lines 4 and 20). For consequence calculations, the *1992 Performance Assessment* considered only a single intrusion at 1000 years. This is clearly counter to the spirit and letter of analyzing human intrusions for the entire 10000-year regulatory period. If one assumes that the computer program by Professor Hora [vol. 3, p. A-92ff] captures the essence of the Futures and Markers Panels (which we do not) Appendix D of vol. 3 of the *1992 Performance Assessment* contains 12 pages of realizations of drilling intensity functions. The graphs in Appendix D show the intrusion rate and cumulative number of intrusions as a function of time to 10,000 years. Showing these graphs to 10,000 years is misleading because the WIPP Performance Assessment Department discarded the Panels'

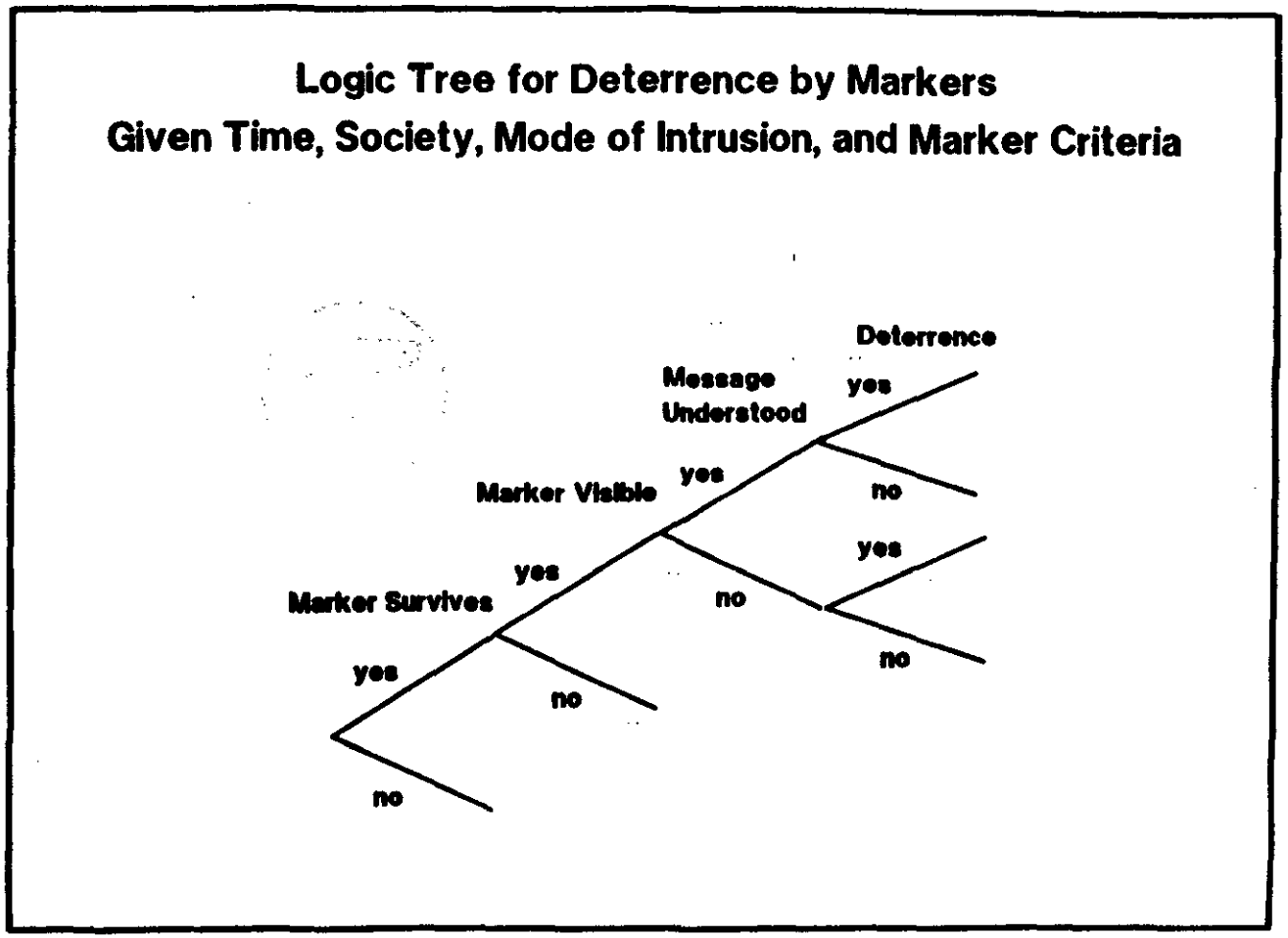

Figure 3. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's concept of the elicitation.

recommendations, assuming the intrusion rate to be zero after 2000 years.

3.3.8 The elicitation process is described in the Hora memo, vol. 3, pp. A-71 through A-99. The memo includes a FORTRAN program to sample among the panels, and produces realizations of intrusion intensities as functions of time for use in the 70 Monte Carlo runs. On page A-94, line 13, a three-dimensional array BOSTAB2 is undimensioned and undefined, thus the program cannot possibly work. In May 1993, EEG requested a working copy of this program, first from Professor Hora, then from WIPP Performance Assessment Department, and finally obtained a copy on December 31, 1993. This program creates Monte Carlo realizations of rates of human intrusion, drawn primarily from Prof. Hora's interpretation of the Futures and Markers Panels.

3.4 EEG suggests a simplified, focused and understandable alternative.

Figure 4 shows what EEG believes the exploratory drilling rate to be in any specific area, and illustrates the evolution of oil and gas drilling as a function of time.

Figure 4 shows a historical record of drilling in this area, a known rate, a holes per area per year, $a > 0$. The U.S. Environmental Protection Agency's guidance (40 *CFR* 141, Appendix C) of thirty boreholes per kilometer^2 over 10,000 years is such a rate.

Giving no credit for passive institutional control, because of recent experience (Silva 1994), we extend the historical drilling rate some time into the future, b years, $b > 0$. Geologic knowledge should be used for this extension. If there is current oil and gas drilling, then it is likely for the exploration and development to continue for some time. If there is no current drilling in this area, then there may not be any drilling until some new mineral is discovered in this area. This extension should extend beyond the period of active institutional control.

Given our present understanding of energy economics, we may postulate a decrease in oil and gas drilling, after a period of time, due to either exhaustion of the resource, or technological developments in some other fuel sources, or both. This decline can be represented by an exponential decay function, $y = y_0 \exp^{-ct}$. The rate of decrease is characterized by a single parameter, c.

For the long-term, there should be a rate of intrusion that is

(a) non-zero; and

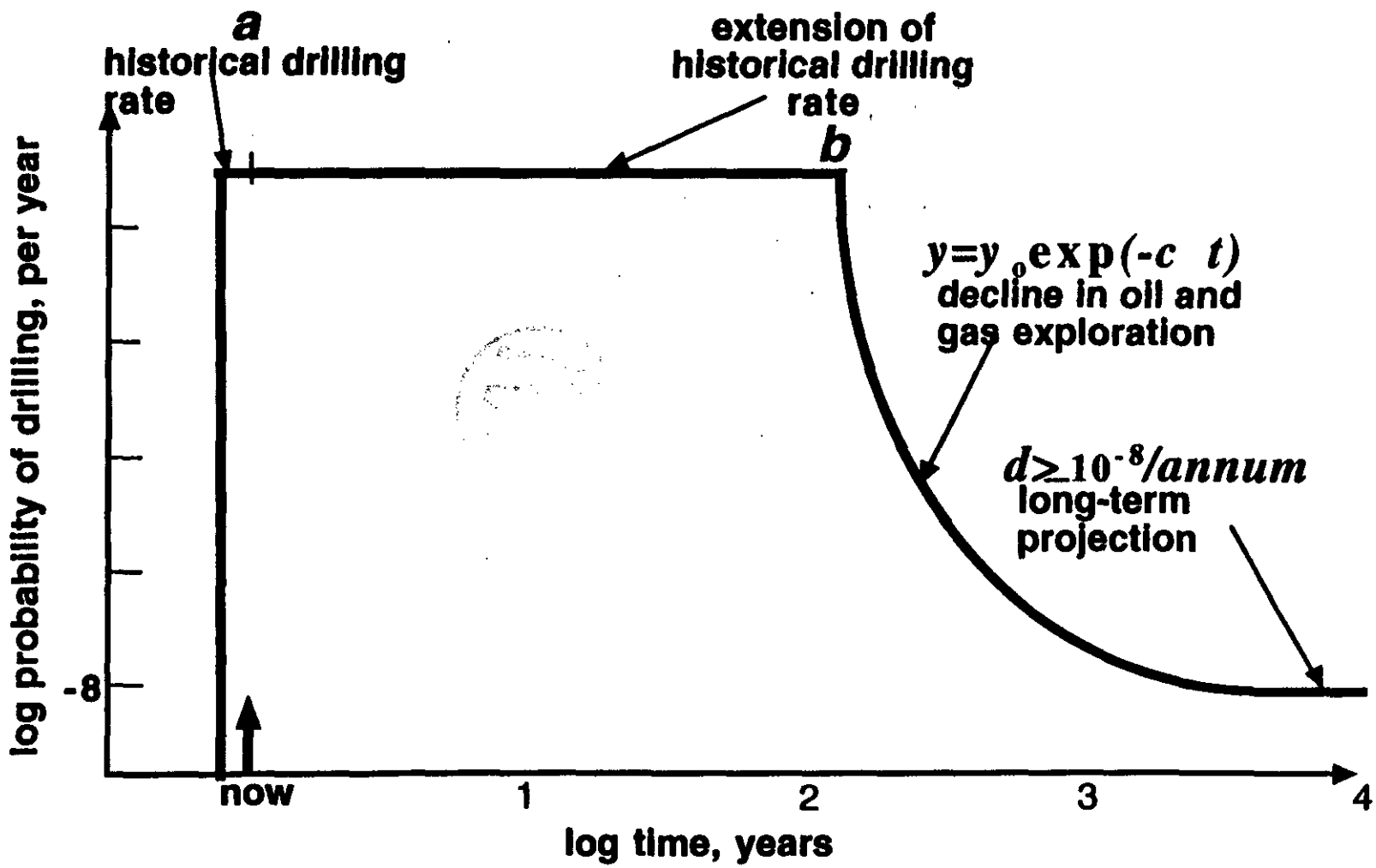

Figure 4. EEG's suggestion for a rate of human intrusion by drilling.

(b) above the USEPA threshold probability for events and scenarios to be considered, or 10^{-8} per year. Call the rate d holes per area per year, $d \geq 10^{-8}$ per year.

Because the waste will not have decayed to harmless levels after 10,000 years, and because the site may still contain resources, the intrusion rate should not be zero for any time within the regulatory period. To ignore such probabilities is to do an incomplete analysis.

The parameters a, b, c, and d completely specify the rate of inadvertent human intrusion in a readily understandable way. Subjective elicitation can now focus on these four parameters. The Department of Energy has experts in the history of oil and gas fields in the Energy Information Administration, and also experts in prospects for solar and other new energy sources.

In the USDOE response to EEG's preliminary comments, SNL stated four principles upon which to object to EEG's suggestion. In brief they are: Avoid Problem Definition, Avoid Bias, Put Rationale Before Results, and Do Elicitation Only on Physical Quantities.

A subjective elicitation requires problem definition. Figure 2 shows SNL's definition before the elicitations. Apparently SNL fitted the results of the elicitation into its preconceived structure. Although the EEG is not free of judgment, it focuses judgment on relevant parameters. SNL should heed its own advice about following USEPA's guidance and limit the elicitation to inadvertent drilling for minerals, without exploring irrelevant intrusion modes.

We will illustrate the bias that SNL imparted to the panelists on the topic of oil and gas resources at WIPP. In the orientations, SNL cited three different studies that there is no economically recoverable oil near WIPP, shown in Figures 5, 6, and 7, augmented by SNL's own conclusion that (Figure 8)

> Crude oil will not be the target for exploration unless the price is drastically higher than the present [1990].

Figure 9 shows the number of oil wells near the WIPP site in October 1993. Table II shows the recent history of wells in the same locations. Figure 9 and Table II belie the suggestion that there is no economically recoverable oil near WIPP. Actually, SNL did tell the panelists about oil and gas production near the WIPP. Figure 10 is a viewgraph shown to the panels by the speaker on cultural resources. That the panelists did not raise questions suggests that

TOTAL MINERAL AND ENERGY RESOURCES
(Brausch and others, 1982)

ESTIMATES ARE FOR ALL FOUR CONTROL ZONES

RESOURCE			
Caliche	185 MT	at surface	Not a reserve
Gypsum	1.3 BT	300-1,500 ft	Not a reserve
Salt	198 BT	500-4,000 ft	Not a reserve
Potash			
Sylvite	133.2 MT	1,600 ft	27.43 MT reserves
Langbeinite	351.0 MT	1,800 ft	48.46 MT reserves
Hydrocarbons			
Crude Oil	37.50 MB	4,000-20,000 ft	Not a reserve
Natural Gas	490 BCF	4,000-20,000 ft	44.62 BCF at 14K ft
Distillate	5.72 MB	4,000-20,000 ft	0.12 MB at 14K ft

Figure 5. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a resource study.

ESTIMATES OF UNDISCOVERED HYDROCARBON RESOURCES--PROVINCE 092 (Mast and others, 1989)

RESOURCE	Mean	F95	F5
Crude Oil			
recoverable	0.02 BB	Negl.	0.05 BB
economically recoverable	0.02 BB	Negl.	0.05 BB
Natural Gas			
recoverable	0.24 TCF	0.05 TCF	0.67 TCF
economically recoverable	0.24 TCF	0.05 TCF	0.67 TCF
Natural-Gas Liquids			
recoverable	0.00	0.00	0.00
economically recoverable	0.00	0.00	0.00

Figure 6. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a second resource study.

GEOLOGICAL CHARACTERIZATION REPORT
(Powers and others, 1978)

POTENTIAL RESOURCES EXAMINED

- Caliche
- Gypsum
- Salt
- Uranium
- Sulfur
- Lithium
- Potash
- Hydrocarbons (crude oil, natural gas)

CONCLUDED

Only potash and natural gas have potential as significant exploitable deposits.

Figure 7. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing the conclusion of a third resource study.

CONCLUSIONS ABOUT THE POTENTIAL FOR ECONOMICALLY IMPORTANT NATURAL RESOURCES AT THE WIPP

1. Crude oil will not be the target for exploration unless the price is drastically higher than at present.
2. Natural gas in the Morrow Formation is the only hydrocarbon of potential economic importance in the area.
3. All currently recognized potash resources are confined to a zone above the waste-filled rooms and drifts.
4. Only the lowest grade of potash ore overlies part of two waste panels.
5. Other resources are present, but because of abundance and greater accessibility elsewhere, these resources at the WIPP are of no economic interest.

Figure 8. Reproduction of a viewgraph shown to the Future and Markers Panels by SNL, showing SNL's conclusion on oil resources near the WIPP.

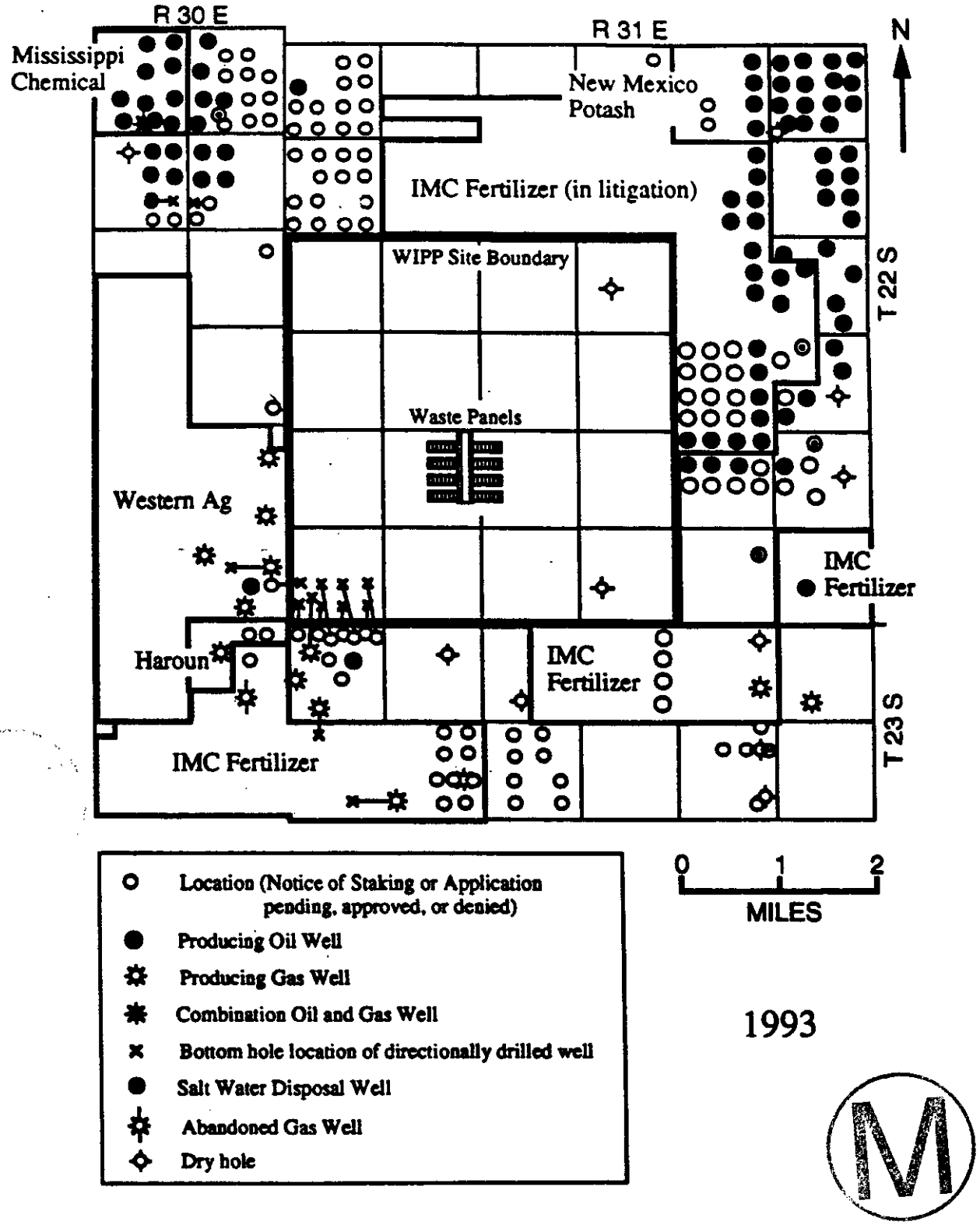

Figure 9. Oil and gas wells near the WIPP, October 1993.

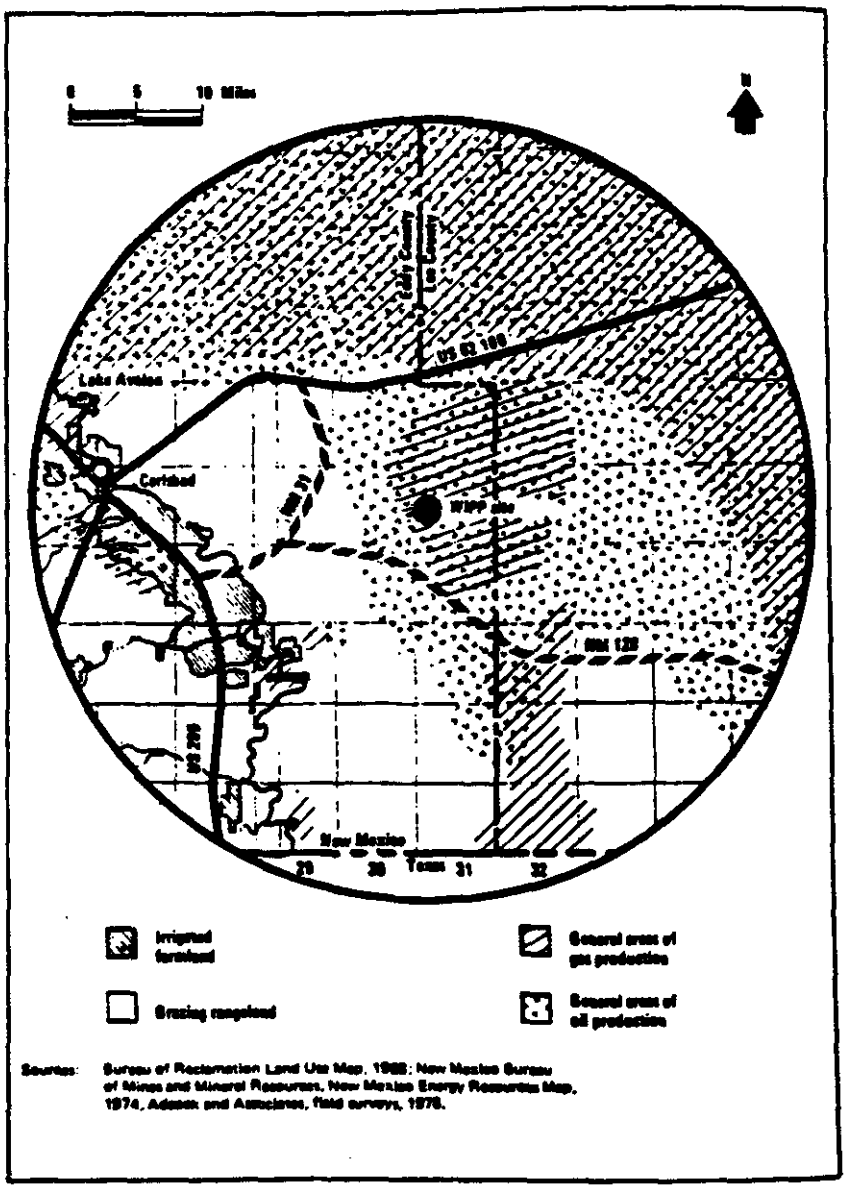

Figure 10. Reproduction of a map shown to the Future and Markers Panels by SNL, showing oil and gas resources near the WIPP.

Table II. Drilling rate for a 124 km^2 area immediately surrounding the WIPP*.

Year	Gas Wells	Oil Wells
1987	0	4
1988	0	2
1989	0	3
1990	0	13
1991	1	37
1992	1	23

*Source: Silva (1994)

SNL was successful in putting bias in the mind of the panelists.

To say that this elicitation puts rationale before numerical results belies the purpose of the effort. The emphasis on rationale may have prompted Prof. Hora to make arbitrary assumptions to obtain numerical results.

> The information for the drilling intensity from the Washington B team indicates that if minerals are extracted in the WIPP region, exploration will occur in the first 200 years or in the next 300 years, but not in both periods. **There does not seem to be adequate information from this team to model with dependence without making arbitrary assumptions**....[Sandia WIPP Performance Assessment Department 1992; vol. 3, p. A-87, emphasis supplied].

To object to elicitation for parameters without physical meaning is a surprise to us. One of the most frequently cited elicitation exercises is on perceived risk (Slovic, Fischhoff and Lichtenstein 1980), in which judges were asked to rank order risks from 40 technologies. The resulting ordinal ranking has no physical meaning. A greater surprise is that SNL would object to eliciting parameters on human intrusion when the entire Future and Markers Panels effort is attempting the same.

3.5 The Effect of Using Subjective Probabilities

We are now in a position to examine the consequences of using subjectively elicited probabilities. EEG has long maintained that a more reasonable conceptual model for intrusion would

include a degrading plug, with the contaminated brine reaching the accessible environment at the ground surface, release Path b in Figure 11. Current oilfield practice in the Delaware Basin is to case the wells down to the top of the salt deposits, preventing contaminated brine from entering the water-bearing zones above the salt. Figure 12 shows CCDFs for the following conditions:

- Brine flow calculated for flow up the borehole, from the *1992 Performance Assessment*;
- Solubilities of all actinides set at 10^{-6} M;
- Intrusion probabilities from subjective elicitation, constant 30 boreholes/km^2/10000 years, or sampled between 0 and 30 boreholes/km^2/10000 years.

Figure 12 shows that if all actinide solubilities are 10^{-6} M, the mean CCDF of 70 would be very close to violating the containment requirement, unless subjective probabilities are used.

Recommendation 3.3. Discard the subjective probabilities for human intrusion used in the *1992 Performance Assessment* and adopt EEG's specific suggestion in Section 3.4.

4. Computer Code Documentation

4.1 The EEG has been concerned about the lack of documentation of computer codes used in the *1992 Performance Assessment*. Of the major codes used in the *1992 Performance Assessment*, as shown in vol. 1, Figure 4-4, only SANCHO and GENII-S have complete documentation. Ironically, no direct results from SANCHO and GENII are shown in the *1992 Performance Assessment*. In response to an EEG inquiry, USDOE provided the following schedule for complete documentation of computer codes shown in Figure 4-4 of vol. 1 (Arthur 1993):

Complete documentation is a requirement of Sandia's own software quality assurance program. For most of the codes shown in Figure 4-4, volume 1, only brief descriptions appear in the *1992 Performance Assessment*, and such descriptions do not present sufficient details for reviewers. As shown in our discussion of human intrusion, it is necessary to review the computational tools at that level of detail. In June 1994, EEG learned that complete documentation of all codes will be available by January 3, 1995.

Technical papers are no substitute for documentation, because technical papers and documentation have different purposes. Documentation is intended to communicate effectively

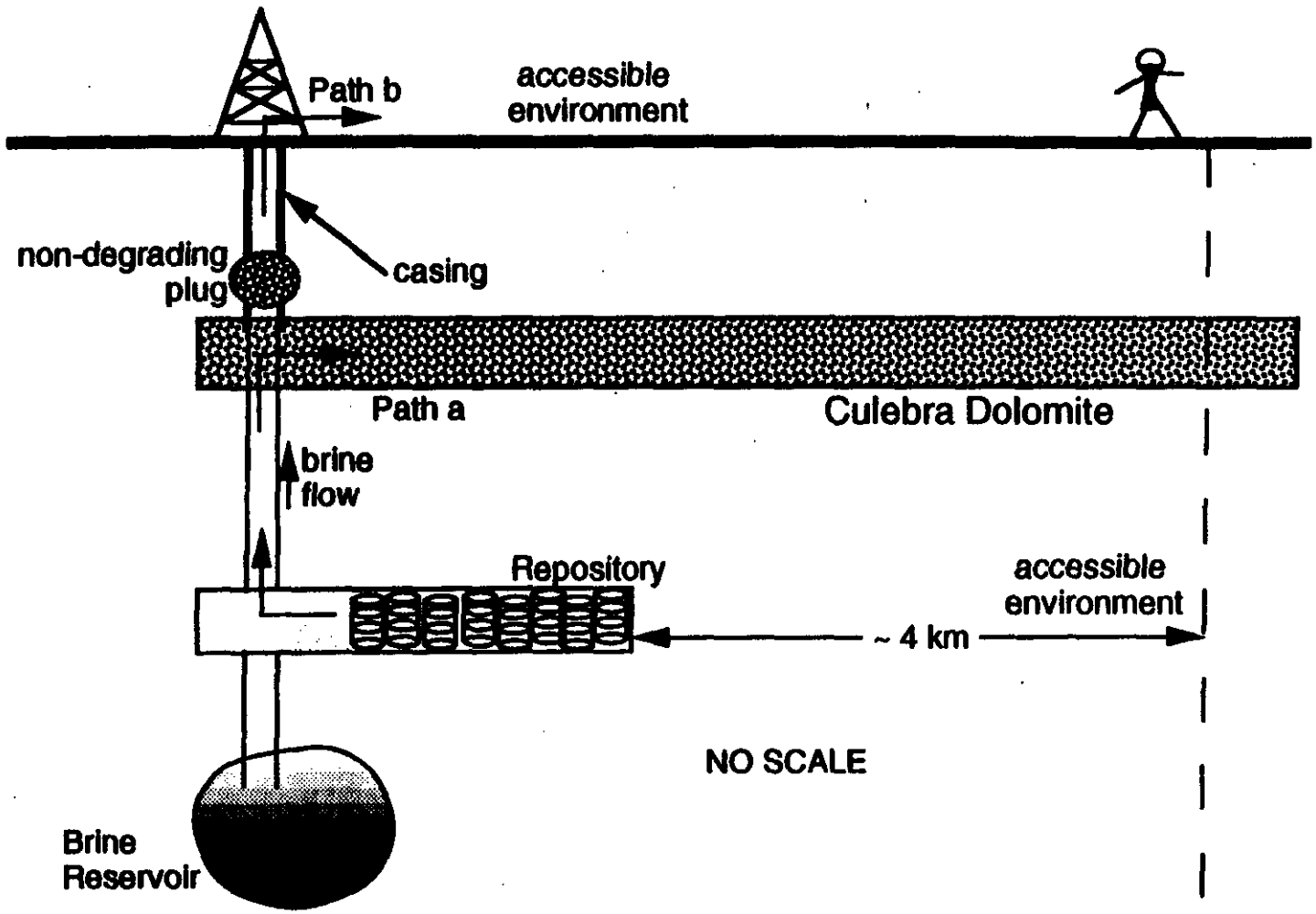

Figure 11. EEG scenario of direct discharge of contaminated brine to ground surface.

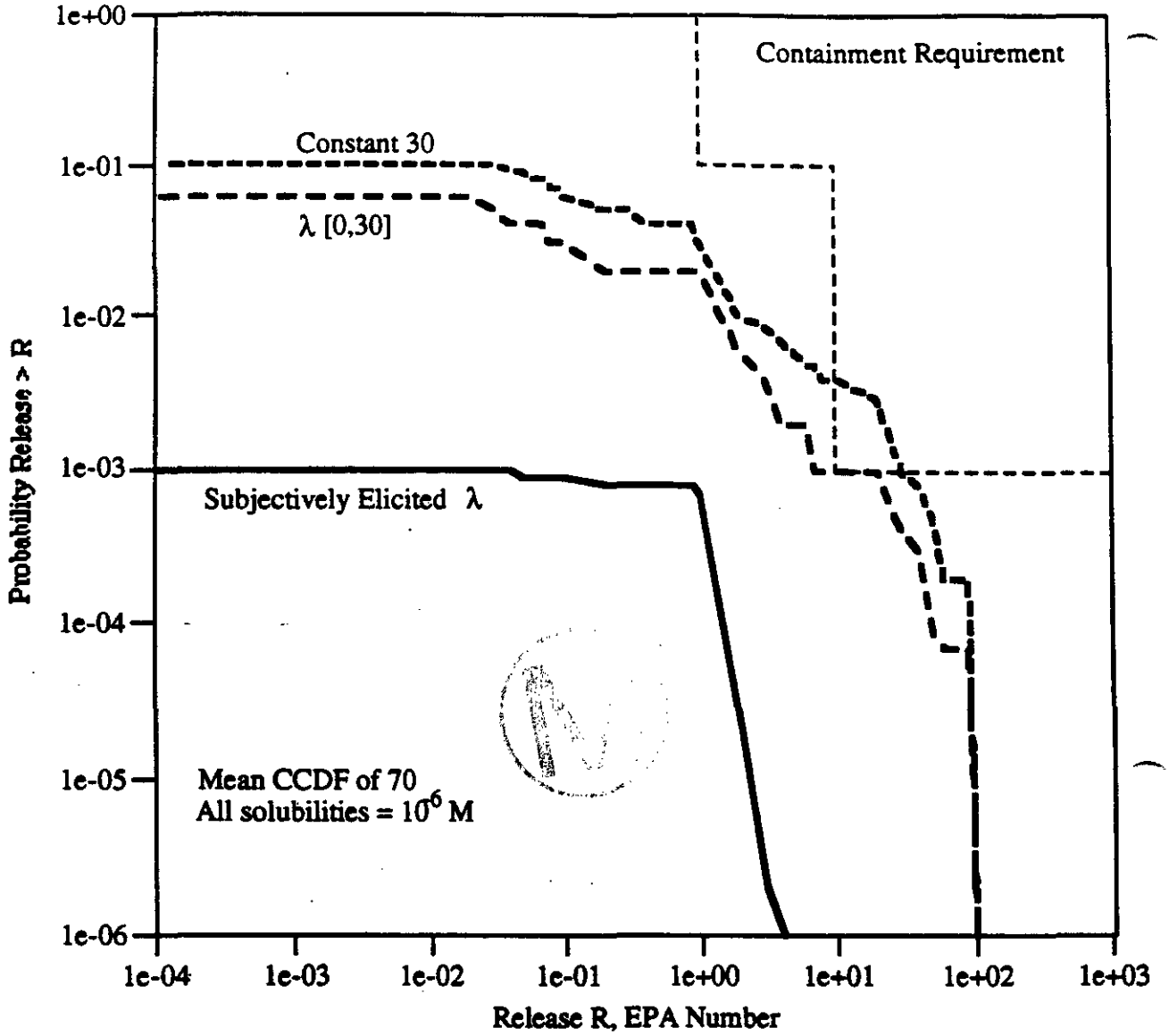

Figure 12. Mean CCDFs from the EEG scenario of direct ground discharge for all actinide solubilities set at 10^{-6} M, using 3 methods of deriving the rate of human intrusion, constant 30 boreholes/km²/10,000 years, uniform sampling between 0 and 30 boreholes/km² /10,000 years, and subjectively elicited probabilites.

Table III. Schedule for Performance Assessment Computer Code Documentation

Code	Aug 9, 93*	Jun 10, 91*
BRAGFLO	DEC 97	Sep 1, 94
CCDFPERM	DEC 94	Dec 1, 94
CUTTINGS	DEC 96	Oct 1, 94
GENII	DEC 96	Jul 1, 94
PANEL	DEC 97	Oct 1, 94
SECOFL2D	DEC 97	Jul 1, 94
SECOTP2D	DEC 97	Jul 1, 94

* Dates of USDOE promise by letter.

the details of the code design and operation so that people with different interests can be convinced of the usefulness and validity of the computer code. Documentation presents the code's logical structure, equations and methods, assumptions and limitations affecting the code's applicability, essential for an effective review.

The brief descriptions in the *1992 Performance Assessment* are inadequate as documentation for the following reasons.

4.2 According to SAND92-0700/3, p. 1-36, PANEL calculates

$$\dot{M}_i = -QC_{di} - \lambda_i M_i + \lambda_{i-1} M_{i-1} \tag{3}$$

where M_i is the mass of the ith nuclide in dissolved form,
Q is the brine flow rate, and
λ is the nuclide's decay constant.

The concentration is calculated

$$C_{di} = \frac{M_i}{\sum_j M_j} S_i, \tag{4}$$

where S_i is the concentration in saturated solution, and this equation calculates the isotopic fraction of solubility over j isotopes.

According to the February 22, 1994 USDOE presentation to USEPA, PANEL actually solves

$$C_{di}(t) = \begin{cases} S_i, & \text{if } I_i(t)/V(t) \geq S_i \\ I_i(t)/V(t), & \text{if } I_i(t)/V(t) < S_i \end{cases} \tag{4a}$$

where $I_i(t)$ is the inventory of element i at time t, and

$V(t)$ is the brine volume in the panel at t. Eq. (4a) incorporates a different concept than eq. (4). This kind of information is needed to fully understand the *1992 Performance Assessment.*

4.3 The transport code SECOTP2D offers the best examples of the need for full documentation. Roache (1993) does not explain how the following important items are handled.

- SECOTP2D is a two-dimensional code. How does it handle the conversion of the source term from zeroth dimension, the solubility, to two dimensions? The source is Qc, where Q is the well injection rate. How is Q determined? Is Qc spread uniformly vertically, uniformly laterally to infinity, making it an infinite line source?

- Two types of matrix diffusion are claimed for the Culebra, in the dolomite and in the clay layer. Is the classic Neretnieks equation for matrix diffusion used for calculating these effects?

- Over the years several codes have been used for the calculation of flow and transport in the Culebra, such as SWIFT, and STAFF2D. Are there benchmarking results?

c. To further demonstrate the inadequacies of technical papers as documentation, the following comments are offered on the Roache paper.

- The paper touts the TVD algorithm but failed to define TVD.

- The algorithm begins with a variable transformation. A key variable J in the transformation is not defined.

- No results are given for verification of the dual porosity option.

Finally, it is often claimed that because a computer code is undergoing continuous development, its documentation cannot be released. This is simply not the case. A calculation done with a computer code is made with a specific version. Subsequent calculations may use the next version. However, for the purpose of documentation, a calculation and the tool (computer code) are inextricably intertwined. For a meaningful review, the code version used and the extant documentation must be made available.

Recommendation 4. Establish a workable system to provide EEG with relevant documentation, so that EEG has reasonable access to perform its work.

5. The Culebra as a Natural Barrier

The *1992 Performance Assessment* elucidates the role of the Culebra as an isolation barrier. Figure 5-6 of vol. 1, claims that WIPP can meet the USEPA's containment requirement (USEPA 1993) without the Culebra as an isolation barrier. That is, if the USEPA containment limit is applied where brine is diverted into the Culebra, WIPP would still be in compliance. With matrix diffusion and sorption, the Culebra would contribute additional isolation.

Recommendation 5. Quantify the extent of matrix diffusion and sorption through accelerated experimentation.

6. Effects of Gas Generation

While the USDOE has analyzed the beneficial effects of gas generation, the EEG continues to be concerned that the deleterious effect of gas generation, particularly the opening of new discharge pathways, has not been analyzed.

Recommendation 6. In future analysis, the deleterious effect of gas generation should be included.

7. Correlation Among Variables

No correlation has been assumed between sampled variables using Latin Hypercube sampling. In real life, many of the variables are related. For example, there is an inverse correlation between VWOOD, the fraction of waste that is wood, and VMETAL, the fraction of waste that is metal.

Recommendation 7. The performance assessment should either give reasons why physical correlations have been ignored, or show results with correlations.

8. Natural Resources Near the WIPP

The *1992 Performance Assessment* is unclear on the extent of natural resources extraction near the WIPP site, and particularly the possible impact of human intrusion. In vol. 1,

Section 2.2 an incorrect statement is made:

> About 56 productive oil and gas wells are located within a radius of 16 km (10 mi) from the WIPP; the wells generally tap Pennsylvanian strata, about 4,200 m (14,000 ft) deep (p.2-4).

This statement is incorrect because there are many more oil and gas wells. The estimate of 56 producing oil and gas wells is based on 1986 data. EEG showed (Silva and Channell, 1992) that some of the 1986 data were incorrect. Furthermore, if the USDOE wishes to take credit for current and accurate public records, then USDOE should have used current information and not obsolete information. Given the importance of drilling for oil and gas on the performance assessment calculations, future iterations should use a more accurate representation of the drilling activity near the WIPP facility. One method of so doing is to show up-to-date and accurate locations of oil and gas wells on a map. Most of the oil and gas wells drilled in the last four years do not tap the deeper Pennsylvanian Formation, but produce from various shallow (1200 to 2400 m) zones within the Delaware Mountain Group Formation.

The statement in the *1992 Performance Assessment* continues:

> The hydrocarbon well closest to the land withdrawal boundary is about 3 km (2 mi) to the south-southwest of the waste panels, and has produced natural gas since 1982 (Silva and Channell, 1992). The surface location of the well is outside the land-withdrawal boundary, but the borehole is slanted to withdraw gas from rocks below the WIPP horizon within the boundary. Except for this well, resource extraction is not allowed within the proposed land-withdrawal boundary (vol. 1, p.2-4).

The 1992 WIPP Land Withdrawal Act recognizes the validity of two specific oil and gas leases in section 31, within the WIPP Site Boundary. The owner of one of these leases has recently filed an application for permits to drill eight directionally drilled oil wells that would be completed within the WIPP Site Boundary but at depths greater than 2,000 m (6,000 ft) to produce oil from within the WIPP Site Boundary. While there was no restriction on drilling within the WIPP Site Boundary contained in the Consultation and Cooperation Agreement between the USDOE and the State of New Mexico, the second modification restricted slant drilling.

The following statement appears in vol. 1, section 3.3.3 (p. 3-10):

> ... the DOE agreed to prohibit further subsurface mining, drilling, slant drilling under the withdrawal area, or resource exploration unrelated to the WIPP Project from the land surface to 6,000 feet (1,830 m) in the subsurface for the 16 square miles under DOE control.

The second modification to the Cooperation & Consultation Agreement has been incorrectly interpreted. The Agreement is not limited to the first 6,000 feet (2,000 m) of depth. The Agreement states "The DOE will not permit subsurface mining, drilling, ..."

Recommendation 8. Performance assessment reports should accurately reflect the status of resource development near the WIPP site.

9. Oil and Gas Production Near the WIPP

In vol. 1, section 5.3.5, the following statement is made regarding the Assurance Requirement (40 *CFR* 191.14) for natural resources:

> Future societies might attempt to exploit natural resources near the WIPP and thereby create the potential for a release of radionuclides into the accessible environment. These issues have been evaluated in several reports (USDOE, 1980, 1981b; USDOE and State of New Mexico, 1981, as modified; Brausch et al., 1982; Weart, 1983; USDOE, 1990a). A recent report summarizes these earlier reports (USDOE, 1991a), and the DOE will continue to document information about natural resources that was used in making the decision to proceed with the WIPP Project (I, p. 5-20).

A detailed reading of the references cited does not appear to support the text.

Silva and Channell (1992) showed that the *USDOE Implementation of the Resource Disincentive Plan in 40 CFR 191.14(e) at the Waste Isolation Pilot Plant* (USDOE, 1991a) is inconsistent in reporting the number of oil and gas leases within the WIPP Site Boundary and the production status of those leases.

The No-Migration Variance Petition (USDOE, 1990a) states:

> Oil and gas exploration has been and continues to occur around the WIPP site. The target horizons for this type of exploration are below the Castile. Oil and

gas exploratory drilling requires permits from the state, and it is unlikely that prospective future well drillers would not be informed about the existence of WIPP. As an additional protective measure, the DOE has purchased all oil and gas leases in the area of the WIPP site to prevent any exploration now and in the future (Section 6.3.2).

The last sentence above is incorrect. Weart (1983), Brausch *et al.* (1982) and Weart *et al.* (1991) failed to recognize the potential crude oil resources for this area. Crude oil is now being produced from the former control zone IV.

Recommendation 9. The performance assessment effort should use the latest and verifiable data on oil and gas production near the WIPP, because the extent of oil and gas resources in this area is likely to be an important determinant of inadvertent human intrusion, and oil and gas production can potentially affect the hydrogeology at and near the WIPP repository.

10. Gas Generation

10.1 BRAGFLO is one of the most important codes in the WIPP performance assessment. A brief summary of BRAGFLO is given in vol. 3, section 1.4.1. Equations 1.4.1-1 and 1.4.1-2 use rate constants and mole fractions (called "stoichiometry factors") to calculate the rate of gas generation. These factors, although not specifically referenced in this section, are referred to in the discussion on pp. 3-44 to 3-45. Median corrosion gas production rates are given as 6.3 $\times 10^{-9}$ moles H_2/m^2-s for inundated steel and 0.1 [-] for humid steel under aerobic conditions, and 0.5 [-] for inundated steel under anoxic conditions. An analogous set of rates are given for microbial gas generation, with units of moles of gas/kg cellulosics given only for inundated conditions. It should be noted that in the development of the equations on pp. 1-24 to 1-26, the rate constants and stoichiometric factors are given with acceptable units. Why aren't the dimensions the same for all these rates, if they are used for the same variable in BRAGFLO? How can a corrosion rate have the units of moles per unit area of exposed substrate in one case and no units in another? How can a dimensionless variable be used interchangeably with a variable with units?

10.2 A more serious question arises about the use of these results. The gas generation rates and stoichiometry factors cited are those calculated by a model and are thus th

result of model inputs rather than experimental data. Table IV summarizes the results of the SNL scientific investigations into gas generation, and distinguishes model calculations from experimental measurements. Model results are only as good as model inputs. Some model inputs include unsupported assumptions, such as the failure to include methane. Experimental data exist - see Table IV- but have not been used in modeling. Moreover, as the Table IV shows, models give different gas generation rates when given different inputs and assumptions, and the median of such calculated rates has little validity.

Although the assumption that radiolysis will contribute only negligible hydrogen formation at WIPP appears to have found general acceptance, the data developed by Kosiewicz (1981) show this need not be the case. In fact, the gas generation problem was first noticed in stored drums of TRU waste in which hydrogen had been generated by radiolysis. Moreover, the microbial generation model does not recognize the dependence of the microbial gas generation rate on the initial and continued presence and availability of microbes. Radiolysis can be the principal source of gas from Pu-238 heat source waste.

Recommendation 10a. The gas generation calculations should include

(a) methane generation,

(b) radiolytically generated hydrogen.

Recommendation 10b. The relationships in the gas generation model should be validated before the gas generation model is incorporated into BRAGFLO.

11. Unanalyzed Scenarios

As Helton (1993) so aptly pointed out, the formulation of scenarios is an integral part of performance assessment. There are a number of assumptions used in the human intrusion scenarios to date that EEG believes need to be reconsidered and either changed or better justified. These have all been related to USDOE in previous written comments and discussed in meetings. For completeness of the record, all significant items are mentioned below.

Some scenarios not currently analyzed in performance assessment need to be considered. See especially the lower half of Figure 4-1 (vol. 2) in the *1992 Performance Assessment.*

Table IV. Gas Generation as Modeled and Tested

	Source	Gas From	Result moles/drum/a	Gas from 1050 drums in an alcove (moles/a)	Pressure P_0 (atm)	$P = nRT/V$ per annum (atm)	Gas Pressure at end of year one $P_1 = P_0 + P$
H_2	Brush *et al.*, (1993)	anoxic corrosion	2.0	2,100	1.0	0.0568	1.06
Total gas	Brush *et al.*, (1993)	microbio. deg.	1.0	1,050	1.0	0.0284	1.03
H_2 - 3 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.97×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 6 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.72×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 12 mos.	Brush *et al.*, (1993)	anoxic corrosion	1.23×10^{-6}	0.0	1.0	0.0	1.0
H_2 - 24 mos.	Brush *et al.*, (1993)	anoxic corrosion	9.9×10^{-7}	0.0	1.0	0.0	1.0
Total gas	Brush *et al.*, (1993)	aerobic microbes	0.5	525	1.0	0.0142	1.01
Total gas	Brush *et al.*, (1993)	anaerobic microbes	1.21	1271	1.0	0.0343	1.03
Total gas	Bixler (1989)		0.3	315	1.0	0.0085	1.01
Total gas	Molecke & Lappin (1990)	Calculated	0.05	52.5	1.0	0.0014	1.00
			0.5	525	1.0	0.06	1.06
			5.0	5,250	1.0	0.59	1.59
Total gas	Kosiewicz (1980)	radiolysis	0.3	315	1.0	0.04	1.04
			0.11	770	1.0	0.01	1.01
			0.016	115	1.0	0.0031	1.00

11.1 A Scenario Involving Nuclear Criticality

In 1984 S. Cohen, an EEG consultant, analyzed potential nuclear criticality in the Culebra Aquifer and concluded that this needed to be thoroughly evaluated by USDOE.

The potential nuclear criticality could occur if:

(1) sufficient quantities of a fissile radionuclide such as Pu-239 or U-233 are adsorbed on a large enough volume of aquifer matrix;

(2) there is sufficient hydrogen or other moderator available in the brine or matrix;

(3) the matrix or brine does not contain sufficient quantities of stable nuclides that can "poison" the reaction.

EEG's analysis indicated that, with the expected elemental composition of the brine and the Culebra aquifer matrix, nuclear criticality could occur in a block 7 m high x 0.5 m wide x 1 m long if the product of the distribution coefficient (K_d, mL/g) and plutonium solubility (S, moles/L) was greater than about 5.6×10^{-5} moles/g.

The possibility of a K_dS product of $> 5.6 \times 10^{-5}$ moles/g is credible. For example, the probability distributions for K_d and solubility from volume 3 of SAND 91-0893 (pages 2-104 and 3-64) have approximate probabilities of occurrence given in Table V.

Table V. Probabilities of Criticality From Sorbed Fissionable Species

Species	Probability $K_dS > 5.6 \times 10^{-5}$ moles/g
Pu^{5+}	0.025
Pu^{4+}	5×10^{-6}
U^{6+}	0.25
U^{4+}	0.11

In response to EEG's comments on the *1990 Preliminary Comparison*, SNL responded that

> A performance assessment task has been initiated to examine the potential for nuclear criticality from post closure processes.

Two pages were devoted to discussing nuclear criticality in the *1991 Preliminary Comparison* (vol. 1, page 4-52). SNL recognized that sorption can also occur in the backfill and at certain components of the seal system as well as in the Culebra Aquifer. The very remote possibility

of a high-yield nuclear explosion is also discussed. We find no analysis of nuclear criticality in the *1992 Performance Assessment*. No schedule has been given for performing additional criticality evaluations.

EEG also believes the possibility of a high-yield nuclear explosion is very remote. One concern is with an instantaneous criticality excursion in which there is a brief burst of energy, neutrons, and gamma radiation. Perhaps more likely in this situation, where fissile material is being added very slowly in a solution, is a delayed criticality where the system does not become promptly critical. Such a system would behave much like a nuclear reactor and could produce fissions, perhaps in bursts, for extended periods of time. This phenomenon has occurred in several process criticality accidents in the U.S., e.g. at Hanford in 1962 one system boiled for 37 hours (Thomas 1978). The Oklo "natural reactor" in Gabon is believed to have operated in a similar fashion.

It is not obvious that a criticality accident would have a significant effect on a repository waste disposal system, even if a criticality accident occurs. Considerable heat would be produced, some brine would be vaporized, and minor amounts of fission products would be formed. It takes 8×10^{20} fissions to produce one curie of Cs-137. Also, the relatively high K_d values that would be necessary to make criticality possible are otherwise a benefit because they retard radionuclide transport.

Recommendation 11.1 The criticality issue needs to be thoroughly evaluated before it can be concluded that its effects are negligible.

11.2 Subsidence

Subsidence could occur in the area overlying the WIPP some time after repository decommissioning. Subsidence can also occur from nearby potash mining. The *1992 Performance Assessment* identifies an event **TS** which is subsidence from mining of potash, but **TS** has not been analyzed.

SNL discussed the potential for subsidence in the *1990 Preliminary Comparison*. They recognized that "subsidence could in turn conceivably affect the disposal system in three ways: by increasing hydraulic conductivity of the Salado Formation, by creating fractures through the Salado Formation, or by disturbing the surface drainage and groundwater flow in overlying units." The incorporation of the effects of subsidence into the performance

assessment is still planned. In the *1991 Preliminary Comparison* SNL presented an analysis of possible caving and subsidence over the waste storage areas from room closure.

SNL's analysis of subsidence concluded that no problems were likely to result for the waste disposal system. The maximum subsidence at the surface was calculated to be only 0.13 meter over an area of 1.54×10^6 m^2. The affected area at the surface was determined by assuming an angle of draw of 35°. It was further stated that if the Rustler-Salado contact residuum had (historically) lost about 400 meters due to dissolution without disrupting the confined water-producing Culebra and Magenta dolomite aquifers, subsidence should not be a problem.

No evaluation has yet been made of subsidence from potash mining. There are significant potash resources within the WIPP site boundary. However, the USEPA Standards requires analysis of only resource exploration drilling on site. However, it is appropriate to consider subsidence effects from potash mining offsite.

Offsite potash mining is highly probable. There are reserves on all sides of the site. Sections to the south of the site are already leased, sections to the north and east are under litigation for potash leases, and the entire western border is leased or expected to be leased. Because the areas leased or expected to be leased to the north and south include the flow path of the Culebra Aquifer across the waste storage area, a potential exists for both upstream and downstream effects on the Culebra. Catchment areas could be formed to the north from subsidence and shafts could provide access to the Culebra for recharge. To the south there could be increased transmissivity from subsidence effects. With the assumption that mining occurs up to the site boundary and the angle of draw is 35° the extent of influence at the Culebra Aquifer horizon would be about 200 meters onto the site. Another possibility is that mining activity near the South Boundary could result in vertical drainage (via shafts or boreholes) from the Culebra Aquifer into underlying mined out areas. This could significantly increase the hydraulic gradient between the injection point of contaminated brine and the site boundary.

Recommendation 11.2 Subsidence effects need to be evaluated in much more detail and incorporated, in some manner, into the human intrusion scenarios. Some scenarios currently analyzed in performance assessment should be re-formulated.

11.3 Contaminated Brine Flows to the Surface

The E1, E2 and E1E2 scenarios assume that the only material reaching the surface is drill-bit cuttings and some "cavings" from the annulus about the drill bit in the waste storage room. Brine flowing to the surface from an encounter with a pressurized Castile brine reservoir was not assumed. EEG believes that brine flows to the surface should be assumed and that the consequences could be significant for the E1E2 scenario.

Sandia and USDOE have described typical drilling practices elsewhere (Appendix C of SAND 89-0462 and in USDOE February 7, 1990 response to EEG's comments on the Draft Supplement EIS). These responses explain how it is possible to have very little flow to the surface by closing in blow-out preventers within a few minutes, determining the pressure, and then preparing drilling mud of sufficient density to stop the flow before resuming drilling. For example, USDOE stated in a February 7, 1990 letter that only 51 barrels flowed at WIPP-12 before shut in by a blow-out preventer.

The February 7, 1990 USDOE letter went on to say that at WIPP-12 an additional 49,224 barrels flowed during deepening, geophysical logging, and further deepening before it was finally shut in for subsequent hydrologic testing. This additional flow was described as resulting from a "conscious decision."

Virtually every time a pressurized Castile brine reservoir was encountered in the vicinity of WIPP, "conscious decisions" were made to allow varying amounts of brine to flow to the surface. Table VI, extracted from two WIPP reports (USDOE 1981a; 1983), describes the remedial measures taken. Although the available data are not as detailed or as quantitative as one would like, it is clear that drilling practice through 1982 included release of brine at the surface whenever pressurized Castile brine reservoirs were encountered. There has been considerable drilling activity around the WIPP Site in the last few years, and brine has been reported in seven wells. In two of these wells brine was reported to have flowed for three hours before being stopped, and in another, brine flowed for at least 12 hours. Records did not indicate how long the remaining wells flowed. It appears that, in most cases, significant amounts of brine flow to the surface before being controlled and performance assessment scenarios should assume that any intruding driller will face similar situations. Also, minor flows may not always be recorded in drilling logs, or perhaps even recognized. Furthermore, it is likely that not all Castile brine encounters have been reported.

Drilling mud return flow would be expected to increase the effective radius of the borehole and bring waste to the surface in suspension and in solution. In the E1E2 scenario brine discharged to the ground surface is expected to be saturated in actinides.

In a November 3, 1992 response to EEG's concern about contaminated brine flow to the surface, SNL stated:

> We will repeat these subsidiary simulations using BRAGFLO for both release during drilling and long-term releases through abandoned boreholes. As you suggested at our previous meeting, there are four cases: (1) E1 or E2 during drilling, (2) E1 while Castile brine is allowed to flow, (3) E1 followed by E2 after Castile brine has been allowed to flow into the panel and then is available to flow through E2 during drilling, and (4) E1E2 after both have been abandoned.

EEG, in a November 9, 1992, letter to SNL, agreed these 4 cases were the appropriate ones to consider and urged SNL to perform the analysis.

Recommendation 11.3 Provide results of the abovementioned analyses, and include contaminated brine flow to the ground surface in future versions of human intrusion scenarios.

11.4 A Brine-Slurry Release Scenario

A brine-slurry release scenario should be analyzed. A brine slurry might result from brine inflow from the Salado salt or intrusion into a Castile brine reservoir. Such a brine slurry could be under greater than hydrostatic pressure and thus have a force capable of driving some or all of the slurry to the ground surface. The potential quantities of ejected brine might be less than that from the E1 scenario but the consequences could still be significant. The possible implications of a brine-slurry filled room were first raised by SNL in 1987 and were also evaluated in 1988 by EEG (Chaturvedi, Channell and Chapman, 1988).

SNL has responded that all evidence indicates that the possibility of a brine slurry existing in a waste storage room is essentially zero and can be ignored (SAND91-0893, vol. 1, Appendix B). Lappin *et al.* (1989) and the Final Supplemental Environmental Impact Statement (USDOE, 1990b) are cited as support for this conclusion.

The brine-slurry release scenario is related to undisturbed performance and cuttings release. Actually a similar, though probably less serious, release is considered in undisturbed perfor-

Table VI. Castile brine reservoir interactions in the WIPP area

Name of Well	Drilled	Initial Flow (bbl/day)	Remedial Action
Mascho-1	1937	8,000	No action to stop flow.
Mascho-2	1938	3,000	No action to stop flow.
Culbertson-1	1945		3,000 barrels estimated to flow to surface. No record of flow rate or duration.
Tidewater	1962	?	12 pound/gallon drilling mud did not stop. Finally controled by casing and cementing.
Shell	1964	20,000	Allowed to flow until artesian flow ceased.
Belco	1974	12,000	Brine flowed to surface for 26 hours with 14 pound/gallon drilling mud.
Gulf	1975	5,000	No records on total volume or duration of artesian flow.
ERDA-6	1975	660	WIPP hole. Estimate 19,000 barrels could be produced by artesian flow.
Pogo	1979	1,440	Initial flow was after 14.6 pound per gallon drilling mud had been added. Stopped after 4 days with 15 pound per gallon mud.
WIPP-12	1981	12,000	WIPP borehole. Over 79,000 barrels produced. Estimate 350,000 bbls producible by artesian flow.

Table VI Sources

- U.S. Department of Energy, 1981a. ***Brine Pocket Occurrences in the Castile Formation, Southeastern New Mexico,*** TME-3080.
- U.S. Department of Energy, 1983. ***Brine Reservoirs in the Castile Formation, Southeastern New Mexico,*** TME-3153.
- R. H. Neill ***et al.***, 1983. ***Evaluation of the Suitability of the WIPP Site.*** EEG-23.

mance when the waste storage room became partially or fully saturated only in the lower portion of the room. An effect of partial saturation and incomplete consolidation of the waste could be to lower the shear strength and result in greater quantities of waste being brought to the surface than calculated with the current cuttings model (E2) assumptions.

Recommendation 11.4 Perform a complete analysis of the brine-slurry release scenario. In addition, variants of the brine-slurry scenario in undisturbed performance and in the E2 scenario need to be better understood.

11.5 Borehole Seals

The USEPA Standards requires human intrusion analysis that would create

> ... a ground water flow path with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open borehole over time... not the permeability of a carefully sealed borehole (40 *CFR* 191, Appendix C).

In the 1991 and 1992 *Performance Assessments* the resultant permeability of human intrusion boreholes was sampled lognormally between 10^{-11} m^2 and 10^{-14} m^2. This value was obtained from Table 2.2 of Freeze and Cherry (1979) for silty sand. The choice of silty sand is SNL's interpretation of USEPA guidance on borehole sealing cited above.

EEG has several problems with the SNL interpretation. Table 2.2 in Freeze and Cherry (1979) shows a permeability range for silty sand from about 8×10^{-11} m^2 to 8×10^{-15} m^2. The same table also shows ranges of 10^{-9} m^2 to 2×10^{-13} m^2 for clean sand and 10^{-7} m^2 to 10^{-10} m^2 for gravel. It appears that a strict following of the USEPA Guidance would require use of higher permeabilities, to include gravel in the borehole.

EEG believes that the assumption of borehole permeability described in the USEPA Standards is reasonable when considered along with the other assumptions in the guidance, but is not conservative in light of observed borehole sealing practices in the Delaware Basin. In 1989 the Bureau of Land Management found 6,527 shut-in and temporarily abandoned wells in New Mexico (USBLM, 1989). A temporarily abandoned well is simply abandoned, without plugging and sealing. The USBLM made the following statement about wells in the Carlsbad area:

> At Carlsbad, we reviewed the status of 2 shut-in and 11 temporarily abandoned

wells on a 15-well lease. These wells had been classified as shut-in or temporarily abandoned since the late 1960s without approval. There was no evidence these wells had been properly tested to ensure they were capable of producing oil or gas and properly classified. The operator of this lease stated that he did not perform well integrity tests because he estimated that it would cost about $2,000 per well. Additionally, he stated that he did not permanently plug wells because that would cost about $10,000 per well (USBLM, 1989).

Recommendation 11.5 Performance Assessment should not assume perfect plugging of abandoned oil and gas wells near the WIPP. For the human intrusion borehole, the range of degraded permeabilities should span sand and gravel.

12. Analysis of Direct Discharge to the Ground Surface

12.1 In the *1992 Performance Assessment*, the program CUTTINGS analyzes steady-state cuttings releases (Table VII) to the ground surface for the following processes

Table VII. Domain of the CUTTINGS program.

Laminar Flow		Turbulent Flow		Sediment-
Axial	Helical	Axial	Helical	Laden
Yes	Yes	Yes	No	No

EEG has examined the initial Reynolds numbers in the 70 vectors of CUTTINGS analysis for the *1992 Performance Assessment.* The distribution of these initial Reynolds numbers is shown in Figure 13. The mean of these initial Reynolds numbers is 7334 and the standard deviation is 87. These initial Reynolds numbers are well above the range for laminar flow. The analysis for erosion by laminar flow may be elegant, but it appears to be irrelevant. The exclusion of erosion by helical turbulent flow and the effect of sediment erosion is non-conservative.

12.2 In the *1992 Performance Assessment*, the program CUTTINGS analyzes only the E2 scenario. The E1E2 scenario was not analyzed. This was not stated in the *1992 Performance Assessment.*

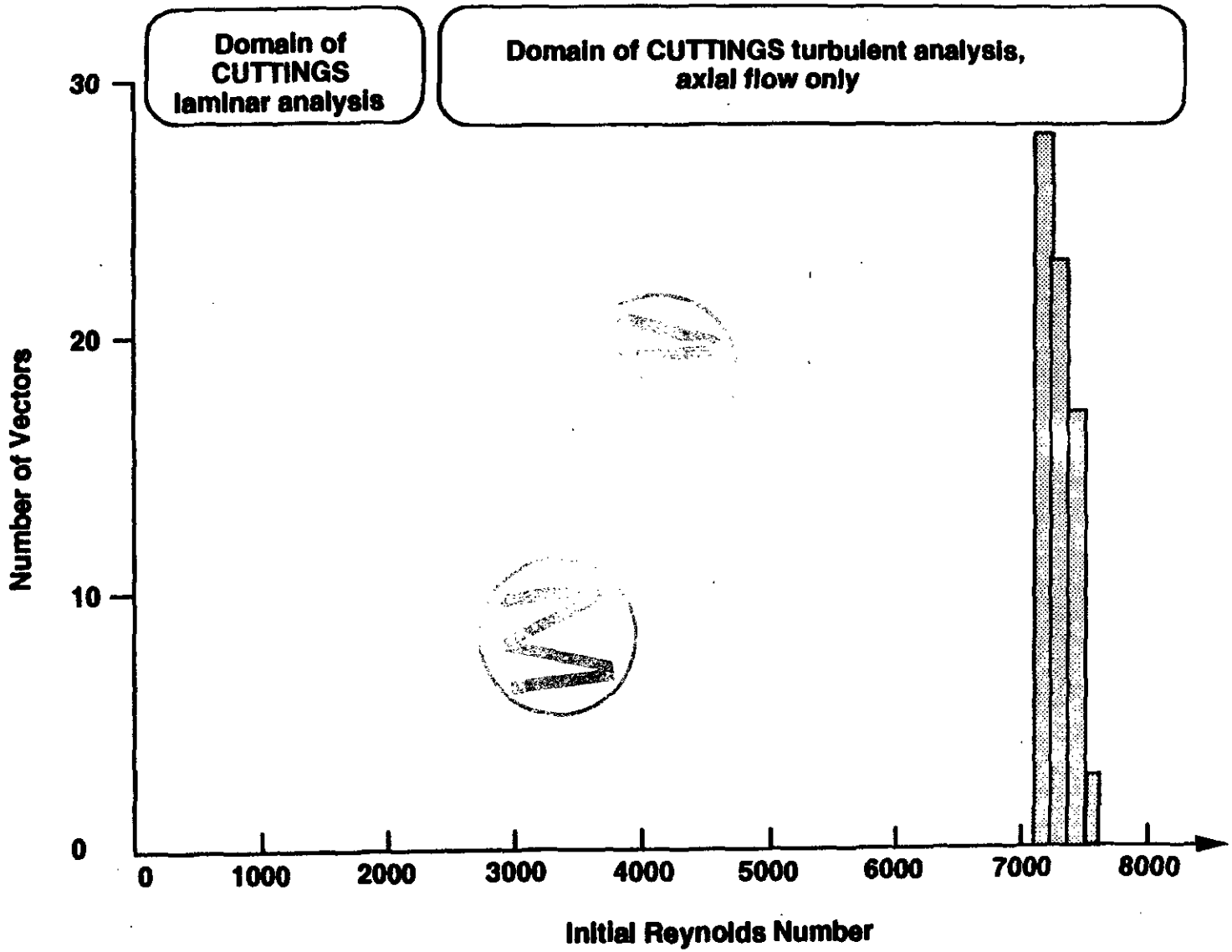

Figure 13. Distribution of initial Reynolds numbers in CUTTINGS vectors.

Recommendation 12. Future performance assessments need to include erosion of waste by helical turbulent flow and the effect of sediment erosion. Also needed is analysis of other relevant scenarios, such as E1E2 and brine slurry discharge to the surface.

13. Inventory

13.1 The radionuclides included in consequences analysis included only actinides plus ^{90}Sr, ^{137}Cs and ^{147}Pm. Missing notably are ^{135}Cs, ^{129}I and ^{99}Tc which are the most important nuclides in most other total system performance assessments. Inventories of these nuclides are available.

13.2 The *1992 Performance Assessment* used five activity levels for contact-handled TRU waste. The cited source is a SNL internal memo by Peterson [vol. 3, Appendix A, pp. A-135-140]. It is not possible to reproduce the results. Using data from input to the 1991 *Integrated Data Base*, (USDOE 1991b), we compare our results for categorizing contact-handled standard waste boxes against Peterson's in Figure 14. It is obvious the two do not match. SNL needs to explain how the results were obtained. The memo by Peterson was dated October 28, 1992, well after most of the computations for the *1992 Performance Assessment* had been completed. SNL should explain what inventory was actually used in calculations.

13.3 The inventory used in the *1992 Performance Assessment* is to be detailed in a report in preparation by Peterson. As of June 30, 1994, that report has not been published.

Recommendation 13.1 Include ^{135}Cs, ^{129}I and ^{99}Tc and other fission product nuclides as appropriate in future performance assessments.

Recommendation 13.2 Show the basis for inventories used.

14. Solubilities

Sandia calculates the flux of radionuclides from the waste by [vol. 3, p. 1-36]

$$\dot{M}_i = -QC_{di} - \gamma_i M_i + \gamma_{i-1} M_{i-1} \tag{3}$$

where M_i is the mass of the ith nuclide in dissolved form,
C_{di} is the dissolved concentration of the ith nuclide,

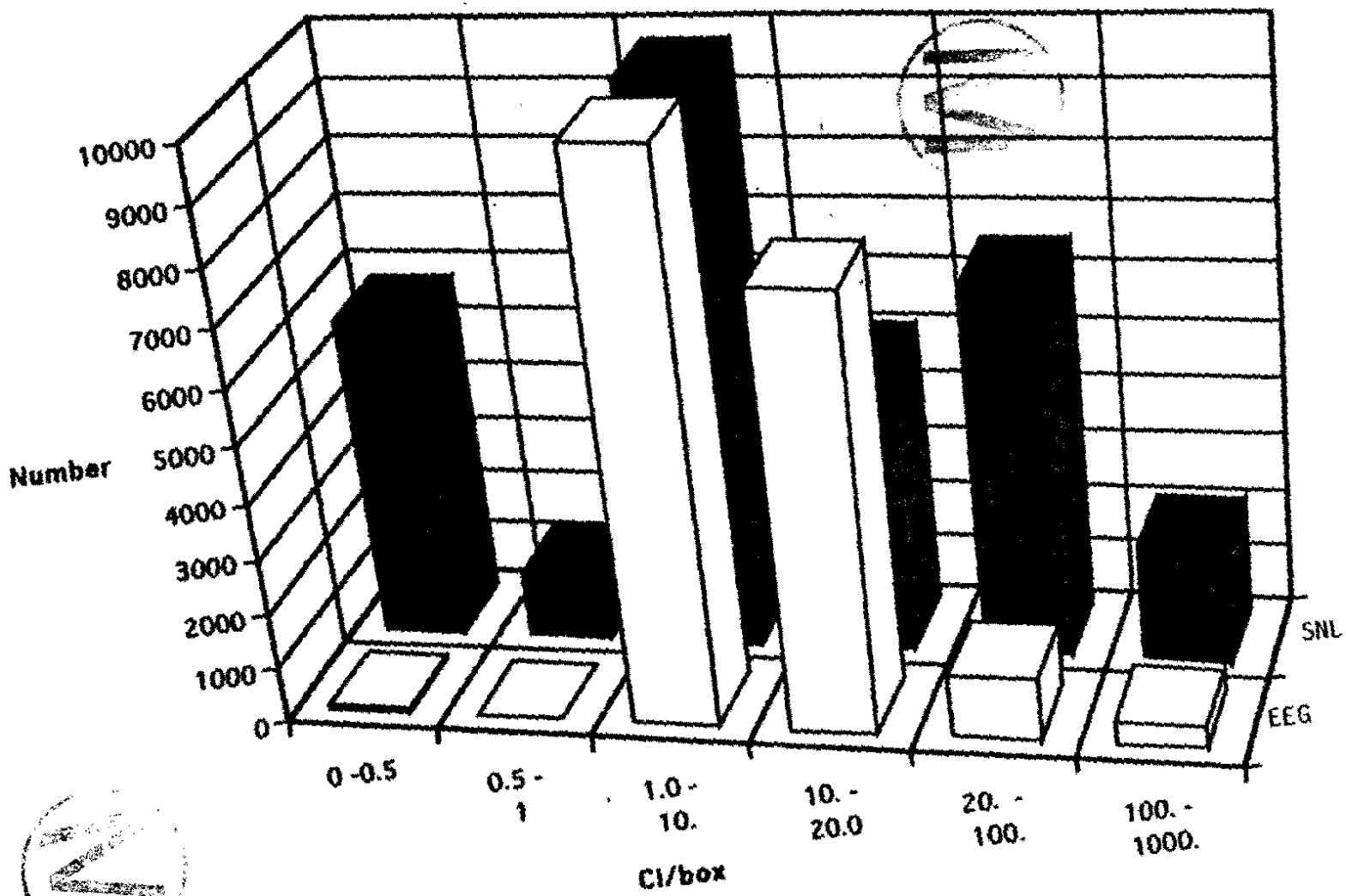

Figure 14. Radioactivity levels in standard waste boxes calculated by EEG and SNL.

Q is the brine flow rate, and

γ is the nuclide's decay constant.

The concentration is calculated as

$$C_{di} = \frac{M_i}{\sum_j M_j} S_i \tag{4}$$

where S_i is the concentration in saturated solution, and this equation calculates the isotopic fraction of solubility over j isotopes.

From these equations, it is clear that solubility would be an important parameter in the calculation of consequences.

Experimentally measured solubility should be used in eq. (4), but few relevant measured actinide solubilities exists. Geochemical calculations, using either experimental or estimated stability constants, could be used. In the *1992 Performance Assessment*, Sandia used neither of these approaches. Instead Sandia used subjective elicitation. A panel of outsider scientists was asked to make estimates. The resultant estimates span a wide range. For instance, the estimated plutonium solubility spans 12 orders of magnitude.

When these wide, subjective estimates are used in Latin Hypercube Sampling of input values, non-conservative solubilities in consequence calculations may result. We shall examine the case for plutonium. In the *1992 Performance Assessment*, the sampling range for plutonium solubility was 5.5×10^{-4} mole/L to 2.5×10^{-17} M [vol. 3, p. 3-40], based on subjective elicitation, as shown in Figure 15. The black circle is the median and the open circle is the mean of the elicited distribution.

Solubility measurements are available at WIPP for Culebra water from the air intake shaft (Nitsche *et al.*, 1992), and for Brine A, a simulant of brine expected to inundate the repository (Nitsche *et al.*, 1993). Nitsche's solubility measurement experiments lasted several hundred days, and were started with various oxidation states of plutonium. Results are also shown in Figure 15. For the various initial oxidation states the steady-state concentration estimates are plotted, assuming the results are normally distributed, and the 25 and 75 percentiles are the edges of the boxes or ends of the arrows. The experimentally measured solubilities are generally greater than 10^{-7} M. However, when one examines the values of plutonium solubilities used in the 70 realizations in the Monte Carlo analysis [vol. 4, p. C-10], one find

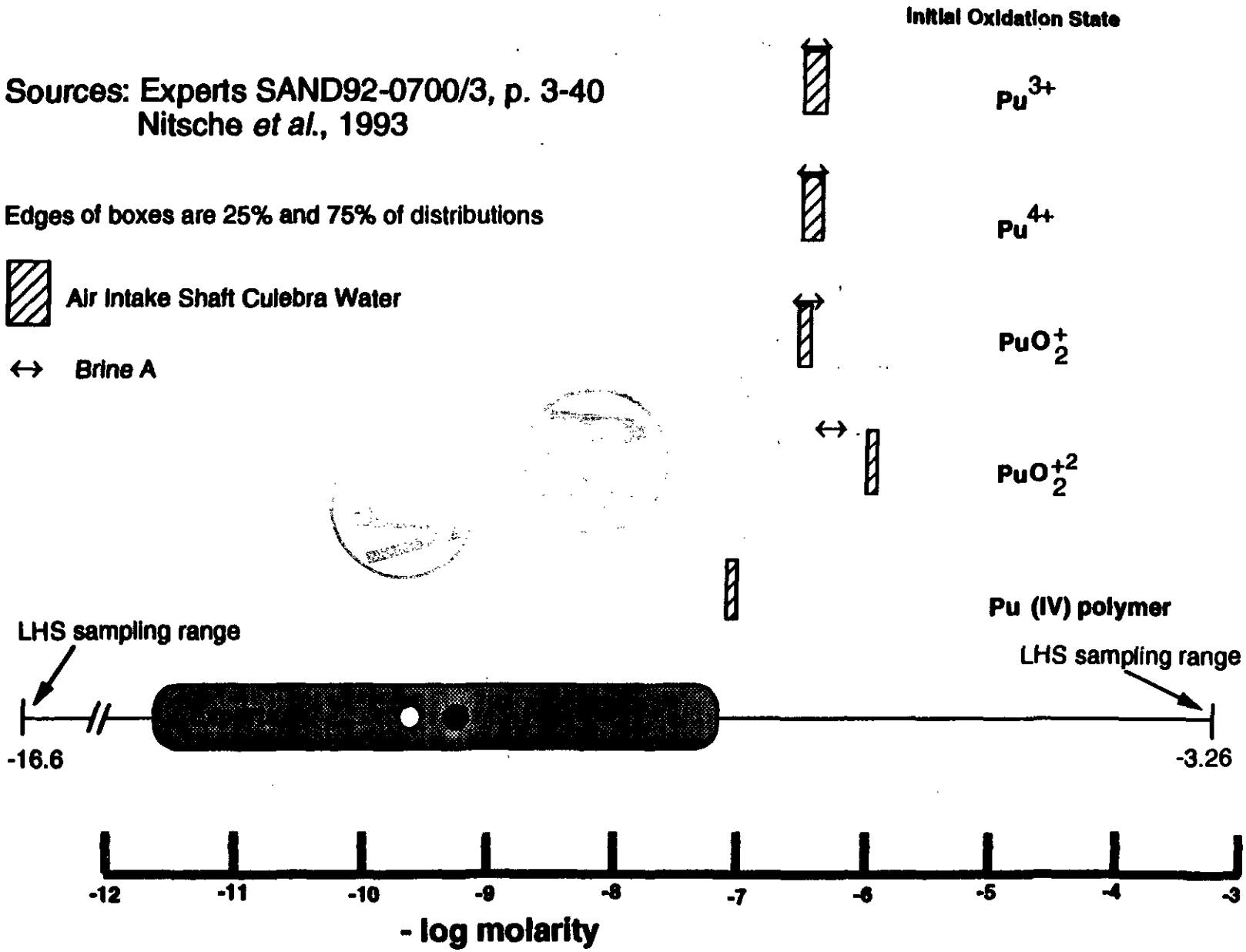

Figure 15. Comparison of subjectively elicited plutonium solubility and experimental solubility.

out that only 14 of the 70 realizations had a plutonium solubility of 10^{-7} M or higher, or 20%. The use of subjective elicitation apparently resulted in a downward bias in estimating plutonium solubility, leading to non-conservative consequences.

Recommendation 14. In future performance assessments, limit the sampling range to the error bands in experimental data.

15. Transport Modeling of Volatile Organics

In the analysis of compliance with 40 CFR 268, there has not been a transport analysis [vol.4, p. 4-38, line 25]. The conclusions in volume 5 are inferences using a flow model.

Recommendation 15. Two-phase transport of volatile organic compounds through gas-fractured interbeds should be analyzed in the future.

16. Corrensite Retardation in the Culebra

The *1992 Performance Assessment* identifies sorption on clay fracture-linings as one of three retardation mechanisms for radionuclide transport through the Culebra. Corrensite was addressed briefly in Recommendation 1.3. We elaborate here.

The concept of corrensite sorption is based on x-ray diffraction and analytical electron microscopy analysis of cores samples from clay-rich layers of the Rustler Formation, from wells drilled primarily in Nash Draw. This concept originates from the work of Sewards and others at the University of New Mexico under contract to the Sandia National Laboratories (Sewards 1991; Sewards, Glenn and Keil, 1991; Sewards, Williams and Keil, 1991; Siegel *et al.*, 1990).

16.1 Review of Corrensite Data

Sewards, Glenn and Keil (1991) presented mineralogical analysis of core samples from a single well, WIPP-19, and made no claim for clay-filled fracture linings in the Culebra.

Sewards (1991) gave data on "whole rock" as well as "fracture surface" compositions of core samples collected from six wells (WIPP-26, 27, 28, 29, 30, 32) in Nash Draw, one borehole (WIPP-33) between Nash Draw and the WIPP site, and three boreholes (WIPP-12,13, and 34) in the northern part of the WIPP site. Clays are expected to be present in the Nash Draw cores because of extensive dissolution, weathering, and erosion in that area. WIPP-3

is located in a sink hole and dissolution, weathering, and erosion are expected. Boreholes 12, 13 and 34 are located north of the WIPP repository and upstream from the expected direction of flow of water in the Culebra. Furthermore, cores are from these wells are in sections with known clay seams. For example, the only sample from WIPP-12 (CS-1) came from the zone 254.09 m (838.5 ft) to 254.15 m (838.7 ft) below the surface. The Basic Data Report for WIPP-12 (SNL and D'Appolonia, 1982) identifies mud seams at 253.85 m (837.7 ft) and 254.76 m (840.7 ft) depths.

Sewards, Williams and Keil (1991) presented mineralogy of 107 core samples from eight wells, three of which are located in the WIPP site. However, clay fraction separates ($< 2\ \mu m$) were obtained for only three samples: WIPP-12 #3, a clay-poor dolomite; WIPP-12 #16, a clay-rich dolomite; and H6B #3, a shale. X-ray diffraction analysis was performed on the clay fractions from these three samples, and one sample (H6B #3) was analyzed under the electron microscope. The electron microscopy on this one sample casts doubt on the results of the x-ray diffraction

> There is, however, a discrepancy between the results of the quantitative XRD analysis and the results of the AEM investigation of sample H6B #3. In that sample, the XRD results show that the sample contains approximately 50% corrensite. When imaging was attempted on the AEM, it was extremely difficult to find any corrensite at all; the dominant phases appeared to be serpentine, illite, and chlorite (Sewards, Williams and Keil (1991); p. VII-19).

The conclusion of this report does not follow from the data analyzed:

> The fact that corrensite is the dominant phase in the Culebra samples is important. Corrensite has a high cation exchange capacity (CEC) and high surface area, thus it is able to sorb radionuclides very efficiently in the event of a low pressure breach in the WIPP facility. Although the clay minerals of only three samples were investigated, the results of Sewards, Glenn and Keil (1991) show that mixed-layer chlorite/smectite is the dominant clay phase throughout the Rustler Formation, so it is reasonable to suggest that the same is true in the Culebra unit (Sewards, Williams and Keil (1991); p. VII-19).

Sewards, Glenn and Keil (1991) made no claim for clays lining fractures in the Culebra. Corrensite was interpreted to be present in some of the samples, as one mineral among

many, when powdered bulk samples were analyzed by x-ray diffraction.

Sewards *et al.*, (1992) presented mineralogical analysis from 47 samples. Of these, 17 samples were taken from the Culebra, and of these only nine are from the WIPP site: six from the Air Intake Shaft and three from WIPP-12. The report states:

> Only small amounts of clay can be sampled from the Culebra fracture coatings; therefore, initial technique and model development for adsorption studies on WIPP clays (Park *et al.*, in review) were carried out with material from a black shale layer in the unnamed member. This material, so-called CorWIPP, is 94% corrensite and is described as Sample AIS-15 in this report. Corrensite has a high cation exchange capacity and affinity for the uranyl ion in dilute solution (Park *et al.*, in review) and could provide significant radionuclide retardation in fractures in the Culebra (Sewards *et al.*, 1992).

The above quotation clearly identifies the problem with using Sewards' work to conclude that corrensite clay-lined fractures in the Culebra may provide retardation for radionuclide migration through the Culebra. The argument is based on a sample from a "black shale layer" obtained from the lower part of the Rustler Formation, below the Culebra, because not much clay could be sampled from Culebra fracture coatings. And yet, information from this sample is used to conjecture that "significant radionuclide retardation in fractures in the Culebra" could be present! This is the basis for continuing research on the adsorption properties of corrensite, model developement for retardation in the Culebra, and the assumptions of additional retardation.

16.2 Corrensite in the *1992 Performance Assessment*

Input to the *1992 Performance Assessment* has correctly evaluated the concept of corrensite retardation:

> Sewards (1991) measured and reported clay abundance for eighteen Culebra samples; thirteen from locations to the north and/or west of the WIPP site, and five from the north end of the WIPP site. None of these samples was from wells along fast transport paths. Because Sewards (1991) was focusing on clay abundance and compositional analyses, it is likely that samples were selected for analysis based on visual appearance of clays. Thus, these data may not be representative of clay abun-

dance on fracture surfaces in the area of interest for transport modeling (Novak, Gelbard and Papenguth, 1992).

Given the above analysis, why did SNL assume additional retardation from corrensite in the *1992 Performance Assessment*?

Recommendation 16. Abandon claiming credit for corrensite sorption as well as additional experiments with corrensite.

17. Ideal Gas Assumption in VOC Migration

In the *1992 Performance Assessment*, all gases are assumed to have the properties of hydrogen (vol. 5, p. 2-9) and behave like an ideal gas. While this assumption may be good for CO_2 and even for CH_4, it is not a good assumption for the volatile organic (VOC) gases regulated under 40 CFR 268. These gases have critical pressures well below lithostatic pressure, so that at lithostatic pressure they would not be expected to behave at all like ideal gases. In Table VIII, we show the ratio of the critical pressures of four prevalent VOC in TRU waste (Reid, Prausnitz and Poling, 1987) to lithostatic pressure of 15.2 MPa.

Table VIII. Ratio of Critical Pressures of Selected VOC to Lithostatic Pressure at Repository Horizon

COMPOUND	P_c (MPa)	P_{lith}/P_c
Carbon Tetrachloride, CCl_4	4.56	3.3
Dichloromethane, CH_2Cl_2	6.30	2.4
1,1,1-trichloroethane, CCl_3CH_3	4.30	3.6
Trichloroethene, $Cl_2C{=}CHCl$	5.05	3.0

Table VIII shows that these four important VOC will not behave like ideal gases.

Recommendation 17. Unless there is experimental evidence that VOC vapors move as ideal gases and move with the low-molecular-weight gases generated by radiolysis, corrosion, or microbial action, movement of VOC vapors should not be modeled as ideal gas flow in showing compliance with 40 CFR 268.

III. DETAILED COMMENTS

Volume 1

Sec. 3.1 p. 3-3 This section says that USEPA expects the implementing Agency to use the same assumptions. But it does not say whether USDOE does or does not.

Table 3-1 p. 3-14, line 15 In this Table, techniques are given for assessing and reducing various kinds of uncertainties. For conceptual model uncertainty, an additional method of assessing its extent is to analyze alternate conceptual models. If alternate conceptual models can be rejected with confidence, then the favorite conceptual model has a better chance!

Table 3-1 p. 3-14 In Parameter Values and Variability, the use of expert judgment is said to be a method of assessing and reducing uncertainty. The fact is that the panel on solubilities greatly EXPANDED the uncertainty range.

Sec. 4.1.1, p. 4-2, line 28 The description of undisturbed performance should include a statement that the deleterious effects of gas fracturing have not been considered. The probability of gas fracturing is clearly above 10^{-4} in 10,000 years. Sandia's own experimental data suggest that without fracturing, the gas pressure is likely to reach and exceed lithostatic in hundreds of years.

Sec. 4.2, p. 4-8, line 38 Why is the maximum number of holes in the 70 simulations only 20 per km^2 when Latin Hypercube is used to sample uniformly (I presume) over interval [0,30]? Isn't the key advantage of Latin Hypercube to "ensures full coverage of the range of each sampled variable." (p. 4-14, line 10)?

Sec. 5.1.2.1.1, p. 5-3, line 27 Is λ really random in both space and time? As implemented it appears to be only a variable of time.

Sec. 5.1.2.1.2, p. 5-4 , line 35 It is not clear why the intrusion and subsurface release times are specified rather than random. If intrusion and release times are random, the source strength can be calculated in PANEL using eq. 1.4.4-11 in vol. 3. Are these six times of intrusion possible times of intrusion, or must the intrusions occur?

Sec. 5.1.2.2, p. 5-6, line 25 Given our comments on the subjective elicitation process in the preceding pages, we do not consider any of the results using λ_t to be valid.

Sec. 5.1.2.2, p. 5-6, line 27 When releases are calculated for six intrusions, is it six holes? Does this correspond to S(4,1,0,1,0,0) in Table 3-2 of SAND 91-0893/1?

Volume 2

Sec. 1.3.2, p. 1-4, line 26 CAMCON controls 75 codes for WIPP Performance Assessment. However, the key codes BRAGFLO, SECOTP2D and CUTTINGS are run outside of CAMCON, and also probably SANTOS-SANCHO. Does this make CAMCOM a general without troops?

Sec. 2.3.2.1, p. 2-47, line 2 The word should probably be "pyrophoric."

Sec. 2.3.2.1, p. 2-47, line 2 The second half of this sentence appears to be incorrect. The limit for pyrophoric ingredients is probably 1% of the weight of the waste, not 1% of the weight of an empty container.

Sec. 2.3.4.1, p. 2-54, line 20 To use ionic-strength corrected data from Well J-13 from Yucca Mountain as the median needs justification.

Sec. 2.3.4.2, p. 2-55, line 4 The laboratory measurements of plutonium solubilities and sorption coefficients in brines fall short for several reasons:

- solubilities and sorption coefficients in Culebra water are needed;
- for the spectrum of possible conditions, calculations are better.

Sec. 2.3.4.2, p. 2-55, line 6 It is not clear how the results of the Source Term Testing Program will be useful or used in performance assessment. The current performance assessment uses the actinide solubility. The LANL experiments give a release rate, rather than a solubility. The LANL release rate will be proportional to inventory. The performance assessment department should state how it intends to use the two different sets of data.

Sec. 2.3.5, p. 2-55, line 13 The statement is made that at decommissioning, free brine will not be present within the emplacement area. Experience over the history of WIPP indicates that brine *may* be present throughout the disposal phase.

Sec. 4.2.3.1, p. 4-11, line 11 Do these plastic containers meet the Waste Acceptance Criteria?

Sec. 4.2.3.2, p. 4-13, line 33 "All borehole plugs... degrade into material with properties

similar to those of silty sand." Why not the plug above the Culebra?

Sec. 5.2, p. 5-2, line 22 Prof. Helton's method of calculating intrusion probabilities is not trivial. The full explanation is worthy of a journal paper. The brief explanation here raises more questions than answers. As a matter of fact, this summary is incomprehensible and confusing.

Sec. 5.2, p. 5-4, line 16 Hora's algorithm gives drilling rates in units of holes/mi^2/10000 years, not holes/km^2/10,000 years.

Sec. 7.2.3, p. 7-3, line 19 Should combustibles be organic?

Sec. 7.2.3, p. 7-3, line 21 Do you mean "biodegradation of organic materials only?" Non-combustible organics may still be biodegradable.

Sec. 7.6.1.2, p. 7-16, line 26 How is the scaling factor chosen? Who decides that it is reasonable? The same questions apply to the choice of A_R, θ, and ϕ in (7-14). Where are the results of climate change shown?

Sec. 7.6.2, p. 7-18, line 5 The numerical model for solute transport is 2-dimensional. The conceptual model shown in Figure 7-4 is 3-dimensional.

Volume 3

Sec. 1.2, p. 1-8, line 9 In the upper right plot in Figure 1.2-1, why is the median/mean of a standardized normal distribution 0.500001?

Sec. 1.4, p. 1-24, line 43 In eq.(1.4.1-9b) and eq.(1.4.1-11), the big dot used here for multiplication is confusing, and it is not needed. The dot is used on the previous two pages only for the dot product.

Sec. 1.4.4, p. 1-34 Instead of using two pages to explain what PANEL does not do, why not just present eq. (1.4.4-10) and explain that C_{di} is treated as a known constant.

Sec. 1.4.5, p. 1-38, line 11 Same comment on the big dot.

Sec. 2.3.3, p. 2-24 The data-source category of "engineering lore" is used here and in other places. "Engineering lore" is not defined on p. 1-13. In this case, the source is a refereed journal paper, which may well be "non-WIPP Literature Data."

Sec. 2.6, p. 2-78, line 14 The equation here does not make sense, and the definition of probability is not proper. For x as a random variate, try

$$P\left[\frac{b_c}{b}\right] = \begin{cases} 0, & 0 < x < 0.5 \\ x-0.5, & 0.5 \leq x \leq 1.0 \end{cases}$$

Sec. 2.6, p. 2-83 Why is the median given here not equal to the median given on the previous page, line 13?

Sec. 2.6, p. 2-93, 94 These are curious tables. The range of partition coefficients extends to a region of no significance. One can calculate the lowest value of K_D which will give a positive retardation coefficient, using

$$R = \frac{\epsilon}{1-\epsilon}\rho K_D$$

where $\epsilon = 0.145$, from p. 2-82, $\rho = 2.82$, from p. 2-76, which gives $K_D > 2.09$, and $\log K_D > 0.32$. Examination of these tables says none of the nuclide's median partition coefficient will give a positive retardation. Why bother? Just forget retardation.

Sec. 3.3, p. 3-22, Table 3.1 A more correct term for "activity conversion" is "specific activity."

Sec. 4.2, p. 4-6. line 7 Certainly this refers to a regular borehole, However, Figure 4.2-2 refers to changes in permeability as a function of "time after intrusion." This legend cannot be correct. Should it be "time after sealing?"

Sec. 4.2, p. 4-6, line 11 Surely the concrete plugs do not have **initially** the permeability and porosity of silty sand. On p. 3-14, the permeability of concrete is given as $2.7\times10^{-19}\text{m}^2$, where the permeability of silty sand has a median value of 3.16×10^{-12} m^2.

Sec. 4.2.1, p. 4-4, line 38 Reference is made to the New Mexico Energy, Minerals, and Natural Resources Department, Oil Conservation Commission as the state agency responsible for negotiating plug and abandonment specifications and conducting inspections. The Oil Conservation Commission has not performed this function since 1978. On March 31, 1978, Division Order No. R-5709 established the Oil Conservation Division to take over the responsibilities of the Oil Conservation Commission and left the Oil Conservation Commission remaining in name as an appellate board. Many people in the industry still refer to OCD as OCC, but that is not technically correct.

Volume 4

p. 2-16, line 1 Assumption 1 states there are no synergistic effect between intrusions, except for the E1E2 scenario. However, on line 25, the statement is made that

> ...there is little reason to believe that the release taking place from one waste panel would affect the release taking place from another waste panel.

This presumes that brine entering one panel would not affect brine in another panel because of perfect panel seals which have not been designed or verified experimentally.

p. 2-16, line 6 The current assumption is that an E1E2-type scenario can only occur in the time interval $[t_{i-1},\ t_i]$. Indeed the *1992 Performance Assessment* only considered E1E2 at the same time. Should an E1E2 scenario occur at say 1995 and 2010 (years after closure), they would be analyzed as two E2, with quite different consequences.

p. 2-16, line 9 Assumption 3 is unsupportable. In the *1992 Performance Assessment* both BRAGFLO and PANEL considers one waste panel at a time. For an E1E2, BRAGFLO and PANEL would calculate Qc, the product of the brine flux Q, and the solubility c. If there are three intrusions, with two E2 holes hitting different panels, the resultant subsurface release is not the same as that of an E1E2 pair. It is likely to be $Q_1c + Q_2c$. Thus this is not an acceptable assumption.

Section 2.3 The current Poisson model assumes that the intrusions are independent, that is, one intrusion does not affect the probability of another. Does one intrusion increase or decrease the probability of additional intrusions? One does not drag a drill rig into an area and just drill one hole! Even the hydropads for WIPP have several wells on each. Exploration geophysicists operate on knowledge of geologic structures. If geologists tried a structure in 1997 AD, they are more likely to return in AD 2097 and try the same structure. Thus some built-in correlation is credible.

p. 2-18, eq. 2.4-14 This should probably read

$$cS^{+-}(l; t_{i-1},\ t_i) = \sum_{j=1}^{5} 2rC_{i,\ell(j)} + rGW2_i,$$

p. 2-18, line 47 A reason given for considering the consequence of only a single intrusion at 1,000 years is "increased radioactive decay." Many actinides have long half life:

Pu-239	24,000 years
Pu-242	376,300 years
Th-230	7,700 years
U-233	158,500 years
U-238	4.468 $\times 10^9$ years.

Not much decay would have occurred in even 10,000 years!

p. 3-4, line 35 The range of LAMBDA is given as [0,1.0] while in Figure 3-1. p. 3-14, the range of LAMBDA is given as [0, 0.4].

Section 4.2.4 Here there are two possible representation between saturation and permeability and capillary pressure. They can be considered two different conceptual models, rather than mixing them 2/3 and 1/3.

p. 4-26, line 37 A reason given for using the van Genuchten equation is to simulate fingering. If fingers are at the scale of centimeters, and BRAGFLO's grid blocks are tens of meters, is this sufficient resolution to see this phenomenon?

p. 7-5, line 37 Should this be Figure 7.2-1?

p. 7-9, line 30 Solving eq. (7.2-5) analytically appears to be possible. Eq. (7.2-6) needs to be solved iteratively.

p. 7-7, Fig. 7.2-2 How is τ_{fail} determined?

p. 8-57, Figure 8.5-1; p. 8-58, Figure 8.5-2 What is the difference between a - and a blank in these tables.

p. 8-43, Figure 8.4-11 In the upper right frame, the mean CCDF is to the northeast of the 90% CCDF. This deserves more explanation. Please also explain why the mean CCDF starts at 8 $\times 10^{-3}$ on the probability scale, when there is a vector with probability of 0.5. According to p. 8-44, line 21, there are 21 vectors with releases, for the case of chemical retardation, matrix diffusion and no clay. Dividing 0.5 by 21, the minimum probability should be 2.38 $\times 10^{-2}$.

p. 8-60, line 31 This discussion of the effect of considering human intrusion for the full 10,000 years should be applied to Figure 9-1, especially Curve 1.

Volume 5

Is MBPERM gas or brine permeability?

p. 2-7, line 28 The word "scaled" should probably be "sealed."

p. 2-8, line 10 The porosity of the damaged rock zone increases from that of intact salt to that of highly fractured rock at time zero. Shouldn't this increase begin when the damage to the salt occurs, at $t = -50$ years, the time of initial excavation?

p. 2-8, line 35 Sensitivity analyses show that BRSAT is the most important parameter in undisturbed performance, and the second most important parameter in 191B performance, yet the range that BRSAT is sampled from is "somewhat arbitrary?" Moreover, the reduction of the high end of the sampling range is because of computational concern! What would the results look like if this sampling is optimized?

p. 5-2, line 4 -A different set of permeabilities is used in the first 200 years. Is the first 200 years after closure, or after adminstrative control?

IV. REFERENCES

Arthur, W. J., 1993. August 9 letter to R. H. Neill, Director, Environmental Evaluation Group.

Bertram-Howery, S.G. *et al.*, 1990. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990.* SAND 90-2347, four volumes, Sandia National Laboratories.

Bixler, N. E., 1989. Memorandum to M. S. Y. Chu, Sandia National Laboratories internal memorandum, January 4, 1989.

Brausch, L.M., A.K. Kuhn and J.K. Register, 1982. *Natural Resources Study, Waste Isolation Pilot Plant Project, Southeastern New Mexico.* WTSD-TME-3156, D'Appolonia Engineers.

Brush, L.H., M.A. Molecke, R.E. Westerman, A.J. Francis, J.B. Geilow, R.H. Vreeland, and D.T. Reed, 1993. *Laboratory Studies of Gas Generation for the Waste Isolation Pilot Plant.* SAND93-9859, Sandia National Laboratories.

Chaturvedi, L., J.K. Channell and J.B. Chapman, 1988. "Potential Problems Resulting from the Plans for the First Five Years of the WIPP Project," *Waste Management '88,* 355.

Edwards, W., 1954. "The Theory of Decision-Making," *Psychological Bulletin 51:* 380.

Freeze, A. and J. Cherry, 1979. *Groundwater.* Englewood Cliffs, NJ: Prentice-Hall.

Helton, J.C. 1993. "Risk, Uncertainty in Risk, and the EPA Release Limit for Radioactive Waste Disposal," *Nuclear Technology 101:* 18.

Hora, S.C., D. von Winterfeldt and K.M. Trauth, 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063, Sandia National Laboratories.

Hora, S.C., 1992. Memo in Sandia WIPP Performance Assessment Department, 1992. *Pre-*

liminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. SAND 92-0700, volume 3, A-69ff, Sandia National Laboratories.

Kosiewicz, S.T., 1981. "Gas Generation from Organic Transuranic Wastes," *Nuclear Technology 54:* 91.

Lappin, A.R., R.L. Hunter, D.P. Garber, P.B. Davies, R.L. Beauheim, D.J. Borns, L.H. Brush, B.M. Butcher, T. Cauffman, M.S.Y. Chu, L.S. Gomez, R.V. Guzowski, H.J. Iuzzolino, V. Kelley, S.J. Lambert, M.G. Marietta, J.W. Mercer, E.J. Novak, J. Pickens, R.P. Rechard, M. Reeves, K.L. Robinson and M.D. Siegel, 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* SAND89-0462, Sandia National Laboratories.

Molecke, M.A. and A.R. Lappin, 1990. *Test Plan Addendum No. 1: WIPP Bin-Scale CH TRU Waste Tests.* SAND90-2082, Sandia National Laboratories.

Neill, R.H., J.K. Channell, L. Chaturvedi, M.S. Little, K. Rehfeldt, and P. Spiegler, 1983. *Evaluation of the Suitability of the WIPP Site.* EEG-23, Environmental Evaluation Group.

Neill, R.H., 1992. July 31 letter W. J. Arthur, WIPP Project Integration Office, U. S. Department of Energy.

Nitsche, H., K. Roberts, R. C. Gatti, T. Prussin, K. Becraft, S. C. Leung, S. A. Carpenter, C. F. Novak, 1992. *Plutonium Solubility and Speciation Studies in a Simulant of Air Intake Shaft Water from the Culebra Dolomite at the Waste Isolation Pilot Plant.* LBL-30877, Lawrence Berkley Laboratory.

Nitsche, H., K. Roberts, R. Xi, T. Prussin, K. Becraft, I. Al Rifau, H.B. Silber, S.A. Carpenter, R.C. Gatti, and C.F. Novak, 1993. "Long-Term Plutonium Solubility and Speciation Studies in a Synthetic Brine," Proceedings 4th International Conference on Chemistry & Migration Behavior of Actinides and Fission Products in the Geosphere.

Novak, C., F. Gelbard and H. Papenguth, 1992. Memo to M. Tierney, in Sandia WIPP Performance Assessment Department, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992.* SAND 92-0700, volume 3, A-127, Sandia National Laboratories.

Rechard, R.P., K.M. Trauth, J.S. Rath, R.V. Guzowski, S.C. Hora and M.S. Tierney, 1993, *The Use of Formal and Informal Expert Judgments When Interpreting Data for Performance Assessments.* SAND92-1148, Sandia National Laboratories.

Reid, R.C., J.M. Prausnitz and B.F. Poling, 1987. *The Properties of Gases and Liquids,* Fourth Edition. New York: McGraw-Hill.

Roache, P., 1993. "The SECO Suite of Codes for Site Performance Assessment," *Proceedings 1993 International High-Level Waste Management,* 1586.

Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982. *Basic Data Report for Drillhole WIPP 12.* SAND82-2336, Sandia National Laboratories.

Sandia WIPP Performance Assessment Department, 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991.* SAND 91-0893, five volumes, Sandia National Laboratories.

Sandia WIPP Performance Assessment Department, 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992.* SAND 92-0700, five volumes, Sandia National Laboratories.

Savage, L.J., 1954. *The Foundations of Statistics.* New York: Wiley.

Sewards, T., 1991. *Characterization of Fracture Surfaces in Dolomite Rock, Culebra Member, Rustler Formation,* SAND90-7019, Sandia National Laboratories.

Sewards, T., R. Glenn and K. Keil, 1991. *Mineralogy of the Rustler Formation in the WIPP-19 Core.* SAND87-7036, Sandia National Laboratories.

Sewards, T., M.L. Williams and K. Keil, 1991. *Mineralogy of the Culebra Dolomite Member of the Rustler Formation.* SAND90-7008, Sandia National Laboratories.

Sewards, T., A. Brearley, R. Glenn, I.D.R. MacKinnon and M.D. Siegel, 1992. *Nature and Genesis of Clay Minerals of the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant in Southeastern New Mexico.* SAND90-2569, Sandia National Laboratories.

Siegel, M.D., J.O. Leckie, S.W. Park, S.L. Phillips and T. Sewards, 1990. *Studies of Radionuclide Sorption by Clays in the Culebra Dolomite at the Waste Isolation Pilot Plant Site, Southeastern New Mexico.* SAND88-0196, Sandia National Laboratories.

Silva, M., 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP.* EEG-55, Environmental Evaluation Group.

Silva, M.K. and J.K. Channell, 1992. *Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards.* EEG-50, Environmental Evaluation Group.

Slovic, P., B. Fischhoff and S. Lichtenstein, 1980. "Facts and Fears: Understanding Perceived Risks," in R.C. Schwing and W.A. Albers (eds.) *Societal Risk Assessment.* New York: Plenum.

Thomas, J. T., 1978. *Nuclear Safety Guide,* NUREG/CR-0095, U. S. Nuclear Regulatory Commission.

Tversky, A. and D. Kahneman, 1974. "Judgment under Uncertainty: Heuristics and Biases," *Science 185:* 1124.

U. S. Bureau of Land Management, 1989. Office of Inspector General Audit Report C-LM-BLM-26-89, U.S. Department of the Interior.

U.S. Department of Energy, 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026.

U.S. Department of Energy, 1981a. *Brine Pocket Occurrences in the Castile Formation, Southeastern New Mexico.* TME-3080.

U.S. Department of Energy, 1981b. "Waste Isolation Pilot Plant Record of Decision," *Federal Register 46:* 9162.

U.S. Department of Energy, 1983. *Brine Reservoirs in the Castile Formation, Southeastern New Mexico.* TME-3153.

U.S. Department of Energy, 1990a. *Waste Isolation Pilot Plant No-Migration Variance Petition.* DOE/WIPP 89-003, Rev. 1.

U.S. Department of Energy, 1990b. *Supplement to the Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026- FS.

U.S. Department of Energy, 1991a. *Implementation of the Resource Disincentive Plan in 40 CFR 191.14(e) at the Waste Isolation Pilot Plant.* DOE/WIPP 91-029.

U.S. Department of Energy, 1991b. *Radionuclide Inventory for the Waste Isolation Pilot Plant.* DOE/WIPP 91-058.

U. S. Environmental Protection Agency, 1993. "Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste," Title 40 *Code of Federal Regulations*, Part 191, 58 *Federal Register.*, 66398.

Weart, W.D., 1983. *Summary Evaluation of the Waste Isolation Pilot Plant Site Suitability.* SAND83-0450, Sandia National Laboratories.

Weart, W.D., S.G. Bertram-Howery, R.V. Guzowski, K.F. Brinster, P N. Swift and S. B. Pasztor, 1991. *Background Information Presented to the Expert Panel on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND91-0928, Sandia National Laboratories.

ACRONYMS

AEM	analytic electron microscopy
BB	billion barrels
bbl	barrels
BCF	billion cubic feet
BT	billion tons
CCDF	complementary cumultive distribution function
CFR	*Code of Federal Regulations*
EEG	Environmental Evaluation Group
LANL	Los Alamos National Laboratory
M	mole/litre
MB	million barrels
MT	million tons
SNL	Sandia National Laboratories
TCF	trillion cubic feet
TRU	transuranic
USBLM	U. S. Bureau of Land Management
USDOE	U. S. Department of Energy
USEPA	U. S. Environmental Protection Agency
VOC	volatile organic compounds
WIPP	Waste Isolation Pilot Plant
XRD	x-ray diffraction

Computer Codes Mentioned

BRAGFLO
CUTTINGS
SANCHO
SECOTP2D
SWIFT
CAMCON
PANEL
SANTOS
STAFF2D

Variable Names

LAMBDA VMETAL VWOOD

ENVIRONMENTAL EVALUATION GROUP

REPORT NUMBER EEG-61

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (ed), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C. and Jim W. Kenney, A Critical Assessment of Continuous Air Monitoring Systems at the Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

EEG-40 Review of the Final Safety Analysis Report (Draft), DOE Waste Isolation Pilot Plant, December 1988, May 1989.

EEG-41 Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, July 1989.

EEG-42 Chaturvedi, Lokesh, Evaluation of the DOE Plans for Radioactive Experiments and Operational Demonstration at WIPP, September, 1989.

EEG-43 Kenney, Jim W., et al., Preoperational Radiation Surveillance of the WIPP Project by EEG, 1985-1988, January 1990.

EEG-44 Greenfield, Moses A., Probabilities of a Catastrophic Waste Hoist Accident at the Waste Isolation Pilot Plant, January 1990.

EEG-45 Silva, Matthew K., Preliminary Investigation into the Explosion Potential of Volatile Organic Compounds in WIPP CH-TRU Waste, June 1990.

EEG-46 Gallegos, Anthony, and James K. Channell, Risk Analysis of the Transport of Contact Handled Transuranic (CH-TRU) Wastes to WIPP Along Selected Highway Routes in New Mexico Using RADTRAN IV, August 1990.

EEG-47 Kenney, Jim W., and Sally C. Ballard, Preoperational Radiation Surveillance of the WIPP Project by EEG During 1989, December 1990.

EEG-48 Silva, Matthew K., An Assessment of the Flammability and Explosion Potential of Transuranic Waste, June 1991.

EEG-49 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1990, November 1991.

EEG-50 Silva, Matthew K., and James K. Channell, Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards, June 1992.

EEG-51 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1991, October 1992.

EEG-52 Bartlett, William T., An Evaluation of Air Effluent and Workplace Radioactivity Monitoring at the Waste Isolation Pilot Plant, February 1993.

EEG-53 Greenfield, Moses A. and Thomas J. Sargent, A Probabilistic Analysis of a Catastrophic Transuranic Waste Hoist Accident at the WIPP, June 1993.

EEG-54 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1992, February 1994.

EEG-55 Silva, Matthew K., Implications of the Presence of Petroleum Resources on the Integrity of the WIPP, June 1994.

EEG-56 Silva, Matthew K., and Robert H. Neill, Unresolved Issues for the Disposal of Remote-Handled Transuranic Waste in the Waste Isolation Pilot Plant, September 1994.

EEG-57 Lee, William W.-L., et al., An Appraisal of the 1992 Preliminary Performance Assessment for the Waste Isolation Pilot Plant, September 1994.

[redacted]

EEG-61

REVIEW OF THE WIPP DRAFT APPLICATION TO SHOW COMPLIANCE WITH EPA TRANSURANIC WASTE DISPOSAL STANDARDS

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March 1996

EEG-61
DOE/AL/58309-61

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FOREWORD

The purpose of the New Mexico Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-ACO4-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.

Since 1978 EEG has been directly involved in quantifying the long-term consequences of radioactive waste releases from WIPP. We evaluated DOE's 1979 analyses contained in the Draft Environmental Impact Statement and published our analysis in 1979. The mission of WIPP at that time included high-level waste as well as transuranic waste.

Consequences were calculated via deterministic analyses in which an event was assumed to occur. EEG published nine reports calculating doses from the long term releases including consideration of brine reservoirs, drilling for mineral resources, sensitivity analysis for hydrological parameters in the Rustler, Breccia chimney and naturally occurring disruptive events. At about the same time that EEG was created in 1978, EPA began drafting standards

for the safe disposal of high level and transuranic waste and the first briefing for EEG on this work by EPA occurred in 1979. EEG commented extensively on the multiple drafts and the standards were promulgated in September 1985.

Although not everyone was satisfied, the standards represented a consensus at that time. When the First Circuit Court vacated the standards in June of 1987, following a challenge by the Natural Resources Defense Council, Inc., the state of New Mexico entered into a formal agreement with DOE within a few days to continue to measure the expected performance against the vacated standards. It made sense since the standards were not expected to change much. Although it took 6.5 years for the agency to repromulgate the standards, DOE has been working since 1985 to show compliance and they currently plan to complete the task of the documentation of compliance for safe disposal by November 1, 1996.

The 1985 EPA standards required probabilistic analyses. The approach by DOE to show compliance has been an iterative one that we support. The last iteration of performance assessment was issued by Sandia National Laboratories in 1992.

Although the DOE draft application is substantially incomplete, we urged the Secretary of Energy in March 1995 to issue the draft report to enable oversight organizations to provide feedback to DOE and we commend DOE for issuing this interim application.

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Don Gray and Sally Ballard provided technical review and evaluation. Betsy Kraus prepared the footnotes for references and provided editorial support. Jill Shortencarier and Patricia Fairchild patiently and diligently provided secretarial support through several drafts of this multi-authored report. Contributions of Susan Stokum and Radene Bradley are also gratefully acknowledged.

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ACRONYMS

BHP	Borehole Plugging Program
BIR	Baseline Inventory Report
CSR	Compliance Status Report
CAM	Continuous Air Monitor
CAO	Carlsbad Area Office
CFR	Code of Federal Regulations
CH-TRU	Contract Handled Transuranic
DCCA	Draft Compliance Certification Application
DOT	U.S. Department of Transportation
DOE	U.S. Department of Energy
ESAAB	Energy Systems Acquisitions Advisory Board
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
FEPs	Features, Events and Processes
FSAR	Final Safety Analysis Report
INEL	Idaho National Engineering Laboratory
GCR	Geologic Characterization Report
MDL	Minimum Detection Levels
NAS	National Academy of Sciences
NMVP	No Migration Variance Petition
NMBM&MR	New Mexico Bureau of Mines and Mineral Resources
NAS	National Academy of Sciences
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PBWAC	Performance Based Waste Acceptance Criteria
QA	Quality Assurance
QAPD	Quality Assurance Program Description
RCRA	Resource Conservation and Recovery Acts
RH-TRU	Remote Handled Transuranic
RTR	Real Time Radiography

ACRONYMS (CONT.)

SAR	Safety Analysis Report
SARP	Safety Analysis Report for Packaging
SNL	Sandia National Laboratories
TRU	Transuranic
USGS	U.S. Geological Survey
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant

EXECUTIVE SUMMARY

Overall Impression

The DOE Draft Compliance Certification Application (DCCA) cannot be considered to be an adequate draft document for demonstrating compliance with the EPA Standards for the Disposal of Transuranic Radioactive Waste (Title 40, Code of Federal Register, Part 191, Subpart B)[ES-1] requirements. It is more a framework for the application than a draft application, since it lacks a logical presentation of the proofs of compliance. A draft document should contain substantial features of the final document. The DCCA preface states that the draft does not provide "detailed information" on a number of topics and the submittal does not present the "complete picture" of long-term performance. In fact, the EEG finds that even the most basic information is lacking in this draft.

History of the Project

The historical sections of the DCCA omit several significant details concerning changes in the purpose and scope of the project, the history of site selection, the site selection criteria, the location of the repository, the design, and the waste acceptance criteria. Many apparent inconsistencies and contradictions in the project can be explained only through a full and accurate description of the history of the WIPP project,

Conceptual Models

The application is weak in describing alternative conceptual models for the projected conditions and processes in the repository and along the potential breach pathways, and in defending the ones selected. For some cases, the experimental data is not currently available to justify a particular model but additional data being collected may do so, as in the case of

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[ES-1] While the title of the DCCA or the text do not state it, the document only addresses compliance with Subpart B of the Standards (40 CFR 191) for disposal. Compliance with 40 CFR 191 Subpart A for the management of TRU waste is required by the Land Withdrawal Act, P.L. 102-579, Section 9 (a), and has to be documented.

radionuclide solubility. In other cases, potentially erroneous interpretations of the data have led to the concepts preferred by the DOE scientists. For example, although EEG clearly pointed out[ES-2] the error in using the limited stable isotope data from the Carlsbad Caverns pools in deciphering the past history of the Rustler aquifers, the DCCA presents only the conceptual model based on that data in estimating the age of the Rustler groundwater.

The EEG and DOE have debated many issues related to conceptual models since 1979, and in many instances additional boreholes or field experiments have led to a general consensus among the scientists; for example, whether pressurized brine exists in the Castile Formation underlying the repository, and whether "deep dissolution" is a threat to the integrity of the repository. However, there remain some instances where relatively inexpensive, but time-consuming, field experiments would provide the answers. The DOE conceptual model of radionuclide retardation in the Culebra aquifer remains a long-standing issue that would require such time-consuming field experiments to resolve; EEG first suggested such field work in 1979. Until the support for the conceptual models is on a solid basis, the WIPP cannot be said to comply with 40 CFR 191.

Hydrology

A basic understanding of the hydrology of the site is yet to be attained. The location of the water table at the WIPP site has not yet been identified; this would require an investigation of the hydrology of the shallow zone overlying the Rustler Formation, including the Dewey Lake Redbeds. The Culebra dolomite plays an important part in the postulated breach scenarios yet knowledge of its recharge and discharge locations and the mechanics of flow and transport in this most important aquifer are currently inadequate. The postulated direction of flow as indicated by the potentiometric heads differs from that obtained from water chemistry--such differences do not lead to confidence in the DOE conceptual models. Several Culebra wells have shown an as yet unexplained rise in water levels in recent years; this, too, should be explained in a compliance application. The DCCA does not adequately address these topics.

[ES-2]Chapman, Jenny B. 1986. *Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area.* Albuquerque, NM: Environmental Evaluation Group, EEG-35.

Containment Requirements

The Sandia National Laboratories (SNL) published three iterations of performance assessment (PA) calculations in 1990, 1991, and 1992 to demonstrate compliance with the containment requirements listed in 40 CFR 191.13. These iterations demonstrated that incorporation of improvements in the methodology--better prediction of drilling probabilities, superior addressing of fracturing due to gas pressure, recognition that borehole plugs can degrade, improved methods of breach scenario calculation--were possible, and important. However, the DCCA offers no further improvement in WIPP performance assessment over the 1992 PA calculations.

Containment requirement calculations should be the heart of the application but only rudimentary information on the topic is supplied in the DCCA. The draft application is seriously deficient in not analyzing several potentially disruptive scenarios, in not adequately establishing the probabilities for a number of potential breach scenarios, and in not providing the basis for calculation of consequences. The exclusion of features, events, and processes eliminated on regulatory or low consequence potential has not been adequately justified; 23 of the 53 parameters listed in appendix PAR lack specific information; no sensitivity analysis is included; the number of consequence calculations has been reduced from 70 in the 1992 performance assessment to 20 in the DCCA; no evidence of computer model validation is included, nor quality assurance of data demonstrated; only a single Complementary Cumulative Distribution Function (CCDF) is shown. These lapses make it impractical to make any judgement about the WIPP's compliance with the EPA's disposal standards on the basis of this draft application.

Waste Inventory and Characterization

Various DOE documents present seriously conflicting pictures of the volume and radioactivity of the TRU waste available and expected to be generated. In the DCCA, performance-based waste acceptance criteria are mentioned, but never identified, perhaps because the DCCA also fails to identify the specific waste parameters important to compliance. Reliance on process knowledge for waste characteristics continues to be insufficiently justified. These conflicts and omissions provide little confidence in the DOE's inventory assessments.

Assurance Requirements

The purpose of the assurance requirements (40 CFR 191.14) is to provide confidence for long-term isolation of the waste that cannot be achieved solely by the numerical containment requirements (40 CFR 191.13). The EPA explained the need for the assurance requirements as follows:

> "There are too many uncertainties in projecting the behavior of natural and engineered components for many thousands of years--and too many opportunities for mistakes or poor judgements in such calculations--for the numerical requirements on overall system performance in subpart B to be the sole basis to determine the acceptability of disposal systems for these very hazardous wastes. These uncertainties and potential errors in quantitative analysis could ultimately prevent the degree of protection sought by the Agency from being achieved."[ES-3]

The assurance requirements should not therefore be confused with the containment requirements. The DOE attitude toward demonstrating compliance with the assurance requirements, however, continues to reflect a lack of commitment, and none of the six elements of 40 CFR 191.14 can be said to have been adequately addressed in the DCCA, as explained below.

Institutional Controls and Monitoring: 40 CFR 191.14(a) and (c) concern active and passive institutional controls; the plans for these are not scheduled to be prepared until October 30, 1997. 40 CFR 191.14(b) requires developing a plan for monitoring of the repository after disposal is completed; there is only a commitment to develop such a plan, with no completion date given, in the DCCA.

Engineered Barriers: 40 CFR 191.14(d) requires engineered barriers to be included in the repository. The EPA definition of engineered barriers (*barrier* in 40 CFR 121.12) includes only three examples: a canister, a waste form, and a material placed over and around the waste (backfill). In various sections of the DCCA, however, the DOE has used the repository

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[ES-3]Preamble to 40 CFR 191, Federal Register, Vol. 50, No. 182, p. 38079.

itself, and the shaft and panel seals as examples of engineered barriers--clearly not the intent of this requirement. The DOE also interprets the 1992 Land Withdrawal Act statement that DOE " ...shall use both engineered and natural barriers, and waste form modifications at WIPP to isolate transuranic waste after disposal to the extent necessary to comply with the final disposal regulations"[ES-4] as requiring no engineered barriers if not required to show compliance with the containment requirement (40 CFR 191.13). The assurance requirement (40 CFR 191.13 d) requires engineered barriers whether or not they are needed to show compliance with the containment requirement. Thus, it is necessary to include engineered barriers at WIPP to comply with the EPA Standards and the Land Withdrawal Act. The DOE position on this issue is indefensible.

Natural Resources: 40 CFR 191.14(e) requires that areas with natural resources be avoided in selecting the sites for nuclear waste repositories, "...unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future". The WIPP site was selected in a resource-rich area in 1974, and the WIPP Final Environmental Impact Statement of 1980[ES-5] estimated the crude oil reserves at the WIPP site as "nil" even though information to the contrary was available[ES-6]. Oil and gas wells and potash mines now surround the WIPP site leaving no doubt about the existence of natural resources in the area. The DCCA uses the time of site selection as an excuse to "grandfather" the site into existence, as the provisions of 40 CFR 191 were not published until 1985. There is no "grandfather" provision in 40 CFR 191; and there has been no formal acceptance of WIPP as a waste repository, nor any waste emplaced. To be constructive, EEG has recommended that instead of debating the favorable characteristics of the site and the degree to which they compensate for the existence of resources, the performance assessment should recognize the characteristics of the site as they are, and consider all plausible scenarios for breach. EEG also notes that siting in a resource-rich area provides another reason for the inclusion of robust engineered barriers in the repository design.

[ES-4]Public Law 102-579, Sec. 8(g).

[ES-5]DOE/EIS-026, 1980, Vol. 1, Table 9-14.

[ES-6]Silva, M.K. 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP site.* Albuquerque, NM: Environmental Evaluation Group, EEG-55, p. 18.

Retrievability: The final assurance requirement, 40 CFR 191.14(f), requires that the removal of the waste be a viable option for a reasonable period of time after disposal. The DCCA offers no plans or data to demonstrate compliance with this requirement.

DOE has failed to adequately address all of the assurance requirements of 40 CFR 191.14 in the DCCA, and no determination of compliance is possible until this important area is adequately assessed.

Individual Protection and Ground Water Protection Requirements

The DCCA has only three pages to show compliance with the requirements of 40 CFR 191.15 and 40 CFR 191.16. The work simply has not been done, and the WIPP's compliance with these requirements cannot be assessed until it is.

DOE Self-Regulation

While the DOE self-regulates several aspects of the WIPP project, and the DOE Orders are applicable to it, the DCCA does not list the DOE in the list of regulatory agencies. The Biennial Environmental Compliance Report (Appendix BECR) provides detailed information on the status of compliance with laws, regulations, and standards by a number of regulatory agencies, but omits any information on the status of compliance with regulations issued by the DOE. An analysis of the DOE Orders, and reviews and approvals by the Office of Environment Safety and Health (ES&H) and the Defense Nuclear Facilities Safety Board (DNFSB) should be included in the BECR. Public accountability of compliance with the DOE requirements is essential.

COMMENTS ON THE DCCA EXECUTIVE SUMMARY

The Purpose of WIPP
Page ES-1

The description of the purpose of the WIPP project continues to remain confused in the DOE documents. "Research and development facility to demonstrate the safe disposal of radioactive waste ..." has never adequately described the purpose of WIPP, even though it is the language in the 1979 Act authorizing WIPP. The second sentence in the Executive Summary of the DCCA, "The facility was constructed in southeastern New Mexico in a manner intended to meet criteria established by the scientific and regulatory community ...", is also convoluted. The following straightforward statement is suggested to describe the purpose of the WIPP project for use in all the WIPP project documents: "The Waste Isolation Pilot Plant is planned to be a permanent geologic repository for transuranic waste generated by the defense activities of the United States."

As appropriate, additional statements about the DOE being the manager of the waste and the repository, the EPA being the certifier of compliance with the environmental regulations, etc., can be added.

Waste Quantity and Radioactivity Limitations
Page ES-2, lines 21 to 25

The paragraph should be changed to correspond with the limitations in the waste amount and radioactivity listed in Sec. 7 of the Land Withdrawal Act.

Assumed Characteristics
Page ES-2, line 28

"Assessments of the repository performance are based in part on <u>assumed</u> characteristics of the waste including factors such as the levels of radioactivity present in the waste, the amount of moisture in the waste, and the quantities of other materials that might have some effect on

the potential for the waste to migrate toward the accessible environment." Emphasis added.

The characteristics of the waste should not have to be assumed; they should be known.

The Results of Analyses
Page ES-3, lines 22-27

In addition to the limitations listed, many plausible scenarios were not considered in developing the CCDFs shown in Figures ES-1 and 6-18. Also, the values of many important parameters used for developing these CCDFs were simply guesses by the scientific investigators, and not the values obtained from experiments. Thus, the results presented in this document are no more than a generic demonstration of the performance assessment procedures. They make no contribution towards assessing the WIPP's compliance with 40 CFR 191.13. Compliance with 40 CFR 191.14, 191.15 and 191.24 has also not been demonstrated.

Authorized Wastes
Page ES-2, line 36

It is stated that the DOE may only emplace the radioactive waste at WIPP that meets the definition of TRU waste in the Land Withdrawal Act (LWA) and the DOE waste acceptance criteria.

The waste must also meet the NRC standards for transportation and the EPA standards for long-term disposal.

CHAPTER 1. INTRODUCTION

Total Projected Quantity of Waste in the Repository
Page 1-1, lines 12-17

The Executive Summary states that the WIPP facility is designed to receive up to 6.2 million cubic feet (175,600 m^3) of contact-handled and 250,000 cubic feet (7,080 m^3) of remote-handled transuranic waste. Chapter 1 states that approximately 2.8 million cubic feet (79,300 m^3) of TRU waste is currently in storage and an additional 2.0 million cubic feet (56,640 m^3) is expected to be generated, although this projection may increase. The estimate of 2.8 million cubic feet (79,300 m^3) of retrievably stored TRU waste is much lower than other estimates by the DOE, and the 4.8 (2.8+2.0) million cubic feet (135,940 m^3) estimate is much lower than the 6.2 million cubic feet (175,600 m^3) capacity of the WIPP repository.

Since the allowable release limits in the EPA Standards 40 CFR 191 are based on the inventory (radionuclides and curie content) to be disposed in the repository, it is important to make an accurate projection of the curie content of each radionuclide to be emplaced. If the actual amount placed is lower than the assumption made to calculate the release limits, then the calculations would not be conservative, i.e. would project higher allowable releases than should be allowed, and vice-versa.

Project Overview
Pages 1-2, 1-3

Only through a full description of the checkered history of the WIPP project can the inconsistencies and contradictions in the project be fully explained. For example, The WIPP facility has <u>not</u> been constructed to "determine the efficacy of an underground repository for disposal of TRU waste and TRU mixed waste" (p. 1-2, lines 11,12). Study of the in situ geomechanical and geohydrological behavior of the repository did not require excavation of the full-fledged repository and waste handling facilities, or the heated room experiments. The facility was constructed prior to the decision to apply EPA standards for the mixed (TRU and chemically hazardous) waste. The WIPP facility was constructed in the 1980s because the

DOE had planned to emplace underground all the then retrievably stored (200,000 drums) transuranic contact-handled (CH-TRU) waste, and limited quantities of high level waste for experiments, before assessing the WIPP's suitability as a permanent repository. Similarly, for those who may not be familiar with the DOE desire to conduct a "test phase" involving emplacement of waste in the Panel 1 rooms and in the alcoves, the provisions of the Land Withdrawal Act are hard to explain. This section should describe the plans prior to October 1993, the reasons for the DOE decision to abandon the idea of testing with the waste at WIPP, and the effect of that decision on the requirements of the Land Withdrawal Act.

An illustration of the difficulty caused by the omission of discussion of the "Test Phase" is provided by the following sentence in the Project Overview section (Sec. 1.2).

> The DOE's decision was reached after all prerequisites for ending construction were met and documented (page 1-3, lines 7 and 8).

The *decision* in this sentence refers to the decision by the DOE Energy Systems Acquisition Advisory Board (ESAAB) in 1991 to start the "Test Phase" by shipping one bin of waste to WIPP. Without identifying what the *decision* was for, this sentence is meaningless. The fact is that the site characterization work is still continuing at the WIPP site, and since only one out of the planned eight waste panels has been excavated, the construction has also not ended. This factor also caused delay in initiating several necessary field and laboratory tests for site and waste characterization. Some of these tests are being conducted now under a tight schedule and others have been abandoned or postponed because they do not fit in this tight schedule. This also explains the sentence, "Additional scientific studies may continue during the disposal phase." (p. 1-3, line 15).

The project is finally on the right track. Only an awareness of the past mistakes and disassociation with the past short-sighted approaches will keep it there.

Page 1-2, line 15

"The LWA requirements relevant to this application focus on the criteria for certification of compliance with the radioactive waste disposal regulations issued by the EPA."

The application focuses on the regulations for disposal. The criteria only clarify those regulations.

Page 1-2, line 30

The text fails to note that the site was moved 1.25 miles south after the publication of the 1980 FEIS.

Page 1-3, line 9

What are the documents?

Page 1-3, line 11

Change "Once the DOE demonstrates compliance..." to "Once the EPA certifies compliance..."

Page 1-3, line 14

While the text states that the disposal phase will last 25 years, the DOE/CAO announced in October 1995 that the disposal will take 35 years.

Page 1-3, line 16

"The disposal phase will end when the design capacity is reached."

Since the current estimate of transuranic waste for emplacement at WIPP is only 2/3 of the design capacity, this would mean the disposal phase would not have an end date.

Page 1-3, line 26

The text states that the purpose of the active and institutional controls is to reduce the likelihood of human intrusion to the extent practicable. While this is a laudable goal, the

standard states that the purpose is "to indicate the dangers of the wastes and their location" (40 CFR 191.14.d).

Site Selection Process

The discussion of the site selection process should include the following facts:

- One of the most restrictive site selection criteria, primarily because of the Lyon (Kansas) experience, was avoidance of drill holes penetrating through the salt within two miles of the repository border (p. 2-5)[1-1].

- The two-mile criterion caused the potential site to be shifted twice as new oil or gas wells were drilled nearby. The separation distance criterion was changed to one mile after the site at the ERDA-6 borehole was found to be unacceptable (p. 2-10[1-2] p. 2-6, 2-7, 2-12[1-1]), (pp. 6-7)[1-3].

- One of the three locations in New Mexico examined in detail to be the WIPP site was the Mescalero Plains area. The salt depth was adequate in that area but it was rejected because of extensive oil-field development (1980, p. 2-10)[1-2].

[1-1]Powers, D. W., S. J. Lambert and S. E. Shaffer. 1978. *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* Albuquerque, NM: Sandia National Laboratories. SAND 78-1596/2 vols.

[1-2]United States Department of Energy. 1980. *Final Environmental Impact Statement Waste Isolation Pilot Plant.* DOE/EIS-0026/2 vols.

[1-3]Environmental Evaluation Group. 1979. *Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U.S. Department of Energy.* Santa Fe, NM: Environmental Evaluation Group. EEG-3 (EEG-2 Appendix III).

- Extensive oil-field development has occurred in the area surrounding the WIPP site with more than 100 producing oil and gas wells in the two mile zone surrounding the 4 mile x 4 mile WIPP Land Withdrawal area (p. 42)[1-4].

- The original location of the WIPP repository was in the north-central part of the 4 mile x 4 mile WIPP site. After the borehole WIPP-12, located one mile north of the center of the WIPP site, encountered pressurized brine in the Castile Formation in November 1981, the repository was relocated to its present site in the south-central part of the WIPP site. A geophysical electromagnetic survey conducted over the present repository in 1987 indicated the presence of brine in the Castile Formation below the repository.

- Selection of the specific horizon, at 2150 ft (655 meters) below the surface, was a compromise. Salt of highest purity is found in the lower Salado Formation but that is too close to the Castile Formation with its brine reservoirs. A marker bed (MB 139) is only 4-5 ft (1-4 m) below the repository and the Marker Bed 138 is located 39 ft (12 m) above the repository roof. There are several anhydrite and clay layers within the repository horizon.

Page 1-3, line 29

The NAS 1957 report also recommended completion of the site characterization work before making a decision to use the site for a repository and before authorizing construction. The DOE did not follow this advice, causing many difficulties for the WIPP project. Also, "1955" on line 29 should be "1957".

[1-4] Silva, M. K. 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP.* Albuquerque, NM: Environmental Evaluation Group. EEG-55.

Page 1-4, line 16

The text indicates that the site was shifted twice to keep it two miles away from the then existing deep boreholes. It fails to mention that the criterion was changed to one mile, since the two mile limit could not be met.

Page 1-5, line 10

The text states that the WIPP site was selected but does not point out that it was moved twice.

Page 1-5, line 10

There were two horizons selected; not one.

Page 1-5, line 13

"The facility has been constructed at a horizon such that operational and rock-support problems are minimized." This statement underestimates the extent of problems associated with rock stability at the WIPP repository horizon. The lower purer salt horizon, not selected for the repository due to its proximity to the Castile brine reservoir horizon, would most likely have been better with respect to the rock-support problems.

Regulatory Framework

This section should describe the EPA's and the New Mexico Environment Department's regulatory authorities over WIPP.

Page 1-5, line 23

Add the 1992 WIPP LWA as an additional authority to establish and implement regulatory standards.

Page 1-6, line 4

The description of the history of 40 CFR 191 fails to mention that within four days after the standard was vacated in June 1987, New Mexico entered into a formal Consultation and Cooperation Agreement with DOE within four days to act as though the standards were fully in effect. Hence there has been no lost time in the applicability of the 1985 standards through the present.

Evaluating Long-Term Performance

Page 1-9, line 3

The text states that the results of sensitivity analyses will be provided in the final application. Since such analyses were provided in the 1992 iteration, why aren't they available now?

Page 1-11, Figure 1-2

Nothing is shown for backfill nor on the current work on waste form modifications at INEL, ORNL or other sites.

Bibliography

Page 1-15

There are more recent iterations of the SAR than the 1990 version.

CHAPTER 2. SITE CHARACTERIZATION

The EEG provided detailed comments on the site characterization issues discussed in the "Compliance Status Report for the WIPP"[2-1] to the DOE on November 21, 1994. The DOE response of August 23, 1995, essentially reiterated the DOE position on these issues and therefore the issues remain unresolved. The EEG comments on the Compliance Status Report (CSR), which are included as Supplement 1 to this report (pages S1-1 through S1-28), should therefore be viewed as a part of the EEG comments on the DCCA[2-2]. The following comments address additional issues that were not covered in our comments on the CSR.

The Culebra Dolomite Member

Sec. 2.1.3.5.2, Page 2-37

The Culebra Dolomite Member of the Rustler Formation was discussed in Lowenstein (1987)[2-3], and not in Lowenstein (1988)[2-4]. The post-burial alteration of the Rustler Formation should be discussed in this chapter (in Sections 2.1.3.5.2, 2.1.6.2.2, 2.1.6.2.3) as a different interpretation based on the detailed sedimentological study by Lowenstein[2-2]. This interpretation is different from the one presented by Holt and Powers (1984)[2-5] and Holt and Powers (1988)[2-6].

[2-1]U.S. Department of Energy. 1994. *Compliance Status Report for the Waste Isolation Pilot Plant.* DOE/WIPP-94-019 Rev. 0).

[2-2]U.S. Department of Energy. 1995. *Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant.* Draft-DOE/CAO-2056.

[2-3]Lowenstein, T.K. 1987. *Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico.* Santa Fe, NM: Environmental Evaluation Group. EEG-36.

[2-4]Lowenstein, T.K. 1988. Origin of Depositional Cycles in a Permian "Saline Giant": The Salado (McNutt Zone) Evaporites of New Mexico and Texas. *Geological Society of America Bulletin* 100 (4): 592-608.

[2-5]Holt, R.M., and Powers, D.W. 1984. *Geotechnical Activities in the Waste Handling Shaft Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico.* Carlsbad, NM: U.S. Department of Energy. WTSD-TME-038.

[2-6]Holt, R.M., and Powers, D.W. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* Carlsbad, NM: U.S. Department of Energy. DOE/WIPP 88-004.

The statement, "After dolomite, Sewards et al. (1991, p. IX-1) report that clay is the second, most abundant mineral of the Culebr[illegible] [illegible]lay minerals include corrensite, illite, serpentine, and chlorite. Clay occurs in bulk rock [illegible] [illegible]acture surfaces." (DCCA, p. 2-37, lines 33-35)[2-2] is not entirely correct. The actual [illegible]nt is, ". [illegible] the Culebra and Magenta units are primarily dolomite with some quartz and clay ..." (p. IX-1)[2-7]. This is very different than clay being the second most abundant mineral in the Culebra. Of course, some clay signatures were seen in the x-ray diffraction tests [illegible] [illegible]he Culebra rock samples, and some might even be found in fractures. The key question th[illegible] [illegible]mpacts the performance assessment and the application for compliance, however, is, "how much credit may be taken for chemical retardation due to the presence of clay in the fractures and in the rock matrix?" The EEG does not believe that a case has been made to take any credit for retardation due to the presence of clay. This issue was discussed at length in our comments on the Compliance Status Report (pages S1-1 through S1-28 of this report).

Incidentally, the reference for Sewards et al. (1991)[2-7], should be "SAND 87-7036" and not "SAND 97-7036" (p. 2-181, line 2).

Castile Hydrology

Sec. 2.2.1.3.2, Page 2-94

The following facts should be added in this section.

- Brine from the borehole WIPP-12 did flow to the surface at a rate of approximately 350 gallons per minute (22 liters per second). More than 1.14 million gallons (4.3 million liters) of brine "unavoidably" flowed to the surface and was collected in a large pond on the surface before the well was brought under control[2-8].

[2-7]Sewards, T., Glenn, R., and Keil, K. 1991. *Mineralogy of the Rustler Formation in the WIPP-19 Core*. Albuquerque, NM: Sandia National Laboratories. SAND87-7036.

[2-8]Popielak, R.S., Beauheim, R.L., Black, S.A., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. *Brine Reservoirs in the Castile Formation [Waste Isolation Pilot Plant] Project Southeastern New Mexico*. Albuquerque, NM: Sandia National Laboratories. 2 Vols. SAND78-1596, p. H-9.

- Steve Lambert of Sandia National Laboratories disagreed with the Popielak et al.[2-8] conclusion that "these fluids originated from ancient seawater and that there is no evidence for fluid contribution from present meteoric waters." Using the uranium-isotope disequilibrium method of determining the age of entrapment of groundwater, Lambert (in Appendix A of Popielak et al.)[2-8] presented calculated ages of the WIPP-12 Castile brine to be between 45,000 years to 2,000,000 years, for different assumptions of leaching and rate of injection.

- The electromagnetic survey conducted in 1987 indicated the presence of brine in the Castile Formation below the present WIPP repository[2-9].

Hydrology of the Rustler-Salado Contact Zone
Sec. 2.2.1.4, Page 2-95

The discussion in this section is unsatisfactory because it does not make full use of the available facts from WIPP studies. It should be revised.

Chaturvedi and Channell (1985, p. 34)[2-10] pointed out that the data from hydrologic testing at the WIPP site shows that the "brine aquifer" of the pre-WIPP investigators[2-11] extends east of Nash Draw to the WIPP site. Most of the WIPP boreholes have found brine in the Rustler/Salado contact zone and, in fact, the water-level recovery rate after pumping from this

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[2-9]Earth Technology Corporation. 1987. *Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site, Final Report.* Albuquerque, NM: Sandia National Laboratories. SAND87-7144.

[2-10]Chaturvedi, L. and J.K. Channell. 1985. *The Rustler Formation as a Transport Medium for Contaminated Groundwater.* Santa Fe, NM: Environmental Evaluation Group. EEG-32.

[2-11]Robinson, T.W., and Lang, W.B. 1938. *Geology and Ground-Water Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal, New Mexico, with Special Reference to the Salt Content of the River Water.* Twelfth and Thirteenth Biennial Reports of the State Engineer of New Mexico for the 23rd, 24th, 25th, and 26th Fiscal Years, July 1, 1934 to July 30, 1938. Santa Fe, NM: State Engineer.

zone was much faster than the Culebra recovery rate in borehole P-18, east of the WIPP site[2-12].

Mercer (1983, p. 53)[2-13] proposed the possibility of leakage from the overlying Culebra as the source of water in the Rustler/Salado contact zone at the WIPP site. With respect to the rate of movement of brine in the Rustler/Salado contact zone, Mercer (1983, p. 20)[2-13] had this to say:

> The rate of movement in the Rustler-Salado contact residuum at the WIPP site has not been determined because the hydraulic properties are extremely variable and because of the lack of a valid value for the effective porosity.

Since 1983, the focus of the WIPP subsurface hydrology program has been almost exclusively on the Culebra member as the most permeable zone in the Rustler. The Rustler/Salado contact zone should also be considered as a pathway of migration of radionuclides from the WIPP site to the Pecos River.

The Culebra Member of the Rustler Formation
Sec. 2.2.1.5.2, Page 2-99

The subject of the remaining uncertainties in the characterization of fluid flow and transport mechanisms in the Culebra should be addressed in this section.

The postulated groundwater travel time in the Culebra from the WIPP repository area to the accessible environment is between 100 and 1000 years. Current projections of transport showing compliance with 40 CFR 191.13 rely on dilution of concentration by diffusion into the static fluid volume of the rock matrix, and additional chemical retardation along the flow

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[2-12]Mercer, J.W., and Orr, B.R. 1979. *Interim Data Report on Geohydrology of Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico.* Albuquerque, NM: U.S. Geological Survey. Water Resources Investigations 79-98, p. 120.

[2-13]Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico.* Washington, D.C.: U.S. Geological Survey. Water Resources Investigations 83-4016.

path. Furthermore, if channeling, instead of the presently assumed dual porosity, is the dominant mechanism of flow and transport, the retardation will be considerably reduced. Thus, the mechanism of flow and the degree of physical and chemical retardation of radionuclides as they are transported through such flow, are critical issues affecting the outcome of the performance assessment. These issues, along with the description of the seven well field tracer tests and the laboratory tests and how they are expected to resolve the issues, should have been discussed in this section.

The issue of the Culebra water chemistry remains unresolved. A full discussion with respect to the flow directions, vertical seepage, karst, present day recharge and paleo-recharge is needed. Chapman's[2-14] criticism of the basis of dating the Culebra water to be "tens of thousands of years" old (DCCA, p. 2-100, line 24)[2-2] should be included. The EEG has never accepted the concept of the Culebra being "a relict of a flow regime of a wetter climate" (p. 2-100. lines 28-29). Chapman[2-14] clearly argued against accepting that concept. Chapman, Ingraham and Hess[2-15] provide additional support for the Chapman[2-14] arguments against using the enrichment in heavy isotopes in the Carlsbad Caverns pools to date the Rustler water.

Finally, this section should also provide an account of the anomalous rise in the water-levels in the Culebra at and south of the WIPP site and discuss possible mechanisms for this phenomenon. The possible causes mentioned in the WIPP Annual Site Environmental Report for C.Y. 1993 (DCCA[2-2] Vol. IX, App. SER, Sec.7.2, page 7-5) are insufficient to explain the anomalous water level rises.

[2-14]Chapman, J.B. 1986. *Stable Isotopes in the Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP area.* Santa Fe, NM: Environmental Evaluation Group. EEG-35.

[2-15]Chapman, J.B., N.L. Ingraham and J.W. Hess. 1992. Isotopic Investigations of Infiltration and Unsaturated Zone Flow Processes at Carlsbad Caverns, New Mexico." *Journal of Hydrology* 133: 343-363.

The Dewey Lake Redbeds
Sec. 2.2.1.6.1, Page 2-104

Much more information about the occurrence of groundwater in the Dewey Lake Redbeds (DLR) Formation, at and surrounding the WIPP site, is available compared to that presented in this section of the report. The water table at the WIPP site is believed to be in the Dewey Lake Redbeds. Water was observed in the DLR in wells H-1, H-2 and H-3, and in the Air Intake Shaft in the center part of the WIPP site. The well P-9 (H-11 hydropad) produced 25 gallons per minute from the DLR. Wells H-14, P-15, P-17, the Barn well and the Ranch well produce water from DLR. The latest WIPP well to produce water from the DLR is the well WQSP-6A, located between H-1 and H-14. It produced 28 gallons per minute in late 1994/early 1995. The statement, "in the vicinity of the WIPP shafts, the Dewey Lake has not produced water" (DCCA, page 2-104, lines 14-15)[2-2] is incorrect.

The statement, "Hydrologic properties of the Dewey Lake are characterized based on only a few measurements compared to the more extensive data set available for member of the Rustler. As a result, the position of the water table is not well known." (DCCA, p. 2-104, lines 7-9)[2-2] is inexcusable for an important document such as this.

The EEG position is that without an understanding of the basic regional hydrologic parameters of an area, such as the water table and the recharge and discharge areas and amounts, the knowledge about the site is incomplete. The EEG has long advocated studies to obtain knowledge of the basic hydrologic framework of the site. This should be done without further delay.

Groundwater Elevation Measurements in 1991
Sec. 2.2.1.7, Page 2-107

Why does the discussion in this section utilize data only until 1991, when observations on the water levels have continued until now, and the application was prepared in 1995?

The water-level rise at and surrounding the WIPP site is a major issue because it potentially implicates the activities in the oil and gas fields in that area. Much information exists in a

number of Sandia National Laboratories (SNL) Memoranda, and it should be used to rewrite this section.

Surface-Water Hydrology
Sec. 2.2.2, Page 2-108

This section should describe the karst topography and hydrology of the WIPP site and vicinity. See, e.g., Chaturvedi and Channell (1985)[2-10].

Groundwater Discharge and Recharge
Sec. 2.2.3, Page 2-110

The recharge area for the Rustler Formation water at the WIPP site has never been identified. On the basis of potentiometric surfaces, Mercer[2-13] suggested Bear Grass Draw (T.18S, R.30E) and the Clayton Basin as possible areas of recharge. After a detailed study, Hunter[2-16] however, concluded, "Existing data are inadequate to determine evaporation from and recharge to the groundwater system in the vicinity of the WIPP site." Several studies suggested by Hunter[2-16] and endorsed by EEG (Chaturvedi and Channell, 1985, p. 71-74)[2-10] have never been carried out.

Similarly, the discharge area has never been identified. We agree with the general concept (DCCA[2-2] p. 2-113, lines 7-11) that the Culebra probably discharges into the Pecos River and some water may flow into the Balmorhea-Loving trough alluvium. As shown by Chaturvedi and Channell (p. 40-42)[2-10], the hydraulic distinction between the water-bearing zones of the Rustler Formation is obliterated at least 2 miles east of the Livingston Ridge and thus the water flowing into Laguna Grande de La Sal and the Pecos River at Malaga Bend may not be identified as belonging to a particular zone of the Rustler Formation.

[2-16]Hunter, R.L. 1985. *A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area.* Albuquerque, NM: Sandia National Laboratories. SAND84-2233.

Detailed arguments against the use of isotopic data to conclude the slow rate of recharge or the age of the Rustler groundwater (DCCA[2-2], p. 2-113, lines 18-25), have been provided by the EEG in commenting on the WIPP Compliance Status Report[2-1]. Those comments are provided at the end of this chapter.

Resources

Sec. 2.3, Page 2-113, line 34

The opening sentence incorrectly states that the section refers only to resources beneath the WIPP Site. The section also refers to resources adjacent to the WIPP Site.

Page 2-113, lines 35 through 37

The definitions for the terms *resources* and *reserves* are given without reference. On the next page the DCCA then ignores its own convention and randomly interchanges the words *reserves* and *resources*.

Page 2-114, lines 1 through 6

The definitions for the terms *proven reserves, probable reserves* and *possible reserves* are incorrect. The correct terms are proved reserves, probable resources, and possible resources (See Figure 1).

The DCCA definitions are given without reference and are inconsistent with the definitions used in Broadhead et al.[2-17], as discussed below.

[2-17]Broadhead, R.F, Luo, F. and Speer, S.W. 1995. Oil & Gas Resource Estimates, Chapter XI, in *Evaluation of Mineral Resources at the Waste Isolation Pilot Plant Site, New Mexico Bureau of Mines and Mineral Resources*. Carlsbad, NM: Westinghouse Electric Corporation.

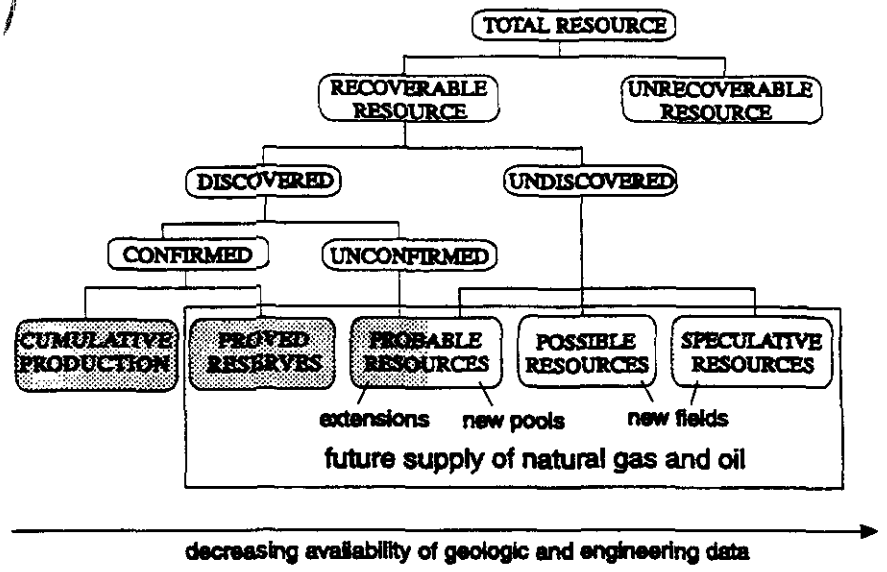

Figure 1. Oil and natural gas resource categories. After Broadhead et al., 1995.[2-17]

Proved Reserves

DCCA definition: For hydrocarbons, *proven reserves* can be expected to be recovered from new wells on undrilled acreage or from existing wells where a relatively major expenditure is required to establish production.

NMBM&MR definition: *Proved reserves* are an estimated quantity of crude oil, natural gas condensate, or natural gas that analyses of geologic and engineering data demonstrate with reasonable certainty to be recoverable in the future form discovered oil and gas pools. Pools are considered proved that have demonstrated the ability to produce by either actual production or by conclusive formation tests[2-17], that is by drilling. This report restricts the definition proved reserves to those producible resources identified as producible by existing wells (whether currently producing or abandoned).

Probable Resources

DCCA definition: *Probable reserves* refer to reserves of hydrocarbons suspected of existing in certain locations based on favorable engineering and/or geologic data.

NMBM&MR definition: *Probable resources (extensions)* consist of oil and gas in pools that have been discovered but have not yet been developed by drilling; their presences and distribution can generally be surmised with a high degree of confidence. *Probable resource (new pools)* consist of oil and gas that are surmised to exist in undiscovered pools within existing fields.

Possible Resources

DCCA definition: *Possible reserves* are based on condition where limited engineering and/or geologic data support recoverable potential.

NMBM&MR definition: *Possible resources* are less assured; they are postulated to exist outside known fields but within productive stratigraphic units in a productive basin or geologic province.

Extractable Resources
Sec. 2.3.1, Page 2-117, line 22

Rather than refer to the United States Geological Survey (USGS) for established grades of potash, it might be better to refer to the U.S. Bureau of Land Management (BLM).

Page 2-117, lines 23 through 26.

The DCCA appears to be making a policy statement that has already been challenged by the BLM. The DCCA maintains that the USGS assumes that the "lease" and "high" grades comprise reserves because some lease-grade ore is mined in the Carlsbad Potash District. Most of the potash that is mined, however, is better typified as the high grade. Even the high-grade resources may not be reserves, however, if their properties make processing

uneconomic. The BLM policy with respect to leasing criteria was recently reiterated in the October 12, 1995, letter from the BLM District Manager[2-18]. The BLM currently uses a leasing criteria of a minimum thickness of 4 feet and an ore grade of 4% K_2O for Langbeinite and 10% for Sylvite as a measure of the quality of potash ore. In use since they were established in 1969 by the USGS, these standards are still effective today. Our records show that during the last five years a significant amount of sylvite ore has been mined at or below the 10% minimum standard. This is also true for langbeinite, meaning the ore is being mined at or below the 4% minimum standard.

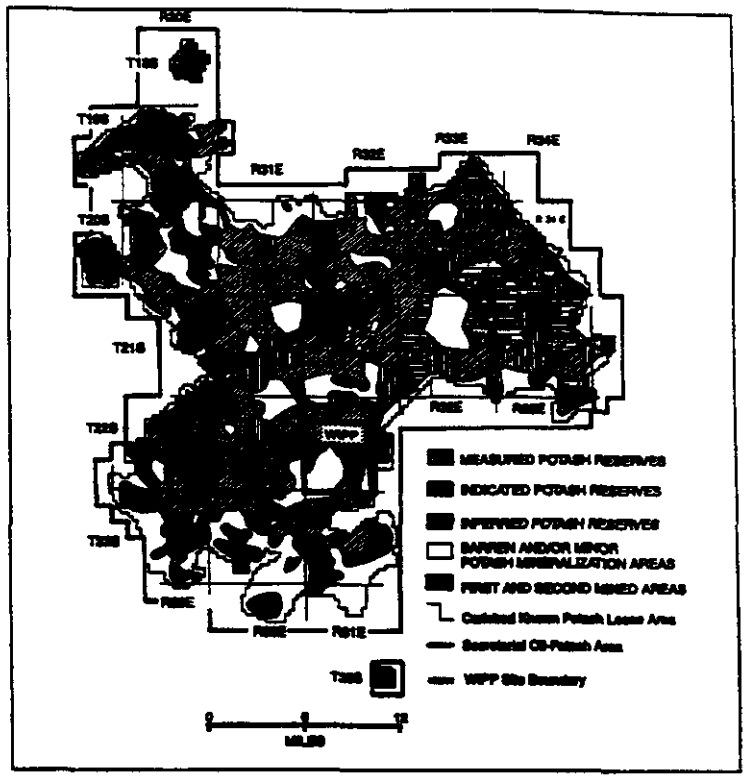

Figure 2. Potash resources. Adapted by M.K. Silva, EEG, from J.A. Olsen, 1993, Federal Management of the Potash Area in Southeastern New Mexico, in *New Mexico Geological Society Forty-Fourth Annual Field Conference, October 6-9, 1993: Carlsbad Region, New Mexico and West Texas*, pp. 39-41. Socorro, NM: New Mexico Geological Society.

Page 2-117, line 34 and Table 2-5.

It appears that the quantities of potash summarized by this table are incorrect and do not reflect the higher quantities considered by the BLM to be reserves as a matter of official policy. The discussion would benefit from maps of the potash resources such as that prepared by Griswold and Broadhead et al.[2-17], and those prepared by Silva for the June 13, 1995, EEG Workshop on waterflooding as shown in Figures 2 and 3.

[2-18]Cone, L.M., Roswell District Manager, BLM. 1995. October 12 letter to G. Griswold.

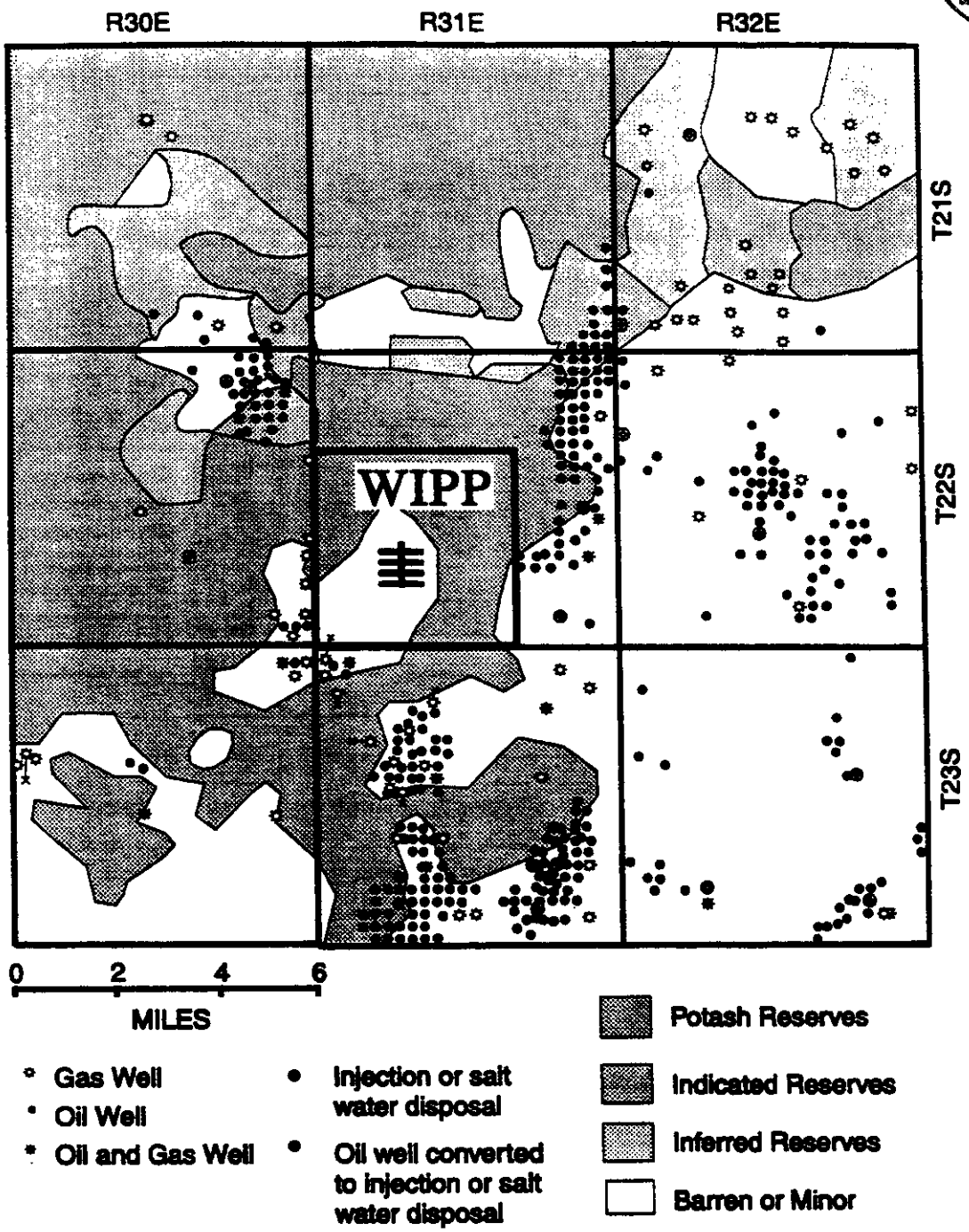

Figure 3. Oil and gas wells restricted from drilling through potash resources. Prepared by M.K. Silva (EEG).

Hydrocarbon Resources at the WIPP Site
Section 2.3.1.2, Page 2-118

The section on hydrocarbon resources would benefit from a presentation of a map of current well locations and a map of existing oil and gas wells and applications for permit to drill as indicative of the interest of the oil and gas industry (Figures 4 and 5). The 1995 summary of previous evaluations by Broadhead et al.[2-17] is mentioned in this section but the 1994 summary and analysis by Silva[2-19] is not mentioned. Proper citation procedure dictates citing Silva[2-19]. It would also be worthwhile to provide a map of proven and probable reserves for the various formations such as those contained in Broadhead et al.[2-17].

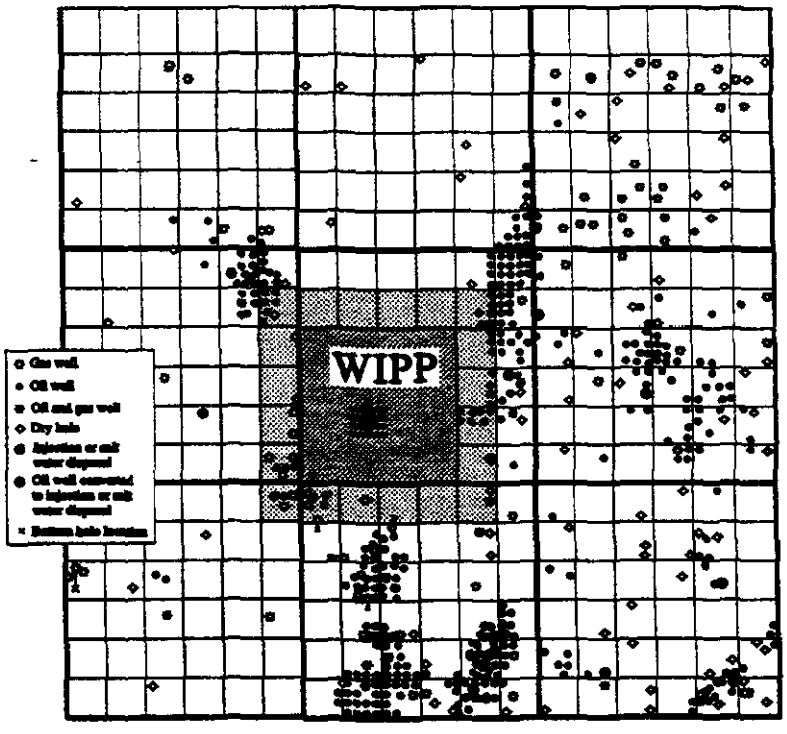

Figure 4. Oil, gas, and injection wells in nine-township project study area. Adapted from Broadhead et al.[2-17] by Matthew Silva (EEG).

[2-19]Silva, M.K., 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP*. Albuquerque, NM: Environmental Evaluation Group. EEG-55.

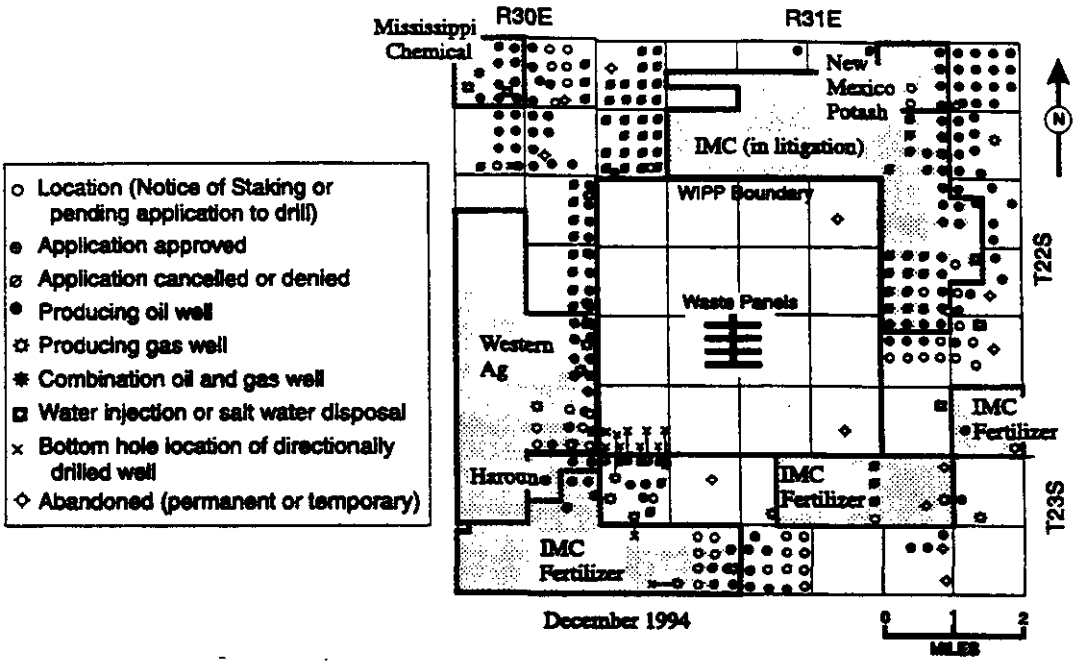

Figure 5. Resource activity and interest in the immediate vicinity of WIPP. Prepared by M.K. Silva (EEG).

Environmental Monitoring

Page 2-133, lines 2-8

The DCCA[2-2] states that WIPP has conducted a radiological monitoring program to "...determine the widespread impacts of nuclear tests at the Nevada Test Site and to evaluate the effects of Project Gnome." The WIPP environmental monitoring program has not included soil, water, biota or air particulates collected from the Gnome site. The only DOE work in the vicinity of the Gnome site was an April 1988 aerial gamma survey. Although the survey detected elevated gamma activity from ^{137}Cs, the presence of other radionuclides such as ^{241}Am, ^{238}Pu and $^{239,240}Pu$ was not detected. The EEG has measured these actinides at the Gnome site and published a report[2-20] in 1995.

[2-20]Kenney, Jim W., Paula S. Downes, Donald H. Gray, and Sally C. Ballard. 1995. *Radionuclide Baseline in Soil Near Project Gnome and the Waste Isolation Pilot Plant.* Albuquerque, NM: Environmental Evaluation Group. EEG-58.

Incorrect Measured Concentrations of Radionuclides
Page 2-137, Table 2-9

The reported concentration of 7.2×10^{-4} Bq/g (19.4 pCi/l) of ^{137}Cs in the water samples from water wells around the WIPP site exceeds levels measured elsewhere in the U.S. Similarly, the reported concentration of 12×10^{-4} Bq/g (32.4 pCi/l) for ^{60}Co appears to be incorrect. In addition, all the reported minimum detection levels (MDL) appear needlessly high. For example, the MDL for ^{90}Sr is considerably lower than the reported value of 7.4×10^{-4} Bq/g (20 pCi/l). EEG has an MDL for ^{90}Sr of 0.5×10^{-4} Bq/g water.

Historic Climate Conditions
Sec. 2.5.1, Page 2-137

There appear to be significant recent scientific advances in the area of reconstruction of the past climatic changes that have not been reported in this section. The EEG is conducting a review of the most current scientific literature in this area and will provide the results of that review in due course.

Seismology
Sec. 2.6, Page 2-143

It appears that the seismicity concerns are mainly for the short-term during the operational period, rather than the long-term (10,000 years). We have provided comments on this subject in our January 17, 1996 review of the Safety Analysis Report. If long-term safety concerns due to postulated earthquakes at the site are identified during our continued review of this topic, we will comment on it later.

Rock Geochemistry

Sec. 2.7, Page 2-151

The last paragraph of this section should be updated to reflect much additional experimental and modeling work on the occurrence of brine in the Salado salt, that has been performed since the publication of the Geologic Characterization Report (GCR)[2-21] in 1979. The baseline position paper by Howarth et al.[2-22] provides a summary of the WIPP project position on this subject and should be used to update this section.

[2-21]Powers, D.W., S.J. Lambert, and S.E. Shaffer. 1978. *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* Albuquerque, NM: Sandia National Laboratories. SAND-78-1596/2 vols.

[2-22]Howarth, S. et al. 1994. *Salado Formation Fluid Flow and Transport Containment Group-White Paper for Systems Prioritization and Technical Baseline*, Rev. 1. Carlsbad, NM: U.S. Department of Energy.

CHAPTER 3. FACILITY DESCRIPTION

Need for more information

The DOE should document the process of demonstrating compliance with the EPA regulations for the management and storage of transuranic waste, contained in Subpart A of 40 CFR 191.

This chapter should describe the important features of the WIPP facility and the operational safety issues, at least those that relate to radiological safety. We realize that the Safety Analysis Report is the primary publication dealing with such issues, but at least a brief description in this chapter would be very beneficial. Such a description should cover at least the following topics:

- A description of the various components of the surface and underground facilities that play a role in the safe handling of the waste from unloading to emplacement in the repository. This discussion should include, for example, the safety features of the waste handling building and either why any accidents involving radioactive material are not likely to happen or what provisions have been made for a quick cleanup if such an event occurs. A discussion of the probability of waste hoist accidents should also form a part of this description.

- A description of the waste handling procedures, from unloading the TRUPACT-II to emplacement underground.

- A description of the underground facilities, including the mining and radiological safety issues. This should include a discussion of the safety of the Panel 1 and approach drifts, operation of continuous air monitors, maintenance operations for mining safety, and measures expected to be taken to keep the operations safe for 35 year operational life of the facility starting in 1998.

- Plans for waste emplacement. This discussion should include the expected rate of waste arrival, initially and later for 35 years; expected time to fill the 7 rooms of Panel 1; plans for emplacement of backfill; plans for closing the entry to each room and the panel; ventilation provisions at various stages; plans for carrying out the maintenance operations such as rockbolt detensioning during the emplacement operation; plans for emplacing the remote-handled TRU (RH-TRU) waste, including the date of first arrival and expected rate; description of the "panel closure system" (previously called the panel seals) as shown in Fig. 3-1 of DCCA[3-1], etc.

- The DCCA does not discuss the continuous air monitoring (CAM) systems currently in use at the WIPP. These CAM systems are an important part of the defense in depth philosophy at WIPP. The FSAR[3-2] classifies the repository CAMs as class IIIA and the Station A CAM as class II. Such important systems should be included in the DCCA repository configuration.

  DOE and the "Energy Systems Laboratory" at Texas A&M University have developed the use of a shrouded probe for single point aerosol sampling. This EPA approved shrouded probe is used in the repository and in the exhaust duct systems to deliver a representative particulate sample to the CAM system at WIPP. The shrouded probes should be identified as a part of the repository configuration in the DCCA.

- This chapter should include a discussion of the impact of abandoning the experimental area north of the shafts, without backfill and without sealing the boreholes that were drilled up to 50 ft above and below the excavated area.

[3-1]United States Department of Energy. 1995. *Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant. Draft-DOE/CAO-2056.*

[3-2]U.S. Department of Energy. 1990. *Final Safety Analysis Report, Waste Isolation Pilot Plant.* WP 02-9.

Waste emplacement requirements
Page 3-1, line 20

In addition to meeting the requirements of the definition of TRU and those that can be certified to the WAC, the TRU waste must also meet the NRC shipping criteria, the RCRA requirements, and approval by EPA.

Time to emplace waste
Page 3-1, line 32

The 25 year waste emplacement period was revised by the DOE in October 1995 to 35 years. The impact of this change does not appear to have been addressed.

WIPP design criteria
Page 3-5, line 6

Although the design criteria in DOE Order 6430.1, General Design Criteria, were applied to the WIPP, DOE is reevaluating the facility in the context of DOE Order 5480.23, April 1992; new DOE safety analysis report guidelines; and 10 CFR 835. The DOE Implementation Plan[3-3], calls for the rewriting and approval of a new disposal phase safety analysis report (SAR), and the disposal phase SAR is not complete. Particular concerns are the DOE regulations and the New Mexico Consultation and Cooperation Agreement, requiring worker and public dose assessments. The dose assessments are a necessary prerequisite to facility risk classification. Before final classification of facilities and structures, the disposal phase SAR must be completed and approved.

[3-3]U.S. Department of Energy. 1994. *Implementation Plan for the FY-95 Annual Update of the WIPP Safety Analysis Report for the Disposal-Phase Operations.* Revision 1.

Self-regulation

Page 3-5, lines 5-36

The approval of the design, the construction and documentation of safety of the DOE WIPP facility is by the DOE Carlsbad Area Office. The system should require approval by another DOE organization such as the Office of Environment Safety and Health.

Engineered barriers

Page 3-9, Sec.3.3

The text states that the design includes engineered barriers that significantly delay the migration of waste. The barriers are not identified nor are calculations presented quantifying the significant delay. The EEG does not consider the panel and shaft seals to be engineered barriers because they represent, at best, an imperfect attempt to undo the damage done to the natural environment by excavation and will not "prevent or substantially delay movement of water or radionuclides toward the accessible environment" any more than the natural environment would have. The definition of *barrier* in 40 CFR 191.12 includes, as examples, "a geologic structure, a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste, provided that the material or structure substantially delays movement of water or radionuclides." This definition does not include panel and shaft seals. This point was clarified by the EPA in 1987, as follows:

> It is EPA's intention that a barrier is a material or structure that prevents or substantially delays the movement of water in all directions emanating from the radionuclides in the waste. This would include at least the waste form, the canister overpack, and the geologic formation. While we encourage any added protection, even if not meeting these requirements completely, *it would not include items such as room and shaft seals*[3-4]. (Italics added).

[3-4]Meyers, S. 1987. May 22 letter from S. Meyers, Director, Office of Radiation Protection, EPA, to G.A. Smithwick, Principal Deputy Assistant Secretary, DOE/ES&H.

The DOE should use proper engineered barriers at WIPP, such as stabilizing waste in a low-solubility waste-form, robust containers, and engineered backfill. All references to the shaft seals as engineered barriers should be deleted from the DCCA and other documents.

Seals and Plugs
Page 3-9, Sec. 3.3.1

This section should be renumbered so that it is not a subsection of the Engineered Barriers section.

The DOE will have to demonstrate, through use of experimental data, that the postulated lowest value of the permeability of the seal system used in the performance assessment for assessing compliance with 40 CFR 191 as well as the No Migration Variance Petition, will be met. To the extent that the DCCA has not demonstrated it, this section is incomplete.

Upper salt column
Page 3-16, line 14

What is the basis for concluding that the upper salt column has no compliance related requirements?

Recompaction of salt
Page 3-16, lines 17, 21, and 34

A number of statements predict the performance of the salt column (80% of density produces intact salt permeability, 85% density results in permeability nearly equivalent to intact WIPP host rock salt), but no supporting evidence is provided.

Lower salt column

Page 3-21, lines 16-19

"Because of uncertainty regarding the marker beds and clay seams in the vicinity of the shaft station, efficient sealing functions are not currently modeled in the performance assessment for either the lower shaft salt component or the shaft station concrete monolith."

When and how will this be done?

Plugging of Boreholes

Page 3-21 to 3-25, Table 3-2

The DOE had planned to develop special borehole plugging procedures for boreholes at the WIPP site. It now appears that conventional plugging procedures for commercial wells will be followed.

The reference to the Christensen and Peterson paper[3-5] (page 3-21, line 35) is made in a wrong context. They do not provide "an evaluation of all vertical penetrations". Christensen and Peterson[3-5] and several other reports and papers by them and their colleagues at Sandia National Laboratories provide the results of research conducted under the Sandia Borehole Plugging Program (BHP), a program "specifically designed to support plugging activities for the proposed Waste Isolation Pilot Plant"[3-5] (Foreword).

This section (3.3.3 Borehole Plugs) should describe the results and recommendations of the BHP and should describe the plans and schedule of plugging the boreholes in the WIPP site area.

[3-5]Christensen, C.L. and E.W. Peterson. 1981. Field-Test Programs of Borehole Plugs in Southeastern New Mexico. In *The Technology of High-Level Nuclear Waste Disposal Advantages in the Science and Engineering of the Management of High-Level Nuclear Wastes*, edited by P.L. Hofman and J.J. Breslin. Oak Ridge, TN: U.S. Department of Energy. DOE/TIC-4621, vol. 1: 354-369 and SAND79-1634C.

The statement, "Only ERDA-9 is drilled to the repository horizon, near the WIPP underground" (page 3-21, lines 26-27) is incorrect. First, the borehole ERDA-9 was drilled to a total depth of 2887 ft, 51 ft into the Castile Formation and 737 ft below the repository horizon. Secondly, there are six boreholes within the WIPP site (ERDA-9, WIPP-12, WIPP-13, DOE-1, Badger Federal, and Cotton Baby), and at least ten just outside the WIPP site boundary, that are deeper than the repository horizon.

CHAPTER 4. WASTE DESCRIPTION

The material in this chapter does not indicate that there are problems in describing the physical, chemical and radiological characteristics of the waste to be emplaced in the repository. DOE states that the chapter documents the characteristics of the waste and provides the bases for the compliance assessments. However, the statement appears on page 4-1, line 9, "Assessments of the performance of the repository are based on assumed characteristics of the waste to be emplaced in the WIPP." [underline added]. The project has yet to identify which waste parameters are significant to compliance (page 4-8, line 21) and specific characterization techniques to determine these parameters have not yet been developed (page 4-8, lines 25-26). Furthermore, the estimated quantities of waste shown in this Chapter do not match values listed in the Baseline Inventory Report (Volume III, App. BIR).

Conflicting Information on the Purpose of the Baseline Inventory Report

The DOE's September 14, 1995, (pages 14 and 15) comments to EPA on the proposed 40 CFR 194 argue for general waste characterization requirements rather than specific waste characterization requirements, citing the Transuranic Waste Baseline Inventory Report as an example of general waste characterization. But the DCCA specifically states that the WIPP Baseline Inventory Report is not a waste characterization document (page 4-2, line 22). Which document specifies the waste characterization requirements of the WIPP?

RH-TRU Waste
Page 4-3, line 16

The DCCA suggests that the amount of RH-TRU is a small percentage of the WIPP TRU inventory. While this is true by volume, the RH-TRU waste is 37% of the total radioactive inventory according to the B.I.R. (Vol. III, page 4-11), and 33% of the total according to Volume I, page 4-15.

The inventory shown in Table 4-1 (page 4-4) does not agree with the inventory shown in Table 4-1 (page 4-5) of the Baseline Inventory Report published in Volume III, the supporting appendix (BIR). The RH-TRU projected inventory has varied widely over the years, as shown at the right[4-1] (Figure 6). DOE should make an effort to explain why the latest values are correct. Rev. 1 of the BIR increased the RH-TRU inventory by a factor of 3 to 4 and Rev. 2, December 1995 (received 2/9/96) increases the RH-TRU inventory by a factor of 5.6 over Rev. 1 to 27.000 m^3, considerably larger than the existing design capacity of 7080 m^3 for the RH-TRU.

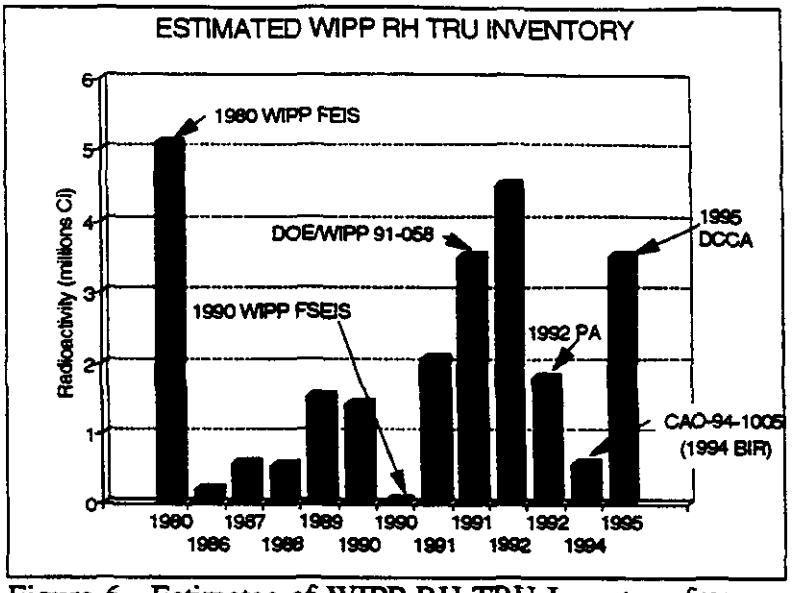

Figure 6. Estimates of WIPP RH-TRU Inventory from 1980 to 1995.

The term "Newly Generated Waste" in Table 4-1, (page 4-4) implies that the waste exists. Since it does not exist, the term "yet to be generated" would be more appropriate.

Actinide Inventory

Page 4-5, line 16

While the list of radionuclides identifies all of them as actinides, ^{90}Sr and ^{137}Cs are not actinides.

[4-1]Silva, M.K and R.H. Neill. 1994. *Unresolved Issues for the Disposal of Remote Handled Transuranic Waste in the Waste Isolation Pilot Plant*, figure 1. Albuquerque, NM: Environmental Evaluation Group, EEG-56.

Waste Acceptance Criteria

Page 4-6, line 22

This section states the objectives of the WAC.

> The primary objectives of the WAC are: (1) to ensure that all TRU wastes are packaged so that handling and subsequent disposal can be performed safely, and (2) to maintain the repository's ability to isolate the waste. Emphasis added.

But in two instances (page 4-6, lines 16 and page 4-7 line 11) DOE states that the existing and current WAC does not include the second objective listed above.

> The current WAC are based on transportation requirements and safe handling and storage criteria. If required, long-term performance-based WAC will be applied to the WIPP inventory baseline when the overall assessment of the disposal system's performance is complete.

The final Waste Acceptance Criteria have not yet been published. Further, the transportation criteria for RH-TRU have not been submitted to NRC for review and approval. The most recent WIPP Disposal Decision Plan, dated October 6, 1995[4-2], indicates that due to delays at DOE Headquarters, the transportation Safety Analysis Report for Packaging (SARP) will be sent to NRC in September 1996 rather January 1996. Current waste acceptance criteria can not be based on RH-TRU transportation criteria because there are none. Further, the waste acceptance criteria are based in part on transportation requirements and cannot be completed until the NRC completes its review of the SARP, which will not even be provided to the NRC by the DOE until September 1996. DOE notified EEG in November 1995 that the WAC were being revised.

[4-2]Dials, G.E., Manager, DOE Carlsbad Area Office. 1995. October 12 letter of transmittal with *WIPP Disposal Decision Plan*, Rev. 2, October 6, 1995, to R.H. Neill, Director, Environmental Evaluation Group.

Performance Based Waste Acceptance Criteria
Page 4-7, line 15

While the text states that the performance based waste acceptance criteria (PBWAC) identify the bounding characteristics of waste for repository performance, there are no published performance based WAC and this program has not yet been developed. It appears that for this draft application, the DOE has not done the calculations to determine the impact of various waste parameters. As part of the draft application, the DOE appears to be relying on a yet to be specified PBWAC to assure compliance. Without the calculations and a detailed PBWAC program, it is not possible to assess the contributions and limitations of these yet to be determined criteria. PBWAC is not even defined in the Glossary, Chapter 8, Vol. III.

Waste Characterization Program
Page 4-8, line 10

The discussion in this section indicates that the project has not yet identified which specific waste parameters are important to compliance, and if found to be important, they will be developed. This section also mentions a yet to be published load management alternative "to ensure the proper mix of waste forms on both panel and room scales." (line 27). If such a load management plan exists, please reference it. The paragraph suggests there may be problems with some waste characteristics. If so, what are they?

Accountability of Radioactivity
Page 4-8, line 19

The sentence, "The DOE must account for more than 1% of the total activity in the container, prior to shipment to WIPP." appears incomplete.

Waste Streams

Page 4-8, line 30

This section describing waste streams should either provide the details or a reference for specific information. It does note that categorizing wastes in specific streams is based on the availability of information.

There are questions on the availability of information, particularly RH-TRU waste. As observed by previous studies at generator/storage sites, records on RH-TRU waste are scarce (Jensen and Wilkinson, 1983, p. 91) and actual data on stored RH-TRU waste are minimal (Stewart et al., 1989).

Recent reports from the generator/storage sites strongly suggest that reliable information is not available for many waste streams. For example, a recent report on the feasibility of treating TRU waste at Oak Ridge National Laboratory states:

> Uncertainties in the characterization—isotopic, physical, and chemical—of TRU waste affect operation and maintenance costs, the retrieval method, processing options, and disposal locations. TRU waste streams at ORNL are not as yet fully characterized. Moreover, there are uncertainties in the characterization data available for TRU waste sludge. Isotopic data are based on best available sample obtained in single-point sampling of only 8 of the 13 BVESTs and MVSTs.[4-3] Detailed physical data such as particle size, hardness, viscosity, and particle distribution are unknown. Chemical data on tank contents are not completely known. To a lesser extent, uncertainties also exist in available characterization data on TRU waste solids. Generally data are available on the physical and radiological content of remotely and contact-

[4-3]Three types of TRU waste stored at ORNL were included in the study: (1) 225,000 gallons of RH-TRU waste stored in eight 50,000 gallon Melton Valley Storage Tanks (MVSTs) and five 50,000 gallon Bethel Valley Evaporator Storage Tanks (BVESTs); RH-TRU waste stored in approximately 300 concrete casks, 2 steel drums, and 13 wooden boxes, and; (3) CH-TRU waste stored in 2600 drums and 60 boxes.

handled TRU waste solids, but there are numerical disparities within this documentation.[4-4]

The DOE has access to this site information and should provide it as part of the application, rather than settle for a statement in the WIPP Baseline Inventory Report, such as:

> The number and types of documents can very greatly from site-to-site so it is impractical to list them as references in this document[4-5].

It is unclear why the "completeness of documentation" (page 4-9, line 11) determines the uncertainty assigned to process knowledge. The Baseline Inventory Report was developed from "best available information and process knowledge."[4-6] According to the DOE Glossary, Vol. III, process knowledge is a qualitative evaluation of the contents of a waste container through study of existing records of production history of the waste. Best available information includes on-site documents and records. In considering the limits of reliability, it is important to remember that documents and records are derived from sources including "...interviews with existing and former workers...".[4-7]

It seems that the statistical analyses of measured waste characteristics rather than the completeness of documentation would be a more scientific and defensible approach to quantifying the reliability and uncertainty in process knowledge. In general, a statistical

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[4-4]Parallax, Inc. 1995. *Feasibility Study for Processing ORNL Transuranic Waste in Existing and Modified Facilities, Management Summary.* Oak Ridge, TN: Lockheed Martin Energy Systems, Inc.

[4-5]U.S. Department of Energy. 1995. *Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant*, vol. III, Appendix BIR vol. 1, section 2.2.1, DRAFT-DOE/CAO-2056.

[4-6]U.S. Department of Energy. 1995. *Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant*, vol. III, Appendix BIR vol. 1, section 1.2, DRAFT-DOE/CAO-2056.

[4-7]U.S. Department of Energy. 1995. *Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant*, vol. III, Appendix BIR vol. 1, section 2.2.1, DRAFT-DOE/CAO-2056.

analysis should first determine the number of samples needed from each waste stream population. The waste inventory and the characteristics for a waste stream should be determined by process knowledge and be recorded prior to sampling. Then the selected waste containers from each stream would be characterized by a physical sampling program to determine the contents of each container. From the measurements of the physical contents, the statistics for that waste stream, including uncertainty (variance or standard deviation), could be calculated. The inventory, as determined by process knowledge, could be compared with the statistics to determine if process knowledge represents the same population.

RH-TRU waste forms

Page 4-12, line 7

The DCCA incorrectly states: "Free liquid or particulate wastes are not associated with processes that generate RH-TRU waste."

For example, in a report on unresolved issues with RH-TRU waste, the EEG notes there are 1900 cubic meters (500,000 gallons) of TRU contaminated liquids and sludges in underground tanks.[4-8,4-9] There are 225,000 gallons of RH-TRU waste stored in eight 50,000 gallon Melton Valley Storage Tanks and five 50,000 gallon Bethel Valley Evaporator Storage Tanks[4-10].

[4-8]Silva, M.K. and R.H. Neill. 1994. *Unresolved Issues for the Disposal of Remote Handled Transuranic Waste in the Waste Isolation Pilot Plant.* Section 3.1. Albuquerque, NM: Environmental Evaluation Group, EEG-56.

[4-9]U.S. Department of Energy. 1991. *Recommended Strategy for the Remote-Handled Transuranic Waste Program.* DOE/WIPP 90-058, Rev. 1, p. 4-2.

[4-10]Parallax, Inc. 1995. *Feasibility Study for Processing ORNL Transuranic Waste in Existing and Modified Facilities, Management Summary.* Oak Ridge, TN: Lockheed Martin Energy Systems, Inc.

Free Liquid Content

Page 4-12, line 14

The project relies on real time radiography to determine the presence of free liquids, which are prohibited by the Waste Acceptance Criteria. While the DCCA notes that drums have been excluded from the WIPP program due to non-conformance with the criteria of no free liquids, the DCCA fails to mention that real time radiography is limited. It is well documented that real time radiography can not detect all free liquids. For example, the visual examination of WAC certified drums for the bin test turned up a drum that contained a full can of free liquid, which was a flammable volatile organic compound[4-11]. The DOE response stated:

> The second concern expressed in your letter was that real time radiography (RTR) did not detect the "flammable organic compounds which were in liquid form." I am sure you are clearly aware the RTR is essentially an x-ray and cannot be used to assess the flammability of any compounds, liquid or solid. The fact that the RTR cannot distinguish between a completely full can or completely empty can is an acknowledged limitation. All measurement technologies have limitations. In the case of RTR, these limitations are known and understood. RTR error is anticipated and is accepted in the same way that all measurement technologies occasionally produce a result outside the accepted confidence interval. We continue to evaluate RTR at the sites where it is used and, through the Interface Working Group on Non-Destructive Evaluation, we will continue to make appropriate enhancements to this and other measurement systems[4-12].

[4-11]Neill, Robert H., Director, Environmental Evaluation Group. 1992. Letter of July 29 to W. J. Arthur III, WIPP Project Integration Office.

[4-12]Arthur, W.J., WIPP Project Director, WIPP Integration Office. 1992. Letter of October 29 to R.H. Neill, Director, Environmental Evaluation Group.

The DCCA should discuss these RTR limitations and provide the references to published reports reflecting the commitment to the continued evaluation of RTR at the sites subsequent to 1992.

Analytical Methods
Page 4-15, line 10

The limitations of each analytical method, radioassay, non-destructive examinations such as real time radiography, and, visual examinations should be discussed in detail with supporting references. For example, there is no system in place to radioassay RH-TRU waste.

Visual Examinations
Page 4-16, line 14

This section cites a miscertification rate of only 2 percent at the INEL. Further, the DCCA claims that this miscertification includes all WAC and Transuranic Package Transporter (TRUPACT)-II Authorized Methods for Payload Control (TRAMPAC) criteria, not just the presence of free liquids. This claim doesn't match data provided in the DOE's annual reports to the EPA on the TRU waste characterization efforts for the now abandoned bin tests. Out of 80 drums selected from a WAC certified population at INEL, 46 failed to meet the WAC and/or the TRAMPAC for a miscertification rate of 58%. The list of excluded drums from the annual report[4-13] to the EPA is shown below (Table 1). The observation tends to support the notion of requiring a thorough characterization as the EPA did for the No-Migration Determination for the Bin Test Program.

[4-13]U.S. Department of Energy. 1993. *No Migration Determination Annual Report for the Period September 1992 through August 1993.* DOE/WIPP 93-062.

TABLE 1. MISCERTIFIED DRUMS EXCLUDED FROM USE IN BINS

Drum Number	Bin Number	Nonconformance	Reason for Exclusion
RF004500559	IDRFBN9100001	Contained U-235[1]	Not applicable
RF002800598	IDRFBN9100001	Contained free liquid	WIPP WAC
RF001902106	IDRFBN9100004	Possible pressurized container	WIPP WAC
RF003101490	IDRFBN9100004	Possible pressurized container	WIPP WAC
RF005400341	IDRFBN9200005	Contained free liquid	WIPP WAC
RF005500375	IDRFBN9200005	Excessive decay heat	TRUPACT-II C of C
RF002800659	IDRFBN9200005	Excessive decay heat	TRUPACT-II C of C
RF000241353	IDRFBN9200005	Excessive decay heat	TRUPACT-II C of C
RF002201038	IDRFBN9200005	Excessive decay heat	TRUPACT-II C of C
RF002800703	IDRFBN9200005	Excessive decay heat	TRUPACT-II C of C
RF002301549	IDRFBN9200005	Less than 100 nCi/g	WIPP WAC
RF003100946	IDRFBN9200005	Less than 100 nCi/g	WIPP WAC
RF001901607	IDRFBN9200005	Possible pressurized container	WIPP WAC
RF001901991	IDRFBN9200005	Excessive decay heat	TRUPACT-II C of C
RF000239134	IDRFBN9200005	Excessive decay heat	TRUPACT-II C of C
RF000108833	IDRFBN9200006	Contained free liquid	WIPP WAC
RF074403825	IDRFBN9200006	Drum flammable VOC[2] >500 ppm	TRUPACT-II C of C
RF000237798	IDRFBN9200006	Excessive decay heat	TRUPACT-II C of C
RF002302673	IDRFBN9200006	Excessive decay heat	TRUPACT-II C of C
RF002202850	IDRFBN9200006	Excessive carbon tetrachloride	NMD
RF001908888	IDRFBN9200006	Excessive decay heat	TRUPACT-II C of C
RF001905358	IDRFBN9200006	Excessive decay heat	TRUPACT-II C of C
RF002203352	IDRFBN9200006	Excessive decay heat	TRUPACT-II C of C
RF001905574	IDRFBN9200006	Excessive decay heat	TRUPACT-II C of C
RF001215294	IDRFBN9200006	Excessive decay heat	TRUPACT-II C of C
RF002500316	IDRFBN9200006	Excessive decay heat	TRUPACT-II C of C
RF074403768	IDRFBN9300007	Contained free liquid/	WIPP WAC
		Excessive decay heat	TRUPACT-II C of C
RF005500406	IDRFBN9300007	Less than 100 nCi/g	WIPP WAC
RF074403890	IDRFBN9300007	Contained free liquid	WIPP WAC
RF000108844	IDRFBN9300007	Less than 100 nCi/g	WIPP WAC
RF074403907	IDRFBN9300007	Contained free liquid	WIPP WAC
RF074403900	IDRFBN9300007	Contained free liquid	WIPP WAC
RF074403740	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C

RF001901846	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF002500319	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF000210253	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF002500321	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF001901850	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF001901849	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF001904355	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF001904149	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF001905199	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF000210256	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF000108870	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF001905261	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C
RF001905674	IDRFBN9300007	Excessive decay heat	TRUPACT-II C of C

[1]At present, INEL is not capable of certifying drums suspected of containing, or determined to contain, U-235.
[2]Usage of the TRUPACT-II prohibits the transportation of containers exceeding the 500 ppmv limit. For this reason, Drum RF074403825 was excluded from Bin IDRFBN9200006.

CHAPTER 5. QUALITY ASSURANCE

Overview

While a compliance application should show evidence that specified requirements have been met, the material in this chapter does not address the requirements of 40 CFR 191, and specifically states that it does not address the proposed 40 CFR 194 QA requirements.

This chapter is mostly a description of the conceptual framework of the current CAO QA program. Many of the sentences seem to be simply lifted from NQA-1 or other such documents, with the verb "shall be" replaced by "is" or "are".

Model Validation

There is no discussion of model validation, which is vital to demonstrating compliance with the containment requirement through performance assessment. A detailed QA process is needed for performance assessments with a complete discussion of plans for model validation.

This chapter does not mention quality assurance for analysis. The Sandia procedures for analysis, choice of parameter values, performing calculations, and software quality control are only peripherically mentioned on the last page of Chapter 5.

Comparison of Chapter 5 (QA) and 40 CFR 191

There are no direct requirements in 40 CFR 191 concerning QA.

A description of the QA/QC performed on the data used to show compliance with the 40 CFR 191 requirements should be included. The requirements in 40 CFR 191 concern containment (191.13), institutional controls, post-closure monitoring, permanent markers, engineered and natural barriers, and waste removal (191.14), individual protection (191.15) and groundwater protection (191.16). Chapter 5 does not address QA for any of these areas.

Comparison of Chapter 5 (QA) and the Proposed 40 CFR 194

The proposed EPA criteria, 40 CFR 194, contain a list of specific QA requirements. However, Chapter 5 lumps QA (194.22) with expert judgment (194.26) and peer review (194.27), and states: "These requirements are not addressed in this document" (page 5.1 lines 15-17).

The draft compliance application should address them. DOE and EPA should develop a common understanding before a final compliance application is written. An examination of DOE WIPP QA documents and 40 CFR 194 requirements shows a gap that needs to be bridged.

The proposed 40 CFR 194.22(a)(1) states that DOE "...shall implement a quality assurance program that meets the requirements of ASME NQA-1-1989 edition, NQA-2a-1990 addenda (part 2.7) to ASME NQA-2-1989 edition, and NQA-3-1989 edition (excluding 2.1 (b) and (c))". DOE is not currently fulfilling this requirement.

DOT Shipping Container Requirements
Page 5-2, line 9

Various federal requirements codified in the Code of Federal Regulations are identified including 10 CFR 71 for Type B shipping containers. Since all CH-TRU waste will be placed in Type A containers, the list should also include 49 CFR 173, the DOT requirements for Type A shipping containers including tests.

QA Program Requirements
Page 5-2, lines 9-14

The NQAs are listed as sources for the QA program. These, and other "sources", are "...directed through the DOE Environmental Management (EM) QA Requirements and Description to the DOE CAO". In the CAO QAPD Revision 0, an appendix to the draft DCCA, only NQA-2 part 2.7 is specifically required (for software). The CAO QAPD Revision 0 is only partly based on NQA-1, and NQA-3 is not mentioned at all.

Revision 1 to the CAO QAPD is currently being developed; the draft also does not specifically require full implementation of the NQA requirements.

The Revision 0 software portion requires NQA-2 part 2.7 but the proposed Revision 1 does not, though it implements many (but not all) of its provisions. It is worthy of note that the proposed 40 CFR 194.23(b) also requires NQA-2 part 2.7 compliance.

The proposed 40 CFR 194.22 (b)(1) also specifies that the NQA-1, 2, and 3 requirements must be met for environmental monitoring, geological measurements, computations, codes, and models used to demonstrate compliance, expert judgements, disposal system design, all other data used to support compliance applications, and anything else "...important to the containment of waste in the disposal system." Documentation of most parts of all of these precede the only evidence provided in the July 15, 1994, CAO QAPD Revision 0 (Appendix QAPD), effective July 15, 1994.

Chapter 5 of the DCCA presents no evidence that full compliance with the NQAs occurred in the past.

WIPP Site Monitoring Programs
Page 5-7

This section describes the system used to assure the validity of the measurements of the environmental surveillance at WIPP. Unfortunately the data for radioactivity in water samples as well as the minimum level of detectability reported in water wells at WIPP on page 2-137 of the DCCA are incorrect. It might be helpful for DOE to reference the data obtained by EEG in our monitoring program for the past eight years.

Program Assessment
Page 5-8, line 10

The text states "Managers at all levels periodically assess the performance of their organization". This is an ideal; at INEL, Argonne West, the September 1995 CAO DOE audit discovered that no assessment of the waste characterization program at the Argonne

West facility had been performed since the previous WIPP-level audit in September 1993. If the statement was "Managers at all levels *are required to* periodically assess the performance of their organization" it would reflect the real QA program as it exists now, which may not necessarily have been true at the time data was gathered.

Qualifications of Existing Data

Page 5-9, line 1

Most of the activities cited in other sections of the DCCA were performed before the conceptual framework shown in Chapter 5 was in place. There are no specific descriptions of QA during the gathering of data for these earlier activities.

Page 5-9, lines 1-17 briefly describe Sandia's "Qualification of Existing Data" program, but provide no information as to which data are involved, what the status is, or when the information will be available.

Evolving requirements

Page 5-9, lines 19-31

This section briefly describes the evolution of the WIPP QA program requirements. Reference is made to NQA-1 as a "standard" for the program over the last 15 years. The proposed 40 CFR 194 requires compliance with NQA-1, NQA-2 part 2.7 (software), and NQA-3 (site characterization). Currently, the CAO QA program still does not require full implementation of ASME NQA-1, NQA-2, and NQA-3. It should be required.

Description Postdates Other Compliance Activities

Most of the activities cited in other sections of the DCCA were performed before the QA system described here was in place. There are no specific descriptions of QA for data obtained during these earlier activities. The work in Chapter 2 on site characterization, in Chapter 3 on the design and building of the WIPP facility, and in Chapter 6 on PA were mostly completed before the CAO QAPD (which became effective on July 15, 1994) was in

place. The CAO QAPD (included as the appendix QAPD) is the only objective evidence presented in this document concerning QA activities.

CHAPTER 6. CONTAINMENT REQUIREMENTS

Basis of Review

The performance assessment in the DCCA has been reviewed by state-of-the-art terms in performance assessment. Because the compliance criteria for the standards were not finalized during our review, the DCCA has not been judged against the requirements of 40 CFR 194. It should be noted, that even with all the disclaimers, the DCCA is in the form of an application. It is no longer a demonstration of the methodology or a dry run. The DCCA must meet a higher expectation and after several iterations of performance assessment, the work is finally ready for a review to assess compliance with the EPA disposal standards for transuranic waste. In particular, the EEG evaluation is focused upon these questions:

Have all relevant scenarios been analyzed?
Are probabilities of scenarios adequately established?
Have consequences been properly stated?

Have All Relevant Scenarios Been Analyzed?

Not all potentially disruptive scenarios have been analyzed. Previous performance assessments for the WIPP analyzed only the effect of human intrusion by inadvertent drilling. In the DCCA, other possible disruptive events and processes have not been considered. Justification has not been provided for Features, Events and Processes (FEPs) not considered for regulatory reasons, or eliminated for low consequence.

What scenarios need to be considered? The EPA Standards stipulate that performance assessments need not consider events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. In terms of analyzing human intrusion, the EPA suggests inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) may be the most severe intrusion scenario assumed.

The EPA standards further state:

> Furthermore, the performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changed by such omissions. (40 CFR 191, Appendix C).

Examination of the EPA's guidance for implementation of 40 CFR 191, subpart B, reveals the following:

- The lower limit for events and scenarios to be considered is 10^{-8} per year. That means, events and processes with a probability of occurrence of between 1 and 10^{-8} per year must be analyzed.

- The most severe human intrusion scenario that requires analysis is drilling into the repository. Less severe scenarios should be analyzed in accordance with the rule above.

- To omit the analysis of a particular event or process because of the lack of impact, first the lack of impact must be demonstrated by an analysis, not an assumption.

Certain human-initiated events and processes are known to be on-going in the vicinity of the WIPP (p. 6-36)[6-1] and have been retained for further analysis. However, these same on-going events and processes have been screened out from further analysis in the postclosure phase, presumably because of EPA's regulatory guidance.

Water injection for secondary recovery of oil and brine reinjection remains to be analyzed. Consider the impact of a specific case of water injection for secondary recovery. In 1991,

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[6-1]U.S. Department of Energy. 1995. *Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant,* Draft-DOE/CAO-2056.

Hartman, a small oil and gas operator, purchased a worked-out lease in the extreme southeast corner of New Mexico and started drilling. While drilling through the Salado Formation, Hartman encountered a massive salt-water blowout. Brine flowed from the well for five days before being controlled. A total of 5.7×10^6 L of brine was trucked away before a pipeline was installed. A New Mexico court determined that a major oil company's water flooding project 3.5 km away was responsible. This incident occurred at the southeastern corner of New Mexico, in the same Salado Formation that overlies the WIPP and is of relevance to the WIPP because within 3.2 km (2 mi) of the WIPP perimeter, there are over 120 producing oil and gas wells. Furthermore, secondary recovery by water flooding and brine re-injection has begun in these recently discovered fields.

Unexpected water flows are not rare events. Between 1978 and 1993, 189 unexpected water flows were reported to the New Mexico Oil Conservation Division for Region One, which encompasses approximately 6000 km^2 in the southeast corner of the state.

One example of a yet to be addressed scenario is as follows. Water or brine is injected into Marker Bed 138 or 139, introducing massive amounts of water into the repository, which carry dissolved radionuclides to the accessible environment.

Other potentially disruptive events that should be analyzed include the impact of potash mining. Over 80% of the potash in the United States is produced within 100 km of the WIPP. From the WIPP site one can see the surface works of three major potash mines. The potash is midway between the Culebra aquifer and the repository horizon. Potash mining has an extraction ratio well above 80%, and potash miners do not usually backfill mined out volumes. Thus massive underground cavities may exist in the future, and may be an additional pathway for radionuclide transport. Subsidence remains a concern that could affect the hydraulic properties of the overlying aquifers.

Are Probabilities of Scenarios Adequately Established?

Because the scenarios of water flooding and potash mining were not considered in the DCCA, no probabilities for these disruptive events have been estimated. The implication is that there is insufficient specification of probabilities.

Have Consequences Been Properly Stated?

The results of the performance assessment described in the DCCA are questionable because "place-holders" are substituted for the most important data.

During 1994 and 1995, the WIPP project undertook a Systems Prioritization study to focus resources on the key variables that control compliance demonstration. The study identified eight groups of variables which needed additional work for the final compliance certification application. For the DCCA, the values used for the eight variables are only estimates made by Sandia National Laboratories staff conducting the experiments. The data from these experiments are expected sometime in 1996 and later. Difficulties caused by using the predictions of the results of the experiments, rather than the experimentallly obtained values, are discussed below.

Solubility

Upon human intrusion by drilling, the release rate of radionuclides is the product of actinide solubilities and brine flux. In the DCCA, generic actinide solubilities are used. For example, the solubilities of Pu(III) and Np(III) are assumed to be equal. If this were true, then there would not be any need for solubility experiments in progress now.

For actinides with multiple oxidation states, they are partitioned according to the following scheme. Let n_1, n_2, n_3, n_4 be random numbers.

$$VI = n_1/5,$$
$$V = n_2\,(1.0 - VI)/(n_2 + n_3 + n_4),$$
$$IV = n_3\,(1.0 - VI)/(n_2 + n_3 + n_4),$$
$$III = n_4\,(1.0 - VI)/(n_2 + n_3 + n_4),$$

This partitioning scheme implies that various oxidation states might exist jointly. At a specific pH and Eh, there is likely to be a unique dominant species and attendant oxidation state. (See WIPP P.A. Dept., 1992, p. 3-43).[6-2] One does not have a 10%, 30%, 30%, 30% mixture of oxidation states.

The solubility of actinides in oxidation state y is then sampled from 1 to 10^{-10} molar. In EEG-57[6-3] we commented on the futility of sampling from a wide range of solubility, and the lack of confidence such a procedure conveyed.

The partitioning of actinides into oxidation states is inconsistent with experimental evidence. In WIPP-commissioned Pu solubility measurements, no matter what the initial oxidation states were at the start of the experiments, 70% to 95% of the final oxidation state at steady state was Pu(VI) (Nitsche, et al., 1994 in Novak.[6-4] Yet in the above partitioning by oxidation states, only 20% or less of the total inventory is allowed to be in VI. The experimentalists could not explain the move to VI, and conjectured that it might be due to α-radiolysis. In the DCCA, it is reasoned that the repository would be reducing. However, the solubility experiments were carried out in contact with the atmosphere, resulting in the final oxidation state being VI. If the conditions in the repository are expected to be reducing, then the oxidation state will not be VI in the repository and the results of the experiments in contact with the atmosphere would not be applicable to the expected repository conditions. All of the aqueous separation processes for plutonium utilize the fact that Pu has a variety of oxidation states, each with widely varying chemical properties. Hence the interconversion of Pu among

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[6-2]WIPP PA (Performance Assessment) Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992 — Volume 1: Third Comparison with 40 CFR 191, Subpart B.* Albuquerque, NM: Sandia National Laboratories, SAND92-0700/1.

[6-3]Lee, W. W-L., L. Chaturvedi, M. K. Silva, R. Weiner, and R. H. Neill. 1994. *An Appraisal of the 1992 Preliminary Performance Assessment for the Waste Isolation Pilot Plant.* Albuquerque, NM: Environmental Evaluation Group. EEG-57.

[6-4] Novak, C.F. 1995. *Actinide Chemistry Research Supporting the Waste Isolation Pilot Plant: FY 94 Results.* Albuquerque, NM: Sandia National Laboratories, SAND94-2274.

its various oxidation states has been the topic of much study.[6-5] Literature on the effect of radiation on the oxidation state of Pu in solution suggests that radiolysis and exposure to oxygen would actually decrease the average oxidation number. In HCl, the medium of the solubility experiments, the average oxidation number did not decrease, consistent with the experimental results. Thus the discrepancy between the experimental results and the partitioning rule needs to be explained.

Perhaps the most important note about the solubilities used in the DCCA is that DOE assumed a distribution of aqueous solubilities with large uncertainty (Appendix PAR, p. 250, 253, 256, 259, DCCA, vol. 1).[6-1]

No attempt has been made to justify the probability distribution used.

Conceptual Model for Flow in the Culebra

The DOE has identified intrusion scenarios that result in contaminated brine discharging into the Culebra Dolomite member of the Rustler Formation. However, for the calculation of direct discharge to the ground surface through borehole cuttings, the contaminated fluid is discharged to the ground surface bypassing entry into the Culebra. Thus, the two scenarios are inconsistent. How can brine enter the Culebra if a well-casing is present? Or, if the well is uncased, why shouldn't the brine enter the Culebra instead of flowing to the surface? The following quotation from the Disposal Room Model Position Paper summarizes current technology in drilling in the Delaware Basin.

> Within the Delaware Basin near the WIPP site, gas and oil wells are started by clearing the site and drilling a shallow hole (40') to house a conductor pipe. The conductor pipe is set in cement and serves to prevent surface sands from sloughing into the wellbore during later drilling. Drilling is continued below

[6-5]Rabideau, S. W., M. J. Bradley and H. D. Cowan. 1959. *Alpha-Particle Oxidation and Reduction in Aqueous Plutonium Solutions.* Los Alamos, NM: Los Alamos National Laboratory, LA-MS-2236.

> the conductor pipe, to 300-600 feet to top of the salt section using a large diameter (17-26 inches diameter) drill bit and another steel casing is set.[6-6]

A similar statement appears in the DCCA.

> . . . oil wells normally have a standard 0.413 m drilled hole to the top salt to accommodate 0.340 m steel casing, and gas wells normally have a standard 0 ·445 m drilled hole to accommodate 0.356 m casing. (Appendix PAR, P. 223, DCCA, vol. 1).[6-1]

Thus, in order for radionuclide contaminated brine to flow into the Culebra, the fluid must flow through the pipe casing. In the 1992 performance assessment there was a nondegraded plug that forced discharge into the Culebra. Now the DOE assumes 100% failure of the casing!

The contaminated brine would not naturally flow into the Culebra and that is reinforced by the fact that the DOE set the permeability of other hydrostratigraphic units to zero to prevent brine from entering those units and to maximize the flow to the Culebra. The Unnamed Lower Member (p. 6-78), the Tamarisk (p. 6-85), and the Forty-Niner (p. 6-86) are all assigned zero permeability, and the Magenta (p. 6-85) and the Dewey Lake Redbeds (p. 6-86) are assigned low permeabilities.

There is a clear need to analyze two different scenarios: One with casing and the other without, and assign appropriate probabilities of occurrence for the two.

Retardation Mechanisms

In the postulated transport of radionuclides in the Culebra, three retardation mechanisms are used (DCCA, p. 6-80).[6-1]

[6-6]Butcher, B. M. et al. 1995. Disposal Room and Cuttings Models, Position Paper.

- Equilibrium Sorption;
- Matrix Diffusion;
- Corrensite Clay Sorption.

Our review raises questions about postulating each of these retardation mechanisms.

Equilibrium Sorption: During the advective-diffusive transport of contaminants, dissolved solute can adsorb onto solid surfaces or precipitate. The suite of processes that lead to contaminants traveling slower than the average pore velocity of ground-water flow is generally referred to as sorption. For many contaminants, many ground-water compositions, and many rock types, a linear isotherm results with

$$\frac{dS}{dC}=K_d \tag{1}$$

where S is the mass of solute adsorbed or precipitated per unit dry bulk mass of rock, C is the solute concentration, and K_d is known as the distribution coefficient. Using the distribution coefficient, one can compute the velocity v_i at which the particular contaminant will travel

$$\frac{v_i}{v}=\frac{1}{1+\rho_b K_d\left(\frac{1-\epsilon}{\epsilon}\right)} \tag{2}$$

where v is the average ground-water velocity, ρ_b is the bulk density of the rock, and ε is the matrix porosity.

Over the years there have been attempts to measure distribution coefficients relevant to the WIPP. However, these distribution coefficients do not represent anticipated conditions in the Culebra. First, because the chemistry of the water has a significant influence on sorption behavior. The isotherm experiments used unrepresentative chemistry for Culebra water, making the resultant distribution coefficients values invalid. Secondly, the distribution coefficients are from single measurements on powdered samples. Powdered samples have a different surface area to volume ratio and experiments with powdered samples are likely to

overstate sorption in the field. As can be seen in eq. (1), it is difficult to obtain a proper K_d from a single measurement. Thirdly, review of the experimental conditions did not provide assurances that equilibrium conditions were reached in the isotherm experiments. Thus we conclude that experimental data valid for use in performance assessments of the WIPP are not currently available on partitioning coefficients for the Culebra Dolomite.

The problem is compounded because performance assessment did not use the flawed experimental data, but subjectively elicited probability distributions of distribution coefficients from Sandia National Laboratories employees. Clearly, additional data are needed.

The DOE is currently conducting a multi-well tracer test at the WIPP site. This test is designed to provide information on flow mechanism, as well as partition coefficients for actinides. In April 1995 the DOE dropped plans for a sorbing tracer test, while keeping the non-sorbing tracer test. Can one use a non-sorbing tracer test to obtain K_d for sorbing species?

For a nonsorbing species, the residence time t_n in a fracture of half-aperture δf is

$$t_n = (\phi_f + \phi_m)\ V_r/Q$$

where V_r is the volume of pores in the rock, Q is the water-flow rate, and ϕ_f and ϕ_m are the fracture and matrix porosities respectively.

For a sorbing species, the residence time in the same system is

$$t_s = (\delta_f + K_s) S_s V_r / Q$$

where K_d is a surface distribution coefficient, and S_s is the specific surface area.

It is apparent that the two residence times are different, and a non-sorbing tracer test cannot be used to obtain K_d for actinides.

Matrix Diffusion: Matrix diffusion has been shown to be an important mechanism in radionuclide retardation.[6-7] Water and contaminants in fracture flow result in transport of the contaminants from the fracture into the microfissures of the rock by diffusion. This diffusion of contaminants into the rock matrix and subsequent sorption onto the surfaces of the microfissures and dead-end pores is a significant retardation mechanism. This diffusive flux of contaminants from the fracture to the rock matrix (z direction) can be represented by

$$q = -\epsilon\tau\left(D'\frac{\partial C'_l}{\partial_z}\right)_{z=0} \tag{3}$$

where D' is the free-water molecular diffusion coefficient in the matrix (L^2/t),

ε is the rock porosity,

C'_l is the concentration of the lth solute in the matrix (M/L^3),

τ is the tortuosity correction (-).

Note the predominance of diffusive parameters.

The WIPP performance assessment takes credit for matrix diffusion, but offers no direct experimental evidence for its extent. The only related experiment was a diffusion test with a non-reactive tracer.[6-8] A series of multi-well, field scale, tracer tests has been planned but it is unclear how the results of these tests would provide unequivocal evidence for matrix

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[6-7]Neretnieks, I. 1980. Diffusion in the Rock Matrix: An Important Factor in Radionuclide Retardation? *J. Geophy. Res.* 85B:4379.

[6-8]Dykhuizen, R. C. and W. H. Casey. 1989. An Analysis of Solute Diffusion in Rocks. *Geochim. et Cosmo. Acta* 53:2797.

diffusion. Lee and Chaturvedi[6-9] have suggested some laboratory experiments to give direct evidence of matrix diffusion.

Corrensite Clay: The DOE identifies sorption on clay fracture-linings as one of three retardation mechanisms for radionuclide transport through the Culebra. The EEG was verbally informed that the assumption of corrensite clay as asorptive clay lining was dropped from future performance assessments. However, the definition sketch for SECOTP2D still shows corrensite clay lining (p. SECOTP2D-3).[6-1] The DOE is also funding basic studies on corrensite sorption mechanism. We will repeat the following comments on the lack of corrensite clay evidence in the Culebra fractures.

The concept of corrensite sorption is based on x-ray diffraction and analytical electron microscopy analysis of cores samples from clay-rich layers of the Rustler Formation, from wells drilled primarily in the Nash Draw, a topographic depression several miles west of the WIPP site and in a known Karst region. This concept originates from the work of Sewards and others.

Sewards, Glenn and Keil[6-10] presented mineralogical analysis of core samples from a single well, WIPP-19, and made no claim for clay-filled fracture linings in the Culebra.

Sewards[6-11] gave data on "whole rock" as well as "fracture surface" compositions of core samples collected from six wells in the Nash Draw, one borehole (WIPP-33) just outside the WIPP site, and three boreholes in the northern part of the WIPP site. Clays are expected to

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[6-9]Lee, W. W-L. and L. Chaturvedi. 1995. Radionuclide Retardation Mechanisms in the Culebra Aquifer at the Waste Isolation Pilot Plant. In *Proceedings of the Conference on Radioactive Waste Management and Environmental Remediation, ICEM "95, held in Berlin, Germany, September 3-7, 1995*, edited by S. Slate, F. Feizollahi, and J. Creer. New York, NY: American Society of Mechanical Engineers, 877-881.

[6-10]Sewards, T.R., R. Glenn and K. Keil. 1991. *Mineralogy of the Rustler Formation in the WIPP-19 Core.* Albuquerque, NM: Sandia National Laboratories, SAND87-7036.

[6-11]Sewards, T. 1991. *Characterization of Fracture Surfaces in Dolomite Rock, Culebra Dolomite Member, Rustler Formation.* Albuquerque, NM: Sandia National Laboratories, SAND90-7019.

be present in the Nash Draw cores because of extensive dissolution, weathering, and erosion in that area. WIPP-33 is located in a sink hole and dissolution, weathering, and erosion are expected. The other boreholes are located north of the WIPP repository and upstream from the expected direction of flow of water in the Culebra. Furthermore, cores from these wells are from sections with known clay seams.

Sewards, Williams and Keil[6-12] presented mineralogy of 107 core samples from eight wells, three of which are located in the WIPP site. X-ray diffraction analysis and an electron microscope were used to identify clays. However, electron microscopy raised doubt about the results of the x-ray diffraction results. When imaging was attempted on the electron microscope, it was extremely difficult to find any corrensite at all. However, Sewards, Williams and Keil[6-12] proceeded to conclude "that corrensite is the dominant phase in the Culebra."

Sewards *et al.*,[6-13] presented mineralogical analysis from 47 samples. Of these, 17 samples were taken from the Culebra, and of these only nine are from the WIPP site: six from the Air Intake Shaft and three from WIPP-12. The report (p. 28) states:

> Only small amounts of clay can be sampled from the Culebra fracture coatings; therefore, initial technique and model development for adsorption studies on WIPP clays (Park, et al., in review) were carried out with material from a black shale layer in the unnamed member. This material, so-called CorWIPP, is 94% corrensite and is described as Sample AIS-15 in this report. Corrensite has a high cation exchange capacity and affinity for the uranyl ion in dilute solution (Park, et al., in review) and could provide significant radionuclide retardation in fractures in the Culebra.[6-13]

[6-12]Sewards, T., M. L. Williams, and K. Keil. 1991. *Mineralogy of the Culebra Dolomite Member of the Rustler Formation.* Albuquerque, NM: Sandia National Laboratories, SAND90-7008.

[6-13]Sewards et al. 1992. *Nature and Genesis of Clay Minerals of the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant in Southeastern New Mexico.* Albuquerque, NM: Sandia National Laboratories, SAND90-2569.

The suggestion that corrensite clay-lined fractures in the Culebra may provide retardation for radionuclide migration is based on a single sample from a "black shale layer" obtained from the lower part of the Rustler Formation, below the Culebra, because not much clay could be sampled from Culebra fracture coatings. And yet, information from this sample is used to conjecture that "significant radionuclide retardation in fractures in the Culebra" could be present! Moreover, clay in fractures can act either as an additional sorption agent, or serve to block mass transfer between the fracture and the matrix. The *1992 Performance Assessment*[6-14] has eliminated the latter role. This is double counting for a mechanism which may not exist. Credit for corrensite sorption should not be taken in WIPP performance assessment unless demonstrated by additional evidence.

Colloids

Colloidal transport, a newly identified concern for the WIPP, has two components. The first concern is hydrodynamic chromatography, where colloidal particles might travel at the maximum velocity in a fracture rather than the average or retarded velocity. The second concern is that actinides might attach themselves to natural colloid particles, resulting in the same acceleration process. In the DCCA, colloids are not allowed to travel faster than the solute. This misses the essence of the concern for colloids in transport. The formation rate of colloids can be measured or calculated, but in the DCCA the initial colloid concentration is arbitrarily set by analysts.

Additional work is underway to delineate the role of colloids as a concern. We await the results.

[6-14]WIPP PA (Performance Assessment) Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992*, 3 vols. Albuquerque, NM: Sandia National Laboratories, SAND922-0700.

Conceptualization of Risk

Section 6.1.1, Page 6-3

Kaplan and Garrick[6-15] are cited as the basis for the ordered triple form of representing risk. Kaplan and Garrick recognize that it is impossible to identify all possible scenarios. In section 3.5 of the cited paper, they recommend the use of an N+1 scenario to represent all unidentified scenarios. Equation 2 is thus a deviation from Kaplan and Garrick that at least needs to be explained. A much better solution is to accommodate the N+1 scenario in the definition of risk and incorporate it as a modifier to the CCDF.

FEP Cutoff of 10^4 Years

Page 6-22, line 20

The 10,000 year cutoff may eliminate scenarios with significant impact. The DOE[6-16] noted that the time of maximum risk occurred at 1.6×10^6 years. The new NAS guidance to EPA for HLW disposal urges the calculation of risks for periods up to 1 million years. It is recognized that the EPA standard only requires 10,000 years in calculations but DOE should extend the time for their assessment.

Criteria for Screening of FEPs

Page 6-20, line 22; Section 6.2; Appendix SCR

By introducing an intermediate step, the draft application departs very sharply from the procedure proposed by Cranwell[6-17] and inappropriately eliminates viable features, events, and processes. A new elimination criteria is inserted as the second "sieve" (Regulations — DOE

[6-15]Kaplan, S. and B. J. Garrick. 1981. On the Quantitative Definition of Risk. *Risk Analysis* 1(1):11-27.

[6-16]U. S. Department of Energy. 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant*, 2 vols. DOE/EIS-0026.

[6-17]Cranwell, R. M., R. V. Guzowski, J. E. Campbell, and N. R. Ortiz. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste: Scenario Selection Procedure.* NUREG/CR-1667. Sandia National Laboratories, Albuquerque, NM, SAND80-1429.

Interpretation) as shown in the figure below. Further, the procedure is such that the DOE determines which scenarios can be eliminated based on the DOE interpretation of the EPA regulations.

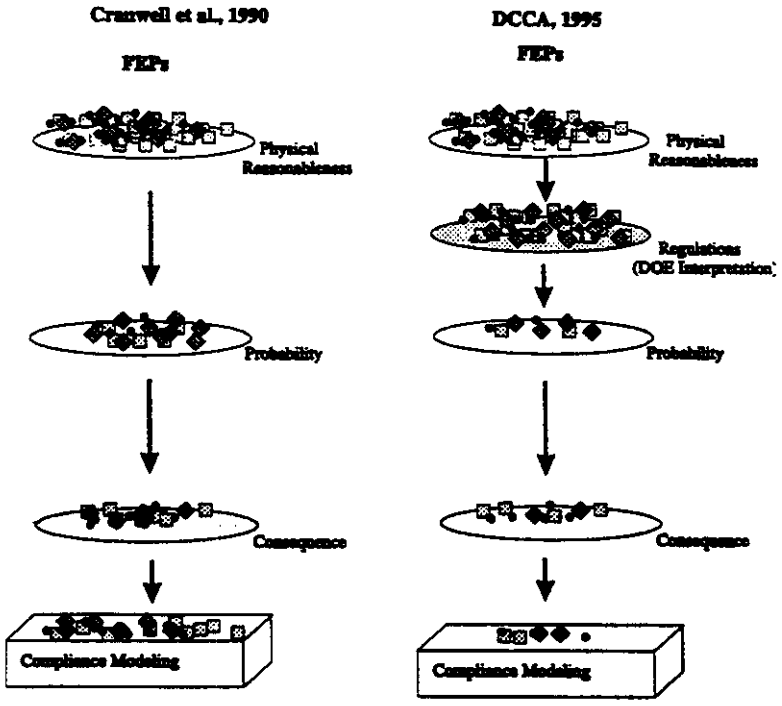

Figure 7. Comparison of Cranwell and DCCA Elimination Criteria.

Page 6-22, lines 18 through 21

Delete as a criteria for elimination of FEPs the new category, "*Regulation or, more broadly, scope and purpose of the assessment...*" The category is entirely subjective as applied and ignores valid technical considerations.

Page 6-23, lines 20 through 27

The paragraph describing FEPs requiring additional documentation appears to be prejudging a yet to be completed study. The statement is made, "the DOE has modeling or experimental work underway to increase understanding of the potential importance of some of these FEPs,

but all are considered of low consequence.... The basis for eliminating these is not yet fully documented." Why are these considered to be of low consequence while the investigations are still underway?

Page 6-24, lines 5 through 8

The paragraph describing FEPs elimination on the basis that they represent a design modification notes that the use of backfill has been eliminated. Yet the DOE has a formal agreement with the State of New Mexico to include backfill in the design of the repository.

Page 6-24, lines 22 through 31

The paragraph describes the category of FEPs that have been eliminated citing the non-binding guidance which was intended for a generic site. Further, the paragraph suggests that the non-binding guidance on FEP elimination reflects screening decisions made by the EPA. Our recommendation is to delete the paragraph and the entire SO-R category.

Page 6-25, line 16 through page 6-26, line 16

It is stated that the "regulatory screening arguments are used largely to limit consideration of future disruptive human-initiated events and processes as discussed in Section 6.4.2." Future disruptive human-initiated events and processes should be evaluated for viability on the basis of probability and consequence. It is unreasonable to present circuitous arguments and a very selective interpretation of non-binding guidance as the basis for eliminating very plausible scenarios such as those associated with resource extraction in a resource rich area. The EEG recommendation is to delete this entire section as well as Section 6.4.2.

Page 6-27, Figure 6-6

Delete the category SO-R to reflect a technical evaluation of the performance of the repository.

Page 6-31, Line 15

Replace the phrase "form the engineered barrier system" with the verb "are." For compliance with 40 CFR 191, the seals in the drifts, shafts, and boreholes are not considered to be engineered barriers.[6-18]

Page 6-31, Line 22

The text mentions a "current set of engineered barriers" without identifying these barriers and without citing a reference for more discussion in the draft application. Identify the barriers.

Page 6-36, Table 6-5a

The comments on this table require a review of the relevant portions of the appendix SCR, which is given below.

Page SCR-64, Line 16 - 22

The paragraph appears to take the position that activities initiated outside the controlled area subsequent to the time of submission of the final application will not be accommodated in the application. Rather, the DOE will rely on periodic reappraisals. However, it seems shortsighted to postpone evaluating the impact of the activities surrounding the WIPP given the following observations.

- Mining, drilling, salt water disposal by injection, enhanced oil recovery, and well abandonment are human activities.
- The WIPP is located in the Potash Enclave.[6-19]

[6-18] Meyers, S. 1987. May 22 letter from S. Meyers, Director, Office of Radiation Protection, EPA, to G.A. Smithwick, Principal Deputy Assistant Secretary, Environmental Safety & Health, DOE.

[6-19] Olsen, J. A. 1993. *Federal Management of the Potash Area in Southeastern New Mexico.* In New Mexico Geological Society Forty-Fourth Annual Field Conference, October 6-9, 1993: Carlsbad Region, New Mexico and West Texas. Socorro, NM: New Mexico Geological Society, 39-41.

- The Potash Enclave represents 80% of the nation's domestic production and 57% of the nation's reserves[6-20] — a scarce resource not widely available elsewhere.
- Commercial mining in the Potash Enclave has been ongoing for more than 60 years[6-20] — an area with long history of mining.
- The WIPP Land Withdrawal Area contains economically minable potash reserves[6-20] — an attractive target for future production.
- The WIPP Land Withdrawal Area is surrounded by potash reserves and active potash leases.[6-21,6-20]
- Potash is obtained by mining[6,20] — a potentially disruptive activity.
- Subsidence occurs over potash mines propagates fractures through overlying aquifers to the land surface[6-22] and poses a hazard to petroleum well casings.[6-19]
- Water level rises in WIPP monitoring wells to the north potentially correlate with brine disposal from the potash industry — a direct impact on the hydrology of the area.
- The EPA has identified the absence of mining scenarios in WIPP performance assessment as a critical omission.[6-23]
- The resource evaluation by the NMBM&MR/Westinghouse[6-20] clearly demonstrates that there are proven and/or probable oil and gas resources under each and every section
    1) within the WIPP Land Withdrawal Area
    2) and surrounding the WIPP.

[6-20]Broadhead, R. F., F. Luo, and S. W. Speer. 1995. *Evaluation of Mineral Resources at the Waste Isolation Pilot Plant Site.* New Bureau of Mines and Mineral Resources. Carlsbad, NM: Westinghouse Electric Corporation.

[6-21]Silva, M. K. 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP.* Albuquerque, NM: Environmental Evaluation Group. EEG-55.

[6-22]Sanchez, P. 1995. September 19 memorandum to Mel Marietta, Sandia National Laboratories on Subsidence Crack at WIPP 28.

[6-23]Oge, M. T. and M. Shapiro. 1994. October 18 letter from the U. S. Environmental Protection Agency to G. E. Dials, Manager, DOE Carlsbad Area Office. 4 pages + attachments.

- Oil and gas reserves are obtained by drilling through the Salado Formation and into the underlying oil and gas bearing formations.
- The oil producing formations in the vicinity of the WIPP also produce high volumes of mobile water.[6-20] Salt water disposal wells surround the WIPP Site and are injecting up to a million barrels of water per year per well into a formation underlying the salt formations.
- In 1988, WIPP monitoring wells experienced sharp water level rises which were strongly correlated with a nearby salt water disposal well operated by the oil and gas industry.[6-24,6-25] The observation strongly suggested leaking salt water disposal is influencing the regional hydrology in an aquifer considered to be a potential pathway for radionuclides.
- Southeast New Mexico has a history of waterflood problems with injected water migrating from adjacent properties through the Salado Formation.[6-26, 6-24, 6-25, 6-27, 6-21]
- The BLM recently denied an application for permit to drill wells within the WIPP Site Boundary citing concerns including the unknown effects of water injection on the repository,[6-28]

The WIPP is undeniably located in a resource rich area as shown in the Figure 8.

[6-24]Bailey, J. 1990. August 13 Memorandum from Certified Professional Geologist #7521, Petroleum Engineer at New Mexico State Land Office to Marsh La Venue, Intera Consulting Company, Contractor to Sandia National Laboratories on Water Level Rises in Culebra Dolomite Monitor Wells.

[6-25]LaVenue, M. 1991. January 28 Sandia National Laboratories Memorandum to distribution on the Anomalous Culebra Water-Level Rises Near the WIPP Site.

[6-26]Ramey, J.D. 1976. May 5 memorandum from the Director of the New Mexico Oil Conservation Division to John F. O'Leary on Water Flows in and near Waterflood Projects in Lea County.

[6-27]Hartman, D. 1993. November 22 letter to Sandia National Laboratories transmitting a copy of a Complaint of Trespass, Nuisance, and Waste filed in the Federal Court for the district of New Mexico, CIV93 1349M.

[6-28]Calkins, W.C. 1994. August 22 letter from W. C. Calkins, State Director, Bureau of Land Management, to the attention of Keith E. Bucy, Bass Enterprises Production Co.

Page SCR-66, Table SCR-3b

The draft application identifies 42 plausible scenarios and then eliminates 37 citing the DOE category SO-R. Among those eliminated by this DOE interpretation include:

Fluid injection:

- Salt water disposal
- Enhanced oil and gas recovery
- Hydrocarbon storage

Potash Mining

(including solution mining)

Flow through abandoned boreholes.

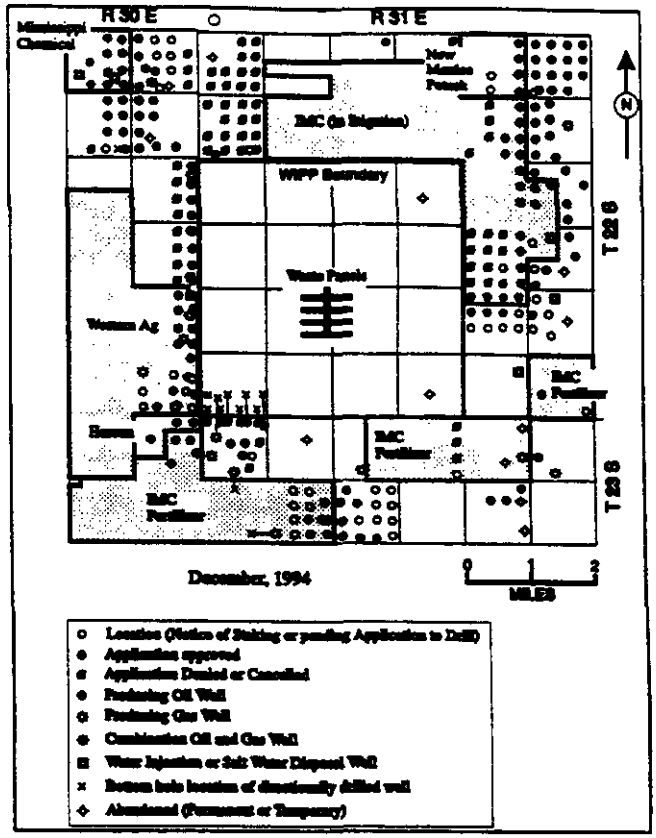

Figure 8. Natural Resources around WIPP site.

Page SCR-64, line 23 through page SCR-67, line 29

This paragraph acknowledges that the analyses of ongoing human initiated events and processes is underway and may be relevant when considering future initiated events and processes. But then the paragraph states that the extension of such analyses to anytime beyond October 1996 is speculative - an inconsistent position for an application that purports to calculate the behavior of a repository for the next 10,000 years.

Seals

Page 6-31, line 15

The statement, "Seals in drifts, shafts and boreholes form the engineered barrier system..." is wrong. The plugs and seals are not engineered barriers (see our comment on Section 3.3). The Panel Closure System shown in Fig. 3-1[6-1] has not been described. The vertical boreholes in the mine that extend upward and downward up to 100′ in the northern part of the WIPP excavations (abandoned in 1995) have not been plugged, and the DOE's WIPP

Experimental Area Mine Management Plan Phase I[6-29] justifies the decision on the basis that the boreholes will close by salt creep.

Salado Interbeds

Page 6-77, line 10

Discussion of the development of the simple interbed brine storage model from a literature search is referred to in Appendix PAR. While the model is described in the Appendix, the literature search is never mentioned.

Drum-Scale Variability in Spallings

Page 6-89 lines 1-9

It is stated that a sufficiently large volume of waste would be transported to the surface through spallings and that drum-scale variability can be neglected. Waste containers vary by several orders of magnitude in the activity of radionuclides they contain. The variation in the abundance of the relatively few activity level 4 or activity level 5 drums of Table 6-23 could dominate the activity of the spallings material. It needs to be demonstrated that the volume of waste entrained through spallings will be large enough to ensure average densities of radionuclides will reach the surface.

APPENDIX HYDRO

This appendix is a poor copy of the USGS Water-Resources Investigations Report 83-4016[6-30] and portions such as Figures 11, 12 and 16 are indecipherable. Originals of this report, that have not been marked up, do exist. If it is necessary to include this report as an appendix, reproductions from a better copy should be made,

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[6-29]U. S. Department of Energy. 1995. *Experimental Area Management Plan Phase I.*

[6-30]Mercer, J. W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico.* Washington, DC: U.S. Geological Survey. Water Resources Investigations 83-4016.

APPENDIX PAR

The formalized structure of Appendix PAR is very helpful. A specification of the equation number that first introduces the parameter in the description of the computational codes would increase the usefulness of the PAR appendix. Is the fracture spacing in the Culebra a SECOFL2D variable? Additional comments on this appendix are provided under the Appendix PAR heading.

APPENDIX BRAGFLO

The following criticism of the BRAGFLO code description may also be used as the EEG comments on code documentation in general. Appendix BRAGFLO presents a detailed and well developed description of the conceptual models implemented in the BRAGFLO code. The level of detail is, however, variable. For example, gas compressibility, Equation 31, is defined by a reference to a document that is not included in the DCCA. Without the referenced document, Equation 31 does not describe the model of gas compressibility.

BRAGFLO is apparently an isothermal code. This is never explicitly stated in the code description. More importantly, there is no defense given for an isothermal treatment of two-phase flow in WIPP. A discussion needs to be included to support such basic approximations. In addition, some assessment of the errors induced by approximations needs to be presented.

A reader friendly approach to identifying approximations is to 1) begin with the most general description of the phenomena to be modeled and then 2) introduce approximations that reduce the general description to the conceptual model implemented in the code. A section listing assumptions and limitations, such as NUTS.11, would also be very helpful.

Page BRAGFLO-21

BRAGFLO uses a user defined parameter to control the update frequency of the Jacobian matrix linearization. What assurances are there that the errors introduced by user control of

code mechanics are acceptable? In general, assurances built into the codes are preferable to administrative controls.

Page BRAGFLO-48 Equation 128

Equation 128 is presented with almost no defense. If parameter n is an important parameter then Equation 128 must also be important and must be defendable. At the least, it must be shown that variance in parameter n is great enough to also cover conceptual model uncertainty. To aid in pursuing such issues, it would be helpful if the Appendix PAR variable name and page number were supplied when a new variable is introduced in a code description. In addition, when the variable is presented in the Appendix PAR it would help if the relevant equation number in the code description were listed as well as the code names.

APPENDIX CUTTINGS

The particular model used for calculations presented in the DCCA was not contained in Berglund (1992) and has not been documented in the DCCA. We understand that the experimental results did not support this model and it is now being discarded in favor of another model. We look forward to the complete documentation of the new model to be used for the final application (CCA).

Page CUTTINGS-10

The blowout calculation is limited to a five minute duration. The five minute limit is an important parameter. While the use of this parameter is justified in the text, it does not seem reasonable to have a fixed five minute time limit. Using a sampled parameter to represent this time limit is more justified. At least some runs should consider the situation of the blowout being allowed to run its course without intervention.

Page CUTTINGS-14

The list of sampled variables is helpful. It would also be helpful if the Appendix PAR variable names were listed along with the appropriate page number in Appendix PAR.

APPENDIX NUTS

This appendix contains material that seems to be in conflict with the usage of the code described on pages 6-97 and 6-98, *e.g.* Radionuclide decay. It is unclear whether the dual porosity and dual permeability features of the code will be used. Code descriptions should focus on those features that are used in the performance assessment modeling.

APPENDICES SECOFL2D and SECOTP2D

The code descriptions for SECOFL2D and SECOTP2D presented in the DCCA are insufficient to adequately defend the use of these codes for performance assessment. The conceptual models behind these codes are never discussed. Parameters are listed without any discussion of reasonable values. The lack of discussion of the use of a dispersion tensor for flow through a single fracture makes the use of Equation 1 questionable.

If the hydraulic transmissivity field of the Culebra Member is an important parameter as indicated on page PAR-230 then the conceptual models of flow and transport through the Culebra are also important. What is the basis for a parallel fracture model? What support is there for clay linings on the fracture walls? What is the influence of this assumption? If channeling is recognized as a possible important feature in anhydrite beds of the Salado Formation, why is it not considered as a possibly significant phenomena in the Culebra?

CHAPTER 7. ASSURANCE REQUIREMENTS

Purpose of Assurance Requirements

Page 7-1, lines 3-13

The document fails to state that the purpose of the assurance requirements in 40 CFR 191.14 is to provide the confidence needed for long-term compliance with the containment requirements of 40 CFR 191.13. The application should state the purpose and then show how the material that follows shows compliance.

The EPA, in 40 CFR 191.14, also notes that the Nuclear Regulatory Commission (NRC) has issued comparable provisions (10 CFR 60) applicable to facilities regulated by the Commission.

Page 7-1, line 36

After ".... effectiveness of those controls" add "in preventing or reducing radionuclide releases." Otherwise the reader is unaware of the reason for the controls.

Useful and Practical Active Institutional Controls

Page 7-2, line 3

The DOE interpretation is that active institutional controls (AICs) should be implemented as long as controls are useful and practical. DOE needs to specify how long they believe AICs are useful and practical.

Oversight Organizations

Page 7-2, line 23

Add EEG to the list of oversight agencies of AIC activities.

WIPP Active Institutional Control Program
Page 7-3, line 28

The steps identified for the WIPP AIC programs are so general and lacking in substance that it is difficult to comment meaningfully. The program should be clearly identified and defended for its projected effectiveness and duration.

Hot Cell as Post-Decommissioning Marker
Page 7-4, line 15

The text indicates that the concrete Hot Cell structure will be left in place. What are the plans for decontamination of that structure and disposal of radioactive material?

Uncontrolled Access to Site
Page 7-4, line 31 and Vol. II, page 13

While the site has 10,240 acres, the surface projection of the waste is only 120 acres. The text suggests that slant drilling is unlikely to occur in the remaining 10,120 acres into the repository. No explanation is offered for this assumption; particularly since the current experience in the Delaware Basin is contrary to the assertion. No restrictions on regular drilling in the site area outside the fenced area are identified which would be contrary to the requirements of active institutional control.

Description of Active and Passive Controls
Page 7-5, lines 30-33

A detailed description of the planned active and passive controls should be provided as a part of the Compliance Application and not "by October 30, 1997".

Monitoring Period
Page 7-7, line 18

Specify the length of time that monitoring would continue. DOE should have some estimate of the length of time that is realistic.

Monitoring
Page 7-7, line 20

Specify any other parameters to be monitored. Subsidence and groundwater in the Rustler are the only ones mentioned.

Groundwater Sampling
Page 7-7, line 21

How and when would the boreholes from the surface to the Rustler dolomite aquifers be plugged? Would the markers include this information?

Disposal System Monitoring
Page 7-8, line 25

How will the geochemical performance be assessed to substantiate assumptions regarding the characterization of brine and waste?

Page 7-8, line 27

What plans are there to monitor the efficacy of borehole plugs as a function of time?

Subsidence

Page 7-9, line 22

In view of the decision not to backfill the experimental area to the north immediately adjacent to the repository, how will one determine the effects of subsidence from the backfilled repository versus subsidence resulting from the experimental area?

Subsidence Measurements

Page 7-9, line 31

The subsidence studies should also predict Culebra settlement now as a result of potash mining. Data exist of the extent of Culebra settling where high potash extraction rates have occurred in the Basin. Such measurements can be made now in areas where potash has been mined to determine whether fracturing has been induced in the Culebra elsewhere in the Basin which could affect performance assessment calculations.

Environmental Radiation Surveillance

Page 7-11, line 1, Baseline Database

The environmental measurements obtained and published by EEG should be included. The EEG measurements cover a longer period of time than DOE's, contain specific radiochemical analyses which DOE has yet to implement, and the EEG Laboratory has participated in the EPA Quality Control programs with excellent results.

Preoperational Data

Page 7-12, lines 10-13

Preoperational data do not include the Aerial Radiological Survey of the Waste Isolation Pilot Plant and Surrounding Area[7-1] which identified ^{137}Cs within a few miles of the WIPP boundary.

[7-1]Berry, H.A., 1989. *An Aerial Radiological Survey of the Waste Isolation Pilot Plant and Surrounding Area, Carlsbad, New Mexico.* EG&G Energy Measurements. AMO-8809.

Future aerial radiological surveys listed on line 4 should include the Gnome site where measurable levels of fission products are on the ground surface. The location and movement of this contamination which contains radionuclides common to elements in the WIPP waste should be closely monitored so as not to be mistaken for WIPP related radioactive materials by future investigators.

Passive Institutional Controls
Page 7-13, line 26

Again, the purpose of PICs is to help provide confidence that the containment limits in 191.13 are met.

Perpetual Care
Page 7-13, line 44

DOE states that they will preserve knowledge of the site in perpetuity. That is much longer than the required 10^4 years.

Existing TRU Waste Markers
Page 7-14, line 7

DOE plans a number of elaborate markers and records. Please describe and reference markers and records currently used at TRU waste disposal sites in Nevada, LANL and ORNL for wastes buried prior to 1970.

Credit for PICs
Page 7-16, line 1

"The DOE believes that PICs will render human intrusion sufficiently unlikely so that the possibility need not be included in the CCDF." What is the basis for this statement? EEG believes it does not make sense to take <u>any</u> credit for a reduced future drilling frequency based on PICs, beyond 100 years.

Status of Passive Institutional Controls to Date
Page 7-16, line 19

The statement that DOE has been successful in gaining control of the subsurface to 6000 feet including the acquisition of oil, gas and potash leases is misleading since there are valid leases for slant drilling of 16 boreholes under the site. Please add a sentence to that effect to insure no confusion.

Buried Markers
Page 7-16, line 44

There is an excellent opportunity to place records in the SPDV experimental area adjacent to the repository now. Why not place messages there before it becomes unsafe to enter?

Missing Radiation Protection Standards
Page 7-22, line 27

The list of documents to be archived does not include a copy of the radiation protection standards used to protect the public health and the environment and the basis for them. There is no reason to believe that standards in place today will be the same in the long term future. Indeed, the allowable dose to the Nevada off-site community from weapons testing in the atmosphere in the 1950's was 3900 mrem per test series. Today, the allowable annual exposures being considered for waste disposal are 10 to 30 mrem. To deter future human intrusion, it is vital that future generations know what the acceptable risks were at the time of disposal.

Notification of Agencies
Page 7-23, line 1

After repeated requests by DOE, in 1992 Congress assigned the 4 mile x 4 mile BLM, DOI site to DOE in perpetuity. To date DOE has not delegated or assigned their authorities back to BLM, Dept. of Interior or to the State of New Mexico to establish a system to prevent drilling permits to be issued. Indeed, elsewhere in the text (Vol. II, Page 13) DOE states

there is zero probability that slant drilling from a site within the 4 mile x 4 mile zone would intersect the repository. Hence, DOE would rely on their interpretation of current slant drilling practices in the Delaware Basin.

Archives
Page 7-23, line 14

DOE would rely on the local office of BLM, DOI to archive information. Local offices are consistently closing and reconsolidating. The information should be sent to all offices of BLM.

Monuments
Page 7-25, line 38

The plans call for expensive monuments. Consideration should be given to leaving the Hot Cell with 3 foot thick walls in place and using it as a monument to store records. This would save the cost of dismantling the Hot Cell and erecting a structure with thick walls to insure longevity.

Additional Study
Page 7-26, lines 1-8

Please add an additional study to evaluate the confusion to future generations where elaborate markers are placed at WIPP with TRU waste at 2150' depth and none are placed at pre-1970 TRU waste disposal sites at depths of a few feet.

Engineered Barriers
Page 7-26, line 35

DOE states that the proposed 40 CFR 194.44 imposes additional requirements. We disagree. The proposed criteria provide a basis to select or reject various proposed engineered barriers.

Page 7-26, line 43

DOE defines the "repository" as an engineered barrier. This is inconsistent with other regulatory agency definitions.

Commitment/Non-Commitment to Backfill

Page 7-27, line 1

DOE states that they will use backfill if appropriate. Line 43 acknowledges the Department has committed to include properly designed backfill in the repository. Which is the correct statement?

Need for Backfill

Page 7-27, line 2

DOE states that using backfill to fill voids or mitigate fires is not needed. That is not the primary purpose of using backfill, and the statement is irrelevant. Backfill can reduce the amount of brine that reaches the waste, reduce the amount of gas being generated, allow earlier room closure and minimize settlement in the overlying strata and reduce the probability of fracturing in the Culebra dolomite. Last but not least, it provides a use for some of the 10 million cu ft. of salt left over on the surface.

Evaluation of Engineered Alternatives

Page 7-27, line 11

The DOE Engineered Alternative Task Force only looked at engineered alternatives from the standpoint of changing the rate of gas generation or the total amount of gas that could be generated. It did not consider any other merits of engineered alternatives.

Defense in Depth Using Engineered Alternatives
Page 7-27, line 14

The DOE/EPA study is a cost-benefit analysis of engineered alternatives. As such it is not meaningful to assign a financial value to improved confidence in predicting that the probability is less than 1/1000 of releasing more than 10 x the Table 1 (40 CFR 191) limits to the accessible environment over 10,000 years. The purpose of the engineered barriers is to improve confidence in our ability to confine the wastes. It was never intended to be quantified.

Page 7-27, line 38

The DOE interpretation that only those engineered barriers and waste form modifications that are necessary to meet the calculated behavior of the transuranic wastes for 10,000 years is, EEG believes, a minimal approach. Relying on the calculations almost exclusively is contrary to the concept of multiple barriers and defense in depth adopted by virtually all organizations engaged in radioactive waste disposal. Also, the Assurance Requirements (40 CFR 191.14) require engineered barriers, irrespective of and in addition, to the ability to demonstrate compliance with the containment requirements
(40 CFR 191.13).

Multiple Engineered Barriers
Page 7-28, line 6

Although DOE repeatedly states they use multiple engineered barriers, the only ones planned are shaft seals. It is interesting to note that NRC will not give DOE any credit for shaft seals as an engineered barrier for HLW disposal in Nevada and DOE has accepted that position. Also, the EPA definition of Barrier (40 CFR 191-12) and the EPA stated position does not allow seals to be an engineered barrier (see our comment on Section 3.3).

Meeting 40 CFR 191.14(e) Requirements
Page 7-28, line 28

DOE states that the intent of this requirement was met during site screening and selection. EEG disagrees. Site screening and selection occurred prior to the 1985 promulgation of 40 CFR 191. Additionally, EEG raised a number of issues in correspondence with DOE in our attached letters of February 13, 1990, August 10, 1990, and December 27, 1991 that were not addressed in the 1993 DOE report "Implications of the Resource Disincentive in 40 CFR 191.14(e) at WIPP."

Page 7-28, line 36 and line 41

The statement that EPA discourages the location of repositories in areas in which valuable material resources are present is misleading in that it omits two other requirements specified in the 40 CFR 191.14(e). They include places where there has been mining for resources, expectations for exploration for scarce resources or a significant concentration of rare material. If a site fails the 3 mineral requirements, the standard requires the applicant to identify the potentially favorable characteristics of the site that outweigh the risks. That has not been done.

Presence of Resources
Page 7-29, line 40

See EEG's Comments on Appendix IRD.

CHAPTER 8. INDIVIDUAL AND GROUNDWATER PROTECTION REQUIREMENTS

To show compliance with the individual protection requirements, a dose calculation needs to be done. To show compliance with the groundwater protection requirements, a concentration calculation has to be made. The DOE has not done either calculation and has not performed the assessments required by 40 CFR 194.55. Hence, it is not possible to provide meaningful comments.

EEG COMMENTS
on the
DCCA APPENDICES

PARAMETERS
(VOLUME I. APPENDIX PAR)

It is disappointing that the DOE has postponed providing specific information on the following 23 of the 53 parameters sampled in the analysis presented in Appendix PAR. The information will not be available until the final CCA is issued.

Page	Parameter
46	Residual Brine Saturation of Halite
56	Threshold Pressure in Halite
60	Intrinsic Permeability of Anhydrite Layers and Marker Beds
82	Threshold Pressure of Anhydrite Layers and Marker Beds
84	Residual Brine Saturation of Anhydrite Layers and Marker Beds
87	Residual Gas Saturation of Anhydrite Layers and Marker Beds
108	Brine Storage Model for Unfractured Interbeds
113	Brine Storage Model for Altered Interbeds
214	Intrinsic Permeability of the Shaft Seals
226	Shear Strength of Waste in the Panel
240	Uranium Oxide State
243	Plutonium Oxide State
247	Neptunium Oxide State
249	Solubility of Aqueous Radionuclides in Oxidation State III
252	Solubility of Aqueous Radionuclides in Oxidation State IV
255	Solubility of Aqueous Radionuclides in Oxidation State V
258	Solubility of Aqueous Radionuclides in Oxidation State VI
261	Fracture Spacing in the Culebra
265	Partition Function for Americium in the matrix of the Culebra
269	Partition Function for Neptunium in the matrix of the Culebra
273	Partition Function for Plutonium in the matrix of the Culebra
275	Partition Function for Thorium in the matrix of the Culebra
279	Partition Function for Uranium in the matrix of the Culebra

Halite Permeability
Page 1

The permeability of the halite blocks in the BRAGFLO model represents the permeability of "impure halite" which is based on extensive testing. It needs to be demonstrated that this representation bound the influences of interbeds of other materials such as polyhalite and anhydrite. Such calculations should include consideration of enhanced anhydrite permeability due to high gas pressures.

Halite Specific Storage
Page 17

The BRAGFLO model represents regions of Salado halite that includes numerous interbeds of varying mineralogy. If halite specific storage is used to represent these regions, it should be demonstrated that the specific storage contribution of these marker beds can be neglected.

Gas Storage Model for Interbeds Altered by Interbed Fracture
Page 105

The range values (1/3 to 10^{-3}) of C_g given in the equations do not agree with the values (1/10 to 10^{-6}) given in the text. The values for other parameters in the equation should be given in the discussion. These are: h_g, e_g and r.

Brine Storage Model for Unfractured Interbeds
Page 109

The discussion for this parameter is identical to the discussion for the brine storage in altered interbeds and applies to that parameter rather than the unfractured interbeds.

Initial Liquid Saturation of Panel and Repository
Page 206

The initial liquid saturation of the panel and the repository is based on an EG&G INEL

memorandum on waste from the Rocky Flats facility. The memorandum presents the data as pints per drum of waste. A recommendation is given in the memorandum that a poisson distribution should be used to characterize the per drum liquid content. The conversion of this data to initial liquid saturation of the panel and the repository is not presented nor is any reference made to a conversion. The cumulative distribution function used in the performance analysis is linear corresponding to a uniform distribution function. No mention is made of whether the recommended poisson distribution has been ignored or whether the uniform distribution is a result of the conversion of the per drum data to panel averages.

The data is from a single source. No discussion is presented about how representative this sample is to the waste to be stored in WIPP. The lack of a description of the data conversion process prevents an evaluation of whether the data used in the performance analysis adequately bounds saturation induced from waste from all potential sites.

SCREENING CRITERIA
(VOLUME I. APPENDIX SCR)

Major Concerns

1. Although various phenomena have been screened out on the basis of low probabilities of occurrence or insignificant consequences, we are concerned about synergistic effects of these independent events occurring which could have a substantial impact on the repository's predicted behavior.

2. There are no calculations or evidence provided to support the conclusions that various FEPs can be assumed to have little if any impact on probabilities or consequences, except for meteorite impact.

3. The impact of potash mining on subsidence and fracturing in the Culebra has not been addressed.

4. EEG does not believe that it is reasonable to automatically exclude human initiated events on the basis that the regulations do not require such analyses. This applies to the impact of potash mining on the geohydrological characteristics of the Culebra, fracturing in the Salado at the repository horizon from brine injection, or other man-made activities. DOE has the authority to self-regulate in other areas and the position taken by the Department to only address failure modes that are *required* by EPA to be addressed will undermine public confidence in the assertion that it is a world-class design.

5. What are the definitions and quantitative thresholds of "low probability" and "lower consequence" used to screen out various phenomena for consideration?

Regional Tectonics

SCR-8. line 19

Please provide an analysis to justify the deletion of regional tectonics on the basis of low consequence to the repository system performance.

Fracture Development

SCR-13, line 29

Naturally induced fractures affecting groundwater flow have been ruled out, but there does not appear to be a discussion of fracture development due to human initiated events.

Deep Dissolution

SCR-17, line 18

While deep dissolution has been ruled out on the basis of a low probability of occurrence, what is the calculated probability over 10^4 years?

SCR-18, line 11

The text states that deep dissolution is not a problem but that dissolution at depth is still taking place. Can this effect be bound?

SCR-19, line 2

Include a discussion on the age and mechanism of collapse breccias.

Flooding

SCR-23, line 2

Include a discussion on the evidence for and against downward percolation of water.

SCR-28, line 12

The position taken by DOE that assessments of the individual dose and impact on ground water are not required by EPA for the disturbed case is not particularly comforting. DOE should undertake such analyses.

Waste and Container Characterization as Described in Chapter 4
SCR-28, line 25

Contrary to the text, the container characteristics are not described in Chapter 4.

Nuclear Criticality
Section 2.3.2, Page SCR-38

EEG looks forward to a detailed analysis of the potential for nuclear criticality and the resultant heat generation. The EEG was actively involved in studying this issue in the 1981-85 period and sent two reports to the DOE. The issue should be reexamined in light of the current design of the repository, Waste Acceptance Criteria, Characteristics of the WIPP mine shafts, and the retardation characteristics of the Rustler aquifers. Both RH and CH-TRU Waste should be considered in such a study.

Copies of three letter reports, dated September 1981; December 30, 1993; and January 18, 1984, from Sanford Cohen and Associates are attached as Supplements 2, 3, and 4 to this report to help DOE prepare an up-to-date report on this subject.

Backfill Commitment
SCR-39, line 21

The text indicates that the repository will not be backfilled. This is contrary to the C&C Agreement between New Mexico and DOE.

Roof Falls
SCR 39, line 29

Add a discussion on the experience in the WIPP mine with roof falls.

Thermally Induced Stress

SCR 40, line 6

What is the basis of the assumption that the effects of thermally induced stress in the repository can be eliminated from performance assessment on the basis of low consequence and the documentation will be available in the final CCA?

The text notes that thermally induced stress could result in pathways for ground water flow in the DRZ, in the anhydrite layers and member beds, and through seals or enhance existing pathways. Please include the analyses to support the assumption of no consequence.

SCR-40, line 24

See EEG comment on SCR-38, line 5

SCR-41, line 3

Flow through sealed investigation boreholes has been eliminated on the basis of low consequence to P.A. An analysis of the impact of the 100 foot boreholes extending upward and downward from the repository horizon should be presented.

Thermal Convection

SCR-42, line 4

Although the statement is made that the extent of thermal convection arising from heat generation has yet to be done, DOE has eliminated thermal convection on the basis of low consequence. The conclusion appears premature.

Backfill

SCR 60, line 16

The DOE conclusion that backfill is not warranted on the basis of little impact on subsidence does not address other more relevant advantages from backfill such as the ability to restore

the near field characteristics to the undisturbed rock quicker, to minimize the effects of roof fall in completed panels during the 35 year waste emplacement, to minimize gas generation by brine inflow, and others.

Human Initiated Events

SCR-60, line 34

EEG disagrees with the position taken by DOE not to evaluate the individual dose or the impact on groundwater because the regulations do not *require* them for human initiated events.

EEG disagrees with the DOE contention that human initiated events that might occur after 1996 should not be addressed.

SCR-61, line 5

EEG disagrees with DOE's contention that the effects of human actions after 1996 which may disrupt the disposal system do not have to be considered.

Deleting Potential Failure Modes

SCR-63, line 31

The logic presented by DOE for not considering various failure modes is to hold EPA responsible for the exclusion. This appears inconsistent with the stated aim of DOE to insure the full protection of the public health and environment.

SCR-64, line 6

DOE's position on post CCA submission is to only consider the effects of potentially disruptive events that occur prior to the 1996 Final Application. EEG does not agree with this and believes potentially disruptive events in the future such as brine injection to enhance oil recovery and potash mining effects should be considered.

Fluid Injection

SCR-72, line 11

DOE concludes that the effects of recent and ongoing fluid injection through boreholes outside the controlled area can be eliminated on the basis of low consequence to P.A. What is the basis for this conclusion?

Events More Severe than Bounding Events

SCR-73, line 11

Eliminating fluid injection from P.A. calculations since it is more severe than the bounding limit (inadvertent intrusion) defies common sense.

M

WIPP ACTIVE ACCESS CONTROLS AFTER DISPOSAL
DESIGN CONCEPT DESCRIPTION DRAFT
(VOLUME II)

Summary

While a considerable amount of detailed information is presented, this section does not identify specific active institutional controls and how they will help fulfill the assurance requirements of 40 CFR 191.14(a) active institutional controls.

Nowhere in this section is the purpose of active institutional controls (AICs) listed. 40 CFR 191.14 states that it is to provide the confidence needed for long-term compliance with the requirements of 191.13 (40 CFR 191.13 containing the Containment Requirements).

The section also addresses passive institutional controls (PICs) without including a definition or explaining their purpose. There is no explanation of how and when the DOE will delegate or assign authorities obtained under the 1992 LWA to the Department of the Interior or to New Mexico to implement a system to prevent issuing a license or permit to drill or mine.

The title of this section does not match the EPA requirement. "Active Institutional Controls" has been changed to "Active Access Controls". Why?

Detailed Comments follow:

Paraphrasing the Regulations

Page 1, Section 1A

The language of the Regulations should not be paraphrased. Example: The text states that Title 40 CFR 191.12 defines Active Institutional Control as.... The exact language is, "Active Institutional Control means...."

Purpose of Active Institutional Controls
Page 1

The text correctly quotes 40 CFR 191. 14(a) but it should include the full 40 CFR 191.14 citation which states that the purpose is to provide confidence that the containment requirements in 191.13 will be met. It is not merely to control access to the site.

Passive Institutional Controls
Page 2

References to Permanent Markers should either be deleted or rewrite this section to clearly indicate that Passive Institutional Controls (PICs) are included as well as AICs. Permanent markers do not constitute active institutional control.

Documentation in Application
Page 2, Paragraph 2

Two other reports, Conceptual Decontamination and Decommissioning Plan and Long Term Monitoring Design are cited. Are they a part of the package to demonstrate compliance with 40 CFR 191.14(a) assurance requirements?

Long-Term Effects of Mining
Page 2

DOE is to be commended for acknowledging potential problems associated with mining.

Incorrect WIPP Mission
Page 3

Change the R&D mission of WIPP to one of disposal.

WIPP Waste Limits
Page 3, Paragraph 4

Since the limit on waste volume is specified, add limits of 5.1 million curies for RH-TRU and 1000 R/hour for 12,500 Cu ft of RH-TRU.

Design of Repository
Page 4

Where are panels 9 and 10?

Site Access
Page 5, Paragraph 2

Explain the term "occasional access to the site". It is unclear whether it means to intrude into the waste or have access to the surface.

Panel Seals
Page 8, Figure I-3

Also show a diagram of proposed panel seals.

Underground Markers
Page 11

Decide now whether to place markers underground in the non-backfilled experimental area adjacent to the repository. The opportunity will soon be lost since access will be too hazardous.

Page 13, Paragraph 2

"The salt formations do not support slant drilling due to insufficient consolidation of the salt material." What is the basis for this statement? The following sentence in the text concludes

that it is not necessary to have a system to prevent slant drilling in the 4 mile x 4 mile area because it is unlikely. Can one assume that there are no plans by DOE to actively prevent vertical drilling in the remaining 10,120 acres of the WIPP site during the first 100 years? This appears to violate the EPA standard and the P.A. has not addressed this scenario of unrestricted mining during the first one hundred years.

Paraphrasing the Standards

Page 16

Top of page. Paraphrasing the exact language in the regulations can lead to confusion. For example, "Title 40 CFR.12 defines Active Institutional Control to include four elements." The verb "include" suggests that one is not necessarily limited to the following list whereas EPA intended it to be limited to only those items that follow.

Misinterpretation of the WIPP Land Withdrawal Act

Page 16, IV, Paragraph 2

Assuming that the mere existence of the 1992 WIPP law will insure the requirements are met without any enforcement for the next 100 years by implementing low technology barriers may be unduly optimistic.

Drilling Probabilities

Page 17, Paragraph 1

"The risk of drilling at a location outside the disposal area surface footprint and inadvertently intruding into the disposal area is essentially zero."

A. Do you mean "risk" or "probability"?
B. Where are the calculations to substantiate this statement?
C. On what basis is the writer confident that the current practice will apply for 100 years?
D. If slant drilling is not practical (as allowed) why has there been extensive slant drilling in salt formations?

Long-Term Monitoring
Page 22

The only long-term monitoring planned by DOE are measurements of subsidence. Other monitoring should be planned as well.

Page 27

The material to be archived should also include a copy of the standards since the allowable risks may be substantially different in the future and future generations may have a different threshold of an acceptable risk. This is much more important than many of the other reports.

Since the EPA standards urge the reader to see comparable provisions issued by the NRC for high level waste, include a comparison of items not being done at WIPP and add 10 CFR 60 to the list of references.

What are the plans for markers, records and active institutional control for TRU waste that has been buried to date? List those plans in the references since those PICs may not all survive. Include an explanation why we have markers for TRU waste buried at 2150 feet and none for TRU waste buried in shallow formations so that future generations can understand our logic.

BIENNIAL ENVIRONMENTAL COMPLIANCE REPORT (BECR)
(VOLUME II)

Background

While DOE is a regulatory agency and DOE Orders are applicable to this project, DOE is not identified as such in the list of regulatory agencies. It is essential that public accountability of compliance with DOE requirements be included. The BECR report provides detailed information on the status of compliance with laws, regulations and standards by a number of regulatory agencies. Unfortunately, the report omits any information on the status of compliance with regulations issued by a key regulatory agency, namely the U.S. Department of Energy. An analysis of the DOE Orders, and the reviews and approvals by the Office of Environment Safety and Health (ES&H) and the Defense Nuclear Facilities Safety Board (DNFSB) should be included.

It should be made clear that the Administrator of EPA or the State, as appropriate, shall determine whether DOE is in compliance with all the regulations and permits listed in Sect. 9(a)(1). Use the full, exact citation in the Land Withdrawal Act.

The cutoff date of a year prior to reporting is needlessly long. It should be six months.

WIPP LWA Requirement
Page 1.2

Provide the specific citation, Section 9(a)(2), in the 1992 LWA that this section shows compliance with.

Codification of Regulations
Page 1-3, 1.3.2

The description of the mechanism for promulgating regulations by federal regulatory agencies is good. It should be noted that DOE, as a regulatory agency, has not published proposed regulations in the Federal Register nor codified them in the Code of Federal Regulations.

DOE has issued regulations as DOE Orders without a public review process. The text on page 13-2 acknowledges that the DOE Orders are not considered to be at the same levels as those in the Code of Federal Regulations. DOE is now beginning to codify regulations in the CFR.

Page 2-8

40 CFR 268.10-12 requires waste for treatment to be evaluated. If the DOE treats mixed TRU waste, additional documentation should be provided.

CRCLA Requirements

Page 3-4

While DOE was required to submit a preliminary assessment for WIPP to EPA by August 5, 1994, the March 31, 1995, DCCA indicates that the brief preliminary assessment is still in preparation. What is the status?

Page 3-4

The March 31, 1995 DCCA states, "An official Local Emergency Planning Committee will be established in 1994." What is the status?

NRC Standards

Page 5-1, Paragraph 3

The statement is made that "NRC standards and requirements are incorporated into DOE Orders." Generally this is not true.

NRC and DOT

Page 5-1

"The NRC's requirements pertain to WIPP only in the transportation of TRU waste from the generator sites to WIPP."

Transportation regulations are established by the U.S. Department of Transportation (DOT). The design of the Type B shipping containers is licensed by NRC under 10 CFR 71.

NESHAPS Limits
Page 6-12, 6.2.2

While EEG agrees that the NESHAPS limit of an effective dose equivalent of 10 mrem/year will not be exceeded, the use of CAP-88 in the 1990 FSAR calculations was applied incorrectly. See EEG-52

Mission of DOE
Page 13-1, Paragraph 2

Contrary to the assertion, the U.S. DOE is not solely involved in national defense activities.

DOE Regulatory Authorities
Page 13-1

An analysis of the DOE system of Orders, notices, and directives to protect the public, the environment and workers from adverse consequences from DOE operations should be included in this section.

RH-TRU Waste Transportation
Page 15-1

There are two types of transuranic wastes to be shipped to WIPP. CH-TRU and RH-TRU waste. The 28 pages of Chapter 15 only describe the shipping container for the CH-TRU waste. Nothing is included on the RH-TRU container which may have 1/3 of the total radioactivity. Revise this section to include the status of the design, and schedule for the RH-TRU container submission to NRC with the expected date of certification.

Compliance

Page 16-1

While DOE is not required to do so, the Department might request the U.S. Department of Transportation to make an evaluation of DOE's determination of compliance with the materials outlined in this section. The same applies to all regulatory agencies in the BECR.

Federal Land Policy and Management Act

Section 18 should provide specific information on the plans to remove the 10 million Cu ft of salt that will be left over at the completion of the project.

BOREHOLE DATA OF SOUTHEASTERN NEW MEXICO
(VOLUME II)

The compilation on borehole data for southeastern New Mexico is incomplete and does not include all oil and gas wells. While there is a reference in Volume I (page 2-114) to a report being prepared on Delaware Basin boreholes, the compilation should be available now, particularly since DOE states that the report being prepared is associated with the prediction of future drilling rates.

Other wells that appear missing from the inventory include:

Engle	James Ranch
USGS 4	James E.
USGS 1	Martha
USGS 8	Dolores
LRL 7	Federal
DD1	Federal
Hudson Federal	Phillips
Culbertson-Erwin	Wright
Bootlegger Ridge	David
Gulf 1-A	Dunes
Pogo	State
Union	I-P.G.-4
Danford	Barclay Federal #1
Belco	Medano State Comm #1
Culbertson	Forty-niner Ridge Unit #3
Covington	Getty "24" Federal #5WD, #'s
Masho 1	Neff "13" Federal #'s 2,3,4,5,6,7,8
Masho 2	
Shell	
Tidewater	
Bilbrey	
Barclay State #1	

None of the boreholes listed in Subsurface Exploration Borehole Data Base have drilling records prior to 1978. Were there none or are the records unavailable?

M

BASELINE INVENTORY REPORT (BIR)
VOLUMES III AND IV

The projected quantities of TRU waste have changed substantially from the February 1995 Baseline Inventory Report (BIR) Rev. 1 estimates used in the DCCA to the December 1995 BIR Rev. 2. An explanation is needed, particularly since DOE is considering a redefinition of defense TRU waste. Additionally, the existing design of 7080 m^3 for RH-TRU waste will not accommodate the 27,000 m^3 of RH-TRU waste to be emplaced in the walls of the rooms.

	REV. 1 2/95 (m^3)	REV. 2 12/95 (m^3)
RH-TRU Waste	4800	27000
CH-TRU Waste	120,000	110,000
Total	125,000	140,000

Commercial TRU Waste

ES-1

Why is commercial transuranic waste included in the inventory since it is specifically precluded both by the NM/DOE C&C Agreement as well as Public Law 102-579?

Disposal Inventory

Page 1-4

The volume shown for CH-TRU waste is high by a factor of 100,000.

Particulate waste

Page 1-5

The text states that all particulate wastes will usually be immobilized prior to shipment to WIPP. This form is not identified as a Waste Matrix Code Group nor is it defined in the Glossary. How will it be immobilized?

RH-TRU Waste Inventory
Page 4-2

The allowable projected volume has an unwarranted multiplier in the expression of 10^5.

CH-TRU Waste Quantities Incorrect
Page 4-2

"The total volume of projected CH-TRU waste from the IDB in Table 4-1, if added to the stored waste volumes from the IDB, exceeds the capacity of WIPP (176,000 m^3)." No, it does not. The sum of the existing and projected volumes from Table 4-1 is less than 176,000 m^3. The whole purpose of the scaling equation on this page is to note that there will be unused space for 30.5% of the design volume or 1.9×10^6 cu ft.

Estimating the Total CH-TRU Waste at Each Site

While an elaborate description is provided of the method to calculate the CH-TRU waste at each site the results of the calculations are not provided in either Chapter 4, Volume I, or in Volume III or Volume IV. They should be shown.

The origin of the 0.65 factor is not shown. The text should note that it is

$$\frac{72{,}000}{64{,}600 - 14{,}600 + 62{,}000}$$

The 14,600m^3 is a correction for low-level waste.
The 62.000 M^3 is a correction for the Savannah River (SR) TRU waste.

Estimating the Total RH-TRU waste at Each Site
Page 4-3

The result of the calculations are not shown.

It would be simpler to show

Existing Waste + Projected Future Waste + Vacant Space = Design Capacity

Vacant Space = 5182 m^3 or 73% of the RH-TRU waste capacity.

The opposite conclusion is presented on page 4-4 which states that the volume of RH-TRU waste identified by the sites exceeds the capacity of the repository.

Low-Level Waste

Page 4-5

It appears that half the waste that has been characterized as TRU may be Low-Level Waste. More information is needed on this.

DECONTAMINATION AND DECOMMISSIONING PLAN
(VOLUME V)

As the title implies, the plan is conceptual in nature and does not provide specific details of the decommissioning process, but it is appropriate that the plan be conceptual and general in nature. It should be expected that regulatory requirements for decommissioning and decontamination and technical capabilities will change prior to facility closure. Appropriate commitments are present and the plan is reasonable.

- Estimates of the amounts of metal to be emplaced in the repository following D&D should be provided.

- What are the plans for TRU and LLW generated during decommissioning?

Specific comments follow:

Page 1, paragraph 3

The reference for the waste acceptance criteria for decontamination and decommissioning (DD-WAC) should be provided for review.

Page 2, paragraph 1

"Mined salt remaining after closure and berm construction will be disposed under Section 2 and 3 of the Minerals Act of 1947."

The requirements of the Act should be discussed in the plan rather than just making reference to the applicable Sections. There will be about 10 million Cu ft of salt left over at the end of the project and a commitment needs to be made to remove it.

Page 2, paragraph 3
Regarding stakeholder involvement.

The actual commitments of NEPA should be specified in the plan, rather than making general references to the Act.

Page 3, paragraph 7

The hot cell may remain as part of a permanent marker.

There is no explanation why the Hot Cell would be allowed to remain as a marker. Plans to decontaminate the Hot Cell should be included.

Page 26, paragraph 1

Reference to shaft seals.

What is an acceptable sealing technique? The basis for establishing such criteria should be provided.

Page 27, paragraph 1

Radiation survey techniques.

Reference the criteria for radiation surveys.

Page 27, paragraph 2

Environmental monitoring.

The criteria for environmental monitoring should be provided.

Considerable site characterization work has occurred since the publication of the GCR. New Issues have arisen, some of which have been resolved and the others remain unresolved.

In August 1979, the EEG published EEG-2 (App. III to EEG-3), titled Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978. A number of EEG reports and papers have since been published (see the list of EEG reports at the end of this report) that relate to the geological characterization issues. The EEG Comments on Chapter 2 of the DCCA reflect the EEG's up-to-date position on many of these issues.

STATISTICAL SUMMARY OF THE RADIOLOGICAL
BASELINE PROGRAM FOR THE WASTE ISOLATION PILOT PLANT
(VOLUME VIII. APPENDIX RBP)

Project Gnome Environmental Radioactivity
Page 1-3

The paragraph about project Gnome states that the surface radioactivity has been reduced to approximately background levels. EEG has conducted a radiological survey of the area and found significant levels of Pu-238, Pu-239+240, and Am-241. The results were published in EEG-58, Radionuclide Baseline in Soil near Project Gnome and the Waste Isolation Pilot Plant, Jim W. Kenney, Paula S. Downes, Donald H. Gray, Sally C. Ballard, July 1995.

The paragraph about the Test Phase should be deleted since these plans are no longer in effect.

Fission Products in Groundwater Samples
Pages 5-7

The reported presence of the fission product Sr-90 in groundwater samples does not appear correct.

Long Lived Radionuclides
Page 6-1

Contrary to the assertion, ^{90}Sr and ^{137}Cs are generally not considered to be long-lived radionuclides as are transuranics.

References
Page 9-1

Add the following EEG publications:

EEG-47, Kenney, Jim W., and Sally C. Ballard, Preoperational Radiation Surveillance of the WIPP Project by EEG During 1989, December 1990.

EEG-49, Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1990, November 1991.

EEG-51, Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1991, October, 1992.

EEG-54, Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1992, February 1994.

EEG-58, Kenney, Jim W., Paula S. Downes, Donald H. Gray, and Sally C. Ballard, Radionuclide Baseline in Soil Near Project Gnome and the Waste Isolation Pilot Plant, July 1995.

Illegible Graphs

Pages A-1 through A-52

The graphs in the appendix, Date Histograms and Probability Distribution Models are not legible.

QUALITY ASSURANCE PROGRAM DESCRIPTION
(VOLUME VIII. APPENDIX QAPD)

The "QAPD" Appendix, consisting of the June 1994 CAO Quality Assurance program Description (QAPD) revision 0, does not specifically address QA as related to any of the 40 CFR 191 requirements, and became effective well after the bulk of the work described in the rest of the DCCA was completed.

The "Draft Compliance Application Guidance (CAG) Document for 40 CFR Part 194 Federal Register Draft" of September 1995 (EPA 402-R-95-014) which postdates the DCCA, provides guidance to the proposed 40 CFR 194.22 for "...submission of information...demonstrating the establishment and execution of Quality Assurance programs..." (p. 22-23). It should be noted, however, that the DCCA states specifically that the requirements of 40 CFR 194.22 are not addressed (p. 5-1, lines 15-17).

The "QAPD" appendix was addressed in several of our comments on Chapter 5 of the DCCA. The bulk of these comments compare the requirements in the proposed 40 CFR 194.22 concerning NQA-1, NQA-2 (part 2.7), and NQA-3 against both the CAO QAPD revision 0 (the "QAPD" appendix) and the draft revision 1 currently under review by CAO. The conclusion is that neither version requires adherence to all of the NQA standards as proposed in 40 CFR 194.

IMPLEMENTATION OF THE RESOURCE DISINCENTIVE IN 40 CFR PART 191.14(e) AT THE WIPP
(VOLUME VIII. APPENDIX IRD)

EEG does not believe the report "Implementation of the Resource Disincentive in 40 CFR Part 191.14(e) at the Waste Isolation Pilot Plant DOE/WIPP 91-029 Revision 1, June 1993" satisfies the Assurance Requirement 40 CFR 191.14(e), which states the following,

> "Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive eco-systems. Such places shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future."

Since WIPP fails all three Criteria (previous mining for resources, reasonable expectation of future exploration, and significant concentration of a rare material) DOE needs to provide documentation on the favorable characteristics. It is important to note that the purpose of the Assurance Requirements is to provide confidence needed for long-term compliance with the Containment Requirements of 40 CFR 191.13.

EEG reviewed the August 1991 draft of the report and provided detailed comments in our December 27, 1991 letter to the WIPP Project Director (Supplement 5). Also attached are copies of the EEG's February 13, 1990 (Supplement 6) and August 10, 1990 letter (Supplement 7) on this subject. There was no response to questions raised in our three letters (see Supplement 8).

The DOE concludes from the Natural Resources Study: "The conclusion of this study is that activities related to potash and hydrocarbon resource extraction and solution mining from within (and outside of) Control Zone IV, using currently available and applicable technology, will not compromise the integrity of the WIPP waste emplacement facility and increase the likelihood of a breaching event." This statement may not be justified in the light of the extensive oil, gas, and potash extraction activities in recent years and the case of Hartman vs. Texaco (see the comments on Chapter 6).

DOE Natural Resources Study
Page 13, paragraph 2 & 3

The specific conclusions reached from the natural resource study need to be reconsidered on the basis of the Hartman vs. Texaco case and the expected waterflooding activities in the vicinity of the WIPP site.

Probability of Resource Extraction in Zone IV
Page 13, and page 16

The summary paragraph states "...any resource recovery operation will be reviewed by the Bureau of Land Management (BLM) (for surface claims) and the Minerals Management Service (for underground claims) prior to its implementation." (page 13) and "the DOE did commit to working out arrangements with the BLM to assure that the DOE receives notification of resource development proposals in the vicinity of the WIPP site." (page 16).

A number of examples were cited in EEG-55 to indicate problems with the assumptions.

Basis of 1980 Site Selection
Page 27

"... the Eastern New Mexico area is not very productive, and has not been subjected to a lot of drilling."

This is a false statement.

Page 30

At the end of section 4.2.1, Table 4-1 should be table 4-2.

Page 32

Table 4-3 should be table 4-4.

SEPTEMBER 1994 WIPP SITE ENVIRONMENTAL REPORT FOR CY 1993
(VOLUME IX. APPENDIX SER)

Preface

"All activities pertaining to the Test Phase will now be conducted at the INEL." The alcove tests would have accounted for most of the waste to be used in the Test Phase. These tests are not being conducted at INEL nor anywhere else.

Additionally, bins that had been characterized at great expense at INEL to measure gas generation have not been used for that purpose at INEL.

The report does not include measurements obtained by EEG over the past decade and published eight reports. There is surface radioactivity caused by the Plowshare atomic weapons test in 1963, six miles southwest of the WIPP site. The document should also reference the EEG work in this area.

Prerequisite to Shipping Waste to WIPP
Page 2-2

Contrary to the statement, the shipment of wastes to WIPP are not predicated on the completion of bench-scale tests at INEL.

"Subsequent to a successful completion of the test phase, the WIPP will be designated as an operational facility and TRU waste will be transported... to the WIPP site." The test phase has been cancelled.

Radioactive Waste at WIPP
Page 3-2

"Most of the waste slated to be sent to the WIPP site is TRU waste." It is <u>all</u> TRU waste.

Potentiometric Surface of Culebra

Page 7-19

The potentiometric surface of the Culebra dolomite in Figure 7-3 is different from that shown in Chapter 2.

Environmental Data from 1989 thru 1993

DOE did not report radiochemical data from environmental samples between 1989 and 1993. Most radiochemical results reported before and after this time were reported as "less than detectable". Such reporting does not allow for determination of a numerical radionuclide baseline.

Concentrations of Gases

Page 6-3

Annual average concentrations for the five gases identified are not provided.

Page 6-3

The air quality monitoring section states, "initial indications show H_2S, SO_2, and NO_x, data values at or below the lower level of detection for these analyzers." The lower limits of detection should be specified for these instruments.

SUPPLEMENT 1
(Chapter 2, DCCA)

EEG COMMENTS ON THE COMPLIANCE STATUS REPORT FOR THE WIPP
(DOE/WIPP 94-019, Rev. 0)
GENERAL REMARKS

The Compliance Status Report (DOE/WIPP 94-019, Rev. 0) for the WIPP project contains descriptions and status of resolution of issues related to the WIPP's compliance with the applicable standards and regulations of the Environmental Protection Agency (EPA). The Environmental Evaluation Group (EEG) has been studying these issues for many years and has a different perspective from DOE on their status of resolution and importance. The differences can perhaps be resolved through further discussion or may require additional field and/or laboratory investigations.

These comments are arranged according to the chapters in the Compliance Status Report (CSR). When a topic is discussed in more than one chapter in the report, the comments are consolidated for the chapter where the topic is first discussed. Specific suggestions for the compliance application are provided, when appropriate. These comments are a part of our continuous review of the compliance issues.

The Compliance Status Report appears to have been prepared by a number of authors, and portions have been apparently taken from other documents. The quality is therefore highly variable. This review addresses only the significant errors or omissions. It is hoped that other more formal WIPP documents, such as the compliance application, will be more carefully prepared.

The EEG recommends that the scientific issues be resolved through scientific arguments and additional analytical or experimental work where necessary. When an issue is very difficult to resolve, it may be acceptable to leave it unresolved on the basis of low probability or low consequence. However, if many significant issues remain unresolved, it may result in loss of credibility of the scientific effort spent on the project. Subject the issues to the SPM process only after the best scientific data and arguments have been analyzed and debated. Moreover, certain issues, such as the knowledge of the hydrologic recharge and discharge areas and the position of the water table, may not directly affect the input parameters for the performance

assessment calculations but are nonetheless important for demonstrating confidence in a basic understanding of the site characteristics.

EXECUTIVE SUMMARY

The Purpose of WIPP

The description of the purpose of the WIPP project continues to remain confused in the DOE documents. "Research and development facility to demonstrate the safe disposal of radioactive waste..." has never adequately described the purpose of WIPP, even though it is the language in the 1979 Act authorizing WIPP. The first sentence in the Executive Summary of the CSR, "WIPP...has been sited and constructed to meet the criteria established by the scientific and regulatory community...", is also unnecessarily convoluted. The following straightforward statement is suggested to describe the purpose of the WIPP project for use in all the WIPP project documents: "The Waste Isolation Pilot Plant is planned to be a permanent geologic repository for transuranic waste generated by the defense activities of the United States."

As appropriate, additional statements about the DOE being the manager of the waste and the repository, the EPA being the certifier of compliance with the environmental regulations, etc., can be added.

CHAPTER 1 - INTRODUCTION

Project Overview

Only through a full description of the checkered history of the WIPP project can the inconsistencies and contradictions in the project be fully explained. For example, the WIPP facility has not been constructed to "determine the efficacy of an underground repository for disposal of TRU waste" (CSR, p. 1-1, second paragraph). Study of the in situ geomechanical and geohydrological behavior of the repository did not require excavation of the full-fledged repository and waste handling facilities, or the heated room experiments. The WIPP facility

was constructed in the 1980s because the DOE had planned to emplace underground all the then existing (200,000 drums) transuranic contact-handled (CH-TRU) waste, and limited quantities of high level waste for experiments, before assessing the WIPP's suitability as a permanent repository. Similarly, for those who may not be familiar with the DOE desire to conduct a "test phase" involving emplacement of waste in the Panel 1 rooms and in the alcoves, the provisions of the Land Withdrawal Act are hard to explain. This section should describe the plans prior to October 1993, the reasons for the DOE decision to abandon the idea of testing with the waste at WIPP, and the effect of that decision on the requirements of the Land Withdrawal Act.

The DOE Energy Systems Acqisition Advisory Board (ESAAB) decision (p. 1-2, last paragraph) was made specifically to start the test phase, so the characterization of this decision to mark "the end of the construction phase" is curious. Since only one-eighth of the planned repository has been excavated, how could the construction phase have ended, anyway? Also, since the CSR and the Experimental Program Plan describe a number of site characterization activities yet to be conducted at WIPP, how could Lappin (1988) have "brought to termination the WIPP site characterization phase" (p. 1-2, third paragraph)? Similarly, it is misleading to state that "The Final Safety Analysis Report (FSAR) was then published." (p. 1-2, last sentence). The 1990 FSAR did not even evaluate the safety of conducting the bin and alcove experiments, that had been planned for WIPP. An Addendum to the FSAR was published in 1991, but it addressed only a small part of the planned tests. A new FSAR is needed to assess the safety of the disposal operations.

Past efforts to represent a very checkered history of the project as a tidy phased development have not succeeded and have only confused successive newcomers on the project. For example, the DOE first announced the end of the Site Characterization phase in 1981, then in 1983, and now it is 1988, but the site characterization is not yet complete because the DOE has not, until now, given a high priority to assessing the facility as a permanent repository. It is not necessary to rewrite history. The project is finally on the right track. Only an awareness of the past mistakes and disassociation with the past short-sighted approaches will keep it there.

The Project Overview should include an assessment of the potential difficulties in carrying out the disposal and decommissioning activities because of the age of the facility. The facility was constructed for a 25 year operation starting in 1988. Since the earliest date to start disposal now is 1998, what is the effect of this 10 year delay on the stability of the excavations and safety of operations?

Site Selection Process

1957 NAS Report: Frequent references to the 1957 National Academy of Sciences (NAS) report (The Disposal of Radioactive Waste on Land, A Report of the Committee on Waste Disposal of the Division of Earth Sciences, NAS-NRC Publication 519, April, 1957) in the WIPP project publications necessitates pointing out some recommendations of that committee which would be useful for the WIPP project to follow:

> "The Committee has in no sense done the research so that such expressions of opinion as are contained herein are predicated on the assumption that the research will be done before any final conclusion is reached on any type of waste disposal." (p. 2 of the report).

> "We stress that the necessary geologic investigation of any proposed site must be completed and the decision as to a safe disposal means established before authorization for construction is given. Unfortunately such an investigation might take several years and cause embarrassing delays in the issuing of permits for construction." (p. 4 of the report, underlining added).

It should also be pointed out that the report was written for disposal of high level liquid waste in salt cavities and as such has very little relevance to WIPP.

Omissions in the History of the WIPP Site Selection: Any history of the WIPP site selection process should include the following important milestones.

- The original WIPP site was abandoned after the borehole ERDA-6 was drilled at that location in 1975 and encountered extreme geologic deformation and a pressurized brine

reservoir at a depth of 2708 ft. Testing in 1981 indicated that the brine reservoir encountered by ERDA-6 contains 100 million liters of brine.

• The two mile criterion was changed to one mile, since a new suitable site could not be found that would be two miles away from any existing drill holes through salt. The new site was selected so that there were no boreholes through salt within one mile of zone II within the WIPP site. The repository was designed to be in the northern part of zone II (see Fig. 8-9, p. 8-17, WIPP Final Environmental Impact Statement, Vol. 1).

• Borehole WIPP-12, located in Section 17, T22S, R31E, within the present WIPP site, 1 mile north of the center of the site and just north of the Zone II, was drilled between November 9 and December 7, 1978, to a depth of 2785.8 ft, 48.3 ft in to the Castile Formation. The original purpose was primarily to investigate an anticlinal structure inferred from seismic reflection profiling. Following a suggestion by the EEG. DOE deepened the well in October-November, 1981, to the base of the Castile Formation, to a total depth of 3925 ft, and in the process encountered pressurized brine at a depth of 3016 ft. Brine started flowing out of the well at a rate of 350 gallons per minute and 1.14 million gallons of brine flowed out of the borehole before the well was controlled.

Based on the results of an extensive series of flow tests conducted in 1981-82, the brine reservoir penetrated by WIPP-12 is estimated to contain 17 million barrels (2.7 billion liters) of brine. The different pressure potentials and some differences in geochemistry between ERDA-6 and WIPP-12 encounters were interpreted to suggest a lack of communication between the two. There was no consensus on the origin and age of the reservoirs. Following a suggestion from the EEG, the WIPP repository was relocated in 1982 to be in the southern part of the WIPP site.

• The WIPP site is much richer in natural resources than was assumed at the time of site selection. The site now is surrounded by more than 100 oil and gas wells within 2 miles of the WIPP site boundary (Silva, 1994).

Regulatory Framework

Section 1.3 should state that the Environmental Protection Agency (EPA) has the authority to approve or disapprove the DOE's determination of compliance with the EPA standards.

Also, add at the top of page 1-9 that the State of New Mexico entered into an agreement with the DOE, soon after the EPA Standards (40 CFR 191) were vacated, to continue the performance assessment work as though the provisions of those Standards remained applicable (C & C Agreement, 2nd Modification, August 4, 1987).

Compliance with RCRA

There may be similarities between the No Migration Variance Petition (NMVP) process for the now-defunct test phase, and the same process for the disposal phase, but there were no procedural precedents set, as the CSR claims (p. 1-8). The NMVP granted by EPA for the test phase incorporated dilution with ventilating air, and that will clearly not happen during the disposal phase. Moreover, the statement about "no migration" on page 1-8 is simplistic. In fact, EPA applies the Draft of Subpart S of 40 CFR 264 (55 FR 30798 *et seq*, 1990) as "standards" that should not be exceeded. EPA has agreed to apply the soil standards for the relevant chlorinated hydrocarbons to the WIPP.

CHAPTER 2 - SITE DESCRIPTION/SITE CHARACTERIZATION

Drilling for Oil and Gas Around WIPP

Oil is being produced from the Delaware Mountain Group Sandstones just outside the WIPP site on all sides, and gas is produced from a well drilled directionally beneath the WIPP site. It is misleading to suggest that these sandstones have been "targets for hydrocarbon exploration elsewhere in the Delaware Basin." (p. 2-9). Furthermore, there is no mention of the deeper stratigraphic units like the Atoka Formation, from which gas is being produced through a directionally drilled gas well located beneath the WIPP site.

Breccia Pipes

Any discussion of Breccia Pipes in the Delaware Basin (e.g. Sec. 2.1.2.2) should address Roger Anderson's hypothesis of formation of the Castiles in the Delaware Basin and other suspected Breccia Pipes in the Basin cited by Anderson and Kirkland (1980) and Anderson (1980). The WIPP project has also not addressed Davies (1984) criticism of the Snyder and Gard (1982) conceptual model of the formation of breccia pipes. Without addressing these alternate conceptual models, the project should not claim that the breccia pipes are confined to the Capitan Reef.

Alternative Conceptual Models for the Culebra

Geological descriptions and interpretations of the observations of the Culebra Member (Sec. 2.1.2.6.2) present only one set of ideas. In many instances, alternative conceptual models exist which should be included. For example, only by ignoring a lot of existing data can it be stated that "density of open fractures in the Culebra decreases to the east". The pattern of fracture distribution and corresponding transmissivity values distribution is too complex to be explained away in a simple statement like that and as expected, has become more complex with additional data acquisition.

Lowenstein (1987) presented an alternative explanation to the Holt and Powers (1988) and Powers and Holt (1990) interpretation of the distribution of halite in the Rustler Formation. Based on a detailed sedimentological study of the Culebra cores from a number of wells at the WIPP site, Lowenstein (1987) interpreted four distinct dissolution zones in the Rustler Formation.

The respective thicknesses of the Rustler and the upper Salado (Chaturvedi and Channell, 1985, Fig. 8, p. 23) call into question the Beauheim and Holt (1990) proposition that dissolution of the upper portion of the Salado Formation may have caused subsidence and fracturing in the Culebra (p. 2-17). The Rustler Formation is 450 ft thick four miles east of the center of the WIPP site and only 300 ft thick from the center of the site westward. The upper Salado (from the top of the Salado to Marker Bed 103), on the other hand, maintains a uniform thickness of about 190 ft over the WIPP site and only decreases in thickness west of

the Salado dissolution front that coincides with the western margin of the WIPP site. It would be more logical to postulate the gradational removal of salt from the Rustler Formation itself to have caused fracturing in the Culebra over the WIPP site. West of the Salado dissolution front (west of the WIPP site), both the Salado and the Rustler have been affected grading into total collapse in the Nash Draw.

If the high transmissivity zone in the southeastern part of the WIPP site is related to the dissolution of gypsum fillings in the Culebra fractures, then the high T zone may extend to the south-central part of the WIPP site (p. 2-21 and Fig. 2-12).

Retardation Through Clays in the Culebra

This section (page 2-21) asserts:

> "--- clay fracture-linings may play an important role in the chemical retardation of radionuclides transport through the Culebra---."

This conclusion is based on the X-Ray Diffraction and Analytical Electron Microscopy analysis of samples collected primarily from clay rich layers of the Rustler Formation from cores of wells drilled primarily in the Nash Draw. Four reports are cited to support this conclusion. These reports are based on the work of Terry Sewards and others at the University of New Mexico under contract to the Sandia National Laboratories.

Sewards, et al, 1991 (a) contains mineralogical analysis of core samples from a single well, WIPP-19, and presents no claim for clay filled fracture linings in the Culebra.

Sewards (1991) presents data on the "whole rock" as well as the "fracture surface" compositions of samples of cores collected from 6 wells (WIPP-26, 27, 28, 29, 30, 32) in the Nash Draw, one borehole (WIPP-33) between the Nash Draw and the WIPP site, and three boreholes (WIPP-12, 13, and 34) in the northern part of the WIPP site. Clays are expected to be present in the Nash Draw cores because of extensive dissolution, weathering, and erosion in that area. WIPP-33 is located in a sink hole and processes similar to Nash Draw have operated there as well. Boreholes 12, 13 and 34 are located north of the WIPP repository and

upstream from the direction of flow of water in the Culebra. Furthermore, the cores from these wells were selected from known clay seams. For example, the only sample from WIPP-12 (CS-1) came from the zone 838.5 to 838.7 ft below the surface. The Basic Data Report for WIPP-12 (Sandia National Laboratories, 1982) identifies mud seams at 837.7 and 840.7 ft depths.

Three Sandia National Laboratory scientists (WIPP Performance Assessment Department, 1992, pp. A-127 to A- 131) correctly evaluated the Sewards (1991) report and stated the following:

> "Sewards (1991) measured and reported clay abundance for eighteen Culebra samples; thirteen from locations to the north and/or west of the WIPP site, and five from the north end of the WIPP site. None of these samples was from wells along fast transport paths. Because Sewards (1991) was focusing on clay abundance and compositional analyses, it is likely that samples were selected for analysis based on visual appearance of clays. Thus, these data may not be representative of clay abundance on fracture surfaces in the area of interest for transport modeling." (WIPP Performance Assessment Department, 1992, Memo from Craig F. Novak, et al to Martin S. Tierney, p. A-127 to A-131).

Having made this statement, it is surprising that the authors of the memo, Messrs. Craig F. Novak, Fred Gelbard and Hans Papenguth, nevertheless recommended assuming the probability of the existence of relative thickness of clay linings in the Culebra fractures to be as high as 0.5.

Sewards et al., 1991 (b) presents mineralogy of 107 samples collected from the cores of 8 wells, 3 of which are located within the WIPP site. However, clay fraction separates (<2 microns) were obtained for only three samples: "WIPP-12 #3, a clay-poor dolomite; WIPP-12 #16, a clay-rich dolomite; and H6B #3, a shale." X-Ray Diffraction analysis was performed on the clay fractions from these three samples, and one sample (H6B #3) was analyzed under the electron microscope. The electron microscopy on this one sample casts doubt on the accuracy of the X-Ray Diffraction technique used:

"There is, however, a discrepancy between the results of the quantitative XRD analysis and the results of the AEM investigation of sample H6B #3. In that sample, the XRD results show that the sample contains approximately 50% corrensite. When imaging was attempted on the AEM, it was extremely difficult to find any corrensite at all; the dominant phases appeared to be serpentine, illite, and chlorite." (Sewards et al 1991 b, p. VII-19).

The conclusion of this report, quoted below, clearly demonstrates how very limited information has been used to make important interpretations:

"The fact that corrensite is the dominant phase in the Culebra samples is important. Corrensite has a high CEC and high surface area, thus it is able to sorb radionuclides very efficiently in the event of a low pressure breach in the WIPP facility. Although the clay minerals of only three samples were investigated; the results of Sewards et al., 1991 show that mixed-layer chlorite/smectite is the dominant clay phase throughout the Rustler Formation, so it is reasonable to suggest that the same is true in the Culebra unit." (Sewards et al, 1991 b, p. VII-19).

Sewards et al., 1991, mentioned in the above quotation, is Sewards et al., 1991 a of this review (Sewards et al, 1991 b of CSR), i.e., "Mineralogy of the Rustler Formation in the WIPP-19 core". As stated earlier, that report makes no claim for clays lining the Culebra fractures. Corrensite is only interpreted to be present in some of the samples, as one mineral among many, when powdered bulk samples were analyzed through X-Ray Diffraction. How can this observation lead to the statement cited above?

The final report by Sewards (Sewards et al, 1992), cited in the CSR, presents mineralogical analysis from 47 samples. Of these, 17 samples were taken from the Culebra, and of these only 9 are from the WIPP site - 6 from the Air Intake Shaft and 3 from WIPP-12. The report states the following with respect to the existence of clay in the fractures of the Culebra Samples:

"Only small amounts of clay can be sampled from the Culebra fracture coatings; therefore, initial technique and model development for adsorption studies on WIPP clays (Park et al., in review) were carried out with material from a black shale layer in the unnamed member. This material, so-called CorWIPP, is 94% corrensite and is described as Sample AIS-15 in this report. Corrensite has a high cation exchange capacity and affinity for the uranyl ion in dilute solution (Park et al., in review) and could provide significant radionuclide retardation in fractures in the Culebra." (SAND90-2569, p. 28).

The above quotation clearly identifies the problem with using Terry Sewards' work to conclude that corrensite clay lined fractures in the Culebra may provide retardation for radionuclide migration through the Culebra. The argument is based on a sample from a "black shale layer" obtained from the lower part of the Rustler Formation, below the Culebra, because not much clay could be sampled from the Culebra fracture coatings! And yet, this information is used to argue that "significant radionuclide retardation in fractures in the Culebra" could be present. It is also the basis for continuing research on the adsorption properties of Corrensite, model development for retardation properties of the Culebra, and the credit for radionuclide retardation taken in the performance assessment work to date.

Any reference to the existence of corrensite or other clay minerals lining the fractures in the Culebra Dolomite member of the Rustler Formation at the WIPP site should be deleted from the project documents because there is no basis for this assumption.

Supra-Rustler Hydrology

The hydrology of the strata overlying the Rustler Formation is poorly understood and serious effort to understand it has not been made (Sec. 2.1.2.7). Basic hydrological parameters such as the location of the water-table and the recharge and discharge areas must be known as clearly as possible, if only to establish the credibility of site characterization. EEG has made specific suggestions for field work in this area since 1985. As long as the position of the water table is not known, it is not possible to say that "Most of the Dewey Lake Red Beds Formation is unsaturated." (p. 2-26, first sentence).

Conceptual Model of Contaminant Transport in the Culebra

The discussion of this topic on page 2-30 is incomplete and presents a single conceptual model while the DOE has decided to perform an important series of field tests to resolve the issue. At this stage, a full discussion of the status of understanding of the mechanism of contaminant transport would include single versus double porosity flow, the role of matrix diffusion and the channeling model.

The estimated flow times in the Culebra, when integrated over the general flow path from the storage panel area to the compliance boundary, range from 100 to 1000 years. The performance assessment has assumed matrix diffusion to retard the radionuclide transport, but the degree of matrix diffusion affecting the transport is not clear. The INTRAVAL participants have pointed out that a conceptual flow-model based entirely on channeling also fits the current hydrological field data, but the current modeling utilizes a dual porosity concept instead. With the channeling model, there would be no matrix diffusion. Sandia National Laboratory plans to start a 7-well tracer test to address these questions. Unless and until these issues are resolved, there is no basis to favor a particular conceptual model.

Culebra Hydrochemical Facies

Section 2.2.2.1 should be revised to assign proper credit for the issues discussed in this section. The EEG has raised the issue of the inconsistency between the inferred direction of flow in the Culebra aquifer and the chemistry of water since the early 1980s and has published three reports on the subject. The issue was first raised by the EEG in 1983 as follows:

> "The unexplained decrease in TDS and a change in the general chemical nature of the Culebra water from sodium and chloride at the site to magnesium, calcium, and sulfate south of the site indicates that insufficient data are presently available to adequately characterize the flow system south of the site." (Neill, et al, 1983, p. 79).

Ramey (1985, Fig. 7) elaborated on this issue and presented the concept of geochemical zonation of the Culebra water. Chapman (1988) further explored the problem and provided a hypothesis to account for the decreasing total dissolved solids in the direction of flow, as follows:

> "As groundwater moves from north to south across the area, the Total Dissolved Solids (TDS) decrease by an order of magnitude and the major hydrochemical facies change from Na-Cl to Ca-SO_4. The only plausible mechanism to effect this change is the influx of a large quantity of low TDS water. The possibility of recharge in the southern area is enhanced by the presence of solution and fill features such as the gypsum caves in the Forty-Niner Member of the Rustler near the Gnome site. These features could behave as conduits supplying fresher water to deeper Rustler units." (Chapman, 1988, p. iv).

The Siegal et al. (1991) report was prepared following a suggestion by the EEG which was incorporated as a requirement of the DOE/State of New Mexico Agreement for Consultation and Cooperation. The EEG considers this issue to remain unresolved, and unless it is resolved, an adequate understanding of the hydrology of the Rustler Formation cannot be claimed.

Hydrogen and Oxygen Isotopes in Groundwater

The EEG (Chapman, 1986) compiled stable isotope data from throughout southeastern New Mexico and compared them to data from the WIPP area. The stable isotopic compositions of most samples of groundwater from the Rustler Formation were found to be similar to the composition of other, verifiably young, groundwater in the area. Though the stable isotope data cannot indicate ages for water in the various aquifers, neither did the data show any distinction between most Rustler groundwater and verifiably young groundwater. A small number of samples, primarily from the Rustler/Salado contact east of Nash Draw, had isotopic compositions that are not characteristic of recently recharged meteoric water. These waters' enrichment in heavy isotopes may be due to mixing with deeper groundwater (supported by

the stable isotopic composition of Salado fluid inclusions and Castile brine) or to exchange between the groundwater and hydrous minerals.

A comparison of the heavy isotope enrichment observed in evaporating waters and the composition of the water at WIPP-29 and Surprise Spring showed that the isotopic composition of these Nash Draw waters could be derived by evaporating Rustler groundwater. Based on stable isotopes, both WIPP-29 and Surprise Spring could be discharge areas for Rustler groundwater moving from elsewhere in Nash Draw and the east.

The enrichment in heavy isotopes found in the water from pools in the Carlsbad Caverns was used by Lambert (1986) as evidence that the relatively depleted Rustler water was recharged during a past, more pluvial, time. However, the uniqueness of the isotopic composition of water in the Caverns' pools suggests that rather than representing the composition of recent recharge, the heavy isotopes are enriched by evaporation and equilibrium isotope exchange in the humid cave environment. Recharge in the extreme karst environment near the cavern may also favor isotopically heavy precipitation.

Radiocarbon Ages of Groundwater

The discussion in section 2.2.2.3 is based on Lambert (1986), although the report is not identified. This report was reviewed for EEG by Dr. Fred Phillips of the New Mexico Institute of Mining and Technology in 1987 who found the conclusions of the report, now presented in the CSR, to be unacceptable. Reasons for our position, based on the review by Dr. Phillips, are discussed below.

While it is true that all of the samples (excluding H-5C, which may possibly be contaminated) are probably in the age range 10,000 to 16,500 years B.P., the ages of the water samples vary in a systematic fashion from youngest (10,000 years) in the north to oldest (16,500 years) in the south (with the exception of H-5, which is clearly on a different flow path than the other ^{14}C sampling wells). This corresponds to the pattern expected from the north-to-south flow direction inferred from the physical hydrology. Thus a more reasonable interpretation of the ^{14}C age distribution is that only a segment has been sampled in the middle of a large-scale flow system. Additional ^{14}C samples to the north and/or east

might well yield Holocene ^{14}C ages. Also, well H-5, although it may be contaminated, may also indicate active recharge.

The major conclusion of the report (Lambert, 1986, p. 5-10 and 81) was, "Because of the questionable validity of the assumptions necessary in applying radiocarbon and radiochlorine dating methods in the evaporite environment of southeastern New Mexico, and because of the previously demonstrated susceptibility of these components to contamination in this groundwater system, these methods will not be pursued beyond this feasibility study." The EEG finds this conclusion to be unnecessary because good results have been obtained from uncontaminated wells. Ground-water systems are fundamentally not amenable to intensive sampling and thus in all ground-water investigations (whether physical or geochemical) assumptions regarding the system are necessary. Useful results can be obtained, even given a wide range in parameters assumed for the ^{14}C dating model. With a properly conducted field study of the system, the parameters could undoubtedly be constrained much more closely and much better refined dates obtained. Because interpreting WIPP site flow patterns by physical hydrology alone is very difficult and uncertain, and because ^{14}C tracing may hold the best hope of elucidating the flow system, the very negative viewpoint expressed by Lambert (1986) is considered by the EEG to be totally unwarranted.

The contamination issue is even more clearcut. Certainly, it is true that a majority of the wells sampled during this study did not yield useful results due to contamination. One does not need to be an expert in ^{14}C to predict that wells crammed with "shredded paper, cottonseed hulls, peanut shells, and various proprietary organic additives" (Lambert, 1986, Section 4.2.6) will not yield meaningful ^{14}C dates! There is very little logic in arguing that because wells deliberately injected with organic material were contaminated, all other wells must also be. Contrary to the statement by Lambert (1986, p.23), contamination during drilling is not "inescapable". The best evidence of this is that four of the wells drilled without organic circulation-loss additives did not show any sign of contamination. There is no evidence that this groundwater system is unusually "susceptible" to contamination. Any system is susceptible to inappropriate drilling practices, and appropriate practices should yield acceptable results at the WIPP site.

Based on the data contained in the report, the EEG came to a different conclusion. In all cases, where ^{14}C could reasonably be expected to give useful results, it did so. Although there were only a limited number of uncontaminated samples, the geographic distribution of the resultant ages is hydrogeologically reasonable. A carefully designed program should be undertaken to expand the number of useful ^{14}C samples and to constrain their interpretation. The EEG advised the DOE not to abandon this potentially very informative avenue of investigation in 1987 and the EEG recommendation was incorporated in the 1988 modification to the DOE/State of New Mexico Consultation and Cooperation Agreement, as follows:

> "Conduct additional radiocarbon studies on Rustler groundwater. The study will consist of two parts. At least 6 wells will be samples to investigate further questions of contamination and system stability raised in SAND86-1054; completion of this study may require resampling of one or two wells known to be contaminated at the time of earlier sampling. In addition, several (approximately 10) new radiocarbon samples will be collected during sampling as part of the Water-Quality Sampling Program (WQSP), in the hope of obtaining direct evidence of groundwater residence times. Samples from the WQSP will be restricted to the near-WIPP environment (not including Nash Draw), and will include reasonable numbers of samples from both high- and low-transmissivity holes. Serious consideration will be given to conducting limited investigations of the metabolic pathways of modern vegetation at the WIPP, and to carbon analysis of both soil gas and soil carbonate, if evaluation indicates these studies would improve the confidence in modeling of WIPP release scenarios."

The target date for completion of this study was September, 1989.

The EEG recommends initiating this study without further delay using the following guidelines:

(1) avoid sampling all wells known to have organic circulation-loss prevention agents added;
(2) sample existing wells at larger distances from the WIPP site that may yield information on

recharge areas, in addition to unsampled wells near the site; (3) collect data on the metabolic pathway characteristics (and thus $\delta^{13}C$) of present vegetation and the $\delta^{13}C$ of modern soil gas and soil carbonates, and (4) use quantitative geochemical modeling to investigate the chemical and isotopic evolution of carbonate species in Rustler groundwater.

Given this approach to a ^{14}C groundwater investigation, there is a high probability of greatly enhancing our understanding of the groundwater flow system at the WIPP site.

Uranium-isotope Disequilibrium Data

The Lambert and Carter (1987) report was reviewed for the EEG by Dr. John Osmond in 1987. Dr. Osmond is the co-inventor of the Uranium-isotope Disequilibrium technique applied to the study of groundwater flow, as acknowledged in the first sentence of Section 2.2.2.6 of CSR. Based on Dr. Osmond's review, the EEG provided comments on the Lambert and Carter (1987) report to the DOE through a letter dated 12/2/1987. The following is a summary of those comments.

The limitations of the application of uranium systematics to groundwater interpretations should be kept in mind:

1) one usually cannot deduce from the uranium data alone the direction of groundwater flow,
2) one usually cannot determine the flow rate of groundwater itself by the use of U-234 decay rates.

The same isotopic data can be used to model water flow in more than one direction. This is because changes in isotopic ratio can be caused either by true ageing (decay or growth of U-234) or by water-rock or water-water interactions. Researchers in this field usually have independently derived information as to flow directions, which they can use to deduce the possibility of uranium leaching or the mixing of two or more groundwater sources.

Investigators can sometimes determine, in deep confined aquifers, the rate of movement of uranium in the system. The rate of flow of the water itself, however, must be inferred from one's estimate of the retardation factor for uranium in that particular aquifer.

That an aquifer is "confined" is usually an assumption of the modelling of slow-moving systems. Mixing with undefined waters, whether from recharge or other aquifers, negates any evolutionary conclusions. The authors of this report recognize the potential problem, but argue against leakage, perhaps too readily.

Finally, when uranium leaching or adsorption is inferred, it should be remembered that only the grain or fracture surfaces of the host rock are involved. The concentration of uranium on these surfaces can be much different than the concentration values of the whole rock.

Therefore, the principal conclusions of the report must be regarded as possibly overstated: 1) it is possible, but not proven, that the Rustler system can be modelled as a confined aquifer, 2) it is plausible that the flow regime has changed direction, but alternative interpretations based on a more steady-state model are readily visualized, and 3) although the inferred rate of movement of uranium through the aquifer near the site is probably about right, the flow rate of the water itself could be appreciably faster.

The basic pattern of occurrence of uranium isotopes in the Rustler ground water in the western half of the study area, as pointed out by the authors, is consistent with a two-source mixing model. These two end members could be water masses represented by H4 and W29 (Fig. 10), or by a water with very little U-238, but considerable excess U-234, that has leached to varying degrees uranium from the aquifer rock. The regression line on Fig. 15 implies that these two end members are leached uranium (infinite concentration) with an atomic ratio (A.R.) of 1.55 and water of zero concentration of U-238 but carrying 13.4 ppb (U-238 equivalent) of U-234.

The authors make use of this pattern to make three different interpretations. Each interpretation is plausible to some degree, but taken together they are somewhat inconsistent.

The most logical has to do with a possible westward flow direction of water from the site toward Nash Draw. Low concentration water (with respect to U) gradually dissolves uranium with lower A.R. values. No information regarding flow rate derives from this model.

The least plausible interpretation assumes that the decrease in A.R. westward is the result of U-234 decay, which leads to deductions regarding low U movement rates (not necessarily low water flow rates). It is recognized by the investigators that such a model is suspect where uranium concentration values are increasing; leaching, if ignored, produces inferred flow rates which are too low.

The third interpretation is inconsistent with the first, so the authors postulate an earlier flow regime and ask as to why the A.R.'s are so high to the East. Such values depend on fractionation processes that often require time periods commensurate with the half-life of U-234, and therefore are nearly always down-flow. In this case, argue the investigators, the estimates of time are apt to be conservative because leaching would hold the A.R. values down.

In all of their modeling, the authors of this report display considerable knowledge and insight; they do not flagrantly misinterpret the data. Their assumptions are made clear. Nevertheless, one aspect of uranium isotope systematics in groundwater is neglected, and could affect their models. In any ancient system, uranium has been moving for much longer than the period of time being modeled. The distribution factor between dissolved and adsorbed uranium (related to retardation) means that any interactions between water and rock are probably independent of whole-rock uranium concentration values. It is the concentration of uranium on adsorption surfaces, rather than that inside the rock particles, which determines how much fractionation occurs, and how fast relative to water movement. The concept of "reducing barrier" is often cited to explain concomitant decreases in U concentration and increases in A.R. over short distances.

The potentiometric contours of the Culebra suggest two flow lines in the study area: to the west, flow is more or less directly south; in the general area of the site, however, there appears to be an easterly flow in the north, a southeasterly flow at the site, and a southerly and westerly flow to the South.

If we postulate a general source area anywhere to the North, with the usual reducing barrier not far from the point of recharge, then all of the water would enter the area with a high A.R. and a low concentration. Water flowing southward in the west would dissolve uranium and take on the higher U and lower A.R. fingerprint. Water flowing in the east would move slower, dissolve less uranium, and have its A.R. altered only gradually with time. When the flow looped west, dissolving and "mixing" with rock-derived uranium would occur.

This scenario combines the three models proposed by Lambert and Carter: mixing in the west and southwest, increasing A.R. due to recoil-type fractionation in the north, and decay of excess U-234 in the general area of the site. If this model has merit, we can deduce uranium movement rates in the aquifer near the site which are consistent with those values proposed by the investigators. Because of the retardation factor, the water flow rate could be higher.

All of these remarks concern the Culebra unit of the Rustler. There are not enough data from the other units to do any regional modelling. However, the fact that none of the A.R. values from above and below are as high as some from the Culebra suggests that the latter is the "tightest" with respect to uranium mobility.

Apparently the data regarding oxidation potential of the Culebra waters is inconclusive; and the same might be said about the other hydrologic and geochemical information that might be used to demonstrate that the Culebra is truly confined. Uranium isotopic data has often been used as evidence in such interpretations. Most deep confined aquifer waters carry uranium at very low concentration levels, on the order of .1 to .001 ppb., and with quite high A.R. values, anywhere from 2 to 20 or more. The Culebra waters have higher uranium concentration than do truly reducing aquifers suggesting the possibility of leakage from shallower horizons. However, the fact that the isotopic data can be used to model flow in systematic ways suggests that such invasions are not the predominant process. Any such oxidative tendencies would favor interactive models (uranium leaching) over the fractionation and time-related models emphasized by Lambert and Carter (1987).

Regarding flow rates and groundwater residence time, Lambert and Carter (1987) consistently confuse <u>uranium</u> residence time with <u>groundwater</u> residence time. The data presented in the report do not allow for the calculation of groundwater ages. Even when the appropriate

retardation factors and grain and fracture surface characteristics are known, there are still serious questions about applying uranium isotopic data to determine basic groundwater flow characteristics. Davis and Murphy (1987), Simpson et al (1985), and Hussain and Krishnaswami (1980) all express serious reservations about the reliability of uranium-disequilibrium dating because of the many difficult-to-substantiate assumptions involved.

The amount and reliability of the data are also questionable. Outside of Nash Draw, the authors have only four wells on which to base conclusions of changes in flow direction. It is important to consider the dual-porosity nature of the Culebra, indicated by the recent hydrologic testing. The very high activity ratios at H-4 and H-5 may be related to the low-transmissivity, matrix flow found at those wells. Conversely, the lower activity ratios at H-6 may be the result of rapid groundwater flow through fractures. More data east of Livingston Ridge, and from fracture-flow areas such as near H-11 and DOE-1 must be collected before any confidence can be placed in conclusions about flow paths.

Considering the serious questions of groundwater contamination in Nash Draw raised by Lambert (1987), there should be an in-depth discussion of the reliability of the presented analyses of a trace constituent like uranium. If contamination with organics is as pervasive in the Nash Draw wells as reported in SAND86-1054, this would very likely alter redox conditions near the wells. Oxidation-reduction potential is an important control on uranium content. Though the authors state on page 6 that the uranium values and isotope ratios have been perturbed at W-29 by wastewater dumping, they then proceed to use this value throughout the report, for instance as an important part of their argument for recharge in southwest Nash Draw.

As previously mentioned, redox conditions are an important factor in modeling uranium behavior. Field evidence (Eh values as reported in Uhland and Randall, 1986 and Uhland et al, 1987) and the relatively high uranium values both argue against reducing conditions in the Culebra. There is no evidence for the "reducing barrier" required by Lambert and Carter's model. The authors should provide some discussion of the physical requirements of the model relative to known aquifer characteristics.

The section on "Implications" for recharge, karst flow, and climate change presents insufficient discussion for reaching the presented conclusions on this broad topic. For instance, if no recharge is supposed to be occurring, there should be some discussion of what happens to rainfall. There is no integrated surface drainage, there are numerous gaps in the Mescalero caliche, and 20 inches of annual rainfall has been common the last few years. The role of southwestern Nash Draw (SWND) is another point requiring additional discussion. The authors present contradictory hypotheses in this section. Lambert and Carter's item number 2 on page 45 says SWND is a recharge area, while item number 4 on page 46 calls for discharge in that area.

Contradictory statements are also made regarding the degree of vertical interconnection in Nash Draw. Item 5 on pages 46 and 47 (Lambert and Carter, 1987) argues that the Magenta and Culebra are freely connected at W-25 and W-27 (as previously discussed in Chaturvedi and Channell, 1985, though overlooked in Lambert and Carter's references). However, item 4 on page 46 argues that recharge to sinkholes in the Tamarisk member cannot be interpreted as providing recharge to the Magenta or Culebra. Are the authors proposing that the Magenta and Culebra are well-interconnected, but <u>not</u> the intervening Tamarisk? Some discussion of this extraordinary hypothesis is warranted. Likewise, more discussion must also be provided of the author's assertion that the dominant process at W-33 is alluvial infilling. The continued presence of this large depression, even after the springs have ceased to flow, argues against infilling at the surface. We are not aware of any evidence or studies that support the author's statement.

In light of the above comments on the Lambert and Carter (1987) report, all the assumptions arising from the conclusions of that report should be reexamined.

<u>Physical Hydrogeology of the Bell Canyon/Capitan Flow Regime</u>

This section (2.2.5) presents contradictory interpretations of the postulated flow between the Culebra and the Bell Canyon aquifers if a connection was made between the two. Mercer (1983) concluded that the flow would be downward, and Beauheim (1986) concluded it would be upward. What is the project's latest position on this issue?

Resources

The estimates of resources reported in the 1980 Final Environmental Impact Statement (FEIS) and all other DOE reports have been shown to be wrong by current exploitation in the field (Silva, 1994). We understand that the DOE has recently contracted with the New Mexico Bureau of Mines and Mineral Resources to prepare new estimates based on current data and look forward to the results of that study.

Background Environmental Conditions

The statement (Section 2.4, p. 2-44), "The effort to establish environmental baseline conditions at the WIPP facility was initiated in 1975.", is wrong.

The earliest environmental data reported by WIPP was collected in 1985. The first report which contained the 1985 data was the Annual Site Environmental Monitoring Report for the Waste Isolation Pilot Plant CY 1985, (DOE-WIPP 86-002).

The WIPP facility is designed to handle and dispose of several million curries of transuranic elements. The environmental baseline has not established a range of specific transuranic elements. The Compliance Status Report only reports gross alpha and gross beta ranges which are several orders of magnitude greater than the fall-out levels of transuranic elements reported for New Mexico by EPA and LANL. This very important portion of the baseline has not been adequately determined by WIPP's Environmental Radiological Surveillance Program.

Climatology and Meteorology

Geological effects of climate change, i.e., dissolution, subsidence, change in hydrological properties of the subsurface strata, etc., should also be considered in scenario screening, in addition to varying the hydraulic head.

Gas Generation

There is considerable discussion (Sec. 2.7.1) of the gas generation model and its development. However, here is a system that can be validated in the laboratory to some extent. What is needed now is not refinement or simplification of the gas generation model, but some laboratory experimentation to see if the right chemical reactions are being modeled. If the model persists in including hydrogen as a product, while actually methane is produced (as is commonly produced in the anaerobic parts of landfills), the model will lead to erroneous conclusions. Testing the gas generation model assumptions in the laboratory is most important.

Salado Formation

The project position on the preferred conceptual model for brine flow from the Salado Formation into the repository should be developed and justified. If it cannot be done without additional analytical or experimental work, then that work should be identified. The EEG does not agree with the strategy of treating various conceptual models to be of equal importance when overwhelming evidence exists that a particular model is far superior than others in explaining the observed phenomena. The EEG recommends that the brine inflow into the repository from the Salado Formation be modeled by assuming Darcy flow in salt, impure salt and fractured anhydrite of the marker beds, and using the in situ measured permeability values for these layers.

REFERENCES CITED

Anderson, R.Y. and D.W. Kirkland, 1980. Dissolution of Salt Deposits by Brine Density Flow. Geology 8(2): 66-69.

Beauheim, R.L., 1986. Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-1364, Sandia National Laboratories.

Beauheim, R.L. and R.M. Holt, 1990. Hydrogeology of the WIPP Site. Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, Field Trip #14 Guidebook. Geological Society of America 1990 Annual Meeting. Dallas Geological Society, Dallas, Texas.

Chapman, Jenny B., 1988. Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico. EEG-39, Environmental Evaluation Group.

Chaturvedi, L. and Channell, J.K., 1985. The Rustler Formation as a Transport Medium for Contamination Groundwater. EEG-32, Environmental Evaluation Group.

Davies, Peter B., 1984. Deep-Seated Dissolution and Subsidence in Bedded Salt Deposits. Ph.D. diss., Stanford University.

Davis, S.N. and E. Murphy, 1987. Dating Ground Water and the Evaluation of Repositories for Radioactive Wastes. NUREG/CR-4912, U.S. Nuclear Regulatory Commission.

Holt, R.M. and D.W. Powers, 1988. Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico. DOE/WIPP 88-004, Westinghouse Electric Corporation.

Hussain, N. and S. Krishnaswani, 1980. U-238 Series Radioactive Disequilibrium in Groundwaters: Implication to the Origin of Excess U-234 and Fate of Reactive Pollutants. Geochimica et Cosmochimica Acta 44: 1287-1291.

Lambert, S.J., 1986. Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and Other Nuclides to the Groundwater Hydrology of the Rustler Formation. SAND86-1054, Sandia National Laboratories.

Lambert, S.J., 1987. Stable-Isotope Studies of Groundwaters in Southeastern New Mexico, SAND85-1978C. In the Rustler Formation at the WIPP Site, Report of a Workshop

on the Geology and Hydrology of the Rustler Formation as it Relates to the WIPP Project, edited by Lokesh Chaturvedi. EEG-34, Environmental Evaluation Group.

Lambert, S.J. and Carter, J. A., 1987. Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico, I: Principles and Preliminary Results. SAND87-0388. Sandia National Laboratories.

Lappin, A.R., 1988. Summary of Site-Characterization Studies Conducted From 1983 through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND88-0157, Sandia National Laboratories.

Lowenstein, T.K., 1987. Post-Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico: Textural, Stratigraphic, and Chemical Evidence. EEG-36, Environmental Evaluation Group.

Mercer, J.W., 1983. Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico. Water Resources Investigations Report 83-4016, U.S. Geological Survey.

National Academy of Sciences, Division of Earth Sciences, Committee on Waste Disposal, 1957. The Disposal of Radioactive Waste on Land. Publication 519, National Academy of Sciences.

Neill, R.H., J.K. Channell, L. Chaturvedi, M.S. Little, K. Rehfeldt, and P. Spiegler, 1983. Evaluation of the Suitability of the WIPP Site. EEG-23, Environmental Evaluation Group.

Powers, D.W. and R.M. Holt, 1990. Sedimentology of the Rustler Formation Near the Waste Isolation Pilot Plant (WIPP) Site. Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, Field Trip #14 Guidebook, Geological Society of America 1990 Annual Meeting. Dallas Geological Society, Dallas, Texas.

Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982. Basic Data Report for Drillhole WIPP 12 (Waste Isolation Pilot Plant - WIPP). SAND82-2336, Sandia National Laboratories.

Sandia WIPP Project, 1992. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 3: Model Parameters. SAND92-0700/3, Sandia National Laboratories.

Sewards, T., 1991. Characterization of Fracture Surfaces in Dolomite Rock, Culebra Dolomite Member, Rustler Formation. SAND90-7019, Sandia National Laboratories.

Sewards, T., R. Glenn, and K. Kiel, 1991a. Mineralogy of the Rustler Formation in the WIPP-19 Core. SAND87-7036, Sandia National Laboratories.

Sewards, T., M.L. Williams, and K. Kiel, 1991b. Mineralogy of the Culebra Dolomite Member of the Rustler Formation. SAND90-7008, Sandia National Laboratories.

Sewards, T., A. Brearly, R. Glenn, I.D. B. Mackinnon, and M.D. Siegel, 1992. Nature and Genesis of Clay Minerals of the Rustler Formation in the Vicinity of the WIPP in Southeastern New Mexico. SAND90-2569, Sandia National Laboratories.

Silva, Matthew K.,1994. Implications of the Presence of Petroleum Resources on the Integrity of the WIPP. EEG-55, Environmental Evaluation Group.

Simpson, H.J., A.L. Herczeg, R.F. Anderson, R.M. Trier, G.G. Mathieu, and B.L. Deck, 1985. Mobility of Radionuclide in High Chloride Environments. NUREG/CR-4237, U.S. Nuclear Regulatory Commission.

Snyder, R.P. and L.M. Gard, Jr., 1982. Evaluation of Breccia Pipes in Southeastern New Mexico and their Relation to the Waste Isolation Pilot Plant (WIPP) Site, with a section on Drill-Stem Tests. USGS/OFR 82-968, U.S. Geological Survey.

Uhland, D.W. and W.S. Randall, 1986. 1986 Annual Water Quality Data Report for the Waste Isolation Pilot Plant. DOE-WIPP-86-006, U.S. Department of Energy.

Uhland, D.W., W.S. Randall, and R.C. Carrasco, 1987. 1987 Annual Water Quality Data Report for the Waste Isolation Pilot Plant. DOE WIPP 87-006, U.S. Department of Energy.

U.S. Department of Energy, 1980. Final Environmental Impact Statement Waste Isolation Pilot Plant. DOE/EIS-0026.

U.S. Department of Energy, 1990. Final Safety Analysis Report, Waste Isolation Pilot Plant. WP 02-9.

U.S. Environmental Protection Agency, 1990. Proposed Rule: Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities. Federal Register (27 July) vol. 55, no. 145, 30798-30884.

SUPPLEMENT 2
(Appendix SCR, DCCA)

CRITICALITY REVIEW

FOR THE

WASTE ISOLATION PILOT PLANT

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1.0 INTRODUCTION

This report discusses the potential for accidental criticality in the Waste Isolation Pilot Plant. Accidental criticality is defined as the inadvertent assemblage of a critical configuration during the processing, storage, or transportation of fissionable materials. A critical configuration occurs when fissionable materials are brought together in such a way that the number of neutrons produced by fission are exactly equal to the number lost by non-fission absorption and leakage--a so-called "chain reaction" occurs. In a "safe," or subcritical configuration, non-fission absorption and leakage predominate.

Inadvertent criticality is of concern because a self-sustaining nuclear chain reaction releases instantaneous radiation--which is hazardous to the health of workers in the vicinity--and creates fission products--which present a hazard to the environment if they are not contained. Thus it is standard practice to conduct detailed analyses of potential criticality prior to the handling of fissionable materials, and to design processes and procedures such that "at least two unlikely, independent, and concurrent changes in process conditions (are required) before a nuclear incident is possible."[1]

The Waste Isolation Pilot Plant (WIPP) is a facility planned to store transuranic (TRU) waste in a mined bedded salt medium well below grade.[2] TRU waste is defined as waste contaminated with certain alpha-emitting radionuclides, including plutonium, transplutonium nuclides, and uranium-233--all fissionable. These wastes are categorized into two classes: contact-handled (CH) and remotely handled (RH), which are separated on the basis of the surface-dose rate.

The wastes originate in a number of DOE laboratories and facilities, and thus are packaged in a variety of containers of differing compositions, geometries, and sizes. Moreover, both the radioisotopic and the inert (defined here as non-radioactive) composition of the packages vary considerably. Thus it has become necessary to define certain bounding

conditions for the wastes in order to address several issues in the design and operation of the repository. This is particularly important in addressing the issue of criticality.

This work does not include the performance of any new, detailed physics calculations. Rather, we have reviewed existing criticality analyses as they apply to the current design of WIPP. The objective is to determine if existing analyses are adequate in demonstrating criticality safety. If they are not, a secondary objective is to determine, from the extrapolation of existing analyses, if inadvertent criticality is likely to pose a serious problem.

We are concerned with the emplacement configuration of TRU wastes. Spent fuel, experimental configurations, and transportation are considered outside of the scope of this review. This exclusion also applies to long-term alterations of the emplacement configuration, potentially involving dissolution, transport, and reconcentration of radioisotopes.

The following Section (2.0) describes briefly the characteristics of the TRU wastes and their containers planned for emplacement within WIPP, and the currently envisioned storage configuration. Summaries are then given of the existing analyses which examine the potential for criticality in WIPP. Section 3.0 discusses the validity of the existing analyses in demonstrating criticality safety in WIPP, and extrapolates to determine if criticality is a serious problem. Finally, Section 4.0 provides conclusions and recommendations.

2.0 BACKGROUND

2.1 Waste Description and WIPP Storage Configuration

Waste compositions and package descriptions are given in the FEIS[2] and the SAR.[3] However, a supporting document[4] provides the best summary description of the salient information, and this is reproduced here in Tables 1 through 3.

The CH storage rooms are about 13 ft. high by 33 ft. wide by 300 ft. long, separated by 100 ft. wide pillars of salt. When the waste material has been emplaced in the storage room, it will be covered with crushed salt backfill at the end of each shift or as required.

According to existing drawings,[5] if a storage room is devoted exclusively to 55-gallon drums, these will be stacked 3 tiers high, 15 drums wide, and an unspecified number of drums long. A storage room could contain as many as 144 drums along the 300 ft. dimension.

If the storage room is devoted exclusively to 83 gallon overpacks these would be stacked 3 tiers high, 10 drums wide, and as many as 135 drums long. Boxes would be stacked 2 tiers high, 6 boxes wide, and as many as 37 boxes long. Other configurations might consist of 83 gallon drums on top of M-3 Bins.

The RH storage area utilizes the walls of the CH waste storage rooms and entries. The RH wastes are contained in Schedule 20, carbon steel pipes, 10 ft. long and 24 in. in outside diameter. These pipes are emplaced horizontally in the pillars of the waste storage area. Current designs envision that the RH waste canisters will be placed on 8 ft. centers. The canisters will be stored in horizontal sleeved holes 6 ft. deeper than the canister lengths.

Table 1
(From Reference 4)

CONTACT HANDLED WASTE CONTAINERS

Package Description	Dimensions	Maximum Fissile Content (grams)
DOT-7A Boxes†		
a. FRP-coated plywood	4' x 4' x 7'	350*
b. Cleated plywood	Random	*
c. Steel boxes (M3-Bins)	50" x 58" x 72"	*
Drums		
a. 55-gallon, 17C	24" dia. x 35" length	200
b. 30-gallon, 17H	19" dia. x 29" length	100
c. 55-gallon, DOT 6M	24" dia. x 35" length	500
d. 83-gallon**	26" dia. x 43" length	200

† Packaged in steel overpack for storage.
* Limited to 5 grams in any cubic foot.
**Used as overpacks for 55-gallon drums.

Table 2

(From Reference 4)

ISOTOPIC CONTENT OF CONTACT HANDLED WASTE DRUMS AND BOXES

Isotope	Total Mass Per Drum, grams	Total Mass Per Box, grams
Pu-238	2.5×10^{-3}	4.0×10^{-3}
Pu-239	7.5	12.0
Pu-240	0.5	0.81
Pu-241	2.7×10^{-2}	4.4×10^{-2}
Pu-242	2.4×10^{-3}	3.9×10^{-3}
Am-241	1.5×10^{-3}	2.5×10^{-3}
Total	8.03	12.86
Typical Fissile Content, grams	7.5	12.0
Typical Plutonium Content, grams	8.0	12.8
Maximum Allowable Fissile Content, grams	200.0	350.0

Table 3

(From Reference 4)

REMOTE HANDLED WASTE ISOTOPIC CONTENT

Isotopes	Mass in Waste, grams
Co-60	0.093
Sr-90/Y-90	59.3
Ru-106/Rh-106	2.0×10^{-8}
Cs-137/Ba-137m	0.5
Eu-152	0.1
Eu-154	3.1×10^{-2}
Pu-238	0.042
Pu-239	126.7
Pu-240	8.7
Pu-241	0.46
Am-241	2.5×10^{-2}
Total	195.95

2.2 Classical Criticality Considerations

The minimum critical mass of a Pu^{239} sphere, moderated and reflected by H_2O, is 520 gms.[6] The ratio of hydrogen to plutonium in the minimum mass sphere is approximately 800. Measurements with polyethylene-moderated systems revealed a minimum Pu^{239} critical mass of 370 gms.[7]

The critical loading of an infinite slab is dependent only on the areal density of fissile material. For slabs consisting of homogeneous mixtures of plutonium and water, the limiting areal density of Pu^{239} is 0.25 gm/cm².[8]

2.3 The SAR Criticality Analysis

The SAR criticality safety analysis is contained in a supplementary document.[4] The calculations were performed using the multi-group, discrete-ordinates, transport theory code, ANISN, in the P_1-S_4 approximation. 27-group cross sections, generated by the AMPX code system, were used in the analysis. The methods were validated by analyzing two critical assemblies.

The RH wastes were modeled as an infinite slab of plutonium, conservatively omitting the steel canister and the other parasitic neutron absorbers. Mixtures of Pu/concrete/water, Pu/glass/water, and Pu/steel/water were considered, in an attempt to simulate both fixed and non-fixed waste forms. The highest calculated k_∞ was 0.11, for the 100% concrete/Pu mixture. The calculated k_∞ of the 100% water/Pu mixture was 0.045.

The 17C 55-gallon drum was selected as the typical CH waste container. It was assumed that the drum is <u>uniformly</u> filled with a homogeneous mixture of Pu^{239} and hydrogen. It was further assumed that 25% of the waste is comprised of combustible material (hydrocarbons), at a packing fraction of 0.5, and at a density of 0.5 gms/cm³. This defined a <u>minimum</u> hydrogen to Pu^{239} ratio of approximately <u>2000</u>. The calculations were performed for higher ratios of H to Pu^{239}. A 90-mil polyethylene liner was assumed to be present on the inside of the 16 gauge steel drum wall.

The results of the calculations, for the three drum loadings considered, are reproduced in Figure 1. The average drum loading was determined by assuming that 3% of the drums contain the maximum 200 gm plutonium, and the remainder contain the typical 7.5 gm. These k_∞ results are for an infinite array of drums, presumably modeled by using a reflecting boundary condition in cylindrical geometry.

2.4 The Rockwell Hanford Operations Calculations

An extensive series of criticality calculations on arrays of 55-gallon drums containing plutonium was performed at Rockwell Hanford Operations.[9] KENO-III and KENO-IV Monte Carlo codes were used, with 18 energy group cross sections generated by the GAMTEC II code. The drum arrays were assumed to be square, however, the somewhat higher fissile densities in triangular arrays were simulated by using a slightly reduced radius. A reflecting boundary condition was used to simulate infinite arrays. For finite vertical dimensions, the actual number of tiers of drums was simulated.

An infinite soil reflector, found to be more effective than water, was used outside of the drums for calculations of finite dimensions. Most of the calculations were performed for fissile loadings of 200 gm Pu^{239} per drum; a few calculations examined higher fissile loadings. Water was used as moderator in most calculations; some calculations explored the effect of polyethylene and cellulose as moderator.

Figure 1

(From Reference 4)

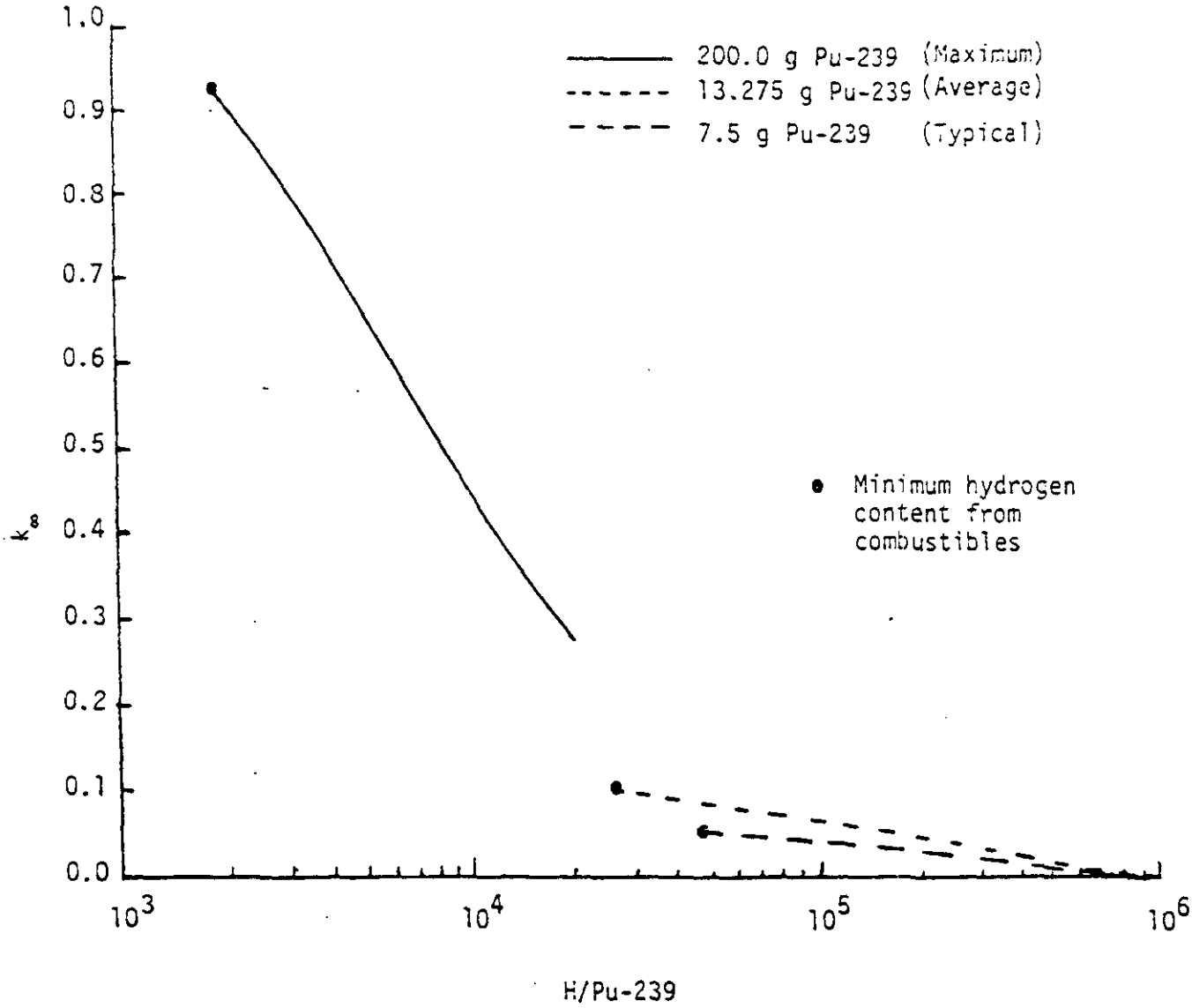

Infinite Multiplication Factor as a Function of H/Pu-239 for Contact Handled Wastes in 17C 55-Gallon Drums

A large number of parameters were studied in this work. These include:

- The hydrogen to Pu^{239} ratios
  $\sim$ 100 to $\sim$ 2500

- Fissile mass
  200 to 400 gm Pu^{239}/drum

- Iron mass in the drum
  0 to 29 Kg

- Reflectors
  1 to 3 ft of soil
  1 ft of water

- Pu^{239} - H_2O mixture density
  Full drum volume down to full theoretical density

- Pu^{239} - H_2O mixture shape
  Full radius, flattened
  Height to diameter ratio = 1.5

- Array shape
  Infinity by infinity by one to seven tiers high
  Three-dimensional arrays

- Effect of polyethylene drum liner

- Effect of substituting polyethylene and cellulose for water

- Effect of array collapse

No attempt will be made to summarize all of the results here (approximately 200 separate calculations were performed). However, the most significant contribution of this work is the clear demonstration of the important effect that shape and density of the fissile material in the drum have on the results. The results demonstrate that modeling the plutonium-moderator mixture as uniformly distributed throughout the drum is <u>not a conservative assumption</u>. This is most clearly demonstrated in Figure 2, reproduced from Reference 9.

Figure 2 contains 3 sets of curves--corresponding to three heights of the array--an infinite number of tiers, 6 tiers, and 2 tiers. Each set of curves is displayed for two hydrogen to plutonium ratios, 1325 and 529. (Note that for the finite number of tiers, the higher H/Pu leads to higher k_{eff} values; this direction is reversed for the infinite number of tiers.) For any one of the curves, the point at the right (100% of drum volume occupied by fissile material) corresponds to the Pu^{239} - H_2O mixture smeared uniformly over the entire drum volume. As we move to the left, the mixture is compressed, either by flattening (denoted by ▭ and ⬭) or by "scrunching" into a cylinder with H/D = 1.5 (denoted by □ and ◇). The mode of volume reduction does not appear to affect the results down to roughly 35-40% reduction in volume for the 2 and 6 tier calculations. At this point the H/D = 1.5 results depart significantly from the flattening results.*

These results demonstrate the significant positive effect on k_{eff} of reductions in volume occupied by the fissile-moderator mixture--as much as +0.40 for the H/D = 1.5 compression. For flattening alone, the effect is smaller--a maximum of +0.17. This effect is derived from the smaller fractional leakage for the compressed shapes, which results in a smaller fractional neutron absorption in the iron drum walls. For the full volume,

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*There is separation between the two results for all percent reductions in drum volume for the infinite tiers. The author points out the crossover in the curves, but pleads ignorant as to its physical explanation.

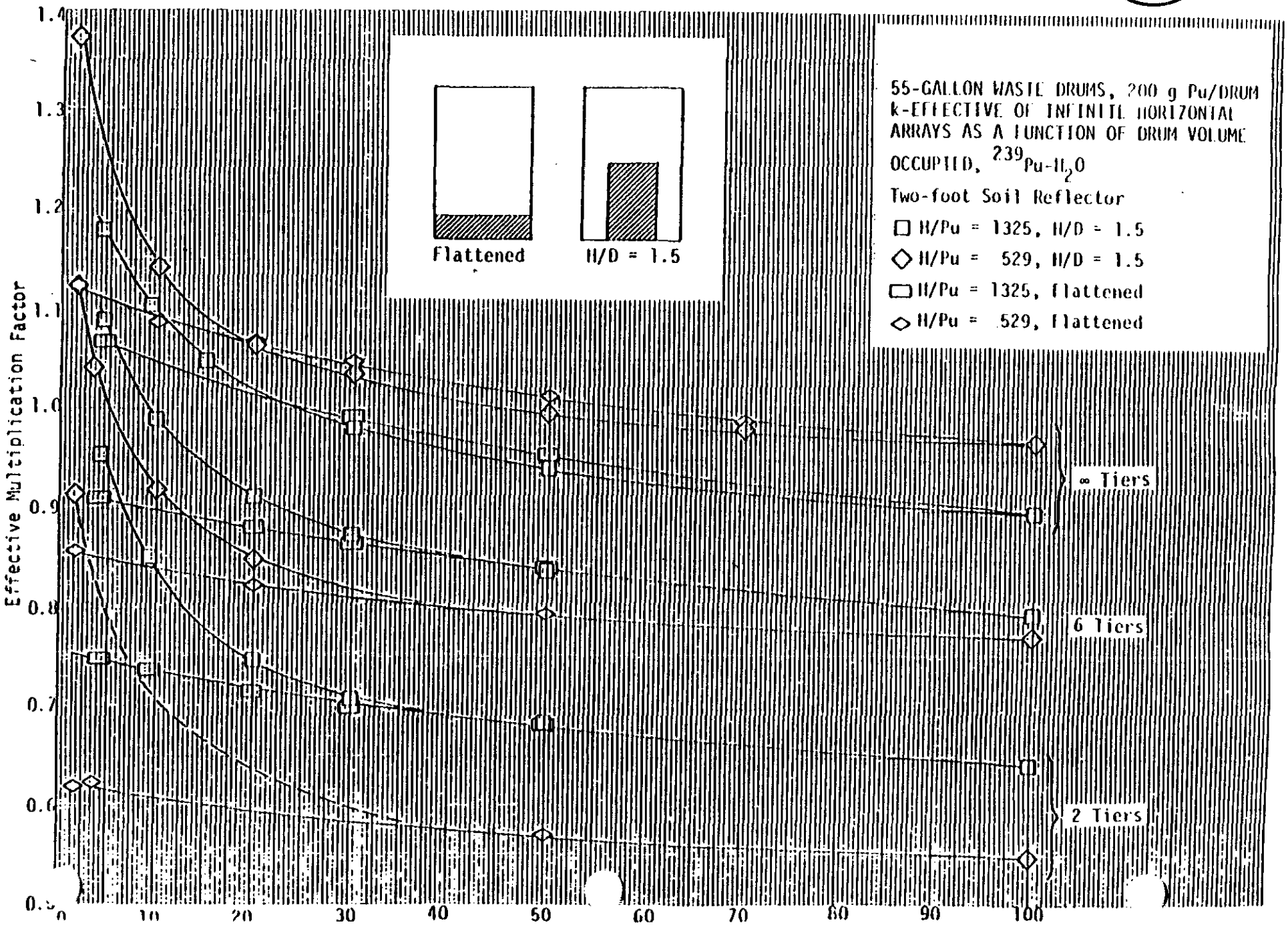

(From Reference 9)

smeared material, the fractional absorption in the drum walls compared to total absorptions plus leakage is 34% (for ∞ x ∞ x 6 arrays). This is reduced to 27% for the full density, flattened shape, and further reduced to 17% for the full density, H/D = 1.5 shape.

2.5 Other Analyses

Criticality analyses on storage arrays have also been performed at EG&G Idaho. The first set of calculations examined arrays of 17C 55-gallon drums containing 200 gm of Pu^{239}.[10] The analysis was performed using the KENO-IV Monte Carlo Code with 16-group Hansen and Roach cross sections. Parameters varied were the hydrogen to plutonium ratio, the array height, and density and shape of the fissile material within the drum.

For an array five drums high, a maximum k_{eff} of 0.68 was obtained at H/Pu ≅ 1200. This is lower than the six tier result of Reference 9, but only by approximately .01 to .05 when the effects of the iron content, height difference, and polyethylene liner are taken into account. The effects of density reduction, both by flattening and reduction in radius, are roughly comparable in magnitude to the results presented in Reference 9, although the radial compression was not accomplished in exactly the same way. Similarly, the effects of height reduction are roughly comparable to the results given in Reference 9, although the magnitude of the effect is not quite as large.

In another set of calculations, EG&G analyzed arrays of DOT-7A, FRP-coated plywood boxes containing a maximum of 350 gm plutonium. The analyses were accomplished using the one-dimensional discrete ordinates code, SCAMP, with 16-group Hansen and Roach cross sections. For array heights of 16 ft., the maximum calculated multiplication factor is approximately 0.64 for H-Pu systems. For a graphite-Pu mixture containing only the additional container wood, the maximum k_{eff} is 0.88 for a 16-ft. high array at optimum C/Pu ratio.

Two sets of relevant criticality calculations were also performed in Silver Spring, using 27-gp. cross sections (generated from the GAM-THERMOS Library using the SCALE program) in the KENO-IV Monte Carlo Code. The first set, for 17C 55-gallon drums, was designed to provide an independent check of the Rockwell Hanford Operations calculations for infinite arrays. We have reproduced these results alongside the appropriate Rockwell Hanford Operations curves in Figure 3. Most of the Silver Spring calculations were designed to simulate the full volume, uniformly smeared configuration (lower curve). Only one calculation was performed for the full density, H/D = 1.5 configuration (top curve). Note that all of the Silver Spring calculations predict higher k values, ranging from +0.01 to +0.14 (the iron density was too low by approximately 2 Kg in the most widely discrepant calculation.), than the comparable Rockwell Hanford Operations calculations. For completeness, the WIPP SAR result for the lowest ratio of hydrogen to plutonium examined is also shown. This result is to be compared against the full volume, uniformly smeared curve (extrapolated).

A few calculations were also performed in Silver Spring for 6M drums containing 500 gm of Pu. The results indicated that infinite arrays of 6M containers <u>without</u> wood between the inner and outer containers may be substantially supercritical.* The infinite arrays <u>containing</u> wood between the inner and outer containers appear to be safely subcritical (highest calculated k_{eff} = 0.46).

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*For an infinite array of 6M containers (no wood) with 500 gm of unmoderated Pu^{239}, the calculated multiplication factor was 1.06. For the same configuration with moderator added to the plutonium (H/Pu ≅ 63), the calculated multiplication factor was 1.62.

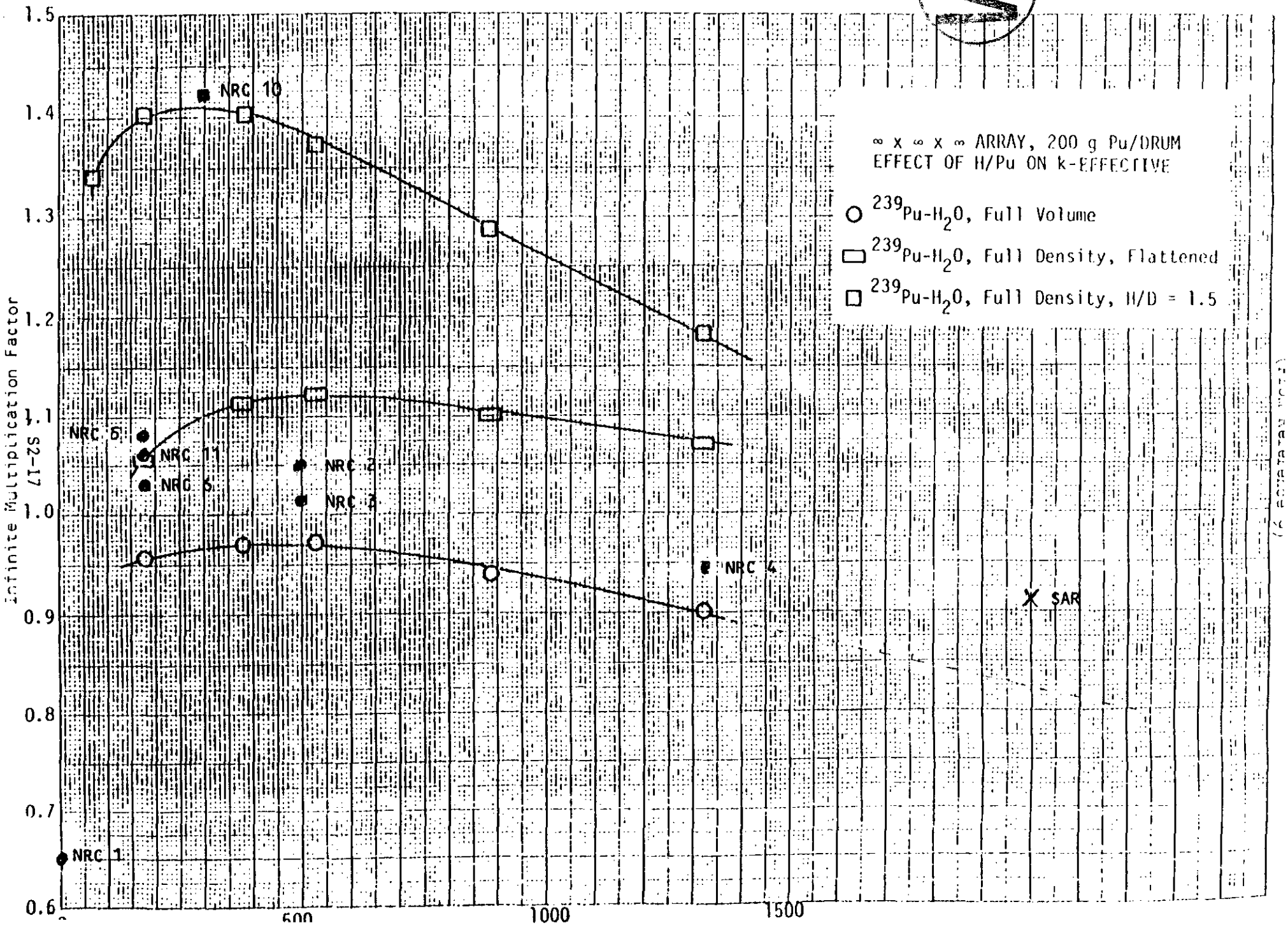
∞ x ∞ x ∞ ARRAY, 200 g Pu/DRUM
EFFECT OF H/Pu ON k-EFFECTIVE
239Pu-H2O, Full Volume
239Pu-H2O, Full Density, Flattened
239Pu-H2O, Full Density, H/D = 1.5
Infinite Multiplication Factor
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
500
1000
1500
NRC 10
NRC 5
NRC 11
NRC 6
NRC 2
NRC 3
NRC 4
NRC 1
SAR

3.0 DISCUSSION

3.1 Validity of the Existing Analyses

The SAR Criticality Analysis

The RH waste analysis appears conservative and the results indicate that the storage configurations are far subcritical for either fixed or non-fixed waste forms, and in the event of complete flooding by water.

Moreover, the safe neglect of all configurations of CH waste except the 17C 55-gallon drums also appears justified. The FRP-coated plywood boxes are shown to be safely subcritical in Reference 11; in fact, classical criticality considerations dictate their safety.*

According to Reference 4, the 83-gallon drums are used only as overpacks on the 55-gallon drums. The ratio of iron to allowable fissile content in the 30 gallon drum is higher than that of a 55-gallon drum,** so a 30-gallon drum array should be subcritical if a comparable array consisting of 55-gallon drums is subcritical. Finally, as long as the wood reinforcement is present, an infinite array of DOT 6M drums was shown to be safe by the calculations performed in Silver Spring.

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*For the 13 ft height limitation in WIPP, the areal density of Pu^{239} is a factor of six below the 0.25 gm/cm² critical areal concentration for H-Pu^{239} systems.[8]

**This is true for most 30- and 55-gallon drums. However, at least two 17H 30-gallon drums weigh less than one-half (27.2 lbs. and 31.4 lbs.) of at least one 17H 55-gallon drum (66.2 lbs).[12] These drums are, however, greater than one-half of the weight assumed in the Rockwell Hanford Operations 55-drum calculations.[9]

The SAR analysis of the 17C 55-gallon drums considers an infinite array in three dimensions. This is conservative because the drums in WIPP will be stacked three tiers high by 15 drums wide. Although three different plutonium contents were modeled, only the 200 gm loading is conservative unless the actual plutonium content will be measured for each drum.

Two assumptions are made in the analysis which are not conservative. The first is the assumed lower limit in the ratio of hydrogen to plutonium (roughly 2000). This assumption is apparently related to a statement in the SAR regarding the combustible content of the wastes. However, the use of the combustible content as a constraint on the range considered for the hydrogen to plutonium ratio does not appear justified. According to the analysis presented in Reference 9 (reproduced in Fig. 3), the difference in the infinite multiplication factor between an optimally moderated array ($H/Pu \cong 300$) and one in which $H/Pu \cong 2000$ (extrapolated from the curve given in Reference 8) is approximately 0.4.* It is noteworthy that the 200 g Pu curve in Figure 1 is climbing steeply toward $k_\infty=1$ at the assumed maximum H/Pu.

The second unconservative assumption is that the plutonium-moderator mixture is spread uniformly throughout the drum. As demonstrated in References 9 and 10, the least reactive configuration is the one in which the fissile material occupies 100% of the drum volume (see Figure 2). In fact, as discussed in Section 2.4, the effective multiplication factor of the full density configuration (with H/D=1.5) is higher than that of the uniform configuration by as much as 0.40.

Although the combined effects of these two unconservative assumptions are not additive, they may in fact exceed the opposing conservative effect of the infinite array approximation. Therefore, the SAR criticality analysis

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*However, the range is not nearly as great for heterogeneous and/or finite arrays.

does not demonstrate criticality safety for the WIPP storage configuration.*

The Rockwell Hanford Operations Analyses

As discussed in Section 2.4, the Rockwell Hanford Operations analyses explored a wide variety of parameters. Certain approximations and assumptions applied consistently throughout the analysis are conservative, tending to bias the calculated multiplication factors on the high side. The most obvious of these are:

1. The ninety-mil polyethylene liners** for 55-gallon drums were omitted from most of the calculations. Incorporation of these liners in the calculations was found to decrease k_{eff} by about 0.03 (at minimum densities) to approximately 0.1 (at maximum densities).

2. Most of the calculations assumed 23 kilograms of iron in the drum, less than the 29 Kg of iron in 17C 55 gallon drums.*** Increasing the iron content by 6 kilograms in the calculations decreases k_{eff} by about 0.015 (at maximum densities) to approximately 0.08 (at minimum densities).

---

*Reference 4 rightly points out that the analysis conservatively omitted parasitic neutron absorption in miscellaneous materials admixed with the plutonium. Although this is undoubtedly true, the waste materials admixed with the fissile material are too variable and poorly defined to rely upon for criticality safety.

**These are available on the Hanford plant drums[9] and were incorporated in the SAR criticality analysis. However, some of the drums at EG&G Idaho have 10-mil polyethylene liners;[10] the extent to which liners are applied to drums from other facilities is not known.

***Some care must be exercised in pinning down the amount of iron in 55-gallon drums. According to one source,[12] the drums range in weight from 55.6 lbs to 66.2 lbs.

3. The existence of the poison, Pu^{240}, was neglected. It is estimated that approximately 7% of the plutonium consists of this isotope.[4] The poisoning effect of this isotope is not negligible, but the magnitude has not been determined.

4. A reduced drum radius was used in the calculations to simulate the higher average fissile density found in triangular arrays. Since square drum arrays are planned for WIPP,[5] this assumption is also conservative. The magnitude of this effect is also not known.

The calculations performed in Silver Spring, however, revealed some discrepancies which are not in the conservative direction (see Figure 3). Most of these calculations provided an independent check on the full volume infinite array analysis of Rockwell Hanford Operations. Eliminating the results which are not comparable on the basis of iron densities (Nos. 2 and 5 in Fig. 3) or cross section structure (No. 11 in Fig. 3), the multiplication factors calculated in Silver Spring are higher than those of Rockwell Hanford Operations by approximately +0.01 to +0.08. The single result for the full density array implies that the discrepancy is significant only for the full volume cases.

The source of this discrepancy, the multi-group iron cross sections, appears to have been identified at Rockwell Hanford Operations.[13] Most of the calculations have been redone, and a revised report is in draft form. However, the revised calculations presumably do not demonstrate changes in the results for arrays with 6 tiers or less.

One additional aspect of the Rockwell Hanford Operations results is worthy of note. This is the analysis of array collapse. [illegible] ray collapse is credible in the underground repository through waste containment or structural failures. Although waste containment failure is essentially assured over the long-term, this review concentrates on the short-term, operational phase of the repository, for which structural failure, at a minimum, should be considered.

The results given in Reference 9 indicate that the increase in multiplication factor brought about by 1-dimensional (i.e., vertical) collapse is negligible. 3-dimensional collapse, however, can lead to an increase in k_{eff} of +0.25 for initially flattened, full density 12 x ∞ x 5 drum arrays.

3.2 Criticality Safety in WIPP

As discussed in the previous section, the criticality analysis in support of the SAR does <u>not</u> demonstrate the safety of 17C 55-gallon waste drum storage arrays in WIPP. None of the many configurations analyzed in Reference 9 is identical to the proposed storage configuration in WIPP. Nevertheless, the safety of the WIPP storage configuration can be <u>inferred</u> from the Rockwell Hanford Operations results.*

The most reactive, physically realistic configuration analyzed in Reference 9 is the ∞ x ∞ x 6 array of drums containing 200 gm of Pu^{239} in a full density, flattened configuration. The fissile material is optimally moderated (H/Pu ≅ 1100) and the vertical dimension of the array is infinitely reflected with soil. The predicted effective multiplication factor is approximately 0.92.

Other results presented in Reference 9 permit an estimate of the effect of additional leakage to be expected from the actual storage configuration. The effect of reducing the vertical dimension from 6 to 3 tiers is estimated to change the multiplication factor by roughly -0.08. The effect of reducing the width of the array from infinity to 15 drums is estimated to be approximately -0.04 in k_{eff}.

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*This statement and the subsequent remarks are predicated on the assumption that the revised analysis (yet to be released) does not result in higher predicted values of k_{eff} for arrays of 6 tiers or less.

Moreover, several additional conservative approximations and assumptions inherent in all of the calculations were pointed out in Section 3.1. The combined effect of these additional conservative assumptions, although not explicitly analyzed, could easily amount to -0.05 to -0.10 in k_{eff}.

Although these negative contributions to the effective multiplication factor are not additive, the combined effect is to provide an additional cushion of conservatism to the analysis. Therefore, it can be concluded that the 55-gall drum storage array in WIPP will be safely subcritical (k_{eff} < 0.95).

In arriving at this conclusion, two very reactive configurations analyzed in Reference 9 have been ignored. The first is the H/D=1.5 shape in the drum, shown to be higher by as much as +0.2 in k_{eff} than that of the flattened shape. That the fissile moderator mixture could assume such a shape in a significant number of drums is considered to be physically unrealistic. The second is the three-dimensional collapse of the array, shown to result in an increase in k_{eff} by as much as +0.25. Although a one-dimensional collapse is considered to be possible (and, according to Reference 9, of negligible consequence), a complete three-dimensional collapse is difficult to envision.*

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*Of course, over the long-term, such an effect is fair game. The long-term, however, is outside of the scope of this review.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Criticality safety in WIPP has not been demonstrated in the SAR. However, a review of independent analyses suggests that criticality safety is assured in the planned configuration for TRU waste storage.*

Criticality safety is dependent on the assumption that no mechanism exists to radially compact the wastes in individual drums or to compress the entire array in all three dimensions. Although this assumption appears reasonable, some thought should be given to potential failure modes that could conceivably undermine its validity. Moreover, a reliable assay method must be specified to assure that the content of plutonium in the drums is less than the prescribed limit (200 gm, for 55-gallon drums).

Other configurations for waste storage in WIPP would require additional analysis before criticality safety can be assured. For example, a configuration in which the drums were to be stacked on their sides has not been shown to be safe. Moreover, if 6M drums containing 500 gm of plutonium are to be stored in WIPP, assurances must be given that each drum will contain the specified wood reinforcement.

Finally, thought should be given to long-term effects that could assemble a critical mass through dissolution, transport, and reconcentration of the fissile material.

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*This conclusion must be regarded as tentative until the revised results of the Rockwell Hanford Operations analyses are released.

5.0 REFERENCES

1. ERDA Manual Chapter 0530, Nuclear Criticality Safety; Approved December 21, 1976 (recently cancelled).

2. Final Environmental Impact Statement, Waste Isolation Pilot Plant, U.S. Department of Energy, October 1980.

3. Safety Analysis Report, Waste Isolation Pilot Plant, U.S. Department of Energy, revised in January 1981.

4. M.H. Lipner and J.M. Ravets, "Nuclear Criticality Safety Analyses for the Waste Isolation Pilot Plant Project," Westinghouse Advanced Energy Systems Division, WAES-TME-3025, April 1980.

5. Repository Level Waste Stacking and Configuration Plan and Sections, Bechtel Drawing No. 51-U-001, Revision E.

6. H.C. Paxton, J.T. Thomas, D. Callihan, and E.B. Johnson, Eds., "Critical Dimensions of Systems Containing U^{235}, Pu^{239}, and U^{233}, USAEC Report TID-7028 (1964).

7. L.C. Davenport and J.K. Thompson, "Survey of Criticality Parameters for Pu^{239} in Organic Media," Trans. Am. Nucl. Soc. 77, p. 419, 1977.

8. J. T. Thomas, Ed., Nuclear Safety Guide, TID-7016, Rev. 2, 1978.

9. W.A. Blyckert and R.D. Carter, "Criticality Parameters of 55-Gallon Waste Drum Arrays," Rockwell Hanford Operations, RHO-SA-133, November 7, 1980.

10. R.R. Jones, Independent Criticality Analysis of 17C Drum Storage at RWMC, EG&G Idaho, Inc., RE-P-81-033, May 1981.

11. R.R. Jones & G.E. Putnam, Independent Criticality Analysis of RWMC Storage and Disposal of Waste with 177 g/m³ Fissile Material Limit, EG&G Idaho, Inc., RE-P-81-050, May 1981.

12. R. Odegaarden, U.S. Nuclear Regulatory Commission, Private Communication, September 4, 1981.

13. R.D. Carter, Rockwell Hanford Operations, private communication, August 31, 1981.

SUPPLEMENT 3
(Appendix SCR, DCCA)

S. COHEN AND ASSOCIATES

RECEIVED
1984
ENVIRONMENTAL EVALUATION GROUP

December 30, 1983

Mr. Robert H. Neill
Director
Environmental Evaluation Group
State of New Mexico
320 E. Marcy Street
P.O. Box 968
Santa Fe, New Mexico 87503

Subject: Reviews of WAESD-TR-83-0015 and TME-3025 Rev.1

Dear Bob:

I have reviewed the subject documents (References 1 and 2 in the attached list) and offer the following comments for your consideration.

In its original WIPP criticality safety analyses,[3] DOE addressed both remote-handled (RH) and contact-handled (CH) wastes. The revised WIPP criticality safety analysis[2] addresses only CH waste. The WAESD report[1] considers the criticality safety of RH waste.

The new RH waste criticality analysis[1] has a different orientation than the original analysis.[3] The original analysis estimated k_∞ for one nominal amount of Pu-239 (126.7 gm), assumed to be uniformly distributed in various solid-water mixtures. The assumed compositions were estimated to be substantially subcritical (k_∞<0.109).

The new analysis <u>determines</u> criticality <u>limits</u> for an array of RH waste containers under double accident conditions. A subcritical margin of 5% Δk is the objective, modified to a value of 8% Δk to account for calculational methods and cross section data uncertainties (at 3σ). The study resulted in two types of limits -- a concentration limit and a mass limit. For those cases in which uniformity of fissile concentration can be assured (the criterion is a maximum of 50% void averaged over any 5 liter volume within the container), a fissile concentration limit of 1.9 gm/liter was derived.* In all other cases, a mass limit of 240 gms obtains (190 gms and 160 gms for fissile assay errors of 25% and 50%, respectively).

Although we do not have the resources to attest to the validity of the results, the RH waste criticality analysis appears to have been professionally executed. The array of containers was modeled using a three-dimensional Monte Carlo code

*Note that this concentration is equivalent to a fissile content of approximately 3 kg in an RH container, roughly a factor of 24 higher than the nominal amount of Pu-239 assumed in the original criticality analysis.[3]

(KENO-IV). Sensitivity to variations in parameters was checked using a one-dimensional transport code (XSDRNPM), which also generates an appropriate neutron spectrum. ENDF/B-4 cross sections were used, with resonance self-shielding accomplished with the NITAWL code. Methods were benchmarked against seven plutonium critical experiments. The calculations considered a number of constituents in the waste matrix, various reflectors surrounding the array, a full range of moderation (H/Pu-239), and compaction/settling of the waste pieces. Additionally, several accident configurations were examined, and double accident conditions were assumed in establishing the limits. In summary, the methods are state-of-the-art and the investigators explored the sensitivity of the results to a very wide range of parameters.

We turn now to the revised CH waste criticality analysis.[2] In my 1981 review of the original CH waste criticality analysis,[3] I pointed out two assumptions which were not conservative.[4] The first was the assumed lower limit on the ratio of hydrogen to plutonium (roughly 2000). The second was the assumed homogeneous distribution of the plutonium throughout the waste.

In the revised CH waste criticality analysis, the former assumption was relaxed, and k_∞ was calculated over the entire range of hydrogen to plutonium ratios. For the maximum fissile content of 200 gm Pu-239, the 17C 55-gallon drum infinite array is critical over the range of 40<H/Pu-239<1500. The maximum calculated k_∞ is approximately 1.2 at a hydrogen to plutonium ratio of approximately 400. However, DOE dismisses these results by stating that "the simultaneous occurrence of a very large array of drums all containing the maximum allowable fissile loading combined with uniform interspersed moderation is considered incredible."

In a February 1982 letter from the WIPP Project Office to the EEG,[5] DOE argues persuasively against the possibility of a significant fraction of the drums being at maximum density. The letter states that "the data package to be provided with every container of waste to be shipped to WIPP will contain the results of an assay of the fissile content in accordance with the WIPP Waste Acceptance Criteria. This assay will be sufficiently accurate to alert the WIPP operator to any trend toward increased fissile loadings."

In its revised criticality analysis, DOE did <u>not</u> relax the second assumption, that the plutonium is admixed homogeneously throughout the waste. In fact, the original erroneous language was not changed, namely that "modeling the plutonium as homogeneously distributed throughout the waste is very conservative since this ignores geometric self-shielding." As demonstrated in Reference 6 and discussed in my 1981 review,[4] compressing the fissile-moderator mixture leads to significant increases

in reactivity because it results in a smaller fractional leakage and less parasitic absorption in the drum walls.

In the February 1982 letter from the WIPP Project Office to the EEG,[5] DOE correctly points out that "reactivity is not significantly affected by settling of the drum's content until the total drum content reaches approximately 30% of the total drum volume." However, DOE further contends that "this settling must occur independent of crushing of the drum, a situation we believe incredible in view of the nature of the drum contents and the limited handling activity involved." I do not agree. This configuration could simply be realized with partially filled drums (with the 70% remainder of the drum empty) or material which has settled to the bottom of the drums.

However, the DOE analysis, coupled with administrative limits on drum loading, would assure subcriticality. The average drum loading (13.275 gm Pu-239) would surely remain subcritical (k_∞ of the homogeneous, infinite array at optimum moderation is less than 0.4), even under conditions of partially filled or settled material in the drums (although this was not explicitly demonstrated by the DOE analysis).

Although I don't suggest that any more resources be expended on this issue, I am still perplexed by DOE's analytical approach to this problem. As discussed in my 1981 review, it is possible to demonstrate subcriticality of a finite array of maximally loaded drums in a flattened configuration.* Relying on this most conservative analysis, DOE would not have to impose administrative limits on drum loading or configuration.

I hope that the foregoing comments are useful to you in your review of these recent DOE documents. Please feel free to contact me if you should have any questions concerning my comments.

Sincerely,

Sanford Cohen

Attachment

SC/gh

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*In fact, the Rockwell Hanford analyses[6] have already done this. At the time of my 1981 review, the Rockwell Hanford calculations were being revised because of changes in the iron cross sections. The revised analyses did not result in higher predicted values of k_{eff} for arrays of 6 tiers or less.[7]

SUPPLEMENT 4
(Appendix SCR, DCCA)

S. COHEN AND ASSOCIATES Inc.

RECEIVED

JAN 20

ENVIRONMENTAL EVALUATION GROUP

January 18, 1984

Mr. Robert H. Neill
Director
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Santa Fe, New Mexico 87503

Dear Bob:

We have completed our analysis of the postulated WIPP reconcentration criticality, and discuss our results in this letter. In summary, we learned that for the material concentrations that you have postulated, a criticality is indeed likely if the high fissile concentration obtains and the dimension of the aquifer is greater than roughly one-half meter. For such a high fissile concentration, the multiplication factor is not affected significantly by the postulated range of carbon adsorption, non-TRU brine composition, or low iron adsorption. High iron adsorption does significantly reduce the multiplication factor, but the thick aquifer is probably still critical. On the other hand, a criticality does not appear achievable if the low fissile concentration obtains for any combination of the other parameters.

The input material concentrations, based on your letter of July 20, 1983*, modified by telephone conversations with Jim Channell on December 19, 1983, are given in Attachment I. The resulting homogeneous atom densities used in the computer analyses are given in Attachment II. A number of the elements contained in Attachment I have been omitted from the calculations. The reasons for these omissions and other assumptions used in computing the atom densities are as follows:

- The calculated atom density of U-233 is three orders of magnitude lower than that of Pu-239, given a uranium distribution coefficient (K_D) of 10; thus U-233 was omitted from the calculation.

- The macroscopic thermal absorption cross sections and potential cross sections of several elements were calculated to be at least three orders of magnitude lower

*Attachment to letter from Robert H. Neill to Sanford Cohen, entitled "Inputs to Criticality Calculation."

than the corresponding macroscopic cross sections for hydrogen, and thus these elements were omitted from the calculations. These omitted elements are barium, cesium, strontium, bromine, flourine, iodine, phosphorus, aluminum, copper, manganese, silicon, and zinc.

- Cross sections for the element chlorine were not available on the master data tape. Chlorine could not be disregarded in the calculations because of its relatively large absorption cross section. Therefore, chlorine was replaced by an equivalent amount of boron, based on the relative thermal neutron (0.025 ev) absorption cross sections of the two elements, i.e.:

$$N_B = \frac{(33.6 \text{ barns})}{755 \text{ barns}} N_{Cl} ,$$

  where N_B and N_{Cl} are the atom densities of boron and chlorine, respectively.

- The element lithium was replaced by the appropriate atom density of lithium-6. The predominant isotope, lithium-7, is relatively transparent and can be safely neglected.

- The "Miscellaneous" material in Case 1 brine is assumed to be nitrogen.

- The hydrogen and oxygen atom densities for Case 2 brine are derived by assuming that the difference between the specific gravity (1.215 gm/cc) and the total dissolved solids (0.328 gm/cc) represents the density of water in the brine.

The computer calculations were performed using the NITAWL and XSDRNPM computer codes installed on the CDC Cybernet system.* NITAWL extracts 123-group cross sections from the master cross

*The codes are summarily described and the input data specified in the AMPX-II manual, "AMPX: A Modular Code System for Generating Coupled Multigroup Neutron-Gamma Libraries from ENDF/B," ORNL/TM-3706, March 1976 (December 1978, Revised).

section library* and prepares them as input to XSDRNPM. It additionally performs any required resonance calculations (only for Pu-240 in our calculation) using the Nordheim Integral Method. XSDRNPM calculates the neutron spectrum and the eigenvalue for a one-dimensional system, accepting fine-group cross sections from NITAWL. It additionally collapses the weighted fine-group cross sections to any specified multi-group set, for input to a multi-dimensional code. For all but one of our calculations (to be described later) we used XSDRNPM in the homogeneous approximation (infinite medium), thus computing the infinite multiplication factor (k_∞).

In all of our calculations, we collapsed cross sections to calculate the diffusion area:

$$L^2 = \frac{D}{\Sigma_a} = \frac{1}{3\Sigma_a \Sigma_{tr}} ,$$

where D is the diffusion coefficient and Σ_a and Σ_{tr} are the macroscopic absorption and transport cross sections, respectively. We also computed the buckling using the following relationship**:

$$B^2 = \left(\frac{\pi}{700 + \frac{1.42}{\Sigma_{tr}}}\right)^2 + \left(\frac{\pi}{d + \frac{1.42}{\Sigma_{tr}}}\right)^2 ,$$

where the first quantity accounts for leakage from the depth (7m) of the slab and the second quantity from the width (d=0.5m or 5.0m) of the slab. (Leakage from the 7m depth is, in all cases examined, negligible.) Then, the effect of leakage on the multiplying system is computed using the one-group, diffusion approximation:

---

*The master library is taken from GAM-II (fast cross sections) and THERMOS (thermal cross sections) cross section sets prepared in the 1960s, and is poorly documented. According to representatives of Oak Ridge National Laboratory, it will be documented in the SCALE manual, which is yet to be published.

**This assumes an unreflected configuration. In actuality, our assemblies are probably reflected by rock. We have neglected the effect of this reflection in our analyses, rendering the results conservative. (The effect of reflection would be to increase slightly the k_{eff} of the assemblies.)

$$k_{eff} = \frac{k_\infty}{1 + L^2B^2} .$$

We examined the accuracy of the above approximation by mocking up the actual geometry (0.5m wide, unreflected slab) in a P_1, S_4*, XSDRNPM spatial transport calculation. We used Case A (Hi fissile, brine 1, no adsorbed Fe, no adsorbed C) for the calculation. The spatial transport calculation resulted in a k_{eff} of approximately 0.83. This is to be compared with an estimated k_{eff} of 0.97 obtained in the one-group, diffusion approximation. Thus the one-group, diffusion approximation appears to underestimate the effect of leakage for the thin slab and thus overestimates the effective multiplication factor. The overestimation in k_{eff} is approximately 0.14 for the 50cm thick slab. Such an error does not significantly affect the results of the study, because it translates into less than 20cm of additional thickness for an unreflected slab. Moreoever, we have assumed in our analysis an unreflected configuration, and the slab would most likely be reflected by unsaturated rock, thus reducing the critical slab thickness.

The final results of the criticality calculations are given in Attachment III. The actual computer output that these results are based on are being sent to you under separate cover. The calculated value of the infinite multiplication factor, k_∞, is tabulated in column 3. The effective multiplication factors, for each slab width, are given in columns 5 and 6. For the five cases identified as A through E, the infinite multiplication factors are also the eigenvalues calculated in corresponding XSDRNPM runs. For the cases denoted with primes, the infinite multiplication factors were obtained by weighting the microscopic fission and absorption cross sections over the unprimed spectra (A' and A" over the spectrum calculated in Case A; E' and E" over the spectrum calculated in Case E), and computing:

$$k = \frac{\nu\Sigma_f}{\Sigma_a} ,$$

using the appropriate number densities for the primed cases. This approximation should be quite accurate for the high fissile cases, since the perturbations are small. For the lo fissile

*The P_1 stands for first order quadrature of the scattering anisotropy; S_4 stands for four discrete angles represented in the spatial transport calculations.

cases, the approximation is less accurate, but sufficient for demonstrating trends for these assemblies, which are estimated to be far subcritical under any of our variations.

The results given in Attachment III demonstrate that an *infinite configuration of the hi fissile concentration is far* supercritical and roughly invariant under all of the modifications examined, with the exception of the hi adsorbed iron case. The insensitivity of the hi fissile case can be expained by the fact that, with the exception of the hi adsorbed iron case, approximately 75% of the absorptions are in the Pu-239.

Conversely, all of the lo fissile concentration cases are subcritical by a substantial margin. This is because only approximately 35% of the absorptions (only 18% for the hi adsorbed iron case) are in the Pu-239. For the lo fissile case with Brine 1, hi adsorbed carbon, and no adsorbed iron, 12% of the adsorptions are in the calcium, 8% in the hydrogen, 35% in the boron (simulated chlorine), 4% in the non-fissile plutonium, and the remaining 16% in the other nuclides.

Leakage from the 5 meter slabs is insignificant, so that k_{eff} is essentially equivalent to k_∞. Leakage from the 0.5 meter slabs is significant; the one-group diffusion analyses indicate that for hi fissile concentrations, with the exception of the hi adsorbed iron case, the configurations may be barely critical ($0.96<k_{eff}<1.07$). Transport calculations indicate that leakage is underestimated. However, we have neglected reflection by the surrounding rock. Therefore, it may be safely concluded that the thin slabs are critical in the thickness range of 0.5 to 1.0 meters.

Two additional perturbations, not tabulated in Attachment III, were examined. The first was the effect of the removal of Pu-238 from Case A.* This results in an increase in k_∞ of approximately 0.01, which is a negligible effect. The second was the effect of the removal of boron, used to simulate the chlorine, from Cases A and E. The results are increases in k_∞ of 0.10 for Case A (hi fissile) and 0.36 for Case E (lo fissile). The results indicate that a 100% error in the simulation of chlorine by boron would not alter the major qualitative results for the high fissile cases, but might for the low fissile cases.

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*Pu-238 has a relatively short half-life, and is unlikely to be present to any significant degree in a repository several hundred years after waste emplacement.

The environmental consequences of a reconcentration criticality incident are highly uncertain. The release of fission products depends on the number of fissions, which in turn depends on the ability of the configuration to remain critical. Most historical criticality incidents result in modest bursts of approximately 10^{16} to 10^{18} fissions; however, as many as ~10^{20} fissions have been recorded.* The historical incidents involving solutions generally proceed in a succession of bursts until the geometry is destroyed by the expulsion of the liquid from the confined configuration. This occurs from the heating and subsequent expansion of the liquid. (10^{20} fissions corresponds to approximately 10^4 Mw-sec, or approximately 10^7 BTU.)

The reconcentration criticality postulated here could have a different physical behavior. The fissile material is deposited on the rock and would presumably remain in place after the brine has been expelled from the generated heat. Moreover, the system would probably fill with fluid again because the source is a flowing aquifer. Thus, the most likely physical behavior is a continual "chugging" of the system, resulting in a continual series of bursts, each resulting in, say, approximately 10^{16} fissions, until the reaction is quenched by the poisoning effect of fission products. Possibly Oklo is the closest analogy.

The quantity of fission products produced can be estimated once the total energy release is determined. However, because of the location of the incident, the consequences to the accessible environment should not be very high. The noble gases may find their way to the atmosphere, but most of the radioiodine would probably be retained in the aquifer or the rock. If Oklo is indeed a reasonable analogy, most of the non-volatiles should be retained in the rock in close proximity to the site of the critical configuation.

I hope that this letter and the Attachments are useful to you in your assessment of the likelihood of a reconcentration criticality resulting from dissolved WIPP transuranic wastes. If you or your staff have any question relating to any of this information, please do not hesitate to call me. I am sending the computer output under separate cover.

Sincerely,

Sanford Cohen

Attachments

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*William R. Stratton, "A Review of Criticality Accidents", LA-3611, September 1967.

Attachment I

MATERIAL CONCENTRATIONS

In Rock (with porosity = 10%)

Element	Density (gm/cc)
Calcium	0.435
Carbon	0.247
Magnesium	0.251
Oxygen	1.045
Hydrogen	0.00234
Sulfur	0.019

TRU Content of Brine

Nuclide	Concentration (mg/l) Hi Fissile	Low Fissile
U-233	1.1	0.11
Pu-238	0.17	0.017
Pu-239	6.6	0.66
Pu-240	0.32	0.032

Concentration factor for rock - 4000

Other Constituents of Brine

Element	Concentration (mg/l) Case 1	Case 2
Oxygen	644	See
Hydrogen	95	attached
Carbon	138	chemistry
Iron	222	for
Sodium	115	WIPP-12
Chlorine	175	brine
Misc. (assume Nitrogen)	55	

Adsorbed Carbon

Concentration in Rock (mg/cc) Low Adsorption	Hi Adsorption
50	500

Adsorbed Iron

Concentration in Rock (mg/cc) Low Adsorption	Hi Adsorption
100	1000

TABLE C.7

CHEMICAL COMPOSITION OF BRINES
SUMMARY OF STATISTICS
ERDA-6, WIPP-12, AND CHION WELLS(1)

SAMPLE TYPE:		FLOW SAMPLE D'APPOLONIA ERDA-6					FLOW SAMPLE D'APPOLONIA WIPP-12					FLOW SAMPLE D'APPOLONIA CHION				
LABORATORY:																
LOCATION:																
FIELD DETERMINATIONS:	UNITS	NO. OF ANALYSES	MINIMUM	MAXIMUM	AVERAGE(2)	CV(3)	NO. OF ANALYSES	MINIMUM	MAXIMUM	AVERAGE(2)	CV(3)	NO. OF ANALYSES	MINIMUM	MAXIMUM	AVERAGE(2)	CV(3)
Temperature	°C	40	21.6(4)	26.7	26.7(5)	0	30	26.2	28.8	26.7	3	--	--	--	--	--
pH	Standard Units	40	6.0	6.5	6.17	0.6	30	6.4	7.16	7.06	5	4	6.95	7.3	7.10	3
Eh	Millivolts	40	-160	-51	-153	8	30	-230	-165	-225	13	4	-250	-164	-233	14
Specific Gravity	--	30	1.214	1.232	1.216	0.2	30	1.210	1.220	1.215	0.3	4	1.210	1.220	1.216	4
Specific Conductance	µmhos/cm @ 25°C	30	351,000	433,000	473,000	3	30	420,000	399,030	344,000	3	4	499,000	542,000	526,000	0.4
Alkalinity(6)	mg/l	20	2265	2910	2600	5	35	2673	3040	2800	3	3	1955	2320	2100	9
Carbonate	mg/l	20	0	0	0	0	35	0	0	0	0	3	0	0	0	0
Bicarbonate	mg/l	20	0	0	0	0	35	0	0	0	0	3	0	0	0	0
Chloride	mg/l	20	170,200	210,000	160,000	3	35	171,000	147,000	167,200	4	3	183,200	183,600	183,000	0.2
Sulfate	mg/l	20	19,200	26,400	19,100	9	40	16,200	21,300	18,500	6	3	18,600	20,100	19,300	6
Total Hardness (as $CaCO_3$)	mg/l	23	2235	6730	3640	6	25	3440	6515	4050	4	3	8950	9160	8970	2
Total Iron	mg/l	20	0.03	0.85	0.22	70	32	0.06	0.69	0.27	70	3	0.13	1.5	0.42	120
Hydrogen Sulfide	mg/l	30	172	837	360	30	30	682	1140	940	19	3	544	612	990	6
LABORATORY DETERMINATIONS:																
pH	Standard Units	10	6.29	6.75	6.42	3	13	7.14	7.80	7.40	3	3	7.2	7.34	7.31	0.4
Specific Conductance	µmhos/cm @ 25°C	10	400,000	510,000	490,000	7	13	480,000	610,000	537,000	14	3	500,000	500,000	500,000	0
Total Dissolved Solids	mg/l	10	320,000	340,000	330,000	3	13	310,000	340,000	318,000	3	3	300,000	310,000	290,000	27
Total Suspended Solids	mg/l	10	33	220	87	60	13	0	92	45	65	3	24	96	70	57
Cations:																
Barium	mg/l	10	0.10	2.3	0.76	100	13	<0.1	0.90	<0.31	100	3	1.5	2.0	1.7	16
Calcium	mg/l	10	470	520	490	3	13	300	420	350	10	3	330	350	340	3
Cesium	mg/l	3	2.4	2.6	2.5	3	10	1.2	1.9	1.6	16	--	--	--	--	--
Lithium	mg/l	10	210	270	240	8	13	320	350	300	15	3	355	365	360	1
Magnesium	mg/l	10	330	540	450	19	13	1600	1700	1600	3	3	1900	2100	2100	10
Potassium	mg/l	10	2000	4400	3600	12	13	3500	3300	3900	0	3	3500	4600	3900	16
Sodium	mg/l	10	109,000	116,000	113,000	3	13	113,000	180,000	138,000	12	3	109,000	113,000	111,000	3
Strontium	mg/l	10	14	20	18	12	13	10	26	19	23	3	11	12	11	3
Anions:																
Alkalinity(6)	mg/l	10	2600	2700	2600	2	13	2560	2800	2700	3	3	1500	1600	1500	4
Bromide	mg/l	10	750	940	880	9	13	300	600	510	16	3	430	500	460	17
Chloride	mg/l	10	160,000	180,000	170,000	6	13	160,000	220,000	170,000	8	3	160,000	180,000	170,000	6
Fluoride	mg/l	10	1.4	1.9	1.7	8	13	2.9	4.3	3.4	16	3	0.88	1.0	0.92	6
Iodide	mg/l	5	15	32	29	51	5	16	29	24	22	--	--	--	--	--
Sulfate	mg/l	10	14,000	18,000	16,000	7	13	16,000	20,000	18,000	7	3	20,000	24,000	22,000	10
Nutrients:																
Ammonia (as Nitrogen)	mg/l	10	840	920	870	2	13	330	630	370	11	3	300	340	310	7
Nitrate (as Nitrogen)	mg/l	10	370	560	420	13	12	340	1300	550	43	3	370	480	440	14
Phosphate (as Phosphorus)	mg/l	10	0.26	0.40	0.37	10	13	<0.10	0.8	<0.3	100	3	<0.1	<0.1	<0.1	0
Other Elements:																
Aluminum	mg/l	10	0.90	3.9	2.4	33	13	1.4	3.9	2.9	37	3	2.4	3.4	2.9	18
Boron	mg/l	10	370	890	600	15	13	700	1600	990	16	3	1000	1300	1100	16
Copper	mg/l	10	0.19	0.96	0.49	53	13	0.36	0.66	0.61	36	3	<0.1	0.4	0.3	60
Iron	mg/l	10	2.4	6.9	3.6	37	13	3.3	4.3	3.7	26	3	1.2	2.6	2.0	49
Manganese	mg/l	10	3.6	7.0	6.0	11	13	0.18	0.92	0.71	30	3	0.6	1.0	0.8	25
Silica (as SiO_2)	mg/l	5	34	51	45	17	10	41	75	57	23	--	--	--	--	--
Zinc	mg/l	10	0.30	0.64	0.53	30	13	0.27	0.51	0.37	20	3	<0.1	1.4	0.63	118

NOTES:

(1) Analyses performed by D'Appolonia. Samples containing drilling fluid contamination excluded from this table.

(2) Average = Arithmetic Mean.

(3) CV = Coefficient of Variance (%) = $\frac{\text{Standard Deviation}}{\text{Average}} \times 100$.

(4) Borehole temperature averaged 21.9°C during Activity ERDA-6.8 from 10/31/81 to 11/4/81 (measured at 400 feet below the surface).

(5) Borehole temperature averaged 26.7°C during Activity ERDA-6.9 (measured at approximately 2472 feet below the surface).

(6) Values are reported as mg/l HCO_3^-. However, analyses of inorganic carbon average only 340 mg/l HCO_3^- in WIPP-12 and 980 mg/l HCO_3^- in ERDA-6.

"--" = Parameter not analyzed.

Attachment I (Cont.)

Attachment II

HOMOGENIZED ATOM DENSITIES (atoms/cc X 10^{24})

Element/Nuclide	Case A Hi Fissile, Brine 1, No Ads.Fe, No Ads.C	Case B Hi Fissile, Brine 1, No Ads.Fe, Hi Ads.C	Case C Hi Fissile, Brine 1, Hi Ads.Fe, No Ads.C	Case D Hi Fissile, Brine 2, No Ads.Fe, No Ads.C	Case E Lo Fissile, Brine 1, No Ads.Fe, Hi Ads.C
Hydrogen	7.07×10^{-3}	7.07×10^{-3}	7.07×10^{-3}	7.33×10^{-3}	7.07×10^{-3}
Lithium-6	0.0	0.0	0.0	1.83×10^{-7}	0.0
Boron	1.32×10^{-5}	1.32×10^{-5}	1.32×10^{-5}	1.89×10^{-5}	1.32×10^{-5}
Carbon	1.31×10^{-2}	3.82×10^{-2}	1.31×10^{-2}	1.24×10^{-2}	3.82×10^{-2}
Nitrogen	2.36×10^{-4}	2.36×10^{-4}	2.36×10^{-4}	3.95×10^{-6}	2.36×10^{-4}
Oxygen	4.17×10^{-2}	4.17×10^{-2}	4.17×10^{-2}	4.23×10^{-2}	4.17×10^{-2}
Sodium	3.01×10^{-4}	3.01×10^{-4}	3.01×10^{-4}	3.61×10^{-4}	3.01×10^{-4}
Magnesium	6.21×10^{-3}	6.21×10^{-3}	6.21×10^{-3}	6.21×10^{-3}	6.21×10^{-3}
Sulfur	3.57×10^{-4}	3.57×10^{-4}	3.57×10^{-4}	3.68×10^{-4}	3.57×10^{-4}
Potassium	0.0	0.0	0.0	4.47×10^{-6}	0.0
Calcium	6.54×10^{-3}	6.54×10^{-3}	6.54×10^{-3}	6.54×10^{-3}	6.54×10^{-3}
Iron	2.39×10^{-4}	2.39×10^{-4}	1.10×10^{-2}	2.91×10^{-9}	2.39×10^{-4}
Pu-238	1.72×10^{-6}	1.72×10^{-6}	1.72×10^{-6}	1.72×10^{-6}	1.72×10^{-7}
Pu-239	6.65×10^{-5}	6.65×10^{-5}	6.65×10^{-5}	6.65×10^{-5}	6.65×10^{-6}
Pu-240	3.21×10^{-6}	3.21×10^{-6}	3.21×10^{-6}	3.21×10^{-6}	3.21×10^{-7}

Attachment III

RESULTS

Case	Description	k_∞	$L^2(cm^2)$	k_{eff} 5.0m	k_{eff} 0.5m
A	Hi Fissile, Brine 1, No Ads.Fe, No Ads.C	1.40	135.	1.39	0.97
A'	Hi Fissile, Brine 1, No Ads.Fe, Lo Ads.C	1.40	130.	1.39	0.97
A"	Hi Fissile, Brine 1, Lo Ads.Fe, No Ads.C	1.38	129.	1.37	0.96
B	Hi Fissile, Brine 1, No Ads.Fe, Hi Ads.C	1.41	92.4	1.41	1.07
C	Hi Fissile, Brine 1, Hi Ads.Fe, No Ads.C	1.18	101.	1.17	0.88
D	Hi Fissile, Brine 2, No Ads.Fe, No Ads.C	1.37	132.	1.36	0.95
E	Lo Fissile, Brine 1, No Ads.Fe, Hi Ads.C	0.68	134.	0.67	0.46
E'	Lo Fissile, Brine 1, Hi Ads.Fe, Hi Ads.C	0.35	56.9	0.35	0.29
E"	Lo Fissile, Brine 1, No Ads.Fe, No Ads.C	0.68	175.	0.67	0.43

SUPPLEMENT 5
(Appendix IRD, DCCA)

ENVIRONMENTAL EVALUATION GROUP

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

7007 WYOMING BOULEVARD, N.E.
SUITE F-2
ALBUQUERQUE, NEW MEXICO 87109
(505) 828-1003

December 27, 1991

Mr. W. John Arthur, III
Project Director
WIPP Project Integration Office
U.S. Department of Energy
P.O. Box 5400
Albuquerque, NM 87115

M

Dear Mr. Arthur:

EEG has reviewed DOE/WIPP 91-029, "Implementation of the Resource Disincentive in 40 CFR Part 191.14(e) at the Waste Isolation Pilot Plant," August 1991. We do not believe that the report accomplishes the objective of satisfying the requirement of 40 CFR 191.14(e) nor does it adequately address concerns expressed in our August 10, 1990 letter (attached). Also, it appears that DOE has not asked EPA's opinion about whether this report would satisfy the 191.14(e) requirement.

However, EEG wishes to be constructive and look to the future to compensate for the lack of this compliance. Because the site has not been shown to possess favorable characteristics to compensate for the handicap of a resource-rich site, its compliance with the containment requirements should be very conservative. Human intrusion into the site should be considered a high probability, engineered modifications of the waste should be seriously considered, and the reliance for long-term integrity should rest on engineered barriers in addition to the geology.

If you agree with this suggestion, it would be necessary to:

(1) abandon the DOE efforts to modify the Human Intrusion portion of the Standard. Suggested modifications would reduce or eliminate the only quantitative deterrent in the Standard against deliberately choosing a resource-rich site;
(2) make a commitment to include robust engineered barriers in the WIPP design similar to NRC and NWTRB recommendations for the high-level repository; and
(3) seriously examine the options for repository design and waste form modification to minimize the release from human intrusion.

We believe that this approach would be more productive than

Providing an independent technical analysis of the Waste Isolation Pilot Plant (WIPP), a federal transuranic nuclear waste repository.

continuation of our six-year-old debate about whether compliance with 40 CFR 191.14(e) has been shown. If you do not agree with this constructive approach, we will have to insist on your publishing a report that shows compliance with the resource disincentive assurance requirement.

Our detailed comments on the report are enclosed.

Sincerely,

James K Channell

Robert H. Neill
for Director

RHN:js
Enclosure

cc: James Bickel, DOE/ALO
Arlen Hunt, DOE/WPO
Mark Frei, WIPP Task Force
William Gunter, EPA

COMMENTS ON "IMPLEMENTATION OF THE RESOURCE DISINCENTIVE IN 40 CFR PART 191.14(e) AT THE WASTE ISOLATION PILOT PLANT (DOE/WIPP 91-029, August 1991)

General Comments

This report states that the "resource disincentive" assurance requirement (40 CFR 191.14(e) that was in the remanded 1985 40 CFR 191 Standard and expected to be in the repromulgated standard has been satisfied. We disagree. The report states "In addressing the natural resource provision of 40 CFR Part 191, the DOE does not propose to provide justification for the selection of the WIPP site." Rather, the report presents the history of how natural resource issues were evaluated during the site selection process. The contention is that the evaluation was extensive, with outside reviewers (including EEG), satisfied the NEPA process, and concluded that the use of the site for a TRU waste repository was of greater benefit than the possible development of the resources. The point was also made that the entire site selection process was completed prior to the issuance of the EPA Standards which contain the "resource disincentive" assurance requirement.

Our page-by-page comments follow. The comments recognize that much of the text is quotes from various documents and we believe it is historically accurate. However, some of these quotes give a misleading picture of the current situation and its applicability to the "resource disincentive."

Page-By-Page Comments

Page 1. The introduction fails to describe the event that prompted DOE to issue a strategy plan. It was a requirement specified in the 1987 modification to the C&C Agreement between DOE and the State of New Mexico.

Page 9, first paragraph, EEG is quoted (in a 1983 report) as suggesting that the loss of resources "is perhaps best handled by the NEPA process" and that health and safety issues from the attractiveness of the resource should be addressed by evaluating the increased probability of human intrusion.

This is still our position. The ultimate determination that a resource-rich site is acceptable can come only after evaluating it against a standard that adequately reflects the increased attractiveness of the site to human intrusion. However, it appears that DOE and SNL are engaging in activities designed to reduce or eliminate the effect that resources have on the human intrusion scenario in the 1985 EPA Standard.

Page 10, second paragraph. The EPA ESAB is quoted as saying that "it may be possible by suitable engineering technique to recover the resources without disturbing a nearby repository or to mitigate the effects of potential human intrusion. The site and engineered barriers should be seen as a system, ..."

EEG is uncomfortable with the concept of recovering resources on the WIPP site (currently permitted by DOE with the existing gas leases) and any general policy to permit this should be considered only after extensive discussions with non-DOE organizations. Also, there are still no commitments by DOE to any type of engineered barrier system to mitigate the effects of human intrusion.

Pages 12 and 61. EPA expects that sites with resources would be used only "if it is reasonably certain that they would provide better overall protection than the practical alternatives that are available." On page 61 the report says "The conclusion is that the favorable characteristics of the site uniquely qualify it for a repository for defense TRU wastes. These characteristics more than compensate for the likelihood of a

future disturbance." What practical alternative to WIPP has been evaluated to determine if the repository provides better overall protection? Storage on the surface? Also, what are the favorable characteristics of the site that uniquely qualify it for a repository?

Pages 14 and 53. The report points out that "care has been taken to avoid such brine reservoirs within the site area." (page 14) and "when the Los Medanos site was initially screened for the WIPP project it was thought that the facility was positioned outside of the known Carlsbad Potash District, and would therefore have a minimal impact on potash resources." (page 53).

The presence of brine reservoirs and potash resources on the site were considered undesirable before site characterization. When it was found they existed on the site it was decided they were acceptable.

Page 13. "There is no indication that an alternative site for the demonstration would pose reduced risk."

Is there any indication that an alternative site would not pose reduced risk? Has the WIPP site been compared to any alternative site?

Pages 16-18. The statement is made three times on these pages that "the consequences of future events, including resource extraction, are acceptably small."

The determination that consequences are acceptably small cannot be made until compliance with the EPA standard is shown. Since compliance is not scheduled to be shown until about 1995 this statement is premature. Also, the standard requires that only the consequences of exploratory drilling be evaluated. Resource extraction does not need to be evaluated.

Page 24. Reference is made to the favorable hydrologic regime at the WIPP and quotes a 1983 report.

The Culebra model now being used is somewhat different than in 1983. Is this statement still correct?

Page 26. EEG-11 (Channell, 1982) is one of the references cited when claiming that "future human intrusion in search of mineral resources will not significantly impact public health and safety."

It is best not to generalize too much about what a report is saying. The EEG-11 scenarios resulted in maximum calculated doses to a nearby resident of >1 rem (committed effective dose equivalent) per year of inhalation and maximum quantities of radionuclides to the surface that were about 2.5 times that permitted by the 1985 EPA Standard. The report concluded that quantities brought to the surface were great enough compared to the 1981 draft of the EPA Standard to require a more detailed evaluation. Furthermore, the data have changed considerably since 1981. For example, the inventory is now believed to be about 10 times as great, the existence of a brine reservoir under the site about 12 times as great, and the amount of brine that might flow to the surface could be about 5 times as great.

Page 48. The following quote was made from the 1978 Geological Characterization Report: "The selection criteria used, however, was sufficient to establish that the site selected was adequate, safe, and acceptable."

We suggest that these words exaggerate the acceptability and safety of the site. The fact is that DOE does not expect to be able to show compliance with the 1985 EPA Standard before 1995. The site cannot be assumed to be safe and acceptable until it is

shown to be in compliance with the EPA Standard.

Pages 49-58. It would have been helpful to have given in-place (gross) and net values of resources with 1991 market prices. Also, the efforts to minimize the impact of not mining langbeinite (pages 54, 56, 59) are not very convincing.

Page 60. The statement is again made that the consequences of an inadvertent intrusion into the repository are small. However, two sentences later the more accurate statement is made: "The final determination of the acceptability of the site will be based on compliance to the performance assessment requirements of 40 CFR 191 Subpart B."

Conclusions on Resource Disincentive

1. DOE did openly address the resource issue during site characterization and had interactions with appropriate State and public organizations. They appear to have satisfied the NEPA process. However, we are surprised there was not more public concern raised about the denial of resources, especially langbeinite.

2. Siting a repository in a resource-rich area has always been considered undesirable and DOE should have expected that when standards were finally enacted they would contain some penalty for such sites. DOE's siting approach was to try and find a site in a resource-rich area that contained lesser amounts of resources than surrounding areas. When the chosen site was found to contain more potash resources and Castile brine reservoirs than originally believed these features were considered acceptable.

3. The report suggests that DOE has compared this site against alternatives and shown that it is an overall superior

location. EEG is unaware that DOE has ever compared the WIPP site against alternatives or identified those favorable characteristics that compensate for choosing a resource-rich area. Thus, we conclude that DOE has not justified the choice of this resource-rich site over a resource-poor site.

4. DOE has incorporated no waste form modifications or engineered barriers in the repository design that would mitigate human intrusion effects.

5. Preliminary results by SNL suggest that the WIPP site might be able to meet the Containment Requirements of 40 CFR 191 despite the resource effect and no design modifications to mitigate the effects of human intrusion. However, since it is not certain the Containment Requirements could be met DOE is doing the following:
   (a) Recommending that the Standard be revised to separate the human intrusion scenario from the Complementary Cumulative Distribution Function. This would downgrade the importance of the human intrusion event and make it easier for WIPP to comply;
   (b) Recommending that the Standard be revised to permit alternatives to the generic radionuclide release limits allowed to reach the accessible environment. This could permit a site performance assessment to meet a lesser standard in some cases;
   (c) SNL is using expert panels on the future, site markers, and site barriers in an attempt to justify reduction in the maximum exploratory drilling rate specified in EPA Guidance. If successful this exercise would have the effect of reducing or eliminating any penalty for choosing a resource-rich site.

6. The probable form of the 1985 EPA Standard and the human intrusion guidance for resource-rich sites was reasonably

well known by mid-1983 when the Decision for Repository Construction was made.

7. EEG has always recognized that the WIPP site is in a resource-rich area and we have never contended that this should be grounds for automatically rejecting the site. However, we believe that since DOE picked a resource-rich site and was aware of the penalties likely to be in the 1985 Standard before they began construction of the repository, they should be prepared to show compliance of the WIPP site with those standards and not try to obtain compliance by getting this portion of the Standard modified.

The proof of the suitability of the site can only be determined by showing compliance with the Containment Requirements with Guidance for a resource-rich site and not by unverified claims that the site is superior to alternatives.

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SUPPLEMENT 6
(Appendix IRD, DCCA)

ENVIRONMENTAL EVALUATION GROUP

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

7007 WYOMING BOULEVARD, N.E.
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ALBUQUERQUE, NEW MEXICO 87109
(505) 828-1003

February 13, 1990

Mr. Arlen Hunt
Acting Project Manager
WIPP Project Office
U. S. Department of Energy
P. O. Box 3090
Carlsbad, New Mexico 88221

Dear Mr. Hunt:

The question has arisen on the Department's plans to demonstrate compliance with the natural resource Assurance requirement of the EPA Standard, 40 CFR 191.14(e). As you know, that particular requirement states that places where there has been mining for resources, a reasonable expectation of future exploration or a significant concentration of a scarce material should be avoided in selecting disposal sites. The requirement states,

> "Such places shall not be used for disposal of the wastes covered by this Part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future."

A recently published Sandia National Laboratory report (SAND 88-1452, Bertram-Howery et al, p. VI-2) states the following with respect to compliance with the natural resources part of the Assurance Requirements (40 CFR 191.14.e):

> "The WIPP project met this requirement when the site was selected, and the Project will issue a finding to that effect."

The site was selected in the seventies and I don't believe that the Project has ever taken the position that the scientific evidence at that time provided any documentation for conclusions on the characteristics of the site--favorable or otherwise. In addition, our understanding was that the Department intended to publish an analysis similar to the October 20, 1988 document which was subsequently withdrawn.

Providing an independent technical analysis of the Waste Isolation Pilot Plant (WIPP), a federal transuranic nuclear waste repository.

Please advise whether the SAND 88-1452 statement reflects the DOE/WPO official position.

Sincerely,

Robert H. Neill
Director

RHN:LC/lsb/ct

cc: Mr. James E. Bickel, Asst. Mgr. for Projects and Energy Programs, DOE-ALO
Mr. Leo P. Duffy, Special Asst. to the Sec. for Coordination of DOE Waste Management, DOE-EH
Ms. Jill E. Lytle, Deputy Asst. Secretary for Nuclear Materials, DOE
Mr. Mark Frei, Chairman, WIPP Task Force

SUPPLEMENT 7
(Appendix IRD, DCCA)

ENVIRONMENTAL EVALUATION GROUP

AN EQUAL OPPORTUNITY / AFFIRMATIVE ACTION EMPLOYER

7007 WYOMING BOULEVARD, N.E.
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August 10, 1990

Mr. Arlen Hunt
Project Manager
WIPP Project Manager
U. S. Department of Energy
P. O. Box 3090
Carlsbad, New Mexico 88221

Dear Mr. Hunt:

On February 13, 1990, EEG asked your office how WPO would show compliance with the natural resource Assurance requirement of the EPA Standard 40 CFR 191.14(e). After 5.5 months, you wrote back on July 31, 1990 to say that the requirement was met when the site was selected, (presumably in 1980 when the WIPP FEIS compared different sites) and you reiterated the position stated in the Sandia December 1989 report that you expect to publish a short report at some unspecified future date that will cite the favorable characteristics.

Fundamental Concerns

This raises some very fundamental concerns on the manner in which DOE is regulating itself in demonstrating compliance with the EPA Standards for safe disposal of TRU wastes at WIPP.

1. Was this conclusion reached by DOE as the implementing agency entrusted with the responsibility of insuring that the EPA Standards are met, or as DOE, the regulated agency that must do the actual demonstration?

2. What other parts of the EPA Standards can DOE, as either the regulator or regulated merely say have been demonstrated at some time in the past? Would the Department as regulator be willing to provide a written list of those portions of the Standards which have been met? It is interesting to note that NRC, as the regulator for HLW disposal, is writing criteria to provide clear guidance to DOE on what they must do to show compliance with 40 CFR 191 as part of 10 CFR 60.

Providing an independent technical analysis of the Waste Isolation Pilot Plant (WIPP), a federal transuranic nuclear waste repository.

3. Have you asked EPA whether your approach to declare portions of the standards to have been met and then document it in the future is what they had in mind? The May 22, 1987 letter by the Director, Office of Radiation Programs, EPA to the Deputy Assistant Secretary DOE, indicates that your position would not be sufficient. Examples like this provide the basis for not allowing the same party to be both a regulator and the regulated.

4. Has DOE-OCRWM asked NRC if they would accept such logic that DOE had satisfied this requirement when they selected Yucca Flats some years ago for a high-level waste repository?

DOE Progress in meeting Assurance Requirements over past 5 years

You point out that EEG often states that DOE has made no progress with the Assurance Requirements (40 CFR 191.14) since they were promulgated 5 years ago and provided examples of progress.

It is important to remember that 3½ years ago DOE said the assurance requirements would be completed by October 1988. Specifically, EPA noted that DOE stated at a March 26, 1987 meeting, "i.e., that projected compliance with Subpart A and th assurance requirements of Subpart B will be shown prior to waste receipt, currently scheduled for October 1988." We are unaware of any published progress.

Active Institutional Controls

You cite the identification of soil preparation techniques and the selection of seed species as progress in active institutional controls. Since the purpose of active institutional controls as defined in the EPA Standards is to prevent radiation exposure and protect the public health in the post-decommissioning phase from radioactive materials located at a depth of 2150 feet in the repository, the examples of work cited by you will not be of any value in this regard. You appear to misunderstand "performing maintenance operations or remedial actions at a site" (40 CFR 191.12(f)(2)) to mean site reclamation when it actually refers to preventing radioactive releases. After 12 years of study and the expenditure of almost $1 billion, one would expect progress in active institutional controls to include specifying how long you intend to leave a fence around the property or keep a watchman on the payroll to prevent human intrusion.

NRC requires early warning monitoring systems to detect any changes in the HLW repository and DOE is designing the facility to handle this including underground sensors to measure any radionuclide migration. Is it not appropriate that WPO should do the same?

Passive Institutional Controls

Your letter states, ". . . through the administrative land withdrawal, the DOE is able to protect the lands from any entry that would compromise the integrity of the disposal system." There is only a request pending by DOE to the Department of the Interior for administrative land withdrawal which has not been acted upon and it is incorrect to imply that the action has occurred. Further, DOE must publish the design of permanent markers, etc. to prevent future generations from drilling into the repository.

Your Department has asked the Congress for exclusive authority to prevent mining without any power to redelegate such authority but has been silent on how it would be done. How can you claim credit for the ability to prevent intrusion (as well as the authority) without providing any plans to show how it will be done?

Your letter states that your contractors have been instructed to evaluate criteria for markers and provide warnings. What progress has been demonstrated through published or unpublished work since this requirement was established 5 years ago? You correctly point out that the DOE HLW commercial repository program has done a large amount of work in this area using WIPP as an example. Since we are not aware of any difference in the technology of markers in the past decade, why not use their work?

Multiple Barriers

You stated that WIPP depends on a combination of engineered and natural barriers. To date, DOE has not selected any engineered barriers as required by the Standards. The waste is soluble, respirable, and in a carbon steel drum and the only commitment to an engineered barrier is a getter of unspecified composition and thickness to be placed above the waste. Your letter only

describes plugs and seals (which DOE is not allowed to take credit as an engineered barrier in the NRC regulated repository in Nevada nor did EPA include room and shaft seals as an engineered barrier for WIPP).

Although my impression may not be totally fair, the tenor of your response suggests a commitment to the absolute minimum as expressed in the philosophy that anything beyond plugs would only be included if it were proven to be necessary through performance assessment. The intent of the Assurance Requirements was clearly spelled out by EPA in the 1985 preamble that it is not necessary to quantify the amount of benefit obtained but was to be done as an assurance of repository integrity due to the inherant uncertainties in the calculations of travel times and leach rates.

Waste Removal

You state that mined geologic repositories such as the WIPP meet the requirement for waste disposal removal with no further action. As the regulator of TRU waste at WIPP, DOE has imposed far less stringent requirements on waste removal at WIPP than the regulator of HLW disposal (NRC) has placed on DOE. Note the requirements in 10 CFR 60 for the SAR which include plans for alternate storage should retrieval prove necessary.

Sincerely,

Robert H. Neill
Director

RHN:lsb
Enclosures: 2/13/90 letter Neill, EEG to Hunt, DOE
7/31/90 letter Hunt, DOE to Neill, EEG

cc: Mr. J. Bickel, DOE-ALO
Mr. L. Duffy, DOE-Headquarters
Ms. J. Lytle, DOE-Headquarters
Mr. M. Frei, DOE-Headquarters

SUPPLEMENT 8
(Appendix IRD, DCCA)

Department of Energy
Field Office, Albuquerque
P.O. Box 5400
Albuquerque, New Mexico 87115

JUN 16 1992

RECEIVED
JUN 18 1992
ENVIRONMENTAL EVALUATION GROUP

Mr. Robert H. Neill, Director
Environmental Evaluation Group
7007 Wyoming, N. E., Suite F-2
Albuquerque, NM 87109

Dear Mr. Neill:

The Department of Energy has received your letter dated December 27, 1991, which provides the Environment Evaluation Group's review comments on DOE/WIPP 91-029, "Implementation of the Resource Disincentive in 40 CFR Part 191.14(e) at the Waste Isolation Pilot Plant" (August 1991). At the present time, we are reviewing a plan to address this complex issue. When we have completed the task of addressing this issue, we will provide you with a detailed response to your referenced letter and its accompanying "Comments."

If you have any questions regarding this transmittal, please call Tracy Loughead of my staff at 845-5977.

Sincerely,

W. John Arthur, III
Project Director
WIPP Project Integration Office

cc:
C&C File (ED9100184)
T. Loughead, WPIO
J. Kenney, EEG

LIST OF EEG REPORTS

LIST OF EEG REPORTS

EEG-1 Goad, Donna, A Compilation of Site Selection Criteria Considerations and Concerns Appearing in the Literature on the Deep Disposal of Radioactive Wastes, June 1979.

EEG-2 Review Comments on Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico SAND 78-1596, Volumes I and II, December 1978.

EEG-3 Neill, Robert H., et al, (eds.) Radiological Health Review of the Draft Environmental Impact Statement (DOE/EIS-0026-D) Waste Isolation Pilot Plant, U. S. Department of Energy, August 1979.

EEG-4 Little, Marshall S., Review Comments on the Report of the Steering Committee on Waste Acceptance Criteria for the Waste Isolation Pilot Plant, February 1980.

EEG-5 Channell, James K., Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes, November 1980.

EEG-6 Geotechnical Considerations for Radiological Hazard Assessment of WIPP. A Report of a Meeting Held on January 17-18, 1980, April 1980.

EEG-7 Chaturvedi, Lokesh, WIPP Site and Vicinity Geological Field Trip. A Report of a Field Trip to the Proposed Waste Isolation Pilot Plant Project in Southeastern New Mexico, June 16 to 18, 1980, November 1980.

EEG-8 Wofsy, Carla, The Significance of Certain Rustler Aquifer Parameters for Predicting Long-Term Radiation Doses from WIPP, September 1980.

LIST OF EEG REPORTS (CONTINUED)

EEG-9 Spiegler, Peter, An Approach to Calculating Upper Bounds on Maximum Individual Doses From the Use of Contaminated Well Water Following a WIPP Repository Breach, September 1981.

EEG-10 Radiological Health Review of the Final Environmental Impact Statement (DOE/EIS-0026) Waste Isolation Pilot Plant, U. S. Department of Energy, January 1981.

EEG-11 Channell, James K., Calculated Radiation Doses From Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine, January 1982.

EEG-12 Little, Marshall S., Potential Release Scenario and Radiological Consequence Evaluation of Mineral Resources at WIPP, May 1982.

EEG-13 Spiegler, Peter., Analysis of the Potential Formation of a Breccia Chimney Beneath the WIPP Repository, May, 1982.

EEG-14 Not published.

EEG-15 Bard, Stephen T., Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon, March 1982.

EEG-16 Radionuclide Release, Transport and Consequence Modeling for WIPP. A Report of a Workshop Held on September 16-17, 1981, February 1982.

EEG-17 Spiegler, Peter, Hydrologic Analyses of Two Brine Encounters in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, December 1982.

LIST OF EEG REPORTS (CONTINUED)

EEG-18 Spiegler, Peter, Origin of the Brines Near WIPP from the Drill Holes ERDA-6 and WIPP-12 Based on Stable Isotope Concentration of Hydrogen and Oxygen, March 1983.

EEG-19 Channell, James K., Review Comments on Environmental Analysis Cost Reduction Proposals WIPP/DOE-136) July 1982, November 1982.

EEG-20 Baca, Thomas E., An Evaluation of the Non-radiological Environmental Problems Relating to the WIPP, February 1983.

EEG-21 Faith, Stuart, et al., The Geochemistry of Two Pressurized Brines From the Castile Formation in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, April 1983.

EEG-22 EEG Review Comments on the Geotechnical Reports Provided by DOE to EEG Under the Stipulated Agreement Through March 1, 1983, April 1983.

EEG-23 Neill, Robert H., et al., Evaluation of the Suitability of the WIPP Site, May 1983.

EEG-24 Neill, Robert H. and James K. Channell Potential Problems From Shipment of High-Curie Content Contact-Handled Transuranic (CH-TRU) Waste to WIPP, August 1983.

EEG-25 Chaturvedi, Lokesh, Occurrence of Gases in the Salado Formation, March 1984.

EEG-26 Spiegler, Peter, Environmental Evaluation Group's Environmental Monitoring Program for WIPP, October 1984.

LIST OF EEG REPORTS (CONTINUED)

EEG-27 Rehfeldt, Kenneth, Sensitivity Analysis of Solute Transport in Fractures and Determination of Anisotropy Within the Culebra Dolomite, September 1984.

EEG-28 Knowles, H. B., Radiation Shielding in the Hot Cell Facility at the Waste Isolation Pilot Plant: A Review, November 1984.

EEG-29 Little, Marshall S., Evaluation of the Safety Analysis Report for the Waste Isolation Pilot Plant Project, May 1985.

EEG-30 Dougherty, Frank, Tenera Corporation, Evaluation of the Waste Isolation Pilot Plant Classification of Systems, Structures and Components, July 1985.

EEG-31 Ramey, Dan, Chemistry of the Rustler Fluids, July 1985.

EEG-32 Chaturvedi, Lokesh and James K. Channell, The Rustler Formation as a Transport Medium for Contaminated Groundwater, December 1985.

EEG-33 Channell, James K., John C. Rodgers and Robert H. Neill, Adequacy of TRUPACT-I Design for Transporting Contact-Handled Transuranic Wastes to WIPP, June 1986.

EEG-34 Chaturvedi, Lokesh, (ed), The Rustler Formation at the WIPP Site, January 1987.

EEG-35 Chapman, Jenny B., Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, October 1986.

EEG-36 Lowenstein, Tim K., Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico, April 1987.

LIST OF EEG REPORTS (CONTINUED)

EEG-37 Rodgers, John C., Exhaust Stack Monitoring Issues at the Waste Isolation Pilot Plant, November 1987.

EEG-38 Rodgers, John C., Kenney, Jim W., A Critical Assessment of Continuous Air Monitoring Systems At he Waste Isolation Pilot Plant, March 1988.

EEG-39 Chapman, Jenny B., Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico, March 1988.

EEG-40 Review of the Final Safety Analysis Report (Draft), DOE Waste Isolation Pilot Plant, May 1989.

EEG-41 Review of the Draft Supplement Environmental Impact Statement, DOE Waste Isolation Pilot Plant, July 1989.

EEG-42 Chaturvedi, Lokesh, Evaluation of the DOE Plans for Radioactive Experiments and Operational Demonstration at WIPP, September, 1989.

EEG-43 Kenney, Jim W., John C. Rodgers, Jenny B. Chapman, and Kevin J. Shenk, Preoperational Radiation Surveillance of the WIPP Project by EEG, 1985-1988, January 1990.

EEG-44 Greenfield, Moses A., Probabilities of a Catastrophic Waste Hoist Accident at the Waste Isolation Pilot Plant, January 1990.

EEG-45 Silva, Matthew K., Preliminary Investigation into the Explosion Potential of Volatile Organic Compounds in WIPP CH-TRU Waste, June 1990.

LIST OF EEG REPORTS (CONTINUED)

EEG-46 Gallegos, Anthony, and James K. Channell, Risk Analysis of the Transport of Contact Handled Transuranic (CH-TRU) Wastes to WIPP Along Selected Highway Routes in New Mexico Using RADTRAN IV, August 1990.

EEG-47 Kenney, Jim W., and Sally C. Ballard, Preoperational Radiation Surveillance of the WIPP Project by EEG During 1989, December 1990.

EEG-48 Silva, Matthew K., An Assessment of the Flammability and Explosion Potential of Transuranic Waste, June 1991.

EEG-49 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1990, November 1991.

EEG-50 Silva, Matthew K., and James K. Channell, Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards, June 1992.

EEG-51 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1991, October 1992.

EEG-52 Bartlett, William T., An Evaluation of Air Effluent and Workplace Radioactivity Monitoring at the Waste Isolation Pilot Plant, February 1993.

EEG-53 Greenfield, Moses A., and Thomas J. Sargent, A Probabilistic Analysis of a Catastrophic Transuranic Waste Hoist Accident at the WIPP, June 1993.

EEG-54 Kenney, Jim W., Preoperational Radiation Surveillance of the WIPP Project by EEG During 1992, February 1994.

EEG-55 Silva, Matthew K., Implications of the Presence of Petroleum Resources on the Integrity of the WIPP, June 1994.

LIST OF EEG REPORTS (CONTINUED)

EEG-56 Silva, Matthew K., and Robert H. Neill, Unresolved Issues for the Disposal of Remote-Handled Transuranic Waste in the Waste Isolation Pilot Plant, September 1994.

EEG-57 Lee, William W.-L., et al., An Appraisal of the 1992 Preliminary Performance Assessment for the Waste Isolation Pilot Plant, September 1994.

EEG-58 Kenney, Jim W., Paula S. Downes, Donald H. Gray, and Sally C. Ballard, Radionuclide Baseline in Soil Near Project Gnome and the Waste Isolation Pilot Plant, July 1995.

EEG-59 Greenfield, Moses A., and Thomas J. Sargent, An Analysis of the Annual Probability of Failure of the Waste Hoist Brake System at the Waste Isolation Pilot Plant (WIPP), November 1995.

EEG-60 Bartlett, William T., and Ben A Walker, The Influence of Salt Aerosol on Alpha Radiation Detection by WIPP Continuous Air Monitors, January 1996.

PEER 20 - Supplemental Information to the Environmental Evaluation Group

ATTACHMENT

DE 9200085

Department of Energy
Field Office, Albuquerque
P.O. Box 5400
Albuquerque, New Mexico 87115

RECEIVED
JUL 27 1992
C+C/CLB

X C & C	X Weddle
X PRC	• Conway
• Anderson	X Kehrman
X Carrell	X Neill
X Cox	X Bedell
X Kuntz	•
• Lee	•
• Mugno	
• Reed	
X Trego	

July 15, 1992

Mr. Robert H. Neill, Director
Environmental Evaluation Group
7007 Wyoming, N.E., Suite F-2
Albuquerque, NM 87109

Dear Mr. Neill:

The Department of Energy (DOE) has reviewed EEG-50, "Implications of Oil and Gas Leases at the WIPP on Compliance With EPA TRU Waste Disposal Standards." Several issues raised in EEG-50 are misleading, incomplete or incorrect and subject to misinterpretation. This letter addresses only our general concerns and is not intended to be a detailed response to your report. A detailed response will be provided in the near future. In general, we believe the report should be revised and reissued.

Our first concern is the report's implication that, because DOE is self regulated with regard to compliance with 40 CFR Part 191, therefore we are not responsible to any external regulator in the context of institutional controls at the Waste Isolation Pilot Plant (WIPP). WIPP is regulated by the Environmental Protection Agency (EPA) and by the State of New Mexico Environment Division (NMED). DOE has obtained a No-Migration Determination (NMD) from the EPA for the Test Phase and will have to obtain another NMD for disposal. In addition, WIPP has applied for a Resource Conservation and Recovery Act (RCRA) Part B permit from the NMED. The Disposal Phase closure plan developed for these WIPP permitting activities will require review and approval by both these regulating agencies. The active and passive institutional control measures will be critical components of that closure plan.

The report's allegation that knowledge of the leases and well for hydrocarbon extraction were "lost" for several years is misleading. These leases and the well have not been overlooked. They are properly recorded and filed with state and federal authorities. This documentation is on file in the appropriate Bureau of Land Management (BLM) offices. As you are aware, continuing dialogue and informational exchange has taken place with the BLM regarding these leases in recent years. In fact, pursuant to agreement between the BLM and DOE, the BLM advised DOE in late

1981 of the application to drill beneath Section 31 below the 6000-foot level and sought DOE comments regarding the application. That notice and comment process remains in place today.

In order to not unnecessarily limit the lessees' rights to develop oil and gas or the State's royalty income, the United States did not condemn the mineral rights located below 6000 feet in Section 31. Those mineral rights may only be accessed by directional drilling from locations outside the land withdrawal area. In Section 31, no one has the right to explore or extract in the area from the surface to a depth of 6000 feet. In the other fifteen sections of the land withdrawal area, no exploration or extraction rights exist. This is clearly stated in the Memorandum of Understanding with the Department of Interior's Bureau of Land Management.

The limitation of 6000 feet provides a sufficient margin of facility protection. The presence of the James Ranch #13 well has been thoroughly reviewed by DOE and EPA and has been determined to not pose any safety or technical issues.

As will be further discussed in our detailed response to EEG-50, the DOE believes that current policies and programs adequately preserve the integrity of WIPP. If you have any questions regarding this matter, please contact Les Gage of my staff at 845-5983.

Sincerely,

W. John Arthur, III
Project Director
WIPP Project Integration Office

cc:

C&C File
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K. Griffith, OCC, AL
L. Gage, WPIO
M. Daugherty, WPSO
R. Anderson, SNL, AL
L. Woodard, BLM

bcc:
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R. Farrell, WID
J. Mewhinney, WPSO
L. Madl, WID

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NOV 0 3 1992

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Dear Mr. Neill:

The Department of Energy (DOE) has reviewed EEG-50, "Implications of Oil and Gas Leases at the WIPP on Compliance With EPA TRU Waste Disposal Standards." The DOE's general concerns regarding EEG-50 were provided to the Environmental Evaluation Group (EEG) with my July 15, 1992, letter. We stated in the July 15 letter that several issues raised in EEG-50 are misleading, incomplete, or incorrect and subject to misinterpretation. Following the DOE's detailed review of EEG-50, our position has not changed. The DOE's detailed comments pertaining to EEG-50 are enclosed with this letter.

The conclusions of EEG-50, relative to institutional controls, are incorrect. The implication that inadvertent exploration has taken place at the Waste Isolation Pilot Plant (WIPP), or that crucial institutional control records have failed with regard to prospective drilling in the area, is a misrepresentation. The implication in EEG-50 is that the Environmental Protection Agency's (EPA's) decision to grant the No-Migration Determination (NMD) had not been reviewed with respect to the existence of the deviated well. To the contrary, the position of the EPA in their March 13, 1991, memorandum to the NMD docket is that the deviated well located beneath Section 31 is "in compliance with institutional controls at the WIPP site" and that the existence of the deviated well beneath Section 31 in no way affects their previous decision to grant the WIPP a No-Migration Determination.

None of the documents listed in EEG-50 as being "incorrect, silent, or inconsistent" are critical to the maintenance of the institutional controls at the WIPP as was implied by the EEG's report. The records that are crucial to protect the site from inadvertent exploration are Bureau of Land Management (BLM) lease records and the internal procedures of the BLM, which require the DOE's review and comment for any permit application to drill within one mile of the WIPP site. Adherence to these policies governing resource extraction at the WIPP has been carefully maintained. Review of the BLM's interface with the DOE for the last 2 years reveals 15 separate instances of the BLM requesting the required DOE comments regarding requests to drill in the vicinity of the WIPP.

Historical documents and correspondence such as the DOE's Revised Interim Policy (and resulting comments and responses) and the 1984 Final Report and Recommendation on Natural Resources at the WIPP Site reflect the priority of protecting the underground repository by prohibiting access from the surface to 6,000 feet of the subsurface. These

records also demonstrate the shared intent of the state and the DOE not to limit access to those resources located beneath 6,000 feet. This perspective was not presented in EEG-50.

In summary, federal institutional controls have worked well under BLM management and have been working well for many years. Under legislative land withdrawal, we will continue to work under a Memorandum of Understanding with the BLM as they carry out their responsibilities for managing oil and gas leases. There are over 30 wells within a mile of the WIPP site boundary. We know about every one of these wells and we know that none of these wells pose a problem for the repository. In addition to the above institutional control system, WIPP conducts and documents monthly inspections of the WIPP boundary. One purpose of these inspections is to spot "wildcat" operations. EEG-50 inappropriately redirects responsibility for management of leases from BLM to DOE and then says DOE has done a poor job of managing something that the BLM has been managing quite well all along.

If you have any further questions or comments regarding this matter, please contact Les Gage of my staff at 845-5389.

Sincerely,

W. John Arthur, III
Project Director
WIPP Project Integration Office

Enclosure

cc w/enclosure:

C&C File (ED9200049)
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R. Mayer, Region VI, EPA
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L. Woodard, BLM

DETAILED COMMENTS

The Environmental Evaluation Group (EEG) issued a report entitled "Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards" (EEG-50). Section 7.0, Conclusions, of EEG-50 states:

> Several U.S. Department of Energy documents failed to record the existence of two active oil and gas leases and a producible gas well within the WIPP Site Boundary. In its performance assessment calculations, the WIPP project has assumed that active institutional control would deter human intrusion for 100 years after decommissioning. The EPA should reexamine whether full credit for 100 years active institutional control is reasonable given the actual experience of inaccurate record keeping. The DOE should also examine the basis for assuming full credit for 100 years control and consider using a lesser amount to reflect the actual experience of the WIPP Project. The EPA Standards should require the implementing agency to publish specific plans on how the agency intends to maintain active institutional control. Even in the absence of such a requirement, the DOE should publish plans now that specify in detail how the Department intends to maintain full control of activities in the area of the repository for 100 years after decontamination and decommissioning and describe how that control will completely deter human intrusion. Finally the DOE needs to describe in detail their passive institutional control system and describe how it will provide a deterrence to inadvertent human intrusion after 100 years.

On July 15, 1992, the Department of Energy (DOE) issued an interim response expressing disagreement with the conclusions and inferences of EEG-50 and committed to providing a detailed response to the EEG at a later date. The following provides DOE's specific comments to EEG-50.

EPA Standards

There are two portions of 40 Code of Federal Regulation (CFR) 191.14, Assurance Requirements, that are cited in EEG-50. The portions of interest are 40 CFR 191.14 (a), which states:

> Active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal; however, performance assessments that assess isolation of the wastes from the accessible environment shall not consider any contributions from active institutional controls for more than 100 years after disposal;

and 40 CFR 191.14 (c), which states:

> Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the waste and their location.

The intent of the Environmental Protection Agency (EPA) for implementation of these requirements is expressed in the preamble to the final rule issued in the Federal Register in September 1985 (FR: 38066 - 38089) and in Appendix B of the final rule.

The preamble to the rule characterizes the assurance requirements as "complements" to the containment requirements that assure the required level of protection is likely to be achieved. Therefore, the assurance requirements do not in themselves guarantee that the site will remain in compliance over the long term. Instead, they mitigate some of the uncertainty associated with the analytical projections, thereby providing "assurance."

The EPA proposed two types of institutional controls as complements to the containment requirements philosophy. The preamble suggests that active institutional controls can be effective in preventing potential releases for the first 100 years. The EPA also stated that although passive institutional controls can not be assumed to eliminate the chance of inadvertent and intermittent human intrusion, they can be effective in deterring systematic or persistent exploitation of the disposal facility and in reducing the likelihood of inadvertent human intrusion.

The degree to which the institutional controls are effective is determined by the implementing agency. Appendix B of the final standard provides information for formulating intrusion scenarios during the passive control period.

In the preamble, the EPA suggests the kinds of active institutional controls that may be implemented at a disposal site. The list includes monitoring, controlling access, guarding, maintenance, and cleanup of spills or releases. The implication is that the implementing agency can perform activities that complement the goals of containment in that they would reduce the likelihood of those types of human activity that may compromise the long-term containment capability of the repository.

In contrast to the statements by the EEG, the standard does not address the topic of what the active controls will or will not do. It simply states that if the implementing agency adopts controls to accomplish a specific goal with regard to protecting the integrity of the site, only 100 years of credit can be taken for these activities. Activities which could be more significant than simply precluding human intrusion would include site restoration, the installation of markers and monuments, and the performance of monitoring programs which will likely provide meaningful near-term data regarding repository performance. Such active controls are not automatic or assumed simply because the standard allows a 100-year active

control period. Furthermore, whatever measures were used to achieve this goal could not be relied upon after 100 years. Whatever risks to the containment system were prevented by such controls would have to be assumed to be present after that time. This would not mean that a breach of the containment is imminent, because the virtues of the containment system are demonstrated through the numerical modeling activity (performance assessment), rather than the implementation of the assurance requirements.

Neither the actions surrounding the history of the James Ranch 13 well (which was drilled in compliance with the regulations in effect at that time) nor the written record suggest that institutional memory was lost. Instead, the control of drilling was managed in accordance with control plans (resource management plans) developed and implemented by the responsible federal agency, the Bureau of Land Management (BLM). The BLM management of these control plans, with DOE input, has been effective in preventing inadvertent wells being drilled. There have been no wells drilled within established no-drilling zones and there is no reason to assume that future control programs would be any less effective. Contrary to EEG-50's implication, the drilling of the well is not relevant to 40 CFR 191 compliance and did not occur during either the active or passive institutional control period at the WIPP repository or when the DOE had jurisdiction for such activities.

EEG's own statement with regard to the markers and the records associated with the well illustrate the effectiveness of both active and passive control programs. EEG-50 failed to demonstrate a single BLM document that "lost" or "forgot" the existence of the well. To argue that the history of the James Ranch 13 well is basis for reducing the active control time period is obtuse. The further attempt to make inferences regarding the viability of the passive institutional control program from this "incident" is particularly implausible.

EEG-50 is incorrect in the statement made in a footnote on page viii regarding future commitments for controlling the WIPP site:

> The DOE has sole regulatory authority to make a determination of compliance of the WIPP facility with Environmental Protection Agency (EPA) standards and proceed with the WIPP as a repository.

The DOE is not self-regulating with regard to operations or closure of the site and implementing programs mandated by the assurance requirements. The imposition of the permitting requirements of the Resource Conservation and Recovery Act (RCRA) on the WIPP facility in 1990 established the EPA and the New Mexico Environment Department as regulators for many of the activities necessitated by the assurance requirements. The recent land withdrawal legislation requires that the disposal phase cannot commence until the Administrator of the EPA certifies that the WIPP facility will comply with the disposal standards. This certification will be a rule-making process which will allow opportunity for public review and comment.

Resource Extraction Policies

The following discussion is provided to clarify events between 1977 and 1983 when critical policy decisions were made on resource extraction and protection of the underground repository.

In 1977, the United States of America, at the request of the Acting Administrator of the Energy Research and Development Administration, entered into condemnation actions (77-071-B and 77-776-B) for the acquisition of land within the boundaries of Control Zone IV (Condemnation Hearings, 1977). These lands included Township 22 South, Range 31 East, N.M.P.M., Eddy County, New Mexico, Section 31. The land being acquired in Section 31 included only the surface and the upper 6,000 feet of subsurface which was that portion of the subsurface necessary to keep the salt beds intact from exploratory drill holes that could penetrate the salt medium in which the underground facility is located. The acquisition of land down to only 6,000 feet protected the salt in the repository location, while reducing acquisition costs and allowing resource extraction.

It should be noted that the decisions as to what would be allowable with regard to the extraction of resources under the site were still being determined at the time of acquisition of Section 31.. On October 10, 1980, a draft position paper on the recovery of resources within Zone IV was transmitted to the DOE from Sandia National Laboratories (SNL) (SNL, 1980). This paper concluded there was no reason to restrict mineral extraction from Zone IV. Although this paper was not formalized, it provided the technical and scientific basis for the position later formalized in several reports and documents, including the Natural Resources Study Final Report, WTSD-TME 3156 (Westinghouse Waste Isolation Division, 1982).

In addition to the draft SNL position paper discussed above, the WIPP Final Environmental Impact Statement (FEIS), DOE/EIS-0026, was published in October 1980 (DOE, 1980). The FEIS discussed drilling and mining in Chapters 9, 12, and 15. The third paragraph on page 9-18 states:

> The DOE has found no technical or safety reason to prohibit drilling and mining in control zone IV of the type now practiced in the area. Therefore, the DOE may allow such drilling and mining: if it does, the impacts of withdrawing minerals, resources and reserves will be reduced from those indicated for the total site.

The second paragraph of Chapter 12.2 (page 12-2) states:

> The DOE may allow drilling for natural gas in control zone IV. Reserves in the inner control zones may eventually become available for exploitation through the use of such techniques as slant-hole drilling from control zone IV or by a future relaxation of the controls now thought prudent for the area.

Finally, in response to comments from the public on the duration of resource denial in all control zones at the Los Medanos site, the statement was made in paragraph 2 of page 15-26 that:

> Drilling for oil and gas may be permitted with the approval of the DOE in Control Zone IV. Deviated drilling to tap the deep gas potential under Zones I, II, and III may also be permitted, provided the hole is deeper than the Castile Formation before crossing into the vertical projection of Zone III.

It is clear from the above statements that the impacts of potential extraction of mineral resources from beneath the site were being examined and that both technical and safety concerns were being considered. In addition, drilling for gas and oil within Zone IV, with DOE approval, was determined not to compromise WIPP's ability to comply with applicable regulations.

On July 1, 1981, the DOE and the State of New Mexico entered into the Stipulated Agreement (U.S. District Court, 1981) and Consultation and Cooperation (C&C) Agreement (DOE, 1981a). The Stipulated Agreement required that the DOE develop a detailed plan which allows recovery of potash and hydrocarbons without disturbance of the repository. The plan was to further evaluate the potential consequences of these activities. In response, the DOE issued an Interim Policy Statement on Resource Recovery at the Waste Isolation Pilot Plant Site on November 3, 1981 (DOE, 1981b), which states:

> The incorporation of multiple buffer zones in the present design is a conservative approach to maintaining the integrity of the site and ensuring that emplaced wastes remain isolated from the environment.
>
> It is the policy of the DOE to maximize the opportunity for resource recovery at the WIPP site, consistent with the requirements to isolate the emplaced radioactive wastes from the biosphere. The interim policy is temporary denial of all resource extraction within the four control zones of the WIPP Site until the decision is made relative to which, if any, of the emplaced waste will be retrieved.
>
> The DOE anticipates the recovery of hydrocarbon resources from Control Zone IV will be 'allowable' following a final decision on waste retrieval. This activity includes drilling, production stimulation, and, possibly, secondary recovery. Resources located beneath Zone IV may be accessed by vertical drilling: Resources located beneath the inner three control zones may be accessed by drilling vertical in Zone IV to a depth of 6,000 feet and then deviating from vertical at the angle required to reach the target resource zone.

On December 18, 1981, the BLM, in accordance with procedures established in a 1981 Cooperative Agreement between the BLM and the DOE, requested comments on a Bass Enterprises application to drill a deviated gas well that would be slant-drilled from outside Zone IV in Section 6 into the company's leasehold beneath the south half of Section 31 (BLM, 1981). The DOE responded on December 30, 1981, referencing the 1977 condemnation of the surface and the first 6,000 feet of certain tracts and requested that any approval preclude drilling through or into the upper 6,000 feet of the tracts which had been condemned by the United States in 1977 (DOE, 1981c).

After BLM's approval of the application, Bass began drilling a deviated well into Section 31 on February 6, 1982. This well was completed on September 21, 1982. The well met the intent of the DOE Interim Policy. The integrity of the site was maintained while allowing resource recovery.

Effective March 30, 1982, the BLM and the DOE entered into a Memorandum of Understanding (MOU) wherein BLM agreed to notify the DOE of any request to drill within the vicinity of the WIPP and to withhold concurrence on these requests until comments were received from the DOE. As with the earlier Cooperative Agreement, this MOU established a protocol for ensuring DOE input regarding drilling and mining activities in the vicinity of the WIPP site.

On September 28, 1982, the Natural Resources Study Final Report, WTSD-TME 3156, was issued by the Westinghouse Waste Isolation Division (WID) (Westinghouse Waste Isolation Division, 1982). The report concluded that hydrocarbon resource extraction and solution mining from within (and outside of) Control Zone IV, using currently available and applicable technology, would not compromise the integrity of the WIPP facility. Page 65 of this report stated:

> In summary, DOE could reevaluate its interim policy to prudently allow resource recovery in Control Zone IV. This is supported by an evaluation of the consequence analyses for resource extraction, as discussed in this report, and the additional consideration that any resource recovery operation will be reviewed by the BLM (for surface claims) and the Mineral Management Service (for underground claims) prior to its implementation. In this fashion, any planned activities will be evaluated on a case-by-case basis to ensure that the integrity of the WIPP facility will not be jeopardized.

Subsequent to the issuance and review of the Natural Resources Study Final Report, the DOE issued a Revised Interim Policy Statement on Resource Recovery at the WIPP Site (DOE, 1982). Discussions between the EEG and DOE regarding the Revised Interim Policy Statement on Resource Recovery at the WIPP Site culminated in a February 24, 1983 letter to the EEG (DOE, 1983a) which concluded:

> As you know, the DOE Revised Interim Policy Statement on Resource Recovery at the WIPP Site is based on the Natural Resources Study which concludes that resource recovery outside the Site Boundary (Zone III) using current technology, will not compromise the integrity of the WIPP underground facility. Accordingly, the DOE does not plan to exercise any control over resource recovery activities outside the Site boundary and will rely, primarily, on other Federal and State regulatory agencies to assure that the WIPP boundaries are not violated. As an additional protection measure, the BLM will notify the DOE of any requests for resource recovery permits within one mile of the WIPP Site boundary so that the DOE will be aware of resource recovery activities near the site.
>
> We do not expect to perform a comprehensive review of resource recovery plans utilizing conventional technology; however, any plans which employ unusual methods or advanced technology will be evaluated to determine possible effects on the underground facility. Upon receipt of notification of unusual or advance technology planned resource recovery activities from the BLM, we will forward the information to the EEG.

In both the Natural Resources Study and the DOE Revised Interim Policy Statement on Resource Recovery at the WIPP Site, DOE recognized BLM's mission and responsibility to manage mining and drilling on federal lands in the WIPP vicinity. The BLM-DOE MOU assured timely and appropriate interface between these two agencies regarding vicinity mineral extraction activities. This interface complemented, reaffirmed, enhanced, and strengthened BLM's responsibility for active institutional control of mining and drilling activities. The position that BLM would be ensuring active institutional controls over mining and drilling was reaffirmed.

On December 7, 1983, the DOE sent a letter to the EEG to clarify the difference between the site boundary and Zone III, and to discuss the acquisition of lease rights and resource recovery at the WIPP site (DOE, 1983b). This letter states:

> All lease rights which have been purchased by the DOE within the site boundary have been purchased in their entirety or alternatively we acquired only the upper 6,000 feet of the leases to reduce the acquisition cost to the DOE and to allow access to potential hydrocarbon resources below the WIPP Site. It was not considered necessary to detail this information in the DOE/BLM June 29, 1983 Memorandum of Understanding or Resource Management Plan because the BLM is required to enforce mineral leasing laws which prohibit violation of adjacent (in this case, DOE's) lease boundaries.

> In summary, the DOE position relative to resource recovery at the WIPP Site is as follows: no potash or other commercial mining or commercial drilling will be allowed within the WIPP Site boundary. That boundary is defined in my February 17, 1983 letter as a square containing 16 sections (10,240 acres). With regard to the 6,000-foot restriction, a leaseholder who has rights to minerals located 6,000 feet or more beneath the surface cannot drill through the upper 6,000 feet without permission of the owner of those lands. Accordingly, application must be made to the BLM for such rights and the MOU does contain provisions for notification of the DOE in that event.

On August 29, 1983, the DOE transmitted to the EEG documentation that described the leasehold and settlement terms for every lease purchased at the WIPP Site through that date (DOE, 1983c). This documentation included a description of Section 31 and clearly stated that only the surface and uppermost 6,000 feet of subsurface had been reserved.

Documentation of Leases

Section 5.0 of EEG-50, "The Forgotten Gas Leases and Well Beneath the WIPP Site," lists documents that the EEG believes provide substantiation for EEG's conclusions regarding institutional controls. These documents are stated to be "incorrect, silent, or inconsistent" on two oil and gas leases beneath Section 31.

The following discussion addresses the EEG's comments on these documents, and the conclusions presented in Section 5.0. Page 24 of EEG-50 states:

> The Final Environmental Impact Statement (FEIS, U.S. DOE, 1980, pp 8-8--8-10) identifies the oil and gas leases held by ten companies in March 1979, yet the 1952 Conoco and 1957 Bass leases in the southwest corner of the WIPP Site on Section 31 are not mentioned.

This statement is misleading in that it fails to address the intent of the FEIS which was to identify those leases which remained to be acquired to protect the integrity of the repository. Page 8-9 of the FEIS states:

> The DOE has acquired oil and gas leases on an additional 7100 acres inside the area. These acquisitions have been necessary to keep the salt beds intact....

The leases in Section 31 were among those which had been resolved when the FEIS was published. The DOE had already acquired the surface rights and the first 6,000 feet and it was not deemed necessary to discuss presettled leases in the FEIS.

Page 34 of EEG-50 states:

> The 1984 report published by the New Mexico Energy and Minerals Department (NMEMD) Task Force on Natural Resources (NMEMD, 1984) stated that the DOE had acquired several oil and gas leases at a cost of over $19.6 million dollars. The report stated that 'As a result of these lease acquisitions, only one hydrocarbon lease remains within the WIPP Site Boundary... an 80-acre tract held by Skelly Oil Company....' (NMEMD, 1984, p. 27). The report did not identify the active gas and oil leases in Section 31, deeper than 6,000 feet (1829 meters).

The NMEMD 1984 "Final Report and Recommendations of the Subcommittee on Natural Resources at the Waste Isolation Pilot Plant (WIPP) Site" identified resource-related issues, problems, and impacts associated with the development of the WIPP and to recommend possible solutions (New Mexico Energy and Minerals Department, 1984). EEG's statement regarding the 1984 report is especially surprising in view of the EEG role in preparation of the report. On January 9, 1984, a letter transmitting the report from NMEMD to the Governor of New Mexico states that the Subcommittee on Natural Resources at the WIPP Site was assisted by the New Mexico EEG in preparing the report. As stated above, the EEG had full knowledge of the existence of the leases beneath Section 31. They had received requested documentation on the leases just four months prior to the issuance of the natural resources report. The subcommittee, in agreement with the EEG, obviously concluded (as the DOE continues to believe) that the leases beneath Section 31 were not an issue of concern, because they had been resolved to the extent necessary to protect the underground salt beds.

In a 1987 modification to the C&C Agreement, the DOE agreed to prospectively preclude "subsurface mining, drilling, or resource exploration unrelated to the WIPP Project on the WIPP site, including "slant drilling under the site from within or from outside the site." The pre-existing 1982 well does not contravene this prospective agreement. Since 1987, no mining, drilling, or resource exploration has taken place within the site.

The WIPP Final Safety Analysis Report (FSAR), issued in May 1990 (DOE, 1990a), reiterated the positions that had been espoused in the Consultation and Cooperation Agreement and the 1984 NMEMD report in that it did not reference the leases located beneath Section 31. This occurred in spite of numerous reviews of the FSAR by outside parties, including the EEG.

The FSAR systematically reviews potential hazards and ensures that appropriate measures are taken to eliminate or adequately mitigate these hazards. The FSAR represents a statement and commitment by the DOE that the WIPP facility can be operated safely and at minimal risk when operated in accordance with the FSAR.

In conclusion, the deviated gas well beneath Section 31 does not and has never posed a significant hazard to the facility. Therefore, it is not necessary to revise the FSAR solely for the purpose of correcting notation of the leases in the area.

Page 40 of EEG-50 discusses statements on page 32 of the DOE "Implementation of the Resource Disincentive Plan in 40 CFR 191.14(e) at the Waste Isolation Pilot Plant." (DOE, 1991a.) Although not clearly stated in the text of the plan, page 32 is discussing producing leases. While the statements on page 32 are not consistent with the correct statements made on page 50 of that document, the omissions do not affect compliance with 40 CFR 191.

Page 39 of EEG-50 states:

> While the Secretary of Energy's Decision Plan for the WIPP had carefully tracked an active potash lease until it was purchased, successive Revisions 6 through 10 did not document the existence of the active oil and gas leases even after the issue had been raised. The potash lease purchase was noted in Revision 5 (U.S. DOE, August 15, 1990). The failure of subsequent revisions to mention the rediscovered gas leases incorrectly suggests that there were no outstanding leases in the WIPP Site Boundary other than the one potash lease.

Although the Secretary of Energy's Decision Plan did not specifically address the leases in question, the document that provides the basis for the recommendation to the Secretary of Energy on the readiness of the WIPP did consider the active oil and gas leases. In September 1991, DOE/EM/45063-3 "Report to the Secretary of Energy Office of Environmental Restoration and Waste Management," was issued (DOE, 1991b). The active leases located below the WIPP site are discussed in Section 3.2.4, "Potash Lease Settlement":

> To protect the 16 sections of land within the WIPP site from human intrusion, it was necessary for the DOE to acquire all surface and subsurface interests within the land withdrawal boundary. On June 29, 1990, the DOE purchased from IMC Fertilizer, Inc., a 1600 acre potash leasehold which encumbered 2 1/2 sections of land within the boundaries of the WIPP. With the purchase of this leasehold, the federal government now holds title to all surface and subsurface interests within the WIPP land withdrawal boundary, except for two outstanding gas well leases.

The No-Migration Variance Petition (NMVP) provided to the EPA in March 1989 did inaccurately reflect the status of oil and gas leases in the WIPP area as noted in EEG-50 (DOE, 1990b). As stated on page 34 of EEG-50:

> With respect to petroleum exploration and the human intrusion issue, the last sentence in this paragraph provided incorrect information to the EPA. The EPA subsequently granted a variance to the DOE in November 1990 (U.S. EPA, 1990).

This information is incomplete and very misleading. It implies that (a) this inaccurate information was pertinent to the granting of the No-Migration Variance Determination, and (b) no actions were taken by the DOE to amend the language in the document. As discussed in the following paragraphs, neither is the case.

One final point regarding EEG's report is its reference to a producible gas well visible from the south access highway. Page 41 of EEG-50 states:

> In terms of active institutional control, the leases were forgotten by the DOE in spite of the lease, drilling, and production records...and the existence of a producible gas well visible from the south access highway into the WIPP facility.

The existence of a "visible" well head is cited three times in EEG-50. These citations imply that the visibility of the well should have been cause for concern. Within the context of EEG-50's conclusions, these references are misleading. DOE is, and has been, aware that numerous oil and gas wells are located in the general vicinity of the WIPP site, including James Ranch 13. There is no visual evidence on the surface that the James Ranch 13 well deviates to some point beneath the WIPP site boundary, and nothing that would suggest that the well is in place contrary to institutional control documentation.

Actions Taken to Address Regulatory Concerns

In October 1990, the DOE, while reviewing a draft of a new MOU between the BLM and DOE, noted a reference to "one 360 acre tract of the public land within the BLM Managed Surface Area leased for oil and gas development." After review of the earlier MOUs and historical correspondence pertaining to the leases as outlined above, it became apparent that the omission of references to these oil and gas leases from certain DOE documents required clarification.

In early November 1990, the EPA and the Chairman of the New Mexico Radioactive Waste Consultation Task Force were verbally informed of the situation. These contacts were made to discuss documents containing language pertaining to the leases at the WIPP. Of primary concern were the C&C Agreement and the NMVP.

On November 15, 1990, the State of New Mexico was formally notified by the DOE of the existence of the leases located beneath Section 31 (DOE, 1990c) stating:

> We do not believe that the existence of this 1982 well contravenes the August 4, 1987 Second Modification to our Agreement for Consultation and Cooperation in which we agreed to prospectively preclude "subsurface mining, drilling, or resource exploration unrelated to the WIPP Project on the WIPP site" [including "slant drilling under the site from within or outside the site"]. Since 1987, the integrity of the WIPP site has been maintained pursuant to our agreement. Nevertheless, in the spirit of consultation and cooperation, we suggest that the record be clarified to reflect the preexistence of the well.

On November 16, 1990, a complete package of information was delivered to the state (DOE, 1990d). A similar package was sent to the EEG on December 3, 1990 (DOE, 1990e).

On January 16, 1991, the DOE formally submitted a data package covering pertinent information relative to Section 31 leases, and the existing deviated well, to the EPA Headquarters (DOE, 1991c).

After reviewing the information, the EPA issued a memorandum March 13, 1991, entitled "Supplemental Information Since the Issuance of the No-Migration Determination for the Waste Isolation Pilot Plant (WIPP)" to the official RCRA docket (Reference Number F-90-NMVP-SO734) (EPA, 1991).

With regard to the EPA's previous review of deviated drilling at the WIPP, the EPA stated:

> The Agency reviewed the issue of deviated drilling while performing the initial review of the DOE no-migration petition, and decided that such wells would not be an issue during the test phase. Because they lie outside of the unit boundary, these wells provide no mechanism for potential release of hazardous constituents from the repository. EPA placed a greater emphasis on the potential for boreholes in the Salado Formation and above the repository, within the land withdrawal area. EPA concluded that these areas have a greater potential impact on the repository. It does not believe that an additional borehole located outside the unit boundary raises any new issues.

Concerning the omission of the well that was finished in Section 31, as described in the NMVP, the memorandum stated:

> This well was not specifically identified in DOE's no-migration petition, although documentation supporting the decision did discuss the possibility of deviated drilling bottoming below the 4-mile by 4-mile WIPP land withdrawal area. After careful review, EPA has concluded that the information provided by DOE does not present concerns not considered in EPA's decision and does not affect its determination of no migration.

The EPA also discussed the existence of the James Ranch 13 well as it specifically pertained to institutional controls stating:

> EPA also recognized in its review that oil and gas exploration and production continue to occur near the WIPP site. Typically, the explorations are located thousands of feet below the Castile Formation. The Bass well is such a well; **the well is in compliance with institutional controls at the WIPP site** noted earlier and it does not penetrate the unit boundary of the WIPP at any location. [Emphasis added.]

Contrary to the implications on page 34 of EEG-50, clearly the existence of the two leases and the presence of the deviated well was not crucial to the granting of the determination. It was the protection of the unit boundary that was of primary importance to the EPA. Additionally, the EPA believed that adequate supporting documentation was in existence regarding deviated drilling at the WIPP site.

As an additional measure, the DOE initiated a review of the deviated well and associated documentation in January of 1991, to ensure that adequate National Environmental Policy Act (NEPA) documentation was in place for the well.

In March 1991, the DOE determined that NEPA documentation for the well was adequate because the well was drilled in accordance with provisions contained in a BLM Environmental Assessment for oil drilling in the district and because the FEIS for the WIPP sufficiently addressed the potential for deviated drilling as it pertained to the potential for this drilling to impact the repository.

Conclusion

It is the position of the DOE that the significant conclusions of EEG-50 relative to institutional controls are incorrect. There is no substantiation for inferences that inadvertent exploration has taken place at the WIPP, or that institutional controls have failed to direct the authorities with regard to drilling in the area. To the contrary, the EPA stated that the NMVP omissions and misstatements had no impact on institutional controls.

None of the documents listed in EEG-50 as being "incorrect, silent, or inconsistent" are a part of the institutional control process at the WIPP. Nor are any of the documents critical to the maintenance of the institutional controls at the WIPP. The controls that are crucial to protect the site from inadvertent exploration are BLM leasing procedures and lease records and the internal procedures of the BLM which require the DOE's review and comment for any permit application to drill within one mile of the WIPP site.

Adherence to policies governing resource extraction at the WIPP has been carefully maintained. Review of the BLM's interface with the DOE reveals numerous requests from the BLM for DOE comments regarding requests to drill in the area.

Historical documents and correspondence such as the DOE's Revised Interim Policy (and resulting comments and responses), and the 1984 Final Report and Recommendation on Natural Resources at the WIPP Site reflect the priority of protecting the underground repository by prohibiting access from the surface to 6,000 feet of the subsurface. These records also document the intent of the State and the DOE not to unnecessarily limit access to those resources located beneath 6,000 feet.

The position of the EPA, as presented in their 1991 memorandum (EPA, 1991), is that the existence of the deviated well beneath Section 31 does not affect their previous decision to grant the WIPP a No-Migration Variance Determination. Furthermore, the EPA does not believe that the institutional controls at the WIPP have been compromised.

The DOE continues to support its position relative to EEG-50 contained in its interim response to the EEG, dated July 15, 1992.

References

Bureau of Land Management, 1981. Letter dated December 18, 1981, from G. B. Koski, BLM, Area Manager, Carlsbad Resource Area, to J.M. McGough, Project Manager, WIPP Project Office.

Condemnation Hearings, 1977 Civil Actions 77-071-B and 77-776-B.

New Mexico Energy and Minerals Department, 1984. Natural Resources at the Waste Isolation Pilot Plant Site, New Mexico Energy and Minerals Department Task Force on Natural Resources, Santa Fe, New Mexico.

Sandia National Laboratories, 1980. Memorandum, Position Paper on Zone IV, dated October 10, 1980, from W. D. Weart, SNL, to J. M. McGough, Project Manager, WIPP Project Office.

U.S. Department of Energy, 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026.

U.S. Department of Energy and State of New Mexico, 1981a. "Agreement for Consultation and Cooperation" on WIPP; First Modification, November 30, 1984, and Second Modification, August 4, 1987.

U.S. Department of Energy, 1981b. Letter dated November 3, 1981, on Interim Policy Statement by U.S. Department of Energy, Resource Recovery at the Waste Isolation Pilot Plant Site, from J. M. McGough, Project Manager, WIPP Project Office, to Dr. George S. Goldstein, Chairman, Governor's Task Force on WIPP, U.S. Department of Energy, WIPP Project Office, Albuquerque, NM.

U.S. Department of Energy, 1981c. Letter dated December 30, 1981, from J. M. McGough, Project Manager, WIPP Project Office, to G. B. Koski, BLM, Area Manager, Carlsbad Resource Area.

U.S. Department of Energy, 1982. Letter dated December 23, 1982, Revised Interim Policy Statement on Resource Recovery at the WIPP Site, from J. M. McGough, Project Manager, WIPP Project Office, to Dr. George S. Goldstein, Chairman, Radioactive Task Force, WIPP Project Office, Albuquerque, NM.

U.S. Department of Energy, 1983a. Letter dated February 24, 1983, from J. M. McGough, Project Manager, WIPP Project Office, to R. H. Neill, Director, Environmental Evaluation Group.

U.S. Department of Energy, 1983b. Letter dated December 7, 1983 from J. M. McGough, Project Manager, WIPP Project Office, to R. H. Neill, Director, Environmental Evaluation Group.

U.S. Department of Energy, 1983c. Letter dated August 29, 1983, from J. M. McGough, Project Manager, WIPP Project Office, to R. H. Neill, Director, Environmental Evaluation Group.

U.S. Department of Energy, 1990a. Final Safety Analysis Report, Waste Isolation Pilot Plant, WP-0209, Rev. 0.

U.S. Department of Energy, 1990b. No-Migration Variance Petition: Waste Isolation Pilot Plant, DOE/WIPP-89-003, Rev. 1.

U.S. Department of Energy, 1990c. Letter dated November 15, 1990, from J.E. Bickel, Assistant Manager for Energy and Special Programs, to A. Lockwood, Chairman of the New Mexico Radioactive Waste Consultation Task Force.

U.S. Department of Energy, 1990d. Letter dated November 16, 1990, from J.E. Bickel, Assistant Manager for Energy and Special Programs, to C. Wentz, Coordinator of the New Mexico Radioactive Waste Consultation Task Force.

U.S. Department of Energy, 1990e. Letter dated December 3, 1990 from A. Hunt, Project Manager, WIPP Project Office, to R. H. Neill, Director, Environmental Evaluation Group.

U.S. Department of Energy, 1991a. Implementation of the Resource Disincentive in 40 CFR Part 191.14 (e) at the Waste Isolation Pilot Plant, DOE/WIPP 91-029.

U.S. Department of Energy, 1991b. Report to the Secretary of Energy Office of Environmental Restoration and Waste Management, DOE/EM/45063-3.

U.S. Department of Energy, 1991c. Letter dated January 16, 1991, from J. E. Lytle, Associate Director, Office of Waste Operations, Environmental Restoration and Waste Management, to M. Hale, Deputy Director, Permits and State Programs Division, Office of Solid Waste (OS-341), U. S. Environmental Protection Agency.

U.S. District Court, 1981, Stipulated Agreement in Civil Action No. 81-0363 JB, State of New Mexico v. The United States Department of Energy, July 1, 1981, filed with the U.S. District Court, Albuquerque, NM, Appendix B, Item 6.

U.S. Environmental Protection Agency, 1991. Memorandum dated March 13, 1991, from J.D. Denit, Office of Solid Waste and Emergency Response, EPA, to RCRA Docket, Reference Number F-90-NMVP-SO734.

Westinghouse Waste Isolation Division, 1982. Natural Resources Study Final Report, WTSD-TME 3156.

PEER 21 - Fracture Expert Group Summary Report

1993 WIPP Performance Assessment
Fracture Expert Group Meeting
Albuquerque, New Mexico
March 23-25, 1993

I. INTRODUCTION

The initial meeting of the WIPP Fracturing Expert Group (FxG) was held March 23-25, 1993, at the La Posada Hotel in Albuquerque, New Mexico. The meeting was a joint meeting of the WIPP Geostatistics, Conceptual Modeling Uncertainty, and the Fracturing Expert groups[1]. The FxG met in plenary sessions with the other groups and separately. The agenda for the plenary sessions and the separate FxG sessions are included in Apendices A, B, and C respectively. The joint meetings of these groups stimulated information flow among the groups and provided an efficient way to orient members of emerging groups - the FxG and the Conceptual Model Uncertainty Group (CMUG) - to the project. The FxG Agenda was designed to compliment the plenary agenda. The Orientation and State of Current Technology sessions provided information that led up to the group's critique of the "first cut" fracture model that is to be used in the Land Withdrawal Act 93 Performance Assessment (LWA 93 PA). The Defensible Fracture Modeling, Testing, Simulation Program session elicited input from the FxG for establishing a program that will produce a defensible fracture simulation for compliance demonstration.

II. SUMMARY

The FxG sessions are summarized in this section. The FxG sessions were divided into three parts: (a) Orientation; (b) Current Technology State; and (c) FxG Recommendations. Presentation titles are included in parenthesis for cross-reference with presentation slides in Appendix E.

A. Orientation Session

Sam Key gave a brief introduction and welcome to the FxG members.

Mel Marrietta described anhydrite layer fracturing concerns at WIPP (*Regulatory Framework* by Mel Marietta). He discussed the no-migration variance petition that covers the storage and disposal of hazardous wastes that is included in the land ban restrictions in federal regulation 40 CFR 268.6[2]. Mel explained that gas generated in the repository has the potential for migrating through fractures in anhydrite layers and violating the no-migration variance.

Peter Swift gave an overview of the WIPP project that discussed the history, mission, repository design, and waste forms that are to be stored (*Introduction to the WIPP* by Peter Swift). The federal regulations that apply to the WIPP repository were also discussed and a generalized description of the geology and hydrology of the WIPP site was presented.

Dave Borns presented a more detailed description of the site geology and a detailed description of the geology of the anhydrite layers (*WIPP Geology/Hydrology* by David J. Borns). In

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[1] Appendix D contains the membership of the FxG.

[2] This regulation is commonly referred to as the RCRA–Resource Conservation and Recovery Act-- regulation in the WIPP project.

addition, Dave provided core and other material samples taken from the WIPP site for examination and discussion.

Sam Key discussed the rational for membership in the FxG. Sam noted that gas migration in the WIPP anhydrite layers is a coupled process involving the mechanics of the media and multiphase flow in fractured and porous media and as such requires an interdisciplinary team.

Sam Key stated the group charter as twofold (*FxG - Charter*):

1. Review the proposed PA93 BRAGFLO models for permeability and porosity as a function of pressure for their adequacy as first order representations of the changes in the anhydrite beds adjacent to the waste disposal horizons due to pressurization of the formation.
2. Recommend for PA94 improvements in the characterization of changes in permeability and porosity in the anhydrite beds adjacent to the waste disposal horizons due to pressurization of the formation.

He discussed activities that may be required before the FxG can make improvements for PA94. Sam also described the WIPP Performance Assessment cycles and the schedule for FxG work (FxG - *PA "Rounds"*).

B. State of Current Technology Session

The following collection of light presentations focused on the current state of understanding of the anhydrite marker beds above and below the WIPP repository horizon. The material provided the context for the work of the FxG.

Peter Davies provided an overview of the technical work that has led up to the current state of the technology for understanding and quantifying the potential for fracturing in the anhydrite layers at the WIPP site and the impact on gas migration (*Evolution of Technical Work on Interbed Fracture Dilation/Growth Due to Pressurization by Waste-Generated Gas* by Peter B. Davies). Peter described the coupling between processes that may occur in the WIPP repository due to waste generated gas. The early geomechanical analysis of fracture initiation adjacent to a pressurized waste disposal region and the early multiphase flow analyses of gas migration through the anhydrite layers were discussed.

Wolfgang Wawersik and Richard Beauheim discussed hydraulic fracturing and hydrologic tests at the WIPP site in two anhydrite layers (MB 139 and MB 140). Wolfgang discussed the technical motivation for these tests and described the tests (*Hydraulic Fracturing and Hydrologic Tests in Marker Beds 139 and 140* by W. R. Wawersik and R. L. Beauheim). He also discussed pre-test analyses and summarized the results obtained to date. Richard Beauheim discussed the hydrogeologic characterization of anhydrite interbeds at the WIPP site (*Hydrologeologic Characterization of Anhydrite Interbeds at the WIPP Site* by Richard L. Beauheim and Randall M. Roberts). He described the anhydrite interbeds tested to date, the types of tests conducted, and observations about hydraulic parameters based on these tests. Richard Beauheim also discussed the evaluation of the effects of hydraulic fracturing on permeability of anhydrite interbeds based on constant-pressure injection and constant-pressure withdrawal tests performed in boreholes before and after hydraulic fracturing (*Evaluation of Effects of Hydraulic Fracturing on Permeability of Anhydrite Interbeds*).

Barry Butcher discussed the mechanisms that are expected to be active during fracturing of the anhydrite layers in response to elevated gas pressure (*Interbed Fracture Mechanisms* by B. M. Butcher). Barry Butcher described two theoretical geomechanical analyses that may be used to bound fracture openings in the anhydrite layers.

Darrell Munson discussed constitutive models of the behavior of the halite surrounding the waste rooms following excavation (*Constitutive Models and Observations* by Darrell E. Munson). These constitutive models are based on observations and measurements from tests at the WIPP site. These models predict room closure due to creep of the halite. Although these models are not directed at fracturing in the anhydrite layers, the closure of the excavated rooms is coupled to fracturing in the anhydrite layers through the gas pressure.

Susan Howarth discussed the laboratory program for measuring two-phase flow properties of the Salado formation at the WIPP site (*Salado Two-Phase Flow Laboratory Program* by Susan Howarth). The program is to provide data that will support the development of mechanistic models and performance assessment models of multi-phase flow in and around the WIPP repository. FY93 were discussed in detail and an overview of FY94 activities was given. Studies that are planned to support investigations of outstanding issues were also discussed.

Peter Davies discussed the results of multi-phase flow studies using models with fracture-like features in the anhydrite layers (*Preliminary "Fracturing" Model Results* by Stephen W. Webb and Peter B. Davies). Peter Davis concluded, based on the results of these studies, that the peak gas pressure and gas migration may be significantly altered by fracturing and that additional work is needed to develop a comprehensive fracture model.

Palmer Vaughn discussed probabilistic two-phase flow modeling in the WIPP performance assessment (*Probabilistic Two-Phase Flow Modeling in the WIPP Performance Assessment* by Palmer Vaughn). Palmer Vaughn described the probabilistic approach and the two-phase flow modeling objectives. He described the computer code BRAGFLO and explained its role in performance assessment. Palmer Vaughn also described the WIPP performance assessment model geometry and discussed the values of fluid pressures in the repository calculated in the 1992 performance assessment simulations. He also introduced the proposed anhydrite layer fracture model for the PA93 calculations.

Mike Lord discussed the PA93 Fracture Model and results of calculations to date using the model (*Proposed Anhydrite Fracture Treatment BRAGFLO Simulation* by Michael Lord). Mike Lord compared results with and without anhydrite fracturing. Mike Lord concluded his presentation with a video showing the dynamics of the repository system including anhydrite fracturing over the 10,000 year regulatory time period.

C. PA93 Fracture Model Critique and Defensible Fracture Modeling, Testing, and Simulation Program for PA94

These sessions were facilitated (Sam Key) discussions among the FxG members and attendees. These sessions produced the recommendations discussed in the next section.

III. RECOMMENDATIONS AND DISCUSSION

The WIPP Performance Assessment Fracture Expert Group (FxG) was asked to respond to the following two directives[3]:

1. Review and comment on the adequacy of the proposed first-order model in BRAGFLO for representing changes in permeability and porosity due to pressure-induced changes in

[3]These directives are a restatement of the FxG charter.

the anhydrite beds above and below the WIPP repository horizon (Marker Beds 138 and 139) that is scheduled for use in the 93 LWA PA simulations.[4]

2. Identify additional factors to be considered or studies needed to support an extended and improved, second-order model in BRAGFLO for pressure-induced hydrological changes in the anhydrite beds above and below the WIPP repository horizon that will be used in the 95 LWA PA simulations.

The FxG provided comments in response to both of these directives.

A. FxG 93 LWA PA Recommendations

The following recommendations were put forward by the FxG regarding the proposed first-order model in BRAGFLO for representing changes in permeability and porosity due to pressure-induced changes in the anhydrite beds above and below the WIPP repository horizon (Marker Beds 138 and 139):

1. "The proposed first-order model in BRAGFLO for representing changes in permeability and porosity due to pressure-induced changes in the anhydrite is an acceptable first approximation."

By way of elaboration on the suitability of the first-order model the FxG noted that:

   A. The pore compressibility is taken as a piecewise linear function of pore pressure, a reasonable first approximation;

   B. The variability of the anhydrite porosity in the simulation is derived from the compressibility as it should be; and

   C. The changes in permeability are related in a reasonable way to the changes in porosity, that is, permeability changes are derived from changes in fracture aperture, the expected dominant form of porosity alteration occurring in the anhydrite.

2. Further, the FxG recommended the following adjunct steps and activities be undertaken to assure the BRAGFLO modeling of the two-phase flow occurring in the altered anhydrite marker beds is an adequate and reasonable representation of the behavior that typically takes place in fracture flow:

   A. Examine the literature on relative permeability for flow in jointed rock masses and in individual rock joints to identify the best accepted functions, considering the possibility that phase interference may be a factor under some conditions.

   B. Incorporate non-zero residual saturations in the simulation as a variable factor, that is, introduce residual saturation as a variable to be sampled in the Monte Carlo simulation suites.

   C. Examine the numerical convergence of the BRAGFLO simulation results by conducting a series of calculations with decreasing grid size and time step size to determine if the grid size and time step size routinely used for the performance assessment simulations is sufficiently fine to produce acceptably accurate simulation solutions.

   D. Conduct 3-D hydrological simulations with independent software to verify the sub-3-D simulations used in BRAGFLO.

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[4]During the workshop, 93 LWA PA was known as PA93 and 95 LWA PA was known as PA94. The terminology henceforth in this text is changed to be in conformance with *au courant* terminology. (4/93)

E. Examine repository design alternatives to provide additional volume within the repository for gas storage as a means of limiting the pressure generated by gas emitted during iron-brine corrosion reactions and organic waste decay.

B. FxG 95 LWA PA Recommendations

The FxG made recommendations for 95 LWA PA work to support an extended and improved, second-order model in BRAGFLO for modeling the two-phase flow occurring in the altered anhydrite marker beds (Marker Beds 138 and 139). The recommendations address the following four separate areas of investigation:

1. In Situ and Field Measurements and Experiments,
2. Laboratory Measurements of Hydrological and Mechanical Properties,
3. Character and Final Spatial Extent of Fracturing, and
4. Coupled Mechanical and Hydrological Simulations.

In each of these, a number of specific requests and/or issues were identified by the FxG for which new or additional work is essential to a credible extension of the BRAGFLO treatment for modeling the two-phase flow in altered anhydrite marker beds.

1. In Situ and Field Measurements and Experiments

In light of the concerns for gas migration, examining existing tests and data on anhydrite and conducting in situ tests and field experiments that focus on determining hydrological properties before, during and after fracturing of the anhydrite beds were considered the most significant activities.

The specific recommendations were:

- Conduct fluid- and gas-driven slow fracturing tests in undisturbed anhydrite in which the entire history of fracture flow and joint aperture are recorded. There are three important points to this recommendation.
    1. The testing should be conducted slower than the natural time scales connected with the damage processes that alter or fracture the anhydrite beds. The information obtained from a "slow" test will more nearly relate to the damage occurring on the time scale over which gas generation and formation pressurization take place.
    2. A fluid should be used first to induce fracturing in the experiments followed by reloading with gas because it is the waste generated gas during the first 1000 years that is to be contained. That is, from a performance assessment perspective, it is the two-phase flow characteristics of gas and brine flow at pressures exceeding the formation pressures that must be understood and modeled.
    3. The relationship between flow rates and fracture aperture must be evaluated to obtain a complete picture of the changes in matrix hydrological properties with pressurization and alteration.
- Determine the horizontal components of the in-situ stress in anhydrite Marker Beds 138 and 139, respectively.
- Examine available cores from MB 138 and MB 139 for structures and features that are or will be important to porosity and permeability before, during, and after damage/alteration.

- Design and field a hydrological repository analog experiment in conjunction with parallel BRAGFLO simulations in order to obtain some degree of software simulation validation.
- Study existing experimental data and bracket the parameters needed for the first-order model for representing changes in permeability and porosity due to pressure-induced changes in the anhydrite beds.
- Use field-scale averaging of locally measured hydrological parameters to develop the values appropriate for the far-field simulations conducted with BRAGFLO.

2. Laboratory Measurements of Hydrological & Mechanical Properties

There was a recognition that laboratory testing and characterization of the anhydrite marker beds significantly lags the characterization of halite. These recommendations address the need for more detailed mechanical property testing and hydrological characterization for the anhydrite beds.

- Bracket the variability in hydrological flow parameters and cross correlate the hydrological flow parameters to limit the diversity in the response predictions to physically attainable behavior.
- Measure anhydrite mechanical properties, particularly, those properties tied to quantifying the alteration and damage that occurs with high internal pore pressure.
- Conduct controlled laboratory experiments in anhydrite to measure multiphase flow characteristics, including gas permeability testing.
- Study flow characteristics in altered/damaged anhydrite to establish the appropriateness of using a Darcy flow representation.

3. Character and Final Spatial Extent of Fracturing

To date, the majority of the performance assessment studies on the pressure-induced alteration in the anhydrite marker beds have been based on two assumptions: (1) the areal extent of the alterations occurring in the anhydrite marker beds is a perfect circular disk (comes from using axisymmetric modeling), and (2) very elementary alteration rules in BRAGFLO are sufficient to define the pressure induced alterations. The adequacy of both of these idealizations needs to be examined. Both idealizations can be studied without resorting to extensive numerical simulations. The field of fracture mechanics frequently considers a number of these issues in examining the failure of manufactured materials, as well as, studying oil well hydrofracturing. The following independent studies will either support the validity of the existing assumptions or support a redefinition of an appropriate description of the pressure-induced alterations expected in the anhydrite:

- Examine various factors such as crack path stability and site heterogeneity factors (dip, anhydrite properties, anhydrite in-situ stress, et cetera) to determine if the final expected crack front should be circular or non-circular at its maximum extent.
- Examine various factors to determine if the crack profile should or is likely to exhibit large scale fingering and channeling around the perimeter at its maximum extent.
- Examine the in-situ stress conditions to see if the expected fracture surfaces within the anhydrite should be horizontal or vertical; in the event that vertical surfaces are preferred, identify the conditions under which the fractures might be expected to propagate into the surrounding halite.

- Examine the possibility that in spite of the complex processes and geometric interactions initially occurring within the repository, the final "equilibrium" state (diameter and thickness) of the fractured anhydrite domain can be predicted from first principles.

4. Coupled Mechanical and Hydrological Simulations

The FxG recognized that performance assessment out of necessity must use a repository containment simulation that for any single discipline might be considered a "reduced" model. However, the FxG felt that a considerable amount of work was needed to relate mechanical alteration and damage in both the halite and anhydrite to a continuum porosity and permeability used in the BRAGFLO hydrological simulation. That is, once mechanical alterations and damage in anhydrite can be predicted due to pressurization and once continuum porosity and permeability can be evaluated from mechanical damage descriptions, coupled mechanical and hydrological simulations need to be undertaken to assure the adequacy of the uncoupled BRAGFLO hydrological simulations.

- Develop expressions for continuum porosity and continuum permeability based on observed mechanical damage in anhydrite.
- Develop stress-strain models for anhydrite and halite that include damage and healing components related to material mechanisms and capable of predicting porosity and permeability for coupling to hydrological simulations.
- Conduct simulations of room closure followed by subsequent "inflation" that include porosity and permeability changes generated by mechanical damage/healing in the domain surrounding the waste disposal room.
- Relate continuum porosity and permeability to "crack extension" generated from mechanical damage in the anhydrite beds.
- Perform coupled mechanical-hydrological simulations to substantiate uncoupled PA hydrological simulations.

Appendix A. Plenary Agenda

PEER 22 - Fanghanel Review Report

Review Report on the WIPP Thermodynamic Model for Trivalent Actinides An(III)

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7 May 1996

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Review Report on the WIPP Thermodynamic Model for Trivalent Actinides An(III)

Introduction

This report presents the results of a review of the WIPP thermodynamic model for trivalent actinides. The review was performed at LLNL during April 30 to May 5, 1996. The following manuscripts, reports, memos, etc., were made available to the reviewer and were used for the review:

- Novak, C.F.; Moore, R.; Bynum, R.V. Prediction of dissolved actinide concentrations in concentrated electrolyte solutions: A conceptual model and model results for the Waste Isolation Pilot Plant (WIPP).
- Novak, C.F.; Crafts, C.C.; Dhooge, N.J. A data base for thermodynamic modeling of +III actinide solubility in concentrated Na-Cl-SO_4-CO_3-PO_4 electrolytes.
- Rao, L.; Rai, D.; Felmy, A.R.; Fulton, R.W.: Solubility of $NaNd(CO_3)_2*6H_2O(c)$ in concentrated sodium carbonate and sodium bicarbonate solutions.
- Rao, L.; Rai, D.; Felmy, A.R.: Solubility of $Nd(OH)_3(c)$ in the aqueous NaCl solution at 25°C and 90°C. Report PNL-SA-26137
- Rai, D.; Felmy, A.R.; Fulton, R.W.: Nd^{3+} and Am^{3+} ion interactions with sulfate ion and their influence on $NdPO_4(c)$ solubility. J. Solution Chem. **24**(1995)879
- Felmy, A.R.; Rai, D; Schramke, J.A.; Ryan, J.L.: The solubility of plutonium hydroxide in dilute solution and high-ionic-strength chloride brines. Radiochim. Acta **48**(1989)29
- Rai, D.; Felmy, A.R.; Fulton, R.W.: Solubility and ion activity product of $AmPO_4*xH_2O(am)$. Radiochim. Acta. **56**(1992)7
- Felmy, A.R.; Rai, D; Fulton, R.W.: The solubility of $AmOHCO_3(c)$ and the aqueous thermodynamics of the system Na^+-Am^{3+}-HCO_3^{2-}-CO_3^{2-}-OH^--H_2O. Radiochim. Acta **50**(1990)193
- Kahalili, F.I.; Symeopoulos, V.; Chen, J.-F.; Choppin, G.R.: Solubility of Nd in brine. Radiochim. Acta **66/67**(1994)51
- Novak, C.F.: Estimates of Dissolved Concentrations for +III, +IV, +V and +IV actinides in a Salado and a Castile brine under anticipated repository conditions. Memo, 28 March 1996
- Novak, C.F.: Confirmatory testing of the inorganic +III actinide dissolved concentration model for Pu(III) and Am(III) in complex brines. Memo, 9 April 1996

The review concerns the model developed for trivalent actinides in the system H-Na-K-Mg-Ca-Cl-SO_4-HCO_3-CO_3-OH-B-H_2O. Organic ligands are not within the scope of this review.

The goal of the WIPP thermodynamic model is the development of a model capable of predicting dissolved actinide concentrations in WIPP brines. The model is based on the principles of equilibrium thermodynamics.

The system under consideration is very complex and necessitates several key assumptions. These assumptions are:

- Complexation, precipitation and dissolution reactions, except redox reactions, are described within the framework of equilibrium thermodynamics.
- Actinides do not sorb on immobile substrates.
- Redox reactions (actinide conversion among the oxidation states) are not equilibrium processes.

These assumptions simplify the model and are conservative. In particular the exclusion of sorption is conservative and leads to an overestimation of the mobile actinide concentrations. Actinides are strongly sorbed on solid surfaces. Applying these assumptions the solubility of actinides and hence the maximum concentration of the actinides in the mobile phase can be estimated by using thermodynamic models. (The formation of colloids is considered in a separate study and not included in the model reviewed.)

Development of a thermodynamic model

The development of a thermodynamic model for actinides in concentrated electrolyte solutions includes two submodels:

- A chemical model which defines the homogeneous and heterogeneous equilibrium reactions and the species that have to be considered.
- An activity coefficient model which is a formalism for calculating activity coefficients of the species defined in the chemical model as function of composition (temperature, pressure).

For the WIPP thermodynamic model the ion interaction approach (Pitzer equations) was chosen for modeling the excess properties of the aqueous solution (activity coefficient model). At present the Pitzer approach is the most sophisticated semiempirical approach for the Gibbs excess energy of a concentrated electrolyte solution. It is widely used and a data base with ion interaction parameters covering a

large variety of different solution species is available. All other known semiempirical extensions of the Debye-Hückel theory are inadequate for modeling the thermodynamic properties of the high concentrated complex brines of the WIPP disposal.

For calculating the properties of the brines a combination of the data bases published by Harvie et al. [1] and by Felmy and Weare [2] are employed. The resulting data base was successfully applied in numerous model calculations of thermodynamic properties of complex brines of the six component sea water system Na-K-Mg-Ca-Cl-SO_4-H_2O including borate and CO_2 at room temperature.

The data base had to be extended for the interaction of actinides in complex concentrated brines.

The applied methodology

- evaluate existing literature data
- design and perform additional experiments
- parameterize the model
- test the predictive capability of the model by predicting properties of given system and comparing the predictions with independent experimental results (not used for the parameterization of the model)

is based on scientific principles and is best suited for the model development.

Oxidation state analogy

In order to simplify the model an oxidation state analogy is applied for the trivalent actinides in the WIPP thermodynamic model. This oxidation state analogy claims that the trivalent actinides under consideration (Pu(III), Am(III)) and the lanthanide Nd(III) have the same or at least very similar thermodynamic and solution chemical properties. This analogy is in general reasonable, but care should be taken when the analogy is extended to other trivalent lanthanides, in particular to the lower lanthanides.

Oxidation state analogy is applied to the following three quantities:

- ion-interaction (Pitzer) parameters
- chemical potentials of aqueous species
- chemical potentials of solid compounds

The first analogy is certainly reasonable. There is no evidence that the parameters accounting for the interaction of Nd(III) species with the major constituents of the brines are different from those of the equivalent An(III) species.

Similar arguments could be applied to the analogy of the equilibrium constants of the aqueous species. The structure of the actinide species is expected to be the same as those of the analog Nd species.

More care has to be taken when the oxidation state analogy is applied to chemical potentials of analog solids. The chemical potentials of solid phases are governed by their structure. Even very small changes in the diameters of different ions could cause a change in the structure and those solids could have different solubilities. It follows that this analogy is not necessarily conservative. A good example for illustration are the two homologue solid compounds $NaNpO_2CO_3*2H_2O$ and $KNpO_2CO_3*2H_2O$. These compound have different structures and the solubility of the sodium compound is about two orders of magnitude higher than that of the homologue potassium compound. Although the differences in the ionic diameters between Na^+ and K^+ are larger than between trivalent actinides and lanthanides and this kind of analogy is not used in the WIPP thermodynamic model, the example demonstrates that solids could have much larger differences in their thermodynamic properties than one would expect from a simple analogy consideration. Thermochemical investigations and comparison with results of other equilibrium thermodynamic studies on $Ln(OH)_3$ and $An(OH)_3$ by Morss at al. [3] clearly demonstrate that there are differences in the solubility products of actinide hydroxides of more than one order of magnitude. The reviewer recommends that individual solubility products be used for the different actinides in the thermodynamic model if they are available in the literature. This will not cause a remarkable increase in the complexity of the model.

Model for trivalent actinides

The WIPP thermodynamic model takes into consideration the interaction or complexation of the trivalent actinides with the following ions/species:

- H^+, Na^+, K^+, Mg^{2+}, Ca^{2+} / Cl^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-, OH^-

and several organic substances, which are outside the scope of the present review.

One of the key problems for the modeling of the behavior of actinides in concentrated aqueous solutions is to decide whether the interaction of a trivalent actinide with a certain ion should be treated as ion-ion interaction or as complex formation (ion

association). In the later case appropriate complex formation equilibria have to be formulated and new species and their interactions with other solution species have to be introduced into the model. This complicates the model and makes it necessary to determine additional chemical potentials and interaction parameters. On the other hand the model becomes more realistic with respect to aqueous chemistry (structural considerations) and from the point of view of electrolyte thermodynamics strong complexes can not be treated as ion-ion interaction without invoking the formation of complex species.

Among the anions considered in the model there are the following potential ligands for trivalent actinides:

- Cl^-
- SO_4^{--}
- HCO_3^-
- CO_3^{--}
- OH^-

It is known from numerous investigations that CO_3^{--} and OH^- form strong complexes with trivalent actinides, while complexes with the other ligands are much weaker or are questionable (e.g. bicarbonato complexes). There is experimental evidence for chloro complexes at very high chloride concentrations (above 4 molal) [4] and for relatively weak sulfate complexes at sulfate concentrations of 0.05 molal and higher [5]. The hydrolysis of trivalent actinides in brines was investigated by several authors. A thermodynamic model for the first and second hydrolysis equilibrium of Cm(III) in 0-6 molal NaCl solution is published [6]. Experimental data for the CO_3^{--} have been published and new spectroscopic investigations are in progress in our institute in Karlsruhe.

The WIPP model treats the interaction of An(III) with Cl^- and SO_4^{--} as strong ion-ion interaction without invoking the formation of complex species. Within the composition range of the WIPP brines this is a reasonable approach which was demonstrated in several comparisons between model calculations and data. Both interactions can also be treated within the framework of the PITZER formalism by taking into account spectroscopically confirmed chloro and sulfato complexes, which is a more realistic approach regarding aqueous solution chemistry and increases the range of applicability of the model to other process such as sorption or ion exchange equilibria. Thermodynamic models for those systems are in preparation at Karlsruhe and will be available soon.

In the WIPP model the carbonato complexes $AnCO_3^+$, $An(CO_3)_2^-$ and $An(CO_3)_3^{--}$ are considered. Pitzer parameters have been derived only for the interaction of $An(CO_3)_3^{--}$

with Na^+ (binary parameters) and with Cl^- (mixing parameters). All other parameters for example those accounting for the interaction of $An(CO_3)_2^-$ with the main cations (Na^+ or Mg^{++}) and of $AnCO_3^+$ with chloride are set to zero. This is mainly caused by the limited number of reliable experimental data available in the concentration range where those species are important. The consequence is that predictions for conditions where the mono and dicarbonato complex govern the aqueous chemistry of the trivalent actinides has to be used with care. With new experimental results the model could certainly be improved. Such investigations are in progress at Karlsruhe. The present model predicts the solubility of $NaAm(CO_3)_2*xH_2O$ in carbonate solutions in reasonable good agreement with independent experimental results. Predictions should be restricted to conditions that are similar to those where the experiments for the parameterization of the model were performed. If the model predictions are extended to CO_2 partial pressures of up to 100 bar the reviewer doubts that reliable results can be expected from the model. Additional experimental data are necessary for those conditions.

A weak point of the present model is neglecting the hydrolysis of trivalent actinides. Hydrolysis species are very strong complexes. They form at pH>7 and are very important in systems with low concentrations of other strong ligands and high pH. Such conditions are realistic for WIPP brines if for example portlandite/calcite are used as backfill materials. Neglecting the hydrolysis in those brines leads to completely wrong predictions of the total An(III) concentration stable in solution. The predicted An concentrations are at least 10 orders of magnitude too low. Under those conditions all of An(III) is stabilized as hydroxo complexes (mainly as $An(OH)_3(aq)$), while the model predicts only the An^{3+} concentration which is negligible under those conditions. Consequently, if pH is high and other strong ligand concentrations like that of CO_3^{2-} are low the model predicts An(III) concentrations that are several orders of magnitude too low. When hydrolysis is considered the model predictions would be reliable as is demonstrated for the solubility of Np(V). The WIPP model takes into account the hydrolysis of Np(V) and predicts a slight increase of the Np(V) solubility when portlandite/ calcite are added to the brines, although Np(V) hydrolysis is much weaker than An(III) hydrolysis and is important only above pH 10. While the model predicts reliable Np(V) solubilities under these conditions the predicted An(III) concentrations are total unrealistic and at least 10 orders of magnitude too low. The WIPP model has to be improved by taking into account the formation of hydrolysis species. Appropriate information is available from the model published for the hydrolysis of Cm(III) in NaCl solutions [6]. This model could easily be incorporated into the present WIPP thermodynamic model.

Conclusions

The applied assumptions for the development of the WIPP thermodynamic model are conservative and simplify the overall model. This is a prerequisite for calculating dissolved actinide concentrations in the very complex repository system.

In general the model represent the present state of the knowledge of aqueous solution thermodynamics. The chosen activity coefficient model and the applied data base are, with a few exceptions, suitable for calculating maximum trivalent actinide concentrations in WIPP brines. The model needs to be improved in some parts. This concerns in particular the hydrolysis equilibria of trivalent actinides which have to be introduced into the model. Moreover the reviewer recommends that the model regarding the interaction of carbonate complexes in concentrated electrolyte solutions be refined.

The development of realistic models based on both our knowledge on aqueous solution chemistry and electrolyte thermodynamics is one of the key issues for the performance assessment of a waste repository. This is not only a matter of the accuracy of the model predictions. Realistic and accurate models give confidence that the basic principles of the behavior of the system are understood which is probably more important for the performance assessment than to predict solubilities with an higher accuracy.

References

1. Harvie, C.E.; Moller, N.; Weare, J.H.: Geochim. Cosmochim. Acta **48**(1984)723
2. Felmy, A.R.; Weare, J.H.: Geochim. Cosmochim. Acta **50**(1986)2771
3. Morss, L.R.; Williams, C.W.: Radiochim. Acta **66/67**(1994)89
4. Fanghänel, Th.; Kim, J.I.; Klenze, R.; Kato, Y.: Journal of Alloys and Compounds **225**(1995)308-311.
5. Paviet, P.; Fanghänel, Th.; Kim, J.I.: Radiochim. Acta (1996) in print.
6. Fanghänel Th.; Kim, J.I.; Paviet, P.; Klenze, R.; Hauser, W.: Radiochim. Acta **66/67**(1994)81

PEER 23 - Independent Technical Review of Bin and Alcove Test Programs

DOE/EM-0130T

Independent Technical Review of the Bin and Alcove Test Programs at the Waste Isolation Pilot Plant

December 1993

Conducted by the
U.S. Department of Energy
Office of Environmental Restoration
and Waste Management
Washington, D.C. 20585

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PREFACE

This report documents an Independent Technical Review (ITR) by the Department of Energy (DOE), Office of Environmental Restoration and Waste Management (DOE-EM) of a transuranic (TRU) waste test program at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. The review was performed at the request of the Director, Office of Waste Management Projects (EM-34) through the Office of Technical Support, Office of Waste Management (EM-35).

Information for the review was drawn from documents provided to the ITR Team by the WIPP Project Integration Office (WPIO), the WIPP Project Site Office (WPSO), Sandia National Laboratories (SNL), Westinghouse Waste Isolation Division (WID), and others; and from presentations, discussions, interviews, and facility inspections at the WIPP Site and Albuquerque, New Mexico during the weeks of July 26-30 and August 30-September 3, 1993. During the week of September 7-10, 1993, the ITR Team developed consensus assessments and recommendations.

The ITR Team consensus assessments and recommendations form the core of this report, and are supported by associated descriptions and discussions. The report is an independent assessment of information available to, and used by, WIPP personnel. Repetition of information to support assessment discussions is not meant to imply discovery of the information by the ITR Team. ITR Team members, however, acting as independent reviewers, may have assessed the information from a perspective that differs significantly from that of WIPP personnel.

This report is based on information obtained and conditions observed during the review interval of July 26 to September 3, 1993. The ITR Review process and normal site work activities usually result in changes in knowledge and organization at the site during report preparation subsequent to the review interval. This document does not comment on evolution of the WIPP program subsequent to the review interval.

A Technical Oversight Board (TOB), composed of senior level individuals with extensive experience in the development, execution, management, and evaluation of large, technically complex projects, is chartered

to review all aspects of the ITR Team's activities. In its Charter, the TOB is directed to review the assessments and recommendations prepared by the ITR Team. The WIPP Charter and review plan were discussed with the TOB at a meeting on July 21, 1993 in Albuquerque, New Mexico. The results of the review were then discussed with the TOB on October 14, 1993 in Salt Lake City, Utah. Guidance of the TOB has been used in the preparation of this report.

ITR EXECUTIVE SUMMARY

iii.1. Review Synopsis

This Independent Technical Review assessed the need for and technical validity of the proposed Bin and Alcove test programs using TRU-waste at the WIPP site. The ITR Team recommends that the planned Bin and Alcove tests be abandoned, and that new activities be initiated in support of the WIPP regulatory compliance processes. Recommendations in this report offer an alternate path for expeditiously attaining disposal certification and permitting.

iii.2. Background

To support compliance demonstration, the WIPP program has proposed two types of underground tests with TRU waste: (1) Bin Tests, using instrumented containers called bins located in a large, easily accessible room; and (2) Alcove Tests, using 1050, 55-gallon drums placed in a sealed room.

Bin Tests use two types of bins: (1) Type I bins hold the contents of six 55 gallon drums of nearly dry waste at ambient pressure, and (2) Type II bins hold the contents of five drums of humid or brine saturated waste at up to 10 atmospheres pressure. Seven Type I and twelve Type II bins are planned to measure the amount of gas generated over one or more years.

Alcove tests use a more realistic emplacement of waste in drums and if design goals are achieved, could allow sampling and analysis of volatile organic compounds and other waste produced gases.

The stated justification for the Bin and Alcove tests has been the need to provide experimental data on gas generation by decomposition of TRU waste and its packaging. Gas generation studies have been proposed because it is postulated that gas generated by metal corrosion, organic biodegradation and radiolysis could create pressure sufficient to fracture the geologic formation allowing nonregulated gases to carry regulated contaminants, such as volatile organic compounds, to the unit boundary. In the event of human intrusion, it is further postulated that gas from the repository or pressurized brine pockets could move regulated contaminants to the accessible environment. These hypotheses have yet to be validated by rock mechanics or other performance

assessment techniques. The ITR Team reviewed the ability of the Bin and Alcove Tests to provide the required gas generation data.

Information was drawn from both published and draft WIPP documents and from interviews with WIPP personnel. In addition, ITR team members listened to representatives of oversight and stakeholder groups, including the National Academy of Science (NAS), the Environmental Evaluation Group, the Southwest Research and Information Center, Concerned Citizens for Nuclear Safety, the NM Office of the Attorney General, and Southeast NM stakeholders, to gain an understanding of their values and opinions of the Bin and Alcove tests.

iii.3. Principal Assessment

The review team concluded that: **there is no scientific, regulatory, or operational imperative to perform the Bin or Alcove tests at WIPP with radioactive waste.** Other tests can and should be performed at WIPP and elsewhere to confirm information used for regulatory compliance demonstration and certification. This is an assessment of the technical justification for the tests, not of the ability of site personnel to perform the tests or of the repository to accept TRU waste.

iii.4. Path Forward Recommendation

Preparation and submission of compliance and permitting packages at the earliest possible date are the foundation of the recommended path forward. All other near term work elements should support these activities. All regulatory permits, approvals, and certification should be acquired before any in situ confirmatory or operational tests are performed in WIPP with radioactive waste.

A lack of clear guidance from cognizant regulators on specific requirements for regulatory compliance should be the only source of future delay in operating WIPP as a TRU waste repository. While most, although not all, of the relevant regulations exist, no clear statement of what constitutes acceptable submissions has been produced by the regulatory bodies. Submission of the regulatory packages, with consequent responses from the regulators, is required to create unequivocal end points for field and laboratory investigations, computer modeling, and performance assessments. DOE/EM and Environmental Protection Agency (EPA) upper management should set the foundation for implementing the proposed path forward. The ITR Team believes that delay will be minimized by making the regulators part of the process through early submission of the regulatory packages.

Although all regulations do not exist and existing regulations may change, the ITR Team believes that sufficient gas generation information is available to complete the performance assessments and other elements required to prepare and submit compliance and permitting packages within 18 months. The recommended conceptual compliance and permitting process will allow the TRU waste disposal phase to begin in three years if specified milestones are met.

Laboratory and field tests currently in progress should be continued if they can confirm assumptions in performance assessment models and calculations used to support regulatory submittals. Ongoing and new tests may be required to reduce unacceptable uncertainties identified by the regulators in review of the submittals. The choice of tests to be continued or initiated will require informed judgment, based on the state and requirements of the regulatory process.

Bench-scale laboratory tests using simulated and/or actual waste should be continued or completed, and additional tests initiated if required. Results of bench-scale tests will not only explain individual gas generation mechanisms but also the synergistic effects of combined mechanisms. Such tests are necessary to confirm (1) that radiolysis has negligible synergistic effects on other processes, and (2) to support the validity of tests that use nonradioactive simulated waste.

Large-scale laboratory tests (multi-drum volume) using nonradioactive, simulated waste should be initiated as required. Large-scale tests should investigate gas generation processes in heterogeneous waste under simulated repository conditions. These tests can be performed above ground, at WIPP or elsewhere, unencumbered by mine safety regulations.

Phased preparation for disposal operation must occur at WIPP while the regulatory permitting and certification process is underway. Current engineering and operations testing should continue to rapid completion. Within a year the site should begin a cold commissioning phase (non-radioactive operations) to test and perfect waste operations, without the encumbrance of radioactivity. When regulatory certification is obtained and permits issued, hot commissioning can begin by introducing increasing amounts of TRU waste into the operations. Phased commissioning, comparable to startup of operations in industrial plants, will ensure an effective operating team and safe transition to disposal operation.

The WIPP mission should be allocated among the principal organizations (DOE, SNL, and Westinghouse), leading to a program that functions along clear lines of communication, authority and responsibility. The principal DOE WIPP office should maintain project vision. Site operations should be supported by a DOE site office that is a functional branch of the

principal WIPP office. Regulatory compliance organizations in SNL and Westinghouse, including performance assessment, should be collocated.

I. SUMMARY ASSESSMENTS

1.1. Introduction

The objective of this independent technical assessment of proposed TRU waste experiments at WIPP, as stated in the Charter (Appendix F), is to:

> "Review the need for, and technical validity of, the Bin and Alcove test programs, as defined in the Test Phase Plan, the Technical Needs Assessment Document, and individual test plans."

Chapter I summarizes assessments of the task areas defined in the Charter:

- Regulatory Interpretation and Compliance,
- Technical Performance Assessment,
- Test Implementation and Approach,
- Test Integration,
- Associated Test Issues, and
- Recommendations.

These assessments are an objective view of the test programs, not a critique of individuals, organizations, or past decisions. They support change to an alternate WIPP certification and permitting strategy such as that presented in Chapter II. Detailed discussion of the assessment basis is presented in Chapter III, and in topic-specific Appendices A through D.

The ITR Team observed three principal unresolved technical questions during their review of the tests:

- The rate and quantity of non-regulated gases generated by metal corrosion and biodegradation of organics in heterogeneous waste at repository conditions remains uncertain.

- Gas interaction with repository geological constituents remains uncertain. Gases generated in sufficient rate and quantity may reach hydrostatic (pore-brine) or lithostatic pressure. As a consequence gas may: drive brine out of the repository possibly limiting further gas generation; fracture the geologic formation allowing gas flow; and transport regulated contaminants toward the unit boundary at

repository depth exposing them to possible biological and/or hydrolytic degradation.

- Mechanisms which might move regulated materials to the accessible environment remain speculative. Trapped gas from waste or brine pockets, tapped by future well drilling for example, may move regulated contaminants to the accessible environment.

1.2. General Assessment

There is no scientific, regulatory, or operational imperative to perform the Bin or Alcove tests at WIPP with radioactive waste. The proposed in situ Bin and Alcove tests cannot adequately quantify or characterize the gas generation phenomena, nor do they duplicate repository conditions.

1.3. Regulatory Approach Assessment

The WIPP program does not have an adequate regulatory compliance program. Regulatory requirements have changed over time, and the WIPP program has not responded to many of these changes in a timely manner. Effective response by WIPP project personnel to regulatory criteria is hampered by inconsistent requirements, and their nonstandard interpretation throughout the program. Although a regulatory strategy document has recently been drafted, documents to support its implementation have not yet been prepared.

DOE has not demonstrated that the proposed Bin and Alcove tests are needed to support compliance determination. Information derived from the Bin and Alcove tests is considered to be confirmatory. Bin and Alcove test data and modeling results, however, may be difficult to correlate. The information presently planned for compliance determination will come from first principles modeling and from bench scale lab tests. Without a direct tie to the compliance determination, the rationale for the Bin and Alcove tests is weak.

RCRA, mine safety, and other regulations governing the generation of new waste, the manipulation of existing waste, and the presence of explosive gases make it in essence impossible to perform sound laboratory tests underground at WIPP. Occupational safety requirements limit the conditions under which waste materials can be examined at WIPP. Appropriate facilities and/or equipment do not exist at WIPP to inspect, analyze or characterize waste before and after testing. Current safety and design considerations do not allow fluids in the bins and drums to be sampled. Design constraints on Type 1 bins limit the maximum flammable gas concentration to 50% of the lower flammability limit. Therefore, bins will be purged with inert gas as this limit is approached. The proposed Type 2 bin design does allow potentially flammable

gas mixtures; the test is not designed, however, to reach lithostatic pressure. This limitation may prevent the system from reaching a natural equilibrium mixture of gases under conditions relevant to those anticipated during the repository disposal phase and thereafter. If waste cannot be subjected to realistic conditions and inspected before and after testing, germane information cannot be obtained.

Program staff do not have a common understanding of compliance requirements. Communication between regulatory compliance and performance assessment personnel is extremely limited. Although a recent effort has been made by program management to define regulatory roles and responsibilities, the number of experienced staff may be insufficient to fill the defined roles. Efficient preparation of a compliance package is further hampered by the physical separation of performance assessment and compliance personnel.

1.4. Assessment of Performance Assessment

Performance Assessment (PA) is not closely coupled to other aspects of the WIPP program. PA output, such as a definitive list of data needs and associated Data Quality Objectives (DQOs) for laboratory and in-situ tests, is not used to provide detailed guidance to the WIPP test program. The most recent detailed sub models and all available experimental data are not yet incorporated into the currently used high-level PA model.

Many of the PA sub-models are first-principles process models calibrated using homogeneous bench scale experimental data. Additional testing may be necessary to confirm that the existing sub-models and data adequately predict gas effects.

Although imperfect, the existing PA total system model is adequate for the preparation of the mid-1995 regulatory compliance packages. Current PA models and the existing WIPP project database can be used to perform PA analyses required to demonstrate regulatory compliance. Deficiencies noted by the regulators during review of the compliance packages can be addressed by future models and experimental data. Periodic PA progress reports discussing calculations based on improved models and confirmatory data from laboratory and field studies will build confidence in modeling and reduce uncertainties in performance measures.

1.5. Bin Test Assessment

Planned Bin tests will provide marginal confirmation of gas generation models because they will not address interaction mechanisms. The Bin tests are not designed to complement laboratory test programs, and are not tied to compliance demonstration.

Radiolysis will be a minor contributor to gas generation in WIPP waste. The presence of radioactive contaminants in the bins will have little measurable effect on the gas generation processes, and will make test activities more complex. Regulations and handling techniques which govern the performance of experiments, particularly those related to underground testing, will make it difficult, if not impossible, to assess gas generation processes and synergistic or inhibiting interactions among gas generation mechanisms. The presence of TRU-waste materials in the Bin Test waste is an inadequate justification for performing these tests.

Waste for the proposed Bin tests is being characterized at INEL. The rate of characterization is very low, about seven bins in two years, but INEL is commended on the video and conventional documentation of the process. Nevertheless, the level of chemical and physical characterization is insufficient to support the data quality objectives necessary for the tests to confirm PA model predictions.

The design of the tests and the hardware is inadequate to provide data relevant to waste disposal and post-closure conditions. The test environment provided for the Bin tests at WIPP does not adequately simulate repository conditions. Regulatory requirements (Section I.3) limit interaction between the bin contents and the surrounding repository environment. The underground test site has no scientific or technical basis, and it limits test conditions.

The Type 2 bin design is conceptual, and incomplete. Conceptual bin seals, for example, may be inadequate to prevent the infiltration of oxygen into the bins, preventing the attainment of anoxic conditions. In addition, outgassing of oxygen from the waste material during the relatively short duration of these tests may also prevent simulation of oxygen free post-closure conditions.

Although many instruments are located on the bins, several are omitted. Corrosion rate monitoring instruments and methods to determine the presence or growth of biological organisms are not included. This is unacceptable because corrosion and biological processes are thought to be primary mechanisms for gas generation.

1.6. Alcove Test Assessment

The planned Alcove test will not provide defensible or cost effective data to demonstrate compliance with 40 CFR 268 or 40 CFR 264 Subpart X. It will provide no knowledge of the volatile organic compound (VOC) source term. Measurement of gas production will be inaccurate because of unmeasurable gas loss into the Disturbed Rock Zone. Gas loss around seals is difficult to estimate and also unmeasurable. Results will not be readily extrapolated to disposal room conditions for use in predicting repository response to stored waste.

II. PATH FORWARD STRATEGY

II.1. Basis for Recommendations

The WIPP Mission, as defined in Public Law 96-164 and repeated in the WIPP Land Withdrawal Act, is "to provide a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission." Extensive interim storage of high-liability TRU waste throughout the defense complex provides the motivation for completing the WIPP compliance process.

The recommendations outlined in Chapter II are based on the ITR Team's consensus that a focused path forward strategy can bring the WIPP Mission to the disposal stage within three years without implementing the proposed Bin and Alcove Tests. Alternative large-scale laboratory tests using nonradioactive simulated waste, and bench-scale tests using radioactive materials are proposed. By providing technical information for the permitting process without introducing radioactive waste into WIPP, the new path forward can avoid the time delay, cost and complexity associated with EPA's review and approval of the proposed radioactive Test Phase Plan required by the LWA for in situ radioactive tests.

Based on observations and assessments of the state of the WIPP Program, and using existing WIPP work elements, the ITR Team developed a framework for a new path forward through certification and permitting to disposal. The success of this path forward depends on completing attainable milestones to meet the regulatory requirements of the EPA and the LWA. To this end, assuming a flat future funding profile, all project participants must commit to completing their tasks within budget and schedule constraints.

In support of WPIO efforts to develop a new organization, the proposed path forward allocates certain tasks among the principal organizations (DOE, SNL, and Westinghouse WID) and provides a work flow for following this structure.

Many WIPP oversight and stakeholder groups understand the technical documentation of WIPP plans and recognize the tenuous tie between the Bin and Alcove tests and the regulatory process. The break from the old path

can form a new basis for more open and cooperative interactions that are consistent with present DOE policies and attitudes.

II.1.1. Motivation

WIPP is a part of a coherent solution to the TRU-waste-disposal problem that was created by the past national mandate for a nuclear arsenal. TRU wastes now residing at generator storage sites collectively represent a large national problem that transcends the local environmental problem envisioned by individual sites. Because all nuclear weapons manufacturing within the defense complex has ceased, significant production-related TRU waste probably will not be generated. Decontamination and decommissioning (D&D) of existing weapons facilities, however, will continue to generate waste. Although the volume of existing waste can be estimated from observations and historical records, the amount of future waste is difficult to predict with confidence. At Rocky Flats, for example, the amount of waste generated by decontaminating a room to a level sufficient to store waste drums has been estimated to exceed the volume of the room cleaned. Many environmental restoration activities cannot proceed without a certified permanent disposal site such as WIPP.

At present, waste from past defense work and cleanup activities is stored retrievably in interim facilities, but the potential for degradation of the waste containers increases over time. Interim remediation of degraded containers increases the costs associated with their storage without providing added value.

Personnel at generator sites cannot successfully carry out D&D activities without a destination for the waste products. Inability to successfully complete these work elements reduces productivity, increases personnel frustration, and causes qualified, motivated people to seek more stimulating jobs. Failure to start TRU disposal activities while funds and personnel are available will leave many facilities in unstable, deteriorating condition.

WIPP is an excellent location for permanent, safe disposal of TRU waste because it has excellent geological characteristics and strong Carlsbad community support. The Carlsbad community believes that their opinions on safety, the local economy, and other societal issues should be weighed heavily because of their proximity to WIPP. They agree that technical personnel should select, design and perform tests necessary to determine repository suitability. Local support is, however, contingent on demonstrable progress toward regulatory compliance.

II.2. Path Forward Strategy

II.2.1. Introduction

The path forward concept shown in Fig. II.1 consists of three elemental time phases: Permit/Certification, Disposal, and Decommissioning. The WIPP Program is presently in the first phase. The end of the first phase and the beginning of the second are the subject of the path forward strategy. The third phase is not considered in this review.

The integrated path forward for the WIPP program is centered on compliance with regulations. Regulatory certification and permitting should precede any underground testing with TRU waste. Tests with radioactive waste are not required to satisfy the Code of Federal Regulations, Land Withdrawal Act, state regulations, or local regulations. The ITR team believes that not performing in-situ tests with TRU wastes will greatly simplify the path forward and make the regulatory approach technically more defensible. The alternative tests proposed can provide data of equivalent or better quality than the planned TRU-waste tests. After certification and permitting, the Disposal Operations section of the LWA applies, and real waste can gradually be introduced into the repository in a Hot Commissioning phase.

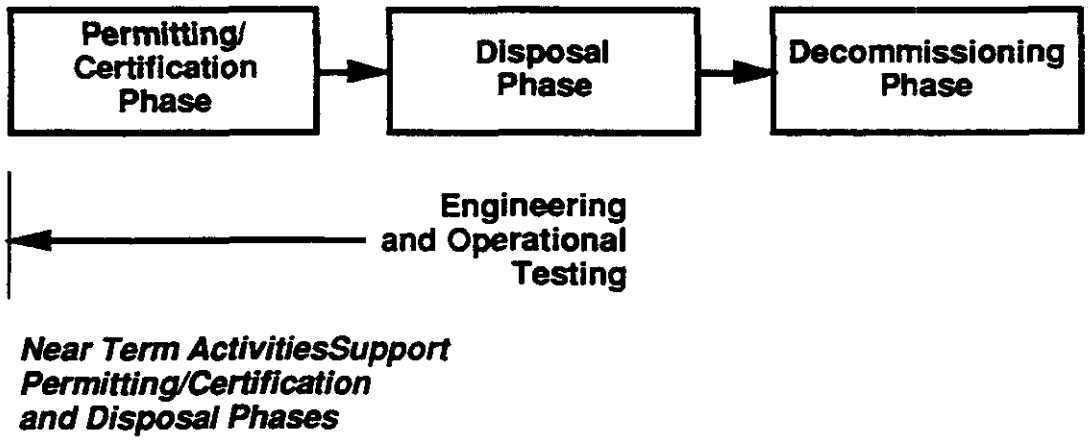

Fig. II.1. WIPP Program Phases

DOE-EM senior management should set the foundation for attaining this compliance goal by establishing a framework for interaction among WIPP regulatory personnel, the EPA and NMED. The programmatic vision and mission must be consistent with the mission stated in the Public Law. Decision makers should commit to the major elements of the path forward. They should commit their organizations to the success of the project and ensure that the lower-level managers are of the highest caliber and share the commitment to the success of the program.

The DOE should also commit to coordinated, active, and open interaction with stakeholder groups by assigning specific, senior-management responsibility for this role. Interactions with stakeholder groups should center on understanding their values related to jobs, economic development, storage of waste in their communities, transportation of waste, societal values attached to land, and other basic issues. Decision makers should consider these values when guiding the program, and should be prepared to explain how the values are incorporated.

The more detailed near-term path forward, shown in Fig. II.2, focuses on the end of the Permit/Certification Phase and the beginning of the Disposal Phase. It depicts broad components, and is not intended to capture the full complexity of testing, compliance, or operational activities. On this path, disposal can be initiated sooner than the current plans propose.

In Fig. II.2, time is shown in elapsed years. The work elements shown on the figure are logically dependent on each other but are not tied to a specific start date. Within this presentation time will be described in elapsed months or years. Where actual dates add clarity to the discussion, they will be place in parentheses next to the elapsed time, based on an assumed start date of October 1, 1993.

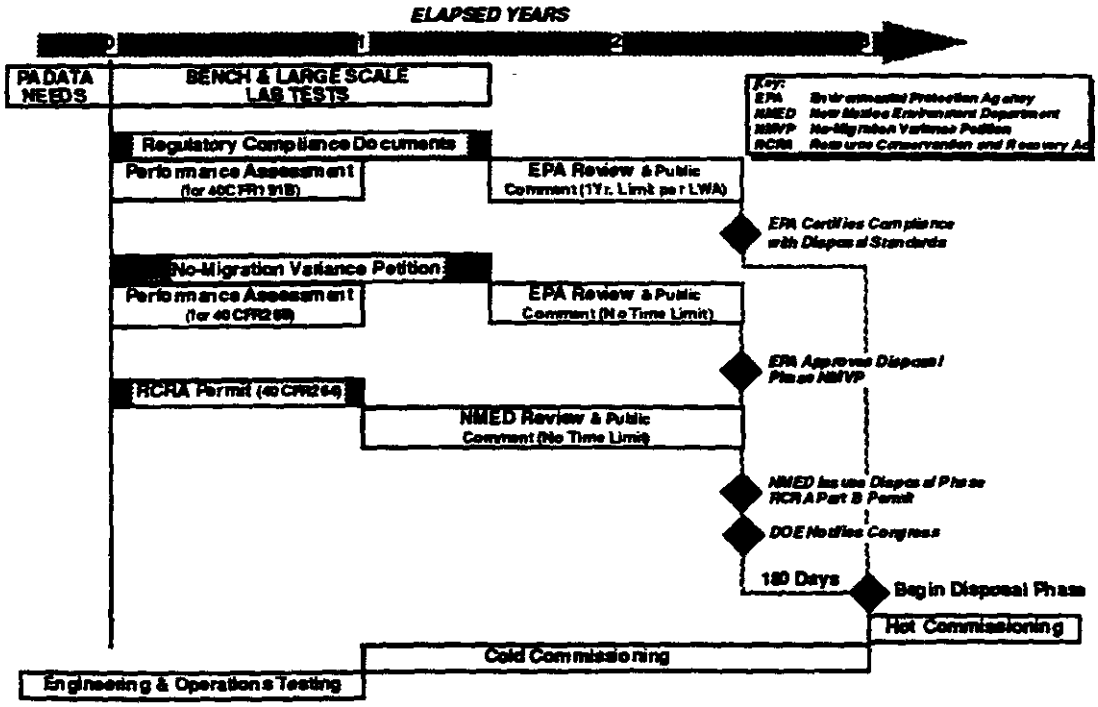

Fig. II.2. WIPP Near-Term Path Forward

The time line focuses on three major activities: (1) lab tests in support of the regulatory process, (2) compliance and permitting paths, and (3) operational and commissioning phases. Hot commissioning should commence immediately after certification and permitting. Diamonds represent major programmatic milestones.

Achievement of the disposal phase milestone within three years requires management of the review and comment processes by cognizant regulators. EPA review and public comment on 40 CFR 191 compliance documents is limited by the Land Withdrawal Act to one year, which is included in the schedule. EPA review and public comment on the no-migration variance petition is not bounded but a year has been allowed in Fig, II-2. NMED review and public comment on the RCRA permit is allowed 18 months. The actual time for these review and comment processes is beyond project control, but can be influenced by improved interactions among personnel from the project, regulatory agencies and stakeholder groups. Success in achieving this milestone is controlled by EPA and NMED.

WIPP personnel should develop the detailed schedule of the proposed near-term path forward. The schedule should consist of discrete work activities with finite scope, fixed cost, bounded schedule, and fixed milestones. The ITR Team recommends that scheduled activities have first funding priority, and that other activities should be funded at a lower priority or be demobilized.

II.2.2. Regulatory Component

Where full knowledge does not exist, speculation about potential regulatory responses to WIPP compliance packages appears to drive WIPP decisions. The ITR proposed regulatory path forward assumes first pass success in all areas even though the team recognizes that incomplete knowledge might require subsequent, additional information to be provided. The philosophy of first pass success was adopted to drive clarification by the regulators of uncertain areas, thereby assuring rapid, ultimate success.

The ITR Team recommends that complete regulatory compliance packages (permits, petitions, certifications, etc.) be prepared to demonstrate compliance with 40 CFR 264, 40 CFR 268 and 40 CFR 191 using existing data, PA methods and models. These compliance packages should be completed and submitted to the regulators within 18 months (mid-1995) as shown in Fig. II.2, and should address all requirements of each cognizant regulatory agency, especially on waste analysis and migration of contaminants. The following specific recommendations support the preparation of these packages on the timelines of Fig. II.2.

- To improve communication and coordinate work required to meet the schedule, the ITR Team recommends collocating all personnel responsible for regulatory compliance documents and performance assessment analyses.

- A strategy for submitting compliance packages to all appropriate regulatory agencies within 18 months (mid-1995) should be immediately developed. Packages should use existing waste and site characterizations and experimental data to substantiate the best possible bounding case analysis, using PA methods and models. The compliance packages submitted within 18 months should include the maximum inventory that can be supported by PA analysis. The package should address uncertainties and should include strategies to ensure that all TRU waste allowed by LWA (section 7 and 16), including mixed waste, will be certifiable for disposal.

- The proposed accelerated schedule assumes that the final EPA certification criteria (40 CFR 194) are not significantly different from the current draft. Currently available data specifically related to gas-generation issues are sufficient to support a defensible PA, and the PA analyses should be completed using existing data bases. Tests that are now underway and any future tests should be used to confirm PA input and assumptions.

- An open dialogue should be quickly established with waste generators to foster appropriate integration of their waste characterization knowledge and methodologies into the preparation of the WIPP regulatory compliance packages.

- Interactions should begin immediately between the DOE and the EPA, at senior management and working levels, to accurately define regulatory compliance package requirements. These interactions should strive to stabilize the regulatory arena and resolve ostensible regulatory incompatibilities, such as the definitions of the accessible environment and site boundaries.

- Negotiations for developing RCRA Part B permit applications should begin immediately with the New Mexico Environment Department, specifically emphasizing waste analysis plans and waste characterization.

- Absence of a well-defined and articulated regulatory strategy for WIPP has allowed some oversight and special interest groups to divert effort toward issues that may not be primary to the overall WIPP Mission. The ITR Team recommends a management function to solicit input from public groups, to incorporate their input into Project decision-

making, and to communicate the decisions and their rationale to these groups. This will help not only to define a long-term strategy but also to follow the strategy to its conclusion.

In the event that the first pass is not fully successful, then specific guidance for full acceptability should be provided by the regulators. Subsequent testing, modeling, and regulatory submissions should be in conformity with this guidance.

II.2.3. Performance Assessment

PA analysis required for regulatory compliance should be completed within 15 months (mid-1995) using the best set of conceptual models, computer codes, parameter ranges, and actual data available in early CY 1994. Detailed process models should be integrated into the PA total system model expeditiously so that the analysis reflects the current state of program knowledge. No new experimental activities should begin until the need for the data is defined by PA analysis performed in response to regulatory feedback to the WIPP regulatory submittals, as discussed in Section II.2.2. Regarding gas generation, recent laboratory tests have confirmed that gas-generation rates and quantities that will be used as input to the PA analyses for the regulatory compliance packages are reasonable estimates. New data are not needed for a defensible performance assessment. New data, however, may be needed if regulations under 40 CFR 194 contain unanticipated requirements, or to reduce uncertainties in PA calculations or gas generation models as part of the regulatory compliance packages to be submitted in mid-1995.

Figure II.3 illustrates the relationship between compliance demonstration and data development (Lab/Field Activities etc.). In Fig. II.3 data flows from technical activities to compliance, and data need flows in the opposite direction i.e., PA defines the need for data. Compliance demonstration is a requirement before waste can be disposed at WIPP. To meet this requirement, performance assessment calculations must be performed demonstrating compliance with appropriate regulations. Sensitivity and uncertainty analyses are performed, with models and results from PA analyses, to define additional data needed to resolve issues preventing compliance demonstration. Similar sensitivity and uncertainty analyses can also be used to develop performance-based Waste Acceptance Criteria. The WIPP organizational work flow should reflect this process.

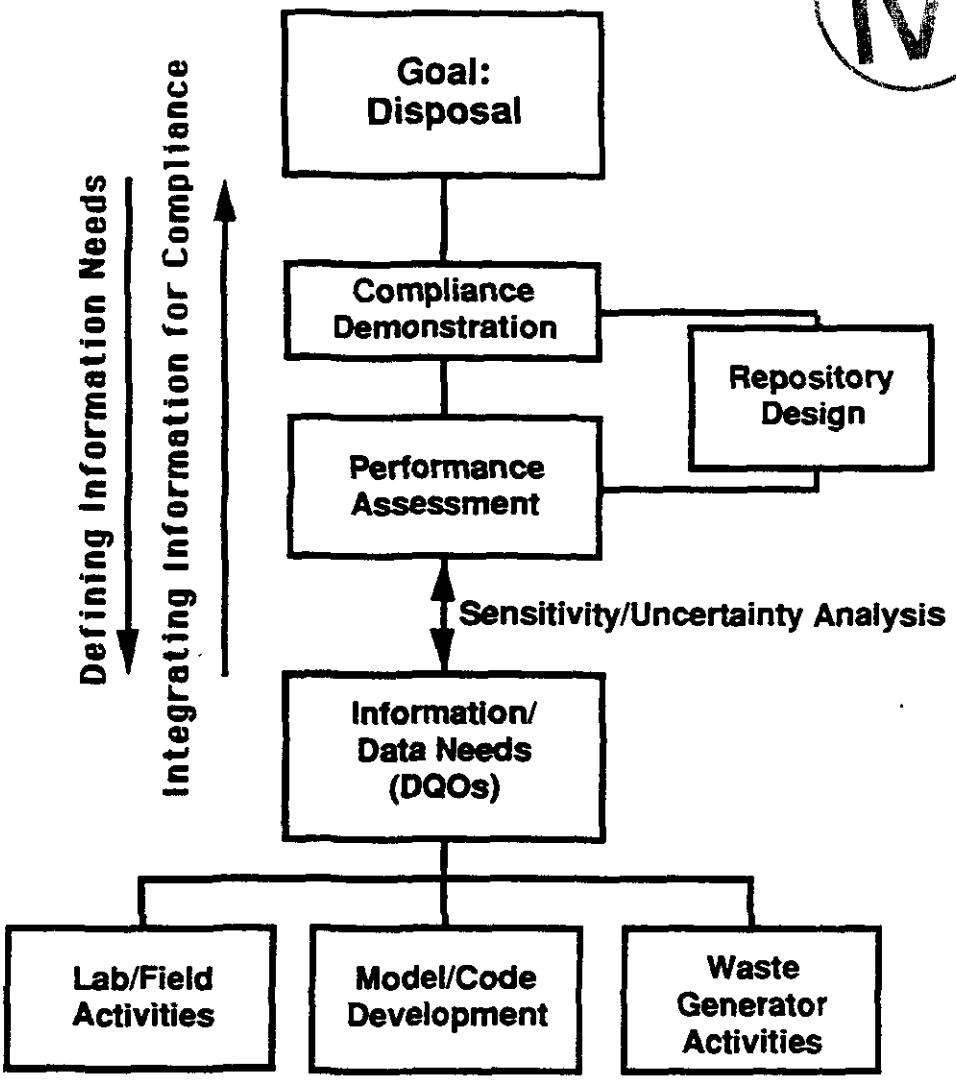

Fig. II.3. Relationship between Regulatory Compliance and Data Collection

The current PA model makes it impossible to perform parameter sensitivity studies rapidly and conveniently, because it does not handle coupled processes and parameters well. The ITR Team recommends that the high level PA model be developed further for performing bounding calculations and sensitivity/uncertainty analyses to focus data collection and to guide the regulatory strategy. This high-level model should be capable of evaluating coupled processes.

II.2.4. Gas Generation Tests

Gas generation phenomena can be evaluated with bench-scale and large-scale laboratory tests.

II.2.4.1. Bench-Scale Laboratory Tests.

PNL and BNL are carrying out bench-scale waste tests (corrosion and microbial, respectively) that fulfill the PA need for a gas generation model. These tests should continue, with completion scheduled in 15 months (end of CY 1994). New tests should be undertaken only if PA sensitivity and uncertainty analyses identify the need.

The ITR Team recognizes that the PA must use current gas generation data, that does not incorporate the results of ongoing tests, to complete compliance and permitting documents in 18 months. Ongoing tests should, however, confirm present estimates of gas generation, add confidence and reduce uncertainties in the gas model, and explain gas generating mechanisms.

Incomplete understanding of the potential interactions among waste, brine, gas, and the surrounding rock yields a conservative response to regulatory compliance. Hold-up of volatile organic compounds through dissolution in brine, adsorption by geologic materials, and biodegradation may help compliance with 40 CFR 268.6. These processes are not considered in a prediction which estimates whether sufficient carrier gas is produced to form pathways to the repository boundary. Consideration should be given to a focused laboratory study of VOC transport, although it is not recommended that it be placed on the critical path for submission of compliance documents.

II.2.4.2. Large-Scale Laboratory Tests.

The proposed Bin Test Program should be abandoned. The ITR team recommends alternative tests be used to meet unfilled data needs. Large-scale laboratory tests using nonradioactive simulated wastes are an alternative. Like the Bin Tests, these alternative tests should contain several drum-equivalents of waste. The volume is not critical but should be large enough to allow testing of representative waste forms and types. The proposed tests can be performed above ground at WIPP or any location where suitable facilities exist. Large scale tests should increase understanding of the effects of scale by examining:

- The effects of waste volume and heterogeneity to support the extrapolation of bench-scale test results to repository volume.
- The effects of synergisms or probable antagonisms, such as metal passivation by microbial gas generation.

Tests and equipment should have the following attributes to meet the data needs:

- Test vessels should be capable of operating at lithostatic pressure to better represent long-term, in-situ repository conditions.

- Test vessels should be fabricated from materials such as those found by PNL to be appropriate for bench-scale tests. The vessels should be hermetically sealed to minimize oxygen infiltration during the long duration of the proposed tests. Provision for in-test gas and liquid sampling should be provided if appropriate.

- Either off-the-shelf or custom built vessels may be used. Scheduling constraints will be a major consideration in this choice.

- Wastes should be characterized before and after the tests to a level similar to that for bench scale tests.

- Instrumentation options should be thoroughly explored and should include in-situ corrosion sensors and pH sensors.

Results from these tests are expected to confirm the conservative nature of previous assumptions about gas generation and are not needed for preparation of the 1995 compliance documents. The tests should be initiated as quickly as possible, however, so that at least one year of data can be collected before the EPA responds to a permit, variance, and/or certification application.

II.2.4.3. VOC Emission from Waste.

The proposed Alcove Test Program should also be abandoned. Data on VOC emissions from waste drums is available from tests that are already being performed at INEL. Test methods may be adapted to increase the value of the data. For example, continuous collection of gases from the drum filters may be feasible. The ITR Team recommends that WIPP participate in analyzing the data, which should form the basis for predicting VOC concentrations and operational releases from the repository. Data collected from waste-storage buildings at generator sites should fulfill WIPP data needs at least as effectively as an Alcove Test.

II.3. Repository Engineering

The ITR team recommends that operational experience be formalized as part of a specifically planned commissioning phase. This phase will serve to focus the transition of WIPP from a scientific project to an operating facility.

The recommended approach is standard practice in engineering project management. It provides for a period of operational testing of system components, cold (nonradioactive) commissioning of the total disposal system and hot (radioactive) commissioning before full scale disposal. No TRU waste should be introduced into the repository until all disposal phase approvals have been obtained. The ITR Team believes that such an approach will satisfy

regulators regarding operational safety and will provide a demonstration to stakeholder groups that WIPP has been soundly engineered.

II.3.1. Design and Engineering

Most design and engineering tasks have been completed. These include most of the facility infrastructure, TRUPACT II, and waste-container-handling systems. Some components of these systems remain undeveloped, however, partly because the emphasis has been on bin handling rather than on drum handling as a result of the Bin Test program. The ITR Team recommends developing and testing the remaining components before the completion of compliance documents.

Engineering operations testing, which covers component and engineering subsystem testing, virtually has been completed. New or re-engineered components should be tested within their subsystem within one year.

II.3.2. Cold Commissioning

The purpose of cold commissioning is to test the total disposal system under realistic loads. Handling drums and Standard Waste Boxes at typical disposal phase rates will confirm the design and operation of safety systems. The system should be run at operational capacity for several weeks, transferring weighted drums underground, emplacing, and backfilling them. Retrieval of drums may also be tested. No operational or safety reason could be found for using radioactive waste during this phase. Cold commissioning should be completed at the time of certification and permitting to allow immediate start of the hot commissioning phase.

II.3.3. Hot Commissioning

Hot commissioning will involve handling, storing, and backfilling TRU waste at rates gradually approaching those anticipated during disposal. Hot commissioning will begin after compliance approvals. All health physics and other radiation safety systems will be tested within the proven waste-handling system. The concept of a sealed and thoroughly monitored disposal room similar to that proposed for the Alcove Test may be valuable as the first activity. The sealed room could: be monitored to provide data for compliance verification reports; have a capability for dose monitoring; and have a high level of containment for the first waste emplaced. The room must be allowed to respond naturally to stresses and movements in the rock mass, however, and not be artificially supported beyond the need for worker safety during emplacement. Eventually the roof will collapse and the waste will be retrievable only at high cost. A well defined and managed hot commissioning phase can assure both the operator and oversight groups that unexpected problems can be readily identified and mitigated.

II.4. Allocation of Mission and Work Flow

To establish clear lines of authority and accountability, DOE should define the roles and responsibilities of all project participants. This will give DOE the opportunity to trim positions or activities that are not needed to support this focused schedule.

Each principal WIPP participant owns a portion of the WIPP mission. Figure II-4 illustrates a possible allocation of tasks based on observed and mandated activities, as follows:

- The DOE should: (a) provide policy and programmatic guidance to the Science Advisor and to the M&O Contractor, (b) interact with stakeholders, and (c) be the formal government signatory to regulatory compliance documents. The DOE should set and communicate clear stable directions to all organizations having an interest in the success of WIPP.

- The Science Advisor (SNL) would: (a) guide the DOE and the M&O on scientific aspects of the program, (b) develop the PA model and perform calculations for demonstration of regulatory compliance, (c) do research and development tasks to support certification and permitting, and (d) manage and report on the research done by its scientific subcontractors.

- The M&O contractor (Westinghouse WID) would: (a) manage and operate the WIPP facility, (b) develop and implement regulatory compliance documents and activities under the guidance of DOE, (c) be a formal signatory to the RCRA compliance documents, and (d) be responsible for design, engineering, and commissioning activities.

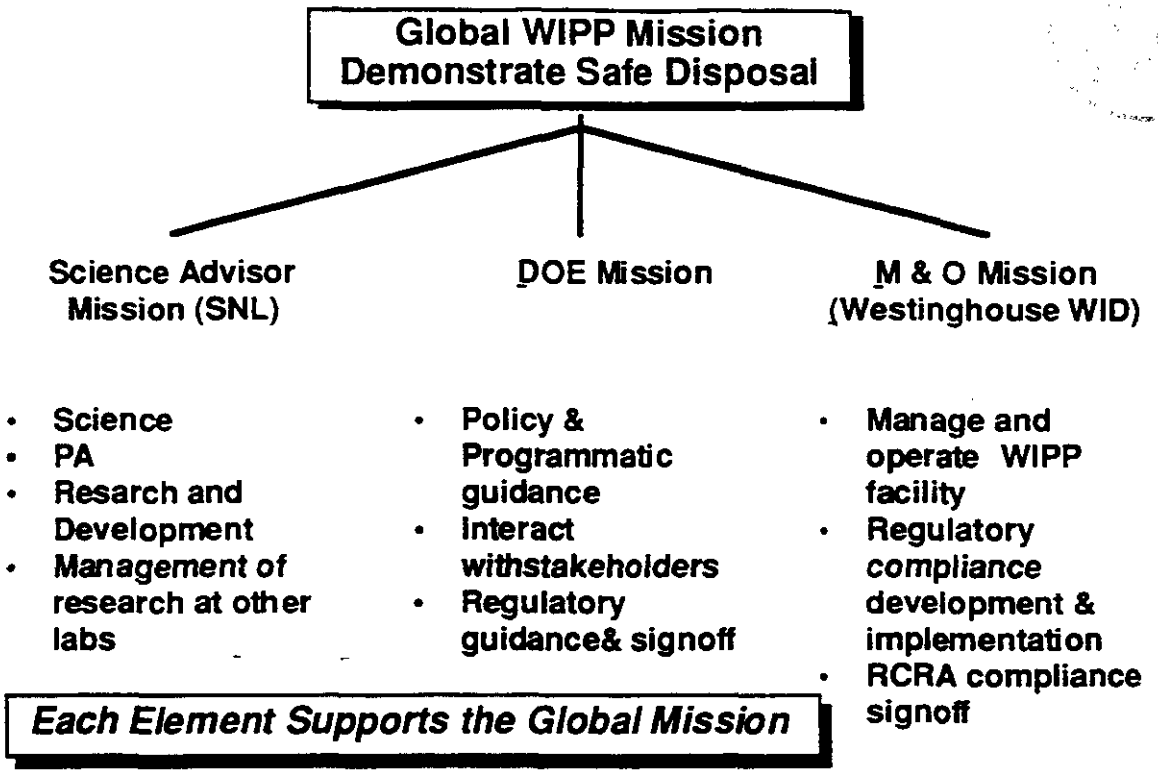

Fig. II.4. Allocation of Mission

Successful mission completion requires an integrated work flow among the participants, as illustrated in Fig. II-5. A functional organization should be developed to reflect this work flow. The recommended structure can provide better focus and improve communications. This structure must not, however, be interpreted as precluding direct interactions among the various organizations when such interactions would best serve the Project mission.

The present principal WIPP Office, WPIO in Albuquerque, owns the DOE portion of the mission. It should function as corporate headquarters, not as a funnel for communication among project participants.

Site operations should be supported by a DOE site office that is a functional branch of the principal WIPP Office. The authority and responsibilities of such an office should be consistent with its role of client's representative overseeing site operations and testing.

The DOE, Westinghouse, and SNL groups supporting compliance and PA-related activities should be collocated. Because demonstrating regulatory compliance is currently the work focus at WIPP, communication among the groups must be straightforward and effective. Good communication is difficult to achieve with the current geographic distribution of offices.

Management priorities at WIPP should begin to reflect the necessary shift in the general focus of work from research to WIPP site operations. This implies that the role of the Science Advisor would diminish or change and that the center of activity, and thus management responsibility, will begin shifting to the WIPP site. Management should also become more active in setting goals for completing discrete tasks within time and budget constraints. Contractor incentives should be considered such that successful completion of tasks or attainment of milestones is rewarded.

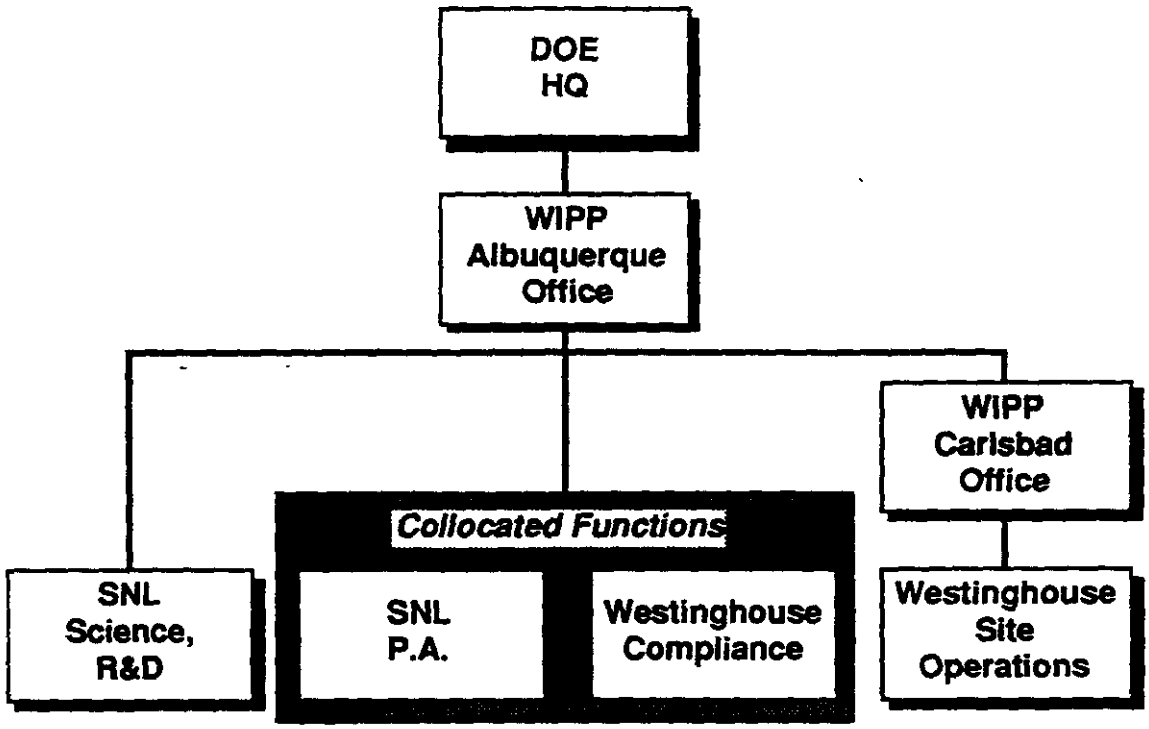

Fig. II.5. WIPP Work Flow

II.5. WIPP Project Management Plan

The present Project Management Plan for WIPP is in draft form. It should be completed consistent with the WIPP Mission, the Path Forward, the Allocation of Mission, and the Functional Work Flow. It will constitute an agreement or contract on work to be performed. It should be agreed to by EM-1 and other major participants, and shared at stages in its preparation with regulators and stakeholders. The draft PUREX/UO3 Deactivation Management Plan, prepared for the US Department Of Energy Office of Environmental Restoration and Waste Management by the Westinghouse Hanford Company in Richland, Washington (WHC-SP-1011, September 1993) is an example of such a plan, and the process used to involve stakeholders and regulators.

III. TECHNICAL EVALUATIONS

III.1. Introduction

The Waste Isolation Pilot Plant (WIPP) project is currently tasked with demonstrating compliance with three major regulations designed and promulgated to protect public health and safety for current and future generations. These regulations are:

- 40 CFR Part 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes,
- 40 CFR Part 264, Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, (Subpart X, Miscellaneous Units) and
- 40 CFR Part 268, Land Disposal Restrictions (Part 268.6, Petitions to allow land disposal of a waste prohibited under subpart C of part 268).

In order to demonstrate regulatory compliance, the WIPP project must show that it can safely manage and handle wastes during disposal operations, and demonstrate that releases of radioactive transuranic and hazardous waste constituents do not exceed release limits set by the regulations for the next 10,000 years. Although demonstration of operation and handling can be observed and certified, demonstrating long-term compliance will mean modeling the performance of the repository based on the current understanding of geologic and chemical processes, combined with a knowledge of the waste inventory for disposal. Such modeling must assess, with adequate confidence, whether or not the WIPP will comply, which will require predicting release mechanisms of radioactive and hazardous waste constituents, transport mechanisms of these constituents, and transport pathways to various regulated boundaries, either existing or induced.

Gas generation occurs via three mechanisms: corrosion of metal drums in which waste will be disposed, as well as waste metals by interacting with brine from the geologic environment; microbial degradation of waste; and radiolysis of organic matter contaminated with radioactive constituents. In addition to the bounding mechanisms, interactions (synergistic or antagonistic effects) amongst these three mechanisms are possible, but not currently well

known--hence, total gas generation and generation rates can be either enhanced or retarded.

The Bin and Alcove Tests proposed by the WIPP project are intended to provide confirmatory data to the gas generation model. In order to evaluate the need for, and the adequacy of the Bin and Alcove Tests, the ITR team was required to evaluate aspects of the entire WIPP project, including the approach to regulatory compliance, overall performance assessment methodology, the gas generation model, tests for gas generation mechanisms, and specifics of the Bin and Alcove tests themselves. Observations, assessments and recommendations on these aspects follow.

III.2. Regulatory Interpretation and Compliance

A brief summary of primary governing regulations is provided in Appendix A.1.

III.2.1. Regulatory Compliance Approach

Observations: The regulatory framework surrounding WIPP has been unstable since its authorization under the Nuclear Energy Authorization Act of 1980, as historically described more fully in Appendix A.2. The changes that contributed to the shifting environment included DOE acknowledging that its facilities were subject to the RCRA; issues related to compliance with the Land Disposal Restrictions in 40 CFR 268; initially unclear authority and responsibility to regulate mixed wastes; the promulgation of radioactive waste standards (40 CFR 191) by EPA without compliance criteria for managing and disposing of spent nuclear fuel, high-level and TRU wastes; and implementation of the Land Withdrawal Act (LWA) of 1992[1].

Because the regulatory requirements of 40 CFR 191 and 40 CFR 268 were developed under different statutory authorities, they have different objectives and thus actions required under one regulation may be inconsistent with actions required under the other. The regulations within 40 CFR 191, under authority of the Atomic Energy Act of 1954 and the Nuclear Waste Policy Act of 1982, provide applicable standards for protecting the general environment from radioactive material. The regulations found in 40 CFR 260-268 were promulgated under authority of RCRA and are intended to "protect human health and the environment" from the effects of hazardous wastes being discharged to the environment. The breadth of the regulatory differences is described more fully in Appendix A.3. Beyond the obvious difference between radioactive materials and mixed waste, the differences can be summarized to focus on the application of points about compliance and approaches to PA.

To date, little progress has been made in resolving potential conflicts between these regulations. Nevertheless, WIPP intends to develop a single compliance approach for securing a variance from 40 CFR 268 and a certification under 40 CFR 191. The WPIO states, "[T]hese regulations are fundamentally similar and have compliance provisions and requirements that are equivalent or substantively similar." [2]

On August 9, 1993, the DOE submitted a document defining the roles and responsibilities among the DOE, the M&O Contractor (WID) and the Scientific Advisor (SA). The policy assigns the M&O Contractor as the organization responsible for the overall regulatory compliance package. SNL, on the other hand, is assigned the responsibility for all PA modeling efforts. However, DOE has not clearly defined effective lines of responsibility among DOE-HQ, the WIPP Project Integration Office, the DOE Albuquerque Operations Office (DOE-ALO), and the WIPP Project Site Office (WPSO).

Communications among the EPA and the DOE's SA and DOE's M&O Contractor have been tightly controlled by DOE.

Assessments: The WIPP Project has not been guided by an adequate regulatory compliance strategy and program. Several factors contributing to the lack of an adequate compliance strategy include regulatory instability and regulatory conflicts between 40 CFR 191 and 40 CFR 268, which are somewhat beyond the Program's direct control. Yet, the lack of clearly defined roles and responsibilities among WIPP Project participants, as well as inadequate interaction with the EPA, have also contributed to the lack of a regulatory compliance strategy.

DOE has been ineffective in settling frequent differences between the M&O Contractor (Westinghouse/WID) and the SA (SNL) regarding regulatory compliance strategies. Out of this confusion, the M&O Contractor emerged as the lead for RCRA compliance (40 CFR 264/268), and SNL took the lead in 40 CFR 191 compliance issues. The two contractors appear to work independently despite the DOE's goal to have a common approach for demonstrating compliance with both regulations.

The lack of access to the regulator on the part of the SA and the M&O Contractor has further thwarted progress towards establishing an appropriate compliance strategy and program.

Recommendations: DOE should immediately strengthen its interactions with EPA and NMED to negotiate an appropriate regulatory approach and to resolve potential differences between the regulations. A framework providing more open dialogue with the regulating agencies and the WIPP Project should be established that does not compromise DOE's fiscal or policy responsibilities.

III.2.2. WIPP's Regulatory Strategy

Observations: DOE appears to have been guided by a policy objective of "getting waste underground." This undocumented policy objective appears to have undermined efforts to develop a comprehensive regulatory compliance strategy for the WIPP Disposal Phase. Efforts have been primarily focused on the WIPP Test Phase, specifically on the Bin and Alcove Tests, rather than later activities.

Significant regulatory accomplishments have been achieved in support of the WIPP Test Phase. A conditional No-Migration Determination was approved by EPA in November 1990, which allows untreated wastes to be received at WIPP, although only for the Test Phase. Further, the State of New Mexico Environment Department (NMED) issued a draft permit under RCRA on August 26, 1993, which would allow the receipt of TRU mixed wastes at WIPP although only for the Test Phase. However, the time-consuming process of permitting Type 1 bins, Type 2 bins and Alcoves has diverted both the regulator's and DOE's resources primarily to the Test Phase. As a result of this emphasis, little effort was spent on developing a comprehensive regulatory compliance strategy for the WIPP Disposal Phase.

DOE has recently recognized the need to develop a comprehensive compliance strategy for the Disposal Phase. In August 1993, DOE prepared a draft "WIPP Regulatory Compliance Strategy and Management Plan." This draft document defines an approach and strategy but does not provide sufficient detail to implement an effective regulatory compliance program. According to Section 4.3 of the draft document, DOE explains that "the 'technical approaches' to be used . . . [to] prepare the necessary permit and Certification Applications will be documented in detailed plans and procedures." These documents have not yet been prepared.

The draft WIPP Regulatory Compliance Strategy and Management Plan describes a "Compliance Demonstration and Recertification/Reapplication Process" that is driven by a performance-based waste inventory. This approach involves the development of waste acceptance criteria based upon results derived from the PA analyses needed for regulatory compliance.

Assessments: The regulatory strategy currently being pursued lacks integration and a firm scientific link between the proposed Bin and Alcove Tests and demonstration of regulatory compliance.

Recommendations: A complete regulatory compliance package should be prepared based on PA. Existing waste characterization and experimental data should be used to substantiate a bounding case analysis. The WIPP Project should perform the PA, based upon a best estimate of the total waste inventory. PA calculations should then be performed using subsets of that

inventory, if necessary, in demonstrating compliance with the radionuclide requirements of 40 CFR 191, and the mixed waste requirements of 40 CFR 268.

It is recognized that the compliance package will be submitted to different regulating agencies, but it should be submitted as an integrated, comprehensive package. The compliance package should include three major compliance documents, each consistent with the WAC:

- the 40 CFR 191 Compliance Document will be submitted to the EPA Office of Radiation and Indoor Air (EPA-ORIA);
- a No-Migration Variance Petition will be submitted to the EPA Office of Solid Waste (EPA-OSW) to satisfy the requirements of 40 CFR 268.6; and
- a RCRA Part B Permit application will be submitted to the State of New Mexico Environment Department (NMED) to fulfill 40 CFR 264 requirements.

Based upon the results of the PA, the WIPP waste acceptance criteria can be finalized. PA-based WAC will modify the existing WAC, which were developed in response to existing regulations applicable for waste transportation and handling. These pre-closure regulatory criteria should be evaluated in light of the PA results, because additional waste acceptability criteria may be needed to meet post-closure requirements.

DOE should immediately begin negotiations with each regulating agency to identify any issues requiring further clarification before final certification and permitting, such as interacting with NMED to determine what degree of waste characterization data will be required to receive TRU wastes at WIPP.

A regulatory review schedule should be negotiated. The WIPP LWA requires that EPA-ORIA make a determination on DOE's 40 CFR 191 Compliance package within one year from submission; however, there is no mandated time limit for the EPA-OSW and the NMED to review the No-Migration Variance Petition and the Part B Permit application, respectively. Such a negotiated review schedule would facilitate the timely completion of all relevant activities.

III.2.3. Regulatory Compliance and Technical Information Needs

Observations: The EPA and others have developed the concept of the DQO process within the regulatory framework. This process, although not unique to RCRA and CERCLA investigations, uses the regulatory requirements that the program must meet to derive data requirements and therefore testing requirements. By using this process, experimental programs are defined by the

nature, precision, accuracy, and imposed conditions derived from the regulatory compliance criteria and standards. Experimental programs that satisfy these requirements can be shown to be clearly necessary for compliance. Interviews with WIPP personnel at all levels confirmed that the DQO process has not been implemented.

Assessments: There is no apparent connection between SNL's in-progress and planned experimental programs with program compliance requirements, and their need or sufficiency for regulatory compliance cannot clearly be demonstrated. Experimental programs that provide data on sensitive parameters or processes identified by PA studies are not tied to quantification requirements established to meet PA/compliance needs.

Recommendations: The DQO process should be implemented in identifying and defining experimental programs. A combined compliance/PA analysis should be performed to identify compliance requirements needing specific and quantitative information. From this effort, experimental programs can be designed, if necessary, to generate the information and satisfy the requirements to the extent possible. Existing and planned experiments should be reviewed to determine if they are necessary and sufficient to meet the technical information needs. Experimental designs may need to be modified, some new experiments may need to be designed, and some currently active or planned experiments may be canceled if they do not meet compliance or operational requirements.

A more intensive effort to integrate regulatory compliance and PA analyses, including sensitivity and uncertainty analyses, should be initiated as soon as possible to make experimental programs conform to program needs with maximum cost-effectiveness.

III.2.4. Bin and Alcove Tests and the Definition of Directly Relevant

Observations: If the Bin and Alcove Tests are to be initiated, then the DOE must submit to the EPA a Test Phase Plan. This plan shall, per the LWA:

> ". . . provide a detailed description of how the test phase activities will provide information *directly relevant* to a certification of compliance with the final disposal regulations or to compliance with the Solid Waste Disposal Act (42 U.S.C. 6901 et seq.); and include justifications for all such activities. " (PL 102-579, Section 5 (b) (3) and (4), emphasis added).

The EPA, in turn, shall

> ". . . approve the test phase plan, or any modification to the plan, in whole or in part, if the Administrator determines that the experiments

will provide data that are *directly relevant* to a certification of compliance with the final disposal regulations or to compliance with the Solid Waste Disposal Act (42 U.S.C. 6901 et seq.)." (PL 102-579, Section 5 (d) (2) (A))

Neither the LWA nor EPA define the term "directly relevant". Although the DOE asserted that the test phase i.e., the Bin and Alcove Tests, will provide data that are directly relevant to the regulations, DOE and EPA evade defining "directly relevant". The DOE defines information that is "relevant" and information that is "necessary":

> "Information is relevant if it is pertinent to developing an understanding of or to predicting effects of parameters, processes, and events important to the assessment of and determination of compliance with the regulatory requirements. Parameters, processes, and events include the design basis performance of the facility and disposal system, waste characterization, waste interactions, and human intrusion or predictable future events."
>
> "Information is relevant if it improves the confidence in technical description (conceptual model) of a parameter, process or event and its representation in compliance assessments."
>
> "Information is necessary if it is specifically required by a regulation or statute, or if it is required by the regulator or the regulatory process to demonstrate, evaluate, or maintain compliance."

Assessments: Under the Land Withdrawal Act, one of the principal criteria for in-situ, radioactive tests is that they be "directly relevant" to compliance and supportive of demonstrating compliance with post-closure PA analyses. No justification exists for either the Bin or Alcove Tests demonstrating their utility or necessity based on proving compliance with any regulation or standard.

There is no obvious connection between the relevance of the proposed Bin and Alcove Tests, and demonstrating compliance with 40 CFR 191. This regulation specifies release limits for the radioactive constituents, none of which are gases. Conceivably, pressure created by gas generated from metal corrosion and from organic biodegradation could fracture the geologic formation, but there is inadequate evidence to support the movement of radionuclides along the fractures until they reach the "accessible environment" (40 CFR 191.12). Considerations about evaluating the potential for human intrusion scenarios are provided in Appendix A.3.

The proposed Bin or Alcove Tests are not "directly relevant", "relevant" or "necessary" to demonstrating compliance with 40 CFR 264, Subpart X and 40

CFR 268. The Bin Tests could provide marginal confirmation of gas-generation models, but the test design and hardware are inadequate. Similarly, the Alcove Test cannot provide defensible or cost-effective data because it will not provide a source term for VOCs, it will not determine gas loss into the rock or around the seals, and the results cannot be readily scaled.

Recommendations: The WIPP Project should abandon the Bin and Alcove Tests and turn its efforts to completing a regulatory compliance package. Without these tests, many of the time consuming requirements of the LWA would not apply, such as the testing approvals from the EPA and New Mexico, along with a test phase plan and a retrieval plan. Certain test phase activities and requirements in the LWA might be deferred until waste disposal operations began after compliance certification. In short, the time and money needed to test waste at WIPP would be better spent securing certifications and permits needed to permanently dispose of waste at WIPP.

III.2.5. Regulatory Barriers to Bin and Alcove Tests.

Observations: The LWA establishes requirements, procedures and schedules whereby actual TRU waste could be emplaced at WIPP. According to the LWA, the Test Phase begins upon the initial receipt of TRU waste at WIPP. Although nonradioactive waste tests have been on-going at WIPP, these tests are not considered to be part of the Test Phase as defined by the LWA.

Several other requirements appear to impose limitations on the tests that would severely restrict the utility of the resulting data, although the various program participants do not agree on the details of these restrictions. For example, EPA states in its NMD that "no waste container should be emplaced in the underground repository if it contains flammable mixtures of gases in any layer of confinement, or mixtures of gases that could become flammable when mixed with air." The EPA further defines any flammable mixture as potentially flammable if it "exceeds 50 percent of the lower explosive limit (LEL) of the mixture in air." Such constraints may require bin purging, and potentially alter test results. The WIPP Safety Analysis Report also limits the generation of potentially flammable gas mixtures within Type 1 Bins to 50 percent of the LEL for the entire duration of the tests. In addition to flammability restrictions, DOE safety requirements restrict the opening of bins after testing. Because there are no double containment capabilities per DOE Order 6430.1A currently at the facility, the bins cannot be opened after testing to examine the wastes and determine the corrosion and other reaction products and processes.

Assessments: As interpreted by the ITR Team, the Test Phase requirements outlined in the LWA will not apply if DOE does not proceed with radioactive testing at WIPP. Specifically, requirements associated with submitting a Test Phase Plan to EPA for approval should not be necessary if no radioactive testing is performed at WIPP before certification.

III.3. Technical Performance Assessment

PA analyses performed to date have been directed at satisfying regulatory requirements of 40 CFR 191. However, the PA analyses have not been directly linked to a clearly defined compliance strategy. This has resulted in the PA analyses being based on a series of assumptions and approaches that are not clearly linked with other elements of the WIPP program. A PA analysis using the most recent conceptual and mathematical models available and a well-documented and reviewed set of parameter ranges would determine the real weaknesses in the data base. The PA analysis is important in assessing the ramifications of gas pressure build-up, particularly for brine flow and room closure, with and without future human intrusion events.

III.3.1. PA Modeling

Observations: The RCRA regulations, 40 CFR 268, and the Radioactive Waste Disposal Standard, 40 CFR 191, call for somewhat different PA approaches. 40 CFR 191 clearly calls for a probabilistic approach to PA, using Complementary Cumulative Distribution Functions (CCDF) methods to show compliance. On the other hand, the RCRA post-closure regulation calls for a deterministic single-value calculation methodology in demonstrating compliance.

Assessments: Many significant uncertainties in conceptual models and parameters cannot be reduced in the deterministic evaluation specified in 40 CFR 268; therefore a probabilistic approach may be the only defensible way of showing compliance in the regulatory/legal environment.

Recommendations: The WIPP program should propose a consistent approach for all regulatory compliance analyses, using the same conceptual model basis and set of computer codes. A database consisting of all available data from all credible sources, including experimental and field data, data from literature surveys, and professional judgment input, must be formalized as a basis for all PA calculations. Specific parameter selection may vary depending on the performance measure selected, as determined by the requirements specific to each regulation.

The use of probabilistic risk assessment based on the intent of a given regulation could be proposed to supplement compliance demonstration.

III.3.2. Model and Parameter Consistency

Observations: Many parameter ranges have been selected primarily on expert judgment or broad literature surveys. It is uncertain how consistent the parameter ranges selected for PA calculations are with the geologic/hydrologic setting. In addition, little effort has been made to auto-

correlate the parameters to account for covariance, which would serve to reduce the uncertainties in the resulting performance measures.

Assessments: Models and selected parameter ranges are not internally consistent, or in many areas, consistent with experimental studies. The process models appear inadequately linked to the hydrogeologic setting, and design and operational conditions.

Parameter distributions are at least as important as parameter ranges, especially when Monte Carlo PA analyses are being performed. The simplest approach is a straight-line distribution between the extreme values of the range, and is necessary when little is known about the natural distribution of parameter values. Selection of a most-likely value, or an average or median value with a Gaussian or log-normal distribution about that value would greatly reduce the probability of extreme values of performance measures, if those values and distributions can be at all justified. Expert judgment can often be used to provide this information if site-specific data are not available.

Recommendations: A critical evaluation of critical parameter ranges and "best values" should be completed before performing the PA analyses used to support the regulatory compliance package. Parameter ranges should be evaluated for consistency with the geology and hydrology of the repository environment. Parameters critical to performance measures of regulatory concern should be identified with multivariate sensitivity and uncertainty analyses, using the models for the performance calculations.

III.3.3. Simple Model for Evaluating Coupled Processes

Observations: Currently the WIPP Program uses detailed process models which are linked serially to perform total system analyses, including sensitivity and uncertainty analyses and bounding calculations. This approach does not readily allow the assessment of interactions between various parameters and processes. Assessment of these coupled processes requires a complex set of interactions among component models and codes, and a careful review of parameter selection rules to assure consistency among interdependent variables.

Assessments: The lack of ability to effectively model interactions among physical processes can result in a misleading, overly-conservative PA analysis. For example, the system of waste-brine-gas-rock is an inter-related process, such that the amount of brine available controls the amount of gas produced as the waste decomposes, the gas pressure build-up controls the rate at which brine can enter the repository volume, and the opening of fractures in the repository wall increases the volume available for the gas to expand into, thus releasing the pressure (but possibly allowing more brine to enter). This coupled inter-relationship is currently modeled using simplistic step functions in a few cases, but complete interactions among the various mechanisms are not allowed.

More detailed coupling mechanisms could better assess the probable course of physical-chemical processes that are likely to operate in the repository and vicinity after closure. Similarly, several sets of parameters are covariant; that is, changes in one parameter require related changes in other related parameters, such as the relation between permeability and porosity in a rock mass under stress. Many other examples exist.

Treating physical processes as independent or as operating in a serial manner leads to weaknesses in the PA analysis that may be questioned by regulators and others. Some treatment of coupled processes and parameters will probably be needed to build confidence in modeling results, or to demonstrate that the TRU disposal system meets regulatory requirements.

Recommendations: System codes and models should be developed or modified to allow analyses of coupled phenomena, if PA analyses do not adequately demonstrate compliance with the various regulations and regulatory standards, using current models, assumptions and data. Such a system code would aid in total system bounding calculations; parameter and process sensitivity and uncertainty analyses; developing DQOs for the test programs; and identifying specific analyses needed using the detailed process models. These developments should be completed as soon as possible after the need is recognized in order to provide guidance for future experimental efforts.

Monte Carlo and other parameter selection techniques should be examined to assure that all correlated parameters are being dealt with properly.

III.3.4. Use of Detailed (First Principle) Models

Observations: The WIPP PA process depends on developing detailed process models and computer codes that are based on a 'first-principles' approach to the processes. Such models require that the chemistry and physics of the subject process be understood in detail, and that critical attributes of the physical system in which the process operates be described in great detail.

Data collected from the site and the laboratory, together with studies of similar processes at other locations, are often the only information available to describe and predict how a process will operate within the WIPP system. This is especially true in describing how physical or chemical processes interact with the heterogeneous geologic, geochemical and hydrogeologic environment.

Assessments: First-Principle models are being developed for all processes instead of using analytical models based on experimental and other empirical information. Because the WIPP repository environment is heterogeneous, many of the complex processes that are expected to operate cannot be described completely in terms of their underlying physical and chemical principles. Moreover, the WIPP program has not made a thorough

examination of models available from sources outside of SNL and other National Laboratories.

Recommendations: First-Principle models should be supplemented with empirical information and empirical models developed, as appropriate, to help bound the limits and effects of processes. Such an approach may not provide a detailed understanding of a process, but empirical models are more amenable to understanding the limits of the process. It is important to ensure that empirical models do not violate basic physical and chemical principles.

The WIPP PA organization should use more of the available data collected at WIPP and data from the technical and scientific literature to build process models that can approximate processes operating under real repository conditions.

Models available from sources outside the National Laboratories should also be investigated rather than relying on building new models from first principles for all processes. Existing models often have the advantage of being more cost-effective, are recognized by the scientific community at large, and have been verified and validated in several applications, thus adding to the credibility of the WIPP PA analyses. Models describing coupled processes and complex processes such as rock mechanics, have been developed, tested and applied to real problems, and are available from other government agencies, universities and specialized consulting firms.

III.3.5. Confidence in PA Verification/Validation

Observations: A systematic traceable path from data collection through model parameter selection to establish a 'pedigree' for all PA compliance calculations does not appear to exist at the present time. Peer review of parameter ranges and distributions, conceptual models, assumptions, and computer codes has not been systematically performed and documented. Peer review is often the only method for building confidence in PA analyses when many of the models and codes used for simulating complex processes may not be validated by observation because of the long time frames or complex nature of the processes.

Assessments: No formal program for building confidence in PA modeling has been developed, including verification, validation, and confirmation experiments. Confidence in the PA calculations required for compliance demonstration is as important as the content of those calculations. Important components of model confidence include documentation of models, codes, data, and model and code verification and validation.

Recommendations: The WIPP program should establish a formal program to build confidence in PA analyses. A set of procedures should be

implemented that requires complete documentation of all PA activities and establishes the mechanisms to be used for verification and validation of all codes that will be used for compliance calculations. The peer review process should also be formally established, particularly as part of, or in lieu of, model validation. The review should evaluate assumptions underlying conceptual models, parameter ranges and distributions, and calculational approaches. To the extent possible, the review should be performed by technical specialists outside of the organization to assure the review's independence.

III.4. Gas Generation and VOCs

Gas generation and VOC data are fundamental to WIPP's ability to assess the future performance of the site and to demonstrate compliance with regulatory standards (See Appendix C). Gases escaping from the repository unit boundary could carry contaminants exceeding regulatory release limits. The most likely path for gas migration away from the repository is the laterally extensive anhydrite layer above and below the repository horizon. A key component of assessing the gas-generation problem is being able to reliably predict the consequences of high gas pressures within the repository, including the potential for gas pressure to exceed the pore-brine pressure and drive the brine towards the regulatory boundaries.

The issues associated with gas generation and VOCs must be resolved to demonstrate regulatory compliance. Indeed, gas generation and VOCs are perceived important at each of the three operational lifetime stages of WIPP: ventilated, transitional, and long term. During the ventilated and transitional stages, the gas and VOC information required by 40 CFR 191 Subpts. A &B, 40 CFR 268.6, and 40 CFR 264 Subpt. X include the gaseous species that may be generated by the wastes, and rates of production under different combinations of repository-environmental conditions. During the long-term stage, 40 CFR 191 Subpt. B, and 40 CFR 268.6 require the above data and information on gas-generation potential and concentrations of hazardous species in brines. Evaluating the concentration of hazardous constituents in the brine is based primarily on estimating brine inflow rates into the repository space, the dissolution of waste forms in brine, leaching of the soluble hazardous constituents, and dissolution of at least some VOCs in the brine.

III.4.1. Gas-generation Model

Observations: In WIPP's terminology, gas-generation models are distinct from the models that deal with VOCs in waste drums, containers, or in the repository rooms and panels. The term gas-generation model designates models dealing with the major gases, such as carbon dioxide, hydrogen, nitrogen, various nitrogen oxides, methane, and hydrogen sulfide.

The latest version of the gas-generation model, developed at SNL for WIPP, treats gas generation, under oxidizing and anoxic conditions, by reactions of water and other gases with metals and by bacterial degradation of organic matter. A summary of the capabilities of the gas-generation model is as follows:

- The gas-generation model is a reaction model based on chemical thermodynamic equilibria in reacting systems and chemical kinetic (reaction rate) data for gas generation by metal corrosion and bacterial degradation of organic compounds.

- The model computes concentrations of reactive gases at an equilibrium with pure iron-containing phases. Depending on the reactive gases used in the model (such as water, carbon dioxide, hydrogen, and hydrogen sulfide), it computes thermodynamic stability fields, at certain temperatures and pressures, of iron oxide, carbonate, or sulfide phases as functions of the partial pressures (or fugacities) of the reactive gases.

- The model computes the masses of gaseous species that can be consumed or produced when chemical equilibria are "instantaneously attained" in systems of gases and iron-containing solid phases.

- The model calculates reaction progress in terms of the masses of gaseous species consumed or produced as a function of time. For this calculation, the model uses data from the literature and laboratory studies on the rates of bacterial degradation of organic materials and the rates of gas generation or consumption in metal-corrosion reactions.

- To account for large uncertainties in the rates of different reactions and other parameters, the model assigns probability distribution functions to individual parameters, and it takes parameter values within their ranges by means of a statistical technique known as "the Latin hypercube." In a calculation of gas pressure as a function of time in a certain chemical reaction (or a set of reactions), the statistical sampling technique produces an envelope of curves for pressure as a function of time. Such an envelope is considered to represent the expected results more reliably.

The development of the gas-generation model during the past several years has been primarily a one-person effort. More recent work on the gas-generation model has been done by approximately 1.5 FTEs: one principal investigator and one part-time computer programmer.

Assessments: The gas generation model is an essential element in the PA process. However, the model contains several inadequacies that limit its

value to overall PA evaluations, and there appears to be a considerable time lag in integrating the state-of-the-art gas generation submodel and information into the overall PA model. This restricts the ability of the PA to reflect the most current understanding of gas generation in the initial compliance assessment and in bi-annual PA updates required by the LWA.

The current version of the gas model is inadequate for the following reasons:

- The model does not account for realistic brine or solid compositions in the solid-brine-gas systems that approximate reactions in the stored wastes. More specifically, the component model for corrosion uses phase stability diagrams for gas-solid interfaces to predict the behavior (passivity) of brine-solid interfaces, and the effects of important aqueous species, such as magnesium and chloride ions, are ignored. Laboratory studies of metal corrosion have demonstrated that significant quantities of gases evolve only when metals react with brines. On a time scale of two-year-long tests, gas generation is insignificant when metals are in contact with water vapor only.

- The gas-generation model stops at "the edge of the waste" without looking at the gas-brine-solid system in the rock. In microbial gas production, brine is a necessary medium for halophilic bacteria and, generally, water is one product of oxidation or respiration of organic matter. A brine, containing high concentrations of magnesium, sodium, calcium, and chloride ions, may react with pure metals, metal oxides, or sulfides, making solid phases that are not accounted for in the model. To determine whether the brines react with the metallic or other solid phases in the waste, the model must eventually reflect the complex chemical speciation needed to describe three-phase multicomponent systems. The model will then be able to identify the potential role of biogeochemical processes in PA of the geologic setting.

- The gas-generation and fluid-flow models cannot take into account the physical heterogeneity of the waste sources in larger-scale tests, such as the proposed Bin Tests, or of the real waste destined for WIPP.

- The gas-generation model does not analyze any of the mechanisms that may limit or reduce the gas pressure within the repository. A "worst possible case" of gas generation dictates an unrealistic scenario where a rise in gas pressure and its mass in the repository is not countered by any physical or chemical processes, such as sorption, liquefaction, dissolution in brines or mineral-forming reactions.

- The analysis of the brine and gas-flow models is focused on the physical aspects of gas behavior within and outside the repository space, but it does not sufficiently address the chemical interactions and their potential consequences. Indeed, no activities were identified during the review that dealt with the geochemical behavior of gases downstream from their sources in the waste, within the geological environment beyond the boundaries of the waste storage rooms.

The model is perceived by program managers at DOE/WPIO and SNL as very important to providing inputs to gas and brine-flow modeling and to PA. However, except for the principal investigator for gas-generation modeling, it is not apparent that a single individual in the DOE-SNL-WIPP complex has any sufficiently thorough, hands-on understanding of the fundamentals, working functions, and limitations of the model. There has been only limited exposure of the model to the technical community, there have been no in-depth peer reviews, and insufficient documentation is available to enable outsiders to exercise the model and judge its merits.

Recommendations: A peer review of the gas-generation model should be conducted at the earliest possible time to develop a working understanding of the model, evaluate the technical data needed, and assess the level of future model refinement needed for performance assessment.

The entire gas modeling effort should be expanded to address solid-brine-gas interactions, and which gases should be considered, under the expected range of environmental conditions in the repository and geological setting. Consideration should also be given to incorporating such effects as:

- passivation of carbon steel by $FeCO_3$, FeS, FeS_2, or oxides that may prevent gas generation should be predicted with potential-pH (Pourbaix) diagrams calculated specifically for carbon steel (or iron) in contact with brine solutions
- gas-interaction or gas-behavior models in the geological surroundings of the repository
- sorption of gases on solids
- mineral-gas and brine-gas reactions
- important aqueous species, such as magnesium and chloride ions, to predict the formation of known corrosion products

Expertise should be more thoroughly integrated with the modeling program in related fields such as metal corrosion, radiolysis, microbiological corrosion, chemical/ionic speciation in brines and gases, solid-brine-gas reactions, and organic compounds in gaseous phases and solutions.

Interactions with and inputs to the gas-generation modeling activity should be increased with the PA Program, the WPIO Technical Support Group, and other relevant scientific/performance assessment groups.

A literature review and a search for analogs, natural or engineered, should be conducted of those gas-generating processes that are of concern to WIPP's mission. If there are analogs, then they should be analyzed and results integrated relative to their importance.

The credibility of the gas-generation model and other activities that receive its input should be strengthened by accelerating their development and directing them toward the goals of demonstrating compliance with the regulations, the geological environment of the repository, and larger-scale tests as appropriate.

III.4.2. Laboratory Evaluations of Gas Generation

Observations: Laboratory studies of gas generation deal primarily with the major gases generated by metal corrosion, microbial processes and radiolysis: hydrogen, carbon dioxide, nitrogen and its oxides (N_2O, NO_x), methane, and hydrogen sulfide. A detailed description of gas-generation phenomena is presented in Appendix B. Plans exist to study VOCs, as gaseous and dissolved species, that may form from organic species in alpha-radiation fields.

The current phase of laboratory studies of gas generation (See Appendix D) is managed and coordinated by SNL through subcontracts with PNL (metal corrosion), ANL (radiolysis of brines and plastic materials), and BNL (bacterial degradation of cellulose, irradiated plastics and rubber materials). Studies of gas generation by metal corrosion, alpha-particle radiolysis of brines, and bacterial degradation of cellulose-containing materials are in various stages of completion.

Assessments: The laboratory studies of gas generation are, as a whole, consistent with the current state of knowledge of the field and with the results of other investigators reported in the literature. Many results emerging from gas-generation studies are empirical in nature, such as the dependence of steel passivation on carbon dioxide pressure, or the dependence of gas-generation rates on the pressure of hydrogen-gas in the experimental system. Similarly, the results of bacterial gas-production experiments are within the bounds of carefully obtained empirical data.

The SNL reports strongly emphasize careful documentation of the laboratory procedures, description of the experiments, and discussion of the results. This emphasis on the experimental data and time constraints of the program probably explain a certain lack of theoretical depth in the released

reports. However, a theoretical understanding of phenomena can support certain laboratory results, can influence the development of gas-generation models, and may help reduce uncertainties that are inherent in the current version of the gas-generation model.

The results of gas-generation studies in the National Laboratories are consistently used in the Gas-Generation Model Program. However, it is far from clear, to what extent (if at all) laboratory and model studies are driven by any data needs for the higher-level PA models.

III.4.2.1. Corrosion Induced Gas Generation

Observations: Bench-scale corrosion experiments for the WIPP program were started at PNL in November, 1989 with the objective of measuring rates of gas evolution caused by corrosion. The corrosion laboratory is very well equipped and more specific information on PNL activities can be found in Appendix D.2.

It is believed that waste inside WIPP will eventually be inundated with brine, with an overpressure of hydrogen, carbon dioxide, and other gases. Therefore, experiments are being done with both humid and inundated wastes, using Type A brine which simulates the brine expected in WIPP. In the case of inundated wastes, the composition of the brine is known at the beginning of experiments, and the composition of the brine at the end of the experiment is measured. Brine samples could be taken during the course of experiments, but are not. Corrosion coupons (carbon steel samples) are removed from pressure vessels at the end of experiments for evaluation.

Most of the oxic corrosion is believed to occur while drums are stored at generator sites and that this mode of corrosion will not be important inside WIPP, unless air inside the repository is continuously replenished during the life of the repository. Likewise, anoxic corrosion is anticipated to be responsible for most of the gas generation inside the repository. Based upon laboratory experiments, tit has been concluded that low concentrations of oxygen can accelerate the rate of anoxic corrosion. This acceleration is attributed to the reduction of oxygen on the corroding metal surface. Rates of anoxic corrosion and associated gas generation will accelerate if the brine becomes oxygenated.

Molar gas-generation rates are calculated from the plenum volume and the measured gas pressure with the initial pressure subtracted. The ideal gas law cannot be used for evaluating hydrogen and carbon dioxide; an equation of state based upon the Van der Waals theory is used for these gases. Gas dissolved in the brine is accounted for with Henry's Law. Some hydrogen can be lost by the reduction of metal oxide, but the loss is not accounted for. Rates of gas generation are verified by comparing data to weight loss measurements of metal samples. Before weighing samples, inhibited hydrochloric acid is used to

remove all corrosion. Typically, gas-generation data and weight loss measurements agree within 5%, which is exceptional. Results of all experiments are thoroughly documented in reports that are sent to the contract manager at SNL.

Passivation. Passivation of active metal surfaces by gases in the repository may significantly reduce the rates of corrosion and hydrogen generation. PNL has observed passivation of carbon steel surfaces by hydrogen sulfide at a threshold partial pressure of about 5 atm. These results are slightly different from those published by other research groups in that they think surfaces are passivated by protective films of FeS. Other groups claim that the formation of FeS_2, not FeS, is required for passivation.

PNL has also observed the passivation of carbon steel surfaces by carbon dioxide. They conducted experiments at various ratios of carbon dioxide to metal surface area and found that passivation can be limited by carbon dioxide availability. No passivation was observed without carbon dioxide. At a carbon dioxide level of 0.32 mol/m^2 of metal surface, surfaces were completely passivated by siderite, $FeCO_3$. The threshold carbon dioxide level for passivation was about 0.16 mol/m^2 of metal surface. Before passivation, rates of corrosion and gas generation are enhanced by acidification of the brine, which is due to dissolved carbon dioxide in the form of carbonic acid. Though no actual pH measurement has been made at high pressure to confirm this conclusion, theoretical calculations indicate that significant pH suppression is possible ($3.3 < pH < 3.4$).

Nonadhering Corrosion Products. Gas generation can also be inhibited by the accumulation of nonadherent solid corrosion products on the surface of corroding metal. After compressing the waste, rock will hold such corrosion products on metal surfaces, thereby preventing corrosion. Such effects were observed by PNL during experiments with moist salt and in the absence of brine at a temperature of 150°C and pressures of a few atmospheres. Clay-like deposits formed on corroding metal surfaces in high-magnesium brines (similar to Type A brine), and were identified as amakinite ($Fe_xMg_{1-x}(OH)_2$), a bluish gray, non-adherent, non-protective deposit. The corrosion rate was greatly reduced because mass transport limitations were imposed by this layer.

PNL has observed the formation of a blue-green-gray corrosion product that looks like amakinite on samples from experiments with simulated WIPP brine. X-ray diffraction indicated, however, that this product was not amakinite; it could not be identified with data in the PNL x-ray-diffraction library. However, no effort has been made to identify this corrosion product when sent to SNL for identification. In general, this product does not adhere to the surface of corroding metal and is non-protective. It usually forms a colloidal suspension that coats the walls of pressure vessels.

Brine/Salt Interactions. Researchers at PNL are conducting a wide range of experiments that account for both inundated and humid conditions. For all practical purposes, metallic samples in the vapor phase remain unreacted, except for a slight tarnish. No (significant) corrosion has been observed in the vapor phase.

Brines have not reacted with Hastelloy C-22, Hastelloy C-276, Inconel 625, or Titanium Grade 12 pressure vessels. Not one of the 316 stainless steel tubes in the Bourdon pressure gauges has failed.

Metallic corrosion specimens have been contacted with salt (halite) from the floor of WIPP in experiments at PNL. The current test plan proposes to use a simulated backfill that consists of 30% bentonite and 70% salt. In the past, the use of an alkaline backfill has been proposed.

Assessments: In general, the PNL studies currently being performed provide data pertinent to evaluating corrosion-induced gas generation. However, data needs should be defined more precisely before additional money is invested in costly experimental work.

An alkaline backfill ($12 < pH < 13$) could reduce corrosion and associated gas-generation rates by orders of magnitude, provided that there is relatively little aluminum, which corrodes very quickly in an alkaline environment.

Recommendations: Bench-scale corrosion experiments should be conducted with alkaline backfill, however, to assess the potential for reducing corrosion induced gas generation. Bench-scale corrosion tests could be conducted with actual TRU wastes, and wastes could be subjected to expected repository conditions (lithostatic pressure).

If large-scale corrosion experiments are required based on an assessment of data needs, then they should use (a) well-characterized simulated wastes; (b) a more realistic test environment; (c) a corrosion-resistant vessel with a hermetic seal; and (d) in situ corrosion sensors. Simulated wastes can be more fully characterized than TRU wastes, and large-scale laboratory tests with simulated wastes would allow complete characterization of wastes and products after completing the experiments using mass balance determinations. Vessels could be used that would allow experimentation at lithostatic pressure. Personnel with extensive experience in designing and performing large-scale corrosion experiments need to be directly involved in planning any large-scale laboratory tests.

More elaborate in situ corrosion monitoring should be considered. For example, corrosion rates could be measured with electrical-resistance probes. The corrosion potential could be determined by monitoring the voltage

differences between a carbon steel sample and a saturated calomel electrode. The pH, which is sensitive to dissolved carbon dioxide, could also be measured in situ.

III.4.2.2. Microbiologically Induced Gas Generation

Observations: Excellent bench-scale, microbial gas-generation studies have been conducted and have confirmed earlier studies[3] (summarized in Appendix B.2.3) and gas-generation model estimates. Most studies have been completed or are nearing completion, enabling data input into the anticipated 1994 PA. Other bench-scale, microbial tests underway or planned include:

- confirming radiolysis effects on the biodegradability of plastic and rubber waste materials,
- characterizing synergism/antagonism between biodegradation and corrosion of wastes,
- quantifying effects of pressure on waste biodegradation,
- characterizing waste biodegradation products, and
- demonstrating realistic limitations to microbial gas generation.

The focused and aggressive bench-scale, laboratory-test program at BNL:

- has provided microbial gas-generation data to support estimates predicted to date by theoretical calculations;
- has elucidated the effects on microbial gas generation of (a) humid and brine-inundated conditions, (b) limited nutrient availability (e.g. nitrate as an electron acceptor), and (c) backfill (bentonite) addition, which catalyzes gas generation;
- is addressing and quantifying synergistic/antagonism effects between microbial gas generation and corrosion through a cooperative program with PNL;
- is examining the vulnerability of irradiated plastic and rubber materials to biodegradation and gas generation in a cooperative study with ANL;
- has isolated and characterized halophilic (salt-loving) microorganisms from within the WIPP facility and surrounding environs, demonstrating their ability to degrade cellulose[4];

- is producing results representative of long-term repository conditions in reasonably short periods of time, because test conditions can be closely controlled and designed to obtain rapid results;

- is examining and quantifying degradation products (e.g. organic acids, alcohols) from cellulose biodegradation; and

- will evaluate the effect of pressure on the cellulose degrading activity of the halophilic enrichment cultures and isolates from the WIPP site. The current plan specifies a pressure test at 150 psia, which is the design criterion for the Type 2 bin.

Researchers at PNL and BNL are now collaborating on microbial-induced corrosion, a collaboration which was initiated by SNL.

Plutonium-microbe interactions may also be important because low concentrations of plutonium may be toxic to microbes and alpha radiolysis may convert non-biodegradable material into biodegradable material. In collaboration with BNL, ANL is initiating studies of plutonium-microbe interactions, an interaction which was also initiated by SNL.

Assessments: There is a great deal of uncertainty regarding the potential activities of microorganisms in the underground environment at WIPP during the ventilated, transitional and long-term timeframes. This uncertainty means that the amounts, types and production rates of gases from microbial degradation of organic wastes can not be predicted with much confidence. The most critical factor concerning microbial gas generation is brine inflow. If the repository environment remains dry, microbial activity will be limited by moisture in the waste, and gas generation should be minimal. If, however, the wastes become inundated with brine, microorganisms could flourish until nutrients, most likely phosphate, become limiting. Under brine inundation, microbial populations would likely degrade organic wastes using a sequence of electron acceptors and produce a variety of gases (CO_2, H_2S, N gases and CH_4). The production rates and amounts of these gases are highly speculative and are dependent on how rapidly oxygen is consumed, the breaching of drums and intermixing of drum contents and other highly indeterminate events. The gas generation model assumes complete biodegradation of wastes with attendant gas production. This is highly unlikely, because in the natural environment such efficiency does not occur. One notable example is the burial of organic matter over geologic time which underwent partial microbial degradation over time, producing today's principal energy resources -- coal, petroleum and natural gas.

Recommendations: Bench-scale, laboratory tests to evaluate microbiological effects on gas generation should be conducted at WIPP lithostatic pressure to be representative of anticipated long-term, repository conditions.

III.4.2.3. Radiolysis Induced Gas Generation

Observations: Radiolysis experiments for WIPP have been conducted by researchers at ANL since June, 1989 to investigate the effects of radiolysis on WIPP brines and various organic wastes. The alpha radiolysis of brine produces both hydrogen and oxygen due to the decomposition of water, whereas radiolysis of organic wastes produces VOCs. Radiolysis may also alter the susceptibility of organic wastes to other types of degradation.

Radiolysis effects in WIPP will be primarily due to alpha particles emitted during the decay of dissolved or suspended ^{238}Pu and ^{239}Pu. Both the alpha dose and hydrogen generation depend on plutonium concentration. Experiments conducted with plutonium concentrations of 10^{-4}, 10^{-6}, and 10^{-8} molar have indicated that the contribution of radiolysis to net gas buildup is negligible at plutonium concentrations less than 10^{-3} molar, although lower concentrations can affect the gas composition because carbon dioxide can be produced at the expense of oxygen.

The yield (G value) for the radiolysis reaction has been measured for four different brine compositions and ranges from 0.6 to 1.4 molecules of hydrogen produced per 100 eV of energy absorbed. The average yield (G value) for all brines evaluated is approximately 1.2 ± 0.2 molecules of hydrogen produced per 100 eV of energy absorbed.

ANL has found that a large number of VOCs are generated by the dry radiolysis of dry plastics by alpha particles. Thus far, thirty or forty radiolysis-generated VOC products have been identified. The yield values are anticipated to be small, but have not yet been quantified.

Radiolysis effects in the proposed repository at Yucca Mountain will be due primarily to gamma radiation emitted from solid waste forms. Based on gamma radiolysis evaluations, there is little evidence to support the hypothesis that alpha radiolysis can significantly impact rates of corrosion in WIPP. In the past, the effect of gamma radiation on corrosion rates in salt was evaluated, and corrosion rates were found to increase by a factor of two (2X) at radiation levels above 10^5 rad/hr. The effects of radiation on corrosion were unimportant at levels below 10^3 rad/hr, which is greater than the radiation levels anticipated for contact handled TRU waste proposed for WIPP disposal.

Assessments: Radiolysis is not perceived to be a major contributor to gas generation. Bench-scale laboratory test currently underway should confirm whether radiolysis of plastics and rubber materials makes these materials amenable to biodegradation, hence gas generation.

III.4.3. Volatile Organic Compounds

Observations: Volatile Organic Compounds (VOCs) to be evaluated under 40 CFR [illegible] 8 can be generated by radiolysis of the waste, microbial waste degradation, or can be from solvents contaminating the waste. Radiolysis is not considered an important gas generation mechanism, and the contribution of radiolytically-produced VOCs to the increase in gas pressure should be negligible. Volatile organics generated by microbial degradation would probably not be regulated VOCs.

The degradation of VOCs in brine by either hydrolysis or biological reactions has not been investigated.

The migration of VOCs is thought to be driven by increasing gas pressure caused by gas generation, and the VOCs could be transported to regulatory boundaries by other gases.

Assessments: As important as the VOCs are for demonstrating WIPP's ability to comply with the environmental safety regulations, the studies of these compounds seem to lag behind the studies of other gases. There is insufficient evidence that either radiolysis or microbial actions generates a large enough volume of VOCs to affect the results of, or be included in, the gas generation model.

Solubility of VOCs in brine, the adsorption of VOCs to geological materials, and biodegradation of VOCs, or all of these considerations have not been adequately examined. Any of these effects would likely minimize the possibility of VOC migration to regulatory boundaries.

III.4.4. Gas Effects on Repository Performance

Observations: Currently, rock mechanics models predict gas pressures in the disposal room at various times and at different assumed gas-generation rates by coupling room closure with gas generation from waste. Modeling results reported during the review did not substantiate the thesis that extensive fracture propagation will take place along horizontal discontinuities. However, the continuum model which analyzes simulated gas pressure effects operates in a relatively simplistic manner. Neither two-phase fluid flow nor fracture propagation behavior is explicitly coupled to the mechanical model to allow prediction of the consequences of high gas pressures. The assumption that fractures will propagate or that existing fractures in anhydrite marker beds will dilate appears to be largely subjective, rather than being based upon any specific modeling results; WIPP scientists disagree about the validity of this assumption.

Model development aimed at more accurate characterization of the Disturbed Rock Zone that surrounds all excavations is underway (primarily to

support seal design activities), but it is not clear that the more significant need for coupling of a fracture propagation/flow model will be addressed within a sufficient time frame to support gas generation aspects of PA.

Repository design concepts employed for WIPP currently aim at a final post-closure state having minimum achievable void space. This strategy includes optimum space utilization for waste storage (all rooms and entries will be filled to the maximum possible extent) and emplacement of salt or salt/bentonite backfill that will compact to minimal (less than 5%) void space in the transitional to long-term time frame. Despite minimizing gas volume at a given gas pressure, and thus minimizing stored energy, the strategy maximizes the likelihood of achieving fracture pressures, and does not appear to reduce the assumed gas generating potential of the waste inventory.

Assessments: Knowledge of the future environment inside the repository is the greatest source of uncertainty in modeling gas generation because of corrosion, microbial growth, and radiolysis. The rates of gas generation from both anoxic corrosion and microbial growth will probably be high if the waste is inundated with brine, but otherwise, gas generation will be relatively insignificant.

Recommendations: It is recommended that external sources of such programs be explored and representative analyses be performed to increase confidence in predictions of the consequences of high gas pressure on the repository environment. Computer programs capable of more realistic modeling of the coupled stress/flow problem exist and should be used to confirm present assumptions about the effects of high gas pressures. In recent years, considerable advances have been made in the capabilities of both geotechnical and reservoir engineering simulation programs, and there are examples of both that can model problems of this type.

Existing geohydrology codes should be used to determine if the repository environment is most likely to be dry, humid, inundated, or have mixed conditions during the 10,000 year life of the repository.

Engineered alternatives to the present design concept should be further explored to determine if aiming for minimum achievable void space results in optimum repository performance over the long term. The use of alternative backfills (such as coarse rock fill or pelletized gas getters) or increased repository volume are examples of strategies for obtaining similar waste containment with increased void space. Useful work in this general area was begun by the Engineered Alternatives Task Force, and the ITR Team recommends that further studies of repository design, storage configuration, and backfill methods be undertaken as part of future PA activities.

III.5. Testing with Radioactive Waste

The Bin and Alcove Tests are only a small part of all the tests or studies addressing gas behavior in the wastes, repository, and geological medium. The studies in the gas group, as well as most of the other studies in the Test Phase Plan, are written with a clear understanding of the technical issues involved, programmatic goals, and many constraints and uncertainties that lie on the paths to obtaining the necessary answers from the studies. Some studies are in various stages of progress, but many are thought of as being done at some future date.

III.5.1. Bin-Scale Testing

Observations: The Technical Needs Assessment Document (TNAD)[5], describes the Bin Test program as providing confirmatory information relative to the gas-generation model that feeds PA. A direct data input between the Bin Tests to the model or to PA does not exist. Consequently, it would be difficult to use the Bin Test data in verifying or directly confirming the models used for gas generation or PA.

The primary data to be obtained from the Bin Tests would be the time history of the gas-generation rates, gaseous species, and gas pressures within individual bins. In addition, the species in the brines in Type 2 bins would possibly be chemically analyzed at the end of the test period (1-5 years). However, the test data are stated as only indirectly linked to 40 CFR 191 and 40 CFR 268 because gas generation is not directly regulated by these two regulations. Rather, gas generation data is used to evaluate the potential for providing pathways for the loss of regulated contaminants (radionuclides or VOCs) from the repository if gas pressures approached or exceeded lithostatic pressure.

The latest test plan for the bin program was the "Test Plan: WIPP Bin-Scale CH TRU Waste Tests (Type 2 bin)"[6] and was specific to the Type 2 bins. An earlier test plan, which was published in 1990[7], suggested experiments with 144 bins (Type I), each holding about six drum-volume equivalents of contact-handled (CH) TRU wastes. These wastes were to be selected based on being representative of the national TRU waste inventory. The bin-scale test program was subsequently decreased in scope to include TRU wastes in only seven Type 1 bins and 12 Type 2 bins.

According to the Bin-Test Addendum #1, about six drum-volume equivalents of TRU wastes were to be loaded into a Type 1 bin; however, only five drum-volume equivalents were actually loaded into each of the seven Type 1 bins. Five drum-volume equivalents are intended to be loaded into a Type 2 container after they are characterized for their radionuclide content and waste matrix type. Other materials (metals, brine, salt, etc.) might be added to the bin depending upon the individual test to be monitored. The instrumented bin

would be overpacked within another container. The rates and quantities of evolved gases would then be determined. While the Type 2 bins would have a design capability of 700 psia, they would be operated at a pressure of 150 psia.

Assessments: Bin Tests should not be conducted underground at WIPP. Comparable data can be acquired in scientifically-defensible tests at a location that imposes minimal constraints on the test conditions. Lessons learned from the design of the Type 1 bin and its associated instrumentation and control systems should be applied to any proposed alternate test design.

III.5.1.1. Type 1 Bin Testing

Observations: Type 1 Bin Tests would be conducted under nearly dry conditions, and the amounts of gas that may be generated in the one to two years of testing are expected to be very small. Increases in the gas pressure within the bins are expected to be of an order of 0.03 atm (about 0.4 psi). The head space of a Type 1 bin measures 500 liters. At the initial atmospheric pressure, it contains approximately 20 moles of gas. An increase in the pressure by a small magnitude of 0.03 atm corresponds to an addition of about 0.55 moles of gas to the head space.

Type 1 bin design is severely constrained by the bin's similarity to a Standard Waste Box. This has resulted in an extremely large lid gasket area which adds to the uncertainties in achieving the design criteria for leakage for each of the bins in the test matrix. Although the criterion for a helium leak rate of 10^{-7} cc/s was achieved in conformance testing, leakage of the bins and associated test systems is still expected to be a significant factor limiting the quality of the test data. It is probable that test data will be purely qualitative, at best confirming the general hypotheses of oxygen reduction and hydrogen generation, rather than providing data adequate to confirm or add confidence in the gas-generation model.

Instrumentation, control and sampling systems on the Type 1 bins have undergone extensive development and testing. They are believed to be reliable and it is unlikely that they will place significant constraints on data quality. Primary data will actually be derived from laboratory analyses of gas samples rather than the instrumentation system.

System designers have learned useful lessons from their work on the Type 1 bins that will be applicable to the design of any future large-scale laboratory test. In particular, the Westinghouse Model Shop at WIPP, in which recent control system work for the Type 1 bin has been undertaken, provides an effective engineering development facility for rapid solution of design problems.

Assessments: There are no apparent reasons for conducting Type 1 Bin Tests underground at WIPP. Type 1 Bin Tests fall far short of any reasonable

expectations, and they would add nothing substantive to the demonstration of WIPP's ability to meet regulatory requirements. Any future comparison between the results of the Type 1 Bin Tests and of the gas-generation model may be disappointing and not worth the great costs and regulatory constraints placed on the execution of the tests.

Type 1 Bin Tests will be conducted with both dry and humid conditions. Since little or no gas was generated during bench-scale corrosion experiments conducted under dry and humid conditions, the results of Type 1 Bin Tests will be of limited value to PA.

The Type 1 Bin Tests, as currently designed[8], will not provide technically defensible nor sufficient data on microbial gas generation for use in the gas-generation and PA models. Some Type 1 bins, containing organic matter under humid conditions, may produce some carbon dioxide from biodegradation of the organic matter under oxic conditions. This gas generation, however, will occur very slowly, because the only microorganisms present to consume the waste are those resident on the waste when it was placed in the bins (Type 1 bins will not be inoculated). Insufficient gas will be generated during the time frame of the test to confirm the models before submittal of compliance documents. Carbon dioxide generation from microbial activity during the oxic phase would not be distinguishable from carbon dioxide generated from radiolysis. Because no post-test analysis of the contents of the bins is planned, no microbial growth or microbial bioproduct determinations can be made to confirm biological activity and gas generation. The method of analyzing the waste before filling of the bins does not allow for quantifying the amounts of cellulose and other organic matter present. Therefore, it is not possible to theoretically calculate possible gas generation from the microbial degradation of organic matter.

It is unlikely that anoxic conditions will be achieved in the Type 1 bins because of (1) the ingress of oxygen around the bin seals, (2) possible slow aerobic, microbial reaction rates during the time frame of the test, (3) possible lack of a resident, anaerobic, microbial population on the wastes (the Type 1 bins will not be inoculated), and (4) the possibility that no suitable electron acceptor (e.g. NO_3^-, SO_4^{2+}) will be available in the bin environment. Therefore, transitional and long-term time frames will not be represented in the Type 1 bin study.

The initial characterization of the wastes placed in the first six Type 1 bins is insufficient for any substantive analysis of gas generation that may be detected by the tests. The procedures of waste characterization for Type 1 Bin Tests include broad categories of different materials and their weights, but they do not include the necessary and more detailed data on the chemical and physical characteristics, or the data on the physical configuration of the waste in

the bins. The bin-test procedures do not allow the bins to be opened and the waste examined at the end of the tests.

III.5.1.2. Type 2 Bin Tests

Observations: Type 2 Bin Tests include combinations of nonradioactive and TRU waste materials under humid or brine-saturated conditions, and in the presence of the backfill material, presently thought of as a mixture of rock salt (70%) and bentonite (30%)[9]. The bins will be operated at a total pressure of up to 10 atm (150 psi), for a period of two to five years. A stringent oxygen-exclusion criterion specifies and oxygen penetration rate of no more than 2 ppm per year.

The gas-generation results of Type 2 Bin Tests will be compared against the predictions of the gas-generation model. If the bin-test results fall within an acceptable band of the model predictions, the tests will be considered to add confidence to the gas-generation model. If not, experts will be convened to analyze the discrepancies. Interpretation of the Type 2 test results will also be constrained because there is no planned examination of the bin waste at the end of the tests, and the brines will be sampled only once at the end of the tests.

Instrumentation and control systems for the Type 2 bin have not been designed, although much of the same equipment developed and tested for the Type 1 bin is likely to be directly applicable. This applies particularly to the Data Acquisition Package. Pressure and temperature are the primary data required from the Type 2 bin instrumentation; other instrumentation such as oxygen sensors and humidity gauges are considered to be of secondary importance because primary data would be obtained from head space gas sample analysis. Primary instrumentation is expected to perform within the specified DQO limits, although difficulty in locating secondary instrumentation capable of functioning at high pressure was identified as a problem by project personnel.

A detailed design of the hardware for Type 2 Bin Tests does not exist. The shape of the pressure vessel is unknown (spherical vessels, cylindrical vessels with elliptical ends, and cylindrical vessels with flat ends are all under consideration). Adequate materials for construction of pressure vessels and related hardware have not been identified. PNL's knowledge and experience in the design of pressure vessels for corrosion testing has not been made directly accessible to Westinghouse engineers.

Westinghouse has investigated commercially available pressure vessels for Type 2 bins. However, there are a number of constraints on the Type 2 bins that may preclude using such commercial hardware for the proposed in-situ tests. For example, these pressure vessels must be shippable in a TRUPACT-II container. Furthermore, each vessel must be able to hold the contents of 5

waste drums at elevated pressure. These constraints are summarized in DOE/WIPP 93-037[10] and are based on SNL specifications.

Several commercially available pressure vessels have been proposed for Type 2 Bin Testing, including a spherical pressure vessel. The estimated cost of a commercial vessel, capable of meeting all SNL specifications, is approximately $90K, assuming 304L or 316L stainless steel is the material of construction. The pressure vessels would have a maximum operating pressure of approximately 300 psi (psig).

It is very difficult to seal pressure vessels for high pressure corrosion and gas-generation experiments, but no detailed seal design beyond the conceptual stage has been prepared for Type 2 bins. A vacuum-flange seal design has been proposed, as well as a design that is based on two concentric, soft-annealed, solid-nickel O-rings. According to SNL, such metal-metal seals should be able to handle the nominal operating pressure of 150 psi (psig) very easily. SNL also noted that such a seal should be compatible with the materials used to fabricate pressure vessels.

Assessments: The Type 2 Bin Tests, as currently designed[11] will not distinguish between differing gas-generation mechanisms (corrosion, microbial degradation, radiolysis), and are inadequate for characterizing microbial gas generation for the WIPP facility during the ventilated, transitional and long-term time frames.

The practical experience with pressure vessels and results of corrosion testing gained at PNL have not been adequately communicated to those responsible for the design of the Type 2 bins. Though pressure vessels for Type 2 Bin Tests will contain a relatively corrosive brine, with both magnesium and chloride ions, little thought has yet been given to the possibility of stress corrosion cracking. During extended testing under these conditions, both 304 and 316 stainless steels, which are the materials proposed in the conceptual design of Type 2 bins, are prone to stress corrosion cracking in magnesium-containing brines. Hastelloy C-22, Hastelloy C-276, and Inconel 625 are less susceptible to such failure will not contribute to gas generation and should be investigated as a material of construction.

There appeared to be considerable uncertainty that the Type 2 bins can achieve their required leak tightness. In addition, some Project personnel expressed concern that the contained waste matrices in the bins would outgas oxygen for a very long time, thus preventing anoxic conditions from being achieved.

The difficulties and uncertainties in waste characterization that were mentioned in the assessment of Type 1 Bin Tests carry to Type 2 tests as well. In Type 2 tests, the pressure limit of 10 atm is not justified by any known behavior

of the solid-brine-gas systems under the expected repository conditions, where the pressures may go much higher, into the hydrostatic or lithostatic range of about 65 to 150 atm.

Since wastes will be inundated with brine in Type 2 Bin Tests, the rate of gas generation is expected to be significant.

Some Type 2 bins will be inundated with a brine containing a microbial inoculum derived from WIPP brine, muck and other sources (surface lakes and sediments). Microbial gas generation from these bins is expected. However, the design of the Type 2 Bin Tests precludes obtaining technically defensible data because:

- Other gas-generation mechanisms can potentially produce the same gases as microbial degradation. An exception is N_2O, a distinctive microbial gas product. Therefore, gas-generation mechanisms can't be assigned.

- The pressure limit on the Type 2 bins is well below the lithostatic pressure that could potentially be developed after repository closure and gas generation. Therefore, the effects of gas pressure on microbial activity will not be evaluated in this test program.

- The characterization of the waste being placed in the bins is not sufficient to theoretically calculate gas generation with sufficient accuracy to correlate the results with actual gas generation.

- After the tests are completed, the bin waste contents will not be analyzed; therefore products of microbial degradation, corrosion and radiolysis will not be determined. This will not allow for determining mass balance, quantifying gas generation based on mechanisms, or assessing synergistic/antagonistic mechanisms controlling gas generation (e.g. the passivation of metal due to microbial carbon dioxide generation).

- The proposed brine analysis is inadequate to analyze microbial activity for correlation of microbial gas generation. Microorganisms generally attach to solid products (in this case, the cellulosic materials in the TRU waste) making it impossible to adequately correlate microbial populations in the brine with actual conditions in the solid materials and gas production.

The design of experiments and hardware for the Bin Tests are inadequate. Specific problems include: poor waste characterization; an unrealistic test environment; incomplete design for the pressure vessel and seal; and limited use of instrumentation. Ideally, a bin should be able to contain waste

from six drums, operate at lithostatic pressure, and fit inside a TRUPACT II container. However, such vessels could be too large and too heavy to fit inside a TRUPACT II container, under current container constraints.

Originally, Type 2 Bin Tests were to be conducted at elevated (lithostatic) pressure. However, SNL/WPIO have decided to limit the operating pressure to 150 psi (approximately 10 atm). This pressure is not based on scientific reasoning or the needs of PA.

The current experimental plan calls for only one brine sample at the end of the experiment. More frequent brine sampling would require periodic circulation of the brine so representative samples could be obtained. Such circulation would perturb rates of mass-transfer conditions and gas generation in the bin, making results difficult or impossible to interpret.

The duration of Type 2 Bin Tests will be relatively short compared to the life of the repository and cannot be used as justification for doing the tests. The duration of these tests is comparable to the duration of bench-scale experiments that are better controlled and characterized.

III.5.1.3. Waste Characterization

Observations: The Type 1 Bins were filled at the Argonne West facility at Idaho with "real" TRU waste that originated at Rocky Flats, and was stored in the Air-Support Building at Idaho National Engineering Laboratory (INEL). There are approximately 33,000 drums of waste stored in the INEL Air-Support Building, of which approximately 9,000 were identified as being certifiable for shipment to WIPP under the existing WIPP Waste Acceptance Criteria (WAC). A summarized version of the existing WIPP WAC and relevant transport regulations is attached as Table III.5-1. A statistical sampling program was recommended by SNL to randomly select the required number of drums from this population, for the Bin filling. It should be noted that only whole drum contents can be taken and placed into the Bins, to avoid the situation of generating new waste if drum contents were allowed to be split and segregated.

In total, over a period of almost 2 1/2 years, seven Type 1 Bins have been filled with TRU waste. Each bin contains the waste from 4 or 5 TRU waste drums. Table III.5-2 summarizes the contents of the first six Bins filled. Bin 7 was still undergoing data QA checking at the time of the review. The drum contents were originally selected from their TRU Contents Codes (TRUCON Codes), and at the time of commencement of the filling operation, it was intended to fill some 144 Bins. Hence, although it now does not seem appropriate that three Bins contain mainly glass waste, at the time of filling, these Bins were only to be a small proportion of the overall number. Glass waste is fairly innocuous, in that it is not expected to generate significant quantities of gas

but it is also relatively easy to identify and to certify as compliant with Transportation and WIPP WAC requirements.

The filling of the bins at Argonne West was carried out within a hot-cell facility, using remote manipulators to handle the waste. Before entering the hot-cell, drums were examined using Real-Time Radiography and NDA (Non-Destructive Analyses), and were headspace gas sampled, to analyze for the presence of VOCs. Real-Time Radiography is basically x-ray examination of the drum, to look for the presence of noncompliant materials (e.g. free liquids), and NDA is used to give an estimation of the plutonium content, by assessing neutron and gamma energy emissions from the drum. The Real-Time Radiography operators also estimated the weights of the individual items, by type, within the waste (e.g. weight of

Table III.5-1. Summary of Radioactive Waste Acceptance Criteria[12,13]

Criteria	TRU Waste
General	Heavy and bulky objects must be blocked or padded so as to not damage container during shifting
Containers	55-gallon drums or Standard Waste Boxes (assay only). All containers must be fitted with a filtered vent.
Package Weight	1,000 lb. gross for 55-gal drums 4,000 lb. gross for Standard Waste Boxes
Free Liquids	Less than 1 vol% in internal containers, aggregate amount < 1 vol% of external containers
Explosives & Compressed Gases	No explosives permitted, gas cylinders must be permanently vented and drained.
Particulates	Immobilization of Particulates required if over 1 wt% is below 10 micron diameter or if over 15 wt% is below 200 microns in diameter
Mixed Waste	Must be characterized and exist as co-contaminants
Thermal Power	Maximum of 20 watts per Standard Waste Box, 2.85 watts per 55-gallon drum, or 40 watts per TRUPACT; further restricted by content code and number of packaging layers.
Fissile Material	Including two times the measurement error, shall be less than 200 grams ^{239}Pu FGE per Drum, 325 grams per Standard Waste Boxes, or 325 grams per TRUPACT; further restricted by content code and number of packaging layers
Plutonium Equivalent Activity	No more than 1,000 Plutonium equivalent Curies (PE-Ci) per container.
Dose Rate	Maximum 200 mrem/hr Total at surface and max of 10 mrem/hr at 2 meters. Neutron contributions of >20 mrem/hr must be documented.
Surface Contamination	Maximum 50 pCi/100cm^2 alph. ; 450 pCi/100cm^2 beta-gamma (as matter of practicality, no detectable removable surface contamination will be acceptable).
Labeling	DOT Labels, RCRA Labels, Bar Code ID Number. Labels must have 10 Year life expectancy
Data Package	Data Package required for each container with certification statement and all data identified in WIPP/DOE-69.

Table III.5-2. Type-1 Bin Contents Summary

Waste Cat.	No. Drums	Pu (g)	Comments
Glass	4	73.67	Mainly glassware plus Raschig rings some plastic (bags and polybottles) some cellulosics (fiber- board) some metal plus vermiculite/oil-dry.
Glass	4	9.98	Glassware/Raschig rings 132 kg steel 11 kg plastics 18 kg cellulosics 6 kg plus vermiculite/oil-dry.
Metal	5	9.56	Cellulosics 1 kg plastics 21 kg rubber 4 kg steel 100 kg Al 36 kg other non-corroding metal 7 kg vermiculite/oil-dry 8 kg.
Metal	5	14.10	Cellulosics 6 kg plastics 22 kg rubber 3 kg steel 175 kg Al 16 kg other non-corroding metal 39 kg vermiculite/oil-dry 7 kg.
Combustibles	5	9.11	Cellulosics 16 kg plastics 65 kg rubber 41 kg steel 6 kg non-corroding metal 33 kg vermiculite/oil-dry 45 kg.

plastics or cellulosics),utilizing both the TRUCON Code data and the Real-Time Radiography data. The drums of waste were then posted into the hot-cell, and were opened and their contents removed. Individual packets in the drum were opened, and contents were classified by type, weighed, and loaded into the bin. Samples of the atmospheres within packets were taken for analysis for VOCs. The whole process was recorded on video tape, and was well documented and QA checked.

Assessments: INEL had little operational experience using Real-Time Radiography when the bins were filled, and a great deal of valuable hands-on experience was gained from this process.

In the future, certification for WIPP-bound waste will be primarily based on a combination of process knowledge, Real-Time Radiography (or an equivalent non-destructive examination) and NDA. Because access to the waste is limited by radioactivity, and because there is no desire to set unnecessary precedents adversely affecting future generators, the level of waste characterization carried out for the Type 1 Bin Tests was considered acceptable.

Recommendations: Even though the waste characterization for the Type 1 Bin Test was probably as good as it could be, better characterization and understanding of the waste source term should rely on laboratory testing. Laboratory testing can utilize real wastes, can be undertaken at different scales, and above all else, offer the capability of carefully controlling the input materials. Laboratory testing could evaluate the complete segregation of controlled amounts of waste materials, then assess controlled combinations of materials to look for synergistic effects.

III.5.1.4. Bin Tests and the Repository

Observations: Room 1, Panel 1 provides a stable environment for the proposed bin scale tests. Roof support has been proven adequate in the short term and it is highly probable that safe conditions will be maintained for the duration of the planned test phase. Temperatures remain reasonably stable (varying annually by about 7° C) and the room is clean and reasonably dust free. No detrimental effects on test instrumentation or test data quality assurance are expected to result from their being conducted underground. However, interdependencies between the test objectives and the proposed test location present some constraints that may limit the value of the tests and that detract from the WIPP mission of demonstrating safe disposal of TRU waste.

With regard to the test objectives, requirements for purging flammable gases from the Type 1 bins, and possible difficulties in maintaining absolute humidity in Type 1 and Type 2 bins at a value equivalent to closed repository conditions, have the potential for limiting the data value.

Assessments: Room 1, Panel 1 contains roof support far in excess of requirements for roof support in an operational repository. There have been some benefits derived from the design, installation and monitoring of the support system, particularly with regard to developing an understanding of roof deterioration. It is noted, for instance, that analysis of load cell results has caused a change in assumptions regarding mechanisms of roof deformation. Nonetheless, it is felt that using a disposal panel room as a long term test site is a departure from the WIPP mission unless waste-repository interactions are being

studied specifically. Using a room merely as a surrogate for a surface laboratory imposes constraints that may later be viewed as precedents for other tests or for repository development.

III.5.1.5. Post-Test Brine Sampling

Observations: Sampling will be performed at the end of Type 2 Bin Tests, but periodic brine sampling during the testing would require agitating the liquid in the brine, thereby disturbing the gas-generation mechanisms. Active (periodic) brine sampling could be done during the experiment, but it would be more difficult, and must be done in accordance with DOE Order 6430.1A. A conceptual design for brine sampling was shown using a simple siphon[14]. Westinghouse has visited nuclear reactor sites to investigate radioactive liquid sampling techniques with glove boxes.

Westinghouse WID has a requirement that before receiving waste (for Tests, or any other reasons) there must be a means in place to return, to the point of origin, waste and potential waste arising from abnormal occurrences. In the case of the Type 2 Bin Tests, the capability to remove all liquid (brine) from the Bins following test completion must be provided, and such liquid must be immobilized for return. The pre-conceptual design of the proposed immobilization process would circulate hot gas through the Bin, followed by the application of a light vacuum to condense the liquid as "clean" water. WID also proposes to use computer tomography to certify that the bins are effectively free of liquids.

Assessments: Useful chemical information could potentially be obtained from brine analyses. However, specific information on how the brine would be removed from the Type 2 bins and stabilized, or the costs associated with the process, were not available. A very rough ITR estimate of the cost for an immobilization facility would be in the tens of millions of dollars, yet WID's cost estimate for this facility was reported to be in the range of a few million dollars.

The process for liquid immobilization is unproved, and will probably require significant design and development activities.

III.5.2. Alcove Test Program

III.5.2.1. Test program scope

Observations: The TNAD[5] described the Alcove Test program as being relevant to compliance with 40 CFR 264, Subpart X, 40 CFR 268, and 40 CFR 191. The Test Phase Plan[15] provided a brief narrative on the design of the Alcove Test. The new Alcove Test plan[16] was refocused to provide data to address 40 CFR 264 and 40 CFR 268. As currently proposed, the primary data to be obtained is the VOC concentration in the alcove atmosphere. The Alcove Test

plan stated other potential test objectives, but provided qualifiers that many of them might be unobtainable.

In addition to the VOCs, the Alcove Test plan requires measuring other gaseous components in the alcoves. However, no measurement of the total VOC inventory in the tested drums was proposed (nor is it feasible). Consequently, the source term for the VOCs would be unknown.

III.5.2.2. Test Plan definition

Observations: The Final Draft Alcove Test Plan[17] provides background information on the development of the Alcove Test program. Portions of this section of the ITR report are taken from that test plan.

The original Alcove Test plan [18], published in 1990, proposed a test matrix of up to six alcoves with up to 3850 drums (total) of TRU waste selected to be representative of the major categories of the national TRU waste inventory. Based on certain NAS concerns, the Alcove Test was decreased in scope to one alcove with 1050 drums of TRU wastes and another alcove as a control, i.e., no TRU wastes in it.

For the test, the 1050 TRU drums would be emplaced in an alcove and allowed to emit gases into the alcove atmosphere. The proposed alcove would have one quarter the volume of a full size disposal room. It is expected that it would be somewhat more geologically stable than a full size room because of its smaller width (25 ft versus 33 ft). The number of drums to be emplaced (1050) is approximately one sixth that for a full size disposal room. Consequently, the VOC releases into an alcove would be expected to produce a lower concentration than in the full room.

A conceptual seal barrier is proposed to contain the evolved gases, yet allow sampling of them for chemical analysis. This seal will be specifically designed for the alcove and will not provide useful data for design of seals used in the disposal phase.

The alcove gas seal barrier seal has very stringent leakage requirements (~1% alcove volume per day). These requirements can probably only be satisfied if a very stiff liner is installed as soon as possible after excavation. However, the proposed alcove gas barrier design is only conceptual. Thus, it has not been possible to review it critically. Room or panel seals will be of different construction from the conceptual (and most likely) alcove gas barrier and will not be installed under similar circumstances. Therefore, little of the experience gained in constructing and monitoring the alcove gas barrier can be directly applied to disposal room seals.

Some gas losses into the Disturbed Rock Zone around the alcove will occur. These losses will be difficult to quantify. The Final Draft Alcove Test Plan notes that there is considerable uncertainty in the estimates of total leakage and that the upper limits of those estimates would lead to an unacceptable test. Using the upper leakage limit stated in the test plan, as much as 50,000 liters/day could leak into the Disturbed Rock Zone. This level of leakage represents about 80% of the void volume of the alcove.

Geometrical and age differences between the alcove and disposal rooms are likely to result in considerably different loss rates. These uncertainties make it both difficult to plan a valid test and to extrapolate the test data to a meaningful analysis of disposal phase operating conditions.

Assessments: The Alcove Test plan is insufficiently developed and has no technical basis for compliance demonstration. The latest version of the test plan (1) showed large improvements from the first test plan However, many details were still at a conceptual rather than a specific and concrete stage. Frequent comments required cross referencing between the test plan documents; this caused additional confusion in the ITR Team's review of the test plans. This lack of a unified test plan document was viewed as an additional weakness of the test program.

Because the total amount of VOCs in the test drums would not be measured, the source term for the gases cannot be estimated. Measurements of VOCs in the wastes will have to be made at the waste generating sites, e.g.. INEL, WHC, LANL, SRS, etc. if these data are required. Data of this type is currently being generated at INEL where some capability for modeling VOC emission rates is being developed[19]. Drum headspace analyses will allow defensible statistical VOC concentrations to be determined from large drum populations and enable reasonable predictions of emission rates to be made. Storage buildings at the generator sites allow VOC concentrations in ventilation air to be quantified in an environment without large uncertainties introduced by losses that bypass the collection system. Continued support for this work is encouraged. The data will be of significant value in designing disposal room ventilation systems that can provide air quality within regulatory limits.

An additional concern was that corrosion of test drums could occur if there were puddling of brine and subsequent contact of the brine with the drums. Such corrosion could lead to radionuclide releases during retrieval with a subsequent increase in the volume of TRU waste because of contamination of the salt and brine. This could pose a significant, but not insurmountable, decontamination problem.

The alcove will not be backfilled, therefore any absorption of VOCs that might occur in the backfill, and any effects of the backfill on gas diffusion rates will not be addressed.

Requirements for waste retrievability during the test phase (mandated by the LWA and No Migration Determination) place additional constraints on the Alcove Test that limit the test's value. For instance, backfill cannot be used, as noted above, and roof support must be installed to ensure safe conditions for the duration of the test. The effect of potential roof collapse on drum integrity cannot be assessed. Sudden VOC or radionuclide releases associated with the breaching of drums by a large roof fall are a potentially significant operational problem, but one that cannot be addressed by the proposed test phase. In general, the limitations of maintaining retrievability (if only in theory) minimize the interactions between the waste and the repository that would be the strongest justification for underground testing.

Retrieval of waste from any underground test that approaches operational conditions would be extremely expensive. Even minor problems, such as leakage of just a few drums because of corrosion at the floor level or drum penetration from a failed rock bolt could cause major difficulties. Seepage of contaminated brine into fractures in the floor could occur. Recovery of this material would require mining equipment that would in turn be contaminated. Rehabilitation of roof support in the event that roof instability was detected would probably require working above stacked drums with limited headroom. It would be difficult to demonstrate sufficient confidence in predictions of roof falls to allow work crews to access the room for drum retrieval without some remedial rock bolting. The risk of these difficulties, while small, is not warranted for obtaining the type and quality of data expected from the Alcove Test program.

Failure of either the roof rock or elements of the roof support system may result in breaching waste drums, and would considerably increase the cost and difficulty of waste retrieval during a disposal phase. Furthermore, roof support designs which ensure at least 5 years of maintenance-free life without failure of either part of the salt roof or some of the rock bolts has not been demonstrated at WIPP. Mechanically anchored rock bolts, used in the conventional drift roof support at WIPP, can fail under high loads, and are susceptible to an increased likelihood of failure in the more humid and corrosive environment of a sealed alcove[20]. The roof support in Room 1 Panel 1, which is the most thoroughly researched support system at WIPP, is expected to provide reliable support for considerably longer than 5 years, but it requires regular maintenance. If the tension in the bolts is not relieved regularly, they would probably fail. In fact, the precedent set by this overly-engineered roof system is believed to be an impediment to future, more rational roof support design. A different, still conceptual, roof support system being considered by project personnel uses new rock bolt technology with sliding nuts, but the concept has not been tested with corrosion protection needed in the humid repository atmosphere. The roof support system for the alcove has not yet been chosen and was not reviewed.

Recommendations: The Alcove Test program should be abandoned. Data on VOC emissions from large populations of drums can be obtained more cost effectively and accurately from measurements taken at generator sites. VOC emissions from sealed panels via the Disturbed Rock Zone and open fractures within marker beds may be a concern during disposal operations if they occur in areas with low ventilation rates, or if the leakage rates are sufficiently high to impact the overall repository air quality. However, leakage effects can best be estimated from the previously mentioned VOC data and gas leak tests using representative panel seals. The Alcove Test is unlikely to reduce significantly the uncertainty in the results of these calculations because of differences in seal design, drift age and geometry, as noted above.

A test similar in concept to the Alcove Test may be more appropriately incorporated into the disposal phase, when it could provide data on gas and VOC emission from TRU waste under realistic repository conditions. The ITR Team has made no assessment of the operational or regulatory need for these data. A large-scale test replicating repository conditions to assess disposal phase health hazards related to VOC emissions could also be considered during the disposal phase.

Seal tests proposed by SNL to support disposal phase seal design should be completed independently of the Alcove Test.

III.5.2.3. Alcove Test Contribution to Technical Information Needs

Observations: Based on interviews, data to be generated by the Alcove Test program would not have any linkage to either the gas-generation model or PA. The program was generally described as ". . . having the potential for showing scaling and synergistic effects of the waste within the repository." No details on the specific effects were provided by Project personnel. No suggestions were provided for how data could be extrapolated to the national TRU inventory.

The TNAD suggested that potential decreases in radiolytically generated gases might be observed in the TRU alcove. However, Attachment B to the test plan provided calculations that showed that only very small amounts of radiolytically-evolved gases would be generated. It will be difficult (or impossible) to measure small changes in gas generation if the total gas produced by radiolysis is small to begin with.

Absorption of VOCs onto the alcove walls as well as migration into the Disturbed Rock Zone cannot be accounted for from the test data to be measured.

Assessments: There is no connection between the Alcove Test data and PA. Although VOC data will be required to support a disposal phase NMD, the Alcove Test program will not provide that data in a cost-effective manner.

Project personnel provided the ITR Team with documentation that estimated costs of 20M$ for the alcove program, yet waste characterization efforts were estimated at 19.4M$ in the WIPP Desk Reference Manual. Other, more cost effective methods for obtaining the VOC data appear to be available as noted previously.

The Alcove Test Program, as proposed[21], will not provide data on microbiological gas generation or any information on microbial degradation of VOCs. No significant biodegradation of TRU waste constituents is expected to occur in the Alcove Test[22], because of the low moisture content of the wastes deposited in WIPP and the short duration of the tests.

Microbial degradation of VOCs adsorbed to rock matrices potentially could occur, diminishing the likelihood of VOCs reaching the WIPP regulatory boundaries through fractures. Subsurface biodegradation of some VOCs is used effectively in a bioventing process for soil remediation. This entails using microorganisms attached to mineral particles (a biofilter) for in situ degradation of VOCs transported in air[23,24]. Conceivably, microorganisms that have already been enriched and isolated from brine and solid samples collected underground at WIPP[25] could colonize rock surfaces and degrade VOCs adsorbed to rock materials. Adsorbed VOC biodegradation testing could be completed inexpensively and expeditiously by coupling SNL's bench-scale VOC adsorption test plan with a microbial degradation study.

To provide stability of the Alcove Test room for the duration of the test and to ensure retrievability of the emplaced TRU test wastes, very stringent roof support would be required. The use of such an extensive support system might establish an unnecessary precedent for the repository during disposal operations with attendant increased disposal costs.

III.5.3. Bin and Alcove Test Integration with Laboratory Tests

Observations: There is no connection between the VOC data being obtained at INEL and the Alcove Test program. From preliminary information provided to the ITR Team by INEL personnel, the VOC data obtained there appear to correlate reasonably well with a VOC model that the INEL personnel have produced. Enhancement of their model and measurements appears to be more cost effective and timely than pursuit of the Alcove Test.

The integration of gas-generation modeling with bench-scale laboratory studies of corrosion, radiolysis, and microbial gas production is very good. Information is exchanged both ways. Unfortunately, Bin Tests don't adequately complement the bench-scale laboratory test program because the Bin tests provide only partial confirmation of the gas generation model.

Assessments: The Alcove Test program is not integrated into the lab-scale or bin-scale test programs. No data feeds exist between them. The Alcove Test program will not provide data to support long term waste isolation in the repository.

III.5.4. Repository Conditions and Operations

Assessments: The WIPP underground should be used for tests related specifically to advancing the knowledge of waste containment and repository performance. Long term maintenance-free stability of rooms is not a reasonable expectation in bedded salt at a depth of over 2000 feet; in fact the reason for choosing WIPP as a repository site was in part the ability of salt to deform rapidly to encapsulate and immobilize the waste. Tests having this requirement of long term stable environments should be conducted at other locations.

Further lessons can probably be learned from continued monitoring and adjustment of the Room 1 support system and it is recommended that this work be continued until detachment of the roof slab from the main roof has occurred. This is likely to provide information on the development of shear fractures and bed separations that will have value when designing room monitoring systems during the disposal phase. This is particularly relevant since Room 1 is likely to be the least stable room of each panel.

The WIPP can justifiably be regarded as a state-of-the-art facility, containing excellent equipment that is extremely well maintained. It has served as the site for some first class research that has benefited both the goal of waste disposal and more generally, the technical community involved in underground mining and disposal. However, once waste is emplaced in WIPP, there will be little flexibility for large-scale experimentation with mining methods like those occurring at most mines. As a result, the operator must make the most of every opportunity to learn about the behavior of the rooms and repository, and to develop mining skills prior to waste disposal. It is important to note that there is presently a very small area of 'open ground' at WIPP, and that ground conditions may be very different by the time Panel 8 is mined.

Panel 1 offers opportunities to test various room profiles to determine their stability and closure rate and to develop the monitoring procedures that will be used in disposal rooms. Some work along these lines is underway and should be continued. Room profile tests can be undertaken relatively cheaply and will be helpful in maintaining operator skill in the pre-certification/permitting period. The aim of room profile testing should be to develop roof shapes that can be maintained safely with a minimum degree of artificial support. This will result in reduced likelihood of drum breaching from large rockfalls during the disposal phase and will minimize bed separations in the roof, thereby enhancing waste containment.

Engineering staff from the M&O have visited a few evaporite mining operations to widen their experience of design and ground control techniques. Roof and floor stability in bedded salt is highly dependent upon relative room and pillar widths and roof/floor beam thickness. Gas emissions from disposal rooms, in which only minimal seals are expected to be placed, may be sensitive to roof and floor bed separations. Lessons regarding mitigation of these problems can be learned by a wider review of North American mining methods and close contact with mining companies.

Engineering staff should be encouraged to share operational experience with the technical community, in addition to the primarily theoretical developments that are shared today. The mining industry comprises many individuals and companies with extensive practical experience who can critically review operational information, but relatively few who can offer useful opinion on salt mechanics theory.

Backfill systems: Backfilling is practiced in several evaporite mining operations around the world, but experience with placing fill in the confined geometry anticipated in disposal rooms is limited, and has in general not been very encouraging. The operational difficulties of placing fill close to the roof, above and around waste drums should not be overlooked. In particular, there is a big difference between placing small amounts of fill for a single test and running a system on a continuous or regular basis. Dust, corrosion, and spill clean up are typical problems that may severely limit room or equipment availability. Low in-place densities are typical with dry placement systems unless very coarse backfill is used with a high speed pneumatic or mechanical flinger system. Although some problems may have been studied already, the time needed to implement and prove an effective operational backfill system should not be underestimated.

Instrumentation: The instrumentation that is being used and will be used in the disposal phase is standard "off the shelf" equipment, and there are no apparent instrument issues. The operational tests and commissioning phase will provide DOE with the opportunity to test the instrumentation under real repository conditions. The repository environment will be a harsh environment compared to laboratory conditions. Dust and possibly humidity will have to be dealt with on a normal routine basis. Instruments will have to be located and protected from unanticipated rock movement (i.e.. roof fall or rock slip) and from operators and machinery working in the tight and somewhat darker areas of the underground repository openings.

Operational scale-up: Any mine, repository or plant in which several processes must work together to facilitate safe and efficient completion of an overall objective must be commissioned according to a carefully controlled plan.

WIPP is an unusual facility in that it has functioned for a number of years as a scientific test site and many of its components have been used to support those tests rather than the longer term mission of safe TRU disposal. As a result of this long period of activity, there may be a temptation to view it as an operationally ready facility, rather than one that only is in the first stage of the Engineering project plan described above. Reliance on in situ tests such as the proposed Bin Tests tends to enhance the image of operational readiness while actually deflecting resources from the real tasks required for commissioning. As an example, waste handling and health physics personnel have concentrated for several years on procedures for the receiving, purging, and transferring underground of seven Type 1 bins. The real goal of being able to handle tens of thousands of drums and Standard Waste Boxes each year has become subsidiary. This is believed to be a serious shortcoming in medium and long term planning.

Engineering Operations Testing. The main objective of the testing phase of a project is to demonstrate that all engineering systems are installed and function correctly. Simplistically, this could be thought of as checking that everything functions once. The main stages of the testing phase can be summarized (in generic terminology) as:

Performance Acceptance Tests (PATs): These tests check that equipment has been constructed and installed in accordance with Engineering Drawings. PATs may be carried out at an equipment manufacturer's facility, but may also need to be repeated on installation at Site, to confirm that no damage has occurred during transportation. At this stage of testing, no sources of external power (e.g. electrical, hydraulic, etc.) are connected to machinery. Dimensions and material of construction are checked, moving components may be moved by hand to check freedom from interferences.

Loop Acceptance Tests (LATs): These tests check that control loops function appropriately (e.g., if a level detection switch is reached, then the signal to switch a pump is sent).

Facility Acceptance Tests (FATs): These check that engineering sub-system function correctly, and allow sub-systems to be combined to correct facility operation. At this stage of testing, power is applied to moving components, control loops are integrated into testing, and whole sections of the facility are operated.

Following completion of the above three stages of testing, it will have been demonstrated that the facility has operated at least once. At this stage, where appropriate, a facility can be handed over from an Engineering (Construction and Installation) Contractor to the Operating Contractor. In the case of WIPP, the M&O Contractor has responsibility for both these functions.

III.6. Associated Test Issues

III.6.1. Management

Observations: During this review, changes in the WIPP project management structure were being made by the DOE, consistent with the views and management policies of DOE/HQ, and the WIPP mission statement.

III.6.1.1. Management Path Forward

Assessments: Increased regulatory and stakeholder oversight, changing regulatory requirements and uncertain compliance criteria have produced an attitude of risk aversion which impedes changes in programmatic direction and organizational culture, though the benefits may be clear.

Although the Bin and Alcove Test Program may originally have been based on scientific merit, it appears to the ITR Team that the Bin and Alcove Tests have evolved in response to a perceived need to introduce radioactive waste into the repository.

Recommendations: The WIPP mission statement should be used as the basis of a clear vision of the path forward. WIPP management should use this vision to create an organization committed to successfully obtaining certification and permits within a defined period contingent on EPA and NMED actions.

The WIPP management structure should be based on strong, focused leadership that develops clear lines of authority, responsibility and accountability. To support this, management changes should be directly tied to the future state of the project, as proposed in the WIPP Near Term Path Forward, the Allocation of Mission, and the WIPP Work Flow (Chapter II). These should be presented, with other basic management information, in the WIPP Project Management Plan.

Management decisions about WIPP activities and testing should be clearly based on scientific merit and linked to technical data needs derived from PA and compliance demonstration. The Bin and Alcove Tests could fill that need, however, regulations governing activities underground at WIPP limit the scientific justification and value of the tests. Future non-technical WIPP decisions should be preceded and supported by a firm technical and scientific foundation.

The conflicting and changing desires of multiple oversight and stakeholder groups contribute to a lack of project focus. This should be managed by assuring availability of information and an increase in the level of interaction with regulators, stakeholders, and oversight groups. Before decision points are reached, WIPP should discern the values of oversight and stakeholder

organizations, and create oversight and stakeholder understanding of the WIPP path forward. With proper preparation, decisions should become pro forma.

III.6.1.2. Programmatic Document Hierarchy

Assessments: The hierarchy of project documentation was unclear. Many documents normally associated with a project of the magnitude and complexity of WIPP were not found. The WIPP Project Management Plan, for example, was still in draft form, and was not used to manage the project. The apparent lack of system engineering plans, operating program plans, and a DQO process are other examples.

Recommendations: Decisions at upper management levels are generally based upon summarized information. Concise overview documents discussing key project issues are an important element of effective management and decision making. For complex projects like WIPP, the executive summaries of a series of large reports are an inadequate substitute for short, clear, overview documents explaining key issues in non-scientific terms. The WIPP project management plan should be completed consistent with the near term path forward and serve as the cornerstone document defining key project issues in concise and understandable terms.

III.6.1.3. Tenure of Personnel

Observations: The tenure of many WIPP Project personnel (DOE, SNL, WID) in their present positions is short. Personnel turnover appeared to be high. For example, over a period of three years, there were three SNL bin-scale test project managers, and the SNL principal investigator was changed. Similar personnel turnover has occurred within DOE/WPIO. Often, project personnel lacked the general knowledge necessary to answer questions beyond their areas of job specialization or tenure. Perturbations in management and test plans, coupled with regulatory changes make it difficult for project personnel to understand their roles in the path toward certification and permitting. Loss of knowledgeable personnel impedes progress by reducing the understanding of the historical context of the project (i.e., corporate memory) and increasing the potential to revisit past problems and decisions.

Recommendations: The WIPP project should view the retention of capable, knowledgeable personnel as important to program success. Communication should be maintained with knowledgeable people no longer active in the project so that historical perspective is maintained during changes in staff and direction.

III.6.1.4. Intra-Project Communication

Observations: A significant number of organizations are involved within the WIPP project. It was unclear that communication among these organizations is structured and focused on the achievement of the common WIPP Mission. For example, key issues identified by performance assessment as critical to regulatory compliance were not communicated to many program participants.

Each organization (DOE, SNL, WID) has its own Quality Assurance plan. It appears that these Quality Assurance plans are not connected through a normal flow from DOE to Westinghouse and/or DOE to SNL.

The Westinghouse Quality Assurance plan is being transformed into a less prescriptive graded NQA-1 program. A program that is not prescriptive is more readily accepted by project participants, and can enhance progress. A graded NQA-1 program allows quick QA plan changes and can accommodate unanticipated conditions or eliminate unnecessary steps, while assuring the health and safety of the work force. This can form the basis for a uniform project wide QA plan.

Recommendations: Communication between the scientific advisor and the M&O contractor, should be continuous rather than on an "as-needed" basis.

All quality assurance plans and programs for this project should be reviewed for consistency and changed to reflect the proper flow from organization to organization.

The quality assurance plan should be tested during the Engineering and Operations Testing, Cold Commissioning, and Hot Commissioning Phases proposed in the near term path forward. This will provide WID with the opportunity to train people to the QA plan and procedures under actual field conditions.

III.6.1.5. Inter-Program Communication

Observations: Based on experience from past Independent Technical Reviews, and the working knowledge of members of the WIPP ITR Team, it appears that TRU-waste disposal within the overall defense complex is not uniformly treated as an integrated system problem. Waste characterization and modification, waste acceptance criteria, generator utilization, and repository disposal are often dealt with in a piecemeal, locale-specific fashion. Some waste generators believe that they will not be involved in the proposal and development of treatment processes for TRU waste at WIPP.

Recommendations: A fundamental statement of the national TRU waste disposal strategy should be promulgated by DOE. Waste generator experiences with characterization, treatment, and interim storage should be utilized in preparation of a national strategy.

TRU waste generator disposal near-term needs should support certification and permitting of the WIPP project. Information on characteristics and properties of TRU waste relevant to disposal at WIPP is available at waste generator sites. Together, WIPP and the generator sites should determine the scope and value of this information before alternative tests are planned.

Actual VOC generation rates and species could be measured at the generators' sites. A large, random population of drums can be selected and measurement of gas-generation rates can possibly be made with a gas monitoring system. TRUCON Code (waste type), fissile content, age of waste, and external temperature can be taken into account. Results could determine which drums produce an unusually high gas output and they could be opened and investigated in a facility such as that at Argonne West. This will give more information of better quality at lower cost than the proposed Bin and Alcove tests.

III.6.2. Cost & Schedule

Observations: Based on this review, it appears that WIPP expended significant effort in FY1993 toward development of realistic cost and schedule baselines. Determination of the cost of proposed tests remains difficult because estimates are simplistic and performed by many participants. Consistent work breakdown structures or costing systems did not appear to be used by the principal WIPP organizations.

It is unclear whether waste characterization is included in the Alcove Test program cost estimate. The table entitled "FY 1993 WIPP Total Participant Funding" in the WIPP Desk Reference Manual cites a projected FY1993 waste characterization expense of $19M, but the estimated total cost of the Alcove Test program is $20M. These estimates cannot be consistent.

Recommendations: Evaluation of the cost effectiveness of proposed tests is enhanced when cost estimates are available and realistic. The rationale for setting resource allocation priorities should be clearly delineated. Realistic cost and schedule baselines for anticipated testing, regulatory or disposal decisions should be created. A consistent accounting system and work breakdown structure, shared by the primary program participants, should be considered.

III.6.3. Contingency Tests

Observations: The Contingency Test Task Force (CTTF) provided a thorough and well organized review of alternatives to the Bin and Alcove Tests, and a basis for considering alternative large-scale tests. Assumption A in Section 3.4 of the CTTF report[26] specified, "CTs (contingency tests) should provide the same type and quality of information as baseline tests." This limited the range of options considered. The CTTF review found that alternative sources of information on VOCs can be used to meet WIPP project needs.

Recommendations: Alternatives beyond those reviewed by the CTTF should be considered when developing large scale laboratory tests. Other sources of information on VOCs generated by TRU waste (INEL data for example) should be used by the WIPP project.

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[1]Land Withdrawal Act, 1992

[2]DOE, 1993a

[3]D. E. Caldwell, R. C. Hallet, M. A. Molecke, E. Martinez, and B. J. Barnhart, "Rate of CO_2 Production from the Microbial Degradation of Transuranic Wastes under Simulated Geologic Isolation conditions," SAND87-7170 (January 1988).

[4]R. I. Vreeland, Personal Communication, West Chester University, West Chester, PA (August 31, 1993).

[5]Gas-Generation and Source-Term Programs: Technical Needs Assessment for the Waste Isolation Pilot Plant Test Phase, Revision 0, DOE/WIPP 92-062

[6]"Test Plan: WIPP Bin-Scale CH TRU Waste Tests (Type 2 bin), July 9, 1993" (SAND93-1559)

[7]Molecke, SNL, Test Plan: WIPP Bin-Scale CH TRU Waste Tests, SAND90-1974

[8]Pickering and Orrell, 1993

[9]A. C. Peterson, S. A. Orrell, J. T. Holmes/SNL, Test Plan: Waste Isolation Pilot Plant Bin-Scale CH TRU Waste Tests (Type 2 Bin), SAND93-1550

[10]DOE/WIPP 93-037, August, 1993, p. 11

[11]Peterson et al. 1993

[12]WIPP-DOE-069, Rev 4

[13]TRUPACT SARP

[14]WIPP 93-037, August, 1993, Figs. 4b, p. 15

[15]Test Phase Plan for the Waste Isolation Pilot Plant, Revision 1, DOE/WIPP 89-011

[16]Alcove Test plan

[17]The Final Draft Alcove Test Plan

[18]Original Alcove Test Plan (

[19] Connolly, M.J. to P.J. Higgins, "Transmittal of Requested Information--MJC-45-93," *Idaho National Engineering Laboratory Letter*, 8/23/93.

[20]Lucas, 1984

[21] Alcove Test Program, DOE/WIPP 93-035

[22] DOE/WIPP, August 1993

[23]Brown and Jasiulewicz 1992

[24]Davis and Madsen, 1991

[25]Vreeland et al. 1993

[26]Contingency Test Task Force Report Evaluation of Alternate Tests as Contingencies to Replace the Currently Planned Bin and Alcove Tests at WIPP

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APPENDIX A

REGULATORY REFERENCE

A.1. Major Laws and Regulations Affecting WIPP

Certain laws and regulations form the mission and basis for WIPP, and significantly influence compliance demonstration activities.

A.1.1. Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980, Public Law 96-164.

Section 213 of this law authorized the construction of WIPP for the "purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission."

A.1.2. Waste Isolation Pilot Plant Land Withdrawal Act of 1992, Public Law 102-579.

The WIPP Land Withdrawal Act (LWA) was enacted on October 30, 1992. In addition to withdrawing public lands surrounding the WIPP site, the LWA established about 140 separate requirements, of which about 80% are new requirements for DOE and other Federal agencies. Key among the new requirements is a new regulatory framework in which EPA must certify WIPP's compliance with the radioactive waste disposal standards (40 CFR 191) prior to establishing WIPP as a disposal site. The LWA also established numerous requirements involving close and extensive interactions with other agencies, other agency reviews and certifications, and intensive DOE documentation of compliance with applicable regulations. The key actions required by the LWA are represented in Figures A.1 and A.2. In these figures, actions required of DOE are above the horizontal timeline, while actions required of EPA are below it. The LWA includes a number of new prerequisites to starting the Test and Disposal Phase with TRU waste.

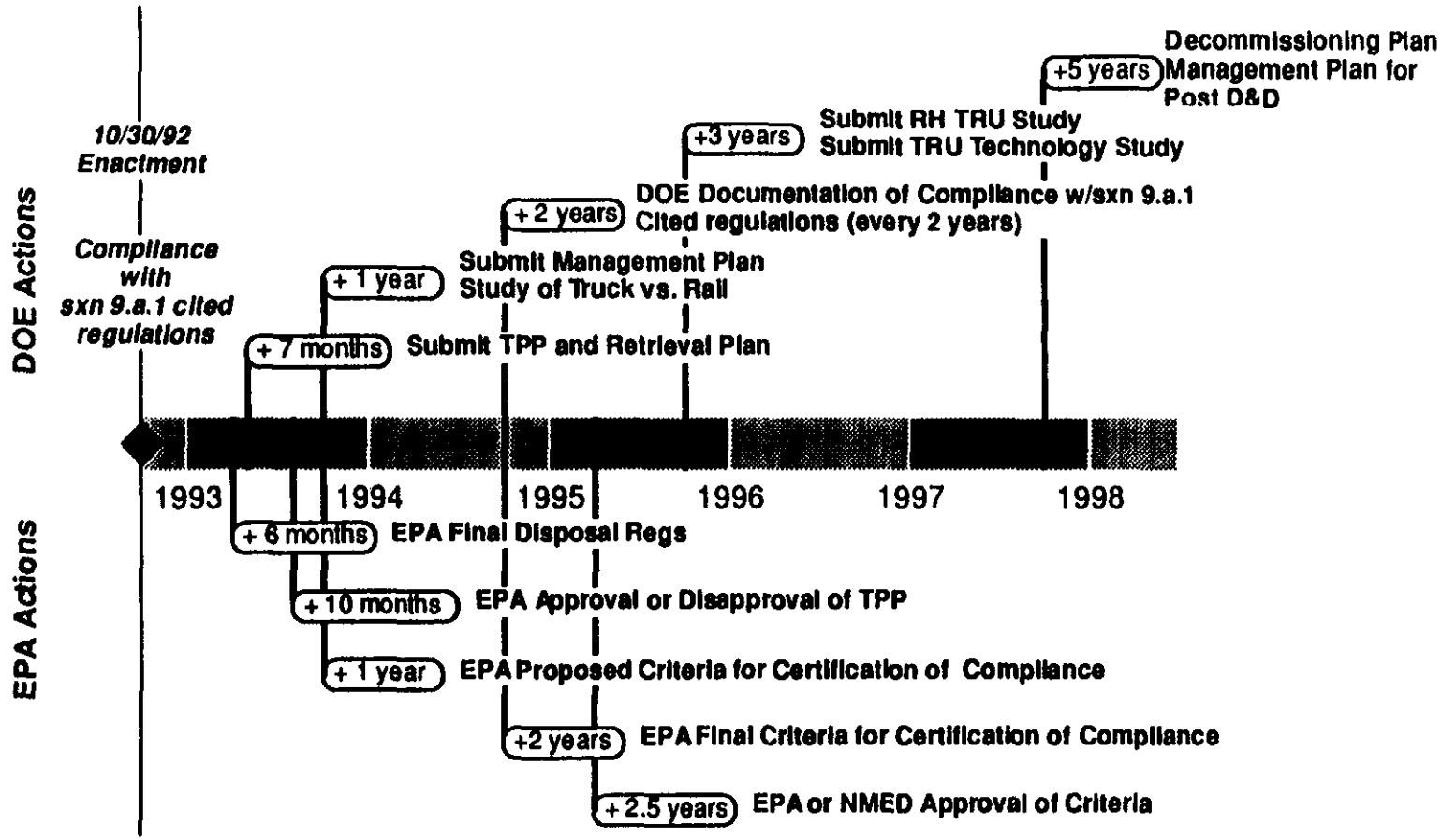

If no TRU Waste Tests at WIPP, then no requirement for:

- *Test Phase Plan*
- *Retrieval Plan*
- *Certification of Safety*
- *Stability of Test Rooms*
- *Final Disposal Regulations to Start Tests*
- *Compliance with NMD*
- *Payment of $20M/Year to N.M.*
- *Transportation Training*

Fig. A.1. LWA Mandated Activities by DOE and EPA

Key prerequisites that must be met before the first Test Phase shipments can begin include the following:

- EPA must promulgate final 40 CFR 191, Subpart B, disposal regulations within 6 months of the date of enactment.
- DOE must submit for EPA's formal review and approval its Test Phase Plan and Waste Retrieval Plan within 7 months. EPA must approve the plans (or portions of the Test Phase Plan) within 10 months of enactment.
- EPA must determine WIPP's compliance with the terms and conditions of the No-Migration Determination issued by EPA under RCRA.
- The Mine Safety and Health Administration (MSHA) must concur in the adequacy of DOE's plan for assuring room stability in the underground test rooms.
- The Occupational, Safety and Health Administration (OSHA) must certify DOE's accident prevention and emergency response training.

Key Disposal Phase prerequisites include the following:

- EPA must certify, by rulemaking, that DOE will comply with the disposal regulations (40 CFR 191, Subpart B).
- DOE must notify Congress of compliance with all applicable environmental laws and regulations.
- DOE must submit to Congress recommendations for the disposal of all TRU waste under DOE control, including a timetable for disposal of such waste.
- DOE must complete a survey identifying all TRU waste types at all sites from which wastes are to be shipped to WIPP, with notice and opportunity for public comment, and provide results to EPA.
- DOE must submit to Congress decommissioning and post-decommissioning plans.
- DOE must wait 180 days after notifying Congress that DOE is in compliance with all applicable environmental laws and regulations.
- DOE must acquire 2 existing oil/gas leases, if EPA determines such acquisition is required to comply with the final disposal regulations or with the Solid Waste Disposal Act.

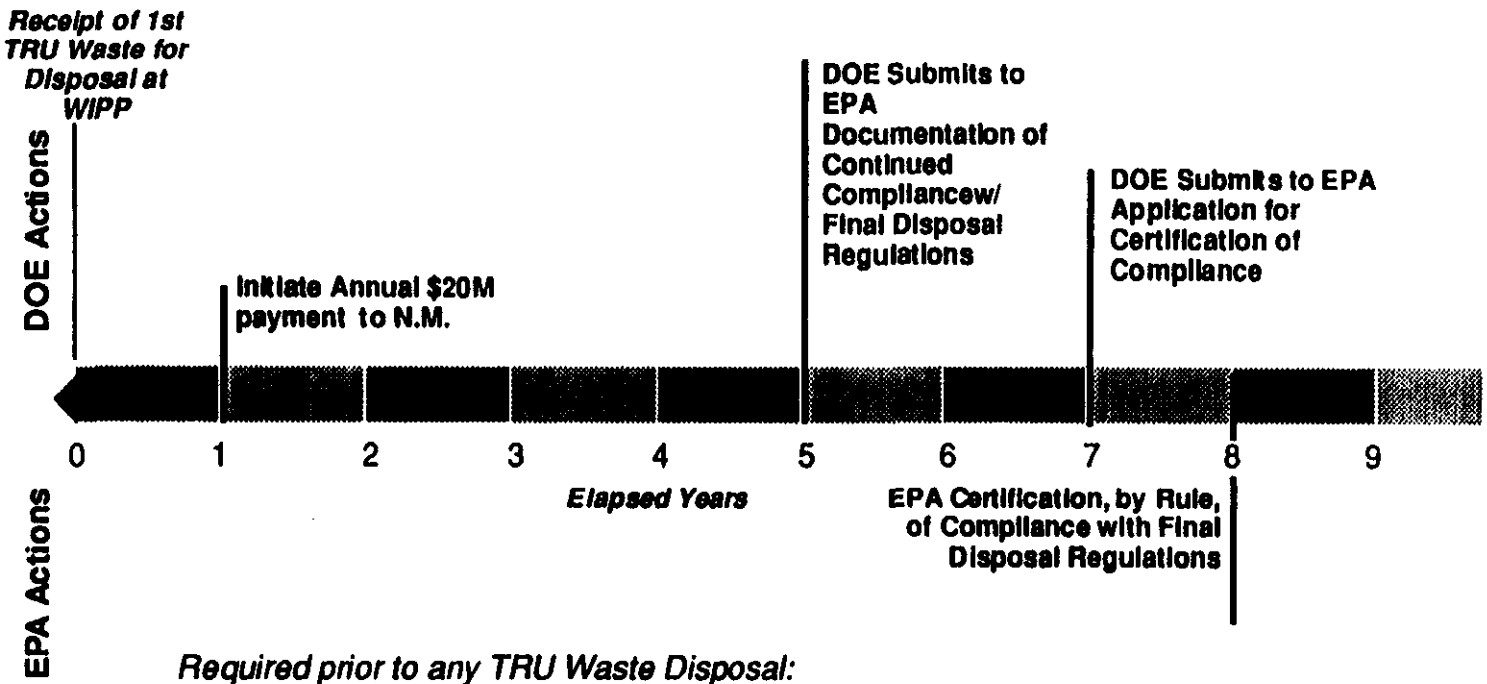

Required prior to any TRU Waste Disposal:

- *EPA certification that WIPP complies with disposal regulations*
- *Decommissioning and post-decommissioning Plans*
- *180 day waiting period after DOE notifies Congress of WIPP compliance with sxn 9.a..1*
- *DOE acquisition of any necessary oil and gas leases*
- *Plan submitted to Congress for disposal of all DOE TRU wastes*
- *Survey of all DOE TRU waste*
  - *Results given to EPA*
  - *Results given to public*

Fig. A.2. LWA Mandated Disposal Actions by DOE and EPA

A.1.3. Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, 40 CFR 191.

Subpart A of the regulation applies to radiation doses received of the public as a result of the management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes. Subpart B applies to radioactive materials released into the accessible environment as a result of the disposal of spent nuclear fuel of high-level or transuranic wastes; radiation doses received by members of the public as a result of such disposal; and radioactive contamination of certain sources of ground water in the vicinity of disposal systems for such wastes.

A.1.4. Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, 40 CFR 264.

These standards apply to owners and operators of facilities, including WIPP, which treat, store, or dispose of hazardous waste. Subpart X of this regulation pertains to "miscellaneous units," as defined by RCRA regulation. WIPP has been identified as a miscellaneous unit.

A.1.5. Land Disposal Restrictions, 40 CFR 268.

This regulation identifies hazardous wastes that are restricted from land disposal and defines those circumstances under which an otherwise prohibited waste may continue to be land disposed. A petition process is identified in 40 CFR 268.6, which outlines the process of seeking an exemption from a prohibition. Since DOE intends to dispose of untreated wastes at WIPP, it must petition the EPA for a variance under 40 CFR 268.6.

A.1.6. Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant, 55 FR 47700, November 14, 1990.

In response to a petition from the DOE under 40 CFR 268.6, EPA made a determination of no migration for the placement of hazardous waste at WIPP during the Test Phase. This determination imposes several conditions on such placement and is for a maximum of 10 years. As a result of this determination, DOE may place a limited amount of untreated waste subject to the land disposal restrictions in WIPP for the purposes of testing and experimentation.

A.2. Regulatory Instability

Since WIPP was authorized by the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980, the WIPP project has been subjected to a constantly changing regulatory

framework. Most significant was the DOE's acknowledgment in 1987 that its facilities were subject to the RCRA. Until then, the DOE had not been involved in rulemaking activities that related to RCRA. Subsequently, the DOE became subject to RCRA regulations, and the WIPP project was forced to react to a new set of regulatory requirements. The Land Disposal Restrictions in 40 CFR 268 are of particular concern, because they require that all hazardous wastes be treated before disposal to the land. Since the DOE had planned to dispose of untreated wastes at WIPP, its basic strategy was to apply for a variance under 40 CFR 268 rather than to treat TRU mixed wastes.

After the DOE acknowledged that its facilities were subject to RCRA regulations, DOE facilities that were storing, treating, and/or disposing of hazardous wastes were required to submit Part A permit applications to the appropriate regulatory authorities. By so doing, these facilities would qualify as "interim status" facilities until their final (Part B) permits were prepared and approved. Not knowing which regulatory body was responsible for the WIPP site, the DOE submitted applications to both the EPA Region 6 and the State of New Mexico Environmental Improvement Division (NMEID). Because the EPA had delegated its basic program to the NMEID, EPA would not accept DOE's application. Because the NMEID had not yet been authorized to regulate mixed waste, it would not take action on DOE's application either. The WIPP site was thus caught in a "regulatory limbo."

The NMEID [now called the New Mexico Environment Department (NMED)] was not authorized to regulate mixed waste until 1990. Shortly after being authorized to regulate mixed waste, the NMEID required that DOE submit both the Part A and Part B RCRA applications. The DOE maintains that it followed all procedural requirements, thereby qualifying for interim status. As an interim status facility, the DOE would be authorized to treat, store, and/or dispose of hazardous waste before receiving approval of its Part B application. The Attorney General of New Mexico challenged the Department of Interior's Administrative Withdrawal of WIPP lands and the DOE's assertion that WIPP qualified as an interim status facility and filed suit in U.S. District Court. This lawsuit resulted in a court-ordered permanent injunction in January 1992 prohibiting shipments of waste to WIPP. In July 1992, the U.S. Court of Appeals reversed the U.S. District Court's ruling; however, the permanent injunction is still in effect and must be lifted by the U.S. District Court before shipments can begin.

In 1985, the EPA promulgated its environmental radiation protection standards for the management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes. In 1987, following a legal challenge by the Natural Resources Defense Council, the U.S. Court of Appeals remanded subpart B of the 1985 standards to the EPA for further consideration. Due to a lack of binding standards, the DOE agreed that it would comply with the 1985 standard

until a new standard was promulgated. The WIPP LWA of 1992, however, reinstated the 1985 disposal standards except three aspects of sections 40 CFR 191.15 and 191.16 that were subject to the remand ordered by the Court. EPA has yet to repromulgate its final disposal standards. The WIPP LWA also established EPA as the regulator under 40 CFR 191. Until that time, the EPA was responsible only for establishing the standard and it was the DOE's responsibility to certify that the standard was satisfied.

In addition to the final disposal standard, EPA has yet to issue its certification criteria (40 CFR 194). The certification criteria are intended to establish requirements that will support a "reasonable expectation" of compliance and to identify the required format and content of WIPP's certification application. The LWA requires that EPA issue proposed criteria by October 1993 and its final criteria by October 1994. However, the EPA has indicated that the draft rule will not be available for public comment until early 1994 and does not expect to issue the final rule until early 1995.

The EPA is currently soliciting advice and counsel from the National Advisory Council for Environmental Policy and Technology (NACEPT) regarding WIPP activities. The WIPP Review Committee was formed as a NACEPT Subcommittee to provide independent advice and counsel on specific EPA activities, issues, and needs as they relate to the EPA's implementation of the Land Withdrawal Act. This committee will advise the EPA Administrator on policy and technical matters including:

- EPA's decision to approve/disapprove DOE's Test and Retrieval Plans for the WIPP;
- EPA's development of compliance criteria for implementing 40 CFR 191 disposal standards; and
- EPA's decision whether or not the WIPP complies with 40 CFR 191.

After this review, the public provided comment on three compliance questions:

- To reduce uncertainty in compliance assessment, should the EPA specify certain "future states" assumptions? If so, what aspects of the future should the EPA address and how?
- To reduce uncertainty in compliance assessment, should the EPA specify certain assumptions related to human intrusion? If so, what aspects of human intrusion should the EPA address and how?
- Should the EPA address the use of engineered barriers at the WIPP? If so, why and how?

Each issue is significant and the answers to these questions will significantly impact the DOE's compliance strategy.

A.3. Regulatory Conflicts Between 40 CFR 191 and 40 CFR 268.

The RCRA discourages land disposal of hazardous wastes. RCRA states, ". . . reliance on land disposal should be minimized or eliminated, and land disposal, particularly landfills and impoundments, should be the least favored for managing hazardous wastes." (RCRA, Section 1002(b)(7)). This law motivated the EPA to issue regulations, i.e. 40 CFR 268, that encourage treatment of hazardous wastes rather than land disposal. On the other hand, the NWPA and the LWA are supportive of disposal of radioactive wastes in deep geologic repositories. These laws motivated the EPA to issue and recently re-issue regulations, i.e., 40 CFR 191 that are stringent but do not require that the waste be treated. Since the WIPP must also comply with 40 CFR 268, however, the DOE is evaluating compliance options and to what extent TRU wastes need to be treated before being disposed of at WIPP.

Currently, the DOE plans to dispose of untreated TRU wastes at WIPP. In order to comply with EPA's Land Disposal Restrictions (40 CFR 268), the DOE must either treat its waste using EPA's performance standards/technologies or it can petition for a variance under 40 CFR 268.6. This variance, if granted, would allow untreated waste to be emplaced at WIPP. This variance petition would require a performance assessment to be performed, similar to that required under 40 CFR 191, that would demonstrate that the waste "will not migrate for as long as the waste remains hazardous."

The regulations specify different points of compliance: a "unit boundary" per 40 CFR 268 and the "accessible environment" which lies beyond a "controlled area" per 40 CFR 191, as schematically shown in Figure A.3. For surface impoundments, landfills, and waste piles (none of which compare to the WIPP), the unit boundary is defined as the outermost extent of the engineered barrier(s), such as a liner, ditches or berms, that contain the waste. Hazardous wastes that cross this boundary cannot exceed the EPA's soil contamination limits. If the wastes are not enclosed, the unit boundary includes the downwind edge of the disposal unit at a height of 1.5 meters, the typical height at which humans could inhale hazardous material. Hazardous gases and suspended particulates that cross this boundary cannot exceed the EPA-established limits.

The concept of a unit boundary was developed for disposal facilities that lie at or just below the ground surface. The WIPP, however, lies 2100 feet below the surface of the ground. Consequently, the EPA moved the unit boundary from the surface to the portion of the Salado Formation that falls within the WIPP land withdrawal area[1]. The top of the Salado lies 1000 feet beneath the surface and its lower member extends down to 3000 feet. Hazardous

gases that cross the top of the Salado Formation cannot exceed the EPA's air contamination limits, even though there is essentially no air 1000 feet below the ground for humans to inhale.

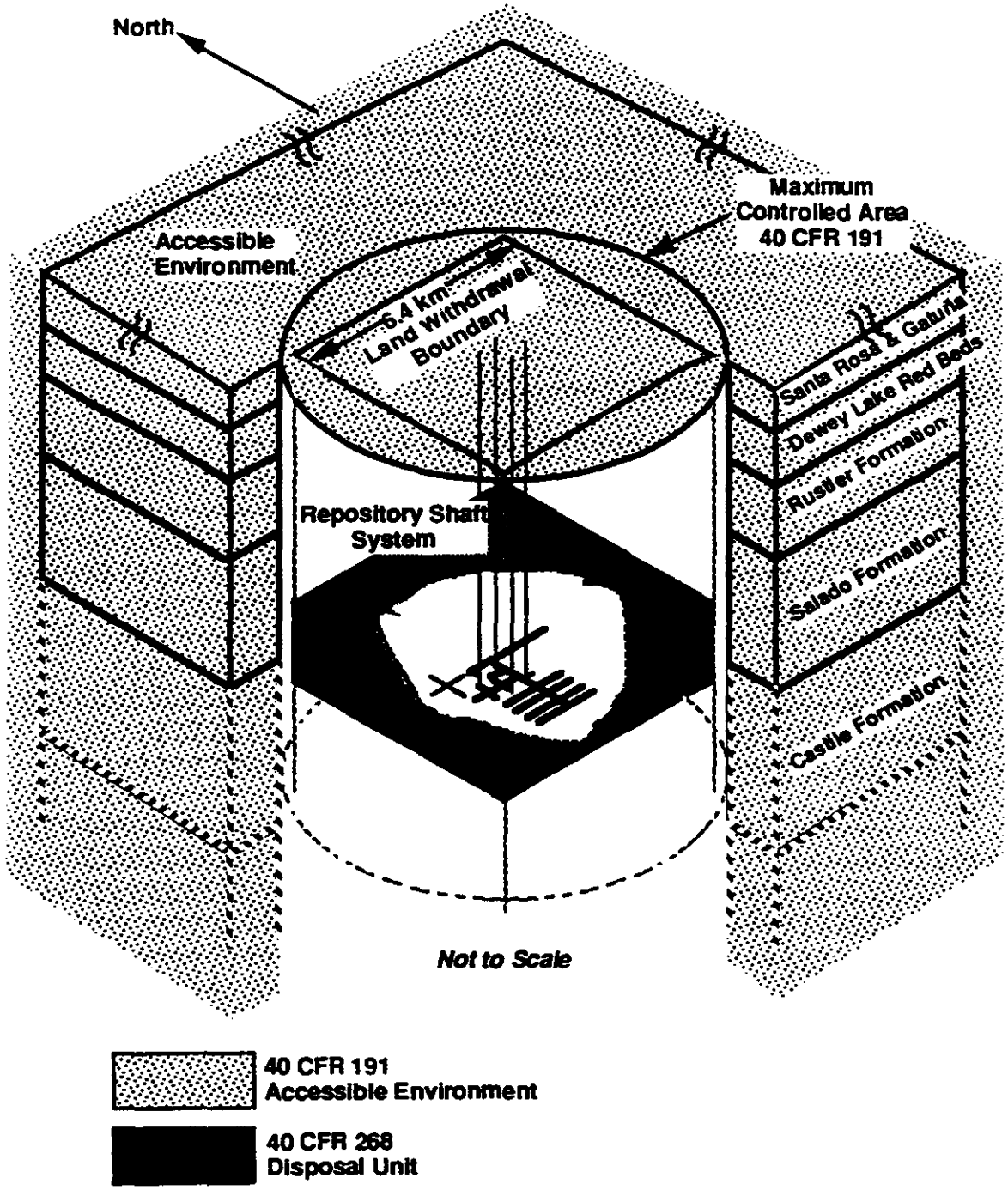

Fig. A.3. WIPP Regulatory Boundaries

As defined in 40 CFR 191, the controlled area would allow the WIPP to take more credit for the surrounding geology. However, DOE restricted the controlled area so that it coincides with the land withdrawal area. Still, the controlled area encompasses more geology than the unit boundary. The top of the controlled area lies at the land surface, but the top of the unit boundary lies 1000 feet below the surface.

Finally, the regulations dictate different approaches to performance assessments. The RCRA regulations, including 40 CFR 268, are deterministic i.e., they call for a single value calculation while 40 CFR 191 is probabilistic i.e., a complementary cumulative distribution function plots the probability of exceeding multiples of the EPA's release limits. In addition to those already stated, other differences can be found between these regulations, such as different monitoring requirements.

A.4. Human Intrusion Scenarios.

Appendix B, Subpart B, 40 CFR 191, provides guidance regarding how human intrusion should be addressed in Performance Assessments. Although this guidance is not mandated by regulation, the applicant must demonstrate that any alternative approach will provide adequate protection of the general environment from radioactive material. According to Appendix B, performance assessments can assume that "... the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations..." (40 CFR 191, Subpart B, Appendix B). When applied to the Delaware Basin, this assumption yields 900,000 boreholes per 10,000 years of which 15 would penetrate the WIPP facility[2].

The New Mexico Attorney General[3] claims that the drilling frequency at the WIPP would be at least ten times higher than the EPA's worst case, and the New Mexico Environmental Evaluation Group[4] claims that the frequency would be almost 18 times higher. The Attorney General reports that in the two-mile band surrounding the WIPP site, 63 boreholes have been drilled since 1977, making the actual drilling rate in that area 340 holes per square kilometer per 10,000 years. The EEG reports that within the same area, 99 wells have been drilled since 1978, making the actual drilling rate 530 holes per square kilometer per 10,000 years. Thus, depending upon how the data are manipulated, the "worst case" for human intrusion could be 15 to 255 hits per 10,000 years.

The "hits" generally fall into three categories or scenarios[5]:

(1) boreholes penetrate a waste-filled room or drift and into a pressurized brine reservoir in the underlying Castile Formation;

(2) boreholes penetrate only a waste-filled room or drift; and

(3) while (1) and/or (2) occurs, water within the Culebra formation, which lies above the repository, is pumped from a well located downstream from the repository.

Human intrusion is the most likely scenario whereby the WIPP repository could release radionuclides. Assessment of such scenarios indicates that most of the radioactive release would be pumped out of the borehole with the drill cuttings. The concentration of the radionuclides depends upon two highly uncertain parameters: the size of the hole and the duration of the drilling. Because the DOE's compliance argument hinges on these parameters, models are being developed to determine the amount of waste that would be removed by the drill cuttings and by erosion of the borehole caused by the circulating drilling fluid.

Assessments of scenarios (2) and (3) indicate that radionuclides could contaminate the Culebra groundwater[5]. Without human intrusion, however, radionuclides are not predicted to reach the Culebra formation. Regional and local groundwater flow within the Culebra formation are also being modeled to determine radionuclide concentrations and transport time. In addition to the model, 21 studies are currently in progress or will be undertaken ". . . to evaluate the ability of the Culebra and surrounding units to adequately confine the waste disposed of in the repository after inadvertent human intrusion."[6].

Besides modeling, laboratory, and field studies, DOE has utilized "expert opinion" to estimate the probability of future human intrusion. The DOE convened four panels of independent experts to determine the probability that humans would disturb WIPP. The estimates ranged from 0.01 to nearly 1[7]. Other experts[8], working for the former Basalt Waste Isolation Project, could not agree on a probability that humans may disturb a potential repository in Hanford, Washington. Recently, protective barriers were surveyed[9] that could deter human intrusion. Among others, he suggests that warnings be inscribed on a large number of small (several centimeters) markers. The markers would be buried with the waste and when a drill hits them, they would be brought to the surface and frighten the drillers away. According to the EPA, monument could be used to reduce the probability of human intrusion. However, none of the experts would say by how much.

Recognizing the potential impacts of human intrusion, the EPA is considering the benefits of promulgating criteria for engineered barriers[10]. According to the EPA, such barriers could mitigate releases, provide defense- in-depth and compensate for uncertainty[11]. Because natural disturbances do not affect the WIPP repository, we assume that engineered barriers would lessen the impact of human intrusion.

In summary, human intrusion is the most likely scenario whereby radionuclides could be released into the accessible environment. Although 40 CFR 191, Subpart B, Appendix B offers guidance on acceptable methods for handling human intrusion, it is not the only allowable approach. Some effort has been made to examine alternative human intrusion scenarios and resulting conceptual models. Currently, the EPA is soliciting input from the public on how it should proceed in developing its compliance criteria related to human intrusion. Therefore, the DOE needs to formalize and document its alternative approach quickly, based upon declining oil dependency, creep closure of boreholes, and effectiveness of passive institutional controls, and include the approach for earliest submission to the regulator.

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[1]EPA, 1990

[2] Guzowski, 1991

[3] Udall, 1993

[4] EEG, 1993

[5]Bertram-Howery, et al., 1990

[6]DOE, 1993b, page 5-1

[7]Hora et al., 1991

[8]Davis and Runchal, 1984

[9]Tolan, 1993

[10]EPA, 1993

[11]Petti, 1993

APPENDIX B

GAS GENERATION PHENOMENA

TECHNICAL REFERENCE

Appendix B provides a background discussion of the anticipated principal WIPP TRU waste gas generation mechanisms. Section B.1. discusses corrosion, and B.2. microbial processes, which are considered to be the principal gas generation mechanisms. Radiolysis, a minor generator of gas, is discussed in Section B.3. Section B.4. comments on volatile organic compounds. These discussions are topical and not meant to be complete or exhaustive. Other sources such as books, technical journals and WIPP reports, should be consulted for detailed information.

B.1. Corrosion Gas Generation Mechanisms

B.1.1. Corrosion of Carbon Steel in Air.

The corrosion of iron or carbon steel that is in contact with a gas phase is due to oxidation by water vapor or oxygen.

$$2Fe + 3H_2O \longrightarrow Fe_2O_3 + 3H_2$$

$$4Fe + 3O_2 \longrightarrow 2Fe_2O_3$$

If the partial pressure of hydrogen becomes sufficiently high, the hydrogen will back react to water.

B.1.2. Corrosion of Carbon Steel in Brine.

The corrosion of iron or carbon steel in contact with brine involves two simultaneous electrochemical reactions, one anodic and the other cathodic. The anodic reaction results in "active" corrosion (or dissolution) that liberates electrons.

$$Fe \xrightarrow{\text{brine}} Fe^{2+} + 2e^-$$

The cathodic reaction involves the dissociation of water, followed by the cathodic evolution of hydrogen from the metal surface.

$$H_2O \xleftrightarrow{\text{brine}} H^+ + OH^-$$

$$2H^+ + 2e^- \xrightarrow{\text{brine}} H_2 \uparrow$$

Electrons liberated by the anodic dissolution of iron are consumed by cathodic evolution of hydrogen. Increasing temperature, increasing ionic strength of the brine, and decreasing pH all increase the reaction rates. Under certain conditions, the reaction rates at the bare metal surface become negligible and the surface is said to be *immune* to corrosion. Under other conditions, protective films of oxides or other compounds form on surfaces, thereby preventing corrosion and gas generation. If they are adherent, such films can prevent the sustained oxidation of the underlying metal substrate. Metal surfaces protected by such films are called "passive."

Passivation prevents gas generation. Carbon steel can be passivated by an oxide formed by the reaction of water and iron. It can also be passivated by any one of several gases that are anticipated in the WIPP environment, including carbon dioxide and hydrogen sulfide. The first step in forming a passive film of siderite, $FeCO_3$, involves the production of carbonic acid during the dissolution of gaseous carbon dioxide, and its dissociation into hydrogen, bicarbonate and carbonate ions:

$$CO_2 + H_2O \xrightarrow{\text{brine}} H_2CO_3$$

$$Fe^{2+} + CO_3^{2-} \xrightarrow{\text{interface}} FeCO_3 \downarrow$$

Similarly, the first step in forming a passive film of iron sulfide involves the dissolution of gaseous hydrogen sulfide, H_2S, producing sulfide anions.

$$H_2S \xrightarrow{\text{brine}} HS^- + H^+$$

$$HS^- \xrightarrow{\text{brine}} S^{2-} + H^+$$

Dissolved hydrogen sulfide (sulfide anions) can react with dissolved iron cations to form passive films of troilite (FeS).

$$Fe^{2+} + H_2S \xrightarrow{\text{interface}} FeS \downarrow + 2H^+$$

$$Fe^{2+} + HS^- \xrightarrow{\text{interface}} FeS \downarrow + H^+$$

$$Fe^{2+} + S^{2-} \xrightarrow{\text{interface}} FeS \downarrow$$

If the reduction of hydrogen is included, the overall reaction becomes

$$Fe + H_2S \xrightarrow{\text{interface}} FeS + H_2 \uparrow$$

Polysulfide can react with dissolved iron to form passive films of pyrite, FeS_2. If the reduction of hydrogen is included, the overall reaction becomes

$$Fe + H_2S_2 \xrightarrow{\text{interface}} FeS_2 + H_2 \uparrow$$

In some cases, nonadherent corrosion products are formed. For example, consider the formation of anakinite on carbon steel submersed in a magnesium-containing WIPP brine.

$$xFe^{2+} + (1-x)Mg^{2+} + 2OH^- \xrightarrow{\text{interface}} Fe_xMg_{1-x}(OH)_2 \downarrow$$

Although this corrosion product does not form an adherent passive film, it can inhibit corrosion if it is held at the metal surface by gravity or compression. Note that other corrosion phenomena, such as pitting, may become important even if surfaces are passivated. Halide ions, such as chloride ion, can result in localized breakdown of passive oxide films.

B.1.3. Maximum Possible Gas Evolution.

The complete corrosion of one mole of iron in brine generates from $^2/_3$ to $1^1/_2$ moles of hydrogen gas. If the weight of an empty 55-gal carbon steel drum [about 60 lb (27 kg)] is equivalent to 488 moles of iron, about 488 moles of corrosion-generated hydrogen per drum would be expected if all the iron is reacted. About 110 lb (50 kg) of carbon steel per drum would be required to produce the 900 moles of hydrogen per drum that has been quoted in various WIPP documents. But, this amount of gas can only be produced if there is adequate brine available to support the corrosion. It is important, consequently, for the WIPP Project to obtain realistic bounds on the amount of brine that might contact metals in the repository.

B.1.4. Brine Availability.

Brine availability is one of the most important sources of uncertainty in the PA component model for corrosion. The rates of gas generation by both anoxic corrosion and microbial growth will probably be high if the waste is inundated with brine. Otherwise, gas generation will be insignificant.

As a first-order approximation, we can assume that gas is generated only when waste comes in contact with brine (inundated condition) and that these reactions are fast (essentially instantaneous). Gas generation by waste under humid conditions is relatively insignificant. In the latter case, it is unlikely that lithostatic pressure will be exceeded. Thus, gas generation will be of very little concern.

B.2. Microbial Gas Generation

B.2.1. Interactions Between Microorganisms and TRU-Wastes in the WIPP Repository

The purpose of Section B.2. is to review what is known about microorganisms inhabiting the WIPP environment, and the significance of microorganism-waste interactions on long-term disposal of TRU wastes in the repository. Section B.2. also highlights the uncertainties relative to microbe-waste interactions and estimates their magnitude.

B.2.2. Microbial Ecology Background.

Because microorganisms are ubiquitous, TRU wastes will be contaminated with microorganisms indigenous to the generator sites. Most waste will be dry except sludges to which cement is added to reduce free water in the waste containers. Microorganisms will survive in the waste container environment and sustain themselves by slowly degrading organic materials (readily oxidizable organic matter entrained in the paper tissues, cellulosic materials, and possible organic solvents). Limited entrapped moisture will probably restrict biodegradation of waste in intact containers.

After the waste containers are emplaced underground at WIPP, microorganisms brought in by the ventilation system (predominantly organisms from the above-ground vicinity at WIPP) and organisms present in the brine seeps, muck, backfill material and salt crystals can be expected to contaminate the waste through drum seals and most certainly when the drums are breached. Microorganisms from the WIPP environs will probably be halobacteria [halophilic (salt-loving) or halotolerant (tolerant of salt) organisms], because the highly saline environment in and around the WIPP site selects such organisms. The humid conditions of the repository and possible brine intrusion could potentially create conditions that would allow the halophilic/halotolerant organisms to reproduce and to degrade the wastes. If brine inundation of the waste occurs, those organisms that were resident on the waste at the time of generation would probably not survive, because of salt intolerance. The predominant population on the waste would become the halophilic bacteria inhabiting the WIPP site.

The study of bacteria in hypersaline environments is in its infancy. Halobacteria require salt concentrations between 1.5 M (9%) NaCl and 3.5 to 4.5 M (21 to 27%) NaCl. Their briny habitat may also be rich in other ions, including potassium, magnesium, sulfate, carbonate, and hydroxide. Many halobacteria exhibit active growth and motility (motion) in saturated salt solutions and are only mildly inconvenienced by the salt crystals they encounter[1]. The most halophilic, Archaea, often become trapped in fluid inclusions and survive extremely well within the salt crystals. The organisms' ability to be captured and survive in brine inclusions is perhaps their most critical survival skill. The

metabolic diversity of these organisms and their long-term survival in fluid inclusions inside salt crystals are only two of the many questions regarding these bacteria[1]. Little is known about the survivability and metabolism of the halobacteria. SNL studies have emphasized isolating the bacteria from surface and subsurface locations at WIPP and enriching the cultures to study their waste-degrading characteristics.

B.2.2.1. Caldwell Study on Microbial Populations Above Ground at WIPP. In 1978 a preliminary biogeochemical investigation[2] was undertaken to identify and quantify some of the key microbial agents and processes occurring in the surface soils and waters of the WIPP site and vicinity. Halophilic and thermophilic (heat-loving) microorganisms were identified in this population study. Microorganisms were abundant in all surface environments that were sampled, but the data did not quantify any potential biogeochemical cycle that could affect the transport and fate of radionuclides.

B.2.2.2. West Chester University Study of the WIPP Environs. A more substantive investigation of the microflora above-ground and below-ground at the WIPP site was undertaken in 1990 by West Chester University[3]. The cultures were obtained by creating culture conditions that select microorganisms with a specific type of metabolism (for example, microorganisms that can oxidize cellulose using sulfate as an electron acceptor). The goals of this study were: (1) to assess bacterial population sizes and distributions in Nash Draw (a surface region characterized by brine lakes near the WIPP) and in the underground WIPP facility and (2) to examine and compare the degradation rates of different types of papers (cellulosics) by organisms isolated from the WIPP environs. Results of this study were reported to SNL in monthly and annual reports but have not been published.

The West Chester University study isolated large numbers [106 CFU/ml (colony-forming-units)] of halobacteria from mud and lake samples from Nash Draw. Brine samples from underground at WIPP contained 104 CFU/ml. Solid, dry salt crystals from the WIPP underground contained from 0 to 104 CFU/gram of salt. Viable halobacteria from salt crystals presumably come from fluid inclusions. The results of a taxonomic study indicate that a biochemically diverse population of extremely halophilic and halotolerant bacteria exists at and within the WIPP site. These studies suggest that gas may be generated under a variety of environmental conditions. Preliminary studies on bacterial cellulose degradation showed that after halobacteria and cellulose fibers were exposed to brine, the organisms attached to the fibers within two hours, and then visible biofilms with red or pink pigmentation developed. Many halobacteria are facultative anaerobes (grow under either aerobic or anaerobic conditions). Under anaerobic conditions, the halophilic facultative anaerobes degrade carbohydrates, cellulose, or amino acids and produce gas. Preliminary

studies have also demonstrated that microbial degradation of cellulosics produces various organic acids.

B.2.3. Biogeochemical Processes that could Affect TRU Waste Disposal.

Microbial degradation of organic matter produces gases, by-products, and conditions that can transform the types of metals and radionuclides that are present in the TRU-waste inventory. Such processes include (1) aerobic respiration, (2) anaerobic respiration using various electron acceptors, (3) fermentation and methanogenesis, and (4) metal/radionuclide bioaccumulation or biotransformation or both. The following subsections briefly describe the bioprocesses and their implications for the disposal of TRU wastes at WIPP. They also summarize the results and conclusions of ongoing BNL studies[4] on biodegradation of organic-matrix, simulated TRU wastes using halobacterial isolates/enrichments under anticipated repository conditions.

B.2.3.1 Aerobic Respiration. Cellulose is composed of glucose units bound together in a long, linear chain. Many microorganisms must decompose cellulose since the microbial cell is impermeable to the large cellulose polymer. Such microorganisms excrete enzymes that hydrolyze the insoluble cellulose, converting it into soluble sugars that penetrate the cell membrane:

$$\underset{\text{cellulose}}{(C_6H_{10}O_5)_n} + n\,H_2O \longrightarrow \underset{\text{glucose}}{nC_6H_{12}O_6}$$

The hydrolysis of cellulose consumes water. In the presence of oxygen, the glucose molecule, $C_6H_{12}O_6$ (or more simply $[CH_2O]_6$) is oxidized by aerobic microorganisms producing carbon dioxide and water:

$$CH_2O + O_2 \longrightarrow CO_2 + H_2O$$

The microorganisms derive energy for cellular activities and reproduction from this reaction. Some of the glucose is converted to biomass ($C_5H_7O_2N$). Nitrogen compounds are required for biomass production.

$$CH_2O + 0.11\,H^+ + 0.11\,NO_3^- + 0.21\,0_2^- \longrightarrow$$

$$0.11\,C_5H_7O_2N + 0.67\,H_2O + 0.44\,CO_2$$

The biological oxidation of glucose produces water. The water budget is difficult to calculate for TRU-waste. The amount of water consumed in cellulose hydrolysis is equivalent to the number of glucose units making up the cellulose polymer. The water produced from oxidation of glucose is dependent

on how much glucose is converted to biomass versus how much is oxidized directly to carbon dioxide and water.

Aerobic microbial degradation of cellulose is anticipated to occur[5] until the oxygen entrained in the TRU-waste, or produced from radiolysis of brine or sludges, is consumed. Limitations to bio-oxidation of cellulose are lack of water for cellulose hydrolysis and/or the availability of nitrogen compounds for biomass production. Brush[5] estimated that only about 1% to 2% of the estimated 10 kg of cellulosic material per drum can be oxidized because of limited oxygen availability.

BNL studies[4] have shown that when halobacteria isolated from the WIPP site oxidized cellulose, the amount of CO_2 generated compared well with theoretical estimates used for models (Brush, December 1991).

Estimated Gas Production Rate[6]
from Inundated Waste (moles gas/drum/year)

Minimum = 0
Best = 1
Maximum = 5

Laboratory Gas Production Rates[4]
from Inundated Waste (moles gas/drum/year)

Environment	No additions	Inoculated	Inoculated + Nutrients	Inoculated + Nutrients + NO_3^-
Aerobic	0.16	0.0	1.28	3.68
Aerobic with bentonite	0.48	0.16	4.48	5.44

Barnhart[7] and Caldwell[8] reported carbon dioxide production from aerobic and anaerobic biodegradation of simulated, organic-matrix, TRU wastes. The inoculum for these studies, derived from a shallow, TRU-waste, burial site at Los Alamos National Laboratory, was not representative of the microflora from the WIPP site. Therefore, gas generation data from this study are not comparable to present data of BNL investigators[4] who are using a halobacteria inoculum from the WIPP site.

Carbon dioxide produced by aerobic bacterial oxidation of glucose could passivate metals minimizing chemical corrosion. This potential synergistic effect is being evaluated by collaborative investigations between BNL and PNL.

B.2.3.2. Anaerobic Respiration of Cellulosics. In the absence of oxygen as an electron acceptor, microorganisms resort to anaerobic respiration in which the final electron acceptors are such compounds as nitrate, manganese oxides or hydroxides, iron oxides or hydroxides, and sulfate. The use of these electron acceptors is dependent on their availability, the capability of the microbial population to use these electron acceptors, and the oxidation-reduction potential of the system. As the system becomes less oxidizing (more reducing), the electron acceptors will be used in the order presented. That is, after oxygen depletion, nitrate would be used first, if available. After the most easily oxidized materials are consumed, sulfate will be used as an electron acceptor by the appropriate microbial population. Anaerobic respiration reactions and laboratory results on the biodegradation of cellulosics by halobacteria from WIPP are summarized below.

- **Nitrate Reduction/Denitrification.** Nitrate is the first electron acceptor to be used by microorganisms after the depletion of oxygen:

$$CH_2O + 0.8\ NO_3^- \longrightarrow 0.6\ H_2O + 0.8\ HCO_3^- + 0.2\ CO_2 + 0.4\ N_2$$

$$CH_2O + 0.46\ H^+ + 0.46\ NO_3^- \longrightarrow$$

$$0.076\ C_5H_7O_2N + 0.96\ H_2O + 0.624\ CO_2 + 0.192\ N_2$$

While some bacteria convert nitrate into nitrite and ammonia, other microorganisms are capable of reducing nitrate all the way to nitrogen. This latter process is called denitrification. In some instances, certain gaseous intermediates, such as nitrous oxide, will be produced. Note that this process produces not only gaseous nitrogen products, but carbon dioxide as well.

Nitrate reduction/denitrification is expected to occur in the WIPP repository, because the WIPP waste inventory contains copious amounts of nitrate[5]. Nitrate-containing wastes and the cellulosic wastes will be in separate containers. Therefore, the waste containers must be breached and brine inflow into the repository must occur to mix the two wastes before microbial nitrate reduction/denitrification takes place.

Studies at BNL[4] have shown that in an inundated brine environment, halobacteria from the WIPP site can produce gas during cellulose degradation,

using nitrate as an electron acceptor. Table B-1 summarizes this laboratory produced information.

TABLE B-1

Gas Production rates under Anaerobic conditions with Nitrate as an Electron Acceptor (moles gas/drum/year)

Environment	No Additions	Inoculated	Inoculated + Nutrients	Inoculated + Nutrient + NO_3^-
Anaerobic	0	0.48	3.36	6.24
Anaerobic + Bentonite	0	1.12	2.08	4.0

- **Manganese Reduction.** After all nitrate is consumed, some microorganisms can use manganese (IV) oxides and hydroxides as electron acceptors:

$$CH_2O + MnO_2 \longrightarrow Mn^{2+} + CO_2 + H_2O$$

Manganese reduction is not believed to be important in the WIPP repository because manganese is not present in the waste inventory nor in the geologic matrix of the mine. Hence, no laboratory studies using manganese as an electron acceptor have been performed or proposed.

- **Iron Reduction.** As conditions become still more reducing in the environment, some microorganisms will use Fe(III) as an electron acceptor:

$$HCOOH + 2Fe^{3+} \longrightarrow 2Fe^{2+} + 2H^+ + CO_2$$

A considerable amount of iron is present in the WIPP inventory from drums and metal parts. It is unclear, however, how much iron will be in a form available for microbial reduction because some of it will be combined as various corrosion products[5]. If magnetite (Fe_3O_4) forms, however, microbial iron reduction could be a significant process. At this time, no laboratory studies are underway to evaluate this possibility.

- **Sulfate Reduction.** Under highly reducing conditions and in the absence of other electron acceptors, some microorganisms will use sulfate as an electron acceptor and produce hydrogen sulfide:

$$CH_2O + 0.5\,SO_4^{2-} \longrightarrow 0.5\,H_2S + HCO_3^-$$

Bacterial sulfate reduction could be a significant gas generation process in the WIPP environment. Sulfate is abundant in the brines, and sulfate from evaporite minerals may also become available to the bacteria under inundated conditions. Laboratory studies[4] have demonstrated that halophilic, sulfate-reducing bacteria from the WIPP environs are capable of using cellulosics inundated in brine as an energy source. Gas generation is still being evaluated. If hydrogen sulfide is generated in the WIPP repository, it would be expected to react with iron, producing several corrosion products (FeS_2 and H_2). The formation of FeS_2 could produce passive films which further decrease corrosion (Section B.2.).

B.2.3.3. Fermentation and Methanogenesis. Fermentation is carried out by anaerobic bacteria that use organic compounds as electron donors and acceptors. Many reactions can lead to the evolution of methane in oxygen-depleted environments. A very common mechanism for methane formation is the reduction of carbon dioxide. Methanogenic bacteria can ferment simple organic molecules using carbon dioxide as an electron acceptor:

$$CH_3COOH + 2\,H_2O \longrightarrow 2\,CO_2 + 8\,(H)$$

$$\underline{8\,(H) + CO_2 \longrightarrow CH_4 + 2\,H_2O}$$

$$\text{Net: } CH_3COOH \longrightarrow CH_4 + CO_2$$

They can also use hydrogen as an energy source with carbon dioxide as the electron acceptor:

$$4\,H_2 + CO_2 \longrightarrow CH_4 + 2\,H_2O$$

Cellulosic degradation by halobacteria from the WIPP environment has produced several fermentation products. Methane production, however, has not yet been noted in the experiments underway at BNL[4]. Methane has been shown to be produced, however, from low-level radioactive wastes disposed of in shallow-land trenches and pits[9] and is expected to be produced eventually in certain tests now in progress at BNL. Brush[5] believes that fermentation and methanogenic reactions could be important gas-generating mechanisms in the WIPP environment because they could occur in unbreached drums/waste boxes without electron acceptors from sludges or brines.

• **Organic Acid Formation.** Byproducts of cellulose biodegradation and fermentation can be organic acids. Organic acids are important for mobilizing radionuclides and heavy metals[10] by changing the pH and Eh of the environment and because of chelation properties[7]. Organic acids have been detected as a product of biodegradation of cellulosics by halobacteria from the WIPP site[3 4].

B.2.3.4. Toxicity, Irradiation and Pressure Effects. Environmental factors, including metal toxicity, irradiation and pressure, can affect the microbial degradation of the cellulosics in the WIPP waste inventory. Metals from the waste and from the containers can be expected to corrode, releasing soluble metals into the brine. In addition, radionuclides (americium, plutonium, thorium, and uranium) may be solubilized. Soluble metals/radionuclides can potentially diminish or inhibit biological activity because of toxicity[11]. Microorganisms can readily adapt to soluble heavy metals, particularly if the release of soluble metals into the brine is slow. The toxic effects of plutonium will be evaluated at BNL in conjunction with ANL in studies that examine synergism between radiolysis and microbial gas generation[4].

Irradiation has the potential to influence microbial degradation of organic wastes in two ways: (1) irradiation can potentially inactivate microorganisms, and (2) irradiation can alter plastic and rubber materials making them either more resistant or less resistant to microbial attack.

Barnhart[7] reported on bacteria isolated from a shallow, TRU-waste burial site at Los Alamos National Laboratory, that are resistant to total doses of 54 krads of x-irradiation. Caldwell[8] found that a microbial inoculum taken from the same LANL burial site demonstrated a 70% reduction in CO_2 generation from cellulose degradation when 300 mg (20 mCi) of PuO_2 was added to the culture. The two studies cannot be compared directly. The Barnhart[7] study involved irradiating the organisms and then cultivating them on an organic energy source. In the Caldwell[8] study, the irradiation source was incorporated into the growth substrate, more closely simulating the environmental situation at the WIPP. Because neither study used halobacteria from the WIPP, the results cannot be considered definitive for the WIPP environment. BNL and ANL will collaborate to evaluate radiolysis effects on microbial degradation of wastes. The study will examine irradiation effects as well because a plutonium source will be used[4] with the culture.

Ionizing radiation alters some plastics by fragmenting the main polymer chains, creating C-C double bonds and altering the chemical composition of the material[5]. The effects of ionizing radiation on rubber materials are less well known. Radiolysis effects on plastic and rubber materials may enhance the biodegradation of these materials. If so, gas generation estimates should be increased to accommodate the presence of these altered

materials in the waste inventory. BNL has initiated a bench-scale program to evaluate radiolysis on the biodegradation and gas generation potential of plastic and rubber materials[4]. Results of accelerated testing are expected soon.

Studies have not yet been carried out on the effect of pore-brine or lithostatic pressure on microbial degradation of organic wastes in the WIPP repository. BNL experiments at 150 psia[4] were designed to support the proposed Type #2 Bin Test Program and did not simulate possible repository conditions. The effect of lithostatic pressure on biodegradation should be the objective of laboratory studies. Studies conducted on microorganisms in deep ocean trenches[12] revealed that microorganisms can withstand high pressures.

B.2.3. Biotransformation of Radionuclides in the WIPP Repository.

Microorganisms can transform metals and radionuclides through the following mechanisms: (a) solubilization, (b) precipitation, (c) accumulation, and (d) volatilization[13, 14, 15, 16, 17, 18]. Changes in redox potential, pH, and the biodegradation of chelating agents have been shown to mobilize or precipitate metals and radionuclides. Organic acids, such as those found in WIPP brines, can alter brine pH and can act as chelating agents for radionuclides. Microorganisms readily accumulate metals (including radionuclides) within their cells or on their surfaces[13 16]. This immobilizes the radionuclides, which can mitigate dispersion. Microbial methylation of several metals (such as mercury, tin, arsenic) and metalloids (selenium, tellurium) occurs readily , sometimes rendering the metals volatile. Barnhart[7] examined the potential methylation of TRU elements, but results were inconclusive.

B.2.4. Biodegradation of Volatile Organic Compounds

After TRU-wastes are emplaced at WIPP, release of hazardous VOCs into the repository is expected. Migration of VOCs is currently assumed by SNL and DOE to occur if gas generation induces fractures in the geologic formations, creating a migration path to the regulatory boundaries. Current transport models do not consider the solubility of VOCs in the brine, hydrolysis of the VOCs in brine, adsorption of the VOCs on rock matrices, or in-situ biodegradation of VOCs. These processes can significantly reduce the transport of VOCs in the subsurface environment. Biodegradation of chlorinated aliphatic solvents, such as trichloroethylene, carbon tetrachloride and others, has been shown to occur in anaerobic environments by methane-utilizing microorganisms[19 20]. In-situ biodegradation of the VOCs at the WIPP site could totally eliminate the possibility of these hazardous compounds migrating to the regulatory boundaries in concentrations exceeding regulatory limits. Results from studies of mechanisms which decompose VOCs before they reach the site boundary will be important to the certification and permitting processes, and their inclusion in the test program should be considered.

B.3. Radiolytically Generated Gas—An Alpha Radiolysis Primer

The intent of Section B.3. is to provide a basic overview of alpha radiolysis of materials, focusing on the potential for gas production. Portions of this section are taken from Spinks and Woods[21] and the TRUPACT II SAR[22] Appendix on "Radiolytic G Values For Materials -- Application to Transportation of CH-TRU Wastes," written by Dr. Marilyn M. Warrant (SNL). For more information, the reader is referred to that section of the TRUPACT II SAR because it represents the most extensive review on alpha radiolysis performed to date.

B.3.1. Basic Mechanism

Ionizing radiation interacts with matter as it passes through it. Most of the radiation from contact-handled TRU wastes consists of alpha particles. Alpha particles are a form of ionizing radiation consisting of helium atoms stripped of their electrons; hence, they have a double positive charge. An alpha particle interacts with matter primarily by losing energy through inelastic collisions with electrons. The collision leads to excitation and ionization of the atoms or molecules to which those electrons belong. Free radicals may also be formed. The number of ion pairs formed is approximately linear with distance until the alpha particle nears the end of its path in a given material. At that point, it will produce a much larger number of ion pairs.

The rate of energy loss by ionizing radiation is expressed in terms of linear energy transfer (LET). Alpha particles have very high LET. The tracks formed by the passage of an alpha particle contain ions, free radicals, and atoms. The free radicals are extremely reactive; gases may be produced by their recombination. For example, if the concentrations of hydrogen free radicals in a track or spur are high enough, they will recombine to form a hydrogen molecule. Other reactions may compete for the hydrogen free radicals through scavenging processes. Consequently, not all hydrogen free radicals produce hydrogen molecules (gas).

B.3.2. Distance Traveled

An alpha particle will traverse a distance of approximately one centimeter in dry air. A single sheet of paper will stop it as will the layer of dead skin on a person's body. It will travel about 50 microns in a particle of plutonium dioxide. Most likely, the plutonium in contact-handled TRU material will be in the oxide form.

B.3.3. Alpha Radiolysis of Organic Materials

As stated in the SAR, alpha radiolysis of organic materials will generate gases. Depending on the organic matrix, the evolved gases may be hydrogen, carbon dioxide, carbon monoxide, methane, etc. Radiolysis of cements, sludges, water, and brine will also generate gases. A measure of the gas production potential of a material is the G(value). It is defined as the number of

molecules of gas produced per 100 electron volts (eV) of energy deposited in the matrix.

Kosiewicz[23] reported the G(values) for rubber materials to be about 0.04 to 0.15, plastics at 2.0 to 6.3, bitumen at 1.1, and cellulose at 1.4. With increasing dose deposited in a waste matrix, the values decreased. This decrease was attributed to depletion of the waste matrix within the limited range of penetration of the alpha particles. Reed[24] has reported G(values) for hydrogen to be 1.1 to 1.4 for alpha radiolysis of WIPP brine A. In a sludge or brine, depletion might not occur if more molecules of water were bought within the range of the alpha particles.

The following very simple equation can be used to estimate the amount of gas produced by alpha radiolysis:

Moles gas/(year-drum) = (0.1 mol)(# alpha Curies)(G(gas))

This equation does not correct for the decrease in gas evolution caused by matrix depletion. Confusion may occur when trying to make comparisons with calculations done in the TRUPACT II SAR because the SAR converts the radionuclide decay energy into wattage. It is not the intent of the SAR to suggest that thermal heat is the cause of gas production, but rather wattages are a way to use the dose deposited in the waste matrix for calculations.

B.4. VOCs

A VOC is a compound whose normal boiling point is less than 200°C. Examples of some VOCs are trichloroethane, acetone, carbon tetrachloride, and methylene chloride. VOCs are present in some TRU wastes as residues from the processes which produced the wastes. Some of these processes include liquid-liquid extractions, degreasing of machining parts, and clean up of equipment or gloveboxes. Because the VOCs are volatile, they evaporate off the waste matrices on which they were originally absorbed.

B.4.1. Liquefaction of VOCs.

Repository pressure can range from surface ambient (1 atm) to the hydrostatic pressure of the salt-pore brine in the Salado formation (about 65 atm) or the lithostatic pressure at the repository depth (about 150 atm). At the higher pressures volatile organic compounds, if present at high enough partial pressures, may liquefy.

Conditions for existence of a VOC liquid phase are: local temperature between triple point and critical point temperatures, and VOC partial pressure at or above the saturation pressure corresponding to the local temperature. The triple and critical point temperatures, and saturation pressure are thermodynamic properties. For volatile organic compounds, the triple point

temperatures are too low to be of concern, critical temperatures are higher than 30°C and saturation pressures at 30°C are below one atmosphere. WIPP conditions may allow a VOC condensate phase to form.

B.4.2. Solubility in Brine:

An increase in pressure within the repository can also increase the solubilities of gases and liquids in the brine. The likelihood of degradation of VOCs is enhanced because they may degrade through hydrolysis or biodegradation when they are dissolved in brine.

B.4.2. VOC Quantities:

A sensitivity calculation was performed to determine what quantity of a VOC would have to be present in an alcove to be analytically detectable. The calculation assumed that the volume of the alcove minus the volume of drums in it produced a void volume of 664 M^3 as was suggested in the Alcove test plan. Only 4.5 grams of carbon tetrachloride are required in the alcove to meet the analytical DQO of 1 ppm (vol).

Similarly:

trichloroethylene	≈4.0 gm
trichloroethane	≈ 4.0 gm
dichloromethane	≈ 2.6 gm

The calculation suggests that it takes only a small amount of a compound to reach the 1 ppm (vol) level. This corresponds roughly to 1 drop of liquid carbon tetrachloride per every ten 55-gallon drums in the alcove.

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[1] C. F. Norton, "Rediscovering the Ecology of Halobacteria," *American Society of Microbiology (ASM) News* 58, 363-367 (1992).5

[2] D. E. Caldwell, "Microbial Biogeochemistry," in *A Report of Biological Investigations at the Los Medanos Waste Isolation Pilot Plant (WIPP) Area of New Mexico during FY1978* (T. L. Best and S. Neuhauser, Eds.), SAND79-0368 (March 1980).

[3] R. I. Vreeland, Personal Communication, West Chester University, West Chester, PA (August 31, 1993).

[4] Francis, A. J., J. B. Gillow and M. R. Giles, Personal communication, Brookhaven National Laboratory, Uptown, NY (August 31, 1993).

[5] L. H. Brush, "Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant," SAND90-0266 (January 1990).

[6] L. H. Brush, "Current Estimates of Gas Production Rates, Gas Production Potentials, and Expected Chemical conditions Relevant to Radionuclide Chemistry for the Long-Term WIPP Performance Assessment," in *WIPP Performance Assessment Division, Preliminary comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant,* SAND91-0893/3, (December 1991) pp. A-27 to A-36.

[7] B. J. Barnhart, E. W. Campbell, E. Martinez, D. E. Caldwell and R. Hallett, "Potential Microbial Impact on Transuranic Wastes under Conditions Expected in the Waste Isolation Pilot Plant (WIPP), October 1, 1978 - September 30, 1979," Los Alamos National Laboratory, NM, Report No. LA-8297-PR. (July 1980).

[8] D. E. Caldwell, R. C. Hallet, M. A. Molecke, E. Martinez, and B. J. Barnhart, "Rate of CO_2 Production from the Microbial Degradation of Transuranic Wastes under Simulated Geologic Isolation conditions," SAND87-7170 (January 1988).

[9] A. J. Francis, S. Dobbs and R. F. Doering, "Biogenesis of Tritiated and Carbon-14 Methane from Low-Level Radioactive Waste," *Nuclear & Chemical Waste Management* **1**, 153-159 (1980).

[10] A. J. Francis, "Microbial Transformation of Low-Level Radioactive Waste," in *Proceedings of a Workshop of the International Union of Radio Ecologists* (E. Bonnyns-Van Gelder and R. Kirchmann, Eds.) Brussels (April 25-27, 1984) pp. 229 - 238.

[11] M. R. Tolley, P. Smyth and L. E. Macaskie, "Metal Toxicity Effects on the Biological Treatment of Aqueous Metals Wastes: Is a Biocatalytic System Feasible for the Treatment of Wastes Containing Actinides?" *Journal of Environmental Science and Health* **A27**, 515-532 (1992).

[12] H. W. Jannash and C. O. Wirsen, "Microbial Life in the Deep Sea," *Scientific American* **236**, 42-52 (1977).

[13] C. L. Brierley, "Metal Immobilization Using Bacteria," in *Microbial Mineral Recovery* (H. L. Ehrlich and C. L. Brierley, Eds.), McGraw-Hill, New York (1990) pp. 303-323.

[14] A. J. Francis, "Characteristics of Nuclear and Fossil Energy Wastes," *Experientia* **46**, 794-796 (1990a).

[15] A. J. Francis, "Microbial Dissolution and Stabilization of Toxic Metals and Radionuclides in Mixed Wastes," *Experientia* **46**, 840 - 851 (1990b).

[16] L. E. Macaskie, The Application of Biotechnology to the Treatment of Wastes Produced from the Nuclear Fuel Cycle: Biodegradation and Bioaccumulation as a Means of Treating Radionuclide-Containing Streams. *Critical Reviews in Biotechnology* **11**, 41-112 (1991).

[17] A. J. Francis, C. J. Dodge and J. B. Gillow, "Biodegradation of Metal Citrate Complexes and Implications for Toxic-Metal Mobility," *Nature* **356**, 140-142 (1992).

[18] Francis et al., 1990

[19] J. M. Thomas and C. I. Ward, "In Situ Biorestoration of Organic Contaminants in the Subsurface," *Environmental Science and Technology* 23, 760-766 (1989).

[20] P. Howard II, et al., *Handbook of Environmental Degradation Rates*,, Lewis Publishers, Inc. (1991) Vol. 1.

[21] J. W. Spinks and R. J. Woods, *An Introduction to Radiation Chemistry*, John Wiley & Sons, New York (1976).

[22] NuPac TRUPACT II SAR, Rev.1, July 1989.

[23] S. T. Kosiewicz, "Comments on 'Gas Generation from Organic Transuranic Wastes. 1. Alpha Radiolysis at Atmospheric Pressure," *Nucl. Techn.* 92, 428 (1990).

[24] D. T. Reed, et al, "Radiolytically-Induced Gas Production in Plutonium-Spiked WIPP Brine," Boston Materials Research Society Meeting, Symposium V11.30, Boston, MA. (Nov. 30-Dec. 4, 1992).

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APPENDIX C

CONCEPTUAL RELATIONSHIP OF GAS STUDIES

C.1 Satisfying Regulatory Compliance

An aspect of compliance with the EPA environmental safety regulations is demonstrating that flows of regulated hazardous components (VOCs or radionuclides) at the compliance-control boundaries will not exceed the regulatory levels. There are two major and distinct parts of the compliance issue related to the generation, release, and flow of VOCs. These are

- generation of gaseous contaminants (including VOCs) in the repository and subsequent release to the geologic medium; and
- transport of VOCs to the regulatory boundaries of the site.

About 20 of the 95 studies listed in the 1993 Test Phase Plan address these two issues of gas generation and transport.

The regulatory levels for potential hazardous contaminants at site boundaries are presented in terms of the contaminant concentration value in such media as surface waters, ground waters, soils, soil gases, or air. This is true even if the regulations are written in a language requiring that certain upper-bound values will not be exceeded for health risk, ingestion of cumulative amounts of radioactivity, dose risk, or exposure to certain amounts of a contaminant over a specified period of time. The WIPP site boundaries are surfaces that envelope a specified volume of geologic formation. The lower boundary is deeper than the repository floor, the upper is above the repository but below the ground surface, and others bound the site laterally.

A concentration value of a VOC, (C_u), for which an upper limit has been set by EPA cannot be exceeded at the site boundary. The design of the repository and the engineered barriers of the site should minimize the expected concentration, C, that may reach the site boundaries. The attenuation of a VOC at the site boundary is the ratio C/C_u. To satisfy compliance requirements the attenuation value needed is

$$\frac{C}{C_u} < 1 \qquad \text{(C - 1)}$$

but lower attenuation values may be considered to be desirable performance targets.

C.2. Site-boundary Attenuation Ratio (N_b)

The concentration of a VOC, (C_u), at the site boundary is a function of the amount released from the repository, the rate of transport by gas or brine flow through the geological medium, and any process that may retain, decrease, or release the VOC in the geological medium. A simple combination of these processes defines the conservation of mass of the VOC to produce the attenuation ratio, N_b, as follows:

$$N_b = \frac{F_H \pm G}{QC_u} \bullet t \qquad \text{(C-2)}$$

$$= \frac{C}{C_u} \qquad \text{(C-3)}$$

where

F_H is the total mass flow of the VOC gas that migrates from the repository space into the geological medium (moles/year)

G is the total mass flow of the VOC that is either retained in (-), or added from (+), the geological medium (moles/year)

Q is the rate of total volume flow that transports the VOC to the site boundaries (liters/year)

C_u is the regulatory upper-limit concentration of the hazardous gas species at the site boundaries

C is the expected concentration of the VOC at the site boundaries

t time of the process (years)

The value of N_b that is needed to satisfy compliance requirements is:

$$N_b < 1 \qquad \text{(C-4)}$$

To produce values for use in PA models for each parameter in Eq. (C - 3) a long list of technical data needs has to be developed. Each technical data need requires tests and modeling of the heterogeneous wastes in the repository, their gas-generation reactions, and travel paths in the geological environment. As stated earlier, among 95 studies listed in the 1993 Test Phase Plan, at least 20

address the issues of gas generation and transport. A list of activities and studies in the Test Phase Plan for WIPP that support the data needs of the individual parameters of N_b is presented in Table C.2-1.

Table C.2-1. Parameters for Gas Issues Hierarchy and their Supporting Tests.

Parameter		Activity or Study in Test Phase Plan	
Site-Boundary Attenuation Ratio	N_b	Regulatory requirements	2.1
		Compliance/long-term performance for §191	3.1
		Same for §268.6	4.1
Regulatory concentration at the site boundary	C_u	*Not identified explicitly*	2.1
Flux of gaseous contaminants out of the repository	F_H	?—Possibly included in G and F	—
		Gas-Generation Characteristics	5.3.1
		RCRA Constituents Source Term	5.3.4
Retention of gaseous contaminants by the geological medium	G	Regional Geochemical Studies	5.1.1.5
		Adsorption Studies/Non-Salado	5.1.2.1
		Radionuclide Solubility & Speciation/Non-Salado	5.1.2.2
		Gas Solubility in Salado Brines	5.1.4.1
		Retardation in the Salado	5.1.4.2
		RCRA Constituents Retardation in the Salado	5.1.4.4
Fluid volume flow to site boundaries	Q	Regional-Scale Transport/Non-Salado	5.1.1.2
		Model Development for the Non-Salado	5.1.1.3
		Field Testing/Non-Salado Hydrology	5.1.1.4
		Salado Hydrologic Properties	5.1.3
		Tracer and Transport Testing/Salado	5.1.4.3

One conclusion to be drawn from Table C.2-1 is that the Bin and Alcove Tests (activity 5.3.1. that supports parameter F_H) constitute only a small fraction of the many studies believed to be needed in the Test Phase of the repository. Table C.2-1 implies that the Test Phase Plan is not being driven by any explicit regulatory values of the concentrations of hazardous gas species at the site boundaries—parameter C_u has no value assigned to it for any individual gas species.

An analysis should be performed of conceptual relationships, such as that expressed in a mathematical form by the attenuation ratio N_b , to accelerate the resolution of all essential gas-related issues. The breadth of the parameters in Table C.2-1 and their related studies emphasizes the need to develop close working linkages among the individual tests.

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APPENDIX D

COMMENTS ON SOME LABORATORY STUDIES SUPPORTING WIPP

D.1. Historical Perspective on Gas Generation

Laboratory studies of gas generation on TRU wastes destined for WIPP were carried out for about four years, concluding in 1979. They were funded by DOE and coordinated by SNL, and were done primarily at LANL and SNL. Molecke summarized the data produced by the experimenters in 1979[1]. The program addressed four gas generation mechanisms:

- bacterial degradation of waste,
- thermal degradation,
- metal corrosion, and
- radiolysis of the organic waste matrices.

In the 1970s, thermal degradation of waste was considered a mechanism of potential importance because plans to dispose of high-level radioactive wastes in the salt repository would cause the repository temperature to rise substantially above the ambient rock temperature (about 25°C) Temperatures of 40°C or 70 °C were postulated depending on various heat loading scenarios.

Highlights of the 1970s laboratory studies included establishing the relative importance of the different gas-generation mechanisms and estimating the amounts of gas that could form in wastes of different composition and under different sets of environmental conditions. Bacterial degradation of organic wastes was identified as a very important gas-generating mechanism. Radiolytically evolved gases were not considered to be major contributors to the overall repository gas budget. While metal corrosion in a dry or nearly waterless environment was not considered to be significant, these early studies showed that corrosion under anoxic conditions in saline brines was the primary mechanism responsible for generating gas.

Estimates of both gas-generation rates and the upper bounds on the gas masses that may be produced by different kinds of waste have not changed drastically since the 1970s. About the same upper bounds for gas-generation

rates (a few moles of gas per drum of waste per year) and total gas masses (up to about 5,600 moles per drum) continue to be cited in present reports.

The laboratory studies of gas generation by TRU wastes were terminated in 1979 as a consequence of permeability measurements of WIPP salt. When permeabilities were measured on salt core samples brought to the surface, they were found to be high enough that no overpressurization would occur in the repository. However, these cores had microfractures (due to relief of the overburden pressure) which provided erroneously high permeability values. In 1988, salt permeabilities measured in situ were three orders of magnitude lower than those obtained in the earlier laboratory determinations. Thus, the potential production of gases by the wastes in the repository and their accumulation in the repository became an issue of renewed concern.

The gas generation program was revived in 1988. In the mid 1980s, the main regulations bearing on the release and migration of radioactive wastes to the boundaries of the disposal site were those contained in 40 CFR 191. Gas generation in TRU wastes and its potential flow to the boundaries of the repository were at the time correctly judged to be of no importance to the transport of radionuclides. Since 1987, however, new regulations of the EPA (based on the RCRA and contained in 40 CFR 268.6) have required WIPP to demonstrate that certain hazardous components of the waste, including VOCs, would not exceed the regulatory concentration limits at the boundaries of the disposal site. Since VOCs are gases at the ambient operating conditions of the repository, they may be transported as minor components in mixtures of other gases that may form in the waste by various chemical or biological processes. Hence, the need to characterize and bracket gas-generation mechanisms in wastes resurfaced.

D.2 Summary of Current Laboratory Activities Evaluating Gas Generation

The current laboratory studies of gas generation are managed and coordinated by SNL (and funded by DOE) through subcontracts with PNL (metal corrosion), ANL (radiolysis of brines and plastic materials), and BNL (bacterial degradation of cellulose and irradiated plastics). Studies of gas generation by metal corrosion, alpha radiolysis of brines, and bacterial degradation of organic materials are in various stages of completion. Interactive studies of the following scope are planned for the near future:

- corrosion in the presence of byproducts of bacterial metabolism;
- corrosion in the presence of ^{239}Pu and ^{238}Pu in brines;
- bacterial degradation of irradiated plastics and rubber materials;

- bacterial degradation in the presence of ^{239}Pu in the growth medium.

The main gas-generating processes that are either under study or in planning for the near future, are:

- Production of hydrogen gas by corrosion of steel and other metals in saline brines.
- Corrosion and passivation of steel by reactions with carbon dioxide and hydrogen sulfide in gas and brine phases.
- Formation of gases and reactive radicals by alpha-particle radiolysis of brines and organic materials. Radiolysis is effected by plutonium in solids and brines.
- Effects of radiolysis on metal corrosion and, subsequently, gas generation.
- Bacterial metabolism utilizing organic materials, the products of which are such gases as carbon dioxide, hydrogen sulfide, nitrogen, nitrous oxide, other nitrogen oxides, and methane.
- Effects of radiolysis on bacterial gas generation, and on production of volatile and soluble organic compounds from metabolic byproducts.

Gas-generation studies focus primarily on the potential gas species and their rates of evolution from the main constituents of the TRU wastes or the materials that may be included in its packaging. At present, three major types of materials are used in gas-generation studies: metals in corrosion tests, organic materials in biodegradation experiments, and sodium-magnesium-chloride brines in alpha-radiolysis.

Components of these materials are:

Organics: biodegradable materials (cellulosics, sludges and other organic materials) and not-easily biodegradable components (plastics, including polyethylene, and leaded rubber).

Metals: low-carbon steels, other alloys and metals (aluminum, copper, titanium).

Brines: brine types A and B, magnesium-sodium-chloride type; dissolved radionuclide species included.

D.3 Laboratory-scale Corrosion Testing at PNL

Westerman at PNL found that sixty Hastelloy C-276 or Titanium Grade 12 autoclaves were capable of maintaining pressure-tight seals for more than one year. Most of these vessels have a 1 gal volume and can be operated at pressures as high as 3000 psig. Three vessels are unusually large (10 ft deep and 2 ft in diameter). Maximum operating temperature of 300 to 400°C can be maintained with proportional controllers.

Three autoclaves are being used for WIPP studies at pressures approaching lithostatic conditions, 900 psig carbon dioxide, 2000 psig hydrogen, or 2000 psig nitrogen at 30°C. These experiments were started in June 1993, and should be completed by December, 1993. Corrosion data are not yet available.

Some experiments must be conducted in pressure vessels constructed from Hastelloy C-22 pipes. These must be hermetically sealed with welds to maintain seal integrity. Because these vessels are not pressure coded, the maximum operating pressure is 300 psig. The vessels have a plenum volume of approximately 2 L. If a vessel passes a helium leak test, it has usually been found to be capable of holding pressure for at least two years. The biggest experimental problem encountered is sealing the high-pressure high-vacuum valves.

X-ray diffraction is used to identify corrosion products on the coupon samples removed from experiments. In some cases, x-ray fluorescence has been used to determine the elemental composition of the films (nickel, iron, zinc, etc.).

All laboratory WIPP work done at PNL is summarized in a report entitled *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments*, by M. R. Telander and R. E. Westerman[2]. This report will not be officially released until internal review is completed.

In addition to conducting corrosion research for WIPP, PNL has conducted corrosion research for the BWIP and Yucca Mountain Projects, as well as other large projects at Hanford. Their laboratory is staffed with several good electrochemists, and is equipped with several potentiostats.

Primary Data for Performance Assessment. Bin Tests, as now defined, will not provide primary data for the development of gas-generation models. The bench-scale laboratory program will provide more valuable data and is much more cost effective. These laboratory tests at Battelle PNL, ANL, and BNL are being conducted with well-characterized simulated wastes (substrates), and can be extended to include real wastes. Consequently, it should be possible to identify gas generation mechanisms and interactions (synergistic effects) from them. Furthermore, bench-scale experiments can potentially be conducted at lithostatic pressure in existing high-pressure autoclaves. Data from this laboratory program should provide high-quality data for incorporation into gas generation models.

Confirmatory Testing. SNL has predicted 35 pressure transients (pressure vs. time curves) that could be compared to experimental data from the proposed Bin Tests. Even though agreement of these predictions with such experimental data may help confirm gas generation models used by performance assessment, they will not provide complete confirmation because of inadequate waste characterization. Large-scale laboratory tests are needed to investigate waste interactions, as well as mechanistic synergisms.

D.4 Source Term Test Program (STTP)

Because SNL personnel stated that some type of VOC analyses would be done in the Source Term Test at LANL, one member of the ITR team interviewed the LANL STTP Project Leader to determine if the VOC analyses were related to TRU disposal. It was determined that these VOC analyses are not considered to be an alternate source of VOC information for WIPP disposal.

The Actinide Source Term Program (ASTP) has three major components: modeling; Los Alamos National Laboratory (LANL) measurements of leachates obtained from TRU-wastes; and laboratory experiments at other laboratories (SNL, LLNL, FSU, and LBL). The LANL Source Term Test Program(STTP) is described in the test plan provided to the ITR Team in July 1993[3]. The test plan states that concentrations of dissolved and suspended actinides in WIPP brines are a priority need for demonstrating compliance with 40 CFR 191, Subpart B.

The LANL actinide test program will include bench-scale tests using 1-5 liter containers and drum-scale tests using 65-gallon containers. Some of the bench-scale tests will be done at pressures up to 875 psig (60 bar). It is scheduled to start in April 1994. LANL personnel will not interpret the data, the first of which may be sent to SNL in August 1994.

There is an ambitious list of variables for potential measurement of properties of materials from brine leachate samples obtained during these tests.

Although, complexation and retardation are highly dependent on oxidation states, actinide oxidation state speciation is not definitely planned to be done. Oxidation state data could be combined with data on complexing and chelating agents to derive significant information on the potential for actinide mobility in WIPP.

Headspace gases in test containers will be analyzed for VOC's even though this is not required by the test plan. This will be done because the New Mexico Environment Department informally requested (not required) this information. No analysis will be performed of the headspace gases in the waste drums used to supply materials for the tests.

[1] Molecke, M. A., "Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation," SAND79-1245 (July 1979).

[2] Telander, M. R., Westerman, R. E., "Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments," SAND92-7347, in press.

[3] LANL document CLS1-STP-SOP5-012/0, May 1993.

APPENDIX E

LIST OF ACRONYMS

Acronym	Definition
ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
AOP	Annual Operating Plan
API	Applied Physics, Incorporated
ASTM	American Society for Testing Materials
ASTP	Actinide Source Term Program
BWIP	Basalt Waste Isolation Project
CCDF	Complementary Cumulative Distribution Functions
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
CH	Contact Handled
D&D	Decontamination and Decommissioning
D&E	Design and Engineering
DNFSB	Defense Nuclear Facility Safety Board
DOE	Department of Energy
DOE/EM	DOE Office of Environmental Restoration and Waste Mgt.
DOE/HQ	DOE Headquarters

DOT	Department of Transportation
DQO	Data Quality Objectives
DRZ	Disturbed Rock Zone
EEG	Environmental Evaluation Group
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ER	Environmental Restoration
FAT	Facility Acceptance Test
FGE	fission gram equivalent
FTIR	Fourier transform infrared
HVAC	Heating, Ventilation and Air Conditioning
ICP	inductively coupled plasma
INEL	Idaho National Engineering Laboratory
ITR	Independent Technical Review
LANL	Los Alamos National Laboratory
LAT	Loop Acceptance Test
LEL	Lower Explosive Limit
LWA	Land Withdrawal Act
M&O	Management and Operations
M&OC	Management and Operations Contractor
MIC	microbial-induced corrosion
MIIT	Materials Interface Interactions Test
NDA	Non-Destructive Assay
NDE	Non Destructive Examination

NEPA	National Environmental Policy Act
NESHAP	National Emission Standard for Hazardous Air Pollutants
NIST	National Institute of Science and Technology
NMD	No-Migration Determination
NMED	New Mexico Environment Department
NMV	No-Migration Variance
NQA	Nuclear Quality Assurance
OBES	DOE/Office of Basic Energy Sciences
ORIA	EPA Office of Radiation and Indoor Air
OSW	EPA Office of Solid Waste
PA	Performance Assessment
PAT	Performance Acceptance Test
PI	Principal Investigator
PNL	Pacific Northwest Laboratories
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
RH	Remote Handled
RTR	Real-Time Radiography
SA	Science Advisor
SAR	Safety Analysis Report
SARP	Safety Analysis Report, per NRC convention
SCC	stress corrosion cracking

SDD	System Design Description
SIMS	secondary ion mass spectrometry
SNL	Sandia National Laboratories
SRS	Savannah River Site
STP	Source Term Program
STT	Source Term Test
STTP	Source Term Test Program
SWB	Standard Waste Box
TNAD	Technical Needs Assessment Document
TOB	Technical Oversight Board
TPP	Test Phase Plan
TRU	Transuranic
TRUPACT-II	Transuranic Package Transporter
TSG	Technical Support Group
U.S.C.	United States Code
VOC	Volatile Organic Compound
WAC	Waste Acceptance Criteria
WBS	Work Breakdown Structure
WHC	Westinghouse Hanford Co.
WID	Waste Isolation Division of Westinghouse
WIPP	Waste Isolation Pilot Plant
WM&ER	Waste Management and Environmental Restoration
WPIO	DOE/WIPP Project Integration Office
WPSO	DOE/WIPP Project Site Office

XRD	X-ray diffraction
XRF	X-ray fluorescence
YMP	Yucca Mountain Project

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APPENDIX F

SCOPE AND METHOD OF ASSESSMENT

F.1. Scope of Assessment

The scope of the Independent Technical Review of the proposed Bin and Alcove test programs at the WIPP site was limited in duration and focus. The review focused primarily on the regulatory approach used to show compliance with federal and state laws and regulations, the technical information needs required for performance assessment, and the ability of the proposed in-situ bin and Alcove test programs to provide the information. The review was further bounded by the situation at the time of the review, which included two periods of direct site interactions (July 26-30 and August 30-September 3, 1993). Modifications to the test phase plans, the tests programs or regulatory strategy after the review period were not considered in the assessment.

F.2. Method of Assessment

This ITR was based on the "Charter for the Independent Technical Review of Transuranic Waste Experiments at the Waste Isolation Pilot Plant" (Section F.3), developed and approved by DOE prior to the review.

Based on the Charter and previous ITR charters, the purpose of Independent Technical Reviews is to assess whether engineering practice is developed to a point that specific major projects/activities can be executed without significant technical problems. The objective of the ITR Team is to produce a documented, independent, engineering review of major projects funded by DOE-EM. Each review provides a factual understanding of the actual situation at the time of the review. The output of the review is a clear articulation of the strengths and weaknesses in the technology and engineering practice, the major uncertainties, and suggestions on beneficial courses of action.

Figure F.2-1 outlines the structure of the Independent Technical Review Organization which is subdivided into two groups, the ITR Team, and the Technical Oversight Board (TOB). The ITR Team is comprised of technical experts who examine the details of a given project, develop a thorough understanding of the Project and the factors and conditions that are important to its eventual success, and then use that input as the basis for developing a technical assessment of the project's status. The TOB is composed of senior level individuals who have extensive experience in the development, execution,

management and evaluation of large and technically involved projects. They provide a solid reference point of experience and ideas against which the ITR Team can test its ideas regarding lines of inquiry, and the logic and validity of findings and conclusion.

The WIPP Independent Technical Review Team consisted of 9 technical personnel and associated support personnel. The members were employees of various organizations including: DOE, Los Alamos National Laboratory, Lawrence Livermore National Laboratory and private consultants. Resumes of the WIPP ITR members and a listing of the TOB membership are provided in Appendix J.

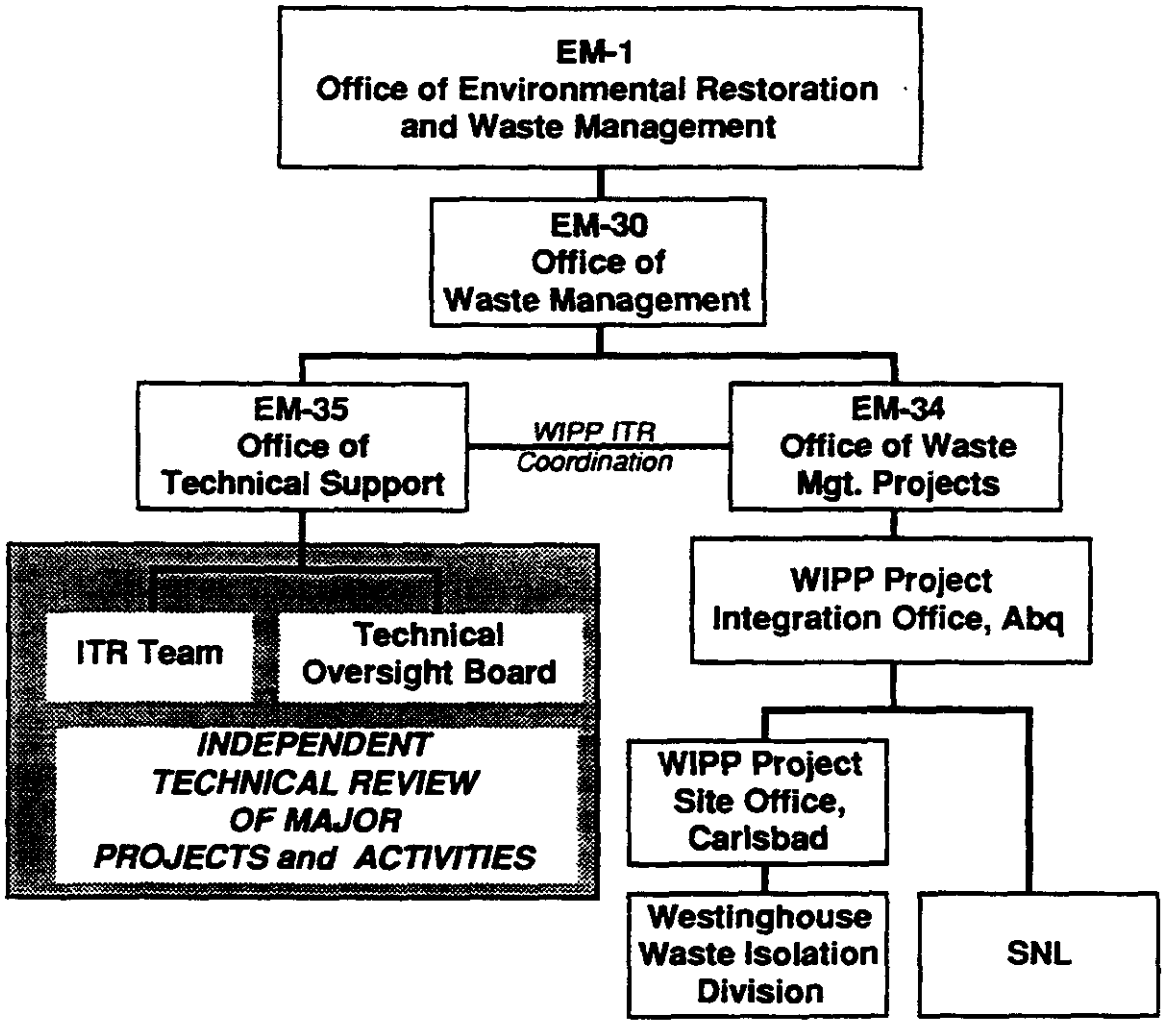

Fig. F.2-1 Independent Technical Review Organization

The review process consisted of document review, formal presentations by WPIO, WPSO, WID, SNL and other associated agencies.

During the first week of interactions with the project, July 26-30, 1993, the ITR Team listened to formal presentations given, toured the WIPP repository and associated facilities, reviewed documents, participated in informal group and individual discussions and interviews with WPIO, WPSO, WID and SNL personnel, and gathered information. During the week of August 16, 1993, the ITR Team met in Denver Colorado and reevaluated the review lines of inquiry for the second week site visit, and read documentation. During the second week of site interactions, August 30 September 3, 1993, the ITR Team interviewed personnel on specific topics and lines of inquiry. During the week of September 7, the ITR Team met at Los Alamos National Laboratory to develop consensus assessment issues and recommendations, and to initiate preparation of a draft Assessment Report.

F.3. Charter for the Independent Technical Review of Transuranic Waste Experiments at the Waste Isolation Pilot Plant

The following charter was used to direct the activities and evaluations of the WIPP ITR.

F.3.1. Mission

The mission of the Independent Technical Review (ITR) Team is to perform a review of the planned transuranic (TRU) waste experiments to be conducted at the Waste Isolation Pilot Plant (WIPP) for the U. S. Department of Energy (DOE-HQ). The purpose of the experiments is to provide information needed for models and calculations used in performance assessments, which are prepared to demonstrate regulatory compliance with disposal standards and provide safe management and disposal of radioactive and hazardous wastes.

The TRU-waste experiments include the bin test program and the Alcove test program. The proposed bin test program will provide data on gas generated by the degradation of TRU-waste in terms of generation rates, species and potential, which will then be used to confirm the predictive results of gas-generation models supporting performance assessment analyses. The Alcove test program will address the release of volatile organic compounds (VOC) for subsequent use in No-Migration calculations needed for compliance with RCRA (Resource Conservation and Recovery Act).

F.3.2. Objective

The objective of this ITR assessment is to review the need for, and technical validity of, the bin and Alcove test programs, as defined in the Test Phase Plan, the Technical Needs Assessment Document, and individual test plans. The test programs will be evaluated primarily with regard to providing data used for performance assessments, demonstrating WIPP regulatory compliance, and supporting the safe, timely disposal of waste. The ITR Team

will document their independent review findings and recommendations in an unbiased, logical technical engineering report.

F.3.3. <u>ITR Interfaces</u>

The ITR Team will perform its activities under the general direction of DOE-HQ Office of Technical Support, EM-35. The DOE-HQ Waste Management Projects, EM-34, and the DOE-HQ WIPP Project Division, EM-342, will serve as advisors to EM-35, and will be informed of review activities.

The DOE WIPP Project Integration Office (WPIO) will coordinate the interface between the ITR Team, the WIPP Project Site Office (WPSO) and the two prime contractors: the Waste Isolation Division (WID) of Westinghouse, and Sandia National Laboratory (SNL). Direct discussions with WPSO, WID, and SNL staff will be required during performance of the review, and to the extent practical, WPIO shall participate in these discussions.

F.3.4. <u>ITR Task Descriptions</u>

The work to be performed under this charter is comprised of the following tasks:

<u>Task 1:</u> **Regulatory Interpretation and Compliance**

The ITR Team will review the WIPP approach to interpreting regulations and regulatory requirements (such as the 40 CFR 191 Disposal Standards, regulations implementing RCRA, and the WIPP Land Withdrawal Act [LWA]), formulating regulatory compliance strategies, developing compliance analysis processes and deriving informational needs, with regard to the currently defined bin and Alcove test programs. The ITR Team will compare the informational needs to the type of test results anticipated from the test programs to assess the scientific basis for, and the direct relevance, credibility and defensibility of, the data to be produced.

<u>Task 2:</u> **Technical Performance Assessment**

The ITR Team will review and ass ss the relationship of the bin and Alcove test programs to long-term performance assessment activities with respect to model verification, evaluation of synergistic effects, and uncertainty analyses.

The ITR Team will review and assess the association of the proposed bin test program with the scientific basis and technical understanding of TRU-waste gas generation (dominated by corrosion, radiolytic and microbiological mechanisms), and its affect on the long-term safe performance of WIPP.

Likewise, the ITR Team will review and assess the technical connection between the proposed Alcove test program, determining the release of volatile

organic compounds and calculating gaseous source terms, and petitioning for a No Migration Determination under RCRA.

Task 3: Test Implementation and Approach

The ITR Team will review the approach to implementing the bin and Alcove test programs to assess: test scope adequacy; test plan definition; hardware design sufficiency; differences between testing and expected repository conditions; instrumentation and control system influences on data accuracy and reliability; and quality control/quality assurance practices.

Task 4: Test Integration

The ITR Team will evaluate the plans for integrating the bin and Alcove test programs with lab-scale programs, and with the total WIPP test program, to assess how experimental results will be incorporated into modeling verification tools for performance assessments. The utility of different test-scale and test-type results for use in WIPP performance assessment efforts will also be considered.

The ITR Team will also assess the integration of the bin and Alcove test programs into the function of WIPP as a geologic waste repository.

Task 5: Associated Test Issues

The ITR Team will review and assess the relationship of the proposed bin and Alcove test programs to such issues as: the adequacy of cost and schedule to support waste disposal decisions; the approach used to evaluate the need for, and adequacy of, contingency tests; the management approach to, and influence on, testing and operational status; the definition of acceptable waste forms; barriers to regulatory compliance; the technical preparedness of WIPP to transition from standby status to testing with TRU-waste.

Task 6: Recommendations

The ITR Team will provide suggestions, recommendations and/or alternate strategies, as appropriate, on the approach and implementation of the bin and Alcove test programs, their relationship with promoting the expeditious generation of information needed for performance assessments, and demonstrating WIPP regulatory compliance.

F.3.5. **ITR Team Qualifications**

The ITR Team will consist of a core group of knowledgeable, independent reviewers with expertise in one or more of the following areas:

- Defense TRU-waste knowledge with a broad understanding of the nuclear industry

- Generator Waste Processing, specifically in the areas of: TRU-waste generation and waste processing at DOE facilities; and the effect of various waste form alternatives on the basic waste generation processes.

- Geochemistry, with specific knowledge of WIPP and regional geology/geochemistry, and an understanding of geochemical interactions associated with hazardous and radioactive waste disposal.

- Metallurgy and Corrosion, specifically in the areas of: corrosion mechanisms; products of corrosion; corrosion inhibition; and the effects of near saturated brines on metal corrosion.

- Microbiology/Biogeochemistry, specifically in the areas of: bacterial degradation of hazardous, mixed waste, and nuclear waste forms; bacterial energetics; reactions of halotolerant and halophylic organisms, and the effect of salt environments on bacterial communities.

- Performance Assessment, specifically in the areas of: EPA Standards 40 CFR 191; requirements to conduct performance assessment of deep geologic repositories; and current performance assessment activities and challenges.

- Regulatory Compliance, specifically in the areas of: 40 CFR 191; RCRA 40 CFR 268; New Mexico state permitting requirements; the probability of permitting new technologies by state and federal governments.

- Test and Design Engineering, including instrumentation and data acquisition systems, design and test engineering

- Emanometry, including the physics and chemistry of gas generation and transport under deep geologic pressures and temperatures, with specific attention to the interpretation of time-dependent non-ideal behavior of generated gases, natural and waste related gas interactions, impacts of gas pressures on geologic medium (including salts) and brine migration.

- Repository Operations, including operation and/or engineering experience in repository operations including familiarity with mining, surface and underground facility design.

The team members shall be independent of WPIO, WPSO, WID and SNL, or any other group, agency or company presenting a potential conflict of interest. The team leader will be selected by DOE-HQ Office of Technical Support, EM-35, and will document that each team member's educational and experience background has been verified.

F.3.6. **ITR Schedule**

Team mobilization planning	start June 1, 1993
Initial pre-site visit	June 16-17
Document Request Memorandum	week of June 14
Team Member Orientation	July 20-22
Technical Oversight Board Evaluation of Review Plan	July 21
1st On-site Assessment	July 26-30
Review Plan Revision and Document Review	August 16-18
2nd On-site Assessment	August 30-September 3
Consensus Assessment Summary Preparation	September 7-10
TOB Review of Assessment Summary	week of September 20
Assessment Summary to WPIO	week of September 27
Draft Assessment Report Issued and Site Review	week of October 18
Final Assessment Report to DOE-HQ	week of November 1

F.4. **Independent Technical Review Plan for Bin and Alcove test Programs for the Waste Isolation Pilot Plant (WIPP), Revision 1**

NOTE: The Modifications to the Review Plan of 7/22/93 are highlighted by change bars in the right hand margins. The issues and lines of inquiry provided in this Review Plan, dated 8/24/93, can be modified at the discretion of the Independent Technical Review Team,

as appropriate, based on information provided and evaluated during the review process.

F.4.1. Introduction

Independent Technical Review (ITR) of Major Projects, Major System Acquisitions, and programs was established as a Department of Energy, Office of Environmental Restoration and Waste Management (DOE-EM) activity in a memorandum from the Under Secretary of Energy, dated March 29, 1991, on the Status of the Hanford Waste Vitrification Plant. The DOE-EM ITR process was developed from this base.

F.4.2. Structure of the Review Process

This ITR will focus on understanding the need for, and technical validity of the WIPP *in-situ* bin and Alcove test programs, as defined in the Test Phase Plan and the Technical Needs Assessment Documents. The test programs will be evaluated primarily with regard to providing data to be used for performance assessments, demonstrating WIPP regulatory compliance, and supporting disposal of transuranic (TRU) waste. The ITR Team will document its review findings and recommendations in an unbiased, logical, technical, engineering report. The specific aspects are presented as six tasks in the charter and are summarized here:

1. The WIPP project approach to regulatory interpretation as well as compliance strategies to assess data needs required of the *in-situ* bin and Alcove test programs;

2. The relationship of the proposed bin and Alcove test programs to verification of the performance assessment model, the technical association of the bin test program to long-term repository performance, and the technical association of the Alcove test program to support a petition for a No Migration Determination for disposal of mixed TRU wastes;

3. The adequacy of the bin and Alcove test progr ms for implementation and experimental approach, including test plans, hardware, QA/QC, and extrapolation of test results to anticipated repository conditions;

4. Evaluation of the integration of the bin, alcove, and lab test programs with each other and with the total WIPP test program to provide model verification for performance assessment;

5. Associated bin and Alcove test issues, such as: programmatic costs and scheduling , project management and control, final waste form definition, barriers to regulatory compliance, the effect of public and oversight group interactions, and contingency tests;

6. If appropriate, the development of recommendations and/or alternate strategies for the bin and Alcove test programs to facilitate TRU waste disposal decisions / operations.

F.4.3. <u>Approach to the Review</u>

The review of the proposed WIPP *in-situ* transuranic experiments will follow the basic process developed for other ITR reviews, with modifications specific to this application. For example, this review will employ one team of approximately 10 individuals, which will subdivide to review specific topics, as necessary.

The review team will consist of a DOE Team Leader, an ITR Team Leader, team members and support personnel as required. Team members will have expertise in at least one of the following areas: (1) defense TRU waste, (2) generator waste processing, (3) geochemistry , (4) metallurgy and corrosion, (5) microbiology / biogeochemistry, (6) performance assessment, (7) regulatory compliance, (8) repository operations, and (9) emanometry. As required, the team will call upon expert consultants for highly specialized information and knowledge.

Prior to the review, the ITR Team will complete the development of the draft review plan with specific lines of inquiry. Following the review, the team leaders and team members will develop an overall consensus assessment report, with appropriate appendices to document supporting information and issues.

The WIPP *in-situ* transuranic bin and Alcove test program review plan and assessment report will be reviewed by the Technical Oversight Board (TOB). The TOB is composed of senior level individuals who have extensive experience in the development, execution, management, and evaluation of large and technically involved projects. They provide a solid reference point of experience and ideas against which the ITR Team can test its ideas regarding lines of inquiry, and the logic and validity of findings and conclusions. The TOB will function as a check to assure that the scope and depth of the science and engineering review are adequate to achieve the stated goal, and to assure the proper systematic evaluation of the project. The Board will also examine the results of the review, as appropriate to assure internal technical consistency and to confirm that findings are supported with sufficient information.

Initial preparation for the review was carried out by the ITR Team Leader. This will include: team mobilization, initial site visits, initial document requests, preparation of the draft review plan, and review plan presentation to the Technical Oversight Board. Subsequent activities will include team members.

The team members will be involved in three primary activities: (1) preparation for the review, (2) the review process, and (3) report writing. Preparation for the review will include three days during which team members

will: review the ITR process, as described in the Independent Technical Review Team Handbook; complete the development of the review plan, with special focus on the lines of inquiry; discuss the application of the ITR process to review of the transuranic waste experiments to be conducted at WIPP; consult with independent, non-site individuals with specific technical and/or historical information about the WIPP tests and associated issues. Preparation may also involve other activities such as: revision of the review plan in the interval between the first and second weeks of the review at the WIPP site.

During the review, the team will have two primary site interactions: the first interaction will concentrate on a "horizontal" understanding of the project scope, underlying technical bases, and the site's perspective of the issues, through presentations, tours and document reviews; the second site interaction will use a "vertical slice" review approach to pursue lines of inquiry on points considered to be the potential bases for significant issues, via interviews, discussions and document evaluations. The second site interaction will also assure that initial information and understandings are correct and that potential implications related to issues are accurately perceived and understood. During both site interactions, the team will meet in private, as required, to consider the progress of the review, and to revise the review plan, as necessary, to successfully achieve its goals. Revisions to the review plan may require changes in the team's activities scheduled at the WIPP site.

Preliminary assessment report preparation can begin anytime during the review period. Immediately following the second week site review, the ITR team will convene at Los Alamos and prepare a consensus assessment summary as the first chapter of the report, which when completed, will be presented to the TOB and to DOE Headquarters. The assessment report will be compiled by the DOE and ITR Team Leaders, based on information compiled and written by team members. Additional visits, phone conversations or other communication may be required to address specific issues that arise during the assessment report preparation. The draft report will be reviewed by the WIPP site for factual errors, and the ITR Team will incorporate corrections as necessary. Upon completion, the assessment report will be submitted to DOE/HQ for disposition.

F.4.4. Lines of Inquiry

Lines of inquiry for the tasks will be developed during the Team Member Orientation meeting at Los Alamos National Laboratory (LANL), and revised based on information presented at the WIPP site following the first week of the review.

The following lines of inquiry were identified by ITR Team members as generally pertaining to more than one specific charter task:

- What is the regulatory and engineering justification for the Bin and Alcove test?

- What is the status of the test phase plan and the retrieval plan with respect to the Land Withdrawal Act (LWA)?
- How does performance assessment (PA) and data collection interact?
- How do Bin and Alcove tests integrate with other tests to define the repository environment or support PA?
- How are potential contaminant migration pathways being characterized?
- How will gas generation test results affect instrumentation and WIPP operations?
- What "off-site" issues affect the Bin and Alcove test programs?
- What procedural approvals are needed to initiate the Bin and Alcove tests?
- What are the personnel qualification criteria for the Bin and Alcove tests?

Task 1: Regulatory Interpretation and Compliance

Per the charter...

The ITR Team will review the WIPP approach to interpreting regulations and regulatory requirements (such as the 40 CFR 191 Disposal Standards, regulations implementing RCRA, and the WIPP Land Withdrawal Act [LWA]), formulating regulatory compliance strategies, developing compliance analysis processes and deriving informational needs, with regard to the currently defined bin and Alcove test programs. The ITR Team will compare the informational needs to the type of test results anticipated from the test programs to assess the scientific basis for, and the direct relevance, credibility and defensibility of, the data to be produced.

Examples of generic issues that can be addressed include:

- The laws, regulations, and DOE Orders that apply to Bin and Alcove tests
- The processes used to develop technical needs, including the issues hierarchy, analysis, and data quality objectives (DQO)

Potential lines of inquiry include:

- What is the definition of regulatory compliance?

- What laws, regulations, and DOE Orders apply to Bin and Alcove tests? What plans and procedures have been used to implement these laws, regulations and DOE Orders? What is the "flow-down" from the laws, regulations and DOE Orders to the Bin and Alcove tests? What is the connection between 40 CFR 191, RCRA 264, and 268 and the Bin and Alcove tests?

- What are the methods (e.g. performance assessment, expert opinion) that WIPP has used to demonstrate compliance with these requirements? Which of these methods require new experimental data?

- What is the anticipated influence on the Bin and Alcove test Programs of EPA's disposition of DOE's comments on 40 CFR 191?

- What process was used to develop technical needs? (including regulatory hierarchy, issues analysis, & data quality objectives [DQO])

- What regulations in CFR govern the masses and production rates of gases in the repository and their migration towards the accessible environment? What are the regulatory limits on gas migration?

- When will the data from the test programs be made available for performance assessment? What is the relationship between these two, the SAR, and other scheduled regulatory milestones?

- What are the specific test results that will be uniquely produced by the Bin and Alcove tests? What is the confidence level that these test results will be defensible?

- What is the basis for determining the time period needed to produce adequate test data?

- What industry experience has been evaluated to achieve no migration variances?

- What additional data are required to obtain the No Migration Determination to allow waste disposal?

- How does data derived from Bin and Alcove tests demonstrate retrievability? Will bin and alcove waste be retrievable as required by the Land Withdrawal Act? How long is the period

of retrievability and how is retrievability defined? Are any of the containers allowed to deteriorate beyond retrievability?

- What have been the previous technical criticisms of these tests by oversight groups? What is the relevancy of these criticisms to the currently proposed test programs?

- What is the DOE's approach to ensuring compliance with requirements established in the Land Withdrawal Act?

- How is the Program intending to address NEPA issues associated with Type II Bin and Alcove tests?

- How can regulatory requirements be consolidated?

- What credit is given for emplacement of waste at repository horizon?

Task 2: Technical Performance Assessment

Per the charter...

The ITR Team will review and assess the relationship of the bin and Alcove test programs to long-term performance assessment activities with respect to model verification, evaluation of synergistic effects, and uncertainty analyses.

The ITR Team will review and assess the association of the proposed bin test program with the scientific basis and technical understanding of TRU-waste gas generation (dominated by corrosion, radiolytic and microbiological mechanisms), and the affect of gas generation on the long-term safe performance of WIPP.

Likewise, the ITR Team will review and assess the technical connection between the proposed Alcove test program, determining the release of volatile organic compounds and calculating gaseous source terms, and petitioning for a No Migration Determination under RCRA.

Examples of generic issues that can be addressed include:

- Room expansion will relieve pressure. Will the pressure relief be sufficient to prevent regulatory problems based on the PA model estimates?

- The performance assessment model and submodels to be used to demonstrate for regulatory compliance

- Identification of sensitive parameters and derived data needs for Performance Assessment requirements.

- Relationship of the bin and Alcove test programs to performance assessment

- Relationship of the lab test program to performance assessment

- Potential of the proposed bin test program to provide new scientific and technical understanding of the major gas generation mechanisms (corrosion, microbial, and radiolytic) of TRU waste

- Potential for gas generation to compromise long-term safe performance (via release of either the hazardous component or radionuclides) of the repository

- Potential for coupled processes to be impacted by gas releases

Potential lines of inquiry include:

- What is the performance assessment model? What (if any) independent verification of the model is available? What is the QA process for the performance assessment model? What is the minimum new information needed to meet PA requirements?

- What is the sensitivity of the performance assessment model to parameter variations? What parameters affect the model the most? How much and what types of additional work are required to minimally validate regulatory compliance? What is the role of gas generation in the additional work?

- What is the sensitivity of the model to variations in the gas source term? How does model uncertainty compare to the regulatory release limit? What is the maximum, credible amount of gas that can be derived from the TRU waste inventory? Which gas generation mechanisms are dominant at what time?

- An abundance of data exists from the German test at Asse where waste drums were exposed to brine. How long were these drums retrievable? How are these data being integrated into performance assessment models?

- Were the performance assessments to date based on a best case scenario, conservative (worst case) scenario, or something else? How was it chosen? Probabilistic or deterministic? How have data adequacy criteria been determined (DQO process)?

- What level of waste characterization data will be available, with appropriate QA/QC, to support the Performance Assessment and No-Migration Variance Petition?

- What is the process for incorporating results of tests into PA models? How are PA models evaluated and modified as a result of data incorporation? How will tests be evaluated and modified as a result of assessment of performance?

- What other mechanisms can be used to provide equivalent information to meet PA requirements?

- Are the performance assessment models driven by the results of the laboratory, Bin and Alcove tests, or are the models used to gauge the validity of the experimental results?

- How do the Yucca Mountain Project and WIPP Performance Assessment teams interact, i.e., how are lessons-learned and methodology advances transferred?

- What data are needed to "build confidence " in the gas generation and performance assessment models?

- What is planned to address performance assessment model validation, verification and confirmation?

- What is the maximum amount of brine that is estimated to be available for radiolytic, corrosive, or microbial gas generation? Of these mechanisms, which one can consume the brine to produce a maximum amount of gas? How much gas would that be? Would that quantity of gas compromise long-term performance of the repository? How does gas pressure buildup affect brine migration/availability?

- What analytical procedures are established for the analysis of trace contaminant levels in saturated brines?

- Which of the gas generation mechanisms is expected to dominate the gas production under maximum credible conditions in WIPP for the various time phases of the repository - ventilation, transitional, and long-term? How much gas can be formed under what (different) conditions? How will the Bin and Alcove tests define the microbiological gas evolution? How will gas contributed by the various mechanisms be differentiated?

- According to the TPP, gas generation will prevent room closure and consolidation of wastes, while promoting the outflow of radionuclides, VOCs, and other regulated sub stances. How sensitive are these effects to gas pressure?

- What gaseous species and gas masses are expected to be generated by different kinds of wastes? What are the waste form effects on gas generation?

- How is a complete mass balance done around the Alcove test? How much gas will corrosion of root bolts, beams, etc. contribute to the gas inventory of the Alcove?

- What are the physical and chemical bounds on the characteristics of the waste that will be used in the Bin and Alcove tests? What is the relationship between the waste inventory data (on hazardous constituents) and the proposed Alcove test program? How are the Source Term Test (STT) program and Alcove test program related to each other with respect to providing information on the potential for VOC migration in WIPP?

- What are the potential mechanisms for migration of gases in the repository? Does the geologic setting (rock minerals and brines) play any expected role in migration of different gaseous species out of the repository space?

- For the transition from oxic to anoxic corrosion, how is the transition time calculated? Most of the gas pressure of concern will come for anoxic corrosion after closure. How much unreacted metal will remain at the end of the period of oxic corrosion?

- Could galvanic coupling of dissimilar metals enhance rates of corrosion? If so, how are the effects of galvanic coupling being accounted for?

- The degradation of organic material and microbial action could generate a variety of chelating agents. How will these chelating agents effect the Pourbaix diagram, passivity, rates of corrosion, and the associated gas generation?

- How are mass balances determined around corroded surfaces? Where do corrosion products go? How is inventory kept? How were bounding conditions established for calculation of

corrosion rates? How are bounding conditions confirmed to be conservative?

- What is the test plan for potentially significant microbial processes on radionuclide chemistry and microbial corrosion? How will information from these tests be incorporated into the PA model?

- What have been the previous technical criticisms of the microbiological test plan and what has been done to respond to these criticisms?

- In regard to retrievability, what are the anticipated rates of general and localized corrosion and how were these estimated?

- Some fraction of the waste containers will contact electrolyte. On the basis of statistics, how many?

- Radiolysis will generate NO_x and microbial growth will generate H_2S. Will such species be present at high enough concentrations to effect passivation, the rate of generalized corrosion, and related gas generation?

- How were literature data on oxic corrosion documented and used? Was documentation consistent with the QA plan?

- Have corrosion coupons already been placed inside the WIPP mine? If so, how many samples are emplaced and what metals do they represent? What are the rates of corrosion determined from these in situ test coupons?

- Though stress corrosion cracking is unimportant in direct gas generation, stress corrosion cracking will limit the life of roof bolts in the mine. In addition to affecting safety, bolt failure will affect the time to room closure by collapse and creep. How important is potential failure of the roof bolts?

- What is the potential for coupled-processes (synergisms) and how have they been considered?

- What analytical procedures are established for the analysis of waste sludges?

Task 3: Test Implementation and Approach

Per the charter...

The ITR Team will review the approach to implementing the bin and Alcove test programs to assess: test scope adequacy; test plan definition; hardware design sufficiency; differences between testing and expected repository conditions; instrumentation and control system influences on data accuracy and reliability; and quality control/quality assurance practices.

Examples of generic issues that can be addressed include:

- The QA program for the Bin and Alcove tests
- Engineering design of the bin hardware
- Engineering design of the alcove seals
- Relationship of test conditions to repository conditions, including the sensitivity of test data and data uncertainty
- Characterization of the test wastes
- Relationship of test wastes to DOE waste inventory
- Relationship of test wastes to major gas generators in DOE waste inventory
- Relationship of waste simulants to real wastes
- Proposed test hardware

Potential lines of inquiry include:

- What pressures are estimated in the bins or alcove by the end of the test programs? What hydrogen levels are anticipated in the bins or Alcove tests by their end? Based on leak test criteria, how much gas could be lost from the individual test bins during the five year test period? What are the specific effects on additional gas generation caused by purging of the gases (if necessary) in the test bins? Ditto for the alcove?
- How will the wastes to be generated differ from the wastes generated to date?
- To what extent are standard ASTM tests being used when possible?
- What documented/approved QA plan has been provided for all testing. (including test and objective descriptions, calibrations), and what is the trace of metallic samples.

- How has instrumentation reliability in the humid environment been validated?

- How was the limit of 2 psi determined for Type I bin and 80 psi for Type II bin? What is the influence of repository temperature fluctuations on these psi limits?

- What are the assurances that the bins will not release VOCs into the repository ventilation system?

- What is the conservative, worst case test schedule for alcove and Bin tests?

- Will the Alcove test room be backfilled, and if so, how?

- What are the reasons for conducting these tests at WIPP?

- What are the location-dependent factors?

- What is the timing of acquiring waste for the Bin Alcove tests? How were the number of test barrels/bins determined? How long to decide on "specific" tests and timing to initiate the full suite of bins (33)? Ditto for the conditionally planned bins. Ditto for Alcove tests.

- What is the waste characterization process? What sources of information are used to obtain data on the volatile organic chemical constituents of the waste inventory?

- Define "bounding" approach for waste characterization and waste acceptance criteria?

- What simulants are used for actual inventory waste matrices?

- What work from outside the WIPP program has been evaluated in order to develop Bin and Alcove tests, with specific attention to international programs?

- The LWA requires DOE to submit comprehensive recommendations for disposal of all TRU wastes. Because some of the TRU wastes are Pu-238, what are the plans for making these recommendations to include Pu-238?

- What is the relevance of alcove conditions to repository room conditions? (excavation, design, and support & seal performance)

- What new data on VOC constituents will be obtained in these tests?

- What are the various filter and drum seal configurations? How do the various filter and seal configurations influence VOC emission and data interpretation.

- What are the major issues in a repository operation? (repository ops = how they open the mine, how the waste interacts with the mine, what happens with the roof support, ventilation). Which tests apply to these issues? How do the tests apply to these issues? How is the data from these tests assured to be defensible to answer these issues? How do these tests adversely affect repository operations?

- What are the important factors of the repository environment which will affect the tests?

- How is test data extrapolated to long term repository conditions

- What defines seal performance?

- What are the changes of brine chemistry over time?

- What does geochemistry tell about past, present and future isolation?

- What do the tests tell about radiation, mechanical stress, and thermal fields on the geologic setting?

- How is the transmissivity of the marker bed characterized? How is the potential damage to the marker bed during mining operations evaluated?

- How was the requirement for 70% humidity determined?

- Assuming a corrosive environment, what impact will there be due to the metallic ground support system?

- How will Bin and Alcove tests define waste and fluid interactions? What is the time frame for data collection? What is the sensitivity of the tests? Is this sensitivity required for modeling? What is the uncertainty of the data collected?

- What is the composition of currently existing brine? What is the model for compositional changes with time?

Task 4: Test Integration

Per the charter...

The ITR Team will evaluate the plans for integrating the bin and Alcove test programs with lab-scale programs, and with the total WIPP test program, to assess how experimental results will be incorporated into modeling verification tools for performance assessments. The utility of different test-scale and test-type results for use in WIPP performance assessment efforts will also be considered.

The ITR Team will also assess the integration of the bin and Alcove test programs into the function of WIPP as a geologic waste repository.

Examples of generic issues that can be addressed include:

- Interconnections between the test programs
- Contributions of the bin, alcove, and lab test programs to the overall WIPP test program
- Relationship of the waste matrices used in the WIPP test programs to the overall DOE waste inventory
- The potential for WIPP to dispose of the TRU waste inventory from the entire DOE complex

Potential lines of inquiry include:

- How are the bin, alcove, and lab test programs integrated? Where is this integration specifically shown? What are the specific data outputs to be provided by the individual test programs? When are these data outputs obtained? How are the test programs complementary to each other? Where is there overlap between the programs as additional quality checks on the data?
- What are the mutual dependencies of the results of the lab, Bin and Alcove tests?
- How much additional time would be required to significantly decrease the data uncertainty? How would costs increase if the schedule is extended by the length of time?
- What are the most essential impacts of the lab, Bin and Alcove test results on the future development of the repository?

Task 5: **Associated Test Issues**

Per the charter...

The ITR Team will review and assess the relationship of the proposed bin and Alcove test programs to such issues as: the adequacy of cost and schedule to support waste disposal decisions; the approach used to evaluate the need for, and adequacy of, contingency tests; the management approach to, and influence on, testing and operational status; the definition of acceptable waste forms; barriers to regulatory compliance; the technical preparedness of WIPP to transition from standby status to testing with TRU-waste.

Examples of generic issues that can be addressed include:

- Startup and operational plans and procedures
- Cost estimation basis and control
- Contingency tests
- Engineered Alternatives Task Force Recommendations
- Decision processes
- Communications paths and documentation
- Roles, responsibilities and accountability
- Involvement of the public and oversight groups

Potential lines of inquiry can include independent assessments to determine:

- What additional work must be done at the WIPP site before TRU test wastes can be introduced into it?
- What is the total estimated cost of the Bin and Alcove tests? What is the total WIPP test budget?
- What percentage is the total estimated cost of the Bin and Alcove test program of the total WIPP budget? What percentage of the testing budget?
- How do the bin or Alcove test programs assist in providing a baseline for an operational test phase?

- What oversight groups could affect the bin and Alcove test programs?

- What is the approach for evaluating the need for, and adequacy of, contingency tests? What are the contingency tests contingency for?

- What, if any, waste form definition may be provided from the bin and Alcove test results? What contingencies exist to modify the waste forms to meet performance assessment requirements? Which of these can be implemented on a cost effective basis? What work is ongoing based on the Engineered Alternatives Task Force report?

Task 6: Recommendations

Per the charter...

The ITR Team will provide suggestions, recommendations and/or alternate strategies, as appropriate, on the approach and implementation of the bin and Alcove test programs, their relationship with promoting the expeditious generation of information needed for performance assessments, and demonstrating WIPP regulatory compliance.

Recommendations on the test programs or process will be developed at the end of the review, as necessary.

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APPENDIX G

INTERVIEWEES

Name	Organization
Anderson, R.	SNL
Arthur, W. J.	DOE/WPIO
Beauheim, R.	SNL
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Conway, C.	WID
Dickman, P.	DOE/WPIO
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Fitch, L.	WID
Fort, P.	INTERA
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Garcia, J.	WID
Gelbard, F.	SNL
Glora, M.	WTAC
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Olona, D.	DOE/WPIO
Orrell, A.	SNL
Reed, D.	ANL (Argonne, IL)
Rempe, N.	WID
Sethi, S.	WID
Sorensen, N.	SNL
Tillerson, J.	SNL
Trujillo, T.	DOE/WPIO
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Vreeland, R.	West Chester University, PA

Weart, W.	SNL
Westerman, R.	Battelle-PNL

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APPENDIX H

ITR BIBLIOGRAPHY

Title	Author	Document #
3D Structure Analysis of SPDV Test Room 2 and Cross Drift Intersections at the WIPP	J. G. Arguello, P. L. Ehgartner	SAND90-1820A
1993 Q&RA Independent Review	Q&RA Independent Assessment Team	QA:93:00627
A Comparison of Brines Relevant to Nuclear Waste Experimentation	M. A. Molecke	SAND83-0516.UR
A Letter Report by the Panel on the Waste Isolation Pilot Plant Board on Radioactive Waste Management Major Conclusions with Letter To: L. P. Duffy From: C. Fairhurst Dated 6/17/92	Panel on the Waste Isolation Pilot Plant	None
A Letter Report by the Panel on the Waste Isolation Pilot Plant Board on Radioactive Waste Management National Research Council/National Academy of Science Summary of Recommendations, April 1991	Panel on the Waste Isolation Pilot Plant	None
A Plan for the Implementation of Assurance Requirements in Compliance with 40 CFR 191.14 at the Waste Isolation Pilot Plant	Waste Isolation Pilot Plant	DOE/WIPP 87-016
A Report of Biological Investigations at the Los Medanos Waste Isolation Pilot Plant (WIPP) Area of New Mexico During FY1978	T. L. Best, S. Neubauser	SAND79-0368.UC-48
Alcove Hardware/Support System Description with a memo To: WPSO:MHM 93-0641 From: Michael H. McFadden	Waste Isolation Pilot Plant, DOE/AFO	None Pre-Decisional Draft
Alcove Test Plan	Unknown	None Pre-Decisional Draft

Anaerobic Cellulose Degradation Under A Saline and Hyper-Saline Condition	X. Tong, J. P. Black, J. Mueller-Vollmer, Stanford University	SAND91-7054A
Analysis of Failed Hardware at WIPP	N. R. Sorensen, SNL	WP077370
Analysis of Rock Bolt Material Failure at WIPP	J. P. Lucas	SAND84-0224
Annual Report on Work Performed for FY 84	N. R. Sorensen, SNL	WPO1127
Bin Case Data Package Final Report, Bin No. IDRFBN9200006, Serial No: 063, SWB No: 00711		
Bin Program - TRU Waste Tests		None
Calculations of Brine Flux and Cumulative Brine Volume for Room Q, Based on a Darcy-Flow Model	D. F. McTigue, Sandia National Laboratory	None
Chart and Narrative of the Type 1 Bins Estimated Program Cost Draft		None
Chart of the WIPP Disposal Decision Plan, Rev. 0		None
Chart on SPDV Test Room Convergence Data Combination 8001 and 14001	Unknown	None
Charts of Alcove Program Estimated Program Cost, Draft		None
Charts of Type II Bins Estimated Program Cost		None
Comments by New Mexico Attorney General Tom Udall to the Waste Isolation Pilot Plant Subcommittee of the National Advisory Council for Environmental Policy and Technology		None
Comments on the Advance Notice of Proposed Rulemaking (ANPR) attachment DOE Comments on EPA's Advanced Notice of Proposed Rulemaking for the Certification of Compliance with 40 CFR 191 Disposal Regulations	P. D. Grimm	None

Comments on the Proposed Role to amend 40 CFR 191 with attachment "U. S. Department of Energy Comments on the Proposed Amendments to 40 CFR Parts 144 and 191 -- Environmental Protection Standards for the Management and Disposal of Spent Fuel, High-Level and Transuranic Radioactive Waste	P. D. Grimm	None
Conceptual Structure of Performance Assessments Conducted for the Waste Isolation Pilot Plant	J. C. Helton, M. G. Marietta, R. P. Rechard	SAND92-2285
Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP) (Federal Register)		None
Constitutive Modeling of Salt Behavior - State of the Technology	D. E. Munson and W. R. Wawersik	SAND91-1614
Contingency Test Task Force Report Evaluation of Alternate Tests as Contingencies to Replace the Currently Planned Bin and Alcove Tests at WIPP	U.S. Department of Energy	693B:1556
Convergence Measurements in SPDV Room 1 Memo To: Thomas E. Lukow	R. F. Cook	WD:88:01426
Corrosion Analysis of TRU Drums	N. R. Sorensen, SNL	
Critical Comments on the U. S. Environmental Protection Agency Standards 40 CFR 191	C. G. Pflum, R. A. VanKonynenburg, P. Krishna	None
Design Concept Selection for the Type 2 Phase 1 Bin	C. E. Conway	Report #: WD:93:00633
Design Description of the Type 2 Bin and Systems for Wet Waste Testing	Waste Isolation Pilot Plan	DOE/WIPP 93-037
Desk Reference Manual for FY1993 Baseline Documents	Department of Energy	None
DRAFT Uncertainty and Sensitivity Analyses for Gas & Brine Migration at the WIPP, May 1992	J. C. Helton, J. E. Bean, B. M. Butcher, J. W. Garner, J. D. Schreiber, P. N. Swift, P. Vaughn	SAND92-2013

Environmental Protection Agency CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel High-Level and Transuranic Radioactive Wastes	Environmental Protection Agency	None
Equipment Design Criteria Wet Waste Testing Program, Revision 1	Unknown	WP 09-15, Rev. 1 Draft
ES&H Independent Assessment	L. L. Reed	None
Evaluating Design Procedures for Structures in Rock Salt	W. R. Wawersik, H. S. Morgan	SAND86-2597C
Evaluation of the DOE Plans for Radioactive Experiments and Operational Demonstration at WIPP	L. Chaturvedi, Environmental Evaluation Group	EEG-42
Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force, Volume I, Revision 0	Waste Isolation Pilot Plant	DOE/WIPP 91-007
Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force, Volume II Appendices, Revision 0	Waste Isolation Pilot Plant	DOE/WIPP 91-007
Evaluation of the Role of Threshold Pressure in Controlling Flow of Waste-Generated Gas into Bedded Salt at the Waste Isolation Pilot Plant	P. B. Davies	SAND90-3246
Experimental Test Program Implementation Plan		WP 09-11
Expert Judgment as Input to Waste Isolation Pilot Plant Performance-Assessment Calculations Probability Distributions of Significant System Parameters	K. M. Trauth, S. C. Hora, R. P. Rechard, SNL	SAND91-0625.
Final Draft Alcove Test Plan		DOE/WIPP 93-035
Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation	M. A. Molecke, SNL	SAND79-1245
Gas-Generation and Source-Term Programs: Technical Needs Assessment for the Waste Isolation Pilot Plant Test Phase, Revision 0	US Department of Energy, WIPP Project Integration Office	DOE/WIPP 92-062

Geotechnical Data From Site and Preliminary Design Validation Test Rm. 1	T. W. Halverson	WD:90:02204
Growth on, and Production of Organic Acids from Two Types of Common Laboratory Papers by Mixed Populations of Halophilic Bacteria	A. F. Piselli, R. H. Vreeland, West Chester University	None
Hardcopies of Vugraphs WIPP Underground Compliance/Operational Needs Test Program		None
Hardcopies of vugraphs on WIPP Integration Disposal Decision Alternatives Group	Department of Energy	None
Hardcopy of vugraphs Effects of Microbial Processes on Gas Generation from TRU Waste Under WIPP Site Test Conditions	A. J. Francis, J. B. Gillow, M. R. Giles, Brookhaven National Laboratory	None
Highlights and Issues Summary DOE/EPA Technical Exchange on the Test Phase Plan and Waste Retrieval Plan for the Waste Isolation Pilot Plant (WIPP)		None
Horizontal Darcy Flow to Room Q	D. F. McTigue, SNL	None
Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments	M. R. Telander, R. E. Westerman	SAND92-7347
Hydrogen Uptake by Grade 12 Ti	N. R. Sorensen, SNL	
Important Parameters identified by the 1st four interactions of PA	D. "Rip" Anderson, SNL	
In response to letter to William K. Reilly on Draft Final Plant for the Waste Isolation Pilot Plant (WIPP) Test Phase; Letter To: Leo P. Duffy	R. J. Guimond and S. Lowrance	None

M

Information Relative to the Calculation of the VOC Source Term Utilized in the WIPP No Migration Variance Petition within Appendix A: Calculation of the Headspace Gas Concentrations of Hazardous Chemicals in the TRU Waste; and Appendix B: Operational VOC Dose Calculations taken from the WIPP FSAR; Appendix C: VOC Source Term Presentation from May 7, 1993, Technical Exchange Meeting with the EPA	Department of Energy/Waste Isolation Pilot Plant	DOE/WIPP 89-003. Rev. 1
Integrated Data Base for 1992: U. S. Spent Fuel and Radioactive Waste Inventories Projections and Characteristics	Oak Ridge National Laboratories; U. S. Department of Energy	DOE/RW-0006, Rev. 8
Integrated Systems Checkout Program Development and Implementation	R. J. Rodriguez	WP 15-AD3015
Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report	R. L. Beauheim, G. J. Saulnier, J. D. Avis	SAND90-0083
Interpretation of In-Situ Pressure and Flow Measurements of the Salado Formation at the Waste Isolation Pilot Plant	S. M. Howarth, E. W. Peterson, P. L. Lagus, K-H Lie, S. J. Finley, E. J. Nowak	SPE 21840
Investigation into Coupled Fluid Flow and Mechanical Closure Behavior of Waste Disposal Rooms in Bedded Salt	F. T. Mendenhal, B. M. Butcher, P. B. Davies	SAND91-0686C
Latest draft (or documentation equivalent) of Source Term Tests	R. Villarreal, LANL, CLS-1	
WID Declaration of Readiness; Letter To: V. Daub, Chairman, WPSO Senior Review Board	C. M. Cox, Westinghouse	WD:93:00169 AA:93:1012
Long-Term Gas and Brine Migration at the Waste Isolation Pilot Plant: Preliminary Sensitivity Analyses for Post-Closure 40 CFR 268 (RCRA), May 1992	WIPP Performance Assessment Dept., SNL	SAND92-1933.
Management Assessment of WIPP Organizational Communication	Westinghouse Electric Corporation, Waste Isolation Division	None

Meeting Summary DOE/EPA WIPP Test Phase Plan Technical Information Orientation		None
Meeting Technical Summary National Academy of Sciences/National Research Council, Board on Radioactive Waste Management, Committee on the Waste Isolation Pilot Plant (WIPP)		None
Modeling of the Chemical Alteration of SPC Brine as a Function of CO2(g) Fugacity, Modeling the Fugacity of Pure CO2(g) as a Function of Pressure	J. Nowak, SNL	None
No-Migration Determination Annual Report for the Period October 1991 through August 1992	U. S. Department of Energy, Waste Isolation Pilot Plant	DOE/WIPP 92-057
No-Migration Variance from Land Disposal Restrictions for Exxon Company U.S. A. Billings, Montana New South Land Treat Unit	Environmental Protection Agency	58 FR 40134 No. 142
Panel on the Waste Isolation Pilot Plant (WIPP) Roster	Waste Isolation Pilot Plant Panel	None
Preconceptual Design Description of the Type 2 Bin and Systems for Wet Waste Testing	Test Program Engineering, Westinghouse Waste Isolation Division	None
Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991 Volume 4: Uncertainty and Sensitivity Analysis Results	J. C. Helton, J. W. Garner, R. P. Rechard, D. K. Rudeen, P. N. Swift	SAND91-0893/4.
Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991: Volume 6: Guidance to the WIPP Project from the December 1991 Performance Assessment	Sandia National Laboratory	SAND91-0893/6
Preliminary Evaluation, Uncertainties, Conclusions, and Programmatic Recommendations for Studies Concerning The Role of Gas in WIPP Compliance with Long-Term-Containment Provisions of 40 CFR 268.6 (RCRA; No -Migration Determination)		None

Preliminary Performance Assessment for the Waste Isolation Pilot Plant December 1992 Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance	Sandia National Laboratories, WIPP Performance Assessment Department	SAND92-0700/5
Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B	Sandia National Laboratories	SAND92-0700/4.
Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992; Volume 1: Third Comparison with 40 CFR 191, Subpart B	Sandia National Laboratories	SAND92-0700/1.
Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992; Volume 2: Technical Basis	Sandia National Laboratories	SAND92-0700/2.
Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992; Volume 3: Model Parameters	Sandia National Laboratories, WIPP Project	SAND92-0700/3.
Preliminary Review of the DOE Test Phase Plan for the Waste Isolation Pilot Plant (DOE/WIPP 89-011, Rev. 1, March 1993) with Letter To: W. J. Arthur, III, From: R. H. Neill, Dated: 5/15/93	New Mexico Environmental Evaluation Group	None
Process for the Waste Isolation Pilot Plant (WIPP) Disposal Decision Path Alternatives	Unknown	M93-GT-0388
Program/schedule which shows all of the current activities which are currently being carried out in preparation for bin tests	Westinghouse	
Programmer's Manual for CAMCON: Compliance Assessment Methodology Controller	R. P. Rechard, A. P. Gilkey, H. J. Luzzolino, D. K. Redeen, K. A. Byle	SAND90-1984
Public Law 96 - Original WIPP Authorization		None
Quality Assurance Plan WIPP Analytical Laboratory	Waste Isolation Pilot Plant	WP 12-13

Quality Assurance Program Plan for the Waste Isolation Pilot Plant Experimental-Waste Characterization Program (QAPP)	Environmental Restoration and Waste Management, US Department of Energy	DOE/EM/48063-1
Quality Assurance Project Plan, Revision 1		DOE Order 48063.1
Quarterly Report for WIPP Project for the Period January 1, 1984 through March 31, 1984; Memo TO: M. A. Molecke	N. R. Sorensen, SNL	None
Rates of CO_2 Production from the Microbial Degradation of Transuranic Wastes under Simulated Geologic Isolation Conditions	D. E. Caldwell, R, C, Hallet,UNM; M. A. Molecke, SNL; E. Martinez, LANL; B. J. Barnhart, Midwest Research Institute	SAND87-7170.UC-70
Rationale for Revised Bin-Scale Gas Generation Tests with Contact-Handled Transuranic Wastes at the Waste Isolation Pilot Plant	A. R. Lappin, C. A. Gotway, M. A. Molecke, R. L. Hunter, E. M. Lorusso, SNL	SAND90-2481.
RCRA Waste Profile Form, with Bin Case Data Package Final Report, Bin No. IDFRBN9100001		
RCRA Waste Profile Form, with Bin Case Data Package Final Report, Bin No. IDFRBN9100002		
RCRA Waste Profile Form, with Bin Case Data Package Final Report, Bin No. IDFRBN9100003		
RCRA Waste Profile Form, with Bin Case Data Package Final Report, Bin No. IDFRBN9100004		
RCRA Waste Profile Form, with Bin Case Data Package Final Report, Bin No. IDFRBN9100005		
Readiness Review Board Recommendation of Site Readiness	Westinghouse	RB:93:0320
Recovery for SPDV Rooms 1 and 2 Letter To; Distribution (WPO, WID, SNL, IT/WPO; From: Daryl Mercer	D. Mercer	None

Regulatory Compliance Strategy (draft document discussed by E. Maestas)	U. S. Department of Energy, WIPP Project Integration Office	DOE-WIPP 86-013, Rev. 1
Repository Convergence Process Flow Chart	Unknown	PC0586
Response to Letter from W. K. Reilly concerning review of the DOE Draft Plan for the WIPP Test Phase; Letter To: Chairman J. Bennett Jonston, Committee on Energy and Natural Resources	R. J. Guimond	None
Review Comments on DOE Document DOE/WIPP 89-011: Draft Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration WITH letter To; Leo Duffy;	F. L. Parker	None
Review Comments on DOE Document DOE/WIPP 89-011: Draft Plan for this Waste Isolation Pilot Plant Test Phase: Performance Assessment and Operations Demonstration with Letter To: L. Duffy; From: F. L. Parker dated: 7/20/89	WIPP Panel; C. Fairhurst, J. O. Blomeke, J. D. Bredehoeft, K. P. Cohen, F. M. Ernsberger, R. C. Ewing, D. A. Shock	None
Review Criteria for Completeness of DOE's Test & Retrieval Plans	Unknown	None
Risk, Uncertainty in Risk, and The EPA Release Limits for Radioactive Waste Disposal (Published Nuclear Technology, Vol. 101, Jan. 1993)	J. C. Helton, Arizona State University, Dept. of Mathematics	None
Roles and Responsibilities for the WPIO and the WIPP Project Site Office including Organizational Charts with a memo To: WPIO:MLM:93-0126M	W. J. Arthur III	None
Roof Conditions in SPDV Test Room 1 (Workshop Area) Memo To: Dave Rasmussen	Engineering and Repository Technology	HA:88:70007
Roof Conditions in the SPDV Test Rooms Memo To: Vince Likar	R. F. Cook, Westinghouse	HA:88:7026
Roof Stability and Closure of SPDV Rooms 1 and 2 MEMO To: Distribution (DOE, WID, IT)	R. F. Cook, Westinghouse,	WD:89:00559
Room Q Data Report: Test Borehole Data From April 1989 through November 1991	R. Beauheim	SAND92-1172

Scale CH TRU Waste Tests		S.U. Pickering and S. A. Orrell/SNL
Specifications for Standard Waste Box and Ten Drum Overpack		(Appendix of NuPac TRUPACT-II SAR – Appendix 1.3.4) Rev. 12
Status of Gamma Radiation Experiments	N. R. Sorensen, SNL	
Status Report on Iron Contamination Work	N. R. Sorensen, SNL	None
Strategy for the Waste Isolation Pilot Plant Test Phase, Revision 3	DOE/EM	DOE/EM/480 63-2 Draft
Summary Description Rationale for the Bin-Scale and Alcove Waste Test Programs at the Waste Isolation Pilot Plant	Unknown	None
Summary of the WIPP Disposal Phase Decision Plan	U. S. Department of Energy	M93-GT-0171
Summary of WIPP Materials Interface Interactions Test Data on Metals Interactions and Leachate Brine Analyses	M.A. Molecke, N. R. Sorensen, J. L. Krumhansl, SNL	SAND88-2023C
Survey of Microbial Degradation of Asphalts with Notes on Relationship to Nuclear Waste Management	C. E. Zobell, Scripps Institute of Oceanography & M. A. Molecke, SNL	SAND78-1371
Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989	A. R. Lappin, R. L. Hunter, D. P. Garber, P. B. Davies,	SAND89-0462.UC-70
Technical Support Group Preliminary Report of Findings on the Potential for Gas Generation within the WIPP Repository and the Possible Effects of the Resultant Gas Pressure	Unknown	None Draft Predecisional Information
Test Phase Plan for the Waste Isolation Pilot Plant, Revision 1	US Department of Energy, WIPP Project Integration Office	DOE/WIPP 89-011

Test Phase Plant for the Waste Isolation Pilot Plant	DOE Waste Isolation Pilot Plant, Project Integration Office	DOE/WIPP 89-011 Revision 2
Test Plan Addendum #1: Waste Isolation Pilot Plant Bin-Scale CH TRU Waste Tests	M. A. Molecke, A. R. Lappin, Sandia National Laboratories	SAND90-2082.
Test Plan Addendum #2: Waste Isolation Pilot Plant Bin-		SAND93-1676
Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant	L. H. Brush, SNL	SAND90-0266.
Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the WIPP	L. H. Brush, SNL	SAND90-0266
Test Plan: Gas-Threshold-Pressure Testing of the Salado Formation in the WIPP Underground Facility	G. J. Saulnier, Jr. INTERA Inc.	105400R156
Test Plan: Waste Isolation Pilot Plant Bin-Scale CH TRU Waste Tests (Type 2 Bin)	A. C. Peterson, S. A. Orrell, J. T. Holmes/SNL	SAND93-1550
Test Plan: WIPP Bin-Scale CH TRU Waste Tests	M. A. Molecke, SNL	SAND90-1974.
Test Plan: WIPP Bin-Scale CH TRU Waste Tests (Type 2 Bin), Revision 0.1	A. C. Peterson, S. A. Orrell, J. T. Holmes, SNL	SAND93-XXX Pre-Decisional Draft
Test Plan: WIPP Bin-Scale CH TRU Waste Tests (Type 2)	A. C. Peterson, S. A. Orrell, J. T. Holmes	SAND93-1550
Test Plan: WIPP Materials Interface Interactions Test (MIIT)	M. A. Molecke, G. G. Wicks, SNL/SRL DuPont	None
Test Plant Addendum #2: Waste Isolation Pilot Plant Bin-Scale CH TRU Waste Tests	S. Y. Pickering, S. A. Orrell, SNL	SAND93-1676 Pre-Decisional Draft
Test Room Stability Plan	Waste Isolation Pilot Plan	DOE/WIPP 93-010

The Environmental Protection Agency's (EPA) Comments on DOE/WIPP 89-011, *The Draft Plan for the Waste Isolation Pilot* Plant Test Phase: Performance Assessment and Operations Demonstration With memo To: Jill E. Lytle From: R. J. Guimond and S Lowrance	R. J. Guimond, S. Lowrance	None
Total Bin Brine Formulation and Preparation for Use in Bin-Scale Tests Memo To: D. R. Schafer;	M. A. Molecke	None
TRU Waste Sampling Program: Volume I– Waste Characterization	T. L. Clements, Jr.; D. E. Kudera	EGG-WM-6503
TRU Waste Sampling Program: Volume II--Gas Generation Studies	T. L. Clements, Jr.; D. E. Kudera	EGG-WM-6503
Type 2 Bin Preconceptual Design Description		HA:93:3168
Type II Bin Test Plan	A. C. Peterson, S. A. Orrell J. T. Holmes	
Vugraph hard copy of showing comparison to the actual brine inflow results with a memo To: D. Schafer From: A. L. Jensen, dated 8/10/93 re: response to *request for information by ITRT*	A. L. Jensen, SNL,	None
Waste Characterization Program Plan for the Waste Isolation Pilot Plant , Revision 1	Waste Isolation Pilot Plant	DOE/WIPP 89-025
Waste Characterization Program Plan for the Waste Isolation Pilot Plant , Revision 2.0	Waste Isolation Pilot Plant	DOE/WIPP 89-025
Waste Isolation Pilot Plant (WIPP) Bibliography	None	None
Waste Isolation Pilot Plant (WIPP) Program Management Plan	Department of Energy	None
Waste Isolation Pilot Plant (WIPP): Alcove Gas Barrier Trade Off Study	M. S. Lin, L. L. VanSambeer	SAND91-7099
Waste Isolation Pilot Plant Compliance Strategy for 40 CFR 191	Westinghouse	DOE/WIPP 86-013
Waste Isolation Pilot Plant Final Safety Analysis Report Addendum Dry Bin-Scale Test	Westinghouse Electric Corporation	WP 02-9
Waste Isolation Pilot Plant No-Migration Determination Annual Report for the Period November 1990	U. S. DOE, Waste Isolation Pilot Plant	DOE/WIPP 91-059

Waste Isolation Pilot Plant Program Overview by W. John Arthur, Director, DOE Waste Isolation Pilot Plant, Project Integration Office	DOE Waste Isolation Pilot Plant, Project Integration Office	None
Waste Isolation Pilot Plant Safety Assessment Report The Inventory of Radioactive of Radioactive Material in the Event of an Underground Accident at the Point of Release, its Pathway to Station A, and the Consequence of Off-Site Dose to the Public	Westinghouse Electric Corporation	DOE/WIPP 92-017
Waste Isolation Pilot Plant Sandia Reports (This is a list of Sandia Reports Pertaining to WIPP)	Sandia National Laboratories	None
Waste Isolation Pilot Plant, Integrated Project Schedule, Predecisional Draft	U. S. Department of Energy, WIPP Project Integration Office	None
Waste Retrieval Plan for the Waste Isolation Pilot Plant	DOE, Waste Isolation Pilot Plant	DOE/WIPP 89-022
Waste-Generated Gas at the Waste Isolation Pilot Plant: Papers Presented at the Nuclear Energy Agency Workshop on Gas Generation and Release from Radioactive Waste Repositories	P. B. Davies, L. H. Brush, M. A. Molecke, F. T. Mendenhal, S. W. Webb	SAND91-2378
WID Operational Readiness Review Implementation Plan for Initiation of the WIPP Test Phase with Transuranic/Mixed Waste, Rev. 1	Unknown	None
WID Quality Assurance Program Description Approvals	Westinghouse Electric Corporation-Waste Isolation Division	WP 13-1, Revision 14
WIPP Alcove Gas Barrier Final Design Report	M. S. Lin, L. L. Van Sambeek	4060A220-TR03
WIPP Project Master Contact List	Department of Energy	None
WIPP RCRA Part B Permit Application Revision 3 (Chapter D)		DOE/WIPP 91-005

WIPP Record of Meeting Minutes Subject: Gas Masters: Review of Gas Generation Potentials and repository Response with letter To: W. John Arthur, III; From John Thies	D. Lechel	None
WIPP Supplementary Roof Support System Room 1, Panel 1 Geotechnical Field Data Analysis Bi-Annual Report	Waste Isolation Pilot Plan	DOE/WIPP 92-024
WIPP Supplementary Roof Support System Room 1, Panel 1 Geotechnical Field Data Analysis Report		DOE/WIPP 93-012
WIPP Test Phase Activities in Support of Critical Performance Assessment (40 CFR 191 B) Information Needs		None
WIPP Test Phase Activities in Support of Critical Performance Assessment (40 CFR 191 B) Information Needs	Waste Isolation Pilot Plant	None
WIPP/SRL In Situ Tests—Part II: Pictorial History of MIIT and Final MIIT Matrices, Assemblies and Sample Listings	G. G. Wicks; M. E. Weinle, M. A. Molecke	DP-1733

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APPENDIX J

INDEPENDENT TECHNICAL REVIEW TEAM AND TECHNICAL OVERSIGHT BOARD MEMBERSHIP AND CREDENTIALS

J.1. <u>Independent Technical Review Team Members:</u>

Dr. Stephan Brocoum, DOE Team Leader

Dr. Philip Thullen, ITR Team Leader

Ms. Deborah Bennett, ITR Team Leader

Mr. Richard Beddoes

Dr. Corale Brierley

Dr. Jan Docka

Dr. Joseph Farmer

Mr. Ron Guymon

Dr. Stan Kosiewicz

Dr. Abraham Lerman

Mr. John Shaler

Dr. Terry Steinborn

Mr. Dave Swale

J.2. <u>Technical Oversight Board Members</u>

Dr. Colin Heath, Chairman

Mr. Richard Baxter

Mr. William Hamilton

Dr. Mujid Kazimi

Mr. Dennis Lachel

Mr. John Maddox

Ms. Deborah Marsh

J.3. ITR Member Credentials

Name: **Beddoes, Richard**

Affiliation: Golder Associates

Education: B.Sc. in Civil Engineering, University of Leeds, England, 1977
M.Sc. in Civil Engineering, University of Calgary, 1980

Experience: Mr. Beddoes fields of expertise include instrumentation, rock mechanics, foundation engineering, laboratory testing, stress analysis and stability studies for underground mines. He is highly experienced in evaporates and in instrumentation of multiple level mines, and is recognized for his expert stress analysis skills of underground mines.

Name: **Bennett, Deborah R.**

Affiliation: LANL, N-DO/RT

Education: B.S., Mechanical Engineer, University of New Mexico, 1978
Completed coursework for M.S. M.E., University of New Mexico

Experience: Ms. Bennett has been associated with Independent Technical Reviews since early 1992, and has most recently been the Team Leader for the In-Tank Precipitation and Extended Sludge Processing ITR at Savannah River. She participated in activities for the Defense Waste Processing Facility review at the Savannah River Site, the PUREX review at Hanford, and numerous post-review activities. She was the Resident Engineer between LANL and the New Production Reactor program in WDC from 1990-91, supporting the independent safety evaluations of the proposed NPR concepts. Prior to that, she managed a team evaluating the technical capabilities of nuclear subsystems in the SP-100 Space Nuclear Power program. Experience with space nuclear power systems was based on the technical assistance provided to

DOE/NE on the general development of Space Reactor Power System (SRPS) programs, and specifically the Thermionic Fuel Element Verification Program. Other previous nuclear-related experiences at LANL have included: providing technical assistance to NRC on technical issues associated with gas-cooled reactor systems, carbide fuel experiments; and experimental evaluations of fuel/cladding relocation phenomena during decay heat modes for the Gas-Cooled Fast Reactor program.

Name: <u>Brierley, Corale L.</u>

Affiliation: Private Consultant

Education: B.S. in Biology, New Mexico Institute of Mining & Technology, 1968
M.S. in Chemistry, New Mexico Institute of Mining & Technology, 1972
Ph.D. in Environmental Sciences, University of Texas at Dallas, 1981

Experience: Ms. Brierley has over twenty years of increasingly responsible experience in mining and biotech companies. She has extensive knowledge of environmental and biohydrometallurgical process specifications, and has recommendations from mineral and metal industries. Ms. Brierley has had full management and budget responsibility for start-up biotech product and process company achieving world-wide recognition for developments and publications. She is also recognized for excellent analytical and problem solving skills.

Name: <u>Brocoum, Stephan</u>

Affiliation: Department of Energy, Office of Geologic Disposal, Director of Analysis and Verification Division.

Education: B.S. in Geology, Brooklyn College, City University, 1963

Ph.D. in Earth Science, Columbia University, 1971

Post-Doc, Columbia University, 1971-1973

Experience: Over 15 years of experience with regulators , contractors, and DOE on issues related to nuclear facilities' siting, regulations, and

verification. Increasing levels of management responsibility including Director of Analysis and Verification Division, Office of Geologic Disposal HQ Division, Office Civilian Radioactive Waste Management. Responsible for major interfaces among YMPO and other OCRWM and DOE offices. Contributor to development of 10CFR60 and 10CFR72.

Name: Docka, Janet A.

Affiliation: Roy F. Weston, Inc., Department Manager, Geologic Disposal Department, Weston CRWM Technical Support Team

Education: B.A. in Geology, Knox College, 1977
M.S. in Geology, Northern Illinois University, 1979
Ph.D. in Geology, Harvard University, 1985

Experience: Fifteen years of experience as a professional geologist in the collection and evaluation of geologic and hydrologic data, including mineral/fluid phase equilibria in geologic systems; thermal stability of minerals; mass transfer diffusion; and heat flow modeling in geologic systems. Currently responsible for management and supervision of 11 professional geoscientists and engineers involved in the development and review of programmatic and technical documents, technical review of Study Plans under quality assurance procedures; technical analysis of suitability, licensing, environmental, health, and safety; and risk assessment issues relevant to site characterization and geologic disposal of spent nuclear fuel and high-level radioactive waste for the Office of Geologic Disposal, DOE Office of Civilian Radioactive Waste Management.

Name: Farmer, Joseph C.

Affiliation: Lawrence Livermore National Laboratory, Principal Investigator (C&MS) and Deputy Group Leader (SIS)

Education: B.S. in Chemical Engineering, Virginia Polytechnic Institute and State University, 1977
Ph.D. in Chemical Engineering, University of California, Berkeley, 1983

Experience: Worked on Yucca Mountain and Laser Isotope Separation Programs, as well as a variety of applied and basic research projects. Expertise includes materials development; corrosion science; electrochemistry; electrochemical engineering; treatment processes for mixed and hazardous wastes; catalysis and chemical reaction engineering; and development of various optical techniques. Numerous publications, presentations, patents, and awards from international scientific and technical societies.

Name: Guymon, Ronald H.

Affiliation: Ogden Environmental and Energy Services, Branch Manager, Environmental Sciences & Engineering

Education: B.S. in Chemical Engineering, University of Arizona, 1979

Experience: Mr. Guymon has more than 13 years experience in project management and engineering.. During the past seven years he has provided technical and management support to a variety of waste management programs for the Department of Energy (DOE) Waste Isolation Pilot Plant (WIPP) and Hanford facilities. He is thoroughly familiar with Federal environmental statutes and regulations governing the proper management (treatment, storage and disposal) of radioactive and mixed wastes. Mr. Guymon is currently the Manager of Environmental Sciences and Engineering in the Albuquerque Office, and is responsible for such areas as environmental assessments/impact statements, environmental compliance assessments, environmental permitting, risk assessments, and other similar activities.

Name: Kosiewicz, Stanley T.

Affiliation: Los Alamos National Laboratory, EM-7, Technical Staff Member

Education: B.S. in Chemistry, University of Illinois, 1967
M.S. in Analytical Chemistry, University of Wisconsin, 1969
Ph.D. in Analytical Chemistry, University of Wisconsin, 1973

Experience: An expert in the field of TRU Waste. He has worked on TRU waste characterization and TRU operations, including applied studies on gas generation. He was project manager for a drum venting

system and a peer reviewer of major experiments for WIPP. Led teams to investigate root causes of corrosion of TRU waste containers and was a committee member of a National DOE Technology team for mixed waste treatment. He has developed, taught, and trained in Chemical Hazard Communication. Conducted experiments on plutonium mobility in environmental systems. Served as the technology interface for the Los Alamos National Laboratory environmental restoration program.

Name: Lerman, Abraham

Affiliation: Northwestern University, Professor

Education: M.Sc. in Geology, The Hebrew University, Jerusalem, Israel, 1960
Ph.D. in Geology, Harvard University, 1964

Experience: An expert on geochemical processes. Experience in geochemical balances and human inputs to freshwater lake systems, acid precipitation and its effects on natural materials, uptake and retention of contaminants in landfill and industrial facilities, underground injection of acidic wastes, and transport of gaseous and dissolved contaminants in waste repositories in salt. Serves on numerous panels and committees, advising on governmental and industrial waste disposal issues. Has written two books, and many book chapters and research papers.

Name: Shaler, John E.

Affiliation: Private Consultant

Education: B.S. in Civil Engineering, Clarkson University, 1970
Graduate Studies, Civil Engineering, Mississippi State University

Experience: Senior manager with over 22 years of experience in managing, engineering, construction, geotechnical and environmental programs with over 10 years experience supporting DOE and DOE cost-share programs at SAIC. Responsible for work quality of the Operation that provides environmental (NEPA, RCRA, CERCLA), geotechnical, engineering, quality assurance, and project management support to the DOE, USGS, DoD (Air Force and Corps of Engineers), EG&G, and commercial clients. Project Manager providing technical and management support services to the USGS

in support of DOE's Yucca Mountain program in areas of Project Control, Quality Assurance, Training, Records Management, and technical support.

Name: Steinborn, Terry L.

Affiliation: Applied Research Associates, Inc., Group Leader and Senior Technical Advisor

Education: B.A. in Chemistry, Reed College, 1968
M.S. in Geology, University of Oregon, 1972
Ph.D. in Geology, University of New Mexico, 1976

Experience: A Professional Hydrogeologist with the American Institute of Hydrology. Presently responsible for providing technical and management guidance on large DOE-funded environmental program, including performance and risk assessment, technical reviews, responses to management (DOE and Sandia National Laboratories) information requests, management of RCRA and CERCLA projects including budget and schedule generation and analysis and workplan preparation, quality assurance, and regulatory analysis of EPA, DOE, State and other regulations, orders and guidance. Experience as a waste management specialist and as a senior staff geochemist. Managed Site Performance Assessment and all geochemistry activities on DOE Salt Repository Project.

Name: Swale, David J.

Affiliation: British Nuclear Fuels Limited, Design Integration Manager

Education: B. Tech. in Chemical Engineering, Bradford University, 1977

Experience: Over fifteen years of increasingly responsible positions in plant start-up and operation, the last twelve of which have been in nuclear waste treatment and TRU waste handling facilities. Was an Operational Manager for BNFLs alpha processing facilities and the manager for the start-up of the Waste Treatment Complex, a facility for the classification, segregation, shredding, and packaging in drums of TRU waste at BNFLs Sellafield site. Also directed a group of up to twenty seven technical people providing technical and safety support of facilities operation at Sellafield.

Currently WRAP (Waste Receipt and Processing Facility) Project Manager for the Hanford site.

Name: Philip Thullen

Affiliation: LANL, N-DO/RT

Education: B.S., Mechanical Engineering, Purdue University, 1965
M.S., Mechanical Engineering, MIT, 1967
Sc.D., MIT, 1969

Experience: From 1969 through 1976, prior to joining the Los Alamos National Laboratory, Dr. Thullen was Associate Professor of Mechanical Engineering at MIT. He was a member of the Thermal and Fluid Sciences Division performing research on the application of superconductors to electrical power equipment, and teaching classical thermodynamics, cryogenic engineering and related subjects. Since 1976 he has been at Los Alamos where he has been a staff member, Deputy Group Leader and Program Manager working principally in energy related fields. He continued to work on engineering applications of superconductivity and the design of electromagnetic systems for plasma fusion applications. From 1985 to 1991 he was the Program Manager for Construction of the Confinement Physics Research Facility (CPRF), an $80M, seven year construction project employing 70 FTEs. This experience has given Dr. Thullen a depth of experience in both applied research and in the organization and management of R&D facility construction. From January to June 1991 he was a member of the Los Alamos New Production Reactor, Safety Project Office working in the area of system integration. Since June 1991 he has been the Los Alamos Program Manager for Red Team Reviews and Hanford Support. His principle activity is management of Independent Technical Reviews for DOE-EM.

PEER 24 - Performance Assessment Reviews (1990 to 1992)

1991 PERFORMANCE ASSESSMENT REPORT

INTERA REVIEW

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Review of the

1991 WIPP Assessment

(SAND91-0893)

Intera Information Technologies Limited
Park View House, 14B Burton Street, Melton Mowbray, Leicestershire, LE13 1AE, United Kingdom
Tel 0664 411445 Fax 0664 411402

INTERA

Our Ref: DAG/jab/SAND-5

27th March 1992

M Marietta Esq.
Sandia National Laboratories
Division 6342
P O Box 5800
Albuquerque
New Mexico, 87185
USA.

Dear Mel,

Review of the 1991 WIPP Assessment (SAND91-0893)

Enclosed, please find two copies of our review of SAND91-0893, Volumes 1-3. I have read and commented in detail on all the Volumes, giving particular attention to the Chapters highlighted in the contract. In addition, I have incorporated numerous comments from several other Intera staff, notably Peter Robinson (who has re-done some of the CCDFs!). All of the contributors are listed on the cover of the review document.

I have structured the review document into three parts: an introduction, a general overview of comments and, the largest part, a section-by-section technical commentary on the three Volumes. Many suggestions for improvements are made in the enclosed document but I should like to draw your attention in particular to two areas where further input may be especially helpful.

One of the weakest points of the documentation is, in fact, that a concise, readable overview of what you have done is lacking. It may be that you have not had sufficient time to do this or, perhaps, that the support staff working on the project are all too close to the work or too narrow in their outlook. It would be extremely interesting if an independent party were to try to explain to you what you had done, based on the information contained in SAND91-0893 (and possibly some supporting documentation). The draft 1992 assessment documentation could also be taken as the starting point for this overview but it would, in any case, need to be updated regularly. Such an overview would let you know whether what you had intended to present was in fact properly presented. It would also help in the process of completing the concise readable overview that is so desperately needed.

A second area of weakness concerns the scenario development work which reflects a parochial and out-of-date understanding of work in this field. The scenario development is, however, one of the foundations of the performance assessment and you have rightly recognised this by the attention given to it in Volume 1 of SAND91-0893. I feel we should be in a good position to contribute to further work in this field, based on our experience of scenario development work at international level and in support of such exercises for clients in Sweden, Switzerland and the United Kingdom.

Cont/...

INTERA

Many other recommendations have been put forward in the enclosed document and I await your views on the work we have done.

Finally, I should emphasise here that we never received Volumes 4 and 5 and have, therefore, spent the resources available for the review on Volumes 1 - 3. Please let me know what to do about Volumes 4 and 5.

Also, should you see the need for me to come to Albuquerque in the near future (i.e., around the time of the Las Vegas meeting), please let me know. Possible discussion topics include:

- comments on SAND91-0893, Volumes 1 - 3 and possible follow-up,
- proposed PSACOIN Level 2 exercise and development of draft case specification for the Task Group meeting in May. I should also propose to meet with Jim Sinclair and Peter Robinson (and Brian Thompson, if available) for one day in advance of leaving the UK so that I could represent their views,
- discussion of draft input to NEA Human Intrusion Working Group report. I might also be able to have this completed in advance of leaving the UK,
- other work and associated funding for FY93.

I trust that the enclosed documentation meets your expectations and I should welcome any feedback.

Best regards.

Yours sincerely,

Dr Daniel A Galson
Geosciences Group
Environmental Division

Encl. as stated

IG-3091-1
Version 1

Review of the

1991 WIPP Assessment

(SAND91-0893)

D.A. Galson, P.C. Robinson, T.J. McEwen

K.J.Worgan, M.J. Apted, M.D. Impey

March 1992

Intera Information Technologies
Park View House, 14B Burton St, Melton Mowbray, Leicestershire, LE13 1AE, UK
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INTERA
Environmental Division

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Review of the 1991 WIPP Assessment (SAND91-0893)

D.A. Galson et al.

Summary

This document presents a review of Volumes 1-3 of the Sandia report, "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991" (SAND91-0893). The review has been based on the published version of the 1991 WIPP performance assessment, and the results are intended to be used in preparing the 1992 and future-year assessments. As requested by Sandia, this review has considered technical questions pertaining to the performance assessment methodology and its application and results, as well as issues of organization, presentation and flow of information between the various sections, chapters and volumes.

We consider the 1991 assessment documentation a valuable and impressive contribution to the performance assessment literature. The WIPP Program is in the process of coming to terms with most of the contentious issues surrounding the deep geological disposal of long-lived wastes. Many parts of the report are of extremely high quality; we have, however, focused our comments on those parts of the report where we considered improvements could be made.

Our major technical concerns are in the general area of treatment of uncertainty in the assessment, including in particular treatment of scenario uncertainty, data and parameter uncertainty, and model uncertainty. We have also suggested a possible modification to the methodology for generating CCDFs for human intrusion events, and have noted that the treatment of human intrusion, as a particular class of scenarios, is imbalanced in places. The document contains a general overview of our concerns, as well as a detailed section-by-section technical commentary.

With regard to presentation and organization of the report, there is substantial room for improvement, reflecting the difficulty in both completing an assessment and clearly and succinctly documenting it within a twelve-month period. In particular, the report is excessively long, and very much in need of a good summary of the order of 100 pages (or less). More attention needs to be paid to the relevance of the information presented

to the final assessment results, and to the potential audience for the report. Excessive use of mathematics is made throughout the report, and figures are too few in number, are poorly explained or are too complex. In addition, relatively minor errors are rife, particularly in Volume 3.

Review of the 1991 WIPP Assessment (SAND91-0893)

1 Introduction

This document presents a review of the Sandia report, "Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991" (SAND91-0893). The Sandia report consists of five volumes:

Volume 1: Methodology and Results

Volume 2: Probability and Consequence Modeling

Volume 3: Reference Data

Volume 4: Uncertainty and Sensitivity Analyses

Volume 5: Dose Calculations

At the time of the review, however, only the first three volumes were available.

The review has been undertaken by Intera Information Technologies for the WIPP Performance Assessment Division at Sandia National Laboratories. The review has been led and coordinated by D.A. Galson. Contributions were also made by P.C Robinson, T.J. McEwen, K.J.Worgan, M.J. Apted and M.D. Impey.

The WIPP Performance Assessment Division will revise and refine the "Preliminary Comparison..." documentation on an annual basis, up until the time that an application for an operating license for the WIPP is made. The "Final Comparison..." is currently scheduled to be completed in about five year's time.

This is the first review of the WIPP assessment documentation carried out by Intera. The review has been based on the published version of the 1991 assessment (Volumes 1-3). It is foreseen that further reviews will be conducted of draft assessment documents on an annual basis, normally in a September timeframe (although future versions of Volume 3 may be available sooner).

Given that the 1991 assessment of compliance with the EPA Standard has already been published, and the undertaking by Sandia to update the assessment on an annual basis, the purpose of this review of the 1991 documentation has been to provide the WIPP Program a set of comments that can be used in preparing the 1992 and later-year assessments. A further objective was to familiarise Intera staff with the WIPP Performance Assessment Program, in order that future requests by Sandia for reviews of assessment documents in draft form could be responded to efficiently and rapidly. It is expected that future reviews will need to be completed in less than one month. This independent review of the Sandia performance assessment work should ultimately provide Sandia and Department of Energy management greater confidence that the assessment work is clearly presented and represents the state-of-the-art in assessment technology at international level.

As requested by Sandia, this review has considered technical questions pertaining to the performance assessment methodology and its application and results, as well as issues of organization, presentation and flow of information between the various sections, chapters and volumes.

All of Volumes 1-3 have been considered, but in varying levels of detail. In particular, Intera was requested to give closer technical attention to Chapters 3 and 4 of Volume 1, Chapters 2, 3, 5, 6 and 7 of Volume 2, and the entirety of Volume 3. In addition, it was found essential to review Chapter 5 (Compliance-Assessment System) of Volume 1 in detail, because the material contained therein provides an important conceptual basis for much of the assessment. However, comments have been made section by section where necessary on most other chapters throughout the three volumes. Finally, somewhat more focus was placed on the near-field part of the assessment than on the far-field; this emphasis reflects the relative importance of the near-field in the WIPP assessment.

This document contains a general overview of concerns in Section 2 and a detailed technical commentary in Section 3.

2 General Overview

The Waste Isolation Pilot Plant is likely to be the world's first deep underground disposal system for long-lived radioactive wastes. Site characterization work, initiated about 15 years ago, has already been extensive, and the performance assessment activities have been underway for several years. The commitment to produce performance assessments on an annual basis prior to licensing reflects the importance given to such work by the WIPP Program. This commitment places heavy demands on the staff of the Sandia and supporting contractors, not least because each assessment requires timely input from a multitude of technical disciplines, and the coherent integration of the work and review of some 100 scientists. In addition, the WIPP Program has expressed its awareness that not only should the work be documented, but that it should be documented in a clear and accessible format, in order to involve as many interested outside observers as possible in the process leading up to licensing of the WIPP. Thus, the task at hand is substantial, and the 1991 assessment is to be viewed as only one step in the ongoing iterative process of data collection/interpretation and performance assessment.

In view of the above, we consider the 1991 assessment documentation a valuable and impressive contribution to the performance assessment literature. The WIPP Program is in the process of coming to terms with most of the contentious issues surrounding the deep geological disposal of long-lived wastes. All of the main issues of concern to such assessments have been clearly identified, including those issues for which time and resources have not yet allowed an adequate treatment.

Much of the report is of extremely high quality. We have, however, focused our comments on those parts of the report where we considered improvements could be made. That we have identified many such areas is unsurprising, given the evolving developments in performance assessment technology and supporting data bases within the WIPP Program, as well as internationally. Our general comments are summarized in this Section, based on the extensive and more detailed comments contained in Section 3.

2.1 Report Organization and Presentation

There is substantial room for improvement, reflecting the difficulty in both completing an assessment and clearly and succinctly documenting it within a twelve-month period. This timescale presents a challenge which has not been undertaken within other national programs, but which the

WIPP Program has committed itself to meet.

In particular, the report is excessively long, and is in desperate need of a good summary of the order of 100 pages (or less). Volume 1 could be developed into a proper summary volume, with much of the detail relegated to Appendices or to Volume 2, which could present the detailed technical basis for the Volume 1 summary. On the other hand, the synopses presented at the end of each chapter in Volume 1 are excellent; much of the information for preparing a good summary report has already been assembled.

Much of the report reads as if it were a "dump" of potentially relevant information available to the author. More attention should be paid to the relevance of the presented information to the final assessment results.

In preparing a summary volume, as well as the more detailed supporting volumes, care should be paid to the intended audience for the report in general, and for the different volumes in particular. It is stated in the preface that the main audience includes "interested parties", but large parts of the report would be inaccessible to the general reviewer.

Some of the material in Volume 1 is poorly organized. For example, a good overview of the site and disposal system should precede the scenario analysis. The approach to performance assessment should be placed later in the volume. Several of the later chapters could be combined. In addition, the numerous references made early in the volume about the lack of releases for the base case scenario are annoying, as this is not demonstrated until much later in the volume.

Excessive use of mathematics is made throughout the report, particularly in Volume 1 (Chapters 3-4) and Volume 2. Much of the mathematics could be relegated to supporting documentation for the assessment. Its appearance in this report serves mainly to distract the reader from the flow of the arguments, and from seeing what has really been done in the assessment.

There are generally too few figures, most of the figures that do exist are poorly explained, and many are much too complex, containing too much detailed information, that obscures the main point to be made. Chapter 4 of Volume 1 (Scenarios for Compliance Assessment) in particular is poorly illustrated.

In addition to this presentational aspect, many of the figures and tables have been carelessly compiled, and errors are rife, particularly throughout Volume 3.

Parts of the report are extremely repetitious, particularly the various discussions concerning development of CCDFs and concerning the content and interpretation of the EPA Standard. In particular, a new section which brings together the analysis and interpretation of the EPA Standard scattered throughout the report should be developed, and could then be referred to whenever needed.

2.2 Treatment of Uncertainty

With all the mathematics contained in the report, an important aspect to the treatment of uncertainty has been forgotten: the need to describe and treat uncertainty in a manner that sheds greater light on the assessment results. Great play is made of the importance of distinguishing between two types of uncertainty, stochastic and subjective. On the one hand, we do not find this distinction meaningful or helpful in the context of the WIPP assessment; on the other hand, other aspects of treating uncertainty have received insufficient attention.

For example, the potential impact of spatial variability and heterogeneity has been largely ignored (a notable exception, however, is the work on transmissivity fields in the Culebra Dolomite). The work on scenario development seems biased, and takes little account of developments in thinking since the late 1970s (outside the U.S.). In addition, the report correctly notes that the crucial issue of conceptual model uncertainty has not yet been examined.

2.3 Scenario Uncertainty

2.3.1 INITIAL IDENTIFICATION

The completeness of the initial set of events and processes compiled as input for the scenario development is unclear. Apparently, no formal site-specific process was followed. Rather, a generic list developed about fifteen years ago and reported in Cranwell et al. (1990) was used, and this was supplemented by three additional potentially disruptive events and processes known to be of concern to the WIPP. The ad hoc procedure followed does not provide confidence that the scenario development was based on a sound initial compilation of potentially disruptive events and processes. For example, in the area of human intrusion, several additional scenarios of potential concern have been identified in this review (see detailed comments). Scenario development is an area that would very much benefit by the expert panel approach used in other areas of the performance

assessment.

In addition, the most up-to-date generic list for events and processes of potential importance to disposal system safety is probably that contained in the report of the NEA/PAAG Working Group on scenario development (OECD/NEA, 1992). This work is not referenced at all.

2.3.2 SCREENING

The procedure used to screen the events and processes as input to the scenario development lacks rigour, and appears to be biased in many places, as detailed in Section 3. The intention appears to be to rule out from consideration a priori as many events and processes as possible, without serious consideration as to the possible effects or likelihoods of occurrence. In particular, screening out events and processes on the basis of low consequence, without proper analysis of the potential consequences, should be avoided. This same point is also made by Cranwell et al. (1990).

On the other hand, the performance assessment work to date suggests that the site is fundamentally sound. An effort should be made to be more open-minded and imaginative in the scenario development work. Again, much needed confidence in the scenario screening could be obtained through independent geological input outside of the WIPP performance assessment group.

Although screening is an important aspect of scenario development, an equally important aspect is to explore the range of the possible. The contrast with the input provided for human intrusion (admittedly an important class of scenarios) is notable.

2.4 Parameter Uncertainty

Although we have some concerns over the details of the methodology used to obtain the reference data provided in Volume 3, our general impression of the data gathering exercise is that it is very systematic and comprehensive.

There seems to be a confusion between uncertainty and variability. Repeated measurements of a variable may give different results for a number of reasons (spatial variability, experimental error, lack of control of experimental environment, etc.), and this will lead to an uncertainty as to the true value of this parameter. However, it is only when the parameter varies stochastically that the observations can be taken as a direct indi-

cation of uncertainty. In other cases, the varying measurements require careful consideration by experts to determine a reasonable characterisation of uncertainty.

Some of the confusion in terminology may result from the more or less direct translation of reactor PRA methodology and terminology to waste disposal system performance assessment. It is not sensible to apply directly all of the reactor PRA concepts to natural geological systems. For example, large parts of a reactor can be treated as an engineered system comprised of components of more or less constant (but imprecisely known) properties. This same thinking is not easily applied to disposal systems.

In the chapters describing the treatment of individual parameters in Volume 3, it is not always clear whether or not the parameter was sampled and, in many cases, it is not clear how the parameter entered into the performance assessment. An additional point of confusion is that often the performance assessment calculations used different values for parameters than those appearing in the summary tables and boxes. In this case, we presume that the summary values were used solely for the purpose of sensitivity analyses (reported in Volume 4). The distinction should be made clearly.

In addition, the detailed discussions contained for many of the parameters in some cases shed little light on the basis for the median and range used in the assessment. More attention needs to be paid to the clarity of these discussions, and to the link between the discussions and the final summary information presented in the "boxes" and tables.

2.5 Generation of CCDFs

The approach taken for developing CCDFs is clearly explained (Volume 1, Chapter 3), but has not been adequately justified. The methodology seems in part geared toward the analysis of the scenarios arising from the scenario development work presented in Chapter 4. It is concluded there that human intrusion is the only credible scenario that may affect the integrity of the disposal system over the 10,000-year regulatory period.

This area is complex and is full of controversies, many of them philosophical. We are therefore wary of criticising the approach used. Nonetheless, it is worth raising the issues that cause concern.

In essence, the question is why such distinctly different approaches are taken to scenario uncertainties and parameter uncertainties. It is claimed that scenario uncertainties are stochastic in nature, while parameter uncer-

tainties are subjective. In our view, almost all uncertainties are essentially subjective, with the exception being stochastic events (probably including particular human intrusion events).

It is stated that the CCDF over scenarios arises because *a number of different occurences have a real possibility of taking place*, whereas *fixed, but unknown quantities are needed in the estimation of a CCDF*. This seems to suggest that there are many possible futures, but that there is only one possible set of parameter values. We would argue that there are **many possible** futures and **many possible** parameter sets, but that there is only **one actual** future and only **one actual** set of parameter values. Both for futures and parameters the problem is that the actual cannot be distinguished from the possible, and therefore the same methodology is appropriate for both.

We agree with the views expressed by Bonano and Wahi (1990, Chapter 4), and in particular, the construction of a single CCDF including both scenario and parameter uncertainty. It seems that this is the single CCDF referred to in the EPA Standard.

In addition, in our comments on Chapter 3 of Volume 2, we present an alternative methodology for generating the CCDFs for human intrusion. This uses a simulation approach which is easy to describe and implement. Using our approach, we have been able to reproduce efficiently the results given in this chapter of the report.

2.6 Model Uncertainty

We would stress that conceptual model uncertainty may be the most important source of uncertainty in the final assessment. The WIPP Program needs to identify clearly the source of such uncertainties, and develop a position on how such uncertainties will be treated in the final assessment documentation.

2.7 Human Intrusion

The approach taken in treating human intrusion is imbalanced in places. For example, an extremely (and overly) complicated mathematical model is developed to analyse cuttings releases, whereas there is only very limited discussion of current drilling practices in the Delaware Basin. In addition, although an interesting exercise in its own right, we do not consider that the expert panel approach taken to develop models for future societal development and corresponding probabilities for future human intrusion

will increase the confidence in this part of the assessment. It would be more conservative to assume that intrusion was going to occur, and to assess the potential consequences of various kinds of intrusion occurring at different times in the future and assuming present-day drilling practices.

The EPA Standard, as promulgated in 1985, implies that human intrusion should be folded into a single CCDF to demonstrate compliance with the containment requirements. The report would nonetheless benefit from a less constrained consideration of the rationale and philosphical basis behind the treatment of human intrusion. We suggest this because consequence estimates for potential future intrusion scenarios, although potentially useful in siting (and possibly designing) repositories, are unlikely to provide a useful quantitative basis for the licensing of deep geological disposal systems, no matter how much modelling is involved and how many experts are called to bear. Human intrusion seems to have taken on undue importance within the WIPP Assessment Program because of the supposed absence of releases by any other means.

2.8 Assessment Timeframe

The containment requirements of the EPA Standard are expressed in terms of a limitation on the probability of exceeding various levels of cumulative release to the accessible environment over a 10,000-year period. The assessment has therefore largely focused on this intitial 10,000-year period, and little information is given about the longer-term performance of the repository system. What information is presented does suggest that the longer-term performance has been considered, and that the site is likely to provide excellent confinement for periods much longer than 10,000 years.

One piece of information presented in Volume 3 does however confuse this picture. There it is shown that the normalized radionuclide activities within the repository, after an initial sharp decline, start to rise steeply with time after about 2000 years, and are still rising steeply at 10,000 years. This begs the question of when does the total activity level off, and at just what level? Also, regulatory timeframe notwithstanding, how does the temporal variation in activity after 10,000 years affect longer-term performance?

Clearer treatment of the post-10,000-year performance of the disposal system would be beneficial. Questions concerning this longer-term performance may well be raised during licensing.

3 Detailed Comments

3.1 Volume 1: Methodology and Results

Preface

The preface seems unnecessarily long. Much of the second half is unnecessary, or would be better off in the main text (where most of it can in any case already be found).

3.1.1 Chapter 1. INTRODUCTION

Section 1.1 40 CFR Part 191, The Standard (1985)

The EPA Standard plays a central role in the assessment documentation, and reference is made throughout the report to the provisions and requirements of the Standard. Often these references include a certain amount of what could be termed regulatory analysis or interpretation. Much of this information in later sections is extremely repetitive, and it would be a good idea to draw together all the key elements of concern to assessing compliance with the Standard in one section or chapter, and simply refer back to this in later chapters. This section could be entitled, for example, "Regulatory Analysis" (and may fit better in Chapter 2). The method of dispersed presentation adopted makes the Standard appear extremely complex, whereas most of the provisions are in fact relatively straightforward.

Section 1.2 Application of Additional Regulations to the WIPP

No comments.

Section 1.3 Organization of the Comparison

No comments per se, but should consider comments on possible reorganization of the documentation provided in comments on sections 1.1 and 1.4 of Volume 1.

Section 1.4 Description of the WIPP Project

The geological parts of Chapter 1, sections 1.4.1 to 1.4.3, are not as helpful as they could be. In addition, much of the information presented in this section is also contained in Chapter 5 and, in part, in more detail in Volume 3, section 2.1.1, where some very relevant information is presented for the first time. It would be particularly useful here if there were cross sections through the WIPP from outside the Delaware Basin in approximately north-south and east-west directions. Figure 1-5 (page 1-16), showing the generalized stratigraphy in the WIPP area, is not sufficient for this purpose, and is too simplified (although note that many other diagrams are overly complex).

A better appreciation and understanding of the scenarios described in Chapter 4 would be possible if more were known about the WIPP area before this chapter were read. This could be achieved either by presenting better geological information in Chapter 1, and/or by placing Chapter 5 before Chapter 4.

Pages 1-17/18. Figure 1-6 contains a shaded line, presumably the southern limit of the Capitan Reef, but there is no explanation in the text or in the figure of what this line is and what, if any, significance it is supposed to have.

Page 1-25, line 16. The reference to figure 1-7 is incorrect. The only relevant figure is figure 1-5, but this figure is partly diagrammatic (i.e., no bedding is shown), and it therefore cannot show the existence of an angular unconformity between the Dewey Lake Beds and the Dockum Group.

Page 1-29, line 14. Care should be taken to avoid mixing between SI units and "English" (i.e., U.S.) units, or conversions to SI should be provided throughout the text. Although conversions are frequently provided, an inconsistent approach has been taken.

3.1.2 Chapter 2. APPLICATION OF SUBPART B TO THE WIPP

See comments under section 1.1 above.

Page 2-2, line 30. We agree strongly with the emphasis placed on development of adequate and clear documentation, as one of the cornerstones to assessing compliance with the EPA Standard. We trust that our review will be of use in this respect!

Section 2.1 Containment Requirements

Page 2-6 to 2-7. It is difficult to understand parts of the discussion of release limits without reference to Table 1 in Appendix A, and a detailed understanding of the EPA Standard. It might be better to reproduce the necessary parts (or all) of the Standard in one place in the main text (e.g., Table 1 can be found later in the main text).

Page 2-7, lines 35-38. This section states that expert judgement will be used, but this is obvious, because expert judgement pervades every aspect of long-term performance assessments. More important to know is how expert judgement will be used (e.g., in some kind of formalised way in specific instances) in the performance assessment process.

Page 2-8, lines 21-23. This states that completeness in scenario development is most appropriately addressed through peer review and probability assignment. We assume that the term completeness refers to the need to ensure that all features, events, and processes, and resultant scenarios, of potential importance to disposal system safety have been identified. Scenario uncertainty is in fact best addressed through the use of a systematic approach to the identification of features, events and processes, and in the development of scenarios, and by a thorough documentation of the scenario development procedure (e.g., see OECD/NEA, 1992). Peer review will mainly check this process, but it will not ensure completeness per se. In addition, it is not clear how probability assignment addresses the issue of completeness.

Page 2-9, Table 2-1. This table and the associated text purport to outline the range of methods to be used in assessing or reducing uncertainty in the WIPP performance assessment. The table is misleading, however, because almost all the methods really serve only to assess uncertainty. Data collection - or making better or fuller use of existing data - and the use of detailed modelling to improve understanding are arguably the only ways to reduce fundamental uncertainties in the performance assessment, regardless of the source of the uncertainty. Note that the fuller use of existing data means the use of both direct and "indirect" information (e.g., the use of hydrochemical data to infer groundwater flow patterns).

Page 2-19, lines 8-10. The text here (and elsewhere in the report) states that models will be validated to the extent possible, and that expert judgement will be relied upon where validation is impossible. While this would seem correct, the approach and wording of such statements should be carefully considered (perhaps with input on the legal side) in view of existing environmental litigation in the United States. There is a legal precedent establishing the need for validation. In particular, the issue of model val-

idation was the basis for the decision in a court case involving the State of Ohio and the Environmental Protection Agency (23 ERC 2091, Sixth Circuit, 1986). The U.S. Court of Appeals ruled that the EPA had acted arbitrarily in using the CRSTER computer code as a basis for establishing limitations on sulphur-dioxide emissions from two electrical utility plants. Specifically, the court criticised the use of a code that had not been validated using site-specific information. The court stated that "...no on-site study had been performed on the CRSTER model...no one had tested the model or cross-checked its predictions against reality at the locations of the company's power plants."

Page 2-19, lines 29-38. These statements suggest a potential misinterpretation of the EPA Standard. It is suggested that should the CCDF exceed the specified limits, then additional qualitative judgements may still lead to a "reasonable expectation" of compliance. Extensive human judgement (almost by definition qualitative) will be used in developing any CCDF, particularly insofar as human intrusion is concerned. If the (presumably best available) quantitative and qualitative judgement used to derive the CCDF do not lead to a reasonable expectation of compliance, additional qualitative judgements are unlikely to prove deciding in a decision on "reasonable expectation". In addition, it seems nonsensical to take the view that if one subjective judgement pushes a CCDF over the regulatory limit, another may be used to argue for compliance in any case. Rather, the conditions leading to a potential violation should be examined in detail. Perhaps some of the assumptions will be seen to have been overly conservative. Also, the wording on lines 35-38 is difficult to understand.

3.1.3 Chapter 3. PERFORMANCE ASSESSMENT OVERVIEW

Section 3.1 Conceptual Model for WIPP Performance Assessment

In this section the approach to generating CCDF curves is described. It describes what is done in reasonably clear terms (with only the necessary amount of mathematical formalism). However, it was not really clear why it is done this way. The methodology seems in part geared toward the analysis of the scenarios arising from the scenario development work presented in Chapter 4. It is concluded there that human intrusion is the only credible scenario that may affect the integrity of the disposal system over the 10,000-year regulatory period. If this is the case, then say so. It may also be easier to understand the approach if the details of the methodology were presented after Chapter 4.

This area is complex and is full of controversies, many of them philosophical. We are therefore wary of criticising the approach used. Nonetheless, it is worth raising the issues that cause concern.

In essence, the question is why such distinctly different approaches are taken to scenario uncertainties and parameter uncertainties. It is claimed that scenario uncertainties are stochastic in nature, while parameter uncertainties are subjective. In our view, almost all uncertainties are essentially subjective, with the exception being stochastic events (probably including particular human intrusion events).

In addition, the words "conceptual model" in the title of this section should be changed (to "approach"?) to avoid confusion with other uses of the term (i.e., as used in models of radionuclide release and transport in the performance assessment).

Page 3-2, line 13. Confusing use of the term conceptual model.

Page 3-10, Figure 3-4. There are numerous examples throughout this Chapter of illustrations of the methodology based on nuclear reactor PRA work (e.g., the paper by Breeding et al., from which five or six examples and figures are taken). It would be preferable if the methodology were illustrated by reference to results from the WIPP performance assessment.

Page 3-13, line 39. It is stated that the CCDF over scenarios arises because *a number of different occurences have a real possibility of taking place*, whereas *fixed, but unknown quantities are needed in the estimation of a CCDF*. This seems to suggest that there are many possible futures, but that there is only one possible set of parameter values. We would argue that there are **many possible** futures and **many possible** parameter sets, but that there is only **one actual** future and only **one actual** set of parameter values. Both for futures and parameters the problem is that the actual cannot be distinguished from the possible, and therefore the same methodology is appropriate for both.

We agree with the views expressed by Bonano and Wahi (1990, Chapter 4), and in particular, the construction of a single CCDF including both scenario and parameter uncertainty. It seems that this is the single CCDF referred to in the EPA regulations.

The discussion in section 3.1.5 is out of place in this report. It is not at all necessary to understand the concept of a Borel algebra in order to follow what has been done in the assessment. The section should be deleted.

Section 3.2 Definition of Scenarios

The definition of the eight scenarios in section 3.2.1 is not as complicated as the notation might lead a reader to suspect. The scenarios can be defined without recourse to set theory or logic diagrams.

The discussion in section 3.2.2 introduces a lot more notation. This is unhelpful to the reader. This issue is reviewed in detail for Volume 2, Chapter 2.

Section 3.3 Determination of Scenario Probabilities

See the comments on Volume 2, Chapter 2.

Section 3.4 Calculation of Scenario Consequences

See the comments on Volume 2, Chapter 3.

Section 3.5 Uncertainty and Sensitivity Analysis

The choice of a Monte Carlo approach here is wholely sensible. The section is however much longer and more detailed than need be to understand the actual methodology chosen. A general treatise on uncertainty and sensitivity techniques is not needed. More helpful would be some representative examples of the techniques actually employed in the WIPP performance assessment, drawn perhaps from Volumes 3 and 4.

Page 3-63, lines 40-41. It is claimed that Importance Sampling is a particular type of stratified sampling. This is not how the phrase is used within the NEA PSAG. Importance Sampling is a scheme which uses different distributions to generate samples than are used to characterise uncertainty, with a view to focusing sampling on important regions of parameter space. This method has been shown to be much more efficient than random sampling or Latin Hypercube Sampling in particular waste disposal assessments (Robinson, Roberts and Sinclair, PSAG meeting, November 1991). Given the expensive nature of running each sample in the WIPP methodology, Importance Sampling should be seriously considered.

Page 3-66, line 43. It is stated that a sample of size 60 was generated from the 45 uncertain variables. No justification for using such a small number of samples is given. It might be a coincidence, but 60 is 4/3 times 45,

and the claim has been made that the number of samples needed in Latin Hypercube Sampling is only 4/3 time the number of variables. This claim is not sustainable in general, and if it is true for the particular case of the WIPP assessment models, then this needs to be demonstrated.

To illustrate why 60 samples seems to be too small a number, consider the samples generated for one particular variable. With 60 samples, the expected largest and smallest samples leave one percent of the distribution at each end unrepresented. Since the EPA regulation involves the 0.1 percentile, this is dangerous.

3.1.4 Chapter 4. SCENARIOS FOR COMPLIANCE ASSESSMENT

Section 4.1 Definition of Scenarios

Section 4.1.1 Conceptual basis for scenario development

The introduction to this chapter describes scenarios in terms of the notation developed in Chapter 3. This notation seems unnecesary and merely overcomplicates what is really a relatively simple concept. A comparison with the scenario development carried out by SKI, based on the Sandia approach, will illustrate the difference.

Page 4-4, Figure 4-2. The base case scenario as defined excludes human intrusion, and therefore may be considered to have a relatively low probability over 10.000 years. Its placement in the figure implies a very high probability (greater than 0.9).

Section 4.1.2 Definition of summary scenarios

The completeness of the initial set of events and processes compiled as input for the scenario development is unclear. Apparently, no formal site-specific process was followed. Rather, a generic list developed about fifteen years ago and reported in Cranwell et al. (1990) was used, and this was supplemented by three additional potentially disruptive events and processes known to be of concern to the WIPP. The ad hoc procedure followed does not provide confidence that the scenario development was based on a sound initial compilation of potentially disruptive events and processes. This is an area that would very much benefit by the expert panel approach used in other areas of the performance assessment.

In addition, the most up-to-date generic list for events and processes of

potential importance to disposal system safety is probably that contained in the report of the NEA/PAAG Working Group on scenario development (OECD/NEA, 1992). This work is not referenced at all.

For example, in the area of human intrusion, which is especially critical for the WIPP, several additional scenarios of potential concern could be added to the list given in the text:

1. The possibility (see below) of unsealed boreholes or shafts (as opposed to a degraded seal). Experience from the mining industry suggests that this is not an infrequent occurrence.

2. The possibility that undetected older exploration boreholes exist at the site, and have been left unsealed. Again, this is conceivable because the WIPP is located in an area of intensive resource exploration and production.

3. The possibility that excavation and mining occur at depth (e.g., for potash) adjacent to the site (but not within the controlled area, because the EPA Standard suggests that this can be excluded). Such off-site mining may still affect the integrity of the disposal system, either through the establishment of a horizontal access that intersects the waste panels or a contaminated part of MB 139, or via an indirect effect on the geological confinement capacity of the system.

Section 4.1.3 Evaluation of natural events and processes

The procedure used to screen the events and processes as input to the scenario development lacks rigour, and appears to be biased in many places, as detailed below. The section reads as if the intention is to rule out from consideration a priori as many events and processes as possible, without serious consideration as to the possible effects or likelihoods of occurrence. In particular, screening out events and processes on the basis of low consequence, without proper analysis of the potential consequences, should be avoided. This same point is also made by Cranwell et al. (1990).

On the other hand, the performance assessment work to date suggests that the site is fundamentally sound. An effort should be made to be more open-minded and imaginative in the scenario development work. Again, much needed confidence in the scenario screening could be obtained through independent geological input outside of the WIPP performance assessment group.

Although screening is an important aspect of scenario development, an equally important aspect is to explore the range of the possible. The

contrast with the input provided for human intrusion (admittedly an important class of scenarios) is notable.

Mass wasting

Page 4-18, lines 43-45. Some words are probably missing. The Pecos River is presumably not more than 90 m lower in elevation than the waste panels (as stated in the report), but rather 90 m lower in elevation than the land surface overlying the waste panels.

Diapirism

Page 4-20, lines 25-31. More care is needed with the wording, here as elsewhere in section 4.1.3. The first part of this text implies that salt diapirism (over the next 10,000 years) is a low-probability event; the following sentence suggests that salt diapirism is not physically reasonable. The two sentences make different and conflicting statements (although both may lead to a similar conclusion).

Seismic activity

Page 4-21. It is stated that there are unlikely to be any changes in the geologic or hydrologic systems due to seismic activity, presumably because no evidence is available to suggest that any such changes have taken place in the past. It is not made clear what evidence would be expected if seismic events had altered, in particular, the hydrologic system at depth. Until relatively recently, with radioactive waste disposal, geothermal research, etc. producing interest in deep groundwater evolution and ages, no one would have collected any data that would be of relevance to substantiating this statement. It is only in the last ten years, with ideas on seismic pumping becoming more prevalent, that much consideration has been given to the effects of seismicity or in situ stress regimes of groundwater flow and evolution.

Ground motion is not of much relevance here, as any significant seismic influences would be related to changes that could have occurred at depth which might have affected groundwater chemistries, or in the extreme, hydraulic conductivities. The argument needs to be placed more in this context, rather than in terms of vibration, though of course these processes are linked.

Finally, at the end of this section, it is stated that future seismic activity will be of no consequence in the performance assessment. While it seems unlikely that seismic activity will be important in the performance assessment, this has not been demonstrated by the arguments provided. In any case, later summaries contained in this chapter are contradictory because

they indicate that the effects of seismic activity have been included in the base case (e.g., page 4-86). If so, how has this been done?

Magmatic activity

Page 4-23. We agree with the comments presented in this section of Hunter's (1989) calculation regarding magmatic activity. This is a particularly good example of a misunderstanding of natural processes resulting in erroneous probabilites being calculated. It is essential that such probabilites are estimated by experts with suitable geological knowledge.

Deep Dissolution

Page 4-25. This section contains a discussion of a dissolution structure (Hill A) which is not present on any figure, though there is a Dome A in figures 1-6 and 5-16, which presumably is the same structure. It is unhelpful to refer to specific structures that are not also present in figures. Indeed, there is no need to mention Hill A at all, as it is superfluous to the general argument. This is an example of unnecessary text being presented, whereas better and more figures would put over the concepts in a more cohesive manner.

Shallow dissolution

It would be useful to have a diagram or a cross section which shows the relationship of Nash Draw with the surrounding formations, illustrating the shallow dissolution effects listed in this section.

Page 4-26, lines 28-29. Dissolution of the Rustler Formation by vertical infiltration from the surface has been eliminated because of low consequence, yet the potential consequences have not been analysed in any detail. This should be done for both present-day and pluvial climatic conditions.

Page 27, lines 14-16. Dissolution by flow along the Rustler-Salado contact zone has also been screened out because of low consequences, but here again the qualitative arguments provided are insufficient to justify the screening choice.

In addition, evidence is presented in Chapter 5 that dissolution in the underlying Rustler-Salado contact zone has caused fracturing of the unnamed Lower Member (page 5-14, lines 18-21), and that post-depositional dissolution of salt in the Rustler Formation may have caused fracturing in the Culebra (page 5-16, lines 5-6).

Faulting

Page 4-29. Here is another example of a discussion of geological structures with no accompanying figure. A figure that combined the location of the dykes and the faults would provide a much better idea to the reader of what structures were being discussed.

Section 4.1.5 Evaluation of human-induced events and processes

Injection wells

This section is confusing. The argument is rightly made on page 4-36 that injection wells may have the same effect as exploratory drilling, and cannot be eliminated from consideration on the basis of low probability. At the top of page 4-37 (lines 3-8), it is however suggested that injection wells can be eliminated because the driller will "soon" detect the incompatibility of his activities with the area. "Soon" is not defined in Appendix B of the Standard, but seems to be defined here so as to eliminate injection wells from consideration. This is an inappropriate place to define terms appearing in the Standard and, in any case, the same definition has not been used to eliminate exploratory drilling elsewhere in this section.

Finally, at the end of the section (page 4-37, lines 10-15), another argument for elimination of injection wells is given. It is suggested that they can be eliminated because the fluid injection will have no effect on the disposal system, but no analysis of the possible effect on the disposal system of a well undergoing injection (and passing through the repository) is given.

Withdrawal wells

Page 4-37, lines 26-29. Wording could be clearer. The text jumps from water wells to exploratory drilling for resources.

Page 4-38, lines 4-18. Drinking wells are eliminated because of lack of physical reasonableness, but if they are to be eliminated, this could only be on the basis of low probability, because potable water evidently does exist in local areas, and the effect of a more pluvial climate may be to extend the area in which potable water could be obtained. In addition, desalination could be undertaken in future.

Damming of streams and rivers

Page 4-41, lines 29-30. Additional damming of the Pecos River is eliminated because of low consequence, although this has not been demonstrated. Additional damming would probably only make sense in more plu-

vial conditions. Could the consequence under such conditions be demonstrated by some kind of relatively simple bounding calculation?

Page 4-42, lines 25-26. An extensive discussion of damming of Nash Draw is provided, and then this event is eliminated on the grounds of physical unreasonableness. The discussion and conclusion are nonsensical, however, because damming of Nash Draw would only be likely during more pluvial conditions (which are not discussed at all). It may nonetheless be possible to eliminate this event on other grounds (e.g., low probability?).

Section 4.1.5 Evaluation of repository- and waste-induced events and processes

Caving and subsidence

Pages 4-43 to 4-49. A semi-quantitative treatment is provided for eliminating this category of events, which makes a change from the more qualitative arguments provided for other categories of events. A parallel with the regional dissolution of the Salado Formation is drawn, but the significance is unclear. Salado dissolution is occurring regionally, whereas subsidence above the repository would be a strictly local feature. Local subsidence could conceivably lead, for example, to an increase of leakage between the Culebra and the Magenta, increased dissolution of the Rustler, etc.

In addition, dissolution of the Salado and any associated subsidence will have occurred over periods orders of magnitude longer than the subsidence associated with the repository (and associated local fracturing).

Finally, evidence is in fact presented in Chapter 5 that fracturing in the Culebra has been caused by previous subsidence [associated with post-depositional dissolution of salt in the Rustler Formation, or with stress relief from removal of overburden (page 5-16, lines 5-6)].

Shaft and borehole seal degradation

Page 4-49. Seal degradation has been considered and included in the base case. However, the situation of a totally unsealed borehole has not been considered (e.g., what if ERDA-9 was accidentally left totally unsealed?). It may have to be assumed that one or more boreholes will be left unsealed, either now or in the future. This is a potentially important event has not been considered.

Explosions

Page 4-52. Are explosions in the waste panels expected to occur? The

text indicates that they are, but suggests that the 800 psi generated in an explosion will not be problematical, and they have therefore been eliminated because of lack of consequence. The potential consequences have not however been properly evaluated. For example, an explosion of the force indicated might also induce local fracturing in the rock. What would the magnitude of this effect be?

A more sensible approach to the presence of explosive gases would be to attempt to engineer around the problem, so that it could be eliminated on the grounds of physical unreasonableness or low probability. It would be wise to avoid a situation where the public were to be told that the explosions within the waste panels were expected, but that it was thought that the repository had been designed to withstand the shock of these explosions!

Section 4.1.6 Summary of screened events and processes

Page 4-54: It is stated that a pluvial climate is certain to occur in the future, but that damming has been eliminated on grounds of physical unreasonableness (i.e., lack of water supply). However, the consideration of poor water supply only relates to the current climatic conditions.

Page 4-56 , Table 4-2. There is an error in the table. Shaft and borehole seal degradation should be placed on one line only, and the "X" in the "retained for scenario development" column should be deleted.

Section 4.1.7 Developing summary scenarios

Page 4-59, lines 22-24. Page 4-61. Figure 4-5. E3 (water wells) was retained for scenario development (e.g., see table 4-2, page 4-56), but has been eliminated without reason here. Also, why are only the E1, E2 and E1E2 scenarios described and considered further? The argument for eliminating all TS scenarios is unclear.

Page 4-62, line 1-3. It is claimed that the EPA Standard provides a basis for eliminating scenarios having a likelihood of occurrence of less than 1 chance in 10,000 in 10,000 years. This represents a misinterpretation of the EPA Standard. The EPA Standard refers to categories of events and processes (i.e., before their combination into scenarios), and not to the scenarios themselves.

Page 4-62, line 9-14. This statement is unclear and confusing. Is the word "less" on line 11 supposed to be "greater"?

Page 4-63.

1. On line 21, figure 4-4 should read 4-6.

2. The base case summary scenario is here being discussed with very little knowledge of the geology, lithology and structure of the Salado Formation, nor of the engineered barriers. Most of the important detail is contained in Chapter 5; for example, there is no indication here of the separation of MB 139 from the galleries, nor any description of what MB 139 actually is. All explanation related to the DRZ is also contained in Chapter 5, so that the reader cannot assess the reasonableness of the proposed base case scenario in this section. Similar arguments apply to all the remaining parts of the descriptions of the base case scenario.

3. The term DRZ is used in the text and in figure 4-6 (page 4-65) without any explanation of what it means.

4. None of the discussion of the development of gas pressures and migration within and from the waste panels refers to the description of the various processes involved which are presented in section 5.2.5.

5. On line 42, the wording ("some...some") suggests that relatively few waste containers will contain organic material. What fraction of waste containers will contain organic material?

Page 4-69, lines 39-41. In the E2 summary scenario, it is assumed that the borehole plug does not degrade. What happens if the borehole is left unplugged (or if the plug degrades quickly)?

Section 4.1.8 Definition of computational scenarios

No comments.

Section 4.2 Determination of Scenario Probabilities

In section 4.1.2, the event probabilities are presented without justification. Moreover, it is unlikely to be possible to develop credible probability estimates for human intrusion events. The human intrusion event probabilities seem relatively low. It would be more conservative to assume that human intrusion (through exploratory drilling) had a probability of occurrence of close to 1 (which would equally imply that the base case as defined had a very low probability of occurrence). It is especially important to be open-minded on this question early in the assessment process, so that the full range of possibilities is properly explored (e.g., via sensitivity

analyses).

In addition, it is unclear why the human intrusion scenarios have such low probabilities of occurrence over 10,000 years, given the guidance in Appendix B of the EPA Standard of 30 boreholes per square kilometre of repository area per 10,000 years (upper limit on frequency of drilling into the repository). It seems to be implied in the subsequent section that the guidance in the Standard would lead to an assumption of about 3 boreholes in 10,000 years.

Also, the period of time to which the probability estimates presented in this section apply should be explicitly stated (it is not stated anywhere).

Section 4.3 Expert Judgement on Inadvertent Human Intrusion

This section gives the impression that the possibility or even the probability of future human intrusion events can be identified. It tends to elevate the whole issue of human intrusion to a pseudo-science, when, in fact, the approach to treating human intrusion assessment must be largely philosophical, regulatory requirements notwithstanding.

3.1.5 Chapter 5. COMPLIANCE-ASSESSMENT SYSTEM

Section 5.1 The Natural Barrier System

Page 5-9, Figure 5-6. There is no indication of what the shaded line is in the northern part of the figure.

Page 5-12, line 9. The difference in hydraulic conductivies between well tests and in situ tests in the Salado Formation is not necessarily due to disturbance. The difference may merely be due to the normal scale effects seen in most rocks.

Page 5-13, Figure 5-7. Is this cross section partly diagrammatic? If not it is incorrect. The change of dip of the Rustler Formation on the eastern margin of Nash Draw appears unnatural and would seem to be an artefact related to the position of borehole WIPP-26. The dip of the Culebra Dolomite changes without there being any equivalent change in dip of the Magenta Dolomite or the Tamarisk Member, and from the structure of the area this seems improbable. In addition, the cross sections implies that the Tamarisk Member suddenly thickens, whereas on page 5-16 it states that dissolution of evaporites within this Member has reduced the separation of the Magenta and Culebra Dolomites, and therefore the opposite is true.

(Figure 2.6-2. Volume 3 shows the true distribution of the strata, though even in this figure the repeated changes in thicknesses of the beds appear unnatural.)

Page 5-16, lines 9-10. Both figures 5-8 and 5-9 should be referred to here for clarity.

Page 5-32, line 13. It is stated here that discharge takes place from the Tamarisk Member. In the description of the Tamarisk Member on page 5-16 it is indicated that in the region of Nash Draw the evaporites have been dissolved from the Member and even the siltstone within the Member has a low transmissivity. It would seem with these transmissivity values that only minimal discharge or recharge (referred to on page 5-33, line 16) would take place. Either the description of the Tamarisk Member on page 5-16 is misleading, or there would appear to be some inconsistencies between its description and the description of potential recharge and discharge zones.

Section 5.2 The Engineered Barrier System

Do engineered barriers "minimise the likelihood (i.e., probability) of radionuclides migrating" or do they minimise the rate of migration given the occurrence of water (either by intrusion or microbially generated) within the waste repository?

Section 5.2.1 The Salado Formation at the repository horizon

At what scale is the stratigraphy of the Salado Formation laterally "consistent"? Are there small, discontinuous stringers of clay and/or anhydrite that occur within the planned repository horizon? Given the approach of assigning probability distributions to parameters affecting source-term (e.g., solubility, rock permeability), what is the estimated probability distribution for small-scale variation in stratigraphy (perhaps a plot of observed frequency versus size of stringer would be helpful).

Section 5.2.2 Repository and seal design

Waste Characterisation

Do the Waste Acceptance Certification requirements say anything about dissolution or leach rate of waste? If so, that should be stated in this section.

Page 5-45, lines 1-2 (and again in Section 5.2.3). The uncertainty in waste inventories and characteristics are cited as potentially large. The reader is left wondering how large is "large", if there is any sensible bound to this estimated uncertainty and, perhaps most importantly, what are the factors that affect this uncertainty. If these issues on waste uncertainty have been addressed, they ought to be cited. If they have not been previously addressed, the text should explain if and when such studies will be undertaken.

Page 5-45, line 27. There are many types of "steels" having various modes and degrees of reaction with water or gases; it would be helpful if these steels for waste boxes and drums were specified with a brief modifier.

Seals

Page 5-46, Figure 5-19, Page 52, Figure 5-20 and Page 5-54, Figure 5-21. These all indicate that the separation of MB 139 from the base of the disposal vaults is greater than is actually the case, and in the case of figures 5-20 and 5-21 greater than the distance to Anhydrite B. This is not correct. Figure 5-19 is particularly misleading in terms of scale because a real vertical scale is implied in the figure illustrating the drift backfill and plug seals. The vertical dimensions implied by the thickness of the disposal vault in this figure compared with the vertical separation of the vault with MB 139 and the thickness of MB 139 are all incorrect. Either this diagram should state that it is only diagrammatic, and therefore should contain no dimensions of any sort, or better still it should be drawn to a true scale.

Page 5-47, lines 10-13. The terms "long-term" and "short-term" are too vague; perhaps cross-reference to section 3.2.1 in Volume 3 would be appropriate.

Page 5-47, lines 31-32. "Over time" is vague, as is reference to "other interbeds", presumably meaning Anhydrite Layers A and B. The text should be more specific.

Backfill

Page 5-47, lines 36-45.

1. The text discusses backfilling of underground workings but does not specifically mention using consolidated materials; is it correct to infer that unconsolidated materials will be used?

2. It is claimed that permeability will be initially reduced (prior to consolidation) of this backfilling but the text does not quantify the extent to which permeability is reduced or how effective this reduction is in limiting water migration into the waste panel.

3. It is also claimed, without supporting reference, that consolidation will occur to limit water inflow but it is not said how long this will take. A plot of permeability (or degree of consolidation) versus time would be extremely helpful. It would seem that brine would be flowing into the waste panel during (and in response to) this consolidation.

4. This paragraph introduces the possibility of clay backfills but leaves the reader wondering if this consideration is an attempt to correct expected poor or unpredictable behaviour of the salt backfill or whether clay is being considered for the positive characteristics of the clay itself that may enhance the near-field performance.

Section 5.2.3 The radionuclide inventory

Page 5-48, line 34. Again, how large is "large"; the text should strive to be more specific or quantitative or bounding, rather than using qualitative, relative modifiers such as this. Also, is there any reference that analyses the factors that affect this "large" uncertainty?

Page 5-49, lines 9 and 11. Please be more specific than "short half-lives" and "low toxicity" (in contrast, the "low activity" term is properly specified).

Page 5-49, lines 9-10. It would help if the text defined the edge of the "repository" from which radionuclides are leaving.

Page 5-49, line 20. While radium-226 activity will be insignificant during the first 10,000 years, to what levels will it increase over 100,000 or 1,000,000 years? It may represent a safety/risk concern over these longer time scales and should not be dismissed solely on the limited time frame of current regulatory guidance.

Section 5.2.4 Radionuclide solubility and the source-term for transport calculations

Solubility is described as "the most important single contributor to variability in total cumulative release". This admission indicates that it would be prudent to include a comprehensive and systematic treatment of this subject within this volume. Supporting references should be (and are) provided in the text. Yet the critical sensitivity of solubility may necessitate that all essential details be explicitly presented in this summary. The current text is too brief for the importance of the topic and too confusing to be helpful to both technical and non-technical readers. Suggested

revisions are outlined below.

Page 5-49, lines 25-27. It would be helpful to describe the specific source-term model used in WIPP analyses so that readers could judge for themselves the relative sensitivity of release rates on solubilities and other parameters. A listing of the mathematical formulation for release would be especially instructive.

An explanation should be provided for the selection of a specific type of distribution (e.g., loguniform) and specific range for solubility values, and the reasoning behind assigning such fixed distributions to all radionuclides. Although the WIPP Project is moving beyond this approach, a fuller explanation of how and why such an approach was initially adopted for such an admittedly crucial parameter would be important to the concerned reader.

Page 5-49, line 34. There is not an "absence" of data; rather, a paucity of data exists on radionuclide solubility in brines. For example, Dr Dhan Ral and colleagues at the Pacific Northwest Laboratory have conducted and published several papers on experimental measurements and theoretical models they have developed for the previous salt program for disposal of high-level waste. Other workers have also studied this topic, notably for the German repository program. The assertion that there is an absence of data indicates, at best, a surprising unfamiliarity with the scientific literature; at worst, it shows a predilection toward substituting expert judgement in place of experimental data. Either case severely undercuts the credibility of the expert panel approach adopted by the WIPP Program. Accordingly, it is suggested that the text be corrected and expanded on this key topic of existing experimental data.

In particular, no references could be found in section 5.2.4 or in section 3.3.5 on existing experimental data. The brief mention of existing data on page 5-50, line 38 is entirely inadequate for a parameter which has the most important uncertainty in the entire performance assessment.

Page 5-49, line 42. The terminology used here is "expert panel on source term", whereas page 5-49, lines 36-37 and page 5-50, line 37 indicate that it was an expert panel on solubility. Clearly the latter is a small, albeit important, subset of the former. It is crucial to understanding of the approach that the technical subject for the expert panel be clarified and consistently cited.

Page 5-50, lines 9-10. The emphasis on "complementary areas", "breadth" and "balance" seems contradictory to the purpose of invoking a single expert panel on a single issue (i.e., solubility of specific radionuclides under variable Eh and pH conditions). It would seem that this was not a single

expert panel but rather four separate one-member panels in four different areas. This separateness of expertise in members of an expert panel elicited for a single purpose is reinforced in lines 34-35, which refers to "each panelist's particular expertise". Readers, especially those who are not specialists in organisation and elicitation of expert panels, will almost certainly be confused by this seeming contradiction.

Page 5-50, lines 12-15. This sentence seems to make a distinction without a difference. The difference between "considering a solubility limit" and "to consider explicitly the individual radionuclide concentrations" should be clarified. Is it suggested that solubility limits will not be reached or that metastable compounds will form or that colloids will be a major contributor for all of these radioelements?

Page 5-50, lines 23-25. The text should note if the communications among panelists were documented and if the panelists communicated with any other "experts" outside the panel during this time. If so, further clarification for the non-specialist is needed to establish the appropriateness of this procedure within the accepted precepts of expert panel elicitation.

Page 5-50, line 39. The single citation of pH as an example of an environmental factor considered is inadequate, again given the acknowledged importance of the solubility values. For example, were pressure solution effects on solubility arising from salt creep considered as a factor? If not, why not?

Page 5-51, lines 1 and 14. Phosphates are well established as important compounds/complexants of actinides. Does the absence of a citation to phosphate imply that such compounds were not considered? The brevity of this treatment of solubility and the expert panel tends to raise more questions than it resolves.

Page 5-51, lines 6-7. This admission is astounding and seemingly in contradiction with the rationale for convening the expert panel. The initial justification for the expert panel was to provide judgement about radionuclide concentrations (page 5-50, lines 12-15) because it was (erroneously) considered that there was an absence of experimental data (page 5-49, line 34). Now the panel was allowed to cease its efforts on this very topic because "available data was insufficient". The reader is left wondering if perhaps these experts might not be so expert after all and whether the WIPP Program has forgotten the basis for convening the panel. This is an unsatisfactory conclusion to this effort.

Section 5.2.5 Performance assessment model for the repository shaft system

Page 5-51, line 40. Will fractures also develop in Anhydrite A and B layers and will these fractures also fill with brine? Figure 5-20 (page 5-32) would seem to suggest this is true.

Page 5-53, line 1. The use of the word "could" indicates that other time durations are possible. What is the effect on performance assessment if closure is complete in 10 years or in 1000 years? Are these possibilities addressed somewhere?

Page 5-53, line 23. Could the activity of other types of microbes generate other gases such as carbon dioxide or methane? If such events have been eliminated, it would be useful to know the basis for their elimination.

Page 5-55, line 34. Rather than merely state that neither pathway resulted in radionuclides reaching the Culebra Dolomite within 50,000 years, it would be helpful if some indication were given of the time interval over which radionuclides did reach this formation and what their subsequent migration was thought to be.

Page 5-55, lines 37-42. It is noted that SUTRA and STAFF2D have been used to model undisturbed performance. Brine flow only is considered, and gas generation is not directly considered in the simulations. The WIPP Performance Assessment Division has already recognised the weakness of the approach adopted, and so no detailed review of this material is provided (see also Volume 2, Chapter 4 comments).

Page 5-56, line 32. How are the rates of these processes determined? Is there an unstated assumption that the limiting step on corrosion is the influx rate of brine or are specific corrosion kinetics considered for metals and, if so, how are available surface areas determined?

Page 5-59, lines 12-21. The relative degree of conservatism for each of the assumptions should be noted. If metastable compounds form containing radionuclides, is the chemical equilibrium assumption likely to be conservative?

Page 5-59, line 43. Is it also assumed that future extraction technologies will be comparable to those of the present?

Page 5-60. The discussion on borehole intrusion into a waste vault is imbalanced, as it appears to miss out several aspects of the argument which are likely to be important. It would seem unlikely that any driller would ignore the effect of the drill bit intersecting a shielded waste container,

for example, because this would probably be detectable at the surface in terms of changes in torque, vibration, rate of penetration and perhaps mud returns. Damage to the drill bit would be probable. As some aspects of the borehole intrusion scenario have been considered in great detail, there is a notable lack of discussion of whether intrusion into the waste galleries would be detectable by the drillers, and what the consequences would be of their probable resulting actions.

A discussion of drilling into a SKB-type HLW repository, admittedly using very different drilling techniques, is presented in Charles and McEwen (1991), where more realistic assumptions on drilling intrusion have been applied.

We agree with the comments made by EEG presented in Appendix B, pages B-30 to B-36 concerning human intrusion by drilling. It is important that if so much is to be made of intrusion as the one method by which radionuclides can be brought to man's environment within the 10,000-year period, then totally credible scenarios should be considered.

Section 5.3 CAMCON: Controller for Compliance-Assessment System

This section describes the CAMCON system developed to control data flow and code linkage in the performance assessment calculations. The CAMCON package is extremely complex, and apparently completely unverified. What has been done to provide confidence that the executive system is functioning as intended? For example, it might be of interest to run some of the early NEA/PSACOIN exercises, or to undertake some other PSA code intercomparison activity. In addition, the information in table 1 (pages 5-67 to 5-72) suggests that all but one of the 79 submodels in CAMCON are still unverified. Is this really the case?

3.1.6 Chapter 6. CONTAINMENT REQUIREMENTS

Pages 6-9 to 6-11, Table 6-3. The systematic listing of major assumptions made in obtaining the assessment results provided in this chapter is an important component of the report. These assumptions define many of the conceptual models used in the assessment. This table leads directly to the question of conceptual model uncertainty. It is stated elsewhere that conceptual model uncertainty has not yet been explicitly treated in the assessment work. This will be an important development for future year assessment reports. Although some of the assumptions listed in this

table may be adequately considered through bounding calculations or sensitivity analyses. others may relate more directly to the modelling system selected for the assessment. Examples range from the assumptions that no radionuclide transport occurs in colloidal form, to the decision to ignore the contribution of RH-waste to subsurface groundwater releases to the accessible environment, to the decision to model the Culebra dolomite as a two-dimensional confined aquifer, with a single-porosity Darcy flow model and a dual-porosity transport model (for retardation effects).

3.1.7 Chapter 7. INDIVIDUAL PROTECTION REQUIREMENTS

No comments.

3.1.8 Chapter 8. ASSURANCE REQUIREMENTS

Page 8-10, lines 33-35. It is indicated that one objective of active institutional control is to restore the land surface to its original condition. However, this activity would seem to be incompatible with the current plan for passive institutional control to establish a system of permanent markers around the site (page 8-11, lines 9-11), particularly considering the type of large-scale marker systems being recommended by the WIPP Markers Panel.

3.1.9 Chapter 9. GROUNDWATER PROTECTION REQUIREMENTS

No comments.

3.1.10 Chapter 10. COMPARISON TO THE STANDARD

This chapter is little more than a repetition and summary of material provided in the preceding four chapters. Excellent synopses already exist for these chapters. It might be preferable to combine the material in these four chapters into a single chapter, as they are all relatively short.

3.1.11 Chapter 11. STATUS

The main focus of this chapter is to indicate where additional work needs to be done to increase confidence in the assessment results. A very long table is presented, suggesting that a great deal of work still needs to be done, yet the assessment results presented in Chapters 6-10 show either certain compliance or a high degree of confidence. Nearly all of the assessment work is focused on section 191.13 of the Standard (the containment requirements), but even here, with the currently available knowledge, there appears to be many orders of magnitude to spare. The disposal system is robust, and human intrusion may well be the only credible scenario of concern. Because of the apparent contradiction between the assessment results and the presentation in this chapter, there is a need to prioritise the information presented in the table on the basis of the sensitivity analyses already completed and reported in Volume 4 (note however that we have not yet received this important Volume for review).

3.2 Volume 2: Probability and Consequence Modeling

3.2.1 Chapter 1. INTRODUCTION

No comments.

3.2.2 Chapter 2. DRILLING INTRUSION PROBABILITIES

This chapter addresses the issue of generating the scenarios to be used in computing a CCDF. This has two components – the philosophy behind the CCDF construction and the mechanics of generating the scenarios. The comments below refer mainly to the latter, comments on the construction having already been made for Volume 1, Section 3.1.

The overall impression of this chapter is that

- the presentation is unnecessarily mathematical;
- the full generality that is maintained is unnecessary, and contributes to the previous point;
- a simulation approach would have been easier to implement and explain.

The excessive use of mathematics obscures some of the important questions that should be asked about the treatment of human intrusion presented. Most importantly, does the approach lead to greater confidence in the assessment results? The reason for developing the many computational scenarios from the small number of summary scenarios is to obtain a finer resolution of the CCDF. Is this needed if the rougher resolution of the CCDF (e.g., just based on the small number of summary scenarios) can be used to demonstrate compliance? It seems that sight has been lost of an important objective in evaluating uncertainty and in presenting the results of performance assessments. The approach taken to treat uncertainty should be done so because it leads to a clear presentation of assessment results and associated uncertainties, and not only to ensure mathematical rigour.

After specific comments on each section and on the following chapter, the simulation approach is described and illustrated by regenerating some of the CCDF curves.

Section 2.1 Introduction

This section restates the EPA regulation, and addresses the issue of constructing a single CCDF. Our comments on Volume 1, Section 3.1 also apply here, since much of the material is common.

Page 2-4, Equation 2-4. The notation $\stackrel{\bullet}{=}$ is not a familiar one, and is not explained.

Section 2.2 Mathematical Preliminaries

There should be a section prior to this to remind the reader what is being calculated and why. The purpose seems to be to give scenarios with single or multiple intrusions. These will be used in the next chapter to generate CCDFs.

As for this section itself, it is unhelpful to the reader. Although almost certainly mathematically correct and rigorous, it presents ideas which need only appear in a pure mathematics textbook or journal paper. It is impossible to give a detailed review of the whole section; instead some particular examples of these points are made below.

- Pages 2-7 to 2-8. Equations 2-6, 2-7 and 2-8 present three ways of writing mathematically the statement of lines 6 and 7 of page 2-8. For the general reader this is unhelpful and for the mathematical reader it is merely repetitive.
- Page 2-8. Various possible forms of $F(u, v)$ are given. No indication is given as to which is actually used in the assessment. Later in the report it is clear that the simplest and most conventional form (equation 2-9) is in fact used, and this is a sensible choice. Focusing on this case throughout would reduce the need for much of the complexity, and enable the reader to see what is actually being done.
- Pages 2-9 to the middle of 2-11. This material again belongs in a textbook or journal paper, not in an assessment report. Most readers will simply be intimidated by such a presentation.

Section 2.3 Computational Scenario Probabilities for Single Time Intervals

Again the generality is unnecessary: the actual case used should be described.

Section 2.4 Computational Scenario Probabilities for Multiple Time Intervals

Same comment as for section 2.3.

Section 2.5 Computational Scenario Probabilities for Pressurized Brine Pockets

Same comment as for section 2.3.

Section 2.6 Example Results.

The decision to use just five time intervals is not well justified. It seems to be based on consideration of combinatorics rather than on the accuracy of calculated results.

The result of all the effort in this chapter is a series of rather daunting tables for input to the next chapter. Given the methodology chosen, these tables are required but need not be presented in such a stark fashion.

3.2.3 Chapter 3. CONSTRUCTION OF COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTIONS

Section 3.1 Introduction

This section repeats much of section 2.1 and Volume 1, section 3.1.

Section 3.2 Construction of a CCDF

Again this is too mathematical.

Section 3.3 Computation of Activity Loading Effects

This section dwells too much on the combinatoric problems caused by the methodology that has been chosen. As an example of this, table 3-2 (page 3-10) serves no purpose as far as the reader is concerned.

In a number of places alternative approaches are discussed but it is unclear which has finally been chosen.

Section 3.4 Examples of CCDF Construction

No justification is given for the use of only 60 samples to study parameter uncertainty.

Page 3-17. Equation 3-37 and the preceeding text is confusing, since it seems to contradict table 2-5 (page 2-35) where the relationship between area of brine pockets and area of waste panels was set out.

Page 3-19. Table 3-3 indicates that the consequence changes only slowly with time. This might be used to justify the use of just five time intervals; however no such argument is presented.

Pages 3-20 to 3-25. Tables 3-4 and 3-5 are unhelpful: something with more visual impact would be much better.

Page 3-28. The issue of non-conserved probabilities points to using a different approach. An example of such an approach is given in the next section of this review.

An Alternative Approach using Simulation of Intrusion Events

In this section an alternative simulation methodology is presented for generating the CCDFs for intrusion. The alternative approach is outlined here to illustrate the use of a simpler and more straightforward mathematical and computational approach (than that adopted by Sandia) to the development of a CCDF for human intrusion events. In addition, adoption of the suggested approach would allow the time-dependent consequences of human intrusion events to be clearly illustrated. The suggested approach is easy to describe and implement.

There are an infinite number of possible futures for the repository. In any one future a number of intrusion events will occur and these will have consequences, in terms of releases to the accessible environment, which can be predicted by using the various models available.

The consequences of individual intrusion events or of multiple interacting events (of the E1E2 type) will be time-dependent. The time-dependency can be represented as a piecewise-constant as in the current methodology, or in any convenient form.

The suggested approach generates sequences of intrusions numerically from the basic assumption that this is a Poisson process. If other processes are to be used a similar methodology could be developed.

By generating large numbers of possible futures, and calculating the consequence of each, the CCDF can be directly formed. In the example given below 10^6 futures were generated (taking 8 minutes on a Macintosh computer).

To illustrate the ease with which such an approach can be implemented, the results given in figure 3-4 for cuttings have been reproduced using a small C-program. For each future a sequence of intrusions is generated and the consequence cumulated. When activity loading is considered, the activity level of the penetrated waste is determined randomly according to the given probabilities.

Using this program, and binning the results, the CCDFs are generated. Those shown in figure 1 can be directly compared to figure 3-4 of the WIPP assessment Volume 2, and are found to be virtually identical.

In addition to reproducing the results given, the simulator can be used to look at the possible effect of including time-dependence of the consequence more precisely. Obviously from the five time values given we cannot generate a full time history, and so we have interpolated (and extrapolated for early and late times) from these values. The tables in Appendix B indicate that the normalized releases are dominated by one or two nuclides and so tend to fall off exponentially. Therefore, a linear interpolation and extrapolation scheme has been used for the logarithm of the normalized release. The results with this scheme are shown in figure 2.

The major effect of this change is to smooth the CCDF somewhat. This is a direct result of the elimination of the discontinuities in consequence at 2000-year intervals.

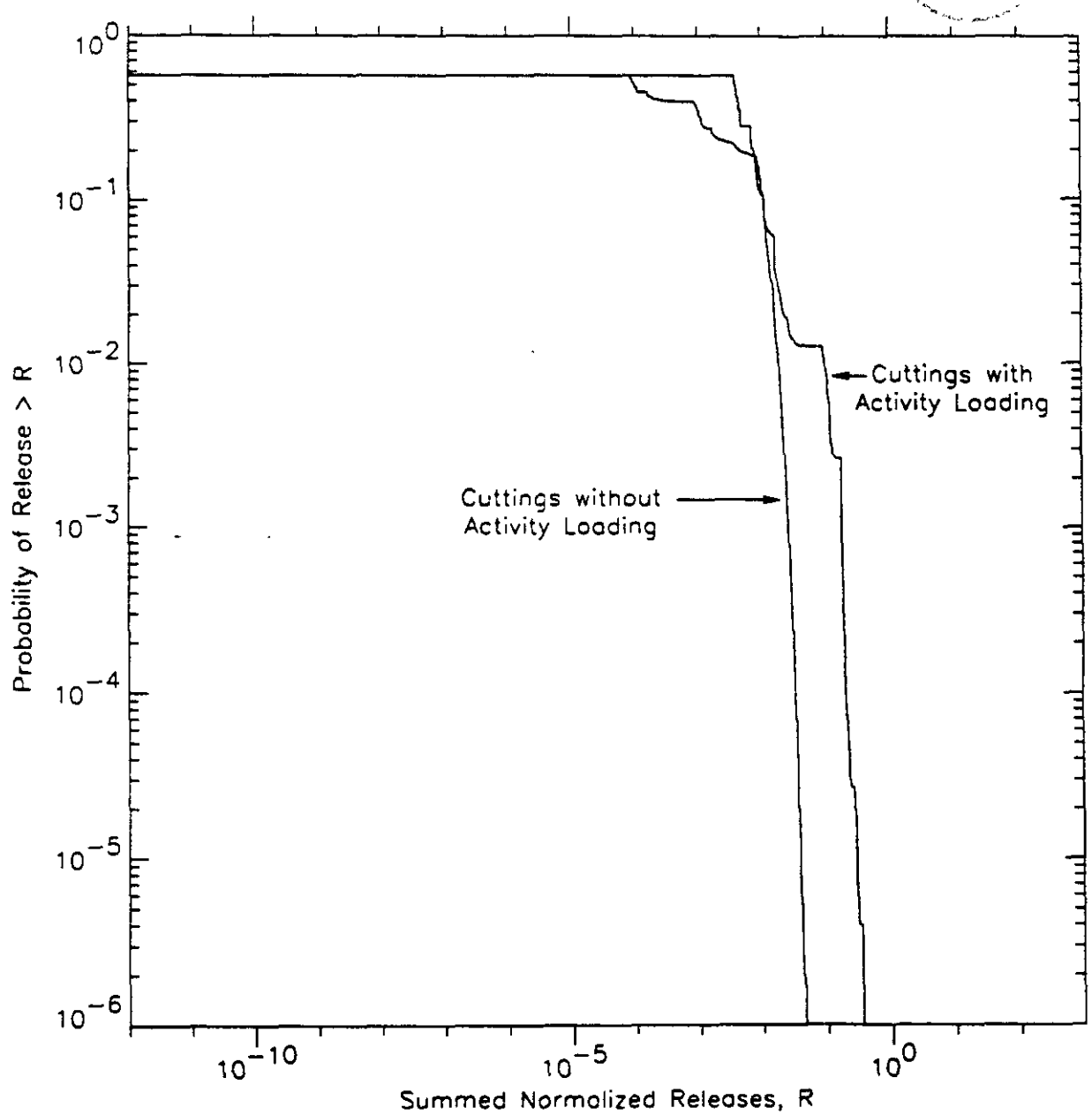

Figure 1: CCDF for cuttings produced by simulation approach.

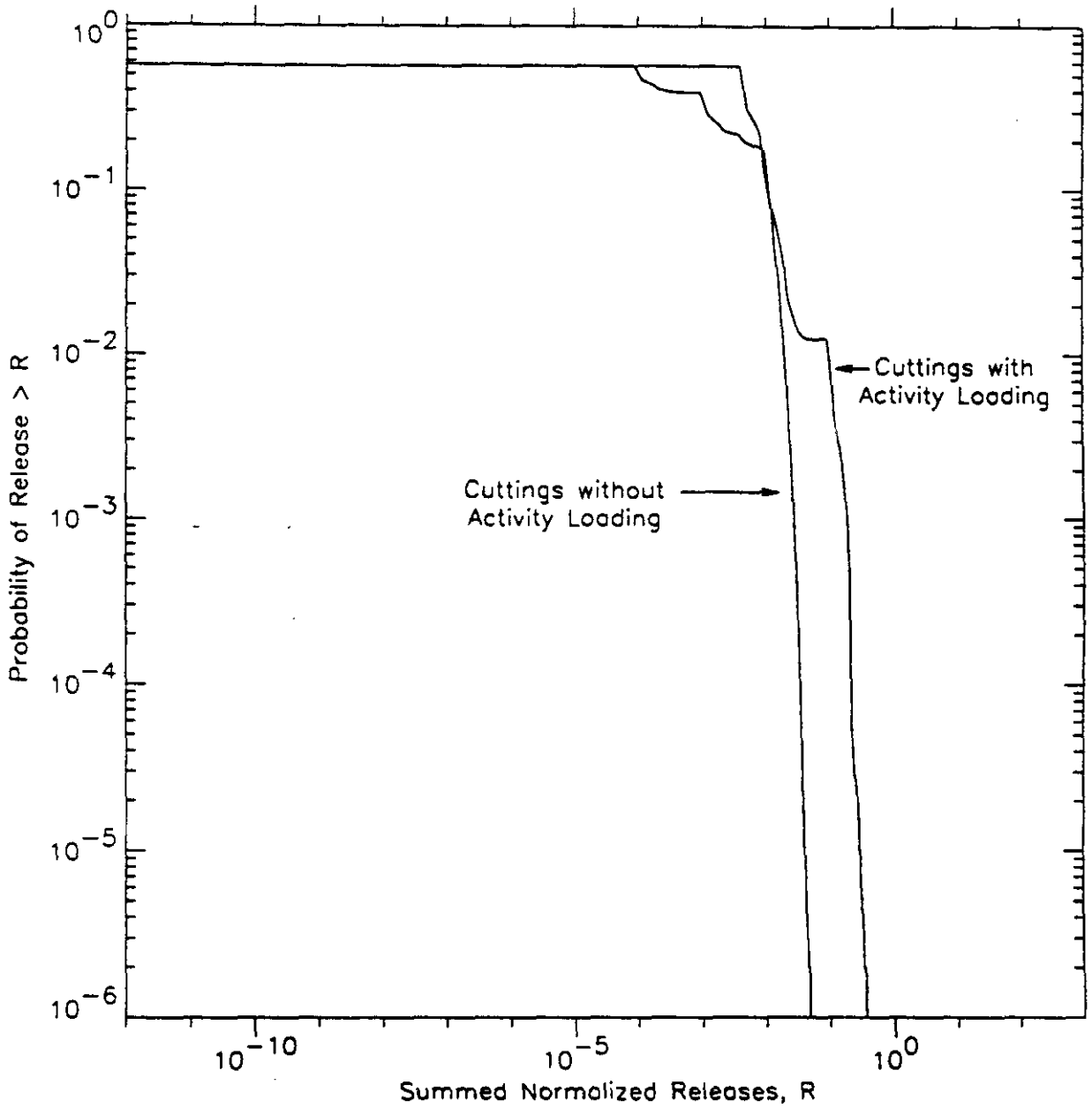

Figure 2: CCDF for cuttings produced by simulation approach with continuously time-varying consequence.

3.2.4 Chapter 4. UNDISTURBED PERFORMANCE OF REPOSITORY/ SHAFT

The 1991 undisturbed performance calculations were made largely on the basis of results from the SUTRA and STAFF2D one-phase-flow codes. We have not reviewed this chapter in any detail, because we understood that a decision has already been made to model the undisturbed performance with the BRAGFLO two-phase-flow code for the 1992 assessment.

3.2.5 Chapter 5. DISTURBED CONDITIONS OF REPOSITORY/SHAFT

Section 5.1 Conceptual Model

Pages 5-1 to 5-2. The initial introduction serves as a reminder of the scenarios modelled and it would help the reader to have a diagram to refer to, either in this chapter or by reference to one in the preceding chapter. It is clearly stated here that scenario E2 includes the possibility of more than one borehole drilled to the same panel, whereas later in the text (section 5.4, page 5-59, lines 5-6), E2 is described as a single intrusion scenario. The rationale for modelling multiple boreholes as a single one is explained for the E1E2 scenario but is not justified for the E2 scenario.

The assumption that multiple wells drilled to the panel are hydraulically isolated is questionable. No explanation is given apart from a vague reference to Chapter 5 of Volume 1. On reading this chapter, the only reference to hydrological isolation of wells refers to wells drilled into the Castile formation, where data suggest that the brine pockets in this formation are isolated. This does not correspond to the E2 scenario, however, in which the wells terminate in the panel. For unmodified waste, the panel has a higher permeability and porosity (Volume 3, section 3.4.7) than that of the Castile formation between brine pockets (Volume 1, Chapter 5, section 5.1.2). More explanation should be provided on this point, as it is not clear that if mutiple wells are modelled as isolated, then conservative results can be guaranteed. Multiple wells will provide additional escape routes for the gas, assisting the depressurisation of the panel and allowing more brine to enter from the far field at an earlier time, than if the wells are considered in isolation. It should be possible to check the performance of mutiple wells for a few example cases using a 3-D reservoir model, such as the TOUGH code used in the verification examples.

Page 5-1, lines 12-14. The use of the term "flow" seems unnecessary. Why not simply use the correct term, cumulative volume, and avoid any possible misunderstanding and the constant repetition of the quotes (which seem

to be forgotten about in later sections anyway). The reminder that the volume is accumulated over 10,000 years can then be given once in the text, and also in the figures.

Pages 5-2 to 5-3. The subsections describing the approximations to the various scenarios are unclear. It would be more helpful to deal with each scenario in turn and explain the assumptions made in the calculations for each one, rather than mixing them up in this fashion. Subsection 5.1.2, on the approximation to the E1 scenario is particularly confusing, referring to all three scenarios and also presenting some of the results. The results are presented as justification for the assumptions made (including the apparant interchange of scenarios) but, at this stage of the chapter, they do not enhance the understanding of the modelling procedure.

Page 5-5, Figure 5-2. There seems to be a discrepancy between the results for the single-phase flow calculations performed using PANEL (figure 5-2, page 5-5) and those using BRAGFLO (figure 5-9, page 5-33). The PANEL results indicate that there is a considerable reduction in the cumulative volume of brine for the 1,000-year intrusion vectors, compared with the two-phase flow results shown in figure 5-1 (page 5-4). Results in later sections using BRAGFLO alone indicate the reverse situation, with the single-phase flow calculations giving higher cumulative volumes for the E2 scenario for the 1,000-year intrusion vectors. As the results are calculated using different models there is probably a simple explanation for the discrepancy, but it should be explained (one possibility is that the axes in figure 5-2 are incorrectly labelled by a factor of 10). Again, however, it would be less confusing if results were not introduced at this stage.

Section 5.2 Two-Phase Flow: BRAGFLO

A clear summary of the conceptual basis of the BRAGFLO model is given here and in Appendix A.

Section 5.2.2 Model description

Page 5-8, line 22. The nomenclature here should read k_{rl}, rather than k_{re}.

Pages 5-11 and 5-12. Figures 5-3 and 5-4. These figures present results for 1-D benchmark calculations using BRAGFLO, BOAST and TOUGH. The graphs of repository pressure vs. time and gas saturation vs. time for TOUGH each contain two lines, one labelled *all brine* and the other labelled *gas saturation*, but there is no explanation for this in the text. In the example, the gas generation rate is fixed at 2×10^{-7} kg/s/m^3 and

results in a pressure rise from 0.1 to 12 MPa in a time period of 600 years.

Page 5-13. Figure 5-5. In contrast to the 1-D examples, the 2-D example has a lower gas generation rate (1.7×10^{-10} kg/s/m^3 for 525 years and 5.7×10^{-11} kg/s/m^3 for 185 years), but the pressure rises to 45 MPa in 550 years. The high pressure is attributed to the low value of porosity assigned to the panel, but the porosity value used in the 1-D example is not given for comparison. It would be more instructive to compare the 1-D and 2-D results using common parameters, so that the impact of the second dimension can be judged. The 2-D results for BRAGFLO and BOAST are very similar up to the time of intrusion, where the simulations stop. The section should be completed by presenting the TOUGH simulation results, as in the 1-D case. This will have the additional benefit of comparing results beyond the time of intrusion.

Pages 5-14 to 5-16. In section 5.2.2.4. Fundamental Equations, K is used for the absolute permeability, whereas it is defined in the nomenclature (section 5.2.2.1) using k.

Page 5-15, line 21. There is a change in nomenclature from C_{Nw} to C_{Gb}, before it is formally introduced on page 5-16, after equations 5-6 and 5-7.

Page 5-15, line 28. This talks about an *oil* phase of brine and dissolved gas, instead of a wetting phase.

Pages 5-16 to 5-17. Section 5.2.2.5 on wells is clearly presented. It would however be useful if computational times for problems using the simple well model and full spatial representation were included, together with discussion of whether the results for the full representation could be used to calibrate the simple model, in the absence of production history data.

Pages 5-18 to 5-21. The description of updating the time step (section 5.2.2.6) is not as clear, as it implies that the Δz^* are chosen to keep the time step constant. Presumably this occurs only if the maximum changes in the dependent variables Δz_m at any stage in the calculation are equal to the fixed input parameters Δz^*.

Section 5.2.3 Spatial and temporal grids

Pages 5-22 to 5-23. This section discusses the spatial representation of the region but there is no mention of temporal grids, as suggested in the title.

Page 5-23, line 2. Reference to figure 4-1 would be more helpful if it occurred in the first paragraph, so the reader may refer to it straight away.

Section 5.2.5 Results and discussion

Generally the discussion here is easier to understand than that given in the introductory sections of this chapter (see above comments). However, there is no discussion of how results are obtained for multiple intrusions into the panel. The introduction clearly states that multiple intrusions of this kind are included in the computational scenarios, and distribution functions for times of multiple intrusions are given in Chapter 5 of Volume 3. It is not made clear whether the results presented actually include multiple intrusion cases for scenario E2. If they do, it should be explained how such results are derived, as the BRAGFLO model is restricted by the use of cylindrical geometry to modelling single wells.

It was also noted earlier that the discussion of the comparison between single-phase and two-phase flow results is restricted to the BRAGFLO results. There is no explanation of the apparant decrease in cumulative volume obtained for the E1 and E2 scenarios for the 1,000 year intrusion vectors, using the single-phase flow model, PANEL (if indeed this decrease is not simply due to errors in labelling the axes of the figure).

Page 5-30, lines 29-30. The text should read "when gas is *not* generated".

Page 5-31, Figure 5-7. The left axis indicating E2 flows would appear to be a factor of ten low, by comparison with other results presented in this chapter.

Section 5.3 Repository Discharge (PANEL)

The lengthy mathematical description of the relatively simple flow model used in PANEL seems out of place here, particularly as the flow model is not used in the consequence analysis (other than for the results shown in figure 5-2). It would be easier to read if reduced to the level of description given for the waste mobilization and transport model (section 5.3.2), which is brief but clear.

Page 5-49, equation 5-12. $\zeta^i_{\omega_j}$ should be $\zeta^i_{b_j}$.

Page 5-49, line 23. The text refers to p_0 instead of P_0.

Page 5-55, line 37. An additional line is included, by mistake.

Page 5-56, lines 6-8. It would be helpful to include a description of the estimation procedure referred to, for calculation of the final discharge rates to the Culebra Dolomite and the contaminant concentrations.

Pages 5-57 and 5-58. Figure 5-23 and 5-24. The explanation of "Flow" included in both figures 5-23 and 5-24 is not necessary, as the graphs show normalized release rather than cumulative volume. In addition, the caption for figure 5-24 should read E1E2 Releases..., not E2 Releases...

Section 5.4 Summary of Results for Disturbed Performance

Pages 5-59 to 5-60. This section summarises the modelled scenarios once more, and here the description of the E2 scenario is reduced to a *single* intrusion of the waste panel, again with no discussion of how results for the multiple intrusion cases are inferred. It also states that the E1 scenario is assumed identical to the E2 scenario. It would be better to remind the reader why this assumption is made, or simply to say (as in earlier sections) that E2 results, in general, provide an upper limit on the E1 results.

Page 5-59. Numerous examples of poor grammar or lax editing, e.g. -

line 9. "was" should be "were".

line 14. "the" should be deleted.

line 16. "radionuclide" should be plural.

line 33. "was" should be "were".

3.2.6 Chapter 6. DISTURBED GROUNDWATER FLOW AND TRANSPORT

Chapter 6 introduces the conceptual model for disturbed groundwater flow and transport within the Culebra Dolomite. In general, the chapter gives a clear description of the details of the implementation of the model, but it lacks an overview of the links between the three aspects described in sections 6.3, 6.4 and 6.5.

Section 6.1 Conceptual Model

Here the authors clearly describe the requirement to generate realizations of transmissivity honouring point estimates at well locations, but do not make explicit the reasons why a geostatistical approach is an improvement on the zonal technique discussed. A discussion of the effect, on transport, of spatial variability on a range of scales would clarify this.

Section 6.2 Generation of Transmissivity Fields by Geostatistics

The first part of section 6.2.1. on the generation of conditional random fields, could also benefit from clarification. First, there is no discussion of the basic underlying assumption of geostatistics, that the measured values are regarded as realizations of a random field. Second, the description of the variogram is confusing. Third. the statement that each realization has the correct spatial structure of the true field overstates the functionality of the geostatistics approach. There is no reference to the implicit assumption that the measured values and the true field have the same spatial structure. Furthermore, although methods such as turning bands give a specified ensemble spatial structure over a number of realizations, it is not clear whether all individual realizations have the desired spatial structure.

The desirability of assessing conceptual model uncertainty is clearly presented in section 6.2.3. A rather fuller description of the four alternative models would be beneficial.

Section 6.3 Selection of Transmissivity Fields

In this section. the authors discuss the rationale for selecting transmissivity fields. and the calculation of travel times through the selected fields. An indication of the grid dependence of the results, and a discussion of why a 52 x 44 grid was used. would be of interest. The inclusion of all 60 selected transmissivity fields in an overview of the results is unnecessary.

Section 6.4 Fluid Flow Modeling with SECO2D

This section discusses fluid flow modelling with SECO2D. Undue emphasis has been placed on the general capabilities of the code (sections 6.4.1.2 - 6.4.1.7). to the detriment of the discussion of the results of the 1991 calculations. The section could also benefit from a clearer discussion of the links between the 1991 calculations with SECO2D and other aspects of the calculations discussed in this chapter. The transmissivity fields generated using the geostatistics discussed in section 6.3 are only mentioned very briefly. It would also be of interest if a clearer indication of the range of behaviour due to different transmissivity fields was discussed.

Section 6.5 Transport Modeling (STAFF2D)

This section gives a clear, detailed description of local flow and transport modelling. The section introduces a number of assumptions and limitations (section 6.5.2.3). It would be of interest if the authors discussed further the basis for the assumptions. It would also be beneficial if the discussion of the results in section 6.5.2.10 included a more complete description of different scenarios considered (e.g., scenario E2 is introduced without any discussion). This section, as for section 6.4, could also benefit from a fuller discussion of the links between the work discussed and the other aspects of the 1991 calculations. The link between regional and local velocity fields and grids could be made more explicit.

3.2.7 Chapter 7. CUTTINGS REMOVAL DURING DISTURBANCES

Generally, the work reported in this section is excessively detailed for the state of knowledge.

Section 7.1 General Considerations

This subsection begins by restricting attention to a hydrocarbon exploration well using current rotary drilling techniques. While this is clearly a good basis for consideration of the human intrusion scenario, it must be admitted that our ability to predict future human behaviour is minimal. Thus, it cannot be said why a borehole would be drilled, or how it would be drilled. The introduction of sophisticated modelling cannot disguise these basic facts. In order to make a fair assessment of the potential risks arising from such intrusions, it is necessary to estimate both their frequency and scale. The frequency is already estimated (as a probability distribution) directly from expert judgement. The scale of intrusion should be similarly estimated.

Section 7.2 Analysis

Given the comments of the previous section, we consider the analysis presented in sections 7.2.1 and 7.2.2 unnecessary (and have not reviewed it in detail).

In section 7.2.3, the Bateman equations for radioactive decay and ingrowth are stated and solved for the particular case of a 5-member chain. The explicit expansion of the solution as presented is not very helpful, since

it is not an efficient way of actually calculating inventories against time. Moreover, it is not necessary to solve the equations in terms of numbers of atoms and then perform messy conversions.

The Bateman equations in terms of activity are simply

$$\frac{dN_i}{dt} = -\lambda_i N_i + \lambda_i N_{i-1}.$$

For given initial inventories $N_i^{(0)}$ [arbitrary units of activity], the solution can be written

$$N_i(t) = \sum_{j=1}^{i} a_{i,j} e^{-\lambda_j t},$$

where the coefficients $a_{i,j}$ are defined by the recurrence relations

$$\begin{aligned} a_{i,i} &= N_i^{(0)} - \sum_{j=1}^{i-1} a_{i,j}, \\ a_{i,j} &= \frac{\lambda_i}{\lambda_i - \lambda_j} a_{i-1,j} \qquad i > j. \end{aligned}$$

This is valid for any length chain and leads directly to an efficient and compact numerical algorithm.

Section 7.3 Code Description

No comments, except that that above solution method should be used for solving the Bateman equations.

Section 7.4 Drilling Parameters

As commented above, the scale of intrusions should be directly estimated.

Section 7.5 Results and Discussion

Why not show the full CCDF?

Pages 7-17 to 7-18. Tables 7.1 and 7.2 both have the 7000-year column incorrectly labelled.

3.3 Volume 3: Reference Data

Although we have some concerns over the details of the methodology used to obtain the reference data, our general impression of the data gathering exercise is that it is very systematic and comprehensive.

On the other hand, in the chapters describing the treatment of individual parameters, it is not always clear whether or not the parameter was sampled and, in many cases, it is not clear how the parameter entered into the performance assessment. An additional point of confusion is that often the performance assessment calculations used different values for parameters than those appearing in the summary tables and boxes. In this case, we presume that the summary values were used solely for the purpose of sensitivity analyses (reported in Volume 4). The distinction should be made clearly.

In addition, the detailed discussions contained for many of the parameters in some cases shed little light on the basis for the median and range used in the assessment. More attention needs to be paid to the clarity of these discussions, and to the link between the discussions and the final summary information presented in the "boxes" and tables.

3.3.1 Chapter 1. INTRODUCTION

Section 1.1 Purpose and Organization of the Report

No comments.

Section 1.2 Conventions

Page 1-2, line 48. Equation 1.2-1 has a missing x after the integral.

Page 1-2, line 55. It is noted that $\bar{x}$ is used to denote both the true mean of a distribution and its sample mean. These two quantities should be clearly distinguished.

Page 1-3, line 11. It is stated that normal distributions are truncated at the 1st and 99th percentiles. Given that the regulation is concerned with the 0.1 percentile of the distribution of consequences, this cannot be justified on mathematical grounds. Presumably the justification is that the normal distribution is only a convenient way of representing some types of uncertainty and so its tails should not be included.

Page 1-3 to 1-4. Section 1.2.3 Constructed Distribution (Empirical). There seems to be a confusion between uncertainty and variability. Repeated measurements of a variable may give different results for a number of reasons (spatial variability, experimental error, lack of control of experimental environment, etc.), and this will lead to an uncertainty as to the true value of this parameter. However, it is only when the parameter varies stochastically that the observations can be taken as a direct indication of uncertainty. In other cases, the varying measurements require careful consideration by experts to determine a reasonable characterisation of uncertainty.

Some of the confusion in terminology may result from the more or less direct translation of reactor PRA methodology and terminology to waste disposal system performance assessment. It is not sensible to apply directly all of the reactor PRA concepts to natural geological systems. For example, large parts of a reactor can be treated as an engineered system comprised of components of more or less constant (but imprecisely known) properties. This same thinking is not easily applied to disposal systems.

Page 1-12, lines 12-18. The neglect of correlations has a potentially significant effect on calculated results and should not be dismissed so lightly. It is often suggested that correlations be included by reordering samples (produced by Latin Hypercube Sampling or straighforward Monte Carlo sampling) to satisfy a specified correlation matrix. This approach is however much less satisfactory than an approach based on identifying the reasons for correlations (in terms of functional relationships) and reparameterising accordingly. In the later parts of this volume, correlations are given as rank-correlation coefficients, presumably indicating an intention to use a reordering method.

Section 1.2.7 to some extent addresses the issue raised above about Empirical distributions. We have not yet been able to review it in detail, but it is at first sight a useful contribution.

Section 1.3 Background on Selecting Parameter Distribution

The method for selecting appropriate parameter distributions is well described.

Page 1-18, lines 33-38. The procedure in step 3 again raises the issue of confusing variability and uncertainty.

Page 1-20, line 49. Some words have been mistakenly repeated.

Section 1.4 Performance-Assessment Methodology

The material in this section is very similar to that contained in Volume 1, Chapter 3 and in Volume 2, Chapter 3. It is not reviewed in detail here.

Page 1-27, line 14. There is a missing symbol between the words "of" and "into", presumably S.

Page 1-27, line 19. The reference to S seems incorrect; this should presumably be replaced by S.

Page 1-29, lines 4-6. The reference to "variable uncertainty" again seems to confuse the distinction between variability and uncertainty. Uncertainty can also arise owing to spatial (and/or temporal) variability of the parameter (e.g., limited spatial characterisation of the disposal system), in which case the uncertainty is more appropriately referred to as "variability". In addition, because of the difficulty of using the expression, "variable variability", we would argue for the substitution of the word "parameter" for "variable" throughout the text.

Section 1.5 Background on WIPP

Page 1-36, lines 28-31. The explanation provided for the repository location is meaningless. It is perhaps not the purpose of this report to explain why the repository has been located where it has been (both horizontally and vertically) but, because it is a logical question to ask, this information would be extremely useful for the reader.

3.3.2 Chapter 2. GEOLOGIC BARRIERS

Section 2.1 Areal Extent of Geologic Barriers

No comments.

Section 2.2 Stratigraphy at the WIPP

Page 2-5, line 12. The existence of 45 siliceous and sulphate units within the Salado Formation is important information regarding the formation, and should be given in Chapter 1 of Volume 1.

Page 2-5, line 13. What has lithostatic and hydrostatic pressure to do with stratigraphy? This information should be presented elsewhere, perhaps

under hydrologic parameters.

Page 2-7, Figure 2.2-2. This the first figure in Volumes 1 to 3 where the true spatial relationships between the disposal vaults and the marker beds are displayed. This information should have been presented in simplified form at the beginning of Volume 1. Figure 2.2-3 (page 2-8) is even more useful in this respect; information contained in this figure is needed in order to understand the development of the base case scenario.

Page 2-10. Figure 2.2-5. This figure contains too much information, and little of it is self-explanatory or explained in the caption. How were the various curves and data points shown derived?

Section 2.3 Hydrologic Parameters for Halite and Polyhalite within Salado Formation

Section 2.3.3 Dispersivity

Page 2-25. Figure 2.3-5. Values for transverse dispersivity shown in the figure do not reflect the discussion in the text or in the summary box. It is stated on page 2-21 that transverse dispersivity was assumed to be a factor 10 smaller than longitudinal dispersivity. Also, the bottom axis of the figure has not been defined.

Section 2.3.5 Permeability

Page 2-28. Figure 2.3-7. The figure has been mislabelled. It should be figure 2.3-6.

Page 2-29. The entire discussion on rank correlation between halite and anhydrite permeability in the Salado Formation is nonsensical because there are only two sets of paired data. The correlation coefficient finally settled on (0.8) is justified by a desire not to contradict the conceptual model. This is a backwards argument - the conceptual model should account for the range of parameters, not vica versa.

Page 2-30, line 45. Figure 2.3-6 does not show rank correlations; the referenced figure does not exist in the report.

Page 2-31, line 24. The text states that "Often the PA Division does not model the disturbed zone when it is conservative to do so..." This wording is ambiguous and should be clarified. The text could be read to mean that sometimes, even though it would be conservative to model the disturbed

zone, the PA Division does not do so (i.e., a nonconservative choice is made).

Section 2.3.6 Pore pressure at repository level in halite

Page 2-33, Figure 2.3-9. The figure is wrong: the units along the right-hand axis (probability density) are undefined; the bottom axis shows pressure in MPa, and not x 10 Mpa as indicated.

Page 2-34, line 20. It would be useful if a reference were provided to the section of the text that discusses anhydrite pore pressures (i.e., section 2.4.6, pages 2-61 to 2-62).

Section 2.3.8 Specific storage

Page 2-43, line 51. Some words are missing (perhaps just "in" at the end of the line?).

Section 2.4 Hydrologic Parameters for Anhydrite Layers within Salado Formation

2.4.4 Partition coefficients and retardations

Page 2-56, Table 2.4-2. The table is unclear and would be easy to take out of context. It should be indicated that the values provided are maximum partition coefficients for use in sensitivity analyses, and that coefficients of zero were assumed for the actual performance assessment calculations.

Section 2.4.6 Pore pressure at repository level in anhydrite

Page 2-62, line 20. The reference to figure 2.4-6 is incorrect. The referenced figure does not exist in the report.

Page 2-62, lines 27-29. The interpretation of the data provided in figure 2.4-8 is nonsensical. The data do not fit the curves. The modelled asymptotic value of pore pressure (10 MPa) is concluded to be significantly less than many of the measured data. The median value selected for the performance assessment of 13 MPa supports this view.

Section 2.5 Mechanical Parameters for Materials in Salado Formation

No comments because this section of the text is evidently still to be written. Is the implication of no text that the referenced parameters are unimportant to or not used in the performance assessment?

Section 2.6 Parameters for Culebra Dolomite Member of Rustler Formation

Section 2.6.2 Dispersivity

Page 2-78. Figure 2.6-5. The bottom axis of the figure is defined as porosity. It should be longitudinal dispersivity.

Page 2-78. Figure 2.6-6. The figure is unclear. It seems to show distributions used for sensitivity analyses only, not those used in the performance assessment calculations (box on page 2-77). As suggested in the box and at the bottom of page 2-77, these seem to differ slightly. Also, the bottom axis of the figure has not been defined.

Section 2.6.7 Tortuosity

Page 2-94, line 11. The reference to figure 2.6-9 is incorrect. It should be figure 2.6-15.

3.3.3 Chapter 3. ENGINEERED BARRIERS AND SOURCE TERM

Section 3.1 Dimensions of Underground Facility

Page 3-4. Figure 3.1.2. The meaning of the tiny black dot is unclear. Is this the location of the intrusion borehole for transport calculations?

Page 3-10, line 10. This is the first use of the abbreviation SWB, and it should be defined.

Section 3.2 Parameters for Backfill Outside Disposal Region

Section 3.2.1 Description of the reference design for backfill

Page 3-16, line 18. The 200-year period is cited but what are the consequences if the time required for consolidation is much shorter (e.g., 20 years) or much longer (e.g.. 2000 years)? Also, the 200-year figure cited in line 18 seems to contradict the 100-year figure cited in line 31 on this page and in line 4 on page 3-17.

Page 3-17, line 25. As noted in Chapter 5 of Volume 2, the conditions and factors under which it will be determined that a clay backfill will be "necessary" are not well documented. Will clay backfill be considered as a redundant barrier based on its own desirable properties or will it be included because of expected or demonstrated poor performance of consolidated salt? These questions should be answered in at least a brief manner.

Page 3-19, Figure 3.2-3. The scale on the uppermost figure in this group is misleading, as the separation of MB 139 from the waste vault (and its thickness) is much greater than it should be. The provision of precise numbers and a scale implies that the diagram is to scale.

Section 3.2.4 Partition coefficients for salt backfill

Page 3-27, line 38. Table 3.2-2 is solely for "salt and trace amounts of clay", wording that would imply an unintended, coincidental connection between these partition coefficients and those for anhydrite. A possible word change on line 38 to "approximately the same order of magnitude as anhydrite" might make the same point without the unintended connection between clayey salt and anhydrite.

Section 3.3 Parameters for Contaminants Independent of Waste Form

Page 3-30, Figures 3.3-1 and 3.3-2. The left-hand axis of both of these figures is visually daunting because of all the zeros. The axis should be relabelled (e.g., using exponents) to improve readability. Also, the term "scaled" waste is used, but not defined until later in the chapter. The term is unclear.

Pages 3-31 to 3-38, Table 3.3-1. Is this lengthy table needed? All of the

information is repeated in later tables, and without the apparent errors that have crept into this table. There are at least two errors. First, the design inventory for Am-241 in CH-waste is given as four times less than the anticipated inventory (page 3-31). Later in the chapter (figure 3.3-3, tables 3.3-4/5), the anticipated inventory for CH-waste is given as 665,000 Ci. Second, the anticipated inventory of Pu-239 in RH-waste is given as being greater than the design inventory (page 3-35). Later in the chapter (table 3.3-7), the anticipated inventory is given as 1165 Ci.

Section 3.3.1 Inventory of radionuclides in contact-handled waste

Page 3-45. Table 3.3-4. It is unclear what the information presented on the line entitled "System Total" represents, or how the data were derived. A comparison with figure 3.3-5, suggests that this line should probably have been labelled "Total Design Inventory", and that all values are one column removed from their correct position.

Page 3-46. Table 3.3-5 (and Page 3-50, Table 3.3-6). The column entitled "Waste Unit Factor" should be defined. The term is not defined until much later in the chapter (page 3-61).

Section 3.3.2 Inventory of remotely handled waste

Page 3-50, Table 3.3-6. An additional column entitled "Total" should be added to this table, to facilitate comparison with the "PA Calculations Design 1990" column. Total design inventory seems to be about twice as great as that used in the PA calculations, implying that the PA calculations are not conservative. In fact, the inventory value used for the PA calculations (1,700,000 Ci) is also less than the total of stored and projected waste arising shown in table 3.3-7 (2,600,000 Ci).

Section 3.3.3 Radionuclide chains and half-lives

Page 3-53, line 40. Contrary to what is stated in the text, figure 3.3-7 (page 3-59) indicates that the total normalized activity is about 3% of the EPA limit (at 10,000 years after repository closure). The normalized activity of Ra-226 is less than 2% of the EPA limit. The most interesting aspect of the figure, however, is that the normalized activities rise steeply with time after about 2000 years, and are still rising steeply at 10,000 years. This begs the question of when does the total activity level off, and at just what level? Also, regulatory timeframe notwithstanding, how does

the temporal variation in activity after 10,000 years affect longer-term performance?

Section 3.3.5 Solubility

See the detailed comments on section 5.2 of Volume 1. In addition, it would be helpful here if the information presented in figure 3.3-8 (page 3-63) was also presented in the pdf and cdf form used for other parameters in this volume, as well as in the "box" form used for other parameters.

Section 3.3.7 Molecular diffusion coefficient

Page 3-69, Figure 3.3-10. The left- and right-hand axes should be reversed for consistency with other such figures presented in this volume.

Sections 3.3.8-3.3.10 Gas production

Page 3-71, line 20; Page 3-72, Figure 3.3-12; Page 3-80, line 20; Page 3-81, Figure 3.3-16. The presentation is unclear. The information presented on relative gas production rates from corrosion and from microbilogical degradation under humid conditions, should say relative to what (i.e., to the inundated rate). Also, why is a relative rate used, as opposed to an absolute rate? The former is calculated from the latter, and the latter would seem to convey more information.

Page 3-73, lines 24-25; Page 3-74, lines 17-18; Page 3-82, lines 13-20; Page 3-85. The units used here are expressed in terms of years, whereas elsewhere in these sections they are expressed in terms of seconds, making the discussion difficult to follow. The use of years on page 3-85 in section 3.3-10 is particularly unfortunate, because this makes cross comparison with the information presented in sections 3.3-8 and 3.3-9 unnecessarily difficult. Perhaps more importantly, it would be useful to present information on total (for the entire repository, or for one waste panel) estimated gas production rates by each of the three mechanisms in these sections, because the units used are different in the three sections.

Section 3.4 Parameters for Unmodified Waste Form Including Containers

Page 3-89, Table 3.4-2, line 24. The word "greater" should presumably be "less".

Section 3.4.1 Composition of CH-TRU contaminated trash (non-radionuclide/non-RCRA inventory)

The tables and boxes in this section should be thoroughly examined to improve their clarity and accuracy. Several examples are given below.

Page 3-91. The information presented in the summary boxes is incorrect. On lines 6-22, all of the values presented are an order of magnitude too great. In addition, the median values do not agree with those provided in table 3.4-6 (page 3-99). In this table, the volume fraction of combustibles is given as 0.403 (not 0.384), and the volume fraction of metals and glass is given as 0.368 (not 0.376). Finally, the reference to table 3.4-10 seems incorrect; table 3.4-6 is the correct table to reference. On lines 32 and 42, the reference to figure 3.1-3 seems incorrect. It is unclear what the source of the data is for the volumes of backfill and air in the repository.

Page 3-103, Table 3.4-7. This table also contains many errors, making it difficult to understand. On line 9, the units should be expressed as Gg (not kg). The summed mass of PVC (on line 38) does not agree with the two values on lines 21 and 28; the source of the error is unclear. On line 36, the total volume of waste is incorrect (too low) by a factor of one million.

Page 3-104, Table 3.4-8. Yet another problematical table. The derivation of the values is unclear and is not explained in the text or in the caption. In addition, on line 33, the total number of SWBs is incorrect (too low) by a factor of one million.

Page 3-105, Table 3.4-9. Yet another example of a table carelessly put together. On line 7, the units of volume are missing (i.e., m^3). On line 29, the reference to table 3.4-3 is incorrect; the correct reference is table 3.4-4.

Page 3-107, lines 13-21. The discussion presented here, on estimation of inventory accessed by intrusion boreholes, and on information presented in figure 3.4-11 is totally unclear and confusing. The logic is absent.

Page 3-111, lines 26-30. The discussion does not distinguish clearly the

differences between the information contained in columns 7 and 8 of table 3.4-10 (page 3-106). Neither does the table provide sufficient information to understand clearly how the information contained in these two columns was derived.

Page 3-112, Table 3.4-12, line 25. The data are not in the correct row. Do these data refer to the combination of polyethylene and PVC?

Section 3.4.4 Capillary pressure and relative permeability

Page 3-121, lines 5-7. The median value for the threshold displacement pressure and the lower limit of the range are reversed. In addition, the discussion indicates that a pressure of zero was assumed in the performance assessment calculations. How does this assumption correspond with the summary presentation in the box on this page (the distinction should be noted in the box)?

Section 3.4.5 Drilling erosion parameters

Page 3-128, line 30. The reference to figure 4.2-6 is incorrect. This figure shows the probability of drilling a borehole of specified diameters (not shear strengths). The referenced figure does not exist in the report.

Section 3.4.6 Partition coefficients for clays in salt backfill

Page 3-129. Same comments as given under section 3.2.4 (page 3-27).

Section 3.4.7 Permeability

Page 3-131. There is no discussion of the permeability of sludges in the drums. The mean permeability of a drum cannot be derived without this information.

Page 3-131, line 8. The *exponent* is wrong by ten.

Page 3-132, line 22. The reference to figure 3.4-8 is incorrect; the reference should be to figure 3.4-9.

Section 3.4.8 Porosity

Page 3-135. Despite (or perhaps because of) the ten pages of text that follow in this section, the derivation of porosities in the summary box remains unclear. Were they simply drawn from the paper of Butcher et al. (1991). If so, what is the point of the discussion?

Page 3-135, lines 7-8 (and in summary table 3.4-1, page 3-88) . The median and lower range values for porosity of combustibles have been reversed.

Page 3-144, line 9. The porosity estimates referred to are not shown "above"; reference should be made here instead to figure 3.4-10 on page 3-146.

Page 3-144, line 21. The reference to table 3.4-9 is incorrect. The porosity ranges referred to are presumably those from the summary box on page 3-135.

Section 3.5 Parameters for Salt-Packed Waste Form

No comments.

3.3.4 Chapter 4. PARAMETERS OF GLOBAL MATERIALS AND AGENTS ACTING ON DISPOSAL SYSTEM

Section 4.1 Fluid Properties

Section 4.1.1 Salado brine

Page 4-5, lines 22 and 27. Line 22 indicates that the range of the density measurements on six samples of Salado brine was 1224 -1249 kg/m^3, and line 27 gives a range of 1208-1255 kg/m^3 (used in the assessment). Where does the difference arise?

Section 4.1.4 Hydrogen gas

Page 4-15, lines 21-23. Almost the same information has been unnecessarily repeated one line later (on page 4-16, lines 4-5).

Pages 4-16 to 4-20. The discussion on hydrogen gas density is unclear. It does not appear that the information has been used to derive the density

values that appear in the box on page 4-15.

Page 4-21, lines 25 and 27. The information on hydrogen viscosity is unnecessarily repeated on these two lines.

Page 4-25, Figure 4.1-6. The right-hand axis (mole fraction for hydrogen solubility in brine) is incorrect: the numbers provided do not agree with those tabulated in the boxes on pages 4-23 and 4-25.

Section 4.1.5 Drilling mud properties

Pages 4-28 to 4-31. It is unclear how the discussion relates to the values of viscosity and yield stress given in the box on page 4-26. Page 4-31, lines 16-23 indicate that the values on page 4-26 were derived from the work of Pace (1990). What is the point of all the discussion?

Page 4-28, line 7. The referenced figure (1.6-2) does not exist in the report.

Page 4-30, Figure 4.1-8. The figure is totally unclear. It contains too much information and little of it is self-explanatory or is properly explained in the text. The caption also provides no useful information.

Page 4-32, Figure 4.1-10. The units of pressure (Pa?) along the bottom axis are missing.

Section 4.2 Human-Intrusion Borehole

Section 4.2.1 Borehole fill properties

Page 4-39, Figure 4.2-3. The figure is incorrect. The units on the bottom axis are wrong by many orders of magnitude. The median value of permeability does not agree with that contained in the box on page 4-35. In addition, the left- and right-hand axes should be reversed for consistency with other figures presented in this volume.

Section 4.2.2 Drilling characteristics

Page 4-43, Figure 4.2-6. The figure seems to be incorrect: the range of diameters given in the figure (approximately 0.29-0.52 m) does not agree with that presented in the box on page 4-42 (0.27-0.44 m).

Page 4-44, lines 29 and 34. The two references to figure 4.2-6 are incorrect.

Section 4.3 Parameters for Castile Formation Brine Reservoir

Page 4-50, Figure 4.3-1. What is the "Disturbed Zone" of Borns et al. (1983)? This should be defined.

Section 4.3.1 Analytic brine reservoir model

Page 4-57, line 49. The value of 20 m^3/Pa is incorrect; the assumed maximum bulk storativity discussed elsewhere is 2 m^3/Pa.

Page 4-59, Figure 4.3-5. The figure is unclear; most of it (e.g., the various Qs) is undefined, either in the text or in the caption.

Section 4.3.2 Numerical brine reservoir model

Page 4-60. It is unclear how the permeabilities of intact and fracture matrix in the boxes were derived. They are not in agreement with the values quoted in summary table 4.2-1 (page 4-33), in contrast to suggestions in the text. Also, on page 4-61, line 2, it is indicated that a permeability of zero was assigned to the intact Castile matrix.

Page 4-61, line 6. Cross references within section 4.3.2 to sections 4.3 and 4.3.2 [sic] are confusing and seem incorrect.

Page 4-64, line 49. This line has been repeated by mistake at the top of page 4-65.

Section 4.4 Climate Variability and Culebra Member Recharge

Page 4-66, Equation 4.4-1. The various parameters in this equation are not defined until page 4-71. The equation can be safely omitted here.

Page 4-77, Equation 4.4-2. Some of the parameters in the equation need to be defined (e.g., the h's).

Page 4-78, lines 13 and 20. The recharge amplitude factor has been defined earlier as "Am" (not "r"). Also, the lower bound is Am=0 (not 1).

3.3.5 Chapter 5. PARAMETERS FOR SCENARIO PROBABILITY MODELS

Section 5.1 Area of Brine Reservoirs

Section 5.1.1 Area of Castile brine reservoir below WIPP disposal area

Page 5-3, line 35. "Anticlinal" is misspelled.

Page 5-3, line 41. The reference to figure 5.1-1 is incorrect. The reference should be to figure 5.1-3.

Page 5-3, line 47. The reference to figure 5.1-2 seems incorrect. The reference should be to figure 5.1-3.

Page 5-3, line 48. The text here provides a value of 45%, whereas the table referred to (5.1-1, page 5-6) suggests that a value of 40% would be more appropriate (at -200 m maximum elevation).

Page 5-4 and 5-5. Figures 5.1-2 and 5.1-3. These figures are meant to be inspected together, but this is extremely difficult because they are presented at different scales and figure 5.1-2 is in terms of depth whereas figure 5.1-3 is in terms of elevation (below sea level). This distinction alone was difficult enough to decipher. In addition, units are lacking on both figures and the axes are undefined.

Page 5-6. Table 5.1-1. The table caption and column headings refer to maximum depths, whereas the values provided seem to be in terms of elevation (below sea level).

Page 5-12, line 9. Grammar. "Were" should be "was".

Page 5-13, lines 25-26. Vital information on the geological controls on brine reservoir locations is provided. This information should be considered much earlier in the discussion.

Section 5.1.2 Location of intrusion

Page 5-15, lines 4-8. There is confusion between the location of the intrusion borehole for transport modelling, and the location of the borehole for input to the source term. For example, the number of boreholes and the activity levels of waste were sampled parameters, yet the single borehole location for transport does not even fall within a disposal area of the repository. This distinction and the reason for it should be clarified

throughout the text of all volumes.

In addition, the reference to figure 3.1-2 is unhelpful, as the borehole location is not clearly shown. The only evident indication in this figure of a possible intrusion location is a tiny black dot with defined coordinates. If this is the assumed location, say so; if not, indicate clearly where the intrusion occurs.

Section 5.2 Human-Intrusion Probability (Drilling) Models

Section 5.2.1 Drilling rate function

This section presents the argument for the range of values used in the assessment for lambda, the drilling rate function. The range was assumed to extend from 0 to the EPA Appendix B recommended upper bound, with a uniform distribution. However, the justification for using (nonconservative) values less than the EPA upper bound is lacking. In the absence of information to support a lower value of λ, it would be more conservative to assume a constant drilling rate function equal to the EPA upper bound.

3.3.6 Chapter 6. SUMMARY OF PARAMETERS SAMPLED IN 1991

Page 6-6, line 21. The number 13 is incorrect. It should be 15.

Page 6-6, line 39. It is unclear from the information presented here what has been done in the performance assessment with respect to sampling on solubility limits. The correlation between solubilities of different radionuclides was referred to in Chapter 3, but no evidence for the correlation was presented, nor was sufficient detail provided to justify the summary information provided in this list.

4 References

ERC 2091. Sixth Circuit. 1986. Ohio v. EPA, U.S. Court of Appeals, Sixth Circuit. 23 ERC 2091 - 23 ERC 2097.

Bonano, E.J. and Wahi, K.K.. 1990. Use of performance assessment in assessing compliance with the containment requirements in 40 CFR Part 191. NUREG/CR-5521, SAND90-0127.

Charles, D. and McEwen, T. J.. 1991. Radiological consequences of drilling into a deep repository for high level waste. Intera Sciences Report, I2466-1, Version 2, prepared for the Swedish National Institute for Radiation Protection.

OECD/NEA. 1992. Systematic approaches to scenario development (A report of the NEA Working Group on the identification and selection of scenarios for performance assessment of radioactive waste disposal). OECD/NEA, Paris.

Robinson, P., Roberts, D. and Sinclair, J.. 1991. Comparative study of sampling methods. Presentation at Twelfth Meeting of NEA/PSAG (Paris, 12th-14th November 1991).

IG3091-1
Addendum 1

REVIEW OF THE 1991 WIPP ASSESSMENT (SAND91-0893)

ADDITIONAL COMMENTS

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31st March 1992

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Review of the 1991 WIPP Assessment (SAND91-0893) Additional Comments

Volume 3: Reference Data

Section 2.6.10 Partition coefficients and retardations

Partition coefficients are vitally important to the performance assessment, and the underlying basis for selected values should, therefore, be presented clearly and in sufficient detail for an independent reviewer to assess the effectiveness of the selection process. Such a presentation has not been achieved in this section.

The main criticism lies in the absence of any experimental data included in support of recommended values by any of the three experts. Such data, when available, should be directly accessible to the reviewer, who should not have to rely on examining source references. For example, the statement is made on Page 2-102 (2nd paragraph), that the recommended K_d cdfs are "considered to be realistic in light of available data", yet these available data are not provided, either in support of the recommended K_d values, or to illustrate the paucity of data overall. Some background is discussed in Novak's September 4, 1991 memorandum, but this level of detail is insufficient, particularly when recommended cdf values are "subjective estimates only". At least the recommendations which Siegel provides include references and some detail on his selection process. It is ironic, therefore, that his values have been excluded from the "panel's" selected partition coefficients.

The basis for excluding Siegel's recommendations is not clear. It appears from the text (Page 2-108) that exclusion is due to non-agreement of Siegel's values with those of the other two experts, Dosch and Novak, and/or the use of a different methodology for deriviation of the cdfs. We agree that, in such circumstances, combination/aggregation of all three sets of data is not recommended; however, the decision that 'the majority should rule' as a means of selecting final values (implied by the text) requires greater justification than is provided here.

It is unclear why Siegel's approach is any less valid than that of the other two experts, especially when the available data are obviously sparse. In addition, the upper bounds on K_d provided for each element by Dosch and Novak suggests that these K_d values reflect sorption processes which include precipitation, in which case the assessment is not valid for the true thermodynamic K_d parameter. Is this what is meant by Novak in his memorandum (September 4, 1991) that the "K_d model . . . may have limited applicability to the WIPP Culebra system" and that the resultant cdfs could be rendered "inadequate"? If not, what do these statements mean? It does suggest at least that Novak has some reservations with the selection process.

Additional comments

1. For Ra and Pb, the cdfs presented in Novak's memorandum (Tables 1 and 2) for rock matrix and fractures do not differ by a factor of 10 in the case of the other elements. However, in tables 2.6 8 and 2.6 9, the factor of 10 difference is maintained. This inconsistency should be corrected.

2. A clear statement (or table) is recommended in this section to define reference conditions, i.e., water composition, pH, Eh conditions (values or ranges of values) for which cdfs are being provided.

3. A clear statement of the sorption processes for which K_d is being estimated (K_d model?) should be included early in this section.

4. Page 2-102, end of 3rd paragraph: the statement "more thorough description of Novak's values is provided in Appendix A of this report" is misleading, as no additional details are provided other than the actual recommended values

5. The way in which the recommendations of Dosch and Novak were "averaged" is not specified and should be discussed.

6. Page A-102 (Novak's September 4 memorandum), 2nd paragraph: some detail or discussion of the basis for selecting chemical analogues is advisable, when discussing sorption processes, possible complexation, and sorbing species.

Conclusion

We agree with the statements that cdfs for K_ds "do not substitute for actual data", and that "additional studies should be performed to quantify the potential for radionuclide retardation". We recommend that efforts be made during experimentation to identify and distinguish precipitation from sorption (isotherm measurements).

In addition, because of the uncertainty in the meaningfulness of both the process for deriving cdfs and the cdfs themselves, we suggest that this area would benefit from the use of independent expertise outside the WIPP performance assessment program.

1992 PERFORMANCE ASSESSMENT REPORT

COMMENTS AND RESPONSES

EPA REVIEW OF VOLUMES 4-5

Department of Energy
Carlsbad Area Office
P. O. Box 3090
Carlsbad, New Mexico 88221

JAN 24 1996

Larry Weinstock
Office of Radiation and Indoor Air
U.S. Environmental Protection Agency
401 M. Street SW
Washington, DC 20460

Dear Mr. Weinstock:

Enclosed is the Carlsbad Area Office's (CAO) response to your comments on Volumes 4 and 5 of the 1992 Performance Assessment (PA). Hopefully, these responses will assist you with any questions that may not have been fully answered during the Technical Exchanges. The CAO hopes that you will find these responses helpful in your understanding of the specifics of the 1992 PA.

We would like to extend our gratitude to you for your comments on the 1992 PA. Your comments will assist us in developing a better customer oriented product. The responses to your comments on the 1992 PA may not necessarily reflect the exact approach that the CAO will embark upon in the upcoming performance assessment for the Waste Isolation Pilot Plant Compliance Application, because the CAO is in the process of finalizing a management plan for the structure of the Certification Compliance Application.

If you have any questions regarding this response, please contact George T. Basabilvazo of my staff at (505)-234-7488.

Sincerely,

James A. Mewhinney

Dr. James A. Mewhinney
Compliance Team Leader
Office of Regulatory Compliance

Enclosure

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RESPONSES TO COMMENTS FROM
THE U.S. ENVIRONMENTAL PROTECTION AGENCY
ON VOLUMES 4 AND 5 OF
THE PRELIMINARY PERFORMANCE ASSESSMENT FOR THE
WASTE ISOLATION PILOT PLANT
SAND92-0700/4 AND SAND92-0700/5

EPA Comment 1. Scenarios
While much work has gone into the identification and screening of scenarios, we agree with the document that current treatment of scenarios is incomplete. As presented in the 1992 Performance Report (Volume 2, Figure 4-1) only four scenario combinations were modeled, and more scenario combinations need to be considered and modeled for 10,000 years.

The "base case" or the undisturbed scenario and disruptive scenarios need to include events outside the Land Withdrawal Boundary that may effect repository performance. For example, the performance assessment should consider effects of human initiated activities such as oil, gas, and injection wells around the Land Withdrawal Boundary. It is possible that such activities may increase releases from the repository, even if no borehole penetrates the repository itself. For example, your staff has postulated that an injection well south of the Land Withdrawal Boundary could affect the Culebra. Other potential effects of human-initiated events could include local dissolution of salt, as has happened in part of the Delaware Basin in Texas. In addition, the cumulative effect of multiple intrusions on radioactivity releases due to intrusions and base case releases need to be summed.

The 1992 PA states that effects of potash mining (i.e., subsidence) will be considered in future analyses (scenario TS). We agree that the effects of potash mining should be considered; indeed, all potential effects of the mining should be explored, such as connections between boreholes. This should include the effects of potash mining both within and around the Land Withdrawal Boundary.

We also agree that you need to consider the effects of water withdrawal wells (scenario E3) in the Culebra. The 1992 PA document provides very little information on this scenario, but we would suggest that the water quality is not as an important consideration for the purposes of the containment requirements (191.13) as it is for individual and groundwater protection requirement analyses. This is because it is possible for Culebra water to be used for non-drinking purposes, and this use may (or may not) have an effect on flow in the Culebra. Also, if a well penetrates a contaminated plume, then more radioactivity could be brought to the accessible environment. We do not know how significant the impact of these scenarios will be,

but we believe that they should be examined. Additional scenario topics are addressed in the attachment.

Response. *The CAO's current approach to scenario development is described in two documents that have been published more recently than the report on the 1992 PA:*

> *(1) The Position Paper that was prepared during the Systems Prioritization Method (SPM), entitled: "Scenario Development for Postclosure Performance Assessments of the WIPP: Input to Systems Prioritization and Project Technical Baseline"; and*
>
> *(2) The draft Compliance Certification Application (DCCA) (DOE, 1995).*

These documents present a systematic reevaluation of scenarios since the 1992 PA exercise in order to be as complete as possible. The CAO assumes that future exploratory drilling (within or outside the controlled area) that does not intersect the repository can be eliminated from performance assessments on the basis of low consequence. Thus the effects of a well penetrating a contaminated plume outside the controlled area can be eliminated on the basis of low consequence. Work is underway to evaluate the adequacy of this assumption and additional material in support of low probability and low consequence screening decisions will be included in future drafts of the Position Paper and the final compliance certification package.

EPA Comment 2. BRAGFLO and SANCHO Relationship

Salt creep-closure of the repository rooms and the interactions of the waste and brine are topics that need to be more closely examined. The repository horizon rock mass is deformable and permeable, but the current modeling is not able to take this into account. Separate codes look at deformation and fluid flow. It is our understanding that SANCHO calculates creep closure while BRAGFLO separately calculates fluid flow. SANCHO does not consider the rock mass to be a permeable, porous solid, while BRAGFLO does not consider the rock mass to be deformable. We believe that the physical coupling between fluid flow and deformation needs to be improved because the current method by which data from SANCHO is used in BRAGFLO is suspect enough to cast doubt on the results from the two codes. We suggest that the incompatibility be investigated. You may want to examine the possibility of modeling fluid flow and pressure effects (deformation) simultaneously within one code or in two codes which pass information to one another.

Response. *Sandia National Laboratories (SNL) has completed a detailed study of coupled mechanical deformation-fluid flow codes for performance assessment (PA) since the 1992 PA. This study evaluated the strength of the coupling between brine and/or gas flow into or out of the disposal room, the various methods of coupled analysis and reasonable numerical solutions for PA calculations. Several coupled methods have been implemented for detailed testing: (1)*

the porosity surface approach with the porosity surface calculated by either SANTOS or SPECTROM 32 (2) a coupled flow-mechanical analysis using PHENIX to interface the code for room closure with the code for fluid flow and room pressure at each time step. This approach incorporates the dependence of gas generation on brine availability into the analysis; (3) three-phase flow approximations; and (4) a theoretical model with true coupling of deformation to pore mechanics, including interbed fracturing.

The first two methods have been documented in published reports [Butcher and Mendenhall, 1993; Larsen memorandum in Volume II, Appendix G of the SPM Position Paper "Disposal Room and Cuttings Models White Paper for Systems Prioritization and Technical Baseline"]. The results of the three-phase flow calculations will be published in the near future. The theoretical model is still in development.

All work to date indicates that the porosity surface method is sufficiently accurate for PA calculations and it is therefore being used for all PA calculations.

EPA Comment 3. Culebra Groundwater Model

The Culebra Member of the Rustler Formation has been identified as one of the major potential pathways to the accessible environment. We have concerns and questions about how the Culebra transmissivity field is being modeled and the resulting ground-water travel times.

Alternative conceptual models and computer algorithms can be applied to the existing data to produce different interpretations of the transmissivity fields than those used in the current performance assessment. Indeed, Sandia National Laboratory and their contractors have used different models that have produced different results. The current estimate of ground-water travel times to the boundary of around 15,000 years (with a range of 9,000 years to 32,000 years) appears to be quite high, relatively to previous estimates. Using data from some of the wells in the southern section of the WIPP site, other reasonable approaches could produce travel times that are shorter by several thousand years. Perturbations to the repository/Culebra system (e.g., pressurized brine from the repository or Castile Formation that enters the Culebra at a faster rate than that currently modeled) could produce even faster travel times. Since this is such an important topic, we are considering holding a workshop, in which we would invite your experts and outside experts to further explore this topic. Our comments on this topic are further discussed in the attachment.

Response. *The WIPP project has established a formal program to build confidence in conceptual models and the associated PA analyses by broadening the involvement of outside experts and stakeholders in the PA process and by revising and updating the SNL QA Program for computational activities. WIPP's formal program includes the following activities: (1) involving the international community in hydrologic model development, verification and validation through the INTERVAL programs of the NEA; (2) preparing a series of PA*

calculations (the '91 PA, the '92 PA, the DCCA and the CCA) which show the progression of conceptual models and technical data. The results from these PA analyses have been or will be reviewed by the EPA, stakeholder groups, the NAS and by the international community through the NEA to increase confidence in the PA calculations; (3) involving all of the stakeholders in preparation of the final CCA; and (4) involving regulatory agencies and stakeholder groups in the SPM process.

Transmissivity fields are calculated from the field data using whole-rock porosity values, resulting in high ground-water travel time predictions (ranging from 9,000 to 32,000 years). In performance assessment, the conservative approach of calculating the transmissivity fields using the much smaller fracture porosities is implemented. This approach results in travel times predictions that are much lower than the range cited, some as low as hundreds of years.

The spatial variations in transmissivity are implemented by numerically generating realizations conditioned on observed head and transmissivity values using the pilot point technique (La Venue and RamaRao, 1992). Multiple realizations are generated and sampled on to address the uncertainty associated with the transmissivity field. This approach has been extensively reviewed.

EPA Comment 4. Inventory Estimates and Waste Analyses

The presentation of the inventory and the types of waste to be disposed at WIPP needs improvement. We have attempted to conduct analyses using the inventory numbers provided in the Appendix of volume 3, but the description of how the inventory was used in the analysis is unclear and incomplete. With the explanation on the inventory given in the Performance Assessment report, it is possible to calculate a range of curie levels between 650,000 curies and 36 million curies. While neither of these activity levels is realistic, the fact that they can be derived from information provided in the PA points to the need for a better discussion. This is a crucial topic because release limits will be based on the information presented in the application. It will be important for DOE to provide clear and accurate documentation of the origin of the inventory estimates. In addition, there should be an analysis and discussion of the potential interactions between the hazardous waste constituents and the radionuclides.

Response. *Since the 1992 PA, the CAO has continued to refine and update the transuranic (TRU) and mixed waste inventories that are destined for disposal at the WIPP. The latest data on the TRU waste disposal inventory are presented in the Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report (WTWBIR) [DOE, 1995]. The WTWBIR inventory data are derived from information provided by the TRU waste generator/storage sites. The WTWBIR inventory data are the basis for the PA in the DCCA and for all subsequent PA analyses.*

The release limits given in Volume 3 of the 1992 PA used the waste unit factor of 1.814×10^7 Ci from the 1991 PA (SAND91-0893). The referenced memo by Peterson (Preliminary Contact Handled (CH) Radionuclide and Nonradionuclide Inventories and Remote Handled (RH) Radionuclide Inventory for Use in 1992 Performance Assessment, October, 28, 1992) gives 11.74×10^6 Curies. Because the discrepancy was small, the same number was used for the 1992 PA as for the 1991 PA. This number was then multiplied by an applicable release limit requirement for each radionuclide to yield the waste unit factor that is then used as the normalization factor for the release limits.

In accordance with 40 CFR Part 191, Appendix A, Note 1(e), the waste unit factor includes alpha emitters with half-lives longer than 20 years (Cm-244 with a half-life of 18.11 years is included because it decays to Pu-240). CCDFs, however, are calculated using the entire radionuclide inventory given in the referenced tables and therefore include radionuclides in addition to those in the waste unit factor.

The CAO also has an ongoing program to investigate the interactions between hazardous waste constituents and radionuclides. For example, extensive testing has been performed at the Idaho Nuclear Engineering Laboratory (INEL) to determine the concentrations of gas-phase volatile organic compounds (VOCs) in TRU waste containers. This effort included the measurement of VOCs in 66 drums of TRU waste at INEL and at the Rocky Flats Environmental Technology Site and simulated waste experiments coupled with VOC transport model development to predict drum headspace VOC concentrations [Connolly et al., 1995].

EPA Comment 5. Institutional Controls

The current performance assessment assumes active and passive institutional controls will be in place to deter human intrusion. The performance assessment assumes no intrusion for 100 years after the repository is closed, and credit is taken for a reduction of drilling rate due to passive controls. However, the performance assessment does not provide details on the nature of either active or passive controls. In future analyses, DOE will have to provide detailed information on the active and passive institutional controls it plans to use and justify any credit taken in the quantitative analyses. The Compliance Criteria (40 CFR 194) will further address the topic.

Response. *DOE recognizes the significance of active and passive controls to deter human intrusion. The performance and associated assumptions for institutional controls are discussed in detail in Section 7, Assurance Requirements, of the DCCA. In the future, the CAO will respond to the requirements of 40 CFR 194 through the final Compliance Certification package, which will be submitted in December 1996.*

EPA Comment 6.
Although the document presents a wealth of information regarding radionuclides, in some instances the document ignores related issues pertaining to RCRA-hazardous constituents. Including hazardous constituents in the PA is important because the presence of hazardous constituents could have an effect on the ability of radionuclides to migrate out of the repository. The presence of RCRA-hazardous constituents and their effects on the radionuclides must be addressed.

Response. *The 1992 PA addressed the requirements in 40 CFR 191 for long-term isolation of radionuclides from the accessible environment; it did not consider RCRA. The integration of RCRA requirements into the PA process is discussed in the response to EPA Comment 7.*

EPA Comment 7. Improvements need to be made in modeling gas generation, RCRA-hazardous constituent transport, and radionuclide and RCRA-hazardous constituent concentrations. Furthermore, a comprehensive RCRA-based risk assessment could be performed (using model results) to assess the risk to the public from RCRA-hazardous constituents. Such an assessment, although not required (but of the type requested by the NAS WIPP Panel), would provide additional support to the NMVP.

Response. *The DCCA represents an integrated, comprehensive package that addresses the long-term requirements of RCRA and 40 CFR 191 using a consistent PA methodology. The Project Technical Baseline (PTB) documents the data and models that will be used for evaluating compliance with the long-term requirements of RCRA, 40 CFR 191 and 40 CFR 194. The PA calculations for the DCCA are based on existing or best-estimate data from experimental programs and on the most current estimates of the TRU waste inventory. Computational models and codes used in performance assessment will be the same for the two standards where appropriate; differences in regulatory performance measures will cause computational models to differ in some cases.*

The CAO intends to comply with all requirements of RCRA, 40 CFR 191 and 40 CFR 194. Any decisions about future activities with regard to the NMVP must await review and discussion of the DCCA by the EPA and stakeholders.

EPA Comment 8.
The undisturbed PA scenario to date does not address potentially critical issues such as the impact of anhydrite fracturing, room closure, gas transport, impact of nearby mining, and the lower shaft seal threshold permeability. These issues need to be modelled and analyzed, not only in a segmented fashion, but also in an interrelated fashion concurrent with "worst-case" gas generation scenarios.

For example, the undisturbed scenario is constructed in such a way that it does not evaluate the potential for any mining activity occurring at or near the Land Withdrawal Act (LWA) Boundary. Such mining might impact WIPP (within 10,000 years) while not physically intruding into it. Discussion of the RETSOF commercial salt mine (discussed in detail in the technical comments) suggests how severe the impact could be.

Response. *The undisturbed scenario for the DCCA includes the geological characteristics and fluid properties of the Salado and Non-Salado, including anhydrite fracturing, the rock mechanics of room closure, gas generation processes, and seal permeability. 40 CFR 191 requires probabilistic modeling and specifies reasonably expected not "worst case". However, "worst-case" is included in the distributions used in the probabilistic modeling.*

The DOE believes that disturbances of the disposal system caused by mining activity outside the controlled area need not be evaluated in the undisturbed scenario (see response to Comment 1).

EPA Comment 9.
The undisturbed case scenarios modelled to date exclude potential impacts of mining, at least in part under the assumption that 40 CFR 268.6 excludes consideration of any unnatural or human intrusion occurrences. The 1991 Performance Assessment states "The RCRA applies only to undisturbed performance." (Volume 6, page 2-5; SAND91-0893/6.) These positions have been maintained in the 1992 Assessment, and no developed mining scenarios are included.

While the PA does state that the "effect of subsidence of potash mining will be added in future PAs" (Volume 1, Chapter 4, page 4-2, line 15), the degree of expected emphasis on this scenario varies throughout the PA. For example, a potash mining scenario is identified in the 1992 Summary of Screened Events and Processes (Volume 2, pages 4-6 and 4-7) as being "retained for consideration," but apparently has not been investigated. Volume 1, Chapter 3 (page 3-11) states that consequences of potash mining outside the WIPP boundary "...will be addressed in future analyses when a three-dimensional model for regional groundwater flow is available."

Several factors suggest expansion of this approach. The following paragraphs explain reasons to adopt an emphasis on potential impacts of potash and other resource (e.g., salt) extraction in the final PA.

Since any nearby potash mining would most likely occur in the McNutt zone, above the repository level but still within the Salado formation, it is unlikely that direct "intrusion" would occur. However, the long-term effects of mine subsidence might include significant increases in fracturing, porosity and permeability at distances far from the mined zone, which

could reach the WIPP Controlled Area, or even the waste panels themselves. Salt and chlorine production might involve massive room and pillar or other typical shaft and drift operations at or below the repository elevation. These scenarios may be appropriately investigated under either—or even both—"undisturbed" and "human intrusion" conditions. (Undisturbed conditions would include long-term effects of nearby mining, without direct penetration of panels.)

Operators of a mine of this type would be likely to perform horizontal exploratory drilling to determine the extent and characteristics of the resource. This is a direct waste panel intrusion scenario similar to oil and gas drilling.

The 1991 Sandia report mentioned above, "Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant" (SAND90-3063 UC-721) provides reasons to extend the consideration of potential intrusions (or perturbation of "undisturbed" conditions) beyond the oil and gas drilling scenarios evaluated to date. The paper includes estimates of the current market values of mineral resources inside the "controlled area" of the WIPP (a circle of radius 5 km), such as salt, chlorine, potash and magnesium. These values are all greater than the value estimated for oil and gas (combined) within the WIPP controlled area. The value of magnesium is estimated as two thousand times, and potash twenty times, the oil and gas value.

Three potash mines are currently in operation within 10 miles from the WIPP, and the "...nearest economically exploitable potash reserves are 1 km (0.6 mi) from the waste panels..." (1992 PA Volume 1, page 2-4). There are no existing or planned regulations or legislation which would prevent the future expansion of these or other new mines up to the WIPP Land Withdrawal Act boundary, which is at minimum 2414 meters (7916 feet) from the closest (south) edge of the repository.

The Expert Panel report quoted above also noted that the potential impacts of mining at or near the WIPP site were the greatest of any scenario considered, but were discounted on the basis of the interpretation of Appendix B of 40 CFR 191. (Scenarios with impacts greater than oil and gas drilling were excluded from the final conclusions.) This has led to inclusion of statements in the 1992 PA which are directly at odds with the Expert Panel's report, e.g., "...exploratory drilling...has been demonstrated by past analyses...to be the only event likely to lead to radionuclide releases close to or in excess of regulatory limits" (Volume 1, page 4-5). The statements which cite the Expert Panel report (e.g., Volume 1, page 5-4) do not mention the panel's discussions of the probability or potential impacts of mining.

Another reason to reconsider a near-WIPP mine scenario is a specific current example of "worst case" mining impact. A commercial salt mine (RETSOF) near Rochester, New York is a large (11 square miles) room and pillar operation which has supplied much of the east coast with road salt for many years. An unconfined aquifer overlies the mine, which is about 1,100 feet below the ground surface. In mid-March of this year, a portion of the mine

collapsed, leading to massive uncontrolled inflow of water (estimated at 14,000 gallons per minute) and widespread subsidence which extends to the ground surface. Efforts to plug fractures which provide water flow paths have so far been futile. If the effort is abandoned, most of the mined zone is expected to collapse due to pillar dissolution. In addition to surface damage (a small town is within the probable 11 square mile collapse area), the predictable results of this event will include dramatic increases in porosity and permeability of the overlying "disturbed rock zone," relatively rapid future dissolution of huge portions of the salt formation, and groundwater contamination.

Economic motive exists for future extraction of salt, chlorine, potash and magnesium resources in the near vicinity of the WIPP, according to the Expert Panel on Human Intrusion, even if oil and gas drilling is more likely to occur in the short term. Mining may involve construction of large diameter injection/withdrawal wells and/or access shafts and drifts, pumping of significant quantities of mine water or extraction solution, and placement of large quantities of removed minerals and water on the ground surface. The Final PA could include evaluation of the effects on the WIPP of such mining.

A final reason to place greater emphasis on the mining scenarios is the ready availability of numerous three-dimensional groundwater flow models. The absence of such a model is the only specific reason given in the 1992 PA (Volume 1, page 3-11) for not including any mining scenarios. The document provides no explanation for the difficulty in finding and applying such a model. Instead, an entirely new 3-D version of the 2-D BRAGFLO model is being written, especially for PA purposes (Volume 5, page 2-4), and the new model "...should be practical by next year" (i.e., 1993). The need for such a new, customized program is unclear.

German investigations of potential radioactive waste disposal sites (in the Gorleben salt dome) have used a 3-D flow and transport model for at least 5 years (Bundrock, G. and H. J. Engelmann, "Groundwater Aspects of High-Level Radioactive Waste Disposal," in *Recent Advances in Groundwater Hydrology*, American Institute of Hydrology, 1989). The International Groundwater Modeling Center in Golden, CO distributes several three-dimensional flow and transport models which are in wide use, such as MODFLOW and SOLUTE.

Response. *The DCCA and the Scenario Position Paper present a systematic reevaluation of scenarios since the 1992 PA. The CAO assumes that future exploratory drilling (within or outside the controlled area) that does not intersect the repository can be eliminated from performance assessments on the basis of low consequence. Work is underway to evaluate the adequacy of this assumption and additional material in support of low probability and low consequence screening decisions will be included in future drafts of the Position Paper and the final compliance certification package.*

DOE believes the reference to the RETSOF mine is inappropriate as no unconfined aquifer capable of massive inflows of waste exist above the WIPP facility.

Promulgation of 40 CFR 194 will provide criteria for certification of the WIPP repository to 40 CFR 191, possibly changing some of the guidance in Appendix C of 40 CFR 191 under "Inadvertent Human Intrusion into Geologic Repositories". The features, events and processes (FEPs) relating to oil and gas resource extraction and potash mining are still retained for evaluation and have not been screened out. These FEPs will be analyzed and included in the final compliance certification package, if appropriate.

EPA Comment 10.
The focus of surface release scenarios is limited to solid "cuttings" (including waste particles and spallings) removed from waste panels penetrated by boreholes (Volume 1, Section 4.1.2 and Volume 2, page 4-13). However, some of the model runs resulted in waste panel pressures much greater than lithostatic (Volume 4, Figures 5.2-1 and 5.2-11) at the time of intrusion. Volume 1 (page 4-6) states that Volume 4 will contain preliminary analyses of the potential for releases by discharge of brine at the surface both during drilling and after plug degradation, but such analyses were not found. Volume 2 (Section 4.2.3.2) and Volume 4 (Section 5.2) include only two types of releases to the accessible environment: cuttings deposited on the surface; and brine flow into the Culebra Formation. The solubility of gas in the brine is assumed to be negligible by the PA (Volume 2, Chapter 7, Page 7-5, line 4). This is inconsistent with existing experimental and theoretical data for gas solubilities in water and brines and may be a key means of gas transport outside the WIPP unit boundary as pressure increases in the repository. Gas mixtures which contain hazardous constituents should also be considered.

Response. *This comment covers several issues which require individual discussion. Repository pressure exceeding lithostatic pressure arose in the 1992 PA because models for fracturing or fracture inflation at high pressure had not been incorporated into the PA models at that time. Models for fracture behavior are under development.*

Volume 1 does indicate that preliminary analyses relating to the potential for release by discharge of brine at the surface are discussed in Volume 4. Actually Volume 4 makes only very brief reference to this possibility. The preliminary analyses were not complete when Volume 4 was compiled and it was not possible to change the already published statement in Volume 1. Investigation of intrusion releases is ongoing, with several different mechanisms under analysis.

The discharge of brine and other release mechanisms at the surface are being investigated in later studies.

The volume of gas that can be dissolved in the brine at the pressures under consideration is far less than the volume of gas that will remain in the gas phase. The assumption of zero solubility is the worst case for purposes of computing repository pressurization as the driver for brine migration out of the repository (for either disturbed or undisturbed conditions). In the 1992 PA, the main emphasis was on whether brine would reach the unit boundary. Development of models for addressing concentrations and transport of hazardous constituents is currently underway.

EPA Comment 11.
The intrusion model is based in part on the assumption that the intruding drilling technology will be "comparable" to current technology (Volume 2, Chapter 2, page 2-51). However, the modeled intrusion scenarios exclude typical casing through water-bearing zones (e.g. the Culebra) and do not account for the immediate, short-term effects of sudden increases in downhole pressure, such as would be encountered by drilling into a waste panel. If the surface casing was not equipped with blowout preventers, large volumes of both gas and brine would likely be expelled. Assuming blowout preventers were in place, continued drilling may require circulation of contaminated brine up the hole along with cuttings. Therefore, the intrusion scenarios should account for some volume of brine from a waste panel reaching the surface (mud pit) along with cuttings.

Response. *The discharge of brine and other release mechanisms at the surface are being investigated in later studies. The current status of models for these discharge and release mechanisms is presented in Section 4 of the SPM Position Paper: "Disposal Room and Cuttings Models White Paper for Systems Prioritization and Technical Baseline".*

EPA Comment 12.
With regard to the undisturbed scenario, the impact of gas transport has not been modelled. EPA believes that additional analyses of gas and brine migration may show a potential for gas migration, and therefore recommends that this modeling effort be included in the proposed no-migration petition that DOE intends to submit next year.

Response. *The current PA analyses use BRAGFLO, a two-phase computer code, to simulate the flow and migration of gas and brine in the Salado formation.*

EPA Comment 13.
A related concern is the absence of modeling for potential transport of colloidal contaminants in the brine and cuttings which escape the waste panel. Although solubility of some hazardous constituents, plutonium and other potential brine contaminants is very low, colloids are known

to provide a mechanism for transport of these elements or compounds (at Hanford, INEL and Los Alamos) at concentrations above solubility limits.

Response. *Experimental programs in actinide solubility and radionuclide transport, including the influence of colloids, are currently being performed by the WIPP Project. A snapshot of these experimental programs, including the colloidal studies, is presented in the Actinide Source Term Position Paper. The results from these studies will be incorporated into the PA for the final compliance certification package.*

EPA Comment 14.
Figure 1.5-1 (Volume 3, Chapter 1, page 1-48) shows the location of the Gnome Project Site, but it is not explained in the text. The PA needs to provide an explanation on the Gnome Project and assess its potential impacts on the WIPP.

The Plowshare Project Gnome Test site is approximately six miles southeast from the WIPP LWA boundary (Volume 3, Figure 1.5-1). The map identification is the only reference to this site found in the PA. According to Benford, et al, in "Ten Thousand Years of Solitude?", a report included in SAND90-3063.UC-721 *Expert Judgment on Inadvertent Human Intrusion into the WIPP*, a fission device was detonated at the site at a depth of 1250 feet. A separate report indicates that the yield was 5 kilotons (TNT equivalent) and the year of the test was 1965.

The site deserves further consideration in the future (final) PA for several reasons. The most obvious reason is the (slight) similarity of the blast cavity to either future mines, or to the WIPP itself. Lessons available from the Gnome site may be applicable to the WIPP in several ways. Since almost no information has been provided about the Gnome site in the PA documents, the related comments are stated in the form of questions:

How large was the cavity created in the Salado by the blast?

Has any follow-up monitoring been performed to determine the current status of the cavity? (For example: is it completely collapsed or porous rubble-filled; creep effects in the last 29 years; disturbed rock zone (DRZ) extent; characteristics of the water/brine which presumably fills it; has ground surface subsidence occurred, etc.)

What are the major differences between the Gnome cavity and possible future mine cavities?

Has any monitoring been performed to determine impacts on groundwater flow and transport of radionuclides or hazardous constituent metals? (Could K values for the Salado and Culebra be verified through such investigations?)

Is there any potential impact on the WIPP, such as increased porosity and permeability in the Salado and overlying formations which could extend from the Gnome site to the WIPP LWA boundary in 10,000 years?

Response. *The Project Gnome Test Site is approximately 6 miles southwest from the WIPP land withdrawal boundary. The fission device was detonated at a depth of 1,184 feet, with a yield of 3 kilotons, and took place December 10, 1961.*

The cavity created in the Salado Formation by the blast produced a sphere with an average diameter of 124 feet.

The cavity did not collapse because it was backfilled with slurried muck from the excavation; therefore there are no means of measuring creep effects. There are no measurable subsidence effects because of the backfill. Further, there is no indication of brine above the rubble-pile. The extent of the DRZ was approximately 350 feet from the detonation point in the upward direction and remained entirely within the salt beds.

The Gnome cavity was formed by internal pressures which forced the rock outward. The DRZ resulting from the Gnome blast was a result of rapid shock wave compression and subsequent relaxation. In projects such as the WIPP, which involve excavation, the DRZ is a result of slow stress release and is not shock-related. Given the differences in mechanism and time scale, it will be very difficult to extrapolate data on the DRZ of the Gnome cavity to the WIPP repository.

The site has been monitored since the test. EPA takes samples once per year and no radioactive contamination has been found, nor have any fission products from the detonation. Tracer tests with non-sorbing isotopes were done before the blast but, because they are non-sorbing, no information is provided on retardation. Sandia continues to make use of the hydrologic information being obtained from the Gnome monitoring wells.

There is no potential for effects from the Project Gnome blast to impact repository performance because the strong shock waves from the Gnome detonation did not extend beyond a few hundred feet and permanent effects did not extend the six miles to the WIPP site. For additional information, see the report that summarizes the reentry, Project Gnome, Carlsbad New Mexico 1961: The Environment Created by a Nuclear Explosion in Salt.

EPA Comment 15.

The modeling performed to date has not taken into account the probable fracturing of anhydrite strata (especially Marker Beds 138 and 139) which may be exposed to high gas and/or brine pressures (perhaps well above lithostatic) during the first several hundred to two thousand

years after closure. This phenomenon has been experimentally demonstrated at the WIPP, and the Agency believes that this modeling is necessary to determine whether repository pressurization has been overstated, or if lateral gas migration has been understated.

Response. *A model for interbed fracturing has been incorporated in the current PA system and will be used in all future analyses. It is not clear whether or not pressure in fractures will change the transport to the accessible boundary, although as soon as pressure in the repository exceeds the threshold pressure in the interbeds, flow into the interbeds begins. Flow is expected to begin between 12.1 MPa and 13.1 MPa.*

EPA Comment 16.
The analyses and model runs for potential flow through the lower shaft seal do not appear to include consideration of the interface of the seal materials with the host rock (salt). The seal itself theoretically performs very well (no gas flows through the seal in 10,000 years), even though gas reaches the bottom of the seal in many cases. However, the interface may be of greater concern, because of natural inhomogeneities, stress relief and repressurization, and other factors such as differences in compressibility and moisture retention, in the surrounding rock as compared to the seal materials.

Within the seal itself, it is stated that the backfill component of the lower shaft seal will achieve final permeabilities comparable to the Salado formation host rock after consolidation due to creep occurs; however, no calculations or modeling is presented directly in the PA to support this assumption (Volume 3, Chapter 3, page 3-14). Specifically, the PA does not provide experimental data to support the assertion that the crushed salt will compact to 95% of initial density within 100 years (Volume 2, Chapter 2, page 2-48, line 19), and that the associated permeability design objectives will be met.

Response. *Experimental data and calculations to support the assertion that the crushed salt will compact to 95 percent of initial density within 100 years have not been included in the 1992 PA report. The experimental data and calculations to support these assertions are found in Nowak, et al. (1987) and Sjaardema, et al. (1987).*

Scoping model calculations for the reconsolidation of crushed salt in WIPP shafts are presented in Nowak, et al. (1987). The scoping model calculations supported an estimate that the reconsolidating crushed salt in the lower third of a WIPP shaft is likely to meet the criterion of acceptability for shaft sealing in less than 200 years.

Further work by Sjaardema, et al. (1987) refined the time required for salt consolidation to 95 percent of intact WIPP salt density through the use of a constitutive model for crushed WIPP salt. The experimental results of modeling the consolidation of crushed salt, to be used as backfill in shaft and drift configurations, is shown in Table 4.1 (page 39) of the report.

EPA Comment 17.
The final extent of the DRZ after 100 years or more of reconsolidation is unknown, because the exact behavior of the salt as it creeps into waste rooms, compacts the waste and backfill, and reseals fractures in the outer DRZ, cannot be precisely predicted. The PA suggests that the final limits of the DRZ, and parameter values characterizing the DRZ, should not be inferred from contemporary measurements (Volume 3, page 2-32). However, the single "disturbed permeability" parameter value used in gas and brine flow calculations was taken from a selection of actual "nonfar-field" measurements (Volume 3, page 2-37) which may not reflect either current or future larger-scale (bulk, i.e., fracture) permeability. This parameter was not sampled or varied in the 1992 BRAGFLO model runs, apparently because it was ranked low in previous sensitivity analyses. The DRZ may deserve further attention, based on the wide range in existing permeability data—as much as 5 orders of magnitude larger than the value used in BRAGFLO—and the DRZ thickness values used in this model.

Response. *Using a contemporary "non far-field" disturbed permeability value for the DRZ in the gas and brine flow calculations, as opposed to a value that would reflect disturbed permeability in the future, provides an idea of the maximum flow quantities expected in the system. As creep closure heals the DRZ, the DRZ permeability should decrease with time.*

There is a wide range of existing permeability data (as much as 5 orders of magnitude larger than the value used in BRAGFLO) and DRZ thickness values used in characterizing the zone. Further work to refine the DRZ characterization has focused on incorporation of fractured interbeds into the new PA model. The current PA uses permeabilities several magnitudes higher than the near-field values, so the analyses use conservative values for the DRZ.

EPA Comment 18.
The PA does not evaluate the impact of Room Closure relative to enhancement of gas pressure and concomitant anhydrite fracturing. In Volume 2, Chapter 7, pages 7-7 and 8, it is implied that the total pore space is constant and as such, room closure (creep) is not taken into account. However, the text also states that room closure is accounted for "in an indirect way" (Volume 2, Chapter 7, page 7-5). Please explain that process.

Response. *The 1992 PA did not address the possibility of fracture formation or inflation of pre-existing fractures in anhydrite layers. Models are being developed for this effect.*

Effects of room closure on gas pressure buildup were addressed. In Volume 2, page 7-8, lines 13 and 14, it is stated that the total pore space in the idealized, collapsed WIPP panel is constant. This is a post-closure condition. Also, the assumptions on pages 7-7 and 7-8 are specifically stated to be for modeling waste mobilization in the E1 and E1E2 scenarios.

High pressure gas in the repository will be released during drilling of intrusive borehole(s) or very early in the period after plug deterioration. Consequently pressure changes, and hence creep effects, are minor during waste mobilization and transport for these scenarios.

EPA Comment 19.
Consequence assumption number 5 (Volume 2, Chapter 7, page 7-8) states that the pore spaces of the idealized panel are fully saturated with brine at all times. In Chapter 4, page 4-18 of Volume 2, the last paragraph states that assumptions for the E1 borehole show "Brine flows from the waste into the E1 borehole exceed those into the E2 borehole only for those realizations in which total flow is small because the panel was not brine-saturated at the time of intrusion." Please explain the differences regarding brine saturation between the two assumptions.

Response. *The 1992 PA waste mobilization computations for the E2 and E1E2 scenarios concentrated on completely brine saturated conditions because this represents the most severe case for potential release.*

The sentence from Volume 2, page 4-18 quoted in the comment is identified (on page 4-18) as a summary of certain findings from the 1991 PA. Thus it does not contradict the assumptions given for the 1992 PA. The sentence in question is presented as part of a discussion explaining that in '91 it was determined that the E1 scenario always produces releases that are less than or equal to those for E2 except in cases where the release is small. Hence, in '92, separate waste transport calculations were not made for E1 (although specific probability of occurrence calculations were made for E1).

EPA Comment 20.
The document states waste characterization estimates used in the PA have the potential for large uncertainty (Volume 2, Chapter 2, page 2-47). Please provide clarification of waste characterization estimate uncertainties, and measures to reduce them (i.e., how will the waste estimates be reconciled with the projections made from the inventory required by the Federal Facilities Compliance Act?).

Response. *The WIPP TRU waste inventory characterization is largely based on process knowledge. The uncertainties will be reduced by verifying the waste categories using real-time radiography, head-space analysis, and some visual inspection. These verification requirements are defined in the Draft Transuranic Waste Characterization Quality Assurance Plan. The high efficacy of process knowledge in determining waste categories is discussed in the appendices to Chapter 2 of the Background Information Document for Proposed 40 CFR Part 194 (EPA 402-R-95-002).*

EPA Comment 21
Volume 3, Chapter 3 of the document presents the characteristics of the expected WIPP waste inventory. Radionuclides are addressed in detail, but RCRA-hazardous constituents are not provided.

Response. *All relevant information requirements outlined in the EPA's (1992) No-Migration Variance Petition (NMVP) guidance document (EPA-530-R-92-023) will be completed with the Phase II NMVP submittal in June, 1996. This relevant information includes waste code, hazardous properties, physical, chemical and biological characteristics, and waste characterization data. Parameter distributions and assumptions necessary for demonstrating compliance will be documented for the phase II NMVP (June, 1996). Some of this information has already been documented in the Hazardous Constituent Source Term Position Paper, the Phase I NMVP and the WIPP TRU Waste Baseline Inventory Report (WTWBIR).*

EPA Comment 22.
There are inconsistencies concerning discussions on waste inventories in the PA. For example, the RH-TRU inventory is based on 1990 Integrated Data Base figures of 5,300 m^3 over the WIPP design capacity of 6,784 m^3. The PA indicates that the waste generators partially fill the canisters with different volumes of waste and that the actual volume of waste would therefore be lower than the design capacity (Volume 3, Chapter 3). The PA should explain why the lower number was chosen rather than the higher.

The PA states that the inventory of RH-TRU was estimated using an "unknown" slurry mixture from Hanford to provide the isotopic distribution, without explanation (Volume 3, Chapter 3, page 3-28). Please provide the rationale for choosing this waste as representative, and the hazardous constituents and/or characteristics of this waste.

Response. *The DOE is generating a consistent TRU waste inventory for the WIPP, based on information from DOE generator sites. This document, the WTWBIR, defines the TRU waste inventory available for WIPP and provides a description of the physical and source characteristics of the waste, the potential gas-generating waste material parameters, EPA hazardous waste codes, and existing and estimated future inventories. Each site reports the total stored radionuclide inventories (both CH and RH) at the site level and uses these data as the basis for estimating projected radionuclide inventories. The PA for the DCCA and all future PA analyses will be based on the inventory defined in the WTWBIR.*

EPA Comment 23.
A preliminary safety assessment could be prepared for long-term consequences to the public health as a result of the RCRA hazardous constituents of the wastes emplaced in the WIPP (Volume 1, Chapter 1, page 1-2). Although Monte Carlo analysis is part of a widely used risk

assessment methodology, the Monte Carlo analysis performed for this PA stops short of performing a RCRA-based risk assessment for the RCRA-hazardous constituents (Volume 1, Chapter 4, page 4-1). As stated earlier, a comprehensive RCRA-based risk assessment. (as outlined by the NAS WIPP Panel) would provide a stronger basis for future public review, hearings, and regulatory decisions.

Response. *The CAO intends to comply with all requirements of RCRA, 40 CFR 191, and 40 CFR 194. Any decisions about future activities with regard to a RCRA-based risk assessment must await review and discussion of the DCCA by the EPA and stakeholders.*

EPA Comment 24.
The document states the logarithmic K_d distributions used in the PA required a number of subjective assumptions derived from an internal expert judgement process (Volume 3, Chapter 2, page 2-92). Please provide the rationale and procedure for using subjective judgement.

Response. *This expert panel was assembled because of the limited data available for the distribution coefficient, K_d, in the Culebra. The expert judgment process included 3 Sandia personnel who participated in individual elicitation sessions to develop the probability distributions regarding radionuclide retardation in the Culebra. The use of logarithmic K_d distributions is considered realistic, based on the evaluations of the expert panel with the data that were available at that time.*

The use of expert panels includes several steps to derive realistic distributions. First, applicable experimental information is evaluated to ascertain potential applications to the development of distribution coefficients for the Culebra. Once these values are determined to be applicable, an elicitation process is conducted. This process includes meeting with other experts in the field as well as other principal investigators and performance assessment personnel. The proposed parameter values are reviewed and the judgments, along with associated rationales, are discussed for implementation into the PA models. The results of the elicitation are then documented and reviewed by the elicitor of the meeting for accuracy.

EPA Comment 25.
The PA does not integrate several key codes into the CAMCON system, namely BRAGFLO, SECOTP2D and CUTTINGS. This is not a computationally efficient approach and is prone to QA breakdowns given the heavy emphasis on manual data entry transfers and analysis. This approach also limits the modeling from the standpoint of the model's ability to handle complexities and the shear number of scenarios that can be modelled.

Response. *The CAMCON system has been expanded to include the BRAGFLO, SECOTP 2D and CUTTINGS codes since the 1992 PA was performed.*

EPA Comment 26.
The second paragraph in Volume 2, Chapter 4, page 4-7 indicates that two scenarios selected for modeling in the screening procedure, TS (potash mining outside the waste panels) and E3 (drilling of water withdrawal wells), were not evaluated. No justification for these omissions was provided.

Response. *Please see the responses to Comments 1 and 9 regarding the current approach to scenario development, including the evaluation of the potential effects of such FEPs as potash mining and water withdrawal wells on repository performance.*

EPA Comment 27.
Gas transport of RCRA-hazardous constituents is not modelled or investigated, although several model runs indicate the possibility of gas migration beyond the LWA boundary. The potential for transport of hazardous constituents needs further attention to address 40 CFR 268.6 compliance concerns. Evaluation of transport mechanisms is necessary before soil concentrations can be estimated at given locations (e.g., the LWA boundary).

Response. *As noted previously, the 1992 PA addressed the requirements in 40 CFR 191 for long-term isolation of radionuclides from the accessible environment; it did not consider RCRA.*

The Hazardous Constituent Source Term Position Paper outlines the conceptual model and assumptions required for modeling gas and liquid phase hazardous constituents. The Salado Formation Fluid Flow and Containment Position Paper discusses gas and liquid phase contaminant transport. Evaluation of all transport mechanisms is an explicit requirement identified in the EPA (1992) NMVP guidance document (EPA-530-R-92-023). All relevant aspects will be considered for the final compliance certification package and NMVP.

EPA Comment 28.
In general, more discussion on Latin Hypercube Sampling (LHS) is needed. For example, the procedure for excluding variables is not defined nor is documentation presented to justify the exclusions. Also, the impact of uncertainties introduced by the LHS needs to be evaluated. The PA does not define a procedure for determining the sampling error of LHS-derived estimates. Also, the current PA LHS procedures treat the uncertain input variables as uncorrelated without adequate justification.

Response. *These issues will be considered for the final CCA.*

EPA Comment 29.
The PA does not include a detailed discussion of Quality Control and Quality Assurance (QC/QA) issues such as the procedures covering experiment execution, computation development and code execution (Volume 1, Chapter 3, page 3-17, line 41). The document makes no distinction between Quality Control (i.e., data validation, checking of calculations) and Quality Assurance (system validation; checking overall model methodology against actual measurements). For example, the PA notes that CAMCON "automatically handles quality assurance during the calculations" (Volume 2, Chapter 1, Page 1-3, line 30), but provides no discussion as to how this is achieved. Also, the PA provides no indication of efforts to assess the quality of parameter data used in modeling. Parameter sheets should be supported with a statement of data quality and/or a statement of confidence level for each parameter. For example, in some cases expert panel judgement and investigator knowledge are used in lieu of actual data (Volume 2, Chapter 2, page 2-39 and Volume 3, Chapter 3, pages 3-1 to 3-7). No procedure is provided for how data from these sources are reviewed from a quality and level of confidence standpoint.

Response. *The WIPP project has established a formal program to build confidence in PA analyses by broadening the involvement of outside experts and stakeholders in the PA process and by revising and updating the SNL QA Program for computational activities.*

The revised QA program includes implementing procedures to control the entire PA process, including: (1) selection of applicable conceptual models to represent processes and events, (2) development of computer codes (software) to represent these conceptual models, (3) development of numerical values for parameters associated with the respective models for both discrete-valued parameters and distributed-value parameters, (4) configuration control of software during the overall development and implementation process, and (5) operational control of the overall analysis process.

The WIPP Project is currently developing documentation for all PA codes. This documentation includes an expanded description of the CAMCON operating system in a report that will be published shortly (Rechard, 1995).

Finally, Sandia has a formal QA procedure for the use of expert judgment (Rechard et al., 1992). Further refinements of this QA procedure can and have been incorporated into WIPP Procedure No. PAP06, Use of Expert Judgment Panel Quality Assurance Procedures.

EPA Comment 30.

Wherever possible, the use of expert judgement and investigator judgement should be replaced with actual data. This is particularly important for those parameters considered important from the standpoint of sensitivity and uncertainty analyses. For example, distribution coefficients (K_d) should be based on experimentally justified data and not based solely on expert panel judgement (Volume 2, Chapter 2, Pages 2-38 to 2-39).

Response. *The CAO agrees with the need to base PA calculations on as strong a site-specific date base as possible. However, because of the generalization processes inherent in probabilistic PA, it must be noted that there is always some level of expert/professional judgment involved in extrapolating any experimentally derived data base over a period of 10,000 years and to different spatial scales.*

The recently completed SPM-2 iteration has served to refocus the experimental programs on those parameters and programs which are important to compliance. The SPM-2 results have highlighted the importance of distribution coefficients and colloids in the NonSalado, resulting in a renewed emphasis on laboratory and field testing programs in these areas.

EPA Comment 31.
The DOE has discussed in verbal presentations an INTRAVAL study of the Culebra model but presents none of INTRAVAL's comments in the PA itself and the impact of these comments on future PAs. Also, DOE has subsequently verbally identified a second INTRAVAL review of the Salado Brine model but has not provided any discussion of INTRAVAL's comments in the PA. Given the PA's heavy reliance on "expert judgement" and "investigator judgement" unbiased, third-party expert input would be useful to assure the overall PA quality is consistent with international efforts.

Response. *The WIPP project has established a formal program to build confidence in PA analyses by broadening the involvement of outside experts and stakeholders in the PA process and by revising and updating the SNL QA Program for computational activities. The QA activities are described in more detail in the response to Comment 29.*

WIPP's formal program to build confidence in PA analyses includes the following activities: (1) involving the international community in hydrologic model development, verification and validation through the INTERVAL programs of the NEA; (2) preparing a series of PA calculations (the '91 PA, the '92 PA, the DCCA and the CCA) which show the progression of conceptual models and technical data. The results from these PA analyses have been or will be reviewed by the EPA, stakeholder groups, the NAS and by the international community through the NEA to increase confidence in the PA calculations; (3) involving all of the stakeholders in preparation of the final CCA; and (4) involving regulatory agencies and stakeholder groups in the SPM process.

EPA Comment 32. Disturbed Performance: Culebra Flow and Transport
Evaluation of the site must address the potential for climatic changes that could alter the long-term waste isolation capability of the site. The 1992 PA climatic modeling results indicate that climatic influences have little effect on the results, but the assumption of no recharge moving through the site should be reconsidered.

The vector plots, presented in Volume 4, Section 6 of the 1992 PA, suggest that almost no groundwater entering the model domain along the "recharge strip" reaches the WIPP Land Withdrawal Boundary because it is routed to the southwestern portion of the modeled area and exits through this fixed head boundary. An alternative approach that should be considered is to assume that the increased rainfall would make the Nash Draw region a recharge area rather than a no-flow boundary. The southwestern side of the modeled area could also be set as a recharge boundary. The effect of these changes would be to allow water from the "climatic recharge boundary" to reach the WIPP Land Withdrawal Boundary, unlike the current situation where almost no water from the recharge boundary is allowed to reach the site. These proposed changes to the model boundaries are supported by the problems encountered during the model calibration activities conducted by LaVenue (LaVenue 92), as well as by the inconclusive evidence as to whether the Malaga Bend and Nash Draw areas are acting as regional recharge or discharge boundaries.

Response. *We recognize the need to improve the modeling of recharge and discharge near the WIPP site under possible wetter climate conditions of the future. A three-dimensional model of flow in the saturated zone of the entire groundwater basin (that is, the area bounded by groundwater divides) is being used for analysis and FEP screening [Corbet and Wallace, 1993]. This model will be used to evaluate the effects of future wetter climates, along with other features, events, and processes affecting recharge.*

EPA Comment 33. Contaminated Brine in Marker Bed 139 (MB-139)
A human intrusion borehole that misses a waste storage room could intercept the anhydrite Marker Bed 139 (MB-139) in an area where it contains contaminated brine.

If contaminated brine is located beneath or in the area surrounding a waste panel that is intercepted by a human intrusion borehole (E1, E2, or E1E2), some of this brine would be brought to the surface with the drilling mud and thereby contribute to the release to the accessible environment. This has not been included in SNL's human intrusion scenarios to date but it should be examined along with the general category of brine being brought to the surface during drilling from waste storage rooms or Castile brine reservoirs. This will require a distribution of values for several parameters, including brine pressure, permeability in MB-139, and the level of contamination in the brine.

The modeling in Volume 4 predicts that the area in MB-139 containing brine that has been in contact with wastes could be large. An estimation of the level of contamination of this brine has not yet been made. A human intrusion borehole away from the waste rooms and into the contaminated portion of MB-139 would be a new scenario since E1, E2, and E1E2 apply only to those boreholes intercepting waste storage rooms or drifts. This borehole would bring additional quantities of radionuclides either to the surface or to the Culebra Aquifer.

Response. *The effect of an intrusive borehole intercepting contaminated brine in MB139 has not yet been addressed in the investigation of human intrusions. Clearly, the results of such a scenario will depend heavily on the permeability, storage capacity, and any retardation effects assigned to the anhydrite layer. Model development for assessing anhydrite behavior is currently underway. In addition, the volume of brine that might be released to MB139 may be modified by various engineered alternatives that are under consideration. Also see the response to Comment 1.*

The commentor also points out that brine brought to the surface during drilling would be a contribution to release in the E1, E2, and E1E2 scenarios. The continuing studies referred to in Comment 10 considered the conditions for release of contaminated brine during drilling. The conditions necessary for releasing significant quantities are rather restrictive. Furthermore, brine released during drilling would, in large part, be a subtraction from the amount of brine (or at least from the amount of contaminants) that would be available for release later in the other scenarios. Consequently, release of brine during drilling was not explicitly incorporated into the 1992 PA.

EPA Comment 34. Modifications to Existing Scenarios: Brine Flows to the Surface During Drilling

The E1E2 scenario should include the potential for contaminated Castile brine to flow to the surface.

Brine is present to some extent in the waste rooms even in the absence of an E1 scenario. Current modeling of the E2 scenario (Volume 4 of the 92 PA) shows that in 20 percent of the realizations, there will be enough brine to provide a long-term flow into the Culebra Aquifer through an intrusion borehole. Thus, there should be sufficient brine and pressure for some flow to the circulating drilling mud and transport to the surface.

All intrusion boreholes intercepting a waste room are assumed to continue through MB-139. Brine in MB-139 immediately below the waste rooms is expected to be contaminated and would also be available for inflow to the drilling mud.

Response. *Please see the responses to Comments 10 and 33.*

EPA Comment 35. Modifications to Existing Scenarios: Plug Degradation
Present assumptions set the intrusion borehole plugs between the Culebra and the surface as perfect barriers against migration of brine to the surface. This assumption maximizes the quantity of brine that will be diverted into the Culebra for transport toward the accessible environment. It is unrealistic to assume these plugs will be any better than ones between the Culebra and the repository. Plug degradation should be modeled.

Response. *We assume that this comment refers to the arbitrary perfect plug that the 1992 PA placed above the Culebra to maximize flow to that unit. Degradation of the arbitrary perfect plug above the Culebra was not modeled in the 1992 PA because the intent in these preliminary analyses was to focus on possible releases through the Culebra and because the assumption that the plug does not degrade was a conservative assumption for the scenario. The 1992 PA assumed that other borehole plugs would degrade into material with properties similar to silty sand. This latter assumption was in keeping with the guidance in Appendix C of 40 CFR 191.*

More recent PA analyses for the DCCA do not use the arbitrary perfect plug and consider flow into units other than the Culebra.

EPA Comment 36. Shaft Seal Failure: Volume 4, page 4-7, line 40
DOE states that radionuclide transport is not modeled for the undisturbed case because releases will not occur into the Culebra. Seal failure is a distinct possibility. Has a failure of the shaft and other seal system been considered as an scenario occurrence?

Response. *Seal failure/degradation has been considered as an occurrence. Seal failure has been retained for further consideration prior to a final screening decision.*

EPA Comment 37. Synergistic Effects From Drilling: Volume 4, Page 2-16, Lines 1–4
DOE assumes that no synergistic effects result from multiple boreholes for disturbed scenarios other than E1E2. This implies that for scenarios E1 and E2, single boreholes into multiple panels is contemplated. The total release then would be determined by adding the releases occurring from each individual borehole. Does this mean that DOE is evaluating the effects of releases from multiple boreholes/panels in the E1 and E2 scenarios, rather than just from one borehole/panel? The PA needs to be clearer on the communication that occurs between panels during multiple intrusions.

Response. *Human intrusion scenarios in the 1992 PA assumed no communication between panels. Multiple intrusions into a single panel were modeled.*

EPA Comment 38. Loading management/Scenarios
There is no analysis of how various loading management schemes could affect potential releases. The assumption that the waste will be homogenized (to the same material properties and activity level everywhere in the repository) is used to simplify the analyses, but it would be useful to analyze scenarios in which it is assumed that the drums have the varying activity levels presented in Volume 3 (A-138). If the activity level in the drums and the number of drums is varied, then the release limits may be violated much more easily than the current PA analyses indicates.

Response. *The "varying activity levels" in Volume 3 refers to estimates of the curie content of drums and standard waste boxes. These estimates were used in the 1992 PA because of uncertainty about the final waste inventory. Cuttings releases were calculated for varying activity levels. Given uncertainty about brine flow through the waste, it was entirely appropriate to assume a homogenized waste form for dissolved concentrations. If future performance assessments demonstrate waste forms to be significant to compliance, then this issue will have to be reevaluated. If necessary, waste homogeneity could be assured through various engineered alternatives.*

EPA Comment 39. Uncertainty of Scenario Probabilities
The examination of the uncertainty in scenario probabilities for risk representation R_1 using a constant drilling rate presented in Section 8.1 of Volume 4 is restricted by the following assumptions:

1. A simple Poisson model with a constant rate parameter.

2. Multiplication of the maximum intrusion rate of 30 boreholes per km^2 per 10,000 years by a uniform random variable between 0 and 1 in the LHS procedure to simulate the sampled drilling rate.

3. Imposition of an intrusion rate of zero for the first 100 years.

4. Imposition of an intrusion rate of zero for the last 8,000 years.

The combined effect of these assumptions leads to a very narrow range of uncertainty for the probability of the "no intrusion" scenario, denoted as S(0,0). A summary of the analysis in Section 8.1, also corroborated by the data in Table 2.5-4, concludes that there is no more than a 50 percent probability that intrusions will occur, given these assumptions.

Probabilities far less than 50 percent may occur in individual sample runs due to assumption two. Presumably, the uniform random number assumption was included in previous PAs as an

attempt to ensure that 30 boreholes per km^2 per 10,000 years is the maximum possible intrusion rate for the simulation.

The use of assumption three is inappropriate because the report does not indicate the types of active institutional controls and their ability to reduce drilling.

Removal of assumption four dramatically increases the maximum possible probability of an intrusion to approximately 98 percent, as shown in Table 2.5-1. This would generate a box plot for the S(0,0) scenario in Figure 8.1-1 that is approximately twice as wide, and increase the upper range of uncertainty for the remaining "intrusion" scenarios. To show the full range of uncertainty in this figure, assumption four should be removed and analyzed for the 10,000-year regulatory period (this point is further addressed in EPA's January 1994 comments on the PA). The use of an intrusion rate of zero for the last 8,000 years is unacceptable.

The time-dependent drilling rate model replaces assumption one with a time-dependent Poisson process. Assumptions three and four are retained for this analysis, but assumption two is not. As a result, the range of uncertainty shown for the "no intrusion" scenario in the expert panel, time-dependent drilling rate model in Figure 8.1-1 is extremely narrow when compared to the constant rate model results.

Response. *The 1992 PA was not intended as a compliance application. Rather, its primary purpose was to provide interim guidance to the DOE about potentially important processes and parameters. Varying the intrusion rate allowed for an assessment of the sensitivity of the performance measure to changes in the intrusion rate. In fact, the intrusion rate was shown to be the single most important parameter in the analysis.*

Assumptions 1 and 3 are based directly on interpretations of regulatory guidance. Assumption 4 was simply based on resource and time constraints. We acknowledge that this approach should have been explained better.

EPA Comment 40. Distribution of Uncertain Variables

The definition of the joint distribution of the uncertain variables in the vector $\underline{x}$ Equation 2.1-4 (Volume 4, p. 2-3) should be defined as a multivariate distribution $f(x) = f(x_1, x_2, \ldots, x_k)$ if correlations between these variables are to be considered. The D_k appearing in the equation would then denote the marginal (subjective) variate distribution assigned to each variable. The distribution f(x) used in the analyses was constructed from the D_k under the assumption that most pairs of variables have zero rank correlation, while others have non-zero pairwise rank correlations.

It should be noted in the text that a large amount of uncertainty exists in the method of constructing of the multivariate distribution f(x) from the univariate distributions D_k. Uncertainty in the assignment of correlations has not been addressed adequately in the report. From the discussion, it appears that the marginal distributions D_k were assigned subjectively with no consideration of possible correlations, then the correlations were added later. Is this true? More information on the assignment of subjective distributions to variables with assigned rank correlations is needed.

Response. *Yes, it is true that the correlations were added later based upon the judgement of individual PIs. But it should be noted that very few correlations were used in the 1992 PA (see Table 3-1, Volume 4).*

EPA Comment 41. Disposal-Room Modeling: General Comments
A weakness in the disposal-room material modeling is the lack of a deformable, porous model. Contaminant transport via brine and gas flow from the site is a threat that could only be realized in the presence of porous, fractured rock (i.e., permeable strata). At the same time, pore pressure has a significant effect on room response. SANCHO lacks porous media modeling capability and does not account for the role of effective stress on strata deformation and possible failure. On the other hand BRAGFLO calculates fluid flow but does not account for deformation.

A consequence of the lack of porous media modeling capability is the inability to incorporate starting formation pore fluid pressures into an analysis (and pore pressure changes). Strata failure induced by repository mining cannot therefore be anticipated.

In view of the potential effects of disposal room excavation and subsequent deformation beyond compaction of backfill and waste within a room, the objective of disposal-room modeling needs to be broadened to include effects of deformation on fluid flow as well as the effects of fluid pressure on deformation. This objective cannot be achieved within SANCHO at present.

Response. *The coupling of flow and deformation effects in the disposal room modeling for the 1992 PA was, indeed, limited. Since the 1992 PA, the WIPP Project has investigated four computational approaches to coupling flow and deformation effects in the disposal room response. The WIPP Project also has ongoing work to model the formation of new fractures or the response of existing fractures to the buildup of gas pressure in the rooms. The new approaches for coupling flow and deformation effects in disposal room modeling are discussed in the responses to Comments 2 and 18.*

EPA Comment 42. Starting Conditions
The actual initial site conditions of stratigraphy, preexcavation stress state, rock mass properties, formation pressure and excavation sequence are seemingly ignored in most of the disposal-room analyses, although Butcher and Mendenhall state in SAND93a, pp. 3-1, that a modified stratigraphy and creep law (R-D model) was used in "all subsequent SANCHO calculations."

Response. *A superior capability of the models to match observed deformations at the site has been developed since the 1992 PA. This capability was achieved by introducing more detailed and complete treatment of the stratigraphy and the material properties, particularly creep models and the representation of thin seams.*

EPA Comment 43. Stratigraphy Ignored
The stratigraphy is largely ignored, ostensibly on the basis of prior analyses which suggested rather tentatively that the presence of various strata besides bedded salt did not have a large effect on disposal-room volume change (SAND 93a, Appendix A). However, analysis with stratigraphy showed that the presence of anhydrite beds changed the time for complete closure to 400 or 500 years from about 195 years. Comparisons at 100 years showed room volume changes of 75 percent without stratigraphy compared with 56 percent with inclusion of stratigraphy. In addition, thin seams modeled as slide lines had a pronounced effect on room deformation, in keeping with mining experience.

Response. *Since the 1992 PA, a more detailed representation of the stratigraphy, particularly the weak interbeds close to the repository level, has been introduced along with revision of the halite creep model, revised material properties, and representation of transient creep.*

EPA Comment 44. Disturbed Rock Zone
The DRZ concept is used explicitly in BRAGFLO where the extent of the DRZ is an input parameter. Since the DRZ is not actually calculated in any objective fashion, how is it determined and what are the consequences of the DRZ extent for BRAGFLO?

If the DRZ is important to performance assessment, then it should be an outcome of numerical modeling of mechanical and hydrologic responses which may be coupled both ways, each affecting the other. A specific equivalent material properties procedure for averaging the heterogeneous DRZ properties to an equivalent uniform zone is needed unless spatially dependent properties are used.

Response. *The DRZ in the underground facility has been characterized by three approaches: visual observation, geophysical methods, and in situ hydrologic testing (Borns, 1985; Bechtel National, 1985; USDOE, 1988). Geophysical studies have utilized seismic refraction, seismic*

tomography, surface wave analysis, electromagnetic (EM) methods, and direct current (DC) methods (Borns and Stormont, 1989; Borns et al., 1990; Holcomb, 1988; Jung et al., 1991; Pfeifer et al., 1989). These studies, when taken in conjunction with the in situ hydrologic tests, define a DRZ extending to a depth of 1 to 5 meters throughout the underground facility (Munson et al., 1995).

The air intake shaft (AIS) at WIPP has been well instrumented (Munson et al., 1992a) to assist in the characterization of the DRZ around the shafts. Further DRZ characterization in the form of permeability, as well as brine and gas flow testing in the AIS, is planned.

The DRZ extent is important because it provides a potential pathway for brine and gas migration. The BRAGFLO model uses Darcian flow to model brine and gas flow through porous and permeable media. BRAGFLO will be influenced by both the extent (thickness) and physical properties, such as porosity and permeability, within the DRZ (SAND92-0700/2; page 7-2).

Porosity and fractures within the DRZ will influence fluid flow and may provide gas storage volume. DRZ porosity is at the expense of porosity in the room. The issue is how much of it is squeezed out by closure, and whether it can reopen by gas pressurization. While porosity and fracture within the DRZ will influence fluid flow and other factors such as whether communication paths to anhydrite interbeds exist, these parameters are not expected to have much effect on the mechanical part of closure.

No simplified model of the DRZ is presently in closure codes and implementation of such a model would be a major effort. The reader is referred to the Position Paper "Rock Mechanics: Creep, Fracture, and Disturbed Rock Zone (DRZ)" for further discussion of this topic.

The present assessment of the DRZ's role in PA is that it is not important because most of the enhanced porosity is eliminated by closure by the time any substantial gas pressurization of the repository occurs; i.e., the DRZ is assumed to close up rapidly, and it is not an important part of the gas storage volume within and immediately adjacent to the waste (Butcher et al., 1995).

EPA Comment 45. Unclear Disposal-Room Modeling Features

The documentation on room modeling is extensive, but a great deal of information is relegated to memoranda, some of which are included in extensive appendices. These are helpful, but generally contain references to earlier work. The tabulation of parameters in Volume 3 of the 1992 PA was useful but not always complete in the sense that one could not determine whether a parameter of interest was determined by experiment or simply estimated on the basis of experience. For example, the importance of anhydrite bed response has become apparent, so the mechanical parameters that characterize anhydrite behavior are of interest. These are given in a memorandum in an appendix to Volume 3 of the 1992 PA (SAND 92c, pp. A-109,

A-124) along with a reference to the source of the data, but no information is given as to whether they were measured or otherwise determined. The same is true of slide-line mechanical properties. Slide-lines are apparently cohésionless, but it is not clear whether separation of the surfaces in contact is allowed. A simple diagram of the stratigraphy used and the corresponding rock properties should accompany each analysis of disposal-room behavior.

Response. *The reports for the 1992 PA were intended to communicate with a broad audience and we have followed the common practice in technical documents of using references to avoid overburdening the report with technical details. Nonetheless, efforts are being made to improve the presentation of data and guidelines have been established for referencing memoranda.*

EPA Comment 46. Gas Pressure in SANCHO

How is gas pressure actually used in SANCHO and related codes which do not have pore pressure capability? Presumably, the gas pressure is applied as a normal traction on the current disposal room free surface. However, what happens when contact is made between room surface and room contents (backfill and waste)?

Response. *SANCHO has been replaced with a related code named SANTOS. In both codes, the available void volume is computed as the difference between the room volume and the solid volume of waste and backfill in the room at each time step. Gas pressure is calculated from this void volume and the gas generation rate. This pressure is then applied as a normal traction on the disposal room surfaces. In SANTOS, a contact surface routine is used to reconfigure the disposal room surfaces and provide for stress redistribution when contact is made between the room surface and room contents (backfill and waste).*

EPA Comment 47. Porosity Surface

The porosity surface calculation in SANCHO and its incorporation into BRAGFLO needs a better explanation.

Response. *A detailed discussion of room closure modeling, including the porosity surface approach, is presented in the Disposal Room Position Paper (Butcher et al., 1995). Briefly, the SANCHO continuum mechanics code was used to make an extensive series of computations of waste (effective) porosity as a function of time and gas generation rate (which determines pressure history). These results were used to compile a "map" of waste porosity as a function of time and pore pressure (the "porosity surface"), which was then used in the porous media flow code, BRAGFLO, to determine waste porosity as a function of these variables. With the porosity surface approach, the effect of room closure is coupled to repository pressure and porosity in the BRAGFLO computation.*

EPA Comment 48. Modeling of Backfill
Another related question concerns the treatment of backfill and the inevitable air gap present between room roof and top of the backfill. Is this gap represented by "air" elements or how are the room contents—air gap, backfill, solid waste—represented in SANCHO? The mesh diagrams suggest air elements, but are they compressed to flatness before contact between roof and backfill is made?

Response. *For the SANCHO calculations, any air or gas in the disposal room is represented as a pressure on the boundaries of the halite or backfill; there are no zones or elements that represent the air (or gas). Within the SANCHO model, a contact surface (permitting sliding or separation, but transmitting compressive stress when contact exists) was used between the mesh in the intact halite and the mesh in the backfill. The initial condition was a separation corresponding to the height of the air gap. Gas pressure was applied as a normal traction on the halite and backfill surfaces. The meshes were free to come in contact and then separate again at later time if gas pressure was sufficiently high.*

EPA Comment 49. Fluid Pressure
Fluid pressure in formation void space, in pores and fractures, needs to be included in the constitutive equations describing (porous) solid deformation. Even in the purely elastic range, fluid pressure needs to be properly taken into account. Pore and fracture fluid pressure is essential to the determination of failure in non-salt beds; it is the effective stresses that should be used in a Druck-Prager yield condition, for example.

Response. *DOE is aware of the importance of fluid pressure in porous material response. Porosity in the halite is quite low. The mechanical properties for halite are drawn from measurements on bulk samples with pore fluid. Recent modeling with improved representation of stratigraphy, including formation specific material properties, and with an improved creep law that incorporates transient creep, has been successful in closely matching observed deformation in the excavated cavities at the site. Development of appropriate models for simulating failure in the non-salt beds is continuing.*

EPA Comment 50. Salt Mine Closure, Subsidence Analogs
Is there evidence that salt mines containing rooms and pillars of similar size close in 100 years or so? If so, it would be helpful to tabulate such observations in support of laboratory creep-rate data and calculated disposal-room closure times.

A survey of subsidence and the potential for caving in mines nearby, or mines in similar geologic settings, would also be helpful. Subsidence analyses would seem in order in any event. Such analyses should address the question of interbed fracturing, especially in the Rustler formation.

The effect of overburden removal from the generic, two-dimensional mesh is of interest. Although the effect on room closure may be small, it should examined to make sure. Any opportunity to remove untested assumptions, explicit or tacit, should be considered.

Test Case
Are there any mines in similar geologic settings where the model could be applied?

Response. *DOE reviewed data from various salt mines early in the WIPP Project. The difficulty with these data is that every case has its own unique features of local stratigraphy, hydrologic regime, and mine design, often with limited documentation. The time scale calculated for WIPP is not inconsistent with other sites in broad terms, but there are no easily comparable cases. At this point in time, a good base of high quality, precisely documented data have been accumulated for the excavations at the WIPP site, and these observations are viewed as the best data set for model validation.*

Consideration is currently being given to issues such as subsidence and the testing of as many modeling assumptions as possible.

EPA Comment 51. SANCHO/BRAGFLO Room Porosity Values (in Appendix B)
Room porosity values for BRAGFLO and SANCHO are different numbers. Appendix B to Volume 4 of the PA (performance assessment) describes the derivation of the relationship between the two porosities. This relationship is in error because it is based on the assumption of a constant volume of solids. In fact, iron and cellulosic wastes are consumed relatively fast in chemical reactions. These reactions are largely responsible for gas generation that, in turn, affects room closure and fluid flow about waste-filled disposal rooms. Whether this inconsistency is important not is unknown.

Response. *For the 1992 PA, the volume of waste solids (exclusive of pore volume) was held constant. Note, that the "consumption" of iron, which is a major part of the gas generation, involves conversion of the iron to various oxidized compounds; hydrogen is released, but the solids remain. Additionally, the chemical reactions referred to are dependent on brine availability. In a large number of realizations, the brine inflow is insufficient to "consume" these wastes.*

EPA Comment 52. Permeability and Porosity
Permeability of disposal rooms containing waste and backfill is presumably related to porosity, although it is not certain how permeability of disposal rooms is determined. While an average porosity for the heterogeneous room contents is useful for gas and brine storage considerations, it is not evident what permeability value of room flow control should be assigned.

The values that are obtained from SANCHO are total porosities, whereas, BRAGFLO uses effective porosities as input parameters. The importance of this is that effective porosities will always be lower than total porosities and will provide less storage within the matrix. If effective porosities had been used pressures would have reached higher levels and the migration potential would have been increased.

Response. *Permeabilities are discussed in Volume 3 of the 1992 PA (see also the response to Comment 130). Permeability and porosity were not coupled in the computations for the 1992 PA; permeability was held constant. Determining exactly what permeability behavior should be attributed to the waste after the material has been compressed and the waste is partially or completely degraded is obviously a difficult problem. However, sensitivity analysis has shown that results are not particularly sensitive to this variable. This is not surprising because the room is surrounded by regions having quite low permeability and flow path lengths much greater than the dimensions of the room. These regions therefore control the total transport process.*

Since the waste and backfill are initially unconsolidated material and retain substantial porosity even after compaction, total and effective porosity are expected to be very close.

EPA Comment 53. Specific Comments on Disposal-Room Modeling

Volume 4, Page 4-17, Lines 31 to 34:

This section states that additional SANCHO simulations are necessary to more adequately describe the deformation of halite when both brine and gas are considered. Such additional simulations would be advisable.

Volume 4, Page 4-23, Line 44:

Here it is stated that BRAGFLO uses a modified rock compressibility, but no rationale or justification is given. Please clarify why a modified rock compressibility is warranted.

Volume 4, Page 4-26, Lines 4 to 7:

This section states that the same sampled values of relative permeability parameters are used for halite, anhydrite, the transition zone, and the DRZ. Conceptually, this does not seem to be appropriate. Page 4-24, footnote 3 states that relative permeability is a function of saturation of the phase of interest. The degree of saturation of a media would depend on the media or rock type, type and amount of fractures and effective and intrinsic porosity. Such parameters would seem to have different values for the halite, anhydrite, transition zone and DRZ. Page 7-2 of Volume 2 states that relative permeability is the ratio of the permeability of the rock with the fluid at a given saturation to the permeability of the material when it is 100 percent saturated with the fluid. Again, such parameters would seem to have different values for different materials having different permeabilities. Please explain.

Volume 4, Page 4-26, Lines 10 and 11:
The parameter values for relative permeability are stated to be based on the surrogate materials identified in Section 2.3.1 of Volume 3 of the 1992 PA. Section 2.3.1 states that a low permeability sand was used to determine the relative permeability parameters of the halite and the anhydrite. Does this include the halite and anhydrite which comprise the transition zone and the DRZ? If so, please clarify the appropriateness of applying the same surrogate material to both the undisturbed media and the disturbed media The undisturbed halite and anhydrite should by definition have a much different effective porosity and permeability.

Response. *The responses to these four specific comments are as follows:*

(1) Since the 1992 PA was published, SANCHO was used to make an extensive series of computations of waste (effective) porosity as a function of time and gas generation rate (which determines pressure history). These results were used to compile a "map" of waste porosity as a function of time and pore pressure (the "porosity surface"), which was then used in the porous media flow code, BRAGFLO, to determine waste porosity as a function of these variables. A detailed discussion of room closure modeling, including the porosity surface approach, is presented in the Disposal Room Position Paper (Butcher et al., 1995).

(2) The reference to use of modified rock compressibility in BRAGFLO simply indicates that the code is formulated with compressibility defined as the relative change in porosity produced by a change in pressure (one over porosity times the partial derivative of porosity with respect to pressure, Equation 4.2-7 on page 4-23 of Volume 4), rather than the more common definition of compressibility (the partial derivative of porosity with respect to pressure) given by Equation 4.2-6 on the same page. The reference to this as a "modified" rock compressibility is not an ideal choice of terminology. No modification is made to the measured properties of the rock. The point is simply that the "compressibility" value input to BRAGFLO is not the same as the value that would be used in a code formulated with compressibility defined by Equation 4.2-6.

(3) Lines 4 to 7 on page 4-26 in Volume 4 are intended to indicate that the same relative permeability description is used for the halite, anhydrite, transition zone and DRZ for any single realization. There were no cases in which some of these regions were described using Brooks-Corey, while others were van Genuchten-Parker. The intrinsic permeability was different for each region and saturation was allowed to vary independently. The parameters for the relative permeability model were sampled independently for each material, but, for lack of more specific information at the time of the 1992 PA, the same ranges were sampled for all 4 regions.

(4) This does mean that, as indicated on lines 10 and 11 of page 4-26, the relative permeability characteristics of a low permeability sand were applied to undisturbed halite and anhydrite and to the transition zone and DRZ. However, as is stated on pages 4-8 through

4-11 of Volume 4, the halite, anhydrite, and DRZ intrinsic permeabilities and porosities were sampled over very different ranges. Please see EPA Comment 138.

EPA Comment 54. Disposal Room Modeling
Volume 5, Page 2-9, Table 2-1:
This table provides a list of the assumptions used in BRAGFLO for the Undisturbed Performance analyses. The information provided in the table appears to be a shortened version of the more detailed information provided in Volume 4, Chapter 4. No information is provided, however, regarding the assumptions used in SANCHO. As stated on page 2-1, of this volume, SANCHO is used to simulate halite creep and its modelling results are incorporated into BRAGFLO. Some of the assumptions of SANCHO, however, appear to be incompatible or inconsistent with the assumptions used in BRAGFLO. In addition, similar to BRAGFLO, the impact of the SANCHO assumptions are difficult to quantify. To not include the SANCHO assumptions in this table seems to negate their importance on the Undisturbed Performance analyses.

Response. *The recently published Position Papers and the DCCA contain expanded discussions of the assumptions and limitations for the current PA models. The need for more complete explanation of the impacts of modeling assumptions on compliance is noted for future code documentation and the final compliance certification package.*

EPA Comment 55.
Volume 5, Page 2-9, Line 25:
Please specify which "selected regions" are adjusted with respect to permeability and porosity.

Response. *Regions that are backfilled with crushed salt for sealing purposes had permeability and porosity adjusted to reflect the creep compaction of the seal.*

EPA Comment 56.
Volume 5, Page 4-18, Line 20:
Should this line reference Cell 4 rather than Cell 6?

Response. *The line in question does refer to Cell 4, not Cell 6.*

EPA Comment 57.
Volume 5, Page 4-50, Lines 1-3:
This sentence states that conditional on conceptual models and parameter distributions, creep closure modeling may not be necessary. The phrase "...conditional on conceptual models and

parameter distributions..." should be clarified. Information regarding the incorporation of SANCHO results into BRAGFLO (provided in Volume 4, Pages 4-15 through 4-18) should be referenced in this volume (either here or in Section 4.1). The application of SANCHO simulations into the BRAGFLO simulations is an initial attempt and, as stated on Page 4-17 of Volume 4, strictly applied only to the case where the pore space is occupied by gas, rather than where pore space is occupied by both gas and brine. Given the discussion of the inconsistencies between the SANCHO and BRAGFLO assumptions, it is not timely to make the statement that creep closure modelling may not be necessary.

Response. *The sentence in question appears in a section of text introducing the discussion of results from sensitivity analyses using a major excursion in closure characteristics (waste panel porosity set to the post-closure condition from time zero). The sensitivity analysis shows that even this very large (indeed, unrealistically large) excursion in the effects of creep closure had minimal impact on the results from the 1992 PA models for undisturbed performance. Both transport and closure modeling are being revised and expanded since the 1992 PA. The statement in the 1992 PA was intended to apply only to the status of the modeling as it existed at that time.*

EPA Comment 58. DRZ Zone Not Consistent in Scenarios
Volume 4, page 5-4, Figure 5.1-2 and Figure 5.1-3:
There should be a DRZ between the waste panel and the halite in the center of the panel model. The undisturbed case has the DRZ in this location and it seems it should also be in the disturbed case. Line 15, page 5-3 states that "a disturbed rock zone (DRZ) surrounding the waste-storage area" is not shown in the figure as described.

Response. *The portion of the DRZ at the radial boundary of the waste panel, between the repository and the halite, was inadvertently omitted from the referenced figure.*

EPA Comment 59. Conserving Void Volume
Volume 4, pages 4-13 to 4-23
The porosity conversion outline in Equation 4.2-2 and amplified in Appendix B seems unreasonable. What does it mean to conserve void volume while adjusting the porosity value in volume?

Response. *In both SANCHO and BRAGFLO, the porosity of a mesh element is the ratio of the pore volume to the total volume of the element. However, the mesh element volumes in SANCHO and BRAGFLO are not always the same. Even if the initial meshes are created so that the volume of elements are initially equal, the mesh for SANCHO deforms with time while the BRAGFLO mesh does not. The porosity for the cell in BRAGFLO that contains the*

repository is calculated so that BRAGFLO has the same total repository void volume (as a function of time and pressure) as that found in SANCHO.

EPA Comment 60. Creep Closure Effects
Volume 4, pages 5-18 & 5-33
It is our understanding (see earlier comments) that BRAGFLO does not actually account for creep closure but only implements the effects of creep closure passed by SANCHO which does account for creep closure. This effect in SANCHO is passed to BRAGFLO by an adjustment of the porosity values calculated. As stated on page 4-18, line 7 the ultimate effect of this implementation is unknown? Could this effect the implementation of the creep closure to make it a "pseudo-closure" in BRAGFLO that is incorrect?

The present implementation of creep closure appears to be so incomplete that the conclusion, "Overall, dynamically modeling creep closure results in only minor differences compared with using a fixed porosity," is the only conclusion DOE/SANDIA can make. Could the "minor differences" be a result of the limited ability of the '92 code? It seems inappropriate to draw such conclusions from an admittedly faulty model (page 4-18).

Response. *It is not really correct to say that BRAGFLO does not "account" for creep closure. BRAGFLO does not compute closure. Creep closure is accounted for in BRAGFLO by using a time and pore pressure dependent repository porosity, which is drawn from the results of calculations made with SANCHO. This is a real closure, not a "pseudo-closure". Although it may not be identical to the closure that would be computed by a fully coupled flow and deformation code, at least it is a reasonable approximation in terms of transient behavior.*

As discussed in the response to EPA Comment 57, sensitivity analysis with a fixed porosity, which produced a large excursion in the transient repository pressure, showed only minor differences in release volumes. It is certainly possible that this result stems from limitations in the ability of the 1992 PA codes, but it is unlikely that it is the limited coupling of the closure computation that is primarily responsible.

EPA Comment 61, Performance Assessment Representations Used in 1992
There appear to be some small discrepancies in the numbers presented throughout Tables 2.5-1 through 2.5-4. In Table 2.5-2, for example, using 3.78×10^{-4} for the constant drilling intrusion rate, the probability of zero intrusions in 9,900 years is calculated as
$\exp\{(-9900)(0.126)(30)/10000\} = 0.0237019$ using a simple hand-held calculator.
Tables 2.5-2 (column with footnote b, line 17) and 2.5-4 (column with footnote b, line 18) report 0.02378, which is a small difference, but it seems too large to be accounted for by rounding error alone. Similar comments apply throughout these tables.

In Tables 2.5-1 and 2.5-3, using a time-integrated intrusion rate of 0.99 per km^2 per 10,000 years as shown in Figure 2.5-1 (1 at 10,000 years minus .01 at 100 years), the probability of zero intrusions may be calculated as $\exp\{(-9900)(0.126)(0.99/10000\} =$ 0.883828. The tables report 0.8703. These discrepancies may be removed by one of the following steps: report fewer digits in these tables; refine the calculation procedure to eliminate this annoying discrepancy; or explain the calculation procedure better, if the values in the tables are accurate.

Response. *Thank you for bringing these discrepancies to our attention. In the future, the tables will be checked for consistency and/or fewer significant figures will be reported to eliminate this problem.*

EPA Comment 62.

Use of Median Values for Variables Not Sampled

In the evaluation of sensitivity of the model to variations of a given input parameter, the other variables in the model are held to constant values as the parameter in question is varied. WIPP procedures call for holding the other variables at their median value rather than at the expected value. Please explain the reasoning for this decision.

Sampling Error for Estimated CCDFs

The following statement appears on page 3-21: "...the use of a Latin hypercube sample of size 70 to assess the effects of subjective uncertainty has *no effect on the estimation* of the 0.1 and 0.001 exceedence probabilities in the individual CCDFs used in comparison with the EPA release limits." (Italics added.) Although the italicized phrase is ambiguous, this assertion appears to be based on the faulty premise that individual CCDFs should be compared to the release limits.

The LHS sampling is very important for comparison of PA results to the EPA release limits. While the separation of stochastic and subjective uncertainty is a noteworthy achievement of the WIPP PA process, the point of LHS sampling is to determine the uncertainty inherent in any comparison made with the EPA release limits. Individual CCDFs developed using LHS are less important than the summary CCDFs derived from them. A summary CCDF, such as the mean CCDF, will probably be used to compare results of the PA to the Standard. LHS is an important tool for assessing the degree of uncertainty in the estimated mean CCDF resulting from the sampling. Procedures for estimating the confidence interval for the mean CCDF from the LHS results should be established.

Response.

Use of Median Values for Variables Not Sampled

The median value is precisely defined given the probability distribution. The expected value is less clearly established for many variables, especially at the time of the 1992 PA. The decision

was therefore made to use median values in order to provide a systematic and consistent approach.

Sampling Error for Estimating CCDFs
The PA for the compliance certification package will include activities to estimate the uncertainty and confidence interval that are relevant to comparison of CCDFs with the EPA release limits. However, in accordance with the direction given above and in 40 CFR 191, a mean CCDF will be used to compare results of the PA to the Standard.

EPA Comment 63.
Comments on Table 3-1 Variables
Comments on uncertain variables are limited to only those few on which information was readily available. No attempt has been made to address certain generic questions regarding these variables such as: (1) are some of these unnecessary; (2) should additional ones be added; and (3) is there a problem of co-variance that is being ignored (i.e., two or more variables that are really correlated but are being sampled here as if they were uncorrelated). These three items eventually need to be thoroughly evaluated. Also, the distribution of values for each of these variables needs to be evaluated from both WIPP and broader scientific literature.

BHPERM
Borehole permeability has been identified by SNL as one of the more sensitive parameters for performance assessment. The range of values used (1×10^{-14} m^2 to 1×10^{-11} m^2) is said to represent silty sand as defined in Table 2-2 of a book by Freeze and Cherry. The range of values actually shown in Freeze and Cherry is $\sim 7 \times 10^{-14}$ m^2 to 7×10^{-11} m^2.

The assumption that any abandoned borehole is filled with silty sand is a very unconservative assumption and does not appear to be justified from either the site conceptual model or from the site data. Although the 1985 EPA Guidance indicates that it is not necessary to assume that the borehole is completely open, but rather that it may be filled with soil or gravel, the DOE takes the least conservative assumption regarding the EPA guidance by adopting borehole permeabilities as those typical of a silty sand. The intrusion that may disturb the repository will, at first, be essentially open and over time will eventually be filled or sealed by collapse of the borehole. The DOE does not present any rationale as to why it was assumed that the borehole should have such a low permeability.

BPPRES
The range given for the initial pressure in a brine pocket in the Castile Formation is 13 to 21 MPa, with a median of 17. The range given in two places in Volume 3 is 11 to 21 MPa with a median of 12.6. The values used in Volume 3 are supported by the data presented in

DOE 83 and appear to be preferable. The reason for the discrepancy between Volumes 3 and 4 is not known.

BPSTOR

It is not clear how the range (0.02–2.0 m^3/Pa) and median (0.2 m^3/Pa) for the bulk storativity were developed from the reference (DOE 83). The overall flow data for WIPP-12 suggest a value of 0.04 m^3/Pa, and a value for the small fracture portion of the system of about 0.07 m^3/Pa (page H-54). Is this a variable that needs to be sampled?

BRSAT

Initial fluid (brine) saturation of the waste was assumed to range from 0.0 to 0.14 with a median of 0.07. These values were obtained purely by PA Investigator Judgement. Yet this parameter is listed as important to compliance with 40 CFR 191 and (in Volume 5) as very important to compliance with 40 CFR 268.6. Also, the Experimental Program Plan does not mention plans to study this parameter. There is not adequate information for this important parameter. In the absence of data, it would seem appropriate to determine and use a plausible value that would result in the greatest consequence.

DBDIAM

It is noted that drill bit diameter is the only one of the 49 variables sampled that is not listed in Table 9-3 as being important for 40 CFR 191B. Is this an oversight?

FKDxx and MKDxx—DISTRIBUTION COEFFICIENTS

All of the fracture and matrix distribution coefficients for the individual elements are listed in Chapter 9 as important or very important to PA. For the 1992 PA, those values were determined based on expert judgement by SNL scientists. These parameters are too important to be determined in this manner. Laboratory studies are underway and the data obtained should be used in future performance assessments.

SOLxx—Radionuclide Solubilities

The values of plutonium solubilities, developed by SNL expert opinion were considerably less than those from ongoing SNL-supported studies at Lawrence Berkeley Laboratory. Future performance assessments should not rely on expert judgment if data is available.

Response.

a. Comments on Table 3-1 Variables

(1) Are some of the variables unnecessary?

The goal of the PA analyses was to be as complete as possible in identification of variables, even though some of the variables may be less important than others in term of model sensitivity.

(2) Should additional variables be added?

As alternative conceptual models are evaluated and incorporated in the PA analyses, additional variables may need to be added. The current variable identification is consistent with the needs of the current models. Future calculations may require different input parameters as more sophisticated models are developed and tested.

(3) Is there a problem of covariance, in that covariance is being ignored (i.e., two or more variables that are realty correlated, but are being sampled here as if they were uncorrelated)? The effects of not including variable correlations are being investigated.

b. BHPERM

Volume 3, Section 4.2.1, indicates that the selected value of borehole fill-material permeability was based on the investigator's judgment that the borehole fill material would be a "silty sand" (as identified by Freeze and Cherry). For the purpose of the initial sensitivity studies, the choice of a relatively low-permeability material (silty sand, for example, instead of a gravel) is not unreasonable, since a silty sand is approximately mid-range on a scale of potential unconsolidated, granular materials expected to degrade from the borehole wall or be placed in the borehole upon borehole abandonment.

The permeability of silty sand is also felt to be conservative given the range of expected borehole fill materials. The borehole fill is expected to be a granular and uniform material. Its physical characteristics will be determined by grain size and uniformity of the source material from which it is derived. If a concrete plug is placed in the borehole, it will degrade to a material similar to silty sand after hundreds of years. If the borehole is unfilled, the borehole is closed by salt creep. This would result in a lower permeability than a silty sand. A range of borehole fill-material permeability values will be modeled in future PA analyses.

The description of initial borehole plug permeability on page 4-4, Section 4.2.1, Volume 3 also indicates that plug permeabilities depend strongly on the host rock in which the plug is emplaced. Because most experimental studies of plug-borehole interaction extend for only hundreds of days or less, data are limited. Any PA calculations that start from initial conditions assume permeabilities of 10^{-15} m^2 for plugs in the Castile Formation and 10^{-18} m2 in the Salado and Rustler Formations. These values are more conservative than the silty-sand permeability used in the PA modeling.

c. BPPRES

The correct distribution is identified in Volume 3, Section 4.3.1. The data in Volume 3 are based on WIPP-12 and other borehole measurements. The higher pressure value (from Volume 4, Table 3-1) was used in the PA and represents a more conservative value in terms of potential releases. The data range included in Volume 4, Table 3-1, however, appears to be incorrect, an error which was missed during the consistency checks on the data in the PA report.

d. BPSTOR

The brine pocket storativity is used to determine the amount of brine that is potentially available for upward flow in an intruding borehole. It is a necessary parameter in evaluating the disturbed scenario. It is sampled because the 1992 PA evaluated a range of possible values for the CCDF development.

e. BRSAT

The brine saturation in a hypothetical brine pocket below the repository is an important parameter for the disturbed scenario. Since the 1992 PA, data have been obtained through additional research involving literature reviews and experimentation. Estimates of the range of initial brine saturation have been reduced to between 0.004 and 0.052 based on this more recent EEG data (Howarth, 1994). The new range of values is used in the 1995 Draft Compliance Certification Application (DCCA, 6-115).

f. DBDIAM

The drill bit diameter is one of the 49 variables sampled in the 1992 PA. It was an oversight that this variable is not included in Table 9-3.

g. FKDxx and MKDxx—DISTRIBUTION COEFFICIENTS

Improved values of fracture and matrix distribution coefficients for the individual radionuclides will be included in future PAs as data become available from the ongoing laboratory studies.

h. SOLxx—Radionuclide Solubilities

Improved values of actinide solubilities will be included in future PAs as data become available from the ongoing laboratory studies.

EPA Comment 64. Initial and Boundary Conditions

The initial conditions which are assumed for the scenarios will significantly affect the modeling results. However, the modeling that was described in the 1992 PA to obtain the initial conditions (e.g., repository pressures and brine saturations) provides only limited rationale for the assumptions. The approach needs to be better described in general. Furthermore, it appears that none of the considerable uncertainty which is associated with the initial conditions has been quantified. As much emphasis should be placed on obtaining the initial conditions for brine saturation and pressure distributions as any other aspect of the modeling. While this refers to BRAGFLO, initial and boundary conditions for all models should be thoroughly evaluated before they are chosen, and fully discussed in future reports.

Mechanical modeling of disposal room and rock mass motion with SANCHO apparently uses room gas pressure as a boundary condition. This varies in time as consequence of gas generation which is also variable. Rock mass and room contents are deformable, porous media through which seepage of gas and brine occurs. As a consequence, there is a difference

in total stress, effective stress and fluid pressure and corresponding differences in boundary conditions. Also, effective stress should be used in the constitutive equations. However, these distinctions are not made in SANCHO nor does BRAGFLO accommodate deformation. The consequences are unknown, but may be worth examining.

At the end of 50 years of operation, the DRZ is considered to be "dewatered" and only partially saturated with brine; the fluid pressure is reset to atmospheric pressure. These assumptions and decisions should be evaluated in light of actual calculations. While the fluid pressure in the DRZ may decrease from ambient towards the excavation, it is not certain that desaturation follows.

The regional boundary conditions will have an effect on releases to the accessible environment. Currently, there is a great deal of uncertainty associated with regional boundary conditions, yet the effect of this uncertainty of the boundary conditions on the modeling results has not been evaluated.

Response.

a) The basis for the definition of PA model initial conditions is provided in the source documents cited in the 1992 PA reports. A summary of results from these source documents and the rationale that leads to the selection of the parameter distributions used as the model initial conditions will be included in future PAs or in related reports.

The boundary conditions depend on the specific model or code. For mechanical models which calculate the rock deformation, the boundary conditions include either the stress or velocity conditions applied to the external and/or interior boundaries of the model. For hydrological models, the conditions include either the hydraulic potential or the fluid flux at the external and/or internal boundaries. Boundary conditions also need to be consistently applied between models for regional-scale, local-scale, repository-scale, panel-scale, and room-scale phenomena. The CAMCON system assists in defining and documenting the appropriate interfaces between the various PA models, particularly in terms of data transfer for boundary-conditions. See also the responses to EPA Comments 25 and 117.

b) The pressure-time history in a disposal room is appropriately modeled as an internal pressure boundary condition in the SANCHO code. SANCHO computes disposal room closure (and expansion when room pressure exceeds lithostatic pressure) in response to the total stress field in the rock. The validity of this approach is demonstrated by the excellent agreement between SANCHO calculations and in situ measurements of room closure at the WIPP facility. The results of SANCHO calculations are not used directly in the PA analyses, but are summarized as a porosity surface for the BRAGFLO code. This porosity surface provides BRAGFLO with the capability to account for the effects of room closure and gas pressure on porosity and permeability of the waste. See also the resolution of EPA Comment 18.

There is a difference in total stress, effective stress, and fluid pressure and corresponding differences in boundary conditions. SANCHO calculates the total stress field, NOT the effective stress (total stress minus fluid pressure). SANCHO, therefore, does not include effective stress in the definition of the boundary conditions or in its constitutive equations.

BRAGFLO does not calculate deformation, but the effects of deformational changes are passed from SANCHO. The BRAGFLO fluid flow boundary conditions are developed from SANCHO input, in particular the internal (room) boundary conditions for fluid pressure (or hydraulic potential) and the initial conditions for porosity.

c) BRAGFLO calculations for the 1992 PA and all subsequent PAs indicate that the disturbed rock zone (DRZ) will be unsaturated. As indicated in Volume 2, Section 2.3.5, page 2-55, brine seepage from the Salado Formation will have filled fractures in anhydrite interbeds above and below the emplacement horizon [Lappin et al., 1989, and Rechard et al., 1990b]. Brine will also flow into the excavated disposal rooms/panels. The computational and experimental data indicate that the DRZ will indeed be desaturated.

d) The region boundary conditions will have an effect on releases to the accessible environment. Volume 2, Section 2.2.3.6, page 2-30 describes the process used to incorporate the regional potentiometric conditions in the repository-scale models. The uncertainties of regional-scale boundary conditions and how they are incorporated into local- and repository-scale models are currently being studied with three-dimensional, regional models that are designed to enhance the conceptual understanding of the site.

EPA Comment 65. Results and Discussion (Undisturbed Performance)
A major point in the discussion of results is the rise in gas pressure that in some cases exceeds lithostatic pressure. Pressure in excess of lithostatic could conceivably lift the overburden, arch the surface, and stress intervening strata in tension (or open vertical joints). Such an outcome is the opposite of subsidence. Neither are considered in PA uncertainties.

Whether the pressure increases at a sufficient rate for fracture depends on treatment of the rock mass as a porous or non-porous medium. In fact, the rock mass is a porous, permeable medium, so it may be the effective stress that needs to be considered in fracture analysis, not the total stress.

Response. *The effect of disposal room/panel gas pressures when above the lithostatic pressure is currently under study. The opening of fractures by gas pressurization is considered to occur primarily within the interbeds because they contain evidence of preexisting fracturing and therefore have very low tensile strength. A discussion of the interbed fracture flow model can be found in the Position Paper on Salado Formation Fluid Flow and Transport. See also the resolution to EPA Comment 15.*

EPA Comment 66. Radionuclide Inventory Available for Removal: Cuttings Release
The values in expression 7.3 -2 on page 7-13 are taken from the 1991 PA report. The values from Table 7.3-3 would be more appropriate. The scale factor is 39.32 and is the same at all time periods because of the manner in which the table was calculated.

Response. *The numbers used in Equation 7.3-2 should have been updated. Care will be taken not to repeat the mistake in later documents.*

EPA Comment 67. Decay of Radionuclide Levels
The method used for decaying the projected activity levels in Table 7.3-3 is not correct for the WIPP inventory for reasons explained below.

All activity levels in the Table are decayed at the same rate for the entire inventory[1]. These overall decay rates are correct for the inventory being used. However, the waste containers with the high initial radioactivity levels do not contain the average mixture of radionuclides. This is apparent by comparing the isotopic mix of radionuclides at the Savannah River Site (SRS), the origin of most of the high-curie containers. At SRS, 96.9 percent of the Curies are from 238Pu (half-life of 87.7 years) and only 2.8 percent are from 239Pu and 240Pu (half lives of 24,100 years and 6,560 years). Related values for the entire inventory are 72.6 percent 238Pu and 10.4 percent 239Pu and 240Pu. Because of these differences in half-life, the high activity containers will decay at a much faster rate than the inventory as a whole.

The decay values for the Activity Levels in Table 7.3-3 should be recalculated using the actual radionuclide compositions that exist for each of the initial activity levels chosen.

Response. *The "average for CH waste" decay shown in Table 7.3-3 of V.4 is the <u>total</u> activity of the radionuclides shown in Table 7.3-1. The decay chains were simplified to include only long-lived alpha-emitters, and decay was calculated using the activity form of the Bateman equations (see Volume 2 of the 1992 PA report).*

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[1] Inspection of Volume 4 Table C-6 in Appendix C shows a constant proportion of contribution from each radionuclide across all sampled vectors. This lack of variation in activity levels within the repository at the selected time of intrusion indicates that the waste characteristics have not been modeled adequately. Development of an alternative approach to modeling activity levels should be considered. As a last resort, such variations could be captured by adding one or more uncertain activity variables to the LHS procedure.

This comment assumes that loading will be such that waste from one generating site (e.g., SRS) will be concentrated in one area. This situation is not reflected in Table 7.3-3. The activity levels assume a normal distribution of activity throughout the repository, and reflect the relative amounts of lower specific activity and higher specific activity in the waste. They are not "actual" activity levels because the loading pattern is not pre-determined. The activities shown in Table 7.3-1 will be modified and amended as the WTWBIR is developed.

EPA Comment 68. Discussion of Activity Levels Procedure

It is not obvious what the overall effect of using recalculated decay activities will be. Obviously, the activities at later time periods in Activity Level Four will be less if a more rapidly decaying radionuclide composition is used and this will reduce calculated release from Activity Level Four. However, at lower activity levels the reverse is true and these are the much more probable occurrences. For example, consider the radionuclide components for 66,030 stored INEL drums (page A-10 in DOE/WIPP 91-058) which have an average of 5.027 Ci/drum total and 2.119 Ci/drum of alpha-emitting transuranics. These drums will have about 2.4 times the fraction of the initial activity remaining at 1,000 years to 7,250 years as is indicated for Activity Levels One and Two in Table 7.3-3. These two activity levels have a probability of occurrence about 125 times that of Level Four.

Other ways in which the Activity Levels could be addressed should be considered. It is useful to compare the curies that might be brought to the surface at 125 years with values calculated by SNL. For a 0.1 m^2 borehole (the size used in the 1992 PA), the Table 7.3-3 value would be 79.9 Ci. Drilling through one drum that contained 1,100 Ci 238Pu at time 0.0 would bring 166 Ci to the surface at 125 years. If three such drums were intercepted by this drill bit (this would be a low probability occurrence but would be possible and permissible under current WIPP procedures for emplacing wastes) the total would be 498 Ci. For drums containing 1,000 Ci of 241Am, the activity brought to the surface at 125 years would be 332 Ci for one drum and 996 Ci for 3 drums.

A borehole through an RH-TRU canister that initially contained 23 Ci/l of 137Cs and 137mBa (the maximum permitted at WIPP) would bring 43 Ci of 137Cs to the surface at 125 years.

The procedure used assumes that the various activity levels are placed randomly in the repository which may or may not be the best assumption. Note that if it is assumed that a three-drum high stack in the repository would never contain more than one drum with greater than 100 curies, the 5,159 drums in this activity level (four) would have a surface area of 1,326 m^2, or 0.0105 of the total waste surface area (rather than 0.0060).

The New Mexico Environmental Evaluation Group (EEG) has considered intrusion scenarios where a borehole intrudes into a waste room location that has a concentration of average activity drums from SRS and Los Alamos National Laboratory (LANL). The basis for this

assumption is that when seven-packs come into the repository together, they will be emplaced together. Thus, different locations will have somewhat higher or lower average concentrations.

In the absence of load management, the possibility and consequences of waste emplacement where average concentrations within a room or panel vary significantly from the average needs to be evaluated (Chat 88).

More information on the distribution of radioactivity levels within the various activity levels would be helpful. The alpha curies in Activity Level Four are equivalent to 217 Ci/drum (at time zero) with the calculation used. Is this too low? Too high? Or about right?

Because alternative procedures for developing activity levels have not been evaluated and presented, it cannot be concluded at this time that the procedure used, even after correcting the decay values, is the most appropriate one.

Response. *The DOE has developed a detailed radionuclide inventory in the WTWBIR and Revision 11 of the IDB. The radionuclide inventories in both documents are being developed from the same data call to ensure consistency. These documents present the CH and RH radionuclide inventories by isotope, site, and total for the WIPP. This new inventory will be used by Performance Assessment to model releases under various scenarios.*

Any increased precision in determining what drums (or rooms) would be breached by a cuttings scenario implies a load management scheme, which does not exist. Load management in the repository is not planned at this time. If the human intrusion scenarios indicate that load management is a necessary activity, DOE will conduct further evaluations to determine appropriate load management options.

Since completion of the 92 PA, the estimates of the waste inventory and activity levels for WIPP have been updated and revised several times; therefore, it may not be worthwhile to go into specific calculations. However, with regard to the question posed by the reviewer on activity level per drum, the estimate of 217 Ci per drum for the RH waste at time zero appears to be correct.

EPA Comment 69. Total Release to Accessible Environment: LHS Sampling Error
No information on sampling error for LHS-derived estimates are given in the current PA. Summary curves, such as the mean or percentile CCDFs, are generated by averaging the results of 70 LHS trials. It is expected that the estimated mean CCDF will have a relatively wide uncertainty region due to sampling variation from a relatively small sample size. After analysis of sampling variations, it may be found necessary to reduce the magnitude of sampling error by increasing the LHS sample size. Even if the increased sample size did not

dramatically affect the estimated mean, the estimated confidence intervals could be reduced substantially by increasing the sample size.

Response. *The 1992 PA was one of a series of annual PA updates from 1990 through 1992. Its purpose was to evaluate and improve the existing PA models and computational strategies, but it was never intended to demonstrate compliance. Given this purpose, the use of 70 LHS trials was very appropriate. The specific number of LHS trials for the final compliance calculations will be determined on technical merit and through consultation with the EPA and the stakeholders.*

EPA Comment 70. Discussion

This chapter reflects on the findings of the Uncertainty and Sensitivity Analyses in Volume 4 and on the implications for future studies and demonstration of compliance with 40 CFR 191. The current PA is based on the assumption of Darcian flow within the Salado. However, other conceptual models exist for flow and transport within the Salado at the WIPP in which flow is non-Darcian. It would have been very helpful if Chapter 9 included a discussion which addressed how some of the results may have changed if alternative conceptual models had been adopted.

The numerous references to what will be modeled in future performance assessments should be summarized in Chapter 9 (e.g., interbed fracturing p. 4-8).

Response. *The WIPP Project has investigated numerous conceptual models since the 1992 PA was performed. For example, the WIPP Project is currently considering three alternate conceptual models for fluid flow in the Salado: a far-field (Darcy) flow model, a redistribution model for the DRZ and a clay consolidation model. These three models have been discussed in detail with the EPA through technical exchange meetings and with stakeholders through the SPM process. However, it would have been inappropriate to speculate in the 1992 PA report on "how the results may have changed" until the studies and analyses of alternate conceptual models were completed.*

The status of the current PA models is documented in the Position Papers for the SPM and in the DCCA. The DOE has no plans to modify the 1992 PA report with discussions of changes for future PA analyses.

EPA Comment 71.

Five parameters are said to be important when analyzing the repository/shaft barrier effect: (1) drilling intensity; (2) intrusion borehole permeability; (3) Salado (marker bed) permeabilities; (4) radionuclide solubilities; and (5) drill-bit diameter. Sandia observes that only solubility can be affected by actions taken in the repository. Only Salado (marker bed)

permeabilities can be reduced in uncertainty by continued in-situ investigation. The other three parameters are determined by regulatory guidance. Comments on the SNL discussion of each of these parameters are given below.

Drilling Intensity

It is correct that drilling intensity will probably be decided by regulatory guidance. However, these are references to taking credit for passive institutional control, which also will likely be influenced by regulatory guidance. It is implied in more than one place in Volume 4 that the only reduction in drilling intensity being used in the 1992 PA is due to passive institutional controls. This is incorrect. Actually, the major reduction is due to use of a much lower raw drilling intensity that was developed by expert panels. In addition, the PA has not provided any plans for passive controls and so no credit for reduced drilling should have been taken.

Salado (Marker Bed) Permeabilities

It is agreed that this is an important parameter that needs continued study to reduce uncertainty. The statement is made (bottom of page 9-4) that this is not a parameter that can be changed by action taken within the repository. While this is true for the permeability value itself, there are engineering alternatives that could be employed to reduce the void space in the repository and thereby reduce the amount of brine that flows through the wastes.

Drill Bit Diameter

The entire drilling area needs further evaluation. Drill bit diameter and erosion are the best understood mechanisms at present. There are plans to study spalling phenomena. There is also a need to model the quantities of pressurized brine from waste rooms, Marker Bed-139, and Castile brine reservoirs that will flow to the surface during typical drilling operations. Also, activity levels in cuttings need to be re-evaluated. This study should include the effects of a variable inventory and "non-average" waste emplacement in the repository.

Some documentation should be referenced or provided regarding the specific comments or major contributions that the various experts listed in the front of the document have made regarding the 1992 PA. This would help the EPA to access the level of independent review that the studies and activities described in the PA have received.

Response.

Drilling Intensity

The major reduction in drilling intensity for the 1992 PA is due to the guidance from the Futures Panel and the Markers Panel.

The charge given to the Futures Panel was broader than a limited consideration of current oil and gas drilling rates and included identification of possible future societies and how they may intrude over the next 10,000 years. Extending current drilling rates for the next 10,000 years and using them in performance assessment calculations assumes that drilling for oil and gas

will continue at the same rate as today. One justification for using drilling rates lower than EPA's maximum is that the world may move away from a petroleum-based economy within hundreds of years.

The extent to which passive institutional controls may deter inadvertent human intrusion, and thus reduce the intrusion rates used in the calculations, is based on the durability of the markers and their ability to communicate correctly over long periods of time.

The 1992 PA presented calculations and results for intrusion probabilities estimated for cases with and without passive markers. Complete modeling of repository performance must include the effects of the entire system. Determining the effects of the Passive Institutional Controls is important in consequence analysis.

Work is continuing, through PA efforts, to strengthen the DOE position on quantitative results from passive institutional controls for inclusion in disposal system performance predictions.

Salado (Marker Bed) Permeabilities
Westinghouse Isolation Division is currently studying engineered alternatives, including various engineered backfill materials, that will reduce the void space in the disposal rooms and help to isolate the waste from brine inflows.

Drill Bit Diameter
The 1992 PA was only a preliminary analysis and it was recognized that additional work was needed. Some of the points raised in this comment, such as the issue of pressurized brine reaching the surface, have already been dealt with elsewhere in our responses (see, e.g., response to EPA Comment 10). Efforts are currently underway to gain a better understanding of releases from spallings and cuttings. The assumption in the 1992 PA that all waste was homogenized is still in use in current PA analyses.

Documentation
The DOE will consider the suggestion that the authors of major contributions be identified in the PA documentation.

EPA Comment 72.
Volume 4, page 2-18
The last paragraph on this page provides the rationale for selecting only one intrusion time (i.e., computational cost), but does not provide adequate rationale for why 1,000 years was selected. An E1E2-type scenario simulated at 101–500 years would have resulted in higher cumulative releases. The gas generation reactions would not be brine limited and there would already be a pathway to the Culebra.

Response. *The 1992 PA was only a preliminary analysis and it was recognized that additional work was needed in many areas. With regard to the intrusion time, subsequent PA calculations have expanded the number and range of intrusion times. For example, the PA for the DCCA considers intrusions occurring at 100, 125, 175, 350, 1000, 3000, 7250 and 10,000 years after decommissioning (see Section 6.3, Determination of Scenario Probabilities in the DCCA).*

EPA Comment 73.
Volume 4, page 2-18
Where are the referenced "Table 3-4 of Volume 3" and "Table 3-5 of Volume 3"?

Response. *Tables 3-4 and 3-5 are found on pages 3-20 to 3-25 of Volume 2 of SAND91-0893, denoted as reference WIPP PA Division (1991b) .*

EPA Comment 74.
Volume 4, page 3-1

(a) Table 3.1. To obtain the mass flux which was input into PANEL, the BRAGFLO simulations included the Culebra. However, it is unclear which transmissivity fields were used and where the two phase flow parameters assigned to the Culebra can be found.

(b) There is a discrepancy between the range that is provided for matrix porosity in Volume 3 (p. 2-83) and that which is presented in this table. The range should be .028-.303, with a median of .145 rather than .139.

(c) The bulk storage range for the Culebra is missing from the Table and is required for the transient simulations.

(d) The clay effective porosity (CULCLYP) appears to be unreasonably high. As pointed out in Volume 3 (p. A-130), a lower porosity would probably be more realistic (18 percent) for the actinides. Unrealistically high porosities would overestimate retardation by matrix diffusion.

Response.
a) Two-phase flow parameters for the BRAGFLO code are described in Volume 3, Section 1.4.1. Single-phase (liquid) fluid flow parameters (including the transmissivity field) for the Culebra are currently developed for the SECO2D code (see Volume 3, Sections 1.4.5 and 2.6). Two-phase flow processes are modeled by BRAGFLO at the repository-scale, including the Salado, but excluding the Culebra. Two-phase flow for the Culebra is not included in the 1992 PA, but will be included in future PA modeling.

b) The noted discrepancy for the Culebra matrix porosity (Volume 3, page 2-83, Figure 2.6-6, Culebra porosity distribution and Volume 4, page 3-3, Culebra matrix porosity (CULPOR) range and median) is an oversight in the data consistency checking of 1992 PA reports. The distribution presented in Volume 3 is the correct definition of the matrix porosity for the Culebra.

c) The storage coefficient for the Culebra is included in Table 2.6-1, page 2-76 of Volume 3. The storage coefficient is used with the transmissivity and other hydrologic parameters in the SECO2D code to compute ground-water velocity and discharge. The storage coefficient is required for the transient groundwater flow simulations, however, the variables included in Table 3-1 are ONLY those variables sampled for 1992 PA. Storativity is not included in this sampling, and therefore is not included in Table 3.1 of Volume 4.

d) The porosity of the clay-lined fractures in the Culebra (CULCLYP) range from 0.05 to 0.5 (dimensionless), median 0.275. A value of 0.18 is referenced in Volume 3, page A-130. The data inconsistencies will be removed in future PA reports. Effective fracture porosities can be very high when a fracture is open and not clay lined. The clay lining may significantly reduce the effective porosity. Future PA reports will provide additional discussion on the expected values.

EPA Comment 75
Volume 4, page 3-1

Where are the parameters for the seals?

Response. *The seal parameters used in the 1992 PA are listed in Volume 4 of the 1992 PA report at the end of Table 3-1 on pages 3-5 and 3-7. These variables relate to the parameters listed in Volume 3 of the 1992 PA report on page 6-3, Table 6.0-2, "Distributions of Sample Parameters in December 1992 WIPP Performance Assessment for Engineered Barriers."*

EPA Comment 76
Volume 4, page 4-17
An additional shortcoming is that the output from SANCHO is in the form of total porosities which were not transformed into effective porosities as required input for BRAGFLO. The effect of this will be that BRAGFLO will overestimate storage and underestimate the amount of pressure buildup and distance that brine may potentially migrate.

Volume 4, page 4-19
Apparently gas-generation is active for 1,050 years. However, when the gas generation is at a maximum, there would be the least potential for brine intrusion. Therefore, a single intrusion at this time would result in minimized releases to the environment in an E2 scenario.

Response.
Volume 4, page 4-17
Effective porosity is the amount of interconnected pore space through which fluids can pass, expressed as a percentage of bulk volume. Part of the total porosity will be occupied by static fluid being held to the matrix grains by surface tension, so effective porosity will be less than total porosity. Isolated pore space (containing fluids or not) within the matrix is part of the total porosity, but is not part of effective porosity.

The difference in BRAGFLO and SANCHO porosity formulation and application is recognized. As discussed in the 1992 PA report, the formulation of the porosity interface between the two codes was being evaluated for the first time; the difficulties are outlined in the report. Future PA reports will address the differences between the use of total porosity in SANCHO and the effective porosity used in BRAGFLO. For the 1992 PA, the effective porosity and total porosity are assumed to be the same. As noted on page 4-17, an improved way of dealing with these inconsistencies is planned for future performance assessments.

Volume 4, page 4-19
The comment is correct.

EPA Comment 77.
Volume 4, page 4-24
In the manipulation of the specific storage equation to solve for rock compressibility, what is the basis for the values for specific storage of the anhydrite and halite? These are fairly critical values as they will strongly influence the pressures attained. It is odd that a distribution was not assigned and there is no mention of these parameters in Table 3.1. Furthermore, how was the alpha for the waste itself determined?

Response. *The basis for the specific storage values for anhydrite and halite used in the manipulation of the specific storage equation to solve for compressibility (Volume 4, page 4-24) is found in Volume 3 of the 1992 PA, pages 2-44 for halite and 2-49 for anhydrite. The ranges for specific storage for both rock types are recorded as follows:*

SPECIFIC STORAGE (m^{-1})

Rock Type	*Range*	*Median*
Halite	*$2.8x10^{-8}$ to $1.4x10^{-6}$*	*$9.5x10^{-8}$*
Anhydrite	*$9.7x10^{-8}$ to $1x10^{-6}$*	*$1.4x10^{-7}$*

The specific storage values for anhydrite and halite listed in Volume 4, page 4-24 represent the high end values for each range for each rock type.

Although specific storage can affect formation pressure response, pressure response in the formation is in itself not a critical criteria for long term performance of the WIPP. The sensitivity of room pressure, gas migration, brine migration, gas mass outflow, and brine mass outflow to formation specific storage have more affect.

The alpha for the waste is not used. Compaction has been investigated through both a volumetric plasticity (crushable foam) model and the Nonlinear Elastic Waste model (Butcher, et al., 1995).

EPA Comment 78.
Volume 4, page 4-23
Generally, the van Genuchten-Parker formulae provide a better model for relative permeability and capillary pressure. Typically the Brooks-Corey formulation is only used because of its numerical efficiency. The method by which the van Genuchten approach treats the air entry pressures suggests that it is not only more conservative but also more realistic. Further information justifying the selection of one formulation over the other should be provided. In addition, the use of the combination of formulae seems to be arbitrary.

Response. *A comparison of the van Genuchten-Parker and Brooks-Corey formulations, as well as the rationale for selection of a two-phase flow model for the latest PA analyses, is discussed in Sections 5.6 and 5.7 of the SPM Position Paper on Salado Flow and Transport (Howarth et al., 1995) and in Webb (SAND93-3912).*

EPA Comment 79.
Volume 4, page 4-28
The means by which the initial conditions were determined for the simulations needs to be better justified. Essentially all of the results will be significantly affected by the assumptions that are made in estimating the initial conditions. The description that is presented in the PA should be as detailed for this phase of the modeling as it is for the remainder of the analysis. For example, the rationale for treating excavated regions as an atmospheric pressure initial

condition rather than as a boundary condition is not presented. It seems that in reality the excavation will serve more as a boundary than as an initial condition. If the excavation were treated as a boundary condition, far more depressurization and brine desaturation would occur. Furthermore, if the depressurization reaches the no flow boundary at the base of the model, the depressurization will be over-predicted. This needs to be checked and discussed.

Response. *The selection of initial and boundary conditions for the SANCHO and BRAGFLO codes is discussed in detail in the response to EPA Comment 64.*

EPA Comment 80.

Volume 4, page 4-30

Why was a distribution not placed on the Culebra permeability when it is set from zero back to 2.1×10^{-14} m^2? Where did this number come from?

Volume 4, page 4-31

The very high permeability that is referenced as being assigned to the excavated region to simulate cavities is equivalent to that of a gravel. Were higher permeabilities not assigned because of convergence problems? If this is the case, what overall effect does this assumption (i.e., regarding the permeability of the open rooms being relatively low as compared to a cavity) have on the model results?

Response.

Volume 4, Page 4-30

The purpose of Table 4.3-1 on page 4-30 is to illustrate the procedure for running a single PA realization for the undisturbed case. The permeability value of 2.1×10^{-14} m^2 is simply the choice made by the analyst for this particular calculation (as exemplified by the values in the table).

Single values for variables, such as the Culebra permeability, are assigned for each PA realization. These single values are selected by sampling from the appropriate parameter distribution. It would be inappropriate to assign a distribution of values here because the table is intended as a realization for a particular PA calculation.

Volume 4, Page 4-31

Two options can be used to simulate internal cavities in a permeable medium: (1) definition of an internal model boundary across which fluid could flow; or (2) definition of a very high-permeable material into which fluid would flow. In the analysis described on page 4-31, the high-permeable material was used successfully with no convergence problems. Further increases in permeability of the excavated zone will have no impact on the PA results because once the excavation permeability is more than three orders of magnitude greater than the

permeability of the surrounding Halite, the Halite permeability will control brine flows into and out of the disposal rooms.

EPA Comment 81
Volume 4, page 4-46
Given the assumptions provided in the text (e.g. radial flow), the determination made regarding the farthest distance that brine may have moved in MB139 does not appear to be correct. The formula, $V = (\pi)(r^2)(h)(\text{effective porosity})$, where $V = 1800\ m^3$; $h = 0.85$ meter; porosity = 0.001 yields a value of r of 821 meters. The far end of this grid block would be 2,500 meters or 100 meters beyond the repository boundary. Furthermore, these calculations do not account for the gas which may follow behind the brine and move it considerably greater distances. The effects of gas and the brine should be added to make this determination.

Response. *Since the 1992 PA, the methods of calculating brine outflow have been modified. The recently published Position Paper: Non-Salado Flow and Transport (Axness, C.,1994) contains a discussion of the brine flow calculations.*

EPA Comment 82.
Volume 4, page 4-46
The second illustration which provides percent gas saturations also appears to be incorrect. Using the above formula and correcting for gas saturations, a radial migration distance of 806 meters was obtained. The far end of this grid block would also be 2,500 meters.

Response. *Since the 1992 PA, the methods of calculating brine outflow have been modified. The recently published Position Paper: Non-Salado Flow and Transport (Axness, C.,1994) contains a discussion of the brine flow calculations.*

EPA Comment 83.
Volume 4, page 4-48
The analysis and objectives of the creep closure effects needs to be better explained. The text states "...the panel porosity was initially 66 percent and dropped as creep progressed, leveling off at 12 percent to 21 percent. In the fixed-porosity calculations, the waste panel porosity was initially 19 percent which is the median final-state porosity of the wastes. (See Table 3.4.-1 in Volume 3 of this report)." In Volume 3 it is indicated that 19 percent was the value of porosity used for the 1991 PA. Therefore, it is probably not the median of the 1992 analysis where porosity values ranged from 12 to 21 percent. It appears that the fixed porosity analysis was actually part of the 1991 PA, but this is, not clear in the text. Furthermore, the 12 to 21 percent range is a minimum as stated on page 4-33. The range of pore pressures that

are shown in Figure 4.4-2 for creep closure simulations is approximately 12 to 34 percent. It appears that both approaches used porosities that were very close. Therefore, it is not surprising that the text concludes "The overall effect of modeling creep closure dynamically was minor." Why not, for the fixed porosity simulation, set the porosity at the low end of the porosity range for the creep model and perform a conservative bounding analysis?

Response. *Performance assessment studies have shown that the permeability of the waste has to be within three orders of magnitude of the permeability of the host rock to have any influence on the time for brine to flow through the facility. That is, the flow through the high permeability element (the waste) is for all practical purposes instantaneous when the waste is much more permeable than the host rock. This can be understood by considering two volumes (elements) in parallel. If the difference in permeability is greater than a factor of 1000, all of the flow is concentrated in the high permeability element and this flow occurs instantaneously, for all practical purposes, relative to parallel flow through the low permeability element.*

EPA Comment 84.
Volume 4, page 5-7
DOE needs to discuss why it decided it was not important to statistically sample the hydraulic conductivity (2.24 x 10-7 m/s) of the Culebra. This will be a critical factor in estimating source term flux. A single value of hydraulic conductivity will yield a single permeability value which will have a significant impact on how much of any release migrates into the Culebra.

Response. *BRAGFLO calculates the radionuclide source-term for SECO calculations of transport in the Culebra. The parameter variations in the Culebra are accomplished by sampling on the transmissivity fields used by SECO and on the fracture spacing.*

EPA Comment 85.
Volume 4, page 5-9
Specific storage is a critical parameter. Why has it not been statistically sampled?

Response. *Specific storage is important in the physical response of certain parts of the system; however, previous research and a recent publication (Freeze, et. Al, 1995) have shown that variation of specific storage in Performance Assessment does not affect regulatory performance measures related to brine migration, repository pressurization, and gas migration. The processess are dominated by other physical phenomena, such as waste collapse and fracturing.*

Reference: G.A.Freeze, K.W. Larson, and P.B Davies, 1995, *Coupled Multiphase Flow and Closure analysis of Repository Response to Waste-Generated Gas at Waste Isolation Pilot Plant (WIPP)*, SAND93-1986, Albuquerque, NM : Sandia National Laboratories

EPA Comment 86

Volume 4, page 5-9

The van Genuchten model should be strongly considered for the borehole material to ensure a conservative approach.

Response. *The van Genuchten model will be considered in future PA analyses. See also resolution of Comment 92PA EPA-78.*

However, it should be pointed out that it may not be appropriate to assume that the use of van Genuchten model will always ensure a conservative approach. The differences between the two model formulations is most significant at the extremes of very low saturation of brine or of gas. The van Genuchten model predicts easier gas penetration into pore space that is initially 100 percent brine saturated. This can have a significant impact on calculations of the migration of gas out of the repository panels into the surrounding, very low permeability, small pore volume, halite. For something like borehole fill material, with significantly greater permeability and pore size and where most important release mechanism may be brine transport to the surface, application of the van Genuchten model may not be at all conservative; or it may be that there will be little difference between the results achieved with the two models because the saturation levels are in the intermediate range where the predictions of the models do not differ greatly. The decision to use one model or the other or to employ a sampling strategy will have to be based on examination of how well each model is able to match measured or literature derived characteristics of appropriate fill material, issues of conservatism, and also, whether the choice of model, in this particular situation, makes significant difference to the calculated outcomes.

EPA Comment 87

Volume 4, page 5-10

The rationale for Castile brine pressure and storage needs to be discussed. The pressure range (12.6–21 MPa) appears to have been selected because it falls between lithostatic and hydrostatic pressures. This pressure range, therefore assumes that the deepest brine reservoir that will be breached is at 900 meters. This assumption needs more discussion.

Volume 4, page 5-11

The second paragraph in Section 5.1.3 describes what would normally be considered as a boundary rather than an initial condition. The reasons for not setting the excavations at atmospheric pressure for the entire 20 years needs to be discussed.

The initial conditions are so critical to the analysis that there needs to be substantially more discussion and justification as to how the pressure and saturation distributions were reached. For example, it appears that no statistical sampling was performed on any of the rock properties from which the initial conditions were obtained. As much emphasis should be placed on the determination of initial conditions as for the rest of the modeling exercise.

The importance of the initial conditions is illustrated by Figure 4.4-3 which indicates that once the brine within the waste is consumed during the gas generation reactions, the saturation within the waste never increases (i.e. there is only very limited brine flow into the waste panels). Therefore, the assumed initial conditions will simply shift, in time, the peak saturations and pressures which are the critical aspects of the analysis. High initial saturations and pressures will not only shift the peaks to the earlier times, but also to higher magnitudes. Lower initial saturations and pressures will shift the peaks to the later times and lower their magnitudes. Therefore, the uncertainty associated with the assumed initial conditions will be propagated through the entire modeling analysis. Apparently, no attempts have been made to quantify the affect that this uncertainty will have on the modeling analysis.

Response.

Volume 4, page 5-10

Two types of data are considered to be best suited for determining initial reservoir pressure. The first is the earliest buildup data recorded after encountering the brine reservoir, and the second is the longest buildup data recorded. A varying number of wells drilled in and around the WIPP site were used to estimate Castile brine reservoir pressures and volumes. Further discussion of these parameters can be found in Reeves et al., 1989. The pressure range (12.6 MPa to 21 MPa) was estimated from several wellhead measurements at WIPP-12 and other boreholes that encountered pressurized Castile brine. The initial range was between 7.0 and 17.4 MPa. However, because the range of pressures includes measurements in wells completed at various elevations, a correction for differences in elevation was required. This calculated range is similar to the maximum and minimum possible range of 11 and 21 MPa, assuming hydrostatic and lithostatic pressures at the elevation of the WIPP-12 brine reservoir. The pressure range therefore assumes a maximum depth of approximately 900 meters below ground surface based on these calculations and assumptions. Further discussion of the Castile brine reservoirs can be found in Lappin et al., 1989, Volume 3 of 1992 PA (Pages 4-10 to 4-17), and in DOE document Brine Reservoirs in the Castile Formation TME 3153.

Volume 4, page 5-11

Pressure in the repository during the operational period is unchanging due to ventilation; this is a boundary condition. However, BRAGFLO cannot accommodate fixed pressures internal to the fluid flow domain. Therefore, the initial pressure is set for the start-up period, which is short, and is allowed to change due to flow, etc. The magnitude of changes is slight, however, and the atmospheric pressure initial condition is essentially an atmospheric pressure boundary condition for a short period of time.

The commentor should also note that the complexity of the modeled system is such that "insight" based on experience with simpler models is often incorrect.

EPA Comment 88.
Volume 4, page 5-15
The statement "In only two vectors did the pressure exceed lithostatic (14.8 MPa), probably a result of rapid gas-generation rates and high initial brine content in the waste" is misleading. It appears that the reason only two vectors exceeded lithostatic pressure is that the simulated intrusion occurred before the other twenty or so vectors could also exceed lithostatic pressure as indicated in Figure 5.2.-1.

It is not clear from the text how the intrusion was simulated (i.e., initial or a time-dependent boundary condition).

The statement "Once the borehole is filled with brine, the pressure in the waste reaches hydrostatic relative to the Culebra pressure, and then levels off," raises an important point in that the Culebra pressure has been held constant despite the effects of the intrusion. What is likely to actually happen is that the pressure in the Culebra will also locally rise, will drop the potential between the two formations, and reduce the brine flow from the Salado to the Culebra to levels below which has currently been predicted given the constant permeability used in the Culebra.

Response.
It is true that a later intrusion may penetrate a higher pressure repository.

The intrusion is modelled as a time-dependent permeability change in the code.

The statement regarding local pressure rise in the Culebra that reduces potential between the two formations is probably correct because of the formulation of the model. What is suggested probably did occur, but at so low a magnitude that it was not observed from the plots generated.

EPA Comment 89
Volume 4, page 5-16
At the top of the page it states that "The only parameter that distinguishes these two from the other 68 is that they have the highest sampled anhydrite permeabilities, which would have provided good communication to the higher far field pressures." Again, the distance to these far field pressures will be based on the initial conditions.

Response. *The initial depressurized zone around the repository, developed over 20 years, has little impact on the distance to high far-field pressures over 10,000 years. High k anhydrite is*

an effective conduit for flow and associated pressure change, and with 10,000 years, a 20-year perturbation at the onset is essentially meaningless.

EPA Comment 90
Volume 4, page 5-33
At the top of the second paragraph the text states "...reach similarly unrealistically high values, up to 38 MPa." What is the basis for estimating if a pressure value is unrealistic?

Response. *The "unrealistic values, up to 38 MPa" are approximately 2.5 times lithostatic pressure and are considered to be in excess of the overlying rock strength under tension. Lithostatic pressure at the repository level is 14.8 MPa (SAND92-0700/4 page 4-33) and decreases as one goes up towards ground surface. Pressures within the repository in excess of lithostatic pressure change the stress conditions in the overlying rock from compression to tension. Sedimentary rocks at the WIPP site are inherently weak when placed under tension. Repository pressures in excess of lithostatic pressure, such as up to 38 MPa, cannot be maintained because tensile failure of the host rock, probably through fracturing, will tend to relieve the repository pressure.*

EPA Comment 91
Volume 4, page 6-1
The first bullet on the page leads the reader to the conclusion that the dual porosity model provided the best fit to the data, whereas in actuality other models (e.g., networks of fractures) fit the data equally as well (Jones 92).

Response. *The data from ongoing laboratory and field experiments will assist in defining the proper conceptual model for fluid flow in the Culebra.*

***EPA Comment* 92**
Volume 4, page 6-1
The second bullet also raises a concern regarding the calibration to fresh water head. If the flow varies across the thickness of the Culebra, the densities may also vary. Furthermore, the velocities could be considerably greater through these sections of the Culebra than those velocities which are currently assumed.

Response. *A three-dimensional numerical representation of the groundwater basin model, using the SECO3D code, is currently being developed and may be used to investigate long-term regional flow of groundwater in strata above the Salado Formation. Over the modeling periods of concern, flow deviations due to density effects are expected to be minimal, as discussed in the Non-Salado Position Paper (Axness et al., 1995).*

EPA Comment 93
Volume 4, page 6-2
Regarding the fourth bullet, future climate change could also affect density gradients as well as transmissivity through active dissolution of the dolomite.

Response. *Future climate change affects the Culebra by changing the recharge rates. It is expected that, even as recharge rates might change, the chemistry of the groundwater reaching the Culebra will be similar to the chemistry of present day recharging groundwater. Thus, density gradients and dolomite dissolution rates are not expected to change as a result of climate change.*

EPA Comment 94
Volume 4, page 6-2
The last bullet on the page also needs to be further addressed. In addition, the three-dimensional model which is currently being developed should evaluate the hydraulic relationship among the two units as well as the potential for greater density driven flow and transport.

Response. *Further discussion of the last bullet is included in SAND 89-7069 (Reeves, et al., 1989). The importance of density driven flow was addressed in Davies, 1989, USGS open file report 88-490, who found that within the Land Withdrawal Boundary, density-driven flow is not important. The hydraulic connection between Salado and Culebra in the absence of a borehole to the repository or brine reservoir is assumed to be slight due to the low permeability of the Salado. However, the connectivity is modelled in BRAGFLO.*

EPA Comment 95
Volume 4, page 6-4
The local grid boundary conditions which are mentioned in the last sentence of Section 6.2.2 should be presented for each of the 70 analyses in Volume 3.

The regional control for the determination of the 70 transmissivity fields is very poor. Furthermore, the uncertainties, discussed in LaVenue (LaVen 92) regarding the transmissivity fields, need further attention. Specifically, the differences between GRASP-INV and the 1990 calibrated fields illustrated in Figure 4-5 indicate that the GRASP-INV calibration yielded significantly lower transmissivities in the regions immediately south of the WIPP repository along the most likely travel path of contaminant releases. LaVenue indicates that the travel time determined in the 1990 study was approximately 14,000 years, whereas, the travel time with the GRASP-INV code is approximately 30,000 years. The higher travel time was attributed to the lower transmissivity north of the H-3 borehole south of the WIPP Site.

Furthermore, considerable uncertainties with respect to the regional boundaries have been propagated through the analysis, apparently without any attempts to quantify the effect on the analysis results.

Response. *The local grid boundary conditions (regional head solutions) would be better placed in Volume 3, section 2.6.3.*

Details are provided in La Venue (SAND92-7306, page 61) for the model results, including the apparent discrepancy in transmissivities in the region of the H-3 borehole. The section explains that if the differences in the observed and calculated heads at the H-1 borehole were reduced, the likely result would be increased transmissivity north of H-3, allowing for a travel time closer to 14,000 years. Because there may not be enough pilot points to adequately modify the transmissivity field, additional pilot points may be needed to produce a correlation that is closer to empirical findings. In addition, the discussion on pages 103 to 107 of LaVenue (SAND92-7306) discusses the variability in calculated values. Uncertainty in the models originates from identifiable contributing parameters that are analyzed for closeness of fit to observed data. These models are then used for a best-case model.

EPA Comment 96

Volume 4, page 6-9

The statement in Section 6.3, "all other hydrologic parameters were held constant, at values described in Volume 3 of this report," introduces some confusion as to exactly how the local boundaries were assigned for each simulation. Each of the local flow and transport simulations would have required unique and different local boundaries obtained from the respective regional realization.

The last sentence on this page which states "heads in the strip were prescribed as a function of a sinusoidal climate function applied to the initial calibrated heads derived from the steady-state solution for each transmissivity field," is misleading and suggests that the heads in this region have been calibrated. In reality the heads along the boundary where the climate function has been superimposed are actually obtained from a best guess approximation. The uncertainty of the results of the transmissivity field calculations associated with this boundary approximation have not been assessed.

Response. *The statement in Section 6.3 refers to hydrologic properties of the rock, such as porosity, transmissivity, etc. The boundary conditions for the local model were consistent with the specific regional flow field for each realization.*

The efforts to divide the groundwater model into two separate grids significantly reduces but does not eliminate the effects of boundary conditions on performance assessment calculations.

EPA Comment 97
Volume 4, page 6-11
All of the climatic change vector plots should have been included in Volume 3.

The vector plots in Figure 6.5-1 suggest that, even though this analysis was selected to illustrate climatic effects because it had the largest sampled climatic impact factor, there is almost no ground water entering the model domain along this recharge boundary. This is probably due to the low transmissivity in this region for this particular realization. The last sentence in Section 6.5 on Page 6-19 states "...and subsurface releases of radionuclides are not sensitive to climatic variation of heads along the modeled "recharge strip." First, there is an extremely large degree of uncertainty associated with predicting what the regional boundaries will be as the climate changes. This is acknowledged in the first sentence in the second paragraph on Page 6-11 which states "The effect of climatic changes on regional boundary conditions cannot be modeled directly because of uncertainty in the location of present and future recharge and uncertainty in the hydrologic properties affecting the flow path from the recharge area to the regional domain boundary." Although this statement recognizes the uncertainties, it also illustrates a major problem with the approach that has been taken to model potential climatic-changes.

Figure 6.5-2 indicates that regardless of how high the heads are set in the recharge region to simulate the climatic changes, there will be very little effect on the flow field in the vicinity of the WIPP site. The arrows (i.e., specific discharge) indicate that almost no water is entering the system. This is due largely to the low transmissivities. Furthermore, the water that does enter the system is drained away to the southwest due to boundary condition specifications.

It is difficult to determine whether any increase in gradients caused by the climatic change would affect the contaminant release. In the case of cumulative releases, if all of the contaminants reach the boundary regardless of climate change, both scenarios will have the same results. However, differences in peak arrival times would be observed under different gradients.

A more conservative and possibly more realistic approach would be to assume that the increased rainfall will cause the Nash Draw region to become a recharge area rather than a no flow boundary. The southwestern side of the modeled area could also be a recharge boundary. The effect of these would be to allow water to reach the WIPP Land Withdrawal Boundary, unlike the current situation. These proposed changes to the model boundaries relate to the discussion on Page 6-26 which indicates that the boundary conditions specified along the southern and western boundaries are not consistent with the observed heads and that "If the specified heads are increased along the southern boundary to fit H-7 and USGS-1, the southern boundary converts from a discharge boundary to a recharge boundary." Furthermore, the statement "however, the Pecos River, and the Malaga Bend region in particular, has been determined to behave as a discharge region for regional flux from the Rustler (Mercer, 1983),"

does not recognize the uncertainty that other investigators have regarding these areas (LaVen 92). Furthermore, the relevance of the statement at the bottom of page 6-26 that "this may indicate a ground-water divide occurs between the H-9 borehole and the H-8 borehole south of the model domain," needs to be better explained.

Response. *In future reports, the DOE may include additional groundwater (specific-discharge) vector plots for anticipated future climate conditions and regional hydrological boundary conditions if these plots will enhance understanding of the results for potential climatic change scenarios.*

Any increase in gradients will affect contaminant release. However, it is difficult to determine a climate change scenario that will significantly change gradients. The assumptions for the 1992 PA disregard the energy loss (head loss) by groundwater recharging the system as it passes through overlying strata; this is extremely conservative. Additionally, the reason there is little flow around the WIPP boundary is not due to uncertainty in boundary conditions in the regional domain, but rather because the transmissivity of the Culebra is reduced there.

Recharge from Nash Draw is probably unrealistic. Nash Draw is a topographic low that serves either as a discharge point or as a groundwater divide or both. Due to the effect of topography or hydraulic head and established regional gradients, there is more hydraulic head in Culebra and Magenta groundwater than will be in Nash Draw. More rainfall in Nash Draw will result in a larger Laguna Grande de la Sal.

EPA Comment 98

Volume 4, page 6-19

It is unclear whether the climatic change boundaries were used for these flow and transport simulations. If they were not, why were transient rather than steady-state heads used in the analysis since source-term flux was not assumed to change the ambient flow field? Furthermore, if the initial conditions were assumed to be transient because of the climatic change, the local boundary conditions obtained from the regional modeling would have also had to have been assumed to be transient. This does not appear to be the case.

The following discussion recited from Section 4.2 (LaVen 92) indicates that the prescribed-pressure model boundaries used for the determination of transmissivity fields are not only poorly understood, but they were also not systematically investigated in the uncertainty analysis.

"Several iterations were made to the boundary conditions prior to beginning the calibration exercise. The iterations were necessary due to the difficulty in matching the H-7, USGS-1, and H-9 observed heads while properly fitting the heads in the rest of the domain. The difficulty arises from the existence of the no-flow region along the southern boundary to fit

H-7 and USGS-1, and the southern boundary converts from a discharge to a recharge boundary. Recently, discussions on the Culebra have lead toward considering this possibility. One problem, however, stems from the fact that the Pécos River, and the Malaga Bend region in particular, has been hypothesized to behave as a discharge region for regional flux from the Rustler (Mercer 83). While no absolute conclusions may be made yet concerning the direction of groundwater flow in the region south of the WIPP site, the results determined in this study have indicated that there is an inconsistency between the assumption the groundwater flows southward throughout the model domain and the observed heads in the area. Thus, a compromise between the fits at the southern boreholes and the rest of the model area was necessarily implemented through the boundary conditions."

The large degree of uncertainty in understanding the system boundary conditions has serious implications regarding not only the determination of the alternative transmissivity fields, but also the entire conceptualization of the system. If the model boundaries vary significantly from what is actually occurring in the field, then the solution of the model domain (i.e., transmissivity field) for the 70 simulations would be in error by some unknown and untested quantity. Furthermore, even if the conceptual model was better defined, the current approach that has been taken to obtain the 70 transmissivity fields does not evaluate the sensitivity of the boundary conditions to the overall model results.

Response. *The climate change boundaries were used for radionuclide transport. It is not understood what the commentor's sentence "if initial conditions were assumed to be transient. . ." means since initial conditions necessarily cannot be transient. While there is admitted uncertainty regarding the adequacy of the boundary conditions of the regional model in the 1992 PA, there are two facts to bear in mind: 1) The uncertainty in the southern section of the regional grid may not impact radionuclide travel times in the disposal system; and (2) the regional system is currently being analyzed on a much larger scale with three-dimensional models (Axness, C, et al, 1995). The intent of this modeling is to provide an assessment of groundwater flow on a basin-wide scale to which approximations made in Performance Assessment can be compared.*

EPA Comment 99
Volume 4, page 6-28
Where is the source for the matrix effective porosity value of 16 percent come from?

Response. *As noted on page 6-26 of Volume 4, the purpose of these analyses was to characterize the transmissivity fields, not to predict radionuclide transport or to provide input to a CCDF for a compliance application. The matrix porosity of the Culebra is described in Sections 2.6.1 and 2.6.2 of Volume 3 and has a median of 0.139. The 16 percent value is the analyst's choice in this particular analysis.*

EPA Comment 100
Volume 4, page 7-13
Equation 7.3-2 appears to be in error. Based on information in Table 7.3-3, the correct formulation should be:

$$SF_{44} = 138.67/3.527 = 39.32$$

The text defines AL_i as the average activity level. According to Volume 3, Table 3.3-1, waste inventories are median values. Is AL_i actually a median activity level?

Response. *The release of activity level 4 at 3,000 years can be obtained by multiplying the average activity level release at 3,000 years by the following scaling factor:*

$$SF_{54} = 138.67/3.527 = 39.32$$

The average activity level was derived by dividing the total activity (based on the memorandum by Peterson in Appendix A of Volume 3 and compensating for decay) by the total surface area of CH waste. AL_i is not a "median" level but the total activity/m^2 at the designated time, based on the radionuclides shown in Table 7.3-1. AL_i is thus the average activity per square meter.

EPA Comment 101
Volume 4, page 8-30

Why has the relatively short half-life of Am-241 and decay to Np-237 not reduced the release of this nuclide to the accessible environment from that which is released to the Culebra?

Response. *Americium-241 should be reduced proportional to the amount of travel time in the Culebra. However, the postulated travel times of 10^2 to 10^3 years would reduce Am-241 ($t_{1/2}$ = 432 years) by about a factor of 3 at most.*

The statement in Volume 4, page 8-30, to the effect that releases to the accessible environment are essentially identical to releases to the Culebra was not intended to imply that decay of short-lived isotopes does not occur during the transport in the Culebra. The plot on page 8-31 shows that calculated releases to the Culebra vary over a range of nearly four orders of magnitude. Because the plot on page 8-31 is on a log-log scale covering quite a few decades, it is necessary to examine the figure closely to see that the calculated releases to the accessible environment are indeed less than the releases to the Culebra. For the vectors that featured the longest residence times in the Culebra, decay of the short half isotopes (which make up only a part of the total activity level) reduced the released activity level by as much as a factor of 2 or 3. However, there were only a very few such vectors, and compared to the four order of

magnitude spread in calculated releases to the Culebra even a factor of 3 reduction in the release to the accessible environment may look negligible.

EPA Comment 102

Volume 4, page 8-30

The inclusion of clay thickness in the Chemical Retardation, Clay-Lined Fractures, No Matrix Diffusion scenario is questionable. The sorption is assumed to be linear and non-reversible. Therefore, as long as clay is present, a retardation factor will be applied regardless of the thickness. Since there is no matrix diffusion, there is no means by which the radionuclides can reach the matrix to have a distribution coefficient applied for the dolomite which is different from that of the clay.

In addition, the assumption that clay-lined fractures (e.g., with corrensite) are common is very questionable - and is questioned by researchers even within Sandia. The presence of clay-lined fractures should be reconsidered.

Volume 4, page 8-44

In this section, there is no mention of varying clay thicknesses which should have been used in these simulations due to different diffusion rates and distribution coefficients for the clay lining and the dolomite matrix.

Response. *The WIPP Project is currently performing laboratory and field experiments to determine the presence and potential impact of clay deposits on radionuclide transport and retardation in the Culebra.*

EPA Comment 103.

Volume 4, page A-16

Pinch nodes should be added to the capability of SECO to avoid having to perform regional and local in a disjointed fashion.

Response. *Comment noted. Future PA modeling will use the CAMCON methodology to couple regional and local models.*

EPA Comment 104

Appendix C

The listings of LHS sampled variables in Table C-2 are useful for a serious reader interested in recalculating certain portions of the analysis. For the casual reader, a reference to the cumulative distribution plots of these sample variables provided in Figure 3-1 should be

included. Scatterplots of one variable versus the other should be provided for all uncertain variables which were assumed to exhibit pairwise correlation.

Table C 1 is garbled. The vectors are not ordered, and many vectors appear in the Table more than once with different discharges.

Response. *The graphical representation of the LHS sampling has not been included in Appendix C due to the number of scatter plots used in PA. However, Chapter 8 of Volume 4 includes a significant number of scatterplots which may assist in understanding the correlation of data.*

Table C-1 of Appendix C is a summary of the 49 variables discussed in Chapter 3 of this document. In this chapter, each variable is briefly summarized including identification of the distributions, vectors, and other relative references. After further review of Table C-1, we have been unable to identify repeated vectors or inconsistencies with the summaries in Chapter 3.

EPA Comment 105

Appendix C

Table C-5 is unclear. Why are three sets of 70 vectors shown in the table? Sub-headers such as in Tables C-6 and C-7 should be used to explain the different sets of vectors, if three sets are appropriate.

Response. *The presentation of data in the compliance certification package will be clarified as much as possible.*

EPA Comment 106

Hazardous Waste and the PA: Throughout PA

The 1992 PA does not include an evaluation of the influence of hazardous constituents in its analysis. What effect will these materials have on the transport and activity of radionuclides? Are there any synergistic interactions that can effect compliance? What experiments have been done to determine these issues? What are the plans for the future?

Response. *The commentor is correct: the 1992 PA does not include an evaluation of the influence of hazardous constituents in its analysis. However, it is expected that these materials will have no effect on the transport and activity of radionuclides. In theory, there could be an occasional alpha radiolysis of organic compounds, but it is believed that the compounds would then be reduced to non-RCRA compounds. The WIPP Project has not conducted specific experiments to address the above issues because there is an extensive literature on this topic. There are no plans to conduct experiments in this area in the future.*

EPA Comment 107

Probability Calculations: Volume 4, page 2-20, lines 5 & 18

Please include examples of how the probabilities are calculated for Tables 2.5-1 to 2.5-4.

Response. *A detailed description of the methodology for computing probabilities can be found in (Helton and Iuzzolino, 1993).*

EPA Comment 108

$2\pi r$ Relationship: Volume 4, page 4-7, line 6

This paragraph needs to be explained more clearly.

Response. *The $2\pi r$ relationship will be explained more clearly in future PA documentation.*

EPA Comment 109

More Unjustified Conclusions: Volume 4, page 5-18, line 22

Once again a conclusion is presented without justification or supporting data or calculations. However, if the porosity is as low as can be expected, 0.001, this brine would travel only 935m radially from the panel", this may be a simple question but how the 935m distance is calculated should be shown. Besides the range of MB139 porosity is from .001 to .03. What would the travel distance be for porosity = .03?

Unrealistic Initial Conditions: Volume 4, page 5-18, 5-33, 4-48

Using the assumption of an initial porosity of 19% to compare non-creep closure to creep closure results intuitively seems unreasonable. The results of unrealistically high peak pressures seems to invalidate the assumptions.

Response. *As shown in Figure 5.1-2 on page 5-4 of Volume 4, the radius of the waste panel was taken to be about 61 m and MB139 as modeled as being 0.85 m thick. A released volume of 2500 m^3 in a layer 0.85 m thick with a porosity of 0.001 will occupy the annular volume from 61 m out to a radius of about 970 m, which implies migration of about 910 m. The 935-m value was not quite right. A porosity of 0.03 would imply about 150 m migration radially beyond the waste panel.*

The fixed porosity case was run for the purpose of investigating the sensitivity of the PA results to the creep closure calculation. Using the fixed 19% porosity created a large excursion in repository pore pressure for the sensitivity analysis. The fact that assuming a constant 19%

porosity would not be realistic does not affect the process of assessing the sensitivity of the model.

EPA Comment 110
"Excellent Communication": Volume 4, page 5-28, line 22
Is "excellent communication another way of saying that brine will be flowing into the far field?

Response. *Yes, excellent communications refers to brine flow to the far field.*

EPA Comment 111
"Reference Conditions": Volume 4, page 5-31, line 14
What are "reference conditions? Are they standard temperature and pressure?

Response. *The reference conditions used in the pressure calculation are not Standard Temperature and Pressure (STP). Rather, the pressure is calculated using the calculated WIPP void volume and the (constant) WIPP temperature, 27 degrees Centigrade. The volume is derived from the time-dependent porosity surface calculation.*

EPA Comment 112
Four Vectors: Volume 4, page 5-31, line 27
What are the four vectors in "Only in four vectors was there any net outward flow of brine..."? These are the kind of results EPA needs to see in detail not in a summary statement.

Response. *This information will be included in the final compliance certification application.*

EPA Comment 113
Minimum Porosity: Volume 4, page 5-31, line 39
If the brine will travel in the MB139 no more than 500m with a porosity of 0.001, how far will brine travel with a porosity of 0.03 (the maximum allowable)?

Response. *The brine will travel 150 meters with an effective porosity of 0.03 (the maximum allowable). The overall radial flow distance will decrease because materials with higher effective porosities will entrain more brine. Note that a travel distance of 500 m is well within the 2,400 meter boundary limit.*

EPA Comment 114

Current Creep Closure Model: Volume 4, page 5-36, line 12

Once again a conclusion is drawn that may not be completely defendable and justified. It appears that the present creep closure model may not adequately model the effect.

Response. *Since the 1992 PA report was published, the MDCF creep model has been extensively validated against in situ data for room closure. The code does model the effect on transient behavior (such as waste pressures). The Rock Mechanics Position Paper (Munsen et al., 1995) presents details of the creep model and the validation calculations.*

EPA Comment 115

Vertically Integrated Model: Volume 4, chapter 6, page 6-2, line 2

Please clearly define a "vertically integrated two-dimensional model"? What advantages and disadvantages does it have? How realistic is it? Does it account for the results of test?

Response. *In this case, "vertical integration" means that the parameters in the model do not vary in the vertical direction; i.e., the hydrological properties are constant with aquifer elevation. Since the groundwater flow to the accessible environment is expected to be predominantly lateral (not vertical) through the relatively thin Culebra Dolomite Member, the horizontal hydrological parameter components are of primary interest. As noted in Chapter 6, most of the well test data that exist are for the lateral/radial properties of the Culebra aquifer. A "vertically integrated two-dimensional model," in this case, is simply a model that includes no vertical variation in properties values. This is consistent with aquifer tests in the Culebra which typically measure aquifer properties across the entire vertical extent of the aquifer at a point.*

EPA Comment 116

Potential Fluid Discharge into the Culebra: Volume 4, page 6-2, line 41

What is the basis for the assumption that fluid injected will have no effect on Culebra fluid density?

Response. *The basis for the assumption of minimal effect on groundwater flow from fluid injection into the Culebra is deduced from calculations of disturbance to natural flow fields found in SAND89-7069, pages 3-11 through 15. These calculations demonstrate that stream lines of flow become relatively straight and parallel a short distance from the borehole, showing that the velocities are about equal to the natural flow field. Likewise, this suggests little effect on Culebra fluid densities since magnitude and direction of flow are minimally changed.*

Additionally, Davies (1989), USGS open file report 88-490, studied natural variation in Culebra groundwater density and found density differences within the Land Withdrawal Boundary to be of low importance with respect to overall groundwater flow directions.

EPA Comment 117

Regional and Local Domains: Volume 4, page 6-4

The regional and local grids are significantly different, the size of the grid blocks (elements) are quite different. How are values at these grid boundaries passed from the local to the regional grids? Are they interpolated or "fit" in any way? What assumptions are used in these calculations? What effect do these assumptions have on the transmissivity fields. It is stated on page 6-11, line 15 that SECO-FLOW interpolates boundary condition for the local grid. Please explain how this is done and does it introduced any unusual effects in the results? Has this been tested in any way?

Response. *The information at the boundary of the local grid is obtained from the numerical solution for the regional grid by second-order accurate linear interpolation in space and time of heads. The property data (e.g., transmissivity) is obtained by conservative interpolation using the Dukowitz-Knupp algorithm. Thus the local grid boundary conditions are always Dirichlet (specified dependent variable) values of head (time-dependent values for the time-dependent regional grid problem). The result is that Darcy velocities (specific discharges) are preserved.*

The only "assumption" involved is that a coarse grid solution over a much larger area provides better (less constrained) boundary conditions for the local grid than the usual practice of setting no-flow boundary conditions. Virtually anything would be defensible as an improvement over the usual practice. The method used here has obvious advantages.

This method has been tested and exercised in many calculations. A revealing test involves over-plotting head contours in the same region of space obtained by both the regional and local grid solutions. When the grid resolution in both regional and local grids are comparable, the contour plots virtually overlay, as expected. When the local grid resolution is much higher, as intended in the concept and as used in the 1992 PA calculations, there is some difference. Most importantly, the head contour lines in the local grid solution vary smoothly and align with the regional grid solution at the boundary of the local grid, indicating no distortion from the interpolation procedure (again, as expected from the theory).

It is worth noting that transport calculations in the 1992 PA calculations (and in later WIPP PA calculations) do not extend across the local grid boundaries, i.e., the regulatory boundaries are inside the local grid. Thus, there is no question about the boundary conditions for the transport equations. This level of detail in the algorithm description was not included in the 1992 PA calculations for the obvious reason that it is inappropriate for an already

massive document on preliminary results. Examples of the overplots have been shown to EPA personnel during one of their visits to SNL.

EPA Comment 118

SECO-FLOW Regional to Local Grid Interpolation: Volume 4, page 6-11, line 15

You state that SECO-FLOW uses interpolation to establish boundary conditions for the local grid from the regional grid elements because the local grid elements do not exactly overlay the regional grid elements. What type of interpolation is used, linear? Does this process introduce any distortion into this pass of data? Has this effect, if any, been evaluated?

Response. *Please see the response to Comment 117.*

EPA Comment 119

Inconsistency in Hydrostatic Heads: Volume 4, page 6-26, line 13

The inconsistencies between the boundary conditions and the observed heads may be significant. What has been done to rectify this difficulties?

Response. *Please see the response to Comment 97.*

EPA Comment 120

Transmissivity: Volume 4, Chapter 6

The main explanations for high transmissivities in general at the WIPP site are: the lack of halite and reduced overburden that create fractures (Section 2.1.4 in LaVenue et al., SAND89-7068/1, Ground-Water Flow Modeling of the Culebra Dolomite; pages IV-47, IV-48 in Brinster, SAND89-7147, Preliminary Geohydrologic Conceptual Model of the Los Medaños Region Near the WIPP for the Purpose of Performance Assessment). These explanations are most valid west of the WIPP, but they fail to explain the high transmissivities in the southeast where the overburden is thicker and the halite is more intact. What is thought to be the reason for the high transmissivity in the southeast portion of the WIPP site, and could the high transmissivity extend further west of well H-11 to directly south of the site?

Response. *In reference to SAND89-7147, Preliminary Geohydrologic Conceptual Model of the Los Medaños Region Near the WIPP for the Purpose of Performance Assessment, the author states that transmissivity values taken from wells in the southeastern portion of the WIPP site are not reported to be high in terms of transmissivity values for the WIPP site. Referring to Figure III-16, page II-29 of SAND89-7147, distribution of halite in the Rustler Formation shows transmissivity values for wells in and around the WIPP site. Transmissivity values for wells southeast and south of the WIPP site have lower values than those to the west. It is concluded that the transmissivity values of well H-11 are a result of local effects.*

It does not appear that high transmissivity can extend further west of well H-11 to directly south of the site. Transmissivity values of wells directly south of the WIPP site show values approximately two orders of magnitude lower than well H-11 (such as the value of 3.0×10^{-7} Cabin Baby-1 versus the value of 2.9×10^{-5} for H-11). Further discussion of well H-11 can be found in SAND89-7147, pages IV-55 to IV-68.

EPA Comment 121

Transmissivity: Volume 4, Chapter 6

On Page 6-26 of Volume 4 there is a discussion of groundwater travel times (Section 6.8.3). The text states "The purpose of the groundwater-travel-time calculations described here is to characterize the transmissivity fields, not to predict the transport of radionuclides."

The approach that was taken in the PA uses GRASP-INV to solve the groundwater inverse problem as described by LaVenue and RamaRao (1992). In this publication the authors' state:

"In the earlier modeling efforts for the Culebra Dolomite aquifer (Haug et al., 1988, LaVenue et al., 1990), kriging was employed to address the spatial variability in transmissivity. In an effort in which only one calibrated field is to be produced, kriging becomes an obvious choice. Kriging provides an optimal estimate of the transmissivity at a point, i.e., the mean value. Simulated transmissivity values reproduce the fluctuation patterns in transmissivity, which may lead to extreme values in travel times. Thus simulated fields are useful to resolve the residual uncertainty not addressed by kriging."

This suggests that the approach that was used to create transmissivity fields for the PA would result in a greater range [extreme values] of possible travel times. It does not appear, however, that the transmissivity fields yield extreme travel time values or adequately describe the probable distribution of travel times.

The travel time results presented in Figure 6.8-6 indicate that the travel times range from approximately 9,000 years to 32,000 years. The histogram of travel times, from the ensemble of transient calibrated fields, does not appear to be consistent with the actual field data or with LaVenue's calibrated model (LaVenue et. al., 1990).

LaVenue et. al. (1990) performed a detailed model calibration that yielded an excellent correlation between observed and simulated events. Therefore, something appears intuitively wrong when LaVenue (1990) predicted travel times for the transient calibration of 14,000 years, and 75% of the travel times in the 1992 PA were greater than 14,000 years, while only 10 percent were less. Furthermore, the shortest travel time predicted in the PA was approximately 9,000 years, a difference of 5,000 years from the calibrated value, whereas, the longest travel time is approximately 32,000, or two and a half times greater than the calibrated model would have predicted. There does not appear to be a good reason as to why the longer

travel times are over represented. To further represent this point calculations have been included.

Response. *As stated in Volume 4 on page 6-26, line 43, "These travel times were calculated assuming advection of groundwater through a single-porosity medium without fracture flow..." Performance assessment calculates groundwater travel times assuming fracture flow conditions with porosities on the order of 1/100 of the values used for creating the calibrated transmissivities. This is a very conservative use of transmissivity fields which results in radionuclide travel times approximately 1/100 of those discussed in this section.*

EPA Comment 122

Transmissivity: Volume 4, Chapter 6

Figure 6.8-8 indicates that the majority of travel paths run southeast from their starting point near H-3 and run towards DOE-1 before taking a more southerly direction. The hydraulic properties of the majority of these paths would, therefore, best be described by hydraulic property data collected from wells H-1, H-3, DOE-1 and H-11. The transmissivity data, collected from these wells and tabulated in LaVenue et. al. 1990 are presented in Table 1.

The geometric mean of hydraulic conductivity measured from these wells is 22 m/y. The overall gradient of 0.0034 may be obtained from wells H-1 and H-11 (923.3 m -913.1 m -10.2 m), which are approximately 3000 meters apart.

The bend in the travel paths suggest a somewhat longer distance than a straight line approximation, and for most of the paths, 3250 m would be a reasonable estimate. Assuming an effective porosity of 16 percent, as was done in the 1992 PA, and applying Darcy's law, a groundwater velocity of 0.47 m/y was calculated which results in a travel time of approximately 6,900 years. If the shortest possible travel path was assumed the travel time would have been 5300 years. All of these assumptions are reasonable and yet, the shortest travel time predicted by the 1992 PA was 9000 years.

Table 1. Hydraulic Property Data for the Culebra Dolomite

Well No.	Transmissivity m^2/sec	m^2/yr	Hydraulic Conductivity m/yr
H-1	9.4×10^{-7}	29.64	3.85
H-3	2.5×10^{-6}	78.84	10.24
DOE-1	1.2×10^{-5}	378.40	49.14
H-11	3.1×10^{-5}	97.76	12.70

Response. *The shortest travel time predicted by 1992 PA was likely less than 100 years due to the use of a fractured media assumption for radionuclide transport.*

EPA Comment 123

Flowpath: Volume 4, Chapter 6.8

The southern and southeast quadrants are shown to have high transmissivities in Figures 6.8-2 and 6.8-3. Figures 6.8-8 and 6.8-11 show travel paths that veer southeast before turning south. Given that the flow model has numerous "calibration points" and the location of highly transmissive zones in the transmissivity figures, it would appear that a reasonable alternative conceptual model could include a dominant travel path that goes directly south from the repository site to the boundary, thus reducing the travel time needed to reach the boundary. Has this alternative model been considered in DOE's analysis?

Response. *The alternative model proposed by the commentor (i.e., flow directly south from the repository) is included through the stochastic variation of input parameters for the more general SECO-2D computational model. The flow paths shown in Figures 6.8-8 and 6.8-11 indicate a predominant southeast and south flow direction from the repository. These paths correspond to the 70 transmissivity field realizations performed as a part of the analysis described in Section 6.8. The flow paths are based on SECO-2D calculations performed with different transmissivity fields and on the hydraulic head measurements made in surrounding observation wells (i.e., calibration points). Depending on the realizations performed, some of*

the flow paths are directed due-south from the repository. These flow paths, as well as all other computed flow paths, are used to evaluate the groundwater travel times shown in Figure 6.8-9. There is no need for a special model within the probabilistic framework of the PA.

EPA Comment 124

Spalling form Borehole Wall: Volume 4, page 7-1, line 18

What is the progress of the work to include spalling of the borehole wall? What knowledge was gained from the laboratory work?

Spallation needs to be incorporated into the modeling.

Variables Not Defined: Volume 4, page 7-9, line 53

Variables Q and R_i are not defined.

Assumptions Not in PA: Volume 4, page 7-10, line 32

Modeling assumptions and approaches should be included in the PA/Application. Information of this importance should be included not referenced.

Response. *Preliminary models for spalling and erosion of the borehole wall have been developed and are being revised and improved. Laboratory testing has been ongoing since 1994. The current status of the spallation model is described in the Disposal Room Position Paper (Butcher et al., 1995).*

The omission of definitions for Q and R_i and the comment regarding modeling assumptions will be taken into consideration so that a more complete presentation can be made in future documents.

EPA Comment 125

Volume 4, Page 1-2, Line 21

Uncertainty and sensitivity analysis also identify and direct experimental areas which can reduce uncertainty in PA results.

Volume 4, Page 1-3, Lines 9 & 10

This paragraph states that radionuclide transport was not modeled in the undisturbed scenario, because other results indicated that brine which was in contact with the waste did not reach the accessible environment during the 10,000-year regulatory time-frame. The decision not to model radionuclide transport seems logical provided that the incorporation of the radionuclides (and/or other waste constituents) will not increase the brine transport rate, e.g., mobilization of metals by leachate containing solvents.

Response. *The DOE is currently using uncertainty and sensitivity analyses to identify experiments that can reduce the uncertainties in PA. The 1992 PA and SPM-2 have been used to identify those experiments needed to reduce the uncertainty for demonstration of compliance.*

The concentrations and chemical reactions of the radionuclides will not increase brine transport to the unit boundary. Hence the use of brine travel time to limit radionuclide transport seems appropriate.

92PA EPA Comment 126

Volume 4, Page 3-1, Lines 32 to 35

Section 2.3.1 does not provide enough information regarding this variable. Please provide some additional clarification.

Volume 4, Page 3-2, Lines 17 to 19

Section 3.4.3 does not provide any discussion regarding this variable and the basis for determination of the range and median. Since the values were determined completely by investigator judgement (with no additional data sources), it would be helpful to know how the PA investigator determined the values.

Response. *The compliance certification package will contain an appendix, probably called PARameters, that will define all variables for the PA.*

With reference to the comment concerning Volume 4, page 3-1, line 32-35, the variable BCFLG is a pointer variable of characteristic curves for capillary pressure and permeability. The parameters used for these calculations are arbitrary with the initial ranges selected for the purpose of being able to run sensitivity studies. The ranges of the parameters for the model which supports generation of this variable were estimated using natural-analog data from materials which contain the same characteristics (permeability and porosity) as anhydrite, halite, and the waste room.

EPA Comment 127

Volume 4, Page 3-3, Line 8

Please clarify how the Culebra matrix porosity is used in BRAGFLO.

Response. *The Culebra matrix porosity was not used in BRAGFLO for the 1992 PA. Table 3-1 (CULPOR) should be changed by eliminating the reference to BRAGFLO to reflect this fact.*

EPA Comment 128

Volume 4, Page 3-4, Lines 19 to 33

Supporting information regarding the selection of range and median values for these variables should be provided in Volume 3, rather than referenced.

Volume 4, Page 3-6, Lines 28 to 35

Supporting information regarding the selection of range and median values for these variables should be provided in Volume 3, rather than referenced.

Response. *The compliance certification package will contain appropriate information regarding the selection of range and median value for PA variables.*

EPA Comment 129

Volume 4, Page 4-4, Lines 13 to 17

Please note that Figure 4.1.2 also shows the Unnamed Member. Given that the basal interval of the Unnamed Member contains siltstones and sandstones having a sufficient transmissivity to allow groundwater flow (Page 2-16, Volume 2, 1992 PA), it does appear that the Unnamed Member should be considered. Please clarify why the Rustler/Salado Residuum has not been included. Page 2-12 of Volume 2 of the 1992 PA states that in the shafts excavated at WIPP the residuum shows evidence of channeling, filling, fossils and bioturbation indicating some past dissolution occurred prior to deposition of the Rustler Formation (Holt & Powers, 1988). In addition, it is EPA's understanding that DOE has stated that vertical flow from the Residuum may be upward and into the Culebra Member.

Response. *Transmissivity values of the Culebra Dolomite range from 10^{-7} to 10^{-3} m^2/s. By contrast, the transmissivity values of the unnamed lower member is generally less than 6×10^{-10} m^2/s.*

The difference between the hydraulic head potentials in the units indicates drainage is very slow. Water levels take months to years to stabilize in wells completed in low-transmissivity zones such as the unnamed member. At the site, the relative head potentials between the Magenta and Forty-niner Members indicate that there is no modern vertical recharge from the Dewey Lake Red Beds into any portion of the Rustler Formation below the Forty-niner member. West of the site however, the decreasing difference between the Magenta and Culebra heads may indicate a combination of westward and downward drainage of the Magenta Dolomite.

From a hydrostratigraphic point of view, the bottom several feet of the unnamed member, consisting of anhydrite/gypsum, polyhalite and halite, represents a confining bed indistinguishable hydraulically from the underlying Salado Formation. The lower siltstone unit of the unnamed member (the transition zone and bioturbated clastic interval of Holt and

Powers {1988}) can be considered to be the lowermost Rustler water-producing zone, and the overlying halite and anhydrite/gypsum units act as another confining bed. The top unit of the unnamed member is composed of siltstone, mudstone and claystone. The PA for the final CCA will model the five members of the Rustler discretely.

EPA Comment 130
Volume 4, Page 4-8, Lines 19 and 23
Please provide the basis or reference for the assigned permeability values given for DRZ and waste. Please clarify if all the permeability values/ranges given in Lines 8 through 23 are intrinsic permeability.

Response. *Tests have been performed on simulated unprocessed waste with compaction of the material to full lithostatic pressure. Permeabilities were found for compacted combustible wastes, metals and glass, and sludges. Mean permeability was estimated based on a weighted volume average for these waste categories. The calculation of the range and median for the permeability of the waste can be found on page 3-130 in Volume 3 of the 91 PA document, SAND90-0893.*

Information on permeabilities for disturbed halite and anhydrite can be found in Volume 3, pages 2-36 and 2-61 of SAND92-0700. The value given for the DRZ on page 4-8 of Volume 4 is the same as that for disturbed anhydrite on page 2-61 of Volume 3. This value is an arbitrary (but conservative) choice made by SNL in the absence of specific information at the time of the 1992 PA. Values in the Table are for intrinsic permeability.

EPA Comment 131
Volume 4, Page 4-8, Line 37
Please correct the referenced section to Section 5.1.2.1.

Response. *Reference section will be corrected. Thank you.*

EPA Comment 132
Volume 4, Page 4-11, Lines 1 to 25
Please provide references for all values shown. In addition, clarify if the porosity values given here are total, effective, matrix, and/or fracture porosity.

Response. *The porosity values given on the cited page are total porosity values for the undisturbed case. In the BRAGFLO model, total porosity equals effective porosity, so the values are also the effective porosities. Matrix and fracture porosity components are not delineated on the cited page. In this analysis, the porosity values are time-independent.*

The porosity values for the undisturbed case are described in additional detail in Volume 4, Table 3-1 and Volume 3. In Volume 3, Salado (halite) porosity is described and source documents referenced in Section 2.3.7. In Volume 3, the Salado anhydrite interbed porosity is described and source documents referenced in Section 2.4.4.

EPA Comment 133
Volume 4, Page 5-1, Line 25
Should this sentence reference Figure 5.1-1 rather than Figure 4.1-1?

Response. *Yes.*

EPA Comment 134
Volume 4, Page 5-3, Lines 8 to 16
Please clarify why Figure 5.1-2 does not also show the Unnamed Member of the Culebra as does Figure 4.1.2. Again, as stated in an earlier comment regarding the use of BRAGFLO to model the undisturbed conditions, it does appear appropriate to consider inclusion of the Unnamed Member in the modeling grid. Please clarify why the Rustler/Salado Residuum has not been included. Please see the comment concerning Volume 4, Page 4-4. Lines 13-17.

Response. *Figure 5.1-2 does not show the Unnamed Member of the Culebra because the 1992 PA did not directly model this stratum. The rationale for eliminating the Unnamed Member from the model is discussed in the response to Comment 129. The PA for the final CCA will model the five members of the Rustler as discrete units.*

EPA Comment 135
Volume 4, Page 5-5, Lines 20, 24, and 26
Please provide the basis or reference for the assigned permeability values given for DRZ, waste and Castile brine reservoir. Please clarify if all the permeability values/ranges given in Lines 13 through 26 are intrinsic permeability.

Response. *Permeabilities for the DRZ, waste and Castile brine reservoir are addressed in Volume 3, Section 3.2, Volume 3, Section 3.4, and Volume 3, Section 4.3 respectively. The permeability values/ranges given in Lines 13 through 26 are intrinsic permeabilities.*

EPA Comment 136

Volume 4, Page 5-7, Lines 1 to 4

This section states that BRAGFLO uses intrinsic permeability rather than hydraulic conductivity for Culebra Member. Is the use of intrinsic permeability in BRAGFLO exclusive to the Culebra Member or is it used for the other strata as well?

Response. *The use of intrinsic permeability in BRAGFLO is not exclusive to the Culebra Member. In BRAGFLO, the intrinsic permeability and fluid viscosity are represented discretely in the groundwater flux equation. For additional information, refer to the DCCA, Appendix BRAGFLO: Two-Phase Flow.*

EPA Comment 137

Volume 4, Page 5-7, Lines 35 to 42

Please provide references for all values shown. In addition, please clarify if the porosity values given here are total, effective, matrix, and/or fracture porosity.

Response. *The porosity values given on the cited page are total porosity values for the disturbed case; this is similar to the values for the undisturbed case (see Comment 132). In the BRAGFLO model, total porosity equals effective porosity, so the values also are the effective porosities. Matrix and fracture porosity components are not delineated on the cited page.*

The porosity values for the disturbed case are described in additional detail in Volume 4, Table 3-1 and Volume 3. In Volume 3, Salado (halite) porosity is described and source documents referenced in Section 2.3.7. In Volume 3, the Salado anhydrite interbed porosity is described and source documents referenced in Section 2.4.4.

EPA Comment 138

Volume 4, Page 5-9, Lines 30 & 31

This section states that the relative permeability parameters are varied and are the same for all materials except the waste and the DRZ. How can the parameters be varied and the same? In addition, please note that the comment made addressing Page 4-26, Lines 4 to 7 would also apply here.

Response. *The wording of the section leads to a confusing statement. The statement may be said more accurately as: "Relative permeability parameters are varied in an identical way for all materials..." That is, the same method of variance was used for relative permeability parameters for all materials.*

EPA Comment 139

Volume 4, Page 6-2, Lines 5 to 15

This paragraph introduces the assumption that vertical flow is not occurring (or is occurring too slowly to be significant) between the Culebra and the overlying (Tamarisk) and underlying (Unnamed) members of the Rustler Formation as well as between the Culebra and the Rustler-Salado Residuum. The information provided on page 2-34 of Volume 2 is not detailed enough to substantiate this assumption. Please provide a more detailed discussion regarding supporting information for this assumption. In addition, please specify and discuss the laboratory and/or field data which will be used to support the regional hydrologic modelling proposed here.

Response. *The following is a summary of several descriptions included in the 1992 PA reports:*

Reference is made to Haug et al., 1987 and Davies, 1989 in Volume 2 (page 2-30) for additional information on the no vertical flow assumption. Brinster (1991) and Beauheim (1987a) present analyses of vertical hydraulic gradients on a well-by-well basis. These analyses suggest that, if flow occurs, the direction of flow between the Magenta and the Culebra is downward through the WIPP area. Directly above the repository, flow may be upward from the Rustler-Salado residuum to the Culebra Dolomite. Elsewhere in the region, both upward and downward flow directions exist between the two units.

The Salado Formation has very low permeabilities. Table 2.4.2 of Volume 3 (page 2-59) provides a summary of measurements of Salado anhydrite interbeds. Figures 2.4-2 and 2.4-3 provide permeability distribution data used in the 1991 and 1992 PAs. Permeability of the anhydrite layers is on the order of 10^{-19} to 10^{-21} m^2. These permeabilities will result in very limited flow. This is further substantiated by the very limited seepage conditions which occur in the Salado Formation today, as observed directly in the WIPP underground facility.

b) As noted in Volume 4 on page 6-2, the validity of the assumption that leakage between the Culebra and the over-and underlying-units can be neglected is uncertain. The WIPP Project is currently performing three-dimensional, regional hydrological modeling to evaluate the importance of vertical fluxes between the Culebra and adjacent strata. In addition, single and multiwell conservative tracer tests are planned to evaluate the effects of heterogeneity, anisotropy, and layering on transport (Sattler, A.R., 1995).

EPA Comment 140

Volume 4, Page 9-4, Lines 10 to 44

This discussion states that regression analyses indicates that Salado halite and anhydrite permeabilities are considered important parameters with respect to the total projected releases from WIPP. The discussion further states that the uncertainty in the permeability values can

be decreased with continued in-situ investigation. SAND93-1197 indicates that the experimental values will not be available until December 1996. In light of the accelerated compliance schedule, has the experimental schedule been revised to allow an earlier incorporation of the measurements into the PA calculations?

In addition, since this experimental program is initially focusing only on the anhydrite interbreeds, has a determination been made as to whether or not to expand the program to encompass both impure and pure halite?

Response. *Following the SPM-2 iteration, the schedules of all high priority experimental activities have been revised to allow input of new data to the PA models by March, 1996. These high priority experimental activities include laboratory testing and in situ field testing for hydrological and transport properties of the Culebra. However, further permeability testing for both pure and impure halite is not planned because repository performance appears insensitive to the uncertainty in Salado permeabilities.*

EPA Comment 141

Volume 4, Page 9-8 and 9-9, Table 9-3

Capillary pressure and relative permeability parameters (Brooks-Corey/van Genuchten-Parker parameters) are listed in this Table as being less important parameters with respect to compliance for the disturbed performance scenarios. SAND93-1197, however, indicates that threshold displacement pressure, one of the capillary pressure/relative permeability parameters, may be an important parameter. Page 10 of that report states that the uncertainty in the threshold displacement pressure values for the Salado rock is large and may prevent a clear prediction of repository behavior in both the undisturbed and disturbed scenarios. Please clarify.

Response. *The referenced report (Howarth, 1993) concerns the Salado Two-Phase Flow Laboratory Program. One of the objectives of this program is to quantify the Salado anhydrite rock and flow parameters that describe the ability of the Salado to transmit and store brine and gas as a function of the initial conditions and time-dependent material damage.*

The flow of waste-generated gas from the repository is predicted to be controlled by three physical properties of the Salado: (1) pore fluid pressure, (2) threshold displacement pressure, and (3) gas-brine relative permeability. The permeabilities of both halite and anhydrite were very important parameters in the 1992 PA as shown in Table 9-3 (WIPP 1992 PA, Vol. 4). Since neither threshold pressure nor relative permeability for the Salado had been measured before the 1992 PA, the Brooks and Corey and van Gnuchten-Parker correlations were used to model these parameters. These two models are based on capillary relationships from a sandstone core from which wetting phase relative permeability is derived.

Whereas it is true that there is uncertainty associated with not having measured two-phase properties, PA has developed an approach for addressing this uncertainty based on sampling the van Genuchten-Parker and Brooks-Corey sets of equations and their associated parameters. This approach provides a rational means of predicting repository behavior in both the undisturbed and disturbed scenarios. In effect, the importance of reducing uncertainty for performance assessment (as established by ranking the sensitivty of compliance against other parameters) is not necessarily the same as stated for the scientific studies described in SAND93-1197.

EPA Comment 142

Volume 1, Page 1-1, Lines 35 to 45

This section should be updated to discuss the Experimental Program Plan, rather than the Test Phase Plan.

Volume 1, Page 1-2, Lines 1 to 7

This section should be updated to discuss the Experimental Program Plan, rather than the Test Phase Plan.

Volume 1, Page 1-2, Lines 9 through 11

This paragraph states that the results of laboratory and field studies conducted during the Site Characterization Phase form the basis for the data used in the PAs. It is EPA's understanding that the Site Characterization Phase was not conducted under the same level of quality assurance currently employed by DOE today. It is also EPA's understanding that DOE recently has evaluated the quality of the data collected during the Site Characterization Phase. Since so much of the PA is based on this data, it would be helpful if a discussion of the quality evaluation results were included here.

Response. *Following the SPM-2 iteration, the scientific activities for the WIPP Project have been refocused on those high priority activities that are required for a successful compliance certification application. The Experimental Program Plan, which was written before the SPM process began, is now obsolete and will not be reissued by the CAO. Rather, individual Test Plans for the eight high-priority scientific activities have been or are being developed by SNL.*

The CAO is aware that the Site Characterization Phase was not conducted under the same level of quality assurance currently employed by DOE today. A QA process has therefore been established to evaluate and requalify these old data using independent technical review (ITR) teams. The results of the reevaluations by the ITRs will be discussed in the CCA.

EPA Comment 143

Volume 1, Page 1-8, Lines 30 to 36

DOE may wish to note here or in subsequent chapters of the PA (e.g., Volume 3, Chapter 3, Page 3-68) that additional generator/storage facilities may be sending TRU and mixed TRU waste to WIPP for disposal. For example, Volume 2 of the April 1993 Interim Mixed Waste Inventory Report states that DOE also plans to ship to WIPP wastes generated by the Energy Technology Engineering Center located in California (waste volume currently in storage reported as 2.32 m^3) and the Argonne National Laboratory-West located in Idaho (waste volume currently in storage reported as 0.59 m^3 and waste volume to be generated reported as 2.15 m^3).

Response. *Updated versions of the PA will include waste inventories defined by the WIPP Transuranic Waste Baseline Inventory Report (WTWBIR). This report is an aggregate representation of all the currently stored, projected and scaled inventories scheduled to be shipped to WIPP during the disposal period. Several smaller generators may also ship wastes to WIPP, assuming all acceptance criteria are attained. However, most of the smaller generators will ship their wastes to the larger facilities for certification and transport to WIPP in the TRUPACT II containers.*

EPA Comment 144

Volume 3

It would be extremely helpful if either the PA or the EPP had identified the experimental studies which are intended to reduce the uncertainty of the parameters identified in Volume 3.

As stated before in the January 1994 comments, the process of identifying each input parameter and their values, each variable input parameters and their distribution should be addressed in detail.

Response. *Following the SPM-2 iteration, the scientific activities for the WIPP Project have been refocused on eight high priority activities that are required for a successful compliance certification application. In general, these eight activities will also reduce the uncertainty in the critical parameters and in the CCDFs themselves.*

The CCA will provide complete documentation of input parameters, including their values and/or distributions and the sources for the data. Appendix PARamters in the DCCA is the first draft of this documentation for the WIPP Project.

EPA Comment 145
Volume 3, Page 1-21, Lines 3 to 5
This section states that most of the 49 sampled parameters were assumed to be independent random variables even though some was known to be dependent upon others. What efforts have been made since the drafting of the 1992 PA or will be made in the future, to correlate appropriate parameters (e.g., porosity, permeability, transmissivity, storativity, hydraulic conductivity)? If such correlation is not planned, please discuss to what extent this lack of correlation of known dependent parameters will have on the credibility of the current PA modelling results.

Response. *Where correlations were known in the 1992 WIPP PA, they were described in Table 3-1, Volume 4. However, there were very few correlations. Where correlations in sampled parameters are known, they will be reflected in the next PA iteration. It is thought that the lack of correlation between known dependent parameters will have the effect of making any performance assessment overly conservative because dependent variables will be modeled as independent variables.*

EPA Comment 146
Volume 3, Page 2-3, Figure 2.1-3
This map is intended to show topography, well location and modeling domains. Yet, the scale is not large enough to provide such information in an usable fashion. A topographic map as described in 40 CFR Section 70.14(b)(19) of EPA's RCRA regulations would be more useful for discerning topography and well locations.

Response. *We believe the scale used in this map is appropriate because of the largeness of the domain discussed in this volume.*

Similar information can be found in Figure 3 in SAND88-7002 (Figure 3.1); Figure IV-14 in SAND89-7147; and Figure 3 in SAND93-2266. The first two maps listed above may require some updates to reflect the subsurface mine/unit and any proposed wells/borings.

An appendix containing all borings within the WIPP site boundary is found in the DCCA, March 1995. DOE has identified over 118 holes for this appendix. The CCA will contain additional maps as required.

EPA Comment 147
Volume 3, Page 2-6, Figure 2.2-2
The title of this figure is "Reference local stratigraphy near repository." It is recommended that the word "local" be deleted from the title. The intent of this figure and its derivation is explained in Volume 3, but is not explained prior to the figure's presentation in earlier

volumes of the PA (Volume 1, Page 2-10, Figure 2-5 and Volume 2, Page 2-43, Figure 2-20a). In addition, it is assumed that the elevations are in reference to meters above mean sea level. Also, it should be noted that "Halite" is missing from the legend and that a well location map would be useful in interpreting this figure.

Response. *The word "local" was used because the stratigraphy is that which surrounds room D in the WIPP underground. The reviewer's assumption is correct that the elevations stated are meters above mean sea level. The legend for halite was inadvertently omitted; it will be included in future versions of this figure. Since the stratigraphy is local (around room D in the WIPP facility), a well location map would not be necessary because there are no wells drilled from the surface in the immediate area of room D.*

EPA Comment 148

Volume 3, Page 2-12, Lines 3 to 27

This section states that the capillary pressure and relative permeability parameters (i.e., residual wetting (brine) phase saturation) have not been experimentally determined for the Salado halite (permeability of 10^{-19} to 10^{-24} m^2) or anhydrite (permeability of 10^{-16} to 10^{-21} m^2). Instead, measurements from a low permeability sand (permeability of 10^{-16} to 10^{-19} m^2) have been used since such measurements have not been made for other material with a lower permeability. Since sand has a relatively high porosity, it is assumed that the sand referenced here, is actually a cemented sandstone or perhaps a quartzite. Please state the possible implications or effects of using an analog having a higher permeability and different physical and chemical properties than halite and anhydrite. SAND93-1197 notes that the analog values were developed from only one core sample and that the validity of these values for use with respect to Salado rock has not been experimentally justified. Such information should be provided in the PA. This is particularly important in view of the statement made on page 10 of SAND93-1197 that the uncertainty in the threshold displacement pressure values for the Salado rock is large and may prevent a clear prediction of repository behavior in both the undisturbed and disturbed scenarios.

Response. *The possible implication of using an analog having a higher permeability and different physical and chemical properties than halite and anhydrite is that the calculations might represent a condition that is not realistic for WIPP. DOE has allowed for this possibility by attaching a wide range of uncertainty to the tight gas sand analogue measurements. This uncertainty is manifest in the PA approach by using both equation sampling (Brokes-Corey versus van Genuchten-Parker) and parameter sampling (S_l S_{gr}, λ, P_t).*

EPA Comment 149
Volume 3, Page 2-12, Lines 3 to 27
It is EPA's understanding that the Salado Two-Phase Flow Laboratory Program was established to provide measurements of threshold pressure, relative permeability, capillary pressure, rock compressibility, total and effective porosity, intrinsic permeability and core damage assessment for the Salado anhydrite. Such measurements will decrease the level of uncertainty of the parameters discussed here in Volume 3. SAND93-1197, however, states that the data results and reports will not be available until December 1996. In light of the accelerated compliance schedule, has this laboratory program schedule been revised to allow an earlier incorporation of the measurements into the PA calculations? In addition, since this laboratory program is initially focusing only on the anhydrite interbeds, has a determination been made as to whether or not to expand the program to encompass both impure and pure halite?

Response. *Following the SPM-2 iteration, the schedules of all high priority experimental activities have been revised to allow input of new data to the PA models by March, 1996. These high priority experimental activities include laboratory testing and in situ field testing for hydrological and transport properties of the Culebra. However, further testing under the Salado Two-Phase Laboratory Program is not planned because repository performance appears insensitive to the uncertainties in hydrological parameters in the Salado anhydrite and halite.*

EPA Comment 150
Volume 3, Page 2-12, Lines 3 to 27
It also would be helpful, if the PA referenced the experiment proposed to reduce uncertainty for particular parameters. This would alert the reviewer that DOE anticipates reducing the uncertainty associated with particular parameters and would enhance credibility of future modelling results. For example, the parameters provided in this section of Volume 3 have not been measured for the Salado halite and anhydrite, necessitating the use of natural analogs. The EPP notes that three of these parameters are proposed to be measured for future PA calculations. These parameters are threshold pressure, relative permeability and porosity. SAND93-1197, discusses, in greater detail, these same parameters and 4 additional parameters which will be addressed in the Salado Two-Phase Flow Laboratory Program. Providing the reviewer the information that the parameters will be measured at a future data will elicit less criticisms regarding the use of analogs.

Response. *The CAO has recently identified eight scientific activities that are critical for demonstrating compliance. The selection of these activities is based on programmatic and schedule considerations, input from the WIPP scientific advisor (SNL) and the results of the SPM-2 iteration. The EPA and stakeholder groups have had extensive input into this selection process, primarily through technical interchanges and review of the Position Papers during the*

SPM process. The relevant Position Papers, which describe the experimental programs in general terms, are supported by detailed Test Plans that have been or are being prepared for individual experiments. As noted in the response to Comment 149, further testing under the Salado Two-Phase Laboratory Program is not planned because repository performance appears insensitive to the uncertainties in hydrological parameters in the Salado anhydrite and halite

In addition to the Position Papers, the CAMCON data base and code interrelationships (described in Volume 2, Section 3.1, page 1-3) provides the data management relationships between the PA models and the reference material properties databases. PA/QA is extending the data management interfaces to the source documents which contained the initial data for the material properties and to tests, experiments, and other analyses that are planned to reduce the uncertainty of the stated parameter values (described in the PA reports).

EPA Comment 151

Volume 3, Page 3-29, Lines 17 to 33

Pursuant to the Integrated Data Base, 70 radionuclides have been identified as known components of CH TRU waste. Of these 70 radionuclides, 23 are considered to be the primary radionuclides in the CH TRU waste inventory. These 23 radionuclides are being used in calculating the cuttings radionuclide releases resulting from human intrusion and in calculating the radionuclide concentrations within the repository prior to transport into the Culebra. Only 9 of the 23 radionuclides are being used to calculate transport within the Culebra. There should have been a more complete discussion on the rationale behind this. Is the decrease in the number of radionuclides being considered in the calculations due to radioactive decay and assumptions regarding the length of time it will take for the release to reach the Culebra?

Response. *WIPP calculations use eight radionuclides for calculating release values, not nine as indicated in the comment. These eight radionuclides are selected on the basis of their contribution to the total radioactive material inventory that is available for transport. The primary selection parameters are the quantity of the material in the waste and its half-life ($t_{1/2}$). The release quantities for the eight radionuclides are adjusted through decay calculations using the PANEL code.*

In general, a radionuclide with a $t_{1/2}$ of less than 20 years is not included in the analysis. However, if there is a large quantity of radionuclide or if there may be significant in-growth due to radioactive decay of other radionuclides, it may be included (such as Curium with a $t_{1/2}$ of less than 20 years). The change in the amount of radionuclides over time is also factored into this selection process.

EPA Comment 152
Volume 3, Page 4-8, Line 44
Please clarify why 0.0889 was selected.

Response. *This value (0.0889 meters, or 3.5 inches) was chosen to reflect uncertainty about the diameter of future oil and gas boreholes. It corresponds to the difference in diameter today between standard gas holes at the WIPP horizon (14 inches) and the largest diameters in the region (17.5 inches), generally used at higher horizons.*

EPA Comment 153
Assurance Requirements
The language in 40 CFR part 191 says that active institutional controls are not to be considered for more than 100 years. It does not state that active controls can automatically be considered for 100 years. There is an implied burden on the applicant to justify the effectiveness of such controls for any period of time up to 100 years. DOE needs to describe in some detail its plans and commitments for providing active institutional controls which will be effective in precluding inadvertent human intrusion during the 100-year period after disposal.

In the 1992 PA, SNL states that credit for 100 years of active institutional controls is taken by assuming that no intrusions occur during that period (for example, SAND 93a, p. 2-21 or SAND 92a, p. 5-18). However, many of the diagrams presented in Appendix D, SAND 92c show non-zero intrusion rates. DOE needs to clarify how the period of assumed active institutional controls was actually treated.

Response. *DOE's plans and commitments for institutional controls are outside the limits of the 1992 PA. Further information on these plans and commitments for institutional controls can be found in the response to Comment 5.*

The 1992 PA assumes no intrusions during the 100-year institutional control period.

EPA Comment 154
Inventory and Area of Repository: Volumes 3 and 4 and the February 1994 Presentation
According to the February, 1994 presentation by Harold Iuzzuloni the WIPP inventory as modeled is assumed to be homogenized with an activity per square meter of about 37.89. This number comes from 4.226 million Curies divided by 0.115 km^2, the area of the repository. $(4.226 \times 10^6 \text{ Ci})/.111520 \times 10^6 \text{ m}^2) = 37.9 \text{ Ci/m}^2$. However, in Volume 4, the area of the repository used for drilling rate calculations is 0.126 km^2. $(4.226 \times 10^6 \text{ Ci})/.126 \times 10^6 \text{ m}^2) = 33.5 \text{ Ci/m}^2$.) The only place areas are listed is Table 7.3-3 on page 7-15 of volume. Even in the table, it is not easy to understand the reasoning for the different areas, making it difficult to reproduce analyses in the PA. Unclear information such as this could be grounds for considering an application incomplete.

Response. *The activity per square meter is based on the floor space of the repository (0.115 km^2). The area of the repository for drilling rate calculations equals the area of the floor space plus the area for the RH-TRU waste canisters, which are emplaced in the walls of the emplacement rooms and access tunnels.*

Inventory

Volume 3, p. A-138

Given the information in Table 2 on page A-138 and the limited discussion on its development (and use), it is not possible to reconcile Table 2 with the 4,225,000 curie inventory in Table 1 on A-137. Using the numbers provided in the table (p. A-138), the projected total curies is between 650,000 and 36 million curies, with an average drum equivalent curie content of between 0.8 and 6 curies. One set of our calculations is close to the 4.2 million curies used in the PA analyses, but it was still off by 5% at the closest. A discrepancy in the inventory and its use has implications in potential releases from the repository, especially releases to the surface from drilling. The uncertainty in the inventory and its distribution within the repository should be more closely analyzed. EPA should be able to reproduce DOE's calculations, and so it will be necessary for DOE to provide a clear discussion and a traceable set of calculations. For example, the 8.22 box to drum ration was not with the inventory information in Peterson's memo in Appendix A.

Estimates of Currently Stored and Future Projected TRU Waste
Calculated As Listed in Table 2, A-138

Total Drums	Lowpt. Ci/drum	Weighted Avg.	Total Drums	Midpt. Ci/drum	Weighted Avg.	Total Drums	Hipt. Ci/drum
207,371	0	0	207,371	0.25	0.07	207,371	0.5
55,380	0.5	0.04	55,380	0.75	0.05	55,380	1
294,292	1	0.38	294,292	5	1.92	294,292	10
91,048	10	1.19	91,048	15	1.78	91,048	20
95,744	20	2.50	95,744	60	7.50	95,744	100
21,928	100	2.86	21,928	550	15.75	21,928	1000
Total Drums	Average Activity (Curies)	Total Activity (Curies)	Total Drums	Average Activity (Curies)	Total Activity (Curies)	Total Drums	Average Activity (Curies)
765,813	7.0	5,340,620	765,813	27.1	20,736,231	765,813	47.6

Estimates of Currently Stored and Future Projected TRU Waste
Curie Activity in Boxes Were Divided by 8.22 to Get DrumEquivalent

Total Drums	Lowpt. Ci/drum	Weighted Avg.	Total Drums	Midpt. Ci/drum	Weighted Avg.	Total Drums	Hipt. Ci/drum
207,371	0/8.22 = 0	0.0	207,371	0.25/8.22 = 0.01	0.01	207,371	0.5/8.22 = 0.06
55,380	0.5/8.22 = 0.06	0.0	55,380	0.75/8.22 = 0.01	0.01	55,380	1/8.22 = 0.12
294,292	1/8.22 = 0.12	0.05	294,292	5/8.22 = 0.61	0.23	294,292	10/8.22 = 1.22
91,048	10/8.22 = 1.22	0.14	91,048	15/8.22 = 1.82	0.22	91,048	20/8.22 = 2.43
95,744	20/8.22 = 2.43	0.30	95,744	60/8.22 = 7.3	0.91	95,744	100/8.22 = 12.17
21,928	100/8.22 = 12.17	0.35	21,928	550/8.22 = 66.91	1.92	21,928	1000/8.22 = 65
Total Drums	Average Activity (Curies)	Total Activity (Curies)	Total Drums	Average Activity (Curies)	Total Activity (Curies)	Total Drums	Average Activity (Curies)
765,813	0.8	649,710	765,813	3.3	2,522,656	765,813	5.8

92PA EPA Comment 155

Inventory: Volume 1, page 2-16, ¶1

States that "...all analyses [involving the inventory] will be based on current projections of a design volume inventory, estimated at about 532,500 drums and 33,500 boxes of CH-TRU waste." At 1 box = 8.22 drum equivalents, this totals 807,870 drum equivalents, yet the PA analysis apparently uses 765,813 as described in volume 3 page A-138 and the 11/12/92 note that Harold Iuzzolino used in his presentation at the February, 1994 technical exchange.

In a previous PA (SAND90-2347) SNL has estimated that the capacity of the WIPP is as much as 863,000 drum equivalents and about 10,000,000 curies (and nearly 12 million curies in the 1991 PA). The current PA uses an estimate of 765,813 drum equivalents and 4,226,000 curries. What is expected to be the maximum number of drums and activity level? These numbers should be made final for a draft application. These may be especially important in determining how large the repository will be because different activity levels may require different loading management approaches. This is in turn could affect the area of the repository.

Response. *The WIPP facility is designed to receive up to 6.2 million cubic feet (175,600 cubic meters) of contact-handled transuranic (CHTRU) waste and 250,00 cubic feet (7,080 cubic meters) of remote-handled transuranic (RHTRU) waste. However, the WIPP Land Withdrawal Act (LWA) limits the volume of CHTRU and RHTRU waste to be emplaced at the WIPP to 6.2 million cubic feet (175,600 cubic meters), of which only 250,000 cubic feet (7,143 cubic meters) can be RHTRU waste. The LWA further restricts RHTRU waste to a maximum activity of 23 curies per liter, not to exceed a total of 5.1 million curies [LWA §7, Public Law 102-579]. Page A-138 of the 1992 PA (SAND92-0700 v.3) gives a total estimate of 517,182 drums and 28,207 waste boxes. The estimated total curie content in the 1992 PA is 8.206×10^6 CHTRU (p. A137) and 3.54×10^6 RHTRU, for a total of 11.746×10^6 curies. As the memo (pp. A135-A136) explains, these values were obtained from the 1991 Integrated Data Base (IDB) inputs.*

This inventory estimate has now (1995) been superseded. Current anticipated TRU waste inventories are derived from the Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report (WTWBIR). To maintain a consistent volume for performance assessment, the data in the WTWBIR are scaled to the full volume of the repository. The latest available revision of the WTWBIR will be used in all future performance assessment.

The normal disposal room configuration is waste in drums stacked in units of seven, three drums high, surrounded by backfill in waste storage (disposal) rooms 4 m (13 ft) high, 10 m (22 ft) wide, and 91.4 m (300 ft) long. For computational purposes, the absolute maximum (perfect) packing of 6,804 drums within each room is assumed, even though it is unlikely in practice that so many drums can actually be emplaced within a room. After the eight panels

(seven rooms each) are filled, waste will be emplaced in the four access drifts. Waste will also be placed in accessways to the storage panels in the same mode as in the storage room.

To date there has not been a need to resolve effects introduced by emplacement of different types of waste in different regions of the room. The waste is assumed to be a homogeneous mixture throughout the repository.

Comment 156
Communication: All volumes
The discussion in the text of the modeling that was done needs to better reflect what actually has been modeled. For example, throughout the PA the E1E2 scenario is described as a two borehole scenario. However in chapter 5, Volume 4, there a several diagrams of the model geometry, and none of them has more than one borehole. The difference between the E1 and E1E2 scenario is the assumptions that used in each scenario. This was briefly described in the 1991 PA, but it should have been explicitly stated in the 1992 PA.

Response. *The text describing the modeling assumptions for the E1 and E1E2 scenarios appears in Section 4.2.4 of Volume 2 of the 1992 PA. These assumptions will be cross-referenced or explicitly stated, as you suggest, in the CCA.*

EPA Comment 157
Referencing: Future documentation
It has been stated by DOE and Sandia that the 1992 PA and earlier PA reports were "snapshots" in time. Information is added or changed in each report, resulting in a dynamic set of interpretations, with some being abandoned. For this reason, future performance assessment reports should not reference previous performance assessments.

Response. *The final CCA will be a standalone document that fully describes the PA models and calculations for compliance certification purposes. Some information, such as code manuals and QA documentation, will obviously be referenced, but it is the CAO's intent to prepare as complete a compliance certification package as possible.*

EPA Comment 158
Volume 5, page 1-1
Undisturbed performance is also of interest for the Containment Requirements (191.13) of 40 CFR 191 (line 30).

Response. *Your observation is correct. Omission of a reference to the containment requirements was simply an oversight.*

EPA Comment 159

Volume 5, page 2-7

The modeling of formation dewatering during the disposal stage should more reasonably represent the condition when a panel is sealed. However, using a 50-year disposal period seems excessive. After disposal operations are underway it should be possible to excavate a panel in one to two years, fill it with wastes in three or four years, and backfill plus seal in another one or two years. This would total only five to eight years. The observed problems of room stability when rooms remain open for extended periods should encourage a policy of minimizing time between excavating and sealing of a panel. Even recognizing that Panel 1 and the north/south access drifts will be open for longer periods, the use of an average time of 10 or 15 years would be more reasonable (lines 26–33).

Volume 5, page 2-8

The discussion of the manner in which the initial brine saturation range was chosen is not very reassuring. This is stated on page 4-1 to be a very important parameter. Yet, no data exists and the Experimental Program Plan apparently will not obtain data. The reduction from the 1991 PA values, which included the maximum value, appears to have been done for modeling convenience. Data should be obtained on this parameter. If this is not done, then bounding analyses could be used to identify the value leading to the greatest consequences (lines 25–38).

Volume 5, page 2-9

The development of a model for pressure dependent fracturing of anhydrite interbeds is important and needs to be accomplished as soon as possible. Also, the degree of correlation between permeabilities and porosities needs to be determined.

Response.

A shorter 5-year, start-up period is now used.

Admittedly, the range of values chosen for initial brine saturation in the 1992 PA was "somewhat arbitrary" [Vol. 5, page 2-8, line 35]. However, the estimated range of initial brine saturation has since been reduced to between 0.004 and 0.052 based on recent EG&G/INEL data and transportation restriction on the amount of free liquid the waste can contain.

A model for interbed fracture has been developed and implemented in PA. Although work is underway, there have been no new developments on ascertaining the correlation, if any, between permeability and porosity in the interbed alteration model. The model implemented in BRAGFLO since the 1992 PA for pressure-dependent alteration of the anhydrite interbeds contains a pressure at which alternation begins. At pressures above the alteration pressure, permeability increases by the magnitude of porosity raised to a power (the so-called power-law

assumption). Concerns about the power-law assumption for correlating permeability and porosity resulted in a suggestion for an alternative approach (Memo form K. Larson and P. Davies to M. Tierney, October 11, 1993, found at Appendix D, Salado Position Paper, March 17, 1995). This alternative approach correlates permeability changes directly with fracture aperture, and for that reason has been termed the Aperture Model. Although not implemented in performance assessment, the Aperture Model illustrates the uncertainty that exists in attempting to correlate permeability with porosity.

92PA EPA Comment 160

Volume 5, page 4-1, last paragraph

In the statement, "brine saturation in the waste rises steeply during the first 100–300 years as creep closure reduces the pore volume of the waste more rapidly...," the assumption and the numbers that are being used should be supported.

Volume 5, page 4-2, last paragraph

Based on what data or assumptions were used to come-up with the numbers in this paragraph.

Response. *The statement on page 4-1 in Volume 5 of the 1992 PA regarding brine saturation in the waste was intended as a general introductory remark and is based on computer runs that are reflected in Figures 4-2 and 4-3. This introductory statement is amplified on page 4-4, lines 18-33. Model assumptions for the disposal room are set out on page 2-12 in Table 2-1 of Volume 4.*

Based on this and other comments, the DOE will identify the sources of data for input parameters and to document the logic for derivation of parameter values in the final CCA in a straightforward and clear fashion.

EPA Comment 161

Volume 5, page 4-10

a) It is not clear how the total iron content was calculated.

Volume 5, page 4-14

b) Does the DOE design prevent fluids from bypassing the seals via the DRZ?

c) Drift seals as modeled do not prevent fluids from bypassing the seals by way of the DRZ. This result should also be true of panel seals and has implications for the E1E2 scenario where it is presently assumed that boreholes must be in the same panel to be hydraulically connected (lines 11–12).

d) The reference to plug flow at the bottom of the page is misleading since it suggests that this is how the brine will move. There is no reason to believe that such flow will take place. It is more likely that flow will occur by displacing portions of the brine already present in the pores rather than all of it. Furthermore, paths may be selective (i.e., MB-139) and brine will only move through a small percentage of the units and, therefore, not nearly all of the brine at a uniform radial distance would have to be displaced.

Volume 5, page 4-18

e) The results of the realizations have little meaning without the input parameters that went into each realization. In the future, identify where this information is provided.

Response.

a) The total iron content for the 1992 PA was the same as for the 1991 PA. SAND91-0893/3 Page 3-140 identifies iron from both the waste (Table 3.4-12 instead of Table 3.4-11) and the metal containers (Table 3.4-10 instead of Table 3.4-8).

b) No. Panel and drift systems do not impede fluid flow in BRAGFLO.

c) Panel and drift seals do not impede fluid flow in BRAGFLO.

d) Plug flow in the marker beds is currently one of several possible flow behaviors modelled in PA.

e) The final CCA will include all parameters for all realizations.

EPA Comment 162

BRSAT: Volume 5, page 5-7

BRSAT, Initial brine saturation in waste: Does this refer to the starting time of saturation?

"The variable selected in the analysis is BRSAT, the initial brine saturation in the waste, which has a positive regression coefficient and can account for 49% of the variability in gas generation by inundated corrosion." What is the range of parameter values that account for the 49% of the variability?

Response. *BRSAT refers to the initial water content of the waste at the time of repository closure. The initial water content is assumed to be a combination of liquid in the waste and brine in the backfill. For the 1992 PA, BRSAT parameters ranged in value from 0 to 0.14 with a median value of 0.07 [Table 3-1, Vol. 5; see also paragraph 3.4.3, Vol. 3].] This is the range of parameter values that account for the 49 percent variability in gas generated by inundated corrosion. Recent data has reduced the values and uncertainty in this parameter. See response to EPA comment #159.*

EPA Comment 163
Volume 5, page 5-9
The first paragraph needs rewording.

Response. *DOE will ensure that the final CCA is worded in as clear a fashion as possible.*

92PA EPA Comment 164
Volume 5, page 5-23, last paragraph
What is meant by last sentence? Based on what is written here, it is not clear that brine influx has minor impact on gas generation.

Response. *The intent of this discussion was to illustrate that corrosion of metals may be sensitive to other factors (other than brine inflow from the interbeds). However, it would be correct to say that anhydrite permeability does have an effect on corrosion rates and a higher permeability would have a higher brine influx which provides more water for corrosion.*

EPA Comment 165
Sensitivity Analysis Process: Volume 5, chapter 5
A more thorough explanation of the three analysis techniques; scatterplots, stepwise regression analysis, and partial correlations analysis may be very useful to assist the reviewer. We generally know how these techniques are used and applied, but how was each applied to the PA data? For all of the cases/runs what variable(s) varied and what parameters held constant? Was this procedure used in all cases, such as each major segment: "Brine Flow" or "Distance Gas Flows Out Anhydrite Layers" for example. It would be useful to show complete examples in an appendix of each technique.

Response. *DOE will show complete examples with greater discussion in the compliance certification application.*

EPA Comment 166
Volume 5, page 6-2
The most important parameter listed is the initial brine saturation. What is not listed and was not tested, but is probably of equal importance, are the initial conditions for pressure and saturations in the surrounding rocks.

Response. *Initial pressure in surrounding rocks was in fact tested and was found to be less important than initial brine content of waste. Initial pressure was set between 12 and 13 MPa at MB-139, and adjusted by a hydrostatic gradient to other units accordingly. Saturation is not varied.*

REFERENCES

Axness, C., R. Beauheim, et al., 1995. Systems Prioritization Method - Iteration 2, Baseline Position Paper, Non-Salado Flow and Transport, Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L., W.R. Wawersik and R.M. Roberts, 1993. Coupled Permeability and Hydrofracture Tests to Assess the Waste-Containment Properties of Fractured Anhydrite. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts. Vol. 30, No. 7, p. 1159–1163.

Bertram Howery, C.G., 1990. Preliminary Comparison With 40 CFR 191, Subpart B for the Waste isolation Pilot Plant, December 1990, SAND90-2347. Albuquerque, NM: Sandia National Laboratories.

Brinster, K.F., 1991. Preliminary Geohydrolgic Conceptual Model of the Los Medanos Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment. SAND89-7147 (SAIC Contractor Report). Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M., S.W. Webb, J.W. Berglund and P.R. Johnson, 1995. Systems Prioritization Method—Iteration 2, Baseline Position Paper: Disposal Room and Cuttings Models Volume 1. Albuquerque, NM: Sandia National Laboratories.

M.J. Connolly, S.M. Djordjevic, K.J. Liekhus, C.A. Loehr and L.R. Spangler, 1995. Position for Determining Gas Phase Volatile Organic Compound Concentrations in Transuranic Waste Containers, INEL-95/0109, Lockheed Idaho Technologies Company, Idaho Falls, ID. Publication pending completion of DOE review and final approval.

Corbet, T.F. & M.G. Wallace, 1993. Post-Pleistocene Patterns of Shallow Groundwater Flow in the Delaware Basin, Southeastern New Mexico and West Texas. Carlsbad Region, New Mexico and West Texas New Mexico Geological Society, Forty-Fourth Annual Field Conference. SAND93-1318J. Roswell, NM: New Mexico Geological Society.

Hansen, F., M. Pickens, J. Tillerson, J. Schreiber, and P. Vaughn, 1994. Repository Seals Program Position Paper. Albuquerque, NM: Sandia National Laboratories.

Galson, D.A., 1993. Assessment of Future Human Actions at Radioactive Waste Disposal Sites (Draft). Report of an NEA Working Group, 9203b-2, version 4.

Galson, D.A., T.W.Hicks, R.D. Wilmot, & P.N. Swift, 1995. Systems Prioritization Method—Iteration 2, Baseline Position Paper: Scenarios Development for Long-Term Performance Assessments of the WIPP. (Version 4.2). Galson Sciences, LTD.

Helton, Jon C., 1993. "Uncertainty and Sensitivity Analysis Techniques for Use in Performance Assessment for Radioactive Waste Disposal, Reliability Engineering and System Safety, Vol. 42.

Howarth, S., 1993. Conceptual Plan: Two-Phase Flow Laboratory Program for the Waste Isolation Pilot Plant. SAND93-1197. Albuquerque, NM: Sandia National Laboratories.

Howarth, S., K. Larson, T. Christian-Frear, R. Beauheim, D. Borns, D. Deal, A. Jensen, K. Pickens, D. Powers, R. Roberts, M. Tierney and S. Webb, 1995. Systems Prioritization Method - Iteration 2, Baseline Position Paper, Salado Formation Flow and Transport, Albuquerque, NM: Sandia National Laboratories.

Hunter, R.L. 1985. A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area. SAND84-2233. Albuquerque, NM: Sandia National Laboratories.

Iman, Ronald L., and Conover, W.J., 1982. A Distribution-Free Approach to Inducing Rank Correlation Among Input Variables. Communications in Statistics B, Vol. 11.

Iman, Ronald L., and Helton, Jon C., 1985. A Comparison of Uncertainty and Sensitivity Analysis Techniques for Computer Models. NUREG/CR-3904. Albuquerque, NM: Sandia National Laboratories.

Jones, T.L., 1992. Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site, SAND92-1579. Albuquerque, NM: Sandia National Laboratories.

Lappin, A.R., R.L. Hunter, D.P. Garber and P.B. Davies, 1989. Systems Analysis, Long-Term Radionuclide Transport and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico. SAND89-0462. Albuquerque, NM: Sandia National Laboratories.

LaVenue, A.M., Cauffman, T.L., and Pickens, J.F., 1990. Ground-Water Flow Modeling of the Culebra Dolomite, Volume 1, Model Calibration. SAND89-768. Albuquerque, NM: Sandia National Laboratories.

LaVenue, A.M., A. Haug, and V. A. Kelley. 1988. Numerical Simulation of Ground-Water Flow in the Culebra Dolomite. Second Interim Report. SAND88-7002. (INTERA Technologies Contractor Report). Albuquerque, NM: Sandia National Laboratories.

LaVenue, A.M., and B.S. RamaRao, 1992. A Modeling Approach to Address Spatial Variability within the Culebra Dolomite Transmissivity Field. SAND92-7306. Albuquerque, NM: Sandia National Laboratories.

Marriott, F.H.C., 1990. A Dictionary of Statistical Terms, 5th Ed. New York, NY: Longman Scientific and Technical.

Morgan, M. Granger, and Henrion, Max, 1990. Uncertainty—A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. New York, NY: Cambridge University Press.

Munson, D.E., D.J.Borns, M.K. Pickens, D.J. Holcomb, & S.E. Bigger, 1995. Systems Prioritization Method—Iteration 2, Baseline Position Paper, Rock Mechanics: Creep, Fracture, and Disturbed Rock Zone (DRZ). Albuquerque, NM: Sandia National Laboratories.

Nowak, E.J., & J.C. Stormont, 1987. Scoping Model Calculations of the Reconsolidation of Crushed Salt in WIPP Shafts. SAND87-0879. Albuquerque, NM: Sandia National Laboratories.

Palisade Corp., 1990. Risk Analysis and Modeling: @Risk. Newfield, NY: Palisade Corp.

Popielak, R.S., et al., 1983. Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, TME 3153. Albuquerque, NM: U.S. Department of Energy.

Potential Problems Resulting from the Plans for the First Five Years of the WIPP Project, Waste Management 1988, Volume 2.

Preliminary Comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. SAND91-0893 (3 Volumes). Albuquerque, NM: Sandia National Laboratories.

Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992—Volume 1: Third Comparison with 40 CFR 191, Subpart B. SAND92-0700/1. Albuquerque, NM: Sandia National Laboratories. 1992.

Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992—Volume 2: Technical Basis, SAND92-0700/2. Albuquerque, NM: Sandia National Laboratories.

Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992—Volume 3: Model Parameters. SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories.

Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992—Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B. SAND92-0700/4. Albuquerque, NM: Sandia National Laboratories.

Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992—Volume 5: Uncertainty and Sensitivity Analyses of Gas and Brine Migration for Undisturbed Performance. SAND92-0700/5. Albuquerque, NM: Sandia National Laboratories.

Radhakrishna, R.C., 1973. Linear Statistical Inference and Its Applications, 2nd Edition. New York, NY: John Wiley and Sons.

Rawson, D., C. Boardman & N. Jaffe-Chazan, 1961. The Environment Created by a Nuclear Explosion in Salt. PNE 107F. Carlsbad, NM: Project Gnome.

Rechard, R.P., 1995. An Introduction to the Mechanics of Performance Assessment Using Examples of Calculations Done for the Waste Isolation Pilot Plant Between 1990 and 1992, SAND93-1378. Albuquerque, NM: Sandia National Laboratories. Will be published shortly, pending final management reviews.

Reeves, M., G.A. Freeze, V.A. Kelley, J.F. Pickens & D.T. Upton, 1989. Regional Double-Porosity Solute Transport in the Culebra Dolomite Under Brine-Reservoir-Breach Release Conditions: An Analysis of Parameter Sensitivity and Importance. SAND89-7069. Albuquerque, NM: Sandia National Laboratories.

Sattler, A.R., 1995, *Culebra Transport Program Test Plan: Re-entry of Well H-11b4 for Development of Equipment and Techniques for Hydraulic and Tracer Testing*, Sandia National Lab, Albuquerque, N.M.

Sjaardema, G.D., & R.D. Krieg, 1987. A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analysis of Backfilled Shaft and Drift Configurations. SAND87-1977. Albuquerque, NM: Sandia National Laboratories.

Swift, P.N., 1992. Long-Term Climate Variability at the Waste Isolation Pilot Plant, Southeastern New Mexico. SAND91-7055. Albuquerque, NM: Sandia National Laboratories.

Swift, P.N., B.L. Baker, K Economy, J.W. Garner, J.C. Helton, and D.K. Rudeen, 1993. Incorporating Long-Term Climate Change in Performance Assessment for the Waste Isolation Pilot Plant. SAND93-2266. Albuquerque, NM: Sandia National Laboratories.

Thomas, George B., 1972. Calculus and Analytic Geometry, Alternate Edition. Reading, MA: Addison Wesley Publishing Co.

U.S. Department of Energy (DOE), 1983. Brine Reservoirs in the Castile Formation Waste Isolation Pilot Plant (WiPP) Project southeastern New Mexico. TME 3153. Albuquerque, NM: Department of Energy.

U.S. Department of Energy, 1995a. Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report, CAO-94-1005, Revision 1, February, 1995.

U.S. Department of Energy (DOE), 1995b. Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant. Draft DOE/CAO 2056. Carlsbad, NM: Carlsbad Area Office.

Weart, W.D., S.G. Bertram-Howery, R.V. Guzowski, K.F. Brinster, P.N. Swift, S.B. Pasztor, 1991. Background Information Presented to the Expert Panel on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant. SAND91-0928. Albuquerque, NM: Sandia National Laboratories.

Weart, W.D., 1963. Particle Motion Near a Nuclear Detonation in Halite. PNE-108F. Carlsbad NM: U.S.Atomic Energy Commission Plowshare Program, Project Gnome, 1961.

1992 PERFORMANCE ASSESSMENT REPORT

DR. PATE-CORNELL REVIEW

IV-D-121

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September 13, 1995

SEP 1 1995
EPA AIR DOCKET

Environmental Protection Agency
Docket No. A-92-56, Air Docket
Room M-1500 (6102)
401 M Street, S.W.
Washington, D.C. 20460

To The Docket:

Enclosed is a report prepared for this office by Prof. Elisabeth Paté-Cornell, entitled Conservatism of the Performance Assessment and Decision Criteria for WIPP. Prof. Paté-Cornell is Professor of Industrial Engineering and Engineering Management at Stanford University and is currently President of the Society for Risk Analysis. She has written and lectured extensively on probabilistic risk assessment and has testified in Congress on proposed legislation on the subject.

The report constitutes further comments on the proposed compliance criteria, 40 CFR Part 194, and should be examined fully and carefully. Briefly, Prof. Paté-Cornell concludes as follows:

1. Generally, the 1992 performance assessment ("PA") in fact constitutes a conditional risk assessment, predicated on certain fundamental assumptions (made by EPA) as to the linkage between radionuclide releases and health effects and other assumptions (made by DOE or its contractor, Sandia) as to the probability and consequences of various release events. Whether the EPA assumptions or the DOE assumptions are conservative as judged by the outcome of a full probabilistic risk assessment of the WIPP repository is not known.

2. In inquiring whether the PA curve deemed determinative of compliance meets Prof. Paté-Cornell's standard--that high fractiles of the future frequency of exceedence of potential loss levels should be required to meet the performance criteria with a high level of confidence--it is important to know (a) what fractile of the current CCDF distribution the suggested curve--the mean--corresponds to, and (b) what fractile would the mean correspond to if some of the assumptions of the PA were instead treated probabilistically?

3. In pursuing the same inquiry, it is also important to know where the mean would fall if methods other than the use of expert opinion were used to obtain probability distributions for input variables.

4. Concerning the specific issue of the selection of experts for purposes of expert judgment elicitation, such persons should be required to meet a test of recognition by their peers in the scientific community.

5. Concerning elicitation of expert opinions on parameter values, the process must include the elements of (a) clarity of question, (b) identification of desired central value--probably the mean--and (c) the description of the thought process leading to the estimate.

6. Concerning the selection of variable parameters for PA, the test should be whether the variation of an input value across the possible range could change the final decision.

7. DOE should justify its decision to treat variables whose distribution is critical to the results through expert opinion rather than through experiments or measurement where feasible.

8. Concerning elicitation of expert opinions as to distributions of variable parameters, the process must include (a) construction of a probability distribution for a set of possible hypotheses, (b) identification of the appropriate distribution model for an identified model variable, and (c) given such model, identification of the distribution for the value of the variable.

9. Concerning aggregation of expert opinions of multiple experts, the process must include methods to reduce the range of disagreement, such as requirements that all experts (a) agree on the substance of the question, (b) consider and account for all available data, and (c) articulate the relationship between the data and their judgment as to the probability of the various models. Further, to aggregate different opinions, it is preferable to employ an interactive process wherein the experts (1) discuss the data, (2) explain their models, (3) discuss the probability of each of the models, (4) assess such probabilities, and (5) generate a composite distribution. Aggregation of multiple opinions must be performed systematically as to all expert elicitations. The task of quantifying the uncertainty of alternative assumptions cannot be ignored.

10. The rationality of the mean as a relevant characteristic of a probability distribution does not apply to collective decisions (such as governmental decisions), in which the administrator is concerned not only with the probability distribution of the levels of release but also with the health and safety of the most exposed members of the public, which involves

the choice of a threshold based on prudence. The mean may or may not reflect that threshold, depending on the fractile it represents and the practicality of so demonstrating.

11. A full uncertainty analysis includes (1) structuring alternative hypotheses into realizations so that probability distributions can be assigned to them, (2) aggregation of expert probabilities for each set of assumptions, (3) identification of the models and parameter values (with probabilistic treatment) which correspond to each hypothesis, including interdependencies, (4) propagation of uncertainties for each fundamental hypothesis, and (5) aggregating the results of conditional analyses according to the probabilities of the underlying hypotheses.

12. The full uncertainty analysis of WIPP has not been done and would be extremely difficult. In this situation, it is sensible to apply a test of reasonable expectations to the results of a conditional risk analysis based on fixed hypotheses, provided (1) that the hypotheses are globally conservative and (2) that the mean curves generally correspond to high fractiles of the CCDF families. In such situation the combination of hypotheses and means may provide "reasonable assurance." It must be demonstrated that the global model (health effects plus PA assumptions) is conservative and that a full uncertainty analysis achieves "reasonable assurance." It is appropriate for EPA to find a "reasonable expectation" only if its assumptions as to health effects (including its cancer risk model) provide the additional level of safety consistent with the NRC language of "reasonable assurance."

13. Such demonstration involves identifying the major hypotheses from EPA and DOE and assessing, by analysis of their probabilities and outcomes, their effect on the placement of the current mean curves.

14. EPA cannot simply frame a conditional risk analysis based on certain assumptions and then claim without checking that the conditional means resulting from this analysis necessarily support "reasonable expectation" of human safety. The effects of the hypotheses as to health effects and release models on the mean curves must be assessed. EPA must show that the combination of "reasonable expectation" for the PA and conservatism (if it is so) of the health effect model provides "reasonable assurance" of actual safety.

15. DOE, for its part, must identify the major hypotheses in its PA and show the effects of those hypotheses on the family of release curves. As an example, one can take the five or six most important assumptions of the PA (such as the hypotheses about the frequency, means, and effects of drilling; borehole diameters; groundwater flow model; solubility model; engineered barrier model), generate a set of reasonable alternatives, and show that

the mean curves generated with proper probabilistic analysis of the alternatives show compliance and do not move the mean curves toward lower fractiles of the CCDF families.

16. Depending on how far the current means are (assuming full probabilistic treatment of hypotheses) from a reassuring (but not sacred) 95% fractile, it may be appropriate to ask for additional analysis or a change in risk management strategy.

17. The test of 95% confidence to account for sampling error should be sufficient.

18. It is essential to deal with correlations among variable parameters.

* * *

We have undertaken to draft proposed regulatory language for §§194.26 and 194.34 following the analyses by Prof. Paté-Cornell, and it is attached to our comments, filed today. We request that the Agency consider and adopt the proposed regulatory language.

Very truly yours,

Lindsay A. Lovejoy Jr. (by AS)

LINDSAY A. LOVEJOY, JR.
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Portola Valley, July 5th, 1995

Mr Lindsay Lovejoy
Assistant Attorney General
Office of the Attorney General of New Mexico
P.O. Drawer 1508
Bataan Memorial Building
Santa Fe, New Mexico 87504

Dear Lindsay:

You will find enclosed here my final report to the Attorney General of New Mexico entitled: "Conservatism of the performance assessment and decision criteria for WIPP". I enjoyed my interaction with you in this work and I hope that we will have the opportunity to continue.

Sincerely yours,

M. Elisabeth Paté-Cornell

CONSERVATISM
OF THE PERFORMANCE ASSESSMENT AND
DECISION CRITERIA FOR WIPP

Report to Office of the Attorney General of New Mexico

by

Elisabeth Paté-Cornell

July, 1995

CONSERVATISM OF THE PERFORMANCE ASSESSMENT AND DECISION CRITERIA FOR WIPP

by
M. Elisabeth Paté-Cornell
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1. BACKGROUND AND PROBLEMS

WIPP has been basically constructed and is scheduled to start operating in 1998. At this time, the remaining operational decisions concern the potential need for engineered barriers, the management of the facility in the future, and the timing of the start of operations. EPA has been required by Congress to certify that WIPP will comply with Federal regulations for the storage of high-level wastes. A "performance assessment"(PA) has been done by Sandia National Laboratories for the Department of Energy which is in charge of the design, construction, and operation of the facility.

This performance analysis is in essence, a *conditional* probabilistic analysis based on *mixed methods* involving both a set of fundamental assumptions provided by EPA and a probabilistic release analysis conditional on these assumptions. (There is no probabilistic risk analysis *per se* because the consequences have been determined by EPA through a single-estimate method, presumably using a conservative model.)

1. <u>The set of fundamental assumptions</u> that have been adopted by the EPA concern mostly the linkage between health effects and radionucleide releases. The figures presented in Table 1, Appendix A of 40 CFR 191 are based on a number of hypotheses that I could not all identify. They involve, for instance, the assumption that the different isotopes are released to a large stream of water. EPA's assumptions also affect the framing of the risk analysis problem. For example, EPA has set the requirements "in terms of cumulative

releases of radionucleides at the accessible environment, either at the ground surface or anywhere at depth, 5 kms horizontally from emplaced wastes, over 10,000 years" (Lee). These hypotheses can generally be assumed to be conservative with respect to health effects, but it may not be the case, and their effects on the overall result has to be checked.

2. Sandia's performance assessment is a conditional analysis of the radionucleide release given the hypotheses and constraints set by EPA. It includes an uncertainty analysis within this framework. This analysis is restricted to uncertainties associated with the distributions of the variables of the conditional release model (such as λ, the mean number of human intrusions in 10,000 years per km^2). This uncertainty analysis does not involve the fundamental assumptions originally set by EPA in the containment requirements: these are taken for granted. Therefore, it does not reflect the uncertainties about the outcome of interest: the health effects of the potential release. A second set of assumptions were made by Sandia in the performance analysis. For instance, some of these distribution models were fixed, such as a Poisson model for human intrusions and a uniform distribution for its mean λ. The value of the parameter(s) of these distribution were either based on past data or on expert opinions (here λ=U[0,30]). The propagation of these uncertainties through the analysis has been performed using simulation (Monte Carlo or Latine Hypercube sampling methods) to obtain a description of the uncertainties about the release levels given the uncertainties about the inputs of the analysis (e.g., solubility factors).

The results of the performance assessment are thus families of risk curves that represent, for each release level, a discretization of the conditional probability of exceeding this value in a specified time window (10,000 years in most cases) given the analytical hypotheses specified by EPA. Note again that Sandia does not address directly the uncertainties about the health effects.

I do not know, given the way the performance analysis was done, whether these conditional results and their implications for health effects are conservative or not. In other terms, if instead of using the EPA assumptions plus additional assumptions of their own about the shape of the variable distributions, Sandia had done a complete uncertainty analysis (i.e., had assessed probabilities for these assumptions), would the curves obtained by this full uncertainty analysis about the release be above or under the current conditional curves? (I recognize, of course, that the uncertainty analysis has to stop somewhere). I can only *presume* that, in the EPA's generic studies that led to the release criteria, the accumulation of hypotheses that are generally intended to be conservative in the first place, lead to conservative results in specific analyses such as that of WIPP.

The question is thus whether the EPA hypotheses are in fact conservative with respect to the WIPP site. One of them, as mentioned above, concerns the release of radionucleides to the environment through a large stream, part of which will provide drinking water to the population. Whether this large stream assumption is conservative or not given that WIPP is in the desert, I do not know. Also, the argument was made that the assessment of cancer risk that led to this table was based on japanese epidemiologic data and that they have been found to be unconservative in later studies (EPA, background info, 1993, p 6-5).

It is important to note that the results of this kind of conditional PRA are not directly comparable to the results that one would have obtained if the EPA and Sandia's assumptions had been incorporated and weighted along with alternative assumptions in a fully probabilistic risk analysis of the health effects. Restricting the scope to release levels alone and to the hypotheses that led to Sandia's current results, Figure 1 shows a schematic representation of the full uncertainty analysis of release (for one single Hypothesis 1), and the restriction of Sandia's analysis to one particular realization of Hypothesis 1.

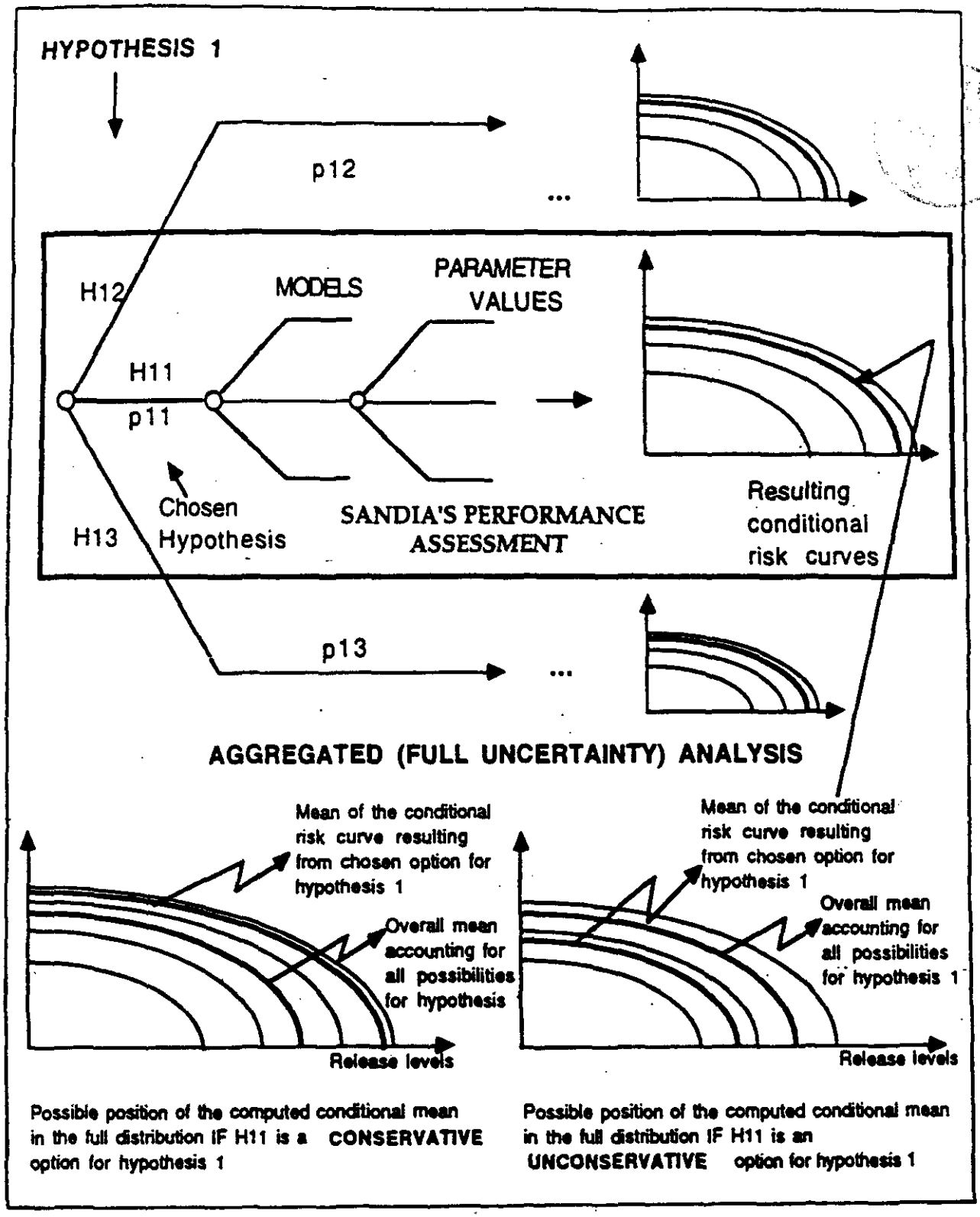

Figure 1: Conditional risk curves (CCDFs), and position of the conditional mean in a full uncertainty analysis.

This would have required using probabilities for the different possible realizations of each hypothesis instead of adopting what is probably (but not necessarily) conservative assumptions. Clearly, a full analysis of this type is complex. It would also involve much larger uncertainties because it would require assessing the probabilities of additional poorly known phenomena. Yet, it may be possible once the conditional analysis is done for the chosen case, to assess (even coarsely) the probable effects of alternative key assumptions on the final results. Therefore, the conservatism of the final safety levels achieved under the proposed criteria (e.g., specifying that the risk curve corresponding to the *mean* must meet the EPA release requirement) has to be examined in the light of the conservatism of the EPA (and later, Sandia's) assumptions.

EPA's compliance criteria involve several components: the assumptions behind the containment criteria, the criteria themselves, the CCDF characteristics (fractiles or moments) to be used to show compliance (second order), and the confidence level that the compliance criteria are met (third order). There are infinite combinations of such choices that lead to the same level of safety. EPA first made its own (single point, presumably conservative) analysis of the link between health effects and release levels. Then, they chose the mean CCDF for its robustness in the face of large uncertainties for the 10,000-year horizon, a set of analytical assumptions for the release model, and a high level of confidence for the mean. The first question is whether the choice of this combination is both prudent and practical. The second question is whether it provides a sufficient level of safety in terms of health effects.

In a 1986 paper, in the Journal of Nuclear Engineering and Design, I wrote an article entitled "Probability and Uncertainty in Nuclear Safety Decisions". In that article, I argue that both qualitative and quantitative safety goals are useful tools, and that *high fractiles* of the future frequency of exceedence of potential loss levels should be required to meet the performance criteria with

a *high level of confidence* (hence the accumulation of two layers of conservatism). I assumed in that discussion that the PRA results came out of a full uncertainty analysis *on the outcomes* (here: health effects). I did not specify that a designated fractile should systematically be used (95% is one possibility). I believe that such a goal should remain flexible, depending on the case, alternative risk management options, and the difficulty of showing compliance (uncertainties, time horizon, etc.).

Therefore, I think that you want to know which one(s) of the *real* risk curves (that would result from a full uncertainty analysis as shown in Figure 1) are tangent to the compliance criteria curve, and possibly, what level of health safety do they represent. Two questions thus arise:

° What fractiles of the current distributions (conditional on Sandia *and* EPA hypotheses) do means correspond to in the *current* analysis? The means are shown in Sandia's results but, in each case, they do not correspond to one single CCDF curve on the whole range of release levels. Although the mean (predictably) appears to be in the high fractiles, I cannot tell which ones.

° Where would these means be in the full (marginal) distributions if some of the assumptions of the release model were treated probabilistically? In other words, how do the current assumptions affect the position of the current mean in the family of CCDFs?

The mean has several advantages in many PRA cases. First, it is compatible with economic efficiency criteria. Second, in the face of large uncertainties, the mean is relatively robust compared to specified fractiles (for example, it can be estimated with smaller sample size). Third, in PRAs as performed so far for nuclear power plants, the means are often among the high fractiles of the risk curves (e.g., 70%, 80% or 90%). This is true because many of the distributions that represent uncertainties in the results are skewed right. The position of the mean does reflect the level of

uncertainty. Typically, the distance between the mean and the median is one measure of the uncertainty: the higher the level of uncertainty, the higher the fractile corresponding to the mean. Therefore, altogether, for studies involving a very high level of uncertainty, the advantage of the mean is that it is a robust estimate that generally corresponds to high fractiles.

In a recent paper entitled "A Perspective on the 1992 Performance Assessment for the Waste Isolation Pilot Plant" (EEG, 1995), William Lee argues that the analysis has been incomplete. I concur with him, to the degree that the Sandia conditional performance analysis does not allow me to estimate the conservatism of some of the basic hypotheses in the WIPP case. Eventually, the issues are: (1) To what extent will additional uncertainty analysis change the PA results? (2) Is it likely to make a difference in policy decisions given the release criteria as set? And (3) what combination of change in performance criteria and performance analysis would result in a change of risk mitigation measures? Lee also argues that expert opinions play a critical role in the PA results, that they may not have been encoded with sufficient care, and that they may not be appropriate given that experimental data could be reasonably obtained instead (e.g., for solubility). I tend to agree with Lee on this last point. Some parameters can be better estimated. The decision to gather more data depends on the "value of information" and on the difference that experimentation would make in the final decision. I believe, however, that the use of panels to assess what might happen in the distant future is unavoidable and appropriate in a probabilistic framework. Clearly, the results are subjective probabilities. There is nothing wrong with that if the encoding is well done: they are the only ones available for this kind of exercise.

At this point, the concern of the Office of the Attorney General of New Mexico is that the combination of the release criteria as set by EPA, the (conditional) performance analysis as done by Sandia for the DoE, and the compliance requirements proposed

by EPA may not provide sufficient conservatism to ensure the long-term safety of the citizens of the state of New Mexico. The central issues are thus:

i. What was the level of conservatism used by EPA in its model linking health effects and release levels?

ii. What is the actual conservatism of Sandia's PA (conditional risk analysis) given the combination of EPA hypotheses and Sandia's choice of distribution models and parameter values for the input variables? In particular: What are the potential problems and possible effects on the PA results of the procedures that were used to obtain probability distributions for the input variables including the choice of distribution models and parameter values, based on expert opinions?

iii. If the proposed compliance criteria are adopted and the case is judged based on the combination of the existing analyses and these criteria, what would be the actual level of safety and with what level of confidence?

iv. Does the Office of the Attorney General of New Mexico want to require (or can require) that EPA issue fractile-based compliance criteria *on the release level* as a general numerical standard?

v. Does the Office of the Attorney General of New Mexico want to require (or can require) that EPA provide a full probabilistic version of its model of the link between radionucleide release and health effects so that one can perform a probabilistic risk analysis (complete with uncertainty analysis) of *the final health effects*?

[Since a large part of the problem relies on the treatment of uncertainties in risk analysis in general and in the Sandia study in particular, you will find in appendix of this report a discussion of this problem based on a report that I recently wrote for the Electric Power Research Institute].

Probabilities are understood in two different ways by different people. For classical statisticians, probability means frequency in very large samples. For the Bayesians, probability is a degree of belief and is updated in a systematic way given each new piece of information.

Uncertainties themselves are also of two different types. The first type is randomness in samples (or aleatory uncertainty to which you refer as stochastic). It can be treated by statistical methods and the frequentists' definition of probability. The second type reflects the limits of fundamental knowledge and can be called epistemic uncertainty (you refer to it as subjective). It cannot be addressed by the frequentist approach to probability. For this second case, one needs Bayesian probability and expert opinions, with the understanding that there are numerous problems associated (1) with the encoding and the validity of this type of information and (2) with the aggregation of expert opinions.

Because of the unavoidable subjectivity of Bayesian probability and expert opinions, some government agencies (such as the EPA) have used, since the late seventies, "plausible upper bounds" of the risks, for instance, for dose-response relationships for carcinogens. These plausible upper bounds are single numbers meant to provide conservative estimates based on an accumulation of worst-case assumptions. This approach, however, has led in the past to regulations that the present Congress found unacceptably costly.

Currently discussed (or recently voted) legislations such as HR 1022 require a "soft" cost-benefit analysis approach to regulation, and therefore, an estimate of central values and a description of uncertainties in addition to plausible upper bounds. EPA, as well as many other governement agencies, is in a state of transition in its approach to risk assessment as they are trying to adapt their methods to this new sensitivity to consistency in rule making. There are several problems with a full probabilistic quantification of health risks. First, the methods of risk analysis are not yet

fully developed, especially in environmental and health risk assessments. This is true, for instance, for cancer risk assessment, for which there is no full probabilistic analysis method. This is why I think that it would be very difficult for EPA, at this time, to provide a probabilistic version of the model that they used to set the release criteria for WIPP, especially over 10,000 years. This model would be necessary for Sandia to do a full probabilistic risk analysis of health effects of radionucleide release at WIPP which would be dominated by cancer risks. Second, there is not enough consensus in the scientific community to base risk acceptance and degree of confidence on analytical results alone. Furthermore, the acceptability of a particular risk level depends on many more factors than its computed magnitude.

As I shall discuss further, the issue of aggregation of expert opinions is still unresolved, i.e., there is no consensus about how to do it. Therefore, the agencies (such as the EPA) tend to focus their initial efforts about uncertainty analysis on the development of methods for the quantification of *randomness* in parameter values. As far as fundamental (epistemic) uncertainties, they are not generally ready to incorporate them in a probabilistic risk analysis and still tend to base their risk assessment on specified hypotheses that are generally conservative. Therefore, for the moment, the results tend to be *conditional risk analyses* of the type performed by Sandia for WIPP and not the type of full PRA that is state-of-the-art in the nuclear power industry.

As a result, the curves that are produced in that way are difficult to interpret. This point is at the core of the problem that you have with the WIPP analysis. Yet, Sandia had no choice: the hypotheses had been set for them by the EPA in the generic studies that led to the release criteria. The methods are still in flux and criteria that one may want to adopt for complete probabilistic risk analysis in which *all* uncertainties have been quantified are not the same as criteria appropriate for mixed methods. In any case, showing that expert data have been gathered in a way that is as objective as

possible, then properly aggregated is going to be both difficult and necessary.

2. QUESTIONS FROM THE OFFICE OF THE ATTORNEY GENERAL OF NEW MEXICO

It is against this background that I will address the five questions posed to me by the Office of the Attorney General of New Mexico.

Question 1:

How should expert judgment elicitations be conducted?

I interpret this question as: elicitation of "best estimates" and elicitation of probability distributions for either a spectrum of hypotheses or for the numerical value of an uncertain parameter.

Question 2 is made of two independent parts:

How should the judgments of multiple experts be combined?

How should the results (and the uncertainties) be incorporated in the regulatory agency's decision making? (I will answer this second question as part of question five).

Question 3: How should variable parameters be selected?

I interpret this question as: in which case should a parameter value be represented by a "best estimate" (i.e., some central value of the distribution to be determined), and when should the uncertainties about a parameter be represented by a full probability distribution?

Question 4: How should probability distribution functions be developed?

Question 5: When a family of risk curves has been generated (by propagating uncertainties about models and parameter values through the risk analysis model), how should compliance with the containment requirements be determined? i.e., what fractile or other characteristic of the CCDF family should be required to meet the criteria and with what level of confidence?

I shall address these questions *from the point of the view of the risk analyst*. I will leave to the Office of the Attorney General of New Mexico the task to translate the scientific answer into regulatory language, which is out of my domain of expertise. It is also important to note that some issues are objective (the discussion of the soundness and the practicality of a methodology), while others are purely subjective and reflect a desired degree of *prudence*. There is no scientific basis for the latter and one can only approach it from the point of view of consistency and practicality.

Q1. HOW SHOULD EXPERT JUDGMENT ELICITATION BE CONDUCTED?

I will separate the question into two parts: choice of the experts, and elicitation of individual expert opinions. Note that the encoding of a distribution for a single expert is fairly standard. The difficulty is in the aggregation of the opinions of several experts to obtain a composite distribution.

Q1.1 Choice of experts and definition of expertise:

The choice of the experts should be limited to people who have demonstrated scientific competence in the field, and have been recognized by a substantial fraction of the corresponding peer scientific group as part of the scientific expert community for this particular domain. The notion of expertise includes knowledge and understanding of the generally admited theories and of the available base of evidence, and capability to reason about the different hypotheses *given the evidence* (i.e., mastering the scientific method of reasoning about existing data). The demonstration of such competence may have been achieved in different ways: publication in the refereed literature, reasoned support of one or several hypotheses, and contribution to research, development, or practice in the field of interest.

In particular, the sole role of advocate, on political grounds alone, of one view or another is not sufficient to constitute expertise. A scientific understanding of the current evidence base

and of the spectrum of possible hypotheses is an essential component of the definition of expertise. Obviously, this definition is not black and white. There is a spectrum of expertise levels based on experience and the ability of an individual to reason scientifically from the evidence base. Therefore, there remains an unavoidable subjective element in the definition of the degree of expertise.

Other issues, such as "no conflict of interest", seem to have been adequatly addressed by EPA and in this respect, EPA language (40 CFR 194.26) generally appears reasonable.

Q1.2 Elicitation of expert opinions for a single point estimate

Clarity test

First of all, questions to the experts must be phrased in such a way that a hypothetical individual who would know the variables with certainty could immediately answer with a single number. This requires that the input variable is clearly defined and that there is no ambiguity such that given perfect information, different values could be given in good faith (in the literature, this is called "the clarity test" Ref. Ron Howard).

Best estimate

Second, if the objective is to elicit a "best estimate", one must understand the thought process by which the expert is going to come up with this figure. Suppose that there are several possible models for this best estimate and several parameter values for each of these models. A simple way for the expert to find a best estimate is to take the most likely model, and for this model the maximum likelihood estimate of the parameter value(s). Note that if the expert does that, the result is unlikely to be equal (or even close) to the mean, and one cannot use this figure as such. Indeed in some cases, e.g., for a remote risk (low probability, high consequences), the most likely mechanism may well be "nothing happens", which does not require any further treatment of parameter values. This process may thus yield an "unconservative" answer which could be inappropriate because of the possibility of severe consequences.

Central values

Central values of the distribution are generally what one wants from the expert.

° The mode (the maximum of a probability density function) is not very helpful because it cannot be easily combined in a risk analysis with other variables (treated either deterministically or by a probability distribution). In other terms, one does not know what the results mean at the end of computations where distributions, means and modes have been mixed.

° The median is more helpful because the experts can think about it relatively easily (variable X is as likely to be larger as smaller than the revealed value). It is not easy, however, to include it in the analysis (i.e., to combine it logically with other variables) except for lognormal distributions of which it is a natural characteristic.

° The mean is the most robust of the central values. But for an expert to come up with a mean sometimes requires a more sophisticated thought process: what are the different possible underlying models for that variable, what is the spectrum of parameter values for each model, and given these, what is the mean that one gets after combining models and parameter values. For skewed distributions, the mean may be driven by extreme values and correspond to high fractiles; in that case, it may not be easy for the expert to assess it directly without analytical support.

Note that for variables for which there is little uncertainty, the mean, the mode, and the median are close enough and the distinction does not matter much.

01.3 Elicitation of expert opinions for a distribution

Encoding the probabilities of fundamental hypotheses

Assume first that the issue is to assign a probability distribution to a spectrum of possible hypotheses. The first step is to

structure them as a set of exhaustive, mutually exclusive possibilities. The second step is to get the expert to elicit a probability distribution for this structured set of hypotheses. At that stage, most experts require first some training and explanation about probabilities, and for what the figures actually mean. To do the actual encoding, one of the best tools is a "wheel of chance". The expert is asked to divide the wheel into "pie portions" whose relative angles represent the relative probabilities of the different hypotheses. Therefore, when the wheel is spinned, for any hypothetical "lottery", the expert is indifferent between playing the lottery with the wheel, and with the true nature of the phenomenon of interest (as if it were to be revealed). The result thus represents the expert's degree of belief in each hypothesis.

This method is adequate for relatively large probabilities. Very small ones must generally be either decomposed into a sequence of conditional variables whose probablities can be more easily assessed, or based on revealed models.

Encoding a distribution for a variable of the model

To encode the distribution for a model variable X, one generally needs: (1) to identify the appropriate distribution model for X (e.g., normal), and (2) given this model, to encode a distribution for the value of its parameter(s) (e.g., the mean and standard deviation of X). The probability distribution for a parameter value can be obtained in two ways: a non-parametric approach based on the wheel of chance described above (e.g., interval by interval), or by a specified probability distribution (e.g., Normal) for which the expert assesses secondary parameter values (e.g., mean and standard deviation for the mean of X).

It is clear that this process of embedded uncertainty analyses has to stop somewhere. A general rule is to stop when additional information is unlikely to influence the final choice given the decision criteria.

Q2. AGGREGATION OF EXPERT OPINIONS

How should the judgments of multiple experts be combined?

One of the greatest challenges of risk analysis is the treatment of expert opinions when they disagree. Note again, that there is no standard, widely accepted procedure to do it at this time. First, one must understand why the experts disagree. One can then proceed to obtain a family of risk curves that represent, for each value on the consequence axis, a composite distribution reflecting the spectrum of opinions.

Q2.1. Sources of disagreement

They can include semantic misunderstandings, differences in experience and evidence base, fundamentally different mental models to treat the evidence base, and disagreement about parameter values (Ref. Bonduelle). Note that, of course, some of the experts may also want to influence the decision to fit their own value system, and may for instance, choose to ignore part of the evidence in their assessment of probabilities.

° Semantic disagreement is often overlooked. Therefore, one should first check that the variables are precisely defined and understood in the same way by all the experts.

° Bases of evidence can differ entirely from expert to expert. First, different experts may have observed the same phenomenon but in different settings. In addition, someone who has seen only "real-world" data (e.g., epidemiological data) may have gathered information that differ significantly from laboratory results. This is why, in the processing of real-world data, all relevant confounding factors must be taken into account. For laboratory experiments, it is their adaptability to the case *in situ* that has to be questioned. In all instances, the experts should not be allowed to arbitrarily truncate the evidence base to fit their views of what should be done.

° Disagreements about models and parameter values are the most difficult to resolve. The first thing to do is to examine the relationship between the probability of the different models and the complete set of data and evidence (e.g., by Bayesian methods). The second is to decide what approach is required by the level of complexity and the importance of the variable in the final decision.

Q2.2 Different approaches to aggregation of expert opinions

There are three classical approaches to this problem.

° The iterative approach: for example, the Delphi technique, in which the experts are required to elicit independently their probabilistic opinions. These opinions are gathered and sent back to the experts who then have the opportunity to revise their assessments in the light of the colleagues'estimates. The process generally converges quickly, but perhaps towards the wrong figures and for the wrong reasons. One of the major problems is that the experts do not have the opportunity to argue about their models, to exchange their evidence bases, and to discuss the probability of each theory given the evidence.

° The analytical approach:

An example of this type of approach is the Bayesian treatment of the opinion of each expert by a "super expert" (presumably the decision maker). The super expert is supposed to compute the probability of different values conditional on the opinion of each expert treated as different pieces of evidence, with possible dependences (Ref. Morris, Winkler). The problem with this approach is the role of the "super expert" who acts as an aggregator, adding one more layer of subjectivity to the process. Besides, it is often politically difficult to attribute different likelihood functions to the opinions of different experts. A simplified version of this procedure is to simply weight the opinions of the different experts, often with equal weights as if they were independent. Unfortunately, in such a case, the result is a direct product of the choice of the group of experts, without a real chance for them to interact and debate the problem. Hence my preference for the third approach:

° Interactive procedures

In an interactive procedure, the experts meet (1) to share the evidence and discuss the existing data, (2) to explain their models and their reasonings of how they conceived the model given the data, (3) to structure the set of models so that they can begin to talk about the probability of each of them, (4) to assess (individually) the probabilities of the different models, and (5) to participate actively and directly in a debate leading to the generation of the composite distribution.

It is important to note that *there is currently no standard procedure for the aggregation of expert opinions*, and that this exercise will remain subjective in nature. I believe that the key to success (matching the evidence and the distributions, and respect of the internal consistency of the probabilistic logic) is to focus on the probabilities of the models and assumptions as opposed to weighting the experts. Having said that, I have to recognize that the two are frequently linked and that the problem often involves personalities and conflicts as well as a scientific issues.

One promising such procedure has been designed and implemented by the Seismic Hazard Assessment Committee (SHAC) chaired by Robert Budnitz. The work of this committee is now in the publication process. Basically, the committee asked the experts to play successive roles in the aggregation process (from proponent of their own model, to technical integrator of the spectrum of opinions). The result of this work is similar, in its form, to the family of risk curves that Sandia has obtained for potential release levels at WIPP. For a given site, the SHAC committee modeled first the different sources of seismic activity, then the propagation of energy from the source to the site. They obtained a family of risk curves representing a discretization of the frequency of exceedence of different peak ground acceleration levels at the choosen site (Ref. SHAC). Note that this analysis integrates uncertainties about both the source model and the attenuation model (as opposed to the

use of conservative hypotheses). These curves are similar to the CCDFs generated by Sandia for WIPP.

How the results (and the uncertainties) should be incorporated in the regulator's decision making is discussed in details in my answer to the fifth question. This answer is based on the assuption that the aggregation of expert opinions will be done systematically for all fundamental assumptions, and that the resulting distributions will be integrated in the risk analysis. Otherwise (e.g., if the disagreement is simply represented by a set of consequence distribution, one per expert), I do not know how to recommend to a decision maker to systematically treat a collection of results, or the results of a conditional risk analysis based on unweighted assumptions. It becomes a matter of faith in the conservatism of the assumptions.

Q3. SELECTION OF INPUT VARIABLES THAT REQUIRE PROBABILISTIC TREATMENT: SENSITIVITY ANALYSIS

It is not necessary in many risk analysis problems to put a probability distribution on all variables. In the decision analysis cycle (Ref. Howard), the first step is to develop models by a deterministic analysis of the link between the consequences and the input variables. Second, a sensitivity analysis for each variable reveals whether or not the variation of an input value across the possible range can change by itself the final decision. Third, the probabilistic analysis is performed: for the variables that do not require full treatment of uncertainty, the mean value is encoded and included in the model. For the variables that do require a probability distribution, this distribution is encoded as described above. The uncertainties are then "propagated" through the analysis by different methods (closed-form solutions, relevant moments, logic/event trees, or simulation, for example, using Monte Carlo or Latin Hypercube sampling).

Q4. DEVELOPMENT OF PROBABILITY DISTRIBUTIONS

Incorporating *all* uncertainties is a risk analysis is indeed a challenge. Therefore, it is important to proceed first to the sensitivity analysis discussed above so as not to lose sight of the ultimate goal (to support a specific decision).

The development of probability distributions is currently a hot topic within the EPA and the environmental/health risk analysis community. [Note, however, that for many years, it has been done systematically for industrial facilities such as nuclear power plants]. Because of the controversial nature of the treatment of epistemic uncertainties by Bayesian probabilities, the solution is often to do only what I consider a partial uncertainty analysis, focusing on randomness in statistical samples and on distributions for the variables explicitly included in the model. The default solution is thus to focus on randomness and on *some* epistemic uncertainties.

There is seldom any attempt to quantify systematically the epistemic uncertainties (about partially known fundamental phenomena) because it requires quantifying explicitly the probabilities of alternative assumptions and, in order to do that, proceeding to an aggregation of expert opinions. For example, in a recent expert-based study of global climate change, Granger Morgan chose to simply present the range of results for each of the different experts without any attempt to come up with a composite distribution. I personally believe that one cannot escape this full uncertainty analysis (i.e., to include the probabilities of alternative hypotheses). Otherwise, the problem is exactly the one that you are facing with WIPP: how to judge of the degree of conservatism of a conditional risk analysis without looking at the conservatism of the hypotheses.

The structure of a full uncertainty analysis is thus the following:

1. Structuring of the different hypotheses into sets of alternative realizations so that probability distributions can be

attributed to these sets of assumptions.

2. Encoding and aggregation of expert probabilities for each set of assumptions.

3. For each fundamental hypothesis, identification of the subsequent models and parameter values (probabilistic treatment). Conditional risk analyses of the type performed by Sandia, but one for each possibility (e.g., each H1i in Figure 1) in a complete set of assumptions, including a measure of possible dependencies through conditional probabilities.

4. Propagation of all relevant uncertainties for each hypothesis (the results are the sets of risk curves shown in Figure 1 for each realization of a given hypothesis).

5. Summing of the results of the conditional analyses weighted by the probabilities of the fundamental underlying assumptions (one then obtains an overall set of risk curves like those presented at the bottom of Figure 1).

(Alternatively, the overall set of risk curves can be obtained directly through the use of a logic tree).

Again, there are different methods for the propagation of uncertainties through each model: closed-form solutions (which is sometimes possible, for example, to treat lognormal distributions and products of variables), computation of the relevant moments, use of logic (event) trees that layout all possible combinations of hypotheses, models, and parameter values, or full simulation (by various methods including Monte Carlo and Latin Hypercube sampling)

Q5. COMPLIANCE CRITERIA GIVEN A FAMILY OF RISK CURVES

How this full uncertainty analysis is used by the decision maker (DM) is a function of his or her own preferences (including risk attitude). Therefore, it is by nature subjective. The consistency of the process, however, can be treated somehow objectively.

For individual decisions, these preferences are represented by a utility function that allows representing risk aversion by putting

higher weights (than linear functions would) on the possibility of higher losses. Note that by virtue of the axioms of rationality for individual decisions, it is the *mean future frequency* that is the relevant characteristic of the probability distribution for the future frequency of the potential loss levels (in the WIPP case: the release level as an intermediate descriptor, but more importantly, the helth effects).

This rationality paradigm does not apply to collective decisions, except if one assumes that one elected decision maker (administrator) has been given complete power to make these decisions according to his or her utility function (which, presumably, would have to be revealed if it were to be used in an analytical model). This is impractical because it does not fit our political process and because there are many attributes to each decision that would require some adaptation of any revealed preferences.

The administrator is not only concerned about the probability distribution of the levels of release and about the economic costs of release (for which mean future frequencies would theoretically suffice), but also about the health and safety of the most exposed individuals in the public. The choice of a threshold and the way one demonstrates that it has not been exceeded should reflect directly a concern for prudence. The mean may or may not do that depending on the fractile(s) that it represents in the family of risk curves, and the practicality of demonstrating by analytical means that the goal has been achieved.

I would like, at this point, to go back to what I wrote in my 1986 paper:

> " The next question is to ensure that the goals have been satisfied with "reasonable certainty". A common procedure is to use "conservative estimates" at every step which means to overestimate the probabilities of initiating events, failures, accidents, etc. The overestimation of the

final result, however, is impossible to assess. It is a wrong approach that may lead to absurd figures and quite possibly to suboptimal decisions, thus defeating the pupose of conservatism itself. This is why the analysis of uncertainties and their explicit treatment in the final decision are critical.

Once this analysis has been done, safety decisions must be made to ensure that with a high probability (e.g., 0.95) the plant is in compliance with a the maximum acceptable individual risk constraint and with the maximum allowable frequency of failure. There is no compelling theoretical reason to use one fractile or a mean value rather than another criterion. In a framework involving numerical safety goals, this certainty level must be specified by the U.S. NRC along with the safety goal"

The example that I was using was safety of nuclear reactors for which the time horizon is relatively short and the uncertainties can be approached systematically. Therefore, the Probabilistic Risk Analyses that are performed for these plants do not involve the types of uncertainties faced with WIPP. Hence the possibility of "reasonable certainty" (which the USNRC calls "reasonable assurance"). In the case of WIPP, part of the analysis (the EPA linkage of release and health effects) is non-probabilistic and presumably, based on conservative modeling. Therefore, given the time frame and the level of uncertainties (e.g., about the future of civilizations in the next 10,000 years), the chosen approach has been different: to start with a set of preliminary results and framing hypotheses, then do a conditional performance analysis based on a mixed method (probabilistic and pre-set health effects estimates). First, one cannot judge directly which fractile(s) the mean curves of the future release levels would actually represent if Sandia had included in the analysis (1) the presumably conservative hypotheses that EPA had specified (complete with alternative assumptions and their probabilities), and (2) the uncertainties attached to the hypotheses that they generated themselves. Second,

one cannot derive from this analysis a probabilistic distribution for the health effects. The problem is that a full risk analysis of this type would be extremely difficult given the state of the art, and that the uncertainties over the next 10,000 years would be so large that the results may not be very informative.

In this highly uncertain, long-term case, I believe that the approach based on some fixed hypotheses, *then* on "reasonable expectations" for the conditional risk results is generally sensible provided (1) that the hypotheses are globally conservative (health effects given release as well as assumptions in the release computation) and (2) that the mean curves for the release of the different radionucleides generally correspond to high fractiles of the risk curve families (CCDFs). If that is the case, the combination of *hypotheses* and *means* may indeed provide the level of "reasonable assurance" that you wish and that is consistent with the USNRC requirements for much shorter life facilities. To check that the overall analysis is "globally conservative" you need to verify that the global model (Health Effects + Performance Assessment) yields conservative results and in particular that the hypothetical health risk results that would have come out of a fully integrated analysis meet the level of "reasonable assurance" that you want to see. This requires that the combination of the health effect model and the Sandia hypotheses provides a higher level of safety than the one demonstrated by the position of the PA mean curves in the PA alone.

Therefore, you may want to examine the effects of hypotheses on the position of the *current means* in the family of CCDFs (fractiles) for release accounting for the EPA/DoE hypotheses as shown in Figure 1. Of course, you do not want to ask Sandia to redo the whole uncertainty analysis, but to give you a feeling for the final degree of conservatism of the release results after this accumulation of assumptions. This involves listing the main hypotheses (both from EPA and from the Sandia PA) and assessing (even coarsely) their cumulative effects on the position of conditional (current) means in

the CCDFs families. If it is the case that the EPA/DoE assumptions are generally *conservative*, it is likely that what are now mean curves in the current conditional performance analysis (Sandia's PA) would correspond to higher fractiles of distributions that would account probabilistically for all hypotheses (Figure 1, bottom left). If the set of assumptions turns out to be altogether *unconservative*, introducing alternative assumptions will tend to make the current means go down in the families of risk curves towards lower fractiles (Figure 1, bottom right).

When you receive this information about the probabilities and the effects of alternatives to the main hypotheses on the position of the mean curves, you want to examine whether the *final* levels of fractiles that would correspond to the *current means* meet the level of conservatism that you want. You may also want to go one step further and look closely at the health effects themselves and at the conservatism of the EPA model of cancer risk. I do not believe that at that stage it would be realistic to require EPA to proceed to a full probabilistic risk assessment (they do not have the methods as far as I know). Yet, you can argue that their "reasonable expectations" are reasonable only if their hypotheses and health effects model provide the additional level of safety that is consistent with the NRC language of "reasonable assurance". In other terms, first their current means for the release of the different radionucleides have to provide at least as much safety as the overall "expected value" of the release that one would from a probabilistic analysis of the hypotheses. Second, the EPA health effect model should provide an additional layer of safety that convinces you that you are indeed in the high fractiles of a hypothetical full risk analysis.

Should you push EPA to specify a fractile level applicable across the board to all cases? I don't believe so, simply because each problem has to be replaced in its context (uncertainties, existence of alternatives, economic and political context, etc.). I believe, however, that examining carefully the range of fractiles

corresponding to the mean in the consequence distribution is a reasonable way to address the question of uncertainties. In the WIPP case, the choice of the mean conditional on a set of hypotheses was based on the long-term nature of the project, the fact that the computation of the mean is more robust than that of specified fractiles, and that the means (given the uncertainties) are likely to be among the high-fractiles anyway. And in any case, requiring the EPA to make a general statement about a "high level of confidence" in the final health effects analysis including all uncertainties would be helpful.

Regulatory language

I think that you can require that EPA be more rigorous in its implementation of the "reasonable expectation" language. They cannot just set hypotheses and models (as those leading to Figure 1, Appendix A of 40CFR191), frame the conditional risk analysis for the applicant, then claim without checking that the conditional means (even with infinite sampling size) resulting from this analysis necessarily support "reasonable expectation" of human safety. Whereas it may be unreasonable (and perhaps, even hazardous given how uncertain the results would be) to leave the choice of hypotheses and model framing to the applicant, it is not unreasonable to require that the effects of these hypotheses on the mean curves be assessed (i.e., simply to check how they displace the mean curve: up or down). In the WIPP case, I would focus on the hypotheses of the intrusion model (frequency, means and effects of drilling) which are the most likely to significantly affect the release results. I would also examine very closely the EPA health effect model.

I would want EPA to show that, in the end, the combination of "reasonable expectation" for the performance assessment and of the conservatism (if it is the case) of the health effect model that they have used to set the release criteria provides "reasonable assurance" of actual safety (i.e., for the ultimate health effects). Because EPA has done the health effects modeling, they are in a good

position to show the conservatism of their own results and of the final health risks when these results are combined with those of the performance assessment.

Therefore, you want to require EPA:
(1) to fully reveal the models that they have used to come up with the release standards,
(2) to list all the major assumptions that they have made (those that are likely to affect the risk analysis results), (3) then, to ask the applicants to show that the combination of these models, hypotheses and their own performance analysis supports the requirement that the current conditional mean is indeed "above" the marginal (overall) mean, and that altogether, the assumptions are in fact "conservative".

By comparison, the uncertainties that result from the sampling are probably (1) cheap to reduce and (2) not very significant compared to effects of the basic hypotheses. Therefore, you may choose either to accept their 95% confidence language, or to require a third level of confidence in the analysis. I do not think that it will make much difference.

3. ADDITIONAL COMMENTS ON ISSUES RAISED IN YOUR LETTER

3.1 Level of confidence in the fractiles (or mean) given the sampling size

This issue is easy to resolve because it is cheap to require additional computer runs if you do not think that the level of confidence achieved is what you want. Of course, the tail of the distribution will not be often reached in the simulation by definition of high consequence/low probability modeling. You may want to press EPA to specify the confidence level in this process (third order treatment of uncertainty, i.e., one level further than what I describe as Level 5 in Figure 2 of the Appendix). But you have to realize that the results will be somehow artificial given the variety of the sources of uncertainties. So, I would not focus so much on the uncertainties due to sampling size because they are

probably "in the noise", as I would on the uncertainties about the fundamental hypotheses.

3.2 Encoding of expert opinions

I agree that you may want EPA to specify better their encoding procedures. Anyway, in the case of WIPP, you want to find out how Sandia exactly did it (especially for parameter values).

3.3 Use of the mean

I generally agree with EPA that the mean *does* convey "a sense of the whole ensemble of the CCDF's generated". It represents an aggregated description of the risk by a single probability distribution (Level 4 of Figure 2) without displaying the higher level of uncertainties (Level 5 in Figure 2). I do not believe, as you do, that the applicant can vary the number of realizations and dilute at will the effects of *any particular CCDF*. What is true, however, is that with a small number of realizations (in the simulation) one may not reach the tail of the distribution. You want Sandia to specify case by case what level of assurance the mean represents (it varies, of course, along the release axis).

3.4 Additional comments

a. Specific guidance for the form of probability distribution functions seems to me impractical.

b. Need to deal with correlations: I agree, this is essential.

c. Appropriateness of the mean: in the case of WIPP, I think that the coupling of EPA assumptions (*if* they are globally conservative) and mean release level (which is likely to be among the high fractiles given the uncertainties) should provide the level of safety that you want. This is what you want Sandia to demonstrate.

d. Calling explicitly for a 95% fractile with 99% confidence would require a full probabilistic treatment of all EPA/DoE hypotheses regarding the release, introducing still more uncertainties in the analysis and probably producing highly questionable results. [I would not suggest this kind of fractile *on top* of the EPA hypotheses.] Again, I would start by checking what the current mean

represents (roughly) in the full picture. To call for the 95% fractile of the *real risk curves (i.e., the health effects)*, would require a whole new risk analysis including both the release model and the health effect model. It is obviously not the direction that was chosen *a priori*.

f. Of course, the process of sampling of 50 parameters, even with an infinite sampling size would dilute the effects of the extremes. It is the nature of probability: the extremes are much less likely than the central range of the distribution. But you want sufficient sample size to have confidence that you have given the extremes their proper weight.

h. Reducing uncertainties can be done in many different ways. Increasing the sampling size of course is one of them; but again, these uncertainties are probably minor compared with the uncertainties involved in the fundamental assumptions.

j. No, it is not easy to identify the various percentiles of crossed curves. Indeed, any mean curve will represent different percentiles in different release ranges.

4. CONCLUSIONS:

I believe that the case of WIPP as it stands now raises issues that are different from those that I addressed in my 1986 article regarding nuclear power plants. But the fundamental concern is the same: reaching an acceptable level of safety with reasonable certainty (or assurance). In the 1986 article, I proposed to do it using high fractiles of the risk curves (which is often where the means are anyway) based on full PRAs including the treatment of all identified and relevant uncertainties (as determined by sensitivity analysis). For WIPP, we do not have risk curves (in the sense of full probability distributions for the consequences,i.e., the health effects). Because of the 10,000-year time horizon, the uncertainties in the case of WIPP are such that this kind of analysis may be a futile exercise. Instead, EPA has chosen to make some assumptions in its performance criteria and to require a conditional performance analysis given these assumptions. Then, EPA specified the use of the conditional means as the basis for the compliance criteria.

In order to verify that the conditional means (conditional on specified health models and hypotheses) provide indeed "reasonable expectation" of safety once the effects of the hypotheses on expected values are carefully considered, you want to ask Sandia to provide additional information about what these conditional means really represent for future release and what they imply for human safety. In particular, you want to question assumptions regarding engineered barriers and the hypotheses that have been made to support the currently planned storage system. This is where you may be able to show that some of the assumptions are unconservative and that the real mean curves are below the conditional ones. Therefore, you may be able to conclude that the current analysis based on conditional means does not meet, on the whole, the "reasonable expectation" standard. I would not focus much on the effect of the sampling size (although it probably does not cost much) because increasing it may not provide large variations of the position of the mean in the overall CCDF family. The hypotheses about the frequency, the means and the effects of drilling are more likely to provide significant variations.

To summarize my conclusions:

4.1 I do not know where the current means stand in terms of fractiles on the distribution of release curves presented by Sandia.
=> You may consider asking Sandia to specify which fractiles are involved in the mean release curves that are presented in their final PA report (these fractiles will vary along the release axis; but Sandia may be able to bracket them).

4.2 I cannot judge the degree of conservatism of the Performance Assessment results because I do not know the effects of the EPA and DoE hypotheses on the release curves.
=> Ask Sandia to list the major hypotheses that have been taken for granted in their PA and to give you an idea (if not a full analysis) of the effects of these hypotheses on the results (i.e., the family of release curves). For example take the five or six most important assumptions of the PA (e.g., the Poisson model of human intrusions,

the diameter of the bore holes, the water flow model, the solubility factor of the main nucleides, etc). Ask Sandia to generate a set of reasonable alternatives to these hypothese and to show you that the mean curves that would be generated with proper probabilistic analysis of these alternative assumptions actually meet the criteria (and that they do not pull the means towards lower fractiles of the risk curve families).

4.3 The expert opinion procedures of encoding could be made more rigorous.
=> You may want to ask Sandia to identify the variables whose distributions are critical for the results (could make WIPP violate the performance criteria), to justify their decision to treat them through expert opinions (as opposed to experiments or measurements when feasible), to better justify their findings by describing exactly how they have encoded and aggregated expert opinions, or to redo the encoding and aggregation of these judgments if you conclude that some of the variables have nor been properly treated.

4.4 The uncertainties about WIPP are such that full probabilistic treatment of all assumptions is likely to introduce large additional uncertainties in the results if they were to be systematically treated through probabilities.
=> You may want to find out what is the level of release risk obtained given the combination of EPA and DoE assumptions and the results of the corresponding conditional risk analysis, judge whether it is reasonable, and if it is not, ask EPA to reveal how it is going to inject additional levels of prudence in its decision. Depending on how far the current means are (assuming full probabilistic treatment of hypotheses) from a reassuring (but not sacred) 95% fractile, you may want to ask for additional analysis or for a change of risk management strategy.

4.5 If you really want to estimate the long-term health risks associated with the possibility of release, you need a probabilistic version of the EPA health effect model and a true risk analysis

involving both release and health effects. I doubt that this is feasible. But:
=> You may want to ask EPA to better justify what they have done to obtain Table 1 of 40CFR191 and DoE to show that the overall risk results (their model plus the PA) provide "reasonable assurance" of safety.

5. APPENDIX
[What follows on this topic is based on a report that I recently wrote for the Electric Power Research Institute].

Six levels of treatment of uncertainties in risk analysis:
The form under which one would like uncertainty analysis to be done depends in large part on the use that one intends to make of the results, i.e., what criteria will apply in the decision making. All decisions do not need full treatment of uncertainties. Different degrees of sophistication in the assessment of the risks can be envisioned depending on the management rule that one intends to apply. Six different levels in the treatment of uncertainty (see Figure 2) can be identified.

Level 0 simply involves the detection of a potential hazard without attempt to assess the risk in any way. It is sufficient, in theory, to support strict zero-risk policies, or to make risk management decisions when the costs are low.

Level 1 is the "worst-case" approach. It does not involve any notion of probability. It is based on the accumulation of worst-case assumptions and yields, in theory, the maximum loss level. In practice, however, whatever the worst-case scenario that has been constructed, it is often possible to imagine still more unlikely circumstances that could worsen the result. It is therefore necessary to truncate the loss distribution.

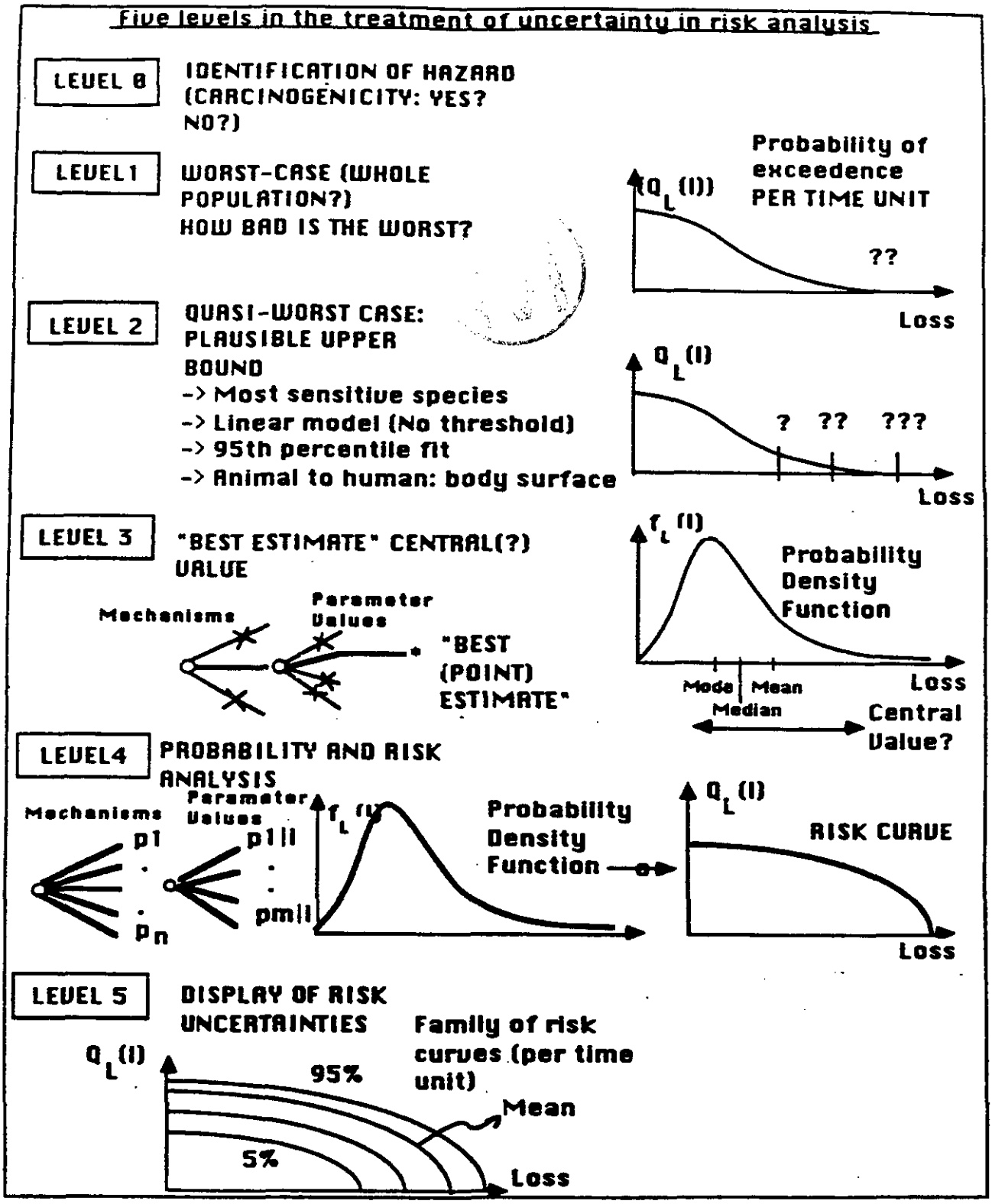

Figure 2: Six levels of treatment of uncertainties in risk analysis (Paté-Cornell, EPRI report, 1995).

Level 2 involves "plausible upper bounds" (or the "quasi-worst case"). This analysis represents an attempt to obtain an evaluation of the worst possible conditions that can be "reasonably" expected (1) when there is some uncertainty as to what the worst case might be, or (2) when the worst case is so unlikely that it is meaningless. Examples of these approaches include the Maximum Credible Earthquake or the Maximum Probable Flood used by the U.S. Army Corps of Engineers in the construction and management of dams.

This popular approach, however, presents major shortcomings. First, there is no way to judge the "conservatism" of these point estimates (the residual risk is unknown). Second, this approach does not allow a meaningful comparison of risks. Ranking among these presumably extreme values may not be related to the ranking of the mean values of the potential losses and there is no reason to believe that priorities set on the basis of plausible upper bounds will ensure maximum risk reduction for the money spent.
analysis.

Level 3 relies on "best estimates" and/or on a search for a central value (e.g., the mean, the median or the mode) of the loss distribution. Generally speaking, the advantage of central values is to provide a reasonable balance to plausible upper bounds. The disadvantage is that the risk is still characterized by a single point estimate and that the uncertainties disappear from the results.

Level 4 relies on probabilistic risk assessment (PRA), also known in engineering as quantitative risk assessment (QRA), or probabilistic safety assessment (PSA). It permits representation of a risk, not by a single point estimate, but by a complete distribution of the potential losses to represent the uncertainties involved. Still, the effects of all uncertainties being aggregated into one risk curve, it is impossible to extract from this information the dispersion due, for example, to expert disagreements about competing models for a fundamental hypothesis.

Level 5 allows display of uncertainties about fundamental mechanisms. This can be done in several ways. One approach is to ask each expert to provide an assessment of the risk based on their favorite model and on their evaluation of the distribution of parameter values, and to display this set of risk curves (one for each expert) without attempting to aggregate the results or to assess the probabilities of the fundamental assumptions on which they rely. The problem is that one popular hypothesis may be favored by a large proportion of experts for a combination of scientific and other reasons. Therefore, if a composite distribution is needed, one must sooner or later address squarely the issue of the relative probabilities of the different hypotheses and proceed to an aggregation of expert opinions. It is important at that stage to depoliticize the process if needed, and to put weights on models (given the evidence available) and not on the experts.

Therefore, in order to reach its logical conclusion, Level 5 requires a full probabilistic treatment of epistemic uncertainties. The result is a *family* of risk curves. These curves provide, for each value of the potential losses, a discretization of the probability distribution of the future frequency of exceedence of this loss value. Both aleatory and epistemic uncertainties are propagated through the analysis, for example, by Monte Carlo simulation or other simulation models such as the Latine Hypercube approach.

WIPP Performance assessment is a mixed case of some aspects of level 2 (plausible upper bounds; conservative hypotheses) and level 5 (full uncertainty analysis).

6. ANNOTATED BIBLIOGRAPHY

A. 40CFR191

1. Russo, September 1991: Updated Uncertainty Analysis of EPA River Mode Pathways Model Used for 40CFR Part 191: Table 1 of 1985 40CFR191 Analysis of Curie release corresponding to 90% level of certainty that effects will be less than or equal to 10 fatal

cancers/10,000 years was completed by an uncertainty analysis in which the probability distributions characterizing uncertainty about model input parameters were based on discussions held with radiological assessment experts taking into account theoretical considerations, variability in published data, and insightful judgment [How was this done?]

2. EPA 520/3-80-006. Population Risk

p. 150: "The expected frequency of human intrusion into a repository ranges from a drilling event every 400 years for granite to a drilling event every 50 years for salt and shale (ADL 79d)." [This is one of the assumptions whose effect on the results should be checked]

3. Federal Register 1985. 40CFR191.

191-13 Containment Requirement:

"Reasonable expectation" language. PA need not provide complete assurance...etc.

4. Response to comments; EPA 520/1-85-0242. p2-5: The median is insufficient. [I agree]. p.2-12: EPA states that the standards, as they are written, will allow demonstrating compliance in a way that will not be "unreasonably difficult or expensive". [Fine].

5. Report of the Review of 40CFR191 by a subcommittee of the SAB.1984. "The subcommittee supports the general form of the proposed standard, including the use of a social objective as an upper bound of acceptable health (cancer and genetic) effects. [The question is: how conservative is the societal risk target *given the assessment method*. Could be very conservative or not. I don't know].

6. Working draft of final 40CFR191: 11/1/83

191.16: Guidance for implementation

"determination of compliance should be based upon "best estimate" predictions (e.g., the mean of the appropriate distribution results)." [Best estimates is generally not a good term to use without specification in regulatory language because it is too vague].

7. Working Draft of final 40CFR191: 2/1/84

"Instead the implementing agency may determine compliance based upon the part of the range of predictions that falls within one standard

deviation of the mean..." [That was an idea but it was not implemented].

8. Working Draft of final 40CFR191: 4/23/84

Mean + one standard deviation => 85% for Normal distribution [Many distributions are not normal but skewed right].

9. Working Draft of final 40CFR191: 3/21/85

191.13: Containment requirements Uncertainties are too large hiven the time frame. => reasonable expectation language [Intended to be: the mean; actually here: conditional means].

Further: compliance with 191.13: Integrate all uncertainties into one risk curve [i.e., the mean risk curve. This is the level four of Figure 1. It is generally sufficient to support the choices of the risk averse decision maker in rational individual decision making].

10. Working Draft of final 40CFR191: 6/15/85

191.13: same language about "reasonable expectation".

11. Working Draft of final 40CFR191: 7/5/85

Uncertainties, and long term => reasonable expectation

12. Report of Meeting with extra-agency personnel concerning EPA Docket Number R-82-3. (with NRC staff personnel). "Subparagraph 191.16a requires that the standards be implemented in terms of the upper 85% confidence level of the simulated cumulative release. In view of the very very large number of judgmental factors that will have entered into the calculation, the use of the specified confidence level as a basis for deciding compliance is highly susceptible to mischief during the licensing process[...]; in view of uncertainties involved, confidence levels must be adressedd in terms of qualitative (e.g., reasonable assurance terms) rather than quantitatively."

Further: "Confidence level: DoE is concerned that the mention of an 85% confidence level will become the required level for all analyses; this would be contrary to EPA's intention."

Further: Guidance for implementation:

Suggestion again that mean + one standard deviation becomes the standard (=>≈85% for Normal distribution).

Further: "Paragraph 191.16.c unclear and calls for a precision level that may not be possible to demonstrate analytically."

13. EPA background information behind 40CFR191 1985
EPA 520/1-85-023.
p.6-3 Problem of uncertainties in EPA modeling of radiation risk estimate (the risk per unit dose are likely to be low)
p 6-13 the risk estimates are not unduly conservative [Important to check and to assess the effect on individual safety].
14. EBASCO study: Uncertainty and sensitivity analysis for the exposure pathway models used in 40CFR191.
p. xiii: levels of certainty for each radionucleide in Table 1.tryin to evaluate the level of conservatisms [Again, effects on conservatism of Sandia's result?].
15. Background information: EPA 93. EPA cancer risks are based on NAS study. Further (p.6-5): dose-response function was based on japanese epidemiology after the Hiroshima bomb. Perhaps unconservative following subsequent studies (p.6-93). p.6-31: estimates of cancer risks are NOT conservative.
16. EPA environmental pathway model, 1986
p.S9: Releases to a river [could be very conservative: WIPP is in the desert; but assumption was based on large rivers; how about small ones?].
17. Analysis of Uncertainties. Envirosphere, June 10, 1983.(problem of the original ore body release and river mode exposure pathway). Another set of uncertainty assessments for Table 2 of 40CFR191.

B. 40CFR194

1. Federal Register
2. 40CFR194 Proposed Rules: Criteria for the Certification and determination of the Waste Isolation Plant's compliance.
p.81: Expert Judgment "should be used provided that it does not substiotute for data that could be obtained through data collection or implementation." [An apparently reasonable set of requirements. No conflict of interest. At least five experts. Not all from DoE].
p.113: results of performance assessment:Risk curves. Monte Carlo of Latin Hypercube. Not the median. Requirement that the number of risk curves be large enough so that the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least 0.95

probability. [Looks conservative. To be checked]

p.114: the criterion itself: "demonstrate that there is at least a 95% level of statistical confidence that the mean of the population of CCDFs meets the requirements of section 13(a) of 40CFR19" [The mean is the most robust measure under the circumstances (smaller sample size required) and it may already be in the 80 to 95% fractile].

3. Background information: EPA 402-R-95002

p.3-7: Disposal systems shall be designed to provide reasonable expectation based upon performance assessments that cumulative releases of radionucleides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

(1) Have a likelihood of less than one chance in ten of exceeding the quantitties calculated according to table 1 (Appendix A) and

(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1.

Table 1 defines a set of permissble releases ("normalized release" for each isotope). [The question is; what were all the hypotheses underlying Table 1].

4. Compliance criteria: March 21, 1995

p.55: results of performance assessments.

5. EEG Comments. April 28, 1995.

p.5: the WIPP site does not meet the there stated criteria of 40 CFR 191.149 (because it is in a resource rich area)=> unconservative assumption. On the other hand, (p.6)EPA claims that the hypotehse are favorable because of the favorable characteristics of the WIPP (located in the desert). [net result??]

p.11: Engineered barriers:

Argument for engineered barriers: unconservative assumptions regarding human intrusion in a resource rich environment. Also: benefits will be small because it would only delay the arrival of actinides in the environment.

1992 PERFORMANCE ASSESSMENT REPORT

COMMENTS AND RESPONSES

EPA/EEG/NMAG/NMED

DOE/WIPP-95-2053

Responses to Comments on the 1992 Preliminary Performance Assessment Report for the Waste Isolation Pilot Plant

June 1995

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

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Introduction

This document contains the Department of Energy's (DOE) responses to comments made by the Environmental Protection Agency (EPA), the Environmental Evaluation Group (EEG), the New Mexico Environment Department (NMED), and the New Mexico Attorney General (NMAG) on the "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992", Volumes 1-3. Each comment and response is listed along with the reference materials. The appendixes contain supportive figures and memos referenced in the document. The subject document is referenced as the 1992 PA (Performance Assessment).

Comment CL1

Cover Letter, Format and Content

"We reviewed this document with the idea that it should contain all of the information needed to allow us to review, understand and evaluate DOE's approaches, and to demonstrate that the approaches were sufficiently justified to support a request for certification of compliance."

Response

The DOE appreciates the perspective taken by the EPA for this review since it provides the DOE with significant insight regarding what should be included in a compliance application. In addition, the EPA's perspective will help identify areas where the two agencies may disagree regarding implementation. It is important to seek resolution to these prior to the preparation of a final application.

The DOE will use EPA's comments and suggestions as a guide on formulating aspects of its compliance program. In addition, the DOE will establish, as a priority, the resolution of any issues or disagreements that have resulted from these comments.

Comment CL2

Cover Letter, Format and Content

"Although the PA provides a large amount of information, it lacks a sufficient description of the analyses that are discussed. The current PA is not a "stand alone" document that uses references as supporting information. Rather, references are often provided as the proof of the validity of DOE's reasoning, with insufficient information presented in the PA to enable the reader to follow that reasoning. ... While we understand that references and accompanying documents will be needed, we feel that the PA (in all its volumes) needs to tell a complete story. In our view, the PA should start with the basic information and, step by step, build up to a demonstration of compliance."

Response

The DOE agrees that the PA is not a "stand alone" document for compliance purposes. In fact, PA is only a tool used to determine compliance with quantitative limits and to understand uncertainty. Numerous other topics are to be included in the compliance application as indicated by the Format and Content Guide issued in May 1994.

This not withstanding, the DOE appreciates the broad perspective used by the EPA in its review as discussed above. The DOE will use this broad review as a guide in preparing the final application.

Comment CL3

Cover Letter, Format and Content

"For example, it would be helpful if the PA presented a listing of scenarios considered, and showed the analysis of probability and consequence for each separate scenario. The presentation of separate analyses would help clarify how scenarios are combined to create a final set of CCDFs."

Response

This material will be included in the compliance application as appropriate. The DOE notes, however, that separate analysis of both probability and consequences may not be appropriate for all scenarios considered. Some scenarios may be shown to be of sufficiently low probability that consequence analyses are unnecessary. Other scenarios may be shown to be of sufficiently low consequence that probability analyses are not required. In other cases, different scenarios may have sufficiently similar consequences that results of a single consequence analysis may be used in conjunction with different probabilities.

Comment CL4

Cover Letter, Format and Content Guide

The outline in the November 1993 Format and Content Guide prepared by the DOE is a significant improvement over the current PA organization.

Response

Comment noted.

Comment CL5

Cover Letter, Access to Information

"We are concerned that much of the information referenced or used as integral part of the PA analyses is not available for review. The current PA cannot be thoroughly reviewed because the supporting information is not accessible. This includes some references,

computer codes, their documentation, laboratory and field data, and the data generated from computer runs, such as the results of the Latin Hypercube Sampling that is used as input for the computer runs. The computer codes and their documentation should be available for public review."

Response

The DOE is currently pursuing access to computer codes and training in their use with the EPA and stakeholders. Documentation of codes is being completed, and will be complete before PA analyses are used in a compliance application.

All source material cited in the 1992 PA, including primary documentation for laboratory and field data, is on file at the WMT library at Sandia National Laboratories. For a compliance application, reference materials will be dealt with in a significantly different manner in order to assure timely access to information by the EPA.

Comment CL6

Cover Letter, Access to Information

"In addition, if they are incompatible with EPA's computer system, they should be remotely accessible on DOE's computers to allow independent examination. I recognize that the codes and their documentation are not in final form; however, our review of the codes will take a long time, so we need the copies used to prepare a performance assessment along with the results of that assessment. If we do not get the codes until the final application, it will significantly slow our review of the application."

Response

The DOE is as concerned as the EPA over the length of time that EPA may require to review DOE's codes. Consequently, the DOE has made code availability a priority. The EPA and the DOE are successfully resolving this issue of access and training.

Computational efficiency is a complex topic and would be a welcome topic for the DOE/EPA technical exchange meetings. Specific recommendations concerning resource allocation, e.g., model development versus collection of experimental data, are to be an integral part of the systems prioritization methodology (SPM) effort. The SPM will have "outside scrutiny" inherent in the process design.

Comment CL7

Cover Letter, Repromulgation of 40 CFR 191

(a) "We realize that 40 CFR 191 had not been repromulgated when the analyses for this version of the PA were being conducted, thus consistency with the rule was impossible. However, the rule is now final, and changes in the PA will need to be made in order to reflect the new 40 CFR 191. The main areas where changes are necessary are in the ground-water and individual protection requirements, and the use of the committed effective dose. The definitions relating to ground water have been changed to reflect EPA's policy of protecting underground sources of drinking water. DOE will need to identify the potential aquifers and their water quality (i.e., total dissolved solids)."

(b) "In addition, the undisturbed performance time frame calculations need to reflect the 10,000 year requirement. With the increase of the time frame from 1,000 years to 10,000 years, DOE may need to include scenarios that were previously omitted."

Response

All aspects of 40 CFR 191, including those portions repromulgated in December 1993, will be incorporated into compliance documentation.

(a) The DOE has taken the position that a decision on when and if underground sources of drinking water should be identified and characterized (i.e., when such a characterization will provide pertinent information for a compliance application) will be based on the expectation of releases. Briefly, identification and characterization of USDWs should not be required if no radionuclide releases to the accessible environment are predicted for 10,000 years or if 10,000 year peak predicted releases to the accessible environment are less than or equal to the applicable Maximum Contaminant Levels (MCLs). USDWs along the pathway should be identified and characterized if peak predicted releases to the accessible environment for 10,000 years are greater than the MCLs.

(b) The DOE agrees that calculations for a compliance application must be performed for a 10,000 year compliance period as stated in 40 CFR 191.

Comment CL8

Cover Letter, Regulatory Issues

"The PA also needs to address both 191 and RCRA compliance."

Response

The DOE has implemented a PA program which examines two-phase flow. This allows the determination of releases via both liquid and gas pathways. For the compliance determination, appropriate transport calculations will be made using these PA models. These calculations will include contaminant transport of interest to each of the regulations.

Comment CL9

Cover Letter, Regulatory Issues (Guidance to 40 CFR 191)

"The Guidance for 40 CFR 191 is generic in its application and it is non-binding to the implementing agency. EPA is evaluating the Guidance's suitability for use at the WIPP site. However, deviations from the Guidance should be clearly explained. The compliance criteria (40 CFR 194) will provide further clarification on this topic."

Response

The DOE agrees that any deviation from the guidance in 40 CFR 191 must be carefully and clearly documented. The DOE realizes that EPA's guidance, while non-binding, is not arbitrary and is provided to assist the implementing agency in meeting EPA's overall goal of protecting human health and the environment. Since EPA's guidance is established as the result of the technical bases developed during rulemaking, the DOE realizes that any significant deviation from this guidance must have equally in-depth technical justification.

Comment CL10

Cover Letter, Regulatory Issues

"The future applicability of the Guidance notwithstanding, DOE did not correctly follow the Guidance in this PA. If DOE was going to follow the Guidance, the PA should have used a constant drilling rate of 30 Boreholes/km^2 per 10,000 years for comparison with the containment requirement. In addition, the PA incorporates credit for passive institutional controls without proper justification."

Response

The maximum rate for human intrusion considered by DOE yielded an expected number of boreholes equal to 30 per square kilometer. Smaller rate constants were also considered to allow the evaluation of the sensitivity of disposal-system performance to uncertainty about future drilling rates. Determining such sensitivities is important to capturing the most significant parameters for the compliance calculations. These sensitivity analyses indicated

that system performance is highly sensitive to the drilling rate and that it may be a very important factor in the compliance decision.

The DOE agrees that any assumptions made regarding the guidance need adequate justification as discussed previously. This applies to the credit taken for passive controls, drilling rates, and other factors.

Comment CL11

Cover Letter, Use of Expert Panels and Peer Review

"There should be documentation of the process used to obtain expert opinion, and the process should follow written procedures."

Response

A formal QA procedure for the use of expert judgment by Sandia National Laboratories was published in 1992 (Rechard et al., 1992). Further refinements of this QA procedure can and have been incorporated into WIPP Procedure No. PAP06, Use of Expert Judgment Panel Quality Assurance Procedures. Compliance documentation will contain documentation in accordance with this or any other formal procedure used by the DOE and its contractors to elicit expert judgment.

Comment CL12

Cover Letter, Use of Expert Panels and Peer Review

"Specifically, we do not agree with the approach taken by DOE to estimate a reduction of the drilling rate from speculations on the use of markers. The markers aren't yet designed; therefore, the panel was asked to provide advise about the effectiveness of the markers at WIPP on the basis of incomplete information. Nor did the panel include all the necessary expertise, e.g., no petroleum engineers or drilling experts were included on the panel. The information from the marker panel was then apparently provided as input to a computer program that produces results in an unclear manner. EPA's compliance criteria will contain additional guidance on the use of expert panels."

Response

This issue has been raised numerous times by the EEG and the DOE has been sensitized to assuring proper care is taken in both establishing the scope of an expert panel and in using the outcome.

With regard to the specific comment on the process used by the DOE, the following is provided:

The process used by the Markers Panel was to first develop design guidelines for long-term communicative markers based on the contributions from individuals in disparate related fields such as materials science, archaeology, and communications. Based on the design guidelines, the two teams comprising the Markers Panel each developed a conceptual design for a system of markers. Estimates of efficacy of the markers system over time were based on the conceptual design. Implicit in the deliberations was the assumption that sufficient testing was undertaken to determine, for example, the appropriate design of the foundation for stone markers to withstand possible fluctuations in surface level and still remain stable. A second assumption in the effort was to evaluate what was possible for a marker system (as a first approximation) with no cost constraints. Cost constraints may come into play regarding the definition of "practicable" in 40 CFR 191. There is much evidence from the fields related to marker design that suggest avenues to pursue to improve long-term survivability and communication.

A petroleum engineer was not included on the Markers Panel, because the thrust was geared to long-term survivability of a marker system and continued interpretability. A petroleum engineer's skills are not such as to contribute to this effort.

M

Comment CL13

Cover Letter, Use of Expert Panels and Peer Review

"In future performance assessments and interim documents, it would be helpful for DOE to identify: 1) the areas where no data exist; 2) where expert panels and expert judgement will be used in lieu of data; and 3) whether the expert judgement will be replaced with data by the time of the final application. We strongly recommend that DOE use data where it is possible to obtain it, instead of relying on expert judgement."

Response

The DOE agrees that the use of expert panels in lieu of data must be carefully documented and justified. The DOE, however, does not agree with the concluding statement in this comment since it is written so broadly. Instead, a level of "practicability" must be applied when designing tests in lieu of expert judgment. This is particularly true when tests may require unrealistically long time frames or represent unreasonable costs.

Comment CL14

Cover letter, Models

"The development and implementation of conceptual, computational, and computer models is one of the most important technical aspects of the performance assessment topics. Therefore, it is imperative that we and the public have a good understanding about the modeling process and the models themselves. In the current PA, a good discussion of conceptual models and their alternatives are provided in only a few instances, such as the porosity model for the Culebra Dolomite. The conceptual models for the potash mining scenario are absent."

Response

The DOE agrees that the development, documentation, and implementation of conceptual, computational, and computer models is critical to a defensible performance assessment. Documentation of models is facilitated by Sandia's formal software Quality Assurance Procedures. The mandatory guidelines and requirements contained in these procedures ensure traceability and verification of computational and computer models, as well as documentation of the underlying conceptual models.

The evaluation of computational-model uncertainty involves evaluation of various conceptual models against relevant repository performance metrics. Current WIPP PA accomplishes this in two ways:

1. An "all-other-things-being-equal" method, in which alternative conceptual models for one component of the system are individually evaluated over the LHS sampling of imprecisely known parameters, while maintaining the variability of parameters not included in the tested sub-model constant.

2. Inclusion of the alternative conceptual models within the sampling of imprecisely known parameters.

Examples of method (1) are inclusion of: a) multiple transport and flow models of the Culebra dolomite (single-porosity vs. dual-porosity vs. fracture-flow only; chemical retardation vs. no chemical retardation); and b) multiple repository and Salado long-term responses (with gas generation vs. without gas generation; with room consolidation vs. without room consolidation; with a representation of fracturing in the Salado vs. with no Salado fracturing).

The example of method (2) to date is inclusion of different two-phase-characteristic curves, e.g. the Brooks/Corey and Van Genuchten/Parker sub-models, and sampling on each.

The DOE believes it is important to evaluate the defensibility of all conceptual models continually, both by examining their supporting experimental data and evidence and by examining whether or not the different models have significantly different impacts on expected performance. Ultimately, the defensibility of a performance assessment depends on the belief of the regulators and major stakeholders that a reasonable conceptual model has been used, and that there is sufficient evidence to support its use. In order to make this evaluation, this history of the development and screening of alternative conceptual models used in the performance assessment must be thoroughly documented.

Comment CL15

Cover Letter, Models

"The next performance assessment iteration should contain a detailed description of all conceptual models chosen and the alternative conceptual models that are or have been under consideration. For those conceptual models no longer under consideration, DOE should justify why they were discarded."

Response

During the development of compliance documentation, a conceptual model screening process that has the goal of examining all conceptual models put forward by Sandia, WID, DOE, and stakeholders will be used to arrive at a prediction of reasonably expected system performance. The screening process will include the reasoning by which the model is accepted or rejected for use in the performance assessment. The compliance documentation will provide the full description of the screening process and its application.

Comment CL16

Cover Letter, Models

"Before DOE submits an application for certification of compliance, there should be general agreement between EPA and DOE on the conceptual models that will be used by DOE."

Response

The DOE agrees that ongoing dialog regarding conceptual models will be very useful.

Comment CL17

Cover Letter, Models

"The development of the computer codes will take time, especially since many of the computer codes are 'state of the art.' Because of the sophistication of the modeling, the peer review and quality assurance of the code will also take time--the more complex the code, the more time it is likely to take. They will also take more time to review. We recommend that DOE takes the necessary time to ensure that the peer review and quality assurance is implemented in a thorough manner, especially where there is uncertainty in the conceptual models used in the codes."

Response

The DOE agrees and has instituted a thorough review of the quality of the codes and data used to implement conceptual models.

Comment CL18

Cover Letter, Quality Assurance

"...the PA does not seem to address data quality objectives or other related issues."

Response

This was not a rigorous objective of the 92 PA. The DOE has recently initiated a quality verification activity to assure data and code quality for compliance determinations.

Comment CL19

Cover Letter, Quality Assurance

(Restatement) EPA is concerned about the implementation of QA for the "old data", such as site characterization or completed laboratory studies.

Response

In 1993, the DOE began an extensive review of early and completed work. The assessment is still in progress. Deficiencies identified in the assessment shall be documented and appropriate corrective action taken. Before the final compliance application is brought to EPA, data, analyses, and resulting conclusions shall be screened against appropriate QA requirements.

Comment T001

Page 1: I. Technical Comments, A. General, Access to Information

Area in document General

"EPA should have access to source codes, code documentation, on-line help files and the executable image. It is recognized that at an early stage of development, a code is a working draft and should not be subjected to a critical outside review. However, if the computer code, references, or other information is adequate for use in the PA, then it is appropriate to have it accessible to EPA and to other interested parties."

Response

The DOE is currently pursuing access to computer codes and training in their use with the EPA and stakeholders. Documentation of codes is being completed, and will be complete before PA analyses are used in a compliance application.

Comment T002

Page 1: I. Technical Comments, A. General, Resource Allocation

Area in document General

"Decisions regarding resource allocation (e.g., model development versus collection of experimental data) should also be subjected to outside scrutiny. In the case of computer resources, DOE should have its computer codes reviewed for their computational efficiency, because of the potential for the algorithms themselves to be unnecessarily resource limiting to the PA effort."

Response

EPA's comment is noted and will be considered by the DOE.

Comment T003

Page 1: I. Technical Comments, A. General, Limited Resources

Area in document Volume 2, Chapter 7, page 7-5, Line 17

"Direct solution of 'fully coupled equation' is said to be unrealistic using present resources. Why is this true? What resources staff, money, or computer capacity would be required? Has DOE tried to use more efficient algorithms and computer program applications? "

Response

The basis for this statement is discussed in Butcher and Mendenhall (1993, page 7-3 middle paragraph). An example of typical computer capacity requirements is given in the same reference, page 6-5, third paragraph. In regard to algorithms and computer applications, the codes used for these analyses have evolved over the past 30 years and represent the most advanced state-of-the-art technology.

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B*. SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T004

Page 2: I. Technical Comments, A. General, Room Modeling

Area in document General

(a) "Has DOE developed a field theory for two-phase flow in a deformable porous media with fractures that can undergo large deformation?"

(b) "Can DOE provide justification for separating (over the various time-and-space scales) the two-phase flow, mechanical rock response, and gas generation models?"

Response

(a) While a single field theory for two-phase flow in a deformable porous media with fractures that can undergo large deformation may be theoretically feasible, it is considered to be technically infeasible because it would be too unwieldy to use in the global context of PA (also see response to previous comment).

(b) The justification for separation is discussed in Chapter 7 of Butcher and Mendenhall (1993).

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B*. SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T005

Page 2: I. Technical Comments, A. General, Poor Referencing of Information: Shaft Consolidation Example

Area in document Volume 3, Chapter #, Page 3-35, Line 7, A137, A140

It is stated that backfill in the lower is parts of the shafts will become consolidated due to salt creep, with a final permeability comparable to that of the host rock of the Salado formation. However, no calculations or modeling results are presented in the PA report to justify this assumption. The 1992 PA cites the 1991 PA, which in turn cites two other reports without discussion how the values were derived. This is but one case out of many in which the reviewer must peruse a succession of documents to find the source of cited data.

Response

The Project is currently investigating the permeability likely to be achieved by the crushed salt components placed in the shafts. The most current published information is summarized in Van Sambeek et al. (1993). Current technical efforts are focused on evaluating the effects of backstress, placement technique, and parameter variability on our ability to achieve an acceptably low permeability in each of the shafts; effective emplacement of the crushed salt components is an important part of the proposed Large-Scale Seal Tests Program.

Reference

Van Sambeek, L.L., D.D. Luo, M.S. Lin, W. Ostrowski, and D. Oyenuga. 1993. *Seal Design Alternatives Study*. SAND92-7340. Albuquerque, NM: Sandia National Laboratories.

Comment T006

Page 2-3: I. Technical Comments, A. General, Radionuclide Inventories

Area in document General, Volume 3

"The source of the radionuclide inventories is the memo from Andrew Peterson, which appears on page A-135 of volume 3. The inventories for the various generator sites are inconsistent: some include the short-lived daughter products of longer-lived parents, while others do not. For example, Y-90 is in secular equilibrium with Sr-90 in the CH waste at Hanford, while it is absent at INEL. ... Furthermore, INEL list[s] different activities of the two nuclides in its RH wastes. The Peterson memo sums the reported activities, showing significantly different totals for the two nuclides. Of greater import, Hanford lists a large CH waste inventory of PU-241, but nothing for its daughter product, Am-241. In fact, ten years after it is generated (for example), each curie of Pu-241 will be in equilibrium with 12.6 mCi of Am-241."

"Steps should be taken to insure that all generator sites use a consistent methodology for estimating their inventories. Absent such a practice, Sandia should obtain enough information to enable it to evaluate the data and make the necessary corrections."

Response

The Project is evaluating the sensitivity of compliance to this issue. Additional detail will be included in Project Technical Baseline report.

The radionuclide inventory used in the 1992 PA was a hypothetical "design" inventory based on the numbers given in the Peterson memo; inconsistencies in the way generator sites quoted the inventories were ignored in forming the design inventory.

The DOE has recently published the Baseline Inventory Report (BIR) which is aimed at achieving the consistency goal referred to in this comment. The BIR focuses on those parameters believed to be the most important to performance assessment.

Comment T007

Page 3: I. Technical Comments, A. General, Inventory and Release Limits

Area in document Volume 3, Chapter 3, Page 3-35, Line 7; A-137,140

"Why are the 1991 release limits presented instead of the 1992 limits used? The inventory in 1991 was 11.87 million Ci of waste. The 1992 PA inventory is listed as 4.227 million Ci (in tables on pages A-137 and A-140). This is more than "slightly different," than the 1991

release limits as stated in volume 3 of the PA, and it effects the release limit. What is the reason for this discrepancy? What numbers were used for the analyses?"

Response

Possible reasons for this apparent discrepancy (i.e., editorial error, error in interpretation, etc.) are being investigated. The release limits used in the 1992 PA analyses were based on the 1992 PA inventory. Future compliance documents will base inventory information on the BIR which combines information from numerous sources.

Comment T008

Page 3: I. Technical Comments, A. General, Inventory and Release Limits

Area in document Volume 3, Chapter 3, Page 3-35, Line 7; A-137, A-140

"What is the estimate of uncertainty in the waste inventory and the estimate of the release limits? What is being done to decrease this uncertainty? Will bounding values be used?"

Response

Uncertainties in all waste characteristics (e.g., the composition of the waste as well as its radionuclide inventory) are presently unknown. The radionuclide inventory used in the 1992 PA was a fixed, hypothetical "design" inventory based on estimates given by Peterson (see response to preceding Comment T006); uncertainty was arbitrarily added to certain waste characteristics also estimated by Peterson (volumes of cellulosics and corrodible metallics) in order to test the sensitivity of performance measures to variations in these characteristics.

Comment T009

Page 3: I. Technical Comments, A. General, Colloid Transport

Area in document Volume 2, Chapter 2, Page 2-39, Line 9

"EPA strongly agrees with the State of New Mexico that distribution coefficients (K_d's) be based on 'experimentally justified data' and not based solely on expert panel judgment."

Response

The DOE has planned an experimental program to provide these data if needed.

Comment T010

Page 3: I. Technical Comments, A. General, Uncertainty

Area in document Volume 1, Chapter 3, Page 3-13, Line 44

"Please provide a detailed explanation of all methods used to reduce uncertainty and methods used to evaluate uncertainty."

Response

The line referred to in the text references Table 3-1 on the following pages of Volume 1. This table contains approximately 48 references and internal cross-references to examples of techniques used to assess or reduce uncertainty. The reviewer is referred to the table for more detail than the text provides and to the cited documents for additional detail. The DOE will include the information in these references in the final compliance application to a level deemed appropriate.

Comment T011

Page 3: I. Technical Comments, A. General, Uncertainty

Area in document Volume 2, Chapter 3, Page 3-22, Line 1

"Please provide more discussion on how uncertainty is 'propagated through a model'."

Response

The referenced line of text refers to the propagation of a sample through a model. That step of the analysis is briefly explained in the previous section on the previous page, and is explained in detail in later chapters of Volume 2 and in Volumes 4 and 5. Propagation of the sample through the model simply refers to the calculation of consequences for each Latin hypercube sample, using each of the consequence models in the system.

As discussed in general terms in Section 3.5 of Volume 2, and in extensive detail in the references cited therein, the WIPP PA has selected a Monte Carlo methodology to allow estimation of the uncertainty in model outcomes that results from uncertainty in input parameters.

Comment T012

Page 3: I. Technical Comments, A. General, Grout Seal in MB-139

Area in document Volume 1, Chapter 4, Page 4-4 (Figure 4-2a)

How does the "Grout Seal" get into Marker Bed 139?

Response

Effective placement of grout into Marker Bed 139 has been part of the technology development activities performed at the WIPP facility. Specifically, as indicated in the test plan for the Small-Scale Seal Performance Test-Series F (Ahrens, 1992), this underground test at the WIPP was "intended to demonstrate equipment and techniques for producing, injecting, and evaluating microfine cementitious grout." The grouting was completed in March, 1993, and the final report is currently being prepared.

Reference

Ahrens, Ernst H. 1992. *Test Plan - Sealing of the Disturbed Rock Zone (DRZ), Including Marker Bed 139 (MB139) and the Overlying Halite, Below the Repository Horizon, at the Waste Isolation Pilot Plant - Small-Scale Seal Performance Test - Series F.* Albuquerque, NM: Sandia National Laboratories.

Comment T013

Page 4: I. Technical Comments, A. General, Grout Seal in MB-139

Area in document Volume 1, Chapter 4, Page 4-4 (Figure 4-2a)

How will the seal location be selected?

Response

Tentative locations for the seal components have been identified in the reference seal design report (Nowak et al., 1990) and the logic for the locations is identified. In general, locations were selected on the basis of the sealing strategy (combination of long- and short-term components with some desirable redundancy) and needed function (e.g., limit water flow into the shaft) of a particular component. Locations have been slightly modified in a recent update of the reference seal design; documentation of the updated design is in progress. Additional information related to the intended seal locations will be included in design reports on the various components that will be primary references for compliance documents. At the time

of actual placement of the seals, it is likely that location-specific factors such as degree of fracturing or observed water inflow will influence the final placement.

Reference

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant*. SAND90-0355. Albuquerque, NM: Sandia National Laboratories.

Comment T014

Page 4: I. Technical Comments, A. General, Bell Canyon Formation Characteristics

Area of document Volume 2, Chapter 2, Page 2-10, Lines 20-22

"If the Bell Canyon aquifers can possibly act as a source of groundwater into the repository due to exploration activity, then it would be prudent to know more about the hydrostatic head gradient of the formation. If there is data on this topic, it was not presented in the PA."

Response

The regional potentiometric surface of the Bell Canyon Formation is presented in Figure 9 of Mercer (1983) and extrapolated static bottomhole pressures in the Bell Canyon in three boreholes (AEC-7, AEC-8, and ERDA-10) tested by the WIPP project are given in Table 4 of the same reference. Pressure and hydraulic head data from the Bell Canyon in two additional boreholes (Cabin Baby-1 and DOE-2) tested by the WIPP project are given in Beauheim et al. (1983) and Beauheim (1986). Data from all five holes indicate that Bell Canyon heads are sufficient to drive brine to the level of the repository in an open borehole; whether flow would be upwards or downwards in this borehole would depend on the pressure conditions existing in the repository at the time.

References

Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico*. U.S. Geological Survey Water-Resources Investigations Report 83-4016. Albuquerque, NM: U.S. Geological Survey.

Beauheim, R.L., B.W. Hassinger, and J.A. Klaiber. 1983. *Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico*. WTSD-TME-020. Albuquerque, NM: U.S. Department of Energy.

Beauheim, R.L. 1986. *Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-1364. Albuquerque, NM: Sandia National Laboratories.

Comment T015

Page 4: I. Technical Comments, A. General, Area of Drifts, Waste Panels

Area in document Volume 3, Chapter 5

"Please clarify the size of the area of the drifts, waste panels and the repository as a whole. The PA uses different numbers for area: 0.5 sq. km and 109,354 sq. meters. What is used in estimating the number of boreholes?"

Response

The areas of the drifts, waste panels, and other features of the repository are given in Table 3.1-1 (which is also keyed to Figure 3.1-2) on page 3-4 of Volume 3. The total excavated area of the disposal region is 111,520 meters^2 but the total area of the disposal region (including pillars and room separators) is 0.5069 kilometers^2. The area used in the 1992 PA to compute the drilling intensity into the repository includes the 111,520 meters^2 of area for CH TRU waste and 14,480 meters^2 hypothetically occupied by RH waste emplaced in the walls of the waste-emplacement panels (total target area of 126,000 meters^2).

Comment T016

Page 4: I. Technical Comments, A. General, Crushed Salt

Area in document Volume 2, Chapter 2, Page 2-48, Line 19

What process was used to prove that crushed salt will compact to 95% of initial density within 100 years?

Response

Creep modeling activities, supported by laboratory measurements on crushed salt and host rock salt, have led to the belief that sufficient deformation will be attained to achieve compaction to about 95%. The most recent modeling efforts are summarized in Van Sambeek et al. (1993). The timing for when the degree of compaction reaches about 95% is directly dependent upon numerous factors such as the steady-state creep rate of the host rock, the initial or emplacement density of the crushed salt, the backstress exerted on the formation by the crushed salt, moisture content of the crushed salt, etc.

Reference

Van Sambeek, L.L., D.D. Luo, M.S. Lin, W. Ostrowski, and D. Oyenuga. 1993. *Seal Design Alternatives Study*. SAND92-7340. Albuquerque, NM: Sandia National Laboratories.

Comment T017

Page 4: I. Technical Comments, A. General, Colloid Transport

Area in document Volume 2, Chapter 2, Page 2-54

"Colloids could potentially have a large impact on the migration or retardation of the radionuclides; they could have a noticeable effect on solubility and sorption of the radionuclides. When will data on colloid formation and transport be collected?"

Response

A laboratory program to determine important information about colloid formation and transport in Salado and Rustler brines is in progress. Some qualitative information from this program has already been transferred to PA for inclusion in future calculations; other information will be provided for the compliance analysis.

Two colloid laboratory programs address the two major types of radiocolloids. Actinide intrinsic colloids, which form by condensation reactions from dissolved radionuclides, are being investigated by a series of screen experiments. Potential carrier colloids, which are ordinarily non-radioactive particles that may act as a substrate for sorption, are being investigated separately, by a series of screening experiments that focuses on evaluating their stability in brines. Results from those two laboratory programs will be incorporated into a model that describes the concentrations of colloid-borne actinides in the disposal room environment. Predictions made with the model will be compared with results from the Source-Term Test Program (STTP) being conducted as part of the Actinide Source-Term Program (see Phillips and Molecke, 1993).

Reference

Phillips, M.L.F., and M.A. Molecke. 1993. *Technical Requirements for the Actinide Source-Term Waste Test Program*. SAND91-2111. Albuquerque, NM: Sandia National Laboratories.

Comment T018

Page 5: I. Technical Comments. A. General, Colloid Transport

Area in document Volume 2, Chapter 2, Page 2-54, Line 29

"When will it [colloid formation and transport] be modeled in future PAs?"

Response

Transport of colloids will be considered for inclusion in the SPM. Any decision on how to incorporate it in PA for a compliance application will depend on the outcome.

Comment T019

Page 5: I. Technical Comments, A. General, Colloid Transport

Area in document Volume 2, Chapter 2, Page 2-54, Line 29

"How does the lack of information on colloids affect the geochemical and hydrology models developed or under development?"

Response

Colloids may impact current PA modeling in two places: by affecting total concentrations of radionuclides transported in disposal-room brine, and by affecting transport of radionuclides in the Culebra.

Disposal-room actinide concentrations are presently based on values for solubility limits derived from an expert panel (Trauth et al., 1992). The "solubility" panel recognized that suspended forms could contribute to the total concentrations, but concluded that they lacked the information to make any estimate of what that contribution could be.

The distribution coefficients used to describe actinide sorption are also based on expert panel judgment (Trauth et al., 1992), and also do not include colloidal effects. The 1992 PA reported releases into the Culebra and releases transported in fractures only without any sorption. These calculations do not consider the effects of colloids in the disposal room. With regard to colloid-facilitated radionuclide transport in the Culebra, it has been argued that colloids may increase transport rates relative to dissolved species, because colloids may have little retardation and may be preferentially transported in the center of channels where velocities are greater.

Reference

Trauth, K.M., S.C. Hora, R.P. Rechard, and D.R. Anderson. 1992. *The Use of Expert Judgment to Quantify Uncertainty in Solubility and Sorption Parameters for Waste Isolation Pilot Plant Performance Assessment.* SAND92-0479. Albuquerque, NM: Sandia National Laboratories.

Comment T020

Page 5: I. Technical Comments, A. General, Room Closure -vs- Constant Pore Space

Area in document Volume 2, Chapter 7, Page 7-8, Line 13

"If the 'total pore space ... is constant' then room closure (creep compression is not taken into account. However, it is stated on page (7-5) Line 25 room closure is accounted for 'in an indirect way'. This appears to be inconsistent. If you have closure the pore space must decrease. The model appears to be deficient on this point."

Response

The statements referring to constant volume and constant porosity in Volume 2 page 7-7, lines 20 to 24 refer to how the repository was conceptualized prior to 1992. In 1992 the porosity and volume in a disposal room varied in time according to the SANCHO predicted consolidation results, as described in Volume 2, page 7-5.

Comment T021

Page 5: I. Technical Comments, A. General, Boundary Conditions

Area in document Volume 2, Chapter 7, Page 7-16

"How are values transferred between the regional and the local grids? What is the data/information loss across these boundaries?"

Response

The data between regional and the local grids is transferred by interpolation of heads using either bilinear or integral-preserving (Dukowitz) interpolation. For a locally linear variation of head in the regional grid, no information is lost, neither on heads, gradients, nor fluxes. The motivation for the regional and local grid domain decomposition is to provide improved far-field boundary conditions for the local grid. The compatibility of the interpolation

procedure is demonstrated by overlaid contour plots of head, gradients, and fluxes obtained from both regional and local grids.

Comment T022

Page 5: I. Technical Comments, A. General, Boundary Conditions

Area in document Volume 2, Chapter 7, Page 7-16

"What source (e.g., data and investigator judgment) is used to establish the initial boundary conditions in DOE's modeling efforts?"

Response

The specification of boundary conditions is discussed on page 7-16 in general terms. The sources of boundary condition information for the regional groundwater flow domain are described in more detail in Volume 4, page 6-9 through 6-11.

Comment T023

Page 5: I. Technical Comments, A. General, Boundary Conditions

Area in document Volume 2, Chapter 7, Page 7-16

"How are the initial boundary conditions peer reviewed?"

Response

There was no formal review limited only to model boundary conditions. Boundary conditions are discussed on page 7-16 only in general terms. Specific boundary conditions for the regional groundwater flow domain are in Volume 4 of the 1992 PA, pages 6-9 through 6-11. Boundary conditions received the same peer review as other aspects of the 1992 PA: internal reviews were performed prior to publication by coauthors and coworkers, by formal SNL technical reviewers, by the Performance Assessment Peer Review Panel, and by SNL and DOE management.

Comment T024

Page 5: I. Technical Comments, A. General, Categories of Distributions and Parameter Selection

Area in document Volume 1, Chapter 4, Page 4-13; Volume 3, Chapter 1, Page 1-7; Volume 3, Chapter 2, Page 2-11

"The PA discusses categories of distributions for different parameter types: continuous, discrete, constructed based on experiments, constructed based on expert judgement, and miscellaneous categories."

"The process used to select a distribution for each parameter needs to be discussed. How is a distribution chosen for a particular set of parameters?"

Response

For more detailed discussions of the ways in which distributions of uncertain parameters were constructed in the 1990, 1991 and 1992 PAs, see Tierney (1990, in particular, Figure E-1) and Tierney (1994).

References

Tierney, M.S. 1990. *Constructing Probability Distributions of Uncertain Variables in the Models of the Performance of the Waste Isolation Pilot Plant (WIPP)*. SAND90-2510. Albuquerque, NM: Sandia National Laboratories.

Tierney, M.S. 1994. "Using Data and Information to Form Distributions of Model Parameters in Stochastic Simulations of Performance of the Waste Isolation Pilot Plant (WIPP)", *Proceedings of PSAM-II, San Diego, California, U.S.A., March 20-25, 1994.* 051-9 to 051-16.

Comment T025

Page 5: I. Technical Comments, A. General, Categories of Distributions and Parameter Selection

Area in document Volume 1, Chapter 4, Page 4-13, Volume 3, Chapter 1, Page 1-7, Volume 3, Chapter 2, Page 2-11

"How representative are these distributions of actual data?"

Response

Of the distributions of the 49 parameters sampled for human intrusion analyses in the 1992 PA (Volume 3): five were histograms of actual field measurements; three were distributions inferred from actual measurements (e.g., Culebra transmissivities); 18 were constructed by formal elicitation of expert opinion, which may indirectly be linked to data; and the remainder (23) were constructed on the basis of informal expert judgment using the five-step procedure described in Figure E-1 of Tierney (1990). It is not known at this time how well subjectively determined distributions reflect the true uncertainty in a model parameter or how well these distributions represent actual WIPP-specific conditions.

Reference

Tierney, M.S. 1990. *Constructing Probability Distributions of Uncertain Variables in the Models of the Performance of the Waste Isolation Pilot Plant (WIPP)*. SAND90-2510. Albuquerque, NM: Sandia National Laboratories.

Comment T026

Page 5-6: I. Technical Comments, A. General, Categories of Distributions and Parameter Selection

Area in document Volume 1, Chapter 4, Page 4-13, Volume 3, Chapter 1, Page 1-7, Volume 3, Chapter 2, Page 2-11

"The constructed distribution type should differentiate between values derived from measurements and those derived from expert judgement."

"How were the input parameters chosen? How many are there, and how many are variable? Which ones are important?"

Response

In theory, expert judgment is founded in measurements and other data collection activities albeit not necessarily WIPP specific. Consequently, to use the general rule indicated here may not be reasonable. Instead, some rationale should be provided for the combination of the two sources of parameter values.

Input parameters are dictated by the nature of the mathematical models used in the PA (see Section 1.4 of Volume 3). There were nearly 400 input parameters in the 1992 PA; 49 of them were treated as uncertain (variable) for the purposes of sensitivity/uncertainty analyses for human intrusion analyses (see sections 6.1 and 6.2 of Volume 3). The most sensitive

(important?) parameters in the 1992 PA are described in Table 9-3 of Volume 4, and Table 6-1 of Volume 5.

Comment T027

Page 6: I. Technical Comments, A. General, Assignment of Probability Distributions

Area in document Volume 3, Chapter 1, Page 1-18, Line 37

"Very general procedures are described for assigning probability distributions, but these procedures are incomplete and do not answer critical questions."

"Please clarify the review process used for assigning probability distributions? How do you determine confidence in the probabilities?"

"What are the constructed distributions and which does DOE expect will be replaced by data? (Volume 2, page 6-4)."

Response

The "replacement of constructed distributions by data" is an activity that will be considered for inclusion in the SPM, i.e., the addition of experimental data where required to support a compliance application.

The review process used to assign probability distributions in the 1992 PA is briefly described in Section 1.3.1 of Volume 3; evidence of the implementation of this process is shown in the many memos of Appendix A of the latter document. All parameters used in the 1992 PA were classified as "X" among the three quality-assurance categories of ascending confidence, X, C, and A. To be classified as "C", a parameter would have to have documentation of the line of reasoning that established its distribution and the sources of any data used in constructing the distribution. An "A" class parameter must also have received a documented peer review.

Constructed distributions are explained on page 1-10 of Volume 3. This category of distributions is characterized by direct use of data to form an empirical cumulative distribution function; the "data" may be measurements of real quantities or the set of percentiles obtained from an elicitation of subjective opinion. Ideally, all constructed distributions would be based on real measurements; however, the Project must focus on sensitive parameters.

Additional detail on the construction and use of distributions will be included in the final compliance application.

Comment T028

Page 6; I. Technical Comments, A. General, Heterogeneous Reservoirs

Area in document Volume 3, Chapter 1, Page 1-21 - Line 60

"What is meant by 'reservoirs' in the context of the BRAGFLO model?"

Response

The term reservoir is used in the context of formation, host rock, and porous media, etc., not in the context of brine reservoir per se. The predecessor to BRAGFLO was a multi-phase flow code used in the petroleum field -- thus the use of the term 'oil reservoir' or 'reservoir' model.

Comment T029

Page 6: I. Technical Comments, A. General, Brine Reservoirs

Area in document Volume 3, Chapter 1, Page 1-30, Line 15

"Why is the 'sample intensity function' multiplied by the 'fraction of the repository area that is underlain by brine reservoirs'?"

Response

This question arises in the context of the brief description of the model for computing computational scenario probabilities given in Section 1.4.2 of Volume 3. A more thorough treatment of the same subject, models used to compute human-intrusion probabilities for different summary scenarios, is given in Section 5.2 of Volume 2; the answer to the present question is given by lines 10 thru 28 of page 5-4, including Equation (5-13), in the latter reference.

The cited text is simply an example being given wherein the fraction of repository area underlain by brine reservoirs is of interest for a particular intrusion event, E1 (E1 is an event in which one or more boreholes pass through a waste panel and into a brine reservoir).

Comment T030

Page 6: I. Technical Comments, A. General, Viscosity

Area in document Volume 3, Chapter 1, Page 1-34, Line 9

"DOE states that 'viscosity measurements for an oil-based, 1.7 - kg/m^3 mud'. Why would an oil-based mud be used to drill through the Salado Salt Beds instead of a high-salt water-based mud?"

Response

A high-salt, water based mud is assumed to be the drilling mud used when drilling through the Salado. The Oldroyd model requires a value for the ratio of the initial viscosity (at zero shear rate) to the plastic viscosity, to fully define the model in the low shear regime. This ratio was not available for a high-salt, water-based mud in 1992 so a ratio based on an oil based mud was chosen. Since high shear rates occur at the borehole wall the value chosen for the ratio was expected to have little impact on the final model diameter. The Project is evaluating the sensitivity of eroded diameter to this issue.

Comment T031

Page 7: I. Technical Comments, A. General, "Dual Porosity" Model

Area in document Volume 3, Chapter 1, Page 3-39, Line 1

"The way the 'dual porosity' model is described generates confusion. Does the model really allow diffusion through the rock matrix?"

Response

Yes, the PA's dual porosity model allows diffusion through the rock matrix. In this transport model fluid only flows (advects) along fractures. In this way, solutes (i.e., dissolved actinides) are advectively transported in the fracture void volume and diffuse into the much larger matrix void volume. The SECOTP transport code numerically simulates the diffusion process with a mass transfer term. This term incorporates the free water molecular diffusion of each solute, the tortuosity of the matrix, and the solute concentration gradient between the fractures and the matrix.

References

Jones, T.L., V.A. Kelley, J.F. Pickens, D.T. Upton, R.L. Beauheim, and P.B. Davies. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra*

Dolomite at the Waste Isolation Pilot Plant Site. SAND92-1579. Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L., and P.B. Davies. 1992. *Experimental Plan for Tracer Testing in the Culebra Dolomite at the WIPP Site.* Revision A. Albuquerque, NM: Sandia National Laboratories.

Comment T032

Page 7: I. Technical Comments, A. General, "Dual Porosity" Model

Area in document Volume 3, Chapter 1, Page 1-39, Line 1

"How does the flow model (SECO2D) compare with laboratory results? Is it verifiable?"

Response

Results from the SECO2D code have not been compared to laboratory results. This code is designed to simulate flow that occurs at a scale that is larger than what could be represented in a laboratory experiment. The SECO2D flow code solves the partial differential flow equation for heads in a 2D, confined, heterogeneous aquifer that obeys Darcy's Law. The flow code has been benchmarked, tested and verified for freedom from coding errors, order of convergence, and discretization consistency (Roache et al., 1990).

Reference

Roache, P., P.M. Knupp, S. Steinberg, and R.L. Blaine. 1990. "Experience with Benchmark Test Cases for Groundwater Flow," *Forum on Benchmark Test Cases for Computational Fluid Dynamics, ASME Fluid Engineering Division Spring Conference, Toronto, Ontario, Canada., June 4-7, 1990.*

Comment T033

Page 7: I. Technical Comments, A. General, Base of Anhydrite III

Area in document Volume 3, Chapter 2, Page 2-4, Line 14

"If the base of the Anhydrite III is so important it would seem more accurate, to create a regional contour map of the base of the Anhydrite III. The North-South geologic cross-section may not account for all unknowns."

Response

The point is well taken. The exact elevation of the base of Anhydrite III beneath the WIPP is not well constrained. Well data are not available for the region immediately beneath the panels. Other methods, including the construction of regional contour maps on the base of the unit could have been used to estimate its elevation. Regional dips are small, however, and the uncertainty introduced locally by a limited stratigraphic data base may be small compared to the uncertainty in the interpretation of the depth to the conducting layer and the interpretation of the conducting layer as brine (see page 5-2 and following text in Volume 3 of the 1992 PA).

Comment T034

Page 7: I. Technical Comments, A. General, Top of Bell Canyon

Area in document Volume 3, Chapter 2, Page 2-10

"A more accurate value for the Top of Bell Canyon can be found by the method outlined in the comment for the Base of Anhydrite III (above)."

Response

The point is valid. The exact elevation of the top of the Bell Canyon Formation beneath the WIPP is not well constrained. Well data are not available for the region beneath the panels. Other methods, including the construction of regional contour maps on the base of the unit, could have been used to estimate its elevation. As seen in well and seismic data, however, regional dips are small, and the uncertainty introduced by limited stratigraphic control may be small compared to the uncertainty in the interpretation of the depth to the conducting layer and the interpretation of the conducting layer as brine (see page 5-2 and following text in Volume 3 of the 1992 PA).

Comment T035

Page 7: I. Technical Comments, A. General, Natural-Analog Data

Area in document Vol 3, Chapter 2, Page 2-12

"It would seem using parameters of sandstones and substituting them for salt is inappropriate because the stress characteristics, the permeability and the porosities are quite different. The performance of salt does not compare to sandstone."

Response

Two-phase characteristics of salt (capillary pressure, relative permeability) have not been measured experimentally for WIPP-specific materials. Very little research has been done on the two-phase properties of very low permeability rock. A search failed to produce data and/or curves that are directly applicable to WIPP. Therefore, an approximate analog approach was taken, based on the lowest permeability rock for which capillary pressure and relative permeability data have actually been measured. A tight gas sand core (Sample MWX 67-35) from the multi-well experiment (Morrow et al., 1986) was selected as the best analog material. This sample is a fine-grained sandstone with bedding and 12 percent porosity. The dominant pore geometry consists of intergranular cracks between abutting quartz grains and solution pores partially filled with dolomite. The permeability of this sample to brine is 43 microdarcies ($\sim 43. \times 10^{-18}$ m^2) at 3.4 MPa confining pressure and 24 microdarcies ($\sim 24. \times 10^{-18}$ m^2) at 34 MPa confining pressure. Based on these results, and a study of threshold pressure (Davies, 1991), two-phase flow in pure or impure halite units is not anticipated. Two-phase flow is confined to the various anhydrite marker beds within the Salado Formation, making the selection of two-phase properties in the halite units (except for threshold pressure) unimportant.

References

Morrow, N.R., J.S. Ward, and K.R. Brower. 1986. "Rock Matrix and Fracture Analysis of Flow in Western Tight Gas Sands," *1985 Annual Report, New Mexico Institute of Mining and Technology*. DOE/MC/21179-2032.

Davies, P.B. 1991. *Evaluation of the Role of Threshold Pressure in Controlling Flow of Waste-Generated Gas into Bedded Salt of the Waste Isolation Pilot Plant*. SAND90-3246. Albuquerque, NM: Sandia National Laboratories.

Comment T036

Page 8: I. Technical Comments, A. General, Lack of Halite and Polyhalite Chemical Interaction

Area in document Volume 3, Chapter 2, Page 2-28, Line 42.

"What justification or data is there to support the comment that 'halite and polyhalite ... are assumed ... not to interact chemically with any contaminants'? This is a very important assumption."

Response

This statement is misleading. The statement should say that the salts have limited sorption potential, and therefore do not provide a significant retardation mechanism. A conservative assumption of 0 for the partition coefficient is used.

Comment T037

Page 8: I. Technical Comments, A. General, Radionuclides for Transport Modeling

Area in document Volume 3, Chapter 3, Page 3-29, Line 31

"Why were only nine radionuclides considered in the 1992 PA transport calculations (and solubility estimates) for CH-TRU waste? This needs to be more clearly explained."

Response

The answer can be found in Section 7.3 of Volume 4 of the 1992 PA. Figure 7.3-1 (page 7-12 of Volume 4) shows plots of radionuclide inventory through time in normalized EPA units. With the exception of Pu-238, only those radionuclides that exist at 1,000 years or later in activities greater than 10^{-2} EPA units were included in transport modeling. The reason for excluding the others is straightforward: they cannot contribute to exceeding regulatory limits even if their entire inventory is released. Pu-238 was omitted from groundwater transport calculations in error and will be included in future analyses—it is a major factor in total inventory before 1,000 years, but rapidly drops out of the inventory after 1,000 years. However, for the fracture-only transport model travel times are sufficiently short that some Pu-238 could reach the accessible environment boundary. The effect on fracture-only transport releases could be significant for intrusions occurring before 1,000 years.

Note that the use of the cutoff of 10^{-2} EPA units is cautious; the total release limit is 1 EPA unit.

Note also that a total of 23 radionuclides were included in cuttings releases, allowing for the full consideration of short-lived species in the cuttings releases.

See Appendix D of Volume 4 for memoranda describing the use of this reasoning in designing actinide and transport experimental programs.

Comment T038

I. Technical Comments, A. General, Excavated Area Underlain by Brine Reservoir

Area in document Volume 3, Chapter 5, Pages 5-2 to 5-11

(a) "What is the accuracy of Transient Electromagnetic Methods? The depth precision 'may be ± 75 m,' but what about the accuracy of the process itself to 'see' fluids? Electromagnetic (EM) methods tend to be gross estimators at best. Why was the data not extended to the ERDA-9 borehole to calibrate the measurements?"

(b) "Has DOE investigated the use of a High-Frequency Three-Dimensional (3D) Common Depth-Point Seismic Survey over the WIPP disposal panels with extended coverage of one-half mile around the panels? The survey should include the ERDA-9 borehole as a reality check. If these pressurized brine reservoirs are associated with anticlinal structures in the upper anhydrite layer then a 3D Survey will clearly, with high confidence, define even a small closure at this depth."

Response

We believe that the geophysical studies are complete and adequately documented. At present, we believe that the resistivity characterization of possible brine distribution beneath the waste panels has provided information to a level of detail exceeding that provided by on-site/near-site stratigraphic data presently available. However, we believe that the assumption that any conductor identified within the Castile is due to the presence of brine is reasonably conservative for purposes of PA.

The Project has investigated and resolved these issues as follows:

1. The validation (accuracy) of the transient electromagnetic method to detect brine was done at the same time as the panel survey by running the same survey over the WIPP-12 area (brine reservoir present known from drilling) and the DOE-1 area (brine reservoirs absent known from drilling) (Reference SAND87-7144, p. 14, Fig. 3-8). Additional validation work with several methods was done prior to the panel survey using the known brine reservoir at WIPP-12 and an artificial target placed in the underground WIPP facility. ERDA-9 was not drilled deep enough into the Castile for most brine occurrences. However, the results of the dual-induction log of hole ERDA-9 was used directly to constrain the resistivity of brine-free Salado/Castile halites and anhydrites.

2. Seismic methods were not the method of choice for brine reservoir delineation after the Project's experience with the original seismic reflection lines for several reasons: a) While seismic studies delineate deformed areas within the Castile (called deformation zone, DZ, in Borns and others, 1993), not all anticlines contain brine reservoirs. Drillholes, such as WIPP-12, in areas of moderately deformed Castile, as well as

drillholes in severely deformed Castile both encounter brine and; b) Lateral velocity structures produce false anticlines. In 1982, drillhole DOE-1 was drilled into an apparent anticline that was based on the seismic surveys. This structure was nonexistent, and the original interpretation was due to the lateral velocity variations; c) it has proven difficult to propagate high frequency signals in the portion of the basin; d) brine reservoirs are characterized by a low fracture porosity (1%), which does not result in a change in velocity much above background variation in velocity. The contrast between the resistivity of a brine reservoir (1 ohm-m) and the background anhydrite (100 - 1000 ohm-m) is significant. Several early Project conclusions were that (1) seismic methods alone are not sufficient to answer whether brine reservoirs are under the site and (2) gravity methods were not effective in mapping deformation.

Considerable development and review went into the selection of methods. Specifically for the brine reservoirs in the early 1980s, WIPP began to study methods based on the measurement of electrical conductivity or resistivity (for example, Controlled Source Audio Magneto Telluric--CSAMT and charged body--mis-a-la-masse) (Elliot, 1982). The basic assumption is that the brine-charged fractures of a brine reservoir will represent a significant conductivity contrast within the Castile. CSAMT was the method most extensively tried at WIPP during this period (Bartel and others, 1983) to delineate the brine reservoirs in the Castile. The EEG sponsored review of the Sandia program for delineating brine reservoirs and the CSAMT method by J. Waite (U or A) and Peter Hoekstra (Geophysicon). This review suggested that WIPP consider other electromagnetic methods specifically the transient electromagnetic method (TEM) a.k.a. time domain electromagnetic methods (TDEM). In 1985, SNL conducted validation surveys in an area around a known brine occurrence (WIPP 12) using several methods (CSAMT, TEM, and Frequency Domain Electromagnetic methods [FEM]) with the Colorado School of Mines and Phoenix Geophysics. Some of the surveys also delineated an artificial target placed in the WIPP underground. Analyses of survey results concur with EEG review recommendations that transient (or time-domain) electromagnetic methods are best suited for delineation of brine reservoirs at the WIPP site.

Comment T039

Page 8: I. Technical Comments, A. General, Organic Containers

Area in document Volume 3, Chapter 3, Page 3-9

"The text on page 3-9 [of Volume 3] states that containers are 55 gallon drums or SWBs, yet on page 4-11 [of Volume 2] it states that some 'waste containers' will be composed of organic material. Please explain this discrepancy."

Response

This is an editorial error: The words "and some waste containers" should be deleted in lines 11-12 on page 4-11 (Volume 2) .

Comment T040

Page 9: I. Technical Comments, A. General Comments, Ideal Gas Law

Area in document Volume 2, Chapter 2, Page 2-34

"How valid is the use of the ideal gas law at lithostatic or hydrostatic pressures? How sensitive a parameter is it? Assumptions of this nature should be explained and justified."

Response

A set of comparative calculations were made using the ideal gas law and several non-ideal equations of state. These calculations showed very little variation in the calculated properties (< 10%). This amount of uncertainty has very little effect on PA calculations, since other sources of uncertainty are much more important.

Comment T041

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, Line 13

"The screening process described in detail in the 1991 documentation should be included in the EPA PA."

Response

The 1992 PA was not intended to be interpreted as a compliance application. Additional material will be included as needed in the compliance application.

Comment T042

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, Line 13

"The possibility of nuclear criticality should be investigated further before it is screened out."

Response

The DOE has initiated further evaluation of nuclear criticality.

Comment T043

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, Line 13

"How will the changes in the repromulgated 40 CFR 191 effect the scenarios that are included?"

Response

This question is still under evaluation. No changes in scenarios specific to the repromulgation of 191.15 and Subpart C are identified at this time. Clearly, the time interval that must be considered for 191.15 and Subpart C has changed. However, 10,000 yr undisturbed performance was already included in the scenario development process as the base case for 191.13.

Comment T044

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, Line 13

"How are scenario uncertainties propagated through the analyses; if scenario uncertainties were included in the screening process, would more scenarios be included?"

Response

As discussed in Chapter 4 of Volume 2, Section 4.2, scenarios are constructed from the events and processes that may affect the system in the future. Uncertainties about these

events and processes are explicitly considered in the screening process. Those events and processes that survive the screening process (based on the criteria discussed in the previous section of Chapter 4 of Volume 2) are used to construct the scenarios for consideration. Uncertainty about the occurrence of those events is reflected in the estimation of the probability of their occurrence, which in turn is reflected in the estimation of scenario probabilities.

Comment T045

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, 4-19

"DOE says that the 'effect of subsidence of potash mining will be added in future PAs'. How is the WIPP site influenced by potash mining and its associated water use? When will the effect of subsidence due to potash mining be added?"

"The mining scenario should consider mining in the potash zone in the controlled area, but above the repository."

Response

The text in question has been paraphrased, rather than quoted exactly, in the comment. The relevant phrase occurs on line 21, and states "...the impact of subsidence events will be examined in future analyses." A decision to add consequence modeling of subsidence effects to the full PA cannot be made until these analyses are available. As noted elsewhere in this volume, "consequences of such potash mining ... will be addressed in future analyses when a three-dimensional model for regional groundwater flow is available" (Volume 1, page 3-11, lines 16-19; see also page 6-3, lines 19-22). A three-dimensional flow model is now operational and ready for preliminary analyses.

As discussed in the event and process screening text in Volume 1 of the 1991 PA (SAND91-0893/1, page 4-35, lines 7-13), subsidence over mines has the potential to affect regional groundwater flow both by creating catchment basins at the surface (changing recharge) and by fracturing hydrostratigraphic units (altering hydraulic conductivity).

The final point here, that mining should be considered within the controlled area, is a point of regulatory interpretation. The wording of Appendix C of 40 CFR 191 indicates that systematic exploitation can be effectively deferred by controls. Mining is such a systematic process and does not occur inadvertently and intermittently.

Comment T046

Page 10: I. Technical Comments, A. General, Probabilities

Area in document Volume 1, Chapter 4, Page 4-2

"How are the probabilities used in the cutoff comparison found, calculated, etc. This explanation should be within the PA."

Response

As the text on page 4-2 of Volume 1 notes, this information is summarized in Chapter 4 of Volume 2 and described in detail in Volume 1 of the 1991 PA (SAND91-0893).

Comment T047

Page 10: I. Technical Comments, A. General, Probabilities

Area in document Volume 1, Chapter 4, Page 4-2

"What are the expected probabilities for each scenario? They should be stated on the same page as the event tree or on the event tree."

Response

The event tree displays summary scenarios, as described in more detail in Section 3.2.2 of Volume 2. These summary scenarios are further subdivided into computational scenarios on the basis of time and number of intrusions, as discussed in detail in Chapter 2 of Volume 4 of the 1992 PA. Probabilities estimated using the Poisson model for intrusion are assigned to computational scenarios, rather than to the summary scenarios, and therefore cannot be displayed on Figure 4-1 as requested. Probabilities for selected computational scenarios are given in table form in Chapter 2 of Volume 4 for specific values of the Poisson rate constant.

Comment T048

Page 10: I. Technical Comments, A. General, Base Case Explanation

Area in document Volume 1, Chapter 4, Page 4-2, Line 40

"All of the events placed in the 'base case' need to be described in detail with an explanation of how the event probability was developed and provide justification for placing these scenarios in the base case."

Response

As discussed in more detail in Volume 2 and in Volume 1 of the 1991 PA (SAND91-0893), all events placed in the base case were assigned a probability of 1. In compliance documentation, a rationale for the assignment of probabilities will be given.

Comment T049

Page 10: I. Technical Comments, A. General, Nearby Boreholes as Communication Pathways

Area in document Volume 1, Page 4-4; Volume 2, Page 2-16

"Have you considered transport to and through boreholes that don't hit the repository, but which could increase the transport of radionuclides?"

"Would current and future boreholes alter the vertical flow regime between units? (Volume 2, page 2-30)"

"Is it possible for the high drilling density around the WIPP site to cause salt dissolution much like in oil and gas fields in Pecos County, Texas? Should this scenario be considered?"

Response

The issue of the consequences of "near misses" potentially affects the compliance analysis and will be reexamined and evaluated. Rates of brine flow from the repository to a "near miss" were examined quantitatively in 1991 in response to comments by the EEG on the 1990 PA. Results of these analyses are reported in pages B-18 through B-26 of Volume 1 of the 1991 PA (SAND91-0893/1). For the assumptions of these analyses (including no lateral development of the DRZ), flow rates were shown to decrease more than two orders of magnitude 0.25 m from the waste. Flow was decreased further at greater distances. Based on these analyses, PA concluded that radionuclide releases up a borehole that directly penetrated the waste would be greater than those from a "near miss."

The Project is currently investigating the issue of existing and future boreholes that could alter the vertical flow regime. Three-dimensional regional flow modeling is in progress to permit evaluation of possible consequences.

The Project has already investigated and resolved the issue of dissolution of salt by oil field drilling and work is complete. Dissolution of salt by oil field drilling has been considered quantitatively in the past by the WIPP Project (see Christensen et al., 1983), although not on the scale proposed here. Previous work has indicated that dissolution by freshwater flowing

through a single well does not pose a threat to the WIPP. Possible effects of high-density drilling outside the controlled area can be evaluated for inclusion in the system prioritization. High-density drilling within the controlled area constitutes an intrusion scenario more severe than "inadvertent and intermittent...exploratory drilling."

Reference

Christensen, C.L., C.W. Gulick, and S.J. Lambert. 1983. *Sealing Concepts for the Waste Isolation Pilot Plant (WIPP) Site.* SAND81-2195. Albuquerque, NM: Sandia National Laboratories.

Comment T050

Page 10: Section: I. Technical Comments, A. General, Thermal Effect of Pu-238

Area in document General

"Has the thermal effect of Pu-238 been taken into account in PA Analyses? What would its effect be?"

Response

It is assumed that the comment refers to the thermal load of radioactive waste. Justification for ignoring radioactive induced thermal effects is given in Butcher and Mendenhall (1993, Section 3.7, page 3-26).

In addition, the Performance Assessment Department looked into this issue and concluded a maximum temperature rise of 2° C in the repository falling to 1° C after 80 years (Volume 1, page 4-50 of the 1991 PA [SAND91-0893/1]).

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B.* SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T051

Page 11: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

"...at issue is the behavior of the clay (bentonite) units "sandwiched" between concrete plugs."

Response

In the reference seal design report (Nowak et al., 1990), the reasons for using swelling clay components are summarized and references to more detailed discussions are provided. In response to the specific questions regarding the clay, it is believed that the clay units may become fully saturated. Clay is not likely to intrude into all exposed fractures and voids although it is obvious that flow through many of these will be limited by the clay. It is intended that the swelling pressure will be controlled (via the initial density of the material) to preclude significant, deleterious fracturing due to the swelling.

Reference

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant*. SAND90-0355. Albuquerque, NM: Sandia National Laboratories.

Comment T052

Page 11: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

(Paraphrase) Numerous specific questions are offered related to the removal of shaft liners. The essence of the questions is captured by: Is it necessary to remove the liner? Can this be done safely? What are the consequences?

Response

The question of whether or not to remove the shaft liners (or portions of them) remains an active question within the WIPP sealing program. It is clear that if the liners need to be removed in order to assure effective seals, they can and will be removed. Safe removal of portions of shaft liners has been accomplished in the Carlsbad area in nearby potash mine shafts. Only small amounts of water inflow have been encountered during construction operations and drilling operations conducted in the WIPP shafts. Design and performance

considerations for the WIPP shaft seals generally stress reliance upon the components placed within the Salado formation below the current shaft liner and key; if the final designs maintain this reliance, it may not be necessary to remove any significant portions of the existing liners. Detailed design descriptions to be included in compliance documentation will describe whether or not removal is intended and (if needed) procedures for the safe removal of this material.

Comment T053

Page 11-12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

"Compaction details have not been provided which may further impact on the method in which the backfill is emplaced and the effectiveness of the backfill as a seal."

Response

This is an ongoing area of significant effort. While the Small-Scale Seal Test Program in Test Series C and D have provided (see summary in Finley and Tillerson [1992]) an indication that an initial relative density of about 80% can be achieved, additional demonstrations are planned to determine if a relative density of at least 85% can be achieved. These additional demonstrations are part of the planned Large-Scale Seal Tests proposed for the WIPP. Results of the demonstrations are intended to be part of the compliance documentation.

Reference

Finley, R.E., and J.R. Tillerson. 1992. *WIPP Small Scale Seal Performance Tests - Status and Impacts*. SAND91-2247. Albuquerque, NM: Sandia National Laboratories.

Comment T054

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

"Small amounts of water are considered beneficial in the consolidation of the salt backfill (St 88), but the effects of channelling on individual blocks of salt is uncertain. Channelling of water from upper aquifers seems more likely than a uniform dispersion throughout the backfill. This potential problem needs to be addressed in the PA.

Response

At the present time, efforts are focusing on evaluating methods for in-place compaction of crushed salt. The use of salt blocks is at present considered a backup technology. If in-place compaction of the crushed salt is successful, there will be no reason to do further evaluation of the behavior of blocks. On the other hand, if the use of precompacted blocks of crushed salt becomes the preferred technology, evaluations of phenomena such as this will be completed.

Comment T055

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

"...to insure conformance with the circular shaft walls, blocks must be specially milled and placed. No estimate to the amount of time required to fill each shaft by carefully placing blocks has been provided. Such information is necessary to establish the practicality of the approach."

Response

If blocks are to be used in the shafts as part of the sealing approach, there is no question but that the practicality of their emplacement must be established. In the Small-Scale Seal Performance tests, the feasibility of making and emplacing blocks was demonstrated. At the present time however, efforts are focusing on evaluating methods for in-place compaction of crushed salt. If this technology can be demonstrated to achieve the desired degree of compaction, it offers advantages related to cost and safety. Demonstration tests are currently being planned which will evaluate the degree of compaction that can be achieved. If in-place compaction of the crushed salt is successful, there will be no reason to further evaluate the behavior of blocks. On the other hand, if the use of precompacted blocks of crushed salt becomes the preferred technology, evaluations of the practicality of full-scale placement of blocks will be initiated. Because of the planned sequence of evaluations, the use of salt blocks is at present considered a backup technology and very little resources are being expended to evaluate phenomena specific to this technology.

Comment T056

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 1, Page 5-20

"It is stated that the repository will use bentonite and crushed-salt backfill as a barrier in waste emplacement panels. Isn't it more correct to say that SNL has recommended this backfill but that DOE has made no commitment to use it?"

Response

The EPA suggested statement is correct. SAND90-3074 discusses the scientific aspects of crushed salt/bentonite backfill but no determination has yet been made. Backfill will be considered in the SPM.

Reference

Butcher, B. M.,1991, *The Advantages of Salt/Bentonite Backfill for the WIPP Disposal Rooms*, SAND90-3074, Albuquerque, NM: Sandia National Laboratories.

Comment T057

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Page 2-48

(Restatement) What data are there to support the assumed long-term permeabilities in the shaft seals?

Response

Numerous laboratory studies have been completed which document the permeability of compacted, crushed salt samples. These data are summarized in Figure 4 of Hansen et al. (1993). The relationship is shown between the permeability of the crushed salt samples and the relative/fractional density of the sample. This paper also references the numerous reports in which the data were first documented. In addition, the small-scale seals and the thermal-structural interaction tests are providing some useful information regarding the transfer of the lab studies and analysis results to field situations.

Reference

Hansen, F.D., G.D. Callahan, and L.L. Van Sambeek. 1993. "Reconsolidation of Salt as Applied to Permanent Seals for the Waste Isolation Pilot Plant," *3rd Conference on the Mechanical Behavior of Salt, September 14-16, 1993, Ecole Polytechnique, 91129 Palaiseau, Cedex-France.*

Comment T058

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Page 2-48

"What is the likelihood that the panel and shaft seals will be able to prevent migration through MB-139, both under the excavation and away from the excavation in the Disturbed Rock Zone?"

Response

The shaft seals are not designed to prevent lateral migration through MB-139: flow up the shafts from MB-139 would be very limited by the combination of short and long term components included in the shaft system.

The sealing concepts for the WIPP panel seals (see Nowak et al. [1990]) include provisions for grouting of the Marker Beds or the DRZ in the halite as necessary to limit flow. Effective placement of grout into Marker Bed 139 has been part of the technology development activities performed under the direction of Sandia National Laboratories. Specifically, as indicated in the test plan for the Small-Scale Seal Performance Test-Series F (Ahrens, 1992), this underground test at the WIPP was "intended to demonstrate equipment and techniques for producing, injecting, and evaluating microfine cementitious grout." The grouting was completed in March, 1993, and the final report is currently being prepared.

From the standpoint of long-term performance of the disposal system, the sealing of the marker bed in the immediate vicinity of the waste rooms is of little consequence since virgin conditions will exist within the near vicinity of the excavation. It is these virgin conditions that provide the robust natural barrier to contaminant transport. The project is currently evaluating the advantages of sealing these units, however, from an operational standpoint.

References

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant.* SAND90-0355. Albuquerque, NM: Sandia National Laboratories.

Ahrens, Ernst H. 1992. *Test Plan - Sealing of the Disturbed Rock Zone (DRZ), Including Marker Bed 139 (MB139) and the Overlying Halite, Below the Repository Horizon, at the Waste Isolation Pilot Plant - Small-Scale Seal Performance Test - Series F.* Albuquerque, NM: Sandia National Laboratories.

Comment T059

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Pages 2-48 and 2-50

"It is correctly stated that the current backfill design (which is used in the 1992 PA calculations) is "pure, unconsolidated crushed salt with a relatively high permeability that provides little resistance to fluid flow." Salt and bentonite backfill have been studied and said to be available if needed. However, the PA has not yet reported any analyses to indicate the benefits this mixture might provide."

Response

The backfill condition stated here was a PA assumption for the 1992 calculations. In actuality, the backfill is expected to rapidly consolidate to a dense, low permeable state as described in Butcher (1991, Figure 4-4, page 28).

Optimization analyses have not been performed. Preliminary sensitivity analyses showing the potential benefits of reducing porosity and permeability within the waste-disposal area were performed using the 1989 PA modeling system and reported in Bertram-Howery and Swift (1990).

References

Butcher, B.M. 1991. *The Advantages of a Salt/Bentonite Backfill for Waste Isolation Pilot Plant Disposal Rooms.* SAND90-3074. Albuquerque, NM: Sandia National Laboratories.

Bertram-Howery, S.G., and P.N. Swift. 1990. *Status Report: Potential for Long-Term Isolation by the Waste Isolation Pilot Plant Disposal System.* SAND90-0616. Albuquerque, NM: Sandia National Laboratories.

Comment T060

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Pages 2-48 and 2-50

"Neither have analyses been performed to determine the benefit of reducing the initial void space in the backfill."

Response

Analyses have not been performed, but backfill consolidation is estimated to occur so rapidly that reduction of the initial void space would correspond to accelerating closure by no more than 10 years. Crushed-salt porosities are estimated to decrease to less than 10% within 40 years. For this reason, control of initial emplacement density is considered unimportant, as discussed in Butcher and Mendenhall (1993, page 42).

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B.* SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T061

Page 12-13: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Pages 2-48 and 2-50

"The design of backfill is part of the engineered alternatives (engineered barriers) issue and evaluations of relative benefits should be included."

Response

Crushed salt backfill with additives is an engineered alternative that DOE will evaluate for consideration in the SPM. These will also be part of the engineered alternatives benefit/detriment study being performed by the DOE.

Comment T062

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 6-1, Line 9

"The statement that the PA Department has a high level of confidence, etc., is perhaps premature."

Response

The 1992 PA was not intended as a compliance application. The sentence in question does not say that the PA Department is confident that compliance has been demonstrated. Rather, the statement was made that PA Department is confident that "the WIPP will be able to comply with the quantitative requirements of the Standard...."

Comment T063

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 6-2, Lines 20-28

"More documentation is needed before it can be concluded 'that no radionuclides will reach the accessible environment from the undisturbed repository for 10,000 years.'"

Response

The 1992 PA was not intended to be a compliance application. More documentation will be provided in the compliance application. The Format and Content Guide provides a snapshot of the comprehensive nature of the application.

Comment T064

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Chapter 6, Page 6-2, Line 37-44

"Any conclusions about meeting the Groundwater Protection Requirements are premature since these requirements have been changed in the repromulgated standard."

Response

Conclusions for the 1992 PA were based on 40 CFR 191 as it existed at that time. All aspects of 40 CFR 191, including those portions repromulgated in December 1993, will be incorporated in future performance assessments. The specific conclusion about the ability to meet the Groundwater Protection Requirements depended only on the reported results (i.e., no releases to the accessible environment).

As was stated in the 1992 PA (Volume 1, Chapter 3, p. 3-23, l. 25-31), "One of the products of scenario development for the Containment Requirements is a base-case scenario for the WIPP that describes undisturbed conditions. The undisturbed performance of the repository is its design-basis behavior, including variations in that behavior resulting from uncertainties in the 10,000-year performance of natural and engineered barriers and excluding human intrusion and unlikely natural events, as defined in §191.12(p)." Thus, the 10,000 year issue has already been addressed for the undisturbed case, i.e., Groundwater Protection Requirements and Individual Protection Requirements. Future performance assessment calculations, if conducted similarly to those in 1992, will not cause a change in the conclusions since nothing has yet to be shown to be released from the disposal system for undisturbed performance. The results of any future performance assessment calculations conducted using different conceptual models, probability distributions, etc., will of course be evaluated for compliance with the Groundwater Protection Requirements.

The concentration limits for the Groundwater Protection Requirements have not changed between the 1985 and 1993 versions of 40 CFR 191. While not called such, the limits in the 1985 version were the Maximum Contaminant Levels (MCLs) from 40 CFR 141 (5 pCi/l for Ra-226 and Ra-228; 15 pCi/l for gross alpha particle activity; 4 mrem/yr for beta particles and photon radioactivity). Those MCLs have not been changed since, and are now officially incorporated into 40 CFR 191. The definition of the groundwater that is to be protected did change between the 1985 (special sources of groundwater) and 1993 (underground sources of drinking water) versions of 40 CFR 191. The revised definition may cause programmatic changes if DOE is required to identify all potential underground sources of drinking water. As stated in a paper recently presented at the Waste Management '94 conference (Trauth et al., 1994), we propose to determine when and if underground sources of drinking water should be identified and characterized (i.e., when such a characterization will provide pertinent information for a compliance application). Briefly, identification and characterization of USDWs should not be required if no radionuclide releases to the accessible environment are predicted for 10,000 years or if 10,000 year peak predicted releases to the accessible environment are less than or equal to the applicable Maximum Contaminant Levels (MCLs). USDWs along the pathway should be identified and characterized if peak predicted releases to the accessible environment for 10,000 years are greater than the MCLs.

Reference

Trauth, K.M., S.G, Bertram, and B. Bower. 1994. "Considerations for Guidance for Radioactive Waste Disposal Arising from Rules Under 40 CFR 191 and 40 CFR 194," *Proceedings of Waste Management '94 Conference, Tucson, AZ, February 27-March 3, 1994.*

Comment T065

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 8-2 (first paragraph)

"The following needs in performance assessment should be added to those mentioned:

(1) the determination of the extent that expert judgment should be used in PA and development of an acceptable procedure to incorporate this expert judgment into distributions in the various parameters;"

Response

The referenced page does not exist. The answer is given assuming the question refers to page 6-3 of Volume 1.

The concern is appropriate and the DOE looks forward to discussions with the EPA in this matter.

Comment T066

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 8-2 (first paragraph)

"The following needs in performance assessment should be added to those mentioned:

(2) the inclusion of the scenarios recommended elsewhere in these comments;"

Response

The referenced page does not exist. The following response is given assuming the question refers to page 6-3 of Volume 1.

Scenario development is an ongoing process and the suggested events will be considered for inclusion.

Comment T067

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 8-2 (first paragraph)

"The following needs in performance assessment should be added to those mentioned:

(3) the use of plausible radionuclide inventories (including radionuclide composition and specific activity) and their uncertainty in the performance assessment. (To date, the inventory has not been treated as an uncertain variable, even though the PA states that uncertainty in this inventory is large [Volume 2, page 2-51])."

Response

The referenced page does not exist. The following response is given assuming the question refers to page 6-3 of Volume 1.

Because 40 CFR 191 sets limits on the probability of radionuclide releases that have been normalized to the total transuranic inventory in the system, performance is not likely to be strongly sensitive to uncertainty in the radionuclide. This observation has not been tested by formal sensitivity analyses, but can be partially supported by comparison of the 1991 and 1992 preliminary PAs, which used different inventories. Uncertainty in the radionuclide inventory will be considered in future evaluations.

Comment T068

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 2 Page 3-18, (Line 5)

"Is temperature a variable in BRAGFLO?"

Response

Temperature is not treated as an unknown variable -- the repository is assumed to be isothermal. Temperature is used to calculate the physical properties of the fluid so temperature is a parameter, i.e., a value assumed constant for the purposes of computation.

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B.* SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T069

Page 14: I. Technical Comments, C. General Geology and Hydrology

Area in document Volume 2, Chapter 2, Page 2-38, Line 12

"How will the 'location and amount of future' groundwater flow be dealt with in future PAs? How will DOE deal with such vast uncertainties?"

Response

A three-dimensional computer model of regional groundwater flow is being developed. This model uses a free surface/seepage face as the upper boundary. This model is designed to simulate areas of discharge and recharge, and patterns of groundwater flow for assumed spatial and temporal distributions of maximum potential infiltration to the water table. The Project is using this model to evaluate the sensitivity of compliance to this issue.

Comment T070

Page 14: I. Technical Comments, C. General Geology and Hydrology, Low Values of Total Dissolved Solids

Area in document Volume 2, Chapter 2, Page 2-34

(a) "What is the explanation for the wells with the low TDS?"

(b) "What is the TDS level in all the potential aquifers?"

Response

(a) Hypotheses concerning the possible lack of consistency between inferred north-to south flow in the Culebra and hydrochemical facies are discussed on page 2-36, lines 11 - 20. Also see response to the comment from the EPA document, page 19 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow and Hydrogeochemical Facies Differences).

(b) For this response, "potential aquifers" is assumed to mean Potential Underground Sources of Drinking Water, as defined in Subpart C to 40 CFR Part 191, in strata above the Salado Formation. The principal stratigraphic units known to be able to produce sufficient amounts of water are the Culebra and Magenta dolomites. The TDS of waters in these units is summarized on page 2-34, lines 24 - 31 in Volume 2 of the 1992 PA. Measured TDS values from drill holes in the vicinity of WIPP are given in Table 2-2 of Siegel et al. (1991). Furthermore, TDS values are measured routinely as part of the WIPP Groundwater Quality and Sampling Program.

As stated in a paper recently presented at the Waste Management '94 conference (Trauth et al., 1994), we propose to determine when and if underground sources of drinking water should be identified and characterized (i.e., when such a characterization will provide pertinent information for a compliance application). Briefly, identification and characterization of USDWs should not be required if no radionuclide releases to the accessible environment are predicted for 10,000 years or if 10,000 year peak predicted releases to the accessible environment are less than or equal to the applicable Maximum Contaminant Levels (MCLs). USDWs along the pathway should be identified and characterized if peak predicted releases to the accessible environment for 10,000 years are greater than the MCLs.

References

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.G, Bertram, and B. Bower. 1994. "Considerations for Guidance for Radioactive Waste Disposal Arising from Rules Under 40 CFR 191 and 40 CFR 194," *Proceedings of Waste Management '94 Conference, Tucson, AZ, February 27-March 3, 1994.*

Comment T071

Page 14: I. Technical Comments, C. General Geology and Hydrology, Low Values of Total Dissolved Solids

Area in document Volume 2, Chapter 2, Page 2-34

"How much uncertainty reduction in aquifer characteristics would there be if DOE drilled more test wells near the controlled area?"

Response

The Project requests clarification of this question to insure that the response is appropriate. We are unclear whether the reviewer is concerned about: 1) the errors of estimation of total dissolved solids at unmeasured locations near the controlled area, or 2) the effect of the uncertainty in total dissolved solids on estimates of transmissivity or other aquifer properties.

The Project believes that there will always be uncertainty in aquifer characteristics, and that the acceptable level of uncertainty is related to the effect of that uncertainty on regulatory performance measures.

Comment T072

Page 14: I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow above the Salado Formation

Area of document General

"Current and historical head measurements of the wells penetrating post-Salado strata would be helpful in interpreting the significance of seasonal or annual fluctuations in the reported potentiometric surface."

Response

Hydrographs for all wells at the WIPP site are presented in Hydrologic Data Reports #1-8 (Hydro Geo Chem, Inc., 1985; Intera Technologies, Inc. and Hydro Geo Chem, Inc., 1985a,b; Saulnier et al., 1987; Stensrud et al., 1988a,b; Stensrud et al., 1990), Richey (1987), and Cauffman et al. (1990). No fluctuations related to seasonal or annual cycles have ever been identified nor, given the depth and degree of confinement of Rustler Formation units at the WIPP site, are any expected to occur.

References

Hydro Geo Chem, Inc. 1985. *WIPP Hydrology Program Waste Isolation Pilot Plant, SENM Hydrologic Data Report #1.* SAND85-7206. Albuquerque, NM: Sandia National Laboratories.

Intera Technologies, Inc., and Hydro Geo Chem, Inc. 1985a. *WIPP Hydrology Program Waste Isolation Pilot Plant, Southeastern New Mexico Hydrologic Data Report #2.*

SAND85-7263. Albuquerque, NM: Sandia National Laboratories.
Intera Technologies, Inc., and Hydro Geo Chem, Inc. 1985b. *WIPP Hydrology Program Waste Isolation Pilot Plant, Southeastern New Mexico Hydrologic Data Report #3.*

SAND86-7109. Albuquerque, NM: Sandia National Laboratories.

Saulnier, G.J., Jr., G.A. Freeze, and W.A. Stensrud. 1987. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #4.* SAND86-7166. Albuquerque, NM: Sandia National Laboratories.

Stensrud, W.A., M.A. Bame, K.D. Lantz, A.M. LaVenue, J.B. Palmer, and G.J. Saulnier, Jr. 1987. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #5.* SAND87-7125. Albuquerque, NM: Sandia National Laboratories.

Stensrud, W.A., M.A. Bame, K.D. Lantz, T.L. Cauffman, J.B. Palmer, and G.J. Saulnier, Jr. 1988a. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #6.* SAND87-7166. Albuquerque, NM: Sandia National Laboratories. *WIPP*

Stensrud, W.A., M.A. Bame, K.D. Lantz, J.B. Palmer, and G.J. Saulnier, Jr. 1988b. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #7.* SAND88-7014. Albuquerque, NM: Sandia National Laboratories.

Stensrud, W.A., M.A. Bame, K.D. Lantz, J.B. Palmer, and G.J. Saulnier, Jr. 1990. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #8.* SAND89-7056. Albuquerque, NM: Sandia National Laboratories.

Richey, S.F. 1987. *Water-Level Data from Wells in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* Open-File Rpt 87-120. Albuquerque, NM: USGS.

Cauffman, T.L., A.M. LaVenue, and J.P. McCord. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite, Volume II: Data Base.* SAND89-7068/2. Albuquerque, NM: Sandia National Laboratories.

Comment T073

Page 14-15: I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow above the Salado Formation, Groundwater geochemistry

Area in document Volume 2, Chapter 2, Page 2-34

"Inferred north to south groundwater flow directions in the Culebra Dolomite (based on the potentiometric surface in the Culebra Dolomite) are inconsistent with the distribution of geochemical facies in the Culebra groundwaters (salinities decrease from north to south).

Attempts are made to explain this apparent discrepancy, but alternative working hypotheses should be explored, including the possibility that the potentiometric surface is inaccurate."

Response

The comment notes that several hypotheses have been advanced to explain the apparent discrepancy, but that additional (alternative) hypotheses should be explored. This issue affects the compliance analysis in that it relates to alternative conceptual models of groundwater flow in the Culebra. Additional work to evaluate alternative hypotheses concerning Culebra geochemistry will be considered for inclusion in the systems prioritization.

The Project will record the issue that the potentiometric surface might be inaccurate. Pending the outcome of the systems prioritization, the Project may consider this issue. It should be noted that, because of variations in fluid density, the potentiometric surface is not the best indicator of flow directions. Instead, calculated velocity fields should be used. These depend on measured values of pressure, fluid density, and transmissivity, as well as the assumptions of the model used to calculate them.

See also responses to comments in the EPA document, p. 14 (I. Technical Comments, C. General Geology and Hydrology, *Low Values of Total Dissolved Solids*); p. 18 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields); and p. 19 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow and Hydrogeochemical Facies Differences).

Comment T074

Page 15: I. Technical Comments, C. General Geology and Hydrology

Area in document Volume 2, Chapter 2, Page 2-34

"Points of groundwater recharge and discharge into post-Salado strata are very poorly constrained. Further study is needed to document these important aspects of the hydrology across the WIPP site."

Response

A three-dimensional computer model of regional groundwater flow is being developed. This model uses a free surface/seepage face as the upper boundary. This model is designed to simulate areas of discharge and recharge, and patterns of groundwater flow for assumed spatial and temporal distributions of maximum potential infiltration to the water table. The Project is using this model to evaluate the sensitivity of this issue to compliance.

Comment T075

Page 15: I. Technical Comments, C. General Geology and Hydrology, Hydrologic Parameters

Area in document General

(a) "It is not clear why only horizontal fractures were used in PA models for the Culebra Dolomite member (Volume 3, p. 2-85), as vertical fractures are more likely to have greater connectivity in most subsurface environments."

(b) "More data need to be acquired for all relevant stratigraphic units at the WIPP site (i.e., Castile through Dewey Lake Redbeds."

Response

(a) When modeling a formation as a dual-porosity continuum, the actual orientations of fractures are unimportant. The modeled fractures are not used to provide connections between points. The important fracture parameters to be captured in the models are the fracture porosity, which will control the flow velocity, and the surface area of the fractures, which will control the amount of matrix diffusion that occurs. As long as the fracture porosity and surface area are kept constant, it does not matter if the fractures are modeled as single sets of horizontal or vertical fractures or as three orthogonal sets of fractures. Single sets of horizontal fractures are the simplest to model, so that is what PA has used.

(b) The need for additional hydrologic data for various stratigraphic units may be considered for inclusion in the SP.

Comment T076

Page 16: I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields

Area in document Volume 2, Section 7.5 and Appendix D

(Summary) This paragraph follows the introductory comment that many problems associated with the transmissivity fields are related to calibration to fresh-water heads. The second paragraph points out that neglecting spatial variations in density of Culebra groundwaters could potentially cause significant errors in the calibrated transmissivity fields, as well as predicted flow directions.

Response

The transmissivity fields are actually calibrated to pressure rather than fresh-water head (Volume 2 of the 1992 PA, Section 7.5, p. 7-10, l. 14-17). However, given that the elevations of the measuring points are known, it really does not matter which parameter, pressure or fresh-water head, is used for calibration. The important point is that the flow portion of the code (SWIFT II) used for the calibration solves differential equations formulated in terms of pressure. Variations in density are fully accounted for in the code. In these calibrations, it is assumed that the density of water varies with position but is fixed in time. The evolution of the chemistry of Culebra waters is not sufficiently well understood to determine if the assumption that the density distribution does not change over long periods of time is valid.

Comment T077

Page 16: I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields

Area in document Volume 2, Section 7.5 and Appendix D

"...Simulations which are based on equivalent freshwater head may produce erroneous velocity magnitudes and flow directions in this critical area."

Response

See preceding response. Transmissivity fields calibration accounts for variable density. The SECO-FLOW calculations in the 1992 PA used the calibrated transmissivity fields but assumed constant fluid density. Modifications to SECO-FLOW now permit variable-density flow calculations in PA.

Comment T078

Page 16: I. Technical Comments, General Geology and Hydrology, Groundwater Transmissivity Fields

Area of document General

"The means by which the aquifer test results were incorporated as known values into the calibration of the transmissivity fields is unclear. However, the aquifer test analysis should have considered density effects on pumping responses in the monitoring wells."

Response

Transmissivities derived from single-well hydraulic tests or from interference (pumping) test responses over distances less than 50 m formed the data base for kriging of the transmissivity field. The measured transmissivities were preserved in the kriged transmissivity fields, within the estimated error bounds of the measurements. When the model domain was discretized into grid blocks, however, average values of the kriged field were calculated for and assigned to each grid block. Therefore, the average value assigned to a particular grid block need not coincide with the transmissivity determined at an individual well lying within that grid block. The process of defining transmissivity fields using aquifer-test results is discussed in LaVenue et al. (1990).

The aquifer-test analyses did take density effects into account. All analyses were done in terms of pressure changes, not water-level changes, providing results in the form of permeability-thickness products, not transmissivities. Transmissivities were then calculated based on the brine density at each location. Aquifer-test analysis procedures are discussed in Beauheim (1989).

References

LaVenue, A.M., T.L. Cauffman, and J.F. Pickens. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume I: Model Calibration.* SAND89-7068/1. Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L. 1989. *Interpretation of H-11b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site.* SAND89-0536. Albuquerque, NM: Sandia National Laboratories.

Comment T079

Page 16-17: I. Technical Comments, C. General Geology and Hydrology, Culebra Transmissivity

Area in document Volume 2, Chapter 2, Page 2-34

"Transmissivity values obtained from the tests should also have been converted to hydraulic conductivities due to the assumption of a uniform thickness over the area. If transmissivity values were used as calibration points directly, they would have been in error by a factor of the effective thickness versus the assumed model thickness of 7.7 meters."

Response

The hydraulic tests within the Culebra were interpreted using the full thickness of the Culebra because the wells are fully screened across the Culebra. Given the uncertainty of the effective thickness across the site, the average thickness of the Culebra was used in the numerical model. The thickness of 7.7 m is smaller than the actual thickness in the southwestern portion of the model area where the transmissivities are the largest. However, the small difference in the conductivity that the uniform thickness assumption would make would have no appreciable difference in the model results since the transmissivity field is significantly changed through the process of calibrating the model to the measured steady-state and transient pressures.

Comment T080

Page 17: I. Technical Comments, C. General Geology and Hydrology, Culebra Transmissivity, Grid Sensitivity

Area in document Volume 2, Chapter 2, Page 2-34

"A sensitivity analysis on the finite-difference grid that was used to generate the 70 transmissivity fields should be performed. ...A finer grid may lead to significantly different transmissivity fields and should be evaluated."

Response

The Project has recently begun a local scale modeling effort with a much finer grid to investigate the transmissivity distribution within the near field (i.e., within the WIPP site). However, the numerical grid used in the 1992 PA flow modeling was designed to represent the regional groundwater flow surrounding the WIPP site and the transient events which have been conducted within the WIPP-site boundary. The 50 x 57 x 1 grid used in the model has larger grid blocks (e.g., 1,000 m to 2,500 m) away from the WIPP site and smaller grid blocks (e.g., 75 m to 250 m) within the WIPP-site boundary where the transient tests have been conducted. The grid resolution is believed acceptable given the objectives of the modeling study (i.e., to determine plausible regional transmissivity distributions within the Culebra).

Different grids (either coarser or finer) may lead to different transmissivity fields because the inverse procedure identifies effective or average transmissivity values at the scale of the grid. Differences in transmissivity values using grids with different resolution may reflect a scaling property of transmissivity, rather than indicating non-convergence of the inverse problem. Convergence of the travel time distribution is important, but that convergence of transmissivity estimates themselves may not be expected, and is not essential by itself.

Comment T081

Page 18: I. Technical Comments, C. General Geology and Hydrology, Culebra transmissivity, Boundary condition uncertainty

Area in document Volume 2, Chapter 2, Page 2-34

"The uncertainty with which the system boundary conditions are understood has serious implications ... the current approach that has been taken to obtain the 70 transmissivity fields does not evaluate the sensitivity of the overall model results to the boundary conditions."

Response

The Project is currently investigating this issue through the development of a three-dimensional model to assess vertical recharge into the Culebra. In addition, elicitation and examination of other conceptual models is an important part of the SP. The boundary conditions used in the 1992 Culebra flow model were estimated from regional water-level measurements and by specifying Nash Draw as a no-flow boundary condition. The south-western boundary condition has some uncertainty due to the variation in water-level measurements in this area.

Note that the horizontal boundary conditions may not produce significant changes to transmissivities within the WIPP-site boundary given the conceptual model used in 1992. This is because of the significant influence that the transient pumping tests have had upon the Culebra. These tests have stressed the Culebra to the extent that the effect of boundary conditions is small.

Comment T082

Page 18: I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields

Area in document Volume 2, Section 7.5 and Appendix D

(Summary) This paragraph contains two points:

> If the area along the Pecos River south of the WIPP site acts as recharge area and groundwater flow is to the east, the low ionic strength water could be dissolving dolomite, thereby creating secondary permeability.
>
> It is unclear why more emphasis in the performance assessment has not been placed on integrating the geochemical data with the hydrogeological data to form a cohesive conceptual model(s).

Response

It is possible that regions of higher transmissivity are due to dolomite dissolution. However a few points should be clarified. There is no indication that flow is presently toward the east from the Pecos River. The possibility that eastward flow occurred in the late Pleistocene has been proposed by Lambert and Carter (1987) and Lambert (1991). While dolomite dissolution might play a role, the distribution of fracture density and the degree to which gypsum and halite presently fill fractures have been proposed as more important controls on the transmissivity distribution (Holt and Powers, 1988). Circulation of low ionic strength water would likely dissolve gypsum and halite from the fractures.

The Project has placed a strong emphasis on integrating geochemical and hydrogeological data. The Siegel et al. (1991) report is an example. Additional work to integrate geochemical and hydrogeological data will be considered for inclusion in the systems prioritization.

See also responses to comments in the EPA document, p. 14 (I. Technical Comments, C. General Geology and Hydrology, Low Values of Total Dissolved Solids); p. 14-15 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow above the Salado Formation, Groundwater Geochemistry); and p. 19 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow and Hydrogeochemical Facies Differences).

References

Lambert, S.J., and J.A. Carter. 1987. *Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico. I: Principles and Preliminary Results.* SAND87-0388. Albuquerque, NM: Sandia National Laboratories.

Lambert, S.J. 1991. "Fossil Meteoric Groundwaters in the Delaware Basin of Southeastern New Mexico," *Stable Isotope Geochemistry: A Tribute to Samuel Epstein.* Eds. H.P. Taylor, Jr., J.R. O'Neil, and I.R. Kaplan. Special Publication No. 3. SAND89-2660. San Antonio, TX: Geochemical Society. 135-156.

Holt, R.M., and D.W. Powers. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP-88-004. Carlsbad, NM: Westinghouse Electric Corporation.

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T083

Page 18-19: I. Technical Comments, C. General Geology and Hydrology, Culebra Transmissivity, Recharge Uncertainty

Area in document Volume 2, Chapter 2, Page 2-34

"In addition to LaVenue's suggestion (SAND 92-7306) that recharge to the Culebra may be occurring in the vicinity of the Pecos River, at least one other alternative conceptual model has been proposed which also involves vertical recharge to the Culebra. This alternative model considers significant vertical recharge to the Culebra over the entire southern region of the modeled area (SAND 88-0196). In either case, if vertical recharge occurs, the 70 transmissivity fields calibrated to the aquifer tests and equivalent fresh-water heads would be lower (i.e. slower velocities) than those which would be calculated with the present model. Vertical recharge should be evaluated in the sensitivity analysis."

Response

The Project is currently investigating this issue through the development of a three-dimensional model to assess vertical recharge into the Culebra. Future modeling studies may include these estimates in the calibration process. It should be recognized that the exclusion of vertical recharge in the region upgradient of the WIPP site leads to higher transmissivity estimates and higher groundwater velocities as noted by the EPA reviewer. This is conservative from a groundwater travel time viewpoint.

Comment T084

Page 19: I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow and Hydrogeochemical Facies Differences

Area in document Volume 2, Chapter 2, Page 2-36, Lines 11-20

"What is being done to examine the differences between the north-to south flow in the Culebra and the hydrogeochemical facies data? How does this discrepancy impact the confidence of the flow modeling?"

Response

It should be emphasized that it is not certain that a discrepancy between flow directions and hydrochemical facies actually exists. The apparent discrepancy might instead be due an incomplete understanding of the hydrogeochemical system.

Several hypotheses have been advanced to explain the apparent discrepancy, as referenced in lines 11-20 in Volume 2 of the 1992 PA. Also, lines 32-35 on page 2-33 and lines 1-3 on page 2-36 reference the strong correlation between the region of high molality sodium-chloride water and the presence of halite in adjacent strata (see Figure 1-13 in Siegel et al., 1991). It is anticipated that a three-dimensional computer model of regional groundwater flow that is being developed (EPP study 5.1.1.2, p. 5-8) will provide information that could be used to evaluate and/or modify the existing hypotheses. Additional work to integrate hypotheses concerning Culebra geochemistry with the results of the regional model will be considered in the systems prioritization.

This apparent discrepancy affects confidence in the flow modeling in that it suggests the need to consider alternative conceptual models of groundwater flow in the Culebra. Consideration of alternative conceptual models is an objective of the SP.

See also responses to comments from the EPA document, p. 14 (I. Technical Comments, C. General Geology and Hydrology); p. 14-15 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow above the Salado Formation, Groundwater geochemistry); p. 15 (I. Technical Comments, C. General Geology and Hydrology); and p. 18 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields).

Reference

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T085

Page 19: I. Technical Comments, C. General Geology and Hydrology, Fracture Density

Area of document Volume 2, Chapter 2, Page 2-19

"Since good information on Culebra fracture density is lacking, please explain why you do not use the higher fracture density where it can be observed."

Response

As the comment states, good information on Culebra fracture density is lacking. It is not clear what is meant by "use the higher fracture density where it can be observed" because fracture density can't be observed in the subsurface except in shafts (Holt and Powers, 1990). Also, all fractures, whether observed or not, are not hydraulically significant. Through tracer tests, we seek to determine the fracture density that is important for transport

through the Culebra (see Jones et al., 1992). The interpreted "effective" fracture density is always less than observed fracture densities. Were we to use observed fracture densities in our models, much more physical retardation would occur as a result of matrix diffusion than our tracer tests show to be realistic.

References

Holt, R.M., and D.W. Powers. 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant.* DOE/WIPP-90-051. Carlsbad, NM: Westinghouse Electric Corporation.

Jones, T.L., V.A. Kelley, J.F. Pickens, D.T. Upton, R.L. Beauheim, and P.B. Davies. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site.* SAND92-1579. Albuquerque, NM: Sandia National Laboratories.

Comment T086

Page 19: I. Technical Comments, C. General Geology and Hydrology, Vertical Fractures

Area of document Volume 2, Chapter 2, Page 2-19

"In volume 3 (1-39) it states that vertical fractures in the Culebra are not used in the calculations. Why? How are vertical fractures handled or what assumptions are used?"

Response

When modeling a formation as a double-porosity continuum, the actual orientations of fractures are unimportant. The modeled fractures are not used to provide connections between points. The important fracture parameters to be captured in the models are the fracture porosity, which will control the flow velocity, and the surface area of the fractures, which will control the amount of matrix diffusion that occurs. As long as the fracture porosity and surface area are kept constant, it does not matter if the fractures are modeled as single sets of horizontal or vertical fractures or as three orthogonal sets of fractures. Single sets of horizontal fractures are the simplest to model, so that is what PA has used.

Comment T087

Page 20: I. Technical Comments, C. General Geology and Hydrology, Effects of the Magenta Dolomite in Transport Calculations

Area in document Volume 2, Chapter 2, Page 2-23 to 2-24

"Most of the focus is on the Culebra for transport because it has the highest transmissivity. What is the effect on the release when the Magenta and Culebra Dolomites are combined in the calculations?"

Response

The Project is using a three-dimensional computer model of regional groundwater flow (EPP Study 5.1.1.2, p. 5-8) to evaluate the sensitivity of releases into other hydrologic units to compliance.

A three-dimensional computer model of regional groundwater flow is being developed. This model uses a free surface/seepage face as the upper boundary. This model is designed to simulate areas of discharge and recharge, and patterns of groundwater flow for assumed spatial and temporal distributions of maximum potential infiltration to the water table. The Project is using this model to evaluate the sensitivity of this issue to compliance.

Comment T088

Page 20: I. Technical Comments, C. General Geology and Hydrology, Use of Crushed Culebra Rock

Area in document Volume 2, Chapter 2, Page 2-40/41

"Please expand the discussion on [*how*] the tests involving crushed Culebra rock will help *determine* K_ds? Is this to simulate the effect of clays? If many of the fractures are clay lined, are any tests being conducted on the clay?"

Response

Early laboratory investigations of chemical retardation in the Rustler Formation were conducted using traditional batch sorption experiments with crushed rock. The early experiments were largely intended to be scoping experiments to ascertain whether chemical retardation was significant and they were conducted under specific experimental conditions. Results of those experiments are expected to be valuable, however, in providing independent checks on results from the present experimental approaches (see, for example, Lynch and Dosch [1980] and the review by Novak [1992]). Currently, mechanistic adsorption

experiments coupled with surface complexation modeling are in progress on very carefully prepared ground mineral constituents of the Culebra, dolomite and corrensite, the primary clay mineral constituent. The resulting surface complexation model will predict values for K_d as a function of mineralogy, fluid composition, and adsorbates. On the basis of published information in peer-reviewed journals (see also Siegel et al., 1990), we have strong evidence that results from mechanistic experiments will be representative of the phenomena occurring in the intact Culebra rock. To confirm this, comparisons will be made with the column experiments and sorption experiments with thin slabs or ground samples of Culebra rock.

References

Lynch, A.W., and R.G. Dosch. 1980. *Sorption Coefficients for Radionuclides on Samples from the Water-Bearing Magenta and Culebra Members of the Rustler Formation.* SAND80-1064. Albuquerque, NM: Sandia National Laboratories.

Novak, C.F. 1992. *An Evaluation of Radionuclide Batch Sorption Data on Culebra Dolomite for Aqueous Compositions Relevant to the Human Intrusion Scenario for the Waste Isolation Pilot Plant.* SAND91-1299. Albuquerque, NM: Sandia National Laboratories.

Siegel, M.D., J.O. Leckie, S.W. Park, S.L. Phillips, and T. Sewards. 1990. "Studies of Radionuclide Sorption by Clays in the Culebra Dolomite at the WIPP Site, Southeastern New Mexico," *Waste Management '90, Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education, Tucson, AZ, February 25-March 1, 1990.* Ed. R.G. Post. SAND89-2387. Tucson, AZ: University of Arizona. Vol. 2, 893-900.

Comment T089

Page 20: I. Technical Comments, B. Additional General Comments, Groundwater Age Discussion

Area in document Volume 2., Chapter 2, Page 2-37, Lines 22-32

"The section on the isotopic and tritium data is confusing. DOE states that tritium levels indicate minimal contributions from the atmosphere since 1950. If the waters have even 'minimal' contributions, then that would indicate the waters are not that old. Please clarify what is meant. In addition, what is being done to resolve uncertainty about groundwater age?"

Response

For a discussion of the isotopic data, including tritium, see Chapter 5 of Siegel et al. (1991) and the references cited therein. The statement quoted from Volume 2 of the 1992 PA is consistent with the observed data. Meaningful nonzero tritium measurements suggest either

contamination during drilling or sampling or some degree of mixing with modern surface water in the hydrostratigraphic unit. For the WIPP, these measurements indicate that the amount of mixing has been either zero or extremely small. As stated in the text in Volume 2, this in turn suggests that groundwater travel time (i.e., the mean travel time) from the surface to the sampled units is long. The presence of some "younger" water from the surface does not imply that all water is "young," nor does it imply that recharge is rapid.

Effects on disposal-system performance about the rates of vertical flow, and therefore about groundwater age, are being examined through regional 3D modeling.

Reference

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T090

Page 21: I. Technical Comments, C. General Geology and Hydrology, Porosity of Anhydrite Interbeds

Area in document **Volume 2, Chapter 2, Page 2-42, Lines 15-21**

"Are the porosities of the anhydrite interbeds matrix porosity, fracture porosity or both? Will DOE assume that anhydrite fracturing continues to the accessible environment?"

Response

Porosities for the anhydrite reference in the cited area of Volume 2 are presented in Volume 3, Chapter 2, p. 2-65 of the 1992 PA. The porosities given are estimates, not measurements, and are intended to represent the total porosity of the anhydrite. No distinction between fracture and matrix porosity is necessary because PA treats the anhydrite as a porous, not fractured, medium. A laboratory program is underway to measure anhydrite porosity, both in an unloaded state and as a function of stress (Howarth, 1994).

PA assumes that the fracturing naturally present in the anhydrites continues to the accessible environment. The 1992 PA did not explicitly include induced fracturing outside of the disturbed rock zone around the repository. It is planned that future PAs will include a relationship between pressure in the fractures and fracture porosity and permeability. Whether or not the pressure in the fractures, and hence the porosity and permeability, changes at the accessible environment boundary will depend on the conditions in the model.

Reference

Howarth, S.M. 1994. *Test Plan: Two-Phase Flow Laboratory Program for the Waste Isolation Pilot Plant (WIPP).* Albuquerque, NM: Sandia National Laboratories.

Comment T091

Page 21: I. Technical Comments, C. General Geology and Hydrology, Average Undisturbed Pore Pressure in Anhydrite

Area in document Volume 3, Chapter 2, Page 2-63

"It is unclear how the average undisturbed pore pressure in the anhydrite was developed. Table 2.3-2 (p 2-33) does not have any measurements greater than 9.5 MPa, yet the mean and median pressures are between 12 and 13 MPa."

Response

Table 2.3-2 shows only halite pore pressure data. Anhydrite data are presented in Table 2.4-2 on p. 2-59. The three values between 12.4 and 12.6 MPa are considered to provide the best representation of anhydrite pore pressures undisturbed by the excavations.

Comment T092

Page 21: I. Technical Comments, C. General Geology and Hydrology, Culebra Matrix Porosity

Area in document Volume 3, Chapter 2, Page 2-83

"If only intact rock was measured for porosity and there was a large amount of core lost in porous (vuggy) and/or fractured portions of the Culebra, is the matrix porosity used in the models: 1) adjusted upward to reflect the higher bulk matrix porosity; or 2) is the data indicating the vugs and fracturing considered as part of the fractured porosity? It is not clear if the Culebra matrix porosity values include these features or not."

Response

The matrix porosity used in the models has not been adjusted to compensate for unsampled, presumably higher porosity, portions of the Culebra. The data include vugs and fractures only to the extent that they were present in the core samples tested. Both fractures and vugs could be included in the "fracture" porosities determined from tracer tests (e.g., Jones et al., 1992), which represent what might be called the effective flow porosity of the Culebra. The

matrix porosity might, in turn, be called the diffusion porosity. If matrix porosity is being underestimated, the potential for matrix diffusion is also being underestimated. See also response to comment in EPA's document, p. 25 (I. Technical Comments, D. Additional Comments on General Geology and Hydrology).

Reference

Jones, T.L., V.A. Kelley, J.F. Pickens, D.T. Upton, R.L. Beauheim, and P.B. Davies. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site.* SAND92-1579. Albuquerque, NM: Sandia National Laboratories.

Comment T093

Page 22: I. Technical Comments, C. General Geology and Hydrology, Data on pH and Eh

Area in document Volume 3, Chapter 3, Page 3-41

"What are the current data or expected values of the pH and Eh in the Culebra under existing conditions? If the data exist, they could not be found in the PA."

Response

Ranges for pH conditions in the Culebra Dolomite have been well defined and range between about 6.5 and 8.0 (see Siegel, 1991, Chapter 2). The pH of the Culebra is expected to be narrowly constrained because of the tremendous buffering capacity of carbonate minerals. Any artificially induced perturbation in pH would rapidly be eliminated by dissolution/precipitation reactions.

Ranges for Eh in Culebra Dolomite groundwaters were investigated by Myers et al. (see Siegel, 1991, Chapter 6 and Appendix 6A). Myers et al. attempted to characterize Eh by evaluating four redox couples (As, N, I, and Se) with measurements with a platinum electrode (refer to Table 6-4 and Figure 6-2 of Siegel, 1991). Unfortunately, many of the measurements for individual redox species were below the analytical detection limits. Consequently, Myers et al. were only able to bound the Eh conditions and were not able to decisively quantify values. Myers et al. did speculate that groundwaters south of the site boundary are more oxidizing relative to groundwaters to the north (see Figure 6-1 and discussion on p. 6-22 of Siegel, 1991).

Reference

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico*. SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T094

Page 22: I. Technical Comments. D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 2-6 (Figure 2-3)

"The generalized stratigraphy of the Delaware Basin is inaccurate on several accounts.

- Castile formation onlaps the terminal platform margin of the Capitan Limestone and extends further onto inner parts of the Capitan platform. Figure 2-3 shows the top of the Castile formation being located stratigraphically lower than the top of the Capitan Limestone. Figure 2-5 on p. 2-8 more accurately depicts the relationship of the Capitan and Castile formations.

- The Dewey Lake Red Beds are Ochoan in age and should be included in this stage, along with the Castile, Salado, and Rustler formations."

Response

Both points in the comment are correct as stated by the EPA reviewer. Editorial corrections in future documents are appropriate.

Comment T095

Page 22: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 2-10 (Section 2.2.2.2)

"No mention is made of the wide variety of depositional facies that actually comprise the Capitan Limestone. A potentially important lithofacies, at least with regard to the hydrologic characteristics of the Capitan Limestone, is the forereef or foreslope facies, which consists of poorly sorted carbonate clasts shed from the high relief Capitan margin. This facies is

poorly mapped, may have very different flow characteristics than for other facies in the Capitan Limestone, and tongues of this facies may extend close to or beneath the WIPP site."

Response

The first sentence of the comment is plainly correct. We are unaware of evidence for forereef deposits extending 10 to 15 km into the basin for very different flow characteristics within these deposits. We would be willing to discuss this topic with the EPA during technical exchange meetings.

Comment T096

Page 22-23: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 2-10, Line 35

"'Lateral variations in depositional environments (in the Culebra Dolomite) were small within the mapped region...' What is the evidence for this statement? Detailed lithologic columns for the Culebra Dolomite with lithologies and sedimentary structures should be shown."

Response

Additional detail in the level of referencing will be included as appropriate in the PTB/draft compliance application. It is not clear that inclusion of stratigraphic columns is relevant to compliance, except along possible radionuclide-release paths.

Page 5-11 of Holt and Powers (1988) states: "The bulk of the Culebra is microlaminated to thinly laminated. The strata may be flat to wavy to locally contorted and discontinuous. Portions of the Culebra appear macroscopically devoid of depositional fabric. The dolomite is mottled in some zones. With the exception of the upper and lower contact zones, there is very little variation of depositional sedimentary features throughout most of the Culebra." Additional detail from the same page includes: "The lowermost foot (30 cm) of the Culebra locally is thinly laminated to laminated, with alternating light and dark brown laminae." "The uppermost few inches to 1 ft (30 cm) of the Culebra often differs radically from the underlying dolomite. The gamma ray signature of this zone is unique and is present throughout the Delaware Basin." We agree that the detail of referencing needs to be increased; generalized referencing in important areas, is inappropriate.

A large number of detailed correlations, cross-sections, and stratigraphic columns of the Rustler Formation are contained in Holt and Powers (1988).

use of conservative hypotheses). These curves are similar to the CCDFs generated by Sandia for WIPP.

How the results (and the uncertainties) should be incorporated in the regulator's decision making is discussed in details in my answer to the fifth question. This answer is based on the assuption that the aggregation of expert opinions will be done systematically for all fundamental assumptions, and that the resulting distributions will be integrated in the risk analysis. Otherwise (e.g., if the disagreement is simply represented by a set of consequence distribution, one per expert), I do not know how to recommend to a decision maker to systematically treat a collection of results, or the results of a conditional risk analysis based on unweighted assumptions. It becomes a matter of faith in the conservatism of the assumptions.

Q3. SELECTION OF INPUT VARIABLES THAT REQUIRE PROBABILISTIC TREATMENT: SENSITIVITY ANALYSIS

It is not necessary in many risk analysis problems to put a probability distribution on all variables. In the decision analysis cycle (Ref. Howard), the first step is to develop models by a deterministic analysis of the link between the consequences and the input variables. Second, a sensitivity analysis for each variable reveals whether or not the variation of an input value across the possible range can change by itself the final decision. Third, the probabilistic analysis is performed: for the variables that do not require full treatment of uncertainty, the mean value is encoded and included in the model. For the variables that do require a probability distribution, this distribution is encoded as described above. The uncertainties are then "propagated" through the analysis by different methods (closed-form solutions, relevant moments, logic/event trees, or simulation, for example, using Monte Carlo or Latin Hypercube sampling).

Q4. DEVELOPMENT OF PROBABILITY DISTRIBUTIONS

Incorporating *all* uncertainties is a risk analysis is indeed a challenge. Therefore, it is important to proceed first to the sensitivity analysis discussed above so as not to lose sight of the ultimate goal (to support a specific decision).

The development of probability distributions is currently a hot topic within the EPA and the environmental/health risk analysis community. [Note, however, that for many years, it has been done systematically for industrial facilities such as nuclear power plants]. Because of the controversial nature of the treatment of epistemic uncertainties by Bayesian probabilities, the solution is often to do only what I consider a partial uncertainty analysis, focusing on randomness in statistical samples and on distributions for the variables explicitly included in the model. The default solution is thus to focus on randomness and on *some* epistemic uncertainties.

There is seldom any attempt to quantify systematically the epistemic uncertainties (about partially known fundamental phenomena) because it requires quantifying explicitly the probabilities of alternative assumptions and, in order to do that, proceeding to an aggregation of expert opinions. For example, in a recent expert-based study of global climate change, Granger Morgan chose to simply present the range of results for each of the different experts without any attempt to come up with a composite distribution. I personally believe that one cannot escape this full uncertainty analysis (i.e., to include the probabilities of alternative hypotheses). Otherwise, the problem is exactly the one that you are facing with WIPP: how to judge of the degree of conservatism of a conditional risk analysis without looking at the conservatism of the hypotheses.

The structure of a full uncertainty analysis is thus the following:

1. Structuring of the different hypotheses into sets of alternative realizations so that probability distributions can be

attributed to these sets of assumptions.

2. Encoding and aggregation of expert probabilities for each set of assumptions.

3. For each fundamental hypothesis, identification of the subsequent models and parameter values (probabilistic treatment). Conditional risk analyses of the type performed by Sandia, but one for each possibility (e.g., each H1i in Figure 1) in a complete set of assumptions, including a measure of possible dependencies through conditional probabilities.

4. Propagation of all relevant uncertainties for each hypothesis (the results are the sets of risk curves shown in Figure 1 for each realization of a given hypothesis).

5. Summing of the results of the conditional analyses weighted by the probabilities of the fundamental underlying assumptions (one then obtains an overall set of risk curves like those presented at the bottom of Figure 1).

(Alternatively, the overall set of risk curves can be obtained directly through the use of a logic tree).

Again, there are different methods for the propagation of uncertainties through each model: closed-form solutions (which is sometimes possible, for example, to treat lognormal distributions and products of variables), computation of the relevant moments, use of logic (event) trees that layout all possible combinations of hypotheses, models, and parameter values, or full simulation (by various methods including Monte Carlo and Latin Hypercube sampling)

Q5. COMPLIANCE CRITERIA GIVEN A FAMILY OF RISK CURVES

How this full uncertainty analysis is used by the decision maker (DM) is a function of his or her own preferences (including risk attitude). Therefore, it is by nature subjective. The consistency of the process, however, can be treated somehow objectively.

For individual decisions, these preferences are represented by a utility function that allows representing risk aversion by putting

higher weights (than linear functions would) on the possibility of higher losses. Note that by virtue of the axioms of rationality for individual decisions, it is the *mean future frequency* that is the relevant characteristic of the probability distribution for the future frequency of the potential loss levels (in the WIPP case: the release level as an intermediate descriptor, but more importantly, the helth effects).

This rationality paradigm does not apply to collective decisions, except if one assumes that one elected decision maker (administrator) has been given complete power to make these decisions according to his or her utility function (which, presumably, would have to be revealed if it were to be used in an analytical model). This is impractical because it does not fit our political process and because there are many attributes to each decision that would require some adaptation of any revealed preferences.

The administrator is not only concerned about the probability distribution of the levels of release and about the economic costs of release (for which mean future frequencies would theoretically suffice), but also about the health and safety of the most exposed individuals in the public. The choice of a threshold and the way one demonstrates that it has not been exceeded should reflect directly a concern for prudence. The mean may or may not do that depending on the fractile(s) that it represents in the family of risk curves, and the practicality of demonstrating by analytical means that the goal has been achieved.

I would like, at this point, to go back to what I wrote in my 1986 paper:

> " The next question is to ensure that the goals have been satisfied with "reasonable certainty". A common procedure is to use "conservative estimates" at every step which means to overestimate the probabilities of initiating events, failures, accidents, etc. The overestimation of the

final result, however, is impossible to assess. It is a wrong approach that may lead to absurd figures and quite possibly to suboptimal decisions, thus defeating the pupose of conservatism itself. This is why the analysis of uncertainties and their explicit treatment in the final decision are critical.

Once this analysis has been done, safety decisions must be made to ensure that with a high probability (e.g., 0.95) the plant is in compliance with a the maximum acceptable individual risk constraint and with the maximum allowable frequency of failure. There is no compelling theoretical reason to use one fractile or a mean value rather than another criterion. In a framework involving numerical safety goals, this certainty level must be specified by the U.S. NRC along with the safety goal"

The example that I was using was safety of nuclear reactors for which the time horizon is relatively short and the uncertainties can be approached systematically. Therefore, the Probabilistic Risk Analyses that are performed for these plants do not involve the types of uncertainties faced with WIPP. Hence the possibility of "reasonable certainty" (which the USNRC calls "reasonable assurance"). In the case of WIPP, part of the analysis (the EPA linkage of release and health effects) is non-probabilistic and presumably, based on conservative modeling. Therefore, given the time frame and the level of uncertainties (e.g., about the future of civilizations in the next 10,000 years), the chosen approach has been different: to start with a set of preliminary results and framing hypotheses, then do a conditional performance analysis based on a mixed method (probabilistic and pre-set health effects estimates). First, one cannot judge directly which fractile(s) the mean curves of the future release levels would actually represent if Sandia had included in the analysis (1) the presumably conservative hypotheses that EPA had specified (complete with alternative assumptions and their probabilities), and (2) the uncertainties attached to the hypotheses that they generated themselves. Second,

one cannot derive from this analysis a probabilistic distribution for the health effects. The problem is that a full risk analysis of this type would be extremely difficult given the state of the art, and that the uncertainties over the next 10,000 years would be so large that the results may not be very informative.

In this highly uncertain, long-term case, I believe that the approach based on some fixed hypotheses, *then* on "reasonable expectations" for the conditional risk results is generally sensible provided (1) that the hypotheses are globally conservative (health effects given release as well as assumptions in the release computation) and (2) that the mean curves for the release of the different radionucleides generally correspond to high fractiles of the risk curve families (CCDFs). If that is the case, the combination of *hypotheses* and *means* may indeed provide the level of "reasonable assurance" that you wish and that is consistent with the USNRC requirements for much shorter life facilities. To check that the overall analysis is "globally conservative" you need to verify that the global model (Health Effects + Performance Assessment) yields conservative results and in particular that the hypothetical health risk results that would have come out of a fully integrated analysis meet the level of "reasonable assurance" that you want to see. This requires that the combination of the health effect model and the Sandia hypotheses provides a higher level of safety than the one demonstrated by the position of the PA mean curves in the PA alone.

Therefore, you may want to examine the effects of hypotheses on the position of the *current means* in the family of CCDFs (fractiles) for release accounting for the EPA/DoE hypotheses as shown in Figure 1. Of course, you do not want to ask Sandia to redo the whole uncertainty analysis, but to give you a feeling for the final degree of conservatism of the release results after this accumulation of assumptions. This involves listing the main hypotheses (both from EPA and from the Sandia PA) and assessing (even coarsely) their cumulative effects on the position of conditional (current) means in

the CCDFs families. If it is the case that the EPA/DoE assumptions are generally *conservative*, it is likely that what are now mean curves in the current conditional performance analysis (Sandia's PA) would correspond to higher fractiles of distributions that would account probabilistically for all hypotheses (Figure 1, bottom left). If the set of assumptions turns out to be altogether *unconservative*, introducing alternative assumptions will tend to make the current means go down in the families of risk curves towards lower fractiles (Figure 1, bottom right).

When you receive this information about the probabilities and the effects of alternatives to the main hypotheses on the position of the mean curves, you want to examine whether the *final* levels of fractiles that would correspond to the *current means* meet the level of conservatism that you want. You may also want to go one step further and look closely at the health effects themselves and at the conservatism of the EPA model of cancer risk. I do not believe that at that stage it would be realistic to require EPA to proceed to a full probabilistic risk assessment (they do not have the methods as far as I know). Yet, you can argue that their "reasonable expectations" are reasonable only if their hypotheses and health effects model provide the additional level of safety that is consistent with the NRC language of "reasonable assurance". In other terms, first their current means for the release of the different radionucleides have to provide at least as much safety as the overall "expected value" of the release that one would from a probabilistic analysis of the hypotheses. Second, the EPA health effect model should provide an additional layer of safety that convinces you that you are indeed in the high fractiles of a hypothetical full risk analysis.

Should you push EPA to specify a fractile level applicable across the board to all cases? I don't believe so, simply because each problem has to be replaced in its context (uncertainties, existence of alternatives, economic and political context, etc.). I believe, however, that examining carefully the range of fractiles

corresponding to the mean in the consequence distribution is a reasonable way to address the question of uncertainties. In the WIPP case, the choice of the mean conditional on a set of hypotheses was based on the long-term nature of the project, the fact that the computation of the mean is more robust than that of specified fractiles, and that the means (given the uncertainties) are likely to be among the high-fractiles anyway. And in any case, requiring the EPA to make a general statement about a "high level of confidence" in the final health effects analysis including all uncertainties would be helpful.

Regulatory language

I think that you can require that EPA be more rigorous in its implementation of the "reasonable expectation" language. They cannot just set hypotheses and models (as those leading to Figure 1, Appendix A of 40CFR191), frame the conditional risk analysis for the applicant, then claim without checking that the conditional means (even with infinite sampling size) resulting from this analysis necessarily support "reasonable expectation" of human safety. Whereas it may be unreasonable (and perhaps, even hazardous given how uncertain the results would be) to leave the choice of hypotheses and model framing to the applicant, it is not unreasonable to require that the effects of these hypotheses on the mean curves be assessed (i.e., simply to check how they displace the mean curve: up or down). In the WIPP case, I would focus on the hypotheses of the intrusion model (frequency, means and effects of drilling) which are the most likely to significantly affect the release results. I would also examine very closely the EPA health effect model.

I would want EPA to show that, in the end, the combination of "reasonable expectation" for the performance assessment and of the conservatism (if it is the case) of the health effect model that they have used to set the release criteria provides "reasonable assurance" of actual safety (i.e., for the ultimate health effects). Because EPA has done the health effects modeling, they are in a good

position to show the conservatism of their own results and of the final health risks when these results are combined with those of the performance assessment.

Therefore, you want to require EPA:
(1) to fully reveal the models that they have used to come up with the release standards,
(2) to list all the major assumptions that they have made (those that are likely to affect the risk analysis results), (3) then, to ask the applicants to show that the combination of these models, hypotheses and their own performance analysis supports the requirement that the current conditional mean is indeed "above" the marginal (overall) mean, and that altogether, the assumptions are in fact "conservative".

By comparison, the uncertainties that result from the sampling are probably (1) cheap to reduce and (2) not very significant compared to effects of the basic hypotheses. Therefore, you may choose either to accept their 95% confidence language, or to require a third level of confidence in the analysis. I do not think that it will make much difference.

3. ADDITIONAL COMMENTS ON ISSUES RAISED IN YOUR LETTER

3.1 Level of confidence in the fractiles (or mean) given the sampling size

This issue is easy to resolve because it is cheap to require additional computer runs if you do not think that the level of confidence achieved is what you want. Of course, the tail of the distribution will not be often reached in the simulation by definition of high consequence/low probability modeling. You may want to press EPA to specify the confidence level in this process (third order treatment of uncertainty, i.e., one level further than what I describe as Level 5 in Figure 2 of the Appendix). But you have to realize that the results will be somehow artificial given the variety of the sources of uncertainties. So, I would not focus so much on the uncertainties due to sampling size because they are

probably "in the noise", as I would on the uncertainties about the fundamental hypotheses.

3.2 Encoding of expert opinions

I agree that you may want EPA to specify better their encoding procedures. Anyway, in the case of WIPP, you want to find out how Sandia exactly did it (especially for parameter values).

3.3 Use of the mean

I generally agree with EPA that the mean *does* convey "a sense of the whole ensemble of the CCDF's generated". It represents an aggregated description of the risk by a single probability distribution (Level 4 of Figure 2) without displaying the higher level of uncertainties (Level 5 in Figure 2). I do not believe, as you do, that the applicant can vary the number of realizations and dilute at will the effects of *any particular CCDF*. What is true, however, is that with a small number of realizations (in the simulation) one may not reach the tail of the distribution. You want Sandia to specify case by case what level of assurance the mean represents (it varies, of course, along the release axis).

3.4 Additional comments

a. Specific guidance for the form of probability distribution functions seems to me impractical.

b. Need to deal with correlations: I agree, this is essential.

c. Appropriateness of the mean: in the case of WIPP, I think that the coupling of EPA assumptions (*if* they are globally conservative) and mean release level (which is likely to be among the high fractiles given the uncertainties) should provide the level of safety that you want. This is what you want Sandia to demonstrate.

d. Calling explicitly for a 95% fractile with 99% confidence would require a full probabilistic treatment of all EPA/DoE hypotheses regarding the release, introducing still more uncertainties in the analysis and probably producing highly questionable results. [I would not suggest this kind of fractile *on top* of the EPA hypotheses.] Again, I would start by checking what the current mean

represents (roughly) in the full picture. To call for the 95% fractile of the *real risk curves (i.e., the health effects)*, would require a whole new risk analysis including both the release model and the health effect model. It is obviously not the direction that was chosen *a priori*.

f. Of course, the process of sampling of 50 parameters, even with an infinite sampling size would dilute the effects of the extremes. It is the nature of probability: the extremes are much less likely than the central range of the distribution. But you want sufficient sample size to have confidence that you have given the extremes their proper weight.

h. Reducing uncertainties can be done in many different ways. Increasing the sampling size of course is one of them; but again, these uncertainties are probably minor compared with the uncertainties involved in the fundamental assumptions.

j. No, it is not easy to identify the various percentiles of crossed curves. Indeed, any mean curve will represent different percentiles in different release ranges.

4. CONCLUSIONS:

I believe that the case of WIPP as it stands now raises issues that are different from those that I addressed in my 1986 article regarding nuclear power plants. But the fundamental concern is the same: reaching an acceptable level of safety with reasonable certainty (or assurance). In the 1986 article, I proposed to do it using high fractiles of the risk curves (which is often where the means are anyway) based on full PRAs including the treatment of all identified and relevant uncertainties (as determined by sensitivity analysis). For WIPP, we do not have risk curves (in the sense of full probability distributions for the consequences,i.e., the health effects). Because of the 10,000-year time horizon, the uncertainties in the case of WIPP are such that this kind of analysis may be a futile exercise. Instead, EPA has chosen to make some assumptions in its performance criteria and to require a conditional performance analysis given these assumptions. Then, EPA specified the use of the conditional means as the basis for the compliance criteria.

In order to verify that the conditional means (conditional on specified health models and hypotheses) provide indeed "reasonable expectation" of safety once the effects of the hypotheses on expected values are carefully considered, you want to ask Sandia to provide additional information about what these conditional means really represent for future release and what they imply for human safety. In particular, you want to question assumptions regarding engineered barriers and the hypotheses that have been made to support the currently planned storage system. This is where you may be able to show that some of the assumptions are unconservative and that the real mean curves are below the conditional ones. Therefore, you may be able to conclude that the current analysis based on conditional means does not meet, on the whole, the "reasonable expectation" standard. I would not focus much on the effect of the sampling size (although it probably does not cost much) because increasing it may not provide large variations of the position of the mean in the overall CCDF family. The hypotheses about the frequency, the means and the effects of drilling are more likely to provide significant variations.

To summarize my conclusions:

4.1 I do not know where the current means stand in terms of fractiles on the distribution of release curves presented by Sandia.
=> You may consider asking Sandia to specify which fractiles are involved in the mean release curves that are presented in their final PA report (these fractiles will vary along the release axis; but Sandia may be able to bracket them).

4.2 I cannot judge the degree of conservatism of the Performance Assessment results because I do not know the effects of the EPA and DoE hypotheses on the release curves.
=> Ask Sandia to list the major hypotheses that have been taken for granted in their PA and to give you an idea (if not a full analysis) of the effects of these hypotheses on the results (i.e., the family of release curves). For example take the five or six most important assumptions of the PA (e.g., the Poisson model of human intrusions,

the diameter of the bore holes, the water flow model, the solubility factor of the main nucleides, etc). Ask Sandia to generate a set of reasonable alternatives to these hypothese and to show you that the mean curves that would be generated with proper probabilistic analysis of these alternative assumptions actually meet the criteria (and that they do not pull the means towards lower fractiles of the risk curve families).

4.3 The expert opinion procedures of encoding could be made more rigorous.
=> You may want to ask Sandia to identify the variables whose distributions are critical for the results (could make WIPP violate the performance criteria), to justify their decision to treat them through expert opinions (as opposed to experiments or measurements when feasible), to better justify their findings by describing exactly how they have encoded and aggregated expert opinions, or to redo the encoding and aggregation of these judgments if you conclude that some of the variables have nor been properly treated.

4.4 The uncertainties about WIPP are such that full probabilistic treatment of all assumptions is likely to introduce large additional uncertainties in the results if they were to be systematically treated through probabilities.
=> You may want to find out what is the level of release risk obtained given the combination of EPA and DoE assumptions and the results of the corresponding conditional risk analysis, judge whether it is reasonable, and if it is not, ask EPA to reveal how it is going to inject additional levels of prudence in its decision. Depending on how far the current means are (assuming full probabilistic treatment of hypotheses) from a reassuring (but not sacred) 95% fractile, you may want to ask for additional analysis or for a change of risk management strategy.

4.5 If you really want to estimate the long-term health risks associated with the possibility of release, you need a probabilistic version of the EPA health effect model and a true risk analysis

involving both release and health effects. I doubt that this is feasible. But:
=> You may want to ask EPA to better justify what they have done to obtain Table 1 of 40CFR191 and DoE to show that the overall risk results (their model plus the PA) provide "reasonable assurance" of safety.

5. APPENDIX
[What follows on this topic is based on a report that I recently wrote for the Electric Power Research Institute].

Six levels of treatment of uncertainties in risk analysis:
The form under which one would like uncertainty analysis to be done depends in large part on the use that one intends to make of the results, i.e., what criteria will apply in the decision making. All decisions do not need full treatment of uncertainties. Different degrees of sophistication in the assessment of the risks can be envisioned depending on the management rule that one intends to apply. Six different levels in the treatment of uncertainty (see Figure 2) can be identified.

Level 0 simply involves the detection of a potential hazard without attempt to assess the risk in any way. It is sufficient, in theory, to support strict zero-risk policies, or to make risk management decisions when the costs are low.

Level 1 is the "worst-case" approach. It does not involve any notion of probability. It is based on the accumulation of worst-case assumptions and yields, in theory, the maximum loss level. In practice, however, whatever the worst-case scenario that has been constructed, it is often possible to imagine still more unlikely circumstances that could worsen the result. It is therefore necessary to truncate the loss distribution.

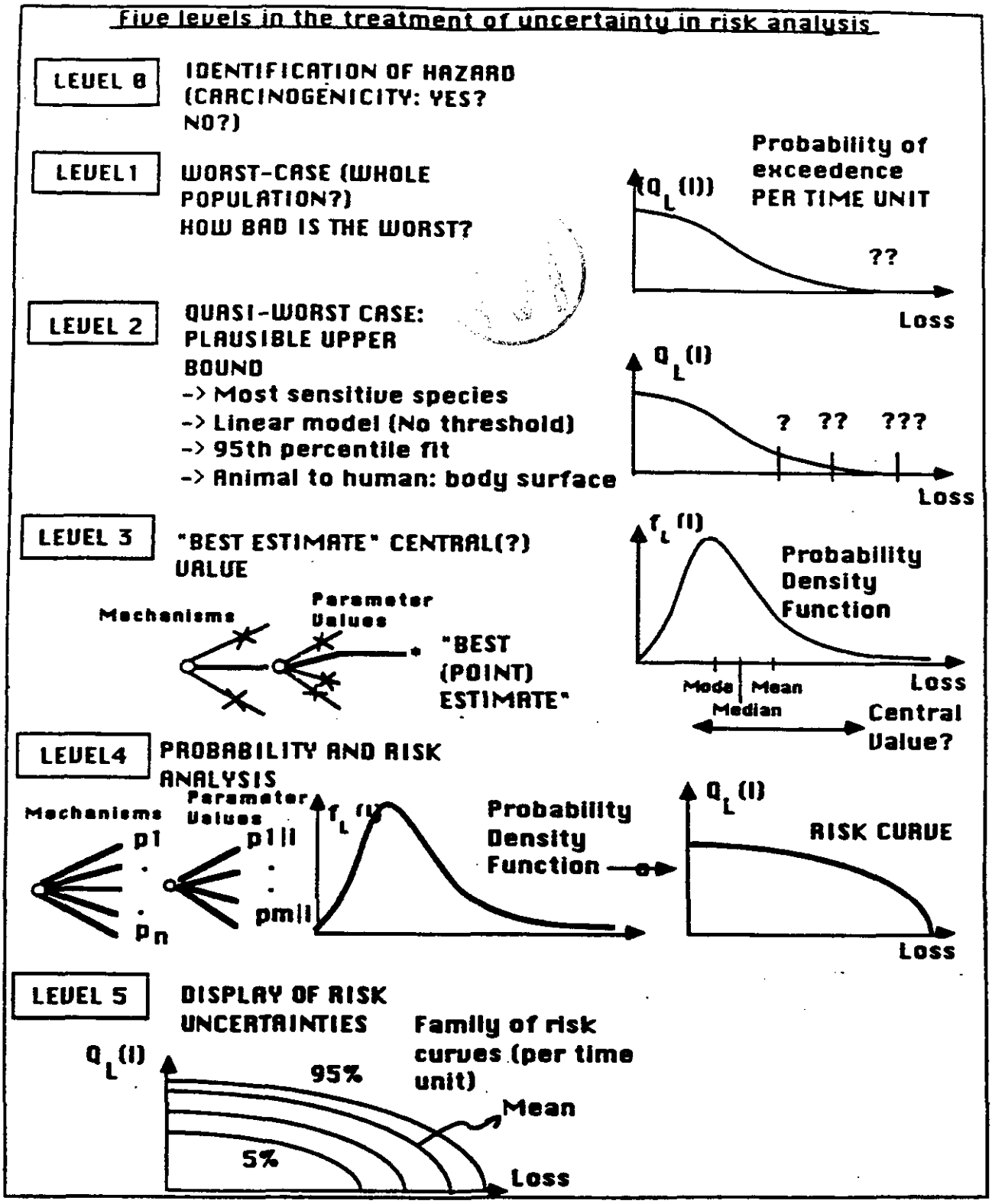

Figure 2: Six levels of treatment of uncertainties in risk analysis (Paté-Cornell, EPRI report, 1995).

Level 2 involves "plausible upper bounds" (or the "quasi-worst case"). This analysis represents an attempt to obtain an evaluation of the worst possible conditions that can be "reasonably" expected (1) when there is some uncertainty as to what the worst case might be, or (2) when the worst case is so unlikely that it is meaningless. Examples of these approaches include the Maximum Credible Earthquake or the Maximum Probable Flood used by the U.S. Army Corps of Engineers in the construction and management of dams.

This popular approach, however, presents major shortcomings. First, there is no way to judge the "conservatism" of these point estimates (the residual risk is unknown). Second, this approach does not allow a meaningful comparison of risks. Ranking among these presumably extreme values may not be related to the ranking of the mean values of the potential losses and there is no reason to believe that priorities set on the basis of plausible upper bounds will ensure maximum risk reduction for the money spent.
analysis.

Level 3 relies on "best estimates" and/or on a search for a central value (e.g., the mean, the median or the mode) of the loss distribution. Generally speaking, the advantage of central values is to provide a reasonable balance to plausible upper bounds. The disadvantage is that the risk is still characterized by a single point estimate and that the uncertainties disappear from the results.

Level 4 relies on probabilistic risk assessment (PRA), also known in engineering as quantitative risk assessment (QRA), or probabilistic safety assessment (PSA). It permits representation of a risk, not by a single point estimate, but by a complete distribution of the potential losses to represent the uncertainties involved. Still, the effects of all uncertainties being aggregated into one risk curve, it is impossible to extract from this information the dispersion due, for example, to expert disagreements about competing models for a fundamental hypothesis.

Level 5 allows display of uncertainties about fundamental mechanisms. This can be done in several ways. One approach is to ask each expert to provide an assessment of the risk based on their favorite model and on their evaluation of the distribution of parameter values, and to display this set of risk curves (one for each expert) without attempting to aggregate the results or to assess the probabilities of the fundamental assumptions on which they rely. The problem is that one popular hypothesis may be favored by a large proportion of experts for a combination of scientific and other reasons. Therefore, if a composite distribution is needed, one must sooner or later address squarely the issue of the relative probabilities of the different hypotheses and proceed to an aggregation of expert opinions. It is important at that stage to depoliticize the process if needed, and to put weights on models (given the evidence available) and not on the experts.

Therefore, in order to reach its logical conclusion, Level 5 requires a full probabilistic treatment of epistemic uncertainties. The result is a *family* of risk curves. These curves provide, for each value of the potential losses, a discretization of the probability distribution of the future frequency of exceedence of this loss value. Both aleatory and epistemic uncertainties are propagated through the analysis, for example, by Monte Carlo simulation or other simulation models such as the Latine Hypercube approach.

WIPP Performance assessment is a mixed case of some aspects of level 2 (plausible upper bounds; conservative hypotheses) and level 5 (full uncertainty analysis).

6. ANNOTATED BIBLIOGRAPHY

A. 40CFR191

1. Russo, September 1991: Updated Uncertainty Analysis of EPA River Mode Pathways Model Used for 40CFR Part 191: Table 1 of 1985 40CFR191 Analysis of Curie release corresponding to 90% level of certainty that effects will be less than or equal to 10 fatal

cancers/10,000 years was completed by an uncertainty analysis in which the probability distributions characterizing uncertainty about model input parameters were based on discussions held with radiological assessment experts taking into account theoretical considerations, variability in published data, and insightful judgment [How was this done?]

2. EPA 520/3-80-006. Population Risk

p. 150: "The expected frequency of human intrusion into a repository ranges from a drilling event every 400 years for granite to a drilling event every 50 years for salt and shale (ADL 79d)." [This is one of the assumptions whose effect on the results should be checked]

3. Federal Register 1985. 40CFR191.

191-13 Containment Requirement:

"Reasonable expectation" language. PA need not provide complete assurance...etc.

4. Response to comments; EPA 520/1-85-0242. p2-5: The median is insufficient. [I agree]. p.2-12: EPA states that the standards, as they are written, will allow demonstrating compliance in a way that will not be "unreasonably difficult or expensive". [Fine].

5. Report of the Review of 40CFR191 by a subcommittee of the SAB.1984. "The subcommittee supports the general form of the proposed standard, including the use of a social objective as an upper bound of acceptable health (cancer and genetic) effects. [The question is: how conservative is the societal risk target *given the assessment method*. Could be very conservative or not. I don't know].

6. Working draft of final 40CFR191: 11/1/83

191.16: Guidance for implementation

"determination of compliance should be based upon "best estimate" predictions (e.g., the mean of the appropriate distribution results)." [Best estimates is generally not a good term to use without specification in regulatory language because it is too vague].

7. Working Draft of final 40CFR191: 2/1/84

"Instead the implementing agency may determine compliance based upon the part of the range of predictions that falls within one standard

deviation of the mean..." [That was an idea but it was not implemented].

8. Working Draft of final 40CFR191: 4/23/84

Mean + one standard deviation => 85% for Normal distribution [Many distributions are not normal but skewed right].

9. Working Draft of final 40CFR191: 3/21/85

191.13: Containment requirements Uncertainties are too large hiven the time frame. => reasonable expectation language [Intended to be: the mean; actually here: conditional means].

Further: compliance with 191.13: Integrate all uncertainties into one risk curve [i.e., the mean risk curve. This is the level four of Figure 1. It is generally sufficient to support the choices of the risk averse decision maker in rational individual decision making].

10. Working Draft of final 40CFR191: 6/15/85

191.13: same language about "reasonable expectation".

11. Working Draft of final 40CFR191: 7/5/85

Uncertainties, and long term => reasonable expectation

12. Report of Meeting with extra-agency personnel concerning EPA Docket Number R-82-3. (with NRC staff personnel). "Subparagraph 191.16a requires that the standards be implemented in terms of the upper 85% confidence level of the simulated cumulative release. In view of the very very large number of judgmental factors that will have entered into the calculation, the use of the specified confidence level as a basis for deciding compliance is highly susceptible to mischief during the licensing process[...]; in view of uncertainties involved, confidence levels must be adressedd in terms of qualitative (e.g., reasonable assurance terms) rather than quantitatively."

Further: "Confidence level: DoE is concerned that the mention of an 85% confidence level will become the required level for all analyses; this would be contrary to EPA's intention."

Further: Guidance for implementation:

Suggestion again that mean + one standard deviation becomes the standard (=>≈85% for Normal distribution).

Further: "Paragraph 191.16.c unclear and calls for a precision level that may not be possible to demonstrate analytically."

13. EPA background information behind 40CFR191 1985
EPA 520/1-85-023.
p.6-3 Problem of uncertainties in EPA modeling of radiation risk estimate (the risk per unit dose are likely to be low)
p 6-13 the risk estimates are not unduly conservative [Important to check and to assess the effect on individual safety].
14. EBASCO study: Uncertainty and sensitivity analysis for the exposure pathway models used in 40CFR191.
p. xiii: levels of certainty for each radionucleide in Table 1.tryin to evaluate the level of conservatisms [Again, effects on conservatism of Sandia's result?].
15. Background information: EPA 93. EPA cancer risks are based on NAS study. Further (p.6-5): dose-response function was based on japanese epidemiology after the Hiroshima bomb. Perhaps unconservative following subsequent studies (p.6-93). p.6-31: estimates of cancer risks are NOT conservative.
16. EPA environmental pathway model, 1986
p.S9: Releases to a river [could be very conservative: WIPP is in the desert; but assumption was based on large rivers; how about small ones?].
17. Analysis of Uncertainties. Envirosphere, June 10, 1983.(problem of the original ore body release and river mode exposure pathway). Another set of uncertainty assessments for Table 2 of 40CFR191.

B. 40CFR194

1. Federal Register
2. 40CFR194 Proposed Rules: Criteria for the Certification and determination of the Waste Isolation Plant's compliance.
p.81: Expert Judgment "should be used provided that it does not substiotute for data that could be obtained through data collection or implementation." [An apparently reasonable set of requirements. No conflict of interest. At least five experts. Not all from DoE].
p.113: results of performance assessment:Risk curves. Monte Carlo of Latin Hypercube. Not the median. Requirement that the number of risk curves be large enough so that the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least 0.95

probability. [Looks conservative. To be checked]

p.114: the criterion itself: "demonstrate that there is at least a 95% level of statistical confidence that the mean of the population of CCDFs meets the requirements of section 13(a) of 40CFR19" [The mean is the most robust measure under the circumstances (smaller sample size required) and it may already be in the 80 to 95% fractile].

3. Background information: EPA 402-R-95002

p.3-7: Disposal systems shall be designed to provide reasonable expectation based upon performance assessments that cumulative releases of radionucleides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

(1) Have a likelihood of less than one chance in ten of exceeding the quantitties calculated according to table 1 (Appendix A) and

(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1.

Table 1 defines a set of permissble releases ("normalized release" for each isotope). [The question is; what were all the hypotheses underlying Table 1].

4. Compliance criteria: March 21, 1995

p.55: results of performance assessments.

5. EEG Comments. April 28, 1995.

p.5: the WIPP site does not meet the there stated criteria of 40 CFR 191.149 (because it is in a resource rich area)=> unconservative assumption. On the other hand, (p.6)EPA claims that the hypotehse are favorable because of the favorable characteristics of the WIPP (located in the desert). [net result??]

p.11: Engineered barriers:

Argument for engineered barriers: unconservative assumptions regarding human intrusion in a resource rich environment. Also: benefits will be small because it would only delay the arrival of actinides in the environment.

1992 PERFORMANCE ASSESSMENT REPORT

COMMENTS AND RESPONSES

EPA/EEG/NMAG/NMED

DOE/WIPP-95-2053

Responses to Comments on the 1992 Preliminary Performance Assessment Report for the Waste Isolation Pilot Plant

June 1995

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

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Introduction

This document contains the Department of Energy's (DOE) responses to comments made by the Environmental Protection Agency (EPA), the Environmental Evaluation Group (EEG), the New Mexico Environment Department (NMED), and the New Mexico Attorney General (NMAG) on the "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992", Volumes 1-3. Each comment and response is listed along with the reference materials. The appendixes contain supportive figures and memos referenced in the document. The subject document is referenced as the 1992 PA (Performance Assessment).

Comment CL1

Cover Letter, Format and Content

"We reviewed this document with the idea that it should contain all of the information needed to allow us to review, understand and evaluate DOE's approaches, and to demonstrate that the approaches were sufficiently justified to support a request for certification of compliance."

Response

The DOE appreciates the perspective taken by the EPA for this review since it provides the DOE with significant insight regarding what should be included in a compliance application. In addition, the EPA's perspective will help identify areas where the two agencies may disagree regarding implementation. It is important to seek resolution to these prior to the preparation of a final application.

The DOE will use EPA's comments and suggestions as a guide on formulating aspects of its compliance program. In addition, the DOE will establish, as a priority, the resolution of any issues or disagreements that have resulted from these comments.

Comment CL2

Cover Letter, Format and Content

"Although the PA provides a large amount of information, it lacks a sufficient description of the analyses that are discussed. The current PA is not a "stand alone" document that uses references as supporting information. Rather, references are often provided as the proof of the validity of DOE's reasoning, with insufficient information presented in the PA to enable the reader to follow that reasoning. ... While we understand that references and accompanying documents will be needed, we feel that the PA (in all its volumes) needs to tell a complete story. In our view, the PA should start with the basic information and, step by step, build up to a demonstration of compliance."

Response

The DOE agrees that the PA is not a "stand alone" document for compliance purposes. In fact, PA is only a tool used to determine compliance with quantitative limits and to understand uncertainty. Numerous other topics are to be included in the compliance application as indicated by the Format and Content Guide issued in May 1994.

This not withstanding, the DOE appreciates the broad perspective used by the EPA in its review as discussed above. The DOE will use this broad review as a guide in preparing the final application.

Comment CL3

Cover Letter, Format and Content

"For example, it would be helpful if the PA presented a listing of scenarios considered, and showed the analysis of probability and consequence for each separate scenario. The presentation of separate analyses would help clarify how scenarios are combined to create a final set of CCDFs."

Response

This material will be included in the compliance application as appropriate. The DOE notes, however, that separate analysis of both probability and consequences may not be appropriate for all scenarios considered. Some scenarios may be shown to be of sufficiently low probability that consequence analyses are unnecessary. Other scenarios may be shown to be of sufficiently low consequence that probability analyses are not required. In other cases, different scenarios may have sufficiently similar consequences that results of a single consequence analysis may be used in conjunction with different probabilities.

Comment CL4

Cover Letter, Format and Content Guide

The outline in the November 1993 Format and Content Guide prepared by the DOE is a significant improvement over the current PA organization.

Response

Comment noted.

Comment CL5

Cover Letter, Access to Information

"We are concerned that much of the information referenced or used as integral part of the PA analyses is not available for review. The current PA cannot be thoroughly reviewed because the supporting information is not accessible. This includes some references,

computer codes, their documentation, laboratory and field data, and the data generated from computer runs, such as the results of the Latin Hypercube Sampling that is used as input for the computer runs. The computer codes and their documentation should be available for public review."

Response

The DOE is currently pursuing access to computer codes and training in their use with the EPA and stakeholders. Documentation of codes is being completed, and will be complete before PA analyses are used in a compliance application.

All source material cited in the 1992 PA, including primary documentation for laboratory and field data, is on file at the WMT library at Sandia National Laboratories. For a compliance application, reference materials will be dealt with in a significantly different manner in order to assure timely access to information by the EPA.

Comment CL6

Cover Letter, Access to Information

"In addition, if they are incompatible with EPA's computer system, they should be remotely accessible on DOE's computers to allow independent examination. I recognize that the codes and their documentation are not in final form; however, our review of the codes will take a long time, so we need the copies used to prepare a performance assessment along with the results of that assessment. If we do not get the codes until the final application, it will significantly slow our review of the application."

Response

The DOE is as concerned as the EPA over the length of time that EPA may require to review DOE's codes. Consequently, the DOE has made code availability a priority. The EPA and the DOE are successfully resolving this issue of access and training.

Computational efficiency is a complex topic and would be a welcome topic for the DOE/EPA technical exchange meetings. Specific recommendations concerning resource allocation, e.g., model development versus collection of experimental data, are to be an integral part of the systems prioritization methodology (SPM) effort. The SPM will have "outside scrutiny" inherent in the process design.

Comment CL7

Cover Letter, Repromulgation of 40 CFR 191

(a) "We realize that 40 CFR 191 had not been repromulgated when the analyses for this version of the PA were being conducted, thus consistency with the rule was impossible. However, the rule is now final, and changes in the PA will need to be made in order to reflect the new 40 CFR 191. The main areas where changes are necessary are in the ground-water and individual protection requirements, and the use of the committed effective dose. The definitions relating to ground water have been changed to reflect EPA's policy of protecting underground sources of drinking water. DOE will need to identify the potential aquifers and their water quality (i.e., total dissolved solids)."

(b) "In addition, the undisturbed performance time frame calculations need to reflect the 10,000 year requirement. With the increase of the time frame from 1,000 years to 10,000 years, DOE may need to include scenarios that were previously omitted."

Response

All aspects of 40 CFR 191, including those portions repromulgated in December 1993, will be incorporated into compliance documentation.

(a) The DOE has taken the position that a decision on when and if underground sources of drinking water should be identified and characterized (i.e., when such a characterization will provide pertinent information for a compliance application) will be based on the expectation of releases. Briefly, identification and characterization of USDWs should not be required if no radionuclide releases to the accessible environment are predicted for 10,000 years or if 10,000 year peak predicted releases to the accessible environment are less than or equal to the applicable Maximum Contaminant Levels (MCLs). USDWs along the pathway should be identified and characterized if peak predicted releases to the accessible environment for 10,000 years are greater than the MCLs.

(b) The DOE agrees that calculations for a compliance application must be performed for a 10,000 year compliance period as stated in 40 CFR 191.

Comment CL8

Cover Letter, Regulatory Issues

"The PA also needs to address both 191 and RCRA compliance."

Response

The DOE has implemented a PA program which examines two-phase flow. This allows the determination of releases via both liquid and gas pathways. For the compliance determination, appropriate transport calculations will be made using these PA models. These calculations will include contaminant transport of interest to each of the regulations.

Comment CL9

Cover Letter, Regulatory Issues (Guidance to 40 CFR 191)

"The Guidance for 40 CFR 191 is generic in its application and it is non-binding to the implementing agency. EPA is evaluating the Guidance's suitability for use at the WIPP site. However, deviations from the Guidance should be clearly explained. The compliance criteria (40 CFR 194) will provide further clarification on this topic."

Response

The DOE agrees that any deviation from the guidance in 40 CFR 191 must be carefully and clearly documented. The DOE realizes that EPA's guidance, while non-binding, is not arbitrary and is provided to assist the implementing agency in meeting EPA's overall goal of protecting human health and the environment. Since EPA's guidance is established as the result of the technical bases developed during rulemaking, the DOE realizes that any significant deviation from this guidance must have equally in-depth technical justification.

Comment CL10

Cover Letter, Regulatory Issues

"The future applicability of the Guidance notwithstanding, DOE did not correctly follow the Guidance in this PA. If DOE was going to follow the Guidance, the PA should have used a constant drilling rate of 30 Boreholes/km^2 per 10,000 years for comparison with the containment requirement. In addition, the PA incorporates credit for passive institutional controls without proper justification."

Response

The maximum rate for human intrusion considered by DOE yielded an expected number of boreholes equal to 30 per square kilometer. Smaller rate constants were also considered to allow the evaluation of the sensitivity of disposal-system performance to uncertainty about future drilling rates. Determining such sensitivities is important to capturing the most significant parameters for the compliance calculations. These sensitivity analyses indicated

that system performance is highly sensitive to the drilling rate and that it may be a very important factor in the compliance decision.

The DOE agrees that any assumptions made regarding the guidance need adequate justification as discussed previously. This applies to the credit taken for passive controls, drilling rates, and other factors.

Comment CL11

Cover Letter, Use of Expert Panels and Peer Review

"There should be documentation of the process used to obtain expert opinion, and the process should follow written procedures."

Response

A formal QA procedure for the use of expert judgment by Sandia National Laboratories was published in 1992 (Rechard et al., 1992). Further refinements of this QA procedure can and have been incorporated into WIPP Procedure No. PAP06, Use of Expert Judgment Panel Quality Assurance Procedures. Compliance documentation will contain documentation in accordance with this or any other formal procedure used by the DOE and its contractors to elicit expert judgment.

Comment CL12

Cover Letter, Use of Expert Panels and Peer Review

"Specifically, we do not agree with the approach taken by DOE to estimate a reduction of the drilling rate from speculations on the use of markers. The markers aren't yet designed; therefore, the panel was asked to provide advise about the effectiveness of the markers at WIPP on the basis of incomplete information. Nor did the panel include all the necessary expertise, e.g., no petroleum engineers or drilling experts were included on the panel. The information from the marker panel was then apparently provided as input to a computer program that produces results in an unclear manner. EPA's compliance criteria will contain additional guidance on the use of expert panels."

Response

This issue has been raised numerous times by the EEG and the DOE has been sensitized to assuring proper care is taken in both establishing the scope of an expert panel and in using the outcome.

With regard to the specific comment on the process used by the DOE, the following is provided:

The process used by the Markers Panel was to first develop design guidelines for long-term communicative markers based on the contributions from individuals in disparate related fields such as materials science, archaeology, and communications. Based on the design guidelines, the two teams comprising the Markers Panel each developed a conceptual design for a system of markers. Estimates of efficacy of the markers system over time were based on the conceptual design. Implicit in the deliberations was the assumption that sufficient testing was undertaken to determine, for example, the appropriate design of the foundation for stone markers to withstand possible fluctuations in surface level and still remain stable. A second assumption in the effort was to evaluate what was possible for a marker system (as a first approximation) with no cost constraints. Cost constraints may come into play regarding the definition of "practicable" in 40 CFR 191. There is much evidence from the fields related to marker design that suggest avenues to pursue to improve long-term survivability and communication.

A petroleum engineer was not included on the Markers Panel, because the thrust was geared to long-term survivability of a marker system and continued interpretability. A petroleum engineer's skills are not such as to contribute to this effort.

M

Comment CL13

Cover Letter, Use of Expert Panels and Peer Review

"In future performance assessments and interim documents, it would be helpful for DOE to identify: 1) the areas where no data exist; 2) where expert panels and expert judgement will be used in lieu of data; and 3) whether the expert judgement will be replaced with data by the time of the final application. We strongly recommend that DOE use data where it is possible to obtain it, instead of relying on expert judgement."

Response

The DOE agrees that the use of expert panels in lieu of data must be carefully documented and justified. The DOE, however, does not agree with the concluding statement in this comment since it is written so broadly. Instead, a level of "practicability" must be applied when designing tests in lieu of expert judgment. This is particularly true when tests may require unrealistically long time frames or represent unreasonable costs.

Comment CL14

Cover letter, Models

"The development and implementation of conceptual, computational, and computer models is one of the most important technical aspects of the performance assessment topics. Therefore, it is imperative that we and the public have a good understanding about the modeling process and the models themselves. In the current PA, a good discussion of conceptual models and their alternatives are provided in only a few instances, such as the porosity model for the Culebra Dolomite. The conceptual models for the potash mining scenario are absent."

Response

The DOE agrees that the development, documentation, and implementation of conceptual, computational, and computer models is critical to a defensible performance assessment. Documentation of models is facilitated by Sandia's formal software Quality Assurance Procedures. The mandatory guidelines and requirements contained in these procedures ensure traceability and verification of computational and computer models, as well as documentation of the underlying conceptual models.

The evaluation of computational-model uncertainty involves evaluation of various conceptual models against relevant repository performance metrics. Current WIPP PA accomplishes this in two ways:

1. An "all-other-things-being-equal" method, in which alternative conceptual models for one component of the system are individually evaluated over the LHS sampling of imprecisely known parameters, while maintaining the variability of parameters not included in the tested sub-model constant.

2. Inclusion of the alternative conceptual models within the sampling of imprecisely known parameters.

Examples of method (1) are inclusion of: a) multiple transport and flow models of the Culebra dolomite (single-porosity vs. dual-porosity vs. fracture-flow only; chemical retardation vs. no chemical retardation); and b) multiple repository and Salado long-term responses (with gas generation vs. without gas generation; with room consolidation vs. without room consolidation; with a representation of fracturing in the Salado vs. with no Salado fracturing).

The example of method (2) to date is inclusion of different two-phase-characteristic curves, e.g. the Brooks/Corey and Van Genuchten/Parker sub-models, and sampling on each.

The DOE believes it is important to evaluate the defensibility of all conceptual models continually, both by examining their supporting experimental data and evidence and by examining whether or not the different models have significantly different impacts on expected performance. Ultimately, the defensibility of a performance assessment depends on the belief of the regulators and major stakeholders that a reasonable conceptual model has been used, and that there is sufficient evidence to support its use. In order to make this evaluation, this history of the development and screening of alternative conceptual models used in the performance assessment must be thoroughly documented.

Comment CL15

Cover Letter, Models

"The next performance assessment iteration should contain a detailed description of all conceptual models chosen and the alternative conceptual models that are or have been under consideration. For those conceptual models no longer under consideration, DOE should justify why they were discarded."

Response

During the development of compliance documentation, a conceptual model screening process that has the goal of examining all conceptual models put forward by Sandia, WID, DOE, and stakeholders will be used to arrive at a prediction of reasonably expected system performance. The screening process will include the reasoning by which the model is accepted or rejected for use in the performance assessment. The compliance documentation will provide the full description of the screening process and its application.

Comment CL16

Cover Letter, Models

"Before DOE submits an application for certification of compliance, there should be general agreement between EPA and DOE on the conceptual models that will be used by DOE."

Response

The DOE agrees that ongoing dialog regarding conceptual models will be very useful.

Comment CL17

Cover Letter, Models

"The development of the computer codes will take time, especially since many of the computer codes are 'state of the art.' Because of the sophistication of the modeling, the peer review and quality assurance of the code will also take time--the more complex the code, the more time it is likely to take. They will also take more time to review. We recommend that DOE takes the necessary time to ensure that the peer review and quality assurance is implemented in a thorough manner, especially where there is uncertainty in the conceptual models used in the codes."

Response

The DOE agrees and has instituted a thorough review of the quality of the codes and data used to implement conceptual models.

Comment CL18

Cover Letter, Quality Assurance

"...the PA does not seem to address data quality objectives or other related issues."

Response

This was not a rigorous objective of the 92 PA. The DOE has recently initiated a quality verification activity to assure data and code quality for compliance determinations.

Comment CL19

Cover Letter, Quality Assurance

(Restatement) EPA is concerned about the implementation of QA for the "old data", such as site characterization or completed laboratory studies.

Response

In 1993, the DOE began an extensive review of early and completed work. The assessment is still in progress. Deficiencies identified in the assessment shall be documented and appropriate corrective action taken. Before the final compliance application is brought to EPA, data, analyses, and resulting conclusions shall be screened against appropriate QA requirements.

Comment T001

Page 1: I. Technical Comments, A. General, Access to Information

Area in document General

"EPA should have access to source codes, code documentation, on-line help files and the executable image. It is recognized that at an early stage of development, a code is a working draft and should not be subjected to a critical outside review. However, if the computer code, references, or other information is adequate for use in the PA, then it is appropriate to have it accessible to EPA and to other interested parties."

Response

The DOE is currently pursuing access to computer codes and training in their use with the EPA and stakeholders. Documentation of codes is being completed, and will be complete before PA analyses are used in a compliance application.

Comment T002

Page 1: I. Technical Comments, A. General, Resource Allocation

Area in document General

"Decisions regarding resource allocation (e.g., model development versus collection of experimental data) should also be subjected to outside scrutiny. In the case of computer resources, DOE should have its computer codes reviewed for their computational efficiency, because of the potential for the algorithms themselves to be unnecessarily resource limiting to the PA effort."

Response

EPA's comment is noted and will be considered by the DOE.

Comment T003

Page 1: I. Technical Comments, A. General, Limited Resources

Area in document Volume 2, Chapter 7, page 7-5, Line 17

"Direct solution of 'fully coupled equation' is said to be unrealistic using present resources. Why is this true? What resources staff, money, or computer capacity would be required? Has DOE tried to use more efficient algorithms and computer program applications? "

Response

The basis for this statement is discussed in Butcher and Mendenhall (1993, page 7-3 middle paragraph). An example of typical computer capacity requirements is given in the same reference, page 6-5, third paragraph. In regard to algorithms and computer applications, the codes used for these analyses have evolved over the past 30 years and represent the most advanced state-of-the-art technology.

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B*. SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T004

Page 2: I. Technical Comments, A. General, Room Modeling

Area in document General

(a) "Has DOE developed a field theory for two-phase flow in a deformable porous media with fractures that can undergo large deformation?"

(b) "Can DOE provide justification for separating (over the various time-and-space scales) the two-phase flow, mechanical rock response, and gas generation models?"

Response

(a) While a single field theory for two-phase flow in a deformable porous media with fractures that can undergo large deformation may be theoretically feasible, it is considered to be technically infeasible because it would be too unwieldy to use in the global context of PA (also see response to previous comment).

(b) The justification for separation is discussed in Chapter 7 of Butcher and Mendenhall (1993).

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B*. SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T005

Page 2: I. Technical Comments, A. General, Poor Referencing of Information: Shaft Consolidation Example

Area in document Volume 3, Chapter #, Page 3-35, Line 7, A137, A140

It is stated that backfill in the lower is parts of the shafts will become consolidated due to salt creep, with a final permeability comparable to that of the host rock of the Salado formation. However, no calculations or modeling results are presented in the PA report to justify this assumption. The 1992 PA cites the 1991 PA, which in turn cites two other reports without discussion how the values were derived. This is but one case out of many in which the reviewer must peruse a succession of documents to find the source of cited data.

Response

The Project is currently investigating the permeability likely to be achieved by the crushed salt components placed in the shafts. The most current published information is summarized in Van Sambeek et al. (1993). Current technical efforts are focused on evaluating the effects of backstress, placement technique, and parameter variability on our ability to achieve an acceptably low permeability in each of the shafts; effective emplacement of the crushed salt components is an important part of the proposed Large-Scale Seal Tests Program.

Reference

Van Sambeek, L.L., D.D. Luo, M.S. Lin, W. Ostrowski, and D. Oyenuga. 1993. *Seal Design Alternatives Study*. SAND92-7340. Albuquerque, NM: Sandia National Laboratories.

Comment T006

Page 2-3: I. Technical Comments, A. General, Radionuclide Inventories

Area in document General, Volume 3

"The source of the radionuclide inventories is the memo from Andrew Peterson, which appears on page A-135 of volume 3. The inventories for the various generator sites are inconsistent: some include the short-lived daughter products of longer-lived parents, while others do not. For example, Y-90 is in secular equilibrium with Sr-90 in the CH waste at Hanford, while it is absent at INEL. ... Furthermore, INEL list[s] different activities of the two nuclides in its RH wastes. The Peterson memo sums the reported activities, showing significantly different totals for the two nuclides. Of greater import, Hanford lists a large CH waste inventory of PU-241, but nothing for its daughter product, Am-241. In fact, ten years after it is generated (for example), each curie of Pu-241 will be in equilibrium with 12.6 mCi of Am-241."

"Steps should be taken to insure that all generator sites use a consistent methodology for estimating their inventories. Absent such a practice, Sandia should obtain enough information to enable it to evaluate the data and make the necessary corrections."

Response

The Project is evaluating the sensitivity of compliance to this issue. Additional detail will be included in Project Technical Baseline report.

The radionuclide inventory used in the 1992 PA was a hypothetical "design" inventory based on the numbers given in the Peterson memo; inconsistencies in the way generator sites quoted the inventories were ignored in forming the design inventory.

The DOE has recently published the Baseline Inventory Report (BIR) which is aimed at achieving the consistency goal referred to in this comment. The BIR focuses on those parameters believed to be the most important to performance assessment.

Comment T007

Page 3: I. Technical Comments, A. General, Inventory and Release Limits

Area in document Volume 3, Chapter 3, Page 3-35, Line 7; A-137,140

"Why are the 1991 release limits presented instead of the 1992 limits used? The inventory in 1991 was 11.87 million Ci of waste. The 1992 PA inventory is listed as 4.227 million Ci (in tables on pages A-137 and A-140). This is more than "slightly different," than the 1991

release limits as stated in volume 3 of the PA, and it effects the release limit. What is the reason for this discrepancy? What numbers were used for the analyses?"

Response

Possible reasons for this apparent discrepancy (i.e., editorial error, error in interpretation, etc.) are being investigated. The release limits used in the 1992 PA analyses were based on the 1992 PA inventory. Future compliance documents will base inventory information on the BIR which combines information from numerous sources.

Comment T008

Page 3: I. Technical Comments, A. General, Inventory and Release Limits

Area in document Volume 3, Chapter 3, Page 3-35, Line 7; A-137, A-140

"What is the estimate of uncertainty in the waste inventory and the estimate of the release limits? What is being done to decrease this uncertainty? Will bounding values be used?"

Response

Uncertainties in all waste characteristics (e.g., the composition of the waste as well as its radionuclide inventory) are presently unknown. The radionuclide inventory used in the 1992 PA was a fixed, hypothetical "design" inventory based on estimates given by Peterson (see response to preceding Comment T006); uncertainty was arbitrarily added to certain waste characteristics also estimated by Peterson (volumes of cellulosics and corrodible metallics) in order to test the sensitivity of performance measures to variations in these characteristics.

Comment T009

Page 3: I. Technical Comments, A. General, Colloid Transport

Area in document Volume 2, Chapter 2, Page 2-39, Line 9

"EPA strongly agrees with the State of New Mexico that distribution coefficients (K_d's) be based on 'experimentally justified data' and not based solely on expert panel judgment."

Response

The DOE has planned an experimental program to provide these data if needed.

Comment T010

Page 3: I. Technical Comments, A. General, Uncertainty

Area in document Volume 1, Chapter 3, Page 3-13, Line 44

"Please provide a detailed explanation of all methods used to reduce uncertainty and methods used to evaluate uncertainty."

Response

The line referred to in the text references Table 3-1 on the following pages of Volume 1. This table contains approximately 48 references and internal cross-references to examples of techniques used to assess or reduce uncertainty. The reviewer is referred to the table for more detail than the text provides and to the cited documents for additional detail. The DOE will include the information in these references in the final compliance application to a level deemed appropriate.

Comment T011

Page 3: I. Technical Comments, A. General, Uncertainty

Area in document Volume 2, Chapter 3, Page 3-22, Line 1

"Please provide more discussion on how uncertainty is 'propagated through a model'."

Response

The referenced line of text refers to the propagation of a sample through a model. That step of the analysis is briefly explained in the previous section on the previous page, and is explained in detail in later chapters of Volume 2 and in Volumes 4 and 5. Propagation of the sample through the model simply refers to the calculation of consequences for each Latin hypercube sample, using each of the consequence models in the system.

As discussed in general terms in Section 3.5 of Volume 2, and in extensive detail in the references cited therein, the WIPP PA has selected a Monte Carlo methodology to allow estimation of the uncertainty in model outcomes that results from uncertainty in input parameters.

Comment T012

Page 3: I. Technical Comments, A. General, Grout Seal in MB-139

Area in document Volume 1, Chapter 4, Page 4-4 (Figure 4-2a)

How does the "Grout Seal" get into Marker Bed 139?

Response

Effective placement of grout into Marker Bed 139 has been part of the technology development activities performed at the WIPP facility. Specifically, as indicated in the test plan for the Small-Scale Seal Performance Test-Series F (Ahrens, 1992), this underground test at the WIPP was "intended to demonstrate equipment and techniques for producing, injecting, and evaluating microfine cementitious grout." The grouting was completed in March, 1993, and the final report is currently being prepared.

Reference

Ahrens, Ernst H. 1992. *Test Plan - Sealing of the Disturbed Rock Zone (DRZ), Including Marker Bed 139 (MB139) and the Overlying Halite, Below the Repository Horizon, at the Waste Isolation Pilot Plant - Small-Scale Seal Performance Test - Series F.* Albuquerque, NM: Sandia National Laboratories.

Comment T013

Page 4: I. Technical Comments, A. General, Grout Seal in MB-139

Area in document Volume 1, Chapter 4, Page 4-4 (Figure 4-2a)

How will the seal location be selected?

Response

Tentative locations for the seal components have been identified in the reference seal design report (Nowak et al., 1990) and the logic for the locations is identified. In general, locations were selected on the basis of the sealing strategy (combination of long- and short-term components with some desirable redundancy) and needed function (e.g., limit water flow into the shaft) of a particular component. Locations have been slightly modified in a recent update of the reference seal design; documentation of the updated design is in progress. Additional information related to the intended seal locations will be included in design reports on the various components that will be primary references for compliance documents. At the time

of actual placement of the seals, it is likely that location-specific factors such as degree of fracturing or observed water inflow will influence the final placement.

Reference

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant*. SAND90-0355. Albuquerque, NM: Sandia National Laboratories.

Comment T014

Page 4: I. Technical Comments, A. General, Bell Canyon Formation Characteristics

Area of document Volume 2, Chapter 2, Page 2-10, Lines 20-22

"If the Bell Canyon aquifers can possibly act as a source of groundwater into the repository due to exploration activity, then it would be prudent to know more about the hydrostatic head gradient of the formation. If there is data on this topic, it was not presented in the PA."

Response

The regional potentiometric surface of the Bell Canyon Formation is presented in Figure 9 of Mercer (1983) and extrapolated static bottomhole pressures in the Bell Canyon in three boreholes (AEC-7, AEC-8, and ERDA-10) tested by the WIPP project are given in Table 4 of the same reference. Pressure and hydraulic head data from the Bell Canyon in two additional boreholes (Cabin Baby-1 and DOE-2) tested by the WIPP project are given in Beauheim et al. (1983) and Beauheim (1986). Data from all five holes indicate that Bell Canyon heads are sufficient to drive brine to the level of the repository in an open borehole; whether flow would be upwards or downwards in this borehole would depend on the pressure conditions existing in the repository at the time.

References

Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos Area, Southeastern New Mexico*. U.S. Geological Survey Water-Resources Investigations Report 83-4016. Albuquerque, NM: U.S. Geological Survey.

Beauheim, R.L., B.W. Hassinger, and J.A. Klaiber. 1983. *Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico*. WTSD-TME-020. Albuquerque, NM: U.S. Department of Energy.

Beauheim, R.L. 1986. *Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-1364. Albuquerque, NM: Sandia National Laboratories.

Comment T015

Page 4: I. Technical Comments, A. General, Area of Drifts, Waste Panels

Area in document Volume 3, Chapter 5

"Please clarify the size of the area of the drifts, waste panels and the repository as a whole. The PA uses different numbers for area: 0.5 sq. km and 109,354 sq. meters. What is used in estimating the number of boreholes?"

Response

The areas of the drifts, waste panels, and other features of the repository are given in Table 3.1-1 (which is also keyed to Figure 3.1-2) on page 3-4 of Volume 3. The total excavated area of the disposal region is 111,520 meters^2 but the total area of the disposal region (including pillars and room separators) is 0.5069 kilometers^2. The area used in the 1992 PA to compute the drilling intensity into the repository includes the 111,520 meters^2 of area for CH TRU waste and 14,480 meters^2 hypothetically occupied by RH waste emplaced in the walls of the waste-emplacement panels (total target area of 126,000 meters^2).

Comment T016

Page 4: I. Technical Comments, A. General, Crushed Salt

Area in document Volume 2, Chapter 2, Page 2-48, Line 19

What process was used to prove that crushed salt will compact to 95% of initial density within 100 years?

Response

Creep modeling activities, supported by laboratory measurements on crushed salt and host rock salt, have led to the belief that sufficient deformation will be attained to achieve compaction to about 95%. The most recent modeling efforts are summarized in Van Sambeek et al. (1993). The timing for when the degree of compaction reaches about 95% is directly dependent upon numerous factors such as the steady-state creep rate of the host rock, the initial or emplacement density of the crushed salt, the backstress exerted on the formation by the crushed salt, moisture content of the crushed salt, etc.

Reference

Van Sambeek, L.L., D.D. Luo, M.S. Lin, W. Ostrowski, and D. Oyenuga. 1993. *Seal Design Alternatives Study*. SAND92-7340. Albuquerque, NM: Sandia National Laboratories.

Comment T017

Page 4: I. Technical Comments, A. General, Colloid Transport

Area in document Volume 2, Chapter 2, Page 2-54

"Colloids could potentially have a large impact on the migration or retardation of the radionuclides; they could have a noticeable effect on solubility and sorption of the radionuclides. When will data on colloid formation and transport be collected?"

Response

A laboratory program to determine important information about colloid formation and transport in Salado and Rustler brines is in progress. Some qualitative information from this program has already been transferred to PA for inclusion in future calculations; other information will be provided for the compliance analysis.

Two colloid laboratory programs address the two major types of radiocolloids. Actinide intrinsic colloids, which form by condensation reactions from dissolved radionuclides, are being investigated by a series of screen experiments. Potential carrier colloids, which are ordinarily non-radioactive particles that may act as a substrate for sorption, are being investigated separately, by a series of screening experiments that focuses on evaluating their stability in brines. Results from those two laboratory programs will be incorporated into a model that describes the concentrations of colloid-borne actinides in the disposal room environment. Predictions made with the model will be compared with results from the Source-Term Test Program (STTP) being conducted as part of the Actinide Source-Term Program (see Phillips and Molecke, 1993).

Reference

Phillips, M.L.F., and M.A. Molecke. 1993. *Technical Requirements for the Actinide Source-Term Waste Test Program*. SAND91-2111. Albuquerque, NM: Sandia National Laboratories.

Comment T018

Page 5: I. Technical Comments. A. General, Colloid Transport

Area in document Volume 2, Chapter 2, Page 2-54, Line 29

"When will it [colloid formation and transport] be modeled in future PAs?"

Response

Transport of colloids will be considered for inclusion in the SPM. Any decision on how to incorporate it in PA for a compliance application will depend on the outcome.

Comment T019

Page 5: I. Technical Comments, A. General, Colloid Transport

Area in document Volume 2, Chapter 2, Page 2-54, Line 29

"How does the lack of information on colloids affect the geochemical and hydrology models developed or under development?"

Response

Colloids may impact current PA modeling in two places: by affecting total concentrations of radionuclides transported in disposal-room brine, and by affecting transport of radionuclides in the Culebra.

Disposal-room actinide concentrations are presently based on values for solubility limits derived from an expert panel (Trauth et al., 1992). The "solubility" panel recognized that suspended forms could contribute to the total concentrations, but concluded that they lacked the information to make any estimate of what that contribution could be.

The distribution coefficients used to describe actinide sorption are also based on expert panel judgment (Trauth et al., 1992), and also do not include colloidal effects. The 1992 PA reported releases into the Culebra and releases transported in fractures only without any sorption. These calculations do not consider the effects of colloids in the disposal room. With regard to colloid-facilitated radionuclide transport in the Culebra, it has been argued that colloids may increase transport rates relative to dissolved species, because colloids may have little retardation and may be preferentially transported in the center of channels where velocities are greater.

Reference

Trauth, K.M., S.C. Hora, R.P. Rechard, and D.R. Anderson. 1992. *The Use of Expert Judgment to Quantify Uncertainty in Solubility and Sorption Parameters for Waste Isolation Pilot Plant Performance Assessment.* SAND92-0479. Albuquerque, NM: Sandia National Laboratories.

Comment T020

Page 5: I. Technical Comments, A. General, Room Closure -vs- Constant Pore Space

Area in document Volume 2, Chapter 7, Page 7-8, Line 13

"If the 'total pore space ... is constant' then room closure (creep compression is not taken into account. However, it is stated on page (7-5) Line 25 room closure is accounted for 'in an indirect way'. This appears to be inconsistent. If you have closure the pore space must decrease. The model appears to be deficient on this point."

Response

The statements referring to constant volume and constant porosity in Volume 2 page 7-7, lines 20 to 24 refer to how the repository was conceptualized prior to 1992. In 1992 the porosity and volume in a disposal room varied in time according to the SANCHO predicted consolidation results, as described in Volume 2, page 7-5.

Comment T021

Page 5: I. Technical Comments, A. General, Boundary Conditions

Area in document Volume 2, Chapter 7, Page 7-16

"How are values transferred between the regional and the local grids? What is the data/information loss across these boundaries?"

Response

The data between regional and the local grids is transferred by interpolation of heads using either bilinear or integral-preserving (Dukowitz) interpolation. For a locally linear variation of head in the regional grid, no information is lost, neither on heads, gradients, nor fluxes. The motivation for the regional and local grid domain decomposition is to provide improved far-field boundary conditions for the local grid. The compatibility of the interpolation

procedure is demonstrated by overlaid contour plots of head, gradients, and fluxes obtained from both regional and local grids.

Comment T022

Page 5: I. Technical Comments, A. General, Boundary Conditions

Area in document Volume 2, Chapter 7, Page 7-16

"What source (e.g., data and investigator judgment) is used to establish the initial boundary conditions in DOE's modeling efforts?"

Response

The specification of boundary conditions is discussed on page 7-16 in general terms. The sources of boundary condition information for the regional groundwater flow domain are described in more detail in Volume 4, page 6-9 through 6-11.

Comment T023

Page 5: I. Technical Comments, A. General, Boundary Conditions

Area in document Volume 2, Chapter 7, Page 7-16

"How are the initial boundary conditions peer reviewed?"

Response

There was no formal review limited only to model boundary conditions. Boundary conditions are discussed on page 7-16 only in general terms. Specific boundary conditions for the regional groundwater flow domain are in Volume 4 of the 1992 PA, pages 6-9 through 6-11. Boundary conditions received the same peer review as other aspects of the 1992 PA: internal reviews were performed prior to publication by coauthors and coworkers, by formal SNL technical reviewers, by the Performance Assessment Peer Review Panel, and by SNL and DOE management.

Comment T024

Page 5: I. Technical Comments, A. General, Categories of Distributions and Parameter Selection

Area in document Volume 1, Chapter 4, Page 4-13; Volume 3, Chapter 1, Page 1-7; Volume 3, Chapter 2, Page 2-11

"The PA discusses categories of distributions for different parameter types: continuous, discrete, constructed based on experiments, constructed based on expert judgement, and miscellaneous categories."

"The process used to select a distribution for each parameter needs to be discussed. How is a distribution chosen for a particular set of parameters?"

Response

For more detailed discussions of the ways in which distributions of uncertain parameters were constructed in the 1990, 1991 and 1992 PAs, see Tierney (1990, in particular, Figure E-1) and Tierney (1994).

References

Tierney, M.S. 1990. *Constructing Probability Distributions of Uncertain Variables in the Models of the Performance of the Waste Isolation Pilot Plant (WIPP)*. SAND90-2510. Albuquerque, NM: Sandia National Laboratories.

Tierney, M.S. 1994. "Using Data and Information to Form Distributions of Model Parameters in Stochastic Simulations of Performance of the Waste Isolation Pilot Plant (WIPP)", *Proceedings of PSAM-II, San Diego, California, U.S.A., March 20-25, 1994.* 051-9 to 051-16.

Comment T025

Page 5: I. Technical Comments, A. General, Categories of Distributions and Parameter Selection

Area in document Volume 1, Chapter 4, Page 4-13, Volume 3, Chapter 1, Page 1-7, Volume 3, Chapter 2, Page 2-11

"How representative are these distributions of actual data?"

Response

Of the distributions of the 49 parameters sampled for human intrusion analyses in the 1992 PA (Volume 3): five were histograms of actual field measurements; three were distributions inferred from actual measurements (e.g., Culebra transmissivities); 18 were constructed by formal elicitation of expert opinion, which may indirectly be linked to data; and the remainder (23) were constructed on the basis of informal expert judgment using the five-step procedure described in Figure E-1 of Tierney (1990). It is not known at this time how well subjectively determined distributions reflect the true uncertainty in a model parameter or how well these distributions represent actual WIPP-specific conditions.

Reference

Tierney, M.S. 1990. *Constructing Probability Distributions of Uncertain Variables in the Models of the Performance of the Waste Isolation Pilot Plant (WIPP)*. SAND90-2510. Albuquerque, NM: Sandia National Laboratories.

Comment T026

Page 5-6: I. Technical Comments, A. General, Categories of Distributions and Parameter Selection

Area in document Volume 1, Chapter 4, Page 4-13, Volume 3, Chapter 1, Page 1-7, Volume 3, Chapter 2, Page 2-11

"The constructed distribution type should differentiate between values derived from measurements and those derived from expert judgement."

"How were the input parameters chosen? How many are there, and how many are variable? Which ones are important?"

Response

In theory, expert judgment is founded in measurements and other data collection activities albeit not necessarily WIPP specific. Consequently, to use the general rule indicated here may not be reasonable. Instead, some rationale should be provided for the combination of the two sources of parameter values.

Input parameters are dictated by the nature of the mathematical models used in the PA (see Section 1.4 of Volume 3). There were nearly 400 input parameters in the 1992 PA; 49 of them were treated as uncertain (variable) for the purposes of sensitivity/uncertainty analyses for human intrusion analyses (see sections 6.1 and 6.2 of Volume 3). The most sensitive

(important?) parameters in the 1992 PA are described in Table 9-3 of Volume 4, and Table 6-1 of Volume 5.

Comment T027

Page 6: I. Technical Comments, A. General, Assignment of Probability Distributions

Area in document Volume 3, Chapter 1, Page 1-18, Line 37

"Very general procedures are described for assigning probability distributions, but these procedures are incomplete and do not answer critical questions."

"Please clarify the review process used for assigning probability distributions? How do you determine confidence in the probabilities?"

"What are the constructed distributions and which does DOE expect will be replaced by data? (Volume 2, page 6-4)."

Response

The "replacement of constructed distributions by data" is an activity that will be considered for inclusion in the SPM, i.e., the addition of experimental data where required to support a compliance application.

The review process used to assign probability distributions in the 1992 PA is briefly described in Section 1.3.1 of Volume 3; evidence of the implementation of this process is shown in the many memos of Appendix A of the latter document. All parameters used in the 1992 PA were classified as "X" among the three quality-assurance categories of ascending confidence, X, C, and A. To be classified as "C", a parameter would have to have documentation of the line of reasoning that established its distribution and the sources of any data used in constructing the distribution. An "A" class parameter must also have received a documented peer review.

Constructed distributions are explained on page 1-10 of Volume 3. This category of distributions is characterized by direct use of data to form an empirical cumulative distribution function; the "data" may be measurements of real quantities or the set of percentiles obtained from an elicitation of subjective opinion. Ideally, all constructed distributions would be based on real measurements; however, the Project must focus on sensitive parameters.

Additional detail on the construction and use of distributions will be included in the final compliance application.

Comment T028

Page 6; I. Technical Comments, A. General, Heterogeneous Reservoirs

Area in document Volume 3, Chapter 1, Page 1-21 - Line 60

"What is meant by 'reservoirs' in the context of the BRAGFLO model?"

Response

The term reservoir is used in the context of formation, host rock, and porous media, etc., not in the context of brine reservoir per se. The predecessor to BRAGFLO was a multi-phase flow code used in the petroleum field -- thus the use of the term 'oil reservoir' or 'reservoir' model.

Comment T029

Page 6: I. Technical Comments, A. General, Brine Reservoirs

Area in document Volume 3, Chapter 1, Page 1-30, Line 15

"Why is the 'sample intensity function' multiplied by the 'fraction of the repository area that is underlain by brine reservoirs'?"

Response

This question arises in the context of the brief description of the model for computing computational scenario probabilities given in Section 1.4.2 of Volume 3. A more thorough treatment of the same subject, models used to compute human-intrusion probabilities for different summary scenarios, is given in Section 5.2 of Volume 2; the answer to the present question is given by lines 10 thru 28 of page 5-4, including Equation (5-13), in the latter reference.

The cited text is simply an example being given wherein the fraction of repository area underlain by brine reservoirs is of interest for a particular intrusion event, E1 (E1 is an event in which one or more boreholes pass through a waste panel and into a brine reservoir).

Comment T030

Page 6: I. Technical Comments, A. General, Viscosity

Area in document Volume 3, Chapter 1, Page 1-34, Line 9

"DOE states that 'viscosity measurements for an oil-based, 1.7 - kg/m^3 mud'. Why would an oil-based mud be used to drill through the Salado Salt Beds instead of a high-salt water-based mud?"

Response

A high-salt, water based mud is assumed to be the drilling mud used when drilling through the Salado. The Oldroyd model requires a value for the ratio of the initial viscosity (at zero shear rate) to the plastic viscosity, to fully define the model in the low shear regime. This ratio was not available for a high-salt, water-based mud in 1992 so a ratio based on an oil based mud was chosen. Since high shear rates occur at the borehole wall the value chosen for the ratio was expected to have little impact on the final model diameter. The Project is evaluating the sensitivity of eroded diameter to this issue.

Comment T031

Page 7: I. Technical Comments, A. General, "Dual Porosity" Model

Area in document Volume 3, Chapter 1, Page 3-39, Line 1

"The way the 'dual porosity' model is described generates confusion. Does the model really allow diffusion through the rock matrix?"

Response

Yes, the PA's dual porosity model allows diffusion through the rock matrix. In this transport model fluid only flows (advects) along fractures. In this way, solutes (i.e., dissolved actinides) are advectively transported in the fracture void volume and diffuse into the much larger matrix void volume. The SECOTP transport code numerically simulates the diffusion process with a mass transfer term. This term incorporates the free water molecular diffusion of each solute, the tortuosity of the matrix, and the solute concentration gradient between the fractures and the matrix.

References

Jones, T.L., V.A. Kelley, J.F. Pickens, D.T. Upton, R.L. Beauheim, and P.B. Davies. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra*

Dolomite at the Waste Isolation Pilot Plant Site. SAND92-1579. Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L., and P.B. Davies. 1992. *Experimental Plan for Tracer Testing in the Culebra Dolomite at the WIPP Site.* Revision A. Albuquerque, NM: Sandia National Laboratories.

Comment T032

Page 7: I. Technical Comments, A. General, "Dual Porosity" Model

Area in document Volume 3, Chapter 1, Page 1-39, Line 1

"How does the flow model (SECO2D) compare with laboratory results? Is it verifiable?"

Response

Results from the SECO2D code have not been compared to laboratory results. This code is designed to simulate flow that occurs at a scale that is larger than what could be represented in a laboratory experiment. The SECO2D flow code solves the partial differential flow equation for heads in a 2D, confined, heterogeneous aquifer that obeys Darcy's Law. The flow code has been benchmarked, tested and verified for freedom from coding errors, order of convergence, and discretization consistency (Roache et al., 1990).

Reference

Roache, P., P.M. Knupp, S. Steinberg, and R.L. Blaine. 1990. "Experience with Benchmark Test Cases for Groundwater Flow," *Forum on Benchmark Test Cases for Computational Fluid Dynamics, ASME Fluid Engineering Division Spring Conference, Toronto, Ontario, Canada., June 4-7, 1990.*

Comment T033

Page 7: I. Technical Comments, A. General, Base of Anhydrite III

Area in document Volume 3, Chapter 2, Page 2-4, Line 14

"If the base of the Anhydrite III is so important it would seem more accurate, to create a regional contour map of the base of the Anhydrite III. The North-South geologic cross-section may not account for all unknowns."

Response

The point is well taken. The exact elevation of the base of Anhydrite III beneath the WIPP is not well constrained. Well data are not available for the region immediately beneath the panels. Other methods, including the construction of regional contour maps on the base of the unit could have been used to estimate its elevation. Regional dips are small, however, and the uncertainty introduced locally by a limited stratigraphic data base may be small compared to the uncertainty in the interpretation of the depth to the conducting layer and the interpretation of the conducting layer as brine (see page 5-2 and following text in Volume 3 of the 1992 PA).

Comment T034

Page 7: I. Technical Comments, A. General, Top of Bell Canyon

Area in document Volume 3, Chapter 2, Page 2-10

"A more accurate value for the Top of Bell Canyon can be found by the method outlined in the comment for the Base of Anhydrite III (above)."

Response

The point is valid. The exact elevation of the top of the Bell Canyon Formation beneath the WIPP is not well constrained. Well data are not available for the region beneath the panels. Other methods, including the construction of regional contour maps on the base of the unit, could have been used to estimate its elevation. As seen in well and seismic data, however, regional dips are small, and the uncertainty introduced by limited stratigraphic control may be small compared to the uncertainty in the interpretation of the depth to the conducting layer and the interpretation of the conducting layer as brine (see page 5-2 and following text in Volume 3 of the 1992 PA).

Comment T035

Page 7: I. Technical Comments, A. General, Natural-Analog Data

Area in document Vol 3, Chapter 2, Page 2-12

"It would seem using parameters of sandstones and substituting them for salt is inappropriate because the stress characteristics, the permeability and the porosities are quite different. The performance of salt does not compare to sandstone."

Response

Two-phase characteristics of salt (capillary pressure, relative permeability) have not been measured experimentally for WIPP-specific materials. Very little research has been done on the two-phase properties of very low permeability rock. A search failed to produce data and/or curves that are directly applicable to WIPP. Therefore, an approximate analog approach was taken, based on the lowest permeability rock for which capillary pressure and relative permeability data have actually been measured. A tight gas sand core (Sample MWX 67-35) from the multi-well experiment (Morrow et al., 1986) was selected as the best analog material. This sample is a fine-grained sandstone with bedding and 12 percent porosity. The dominant pore geometry consists of intergranular cracks between abutting quartz grains and solution pores partially filled with dolomite. The permeability of this sample to brine is 43 microdarcies ($\sim 43. \times 10^{-18}$ m^2) at 3.4 MPa confining pressure and 24 microdarcies ($\sim 24. \times 10^{-18}$ m^2) at 34 MPa confining pressure. Based on these results, and a study of threshold pressure (Davies, 1991), two-phase flow in pure or impure halite units is not anticipated. Two-phase flow is confined to the various anhydrite marker beds within the Salado Formation, making the selection of two-phase properties in the halite units (except for threshold pressure) unimportant.

References

Morrow, N.R., J.S. Ward, and K.R. Brower. 1986. "Rock Matrix and Fracture Analysis of Flow in Western Tight Gas Sands," *1985 Annual Report, New Mexico Institute of Mining and Technology*. DOE/MC/21179-2032.

Davies, P.B. 1991. *Evaluation of the Role of Threshold Pressure in Controlling Flow of Waste-Generated Gas into Bedded Salt of the Waste Isolation Pilot Plant*. SAND90-3246. Albuquerque, NM: Sandia National Laboratories.

Comment T036

Page 8: I. Technical Comments, A. General, Lack of Halite and Polyhalite Chemical Interaction

Area in document Volume 3, Chapter 2, Page 2-28, Line 42.

"What justification or data is there to support the comment that 'halite and polyhalite ... are assumed ... not to interact chemically with any contaminants'? This is a very important assumption."

Response

This statement is misleading. The statement should say that the salts have limited sorption potential, and therefore do not provide a significant retardation mechanism. A conservative assumption of 0 for the partition coefficient is used.

Comment T037

Page 8: I. Technical Comments, A. General, Radionuclides for Transport Modeling

Area in document Volume 3, Chapter 3, Page 3-29, Line 31

"Why were only nine radionuclides considered in the 1992 PA transport calculations (and solubility estimates) for CH-TRU waste? This needs to be more clearly explained."

Response

The answer can be found in Section 7.3 of Volume 4 of the 1992 PA. Figure 7.3-1 (page 7-12 of Volume 4) shows plots of radionuclide inventory through time in normalized EPA units. With the exception of Pu-238, only those radionuclides that exist at 1,000 years or later in activities greater than 10^{-2} EPA units were included in transport modeling. The reason for excluding the others is straightforward: they cannot contribute to exceeding regulatory limits even if their entire inventory is released. Pu-238 was omitted from groundwater transport calculations in error and will be included in future analyses—it is a major factor in total inventory before 1,000 years, but rapidly drops out of the inventory after 1,000 years. However, for the fracture-only transport model travel times are sufficiently short that some Pu-238 could reach the accessible environment boundary. The effect on fracture-only transport releases could be significant for intrusions occurring before 1,000 years.

Note that the use of the cutoff of 10^{-2} EPA units is cautious; the total release limit is 1 EPA unit.

Note also that a total of 23 radionuclides were included in cuttings releases, allowing for the full consideration of short-lived species in the cuttings releases.

See Appendix D of Volume 4 for memoranda describing the use of this reasoning in designing actinide and transport experimental programs.

Comment T038

I. Technical Comments, A. General, Excavated Area Underlain by Brine Reservoir

Area in document Volume 3, Chapter 5, Pages 5-2 to 5-11

(a) "What is the accuracy of Transient Electromagnetic Methods? The depth precision 'may be ± 75 m,' but what about the accuracy of the process itself to 'see' fluids? Electromagnetic (EM) methods tend to be gross estimators at best. Why was the data not extended to the ERDA-9 borehole to calibrate the measurements?"

(b) "Has DOE investigated the use of a High-Frequency Three-Dimensional (3D) Common Depth-Point Seismic Survey over the WIPP disposal panels with extended coverage of one-half mile around the panels? The survey should include the ERDA-9 borehole as a reality check. If these pressurized brine reservoirs are associated with anticlinal structures in the upper anhydrite layer then a 3D Survey will clearly, with high confidence, define even a small closure at this depth."

Response

We believe that the geophysical studies are complete and adequately documented. At present, we believe that the resistivity characterization of possible brine distribution beneath the waste panels has provided information to a level of detail exceeding that provided by on-site/near-site stratigraphic data presently available. However, we believe that the assumption that any conductor identified within the Castile is due to the presence of brine is reasonably conservative for purposes of PA.

The Project has investigated and resolved these issues as follows:

1. The validation (accuracy) of the transient electromagnetic method to detect brine was done at the same time as the panel survey by running the same survey over the WIPP-12 area (brine reservoir present known from drilling) and the DOE-1 area (brine reservoirs absent known from drilling) (Reference SAND87-7144, p. 14, Fig. 3-8). Additional validation work with several methods was done prior to the panel survey using the known brine reservoir at WIPP-12 and an artificial target placed in the underground WIPP facility. ERDA-9 was not drilled deep enough into the Castile for most brine occurrences. However, the results of the dual-induction log of hole ERDA-9 was used directly to constrain the resistivity of brine-free Salado/Castile halites and anhydrites.

2. Seismic methods were not the method of choice for brine reservoir delineation after the Project's experience with the original seismic reflection lines for several reasons: a) While seismic studies delineate deformed areas within the Castile (called deformation zone, DZ, in Borns and others, 1993), not all anticlines contain brine reservoirs. Drillholes, such as WIPP-12, in areas of moderately deformed Castile, as well as

drillholes in severely deformed Castile both encounter brine and; b) Lateral velocity structures produce false anticlines. In 1982, drillhole DOE-1 was drilled into an apparent anticline that was based on the seismic surveys. This structure was nonexistent, and the original interpretation was due to the lateral velocity variations; c) it has proven difficult to propagate high frequency signals in the portion of the basin; d) brine reservoirs are characterized by a low fracture porosity (1%), which does not result in a change in velocity much above background variation in velocity. The contrast between the resistivity of a brine reservoir (1 ohm-m) and the background anhydrite (100 - 1000 ohm-m) is significant. Several early Project conclusions were that (1) seismic methods alone are not sufficient to answer whether brine reservoirs are under the site and (2) gravity methods were not effective in mapping deformation.

Considerable development and review went into the selection of methods. Specifically for the brine reservoirs in the early 1980s, WIPP began to study methods based on the measurement of electrical conductivity or resistivity (for example, Controlled Source Audio Magneto Telluric--CSAMT and charged body--mis-a-la-masse) (Elliot, 1982). The basic assumption is that the brine-charged fractures of a brine reservoir will represent a significant conductivity contrast within the Castile. CSAMT was the method most extensively tried at WIPP during this period (Bartel and others, 1983) to delineate the brine reservoirs in the Castile. The EEG sponsored review of the Sandia program for delineating brine reservoirs and the CSAMT method by J. Waite (U or A) and Peter Hoekstra (Geophysicon). This review suggested that WIPP consider other electromagnetic methods specifically the transient electromagnetic method (TEM) a.k.a. time domain electromagnetic methods (TDEM). In 1985, SNL conducted validation surveys in an area around a known brine occurrence (WIPP 12) using several methods (CSAMT, TEM, and Frequency Domain Electromagnetic methods [FEM]) with the Colorado School of Mines and Phoenix Geophysics. Some of the surveys also delineated an artificial target placed in the WIPP underground. Analyses of survey results concur with EEG review recommendations that transient (or time-domain) electromagnetic methods are best suited for delineation of brine reservoirs at the WIPP site.

Comment T039

Page 8: I. Technical Comments, A. General, Organic Containers

Area in document Volume 3, Chapter 3, Page 3-9

"The text on page 3-9 [of Volume 3] states that containers are 55 gallon drums or SWBs, yet on page 4-11 [of Volume 2] it states that some 'waste containers' will be composed of organic material. Please explain this discrepancy."

Response

This is an editorial error: The words "and some waste containers" should be deleted in lines 11-12 on page 4-11 (Volume 2) .

Comment T040

Page 9: I. Technical Comments, A. General Comments, Ideal Gas Law

Area in document Volume 2, Chapter 2, Page 2-34

"How valid is the use of the ideal gas law at lithostatic or hydrostatic pressures? How sensitive a parameter is it? Assumptions of this nature should be explained and justified."

Response

A set of comparative calculations were made using the ideal gas law and several non-ideal equations of state. These calculations showed very little variation in the calculated properties (< 10%). This amount of uncertainty has very little effect on PA calculations, since other sources of uncertainty are much more important.

Comment T041

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, Line 13

"The screening process described in detail in the 1991 documentation should be included in the EPA PA."

Response

The 1992 PA was not intended to be interpreted as a compliance application. Additional material will be included as needed in the compliance application.

Comment T042

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, Line 13

"The possibility of nuclear criticality should be investigated further before it is screened out."

Response

The DOE has initiated further evaluation of nuclear criticality.

Comment T043

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, Line 13

"How will the changes in the repromulgated 40 CFR 191 effect the scenarios that are included?"

Response

This question is still under evaluation. No changes in scenarios specific to the repromulgation of 191.15 and Subpart C are identified at this time. Clearly, the time interval that must be considered for 191.15 and Subpart C has changed. However, 10,000 yr undisturbed performance was already included in the scenario development process as the base case for 191.13.

Comment T044

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, Line 13

"How are scenario uncertainties propagated through the analyses; if scenario uncertainties were included in the screening process, would more scenarios be included?"

Response

As discussed in Chapter 4 of Volume 2, Section 4.2, scenarios are constructed from the events and processes that may affect the system in the future. Uncertainties about these

events and processes are explicitly considered in the screening process. Those events and processes that survive the screening process (based on the criteria discussed in the previous section of Chapter 4 of Volume 2) are used to construct the scenarios for consideration. Uncertainty about the occurrence of those events is reflected in the estimation of the probability of their occurrence, which in turn is reflected in the estimation of scenario probabilities.

Comment T045

Page 9: I. Technical Comments, A. General, Screening Process

Area in document Volume 1, Chapter 4, Page 4-2, 4-19

"DOE says that the 'effect of subsidence of potash mining will be added in future PAs'. How is the WIPP site influenced by potash mining and its associated water use? When will the effect of subsidence due to potash mining be added?"

"The mining scenario should consider mining in the potash zone in the controlled area, but above the repository."

Response

The text in question has been paraphrased, rather than quoted exactly, in the comment. The relevant phrase occurs on line 21, and states "...the impact of subsidence events will be examined in future analyses." A decision to add consequence modeling of subsidence effects to the full PA cannot be made until these analyses are available. As noted elsewhere in this volume, "consequences of such potash mining ... will be addressed in future analyses when a three-dimensional model for regional groundwater flow is available" (Volume 1, page 3-11, lines 16-19; see also page 6-3, lines 19-22). A three-dimensional flow model is now operational and ready for preliminary analyses.

As discussed in the event and process screening text in Volume 1 of the 1991 PA (SAND91-0893/1, page 4-35, lines 7-13), subsidence over mines has the potential to affect regional groundwater flow both by creating catchment basins at the surface (changing recharge) and by fracturing hydrostratigraphic units (altering hydraulic conductivity).

The final point here, that mining should be considered within the controlled area, is a point of regulatory interpretation. The wording of Appendix C of 40 CFR 191 indicates that systematic exploitation can be effectively deferred by controls. Mining is such a systematic process and does not occur inadvertently and intermittently.

Comment T046

Page 10: I. Technical Comments, A. General, Probabilities

Area in document Volume 1, Chapter 4, Page 4-2

"How are the probabilities used in the cutoff comparison found, calculated, etc. This explanation should be within the PA."

Response

As the text on page 4-2 of Volume 1 notes, this information is summarized in Chapter 4 of Volume 2 and described in detail in Volume 1 of the 1991 PA (SAND91-0893).

Comment T047

Page 10: I. Technical Comments, A. General, Probabilities

Area in document Volume 1, Chapter 4, Page 4-2

"What are the expected probabilities for each scenario? They should be stated on the same page as the event tree or on the event tree."

Response

The event tree displays summary scenarios, as described in more detail in Section 3.2.2 of Volume 2. These summary scenarios are further subdivided into computational scenarios on the basis of time and number of intrusions, as discussed in detail in Chapter 2 of Volume 4 of the 1992 PA. Probabilities estimated using the Poisson model for intrusion are assigned to computational scenarios, rather than to the summary scenarios, and therefore cannot be displayed on Figure 4-1 as requested. Probabilities for selected computational scenarios are given in table form in Chapter 2 of Volume 4 for specific values of the Poisson rate constant.

Comment T048

Page 10: I. Technical Comments, A. General, Base Case Explanation

Area in document Volume 1, Chapter 4, Page 4-2, Line 40

"All of the events placed in the 'base case' need to be described in detail with an explanation of how the event probability was developed and provide justification for placing these scenarios in the base case."

Response

As discussed in more detail in Volume 2 and in Volume 1 of the 1991 PA (SAND91-0893), all events placed in the base case were assigned a probability of 1. In compliance documentation, a rationale for the assignment of probabilities will be given.

Comment T049

Page 10: I. Technical Comments, A. General, Nearby Boreholes as Communication Pathways

Area in document Volume 1, Page 4-4; Volume 2, Page 2-16

"Have you considered transport to and through boreholes that don't hit the repository, but which could increase the transport of radionuclides?"

"Would current and future boreholes alter the vertical flow regime between units? (Volume 2, page 2-30)"

"Is it possible for the high drilling density around the WIPP site to cause salt dissolution much like in oil and gas fields in Pecos County, Texas? Should this scenario be considered?"

Response

The issue of the consequences of "near misses" potentially affects the compliance analysis and will be reexamined and evaluated. Rates of brine flow from the repository to a "near miss" were examined quantitatively in 1991 in response to comments by the EEG on the 1990 PA. Results of these analyses are reported in pages B-18 through B-26 of Volume 1 of the 1991 PA (SAND91-0893/1). For the assumptions of these analyses (including no lateral development of the DRZ), flow rates were shown to decrease more than two orders of magnitude 0.25 m from the waste. Flow was decreased further at greater distances. Based on these analyses, PA concluded that radionuclide releases up a borehole that directly penetrated the waste would be greater than those from a "near miss."

The Project is currently investigating the issue of existing and future boreholes that could alter the vertical flow regime. Three-dimensional regional flow modeling is in progress to permit evaluation of possible consequences.

The Project has already investigated and resolved the issue of dissolution of salt by oil field drilling and work is complete. Dissolution of salt by oil field drilling has been considered quantitatively in the past by the WIPP Project (see Christensen et al., 1983), although not on the scale proposed here. Previous work has indicated that dissolution by freshwater flowing

through a single well does not pose a threat to the WIPP. Possible effects of high-density drilling outside the controlled area can be evaluated for inclusion in the system prioritization. High-density drilling within the controlled area constitutes an intrusion scenario more severe than "inadvertent and intermittent...exploratory drilling."

Reference

Christensen, C.L., C.W. Gulick, and S.J. Lambert. 1983. *Sealing Concepts for the Waste Isolation Pilot Plant (WIPP) Site.* SAND81-2195. Albuquerque, NM: Sandia National Laboratories.

Comment T050

Page 10: Section: I. Technical Comments, A. General, Thermal Effect of Pu-238

Area in document General

"Has the thermal effect of Pu-238 been taken into account in PA Analyses? What would its effect be?"

Response

It is assumed that the comment refers to the thermal load of radioactive waste. Justification for ignoring radioactive induced thermal effects is given in Butcher and Mendenhall (1993, Section 3.7, page 3-26).

In addition, the Performance Assessment Department looked into this issue and concluded a maximum temperature rise of 2° C in the repository falling to 1° C after 80 years (Volume 1, page 4-50 of the 1991 PA [SAND91-0893/1]).

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B.* SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T051

Page 11: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

"...at issue is the behavior of the clay (bentonite) units "sandwiched" between concrete plugs."

Response

In the reference seal design report (Nowak et al., 1990), the reasons for using swelling clay components are summarized and references to more detailed discussions are provided. In response to the specific questions regarding the clay, it is believed that the clay units may become fully saturated. Clay is not likely to intrude into all exposed fractures and voids although it is obvious that flow through many of these will be limited by the clay. It is intended that the swelling pressure will be controlled (via the initial density of the material) to preclude significant, deleterious fracturing due to the swelling.

Reference

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant*. SAND90-0355. Albuquerque, NM: Sandia National Laboratories.

Comment T052

Page 11: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

(Paraphrase) Numerous specific questions are offered related to the removal of shaft liners. The essence of the questions is captured by: Is it necessary to remove the liner? Can this be done safely? What are the consequences?

Response

The question of whether or not to remove the shaft liners (or portions of them) remains an active question within the WIPP sealing program. It is clear that if the liners need to be removed in order to assure effective seals, they can and will be removed. Safe removal of portions of shaft liners has been accomplished in the Carlsbad area in nearby potash mine shafts. Only small amounts of water inflow have been encountered during construction operations and drilling operations conducted in the WIPP shafts. Design and performance

considerations for the WIPP shaft seals generally stress reliance upon the components placed within the Salado formation below the current shaft liner and key; if the final designs maintain this reliance, it may not be necessary to remove any significant portions of the existing liners. Detailed design descriptions to be included in compliance documentation will describe whether or not removal is intended and (if needed) procedures for the safe removal of this material.

Comment T053

Page 11-12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

"Compaction details have not been provided which may further impact on the method in which the backfill is emplaced and the effectiveness of the backfill as a seal."

Response

This is an ongoing area of significant effort. While the Small-Scale Seal Test Program in Test Series C and D have provided (see summary in Finley and Tillerson [1992]) an indication that an initial relative density of about 80% can be achieved, additional demonstrations are planned to determine if a relative density of at least 85% can be achieved. These additional demonstrations are part of the planned Large-Scale Seal Tests proposed for the WIPP. Results of the demonstrations are intended to be part of the compliance documentation.

Reference

Finley, R.E., and J.R. Tillerson. 1992. *WIPP Small Scale Seal Performance Tests - Status and Impacts*. SAND91-2247. Albuquerque, NM: Sandia National Laboratories.

Comment T054

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

"Small amounts of water are considered beneficial in the consolidation of the salt backfill (St 88), but the effects of channelling on individual blocks of salt is uncertain. Channelling of water from upper aquifers seems more likely than a uniform dispersion throughout the backfill. This potential problem needs to be addressed in the PA.

Response

At the present time, efforts are focusing on evaluating methods for in-place compaction of crushed salt. The use of salt blocks is at present considered a backup technology. If in-place compaction of the crushed salt is successful, there will be no reason to do further evaluation of the behavior of blocks. On the other hand, if the use of precompacted blocks of crushed salt becomes the preferred technology, evaluations of phenomena such as this will be completed.

Comment T055

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document General

"...to insure conformance with the circular shaft walls, blocks must be specially milled and placed. No estimate to the amount of time required to fill each shaft by carefully placing blocks has been provided. Such information is necessary to establish the practicality of the approach."

Response

If blocks are to be used in the shafts as part of the sealing approach, there is no question but that the practicality of their emplacement must be established. In the Small-Scale Seal Performance tests, the feasibility of making and emplacing blocks was demonstrated. At the present time however, efforts are focusing on evaluating methods for in-place compaction of crushed salt. If this technology can be demonstrated to achieve the desired degree of compaction, it offers advantages related to cost and safety. Demonstration tests are currently being planned which will evaluate the degree of compaction that can be achieved. If in-place compaction of the crushed salt is successful, there will be no reason to further evaluate the behavior of blocks. On the other hand, if the use of precompacted blocks of crushed salt becomes the preferred technology, evaluations of the practicality of full-scale placement of blocks will be initiated. Because of the planned sequence of evaluations, the use of salt blocks is at present considered a backup technology and very little resources are being expended to evaluate phenomena specific to this technology.

Comment T056

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 1, Page 5-20

"It is stated that the repository will use bentonite and crushed-salt backfill as a barrier in waste emplacement panels. Isn't it more correct to say that SNL has recommended this backfill but that DOE has made no commitment to use it?"

Response

The EPA suggested statement is correct. SAND90-3074 discusses the scientific aspects of crushed salt/bentonite backfill but no determination has yet been made. Backfill will be considered in the SPM.

Reference

Butcher, B. M.,1991, *The Advantages of Salt/Bentonite Backfill for the WIPP Disposal Rooms*, SAND90-3074, Albuquerque, NM: Sandia National Laboratories.

Comment T057

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Page 2-48

(Restatement) What data are there to support the assumed long-term permeabilities in the shaft seals?

Response

Numerous laboratory studies have been completed which document the permeability of compacted, crushed salt samples. These data are summarized in Figure 4 of Hansen et al. (1993). The relationship is shown between the permeability of the crushed salt samples and the relative/fractional density of the sample. This paper also references the numerous reports in which the data were first documented. In addition, the small-scale seals and the thermal-structural interaction tests are providing some useful information regarding the transfer of the lab studies and analysis results to field situations.

Reference

Hansen, F.D., G.D. Callahan, and L.L. Van Sambeek. 1993. "Reconsolidation of Salt as Applied to Permanent Seals for the Waste Isolation Pilot Plant," *3rd Conference on the Mechanical Behavior of Salt, September 14-16, 1993, Ecole Polytechnique, 91129 Palaiseau, Cedex-France.*

Comment T058

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Page 2-48

"What is the likelihood that the panel and shaft seals will be able to prevent migration through MB-139, both under the excavation and away from the excavation in the Disturbed Rock Zone?"

Response

The shaft seals are not designed to prevent lateral migration through MB-139: flow up the shafts from MB-139 would be very limited by the combination of short and long term components included in the shaft system.

The sealing concepts for the WIPP panel seals (see Nowak et al. [1990]) include provisions for grouting of the Marker Beds or the DRZ in the halite as necessary to limit flow. Effective placement of grout into Marker Bed 139 has been part of the technology development activities performed under the direction of Sandia National Laboratories. Specifically, as indicated in the test plan for the Small-Scale Seal Performance Test-Series F (Ahrens, 1992), this underground test at the WIPP was "intended to demonstrate equipment and techniques for producing, injecting, and evaluating microfine cementitious grout." The grouting was completed in March, 1993, and the final report is currently being prepared.

From the standpoint of long-term performance of the disposal system, the sealing of the marker bed in the immediate vicinity of the waste rooms is of little consequence since virgin conditions will exist within the near vicinity of the excavation. It is these virgin conditions that provide the robust natural barrier to contaminant transport. The project is currently evaluating the advantages of sealing these units, however, from an operational standpoint.

References

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant.* SAND90-0355. Albuquerque, NM: Sandia National Laboratories.

Ahrens, Ernst H. 1992. *Test Plan - Sealing of the Disturbed Rock Zone (DRZ), Including Marker Bed 139 (MB139) and the Overlying Halite, Below the Repository Horizon, at the Waste Isolation Pilot Plant - Small-Scale Seal Performance Test - Series F.* Albuquerque, NM: Sandia National Laboratories.

Comment T059

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Pages 2-48 and 2-50

"It is correctly stated that the current backfill design (which is used in the 1992 PA calculations) is "pure, unconsolidated crushed salt with a relatively high permeability that provides little resistance to fluid flow." Salt and bentonite backfill have been studied and said to be available if needed. However, the PA has not yet reported any analyses to indicate the benefits this mixture might provide."

Response

The backfill condition stated here was a PA assumption for the 1992 calculations. In actuality, the backfill is expected to rapidly consolidate to a dense, low permeable state as described in Butcher (1991, Figure 4-4, page 28).

Optimization analyses have not been performed. Preliminary sensitivity analyses showing the potential benefits of reducing porosity and permeability within the waste-disposal area were performed using the 1989 PA modeling system and reported in Bertram-Howery and Swift (1990).

References

Butcher, B.M. 1991. *The Advantages of a Salt/Bentonite Backfill for Waste Isolation Pilot Plant Disposal Rooms.* SAND90-3074. Albuquerque, NM: Sandia National Laboratories.

Bertram-Howery, S.G., and P.N. Swift. 1990. *Status Report: Potential for Long-Term Isolation by the Waste Isolation Pilot Plant Disposal System.* SAND90-0616. Albuquerque, NM: Sandia National Laboratories.

Comment T060

Page 12: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Pages 2-48 and 2-50

"Neither have analyses been performed to determine the benefit of reducing the initial void space in the backfill."

Response

Analyses have not been performed, but backfill consolidation is estimated to occur so rapidly that reduction of the initial void space would correspond to accelerating closure by no more than 10 years. Crushed-salt porosities are estimated to decrease to less than 10% within 40 years. For this reason, control of initial emplacement density is considered unimportant, as discussed in Butcher and Mendenhall (1993, page 42).

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B.* SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T061

Page 12-13: I. Technical Comments, A. General, Shaft Seals and Salt Backfill

Area in document Volume 2, Pages 2-48 and 2-50

"The design of backfill is part of the engineered alternatives (engineered barriers) issue and evaluations of relative benefits should be included."

Response

Crushed salt backfill with additives is an engineered alternative that DOE will evaluate for consideration in the SPM. These will also be part of the engineered alternatives benefit/detriment study being performed by the DOE.

Comment T062

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 6-1, Line 9

"The statement that the PA Department has a high level of confidence, etc., is perhaps premature."

Response

The 1992 PA was not intended as a compliance application. The sentence in question does not say that the PA Department is confident that compliance has been demonstrated. Rather, the statement was made that PA Department is confident that "the WIPP will be able to comply with the quantitative requirements of the Standard...."

Comment T063

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 6-2, Lines 20-28

"More documentation is needed before it can be concluded 'that no radionuclides will reach the accessible environment from the undisturbed repository for 10,000 years.'"

Response

The 1992 PA was not intended to be a compliance application. More documentation will be provided in the compliance application. The Format and Content Guide provides a snapshot of the comprehensive nature of the application.

Comment T064

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Chapter 6, Page 6-2, Line 37-44

"Any conclusions about meeting the Groundwater Protection Requirements are premature since these requirements have been changed in the repromulgated standard."

Response

Conclusions for the 1992 PA were based on 40 CFR 191 as it existed at that time. All aspects of 40 CFR 191, including those portions repromulgated in December 1993, will be incorporated in future performance assessments. The specific conclusion about the ability to meet the Groundwater Protection Requirements depended only on the reported results (i.e., no releases to the accessible environment).

As was stated in the 1992 PA (Volume 1, Chapter 3, p. 3-23, l. 25-31), "One of the products of scenario development for the Containment Requirements is a base-case scenario for the WIPP that describes undisturbed conditions. The undisturbed performance of the repository is its design-basis behavior, including variations in that behavior resulting from uncertainties in the 10,000-year performance of natural and engineered barriers and excluding human intrusion and unlikely natural events, as defined in §191.12(p)." Thus, the 10,000 year issue has already been addressed for the undisturbed case, i.e., Groundwater Protection Requirements and Individual Protection Requirements. Future performance assessment calculations, if conducted similarly to those in 1992, will not cause a change in the conclusions since nothing has yet to be shown to be released from the disposal system for undisturbed performance. The results of any future performance assessment calculations conducted using different conceptual models, probability distributions, etc., will of course be evaluated for compliance with the Groundwater Protection Requirements.

The concentration limits for the Groundwater Protection Requirements have not changed between the 1985 and 1993 versions of 40 CFR 191. While not called such, the limits in the 1985 version were the Maximum Contaminant Levels (MCLs) from 40 CFR 141 (5 pCi/l for Ra-226 and Ra-228; 15 pCi/l for gross alpha particle activity; 4 mrem/yr for beta particles and photon radioactivity). Those MCLs have not been changed since, and are now officially incorporated into 40 CFR 191. The definition of the groundwater that is to be protected did change between the 1985 (special sources of groundwater) and 1993 (underground sources of drinking water) versions of 40 CFR 191. The revised definition may cause programmatic changes if DOE is required to identify all potential underground sources of drinking water. As stated in a paper recently presented at the Waste Management '94 conference (Trauth et al., 1994), we propose to determine when and if underground sources of drinking water should be identified and characterized (i.e., when such a characterization will provide pertinent information for a compliance application). Briefly, identification and characterization of USDWs should not be required if no radionuclide releases to the accessible environment are predicted for 10,000 years or if 10,000 year peak predicted releases to the accessible environment are less than or equal to the applicable Maximum Contaminant Levels (MCLs). USDWs along the pathway should be identified and characterized if peak predicted releases to the accessible environment for 10,000 years are greater than the MCLs.

Reference

Trauth, K.M., S.G, Bertram, and B. Bower. 1994. "Considerations for Guidance for Radioactive Waste Disposal Arising from Rules Under 40 CFR 191 and 40 CFR 194," *Proceedings of Waste Management '94 Conference, Tucson, AZ, February 27-March 3, 1994.*

Comment T065

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 8-2 (first paragraph)

"The following needs in performance assessment should be added to those mentioned:

(1) the determination of the extent that expert judgment should be used in PA and development of an acceptable procedure to incorporate this expert judgment into distributions in the various parameters;"

Response

The referenced page does not exist. The answer is given assuming the question refers to page 6-3 of Volume 1.

The concern is appropriate and the DOE looks forward to discussions with the EPA in this matter.

Comment T066

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 8-2 (first paragraph)

"The following needs in performance assessment should be added to those mentioned:

(2) the inclusion of the scenarios recommended elsewhere in these comments;"

Response

The referenced page does not exist. The following response is given assuming the question refers to page 6-3 of Volume 1.

Scenario development is an ongoing process and the suggested events will be considered for inclusion.

Comment T067

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 1, Page 8-2 (first paragraph)

"The following needs in performance assessment should be added to those mentioned:

(3) the use of plausible radionuclide inventories (including radionuclide composition and specific activity) and their uncertainty in the performance assessment. (To date, the inventory has not been treated as an uncertain variable, even though the PA states that uncertainty in this inventory is large [Volume 2, page 2-51])."

Response

The referenced page does not exist. The following response is given assuming the question refers to page 6-3 of Volume 1.

Because 40 CFR 191 sets limits on the probability of radionuclide releases that have been normalized to the total transuranic inventory in the system, performance is not likely to be strongly sensitive to uncertainty in the radionuclide. This observation has not been tested by formal sensitivity analyses, but can be partially supported by comparison of the 1991 and 1992 preliminary PAs, which used different inventories. Uncertainty in the radionuclide inventory will be considered in future evaluations.

Comment T068

Page 13: I. Technical Comments, B. Additional General Comments

Area in document Volume 2 Page 3-18, (Line 5)

"Is temperature a variable in BRAGFLO?"

Response

Temperature is not treated as an unknown variable -- the repository is assumed to be isothermal. Temperature is used to calculate the physical properties of the fluid so temperature is a parameter, i.e., a value assumed constant for the purposes of computation.

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B.* SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T069

Page 14: I. Technical Comments, C. General Geology and Hydrology

Area in document Volume 2, Chapter 2, Page 2-38, Line 12

"How will the 'location and amount of future' groundwater flow be dealt with in future PAs? How will DOE deal with such vast uncertainties?"

Response

A three-dimensional computer model of regional groundwater flow is being developed. This model uses a free surface/seepage face as the upper boundary. This model is designed to simulate areas of discharge and recharge, and patterns of groundwater flow for assumed spatial and temporal distributions of maximum potential infiltration to the water table. The Project is using this model to evaluate the sensitivity of compliance to this issue.

Comment T070

Page 14: I. Technical Comments, C. General Geology and Hydrology, Low Values of Total Dissolved Solids

Area in document Volume 2, Chapter 2, Page 2-34

(a) "What is the explanation for the wells with the low TDS?"

(b) "What is the TDS level in all the potential aquifers?"

Response

(a) Hypotheses concerning the possible lack of consistency between inferred north-to south flow in the Culebra and hydrochemical facies are discussed on page 2-36, lines 11 - 20. Also see response to the comment from the EPA document, page 19 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow and Hydrogeochemical Facies Differences).

(b) For this response, "potential aquifers" is assumed to mean Potential Underground Sources of Drinking Water, as defined in Subpart C to 40 CFR Part 191, in strata above the Salado Formation. The principal stratigraphic units known to be able to produce sufficient amounts of water are the Culebra and Magenta dolomites. The TDS of waters in these units is summarized on page 2-34, lines 24 - 31 in Volume 2 of the 1992 PA. Measured TDS values from drill holes in the vicinity of WIPP are given in Table 2-2 of Siegel et al. (1991). Furthermore, TDS values are measured routinely as part of the WIPP Groundwater Quality and Sampling Program.

As stated in a paper recently presented at the Waste Management '94 conference (Trauth et al., 1994), we propose to determine when and if underground sources of drinking water should be identified and characterized (i.e., when such a characterization will provide pertinent information for a compliance application). Briefly, identification and characterization of USDWs should not be required if no radionuclide releases to the accessible environment are predicted for 10,000 years or if 10,000 year peak predicted releases to the accessible environment are less than or equal to the applicable Maximum Contaminant Levels (MCLs). USDWs along the pathway should be identified and characterized if peak predicted releases to the accessible environment for 10,000 years are greater than the MCLs.

References

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.G, Bertram, and B. Bower. 1994. "Considerations for Guidance for Radioactive Waste Disposal Arising from Rules Under 40 CFR 191 and 40 CFR 194," *Proceedings of Waste Management '94 Conference, Tucson, AZ, February 27-March 3, 1994.*

Comment T071

Page 14: I. Technical Comments, C. General Geology and Hydrology, Low Values of Total Dissolved Solids

Area in document Volume 2, Chapter 2, Page 2-34

"How much uncertainty reduction in aquifer characteristics would there be if DOE drilled more test wells near the controlled area?"

Response

The Project requests clarification of this question to insure that the response is appropriate. We are unclear whether the reviewer is concerned about: 1) the errors of estimation of total dissolved solids at unmeasured locations near the controlled area, or 2) the effect of the uncertainty in total dissolved solids on estimates of transmissivity or other aquifer properties.

The Project believes that there will always be uncertainty in aquifer characteristics, and that the acceptable level of uncertainty is related to the effect of that uncertainty on regulatory performance measures.

Comment T072

Page 14: I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow above the Salado Formation

Area of document General

"Current and historical head measurements of the wells penetrating post-Salado strata would be helpful in interpreting the significance of seasonal or annual fluctuations in the reported potentiometric surface."

Response

Hydrographs for all wells at the WIPP site are presented in Hydrologic Data Reports #1-8 (Hydro Geo Chem, Inc., 1985; Intera Technologies, Inc. and Hydro Geo Chem, Inc., 1985a,b; Saulnier et al., 1987; Stensrud et al., 1988a,b; Stensrud et al., 1990), Richey (1987), and Cauffman et al. (1990). No fluctuations related to seasonal or annual cycles have ever been identified nor, given the depth and degree of confinement of Rustler Formation units at the WIPP site, are any expected to occur.

References

Hydro Geo Chem, Inc. 1985. *WIPP Hydrology Program Waste Isolation Pilot Plant, SENM Hydrologic Data Report #1.* SAND85-7206. Albuquerque, NM: Sandia National Laboratories.

Intera Technologies, Inc., and Hydro Geo Chem, Inc. 1985a. *WIPP Hydrology Program Waste Isolation Pilot Plant, Southeastern New Mexico Hydrologic Data Report #2.*

SAND85-7263. Albuquerque, NM: Sandia National Laboratories.
Intera Technologies, Inc., and Hydro Geo Chem, Inc. 1985b. *WIPP Hydrology Program Waste Isolation Pilot Plant, Southeastern New Mexico Hydrologic Data Report #3.*

SAND86-7109. Albuquerque, NM: Sandia National Laboratories.

Saulnier, G.J., Jr., G.A. Freeze, and W.A. Stensrud. 1987. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #4.* SAND86-7166. Albuquerque, NM: Sandia National Laboratories.

Stensrud, W.A., M.A. Bame, K.D. Lantz, A.M. LaVenue, J.B. Palmer, and G.J. Saulnier, Jr. 1987. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #5.* SAND87-7125. Albuquerque, NM: Sandia National Laboratories.

Stensrud, W.A., M.A. Bame, K.D. Lantz, T.L. Cauffman, J.B. Palmer, and G.J. Saulnier, Jr. 1988a. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #6.* SAND87-7166. Albuquerque, NM: Sandia National Laboratories. *WIPP*

Stensrud, W.A., M.A. Bame, K.D. Lantz, J.B. Palmer, and G.J. Saulnier, Jr. 1988b. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #7.* SAND88-7014. Albuquerque, NM: Sandia National Laboratories.

Stensrud, W.A., M.A. Bame, K.D. Lantz, J.B. Palmer, and G.J. Saulnier, Jr. 1990. *WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #8.* SAND89-7056. Albuquerque, NM: Sandia National Laboratories.

Richey, S.F. 1987. *Water-Level Data from Wells in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* Open-File Rpt 87-120. Albuquerque, NM: USGS.

Cauffman, T.L., A.M. LaVenue, and J.P. McCord. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite, Volume II: Data Base.* SAND89-7068/2. Albuquerque, NM: Sandia National Laboratories.

Comment T073

Page 14-15: I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow above the Salado Formation, Groundwater geochemistry

Area in document Volume 2, Chapter 2, Page 2-34

"Inferred north to south groundwater flow directions in the Culebra Dolomite (based on the potentiometric surface in the Culebra Dolomite) are inconsistent with the distribution of geochemical facies in the Culebra groundwaters (salinities decrease from north to south).

Attempts are made to explain this apparent discrepancy, but alternative working hypotheses should be explored, including the possibility that the potentiometric surface is inaccurate."

Response

The comment notes that several hypotheses have been advanced to explain the apparent discrepancy, but that additional (alternative) hypotheses should be explored. This issue affects the compliance analysis in that it relates to alternative conceptual models of groundwater flow in the Culebra. Additional work to evaluate alternative hypotheses concerning Culebra geochemistry will be considered for inclusion in the systems prioritization.

The Project will record the issue that the potentiometric surface might be inaccurate. Pending the outcome of the systems prioritization, the Project may consider this issue. It should be noted that, because of variations in fluid density, the potentiometric surface is not the best indicator of flow directions. Instead, calculated velocity fields should be used. These depend on measured values of pressure, fluid density, and transmissivity, as well as the assumptions of the model used to calculate them.

See also responses to comments in the EPA document, p. 14 (I. Technical Comments, C. General Geology and Hydrology, *Low Values of Total Dissolved Solids*); p. 18 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields); and p. 19 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow and Hydrogeochemical Facies Differences).

Comment T074

Page 15: I. Technical Comments, C. General Geology and Hydrology

Area in document Volume 2, Chapter 2, Page 2-34

"Points of groundwater recharge and discharge into post-Salado strata are very poorly constrained. Further study is needed to document these important aspects of the hydrology across the WIPP site."

Response

A three-dimensional computer model of regional groundwater flow is being developed. This model uses a free surface/seepage face as the upper boundary. This model is designed to simulate areas of discharge and recharge, and patterns of groundwater flow for assumed spatial and temporal distributions of maximum potential infiltration to the water table. The Project is using this model to evaluate the sensitivity of this issue to compliance.

Comment T075

Page 15: I. Technical Comments, C. General Geology and Hydrology, Hydrologic Parameters

Area in document General

(a) "It is not clear why only horizontal fractures were used in PA models for the Culebra Dolomite member (Volume 3, p. 2-85), as vertical fractures are more likely to have greater connectivity in most subsurface environments."

(b) "More data need to be acquired for all relevant stratigraphic units at the WIPP site (i.e., Castile through Dewey Lake Redbeds."

Response

(a) When modeling a formation as a dual-porosity continuum, the actual orientations of fractures are unimportant. The modeled fractures are not used to provide connections between points. The important fracture parameters to be captured in the models are the fracture porosity, which will control the flow velocity, and the surface area of the fractures, which will control the amount of matrix diffusion that occurs. As long as the fracture porosity and surface area are kept constant, it does not matter if the fractures are modeled as single sets of horizontal or vertical fractures or as three orthogonal sets of fractures. Single sets of horizontal fractures are the simplest to model, so that is what PA has used.

(b) The need for additional hydrologic data for various stratigraphic units may be considered for inclusion in the SP.

Comment T076

Page 16: I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields

Area in document Volume 2, Section 7.5 and Appendix D

(Summary) This paragraph follows the introductory comment that many problems associated with the transmissivity fields are related to calibration to fresh-water heads. The second paragraph points out that neglecting spatial variations in density of Culebra groundwaters could potentially cause significant errors in the calibrated transmissivity fields, as well as predicted flow directions.

Response

The transmissivity fields are actually calibrated to pressure rather than fresh-water head (Volume 2 of the 1992 PA, Section 7.5, p. 7-10, l. 14-17). However, given that the elevations of the measuring points are known, it really does not matter which parameter, pressure or fresh-water head, is used for calibration. The important point is that the flow portion of the code (SWIFT II) used for the calibration solves differential equations formulated in terms of pressure. Variations in density are fully accounted for in the code. In these calibrations, it is assumed that the density of water varies with position but is fixed in time. The evolution of the chemistry of Culebra waters is not sufficiently well understood to determine if the assumption that the density distribution does not change over long periods of time is valid.

Comment T077

Page 16: I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields

Area in document Volume 2, Section 7.5 and Appendix D

"...Simulations which are based on equivalent freshwater head may produce erroneous velocity magnitudes and flow directions in this critical area."

Response

See preceding response. Transmissivity fields calibration accounts for variable density. The SECO-FLOW calculations in the 1992 PA used the calibrated transmissivity fields but assumed constant fluid density. Modifications to SECO-FLOW now permit variable-density flow calculations in PA.

Comment T078

Page 16: I. Technical Comments, General Geology and Hydrology, Groundwater Transmissivity Fields

Area of document General

"The means by which the aquifer test results were incorporated as known values into the calibration of the transmissivity fields is unclear. However, the aquifer test analysis should have considered density effects on pumping responses in the monitoring wells."

Response

Transmissivities derived from single-well hydraulic tests or from interference (pumping) test responses over distances less than 50 m formed the data base for kriging of the transmissivity field. The measured transmissivities were preserved in the kriged transmissivity fields, within the estimated error bounds of the measurements. When the model domain was discretized into grid blocks, however, average values of the kriged field were calculated for and assigned to each grid block. Therefore, the average value assigned to a particular grid block need not coincide with the transmissivity determined at an individual well lying within that grid block. The process of defining transmissivity fields using aquifer-test results is discussed in LaVenue et al. (1990).

The aquifer-test analyses did take density effects into account. All analyses were done in terms of pressure changes, not water-level changes, providing results in the form of permeability-thickness products, not transmissivities. Transmissivities were then calculated based on the brine density at each location. Aquifer-test analysis procedures are discussed in Beauheim (1989).

References

LaVenue, A.M., T.L. Cauffman, and J.F. Pickens. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume I: Model Calibration.* SAND89-7068/1. Albuquerque, NM: Sandia National Laboratories.

Beauheim, R.L. 1989. *Interpretation of H-11b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site.* SAND89-0536. Albuquerque, NM: Sandia National Laboratories.

Comment T079

Page 16-17: I. Technical Comments, C. General Geology and Hydrology, Culebra Transmissivity

Area in document Volume 2, Chapter 2, Page 2-34

"Transmissivity values obtained from the tests should also have been converted to hydraulic conductivities due to the assumption of a uniform thickness over the area. If transmissivity values were used as calibration points directly, they would have been in error by a factor of the effective thickness versus the assumed model thickness of 7.7 meters."

Response

The hydraulic tests within the Culebra were interpreted using the full thickness of the Culebra because the wells are fully screened across the Culebra. Given the uncertainty of the effective thickness across the site, the average thickness of the Culebra was used in the numerical model. The thickness of 7.7 m is smaller than the actual thickness in the southwestern portion of the model area where the transmissivities are the largest. However, the small difference in the conductivity that the uniform thickness assumption would make would have no appreciable difference in the model results since the transmissivity field is significantly changed through the process of calibrating the model to the measured steady-state and transient pressures.

Comment T080

Page 17: I. Technical Comments, C. General Geology and Hydrology, Culebra Transmissivity, Grid Sensitivity

Area in document Volume 2, Chapter 2, Page 2-34

"A sensitivity analysis on the finite-difference grid that was used to generate the 70 transmissivity fields should be performed. ...A finer grid may lead to significantly different transmissivity fields and should be evaluated."

Response

The Project has recently begun a local scale modeling effort with a much finer grid to investigate the transmissivity distribution within the near field (i.e., within the WIPP site). However, the numerical grid used in the 1992 PA flow modeling was designed to represent the regional groundwater flow surrounding the WIPP site and the transient events which have been conducted within the WIPP-site boundary. The 50 x 57 x 1 grid used in the model has larger grid blocks (e.g., 1,000 m to 2,500 m) away from the WIPP site and smaller grid blocks (e.g., 75 m to 250 m) within the WIPP-site boundary where the transient tests have been conducted. The grid resolution is believed acceptable given the objectives of the modeling study (i.e., to determine plausible regional transmissivity distributions within the Culebra).

Different grids (either coarser or finer) may lead to different transmissivity fields because the inverse procedure identifies effective or average transmissivity values at the scale of the grid. Differences in transmissivity values using grids with different resolution may reflect a scaling property of transmissivity, rather than indicating non-convergence of the inverse problem. Convergence of the travel time distribution is important, but that convergence of transmissivity estimates themselves may not be expected, and is not essential by itself.

Comment T081

Page 18: I. Technical Comments, C. General Geology and Hydrology, Culebra transmissivity, Boundary condition uncertainty

Area in document Volume 2, Chapter 2, Page 2-34

"The uncertainty with which the system boundary conditions are understood has serious implications ... the current approach that has been taken to obtain the 70 transmissivity fields does not evaluate the sensitivity of the overall model results to the boundary conditions."

Response

The Project is currently investigating this issue through the development of a three-dimensional model to assess vertical recharge into the Culebra. In addition, elicitation and examination of other conceptual models is an important part of the SP. The boundary conditions used in the 1992 Culebra flow model were estimated from regional water-level measurements and by specifying Nash Draw as a no-flow boundary condition. The south-western boundary condition has some uncertainty due to the variation in water-level measurements in this area.

Note that the horizontal boundary conditions may not produce significant changes to transmissivities within the WIPP-site boundary given the conceptual model used in 1992. This is because of the significant influence that the transient pumping tests have had upon the Culebra. These tests have stressed the Culebra to the extent that the effect of boundary conditions is small.

Comment T082

Page 18: I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields

Area in document Volume 2, Section 7.5 and Appendix D

(Summary) This paragraph contains two points:

> If the area along the Pecos River south of the WIPP site acts as recharge area and groundwater flow is to the east, the low ionic strength water could be dissolving dolomite, thereby creating secondary permeability.
>
> It is unclear why more emphasis in the performance assessment has not been placed on integrating the geochemical data with the hydrogeological data to form a cohesive conceptual model(s).

Response

It is possible that regions of higher transmissivity are due to dolomite dissolution. However a few points should be clarified. There is no indication that flow is presently toward the east from the Pecos River. The possibility that eastward flow occurred in the late Pleistocene has been proposed by Lambert and Carter (1987) and Lambert (1991). While dolomite dissolution might play a role, the distribution of fracture density and the degree to which gypsum and halite presently fill fractures have been proposed as more important controls on the transmissivity distribution (Holt and Powers, 1988). Circulation of low ionic strength water would likely dissolve gypsum and halite from the fractures.

The Project has placed a strong emphasis on integrating geochemical and hydrogeological data. The Siegel et al. (1991) report is an example. Additional work to integrate geochemical and hydrogeological data will be considered for inclusion in the systems prioritization.

See also responses to comments in the EPA document, p. 14 (I. Technical Comments, C. General Geology and Hydrology, Low Values of Total Dissolved Solids); p. 14-15 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow above the Salado Formation, Groundwater Geochemistry); and p. 19 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow and Hydrogeochemical Facies Differences).

References

Lambert, S.J., and J.A. Carter. 1987. *Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico. I: Principles and Preliminary Results.* SAND87-0388. Albuquerque, NM: Sandia National Laboratories.

Lambert, S.J. 1991. "Fossil Meteoric Groundwaters in the Delaware Basin of Southeastern New Mexico," *Stable Isotope Geochemistry: A Tribute to Samuel Epstein.* Eds. H.P. Taylor, Jr., J.R. O'Neil, and I.R. Kaplan. Special Publication No. 3. SAND89-2660. San Antonio, TX: Geochemical Society. 135-156.

Holt, R.M., and D.W. Powers. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP-88-004. Carlsbad, NM: Westinghouse Electric Corporation.

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T083

Page 18-19: I. Technical Comments, C. General Geology and Hydrology, Culebra Transmissivity, Recharge Uncertainty

Area in document Volume 2, Chapter 2, Page 2-34

"In addition to LaVenue's suggestion (SAND 92-7306) that recharge to the Culebra may be occurring in the vicinity of the Pecos River, at least one other alternative conceptual model has been proposed which also involves vertical recharge to the Culebra. This alternative model considers significant vertical recharge to the Culebra over the entire southern region of the modeled area (SAND 88-0196). In either case, if vertical recharge occurs, the 70 transmissivity fields calibrated to the aquifer tests and equivalent fresh-water heads would be lower (i.e. slower velocities) than those which would be calculated with the present model. Vertical recharge should be evaluated in the sensitivity analysis."

Response

The Project is currently investigating this issue through the development of a three-dimensional model to assess vertical recharge into the Culebra. Future modeling studies may include these estimates in the calibration process. It should be recognized that the exclusion of vertical recharge in the region upgradient of the WIPP site leads to higher transmissivity estimates and higher groundwater velocities as noted by the EPA reviewer. This is conservative from a groundwater travel time viewpoint.

Comment T084

Page 19: I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow and Hydrogeochemical Facies Differences

Area in document Volume 2, Chapter 2, Page 2-36, Lines 11-20

"What is being done to examine the differences between the north-to south flow in the Culebra and the hydrogeochemical facies data? How does this discrepancy impact the confidence of the flow modeling?"

Response

It should be emphasized that it is not certain that a discrepancy between flow directions and hydrochemical facies actually exists. The apparent discrepancy might instead be due an incomplete understanding of the hydrogeochemical system.

Several hypotheses have been advanced to explain the apparent discrepancy, as referenced in lines 11-20 in Volume 2 of the 1992 PA. Also, lines 32-35 on page 2-33 and lines 1-3 on page 2-36 reference the strong correlation between the region of high molality sodium-chloride water and the presence of halite in adjacent strata (see Figure 1-13 in Siegel et al., 1991). It is anticipated that a three-dimensional computer model of regional groundwater flow that is being developed (EPP study 5.1.1.2, p. 5-8) will provide information that could be used to evaluate and/or modify the existing hypotheses. Additional work to integrate hypotheses concerning Culebra geochemistry with the results of the regional model will be considered in the systems prioritization.

This apparent discrepancy affects confidence in the flow modeling in that it suggests the need to consider alternative conceptual models of groundwater flow in the Culebra. Consideration of alternative conceptual models is an objective of the SP.

See also responses to comments from the EPA document, p. 14 (I. Technical Comments, C. General Geology and Hydrology); p. 14-15 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Flow above the Salado Formation, Groundwater geochemistry); p. 15 (I. Technical Comments, C. General Geology and Hydrology); and p. 18 (I. Technical Comments, C. General Geology and Hydrology, Groundwater Transmissivity Fields).

Reference

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T085

Page 19: I. Technical Comments, C. General Geology and Hydrology, Fracture Density

Area of document Volume 2, Chapter 2, Page 2-19

"Since good information on Culebra fracture density is lacking, please explain why you do not use the higher fracture density where it can be observed."

Response

As the comment states, good information on Culebra fracture density is lacking. It is not clear what is meant by "use the higher fracture density where it can be observed" because fracture density can't be observed in the subsurface except in shafts (Holt and Powers, 1990). Also, all fractures, whether observed or not, are not hydraulically significant. Through tracer tests, we seek to determine the fracture density that is important for transport

through the Culebra (see Jones et al., 1992). The interpreted "effective" fracture density is always less than observed fracture densities. Were we to use observed fracture densities in our models, much more physical retardation would occur as a result of matrix diffusion than our tracer tests show to be realistic.

References

Holt, R.M., and D.W. Powers. 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant.* DOE/WIPP-90-051. Carlsbad, NM: Westinghouse Electric Corporation.

Jones, T.L., V.A. Kelley, J.F. Pickens, D.T. Upton, R.L. Beauheim, and P.B. Davies. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site.* SAND92-1579. Albuquerque, NM: Sandia National Laboratories.

Comment T086

Page 19: I. Technical Comments, C. General Geology and Hydrology, Vertical Fractures

Area of document Volume 2, Chapter 2, Page 2-19

"In volume 3 (1-39) it states that vertical fractures in the Culebra are not used in the calculations. Why? How are vertical fractures handled or what assumptions are used?"

Response

When modeling a formation as a double-porosity continuum, the actual orientations of fractures are unimportant. The modeled fractures are not used to provide connections between points. The important fracture parameters to be captured in the models are the fracture porosity, which will control the flow velocity, and the surface area of the fractures, which will control the amount of matrix diffusion that occurs. As long as the fracture porosity and surface area are kept constant, it does not matter if the fractures are modeled as single sets of horizontal or vertical fractures or as three orthogonal sets of fractures. Single sets of horizontal fractures are the simplest to model, so that is what PA has used.

Comment T087

Page 20: I. Technical Comments, C. General Geology and Hydrology, Effects of the Magenta Dolomite in Transport Calculations

Area in document Volume 2, Chapter 2, Page 2-23 to 2-24

"Most of the focus is on the Culebra for transport because it has the highest transmissivity. What is the effect on the release when the Magenta and Culebra Dolomites are combined in the calculations?"

Response

The Project is using a three-dimensional computer model of regional groundwater flow (EPP Study 5.1.1.2, p. 5-8) to evaluate the sensitivity of releases into other hydrologic units to compliance.

A three-dimensional computer model of regional groundwater flow is being developed. This model uses a free surface/seepage face as the upper boundary. This model is designed to simulate areas of discharge and recharge, and patterns of groundwater flow for assumed spatial and temporal distributions of maximum potential infiltration to the water table. The Project is using this model to evaluate the sensitivity of this issue to compliance.

Comment T088

Page 20: I. Technical Comments, C. General Geology and Hydrology, Use of Crushed Culebra Rock

Area in document Volume 2, Chapter 2, Page 2-40/41

"Please expand the discussion on [*how*] the tests involving crushed Culebra rock will help *determine* K_ds? Is this to simulate the effect of clays? If many of the fractures are clay lined, are any tests being conducted on the clay?"

Response

Early laboratory investigations of chemical retardation in the Rustler Formation were conducted using traditional batch sorption experiments with crushed rock. The early experiments were largely intended to be scoping experiments to ascertain whether chemical retardation was significant and they were conducted under specific experimental conditions. Results of those experiments are expected to be valuable, however, in providing independent checks on results from the present experimental approaches (see, for example, Lynch and Dosch [1980] and the review by Novak [1992]). Currently, mechanistic adsorption

experiments coupled with surface complexation modeling are in progress on very carefully prepared ground mineral constituents of the Culebra, dolomite and corrensite, the primary clay mineral constituent. The resulting surface complexation model will predict values for K_d as a function of mineralogy, fluid composition, and adsorbates. On the basis of published information in peer-reviewed journals (see also Siegel et al., 1990), we have strong evidence that results from mechanistic experiments will be representative of the phenomena occurring in the intact Culebra rock. To confirm this, comparisons will be made with the column experiments and sorption experiments with thin slabs or ground samples of Culebra rock.

References

Lynch, A.W., and R.G. Dosch. 1980. *Sorption Coefficients for Radionuclides on Samples from the Water-Bearing Magenta and Culebra Members of the Rustler Formation.* SAND80-1064. Albuquerque, NM: Sandia National Laboratories.

Novak, C.F. 1992. *An Evaluation of Radionuclide Batch Sorption Data on Culebra Dolomite for Aqueous Compositions Relevant to the Human Intrusion Scenario for the Waste Isolation Pilot Plant.* SAND91-1299. Albuquerque, NM: Sandia National Laboratories.

Siegel, M.D., J.O. Leckie, S.W. Park, S.L. Phillips, and T. Sewards. 1990. "Studies of Radionuclide Sorption by Clays in the Culebra Dolomite at the WIPP Site, Southeastern New Mexico," *Waste Management '90, Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education, Tucson, AZ, February 25-March 1, 1990.* Ed. R.G. Post. SAND89-2387. Tucson, AZ: University of Arizona. Vol. 2, 893-900.

Comment T089

Page 20: I. Technical Comments, B. Additional General Comments, Groundwater Age Discussion

Area in document Volume 2., Chapter 2, Page 2-37, Lines 22-32

"The section on the isotopic and tritium data is confusing. DOE states that tritium levels indicate minimal contributions from the atmosphere since 1950. If the waters have even 'minimal' contributions, then that would indicate the waters are not that old. Please clarify what is meant. In addition, what is being done to resolve uncertainty about groundwater age?"

Response

For a discussion of the isotopic data, including tritium, see Chapter 5 of Siegel et al. (1991) and the references cited therein. The statement quoted from Volume 2 of the 1992 PA is consistent with the observed data. Meaningful nonzero tritium measurements suggest either

contamination during drilling or sampling or some degree of mixing with modern surface water in the hydrostratigraphic unit. For the WIPP, these measurements indicate that the amount of mixing has been either zero or extremely small. As stated in the text in Volume 2, this in turn suggests that groundwater travel time (i.e., the mean travel time) from the surface to the sampled units is long. The presence of some "younger" water from the surface does not imply that all water is "young," nor does it imply that recharge is rapid.

Effects on disposal-system performance about the rates of vertical flow, and therefore about groundwater age, are being examined through regional 3D modeling.

Reference

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T090

Page 21: I. Technical Comments, C. General Geology and Hydrology, Porosity of Anhydrite Interbeds

Area in document **Volume 2, Chapter 2, Page 2-42, Lines 15-21**

"Are the porosities of the anhydrite interbeds matrix porosity, fracture porosity or both? Will DOE assume that anhydrite fracturing continues to the accessible environment?"

Response

Porosities for the anhydrite reference in the cited area of Volume 2 are presented in Volume 3, Chapter 2, p. 2-65 of the 1992 PA. The porosities given are estimates, not measurements, and are intended to represent the total porosity of the anhydrite. No distinction between fracture and matrix porosity is necessary because PA treats the anhydrite as a porous, not fractured, medium. A laboratory program is underway to measure anhydrite porosity, both in an unloaded state and as a function of stress (Howarth, 1994).

PA assumes that the fracturing naturally present in the anhydrites continues to the accessible environment. The 1992 PA did not explicitly include induced fracturing outside of the disturbed rock zone around the repository. It is planned that future PAs will include a relationship between pressure in the fractures and fracture porosity and permeability. Whether or not the pressure in the fractures, and hence the porosity and permeability, changes at the accessible environment boundary will depend on the conditions in the model.

Reference

Howarth, S.M. 1994. *Test Plan: Two-Phase Flow Laboratory Program for the Waste Isolation Pilot Plant (WIPP).* Albuquerque, NM: Sandia National Laboratories.

Comment T091

Page 21: I. Technical Comments, C. General Geology and Hydrology, Average Undisturbed Pore Pressure in Anhydrite

Area in document Volume 3, Chapter 2, Page 2-63

"It is unclear how the average undisturbed pore pressure in the anhydrite was developed. Table 2.3-2 (p 2-33) does not have any measurements greater than 9.5 MPa, yet the mean and median pressures are between 12 and 13 MPa."

Response

Table 2.3-2 shows only halite pore pressure data. Anhydrite data are presented in Table 2.4-2 on p. 2-59. The three values between 12.4 and 12.6 MPa are considered to provide the best representation of anhydrite pore pressures undisturbed by the excavations.

Comment T092

Page 21: I. Technical Comments, C. General Geology and Hydrology, Culebra Matrix Porosity

Area in document Volume 3, Chapter 2, Page 2-83

"If only intact rock was measured for porosity and there was a large amount of core lost in porous (vuggy) and/or fractured portions of the Culebra, is the matrix porosity used in the models: 1) adjusted upward to reflect the higher bulk matrix porosity; or 2) is the data indicating the vugs and fracturing considered as part of the fractured porosity? It is not clear if the Culebra matrix porosity values include these features or not."

Response

The matrix porosity used in the models has not been adjusted to compensate for unsampled, presumably higher porosity, portions of the Culebra. The data include vugs and fractures only to the extent that they were present in the core samples tested. Both fractures and vugs could be included in the "fracture" porosities determined from tracer tests (e.g., Jones et al., 1992), which represent what might be called the effective flow porosity of the Culebra. The

matrix porosity might, in turn, be called the diffusion porosity. If matrix porosity is being underestimated, the potential for matrix diffusion is also being underestimated. See also response to comment in EPA's document, p. 25 (I. Technical Comments, D. Additional Comments on General Geology and Hydrology).

Reference

Jones, T.L., V.A. Kelley, J.F. Pickens, D.T. Upton, R.L. Beauheim, and P.B. Davies. 1992. *Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site.* SAND92-1579. Albuquerque, NM: Sandia National Laboratories.

Comment T093

Page 22: I. Technical Comments, C. General Geology and Hydrology, Data on pH and Eh

Area in document Volume 3, Chapter 3, Page 3-41

"What are the current data or expected values of the pH and Eh in the Culebra under existing conditions? If the data exist, they could not be found in the PA."

Response

Ranges for pH conditions in the Culebra Dolomite have been well defined and range between about 6.5 and 8.0 (see Siegel, 1991, Chapter 2). The pH of the Culebra is expected to be narrowly constrained because of the tremendous buffering capacity of carbonate minerals. Any artificially induced perturbation in pH would rapidly be eliminated by dissolution/precipitation reactions.

Ranges for Eh in Culebra Dolomite groundwaters were investigated by Myers et al. (see Siegel, 1991, Chapter 6 and Appendix 6A). Myers et al. attempted to characterize Eh by evaluating four redox couples (As, N, I, and Se) with measurements with a platinum electrode (refer to Table 6-4 and Figure 6-2 of Siegel, 1991). Unfortunately, many of the measurements for individual redox species were below the analytical detection limits. Consequently, Myers et al. were only able to bound the Eh conditions and were not able to decisively quantify values. Myers et al. did speculate that groundwaters south of the site boundary are more oxidizing relative to groundwaters to the north (see Figure 6-1 and discussion on p. 6-22 of Siegel, 1991).

Reference

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico*. SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T094

Page 22: I. Technical Comments. D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 2-6 (Figure 2-3)

"The generalized stratigraphy of the Delaware Basin is inaccurate on several accounts.

- Castile formation onlaps the terminal platform margin of the Capitan Limestone and extends further onto inner parts of the Capitan platform. Figure 2-3 shows the top of the Castile formation being located stratigraphically lower than the top of the Capitan Limestone. Figure 2-5 on p. 2-8 more accurately depicts the relationship of the Capitan and Castile formations.

- The Dewey Lake Red Beds are Ochoan in age and should be included in this stage, along with the Castile, Salado, and Rustler formations."

Response

Both points in the comment are correct as stated by the EPA reviewer. Editorial corrections in future documents are appropriate.

Comment T095

Page 22: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 2-10 (Section 2.2.2.2)

"No mention is made of the wide variety of depositional facies that actually comprise the Capitan Limestone. A potentially important lithofacies, at least with regard to the hydrologic characteristics of the Capitan Limestone, is the forereef or foreslope facies, which consists of poorly sorted carbonate clasts shed from the high relief Capitan margin. This facies is

poorly mapped, may have very different flow characteristics than for other facies in the Capitan Limestone, and tongues of this facies may extend close to or beneath the WIPP site."

Response

The first sentence of the comment is plainly correct. We are unaware of evidence for forereef deposits extending 10 to 15 km into the basin for very different flow characteristics within these deposits. We would be willing to discuss this topic with the EPA during technical exchange meetings.

Comment T096

Page 22-23: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 2-10, Line 35

"'Lateral variations in depositional environments (in the Culebra Dolomite) were small within the mapped region...' What is the evidence for this statement? Detailed lithologic columns for the Culebra Dolomite with lithologies and sedimentary structures should be shown."

Response

Additional detail in the level of referencing will be included as appropriate in the PTB/draft compliance application. It is not clear that inclusion of stratigraphic columns is relevant to compliance, except along possible radionuclide-release paths.

Page 5-11 of Holt and Powers (1988) states: "The bulk of the Culebra is microlaminated to thinly laminated. The strata may be flat to wavy to locally contorted and discontinuous. Portions of the Culebra appear macroscopically devoid of depositional fabric. The dolomite is mottled in some zones. With the exception of the upper and lower contact zones, there is very little variation of depositional sedimentary features throughout most of the Culebra." Additional detail from the same page includes: "The lowermost foot (30 cm) of the Culebra locally is thinly laminated to laminated, with alternating light and dark brown laminae." "The uppermost few inches to 1 ft (30 cm) of the Culebra often differs radically from the underlying dolomite. The gamma ray signature of this zone is unique and is present throughout the Delaware Basin." We agree that the detail of referencing needs to be increased; generalized referencing in important areas, is inappropriate.

A large number of detailed correlations, cross-sections, and stratigraphic columns of the Rustler Formation are contained in Holt and Powers (1988).

Reference

Holt, R.M., and D.W. Powers. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP-88-004. Carlsbad, NM: Westinghouse Electric Corporation.

Comment T097

Page 23: I. Technical Comments, D. Additional Comments on General Geology and Hydrology, General

Area of document Volume 2, Chapter 2, Page 2-19

"Use of tools like Schlumberger's Formation MicroScanner may help to characterize *in situ* fractures in most stratigraphic units at the WIPP."

Response

New geophysical tools such as FMS are being evaluated for their potential use during tests associated with new tracer tests in the Culebra dolomite (Beauheim and Saulnier, 1994).

Comment T098

Page 23: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 2-24, Line 27

"'These rocks are absent...' Which rocks are absent: the Dewey Lake Red Beds? or the Dockum Group?"

Response

The Dockum Group (which includes the Santa Rosa sandstone). We recognize that the subject sentence had an unclear antecedent.

Comment T099

Page 23: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 2-39, Line 26

"Will the effect of gases on K_ds for radionuclides be considered in experiments?"

Response

Gases produced in the WIPP disposal room may include hydrogen, methane, carbon dioxide, hydrogen sulfide, nitrogen, and ammonia from corrosion and microbial processes (see Brush, 1990). The primary gasses produced, however, are likely to be hydrogen, carbon dioxide, and methane. Quantification of the gases produced by corrosion and microbial degradation is currently being investigated. The disposal room is expected to become anoxic in a relatively short period of time. In the event of a human intrusion, an influx of radionuclides into the Culebra Dolomite would be accomplished by some of those disposal-room gases.

The effect is expected to be negligible. In order for gases to affect sorption processes (includes adsorption and ion exchange), the dissolved gas must interact with either the dissolved radionuclides or with species on mineral surfaces. Methane is not recognized as a strong complexant for dissolved ions, nor is it likely to interact with mineral surface species. The effect of hydrogen is indirect, in that it affects pH, which plays a strong role in controlling the reactivity of mineral surface species and the extent of complexation in solution. As mentioned in the response to an earlier comment, however, pH is constrained by the presence of vast quantities of carbonate minerals in the Culebra Dolomite. An influx of hydrogen from the disposal room cannot significantly perturb the natural equilibrium in the Culebra, unless massive quantities are introduced in a short time. Like hydrogen, the concentration of carbon dioxide is strongly tied to pH, which is constrained in the Culebra Dolomite. The range of pCO_2 is limited to between about $10^{-3.5}$ atm (atmospheric pCO_2) and about $10^{-2.5}$ atm (10x atmospheric) based on equilibrium calculations (see Siegel et al, 1991, Chapter 2). However, both pH and pCO_2 are experimental parameters in the mechanistic adsorption experiments being conducted on dolomite and corrensite.

Reference

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Comment T100

Page 23: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 4-4, Lines 17-19

"The wording suggests that the effects of pluvial periods (which would increase recharge and thereby increase the hydraulic gradient and shorten transport time to the accessible environment), although incorporated into the base case scenario, are not used in transport calculations in the disturbed scenario. The reasons for the differing treatment should be explained."

Response

The sentence in question is badly worded and is misleading. All events and processes included in the base case are also included in all disturbed-performance scenarios. The intended point was that because they are included in all scenarios, they are not used in the process of distinguishing between the disturbed-performance scenarios.

Note that the parenthetical observation in the comment, although logical, is in part unsupported speculation. Increased precipitation would very likely lead to an increase in recharge (dependent on other factors such as temperature, topography, and plant cover). However, increased recharge need not lead to an increase in hydraulic gradient and shorter transport times. Three-dimensional modeling of the regional flow system is in progress to provide the basis for observations of this sort.

Comment T101

Page 23: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 4-7, Lines 18-20, and Figure 4-1

(Paraphrase) The EPA notes that the water quality in the Culebra may be adequate for dust control, oil field injection, and fire control. "A requirement that the water be potable for human or stock use (which is implied by this statement) is not necessarily a prerequisite for all water-well development."

Response

This suggestion will be considered for inclusion in the systems prioritization.

The statement does not imply a requirement of potability; the E3 event is withdrawal for any use (see the reference on page 4-4, line 12 of Volume 2).

Comment T102

Page 23: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 2, Page 7-5, Line 4

"The solubility of gas in brine is assumed to be negligible. This requires justification. Abundant experimental and theoretical data exist for gas solubilities in water and brines and should be used to form a basis for this claim. Transport of gas out of the repository as dissolved species may turn out to be the most important means of gas transport in the WIPP environment, particularly as pressures increase from atmospheric to near lithostatic as the salt collapses on the waste panels."

Response

Information on the solubility of gases in NaCl brines has been evaluated and published by Cygan (1991). The transport of gas out of the repository as dissolved gas is not currently modeled in PA. The PA model (BRAGFLO) has the capability to consider gas solubility in brine, but preliminary evaluation suggests this to be a minor secondary effect. A more systematic analysis needs to be performed and is planned to better evaluate the assumption of negligible gas solubility. The issue will be considered for inclusion in the SP.

Reference

Cygan, R.T. 1991. *The Solubility of Gases in NaCl Brine and a Critical Evaluation of Available Data.* SAND90-2848. Albuquerque, NM: Sandia National Laboratories.

Comment T103

Page 17: I. Technical Comments, C. General Geology and Hydrology

Area in document Volume 2, Chapter 7, Page 7-1

"The last sentence on this page indicates that the storage coefficients and the Culebra thickness were treated as constants (as opposed to functions of position) in the 1992 series of calculations. How was the sensitivity of the storage coefficient evaluated in the transient transmissivity calculations described in Section 4.3 of LaVenue (SAND 92-7306)?"

Response

The storage coefficient used in the model was taken from averaging the $\log_{10}$ of the measurements taken from the Culebra tests. The sensitivity of the model results to the storage coefficient has not been investigated thus far. We believe that assigning a fixed value for storage coefficient leads to smaller travel times than would result from calibrating on storage coefficient as well as transmissivity, based on the following argument:

> Calibration of the response of wells H-15 and DOE-1 to the H-11 pumping test provides critical information on aquifer properties along potential Culebra flow paths. The drawdown at well H-15 is not well matched using transmissivity fields calibrated from steady-state data alone (LaVenue et al., 1990 SAND89-7068/1 Figure 5.6a). Simulated drawdown at H-15 might be increased by increasing transmissivity between H-11 and H-15, or by lowering the storage coefficient. The effect of adjusting only the transmissivity can be seen in Figure 4-32 of LaVenue 1992 (SAND92-7306) which shows a significant reduction in travel time due to including transient data in the calibration. If storage coefficients were also adjusted in the calibration, a smaller increase in transmissivity would be required to match the critical drawdown observations during the H-11 pumping test. The resulting travel times would therefore be larger than the travel times produced by adjusting transmissivity alone. We therefore believe that excluding storage coefficients from the calibration produces a conservative estimate for travel time.

References

LaVenue, A.M., T.L. Cauffman, and J.F. Pickens. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume I: Model Calibration.* SAND89-7068/1. Albuquerque, NM: Sandia National Laboratories.

LaVenue, A.M., and B.S. RamaRao. 1992. *A Modeling Approach To Address Spatial Variability within the Culebra Dolomite Transmissivity Field.* SAND92-7306. Albuquerque, NM: Sandia National Laboratories.

Comment T104

Page 24: I. Technical Comments, D. Additional Comment on General Geology and Hydrology

Area in document Volume 3, Pages 1-36

"The nature of the post-closure repository will probably resemble a fracture network more closely than a porous media, the equation for calculating retardation factors in PANEL should perhaps be based on surface area as is described in Section 7.6.2.2 of [Volume 2]."

Response

Comment acknowledged; the discussion of the waste-mobilization model (PANEL) in Section 1.4.4 of Volume 3 is a general discussion, allowing for non-zero K_ds. In actual calculations with PANEL, the K_ds have so far been set to zero, thus simulating the retardation in a fracture network.

Comment T105

Page 24: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 1-47, Lines 30 - 32; Volume 3, Page 1-47, Lines 36-37

(lines 30 - 32) "'Geologic history of the Delaware Basin ...began...during the Ordovician period...' *This is inaccurate because at least part of the Bliss Formation and lower* Ellenburger Group are Cambrian in age."

(lines 36-37) "'...the Central Basin Platform uplifted during the Pennsylvanian Period..' Subtle uplift of the Central Basin Platform probably began as early as the Mississippian (WU 86) and continued on into the Wolfcampian (early Permian) (Wu 86, Ya 93, YaDo 92, YaDo 93)."

Response

Additional detail will be included in the PTB report, as appropriate. Regardless of the impact on compliance or lack of same, we must ensure that what is stated in the PTB report and/or compliance submittal is technically correct, to the extent possible. Some level of disagreement in some areas of geologic work will always be present.

We recognize that there is some uncertainty concerning the ages of the Bliss and Ellenburger formations, and that the terminology regarding the beginning of the history of the "Delaware Basin" is open to different interpretations. We also recognize that there is some uncertainty regarding the timing of uplift of the Central Basin Platform. We were previously unaware of the reference (Wu86), and appreciate the information.

In general, the point we would like to raise is that some level of uncertainty and/or disagreement about some aspects of geologic history in a region as large as the Delaware Basin is unavoidable, and should be acceptable, unless it has a clear bearing on regulatory compliance. It is not clear that the level of disagreement indicated in this comment has a direct role in compliance evaluation. However, we recognize that, certainly in areas having a direct role in compliance, no information which is demonstrably incorrect should be stated, no matter how "minor."

Comment T106

Page 24: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 2-12

"Relative permeabilities are somewhat dependent on the nature of the two phases present. For which liquid and gas compositions have the relative permeabilities curves been measured experimentally and/or calculated?"

Response

The Project is currently investigating the issue as discussed in the EPP, Section 5.1.3, Salado Hydrologic Properties Activity.

Relative permeability curves have not been measured experimentally for WIPP-specific materials, although laboratory studies are planned (Howarth, 1993). The absence of such measurements is recognized as a significant source of uncertainty in present analyses. Current relative permeability calculations rely on models developed by Brooks and Corey (1964) and by van Genuchten (1980) and Parker et al. (1987). Brooks and Corey developed their model from relative permeability data using oil and air as the fluids. Van Genuchten used some of the Brooks and Corey data with oil and air as the fluids as well as some other data with unspecified fluids. The Parker et al. (1987) extension to van Genuchten for the nonwetting phase relative permeability did not include any data-model comparisons in their development.

References

Howarth, S.M. 1993. *Conceptual Plan: Two-Phase Flow Laboratory Program for the Waste Isolation Pilot Plant.* SAND93-1197. Albuquerque, NM: Sandia National Laboratories.

Brooks, R.H., and A.T. Corey. 1964. "Hydraulic Properties of Porous Media," *Hydrology Papers No. 3.* Colorado State University.

van Genuchten, M.Th. 1980. "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils," *Soil Sci. Soc. Am. J.* Vol. 44, 892-898.

Parker, J.C., R.J. Lenhard, and T. Kuppusamy. 1987. "A Parametric Model for Constitutive Properties Regarding Multiphase Flow in Porous Media," *Water Resour. Res.* Vol. 23, No. 4, 618-624.

Comment T107

Page 24: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 2-43

"The 'disturbed porosity' in halite and polyhalite within the Salado formation is, at best, an estimate. *In situ* data may be necessary to refine estimates for this parameter."

Response

The Project acknowledges that this parameter is estimated. Currently there are no plans to collect *in situ* data.

Comment T108

Page 24: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 2-61

"The 'disturbed permeability' in anhydrite layers within the Salado formation is only an estimate. *In situ* data may be necessary to refine estimates for this parameter."

Response

The Project acknowledges that this parameter is estimated. Currently there are no plans to collect *in situ* data.

Comment T109

Page 24-25: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3 Page 2-72, Line 23

"'The cause of fracturing (in the Culebra Dolomite), however, is unresolved.' A better understanding of the origin of fractures in the Culebra Dolomite would help constrain the models on the flow of groundwater and brine."

Response

The reviewer's comment is valid. However, the sentence referred to in Volume 3 is not particularly informative. Considerably more information is known about Culebra fracturing than is implied here. See, for example, the discussion in Volume 2 of the 1992 PA (p. 2-16, line 33 through p. 2-23, line 13) and the references cited therein for more information on the relationship between fractures and hydrologic properties of the Culebra. Questions remain about the precise origin of fractures in the Culebra (and in most geologic environments). Present work emphasizes the relationship between the present condition of fractures (rather than their origin) and hydrologic properties. Regional 3-D groundwater flow modeling in progress (EPP 5.1.1.2) uses the present spatial distribution of fracturing in the Rustler Formation and Dewey Lake Red Beds as a basis for characterizing hydraulic conductivity.

Comment T110

Page 25: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 2-77 (Figure 2.6-2)

"No well control points or total depths are indicated on this cross section."

Response

The point is well taken. Control points are given for ERDA-9, although in a way that is nonstandard for most geologists. The caption should have noted that this is a schematic cross-section.

Comment T111

Page 25: I. Technical Comments, C. General Geology and Hydrology

Area in document Volume 3, Page 2-77

"Clay filling in fractures through the Culebra Dolomite is poorly characterized. Fracture aperture, clay (and other phases) mineralogy, clay volume, and petrographic relationships are not fully documented. These may affect transport of radionuclides through permeable fracture systems in the Culebra Dolomite."

Response

A significant amount of effort has been given to investigating the sedimentology and petrology of the Culebra (see Powers et al. [1978]; Ferrall and Gibbons [1980]; Sewards et al. [1991]; Siegel et al. [1990]; Krumhansl et al. [1990]; Sewards et al. [1992]; Sewards [1991]; Holt and Powers [1986]; Holt and Powers [1988]; Holt and Powers [1990]; Chaturvedi [1987]; Lowenstein [1987]; U.S. DOE [1984]). A concise and accurate summary of this work can be found in Volume 2 of the 1992 PA, p. 2-19 and 2-23. As is stated there, "...clay fracture-linings may play an important role in the chemical retardation of radionuclides during potential transport...." A significant amount of information exists, and is being assimilated in conjunction with additional, more specific information that has not yet been published. This work will be published at a future date. The sensitivity of compliance to this issue will be considered for inclusion in the systems prioritization.

References

Powers, D.W., S.J. Lambert, S-E. Shaffer, L.R. Hill, and W.D. Weart, eds. 1978. *Geological Characterization Report Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND78-1596. Albuquerque, NM: Sandia National Laboratories.

Ferrall, C.C., and J.F. Gibbons. 1980. *Core Study of Rustler Formation Over the WIPP Site.* SAND79-7110; CSI 2055-03. Albuquerque, NM: Sandia National Laboratories.

Sewards, T. 1991. *Characterization of Fracture Surfaces in Dolomite Rock, Culebra Dolomite Member, Rustler Formation.* SAND90-7019. Albuquerque, NM: Sandia National Laboratories.

Siegel, M.D., J.O. Leckie, S.W. Park, S.L. Phillips, and T. Sewards. 1990. "Studies of Radionuclide Sorption by Clays in the Culebra Dolomite at the WIPP Site, Southeastern New Mexico," *Waste Management '90, Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education, Tucson, AZ, February 25-March 1, 1990.* Ed. R.G. Post. SAND89-2387. Tucson, AZ: University of Arizona. Vol. 2, 893-900.

Krumhansl, J.L., K.M. Kimball, and C.L. Stein. 1991. *A Review of WIPP Repository Clays and their Relationship to Clays of Adjacent Strata.* SAND90-0549. Albuquerque, NM: Sandia National Laboratories.

Sewards, T., A. Brearley, R. Glenn, I.D.R. MacKinnon, and M.D. Siegel. 1992. *Nature and Genesis of Clay Minerals of the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant in Southeastern New Mexico.* SAND90-2569. Albuquerque, NM: Sandia National Laboratories.

Sewards, T. 1991. *Characterization of Fracture Surfaces in Dolomite Rock, Culebra Dolomite Member, Rustler Formation.* SAND90-7019. Albuquerque, NM: Sandia National Laboratories.

Holt, R.M., and D.W. Powers. 1986. *Geotechnical Activities in the Exhaust Shaft - Waste Isolation Pilot Plant.* DOE-WIPP-86-008. Carlsbad, NM: Westinghouse Electric Corporation.

Holt, R.M., and D.W. Powers. 1988. *Facies Variability and Post-Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP-88-004. Carlsbad, NM: Westinghouse Electric Corporation.

Holt, R.M., and D.W. Powers. 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant.* DOE/WIPP-90-051. Carlsbad, NM: Westinghouse Electric Corporation.

Chaturvedi, L., ed. 1987. *The Rustler Formation at the WIPP Site.* EEG-34. Santa Fe: NM: Environmental Evaluation Group.

Lowenstein, T.K. 1987. *Post-Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico: Textural Stratigraphic and Chemical Evidence.* EEG-36, DOE/AL/10752-366. Santa Fe, NM: New Mexico Environmental Evaluation Group.

U.S. DOE (Department of Energy). 1984. *Geotechnical Activities in the Waste Handling Shaft - Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico.* WSTD-TME-038. Carlsbad, NM: U.S. Department of Energy.

Comment T112

Page 25: I. Technical Comments, C. General Geology and Hydrology

Area in document Volume 3, Page 2-81

"How was "clay porosity" measured?"

Response

Clay porosity was not measured. It was estimated by WIPP investigators (see 1992 PA, Volume 3, p. A-130).

Comment T113

Page 25: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Chapter 2, Page 2-83, Lines 9-12

"'For many of the wells, a large amount of core was lost in porous (vuggy) and/or fractured portions of the Culebra Dolomite Member. Thus only intact matrix porosity is reported here.' Vuggy and/or highly fractured zones may control flow paths in the Culebra Dolomite and measurements of matrix porosity may be inconsequential."

Response

The Project agrees that vuggy and/or highly fractured zones probably control flow paths in the Culebra, but this does not make matrix porosity irrelevant. Matrix porosity is still important because it represents the potential storage reservoir available for diffusion of radionuclides from the fractures. This diffusion will act to retard transport of radionuclides to the accessible environment. In addition to the physical retardation provided directly by matrix diffusion, sorption occurring following diffusion into the matrix porosity will provide a chemical retardation mechanism. See also response to comment in EPA document, p. 21 (I. Technical Comments, C. General Geology and Hydrology, Culebra Matrix Porosity).

Comment T114

Page 25: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 2-85, Lines 4-5

"Why did the PA models use only horizontal fracture sets? This seems unrealistic and could lead to very inaccurate model results."

Response

Comment acknowledged. The models in question (SECO2D and SECO/TP) are briefly described in Sections 1.4.5 and 1.4.6 of Volume 3 of the 1992 PA, and in more detail in Sections 7.5, 7.6 and Appendix C of Volume 2.

When modeling a formation as a dual-porosity continuum, the actual orientations of fractures are unimportant. The modeled fractures are not used to provide connections between points. The important fracture parameters to be captured in the models are the fracture porosity, which will control the flow velocity, and the surface area of the fractures, which will control

the amount of matrix diffusion that occurs. As long as the fracture porosity and surface area are kept constant, it does not matter if the fractures are modeled as single sets of horizontal or vertical fractures or as three orthogonal sets of fractures. Single sets of horizontal fractures are the simplest to model, so that is what PA has used.

Comment T115

Page 25: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 2-92/101

"Partition coefficients of radionuclides are very poorly constrained and further experimental work is necessary."

Response

An experimental program designed to address retardation is planned. This program includes

- Mechanistic adsorption studies (surface complexation modeling) on primary mineral constituents of the Culebra,
- Column experiments with intact Culebra core, and, if needed and justified
- Field sorbing multi-well tracer test.

The model describing actinide sorption to be developed from these experiments will provide data to PA.

Comment T116

Page 25-26: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 3-17

"In the Waste Retrieval Plan (DOE 93), the depth of the repository is 2,150 feet below the surface, which is the depth at the floor or sill. In the performance assessment (Volume 3), the surface elevation is given as 1,023.3 meters and the repository level at 379.0 meters or a depth of 644.3 meters, which equates to 2,114 feet -- a difference of 36 feet. Other differences include the thickness of the Magenta member of the Rustler Formation, listed as 25 feet thick in Volume 3 and ranging from 22 to 35 feet thick in reference No 90; and the thickness of the Culebra member, listed as 23 feet in Volume 3, and ranging from 22 to 29 feet in reference No. 90."

Response

We recognize that some Project-internal contradictions in quoted elevations/depths within the WIPP repository have arisen through time. As part of the plugging and sealing program at Sandia, the Project has initiated the effort of standardizing the reference depths, especially in the WIPP shafts. It should also be noted, however, that there is some variability in both depth and elevation within the repository, due to the slight dip of both the Salado Formation and the land surface.

Table 2.6-1 (pg. 2-76) of Volume 3 lists a thickness range for the Culebra of from 5.5 to 11.3 m. However, this thickness range was not sampled on for these calculations. Instead, as noted on page 2-72 of Volume 3, the "PA department has chosen 7.7 m as a reference thickness." A similar situation exists in the case of the Magenta dolomite, although it is not considered as a potential radionuclide-release pathway in these calculations.

Comment T117

Page 26: I. Technical Comments, C. General Geology and Hydrology

Area in document Volume 3, Page 3-37

"It is unclear how the range for the free-liquid diffusion coefficients in Table 3.3-4 were determined. Typically, free-liquid diffusion coefficients are determined in low ionic strength solutions which precludes competition among ions. However, diffusion coefficients for the radionuclides at WIPP should be determined under expected salinities to ensure that diffusion is not overestimated."

Response

The source of the free-liquid diffusion coefficients in Table 3.3-4 is Table E-7 of Lappin et al. (1989). A discussion of the uncertainties in these numbers is given in Section E.2.4.2 of the same document. Please refer also to: Dykhuizen and Casey (1989).

References

Lappin, A.R., R.L. Hunter, D.P. Garber, and P.B. Davies, eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989.* SAND89-0462. Albuquerque, NM: Sandia National Laboratories.

Dykhuizen, R.C., and W.H. Casey. 1989. *An Analysis of Solute Diffusion in the Culebra Dolomite.* SAND89-0750. Albuquerque, NM: Sandia National Laboratories.

Comment T118

Page 26: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 3-37

"The last sentence in the first paragraph which states "Because of the improbability of developing interconnected vertical fractures in plastic halite, this pathway is not modeled in performance assessment." needs to be supported and a reference included."

Response

Initial justification for not including vertical crack development is provided in Section 5.2.1.1, pages 5-23 to 5-27 in Butcher and Mendenhall (1993). This question raises issues that will be considered for inclusion in the system prioritization.

Reference

Butcher, B.M., and F. T. Mendenhall. 1993. *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B*. SAND92-0427. Albuquerque, NM: Sandia National Laboratories.

Comment T119

Page 26: I. Technical Comments, D. Additional Comments on General Geology and Hydrology

Area in document Volume 3, Page 5-3 (Figure 5.1-2) and Volume 3, Page 5-4 (Figure 5.1-3)

"Volume 3, page 5-3 (Figure 5.1-2). No contour interval is given for this map. It may be obvious, but the contour interval should still be indicated."

"Volume 3, page 5-4 (Figure 5.1-3). No contour interval is given for this map. It may be obvious, but this contour interval should still be indicated."

Response

Comment accepted. In Figure 5.1-2, the contour interval is 100 m. In Figure 5.1-3, the contour interval is 50 m, with the even 100-m intervals being indicated by a heavier line.

Comment T120

Page 26: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments, Time of intrusion for Modeling Purposes

Area in document Volume 1, Chapter 4, Page 4-8, Line 11

"The PA should model subsurface radionuclide releases at more than the one intrusion at 1000 years. What support does DOE have for not including additional releases? Have different time periods been modeled and put into a sensitivity analysis?"

Response

The sampling of intrusion times may be needed for a complete analysis that would be used for compliance application. The 1992 PA was not intended as a compliance application. The decision to limit subsurface release calculations to a single time of intrusion was based solely on resource limitations in 1992.

The 1991 PA included analysis of subsurface releases from 5 times of intrusion (1,000, 3,000, 5,000, 7,000, and 9,000 yr). Comparison of figures 4.1-2 (lower right frame) and 5.1-4 (upper right frame) of Volume 4 of the 1991 PA (SAND91-0893/4) shows the effect of later times of intrusion on dual-porosity subsurface releases. The 1990 PA sampled the time of intrusion (rather than including it in the probability model), and results of a formal sensitivity analysis including time of intrusion are published in Helton et al. (1991).

Reference

Helton, J.C., J.W. Garner, R.D. McCurley, and D.K. Rudeen. 1991. *Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant.* SAND90-7103. Albuquerque, NM: Sandia National Laboratories.

Comment T121

Page 27: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments, Human Intrusions in 10,000 Years

Area in document Volume 3, Chapter 2, Page 2-3 (Figure 2.1.3)

"On Figure 2.1-3, are these DOE or commercial wells?"

Response

They include both. Note that this is not an exhaustive listing of wells. As the caption indicates, it is a map of wells that provided information about general stratigraphy. Note also that the total depth of these wells is not given. Many are wells drilled for potash exploration, and do not penetrate the repository horizon. These wells should not be included in an attempt to estimate the probability of penetrating the repository.

Comment T122

Page 27-28: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments, Human Intrusions in 10,000 Years

Area in document Volume 3, Chapter 2, Page 2-3 (Figure 2.1.3)

a) "Assuming that the wells are commercial wells, a simple calculation of human intrusion based on the boreholes shown on Figure 2.1-3 derives a value of 28 boreholes/km^2 per 10,000 years. These results are based on 459 boreholes drilled on 13356.6 km ^{2}. It was assumed that these boreholes were drilled during 50 years."

b) "A study of oil and gas drilling will discover a cyclic nature. Early exploration will generally be shallow drilling with high density drilling for easy oil prospects, then this phase will subside. After a time of hiatus, the next phase will progress to deeper oil and gas prospects with additional increased density drilling. This phase may include enhanced recovery from old shallow production such as steam or water flood techniques, this may also increase drilling density. Then with advancements in technology, after another hiatus, enhanced recovery techniques will progress and deeper more aggressive prospects will be drilled."

c) "The number of boreholes drilled per area may increase with time, potentially to very high densities. The oil fields of Pennsylvania, which are more than one hundred years old, may provide a way to gain an understanding of this cycle of drilling."

Drilling Rate Model

d) "The expert panel results lead to a significantly lower number of boreholes per square kilometer in 10,000 years than suggested in the Appendix B Guidance to 40 CFR 191. The probability of zero intrusions over 10,000 years is increased from 2.4 percent for a constant drilling rate of 3.28 x 10^{-4} per year (Volume 4, Table 2.5-2) to 87 percent if the time-dependent drilling-rate function with the highest cumulative number of intrusions is used (Volume 4, Table 2.5-1). The use of "expert" opinion to reduce the drilling rate by this amount appears to belie the original intention of including the guideline of 30 boreholes per square kilometer in 10,000 years. Other expert panels could be commissioned to devise

additional future scenarios leading to lower or higher drilling rates, a situation which the guideline intended to avoid."

e) "As mentioned above, the maximum value for the drilling-rate parameter used in both the 1991 and 1992 PAs is 3.28 x 10^{-4}/year. This is equivalent to a disposal area of approximately 0.11 km^2. Yet the 1991 and 1992 PA used 0.5 km^2 as an approximate disposal area. In addition, the 1992 PA (Volume 1, page 5-3) notes that of the seventy sample vectors of inputs used in the 1991 study, the maximum number of boreholes obtained by the sampling procedure as implemented was equivalent to a drilling rate of only 20 boreholes/ km^2 in 10,000 years. This discrepancy was noted in the comments received from EEG (Volume 1, p. B-19, Comment 22) and has not been addressed adequately in the current PA."

Response

Performance assessments conducted for the WIPP have made every effort to be consistent with the provisions of 40 CFR 191 and with the guidance in Appendix C (previously Appendix B) and in the Supplementary Information published in the Federal Register with 40 CFR 191.

The reviewer's observations in parts b) and c) about exploration practices are useful.

a) We were not able to calculate 28 boreholes/km^2 per 10,000 years from the numbers provided. Using your value of 459 boreholes with an area of around 4000 km^2 for Figure 2.1-3, yields a value of approximately 22-23 boreholes/km^2 per 10,000 years. However, many of the wells in Figure 2.1-3 would not be included according to Appendix C and the supplemental information (also see response to previous comment).

An evaluation of drilling rates for areas underlain by bedded salt indicates a value of approximately 20 boreholes/km^2 per 10,000 years for New Mexico (Cranwell et al., 1990, Appendix C).

b) The discussion of the cyclic nature not just of exploration, but of development appears to be in conflict with guidance in Appendix C (previously Appendix B) that only exploratory boreholes are to be considered, not exploratory and development boreholes:

> "Therefore, inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided ;by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies."

Discussions of drilling practices and rates should carefully distinguish between exploratory wells and development wells.

The discussion of initial shallow drilling highlights a second important point. Shallow wells that do not interfere with the performance of the repository would not constitute human intrusion. These shallow wells should not be included in the calculation/consideration of boreholes/km^2 per 10,000 years.

d) There may be some misunderstanding about the use of expert judgment and the "original intent" of the guidance in Appendix C. referring to the guidance about both the "chance and consequences of intrusion" contained in the Appendix, the Supplementary Information to the 1985 Standard States:

> "The implementing agencies are free to use other assumptions if they develop information considered adequate to support those judgments" (50 FR 38080b).

Clearly, the EPA did not intend at that time to require the DOE to include 30 boreholes per square kilometer per 10,000 yr. The reviewer's comment here may imply an extension of the existing regulatory requirements.

Specifically, the following response to the reviewer's comments that "The expert panel results lead to a significantly lower number of boreholes per square kilometer in 10,000 years than suggested in the Appendix B Guidance to 40 CFR 191," and "The use of 'expert' opinion to reduce the drilling rate by this amount appears to belie the original intention of including the guideline of 30 boreholes per square kilometer in 10,000 years" is based on previously published EPA guidance.

Guidance from the EPA in Appendix C (previously Appendix B) indicates that the DOE, as the implementing agency:

> "...*should consider the effects of each particular disposal system's site, design, and* passive institutional controls in judging the likelihood and; consequences of such inadvertent exploratory drilling."

There is additional explanatory text in the Supplementary Information published in the Federal Register with 40 CFR 191 that indicates an appreciation that the value of 30 probably would and should be reduced:

> "However, assessing the ways and the reasons that people might explore underground in the future--and evaluating the effectiveness of passive controls to deter such exploration near a repository--will entail informed judgement and speculation. It will not be possible to develop a 'correct' estimate of the probability of such intrusion. The Agency believes that performance assessments should consider the possibilities of such intrusion, but that limits should be placed on the severity of the assumptions used to make the assessments. Appendix B to the final rule describes a set of parameters about the likelihood and consequences of inadvertent intrusion that the Agency assumed were the <u>most pessimistic that would</u>

be reasonable in making performance assessments [emphasis added]. The implementing agencies may adopt these assumptions or develop similar ones of their own." (50 FR 38077a)

Making assumptions allowing the effect of markers to lower the probabilities is consistent with text in the Supplementary Information:

"Therefore, determining compliance with the standards involves performance assessments that consider the probabilities and consequences of a variety of disruptive events, including potential human intrusion. Not allowing passive institutional controls to be taken into account to some degree when estimating the consequences of inadvertent human intrusion could lead to less protective geologic media being selected for repository sites." (50 FR 38080b,c)

The reviewer's comment that "Other expert panels could be commissioned to devise additional future scenarios leading to lower or higher drilling rates, a situation which the guideline intended to avoid" is inconsistent with EPA guidance. Guidance in the Supplementary Information quoted above clearly states that "informed judgment and speculation" would be involved and indicates that the impact of passive institutional controls should be taken into account when considering the likelihood of inadvertent human intrusion. In addition, the guidance clearly states that in fact there is no 'correct' value and apparently one was expected.

e) The points raised in the final paragraph call attention to errors and a lack of clarity in the PA documentation. The maximum rate constants were not the same in 1991 and 1992 (compare Table 2.3-1 in the 1991 V.2 and Table 2.5.2 in the 1992 V.4), although the difference is not significant. Both rate constants yield expected values of 30 boreholes/km^2 per 10,000 years. They differ only because the target area of the waste was adjusted from 0.109 km^2 in 1991 to 0.126 km^2 in 1992, reflecting the inclusion of the area occupied by horizontal RH-TRU waste emplacement. References to 0.5 km^2 in both the 1991 and 1992 PAs are errors. That area includes the enclosed volume (the pillars), and was not used in probability modeling. The statement that a maximum of 10 intrusions occurred in the 1992 PA is correct. However, those intrusions occurred into 0.126 km^2 rather than into 0.5 km^2. This corresponds to 79 intrusions in 1 km^2, more than twice the number suggested in the EPA guidance.

Comment T123

Page 28: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments

Area in document Volume 1, Page 4-6

"In the E1 and E2 scenarios, any plugs between the repository and the Culebra are assumed to fail immediately..." Figure 4.2-2 on page 4-6 of [Volume 3] shows permeability remaining constant for 75 years at 10^{-18} m^2 and increasing to 10^{-12} m^2 at 150 years after intrusion. Which values were used in the calculation?"

Response

The 1992 PA assumed that the borehole permeability immediately following intrusion was that of a silty sand, lognormally distributed with a range of 10^{-14} to 10^{-11} m^2 (see page 4-3 of Volume 3 of the 1992 PA). Figure 4.2-2 was included to provide background information.

Comment T124

Page 28: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments

Area in document Volume 1, Page 4-9, Lines 12-14. "It is not clear how these values for number of intrusions are related to the 70 realizations shown in Appendix D of Volume 3 where the largest number of intrusions in 10,000 years was slightly greater than one per square kilometer."

Area in document Volume 1, Page 5-3, Lines 35-37. "It is stated here that "the largest number of intrusions in the 0.5 km^2 of the waste-disposal area was 10..." The largest number shown for the 70 realizations shown in Volume 3, Appendix D, was slightly greater than 1 for one square kilometer. Why don't these numbers agree? In addition why does 0.5 km^2 appear to be used when the waste area has a footprint of about 0.11 km^2 (Volume 3, Table 3.1-1)? (As an aside it should be noted that the shifting frame of reference from holes per km^2 to holes per 0.5 km^2 creates further confusion in understanding an already complex subject.)"

Response

The discussion in the 1992 PA was less than clear.

First, all references to 0.5 km^2 were incorrect. The target area for the waste used in the 1992 PA was 0.126 km^2.

Second, the curves labeled "intrusions" in Appendix D of Volume 3 should more properly have been labeled "integrated intrusion rate". The integrated rate constant does not yield the number of intrusions that are included in the PA. Rather, it yields the expected value of the Poisson equation. (See section 5.2 of Volume 2). The assumption that drilling is random in time and space (i.e., a Poisson process) means that there is no absolute upper bound on the total number of intrusions. For any nonzero rate constant, there is always some finite probability that one more intrusion will occur within the time interval. The rate constant defines the expected value of the function, not its limit. In the 1992 PA, the total number of intrusions considered in consequence analyses were limited to either those which occurred with a probability greater than 10^{-6} in 10,000 years or to the number 10, whichever occurred first. Note that 10 intrusions in 0.126 km^2 corresponds to 79 intrusions in 1 km^2.

Solving the following simplified Poisson equation

$$p[E_n(\Delta t)] = \frac{[\lambda(\Delta t)]^n}{n!} e^{-\lambda \Delta t} \qquad (Eq\ 1)$$

for = 3.78×10^{-4} /yr and n = 10 indicates that 10 intrusions occur in 10,000 yr with a probability of 3.75×10^{-3}. As shown in Tables 2.5-2 and 2.5-4 of Volume 4 of the 1992 PA (pages 2-24 and 2-30), the assumption of 100 years of institutional control reduces this probability to 3.50×10^{-3}. Consideration of only one time interval (0-2,000 yr) reduces this probability to 4.87×10^{-9}.

Inspection of Tables 2.5-2 and 2.5-4 of Volume 4 indicates that the maximum number of intrusions occurring in the time interval (0,2000 yr) with a probability greater than 10^{-6} is 7. Thus, the largest number of intrusions included in subsurface releases in 1992 was 7. Cuttings releases calculated for all time intervals contained up to 10 intrusions.

Comment T125

Page 29: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments

Area in document Volume 2 Page 4-4, Lines 30-35

"Exploratory water-well drilling into the Culebra Aquifer is reasonable at the WIPP site and has potential consequences. Also, exploratory drilling for potash could penetrate close enough to the repository level to have consequences. To date, drilling considerations have centered only on oil and gas exploratory drilling and other possibilities have largely been ignored."

Response

Scenario development is not a closed process. These suggestions will be considered for inclusion in the systems prioritization. Direct intrusion into the waste by drilling for either potash in the McNutt zone of the Salado or water in the Culebra is not a threat because both units are well above the repository horizon.

Comment T126

Page 29: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments

Area in document Volume 2, Page 4-7, Lines 8-9

"Is there a reference for the conclusion that explosions have no effect on the long-term performance of the repository?"

Response

Yes. See Chapter 4 of Volume 1 of the 1991 PA (SAND91-0893). The appropriate text is on page 4-52, lines 5-26.

Comment T127

Page 29: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments, Drilling Rate Model

Area in document Volume 2, Page 7-26, Line 19

"The equations presented for calculating the pressure drop for turbulent flow appear accurate. ... Muds having high salt contents seldom have high gelation properties."

Response

We agree with these observations. Activities relating to them fall under ongoing cuttings release model development and laboratory studies.

Comment T128

Page 29: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments, Drilling Rate Model

Area in document Volume 2, Page 7-27, Line 23

"The possibility of high pressure gas being created by the waste material and eventually flowing into the wellbore is an important factor. Should such events occur, they would indeed contribute to the contamination problem by compromising the stability of the borehole wall and contributing to the quantity of waste material that reaches the surface."

Response

We refer to the process described in the comment as cuttings removal by spall, and currently consider its definition our top priority with regard to cuttings release.

Comment T129

Page 29: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments, Drilling Rate Model

Area in document Volume 2, Page 7-28, Line 15

"The scenario presented, in which the driller gradually works his way through such a formation is questionable, and would depend on the properties of the compacted waste material. The waste material may respond as a very compacted, solidified rock and not be detected at the surface except for its radioactive properties, or it may respond as "a Montmorillonite clay suspension" with all solids suspended in a highly pressurized slurry which flows into the wellbore. This latter scenario would be very troublesome because it would not be possible to shut the well in using normal well control procedures, without fracturing other formations in the uncased portion of the hole."

Response

We agree with these observations. However, the prospect of a montmorillonite clay suspension is considered very unlikely. Activities relating to these comments fall under ongoing cuttings release model development and laboratory studies.

Comment T130

Page 30: I. Technical Comments, E. Drilling Rate and Intrusion Related Comments, Drilling Rate Model

Area in document Volume 3, Page 3-57 (Table 3.4-1)

"Drilling erosion parameters are given here. Throughout the three volumes there is considerable discussion about the theory of drilling and the various factors that determine the effective borehole diameter in waste storage rooms. However, no values for the range and average of the effective borehole diameter or the volume of cuttings being brought to the surface was found anywhere. This type of presentation makes it very difficult for a reviewer who does not actually do the calculations with the SNL codes to evaluate the reasonableness of the computations."

Response

This was indeed an oversight in Volumes 1, 2, and 3 of the 1992 PA and will be corrected in future documentation. Typically for the 1992 PA the final eroded diameter was 2-3 times the sampled drill bit diameter.

Comment T131

Page 30: I. Technical Comments, F. Source Term, Waste Related Issues

Area in document General

"The performance assessment analysis is only as good as the data on which it is based. Using the PA to identify critical or key parameters to evaluate the overall integrity of the repository is appropriate. The PA should serve as the driver to clearly identify those parameters on which activities such as waste characterization and experimental testing need to focus. For example, assumed parameter ranges, values, or repository conditions identified in the performance assessment should be tested with experiments to the extent possible. For instance, the actinide source-term has been identified as a key component to the evaluate [sic] the total performance of the repository. The source-term test program must use a waste source reflective of a comprehensive review of waste process knowledge and characterization. This requires input from the waste characterization program. A source-term test using representative or bounding waste sets the stage to study synergistic affects waste [sic] that could support or nullify the current values used in the PA. A test performed with non representative waste does not."

Response

Non-radioactive constituents of the wastes are expected to alter the brine composition (for example, dissolution of portions of cement and/or the generation of CO_2 gas from the microbial degradation of combustibles). The brine composition controls radionuclide solubilities. The Source-Term Test Program, designed to assess the appropriateness of the Actinide Source-Term Model, uses waste forms that were selected to have significant potential impacts on the brine composition, and hence on the actinide solubilities (and potential colloid formation). The DOE invites further discussion on these topics.

Comment T132

Page 31: I. Technical Comments, F. Source Term, Waste Related Issues

Area in document General

"In addition to the experimental testing program, the PA can also identify the important parameters necessary for waste characterization. Data generated from waste experiments aimed at gas generation, solubility, viscometric functions, and evaluation of chelating agents and colloid formation, needs to be verified by identifying the appropriate waste streams."

Response

Non-radioactive constituents of the wastes are expected to alter the brine composition (for example, dissolution of portions of cement and/or the generation of CO_2 gas from the microbial degradation of combustibles). The brine composition controls radionuclide solubilities. The Source-Term Test Program, designed to assess the appropriateness of the Actinide Source-Term Model, uses waste forms that were selected to have significant potential impacts on the brine composition, and hence on the actinide solubilities (and potential colloid formation). The DOE invites further discussion on these topics.

Comment T133

Page 31: I. Technical Comments, F. Source Term, Waste Related Issues

Area in document Volume 2, Page 7-27, Line 31

"It is mentioned that the waste produced as a result of spalling is very dependent on the constitutive nature of the compacted composite waste. DOE should address in the PA its approach for determining how assumed values or ranges of factors such as viscometric functions of the waste will be supported by information obtained by characterizing waste. This would determine the complete response of such compacted waste materials, should it be

over pressured with gas. Such an occurrence is similar to what happens in normal oil and gas drilling when "unconsolidated sandstone" formations are penetrated. In such cases, if the wellbore pressure is less than that of the fluid pressure in the unconsolidated sand, immediate flow occurs, the well is blocked and prompt remedial action must be taken. Other formations which exhibit similar behavior are thick salt beds drilled at great depths, and "gumbo shale" drilled at shallow depths."

Response

We agree with these observations and they are included in our thinking in regard to direction of the ongoing cuttings release model development and laboratory studies.

Comment T134

Page 31: I. Technical Comments, F. Source Term, Uncharacterized RH-TRU Waste

Area in document Volume 2, Page 2-51, Line 19

"There is very little information about the RH-TRU waste inventory."

Response

From a Performance Assessment (PA) perspective, large quantities of data are not required for RH TRU. The waste streams are not significantly different from CH TRU except for the fuel examination samples. There is , of course, another difference - the radioactive component, which is stated relative to PA: otherwise it is only an operational concern.

Comment T135

Page 31: I. Technical Comments, F. Source Term, Uncharacterized RH-TRU waste

Area in document Volume 2, Chapter 2, Page 2-51, Line 19

"What does 'uncharacterized waste' mean in regards to RH-TRU waste?"

Response

The category "uncharacterized waste" is mentioned in the 1991 IDB (U.S. DOE, 1991); it applies to wastes that are suspected to be TRU contaminated materials but whose other characteristics are presently unknown.

Reference

U.S. DOE (Department of Energy). 1991. *Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics.* DOE/RW-006, Rev. 7. Oak Ridge, TN: Oak Ridge National Laboratory.

Comment T136

Page 32: I. Technical Comments, F. Source Term, Solubility

Area in document Volume 2, Chapter 2, Page 2-52

"What data are available on solubilities of the target elements (& their various species)?"

Response

Additional detail will be included in Project Technical Baseline.

Some data exist for solubilities of target elements in specific brine compositions, but these data cannot be generalized to cover all expected changes in brine compositions due to waste interactions with brines (including gas generation). The solubility model under development is designed to calculate the variation of actinide solubilities as a function of brine composition, which in turn will allow solubility analyses to be related to the types of waste in the repository. Large amounts of data have been generated in this program, and these data are being used to develop a numerical model. The Project is working to assimilate existing information and gather the new information necessary to complete the solubility model. The relative importance of the experimentally based ac[illegible]e concentration information compared with other information needed for the performance [illegible]ssment will be considered for inclusion in the systems prioritization analysis.

Comment T137

Page 32: I. Technical Comments, F. Source Term, Solubility

Area in document Volume 2, Chapter 2, Page 2-52

"Will the source term expert panel be superseded by actual data on solubilities and colloids? When?"

Response

The objective of the ongoing Actinide Source-Term Program is to provide model predictions of actinide concentrations in WIPP brines to the performance assessment process, where the model output includes both solubilities and colloids and the model is based on experimental data. The current plan is to use this experimentally based actinide concentrations model to support the compliance application. The relative importance of the experimentally based actinide concentration information compared with other information needed for the performance assessment included in the SP analysis.

Comment T138

Page 32: I. Technical Comments, F. Source Term, Quantity and General Form of Waste

Area in document Volume 3, Chapter 3, Page 3-9, 10.

"Please identify the quantity of radionuclides and the general form that they are in, e.g., sludge, on rags, etc. How would this effect the PA?"

Response

The quantities of radionuclides assumed in the 1992 PA are listed in Table 3.3-1 of Volume 3 of the 1992 PA; the assumed physical compositions of both CH-TRU and RH-TRU wastes are stated in Section 3.4 (see especially Table 3.4-1) of that report.

The 1992 series of sensitivity and uncertainty analyses did not investigate the effects of uncertainty in radioactivity content of the waste. The effects of uncertainty of physical compositions (varying volume fractions of cellulosics, metallics and sludges) were investigated and results of these investigations may be found in Table 9-3 of Volume 4 of the 1992 PA.

Comment T139

Page 32: I. Technical Comments, F. Source Term, Quantity and General Form of Waste

Area in document Volume 1, Page 5-4

"How sensitive are the cuttings release estimates to the waste inventory and waste form?"

Response

Formal sensitivity analyses have not been performed using an uncertain radionuclide inventory. In general, integrated normalized radionuclide releases are relatively insensitive to changes in the inventory because they are normalized to the total regulated curie content of the system. This effect can be observed informally by comparing cuttings releases from the 1991 and 1992 PAs, as shown in Figure 4.1-2 of Volume 4 of the 1991 PA (SAND91-0893/4) and Figure 8.2-3 of Volume 4 of the 1992 PA. Despite differences between 1991 and 1992 in both the total number of curies considered and the relative abundance of specific radionuclides, and the inclusion of early-time intrusions in 1992, cuttings-only CCDFs for the two PAs lie within an order of magnitude of each other.

Waste form may affect cuttings releases by influencing the amount of waste eroded by circulating drilling fluid or spalled into the borehole. The 1990 PA examined sensitivity of cuttings releases to a change in effective waste shear strength from 1 Pa to 5 Pa, and observed little effect (Bertram-Howery et al., 1990, Figure VI-5). Subsequent PAs have used a fixed value of 1 Pa for waste shear strength. Other values of waste shear strength have not been examined in full PAs. Sensitivity of eroded borehole diameter to changes in borehole roughness and waste shear strength has been reported by Berglund (1992, Figures 2-5 and 2-6). Modeling and experimental work in progress (EPP 5.4) will provide additional information about the bounding cuttings releases. More detail will be provided in the PTB report.

References

Bertram-Howery, S.G., M.G. Marietta, R.P. Rechard, P.N. Swift, D.R. Anderson, B.L. Baker, J.E. Bean, Jr., W. Beyeler, K.F. Brinster, R.V. Guzowski, J.C. Helton, R.D. McCurley, D.K. Rudeen, J.D. Schreiber, and P. Vaughn. 1990. *Preliminary Comparison with 40 CFR 191, Subpart B for the Waste Isolation Pilot Plant, December, 1990.* SAND90-2347. Albuquerque, NM: Sandia National Laboratories.

Berglund, J.W. 1992. *Mechanisms Governing the Direct Removal of Wastes from the Waste Isolation Pilot Plant Repository Caused by Exploratory Drilling.* SAND92-7295. Albuquerque, NM: Sandia National Laboratories.

Comment T140

Page 32: I. Technical Comments, E. Drilling and Intrusion Related Comments, Waste Brought to Surface

Area in document Volume 2, Chapter 4, Page 4-13

"How much waste (i.e., # of barrels and associated radiation) is assumed to be brought to the surface? What is the average and maximum curie content of the drums in these analyses? How do these values compare to the known inventory?"

Response

The volume of waste brought to the surface due to a drilling intrusion is not assumed but calculated based on several drilling parameters and the effective shear strength for erosion of the compacted decomposed waste. The computation is accomplished in the code CUTTINGS. In 1992 calculations only the drillbit diameter was sampled and all the remaining drilling parameters were set at their median values. The maximum volume computed to be released to the surface in the 1992 analyses was approximately 3.3 m^3 of uncompacted waste. The CUTTINGS code computes the curie content of the volume removed based on the best estimate of the inventory uniformly distributed over the disposal area of the repository decayed to the time of intrusion.

Transportation and WAC requirements were not explicitly considered in the formulation of the activity levels for CCDF construction, and the activities reported at later times for the highest level exceed the 200 fissile-gram-equivalent requirement of the WAC. The decision to include "nontransportable" waste in the 1991 PA was deliberate, and was based on uncertainty about future transportation requirements. (Recall that the 1991 and 1992 PAs were preliminary, and were not intended to be interpreted as compliance applications.) The effect also occurs in the 1992 PA.

The effect of the "nontransportable" waste on CCDFs is minor, and results in an overestimation of the lower-probability/higher-consequence cuttings releases. Figure 3-4 in Volume 2 of the 1991 PA (SAND91-0893/2) shows cuttings-only CCDFs calculated for a single realization using average-activity cuttings and cuttings of multiple activity levels.

Comment T141

Page 32: I. Technical Comments, G. Source Term

Area in document General

"Changes in DOE's mission are acknowledged in the 1992 Integrated Data Base (IDB 92), but only one generator (RFP) has included the effect of their waste projections and revised them accordingly. Since the initial projections of waste type, isotopic composition, production rate, and volume were based on assumptions regarding DOE's continued production of nuclear weapons and their associated support functions, these projections need to be reassessed in light of DOE's changed mission. This is not adequately addressed in the 1992 PA.

Response

The conclusion is accurate and the DOE acknowledges that additional data are required. The DOE has assigned a task to update this type of information and is planned for publication as the WIPP transuranic Waste Baseline inventory Report, Revision 1, in December, 1994. Sandia will receive the source information contained in this document by the end of November, 1994, to use in their ongoing PA analyses.

Comment T142

Page 33: I. Technical Comments. G. Source Term

Area in document Volume 1, Page 2-16

"The uncertainties associated with the source term need to be resolved. For example the PA states that 'Many of these chemicals [RCRA constituents], if present in significant quantities, could affect the ability of radionuclides to migrate out of the repository by influencing rates of degradation of the organics, microbial activity, and gas generation. The effects of these processes are being studied.' The status of these studies should be reported in the next PA."

Response

The term "chemicals" in the quoted text referred to all chemicals in the waste, and not merely the RCRA-regulated constituents. In fact, with the exception of some metals, all indications are that for most wastes, the RCRA-regulated chemicals are in insignificant quantities (Table 2-1, DOE/WIPP 89-003).

This information will be reported in future compliance applications and other documents when available.

Reference

U.S. DOE (Department of Energy). 1990. *No-Migration Variance Petition for the Waste Isolation Pilot Plant*. DOE/WIPP-003, Appendix B. Carlsbad, NM. Waste Isolation Pilot Plant.

Comment T143

Page 33: I. Technical Comments. G. Source Term

Area in document Volume 2, Page 2-47

"Using a 'scale-up' of masses estimated from expanded waste characterization information is only as accurate as the degree to which the projected waste agrees with what is produced currently. As indicated elsewhere in this report, this is very uncertain.

Response

The comment is correct. The data were entered in 1992 using available records. The DOE has initiated a task to improve the waste inventory data and has called for new projections from every site based on current site missions. This report will be issued in December, 1994, as the WIPP Transuranic Waste Baseline Inventory Report, Revision 1. A subsequent update to that document is scheduled for 1995. The 1994 data will be used for any new assessments conducted.

Comment T144

Page 33: I. Technical Comments. G. Source Term

Area in document Volume 2, Page 2-50

The PA uses the design volume for CH-TRU wastes and the RH-TRU maximum curie limit for calculations. The Integrated Data Base (IDB) in its current form cannot provide any more than a rough estimate of waste volumes, types, and isotopic compositions. Some of the sources of uncertainty in the IDB with the potential to affect the PA are as follows:

a) The rational for classifying certain RH-TRU wastes currently in interim storage at Hanford (HANF) and the Savannah River Site (SRS) is unclear. These wastes are irradiated fuel components that the sites manage as RH-TRU, apparently for administrative reasons. Based on the nature and origin of these materials they appear to better meet the definition of high-level waste as defined in the Nuclear Waste Policy Act. Should these be reclassified as

other than RH-TRU, they would not go to WIPP, which could affect performance assessment by reducing the RH component of the source term for modeling purposes.

b) The accumulation of data to produce the estimates in the IDB is disconnected from those activities that can provide the best quality information regarding radionuclide inventory, i.e., waste characterization. Additionally, there are several sources of uncertainty within DOE's waste characterization program. TRU waste generators tend to take a conservative approach when categorizing wastes, leading to classification of many "suspect" wastes as TRU. It appears that as much as 37% of these wastes could be reclassified as low-level wastes, based on their radioassay.

c) The IDB contains many internal inconsistencies, i.e., Section 3.42, Table 3.13 vs. Table 3.16. etc. Site-specific radionuclide inventories are based on the information obtained from "data calls" made to the generators. These calls take the form of requests for information on current and projected radionuclide concentrations and waste volumes. Due to the site-specific differences in waste characterization, radionuclide mix and data reporting, and the need to fit diverse data into a single format, much of this information is of limited utility.

d) The 1992 IDB lists the changes relative to the 1991 IDB. Of these, the volumes of TRU waste increased 35% for SRS, 30% for HANF, and "dramatic" for LANL; projections of future wastes from RFP were reduced and small changes in current inventories were reported for all other generators except INEL, which reported no significant changes. It is difficult to conduct reasonable performance assessments when a defining characteristic of the source term, radionuclide inventory, is subject to this amount of annual change.

Response

a) Part of the weapon's program was the sectioning of the fuel rods for metalographic examination. The fuel was irradiated specifically for the production of plutonium. These slices of fuel were polished in hot cells at Hanford and Savannah River, as well as at other laboratories. The grit, polishing material, phenolic sample holders, and small fuel samples were then discarded as RH TRU waste, because of the preponderance of plutonium contamination. Most likely these will not be reclassified as high level waste by the DOE at the sites mentioned, therefore, they are maintained in the RH TRU waste inventory. Even if they were to be reclassified, there are large inventories of other wastes that are suspect RH TRU. Those will be characterized, and if RH TRU, would fill the voided capacity.

b) The estimates made in the IDB were the results of many years of accumulation of TRU wastes. Instrumentation used for classification could not always discern the lower limits applied at that time. As these wastes are retrieved, they will be assayed with modern instrumentation and if classified as low level waste, will be removed from the CH TRU inventory. There remains a large quantity of unknown waste that will come from the DOE facility decontamination and decommissioning activities, some of which will be classified as

CH TRU. In any event, there is a sufficient quantity of waste to be generated to meet the WIPP stated volume capacity.

c) The PA used the available data and the IDB happened to be the best available . The DOE has developed an updated waste inventory, based on the Federal Facilities Compliance Act mandated Mixed Waste Inventory Report and later versions of the IDB. This WIPP Transuranic Waste Baseline Report (BIR) has been generated and is in draft for its first revision, which is due to be published in December, 1994. Sandia will receive the updated data at the end of November, 1994, for their use. The data contained in this report is more uniform than the data in the previous IDBs and future data calls will be used as the same input for both the BIR and the IDB.

d) The commentor is absolutely correct. As stated, immediately above, the DOE recognized the need to improve this situation and it is being corrected with the BIR. This is not a short term effort, however. It will take time to get all the databases into a compatible form. The 1995 data call will be only one, which will be used to supply data to the other databases. The PA will be able to use updated data beginning in December, 1994.

Comment T145

Page 34: I. Technical Comments, G. Source Term

Area in document Volume 2, Pages 2-50 and 2-51

"The first two paragraphs [of Section 2.3.3 of Volume 2] correctly note the uncertainty in the future radionuclide inventory caused partially by anticipated changes in weapons production. This inventory change is likely to also change the radionuclide composition and this could affect the location of the CCDF curve. Changes in the waste form mix could also alter the fraction that escapes to the accessible environment."

Response

This comment is acknowledged.

Comment T146

Page 34-35: I. Technical Comments, G. Source Term

Area in document Volume 2, Page 2-51, Line 20-23

"The number of curies of RH-TRU in Peterson's memo is incorrect because his Table 4 does not contain all the short-lived radioactive daughters of Cs-137, Sr-90, Ru-106, and Ce-144.

The WIPP Land Withdrawal Act (PL 102-579, Section 7) limitation of 5.1 million curies in RH-TRU waste includes all the short-lived radioactive daughter products. The total in Table 4 should be 3.97 million Curies. Also, the TRU waste unit factor from Table 4 should actually be 3.91 E+04 because Cm-244 has a half-life of < 20 years and should not be included."

Response

This comment is acknowledged. Peterson's memo was prepared using the only documented material available at the time (e.g., DOE, 1991) and all of that material predated the passage of the WIPP Land Withdrawal Act (October 1992). The EPA Standard, 40 CFR Part 191, Subpart B, was the only standard guiding selection of radionuclides that should be counted among the WIPP inventory in the 1992 PA.

Reference

U.S. DOE (Department of Energy). 1991. *Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics.* DOE/RW-006, Rev. 7. Oak Ridge, TN: Oak Ridge National Laboratory.

Comment T147

Page 35: I. Technical Comments, G. Source Term

Area in document Volume 2, Page A-3, Line 24

"It was stated previously, on page 7-5, line 4, that the amount of gas in the brine is negligible, but here it states that gas exists in the brine. Why? Is the amount of gas in the brine considered in the flow equations? Is the change in gas solubility with changing pressure considered?"

Response

The only significant effect of gas dissolved in brine recognized to date is the effect of gases such as CO_2 and H_2S on brine pH. Brine pH is extremely important to corrosion and gas generation calculations and potentially to radionuclide solubilities. The effect of dissolved gases on brine physical properties is considered to be minor, although future model calculations will address this question. Solubility data for gas dissolved in brine are summarized by Cygan (1991).

The two-phase flow equations solved by BRAGFLO and described in Volume 2, Appendix A, of the 1992 PA contain terms which account for the effect on flow of dissolving gas in brine and its gas solubility dependence on pressure. In the case of H_2, the dominant

gas phase component, this effect is of a secondary nature and the term in the equation was assumed to be zero in the 1992 calculations. If significant amounts of CO_2 are present, which is likely if biodegradation occurs, then more significant amounts of dissolved gas may occur. The Project is currently investigating this effect on brine and gas flow through numerical modeling sensitivity studies.

Reference

Cygan, R.T. 1991. *The Solubility of Gases in NaCl Brine and a Critical Evaluation of Available Data.* SAND90-2848. Albuquerque, NM: Sandia National Laboratories.

Comment T148

Page 35: I. Technical Comments, G. Source Term

Area in document Volume 3, Page 3-20, Line 22

"The estimated inventory also includes over 600,000 Ci each of Strontium-90 and Cesium-137 which have half-lives greater than 20 years."

Response

Inventories of Sr-90 and Cs-137 are listed in Table 3.3-1 of Volume 3. Indeed, the inventory of each of these radioisotopes is over 600,000 Ci.

Comment T149

Page 35: I. Technical Comments, G. Source Term

Area in document Volume 3 Page 3-20, Line 34

"The volume limit on RH-TRU waste is 250,000 ft^3 (about 7,080 m^3) not 250,000 m^3."

Response

Comment noted.

Comment T150

Page 35: I. Technical Comments, G. Source Term

Area in document Volume 3, Page 3-21

"DOE has often used detailed data from generators and draft reports (that have not been made available to reviewers) to develop their inventory (e.g., Peterson in Appendix A cites Draft Report DOE/WIPP 91-058). It is very important that all of this input data be made accessible to EPA.

Response

All relevant information and data sources used in the demonstration of compliance will be made available to the EPA.

Comment T151

Page 35-36: I. Technical Comments, G. Source Term

Area in document Volume 3, Page 3-28

"The statements made on this page about RH-TRU being of less long-term concern than CH-TRU are correct for the current understanding of the RH-TRU inventory. However, the inventory is much more uncertain than that for the CH-TRU. Little attention has been given to the behavior of an RH-TRU canister after it is placed in the wall of a CH-TRU storage room and creep closure begins. The RH-TRU canister is simply three 55-gallon drums of untreated waste placed inside a metal pipe that is sealed at each end. The waste is expected to have gas generation characteristics similar to CH-TRU waste of the same composition. The RH-TRU waste would have a surface area about 13% of the CH-TRU and this area needs to be included when calculating the number of drilling intrusions. The statements about RH-TRU will need to be verified by a more detailed analysis in the future."

Response

The gas generation potential associated with the RH-TRU waste, containers, and plugs is included in the current 1994 data base. It was not considered for the 1992 PA "snapshot".

The repository footprint used to determine the number of drilling intrusions was increased 15.5% (from 1.09×10^5 m^2 in 1991 to 1.26×10^5 m^2 in 1992) to account for emplacement of RH waste in the side walls. This larger footprint value was used in the 1992 PA calculations (Volume 3 of the 1991 PA [SAND91-0893/3], p. 5-17, line 45; Volume 4 of the 1992 PA, p. 2-20, line 35).

Comment T152

Page 36: I. Technical Comments, G. Source Term

Area in document Volume 3, Page 3-36 to 3-43

"It is clear that the radionuclide solubilities estimated by various workers show a very large range, and that these solubilities are dependent on the pH and Eh of the solutions. As noted in the PA, better understanding of the radionuclide solubilities under conditions similar to those expected to exist at WIPP is essential to reducing the overall uncertainty in the PA."

Response

The objective of the ongoing Actinide Source-Term Program is to provide model predictions of actinide concentrations in WIPP brines to the performance assessment process. Where the model output includes both solubilities and colloids, the model is suitable for post-closure conditions expected to exist at WIPP, and the model is based on experimental data. The relative importance of the experimentally based actinide concentration information compared with other information needed for the performance assessment will be considered for inclusion in the systems prioritization analysis.

Comment T153

Page 36: I. Technical Comments, G. Source Term

Area in document Volume 3, Page 3-55, 1st paragraph

(Restatement) The commentor notes two typographical errors on page 3-55 of Sandia WIPP Project, 1992.

Response

Thank you for pointing out these typographical errors.

Comment T154

Page 36: I. Technical Comments, G. Source Term

Area in document Volume 3, Page 3-55, 2nd paragraph

"RH-TRU waste to be emplaced at WIPP is limited by volume to 7.08×10^3 m^3 and by activity to 5.1×10^6 Ci."

Response

Agreed.

Comment T155

Page 36: II. Format and Content, Stand Alone Document

Area in document Throughout

"The performance assessment should be a stand alone document as much as possible. Key referenced information should be included, and references should be minimized. In order to help develop the next PA, DOE may want to develop an 'example section' for external comment."

Response

The DOE has prepared the 1994 Compliance Status Report (CSR), in part, to solicit external comment on the appropriate format and content of a compliance application. It would be helpful for EPA to revisit this comment when reviewing the CSR and indicate whether the CSR outlines an appropriate approach for a compliance application. Note that the PA is incorporated into the CSR as an integral part of compliance documentation as apposed to a stand-alone document. The usefulness of the comment as it applies to a future compliance application is acknowledged.

Comment T156

Page 37: II. Format and Content, Including Examples

Area in document Volume 2, Page 3-1, Page 6-1, Throughout

"The PA should include calculations (e.g., associated with CCDFs and Latin Hypercube Sampling) with actual data to illustrate how the mathematics were implemented."

Response

This was done in Chapter 3 of Volume 2 of the 1991 PA (SAND91-0893/2) for sample element 46. LHS input vectors and selected performance measures are reported for all sample elements in the 1992 PA in appendices to Volumes 4 and 5 of the 1992 report.

Comment T157

Page 37: II. Format and Content, CCDF Development

Area in document Volume 1, Chapter 3, Page 3-18, Line 19

"The development and construction of CCDFs should be explained in more detail, with examples actually used, in the PA to the EPA. How are computational results converted into the CCDF display format: What uncertainties are introduced?"

Response

This material can be included in the compliance application. Chapter 3 of Volume 2 of the 1991 PA (SAND91-0893/2) contains a useful discussion of this subject.

Comment T158

Page 37-39: II. Format and Content, Latin Hypercube Sampling

Area in document Volume 1, Chapter 4, Page 4-9, Line 39; Page 4-14, Line 9

"The discussion on Latin Hypercube Sampling (LHS) is incomplete. There should be an example of how it was used in the performance assessment. Does LHS introduce additional uncertainty into the PA?"

"Please provide evidence that 4/3 times the number of uncertain variables is sufficient for Latin Hypercube Sampling procedures. The reference quoted in the PA provides no further information on the specific criteria."

Measures of Sampling Error for Estimated Curves

"The lack of information on sampling error for LHS-derived estimates is a serious omission in the current PA methodology. When summary curves, such as the mean or percentile CCDFs, are generated from the set of LHS CCDFs, a procedure for determining the sampling error of the estimated mean and percentile curves should be established. One procedure suggested in the PA is to use multiple LHS samples. An alternative procedure for estimating sampling error based on resampling methods within a single LHS sample may be more efficient."

"It is to be expected that estimates of the mean and extreme percentiles will have rather wide regions of sampling variation for a sample size of 70. After such analysis, it may be found necessary to reduce the magnitude of sampling error by increasing the sample size."

"The sampling error may also vary with the level of the normalized release. Information on such variation would be required to determine the level of confidence for concluding that the selected summary curve satisfies requirements (1) and (2) of Section 191.13(a)."

Correlation between LHS variables

"Current LHS procedures treat the uncertain input variables as uncorrelated. Although this is a generally accepted statistical practice, some justification for this assumption is necessary. Several variables may be expected to exhibit correlation, such as permeability and porosity. Others may also be identified. Parameters with strong correlations should transformed to a more orthogonal parameterization for the LHS procedures. For example, if the parameters $X > 0$ and $Y > 0$ are strongly correlated, then a new parameterization defined as X and the ratio X/Y will often be less correlated."

List of Variables not included in LHS Procedures.

"The selection procedure by which variables were excluded from the LHS procedures is unclear. Starting with a list of all input variables, and the models affected by each, documentation should be provided of the reasoning by which each variable was excluded from the LHS procedures. What evidence can be presented that these excluded variables are 'better known' than those selected for assignment of LHS distributions? The sensitivity of model results to these variables and estimates of the precision of each variable should be included in a discussion of the rationale for their selection or omission."

Response

More complete discussions of LHS can be found in Chapter 3 of Volume 2 of the 1992 PA, in Chapter 3 of Volume 1 of the 1991 PA (pages 3-62 and following), and in references cited in those places.

The Project is currently investigating the issues of the "four thirds" rule, the effect of sample size on CCDFs, correlations between LHS variables, and documentation of selecting variables for sampling.

There is no specific evidence that the "four thirds" rule is sufficient for analyses of this type. The rule has been used for convenience, and demonstration of its acceptability remains to be done.

The reviewer's comments on the lack of information about the effect of the sample size on the location of the summary CCDFs are useful.

Correlations between LHS variables will be included when a defensible basis for such correlations is available. Until data are available to defend correlations, it is appropriate to sample variables independently.

The reviewer's comment on the need for documentation on the method for selecting variables for sampling is useful. Such documentation can be included in a compliance application. Some clarification of how "variable" is defined may be useful: there are many "constants" used in modeling.

Comment T159

Page 39: II. Format and Content, List of Variables not Included in LHS Procedures

Area in document Volume 1, Pages 5-9 to 5-15.

"These CCDF plots for different conceptual models and the supporting discussion are very useful and lead to several observations. The points noted below assume the plots are correct although it will be necessary in the future to thoroughly review the models, the probabilities, and the calculations."

> "(1) The PA department's "most realistic conceptual model" indicates that releases are less than 1% of the amounts allowed by the Standard. Yet some of the values being used are unproved; e.g., the use of plutonium solubility values that are two to three orders-of-magnitude less than those being found in SNL laboratory reports (SAND92-1579). The very important drilling rate parameter is less than 1% of the maximum suggested in the Guidance to the 40 CFR 191 Standard. The K_d=0 assumption is consistent with the agreement between DOE and the State of New Mexico unless valid experimental values are obtained.
>
> (2) The maximum curve plotted has releases that are 30-40% of the Standard. While it seems unlikely that both the K_d and single porosity values will turn out to be as pessimistic as indicated here, several potentially negative phenomena are not incorporated. These include: (a) various scenarios bringing brine to the surface; (b) greater solubility values for transuranics in the waste storage room and Culebra Aquifer; (c) the formation and transport of colloids in the Culebra Aquifer or to the surface; (d) uncertainties in the inventory; (e) uncertainties in the scenario probabilities; and (f) use of the maximum drilling rate of 30 boreholes/km^2 over 10,000 years."

Response

All but one of the reviewer's points here are essentially correct and well taken. The 1992 PA was not intended to be a compliance application. Most of these caveats are noted in the text of the 1992 PA. (See, for example, page 6-3 of Volume 1 of the 1992 PA for comments about additional work needed in the areas of actinide solubility, K_ds, and brine flows to the surface.) Because 40 CFR 191 sets limits on the probability of radionuclide releases that have been normalized to the total transuranic inventory in the system, performance is not likely to be strongly sensitive to uncertainty in the radionuclide. This

observation has not been tested by formal sensitivity analyses, but can be partially supported by comparison of the 1991 and 1992 preliminary PAs, which used different inventories.

One point warrants further discussion. The reviewer's implied requests for the use of the maximum intrusion rate and a consideration of the effect of uncertainties in scenario probabilities are inconsistent. The 1991 and 1992 PAs used a sampled intrusion rate constant, rather than a fixed value, specifically to allow consideration of the uncertainty in scenario probability. If the guidance in the Standard is to be interpreted as specifying both the most severe intrusion scenario to be considered and its probability, then there is little remaining uncertainty in scenario probabilities.

Comment T160

Page 40: II. Format and Content, Estimated Dose

Area in document Volume 1, Chapter 3, Page 3-23, Line 23

(a) "EPA needs to have the complete detailed method used to estimate dose included in the PA."

(b) "In addition, future assessments will need to use the committed effective dose as required in the new 40 CFR 191."

Response

(a) The complete, detailed method used to calculate committed effective dose can be included in a compliance application. The GENII-S code is capable of calculating the committed effective dose. There was no detail on this code provided in the 1992 PA because no radionuclide releases occurred from the undisturbed repository and therefore doses were zero. The detail requested will be provided in the Project Technical Baseline (PTB) report.

(b) All aspects of 40 CFR 191, including those portions repromulgated in December 1993, will be incorporated in future performance assessments.

Comment T161

II. Format and Content, Definitions

Area in document Activity load categories (Volume 1. Page 5-6, Line 29) Gauge Borehole (Volume 2, Chapter 7, Page 7-25, Line 3) Dimensions of the controlled area (Volume 1., p 3-5) Salt String (Volume 2., Chapter 7, Page 7-24, Figure 7-6)

"Please explain 'Salt String'. Oil and gas operators in the Delaware Basin 'set' an intermediate string of approximately nine inch casing at around 4000 feet depth. This string of casing appears to be at the lower limit of the salt beds. Is this casing the same as 'salt string'?"

CH-TRU vs RH-TRU (General)

"How does DOE define radioactive waste (as RH-TRU or CH-TRU) if the surface dose exposure is < 200 mrem/hr because of internal lead shielding?"

"Since a performance assessment is such an interdisciplinary activity, it would be useful to have a glossary of terms in addition to the list of acronyms."

Response

The State of New Mexico Oil Conservation Division (OCD) provides a detailed definition of the "Salt Protection String" required in the Potash Area of Eddy and Lea Counties (including the WIPP) in Order R-111-P:

> "A salt protection string of new or used oil field casing in good condition shall be set not less than one hundred (100) feet nor more than six hundred (600) feet below the base of the salt section; provided that such string shall not be set below the top of the highest known oil or gas zone." (OCD Order R-111-P, page 7; two additional pages of text follow specifying procedures for installation of the salt string).

The distinction between CH-TRU and RH-TRU waste for transport to the WIPP is described in the WIPP Waste Acceptance Criteria (U.S. DOE, 1991) on page 3-45, and is based on TRUPACT-II Requirements.

> "The external dose rates on the loaded TRUPACT-II placed on the trailer are limited to 200 mrem/hr at the surface of the TRUPACT-II and 10 mrem/hr at two meters. Dose rates on the TRUPACT-II must comply with 10 CFR 71.47. Drums or SWBs shall not exceed the 200 mrem/hr surface reading or 10 mrem/hr at two meters. Shielded waste containers are allowed for As Low As Reasonably Achievable (ALARA) purposes only and must comply with Section 12.0 of Appendix 1.3.7 of the TRUPACT-II SARP."

The TRUPACT-II SAR (page 1.3.7-55) further states:

"Occasionally, drums of TRU waste that meet the radiation level (surface dose rate) requirements require ALARA/dose reduction shielding to meet DOE site requirements....If the measured radiation levels are below the specified levels, but do not meet the site criteria, shielding may be added to the drum."

A glossary of terms can be included with the compliance application if necessary.

Reference

U.S. DOE (Department of Energy). 1991. *Waste Acceptance Criteria for the Waste Isolation Pilot Plant.* WIPP-DOE-069, Rev. 4. Carlsbad, NM: Westinghouse Electric Corporation.

Comment T162

Page 41: II. Format and Content, Use of Bounding Analyses in PA (General)

Area in document General

"The PA should include results from bounding analysis in areas such as the evaluation of alternative conceptual models."

Response

While there may be cases when bounding analyses are appropriate, they, as a general rule, are discouraged for compliance determinations. The reason for this is clear, the Standard encourages reasonableness in expectation. Bounding analyses may be useful for parameters that are of little consequence or alternative conceptual models that are clearly bounded by the conceptual model being pursued.

Comment T163

Page 41: II. Format and Content, Misnumbered Equation

Area in document Volume 2, Appendix A, Page A-14, Line 1

"Should Equation (A-11) be (A-10)?"

Response

Yes.

Comment T164

Page 41: II. Format and Content; Potential WIPP Resources

Area in document Volume 1, Page 2-4

"There should be an update on the potential resources at and around WIPP. These should be portrayed graphically, so that it is clear where the expected resources are located."

Response

The Project has initiated a re-evaluation of resources based on available data and current market conditions. This information will be part of the Project Technical Baseline and will be used in the compliance application.

Comment T165

Page 41: II. Format and Content, Additional Format and Content Comments

Area in document Volume 1, Page 4-6

"The statement is made that Volume 4 of the 1992 PA documentation will contain preliminary analyses of the potential for the releases of radionuclides dissolved in brine at the ground surface. No analyses or discussion of this scenario was found in Volume 4."

Response

The analyses were not performed because of time and resource constraints. They will be considered for inclusion in the systems prioritization. The decision to omit the analysis was made after publication of Volume 1.

Comment 166

Page 41: II. Format and Content, Additional Format and Content Comments

Area in document Volume 1, Page 5-17, Lines 25-27

"It states here that Volume 4 will contain results of the 1992 preliminary performance assessment for informal comparison with the Individual Protection Requirements. Volume 4 does not contain these results."

Response

Volume 4 does not highlight the results of the undisturbed performance analyses in its Abstract or Conclusion. The results are reported in considerable detail, however, in Chapter 4 of Volume 4, "Undisturbed Performance (Repository/Shaft)." The conclusion is clearly stated on page 4-53, lines 1-3: "Neither in the previous [1991] analyses nor in the 1992 PA was there any release of contaminated brine to the accessible environment in the undisturbed scenario."

Comment T167

Page 42: III. Models, Conceptual Models

Area in document Throughout; Volume 1, Chapter 6, Page 6-1, 6-2

"Conceptual models should be fully explained and justified (soon) so that EPA and the public understand the conceptual models that DOE plans to use in its compliance assessment package. Future assessments should include the reasons why discarded conceptual models are no longer being considered."

Response

Alternative conceptual model screening will be part of the SP.

Comment T168

Page 42: III. Models, Conceptual Models

Area in document Throughout; Volume 1, Chapter 6, Page 6-1, 6-2

"The PA uses 'three conceptual modes for radionuclide transport in the Culebra and two approaches to estimating the probability of inadvertent human intrusion into the WIPP by

exploratory drilling.' (The 1,000 year period used for the comparison limit needs to be revised to a 10,000 year period.)"

"What other alternate conceptual models are to be included in the future? The PA should contain results using alternative conceptual models where there is a significant difference between the alternatives, and the models that DOE prefers."

Response

The SP will examine other alternative conceptual models. The Project agrees that consideration of alternative conceptual models is an important part of the PA. It is not possible now to list alternatives that will be identified and considered in the future.

(Regarding the parenthetical comment, the Project agrees that intrusions need to be considered in the full 10,000 yr time interval. Note that the integrated releases displayed in the 1992 PA do consider a 10,000 yr period for transport. Only the time of intrusion is limited to 1000 yr.)

Comment T169

Page 42: III. Models, Computer Generated Maps

Area in document Volume 2, Chapter 2, Figures 2-9, 2-14, 2-16 to 2-17

"The grid spacing selected for the computer generated maps could be improved. For example, on the southern half of the map in figure 2-18 the computer generated "goose eggs" around the sparse well data look questionable. A more realistic map would continue the regional character and shape established in the northern portion of the map."

Response

The point is well taken: the "goose eggs" are probably not realistic. However, subjective contouring of sparse data could create the impression of more information than is actually available. A more suitable approach might be to simply display the data points without contours.

Note that the maps are shown for display purposes only. These contours are not used in quantitative consequence analysis.

Comment T170

Page 43-44: III. Models, Code Linkage and Data Flow

Area of document Volume 2, Section 1.3, Page 1-3 through 1-5

"The discussion of code linkage and data flow in Section 1.3 of Volume 2 is incomplete. The secondary data base, which contains all the information on the conceptual model that is utilized by the WIPP performance assessment analyses, is discussed in one brief paragraph. No information is presented on the structure of the files in this data base, how access to the data is controlled, QA procedures, etc. The computational data base CAMDAT, which is at the heart of code linkage in the PA analyses, receives an even briefer discussion--there is no explanation of what is meant by the "zig-zag" connection nor how it is achieved."

"Contrary to the assertion in the report that CAMDAT is fully described in the CAMCON user's manual (Re 92), that manual still fails to present a comprehensive discussion of the structure of the data base and its role in code linkage and data flow, although it presents a brief conceptual discussion of CAMDAT which somewhat expands the previous discussion. It is necessary to turn to a third reference, a separate report on this topic (Re 89), to find such information. This last report does, in fact, present a thorough discussion of the structure and function of the two aforementioned data bases. This material should be included in the PA report."

"The overall plan for code linkage and data flow described in the PA report and the supporting documents cited above, if fully implemented, constitutes a consistent and tractable methodology for assessing the performance of the repository at this stage of the analysis."

"One shortcoming of the 1992 PA was the failure to integrate several key codes into the CAMCON system, namely BRAGFLO, SECOTP2D and CUTTINGS. Since 70 simulations of three distinct scenarios were analyzed, this posed a large burden on the individual analysts, requiring hundreds of manual data transfers with concomitant chances of errors and breakdowns of the QA process. Integrating these codes should be a high priority."

"Given the fact that substantial manual data transfer is currently necessary, it is unclear how uncertainty and parameter sensitivities are being carried through from one model to the next. For example, once the sensitivity and uncertainty analysis is performed on the source-term model, how are the distribution of release rates, etc. being input into the flow and transport models such as SECO and BRAGFLO? Furthermore, it is not clear how sensitivities to various uncertainties associated with the model boundary conditions for each of the models are being accommodated within the analysis."

"Two areas where improvements could have major impacts on future PAs are better code integration and expanded computational facilities. Despite its current drawbacks, the CAMCON system is a practical approach to linking disparate codes which have been and

continue to be developed by various code designers working with specialists in different disciplines. It seems to be a suitable methodology to use at the present state of model development. However, in the long run, CAMCON is not a substitute for a single, fully integrated model. As described in the cited references, it is not computationally efficient. Each pre- and post-processor to the major codes involves additional computational steps. Furthermore, running each code *ab novo* for each realization involves many repetitive calculations, whereas a fully integrated model should be able to repeat only those calculations required by a changed parameter, in some cases perhaps scaling the results of a previous calculation. More than inconveniencing the analysts, this lack of efficiency severely limits the scope of the analysis, limiting the number of Monte Carlo simulations, the complexities of the models which can be employed, and the number of scenarios which are modeled."

Response

CAMCON and CAMDAT are an integral part of the code linkage and data communication process which provide the computational structure of WIPP performance assessment. It is important that sufficient detail be presented in a compliance application or supporting information that the regulator can easily understand the computational structure and methodology used. The level of detail in describing CAMCON and CAMDAT in Section 1.3 of Volume 2 is inadequate and will be expanded for the application.

The Project is currently investigating the issue of software QA. Computational codes such as BRAGFLO, SECO TRANSPORT 2D, and CUTTINGS were not included within the CAMCON system primarily because these codes were still in the development and transition stages. One of the highest priority tasks for PA in 1994 is in the area of software QA. BRAGFLO currently receives all of its input from CAMDAT via a pre-processor and writes all of its output to CAMDAT via a post-processor.

Manual data transfer was not done in the 1992 PA. This was an unfortunate choice of words which incorrectly suggests that the data entry and data transcribing process was inconvenient,

Inefficient, and possibly error prone. Actually, what was meant by "manual data transfer" was "electronic data transfer outside of the CAMCON executive controller." This involved the direct reading of output of one model by another to obtain the latter's input.

The issue of using a single numerical model was considered in the past and dismissed. In a modeling environment as large as that of the WIPP PA, and characterized by diverse and distinct phenomena occurring in well-defined regions within the repository and natural barrier systems, it is not only inefficient but undesirable to develop a single all-encompassing numerical model. It is inefficient because phenomena important in one region would be carried along as extra baggage in other regions. Sensitivity analyses often require intermediate results which focus only on the performance of a small portion of the disposal system, and should not require running the entire modeling system. It is more efficient to split the larger picture into smaller, more manageable, portions and model each portion's

particulars as rigorously as necessary. The amount of computational effort expended in linking the models together is negligible compared to the effort of simulating the physics. The CAMCON approach is computationally efficient when placed in the context of the PA modeling scope and demands.

Comment T171

Page 44-45: III. Models, Cuttings Model

Area in document General

"Most of the technical assumptions and data quality appear to be reasonable and accurate."

"It is important to reiterate the comment that the spalling mechanism is difficult to handle and is not well understood. This does not mean the issue should not be vigorously addressed. Using the 'Unconsolidated Sand' analogy, as discussed in the SAND92-7295 report, is a good approach."

"Assumptions made for the calculation of erosion including effective shear strength for erosion of waste material and volume of material discharged to the surface need further technical support. The plugging and abandoning procedures and the data for drilling in the Delaware basin seem to be in order."

"One obvious weakness observed in the CUTTINGS model is the lack of physical property data for the waste material. The predictions for drilling, erosion, and spalling, are highly dependent on the material properties. These properties may need to be developed through a joint effort between people working on performance assessment and waste characterization. A very soft, highly pressurized material may present a unique 'blow-out' potential."

Response

The Project is currently investigating the issue.

We agree with these observations and they are included in our thinking in regard to direction of the ongoing cuttings release model development and laboratory studies (see EPP 3.2.4.3, 5.4.3.1, 5.4.3.2).

Comment T172

Page 45: II. Format and Content, Cuttings Model

Area in document General

"A second weakness observed is in the rheology model which used only two data points to develop a model which describes the entire rheogram."

Response

The observation is correct. The data used to characterize the high salt drilling mud is consistent with a Bingham model which requires only two parameters, the plastic viscosity and yield point. To fully define the Oldroyd model the ratio of the initial viscosity (at zero shear rate) to the plastic viscosity is also necessary.

A high-salt, water based mud is assumed to be the drilling mud used when drilling through the Salado. The Oldroyd model requires a value for the ratio of the initial viscosity (at zero shear rate) to the plastic viscosity, to fully define the model in the low shear regime. This ratio was not available for a high-salt, water-based mud in 1992 so a ratio based on an oil based mud was chosen. Since high shear rates occur at the borehole wall the value chosen for the ratio was expected to have little impact on the final model diameter. The Project is evaluating the sensitivity of eroded diameter to this issue.

Comment T173

Page 45: III. Models, Cuttings Model

Area in document Volume 2, Figure 7.6, Page 7-24

"Figure 7.6 located on page 7-24 of Volume 2 shows the drill pipe being rotated an a counter clockwise direction, which is inconsistent with standard drilling processes. Although this misrepresentation will not affect the actual calculations for waste removal, if does present an unrealistic condition which could be construed as lack of understanding of drilling technology. Should the drill pipe be rotate as shown, the entire drilling assembly would come apart because of the tool joint would unscrew as torque is applied to the bit."

Response

Thank you for pointing out this error. The rotation direction in the figure has been corrected.

Comment T174

Page 45: III. Models, Cuttings Model

Area in document General

"In Volume 2 of SAND 91-0893 it is stated, on page 7-16, that when modeling erosion, turbulence existed as the hole washed out from 0.4445 m to 0.994 m. It is difficult to imagine flow through a 0.994 m wellbore having a Reynolds number of 4319. This calculation should be checked."

Response

The computation was rechecked and found to be correct.

Comment T175

Page 45-46: III. Models, Cuttings Model

Area in document General

"In further refining the CUTTINGS model, the following should be considered:

- Include uncertainties associated with the range of waste inventory instead of basing source term on drum equivalent.
- Additional analyses are needed on the practicability of drilling exploratory wells in the Delaware basin using slim holes
- The physical properties including viscometric properties of compacted slurries of waste material are needed. Evaluations possibly tests should be performed under drained and undrained conditions.
- Spallation predictions are an important topic requiring additional work.
- A more detailed rheogram, based on multi-speed viscometer data, should be used for calculating shear stresses at the wellbore wall, and for calculating the occurrence of turbulence for a multiphase non-newtonian fluid of cuttings and drilling mud.
- Local concentrations of radionuclides near the waste panel should be added to the cuttings volume"

Response

These comments raise issues that will be considered for inclusion in the SP.

Comment T176

Page 46-47: III. Models, BRAGFLO Changes

Area in document Volume 2, Appendix A, Page A-19, Line 10Volume 2, Chapter 7, Page 7-3 to 7-5

"When you say 'time constraints' do you mean you don't have enough time to accomplish the changes to BRAGFLO, or do you mean that the code itself takes so long to run? It would seem the addition of general behavior would enhance versatility and the value of BRAGFLO. Will there be time in the future to generalize this aspect of BRAGFLO?. . ."

". . . However, based on the presentation of boundary condition formulation on Page A-17 of volume 2, it does not appear that the well boundary conditions are properly formulated."

Response

Clarification of the 1992 PA, Volume 2, Page A-19, lines 9-10:

> "To program the integration and summary calculations to be completely general to enable it to perform on any mesh is not feasible under the PA time constraints."

The time constraints referred to are not computing or run time for BRAGFLO, but rather analysts' and code developers' time. This includes code that might make BRAGFLO more versatile or easier to use for users outside PA. Tools already existed for performing the integrations and summary calculations outside BRAGFLO within the CAMCON system. Although BRAGFLO had not been adapted to use these tools in the 1992 version, the code has since been upgraded to use them. BRAGFLO can now print out "history variables," which are results printed out at every time step, thereby enabling integrations to be performed in post-processing to the same degree of accuracy as they could be done internally to BRAGFLO. Algebra is then used to perform integrations or other summary calculations. This capability frees BRAGFLO from having to be hard-wired to a particular mesh.

Clarification of the BRAGFLO boundary condition treatment:

In BRAGFLO, relative flows of each phase across the boundary in a grid block containing a constant pressure well are proportional to their relative saturation in the well block. In this way, the model does calculate these percentages.

Comment T177

Page 47: III. Models, BRAGFLO Changes

Area in document Volume 2, Appendix A, Page A-19, Line 10; Volume 2, Chapter 7, Page 7-3 to 7-5

a) "The temporal and spatial discretization methods used in BRAGFLO are very inefficient and would lead to very long simulation times. Specifically, the finite-difference spatial discretization scheme should be reexamined; numerous pre-processing packages are available to facilitate the finite element grid construction, thus eliminating any advantage of the finite-difference techniques. This is particularly true when a telescoping mesh procedure is used in the WIPP modeling to refine the model domain. A finite-element mesh would have allowed the same descretization without sacrificing the ability to evaluate the sensitivity as the solution to regional model boundary variations."

b) "It is stated on page A-5 of volume 2 that 'The BRAGFLO flow model simultaneously solves five equations.' This approach is very inefficient and by substituting the constraints into the balance equations only two unknowns would have to be simultaneously solved. Furthermore, adaptive implicit procedures exist which would allow only one unknown to be solved at nodes where only one phase (i.e., gas or brine) exists."

Response

a) The temporal discretization method used in BRAGFLO is adaptive and therefore efficient. The spatial discretization and solution method is driven by the need for robustness. The particular 2-phase problems solved for the WIPP, with large pressure gradients and property discontinuities (of several orders of magnitude) is very demanding of numerical methods.

b) BRAGFLO actually only solves two equations per grid block. The three constraints are used to eliminate unknowns in the differential equations. The unknowns solved for are brine pressure and gas saturation. Adaptive implicit methods, adaptive in the sense of switching dependent variables, are difficult to implement in a robust form when the dependent variable at a node/element switches within a time step, i.e., when one phase disappears or reappears.

Comment T178

Page 47-48: III. Models, BRAGFLO Changes

Area in document Volume 2, Appendix A, Page A-19, Line 10; Volume 2, Chapter 7, Page 7-3/5

"The PA assumes that the properties of the gas phase are approximated by those of hydrogen (Volume 2, p. 7-3). The PA further states that using hydrogen serves as a 'worst case'

analog because hydrogen is much less viscous than the other gases expected to exist in the repository (CO_2, etc.) and, as a result, would more likely be transported to the accessible environment. This assumption is valid, but the ease with which hydrogen escapes from the repository may in fact alter the ease with which brine moves out of the repository. In two-phase flow modeling, it is important to note that each phase present affects the relative permeability of the other phase, and by removing hydrogen from the repository the predicted movement of brine may be affected. As CO_2 may be more representative of the fluid flow properties of gases present, why not use CO_2 in the model or at least compare the behavior of the two gases?"

Response

Hydrogen produced by corrosion is expected to be the most abundant gaseous component in the WIPP environment. Approximately 2/3 of the gas to be generated is believed to be H_2 and the remainder to be CO_2. Assuming less mobile properties for the gas is not expected to increase the migration of either the gas or brine phase. Calculations are planned to evaluate this effect and the current PA assumptions.

Comment T179

Page 48: III. Models, BRAGFLO Changes

Area in document Volume 2, Appendix A, Page A-19, Line 10; Volume 2, Chapter 7, Page 7-3/5

"The model also assumes that none of the gas is transported as a dissolved component in the brine (Volume 2, p. 7-5). Considerable data exist on gas solubilities in water and salt solutions at pressure-temperature conditions similar to those expected to exist at WIPP (SAND90-2848 ...), and these should be built into the model, rather than assuming no solubility of gases in the brine."

Response

The Project is evaluating the sensitivity of compliance to this issue by means of performance assessment and other modeling sensitivity studies.

Information on the solubility of gases in NaCl brines has been evaluated and published by Cygan (1991). The transport of gas out of the repository as dissolved gas is not currently modeled in PA. The PA model (BRAGFLO) has the capability to consider gas solubility in brine, but preliminary evaluation suggests this to be a minor secondary effect. A more systematic analysis needs to be performed and is planned to better evaluate the assumption of negligible gas solubility.

Reference

Cygan, R.T. 1991. *The Solubility of Gases in NaCl Brine and a Critical Evaluation of Available Data.* SAND90-2848. Albuquerque, NM: Sandia National Laboratories.

Comment T180

Page 48: III. Models, BRAGFLO Changes

Area in document Volume 2, Appendix A, Page A-19, Line 10; Volume 2, Chapter 7, Page 7-3 to 7-5

"The algorithm that describes flow of brine and gas from the repository is only concerned with the conservation of mass. Presumably, flow is assumed to be isothermal, since conservation of energy and momentum are not required. Cooling (or heating) of the brine-gas mixture as it flows into or out of the WIPP repository might have a significant affect on the transport of hazardous materials, particularly, VOCs, to the accessible environment. Are there plans to incorporate energy and momentum conservation into the flow equations?"

Response

The Project has already investigated and resolved the issue of thermally driven repository processes and work is complete. With respect to analyses primarily concerned with horizontal pathways the assumption of isothermal flow is considered to be an appropriate representation. However, for vertical migration, the effect of the geothermal gradient on migration of radionuclides and VOCs has not been addressed.

This issue affects the compliance analysis as follows: For issues associated with vertical migration there may be a need for analyses to determine the effect of the geothermal gradient on migration of radionuclides and RCRA constituents. The issue will be considered for inclusion in the systems prioritization.

Comment T181

Page 48-49: IV. Regulatory Issues, Include 40 CFR 191 Changes in Future Assessments

Area in document Throughout

(a) (Restatement) Consider changes to the Groundwater Protection Requirements.

(b) "Future assessments should identify the potential aquifers, the water quality (i.e., total dissolved solids), and potential underground sources of drinking water."

Response

(a) All aspects of 40 CFR 191, including those portions repromulgated in December 1993, will be incorporated in future performance assessments.

(b) As stated in a paper recently presented at the Waste Management '94 conference (Trauth et al., 1994), we propose to determine when and if underground sources of drinking water should be identified and characterized (i.e., when such a characterization will provide pertinent information for a compliance application). Briefly, identification and characterization of USDWs should not be required if no radionuclide releases to the accessible environment are predicted for 10,000 years or if 10,000 year peak predicted releases to the accessible environment are less than or equal to the applicable Maximum Contaminant Levels (MCLs). USDWs along the pathway should be identified and characterized if peak predicted releases to the accessible environment for 10,000 years are greater than the MCLs.

Reference

Trauth, K.M., S.G, Bertram, and B. Bower. 1994. "Considerations for Guidance for Radioactive Waste Disposal Arising from Rules Under 40 CFR 191 and 40 CFR 194," *Proceedings of Waste Management '94 Conference, Tucson, AZ, February 27-March 3, 1994.*

Comment T182

Page 49: IV. Regulatory Issues, Use of Passive Institutional Controls

Area in document Volume 1, Page 3-11; Throughout

"The Guidance does state that passive institutional controls could reduce the likelihood and consequences of inadvertent drilling intrusion, but DOE should present the calculation and their results before taking credit for the passive controls."

Response

The 1992 PA did this. Results are presented in Chapter 5 for intrusion probabilities estimated both with and without the effects of passive markers.

Comment T183

Page 49: IV. Regulatory Issues, Justification of Drilling Rate

Area in document Volume 1, Chapter 3, Page 3-11, 3-12

"While the 40 CFR 191 Guidance states 'that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years...,' DOE still needs to justify its rationale for accepting or not accepting the Guidance drilling rate. The drilling rate used in the performance assessment is dramatically different than that discussed in the Guidance. The compliance criteria will further address this topic."

Response

The drilling rates used in PA will be reevaluated when the compliance criteria are available. Past PAs have deliberately used an uncertain rate (i.e., they have sampled values of the Poisson rate constant from a range which results in an expected value of $30/km^2/10{,}000$ yr at its maximum) to examine system sensitivity to the drilling rate. These preliminary PA analyses have demonstrated that performance is extremely sensitive to future drilling rates.

Comment T184

Page 49-50: IV. Regulatory, Engineering Measures

Area in document Volume 1, Chapter 5, Page 5-20, Line 12; Volume 2, Chapter 2, Page 2-50

"The 'additional engineering measures for the WIPP' should be modeled in the PA to evaluate the effect of these measures on the institutional control even during construction of WIPP (EEG 92)."

Response

Engineered alternatives will be evaluated for inclusion in the systems prioritization.

Comment T185

Page 50: IV. Regulatory Issues, Undisturbed Performance

Area in document Volume 1, Chapter 5, Page 5-21, Line 9

(a) "The new Subpart C requires the disposal system be designed for 10,000 years of undisturbed performance."

(b) "All possible groundwater uses should be considered and evaluated."

Response

(a) All aspects of 40 CFR 191, including those portions repromulgated in December 1993, will be incorporated in future performance assessments.

(b) The text in question refers to the consideration of "special sources of groundwater" as defined in the 1985 version of 40 CFR 191. The regulation now requires consideration of underground sources of drinking water in the accessible environment. Future documentation will reflect that requirement.

Comment T186

Page 50: IV. Regulatory Issues, Incompleteness of Modeling System and Database

Area in document Volume 1, Chapter 6, Page 6-1, Line 12

"What parts of the modeling system and database are still incomplete? What is being done to fill the data gaps? Statements like this should not be presented in the PA without explanation. This problem occurs throughout the PA."

Response

The complete sentence referred to begins: "As summarized in the following discussion, however, the modeling system and data base are still incomplete..." The discussion following on Page 6-3 provides a very brief summary of the major parts of the system that remain incomplete. It was not possible to compress this information into a single sentence. Instead, the caveat was supplied with the reference to the following text for additional information.

Comment T187

Page 50-51: IV. Regulatory Issues, Incompleteness of Modeling System and Database

Area in document Volume 1, Chapter 6, Page 3-11

(a) "Active institutional control has been assumed by SNL in prior preliminary comparisons to eliminate any possibility of inadvertent human intrusion during the first 100 years after WIPP decommissioning. However, in the 1992 PA this possibility is included. This is a preferred interpretation because a 100-year period of institutional control is not required by the Standard or the LWA and DOE has not committed to such action."

(b) "There have been lapses in institutional control even during construction of WIPP."

Response

(a) Hora's memo in (Volume 3, Appendix A, p. A-69 to A-99) contains guidance from the Futures Panel on the timing of intrusions, including the possibility of intrusions in the first 100 years after closure of the repository. In the performance assessment calculations, intrusions in the first 100 years were precluded based on Guidance to 40 CFR 191 that active institutional controls may be able to "prevent or limit potential releases of waste from a disposal system" (50 FR 38080a) for some time after closure, not to exceed 100 years. This is clearly stated in Volume 1, Chapter 5, p. 5-18, l. 20-22 that in the 1992 PA "no intrusions are assumed to occur during the first 100 years after decommissioning." Details of the DOE's active institutional control will be included in the compliance application.

(b) The reference to lapses could not be located in EEG 92. It was assumed that the reference was to the JR-13 well. Neither the actions surrounding the JR-13 well (which was drilled in compliance with the regulations in effect at the time) nor the written record suggest that institutional memory was lost. Proper control of the activities taking place in the area of the WIPP was maintained throughout the construction of the WIPP.

Comment T188

Page 51: IV. Regulatory Issues, Incompleteness of Modeling System and Data Base

Area in document Volume 1, Page 3-21

"It is stated that 'Thus, the EPA assumes that satisfying the numeric requirements is sufficient to demonstrate compliance with 191.13(a) but not mandatory.' This statement is incorrect. EPA did not make such an assumption. EPA's statements about 40 CFR 191 appear to have been taken out of context and misinterpreted in the PA report."

Response

EPA is requested to clarify the meaning of the text quoted on pages 3-20, lines 24-33 and 39-49, and page 3-21, lines 1-3. This text is from 40 CFR 191.13(a) and from Appendix C to 40 CFR 191.

Comment T189

Page 51: IV. Regulatory Issues, Incompleteness of Modeling System and Database

Area in document Volume 1, Chapter 5, Page 5-17, Line 39-42

(Restatement) "...in the final PA suggests assurance requirements will be used quantitatively and only if needed." EPA states that this is inconsistent with the 1985 Standard Guidance and Preamble that assurance requirements are a qualitative measure only.

Response

Guidance in what is now Appendix C (identical to the text that was Appendix B in the 1985 promulgation of 40 CFR 191) states: "The implementing agencies should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of such inadvertent exploratory drilling." EPA has stated that the impact of passive institutional controls should be considered in a quantitative fashion. The Supplementary Information to the 1985 promulgation of 40 CFR 191 included:

"Not allowing passive institutional controls to be taken into account to some degree when estimating the consequences of inadvertent human intrusion could lead to less protective media being selected for repository sites." (50 FR 38080b,c)

and

"The Agency also assumed that passive institutional controls should reduce the chance of inadvertent intrusion compared to the likelihood if no markers and records were in place. Specific judgments about the chances and consequences of intrusion should be made by the implementing agencies when more information about particular disposal sites and passive control systems is available." (50 FR 38080b)

Comment T190

Page 51: IV. Regulatory Issues, Incompleteness of Modeling System and Database

Area in document Volume 1, Chapter 5, Page 5-18

(a) "The Standards do not automatically grant a 100-year period free from intrusions. The statement on page 3-11 is a more accurate interpretation."

(b) "The assumptions used in future PAs should be consistent with the length and degree of active institutional control to which DOE eventually commits and considerations of failure in preventing all human intrusions."

Response

(a) Text in the Supplementary Information for the 1985 version of 40 CFR 191 included:

"The proposed rule limited reliance on 'active institutional controls' (such as controlling access to a disposal site, performing maintenance operations, or cleaning up releases) to a reasonable period of time after disposal," (50 FR 38079c-38080a)

In the final rule, the "reasonable period of time" was changed to no more than 100 years. PA calculations use what was considered to be a "reasonable period of time."

The text on page 3-11 was not clear in stating that in 1992, as in previous years, no intrusions were allowed during the first 100 years. Text on page 5-18, lines 21-22 is clearer.

(b) Comment acknowledged. The DOE's active control program will be described in the compliance application.

Comment T191

Page 51: IV. Regulatory Issues, Incompleteness of Modeling System and Database

Area in document Volume 1, Chapter 5, Page 5-19, Line 39

(a) "It is stated here that, with respect to drilling, DOE has control of the area within the land-withdrawal boundary from the surface to a depth of 6,000 feet. This is not accurate."

(b) "The WIPP Land Withdrawal Act provides no lower limit to the control of the subsurface, except for those two leases which underlie Section 31 and for which the 6,000 foot limit currently applies."

Response

(a) Text immediately preceding this text quotes from the Land Withdrawal Act about the withdrawal of the land from entry appropriation and disposal (Section 3(a)(1)). It should also quote the exception (Section 4(b)(4)) for the rights under Federal Oil and Gas Leases No. NMNM 02953 and No. NMNM 02953C.

(b) It is correct that the Land Withdrawal Act places no lower limit on the withdrawal of land from use (with the above exceptions). EPA needs to clarify what is considered inaccurate in the statement (i.e., surface to 6,000' or below 6,000').

Comment T192

Page 51: IV. Regulatory Issues

Area in document Volume 2, Page 4-4, Lines 26-27

"The regulatory requirements which preclude the possibility of inadvertent explosions in waste storage rooms from gases created by degradation of waste should be cited."

Response

The sentence referred to is poorly worded, and does not clearly state the intended position.

The reasoning behind the sentence can be found in the expanded description of the event and process screening procedure in Volume 1 of the 1991 PA (SAND91-0893/1), page 4-31, lines 3-12. The reference should have been only to inadvertent explosions that are not a spontaneous result of the behavior of the disposal system (e.g., accidental nuclear bombing of the site). The PA interpreted the guidance to 40 CFR 191 indicating that "exploratory drilling...can be the most severe intrusion scenario..." to allow the exclusion of accidental explosions.

Explosions of waste-generated gas are considered on page 4-52 of Volume 1 of the 1991 PA (SAND91-0893/1). Quantitative analysis of possible peak pressures resulting from a waste-gas explosion indicate no potential to affect performance of the panel seals.

Comment T193

Page 51-52: IV. Regulatory Issues, Incompleteness of Modeling System and Data Base

Area in document Volume 3, Page 1-51, Lines 11-13

"The statement about the extent of the WIPP control area is confusing. It took two years for Congress to pass the LWA which designated the specific area to be withdrawn for WIPP."

Response

The statement was overtaken by events when the LWA was passed (October 30, 1992). This volume was already in publication, and the text wasn't updated. The controlled area is the area withdrawn.

Comment T194

Page 52: V. Quality Assurance, Including Quality Assurance

Area in document Volume 1, Chapter 3, Page 3-17, Line 41

"Quality assurance (QA) aspects of experiments, computation development, code development, and code execution must be combined and included as part of the PA documentation."

Response

The PA reports are considered snapshots, and never were intended to be stand alone documents upon which to base compliance. The amount of material suggested above is significant. Is EPA suggesting that all QA supporting documentation be included directly in the compliance application or in the docket?

QA documentation is currently contained in the Project's records center.

Comment T195

Page 52: V. Quality Assurance, CAMCON Control Code

Area in document Volume 2, Chapter 1, Page 1-3, Line 30

"How does CAMCON 'automatically handle quality assurance during the calculations'?"

Response

No system can completely automatically handle all aspects of quality assurance. CAMCON provides an analyst with a system to aid in QA. CAMCON does this through database management, directory structure, and an on-line help file system.

Comment T196

Page 52: V. Quality Assurance, Data Quality Objectives

Area in document Volume 1, Chapter 3, Page 3-17, Line 41; Volume 2, Chapter 1; Volume 3 data

(a) "How does the PA require that the data is good enough for the purpose for which it is used?"

(b) "What data quality objectives are required of the data in the database?"

(c) "Are the data being used for the purpose(s) that they were collected for?"

Response

The Project is currently investigating the issue.

(a) The 1990 - 1992 series of preliminary PA studies drew upon a wide variety of sources of data and information, but mainly from the work of SNL principal investigators (PIs).

(b) Data quality objectives for experimentally derived data and information are described in each PI's Test Plan. But these objectives do not directly address the quality of entries in PA's database of model parameters. QA procedures for construction of model parameters are being developed and early versions of these procedures are described in Rechard et al. (1992).

If the term "data quality objectives" used by the reviewers means the specific DQO processes outlined in EPA QA documents, then the following should also be considered: The WIPP Project believes that the DQO process outlined in EPA documents is not directly applicable to data used in forming the parameters of the complex numerical models that simulate WIPP performance. The EPA's DQO process appears to apply to situations in which measured quantities (the "data") are used directly to determine compliance with standards, e.g., water-quality standards.

The WIPP performance assessment is very different from these situations in that field and laboratory data are used as indirect inputs to a large numerical model that generates

compliance-related quantities, e.g., the CCDF required in 40 CFR Part 191, Subpart B. Data priorities, but not data quality, can be determined through sensitivity analyses with these large numerical models of the WIPP. In general, existing WIPP QA procedures for assuring the quality of the (field data to model parameter) process strongly emphasize peer review and careful documentation.

(c) Much of the data used by the Project was generated prior to 1985 for the purpose of establishing baseline conditions (site descriptions, hydrology, etc.) in the WIPP Environmental Impact Statement. While quality assurance has always been applicable to the WIPP, the more stringent data requirements of a compliance determination mandated in 40 CFR Part 191 became apparent later, and only within the past five years were data-gathering programs begun to specifically address the needs for data that are used chiefly in a determination of compliance.

Reference

Rechard, R.P., K.M. Trauth, and R.V. Guzowski. 1992. *Quality Assurance procedures for Parameter Selection and Use of Expert Judgment Panels Supporting Performance Assessments of the Waste Isolation Pilot Plant*. SAND91-0429. Albuquerque, NM: Sandia National Laboratories.

Comment T197

Page 53: V. Quality Assurance, Parameter Sheet Format and Data Quality Indicators

Area in document Volume 3, Chapter 1, Page 1-12

"The quality of the parameters used in the PA are of critical importance. The parameters presented on the parameter sheet are not graded as to quality or level of confidence. Parameter sheets should have a statement of data quality or a statement of the level of confidence for each parameter."

Response

The point is well taken. The form will be reviewed.

Comment T198

Page 53: VI. Use of Expert Panels and Review, Expert Panels and Expert Judgment

Area in document Volume 2, Chapter 2, Page 2-39; Throughout

(a) "Expert panel judgement and investigator knowledge may be necessary in lieu of actual data parameters. However, a procedure should be developed to insure such information is of the highest level of confidence. DOE should consult with EPA as it develops expert panel elicitation procedures."

(b) "The use of expert judgement should be replaced with data as soon as data become available, especially for data or parameters that are considered to be important from the sensitivity and uncertainty analyses. DOE should clearly identify areas where expert judgement is or will be used and when it expects that it will be replaced by actual data."

Response

(a) A formal QA procedure for the use of expert judgment was published in 1992 (Rechard et al., 1992). Further refinements of this QA procedure can and have been incorporated into WIPP Procedure No. PAP06, Use of Expert Judgment Panel Quality Assurance Procedures.

Specific uses of expert judgment are documented in Hora et al. (1991), Trauth et al. (1993), and Trauth et al. (1992). A further SAND report is being prepared by the expert panel addressing solubility to provide additional information on the process and results.

With respect to "substituting estimates for actual data," even when additional WIPP-specific data are collected, judgment may still be required to reconcile WIPP and non-WIPP data, to reconcile possible conflicting data, and to interpret the data for the current probabilistic application.

(b) It is appropriate to describe how experimental data are used in the current application. However, it may be more useful to discuss the type of data available rather than those limited cases where no data at all exist. Judgments are based on the available data (however abundant or sparse, under whatever experimental conditions they were collected). For example, all data may not be WIPP-specific. All data may not have been collected for the current application (to answer the current questions). In addition data may exist, yet there may also exist methods by which to collect additional data to improve the understanding (e.g., batch K_d data vs. column experiments). Even when additional WIPP-specific data are collected, judgment may still be required to reconcile WIPP and non-WIPP data, to reconcile possible conflicting data, and to interpret the data for the current probabilistic application.

References

Rechard, R.P., K.M. Trauth, and R.V. Guzowski. 1992. *Quality Assurance Procedures for Parameter Selection and Use of Expert Judgment Panels Supporting Performance Assessments of the Waste Isolation Pilot Plant.* SAND91-0429. Albuquerque, NM: Sandia National Laboratories.

WIPP PA Department. *Use of Expert Judgment Panel Quality Assurance Procedures.* PAP-06. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, R.P. Rechard, and D.R. Anderson. 1992. *The Use of Expert Judgment to Quantify Uncertainty in Solubility and Sorption Parameters for Waste Isolation Pilot Plant Performance Assessment.* SAND92-0479. Albuquerque, NM: Sandia National Laboratories.

Comment T199

Page 53-54: VI. Use of Expert Panels and Review,

Area in document Volume 3, Chapter 1, Page 1-27, Line 62-64; Volume 3, Appendix A, Page A-71 to A-99

(a) "Since extreme care needs to be taken when substituting estimates for actual data, DOE should consult with EPA and the public on the use of expert panels. There should be documentation of the process used to obtain expert opinion, and the process should follow written guidelines in a clearly defined process."

(b) "Specifically, we do not agree with the approach taken by DOE in using the marker panel to estimate a reduction of the drilling rate from the use of markers. ...Nor did the panel include all the necessary expertise, e.g., no petroleum engineers or drilling experts were included on the panel..."

(c) "Although the compliance criteria will determine the final approach to human intrusion, DOE should...study the drilling experience in the oil, gas, mineral, and water exploration industries and develop historical trends to establish characteristics of drilling."

Response

(a) A formal QA procedure for the use of expert judgment was published in 1992 (Rechard et al., 1992). Further refinements of this QA procedure can and have been incorporated into WIPP Procedure No. PAP06, Use of Expert Judgment Panel Quality Assurance Procedures.

Specific uses of expert judgment are documented in Hora et al. (1991), Trauth et al. (1993), and Trauth et al. (1992). A further SAND report is being prepared by the expert panel addressing solubility to provide additional information on the process and results.

With respect to "substituting estimates for actual data," even when additional WIPP-specific data are collected, judgment may still be required to reconcile WIPP and non-WIPP data, to reconcile possible conflicting data, and to interpret the data for the current probabilistic application.

(b) The process used by the Markers Panel was to first develop design guidelines for long-term communicative markers based on the contributions from individuals in disparate related fields such as materials science, archaeology, and communications. Based on the design guidelines, the two teams comprising the Markers Panel each developed a conceptual design for a system of markers. Estimates of efficacy of the markers system over time were based on the conceptual design. Implicit in the deliberations was the assumption that sufficient testing was undertaken to determine, for example, the appropriate design of the foundation for stone markers to withstand possible fluctuations in surface level and still remain stable. A second assumption in the effort was to evaluate what was possible for a marker system (as a first approximation) with no cost constraints. Cost constraints may come into play regarding the definition of "practicable" in 40 CFR 191. There is much evidence from the fields related to marker design that suggest avenues to pursue to improve long-term survivability and communication.

We did not include a petroleum engineer on the Markers Panel, whose efforts were geared to long-term survivability of a marker system and continued interpretability. We concluded that a petroleum engineer's skills are not such as to contribute to long-term communication with future societies or construction of durable markers.

(c) If this guidance is included in 40 CFR 194, expert judgment will still be required to evaluate existing data, considering fluctuations in drilling intensity and depletion of resources, to estimate drilling intensities to use. Expert judgment will still need to be used in the design and evaluation of passive institutional controls for the consideration of their impact on inadvertent human intrusion, as allowed by Appendix C of 40 CFR 191: "The implementing agencies should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of such inadvertent exploratory drilling."

References

Rechard, R.P., K.M. Trauth, and R.V. Guzowski. 1992. *Quality Assurance Procedures for Parameter Selection and Use of Expert Judgment Panels Supporting Performance Assessments of the Waste Isolation Pilot Plant.* SAND91-0429. Albuquerque, NM: Sandia National Laboratories.

WIPP PA Department. *Use of Expert Judgment Panel Quality Assurance Procedures.* PAP-06. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, R.P. Rechard, and D.R. Anderson. 1992. *The Use of Expert Judgment to Quantify Uncertainty in Solubility and Sorption Parameters for Waste Isolation Pilot Plant Performance Assessment.* SAND92-0479. Albuquerque, NM: Sandia National Laboratories.

Comment T200

VI. Use of Expert Panels and Review, Review of Investigator Judgement

Area in document Volume 3, Chapter 1, Page 1-7

"Is there any quality control or review of parameters derived from investigator's judgement?... Is there a way to specify the level of confidence in the investigator's judgement?

Response

All PA reports, published as SAND reports, undergo independent technical peer review.

As to the confidence in investigator's judgement, further discussion on this topic with EPA would be useful. EPA is requested to provide clarification.

Comment T201

Page 55: VII. EPA Review of SNL Responses to selected EEG Comments, Comment No. 3 (part 1).

Area in document Volume 1, Appendix B

(Restatement) The EPA agrees that SNL's request that EEG direct "constructive criticism...[toward] data...and models rather than on labeling the outcome as 'nonconservative'" is reasonable, but notes that the modeling system is complex and its evaluation requires "specialized expertise and significant personnel resources. No outside review group, including EEG has rigorously evaluated the basic mathematical and statistical theory underlying the computational procedures. In addition, the QA status of computer codes and data used in the WIPP PA severely limits the scope of review in these areas."

The EPA suggests that SNL should perform "bounding or conservative analyses for several reasons, including: 1) Bounding analysis can be useful in determining the level of effort to apply to alternative conceptual models. Performing only realistic modeling could severely limit the number of alternative conceptual models or issues that are evaluated; and 2) The bounding analysis can be used as a screening tool to evaluate the relative impacts of scenarios or alternative conceptual models and help identify important parameters."

Response

Review of the WIPP PA may well require considerable expertise and effort. QA on computer codes and reviewer access to the modeling system are high priorities for SNL.

"Bounding or conservative" analyses will be considered for inclusion in the systems prioritization.

While there may be cases when bounding analyses are appropriate, they, as a general rule, are discouraged for compliance determinations. The reason for this is clear, the Standard encourages reasonableness in expectation. Bounding analyses may be useful for parameters that are of little consequence or alternative conceptual models that are clearly bounded by the conceptual model being pursued.

Comment T202

Page 55-56: VII. EPA Review of SNL Responses to selected EEG Comments, Comment No. 3 (part 2)

Area in document Volume 1, Appendix B

(Restatement) The EPA repeats the EEG's observations that the 1991 PA was not conservative, noting that "the 1991 PA report used mean/median values for most key parameters." The comment further notes that PA analyses suggest that "the maximum amount of brine saturation that will ever occur in an undisturbed room (at the 10^{-4} probability level) is about 30%. This seems to be inconsistent with some assumptions in the Test Phase Plan and elsewhere where testing under fully inundated conditions is considered important."

Response

The 1991 PA (and the 1992 PA) did not use mean or median values for "most key parameters." Mean or median values were used for many of the hundreds of parameters required in mathematical modeling, but not for the "key" parameters. Those parameters for which uncertainties were deemed to be large or which had a strong influence on model outcomes were sampled from a distribution (see Section 6.2 of Volume 3 of the 1992 PA).

As long as any portion of the waste is saturated with brine, inundated gas-generation processes are important. Note that if the brine saturation in the disposal area is 30%, then inundated gas-generation reactions will occur in 30% of the waste. Note also that all values of brine saturation after time zero, including the 30% value referred to here, are model outcomes, rather than model assumptions or externally imposed limits. They are simply observations of the results of simulations involving complex coupled processes. Conceptual models and data used in the 1992 PA for two-phase flow and gas generation resulted in a wide range of brine saturations in the undisturbed waste (up to about 60%, see Volume 4, Figure 4.4-3). These conceptual models and alternatives will be considered for inclusion in the systems prioritization.

Comment T203

Page 56: VII. EPA Review of SNL Responses to selected EEG Comments, Comment Nos. 15, 25, 82

Area in document Volume 1, Appendix B

(Restatement) The EPA repeats the EEG's comment that level 4 activity levels used in calculating cuttings releases could not exist at 3,000 years or later, because radioactive decay would have reduced the activity to lower levels. Activity levels high enough at time zero to

result in activity level 4 of 184.01 Ci/m^2 at 3,000 years would be higher than anything reported in the system.

Response

The EEG's observation on the 1991 PA is correct. Transportation and WAC requirements were not explicitly considered in the formulation of the activity levels for CCDF construction, and the activities reported at later times for the highest level exceed the 200 fissile-gram-equivalent requirement of the WAC. The decision to include "nontransportable" waste in the 1991 PA was deliberate, and was based on uncertainty about future transportation requirements. The effect also occurs in the 1992 PA.

The effect of the "nontransportable" waste on CCDFs is minor, and results in an overestimation of the lower-probability/higher-consequence cuttings releases. Figure 3-4 in Volume 2 of the 1991 PA (SAND91-0893/2) shows cuttings-only CCDFs calculated for a single realization using average-activity cuttings and cuttings of multiple activity levels.

Comment T204

Page 56: VII. EPA Review of SNL responses to Selected EEG comments, Comment No. 53

Area in document Volume 1, Appendix B

"EEG stated 'the effect of colloidal materials and chelation on radionuclide transport has not been addressed in PA to date, nor has the full interaction of gas pressurization on transport down MB139 been fully conceptualized.' Sandia's response merely referred to two previous responses, neither of which addressed colloids, chelation or transport down MB139. EPA agrees this issue needs to be addressed in the PA."

Response

All of these issues are presently being examined, and will be included in the system prioritization. Colloids and chelating agents in the disposal room are considered in the actinide source term program (see Experimental Program Plan [EPP] 5.3.2.2 and 5.3.2.1). Colloids and chelating agents in the Culebra are considered in the non-Salado Transport Activity (see EPP 5.1.2). Pressure-dependent fracturing of anhydrite marker beds is being examined in the field with the Hydrofracture Studies (see EPP 5.2.4.7), and transport of VOCs is being considered in the Salado Transport Activity (see EPP 5.1.4).

Comment T205

Page 57: VII. EPA Review of SNL Responses to selected EEG Comments, Comment No. 88

Area in document Volume 1, Appendix B

(Restatement) EPA repeats the EEG's request for modeling of a scenario that includes flow of Castile brine to the surface. The EEG indicates that SNL agreed in 1992 to consider four cases: "(1) E1 or E2 during drilling; (2) E1 while Castile brine is allowed to flow; (3) E1 followed by E2 after Castile brine is allowed to flow; and (4) E1E2 after both have been abandoned."

Response

These scenarios may be considered for inclusion in the SPM.

Comment Intro 1

Page 1

"For individual and ground-water protection, calculations have been done to 1000 years, whereas the Standards (40 CFR 191) required by the Act would require calculations to 10000 years."

Response

The compliance application will include performance assessments for the required time periods.

Comment MI-01

Page 2

"Very few new results are presented in volumes 1, 2, and 3 of the *1992 Performance Assessment*."

Recommendation:

"We look forward to additional results on undisturbed performance, disturbed performance, sensitivity and uncertainty analysis in future volumes."

Response

Volumes 4 and 5 of the 1992 PA were published in the fall of 1993, and contain the additional results mentioned.

Comment MI-2

Page 2

"In previous performance assessments, the DOE noted that the calculated CCDF's are at least an order of magnitude below the allowable limits in the EPA Standards. In the *1992 Performance Assessment*, for the case of total release from fracture-flow in the Culebra, no sorption, and a constant intrusion rate, the mean CCDF comes to within a factor of two or three of the EPA containment requirement [Vol. 1, Fig. 5-4]. Despite this factor of safety, the outlier CCDFs may lie in the zone of violation of the containment requirements. For dual porosity flow and the same parameters, the mean CCDF is about a factor of ten away from the containment requirement."

Recommendation:

"The DOE should show the full uncertainty band of CCDFs when comparison with the containment requirement (40 CFR 191) is made."

Response

The families of CCDFs and selected percentile curves are displayed in Volume 4 of the 1992 PA. The presentation of a single CCDF is consistent with the guidance in what is now Appendix C as follows:

> "Compliance with §191.13. The Agency assumes that, whenever, practicable, the implementing agency will assemble all of the results of the performance assessments to determine compliance with §191.13 into a "complementary cumulative distribution function" that indicates the probability of exceeding various levels of cumulative release. When the uncertainties in parameters are considered in a performance assessment, the effects of the uncertainties considered can be incorporated into a single such distribution function for each disposal system considered. The Agency assumes that a disposal system can be considered to be in compliance with §191.13 if this single distribution function meets the requirements of §191.13(a)." [40 CFR 191 App. C]

The recommendation that the entire family of CCDFs should be used in a compliance application suggests guidance that goes beyond the recommendations for implementing 40 CFR §191.13(a). The EPA is expected to provide relevant criteria in 40 CFR 194.

Comment MI-3a

Page 2

"Beginning with the 1992 Performance Assessment, "expert judgment" is used for a: solubilities of actinides. . ."

Recommendation:

"As experimental solubility values become available (e.g. Nitsche et al., 1992), use them in performance assessment."

Response

The DOE is currently investigating the issue and an activity involving the collection of experimental solubilities will be included in the System Prioritization Methodology (SPM).

SNL is developing a model that describes actinide solubility and colloid stability that will utilize experimental results as they become available to replace the current solubility estimates based on expert judgement. The sensitivity of compliance performance assessment to radionuclides solubilities will be investigated during SPM. SPM will also help in determining data quality objectives (DQOs) for the experimental program.

Comment MI-3b

Page 3

"For retardation coefficients, the second modification of the Cooperation and Consultation Agreement between the DOE and the State of New Mexico specifies that retardation coefficients shall be set to zero unless there are experimental data otherwise. Results using zero and non-zero retardation coefficients appear in Chapter 5 of Volume 1."

Recommendation:

"As experimental retardation coefficients become available, use them in performance assessment."

Response

The DOE is currently investigating the issue, and an activity involving the determination of non-zero retardation coefficients will be addressed by SPM.

The 92 PA was not intended to be a compliance document. Ranges of many parameters, including retardation coefficients, were included to determine the sensitivity of various performance measures to parameter variations. SNL is currently conducting experiments designed to collect data upon which a defensible retardation model can be constructed, for use in future compliance PAs. Measured K_d data will be used directly to the extent possible and meaningful.

Comment MI-3c

Page 3

This quotation summarizes our view on "expert judgment":

> Expert judgments are not statements about nature but rather about beliefs. Nor are they statements which can be extrapolated to a larger population of events and beliefs. Therefore, while there is a chance that conclusions based on an

expert judgment may be true about the world, it is not a good idea to say so because there is no justification in the method which allows this (Fleming 1991).

Recommendation:

"We object to the elicitation of subjective probabilities as practiced to estimate the probability of inadvertent intrusion and we offer a specific alternative suggestion, beginning on page six. Our specific objections are detailed below."

"(a) The probabilities that have been elicited from panels for the purpose of estimating future intrusion intensity (Hora, von Winterfeldt and Trauth, 1991) are subjective probabilities. To call them "expert judgment" is to give them an aura of respectability they do not deserve. The methods for eliciting such probabilities come from statistics (Savage, 1954) and experimental psychology (Edwards, 1954). The term "recognized expert" is usually applied to an individual who has published extensively in the particular field, but the interpretation of a "recognized expert" carries no more weight, and is not necessarily better, more accurate, or more valid, than the interpretation of an inexperienced investigator. Experience does not guarantee accurate interpretation; knowledge does. To foretell the future, each of us has insights, and scientists do not possess more insights than the common person. While the elicitation of opinions is valid, the elicitation of expert opinion on the future is gratuitous. That there has been no attempt to establish the qualifications of the panel members as experts on the future is telling. They simply are not."

"(b) The WIPP Performance Assessment Department invokes the interdisciplinary nature of an expert judgment panel as a reason to use such a panel. But "interdisciplinary" is not a synonym for "good" or "appropriate" any more than "single disciplinary" [sic] is a synonym for "bad" or "inappropriate." The advantage of multidisciplinary data interpretation over interpretation by an expert in a single discipline is not at all clear. For example, the marker panel (Rechard et al, 1993; Table I) lists experts in materials science, architecture, linguistics, communications, etc. How is the judgment of a linguist on materials hardness and durability relevant? Either the linguist accepts the material scientist's judgment, in which case the interpretation is not interdisciplinary, or the two differ in interpretation, in which case the material scientist's interpretation is clearly the more valid and that judgment should not be diluted."

"(c) The panels are not representative of modern United States, not representative of the modern world, and not representative of the historical continuity of the human race. There was only one woman on the markers panels [sic] and none in the futures panels [sic]. There are no representatives of indigenous cultures of the southwestern United States."

"(d) The elicitation process used was open-ended. While it is true that what people will want to mine over 10,000 years is unknown, let alone where they want to mine it, for a

specific area the problem is simpler. An example is the Outer Continental Shelf Lands Act, which allows for oil and gas drilling in the sea beyond the three-mile limit, with a clause for "other minerals." When the Outer Continental Shelf Lands Act was first passed in the early fifties "other minerals" referred to sulfur. By the mid-1970's the focus of other minerals became construction aggregates around coastal cities. In the early 1990's, it is manganese crusts. For a specific location, with geologic information, we know what can be mined now and in the future. The propensity to mine will only change if there is a metamorphosis, or society changes its needs dramatically. If that had been borne in mind, the problem is much more circumscribed, and less fiction would have resulted."

"(e) Results of the open-ended elicitation process used by Hora (Hora, von Winterfeldt and Trauth, 1991) appears to have been used selectively. If a more circumscribed process had been used, then the methods available to combat cognitive bias (Tversky and Kahneman, 1974) could have been used. Unfortunately, the results used in the 1992 Performance Assessment reflect strongly the intervention of the analyst. The final result used a form

$$\lambda_t = d(1-p_1p_2)$$

where λ is the intrusion intensity, number of holes per time, d is the raw drilling intensity number of holes per time, p_1 is the probability of markers surviving, and p_2 is the probability that surviving markers are effective in deterring drilling, all functions of time. The paradigm was not elicited from any one panel but the result is a mixture of results from the panelists who probably did not understand how their inputs would be used."

"(f) A flagrant and important abuse of the analyst-assessor role is when Hora decided that there will be no intrusions allowed after 300 years (Hora memo, Vol. 3, p. A-76, last sentence). If institutional control prevents drilling from 0 to 100 years after closure, and by fiat no intrusions after 300 years, then the 1992 Performance Assessment considered only intrusion from 100 to 300 years. Are only flow and transport to be considered from 300 to 10,000 years? This is clearly counter to the spirit and letter of analyzing human intrusions for the entire regulatory period."

"(g) Most of the elicitation process is given in the Hora memo, volume 3, pp. A-71 through A-99. This memo includes a FORTRAN program to sample among the panels [sic], and produce realizations of intrusion intensities as functions of time for use in the 70 Monte Carlo runs. The computer program does not work. On page A-94, line 13, there is a three-dimensional array BOSTAB2 which is undimensioned and undefined, thus the program cannot possibly work. Since May 1992, EEG has requested a working copy of this program, first from Professor Hora, then from WIPP Performance Assessment Department, to no avail."

"(h) Appendix D of Vol. 3 of the 1992 Performance Assessment contains 12 pages of realizations of drilling intensity functions that are purportedly the results of using Hora's

algorithm. The graphs show the intrusion rate and the cumulative number of intrusions as a function of time to 10,000 years. As noted above, Hora's program sets the intrusion rate to zero after 300 years, therefore these graphs cannot possibly be the results using Hora's computer program. If the analyses used a zero intrusion rate after 300 years, it is misleading to show the Appendix D graphs which show intrusion rates to 10,000 years."

"(i) **This is EEG's specific suggestion.** We suggest a simplified, focused and understandable alternative.

Figure 1 shows what we believe the exploratory drilling rate to be in any specific area. This figure shows how we see the evolution of oil and gas drilling as a function of time.

First there is a historical record of drilling in this area. This rate may be high, or it may be close to zero, but it is known. Call it a holes per area per year, $a > 0$. The U.S. Environmental Protection Agency's guidance of thirty boreholes per kilometer^2 over 10,000 years is such a rate.

We extend the historical drilling rate some time in the future. Call this b years, $b > 0$. Geologic knowledge should be used for this extension. If there is current oil and gas drilling, then it is likely for the exploration and development to continue for some time. If there is no current drilling in this area, then there will probably not be any drilling until we discover some new mineral to explore for in this area. This extension should extend beyond the period of active institutional control.

Given our present understanding of energy economics, we may postulate a decrease in oil and gas drilling, after a period of time, due to either exhaustion of the resources, or technological developments in some other fuel sources, or both. This decline can be represented by an experimental [sic] decay function, $y = y_0 \exp^{-ct}$. The rate of decrease is characterized by a single parameter, c.

For the long term, there should be a rate of intrusion that is

(a) non-zero; and

(b) above the USEPA threshold probability for events and scenarios [sic] to be considered or 10^{-4} per year. Call the rate d holes per area per year, $d \geq 10^{-4}$ per year.

The long-term, low intrusion rate cannot be zero because the hazard of the waste in the repository would not have decayed to harmless levels in just a few thousand years. To ignore such probabilities is to do an incomplete analysis.

The parameters a, b, c, and d completely specify the rate of inadvertent human intrusion in a readily understandable way. Subjective elicitation can now focus on these four

parameters. Experimental methods are available to improve the elicitation process when it is focused on continuous variables (Seaver, Von Winterfeldt and Edwards, 1978)."

Response

(a) The panel members were chosen through an extensive and impartial process. They were selected because they have made part of their life's work the study of methodologies for futures research and have thought long and hard about the path that the future may take. The goal here is to scope the collection of foreseeable futures for a very broad discussion of who might be intruding, how they might be intruding, and why they might be intruding. This information can be applied to efforts to develop effective institutional controls. A discussion of how frequently future societies might be intruding can be utilized to determine how to implement EPA's guidance that exploratory drilling for resources is the most severe intrusive event that must be examined for compliance.

The sentence "Experience does not guarantee accurate interpretation; knowledge does" is confusing. One of the definitions for "knowledge" in The American Heritage Dictionary is "Familiarity, awareness, or understanding gained through experience or study." Experience (defined as "Active participation in events or activities, leading to the accumulation or knowledge or skill") is the basis upon which available data and information can be interpreted. Data in and of itself is useless without proper interpretation and appropriate application.

(b) The entire Markers Panel was not asked to interpret hardness and durability data. The Markers Panel was asked to develop marker design criteria, which have materials and communication aspects, among others. Each member of the team brought to the deliberations the contributions of his or her discipline to the development of an effective marker system. Recommendations based on a narrow materials science perspective (e.g., use titanium for markers as it is highly resistant to corrosion) may be subject to other constraints (human beings will recycle any materials from an unattended marker system if recycling is cost effective) and may need to be modified (use only a small subset of buried markers made from titanium to make mining an uneconomical prospect).

The point is that the teams are interdisciplinary, not the individual experts. The rationale for using teams of experts from many fields is that all questions related to human intrusion and passive institutional controls cannot be fielded from any single field of study. The issues to be addressed demand this organization. A discussion of interdisciplinary teams is provided in Bonano et al. (1989).

(c) The selection of the members of the Futures Panel and the Markers Panel focused more on the expertise within the pertinent disciplines rather than on strict representativeness. It should be recognized that the community of scientists active today is probably not a reflection of the cultural and ethnic make-up of the U.S. or the world. The range of organizations from which the experts were selected (Natural Resources

Defense Council, universities, institutes, etc.) provides rich diversity in political and environmental organizations. It should also be noted that both teams within the Markers Panel believed that testing was necessary before a final design for a marker system could be selected. In part, this testing was seen as necessary to ensure that messages are interpretable by individuals from a variety of cultures and whose societies have varying levels of technological sophistication. Such testing addresses concerns about diversity in the initial design process, and the inability to include individuals from all such groups in the initial deliberations.

(d) This comment proposes that the experts be directed as to what potentially intrusive activities to study. We believe that this is inappropriate and would be seen by peer reviewers as excessive direction from the analytic staff. The intent in examining possible future societies is to provide insights into the development of institutional controls and in how to implement EPA's guidance on frequencies of human intrusion. A narrow consideration of possible future societies would be inappropriate because it would not provide these insights.

(e) The members of the Futures Panel and the Markers Panel understood how their inputs would be used in performance assessment. This was accomplished during the training sessions held with the panel members and is supported by copies of the viewgraphs that were distributed and discussed. The training sessions allowed ample time for any questions to be clarified.

The Futures Panel was shown a viewgraph entitled "Logic Tree for Deterrence by Markers Given Time, Society, Mode of Intrusion, and Marker Criteria." This viewgraph shows the concept of intrusion deterrence being a function of a set of sequential states, each conditional on the previous state occurring, dealing with the physical markers and their ability to communicate. The probability of deterrence is then calculated as the product of this set of sequential states, which is consistent with the equation used to calculate the effective drilling intensity.

The Markers Panel Issue Statement describes the probabilities that are to be elicited, all of which are conditional on the previous sequential state occurring. The Markers Panel was shown a viewgraph entitled "How will the Expert Judgments be Used in the WIPP Performance Assessment?" This viewgraph states, in part, that marker system effectiveness will be used to modify the frequencies of intrusion as developed by the Futures Panel. This was reinforced by a training example showing the calculation of needed information from a series of sequential states that together define the information required.

This part of the comment seems to contradict part d of this comment and also the EEG's specific suggestion.

(f) This comment is factually in error. The paragraph referred to deals exclusively with the findings of the Boston team and not with the findings of all four teams. The paragraph from which the sentence was extracted reads:

The Boston team provided assessments for the drilling intensity that are conditional on both time and level of technology. The responses for exploratory drilling for hydrocarbons are shown in the following tables. Exploratory drilling for hydrocarbons was not thought to extend further than 300 years in the future.

This paragraph is followed immediately by a table labeled "BOSTON TEAM---DRILLING INTENSITY DISTRIBUTIONS.

Particularly in light of the following discussions of the findings of the three other teams, the assembly and analysis of results, and the listing in Volume 1 (pp. 4-8 and 5-4) of the six times of intrusion (100, 175, 350, 1000, 3,000, and 7250 years after decommissioning), we do not understand the confusion on this point.

(g) EEG's observation that they have been requesting the computer program since May 1992 is perhaps in error. The first draft of Dr. Hora's memo explaining how the judgments of the Futures and Markers Panels could be incorporated into the performance-assessment calculations (including a FORTRAN code for assembling human intrusion judgments) that SNL received was dated June 9, 1992.

The comment refers to an early version of the program that was modified prior to implementation. This amounted to a simple bypass of the program statements concerning the array BOSTAB2. This was done when a decision was made to include only exploratory boreholes, as required by 40 CFR 191. The correct version of the program and the data files were forwarded to the EEG in December 1993.

(h) The response to this comment is the same as part f of this response.

(i) The EEG proposal does not include any consideration of the potential impact of passive institutional controls in deterring inadvertent human intrusion. This is contrary to EPA's intent as stated in the guidance to 40 CFR 191:

"The Agency assumes that, as long as such passive institutional controls endure and are understood, they: (1) can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency. However, the Agency believes that passive institutional controls can never be assumed to eliminate the chance of inadvertent and intermittent human intrusion into these disposal sites."

The WIPP Project will continue to follow EPA's guidance related to inadvertent human intrusion and passive institutional controls in future performance assessments.

As an alternative to the procedures used by the WIPP Performance Assessment staff, EEG offers another methodology. Of course, in a human intrusion analysis, there is no obvious right or wrong way to approach the problem. Thus, one must return to basic principles in order to design the process. These principles include allowing the experts freedom to fully express their judgments, not biasing the experts either through the questions asked or the way the questions are asked, collecting the rationales for the judgments as well as the numerical encoding of the judgments, and asking questions relating to physically realizable values.

With regard to the first principle:

The WIPP analysis allows the experts to provide their own structure for analyzing the problem rather than having to accept an arbitrary structure such as that imposed by the EEG procedure. There is a growing body of evidence (Armstrong, Denniston, and Gordon [1975]; Hora, Dodd, and Hora [1992]; MacGregor, Lichtenstein, and Slovic [1988]) that demonstrates that the decomposition or structure used to analyze a problem is one of the most important determinants of the findings. This has long been known to decision analysts and is often used in probability elicitation for complex issues (Electric Power Research Institute [1986]). The EEG proposal would constrain the experts and precondition their answers. Moreover, the results would present an unduly limited view of possible intrusion modes.

With regard to the second principle:

Biased results can derive from several sources. The experts may be selected in a way that the group is biased. Psychological biases (e.g., overconfidence, availability, anchoring) may enter in the elicitation process. Questions may be asked in such a way that the answers are conditioned. We believe that every effort was made to keep the two panels as neutral in a collective sense as possible. Extensive training in psychological biases was conducted prior to the elicitation. This training lasted a little more than one-half day and included lecture, discussion, examples, and training quizzes. Recognized decision analysts conducted the elicitation sessions. During these sessions, the decision analysts were alert to identifying psychological biases and to assisting the experts in counteracting these biases.

With regard to the third principle:

The expert elicitation methodology explicitly put the importance of rationales ahead of the numerical findings. This is because the numerical findings are not credible without the rationales and the rationales are apt to be more useful in the long run than the numerical assessments. A key to obtaining these rationales is to allow the experts to analyze (decompose) the problem in a manner that matches their thinking. The EEG proposal would substitute a rigid model and would thwart obtaining the rationales for the judgments.

With regard to the fourth principle:

Specialists in expert judgment have long recognized that experts should be asked to respond to questions about physically realizable quantities and not be asked to respond to questions about parameters that do not have a direct physical embodiment (Winkler [1967]; Cooke [1992]). The exponent in the proposed EEG model is a parameter that does not have a directly realizable value. What meaning would the probability elicitation have if the expert did not believe in this model? How could an expert respond to questions about parameters that she/he does not believe in?

Regarding the specifics of the proposal, what justification is there for the exponential decay in drilling frequency? What justification is there for an exponential decay over time plotted on a log scale? Have these been derived from economic principles? They seem to be judgments made as a convenience to the analyst. It should be clear that the path taken by the WIPP PA team requires more effort on the part of the experts and the analysts because convenient assumptions are <u>not</u> substituted for deep and hard thinking. The EEG is requested to provide any references supporting the use of the exponential decay equation and the log time scale postulated.

Consider also the use of the historical drilling rate, a. The guidance provided by the EPA in 40 CFR 191 states that:

> "Therefore, inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies."

The EPA assumes this because:

> "Furthermore, the implementing agencies can assume that passive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities."

Therefore, the use of the historical drilling rate (including exploration <u>and</u> development) is a judgment by the EEG that the EPA's guidance on the matter should not be followed. While the EPA's guidance states that only exploratory drilling be considered, the EEG has made a judgment that exploratory drilling and drilling for the development of resources should both be considered. The use of a drilling rate unmodified by the impact of active and passive institutional controls is also a judgment by the EEG to ignore the EPA's guidance on the efficacy of institutional controls.
Consider next the variable b, the extension of the historical drilling rate some time into the future. The EEG proposal states both that "Geologic knowledge should be used for this extension." and that "This extension should extend beyond the period of active

institutional control." Should b be based on geologic knowledge c G's policy judgments?

On page 6 of the comments, the sixth line from the bottom, a justification is attempted for a 10^{-8} cutoff on drilling rates. The statement is made that the drilling rate cannot fall to zero because the radioactive waste would still be harmful. What is the basis for linking exploratory drilling to the hazard of the waste?

In the discussion of the impact of passive institutional controls on inadvertent human intrusion, the EPA states in the guidance to 40 CFR 191 that:

> "The Agency assumes that, as long as such passive institutional controls endure and are understood, they: (1) can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency. However, the Agency believes that passive institutional controls can never be assumed to eliminate the chance of inadvertent and intermittent human intrusion into these disposal sites."

It is for this reason that the WIPP Project has not assumed that the probabilities of such intrusions can be reduced to zero.

The EEG should realize that this proposal (and its basic framework) involves replacing the explicit use of expert judgment from an independent panel with the implicit judgment of the EEG ("Figure 1 shows what <u>we</u> [emphasis added] believe the exploratory drilling rate to be in any specific area. This figure shows how <u>we</u> [emphasis added] see the evolution of oil and gas drilling as a function of time."). Judgment is still employed, but now the very important framework is provided by a different entity. Part of the proposal also includes EEG's judgment that EPA's explicit guidance for (1) considering the impact of passive institutional controls in deterring inadvertent human intrusion and (2) including the rate of <u>exploratory</u> borehole drilling for the consideration of human intrusion should both be ignored.

The above discussion indicates that any consideration of human intrusion requires judgment, no matter what attempt is made to simplify the process. Any new treatment of human intrusion for the WIPP should be addressed by an independent expert judgment panel with appropriate expertise. The process should be approached in a manner whereby all unknowns/parameters are investigated in a way that reduces the assumptions made by interested parties.

References

Armstrong, J.S., W.B. Denniston, and M.M. Gordon. 1975. "The Use of the Decomposition Principle in Making Judgments," **Organizational Behavior and Human Performance. 14**, 257-263.

Bonano, E.J., S.C. Hora, R.L. Keeney, and D. von Winterfeldt. 1990. **Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories**. NUREG/CR-5411, SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Cooke, R.M. 1991. ***Experts in Uncertainty: Expert Opinion and Subjective Probability in Science***. Oxford, UK: Oxford University Press.

Electric Power Research Institute (EPRI). 1986. **Seismic Hazard Methodology for the Central and Eastern United States, Vol. 1, Methodology**. EPRI-NP-4/26. Palo Alto, CA: EPRI.

Hora, S.C., N.G. Dodd, and J.A. Hora. 1983. "The Use of Decomposition in Probability Assessments of Continuous Variables," **The Journal of Behavioral Decision Making. 6**, 133-147.

Hora, S.C., J.A. Hora, and N.G. Dodd. 1992. "Assessment of Probability Distributions for Continuous Random Variables: A Comparison of the Bisection and Fixed Value Methods," **Organizational Behavior and Human Decision Processes. 51**, 133-155.

MacGregor, D., S. Lichtenstein, and P. Slovic. 1988. "Structuring Knowledge Retrieval: An Analysis of Decomposing Quantitative Judgments," **Organizational Behavior and Human Decision Processes. 42**, 303-323.

Winkler, R.L. 1967. *Quantification of Judgment: Some Methodological Suggestions*," **Journal of the American Statistical Association. 62**, 1105-1120.

Comment MI-4

Page 8

The EEG is distressed about the status of documentation of computer codes used in the 1992 Performance Assessment.

Recommendation:

"DOE is urged to come up with a workable system of providing EEG with relevant documentation, so that EEG has reasonable access without undue burden on the workers."

Response

Documentation of computer codes necessary for compliance is in progress and will be completed to the extent needed to support the compliance application.

This documentation of WIPP performance assessment models and codes necessary for compliance is anticipated to be completed by the end of September 1995 or shortly thereafter.

Comment MI-4a

Page 9

"For PANEL, the actual equation solved is given at page 1-33. The documentation is needed to see if it is true."

Recommendation:

"DOE is urged to come up with a workable system of providing EEG with relevant documentation, so that EEG has reasonable access without undue burden on the workers."

Response

PANEL is currently at QA level "C" and is available on the remote access PA computer system in executable-only form. Work is underway to bring the code to full QA level "A" by September 30, 1995. Documentation and the source code will be available at that time.

Comment MI-4b

Page 9

SECOTP2D needs full documentation. The following questions need to be addressed in such documentation.

- How does SECOTP2D handle the conversion of the source term from zeroth dimensions? How is the injection rate, Q, determined? How does the source, Qc, spread?
- How are matrix diffusion effects in the Culebra calculated?
- Are there benchmarking results for the codes used for flow and transport calculations for the Culebra?

Recommendation:

"DOE is urged to come up with a workable system of providing EEG with relevant documentation, so that EEG has reasonable access without undue burden on the workers."

Response

Documentation of SECOTP2D is in progress and will be completed along with other WIPP performance assessment models necessary for compliance by September 30, 1995. Documentation is currently available for PRESECOTP2D, POSTSECOTP2D, PRESECOFL2D, and POSTSECOFL2D.

We acknowledge your comment and the following information will be included in documentation.

The 1992 PA involved only 2-D flow and transport calculations. The source term Q is introduced at a single computational cell. (This could be viewed as a vertical "line source", but this is redundant terminology for a 2-D calculation.) Physically, the source term is not "zeroth dimension". Certainly the source is not modeled as being spread out horizontally. The Qc term is provided by a decoupled calculation involving two-phase flow at the site and flow up the borehole (calculated by BRAGFLO and PANEL) as indicated in the 1992 PA documentation.

The "classic Neretnieks equation for matrix diffusion" is not used in our calculations. That approach is criticized in Huyakorn et al.,1983. The method outlined in Huyakorn is followed in the 1992 PA calculations.

There are benchmarking results comparing SWIFT and STAFF2D to the SECO codes. The SWIFT results agree with SECO- FLOW, as expected, except for one peculiar boundary condition problem for which SWIFT degenerates to only first order accuracy. These comparisons are presented in detail in an open literature publication from 1990. In 1993, open literature publication of the description of the SECO-TRANSPORT code (with many details) included a sample comparison with the STAFF2D algorithm (Roache, 1993a; Roache, 1993b; Salari et al., 1992; Roache, 1992; Roache, 1991; Roache et al., 1990). There is no need to perform extensive benchmarking, since the sample calculation already confirmed what is obvious from examination of the algorithms; STAFF2D is only first order accurate, while SECO-TRANSPORT is second order

accurate, as well as 1-2 orders of magnitude more efficient for the same time step. There is no purpose served in examining STAFF2D since it has been superseded. The 1992 PA calculations were snapshots of progress at that time, requested by the National Academy of Sciences and DOE.

References

Huyakorn, et al., Water Res. Res. Vol. 19, No. 3, Page 841, June 1983.

Roache, P.J. 1993. The SECO Code Algorithms for Groundwater Flow and Transport. *Finite Elements in Fluids.* Morgan, K., Ofiate, E., Periaux, J., and Zienkiewicz, O.C., eds. Pineridge Press. 1993.

Salari, K., Knupp, P., Roache, P.J., and Steinberg, S. 1992. TVD Applies to Radionuclide Transport in Fractured Porous Media. Numerical Methods in Water Resources: IX International Conference on Computational Methods in Water Resources. Denver, Colorado, 9-12 June 1992.

Roache, J.P., Knupp, P.M., Steinberg, S., and Blaine, R.L. 1990. Experience with Benchmark Test Cases for Groundwater Flow. *Benchmark Test Cases for Computational Fluid Dynamics.* Celik, I. and Freitas, C.J., eds.

Roache, P.J. 1993. The SECO Suite of Codes for Site Performance Assessment. 1993 International High-Level Radioactive Waste Management Conference, April 26-30, 1993, Las Vegas, Nevada.

Roache, P.J. 1992. Computational Fluid Dynamics Algorithms Developed for WIPP Site Simulations. IX International Conference of Computational Methods in Water Resources. Denver, Colorado, 9-12 June 1992.

Roache, P.J. 1991. Computational Fluid Dynamics Algorithms and Codes Developed for WIPP Site Simulations. *Computational Mechanics.* Cheung, Lee, and Leung, eds. Balkema, Rotterdam. 1991.

Comment MI-4c

Page 9

The technical paper by Roache, 1993, touts the TVD algorithm, but does not define it. The algorithm begins with a variable transformation, and a key variable J is not defined. No results are given for verification of the dual porosity option in the paper.

Recommendation:

"DOE is urged to come up with a workable system of providing EEG with relevant documentation, so that EEG has reasonable access without undue burden on the workers."

Response

Documentation of all WIPP performance assessment models and codes necessary for compliance will be completed by September 30, 1995 or shortly thereafter.

The technical papers written and cited are not intended to be a substitute ultimately for full user documentation. However, neither are internal Sandia reports a substitute for open literature publications which have the advantage of wider scrutiny. We have produced 6 papers for external release on the SECO suite of codes, and more are in preparation.

"TVD" is a class of Total Variation Diminishing algorithms. There are more accurate algorithms than TVD in existence, though not, to our knowledge, embodied in robust production codes. There are also several algorithm families of comparable accuracy. Any tone of "touting" TVD occurs inadvertently due to the comparison with the inaccurate algorithms used in STAFF2D, for example. The variable J is the Jacobian of the transformation. No results were given for the dual porosity option because of time and space limitations; these results will be included in open literature papers now in preparation as well as in the final documentation.

Comment MI-4d

Page 9

"Finally, it is often claimed that because a computer code is constantly being revised, its documentation status is affected."

Recommendation:

"DOE is urged to come up with a workable system of providing EEG with relevant documentation, so that EEG has reasonable access without undue burden on the workers."

Response

We agree that the documentation status of specific code versions used in PA calculations are not affected by subsequent revisions. However, none of the codes used in the 1992 PA Snapshot were at QA level A, a requirement for release of source code. The primary reason for this is that the PA effort was focused on annual snapshots of

compliance, model development required to capture alternate conceptual models, and QA of current code versions. PA codes necessary for compliance will be at a QA level A by the end of September 1995 or shortly thereafter. Codes are currently being made available to EPA and EEG on the WIPP Open VMS Network. Prioritization of the availability of codes is being set by EPA.

Comment MI-05

Page 10

"The *1992 Performance Assessment* elucidates the role of the Culebra as an isolation barrier. From Figure 5-6 of Vol. 1, it is seen that if there is enough flow in the Culebra, it does not offer much help in isolation. With matrix diffusion and sorption, the Culebra is a major natural barrier."

Recommendation:

"The DOE should delineate the roles of matrix diffusion and sorption through accelerated experimentation."

Response

SNL is currently conducting experiments designed to collect data upon which a defensible retardation model can be constructed, for use in future compliance PAs. These experiments examine the roles of matrix diffusion (physical retardation) and sorption (chemical retardation), and resulting model will also contain both mechanisms.

Comment MI-06

Page 10

"While the DOE has analyzed the beneficial effects of gas generation, the EEG continues to be concerned that the deleterious effect of gas generation, particularly the opening of new discharge pathways, has not been analyzed."

Recommendation:

"In future analysis, the deleterious effect of gas generation should be included."

Response

This question raises issues that will be included in the SPM.

In the past the project has studied gas generation mechanisms, its impact on fluid transport in the Salado, and its effect on room closure mechanisms. Currently the project is evaluating the potential for gas-driven enhanced permeability in the markerbeds as well as gas-driven spalling mechanisms.

The deleterious effects of gas generation are recognized. This question is very similar to EPA comment 118 and our answer is the same; these issues are not fully resolved and the project intends to use the SPM to identify acceptable methods for dealing with these concerns.

Comment MI-07

Page 10

"Currently, there is no correlation between sampled variables using Latin Hypercube sampling. In real life, many of the variables are related."

Recommendation:

"The performance assessment should either give reasons why physical correlations have been ignored, or show results with correlations."

Response

Correlations between variables will be included if and when defensible information is available to quantify them. In the absence of defensible data to support correlations, it is appropriate to treat variables as independent. In general, so long as the sampled parameter range includes the range of coupled parameters, we believe that the treatment of uncoupled parameters, as used in the 1992 PA, is conservative.

Comment MI-08

Page 10

The '92 PA is incorrect and unclear on the extent of natural resources near the WIPP site. There are more than oil and gas wells than the 56 indicated in the PA. DOE is basing its estimate on incorrect information from 1986. EEG showed (Silva and Channell, 1992) some of this [sic] data were incorrect.

The PA also states that with the exception of one well, resource extraction is not allowed within the proposed land withdrawal boundary.

The 1992 WIPP Land Withdrawal Act recognizes the validity of two specific oil and gas leases within the WIPP site boundary. The owner of one of those leases has recently filed an application for permits to drill eight directionally drilled oil wells that would be completed within the WIPP site boundary, but at depths greater than 6,000 feet to produce oil from within the WIPP site boundary. Thus, there seems to be no basis for the statement in the PA which indicates that resource extraction is not allowed within the boundary, except that the restriction is contained in the second modification to the Cooperation and Consultation Agreement (C & C) between the DOE and State of New Mexico.

EEG believes the second modification to the C & C has been incorrectly interpreted. The agreement is not limited to the first 6,000 feet of depth.

Recommendation:

"As in all DOE reports, performance assessment reports should accurately reflect the status of resource development near the WIPP site."

Response

The WIPP project continues to collect information on the existence and nature of natural resource-related boreholes in the vicinity of the WIPP site. The WIPP position on this issue was discussed at length in the DOE's response to EEG-50 (Memo Arthur to Neill, November 3, 1992; Copy sent to EPA) and will not be reiterated here.

Comment MI-09

Page 12

Silva and Channell (1992) showed that the document, "DOE Implementation of the Resource Disincentive Plan in 40 CFR 191.14(e) at the Waste Isolation Pilot Plant" (U.S. DOE, 1991) is inconsistent in reporting the number of oil and gas leases within the WIPP site boundary and the production status of those leases.

In the No-Migration Variance Petition (U.S. DOE, 1990a) the DOE states:

". . . Oil and gas exploratory drilling requires permits from the state and it is unlikely that prospective future well drillers would not be informed about the existence of WIPP. As an additional protective measure, the DOE has purchased all oil and gas leases in the area of the WIPP site to prevent any exploration now and in the future (Section 6.3.2)."

With respect to petroleum exploration and the human intrusion issue, the last sentence in this paragraph is simply wrong.

Weart (1983) and Brausch et al (1982) failed to recognize the potential crude oil resources for this area. Crude oil is now being produced from the former control zone IV.

Recommendation:

"The performance assessment effort must use the latest and verifiable data on oil and gas production near the WIPP, because the extent of oil and gas resources in this area is likely to be an important determinant of inadvertent human intrusion."

Response

The WIPP project continues to collect information on the existence and nature of natural resource-related boreholes in the vicinity of the WIPP site. The WIPP position on this issue was discussed at length in the DOE's response to EEG-50 (Memo Arthur to Neill, November 3, 1992; Copy sent to EPA) and will not be reiterated here.

Comment MI-10

Page 13

"One of the most important codes in the WIPP performance assessment is BRAGFLO and a brief summary is given in vol. 3, section 1.4.1. Equations 1.4.1-1 and 1.4.1-2 use rate constants and mole fractions (called "stoichiometry factors") to calculate the rate of gas generation. These factors, although not specifically referenced in this section, are referred to in the discussion on pp. 3-44 to 3-45. Median corrosion gas production rates are given as 6.3×10^{-9} moles H_2/m^2-s for inundated steel and 0.1 [-] for humid steel under aerobic conditions, and 0.5 [-] for inundated steel under anoxic conditions. An analogous set of rates are given for microbial gas generation, with units of moles of gas/kg cellulosics given only for inundated conditions. It should be noted that in the development of the equations on pp. 1-24 to 1-26, the rate constants and stoichiometric factors are given with perfectly acceptable units. Why aren't the dimensions the same for all these rates, if they are used for the same variable in BRAGFLO? How can a corrosion rate have the units of moles per unit area of exposed substrate in one case and no units in another? How can a dimensionless variable be used in the same place in an equation as a variable with units?"

Response

The gas production rate associated with inundated corrosion has units of mole gas/m^2-s. The units for the gas production rate associated with humid corrosion are the same. What is reported and stated in vol. 3 p. 4-46 is the relative humid rate. The product of the relative humid rate and the inundated rate is the humid rate. Similarly for

biodegradation, the units for gas production rate due to biodegradation are reported as mole gas/kg-cellulosic/s not moles gas/kg, vol. 3 p. 3-50. The reason these units are different are due to differences in the way the rates are measured experimentally. Both corrosion rates and biodegradation rates are converted in the BRAGFLO preprocessor to units of [kg-metal/m^3/s] or [kg-cellulose/m^3/s] as required by BRAGFLO, vol. 3 p. 1-22.

Comment MI-10a

Page 14

"Although the assumption that radiolysis will contribute only negligible hydrogen formation at WIPP appears to have found general acceptance, the data developed by Kosiewicz (1981) show this need not be the case. In fact, the gas generation problem was first noticed in stored drums of TRU waste in which hydrogen had been generated by radiolysis. Moreover, the microbial generation model does not recognize the dependence of the microbial gas generation rate on the initial and continued presence and availability of microbes."

Recommendation:

"The gas generation calculations should include
(a) methane generation,
(b) radiolytically generated hydrogen."

Response

Radiolysis of combustibles and of brine is included in the reaction-path gas generation model currently under development, and will be evaluated as part of the SPM for inclusion in future (compliance) PAs. Current experimental information suggests that H_2 production by brine radiolysis is insignificant if actinide solubilities are as predicted by the expert panel. If current and planned experiments determine actinide concentrations (including colloids) to be significantly higher than predicted, then radiolytic hydrogen production may be significant and will be included in future PAs. Methane generation is addressed in the response to the next comment, MI - 10b.

Comment MI-10b

Page 14

"A more serious question arises about the use of these results. The gas generation rates and stoichiometry factors cited are those calculated by a model and are thus the

result of model inputs rather than experimental data. Table I summarizes the results of the Sandia scientific investigations into gas generation, and distinguishes model calculations from experimental measurements. Model results are only as good as model inputs. Some model inputs include unsupported assumptions, such as the failure to include methane. Experimental data exist -- see Table I -- but have not been used in modeling. Moreover, as the Table I shows, models given different gas generation rates when given different inputs and assumptions, and the median of such calculated rates has little validity."

Recommendation:

"The relationships in the gas generation model should be validated before the gas generation model is incorporated into BRAGFLO."

Response

Methane production was not included in the 92 PA calculations. However, microbial methane production (methanogenesis) is included in the reaction-path gas generation model currently being developed. The SPM will examine the utility of the reaction path model. It should be noted that current experimental information has not resolved whether methanogenesis will occur, and, if so, whether it will result in a net increase or decrease in the total amount of gas in the repository. Current and planned experiments investigate microbial gas production under a range of conditions. The effect of the availability of microbes is being investigated (implicitly) by varying parameters such as the amount of nutrients in the various experiments, inoculation, humid vs. inundated conditions, etc. The possible long-term existence of microbes is simulated by non-inoculated experiments. The gas generation rates were based on experimental data and expert estimates. Additional relevant experimental data continue to be collected.

Comment: MI-11a

Page 16-17

In 1984 an EEG consultant analyzed potential nuclear criticality in the Culebra Aquifer and concluded that this needed to be thoroughly evaluated by DOE.

The potential nuclear criticality could occur if:

(1) sufficient quantities of a fissile radionuclide such as Pu-239 or U-233 are adsorbed on a large enough volume of aquifer matrix;

(2) there is sufficient hydrogen or other moderator available in the brine or matrix;

(3) the matrix or brine does not contain sufficient quantities of stable nuclides that can "poison" the reaction.

EEG's analysis indicated that, with the expected elemental composition of the brine and the Culebra aquifer matrix, nuclear criticality could occur in a block 7 m high x 0.5 m wide x 1 m long if the product of the distribution coefficient (K_d, mL/g) and plutonium solubility (moles/L) was greater than about 5.6×10^{-5} moles/g.

The possibility of a K_dS product of $> 5.6 \times 10^{-5}$ moles/g is credible. For example, the probability distributions for K_d and solubility from Volume 3 of SAND 91-0893 (pages 2-104 and 3-64) have approximate probabilities of occurrence of:

Species	Probability $K_dS \rangle 5.6 \times 10^{-5}$
Pu^{5+}	0.025
Pu^{4+}	5×10^{-6}
U^{6+}	0.25
U^{4+}	0.11

Two pages were devoted to discussing nuclear criticality in the *1991 Preliminary Comparison* (Volume 1, page 4-52). SNL recognized that sorption can also occur in the backfill and at certain components of the seal system as well as in the Culebra Aquifer. The very remote possibility of a high-yield nuclear explosion is also discussed. We find no analysis of nuclear criticality in the *1992 Performance Assessment*. No schedule has been given for performing additional criticality evaluations.

EEG also believes the possibility of a high-yield nuclear explosion is very remote. One concern is with an instantaneous criticality excursion in which there is a brief burst of energy, neutrons, and gamma radiation. Perhaps more likely in this situation, where fissile material is being added very slowly in a solution, is a delayed criticality where the system does not become promptly critical. Such a system would behave much like a nuclear reactor and could produce fissions, perhaps in bursts, for extended periods of time. This phenomena has occurred in several process criticality accidents in the U.S., e.g. at Hanford in 1962 one system boiled for 37 hours. Also, the Oklo "natural reactor" in Gabon is believed to have operated in a similar fashion.

It is not obvious that a criticality accident would have a significant effect on a repository waste disposal system, even if a criticality accident occurs. Considerable heat would be produced, some brine would be vaporized, and minor amounts of

fission products would be formed (it takes 8×10^{20} fissions to produce one curie of cesium-137). Also, the relatively high K_d values that would be necessary to make criticality possible are otherwise a benefit because the retard radionuclide transport.

Recommendation:

"The criticality issue needs to be thoroughly evaluated before it can be concluded that its effects are negligible.

Response

Criticality will be considered in analyses for event and process screening. A decision will be made whether to include it in the SPM.

Comment MI-11b

Page 17

"Subsidence could occur in the area overlying the WIPP some time after repository decommissioning. Subsidence can also occur from nearby potash mining. The *1992 Performance Assessment* identifies an event TS which is subsidence from mining of potash, but TS has not been analyzed. . ."

"No evaluation has yet been made of subsidence from potash mining. There are significant potash resources within the WIPP site boundary. However, the USEPA Standard requires analysis of only resource exploration drilling on site. But, it is appropriate to consider subsidence effects from potash mining offsite. . ."

Recommendation:

"EEG believes that subsidence effects need to be evaluated in much more detail and incorporated, in some manner, into the human intrusion scenarios."

Response

As noted in the 1992 preliminary PA (e.g., V. 1, p. 3-11, l. 16-19; V. 1, p. 6-3, l. 19-24), the effects on groundwater flow and radionuclide transport of subsidence related to potash mining will be examined using the regional three-dimensional hydrologic model that has been developed since the 1992 PA was completed.

Comment MI-11c

Page 18-21

The E1, E2 and E1E2 scenarios assume that the only material reaching the surface is drill-bit cuttings and some "cavings" from the annulus about the drill bit in the waste storage room. Brine flowing to the surface from encounter with a pressurized Castile brine reservoir was not assumed. EEG believes that brine flows to the surface should be assumed and that the consequences could be significant for the E1E2 scenario. Our reasons follow:

Sandia and DOE have described typical drilling practices elsewhere (Appendix C of SAND 89-0462 and in DOE February 7, 1990 response to EEG's comments on the Draft Supplement EIS). These responses explain how it is possible to have very little flow to the surface by closing in blow-out preventers within a few minutes, determining the pressure, and then preparing drilling mud of sufficient density to stop the flow before resuming drilling. For example, it was stated (in the February letter) that only 51 barrels flowed at WIPP-12 before shut in by a blow-out preventer.

The February 7, 1990 DOE letter went on to say that at WIPP-12 an additional 49,224 barrels flowed during deepening, geophysical logging, and further deepening before it was finally shut in for subsequent hydrologic testing. This additional flow was described as resulting from a "conscious decision."

It appears that virtually every time a pressurized Castile brine reservoir has been encountered in the vicinity of WIPP that "conscious decisions" have been made to allow varying amounts of brine to flow to the surface. Table II, extracted from tow WIPP reports (TME-3080 and TME-3153), describes remedial measures taken. Although the available data are not as detailed or as quantitative as one would like, it is clear that drilling practice through 1982 included release of brine at the surface whenever pressurized Castile brine reservoirs were encountered. There has been considerable drilling activity about the WIPP Site in the last few years and brine has been reported in seven wells. In two of these wells brine was reported to have flowed for three hours before stopping and for at least 12 hours. Records did not indicate how long the remaining wells flowed. It appears that, at least in some cases, commercial drillers still allow significant amounts of brine to flow to the surface and we believe scenarios should assume that any intruding driller will do likewise. Also, minor flows may not always be recorded in drilling logs, or perhaps even recognized.

Name of Well	Date Drilled	Initial Flow bbl/day	Remedial Action
Mascho-1	1937	8,000	No action to stop flow.
Mascho-2	1938	3,000	No action to stop flow.
Culbertson-1	1945		3,000 barrels estimated to flow to surface. No record of flow rate or duration.
Tidewater	1962	NA	12 pound/gallon drilling mud did not stop. Finally controlled [sic] by casing and cementing.
Shell	1964	20,000	Allowed to flow until artesian flow ceased.
Belco	1974	12,000	Brine flowed to surface for 26 hours with 14 pound/gallon drilling mud.
Gulf	1975	5,000	No records on total volume or duration of artesian flow.
ERDA-6	1975	660	WIPP hole. Estimate 19,0000 barrels could be produced by artesian flow.
Pogo	1979	1,440	Initial flow was after 14.6 pound per gallon drilling mud had been added. Stopped after 4 days with 15 pound per gallon mud.
WIPP-12	1981	12,000	WIPP borehole. Over 79,000 barrels produced. Estimate 350,000 barrels producible by artesian flow.

Table II References

U.S. Department of Energy, 1981a. *Brine Pocket Occurrences in the Castile Formation, southeastern* [sic] *New Mexico*, TME-3080.

U.S. Department of Energy, 1983. *Brine Reservoirs in the Castile Formation, Southeastern New Mexico*, TME-3153.

R.H. Neill *et al.*, 1983. *Evaluation of the Suitability of the WIPP Site.* EEG-23.

Brine released at the surface from the E2 scenario would be expected to increase the effective radius of the borehole and thus increase the amount of waste brought to the surface in suspension and in solution. The major effect could occur in the E1E2 scenario because brine present in the repository from the first encounter (which would be expected to be saturated in actinides) would be discharged at the surface.

In a November 3, 1992 response to EEG's concern about contaminated brine flow to the surface, SNL said: "We will repeat these subsidiary simulations using BRAGFLO for both release during drilling and long-term releases through abandoned boreholes. As you suggested at our previous meeting, there are four cases: (1) E1 or E2 during drilling, (2) E1 while Castile brine is allowed to flow, (3) E1 followed by E2 after Castile brine has been allowed to flow into the panel and then is available to flow through E2 during drilling, and (4) E1E2 after both have been abandoned.

EEG, in a November 9, 1992 letter to SNL, agreed these 4 cases were the appropriate ones to consider and urged SNL to perform the analysis posthaste.

Recommendation:

"EEG looks forward to seeing the results of the above mentioned analysis, and to include contaminated brine flow to the ground surface in future versions of human intrusion scenarios."

Response

These scenarios will be considered for inclusion in the SPM.

Comment MI-11d

Page 21

"A brine-slurry release scenario should be analyzed. A brine slurry might result from creep closure and gas generation. Such a brine slurry could be under greater than hydrostatic pressure and thus have a force capable of driving some or all of the slurry to the ground surface. The potential quantities of ejected brine might be less than that from the E1 scenario but the consequences could still be significant. The possible implications of a brine-slurry filled room were first raised by SNL in 1987 and were also evaluated in 1988 by EEG (Chaturvedi, Channell and Chapman, 1988)."

"SNL has responded that all evidence indicates that the possibility of a brine slurry existing in a waste storage room is essentially zero, and can be ignored

(SAND91-0893, Volume 1, Appendix B). Lappin et al., (1989) and the FSEIS (U.S. DOE, 1990b) are cited as support for this conclusion."

"The brine-slurry release scenario is related to undisturbed performance and cuttings release. Actually a similar, though probably less serious, release is considered in undisturbed performance when the waste storage room became partially or fully saturated only in the lower portion of the room. An effect of partial saturation and incomplete consolidation of the waste could be to lower the shear strength and result in greater quantities of waste being brought to the surface than calculated with the current cuttings model (E2) assumptions."

Recommendation:

"The EEG recommends a complete analysis of the brine-slurry release scenario. In addition, variants of the brine-slurry scenario in undisturbed performance and E2 need to be better understood."

Response

The Project believes a brine-slurry release in any context is unlikely. As stated in the comment several studies have been performed within the last several years on the possibility of brine-slurry in salt backfill in the underground environment. Results of the studies indicated brine-slurry in salt backfill would not impact performance because room closure rates (even considering likely gas generation rates) will decrease the available volume and recompact the salt to a point that even if brine fills the residual porosity a slurry cannot develop.

With respect to slurries forming from decomposing waste, itself, we believe closure rates and compaction would result in an end product with sufficient shear strength that a mobile slurry would not form. For further information, see Disposal Room and Cuttings Model Position Paper for Systems Prioritization and Technical Baseline, Section 4.2.4.5.

A model for representing incomplete consolidation of the waste in various degrees of decomposition has been developed, but it is not yet part of cuttings release calculations. Attention has been focused on pressurized gas. To date, the spall issue has usually been cast in terms of inflow of a fluid into an intrusion well, and the material that is carried along in this process. Variable strength materials will eventually be incorporated into the cuttings release calculations to encompass concerns that may exist about whether appropriate strength materials have been modeled.

Comment MI-11e

Page 22

"The USEPA Standard calls for human intrusion analysis that would create

> ... a ground water flow path with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open borehole [sic] over time—not the permeability of a carefully sealed borehole."

"In the 1991 and 1992 *Performance Assessments* the permeability of human intrusion boreholes was sampled lognormally between 10^{-11} m^2 and 10^{-14} m^2. This value was obtained from Table 2.2 of Freeze and Cherry (1979) for silty sand. The choice of silty sand is SNL's interpretation of USEPA guidance on borehole sealing cited above."

"EEG has several problems with the SNL interpretation. Table 2.2 in Freeze and Cherry (1979) shows a permeability range for silty sand from about 8×10^{-11} m^2 to 8×10^{-15} m^2. The same table also shows ranges of 10^{-9} m^2 to 2×10^{-13} m^2 for clean sand and 10^{-7} m^2 to 10^{-10} m^2 for gravel. It appears that a strict following of the EPA Guidance would require use of higher permeabilities, to include gravel in the borehole."

"EEG believes that the assumption of borehole permeability described in the EPA Standard is reasonable when considered along with the other assumptions in the guidance, but is not conservative in light of observed borehole sealing practices in the Delaware Basin. In 1989 the Bureau of Land Management found 6,527 shut-in and temporarily abandoned wells in New Mexico (USBLM, 1989). A temporarily abandoned well is simply abandoned, without proper plugging and sealing. The BLM made the following statement about wells in the Carlsbad area:

> At Carlsbad, we reviewed the status of 2 shut-in and 11 temporarily abandoned wells on a 15-well lease. These wells had been classified as shut-in or temporarily abandoned since the late 1960s without approval. There was no evidence these wells had been properly tested to ensure they were capable of producing oil or gas and properly classified. The operator of this lease stated that he did not perform well integrity tests because he estimated that it would cost about $2,000 per well. Additionally, he stated that he did not permanently plug wells because that would cost about $10,000 per well (USBLM, 1989)."

Recommendation

"Performance Assessment assumptions should consider conditions as they exist, not at the state-of-the-art or in full compliance with regulatory standards that are not being met now and may not be met in the future. For the human intrusion borehole, the range of degraded permeabilities should span sand and gravel."

Response

The DOE does not dispute the principal point raised here by the EEG, which is that boreholes are sometimes abandoned without proper plugging.

The DOE has interpreted the guidance quoted by the EEG to allow for consideration of the make-up of the formations penetrated by the borehole. The guidance indicates that the fill material should be that which would "normally settle into an open borehole over time." Detailed examination of the geologic column in the Air Intake Shaft (Holt and Powers, 1990, DOE/WIPP-90-051) revealed no gravel beds between the repository and the ground surface. Sandstones occur in the Gatuña Formation, the Dockum Group, and the Dewey Lake Red Beds, but they are generally composed of fine sands and silts, and are interbedded with siltstones. The cleanest sand that might enter the borehole is that which is present at the ground surface, and it is simply not credible to imagine a circumstance in which the entire length of an open borehole from the repository to the surface is filled with nothing but clean sand. As a further consideration on this point, open holes are not empty when abandoned: at the least, they contain the remains of the fluid used to drill the hole. For holes drilled below the salt section in the Delaware Basin, this fluid is a "mud" containing clays and other additives. These materials should also be included in estimation of the final permeability of an open hole. The DOE believes that silty sand is an appropriate approximation of the fill material in an unplugged borehole. For boreholes which have been plugged, the DOE believes that silty sand is an appropriate approximation for fill material in the entire hole, including both the degraded concrete plugs and intervening open sections.

Second, the DOE is aware of the 1989 BLM Office of Inspector General Audit Report, and agrees that it provides evidence that borehole plugging procedures are not always followed. The EEG's implication that the quoted paragraph has direct relevance to the WIPP, however, is inappropriate given the guidance in Appendix C of 40 CFR 191 that "inadvertent and intermittent intrusion by exploratory drilling...can be the most severe intrusion scenario assumed..." and that "the drillers [will] soon detect, or be warned of, the incompatibility of the area with their activities." The quote from the BLM report probably refers to production wells, rather than exploratory wells. Fifteen wells on a single lease are not examples of "intermittent" drilling. The BLM report does not distinguish between exploratory wells and production wells in its total number of improperly plugged wells in New

Mexico. All anecdotal examples described in the report appear to be production wells rather than exploratory wells, and were presumably abandoned many years after they were drilled.

Reference

Holt, R.R. and Powers, D.W 1990. *"Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant"*. Report Number DOE/WIPP 90-051.

DETAILED COMMENTS

Comment DC-01

Page 23

Area in document Volume 1, Section 3.1, Page 3-3

This section says that EPA expects the implementing Agency to use the same assumptions. But it does not say whether DOE does or does not.

Response

Appendix B defines the assumptions that may be used in determining compliance with Subpart B. The DOE recognizes these assumptions and has used them in the 1992 PA calculations. These assumptions may change with the release of 40 CFR 194 and as such will be incorporated in future PA calculations where appropriate.

Comment DC-02

Page 23

Area in document Volume 1, Table 3-1, Page 3-14, Line 15

"In this Table, techniques are given for assessing and reducing various kinds of uncertainties. For conceptual model uncertainty, an additional method for assessing its extent is to analyze alternate conceptual models. If alternate conceptual models can be rejected with confidence, then the favorite conceptual model has a better chance!"

Response

The DOE agrees with the comment. The importance of alternative conceptual models was discussed on the previous page of Volume 1 of the 1992 PA. Analysis of alternative conceptual models will be part of the SPM.

Comment DC-03

Page 23

Area in document Volume 1, Table 3-1, Page 3-14

"In Parameter Values and Variability, the use of expert judgment is said to be a method of assessing and reducing uncertainty. The fact is that the panel on solubilities greatly expanded the uncertainty range."

Response

The EEG's comment is correct. However, the heading on the column in question in the table is "Technique for Assessing or Reducing Uncertainty" (emphasis added). There was no intent to imply that expert panels should be expected to reduce uncertainty.

Comment DC-04

Page 23

Area in document Volume 1, Section 3.3.4, Page 3-17, Line 17

"The marker panel has not issued a report."

Response

The report has been published as:

Trauth, K. M., S. C. Hora, and R. V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment DC-05

Page 23

Area in document Volume 1, Section 4.1.1, Page 4-2, Line 28.

"The description of undisturbed performance should include a statement that the deleterious effects of gas fracturing have not been considered. The probability of gas fracturing is clearly above 10^{-4} in 10,000 years. Sandia's own experimental data suggest that without fracturing, the gas pressure is likely to reach and exceed lithostatic in hundreds of years."

Response

The DOE agrees that consequence analysis of undisturbed performance should include pressure-dependent effects on the permeability of anhydrite interbeds. The text referred to in the comment does not discuss consequence modeling. Rather, it defines undisturbed performance independently of modeling capabilities, to include "all expected changes in the system and associated uncertainties for the 10,000 years of concern...." "Fracturing" is included in the base case definition.

A statement relevant to the comment occurs in Section 4.3.1 of Volume 1 (page 4-12, lines 22-25): "The model used to represent the response of the repository and the surrounding strata to the generation of gas by waste degradation does not include effects of possible pressure-dependent fracturing of anhydrite layers within the Salado Formation."

Comment DC-06

Page 24

Area in document Volume 1, Section 4.2, Page 4-8, Line 38

"Why is the maximum number of holes in the 70 simulations only 20 per km^2 when Latin Hypercube is used to sample uniformly (I presume) over interval [0,30]? Isn't the key advantage of Latin Hypercube to "ensure full coverage of the range of each sampled variable.: (p. 4-14, line 10)?"

Response

The indicated statement in the 1992 PA documentation is incorrect. The rate constant for drilling intrusions was sampled uniformly on the interval [0,3.78x10^{-4} yr^{-1}], which is equivalent to sampling on the interval [0,30/km^2/10^4 yr]. Specifically, the

area of the waste panels in the 1992 PA was 0.126 km^2, which resulted in a maximum value for λ of

$$\lambda_{max} = (30/km^2/10^4\ yr)(0.126\ km^2) = 3.78 \times 10^{-4}\ yr^{-1}.$$

Confusion here arises from the erroneous statement in the 1992 PA that the number of intrusions are based on a waste area of 0.5 km^2. Note that 10 intrusions into 0.126 km^2 corresponds to 79.4 intrusions per 1 km^2.

Comment DC-07

Page 24

Area in document Volume 1, Section 5.1.2.1.1, Page 5-3, Line 27

"Is λ really random in both space and time? As implemented it appears to be only a variable of time."

Response

The rate constant λ is variable in neither time nor space for the "constant λ" cases. It varies nonrandomly with time (i.e., based on expert panel judgment about possible effectiveness of markers) and is fixed in space for the "time-dependent λ" cases in the 1992 PA.

The assumption of the Poisson process does involve the assumption that drilling is random in both space and time. Intrusions are assumed to be equally likely to occur anywhere within the region of interest, regardless of spatial location.

Consequence modeling (as opposed to probability modeling) for the 1991 and 1992 PAs assumed that all intrusions were located at the center of the waste disposal area for computational convenience. This assumption was made independently of the Poisson model used to determine intrusion probabilities.

Comment DC-08

Page 24

Area in document Volume 1, Section 5.1.2.1.2, Page 5-4, Line 35

"It is not clear why the intrusion and subsurface release times are specified rather than random. If intrusion and release times are random, the source strength can be

calculated in PANEL using eq. 1.4.4-11 in Vol. 3. Are these 6 times of intrusion possible times of intrusion, or must the intrusions occur?"

Response

Documentation resolving this is available in Chapter 3 of Volume 1 of the 1991 PA (SAND91-0893/1) and in Chapter 3 of Volume 2 of the 1992 PA.

The 1992 PA used an importance sampling procedure based on the subdivision of the 10,000 year time period specified in 40 CFR § 191.13(a) into six subintervals. Scenarios were then defined by taking combinations of drilling intrusions in these time intervals. The randomness of the intrusion times is incorporated into the probabilities of these scenarios. For computational efficiency, releases were calculated only for drilling intrusions occurring at the midpoints of the six time intervals. Thus, the six times of intrusion serve as a representative time of intrusion for each subinterval and not an exact time for a particular intrusion. Although not used in the 1992 WIPP PA, Monte Carlo procedures that involve sampling the number, time, and location of drilling intrusions in the construction of CCDFs exist. However, these procedures would still require the mechanistic calculation of releases at a relatively small number of intrusion times, with these releases then being used in conjunction with appropriate interpolation techniques to estimate the releases associated with the randomly selected intrusion times.

A detailed description of the CCDF construction procedure used in the 1992 WIPP PA is given by Helton and Iuzzolino (1993). A description of a Monte Carlo procedure for the construction of CCDFs is currently being developed.

Reference

Helton, J. C., and J. J. Iuzzolino. 1993. "Construction of Complementary Cumulative Distribution Functions for Comparison with the EPA Release Limits for Radioactive Waste Disposal." *Reliability Engineering and System Safety* **40**: 277-293.

Comment DC-09

Page 24

Area in document Volume 1, Section 5.1.2.2, Page 5-6, Line 25

"Given our comment on the subjective elicitation process in Major Issues, we do not consider any of the results using λ_t to be valid."

Response

The probability of human intrusion will be reevaluated if and when additional guidance is available from the EPA.

Comment DC-10

Page 24

Area in document Volume 1, Section 5.1.2.2, Page 5-6, Line 27

"When releases are calculated for six intrusions, is it six holes? Does this correspond to S(4,1,0,1,0,0) in Table 3-2 of SAND91-083/1?"

Response

Releases are calculated for six times of intrusion, rather than for six intrusions. Up to 10 intrusions occur at these six times in the 1992 PA. Tables 2.5-3 and 2.5-4 in Volume 4 of the 1992 PA provide a listing of the computational scenarios considered (i.e., the combinations of intrusions in each time interval), together with the probabilities of these computational scenarios calculated using a selected time-dependent Poisson rate constant (Table 2.5-3) and the maximum value for the time-invariant rate constant (Table 2.5-4).

Comment DC-11

Page 24

Area in document Volume 2, Section 1.3.2, Page 1-4, Line 26

"CAMCON controls 75 codes for WIPP Performance Assessment. However, the key codes BRAGFLO, SECOTP2D, and CUTTINGS are run outside of CAMCON, and also probably SANTOS-SANCHO. Does this make CAMCON a general without troops?"

Response

BRAGFLO, SECOTP2D, and CUTTINGS interface to CAMCON through the Computational Data Base (CDB). This is accomplished through the use of pre- and post-processors which extract information or write results to the CDB. The CDB is common and available to all models used in PA calculations whether the models physically reside within CAMCON or not.

Once codes such as BRAGFLO and CUTTINGS become stabilized (from a conceptual point of view), they will be included within CAMCON. Until then, they will remain interfaced to CAMCON so the QA history (information trail) of each calculations is traceable. As long as traceability is maintained, it is not clear how compliance may be affected.

Comment DC-12

Page 24

Area in document Volume 2, Section 2.3.2.1, Page 2-47, Line 2

"The word should probably be 'pyrophoric'."

Response

The DOE agrees with the comment.

Comment DC-13

Page 24

Area in document Volume 2, Section 2.3.2.1, Page 2-47, Line 2

"The second half of this sentence does not make sense. I doubt if the limit is 1% of the weight of an empty container."

Response

The text referred to is incorrect. The correct wording is "1% of the weight of the waste package."

Comment DC-14

Page 24

Area in document Volume 2, Section 2.3.4.1, Page 2-54, Line 17

"The fractile method was used in eliciting estimates of actinide solubility. Seaver, von Winterfeldt and Edwards (1978) fo[illegible] experimentally that other procedures were superior. The use of the fractile m[illegible]d needs to be justified."

Response

The experimental work reported in Seaver, von Winterfeldt, and Edwards (1978) has been found to be flawed with respect to the findings concerning the fractile method of elicitation. In the referenced study, the bounds (0th and 100th quantiles) were provided to the subjects under the direct assessment regime but not under the fractile assessment regime. This difference led to the apparent differences in calibration. The more recent work of Hora, Hora, and Dodd (1992) shows virtually no differences in calibration between direct and fractile assessments among scientists and engineers who participated in the NUREG-1150 study of nuclear power plant safety. Hora, Hora, and Dodd point up the mistake of Seaver, von Winterfeldt, and Edwards on page 149 of the reprint.

Reference

Hora, S.C., J.A. Hora, and N.G. Dodd. 1992. "Assessment of Probability Distributions for Continuous Random Variables: A Comparison of the Bisection and Fixed Value Methods," *Organizational Behavior and Human Decision Processes.* Vol. 51, 133-155.

Comment DC-15

Page 25

Area in document Volume 2, Section 2.3.4.1, Page 2-54, Line 20

"To use ionic-strength corrected data from Well J-13 from Yucca Mountain as the medium needs justification. There is increasing doubt at the Yucca Mountain Project that J-13 water is representative of anything."

Response

This was the only relevant data we had at the time of the 1992 PA. Research is underway to provide WIPP-specific data.

Comment DC-16

Page 25

Area in document Volume 2, Section 2.3.4.2, Page 2-55, Line 4

"The laboratory measurements of plutonium solubilities and sorption coefficients in brines fall short for several reasons:

- other actinides need to be measured;
- solubilities and sorption coefficients in Culebra water are needed;
- for the spectrum of possible conditions, calculations are better."

Response

In general, the SPM will help resolve this issue by:

- producing the project technical baseline document which will include "project defensible baseline data and assumptions".
- EEG will be asked to comment on the position paper used to define the baseline, which may or may not include the measurements referred to.

The current actinide source term program contains lab research and model development activities that address this issue.

Comment DC-17

Page 25

Area in document Volume 2, Section 2.3.4.2, Page 2-55, Line 6

"It is not clear how the results of the Source Term Testing Program will be useful or used in performance assessment. The current performance assessment uses the actinide solubility. The LANL experiments give a release rate, rather than a solubility. The LANL release rate will be proportional to inventory. The performance assessment department should state how it intends to use the two different sets of data."

Response

The current project technical baseline does not rely on solubility limits. Several sets of possible actinide solubility limits will be considered with the SPM methodology

sets will include results from source term model development and data collection (LANL) to test the model.

The compliance PA will use input from the actinide source term model (under development) that will include solubility and colloid species, if stable. The LANL tests will provide confirmatory solubility and colloid data from actual waste materials.

Comment DC-18

Page 25

Area in document Volume 2, Section 2.3.5, Page 2-55, Line 13.

"The statement is made that at decommissioning, free brine will not be present within the emplacement area. Experience over the history of WIPP indicates that brine may be present throughout the Test Phase and Disposal Phase."

Response

The statement 'free brine will not be present within the emplacement area' should be replaced with 'some brine will be initially present within the emplacement area.' The PA conceptual model of the repository treats the amount of this initial brine or water content as an imprecisely known parameter and it is sampled as such.

Comment DC-19

Page 25

Area in document Volume 2, Section 4.2.3.1, Page 4-11, Line 11

"Some 'waste containers' will be composed of organic material? Do such containers meet the Waste Acceptance Criteria?

Response

The text in question is incorrect. All waste shipped to and emplaced in the WIPP must meet the Waste Acceptance Criteria (WAC). Section 3.2.1.1 of the WAC states "Waste containers for emplacement in the WIPP shall be non-combustible and meet all applicable requirements of 49 CFR §173.412 for Type A packaging." Currently, no organic containers exist which meet the WAC. In addition, the TRUPACT-II Certificate of Compliance section 5(b)(1) states that "Wastes must be packaged in 55-gallon drums, standard waste boxes (SWB), 55 gallon drums within standard waste

boxes, or bins with standard waste boxes," all of which are of steel construction. The 55 gallon drums may indeed contain an organic poly liner, but currently the liner must be used in conjunction with the steel drum (the poly liner does not meet Type A requirements).

Comment DC-20

Page 25

Area in document Volume 2, Section 4.2.3.2, Page 4-13, Line 33

"All borehole plugs... degrade into material with properties similar to those of silty sand. Why not then plug above the Culebra?"

Response

The question is partially answered 4 lines later in the same paragraph: "A single plug above the Culebra is assumed to remain intact for Scenario E1, diverting all upward flow into the Culebra and maximizing radionuclide transport into that unit and toward the subsurface boundary of the accessible environment." (Volume 2, page 4-15, lines 6-8). Restricting flow and transport to a single unit yields an upper bound for subsurface radionuclide release, assuming that unit provides the most rapid transport path.

The question is also addressed in Volume 1 (page 4-6, lines 35-39): "In all three of these intrusion scenarios, borehole plugs are assumed to be emplaced and to perform so as to maximize fluid flow into the Culebra Dolomite Member of the Rustler Formation. These plug configurations have been chosen to facilitate examination of the specific scenarios, and do not reflect the most realistic conditions expected."

Future analyses conducted as part of the SPM will evaluate conditions in which the entire length of the borehole is assumed to have the properties of silty sand (representing degraded plugs and material which might settle into an open hole). Flow will be allowed to the ground surface and into stratigraphic units other than the Culebra.

Comment DC-21

Page 25

Area in document Volume 2, Section 5.2, Page 5-2, Line 22

"Prof. Helton's method of calculating intrusion probabilities is not trivial. The full explanation is worthy of a journal paper. The brief explanation here raises more questions than answers. As a matter of fact, this summary is incomprehensible and confusing."

Response

The material has been published as a journal article. See Helton (1993).

Reference

Helton, J. C. 1993. "Drilling Intrusion Probabilities for Use in Performance Assessment for Radioactive Waste Disposal." *Reliability Engineering and System Safety 40:* 259-275.

Comment DC-22

Page 25

Area in document Volume 2, Section 5.2, Page 5-4, Line 16

"Prof. Hora's algorithm gives drilling rates in units of holes/mi^2/10000 years, not holes/km^2/10,000 years."

Response

The Futures Panel provided their judgments in terms of mi^2. Subsequent calculations using the judgments were carried out in terms of the units provided. Conversion to km^2 was performed when the output was to be used in the performance assessment calculations.

Comment DC-23

Page 25

Area in document Volume 2, Section 5.3.2, Page 5-7, Line 22

The prior intrusion probability distribution was actually obtained from only the Boston Team, one of four Futures panels [sic], consisting of one lawyer, two social scientists and one physicist. Note that no one from a mineral-related field is on the panel.

Response

The statement that the prior intrusion probability distribution was obtained from only the Boston Team is factually in error. The paragraph referred to deals exclusively with the findings of the Boston team and not with the findings of all four teams. The paragraph from which the sentence was extracted reads:

The Boston team provided assessments for the drilling intensity that are conditional on both time and level of technology. The responses for exploratory drilling for hydrocarbons are shown in the following tables. Exploratory drilling for hydrocarbons was not thought to extend further than 300 years in the future.

This paragraph is followed immediately by a table labeled "BOSTON TEAM---DRILLING INTENSITY DISTRIBUTIONS.

Particularly in light of the following discussions of the findings of the three other teams, the assembly and analysis of results, and the listing in Volume 1 (pp. 4-8 and 5-4) of the six times of intrusion (100, 175, 350, 1000, 3,000, and 7250 years after decommissioning), we do not understand the confusion on this point.

The material that was presented to the Futures Panel, as well as the written material that they received, contained information about resource potential at the site. The reasoning behind the make-up of each team within the Futures Panel was to encourage a broader consideration of possible future societies rather than relying on current exploratory drilling rates.

Comment DC-24

Page 25

Area in document Volume 2, Section 7.1, Page 7-1, Line 2

"For the Bateman equations why not reference Bateman himself?"

Response

The Bateman equations will be referenced to the original source in future documents.

Comment DC-25

Page 26

Area in document Volume 2, Section 7.2.3, Page 7-1, Line 2

"Do you mean biodegradation of organic materials only?"

Response

Yes, the 92 PA assumed that gas was produced from 100% of the cellulosics, 50% of the rubber and none of the plastic waste.

Comment DC-26

Page 26

Area in document Volume 2, Section 7.6, Page 7-13, Line 3

"The use of the word compounds here is erroneous. A better word is fluid."

Response

The phrase in question is "may result in mobilization of dissolved, radionuclide-bearing compounds from waste...." The DOE agrees that "compounds" is the wrong word. "Dissolved" is also misleading here, because liquids may also transport radionuclides in suspended forms. Better wording would be "may result in mobilization of radionuclide-bearing fluids...."

Comment DC-27

Page 26

Area in document Volume 2, Section 7.6.1.2, Page 7-16, Line 26

"How is the scaling factor chosen? Who decides that it is reasonable? The same questions apply to the choice of $A_{R,\theta}$, and ϕ in (7-14). Where are the results of climate change shown?"

Response

The SPM will assess the system sensitivity to climate change. Documentation of the application of climate change in the 1992 PA is complete, and references are provided below.

The scaling factor g is chosen to ensure that for the maximum value of A_R heads will be approximately at the elevation of the spill point of Clayton Basin, in the hypothesized recharge area consistent with the confined-aquifer conceptual model used in the PA. The decision to limit future heads to this elevation was made by WIPP PA analysts, and is discussed in Section 6.4.1 of Volume 4 of the 1992 PA. Values for other terms in Eq. 7-14 are discussed in a memorandum by Swift in Appendix A of Volume 3 of the 1991 PA (SAND91-0893/3), and are also discussed in Section 6.4.1 of Volume 4 of the 1992 PA. Note that Eq. 7-14 is not intended to predict future climate variability: rather, it is designed to permit examining system sensitivity to uncertainty in climatic change. If system-level sensitivity warrants, different values for all climatic parameters can be considered.

Results of climate-change modeling in the 1992 PA are presented in Section 6.5 of Volume 4 of the 1992 PA. They are also reported by Swift et al. (1994).

Additional analyses of climate change are included in ongoing three-dimensional regional groundwater flow modeling.

Reference

Swift, P. N., B. L. Baker, K. Economy, J. W. Garner, J. C. Helton, and D. K. Rudeen. 1994. *Incorporating Long-Term Climate Change in Performance Assessment for the Waste Isolation Pilot Plant*. SAND93-2266. Albuquerque, NM: Sandia National Laboratories.

Comment DC-28

Page 26

Area in document Volume 2, Section 7.6.2, Page 7-18, Line 26

"The numerical model for solute transport is 2-dimensional. The conceptual model shown in Figure 7-4 is 3-dimensional."

Response

We agree that the statement on lines 5 and 6 of page 7-18 incorrectly implies that the conceptual model is two-dimensional. The correct point is that a two-dimensional numerical model is used to represent a three-dimensional conceptual model. The vertical (z) direction is introduced into the transport model by incorporating molecular diffusion of solutes in the vertical direction. (See equations 1.4.6-1 and 1.4.6-9 of Section 1.4.6 of Volume 3 of the 92 PA).

Comment DC-29

Page 26

Area in document Volume 2, Section 7.6.2, Page7-22, Line 13

"In a fracture, clay particles are unlikely to be regularly packed as in a crystalline lattice. There are ways to analyze random packing but we fail to see why it is necessary. The result in (7-22) is different from (7-21) by a factor of $a/3$. Because there is little justification for (7-22), why not just use (7-21)."

Response

We disagree that there is little justification for (7-22); the equation 7-22 approximates the retardation potential of clay particles packed in a fracture. Equation 7-21 is for the retardation from an unfilled fracture.

Comment DC-30

Page 26

Area in document Volume 2, Section 7.1, Page7-1, Line 7

"N_i here is the number of atoms of radionuclide I, not the activity. The activity of I is $\lambda_i N_i$."

Response

Correction accepted.

Comment DC-31
Page 26

Area in document Volume 3, Section 1.2, Page 1-8, Line 9

"In the upper right plot in Figure 1.2-1, why is the median/mean of a normal distribution 0.500001?"

Response

This is a typographical error; mean and median are the same for a normal distribution and both should be 0.5.

Comment DC-32

Page 26

Area in document Volume 3, Section 1.4, Page 1-24, Line 43

"In equation (1.4.1-9b) and eq. (1.4.1-11), the big dot used here for multiplication is confusing, and it is not needed. The dot is used on the previous two pages only for the dot product."

Response

Comment accepted.

Comment DC-33

Page 26

Area in document Volume 3, Section 1.4.4, Page 1-34

"....*present equation (1.4.4-10) and explain that Cdi is treated as a known constant.*"

Response

Comment accepted; but "two page" development shows generality of PANEL (i.e., what it is capable of doing, not just what was done in 1992).

Comment DC-34

Page 26

Area in document Volume 3, Section 1.4.5, Page 1-38, Line 11

"Same comment on the big dot."

Response

The "big dot" in this case does mean dot product since the quantity K is a tensor.

Comment DC-35

Page 26

Area in document Volume 3, Section 2.3.3, Page 2-4

"The category of data source of engineering lore is used here in and in other places. Engineering lore is not defined on p. 1-13. In this case, the source is a refereed journal paper, which may well be non-WIPP Literature Data."

Response

Another editorial error: the parenthetical phrase "engineering lore" should have been deleted in the final draft of this report.

Comment DC-36

Page 26

Area in document Volume 3, Section 2.6, Page2-78, Line 14

The equation here does not make sense, and the definition of probability is not proper. For x as a random variate, try

$$P[b_r/b] = \{ 0, (0<x<0.5); \ x-0.5, (0.5<x\leq 1.0)"$$

Response

We disagree. This formula correctly represents the CDF if the unit step function is defined as $U(y) = 0$ if $y<0$; $U(y) = 1$ if $y \geq 0$.

Comment DC-37

Page 27

Area in document Volume 3, Section 2.6, Page 2-83

"Why is the median given here not equal to the median given on the previous page, line 13?"

Response

This is a typographical error; the median quoted in line 13 of pg. 2-82 should be 0.139, not 0.145.

Comment DC-38

Page 27

Area in document Volume 3, Section 2.6, Page 2-93

"This is a curious table. The range of partition coefficients extends to a region of no significance. One can calculate the lowest value of K_d which will give a positive coefficient using the *[given]* equation and data . Examination of this table says none of the nuclide's median partition coefficient will give a positive retardation. Why bother? Just forget retardation."

Response

The conclusions drawn in the comment are incorrect. The equation presented in the Comment is in error. The proper equation is Equation 1.4.6-8 on p. 1-42 (Vol. 3) of the 92 PA. This equation reduces to:

$$R = 1 + (0.48)K_d$$

Any value of K_d greater than zero will yield retardation greater than one. All of the ranges and medians given in the table produce positive retardation.

Comment DC-39

Page 27

Area in document Volume 3, Section 3.3, Page 3-22, Table 3.1

"A more correct term for 'activity conversion' is specific activity."

Response

The suggested editorial change will be made in future documents.

Comment DC-40

Page 27

Area in document Volume 3, Section 3.3, Page 3-24

"The *Table of Isotopes* gives the half life of Pu-239 as 7.61×10^{11} s."

Response

The *Chart of the Nuclides* gives the half life of Pu-239 as 2.41×10^4 years, which converts to 7.60×10^{11} s. The most recent value for this parameter will be used in future documents.

Comment DC-41

Page 27

Area in document Volume 3, Section 3.4.2, Page 3-67

"Please identify the source given an 'input to the 1990 IDB'."

Response

The generator sites provide input data to Oak Ridge which were used in their compilation of the Integrated Data Base. Those input data are not independently published.

Comment DC-42

Page 27

Area in document Volume 3, Section 4.2, Page 4-6, Line 7

"Certainly this refers to a regular borehole. However, Figure 4.2-2 refers to changes in permeability as a function of 'time after intrusion. This legend cannot be correct. Should it be time after sealing?"

Response

On time scales of thousands of years, the difference between the "time of intrusion" and the "time of borehole sealing" is negligible.

Comment DC-43

Page 27

Area in document Volume 3, Section 4.2, Page 4-6, Line 11

"Surely the concrete plugs do not have initially the permeability and porosity of silty sand. On p. 3-14, the permeability of concrete is given as 2.7×10^{-19} m^2, where the permeability of silty sand has a median value of 3.16×10^{-12}m^2."

Response

The PA assumptions are shown in Figure 4.2-2; in that figure, borehole permeability increases from initial values from approximately 10^{-19} to 10^{-15} m^2 to final values of approximately 10^{-12} m^2 at 150 years.

Comment DC-44

Page 27

Area in document Volume 3, Section 4.2.1, Page 4-4, Line 38

"Reference is made that the New Mexico Energy, Minerals, and Natural Resources Department, Oil Conservation Commission is the state agency responsible for negotiating plug and abandonment specifications and conducting inspections. The Oil Conservation Commission has not performed this function since 1978. On March 31, 1978, Division Order No. R-5709 established the Oil Conservation Commission remaining in name as an appellate board. Many people in the industry still refer to OCD as OCC, but that is not technically correct."

Response

Comment acknowledged.

Comment C1

"Sensitivity and uncertainty analysis identified that solubilities and retardation coefficiencies are the most important variables amendable to additional site or lab work.

The EEG objects to the use of subjective estimates of solubilities and retardation coefficients.

Current "expert" estimated solubilities span some 10^{12}M.

The sensitivity to solubilities is actually sensitivity to the source term.

The roles of the LANL Source Term Testing program and measurements of thermodynamic solubilities in PA are not clear."

Response

The current actinide source term program is developing experimental solubility and colloid data that will be related to PA through the actinide source term model. The LANL tests will be used to build confidence in the predictive capability of the model.

Comment C2

"Analysis of undisturbed repository performance shows significant potential for gas fracturing of anhydrite layers.

Even without fracturing, with anhydrite permeability near mean values and the availability of water, there will be gas flow to the disposal unit boundary.

Current analysis show that seals are not effective gas movement barriers.

There is a need for true multi-phase transport modeling, not currently done (SAND92-0700, V, p. 4-2)."

Response

Multi-phase transport modeling of VOCs and radionuclides in the Salado formation are being studied which can interface with BRAGFLO, a multi-phase flow code. The model VAST simulates gas phase transport of VOC and the model NUTS simulates brine phase transport. This should give the DOE the ability to study multi-phase flow and transport processes. As discussed in EEG question MI-6 the deleterious effects of gas generation and possible fracturing are recognized. Also note experimental programs in the lab and in the field are acquiring data to better assess 2-0 flow.

Comment C3

"Sensitivity and uncertainty analysis identified that the following sampled variables are NOT in the top 5 in importance:

- Culebra transmissivity fields
- Corrensite in fractures

Do not waste money with additional studies."

Response

Importance of these topics will be examined in the SPM.

Comment

(Restatement): Documentation of computer codes is not available. Reviewers need documentation on discontinued as well as current codes to properly assess the WIPP.

Response

Documentation of all computer codes necessary for compliance is in progress and will be included in the compliance application package.

Complete documentation of all WIPP performance assessment models and codes necessary for compliance will be completed by the end of September 1995 or shortly thereafter.

Comment P1

(Paraphrase): We are much more concerned about the use of subjective probabilities in human intrusion analysis. While we agree that human judgment is the only method of estimating these probabilities, we question the art and science used in volumes 1, 2, and 3.

This quotation summarizes our view on "expert judgment";

"Expert judgments are not statements about nature but rather about beliefs. Nor are they statements which can be extrapolated to a larger population of events and beliefs. Therefore, while there is a chance that conclusions based on an expert judgment may be true about the world, it is not a good idea to say so because there is no justification in the method which allows this (Fleming, 1991)."

Response

The Use of Expert Judgment as It Relates to the Consideration of Inadvertent Human Intrusion and Passive Institutional Controls

Within the containment requirements in 40 CFR 191.13, the EPA specifies that performance assessments will consider "all significant events and processes that may affect the disposal system". Human intrusion is one such event that could potentially affect a disposal system:

"The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion."

40 CFR 191 also places the consideration of human intrusion in a probabilistic sense by specifying the probabilities with which cumulative releases may occur:

"...cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant events and processes that may affect the disposal system shall: (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)."

The nature of potential human intrusion is that it is not guaranteed to happen. Thus, it is possible to intervene to impact human actions. 40 CFR 191 addresses the uncertainty of actions and the possibility of intervention in the following manner:

"To provide the confidence needed for long-term compliance with the requirements of 191.13, disposal of spent fuel or high-level or transuranic wastes shall be conducted in accordance with the following provisions [the assurance requirements, 40 CFR 191.14] ...(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the waste and their location."

Guidance in Appendix B of 40 CFR 191 suggests that information about the consequences of actions constitutes an intervention and will cause a change in behavior:

> "Furthermore, the implementing agencies can assume that passive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities."
>
> and;
>
> "The [EPA] assumes that, as long as such passive institutional controls endure and are understood, they: (1) can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency."

Given the assumption that intervention is possible and can change behavior, 40 CFR 191 established the appropriate approach to incorporating intervention efficacy issues (based on design recommendations) in the performance assessments:

> "Determining compliance with § 191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the

implementing agencies to make use of...prevalent expert judgment relevant to the numerical predictions."

Further guidance from the EPA in Appendix B indicates that the DOE, as the implementing agency:

> "...should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of such inadvertent exploratory drilling."
>
> and;
>
> "In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well."

This text suggests a dual realization (1) that existing information or information that is being developed that is pertinent to performance assessments must be considered, and can be of use even for complex issues such as human intrusion and passive institutional controls, and (2) that the human mind is the best tool for assimilating information and producing judgments. Expert judgment is particularly suited to examining experimental or observational data collected under conditions or for purposes different from those of current interest, and for cases where the data and information are not available exactly in terms of traditional laboratory experiments or are from disparate sources. Such expert judgment does not create information, but is a synthesizing process to provide meaningful input for current requirements.

Absent guidance from the EPA as to a set future to assume, and relying on EPA guidance in Appendix B of 40 CFR 191 for calculations involving human intrusion, performance assessments for the WIPP have addressed this issue. In light of the importance of human intrusion in performance-assessment calculations and the inability to conduct experiments relating to future societies, the SNL WIPP Project has deemed it appropriate for the WIPP to consider the input of individuals (independent of the Project) whose experience and expertise are involved in examining human actions, history, trends, technology, etc. Without outside, independent judgments, assumptions made within the Project might have been called into question. This was done to ensure that judgments were objective with respect to compliance. While the expert judgment process was undertaken to address human intrusion in the most adequate means practicable, it was done so with the knowledge that any attempt to quantify the actions of possible future societies is incomplete and fraught with controversy.

The consideration of potential future societies is important not only because of the need to consider the frequency of inadvertent human intrusion in performance assessments, but also for the benefit of thinking broadly when considering how to attempt to communicate

with humans over the 10,000 year period of regulatory concern. The consideration of a broad range of motivations for capabilities of inadvertent human intrusion can be instructive as a base for setting "with whom" one may be trying to communicate. This was, in fact, one of the motivations for convening an expert panel to address future human intrusion. This broad thinking on human intrusion became input for a second expert panel charged with addressing the need for markers intended to communicate the dangers and location of the wastes.

Performance assessments for the WIPP will continue to be conducted in accordance with the requirements of 40 CFR 191 and the EPA's accompanying guidance. Any new guidance from the EPA would be implemented in the WIPP performance assessment calculations.

Comment P2

"The 1992 Performance Assessment shows compliance with the EPA standard under various conceptual models (1, Fig. 5-6, p. 5-14)."

"Would there be compliance if the intrusion probabilities of 1991 were used?"

"Differences between 1991 and 1992 are:

λ subjectively elicited in 1992

$\lambda = 0$, for $t > 2000$ years in 1992"

Response

This comment does not raise technical or regulatory issues.

Both the 1991 and 1992 PAs were preliminary, and show neither compliance nor noncompliance with the EPA standard. Determination of compliance will be based on a compliance application.

Because subsurface releases were not calculated for later times of intrusion in the 1992 PA, it is not possible to quantify the effect of the simplification on the location of the CCDF.

Results were presented in 1992 separately using both subjectively elicited functions for λ (the "time-dependent λ case") and the same time-invariant construction used in the 1991 PA (the "constant λ case").

Lambda was assumed to be equal to zero after 2,000 years only for subsurface releases. Cuttings releases at the surface from intrusions were calculated for the full interval from 100 to 10,000 years (see Figures 5-1 and 5-2 in Volume 1 of the 1992 PA).

Comment S1

"As a reminder, the assumption of 100 yr of administrative control in which no drilling intrusion can occur is equivalent to assume that $\lambda(t) = 0$ for $0 < t < 100$ yr." SAND92-0700/4, p. 2-19, at 49.

"...drilling intrusions assumed to be zero after 2000 yr." SAND92-0700/4, p. 2-19, l. 3.

"EEG objects to assuming away the problem."

Response

Decisions about the probability of drilling during the first 100 years after decommissioning may be reevaluated when additional guidance is available from the EPA.

It is correct that, for the purpose of calculating subsurface releases, the assumption that no intrusions occur after 2000 yr was made in the 1992 PA. Cuttings releases were calculated for the full interval from 100 to 10,000 years. The 1992 PA was preliminary, and results were not intended to be used as the basis for a compliance decision. The compliance application for WIPP will not be constrained in this manner.

Comment S2

"The analysis of CUTTINGS release is elegant. However, the effect of spallation of waste panels is not yet analyzed.

Moreover, the current cuttings analysis assumes perfect blow-out preventers acting immediately.

Drilling practice through 1982 included release of brine at the surface whenever pressurized Castile brine reservoirs were encountered. See Table 1."

Response

The DOE is currently investigating the issue, and it will be included in the SPM. (See EPP 5.4.3)

The effects of spalling are being examined by the DOE (EPP 5.4.3), and will be included in the SPM. Flow of brine to the ground surface during drilling, with and without blowout preventers, may also be evaluated in the SPM.

Comment S3

"The EEG reiterates that the following scenarios need attention.

- Removal of miracle plugs and seals
- Brine slurry discharge to the surface
- Subsidence from potash mining
- Criticality"

Response

The DOE is currently investigating each of these issues except for brine slurry formation, and they may be included in the SPM.

Modifications to the stratigraphic conceptualization used in BRAGFLO have been made since the 1992 PA that will allow simulation of borehole flow without the arbitrary perfect plugs above the Culebra.

Effects on groundwater flow of subsidence related to potash mining will be examined in the regional three-dimensional flow modeling (EPP 5.1.1.2).

The likelihood and consequence of criticality within the disposal system is presently under investigation (WBS 1.1.6.2.1).

References

Armstrong, J.S., W.B. Denniston, and M.M. Gordon. 1975. "The Use of the Decomposition Principle in Making Judgments," *Organizational Behavior and Human Performance*. Vol. 14, 257-263.

Bonano, E.J., S.C. Hora, R.L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories*. NUREG/CR-5411, SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Cooke, R.M. 1991. *Experts in Uncertainty: Expert Opinion and Subjective Probability in Science*. Oxford, UK: Oxford University Press.

Electric Power Research Institute (EPRI). 1986. *Seismic Hazard Methodology for the Central and Eastern United States, Vol. 1, Methodology*. EPRI-NP-4/26. Palo Alto, CA: EPRI.

Hora, S.C., N.G. Dodd, and J.A. Hora. 1983. "The Use of Decomposition in Probability Assessments of Continuous Variables," *The Journal of Behavioral Decision Making*. Vol 6, 133-147.

Hora, S.C., J.A. Hora, and N.G. Dodd. 1992. "Assessment of Probability Distributions for Continuous Random Variables: A Comparison of the Bisection and Fixed Value Methods," *Organizational Behavior and Human Decision Processes*. Vol. 51, 133-155.

MacGregor, D., S. Lichtenstein, and P. Slovic. 1988. "Structuring Knowledge Retrieval: An Analysis of Decomposing Quantitative Judgments," *Organizational Behavior and Human Decision Processes*. Vol. 42, 303-323.

Winkler, R.L. 1967. "Quantification of Judgment: Some Methodological Suggestions," *Journal of the American Statistical Association*. Vol. 62, 1105-1120.

Huyakorn, et al., Water Res. Res. Vol. 19, No. 3, p. 841, June 1983.

Roache, P.J. 1993. "The SECO Code Algorithms for Groundwater Flow and Transport". *Finite Elements in Fluids*. Morgan, K., Ofiate, E., Periaux, J., and Zienkiewicz, O.C., eds. Pineridge Press. 1993.

Salari, K., P. Knupp, P.J. Roache, and S. Steinberg. 1992. TVD Applies to Radionuclide Transport in Fractured Porous Media. Numerical Methods in Water Resources: IX International Conference on Computational Methods in Water Resources. Denver, Colorado, 9-12 June 1992.

Roache, J.P., P.M. Knupp, S. Steinberg, and R.L. Blaine. 1990. Experience with Benchmark Test Cases for Groundwater Flow. *Benchmark Test Cases for Computational Fluid Dynamics*. Celik, I. and Freitas, C.J., eds.

Roache, P.J. 1993. The SECO Suite of Codes for Site Performance Assessment. 1993 International High-Level Radioactive Waste Management Conference, April 26-30, 1993, Las Vegas, Nevada.

Roache, P.J. 1992. Computational Fluid Dynamics Algorithms Developed for WIPP Site Simulations. IX International Conference of Computational Methods in Water Resources. Denver, Colorado, 9-12 June 1992.

Roache, P.J. 1991. Computational Fluid Dynamics Algorithms and Codes Developed for WIPP Site Simulations. *Computational Mechanics*. Cheung, Lee, and Leung, eds. Balkema, Rotterdam. 1991.

Trauth, K. M., S. C. Hora, and R. V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Helton, J. C., and J. J. Iuzzolino. 1993. "Construction of Complementary Cumulative Distribution Functions for Comparison with the EPA Release Limits for Radioactive Waste Disposal." *Reliability Engineering and System Safety* . Vol. 40: 277-293.

Helton, J. C. 1993. "Drilling Intrusion Probabilities for Use in Performance Assessment for Radioactive Waste Disposal." *Reliability Engineering and System Safety* . Vol. 40: 259-275.

Swift, P. N., B. L. Baker, K. Economy, J. W. Garner, J. C. Helton, and D. K. Rudeen. 1994. *Incorporating Long-Term Climate Change in Performance Assessment for the Waste Isolation Pilot Plant*. SAND93-2266. Albuquerque, NM: Sandia National Laboratories.

Comment AG-I1

Page 1

Initially, it is unfortunate that the 1992 PA contains no analysis of the performance of the proposed repository based on alternative engineered barriers and waste form modifications. DOE has an obligation to make an informed selection among engineered alternatives, such as cementation, vitrification, shredding, supercompaction, incineration, improved containers, various backfill materials, melting and possible removal of metals, waste loading configurations, disposal room configurations, and the like. An informed selection requires careful study of the benefits of alternative engineered barriers and waste form modifications.

Response

The DOE agrees on the benefit derived from such a study. An engineered alternatives benefit/detriment analysis is currently underway. This study will analyze possible alternatives such as those listed above and evaluate enhancements to performance with system-wide impacts. The results of this study will be complete late in fiscal-year 1995. This study will allow an informal selection of alternatives to the extent such alternatives are needed to comply with the performance standards.

Comment AG-I2

Page 1

An objective release rate standard should be applied to such modifications (see e.g., 10 C.F.R. §60.113), in addition to the CCDF.

Response

This comment suggests the creation of a regulatory standard not currently in effect for the WIPP. The DOE believes that the current regulatory standards provide adequate protection of human health and the environment.

Comment AG-I3

The precise form of such analysis raises further issues (e.g., what assumptions should be made as to future states and the nature of future human intrusions?) The PA is incomplete without such an analysis.

Response

The WIPP Project anticipates that 40 CFR 194 will provide guidance for assumptions on future states and future human intrusions.

Comment AG-I4

Page 1

Further, the PA contains no analysis of the performance of the WIPP site as compared with the performance of a site located outside a resource zone and, thus, not vulnerable to likely human intrusions. DOE should carry out a comparative analysis of one or more hypothetical sites to assess the disadvantages of the resource-rich WIPP site.

Response

By nature, a comparison of alternative sites should be qualitative. The PA report is not inherently designed to perform this type of analysis. The site selection process has already considered such alternative sites as specified in the Assurance Requirements of 40 CFR 191, specifically, the resource disincentive requirement. DOE/WIPP 91-029, Revision 1 states that:

> .....Any comparison of the overall protection afforded by one site to the overall protection of another, for purposes of compliance with §191,14(e), should be done on a purely qualitative basis. [The RDR] is a preliminary siting criteria. Thus, its primary purpose is to distinguish between potentially acceptable and potentially unacceptable sites. It is then the purpose of the containment requirements, the other assurance requirements, the individual protection requirements and the groundwater protection requirements to determine the ultimate acceptability of the site as a disposal system for radioactive wastes.

The results of this comparison conclude that the favorable features of the WIPP are reasonably expected to offset any enhanced risk of human intrusions associated with resources.

Reference

Department of Energy, 1991. *Implementation of the Resource Disincentive in 40 CFR Part 191.14 (e) at the Waste Isolation Pilot Plant.* DOE/WIPP 91-029, Revision 1. Carlsbad, New Mexico.

Comment AG-1a

1. Scenario selection:

This subject is primarily addressed in the 1992 PA in v. 2 ch. 4, which in turn refers to the 1991 PA (1992 PA V. 2, 4-4; 1991 PA, v. 1, ch. 4). The 1992 PA says that the process of scenario screening will be reexamined when the disposal regulation, 40 CFR 191, is repromulgated. (1992 PA, Volume 2, p 4-3). The screening process should also be reexamined when EPA issues its compliance criteria, 40 CFR 194. In such reexaminations the following should be considered:

Screening as now practiced employs the criteria of (a) low probability, (b) physical reasonableness, (c) small consequence, and (d) regulatory limitations. (1991 PA, Volume 1, p. 4 -12). In general we find that certain scenarios, once selected, have been screened or eliminated on bases that are not adequately explained in quantitative terms. We note in particular:

a. Erosion, sedimentation, flooding, mass wasting, glaciation, and sea level changes causing releases are excluded as not physically reasonable on the premise that climate changes in the next 10,000 years will be within the ranges of conditions occurring within the past 10,000 years (at 4-14, 4-15, 4-18, 4-19). Comments submitted to the EPA by Prof. Roger Y. Anderson (March 16, 1993) point out that the past 10,000 years have been extremely dry in comparison with the average of the past 800,000 years. During at least half of the next 240,000 years climatic conditions are expected to be significantly wetter than at present. Past changes in precipitation and streamflow in the area have involved brief and strong climate episodes departing greatly from average climate. Thus, the assumption of average climate appears to be inappropriate, and these scenarios should therefore be reexamined for inclusion.

Response

These events and processes have been reconsidered in the current scenario screening work. The observation here that each has the potential to be effected by climate change is correct. However, even assuming climatic changes during the next 10,000 years equivalent to the most extreme climates of the last two million years (an improbable assumption), none of these events and processes will effect disposal system performance. Arguments supporting these assertions will be provided for review with the documentation of the scenario development work.

The concern raised by Prof. Anderson in his letter to the EPA was not that the WIPP Project's approach to treating climatic variability during the next 10,000 years was inappropriate, but rather that the EPA should consider a regulatory period longer than 10,000 years. In this regard, both Prof. Anderson and the New Mexico Attorney

General's Office are proposing the creation of a new regulatory standard for radioactive waste disposal.

Comment AG-1b

Page 2

Pluvial periods are retained for further consideration. (1991 PA, Volume 1, p. 4-15). We note the fact and look to future performance assessments for analysis.

Response

Climatic change is retained in the scenario development work for inclusion in consequence analysis.

Comment AG-1c

Page 2

Magmatic activity is excluded on the basis of physical unreasonableness, with the explanation that a mid-Tertiary dike system within a zone of crustal weakness was not followed by similar magmatic formations during Pliocene-Pleistocene uplift and fracturing (1991 PA, v. 1, 4-23). The 1991 PA concludes that "a change in the geologic processes at this location has occurred." Such explanation is entirely too conclusory; a coherent factual hypothesis is required.

Response

Work is in progress to develop a sufficient basis for the screening magmatic activity out from further consideration in performance assessments. This work will be documented in a future version of the scenario development position paper. There is no reason to suspect that evidence will be found indicating that magmatic activity could be of sufficient probability or consequence to warrant inclusion in scenario development.

Comment AG-1d

Page 3

Deep dissolution is said to be part of the base-case scenario, insofar as it concerns dissolution along the Salado-Rustler contact. (1991 PA, v. 1, 4-27). It is not

demonstrated how deep dissolution is incorporated into the modeling of base-case performance.

Response

Dissolution along the Rustler-Salado Contact Zone is treated in both the 1991 PA and in the current scenario development work as shallow dissolution, rather than deep dissolution (see 1991 PA, Volume 1, p. 4-25 through 4-28). In the 1991 PA, shallow dissolution was retained for inclusion in the base case because it is an ongoing process. The current scenario development work concurs that shallow dissolution is an ongoing process in the region, but screens it out from further consideration on the grounds that there is a low probability that its occurrence during the next 10,000 years can affect system performance.

Comment AG-1e

Page 3

The discussion of human-induced explosions state that seismic effects on the source term or the disposal system are likely to be addressed within parameter uncertainty during modeling. (v. 1, 4-32, 4-32). It should be demonstrated that in fact this will be done.

Response

Current scenario development work recognizes three categories of future human-induced explosions that could potentially affect the WIPP: explosions for resource recovery, underground nuclear testing, and acts of war. Explosions for resource recovery are considered to be of low consequence because liquid or gas resources suitable for recovery through fractures are not found at the repository horizon. Underground nuclear testing is presently retained for further consideration, although work is in progress to prepare a screening argument based on low probability. Acts of war are screened out on the basis that they are beyond the scope of the regulatory requirements. Parameter uncertainty analyses of the consequences of explosions will not be performed unless screening arguments indicate that explosions require further analysis.

Comment AG-1f

Page 3

The limitation of the type and amount of human intrusion to be considered is said to be based on the guidance in Appendix B of the 1985 version of 40 CFR 191. That guidance will be supersede by the forthcoming EPA compliance criteria, 40 CFR 194. Thus, the

nature of intrusion to be considered must be reconsidered based on forthcoming EPA pronouncements. Further, even following the 1985 guidance, it is not accurate to state that each of the Futures Panel teams estimated future drilling densities substantially lower than 30 boreholes/km² in 10,000 years (1991 PA, v. 1, 4-33). The Boston Team, for example, developed a conditional distribution for the average number of boreholes per square mile per 10,000 years, ranging from 12.45 to 199.2 boreholes/mi² (SAND 90-3063, at IV-15). In addition, to consider potash and natural gas as the only two resources with economic potential at the WIPP (at 4-33, 4-38) ignores the substantial oil resources in the area (See EEG 9/93 Comments; Implications of Oil and Gas Leases at the WIPP on Compliance with EPA TRU Waste Disposal Standards, EEG-50 (June 1992), at 13).

Response

Drilling probabilities for use in a compliance application will be reevaluated following promulgation of 40 CFR 194.

With regard to the observation about the drilling rates estimated by the Boston Team, the appropriate information is given in Table IV-14, on page IV-16 of Hora et al., 1991 (SAND90-3063). Table IV-13, on page IV-15 of Hora et al. (1991), is an intermediate step in the analysis and was included as an example demonstrating the methodology used. Table IV-13 does not represent the conclusions of the Boston Team. As the reviewer notes, the probabilities given in Table IV-13 are conditional: in this case, on the certain occurrence of a particular set of future states that the Boston Team believed were in themselves unlikely.

Reference

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgement on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

(AG/92PA-1f)

Comment AG-1g

Page 3

Human intrusion of various types must plainly be considered in applying the containment requirements. The 1991 PA excludes mining intrusions at the WIPP site based on the 1985 EPA guidance (1991 PA v. 1, 4-43). We disagree that the EPA guidance excludes this scenario. Again, this exclusion must be reconsidered based upon the compliance criteria. We note that mining beyond the area of the waste panels is retained for

scenario development (1991 PA, v. 1, 4-35) and anticipate that future PA's will evaluate such a scenario.

Response

Current scenario development work retains potash mining within the controlled area for further consideration. This decision will be reconsidered as appropriate following promulgation of 40 CFR 194.

Comment AG-1h

Page 3

Injection wells are also said to be limited in their PA consideration by the 1985 guidance (1991 PA, v. 1, 4-37). This scenario is not excluded even under the 1985 guidance, and Futures Panel teams were unable to estimate its probability (1992 PA, v. 2, 5-7). The scenario must also be reassessed based on the forthcoming compliance criteria. The PA statement that injection wells can be excluded based on lack of consequence (1991 PA, v. 1, 4-37) must be reconsidered in light of the demonstrable widespread effects of well injection in the course of secondary recovery of hydrocarbons typical of the Delaware Basin.

Response

Current scenario development work retains injection wells for further consideration in the PA. Injection of fluids for enhanced recovery of hydrocarbons or waste disposal is highly unlikely to occur directly into the Salado Formation or overlying strata. However, injection wells have the potential for some fluid to enter these strata inadvertently through faulty well casing and hence might affect disposal system performance.

Comment AG-1i

Page 4

The statement is made that withdrawal wells within the repository area are excluded by the 1985 guidance (1991 PA v. 1, 4-37). It is not at all clear that the drilling and operation of oil or gas withdrawal wells would be deemed a more "severe" intrusion scenario than exploration wells. Further, it is stated that water well emplacement is retained for scenario development (event E3), and we look to future PA's to analyze this scenario. EEG has noted that the TDS concentration in the H-L well referred to hovers close to 10,000 mg./1. EEG Preliminary Comments on 1991 Performance Assessment

("EEG 8/92 comments"), at 24). Moreover, water wells may be drilled in the future for purposes other than obtaining potable water.

Response

Wells drilled for any purpose (including withdrawal of hydrocarbons of water) within the controlled area that do not directly intersect waste are retained for further consideration in current scenario development work.

Comment AG-1j

Page 4

The grounds for exclusion of a scenario involving irrigation are not convincing (1991 PA, v. 1, 4-40, 4-41). The prospects of irrigation usage are said to be low based upon current land usage in the southeastern United States, current climate conditions, and current water commitments. Before irrigation can be excluded as a relevant scenario, it must be analyzed for probability and consequence based upon changes in such factors.

Response

Current scenario development work retains irrigation for further consideration before a screening decision can be made. Although irrigation is not presently practiced in the WIPP vicinity, climate change could result in different land use in the future. Modeling of the effect of climate change itself on regional groundwater flow will provide insight into possible consequences of irrigation and will provide the basis for a screening argument.

Comment AG-1k

Page 4

Similarly, the creation of an impoundment at Nash Draw is excluded as improbable, based on present day water supplies and usage (see EEG 8/92 comments, at 24-25). The scenario must be considered based on its probability and consequences, given possible future changes in such factors.

Response

Current scenario development work retains the creation of an impoundment in Nash Draw for further consideration before a screening decision can be made. Although water availability is insufficient at present to justify such an impoundment, climate

change could alter that condition in the future. Modeling of the effect of climate change itself on regional groundwater flow will provide insight into possible consequences of damming and will provide the basis for a screening argument.

Comment AG-1l

Page 4

Subsidence due to the caving of the waste panels is excluded for lack of consequence (1991 PA, v. 1, 4-49), but this conclusion cannot be justified. First, the degree of subsidence is estimated from admittedly inappropriate analogues and using disposal room models that are obsolete. Second, it is assumed that subsidence occurs uniformly and without bed separations--hardly realistic assumptions. Third, the argument that the subsidence of the Rustler-Salado contact member is an analogous event demonstrating on disruptive consequence ignores the fact that naturally-occurring subsidence is much more gradual than collapse caused by mining. The scenario should be retained.

Response

Current scenario development work retains subsidence over the waste panels for further consideration before a screening decision can be made. Such subsidence has the potential to affect groundwater flow in overlying aquifers by providing pathways for increased vertical flow between units.

Note that a modeling study has recently been published by IT (1994) that suggests subsidence due to caving will have no long-term effects on performance of the non-Salado units.

Reference

Westinghouse Electric Corporation, 1994. *Backfill Engineering Analysis Report.* WID, Carlsbad, NM, 1994.

Comment AG-1m

Borehole seal degradation can be considered by sampling a range of input parameters in PA (1991 PA, v. 1, 4-49). Such a method should be adopted. At present assumptions are employed to maximize the flow of brine through the repository and thence to the Culebra, leading to possible underground release. As EEG has pointed out, assumptions as to seal effectiveness are not well-founded factually based on current practices in the basin (EEG 9/93 comments, at 22). PA should evaluate the likelihood and consequences of releases via improperly sealed boreholes.

Response

Current SPM analyses consider boreholes with fully degraded plugs or no plugs. Flow is allowed through degraded borehole-fill material into a simplified representation of all stratigraphic layers and to the ground surface.

WIPP PA analyses in the past have evaluated "consequences of releases via improperly sealed borehole." Borehole plugs were assumed to degrade immediately following emplacement to a silty sand-like material. Arbitrary "perfect" plugs were assumed only to divert flow in specific paths (i.e., through the waste panels and into the Culebra) to maximize flow and transport along these paths for the purposes of consequence analysis. These "perfect" plugs were not intended to represent properly sealed boreholes.

Comment AG-1n

Page 5

It has not yet been determined whether to consider a scenario involving nuclear criticality at some location in the transport of plutonium radionuclides. (1991 PA, v. 1, 4-53). EEG has demonstrated that the probability distributions of plutonium distribution coefficients and solubilities are consistent with the possible occurrence of nuclear criticality in the Culebra (EEG 9/93 comments, at 16). We look to future PA's for analyses of such event.

Response

Criticality will be considered in analyses for event and process screening. The SPM will determine whether to include criticality in PA calculations.

Comment AG-1o

Page 5

Subsidence related to solution mining has not been analyzed, although the 1992 PA recognizes the need (event TS; 1992 PA, v.2, 4-9). We inquire when this will be done.

Response

Current scenario development work retains potash mining for further consideration, without distinguishing between conventional and solution mining.

Comment AG-1p

Page 5

Possible brine flows to the surface during and in consequence of drilling should be analyzed. Any regulatory limitations on such a scenario must be reassessed after EPA issues its compliance criteria. Current practice is not consistent with an assumption that releases of contaminated brine will be minimal. (EEG 9/93 comments, at 18). Several cases for analysis exist (id. 21) and should be considered.

Response

This scenario will be evaluated in the SPM.

Comment AG-1q

Page 5

Formation of a brine slurry which is thereafter released in an intrusion event is another scenario which should be analyzed (see EEG 9/93 comments, at 21). Such analysis is obviously bound up with the PA development of the Radionuclide source term and the modeling of direct releases (cuttings, cavings, and spallings).

Response

The Project believes a brine-slurry release in any context is unlikely. As stated in the comment, several studies have been performed within the last several years on the possibility of brine-slurry in salt backfill in the underground environment. Results of the studies indicated brine-slurry in salt backfill would not impact performance because room closure rates (even considering likely gas generation rates) will decrease the available volume and recompact the salt to a point that even if brine fills the residual porosity a slurry cannot develop.

With respect to slurries forming from decomposing waste, itself, we believe closure rates and compaction would result in an end product with sufficient shear strength that a mobile slurry would not form. For further information, see Disposal Room and Cuttings Model Position Paper for Systems Prioritization and Technical Baseline, section 4.2.4.5.

A model for representing incomplete consolidation of the waste, in various degrees of decomposition has been developed, but is not yet part of cuttings release calculations. Attention has been focused on pressurized gas. To date, the spall problem has usually been cast in terms of inflow of a fluid into an intrusion well, and the material that is carried along in this process. Variable strength materials will eventually be incorporated

into the cuttings release calculations to encompass concerns that may exist about whether appropriate strength materials have been modeled.

Comment AG-2a

Page 5

Human intrusion conceptual models:

Certain assumptions underlying the existing conceptual models of human intrusion appear to be nonconservative.

> "As stated above, the assumed efficacy of the borehole plug above the repository and above the Culebra may be nonconservative (1992 PA, v. 2, 4-15)"

Response

Current analyses consider boreholes with fully degraded plugs or no plugs. Flow is allowed through degraded borehole-fill material into a simplified representation of all stratigraphic layers and to the ground surface.

WIPP PA analyses in the past have evaluated "consequences of releases via improperly sealed borehole." Borehole plugs were assumed to degrade immediately following emplacement to a silty sand-like material. Arbitrary "perfect" plugs were assumed only to divert flow in specific paths (i.e., through the waste panels and into the Culebra) to maximize flow and transport along these paths for the purposes of consequence analysis. These "perfect" plugs were not intended to represent properly sealed boreholes.

Comment AG-2b

Computational approximations do not model E1 explicitly but assume that consequences are the same as E2. (1992 PA, v. 2, 4-18). This assumption should be questioned. The 1992 PA itself says that E1 release may exceed E2 releases (id.). Whether E2 releases will dominate E1 releases may also change when assumptions as to surface brine releases are altered and when spalling is modeled.

Response

Analyses performed for the first iteration of the SPM treated E1 and E2 individually, and assumed that E1-type intrusions would result in some flow of brine from the Castile Formation through the waste.

Comment AG-2c

Page 5

As currently modeled, an E1E2 release takes place only when both boreholes occur in the same time interval. (1992 PA, v. 4, 2-16). Indeed, it is assumed that the E1 and E2 intrusions occur simultaneously (1992 PA, v. 4, 2-18). Given the complexity of the numerous processes involved, it is not now possible to demonstrate that the assumption is conservative. We have been informed that Sandia has made initial experiments involving time-dependent drilling intrusions and inquire as to plans in this regard.

Response

The WIPP Project is currently investigating alternative approaches to CCDF generation that would facilitate consideration of intrusions at different times. This approach will be used in the SPM if it is demonstrated to be suitable.

Comment AG-2d

Page 6

The 1992 PA considers only intrusions at the 1,000 year point as to groundwater transport. The statement appears that the Poisson model of intrusions has a rate term of zero after 2,000 years (1992 PA, v. 4, 2-18, 2-19). These assumptions, which limit intrusions leading to groundwater releases to a single point at 1,000 years, are nonconservative and should be abandoned.

Response

The sampling of intrusion times may be needed for a complete analysis that would be used for compliance application. The decision to limit subsurface release calculations to a single time of intrusion was based solely on project resource limitations in 1992.

The 1991 PA included analysis of subsurface releases from 5 times of intrusion (1,000, 3,000, 5,000, 7,000, and 9,000 yr). Comparison of figures 4.1-2 (lower right frame) and 5.1-4 (upper right frame) of Volume 4 of the 1991 PA (SAND91-0893/4) shows the effect of later times of intrusion on dual-porosity subsurface releases. The 1990 PA sampled the time of intrusion (rather than including it in the probability model), and results of a formal sensitivity analysis including time of intrusion are published in Helton et al. (1991).

Reference

Helton, J.C., J.W. Garner, R.D. McCurley, and D.K. Rudeen. 1991. *Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant.* SAND90-7103. Albuquerque, NM: Sandia National Laboratories.

Comment AG-2e

Page 6

In examining direct releases by human intrusion ("cuttings") the 1992 PA assumes that intrusion times are at years 125, 175, 350, 1,000, 3,000, and 7,250 (1992 PA, v. 4, 2-26). The PA should demonstrate that those assumptions are conservative.

Response

The WIPP Project agrees that the times of intrusion chosen for analysis should be suitably representative of the complete set of all possible times during the regulatory period. This will be demonstrated as part of the compliance application.

Comment AG-3a

Page 6

Salado Formation data:

Sampled parameter values calling for further justification are as follows:

Undisturbed halite permeability is sampled over a narrower range in 1992 than in 1991. This parameter is a sensitive one in that it determines how quickly the panel will fill with brine, furnishing a vehicle for radionuclide release. (1992 PA, v. 3, 2-30). The PA department has stated that neither the 1991 nor the 1992 distribution represents the average far-field permeability, the quantity that should be used in two phase flow model (Id.). Approach based on experimental data seem necessary. What is planned?

Response

Undisturbed halite permeability is sampled over a wider range (not narrower) range in 1992 compared to 1991. The 1991 range was 5.4×10^{-22} m^2 to 8.6×10^{-22} m^2 (1991 Volume 3, p. 2-27). The 1992 range was 10^{-19} to 10^{-24} m^2 (1992 Volume 3, p. 2-29). Both the 1991 and the 1992 ranges are based on experimental measurements; however, the

1992 range, and to a lesser extent, the 1991 range may include data that are influenced by the excavation. This may result in somewhat higher permeabilities for the far field than true undisturbed measurements would suggest. At any rate, the use of these higher permeabilities allows for larger brine inflow than might be representative of intact material.

Comment AG-3b

Page 6

Undisturbed anhydrite permeability clearly requires improved data and modeling in forthcoming PA's. At present there is no representation of fracturing under pressure. The 1992 calculations may underestimate lateral gas migration in the anhydride and overestimate pressurization. (1992 PA, v. 3, 2-57, A-50). When may we expect a model that incorporates pressure-induced fracturing?

Response

An altered anhydrite submodel has been developed and incorporated into BRAGFLO subsequent to the 1992 calculations. In this submodel, permeability and porosity are functions of fluid pore pressure and are enhanced at elevated pressure.

Comment AG-3c

Page 6

The 1992 PA reports that work is in progress on modeling the possible pressure dependency of fracture permeability in anhydride interbeds, and results will be incorporated in future PA's. (1992 PA, v. 2, 2-42). There have been reports concerning such modeling plans at NAS WIPP panel meetings. What is the status of such modeling effort?

Response

See response to previous comment (AG-3b).

Comment AG-3d

Page 6

Anhydrite brine pore pressure in the far-field is another sensitive parameter now estimated by use of regression curves. (1992 PA, v. 3, 2-63). As the PA states, "[w]hether these results make physical sense remains to be determined." (Id.) What further efforts are planned in this area?

Response

PA no longer estimates far field pore pressure by the regression curves discussed in 1992 PA Volume 3, 2-63. PA continues to use data measurements believed to be representative of the far field. In the 1992 PA the far field pore pressure in anhydrite ranged from 12 to 13 MPa. The inclusion of the regression curves, which attempt to characterize pore pressure as a function of distances from the excavation, may cause some confusion. They are meant to be informative and are a possible way to estimate far field values but they are not used by PA.

Comment AG-4a

Page 7

M

Waste properties:

Several issues are unresolved concerning the waste inventory:

Concerning inventory data, the Experimental Program Plan, DOE/WIPP 94-008, refers to waste characterization efforts planned or underway at source facilities. (at 3-38, 4-14). DOE has also mentioned plans to develop performance-based waste acceptance criteria. The current PA model, however, employs inventory data based on data submitted by generator sites to the Integrated Data Base. (1992 PA, v. 3, 3-59 et seq., A-137). There is potentially large uncertainty as to volumes of combustibles and metals/glass (1992 PA, v. 3, 3-62). The parameters are significant to RCRA compliance and also, possibly, to radionuclide releases. DOE needs to clarify its plans to establish inventory data for PA.

Response

The DOE has developed the Baseline Inventory Report (BIR) and Database. This report integrates the waste generator sites' input to the Integrated Data Base and the Mixed Waste Inventory Report required by the Federal Facilities Compliance Act. A revision (Rev. 1) to the BIR is in process and will be provided in the second quarter of

FY 95. The BIR keys on eleven performance parameters that could be significant to PA and reports information relative to these parameters.

Comment AG-4b

Page 7

Initial waste saturation is a highly sensitive parameter for RCRA compliance, since it is a principal control on gas generation (1992 PA, v. 3, 3-69). The range of 0, 0.14 based upon investigator judgment calls for substantiation based on characterization efforts. The PA states that the "range of initial brine saturation currently used does not have a sound basis in measured data, and is expected to change." (1992 PA, v. 5, 6-1). What efforts are planned?

Response

The range of 0.40% to 5.2% was calculated from measured data presented in a memo (DA:93:10052, attached) from John Elliott, Westinghouse-Idaho to L.R. Fitch, WID, dated October 8, 1993. Waste characterization activities underway and planned at the waste generator sites continue to include determination of water content. The range used for compliance performance assessment will be updated to reflect all available data.

Comment AG-5a

Page 7

Radionuclide source term:

The radionuclide source term is highly dependent upon solubility data. We have these questions:

"Solubility" (more specifically, mobile actinide concentration) distributions have been constructed on the basis of expert judgement. For future performance assessments DOE proposes to develop a model and lab data with which to determine whether the constructed distributions are supported. Further, lab data will explore different brine compositions, including Salado brines altered by backfill constituents. At this early stage detailed comment is not appropriate. However we note the following:

The methods whereby test data may be deemed to support or "validate" solubility estimates or ranges must be explicitly stated and justified.

Response

Order-of-magnitude matches between experimentally measured quantities and model predictions will be considered to constitute "good" agreement. If model predictions diverge from measured data by more than an order of magnitude, then steps will be taken to determine the reason(s) for that divergence. The disagreement between predicted and measured quantities may be acceptable for purposes of compliance demonstration if the model is found to predict mobile actinide concentrations reasonably similar to those observed experimentally.

Comment AG-5b

Page 7

The duration of the experiments and the purported attainment of steady-state conditions must be supported by the proponent of data.

Response

We agree with the comment. Experimental data will be evaluated with respect to the degree to which steady-state conditions have been attained to determine the utility of the data to the program. However, the definition of steady-state conditions is complex; i.e., many different equilibria are involved in each potential experiment, and steady state may not be reached simultaneously for all of the equilibria of importance.

Comment AG-5c

Page 8

It must be explicit how data from the model will be incorporated into the BRAGFLO model.

Response

The Actinide Source Term model will be used to generate a table or series of tables which give mobile actinide concentrations under a variety of pH and other physical-chemical conditions. Data from other sources, such as the Gas Generation Program will be used to determine the set of conditions for each PA calculation. This set of conditions will determine, in turn, the table values to use for mobile actinide concentrations for that calculation. There will be a mixture of deterministic and probabilistic parameters involved in the determination of the appropriate set of physical-chemical conditions appropriate for the calculations.

Comment AG-6

Page 8

The hazardous waste source term, if modeled at all, is not yet incorporated into assessments of gas and brine migration. Please explain how this is to be done.

Response

The project is currently evaluating two conceptual models for the hazardous waste source term. One assumes constituents are present in sufficient quantities to saturate the gas phase. The other uses waste characterization data to determine the source term. This topic will be the subject of a position paper and will be included in the SPM.

Comment AG-7a

Page 8

Radionuclide inventory:

For the 1992 PA the radionuclide inventory is estimated based on input to the 1991 Integrated Data Base (1992 PA, v. 2, 2-50). The CH-TRU inventory is scaled up from the current and projected CH-TRU inventory at five high-volume generating sites. However, uncertainty in the CH-TRU inventory is large, particularly given the potential changes in the sources of CH waste due to given the potential changes in the sources of CH waste due to changes in weapons production. (1992 PA, v. 2, 2-5). It is possible that DOE may seek to dispose at WIPP of waste from cleanup operations or weapons dismantlement. The RH-TRU inventory in the IDB is approximately the same as the WIPP design capacity and is not scaled up (id.). However, there is also uncertainty as to the characteristics of yet-to-be characterized RH-TRU waste. There is also talk of performance-based waste acceptance criteria. In these circumstances, we point out the following:

DOE must explore the ranges of uncertainty of radionuclide inventory as an element of its PA uncertainty and sensitivity studies. Further, since radionuclide inventory is within the control of DOE (as opposed to being a subjectively unknown variable), random sampling within a stated range may be inappropriate, and it may be necessary to employ "worst case" assumptions.

Response

Compliance performance assessment will be done according to the requirements of 40 CFR 191, which provides requirements for radionuclide releases based on a normalized

inventory, and thus is not sensitive to uncertainties in the actual transuranic element inventory.

Comment AG-7b

Page 8

DOE should reexamine the determination to exclude RH-TRU waste from calculations of underground releases (1992 PA, v. 3, 3-28) as estimates of RH-TRU inventory are refined and canister design assumptions become clearer.

Response

This decision will be reconsidered in future analyses.

Comment AG-7c

Page 8

DOE must clarify its position as to the time as of which the curie content of TRU waste should be ascertained for purposes of calculating release limits. In a related context DOE has said that the curie content should be determined as of 100 years after disposal. See Final Supplement to EIS, 1990, v.2, at 18-19. Will such procedure be employed in future PA's?

Response

(a) The release limits in 191.13(a), found at Appendix A, Table 1 to 40 CFR Part 191, are designed to regulate releases of radionuclides with half lives of 20 years or more. These limits specifically apply to: Americium-241 or -243, Carbon-14, Cesium-135 or -137, Iodine-129, Neptunium-237, Plutonium-238, -239, -240, or -242, Radium-226, Strontium-90, Technetium-99, Thorium-230 or -232, Tin-126, Uranium-233, -234, -235, -236, or -238; and to any other alpha-emitting radionuclide with a half-life greater than 20 years, and to any other radionuclide with a half-life greater than 20 years that does not emit alpha particles.

The waste unit determines the release limits for a specific repository. EPA based the waste unit derivation on a philosophy of equivalence between the various types of waste regulated by 40 CFR Part 191. Therefore, the curie content of the inventory should be determined at the time that most nearly approximates the assumptions EPA used in deriving the release limits. The following is quoted from a draft report, Risk Assessments of Spent Fuel, Transuranic, and High-Level Radioactive Wastes in Mined

Repositories, Technical Support Document, prepared by S. Cohen & Associates, Inc., January 20, 1994 (RAE-9231/1-3), page 2-23.

In the version of 40 CFR 191 promulgated in 1985, Note 1(c) specified that the Table 1 release limits applied to each 100 million curies of beta/gamma-emitters with half-lives between 20 and 100 years; Note 1(d) stated that the limits applied to each 1 million curies of beta/gamma-emitters with half-lives greater than 100 years; and Note 1(e) stated that they applied to each 1 million curies of transuranic wastes containing alpha-emitters with half-lives over 20 years. EPA did not provide a detailed explanation of the basis for these quantities. The preamble to the proposed 40 CFR 191 published in 1982 stated that the 1 million curie quantity specified in Note 1(e) for TRU waste was chosen "so that the standards would require radioactivity from either high-level or transuranic wastes to be isolated with about the same degree of effectiveness" [U.S. Environmental Protection Agency, Preamble to Proposed 40 CFR Part 191, 47 FR 58200, December 29, 1982.] Furthermore, the Draft EIS stated that the reference values of 1 million curies of TRU waste and 1,000 MTHM of spent fuel "were selected so that about the same fraction of transuranic radionuclides would be retained for either high-level or transuranic waste" [US EPA, "Draft Environmental Impact Statement for 40 CFR 191: Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," EPA-520/1-82-025, December, 1982, p. 116]. These estimates had been made based on looking at the number of TRU curies in 10 year old spent fuel and rounding to the nearest arithmetic order of magnitude.

(b) The Final Supplement to EIS, 1990, Volume 2, at B18-19 discusses the use of the inventory in developing the initial source term for transport calculations. The waste unit upon which the release limits were based in the technical support reference, Lappin et. al., 1989, was the estimated inventory at decommissioning. These are two separate concepts. The waste unit and release limits must be calculated from the initial inventory; transport calculations must take into account the decay of the radioactivity over the course of the 10,000 years of regulatory concern. What the FSEIS reports is the assumption used to start transport calculations, which began after the end of active institutional controls. Table B.2.13 presents the initial radionuclide inventory in CH TRU waste for the assessment of long-term performance, and Table B.2.14 gives the modified inventory, which was modified by assuming that the radioactivity has decayed for 100 years. Table B.2.13 is the source of the waste unit, which may be seen to be 6.66 by summing the activities of TRU radionuclides with halflives greater than 20 years and dividing by 1 million. This is consistent with the method in the technical support document cited by DOE (A. R. Lappin, R. L. Hunter, D. Garber, and P. B. Davies, eds., 1989; Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP) Southeastern New Mexico, March 1989, SAND89-0462, Sandia National Laboratories, Albuquerque, New Mexico).

Calculating the waste unit after the end of the 100-year period of active control would be inconsistent with the spent-fuel equivalency rationale developed by the EPA to allow derivation of a single set of releases limits with effectively equivalent waste units.

Comment AG-7d

Page 8

DOE must ensure that its PA analyses conform to waste inventory projections contained in, e.g., its environment impact statements and other authorizations (e.g., transportation and RCRA permits) and vice-versa.

Response

Due to changes in DOE's mission, the DOE is continuing to evaluate waste inventory projections as the generator site work scopes change. This task included the generation of the WIPP Transuranic Waste Baseline Inventory Report. Sandia will use the source information contained in that document in their ongoing PA analyses. The DOE will continually update and improve inventory projections, to the extent these impact PA, the update will be evaluated.

The other "authorizations" do not affect inventories of radionuclides. Transportation criteria address the radionuclide loading of any single container and/or any TRUPACT-II. This does not limit the total "inventory " used by PA. RCRA does not address radionuclides at all.

Comment AG-8a

Repository-waste interactions:

Page 9

Modeling of the complex interactions among gas generation, repository closure, and brine flow is clearly still in development. Models of particular aspects of these processes are being developed outside of the PA process. Comments prompted by the current state of development are:

As to the gas generation model, numerous uncertainties were outlined by Larry Brush at the July 7-9, 1993 meeting between DOE and EPA. Without reiterating these, it should be clear that such uncertainties need to be addressed, either to resolve them or to determine that they are not important.

Response

The Gas Generation Program is addressing these uncertainties. The first step is to determine if the uncertainty either directly or indirectly has a significant impact on performance. Resolution of uncertainties found to be significant can then be approached by additional experimental work (included as an activity for evaluation by the SPM) or, if that is not possible, then the range of parameter(s) values implied by the uncertainty is sampled during the PA analysis. Alternative conceptual models will be handled the same way.

Comment AG-8b

Page 9

PA should clarify in what sense it is not now possible or practical to use a coupled mechanical and fluid flow model. The transition between the data reported by SANCHO and those employed in BRAGFLO must be made clear. Assumptions employed in the 1992 PA ignore certain factors and should be questioned for conservatism and sensitivity, e.g., representation of porosity changes during decreasing gas pressure; possible differential closure among rooms in a panel; spatial variation in pore pressure and gas generation rate; brine phase in SANCHO; gas escape in SANCHO; constant gas generation rate SANCHO; creep closure after intrusion (1992 PA, v. 4, 4-15 through 4-20).

Response

The use of a fully coupled mechanical and multi-phase fluid flow model is not now technically feasible because, (1) no such general model currently exists for material undergoing time-dependent deformation (creep) and, (2) the computational effort required by such a model would preclude its use in probabilistic PA calculations where many hundreds or thousands of simulations are required. (Such a model could be used to verify isolated cases).

Recent verification studies of the PA implementation of the porosity surface indicate satisfactory prediction of pressure and porosity during creep consolidation (Arguello and Stone, 1994a; Arguello and Stone, 1994b; Arguello and Stone, 1993). The implementation is verified under conditions of undisturbed repository, human intrusion, and high brine saturation cases. This suggests the resources required to develop and use a fully coupled model is not warranted at this time.

References

Arguello, J.G. and C.M. Stone. 1994a. *Corrections to Errata in Memo Entitled: "Performance Assessment Verification Calculations - Revised SANCHO Calculation for Comparison with BRAGFLO Run #63."* Memo. Albuquerque, NM: Sandia National Laboratories.

Arguello, J.G. and C.M. Stone. 1994b. *Performance Assessment Verification Calculations - Revised SANCHO Calculation for Comparison with BRAGFLO Run #63.* Memo. Albuquerque, NM: Sandia National Laboratories.

Arguello, J.G. and C.M. Stone. 1993. *Performance Assessment Verification Calculations - SANCHO Comparisons with BRAGFLO Runs 18, 42, and 63.* Memo. Albuquerque, NM: Sandia National Laboratories.

Comment AG-9a

M

Page 9

Modeling of brine and gas flow in BRAGFLO raises the following questions:

It has been pointed out by EPA (comments at 2/22-25 DOE-EPA meetings) that BRAGFLO assumes a rigid isothermal rock body with no non-Darcy flow and omits consideration of colloids and particulates. Hydrologic properties are symmetrical. Further, whether Darcy's law can be expanded to the continuum modeled by BRAGFLO is not known. In light of these comments, how does DOE propose to justify its conceptual models and support the rejection of alterative conceptual models?

Response

BRAGFLO doesn't assume a rigid rock body in the sense that rock compressibility effects are rigorously modeled in all materials, and the effect of creep consolidation on repository porosity is accounted for. BRAGFLO does assume isothermal Darcy-flow. Data collected at WIPP are analyzed and have been found to fit Darcy-flow models.

The redistribution model and clay consolidation model are also supported by data collected at WIPP. An activity will be planned and included in the SPM to evaluate the advantages of selecting any but the more conservative of these models.

Comment AG-9b

Page 9

Alternative conceptual model uncertainty with respect to relative permeability and capillary pressure is dealt with via a sampling technique (1992 PA, v. 4, 4-24). The supporting Sandia memorandum states that the choice of conceptual models "could be significant" (Webb, at A-149). What approach will be taken better to resolve the uncertainty?

Response

Until sufficient data are collected to establish the two-phase flow parameters for WIPP materials, the uncertainty will continue to be captured by sampling both model description and parameter values over a wide range as in the past. Capillary pressures have been measured for anhydrite in the laboratory. Additional capillary pressure and relative permeability measurements on anhydrite are planned.

Comment AG-9c

The disturbed performance model is scaled to match the initial excavated volume of a single panel. Such a model assumes effective panel seals. In what way will this assumption be tested in future PA's (see 1992 PA, v. 4, 5-1)?

Response

Current PA modeling capability allows consideration of intrusion into a panel separated from the rest of the repository volume by a panel seal. The effectiveness of panel seals in preventing flow and transport between panels can be examined in this model by varying seal permeability.

Comment AG-9d

Page 10

The disturbed performance model extends to the Culebra only. Will more recent strata be incorporated in subsequent PA's?

Response

Yes. The stratigraphy now used in the BRAGFLO model includes a simplified representation of the Rustler and the Dewey Lake.

Comment AG-9e

Page 10

The initial brine saturation of the waste is sampled within the range of 0.0 to 0.14 (1992 PA, v. 4, 5-13; v.5, 2-9). The PA reports that the 1991 sampling range extended from 0.0 to 0.276, the maximum being the residual saturation that the waste could contain and still comply with transportation requirements. (1992 PA, v. 5, 2-8). For the 1992 PA the sampling range has been restricted due to "numerical constraints imposed by the creep closure model that was implemented by 1992" (1992 PA, v. 5, 2-8). Please explain the numerical constraints. What efforts are under way to replace the arbitrary range with a more accurate figure?

Response

The numerical constraints arose from the small time steps needed to correspond to the short time constant required for fluid compression. The 1991 and 1992 PA analyses used artificially high waste moisture content values to test the PA codes for their sensitivity to waste water content. See the reply to Comment AG-4b for a discussion of recent waste moisture content data.

Comment AG-9f

Page 10

Sampling methods admittedly sample correlated variables independently. Will a method be adopted to refine sampling procedures in this respect?

Response

We now sample correlated variables. This was done in the 1991 and 1992 PAs for some variables. The techniques for implementing correlations are available. The problem is obtaining a good characterization of what their correlations should be.

Comment AG-9g

Page 10

The 1992 PA observes, concerning gas and brine migration, that contaminated brine must displace all brine-saturated pore volume in a grid block before it can move to the next grid block (1992 PA, v. 5, 4-14), and that if some of the pore volume is occupied by

gas, travel distances must be increased proportionately (1992 PA, v. 5, 4-15). What is being done with regard to this prospect?

Response

Such estimates of brine migration as done in 1992 and reported in 1992 PA, Volume 5, Chapter 4 are no longer necessary. A new model, "NUTS" will calculate the transport of radionuclides or dissolved constituents in the brine phase directly within the Salado formation. This is a much more rigorous and accurate method for determining how far contaminated brine may migrate.

Comment AG-10

Page 10

The permeability of borehole fill is a sensitive parameter with respect to radiation releases (1992 PA, v. 4, 5-36). PA assumes that initially the drillers place casing and cement and sand plugs (1992 PA, v. 3, 4-4). PA further assumes that the plug conforms to OCD orders, specifying a solid cement plug through the Salado (id.). The figure (1992 PA, v. 3, Fig. 4.2-1) does not depict such plugs. The PA discussion does not indicate the sensitivity of initial borehole plug permeability, and this should be discussed and the assumptions justified, if significant. Also, do the characteristics of silty sand (1992 PA, v. 3, 4-6) reproduce those of a degraded concrete plug?

Response

The 1992 PA made the assumption that degradation of borehole plugs was instantaneous. No assumptions were made about the initial properties of borehole plugs, and performance estimates do not reflect any contribution such plugs might make in delaying or reducing releases.

Quantitative data are not available about the long-term properties of degraded concrete borehole plugs. The use of silty sand as an analog for degraded concrete is a qualitative estimate. However, it should be noted that silty sand is also an appropriate analog to use for material that might fill an open hole, based on the EPA guidance in Appendix C of 40 CFR 191 that analyses should consider a "flowpath with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open hole over time..." Examination of the stratigraphic section above the repository (see Holt and Powers, 1990) indicates that if a hole in the salt were to stay open for any period of time, silty sand provides an appropriate representation for what might settle into an open hole.

Reference

Holt, R.M., and D.W. Powers. 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant.* DOE-WIPP 90-051. Carlsbad, NM: Westinghouse Electric Corporation.

Comment AG-11a

Page 11

Castile brine reservoir:

Several parameters are sensitive in analyses of human intrusion scenarios:

Castile brine pressure is estimated based upon limited (i.e., WIPP-12) wellhead data; the range is derived from the 1989 Systems Analysis (SAND 89-0462), at 3-148, but the data underlying the derivation of the initial pressure base case and range are not set forth.

Response

The underlying data for Castile brine pressure are found in Popielak, R.S., R.L. Beauheim, S.R. Black, W.E. Coons, C.T. Ellingson, and R.L. Olsen. 1983. *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME-3153. Carlsbad, NM: U.S. Department of Energy. (WIPP Observation Data).

Comment AG-11b

Page 11

Bulk storativity is another reservoir attribute estimated from WIPP-12 data. Bulk storativity expresses the ratio of fluid discharged to pressure decrease. It seems correct to base estimates on data as to long-term pressure changes when modeling long-term groundwater releases. However, in modeling surface releases, should not short-term pressure changes be the basis for the estimates?

Response

Bulk storativity is a parameter that is constant over time. At early-time (short-term), fluid discharges are large and pressure decrease is rapid. At later-time (long-term), fluid discharges are smaller and pressure decrease is minimal. The bulk storativity

determined from either short-term or long-term testing is the same and can therefore provide a basis for modeling surface releases, irrespective of duration.

Comment AG-12a

Page 11

Human intrusion probability estimates:

The estimation of the probability of human intrusion will be one of the most sensitive parts of the PA. Draft EPA compliance criteria propose estimation of a rate of intrusion based on historical data. If such process is adopted some of the following comments may be inapplicable:

Is it correct to express the frequency of intrusion as a random variable? The likelihood of an intrusion is affected by the information obtained in--and thus the occurrence of -- prior intrusions. The nonrandom nature of the second and successive holes may be important at WIPP, where the first hole is quite likely to intersect extractable resources. Is it not more appropriate to use a multilevel probability analysis?

Response

Assumptions about the independence of intrusion events are based primarily on the guidance contained in Appendix C of 40 CFR 191. Three points are relevant. "Inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed." Passive institutional controls "can be effective in deterring systematic or persistent exploitation" of the site. "[P]assive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities."

The approach to determining drilling probabilities will be reconsidered if appropriate when 40 CFR 194 is promulgated.

Comment AG-12b

Page 11

The probability of certain scenarios is affected by the fraction of the disposal area overlying Castile brine reservoirs. The PA casts doubt upon attempts to correlate reservoir data points (1992 PA, v. 3, 5-7) and to identify the stratigraphic location of

brine reservoirs in the region (Id., 5-10, 5-11). What efforts are underway to narrow these uncertainties?

Response

The area-fraction of the panels underlain by Castile brine was treated in the 1991 and 1992 PAs as an uncertain parameter, and sampled in the Monte Carlo analyses. Sensitivity analyses in both PAs indicated that uncertainty in this parameter had little effect on overall performance (see Volume 4 of the 1991 PA, Table 6-1, and Volume 4 of the 1992 PA, Table 9-3). No activities are planned at this time to reduce uncertainty in the spatial extent of the brine reservoir.

Comment AG-12c

Page 11

There is a need for an iterative approach to expert judgment estimates of the probability of human intrusion. Performance of this task, like others, ought to improve with practice and refinement.

Response

Future states of society and the probability of intrusion are unknowable. Thus, there is no expectation of closing in on a specific value. While the process and practice of expert judgement may improve, there is no way to tell if the "answer" is any better.

Comment AG-12d

Page 11

Issue identification--the description of the intrusion scenarios to be considered by experts--can be carried out separately from estimation of probabilities. In such event the questions assigned to different groups must be stated with precision. We do not approve the approach of making overlapping assignments, as appears to have occurred as between the Futures Panel and the Markers Panel.

Response

Stephen C. Hora and Detlof von Winterfeldt, two of the four authors of the 1990 Bonano et al. report, were consultants to Sandia on the conduct of the Futures Panel and were the normative specialists for the elicitations. Stephen C. Hora was also part of the Markers Panel effort.

The effort undertaken with the Futures Panel and the Markers Panel was not to identify scenarios for modeling in a performance assessment, but to address alternative futures. SAND90-3063 test prepared by the authors intentionally does not use the term "scenarios." Text prepared by the teams sometimes uses the term "scenarios," since they did not realize the special usage of the term in performance assessment.

The issue statement for the Futures Panel (SAND90-3063, p. G-3) states:

> The future human intrusions team members are asked to address primarily the issues related to societal development and activities that could lead to inadvertent human intrusion in a time frame that extends 10,000 years after disposal. Other expert teams will address the issues related to marker and barrier development.

The Futures Panel was also asked to consider active controls and records systems (as aspects of societal development that could impact intrusion). In fact, they were specifically requested not to consider the impact of markers in considering the frequency of intrusions (p. G-4): "It should be assumed that markers or signs placed to deter human intrusion have vanished or are no longer effective."

The issue statement for the Markers Panel (SAND92-1382, p. A-3) stated: "...consider passive markers for deterring inadvertent human intrusion, defining characteristics for selecting and manufacturing markers to be placed at the WIPP, and judging the performance of these markers over a 10,000 year period."

The members of both panel were briefed on 40 CFR 191 and the requirement for markers. While markers were not in the charter of the Futures Panel, some panel members chose to make statements/recommendations about markers. DOE chose to publish all the material received by the teams and to not censor it.

References

Bonano, E.J., S.C. Hora, R.L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories.* SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12e

Page 12

Selection of panel members: Bonano el al., Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories (1990) suggests that generalists, specialists, and normative (i.e., expert elicitation) experts be selected for each elicitation. Thus, there is a need to identify the applicable specialties with respect to each issue, a task which was done with inadequate care in the 1990 elicitation. For example, to consider a specific issue of hydrocarbon drilling practices, it seems necessary to consult an oil field geologist or similar industry expert, but this was not done in 1990.

Response

Stephen C. Hora and Detlof von Winterfeldt, two of the four authors of the 1990 Bonano et al. report, were consultants to Sandia on the conduct of the Futures Panel and were the normative specialists for the elicitations. Stephen C. Hora was also part of the of the Markers Panel effort.

The Expert Panel Selection Criteria for both the Futures Panel (SAND90-3063, p. K-3) and the Markers Panel (SAND92-1382, p. E-3) contained:

> (1) tangible evidence of expertise, (2) professional reputation, (30) availability and willingness to participate, (4) understanding of the general problem area, (5) impartiality, (6) lack of economic or personal stake in the potential findings, (7) balance among team members so that each team has the needed breadth of expertise, (8) physical proximity to other participants so that teams can work effectively, and (9) balance among all participants so that various constituent groups are represented."

The text and appendices of both SAND90-3063 (pp. 11-2 to 11-4, Appendices h, I, and J) and SAND92-1382 (pp. 2-4 to 2-6, Appendices B, C, and D) indicate the effort that was undertaken to fulfill the selection criteria. Individuals in a variety of disciplines from professional societies, technical journals, universities, and government agencies, as well as individuals from environmental and public interest groups were queried for nominations for both the Futures Panel and Markers Panel.

The materials that was presented to the Futures Panel, as well as the written material that they received, contained information about resource potential at the site. The reasoning behind the make-up of each team within the Futures panel was to encourage a broad consideration of possible future societies.

The consideration of potential future societies is important not only because of the need to consider the frequency of inadvertent human intrusion in performance assessments,

but also for the benefit of thinking broadly when considering how to attempt to communicate with humans over the 10,000 year period of regulatory concern. The consideration of a broad range of motivations for and capabilities of human intrusion can be instructive as a base for setting "with whom" one may be trying to communicate. This was, in fact, one of the motivations for convening an expert panel to address future human intrusion. This broad thinking on human intrusion became input for the Markers Panel, charged with addressing the need for markers intended to communicate the dangers and location of the wastes.

This dual purpose for the Futures Panel opened up the discussion of long-term markers to address a broad range of possible future societies and modes of intrusion, while allowing the performance assessment process to focus on exploratory drilling, as EPA directed in the Guidance.

References

Bonano, E.J., S.C. Hora, R.L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories.* SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12f

Page 12

Formation of judgments: Members may, in principle, be elicited singly, or in panels of members who perform parallel tasks, or as a team which separately perform parts of a single task. Bonano et al. point out the hazard that members may unconsciously be influenced by one another's judgment (at 42-43). Diversity in scientific backgrounds must be deliberately sought (at 15). Conflicts of interest must be carefully avoided (at 14). the tasks of team members must be clearly defined so that members are confined to their specialty (at 15).

Response

Stephen C. Hora and Detlof von Winterfeldt, two of the four authors of the 1990 Bonano et al. report, were consultants to Sandia on the conduct of the Futures Panel and were the normative specialists for the elicitations. Stephen C. Hora was also part of the Markers Panel effort.

(a) Influence

Bonano et. al. (1990, p. 3), in a discussion of the advantages of a formalized expert-judgment process, state:

> *Well-thought-Through Design for Elicitation*. The procedures that will be used in a formal expert-judgment process are designed specially for the problem being faced. The design relies on the knowledge of the problem domain to be studied. *Careful planning of the process can substantially reduce the likelihood of critical mistakes that will render information suspect or biased* [emphasis added]. Mistakes such as including experts with motivational biases, failing to document rationales, inadvertently influencing the experts' responses, failing to check for consistency, and allowing individuals to dominate group interactions *can be avoided* [emphasis added].

(b) Diversity, avoiding conflict of interest

The Expert Panel Selection Criteria for both the Futures Panel (SAND90-3063, p. K-3) and the Markers Panel (SAND92-1382, p. E-3) contained:

> (1) tangible evidence of expertise, (2) professional reputation, (3) availability and willingness to participate, (4) understanding of the general problem area, (5) impartiality, (6) lack of economic or personal stake in the potential findings, (7) balance among team members so that each team has the needed breadth of expertise, (8) physical proximity to other participants so that teams can work effectively, and (9) balance among all participants so that various constituent groups are represented.

The text and appendices of both SAND90-3063 (pp. 11-2 to 11-4, Appendices H, I, and J) and SAND92-1382 (pp. 2-4 to 2-6, Appendices B, C, and D) indicate the effort that was undertaken to fulfill the selection criteria. Individuals in a variety of disciplines from professional societies, technical journals, universities, and government agencies, as well as individuals from environmental and public interest groups were queried for nominations for both the Futures Panel and Markers panel.

(c) Confining experts to their specialty

When dealing with such complex issues as future societies and long-term markers, the concern of confining experts to their specialty does not address the salient point.

For example, the Markers Panel was not asked to interpret hardness or durability data. The Markers Panel was asked to develop marker design criteria, which have materials and communication aspects, among others. Each member of the team brought to the deliberations the contributions of his or her discipline to the development of an effective marker system. Recommendations based on a narrow materials science perspective (use titanium for markers as it is highly resistant to corrosion) may be subject to other constraints (human beings will recycle materials from an unattended marker system for which it is cost effective) and may need to be modified (use only a small subset of buried markers made from titanium to make mining an uneconomical prospect).

The point is that the teams are interdisciplinary. The rationale for using teams of experts is that questions related to human intrusion and passive institutional controls cannot be fielded by an single discipline. The issues to be addressed demand this organization. A discussion of interdisciplinary teams is provided in Bonano et al. (1990), especially see p. 15:

> No expert teams are necessary if the results of expert judgments from individuals or panels are naturally packaged to integrate the analysis. However, at other times the natural package of information based on experts' judgments can only be acquired from an expert team comprised of specialists in related but synergistic disciplines.

The above quote indicates that the natures of the issue dictates whether the judgments from individual experts can be collected separately or whether experts must use the contributions from their disciplines "synergistically" to provide the necessary information.

References

Bonano, E.J., S.C. Hora, R.L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories*. SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND90-3063, Albuquerque, NM: Sandia National Laboratories.

Comment AG-12g

Page 12

Training: Members should be trained in methods to induce an accurate estimate of probabilities and to reduce bias. (at 16-20). The methods include decomposition of an issue into several less complex problems, stating implicit estimates explicitly, and declaring all assumptions.

Response

Both SAND90-3063 (p. 1-3) and SAND92-1382 (p. 2-6) indicate that at the first meeting of each panel, training in the subject of expert judgment/probability assessment took place. Stephen C. Hora and Detlof von Winterfeldt conducted the training for the Futures Panel and Stephen C. Hora conducted the training for the Markers Panel.

The reports documenting the work of the Futures Panel (SAND90-3063) and the Markers Panel (SAND92-1382) show how the issues were decomposed. See also the response to comment AG/92PA-12h.

References

Bonano, E.J., S.C. Hora, R. L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories*. SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C. D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgement on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12h

Page 12

Decomposition of issues: The issue should be decomposed into a decision tree or event tree, including all factors deemed relevant by the members, that will guide the determination of probabilities. Disagreement as to the nature of the appropriate decomposition reflects an aspect of uncertainty.

Response

Bonano et al. (1990) list several types of decompositions for factual (not value) problems. They are fault trees, event trees, conditioning of possible events on known or hypothesized events, decision trees, and algorithmic decomposition (based on a mathematical function).

The Bonano report states:

> The previously described decompositions of factual and value problems are fairly formal in that they express the results as trees or functions. Decomposition can also be used less formally. The goal of a less formal procedure might be to promote deeper insight into the rationale for judgments and to enhance the interchange of beliefs and assumptions about the likely causes of studied events without formally encoding the decomposition. The decompositions might be in terms of causal or mitigating factors that are loosely related to the event or quantity of interest. In this form, decomposition enhances the experts' introspection and communication.

Thus, decomposition does not need to follow a particular rigid format. The Futures Panel and the Markers Panel teams each provide judgments based on decompositions of the issue statement. These decompositions are documented in SAND90-0363 and SAND92-1382.

References

Bonano, E.J., S.C. Hora, R. L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories*. SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C. D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12i

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Documentation of elicitation: The "normative expert" elicitator should document the specialist's judgments and any reasoning offered in support. The intuitive conclusion and any intermediate probability estimates should be recorded and compared and the specialist asked to reconcile any inconsistencies.

Response

The documents produced describing the Futures Panel effort (SAND90-3063) and the Markers Panel effort (SAND92-1382) "document the specialists judgments and any reasoning offered in support."

The expert judgment elicitation process and the judgments derived from it (including intermediate probabilities) are documented in SAND90-3063 and SAND92-1382. Support for the positions taken by the teams can be found in the reports prepared by each team.

The Preface of SAND90-3063 indicates that a draft of the report was sent to the Futures Panel members for their review. The Markers Panel members had two opportunities for review of the elicited material--immediately after the elicitation meeting and again prior to the publication of SAND92-1382 (Preface).

References

Bonano, E.J., S.C. Hora, R. L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories*. SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C. D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M, S.C. Hora, and R. V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12j

Page 12

Scenario selection: When the task involves scenario generation, the normative expert shall be required to employ methods of forward induction, i.e., construction of scenarios by creating a forward-looking "event tree", and backward induction, i.e., reasoning backward based on hypothesized performance or nonperformance of the repository and postulating causes.

Response

As stated in the response to comment AG92/PA-12d, the effort undertaken with the Futures Panel and the Markers Panel was not to identify scenarios for modeling in a performance assessment, but to address alternative futures. SAND90-3063 text prepared by the authors intentionally does not use the term "scenarios." Text prepared by the teams sometimes uses the term "scenarios," since they did not realize the special usage of the term in performance assessments.

Given that the task was not to generate scenarios, Bonano et al. (1990, p. 25) indicate that "value-driven event and scenario generation" and "analogy - or antinomy-driven event and scenario generation" are the two other techniques that can be used for "event and scenario" identification. They go on to state that:

"Any of these three techniques can be combined with various forms of interactions among experts...Furthermore, they can be substantially enhanced by involving individuals with very different perspectives regarding the repository...Since the purpose at this point is to assure comprehensiveness, any inputs that are novel and creative should be appreciated."

In addition, Bonano et al. indicate that:

"Forward and backward induction builds on the notion that scenarios are logical sequences of events linked through processes."

Bonano et al. (1990, pp. 29-30) list several types of decompositions for factual (not value) problems. They are fault trees, event trees, conditioning of possible events on known or hypothesized events, decision trees, and algorithmic decomposition (based on a mathematical function).

The Bonano report (p. 31) states:

"The previously described decompositions of factual and value problems are fairly formal in that they express the results as trees or functions. Decomposition can also be used

less formally. The goal of a less formal procedure might be to promote deeper insight into the rationale for judgments and to enhance the interchange of beliefs and assumptions about the likely causes of studied events without formally encoding the decomposition. The decompositions might be in terms of causal or mitigating factors that are loosely related to the event or quantity of interest. In this form, decomposition enhances the experts' introspection and communication."

Thus, decomposition does not need to follow a particular rigid format. The Futures Panel and the Markers Panel teams each provided judgments based on decompositions of the issue statement. These decompositions are documented in SAND90-3063 and SAND92-1382. The alternative futures developed by the four teams of the Futures Panel followed a variety of techniques (including, but not limited to forward and backward induction) to develop this "novel and creative" input. This creativity was an essential part of broadening the thinking regarding human intrusion.

References

Bonano, E.J., S.C. Hora, R.L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories.* SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12k

Page 13

Probability elicitation techniques: Since the probability issue is critical, criteria should direct the use of probability elicitation techniques to generate the probability estimates. These include fractile techniques, whereby members must estimate the .05, .05, and .95 probabilities, and interval techniques, whereby members must estimate probabilities at various magnitudes of the unknown value.

Response

It is inappropriate that "criteria should direct the use of probability elicitation techniques." As discussed below, the nature of the decompositions themselves indicates the techniques to be used.

Bonano et al. (1990, p. 33) state:

"Drawing on this literature, there appear to be four distinct classes of procedures, depending on the nature of the uncertain quantity (discrete events vs. continuous random variables) and the nature of the questions asked (magnitude judgments about events vs. indifference judgments about gambles). The resulting taxonomy is shown in Table 2.1...The eight techniques listed in this taxonomy [direct probability, direct odds, fractile technique, interval technique, reference gambles (for both discrete and continuous), and certainty equivalent (for both discrete and continuous)] are the most commonly used ones in the quantification of probability judgments."

Both types of information (discrete and continuous) were elicited from the teams, so the techniques used also varied. Information elicited from the Markers Panel was of the discrete form. Information elicited from the Futures Panel was of both the discrete and continuous forms. The types of information elicited are discussed in SAND90-3063 and SAND92-1382. Fractile and interval techniques are only applicable to continuous quantities.

References

Bonano, E.J., S.C. Hora, R.L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories.* SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C., D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M., S.C. Hora, and R.V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant.* SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12l

Page 13

Combinations: Bonano et al. point out that to average probability judgments of different members or teams addressing the same issue would be erroneous, because it would mask the range of uncertainty reflected by the different judgments (at 42-43, 47). In all situations the reported judgments should include the individual members' conclusions.

Response

The topics of future states of society and long-term markers are interdisciplinary ones. The perspectives of different disciplines must be incorporated to fully answer the questions asked. In these cases, the unit of analysis is the interdisciplinary team, so the judgments of the teams and the members of the teams are indicated. Regarding future states of society and long-term markers, the perspectives of individual team members, and thus the disciplines they represent, are equally important and are given equal weighting. An "average" is an analytical combination where all the experts have equal weighting. It is thus appropriate to average over the individual expert (discipline) judgments.

References

Bonano, E.J., S.C. Hora, R. L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories*. SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C. D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M, S.C. Hora, and R. V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12m

Page 13

Documentation: There should be a complete record of the elicitation process, including formulation of issues, selection of member, and each stage of the elicitation process. It is particularly important to subsequent application of estimates to make clear what factors were or were not considered in reaching a probability judgment (e.g., general

knowledge of WIPP; effect of markers). Further, the reasoning giving rise to probability estimates and any support in other methods of probability estimation should be recorded. As stated, individual members' conclusions should be set forth. Members should be identified by name (at 44-45).

Response

SAND90-3063 and SAND92-1382 provide a record of the elicitation process. These reports also include the issue statements and discuss the decomposition of the issues. In addition, the appendices reproducing the individual and team perspectives discuss approaches and rationales.

The topics of future states of society and long-term markers are interdisciplinary ones. The perspectives of different disciplines must be incorporated to fully answer the questions asked. In these cases, the unit of analysis is the interdisciplinary team, so the judgments of the teams and the members of the teams are indicated. Regarding future states of society and long-term markers, the perspectives of individual team members, and thus the disciplines they represent, are equally important and given equal weighting. An "average" is an analytical combination where all the experts have equal weighting. It is thus not inappropriate to average over the individual expert (discipline) judgments.

References

Bonano, E.J., S.C. Hora, R. L. Keeney, and D. von Winterfeldt. 1990. *Elicitation and Use of Expert Judgment in Performance Assessment for High-Level Radioactive Waste Repositories*. SAND89-1821. Albuquerque, NM: Sandia National Laboratories.

Hora, S.C. D. von Winterfeldt, and K.M. Trauth. 1991. *Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND90-3063. Albuquerque, NM: Sandia National Laboratories.

Trauth, K.M, S.C. Hora, and R. V. Guzowski. 1993. *Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant*. SAND92-1382. Albuquerque, NM: Sandia National Laboratories.

Comment AG-12n

M

Page 13

In the 1992 PA conversion from drilling rates to scenario probabilities is inadequately explained. Whether in the future separate futures panel "teams" will constitute a "range" to be sampled is not known. If this is done, it must be made clear what team-estimated conditions (e.g., state of technology) are chosen for sampling and why, and exactly which

probability (or probability density function) is thereafter selected. Conversion to drilling intensity must be made explicit. We are concerned about the observations by EEG that the realizations in Appendix D of v. 3 are not the actual results of the program described in the Hora memorandum in Appendix A and that the probability of intrusion is reduced to zero after year 300 for the Boston Team (EEG 9/93 comments at 5). It also seems plain that the intrusion rate overall is zero after 2,000 years (1992 PA, v. 4, 2-19). This seems erroneous.

Response

Future documents will attempt to more clearly explain the conversion from drilling rates to scenario probabilities. Whether separate future panel "teams" will constitute a range to be sampled in the future will be impacted by the promulgation of 40 CFR 194. We agree that team-estimated conditions chosen for sampling and probabilities and the justification for such choices should be explicitly stated.

The program described in Dr. Hora's memorandum was a slightly earlier version than that used in the analysis. The difference in programs amounted to a simple bypass of the program statements concerning the array BOSTAB2. This was done because a decision was made not to include injection wells in the analysis at the time because the current performance assessment models include only exploratory boreholes, as required by 40 CFR 191. The Boston Team provided assessments for the drilling intensity that are conditional on both time and level of technology. The Boston Team concluded that exploratory drilling for hydrocarbons would not extend further than 300 years in the future and provided their own justification. Dr. Hora's program is a means to sample from the judgments of the Futures Panel and Markers Panel in addressing human intrusion and uses the judgments as developed by the teams. It is correct that for the purpose of calculating subsurface releases, the assumption that no intrusions occur after 2,000 years was made in the 1992 PA. Cuttings releases were calculated for the full interval from 100 to 10,000 years. The 1992 PA was preliminary, and results were not intended to be used as the basis for a compliance decision. The compliance application for WIPP will not be constrained in this manner.

Comment AG-13a

Page 13

Repository/shaft design:

Several questions arise concerning the engineered components of the disposal system:

Seal design and performance: Design standards call for MB 139 and other anhydrite layers to be sealed below and above each panel and drift with grout. (1992 PA, v. 2, 2-48). PA should provide a detailed description of the placement and composition of the grout.

Response

Effective placement of grout into Marker Bed 139 has been part of the technology development activities performed at the WIPP facility. Specifically, as indicated in the test plan for the Small-Scale Seal Performance Test-Series F (Ahrens, 1992), this underground test at the WIPP was "intended to demonstrate equipment and techniques for producing, injecting, and evaluating microfine cementitious grout." The grouting was completed in March, 1993, and the final report is currently being prepared.

Reference

Ahrens, Ernst H. 1992. *Test Plan - Sealing of the Disturbed Rock Zone (DRZ), Including Marker Bed 139 (MB139) and the Overlying Halite, Below the Repository Horizon, at the Waste Isolation Pilot Plant - Small-Scale Seal Performance Test - Series F.* Albuquerque, NM: Sandia National Laboratories.

Comment AG-13b

Page 13

Preconsolidated salt in seals and backfill is said to consolidate to a median permeability of 1 x 10^{-20} m^2 within 100 years. (1992 PA, v. 3, 3-14). Reference must be cited for this permeability figure. Sandia has said recently that permeability of 10^{-18} m^2 or less is necessary to retard gas flow. Experiments have been planned to support such figure but have not yet been conducted. See Nowak et al., Initial Reference Seal System Design: Waste Isolation Pilot Plant (SAND 90-0355), at 27.

Response

Numerous laboratory studies have been completed which document the permeability of compacted, crushed salt samples. These data are summarized in Figure 4 of Hansen et al. (1993). The relationship is shown between the permeability of the crushed salt samples and the relative/fractional density of the sample. This paper also references the numerous reports in which the data were first documented.

Reference

Hansen, F.D., G.D. Callahan, and L.L. Van Sambeek. 1993. *Reconsolidation of Salt as Applied to Permanent Seals for the Waste Isolation Pilot Plant*, 3rd Conference on the Mechanical Behavior of Salt, September 14-16, 1993, Ecole Polytechnique, 91129 Palaiseau, Cedex-France.

Comment AG-14a

Page 14

Culebra flow and transport model:

The following matters deserve attention as to the model of flow and transport in the Culebra:

PA uses past climates to limit projected future variability in precipitation. (1992 PA, v. 2, 2-27; v. 4, 6-11). It has been asserted by Professor Roger Y. Anderson (March 16, 1993 comments to EPA) that a broader range of variability then the range of Pleistocene variation is appropriate. Please comment.

Response

Please see the response to AG-1a. Prof. Anderson's comments to the EPA did not disagree with the approach taken in WIPP PAs to treating climate variability during the next 10,000 years. Rather, Prof. Anderson's purpose was to ask the EPA to consider extending the regulatory period to 100,000 years to allow consideration of a range of climate variability more representative of the entire Pleistocene. This would represent a significant change in present regulatory requirements.

Comment AG-14b

Page 14

Modeling assumes no vertical flow above the Salado (1992 PA, v. 2, 2-24). In light of the imprecise knowledge of recharge patterns (1992 PA, v. 2, 2-36, 2-38) the assumption of no vertical flow must be scrutinized (see 1992 PA, v. 4, 6-2). What is planned?

Response

The WIPP Project is currently investigating the effects of vertical flow and recharge that may vary in both space and time through the use of a three-dimensional regional

groundwater-flow model. Results of this modeling program will be used to evaluate the adequacy of the confined, two-dimensional approximation used to model flow and transport in the Culebra for PA.

Comment AG-14c

Page 14

Hydraulic conductivity in the Culebra is insufficiently characterized, in that the variability of, and controls on variability of, fracture porosity are not known (1992 PA, v.2, 2-16, 2-19). What efforts are planned to improve the state of knowledge? Fracture porosity and spacing are sensitive parameters (1992 PA, v. 3, 2-79, 2-81).

Response

This comment implies that it is necessary to have knowledge of the distribution of fracture porosity in order to characterize hydraulic conductivity. It is correct that the hydraulic conductivity of the Culebra very much depends on the degree to which open fractures are present. However, it is not necessary to know the fracture porosity or spacing in order to use results of hydraulic tests (e.g., pumping tests, slug tests, and drill-stem tests) to calculate values of hydraulic conductivity. Although there is clearly uncertainty in the distribution of hydraulic conductivity, SNL currently believes that this distribution is sufficiently well characterized.

The 92 PA does point out that there is insufficient information about matrix and fracture porosities to map their spatial distribution (v. 2, p. 2-16). Fracture porosity and spacing, as noted in the comment, are sensitive parameters in dual-porosity transport calculations. Values of these parameters have been obtained from tracer tests.

Comment AG-14d

Page 14

The 1992 PA notes that the groundwater geochemistry of the Culebra is inconsistent with a north-south flow pattern (1992 PA, v. 2, 2-36). It is stated that as the groundwater flow model is developed and refined, the potential significance of uncertainty in the location and amount of future recharge will be re-evaluated. (1992 PA, v. 2, 2-38). What are the PA plans to resolve, or examine the significance of, this uncertainty?

Response

It should be emphasized that it is not certain that an inconsistency between the hydrochemical facies of Culebra waters and the inferred north-to-south flow direction actually exists. As discussed in the 1992 PA (Volume 2, p 2-36, 13-20), Lambert and Carter (1987), Lambert (1991), and Chapman (1988) have proposed hypotheses to explain the relationship between the hydrochemical facies and flow directions. Lambert and Carter favor a model in which the hydrochemical facies still reflect a past flow direction. This model considers vertical flow into the Culebra from overlying strata to be insignificant. In contrast, the model proposed by Chapman includes recharge from the surface in the region of facies zone B. Whether or not one of these models provides a satisfactory explanation of the hydrochemical facies is not resolved and it is not clear that the resolution of this issue would have a direct effect on demonstrating compliance.

PA is using a three-dimensional regional model to investigate the impact of spatially and temporally varying recharge on groundwater flow in the vicinity of WIPP. The model calculates recharge distributions and groundwater flow rates and directions given assumptions about the amount of moisture available to infiltrate to the water table. Results of this modeling program will be used to evaluate the adequacy of the confined, two-dimensional, approximating used to model flow and transport in the Culebra for the 1992 PA.

References

Chapman, J.B. 1988. *Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern New Mexico. EEG-39.* Santa Fe, NM: Environmental Evaluation Group, Environmental Improvement Division, Health and Environment Department, State of New Mexico.

Lambert, S.J. 1991. *"Isotopic Constraints on the Rustler and Dewey Lake Groundwater Systems," Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* Eds. M.D. Siegel, S.J. Lambert, and K.L. Robinson. SAND88-0196. Albuquerque, NM: Sandia National Laboratories.

Lambert, S.J., and Carter, 1987. *Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico. 1. Principles and Preliminary Results.* SAND87-0388. Albuquerque, NM: Sandia National Laboratories.

M

Comment AG-14e

Page 14

An agreement between DOE and the State requires that radionuclide retardation be demonstrated with experimental data (1992 PA, v. 4, 6-3). Further, PA notes that experimental data as to distribution factors "cannot be extrapolated directly to a complex natural system" (1992 PA, v. 2, 2-30). At the recent NAS WIPP subcommittee meeting it was specifically stated by one member that laboratory data as to distribution factors is no reliable guide to retardation in the field. What are DOE's plans to develop retardation data that both satisfies its agreement with the State and affords scientific reliability? Will tests on site with nonradioactive analogue tracers be conducted (see 1992 Pa, v. 2, 2-41)?

Response

Decisions about how to proceed with experimental plans to demonstrate retardation at laboratory and field scales will be based on outcomes of SPM analyses that include these activities. At present, SPM2 results that could provide the basis for such decisions are anticipated in the Spring 1995.

Comment AG-14f

Page 15

How will the effect on the Culebra flow field of injection of fluids from the repository via an intrusion wellbore be measured and modeled? (see 1992 PA, v. 4, 6-2).

Response

CAO has no plans at this time to measure directly the effects of the injection of repository brine into the Culebra through an intrusion borehole. Scoping analyses of such effects will be modeled using existing PA codes before a decision is made about including brine injection into full system analyses.

Comment AG-14g

Page 15

The PA states that there is insufficient information to characterize the vertical variability of flow within the Culebra (1992 PA, v. 4, 6-1, 6-2). Will this issue be explored further?

Also, is it appropriate to model the Culebra as a rock body of uniform thickness, and, if not, what improvements are planned? (1992 PA, v. 4, 6-4).

Response

PA calculations of flow and transport in the Culebra involve two basic steps. First a regional flow field of specific discharge is calculated. Specific discharge is the rate at which groundwater flows through a unit cross-sectional area of rock. Although specific discharge has the units of velocity, it does not represent the actual velocity of flow. The actual velocity (interstitial velocity) is faster because fluid can only flow through the area provided by the pores and fractures in the rock, rather than the entire cross-sectional area. Assuming no vertical variability and uniform thickness for the Culebra when calculating the field of specific discharge does not introduce any error because these calculations are based on values of transmissivity, a parameter that integrates the hydraulic conductivity of the unit over its entire thickness. These assumptions do affect the calculated actual velocities. Observations at the Air Intake Shaft (Holt and Powers, 1990) indicate that, at this location, most of the flow in the Culebra occurs through about one quarter of its thickness. Assuming that flow occurs only through one quarter of the Culebra thickness results in a calculated velocity four times greater than would be calculated assuming that flow is over the entire thickness, if the same porosity were assumed for each effective thickness. However, the variation of velocity due to the sampled range of fracture porosity is several orders of magnitude. Therefore, there is no current plan to collect data to better characterize the vertical heterogeneity of the Culebra. Although it would be possible to represent the actual thickness of the Culebra in flow and transport models, the change in calculated velocity would be small compared to uncertainty in fracture parameters.

Reference

Holt, R.M. and D.W. Powers, 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant.* DOE/WIPP 90-051.

Comment AG-14h

Page 15

The radionuclide transport model is a obviously sensitive parameter (1992 PA, v. 4, 6-3, ch. 8). How will DOE select among the alternatives for the next PA?

Response

Future iterations of the SPM will use the transport model that is considered to be consistent with currently available information. Alternative models (e.g., those that take

credit for sorption and/or matrix diffusion) will be examined through consideration of activity sets that may be undertaken if SPM analyses indicate that their completion will lead to an acceptable probability of demonstrating regulatory compliance.

Comment AG-14i

Page 15

The flow and transport model assumes an intrusion over the center of the disposal area. However, the future borehole may be 315 m closer to the subsurface boundary. (1992 PA v. 4, 6-4, 6-7). Will the parameter of borehole location be changed or sampled in future analysis?

Response

Current modeling capabilities permit varying the location of the intrusion borehole. Decisions about the specific analyses for the SPM or for a compliance application will be made after baseline information for the SPM has been determined.

Comment AG-14j

Page 15

The Culebra flow model includes 70 transmissivity fields, which are calibrated to steady-state and transient head data. The exercise generated inconsistencies between the modeled and observed conditions. (1992 PA, v. 4, 6-26). It would seem that the model requires refinement based on data concerning factors, not now incorporated, affecting the observed head data. Is such an effort planned?

Response

The problem indicated in 1992 PA, Volume 4, pg. 6-26 relates to the RMSE of calculated heads at wells H-7 and USGS-1 measured well water levels being 2 to 4.3 meters lower in realizations than the observed well water levels. The comment concerns the effect of boundary conditions at the southern portion of the model domain on the estimation of the transmissivity field within the WIPP site boundary. It is probable that the boundary conditions assumed at the *model boundary* are not of great importance in determining the T-field geostatics *within the WIPP site boundary*. The rationale for this statement is the comparison that was made in papers by Rubin and Dagan (1988, 1989) in which a Green's function approach was used to analyze the effects of a constant head boundary and impervious boundary conditions on the head variogram and cross-covariance of head and lnk. The results of this study showed little difference between

these covariances and the covariances generated for an aquifer with infinite boundaries when the boundary is located a few correlation scales from the area of interest. Assuming an exponential covariance for lnT, the correlation length for the Culebra is around 3km. The SW model boundary is at least 12km from the WIPP boundary so the effect of boundary conditions at this boundary are probably not significant. Finally, since solute transport trends to be in a southerly direction in the WIPP Culebra release scenarios, the effect of lower than measured heads at the southern boundary of the land withdrawal area will tend to increase the NS gradient, and to increase transport out of WIPP. Thus this error is conservative (tending to increase releases). In any case, the sensitivity of the T-field inside the WIPP boundary to bounding sets of boundary conditions should be examined when the next set of T-field calculations are made for completeness.

A re-calculation of the transmissivity field using transmissivity and head data that has been measures since the 1992 PA will be conducted for the final compliance document. Re-calculation of transmissivity fields for the SPM2 may take place if there is sufficient time in the process. The Geostatistical Expert Group (GxG) has conducted a series of blind test problems to determine the adequacy of the pilot point method as well as a number of other inverse methods in estimating the transmissivity field of a number of WIPP-like test problems. The results of this exercise will be available in April 1995. From these results a decision will be made as to whether GRASP-INV or another inverse method is used for future generation of transmissivity field realizations. The code used in calculation of the final transmissivity calculation will be required to be a level A Quality Assurance.

References

Rubin, Y. and G. Dagan, 1988, *Stochastic Analysis of Boundaries Effects on head spatial Variability in Heterogeneous Aquifers*, 1, Constant Head Boundary, Water Res. Res., 24(10), 1689-1797, 1988.

Rubin, Y. and G. Dagan, 1989, *Stochastic Analysis of Boundary Effects on Head Spatial Variability in Heterogeneous Aquifers*, 2, Impervious Boundary, Water Res. Res., 25(4), 707-712, 1989.

Comment AG-14k

Page 15

In the SECO-TRANSPORT model vertical fractures are not incorporated. Should the model be improved in this respect?

Response

The SECO-TRANSPORT is two-dimensional; it contains only lateral directions and therefore does not explicitly include the orientation of fractures. However, the existence of vertical fractures is included in the conceptual model of the Culebra and their affect on flow and transport is fully included in the current version of the model. Therefore, there is no need to change this code in any way to account for vertical fractures.

Comment AG-15a

Page 15

Cuttings model:

The direct release model -- now confined to releases through interaction of drill bit and string and the repository contents -- raises the following questions:

The drill bit diameter is a sensitive parameter under the current PA and is sampled using a cumulative distribution function based on past drilling practice in the Delaware Basin. (1992 PA, v. 4, 7-1). A principal exploration target is gas, and the bit diameter should approximate that used for gas exploration.

Response

As noted in a previous comment (see AG-1f), oil is also a major exploration target in the vicinity of the WIPP. The Project believes that it is appropriate to consider drill bit diameters representative of all drilling activities that reach the repository horizon in the vicinity.

Comment AG-15b

Page 15

The model for spallings releases is still being developed. (1992 PA, v. 2, 7-27). We caution against too rigid assumptions as to the practice which would be followed by a driller who encounters a pressurized zone.

Response

Drilling practices which may affect spalling releases have been examined during development of the spalling model. In part, characterization of these practices is dependent on interpretations of regulatory guidance.

Comment AG-15c

Page 15

Based on the Sandia presentation at the February 22-25 meeting between EPA and DOE, we believe that it cannot be assumed that intruders would soon detect the presence of the repository and discontinue activities. Please comment.

Response

The DOE's interpretation of the "soon detect" guidance provided by the EPA in Appendix C of 40 CFR 191 is given Appendix A of the March 1994 *Draft Compliance Status Report for the Waste Isolation Pilot Plant* (page A-11, entry 64):

> Performance assessment shall be based on the assumption "that passive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities." "Soon detect" shall be defined based on reasonable interpretations of drilling practices and expert judgement. "Soon detect" cannot be strictly interpreted based on current drilling practices since currently, drillers do not worry about encountering underground waste repositories during their operations. Once such repositories are in place, exploratory drillers may become aware of their existence in areas where they are looking for resources.

Comment AG-16a

Page 16

Compliance demonstration:

There are certain fundamental issues with the methods of demonstrating compliance which are not addressed:

How are the variables which are to be sampled selected from among all others? For example, why is the future waste inventory not sampled as to one or more variables?

Response

Parameters were selected for sampling in the 1992 and previous PAs based on several factors, including: degree of uncertainty about the correct values to use in analysis; analyst judgement about the potential affect on outcomes of this uncertainty; information from previous sensitivity analyses; and significant changes in information about the parameter since previous analyses. Because the 1992 PA and previous PAs were

preliminary, and were not intended for use in a compliance application, the total number of sampled parameters was restricted to those believed to be most important. Experience indicates that the 1992 list of sampled parameters did include those to which the 1992 models were most sensitive. The selection of parameters to be used in support of a compliance application will be made when models and data for the application have been determined.

With respect to future waste inventory, parameters characterizing the components that participate in gas generation reactions (i.e., iron, cellulosics, and water) were sampled in the 1992 PA. The radionuclide inventory was not sampled, in part because there was insufficient information available to characterize the uncertainty, and in part because performance is relatively insensitive to the total number of curies emplaced in the system.

Comment AG-16b

Page 16

How is the sufficiency of sampling methods (e.g., range, frequency) evaluated? By what criteria does the occurrence of one or more "outlier" curves dictate a revision in sampling methods?

Response

In general, the occurrence of an outline curve does not dictate a revision in sampling methods. We used two sampling methods in the 1991 and 1992 WIPP PAs: Importance sampling to incorporate stochatic (i.e., aleatory) uncertainty into the analyses and Latin Hypercube Sampling (LHS) to incorporate subjective (i.e., epistemic) uncertainty into the analyses. The robustness of LHS has been investigated previously (e.g., Iman and Helton, 1988; Iman and Helton, 1991). Further, we have conducted comparisons between the use of importance sampling procedures and Monte Carlo procedures for CCDF generation, with both procedures giving similar results. Also, the stability of the importance of sampling procedures is investigated by Helton and Iuzzolino (1993).

References

Iman, R.L. and J.C. Helton, 1998. *An Investigation of Uncertainty and Sensitivity Analysis Techniques for Computer Models.* Risk Analysis. Volume 8, 71-90.

Iman, R.L. and J.C. Helton, 1991. *The Repeatability of Uncertainty and Sensitivity Analyses for Complex Probabilistic risk Assessments.* Risk Analysis. Volume 11, 591-606.

Helton, J.C. and H.J. Iuzzolino, 1993. *Construction of Complementary Cumulative Distribution Functions for Comparison with the EPA Release Limits for Radioactive Waste Disposal.* Reliability Engineering System Safety. Volume 40, no. 3, 277-930.

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Comment AG-16c

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What is the suggested criterion for "reasonable expectation" with respect to the CCDF realizations? What principles, if any, support the selection of mean, median, or a stated percentile?

Response

The DOE's interpretation of "reasonable expectation" is given in Appendix A of the March 1994 *Draft Compliance Status Report for the Waste Isolation Pilot Plant* (p. A-3, entry 15):

> The "reasonable expectation" standard is equivalent to the "reasonable degree of certainty" standard of 40 CFR §268.6. It is a burden of proof greater than the "preponderance of evidence" standard, but not as great as the "beyond a reasonable doubt" standard. The standard requires that reasonably trustworthy information and data be provided such that the totality of the facts and circumstances are sufficient, given the DOE's or the EPA's scientific and technical expertise, to warrant a "firm belief" that performance measures will be met. Quantification of these terms is not appropriate. Assessment of compliance to a "reasonable expectation" or a "reasonable degree of certainty" is therefore, a qualitative assessment of the quantitative results.

Criteria for compliance with 40 CFR §191.13 will be provided by the EPA in 40 CFR 194.

In practice, the final assessment of compliance will always be qualitative as it involves the assessment of many types of information from many sources. However, when a distribution of CCDFs is derived from subjective (i.e., epistemic) uncertainty, it is the location of these CCDFs relative to the boundary line in 40 §CFR 191.13 that is important. Thus, on a formal basis, a summary curve is the logical quantity to consider. However, there is no way to justify any particular curve (e.g., mean or 75%, 90%, 99%...). This is a value judgment on the part of the relevant regulator.

Comment AG-16d

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Why is 4/3 the number of variables a sufficient number of vectors to demonstrate the full range of variability in input parameters? Is another number required to generate a relevant mean, median or other percentile? (see 1992 PA, v. 1, 4-14).

Response

The rule derives from the sample size necessary for the numerical implementation of the Iman/Conover restricted pairing technique.

The robustness of Latin Hypercube Sampling has been investigated in several studies (e.g., Iman and Helton, 1988; Iman and Helton, 1991) and has been found to provide a high degree of repeatability with a relatively small sample size (e.g., 2-3 times the number of variables under consideration. However, a procedure for defining an "optimum" sample size is not known. Iman (1982) has presented a procedure using replicated sampling to place confidence intervals on quantities estimated with Latin Hypercube Sampling.

References

Iman, R.L. and J.C. Helton, 1998. *An Investigation of Uncertainty and Sensitivity Analysis Techniques for Computer Models.* Risk Analysis. Volume 8, 71-90.

Iman, R.L. and J.C. Helton, 1991. *The Repeatability of Uncertainty and Sensitivity Analyses for Complex Probabilistic risk Assessments.* Risk Analysis. Volume 11, 591-606.

Iman, R.L. 1982. *Statistical Methods for Including Uncertainties Associated with Geologic Isolation of Radioactive Waste Which Allow for a Comparison with Licensing Criteria.* In Proceedings of the Symposium on Uncertainties Associated with the Regulation of the Geologic Disposal of High Level Radioactive Waste, Gatlinbximum intrusion rate and a consideration of the effect of uncertainties in scenario probabilities arry, Oak Ridge, TN, pp. 145-57.

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Comment ED/92PA-1

The NMED comment contains extensive discussion of data available on the occurrences of water in the Dewey Lake Redbeds in WIPP-area wells.

The main concerns raised in the comment are summarized in the following two quotes:

"NMED/WIPP staff have concluded that the size and continuity of the Dewey Lake perched ground water zone are not adequately characterized."

"NMED/WIPP staff believe that the...hydrologic investigation documented in the Dewey Lake at H-14 was a test failure, and not an indicator of hydraulic properties of water-bearing zones in
the formation."

Response

Site investigations prior to sinking the shafts showed that the Dewey Lake Formation does not contain enough water to sample in the vicinity of the shafts at the WIPP Site (ref. Bechtel borings, No migration Petitions). This was later confirmed during sinking of the shafts (Holt and Powers 1984, 1986 and 1990) and by the drilling of a number of near-by test wells.

Although there was some moisture that seeped into the Air Intake Shaft (AIS) during construction, most came from just below the fill, four feet below the top of the shaft. The underlying Gatuna Formation (4-13 ft below the surface) was described as locally moist with the exposed surface locally exhibited a NaCl-rich efflorescent crust (Holt and Powers, 1990, Figure 5, Sheet 3 of 22). Moisture and salt crusts were also noted at the base of the Santa Rosa Formation, above the contact with the Dewey Lake (Holt and Powers, 1990, Figure 5, Sheet 3 of 22). The mapping reported fractures in the upper few feet (to a depth of 45 ft below the surface) that were moist and exhibited efflorescence (Holt and Powers, 1990, Figure 5, Sheet 4 of 22). Minor amounts of moisture and salt efflorescence were noted on the shaft surface at approximately 112 ft, 152 ft, 157 ft, and 164 ft. No other moisture was noted on the Dewey Lake surfaces exposed in the shaft at the time of mapping. The contact with the upper Rustler Formation is about 513 ft below the surface.

This water in the Gatuna, Santa Rosa, and upper Dewey Lake was saline and formed salt encrustation as it evaporated in the shaft. Holt and Powers (1990, section 3.4.4) point out that this must have originated as water that came in contact with the WIPP salt storage pile. The source must be very local and the water probably seeped in at the retention pond that is west of the salt pile and north of the parking lot.

Data from 10 test wells drilled between the WIPP shafts and the local ranch water wells confirm that the Dewey Lake is dry and that there is no reason to suspect that there is any potential pathway to connect the shafts to the ranch water supply.

DOE feels that the hydrology of the Dewey Lake is well characterized in the vicinity of the WIPP shafts, and that there is no reasonable potential for the Dewey Lake to provide a release pathway.

Throughout the southwest, where there are surface sand dunes and water is scarce, ranchers typically drill for water at the edges of the dune fields. The dunes collect infiltrating rainwater and funnel that into local, usually perched, water tables in whatever is below the sand. Such water supplies are usually local, subject to rapid depletion, and are easily contaminated. Two wells at the nearby Mills Ranch typify this practice.

No pump testing has been performed at either the Barn or the House wells. These are private ranch wells, not DOE test wells. Additionally, there is no record of how the wells were completed. The DOE did collect water at the Barn well as part of the Water Quality test Program. This water tested high in nitrates (WIPP-DOE 92-007, Section 5.1), logically a product of the animal excrement in the corrals. Test holes drilled between the WIPP shafts and these wells showed that there was no reason to suspect any potential for hydrologic connection.

It is true that the Dewey Lake in the vicinity of the ranch wells is not well characterized. However, the conditions at the ranch are obviously different from and not applicable to those in the vicinity of the WIPP shafts. Since there is no reasonable pathway for release to those wells, the condition at the ranch does not need further characterization. Additionally, since perched, local, water-bearing zones are known to be limited and easily disturbed, the risk of disturbing the local rancher's water supply by DOE pumping test suggest that such tests should not be done unless required by the local ranchers, in which case he would acknowledge that damage to his water supply could occur from the testing that he was requesting.

As of October 13, 1994, WQSP holes 1, 2, 4, 5, and 6 have been drilled. No significant moisture in the Dewey Lake formation was encountered in holes 1, 2, 4, and 5. Fresh water was encountered in WQSP6 (section 29, T22S, R31E, 1667 FSL and 1329 FWL) at a depth of 182-208 feet. Water was produced at a rate of approximately 30 gallons per minute for 15 minutes. This well was cased through the Dewey Lake as per the drilling plan. A second well has been drilled at this site as a test well. The well was completed in the water bearing part of the Dewey Lake Formation, from 180 to 210 feet. For characterization purposes, the well was cored from 160 to 220 feet. The DOE will perform additional testing at this location.

It is important to point out, however, that in the vicinity of the shafts, adequate characterization of the Dewey Lake exists and is valid. There is no reasonable mechanism for a pathway to exist from the WIPP shafts to the WQSP-6 location.

The purpose, nature, and conclusions of the tests performed at H-14 should be restated. First, the purpose of the tests was to try to determine if a water table exists in the lower Dewey Lake Redbeds immediately above the Rustler Formation. The test was never intended to address possible perched water in the Dewey Lake. Second, the tests performed were a drillstem test and a pressure-pulse test. No pump test was performed. Third, the conclusions of the tests were simply that the presence or absence of a water table in the lower Dewey Lake could not be determined from the test data. No conclusions about the presence or absence of perched water at H-14 or any other location were drawn.

Comment ED/92PA-2

Geohydrology of the Dewey Lake.

The Dewey Lake Formation is characterized as a deltaic sequence of alternating, thinly bedded siltstone and mudstone with lenticular interbeds of fine- to coarse-grained sandstone (Mercer, 1983; D'Appolonia 1982b). Mercer (1983) contends that ground water occurs perched or semi-perched in lenticular sands in the upper Dewey Lake. Abundant gypsum-filled veinlets and fractures observed in dry lower portions of the formation suggest several interpretations concerning ground water occurrence in the formation.

- Sulfate-rich water has circulated through the formation at some time in the past (Davies, 1989).
- Water undersaturated with respect to sulfate has not dissolved the gypsum precipitate in the lower unit, and
- Ground water in the formation would most likely occur above the gypsum-filled veinlet zone (in the upper Dewey Lake) (Holt and Powers, 1990).

The zone isolated for the H-14 Dewey Lake hydraulic test was within the lower portion of the formation characterized by gypsum-filled veinlets (SAND89-0202). The zone tested was 30 meters (100 feet) below the deepest onsite occurrences of Dewey Lake ground water.

Response

The DOE agrees with the statement in the bullets. Holt and Powers (1990, section 3.4.4) did note the change in fracture filling from partial, Calcite fillings in the upper part of the Dewey Lake to a depth of 164.5 ft where it changed to the denser, incremental fibrous gypsum filling below that level. They postulate that perched water tables in the Dewey Lake might be held up by the denser fillings below that level. This hypothesis has yet not been tested. However, data from the recently-completed wells at WQSP-6 and the planned testing at that location should help to determine if their idea has merit.

The DOE also agrees with the final comment concerning H-14 tests. If Holt and Powers are correct in their hypothesis, the presence of the gypsum-filled veinlets explain why that part of the Dewey Lake could not be tested. It was probably too impermeable.

Comment ED/92PA-3

Extent of Dewey Lake Ground Water. Mercer (1983) provides a commonly quoted statement suggesting that occurrences of Dewey Lake perched ground water zones are localized and isolated. In fact, on a regional scale, this is probably true. However, the term localized is not well defined, and as demonstrated in the previous discussion, its "localized" nature does not preclude significant occurrence of the aquifer onsite. Furthermore, its localized and isolated character also does not preclude hydraulic connection with off-site zones. The only hydraulic conductivities reported for the Dewey Lake Formation are from packer-permeability tests conducted during the foundation investigation. Given the potential for testing the wrong zone within the Dewey Lake, and the limited areal extent of the foundation investigation, it seems unreasonable to extrapolate this information site wide.

Lambert (1992) has noted meteoric recharge at Ranch Well (Lambert 1992) and Holt and Powers (1990) have suggested recent meteoric rainwater may be responsible for occurrences of moist and wet units described down to 50 meters (165 feet) below the surface in the AIS. NMED/WIPP staff have also observed prodigious amounts of free water seeping in within the Dewey Lake Formation at the Exhaust Shaft. Video surveyors report increased inflow in the Dewey Lake during years of heavy precipitation. The potential for enhanced meteoric recharge in future wetter-cooler climates may increase the size and flow characteristics of the Dewey Lake water-bearing units.

Response

Please provide a reference and documentation from the NMED/WIPP staff supporting your statement that "prodigious amounts of free water" are flowing into the Exhaust Shaft from the Dewey Lake Formation. The DOE acknowledges that condensation

occasionally occurs on the station A instrumentation, but there is no documentation that we know of that moisture is from the Dewey Lake Formation. That portion of the shaft has been lined and grouted, and the last direct inspection showed that the grouting was successful in sealing off the formations above the Salado.

Comment ED/92PA-4

Dewey Lake and Performance Assessment.

Because of its relatively high permeability and regional persistence, the Culebra member of the Rustler Formation has been the focus of migration pathway studies for the WIPP site Performance Assessment. The Dewey Lake Formation has been downplayed, evidently based on limited hydrologic information. Several arguments question the rationale for this decision:

the data reviewed indicate that the Dewey Lake Formation is a ground water resource offsite, although it's characterization as an underground source of drinking water is debatable;

- the areal distribution of the Dewey Lake Formation on-site is uncertain and does not preclude connection of onsite and offsite perched ground water zones; and

- information on water quality, transient recharge and flow characteristics of the Dewey Lake water-bearing zone (s) is nonexistent or not well documented.

Response

See response to ED/92PA-1. The DOE believes that the hydrologic characteristics of the Dewey Lake near the shafts have been adequately characterized. The formation does not yield water and there is no reasonable potential for the Dewey Lake to provide a release pathway.

First bullet: DOE agrees, see comment ED/92PA-1.

Second bullet: The aerial distribution of the Dewey Lake Formation is well known from numerous test borings. It is present and continuous everywhere beneath the site. At the WIPP site the Dewey Lake Redbeds are 476 ft thick and consists of interbedded reddish-brown fine sandstone, siltstone, mudstone, and claystone (Holt and Powers, 1988, section 3.4). The upper part of the unit is indurated and many fractures are filled with calcite. Below 164.5 ft in the AIS, the cement changed to fibrous gypsum, which indicates incremental growth (Holt and Powers, 1990, section 3.4.3). The unit is quite tight and

although no hydrologic tests were performed, rocks of similar composition typically have very low permeabilities.

Third bullet: See response to ED/92PA-1. The Dewey Lake is so dry at the site that it has not been possible to collect water samples. Water from the Barn Well south of the site is quite high in nitrates, probably as a result of contamination from the livestock excrement.

Comment ED/92PA-5

NMED/WIPP staff hope that this transmittal supports and augments the three NMED/WIPP conclusions quoted in Table 1. There are several practical approaches that might address this issue, none of which explicitly involve drilling new wells to respond to this concern:

- If new Sandia research or DOE/WIPP monitoring wells are planned, use air as a circulation media to permit detection of shallow ground water. If a monitoring well is proposed, complete a monitoring zone within the Dewey Lake interval where ground water flow is observed.

- Describe a conceptual hydrologic model of the Dewey Lake Formation, considering potential recharge in future climatic regimes.

- Include or preclude, based on available information, the potential for the Dewey Lake to act as a secondary migration pathway.

Response

New wells for both Westinghouse (WQSP-1 through 6) and Sandia (H-19 b1 through 7) are being drilled using air as the circulation medium. Neutron and television logging will be performed in these wells to try to identify saturated zones within the Dewey Lake. As of October 13, 1994, WQSP holes 1,2,4,5, and 6 have been drilled. No significant moisture in the Dewey Lake Formation was encountered in holes 1,2,4, and 5. Fresh water was encountered in WQSP 6 (Sec. 29, T22S, R31E, 1667 FSL and 1329 FWL) at a depth of 182-208 feet. Water was produced at a rate of approximately 30 gallons per minute for 15 minutes. This well was cased through the Dewey Lake as per the drilling plan. A second well will be drilled at this site and completed in the Dewey Lake to collect water samples and determine the extent of saturation.

Answers to the second and third bullets will come from the three-dimensional modeling program in progress.

Comment ED/92PA-10

The following comment is a ground water monitoring recommendation occurring in "Assessment of Off-Site Radioactivity Surveillance Systems at the Waste Isolation Pilot Plant" (NMED/WIPP 93-002):

> "Current Magenta observation wells are located outside potential contaminant migration pathways. Although the Magenta is not considered in formal risk analyses conducted in support of the Performance Assessment, a ground water monitoring system may require consideration of the potential for contamination of this water-bearing zone. Some investigators have suggested that leakage downward from the Magenta Formation may be a component of recharge for the Culebra water-bearing unit (Mercer, 1983; Seigel et al., 1991). The groundwater radiological baseline could be improved by sampling the Magenta water-bearing zone in the potential contaminant flow path and closer to the western boundary of Zone II (extent of underground excavation)."

This recommendation occurs within the context of environmental monitoring, in which all "potential pathways" are monitored. This is a main theme of EPA's RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (TEGD). The comment seems pertinent to developing a contaminant migration model for PA analyses.

Response

Supra-Salado rock flow properties may be important to facility performance, therefore a strategy aimed at characterizing and measuring these properties over a relatively short time period may be beneficial.

Comment ED/92PA-11

A variety of human-initiated factors, including the quality of borehole completion and abandonment, are proposed as causes for a collapse feature located about 100 miles southeast of WIPP in Texas (Johnson, 1987). In that case, abandoned boreholes evidently provided a pathway through which shallow ground water infiltrated and dissolved Salado salt. This dissolution led to the formation of a cavity and collapse of overlying strata. The development of the War Wink Sink is described in the following article:

K. Johnson, 1987, "*Development of Wink Sink in west Texas due to salt dissolution and collapse*"; 2nd Multidisciplinary Conference on Sinkholes/Orlando; p. 127-136.

There are twenty-eight drill pads with 44 wells within the WIPP land-withdrawal area. Most WIPP-related wells are used for site characterization. Only two penetrate to great depth near the facility, including DOE-1 drilled to 4065 feet and ERDA-9 drilled to 2889 feet. Seven resource exploration boreholes are also located within the site boundary, including oil wells Badger Unit (Section 15) and Cotton Baby (Section 24). Abandoned and sealed during the 1970's, only Badger Unit and Cotton Baby penetrate the entire evaporite sequence. Although there are important differences between the WIPP site location and War Wink Sink, substantial similarities warrant consideration of borehole-induced solution subsidence as a potential PA scenario process. The 1992 preliminary performance assessment considers only collapse of the repository opening and shafts as a human-induced subsidence process.

Response

The DOE agrees with the observations and fails to see any reason for concern. The situation at the WIPP is far different than that of the Wink Sink. For further explanations, please refer to the response to ED/92PA-12.

Comment ED/92PA-12

Supply of Water Undersaturated with Respect to Soluble Evaporates Present at Depth. At the Wink Sink, Dewey Lake and Santa Rosa water bearing zones are proposed as sources of undersaturated ground water. Other potential sources include ponds holding oil field brine and possibly fresh water used as circulation media. Ground water undersaturated with respect to salt also exists at the WIPP site in the Dewey Lake Formation. Whereas the War Wink Sink is an example of accelerated subsidence on a short-time frame, the subsidence/dissolution issue at the WIPP is a much longer-term concern. An increase of 4 or 5 inches/year in average annual precipitation possible during the next 10,000 years may provide an increased source of undersaturated ground water. An increase in precipitation increases the possibility for meteoric water to infiltrate pathways created by boreholes. At present, long-term climatic variability is incorporated only into projections for ground water recharge to the Culebra.

Obviously soluble evaporates exist at the WIPP site and are susceptible to dissolution. The potential for natural deep-dissolution has been addressed in great detail and characterized as physically unreasonable in the 1992 PA analysis. A review of the PA analyses and Sandia reports, however, suggests that artificial causes of solution-subsidence have not been considered. Because they are relevant to borehole-induced subsidence, conclusions regarding natural solution-subsidence are summarized:

- Breccia chimney formation, a natural solution-subsidence structure, is associated exclusively with the Capitan aquifer (Snyder and Gard, 1982). Such structures are believed to result from the collapse of overlying strata into cavities formed in the

Capitan Limestone. The Capitan aquifer does not underlie the WIPP site and there are no examples of breccia features in the vicinity of the WIPP. Consequently, there is only a remote probability of a breccia chimney forming under the facility site.

- Ochoan evaporite deposits in the WIPP area and the northern Delaware Basin have undergone blanket dissolution. Along the western margin of the basin west of the WIPP, dissolution breccia indicates massive removal of the Salado Formation. Within two miles west of the WIPP site is Nash Draw, a dissolution feature cased by removal of the Salado and soluble beds of the Rustler Formation. Assuming the process of dissolution is an advancing front moving toward the WIPP site, there is general agreement that the rate of movement is slow enough to provide an adequate safety factor.

- Anderson (1981) proposed that deep-seated dissolution of Ochoan evaporates has not only occurred over the Capitan aquifer, but also within the basin where selective dissolution in the lower Salado has undercut overlying salt beds. Eight boreholes drilled near the WIPP facility, however, did not show any evidence of extensive dissolution predicted Anderson's model. There is general agreement that this proposed process of natural dissolution will not affect the WIPP repository.

Response

The DOE agrees with these comments and fails to see any reason that natural solution-subsidence is a realistic concern. The situation at the WIPP is far different than that at the site of the Wink Sink.

Bullet 1. The DOE agrees. Breccia chimneys have been discussed in detail elsewhere, and since the WIPP is not over the Capitan Reef, there is no reasonable expectation that such a feature will form at the WIPP.

Bullet 2. The DOE agrees.

Bullet 3. The DOE agrees.

An additional point is that at Wink Sink, there is an overlying fresh-water aquifer in the Triassic Santa Rosa Sandstone that can supply copious amounts of fresh-water to an improperly completed or abandoned drillhole. An oil well drilled in 1928 is located in the middle of the Wink Sink. It was abandoned in 1964, at which time 600 feet of casing was removed. The sink subsequently collapsed in 1980. (Ref.: Baumgardner, B. W., Jr., 1988) Although other scenarios have been proposed, it seems most likely that fresh-water from the Santa Rosa Sandstone flowed down into the salt through the open,

abandoned, drill hole and dissolved the salt to form a large chamber which subsequently collapsed.

No such aquifer exist at the WIPP. Additionally, the fact that the brine pocket in the Castile are maintained at pressures higher than those in the Bell Canyon show that there is no naturally-existing connection between the units in the vicinity of the WIPP which might allow alternative "density current" models proposed to explain Wink Sink to operate.

The DOE also does not feel that artificial causes of solution subsidence are reasonable concerns. There is the potential for small amounts of fluid flow to occur if a man-made connection were made between the Bell Canyon, Salado, and/or the Culebra (Lappin, 1988, Section 2), but this would require a deliberately-created open hole or improperly abandoned hole. For solution to occur in the halite beneath the repository, such a drillhole would have to be through or in the immediate vicinity of the waste storage panels. No such drillholes exist today. The closest well that penetrates the entire evaporate sequence is Badger unit in Section 15, is approximately 2 miles from the WIPP storage panels.

Comment ED/92PA-13

Outlet (Sink) for Dissolved Salts.

At the Wink Sink, the Salado is underlain by the Tansill, Yates and the Capitan sequence, formations that contain numerous vugs and solution cavities for brine to migrate. Fractured, degraded cement and corroded iron well casing are believed to have provided a migration pathway for dissolved salts to reach the permeable and porous pre-Salado strata. The WIPP site is located 17 km (10 miles) from the subsurface extent of the Capitan Reef. Similar to arguments against breccia pipe formation, this suggests a low potential for borehole-induced solution-subsidence. However, conditions for a sink, or outlet, for dissolved solutes may exist under the WIPP site. Zones of porosity are created in the Bell Canyon Formation during primary withdrawal of oil, and could be enhanced by future hydrofracing or secondary/tertiary oil recovery activities. Lateral migration through pre-existing anhydrite dissolution features in the Castile or Salado also provide a possible sink for the brine.

Response

The concern that downward flow into the Bell Canyon Formation could cause catastrophic collapse as occurred at Wink Sink does not seem to be reasonable. There is no source of copious amounts of fresh water above the Salado, as there was at Wink Sink. There is a potential for small amounts of fluid flow to occur if a man-made connection were made between the Bell Canyon, Salado, and/or the Culebra, but this

would require a deliberately-created open hole or improperly abandoned hole. For dissolution to occur in the halite beneath the waste storage panels and create the potential for collapse that might breach the repository, such as a drill hole would have to be through the immediate vicinity of the waste storage panels. No such drillholes exist today. The fact that the brine pockets in the Castile are maintained at pressures higher than those in the Bell Canyon show that there is no naturally-existing connection between the units in the vicinity of the WIPP. The fact also shows that there is also no lateral pathway for fluid flow in the Castile.

Reference

Lappin, A. R., 1988, *Summary of Site-Characterization Studies Conducted From 1983 Through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico*, SAND88-0157. Albuquerque, NM: Sandia National Laboratories.

Comment ED/92PA-14

Energy-Hydrostatic Head or Density Gradient.

A mechanism is required to drive shallow freshwater downward through the salt and the resulting brine into underlying pre-Salado strata. At the Wink Sink, the hydraulic head of the Santa Rosa Formation provides such a mechanism. Hydraulic heads of the Tansill, Yates and Capitan Formation are all lower than the Santa Rosa, suggesting downward flow would be initiated if the shallow and deep aquifers were connected. To determine whether a similar condition exists at the WIPP, Dewey Lake and Bell Canyon hydraulic heads and solution density within the boreholes would need to be considered. Brinster (1991) cites Lappin (1988) as concluding that vertical flow would be downward if the Culebra and Bell Canyon were connected by a borehole. This conclusion is contrary to the vertical flow potential if one only considered a comparison of fresh-water equivalent heads.

Response

Also see response to ED/92PA-12

Vertical flow is controlled by actual hydraulic heads and fluid densities, not by equivalent freshwater heads. If density effects, including probable dissolution of halite that would occur in an open borehole, are taken into account, flow between the Rustler or higher formations and the Bell Canyon would be downward in an open borehole (Beauheim, 1986).

Reference

Beauheim, R.L., 1986. *Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site.* SAND86-1364. Albuquerque, NM: Sandia National Laboratories.

Comment ED/92-PA15

Conduits for Migration of Dissolved Solids.

Upward of 100 boreholes are completed inside or within the one-mile boundary of the WIPP Land withdrawal boundary, including 46 offsite oil and gas wells, 44 onsite WIPP-related boreholes and seven onsite resource exploration boreholes. Most were drilled, completed and plugged using standard oil field practices, including sulfate-resistant cement and corrodible iron-casing. Deep boreholes penetrating the Salado, Castile, or Bell Canyon formations would more likely impact the repository horizon. ERDA-9, DOE-1, Badger Unit and Cotton Baby satisfy such criteria. How these onsite boreholes will perform, and how the multitude of other production wells adjacent to the WIPP boundary will interact on a 10,000 year time frame are underlying issues. Over the long-term, the presence of these wells might influence, to some degree, the current geologic stability of the site.

Response

Possible groundwater flow and radionuclide transport through boreholes that do not directly intersect the waste-emplacement panels are retained for further consideration in the scenario development process.

Comment ED/92PA-16

Extent of Possible Subsurface and Surface Disruption.

The surface expression of the Wink Sink measures 110 m (360 ft) in width and 34 m (110 ft) in depth. Presumably, dissolution occurred over the entire Salado stratigraphic sequence between 396 (1,300) to 655 m (2,150 ft) below the surface. However, the actual size of the cavity causing the collapse is not reported. Based on the size of the surface expression of the Wink Sink, it appears only ERDA-9 could impact the facility. In addition, no wells within roughly 1.5 miles of the facility penetrate the Bell Canyon Formation. This may constrain the size of the disturbed zone to the volume of brine accessible to pre-existing anhydrite dissolution features in the Castile or Salado. In this case, important parameters such as the cavity size and depth of the cavity would be

controlled by the degree of interconnection between boreholes provided by dissolution features.

Response

ERDA-9 was drilled into the top of the Castile Formation at 2,889 feet. It has since been doubled cased, with 10 3/4 inch outer steel casing and, inside of that, a 7 in steel casing. Additionally, the lower 350 ft has been filled with cement, to a depth of about 2,540 ft. There is no source for copious amounts of freshwater to enter ERDA-9. In addition to the 350 ft of cement in the hole, the Castile Formation effectively prevents any downward flow from ERDA-9 to the Bell Canyon. The DOE feels there is no reasonable expectation that ERDA-9 could cause the development of a Wink Sink type feature.

Comment ED/92PA-17

Subsidence Potential: Oil Withdrawal

No discussion occurs in the 1992 preliminary performance assessment concerning the rationale for dismissing surface subsidence caused by withdrawal of oil and gas. The 1991 preliminary comparison, however, succinctly states an NMED concern:

> "Areas where oil and gas are withdrawn have the potential of surface subsidence in response to the removal of the confined fluid that supports some of the weight of the overburden" (SAND89-0893/1, page 4-37) [the reference should be to SAND91-0893/1].

There are several inaccurate statements on page 4-38 of SAND91-0893/1 that have precipitated NMED comment to the Performance Assessment Group on this issue:

> "Natural gas in the Morrow Formation was concluded to be the only possible hydrocarbon resource with economic potential in the area" (Keesey, 1976, 1979).
>
> "Because of the depth and rigidity of the possible production horizons, subsidence would not be expected to occur if gas (if present) was removed" (Brausch et al., 1982).

In regard to the potential for subsidence from oil and gas production activities, Brausch et al. 1982 (TME 3156) acknowledges that the "...withdrawal of hydrocarbons from reservoir horizons (from wells adjacent to WIPP boundary) could, theoretically, lead to subsidence at the WIPP site...(although) such subsidence is not typically associated with

gas production" (TME 3156). As most wells along the WIPP boundary are oil wells producing from the Delaware Mountain Group, this argument is erroneous. Furthermore, considering that oil is currently a viable resource in the area, and specifically adjacent to the WIPP boundary, Keesey's reference seems outdated.

Having reviewed TME 3156 (Brausch et al., 1982) and other subsidence issues on other projects, NMED/WIPP staff believe that the case against subsidence is not adequately covered in TME 3156 or the 1991 performance assessment. There may be some validity for emphasizing the rigidity of the overlying strata as an argument against oil withdrawal subsidence; however, this suggestion is not referenced in TME 3156 (p. 52). TME 3156 analyzes subsidence events related to potash extraction activities insufficient detail, but provides only a brief paragraph on subsidence related to extraction of oil and gas. Additional analyses would require characterization of the area of potential withdrawal zones, the potential for consolidation of these zones, and the rheological properties, thickness and span of strata overlying hydrocarbon resource zones.

Response

The project acknowledges that screening arguments must be updated to reflect recent oil exploration activity in the WIPP area.

Subsidence related to oil and gas extraction will be considered in the scenario development process.

The DOE acknowledges that screening arguments must be updated to reflect recent oil development activity in the WIPP area.

Appendix A EEG Supportive Figures

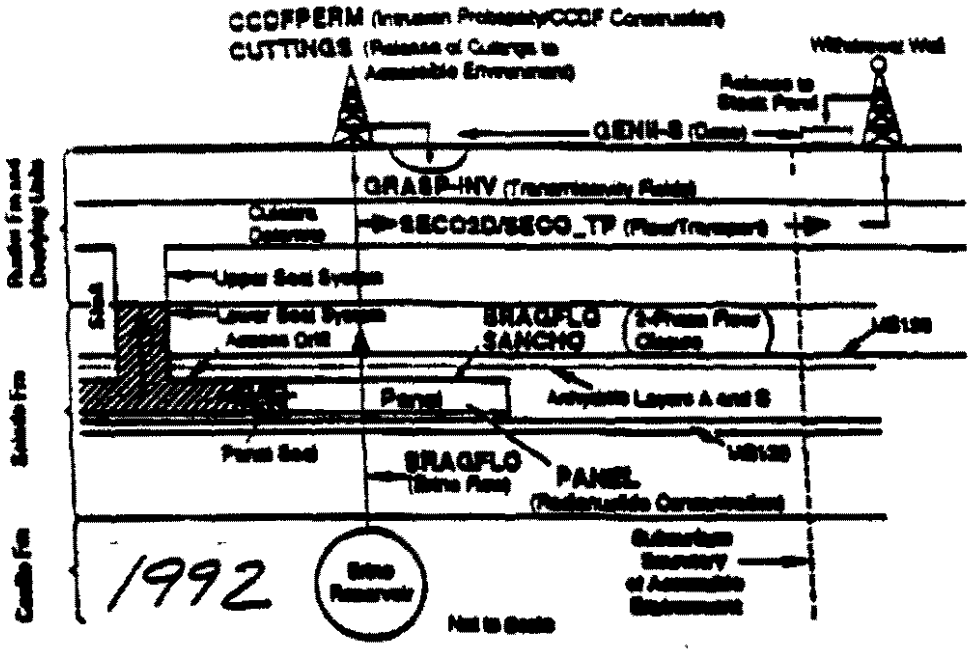

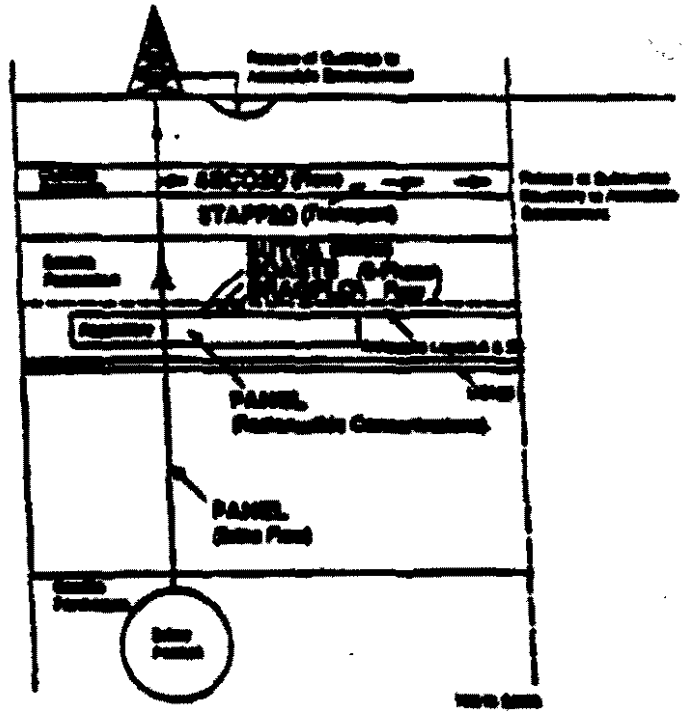

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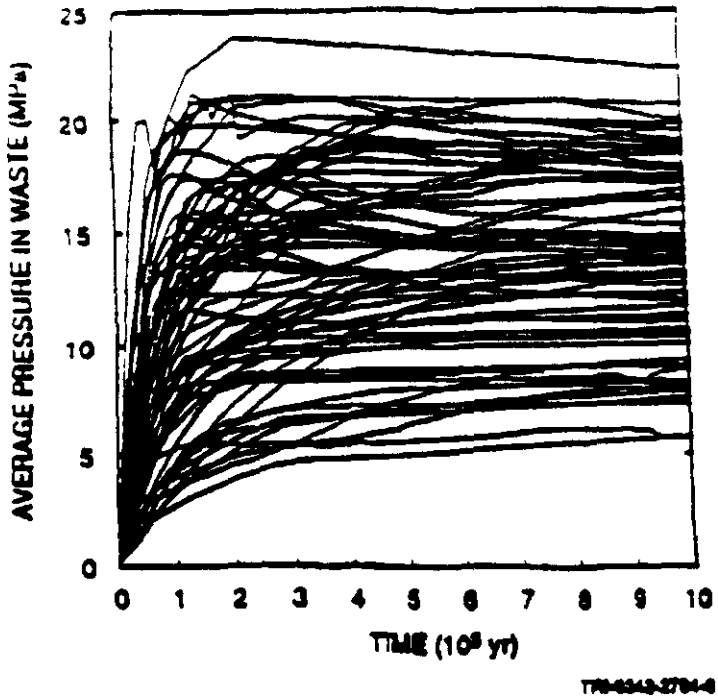

Figure 4-1. Volume Average Pressure in the Waste Repository.

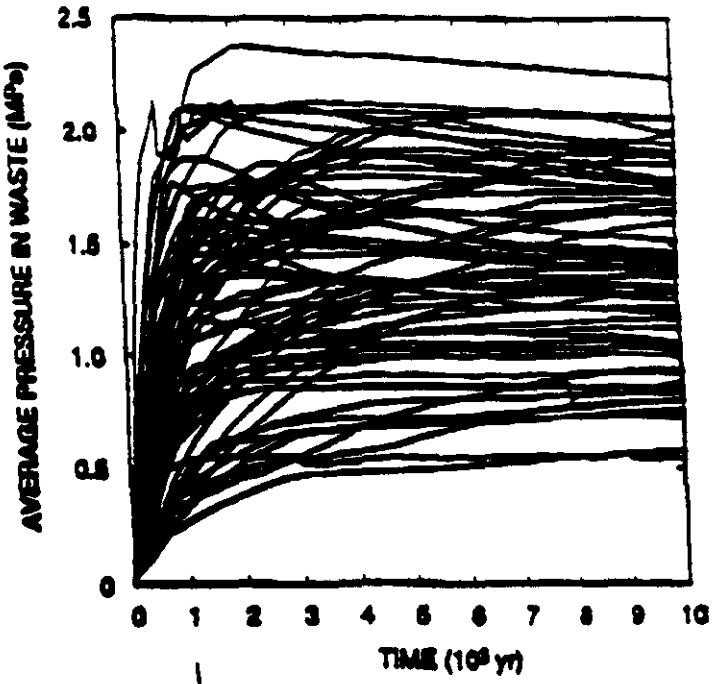

Figure 4-32.

Volume Average Pressure in the Waste Repository, Single Shaft Mo

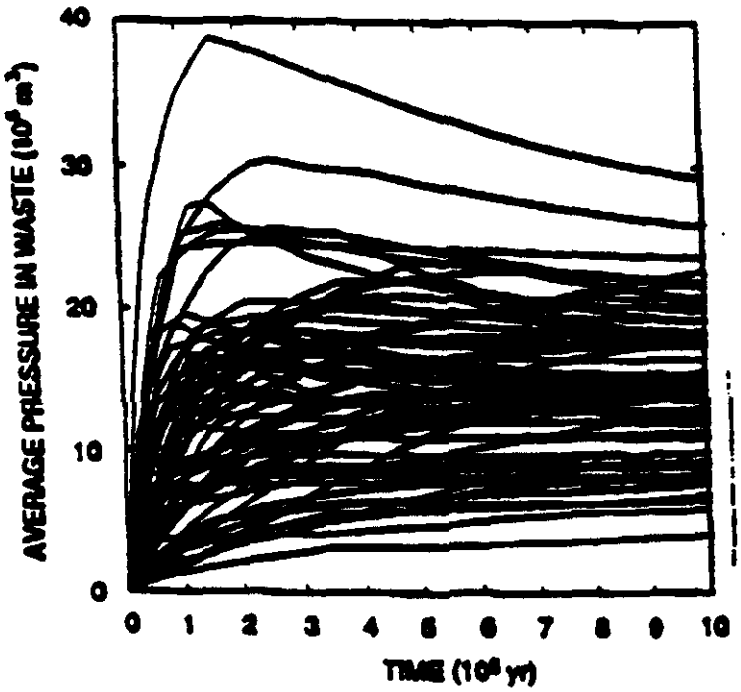

Figure 4-39.

Volume Average Pressure in the Waste Repository, Fixed Waste Porosity Model.

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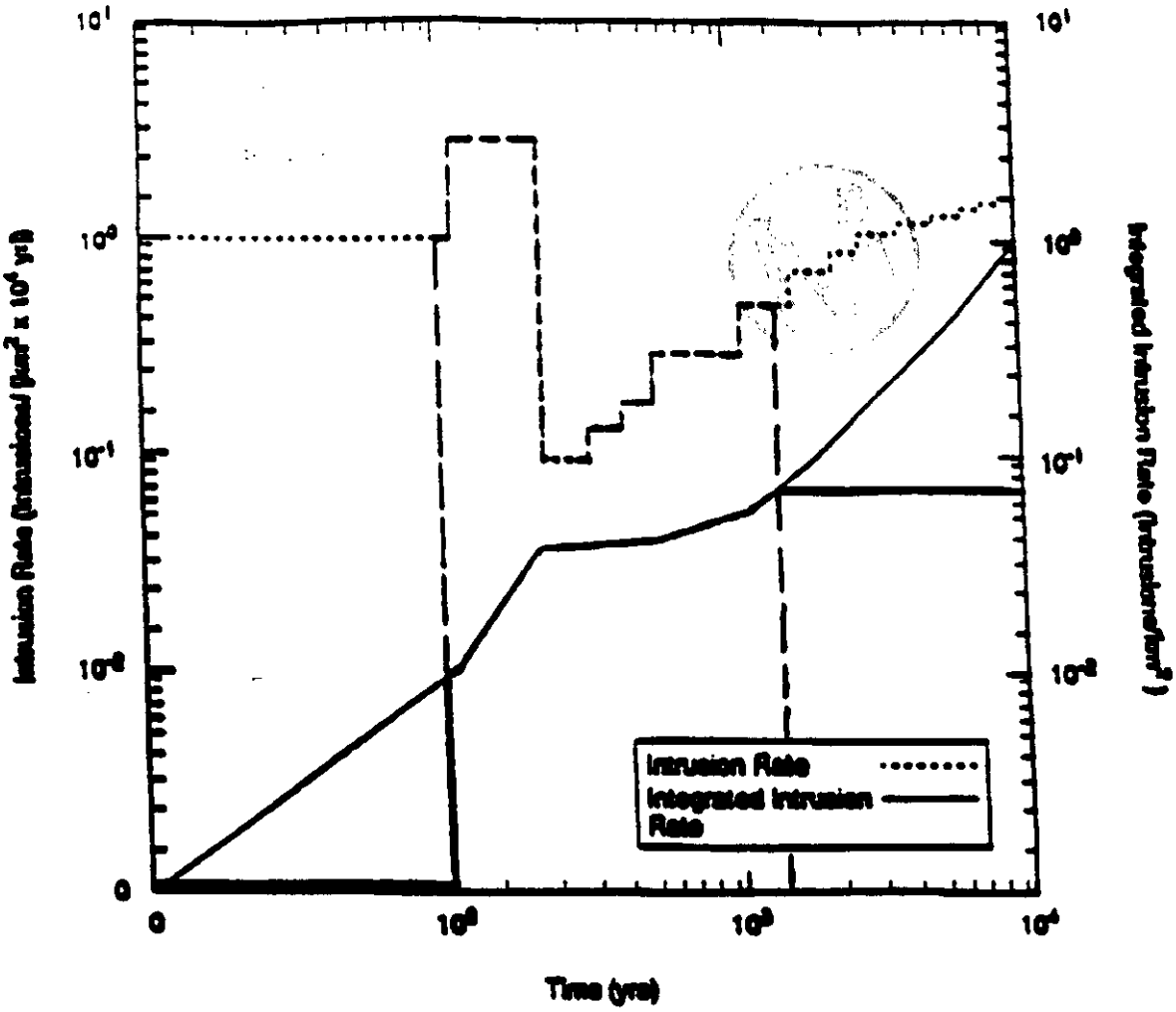

Figure 2.3-1. Example time-dependent rate term used in Poisson model for drilling intrusions in the 1992 WIPP performance assessment (Volume 3, Appendix D, Figure D-43). The rate $\lambda(t)$ as used in this chapter has units of yr^{-1} and is obtained by multiplying the rate indicated in this figure by 0.126 km^2 (i.e., the area of emplaced waste) and performing the indicated division by 10^4; further, $\lambda(t)$ is set to zero for the first 100 yrs when 100 yrs of administrative control is assumed. The rate $\lambda(t)$ was a sampled variable in the 1992 WIPP performance assessment; this figure shows the drilling rate with the largest integrated value (i.e., expected number of drilling intrusions) over 10,000 yr. In this and other similar figures, a hyperbolic sine transformation is used to generate the scales on the abscissa and ordinate; this transformation allows the plotting of zero, which is not possible when a logarithmic transformation is used.

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EEG Figure for Comment S-1

Table II. CASTILE BRINE RESERVOIR INTERACTIONS IN WIPP AREA

Name of Well	Date Drilled	Initial Flow bbl/day	Remedial Action
Mascho-1	1937	8,000	No action to stop flow.
Mascho-2	1938	3,000	No action to stop flow.
Culbertson-1	1945		3,000 barrels estimated to flow to surface. No record of flow rate or duration.
Tidewater	1962	NA	12 pound/gallon drilling mud did not stop. Finally controled by casing and cementing.
Shell	1964	20,000	Allowed to flow until artesian flow ceased.
Belco	1974	12,000	Brine flowed to surface for 26 hours with 14 pound/gallon drilling mud.
Gulf	1975	5,000	No records on total volume or duration of artesian flow.
ERDA-6	1975	660	WIPP hole. Estimate 19,000 barrels could be produced by artesian flow.
Pogo	1979	1,440	Initial flow was after 14.6 pound per gallon drilling mud had been added. Stopped after 4 days with 15 pound per gallon mud.
WIPP-12	1981	12,000	WIPP borehole. Over 79,000 barrels produced. Estimate 350,000 barrels producible by artesian flow.

Table II References

- U.S. Department of Energy, 1981a. *Brine Pocket Occurrences in the Castile Formation, southeastern New Mexico*, TME-3080.
- U.S. Department of Energy, 1983. *Brine Reservoirs in the Castile Formation, Southeastern New Mexico*, TME-3153.
- R. H. Neill et al., 1983. *Evaluation of the Suitability of the WIPP Site*. SEG-23.

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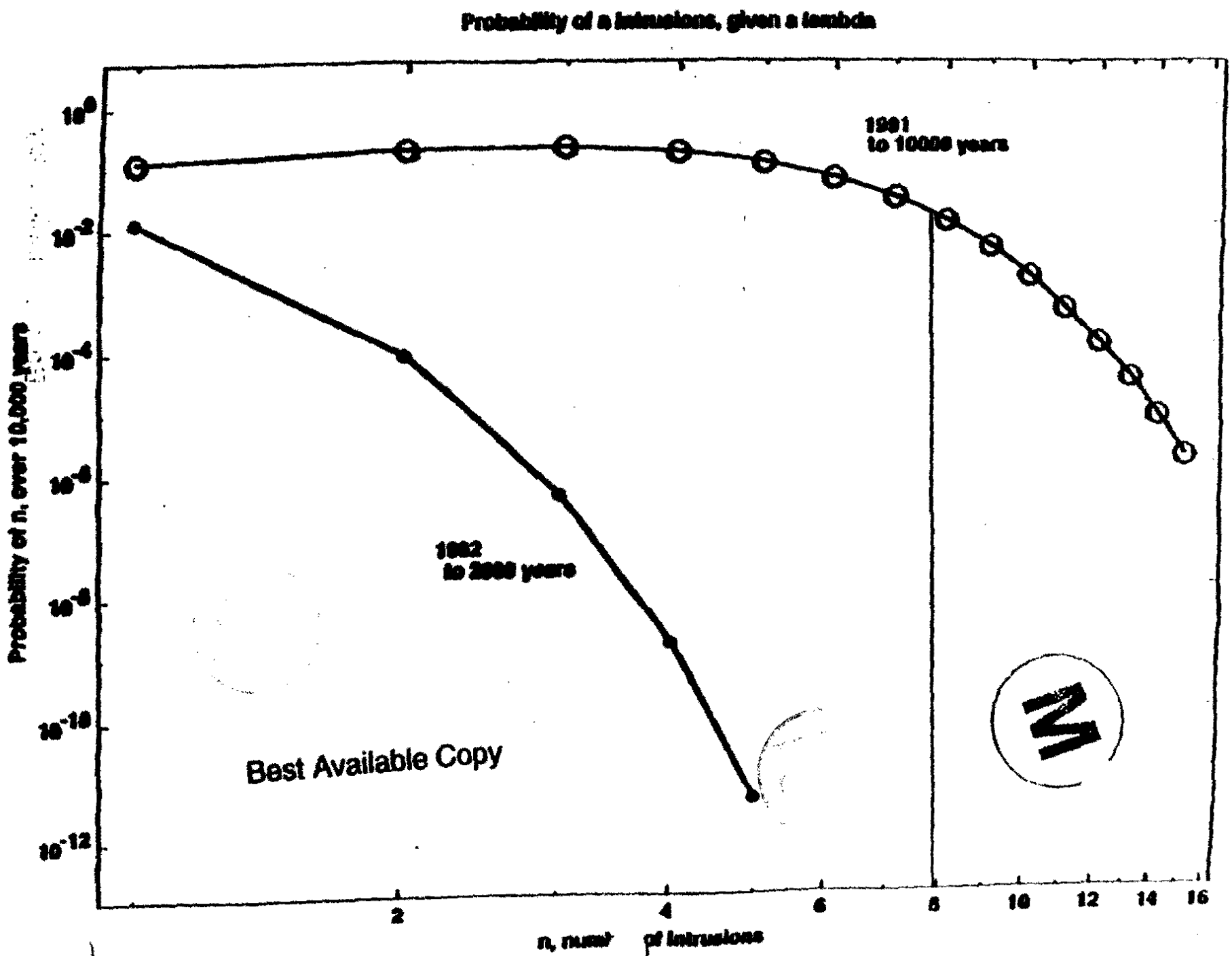

See figure for comment p-2

Appendix B NMAG Supportive Memos

NMAG Supportive Memos for AG-8b

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: April 14, 1994

to: B. M. Butcher, 6345 (MS 1341)

from: J. Guadalupe Argüello and C. M. Stone, 1561

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subject: Corrections to Errata in Memo Entitled: "Performance Assessment Verification Calculations - Revised SANCHO Calculation for Comparison With BRAGFLO Run #63"

As a result of a typographical error, Equation 13 of the subject memorandum [1] is incorrect. We are in complete agreement with Vaughn [2] that Equation 13 should have read as follows:

$$\varphi = \frac{\left[\dfrac{(1-SBAVW)\,PORVOLW}{12.65}\right]}{\left[\dfrac{PORVOLW}{12.65} + 1229\right]}$$

Unfortunately, the error was propagated into the manipulation of the BRAGFLO results used to generate the curve labelled "BRAGFLO" in Figure 5 of the same memo. Consequently, the corrected "BRAGFLO" curve (along with the old one) is shown below.

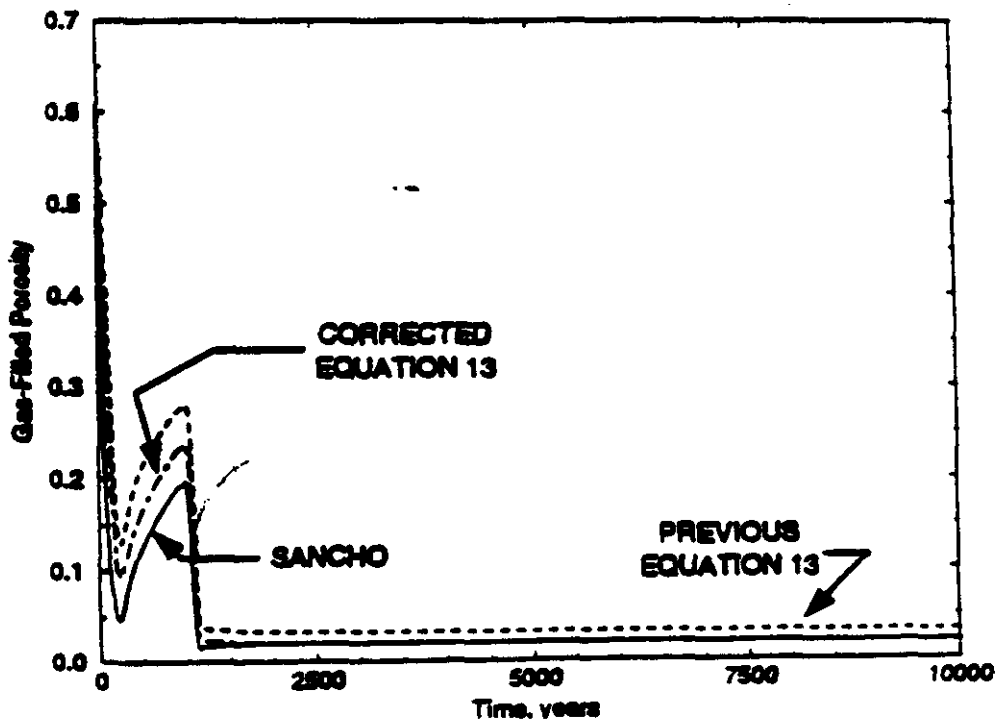

As a result of the corrected manipulations of the BRAGFLO quantities, much better agreement of porosity predictions between BRAGFLO and SANCHO is apparent at later times. Nonetheless, the general conclusion of the memo [1], that there still remain differences between SANCHO and BRAGFLO, remains unchanged. For example, at the local maximum which occurs at about 1000 years, we see that the BRAGFLO porosity results are about 25 % greater than those from SANCHO. Furthermore, because the pressure predictions are unaffected by Equation 13, the difference in pressure predictions between the two codes, as originally discussed in Reference 1, remains as well.

We strongly support the suggestion [2] of a meeting where everyone can get a better understanding of what was done in both codes so that we can reach closure on the issue of the discrepancies between the results.

References

1. Argüello, J. G. and C. M. Stone, "Performance Assessment Verification Calculations – Revised SANCHO Calculation For Comparison With BRAGFLO Run #63," Memorandum to B. M. Butcher, 6345, Sandia National Laboratories, Albuquerque, New Mexico, January 20, 1994.

2. Vaughn, P., "Comments on Argüello and Stone Memo dtd 1/20/94 Concerning Verification of Porosity Surface Under High Brine Saturation Conditions," Memorandum to B. M. Butcher, 6345, Sandia National Laboratories, Albuquerque, New Mexico, March 18, 1994.

JGA:1561

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MS0443	1561	J. G. Argüello

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: January 20, 1994

to: B. M. Butcher, 6345 (MS1341)

J. Arguello CM Stone

from: J. Guadalupe Arguello and C. M. Stone, 1561

subject: Performance Assessment Verification Calculations – Revised SANCHO Calculation For Comparison With BRAGFLO Run #63

Introduction

Performance assessment (PA) of the Waste Isolation Pilot Plant (WIPP) requires that numerous scenarios be investigated to determine if compliance is achievable. This leads to a very large number of analyses that need to be performed during the course of the investigations. Because of the large number of analyses required, the numerical models used by PA must be fast and efficient and consequently contain less detail, in terms of computed disposal room closure, than would be ideal. The reason for this is that the complexity of salt creep and the compute-intensive analyses required to determine its response make it prohibitive to directly calculate disposal room closure in PA analyses at this time. Yet, the effects of disposal room closure must be included in PA compliance analyses. Therefore, detailed disposal room creep closure calculations are typically performed using separate large, complex, nonlinear finite element based codes that are fast and efficient, in their own right, but on a different scale. The calculational results from disposal room creep closure analyses must then be recast in a form suitable for use in PA compliance analyses. The process is as follows:

1) First, a set of disposal room creep closure calculations using a finite element code (e. g., SANCHO or SANTOS) is performed for several discrete values of gas generation (leading to number of moles of gas versus time) and a set of corresponding room porosity histories (room porosity versus time) is obtained for those discrete values.

2) From those results, a "porosity" surface is defined that provides the porosity of a single WIPP disposal room as a function of the number of moles of gas present (or the pressure resulting from that amount of gas) and time.

3) This concept of a "porosity" surface is then used by the PA compliance analysis code (BRAGFLO). The results from the first step are used directly as input to the code; it then interpolates to determine the porosity (in a panel or the repository) as a function of time for any arbitrary gas generation (or pressure) path, accounting for the influence of brine saturation. In this manner, the effects of disposal room closure are indirectly accounted for in the PA calculation.

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The recasting of the finite element analysis disposal room creep closure results into a form suitable for input to PA requires a number of simplifying steps and assumptions, all of which have the potential of introducing uncertainty into the results.

A method for checking the validity of the procedure was previously examined at the request of the project [1]. The method began by recovering data on the variation in gas content and porosity with time in the waste/backfill region of a disposal room from a performance assessment compliance calculation, in which the effects of disposal room closure had been included indirectly via the concept of a "porosity surface"[2]. This surface was derived from the results of several earlier analyses [3] using the gas generation rates and other details defining the Baseline room model [4]. The gas-versus-time data from the compliance calculation was then used as an input gas generation history for a disposal room closure calculation using the SANCHO [5] code to compute the porosity of the room as a function of time. The porosity history obtained from SANCHO was then compared with the original porosity history recovered from the PA calculation. The difference between the two porosity histories represented translation error, and differences arising from the various assumptions and simplifications.

Three cases, designated as runs 18, 42, and 63, from PA's 1992 compliance analysis were investigated in that study [1]. Run #18 represented a human intrusion into a practically dry (low brine saturation) panel; Run #42 was for an undisturbed, practically dry, repository; and Run #63 represented a human intrusion into a panel that became largely brine saturated later in time. Satisfactory agreement was observed between the performance assessment porosity histories and the more detailed histories computed with SANCHO for repository environments with low brine saturations. Results differed, however, for the third case (Run #63) when saturation of the panel occurred. It was suspected that the discrepancy for the third case could be due to the assumption in the SANCHO calculations, that all void volume in the room is occupied by gas (this assumption had always been used, even in the original calculations used to generate the porosity surface), whereas the BRAGFLO calculations explicitly included brine saturation. The details of how this is done in the BRAGFLO calculations are not known to the authors; consequently, it is difficult to comment on how consistent the method of doing so is with the assumptions used in generating the original porosity surface. The purpose of the present investigation is to revisit this third case, adjusting the void volume this time to account for the presence of the brine. A SANCHO calculation has thus been performed in which the void volume in the room, at any time, is reduced by the volume of brine in the room at that time, as computed by BRAGFLO.

This memo thus serves to document the results of a disposal room closure analysis performed with SANCHO using gas-versus-time, *and brine-versus-time*, information from Run #63 of the performance assessment calculations previously performed with the BRAGFLO code. The PA Run #63 BRAGFLO case, and its corresponding computed gas history and brine volume history (used as input to the SANCHO calculations) are briefly described in the next section of the memo. The disposal room geomechanical model used for the SANCHO computation is then discussed. The results from the analysis are then presented, and the porosity histories obtained from SANCHO are compared to those from

the original BRAGFLO runs. Finally, comments on the validity of using "porosity surfaces" in PA analyses are offered for consideration.

Description of PA Run #63 Case

The BRAGFLO results for Run #63 were transmitted to organization 1561 by B. M. Butcher, 6345 using data provided by Jim Bean, 6342. The transmitted information is included in tabular form in Appendix I. Once again, the results in Table I of Appendix I represent a human intrusion into a panel that becomes largely brine saturated.

The information from these tables used as input to the SANCHO calculation was that labelled "GASVOLW," "SBAVW," and "PORVOLW." As indicated in Appendix I, the information in the column labelled "GASVOLW" is the gas volume in the waste – at the corresponding time – in cubic meters at a pressure, P=101325 Pa, and at a temperature,T=300.15 °K. The information in the column labelled "SBAVW" is the average brine saturation in the waste, while that in the column labelled "PORVOLW" is the waste pore volume (gas and brine) in cubic meters computed with BRAGFLO. By using the Ideal Gas Law,

$$PV = nRT, \qquad \text{(EQ 1)}$$

where P is the pressure in Pascals, V is the volume in cubic meters, R is the universal gas constant, and T is the temperature in degrees Kelvin, the number of moles of gas, n, with time was computed. This quantity of moles of gas was divided by 12.65 rooms per panel to get an "equivalent room" value for use in the SANCHO disposal room model. The information was written to a file that was subsequently read by SANCHO during the disposal room closure calculation. The resulting equivalent room gas content history that was written to the file is shown in Figure 1. By multiplying the quantity "SBAVW" by "PORVOLW," the brine volume with time was also computed. This quantity was again divided by 12.65 rooms per panel to get an equivalent room value and was written to a file for use in the SANCHO computation. The resulting equivalent room brine volume history that was written to the file is shown in Figure 2.

Geomechanical Model

A two-dimensional plane strain disposal room model, as shown in Figure 3, was used for the SANCHO analysis. This same model was used for the Baseline calculations described by Stone in his October 6, 1992 memorandum [3]. The model represents the room as one in an infinite array of disposal rooms located at the repository horizon. Consequently, symmetry boundary conditions are applicable between rooms. If it is further assumed that gravity forces do not greatly affect the material response near the room [6] and that the stratigraphy is all-salt, use can be made of vertical symmetry boundary conditions to arrive at the quarter-symmetry model shown in the figure. The model contains 618 elements and 664 nodal points. A zero-displacement boundary condition in the horizontal direction was

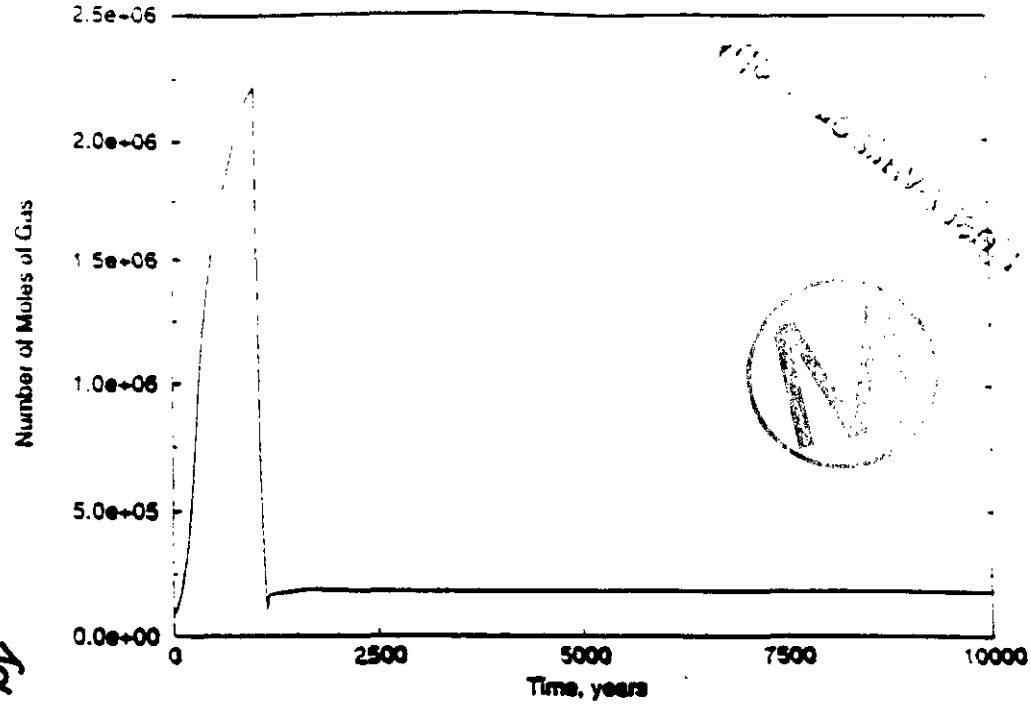

Figure 1. Equivalent Room Gas Content History From BRAGFLO Run #63

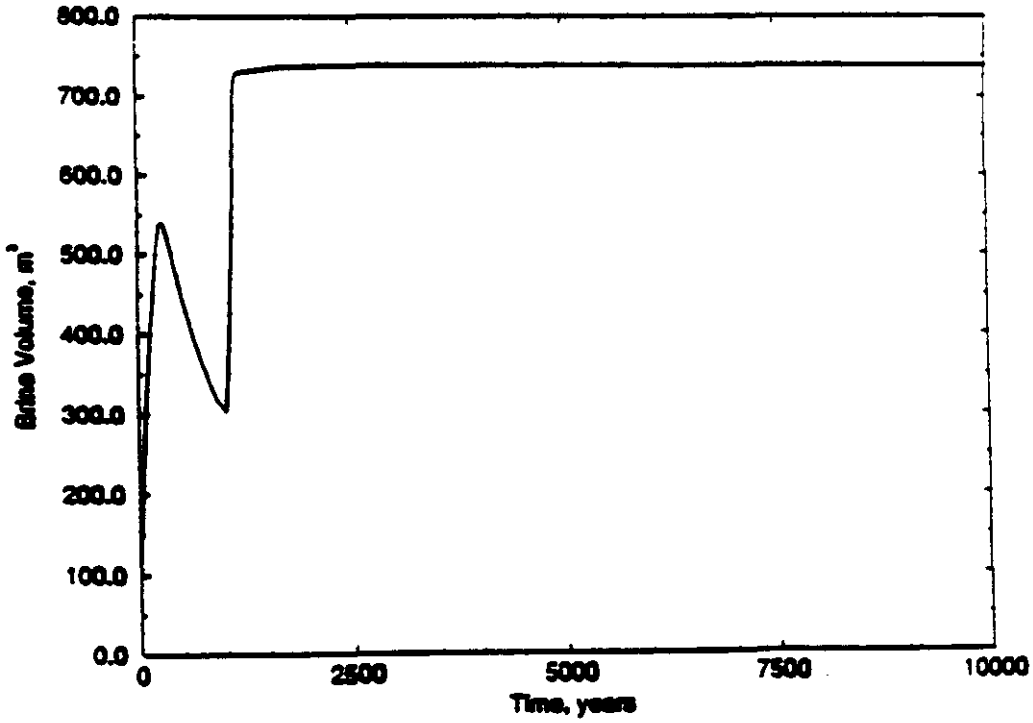

Figure 2. Equivalent Room Brine Volume History From BRAGFLO Run #63

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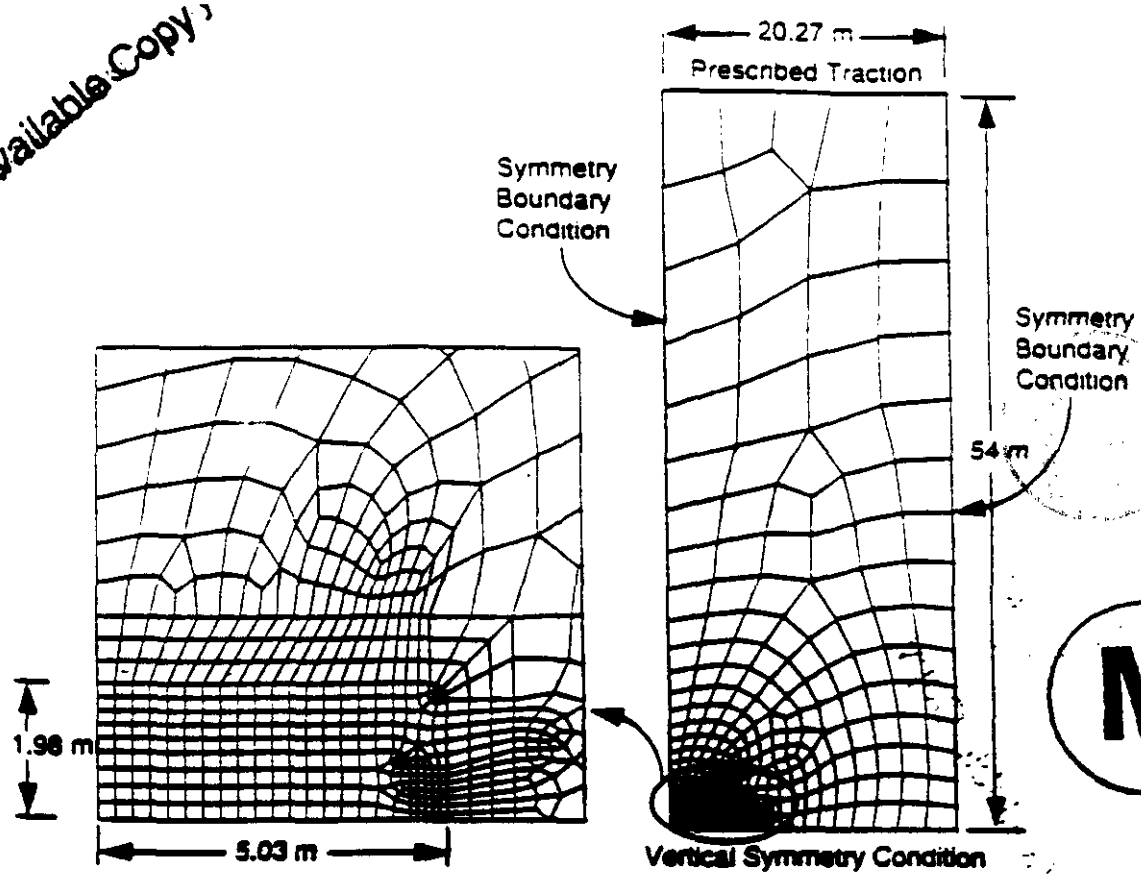

Figure 3. Finite Element Mesh and Boundary Condition Used in SANCHO Analyses

applied on both the left and right boundaries of the model. A zero-displacement boundary condition in the vertical direction was also applied on the lower boundary. A prescribed normal compressive traction of 14.8 MPa was applied on the upper boundary to simulate the overburden load at the repository horizon. Within the room, a pressure $P = (nRT)/V$, was applied along the room boundary. In this case, n was the current number of moles of gas in the room, interpolated from the external file of gas content history, and V was the current void volume in the room reduced by the current brine volume, interpolated from the external file of brine volume history.

As indicated in the idealization of Figure 3, the quarter-room dimensions are 1.98 m high by 5.03 m wide. Within the room is material representing the waste, the crushed salt backfill, and the headspace. The volume of the waste and drums is 1663 m^3 distributed along the 91.44 m length of the room. This results in a nominal cross-sectional area of waste of 18.19 m^2. For the quarter-symmetry room, this translates to a height of 1.01 m and a width of 4.5 m. The remainder of the disposal room volume was filled with crushed salt backfill having a porosity of 0.4. The disposal room volume corresponding to the headspace, 653 m^3, was discretized as though it was crushed salt, and special capabilities previously added to SANCHO [3] were used to model this region and its response. In

essence, the crushed salt material representing the headspace was modeled as a very low modulus, elastic material until the disposal room volume had decreased by 653 m^3. at that point, the crushed salt backfill model was invoked for the remainder of the calculation, thus replacing the elastic material response.

The elastic-secondary creep constitutive model described by Krieg [7] was used for the intact salt. The model can be decomposed into an elastic volumetric part,

$$\dot{\sigma}_{kk} = 3K\dot{\varepsilon}_{kk} \qquad \text{(EQ 2)}$$

and a deviatoric part,

$$\dot{s}_{ij} = 2G\left[\dot{e}_{ij} - (1.5)^{\frac{(n+1)}{2}} A exp\left(-\frac{Q}{RT}\right)(s_{kl}s_{kl})^{\frac{(n-1)}{2}} s_{ij}\right]. \qquad \text{(EQ 3)}$$

In Equation 3, s_{ij} is the deviatoric stress defined as,

$$s_{ij} = \sigma_{ij} - \frac{\sigma_{kk}}{3}\delta_{ij} \qquad \text{(EQ 4)}$$

and e_{ij} is the deviatoric strain defined by

$$e_{ij} = \varepsilon_{ij} - \frac{\varepsilon_{kk}}{3}\delta_{ij}. \qquad \text{(EQ 5)}$$

The material parameters K,G, A, n, Q, R, T appearing in Equations 2 and 3 are the bulk modulus, shear modulus, material creep constant, creep exponent, activation energy, universal gas constant, and absolute temperature in degrees K, respectively. The values of the shear and bulk moduli used in the current work were obtained by dividing the values given by Krieg [7] by a factor of 12.5. This artificial reduction in the moduli has been shown to produce good agreement between computed and in-situ closures [8] when an all-salt stratigraphy is used to model the formation. The material constants are shown in Table 1.

Table 1: Material Constants Used With the Elastic/Secondary Creep Model

PARAMETER	VALUE
G	992. MPa
K	1656 MPa
A	5.79×10^{-36} $Pa^{-4.9}sec^{-1}$
n	4.9
$Q/(RT)$	20.13

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The material models and constants used for the waste and crushed salt backfill were identical to those used in earlier studies [9,10]. The crushed salt backfill model was developed by Sjaardema and Krieg [11] based on data from creep-consolidation experiments on crushed salt. In this material model, creep is included in both the volumetric and the deviatoric response. The form of the model, shown in the following equations,

$$G = G_0 exp(G_1 \rho) \quad \text{(EQ 6)}$$

$$K = K_0 exp(K_1 \rho) \quad \text{(EQ 7)}$$

$$\dot{s}_{ij} = 2G\dot{e}_{ij} - 2GA(\rho_{intact}/\rho)^n exp(-\frac{Q}{RT})(s_{kl}s_{kl})^{\frac{(n-1)}{2}} s_{ij} \quad \text{(EQ 8)}$$

$$\dot{\rho}_{creep} = B_0(exp(B_1 p) - 1) exp(A^* \rho) \quad \text{(EQ 9)}$$

is such that the mechanical response of the crushed salt becomes identical to that of the intact salt as the density of the backfill approaches the density of the intact salt. The variables in Equations 6 through 9 not previously defined are material constants B_0 and B_1 obtained from the creep consolidation experiments and the density ρ computed from the equation:

$$\rho = \rho_0 exp\left(\int_{t_0}^{t} \dot{e}_v dt\right) \quad \text{(EQ 10)}$$

where ρ_0 is the density at time t_0. The intact density of the salt appears in Equation 8 as ρ_{intact}. The elastic moduli are assumed to depend on the density of the backfill through the relationships shown in Equations 6 and 7. The constants K_0 and K_1 were determined by using the least squares method to fit the modulus data to the function in Equation 6. In the fit, the function was constrained so that the bulk modulus of the crushed salt was equal to the bulk modulus of the intact salt when the crushed salt was fully compacted. No experiments have been conducted to determine how the shear modulus varies with density, so the shear modulus was assumed to vary according to the same exponential form as the bulk modulus. The constant G_0 was selected so that the shear modulus for the crushed salt was equal to that of the intact salt when the crushed salt was fully consolidated, and the constant G_1 was assumed to be the same as K_1. Because the shear and bulk moduli of the intact salt were divided by 12.5, G_0 and K_0 were divided by the same factor. Table 2 lists the values of the creep constants and elastic constants used for the backfill material. The stress-strain behavior of the waste was represented by a volumetric plasticity model [5] with a piecewise linear function defining the relationship between the mean stress and the volumetric strain. Compaction experiments on simulated waste were used to develop this relationship. The deviatoric response of the waste material has not been characterized. It is anticipated that when a drum filled with loosely compacted waste is compressed axially,

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Table 2: Material Constants Used With the Crushed Salt Backfill Model

PARAMETER	VALUE
G_0	864 Pa
G_1	6.53×10^{-3} m^3/kg
K_0	1.41×10^{3} Pa
K_1	6.53×10^{-3} m^3/kg
A	5.79×10^{-36} $Pa^{-4.9} sec^{-1}$
n	4.9
Q/RT	20.13
A^*	-17.3×10^{-3} m^3/kg
B_0	1.3×10^{8} kg $(m^3\ sec)^{-1}$
B_1	0.82×10^{-6} Pa^{-1}

the drum will not undergo significant lateral expansion until most of the void space inside the drum has been eliminated.

For the volumetric plasticity model, the yield surface in principal stress space is a surface of revolution with its axis centered about the hydrostat and the open end pointing into the compression direction. The open end is capped with a plane which is at right angles to the hydrostat. The deviatoric part is elastic-perfectly plastic so the surface of revolution is stationary in stress space. The volumetric part has variable strain hardening so the end plane moves outward during volumetric yielding. The volumetric hardening is defined by a set of pressure-volumetric strain relations. A flow rule is used such that deviatoric strains produce no volume change (associated flow). The model is best broken into volumetric and deviatoric parts with the deviatoric part resembling conventional plasticity. The volumetric yield function is a product of two functions describing the surface of revolution and the plane normal to the pressure axis. These are given by

$$\phi_s = \frac{1}{2} s_{ij} s_{ij} - (a_0 + a_1 p + a_2 p^2) \qquad \text{(EQ 11)}$$

$$\phi_p = p - g(e_v) \qquad \text{(EQ 12)}$$

where a_0, a_1, a_2 are constants defining the yield surface, p is the pressure, and e_v is the volume strain. The form of g is defined in this problem by a set of piecewise linear segments relating pressure-volume strain. Table 3 lists the pressure-volumetric strain data used for the waste drum model. The elastic material parameters and constants defining the yield surface are given in Table 4.

Table 3: Pressure-Volumetric Strain Data Used in the Volumetric Plasticity Model for the Waste Drums

PRESSURE (MPa)	$\ln(\rho/\rho_0)$
0.028	0.032
0.733	0.741
1.133	0.898
1.667	1.029
2.800	1.180
10.17	1.536

Table 4: Material Constants Used With the Volumetric Plasticity Model for the Waste

PARAMETER	VALUE
G	333 MPa
K	222 MPa
a_0	0.
a_1	0.
a_2	3.

The analysis was carried out to a simulation time of 10,000 years. The input file for the SANCHO analysis is included in Appendix II.

Results of the Analyses

The results of interest are the pressure buildup in the room and the corresponding disposal room porosity. It is these quantities that will be compared with the PA calculational results to assess if the results derived from the earlier disposal room closure calculations are being correctly incorporated in the PA analyses.

Figure 4 shows the gas pressure within the disposal room computed by SANCHO on the basis of the gas content and brine volume histories coming from BRAGFLO. The pressure increases quickly to a value slightly greater than 20 MPa at around 300 years. It then drops at a slower rate to a value slightly greater than about 15 MPa by the time that the human intrusion occurs at 1000 years. The effect of the human intrusion is to suddenly drop the pressure to a lower value, slightly greater than about 10 MPa, with an immediate reversal to increase it to its maximum value of slightly greater than 23 MPa at around 1200 years. Thereafter, the pressure slowly drops for the remainder of the simulation to a value of

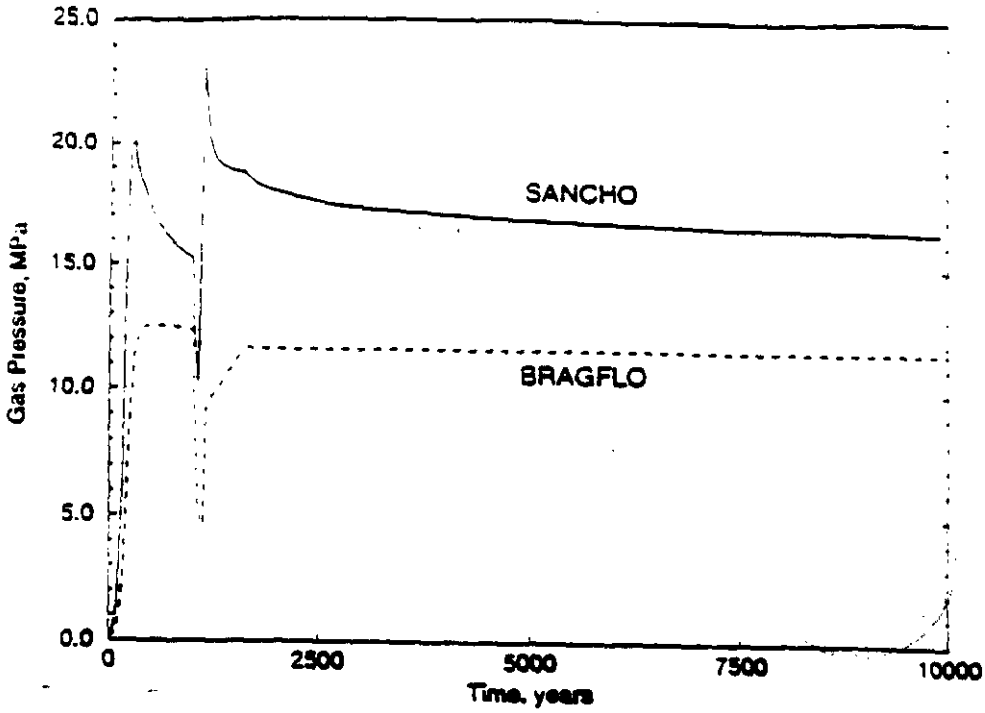

Figure 4. Comparison of Gas Pressure Histories for Run #63

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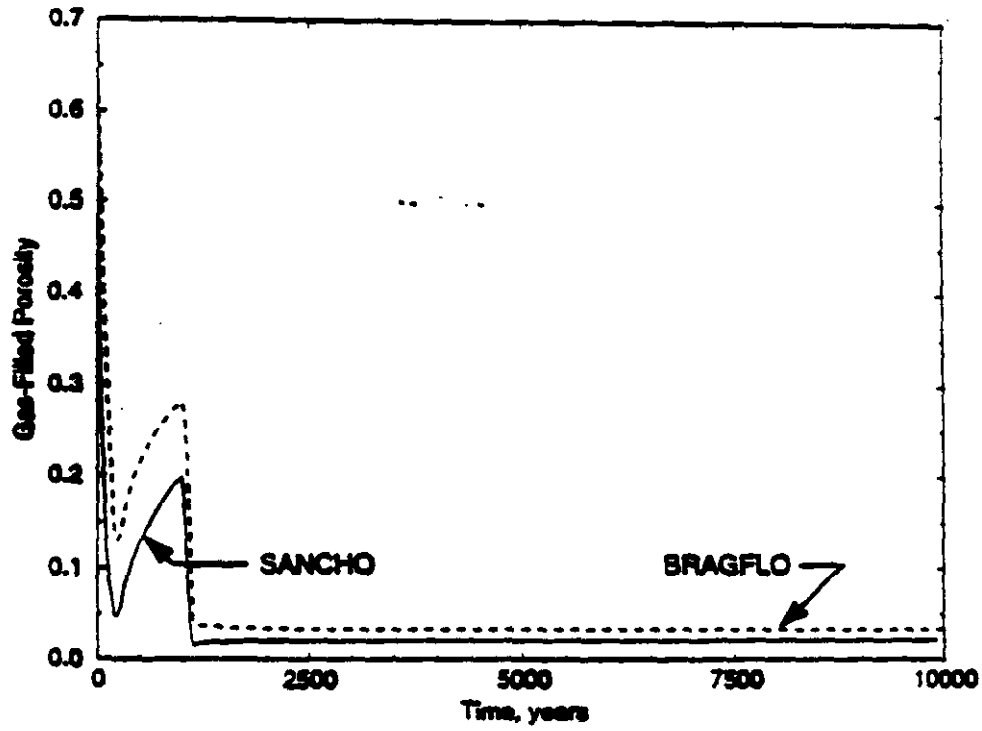

Figure 5. Comparison of Room Porosity Histories for Run #63

around 16.5 MPa at 10,000 years. Shown as well in the figure is a plot of the column labelled "PRESWAST" coming from Table I of Appendix I. This quantity is the waste gas pressure in Pascals computed by BRAGFLO. The BRAGFLO results show a trend similar to the SANCHO results, except that the pressure rises more slowly and to a lower value initially, drops more after the human intrusion, and rises to a much smaller value subsequently. Thus, the BRAGFLO curve shows a rise to about 12.5 MPa in about 300 to 400 years, slowly decreasing by a slight amount until the human intrusion event occurs at 1000 years. The human intrusion results in a drop to a value of about 4.5 MPa at about 1200 years. Thereafter, the pressure increases by a significant amount to a value of about 11.7 MPa at about 1700 years and remains constant. Thus, at the end of the 10,000 year simulation, the SANCHO gas pressure value is about 40 % larger than that for BRAGFLO. However, a basic difference in the nature of the curve is apparent when compared to that from SANCHO in that the reversal that was seen at around 1200 years in the SANCHO results is not seen here for the BRAGFLO results. In fact, it appears as if a pressure cut-off may have been used in the BRAGFLO calculation.

Figure 5 shows the corresponding room porosity history computed by SANCHO. The porosity drops quickly as the room closes and reaches a value of about 0.05 at about 200 years. It then begins to increase and reaches a value of about 0.2 immediately prior to the human intrusion event. The porosity drops quickly after human intrusion and reaches its minimum value of about 0.015. Thereafter, it increases very gradually throughout the remainder of the simulation, reaching a value of about 0.02 at the end. Shown in the figure also is a porosity value computed from the BRAGFLO results provided in Appendix I. This porosity value was computed by using the following equation,

$$\varphi = \frac{\left[\dfrac{(1-\mathrm{SBAVW})\,\mathrm{PORVOLW}}{12.65}\right]}{\left[\dfrac{(1-\mathrm{SBAVW})\,\mathrm{PORVOLW}}{12.65} + 1229\right]}, \qquad \text{(EQ 13)}$$

where "PORVOLW" is the waste pore volume in cubic meters and "SBAVW" is the average brine saturation in the waste (both of these quantities coming from the columns labelled as such in Table I of Appendix I), 12.65 is the number of rooms per panel, and 1229 is the volume of solids in the room. It is apparent that the BRAGFLO porosity results essentially mimic and parallel those described for SANCHO, except that they are higher at all times. The value of porosity from BRAGFLO is seen to asymptote to a value slightly greater than about 0.03. Thus, the value of porosity at the end of the simulation computed with BRAGFLO appears to be about 50 % greater than computed with SANCHO.

Summary and Conclusions

Because recasting of the calculational results for closure of a disposal room model into suitable input for use in performance assessment compliance analyses requires various simplifications and assumptions, all of which have the potential of introducing uncertainty into the results, several calculations to check the validity of the recasting procedure were

performed in an earlier study [1]. The process began by recovering information on the variation in gas content and porosity with time around the waste/backfill region of a disposal room from a performance assessment compliance calculation. This information included the effects of closure of the room indirectly via the concept of a "porosity surface." The gas versus time data was then used as the gas-generation input for a disposal room closure calculation with the SANCHO computer code. The results were then compared with the original porosity history recovered from the performance assessment calculation. Three cases were investigated in that study: a human intrusion into a practically dry (low brine saturation) panel – Run #18; an undisturbed, practically dry (low brine saturation) repository – Run #42; and a human intrusion into a panel that becomes largely brine saturated – Run #63. Satisfactory agreement was observed between the performance assessment porosity histories and the more detailed histories computed with SANCHO for repository environments with low brine saturations. Results differed, however, for the third case (Run #63) when saturation of the panel occurred. A source of the discrepancy for the third case was thought be due to the assumption in the SANCHO calculations, that all void volume in the room is occupied by gas (this same assumption was used in generating the original porosity surfaces used by BRAGFLO), whereas the BRAGFLO calculations explicitly included brine saturation. Thus, it followed that for the case when the panel becomes largely brine saturated, the presence of the brine could prove significant.

A new calculation has been performed for this case, using SANCHO, to determine if the effect of including the brine volume in the SANCHO calculation will resolve the discrepancy between its results and those from BRAGFLO. The new calculation is identical to the earlier one except that the void volume in the room at any time for this case has been reduced by the volume of brine in the room (this information also came from the BRAGFLO run). Results from this analysis show that there still remain differences: at the end of the 10,000 year simulation, the gas pressure computed with SANCHO is about 40 % greater than that coming from BRAGFLO, and the porosity is 50 % smaller. However, the new results are in much better agreement than those from the earlier calculation. This appears to indicate that for cases in which saturation of the repository is significant, the presence of the brine volume in the room will also significantly influence the response of the room.

Better agreement does not necessarily indicate that a complete resolution to the discrepancy between the results for SANCHO and those for BRAGFLO has been achieved. In fact, an inconsistency is inherent in the present calculation in the sense that the brine volume entering the room depends on the pressure within the room, which depends on the closure of the room, which is what we are trying to compute in this calculation. So we are in essence cheating here in that we are assuming that the pore volume computed by BRAGFLO is correct even though it is based on previous SANCHO calculations in which brine was not included. Had it been possible to include brine in those previous calculations used to generate the original porosity surface, the room pressures would have been higher. In short, the process is a coupled one in which closure, gas generation, and brine inflow exert some influence on each other. To attempt to model the process in a staggered manner as has been done in BRAGFLO by using a previously generated porosity surface from SANCHO to predict brine inflow, is bound to lead to results that are inconsistent to some degree.

In addition, without knowing the details of how the information from the original porosity surface from SANCHO is used by BRAGFLO, it will not be possible to completely resolve the inconsistencies that remain. For example, the gas pressure curves from the two codes around the time of human intrusion are very different in nature and it appears that a pressure cut-off may have been invoked in the BRAGFLO calculation.

References

1. Argüello, J. G. and C. M. Stone, "Performance Assessment Verification Calculations – SANCHO Comparisons to BRAGFLO Runs 18, 42, and 63," Memorandum to B. M. Butcher, 6345, Sandia National Laboratories, Albuquerque, New Mexico, November 19, 1993.

2. Mendenhall, F. T. and R. C. Lincoln, "Single-Room Porosity History for Baseline Waste Form and Gas Generation Rates," Memorandum to D. R. Anderson, 6342, Sandia National Laboratories, Albuquerque, New Mexico, February 28, 1992.

3. Stone, C. M., "Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt Due to Gas Generation Produced by Several Alternatives of the Engineered Alternatives Task Force," Memorandum to B. M. Butcher, 6345, Sandia National Laboratories, Albuquerque, New Mexico, October 6, 1992.

4. Beraún, R. and P. B. Davies, "Baseline Design Input Data Base to be Used During Calculations Effort to be Performed by Division 1514 in Determining the Mechanical Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt," Memorandum to Distribution, Sandia National Laboratories, Albuquerque, New Mexico, September 12, 1991.

5. Stone, C. M., R. D. Krieg, and Z. E. Beisinger, *SA HO - A Finite Element Computer Program for the Quasistatic, Large Deformation, astic Response of Two-Dimensional Solids*, SAND84-2618, Sandia Natic Laboratories, Albuquerque, New Mexico, April, 1985.

6. Argüello, J. G., "Use of Midheight Symmetry Plane to Compute Disposal Room Closure," Memorandum to Distribution, Sandia National Laboratories, Albuquerque, NM, January 1990.

7. Krieg, R. D., *Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project*, SAND83-1908, Sandia National Laboratories, Albuquerque, New Mexico, 1984.

8. Morgan, H. S. and R. D. Krieg, *A Comparison of Unified Creep-Plasticity and Conventional Creep Models for Rock Salt Based on Predictions of Creep Behavior Measured in Several In Situ and Bench-Scale Experiments*, SAND87-1867, Sandia National Laboratories, Albuquerque, NM, 1988.

9. Weatherby, J. R., J. G. Arguello, B. M. Butcher, and C. M. Stone, "The structural response of a WIPP disposal room with internal gas generation," *Proceedings of the 32nd U. S. Rock Mechanics Symposium*, Norman, OK, July, 1991.

10. Weatherby, J. R., W. T. Brown, and B. M. Butcher, "The closure of WIPP disposal rooms filled with various waste and backfill combinations," *Proceedings of the 32nd U. S. Rock Mechanics Symposium*, Norman, OK, July, 1991.

11. Sjaardema, G. D. and R. D. Krieg, *A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analyses of Backfilled Shaft and Drift Configurations*, SAND87-1977, Sandia National Laboratories, Albuquerque, New Mexico, 1987.

Appendix I

Results From PA's 1992 Compliance Analysis Using BRAGFLO – Transmittal From B. M. Butcher, 6345, of 7/19/93 (Data Provided by Jim Bean, 6342)

THE DATA IN FILES GROPE_018.DAT, GROPE_042.DAT, AND GROPE_063.DAT
IS OUTPUT FROM BRAGFLO. FILES ARE IN DIRECTORY U7:[JEREMY.BUTCHER]

VARIABLE	DEFINITION
N	= DATABASE STEP NUMBER
TIME	= ELAPSED TIME IN SECONDS
GASGENV	= GAS GENERATION RATE IN CUBIC METERS/SEC
GASGENM	= GAS GENERATION RATE IN MOLES/SEC
SBRNW	= AVERAGE BRINE SATURATION IN WASPS
PORVOLW	= WASPS PORE VOLUME (GAS AND BRINE) IN CUBIC METERS
PRESGAS0	= WASPS (GAS) PRESSURE IN PASCALS
PORGAS0	= PERCENT OF WASPS (VOID VOLUME/TOTAL VOLUME)
GASVOLS0	= GAS VOLUME IN WASPS (CUBIC METERS AT P=101325 PA AND T=300.15K)
GASVOL	= GAS VOLUME AT RESERVOIR CONDITIONS (CUBIC METERS AT P=PRESGAS0)
GASGENC	= CUMULATIVE GAS GENERATED IN WASPS (CUBIC METERS AT P=101325)
	= INTEGRATED VALUES OF GASGENV ACCORDING TO FOLLOWING:
	GASGENC(T=0) = 0
	GASGENC(T) = GASGENC(T-DT) + 0.5*DT*(GASGENC(T) + GASGENC(T-DT))

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Table I. Grope File From PA's Compliance Analysis - Run # 63 (GROPE_063.DAT)

Step	Time	GASGENV	GASGENM	BRAVM	PORVOLM	PRESWART	POROSITY	GASVOLM	GASVOL	GASGENC
1	0.00000E+00	0.00000E+00	0.00000E+00	4.54400E-02	3.04292E+04	1.01325E+05	4.60178E-01	2.90465E+04	2.90465E+04	0.00000E+00
2	2.13042E+05	1.30007E-05	5.31751E-04	6.54399E-02	3.04208E+04	1.01335E+05	6.59996E-01	2.90416E+04	2.90305E+04	1.39005E+00
3	3.84376E+06	1.32744E-05	5.42946E-04	6.07919E-02	3.75873E+04	1.69983E+05	5.26784E-01	2.03993E+04	2.61651E+04	2.67083E+03
4	1.50317E+09	2.21857E-05	9.06204E-04	1.57562E-01	1.02140E+04	2.33603E+05	1.57332E-01	3.55503E+04	1.54286E+04	2.57833E+04
5	2.20403E+09	2.77981E-05	1.13698E-03	2.26665E-01	1.53604E+04	3.65414E+05	1.33635E-01	4.27105E+04	1.18710E+04	4.33084E+04
6	3.82950E+09	3.35540E-05	1.37250E-03	3.97164E-01	1.24193E+04	5.51115E+05	1.51137E-01	5.18690E+04	9.63123E+03	6.24717E+04
7	3.90640E+09	3.47564E-05	1.42160E-03	3.11006E-01	1.30801E+04	5.99612E+05	1.83997E-01	5.29362E+04	9.80740E+03	6.48934E+04
8	3.62143E+09	4.22321E-05	1.72736E-03	6.05661E-01	1.16221E+04	9.02158E+05	2.67609E-01	6.55222E+04	6.02386E+03	9.26489E+04
9	4.50496E+09	5.24130E-05	2.14301E-03	8.20130E-01	9.89168E+03	1.98904E+06	2.14665E-01	8.68736E+04	4.66036E+03	1.38245E+05
10	5.09171E+09	5.65463E-05	2.31270E-03	5.70726E-01	8.37450E+03	2.47559E+06	1.83305E-01	9.50543E+04	3.94923E+03	1.65053E+05
11	5.67662E+09	6.39023E-05	2.57640E-03	6.57872E-01	8.06031E+03	3.07438E+06	1.92603E-01	1.13426E+05	3.03476E+03	2.00810E+05
12	6.49698E+09	6.70941E-05	2.77698E-03	7.37729E-01	8.75675E+03	3.98907E+06	1.90199E-01	1.39782E+05	2.47460E+03	2.56492E+05
13	6.49867E+09	6.79916E-05	2.77723E-03	7.17020E-01	8.76675E+03	3.83752E+06	2.00399E-01	1.40849E+05	2.47300E+03	2.56607E+05
14	6.77356E+09	6.89484E-05	2.82011E-03	7.30641E-01	8.06603E+03	6.66392E+06	1.92614E-01	1.51178E+05	2.38890E+03	2.73360E+05
15	7.52703E+09	6.99416E-05	3.06072E-03	7.43005E-01	9.01898E+03	8.40836E+06	1.95672E-01	1.83438E+05	2.31964E+03	3.25798E+05
16	7.63567E+09	7.01010E-05	3.06723E-03	7.44787E-01	9.00713E+03	8.62101E+06	1.97367E-01	1.87939E+05	2.32198E+03	3.33335E+05
17	7.80928E+09	7.01477E-05	3.06916E-03	7.45329E-01	9.15696E+03	9.16936E+06	1.98422E-01	2.00101E+05	2.33508E+03	3.51128E+05
18	8.68144E+09	6.89859E-05	3.01037E-03	7.30131E-01	9.36332E+03	1.03693E+07	2.03142E-01	2.43756E+05	2.52696E+03	4.06210E+05
19	9.16651E+09	6.88809E-05	2.78663E-03	7.20017E-01	9.48853E+03	1.08087E+07	2.05143E-01	2.67230E+05	2.64739E+03	4.30064E+05
20	9.52261E+09	6.73260E-05	2.74969E-03	7.09857E-01	9.53368E+03	1.12513E+07	2.06038E-01	2.80438E+05	2.76899E+03	4.63495E+05
21	9.76114E+09	6.66852E-05	2.72754E-03	7.02913E-01	9.57703E+03	1.16465E+07	2.07779E-01	3.01163E+05	2.86512E+03	4.79479E+05
22	9.98549E+09	6.61760E-05	2.70674E-03	6.96696E-01	9.61301E+03	1.16059E+07	2.08569E-01	3.12671E+05	2.91566E+03	4.94383E+05
23	1.02424E+10	6.55859E-05	2.68255E-03	6.89460E-01	9.65161E+03	1.17868E+07	2.09397E-01	3.25324E+05	2.99721E+03	5.11302E+05
24	1.04877E+10	6.50483E-05	2.66059E-03	6.82876E-01	9.68416E+03	1.18705E+07	2.10103E-01	3.36566E+05	3.07100E+03	5.27331E+05
25	1.08664E+10	6.43327E-05	2.63723E-03	6.72887E-01	9.73765E+03	1.20276E+07	2.11047E-01	3.52888E+05	3.18204E+03	5.51683E+05
26	1.13974E+10	6.32712E-05	2.58790E-03	6.61111E-01	9.77300E+03	1.21481E+07	2.12031E-01	3.78642E+05	3.33396E+03	5.79285E+05
27	1.17852E+10	6.22661E-05	2.54597E-03	6.48957E-01	9.81433E+03	1.22626E+07	2.12927E-01	3.88798E+05	3.44917E+03	6.09899E+05
28	1.24501E+10	6.08686E-05	2.48373E-03	6.32811E-01	9.85461E+03	1.23358E+07	2.13888E-01	4.10519E+05	3.61899E+03	6.50874E+05
29	1.30740E+10	5.98806E-05	2.45004E-03	6.18031E-01	9.87022E+03	1.24100E+07	2.14140E-01	4.28354E+05	3.75235E+03	6.88616E+05
30	1.37323E+10	5.88734E-05	2.40882E-03	6.07251E-01	9.87274E+03	1.24544E+07	2.14195E-01	4.44117E+05	3.87751E+03	7.27662E+05
31	1.57700E+10	5.60059E-05	2.29090E-03	5.72101E-01	9.87413E+03	1.24769E+07	2.14225E-01	4.84757E+05	4.23434E+03	8.45173E+05
32	1.62990E+10	5.51079E-05	2.25401E-03	5.62055E-01	9.87413E+03	1.24770E+07	2.14225E-01	4.96298E+05	4.32433E+03	8.73617E+05
33	1.93449E+10	4.92261E-05	2.01343E-03	5.15367E-01	9.87413E+03	1.24615E+07	2.14225E-01	5.68690E+05	4.78632E+03	1.03390E+06
34	2.16110E+10	4.69176E-05	1.91901E-03	4.86730E-01	9.87413E+03	1.24507E+07	2.14225E-01	5.80521E+05	5.06809E+03	1.13234E+06
35	2.29306E+10	4.46936E-05	1.80350E-03	4.67366E-01	9.87413E+03	1.24393E+07	2.14225E-01	6.01907E+05	5.25930E+03	1.20145E+06
36	2.43250E+10	4.27993E-05	1.75056E-03	4.50710E-01	9.87413E+03	1.24316E+07	2.14225E-01	6.20367E+05	5.42368E+03	1.26207E+06
37	2.56704E+10	4.16507E-05	1.70359E-03	4.35960E-01	9.87413E+03	1.24163E+07	2.14225E-01	6.36793E+05	5.56952E+03	1.31805E+06

Table I. (Continued)

38	3.69221E+10	4.05867E-05	1.66007E-03	4.22268E-01	9.07613E+03	1.24214E+07	2.14225E-01	6.52019E+05	5.70460E+03	1.37032E+06
39	3.84074E+10	3.07610E-05	1.28021E-03	4.07532E-01	9.07613E+03	1.23897E+07	2.14225E-01	6.67041E+05	5.65011E+03	1.42614E+06
40	3.15570E+10	1.78964E-05	7.31882E-04	3.89731E-01	9.07613E+03	1.23042E+07	2.14225E-01	6.82722E+05	6.02500E+03	1.50083E+06
41	3.15571E+10	1.77974E-05	7.27128E-04	3.88192E-01	9.07622E+03	1.23006E+07	2.14227E-01	6.84330E+05	6.04133E+03	1.50083E+06
42	3.15620E+10	1.77760E-05	7.27067E-04	3.88104E-01	9.07623E+03	1.23000E+07	2.14227E-01	6.84275E+05	6.04121E+03	1.50092E+06
43	3.15640E+10	1.77754E-05	7.27042E-04	3.88101E-01	9.07622E+03	1.23003E+07	2.14227E-01	6.84213E+05	6.04124E+03	1.50097E+06
44	3.18792E+10	1.77776E-05	7.27134E-04	3.88196E-01	9.07393E+03	1.22818E+07	2.14230E-01	6.83203E+05	6.04091E+03	1.50133E+06
45	3.14428E+10	1.77261E-05	7.24945E-04	3.88012E-01	9.04897E+03	1.19603E+07	2.14113E-01	6.65917E+05	6.03100E+03	1.50248E+06
46	3.16700E+10	1.77704E-05	7.26857E-04	3.88144E-01	9.04896E+03	1.17773E+07	2.14047E-01	6.55210E+05	6.02471E+03	1.50290E+06
47	3.17438E+10	1.78053E-05	7.31940E-04	3.90760E-01	9.03976E+03	1.13849E+07	2.13913E-01	6.32069E+05	6.00668E+03	1.50414E+06
48	3.21104E+10	1.88928E-05	7.72760E-04	4.06726E-01	9.03036E+03	9.51667E+06	2.13275E-01	5.19030E+05	5.83208E+03	1.51090E+06
49	3.34004E+10	2.05061E-05	1.16922E-03	5.32202E-01	9.77324E+03	5.07571E+06	2.12016E-01	2.56390E+05	4.57190E+03	1.54152E+06
50	3.37048E+10	2.26907E-05	1.32710E-03	5.66461E-01	9.76470E+03	5.33176E+06	2.11051E-01	2.86438E+05	4.04707E+03	1.55097E+06
51	3.46284E+10	4.40534E-05	1.80107E-03	7.36095E-01	9.78491E+03	6.70204E+06	2.11630E-01	1.16032E+05	2.57437E+03	1.58626E+06
52	3.50058E+10	6.01324E-05	1.96070E-03	7.85031E-01	9.78147E+03	6.62314E+06	2.11611E-01	9.26421E+04	2.00893E+03	1.60365E+06
53	3.57833E+10	6.95104E-05	2.02507E-03	9.24668E-01	9.78260E+03	6.56461E+06	2.11500E-01	3.21300E+04	7.32927E+02	1.66156E+06
54	3.61918E+10	6.95041E-05	2.02400E-03	9.33108E-01	9.70399E+03	6.56269E+06	2.12269E-01	4.07671E+06	6.53600E+02	1.66184E+06
55	3.68344E+10	6.95310E-05	2.02500E-03	9.19158E-01	9.02750E+03	9.33618E+06	2.13213E-01	5.22554E+04	5.98004E+02	1.69366E+06
56	5.16059E+10	1.67392E-05	6.86643E-04	9.44144E-01	9.06150E+03	1.16211E+07	2.13994E-01	5.91643E+04	5.50926E+02	2.10311E+06
57	7.51626E+10	1.91795E-10	7.84678E-09	9.46560E-01	9.06156E+03	1.16241E+07	2.13995E-01	5.66126E+04	5.27029E+02	2.30027E+06
58	1.09723E+11	1.91795E-10	7.84678E-09	9.46763E-01	9.06188E+03	1.16921E+07	2.14005E-01	5.65343E+04	5.25129E+02	2.30028E+06
59	1.44283E+11	1.91795E-10	7.84678E-09	9.46790E-01	9.06402E+03	1.16947E+07	2.14005E-01	5.65196E+04	5.24965E+02	2.30029E+06
60	1.78843E+11	1.91795E-10	7.84678E-09	9.46791E-01	9.06386E+03	1.16901E+07	2.14004E-01	5.65005E+04	5.24950E+02	2.30029E+06
61	2.13403E+11	1.91795E-10	7.84678E-09	9.46763E-01	9.06386E+03	1.16440E+07	2.14002E-01	5.64983E+04	5.25123E+02	2.30030E+06
62	2.47963E+11	1.91795E-10	7.84678E-09	9.46743E-01	9.06376E+03	1.16370E+07	2.13999E-01	5.64881E+04	5.25323E+02	2.30031E+06
63	2.82523E+11	1.91795E-10	7.84678E-09	9.46721E-01	9.06363E+03	1.16298E+07	2.13997E-01	5.64777E+04	5.25524E+02	2.30031E+06
64	3.15570E+11	1.91795E-10	7.84678E-09	9.46700E-01	9.06353E+03	1.16228E+07	2.13994E-01	5.64671E+04	5.25726E+02	2.30032E+06

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Appendix II

Input File for SANCHO (Version 2.0.0) Run

```
PRESSURIZED ROOM CALCULATION - MOLES & BRINE VS TIME FROM BRAGFLO RUN 63
CONTROL,3,2,0,3
PLANE
ELEMENTS,1
ISTRESS,CONSTANT,-14.8E6,-14.8E6,-14.8E6
ISTRESS,OFF,2,3
NODES,1
DXSCALE,.5
PLOT,ELEMENT,STRESS,STRAIN,STATE
PLOT,NODAL,DISP,TEMP,RESIDUAL
PLOT,GLOBAL,RMAG,ITER
PLIMIT,.2E6
SOLUTION,10.,100,2500,100.
TIMESTEP,0.,400000,3.1536E11
TIMEPRNT,0.,3.1536E9,3.1536E11
TIMEPLOT,0.,1.5768E7,3.1536E7,1.5768E8,3.1536E9,3.1536E8,6.3072E10,*
3.1536E9,3.1536E11
ENDSET
MATERIAL,5,1.,0.,0.0
***HALITE***
1.984E9,1.656E9,5.79E-36,4.9,20.13,0,.001
MATERIAL,7,1.,0.,0.
   * * CRUSHED SALT BACKFILL * *
848.,6.53E-3,1408.,6.53E-3,5.79E-36,4.9,20.13,*
-17.3E-3,0.0,1.3E8,0.82E-6,1.300E3,2140.,.0005
MATERIAL,2,1.,0.,0.
* * CRUSHABLE FOAM MODEL FOR DRUMS * *
3.333E8,2.223E8,0.,0.,3.
.03230,.02833E6,.741,.733E6,.898,1.133E6,1.029,1.667E6,*
1.18,2.8E6,1.536,10.167E6
ENDSET
DISPR,1
DISPZ,2
PRESSURE,300,0.
CENTER,0.,0.
PRESSURE,200,14.8E6
PRESTORY,0.,1.0,1.0E12,1.
END
```

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Sandia National Laboratories
Albuquerque, New Mexico 87185

date: November 19, 1993

to: B. M. Butcher, 6345 (MS1341)

from: J. Guadalupe Arguello and C. M. Stone, 1561

subject: Performance Assessment Verification Calculations – SANCHO Comparisons to BRAGFLO Runs 18, 42, and 63

Introduction

Performance assessment (PA) of the Waste Isolation Pilot Plant (WIPP) requires that numerous scenarios be investigated to determine if compliance is achievable. This leads to a very large number of analyses that need to be performed during the course of the investigations. Because of the large number of analyses required, the numerical models used by PA must be fast and efficient and consequently contain less detail, in terms of computed disposal room closure, than would be ideal. The reason for this is that the complexity of salt creep and the compute-intensive analyses required to determine its response make it prohibitive to directly calculate disposal room closure in PA analyses at this time. Yet, the effects of disposal room closure must be included in PA compliance analyses. Therefore, detailed disposal room creep closure calculations are typically performed using separate large, complex, nonlinear finite element based codes that are fast and efficient, in their own right, but on a different scale. The calculational results from disposal room creep closure analyses must then be recast in a form suitable for use in PA compliance analyses. The process is as follows:

1) First, a set of disposal room creep closure calculations using a finite element code (e. g., SANCHO or SANTOS) is performed for several discrete values of gas generation (leading to number of moles of gas versus time) and a set of corresponding room porosity histories (room porosity versus time) is obtained for those discrete values.

2) From those results, a "porosity" surface is defined that provides the porosity of a single WIPP disposal room as a function of the number of moles of gas present (or the pressure resulting from that amount of gas) and time.

3) This concept of a "porosity" surface is then used by the PA compliance analysis code (BRAGFLO). The results from the first step are used directly as input to the code; it then interpolates to determine the porosity (in a panel or the repository) as a function of time for any arbitrary gas generation (or pressure) path, accounting for the influence of brine saturation. In this manner, the effects of disposal room closure are indirectly accounted for in the PA calculation.

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The recasting of the finite element analysis disposal room creep closure results into a form suitable for input to PA requires a number of simplifying steps and assumptions, all of which have the potential of introducing uncertainty into the results.

A method for checking the validity of the procedure has been examined at the request of the project [1]. The method begins by recovering data on the variation in gas content and porosity with time in the waste/backfill region of a disposal room from a performance assessment compliance calculation, in which the effects of disposal room closure have been included indirectly via the concept of a "porosity surface"[2]. This surface was derived from the results of several analyses [3] using the gas generation rates and other details defining the Baseline room model [4]. The gas-versus-time data from the compliance calculation are then used as an input gas generation history for a disposal room closure calculation using the SANCHO [5] code to compute the porosity of the room as a function of time. The porosity history obtained from SANCHO is then compared with the original porosity history recovered from the PA calculation. The difference between the two porosity histories represents translation error, and differences arising from the various assumptions and simplifications. In this manner, we can assess if the results derived from disposal room closure calculations are being correctly incorporated in the PA analyses.

This memo serves to document the results of three disposal room closure analyses performed with the SANCHO code using gas-versus-time data from performance assessment calculations previously performed with the BRAGFLO code. The three PA BRAGFLO cases, and their corresponding computed gas histories (used as input to the SANCHO calculations) are briefly described in the next section of the memo. The disposal room geomechanical model used for the SANCHO computations is then discussed. The results from the analyses are then presented, and the porosity histories obtained from SANCHO are compared to those from the original BRAGFLO runs. Finally, comments on the validity of using "porosity surfaces" in PA analyses are offered for consideration.

Description of PA Cases

Three cases from PA's 1992 compliance analysis, using porosity surface information, were investigated. The BRAGFLO results for each of three cases – designated as runs 18, 42, and 63 – were transmitted to organization 1561 by B. M. Butcher, 6345 using data provided by Jim Bean, 6342. The transmitted information is included in tabular form in Appendix I. Table I in Appendix I shows the results for Run #18 which represents a human intrusion into a practically dry (low brine saturation) panel. Table II shows the results for Run #42 which represents an undisturbed, practically dry, repository. Table III shows the results for Run #63 which represents a human intrusion into a panel that becomes largely brine saturated.

The information from these tables that was used as input to the SANCHO calculations was that labelled "GASVOLW". As indicated in Appendix I, the information in the column labelled "GASVOLW" is the gas volume in the waste – at the corresponding time – in cubic

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meters at a pressure, P=101325 Pa, and at a temperature, T=300.15 °K. By using the Ideal Gas Law,

$$PV = nRT, \qquad \text{(EQ 1)}$$

where P is the pressure in Pascals, V is the volume in cubic meters, R is the universal gas constant, and T is the temperature in degrees Kelvin, the number of moles of gas, n, with time was computed. This quantity was divided by 119.64 rooms per repository or 12.65 rooms per panel to get an "equivalent room" value for use in the SANCHO disposal room model. For each of the three cases, the information was written to a file that was subsequently read by SANCHO during the disposal room closure calculation. The resulting equivalent room gas content histories that were written to these files for the three cases are shown in Figure 1.

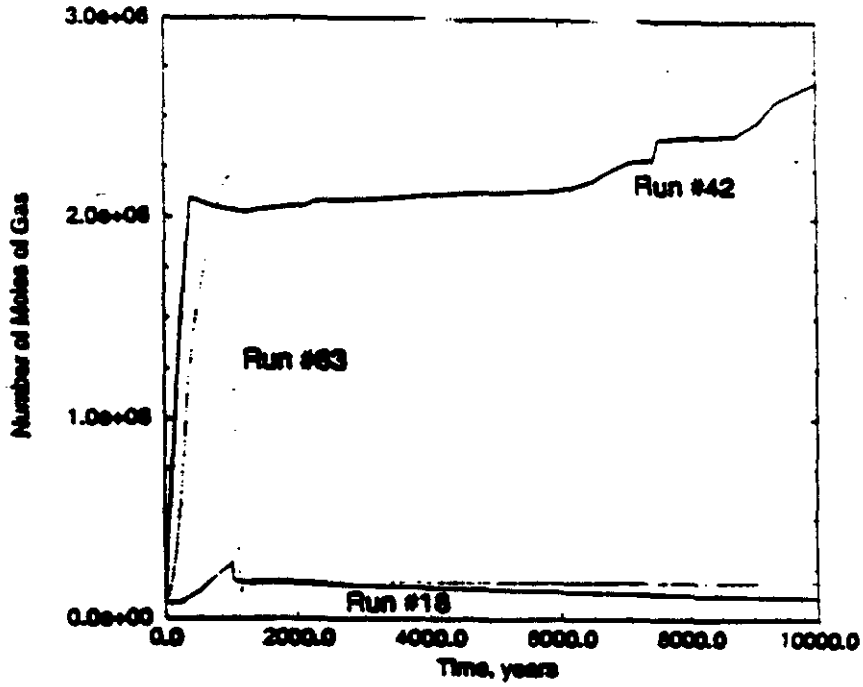

Figure 1. Equivalent Room Gas Content Histories From BRAGFLO Runs

Geomechanical Model

A two-dimensional plane strain disposal room model, as shown in Figure 2, was used for the SANCHO analyses. This same model was used for the Baseline calculations described by Stone in his October 6, 1992 memorandum [3]. The model represents the room as one in an infinite array of disposal rooms located at the repository horizon. Consequently, symmetry boundary conditions are applicable between rooms. If it is further assumed that gravity forces do not greatly affect the material response near the room [6] and that the stratigraphy is all-salt, use can be made of vertical symmetry boundary conditions to arrive at the quarter-symmetry model shown in the figure. The model contains 618 elements and

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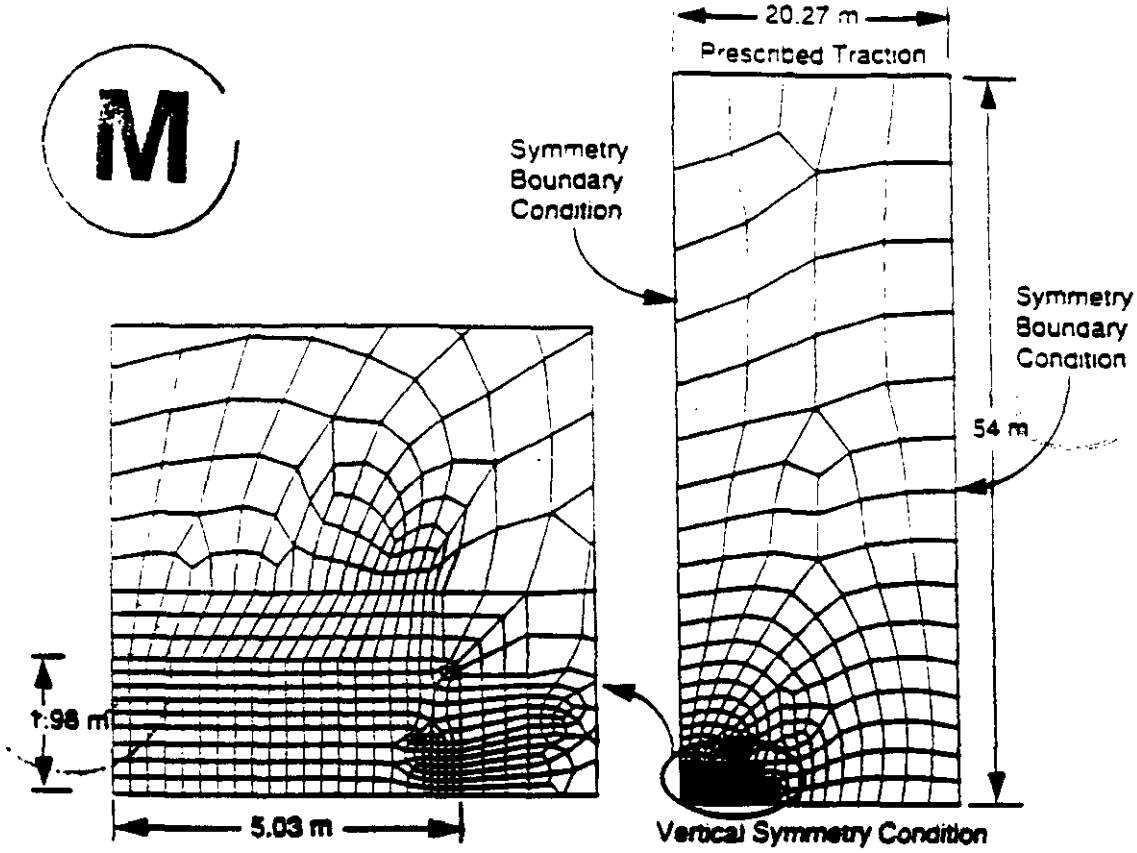

Figure 2. Finite Element Mesh and Boundary Condition Used in SANCHO Analyses

664 nodal points. A zero-displacement boundary condition in the horizontal direction was applied on both the left and right boundaries of the model. A zero-displacement boundary condition in the vertical direction was also applied on the lower boundary. A prescribed normal traction of -14.8 MPa was applied on the upper boundary to simulate the overburden load at the repository horizon. Within the room, a pressure $P = (nRT)/V$, was applied along the room boundary. In this case, n was the current number of moles of gas in the room, interpolated from the external file of gas content history, and V was the current void volume in the room.

As indicated in the idealization of Figure 2, the quarter-room dimensions are 1.98 m high by 5.03 m wide. Within the room is material representing the waste, the crushed salt backfill, and the headspace. The volume of the waste and drums is 1663 m^3 distributed along the 91.44 m length of the room. This results in a nominal cross-sectional area of waste of 18.19 m^2. For the quarter-symmetry room, this translates to a height of 1.01 m and a width of 4.5 m. The remainder of the disposal room volume was filled with crushed salt backfill having a porosity of 0.4. The disposal room volume corresponding to the headspace, 653 m^3, was discretized as though it was crushed salt, and special capabilities previously added to SANCHO [3] were used to model this region and its response. In

essence, the crushed salt material representing the headspace was modeled as a very low modulus, elastic material until the disposal room volume had decreased by 653 m^3; at that point, the crushed salt backfill model was invoked for the remainder of the calculation, thus replacing the elastic material response.

The elastic-secondary creep constitutive model described by Krieg [7] was used for the intact salt. The model can be decomposed into an elastic volumetric part,

$$\dot{\sigma}_{kk} = 3K\dot{\varepsilon}_{kk} \qquad \text{(EQ 2)}$$

and a deviatoric part,

$$\dot{s}_{ij} = 2G\left[\dot{e}_{ij} - (1.5)^{\frac{(n+1)}{2}} A exp\left(-\frac{Q}{RT}\right)(s_{kl}s_{kl})^{\frac{(n-1)}{2}} s_{ij}\right]. \qquad \text{(EQ 3)}$$

In Equation 3, s_{ij} is the deviatoric stress defined as,

$$s_{ij} = \sigma_{ij} - \frac{\sigma_{kk}}{3}\delta_{ij} \qquad \text{(EQ 4)}$$

and e_{ij} is the deviatoric strain defined by

$$e_{ij} = \varepsilon_{ij} - \frac{\varepsilon_{kk}}{3}\delta_{ij}. \qquad \text{(EQ 5)}$$

The material parameters K,G, A, n, Q, R, T appearing in Equations 2 and 3 are the bulk modulus, shear modulus, material creep constant, creep exponent, activation energy, universal gas constant, and absolute temperature in degrees K, respectively. The values of the shear and bulk moduli used in the current work were obtained by dividing the values given by Krieg [7] by a factor of 12.5. This artificial reduction in the moduli has been shown to produce good agreement between computed and in-situ closures [8] when an all salt stratigraphy is used to model the salt formation. The material constants are shown in Table 1.

Table 1: Material Constants Used With the Elastic/Secondary Creep Model

PARAMETER	VALUE
G	992. MPa
K	1656 MPa
A	5.79×10^{-36} $Pa^{-4.9}sec^{-1}$
n	4.9
$Q/(RT)$	20.13

The material models and constants used for the waste and crushed salt backfill were identical to those used in earlier studies [9,10]. The crushed salt backfill model was developed by Sjaardema and Krieg [11] based on data from creep-consolidation experiments on crushed salt. In this material model, creep is included in both the volumetric and the deviatoric response. The form of the model, shown in the following equations,

$$G = G_0 exp(G_1 \rho) \qquad \text{(EQ 6)}$$

$$K = K_0 exp(K_1 \rho) \qquad \text{(EQ 7)}$$

$$\dot{s}_{ij} = 2G\dot{e}_{ij} - 2GA(\rho_{intact}/\rho)^n exp(-\frac{Q}{RT})(s_{kl}s_{kl})^{\frac{(n-1)}{2}} s_{ij} \qquad \text{(EQ 8)}$$

$$\dot{\rho}_{creep} = B_0(exp(B_1 \rho) - 1) exp(A^* \rho) \qquad \text{(EQ 9)}$$

is such that the mechanical response of the crushed salt becomes identical to that of the intact salt as the density of the backfill approaches the density of the intact salt. The variables in Equations 6 through 9 not previously defined are material constants B_0 and B_1 obtained from the creep consolidation experiments and the density ρ computed from the equation:

$$\rho = \rho_0 exp\left(\int_{t_0}^{t} \dot{e}_v dt\right) \qquad \text{(EQ 10)}$$

where ρ_0 is the density at time t_0. The intact density of the salt appears in Equation 8 as ρ_{intact}. The elastic moduli are assumed to depend on the density of the backfill through the relationships shown in Equations 6 and 7. The constants K_0 and K_1 were determined by using the least squares method to fit the modulus data to the function in Equation 6. In the fit, the function was constrained so that the bulk modulus of the crushed salt was equal to the bulk modulus of the intact salt when the crushed salt was fully compacted. No experiments have been conducted to determine how the shear modulus varies with density, so the shear modulus was assumed to vary according to the same exponential form as the bulk modulus. The constant G_0 was selected so that the shear modulus for the crushed salt was equal to that of the intact salt when the crushed salt was fully consolidated, and the constant G_1 was assumed to be the same as K_1. Because the shear and bulk moduli of the intact salt were divided by 12.5, G_0 and K_0 were divided by the same factor. Table 2 lists the values of the creep constants and elastic constants used for the backfill material.

Table 2: Material Constants Used With the Crushed Salt Backfill Model

PARAMETER	VALUE
G_0	864 Pa

Table 2: Material Constants Used With the Crushed Salt Backfill Model

PARAMETER	VALUE
G_1	6.53×10^{-3} m^3/kg
K_0	1.41×10^3 Pa
K_1	6.53×10^{-3} m^3/kg
A	5.79×10^{-36} $Pa^{-4.9} sec^{-1}$
n	4.9
Q/RT	20.13
A^*	-17.3×10^{-3} m^3/kg
B_0	1.3×10^8 kg $(m^3\ sec)^{-1}$
B_1	0.82×10^{-6} Pa^{-1}

The stress-strain behavior of the waste was represented by a volumetric plasticity model [5] with a piecewise linear function defining the relationship between the mean stress and the volumetric strain. Compaction experiments on simulated waste were used to develop this relationship. The deviatoric response of the waste material has not been characterized. It is anticipated that when a drum filled with loosely compacted waste is compressed axially, the drum will not undergo significant lateral expansion until most of the void space inside the drum has been eliminated.

For the volumetric plasticity model, the yield surface in principal stress space is a surface of revolution with its axis centered about the hydrostat and the open end pointing into the compression direction. The open end is capped with a plane which is at right angles to the hydrostat. The deviatoric part is elastic-perfectly plastic so the surface of revolution is stationary in stress space. The volumetric part has variable strain hardening so the end plane moves outward during volumetric yielding. The volumetric hardening is defined by a set of pressure-volumetric strain relations. A flow rule is used such that deviatoric strains produce no volume change (associated flow). The model is best broken into volumetric and deviatoric parts with the deviatoric part resembling conventional plasticity. The volumetric yield function is a product of two functions describing the surface of revolution and the plane normal to the pressure axis. These are given by

$$\phi_s = \frac{1}{2} s_{ij} s_{ij} - (a_0 + a_1 p + a_2 p^2) \qquad \text{(EQ 11)}$$

$$\phi_p = p - g(\epsilon_v) \qquad \text{(EQ 12)}$$

where a_0, a_1, a_2 are constants defining the yield surface, p is the pressure, and e_v is the volume strain. The form of g is defined in this problem by a set of piecewise linear segments relating pressure-volume strain. Table 3 lists the pressure-volumetric strain data

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Table 3: Pressure-Volumetric Strain Data Used in the Volumetric Plasticity Model for the Waste Drums

PRESSURE (MPa)	$\ln(\rho/\rho_0)$
0.028	0.032
0.733	0.741
1.133	0.898
1.667	1.029
2.800	1.180
10.17	1.536

used for the waste drum model. The elastic material parameters and constants defining the yield surface are given in Table 4.

Table 4: Material Constants Used With the Volumetric Plasticity Model for the Waste

PARAMETER	VALUE
G	333 MPa
K	222 MPa
a_0	0.
a_1	0.
a_2	3.

The three SANCHO analyses were carried out to different simulation times depending on how far the calculation ran before reaching a specified time limit on the computer. These will be indicated in the appropriate results section. The input file for one of the SANCHO analyses is included in Appendix II. The other files are identical except for the title line, and the fact that a different external gas content history file was read for each run (this feature was internal to the code and did not change the input file).

Results of the Analyses

The results of interest are the pressure buildup in the room and the corresponding disposal room porosity. It is these quantities that will be compared with the PA calculational results to assess if the results derived from the earlier disposal room closure calculations are being correctly incorporated in the PA analyses.

Run #18

As previously noted, BRAGFLO Run #18 represents the case of a human intrusion into a practically dry (low brine saturation) panel. This SANCHO calculation was carried out for 2200 years of simulation time. Figure 3 shows the gas pressure within the disposal room computed by SANCHO on the basis of the gas content history coming from Run #18. The pressure increases quickly to its maximum value of slightly greater than 2.0 MPa at the time that the human intrusion occurs at 1000 years. The effect of the human intrusion is to suddenly drop the pressure from this maximum to a lower value of around 1.3 MPa. Thereafter, the pressure remains around this lower value for the remainder of the simulation. Shown as well in the figure is a plot of the column labelled "PRESWAST" coming from Table I of Appendix I. This quantity is the waste gas pressure in Pascals computed by BRAGFLO. It can be seen that the maximum gas pressure computed with BRAGFLO is slightly greater than 1.8 MPa. This curve follows the same trend as that for the SANCHO run in that after the human intrusion occurs, the pressure drops to a value that remains relatively steady at a value slightly greater than 1.1 MPa. Thus, there is a difference of approximately 10 % between the SANCHO and the BRAGFLO gas pressure results.

Figure 4 shows the corresponding room porosity history computed by SANCHO. The porosity drops quickly as the room closes and continues to decrease throughout the simulation, reaching a value of about 0.22 at the end. The rate of decrease has slowed down significantly by this time, and the porosity will thus probably level off at around that value. The room pressure at the time of the human intrusion is such that its effect on the porosity history is almost imperceptible, appearing only as a slight blip at 1000 years on this curve. Shown in the figure also is a porosity value computed from the BRAGFLO results provided in Appendix I. This porosity value was computed by using the following equation,

$$\varphi = (PORVOLW/12.65) / (PORVOLW/12.65 + 1229), \qquad \text{(EQ 13)}$$

where "PORVOLW" is the waste pore volume in cubic meters coming from the column labelled as such in Table I of Appendix I, 12.65 is the number of rooms per panel, and 1229 is the volume of solids in the room. The value of porosity from BRAGFLO computed on this basis is seen to asymptote to a value slightly greater than 0.26. Thus, the minimum value of porosity computed with BRAGFLO appears to be about 18 % greater than the minimum computed with SANCHO.

Run #42

BRAGFLO Run #42 represents an undisturbed, practically dry (low brine saturation) repository. The SANCHO calculation in this case was carried out for about 3500 years. Figure 5 shows the computed room gas pressure history from SANCHO. The room pressure rises quickly for about the first 350 to 400 years of the simulation and reaches a value of around 9.0 MPa. Thereafter, it slowly decreases for about 500 years and then slowly increases for the remainder of the simulation period reaching a value just below 9.5 MPa at that time. The BRAGFLO results ("PRESWAST" from Table II of Appendix I) are also seen in the figure. This curve exhibits a more gradual increase with time, earlier,

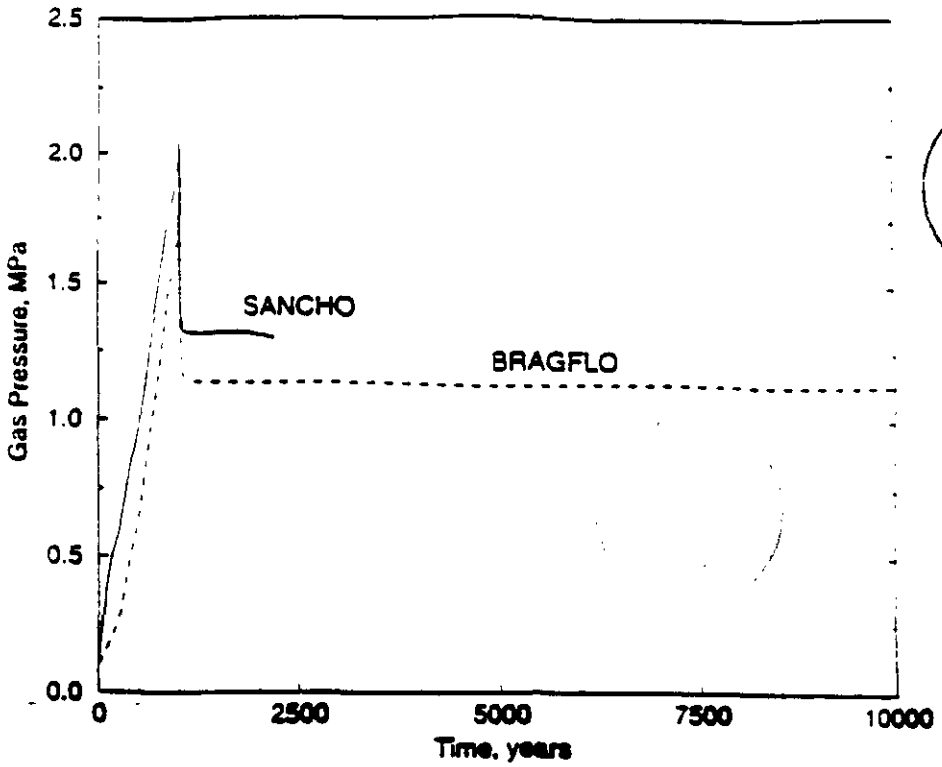

Figure 3. Comparison of Gas Pressure Histories for Run #18

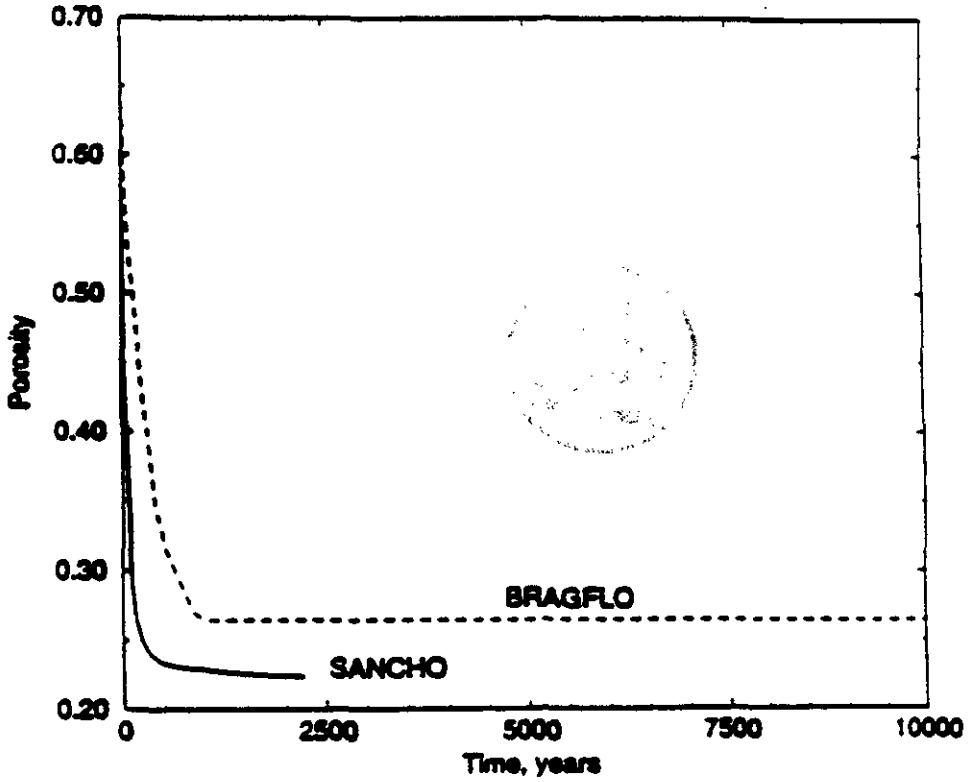

Figure 4. Comparison of Room Porosity Histories for Run #18

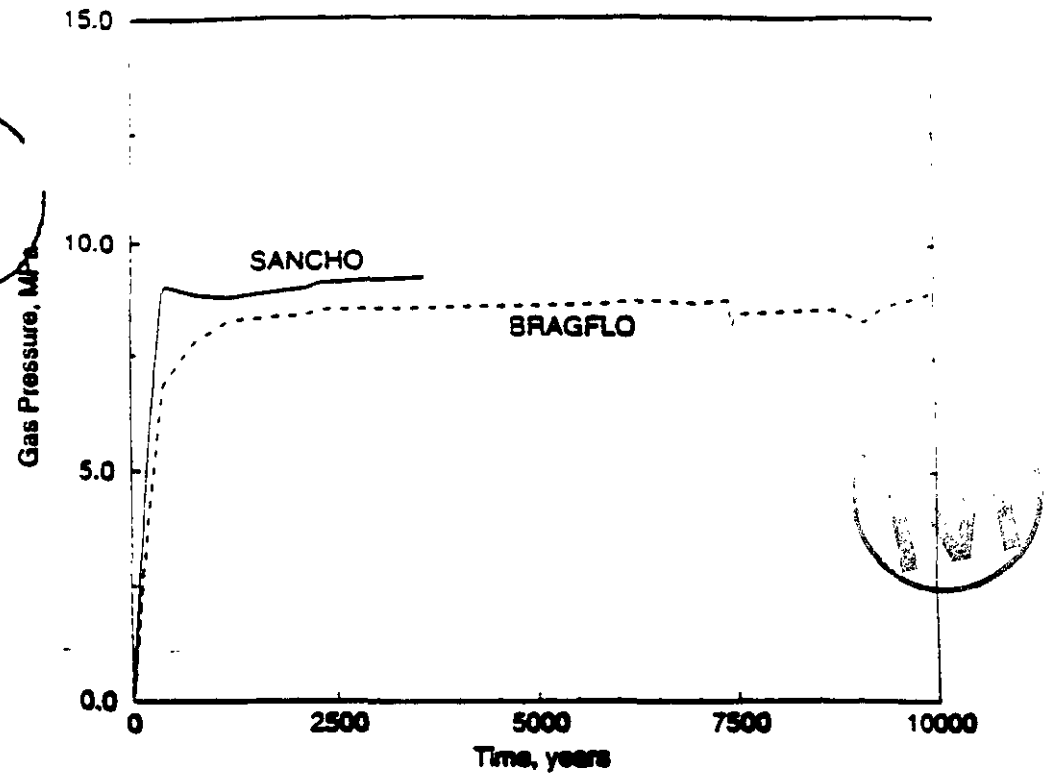

Figure 5. Comparison of Gas Pressure Histories for Run #42

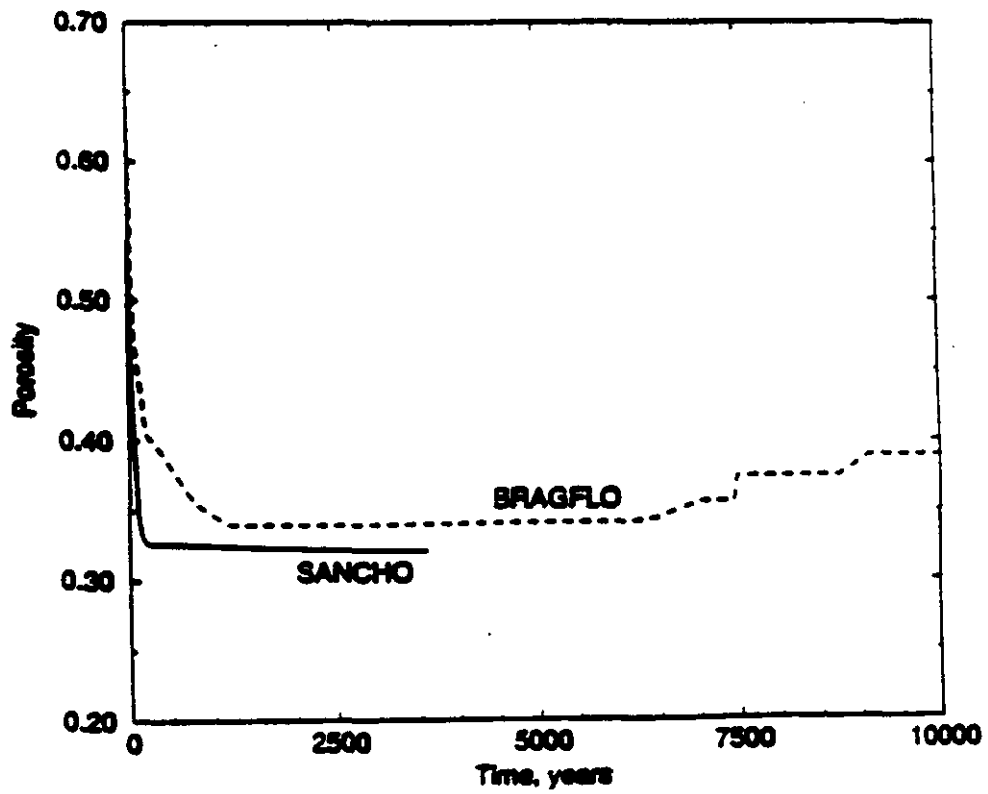

Figure 6. Comparison of Room Porosity Histories for Run #42

to a value of about 8.5 MPa at 3500 years. The pressure increases with time thereafter, but only to a value slightly greater than 8.5 MPa. Once again, as was the case with Run #18, the pressure computed with BRAGFLO remains smaller than that computed with SANCHO. At 3500 years, the BRAGFLO value is approximately 9 % smaller than that computed with SANCHO.

Figure 6 shows the corresponding room porosity histories for both SANCHO and BRAGFLO. For SANCHO, the porosity drops quickly from its initial value to a value of about 0.33 within the first 200 to 250 years. Thereafter, it drops by an extremely small amount for the remainder of the calculation to a value slightly greater than 0.32 at 3500 years. The BRAGFLO results come from using "PORVOLW" in Table II of Appendix I and Equation 13 with 119.64 rooms per repository, instead of the 12.65 rooms per panel. The porosity in this case is seen to decrease more slowly to a value of about 0.34 at around 150 years, remaining practically constant for the next 6000 years. Thus, at 3500 years, the BRAGFLO result is approximately 5 % larger than that for SANCHO.

Run #63

BRAGFLO Run #63 represents a human intrusion into a panel that becomes largely brine saturated. The SANCHO calculation for this case was carried out for about 8800 years. Figure 7 shows the computed room gas pressure histories for both SANCHO and BRAGFLO. For the SANCHO curve, the pressure rises to a maximum value of about 12.5 MPa in 1000 years, at which time the human intrusion event occurs. The human intrusion results in a tremendous drop in the pressure to a minimum value of about 0.15 MPa at about 1200 years. Thereafter, the pressure increases by a small amount to a value of about 1.25 MPa at about 1700 years and remains constant through the end of the simulation. The BRAGFLO results ("PRESWAST" from Table III of Appendix I) show a similar trend, except that the pressure rises more quickly initially, drops less after the human intrusion, and rises to a much larger value subsequently. Thus, the BRAGFLO curve shows a rise to about 15 MPa in about 300 to 400 years, slowly decreasing by a slight amount until the human intrusion event occurs at 1000 years. The human intrusion results in a drop to a value of about 4.5 MPa at about 1200 years. Thereafter, the pressure increases by a significant amount to a value of about 11.7 MPa at about 1700 years and remains constant. Thus, at the end of the SANCHO simulation, at 8800 years, the BRAGFLO gas pressure is about 8.5 times bigger than that for SANCHO.

Figure 8 shows the corresponding room porosity histories for both SANCHO and BRAGFLO. For the SANCHO curve, the room porosity quickly drops to a value of about 0.27 at about 250 years and increases very slightly until the human intrusion event occurs. The effect of the human intrusion is to drop the pressure by a tremendous amount allowing the room to close considerably, leading to a significant decrease in the room porosity. Thus, within the next 1500 years, the porosity drops to a value slightly over 0.22. Thereafter the decrease in porosity slows considerably and appears to asymptote to the 0.22 value. The BRAGFLO results come from using "PORVOLW" in Table III of Appendix I and Equation 13. The porosity in this case is seen to drop quickly to a value of about 0.36 at about 250 years, increase quickly to a value of about 0.39 at 400 years, and remain fairly

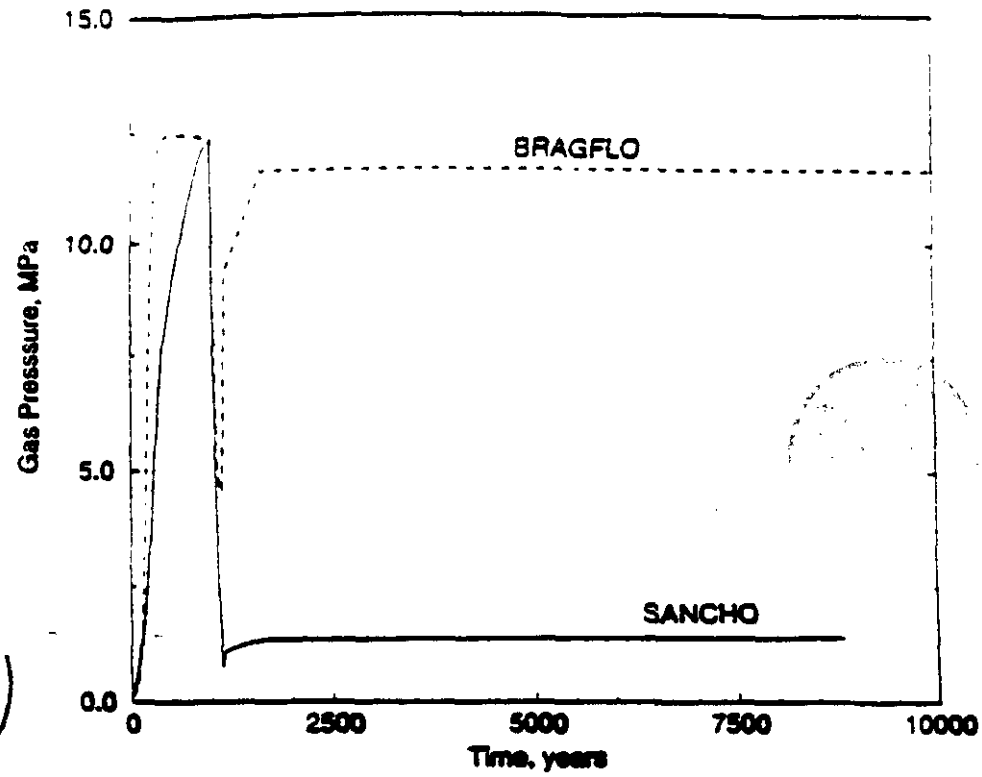

Figure 7. Comparison of Gas Pressure Histories for Run #63

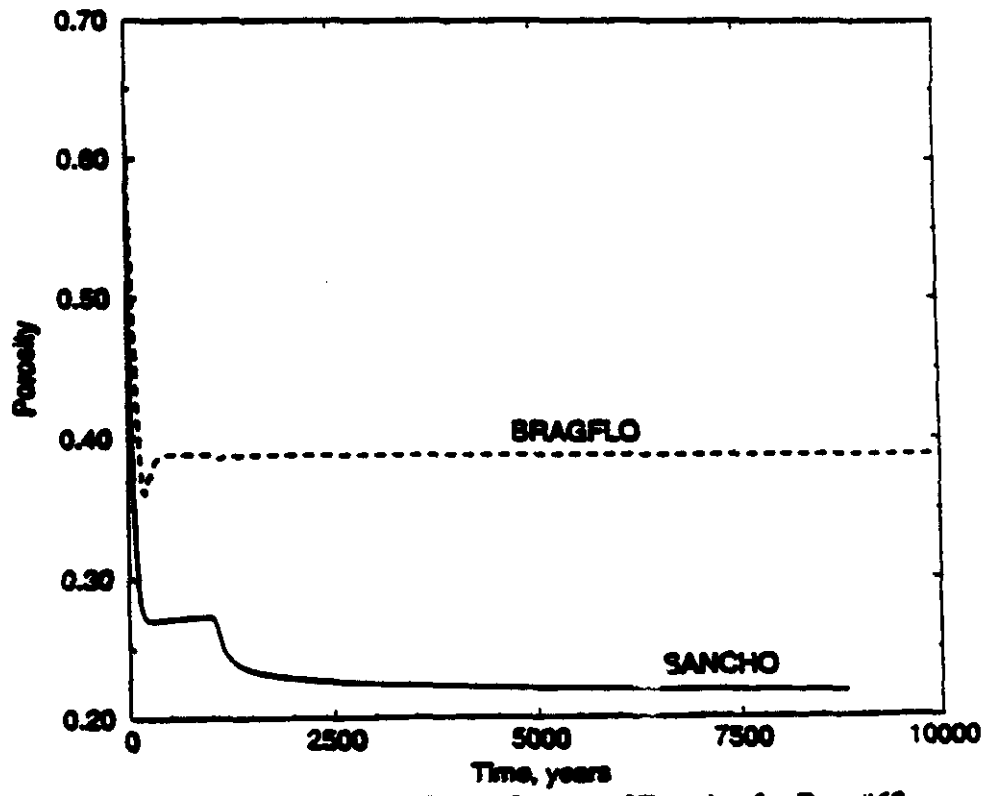

Figure 8. Comparison of Room Porosity Histories for Run #63

constant thereafter, except for a minute blip during the human intrusion. Thus, at 8800 years, the BRAGFLO value of room porosity is about 77 % greater than the value computed with SANCHO.

Summary and Conclusions

Because recasting of the calculational results for closure of a disposal room model into suitable input for use in performance assessment compliance analyses requires various simplifications and assumptions, all of which have the potential of introducing uncertainty into the results, several calculations to check the validity of the recasting procedure have been performed. The process began by recovering information on the variation in gas content and porosity with time around the waste/backfill region of a disposal room from a performance assessment compliance calculation. This information included the effects of closure of the room indirectly via the concept of a "porosity surface." The gas versus time data was then used as the gas-generation input for a disposal room closure calculation with the SANCHO computer code. The results were then compared with the original porosity history recovered from the performance assessment calculation.

Three cases were investigated: a human intrusion into a practically dry (low brine saturation) panel – Run #18; an undisturbed, practically dry (low brine saturation) repository – Run #42; and a human intrusion into a panel that becomes largely brine saturated – Run #63. Satisfactory agreement was observed between the performance assessment porosity histories and the more detailed histories computed with SANCHO for repository environments with low brine saturations. Results differed, however, for the third case when saturation of the repository occurred.

The discrepancy for the third case may be due to the assumption in the SANCHO calculations, that all void volume in the room is occupied by gas (and this has always been the case, even in the original calculations used to generate the porosity surface), whereas the BRAGFLO calculations explicitly include brine saturation. For the case when the room becomes largely brine saturated, this effect may prove significant. A future calculation for this case using SANCHO is planned in which the void volume in the room at any time will be reduced by the volume of brine in the room (this information will also come from the BRAGFLO run). This calculation should provide a resolution to the discrepancy.

References

1. Butcher, B. M., "Performance Assessment Verification Calculations," Memorandum to C. M. Stone and J. G. Argüello, 1561, Sandia National Laboratories, Albuquerque, New Mexico, July 30, 1993.

2. Mendenhall, F. T. and R. C. Lincoln, "Single-Room Porosity History for Baseline Waste Form and Gas Generation Rates," Memorandum to D. R. Anderson, 6342, Sandia National Laboratories, Albuquerque, New Mexico, February 28, 1992.

3. Stone, C. M., "Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt Due to Gas Generation Produced by Several Alternatives of the Engineered Alternatives Task Force," Memorandum to B. M. Butcher, 6345, Sandia National Laboratories, Albuquerque, New Mexico, October 6, 1992.

4. Beraún, R. and P. B. Davies, "Baseline Design Input Data Base to be Used During Calculations Effort to be Performed by Division 1514 in Determining the Mechanical Creep Closure Behavior of Waste Disposal Rooms in Bedded Salt," Memorandum to Distribution, Sandia National Laboratories, Albuquerque, New Mexico, September 12, 1991.

5. Stone, C. M., R. D. Krieg, and Z. E. Beisinger, *SANCHO - A Finite Element Computer Program for the Quasistatic, Large Deformation, Inelastic Response of Two-Dimensional Solids*, SAND84-2618, Sandia National Laboratories, Albuquerque, New Mexico, April, 1985.

6. Argüello, J. G., "Use of Midheight Symmetry Plane to Compute Disposal Room Closure," Memorandum to Distribution, Sandia National Laboratories, Albuquerque, NM, January 1990.

7. Krieg, R. D., *Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project*, SAND83-1908, Sandia National Laboratories, Albuquerque, New Mexico, 1984.

8. Morgan, H. S. and R. D. Krieg, *A Comparison of Unified Creep-Plasticity and Conventional Creep Models for Rock Salt Based on Predictions of Creep Behavior Measured in Several In Situ and Bench-Scale Experiments*, SAND87-1867, Sandia National Laboratories, Albuquerque, NM, 1988.

9. Weatherby, J. R., J. G. Argüello, B. M. Butcher, and C. M. Stone, "The structural response of a WIPP disposal room with internal gas generation," *Proceedings of the 32nd U. S. Rock Mechanics Symposium*, Norman, OK, July, 1991.

10. Weatherby, J. R., W. T. Brown, and B. M. Butcher, "The closure of WIPP disposal rooms filled with various waste and backfill combinations," *Proceedings of the 32nd U. S. Rock Mechanics Symposium*, Norman, OK, July, 1991.

11. Sjaardema, G. D. and R. D. Krieg, *A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analyses of Backfilled Shaft and Drift Configurations*, SAND87-1977, Sandia National Laboratories, Albuquerque, New Mexico, 1987.

Appendix I

Results From PA's 1992 Compliance Analysis Using BRAGFLO – Transmittal From B. M. Butcher, 6345, of 7/19/93 (Data Provided by Jim Bean, 6342)

THE DATA IN FILES GROPE_018.DAT, GROPE_043.DAT, AND GROPE_063.DAT
IS OUTPUT FROM BRAGFLO. FILES ARE IN DIRECTORY U7:[JEREMY.BUTCHER]

VARIABLE	DEFINITION
N	= DATABASE STEP NUMBER
TIME	= ELAPSED TIME IN SECONDS
GASRATV	= GAS GENERATION RATE IN CUBIC METERS/SEC
GASRATM	= GAS GENERATION RATE IN MOLES/SEC
SBRAVG	= AVERAGE BRINE SATURATION IN WASPE
PORVOLW	= WASPE PORE VOLUME (GAS AND BRINE) IN CUBIC METERS
PRESGAS	= WASPE (GAS) PRESSURE IN PASCALS
POROSITY	= POROSITY OF WASPE (VOID VOLUME/TOTAL VOLUME)
GASVOLW	= GAS VOLUME IN WASPE (CUBIC METERS AT P=101325 PA AND T=300.15K)
GASVOL	= GAS VOLUME AT RESERVOIR CONDITIONS (CUBIC METERS AT P=PRESGAS)
GASGEN	= CUMULATIVE GAS GENERATED IN WASPE (CUBIC METERS AT P=101325)
	= INTERPOLATED VALUES OF GASGEN ACCORDING TO FOLLOWING:
	GASGEN(T=0) = 0
	GASGEN(T) = GASGEN(T-DT) + 0.5*DT*(GASGEN(T) + GASGEN(T-DT))

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Table I. Grope File From PA's Compliance Analysis - Run # 18 (GROPE_018.DAT)

Step	Time	GASCONV	GASCONS	SBAVN	PORVOLM	PRESMAST	POROSITY	GASVOLM	GASVOL	GASGENC
1	0.00000E+00	0.00000E+00	0.00000E+00	6.29700E-02	3.04292E+04	1.01325E+05	6.50179E-01	2.05133E+04	2.05133E+04	0.00000E+00
2	1.13329E+06	4.06600E-06	1.66306E-04	6.29700E-02	3.04090E+04	1.01336E+05	6.59740E-01	2.04971E+04	2.04941E+04	2.36398E+00
3	4.70155E+06	4.06661E-06	1.66331E-04	6.29932E-02	2.65173E+04	1.07801E+05	5.75305E-01	2.46535E+04	2.48668E+04	1.90965E+03
4	1.11396E+07	4.06733E-06	1.66361E-04	6.30212E-02	2.33235E+04	1.10097E+05	5.06016E-01	2.56410E+04	2.10536E+04	4.52783E+03
5	1.80556E+07	4.06787E-06	1.66382E-04	6.30619E-02	2.06630E+04	1.11746E+05	4.63913E-01	2.49235E+04	1.91711E+04	7.34090E+03
6	2.36763E+07	4.06819E-06	1.66396E-04	6.30846E-02	1.82307E+04	1.14604E+05	3.95482E-01	2.43817E+04	1.70793E+04	9.62750E+03
7	7.08020E+07	4.06980E-06	1.67038E-04	6.26509E-02	1.15644E+04	1.41872E+05	2.50462E-01	2.79112E+04	1.40895E+04	3.21336E+04
8	1.21777E+10	4.16903E-06	1.69742E-04	6.01663E-02	8.31401E+03	4.03693E+05	1.78225E-01	3.72176E+04	7.67125E+03	4.97870E+04
9	1.50066E+10	4.17600E-06	1.70006E-04	6.72072E-02	7.46059E+03	6.03958E+05	1.61862E-01	4.13612E+04	6.95918E+03	6.35560E+04
10	1.87708E+10	4.18519E-06	1.73382E-04	6.75613E-02	7.24530E+03	6.45509E+05	1.57191E-01	4.23865E+04	6.75580E+03	6.47873E+04
11	2.78394E+10	4.31575E-06	1.76605E-04	7.27663E-02	5.72315E+03	1.45897E+06	1.23950E-01	7.55319E+04	5.29755E+03	1.14081E+05
12	3.02437E+10	4.33594E-06	1.77367E-04	7.33678E-02	5.63526E+03	1.50357E+06	1.22260E-01	8.09175E+04	5.32181E+03	1.26073E+05
13	3.15570E+10	4.36564E-06	1.77736E-04	7.37330E-02	5.59177E+03	1.69360E+06	1.21317E-01	8.57835E+04	5.17947E+03	1.32208E+05
14	3.15570E+10	4.36030E-06	1.77832E-04	7.36630E-02	5.58891E+03	1.74783E+06	1.21276E-01	8.66634E+04	5.17713E+03	1.32208E+05
15	3.15571E+10	4.36032E-06	1.77854E-04	7.36561E-02	5.58891E+03	1.74788E+06	1.21276E-01	8.66644E+04	5.17706E+03	1.32208E+05
16	3.15585E+10	4.35379E-06	1.78077E-04	7.40753E-02	5.58892E+03	1.76831E+06	1.21276E-01	8.66652E+04	5.17584E+03	1.32215E+05
17	3.15957E+10	4.69600E-06	1.83037E-04	7.95840E-02	5.59063E+03	1.76136E+06	1.21279E-01	8.05869E+04	5.16515E+03	1.32379E+05
18	3.17401E+10	5.19671E-06	2.12554E-04	1.06543E-01	5.59065E+03	1.83053E+06	1.21292E-01	8.93440E+04	4.99500E+03	1.33110E+05
19	3.17622E+10	5.24560E-06	2.16557E-04	1.06620E-01	5.59070E+03	1.83563E+06	1.21293E-01	8.93963E+04	4.98651E+03	1.33191E+05
20	3.17627E+10	5.24609E-06	2.16576E-04	1.06646E-01	5.59070E+03	1.83563E+06	1.21293E-01	8.93932E+04	4.98642E+03	1.33194E+05
21	3.17800E+10	5.24943E-06	2.16710E-04	1.06570E-01	5.59060E+03	1.83604E+06	1.21293E-01	8.93120E+04	4.98370E+03	1.33222E+05
22	3.18146E+10	5.33602E-06	2.16198E-04	1.06062E-01	5.58814E+03	1.77293E+06	1.21281E-01	8.66072E+04	4.98595E+03	1.33466E+05
23	3.23069E+10	5.83636E-06	2.85914E-04	1.00202E-01	5.58564E+03	1.26030E+06	1.21184E-01	6.25330E+04	5.02550E+03	1.35994E+05
24	3.31490E+10	6.97472E-06	3.03674E-04	9.79843E-02	5.58459E+03	1.15203E+06	1.21141E-01	5.49674E+04	5.03739E+03	1.40213E+05
25	3.77656E+10	5.00173E-06	3.06579E-04	9.00246E-02	5.58467E+03	1.13904E+06	1.21150E-01	5.62264E+04	5.03167E+03	1.63138E+05
26	5.46325E+10	5.15152E-06	3.18706E-04	1.06796E-01	5.58467E+03	1.13071E+06	1.21150E-01	5.58405E+04	4.99925E+03	2.67769E+05
27	5.87056E+10	5.20516E-06	3.16173E-04	1.09943E-01	5.58467E+03	1.13021E+06	1.21150E-01	5.55515E+04	4.97050E+03	2.70152E+05
28	7.55754E+10	6.61294E-06	3.45939E-04	1.37907E-01	5.58450E+03	1.14206E+06	1.21159E-01	5.39369E+04	4.81391E+03	3.65451E+05
29	1.10135E+11	6.20500E-06	3.57103E-04	1.93093E-01	5.58450E+03	1.14272E+06	1.21159E-01	5.06659E+04	4.50170E+03	5.77972E+05
30	1.44695E+11	3.97181E-06	1.63484E-04	2.45204E-01	5.58441E+03	1.13181E+06	1.21157E-01	4.60047E+04	4.21509E+03	7.55225E+05
31	1.79255E+11	3.83696E-06	1.56930E-04	2.93608E-01	5.58440E+03	1.13089E+06	1.21157E-01	4.37633E+04	3.94437E+03	8.90160E+05
32	1.91797E+11	3.96659E-06	1.62260E-04	3.13293E-01	5.58443E+03	1.13400E+06	1.21157E-01	4.25680E+04	3.83467E+03	9.39096E+05
33	2.00000E+11	4.10017E-06	1.67784E-04	3.24422E-01	5.58443E+03	1.13673E+06	1.21157E-01	4.19817E+04	3.77272E+03	9.72215E+05
34	2.25023E+11	4.32622E-06	1.76950E-04	3.58492E-01	5.58444E+03	1.13560E+06	1.21158E-01	4.00060E+04	3.59922E+03	1.07760E+06
35	2.50002E+11	2.70797E-06	1.10761E-04	3.99322E-01	5.58437E+03	1.12707E+06	1.21156E-01	3.70332E+04	3.35461E+03	1.19915E+06
36	2.94142E+11	2.96682E-06	1.21348E-04	4.68449E-01	5.58430E+03	1.12083E+06	1.21156E-01	3.45276E+04	3.12475E+03	1.29721E+06
37	3.15878E+11	3.13624E-06	1.27869E-04	4.69180E-01	5.58439E+03	1.12941E+06	1.21156E-01	3.29819E+04	2.98329E+03	1.36258E+06

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Table II. Grope File From PA's Compliance Analysis - Run # 42 (GROPE_042.DAT)

Step	Time	GASGENV	GASGENM	SBAVN	PORVOLN	PRESMART	POROSITY	GASVOLN	GASVOL	GASGENC
1	0.00000E+00	0.00000E+00	0.00000E+00	1.99600E-02	2.91726E+05	1.01325E+05	6.60170E-01	2.05909E+05	2.05909E+05	0.00000E+00
2	7.02000E+01	6.44126E-04	3.63650E-02	1.99681E-02	2.91724E+05	1.01327E+05	6.60173E-01	2.05913E+05	2.05907E+05	2.26080E+00
3	2.22192E+06	6.44253E-04	3.63811E-02	2.00629E-02	2.90170E+05	1.02339E+05	6.56657E-01	2.07197E+05	2.06354E+05	1.42907E+03
4	4.16916E+06	6.44600E-04	3.63603E-02	2.02336E-02	2.07526E+05	1.03602E+05	6.50673E-01	2.08259E+05	2.01711E+05	2.60380E+01
5	2.66235E+07	6.48523E-04	3.64030E-02	2.10537E-02	2.75626E+05	1.13160E+05	6.23763E-01	2.01287E+05	2.69823E+05	1.71669E+04
6	3.12879E+08	6.40123E-04	3.65092E-02	2.31136E-02	2.44416E+05	2.00975E+05	5.53115E-01	4.73310E+05	2.30764E+05	2.02130E+05
7	6.56967E+08	6.50709E-04	3.66151E-02	2.510232E-02	2.17287E+05	3.24135E+05	4.91561E-01	6.76671E+05	2.11737E+05	4.24482E+05
8	1.04902E+09	6.556232E-04	3.68161E-02	2.90939E-02	1.80774E+05	5.21613E+05	4.09093E-01	9.01010E+05	1.75515E+05	6.81864E+05
9	2.35755E+09	6.62569E-04	3.70977E-02	3.65751E-02	1.31744E+05	1.30063E+06	2.98130E-01	1.63141E+06	1.27109E+05	1.54427E+06
10	5.00105E+09	6.52453E-04	3.66064E-02	3.65700E-02	1.01771E+05	3.64055E+06	2.30313E-01	3.48796E+06	9.90689E+04	3.80803E+06
11	6.31140E+09	6.49753E-04	3.65760E-02	3.44310E-02	9.86540E+04	6.00601E+06	2.25519E-01	3.75603E+06	9.72211E+04	4.14060E+06
12	1.22170E+10	0.00000E+00	0.00000E+00	0.00000E+00	9.39203E+04	6.04900E+06	2.12542E-01	6.10912E+06	9.39203E+04	6.05945E+06
13	2.44861E+10	0.00000E+00	0.00000E+00	0.00000E+00	8.89603E+04	7.70779E+06	1.83214E-01	5.96288E+06	8.89603E+04	6.05945E+06
14	3.75690E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56201E+04	8.27216E+06	1.71129E-01	5.89269E+06	7.56201E+04	6.05945E+06
15	3.99669E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56216E+04	8.28925E+06	1.71132E-01	5.90422E+06	7.56216E+04	6.05945E+06
16	4.25922E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56233E+04	8.31288E+06	1.71136E-01	5.92019E+06	7.56233E+04	6.05945E+06
17	4.58766E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56251E+04	8.33076E+06	1.71140E-01	5.93266E+06	7.56251E+04	6.05945E+06
18	4.67993E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56260E+04	8.33796E+06	1.71142E-01	5.93761E+06	7.56260E+04	6.05945E+06
19	4.89285E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56266E+04	8.34637E+06	1.71144E-01	5.94338E+06	7.56266E+04	6.05945E+06
20	5.13920E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56275E+04	8.35784E+06	1.71146E-01	5.95103E+06	7.56275E+04	6.05945E+06
21	5.40048E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56289E+04	8.37215E+06	1.71149E-01	5.96105E+06	7.56289E+04	6.05945E+06
22	5.69534E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56302E+04	8.38779E+06	1.71152E-01	5.97177E+06	7.56302E+04	6.05945E+06
23	5.96905E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56313E+04	8.40051E+06	1.71154E-01	5.98048E+06	7.56313E+04	6.05945E+06
24	6.21972E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56320E+04	8.40921E+06	1.71156E-01	5.98643E+06	7.56320E+04	6.05945E+06
25	6.52283E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56328E+04	8.41810E+06	1.71158E-01	5.99253E+06	7.56328E+04	6.05945E+06
26	6.84693E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56338E+04	8.44652E+06	1.71163E-01	6.01061E+06	7.56338E+04	6.05945E+06
27	7.01787E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56390E+04	8.48702E+06	1.71172E-01	6.03973E+06	7.56390E+04	6.05945E+06
28	7.32924E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56425E+04	8.52396E+06	1.71179E-01	6.06503E+06	7.56425E+04	6.05945E+06
29	7.50343E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56437E+04	8.53596E+06	1.71182E-01	6.07322E+06	7.56437E+04	6.05945E+06
30	9.69788E+10	0.00000E+00	0.00000E+00	0.00000E+00	7.56866E+04	8.56338E+06	1.71279E-01	6.09520E+06	7.56866E+04	6.05945E+06
31	1.01288E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.57163E+04	8.56712E+06	1.71346E-01	6.10021E+06	7.57163E+04	6.05945E+06
32	1.05570E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.57459E+04	8.57084E+06	1.71413E-01	6.10512E+06	7.57459E+04	6.05945E+06
33	1.08898E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.57730E+04	8.57601E+06	1.71477E-01	6.11087E+06	7.57730E+04	6.05945E+06
34	1.11540E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.58019E+04	8.58265E+06	1.71540E-01	6.11764E+06	7.58019E+04	6.05945E+06
35	1.14383E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.58319E+04	8.58971E+06	1.71600E-01	6.12405E+06	7.58319E+04	6.05945E+06
36	1.17898E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.58598E+04	8.59672E+06	1.71671E-01	6.13186E+06	7.58598E+04	6.05945E+06
37	1.19942E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.58898E+04	8.60298E+06	1.71739E-01	6.13853E+06	7.58898E+04	6.05945E+06

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Table II. (Continued)

38	1.22976E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.59216E+04	0.60892E+06	1.71811E-01	6.14515E+06	7.59216E+04	6.05945E+06
39	1.25881E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.59514E+04	0.61559E+06	1.71879E-01	6.15209E+06	7.59514E+04	6.05945E+06
40	1.28924E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.59834E+04	0.62144E+06	1.71951E-01	6.15866E+06	7.59834E+04	6.05945E+06
41	1.32047E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.60154E+04	0.62776E+06	1.72023E-01	6.16555E+06	7.60154E+04	6.05945E+06
42	1.35124E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.60451E+04	0.63374E+06	1.72091E-01	6.17202E+06	7.60451E+04	6.05945E+06
43	1.38540E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.60747E+04	0.63770E+06	1.72158E-01	6.17713E+06	7.60747E+04	6.05945E+06
44	1.42443E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.61030E+04	0.63702E+06	1.72357E-01	6.18303E+06	7.61030E+04	6.05945E+06
45	1.50670E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.62240E+04	0.64163E+06	1.72497E-01	6.19199E+06	7.62240E+04	6.05945E+06
46	1.84201E+11	0.00000E+00	0.00000E+00	0.00000E+00	7.62390E+04	0.68034E+06	1.72507E-01	6.22416E+06	7.62390E+04	6.05945E+06
47	1.89400E+11	4.57120E-06	1.86973E-06	1.37743E-06	7.62410E+04	0.71829E+06	1.72534E-01	6.24554E+06	7.62409E+04	6.07181E+06
48	1.91460E+11	4.57437E-06	1.87100E-06	3.03930E-06	7.62747E+04	0.73004E+06	1.72610E-01	6.25604E+06	7.62744E+04	6.08028E+06
49	1.93002E+11	4.57076E-06	1.86952E-06	9.60730E-07	7.63019E+04	0.73712E+06	1.72672E-01	6.26337E+06	7.63016E+04	6.08733E+06
50	1.96376E+11	5.05302E-06	2.06710E-06	4.95602E-06	7.65852E+04	0.74710E+06	1.73313E-01	6.29340E+06	7.65840E+04	6.10357E+06
51	2.00552E+11	5.06009E-06	2.06966E-06	1.75092E-05	7.69070E+04	0.75493E+06	1.74322E-01	6.33174E+06	7.69856E+04	6.12469E+06
52	2.05024E+11	3.79104E-05	1.14150E-03	2.77460E-05	7.74376E+04	0.76074E+06	1.75242E-01	6.37275E+06	7.74355E+04	6.19861E+06
53	2.07996E+11	1.59044E-04	6.53700E-03	4.27207E-05	7.81363E+04	0.76142E+06	1.76623E-01	6.43063E+06	7.81330E+04	6.47741E+06
54	2.12310E+11	1.09049E-04	4.49399E-03	2.65027E-04	7.94400E+04	0.71721E+06	1.79775E-01	6.50510E+06	7.94197E+04	7.05914E+06
55	2.16003E+11	9.07725E-05	4.03996E-04	2.43426E-04	8.02076E+04	0.72327E+06	1.81510E-01	6.57245E+06	8.01001E+04	7.32010E+06
56	2.21440E+11	1.32054E-04	5.43396E-03	4.06492E-04	8.13120E+04	0.68485E+06	1.84010E-01	6.63396E+06	8.12709E+04	7.65903E+06
57	2.23501E+11	5.72600E-05	2.34207E-04	3.03560E-04	8.13120E+04	0.71426E+06	1.84010E-01	6.65567E+06	8.12000E+04	7.00730E+06
58	2.25807E+11	5.71962E-05	2.33934E-04	4.46170E-04	8.13120E+04	0.73006E+06	1.84010E-01	6.66710E+06	8.12757E+04	7.02012E+06
59	2.28031E+11	5.71213E-05	2.33636E-04	5.06167E-04	8.13120E+04	0.74723E+06	1.84010E-01	6.67859E+06	8.12707E+04	7.03283E+06
60	2.31215E+11	1.60951E-04	6.01027E-03	7.25961E-04	8.13120E+04	0.75901E+06	1.84010E-01	6.68570E+06	8.12530E+04	7.04461E+06
61	2.34369E+11	1.76065E-04	7.23409E-03	9.61470E-04	8.13120E+04	0.76892E+06	1.84010E-01	6.69128E+06	8.12330E+04	7.05003E+06
62	2.35514E+11	1.56231E-04	6.14469E-03	3.30242E-03	8.78612E+04	0.19559E+06	1.98705E-01	6.76143E+06	8.75441E+04	7.93057E+06
63	2.37434E+11	1.61164E-04	6.59271E-03	1.19129E-03	8.78612E+04	0.47029E+06	1.98705E-01	6.99257E+06	8.77366E+04	8.23753E+06
64	2.40626E+11	1.52040E-04	6.21903E-03	1.20052E-03	8.78612E+04	0.48205E+06	1.98705E-01	7.00174E+06	8.77350E+04	8.73745E+06
65	2.44028E+11	1.52052E-04	6.21917E-03	1.21064E-03	8.78612E+04	0.49302E+06	1.98705E-01	7.01093E+06	8.77349E+04	9.25472E+06
66	2.46595E+11	1.34230E-04	5.49024E-03	1.25074E-03	8.78612E+04	0.50122E+06	1.98705E-01	7.01646E+06	8.77313E+04	9.45160E+06
67	2.48802E+11	1.37159E-04	5.61002E-03	1.36615E-03	8.78612E+04	0.50730E+06	1.98705E-01	7.02050E+06	8.77231E+04	9.45460E+06
68	2.51804E+11	1.40845E-04	5.76070E-03	1.45994E-03	8.78612E+04	0.51337E+06	1.98705E-01	[illegible]454E+06	8.77130E+04	9.45766E+06
69	2.53530E+11	1.46798E-04	6.00427E-03	1.46394E-03	8.78612E+04	0.52042E+06	1.98705E-01	[illegible]02070E+06	8.76960E+04	9.46130E+06
70	2.56259E+11	1.53366E-04	6.26806E-03	1.84360E-03	8.78612E+04	0.52811E+06	1.98705E-01	7.03341E+06	8.76793E+04	9.46530E+06
71	2.58969E+11	6.92090E-07	2.83000E-05	2.06204E-03	8.78612E+04	0.53351E+06	1.98705E-01	7.03625E+06	8.76630E+04	9.46840E+06
72	2.61501E+11	7.21326E-07	2.95035E-05	2.23430E-03	8.78612E+04	0.53861E+06	1.98705E-01	7.03889E+06	8.76449E+04	9.47024E+06
73	2.64289E+11	7.51806E-07	3.07371E-05	2.43216E-03	8.78612E+04	0.54395E+06	1.98705E-01	7.04169E+06	8.76276E+04	9.47224E+06
74	2.67085E+11	7.82462E-07	3.20040E-05	2.63576E-03	8.78612E+04	0.54953E+06	1.98705E-01	7.04463E+06	8.76097E+04	9.47430E+06
75	2.69880E+11	0.00000E+00	0.00000E+00	2.83916E-03	8.78612E+04	0.55397E+06	1.98705E-01	7.04667E+06	8.75918E+04	9.47540E+06

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Table II. (Continued)

76	2.72685E+11	0.00000E+00	0.00000E+00	3.04342E-03	9.78612E+04	8.55724E+06	1.90785E-01	7.04779E+06	8.75739E+04	9.47548E+04
77	2.75607E+11	1.00100E-06	6.47862E-04	3.23038E-03	9.78612E+04	8.57142E+06	1.90785E-01	7.05759E+06	8.75574E+04	9.49703E+04
78	2.07436E+11	1.63632E-04	6.69262E-03	3.05580E-03	9.36562E+04	8.39932E+06	2.11945E-01	7.28375E+06	9.31827E+04	1.05764E+07
79	2.95007E+11	1.00000E-06	6.40650E-04	3.39571E-03	9.36562E+04	8.62021E+06	2.11945E-01	7.56420E+06	9.33382E+04	1.12558E+07
80	3.00219E+11	3.04370E-06	8.35041E-04	3.66468E-03	9.36562E+04	8.71171E+06	2.11945E-01	7.64011E+06	9.33117E+04	1.13584E+07
81	3.15579E+11	1.00014E-06	6.00000E-04	3.70048E-03	9.36562E+04	8.86930E+06	2.11954E-01	7.85300E+06	9.33137E+04	1.16293E+07

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Table III. Grope File From PA's Compliance Analysis - Run # 63 (GROPE_063.DAT)

Step	Time	GASGENT	GASGENR	SEAVM	PORVOLM	PERMMAST	POROSITY	GASVOLM	GASVOL	GASGENC
1	0.00000E+00	0.00000E+00	0.00000E+00	4.84400E-02	3.06292E+04	1.01325E+05	6.60178E-01	2.90465E+04	2.90465E+04	0.00000E+00
2	0.13062E+05	1.30007E-05	5.31751E-04	4.86399E-02	3.06200E+04	1.01335E+05	6.59996E-01	2.90414E+04	2.90385E+04	1.39005E+00
3	1.06376E+08	1.32744E-05	5.42966E-04	4.87919E-02	2.79072E+04	1.09903E+05	5.96784E-01	2.83993E+04	2.61651E+04	2.62083E+03
4	1.80317E+09	2.21557E-05	9.06266E-04	1.57862E-01	1.03140E+04	2.33603E+05	3.97332E-01	3.55503E+04	1.56284E+04	2.57833E+04
5	2.20402E+09	2.77901E-05	1.13659E-03	2.26665E-01	1.53504E+04	3.65414E+05	3.33035E-01	4.27105E+04	1.10710E+04	4.33084E+04
6	2.82950E+09	3.38560E-05	1.37250E-03	2.97184E-01	1.36192E+04	5.81115E+05	2.91137E-01	5.10690E+04	9.43123E+03	6.24717E+04
7	3.90060E+09	3.47964E-05	1.42160E-03	3.11086E-01	1.30901E+04	5.99612E+05	2.03997E-01	5.29262E+04	9.00740E+03	6.40934E+04
8	3.62161E+09	4.22321E-05	1.73736E-03	4.03461E-01	1.14221E+04	9.82158E+05	2.47809E-01	6.55322E+04	6.81396E+03	9.26469E+04
9	4.38694E+09	5.26130E-05	2.16301E-03	5.20110E-01	9.89349E+03	1.90984E+06	2.14645E-01	8.60736E+04	4.66036E+03	1.30265E+05
10	5.09171E+09	5.65461E-05	2.31276E-03	5.70726E-01	9.37450E+03	2.47859E+06	2.03305E-01	9.50543E+04	3.96923E+03	1.65853E+05
11	5.67662E+09	6.29022E-05	2.57600E-03	6.57872E-01	8.86031E+03	3.07430E+06	1.92403E-01	1.13426E+05	3.03676E+03	2.08810E+05
12	6.49698E+09	6.76941E-05	2.77690E-03	7.17720E-01	8.76675E+03	3.90807E+06	1.90199E-01	1.39702E+05	2.47460E+03	2.56492E+05
13	6.49867E+09	6.79016E-05	2.77729E-03	7.17820E-01	8.76675E+03	3.93753E+06	1.90199E-01	1.40049E+05	2.47300E+03	2.56607E+05
14	6.77256E+09	6.89484E-05	2.82011E-03	7.36641E-01	8.66003E+03	4.66392E+06	1.92616E-01	1.51170E+05	2.30890E+03	2.73340E+05
15	7.52783E+09	6.99416E-05	2.86073E-03	7.42005E-01	9.01890E+03	8.40036E+06	1.95672E-01	1.83430E+05	2.31964E+03	3.25798E+05
16	7.63547E+09	7.01016E-05	2.86725E-03	7.44757E-01	9.09713E+03	8.62101E+06	1.97367E-01	1.87929E+05	2.32190E+03	3.33335E+05
17	7.80930E+09	7.01477E-05	2.86916E-03	7.45129E-01	9.15496E+03	9.16936E+06	1.98622E-01	2.00101E+05	2.33150E+03	3.51128E+05
18	8.68144E+09	6.99059E-05	2.81037E-03	7.30131E-01	9.36332E+03	1.03693E+07	2.03142E-01	2.43756E+05	2.52696E+03	4.06210E+05
19	9.14651E+09	6.88009E-05	2.76662E-03	7.20017E-01	9.45553E+03	1.08907E+07	2.05143E-01	2.67238E+05	2.64739E+03	4.38064E+05
20	9.52241E+09	6.72269E-05	2.74969E-03	7.09557E-01	9.53360E+03	1.12513E+07	2.06038E-01	2.80438E+05	2.76899E+03	4.63495E+05
21	9.76114E+09	6.66052E-05	2.72734E-03	7.03923E-01	9.57703E+03	1.14665E+07	2.07779E-01	3.01183E+05	2.86512E+03	4.79479E+05
22	9.98549E+09	6.61768E-05	2.70674E-03	6.96696E-01	9.61301E+03	1.16059E+07	2.08560E-01	3.12671E+05	2.91566E+03	4.94383E+05
23	1.02439E+10	6.58059E-05	2.68258E-03	6.89460E-01	9.65161E+03	1.17568E+07	2.09397E-01	3.25324E+05	2.99721E+03	5.11202E+05
24	1.04877E+10	6.50483E-05	2.66059E-03	6.82076E-01	9.68416E+03	1.18705E+07	2.10103E-01	3.36564E+05	3.07108E+03	5.27333E+05
25	1.08644E+10	6.42327E-05	2.62723E-03	6.72867E-01	9.72765E+03	1.20376E+07	2.11067E-01	3.52888E+05	3.18284E+03	5.51681E+05
26	1.12976E+10	6.32712E-05	2.58790E-03	6.61111E-01	9.77300E+03	1.21481E+07	2.12031E-01	3.70662E+05	3.31196E+03	5.79285E+05
27	1.17052E+10	6.22461E-05	2.54597E-03	6.48557E-01	9.81432E+03	1.22624E+07	2.12927E-01	3.88790E+05	3.44917E+03	6.09899E+05
28	1.24503E+10	6.09664E-05	2.49372E-03	6.32911E-01	9.85861E+03	1.23258E+07	2.13888E-01	4.10519E+05	3.61899E+03	6.50874E+05
29	1.30740E+10	5.99044E-05	2.45044E-03	6.19831E-01	9.87022E+03	1.24100E+07	2.14140E-01	4.28354E+05	3.75235E+03	6.88616E+05
30	1.37323E+10	5.88734E-05	2.40802E-03	6.07351E-01	9.87274E+03	1.24544E+07	2.14195E-01	4.44117E+05	3.87751E+03	7.27662E+05
31	1.57788E+10	5.60059E-05	2.29090E-03	5.73181E-01	9.87613E+03	1.26789E+07	2.14225E-01	4.86757E+05	4.22434E+03	8.85171E+05
32	1.62988E+10	5.51079E-05	2.25401E-03	5.62055E-01	9.87613E+03	1.26770E+07	2.14225E-01	4.96290E+05	4.32433E+03	8.73617E+05
33	1.93469E+10	4.92261E-05	2.01343E-03	5.15267E-01	9.87613E+03	1.26615E+07	2.14225E-01	5.68690E+05	4.78632E+03	1.03298E+06
34	2.14110E+10	4.69176E-05	1.91901E-03	4.86730E-01	9.87613E+03	1.26507E+07	2.14225E-01	5.80521E+05	5.06869E+03	1.13334E+06
35	2.28364E+10	4.46916E-05	1.80358E-03	4.67366E-01	9.87613E+03	1.26392E+07	2.14225E-01	6.01907E+05	5.25930E+03	1.20145E+06
36	2.63250E+10	4.27993E-05	1.75056E-03	4.50710E-01	9.87613E+03	1.26316E+07	2.14225E-01	6.20367E+05	5.42360E+03	1.26287E+06
37	2.86704E+10	4.16507E-05	1.70359E-03	4.35968E-01	9.87613E+03	1.26263E+07	2.14225E-01	6.36793E+05	5.56952E+03	1.31085E+06

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Table III. (Continued)

38	2.69221E+10	4.05067E-05	1.66007E-03	4.22268E-01	9.07613E+03	1.24216E+07	2.14225E-01	6.52010E+05	5.70460E+03	1.37032E+06
39	2.84870E+10	3.07610E-05	1.28021E-03	4.07532E-01	9.07613E+03	1.23097E+07	2.14225E-01	6.67041E+05	5.85011E+03	1.42614E+06
40	3.15570E+10	1.78064E-05	7.31992E-04	3.89731E-01	9.07613E+03	1.23042E+07	2.14225E-01	6.82722E+05	6.02588E+03	1.50083E+06
41	3.15571E+10	1.77774E-05	7.27125E-04	3.88192E-01	9.07623E+03	1.23006E+07	2.14227E-01	6.84330E+05	6.04113E+03	1.50083E+06
42	3.15620E+10	1.77760E-05	7.27067E-04	3.88184E-01	9.07623E+03	1.23000E+07	2.14227E-01	6.84275E+05	6.04121E+03	1.50092E+06
43	3.15640E+10	1.77754E-05	7.27042E-04	3.88181E-01	9.07623E+03	1.23003E+07	2.14227E-01	6.84213E+05	6.04124E+03	1.50097E+06
44	3.15792E+10	1.77776E-05	7.27134E-04	3.88196E-01	9.07393E+03	1.22818E+07	2.14220E-01	6.83203E+05	6.04091E+03	1.50123E+06
45	3.16495E+10	1.77341E-05	7.24945E-04	3.88012E-01	9.06897E+03	1.19602E+07	2.14113E-01	6.65917E+05	6.03100E+03	1.50244E+06
46	3.16700E+10	1.77700E-05	7.24857E-04	3.85344E-01	9.06596E+03	1.17773E+07	2.14047E-01	6.55210E+05	6.02671E+03	1.50290E+06
47	3.17428E+10	1.78053E-05	7.31560E-04	3.90708E-01	9.05976E+03	1.13848E+07	2.13913E-01	6.32669E+05	6.00668E+03	1.50414E+06
48	3.31106E+10	1.68920E-05	7.72760E-04	4.06725E-01	9.03034E+03	9.81667E+06	2.13275E-01	5.19030E+05	5.83200E+03	1.51090E+06
49	3.34004E+10	2.05061E-05	1.16922E-03	5.32202E-01	9.77324E+03	5.07571E+06	2.12036E-01	2.56390E+05	4.57190E+03	1.54152E+06
50	3.37009E+10	2.26907E-05	1.33710E-03	5.05461E-01	9.76474E+03	5.33176E+06	2.11051E-01	2.06438E+05	4.04707E+03	1.55097E+06
51	3.46286E+10	4.40536E-05	1.80107E-03	7.36095E-01	9.75691E+03	4.70206E+06	2.11630E-01	1.16032E+05	2.57437E+03	1.58626E+06
52	3.50058E+10	4.01326E-05	1.96070E-03	7.05031E-01	9.75367E+03	4.62316E+06	2.11611E-01	9.26421E+04	2.00893E+03	1.60365E+06
53	3.57023E+10	4.95106E-05	2.03507E-03	9.26040E-01	9.75260E+03	4.55461E+06	2.11500E-01	3.21100E+04	7.32927E+02	1.64156E+06
54	3.61919E+10	4.95041E-05	2.02400E-03	9.33100E-01	9.70399E+03	6.56269E+06	2.12269E-01	4.07071E+04	6.53600E+02	1.66184E+06
55	3.68346E+10	4.95310E-05	2.02590E-03	9.39150E-01	9.02750E+03	9.33610E+06	2.13213E-01	5.22554E+04	5.98004E+02	1.69366E+06
56	5.16059E+10	1.67392E-05	6.84663E-04	8.44144E-01	9.86350E+03	1.16213E+07	2.13994E-01	5.91643E+04	5.50936E+02	2.18311E+06
57	7.51626E+10	1.91795E-10	7.84475E-09	9.46560E-01	9.86394E+03	1.16241E+07	2.13995E-01	5.66124E+04	5.27029E+02	2.38027E+06
58	1.09723E+11	1.91795E-10	7.84475E-09	9.46763E-01	9.86398E+03	1.16521E+07	2.14005E-01	5.65363E+04	5.25129E+02	2.38028E+06
59	1.44203E+11	1.91795E-10	7.84475E-09	9.46790E-01	9.86402E+03	1.16567E+07	2.14005E-01	5.65196E+04	5.24865E+02	2.38029E+06
60	1.78043E+11	1.91795E-10	7.84475E-09	9.46781E-01	9.86396E+03	1.16503E+07	2.14004E-01	5.65005E+04	5.24950E+02	2.38029E+06
61	2.13403E+11	1.91795E-10	7.84475E-09	9.46763E-01	9.86306E+03	1.16448E+07	2.14002E-01	5.64903E+04	5.25123E+02	2.38030E+06
62	2.47963E+11	1.91795E-10	7.84475E-09	9.46742E-01	9.86376E+03	1.16370E+07	2.13999E-01	5.64801E+04	5.25323E+02	2.38031E+06
63	2.82523E+11	1.91795E-10	7.84475E-09	9.46721E-01	9.86363E+03	1.16298E+07	2.13997E-01	5.64777E+04	5.25524E+02	2.38031E+06
64	3.15570E+11	1.91795E-10	7.84475E-09	9.46700E-01	9.86352E+03	1.16228E+07	2.13994E-01	5.64671E+04	5.25726E+02	2.38032E+06

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Appendix II

Input File for SANCHO (Version 2.0.0) Run

```
PRESSURIZED ROOM CALCULATION  - MOLES VS TIME FROM BRAGFLO RUN 42
CONTROL,3,2,0,3
PLANE
ELEMENTS,1
ISTRESS,CONSTANT,-14.8E6,-14.8E6,-14.8E6
ISTRESS,OFF,2,3
NODES,1
DXSCALE,.5
PLOT,ELEMENT,STRESS,STRAIN,STATE
PLOT,NODAL,DISP,TEMP,RESIDUAL
PLOT,GLOBAL,RMAG,ITER
PLIMIT,.2E6
SOLUTION,10.,100,2500,100.
TIMESTEP,0.,400000,3.1536E11
TIMEPRNT,0.,3.1536E9,3.1536E11
TIMEPLOT,0.,1.5768E7,3.1536E7,1.5768E8,3.1536E9,3.1536E8,6.3072E10,*
3.1536E9,3.1536E11
ENDSET
MATERIAL,5,1.,0.,0.0
***HALITE***
1.984E9,1.656E9,5.79E-36,4.9,20.13,0,.005
MATERIAL,7,1.,0.,0.
   * * CRUSHED SALT BACKFILL * *
848.,6.53E-3,1408.,6.53E-3,5.79E-36,4.9,20.13,*
-17.3E-3,0.0,1.3E8,0.82E-6,1.300E3,2140.,.000S
MATERIAL,2,1.,0.,0.
* * CRUSHABLE FOAM MODEL FOR DRUMS * *
3.333E8,2.223E8,0.,0.,3.
.03230,.0283E6,.741,.733E6,.898,1.133E6,1.029,1.667E6,*
1.18,2.8E6,1.536,18.167E6
ENDSET
DISPR,1
DISPZ,2
PRESSURE,300,0.
CENTER,0.,0.
PRESSURE,200,14.8E6
PRESTORY,0.,1.0,1.0E12,1.
END
```

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PEER 25 - Technical Support Group Review

TECHNICAL SUPPORT GROUP REVIEW OF EXPERIMENTAL PLAN FOR TRACER-TESTING IN THE CULEBRA DOLOMITE

ADVANCED SCIENCES, INC.

1342
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J.T. copy

February 22, 1993

Mr. W. John Arthur, III
Project Director
WIPP Project Integration Office
6501 Americas Parkway, Suite 903
Albuquerque, NM 87110

Attn: Patrick Higgins, WPIO
Mark Matthews, WPIO
Ravi Batra, WPSO

Re: Transmittal of the Technical Support Groups' Report of Findings on Culebra Tracer Testing

Dear Mr. Arthur:

The Technical Support Group (TSG) was tasked to provide the WPIO Configuration Control Board with recommendations that could facilitate a decision on funding of the SNL proposed Experimental Plan for Tracer Testing in the Culebra Dolomite at the WIPP Site, dated October 15, 1992. Enclosed are four copies of the Technical Support Group Report on Culebra Tracer Testing.

The report is specific to the questions that were asked of the TSG. However, there are several significant issues that were identified during the course of the TSG's analysis of the proposed test plan that are of concern to the TSG. In the interest of expediting the subject report, the TSG will prepare a separate follow on letter report that addresses the additional concerns. The letter report will be to you by the end of February.

6739 Academy Road NE Albuquerque, NM 87109-3345 (505) 828-0959 FAX (505) 828-0173

The recommendations from the TSG are:

1. The types of tests outlined in the reviewed test plan are helpful in resolving the hydrogeologic characterization of the Culebra. However, the test plan should be augmented to present a program that addresses a broader set of issues than the preliminary version does. This augmented plan should also address cost and schedule optimization for the program outlined in the revised plan. The "final" test plan is currently scheduled for completion in September 1993. The TSG recommends the technical questions listed below, at a minimum, be addressed in the final plan.

   A. How will the tests discriminate among candidate conceptual flow models and serve to validate the appropriate choice or combination of choices for the Culebra?

   B. How will the question of "scale-up" of the field flow results to a grid size that matches the grid utilized in performance assessment be approached?

   C. What is the basis for location of the test site(s) and, if preliminary drilling is deemed advantageous, where precisely will it be done and why was that site chosen?

   D. Is it desirable to incorporate existing pumping test data that may not have been analyzed or that require additional interpretation to better define the flow field? If so, what is required to incorporate those data into current analysis?

   E. What drilling procedures will be used to ensure that core and water samples can be obtained that are suitable for laboratory analysis?

   F. How are the laboratory retardation results to be scaled-up and correlated with field retardation results? How will the results be further scaled-up to the performance assessment grid size?

   G. How will all the results be incorporated into performance assessment and how does the experimental schedule mesh with performance assessment schedule commitments?

H. What is the relative importance of each of the experimental objectives (e.g., rank them); and how do each of these objectives contribute to compliance demonstration?

I. How will the experimental data be used to draw conclusions that are valid for the entire regulatory period (10,000 years)?

J. What is the statistical basis for selecting samples utilized in determining the values for the coefficients (elements) of retardation? How will the mechanisms creating retardation be established? Why is the range of geochemistries investigated adequate to bound the conditions that might occur throughout the regulatory period?

K. What tests and methodology will be utilized to resolve the effect of the numerous wells to the south of the site on the present and long term flow field?

2. The apparent disconnect between performance assessment and the experimental program must be resolved. DOE will be judged on the conceptual model, data supporting that model, and resulting calculations. Two specific suggestions for improvement are:

A. Formal procedures could be developed to ensure that the experimental program supports performance assessment data needs and that the performance assessment model reflects experimental understanding. One implication here is that the experimentalist may develop a much greater interest in participating in finalization of the performance assessment conceptual and mathematical models. A question to be considered is who is responsible for defending the results presented by the performance assessment group?

B. SNL should consider instituting some process that ensures communication between the data generation groups and Performance Assessment. A major objective of the process would be to define the data and model elements necessary to provide sufficient resolution of the regional hydrology to support a preferred baseline case for describing the present hydrological condition.

Please do not hesitate to contact me at (505) 845-6321 or Dave Lechel at (505) 845-6290 with any questions you may have concerning this report.

Sincerely,

Kelly M. Pearl

for John A. Thies
Project Manager

cc:
G. Hanson
D. Lechel
B. Root
D. Sala
B. Farrell

Technical Support Groups'
Report of Findings
on
Culebra Tracer Testing

Issue

The WIPP Project Integration Office (WPIO) Change Control Board (CCB) requested the Technical Support Group (TSG) to provide recommendations in support of a decision on partial funding of an $8 million plan for a new set of tracer tests in the Culebra Dolomite Member of the Rustler Formation.

Importance

Human intrusion scenarios, which presume future inadvertent drilling activity intercepts an underlying pressurized brine reservoir and/or the repository, have focused on the Culebra Member of the Rustler Formation as the final barrier in the potential pathway to the 40 CFR 191 Subpart B subsurface compliance boundary. A determination of the effectiveness of the Culebra as a geologic barrier to radionuclide transport is therefore important in demonstrating compliance with this regulation. A sound technical position must be prepared if the U. S. Environmental Protection Agency (EPA) is to accept a U. S. Department of Energy (DOE) position that the Culebra is a natural geologic barrier to the release of radionuclides. The data to be collected from the proposed Culebra Tracer Tests will provide additional information that will be useful in demonstrating the effectiveness of the Culebra barrier. The unresolved issue is whether the proposed additional tests will lead to a successful defense of the radionuclide transport retardation affects included in the performance assessment (PA) model. The objectives of the test program should align with the reduction in uncertainty necessary for validation of the conceptual model, mathematical model and sensitive parameter ranges utilized to predict radionuclide transport.

Scope of Evaluation

The questions to be answered are as follows:
(1) Are additional experiments for fluid flow and transport characterization of the Culebra necessary? If additional testing is necessary, (2) will the planned Culebra Tracer Tests, as described in the proposed test plan, provide a final additional set of data that can be used to establish that the Culebra retards radionuclide transport to the degree necessary to demonstrate the Culebra is an effective geologic barrier? This report is specific to resolving these questions.

February 12, 1993

Conclusions

In response to the two questions stated above. the TSG concludes that additional characterization of the Culebra is necessary but that the preliminary "Experimental Plan for Tracer Testing in the Culebra Dolomite at the WIPP Site", dated October 15, 1992, will not provide a final (comprehensive) set of data. The experimental plan needs substantive modification and refinement. Revisions to this plan (and/or a governing experimental plan of which this specific test plan is a subset) should support an objective of developing a comprehensive set of data that will fulfill all the data requirements for model selection and validation. An important consideration is that the National Academy of Sciences (NAS) has cautioned, in the September and December 1992 meetings, that the proposed Culebra Tracer Tests may not substantially contribute to the overall reduction of an already high uncertainty level. The task confronting the WIPP Project is to define an integrated experimental program that will reduce the uncertainty to acceptable levels or, at least, quickly identify critical performance assessment parameters whose uncertainties will not be reduced to acceptable levels by the planned experiments. Specific TSG conclusions with brief supporting rationale follow:

1. Retardation in the Culebra: Experimentally derived fluid flow velocities indicate fairly rapid movement of fluid to the compliance boundary relative to the regulatory period. Therefore, the Culebra cannot be assumed to be a major barrier to radionuclide transport if retardation is not demonstrated to the satisfaction of the regulatory agencies. An experimental determination of chemical (primarily) and physical retardation is vital to establishing robust evidence that the Culebra is an effective geologic barrier. This must be done in the laboratory with corroboration in the field.

   Summary Rationale: Experimental determination of distribution coefficients (K_d's) is required to establish a conservative range of values for each element of retardation. In fact, DOE has agreed with the State of New Mexico in the Consultation and Cooperation Agreement that, "in the absence of experimentally justifiable values, K_d will equal zero, e.g., no credit for retardation will be taken in the performance assessment calculations". Current field experimental data support estimated fluid flow velocities in the range of 1 meter per day to 1 meter per year. In meetings with the TSG, Sandia National Laboratory (SNL) scientists agreed that the estimated flow velocities, when integrated over the general flow path from the storage panel area to the vertical compliance boundary, translate to fluid arrival times at the subsurface compliance boundary that generally range from 100 to 1,000 years. This is an indication that flow time alone cannot be relied upon to ensure compliance. However, additional phenomena act to reduce the concentrations of radionuclides reaching the boundary. These concentrations will be diluted (at least initially) by chemical and pressure gradient diffusion into the relatively static fluid volume (currently assumed to be about 100 times larger than the dynamic fluid volume) contained in the nonconductive pores of the rock matrix. This dilution, or physical retardation, delays the time it takes to accumulate a total release that may exceed the 40 CFR 191 Subpart B standard, although the delay in some scenarios

may be substantial. Compliance may be assumed if very long-term or permanent chemical retention of the radionuclides in the rock matrix can be shown. Chemical bonding with the host rock and/or filler materials (generally clay) would ensure long-term retention. However, the degree to which this chemical retention occurs has not been established experimentally, which remains as a potential breach of the previous agreement with the State until these experiments are completed.

2. Flow in the Culebra: Additional characterization of the Culebra will enhance the basis for establishing a representative hydrologic model. Selection of a model type that adequately represents all the observations is an important element of compliance demonstration. Care should be exercised to not bias the approach for differentiating between flow model types, especially in light of the strongly held view that dual porosity is the correct model type.

   Summary Rationale: In addition to the retardation, uncertainties still exist with other fundamental issues. These issues include identification of the physical characteristics of the pathways (e.g., layers, channels, fractures, connection of fractures with matrix porosity). For example, there is general agreement within SNL that the Culebra is a layered member, but layering has not been directly incorporated into the model. In another example, INTRAVAL has suggested a conceptual flow model based entirely on channeling also will produce an acceptable fit to the current data; but current modeling utilizes a dual porosity concept instead. The implication is that if only channel flow is occurring the retardation will be considerably reduced. The inability to convincingly answer such questions indicates an incomplete understanding of the flow regime. A well characterized flow regime is necessary to the establishment of acceptable retardation values.

3. Integration of the Performance Assessment and Experimental Programs: As an addendum to these technical conclusions, the TSG notes a lack of integration of the experimental program and the performance assessment group. This is a concern in that it affects the Project's chances of reaching a sound scientific basis for compliance. Finding ways of fostering closer integration, or at least more effective cooperation, would greatly enhance the quality and defensibility of the resulting performance assessment; and therefore is an integral part of rectifying the technical issues addressed in this report.

Recommendations

The TSG review of the "preliminary" Culebra Tracer Test Plan and meetings with SNL staff culminated in the following recommendations. These recommendations will aid in promoting both a comprehensive experimental test program and a broad-based compliance strategy.

1. The types of tests outlined in the reviewed experimental plan are helpful in resolving the hydrogeologic characterization of the Culebra. However, the plan should be augmented to present a program that addresses a broader set of issues than the preliminary version. This augmented plan should also address cost and schedule optimization for the program outlined in the revised plan. This "final" test plan is currently scheduled for completion in September 1993. The TSG recommends the technical questions listed below, at a minimum, be addressed in the final plan.

A. How will the tests discriminate among candidate conceptual flow models and serve to validate the appropriate choice or combination of choices for the Culebra?

B. How will the question of "scale-up" of the field flow results to a grid size that matches the grid utilized in performance assessment be approached?

C. What is the basis for location of the test site(s) and, if preliminary drilling is deemed advantageous, where precisely will it be done and why was that site chosen?

D. Is it desirable to incorporate existing pumping test data that may not have been analyzed or that require additional interpretation to better define the flow field? If so, what is required to incorporate those data into current analysis?

E. What drilling procedures will be used to ensure that core and water samples can be obtained that are suitable for laboratory analysis?

F. How are the laboratory retardation results to be scaled-up and correlated with field retardation results? How will the results be further scaled-up to the performance assessment grid size?

G. How will all the results be incorporated into performance assessment; and how does the experimental schedule mesh with performance assessment schedule commitments?

H. What is the relative importance of each of the experimental objectives (e.g., rank them); and how do each of these objectives contribute to compliance demonstration?

I. How will the experimental data be used to draw conclusions that are valid for the entire regulatory period (10,000 years)?

J. What is the statistical basis for selecting samples utilized in determining the values for the coefficients (elements) of retardation? How will the mechanisms

creating retardation be established? Why the range of geochemistries investigated is adequate to bound the conditions that might occur throughout the regulatory period?

K. What tests and methodology will be utilized to resolve the effect of the numerous wells to the south of the site on the present and long term flow field?

The term "comprehensive" could be substituted for the term "final" used in this report to describe the desired status for the data to be generated from the proposed test program. The important message is that reactionary experimental testing often leads to additional unplanned testing programs. DOE can not afford to be dependent on a test plan that does not address all of the issues or potential issues related to validating a representative flow model. Within the bounds of current knowledge, this test plan must encompass collection of all the data that will be required for validation. In this sense "final" means there is a high level of certainty that unplanned tests will not be required after the proposed tests are concluded.

2. The apparent disconnect between performance assessment and the experimental program must be resolved. DOE will be judged on the conceptual model, data supporting that model, and resulting calculations. Two specific recommendations for improvement are:

   A. Formal procedures should be developed to ensure that the experimental program supports performance assessment data needs and that the performance assessment model reflects experimental understanding. One implication here is that the experimentalist may develop a much greater interest in participating in finalization of the performance assessment conceptual and mathematical models. A question to be considered is who is responsible for defending the results presented by the performance assessment group?

   B. SNL should consider forming a hydrogeology intergroup team or instituting some other process that ensures communication between groups. A major objective of this interactive team would be to define the data and model elements necessary to provide sufficient resolution of the regional hydrology to support a preferred baseline case for describing the present hydrological condition.

Background Observations and Analysis

During this review process, the importance of the national and international scientific interchange sponsored by SNL has become apparent. This interchange has resulted in the identification of issues that need to be addressed by the experimental and performance assessment programs. The SNL initiative to institute the proposed Culebra testing seems to be partially in response to this influential scientific community.

In a joint meeting with SNL performance assessment and experimental program staff, agreement was reached that estimated water flow rates within the WIPP site are bounded by a range of 1 meter per day to 1 meter per year. This estimated range is based on fracture flow. It is generally agreed that the flow over the storage panels will be in an south-easterly direction until it intersects a much higher transmissivity zone with flow to the site boundary in a southerly direction. In a later meeting with the experimental program group, there was agreement that the integration of these variations in flow rates from the storage panels to the site boundary will not exceed an aggregate flow time of 1,000 years and could be as low as 100 years. This conclusion is in apparent disagreement with travel times published in the working draft 1992 Performance Assessment Report (9,000 to 14,000 years).

Features of the present flow system in the Culebra suggest a possible relationship with the oil and gas wells located south of the WIPP site. These features include (1) an anomalous flow direction (south) which is not the direction of the slope of the topography as is the usual case, (2) closed potentiometric depressions to the south that suggest vertical loss of water, and (3) low hydraulic head in the Culebra with respect to the Magenta above the Rustler-Salado Residuum below. The features could be explained by depletion of hydraulic head in the Culebra in the vicinity of the oil and gas wells resulting from vertical leakage between the Culebra and pressure-depleted petroleum production horizons. Consequently, the flow system may change after oil and gas production cease.

The SNL performance assessment report for 1991 discusses recharge and discharge in Volume 1, pages 5-32 to 5-34. This discussion states that "There is no direct evidence for the location of either recharge to or discharge from the Culebra Dolomite" and that "small amounts of inflow may also occur as leakage from overlying units throughout the region." Quantifying this vertical leakage is important because it may have a substantial effect on dilution of any contaminant that enters the Culebra. Note that Figures 5-13 and 5-14 show a hydraulic head difference between the Magenta and Culebra of 45 feet (959-914 at the southeast corner of the WIPP site). These units are separated by the Tamarisk. which has an average thickness of 118 feet at the WIPP (p. 5-16). Thus the vertical hydraulic gradient is about 0.38 ft/ft. If the vertical hydraulic conductivity of the Tamarisk were 10^{-12} m/s (which seems possible), crude Darcy calculations show that most of the flow in the Culebra would be coming from vertical seepage. Furthermore, the head in the Rustler-Salado Residuum is also considerably higher than the head in the Culebra, suggesting the possibility of upward flow as well. These considerations do not prove that vertical recharge to the Culebra is significant, but suggest that it might be and that it is worthy of investigation. Also note that the low head in the Culebra relative to units above and below is consistent with depletion of head in the Culebra by leakage around oil and gas well casings to the south. If the oil and gas wells are affecting head in the Culebra, vertical leakage may change in the future if the effect of the wells changes.

INTRAVAL has suggested that a channel flow model be considered as an alternative to the dual porosity model now used to describe the Culebra. This channel model could possibly result in much less matrix contribution to retardation than is currently assumed. Either the existence of

channel flow needs to be shown to be minimal (on the scale of the performance assessment model) or it needs to be shown that the channel flow and matrix retardation are both occurring and not mutually exclusive. It is unlikely that the system operates as a single porosity system because it is already known from examination of the cores that the matrix is porous and has interconnecting fractures. It is reasonable to attempt to demonstrate by field testing that the system is dual porosity and to quantify the effect of clay fracture linings in answer to the INTRAVAL suggestion. Otherwise, the regulatory agencies may require testing at a late stage of the permitting process.

There are large zones within the regional hydrologic model that have not been well characterized with data, but only modeled by Kriging techniques. An example is the zone south of the repository along the most direct geometric path to the vertical compliance boundary. The Environmental Evaluation Group (EEG) has suggested that a well be placed in this zone. The NAS WIPP panel made the same observation in the December 1992, meeting in Albuquerque. The TSG adds emphasis by reaching the same conclusion. A final set of data should include tests (even if simple) to obtain hydrologic parameters in one or more of the regions that have not been investigated.

There is a prevailing view within SNL that the probabilistic analysis currently used in performance assessment to define the range of possible transport paths and transport times adequately bound the hydrogeologic regime over the range of time required (10,000 years). That may not be true because of scale dependencies not yet accounted for and differences in hydrologic and chemical behavior not yet explained.

Several clauses in the "1988 Modification to the Working Agreement of the Consultation and Cooperation Between Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant" have special relevance to the hydrological mapping of the Culebra and to the determination of transport retardation factors. Quotes from one clause are "Development of a generalized three-dimensional regional flow model extending from the ground surface to the Bell Canyon Formation. Care will be taken that, over the long term, geologic and modeling expertise and interpretations developed as part of WIPP site-characterization activities are included in such modeling." Quotes from a second clause are "DOE recognizes that radionuclide retardation within the Culebra remains to be proven experimentally and remains committed to demonstrate experimentally the actual range of K_d's to be expected for transport within the Culebra. It is unlikely that transport will involve a single set of K_d values, and performance assessment likely must consider a range of values for each element. DOE will select, after consultation with the State, a range of values to be conservative, but reasonable, based on the lowest reasonable values experimentally obtained. In the absence of experimentally justifiable values, K_d will equal zero, i.e., no credit for retardation will be taken in the performance assessment calculations."

One of the major objectives of the Culebra Tracer Tests is to collect enough retardation data to satisfy the Consultation and Cooperation Agreement with the State of New Mexico. This

agreement stipulates, as stated above, that the flow model's radionuclide distribution coefficients must be set to zero until a defensible value has been established experimentally. The planned tests (including the laboratory phase) can provide a valuable set of data. However, additional data from other zones will probably be required.

Despite the uncertainty in the overall model, SNL experimental staff state that physical and chemical retardation of the radionuclides will occur and will provide a very large reduction to total release. This opinion contrasts with some NAS WIPP panel members' comments in the quarterly meetings with WIPP that DOE will not be able to take credit for chemical retardation ("You will have to set the K_d coefficients to zero").

Assuming chemical retardation is important, the hydrogeology over the storage panels should be known with a greater degree of certainty than the higher transmissivity zones to the east. If retardation is demonstrated, most of the retardation should occur in the region above the repository since this is the first region to be exposed. Also the low transmissivity of this region means the brine resides in this region much longer than in the faster flow zones to the east. The TSG designated this region as the "local zone" in our internal discussions because of the relative importance this zone attains if retardation is necessary to demonstrate compliance. Current plans do not include additional characterization of this zone.

The objectives of the Tracer Tests, as described by the SNL staff planning them, are to provide evidence for a matrix retardation component and to further characterize the flow regime in the highest known conductivity path to the boundary. These objectives are important and will contribute to a final resolution. The printed objective of proving or disproving channel flow, although directly related to these real objectives and interesting from a scientific view, is not the basic objective. The basic objective should be to establish a modeling approach that provides a representative description of the Culebra flow.

An important aspect of the proposed field testing is to provide high quality core and fluid samples for laboratory testing. This aspect has not been fully stated and incorporated into the experimental plan.

A recurring question is whether or not credit for physical or chemical retardation of radionuclide transport within the Culebra is even necessary to compliance arguments because compliance might be proven without reliance on the retardation provided by the Culebra. Dr. Wendell Weart pointed out to the TSG that viewing the Culebra, as an additional potential geologic barrier, serves an important role of increasing the confidence in demonstration of regulatory compliance. Even if the additional barrier is not needed or an exact value cannot be put on the effect of the barrier, this is a compelling argument. Dr. Weart's point is valid even if radionuclide retardation within the Culebra aquifer is not needed to demonstrate compliance.

Future changes in the hydrogeology that are a result of climate changes, etc. do not appear to be sufficiently developed in current performance assessment analysis. A major focus has been

to predict transport pathways and transport times based on best-fit transmissivity zones that satisfy the observed hydrological response in existing wells. This means that possible future conditions have to be applied to a maze of best fit transmissivity zones since the baseline definition consists of multiple best fit cases.

№ 5077 –

WTAC Waste Isolation Pilot Plant Technical Assistance Contractor

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December 22, 1993

93 DEC 22 PM 2:40

WPIO

Mr. George Dials, Manager
U.S. Department of Energy
Carlsbad Area Office
P.O. Box 3090
Carlsbad, NM 88221

Attn: Patrick J. Higgins, Branch Chief, EPB, CAO/AL

Re: Technical Support Group's Report of Findings for the Performance Assessment Parameter List

Dear Mr. Dials:

I am pleased to submit the Technical Support Group's (TSG) Report of Findings for the Performance Assessment (PA) Parameter List. The TSG has conducted a detailed review of many of the parameters that form the basis for the PA calculations for the WIPP Project. This effort emphasized the key 49 PA parameters that were sampled in the 1992 PA calculations, and, as time permitted, included a preliminary review of an additional 80 parameters. Data type, data quality, data interpretation, and source documentation were evaluated and each reviewer categorized the data based on their professional judgment. A database called PERFORM was developed to help in the management of the reviews.

The results indicate that the documentation is inadequate for many parameters and a considerable effort will be needed to assemble the documentation necessary to defend the PA parameters. To that end, the TSG recommends that the TSG work with Sandia National Laboratories (SNL/NM) to revise, update, and document as necessary the key 49 PA parameters. The TSG also recommends that it review, revise, and update the remaining PA parameters. The PERFORM database has been very useful in conducting the reviews and the TSG recommends that it continue to be used to manage the large amount of information involved in the review process.

If you have any questions or comments regarding this review, please contact me at 845-6321 or Steve Alcorn at 845-5918.

Sincerely,

Marilyn Baich

John A. Thies
Project Manager

Enclosure

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THE TECHNICAL SUPPORT GROUP'S

REPORT OF FINDINGS

FOR THE

PERFORMANCE ASSESSMENT PARAMETER LIST

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THE TECHNICAL SUPPORT GROUP'S REPORT OF FINDINGS FOR THE PERFORMANCE ASSESSMENT PARAMETER LIST

Issue

More than 300 parameters have been used by Sandia National Laboratories, New Mexico (SNL/NM) for Waste Isolation Pilot Plant (WIPP) performance assessment (PA) calculations. In the most recent 1992 PA calculations, the distributions of the key 49 PA parameters were sampled for use in PA and the remaining were used as constants. Documentation of the sources of these parameter values, their ranges, and their distribution types has been assembled in Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992 Volume 3: Model Parameters (SNL/NM, 1992). In anticipation of eventual regulatory evaluation, there is a need to confirm the quality and completeness of source data and interpretation through an independent review of the PA parameters. The purpose of the Technical Support Group (TSG) review is to ensure that all PA parameters have been adequately documented and are suitable for use in the WIPP PA.

Significance of Issue

The robustness of the PA parameters is crucial because they are used as input to the PA calculations, which are used to assess the long-term performance of the repository. Project records must be adequate to defend the pedigree of each parameter, which means that the source of each parameter must be either solidly anchored in the scientific literature or that the basis for the parameter must be established through experimental data or some other justifiable means.

Approach

An informal check of PA parameter information revealed several gaps in the availability of source data and inconsistencies in interpretations. This check convinced the TSG that some parameter information is not adequate to defend the PA parameters during a regulatory evaluation. Therefore, work was undertaken to provide a new and concise parameter database and associated investigations of parameter values, ranges, and distributions for data quality, interpretation quality, and documentation completeness. The results of that work are reported here. The effort to date has emphasized the key 49 parameters sampled in 1992 PA calculations. In addition, other parameters have undergone a preliminary review.

Several guidelines applied to this work: (1) to review PA parameters only, and not the computational models in which they are used; (2) to avoid reviewer bias by having each reviewer evaluate and draw conclusions independently; (3) to gather information from and interact directly with SNL/NM; (4) to avoid duplication of effort by interacting with the U.S.

Department of Energy (DOE) Headquarters (HQ) Performance Assessment Review Team (PART); and (5) to focus on providing recommendations that further the attainment of regulatory compliance.

A database, called PERFORM, was developed as a management tool to facilitate the organization of the parameters and to document reviewer comments. The PERFORM database was designed to be user friendly and provide an easy way to find the name, value, range, distribution, and pertinent documentation of each parameter as well as to record reviewer comments.

Reviewers with relevant expertise (see Appendix for names, affiliations, and areas of expertise) evaluated the PA parameter values, ranges, and distributions for quality and completeness of data, interpretation, and documentation. Summary judgments and review comments were entered directly into the database. Each reviewer was asked to assume the role of a hypothetical regulator, with emphasis on the following:

- Values, ranges, or distributions that are incompletely documented.
- Data or interpretations that are considered of low or questionable quality.
- Data that are not sufficiently relevant to WIPP.

Where difficulties with the data were found, reviewers were asked to provide suggestions for resolution.

Scope of Evaluation

For this review, the report by SNL/NM (1992), which describes the PA model parameters, was used as the primary source of information on parameters, and it was assumed that this report contained all of the values, ranges, and distributions used in the 1992 PA calculations. This report also served as the basis for further literature searches, and all references cited in it were reviewed. Only published sources of information such as SNL/NM reports, articles in professional journals, and published meeting proceedings were used for this evaluation. All documents used by the reviewers are listed in the PERFORM database.

Table 1 lists the key 49 PA parameters that were reviewed. These parameters were sampled and used in 1992 PA (SNL/NM, 1992). Table 2 lists reviewed parameters that were used in the 1992 PA as constants. The review results for non-sampled parameters are preliminary, but are included to provide useful general information. The parameter names used in this report are taken from an SNL/NM internal database called REF_TRACK, which was compiled for the purpose of finding possible errors in references (Rechard, 1993). In cases where these names are different from those in SNL/NM (1992), the equivalent name can be found by referring to the document page given in the PERFORM database.

Reviewers examined the available PA parameter information for compliance determination suitability from the perspective of a regulatory agency. However, this review was not intended to replace or update the information and expertise originally used by SNL/NM to develop and implement the PA parameters. Instead, the reviewers were tasked to find problems in quality or documentation based solely on what was found in the documentation and references cited and to suggest approaches to solving these problems.

Each reviewer was directed to do the following:

1. **Review parameters within their field(s) of expertise.**
   Reviewers were to read the relevant documentation for each parameter chosen. Emphasis was to be placed on the key 49 parameters sampled in 1992, and, as time allowed, other parameters that are closely related to those sampled were to be reviewed.

2. **Assign each parameter to judgment categories.**
   Reviewers were to assign each parameter to the judgment categories provided in the areas of Data Type, Data Quality, Data Interpretation, and Source Documentation. Examples are "acceptable," "unacceptable," and "needs work." These categories are introduced and explained below.

3. **Explain judgments and make recommendations.**
   Reviewers were to explain judgments and recommend specific solutions in the areas of parameter values, ranges, and distributions. Reviewer comments were to be documented on a signed/dated hard copy of their comments. An example of signed-off reviewer comments is presented on Figure 1.

Reviewers were instructed to act independently. That is, each reviewer was to work alone in forming their judgments, except where help was required in locating source materials.

The use of parameter judgment categories allowed a succinct summary of all reviewers' work to be entered into the database. A definition of each judgment category is presented in Table 3. Comments supporting reviewers' judgments are documented in the database in the categories of Parameter Value, Parameter Range, Parameter Distribution, and General Comments.

Summary of Findings

Each of the key 49 parameters sampled in the 1992 PA documentation was reviewed; 46 of them by two or more reviewers. Eighty non-sampled parameters were also reviewed, 40 of these by two or more reviewers. Results for the key 49 sampled parameters are presented in Table 4; results for the non-sampled parameters are presented in Table 5.

The column labelled "Overall Standing" on these tables provides an assessment of the completeness of the documentation for each parameter. Each parameter is rated as either excellent, needs some work, or needs significant work. The overall standing is a subjective rating determined by John Schatz, the principal author of this Report of Findings. The ratings indicate which parameters appear to be defendable in a regulatory setting (rated "excellent") and the degree of work anticipated to bring the others up to a rating of "excellent."

Data Type. Table 6 summarizes the results for Data Type for the key 49 parameters and for all the parameters reviewed (key 49 parameters + 80 additional parameters). The results indicate that only 20 of the key 49 parameters were judged to be based on an "unjustified assumption" or have an "unknown source" by one or more reviewer. For 5 of the key 49 parameters, two or more reviewers concurred on this judgment. However, this low level of agreement suggests that some of the "unjustified assumption" listings can be fixed by better identification of information sources.

Data Quality. For Data Quality, 24 of the key 49 parameters were found to be "unacceptable" by one or more reviewer; however, two or more reviewers concurred on 10 of the key 49 parameters. Concurrence by reviewers on this unfavorable category occurs more frequently for Data Quality than for Data Type. Where reviewers failed to concur, generally one reviewer chose "unacceptable," while another chose "needs work," reflecting a difference of opinion regarding unacceptability for this category.

Data Interpretation. For Data Interpretation, 18 of the key 49 parameters were found to be "unacceptable" by one or more reviewer. Two or more reviewers concurred on only one parameter. This low level of concurrence indicates considerable overlap between the "unacceptable" and "needs work" categories, a stronger difference of opinion among reviewers than for the other categories.

Source Documentation. For Source Documentation, 32 of the key 49 parameters were found to be "incomplete" by one or more reviewer. For 27 of the key 49 parameters, two or more reviewers concurred. Concurrence occurs for Source Documentation more frequently than for any of the other categories, indicating general agreement among reviewers in cases where documentation could not be found.

Overall Standing. For Overall Standing of the key 49 parameters, 32 were "needs significant work," 13 were "needs some work," and 4 were "excellent."

Conclusions and Recommendations

Results of the TSG review of PA parameters indicate that improvement is needed in areas of Data Quality, Data Interpretation, and Source Documentation. It is the opinion of the TSG that this needs to be accomplished to ensure regulatory compliance.

One or more of the six reviewers who participated placed approximately 50 percent of the key 49 parameters in the unfavorable categories of "unjustified assumption," "unknown

source," "unacceptable," or "incomplete" in various areas. Two or more reviewers concurred in these unfavorable categorizations for 22 percent of the parameters. Concurrence values are lower than individual values primarily because of a difference in opinion in placement in categories such as "incomplete" and "needs work." There were few disagreements among reviewers where, for example, one chose "unacceptable" and another chose "acceptable." When a parameter was judged to have a problem, most reviewers agreed, differing only in their judgment of the magnitude of the problem.

Documentation that DOE is likely to submit to the U.S. Environmental Protection Agency (EPA) in support of compliance (e.g., the supporting data for the 300-plus PA parameters) will need to be comprehensive in scope and yet concise and accurate in detail to help EPA understand the need for the data, data sources and quality, and to trace their interpretation and use. This level of detail does not currently exist in the PA documents and needs to be achieved prior to any submission of a PA compliance statement to the EPA.

The TSG recommends the following:

1. **Revise and update the key 49 PA parameters.** The quality and completeness of data, interpretation and documentation for each PA parameter must be improved. SNL/NM should provide additional, up-to-date information, as available, for the key 49 parameters, with emphasis on the problem areas identified in this report. This information should be incorporated into the PERFORM database. A reasonable first goal is to upgrade the parameters in the "needs some work" category.

   The TSG recently obtained a list of additional documentation from SNL/NM to be used to further clarify the status some of the key 49 parameters. This information needs to be transmitted to the original reviewers for consideration in updating their evaluation of these parameters.

   A periodic status report should be prepared that summarizes the state of the PA parameter list and provides recommendations on how to revise and update it.

2. **Review, revise, and update the remaining 300-plus additional PA parameters.** The TSG should conduct a similar review on the remaining 300-plus PA parameters. Following the review, the TSG and SNL/NM should implement the actions recommended above.

3. **Continue to use the PERFORM database to manage the PA parameters.** It is recommended that the PERFORM database be maintained in the future to manage the PA parameters list. The PERFORM database is a useful management tool which can help DOE and others track the data and its use, especially the document trail to the origin of information.

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Table 1. Key 49 PA Parameters Sampled in 1992

Parameters for Scenario Probability Models

- Areal Extent of Brine Reser fraction
- Index for Drilling Intensity Functions

Parameter of Global Materials and Agents Acting on Disposal System

- Bulk Storativity, Castile Brine Reservoir
- Index for computing recharge amplitude factor
- Intrusion Drill Bit Diameter
- Permeability, Final, BOR H Fill Prop.
- Pressure, Initial, Castile Brine Reser

Engineered Barrier and Source Term

- Anoxic Iron Corrosion Stoichiometry
- Brine Saturation, initial (Waste)
- Gas Generation, Stoichiom. Micro
- Gas Production Rate, Corro Humid
- Gas Production Rate, Corro Inundated
- Gas Production Rate, Micro. Inundated
- Gas Production Rate, Microbial Humid
- Solubility (Am)
- Solubility (Np+5)
- Solubility (Pu+4)
- Solubility (Ra)
- Solubility (Th)
- Solubility (U+6)
- Volume Fraction-IDB, Combustibles
- Volume Fraction-IDB, Metals/Glass

Geologic Barrier

Salado

- Brooks & Corey Exponent (Halite)
- Brooks & Corey Weight Factor
- Index for Computing DRZ Porosity (Salado)
- Permeability, Undist (Anhydrite)
- Permeability, Undisturbed (Halite)
- Pore Pressure at Repos Lev (Anhydrite)
- Porosity, Undisturbed (Anhydrite)
- Residual Gas Saturation (Halite)
- Residual Wetting Phase Saturation (Halite)

Culebra

- Clay Filling Fraction, Culebra
- Fracture Porosity, Culebra
- Fracture Spacing, Culebra
- Index for Culebra Transmissivity Fields
- Matrix Porosity, Culebra
- Partition Coeff. (Cul Fracture) (Am)
- Partition Coeff. (Cul Fracture) (Np)
- Partition Coeff. (Cul Fracture) (Pu)
- Partition Coeff. (Cul Fracture) (Ra)
- Partition Coeff. (Cul Fracture) (Th)
- Partition Coeff. (Cul Fracture) (U)
- Partition Coeff. (Cul Matrix) (Am)
- Partition Coeff. (Cul Matrix) (Np)
- Partition Coeff. (Cul Matrix) (Pu)
- Partition Coeff. (Cul Matrix) (Ra)
- Partition Coeff. (Cul Matrix) (Th)
- Partition Coeff. (Cul Matrix)-(U)
- Porosity of Clay (Culebra)

Table 2. Additional PA Parameters Reviewed

Parameter of Global Materials and Agents Acting on Disposal System

- Amplitude Factor, Precipitation Variation
- Bulk Density (Salado Halite-Borehole Fill)
- Compressibility (Salado Brine)
- Density (Salado Brine, 300K)
- Density, Avg. Storage (Borehole Fill)
- Density, Mud
- Drilling Rate Function—Rate Const. in Poisson Drilling Model
- Elevation of Top, Castile Brine Reservoir
- Glacial Fluctuation, Precipitation
- Historical Drill Bit Diameters
- Mean Annual Precipitation, Regional
- Porosity (Borehole Fill Prop.)
- Recharge Amplitude Factor, Culebra
- Short-Term Precipitation Fluctuation Frequency
- Viscosity (Salado Brine)
- Viscosity, Mud

Engineered Barrier and Source Term

- Absolute Roughness of Waste
- Effective Shear Strength Erosional Unmod.
- Eh-pH Conditions
- Halflife (Ac 227)
- Halflife (Ac 225)
- Halflife (Ac 228)
- Permeability, Combustibles, Final
- Permeability, Metals/Glass, Final
- Permeability, Sludge, Final
- Porosity, Combustibles, Final
- Porosity, Metals/Glass, Final
- Porosity, Sludge, Final
- Solubility (Cm) Log

Geologic Barrier

Salado

- Base of Anhydrite III Elevation above Mean Sea Level @ ERDA-9
- Brooks & Corey Exponent, Anhydrite
- Capillary Pressure, Anhydrite
- Density, Average (Near Field Salado)
- Density, Bulk (Halite)
- Density, Grain (Anhydrite)
- Density, Grain (Halite in Salado)
- Density, Grain (Polyhalite in Salado)
- Dispersivity, Longitudinal (Anhydrite)
- Dispersivity, Long./Trans. Ratio (Anhydrite)

Geologic Barrier, continued

Salado, continued

- Dispersivity, Long./Trans. Ratio (Halite in Salado)
- Dispersivity, Longitudinal (Halite and Polyhalite)
- Log Permeability, Disturbed (Anhydrite)
- Log Permeability, Disturbed (Halite)
- MB139 Thickness (Anhydrite)
- Partition Coefficient (Anhydrite) (Am)
- Partition Coefficient (Anhydrite) (Np)
- Partition Coefficient (Anhydrite) (Pb)
- Partition Coefficient (Anhydrite) (Pb)
- Partition Coefficient (Anhydrite) (Pu)
- Partition Coefficient (Anhydrite) (Ra)
- Partition Coefficient (Anhydrite) (Th)
- Partition Coefficient (Anhydrite) (U)
- Partition Coefficient (Halite and Polyhalite)
- Pore Pressure (Halite)
- Porosity, Disturbed (Anhydrite)
- Porosity, Disturbed (Halite)
- Porosity, Undisturbed (Halite)
- Residual Wetting Phase Saturation (Anhydrite)
- Residual Gas Saturation (Anhydrite)
- Specific Storage (Anhydrite)
- Specific Storage (Halite)
- Top of Bell Canyon Elevation above Mean Sea Level @ ERDA-9
- Tortuosity (Anhydrite)
- Tortuosity (Halite)
- Threshold Displacement Pressure (Salado)
- Threshold Displacement Pressure (Anhydrite)

Culebra

- Density, Bulk Clay (Culebra)
- Dispersivity, Longitudinal (Culebra)
- Dispersivity Ratio (Culebra)
- Head, Freshwater (Culebra)
- Hydraulic Conductivity—5k (Culebra)
- Hydrogen Viscosity @ 27°C
- Matrix Tortuosity, Culebra
- Partition Coefficient (Cul Fracture) (Cm)
- Partition Coefficient (Cul Fracture) (Pb)
- Partition Coefficient (Cul Matrix) (Cm)
- Partition Coefficient (Cul Matrix) (Pb)
- Storage Coefficient (Culebra)
- Thickness, Dolomite (Culebra)
- Tortuosity in Clay Lining (Culebra)

Table 3. Judgment Categories Used to Evaluate PA Parameters

Data Type

Assumption-Unjustified. The original documentation for the parameter value, range, or distribution is found, but no supporting explanation is given for the choice. An example of this would be the use of only the phrase "PA analyst's choice" to describe the source of a parameter value, with no additional documentation, but where other alternatives apparently exist.

Unknown Source. No source is found for the parameter information.

Judgment

Field Data. Parameter information is derived from WIPP-specific field data, but judgment is used, rather than the data only, to arrive at results. Typically, this would be done if the field data are incomplete or not fully representative. In many cases, judgment is used out of necessity.

Lab Data. Parameter information is derived from WIPP-specific laboratory data, but judgment is used, rather than the data only, to arrive at results. Typically, this would be done if the laboratory data are incomplete or not fully representative.

Generic Data. Parameter information is derived from generic data found in the literature, but judgment is used, rather than the data only, to arrive at results. Typically, this would be done to adapt non-WIPP data for use at WIPP.

Measurement

Field Data. Parameter information is derived entirely from WIPP-specific field data, even if an interpretive model must be used to derive the values.

Lab Data. Parameter information is derived entirely from WIPP-specific laboratory data, even if an interpretive model must be used to derive the values.

Handbook Data. Parameter information is derived from handbook data that are deemed specifically applicable to WIPP.

Data Quality

Acceptable. Data quality appears acceptable at this time for compliance justification.

Needs Work. Data quality is lacking, but apparently can be remedied by ongoing or planned work. Reviewer's comments provide further explanation.

Unacceptable. Data quality is severely deficient due to poorly documented sources, non-physically realistic values, lack of clear explanation, apparent lack of quality control, or other reasons as stated in the reviewers' comments.

No Data. No data could be found on which to base a judgment.

Data Interpretation

Acceptable. Data interpretation appears acceptable at this time for compliance justification.

Needs Work. Data interpretation is lacking only in ways that can apparently be remedied by ongoing or planned work. Reviewer's comments provide further explanation.

Unacceptable. Data interpretation is erroneous, unclear, undocumented, or severely deficient in some way, as stated in the reviewer's comments.

No Data. No data could be found on which to base a judgment.

Source Documentation

Complete. All parameter information (even if found unacceptable or needing work in some way) is fully documented.

Incomplete. Some important aspect of the required parameter information is undocumented. Reviewer's comments provide further explanation.

Table 4. Results for the Key 49 PA Parameters Sampled in 1992

PA Parameter	Data Type	Data Quality	Data Interpretation	Source Document	Overall Standing
Parameters for Scenario Probability Models					
Areal Extent of Brine Reservoir Fraction	JF, JF	A, NW	A, NW	C, C	⠿
Index for Drilling Intensity Functions	JG, JG	ND, ND	A, A	C, C	⠿
Parameter of Global Materials and Agents Acting on Disposal System					
Bulk Storativity, Castile Brine Reservoir	MF, MF	A, A	NW, NW	C, C	■
Index for Computing Recharge Amplitude Factor	UA, JG	U, ND	NW, NW	I, I	□
Intrusion Drill Bit Diameter	JF, JG	A, A	A, NW	C, C	■
Permeability, Final, BOR H Fill Prop.	JG, JG	A, A	NW, NW	C, C	⠿
Pressure, Initial, Castile Brine Reservoir	JL, JF	A, A	NW, A	C, C	■
Engineered Barrier and Source Term					
Anoxic Iron Corrosion Stoichiometry	JG, UA	NW, ND	A, U	I, I	□
Brine Saturation, Initial (Waste)	UA, UA	NW, U	NW, U	I, I	□
Gas Generation, Stoichiometry Microbial	JG, JG	A, A	A, A	C, C	■
Gas Production Rate, Corro Humid	UA, JL	U, U	NW, U	I, I	□
Gas Production Rate, Corro Inundated	ML, ML	NW, NW	NW, U	C, I	⠿
Gas Production Rate, Microbial Inundated	JL, ML	NW, NW	NW, NW	C, I	⠿
Gas Production Rate, Microbial Humid	UA, UA	U, U	U, U	I, I	□
Solubility (Am)	US, JG	U, NW	U, NW	I, I	□
Solubility (Np+5)	US, JG	U, NW	U, NW	I, I	□
Solubility (Pu+4)	US, JG	U, NW	U, NW	I, I	□
Solubility (Ra)	US, JG	U, NW	U, NW	I, I	□
Solubility (Th)	US, JG	U, NW	U, NW	I, I	□
Solubility (U+6)	US, JG	U, NW	U, NW	I, I	□

Data Type

- JF Judgment Field Data
- JG Judgment Generic Data
- JL Judgment Lab Data
- MF Measurement Field Data
- MH Measurement Handbook Data
- ML Measurement Lab Data
- UA Unjustified Assumption
- US Unknown Source

Data Quality/ Data Interpretation

- A Acceptable
- NW Needs Work
- U Unacceptable
- ND No Data

Source Documentation

- C Complete
- I Incomplete

Overall Standing

- ■ Excellent
- ⠿ Needs Some Work
- □ Needs Significant Work

Table 4. Results for the Key 49 PA Parameters Sampled in 1992 (continued)

PA Parameter	Data Type	Data Quality	Data Interpretation	Source Document	Overall Standing
Volume Fraction-IDB, Combustibles	JG	NW	U	I	□
Volume Fraction-IDB, Metals/Glass	JG	NW	U	I	□
Geologic Barrier					
Salado					
Brooks & Corey Exponent (Halite)	JG, JG	NW, NW	NW, NW	I, I	□
Brooks & Corey Weight Factor	UA	NW	NW	C	□
Index for Computing DRZ Porosity (Salado)	UA, UA	NW, ND	NW, NW	C, C	□
Permeability, Undisturbed (Anhydrite)	JF, MF	NW, A	U, NW	I, I	■
Permeability, Undisturbed (Halite)	JF, MF	NW, NW	NW, NW	C, C	⠿
Pore Pressure at Repository Level (Anhydrite)	JF, MF	A, A	U, A	I, I	⠿
Porosity, Undisturbed (Anhydrite)	UA, UA	ND, ND	NW, NW	I, I	□
Residual Gas Saturation (Halite)	JG, JG	NW, NW	NW, NW	C, C	⠿
Residual Wetting Phase Saturation (Halite)	JG, JG	NW, NW	NW, NW	C, C	⠿
Culebra					
Clay Filling Fraction, Culebra	JF, UA, UA, UA	NW, NW, ND, ND	NW, NW, NW, U	C, C, C, C	□
Fracture Porosity, Culebra	MF, JF, JF	NW, NW, A	NW, NW, U	C, C, C	⠿
Fracture Spacing, Culebra	JF, JF, JF	NW, NW, A	NW, NW, A	C, C, C	⠿
Index for Culebra Transmissivity Fields	US, MF, MF	A, A, NW	NW, NW, NW	C, C, C	⠿
Matrix Porosity, Culebra	ML, ML, ML	A, A, U	NW, NW, A	C, C, C	⠿
Partition Coefficient (Culebra Fracture) (Am)	UA, JG, JL	U, U, NW	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Fracture) (Np)	UA, JG, JL	U, U, NW	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Fracture) (Pu)	JL, JL, JG	NW, NW, U	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Fracture) (Ra)	UA, JG, JL	U, U, NW	NW, NW, NW	I, I, C	□

Data Type

- JF Judgment Field Data
- JG Judgment Generic Data
- JL Judgment Lab Data
- MF Measurement Field Data
- MH Measurement Handbook Data
- ML Measurement Lab Data
- UA Unjustified Assumption
- US Unknown Source

Data Quality/ Data Interpretation

- A Acceptable
- NW Needs Work
- U Unacceptable
- ND No Data

Source Documentation

- C Complete
- I Incomplete

Overall Standing

- ■ Excellent
- ⠿ Needs Some Work
- □ Needs Significant Work

Table 4. Results for the Key 49 PA Parameters Sampled in 1992 (continued)

PA Parameter	Data Type	Data Quality	Data Interpretation	Source Document	Overall Standing
Partition Coefficient (Culebra Fracture) (Th)	JL, JL, JG	U, U, NW	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Fracture) (U)	JL, JL, JG	A, U, NW	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Matrix) (Am)	JL, JL, JL	NW, NW, U	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Matrix) (Np)	UA, JL, JL	U, U, NW	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Matrix) (Pu)	JL, JL, JL	A, U, NW	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Matrix) (Ra)	JL, JL, JG	U, U, NW	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Matrix) (Th)	JG, JL, JL	U, U, NW	NW, NW, NW	I, I, C	□
Partition Coefficient (Culebra Fracture) (U)	JL, JL, JL	U, U, NW	NW, NW, NW	I, I, C	□
Porosity of Clay (Culebra)	JG, JG, JG	NW, NW, U	NW, NW, U	C, C, I	□

Data Type

JF Judgment Field Data
JG Judgment Generic Data
JL Judgment Lab Data
MF Measurement Field Data
MH Measurement Handbook Data
ML Measurement Lab Data
UA Unjustified Assumption
US Unknown Source

Data Quality/ Data Interpretation

A Acceptable
NW Needs Work
U Unacceptable
ND No Data

Source Documentation

C Complete
I Incomplete

Overall Standing

■ Excellent
⠿ Needs Some Work
□ Needs Significant Work

Table 5. Results of Additional Parameters Reviewed

PA Parameter	Data Type	Data Quality	Data Interpretation	Source Document	Overall Standing
Parameter of Global Materials and Agents Acting on Disposal System					
Amplitude Factor, Precipitation Variation	JG, JG	NW, A	NW, NW	I, C	□
Bulk Density (Salado Halite-Borehole Fill)	UA	NW	NW	I	□
Compressibility (Salado Brine)	ML	A	NW	C	■
Density (Salado Brine, 300K)	ML	A	A	C	■
Density, Avg. Storage (Borehole Fill)	UA	NW	A	I	□
Density, Mud	JG	NW	A	I	□
Drilling Rate Function—Rate Const. in Poisson Drilling Model	___[1]	ND	NW	C	□
Elevation of Top, Castile Brine Reservoir	JF, JF	A, A	NW, A	I, I	⠿
Glacial Fluctuation, Precipitation	JF	A	NW	C	⠿
Historical Drill Bit Diameters	MH	A	NW	C	⠿
Mean Annual Precipitation, Regional	MF	A	NW	C	⠿
Porosity (Borehole Fill Prop.)	JG	A	NW	C	⠿
Recharge Amplitude Factors, Culebra	UA	NW	NW	I	□
Short-Term Precipitation Fluctuation Frequency	JF	A	NW	C	⠿
Viscosity (Salado Brine)	MH	A	NW	C	⠿
Viscosity, Mud	JG	NW	A	I	□
Engineered Barrier and Source Term					
Absolute Roughness of Waste	JG	A	NW	C	⠿
Effective Shear Strength Erosional Unmod.	JG	A	NW	C	⠿
Eh-pH Conditions	UA	U	U	I	□
Halflife (Ac 225)	MH	A	A	C	■
Halflife (Ac 227)	MH	A	A	C	■
Halflife (Ac 228)	MH	A	A	C	■

1 No Reviewer Results for this category. (Judgement dropped out of "Overall Standing" rating system.)

Data Type		Data Quality/ Data Interpretation		Source Documentation		Overall Standing	
JF	Judgment Field Data	A	Acceptable	C	Complete	■	Excellent
JG	Judgment Generic Data	NW	Needs Work	I	Incomplete	⠿	Needs Some Work
JL	Judgment Lab Data	U	Unacceptable			□	Needs Significant Work
MF	Measurement Field Data	ND	No Data				
MH	Measurement Handbook Data						
ML	Measurement Lab Data						
UA	Unjustified Assumption						
US	Unknown Source						

Table 5. Results of Additional Parameters Reviewed (continued)

PA Parameter	Data Type	Data Quality	Data Interpretation	Source Document	Overall Standing
Permeability, Combustibles, Final	JG	NW	NW	C	⠿
Permeability, Metals/Glass, Final	JG	NW	NW	C	⠿
Permeability, Sludge, Final	JG	NW	NW	C	⠿
Porosity, Combustibles, Final	ML	A	A	C	■
Porosity, Metals/Glass, Final	ML	A	A	C	■
Porosity, Sludge, Final	ML	A	A	C	■
Solubility (Cm) Log	JG	NW	NW	I	□
Geologic Barrier					
Salado					
Base of Anhydrite III Elevation above Mean Sea Level @ ERDA-9	JF	NW	A	C	⠿
Brooks & Corey Exponent, Anhydrite	JG, JG	NW, NW	NW, NW	I, I	□
Capillary Pressure, Anhydrite	—[1]	—[1]	—[1]	C	—[2]
Density, Average (Near Field Salado)	JG, JF	A, ND	NW,A	C, I	⠿
Density, Bulk (Halite)	US, MF	U, ND	U, A	I, I	□
Density, Grain (Anhydrite)	MH, MH	NW, A	NW, A	C, C	⠿
Density, Grain (Halite in Salado)	MH, MH	A, A	A, A	C, C	■
Density, Grain (Polyhalite in Salado)	MH, MH	A, A	A, A	C, C	■
Dispersivity, Longitudinal (Anhydrite)	UA, JG	NW, ND	NW, NW	I, I	□
Dispersivity, Long./Trans. Ratio (Anhydrite)	UA, JG	NW, ND	NW, A	I, I	□
Dispersivity, Long/Trans. Ratio (Halite in Salado)	JG, JG	NW, ND	NW, A	I, I	□
Dispersivity, Longitudinal (Halite and Polyhalite)	UA, JG	NW, ND	NW, NW	I, I	□
Log Permeability, Disturbed (Anhydrite)	UA	U	A	I	□
Log Permeability, Disturbed (Halite)	JF, MF	NW, NW	U, A	C, C	□

1 Source Documentation is the only category with reviewer results.
2 Not enough information available from reviewer to develop overall standing.

Data Type		Data Quality/ Data Interpretation		Source Documentation		Overall Standing	
JF	Judgment Field Data	A	Acceptable	C	Complete	■	Excellent
JG	Judgment Generic Data	NW	Needs Work	I	Incomplete	⠿	Needs Some Work
JL	Judgment Lab Data	U	Unacceptable			□	Needs Significant Work
MF	Measurement Field Data	ND	No Data				
MH	Measurement Handbook Data						
ML	Measurement Lab Data						
UA	Unjustified Assumption						
US	Unknown Source						

Table 5. Results of Additional Parameters Reviewed (continued)

PA Parameter	Data Type	Data Quality	Data Interpretation	Source Document	Overall Standing
MB139 Thickness (Anhydrite)	MF, MF	NW, NW	NW, NW	I, I	□
Partition Coefficient (Anhydrite) (Am)	JG, JL	U, NW	NW, NW	C, I	□
Partition Coefficient, (Anhydrite) (Np)	JG, JL	U, NW	NW, NW	C, I	□
Partition Coefficient (Anhydrite) (Pb)	JG, JL	U, NW	NW, NW	C, I	□
Partition Coefficient (Anhydrite) (Pu)	JG, JG	U, NW	NW, NW	C, I	□
Partition Coefficient (Anhydrite) (Ra)	JG, JL	U, NW	NW, NW	C, I	□
Partition Coefficient (Anhydrite) (Th)	JG, JL	U, NW	NW, NW	C, I	□
Partition Coefficient (Anhydrite) (U)	JG, JG	U, NW	NW, NW	C, I	□
Partition Coefficient, Halite and Polyhalite	UA	NW	A	I	□
Pore Pressure (Halite)	JF, MF	U, U	NW, U	C, C	□
Porosity, Disturbed (Anhydrite)	UA, UA	ND, ND	U, NW	I, I	□
Porosity, Disturbed, (Halite)	UA, UA	U, ND	U, NW	C, I	□
Porosity, Undisturbed (Halite)	UA, JF	ND, A	U, NW	I, C	□
Residual Wetting Phase Saturation (Anhydrite)	JG, JG	NW, NW	NW, NW	C, C	⠿
Residual Gas Saturation (Anhydrite)	JG, JG	NW, NW	NW, NW	C, C	⠿
Specific Storage, Anhydrite	US, ML	NW, A	NW, NW	I, I	□
Specific Storage (Halite)	US, ML	A, NW	NW, NW	I, C	⠿
Top of Bell Canyon Elevation above Mean Sea Level @ ERDA-9	JF	NW	NW	C	⠿
Tortuosity (Anhydrite)	UA	NW	NW	C	□
Tortuosity (Halite)	UA, JG	NW, ND	NW, NW	C, C	□
Threshold Displacement Pressure (Salado)	JG, JF	NW, A	NW, A	I, C	□
Threshold Displacement Pressure (Anhydrite)	JG, JG	NW, A	NW, A	I, C	□
<u>Culebra</u>					
Density, Bulk Clay, Culebra	US, US, UA	ND, ND, U	NW, NW, NW	I, I, I	□
Dispersivity, Longitudinal (Culebra)	JG, JG, JG	NW, NW, ND	U, NW, NW	I, I, I	□

Data Type		Data Quality/ Data Interpretation		Source Documentation		Overall Standing	
JF	Judgment Field Data	A	Acceptable	C	Complete	■	Excellent
JG	Judgment Generic Data	NW	Needs Work	I	Incomplete	⠿	Needs Some Work
JL	Judgment Lab Data	U	Unacceptable			□	Needs Significant Work
MF	Measurement Field Data	ND	No Data				
MH	Measurement Handbook Data						
ML	Measurement Lab Data						
UA	Unjustified Assumption						
US	Unknown Source						

Table 5. Results of Additional Parameters Reviewed (continued)

PA Parameter	Data Type	Data Quality	Data Interpretation	Source Document	Overall Standing
Dispersivity Ratio (Culebra)	JG, JG, JG	NW, NW, ND	NW, NW, NW	I, C, I	⠿
Head, Freshwater (Culebra)	MF	A	A	C	■
Hydraulic Conducting—5k (Culebra)	US, US	NW, ND	U __[1]	I, I	□
Hydrogen Viscosity @ 27°C	MH	A	NW	__[1]	⠿
Matrix Tortuosity, Culebra	ML, ML, ML	A, A, A	NW, A, NW	C, C, C	■
Partition Coefficient (Cul Fracture) (Cm)	JG, JL	U, NW	NW, NW	C, I	□
Partition Coefficient (Cul Fracture) (Pb)	JG, JL	U, NW	NW, NW	C, I	□
Partition Coefficient (Cul Matrix) (Cm)	JL, JL	U, NW	NW, NW	C, I	□
Partition Coefficient (Cul Matrix) (Pb)	JG, JL	U, NW	NW, NW	C, I	□
Storage Coefficient, Culebra	MF, JF, MF	A, A, A	NW, A, A	C, C, C	■
Thickness, Dolomite, Culebra	MF, MF, MF, MF	A, A, A, A	NW, A, NW, A	C, C, C, C	■
Tortuosity in Clay Lining, Culebra	UA, UA, JG	ND, ND, ND	NW, NW, NW	C, I, C	□

1 No review results for this category.

Data Type		Data Quality/ Data Interpretation		Source Documentation		Overall Standing	
JF	Judgment Field Data	A	Acceptable	C	Complete	■	Excellent
JG	Judgment Generic Data	NW	Needs Work	I	Incomplete	⠿	Needs Some Work
JL	Judgment Lab Data	U	Unacceptable			□	Needs Significant Work
MF	Measurement Field Data	ND	No Data				
MH	Measurement Handbook Data						
ML	Measurement Lab Data						
UA	Unjustified Assumption						
US	Unknown Source						

Table 6. Summary of Results

	Key 49 PA Parameters		All 129 PA Parameters	
	≥ 1 reviewer	≥ 2 reviewers	≥ 1 reviewer	≥ 2 reviewers
Data Type				
Judgement (all)	39	23	82	46
Measurement (all)	9	4	34	11
Assumption-Unjustified or Unknown Source	20	5	40	10
Data Quality				
Acceptable	13	10	45	14
Needs Work	37	12	80	19
Unacceptable	24	8	41	11
No Data	6	3	21	6
Data Interpretation				
Acceptable	9	2	37	6
Needs Work	42	28	100	58
Unacceptable	18	1	27	1
Documentation				
Complete	32	17	88	29
Incomplete	32	27	74	41

Figure 1. Example of Signedoff Reviewer Comments

PARAMETER: Elevation of Top, Castile Brine Reser
INDEX NUMBER: 006

Data Type	Source Documentation	Data Quality	Interpretation
JUDGEMENT - FIELD DATA	INCOMPLETE	ACCEPTABLE	NEEDS WORK

PARAMETER VALUE:

The value given is stated as the elevation (with respect to sea level) of the point at which brine production began in the well WIPP-12. This is certainly acceptable. It is NOT discussed in Table 3-19 of SAND89-0462, as the reference states. Checking other references, the value appears to be correct, but the reference should be fixed. What is it?

PARAMETER RANGE:

The range chosen corresponds to the top and bottom of the Castile over the area of the WIPP site. It is also incorrectly referenced, but appears to a correct value. This range apparently means that the thickness of the brine reservoir can range from zero to the entire Castile thickness, but it is not directly stated as such.

DISTRIBUTION TYPE:

The distribution heavily weights the observed 170 m depth, but with no stated and clear justification. If there is any sensitivity to this parameter, the distribution may be brought into question and needs to be explicitly justified.

OTHER CONCERNS:

Signature

12/6/93
Date

REFERENCES

Rechard, R.P., 1993. "Personal Communication," June 22, 1993, Sandia National Laboratories, Albuquerque, NM.

SNL/NM, see Sandia National Laboratories/New Mexico

Sandia National Laboratories/New Mexico, 1992. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 3: Model Parameters, SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM.

APPENDIX: PA PARAMETER REVIEW TEAM

The Technical Support Group (TSG) core member expert and reviewer was Paul Drez. John Schatz, a specialist in rock properties analysis and testing, lead the technical effort and provided the initial input of expert comments used for fine-tuning of the database system. He guided the entry, evaluation, and reporting of other expert input. TSG ad hoc reviewers Paul Cloke, Darrel Dunn, Rose Zeiler, and David Dennison provided technical input in the areas of hydrology, geochemistry, and waste package performance. The resumes for all reviewers are in the WIPP Project files. In addition to the review team, several individuals contributed to database support. Jody Cruse and Mark David provided the database organization and programming support, as well as results compilation. D'Ann Bretzke provided database management.

A complete list of reviewers, their affiliations, and their areas of expertise is presented below.

Participant	Affiliation	Area(s) of Expertise
Paul Drez	TSG Core Member	• Waste Characterization • (Geochemistry)*
John Schatz	Consultant	• Geomechanics • (Hydrology)*
Paul Cloke	SAIC-Nevada	• Geochemistry
Darrel Dunn	ASI-Denver	• Hydrology
Rose Zeiler	ASI-Denver	• Hydrology
David Dennison	ASI-Denver	• Geochemistry

* Secondary area of expertise

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix SCR

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

FEPs Screening

M

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ACRONYMS

CCDF	complementary cumulative distribution function
CDF	cumulative distribution function
CFR	Code of Federal Regulations
CH	contact-handled
DFR	driving force ratio
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
EDTA	ethylene diamine tetra-acetate
EPA	Environmental Protection Agency
EPs	events and processes
FEPs	features, events, and processes
FLAC	Fast Lagranian Analysis of Continua
LWA	Land Withdrawal Act
MB	marker bed
NMBMMR	New Mexico Bureau of Mines and Mineral Resources
RH	remote-handled
SMC	Salado mass concrete
TRU	transuranic
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant

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APPENDIX SCR

The methodology used in the Waste Isolation Pilot Plant (WIPP) performance assessments for screening of features, events, and processes (FEPs) is presented in Section 6.2.2 of this application. This appendix presents the results of applying the screening methodology for the analyses that are required to evaluate compliance with the numerical performance requirements provided in Title 40 of the Code of Federal Regulations (CFR) Part 191. This appendix demonstrates comprehensiveness and assembles and organizes relevant decisions and assumptions concerning the phenomena modeled in performance assessments.

Section SCR.1 discusses natural FEPs that are potentially relevant to disposal system[1] performance. Section SCR.2 discusses waste- and repository-induced FEPs. Section SCR.3 discusses human-initiated events and processes (EPs). Key words placed in bold within the text represent FEPs being considered. Section SCR.4 maps retained FEPs into performance assessment codes. Attachment 1 discusses the compilation and construction of the FEP list used in this performance assessment.

SCR.1 Natural FEPs

The natural FEPs discussed in this section are potentially relevant to the analyses conducted to evaluate compliance with the Containment Requirements in 40 CFR § 191.13, the Individual Protection Requirements in 40 CFR § 191.15, and the Groundwater Protection Requirements in 40 CFR § 191.24. While natural FEPs are important to each of these provisions, assessments of compliance with 40 CFR § 191.15 and 40 CFR § 191.24 are based solely upon the undisturbed performance[2] of a disposal system and do not consider disruptions of the disposal system by unlikely natural events.

Unlikely natural events not accounted for in the undisturbed performance of the WIPP are those EPs that have not occurred in the past at a sufficient rate to affect the Salado Formation (hereafter referred to as the Salado) at the repository horizon within the controlled area, or to be expected to cause the release of radionuclides in the regulatory time frame. Further, the U.S. Department of Energy (DOE) believes that, for the WIPP, FEPs eliminated from the performance assessment calculations made to evaluate compliance with 40 CFR § 191.13 can

[1] Note that 40 CFR Part 191 defines the "disposal system" as any combination of engineered and natural barriers that isolates radioactive waste after disposal. Consistent with this definition, the DOE interprets the disposal system to be the repository (excavations, engineered aspects, disturbed rock zone [DRZ]) plus the controlled area, thus incorporating the natural barriers of the controlled area into the disposal system. The definition of the controlled area is provided in 40 CFR § 191.12 and is reproduced in Chapter 6.0.

[2] "Undisturbed performance" is defined in 40 CFR Part 191 to mean "the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events" (§ 191.12).

also be eliminated from the undisturbed performance assessment calculations made to evaluate compliance with 40 CFR § 191.15 and 40 CFR § 191.24.

In the remainder of this section, the DOE discusses natural FEPs in the context of the FEP categorization scheme presented in Table SCR-1. The categories concerned with geology (Section SCR.1.1), subsurface hydrology (Section SCR.1.2), and geochemistry (Section SCR.1.3), relate to the subsurface structure, fluid flow, and fluid chemistry, respectively. The categories concerned with geomorphology (Section SCR.1.4), surface hydrology (Section SCR.1.5), climate (Section SCR.1.6), marine environment (Section SCR.1.7), and ecology (Section SCR.1.8), relate to the potential influence of natural FEPs on conditions at and near the ground surface. FEPs presented in Table SCR-1 are printed in bold in the text of the FEP screening discussions.

SCR.1.1 Geological FEPs

SCR.1.1.1 Stratigraphy

The stratigraphy of the geological formations in the region of the WIPP is accounted for in performance assessment calculations. The presence of brine reservoirs in the Castile is accounted for in performance assessment calculations.

The **stratigraphy** and geology of the region around the WIPP, including the distribution and characteristics of pressurized **brine reservoirs** in the Castile Formation (hereafter referred to as the Castile), are discussed in detail in Section 2.1.3. The stratigraphy of the geological formations in the region of the WIPP is accounted for in performance assessment calculations through the setup of the model geometries (Section 6.4.2). The presence of brine reservoirs is accounted for in the treatment of inadvertent drilling (Sections 6.4.12.6 and 6.4.8).

SCR.1.1.2 Tectonics

The effects of regional tectonics, regional uplift and subsidence, and changes in regional stress have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Regional tectonics encompasses two related issues of concern: the overall level of regional stress and whether any significant **changes in regional stress** might occur.

The tectonic setting and structural features of the area around the WIPP are described in Section 2.1.5. In summary, there is no geological evidence for Quaternary regional tectonics in the Delaware Basin. The eastward tilting of the region has been dated as mid-Miocene to Pliocene by King (1948, 120 – 121) and is associated with the uplift of the Guadalupe Mountains to the west. Fault zones along the eastern margin of the basin, where it flanks the Central Basin Platform, were active during the Late Permian. Evidence for this includes the displacement of the Rustler Formation (hereafter referred to as the Rustler) observed by Holt

Table SCR-1. Natural FEPs and Their Screening Classifications

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
GEOLOGICAL FEPS			SCR.1.1
Stratigraphy			SCR.1.1.1
Stratigraphy	UP		
Brine reservoirs	DP		
Tectonics			SCR.1.1.2
Changes in regional stress	SO-C		
Regional tectonics	SO-C		
Regional uplift and subsidence	SO-C		
Structural FEPs			SCR.1.1.3
Deformation			SCR.1.1.3.1
Salt deformation	SO-P	UP near repository.	
Diapirism	SO-P		
Fracture development			SCR.1.1.3.2
Formation of fractures	SO-P	UP near repository.	
Changes in fracture properties	SO-C	UP near repository.	
Fault movement			SCR.1.1.3.3
Formation of new faults	SO-P		
Fault movement	SO-P		
Seismic activity			SCR.1.1.3.4
Seismic activity	UP		
Crustal processes			SCR.1.1.4
Igneous activity			SCR.1.1.4.1
Volcanic activity	SO-P		
Magmatic activity	SO-C		
Metamorphism			SCR.1.1.4.2
Metamorphic activity	SO-P		
Geochemical FEPs			SCR.1.1.5
Dissolution			SCR.1.1.5.1
Shallow dissolution	UP		
Lateral dissolution	SO-C		
Deep dissolution	SO-P		
Solution chimneys	SO-P		
Breccia pipes	SO-P		
Collapse breccias	SO-P		
Mineralization			SCR.1.1.5.2
Fracture infills	SO-C		
SUBSURFACE HYDROLOGICAL FEPS			SCR.1.2
Groundwater characteristics			SCR.1.2.1
Saturated groundwater flow	UP		
Unsaturated groundwater flow	UP	SO-C in Culebra.	
Fracture flow	UP		
Density effects on groundwater flow	SO-C		
Effects of preferential pathways	UP	UP in Salado and Culebra.	

Table SCR-1. Natural FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Changes in groundwater flow			SCR.1.2.2
Thermal effects on groundwater flow	SO-C		
Saline intrusion	SO-P		
Freshwater intrusion	SO-P		
Hydrological response to earthquakes	SO-C		
Natural gas intrusion	SO-P		
SUBSURFACE GEOCHEMICAL FEPS			SCR.1.3
Groundwater geochemistry			SCR.1.3.1
Groundwater geochemistry	UP		
Changes in groundwater chemistry			SCR.1.3.2
Saline intrusion	SO-C		
Freshwater intrusion	SO-C		
Changes in groundwater Eh	SO-C		
Changes in groundwater pH	SO-C		
Effects of dissolution	SO-C		
GEOMORPHOLOGICAL FEPS			SCR.1.4
Physiography			SCR.1.4.1
Physiography	UP		
Meteorite impact			SCR.1.4.2
Impact of a large meteorite	SO-P		
Denudation			SCR.1.4.3
Weathering			SCR.1.4.3.1
Mechanical weathering	SO-C		
Chemical weathering	SO-C		
Erosion			SCR.1.4.3.2
Aeolian erosion	SO-C		
Fluvial erosion	SO-C		
Mass wasting	SO-C		
Sedimentation			SCR.1.4.3.3
Aeolian deposition	SO-C		
Fluvial deposition	SO-C		
Lacustrine deposition	SO-C		
Mass wasting	SO-C		
Soil development			SCR.1.4.4
Soil development	SO-C		
SURFACE HYDROLOGICAL FEPS			SCR.1.5
Fluvial			SCR.1.5.1
Stream and river flow	SO-C		
Lacustrine			SCR.1.5.2
Surface water bodies	SO-C		
Groundwater recharge and discharge			SCR.1.5.3
Groundwater discharge	UP		

Table SCR-1. Natural FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Groundwater recharge	UP		
Infiltration	UP	UP for climate change effects.	
Changes in surface hydrology			SCR.1.5.4
Changes in groundwater recharge and discharge	UP		
Lake formation	SO-C		
River flooding	SO-C		
CLIMATIC FEPS			SCR.1.6
Climate			SCR.1.6.1
Precipitation (for example, rainfall)	UP		
Temperature	UP		
Climate change			SCR.1.6.2
Meteorological			SCR.1.6.2.1
Climate change	UP		
Glaciation			SCR.1.6.2.2
Glaciation	SO-P		
Permafrost	SO-P		
MARINE FEPS			SCR.1.7
Seas			SCR.1.7.1
Seas and oceans	SO-C		
Estuaries	SO-C		
Marine sedimentology			SCR.1.7.2
Coastal erosion	SO-C		
Marine sediment transport and deposition	SO-C		
Sea level changes			
Sea level changes	SO-C		SCR.1.7.3
ECOLOGICAL FEPS			SCR.1.8
Flora & fauna			SCR.1.8.1
Plants	SO-C		
Animals	SO-C		
Microbes	SO-C	UP for colloidal effects and gas generation	

Table SCR-1. Natural FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Changes in flora & fauna			SCR.1.8.2
Natural ecological development	SO-C		

Legend:

UP	FEPs accounted for in the assessment calculations for undisturbed performance for 40 CFR § 191.13 (as well as 40 CFR § 191.15 and Subpart C of 40 CFR Part 191).
DP	FEPs accounted for (in addition to all UP FEPs) in the assessment calculations for disturbed performance for 40 CFR § 191.13.
SO-R	FEPs eliminated from performance assessment calculations on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.
SO-C	FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of consequence.
SO-P	FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of low probability of occurrence.

and Powers (1988, 4 – 14; see also Appendix FAC) and the thinning of the Dewey Lake Redbeds (hereafter referred to as the Dewey Lake) reported by Schiel (1994). There is, however, no surface displacement along the trend of these fault zones, indicating that there has been no significant Quaternary movement. Other faults identified within the evaporite sequence of the Delaware Basin are inferred by Barrows' figures in Borns et al. (1983, 58 – 60) to be the result of salt deformation rather than regional tectonic processes. According to Muehlberger et al. (1978, 338), the nearest faults on which Quaternary movement has been identified lie to the west of the Guadalupe Mountains and are of minor regional significance. The effects of regional tectonics and changes in regional stress have therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

There are no reported stress measurements from the Delaware Basin, but a low level of regional stress has been inferred from the geological setting of the area (see Section 2.1.5). The inferred low level of regional stress and the lack of Quaternary tectonic activity indicate that regional tectonics and any changes in regional stress will be minor and therefore of low consequence to the performance of the disposal system. Even if rates of regional tectonic movement experienced over the past 10 million years continue, the extent of **regional uplift and subsidence** over the next 10,000 years would only be about several feet (approximately 1 meter). This amount of uplift or subsidence would not lead to a breach of the Salado because the salt would deform plastically to accommodate this slow rate of movement. Uniform regional uplift or a small increase in regional dip consistent with this past rate could give rise to downcutting by rivers and streams in the region. The extent of this downcutting would be little more than the extent of uplift, and reducing the overburden by 1 or 2 meters would have no significant effect on groundwater flow or contaminant transport in units above or below the Salado. Thus, the effects of regional uplift and subsidence have been eliminated

from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.1.3 Structural FEPs

SCR.1.1.3.1 Deformation

Natural salt deformation and diapirism at the WIPP site over the next 10,000 years on a scale severe enough to significantly affect performance of the disposal system has been eliminated from performance assessment calculations on the basis of low probability of occurrence.

Deformed salt in the lower Salado and upper strata of the Castile has been encountered in a number of boreholes around the WIPP site; the extent of existing salt deformation is summarized in Section 2.1.6.1, and further detail is provided in Appendix DEF.

A number of mechanisms may result in **salt deformation**: in massive salt deposits, buoyancy effects or **diapirism** may cause salt to rise through denser, overlying units; and in bedded salt with anhydrite or other interbeds, gravity foundering of the interbeds into the halite may take place. Results from rock mechanics modeling studies (see Appendix DEF) indicate that the time scale for the deformation process is such that significant natural deformation is unlikely to occur at the WIPP site over any time frame significant to waste isolation. Thus, natural salt deformation and diapirism severe enough to alter existing patterns of groundwater flow or the behavior of the disposal system over the regulatory period has been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years.

SCR.1.1.3.2 Fracture Development

Naturally induced changes in fracture properties that may affect groundwater flow or radionuclide transport in the region of the WIPP have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The formation of fractures has been eliminated from performance assessment calculations on the basis of a low probability of occurrence over 10,000 years.

Groundwater flow in the region of the WIPP and transport of any released radionuclides may take place along fractures. The rate of flow and the extent of transport will be influenced by fracture characteristics such as orientation, aperture, asperity, fracture length and connectivity, and the nature of any linings or infills. These characteristics are accounted for in the performance assessment calculations through the description of the hydrogeological properties of the transmissive units (Sections 2.2.1 and 6.4.6.2).

Dissolution and precipitation of minerals in fractures are discussed in Sections SCR.1.1.5.1 and SCR.1.1.5.2, respectively. **Changes in fracture properties** could also arise through natural changes in the local stress field, for example, through erosion or sedimentation

changing the amount of overburden (see Sections SCR.1.4.3.2 and SCR.1.4.3.3). The extent of natural changes in stress is expected to be small, and naturally induced changes in fractures that may affect groundwater flow or radionuclide transport in the region of the WIPP, therefore, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The **formation of fractures** requires larger changes in stress than are required for changes to the properties of existing fractures to overcome the shear and tensile strength of the rock. The regional tectonic setting of the Delaware Basin is described in Section 2.1.5. It is concluded that no significant changes in regional stress are expected over the regulatory period (see also Section SCR.1.1.2). The formation of new fracture sets has therefore been eliminated from performance assessment calculations on the basis of a low probability of occurrence over 10,000 years.

Repository-induced fracturing of the DRZ and Salado interbeds is accounted for in performance assessment calculations, and is discussed in Section SCR.2.3.1.

SCR.1.1.3.3 Fault Movement

The naturally induced formation of new faults and fault movement of sufficient magnitude to significantly affect the performance of the disposal system have been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

Faults are present in the Delaware Basin in both the units underlying the Salado and in the Permian evaporite sequence (see Section 2.1.5.2). According to Powers et al. (1978, 4 – 57, included as Appendix GCR), there is evidence that movement along faults within the pre-Permian units affected the thickness of Early Permian strata, but these faults did not exert a structural control on the deposition of the Castile, the Salado, or the Rustler. Fault zones along the margins of the Delaware Basin were active during the Late Permian Period. Along the eastern margin, where the Delaware Basin flanks the Central Basin Platform, Holt and Powers (Appendix FAC, 4 – 14) note that there is displacement of the Rustler, and Schiel (1994) notes that there is thinning of the Dewey Lake. There is, however, no surface displacement along the trend of these fault zones, indicating that there has been no significant Quaternary movement. Muehlberger et al. (1978, 338) note that the nearest faults on which Quaternary movement has been identified lie to the west of the Guadalupe Mountains.

The absence of Quaternary fault scarps and the general tectonic setting and understanding of its evolution indicate that large-scale, tectonically-induced **fault movement** within the Delaware Basin can be eliminated from performance assessment calculations on the basis of low probability over 10,000 years. The stable tectonic setting also allows the **formation of new faults** within the basin over the next 10,000 years to be eliminated from performance assessment calculations on the basis of low probability of occurrence.

Subsidence above natural dissolution features could lead to the formation of. and movement along, local faults. However, significant dissolution in the region of the waste panels has been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years (see Section SCR.1.1.5.1), so faults arising from dissolution have also been eliminated on the basis of low probability of occurrence.

SCR.1.1.3.4 Seismic Activity

The postclosure effects of seismic activity on the repository and the DRZ are accounted for in performance assessment calculations.

This section is concerned with the effects of seismic activity away from the immediate source region, and only the effects of groundshaking and earthquakes are discussed. Other sections discuss the direct effects of fault movement (SCR.1.1.3.3), and changes in hydrogeology induced by seismic activity (SCR.1.2.2.5).

SCR.1.1.3.4.1 Causes of Seismic Activity

Seismic activity describes transient ground motion that may be generated by several energy sources. There are two possible causes of seismic activity that could potentially affect the WIPP site: natural and human induced. Natural seismic activity is caused by fault movement (earthquakes) when the buildup of strain in rock is released through sudden rupture or movement. Human-induced seismic activity may result from a variety of surface and subsurface activities, such as explosions, mining, fluid injection, and fluid withdrawal that are discussed in Section SCR.3.

SCR.1.1.3.4.2 Groundshaking

Ground vibration and the consequent shaking of buildings and other structures are the most obvious effects of seismic activity. Once the repository and shafts have been sealed, however, existing surface structures will be dismantled. Postclosure performance assessments are concerned with the effects of seismic activity on the closed repository.

In regions of low and moderate seismic activity, such as the Delaware Basin, rocks behave elastically in response to the passage of seismic waves, and there are no long-term changes in rock properties, and the effects of earthquakes beyond the DRZ have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. An inelastic response, such as cracking, is only possible where there are free surfaces, as in the roof and walls of the repository prior to closure by creep. **Seismic activity** could, therefore, have an effect on the properties of the DRZ.

An assessment of the extent of damage in underground excavations caused by groundshaking largely depends on observations from mines and tunnels. Because such excavations tend to take place in rock types more brittle than halite, these observations cannot be related directly

to the behavior of the WIPP. According to Wallner (1981, 244), the DRZ in brittle rock types is likely to be more highly fractured and hence more prone to spalling and rockfalls than an equivalent zone in salt. Relationships between groundshaking and subsequent damage observed in mines will therefore be conservative with respect to the extent of damage induced at the WIPP by seismic activity.

Dowding and Rozen (1978) classified damage in underground structures following seismic activity and found that no damage (cracks, spalling, or rockfalls) occurred at accelerations below 0.2 gravities and that only minor damage occurred at accelerations up to 0.4 gravities. Lenhardt (1988, 392) showed that a magnitude 3 earthquake would have to be within 0.6 mile (1 kilometer) of a mine to result in falls of loose rock. The risk of seismic activity in the region of the WIPP reaching these thresholds is discussed below.

SCR.1.1.3.4.3 Seismic Risk in the Region of the WIPP

Prior to the introduction of a seismic monitoring network in 1960, most recorded earthquakes in New Mexico were associated with the Rio Grande Rift, although small earthquakes were detected in other parts of the region. In addition to continued activity in the Rio Grande Rift, the instrumental record has shown a significant amount of seismic activity originating from the Central Basin Platform and a number of small earthquakes in the Los Medaños area. Seismic activity in the Rio Grande Rift is associated with extensional tectonics in that area. Seismic activity in the Central Basin Platform may be associated with natural earthquakes, but there are also indications that this activity occurs in association with oil-field activities such as fluid injection. Small earthquakes in the Los Medaños region have not been precisely located, but may be the result of mining activity in the region. Section 2.6.2 contains additional discussion of seismic activity and risk in the WIPP region.

The instrumental record was used as the basis of a seismic risk study primarily intended for design calculations of surface facilities rather than for postclosure performance assessments. The use of this study to define probable ground accelerations in the WIPP region over the next 10,000 years is based on the assumptions that hydrocarbon extraction and potash mining will continue in the region and that the regional tectonic setting precludes major changes over the next 10,000 years.

Three source regions were used in calculating seismic risk: the Rio Grande Rift, the Central Basin Platform, and part of the Delaware Basin province (including the Los Medaños). Using conservative assumptions about the maximum magnitude event in each zone, the study indicated a return period of about 10,000 years (annual probability of occurrence of 10^{-4}) for events producing ground accelerations of 0.1 gravities. Ground accelerations of 0.2 gravities would have an annual probability of occurrence of about 5×10^{-6}.

The results of the seismic risk study and the observations of damage in mines due to groundshaking, give an estimated annual probability of occurrence of between 10^{-6} and 10^{-8} for events that could increase the permeability of the DRZ. The DRZ is accounted for in

performance assessment calculations as a zone of permanently high permeability (see Section 6.4.5.3); this treatment is considered to account for the effects of any potential seismic activity.

SCR.1.1.4 Crustal Processes

SCR.1.1.4.1 Igneous Activity

Volcanic activity has been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years. The effects of magmatic activity have been eliminated from the performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.1.4.1.1 Volcanic Activity

The Paleozoic and younger stratigraphic sequences within the Delaware Basin are devoid of locally derived volcanic rocks. Volcanic ashes (dated at 13 million years and 0.6 million year) do occur in the Gatuña Formation (hereafter referred to as the Gatuña), but these are not locally derived. Within eastern New Mexico and northern, central, and western Texas, the closest Tertiary volcanic rocks with notable areal extent or tectonic significance to the WIPP are approximately 100 miles (160 kilometers) to the south in the Davis Mountains volcanic area. The closest Quaternary volcanic rocks are 150 miles (250 kilometers) to the northwest in the Sacramento Mountains. No volcanic rocks are exposed at the surface within the Delaware Basin.

Volcanic activity is associated with particular tectonic settings: constructive and destructive plate margins, regions of intraplate rifting, and isolated hot-spots in intraplate regions. The tectonic setting of the WIPP site and the Delaware Basin is remote from plate margins, and the absence of past volcanic activity indicates the absence of a major hot spot in the region. Intraplate rifting has taken place along the Rio Grande some 120 miles (200 kilometers) west of the WIPP site during the Tertiary and Quaternary Periods. Igneous activity along this rift valley is comprised of sheet lavas intruded on by a host of small-to-large plugs, sills, and other intrusive bodies. However, the geological setting of the WIPP site within the large and stable Delaware Basin allows volcanic activity in the region of the WIPP repository to be eliminated from performance calculations on the basis of low probability of occurrence over the next 10,000 years.

SCR.1.1.4.1.2 Magmatic Activity

Magmatic activity is defined as the subsurface intrusion of igneous rocks into country rock. Deep intrusive igneous rocks crystallize at depths of several kilometers and have no surface or near-surface expression until considerable erosion has taken place. Alternatively, intrusive rocks may form from magma that has risen to near the surface or in the vents that give rise to volcanoes and lava flows. Magma near the surface may be intruded along subvertical and

subhorizontal discontinuities (forming dikes and sills, respectively), and magma in volcanic vents may solidify as plugs. The formation of such features close to a repository or the existence of a recently intruded rock mass could impose thermal stresses inducing new fractures or altering the hydraulic characteristics of existing fractures.

The principal area of magmatic activity in New Mexico is the Rio Grande Rift, where extensive intrusions occurred during the Tertiary and Quaternary Periods. The Rio Grande Rift, however, is in a different tectonic province than the Delaware Basin, and its magmatic activity is related to the extensional stress regime and high heat flow in that region.

Within the Delaware Basin, there is a single identified outcrop of a lamprophyre dike about 40 miles (70 kilometers) southwest of the WIPP (see Section 2.1.5.4 and Appendix GCR for more detail). Closer to the WIPP site, similar rocks have been exposed within potash mines some 10 miles (15 kilometers) to the northwest, and igneous rocks have been reported from petroleum exploration boreholes. Material from the subsurface exposures has been dated at around 35 million years. Some recrystallization of the host rocks took place alongside the intrusion, and there is evidence that minor fracture development and fluid migration also occurred along the margins of the intrusion. However, the fractures have been sealed, and there is no evidence that the dike acted as a conduit for continued fluid flow.

Aeromagnetic surveys of the Delaware Basin have shown anomalies that lie on a linear southwest-northeast trend that coincides with the surface and subsurface exposures of magmatic rocks. There is a strong indication therefore of a dike or a closely related set of dikes extending for at least 70 miles (120 kilometers) across the region (see Section 2.1.5.4). The aeromagnetic survey conducted to delineate the dike showed a magnetic anomaly that is several miles (several kilometers) wide at depth and narrows to a thin trace near the surface. This pattern is interpreted as the result of an extensive dike swarm at depths of less than 2.5 miles (approximately 4.0 kilometers) near the Precambrian basement, from which a limited number of dikes have extended towards the surface.

Magmatic activity has taken place in the vicinity of the WIPP site in the past, but the igneous rocks have cooled over a long period. Any enhanced fracturing or conduits for fluid flow have been sealed by salt creep and mineralization. Continuing magmatic activity in the Rio Grande Rift is too remote from the WIPP location to be of consequence to the performance of the disposal system. Thus, the effects of magmatic activity have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.1.4.2 *Metamorphism*

Metamorphic activity has been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years.

Metamorphic activity, that is, solid state recrystallization changes to rock properties and geologic structures through the effects of heat and/or pressure, requires depths of burial much greater than the depth of the repository. Regional tectonics that would result in the burial of the repository to the depths at which the repository would be affected by metamorphic activity have been eliminated from performance assessment calculations on the basis of low probability of occurrence; therefore, metamorphic activity has also been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years.

SCR.1.1.5 Geochemical FEPs

SCR.1.1.5.1 Dissolution

Shallow dissolution is accounted for in performance assessment calculations. Deep dissolution and the formation of associated features (for example, solution chimneys, breccia pipes, collapse breccias) at the WIPP site have been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years. Lateral dissolution has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

This section discusses a variety of styles of dissolution that have been active in the region of the WIPP or in the Delaware Basin. A distinction has been drawn between **shallow dissolution**, involving percolation of groundwater and mineral dissolution in the Rustler; **lateral dissolution**, involving dissolution at the top of the Salado; and **deep dissolution** taking place in the Castile and the base of the Salado. Dissolution will initially enhance porosities, but continued dissolution may lead to compaction of the affected units with a consequent reduction in porosity. Compaction may result in fracturing of overlying brittle units and increased permeability. Extensive dissolution may create cavities (karst) and result in the total collapse of overlying units. This topic is discussed further in Section 2.1.6.2.

SCR.1.1.5.1.1 Shallow Dissolution

Flow through fractures is an important contributor to groundwater flow in the Culebra and other units of the Rustler, and the conductivity of fractures is the principal control of this flow. East of the WIPP site, a significant proportion of the fractures within the Culebra are infilled with secondary gypsum (see Figure 2-12), whereas to the west of the site most fractures are open. This distribution of infilled fractures closely parallels the spatial variability of lateral transmissivity in the Culebra (Figure 2-30) and is accounted for in performance assessment calculations through the use of geostatistically conditioned transmissivity fields (Section 6.4.6.2).

Groundwater basin modeling indicates that the Culebra becomes progressively more confined toward the east. This corresponds to an increase in the overburden towards the east and a decrease in the fracturing associated with dissolution at the Rustler - Salado boundary. The

analysis presented below indicates that the lateral extent of dissolution at the top of the Salado is not expected to reach the edge of the controlled area for some 225,000 years, and the rates of erosion in this region (see Section SCR.1.4.3.2) are very low. The pattern of vertical transmissivity in the Rustler is therefore not expected to change significantly during the next 10,000 years, and neither the degree of confinement of the Culebra nor the pattern of open fractures in this unit will undergo significant change during this period.

Percolating groundwater will result in some dissolution and precipitation of fracture infills over the next several climate cycles. The present pattern of secondary gypsum in fractures within the Culebra is considered to be the result of changes in precipitation and recharge over many climate cycles and a similar degree of spatial variability is anticipated to persist into the future. The pattern of secondary gypsum is not considered to be the result of progressive movement of a dissolution front across the area, and the extent of changes in lateral transmissivity in the Culebra will be within the degree of uncertainty accounted for by the use of conditioned transmissivity fields.

Thus, the existing features associated with shallow dissolution and changes due to further shallow dissolution are accounted for in performance assessment calculations through the use of multiple transmissivity fields.

SCR.1.1.5.1.2 Lateral Dissolution

Lateral dissolution takes place when percolating groundwater dissolves halite at the top of the Salado, causing collapse of the overlying Rustler with consequent changes in hydrogeological properties. Nash Draw, some 5 miles (8 kilometers) to the west of the WIPP site, is the most prominent lateral dissolution feature in the region. An average lateral dissolution rate of from 6 to 8 miles (10 to 13 kilometers) per million years has been calculated by Bachman et al. (1973, 39) for the Salado based on the assumption that the edge of the salt has moved from the Capitan Reef to its present position over the past 7 to 8 million years. A vertical dissolution rate of 0.06 mile (0.1 kilometer) per million years has similarly been calculated by Bachman (1974, 71; 1980, 97; 1981, 3) using dated ash layers. Although these are average rates and may be exceeded during particular climate states or by advancing tongues ahead of the main dissolution front, these rates indicate that dissolution of the Salado at the edge of the WIPP site would not take place for some 225,000 years, and an additional 2 to 3 million years would be required for dissolution to reach the repository horizon.

Lateral dissolution may also have affected the Rustler directly. In the vicinity of Nash Draw, halite is absent from all the units of the Rustler. Further east, towards the WIPP site, halite progressively appears in younger units. This has led many investigators to conclude that halite has been dissolved from the Rustler by groundwater (see, for example, Lambert 1983, Bachman 1984, and Lowenstein 1987). A sedimentological analysis of the Rustler in 1988 led Holt and Powers (Appendix FAC) to conclude that halite had either not been formed or had dissolved soon after deposition and, therefore, that only limited lateral dissolution has occurred since Permian times. Even if post-depositional dissolution has taken place, the

period over which it occurred is longer than the regulatory period. Lateral dissolution has therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.1.5.1.3 Deep Dissolution

Deep dissolution refers to the dissolution of salt or other evaporite minerals in a formation at depth (see Section 2.1.6.2). Deep dissolution is distinguished from shallow and lateral dissolution not only by depth, but also by the origin of the water. Dissolution by groundwater from deep water-bearing zones can lead to the formation of cavities. Collapse of overlying beds leads to the formation of **collapse breccias** if the overlying rocks are brittle or to deformation if the overlying rocks are ductile. If dissolution is extensive, **breccia pipes** or **solution chimneys** may form above the cavity. These pipes may reach the surface or pass upwards into fractures and then into microcracks that do not extend to the surface. Breccia pipes may also form through the downward percolation of meteoric waters, as discussed earlier. Deep dissolution is of concern because it could accelerate contaminant transport through the creation of vertical flow paths that bypass low-permeability units in the Rustler. If dissolution occurred within or beneath the waste panels themselves, there could be increased circulation of groundwater through the waste as well as a breach of the Salado host rock.

Features identified as being the result of deep dissolution are present along the northern and eastern margins of the Delaware Basin. In addition to features that have a surface expression or that appear within potash mine workings, deep dissolution has been cited by Anderson et al. (1972, 81) as the cause of lateral variability within evaporite sequences in the lower Salado. Observations concerning various features ascribed to deep dissolution are considered in the following subsections.

SCR.1.1.5.1.4 Solution Chimneys

Exposures of the McNutt Potash Member of the Salado within a mine near Nash Draw have shown a solution pipe containing cemented brecciated fragments of formations higher in the stratigraphic sequence. At the surface, this feature is marked by a dome, and similar domes have been interpreted as dissolution features. The depth of dissolution has not been confirmed, but the collapse structures led Anderson (1978, 52) and Snyder et al. (1982, 65) to postulate dissolution of the Capitan Limestone at depth; collapse of the Salado, Rustler, and younger formations; and subsequent dissolution and hydration by downward percolating waters. San Simon Sink (see Section 2.1.6.2), some 20 miles (35 kilometers) east-southeast of the WIPP site, has also been interpreted as a solution chimney. Subsidence has occurred there in historical times according to Nicholson and Clebsch (1961, 14), suggesting that dissolution at depth is still taking place. Whether this is the result of downwards-percolating surface water or of deep groundwater has not been confirmed. The association of these

dissolution features with the inner margin of the Capitan Reef suggest that they owe their origins, if not their continued development, to groundwaters derived from the Capitan Limestone.

SCR.1.1.5.1.5 Dissolution within the Castile and Lower Salado Formations

The Castile contains sequences of varved anhydrite and carbonate (that is, laminae deposited on a cyclical basis) that can be correlated between several boreholes. On the basis of these deposits, a basin-wide uniformity in the depositional environment of the Castile evaporites was assumed. The absence of varves from all or part of a sequence and the presence of brecciated anhydrite beds have been interpreted by Anderson et al. (1972) as evidence of dissolution. Holt and Powers (Appendix FAC) have questioned the assumption of a uniform depositional environment and contend that the anhydrite beds are lateral equivalents of halite sequences without significant postdepositional dissolution. Wedges of brecciated anhydrite along the margin of the Castile have been interpreted by Robinson and Powers (1987, 78) as gravity-driven clastic deposits, rather than the result of deep dissolution.

Localized depressions at the top of the Castile and inclined geophysical marker units at the base of the Salado have been interpreted by Davies (1983, 45) as the result of deep dissolution and subsequent collapse or deformation of overlying rocks. The postulated cause of this dissolution was circulation of undersaturated groundwaters from the Bell Canyon Formation (hereafter referred to as the Bell Canyon). Additional boreholes (notably WIPP-13, WIPP-32, and DOE-2) and geophysical logging led Borns and Shaffer (1985) to conclude that the features interpreted by Davies as being dissolution features are the result of irregularities at the top of the Bell Canyon. These irregularities led to localized depositional thickening of the Castile and lower Salado sediments.

SCR.1.1.5.1.6 Collapse Breccias at Basin Margins

Collapse breccias are present at several places around the margins of the Delaware Basin. Their formation is attributed to relatively fresh groundwater from the Capitan Limestone that forms the margin of the basin. Collapse breccias corresponding to features on geophysical records that have been ascribed to deep dissolution have not been found in boreholes away from the margins. These features have been reinterpreted as the result of early dissolution prior to the deposition of the Salado. This topic is discussed further in Section 2.1.6.2.

SCR.1.1.5.1.7 Summary of Deep Dissolution

Deep dissolution features have been identified within the Delaware Basin, but only in marginal areas underlain by Capitan Reef. There is a low probability that deep dissolution will occur sufficiently close to the waste panels over the regulatory period to affect groundwater flow in the immediate region of the WIPP. Deep dissolution at the WIPP site has therefore been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years.

SCR.1.1.5.2 Mineralization

The effects of fracture infills have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

Precipitation of minerals as **fracture infills** can reduce hydraulic conductivities. The distribution of infilled fractures in the Culebra closely parallels the spatial variability of lateral transmissivity in the Culebra (see Section SCR.1.1.5.1). The secondary gypsum veins in the Rustler have not been dated. Strontium isotope studies (Siegel et al. 1991, 5-53 to 5-57) indicate that the infilling minerals are locally derived from the host rock rather than extrinsically derived, and it is inferred that they reflect an early phase of mineralization and are not associated with recent meteoric waters.

Stable isotope geochemistry in the Rustler has also provided information on mineral stabilities in these strata. Both Chapman (1986, 31) and Lambert and Harvey (1987, 207) imply that the mineralogical characteristics of units above the Salado have been stable or subject to only minor changes under the various recharge conditions that have existed during the past 0.6 million year—the period since the formation of the Mescalero caliche and the establishment of a pattern of climate change and associated changes in recharge that led to present-day hydrogeological conditions. No changes in climate are expected other than those experienced during this period, and for this reason, no changes are expected in the mineralogical characteristics other than those expressed by the existing variability of fracture infills and diagenetic textures. Formation of fracture infills will reduce transmissivities and will therefore be of beneficial consequence to the performance of the disposal system.

SCR.1.2 Subsurface Hydrological FEPs

This section discusses FEPs relating to the natural groundwater system at the WIPP site and FEPs that may lead to changes in its flow and chemical characteristics.

SCR.1.2.1 Groundwater Characteristics

Saturated groundwater flow, unsaturated groundwater flow, fracture flow, and the effects of preferential pathways are accounted for in performance assessment calculations. Density effects on groundwater flow have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Saturated groundwater flow, **unsaturated groundwater flow**, and **fracture flow** are accounted for in performance assessment calculations. Groundwater flow is discussed in Sections 2.2.1, 6.4.5, and 6.4.6.

The most transmissive unit in the Rustler, and hence the most significant potential pathway for transport of radionuclides to the accessible environment, is the Culebra. The properties of Culebra groundwaters are not homogeneous, and spatial variations in groundwater density

(Section 2.2.1.4.1.2) could influence the rate and direction of groundwater flow. A comparison of the gravity-driven flow component and the pressure-driven component in the Culebra, however, shows that only in the region to the south of the WIPP are head gradients low enough for density gradients to be significant (Davies 1989, 53). Accounting for this variability would rotate groundwater flow vectors towards the east (down-dip) and hence fluid in the high transmissivity zone would move away from the zone. Excluding brine density variations within the Culebra from performance assessment calculations is therefore a conservative assumption, and **density effects on groundwater flow** have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The hydrogeologic properties of the Culebra are also spatially variable. This variability, including the **effects of preferential pathways**, is accounted for in performance assessment calculations in the estimates of transmissivity and aquifer thickness.

SCR.1.2.2 Changes in Groundwater Flow

Changes in groundwater flow arising from saline intrusion, freshwater intrusion, or natural gas intrusion have been eliminated from performance assessment calculations on the basis of a low probability of occurrence over 10,000 years. Natural thermal effects on groundwater flow have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. A hydrological response to earthquakes has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.2.2.1 Saline Intrusion

No natural events or processes have been identified that could result in **saline intrusion** into units above the Salado or cause a significant increase in fluid density. Natural saline intrusion has therefore been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years. Saline intrusion arising from human-initiated events such as drilling into a pressurized brine pocket is discussed in Section SCR.3.3.

SCR.1.2.2.2 Freshwater Intrusion

A number of FEPs, including climate change, can result in changes in infiltration and recharge (see Section SCR.1.5.3). These changes will affect the height of the water table and hence could affect groundwater flow in the Rustler through changes in head gradients. The generally low transmissivity of the Dewey Lake and the Rustler, however, will prevent any significant changes in groundwater density from occurring within the Culebra over the timescales for which increased precipitation and recharge are anticipated. No other natural events or processes have been identified that could result in **freshwater intrusion** into units above the Salado or cause a significant decrease in fluid density. Freshwater intrusion has

therefore been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years.

SCR.1.2.2.3 *Thermal Effects*

The geothermal gradient in the region of the WIPP has been measured at about 50°C per mile (30°C per kilometer). Given the generally low permeability in the region, and the limited thickness of units in which groundwater flow occurs (for example the Culebra), natural convection will be too weak to have a significant effect on groundwater flow. No natural FEPs have been identified that could significantly alter the temperature distribution of the disposal system or give rise to **thermal effects on groundwater flow**. Such effects have therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.2.2.4 *Natural Gas Intrusion*

Hydrocarbon resources are present in formations beneath the WIPP (Section 2.3.1.2), and natural gas is extracted from the Morrow Formation. These reserves are, however, some 14,000 feet (4,200 meters) below the surface, and no natural events or processes have been identified that could result in **natural gas intrusion** into the Salado or the units above. Natural gas intrusion has therefore been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years.

SCR.1.2.2.5 *Hydrological Effects of Seismic Activity*

There are a variety of **hydrological responses to earthquakes**. Some of these responses, such as changes in surface-water flow directions, result directly from fault movement. Others, such as changes in subsurface water chemistry and temperature, probably result from changes in flow pathways along the fault or fault zone. According to Bredehoeft et al. (1987, 139), further away from the region of fault movement two types of changes to groundwater levels may take place as a result of changes in fluid pressure:

- The passage of seismic waves through a rock mass causes a volume change, inducing a transient response in the fluid pressure, which may be observed as a short-lived fluctuation of the water level in wells.

- Changes in volume strain can cause long-term changes in water level. A buildup of strain occurs prior to rupture and is released during an earthquake. The consequent change in fluid pressure may be manifested by the drying up or reactivation of springs some distance from the region of the epicenter.

Fluid pressure changes induced by the transmission of seismic waves can produce changes of up to several meters in groundwater levels in wells, even at distances of thousands of kilometers from the epicenter. These changes are temporary, however, and levels typically

return to pre-earthquake levels in a few hours or days. Changes in fluid pressure arising from changes in volume strain persist for much longer periods, but they are only potentially consequential in tectonic regimes where there is a significant buildup of strain. The regional tectonics of the Delaware Basin indicate that such a buildup has a low probability of occurring over the next 10,000 years (Section SCR.1.1.2).

The expected level of seismic activity in the region of the WIPP will be of low consequence to the performance of the disposal system in terms of groundwater flow or contaminant transport. Changes in groundwater levels resulting from more distant earthquakes will be too short in duration to be significant. Thus, the hydrological effects of earthquakes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.3 Subsurface Geochemical FEPs

SCR.1.3.1 Groundwater Geochemistry

Groundwater geochemistry in the hydrological units of the disposal system is accounted for in performance assessment calculations.

The most important aspect of **groundwater geochemistry** in the region of the WIPP in terms of chemical retardation and colloid stability is salinity. Groundwater geochemistry is discussed in detail in Sections 2.2 and 2.4 and summarized here. The Delaware Mountain Group, Castile, and Salado contain basinal brines. Waters in the Castile and Salado are at or near halite saturation. Above the Salado, groundwaters are also relatively saline, and groundwater quality is poor in all of the permeable units. Waters from the Culebra vary spatially in salinity and chemistry. They range from saline sodium chloride-rich waters to brackish calcium sulfate-rich waters. In addition, a range of magnesium to calcium ratios has been observed, and some waters reflect the influence of potash mining activities, having elevated potassium to sodium ratios. Waters from the Santa Rosa are generally of better quality than any of those from the Rustler. Salado and Castile brine geochemistry is accounted for in performance assessment calculations of the actinide source term (Section 6.4.3.4). Culebra brine geochemistry is accounted for in the retardation factors used in performance assessment calculations of actinide transport (see Section 6.4.6.2).

SCR.1.3.2 Changes in Groundwater Chemistry

The effects of saline or freshwater intrusion and of dissolution on groundwater chemistry have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Changes in groundwater Eh and pH have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Natural changes in the groundwater chemistry of the Culebra and other units that resulted from **saline intrusion** or **freshwater intrusion** could potentially affect chemical retardation and the stability of colloids. **Changes in groundwater Eh** and **groundwater pH** could also affect the migration of radionuclides (see Sections SCR.2.5.5 and SCR.2.5.6). No natural events or processes have been identified that could result in saline intrusion into units above the Salado, and the magnitude of any natural temporal variation due to the **effects of dissolution** on groundwater chemistry, or due to changes in recharge is likely to be no greater than the present spatial variation. These FEPs related to the effects of future natural changes in groundwater chemistry have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.4 Geomorphological FEPs

SCR.1.4.1 Physiography

Relevant aspects of the physiography, geomorphology, and topography of the region around the WIPP are accounted for in performance assessment calculations.

Physiography and geomorphology are discussed in detail in Section 2.1.4, and are accounted for in the setup of the performance assessment calculations (Section 6.4.2).

SCR.1.4.2 Meteorite Impact

Disruption arising from the impact of a large meteorite has been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

Meteors frequently enter the earth's atmosphere, but most of these are small and burn up before reaching the ground. Of those that reach the ground, most produce only small impact craters that would have no effect on the postclosure integrity of a repository 2,150 feet (650 meters) below the ground surface. While the depth of a crater may be only one-eighth of its diameter, the depth of the disrupted and brecciated material is typically one-third of the overall crater diameter (Grieve 1987, 248). Direct disruption of waste at the WIPP would only occur with a crater larger than 1.1 miles (1.8 kilometers) in diameter. Even if waste were not directly disrupted, the **impact of a large meteorite** could create a zone of fractured rocks beneath and around the crater. The extent of such a zone would depend on the rock type. For sedimentary rocks, the zone may extend to a depth of half the crater diameter or more (Dence et al. 1977, 263). The impact of a meteorite causing a crater larger than 0.6 mile (1 kilometer) in diameter could thus fracture the Salado above the repository.

Geological evidence for meteorite impacts on earth is rare because many meteorites fall into the oceans and erosion and sedimentation serve to obscure craters that form on land. Dietz (1961) estimated that meteorites that cause craters larger than 0.6 mile (1 kilometer) in diameter strike the earth at the rate of about one every 10,000 years (equivalent to about

2×10^{-13} impacts per square kilometer per year). Using observations from the Canadian Shield, Hartmann (1965, 161) estimated a frequency of between 0.8×10^{-13} and 17×10^{-13} per square kilometer per year for impacts causing craters larger than 0.6 mile (1 kilometer). Frequencies estimated for larger impacts in studies reported by Grieve (1987, 263) can be extrapolated to give a rate of about 1.3×10^{-12} per square kilometer per year for craters larger than 0.6 mile (1 kilometer). It is commonly assumed that meteorite impacts are randomly distributed across the earth's surface, although Halliday (1964, 267 – 277) calculated that the rate of impact in polar regions would be some 50 to 60 percent of that in equatorial regions. The frequencies reported by Grieve (1987) would correspond to an overall rate of about one per 1,000 years on the basis of a random distribution.

Assuming the higher estimated impact rate of 17×10^{-13} impacts per square kilometer per year for impacts leading to fracturing of sufficient extent to affect a deep repository and assuming a repository footprint of 0.9 mile × 1.0 mile (1.4 kilometers × 1.6 kilometers) for the WIPP yields a frequency of about 4×10^{-12} impacts per year for a direct hit above the repository. This impact frequency is several orders of magnitude below the screening limit of 10^{-4} per 10,000 years provided in 40 CFR § 194.32(d).

Meteorite hits directly above the repository footprint are not the only impacts of concern, however, because large craters may disrupt the waste panels even if the center of the crater is outside the repository area. It is possible to calculate the frequency of meteorite impacts that could disrupt a deep repository such as the WIPP by using the conservative model of a cylinder of rock fractured to a depth equal to one-half the crater diameter, as shown in Figure SCR-1. The area within which a meteorite could impact the repository is calculated by

$$S_D = (L + 2\times\frac{D}{2}) \times (W + 2\times\frac{D}{2}) ,$$

where

L = length of the repository footprint (kilometers)
W = width of the repository footprint (kilometers)
D = diameter of the impact crater (kilometers)
S_D = area of the region where the crater would disrupt the repository (square kilometers).

There are insufficient data on meteorites that have struck the earth to derive a distribution function for the size of craters directly. Using meteorite impacts on the moon as an analogy, however, Grieve (1987, 257) derived the following distribution function:

$$F_D \propto D^{-1.8} ,$$

where

F_D = frequency of impacts resulting in craters larger than D (impacts per square kilometer per year).

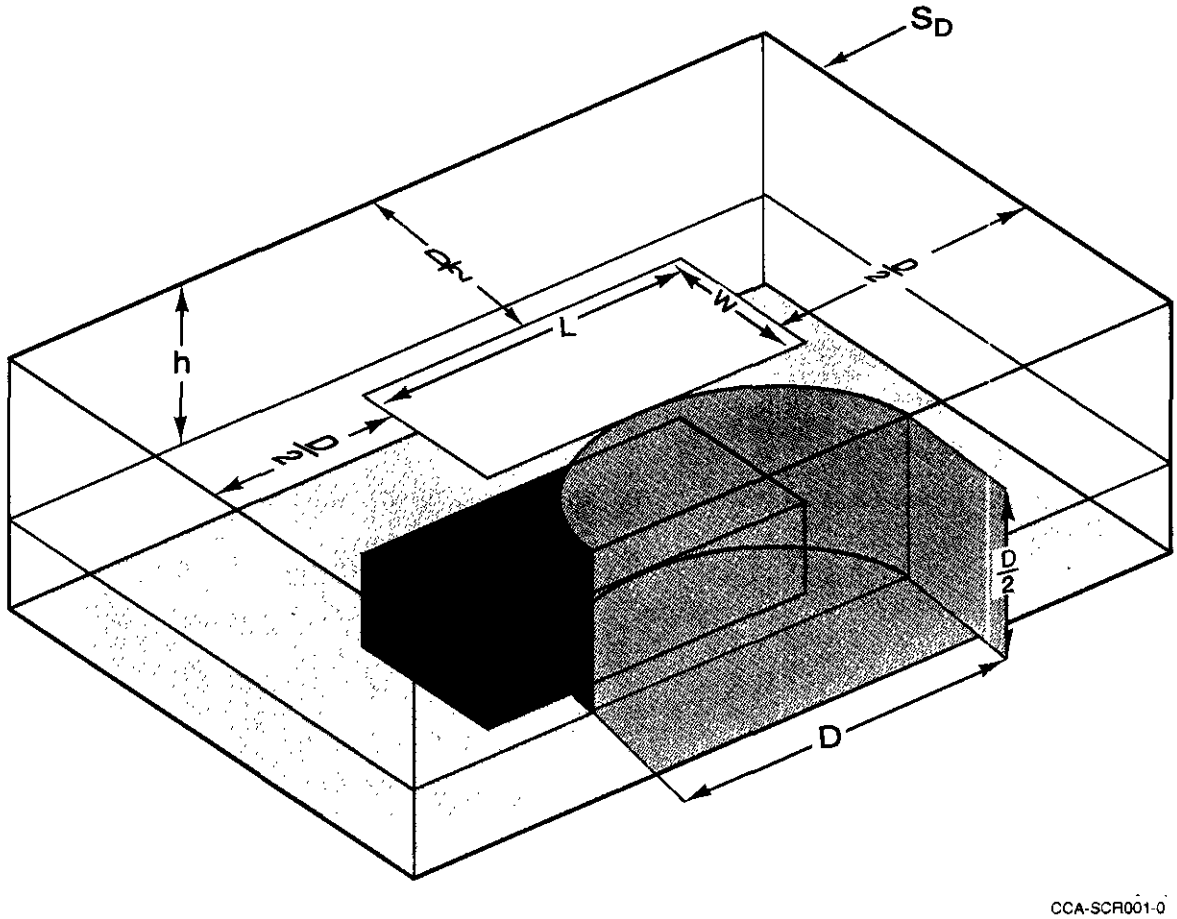

Figure SCR-1. The Critical Region for Meteorite Impacts That Could Result in Fracturing of the Repository Horizon

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If f(D) denotes the frequency of impacts giving craters of diameter D, then the frequency of impacts giving craters larger than D is

$$F_D = \int_D^{\infty} f(D)dD$$

and

$$f(D) = F_1 \times 1.8 \times D^{-2.8} ,$$

where

F_1 = frequency of impacts resulting in craters larger than 1 kilometer (impacts per square kilometer per year)

f(D) = frequency of impacts resulting in craters of diameter D (impacts per square kilometer per year).

The overall frequency of meteorite impacts that could disrupt or fracture the repository is thus given by

$$N = \int_{2h}^{\infty} f(D) \times S_D \, dD ,$$

where

h = depth to repository (kilometers)

N = frequency of impacts leading to disruption of the repository (impacts per year)

$$N = 1.8F_1[1.8LW(2h)^{-1.8} + 0.8(L+W)(2h)^{-0.8} - 0.2(2h)^{0.2}] .$$

If it is assumed that the repository is located at a depth of 650 meters and has a footprint area of 0.9 mile × 1.0 mile (1.4 kilometers × 1.6 kilometers) and that meteorites creating craters larger than 1 kilometer in diameter hit the earth at a frequency (F_1) of 17×10^{-13} impacts per square kilometer per year, then the above equation gives a frequency of approximately 1.3×10^{-11} impacts per year for impacts disrupting the repository. If impacts are randomly distributed over time, this corresponds to a probability of 1.3×10^{-7} over 10,000 years.

Similar calculations have been performed that indicate rates of impact of between 10^{-12} and 10^{-13} per year for meteorites large enough to disrupt a deep repository (see, for example, Hartmann 1979, Kärnbränslesakerhet 1978, Claiborne and Gera 1974, Cranwell et al. 1990, and Thorne 1992). Meteorite impact can thus be eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

Assuming a random or nearly random distribution of meteorite impacts, cratering at any location is inevitable given sufficient time. Although repository depth and host-rock lithology may reduce the consequences of a meteorite impact, there are no repository locations or engineered systems that can reduce the probability of impact over 10,000 years.

SCR.1.4.3 Denudation

SCR.1.4.3.1 Weathering

The effects of chemical and mechanical weathering have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Mechanical weathering and **chemical weathering** are assumed to be occurring at or near the surface around the WIPP site, through processes such as exfoliation and leaching. The extent of these processes is limited and they will contribute little to the overall rate of erosion in the area or to the availability of material for other erosional processes. The effects of chemical and mechanical weathering have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.4.3.2 Erosion

The effects of fluvial and aeolian erosion and mass wasting in the region of the WIPP have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The geomorphological regime on the Mescalero Plain (Los Medaños) in the region of the WIPP is dominated by aeolian processes. Dunes are present in the area, and although some are stabilized by vegetation, **aeolian erosion** will occur as they migrate across the area. Old dunes will be replaced by new dunes, and no significant changes in the overall thickness of aeolian material are likely to occur.

Currently, precipitation in the region of the WIPP is too low (about 13 inches [33 centimeters] per year) to cause perennial streams, and the relief in the area is too low for extensive sheet flood erosion during storms. An increase in precipitation to around 24 inches (61 centimeters) per year in cooler climatic conditions could result in perennial streams, but the nature of the relief and the presence of dissolution hollows and sinks will ensure that these streams remain small. Significant **fluvial erosion** is not expected during the next 10,000 years.

Mass wasting (the downslope movement of material caused by the direct effect of gravity) is important only in terms of sediment erosion in regions of steep slopes. In the vicinity of the WIPP, mass wasting will be insignificant under the climatic conditions expected over the next 10,000 years.

Erosion from wind, water, and mass wasting will continue in the WIPP region throughout the next 10,000 years at rates similar to those occurring at present. These rates are too low to affect the performance of the disposal system significantly. Thus, the effects of fluvial and aeolian erosion and mass wasting have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.4.3.3 Sedimentation

The effects of aeolian, fluvial, and lacustrine deposition and sedimentation in the region of the WIPP have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The geomorphological regime on the Mescalero Plain (Los Medaños) in the region of the WIPP is dominated by aeolian processes, but although some dunes are stabilized by vegetation, no significant changes in the overall thickness of aeolian material are expected to occur. Vegetational changes during periods of wetter climate may further stabilize the dune fields, but **aeolian deposition** is not expected to significantly increase the overall thickness of the superficial deposits.

The limited extent of water courses in the region of the WIPP, under both present-day conditions and under the expected climatic conditions, will restrict the amount of **fluvial deposition** and **lacustrine deposition** in the region.

Mass wasting may be significant if it results in dams or modifies streams. In the region around the WIPP, the Pecos River forms a significant water course some 12 miles (19 kilometers) away, but the broadness of its valley precludes either significant mass wasting or the formation of large impoundments.

Sedimentation from wind, water, and mass wasting is expected to continue in the WIPP region throughout the next 10,000 years at the low rates similar to those occurring at present. These rates are too low to significantly affect the performance of the disposal system. Thus, the effects of aeolian, fluvial, and lacustrine deposition and sedimentation resulting from mass wasting have been eliminated from performance assessment calculations on the basis of low consequence.

SCR.1.4.4 Soil Development

Soil development has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The Mescalero caliche is a well-developed calcareous remnant of an extensive soil profile across the WIPP site and adjacent areas. Although this unit may be up to 10 feet (3 meters) thick, it is not continuous and does not prevent infiltration to the underlying formations. At Nash Draw, this caliche, dated in Lappin et al. (1989, 2-4) at 410,000 to 510,000 years old, is present in collapse blocks, indicating some growth of Nash Draw in the late Pleistocene. Localized gypsite spring deposits about 25,000 years old occur along the eastern flank of Nash Draw, but the springs are not currently active. The Berino soil, interpreted as 333,000 years old (Rosholt and McKinney 1980, Table 5), is a thin soil horizon above the Mescalero caliche. The persistence of these soils on the Livingston Ridge and the lack of deformation indicates the relative stability of the WIPP region over the past half-million years.

Continued growth of caliche may occur in the future but will be of low consequence in terms of its effect on infiltration. Other soils in the area are not extensive enough to affect the amount of infiltration that reaches underlying aquifers. **Soil development** has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.5 Surface Hydrological FEPs

SCR.1.5.1 Fluvial

Stream and river flow has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

No perennial streams are present at the WIPP site, and there is no evidence in the literature indicating that such features existed at this location since the Pleistocene (see, for example, Powers et al. 1978; and Bachman 1974, 1981, and 1987). The Pecos River is approximately 12 miles (19 kilometers) from the WIPP site and more than 300 feet (90 meters) lower in elevation. **Stream and river flow** have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.5.2 Lacustrine

The effects of surface water bodies have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

No standing **surface water bodies** are present at the WIPP site, and there is no evidence in the literature indicating that such features existed at this location during or after the Pleistocene (see, for example, Powers et al. 1978; and Bachman 1974, 1981, and 1987). In Nash Draw, lakes and spoil ponds associated with potash mines are located at elevations 100 feet (30 meters) below the elevation of the land surface at the location of the waste panels. There is no evidence in the literature to suggest that Nash Draw was formed by stream erosion or was at any time the location of a deep body of standing water, although shallow playa lakes have existed there at various times. Based on these factors, the formation of large lakes is unlikely and the formation of smaller lakes and ponds is of little consequence to the performance of the disposal system. The effects of surface water bodies have therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.5.3 Groundwater Recharge and Discharge

Groundwater recharge, infiltration, and groundwater discharge are accounted for in performance assessment calculations.

The groundwater basin described in Section 2.2.1.4 is governed by flow from areas where the water table is high to areas where the water table is low. The height of the water table is governed by the amount of **groundwater recharge** reaching the water table, which in turn is a function of the vertical hydraulic conductivity and the partitioning of precipitation between evapotranspiration, runoff, and **infiltration**. Flow within the Rustler is also governed by the amount of **groundwater discharge** that takes place from the basin. In the region around the WIPP, the principal discharge areas are along Nash Draw and the Pecos River. Groundwater flow modeling accounts for infiltration, recharge, and discharge (Sections 2.2.1.4 and 6.4.10.2).

SCR.1.5.4 Changes in Surface Hydrology

Changes in groundwater recharge and discharge arising as a result of climate change are accounted for in performance assessment calculations. The effects of river flooding and lake formation have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Changes in recharge may affect groundwater flow and radionuclide transport in units such as the Culebra and Magenta dolomites. Changes in the surface environment driven by natural climate change are expected to occur over the next 10,000 years (see Section SCR.1.6.2). Groundwater basin modeling (Section 2.2.1.4) indicates that a change in recharge will affect the height of the water table in the area of the WIPP, and that this will in turn affect the direction and rate of groundwater flow.

The present-day water table in the vicinity of the WIPP is within the Dewey Lake at about 3,215 feet (980 meters) above mean sea level (Section 2.2.1.4.2.1). An increase in recharge relative to present-day conditions would raise the water table, potentially as far as the ground surface locally. Similarly, a decrease in recharge could result in a lowering of the water table. The low transmissivity of the Dewey Lake and the Rustler ensures that any such lowering of the water table will be at a slow rate, and lateral discharge from the groundwater basin is expected to persist for several thousand years after any decrease in recharge. Under the anticipated changes in climate over the next 10,000 years, the water table will not fall below the base of the Dewey Lake, and dewatering of the Culebra is not expected to occur during this period (Section 2.2.1.4).

Changes in groundwater recharge and discharge are accounted for in performance assessment calculations through definition of the boundary conditions for flow and transport in the Culebra (Section 6.4.9).

Intermittent flooding of stream channels and the formation of shallow lakes will occur in the WIPP region over the next 10,000 years. These may have a short-lived and local effect on the height of the water table, but are unlikely to affect groundwater flow in the Culebra.

Future occurrences of playa lakes or other longer-term floods will be remote from the WIPP and will have little consequence on system performance in terms of groundwater flow at the site. There is no reason to believe that any impoundments or lakes could form over the WIPP site itself. Thus, **river flooding** and **lake formation** have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.6 Climatic FEPs

This section discusses climate change and glaciation in the WIPP region.

SCR.1.6.1 Climate

Precipitation and temperature are accounted for in performance assessment calculations.

The climate and meteorology of the region around the WIPP are described in Section 2.5.2. Precipitation in the region is low (about 13 inches [33 centimeters] per year) and temperatures are moderate with a mean annual temperature of about 63°F (17°C). **Precipitation** and **temperature** are important controls on the amount of recharge that reaches the groundwater system and are accounted for in performance assessment calculations by use of a sampled parameter for scaling flow velocity in the Culebra (Section 6.4.9 and Appendix PAR, Parameter 48).

SCR.1.6.2 Climate Change

SCR.1.6.2.1 Meteorological

Climate change is accounted for in performance assessment calculations.

Climate changes are instigated by changes in the earth's orbit, which affect the amount of insolation, and by feedback mechanisms within the atmosphere and hydrosphere. Models of these mechanisms, combined with interpretations of the geological record, suggest that the climate will become cooler and wetter in the WIPP region during the next 10,000 years as a result of natural causes. Other changes, such as fluctuations in radiation intensity from the sun and variability within the many feedback mechanisms, will modify this climatic response to orbital changes. The available evidence suggests that these changes will be less extreme than those arising from orbital fluctuations.

The effect of a change to cooler and wetter conditions is considered to be an increase in the amount of recharge, which in turn will affect the height of the water table (see Section SCR.1.5.4). The height of the water table across the groundwater basin is an important control on the rate and direction of groundwater flow within the Culebra (see Section 2.2.1.4), and hence potentially on transport of radionuclides released to the Culebra through the shafts or intrusion boreholes. Climate change is accounted for in performance assessment

calculations through a sampled parameter used to scale groundwater flow velocity in the Culebra (Section 6.4.9 and Appendix PAR, Parameter 48).

SCR.1.6.2.2 Glaciation

Glaciation and the effects of permafrost have been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

No evidence exists to suggest that the northern part of the Delaware Basin has been covered by continental glaciers at any time since the beginning of the Paleozoic Era. During the maximum extent of continental **glaciation** in the Pleistocene Epoch, glaciers extended into northeastern Kansas at their closest approach to southeastern New Mexico. There is no evidence that alpine glaciers formed in the region of the WIPP during the Pleistocene glacial periods.

According to the theory that relates the periodicity of climate change to perturbations in the earth's orbit, a return to a full glacial cycle within the next 10,000 years is highly unlikely (Imbrie and Imbrie 1980, 951).

Thus, glaciation has been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years. Similarly, a number of processes associated with the proximity of an ice sheet or valley glacier, such as **permafrost** and accelerated slope erosion (solifluction) have been eliminated from performance assessment calculations on the basis of low probability of occurrence over the next 10,000 years.

SCR.1.7 Marine FEPs

SCR.1.7.1 Seas

The effects of estuaries, seas, and oceans have has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The WIPP site is more than 480 miles (800 kilometers) from the Pacific Ocean and from the Gulf of Mexico. **Estuaries** and **seas and oceans** have therefore been eliminated from performance assessment calculations on the basis of low consequence to the disposal system.

SCR.1.7.2 Marine Sedimentology

The effects of coastal erosion, and marine sediment transport and deposition have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The WIPP site is more than 480 miles (800 kilometers) from the Pacific Ocean and Gulf of Mexico. The effects of **coastal erosion** and **marine sediment transport and deposition** have therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.7.3 Sea Level Changes

The effects of both short-term and long-term sea level changes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The WIPP site is some 3,330 feet (1,015 meters) above sea level. Global **sea level change** may result in sea levels as much as 460 feet (140 meters) below that of the present day during glacial periods, according to Chappell and Shackleton (1986, 138). This can have marked effects on coastal aquifers. During the next 10,000 years, the global sea level can be expected to drop towards this glacial minimum, but this will not affect the groundwater system in the vicinity of the WIPP. Short-term changes in sea level, brought about by events such as meteorite impact, tsunamis, seiches, and hurricanes may raise water levels by several tens of meters. Such events have a maximum duration of a few days and will have no effect on the surface or groundwater systems at the WIPP site. Anthropogenic-induced global warming has been conjectured by Warrick and Oerlemans (1990, 278) to result in longer-term sea level rise. The magnitude of this rise, however, is not expected to be more than a few meters, and such a variation will have no effect on the groundwater system in the WIPP region. Thus, the effects of both short-term and long-term sea level changes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.8 Ecological FEPs

SCR.1.8.1 Flora and Fauna

The effects of the natural plants, animals, and microbes (flora and fauna) in the region of the WIPP have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The terrestrial and aquatic ecology of the region around the WIPP is described in Section 2.4.1. The **plants** in the region are predominantly shrubs and grasses. The most conspicuous **animals** in the area are jackrabbits and cottontails. **Microbes** are presumed to be present within the thin soil horizons. The effects of this flora and fauna in the region have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.1.8.2 Changes in Flora and Fauna

The effects of natural ecological development likely to occur in the region of the WIPP have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The region around the WIPP is sparsely vegetated as a result of the climate and poor soil quality. Wetter periods are expected during the regulatory period, but botanical records indicate that, even under these conditions, dense vegetation will not be present in the region (Swift 1992; see Appendix CLI, 17). The effects of the indigenous fauna are of low consequence to the performance of the disposal system and no natural events or processes have been identified that would lead to a change in this fauna that would be of consequence to system performance. **Natural ecological development** in the region of the WIPP has therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2 Waste- and Repository-Induced FEPs

In Section SCR.2, the DOE discusses waste- and repository-induced FEPs in the context of the FEP categorization scheme presented in Table SCR-2. Waste- and repository-induced FEPs are potentially relevant to the analyses conducted to evaluate compliance with 40 CFR § 191.13, 40 CFR § 191.15, and 40 CFR § 191.24. Note that the categories concerned with geology and mechanics (SCR.2.3), hydrology and fluid dynamics (SCR.2.4). and geochemistry and chemistry (SCR.2.5) relate to structure, fluid flow, and fluid chemistry, respectively, within the repository and the rest of the disposal system. The categories concerned with contaminant transport modes (SCR.2.6) and processes (SCR.2.7), and ecology (SCR.2.8) relate to the potential migration of radionuclides through the disposal system to the accessible environment. FEPs presented in Table SCR-2 are printed in bold in the text of the FEP screening discussions.

SCR.2.1 Waste and Repository Characteristics

SCR.2.1.1 Repository Characteristics

The WIPP repository disposal geometry is accounted for in performance assessment calculations.

Disposal geometry is described in Chapter 3.0 and is accounted for in the setup of performance assessment calculations (Section 6.4.3).

SCR.2.1.2 Waste Characteristics

The waste inventory and heterogeneity of the waste forms are accounted for in performance assessment calculations.

Table SCR-2. Waste- and Repository-Induced FEPs and Their Screening Classifications

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
WASTE AND REPOSITORY CHARACTERISTICS			SCR.2.1
Repository characteristics			SCR.2.1.1
Disposal geometry	UP		
Waste characteristics			SCR.2.1.2
Waste inventory	UP		
Heterogeneity of waste forms	DP		
Container characteristics			SCR.2.1.3
Container form	SO-C		
Container material inventory	UP		
Seal characteristics			SCR.2.1.4
Seal geometry	UP		
Seal physical properties	UP		
Seal chemical composition	SO-C	Beneficial SO-C	
Backfill characteristics			SCR.2.1.5
Backfill physical properties	SO-C		
Backfill chemical composition	UP		
Postclosure monitoring			SCR.2.1.6
Postclosure monitoring	SO-C		
RADIOLOGICAL FEPS			SCR.2.2
Radioactive decay			SCR.2.2.1
Radionuclide decay and ingrowth	UP		
Heat from radioactive decay			SCR.2.2.2
Heat from radioactive decay	SO-C		
Nuclear criticality			SCR.2.2.3
Nuclear criticality: heat	SO-P		
Radiological effects on material properties			SCR.2.2.4
Radiological effects on waste	SO-C		
Radiological effects on containers	SO-C		
Radiological effects on seals	SO-C		
GEOLOGICAL AND MECHANICAL FEPS			SCR.2.3
Excavation-induced fracturing			SCR.2.3.1
Disturbed rock zone	UP		
Excavation-induced changes in stress	UP		
Rock creep			SCR.2.3.2
Salt creep	UP		
Changes in the stress field	UP		
Roof falls			SCR.2.3.3
Roof falls	UP		
Subsidence			SCR.2.3.4
Subsidence	SO-C		
Large scale rock fracturing	SO-P		

Table SCR-2. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Effects of fluid pressure changes			SCR.2.3.5
Disruption due to gas effects	UP		
Pressurization	UP		
Effects of explosions			SCR.2.3.6
Gas explosions	UP		
Nuclear explosions	SO-P		
Thermal effects			SCR.2.3.7
Thermal effects on material properties	SO-C		
Thermally-induced stress changes	SO-C		
Differing thermal expansion of repository components	SO-C		
Mechanical effects on material properties			SCR.2.3.8
Consolidation of waste	UP		
Movement of containers	SO-C		
Container integrity	SO-C	Beneficial SO-C	
Mechanical effects of backfill	SO-C		
Consolidation of seals	UP		
Mechanical degradation of seals	UP		
Investigation boreholes	SO-C		
Underground boreholes	UP		
SUBSURFACE HYDROLOGICAL AND FLUID DYNAMICAL FEPS			SCR.2.4
Repository-induced flow			SCR.2.4.1
Brine inflow	UP		
Wicking	UP		
Effects of gas generation			SCR.2.4.2
Fluid flow due to gas production	UP		
Thermal effects			SCR.2.4.3
Convection	SO-C		
GEOCHEMICAL AND CHEMICAL FEPS			SCR.2.5
Gas generation			SCR.2.5.1
Microbial gas generation			SCR.2.5.1.1
Degradation of organic material	UP		
Effects of temperature on microbial gas generation	UP		
Effects of pressure on microbial gas generation	SO-C		
Effects of radiation on microbial gas generation	SO-C		
Effects of biofilms on microbial gas generation	UP		

Table SCR-2. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Corrosion			SCR.2.5.1.2
Gases from metal corrosion	UP		
Galvanic coupling	SO-P		
Chemical effects of corrosion	UP		
Radiolytic gas generation			SCR.2.5.1.3
Radiolysis of brine	SO-C		
Radiolysis of cellulose	SO-C		
Helium gas production	SO-C		
Radioactive gases	SO-C		
Chemical speciation			SCR.2.5.2
Speciation	UP	UP in disposal rooms and Culebra. SO-C elsewhere, and beneficial SO-C in cementitious seals.	
Kinetics of speciation	SO-C		
Precipitation and dissolution			SCR.2.5.3
Dissolution of waste	UP		
Precipitation	SO-C	Beneficial SO-C	
Kinetics of precipitation and dissolution	SO-C	Kinetics of waste dissolution is a beneficial SO-C	
Sorption			SCR.2.5.4
Actinide sorption	UP	UP in the Culebra and Dewey Lake. Beneficial SO-C elsewhere	
Kinetics of sorption	UP		
Changes in sorptive surfaces	UP		
Reduction-oxidation chemistry			SCR.2.5.5
Effect of metal corrosion	UP		
Reduction-oxidation fronts	SO-P		
Reduction-oxidation kinetics	UP		
Localized reducing zones	SO-C		
Organic complexation			SCR.2.5.6
Organic complexation	SO-C		
Organic ligands	SO-C		
Humic and fulvic acids	UP		
Kinetics of organic complexation	SO-C		
Exothermic reactions			SCR.2.5.7
Exothermic reactions	SO-C		
Concrete hydration	SO-C		
Chemical effects on material properties			SCR.2.5.8
Chemical degradation of seals	UP		
Chemical degradation of backfill	SO-C		

Table SCR-2. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
Microbial growth on concrete	UP		
CONTAMINANT TRANSPORT MODE FEPS			SCR.2.6
Solute transport			SCR.2.6.1
Solute transport	UP		
Colloid transport			SCR.2.6.2
Colloid transport	UP		
Colloid formation and stability	UP		
Colloid filtration	UP		
Colloid sorption	UP		
Particulate transport			SCR.2.6.3
Suspensions of particles	DP	SO-C for undisturbed conditions	
Rinse	SO-C		
Cuttings	DP	Repository intrusion only	
Cavings	DP	Repository intrusion only	
Spallings	DP	Repository intrusion only	
Microbial transport			SCR.2.6.4
Microbial transport	UP		
Biofilms	SO-C	Beneficial SO-C	
Gas transport			SCR.2.6.5
Transport of radioactive gases	SO-C		
CONTAMINANT TRANSPORT PROCESSES			SCR.2.7
Advection			SCR.2.7.1
Advection	UP		
Diffusion			SCR.2.7.2
Diffusion	UP		
Matrix diffusion	UP		
Thermochemical transport phenomena			SCR.2.7.3
Soret effect	SO-C		
Electrochemical transport phenomena			SCR.2.7.4
Electrochemical effects	SO-C		
Galvanic coupling	SO-P		
Electrophoresis	SO-C		
Physicochemical transport phenomena			SCR.2.7.5
Chemical gradients	SO-C		
Osmotic processes	SO-C	Beneficial SO-C	
Alpha recoil	SO-C		
Enhanced diffusion	SO-C		

Table SCR-2. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

Features, Events, and Processes (FEPs)	Screening Classification	Comments	Appendix SCR Section
ECOLOGICAL FEPS			SCR.2.8
Plant, animal, and soil uptake			SCR.2.8.1
Plant uptake	SO-R	SO-C for 40 CFR § 191.15	
Animal uptake	SO-R		
Accumulation in soils	SO-C	Beneficial SO-C	
Human uptake			SCR.2.8.2
Ingestion	SO-R	SO-C for 40 CFR § 191.15	
Inhalation	SO-R	SO-C for 40 CFR § 191.15	
Irradiation	SO-R	SO-C for 40 CFR § 191.15	
Dermal sorption	SO-R	SO-C for 40 CFR § 191.15	
Injection	SO-R	SO-C for 40 CFR § 191.15	

Legend:

UP FEPs accounted for in the assessment calculations for undisturbed performance for 40 CFR § 191.13 (as well as 40 CFR § 191.15 and Subpart C of 40 CFR Part 191).

DP FEPs accounted for (in addition to all UP FEPs) in the assessment calculations for disturbed performance for 40 CFR § 191.13.

SO-R FEPs eliminated from performance assessment calculations on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.

SO-C FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of consequence.

SO-P FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of low probability of occurrence.

Waste characteristics, comprising the **waste inventory** and the **heterogeneity of waste forms**, are described in Chapter 4.0. The waste inventory is accounted for in performance assessment calculations in deriving the dissolved actinide source term and gas generation rates (Sections 6.4.3.5 and 6.4.3.3). The distribution of contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste within the repository leads to room scale heterogeneity of the waste forms, which is accounted for in performance assessment calculations when considering the potential activity of waste material encountered during inadvertent borehole intrusion (Section 6.4.7).

SCR.2.1.3 Container Characteristics

The container material inventory is accounted for in performance assessment calculations. The container form has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The **container material inventory** is described in Chapter 4.0, and is accounted for in performance assessment calculations through the estimation of gas generation rates (Section 6.4.3.3). **Container form** will affect container strength through the shape and dimensions of the container and affect heat dissipation through container volume and surface area. Long-term container performance has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system (Section SCR.2.3.8). Heat generation from the waste is also considered of low consequence to the performance of the disposal system (Section SCR.2.2.2). Container form has, therefore, been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.1.4 Seal Characteristics

The seal geometry and seal physical properties are accounted for in performance assessment calculations. The seal chemical composition has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

Seal (shaft seals, panel closures, and drift closures) characteristics, including **seal geometry** and **seal physical properties**, are described in Chapter 3.0 and are accounted for in performance assessment calculations through the representation of the seal system in BRAGFLO and the permeabilities assigned to the seal materials (Section 6.4.4). The effect of shaft **seal chemical composition** on actinide speciation and mobility is discussed in Section SCR.2.5.2 and has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.2.1.5 Backfill Characteristics

The backfill chemical composition is accounted for in performance assessment calculations. Backfill physical properties have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

A chemical conditioner (hereafter referred to as backfill) will be added to the disposal room to buffer the chemical environment. The backfill characteristics are described in Section 6.4.3.4. The mechanical and thermal effects of backfill are discussed in Sections SCR.2.3.8.1 and SCR.2.5.7.2, respectively, where they have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Backfill will result in an initial permeability for the disposal room lower than that of an empty

cavity, so neglecting the hydrological effects of backfill is a conservative assumption with regard to brine inflow and radionuclide migration. Thus, **backfill physical properties** have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The chemical effects of backfill are discussed in Section SCR.2.5.2.1 and the **backfill chemical composition** is accounted for in performance assessment calculations in deriving the dissolved and colloidal actinide source terms (Section 6.4.3).

SCR.2.1.6 Postclosure Monitoring

The potential effects of postclosure monitoring have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Postclosure monitoring is required by 40 CFR § 191.14(b) as an assurance requirement to "detect substantial and detrimental deviations from expected performance." The DOE has designed the monitoring program (see Appendix MON) so that the monitoring methods employed are not detrimental to the performance of the disposal system. Long-term monitoring would not be expected to lead to a need for remedial activities. In summary, the effects of monitoring have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.2 Radiological FEPs

SCR.2.2.1 Radioactive Decay

Radioactive decay and ingrowth are accounted for in performance assessment calculations.

Radionuclide decay and ingrowth are accounted for in performance assessment calculations (see Section 6.4.12.4).

SCR.2.2.2 Heat from Radioactive Decay

The effects of temperature increases as a result of radioactive decay have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Radioactive decay of the waste emplaced in the repository will generate heat. The importance of **heat from radioactive decay** depends on the effects that the induced temperature changes would have on mechanics (Section SCR.2.3.7), fluid flow (Section SCR.2.4.3), and geochemical processes (Section SCR.2.5). For example, extreme temperature increases could result in thermally induced fracturing, regional uplift, or thermally driven flow of gas and brine in the vicinity of the repository.

According to the Waste Acceptance Criteria (WAC) (see Chapter 4.0), the design basis for the WIPP requires that the thermal loading does not exceed 10 kilowatts per acre. The WAC also require that the thermal power generated by waste in an RH-TRU container shall not exceed 300 watts, but the WAC do not limit the thermal power of CH-TRU waste containers.

A numerical study to calculate induced temperature distributions and regional uplift is reported in DOE (1980, 9-149 to 9-150). This study involved estimation of the thermal power of CH-TRU waste containers. The DOE (1980, 9-149) analysis assumed the following:

- All CH-TRU waste drums and boxes contain the maximum permissible quantity of plutonium. According to the WAC, the fissionable radionuclide content for CH-TRU waste containers shall be no greater than 200 grams per 0.21 cubic meter drum and 350 grams per 1.8 cubic meter standard waste box (^{239}Pu fissile gram equivalents).

- The plutonium in CH-TRU waste containers is weapons grade material producing heat at 0.0024 watts per gram. Thus, the thermal power of a drum is approximately 0.5 watts and that of a box is approximately 0.8 watts.

- Approximately 3.7×10^5 cubic meters of CH-TRU waste are distributed within a repository enclosing an area of 7.3×10^5 square meters. This is a conservative assumption in terms of quantity and density of waste within the repository, because the maximum capacity of the WIPP is 1.756×10^5 cubic meters for all waste (as specified by the Land Withdrawal Act [LWA]) to be placed in an enclosed area of approximately 5.1×10^5 square meters.

- Half of the CH-TRU waste volume is placed in drums and half in boxes so that the repository will contain approximately 9×10^5 drums and 10^5 boxes. Thus, a calculated thermal power of 2.8 kilowatts per acre (0.7 watts per square meter) of heat is generated by the CH-TRU waste.

- Insufficient RH-TRU waste is emplaced in the repository to influence the total thermal load.

Under these assumptions, Thorne and Rudeen (1981) estimated the long-term temperature response of the disposal system to waste emplacement. Calculations assumed a uniform initial power density of 2.8 kilowatts per acre (0.7 watts per square meter) which decreases over time. Thorne and Rudeen (1981) attributed this thermal load to RH-TRU waste, but the DOE (1980), more appropriately, attributed this thermal load to CH-TRU waste based on the assumptions listed above. Thorne and Rudeen (1981) estimated the maximum rise in temperature at the center of a repository to be 1.6°C at 80 years after waste emplacement.

Sanchez and Trellue (1996) estimated the maximum thermal power of an RH-TRU waste container. The Sanchez and Trellue (1996) analysis involved inverse shielding calculations to evaluate the thermal power of an RH-TRU container corresponding to the maximum

permissible surface dose; according to the WAC, the maximum allowable surface dose equivalent for RH-TRU containers is 1000 rem per hour. The following calculational steps were taken in the Sanchez and Trellue (1996) analysis:

- Calculate the absorbed dose rate for gamma radiation corresponding to the maximum surface dose equivalent rate of 1000 rem per hour. Beta and alpha radiation are not included in this calculation because such particles will not penetrate the waste matrix or the container in significant quantities. Neutrons are not included in the analysis because, according to the WAC, the maximum dose rate from neutrons is 270 millirem per hour, and the corresponding neutron heating rate will be insignificant.

- Calculate the exposure rate for gamma radiation corresponding to the absorbed dose rate for gamma radiation.

- Calculate the gamma flux density at the surface of a RH-TRU container corresponding to the exposure rate for gamma radiation. Assuming the gamma energy is 1.0 megaelectron volts, the maximum allowable gamma flux density at the surface of a RH-TRU container is about 5.8×10^8 gamma rays per square centimeter per second.

- Determine the distributed gamma source strength, or gamma activity, in an RH-TRU container from the surface gamma flux density. The source is assumed to be shielded such that the gamma flux is attenuated by the container and by absorbing material in the container. The level of shielding depends on the matrix density. Scattering of the gamma flux, with loss of energy, is also accounted for in this calculation through inclusion of a gamma buildup factor. The distributed gamma source strength is determined assuming a uniform source in a right cylindrical container. The maximum total gamma source (gamma curies) is then calculated for a RH-TRU container containing 0.89 cubic meters of waste. For the waste of greatest expected density (about 6,000 kilograms per cubic meter), the gamma source is about 2×10^4 curies per cubic meter.

- Calculate the total curie load of a RH-TRU container (including alpha and beta radiation) from the gamma load. The ratio of the total curie load to the gamma curie load was estimated through examination of the radionuclide inventory presented in Appendix BIR. The gamma curie load and the total curie load for each radionuclide listed in the WIPP BIR were summed. Based on these summed loads the ratio of total curie load to gamma curie load of RH-TRU waste was calculated to be 1.01.

- Calculate the thermal load of a RH-TRU container from the total curie load. The ratio of thermal load to curie load was estimated through examination of the radionuclide inventory presented in Appendix BIR. The thermal load and the total curie load for each radionuclide listed in the WIPP BIR were summed. Based on these summed loads the ratio of thermal load to curie load of RH-TRU waste was calculated to be about 0.0037 watts per curie. For a gamma source of 2×10^4 curies per cubic meter,

the maximum permissible thermal load of a RH-TRU container is about 70 watts per cubic meter. Thus, the maximum thermal load of a RH-TRU container is about 60 watts, and the WAC upper limit of 300 watts will not be achieved.

Note that Sanchez and Trellue (1996) calculated the average thermal load for a RH-TRU container to be less than 1 watt. Also, the total RH-TRU heat load is less than 10 percent of the total heat load in the WIPP. Thus, the total thermal load of the RH-TRU waste will not significantly affect the average rise in temperature in the repository resulting from decay of CH-TRU waste.

Temperature increases will be greater at locations where the thermal power of an RH-TRU container is 60 watts, if any such containers are emplaced. Sanchez and Trellue (1996) estimated the temperature increase at the surface of a 60 watt RH-TRU waste container. Their analysis involved solution of a steady-state thermal conduction problem with a constant heat source term of 70 watts per cubic meter. These conditions represent conservative assumptions because the thermal load will decrease with time as the radioactive waste decays. The temperature increase at the surface of the container was calculated to be about 3°C.

In summary, analysis has shown that the average temperature increase in the WIPP repository, due to radioactive decay of the emplaced CH- and RH-TRU waste, will be less than 2°C. Temperature increases of about 3°C may occur in the vicinity of RH-TRU containers with the highest allowable thermal load of about 60 watts (based on the maximum allowable surface dose equivalent for RH-TRU containers). Potential heat generation from nuclear criticality is discussed in Section SCR.2.2.3 and exothermic reactions are discussed in Section SCR.2.5.7. The effects of repository temperature changes on mechanics (Section SCR.2.3.7), fluid flow (Section SCR.2.4.3), and geochemical processes (SCR.2.5) have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.2.3 Nuclear Criticality

Nuclear criticality has been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

Nuclear criticality refers to a sustained fission reaction that may occur if fissile radionuclides reach both a sufficiently high concentration and total mass (where the latter parameter includes the influence of enrichment of the fissile radionuclides). In the subsurface, the primary effect of a nuclear reaction is the production of **heat**.

The possibility of a nuclear criticality in the waste disposal region has been eliminated from performance assessment calculations because of the low initial concentration of the fissile radionuclides (that is, the WAC limits the fissile radionuclides in the CH- and RH-TRU containers) and because no credible mechanism exists to further concentrate the fissile radionuclides after closure. To elaborate, possible mechanisms for concentration in the waste

disposal region include high solubility, compaction, sorption, and precipitation. First, the maximum solubility of ^{239}Pu in the WIPP repository, the most abundant fissile radionuclide, is orders of magnitude lower than necessary to create a critical solution. The same is true for ^{235}U, the other primary fissile radionuclide. Second, the waste is assumed to be compacted by repository processes to one fourth its original volume. This compaction is still an order of magnitude too disperse (many orders of magnitude too disperse if neutron absorbers that prevent criticality (for example, ^{238}U) are included). Third, any potential sorbents in the waste would be fairly uniformly distributed throughout the waste disposal region; consequently, concentration of fissile radionuclides in localized areas through sorption is improbable. Fourth, precipitation requires significant localized changes in brine chemistry; small local variations are insufficient to separate substantial amounts of ^{239}Pu from other actinides in the waste disposal region that can prevent a criticality (for example, 11 times more ^{238}U is present than ^{239}Pu).

The possibility of a criticality in the far field along the transport pathways to the accessible environment (primarily the Culebra and marker beds in the Salado) has been eliminated from performance assessment calculations because a geometry favorable for criticality will not be achieved by fissile radionuclides that may become immobile in the Culebra or marker beds. As discussed in Section 6.4.6.2 and Appendix MASS Section 15, the porosity in the dolomite consists of intergranular porosity, vugs, microscopic fractures, and macroscopic fractures. As discussed in Section 6.4.5.2, porosity in the marker beds consists of partially healed fractures that may dilate as pressure increases. Advective flow in both units occurs mostly through macroscopic fractures. Consequently, any potential deposition through precipitation or sorption is constrained by the depth to which precipitation and sorption occur away from fractures. This geometry is not favorable for fission reactions and eliminates the possibility of a criticality. Thus, nuclear criticality has been eliminated from performance assessment calculations on the basis of low probability of occurrence. The potential for nuclear criticality is discussed in more detail by Rechard et al. (1996). Potential heat generation from radioactive decay is discussed in Section SCR.2.2.2 and exothermic reactions are discussed in Section SCR.2.5.7.

SCR.2.2.4 Radiological Effects on Material Properties

Radiological effects on the properties of the waste, container, and seals, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Ionizing radiation can change the physical properties of many materials. Strong radiation fields could lead to damage of waste matrices, brittleness of the metal containers, and disruption of any crystalline structure in the seals. However, the low level of activity of the waste in the WIPP is unlikely to generate a strong radiation field. In addition, performance assessment calculations assume instantaneous container failure and waste dissolution according to the source-term model (see Section 6.4.3.4, 6.4.3.5, and 6.4.3.6). Therefore, **radiological effects on the properties of** the **waste**, **containers**, and **seals**, have been

eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.3 Geological and Mechanical FEPs

SCR.2.3.1 Excavation-Induced Fracturing

Excavation-induced host rock fracturing through formation of a DRZ and changes in stress are accounted for in performance assessment calculations.

Construction of the repository has caused local **excavation-induced changes in stress** in the surrounding rock as discussed in Section 3.3.1.5. This has led to failure of intact rock around the opening, creating a **disturbed rock zone** of fractures. On completion of the WIPP excavation, the extent of the induced stress field perturbation will be sufficient to have caused dilation and fracturing in the anhydrite layers a and b, marker bed (MB) 139, and, possibly, MB138. The creation of the DRZ around the excavation and the disturbance of the anhydrite layers and marker beds will alter the permeability and effective porosity of the rock around the repository, providing enhanced pathways for flow of gas and brine between the waste-filled rooms and the nearby interbeds. This excavation-induced, host-rock fracturing is accounted for in performance assessment calculations (Section 6.4.5.3).

The DRZ around repository shafts could provide pathways for flow from the repository to hydraulically conductive units above the repository horizon. The effectiveness of long-term shaft seals is dependent upon the seals providing sufficient backstress for salt creep to heal the DRZ around them, so that connected flow paths out of the repository horizon will cease to exist. These factors are considered in the current seal design.

SCR.2.3.2 Rock Creep

Salt creep in the Salado and resultant changes in the stress field are accounted for in performance assessment calculations.

Salt creep will lead to **changes in the stress field**, compaction of the waste and containers, and consolidation of the long-term components of the sealing system. It will also tend to close fractures in the DRZ, leading to reductions in porosity and permeability, increases in pore fluid pressure, and reductions in fluid flow rates in the repository. Salt creep in the Salado is accounted for in performance assessment calculations (Section 6.4.3.1). The long-term repository seal system relies on the consolidation of the crushed-salt seal material and healing of the DRZ around the seals to achieve a low permeability under stresses induced by salt creep. Seal performance is discussed further in Section SCR.2.3.8.2.

SCR.2.3.3 Roof Falls

The potential effects of roof falls on flow paths are accounted for in performance assessment calculations.

Instability of the DRZ could to lead to localized **roof falls** in the first few hundred years. If instability of the DRZ causes roof falls, development of the DRZ may be sufficient to disrupt the anhydrite layers above the repository, which may create a zone of rock containing anhydrite extending from the interbeds toward a waste-filled room. Fracture development is most likely to be induced as the rock stress and strain distributions evolve because of creep. In the long term, the effects of roof falls in the repository are likely to be minor because salt creep will reduce the void space and the potential for roof falls as well as leading to healing of any roof material that has fallen into the rooms. However, because of uncertainty in the process by which the disposal room DRZ heals, the flow model used in the performance assessment assumes that a higher permeability zone remains for the long term. Thus, the potential effects of roof falls on flow paths are accounted for in performance assessment calculations through appropriate ranges of the parameters describing the DRZ.

SCR.2.3.4 Subsidence

Fracturing within units overlying the Salado and surface displacement caused by subsidence associated with repository closure has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The potential for excavation or repository-induced subsidence to create large-scale rock fracturing and fluid flow paths between the repository and units overlying the Salado has been eliminated from performance assessment calculations on the basis of the low probability of occurrence over 10,000 years.

Subsidence through salt creep or roof collapse associated with excavation might affect the hydrologic properties of units above the repository and might cause **large-scale rock fracturing** between the repository horizon and the surface.

The amount of subsidence that can occur as a result of salt creep closure or roof collapse in the WIPP excavation depends primarily on the volume of excavated rock, the initial and compressed porosities of the various emplaced materials (waste, backfill, panel and drift closures, and seals), the amount of inward creep of the repository walls, and the gas and fluid pressures within the repository. The DOE (Westinghouse 1994) has analyzed potential excavation-induced subsidence with the primary objective of determining the geomechanical advantage of backfilling the WIPP excavation. The DOE (Westinghouse 1994, 3-4 to 3-23) used mass conservation calculations, the influence function method, the National Coal Board empirical method, and the two-dimensional, finite-difference code, Fast Lagrangian Analysis of Continua (FLAC) to estimate subsidence for conditions ranging from no backfill to emplacement of a highly compacted crushed salt backfill. The DOE (Westinghouse 1994,

2-17 to 2-23) also investigated subsidence at potash mines located near the WIPP site to gain insight into the expected subsidence conditions at the WIPP and to calibrate the subsidence calculation methods.

Subsidence over potash mines will be much greater than subsidence over the WIPP because of the significant differences in stratigraphic position, depth, extraction ratio, and layout. The WIPP site is located stratigraphically lower than the lowest potash mine, which is near the base of the McNutt Potash Member (hereafter called the McNutt). At the WIPP site, the base of the McNutt is about 490 feet (150 meters) above the repository horizon. Also, the WIPP rock extraction ratio in the waste disposal region will be about 22 percent, as compared to 65 percent for the lowest extraction ratios within potash mines investigated by the DOE (Westinghouse 1994, 2-17).

The DOE (Westinghouse 1994, 2-22) reported the maximum total subsidence at potash mines to be about 5 feet (1.5 meters). This level of subsidence has been observed to have caused surface fractures. However, the DOE (Westinghouse 1994, 2-23) found no evidence that subsidence over potash mines had caused fracturing sufficient to connect the mining horizon to water-bearing units or the landsurface. The level of disturbance caused by subsidence above the WIPP repository will be less than that associated with potash mining and thus, by analogy, will not create fluid flow paths between the repository and the overlying units.

The various subsidence calculation methods used by the DOE (Westinghouse 1994, 3-4 to 3-23) provided similar and consistent results, which support the premise that subsidence over the WIPP will be less than subsidence over potash mines. Estimates of maximum subsidence at the land surface for the cases of no backfill and highly compacted backfill are 2 feet (0.62 meters) and 1.7 feet (0.52 meters), respectively. The mass conservation method gave the upper bound estimate of subsidence in each case. The surface topography in the WIPP area varies by more than 10 feet (3 meters), so the expected amount of repository-induced subsidence will not create a basin, and will not affect surface hydrology significantly. The DOE (Westinghouse 1994, Table 3-13) also estimated subsidence at the depth of the Culebra using the FLAC model, for the case of an empty repository (containing no waste or backfill). The FLAC analysis assumed the Salado to be halite and the Culebra to have anhydrite material parameters.

Maximum subsidence at the Culebra was estimated to be 1.8 feet (0.56 meters). The vertical strain was concentrated in the Salado above the repository. Vertical strain was less than 0.01 percent in units overlying the Salado and was close to zero in the Culebra (Westinghouse 1994, Figure 3-40). The maximum horizontal displacement in the Culebra was estimated to be 0.08 feet (0.02 meters), with a maximum tensile horizontal strain of 0.007 percent. The DOE (Westinghouse 1994, 4-1 to 4-2) concluded that the induced strains in the Culebra will be uniformly distributed because no large-scale faults or discontinuities are present in the vicinity of the WIPP. Furthermore, strains of this magnitude would not be expected to cause extensive fracturing.

At the WIPP site, the Culebra hydraulic conductivity varies spatially over approximately four orders of magnitude, from 1×10^{-8} meters per second (0.4 meters per year) to 1×10^{-5} meters per second (400 meters per year) (Section 2.2.1.4.1.2). Where transmissive horizontal fractures exist, hydraulic conductivity in the Culebra is dominated by flow through the fractures. An induced tensile vertical strain may result in an increase in fracture aperture and corresponding increases in hydraulic conductivity. The magnitude of increase in hydraulic conductivity can be estimated by approximating the hydrological behavior of the Culebra with a simple conceptual model of fluid flow through a series of parallel fractures with uniform properties. A conservative estimate of the change in hydraulic conductivity can be made by assuming that all the vertical strain is translated to fracture opening (and none to rock expansion). This method for evaluating changes in hydraulic conductivity is similar to that used by the U.S. Environmental Protection Agency (EPA) in estimating the effects of subsidence caused by potash mining (Peake 1996, EPA 1996, 9-38 to 9-60).

The equivalent porous medium hydraulic conductivity, K (meters per second), of a system of parallel fractures can be calculated assuming the cubic law for fluid flow (Witherspoon et al. 1980):

$$K = \frac{w^3 \rho g N}{12 \mu D},$$

where w is the fracture aperture, ρ is the fluid density (taken to be 1,000 kilograms per cubic meter), g is the acceleration due to gravity (9.79 meters per second squared), μ is the fluid viscosity (taken as 0.001 pascal seconds), D is the effective Culebra thickness (7.7 meters), and N is the number of fractures.

For 10 fractures with a fracture aperture, w, of 6×10^{-5} meters, the Culebra hydraulic conductivity, K, is approximately 7 meters per year (2×10^{-7} meters per second). The values of the parameters used in this calculation are within the range of those expected for the Culebra at the WIPP site (Section 2.2.1.4.1.2).

The amount of opening of each fracture as a result of subsidence-induced tensile vertical strain, ϵ, (assuming rigid rock) is $D\epsilon/N$ meters. Thus, for a vertical strain of 0.0001 meters per meter, the fracture aperture, w, becomes approximately 1.4×10^{-4} meters. The Culebra hydraulic conductivity, K, then increases to approximately 85 meters per year (2.7×10^{-6} meters per second). Thus, on the basis of a conservative estimate of vertical strain, the hydraulic conductivity of the Culebra may increase by an order of magnitude. In the performance assessment calculations, multiple realizations of the Culebra transmissivity field are generated as a means of accounting for spatial variability and uncertainty (Appendix TFIELD). A change in hydraulic conductivity of one order of magnitude through vertical strain is within the range of uncertainty incorporated in the Culebra transmissivity field through these multiple realizations. Thus, changes in the horizontal component of Culebra hydraulic conductivity resulting from repository-induced subsidence have been eliminated from performance assessment calculations on the basis of low consequence.

A similar calculation can be performed to estimate the change in vertical hydraulic conductivity in the Culebra as a result of a horizontal strain of 0.00007 meters per meter (Westinghouse 1994, 3-20). Assuming this strain to be distributed over about 1,000 fractures (neglecting rock expansion), with zero initial aperture, in a lateral extent of the Culebra of about 800 meters (Westinghouse 1994, Figure 3-39), then the subsidence-induced fracture aperture is approximately 6×10^{-5} meters. Using the values for ρ, g, and μ, above, the vertical hydraulic conductivity of the Culebra can then be calculated, through an equation similar to above, to be 7 meters per year (2×10^{-7} meters per second). Thus, vertical hydraulic conductivity in the Culebra may be created as a result of repository-induced subsidence, although this is expected to be insignificant.

In summary, as a result of observations of subsidence associated with potash mines in the vicinity of the WIPP, the potential for subsidence to create fluid flow paths between the repository and units overlying the Salado has been eliminated from performance assessment calculations on the basis of low probability. The effects of repository-induced subsidence on hydraulic conductivity in the Culebra have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.3.5 Effects of Fluid Pressure Changes

The mechanical effects of gas generation through pressurization and disruption due to gas flow are accounted for in performance assessment calculations.

The mechanical effects of gas generation, including the slowing of creep closure of the repository due to gas **pressurization**, and the fracturing of interbeds in the Salado through **disruption due to gas effects** are accounted for in performance assessment calculations (Sections 6.4.5.2 and 6.4.3.1).

SCR.2.3.6 Effects of Explosions

The potential effects of gas explosions are accounted for in performance assessment calculations. Nuclear explosions have been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

Explosive gas mixtures could collect in the head space above the waste in a closed panel. The most explosive gas mixture potentially generated will be a mixture of hydrogen, methane, and oxygen which will convert to carbon dioxide and water on ignition. This means that there is little likelihood of a **gas explosion** in the long term, because the rooms and panels are expected to become anoxic and oxygen depleted. Compaction through salt creep will also greatly reduce any void space in which the gas can accumulate. Analysis (see Appendix PCS) indicates that the most explosive mixture of hydrogen, methane, and oxygen will be present in the void space approximately 20 years after panel-closure emplacement. This possibility of an explosion prior to the occurrence of anoxic conditions is considered in the design of the operational panel closure. The effect of such an explosion on the DRZ is expected to be no

more severe than a roof fall, which is accounted for in the performance assessment calculations (Section SCR.2.3.3).

For a **nuclear explosion** to occur, a critical mass of plutonium would have to undergo rapid compression to a high density. Even if a critical mass of plutonium could form in the system, there is no mechanism for rapid compression. Thus, nuclear explosions have been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

SCR.2.3.7 Thermal Effects

The effects of thermally induced stress, differing thermal expansion of components, and thermal effects on material properties in the repository have been eliminated from performance assessment calculations on the basis of low consequence to performance of the disposal system.

Thermally induced stress could result in pathways for groundwater flow in the DRZ, in the anhydrite layers and marker beds, and through seals, or it could enhance existing pathways. Conversely, elevated temperatures will accelerate the rate of salt creep and mitigate fracture development. Thermal expansion could also result in uplift of the rock and ground surface overlying the repository, and thermal buoyancy forces could lift the waste upward in the salt rock.

The distributions of thermal stress and strain changes depend on the induced temperature field and the **differing thermal expansion of repository components** of the repository, which depends on the components' elastic properties. Potentially, **thermal effects on material properties** (such as permeability and porosity) could affect the behavior of the repository.

Radioactive decay (Section SCR.2.2.2), nuclear criticality (Section SCR.2.2.3), and exothermic reactions (Section SCR.2.5.7) are three possible sources of heat in the WIPP repository.

DOE (1980) estimated that radioactive decay of CH-TRU waste will result in a maximum temperature rise at the center of the repository of 1.6°C at 80 years after waste emplacement (Section SCR.2.2.2). Sanchez and Trellue (1996) have shown that the total thermal load of RH-TRU waste will not significantly affect the average temperature increase in the repository (Section SCR.2.2.2). Temperature increases of about 3°C may occur at the locations of RH-TRU containers of maximum thermal power (60 watts). Material properties, such as porosity and permeability, are insensitive to temperature changes of this order.

Argüello and Torres (1988) evaluated the thermomechanical effects of emplacing RH-TRU waste in the walls of a WIPP waste disposal room. Their analysis assumed that the RH-TRU waste canisters had a thermal power of 60 watts and were emplaced in a disposal room 8 feet (2.44 meters) apart, equivalent to an areal thermal loading of 10 kilowatts per acre (2.5 watts

per square meter). This value of the thermal load is significantly greater than the total thermal load of the RH- and CH-TRU waste to be emplaced in the WIPP repository. The thermal and structural responses to the thermal load were evaluated for a six-year simulation period assuming temperature dependent elastic and creep behavior. At the end of this period, the temperature was calculated to have increased by a maximum of about 3°C. Vertical and horizontal room closures were about 4 percent and 7 percent greater, respectively, than under isothermal conditions and changes in stress were negligible. This structural response to temperature change is greater than the expected response in the WIPP repository, because the maximum expected temperature increase from radioactive decay is less than 3°C. Also, the differing thermal expansion of repository components will be insignificant at this magnitude of temperature change. Thus, radioactive decay-induced temperature changes will have negligible effects on the development of the stresses and strains in the repository after waste emplacement.

Thorne and Rudeen (1981) calculated regional uplift and the effects of buoyancy forces resulting from a repository with a thermal power of 2.8 kilowatts per acre (0.7 watts per square meter). The calculated maximum displacement of a point in the repository at the top of the emplacement level was 10.4 millimeters, occurring at about 90 years after emplacement. The maximum surface uplift was calculated to be less than 6 millimeters at about 1,000 years after waste emplacement. This level of uplift will not affect the rock above the repository significantly.

Nuclear criticality has been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years (Section SCR.2.2.3).

Temperature increases resulting from exothermic reactions are discussed in Section SCR.2.5.7. Potentially the most significant exothermic reactions are concrete hydration, backfill hydration, and aluminum corrosion. Hydration of the seal concrete could raise the temperature of the concrete to approximately 53°C and that of the surrounding salt to approximately 38°C one week after seal emplacement (see Section SCR.2.5.7.1). The thermomechanical effects of such temperature increases on the performance of the repository seals have been considered in the seal design program (Loken 1994; Loken and Chen 1995). The program has investigated the durability of large-scale concrete seals, and has formulated Salado mass concrete (SMC) with the aim of achieving the seal design targets reported in Wakeley et al. (1995), which include objectives to minimize thermally-induced cracking. According to Wakeley et al. (1995), the SMC will be prepared and emplaced at low temperatures in order to minimize the difference between the maximum concrete temperature and the ambient temperature in the repository. Temperature increases resulting from cement hydration will be low enough to mitigate thermal stresses and eliminate the potential for significant cracking. Loken (1994) and Loken and Chen (1995) examined the thermal and mechanical effects of emplacing large concrete seals in salt at the WIPP and showed that significant cracking of the seals will be unlikely (see Section SCR.2.5.7.1). Thus, thermomechanical effects associated with concrete hydration have been eliminated from performance assessment calculations on the basis of low consequence to the performance of

the disposal system. As discussed in Section SCR.2.5.7.2, the maximum temperature rise in the disposal panels as a consequence of backfill hydration will be less than 5°C, resulting from brine inflow following a drilling intrusion into a waste disposal panel. Note that active institutional controls will prevent drilling within the controlled area for 100 years after disposal. By this time, any heat generation by radioactive decay and concrete seal hydration will have decreased substantially, and the temperatures in the disposal panels will have reduced to close to initial values.

Under similar conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6°C (see Section SCR.2.5.7.3). These calculated maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 6°C represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously. Temperature increases of this magnitude will have no significant effects on the stress and strain distributions within the disposal system.

In summary, temperature changes in the disposal system will not cause significant thermal expansion in any of the repository components, will not cause significant buoyancy forces, will not result in significant fracture initiation or extension, and will not significantly affect material properties in the disposal system.

Thus, the effects of thermally-induced stress, differing thermal expansion of components, and thermal effects on material properties in the repository have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.3.8 Mechanical Effects on Material Properties

Consolidation of waste is accounted for in performance assessment calculations. Container integrity has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. Movement of containers and the mechanical effects of backfill have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Consolidation of seals and mechanical degradation of seals are accounted for in performance assessment calculations. Flow through sealed WIPP investigation boreholes drilled from the surface has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Flow through isolated, unsealed underground boreholes is accounted for in performance assessment calculations.

SCR.2.3.8.1 *Consolidation of Waste and Container Performance*

Consolidation of waste is accounted for in performance assessment calculations in the modeling of creep closure of the disposal room (Section 6.4.3.1).

Modeling of creep closure and waste dissolution and release conservatively assume immediate container failure. **Container integrity** has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

The chemical conditioners or backfill added to the disposal room will act to resist creep closure. However, calculations have shown that because of the high porosity and low stiffness of the waste and the high waste to potential backfill volume, inclusion of backfill does not significantly decrease the total subsidence in the waste emplacement area or disposal room (Westinghouse 1994). Therefore, the **mechanical effects of backfill** have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The density of compacted waste is estimated to be around 2,000 kilograms per cubic meter (Sandia WIPP Project 1992, 2-69) and the grain density of halite in the Salado is 2,163 kilograms per cubic meter (Sandia WIPP Project 1992, Vol. 3, 2-20). It is unlikely that this density contrast is sufficiently large to overcome drag forces and thus any resultant **movement of containers** and waste in response to these density contrasts is likely to be minimal. RH-TRU waste is stored in robust, carbon steel-based containers and will generate heat through radioactive decay (Section SCR.2.2.2). This heat may induce density changes in the salt and create buoyancy forces on the containers. Vertical movement of high-level waste containers of a similar density to those at the WIPP in response to thermally-induced density changes has been calculated to be around 1 foot (0.35 meters) (Dawson and Tillerson 1978, 22). Containers at the WIPP will generate much less heat, and will therefore move less. Container movement has therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.3.8.2 *Repository and Investigation Borehole Seal Performance*

Mechanical degradation of seals and **consolidation of seals** are accounted for in performance assessment calculations through the permeability range assumed for the seal system (Section 6.4.4).

There are a large number of boreholes drilled from the surface as part of the site investigation program for the WIPP. The majority of these **investigation boreholes** do not reach the repository horizon and terminate in either the Rustler or in the upper part of the Salado. These shallow boreholes could only act as potential pathways if radionuclides were transported into the Culebra via the shafts or intrusion boreholes. Three-dimensional groundwater flow modeling (Corbet 1995) has demonstrated that vertical flow to the Culebra in the controlled area is downwards and, hence, radionuclides will not migrate up these shallow investigation

boreholes to the accessible environment. There are four WIPP investigation boreholes, however, that do intersect the repository horizon within the controlled area (ERDA-9, WIPP-12, WIPP-13, and DOE-1). These could potentially act as pathways to the Culebra or to the surface for radionuclides that migrate along the anhydrite layers a and b, MB138, and MB139.

WIPP investigation boreholes will be sealed using materials and designs in accord with industry standards for the Delaware Basin. A survey of plugging practice (Appendix DEL) shows that the majority of boreholes have a plug below the water-producing zones in the Rustler and a plug at the top of the Bell Canyon. Drilling and abandonment procedures may lead to additional plugs within the Salado. A few boreholes (2 percent of those surveyed), however, have a continuous plug of salt-saturated cement from the top of the Salado to the top of the Bell Canyon. ERDA-9 will be sealed in a similar manner. Other WIPP investigation boreholes will be plugged according to regulatory requirements and standard industry practice. The DOE has committed to plug with cement the portion of these boreholes that penetrate the Salado.

The cement in borehole plugs will react with water that percolates through the plug. If the plug is confined, as is the case for continuous plugs through the Salado and the Castile, the greater volume of the alteration phases will cause a decrease in porosity and permeability, a consequent decrease in the rate of fluid flow through the plug, and hence reduce the rate of alteration. Some corrosion of the steel casing around the concrete will take place, but the overall rate of steel corrosion in a closed environment is insufficient to allow an annulus to form. Salt creep will tend to close any small gaps that do occur in the casing near the base of the section, further reducing the possibility of brine reaching the concrete plug. Although localized alteration may take place, the overall permeability of continuous plugs is assumed to remain equal to or less than the permeability of hardened concrete (5×10^{-17} square meters) for 10,000 years (Appendix MASS, Section MASS.16.3.2).

The cross-sectional area of the WIPP investigation boreholes that penetrate the repository horizon (typically 0.34 square feet [0.03 square meters] each) is small in comparison to that of the shafts (which total about 1025.8 square feet [95.3 square meters]). The effective permeability of the shaft, including the emplaced shaft materials and the DRZ around the shaft, is comparable to the assumed permeability of investigation boreholes. Transport along investigation boreholes will, therefore, be of low consequence in comparison to transport along the shafts, which are explicitly accounted for in performance assessment calculations (Section SCR.2.1.4 and Section 6.4.4).

The design of seals in the investigation boreholes, and the small cross-sectional area of the boreholes in comparison to the shafts, lead to the conclusion that WIPP investigation boreholes can be eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The site investigation program has also involved the drilling of boreholes from within the excavated part of the repository. Following their use for monitoring or other purposes, these **underground boreholes** will be sealed where practical, and salt creep will also serve to consolidate the seals and to close the boreholes. Any boreholes that remain unsealed will connect the repository to anhydrite interbeds within the Salado, and thus provide potential pathways for radionuclide transport. Performance assessment calculations account for fluid flow to and from the interbeds by assuming that the DRZ has a permanently enhanced permeability that allows flow of repository brines into specific anhydrite layers and interbeds. This treatment is also considered to account for the effects of any unsealed boreholes.

SCR.2.4 Subsurface Hydrological and Fluid Dynamic FEPs

SCR.2.4.1 Repository-Induced Flow

Two-phase brine and gas flow and capillary rise (wicking) in the repository and the Salado are accounted for in performance assessment calculations.

Brine inflow to the repository may occur through the DRZ, impure halite, anhydrite layers, or clay layers. Pressurization of the repository through gas generation could limit the amount of brine that flows into the rooms and drifts. Two-phase flow of brine and gas in the repository and the Salado is accounted for in performance assessment calculations (Section 6.4.3.2).

Capillary rise (or **wicking**) is a potential mechanism for liquid migration through unsaturated zones in the repository. Capillary rise in the waste material could affect gas generation rates, which are dependent on water availability. Potential releases due to drilling intrusion are also influenced by brine saturations and therefore by wicking. Capillary rise is therefore accounted for in performance assessment calculations (Section 6.4.3.2).

SCR.2.4.2 Effects of Gas Generation

Fluid flow in the repository and Salado due to gas production is accounted for in performance assessment calculations.

Pressurization of the repository through gas generation could limit the amount of brine that flows into the rooms and drifts. Gas may flow from the repository through the DRZ, impure halite, anhydrite layers, or clay layers. The amount of water available for reactions and microbial activity will impact the amounts and types of gases produced (Section SCR.2.5.1). Gas generation rates, and therefore repository pressure, may change as the water content of the repository changes. Pressure changes and **fluid flow due to gas production** in the repository and the Salado are accounted for in performance assessment calculations through modeling the two-phase flow (Section 6.4.3.2).

SCR.2.4.3 Thermal Effects

Convection has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Temperature differentials in the repository could initiate **convection**. The resulting thermally-induced brine flow or thermally-induced two-phase flow could influence contaminant transport. Potentially, thermal gradients in the disposal rooms could drive the movement of water vapor. For example, temperature increases around waste located at the edges of the rooms could cause evaporation of water entering from the DRZ. This water vapor could condense on cooler waste containers in the rooms and could contribute to brine formation, corrosion, and gas generation.

Nuclear criticality (Section SCR.2.2.3), radioactive decay (Section SCR.2.2.2), and exothermic reactions (Section SCR.2.5.7) are three possible sources of heat in the WIPP repository.

Nuclear criticality has been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years (Section SCR.2.2.3).

The DOE (1980, 9-149) estimated that radioactive decay of CH-TRU waste will result in a maximum temperature rise at the center of the repository of 1.6°C at 80 years after waste emplacement (Section SCR.2.2.2). Sanchez and Trellue (1996) have shown that the total thermal load of RH-TRU waste will not significantly affect the average temperature increase in the repository (Section SCR.2.2.2). Temperature increases of about 3°C may occur at the locations of RH-TRU containers of maximum thermal power (60 watts).

Concrete hydration will result in short-term (a few decades) temperature increases in the vicinity of the concrete seals after emplacement. Loken (1994) and Loken and Chen (1995) showed that, one week after seal emplacement, concrete hydration could raise the temperature of the concrete to approximately 53°C and the temperature of the surrounding salt to approximately 38°C.

As discussed in Section SCR.2.5.7.2, the maximum temperature rise in the disposal panels as a consequence of backfill hydration will be less than 5°C, resulting from brine inflow following a drilling intrusion into a waste disposal panel. Note that active institutional controls will prevent drilling within the controlled area for 100 years after disposal. By this time, any heat generation by radioactive decay and concrete seal hydration will have decreased substantially, and the temperatures in the disposal panels will have reduced to close to initial values.

Under similar conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6°C (see Section SCR.2.5.7.3). These calculated maximum heat generation rates resulting from aluminum corrosion and

backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 6°C represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously.

The characteristic velocity, V_i, for convective flow of fluid component *I* in an unsaturated porous medium is given by (from Hicks 1996);

$$V_i \approx -\frac{k_i}{\mu_i}\left(\alpha_i \rho_{i0} g \Delta T\right) ,$$

where α_i (per degree) is the coefficient of expansion of the ith component, k_i is the intrinsic permeability (square meters), μ_i is the fluid viscosity (pascal second), ρ_{i0} (kilograms per cubic meter) is the fluid density at a reference point, g is the acceleration of gravity, and ΔT is the change in temperature. This velocity may be evaluated for the brine and gas phases expected in the waste disposal region.

For a temperature increase of 10°C, the characteristic velocity for convective flow of brine in the DRZ around the concrete shaft seals is approximately 7×10^{-4} meters per year (2×10^{-11} meters per second), and the characteristic velocity for convective flow of gas in the DRZ is approximately 1×10^{-3} meters per year (3×10^{-11} meters per second) (Hicks 1996). For a temperature increase of 25°C, the characteristic velocity for convective flow of brine in the concrete seals is approximately 2×10^{-7} meters per year (6×10^{-15} meters per second), and the characteristic velocity for convective flow of gas in the concrete seals is approximately 3×10^{-7} meters per year (8×10^{-15} meters per second) (Hicks 1996). These values of Darcy velocity are much smaller than the expected values associated with brine inflow to the disposal rooms of fluid flow resulting from gas generation. In addition, the buoyancy forces generated by smaller temperature contrasts in the DRZ, resulting from backfill and concrete hydration and radioactive decay, will be short-lived and insignificant compared to the other driving forces for fluid flow. The short-term concrete seals will be designed to function as barriers to fluid flow for at least 100 years after emplacement, and seal permeability will be minimized (Wakeley et al. 1995). Thus, temperature increases associated with concrete hydration will not result in significant buoyancy driven fluid flow through the concrete seal system. In summary, temperature changes in the disposal system will not cause significant thermal convection. Furthermore, the induced temperature gradients will be insufficient to generate water vapor and drive significant moisture migration.

Temperature effects on fluid viscosity would be most significant in the DRZ surrounding the hydrating concrete seals (where temperatures of approximately 38°C are expected). The viscosity of pure water decreases by about 19 percent over a temperature range of between 27°C and 38°C (Batchelor 1973, 596). Although at a temperature of 27°C, the viscosity of Salado brine is about twice that of pure water (Rechard et al. 1990, a-19), the magnitude of the variation in brine viscosity between 27°C and 38°C will be similar to the magnitude of the

variation in viscosity of pure water. The viscosity of air over this temperature range varies by less than 7 percent (Batchelor 1973, 594) and the viscosity of gas in the waste disposal region over this temperature range is also likely to vary by less than 7 percent. The Darcy fluid flow velocity for a porous medium is inversely proportional to the fluid viscosity. Thus, increases in brine and gas flow rates may occur as a result of viscosity variations in the vicinity of the concrete seals. However, these viscosity variations will persist only for a short period in which temperatures are elevated, and, thus, the expected variations in brine and gas viscosity in the waste disposal region will not affect the long-term performance of the disposal system significantly.

In summary, temperature changes in the disposal system will not cause significant thermally-induced two-phase flow. Thermal convection has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5 Geochemical and Chemical FEPs

SCR.2.5.1 Gas Generation

Gas generation can affect the mechanical behavior of the host rock and engineered barriers, chemical conditions, and brine flow, and, as a result, the transport of radionuclides. Potential gas generation processes include corrosion, microbial degradation, radiolysis, and helium production.

The amount of water available for gas generation will have a major impact on the amounts and types of gases produced. WIPP waste may contain small amounts of water as residual liquid; the WAC require that the waste containers have no free liquids. For storage sites with no capability to repackage waste, approval may be given for containers that contain residual liquids in well-drained containers as long as such residuals do not exceed 1 percent of the volume of the container. Such residual liquids are expected to be an insignificant source of liquid in the repository. Water may also be introduced by the influx of brine from the Salado, as discussed in Section SCR.2.4.1.

The following sections discuss gas generation by microbial degradation, corrosion, radiolysis, and helium production.

SCR.2.5.1.1 Microbial Gas Generation

Microbial gas generation from degradation of organic material is accounted for in performance assessment calculations, and the effects of temperature and biofilm formation on microbial gas generation are incorporated in the gas generation rates used. The effects of pressure and radiation on microbial gas generation have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Microbial breakdown of cellulosic material, and possibly plastics and other synthetic materials, will produce mainly CO_2, but also N_2O, N_2, H_2S, H_2, and CH_4. The rate of microbial gas production will depend upon the nature of the microbial populations established, the prevailing conditions, and the substrates present. Microbial gas generation from **degradation of organic material** is accounted for in performance assessment calculations.

The following subsections discuss the effects of temperature, pressure, radiation, and biofilms on gas production rates via their control of microbial gas generation processes.

SCR.2.5.1.1.1 Effects of Temperature on Microbial Gas Generation

Calculations and experimental studies of induced temperature distributions within the repository have been undertaken and are described in Section SCR.2.2.2. Numerical analysis suggests that the average temperature increase in the WIPP repository caused by radioactive decay of the emplaced CH- and RH-TRU waste is likely to be less than 3°C (Section SCR.2.2.2).

Temperature increases resulting from exothermic reactions are discussed in Section SCR.2.5.7. Potentially the most significant exothermic reactions are concrete hydration, backfill hydration, and aluminum corrosion. Hydration of the seal concrete could raise the temperature of the concrete to approximately 53°C and that of the surrounding salt to approximately 38°C one week after seal emplacement (see Section SCR.2.5.7.1).

As discussed in Section SCR.2.5.7.2, the maximum temperature rise in the disposal panels as a consequence of backfill hydration will be less than 5°C, resulting from brine inflow following a drilling intrusion into a waste disposal panel. Note that active institutional controls will prevent drilling within the controlled area for 100 years after disposal. By this time, any heat generation by radioactive decay and concrete seal hydration will have decreased substantially, and the temperatures in the disposal panels will have reduced to close to initial values.

Under similar conditions following a drilling event, aluminum corrosion could, at most, result in a short-lived (two years) temperature rise of about 6°C (see Section SCR.2.5.7.3). These calculated maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 6°C represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously.

Relatively few data exist on the **effects of temperature on microbial gas generation** under expected WIPP conditions. Molecke (1979, 4) summarized microbial gas generation rates observed during a range of experiments. Increases in temperature from ambient up to 40°C or 50°C were reported to increase gas production, mainly via the degradation of cellulosic waste

under either aerobic or anaerobic conditions (Molecke 1979, 7). Above 70°C, however, gas generation rates were generally observed to decrease. The experiments were conducted over a range of temperatures and chemical conditions and for different substrates, representing likely states within the repository. Gas generation rates were presented as ranges with upper and lower bounds as estimates of uncertainty (Molecke 1979, 7). Later experiments reported by Francis and Gillow (1994) support the gas generation rate data reported by Molecke (1979). These experiments investigated microbial gas generation under a wide range of possible conditions in the repository. These conditions included the presence of microbial inoculum, humid or inundated conditions, cellulosic substrates, additional nutrients, electron acceptors, bentonite, and initially oxic or anoxic conditions. These experiments were carried out at a reference temperature of 30°C, based on the average temperature expected in the repository. Gas generation rates used in the performance assessment calculations have been derived from available experimental data and are described in Chapter 6.0 (Section 6.4.3.3). The effects of temperature on microbial gas generation are implicitly incorporated in the gas generation rates used.

SCR.2.5.1.1.2 Effects of Pressure on Microbial Gas Generation

Chemical reactions may occur depending on, among other things, the concentrations of available reactants, the presence of catalysts and the accumulation of reaction products, the biological activity, and the prevailing conditions (for example, temperature and pressure). Reactions that involve the production or consumption of gases are often particularly influenced by pressure because of the high molar volume of gases. The effect of high total pressures on chemical reactions is generally to reduce or limit further gas generation.

Few data exist from which the **effects of pressure on microbial gas generation** reactions that may occur in the WIPP can be assessed and quantified. Studies of microbial activity in deep-sea environments suggest (for example, Kato et al. 1994, 94) that microbial gas generation reactions are less likely to be limited by increasing pressures in the disposal rooms than are inorganic gas generation reactions (for example, corrosion). Consequently, the effects of pressure on microbial gas generation have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5.1.1.3 Effects of Radiation on Microbial Gas Generation

Experiments investigating microbial gas generation rates suggest that the effects of alpha radiation from TRU waste is not likely to have significant effects on microbial activity (Barnhart et al. 1980; Francis 1985). Consequently, the **effects of radiation on microbial gas generation** have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5.1.1.4 Effects of Biofilms on Microbial Gas Generation

The location of microbial activity within the repository is likely to be controlled by the availability of substrates and nutrients. Biofilms may develop on surfaces where nutrients are concentrated. They consist of one or more layers of cells with extracellular polymeric material and serve to maintain an optimum environment for growth. Within such a biofilm ecosystem, nutrient retention and recycling maximize microbe numbers on the surface (see, for example, Stroes-Gascoyne and West 1994, 9 – 10).

Biofilms can form on almost any moist surface, but their development is likely to be restricted in porous materials. Even so, their development is possible at locations throughout the disposal system. The **effects of biofilms on microbial gas generation** may affect disposal system performance through control of microbial population size and their effects on radionuclide transport.

Molecke (1979, 4) summarized microbial gas generation rates observed during a range of experimental studies. The experiments were conducted over a range of temperatures and chemical conditions and for different substrates representing likely states within the repository. However, the effect of biofilm formation in these experiments was uncertain. Molecke (1979, 7), presented gas generation rates as ranges, with upper and lower bounds as estimates of uncertainty. Later experiments reported by Francis and Gillow (1994) support the gas generation rate data reported by Molecke (1979). Their experiments investigated microbial gas generation under a wide range of possible conditions in the repository. These conditions included the presence of microbial inoculum, humid or inundated conditions, cellulosic substrates, additional nutrients, electron acceptors, bentonite, and initially oxic or anoxic conditions. Under the more favorable conditions for microbial growth established during the experiments, the development of populations of halophilic microbes and associated biofilms was evidenced by observation of an extracellular, carotenoid pigment, bacterioruberin, in the culture bottles (Francis and Gillow 1994, 59). Gas generation rates used in the performance assessment calculations have been derived from available experimental data and are described in Chapter 6.0 (Section 6.4.3.3). The effects of biofilms on microbial gas generation rates are implicitly incorporated in the gas generation rates.

Biofilms may also influence contaminant transport rates through their capacity to retain and thus retard both the microbes themselves and radionuclides. This effect is not accounted for in performance assessment calculations, but is considered potentially beneficial to calculated disposal system performance. Microbial transport is discussed in Section SCR.2.6.4.

SCR.2.5.1.2 Corrosion

Gas generation from metal corrosion is accounted for in performance assessment calculations, and the effects of chemical changes from metal corrosion are incorporated in the gas generation rates used. Galvanic coupling between the waste and metals external to

the repository has been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

Oxic corrosion of waste drums and metallic waste will occur at early times following closure of the repository and will deplete its oxygen content. Anoxic corrosion will follow the oxic phase and will produce H_2, while consuming water. **Gases from metal corrosion** are accounted for in performance assessment calculations.

The following subsections discuss the effects on gas production rates of galvanic coupling, electrochemical gradients, and chemical changes from metal corrosion.

SCR.2.5.1.2.1 Galvanic Coupling and the Effects of Electrochemical Gradients

Galvanic coupling refers to the establishment of an electrical current through chemical processes. Galvanic coupling could lead to the establishment of potential gradients between metals in the waste form, canisters, and other metals external to the waste form. Such electrochemical effects can potentially influence corrosion processes and therefore gas generation rates and chemical migration.

Metals other than those in the waste form and canisters could potentially include natural metallic ore bodies in the host rock and metallic elements in other parts of the repository. However, the absence of metallic ores in the region (Appendix GCR) allows galvanic coupling between the waste and metals external to the repository to be eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

A variety of metals will be present within the repository (for example, waste metals and canisters), and the potential exists for galvanic cells to be established over short distances. As an example, the presence of copper could influence rates of hydrogen gas production resulting from the corrosion of iron.

The precise interactions that may occur are complex and depend on the metals involved, their physical disposition, and the prevailing conditions (for example, salinity). Good physical and electrical contact between the metals involved is critical to the establishment of galvanic cells. Experience with experimental investigations suggests that this condition is unlikely to be achieved in the repository conditions. In the laboratory, significant efforts are required to assure metal-to-metal contact sufficient for galvanic coupling to occur. Such contact is unlikely to occur to a significant extent in the repository. Consequently, given the preponderance of iron over other metals within the repository and the likely passivation of many nonferrous materials, the influence of these electrochemical interactions on corrosion, and therefore gas generation, is expected to be minimal. Therefore, the effects of electrochemical gradients on gas generation from corrosion have been eliminated from performance assessment calculations on the basis of low consequence.

SCR.2.5.1.2.2 Effects of Chemical Changes from Metal Corrosion on Gas Generation Rates

The predominant **chemical effect of corrosion** reactions on the environment of disposal rooms will be to lower the oxidation state of the brines and maintain reducing conditions.

Molecke (1979, 4) summarized gas generation rates that were observed during a range of experiments. The experiments were conducted over a range of temperatures and chemical conditions representing likely states within the repository. Later experiments reported by Telander and Westerman (1993) support the gas generation rate data reported by Molecke (1979). Their experiments investigated gas generation from corrosion under a wide range of possible conditions in the repository. The studies included corrosion of low-carbon steel waste packaging materials in synthetic brines, representative of intergranular Salado brines at the repository horizon, under anoxic (reducing) conditions.

Gas generation rates used in the performance assessment calculations have been derived from available experimental data and are described in Chapter 6.0 (Section 6.4.3.3). The effects of chemical changes from metal corrosion are, therefore, accounted for in performance assessment calculations.

SCR.2.5.1.3 Radiolytic Gas Generation

Gas generation from radiolysis of brine and cellulosics, and helium production, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The formation and transport of radioactive gases has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

This section discusses gas generation resulting from the radiolysis of brine and cellulosics, helium production, and the formation and transport of radioactive gases.

SCR.2.5.1.3.1 Radiolysis of Brine

Radiolysis of brine in the WIPP disposal rooms, and of water in the waste, will lead to the production of gases and may significantly affect the oxygen content of the rooms. This in turn will affect the prevailing chemical conditions and potentially the concentrations of radionuclides that may be mobilized in the brines.

The overall reaction for the radiolysis of water in the waste and brine is

$$H_2O = H_2 + {}^1/_2O_2 .$$

However, the production of intermediate oxygen-bearing species that may subsequently undergo reduction, such as H_2O_2, ClO_3^-, and ClO_4^-, will lead to reduced oxygen gas yields.

The remainder of this section is concerned with the physical effects of gas generation by radiolysis of brine.

Reed et al. (1993) studied radiolytic gas generation during experiments lasting between 155 and 182 days. These experiments involved both synthetic brines similar to those sampled from the Salado at the WIPP repository horizon, and brines occurring in reservoirs in the Castile, as well as real brines sampled from the Salado in the repository workings. The brines were spiked with ^{239}Pu(VI) at concentrations between 6.9×10^{-9} and 3.4×10^{-4} molal. During these relatively short-term experiments, hydrogen gas was observed as the product of radiolysis. Oxygen gas was not observed; this was attributed to the formation of intermediate oxygen-bearing species. However, given sufficient exposure to alpha-emission, oxygen production may reach 50 percent that of hydrogen.

An estimate of the potential rate of gas generation due to the radiolysis of brine, R_{RAD}, can be made by making the following assumptions:

- Gas production occurs following the reaction above, so that 1.5 moles of gas are generated for each mole of water consumed.
- Gas production occurs as a result of the alpha decay of ^{239}Pu.
- ^{239}Pu concentrations in the disposal room brines are controlled by solubility equilibria.
- All of the dissolved plutonium is ^{239}Pu.

R_{RAD} is then given by

$$R_{RAD} = \frac{1.5 \times 3.15 \times 10^7 C_{Pu} Sa_{Pu} G \overline{E}_\alpha V_B}{N_D N_A},$$

where

R_{RAD}	=	potential rate of gas production (moles per drum per year)
C_{Pu}	=	maximum dissolved concentration of plutonium (molal)
Sa_{Pu}	=	specific activity of ^{239}Pu (5.42×10^{11} becquerels per mole)
$\overline{E}_\alpha$	=	average energy of α-particles emitted during ^{239}Pu decay (5.15×10^6 electron volts)
G	=	number of moles of molecules split per 100 eV
V_B	=	volume of brine in the repository (liters)
N_D	=	number of CH drums in the repository (6.7×10^5)
N_A	=	Avogadro constant (6.0×10^{23} molecules per mole)

The maximum dissolved concentration of plutonium, C_{Pu} has been taken as 3.0×10^{-4} molal based on the dissolved and colloidal actinide source term for the WIPP as described in Chapter 6.0 (Sections 6.4.3.5 and 6.4.3.6). The value of G used in this calculation has been set at 1.5×10^{-2}, the upper limit of the range of values observed (1.1×10^{-2} to 1.5×10^{-2}) during experimental studies of the effects of radiation on WIPP brines (Reed et al. 1993, 432). A maximum estimate of the volume of brine that could potentially be present in the disposal region has been made from its excavated volume (436,000 cubic meters; Sandia WIPP Project 1992, 3-4). This estimate, in particular, is considered to be highly conservative because it makes no allowance for creep closure of the excavation, or for the volume of waste and backfill that will be emplaced, and takes no account of factors that may limit brine inflow. These parameter values lead to an estimate of the potential rate of gas production due to the radiolysis of brine of 0.6 moles per drum per year.

Assuming ideal gas behavior and repository conditions of 30°C and 14.8 megapascals (lithostatic pressure), this is equivalent to approximately 6.8×10^4 liters per year.

Potential gas production rates from other processes that will occur in the repository are significantly greater than this. For example, under water-saturated conditions, microbial degradation of cellulosic waste has the potential to yield between 1.3×10^6 and 3.8×10^7 liters per year; anoxic corrosion of steels has the potential to yield up to 6.3×10^5 liters per year (Chapter 6.0, Section 6.4.3.3).

In addition to the assessment of the potential rate of gas generation by radiolysis of brine given above, a study of the likely consequences on disposal system performance has been undertaken by Vaughn et al. (1995). A model was implemented in BRAGFLO to estimate radiolytic gas generation in the disposal region according to the equation above.

A set of BRAGFLO simulations was performed to assess the magnitude of the influence of the radiolysis of brine on contaminant migration to the accessible environment. The calculations considered radiolysis of H_2O by 15 isotopes of thorium, plutonium, uranium, and americium.

Conditional complementary cumulative distribution functions (CCDFs) of normalized contaminated brine releases to the Culebra via a human intrusion borehole and the shaft system, as well as releases to the subsurface boundary of the accessible environment via the Salado interbeds, were constructed and compared to the corresponding baseline CCDFs calculated excluding radiolysis.

The comparisons indicated that radiolysis of brine does not significantly affect releases to the Culebra or the subsurface boundary of the accessible environment under disturbed or undisturbed conditions (Vaughn et al. 1995). Although the analysis of Vaughn et al. (1995) used data that are different than those used in the performance assessment calculations, performance assessment estimates of total gas volumes in the repository are similar to those considered in the analysis performed by Vaughn et al. (1995).

Therefore, gas generation by radiolysis of brine has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5.1.3.2 Radiolysis of Cellulosics

Molecke (1979) compared experimental data on gas production rates caused by **radiolysis of cellulose** and other waste materials with gas generation rates by other processes including bacterial (microbial) waste degradation. The comparative gas generation rates reported by Molecke (1979, 4) are given in terms of most probable ranges, using units of moles per year per drum, for drums of 0.21 cubic meters in volume.

A most probable range of 0.005 to 0.011 moles per year per drum is reported for gas generation due to radiolysis of cellulosic material (Molecke 1979, 4). As a comparison, a most probable range of 0.0 to 5.5 moles per year per drum is reported for gas generation by bacterial degradation of waste.

The data reported by Molecke (1979) are consistent with more recent gas generation investigations made under the WIPP program, and indicate that radiolysis of cellulosic materials will generate significantly less gas than other gas generation processes. Gas generation from radiolysis of cellulosics therefore can be eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5.1.3.3 Helium Production

Within the WIPP, **helium gas production** will occur by the reduction of α-particles (helium nuclei) emitted from the waste. The maximum amount of helium that could be produced can be estimated by assuming that all of the α-particles generated during radioactive decay are converted to helium gas by the following reaction:

$$({}^{4}_{2}He^{2+},\ \alpha\text{-}particle) + 2e^{-} = He_{(g)}\ .$$

The total inventory (I) that may be emplaced in the repository is approximately 9 million curies or 3.3×10^{17} becquerels (see Appendix BIR). Assuming that the inventory continues to yield α-particles at this rate throughout the 10,000-year regulatory period (that is, that the source does not diminish even though the α-particles are produced during radioactive decay), the maximum rate of helium gas produced (R_{He}) may be calculated from

$$R_{He} = \frac{I}{N_A}\ ,$$

where

R_{He} = rate of helium gas production in the repository (mole per second)
I = waste inventory (3.3×10^{17} becquerels)
N_A = Avogadro constant (6.0×10^{23} molecules per mole)

These assumptions regarding the inventory lead to maximum estimates for helium production because, in reality, the total activity will decrease with time and because some of the radionuclides will decay by beta and gamma emission.

Based on the figures and equation given above, $R_{(He)}$ is approximately 5.5×10^{-7} moles per second. Assuming ideal gas behavior and repository conditions of 30°C and 14.8 megapascals (lithostatic pressure), this is equivalent to approximately 3.0 liters per year.

Gas production rates caused by other processes that will occur in the repository are likely to be significantly greater than this. For example, under water-saturated conditions, microbial degradation of cellulosic waste is estimated to yield between 1.3×10^6 and 3.8×10^7 liters per year; anoxic corrosion of steels is estimated to yield between 0 and 6.3×10^5 liters per year (Chapter 6.0, Section 6.4, and Appendix MASS). Even if gas production by these processes were minimal and helium production dominated gas generation, the effects would be of low consequence because of the low total volumes.

Therefore, by estimation of the maximum possible generation rate, the effects of helium production have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5.1.3.4 Radioactive Gases

Based on the composition of the anticipated waste inventory as described in Appendix BIR, the **radioactive gases** that will be generated in the repository are carbon dioxide (CO_2) and methane (CH_4) containing ^{14}C, and radon (Rn).

Appendix BIR indicates that a small amount of ^{14}C, 2.88 grams, or 12.85 curies, will be disposed in the WIPP. This amount is insignificant in comparison with the 40 CFR § 191.13 cumulative release limit for ^{14}C, estimated to be 525 curies (Appendix BIR).

Notwithstanding this comparison, consideration of transport of radioactive gases could potentially be necessary in respect of the 40 CFR § 191.15 individual protection requirements. ^{14}C may partition into carbon dioxide and methane formed during microbial degradation of cellulosic and other organic wastes (for example, rubbers and plastics). However, total fugacities of carbon dioxide in the repository are expected to be very low because of the action of the MgO backfill which will lead to incorporation of carbon dioxide in solid $MgCO_3$. Similarly, interaction of carbon dioxide with cementitious wastes will limit carbon dioxide fugacities by the formation of solid $CaCO_3$. Thus, because of the formation of solid carbonate phases in the repository, significant transport of ^{14}C as $^{14}CO_2$ has been eliminated from

performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Potentially significant volumes of methane may be produced during the microbial degradation of cellulosic waste. However, volumes of $^{14}CH_4$ will be small given the low total inventory of ^{14}C, and the tendency of ^{14}C to be incorporated into solid carbonate phases in the repository. Therefore, although transport of ^{14}C could occur as $^{14}CH_4$, this effect has been eliminated from the current performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Radon gas will contain proportions of the alpha emitters ^{219}Rn, ^{220}Rn, and ^{222}Rn. All of these have short half-lives, but ^{222}Rn is potentially the most important because it is produced from the abundant waste isotope, ^{238}Pu, and because it has the longest half-life of the radon isotopes ($\approx$ 4 days). ^{222}Rn will exhibit secular equilibrium with its parent ^{226}Ra, which has a half-life of 1.6×10^3 years. Consequently, ^{222}Rn will be produced throughout the 10,000-year regulatory time period. Conservative analysis of the potential ^{222}Rn inventory suggests activities of less than 716 curies at 10,000 years (Bennett 1996).

Direct comparison of the estimated level of ^{222}Rn activity with the release limits specified in 40 CFR § 191.13 cannot be made because the release limits do not cover radionuclides with half-lives less than 20 years. For this reason, production of radon gas can be eliminated from the performance assessment calculations on regulatory grounds. Notwithstanding this regulatory argument, the small potential radon inventory means that the formation and transport of radon gas can also be eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5.2 Chemical Speciation

Chemical speciation is accounted for in performance assessment calculations in the estimates of radionuclide solubility in the disposal rooms, and the degree of chemical retardation estimated during contaminant transport. The effects of cementitious seals on chemical speciation have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. The effects of reaction kinetics in chemical speciation reactions have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Chemical speciation refers to the form in which elements occur under a particular set of chemical or environmental conditions. Conditions affecting chemical speciation include the temperature, pressure, and salinity (ionic strength) of the water in question. The importance of chemical speciation lies in its control of the geochemical reactions likely to occur and the consequences for actinide mobility.

The effects of reaction kinetics in aqueous systems are discussed by Lasaga et al. (1994) who suggest that in contrast to many heterogeneous reactions, homogeneous aqueous geochemical

speciation reactions involving relatively small inorganic species occur rapidly and are accurately described by thermodynamic equilibrium models that neglect explicit consideration of reaction kinetics (for example, Lasaga et al. 1994, 2361). Consequently, the **kinetics of speciation** reactions have been eliminated from performance assessment calculation on the basis of low consequence to the performance of the disposal system.

The following subsections discuss chemical speciation in the disposal rooms, shaft seals, and the Culebra.

SCR.2.5.2.1 *Disposal Room*

The concentrations of radionuclides that dissolve in any brines present in the disposal rooms after repository closure will depend on the stability of the chemical species that form under the prevailing conditions (for example, temperature, pressure, and ionic strength). The method used to derive radionuclide solubilities in the disposal rooms (see Section 6.4.3.5) considers the expected conditions. The MgO backfill will buffer pH values in the disposal room to between 9 and 10. Thus, chemical speciation is accounted for in performance assessment calculations in the estimates of radionuclide solubility in the disposal rooms.

SCR.2.5.2.2 *Repository Seals*

Certain repository materials have the potential to interact with groundwater and significantly alter the chemical speciation of any radionuclides present. In particular, extensive use of cementitious materials in the seals may have the capacity to buffer groundwaters to extremely high pH (for example, Bennett et al. 1992, 315 – 325). At high pH values, the speciation and adsorption behavior of many radionuclides is such that their dissolved concentrations are reduced in comparison with near-neutral waters. This effect reduces the migration of radionuclides in dissolved form. The effects of cementitious seals on groundwater chemistry have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.2.5.2.3 *Culebra*

Chemical speciation will affect actinide retardation in the Culebra. The dependence of actinide retardation on speciation in the Culebra is accounted for in performance assessment calculations by sampling over ranges of distribution coefficients (K_ds). The ranges of K_ds are based on the range of groundwater compositions and speciation in the Culebra, including consideration of nonradionuclide solutes. The methodology used to simulate sorption in the Culebra is described in Section 6.4.6.2.1.

SCR.2.5.3 Precipitation and Dissolution

Waste dissolution and the release of radionuclides in the disposal rooms are accounted for in performance assessment calculations. The effect of reaction kinetics in controlling the rate of

waste dissolution within the disposal rooms has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. The formation of radionuclide bearing precipitates from groundwaters and brines and the associated retardation of contaminants have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

Dissolution of waste and **precipitation** of secondary minerals are relevant because of their control of the concentrations of radionuclides in any brines and groundwaters and the rates of contaminant transport. Waste dissolution is accounted for in performance assessment calculations. Mineral dissolution and precipitation processes also have the potential to alter rock permeabilities and, hence, groundwater flow. Mineral precipitation, for example, may block pores or fill fractures, resulting in modification of the groundwater flow field.

At low temperatures, precipitation and dissolution reactions are caused by changes in fluid chemistry that result in chemical undersaturation or oversaturation (Bruno and Sandino 1987, 12). Precipitation can be divided into two stages: nucleation and crystal growth. Following nucleation, growth rates depend on the rates of surface processes and the transport of materials to the site of growth. The style of mineral dissolution often depends on whether the rate-controlling process is a surface reaction or is related to the transport of material away from the site of dissolution. The former case may result in selective dissolution along crystallographically controlled features, whereas the latter may lead to rapid bulk dissolution (Berner 1981, 117). Thus, it is expected that a range of kinetic behavior will be exhibited by different mineral precipitation and dissolution reactions in different geochemical systems.

The following subsections discuss dissolution of waste in the disposal rooms and precipitation in geological units of the WIPP disposal system.

SCR.2.5.3.1 *Disposal Room*

Waste dissolution in the disposal rooms is accounted for in performance assessment calculations in the estimates of radionuclide solubility used. The WIPP actinide source term model is described in detail in Section 6.4.3.5. The assumption of equilibrium waste dissolution represents a conservative approach to predicting radionuclide concentrations in the disposal room brines because it yields maximum concentration estimates. The **kinetics of dissolution** within the disposal rooms has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.2.5.3.2 *Geological Units*

During groundwater flow, any radionuclide precipitation processes that occur will lead to reduced contaminant transport. No credit is given to the potentially beneficial occurrence of such reactions in performance assessment calculations. The formation of radionuclide-bearing precipitates from groundwaters and brines and the associated retardation of

contaminants has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. The **kinetics of precipitation** reactions have, therefore, also been eliminated from performance assessment calculations because no credit is taken for precipitation reactions. Dissolution of minerals in the Culebra and other geological units is discussed in Section SCR.1.1.5.

SCR.2.5.4 Sorption

Sorption within the disposal rooms, which would serve to reduce radionuclide concentrations, has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. The effects of sorption processes in shaft seals and panel closures have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. Sorption within the Culebra and the Dewey Lake is accounted for in performance assessment calculations. Sorption processes within other geological units of the disposal system have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. Mobile adsorbents (for example, microbes and humic acids), and the sorption of radionuclides at their surfaces, are accounted for in performance assessment calculations in the estimates of the concentrations of actinides that may be carried. The potential effects of reaction kinetics in adsorption processes and of changes in sorptive surfaces are accounted for in performance assessment calculations.

Sorption may be defined as the accumulation of matter at the interface between a solid and an aqueous solution. Within performance assessment calculations, including those made for the WIPP, the use of isotherm representations of **actinide sorption** prevails because of their computational simplicity in comparison with other models (Serne 1992, 238 – 239).

The mechanisms that control the **kinetics of sorption** processes are, in general, poorly understood. Often, sorption of inorganic ions on mineral surfaces is a two-step process consisting of a short period (typically minutes) of diffusion-controlled, rapid uptake, followed by slower processes (typically weeks to months) including surface rearrangement, aggregation and precipitation, and solid solution formation (Davis and Kent 1990, 202). Available data concerning rates of sorption reactions involving the important radionuclides indicate that, in general, a range of kinetic behavior is to be expected.

The relevance to the WIPP of sorption reaction kinetics lies in their effects on chemical transport. Sorption of waste contaminants to static surfaces of the disposal system such as seals and host rocks acts to retard chemical transport. Sorption of waste contaminants to potentially mobile surfaces, such as colloids, however, may act to enhance chemical transport, particularly if the kinetics of contaminant desorption are slow or the process is irreversible (nonequilibrium).

The following subsections discuss sorption in the disposal rooms, shaft seals, panel closures, the Culebra, and other geological units of the WIPP disposal system. Sorption on colloids, microbes, and particulate material is also discussed.

SCR.2.5.4.1 *Disposal Room*

The concentrations of radionuclides that dissolve in waters entering the disposal room will be controlled by a combination of sorption and dissolution reactions. However, because sorption processes are surface phenomena, the amount of material that is likely to be involved in sorption mass transfer processes will be small relative to that involved in the bulk dissolution of waste. WIPP performance assessment calculations therefore assume that dissolution reactions control radionuclide concentrations. Sorption on waste, containers, and backfill within the disposal rooms, which would serve to reduce radionuclide concentrations, has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.2.5.4.2 *Shaft Seals and Panel Closures*

Chapter 3.0 and Appendix SEAL describe the seals that are to be placed at various locations in the access shafts and waste panel access tunnels. The materials to be used include crushed salt, bentonite clay, and cementitious grouts. Of these, the latter two in particular possess significant sorption capacities. No credit is given for the influence of sorption processes that may occur in seal materials and their likely beneficial effects on radionuclide migration rates. The effects of sorption processes in shaft seals and panel closures have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.2.5.4.3 *Culebra*

Sorption within the Culebra is accounted for in performance assessment calculations as discussed in Section 6.4.6.2. The model used comprises an equilibrium, sorption isotherm approximation, employing constructed cumulative distribution functions (CDFs) of distribution coefficients (K_ds) applicable to dolomite in the Culebra. The potential effects of reaction kinetics in adsorption processes are encompassed in the ranges of K_ds used. The geochemical speciation of the Culebra groundwaters and the effects of **changes in sorptive surfaces** are implicitly accounted for in performance assessment calculations for the WIPP in the ranges of K_ds used.

SCR.2.5.4.4 *Other Geological Units*

During groundwater flow, any radionuclide sorption processes that occur between dissolved or colloidal actinides and rock surfaces will lead to reduced rates of contaminant transport. The sorptive capacity of the Dewey Lake is sufficiently large to prevent any radionuclides that enter it from being released to the accessible environment over 10,000 years (Wallace et al.

1995). Thus, sorption within the Dewey Lake is accounted for in performance assessment calculations as discussed in Section 6.4.6.6. No credit is given to the potentially beneficial occurrence of sorption in other geological units outside the Culebra. Sorption processes within other geological units of the disposal system have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.2.5.4.5 Sorption on Colloids, Microbes, and Particulate Material

The interactions of sorption processes with colloidal, microbial, or particulate transport are complex. Neglecting sorption of contaminants on immobile surfaces in the repository shafts and Salado (for example, the clays of the Salado interbeds) is a conservative approach because it leads to overestimated transport rates. However, neglecting sorption on potentially mobile adsorbents (for example, microbes and humic acids) cannot be shown to be conservative with respect to potential releases, because mobile adsorbents may act to transport radionuclides sorbed to them. Consequently, the concentrations of actinides that may be carried by mobile adsorbents are accounted for in performance assessment calculations (see Section 6.4.3.6).

SCR.2.5.5 Reduction-Oxidation Chemistry

The effects of reduction-oxidation reactions related to metal corrosion on reduction-oxidation conditions are accounted for in performance assessment calculations. Reduction-oxidation reaction kinetics are accounted for in performance assessment calculations. The migration of reduction-oxidation fronts through the repository has been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years. The formation of localized reducing zones has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

This section considers aspects of the reduction-oxidation chemistry of groundwaters at the WIPP site.

SCR.2.5.5.1 Reduction-Oxidation Kinetics

In general, investigation of the reduction-oxidation couples present in aqueous geochemical systems suggests that most reduction-oxidation reactions are not in thermodynamic equilibrium (Wolery 1992, 27). The lack of data characterizing the rates of reactions among trace element reduction-oxidation couples leads to uncertainty in elemental speciation. This uncertainty in **reduction-oxidation kinetics** is accounted for in performance assessment calculations in the dissolved actinide source term model (see Section 6.4.3.5), which estimates the probabilities that particular actinides occur in certain oxidation states.

SCR.2.5.5.2 Corrosion

Other than gas generation, which is discussed in Section SCR.2.5.1, the main **effect of metal corrosion** will be to influence the chemical conditions that prevail within the repository. Ferrous metals will be the most abundant metals in the WIPP, and these will corrode on contact with any brines entering the repository. Initially, corrosion will occur under oxic conditions owing to the atmospheric oxygen present in the repository at the time of closure. However, consumption of the available oxygen by corrosion reactions will rapidly lead to anoxic (reducing) conditions. These changes and controls on conditions within the repository will affect the chemical speciation of the brines and may affect the oxidation states of the actinides present. Changes to the oxidation states of the actinides will lead to changes in the concentrations that may be mobilized during brine flow. The oxidation states of the actinides are accounted for in performance assessment calculations by the use of parameters that describe probabilities that the actinides exist in particular oxidation states and, as a result, the likely actinide concentrations.

SCR.2.5.5.3 Reduction-oxidation Fronts

The development of **reduction-oxidation fronts** in the disposal system may affect the chemistry and migration of radionuclides. Reduction-oxidation fronts separate regions that may be characterized, in broad terms, as having different oxidation potentials. On either side of a reduction-oxidation front, the behavior of reduction-oxidation-sensitive elements may be controlled by different geochemical reactions. Elements that exhibit the greatest range of oxidation states (for example, Pu, U, Np) will potentially be the most affected by reduction-oxidation front development and migration. The migration of reduction-oxidation fronts may occur as a result of diffusion processes, or in response to groundwater flow, but will be restricted by the occurrence of heterogeneous buffering reactions (for example, certain mineral dissolution and precipitation reactions). Indeed, these buffering reactions cause the typically sharp, distinct nature of reduction-oxidation fronts.

Within the repository, **localized reducing zones**, bounded by reduction-oxidation fronts, may develop centered on metals undergoing corrosion. However, the formation of such zones would be of low consequence to disposal system performance owing to the small scale over which these zones and associated reduction-oxidation fronts could exert an influence on radionuclide migration. The formation of localized reducing zones has therefore been eliminated from performance assessment calculations on the basis of low consequence.

Of greater significance is the possibility that the flow of fluids having different oxidation potentials from those established within the repository might lead to the development and migration of a large-scale reduction-oxidation front. Reduction-oxidation fronts have been observed in natural systems to be the loci for both the mobilization and concentration of radionuclides, such as uranium. For example, during investigations at two uranium deposits at Poços de Caldas, Brazil, uranium was observed by Waber (1991) to be concentrated along reduction-oxidation fronts at the onset of reducing conditions by its precipitation as UO_2, the

less soluble reduced form, U(IV), of the metal. In contrast, studies of the Alligator Rivers uranium deposit in Australia by Snelling (1992, 21 – 22) indicated that the movement of the relatively oxidized weathered zone downwards through the primary ore body as the deposit was eroded and gradually exhumed led to the formation of secondary uranyl-silicate minerals and the mobilization of uranium in its more soluble U(VI) form in near-surface waters. The available geochemical evidence from these sites suggested that the reduction-oxidation fronts had migrated only slowly, at most on the order of a few tens of meters per million years. These rates of migration were controlled by a range of factors including the rates of erosion, infiltration of oxidizing waters, geochemical reactions, and diffusion processes.

The migration of large-scale reduction-oxidation fronts through the repository as a result of regional fluid flow is considered unlikely over the regulatory period on the basis of comparison with the slow rates of reduction-oxidation front migration suggested by natural system studies. This comparison is considered conservative because the relatively impermeable nature of the Salado suggests that reduction-oxidation front migration rates at the WIPP are likely to be slower than those observed in the more permeable lithologies of the natural systems studied. Large-scale reduction-oxidation fronts have therefore been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

SCR.2.5.6 Organic Complexation

The effects of anthropogenic organic complexation reactions, including the effects of organic ligands, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The presence of humic and fulvic acids is incorporated in performance assessment calculations.

The formation of aqueous complexes between radionuclides and organic materials has the potential to enhance the total dissolved contaminant load, and thus the potential for contaminant migration (Tipping 1993, 520). Both naturally occurring and anthropogenic organic materials may be important and include

- anthropogenic organics associated with the waste (for example, acetate, citrate, oxylate, ethylene diamine tetra-acetate [EDTA]), and
- naturally occurring high molecular weight organics, including humin, **humic, and fulvic acids** derived from soil waste.

The stability of radionuclide organic complexes is affected by the concentration of complexants and environmental factors. In general, complexing is favored by increased concentration of **organic ligands**, increased pH, and decreased ionic strength.

In natural systems such as soils, rocks, and groundwaters where many phases and reactive surfaces exist, individual slow reactions may limit subsequent chemical processes. Biological

uptake of radionuclides and other toxic substances may be limited by the rates of complex dissociation; for certain systems (for example, soils) true equilibrium may never be attained (for example, Rate et al. 1993, 1408). The limited data that exist concerning the **kinetics of organic complexation** reactions indicate that a range of behavior is to be expected, depending on the materials involved and the prevailing chemical conditions. For example, studies of the reactions of certain metals with natural humic materials indicate that desorption rates are influenced by changes in pH, metal and humic concentration ratio, ionic strength, and absolute reaction time (Rate et al. 1993, 1414).

The basis for eliminating anthropogenic organics from performance assessment calculations is described in Appendix SOTERM (Section SOTERM.5).

The occurrence of humic and fulvic acids is incorporated in performance assessment calculations in the models for radionuclide transport by humic colloids (see Section 6.4.6.2.2).

SCR.2.5.7 Exothermic Reactions

The thermal effects of exothermic reactions, including concrete hydration, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Exothermic reactions liberate heat and will alter the temperature of the disposal system and affect the properties of the repository and surrounding materials. Dissipation of heat by conduction through the host rock will act to limit any overall temperature change.

Dependent on the amount and rate of energy release, the geometry of the heat source, the thermal conductivities of the surrounding rocks, and any influence of groundwater or brine flow on heat transport, these exothermic reactions may lead to elevated temperatures. Elevated temperatures may influence the rate of salt creep in the surrounding rock, alter the geochemistry of minerals and waters or brines in the system, and lead to cracking of the seals.

In the WIPP, a range of different types of reactions will occur, including corrosion and gas generation, waste dissolution, and concrete seal and backfill hydration, liberating different amounts of heat.

The amount of heat liberated by the different reactions will depend on the extent of reaction that occurs and the enthalpy of the reactions themselves. The former will depend on the inventory of materials emplaced in the WIPP and the subsequent chemical evolution of the repository system. The latter can be assessed by considering typical enthalpies for the reaction types of interest.

Even though there is uncertainty surrounding the extent of reactions that will occur, consideration of typical reaction enthalpies suggests that the concrete and backfill hydration reactions have the greatest potential to evolve significant amounts of heat (Bennett et al.

1996). The effects of these processes on the WIPP are discussed further below. By contrast, the thermal effects of waste dissolution and gas generation by corrosion will be of low consequence. Potential heat generation from nuclear criticality is discussed in Section SCR.2.2.3 and heat generation from radioactive decay is discussed in Section SCR.2.2.2.

SCR.2.5.7.1 Elevated Temperatures as a Result of Concrete Hydration

Elevated temperatures in the concrete seals may influence the rate of salt creep in the surrounding rock, alter the geochemistry of minerals and waters or brines in the system, and lead to cracking of the seals.

Concrete hydration reactions are known to proceed for extended periods (perhaps thousands of years); however, the rates of these reactions decrease with time and, within the WIPP, the greatest evolution of heat will occur during the short period following seal emplacement and repository closure. A quantitative analysis of the thermal effects of emplacing large concrete seals in salt at the WIPP was made by Loken (1994) and Loken and Chen (1995). The analysis suggests that the energy released by the hydration of the seal concrete could raise the temperature of the concrete to approximately 53° C, and that of the surrounding salt to approximately 38°C, one week after seal emplacement. Loken (1994) and Loken and Chen (1995) also examined the potential for cracking of the seals in response to short-term stresses that could develop as a result of thermal expansion of the concrete and long-term stresses caused by creep of the surrounding salt. At both time scales, radially compressive, horizontal stresses are likely to develop in the concrete due to the presence of the surrounding salt. The magnitude of these stresses caused by short-term thermal pulse was calculated to be less than 9.2 megapascals, well below the design compressive strength of the concrete (which for SMC is 31 megapascals). Maximum long-term stresses will develop in the deepest parts of the seals where lithostatic pressure is greatest (14.8 megapascals). Again, these are well below the design compressive strength of the concrete (31 megapascals). Loken's (1994) and Loken and Chen's (1995) analyses also considered potential vertical stresses in the concrete seals. The magnitude of these stresses depends on the thermal history of the seal and the weight of overburden present. The calculations indicated that 50 years after seal emplacement the thermal changes in the seals could lead to maximum tensile stresses of approximately 3 megapascals. Even for the shallowest parts of the shaft seal system, these stresses will be less than the weight of the overburden (6.0 megapascals), making tensile cracking of the seals unlikely.

Thus, Loken's (1994) and Loken and Chen's (1995) analyses confirm that any temperature changes associated with concrete hydration will occur at early times (at most some decades) after repository closure and suggest that significant cracking of the seals will be unlikely. The effects of any minor thermal cracking of concrete seals on seal permeability are accounted for in performance assessment calculations via the range of seal permeabilities used.

WIPP waste contains cement that is used to solidify liquids, particulates, and sludges. All the waste to be emplaced at the WIPP will contain a total of about 8.5×10^6 kilograms of cement

(Bennett et al. 1996). This is equivalent to about 1.5×10^7 moles of CaO per waste disposal panel, representing the cement as CaO. Although a substantial amount of hydration may occur prior to waste disposal, this process will continue at a slower rate after disposal. Concrete hydration can be described by the reaction

$$CaO + H_2O = Ca(OH)_2$$

Disregarding the hydration that will occur prior to disposal and assuming a brine inflow rate of 200 cubic meters per year (the maximum calculated rate, which occurs for the scenario involving an E1 drilling event at 350 years after disposal), the reaction rate of concrete hydration in the panel will be about 1.1×10^7 moles per year, and the reaction could continue for about 1.4 years. Concrete hydration in the waste will generate a thermal load of about 23 kilowatts, based on a reaction enthalpy of −65 kilojoules per mole. Bennett et al. (1996) estimated that the maximum temperature that could be generated by concrete hydration of the waste within a panel is about 2°C. Such a temperature rise will have an insignificant effect on the performance of the disposal system, as discussed further in Sections SCR.2.3.7 (thermally-induced stress), SCR.2.4.3 (thermal convection), SCR.2.5.1.1 (gas generation), and SCR.2.7.3 (thermochemical transport).

The potential effects of elevated temperatures on chemical reactions in the seals and surrounding regions include increased actinide solubilities and alteration of mineral assemblages leading to altered sorption characteristics. Despite the potential for such effects to occur, the short duration of the thermal pulse caused by concrete hydration is such that it will not significantly affect actinide transport in the long term. Sorption within the seals has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. Consequently, changes to the sorption characteristics of the seals can also be eliminated from performance assessment calculations.

Thus, the effects of exothermic concrete hydration reactions have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5.7.2 *Elevated Temperatures as a Result of Backfill Hydration*

The potential for the development of elevated temperatures in the repository as a result of exothermic backfill hydration reactions has been assessed by Bennett et al. (1996). In their analysis, Bennett et al. (1996) made the following assumptions:

- Hydration of the backfill can be described by the reaction

$$MgO + H_2O = Mg(OH)_2 .$$

- Reaction will proceed rapidly so that the rate of heat generation will be controlled by the rate of brine inflow to the repository.

- Reaction will occur uniformly throughout the repository so that all brine entering will contact and react with backfill.

- All of the backfill emplaced will undergo hydration.

The maximum calculated rate of brine inflow into a panel (about 200 cubic meters per year) occurs for the scenario involving an E1 drilling event at 350 years after disposal. The molar density of water is 5.56×10^4 moles per cubic meter and thus the reaction rate of backfill hydration in the panel will be 1.1×10^7 moles per year. Backfill hydration will generate a thermal load of about 13 kilowatts, based on a reaction enthalpy of 38 kilojoules per mole. There will be about 2×10^8 moles MgO emplaced per panel and thus the reaction could continue for about 20 years if sufficient brine was available. Bennett et al. (1996) estimated the maximum temperature that could be generated by backfill hydration within a panel for such a thermal load. Assuming heat loss will occur by conduction through the salt forming the roof and floor of the panel and that heat losses through the side walls are negligible, the maximum temperature rise in a panel, as a consequence of backfill hydration would be less than 5°C. This magnitude of temperature rise will have an insignificant effect on the performance of the disposal system, as discussed further in Sections SCR.2.3.7 (thermally-induced stress), SCR.2.4.3 (thermal convection), SCR.2.5.1.1 (gas generation), and SCR.2.7.3 (thermochemical transport).

The potential effects of elevated temperatures on chemical reactions in the disposal rooms and surrounding regions include increased actinide solubilities and alteration of mineral assemblages leading to altered sorption characteristics. Despite the potential for such effects to occur, the small temperature rise caused by backfill hydration is such that it will not significantly affect the chemical behavior of the actinides beyond the range of uncertainty considered in estimation of the actinide source term (Section 6.4.3.5). Sorption within the backfill has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. Consequently, changes to the sorption characteristics of the backfill can also be eliminated from performance assessment calculations.

Thus, the effects of exothermic backfill hydration reactions have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.5.7.3 *Elevated Temperatures as a Result of Other Exothermic Reactions*

Bennett et al. (1996) also considered the potential effects on temperature of a number of other exothermic reactions in the repository. These included backfill carbonation, microbial degradation, and aluminum corrosion.

Backfill carbonation will be limited by microbial CO_2 production; the maximum rate of CO_2 production is expected to be 2.9×10^5 moles per year. Backfill carbonation can be described by the reaction

$$Mg(OH)_2 + CO_2(g) = MgCO_3 + H_2O$$

Backfill carbonation will generate a thermal load of about 0.7 kilowatts, based on a reaction enthalpy of −77 kilojoules per mole. About 3.6×10^7 moles CO_2 could be produced in a single panel and thus the reaction could continue for about 125 years. Bennett et al. (1996) estimated the maximum temperature that could be generated by backfill carbonation within a panel to be about 0.6°C.

The maximum reaction rate for microbial degradation in a panel will be about 1×10^5 moles per year and the inventory is about 1.2×10^7 moles $C_6H_{10}O_5$ per panel. Microbial degradation can be described by the reaction

$$C_6H_{10}O_5 + H_2O = 3CH_4 + CO_2$$

This reaction could continue for about 120 years. Microbial degradation will generate a thermal load of about 1 kilowatt, based on a reaction enthalpy of −312 kilojoules per mole. Bennett et al. (1996) estimated the maximum temperature that could be generated by microbial degradation within a panel to be about 0.8°C. Aluminum corrosion can be described by the reaction

$$Al + 3H_2O = Al(OH)_3 + 1.5H_2$$

Thus, the rate of corrosion of aluminum will be controlled by brine availability. The reaction rate of aluminum corrosion in the panel will be about 0.4×10^7 moles per year, assuming a brine inflow rate of 200 cubic meters per year (1.1×10^7 moles per year). This rate of brine inflow represents the maximum calculated rate, which occurs for the scenario involving an E1 drilling event at 350 years after disposal. About 8×10^6 moles of aluminum will be emplaced in each panel and thus aluminum corrosion could continue for two years.

Aluminum corrosion will generate a thermal load of about 51 kilowatts for a reaction enthalpy of −434 kilojoules per mole. Bennett et al. (1996) estimated the maximum temperature that could be generated by aluminum corrosion within a panel to be about 6°C.

These calculated temperature rises resulting from backfill carbonation, microbial degradation, and aluminum corrosion will not have a significant effect on the performance of the disposal system, as discussed further in Sections SCR.2.3.7 (thermally-induced stress), SCR.2.4.3 (thermal convection), SCR.2.5.1.1 (gas generation), and SCR.2.7.3 (thermochemical transport).

SCR.2.5.8 Chemical Effects on Material Properties

The effects of chemical degradation of seals and of microbial growth on concrete are accounted for in performance assessment calculations. The effects on material properties of the chemical degradation of backfill have been eliminated from performance assessment calculations on the basis of low consequence.

The concrete used in the seal systems will degrade due to chemical reaction with the infiltrating groundwater. Degradation could lead to an increase in permeability of the seal system. The main uncertainties with regard to cement degradation rates at the WIPP are the effects of groundwater chemistry, the exact nature of the cementitious phases present, and the rates of brine infiltration. The performance assessment calculations take a conservative approach to these uncertainties by assuming a large increase in permeability of the concrete seals only a few hundred years after closure. These permeability values are based on seal design considerations and consider the potential effects of degradation processes. Therefore, the effects of **chemical degradation of seals** are accounted for in performance assessment calculations through the CDFs used for seal material permeabilities.

Concrete can be inhabited by alkalophilic bacteria which could produce acids thereby accelerating the seal degradation process. Nitrification processes, which will produce nitric acid, tend to be aerobic, and will be further limited at the WIPP by the low availability of ammonium in the brines (Pedersen and Karlsson 1995, 75). Because of the limitations on growth because of the chemical conditions, it is likely that the effects of **microbial growth on concrete** will be small. The effects of such microbial activity on seal properties are, therefore, implicitly accounted for in performance assessment calculations through the CDFs used for seal material permeabilities.

Degradation of the chemical conditioners or backfill added to the disposal room is a prerequisite of their function in buffering the chemical environment of the disposal room (Section SCR.2.5.2). However, the chemical reactions and dissolution involved will change the physical properties of the material. Because the mechanical and hydraulic characteristics of the backfill have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system, the effects of the **chemical degradation of backfill** on material properties have been eliminated from performance assessment calculations on the same basis.

SCR.2.6 Contaminant Transport Mode FEPs

Following waste emplacement brine may contact the waste and radionuclides will dissolve. Radionuclide mobility will be affected by radionuclide speciation, solubility, sorption, and precipitation. Chemical and microbial decomposition of organics in the waste may result in the transport of some radionuclides as organic complexes, colloids, and particulate material. Radionuclides bound to microbes might also be transported. Potentially, radionuclides will

migrate with the brine by advection and diffusion through the repository, seals, the DRZ, and pores and fractures in the rock matrix.

The following subsections discuss briefly the transport of radionuclides in a number of different forms: fully dissolved, colloidal, particulate, bound to microbes, and combined with gas.

SCR.2.6.1 Solute Transport

Transport of dissolved radionuclides is accounted for in performance assessment calculations.

Solute transport may occur by advection, dispersion, and diffusion down chemical potential gradients, and is accounted for in performance assessment calculations (Sections 6.4.5.4 and 6.4.6.2.1).

SCR.2.6.2 Colloid Transport

Formation of colloids, transport of colloidal radionuclides, and colloid retardation through filtration and sorption are accounted for in performance assessment calculations.

Colloids typically have sizes of between 1 nanometer and 1 micrometer and may form stable dispersions in groundwaters. **Colloid formation and stability** depends on their composition and the prevailing chemical conditions (for example, salinity). Depending on their size, **colloid transport** may occur at different rates than those of fully dissolved species. They may be physically excluded from fine porous media, and their migration may be accelerated through fractured media in channels where velocities are greatest. However, they can also interact with the host rocks during transport and become retarded. These interactions may be of a chemical or physical nature and include electrostatic effects, leading to **colloid sorption,** and sieving leading to **colloid filtration** and pore blocking. Colloid formation and stability is accounted for in performance assessment calculations through estimates of colloid numbers in the disposal room based on the prevailing chemical conditions (Section 6.4.3.6). Colloid sorption, filtration, and transport in the Culebra are accounted for in performance assessment calculations (Section 6.4.6.2.2).

SCR.2.6.3 Particulate Transport

The formation of particulates through rinse and subsequent transport of radionuclides in groundwater and brine has been eliminated from performance assessment calculations for undisturbed conditions on the basis of low consequence to the performance of the disposal system. The transport of radionuclides as particulates (cuttings, cavings, and spallings) during penetration of the repository by a borehole, is accounted for in performance assessment calculations.

Suspensions of particles having sizes above the colloidal range are, by definition, unstable because they are subject to gravitational settling. Within the WIPP disposal rooms (the only potential source of active particulates), it is unlikely that brine flow will be rapid enough to generate (through **rinse**) and transport particulate suspensions under undisturbed conditions. Mobilization of any suspensions that may form would have the effect of a local and minor redistribution of radionuclides within the room and is unlikely, therefore, to result in significantly increased radionuclide transport from the repository. The formation of particulates through rinse and subsequent transport of radionuclides in groundwater and brine has therefore been eliminated from performance assessment calculations for undisturbed conditions on the basis of low consequence to the performance of the disposal system.

Inadvertent human intrusion into the repository by a borehole could result in transport of waste material to the ground surface through drilling-induced flow and blowouts (Section SCR.3.2.1.1.2). This waste could include material intersected by the drill bit (**cuttings**), material eroded from the borehole wall by circulating drilling fluid (**cavings**), and material that enters the borehole as the repository depressurizes (**spallings**). Transport of radionuclides by these materials and in brine is accounted for in performance assessment calculations and is discussed in Section 6.4.7.1.

SCR.2.6.4 Microbial Transport

Transport of radionuclides bound to microbes is accounted for in performance assessment calculations. The effects of biofilms on microbial transport have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

Microbes will be introduced into the disposal rooms during the operational phase of the repository and will also occur naturally in geological units throughout the disposal system. Because of their colloidal size, microbes, and any radionuclides bound to them, may be transported at different rates than radionuclides in solution. **Microbial transport** of radionuclides is accounted for in performance assessment calculations (Section 6.4.6.2.2).

Biofilms (see Section SCR.2.5.1) may influence microbial and radionuclide transport rates through their capacity to retain, and therefore retard, both the microbes themselves and radionuclides. This effect has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.2.6.5 Gas Transport

The transport of radioactive gases has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The production and potential **transport of radioactive gases** is discussed in Section SCR.2.5.1.3, where they are eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.7 Contaminant Transport Processes

SCR.2.7.1 Advection

Advection of contaminants is accounted for in performance assessment calculations.

Advection (that is, the transport of dissolved and solid material by flowing fluid) is accounted for in performance assessment calculations (Sections 6.4.5.4 and 6.4.6.2).

SCR.2.7.2 Diffusion

Diffusion of contaminants and retardation by matrix diffusion are accounted for in performance assessment calculations.

Diffusion (that is, the movement of molecules or particles both parallel to and transverse to the direction of advection in response to Brownian forces) and, more specifically **matrix diffusion**, whereby movement is transverse to the direction of advection within a fracture and into the surrounding rock matrix, are accounted for in performance assessment calculations (Section 6.4.6.2).

SCR.2.7.3 Thermochemical Transport Phenomena

The effects of thermochemical transport phenomena (the Soret effect) have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

According to Fick's law, the diffusion flux of a solute is proportional to the solute gradient. In the presence of a temperature gradient there will also be a solute flux proportional to the temperature gradient (the **Soret effect**). Thus, the total solute flux **J** in a liquid phase may be expressed as

$$\mathbf{J} = -D\nabla C - ND\nabla T ,$$

where C is the solute concentration, T is the temperature of the liquid, D is the solute diffusion coefficient, and

$$N = S_T C(1-C) ,$$

in which S_T is the Soret coefficient. The mass conservation equation for solute diffusion in a liquid is then

$$\frac{\partial C}{\partial t} = \nabla \bullet (D \nabla C + ND \nabla T) \ .$$

In liquids having both light and heavy molecules, the heavier molecules tend to concentrate in the colder regions in the presence of a temperature gradient. Typically, large temperature gradients are required for Soret diffusion to be significant compared to Fickian diffusion.

Radioactive decay, nuclear criticality, and exothermic reactions are three possible sources of heat in the WIPP repository. The DOE (1980, 9-149) estimated that radioactive decay of CH-TRU waste will result in a maximum temperature rise at the center of the repository of 1.6°C at 80 years after waste emplacement (Section SCR.2.2.2). Sanchez and Trellue (1996) have shown that the total thermal load of RH-TRU waste will not significantly affect the average temperature increase in the repository. Temperature increases of about 3°C may occur at the locations of RH-TRU containers of maximum thermal power (60 watts). Such temperature increases are likely to be short-lived because of the rapid decay of heat-producing nuclides in RH-TRU waste, such as ^{137}Cs, ^{90}Sr, ^{241}Pu, and ^{147}Pm, whose half-lives are approximately 30, 29, 14, and 3 years, respectively. Soret diffusion generated by such temperature contrasts will be negligible compared to other radionuclide transport mechanisms.

Nuclear criticality is eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years (Section SCR.2.2.3).

Temperature increases resulting from exothermic reactions are discussed in Section SCR.2.5.7. Potentially the most significant exothermic reactions are concrete hydration, backfill hydration, and aluminum corrosion. Hydration of the seal concrete could raise the temperature of the concrete to approximately 53°C and that of the surrounding salt to approximately 38°C one week after seal emplacement (see Section SCR.2.5.7.1). However, the concrete seals will be designed to function as barriers to fluid flow for at least 100 years after emplacement, and seal permeability will be minimized (Wakeley et al. 1995). Thus, short-term temperature increases associated with concrete hydration will not result in significant Soret diffusion through the seal system.

As discussed in Section SCR.2.5.7.2, the maximum temperature rise in the disposal panels as a consequence of backfill hydration will be less than 5°C, resulting from brine inflow following a drilling intrusion into a waste disposal panel. Note that active institutional controls will prevent drilling within the controlled area for 100 years after disposal. By this time, any heat generation by radioactive decay and concrete seal hydration will have decreased substantially, and the temperatures in the disposal panels will have reduced to close to initial values.

Under similar conditions following a drilling intrusion, aluminum corrosion could, at most, result in a short-lived (two years) temperature increase of about 6°C (see Section SCR.2.5.7.3). These calculated maximum heat generation rates resulting from aluminum corrosion and backfill hydration could not occur simultaneously because they are limited by

brine availability; each calculation assumes that all available brine is consumed by the reaction of concern. Thus, the temperature rise of 6°C represents the maximum that could occur as a result of any combination of exothermic reactions occurring simultaneously. Temperature increases of this magnitude will not result in significant Soret diffusion within the disposal system.

In summary, the limited magnitude and spatial scale of temperature gradients in the disposal system indicate that Soret diffusion will be insignificant. Thus, the effects of thermochemical transport phenomena have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.7.4 Electrochemical Transport Phenomena

The effects of electrochemical transport phenomena, comprising electrochemical reactions and electrophoresis, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The effects of galvanic coupling between the waste and metals external to the repository on transport have been eliminated from performance assessment calculations on the basis of low probability of occurrence over 10,000 years.

This section discusses electrochemical transport phenomena, including galvanic coupling, electrochemical reactions, and electrophoretic effects.

Potential gradients may exist in the subsurface as a result of groundwater flow and electrochemical reactions. The development of such potentials may be associated with the weathering of sulfide ore bodies, variations in rock properties at geological contacts, bioelectric activity associated with organic matter, natural corrosion reactions, and temperature and pressure gradients in groundwaters. With the exception of mineralization potentials associated with metallic sulfide ores (see below), the magnitude of such potentials is usually less than about 100 millivolts and the potentials tend to average to zero over distances of several thousand feet (Telford et al. 1976, 458). Temporary currents may be induced over larger distances by activity in the ionosphere, thunderstorms, and nuclear blasts. The short duration and spasmodic nature of these **electrochemical effects** is such that they have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

With regard to the WIPP, **galvanic coupling** refers to the establishment of electrical potential gradients between metals in the waste form, canisters, and other metals external to the waste form. Such electrochemical effects can potentially influence corrosion processes, gas generation rates, and chemical migration. Metals other than those in the waste form and canisters can potentially include natural metallic ore bodies in the host rock and metallic elements emplaced in other parts of the repository. The absence of metallic sulfide ores in the region (Appendix GCR) allows galvanic coupling between the waste and metals external to

the repository to be eliminated from performance assessment calculations on the basis of low probability of occurrences over 10,000 years.

A variety of metals will be present within the repository (for example, waste metals and metal packaging), and cells can be established over short distances. The precise interactions that may occur are complex and depend on the metals involved, their physical characteristics, and the prevailing conditions. Good physical and electrical contact between the metals involved is critical to the establishment of galvanic cells. Experiments suggest that good electrical contact is not likely to be established under repository conditions (Telander and Westerman 1993). Consequently, given the preponderance of iron over other metals within the repository and the likely passivation of many nonferrous materials, the influence of these interactions on corrosion reactions and gas generation have been eliminated from performance assessment calculations on the basis of low consequence. Because electrochemical cells that may be established are small, the effect of such cells on the migration of contaminants (for example, by **electrophoresis**) has also been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.7.5 Physicochemical Transport Phenomena

The effects of alpha-recoil processes on radionuclide transport have been eliminated from performance assessment calculations on the basis of low consequence to performance of the disposal system. The effects of enhanced diffusion across chemical gradients have been eliminated from performance assessments on the basis of low consequence to the performance of the disposal system. The effects of chemical gradients between material boundaries are accounted for in performance assessment calculations through the treatment of mineral fragment colloids (Section 6.4). The effects of osmotic processes have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

Physicochemical transport phenomena discussed in this section are associated with alpha-recoil and chemical gradients. These processes have the potential to influence the transport of contaminants throughout the disposal system.

SCR.2.7.5.1 Alpha Recoil

During decay of certain radionuclides, alpha particles may be emitted with sufficiently high energies that the daughter nuclide recoils appreciably to conserve system momentum. An example is the decay of a ^{238}U atom (originally at rest) to ^{234}Th with the emission of an alpha particle. In this case, the alpha particle is ejected with a considerable kinetic energy (approximately 4.1 megaelectron volts [6.57×10^{-13} joules]). Following the law of conservation of linear momentum, the daughter nuclide, ^{234}Th, recoils with an energy of approximately 0.07 megaelectron volts (1.12×10^{-14} joules). The potential relevance of these alpha-recoil processes to disposal system performance lies in the energy imparted to the ^{234}Th nuclide. The energy is great enough to cause the ^{234}Th nuclide to move a short distance

through a crystal lattice (for example uraninite). If it is close enough to the surface of the crystal, it will be ejected into the surrounding groundwater or transferred to an adjoining solid phase.

^{234}Th decays rapidly to ^{234}Pa and subsequently to ^{234}U. The half-lives of these subsequent decay processes are 24.1 days and 1.17 minutes, respectively. Thus, in combination, these recoil and decay processes can lead to the apparent preferential dissolution or leaching of ^{234}U relative to ^{238}U from crystal structures and amorphous or adsorbed phases. This preferential leaching may also be enhanced by the radiation damage to the host phase during the emission of the alpha particle. Consequently, ^{234}U may exhibit different transport behavior than ^{238}U and contribute differently to any calculated risk.

The potential influence of **alpha-recoil** processes on radionuclide transport through natural geologic media is dependent on many site-specific factors. Among these factors are the mineralogy, geometry, and microstructure of the rocks, as well as geometrical constraints on the type of groundwater flow (for example, porous or fracture flow). Studies of natural radionuclide-bearing groundwater systems often fail to discern any measurable effect of alpha-recoil processes on radionuclide transport above the background uncertainty introduced by the spatial heterogeneity of the geological system under consideration. Consequently, the effects of the alpha-recoil processes that occur on radionuclide transport are thought to be minor. These effects have therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.2.7.5.2 *Chemical Gradients*

The existence of **chemical gradients** within the disposal system, induced naturally or resulting from repository material and waste emplacement, may influence the transport of contaminants in several ways. Such gradients may exist at the interfaces between different repository materials and between repository and geological materials. For example, distinct chemical regimes are likely to be established within the concrete seals and the adjoining host rocks. Similarly, chemical gradients will exist between the waste and chemical conditioners and the surrounding rocks of the Salado. Other chemical gradients may exist as a result of the juxtaposition of relatively dilute groundwaters and brines or between groundwaters with different chemistries. Natural gradients currently exist between different groundwaters in the Culebra.

A possible consequence of chemical gradients that occur at material boundaries is the **enhanced diffusion** of materials. However, it is likely that the length scales over which such enhanced diffusion might occur will be small in comparison to the scale of the disposal system. Furthermore, a significant amount of diffusion across such interfaces will tend to reduce the driving force for migration. Therefore, the effects of enhanced diffusion across chemical gradients at material boundaries have been eliminated from performance assessments on the basis of low consequence to the performance of the disposal system.

Other processes may be induced by the existence of chemical gradients at material boundaries, including the formation or destabilization of colloids. For example, cementitious materials will be emplaced in the WIPP as part of the waste and in the seals. Cementitious materials contain colloidal-sized phases, such as calcium-silicate-hydrate gels, and alkaline pore fluids. Chemical gradients will exist between the pore fluids in the cementitious materials and their less alkaline surroundings. Chemical interactions at these interfaces may lead to the generation of colloids by chemical precipitation, and these colloids could potentially play a role in actinide transport.

The chemical conditions that will develop in the cements are such that any colloids generated from them will be of the inorganic, mineral fragment type. Candidate colloidal compositions include calcium and magnesium oxides, calcium hydroxide, calcium-aluminum silicates, calcium-silicate-hydrate gels, and silica. Experimental investigations of the stability of inorganic, mineral fragment type colloidal dispersions have been carried out as part of the WIPP colloid-facilitated actinide transport program (Papenguth and Behl 1996, 83 – 84). These investigations indicate that the salinities of the brines at WIPP are sufficient to cause kinetic destabilization of mineral fragment type colloidal dispersions. Therefore, concentrations of any colloids generated from concrete within the repository are expected to be extremely low. These concentrations are considered in performance assessment calculations.

The existence of distinct interfaces between waters of different salinities (and therefore different densities) may limit the mixing of the water bodies and affect flow and contaminant transport. Such effects have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Under appropriate circumstances, **osmotic processes** may occur at interfaces between waters of different salinities. Osmosis is the process by which water (or any other solvent) diffuses through a semipermeable (or differentially permeable) membrane in response to a concentration gradient. In geologic settings, osmotic processes can occur if waters of different salinities and/or chemistries exist on either side of a particular lithology (for example, clay) or a lithological boundary that behaves as a semipermeable membrane. At the WIPP, clay layers within the Salado may act as semipermeable membranes across which osmotic processes may occur.

In the absence of hydrological gradients across a semipermeable membrane, water will move by osmosis from the more dilute water into the more saline water. However, because of the nature of the membrane, the migration of dissolved contaminants across the interface may be restricted. The existence of a hydrological gradient across a semipermeable membrane may enhance or oppose water movement by osmosis, depending on its direction and magnitude. In cases where advection dominates over osmosis and reverse osmosis occurs, dissolved contaminants that cannot pass through the semipermeable membrane may be advected towards the membrane and concentrated along the interface. Thus, both osmosis and reverse osmosis can restrict the migration of dissolved contaminants and possibly lead to their

concentration along interfaces between different water bodies. The effects of osmotic processes have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.2.8 Ecological FEPs

SCR.2.8.1 Plant, Animal, and Soil Uptake

Plant uptake, animal uptake, and accumulation in soils have been eliminated from compliance assessment calculations for 40 CFR § 191.15 on the basis of low consequence. Plant uptake and animal uptake in the accessible environment have been eliminated from performance assessment calculations for 40 CFR § 191.13 on regulatory grounds. Accumulation in soils within the controlled area has been eliminated from performance assessment calculations for 40 CFR § 191.13 on the basis of beneficial consequence.

The results of the calculations presented in Section 6.5 show that releases to the accessible environment under undisturbed conditions are restricted to lateral releases through the DRZ at repository depth. Thus, for evaluating compliance with the EPA's individual protection requirements in 40 CFR § 191.15, FEPs that relate to **plant uptake, animal uptake,** and **accumulation in soils** have been eliminated from compliance assessment calculations on the basis of low consequence.

Performance assessments for evaluating compliance with the EPA's cumulative release requirements in 40 CFR § 191.13 need not consider radionuclide migration in the accessible environment. Therefore, FEPs that relate to plant uptake and animal uptake in the accessible environment have been eliminated from performance assessment calculations on regulatory grounds. Accumulation in soils that may occur within the controlled area would reduce releases to the accessible environment and can, therefore, be eliminated from performance assessment calculations on the basis of beneficial consequence.

SCR.2.8.2 Human Uptake

Ingestion, inhalation, irradiation, dermal sorption, and injection have been eliminated from compliance assessment calculations for 40 CFR § 191.15 and Subpart C of 40 CFR Part 191 on the basis of low consequence. FEPs that relate to human uptake in the accessible environment has been eliminated from performance assessment calculations for 40 CFR § 191.13 on regulatory grounds.

As described in Section 8.1.1, releases to the accessible environment under undisturbed conditions are restricted to lateral migration through anhydrite interbeds within the Salado. Because of the bounding approach taken for evaluating compliance with the EPA's individual protection requirements in 40 CFR § 191.15 and the groundwater protection requirements in Subpart C of 40 CFR Part 191 (see Chapter 8.0, Sections 8.1.2.2 and 8.2.3), FEPs that relate

to human uptake by **ingestion, inhalation, irradiation, dermal sorption,** and **injection** have been eliminated from compliance assessment calculations on the basis of low consequence.

Performance assessments for evaluating compliance with the EPA's cumulative release requirements in 40 CFR § 191.13 need not consider radionuclide migration in the accessible environment. Therefore, FEPs that relate to human uptake in the accessible environment have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3 Human-Initiated EPs

The human-initiated EPs discussed in this section are relevant to the analyses conducted to determine compliance with the Containment Requirements in 40 CFR § 191.13, the Individual Protection Requirements in 40 CFR § 191.15, and the Environmental Standards for Ground Water Protection in Subpart C of 40 CFR Part 191. The DOE's consideration of human-initiated EPs draws on the criteria provided in 40 CFR Part 194 for certification of the WIPP's compliance with the 40 CFR Part 191 disposal regulations.

In Section SCR.3.1, the DOE discusses the requirements in 40 CFR Part 191 and criteria in 40 CFR Part 194 concerning the consideration of human-initiated EPs in compliance applications. In the remainder of Section SCR.3, the DOE discusses human-initiated EPs in the context of the FEP categorization scheme presented in Table SCR-3: the human-initiated EPs presented in Table SCR-3 are highlighted in the text of the screening discussions. The geology category (SCR.3.2) is concerned with human activities that could disrupt the subsurface structure. The hydrology and geochemistry category (SCR.3.3) is concerned with the potential effects of disruptive human activities on subsurface fluid flow and chemistry. The categories concerned with geomorphology (SCR.3.4), surface hydrology (SCR.3.5), climate (SCR.3.6), marine environment (SCR.3.7), and ecology (SCR.3.8) relate to potential effects on the disposal system of human-initiated EPs occurring at or near the land surface.

SCR.3.1 Regulatory Requirements

Regulatory requirements on FEPs represent FEP screening decisions made by the EPA. Thus, the logic and rationale for regulatory screening decisions are based on one or both of the following:

- Exclusion by the EPA in language that forms part of the 40 CFR Part 191 standard.
- Exclusion by the EPA in language that forms part of the 40 CFR Part 194 criteria.

Regulatory screening arguments are used largely to limit speculation concerning future, potentially disruptive, human-initiated EPs. In particular, the criterion in 40 CFR § 194.25(a), concerned with predictions of the future states of society, requires that compliance

Table SCR-3. Human-Initiated EPs and Their Screening Classifications

Events and Processes (EPs)	Screening Classification Historical/ Ongoing/ Near Future	Future	Comments	Appendix SCR Section
GEOLOGICAL EPs				SCR.3.2
Drilling			DP for boreholes that penetrate the waste and boreholes that penetrate Castile brine underlying the waste disposal region. SO-C for other future drilling.	SCR.3.2.1
Oil and gas exploration	SO-C	DP		
Potash exploration	SO-C	DP		
Water resources exploration	SO-C	SO-C		
Oil and gas exploitation	SO-C	DP		
Groundwater exploitation	SO-C	SO-C		
Archeological investigations	SO-R	SO-R		
Geothermal	SO-R	SO-R		
Other resources	SO-C	DP		
Enhanced oil and gas recovery	SO-C	DP		
Liquid waste disposal	SO-R	SO-R		
Hydrocarbon storage	SO-R	SO-R		
Deliberate drilling intrusion	SO-R	SO-R		
Excavation activities				SCR.3.2.2
Potash mining	UP	DP	UP for mining outside the controlled area. DP for mining inside the controlled area.	
Other resources	SO-C	SO-R		
Tunneling	SO-R	SO-R		
Construction of underground facilities (for example storage, disposal, accommodation)	SO-R	SO-R		
Archeological excavations	SO-C	SO-R		
Deliberate mining intrusion	SO-R	SO-R		
Subsurface explosions				SCR.3.2.3
Resource recovery				SCR.3.2.3.1
Explosions for resource recovery	SO-C	SO-R		
Underground nuclear device testing				SCR.3.2.3.2
Underground nuclear device testing	SO-C	SO-R		

Table SCR-3. Human-Initiated EPs and Their Screening Classifications (Continued)

Events and Processes (EPs)	Screening Classification Historical/ Ongoing/ Near Future	Screening Classification Future	Comments	Appendix SCR Section
SUBSURFACE HYDROLOGICAL AND GEOCHEMICAL EPs				SCR.3.3
Borehole fluid flow				SCR.3.3.1
Drilling-induced flow				SCR.3.3.1.1
Drilling fluid flow	SO-C	DP	DP for boreholes that penetrate the waste. SO-C for other future drilling.	
Drilling fluid loss	SO-C	DP	DP for boreholes that penetrate the waste, SO-C for other future drilling	
Blowouts	SO-C	DP	DP for boreholes that penetrate the waste and boreholes that penetrate Castile brine underlying the waste disposal region. SO-C for other future drilling.	
Drilling-induced geochemical changes	UP	DP	SO-C for units other than the Culebra.	
Fluid extraction				SCR.3.3.1.2
Oil and gas extraction	SO-C	SO-R		
Groundwater extraction	SO-C	SO-R		
Fluid injection				SCR.3.3.1.3
Liquid waste disposal	SO-C	SO-R		
Enhanced oil and gas production	SO-C	SO-R		
Hydrocarbon storage	SO-C	SO-R		
Fluid-injection induced geochemical changes	UP	SO-R	SO-C for units other than the Culebra	
Flow through abandoned boreholes			Classification distinguishes the time when drilling occurs.	SCR.3.3.1.4
Natural borehole fluid flow	SO-C	DP	DP for boreholes that penetrate Castile brine underlying the waste disposal region. SO-C for other future boreholes.	

Table SCR-3. Human-Initiated EPs and Their Screening Classifications (Continued)

Events and Processes (EPs)	Screening Classification Historical/ Ongoing/ Near Future	Screening Classification Future	Comments	Appendix SCR Section
Waste-induced borehole flow	SO-R	DP	DP for boreholes that penetrate the waste. SO-C for other future boreholes.	
Flow through undetected boreholes	SO-P	NA		
Borehole-induced solution and subsidence	SO-C	SO-C		
Borehole-induced mineralization	SO-C	SO-C		
Borehole-induced geochemical changes	UP	DP	SO-C for units other than the Culebra	
Excavation-induced flow			Classification distinguishes the time when excavation occurs.	SCR.3.3.2
Changes in groundwater flow due to mining	UP	DP	UP for mining outside the controlled area. DP for mining inside the controlled area.	
Changes in geochemistry due to mining	SO-C	SO-R		
Explosion-induced flow				SCR.3.3.3
Changes in groundwater flow due to explosions	SO-C	SO-R		
GEOMORPHOLOGICAL EPs				SCR.3.4
Land use and disturbances				SCR.3.4.1
Land use changes	SO-R	SO-R		
Surface disruptions	SO-C	SO-R		
SURFACE HYDROLOGICAL EPs				SCR.3.5
Water control and use				SCR.3.5.1
Damming of streams or rivers	SO-C	SO-R		
Reservoirs	SO-C	SO-R		
Irrigation	SO-C	SO-R		
Lake usage	SO-R	SO-R		
Altered soil or surface water chemistry by human activities	SO-C	SO-R		
CLIMATIC EPs				SCR.3.6
Anthropogenic climate change				SCR.3.6.1

Table SCR-3. Human-Initiated EPs and Their Screening Classifications (Continued)

Events and Processes (EPs)	Screening Classification Historical/ Ongoing/ Near Future	Future	Comments	Appendix SCR Section
Greenhouse gas effects	SO-R	SO-R		
Acid rain	SO-R	SO-R		
Damage to the ozone layer	SO-R	SO-R		
MARINE EPs				SCR.3.7
Marine activities				SCR.3.7.1
Coastal water use	SO-R	SO-R		
Sea water use	SO-R	SO-R		
Estuarine water use	SO-R	SO-R		
ECOLOGICAL EPs				SCR.3.8
Agricultural activities				SCR.3.8.1
Arable farming	SO-C	SO-R		
Ranching	SO-C	SO-R		
Fish farming	SO-R	SO-R		
Social and technological developments				SCR.3.8.2
Demographic change and urban development	SO-R	SO-R		
Loss of records	NA	DP		

Legend:

UP FEPs accounted for in the assessment calculations for undisturbed performance for 40 CFR § 191.13 (as well as 40 CFR § 191.15 and Subpart C of 40 CFR Part 191).

DP FEPs accounted for (in addition to all UP FEPs) in the assessment calculations for disturbed performance for 40 CFR § 191.13.

SO-R FEPs eliminated from performance assessment calculations on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.

SO-C FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of consequence.

SO-P FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of low probability of occurrence.

assessments and performance assessments[3] "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared." The scope of compliance assessments and performance assessments, with respect to the consideration of human-initiated EPs, is discussed in the following subsections.

[3] The analyses conducted to determine compliance with 40 CFR §191.15 and Subpart C of 40 CFR Part 191 are defined in 40 CFR §194.2 as "compliance assessments." "Performance assessments" (defined in 40 CFR §191.12) are required to determine compliance with the Containment Requirements in 40 CFR §191.13.

SCR.3.1.1 Scope of Compliance Assessments

Compliance assessments need only consider the undisturbed performance of the disposal system (as stated in 40 CFR § 191.15(a) and 40 CFR § 191.24(a)(1)). "Undisturbed performance" is defined in 40 CFR § 191.12 as "...the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events." The scope of compliance assessments is clarified further with respect to human-initiated EPs in 40 CFR § 194.54(b), which states that

> Compliance assessments of undisturbed performance shall include the effects on the disposal system of: (1) Existing boreholes in the vicinity of the disposal system, with attention to the pathways they provide for migration of radionuclides from the site; and (2) Any activities that occur in the vicinity of the disposal system prior to or soon after disposal. Such activities shall include, but shall not be limited to: Existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities.

The DOE assumes that "the vicinity of the disposal system" is a region outside and adjacent to the controlled area that extends far enough to include any activities that can affect the disposal system. Assessments of undisturbed performance must include consideration of human-initiated EPs relating to activities that have taken place or are reasonably expected to take place in the vicinity of the disposal system in the near future.

SCR.3.1.2 Scope of Performance Assessments

Assessments of compliance with the Containment Requirements in 40 CFR § 191.13 require consideration of "all significant processes and events," including human-initiated EPs. The scope of performance assessments is clarified with respect to human-initiated EPs in 40 CFR § 194.32. At 40 CFR § 194.32(a) the EPA states that

> Performance assessments shall consider natural processes and events, mining, deep drilling, and shallow drilling that may affect the disposal system during the regulatory time frame.

Thus, performance assessments must include consideration of human-initiated EPs relating to mining and drilling activities that might take place during the regulatory time frame. In particular, performance assessments must consider the potential effects of such activities that might take place within the controlled area at a time when institutional controls cannot be assumed to eliminate completely the possibility of human intrusion.

In implementing the Assurance Requirements (40 CFR § 191.14), the EPA has provided criteria relating to the effectiveness of institutional controls. With respect to active institutional controls, 40 CFR § 194.41(b) states that

> Performance assessments shall not consider any contributions from active institutional controls for more than 100 years after disposal.

The DOE assumes credit for active institutional controls, such that no human intrusion will take place within the controlled area for 100 years after disposal. However, consistent with 40 CFR § 194.41(b), the DOE assumes no credit in performance assessments for active institutional controls for more than 100 years after disposal.

Criteria concerning the credit that can be used for passive institutional controls in reducing the likelihood of future human intrusion are provided in 40 CFR § 194.43(c):

> The Administrator may allow the Department to assume passive institutional control credit, in the form of reduced likelihood of human intrusion, if the Department demonstrates in the compliance application that such credit is justified because the passive institutional controls are expected to endure and be understood by potential intruders for the time period approved by the Administrator. Such credit, or a smaller credit as determined by the Administrator, cannot be used for more than several hundred years and may decrease over time. In no case, however, shall passive institutional controls be assumed to eliminate the likelihood of human intrusion entirely.

The preamble to 40 CFR Part 194 clarifies that in performance assessments "the likelihood of mining may be decreased by passive institutional controls and active institutional controls, to the extent that can be justified in the compliance application and to a degree identical to that assumed for drilling." The preamble also limits any credit for passive institutional controls in deterring human intrusion to 700 years after disposal. For performance assessment calculations, passive institutional controls are assumed to be 99 percent effective for the period of time from 100 years to 700 years after disposal, as discussed in Section 6.4.12.1. Thus, the rates of future drilling and mining for the duration of this 600-year period are assumed to be 1 percent of the predicted rates of drilling and mining after 700 years.

Further criteria concerning the scope of performance assessments are provided at 40 CFR § 194.32(c):

> Performance assessments shall include an analysis of the effects on the disposal system of any activities that occur in the vicinity of the disposal system prior to disposal and are expected to occur in the vicinity of the disposal system soon after disposal. Such activities shall include, but shall not be limited to, existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities.

Performance assessments must include consideration of all human-initiated EPs relating to activities that have taken place or are reasonably expected to take place in the vicinity of the disposal system in the near future.

SCR.3.1.3 Categorization of Human Activities

In order to implement the criteria in 40 CFR Part 194 relating to the scope of compliance assessments and performance assessments, three categories of human activities have been defined. Distinctions are made between (1) human activities that are currently taking place

and those that took place prior to the time of the compliance application, (2) human activities that might be initiated in the near future after submission of the compliance application, and (3) human activities that might be initiated after repository closure. The first two categories of EPs are considered under undisturbed performance, and EPs in the third category lead to disturbed performance conditions.

SCR.3.1.3.1 Historical, Current, and Near-Future Human Activities

Historical and current human activities include all types of resource extraction activities that have historically taken place and are currently taking place outside the controlled area. These activities are of potential significance insofar as they could affect the geological, hydrological, or geochemical characteristics of the disposal system or groundwater flow pathways outside the disposal system. Current human activities taking place within the controlled area are essentially those associated with development of the WIPP repository, which are considered in Section SCR.2. The observational data obtained as part of WIPP site characterization reflect any effects of historical and current human activities in the vicinity of the WIPP, such as groundwater extraction and oil and gas production. However, such human activities have resulted only in minor disturbances to the hydrological and geochemical conditions within the controlled area, that will have no significant effects on the long-term performance of the disposal system.

Near-future human activities include resource extraction activities that may be expected to occur outside the controlled area based on existing plans and leases. Such activities are of potential significance insofar as they could affect the geological, hydrological, or geochemical characteristics of the disposal system or groundwater flow pathways outside the disposal system. The only human activities that are expected to occur within the controlled area in the near future are those associated with development of the WIPP repository, which are considered in Section SCR.2. In order to bound the analysis of the effects of human activities outside the controlled area, the DOE assumes that any activity that is expected to be initiated in the near future, based on existing plans and leases, will be initiated prior to repository closure. Activities initiated prior to repository closure are assumed to continue until their completion, potentially at some time after disposal.

Compliance assessments (in order to satisfy the criteria in 40 CFR § 194.54(b)) and performance assessments (in order to satisfy the criteria in 40 CFR § 194.32(c)) must consider the potential effects of historical, current, and near-future human activities on the performance of the disposal system. Historical, current, and near-future human-initiated EPs and their screening classification are summarized in Table SCR-3.

SCR.3.1.3.2 Future Human Activities

Future human activities include activities that might be initiated within or outside the controlled area after repository closure. Performance assessments, but not compliance assessments, must consider the effects of future human activities on the performance of the

disposal system. The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a), which limit the scope of consideration of future human activities in performance assessments to mining and drilling. Mining and drilling could occur within the disposal system at a time when institutional controls cannot be assumed to eliminate completely the possibility of such activities. Thus, mining and drilling may occur within the controlled area after the end of the period of active institutional control (100 years after disposal). Future human activities could potentially influence the transport of contaminants within and outside the disposal system, by resulting in direct removal of waste from the disposal system or alteration of the geological, hydrological, or geochemical characteristics of the disposal system. Future human-initiated EPs and their screening classification are summarized in Table SCR-3.

SCR.3.1.3.2.1 Criteria Concerning Future Mining

The EPA provides additional criteria concerning the type of future mining that should be considered by the DOE in 40 CFR § 194.32(b):

> Assessments of mining effects may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system from excavation mining for natural resources. Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame. Performance assessments shall assume that mineral deposits of those resources, similar in quality and type to those resources currently extracted from the Delaware Basin, will be completely removed from the controlled area during the century in which such mining is randomly calculated to occur. Complete removal of such mineral resources shall be assumed to occur only once during the regulatory time frame.

Thus, consideration of future mining may be limited to mining within the disposal system at the locations of resources that are similar in quality and type to those currently extracted from the Delaware Basin.

SCR.3.1.3.2.2 Criteria Concerning Future Drilling

With respect to consideration of future drilling, in the preamble to 40 CFR Part 194, the EPA "reasoned that while the resources drilled for today may not be the same as those drilled for in the future, the present rates at which these boreholes are drilled can nonetheless provide an estimate of the future rate at which boreholes will be drilled." Criteria concerning the consideration of future deep and shallow drilling[4] in performance assessments are provided in 40 CFR § 194.33. These criteria state that, to calculate future drilling rates, the DOE should examine the historical rate of drilling for resources in the Delaware Basin. Historical drilling for purposes other than resource recovery (such as WIPP site investigation) need not be considered in determining future drilling rates.

[4] In 40 CFR §194.2, deep drilling is defined as "drilling events in the Delaware Basin that reach or exceed a depth of 2,150 feet below the surface relative to where such drilling occurs" and shallow drilling is defined as "drilling events in the Delaware Basin that do not reach a depth of 2,150 feet below the surface relative to where such drilling occurred."

In particular, in calculating the frequency of future deep drilling, 40 CFR § 194.33(b)(3)(i) states that the DOE should

> Identify deep drilling that has occurred for each resource in the Delaware Basin over the past 100 years prior to the time at which a compliance application is prepared.

and, in calculating the frequency of future shallow drilling, 40 CFR § 194.33(b)(4)(i) requires that the DOE should

> Identify shallow drilling that has occurred for each resource in the Delaware Basin over the past 100 years prior to the time at which a compliance application is prepared.

An additional criterion with respect to the calculation of future shallow drilling rates is provided in 40 CFR § 194.33(b)(4)(iii):

> In considering the historical rate of all shallow drilling, the Department may, if justified, consider only the historical rate of shallow drilling for resources of similar type and quality to those in the controlled area.

As an example of the use of the criterion in 40 CFR § 194.33(b)(4)(iii), the EPA states in the Supplementary Information to 40 CFR Part 194 that "if only non-potable water can be found within the controlled area, then the rate of drilling for water may be set equal to the historical rate of drilling for non-potable water in the Delaware Basin over the past 100 years." Thus, the DOE may estimate the rate of future shallow drilling within the controlled area based on a determination of the potential resources in the controlled area.

The EPA also provides criteria in 40 CFR § 194.33(d) concerning the use of future boreholes subsequent to drilling:

> With respect to future drilling events, performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of the borehole.

Thus, performance assessments need not consider the effects of techniques used for resource extraction and recovery that would occur subsequent to the drilling of a future borehole.

The EPA provides additional criteria that limit the severity of human intrusion scenarios that must be considered in performance assessments. In 40 CFR § 194.33(b)(1), the EPA states that

> Inadvertent and intermittent intrusion by drilling for resources (other than those resources provided by the waste in the disposal system or engineered barriers designed to isolate such waste) is the most severe human intrusion scenario.

Thus, human intrusion scenarios involving intentional intrusion into the WIPP excavation, for example, to recover resources, need not be considered in performance assessments.

SCR.3.1.3.3 Summary of Regulatory Requirements

Analyses of undisturbed performance of the disposal system, included in compliance assessments and performance assessments, must consider the potential effects of historical, current, and near-future human activities. For the analyses of undisturbed performance, it is assumed that the human-initiated EPs that can be eliminated from performance assessment calculations on the basis of low probability of occurrence, low consequence, or beneficial consequence can be eliminated from compliance assessment calculations on similar bases.

Performance assessments must also include consideration of future human activities that could lead to disturbed performance conditions, although the scope of consideration of future human activities is limited to mining and drilling. In the following sections, in order to distinguish between undisturbed performance and disturbed performance, separate screening discussions and screening decisions are presented for historical, current, and near-future human-initiated EPs, and for future human-initiated EPs.

SCR.3.2 Geological EPs

The human activities discussed in this section are those that could disrupt the geology of the disposal system, or the geology in the vicinity of the disposal system, resulting in or modifying subsurface pathways for fluid flow. Drilling, excavation activities, and subsurface explosions could create interconnections between hydraulically conductive horizons, alter hydrogeological or geochemical characteristics of the disposal system, or result in direct transport of radionuclides to the accessible environment. In this section, the types of geological activities that need to be considered with regard to potential consequences are defined; the subsurface hydrological and geochemical effects of these activities are considered in Section SCR.3.3.

SCR.3.2.1 Drilling

Drilling associated with geothermal energy production, liquid waste disposal, hydrocarbon storage, archeology, and deliberate intrusion into the excavated repository, has been eliminated from performance assessment calculations on regulatory grounds. The effects of historical, current, and near-future drilling associated with water resources exploration, groundwater exploitation, potash exploration, oil and gas exploration, oil and gas exploitation, enhanced oil and gas recovery, and drilling to explore other resources, has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system (Section SCR.3.3.1). Historical shallow drilling associated with water resources exploration, potash exploration, and groundwater exploitation, is accounted for in calculations to determine the rate of future shallow drilling. Historical deep drilling associated with oil and gas exploration, oil and gas exploitation, enhanced oil and gas recovery, potash exploration, and exploration for other resources (sulfur) is accounted for in calculations to determine the rate of future deep drilling.

This section discusses historical, current, and near-future drilling activities within and outside the controlled area and drilling activities that may take place within or outside the controlled area in the future. Drilling may occur within the controlled area in the future after the end of the period of active institutional control (100 years after disposal). Section SCR.3.3.1 discusses the potential effects on the performance of the disposal system of drilling-induced flow, postdrilling processes (fluid extraction and injection), and flow through abandoned boreholes.

SCR.3.2.1.1 Historical, Current, and Near-Future Human-Initiated EPs

Resource exploration and exploitation are the most common reasons for drilling in the Delaware Basin and are the most likely reasons for drilling in the near future. The WIPP location has been evaluated for the occurrence of natural resources in economic quantities. Powers et al. (1978) (Appendix GCR, Chapter 8) investigated the potential for exploitation of potash, hydrocarbons, caliche, gypsum, salt, uranium, sulfur, and lithium. Also, in 1995, the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) performed a reevaluation of the mineral resources at and within 1 mile (1.6 kilometers) around the WIPP site.

Potash resources in the vicinity of the WIPP are discussed in Section 2.3.1.1. Throughout the Carlsbad Potash District, commercial quantities of potash are restricted to the McNutt, which forms part of the Salado above the repository horizon. **Potash exploration** and evaluation boreholes have been drilled within and outside the controlled area.

Drilling associated with **oil and gas exploration** and **oil and gas exploitation** currently takes place in the vicinity of the WIPP (see Section 2.3.1.2). For example, gas is extracted from reservoirs in the Morrow Formation, some 14,000 feet (4,200 meters) below the surface, and oil is extracted from shallower units within the Delaware Mountain Group, some 7,000 to 8,000 feet (2,150 to 2,450 meters) below the surface. Three wells were drilled for oil and gas in the controlled area prior to the LWA of 1992. One of the three wells was drilled directionally from outside the controlled area.

Secondary and tertiary oil and gas production techniques can involve the drilling of additional wells for the injection of fluid to enhance recovery. As indicated by the NMBMMR (1995), secondary production (waterflooding) is employed in the Delaware Basin, the nearest location to the WIPP site being approximately 2 miles (3 kilometers) from the outer boundary of the controlled area. Drilling associated with **enhanced oil and gas recovery** is expected to continue in the near future.

Of the **other resources** investigated by Powers et al. (1978) (Appendix GCR, Chapter 8), the extraction of caliche, gypsum, salt, and lithium is not economically viable in the vicinity of the WIPP because of the widespread occurrence of more easily accessible deposits elsewhere in the region. Uranium is not present in economic quantities near the WIPP site, and no sulfur deposits were identified in the northern Delaware Basin.

Water is currently extracted from formations above the Salado, as discussed in Section 2.3.1.3. The distribution of groundwater wells in the Delaware Basin is included in Appendix USDW (Section USDW.3). **Water resources exploration** and **groundwater exploitation** are expected to continue in the Delaware Basin.

The only other drilling that has taken place or is expected to take place in the near future within or outside the controlled area is drilling associated with WIPP site investigations, which is discussed in Section SCR.2.3.8.2. **Geothermal** energy is not considered to be a potentially exploitable resource because economically attractive geothermal conditions do not exist in the northern Delaware Basin. Oil and gas production byproducts are disposed of underground in the WIPP region, but such **liquid waste disposal** does not involve drilling of additional boreholes. **Hydrocarbon storage** takes place in the Delaware Basin, but it involves gas injection through existing boreholes into depleted reservoirs (see, for example, Burton et al. 1993, 66 – 67). **Archeological investigations** in the WIPP area have involved only minor surface disturbances and have not involved drilling (see Section 2.3.2.3).

In summary, drilling associated with water resources exploration, groundwater exploitation, potash exploration, oil and gas exploration, oil and gas exploitation, enhanced oil and gas recovery, and drilling to explore other resources has taken place and is expected to continue in the Delaware Basin. The potential effects of existing and possible near-future boreholes on fluid flow and radionuclide transport within the disposal system are discussed in Section SCR.3.3.1, where low consequence screening arguments are provided. No drilling associated with geothermal energy production, liquid waste disposal, hydrocarbon storage, and archeology has taken place in the Delaware Basin. Consistent with the future states assumptions in 40 CFR § 194.25(a), such drilling activities have been eliminated from performance assessment calculations on regulatory grounds. Also, consistent with 40 CFR § 194.33(b)(1), all near-future human-initiated EPs relating to **deliberate drilling intrusion** into the WIPP excavation have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.2.1.2 *Future Human-Initiated EPs*

Criteria in 40 CFR § 194.33 require that, to calculate the rates of future shallow and deep drilling in the Delaware Basin, the DOE should examine the historical rate of drilling for resources in the Delaware Basin.

Shallow drilling associated with water, potash, sulfur, oil, and gas extraction has taken place in the Delaware Basin over the past 100 years. However, of these resources, only water and potash are present at shallow depths (less than 2,150 feet [655 meters] below the surface) within the controlled area. Thus, consistent with 40 CFR § 194.33(b)(4), the DOE has used the historical record of shallow drilling associated with **water resources exploration**, **potash exploration**, and **groundwater exploitation**, in calculations to determine the rate of future shallow drilling in the Delaware Basin (see Appendix DEL, Section DEL.7.4).

Oil and gas are the only known resources below the repository horizon that have been exploited over the past 100 years in the Delaware Basin. However, some potash and sulfur exploration boreholes have been drilled in the Delaware Basin to depths in excess of 2,150 feet (655 meters) below the surface relative to where the drilling occurred. Thus, consistent with 40 CFR § 194.33(b)(3)(i), the DOE has used the historical record of deep drilling associated with **oil and gas exploration**, **oil and gas exploitation**, **enhanced oil and gas recovery**, **potash exploration**, and drilling associated with **other resources** (sulfur exploration), in the Delaware Basin in calculations to determine the rate of future deep drilling in the Delaware Basin (see Appendix DEL, Section DEL.7.4).

Consistent with 40 CFR § 194.33 and the future states assumptions in 40 CFR § 194.25(a), drilling for purposes other than resource recovery (such as WIPP site investigation), and drilling activities that have not taken place in the Delaware Basin over the past 100 years, need not be considered in determining future drilling rates. Thus, drilling associated with **geothermal** energy production, **liquid waste disposal**, **hydrocarbon storage**, and **archeological investigations** has been eliminated from performance assessment calculations on regulatory grounds. Furthermore, consistent with 40 CFR §194.33(b)(1), all future human-initiated EPs relating to **deliberate drilling intrusion** into the WIPP excavation have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.2.2 Excavation Activities

Tunnelling and construction of underground facilities (for example, storage, disposal, accommodation) have been eliminated from performance assessment calculations on regulatory grounds. Historical, current, and near-future mining other than for potash and archeological excavations, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Future mining other than for potash, future archeological excavations, and deliberate mining intrusion into the disposal system have been eliminated from performance assessment calculations on regulatory grounds. The effects of historical, current, near-future, and future potash mining are accounted for in performance assessment calculations (Section SCR.3.3.2).

This section discusses historical, current and expected near-future excavation activities outside the controlled area, and excavation activities that may take place within or outside the controlled area in the future. Excavation may take place within the controlled area in the future after the end of the period of active institutional control (100 years after disposal). Section SCR.3.3.2 discusses the potential effects of excavations on the performance of the disposal system.

SCR.3.2.2.1 Historical, Current, and Near-Future Human-Initiated EPs

Excavation activities that can cause underground disturbances include mining, tunnelling, construction of underground storage or disposal facilities, and archeological investigations.

Potash is the only known economically viable resource in the vicinity of the WIPP that is recovered by underground mining (see Section 2.3.1). Potash is mined extensively in the region east of Carlsbad and up to 3.1 miles (5 kilometers) from the boundaries of the controlled area. According to existing plans and leases (see Chapter 2.0, Section 2.3.1.1), **potash mining** is expected to continue in the vicinity of the WIPP in the near future. The DOE assumes that all economically recoverable potash in the vicinity of the disposal system will be extracted in the near future. Excavation for **other resources** does take place elsewhere in the Delaware Basin. In numerous areas, sand, gravel, and caliche are produced, but in all cases, these are surface quarries that are generally shallow (tens of feet).

No **construction of underground facilities (for example, storage, disposal, accommodation [that is, dwellings])** or **tunnelling** has taken place in the Delaware Basin. Gas storage does take place in the Delaware Basin, but it involves injection through boreholes into depleted reservoirs, and not excavation (see, for example, Burton et al. 1993, 66 – 67). **Archeological excavations** in the WIPP area have involved only minor surface disturbances (see Section 2.3.2.3). The only other excavation activities that have taken place in the Delaware Basin are those associated with the construction of the WIPP repository; FEPs associated with the WIPP excavation are discussed in Section SCR.2.

In summary, potash mining is currently taking place and is expected to continue in the vicinity of the WIPP in the near future. The potential effects of historical, current, and near-future potash mining are discussed in Section SCR.3.3.2, and are accounted for in performance assessment calculations. Excavation for resources other than potash and archeological excavations have taken place or are currently taking place in the Delaware Basin. These activities have not altered the geology of the controlled area significantly, and have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Tunnelling and construction of underground facilities have not taken place in the Delaware Basin. Consistent with the future states assumptions in 40 CFR § 194.25(a), such excavation activities have been eliminated from performance assessment calculations on regulatory grounds. Also, consistent with 40 CFR § 194.33(b)(1), all near-future human-initiated EPs relating to **deliberate mining intrusion** into the WIPP excavation have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.2.2.2 *Future Human-Initiated EPs*

According to 40 CFR § 194.32(b), consideration of future mining may be limited to mining within the disposal system at the locations of resources that are similar in quality and type to those currently extracted from the Delaware Basin. Potash is the only resource that has been identified within the controlled area in quality similar to that currently mined elsewhere in the Delaware Basin. Future mining for **other resources** has been eliminated from performance assessment calculations on regulatory grounds. Within the controlled area, the McNutt, which forms part of the Salado above the repository horizon, provides the only potash of appropriate quality. The extent of possible future **potash mining** within the controlled area (occurring

when active institutional controls are ineffective) is discussed in Section 2.3.1.1. The potential effects of future potash mining are discussed in Section SCR.3.3.2, and are accounted for in performance assessment calculations.

Consistent with the future states assumptions in 40 CFR § 194.25(a), excavation activities that have not taken place in the Delaware Basin over the past 100 years need not be included in consideration of future human activities. Thus, **tunnelling**, and **construction of underground facilities (for example, storage, disposal, accommodation)** have been eliminated from performance assessment calculations on regulatory grounds. Also, consistent with 40 CFR § 194.32(a), which limits the scope of consideration of future human actions to mining and drilling, future **archeological excavations** have been eliminated from performance assessment calculations on regulatory grounds. Furthermore, consistent with 40 CFR § 194.33(b)(1), all future human-initiated EPs relating to **deliberate mining intrusion** into the WIPP excavation have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.2.3 Subsurface Explosions

This section discusses subsurface explosions associated with **resource recovery** and **underground nuclear device testing** that may result in pathways for fluid flow between hydraulically conductive horizons. The potential effects of explosions on the hydrological characteristics of the disposal system are discussed in Section SCR.3.3.3.

SCR.3.2.3.1 Resource Recovery

Historical underground explosions for resource recovery have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Future underground explosions for resource recovery have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.2.3.1.1 Historical, Current, and Near-Future Human-Initiated EPs

Neither small-scale nor regional-scale explosive techniques to enhance formation hydraulic conductivity form a part of current mainstream oil- and gas-production technology. Instead, controlled perforating and hydrofracturing are used to improve the performance of oil and gas boreholes in the Delaware Basin. However, small-scale explosions have been used in the past to fracture oil- and natural-gas-bearing units to enhance resource recovery. The size of explosion used to fracture an oil- or gas-bearing unit is limited by the need to contain the damage within the unit being exploited. In the area surrounding the WIPP, the stratigraphic units with oil and gas resources are too deep for explosions to affect the performance of the disposal system. Thus, the effects of **explosions for resource recovery** have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.3.2.3.1.2 Future Human-Initiated EPs

Consistent with 40 CFR § 194.33(d), performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. Therefore, future underground **explosions for resource recovery** have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.2.3.2 Underground Nuclear Device Testing

Historical underground nuclear device testing has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Future underground nuclear device testing has been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.2.3.2.1 Historical, Current, and Near-Future Human-Initiated EPs

The Delaware Basin has been used for an isolated nuclear test. This test, Project Gnome (Rawson et al. 1965, 5, 8, 35), took place in 1961 at a location approximately 8 miles (13 kilometers) southwest of the WIPP waste disposal region. Project Gnome was decommissioned in 1979.

The primary objective of Project Gnome was to study the effects of an underground nuclear explosion in salt. The Gnome experiment involved the detonation of a 3.1 kiloton nuclear device at a depth of 1,190 feet (360 meters) in the bedded salt of the Salado. The explosion created an approximately spherical cavity of about 950,000 cubic feet (27,000 cubic meters) and caused surface displacements in a radius of 1,180 feet (360 meters). No earth tremors perceptible to humans were reported at distances over 25 miles (40 kilometers) from the explosion. A zone of increased permeability was observed to extend at least 150 feet (46 meters) laterally from, and 344 feet (105 meters) above, the point of the explosion. The test had no significant effects on the geological characteristics of the WIPP disposal system. Thus, historical **underground nuclear device testing** has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. There are no existing plans for underground nuclear device testing in the vicinity of the WIPP in the near future.

SCR.3.2.3.2.2 Future Human-Initiated EPs

The criterion in 40 CFR § 194.32(a), relating to the scope of performance assessments, limits the consideration of future human actions to mining and drilling. Therefore, future **underground nuclear device testing** has been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.3 Subsurface Hydrological and Geochemical EPs

The human-initiated EPs considered in this section relate to the potential subsurface hydrological and geochemical effects of the activities involving drilling, excavation, and subsurface explosions, discussed in Section SCR.3.2. The discussion here is limited to those human activities not eliminated from performance assessment calculations on regulatory grounds in Section SCR.3.2.

SCR.3.3.1 Borehole Fluid Flow

Borehole fluid flow during drilling, fluid extraction and injection through boreholes, and flow through abandoned boreholes could result in hydrological or geochemical disturbances of the disposal system and could affect radionuclide transport.

SCR.3.3.1.1 Drilling-Induced Flow

Drilling fluid flow, drilling fluid loss, and blowouts associated with historical, current, near-future, and future boreholes that do not intersect the waste disposal region, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The possibility of a future deep borehole penetrating a waste panel, such that drilling-induced flow results in transport of radionuclides to the land surface or to overlying hydraulically conductive units, is accounted for in performance assessment calculations. Drilling fluid loss into waste panels is accounted for in performance assessment calculations. The possibility of a deep borehole penetrating both the waste disposal region and a Castile brine reservoir is accounted for in performance assessment calculations. Geochemical changes that occur within the controlled area as a result of historical, current, near-future, and future drilling-induced flow are accounted for in performance assessment calculations.

Borehole circulation fluid could be lost to thief zones encountered during drilling, or fluid could flow from pressurized zones through the borehole to the land surface (blowout) or to a thief zone. Such drilling-related EPs could influence groundwater flow and, potentially, radionuclide transport in the affected units. Future drilling within the controlled area could result in direct releases of radionuclides to the land surface or transport of radionuclides between hydraulically conductive units.

Movement of brine from a pressurized zone, through a borehole, into potential thief zones such as the Salado interbeds or the Culebra, could result in geochemical changes and altered radionuclide migration rates in these units.

SCR.3.3.1.1.1 Historical, Current, and Near-Future Human-Initiated EPs

As discussed in Section SCR.3.2.1, drilling associated with water resources exploration, groundwater exploitation, potash exploration, oil and gas exploration, oil and gas exploitation,

enhanced oil and gas recovery, and drilling to explore other resources has taken place or is currently taking place outside the controlled area in the Delaware Basin. These drilling activities are expected to continue in the vicinity of the WIPP in the near future.

Hydraulic effects of drilling-induced flow

Drilling fluid flow will not affect hydraulic conditions in the disposal system significantly unless there is substantial **drilling fluid loss** to a thief zone, such as the Culebra. Typically, zones into which significant borehole circulation fluid is lost are isolated through injection of materials to reduce permeability or through casing and cementing programs. Assuming such operations are successful, drilling fluid loss in the near future outside the controlled area will not affect the hydrology of the disposal system significantly.

Naturally occurring brine and gas pockets have been encountered during drilling in the Delaware Basin. Brine pockets have been intersected in the Castile (as discussed in Section 2.2.1.3) and in the Salado above the WIPP horizon (Section 2.2.1.2.2). Gas **blowouts** have occurred during drilling in the Salado. Usually, such events result in brief interruptions in drilling while the intersected fluid pocket is allowed to depressurize through flow to the surface (for a period lasting from a few hours to a few days). Drilling then restarts with an increased drilling mud weight. Under these conditions, blowouts in the near future will cause isolated hydraulic disturbances, but will not affect the hydrology of the disposal system significantly.

Potentially, the most significant disturbance to the disposal system could occur if an uncontrolled blowout during drilling resulted in substantial flow through the borehole from a pressurized zone to a thief zone. For example, if a borehole penetrates a brine reservoir in the Castile, brine could flow through the borehole to the Culebra, and, as a result, could affect hydraulic conditions in the Culebra. The potential effects of such an event can be compared to the effects of long-term fluid flow from deep overpressurized units to the Culebra through abandoned boreholes. Wallace (1996a) analysed the potential effects of flow through abandoned boreholes in the future within the controlled area (as discussed in Section SCR.3.3.1.4.2), and concluded that interconnections between the Culebra and deep units could be eliminated from performance assessment calculations on the basis of low consequence. Long-term flow through abandoned boreholes would have a greater hydrological impact in the Culebra than short-term drilling-induced flow outside the controlled area. Thus, the effects of fluid flow during drilling in the near future have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

In summary, drilling fluid flow, drilling fluid loss, and blowouts associated with historical, current, and near-future boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Geochemical effects of drilling-induced flow

Radionuclide migration rates are governed by the coupled effects of hydrological and geochemical processes, as discussed in Sections SCR.2.6 and SCR.2.7. Human-initiated EPs outside the controlled area could affect the geochemistry of units within the controlled area if they occur sufficiently close to the edge of the controlled area. Movement of brine from a pressurized reservoir in the Castile through a borehole into potential thief zones, such as the Salado interbeds or the Culebra, could cause **drilling-induced geochemical changes** resulting in altered radionuclide migration rates in these units through their effects on colloid transport and sorption (colloid transport may enhance radionuclide migration, while radionuclide migration may be retarded by sorption).

The treatment of colloids in performance assessment calculations is described in Sections 6.4.3.6 and 6.4.6.2.2. The repository and its contents provide the main source of colloids in the disposal system. By comparison, Castile brines have relatively low total colloid concentrations. Therefore, changes in colloid transport in units within the controlled area as a result of historical, current, and near-future drilling-induced flow have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Sorption within the Culebra is accounted for in performance assessment calculations as discussed in Section 6.4.6.2. The sorption model comprises an equilibrium, sorption isotherm approximation, employing distribution coefficients (K_ds) applicable to dolomite in the Culebra (Appendix MASS, Section MASS.15.2). The CDFs of distribution coefficients used (Appendix PAR) are derived from a suite of experimental studies that include measurements of K_ds for actinides in a range of chemical systems including Culebra and Castile brines, Culebra brines, and Salado brines. Therefore, any changes in sorption geochemistry in the Culebra within the controlled area as a result of historical, current, and near-future drilling-induced flow are accounted for in performance assessment calculations.

Sorption within the Dewey Lake is accounted for in performance assessment calculations, as discussed in Section 6.4.6.6. It is assumed that the sorptive capacity of the Dewey Lake is sufficiently large to prevent any radionuclides that enter the Dewey Lake from being released over 10,000 years (Wallace et al. 1995). Sorption within other geological units of the disposal system has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system. The effects of changes in sorption in the Dewey Lake and other units within the controlled area as a result of historical, current, and near-future drilling-induced flow have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.3.3.1.1.2 Future Human-Initiated EPs – Boreholes that Intersect the Waste Disposal Region

The consequences of drilling within the controlled area in the future will primarily depend on the location of the borehole. Potentially, future deep drilling could penetrate the waste disposal region. If the borehole intersects the waste in the disposal rooms, radionuclides could be transported as a result of **drilling fluid flow**: releases to the accessible environment may occur as material entrained in the circulating drilling fluid is brought to the surface (see Section SCR.2.6.3). Also, during drilling, contaminated brine may flow up the borehole and reach the surface, depending on fluid pressure within the waste disposal panels; **blowout** conditions could prevail if the waste panel were sufficiently pressurized at the time of intrusion. Alternatively, hydraulic and geochemical conditions in the waste panel could be affected as a result of **drilling fluid loss** to the panel and **drilling-induced geochemical changes**.

Hydraulic effects of drilling-induced flow

The possibility of a future borehole penetrating a waste panel, so that drilling fluid flow and, potentially, blowout, results in transport of radionuclides to the land surface or to overlying hydraulically conductive units, is accounted for in performance assessment calculations.

The units intersected by the borehole may provide sources for fluid flow (brine, oil, or gas) to the waste panel during drilling. In the vicinity of the WIPP, the Castile that underlies the Salado contains isolated volumes of brine at fluid pressures greater than hydrostatic. A future borehole that penetrates a Castile brine reservoir could provide a connection for brine flow from the reservoir to the waste panel, thus increasing fluid pressure and brine volume in the waste panel. The possibility of a deep borehole penetrating both a waste panel and a brine reservoir is accounted for in performance assessment calculations.

A future borehole that is drilled through a disposal room wall, but does not intersect waste, could penetrate a brine reservoir underlying the waste disposal region. Such an event would depressurize the brine reservoir to some extent, and thus would affect the consequences of any subsequent intersections of the reservoir. The possibility for a borehole to depressurize a brine reservoir underlying the waste disposal region is accounted for in performance assessment calculations.

Penetration of an underpressurized unit underlying the Salado could result in flow and radionuclide transport from the waste panel to the underlying unit during drilling, although drillers would minimize such fluid loss to a thief zone through the injection of materials to reduce permeability or through the use of casing and cementing. Also, the permeabilities of formations underlying the Salado are less than the permeability of the Culebra (Wallace 1996a). Thus, the consequences associated with radionuclide transport to an underpressurized unit below the waste panels during drilling will be less significant, in terms of disposal system performance, than the consequences associated with radionuclide transport to the land surface

or to the Culebra during drilling. Through this comparison, drilling events that result in penetration of underpressurized units below the waste-disposal region have been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

In evaluating the potential consequences of drilling fluid loss to a waste panel, two types of drilling events need to be considered - those that intercept pressurized fluid in underlying formations such as the Castile (defined in Section 6.3.2.2 as E1 events) and those that do not (E2 events). A possible hydrological effect would be to make a greater volume of brine available for gas generation processes and thereby increase gas volumes at particular times in the future. As discussed in Section 6.4.12.6, of boreholes that intersect a waste panel in the future, 8 percent are assumed to be E1 events and 92 percent are E2 events. For either type of drilling event, on the basis of current drilling practices, the driller is assumed to pass through the repository rapidly. Relatively small amounts of drilling fluid loss may not be noticed or may not give rise to concern. Larger fluid losses would lead to the driller injecting materials to reduce permeability, or to the borehole being cased and cemented, to limit the loss of drilling fluid.

For boreholes that intersect pressurized brine reservoirs, the volume of fluid available to flow up a borehole will be significantly greater than the volume of any drilling fluid that could be lost. This greater volume of brine is accounted for in performance assessment calculations, and is allowed to enter the disposal room (see Section 6.4.7). Thus, the effects of drilling fluid loss will be small by comparison to the potential flow of brine from pressurized brine reservoirs. Therefore, the effects of drilling fluid loss for E1 drilling events have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

For boreholes that do not intersect pressurized brine reservoirs the treatment of the disposal room implicitly accounts for the potential for greater gas generation resulting from drilling fluid loss. Thus, the hydrological effects of drilling fluid loss for E2 drilling events are accounted for in performance assessment calculations within the conceptual model of the disposal room for drilling intrusions.

Geochemical effects of drilling-induced flow

Drilling fluid loss to a waste panel could modify the chemistry of disposal room brines in a manner that would affect the solubility of radionuclides and the source term available for subsequent transport from the disposal room. The majority of drilling fluids used are likely to be locally derived, and their bulk chemistry will be similar to fluids currently present in the disposal system. In addition, the presence of the MgO chemical conditioner in the disposal rooms will buffer the chemistry across a range of fluid compositions, as discussed in detail in Appendix SOTERM. Furthermore, for E1 drilling events, the volume of Castile brine that flows into the disposal room will be greater than that of any drilling fluids; Castile brine chemistry is accounted for in performance assessment calculations. Thus, the effects on

radionuclide solubility of drilling fluid loss to the disposal room have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Movement of brine from a pressurized reservoir in the Castile through a borehole into thief zones, such as the Salado interbeds or the Culebra, could result in geochemical changes in the receiving units, and thus alter radionuclide migration rates in these units through their effects on colloid transport and sorption.

The repository and its contents provide the main source of colloids in the disposal system. Thus, colloid transport in the Culebra within the controlled area as a result of drilling-induced flow associated with boreholes that intersect the waste disposal region are accounted for in performance assessment calculations, as described in Sections 6.4.3.6 and 6.4.6.2.1. The Culebra is the most transmissive unit in the disposal system and it is the most likely unit through which significant radionuclide transport could occur. Therefore, colloid transport in units other than the Culebra, as a result of drilling-induced flow associated with boreholes that intersect the waste disposal region, has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

As discussed in Section SCR.3.3.1.1.1, sorption within the Culebra is accounted for in performance assessment calculations. The sorption model used incorporates the effects of changes in sorption in the Culebra as a result of drilling-induced flow associated with boreholes that intersect the waste disposal region.

Consistent with the screening discussion in Section SCR.3.3.1.1.1, the effects of changes in sorption in the Dewey Lake inside the controlled area as a result of drilling-induced flow associated with boreholes that intersect the waste disposal region have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.3.3.1.1.3 Future Human-Initiated EPs – Boreholes that do not Intersect the Waste Disposal Region

Future boreholes that do not intersect the waste disposal region could nevertheless encounter contaminated material by intersecting a region into which radionuclides have migrated from the disposal panels, or could affect hydrogeological conditions within the disposal system. Consistent with the containment requirements in 40 CFR § 191.13(a), performance assessments need not evaluate the effects of the intersection of contaminated material outside the controlled area.

Movement of brine from a pressurized reservoir in the Castile, through a borehole, into thief zones such as the Salado interbeds or the Culebra, could result in **drilling-induced geochemical changes** and altered radionuclide migration rates in these units.

Hydraulic effects of drilling-induced flow

If radionuclides migrate away from the waste disposal panels through the interbeds, then deep drilling could result in the intersection of a contaminated region within the interbeds. Consequently, contaminated drill cuttings or brine could be transported to the land surface through **drilling fluid flow**. Performance assessment calculations show that lateral radionuclide migration through the Salado from the waste disposal region occurs most extensively in the undisturbed performance scenario; in this case radionuclides are transported through MB139. Based on the calculations of undisturbed performance, Economy (1996) determined the maximum quantity of radioactive material that could be transported from the waste disposal region into MB139 during the 10,000 year regulatory period. Economy (1996) calculated the normalized amount of radioactive material that enters MB139 to be approximately 0.13 EPA units; this quantity was derived using an equation similar to that used for determining normalized radionuclide releases to the accessible environment, which is presented as Equation (1) in Chapter 6.0.

The amount of contaminated material in MB139 that could be removed by drilling during the regulatory period depends primarily on the number of deep boreholes expected to be drilled in the unit area of the controlled area in 10,000 years and the cross-sectional area of these boreholes. As discussed in Appendix DEL (Section DEL.7.4), the expected rate of drilling is approximately 47 boreholes per square kilometer per 10,000 years. Based on a borehole diameter of 1.02 feet (0.311 meters), the cross-sectional area of each borehole within the Salado is approximately 0.76 square meters. Thus, in 10,000 years approximately 3.6×10^{-6} of the interbed volume will be removed from the Salado. Conservatively assuming that MB139 within the disposal system is uniformly contaminated for the entire 10,000 years with 0.13 normalized release units, then approximately 3.6×10^{-6} of the 0.13 normalized release units can be removed by drilling directly to the surface. This is approximately 5×10^{-7} normalized release units. This quantity is insignificant. Therefore, releases resulting from the intersection of contaminated material in MB139 are screened out on the basis of low consequence.

Boreholes penetrating a contaminated Culebra can also release radionuclides to the accessible environment. The maximum normalized release of radioactive material to the Culebra in 1996 performance assessment calculations is approximately 18 EPA release units. As discussed in Appendix DEL (Section DEL.7.4), approximately 69 deep and shallow boreholes per 10,000 years are assumed in performance assessment calculations. By the method presented in the previous paragraph, the maximum normalized release from the Culebra by direct drilling through a plume is on the order of 9×10^{-5}. This is insignificant. Therefore, radionuclide releases resulting from intersection of contaminated material in the Culebra have been eliminated from performance assessment calculations on the basis of low consequence.

Future boreholes could affect the hydraulic conditions in the disposal system. As discussed in Section SCR.3.3.1.1.1, intersection of pockets of pressurized gas and brine, and **drilling fluid loss**, are likely to result in short-term, isolated hydraulic disturbances, and will not affect the hydrology of the disposal system significantly. Potentially, the most significant hydraulic disturbance to the disposal system could occur if an uncontrolled **blowout** during drilling resulted in substantial flow through the borehole from a pressurized zone to a thief zone. For example, if a borehole penetrates a brine reservoir in the Castile, brine could flow through the borehole to the Culebra, and, as a result, could affect hydraulic conditions in the Culebra. The potential effects of such an event can be compared to the effects of long-term fluid flow from deep overpressurized units to the Culebra through abandoned boreholes. Wallace (1996a) analyzed the potential effects of such interconnections in the future within the controlled area (as discussed in Section SCR.3.3.1.4.2), and concluded that flow through abandoned boreholes between the Culebra and deep units could be eliminated from performance assessment calculations on the basis of low consequence. Long-term flow through abandoned boreholes would have a greater impact on Culebra hydrology than short-term drilling-induced flow within the controlled area. Thus, the effects of fluid flow during drilling in the future have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

In summary, drilling fluid flow, drilling fluid loss, and blowouts associated with future boreholes that do not intersect the waste disposal region have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Geochemical effects of drilling-induced flow

Movement of brine from a pressurized reservoir in the Castile through a borehole into thief zones, such as the Salado interbeds or the Culebra, could cause geochemical changes resulting in altered radionuclide migration rates in these units through their effects on colloid transport and sorption.

The contents of the waste disposal panels provide the main source of colloids in the disposal system. Thus, consistent with the discussion in Section SCR.3.3.1.1.1, colloid transport as a result of drilling-induced flow associated with future boreholes that do not intersect the waste disposal region has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

As discussed in Section SCR.3.3.1.1.1, sorption within the Culebra is accounted for in performance assessment calculations. The sorption model accounts for the effects of changes in sorption in the Culebra as a result of drilling-induced flow associated with boreholes that do not intersect the waste disposal region.

Consistent with the screening discussion in Section SCR.3.3.1.1.1, the effects of changes in sorption in the Dewey Lake within the controlled area as a result of drilling-induced flow

associated with boreholes that do not intersect the waste disposal region have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

SCR.3.3.1.2 Fluid Extraction

Historical, current, and near-future groundwater, oil, and gas extraction outside the controlled area has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Groundwater, oil, and gas extraction through future boreholes has been eliminated from performance assessment calculations on regulatory grounds.

The extraction of fluid could alter fluid-flow patterns in the target horizons, or in overlying units as a result of a failed borehole casing. Also, the removal of confined fluid from oil- or gas-bearing units can cause compaction in some geologic settings, potentially resulting in subvertical fracturing and surface subsidence.

SCR.3.3.1.2.1 Historical, Current, and Near-Future Human-Initiated EPs

As discussed in Section SCR.3.2.1, water, oil, and gas production are the only activities involving fluid extraction through boreholes that have taken place or are currently taking place in the vicinity of the WIPP. These activities are expected to continue in the vicinity of the WIPP in the near future.

Groundwater extraction outside the controlled area from formations above the Salado could affect groundwater flow. The Dewey Lake contains a productive zone of saturation south of the WIPP site. Several wells operated by the J.C. Mills Ranch south of the WIPP produce water from the Dewey Lake to supply livestock (see Section 2.2.1.4.2.1). Also, water has been extracted from the Culebra at the Engle Well approximately 6 miles south of the controlled area to provide water for livestock. No water wells in other areas in the vicinity of the WIPP are expected to be drilled in the near future because of the high concentrations of total dissolved solids in the groundwater.

If contaminated water intersects a well while it is producing, then contaminants could be pumped to the surface. Consistent with the containment requirements in 40 CFR § 191.13(a), performance assessments need not evaluate radiation doses that might result from such an event. However, compliance assessments must include any such events in dose calculations for evaluating compliance with the individual protection requirements in 40 CFR § 191.15. As discussed in Chapter 8.0, under undisturbed conditions, there are no calculated radionuclide releases to units containing producing wells.

Pumping from wells at the J.C. Mills Ranch may have resulted in reductions in hydraulic head in the Dewey Lake within southern regions of the controlled area, leading to increased hydraulic head gradients. However, these changes in the groundwater flow conditions in the Dewey Lake will have no significant effects on the performance of the disposal system, primarily because of the sorptive capacity of the Dewey Lake (see Section 6.4.6.6). Retardation of any radionuclides that enter the Dewey Lake will be such that no radionuclides will migrate through the Dewey Lake to the accessible environment within the 10,000-year regulatory period.

The effects of groundwater extraction from the Culebra from a well 6 miles south of the controlled area have been evaluated by Wallace (1996b), using an analytical solution for Darcian fluid flow in a continuous porous medium. Wallace (1996b) showed that such a well pumping at about 0.5 gallons per minute for 10,000 years will induce a hydraulic head gradient across the controlled area of about 4×10^{-5}. The hydraulic head gradient across the controlled area currently ranges from between 0.001 to 0.007. Therefore, pumping from the Engle Well will have only minor effects on the hydraulic head gradient within the controlled area even if pumping were to continue for 10,000 years. Thus, the effects of historical, current, and near-future groundwater extraction outside the controlled area have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Oil and gas extraction outside the controlled area could affect the hydrology of the disposal system. However, the horizons that act as oil and gas reservoirs are sufficiently below the repository for changes in fluid-flow patterns to be of low consequence, unless there is fluid leakage through a failed borehole casing. Also, oil and gas production horizons in the Delaware Basin are well-lithified rigid strata, so oil and gas extraction is not likely to result in compaction and subsidence (Brausch et al. 1982, 52, 61). Furthermore, the plasticity of the salt formations in the Delaware Basin will limit the extent of any fracturing caused by compaction of underlying units. Thus, neither the extraction of gas from reservoirs in the Morrow Formation (some 14,000 feet [4,200 meters] below the surface), nor extraction of oil from the shallower units within the Delaware Mountain Group (about 4,000 to 8,000 feet [1,250 to 2,450 meters] below the surface) will lead to compaction and subsidence. In summary, historical, current, and near-future oil and gas extraction outside the controlled area has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.3.3.1.2.2 Future Human-Initiated EPs

Consistent with 40 CFR § 194.33(d), performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. Therefore, **groundwater extraction** and **oil and gas extraction** through future boreholes have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.3.1.3 Fluid Injection

The hydrological effects of historical, current, and near-future fluid injection (liquid waste disposal, enhanced oil and gas production, and hydrocarbon storage) through boreholes outside the controlled area have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Geochemical changes that occur inside the controlled area as a result of fluid flow associated with historical, current and near-future fluid injection are accounted for in performance assessment calculations. Liquid waste disposal, enhanced oil and gas production, and hydrocarbon storage involving future boreholes has been eliminated from performance assessment calculations on regulatory grounds.

The injection of fluids could alter fluid-flow patterns in the target horizons or, if there is accidental leakage through a borehole casing, in any other intersected hydraulically conductive zone. Injection of fluids through a leaking borehole could also result in geochemical changes and altered radionuclide migration rates in the thief units.

SCR.3.3.1.3.1 Historical, Current, and Near-Future Human-Initiated EPs

The only historical and current activities involving fluid injection through boreholes in the Delaware Basin are **enhanced oil and gas production** (waterflooding), **hydrocarbon storage** (gas reinjection), and **liquid waste disposal** (by-products from oil and gas production). These fluid injection activities are expected to continue in the vicinity of the WIPP in the near future.

Hydraulic fracturing of oil- or gas-bearing units is currently used to improve the performance of hydrocarbon reservoirs in the Delaware Basin. Fracturing is induced during a short period of high-pressure fluid injection, resulting in increased hydraulic conductivity near the borehole. Normally, this controlled fracturing is confined to the pay zone and is unlikely to affect overlying strata.

Secondary production techniques, such as waterflooding, that are used to maintain reservoir pressure and displace oil are currently employed in hydrocarbon reservoirs in the Delaware Basin (Brausch et al. 1982, 29 – 30). Reinjection of gas for storage currently takes place in a depleted gas field in the Morrow Formation of the Delaware Basin (Burton et al. 1993, 66 – 67). Similarly, disposal of liquid by-products from oil and gas production involves injection of fluid into depleted reservoirs. Such fluid injection techniques result in repressurization of the depleted target reservoir and mitigates any effects of fluid withdrawal.

The most significant effects of fluid injection would arise from substantial and uncontrolled fluid leakage through a failed borehole casing. The highly saline environment of some units can promote rapid corrosion of well casings and may result in fluid loss from boreholes.

Hydraulic effects of leakage through injection boreholes

The Vacuum field (located in the Capitan Reef, some 20 miles [30 kilometers] northeast of the WIPP site) and the Rhodes-Yates field (located in the back reef of the Capitan, some 45 miles [70 kilometers] southeast of the WIPP site) have been waterflooded for 40 years with confirmed leaking wells, which have resulted in brine entering the Salado and other formations above the Salado (see, for example, Silva 1994, 67-68). Currently, saltwater disposal takes place in the vicinity of the WIPP into formations below the Castile. However, leakages from saltwater disposal wells or waterflood wells in the near future in the vicinity of the WIPP are unlikely to occur because of the following:

- There are significant differences between the geology and lithology in the vicinity of the disposal system and that of the Vacuum and Rhodes-Yates Fields. The WIPP is located in the Delaware Basin in a fore reef environment, where a thick zone of anhydrite and halite (the Castile) exists. In the vicinity of the WIPP, oil is produced from the Brushy Canyon Formation at depths greater than 7,000 feet (2100 meters). By contrast, the Castile is not present at either the Vacuum or the Rhodes-Yates Field, which lie outside the Delaware Basin.[5] Oil production at the Vacuum Field is from the San Andres and Grayburg Formations at depths of approximately 4,500 feet (1400 meters), and oil production at the Rhodes-Yates Field is from the Yates and Seven Rivers Formations at depths of approximately 3,000 feet (900 meters). Waterflooding at the Rhodes-Yates Field involves injection into a zone only 200 feet (60 meters) below the Salado. There are more potential thief zones below the Salado near the WIPP than at the Rhodes-Yates or Vacuum Fields; the Salado in the vicinity of the WIPP is therefore less likely to receive any fluid that leaks from an injection borehole. Additionally, the oil pools in the vicinity of the WIPP are characterized by channel sands with thin net pay zones, low permeabilities, high irreducible water saturations, and high residual oil saturations. Therefore, waterflooding of oil fields in the vicinity of the WIPP on the scale of that undertaken in the Vacuum or the Rhodes-Yates Field is unlikely.

- New Mexico state regulations require the emplacement of a salt isolation casing string for all wells drilled in the potash enclave, which includes the WIPP area, to reduce the possibility of petroleum wells leaking into the Salado. Also, injection pressures are not allowed to exceed the pressure at which the rocks fracture. The injection pressure gradient must be kept below 0.2 pounds per square inch per foot (4.5×10^3 pascals per meter) above hydrostatic if fracture pressures are unknown. Such controls on fluid injection pressures limit the potential magitude of any leakages from injection boreholes.

[5] The Delaware Basin is defined in the preamble to 40 CFR Part 194 to be "those surface and subsurface formations which lie inside the innermost edge of the Capitan Reef."

- Recent improvements in well completion practices and reservoir operations management have reduced the occurrences of leakages from injection wells. For example, injection pressures during waterflooding are typically kept below about one pounds per square inch per foot (23×10^3 pascals per meter) to avoid fracture initiation. Also, wells are currently completed using cemented and perforated casing, rather than the open-hole completions used in the early Rhodes-Yates wells.

Any injection well leakages that do occur in the vicinity of the WIPP in the near future are more likely to be associated with liquid waste disposal than waterflooding. Disposal typically involves fluid injection though old and potentially corroded boreholes and does not include monitoring to the same extent as waterflooding. Such fluid injection could affect the performance of the disposal system if sufficient fluid leaked into the Salado interbeds to affect the rate of brine flow into the waste disposal panels.

Stoelzel and O'Brien (1996) evaluated the potential effects on the disposal system of leakage from a hypothetical salt water disposal borehole near the WIPP. Stoelzel and O'Brien (1996) used the two-dimensional BRAGFLO model (vertical north-south cross-section) to simulate saltwater disposal to the north and to the south of the disposal system. The disposal system model included the waste disposal region, the marker beds and anhydrite intervals near the excavation horizon, and the rock strata associated with local oil and gas developments. A worst case simulation was run using high values of borehole and anhydrite permeability and a low value of halite permeability to encourage flow to the disposal panels via the anhydrite. Also, the boreholes were assumed to be plugged immediately above the Salado (consistent with the plugging configurations described in Section 6.4.7.2). Values of key parameters for this simulation are shown in Table SCR-4.

Saltwater disposal into the Upper Bell Canyon was simulated, with annular leakage through the Salado. A total of approximately 7×10^5 cubic meters of brine was injected through the boreholes during a 50-year simulated disposal period. In this time, approximately 50 cubic meters of brine entered the anhydrite interval at the horizon of the waste disposal region. For the next 200 years the boreholes were assumed to be abandoned (with open-hole permeabilities of 1×10^{-9} square meters). Cement plugs (of permeability 10^{-17} cubic meters) were assumed to be placed at the injection interval and at the top of the Salado. Subsequently, the boreholes were prescribed the permeability of silty sand (see Section 6.4.7.2), and the simulation was continued until the end of the 10,000-year regulatory period. During this period, approximately 400 cubic meters of brine entered the waste disposal region from the anhydrite interval. This value of cumulative brine inflow is within the bounds of the values generated by performance assessment calculations for the undisturbed scenario. During the disposal well simulation, leakage from the injection boreholes is likely to have had no significant effect on the inflow rate at the waste panels.

Thus, the hydraulic effects of leakage through historical, current, and near-future boreholes outside the controlled area have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Table SCR-4. Parameters and Values Used in Screening the Effects of Water Flooding

Parameter	Value
Halite permeability	1.8×10^{-25} square meters
Anhydrite permeability	7.9×10^{-18} square meters
Effective permeability of leaking borehole	1.0×10^{-11} square meters
Injection depth	4,260 feet (1,300 meters)
Bottomhole injection pressure	3.3×10^{3} pounds per square inch (23×10^{6} pascals)
Injection pressure gradient	0.78 pounds per square inch per foot (1.8×10^{4} pascals per meter)

Effects of density changes resulting from leakage through injection boreholes

Leakage through a failed borehole casing during a fluid injection operation in the vicinity of the WIPP could alter fluid density in the affected unit, which could result in changes in fluid flow rates and directions within the disposal system. Disposal of oil and gas production by-products through boreholes could increase fluid densities in transmissive units affected by leakage in the casing. Operations such as waterflooding use fluids derived from the target reservoir, or fluids with a similar composition, to avoid scaling and other reactions. Therefore, the effects of leakage from waterflood boreholes would be similar to leakage from disposal wells.

Denser fluids have a tendency to sink relative to less dense fluids, and, if the hydrogeological unit concerned has a dip, there will be a tendency for the dense fluid to travel in the downdip direction. If this direction is the same as the direction of the groundwater pressure gradient, there would be an increase in flow velocity, and conversely, if the downdip direction is opposed to the direction of the groundwater pressure gradient, there would be a decrease in flow velocity. In general terms, taking account of density-related flow will cause a rotation of the flow vector towards the downdip direction that is dependent on the density contrast and the dip.

Wilmot and Galson (1996) showed that brine density changes in the Culebra resulting from leakage through an injection borehole outside the controlled area will not affect fluid flow in the Culebra significantly. Potash mining activities assumed on the basis of regulatory criteria to occur in the near future outside the controlled area will have a more significant effect on modeled Culebra hydrology. The distribution of existing leases suggests that near-future mining will take place to the north, west, and south of the controlled area (see Section 2.3.1.1). The effects of such potash mining are accounted for in calculations of undisturbed performance of the disposal system (through an increase in the transmissivity of the Culebra above the mined region, as discussed in Section SCR.3.3.2). Groundwater modeling that

accounts for potash mining shows a change in the fluid pressure distribution, and a consequent shift of flow directions towards the west in the Culebra within the controlled area (Wallace 1996c). A localized increase in fluid density in the Culebra resulting from leakage from an injection borehole would rotate the flow vector towards the downdip direction (towards the east).

Wilmot and Galson (1996) compared the relative magnitudes of the freshwater head gradient and the gravitational gradient and showed that the density effect is of low consequence to the performance of the disposal system. According to Darcy's Law, flow in an isotropic porous medium is governed by the gradient of fluid pressure and a gravitational term

$$\bar{v} = -\frac{k}{\mu}[\nabla p - \rho\bar{g}] ,$$

where

$\bar{v}$	=	Darcy velocity vector	(m s^{-1})
k	=	intrinsic permeability	(m^2)
μ	=	fluid viscosity	(pa s)
∇p	=	gradient of fluid pressure	(pa m^{-1})
ρ	=	fluid density	(kg m^{-3})
$\bar{g}$	=	gravitational acceleration vector	(m s^{-2})

The relationship between the gravity-driven flow component and the pressure-driven component can be shown by expressing the velocity vector in terms of a freshwater head gradient and a density-related elevation gradient

$$\bar{v} = -K\,[\nabla H_f + \frac{\Delta\rho}{\rho_f}\nabla E] ,$$

where

K	=	hydraulic conductivity	(m s^{-1})
∇H_f	=	gradient of freshwater head	
$\Delta\rho$	=	difference between actual fluid density and reference fluid density	(kg m^{-3})
ρ_f	=	density of freshwater	(kg m^{-3})
∇E	=	gradient of elevation	

Davies (1989, 28) defined a driving force ratio (DFR) to assess the potential significance of the density gradient

$$DFR = \frac{\Delta\rho\,|\nabla E|}{\rho_f\,|\nabla H_f|}$$

and concluded that a DFR of 0.5 can be considered an approximate threshold at which density-related gravity effects may become significant (Davies 1989, 28).

The dip of the Culebra in the vicinity of the WIPP is about 0.44° or 8 meters per kilometer to the east (Davies 1989, 42). According to Davies (1989, 47 – 48), freshwater head gradients in the Culebra between the waste panels and the southwestern and western boundaries of the accessible environment range from 4 meters per kilometer to 7 meters per kilometer, with only small changes in gradient arising from the calculated effects of near-future mining. Culebra brines have densities ranging from 1,050 to 1,100 kilograms per cubic meter (Davies 1989, 32). Assuming the density of fluid leaking from a waterflood borehole or a disposal well to be 1,215 kilograms per cubic meter (a conservative high value similar to the density of Castile brine [Popielak et al. 1983, Table C-2]), leads to a DFR of between 0.13 and 0.38. These values of the DFR show that density-related effects caused by leakage of brine into the Culebra during fluid injection operations are not significant.

In summary, the effects of historical, current, and near-future fluid injection (liquid waste disposal, enhanced oil and gas production, and hydrocarbon storage) through boreholes outside the controlled area have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Geochemical effects of leakage through injection boreholes

Injection of fluids through a leaking borehole could affect the geochemical conditions in thief zones, such as the Salado interbeds or the Culebra. Such **fluid injection-induced geochemical changes** could alter radionuclide migration rates within the disposal system in the affected units if they occur sufficiently close to the edge of the controlled area through their effects on colloid transport and sorption.

The majority of fluids injected (for example, during brine disposal) have been extracted locally during production activities. Because they have been derived locally, their compositions are similar to fluids currently present in the disposal system, and they will have low total colloid concentrations compared to those in the waste disposal panels (see Section SCR.3.3.1.1.1). The repository will remain the main source of colloids in the disposal system. Therefore, colloid transport as a result of historical, current, and near-future fluid injection has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

As discussed in Section SCR.3.3.1.1.1, sorption within the Culebra is accounted for in performance assessment calculations. The sorption model used accounts for the effects of any changes in sorption in the Culebra as a result of leakage through historical, current, and near-future injection boreholes.

Consistent with the screening discussion in Section SCR.3.3.1.1.1, the effects of changes in sorption in the Dewey Lake within the controlled area as a result of leakage through historical,

current, and near-future injection boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

Nonlocally derived fluids could be used during hydraulic fracturing operations. However, such fluid injection operations would be carefully controlled to minimize leakage to thief zones. Therefore, any potential geochemical effects of such leakages have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.3.3.1.3.2 Future Human-Initiated EPs

Consistent with 40 CFR § 194.33(d), performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. **Liquid waste disposal** (by-products from oil and gas production), **enhanced oil and gas production**, and **hydrocarbon storage** are techniques associated with resource recovery. Therefore, the use of future boreholes for such activities and **fluid injection-induced geochemical changes** have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.3.1.4 Flow Through Abandoned Boreholes

The effects of natural fluid flow through existing or near-future abandoned boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Flow through undetected boreholes within or outside the controlled area has been eliminated from performance assessment calculations on the basis of low probability of occurrence of such boreholes. Waste-induced flow through boreholes drilled in the near future has been eliminated from performance assessment calculations on regulatory grounds. Waste-induced borehole flow and natural borehole flow through a future borehole that intersects a waste panel are accounted for in performance assessment calculations. The effects of natural borehole flow through a future borehole that does not intersect the waste-disposal region have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Geochemical changes that occur inside the controlled area as a result of long-term flow associated with historical, current, near-future, and future abandoned boreholes are accounted for in performance assessment calculations. The effects of borehole-induced solution and subsidence, and mineralization, associated with existing, near-future, and future abandoned boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Abandoned boreholes could provide pathways for fluid flow and, potentially, contaminant transport between any intersected zones. For example, such boreholes could provide

pathways for vertical flow between transmissive units in the Rustler, or between the Culebra and units below the Salado, which could affect fluid densities, flow rates, and flow directions.

Movement of fluids through abandoned boreholes could result in borehole-induced geochemical changes in the receiving units such as the Salado interbeds or Culebra, and thus alter radionuclide migration rates in these units.

Potentially, boreholes could provide pathways for surface-derived water or groundwater to percolate through low-permeability strata and into formations containing soluble minerals. Large-scale dissolution through this mechanism could lead to subsidence and to changes in groundwater flow patterns. Also, fluid flow between hydraulically conductive horizons through a borehole may result in changes in permeability in the affected units through mineral precipitation.

SCR.3.3.1.4.1 Historical, Current, and Near-Future Human-Initiated EPs

Abandoned water, potash, oil, and gas exploration and production boreholes exist within and outside the controlled area. The DOE assumes that records of past and present drilling activities in New Mexico are accurate and that evidence of any preexisting boreholes would be included in these records. In addition, during site selection for the WIPP, the DOE searched for evidence of boreholes and found no previously unknown holes. Even if undetected boreholes did exist, their effects on the performance of the disposal system would be insignificant, according to arguments similar to those presented below for flow through abandoned boreholes. However, **flow through undetected boreholes** within or outside the controlled area has been eliminated from performance assessment calculations on the basis of low probability of occurrence of such boreholes.

Continued resource exploration and production in the near future will result in the occurrence of many more abandoned boreholes in the vicinity of the controlled area. Institutional controls will prevent drilling (other than that associated with the WIPP development) from taking place within the controlled area in the near future. Therefore, no boreholes will intersect the waste disposal region in the near future, and **waste-induced borehole flow** in the near future has been eliminated from performance assessment calculations on regulatory grounds.

Hydraulic effects of flow through abandoned boreholes

Natural borehole flow through existing or near-future abandoned boreholes within or outside the controlled area could alter fluid pressure distributions within the disposal system.

Fluid flow and radionuclide transport within the Culebra could be affected if deep boreholes result in hydraulic connections between the Culebra and deep overpressurized or underpressurized units, or if boreholes provide interconnections for flow between shallow units. Wallace (1996a) analyzed the potential effects of interconnections between the Culebra

and deep units in the future within the controlled area (as discussed in Section SCR.3.3.1.4.2) and concluded that such interconnections could be eliminated from performance assessment calculations on the basis of low consequence. Also, shallow interconnections via boreholes within the controlled area have been eliminated from performance assessment calculations on the basis of low consequence (see Section SCR.3.3.1.4.2). Long-term flow through abandoned boreholes within the controlled area would have a greater impact on Culebra hydrology than such interconnections outside the controlled area. Thus, the effects of fluid flow through existing and near-future abandoned boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Changes in fluid density resulting from flow through abandoned boreholes

Leakage from historical, current, and near-future abandoned boreholes that penetrate pressurized brine pockets in the Castile could give rise to fluid density changes in affected units. Wilmot and Galson (1996) showed that brine density changes in the Culebra resulting from leakage through an abandoned borehole would not have a significant effect on the Culebra flow field. The effects on Culebra hydrology of potash mining activities expected to occur in the near-future outside the controlled area are likely to be more significant. The effects of mining are accounted for in calculations of undisturbed performance of the disposal system (through an increase in the transmissivity of the Culebra above the mined region, as discussed in Section SCR.3.3.2). Groundwater modeling that accounts for potash mining shows a change in the fluid pressure distribution and a consequent shift of flow directions towards the west in the Culebra within the controlled area (Wallace 1996c). A localized increase in fluid density in the Culebra resulting from leakage from an abandoned borehole would rotate the flow vector towards the downdip direction (towards the east). A comparison of the relative magnitudes of the freshwater head gradient and the gravitational gradient, based on an analysis similar to that presented in Section SCR.3.3.1.3, shows that the density effect is of low consequence to the performance of the disposal system.

Geochemical effects of borehole flow

Movement of fluids through abandoned boreholes could result in **borehole-induced geochemical changes** in the receiving units such as the Salado interbeds or Culebra. Such geochemical changes could alter radionuclide migration rates within the disposal system in the affected units if they occur sufficiently close to the edge of the controlled area, or if they occur as a result of flow through existing boreholes within the controlled area through their effects on colloid transport and sorption.

The contents of the waste disposal panels provide the main source of colloids in the disposal system. Thus, consistent with the discussion in Section SCR.3.3.1.1.1, colloid transport as a result of flow through existing and near-future abandoned boreholes has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

As discussed in Section SCR.3.3.1.1.1, sorption within the Culebra is accounted for in performance assessment calculations. The sorption model used accounts for the effects of changes in sorption in the Culebra as a result of flow through existing and near-future abandoned boreholes.

Consistent with the screening discussion in Section SCR.3.3.1.1.1, the effects of changes in sorption in the Dewey Lake inside the controlled area as a result of flow through existing and near-future abandoned boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

Borehole-induced solution and subsidence

Three features are required for significant **borehole-induced solution and subsidence** to occur through downward percolation of freshwater: a borehole, an energy gradient to drive freshwater downward through underlying brines to the Salado, and a sink or conduit to allow migration of brine away from the site of dissolution. Without these features, minor dissolution in the immediate vicinity of a borehole could occur, but percolating water would become saturated and prevent further dissolution.

An example of borehole-induced dissolution and subsidence occurred about 100 miles (160 kilometers) southeast of the WIPP site (outside the Delaware Basin) at the Wink Sink (Johnson 1987); percolation of shallow groundwater through abandoned boreholes, dissolution of the Salado, and subsidence of overlying units led to a surface collapse feature 360 feet (110 meters) in width and 110 feet (34 meters) deep. At Wink Sink, the Salado is underlain by the Tansill, Yates, and Capitan Formations, which contain vugs and solution cavities through which brine could migrate. Also, the hydraulic head of the Santa Rosa (the uppermost aquifer) is greater than those of the deep aquifers (Tansill, Yates, and Capitan Formations), suggesting downward flow if a connection were established.

The size of the dissolution cavity that caused Wink Sink is not known, but the size of the surface hollow suggests that, of existing boreholes that penetrate below repository depth near the WIPP, only ERDA-9 (see Chapter 2.0, Figure 2-2) is close enough to the repository to be of concern. Sealing of WIPP investigation boreholes (discussed in Chapter 3.0) and plugging of oil and gas boreholes (see Appendix DEL) will, to some extent, reduce the potential for borehole-induced solution and subsidence. However, corrosion of the well casing over the long term could allow percolation of surface-derived and shallow-formation waters into the borehole. Even if extensive seals are emplaced, casing corrosion could still allow a flow path to develop in strata where salt creep is not active. However, the bottom of ERDA-9 is in the Castile, just below the Salado. No sink exists at such a depth for downward percolation of water to persist.

Beauheim (1986) considered the direction of natural fluid flow through boreholes in the vicinity of the WIPP. Beauheim (1986, 72) examined hydraulic heads measured using drill stem tests in the Bell Canyon and the Culebra at well DOE-2 and concluded that the direction of flow in a cased borehole open only to the Bell Canyon and the Culebra would be upward. However, dissolution of halite in the Castile and the Salado would increase the relative density of the fluid in an open borehole, causing a reduction in the rate of upward flow. Potentially, the direction of borehole fluid flow could reverse, but such a flow could be sustained only if sufficient driving pressure, porosity, and permeability exist for fluid to flow laterally within the Bell Canyon. A further potential sink for Salado-derived brine is the Capitan Limestone. However, the subsurface extent of the Capitan Reef is approximately 10 miles (16 kilometers) from the WIPP at its closest point, and this unit will not provide a sink for brine derived from boreholes in the vicinity of the controlled area. A similar screening argument is made for natural deep dissolution in the vicinity of the WIPP (see Section SCR.1.1.5.1.). Thus, the effects of borehole-induced solution and subsidence around existing abandoned boreholes, and boreholes drilled and abandoned in the near-future, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Borehole-induced mineralization

Fluid flow between hydraulically conductive horizons through a borehole may result in changes in permeability in the affected units through mineral precipitation. For example:

- Limited calcite precipitation may occur as the waters mix in the Culebra immediately surrounding the borehole, and calcite dissolution may occur as the brines migrate away from the borehole due to variations in water chemistry along the flow path.

- Gypsum may be dissolved as the waters mix in the Culebra immediately surrounding the borehole but may precipitate as the waters migrate through the Culebra.

The effects of these mass transfer processes on groundwater flow depend on the original permeability structure of the Culebra rocks and the location of the mass transfer. The volumes of minerals that may precipitate and/or dissolve in the Culebra as a result of the injection of Castile or Salado brine through a borehole will not affect the existing spatial variability in the permeability field significantly. Consequently, the effects of **borehole-induced mineralization** on permeability and groundwater flow within the Culebra, as a result of brines introduced via any existing abandoned boreholes, and boreholes drilled and abandoned in the near-future, have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.3.3.1.4.2 Future Human-Initiated EPs

The EPA provides criteria concerning analysis of the consequences of future drilling events in 40 CFR § 194.33(c). Consistent with these criteria, the DOE assumes that after drilling is

complete the borehole is plugged according to current practice in the Delaware Basin (see Section 6.4.7.2). Degradation of casing and/or plugs may result in connections for fluid flow and, potentially, contaminant transport between connected hydraulically conductive zones. The long-term consequences of boreholes drilled and abandoned in the future will primarily depend on the location of the borehole and the borehole casing and plugging methods used.

Hydraulic effects of flow through abandoned boreholes

An abandoned future borehole that intersects a waste panel could provide a connection for contaminant transport away from the repository horizon. If the borehole has degraded casing and/or plugs, and the fluid pressure within the waste panel is sufficient, radionuclides could be transported to the land surface. Additionally, if brine flows through the borehole to overlying units, such as the Culebra, it may carry dissolved and colloidal actinides that can be transported laterally to the accessible environment by natural groundwater flow in the overlying units. Long-term **waste-induced borehole flow** is accounted for in performance assessment calculations (see Section 6.4.7.2).

The units intersected by a future borehole that intersects a waste panel may provide sources or sinks for long-term fluid flow to or from the waste panel. For example, penetration of an underpressurized unit underlying the Salado could result in long-term downward flow and radionuclide transport from the waste panel to the underlying unit. The permeabilities of formations underlying the Salado are less than the permeability of the Culebra (Wallace 1996a). Thus, under similar driving forces, fluids would migrate more rapidly through the Culebra than through units underlying the Salado. The consequences associated with radionuclide transport to an underpressurized unit below the waste panels are likely to be less significant, in terms of disposal system performance, than the consequences associated with radionuclide transport to the land surface or to the Culebra. Through this comparison, radionuclide transport to underpressurized units below the waste-disposal region has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

A future borehole that penetrates a Castile brine reservoir could provide a connection for brine flow from the reservoir to the waste panel, thus increasing fluid pressure and brine volume in the waste panel. Long-term **natural borehole flow** through such a borehole is accounted for in performance assessment calculations (see Section 6.4.8).

Deep abandoned boreholes that intersect the Salado interbeds near the waste disposal panels could provide pathways for long-term radionuclide transport from the waste panels to the land surface or to overlying units. The potential significance of such events were assessed by WIPP Performance Assessment Division (1991, B-26 to B-27), which examined single-phase flow and transport between the waste panels and a borehole intersecting MB139 outside the DRZ. The analysis assumed an in situ pressure of 11 megapascals in MB139, a borehole pressure of 6.5 megapascals (hydrostatic) at MB139, and a constant pressure of 18 megapascals as a source term in the waste panels representing gas generation. Also, MB139

was assigned a permeability of approximately 3×10^{-20} square meters and a porosity of 0.01 percent. The disturbed zone was assumed to exist in MB139 directly beneath the repository only and was assigned a permeability of 1.0×10^{-17} square meters and a porosity of 0.055 percent. Results showed that the rate of flow through a borehole located just 0.25 meters outside the DRZ would be more than two orders of magnitude less than the rate of flow through a borehole located within the DRZ because of the contrast in permeability. Thus, any releases of radionuclides to the accessible environment through deep boreholes that do not intersect waste panels would be insignificant compared to the releases that would result from transport through boreholes that intersect waste panels. Thus, radionuclide transport through deep boreholes that do not intersect waste panels has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Fluid flow and radionuclide transport within the Culebra could be affected if future deep boreholes result in hydraulic connections between the Culebra and deep overpressurized or underpressurized units. Over the 10,000-year regulatory period, a large number of deep boreholes could be drilled within and around the controlled area (see Section 6.4.12.2). The effects on the performance of the disposal system of long-term hydraulic connections between the Culebra and deep units depends on the location of the boreholes. In some cases, changes in the Culebra flow field caused by interconnections with deep units could increase lateral radionuclide travel times to the accessible environment.

As part of an analysis to determine the impact of such interconnections, Wallace (1996a) gathered information on the pressures, permeabilities, and thicknesses of potential oil- or gas-bearing sedimentary units; such units exist to a depth of about 18,000 feet (5,500 meters) in the vicinity of the WIPP. Of these units, the Atoka Unit, some 13,100 feet (4,000 meters) below the land surface, has the highest documented pressure of about 9,300 pounds per square inch (64×10^6 pascals), with permeabilities of about 2×10^{-14} square meters. The Strawn Unit, 12,800 feet (3,900 meters) below the land surface, has the lowest pressures (5,000 pounds per square inch [35×10^6 pascals], which is lower than hydrostatic) and highest permeability (10^{-13} square meters) of the deep units. Thus, in order to assess the maximum potential impact of interconnections between deep units and the Culebra, Wallace (1996a) evaluated the effects of long-term flow through boreholes from the Atoka to the Culebra (source) and from the Culebra to the Strawn (sink). Although the Atoka is primarily a gas-bearing unit, Wallace (1996a) conservatively assumed that the unit is brine saturated; in the long term, gas from the Atoka would most likely flow through a borehole to the land surface and would not affect the Culebra significantly.

Performance assessment calculations indicate that the shortest radionuclide travel times to the accessible environment through the Culebra occur when flow in the Culebra in the disposal system is from north to south. Wallace (1996a) ran the steady-state SECOFL2D model with the performance assessment data that generated the shortest radionuclide travel times (with and without mining in the controlled area) but perturbed the flow field by placing a brine source borehole in the Culebra just north of the waste disposal panels and a sink borehole just

south of the controlled area. The fluid flux through each borehole was determined using Darcy's Law, assuming a borehole hydraulic conductivity of 10^{-4} meter per second (for a permeability of about 10^{-11} square meters), a borehole radius of 0.8 feet (0.25 meters), and a fluid pressure in the Culebra of 1,790 pounds per square inch (12.3×10^6 pascals) at a depth of about 650 feet (200 meters). Thus, the Atoka was assumed to transmit brine to the Culebra at about 1.4×10^{-5} cubic meters per second, and the Strawn was assumed to receive brine from the Culebra at about 1.5×10^{-6} cubic meters per second.

Travel times through the Culebra to the accessible environment were calculated using the SECOFL2D velocity fields for particles released to the Culebra above the waste panels, assuming no retardation by sorption or diffusion into the rock matrix. Mean Darcy velocities were then determined from the distance each radionuclide travelled, the time taken to reach the accessible environment, and the effective Culebra porosity. The results show that, at worst, interconnections between the Culebra and deep units could cause a doubling of the largest mean Darcy velocity expected in the Culebra in the absence of such interconnections.

Performance assessment calculations show that radionuclide retardation in the Culebra limits lateral migration of radionuclides to just a few hundred meters in the 10,000-year regulatory time frame. A doubling of the Darcy velocity would cause only a minor increase in the lateral extent of radionuclide migration through the Culebra and would not lead to any radionuclide releases to the accessible environment in the regulatory time frame. Thus, the effects of fluid flow through a future deep abandoned borehole that does not intersect the waste disposal region have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Future abandoned boreholes could also provide interconnections for long-term fluid flow between shallow units (overlying the Salado). In particular, abandoned boreholes could provide pathways for downward flow of water from the Magenta to the Culebra; the Culebra hydraulic head is lower than the Tamarisk hydraulic head and these units are hydraulically isolated from each other by the relatively low permeability Tamarisk. If a large number of such boreholes were to occur in and around the controlled area in the future, they could result in an effective increase in vertical hydraulic conductivity in the Tamarisk. On the basis of three-dimensional groundwater flow modeling, Corbet (1995) determined that an increase in vertical hydraulic conductivity in the Tamarisk would result in a reduction in hydraulic head in the Magenta and an increase in hydraulic head in the Culebra, although there would be little change in the magnitude of the horizontal hydraulic head gradient in the Culebra. However, the change in the Culebra hydraulic head would be accompanied by a change in flow direction from north-south to northeast-southwest within the controlled area. Culebra hydraulic conductivities to the southwest of the waste panel region are two to three orders of magnitude lower than those to the south of the waste panel region. Therefore, the change in flow direction in the Culebra induced by connections to the Magenta would increase radionuclide travel times laterally through the Culebra to the accessible environment. Note that the Culebra hydraulic head would remain lower than the land surface and, therefore, radionuclides could not be transported vertically through boreholes to the accessible environment. Thus, a

large number of future borehole interconnections between shallow units would be beneficial to the long-term performance of the disposal system.

The most likely conditions under which radionuclide travel times through the Culebra might decrease are those in which a specific configuration of boreholes caused the hydraulic head gradient in the Culebra to increase without changing the flow direction. This might be achieved if one or more future abandoned boreholes were to exist just north of the waste disposal region, providing a pathway for flow from the Magenta to the Culebra. The Culebra hydraulic head would be raised at this point. The increase in hydraulic head gradient caused by such an event would be less than that caused by long-term flow from a deep overpressurized unit such as the Atoka. As discussed above, flow to the Culebra from deep overpressurized units will be of low consequence to the performance of the disposal system. Thus, by comparison, the effects of a connection via a borehole between the Magenta and the Culebra have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Changes in fluid density resulting from flow through abandoned boreholes

A future borehole that intersects a pressurized brine reservoir in the Castile could also provide a source for brine flow to the Culebra in the event of borehole casing leakage, with a consequent localized increase in fluid density in the Culebra. The effect of such a change in fluid density would be to increase any gravity-driven component of groundwater flow. If the downdip direction, along which the gravity-driven component would be directed, is different to the direction of the groundwater pressure gradient, there would be a rotation of the flow vector towards the downdip direction. The groundwater modeling presented by Davies (1989, 50) indicates that a borehole that intersects a pressurized brine pocket and causes a localized increase in fluid density in the Culebra above the waste panels would result in a rotation of the flow vector slightly towards the east. However, the magnitude of this effect would be small in comparison to the effects of the head gradient (see Section SCR.3.3.1.3), and such a localized increase in density would not divert radionuclides into the high-transmissivity zone within the Culebra.

Over the 10,000-year regulatory period a large number of boreholes could be drilled within and around the controlled area (see Section 6.4.12.2). If sufficient of these boreholes intersect pressurized brine pockets and connect with the Culebra, density changes in the Culebra may become widespread.

Gravity effects related to increase in density of Culebra groundwaters south of the waste panels will be small in comparison to freshwater head gradients (see Section SCR.3.3.1.3). The calculations undertaken by Davies (1989, 50) show that a density increase in the northern part of the controlled area could rotate the flow vector and hence affect flow in the region of the waste panels. However, these calculations did not consider any effects of mining on flow in the Culebra, and were based on a relatively flat pressure gradient in this region. Accounting for potash mining (through an increase in the transmissivity of the Culebra above

the mined region) results in a rotation of the freshwater head gradient towards the west (see Wallace, 1996c). Density-related gravity effects would oppose this gradient and increase travel times to the western boundary of the controlled area.

Geochemical effects of flow through abandoned boreholes

Movement of fluids through abandoned boreholes could result in **borehole-induced geochemical changes** in the receiving units, such as the Salado interbeds or Culebra. Such geochemical changes could alter radionuclide migration rates within the disposal system in the affected units through their effects on colloid transport and sorption.

The waste disposal panels provide the main source of colloids in the disposal system. Colloid transport within the Culebra as a result of long-term flow associated with future abandoned boreholes that intersect the waste disposal region are accounted for in performance assessment calculations, as described in Sections 6.4.3.6 and 6.4.6.2.1. Consistent with the discussion in Section SCR.3.3.1.1.1, colloid transport as a result of flow through future abandoned boreholes that do not intersect the waste disposal region has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The Culebra is the most transmissive unit in the disposal system and it is the most likely unit through which significant radionuclide transport could occur. Therefore, colloid transport in units other than the Culebra, as a result of flow through future abandoned boreholes, has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

As discussed in Section SCR.3.3.1.1.1, sorption within the Culebra is accounted for in performance assessment calculations. The sorption model accounts for the effects of changes in sorption in the Culebra as a result of flow through future abandoned boreholes.

Consistent with the screening discussion in Section SCR.3.3.1.1.1, the effects of changes in sorption in the Dewey Lake within the controlled area as a result of flow through future abandoned boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Sorption within other geological units of the disposal system has been eliminated from performance assessment calculations on the basis of beneficial consequence to the performance of the disposal system.

Borehole-induced solution and subsidence

The only conditions under which significant dissolution around future boreholes might occur are those in which such a borehole intersects the WIPP excavation. Following corrosion of the steel borehole casing and degradation of the borehole plug immediately above the Salado (see Section 6.4.7.2), the excavated region could provide a sink for downward flow of water from units overlying the Salado, resulting in dissolution of the borehole wall. Downward flow could only occur prior to the occurrence of significant gas generation, brine inflow, or creep closure in the disposal rooms, when the fluid pressure is less than hydrostatic pressure.

Dissolution will continue until fluid pressures in the disposal room reach hydrostatic and downward flow ceases.

Maximum dissolution, and maximum increase in borehole diameter, will occur at the top of the Salado; dissolution will decrease with depth as the percolating water becomes salt saturated. Eventually, degraded casing and concrete plug products, clays, and other materials will fill the borehole. Long-term flow through a borehole that intersects a waste panel is accounted for in disturbed performance calculations by assuming that the borehole is eventually filled by such materials, which have the properties of a silty sand (see Section 6.4.7.2). However, these calculations assume that the borehole diameter does not increase with time.

The potential extent of enlargement of a borehole that intersects a waste panel can be assessed given flow rates through the borehole and an estimate of the salt dissolution rate. The performance assessment calculations for an E2 drilling event at 1,000 years show a mean value of approximately 2×10^5 cubic feet (5×10^3 cubic meters) of fluid flowing into the intersected waste panel through the borehole up to the end of the 10,000-year regulatory period. Assuming instantaneous dissolution of salt upon contact with freshwater, Christensen et al. (1983, 19) estimated that 0.2 cubic feet of salt are dissolved for every cubic foot of freshwater that flows through a borehole. Thus, if 2×10^5 cubic feet (5×10^3 cubic meters) of water flow through the borehole, then approximately 4×10^4 cubic feet (1×10^3 cubic meters) of salt around the borehole will be dissolved.

The dimensions of a cavity resulting from borehole-induced dissolution can be estimated by assuming that the aspect ratio of such a cavity would be similar to the aspect ratio of the surface subsidence caused by dissolution at Wink Sink. The aspect ratio (depth and width) of the surface collapse at Wink Sink is 0.3 (see Section SCR.3.3.1.4.1). Assuming that the borehole-induced dissolution cavity is conical in shape, then a dissolution cavity of volume 4×10^4 cubic feet (1×10^3 cubic meters) will have a depth of approximately 20 feet (6 meters) and a diameter of approximately 65 feet (20 meters). The salt between the waste panel and the top of the Salado is approximately 1,250 feet (380 meters) thick. Thus, such dissolution will not affect the integrity of the majority of the salt above the waste panels, and it is unlikely to affect the rate of fluid flow through the borehole to the waste panel. The subsidence induced by such a cavity could result in an increase in hydraulic conductivity within the Culebra though increased vertical strain accompanied by fracture opening. However, the change in hydraulic conductivity within the Culebra from borehole-induced solution and subsidence will be restricted to the area above the waste panels, and will have no significant affect on the long-term performance of the disposal system.

In summary, the effects of **borehole-induced solution and subsidence** around future abandoned boreholes have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Borehole-induced mineralization

Fluid flow between hydraulically conductive horizons through a future borehole may result in changes in permeability in the affected units through mineral precipitation. However, the effects of mineral precipitation as a result of flow through a future borehole in the controlled area will be similar to the effects of mineral precipitation as a result of flow through an existing or near-future borehole (see Section SCR.3.3.1.4.1). Thus, **borehole-induced mineralization** associated with flow through a future borehole has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.3.3.2 Excavation-Induced Flow

Changes in groundwater flow due to historical, current, near-future, and future potash mining are accounted for in performance assessment calculations. Changes in geochemistry due to historical, current, and near-future potash mining have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Changes in geochemistry due to future mining have been eliminated from performance assessment calculations on regulatory grounds.

Excavation activities may result in hydrological disturbances of the disposal system. Subsidence associated with excavations may affect groundwater flow patterns through increased hydraulic conductivity within and between units. Fluid flow associated with excavation activities may also result in changes in brine density and geochemistry in the disposal system.

SCR.3.3.2.1 Historical, Current, and Near-Future Human-Initiated EPs

As discussed in Section SCR.3.2.2, potash mining is the only excavation activity currently taking place in the vicinity of the WIPP that could affect hydrogeological or geochemical conditions in the disposal system. Potash is mined in the region east of Carlsbad and up to 3.1 miles (5 kilometers) from the boundaries of the controlled area. Mining of the McNutt in the Salado is expected to continue in the vicinity of the WIPP (see Section 2.3.1.1): the DOE assumes that all economically recoverable potash in the vicinity of the WIPP (outside the controlled area) will be extracted in the near future.

Hydrogeological effects of mining

Potash mining in the Delaware Basin typically involves constructing vertical shafts to the elevation of the ore zone and then extracting the minerals in an excavation that follows the trend of the ore body. Potash has been extracted using conventional room and pillar mining, secondary mining where pillars are removed, and modified long-wall mining methods. Mining techniques used include drilling and blasting (used for mining langbeinite) and continuous mining (commonly used for mining sylvite). The DOE (Westinghouse 1994, 2-17 to 2-19) reported investigations of subsidence associated with potash mining operations located near the WIPP. The reported maximum total subsidence at potash mines is about 5

feet (1.5 meters), representing up to 66 percent of initial excavation height, with an observed angle of draw from the vertical at the edge of the excavation of 58 degrees. The DOE (Westinghouse 1994, 2-22 to 2-23) found no evidence that subsidence over local potash mines had caused fracturing sufficient to connect the mining horizon to water-bearing units or the surface. However, subsidence associated with mining in the McNutt in the vicinity of the WIPP may affect the lateral hydraulic conductivity of overlying units, such as the Culebra, which could influence the direction and magnitude of fluid flow within the disposal system. Such **changes in groundwater flow due to mining** are accounted for in calculations of undisturbed performance of the disposal system (see Section 6.4.6.2.3).

Potash mining, and the associated processing outside the controlled area, have changed fluid densities within the Culebra, as demonstrated by the areas of higher densities around boreholes WIPP-27 and WIPP-29 (Davies 1989, 43). Transient groundwater flow calculations (Davies 1989, 77 – 81) show that brine density variations to the west of the WIPP site caused by historical and current potash processing operations will not persist because the rate of groundwater flow in this area is fast enough to flush the high density groundwaters to the Pecos River. These calculations also show that accounting for the existing brine density variations in the region east of the WIPP site, where hydraulic conductivities are low, would have little effect on the direction or rate of groundwater flow. Therefore, changes in fluid densities from historical and current human-initiated EPs have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

The distribution of existing leases and potash grades suggests that near-future mining will take place to the north, west, and south of the controlled area (see Appendix DEL). Groundwater modeling that accounts for mining (through an increase in the transmissivity of the Culebra above the mined region) shows a change in the fluid pressure distribution, and a consequent shift of flow directions towards the west in the Culebra within the controlled area (Wallace, 1996c). A localized increase in fluid density in the Culebra, in the mined region or elsewhere outside the controlled area, would rotate the flow vector towards the downdip direction (towards the east). A comparison of the relative magnitudes of the freshwater head gradient and the gravitational gradient (based on an analysis identical to that presented for fluid leakage to the Culebra through boreholes) shows that the density effect is of low consequence to the performance of the disposal system.

Geochemical effects of mining

Fluid flow associated with excavation activities may result in geochemical disturbances of the disposal system. Some waters from the Culebra reflect the influence of current potash mining, having elevated potassium to sodium ratios. However, potash mining has had no significant effect on the geochemical characteristics of the disposal system. Solution mining, which involves the injection of freshwater to dissolve the ore body, can be used for extracting sylvite. However, lack of availability of freshwater has resulted in limited use of this mining technique in the Delaware Basin, and solution mining is not expected to occur in the near

future in the vicinity of the WIPP site. Thus, **changes in geochemistry due to mining** (historical, current, and near-future) have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.3.3.2.2 Future Human-Initiated EPs

Consistent with 40 CFR § 194.32(b), consideration of future mining may be limited to potash mining within the disposal system (see Section 3.3.2). Within the controlled area, the McNutt provides the only potash of appropriate quality. The extent of possible future potash mining within the controlled area is discussed in Section 2.3.1.1. Criteria concerning the consequence modeling of future mining are provided in 40 CFR § 194.32(b): the effects of future mining may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system. Thus, consistent with 40 CFR § 194.32(b), **changes in groundwater flow due to mining** within the controlled area are accounted for in calculations of the disturbed performance of the disposal system (see Section 6.4.6.2.3). Other potential effects, such as **changes in geochemistry due to mining**, have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.3.3 Explosion-Induced Flow

Changes in groundwater flow due to historical explosions have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Changes in groundwater flow due to future explosions have been eliminated from performance assessment calculations on regulatory grounds.

This section discusses the potential hydrological disturbances of the disposal system that may occur as a result of explosions.

SCR.3.3.3.1 Historical, Current, and Near-Future Human-Initiated EPs

The small-scale explosions that have been used in the Delaware Basin to fracture oil- and natural-gas-bearing units to enhance resource recovery have been too deep to have disturbed the hydrology of the disposal system (see Section SCR.3.2.3.1).

Also, as discussed in Section SCR.3.2.3.2, the Delaware Basin has been used for an isolated nuclear test (Project Gnome), approximately 8 miles (13 kilometers) southwest of the WIPP waste disposal region. An induced zone of increased permeability was observed to extend 150 feet (46 meters) laterally from the point of the explosion. The increase in permeability was primarily associated with motions and separations along bedding planes, the major pre-existing weaknesses in the rock. This region of increased permeability is too far from the WIPP site to have had a significant effect on the hydrological characteristics of the disposal system. Thus, **changes in groundwater flow due to explosions** in the past have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

SCR.3.3.3.2 Future Human-Initiated EPs

The criterion in 40 CFR § 194.32(a), relating to the scope of performance assessments, limits the consideration of future human actions to mining and drilling. Also, consistent with 40 CFR § 194.33(d), performance assessments need not analyze the effects of techniques used for resource recovery subsequent to the drilling of a future borehole. Therefore, **changes in groundwater flow due to explosions** in the future have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.4 Geomorphological EPs

SCR.3.4.1 Land Use and Disturbances

The effects of historical, current, and near-future surface disruptions have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The effects of future surface disruptions have been eliminated from performance assessment calculations on regulatory grounds. Land use changes have been eliminated from performance assessment calculations on regulatory grounds.

This section discusses surface activities that could affect the geomorphological characteristics of the disposal system and result in changes in infiltration and recharge conditions. The potential effects of water use and control on disposal system performance are discussed in Section SCR.3.5.1.

SCR.3.4.1.1 Historical, Current, and Near-Future Human-Initiated EPs

Surface activities that take place at present in the vicinity of the WIPP site include those associated with potash mining, oil and gas reservoir development, water extraction, and grazing. Additionally, a number of archeological investigations have taken place within the controlled area that were aimed at protecting and preserving cultural resources. Elsewhere in the Delaware Basin, sand, gravel, and caliche are produced through surface quarrying. Although these activities have involved **surface disruptions** within the Delaware Basin, they have not altered the characteristics of the disposal system significantly, and they have therefore been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. There are no existing plans for changes in land use in the vicinity of the WIPP in the near future. Therefore, consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), **land use changes** in the near future in the vicinity of the WIPP have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.4.1.2 Future Human-Initiated EPs

The criterion in 40 CFR § 194.25(a), concerned with predictions of the future states of society, requires that compliance assessments and performance assessments "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared." Therefore, future **land use changes** in the vicinity of the WIPP have been eliminated from performance assessment calculations on regulatory grounds.

Criteria relating to future human activities in 40 CFR § 194.32(a) limit the scope of consideration of future human actions in performance assessments to mining and drilling. Therefore, the effects of future **surface disruptions** have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.5 Surface Hydrological EPs

SCR.3.5.1 Water Control and Use

The effects of historical, current, and near-future damming of streams and rivers, reservoirs, irrigation, and altered soil or surface water chemistry by human activities have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Future damming of streams and rivers, reservoirs, irrigation, and altered soil or surface water chemistry by human activities have been eliminated from performance assessment calculations on regulatory grounds. The effects of lake usage have been eliminated from performance assessment calculations on regulatory grounds.

Irrigation and damming, as well as other forms of water control and use, could lead to localized changes in recharge, possibly leading to increased heads locally, thereby affecting flow directions and velocities in the Rustler and Dewey Lake. Surface activities, such as those associated with potash mining, could also affect soil and surface water chemistry. Note that the potential effects of geomorphological changes through land use are discussed in Section SCR.3.4.1.

SCR.3.5.1.1 Historical, Current, and Near-Future Human-Initiated EPs

In the WIPP area, two topographically low features, the Pecos River and Nash Draw, are sufficiently large to warrant consideration for damming. Dams and **reservoirs** already exist along the Pecos River. However, the Pecos River is far enough from the waste panels (12 miles [19 kilometers]) that the effects of **damming of streams and rivers** can be eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Nash Draw is not currently dammed, and based on current hydrological and climatic conditions, there is no reason to believe it will be dammed in the near future.

Irrigation uses water from rivers, lakes, impoundments, and wells to supplement the rainfall in an area to grow crops. Irrigation in arid environments needs to be efficient and involves the spreading of a relatively thin layer of water for uptake by plants, so little water would be expected to infiltrate beyond the root zone. However, some water added to the surface may infiltrate and reach the water table, affecting groundwater flow patterns. Irrigation currently takes place on a small scale within the Delaware Basin but not in the vicinity of the WIPP, and the extent of irrigation is not expected to change in the near future. Such irrigation has no significant effect on the characteristics of the disposal system. Thus, the effects of irrigation have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system.

Potash mining effluent and runoff from oil fields have altered soil and surface water chemistry in the vicinity of the WIPP. However, the performance of the disposal will not be sensitive to soil and surface water chemistry. Therefore, **altered soil or surface water chemistry by human activities** has been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The effects of effluent from potash processing on groundwater flow are discussed in Section SCR.3.3.2.

Consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), consideration of historical, current, and near-future human activities is limited to those activities that have occurred, or are expected to occur, in the vicinity of the disposal system. There are no large lakes in the vicinity of the WIPP and, therefore, human-initiated EPs related to **lake usage** have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.5.1.2 Future Human-Initiated EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a), that limit the scope of consideration of future human actions in performance assessments to mining and drilling. Therefore, the effects of future **damming of streams and rivers, reservoirs, irrigation, lake usage**, and **altered soil and surface water chemistry by human activities** have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.6 Climatic EPs

SCR.3.6.1 Anthropogenic Climate Change

The effects of anthropogenic climate change (acid rain, greenhouse gas effects, and damage to the ozone layer) have been eliminated from performance assessment calculations on regulatory grounds.

The effects of the current climate and natural climatic change are accounted for in performance assessment calculations, as discussed in Section SCR.6.4.9. However, human activities may also affect the future climate and thereby influence groundwater recharge in the

WIPP region. The effects of anthropogenic climate change may be on a local to regional scale (**acid rain**) or on a regional to global scale (**greenhouse gas effects** and **damage to the ozone layer**). Of these anthropogenic effects, only the greenhouse gas effect could influence groundwater recharge in the WIPP region. However, consistent with the future states assumptions in 40 CFR § 194.25(a), compliance assessments and performance assessments need not consider indirect anthropogenic effects on disposal system performance. Therefore, the effects of anthropogenic climate change have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.7 Marine EPs

SCR.3.7.1 Marine Activities

Historical, current, near-future, and future coastal water use, seawater use, and estuarine water use have been eliminated from performance assessment calculations on regulatory grounds.

This section discusses the potential for human-initiated EPs related to marine activities to affect infiltration and recharge conditions in the vicinity of the WIPP.

SCR.3.7.1.1 Historical, Current, and Near-Future Human-Initiated EPs

The WIPP site is more than 480 miles (800 kilometers) from the nearest seas, and hydrological conditions in the vicinity of the WIPP have not been affected by marine activities. Furthermore, consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), consideration of historical, current, and near-future human activities is limited to those activities that have occurred or are expected to occur in the vicinity of the disposal system. Therefore, human-initiated EPs related to marine activities (such as **coastal water use**, **seawater use**, and **estuarine water use**) have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.7.1.2 Future Human-Initiated EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a) that limit the scope of consideration of future human actions in performance assessments to mining and drilling. Therefore, the effects of future marine activities (such as **coastal water use**, **seawater use**, and **estuarine water use**) have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.8 Ecological EPs

This section discusses the potential effects of agricultural activities and social and technological developments on the hydrogeology and geochemistry of the disposal system.

Ecological FEPs relating to plant, animal, soil, and human uptake of radionuclides are discussed in Section SCR.2.8.

SCR.3.8.1 Agricultural Activities

The effects of historical, current, and near-future ranching and arable farming have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. The effects of changes in future ranching and arable farming practices have been eliminated from performance assessment calculations on regulatory grounds. Fish farming has been eliminated from performance assessment calculations on regulatory grounds.

Agricultural activities could affect infiltration and recharge conditions in the vicinity of the WIPP. Also, application of acids, oxidants, and nitrates during agricultural practice could alter groundwater geochemistry.

SCR.3.8.1.1 Historical, Current, and Near-Future Human-Initiated EPs

Grazing leases exist for all land sections immediately surrounding the WIPP and grazing occurs within the controlled area (see Section 2.3.2.2). Although grazing and related crop production have had some control on the vegetation at the WIPP site, these activities are unlikely to have affected subsurface hydrological or geochemical conditions. The climate, soil quality, and lack of suitable water sources all mitigate against agricultural development of the region in the near future. Therefore, the effects of historical, current, and near-future **ranching** and **arable farming** have been eliminated from performance assessment calculations on the basis of low consequence to the performance of the disposal system. Consistent with the criteria in 40 CFR § 194.32(c) and 40 CFR § 194.54(b), agricultural activities, such as **fish farming**, that have not taken place and are not expected to take place in the near future in the vicinity of the WIPP have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.8.1.2 Future Human-Initiated EPs

The EPA has provided criteria relating to future human activities in 40 CFR § 194.32(a), that limit the scope of consideration of future human activities in performance assessments to mining and drilling. Also, the criterion in 40 CFR § 194.25(a), concerned with predictions of the future states of society, requires that compliance assessments and performance assessments "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared." Therefore, the effects of changes in future agricultural practices (such as **ranching**, **arable farming**, and **fish farming**) have been eliminated from performance assessment calculations on regulatory grounds.

SCR.3.8.2 Social and Technological Developments

Demographic change and urban development in the near future and in the future have been eliminated from performance assessment calculations on regulatory grounds. Loss of records in the future is accounted for in performance assessment calculations.

Social and technological changes in the future could result in the development of new communities and new activities in the vicinity of the WIPP that could have an impact on the performance of the disposal system.

Demography in the WIPP vicinity is discussed in Section 2.3.2.1. The community nearest to the WIPP site is the town of Loving, 18 miles (29 kilometers) west-southwest of the site center. There are no existing plans for urban developments in the vicinity of the WIPP in the near future. Furthermore, the criterion in 40 CFR § 194.25(a), concerned with predictions of the future states of society, requires that compliance assessments and performance assessments "shall assume that characteristics of the future remain what they are at the time the compliance application is prepared." Therefore, **demographic change and urban development** in the vicinity of the WIPP and technological developments have been eliminated from performance assessment calculations on regulatory grounds.

Human activities will be prevented from occurring within the controlled area in the near future. However, performance assessments must consider the potential effects of human activities that might take place within the controlled area at a time when institutional controls cannot be assumed to eliminate completely the possibility of human intrusion. Consistent with 40 CFR § 194.41(b), the DOE assumes no credit for active institutional controls for more than 100 years after disposal. Also, consistent with 40 CFR § 194.43(c), the DOE assumes that passive institutional controls do not eliminate the likelihood of future human intrusion entirely. Thus, the ineffectiveness of institutional controls in the future, represented in the FEP list in Table SCR-3 as **loss of records**, is accounted for in performance assessment calculations.

SCR.4 Modeling Scenario Forming FEPs

The preceding sections of Appendix SCR present the results of applying the methodology for screening FEPs, presented in Section 6.2 of the main text of this application. This section lists the FEPs that remain after screening and identifies

- how each FEP is represented in the mathematical models used in the performance assessment calculations,
- which performance assessment code(s) and/or parameter(s) are used in the treatment of each FEP,
- the section(s) of the application that describe the treatment of the FEP in detail.

The FEPs that remain after screening are accounted for in performance assessment calculations either through explicit representation in the equations that form the mathematical models or implicitly through the specification of parameter values input to the performance assessment codes.[6] Tables SCR-5 and SCR-6 list the FEPs accounted for in calculations of disposal system performance under undisturbed and disturbed conditions respectively. In these tables, FEPs treated through explicit representation in the equations are incorporated as M, and those FEPs treated through the specification of parameters values are incorporated as P. FEPs incorporated as M generally require specification of parameter values as well. In some cases, a submodel is used to generate parameter values that are necessary for the solution of the basic governing equations of a computer code. FEPs incorporated by such submodels are generally denoted P. For example, the creep closure model provides porosity data to BRAGFLO and accounts for several FEPs incorporated as P.

Tables SCR-5 and SCR-6 provide a link between the scenario-forming FEPs that are used to build the scenarios described in Section 6.3 and the conceptual and mathematical models described in Section 6.4. Codes and models mentioned are discussed in Section 6.4 and in appendices referenced from there.

[6] Performance assessment codes are those employed directly in the performance assessment calculations: BRAGFLO, NUTS, PANEL, SECOFL2D, SECOTP2D, CUTTINGS_S, and CCDFGF.

Table SCR-5. The Treatment of FEPs in Undisturbed Performance Scenarios

FEP Categorization	FEP Incorporation	FEP Treatment	Chapter Section
NATURAL FEPs			
Geological FEPs			
Stratigraphy			
Stratigraphy	P	Accounted for in the BRAGFLO model geometry	2.1.3 6.4.2
Structural FEPs			
Seismic activity			
Seismic activity	P	Accounted for in the DRZ permeability used by BRAGFLO	6.4.5.3
Geochemical FEPs			
Dissolution			
Shallow dissolution	P	Accounted for in the Culebra transmissivity fields	6.4.6.2
Subsurface hydrological FEPs			
Groundwater characteristics			
Saturated groundwater flow	M	Accounted for in BRAGFLO treatment of two-phase flow, and in SECOFL2D representation of flow in the Culebra	2.2.1 6.4.5 6.4.6
Unsaturated groundwater flow	M	Accounted for in BRAGFLO treatment of two-phase flow	2.2.1 6.4.6
Fracture flow	M	Accounted for in SECOTP2D treatment of flow in the Culebra	6.4.6.2
Effects of preferential pathways	P	Accounted for in the Culebra transmissivity fields	6.4.6.2
Subsurface geochemical FEPs			
Groundwater geochemistry			
Groundwater geochemistry	P	Accounted for in the actinide source term model, and in the actinide transport and retardation model used by SECOTP2D	2.2.1 6.4.6.2
Geomorphological FEPs			
Physiography			
Physiography	P	Accounted for in BRAGFLO model geometry	2.1.4 6.4.2
Surface hydrological FEPs			
Groundwater recharge and discharge			
Groundwater discharge	P	Accounted for in specification of boundary conditions to SECOFL2D	2.2.2 6.4.10.2
Groundwater recharge	P	Accounted for in specification of boundary conditions to SECOFL2D	2.2.2 6.4.10.2

Table SCR-5. The Treatment of FEPs in Undisturbed Performance Scenarios (Continued)

FEP Categorization	FEP Incorporation	FEP Treatment	Chapter Section
Infiltration	P	Accounted for in specification of boundary conditions to SECOFL2D	2.2.2 6.4.10.2
Changes in surface hydrology			
Changes in groundwater recharge and discharge	P	Accounted for by the climate change model	2.5.1 6.4.9
Climatic FEPs			
Climate			
Precipitation (for example, rainfall)	P	Accounted for by the climate change model	2.5.1 6.4.9
Temperature	P	Accounted for by the climate change model	2.5.1 6.4.9
Climate change			
Meteorological			
Climate change	P	Accounted for by the climate change model	2.5.1 6.4.9
WASTE- AND REPOSITORY-INDUCED FEPs			
Waste and repository characteristics			
Repository characteristics			
Disposal geometry	P	Accounted for in BRAGFLO model geometry	3.2 6.4.3
Waste characteristics			
Waste inventory	P	Accounted for in the actinide source term model	4.1 6.4.3.5 6.4.3.3
Container characteristics			
Container material inventory	P	Accounted for in CDFs for gas generation rates used by BRAGFLO	6.4.3.3
Seal characteristics			
Seal geometry	P	Accounted for in BRAGFLO model geometry	3.8 6.4.4
Seal physical properties	P	Accounted for in seal parameter values used by BRAGFLO	6.4.4 6.4.3
Backfill characteristics			
Backfill chemical composition	P	Accounted for in the actinide source term model	6.4.3.4

Table SCR-5. The Treatment of FEPs in Undisturbed Performance Scenarios (Continued)

FEP Categorization	FEP Incorporation	FEP Treatment	Chapter Section
Radiological FEPs			
Radioactive decay			
Radionuclide decay and ingrowth	M	Accounted for in NUTS, PANEL and SECOTP2D	6.4.12.4
Geological and mechanical FEPs			
Excavation-induced fracturing			
Disturbed rock zone	P	Accounted for in BRAGFLO parameter values and materials definition	6.4.5.3
Excavation-induced changes in stress	P	Accounted for in the creep closure model in BRAGFLO	6.4.3.1
Rock creep			
Salt creep	P	Accounted for in the creep closure model in BRAGFLO	6.4.3.1
Changes in the stress field	P	Accounted for in the creep closure model in BRAGFLO	6.4.3.1
Roof falls			
Roof falls	P	Accounted for in the permeability of the DRZ used by BRAGFLO	6.4.5.3
Subsidence			
Subsidence	P	Accounted for in CDF for permeability of DRZ used by BRAGFLO	6.4.5.3
Effects of fluid pressure changes			
Disruption due to gas effects	M	Accounted for in BRAGFLO fracture model for Salado interbeds	6.4.5.2
Pressurization	M	Accounted for in BRAGFLO fracture model for Salado interbeds	6.4.5.2
Effects of explosions			
Gas explosions	P	Accounted for in the permeability of the DRZ used by BRAGFLO	6.4.5.3
Mechanical effects on material properties			
Consolidation of waste	P	Accounted for in the creep closure model in BRAGFLO	6.4.3.1
Consolidation of seals	P	Accounted for in seal parameters used by BRAGFLO	6.4.4
Mechanical degradation of seals	P	Accounted for in seal parameters used by BRAGFLO	6.4.4
Underground boreholes	P	Accounted for in seal parameters used by BRAGFLO	6.4.5.3

Table SCR-5. The Treatment of FEPs in Undisturbed Performance Scenarios (Continued)

FEP Categorization	FEP Incorporation	FEP Treatment	Chapter Section
Subsurface hydrological and fluid dynamical FEPs			
Repository-induced flow			
Brine inflow	M	Accounted for in BRAGFLO treatment of two-phase flow	6.4.3.2
Wicking	P	Accounted for in BRAGFLO gas generation model	6.4.3.2
Effects of gas generation			
Fluid flow due to gas production	M	Accounted for in BRAGFLO treatment of two-phase flow	6.4.3.2
Geochemical and chemical FEPs			
Gas generation			
Microbial gas generation			
Degradation of organic material	M	Accounted for in BRAGFLO gas generation model	6.4.3.3
Effects of temperature on microbial gas generation	P	Accounted for in CDFs for gas generation rates used by BRAGFLO	6.4.3.3
Effects of biofilms on microbial gas generation	P	Accounted for in CDFs for gas generation rates used by BRAGFLO	6.4.3.3
Corrosion			
Gases from metal corrosion	M	Accounted for in BRAGFLO gas generation model	6.4.3.3
Chemical effects of corrosion	P	Accounted for in CDFs for gas generation rates used by BRAGFLO	6.4.3.3
Chemical speciation			
Speciation	P	Accounted for in the actinide source term model, and in actinide transport and retardation model in SECOTP2D	6.4.3.4 6.4.3.5
Precipitation and dissolution			
Dissolution of waste	P	Accounted for in the actinide source term model	6.4.3.5
Sorption			
Actinide sorption	M	Accounted for in actinide retardation model in SECOTP2D	6.4.3.6
Kinetics of sorption	P	Accounted for in actinide retardation model in SECOTP2D	6.4.6.2.1
Changes in sorptive surfaces	P	Accounted for in actinide retardation model in SECOTP2D	6.4.6.2.1

Table SCR-5. The Treatment of FEPs in Undisturbed Performance Scenarios (Continued)

FEP Categorization	FEP Incorporation	FEP Treatment	Chapter Section
Reduction-oxidation chemistry			
Effect of metal corrosion	P	Accounted for in the actinide source term model	6.4.3.5
Reduction-oxidation kinetics	P	Accounted for in the actinide source term model	6.4.3.5
Organic complexation			
Humic and fulvic acids	P	Accounted for in estimates of the colloidal actinide source term	6.4.3.6 6.4.6.2.2
Chemical effects on material properties			
Chemical degradation of seals	P	Accounted for in seal parameters in BRAGFLO	6.4.4
Microbial growth on concrete	P	Accounted for in seal parameters in BRAGFLO	6.4.4
Contaminant transport mode FEPs			
Solute transport			
Solute transport	M	Accounted for by NUTS in the Salado and SECOTP2D in the Culebra	6.4.5.4 6.4.6.2.1
Colloid transport			
Colloid transport	M	Advection and diffusion of humic colloids in the Culebra is estimated with SECOTP2D.	6.4.6.2.2
Colloid formation and stability	P	Accounted for in the colloidal actinide source term model.	6.4.3.6
Colloid filtration	M	Accounted for in treatment of transport for microbial and mineral fragment colloidal particles.	6.4.6.2.2
Colloid sorption	M	Accounted for in estimates of humic colloid retardation used by SECOTP2D.	6.4.6.2.2
Microbial transport			
Microbial transport	M	Accounted for by treatment of microbes as colloids.	6.4.6.2.2
Contaminant transport processes			
Advection			
Advection	M	Accounted for by NUTS in the Salado and SECOTP2D in the Culebra	6.4.5.4 6.4.6.2
Diffusion			
Diffusion	M	Accounted for by SECOTP2D in the Culebra	6.4.6.2 6.4.5.4
Matrix diffusion	M	Accounted for by SECOTP2D in the Culebra	6.4.6.2

Table SCR-5. The Treatment of FEPs in Undisturbed Performance Scenarios (Continued)

FEP Categorization	FEP Incorpor-ation	FEP Treatment	Chapter Section
HUMAN-INITIATED EPs			
Excavation activities			
Excavation activities			
Potash mining	P	Potash mining outside the controlled area is accounted for by modifying the Culebra transmissivity fields used by SECOFL2D	6.4.6.2.3 6.4.12.8 6.4.13.8
Subsurface hydrological and geochemical EPs			
Borehole fluid flow			
Drilling-induced flow			
Drilling-induced geochemical changes	P	Accounted for in SECOPT2D in the Culebra	6.4.6.2
Fluid injection			
Fluid injection-induced geochemical changes	P	Accounted for in SECOTP2D in the Culebra	6.4.6.2
Flow through abandoned boreholes			
Borehole-induced geochemical changes	P	Accounted for in SECOTP2D in the Culebra	6.4.6.2
Excavation-induced flow			
Changes in groundwater flow due to mining	P	Potash mining outside the controlled area is accounted for by modifying the Culebra transmissivity fields used by SECOFL2D	6.4.6.2.3 6.4.12.8 6.4.13.8

Legend:

M FEP treated through explicit representation in the equations.
P FEP treated through the specification of parameters values.

Table SCR-6. The Treatment of FEPs in Disturbed Performance Scenarios (Disturbed Performance Scenarios include the Undisturbed Performance FEPs tabulated in Table SCR-5)

FEP Categorization	FEP Incorporation	FEP Treatment	Chapter Section
NATURAL FEPs			
Geological FEPs			
Stratigraphy			
Brine reservoirs	M	Accounted for in BRAGFLO for E scenarios	6.4.8 6.4.12.6
WASTE- AND REPOSITORY-INDUCED FEPs			
Waste and repository characteristics			
Waste characteristics			
Heterogeneity of waste forms	P	Accounted for in the waste activity probabilities used by CCDFGF	6.4.12.4
Contaminant transport mode FEPs			
Particulate transport			
Suspensions of particles	M	Accounted for in CUTTINGS_S treatment of releases through boreholes	6.4.7.1
Cuttings	M	Accounted for in CUTTINGS_S treatment of releases through boreholes	6.4.7.1
Cavings	M	Accounted for in CUTTINGS_S treatment of releases through boreholes	6.4.7.1
Spallings	M	Accounted for in CUTTINGS_S treatment of releases through boreholes	6.4.7.1
HUMAN-INITIATED EPs			
Geological EPs			
Drilling			
Oil and gas exploration	P	Drilling of deep boreholes[a] is accounted for in estimates of drilling frequency used by CCDFGF	2.3.1.2 6.4.7 6.4.12.2
Potash exploration	P	Drilling of deep boreholes is accounted for in estimates of drilling frequency used by CCDFGF	2.3.1.1 6.4.7 6.4.12.2

[a] Deep drilling means those drilling events in the Delaware Basin that reach or exceed a depth of 2,150 feet below the surface relative to where such drilling occurred.

Table SCR-6. The Treatment of FEPs in Disturbed Performance Scenarios (Disturbed Performance Scenarios include the Undisturbed Performance FEPs tabulated in Table SCR-5) (Continued)

FEP Categorization	FEP Incorporation	FEP Treatment	Chapter Section
Oil and gas exploitation	P	Drilling of deep boreholes is accounted for in estimates of drilling frequency used by CCDFGF	2.3.1.2 6.4.7 6.4.12.2
Other resources	P	Drilling of deep boreholes is accounted for in estimates of drilling frequency used by CCDFGF	2.3.1.3 6.4.7 6.4.12.2
Enhanced oil and gas recovery	P	Drilling of deep boreholes is accounted for in estimates of drilling frequency used by CCDFGF	2.3.1.2 6.4.7 6.4.12.2
Excavation activities			
Potash mining	P	Potash mining inside the controlled area is accounted for by modifying the Culebra transmissivity fields used by SECOFL2D	6.4.6.2.3 6.4.12.8 6.4.13.8
Subsurface hydrological and geochemical EPs			
Borehole fluid flow			
Drilling-induced flow			
Drilling fluid flow	M	Accounted for in spallings and direct brine release models	6.4.7.1
Drilling fluid loss	P	Accounted for in the BRAGFLO treatment of brine flow	6.4.7.1
Blowouts	M	Accounted for in spallings and direct brine release models	6.4.7.1.1
Drilling-induced geochemical changes	P	Accounted for by SECOTP2D in the Culebra	6.4.6.2
Flow through abandoned boreholes			
Natural borehole fluid flow	M	Accounted for in BRAGFLO treatment of long-term releases through boreholes	6.4.7.2 6.4.12.7 6.4.13
Waste-induced borehole flow	M	Accounted for in BRAGFLO treatment of long-term releases through boreholes	6.4.7 6.4.2.1
Borehole-induced geochemical changes	P	Accounted for by SECOTP2D in the Culebra	6.4.6.2

Table SCR-6. The Treatment of FEPs in Disturbed Performance Scenarios (Disturbed Performance Scenarios include the Undisturbed Performance FEPs tabulated in Table SCR-5) (Continued)

FEP Categorization	FEP Incorporation	FEP Treatment	Chapter Section
Excavation-induced flow			
Changes in groundwater flow due to mining	P	Potash mining inside the controlled area is accounted for by modifying the Culebra transmissivity fields used by SECOFL2D	6.4.6.2.3 6.4.12.8 6.4.13.8
Ecological EPs			
Social and technological developments			
Loss of records	P	Accounted for in estimates of the probability of inadvertent human intrusion.	6.3 6.4.7 6.4.12.1 6.4.12.2

Legend:

M FEP treated through explicit representation in the equations.

P FEP treated through the specification of parameters values.

REFERENCES

Anderson, R.Y., Dean, W.E., Jr., Kirkland, D.W., and Snider, H.I. 1972. Permian Castile Varved Evaporite Sequence, West Texas and New Mexico. *Geological Society of America Bulletin,* Vol. 83, No. 1, pp. 59 – 85.

Anderson, R.Y. 1978. *Deep Dissolution of Salt, Northern Delaware Basin, New Mexico.* Report to Sandia National Laboratories, Albuquerque, NM. WPO 29527 – 29530.

Argüello, J.G., and Torres, T.M. 1988. *Thermal Effects of RH-TRU Waste Emplacement on WIPP Storage Room Thermal/Structural Response.* SAND88-2217. Sandia National Laboratories, Albuquerque, NM.

Bachman, G.O. 1974. *Geologic Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico.* Open-File Report 74-194. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1980. *Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico.* Open-File Report 80-1099. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1981. *Geology of Nash Draw, Eddy County, New Mexico.* Open-File Report 81-31. U.S. Geological Survey, Denver, CO.

Bachman, G.O. 1984. *Regional Geology of Ochoan Evaporites, Northern Part of Delaware Basin.* Circular 184, pp. 1 – 27. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Bachman, G.O. 1987. *Karst in Evaporites in Southeastern New Mexico.* SAND86-7078. Sandia National Laboratories, Albuquerque, NM. WPO 24006.

Bachman, G.O., Johnson, R.B., and Swenson, F.A. 1973. *Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico.* Open-File Report 4339-4. U.S. Geological Survey, Denver, CO.

Barnhart, B.J., Campbell, E.W., Martinez, E., Caldwell, D.E., and Hallett, R. 1980. *Potential Microbial Impact on Transuranic Wastes Under Conditions Expected in the Waste Isolation Pilot Plant (WIPP), Annual Report, October 1, 1978-September 30, 1979.* LA-8297-PR. Los Alamos National Laboratory, Los Alamos NM.

Batchelor, G.K. 1973. *An Introduction to Fluid Dynamics.* First paperback edition. Cambridge University Press, London, UK.

Beauheim, R.L. 1986. *Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site*. SAND86-1364. Sandia National Laboratories, Albuquerque, NM. WPO 27565.

Bennett, D.G. 1996. *Formation and Transport of Radioactive Gases. Summary Memo of Record for GG-8 and RNT-26.* Memo of 16 May, 1996. SWCF-A 1.2.07.3: PA: QA: TSK: GG-8,RNT-26, Sandia National Laboratories, Albuquerque, NM 39406.

Bennett, D.G. Read, D., Atkins, M., Glasser, F.P. 1992. A thermodynamic Model for Blended Cements II: Cement Hydrate Phases; Thermodynamic Values and Modeling Studies. *Journal of Nuclear Materials*, Vol. 190, pp. 315 – 315.

Berner, R.A. 1981. Kinetics of Weathering and Diagenesis. In *Kinetics of Geochemical Processes.* A.C. Lasaga, and R.J. Kirkpatrick, eds. Reviews in Mineralogy. Mineralogical Society of America, Washington, D.C. Vol. 8, pp. 111 – 133.

Borns, D.J., and Shaffer, S.E. 1985. *Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin.* SAND83-1798. Sandia National Laboratories, Albuquerque, NM. WPO 24511.

Borns, D.J., Barrows, L.J., Powers, D.W., and Snyder, R.P. 1983. *Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site.* SAND82-1069. Sandia National Laboratories, Albuquerque, NM. WPO 27532.

Brausch, L.M., Kuhn, A.K., Register, J.K. 1982. *Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* WTSD-TME-3156. U.S. Department of Energy, Waste Isolation Pilot Plant.

Bredehoeft, J.D., Riley, F.S., and Roeloffs, E.A. 1987. Earthquakes and Groundwater. *Earthquakes and Volcanoes,* Vol. 19, No. 4, pp. 138 – 146.

Bruno, J., and Sandino, A. 1987. *Radionuclide Co-precipitation.* SKB Technical Report, No. 87-23, 19 pp. Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.

Burton, P.L., Adams, J.W., and Engwall, C. 1993. "History of the Washington Ranch, Eddy County, New Mexico," *New Mexico Geological Society Guidebook, 44th Field Conference, Carlsbad Region, New Mexico and West Texas.* Eds. D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.W. Austin, and J.M. Barker. SAND93-1318J. New Mexico Geological Society, Roswell, NM. 65-67.

Chapman, J.B. 1986. *Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area.* EEG-35, DOE/AL/10752-35. Environmental Evaluation Group, Santa Fe, NM.

Chappell, J., and Shackleton, N.J. 1986. Oxygen Isotopes and Sea Level. *Nature,* Vol. 324, No. 6093, pp. 137 – 140.

Christensen, C.L., Gulick, C.W., and Lambert, S.J., 1983. *Sealing Concepts for the Waste Isolation Pilot Plant (WIPP) Site.* SAND81-2195. Sandia National Laboratories, Albuquerque, NM. WPO 24405.

Claiborne, H.C., and Gera, F. 1974. *Potential Containment Failure Mechanisms and Their Consequences at a Radioactive Waste Repository in Bedded Salt in New Mexico.* ORNL-TM-4639. Oak Ridge National Laboratory, Oak Ridge, TN.

Corbet, T. 1995. *Two-Dimensional Assumption for Culebra Calculations. Summary Memo of Record for NS-9.* Memo of 21 September, 1995. SWCF-A 1.1.6.3: PA:QA: MGT:FSD. Sandia National Laboratories, Albuquerque, NM.

Cranwell, R.M., Guzowski, R.V., Campbell, J.E., and Ortiz, N.R. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste: Scenario Selection Procedure.* NUREG/CR-1667, SAND80-1429. Sandia National Laboratories, Albuquerque, NM.

Davies, P.B. 1983. Assessing the Potential for Deep-Seated Salt Dissolution and Subsidence at the Waste Isolation Pilot Plant (WIPP). In *State of New Mexico Environmental Evaluation Group Conference, WIPP Site Suitability for Radioactive Waste Disposal, Carlsbad, NM, May 12-13, 1983.* (Copy on file at the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM as WPO 29533.)

Davies, P.B. 1989. *Variable Density Ground-Water Flow and Paleohydrology in the Waste Isolation Pilot Plant (WIPP) Region, Southeastern New Mexico.* Open File Report 88-490. U.S. Geological Survey.

Davis, J.A. and Kent, D.B. 1990. Surface Complexation Modeling in Aqueous Geochemistry. *Mineral-Water Interface Geochemistry*, M.F. Hochella and A.F. White, eds. Reviews in Mineralogy, Mineralogical Society of America, Washington, DC, Vol. 23, pp. 177 – 260.

Dawson, P.R. and Tillerson, J.R. 1978. *Nuclear Waste Canister Thermally Induced Motion.* SAND-78-0566. Sandia National Laboratories, Albuquerque, NM. WPO 27328.

Dence, M.R., Grieve, R.A.F., and Robertson, P.B. 1977. Terrestrial Impact Structures: Principal Characteristics and Energy Considerations. In *Impact and Explosion Cratering,* D.J. Roddy, R.O. Pepin, and R.B. Merrill, eds. Pergamon Press, New York, NY, pp. 247 – 275.

Dietz, R.S. 1961. Astroblemes. *Scientific American,* Vol. 205, No. 2, pp. 50 – 58.

DOE (U.S. Department of Energy), 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026. Vol. 1-2. Washington, DC. WPO 38835, 38838 – 38839.

Dowding, C.H., and Rozen, A. 1978. Damage to Rock Tunnels from Earthquake Shaking. *Journal of the Geotechnical Engineering Division, American Society of Civil Engineers,* Vol. 104, No. GT2, pp. 175 – 191.

Economy, K.E., 1996. *Drilling into a Salado Zone of Contamination Within the Controlled Area; Drilling into a Non-Salado Zone of Contamination Within the Controlled Area. Summary Memo of Record for S-9 and NS-6.* SWCF-A 1.1.6.3:PA:QA:TSK:NS-6,S-9. Sandia National Laboratories, Albuquerque, NM. WPO 39495.

EPA (U.S. Environmental Protection Agency). 1985. 40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. *Federal Register,* Vol. 50, No. 182, pp. 38066 – 38089, September 19, 1985. Office of Radiation and Air, Washington, DC. WPO 39132.

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. Federal Register, Vol. 58, No. 242, p. 66398, December 20, 1993.

EPA (U.S. Environmental Protection Agency). 1996. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations, Background Information Document for 40 CFR Part 194.* EPA 402-R-96-002, January 1996, U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, DC.

Francis, A.J. 1985. *Low-Level Radioactive Wastes in Subsurface Soils, In Soil Reclamation Processes: Microbiological Analyses and Applications.* R.L. Tate, III and D.A. Klein, eds. Marcel DeKker, Inc., New York, pp. 279-331.

Francis, A.J., and Gillow, J.B. 1994. *Effects of Microbial Gas Processes on Generation Under Expected Waste Isolation Pilot Plant Repository Conditions, Progress Report through 1992.* SAND93-7036. Sandia National Laboratories, Albuquerque, NM. WPO 26555.

Grieve, R.A.F. 1987. Terrestrial Impact Structures. *Annual Review of Earth and Planetary Sciences,* Vol. 15, pp. 245 – 270.

Halliday, I. 1964. The Variation in the Frequency of Meteorite Impact with Geographic Latitude. *Meteoritics,* Vol. 2, No. 3, pp. 271 – 278.

Hartmann, W.K. 1965. Terrestrial and Lunar Flux of Large Meteorites in the Last Two Billion Years. *Icarus,* Vol. 4, No. 2, pp. 157 – 165.

Hartmann, W.K. 1979. "Long-Term Meteorite Hazards to Buried Nuclear Waste Report 2." In *Assessment of Effectiveness of Geologic Isolation Systems: A Summary of FY-1978 Consultant Input for Scenario Methodology Development,* B.L. Scott, G.L. Benson, R.A. Craig, and M.A. Harwell, eds. PNL-2851. Pacific Northwest Laboratory, Richland, WA. VI-1 through VI-15 (Chapter 6).

Hicks, T.W. 1996. *Thermal Convection and Effects of Thermal Gradients. Summary Memo of Record for GG-4 and S-10.* Memo of 29 May, 1996. SWCF-A 1.2.07.3: PA: QA: TSK: S10,GG4. Sandia National Laboratories, Albuquerque, NM. WPO 31290.

Holt, R.M., and Powers, D.W. 1988. *Facies Variability and Post-Depositional Alteration within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico.* DOE/WIPP 88-004. U.S. Department of Energy, Carlsbad, NM. (This document is included as Appendix FAC.)

Imbrie, J., and Imbrie, J.Z. 1980. Modeling the Climatic Response to Orbital Variations. *Science.* Vol. 207, no. 4434, pp. 943-953.

Johnson, K.S. 1987. Development of the Wink Sink in West Texas due to Salt Dissolution and Collapse. In *Karst hydrology. Proc. 2nd Conference, Orlando, 1987.* B.F. Beck, W.L. Wilson, eds. Oklahoma Geological Survey, Norman, USA. Balkema. pp. 127 – 136.

Kärnbränslesakerhet. 1978. *Handling of Spent Nuclear Fuel and Final Storage of Vitrified High Level Reprocessing Waste.* Kärnbränslesakerhet (now SKB), Stockholm, Sweden.

Kato, C., Sato, T., Smorawinska, M. and Horikoshi, K. 1994. "High Pressure Conditions Stimulate Expression of Chloramphenicol Acetyltransferase Regulated by the *lac* Promoter in *Escherichia coli," FEMS Microbiology Letters.* Vol. 122, nos. 1–2, 91 – 96.

King, P.B. 1948. *Geology of the Southern Guadalupe Mountains, Texas.* Professional Paper 215. U.S. Geological Survey, Washington, DC.

Lambert, S.J. 1983. *Dissolution of Evaporites in and around the Delaware Basin, Southeastern New Mexico and West Texas.* SAND82-0461. Sandia National Laboratories, Albuquerque, NM. WPO 27520.

Lambert, S.J., and Harvey, D.M. 1987. *Stable-Isotope Geochemistry of Groundwaters in the Delaware Basin of Southeastern New Mexico.* SAND87-0138. Sandia National Laboratories, Albuquerque, NM. WPO 24150.

Lappin, A.R., Hunter, R.L., Garber, D.P., Davies, P.B., Beauheim, R.L., Borns, D.J., Brush, L.H., Butcher, B.M., Cauffman, T., Chu, M.S.Y., Gomez, L.S., Guzowski, R.V., Iuzzolino, H.J., Kelley, V., Lambert, S.J., Marietta, M.G., Mercer, J.W., Nowak, E.J., Pickens, J., Rechard, R.P., Reeves, M., Robinson, K.L., and Siegel, M.D, eds. 1989. *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico, March 1989.* SAND89-0462. Sandia National Laboratories, Albuquerque, NM. WPO 24125.

Lasaga, A.C., Soler, J.M., Ganor, J., Burch, T.E., and Nagy, K.L. 1994. Chemical Weathering Rate Laws and Global Geochemical Cycles. *Geochimica et Cosmochimica Acta,* Vol. 58, No. 10, pp. 2361 – 2386.

Lenhardt, W.A. 1988. Damage Studies at a Deep Level African Gold Mine. In *Rockbursts & Seismicity in Mines, Proceeding of the Second International Symposium, Minneapolis, MN, June 8-10, 1988,* C. Fairhurst, ed., pp. 391 – 393. A.A. Balkema, Brookfield, VT.

Logan, S.E., and Berbano, M.C. 1978. *Development and Application of a Risk Assessment Method for Radioactive Waste Management.* EPA 520/6-78-005. U.S. Environmental Protection Agency, Washington, DC. Vols. 1 – 4.

Loken, M.C. 1994. SMC Thermal Calculations, RSI Calculation No. A141-GE-05, prepared for Parsons Brinckerhoff, San Francisco, CA. RE/SPEC, Inc., Rapid City, SD.

Loken, M.C. and Chen, R. 1994. Rock Mechanics of SMC, RSI Calculation No. A141-GE-07, prepared for Parsons Brinckerhoff, San Francisco, CA. RE/SPEC Inc., Rapid City, SD.

Lowenstein, T.K. 1987. *Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico: Textural, Stratigraphic and Chemical Evidence.* EEG-36, DOE/AL/10752-36. Environmental Evaluation Group, Santa Fe, NM.

Molecke, M.A. 1979. *Gas Generation from Transuranic Waste Degradation.* SAND79-0911C. Sandia National Laboratories, Albuquerque, NM. WPO 28093.

Muehlberger, W.R., Belcher, R.C., and Goetz, L.K. 1978. Quaternary Faulting on Trans-Pecos, Texas. *Geology,* Vol. 6, No. 6, pp. 337 – 340.

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. *Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site.* NMBMMR, Campus Station, Socorro, NM, March 31, 1995.

Nicholson, A., Jr., and Clebsch, A., Jr. 1961. *Geology and Ground-Water Conditions in Southern Lea County, New Mexico.* Ground-Water Report 6. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

Papenguth, H.W., and Behl, Y.K. 1996. Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the WIPP. TP 96-01, Sandia National Laboratories, Albuquerque, NM. WPO 31337.

Pedersen, K., and Karlsson, F. 1995. *Investigations of Subterranean Microorganisms: Their Importance for Performance Assessment of Radioactive Waste Disposal.* SKB Technical Report 95-10, Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.

Popielak, R.S., Beauheim, R.L, Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. *Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME-3153. U.S. Department of Energy, Carlsbad, NM.

Powers, D.W., Lambert, S.J., Shaffer, S.E., Hill, L.R., and Weart, W.D., eds. 1978. *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico.* SAND78-1596, Vols. I and II. Sandia National Laboratories, Albuquerque, NM. (This document is included as Appendix GCR.) WPO 5448 (Volume 1); WPO 26829 – 26830 (Volume 2).

Rate, A.W., McLaren, R.G., and Swift, R.S. 1993. Response of Copper(II)-Humic Acid Dissociation Kinetics to Factors Influencing Complex Stability and Macromolecular Conformation. *Environmental Science Technology*, Vol. 27, pp. 1408-1414.

Rawson, D., Boardman, C., and Jaffe-Chazan, N. 1965. *Project Gnome, the Environment Created by a Nuclear Explosion in Salt.* PNE-107F. Lawrence Radiation Laboratory, University of California, Livermore, CA; Available from National Technical Information Service, Springfield, VA.

Rechard, R. P., Iuzzolino, H. , and Sandha, J. S., 1990. *Data Used in Preliminary Performance Assessment of the Waste Isolation Pilot Plant (1990).* SAND89-2408. Sandia National Laboratories, Albuquerque, NM.

Reed, D.T., Okajima, S., Brush, L.H., and Molecke, M.A. 1993. *Radiolytically-Induced Gas Production in Plutonium-Spiked WIPP Brine.* Scientific Basis for Nuclear Waste Management XVI, Materials Research Society Symposium Proceedings, Boston, MA, November 30 - December 4, 1992. C.G. Interrante and R.T. Pabalan, eds. SAND92-7283C. Materials Research Society, Pittsburgh, PA. Vol. 294, pp. 431 – 438.

Rechard, R.P., Stockman, C.T., Sanchez, L.C., Liscum-Powell, J., and Rath, J.S. 1996. Nuclear Criticality in Near Field and Far Field. Summary Memo of Record for RNT-1. SWCF-A:1.2.07.3:PA:QA:TSK:RNT-1. Sandia National Laboratories, Albuquerque, NM. WPO 40818.

Robinson, J.Q., and Powers, D.W. 1987. A Clastic Deposit Within the Lower Castile Formation, Western Delaware Basin, New Mexico. In *Geology of the Western Delaware*

Basin, West Texas and Southeastern New Mexico, D.W. Powers and W.C. James, eds. El Paso Geological Society Guidebook 18. El Paso Geological Society, El Paso, TX, pp. 69 – 79.

Rosholt, J.N., and McKinney, C.R. 1980. *Uranium Series Disequilibrium Investigations related to the WIPP Site, New Mexico. Part II, Uranium Trend Dating of Surficial Deposits and Gypsum Spring Deposits near WIPP Site, New Mexico,* Open-File Report 80-879, U.S. Geological Survey, Denver, CO.

Sanchez, L. C., and Trellue, H. R. 1996. Estimation of Maximum RH-TRU Thermal Heat Load for WIPP. Memo to T. Hicks (Galson Sciences Ltd.), January 17, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 31165.

Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters.* SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM. WPO 28529.

Schiel, K.A. 1994. A New Look at the Age, Depositional Environment and Paleogeographic Setting of the Dewey Lake Formation (Late Permian). *West Texas Geological Society Bulletin,* Vol. 33, No. 9, pp. 5 – 13. WPO 20465.

Serne, R.J. 1992. "Current Adsorption Models and Open Issues Pertaining to Performance Assessment." In *Proceedings of the DOE/Yucca Mountain Site Characterization Project Radionuclide Adsorption Workshop at Los Alamos National Laboratory, September 11-12, 1990.* Comp. J.A. Canepa. LA-12325-C. Los Alamos National Laboratory, Los Alamos, NM. 43 – 74.

Siegel, M.D., Lambert, S.J., and Robinson, K.L. eds. 1991. *Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico.* SAND88-0196. Sandia National Laboratories, Albuquerque, NM.

Silva, M.K. 1994. *Implications of the Presence of Petroleum Resources on the Integrity of the WIPP.* EEG-55. Environmental Evaluation Group, Albuquerque, NM.

Snelling, A.A. 1992. *Alligator Rivers Analogue Project Final Report, Volume 2, Geologic Setting.* UK DOE Report DOE/HMIP/RR/92/072, SKI Report SKI TR 92:20-2, ISBN 0-642-59928-9. Her Majesty's Inspectorate of Pollution of the Department of the Environment, London; Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.

Snyder, R.P., Gard, Jr., L.M., and Mercer, J.W. 1982. *Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site.* Open-File Report 82-968. U.S. Geological Survey, Denver, CO.

Stoelzel, D.M., and O'Brien, D.G. 1996. The Effects of Salt Water Disposal and Waterflooding on WIPP. Summary Memo of Record for NS-7a. Sandia National Laboratories, Albuquerque, NM. WPO 40837.

Stroes-Gascoyne, S., and West, J.M. 1994. *Microbial Issues Pertaining to the Canadian Concept for the Disposal of Nuclear Fuel Waste.* AECL Report No. AECL-10808, COG-93-54. Atomic Energy of Canada Ltd., Whiteshell Labs, Pinawa, Manitoba, Canada. pp. 39.

Swift, P.N. 1992. *Long-Term Climate Variability at the Waste Isolation Pilot Plant, Southeastern New Mexico, USA.* SAND91-7055. Sandia National Laboratories, Albuquerque, NM. WPO 27093.

Telander, M.R., and Westerman, R.E. 1993. *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Progress Report for the Period November 1989 through 1992.* SAND92-7347. Sandia National Laboratories, Albuquerque, NM. WPO 23456.

Telford, W.M., Geldart, L.P., Sheriff, R.E. and Keys, D.A. 1976. *Applied Geophysics.* Cambridge University Press, Cambridge.

Thorne, B.J., and Rudeen, D.K. 1981. *Regional Effects of TRU Repository Heat.* SAND80-7161. Sandia National Laboratories, Albuquerque, NM. WPO 10281.

Thorne, M.C. 1992. *Dry Run 3 - A Trial Assessment of Underground Disposal of Radioactive Wastes Based on Probabilistic Risk Analysis - Volume 8: Uncertainty and Bias Audit.* DOE/HMIP/RR/92.040. Her Majesty's Inspectorate of Pollution (HMIP) of the Department of the Environment, London.

Tipping, E. 1993. Modeling the Competition between Alkaline Earth Cations and Trace Metal Species for Binding by Humic Substances. *Environmental Science & Technology* Vol. 27, pp. 520 – 529.

Vaughn, P., Lord, M., Garner, J. and MacKinnon, R. 1995. *Radiolysis of Brine.* Errata to Summary Memo of Record GG-1, SWCF-A:1.1.6.3:PA:QA:TSK:GG1,S7, December 21, 1995. Sandia National Laboratories, Albuquerque, NM. WPO 30786.

Waber, N. 1991. *Mineralogy, Petrology and Geochemistry of the Poços de Caldas Analogue Study Sites, Minas Gerais, Brazil, I. Osamu Utsumi Uranium Mine.* Nagra Report NTB-90-20. National Genossen Schaft für die Lagerung Radioaktiver Abfalle (NAORA), Baden, Switzerland.

Wakeley L. D., Harrington P. T., and Hansen F. D., 1995. *Variability in Properties of Salado Mass Concrete.* SAND94-1495. Sandia National Laboratories, Albuquerque, NM. WPO 22744.

Wallace, M. 1996a. Leakage from abandoned boreholes. Summary Memo of Record for NS-7b. SWCF-A 1.1.6.3:PA:QA:TSK:NS-7b. Sandia National Laboratories, Albuquerque, NM. WPO 40819.

Wallace, M. 1996b. *Pumping from the Culebra Outside the Controlled Area. Summary Memo of Record for NS-5.* SWCF-A 1.1.6.3:PA:QA:TSK:NS-5. Sandia National Laboratories, Albuquerque, NM. WPO 40831.

Wallace, M. 1996c. *Subsidence Associated with Mining Inside or Outside the Controlled Area. Summary Memo of Record for NS-11.* SWCF-A 1.1.6.3:PA:QA:TSK:NS-11. Sandia National Laboratories, Albuquerque, NM, Planning memo of record. WPO 40816.

Wallace, M., Beauheim, R., Stockman, C., Alena Martell, M., Brinster, K., Wilmot, R., and Corbert, T. 1995. Dewey Lake Data Collection and Compilation. Summary Memo of Record for NS-1. SWCF-A 1.1.6.3:PA:QA:TSK:NS-1. Sandia National Laboratories, Albuquerque, NM.

Wallner, M. 1981. Critical Examination of Conditions for Ductile Fracture in Rock Salt. In *Proceedings of the Workshop on Near-Field Phenomena in Geologic Repositories for Radioactive Waste, Seattle, WA, August 31-September 3, 1981*, pp. 243 – 253. Organisation for Economic Co-operation and Development, Paris, France.

Warrick, R., and Oerlemans, J. 1990. "Sea Level Rise." In *Climate Change: The IPCC Scientific Assessment,* J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds., pp. 257 – 281. Intergovernmental Panel on Climate Change, Sweden, pp. 257 – 281.

Westinghouse Electric Corporation. 1994. *Backfill Engineering Analysis Report, Waste Isolation Pilot Plant.* Westinghouse Electric Corporation, Carlsbad, NM. WPO 37909.

Wilmot, R.D., and Galson, D.A. 1996. *Human-Initiated Brine Density Changes. Summary Memo of Record for NS17 and NS18.* SWCF-A 1.1.6.3:PA:QA:TSK; NS-17, NS-18. Sandia National Laboratories, Albuquerque, NM. WPO 39424.

WIPP Division, 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 1: Methodology and Results.* SAND91-0893/1, Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

Wolery, T.J. 1992. *EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, Users guide, and Related Documentation (Version 7.0).* Lawrence Livermore National Report No. UCRL-MA-110662 PT III, pp. 1 – 246.

BIBLIOGRAPHY

Bennett, D.G., Wang, Y., and Hicks, T.W. 1996. An Evaluation of Heat Generation Processes for the WIPP. Memo of 20 August, 1996. SWCF-A (Org. 6352), WBS 1.1.09.1(RC).

Blackwell, D.D., Steele, J.L., and Carter, L.S. 1991. "Heat-Flow Patterns of the North American Continent; A Discussion of the Geothermal Map of North America." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., Geological Society of America, Boulder, CO. pp. 423 – 436.

Chapman, J.B., and Hokett, S.L. 1991. *Evaluation of Groundwater Monitoring at Offsite Nuclear Test Areas.* DOE/NV/10845-07. Prepared by the Water Resources Center of the Desert Research Institute for the Nevada Operations Office, U.S. Department of Energy, Las Vegas, NV.

Crawford, M.B. 1996. *Effects of Microbial Growth and Chemistry on Concrete Performance Summary Memo of Record for SP-5 and SP-8.* Memo of 22 May, 1996. SWCF-A 1.2.07.3: PA: QA: TSK: SP-5,SP-8. Sandia National Laboratories, Albuquerque, NM. WPO 31298.

DOE (U.S. Department of Energy). 1995. *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report.* CAO-94-1005, Revision 1, February 1995. WIPP Technical Assistance Contractor for U.S. Department of Energy, Carlsbad, NM.

Earth Technology Corp. 1988. *Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site.* SAND87-7144, Sandia National Laboratories, Albuquerque, NM.

EPA (U.S. Environmental Protection Agency). 1985. *Background Information Document, Final Rule for High-Level and Transuranic Radioactive Wastes.* EPA 520/1-85-023. U.S. Environmental Protection Agency, Office of Radioactive Programs, Washington, D.C.

Knowles, M.K., and Howard, C.L. 1996. "Field and Laboratory Testing of Seal Materials Proposed for the Waste Isolation Pilot Plant." *Waste Management '96 Symposium, Tucson, AZ, February 25-29, 1996.* SAND95-2082C. WPO 30945.

Molecke, M.A., Argüello, J.G., and Beraún, R. 1993. *Waste Isolation Pilot Plant Simulated RH TRU Waste Experiments: Data and Interpretation Report.* SAND88-1314. Sandia National Laboratories, Albuquerque, NM. WPO 29406.

Peake, T. 1996. *WIPP -- Examination of Mining and Hydraulic Conductivity.* Memo to Public Rulemaking Docket A-92-56. January 31, 1996.

Read, D., ed. 1994. *Chemval-2 Project. Report on Stage 1: Status of Six Technical Areas.* Nuclear Science and Technology Report No. EUR 15151 EN, Commission of the European Communities, Luxembourg, p. 236.

Reiter, M., Barroll, M.W., and Minier, J. 1991. "An Overview of Heat Flow in Southwestern United States and Northern Chihuahua, Mexico." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 457 -- 466. Geological Society of America, Boulder, CO.

Richardson, R.M., and Reding, L.M. 1991. North American Plate Dynamics. *Journal of Geophysical Research,* Vol. 96, No. B7, 11, pp. 12,201 – 12,223.

Sanchez, L.C. 1996. *Identification of Important Radionuclides Used in Wipp Performance Assessment.* Memo to John F. Suermann, March 6, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 37431.

Sanford, A.R., Jakasha, L.H., and Cash, D.J. 1991. Seismicity of the Rio Grand Rift in New Mexico. In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., Geological Society of America, Boulder, CO. pp. 229 – 244.

Slezak, S., and Lappin, A. 1990. Potential for and Possible Impacts of Generation of Flammable and/or Detonable Gas Mixtures during the WIPP Transportation, Test, and Operational Phases. In Memorandum to D. Mercer and C. Fredrickson, January 5, 1990. Sandia National Laboratories, Albuquerque, NM. WPO 21224.

Thompson, G.A., and Zoback, M.L. 1979. Regional Geophysics of the Colorado Plateau. *Tectonophysics,* Vol. 61, Nos. 1 – 3, pp. 149 – 181.

Van Sambeek, L.L. 1987. *Thermal and Thermomechanical Analyses of WIPP Shaft Seals.* SAND87-7039. Sandia National Laboratories, Albuquerque, NM. WPO 24144.

Wang, Y. 1996. *Evaluation of the Thermal Effect of MgO Hydration for the Long-Term WIPP Performance Assessment.* Memo of May 9, 1996. Sandia National Laboratories, Albuquerque, NM. SWCF-A (Org. 6352), WBS 1.1.09.1.1(RC). WPO 37743.

Wang, Y. and Brush, L.H. 1996. *Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance Assessment.* Memo to Martin S. Tierney, January 26, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 31943.

Witherspoon, P. A., Wang, J. S. Y., Iwai, K., and Gale, J. E. 1980. Validity of Cubic Law for Fluid Flow in a Deformable Rock Fracture. *Water Resources Research,* Vol. 16, no. 6, pp. 1016-1024. WPO 38853.

Wood, B.J., Snow, R.E., Cosler, D.J., and Haji-Djafari, S. 1982. *Delaware Mountain Group (DMG) Hydrology - Salt Removal Potential, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico.* TME 3166. U.S. Department of Energy, Albuquerque NM.

Zoback, M.L., and Zoback, M.D. 1980. State of Stress in the Conterminous United States. *Journal of Geophysical Research,* Vol. 85, No. B11, pp. 6113 – 6156.

Zoback, M.D., and Zoback, M.L. 1991. "Tectonic Stress Field of North America and Relative Plate Motions." In *Neotectonics of North America,* D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds. Geological Society of America, Boulder, CO. pp. 339 – 366.

Zoback, M.L., Zoback, M.D., Adams, J., Bell, S., Suter, M., Suarez, G., Estabrook, C., and Magee, M. 1991. *Stress Map of North America.* Continent Scale Map CSM-5, Scale 1:5,000,000. Geological Society of America, Boulder, CO.

ATTACHMENT

Attachment 1 Development of a WIPP-Specific List of Features, Events, and Processes for the Compliance Certification Application

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Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

SCR Attachment 1

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Development of a WIPP-Specific List of Features, Events and Processes for the Compliance Certification Application

1 Introduction

The performance assessment (PA) process conducted for the Waste Isolation Pilot Plant (WIPP) uses scenario development as a tool for determining exactly what phenomena and components of the disposal system can and should be dealt with in PA calculations. The Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD/NEA) defined scenario development as the identification, broad description, and selection of alternative futures relevant to a reliable assessment of the safety of a disposal system, and set out four basic steps in the scenario development procedure (OECD/NEA, 1992):

(i) Identification and classification of all phenomena potentially relevant to the performance of the repository and site.

(ii) Elimination of phenomena according to well-defined screening criteria.

(iii) Identification or formation of scenarios relevant to the performance of the repository and site.

(iv) Specification of scenarios for consequence analysis.

The purpose of this report is to describe the development of a list of phenomena potentially relevant to the performance of the WIPP (stage (i) in this procedure). The resulting list of Features, Events and Processes (FEPs) is presented in the Compliance Certification Application (CCA). Screening of these FEPs (stage (ii) in the scenario development procedure) is presented in Appendix SCR of the CCA.

It is important to be as comprehensive and imaginative as possible during the initial stage of identifying FEPs, even if some of these FEPs may be eliminated in later stages of the process. This ensures that interactions between FEPs are not overlooked and that a well-documented response to possible "what-if" questions is available. It is also important that the classification and development of the FEP list is well documented to ensure that decisions can be traced and to build confidence that the scenarios used in PA are reasonable and sufficiently comprehensive.

In order to fulfill the requirements for comprehensiveness and traceability, an initial FEP list was assembled based on FEP lists in use for the WIPP and in other radioactive waste disposal programs. This initial FEP list was used in preparing Appendix SCR of the Draft Compliance Certification Application (DCCA) (U.S. DOE, 1995a, b). Appendix SCR for the final CCA is based in large part on the corresponding sections of the DCCA, with the addition of new screening arguments and revisions to clarify other screening discussions. As part of these revisions, consideration was given to the comments received on the DCCA text and, in

particular, the relationship of the text to the tables of FEPs. As a result, a new FEP list has been developed for the CCA that is closely linked to a generic list and at the same time includes issues specific to the WIPP site.

This document summarizes the development of the initial FEP list used in the DCCA (Section 2), and outlines the drawbacks of this list for use in the CCA (Section 2.3). The development of a WIPP-specific FEP list for the CCA is described in Section 3. A summary of the steps in this development that have built confidence in the comprehensiveness and appropriateness of the CCA FEP list is presented in Section 4. Appendices present the DCCA list and a mapping from this list to the CCA FEP list.

2 Development of an Initial FEP Database

The DCCA compiled by the Department of Energy in March 1995 (U.S. DOE, 1995a) included, in Appendix SCR, screening arguments for many FEPs. These FEPs were derived from a comprehensive list of FEPs established as a means of demonstrating that the WIPP PA had adequately documented the decisions leading to exclusion of FEPs from the PA calculations.

There have been several recent studies in which a variety of national FEP lists were compiled in order to help ensure comprehensiveness (e.g, in the Netherlands (Prij et al., 1993), Sweden (Stenhouse et al., 1993), and the United States (Guzowski and Newman, 1993)). In addition, work is underway at the OECD/NEA to develop a comprehensive FEP list that includes all national work; however, this list was not available at the time the WIPP FEP list was compiled in 1995.

The list established for the DCCA was based on a FEP compilation conducted by the Swedish Nuclear Power Inspectorate (SKI) (Stenhouse et al., 1993) because that compilation was the best documented and most comprehensive. During development of the initial FEP list for the WIPP, key project documents were reviewed, such as the 1991 and 1992 PAs (Sandia National Laboratories, 1991, 1992), and the March 1994 Compliance Status Report (U.S. DOE, 1994). Review of these documents illustrated the need to incorporate additional FEPs into the DCCA list.

2.1 The Swedish study

The Swedish Nuclear Power Inspectorate (SKI) study was conducted by Stenhouse et al. (1993) as part of the SITE-94 performance assessment exercise. This exercise considered the disposal of spent nuclear fuel in crystalline bedrock at a hypothetical site with characteristics based on the Äspö Hard Rock Laboratory site. The purpose of the FEP study was to ensure that all relevant FEPs were considered early in the SITE-94 assessment, and only limited screening of FEPs was done.

SKI compiled an initial raw FEP list based on the nine different FEP identification studies listed in Table 1.

Table 1. Studies used to derive the DCCA FEP list

Study	Country	Number of FEPs identified
Atomic Energy of Canada Limited (AECL) study of disposal of spent fuel in crystalline rock (Goodwin et al., 1994)	Canada	275
SKI & Swedish Nuclear Fuel and Waste Management Company (SKB) study of disposal of spent fuel in crystalline rock (Andersson, 1989)	Sweden	157
National Cooperative for the Storage of Radioactive Waste (NAGRA) Project Gewähr study (NAGRA, 1985)	Switzerland	44
UK Department of the Environment Dry Run 3 study of deep disposal of low- and intermediate-level waste (L/ILW) (Thorne, 1992)	United Kingdom	305
UK Department of the Environment assessment of L/ILW disposal in volcanic rock at Sellafield (Miller and Chapman, 1993)	United Kingdom	79
UK Nuclear Industry Radioactive Waste Executive (NIREX) study of the deep disposal of L/ILW (Hodgkinson and Sumerling, 1989)	United Kingdom	131
SNL study of disposal of spent fuel (Cranwell et al., 1990)[1]	United States	29
Nuclear Energy Agency (NEA) Working Group on Systematic Approaches to Scenario Development (NEA, 1992)	International	122
International Atomic Energy Agency (IAEA) Safety Series (IAEA, 1985)	International	56

SKI divided FEPs from these lists into eight primary categories ("Level 1") based on location of occurrence (six categories) and cause (two categories). The eight categories were waste, canister, buffer/backfill, repository/near-field, far-field, biosphere, geological/climatic evolution, and future human actions. SKI eliminated a number of FEPs from the component lists on the basis of irrelevancy to the SKI disposal concept and site, assessment scope, and incomprehensibility of the FEP.

Because of the way the disposal system was subdivided many FEPs appear more than once on the list. For example, a process such as sorption may occur in the backfill, in the near-field, in the far-field, and in the biosphere, and it would be included on the lists for all of these Level 1 categories. In addition, each Level 1 category was subdivided into between seven and twelve "Level 2" subcategories. Some FEPs occur several times within a single Level 1 category, where they are relevant to the consideration of more than one of the Level 2 subcategories.

[1] This list was in use previously by the WIPP project (Sandia National Laboratories, 1991, 1992).

2.2 *Development of the DCCA FEP list*

The DCCA FEP list was developed by taking the final SKI list, and re-inserting FEPs that had been screened out in the SKI study. Numerous additional FEPs of particular concern to the WIPP were added (see below), and several of the FEPs on the SKI list were subdivided in order to assist with screening them for the WIPP PA calculations. Finally, some duplicate FEPs were eliminated for clarity of presentation, although other duplicate FEPs were retained where a particular FEP could affect more than one part of the disposal system, or could interact with FEPs in more than one subcategory. No other changes were made. In particular, the titles of all FEPs on the SKI list were retained, even though some of them were vague or poorly stated for the situation at the WIPP.

The structure of the DCCA FEP list is provided in Table 2, and the full list is provided in Appendix A. This structure is similar to that in the SKI study. The most notable change to the SKI list was the creation of a new Level 1 category called "seal systems" for the DCCA to reflect the importance of the seal systems to the WIPP safety concept. The SKI list included consideration of seal degradation only under the Level 2 subcategory "repository degradation." The Level 2 subcategories and the FEPs in the DCCA FEP list for the seal systems category reflect those that are in the SKI Level 1 backfill category. A further change was to broaden consideration of radionuclide transport to consideration of all contaminants of concern (i.e., inclusion of volatile organic compounds (VOCs) and heavy metals), in order to improve the applicability of the list to performance assessments presented in the No Migration Variance Petition (NMVP) to satisfy the requirements of 40 CFR §268.6.

2.3 *Drawbacks of the DCCA FEP list*

Internal and external review of Chapter 6 and Appendix SCR of the DCCA highlighted a number of drawbacks in the use of the DCCA FEP list and the presentation of screening arguments. These drawbacks are outlined in the following sections.

2.3.1 Scope of a Generic List

The use of the SKI FEP list as a basis for the DCCA FEP list provided confidence that all FEPs of potential importance were considered. The wide range of disposal concepts that formed the basis of the list, however, led to a significant number of FEPs being classified as not relevant to WIPP. The component FEP lists considered, for example, a range of engineered barriers and were developed under different regulatory frameworks. Furthermore, FEPs relating to the marine environment that are relevant in programs considering coastal sites are not relevant to WIPP.

2.3.2 Use of Subsystems

The SKI list was organized into a series of subsystems: waste, canister, backfill, near-field, far-field, biosphere, geology/climate, and human influences. An additional subsystem - seals - was added in the DCCA to make the list more applicable to the WIPP, but overall the SKI subsystem classification is not ideal for the WIPP disposal concept. For example, in contrast

to the Swedish disposal concept, canister integrity does not have a role in long-term performance of the WIPP. The terms near-field, far-field and biosphere are not unequivocally defined for the WIPP site, nor does the cumulative release criterion (40 CFR § 191.13) require consideration of radionuclide transport in the biosphere.

Table 2. Structure of the DCCA FEP Database - Levels 1 and 2.

1	**WASTE CATEGORY**
1.1	Initial waste characteristics
1.2	Radionuclide decay and growth
1.3	Radiological/radiation effects
1.4	Gas generation and effects
1.5	Heat generation
1.6	Thermo-mechanical effects
1.7	Thermo-chemical effects
1.8	Electro-chemical effects
1.9	Waste degradation/corrosion/ dissolution
1.10	Geochemical reactions/regime
1.11	Radionuclide and contaminant (e.g., heavy metal) chemistry
1.12	Others
2	**CANISTER CATEGORY**
2.1	Canister materials/construction
2.2	Corrosion/degradation processes
2.3	Gas production and effects
2.4	Microbiological effects/microbial activity
2.5	Thermo-mechanical effects
2.6	Electro-chemical effects
2.7	Stress/mechanical effects
2.8	Geochemical reactions/regime
2.9	Radionuclide and contaminant (e.g., heavy metal) transport through canisters
2.10	Others
3	**BACKFILL CATEGORY**
3.1	Buffer/backfill characteristics
3.2	Resaturation/desaturation
3.3	Mechanical effects
3.4	Thermal effects
3.5	Electro-chemical effects
3.6	Gas effects and transport
3.7	Microbiological effects/microbial activity
3.8	Backfill degradation
3.9	Geochemical regime
3.10	Radionuclide and contaminant (e.g., heavy metal) transport processes
3.11	Radionuclide and contaminant (e.g., heavy metal) chemistry
3.12	Others
4	**SEAL SYSTEMS CATEGORY**
4.1	Seal system characteristics
4.2	Resaturation/desaturation
4.3	Mechanical effects
4.4	Thermal effects
4.5	Electro-chemical effects
4.6	Gas effects and transport
4.7	Microbiological effects/microbial activity
4.8	Seal degradation
4.9	Geochemical regime
4.10	Radionuclide and contaminant (e.g., heavy metal) transport processes
4.11	Radionuclide and contaminant (e.g., heavy metal) chemistry
4.12	Others
5	**REPOSITORY/NEAR-FIELD CATEGORY**
5.1	Near-field; repository elements/materials
5.2	Repository degradation
5.3	Hydraulic effects/groundwater flow
5.4	Mechanical effects
5.5	Thermal effects

5.6	Gas effects and transport	7.8	Geochemical regime (general)
5.7	Microbiological/biological activity	7.9	Radionuclide and contaminant (e.g., heavy metal) chemistry
5.8	Geochemical regime	7.10	Radionuclide and contaminant (e.g., heavy metal) transport processes
5.9	Radionuclide and contaminant (e.g., heavy metal) chemistry	7.11	Radiological factors
5.10	Radionuclide and contaminant (e.g., heavy metal) transport processes	7.12	Others
5.11	Others	**8**	**GEOLOGY/CLIMATE CATEGORY**
6	**FAR-FIELD CATEGORY**	8.1	Seismic events/major land movement
6.1	Rock properties	8.2	Rock deformation
6.2	Hydrogeological effects	8.3	Metamorphic processes
6.3	Physical/mechanical effects	8.4	Erosion/weathering (surface)
6.4	Thermal effects	8.5	Groundwater flow and effects
6.5	Gas effects and transport	8.6	Surface water flow and effects
6.6	Microbiological/biological activity	8.7	Sea-level effects
6.7	Geochemical regime	8.8	Magnetic effects
6.8	Radionuclide and contaminant (e.g., heavy metal) chemistry	8.9	Glaciation /glacial effects
6.9	Radionuclide and contaminant (e.g., heavy metal) transport processes	8.10	Climate effects (natural)
6.10	Others	8.11	Others
7	**BIOSPHERE CATEGORY**	**9**	**HUMAN INFLUENCES CATEGORY**
7.1	Human considerations	9.1	Inadvertent intrusion into repository
7.2	Ecological factors	9.2	Surface activities
7.3	Soil/sediment effects	9.3	Subsurface activities
7.4	Surface/near-surface water processes	9.4	Water use
7.5	Coastal water/ocean processes	9.5	Agricultural and fisheries practices
7.6	Gas effects and transport	9.6	Radiological factors
7.7	Microbiological/biological activity	9.7	Others

2.3.3 Presentation of FEP Screening

The text of Appendix SCR in the DCCA did not discuss on an individual basis all FEPs from the comprehensive list of FEPs. Instead, the discussion was organized around a series of topics ranging from individual FEPs for which there was a semi-quantitative basis for screening (e.g. meteorite impact) to groups of FEPs that could be screened out collectively using a qualitative argument (e.g. all FEPs relating to the marine environment).

A series of check-lists was used to ensure that all the individual FEPs were included within the topics discussed in the DCCA. These check-lists were included as tables so that the reader could relate the topics discussed in the body of the report to the complete list of FEPs. Confusion has therefore arisen because individual FEPs in Tables SCR-1, 2 and 3 of the DCCA were not all explicitly discussed in the text of Appendix SCR.

2.3.4 FEP Classification

Appendix SCR of the DCCA (U.S. DOE, 1995b) lists and discusses FEPs included in PA calculations for undisturbed and disturbed performance (classifications UP and DP), FEPs screened out on regulatory, probability or consequence grounds (SO-R, SO-P and SO-C), FEPs not yet screened (RB), FEPs related to deviations from the design (RD), FEPs concerning potential design changes (RE), FEPs representing reserves of performance (RF), and FEPs considered not relevant to WIPP (NR). For the CCA, however, which presents PA calculations for a final design, the only classifications that are appropriate are inclusion in the calculations (UP, DP) or exclusion on well-defined criteria (SO-R, SO-C, SO-P). FEPs relating to the evaluation of different designs or disposal concepts (RD, RE and NR) have therefore been omitted from the CCA FEP list. Work undertaken since the DCCA has resulted in the screening of those FEPs previously categorized as RB, with the majority now screened as SO-C, and this category has become redundant with respect to the CCA. Finally, reviewers did not consider that a separate category for FEPs representing reserves of performance was appropriate, and that FEPs categorized as RF should be screened out on the basis of consequence to performance of the disposal system (SO-C). These relationships between the FEP classification scheme used in the DCCA and that adopted for the CCA are illustrated in Figure 1.

3 The CCA FEP List

For the reasons outlined in Section 2.3, a new, WIPP-specific list of FEPs has been developed for use in the Compliance Certification Application. This list has approximately 240 FEPs, in contrast to approximately 900 FEPs in the DCCA. The reduction in numbers removes the ambiguities caused by use of a generic list, without eliminating any issues from the discussion.

3.1 FEP Categorization

As a framework for the CCA FEP list, and as an aid to the presentation of screening arguments in Appendix SCR, a FEP categorization scheme has been developed for the CCA. FEPs have been categorized using the three major divisions of natural, waste- and repository-induced, and human actions. Each of these divisions is subdivided into categories corresponding to major subject areas such as geology, geochemical, and subsurface hydrology. Further subdivisions of these categories represent groups of related features or processes such as structural effects, gas generation, and repository-induced flow. The full categorization scheme is presented in Table 3.

FEP Classification in DCCA			FEP Classification in CCA
Accounted for in Performance Assessment Calculations	Containment Requirements 40 CFR §191.13	UP, DP	UP, DP
	Individual Dose 40 CFR §191.15 Groundwater Protection 40 CFR §191.24	UP	UP
Eliminated from Performance Assessment Calculations	Regulatory Guidance	SO-R	SO-R
	Consequence	SO-C	SO-C
	Probability	SO-P	SO-P
	Deviations from Design Specifications	RD	Not on CCA FEP list (Irrelevant to assessment of final design)
	Engineering Alternatives	RE	Not on CCA FEP list (Irrelevant to assessment of final design)
	Not Relevant	NR	SO-C (Natural FEPs)
			Not on CCA FEP list (Applicable to other disposal concepts)
Retained for Evaluation in Final CCA	Assumed Low Consequence	RB	Screened (Majority as SO-C)
	Reserve (Potentially Beneficial to Performance)	RF	SO-C

Figure 1. Relationships between the FEP classification scheme used in the DCCA and adopted for the CCA

3.2 Derivation of the CCA FEP list

The following steps have been used to derive the CCA FEP list from that compiled for the DCCA:

- References to subsystems have been eliminated from the CCA FEP list, because the SKI subsystem classification is not ideal for the WIPP disposal concept.

- Duplicate FEPs have been eliminated from the CCA FEP list. Duplicate FEPs arose in the DCCA list because individual FEPs could act in different subsystems. FEPs have a single entry in the CCA list whether they are applicable to several parts of the disposal system or to a single part only.

Table 3. Categorization scheme for the CCA FEP list

NATURAL	Geological	Stratigraphy	
		Tectonics	
		Structural effects	Deformation
			Fracture development
			Fault movement
			Seismic activity
		Crustal processes	Igneous activity
			Metamorphism
		Geochemical effects	Dissolution
			Mineralization
	Subsurface hydrological	Groundwater characteristics	
		Changes in groundwater flow	
	Subsurface geochemical	Groundwater geochemistry	
		Changes in groundwater chemistry	
	Geomorphological	Physiography	
		Meteorite impact	
		Denudation	Weathering
			Erosion
			Sedimentation
		Soil development	
	Surface hydrological	Fluvial	
		Lacustrine	
		Groundwater recharge and discharge	
		Changes in surface hydrology	
	Climatic	Climate	
		Climate change	Meteorological
			Glaciation
	Marine	Seas	
		Marine sedimentology	
		Sea level change	
	Ecological	Flora & fauna	
		Changes in flora & fauna	
WASTE AND REPOSITORY-INDUCED	Waste and repository characteristics	Repository characteristics	
		Waste characteristics	
		Container characteristics	
		Seal characteristics	
		Backfill characteristics	
		Postclosure monitoring	
	Radiological	Radioactive decay	

Table 3. Categorization scheme for the CCA FEP list (continued)

1			Heat from radioactive decay	
2			Nuclear criticality	
3			Radiological effects on material properties	
4		Geological / mechanical	Excavation-induced fracturing	
5			Rock creep	
6			Roof falls	
7			Subsidence	
8			Effects of fluid pressure changes	
9			Effects of explosions	
10			Thermal effects	
11			Mechanical effects on material properties	
12		Subsurface hydrological / fluid dynamical	Repository-induced flow	
13			Effects of gas generation	
14			Thermal effects	
15		Geochemical / chemical	Gas generation	Microbial gas generation
16				Corrosion
17				Radiolytic gas generation
18			Chemical speciation	
19			Precipitation / dissolution	
20			Sorption	
21			Redox chemistry	
22			Organic complexation	
23			Exothermic reactions	
24			Chemical effects on material properties	
25		Contaminant transport mode	Solute transport	
26			Colloid transport	
27			Particulate transport	
28			Microbial transport	
29			Gas transport	
30		Contaminant transport process	Advection	
31			Diffusion	
32			Thermochemical transport phenomena	
33			Electrochemical transport phenomena	

Table 3. Categorization scheme for the CCA FEP list (continued)

		Physicochemical transport phenomena	
	Ecological	Plant, animal and soil uptake	
		Human uptake	
HUMAN ACTIONS	Geological	Drilling	
		Excavation activities	
		Subsurface explosions	Resource recovery
			Underground nuclear device testing
	Subsurface hydrological and geochemical	Borehole fluid flow	Drilling-induced flow
			Fluid extraction
			Fluid injection
			Flow through abandoned boreholes
		Excavation-induced flow	
		Explosion-induced flow	
	Geomorphological	Land use and disturbances	
	Surface hydrological	Water control and use	
	Climatic	Anthropogenic climate change	
	Marine	Marine activities	
	Ecological	Agricultural activities	
		Social and technological developments	

- FEPs relating to high-level waste, long-term behavior of canisters, bentonite backfill, etc. (classified as NR in the DCCA) have been eliminated from the CCA FEP list. These FEPs are included on the generic list to ensure compatibility with a range of design concepts, but they are not relevant to the current WIPP design or inventory.

- FEPs relating to issues such as hazardous metal transport, VOCs, and chemical toxicity, that are not regulated by 40 CFR Part 191 (classified as NR in the DCCA), have been eliminated from the CCA FEP list.

- Natural FEPs classified as not relevant (NR in the DCCA) that will clearly not affect the WIPP (e.g. marine processes) have been composited into a few generalized FEPs on the CCA FEP list. These FEPs are discussed and screened out on the basis of low consequence in the CCA.

- FEPs relating to constructional, operational and decommissioning errors (classified as RD in the DCCA) have been eliminated from the CCA FEP list. The DOE has

administrative and quality control procedures to ensure that the facility will be constructed, operated and decommissioned as specified in the CCA.

- FEPs relating to engineering design changes (classified as RE in the DCCA) have been eliminated from the CCA FEP list. Such FEPs are not relevant to a compliance application based on the current design.

- Detailed FEPs relating to processes in the surface environment have been composited into a small number of generalized FEPs in the CCA FEP list. The surface environment is a significant part of the disposal system for programs required to calculate dose or risk, and hence detailed FEPs relating to this environment are included in generic FEP lists. The surface environment is of less significance for the WIPP PA calculations, and less detail is appropriate in this part of the WIPP-specific CCA FEP list.

- A few FEPs have been re-named to highlight their relationship to key WIPP issues (e.g. wicking, brine inflow).

In the DCCA, the classification SO-C was generally restricted to "low consequence," with the classifications NR and RF being used for "no consequence" and "positive consequence" respectively. In the CCA FEP list those FEPs classified as having a potentially beneficial effect on performance have been re-classified as SO-C. A number of FEPs previously classified as not relevant have also been re-classified as SO-C. These changes mean that the SO-C classification should be interpreted in the more general sense of "screened out on the basis of potential consequence."

A major change between the DCCA FEP list and the CCA FEP list is the elimination of subsystems, and the consequent removal of duplicate FEPs. For example, the DCCA FEP list had separate entries for sorption in canisters, backfill, seals, the near-field and the far-field. In contrast, the CCA FEP list has a single FEP for sorption. If a FEP is included in performance assessment calculations for only part of the disposal system, the UP or DP classification is used in the summary tables, along with a note to this effect, and the text of Appendix SCR is used to present screening arguments for other parts of the disposal system.

The CCA FEP list is presented in Table 4, together with the current screening classification of each FEP. Appendix B provides a mapping between the CCA FEP list and the DCCA FEP list. This mapping shows how duplicate FEPs from different subsystems have been consolidated into single FEPs, and how detailed FEPs relating to environments of little significance to the WIPP have been consolidated. The mapping also shows how some general FEPs on the DCCA list, and FEPs listing a number of more detailed processes, have been mapped to a category or subcategory rather than to individual FEPs on the CCA list.

A number of FEPs on the CCA list do not have corresponding FEPs on the DCCA list. This does not imply that the DCCA list was not comprehensive, but does indicate that a site-specific FEP list may include greater detail for particular parts of the disposal system than generic FEP lists. This detail corresponds to features or issues of concern at a particular site.

Dissolution is thus treated in detail at the WIPP site, with a number of specific FEPs, whereas the generic list includes only a few general FEPs on this topic.

Appendix C lists those FEPs in the DCCA FEP list that have been excluded because they relate to designs different to that forming the basis of the CCA, because they relate to issues such as chemical toxicity that are not regulated by 40 CFR Part 191, or because they are modeling issues rather than FEPs. Modeling issues are discussed elsewhere in the CCA (e.g. in Section 6.4 and Appendix MASS).

4 Comprehensiveness

Development of the CCA FEP list has taken place in parallel to the preparation of an international FEP list by an OECD/NEA Working Group[2]. The WIPP project is represented on the Working Group, and this has provided an assurance that the categorization scheme developed for the CCA is comparable with the international list. As noted above, the list of individual FEPs developed for a specific site is dependent to some degree on the particular features and issues of concern at that site. The OECD/NEA Working Group has not attempted, therefore, to define an international list of detailed FEPs.

- The stages in the development of the CCA FEP list that have built confidence in its comprehensiveness and appropriateness include:

- A compilation of 9 FEP lists developed in different countries and internationally was used as a starting point.

- An extension to WIPP through review of project literature.

- Formal presentations to the EPA (22-23 September 1994) and stakeholders (28 September 1994) of the initial FEP list and screening arguments.

- Extensive, formal, documented review of the DCCA within the project, by stakeholders, and by the EPA.

- Reduction of the DCCA FEP list in a documented, logical manner.

- Formal documented review of the CCA FEP list within the project.

- Participation in the OECD/NEA Working Group to Develop an International Database of FEPs.

[2]The international list will not be available before late 1996.

Table 4. The CCA FEP List and Screening Classifications

FEPs			Screening Classification
NATURAL			
GEOLOGICAL			
	Stratigraphy		
		Stratigraphy	UP
		Brine reservoirs	DP
	Tectonics		
		Changes in regional stress	SO-C
		Regional tectonics	SO-C
		Regional uplift and subsidence	SO-C
	Structural FEPs		
	Deformation		
		Salt deformation	SO-P
		Diapirism	SO-P
	Fracture development		
		Formation of fractures	SO-P
		Changes in fracture properties	SO-C
	Fault movement		
		Formation of new faults	SO-P
		Fault movement	SO-P
	Seismic activity		
		Seismic activity	UP
	Crustal processes		
	Igneous activity		
		Volcanic activity	SO-P
		Magmatic activity	SO-C
	Metamorphism		
		Metamorphic activity	SO-P
	Geochemical FEPs		
	Dissolution		
		Shallow dissolution	UP
		Lateral dissolution	SO-C
		Deep dissolution	SO-P
		Solution chimneys	SO-P
		Breccia pipes	SO-P
		Collapse breccias	SO-P
	Mineralization		
		Fracture infills	SO-C
SUBSURFACE HYDROLOGICAL			
	Groundwater characteristics		
		Saturated groundwater flow	UP
		Unsaturated groundwater flow	UP
		Fracture flow	UP
		Density effects on groundwater flow	SO-C
		Effects of preferential pathways	UP
	Changes in groundwater flow		
		Thermal effects on groundwater flow	SO-C
		Saline intrusion	SO-P
		Freshwater intrusion	SO-P
		Hydrological response to earthquakes	SO-C
		Natural gas intrusion	SO-P

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
SUBSURFACE GEOCHEMICAL			
	Groundwater geochemistry		
		Groundwater geochemistry	UP
	Changes in groundwater chemistry		
		Saline intrusion	SO-C
		Freshwater intrusion	SO-C
		Changes in groundwater Eh	SO-C
		Changes in groundwater pH	SO-C
		Effects of dissolution	SO-C
GEOMORPHOLOGICAL			
	Physiography		
		Physiography	UP
	Meteorite impact		
		Impact of a large meteorite	SO-P
	Denudation		
	Weathering		
		Mechanical weathering	SO-C
		Chemical weathering	SO-C
	Erosion		
		Aeolian erosion	SO-C
		Fluvial erosion	SO-C
		Mass wasting	SO-C
	Sedimentation		
		Aeolian deposition	SO-C
		Fluvial deposition	SO-C
		Lacustrine deposition	SO-C
		Mass wasting	SO-C
	Soil development		
		Soil development	SO-C
SURFACE HYDROLOGICAL			
	Fluvial		
		Stream and river flow	SO-C
	Lacustrine		
		Surface water bodies	SO-C
	Groundwater recharge and discharge		
		Groundwater discharge	UP
		Groundwater recharge	UP
		Infiltration	UP
	Changes in surface hydrology		
		Changes in groundwater recharge and discharge	UP
		Lake formation	SO-C
		River flooding	SO-C
CLIMATIC			
	Climate		
		Precipitation (e.g. rainfall)	UP
		Temperature	UP

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs				Screening Classification
	Climate change			
		Meteorological		
			Climate change	UP
		Glaciation		
			Glaciation	SO-P
			Permafrost	SO-P
MARINE				
	Seas			
			Seas and oceans	SO-C
			Estuaries	SO-C
	Marine sedimentology			
			Coastal erosion	SO-C
			Marine sediment transport and deposition	SO-C
	Sea level changes			
			Sea level changes	SO-C
ECOLOGICAL				
	Flora & fauna			
			Plants	SO-C
			Animals	SO-C
			Microbes	SO-C
	Changes in flora & fauna			
			Natural ecological development	SO-C
WASTE- AND REPOSITORY-INDUCED				
WASTE AND REPOSITORY CHARACTERISTICS				
	Repository characteristics			
			Disposal geometry	**UP**
	Waste characteristics			
			Waste inventory	**UP**
			Heterogeneity of waste forms	DP
	Container characteristics			
			Container form	SO-C
			Container material inventory	UP
	Seal characteristics			
			Seal geometry	UP
			Seal physical properties	UP
			Seal chemical composition	SO-C
	Backfill characteristics			
			Backfill physical properties	SO-C
			Backfill chemical composition	UP
	Postclosure monitoring			
			Postclosure monitoring	SO-C
RADIOLOGICAL				
	Radioactive decay			
			Radionuclide decay and ingrowth	UP
	Heat from radioactive decay			
			Heat from radioactive decay	SO-C
	Nuclear criticality			
			Nuclear Criticality: heat	SO-P

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
	Radiological effects on material properties		
		Radiological effects on waste	SO-C
		Radiological effects on containers	SO-C
		Radiological effects on seals	SO-C
GEOLOGICAL / MECHANICAL			
	Excavation-induced fracturing		
		Disturbed rock zone	UP
		Excavation-induced changes in stress	UP
	Rock creep		
		Salt creep	UP
		Changes in the stress field	UP
	Roof falls		
		Roof falls	UP
	Subsidence		
		Subsidence	SO-C
		Large scale rock fracturing	SO-P
	Effects of fluid pressure change		
		Disruption due to gas effects	UP
		Pressurization	UP
	Effects of explosions		
		Gas explosions	UP
		Nuclear explosions	SO-P
	Thermal effects		
		Thermal effects on material properties	SO-C
		Thermally-induced stress changes	SO-C
		Differing thermal expansion of repository components	SO-C
	Mechanical effects on material properties		
		Consolidation of waste	UP
		Movement of containers	SO-C
		Container integrity	SO-C
		Mechanical effects of backfill	SO-C
		Consolidation of seals	UP
		Mechanical degradation of seals	UP
		Investigation boreholes	SO-C
		Underground boreholes	UP
SUBSURFACE HYDROLOGICAL / FLUID DYNAMICAL			
	Repository-induced flow		
		Brine inflow	UP
		Wicking	UP
	Effects of gas generation		
		Fluid flow due to gas production	UP
	Thermal effects		
		Convection	SO-C
GEOCHEMICAL / CHEMICAL			
	Gas generation		
	Microbial gas generation		
		Degradation of organic material	UP
		Effects of temperature on microbial gas generation	UP
		Effects of pressure on microbial gas generation	SO-C
		Effects of radiation on microbial gas generation	SO-C

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
		Effects of biofilms on microbial gas generation	UP
	Corrosion		
		Gases from metal corrosion	UP
		Galvanic coupling	SO-P
		Chemical effects of corrosion	UP
	Radiolytic gas generation		
		Radiolysis of brine	SO-C
		Radiolysis of cellulose	SO-C
		Helium gas production	SO-C
		Radioactive gas	SO-C
	Chemical speciation		
		Speciation	UP
		Kinetics of speciation	SO-C
	Precipitation / dissolution		
		Dissolution of waste	UP
		Precipitation	SO-C
		Kinetics of precipitation / dissolution	SO-C
	Sorption reactions		
		Actinide sorption	UP
		Kinetics of sorption	UP
		Changes in sorptive surfaces	UP
	Redox chemistry		
		Effect of metal corrosion	UP
		Redox fronts	SO-P
		Redox kinetics	UP
		Localized reducing zones	SO-C
	Organic complexation		
		Organic complexation	SO-C
		Organic ligands	SO-C
		Humic and fulvic acids	UP
		Kinetics of organic complexation	SO-C
	Exothermic reactions		
		Exothermic reactions	SO-C
		Concrete hydration	SO-C
	Chemical effects on material properties		
		Chemical degradation of seals	UP
		Chemical degradation of backfill	SO-C
		Microbial growth on concrete	UP
CONTAMINANT TRANSPORT MODE			
	Solute transport		
		Solute transport	UP

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification
	Colloid transport		
		Colloid transport	UP
		Colloid formation and stability	UP
		Colloid filtration	UP
		Colloid sorption	UP
	Particulate transport		
		Suspensions of particles	DP
		Rinse	SO-C
		Cuttings	DP
		Cavings	DP
		Spallings	DP
	Microbial transport		
		Microbial transport	UP
		Biofilms	SO-C
	Gas transport		
		Transport of radioactive gases	SO-C
CONTAMINANT TRANSPORT PROCESS			
	Advection		
		Advection	UP
	Diffusion		
		Diffusion	UP
		Matrix diffusion	UP
	Thermochemical transport phenomena		
		Soret effect	SO-C
	Electrochemical transport phenomena		
		Electrochemical effects	SO-C
		Galvanic coupling	SO-P
		Electrophoresis	SO-C
	Physicochemical transport phenomena		
		Chemical gradients	SO-C
		Osmosis	SO-C
		Alpha recoil	SO-C
		Enhanced diffusion	SO-C
ECOLOGICAL			
	Plant, animal and soil uptake		
		Plant uptake	SO-R
		Animal uptake	SO-R
		Accumulation in soils	SO-C
	Human uptake		
		Ingestion	SO-R
		Inhalation	SO-R
		Irradiation	SO-R
		Dermal sorption	SO-R
		Injection	SO-R

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs	Screening Classification: Historical, ongoing, and near future	Screening Classification: Future
HUMAN ACTIONS		
GEOLOGICAL		
Drilling		
Oil and gas exploration	SO-C	DP
Potash exploration	SO-C	DP
Water resources exploration	SO-C	SO-C
Oil and gas exploitation	SO-C	DP
Groundwater exploitation	SO-C	SO-C
Archeological investigations	SO-R	SO-R
Geothermal	SO-R	SO-R
Other resources	SO-C	DP
Enhanced oil and gas recovery	SO-C	DP
Liquid waste disposal	SO-R	SO-R
Hydrocarbon storage	SO-R	SO-R
Deliberate drilling intrusion	SO-R	SO-R
Excavation activities		
Potash mining	UP	DP
Other resources	SO-C	SO-R
Tunneling	SO-R	SO-R
Construction of underground facilities	SO-R	SO-R
Archeological excavations	SO-C	SO-R
Deliberate mining intrusion	SO-R	SO-R
Subsurface explosions		
Resource recovery		
Explosions for resource recovery	SO-C	SO-R
Underground nuclear device testing		
Underground nuclear device testing	SO-C	SO-R
SUBSURFACE HYDROLOGICAL AND GEOCHEMICAL		
Borehole fluid flow		
Drilling-induced flow		
Drilling fluid flow	SO-C	DP
Drilling fluid loss	SO-C	DP
Blowouts	SO-C	DP
Drilling-induced geochemical changes	UP	DP
Fluid extraction		
Oil and gas extraction	SO-C	SO-R
Groundwater extraction	SO-C	SO-R
Fluid injection		
Liquid waste disposal	SO-C	SO-R
Enhanced oil and gas production	SO-C	SO-R
Hydrocarbon storage	SO-C	SO-R
Fluid injection-induced geochemical changes	UP	SO-R
Flow through abandoned boreholes		
Natural borehole fluid flow	SO-C	DP
Waste-induced borehole flow	SO-R	DP
Flow through undetected boreholes	SO-P	NA
Borehole-induced solution and subsidence	SO-C	SO-C
Borehole-induced mineralization	SO-C	SO-C
Borehole-induced geochemical changes	UP	DP

Table 4. The CCA FEP List and Screening Classifications (continued)

FEPs			Screening Classification: Historical, ongoing, and near future	Screening Classification: Future
	Excavation-induced flow			
		Changes in groundwater flow due to mining	UP	DP
		Changes in geochemistry due to mining	SO-C	SO-R
	Explosion-induced flow			
		Changes in groundwater flow due to explosions	SO-C	SO-R
GEOMORPHOLOGICAL				
	Land use and disturbances			
		Land use changes	SO-R	SO-R
		Surface disruptions	SO-C	SO-R
SURFACE HYDROLOGICAL				
	Water control and use			
		Damming of streams or rivers	SO-C	**SO-R**
		Reservoirs	SO-C	**SO-R**
		Irrigation	SO-C	**SO-R**
		Lake usage	SO-R	**SO-R**
		Altered soil or surface water chemistry by human activities	SO-C	**SO-R**
CLIMATIC				
	Anthropogenic climate change			
		Greenhouse gas effects	SO-R	**SO-R**
		Acid rain	SO-R	**SO-R**
		Damage to the ozone layer	SO-R	**SO-R**
MARINE				
	Marine activities			
		Coastal water use	SO-R	**SO-R**
		Sea water use	SO-R	**SO-R**
		Estuarine water use	SO-R	**SO-R**
ECOLOGICAL				
	Agricultural activities			
		Ranching	SO-C	**SO-R**
		Arable farming	SO-C	**SO-R**
		Fish farming	SO-R	**SO-R**
	Social and technological developments			
		Demographic change and urban development	SO-R	**SO-R**
		Loss of records	NA	**DP**

Legend:

UP FEPs accounted for in the assessment calculations for undisturbed performance for 40 CFR § 191.13 (as well as 40 CFR § 191.15 and Subpart C of 40 CFR Part 191).

DP FEPs accounted for (in addition to all UP FEPs) in the assessment calculations for disturbed performance for 40 CFR § 191.13.

SO-R FEPs eliminated from performance assessment calculations on the basis of regulations provided in 40 CFR Part 191 and criteria provided in 40 CFR Part 194.

SO-C FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of consequence.

SO-P FEPs eliminated from performance assessment (and compliance assessment) calculations on the basis of low probability of occurrence.

5 References

Andersson, J. (Editor) 1989 *The Joint SKI/SKB Scenario Development Project.* SKB Technical Report 89:35, Stockholm.

Cranwell, R.M., R.V. Guzowski, J.E. Campbell, and N.R. Ortiz. 1990. *Risk Methodology for Geologic Disposal of Radioactive Waste: Scenario Selection Procedure.* SAND80-1429, NUREG/CR-1667. Albuquerque, NM: Sandia National Laboratories.

Goodwin, B.W., Stephens, M.E., Davison, C.C., Johnson, L.H. and Zach, R. 1994. *Scenario Analysis for the Postclosure Assessment of the Canadian concept for Nuclear Fuel Waste Disposal.* Atomic Energy of Canada Limited Report, AECL-10969, COG-94-247.

Guzowski, R.V. and Newman, G. 1993. *Preliminary Identification of Potentially Disruptive Scenarios at the Greater Confinement Disposal Facility, Area 5 of the Nevada Test Site.* SAND93-7100. Albuquerque, NM: Sandia National Laboratories.

Hodgkinson, D and Sumerling, T. 1989. A review of approaches to scenario analysis for repository safety assessment. In: *Proceedings of NEA/IAEA/CEC Symposium on "Safety Assessment of Radioactive Waste Repositories,"* Nuclear Energy Agency, Paris.

IAEA, 1985. *Performance Assessment for Underground Radioactive Waste Disposal Systems.* International Atomic Energy Authority Safety Series, No. 68.

Miller, W.M. and Chapman, N.A. 1993. *Identification of Relevant Processes (System Concept Group Report).* HMIP Assessment of Nirex Proposals, Technical Report IZ3185-TR1.

NAGRA, 1985. *Project Gewahr 1985 - Nuclear Waste Management in Switzerland - Feasibility studies and safety analyses.* Nagra Project Gewähr Report Series, NGB 85-09, Nagra, Baden.

Nuclear Energy Agency. 1992. *Systematic Approaches to Scenario Development.* Paris: OECD/NEA.

Prij, J. 1993. *PROSA. PRObabilistic Safety Assessment - Final Report.* OPLA-1A. Petten, The Netherlands: ECN, Netherlands Energy Research Foundation.

Sandia National Laboratories. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991.* SAND91-0893, Vols 1-4. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

Sandia National Laboratories. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992.* SAND92-0700, Vols 1-5. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

Stenhouse, M.J., Chapman, N.A., and Sumerling, T.J. 1993. *SITE-94 Scenario Development FEP Audit List Preparation: Methodology and Presentation.* SKI Technical Report 93:27. SKI Nuclear Power Inspectorate, Stockholm.

Thorne, M.C. 1992. *Dry Run 3 - A Trial Assessment of Underground Disposal of Radioactive Wastes Based on Probabilistic Risk Analysis - Volume 8: Uncertainty and Bias Audit.* DoE/HMIP/RR/92.040, London: UKDoE/HMIP.

U.S. DOE (Department of Energy). 1994. *Compliance Status Report for the Waste Isolation Pilot Plant.* DOE/WIPP 94-019, Revision 0, Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office.

U.S. DOE (Department of Energy). 1995a. *Draft Title 40 CFR Part 191 Compliance Certification Application for WIPP.* DOE/CAO-Predecisional Draft-2056, Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office.

U.S. DOE (Department of Energy). 1995b. *Draft Title 40 CFR Part 191 Compliance Certification Application for WIPP.* DOE/CAO-Predecisional Draft-2056, July Update, Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office.

APPENDIX A: DCCA FEP LIST BY CATEGORY

This Appendix presents the complete list of FEPs developed as part of the Draft Compliance Certification Application (DCCA). They are categorized according to the following sub-systems:

(1) Waste

(2) Canister

(3) Backfill

(4) Seal systems

(5) Near-field

(6) Far-field

(7) Biosphere

(8) Geology/climate changes

(9) Human influences

WASTE

1.1 Waste: characteristics (initial)

Inventory: radionuclides
Inventory: hazardous constituents (e.g. VOCs, heavy metals)
Long-term physical stability
Heterogeneity of waste forms (chemical, physical)
Stability of glass
Teratogenic contaminants

1.2 Waste: radionuclide decay and ingrowth

Waste: radionuclide decay and ingrowth

1.3 Waste: radiological/radiation effects

Radiolysis
Recoil of alpha-decay
Release of stored energy
Nuclear criticality (preclosure)
Nuclear criticality (postclosure)
Radiation damage of the matrix including embrittlement

1.4 Waste: gas generation and effects

Gas generation: He production
Methane and carbon dioxide by microbial degradation of cellulose and other organic wastes
Active methane, carbon dioxide, radon, tritiated hydrogen and other active gases
Hydrogen by metal corrosion
Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire
Chemical changes due to gas production
Hydrogen: effects of microbial growth on concrete
Methane/CO_2 production: aerobic degradation
Methane/CO_2 production: effects of temperature
Methane/CO_2 production: effects of lithostatic pressure
Methane/CO_2 production: energy and nutrient control of metabolism
Methane/CO_2 production: effects of radiation on microbial populations
Microbiological effects due to cellulose degradation
Gas generation from concrete
Methane/CO_2 production: anaerobic production
Methane/CO_2 production: Inhibition due to the pressure of toxic materials
Methane/CO_2 production: Effects of biofilms
Methane/CO_2 production: Carbonate/bicarbonate exchange with concrete

WASTE (Continued)

1.5 Waste: heat generation
- Radioactive decay: heat
- Nuclear criticality: heat
- Material property changes: heat

1.6 Waste: thermomechanical effects
- Thermal cracking
- Material property changes
- Differing thermal expansion of glass matrix and canister

1.7 Waste: thermochemical effects
- Thermally induced chemical changes (water chemistry)

1.8 Waste: electrochemical effects
- Electrochemical gradients
- Electrical effects of metal corrosion
- Galvanic coupling

1.9 Waste: degradation/corrosion/dissolution
- Dissolution
- Precipitation
- Source terms
- Source terms (hazardous constituents)
- Degradation of plastics and cellulosics
- Release of sorbed VOCs
- Metal corrosion: wastes
- Leaching: wastes
- Rinse
- Internal corrosion due to waste
- Fracturing
- External stress

1.10 Waste: geochemical reactions/regime
- Chemical gradients, osmosis
- Chemical kinetics
- Complex formation: wastes
- Chemical changes due to metal corrosion
- Chemical changes due to gas production
- Chemical effects: geochemical change
- Recrystallization
- Redox potential
- Dissolution chemistry
- Interactions with corrosion products and waste
- Solubility with fuel matrix

1.11 Waste: radionuclide and contaminant chemistry
- Speciation
- Complex formation: wastes
- Solubility within fuel matrix
- Recrystallization
- Solubility
- Precipitation
- Solubility, speciation, precipitation: hazardous constituents

WASTE (Continued)

1.12 Waste: Others

Colloid formation: wastes
Damaged or deviating waste contents
Role of eventual channelling within the canister
I, Cs-migration to fuel surface
Boundary conditions
Correlation
Sudden energy release
Waste incompatibility
Design modifications: waste (e.g. buffer additives)
Nuclear criticality: explosions
Capillary action

CANISTER

2.1 Canister: materials/construction

Inventory

2.2 Canister: corrosion/degradation processes

Container failure (early)
Container failure (long term)
Container healing
Corrosion (including partial corrosion)
Pitting
Radiation damage to container (embrittlement)
Uniform corrosion
Structural container metal corrosion: localized
Structural container metal corrosion: bulk
Structural container metal corrosion: crevice
Structural container metal corrosion: stress corrosion cracking
Chemical changes due to metal corrosion
Chemical reactions (copper corrosion)
Role of chlorides in copper corrosion
Corrosive agents, sulphides, oxygen, etc.
Backfill effects on container corrosion
Swelling of corrosion products

2.3 Canister: gas generation and effects

Hydrogen: corrosion of container steel
Gas transport in the waste container
Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire

2.4 Canister: microbiological effects/microbial activity

Canister: microbiological effects/microbial activity

CANISTER (Continued)

2.5 Canister: thermomechanical effects

- Differing thermal expansion of canister and backfill
- Thermal cracking
- Differing thermal expansion of materials (glass, canister)

2.6 Canister: electrochemical effects

- Electrochemical gradients
- Coupled effects (electrophoresis)
- Natural telluric electrochemical reactions
- Electrochemical cracking
- Galvanic coupling

2.7 Canister: stress/mechanical effects

- Canister movement
- Mechanical canister damage (failure)
- Creeping of copper
- Stress corrosion cracking
- Loss of ductility
- Cracking along welds
- External stress
- Hydrostatic pressure on canister
- Internal pressure
- Swelling of corrosion products
- Hydride cracking

2.8 Canister: geochemical reactions/regime

- Chemical kinetics
- Container corrosion products
- Precipitation
- Dissolution
- Speciation of corrosion products (include in water chemistry)
- Chemical effects: Interactions of waste canister and rock
- Chemical gradients (electrochemical effects and osmosis)

2.9 Canister: Radionuclide and contaminant transport through containers

- Release of radionuclides from the failed canister
- Release of hazardous constituents from the failed canister

2.10 Canister: others

- Channelling within the canister (preferential pathways)
- Radiation effects on canister
- Random canister defects - quality control
- Common cause canister defects - quality control
- Material defects, e.g. early canister failure
- Incomplete filling of canisters
- Boundary conditions
- Correlation
- Time dependence
- Design modifications: canister
- Nuclear criticality: explosions

BACKFILL

3.1 Backfill: characteristics

Backfill characteristics (e.g. hydraulic conductivity)
Long-term physical stability
Buffer additives

3.2 Backfill: resaturation/desaturation

Backfill: resaturation/desaturation

3.3 Backfill: mechanical effects

Preferential pathways in the backfill
Mechanical effects: local fractures/cracks (preferential pathways)
Mechanical failure of backfill (preferential pathways)
Swelling pressure
Movement of canister in backfill
Uneven swelling of bentonite
Swelling of corrosion products
Cracking: concrete
Sealing of cracks: concrete
External stress

3.4 Backfill: thermal effects

Convection (contaminant transport)
Hydrothermal alteration
Variations in groundwater temperature
Differing thermal expansion (canister-backfill, buffer-host rock)
Thermal effects on the backfill material
Soret effect
Natural thermal effects
Thermal effects (e.g. concrete hydration)
Thermochemical effects

3.5 Backfill: electrochemical effects

Natural telluric electrochemical reactions

3.6 Backfill: gas effects and transport

Groundwater flow due to gas production
Gas transport in the near field as gas phase and in solution
Chemical effects: gas generation
Transport of active gases
Methane/CO_2 production
Effects of hydrogen from metal corrosion
Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire
Methane/CO_2 production: effects of hydrogen from metal corrosion
Gas generation from concrete

BACKFILL (Continued)

3.7 Backfill: microbiological effects/microbial activity

Backfill: microbiological effects/microbial activity
Hydrogen: effects of microbial growth on concrete

3.8 Backfill: degradation

Degradation of the bentonite by chemical reactions
Coagulation of bentonite
Radiation effects on bentonite
Erosion of backfill
Alkali-aggregate reaction

3.9 Backfill: geochemical regime

Chemical gradients
Chemical kinetics
Precipitation
Dissolution
Chemical changes due to waste degradation
Chemical changes due to gas production
Chemical changes due to complex formation
Chemical changes due to colloid production
Chemical changes due to sorption
Chemical changes due to speciation
Isotopic dilution
Chemical changes due to corrosion
Saturation of sorption sites
Effects of bentonite on groundwater chemistry
Reactions with cement pore water (include in chemical degradation)
Redox front
Thermochemical changes
Saline groundwater intrusion
Effects at saline-freshwater interface
Natural changes in groundwater flow direction
Biogeochemical changes
Exchange capacity exceeded
Cement sulphate reaction

3.10 Backfill: Radionuclide and contaminant transport processes

Groundwater and gas flow
Advection/dispersion: radionuclides
Advection/dispersion: hazardous constituents
Diffusion: radionuclides
Diffusion: hazardous constituents
Unsaturated transport
Transport of chemically active substances into the near-field
Transport of radionuclides bound to microbes

BACKFILL (Continued)

3.11 Backfill: radionuclide and contaminant chemistry

Precipitation, reconcentration
Recrystallization
Dissolution
Sorption (linear, nonlinear, irreversible)
Speciation
Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)
Dissolution, speciation, sorption, precipitation; hazardous constituents
Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)
Changes in sorptive surfaces
Radiolysis

3.12 Backfill: others

Faulty backfill emplacement
Colloid transport (inorganic and organic)
Extreme channel flow of oxidants and nuclides (preferential pathways)
Inadequate backfill or compaction, voidage
Anion exchange
Groundwater flow: initial conditions
Backfill material deficiencies
Boundary conditions
Correlation
Time dependence
Nuclear criticality: explosions
Nuclear criticality: heat
Design modifications: backfill
Capillary action

SEALS

4.1 Seals: characteristics

Seal characteristics (e.g. hydraulic conductivity)
Long-term physical stability
Concrete
Buffer additives

4.2 Seals: resaturation/desaturation

Seals: resaturation/desaturation

4.3 Seals: mechanical effects

Preferential pathways in the seals
Mechanical effects: local fractures/cracks (preferential pathways)
Mechanical failure of seals (preferential pathways)
Swelling pressure

SEALS (Continued)

External stress
Movement of canister
Uneven swelling of bentonite
Swelling of corrosion products
Cracking: concrete
Sealing of cracks: concrete

4.4 Seals: thermal effects

Convection (contaminant transport)
Hydrothermal alteration
Variations in groundwater temperature
Differing thermal expansion (canister-seal, buffer-host rock)
Thermal effects on the seal material
Soret effect
Natural thermal effects
Thermal effects (e.g. concrete hydration)
Thermochemical effects

4.5 Seals: electrochemical effects

Natural telluric electrochemical reactions

4.6 Seals: gas effects and transport

Groundwater flow due to gas production
Gas transport in the near field as gas phase and in solution
Chemical effects: gas generation
Transport of active gases
Methane/CO_2 production
Effects of hydrogen from metal corrosion
Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire
Methane/CO_2 production: effects of hydrogen from metal corrosion
Gas generation from concrete

4.7 Seals: microbiological effects/microbial activity

Seal: microbiological effects/microbial activity
Hydrogen: effects of microbial growth on concrete

4.8 Seals: degradation

Degradation of the bentonite by chemical reactions
Coagulation of bentonite
Radiation effects on bentonite
Erosion of seals
Alkali-aggregate reaction

4.9 Seals: geochemical regime

Chemical gradients
Chemical kinetics
Precipitation

SEALS (Continued)

Dissolution
Chemical changes due to waste degradation
Chemical changes due to gas production
Chemical changes due to complex formation
Chemical changes due to colloid production
Chemical changes due to sorption
Chemical changes due to speciation
Isotopic dilution
Chemical changes due to corrosion
Saturation of sorption sites
Effects of bentonite on groundwater chemistry
Reactions with cement pore water (include in chemical degradation)
Redox front
Thermochemical changes
Saline groundwater intrusion
Effects at saline-freshwater interface
Natural changes in groundwater flow direction
Biogeochemical changes
Exchange capacity exceeded
Cement sulphate reaction

4.10 Seals: Radionuclide and contaminant transport processes

Groundwater and gas flow
Advection/dispersion: radionuclides
Advection/dispersion: hazardous constituents
Diffusion: radionuclides
Diffusion: hazardous constituents
Unsaturated transport
Transport of chemically active substances into the near-field
Transport of radionuclides bound to microbes

4.11 Seals: radionuclide and contaminant chemistry

Precipitation, reconcentration
Sorption (linear, nonlinear, irreversible)
Speciation
Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)
Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)
Changes in sorptive surfaces
Radiolysis
Dissolution
Recrystallization
Dissolution, speciation, sorption, precipitation; hazardous constituents

SEALS (Continued)

4.12 Seals: others

Faulty seal emplacement
Colloid transport (inorganic and organic)
Extreme channel flow of oxidants and nuclides (preferential pathways)
Inadequate seal or compaction, voidage
Anion exchange
Groundwater flow: initial conditions
Seal material deficiencies
Boundary conditions
Investigation borehole seal failure/degradation
Shaft seal failure/degradation
Design modifications: seals
Correlation
Time dependence
Nuclear criticality: explosions
Nuclear criticality: heat

NEAR-FIELD

5.1 Near-field rock: elements/materials

Disposal geometry
Rock properties (porosity, permeability, hydraulic head, conductivity)
Colloids

5.2 Near-field rock: degradation

Rock property changes (hydraulic conductivity, fractures, pore blocking, channel formation/closure)
Creeping of rock mass
Caving/roof collapse
Physico-chemical degradation of concrete

5.3 Near-field rock: hydraulic effects/groundwater flow

Unsaturated transport
Groundwater flow due to gas production
Groundwater flow (saturated conditions, including fracture flow)
Groundwater flow, effects of solution channels (preferential pathways)
Repository thermally-induced groundwater transport
Naturally thermally-induced groundwater transport
Thermo-hydro-mechanical effects
Resaturation
Disturbed zone (hydromechanical) effects
Natural changes in groundwater chemistry and flow direction

NEAR-FIELD (Continued)

Repository-induced changes in groundwater flow direction

5.4 Near-field rock: mechanical effects

Formation of cracks
Changes in in-situ stress field
Changes in moisture content due to stress relief
Differential elastic response
Non-elastic response
Repository-induced seismicity
Externally-induced seismicity
Differing thermal expansion of host rock zones
Uneven swelling of bentonite
Thermally-induced stress/fracturing in host rock
Excavation-induced stress/fracturing in host rock

5.5 Near-field rock: thermal effects

Convection
Hydrothermal alteration
Variations in groundwater temperature
Thermal effects (e.g. concrete hydration)
Thermal effects and transport (diffusion) properties
Thermal effects on hydrochemistry
Thermal differential elastic response
Thermal non-elastic response

5.6 Near-field rock: gas effects and transport

Gas effects: pressurization
Gas effects: disruption
Gas effects: explosions
Gas effects: fire
Gas transport in the near field as gas phase and in solution
Methane/CO_2 production: effects of microbial growth on properties of concrete
Accumulation of gases under permafrost
Methane intrusion
Transport of active gases
Methane CO_2 production: effects of lithostatic pressure
Methane CO_2 production: effects of hydrogen from metal corrosion
Methane CO_2 production: effects of radiation on microbial populations
Methane and CO_2 production: energy and nutrient control of metabolism

5.7 Near-field rock: microbiological/biological activity

Natural microbial activity
Transport of microbes into the near-field
Rock property changes: microbial pore blocking
Biogeochemical changes

NEAR-FIELD (Continued)

5.8 Near-field rock: geochemical regime

Chemical gradients
Chemical kinetics
Pore blockage: concrete
Cement-sulphate reaction: concrete
Changes in pore water composition, pH, Eh: concrete
Chemical changes due to colloid production (chemical changes)
Chemical changes due to sorption (chemical changes)
Chemical changes due to speciation (chemical changes)
Fracture mineralization
Fluid interactions: dissolution
Chemical effects: interactions of waste canister and rock
Physico-chemical phenomena/effects (e.g. colloid formation)
Reconcentration
Thermochemical changes
Chemical effects of rock reinforcement
Saline (or fresh) groundwater intrusion
Effects at saline-freshwater interface
Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)
Physico-chemical degradation of concrete
Changes in groundwater flow direction

5.9 Near-field rock: radionuclide and contaminant chemistry

Precipitation, reconcentration
Dissolution
Recrystallization
Sorption (linear, nonlinear, irreversible)
Speciation
Dissolution, speciation, sorption, precipitation; hazardous constituents
Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)
Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)
Changes in sorptive surfaces
Dilution (mass, isotopic, species)

5.10 Near-field rock: Radionuclide and contaminant transport processes

Groundwater and gas flow
Advection/dispersion: radionuclides
Advection/dispersion: hazardous constituents
Diffusion: radionuclides
Diffusion: hazardous constituents
Soret effect
Transport of radionuclides bound to microbes
Colloid transport

NEAR-FIELD (Continued)

5.11 Near-field rock: others

Incomplete repository or borehole closure
Unmodeled design features
Inadequate design: shaft seal and exploration borehole seal failure
Open boreholes
Extreme channel flow of oxidants and nuclides (preferential pathways)
Poor quality construction
Abandonment of unsealed repository
Effects of phased operations
Repository flooding during operations
Dehydration of salt minerals
Release of stored energy
Nuclear criticality: heat
Methylation
Cavitation
Improper operation
Monitoring and remedial activities
Preclosure events
Retrievability
Blasting and vibration
Design modification: geometry
Design modification: DRZ (e.g. grouting)
Accidents during operation
Mutation
Boundary conditions
Correlation
Time-dependence
Sabotage
Nuclear criticality: explosions

FAR-FIELD

6.1 Rock properties

Rock properties (porosity, permeability, discharge zones, fractures)

6.2 Hydrogeological effects

Natural rock property changes (porosity, permeability, fractures, pore blocking)
Dewatering
Geothermal gradient effects
Salinity effects on flow
Saturated groundwater flow
Variations in groundwater temperature
Gas-induced groundwater transport

FAR-FIELD (Continued)

Groundwater recharge
Thermal effects: fluid pressure, density, viscosity changes
Thermal effects: fluid migration
Saline groundwater intrusion
Fresh groundwater intrusion
Groundwater conditions (saturated/unsaturated)
Changes in geometry of the flow system
Changes in driving forces of the flow system
Changes in groundwater flow direction
Borehole - well

6.3 Physical/mechanical effects

Repository-induced seismicity
Externally-induced seismicity
Fault activation
Differential elastic response
Subsidence
Non-elastic response

6.4 Thermal effects

Geothermal gradient effects
Thermal differential elastic response
Thermal non-elastic response

6.5 Gas effects and transport

Gas transport into and through the far-field (gas phase and in solution)
Multiphase flow and gas-driven flow
Effects of natural gases
Transport of active gases

6.6 Microbiological/biological activity

Microbial activity
Transport of radionuclides bound to microbes
Biogeochemical changes

6.7 Geochemical regime

Groundwater composition changes (pH, Eh, chemical composition)
Fracture mineralization
Weathering, mineralization
Dissolution of fracture fillings, precipitation
Far field hydrochemistry - acids, oxidants, nitrates
Effects at saline-freshwater interface
Chemical gradients (electrochemical effects and osmosis)
Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)
Salinity: implications of evaporite deposits/minerals

6.8 Radionuclide and contaminant chemistry

Complexation by organics (including humic and fulvic acids)

FAR-FIELD (Continued)

Precipitation, dissolution, recrystallization, reconcentration
Sorption (linear, nonlinear, irreversible)
Speciation
Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)
Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)
Changes in sorptive surfaces
Dilution (mass, isotopic, species)

6.9 Radionuclide and contaminant transport processes

Groundwater flow, advection/dispersion (saturated conditions)
Diffusion (bulk, matrix, surface)
Unsaturated transport
Groundwater flow: fracture
Groundwater flow: effects of solution channels (preferential pathways)
Soret effect
Transport of radionuclides bound to microbes
Gas mediated transport
Colloids: formation & effects (including inorganic and organic colloid transport)

6.10 Others

Boreholes unsealed
Incomplete vault closure
Inadequate design: exploration borehole seal failure
Undetected features (e.g. faults, fracture networks, shear zones, discontinuities, gas)
Radiolysis, radiation damage
Cavitation
Correlation
Nuclear criticality
Explosion

BIOSPHERE

7.1 Human considerations

Space heating
Charcoal production
Land use changes
Demographic change, urban development
Crop fertilization
Crop storage
Peat and leaf litter harvesting
Hydroponics

BIOSPHERE (Continued)

Water leak into underground living space

7.2 Ecological factors

Animal habits (grooming and fishing, soil ingestion, diets, scavengers/predators)
Houseplants
Tree sap
Terrestrial ecological development: natural and agricultural systems
Terrestrial ecological development: Effects of succession
Terrestrial ecological development: Estuarine
Plants: Root uptake, including deep rooting species
Plants: Deposition on surfaces
Plants: Vapor uptake
Plants: Internal translocation and retention
Plants: Washoff and leaching by rainfall
Plants: Leaf-fall and senescence
Plants: Cycling processes
Animals: Uptake by ingestion
Animals: Uptake by inhalation
Animals: Internal translocation and retention
Animals: Cycling processes
Animals: Effects of relocation and migration
Precipitation, temperature and soil water balance
Ecological change (e.g. forest fire cycles)
Ecological response to climate, including glacial/ interglacial cycling, (e.g. desert formation)
Biological evolution
Intrusion (animal)

7.3 Soil/sediment effects

Lake infilling
Erosion - wind
Alkali flats
Capillary rise in soil
Soil properties (type, depth, porewater pH, moisture, sorption)
Soil leaching
Ionic exchange in soil
Sediment resuspension in water bodies
Sedimentation in water bodies
Groundwater discharge to soils: advective, diffusive, biotic, volatilization
Accumulation in sediments
Accumulation in soils and organic debris, including peat
Pedogenesis
Evaporation of soil moisture
Solid discharge via erosional processes
Saltation

BIOSPHERE (Continued)

7.4 Surface/near-surface water processes

Groundwater discharge (to surface water)
Groundwater discharge (springs)
Groundwater discharge (wells)
Flushing of water bodies
Surface water bodies: properties (e.g., pH)
Near-surface runoff processes: overland flow, interflow, return flow, macropore flow
Near-surface runoff processes: variable source area response
Surface flow characteristics: stream/river flow
Surface flow characteristics: sediment transport
Surface flow characteristics: meander migration or other fluvial response
Surface flow characteristics: lake formation/sedimentation
Surface flow characteristics: effects of sea level change
Estuarine surface flow characteristics: tidal cycling, sediment transport, successional development, effects of sea level change
Surface water bodies: water flow
Surface water bodies: suspended sediments
Surface water bodies: bottom sediments
Surface water bodies: effects on vegetation
Surface water bodies: effects of fluvial system development
Surface water mixing
Sediment/water/gas interaction with the atmosphere
Terrestrial water use (including wells and dams)
River flow and lake level changes
Dams
Rivercourse meander
Wetlands
Flood (short-term)
Acid rain
Artificial lake mixing
Drought

7.5 Coastal water/ocean processes

Coastal waters: tidal mixing, residual current mixing, effects of sea level change
Ocean waters: water exchange, effects of sea level change
Groundwater discharge to marine waters including coastal
Estuaries: water flow, suspended sediments, bottom sediments, effects of salinity variation, effects on vegetation, estuarine development and sea level change

BIOSPHERE (Continued)

Coastal waters: water transport, bottom and suspended sediment transport, effects of sea level change, estuarine development and coastal erosion
Estuarine water use
Coastal water use
Sea water use

7.6 Gas effects and transport

Gas leakage into underground living space
Radon emission
Gas transport: gas phase and in solution
Gas discharge

7.7 Microbiological/biological activity

Microbial activity
Bioaccumulation and translocation
Biotoxicity
Soil and sediment transport including bioturbation
Burrowing animals
Transport of radionuclides bound to microbes
Biogeochemical changes

7.8 Geochemical regime (general)

Soil and surface water chemistry (pH, Eh)
Fluid interactions: dissolution, precipitation
Weathering, mineralization
Physico-chemical phenomena/effects (e.g. colloid formation)
Altered soil or surface water chemistry (pH, Eh)
Thermal effects on hydrochemistry
Chemical gradients (electrochemical effects and osmosis)
Colloids, complexing agents

7.9 Radionuclide and contaminant chemistry

Complexation by organics (including humic and fulvic acids)
Precipitation, dissolution, recrystallization, reconcentration
Sorption (linear, nonlinear, irreversible)
Speciation
Chemical changes due to sorption, complex formation, speciation, gas, solubility
Solubility effects (pH and Eh)
Sorption effects (pH and Eh)
Changes in sorptive surfaces
Dilution (mass, isotopic, species)

7.10 Radionuclide and contaminant transport processes

Water flow: advection and dispersion
Diffusion (bulk, matrix, surface)
Gas-mediated transport
Transport of active gases: gas phase and in solution

BIOSPHERE (Continued)

Transport of radionuclides bound to microbes

7.11 Radiological factors

Building materials
Carcasses
Carcinogenic contaminants
Convection, turbulence and diffusion (atmospheric)
Critical group - agricultural labor,
  clothing and home furnishings
  evolution
  house location
  individuality
  leisure pursuits
  pets
Dermal sorption - nuclides other than tritium
Household dust and fumes
Human diet
Food preparation
Human soil ingestion
Precipitation (meteoric)
Deposition (wet and dry)
Radiotoxic contaminants
Showers and humidifiers
Suspension in air
Wind
External exposure: land, sediments, water bodies
Ingestion and drinking water
Ingestion and agricultural crops
Ingestion and domestic animal products
Ingestion and wild plants
Ingestion and wild animals
Ingestion and soils and sediments
Inhalation and soils and sediments
Inhalation and gases and vapors (indoor/outdoor)
Inhalation and biotic material
Inhalation and salt particles
Sediment/water/gas interaction with the atmosphere
Mutagenic contaminants
Dermal sorption - tritium
Sensitization to radiation
Radioactive decay

7.12 Others

Colloids: formation and effects (including inorganic and organic colloid transport)
Greenhouse-induced ecological effects (including food production)
Smoking
Boreholes - unsealed

BIOSPHERE (Continued)

Loss of integrity of borehole seals: seal failure or degradation
Inadequate design: exploration borehole seal failure
Intrusion in accumulation zone in the biosphere (animals)
Chemical toxicity
Correlation
Seasons
Terrestrial surface
Uncertainties
Toxicity of mined rock
Ozone layer failure
Herbicides, pesticides, fungicides

GEOLOGY / CLIMATE CHANGES

8.1 Seismic Events/major land movement

Earthquakes
Regional uplift and subsidence (e.g. orogenic, isostatic)
Externally-induced seismicity
Natural seismicity

8.2 Rock deformation

Salt deformation/diapirism
Faulting/fracturing: change of properties - natural
Faulting/fracturing: change of properties - human-induced
Major incision
Movements at faults
Formation of new faults
Formation of interconnected fracture systems

8.3 Metamorphic and igneous processes

Metamorphic activity
Magmatic activity
Volcanism

8.4 Erosion/weathering (surface)

Aeolian and fluvial denudation
Mass wasting
Changes in topography
Weathering
Extreme erosion and denudation: glacial-induced (e.g. coastal/stream erosion)
Coastal erosion due to sea level change
Erosion: glacial
Stream erosion
Sedimentation
Land slide
Freshwater sediment transport and deposition

GEOLOGY / CLIMATE CHANGES (Continued)

Marine sediment transport and deposition
Solifluction

8.5 Groundwater flow and effects

Variation in groundwater recharge

8.6 Surface water flow and effects

Hydrological change
Flooding
Precipitation, temperature and soil water balance
Snow melt
River flow and lake level changes
Alkali flats
Rivercourse meander

8.7 Sea level effects

Sea level change
River incision/sedimentation due to sea level change

8.8 Magnetic effects

Changes in the Earth's magnetic field

8.9 Glaciation/glacial effects

Glaciation
Glacial/interglacial cycling effects (including sea level changes)
Permafrost
Accumulation of gases under permafrost
No ice age

8.10 Climate effects (natural)

Drought
Dust storms and desertification (massive)
Climate change
Insolation
Ozone layer (failure)
Acid rain

8.11 Others

Anthropogenic climate change drought (greenhouse effect)
Greenhouse-induced effects (e.g. sea level change, precipitation, temp.)
Hurricanes
Tsunamis
Seiches
Meteorite impact
Diagenesis
Greenhouse-induced storm surges
Global effects
Terrestrial surface
Formation of dissolution cavities

HUMAN INFLUENCES

9.1 Inadvertent intrusion into repository

Archeological investigations
Exploratory boreholes (oil, gas)
Resource exploitation (e.g. hydrocarbon, geothermal)
Reuse of boreholes
Intrusion in accumulation zone in the biosphere
Injection wells
Intrusion (deliberate)
- recovery of wastes or associated materials (mining)
- malicious (sabotage, act of war (nuclear))
- recovery of repository materials

9.2 Surface activities

Earthmoving
Altered soil or surface water chemistry by human activities
Human-induced changes in surface hydrology
Heat storage in lakes
Hydrologic stresses: damming of streams or rivers
Quarrying, peat extraction
Quarrying, near surface extraction
Artificial lake mixing
Ashes and sewage sludge
Crop fertilization
Crop storage
Herbicides, pesticides, fungicides
Inject/ingest/inhaling locally produced drugs
Peat and leaf litter harvesting
Biogas production
Earth moving projects
Lake infilling
Blasting and vibration
Hydroponics
Technological advances in food production
Other future uses of crystalline rock
Near storage of other waste

9.3 Subsurface activities

Exploratory boreholes (oil, gas): nonintrusive
Drilling: enhanced oil/gas production: nonintrusive
Drilling: liquid waste disposal: nonintrusive
Drilling: hydrocarbon storage: nonintrusive
Drilling: archeology: nonintrusive
Exploratory boreholes (water, potash)
Dewatering
Wells
Wells (high demand)
Resource exploitation (intersection of zone of contamination)

HUMAN INFLUENCES (Continued)

Heat storage underground
Geothermal energy production
Tunnelling
Construction of underground storage/disposal facilities (e.g. gas storage)
Construction of underground dwellings/shelters
Injection of liquid wastes: nonintrusive
Potash mining
Solution mining
Underground weapons testing (nuclear device)
Mining other than potash
Geothermal energy exploration (and other unidentified resources)
Resource exploitation following intrusion
Injection wells: enhanced oil/gas production, hydrocarbon storage: nonintrusive

9.4 Water use

Industrial use of water
Outdoor spraying of water
Groundwater extraction
Irrigation
Reservoirs
Intentional artificial groundwater recharge or withdrawal

9.5 Agricultural and fisheries practices

Fish farming
Ranching
Agricultural and fisheries practice changes

9.6 Radiological factors (smoking, transport agents)

Radiological factors (smoking, transport agents)

9.7 Others

Demographic change, urban development
Undetected repository intrusions (boreholes, mining)
Undetected boreholes (existing): nonintrusive
Stray materials left
Decontamination materials left
Loss of records
Radioactive waste disposal error
Inadvertent inclusion of undesirable materials
Poor quality construction
Design modifications
Accidents during operation
Backfill/seal material deficiencies
Postclosure monitoring
Unsuccessful attempt of site improvement
Poorly designed repository
Cure for cancer
Sabotage

HUMAN INFLUENCES (Continued)

Acid rain
Sudden energy release
Chemical sabotage
Explosions (resource recovery)
Borehole-induced solution and subsidence
Explosions (act of war)

APPENDIX B: MAPPING OF THE DCCA AND CCA FEP LISTS

This Appendix presents a mapping of the FEPs included in the Draft Compliance Certification Application (DCCA) FEP list to the FEPs on the WIPP-specific FEP list developed for the Compliance Certification Application (CCA).

The DCCA list is presented in Appendix A of this report, ordered by sub-system and by second-level category. For the purposes of this mapping, a number of FEPs have been excluded because they relate to designs different to that forming the basis of the CCA, because they relate to issues such as chemical toxicity that are not regulated by 40 CFR Part 191, or because they are modeling issues rather than FEPs. A list of these FEPs is presented in Appendix C of this report.

In general, the mapping shown in this Appendix links one or more FEPs from the DCCA with a FEP from the CCA list. Exceptions to this occur for two reasons:

- When there are no FEPs on the DCCA list corresponding to WIPP-specific issues. Examples include breccia pipes, cuttings, and blowouts. These are of potential concern to WIPP but are too detailed to have been included on the generic list from which the DCCA FEP list was drawn.

- When the FEP on the DCCA is of a general nature or includes a number of component FEPs. These general FEPs are mapped to a category or sub-category on the CCA list. Examples include:
  - Groundwater conditions (saturated/unsaturated);
  - Chemical changes due to sorption, complex formation, speciation, gas, solubility;
  - Human-induced changes in surface hydrology.

Natural FEPs

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Geological	Stratigraphy		Stratigraphy	Rock properties (porosity, permeability, hydraulic head, conductivity)	Near-field
				Undetected features (e.g. faults, fracture networks, shear zones, discontinuities, gas)	Far-field
				Rock properties (porosity, permeability, discharge zones, fractures)	Far-field
			Brine reservoirs		
	Tectonics		Changes in regional stress		
			Regional tectonics	Changes in the Earth's magnetic field	Geology/climate changes
			Regional uplift and subsidence	Regional uplift and subsidence (e.g. orogenic, isostatic)	Geology/climate changes
	Structural FEPs	Deformation	Salt deformation	Salt deformation/diapirism	Geology/climate changes
			Diapirism		
		Fracture development	Formation of fractures	Formation of interconnected fracture systems	Geology/climate changes
			Changes in fracture properties	Faulting/fracturing: change of properties - natural	Geology/climate changes
		Fault movement	Formation of new faults	Formation of new faults	Geology/climate changes
			Fault movement	Fault activation	Far-field
				Movements at faults	Geology/climate changes
		Seismic activity	Seismic activity	Earthquakes	Geology/climate changes
				Externally-induced seismicity	Near-field
				Natural seismicity	Geology/climate changes
				Externally-induced seismicity	Far-field
				Externally-induced seismicity	Geology/climate changes
				Differential elastic response	Far-field
	Crustal processes	Igneous activity	Volcanic activity	Volcanism	Geology/climate changes
			Magmatic activity	Magmatic activity	Geology/climate changes

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
		Metamorphism	Metamorphic activity	Metamorphic activity	Geology/climate changes
	Geochemical FEPs	Dissolution		Diagenesis	Geology/climate changes
			Shallow dissolution	Dissolution of fracture fillings, precipitation	Far-field
			Lateral dissolution	Fluid interactions: dissolution	Near-field
				Dissolution	Near-field
			Deep dissolution		
			Solution chimneys	Formation of dissolution cavities	Geology/climate changes
			Breccia pipes		
			Collapse breccias		
		Mineralization	Fracture infills	Fracture mineralization	Far-field
				Weathering, mineralization	Far-field
Subsurface hydrological	Groundwater characteristics			Groundwater conditions (saturated/unsaturated)	Far-field
			Saturated groundwater flow	Saturated groundwater flow	Far-field
			Unsaturated groundwater flow	Dewatering	Far-field
				Sediment/water/gas interaction with the atmosphere	Biosphere
			Fracture flow	Groundwater flow: fracture	Far-field
			Density effects on groundwater flow	Salinity effects on flow	Far-field
			Effects of preferential pathways	Groundwater flow: effects of solution channels (preferential pathways)	Far-field
	Changes in groundwater flow			Natural changes in groundwater flow direction	Seals
				Natural changes in groundwater flow direction	Backfill
				Changes in groundwater flow direction	Near-field
				Changes in the geometry of the flow system	Far-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Changes in the driving forces of the flow system	Far-field
				Natural rock property changes (porosity, permeability, fractures, pore blocking)	Far-field
				Changes in groundwater flow direction	Far-field
			Thermal effects on groundwater flow	Naturally thermally-induced groundwater transport	Near-field
				Thermal effects: fluid migration	Far-field
				Geothermal gradient effects	Far-field
				Variations in groundwater temperature	Far-field
				Thermal effects: fluid pressure, density, viscosity changes	Far-field
			Saline intrusion	Saline groundwater intrusion	Far-field
			Freshwater intrusion	Fresh groundwater intrusion	Far-field
			Natural gas intrusion	Methane intrusion	Near-field
				Effects of natural gases	Far-field
			Hydrological response to earthquakes		
Subsurface geochemical	Groundwater geochemistry		Groundwater geochemistry	Salinity: implications of evaporite deposits/minerals	Far-field
	Changes in groundwater chemistry			Natural changes in groundwater chemistry and flow direction	Near-field
				Groundwater composition changes (pH, Eh, chemical composition)	Far-field
			Saline intrusion		
			Freshwater intrusion		
			Changes in groundwater Eh		
			Changes in groundwater pH		

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Effects of dissolution	Fluid interactions: dissolution, precipitation	Biosphere
Geomorphological	Physiography		Physiography	Terrestrial surface	Geology/climate changes
				Terrestrial surface	Biosphere
	Meteorite impact		Impact of a large meteorite	Meteorite impact	Geology/climate changes
	Denudation			Changes in topography	Geology/climate changes
		Weathering		Weathering	Geology/climate changes
			Mechanical weathering		
			Chemical weathering	Weathering, mineralization	Biosphere
		Erosion		Major incision	Geology/climate changes
			Aeolian erosion	Erosion - wind	Biosphere
				Aeolian and fluvial denudation	Geology/climate changes
			Fluvial erosion	Rivercourse meander	Biosphere
				Sediment resuspension in water bodies	Biosphere
				Stream erosion	Geology/climate changes
				Rivercourse meander	Geology/climate changes
			Mass wasting	Mass wasting	Geology/climate changes
		Sedimentation		Sedimentation	Geology/climate changes
			Aeolian deposition	Saltation	Biosphere
			Fluvial deposition	Freshwater sediment transport and deposition	Geology/climate changes
				Surface flow characteristics: sediment transport	Biosphere
				Sedimentation in water bodies	Biosphere
			Lacustrine deposition	Surface water bodies: bottom sediments	Biosphere
				Surface water bodies: suspended sediments	Biosphere
			Mass wasting	Land slide	Geology/climate changes
				Solifluction	Geology/climate changes

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
	Soil development		Soil development	Soil properties (type, depth, porewater pH, moisture, sorption)	Biosphere
				Soil and surface water chemistry (pH, Eh)	Biosphere
				Pedogenesis	Biosphere
				Soil and sediment transport including bioturbation	Biosphere
				Altered soil or surface water chemistry (pH, Eh)	Biosphere
				Soil leaching	Biosphere
Surface hydrological	Fluvial		Stream and river flow	River flow and lake level changes	Geology/climate changes
				River flow and lake level changes	Biosphere
				Surface flow characteristics: meander migration or other fluvial response	Biosphere
				Surface flow characteristics: stream/river flow	Biosphere
	Lacustrine		Surface water bodies	Wetlands	Biosphere
				Surface water bodies: water flow	Biosphere
				Surface water bodies: effects on vegetation	Biosphere
				Surface water bodies: properties (e.g., pH)	Biosphere
				Flushing of water bodies	Biosphere
				Surface water mixing	Biosphere
				Surface flow characteristics: lake formation/sedimentation	Biosphere
				Surface water bodies: effects of fluvial system development	Biosphere
				Alkali flats	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Alkali flats	Geology/climate changes
	Groundwater recharge and discharge		Groundwater discharge	Groundwater discharge to soils: advective, diffusive, biotic, volatilization	Biosphere
				Groundwater discharge to marine waters including coastal	Biosphere
				Groundwater discharge (springs)	Biosphere
				Groundwater discharge (to surface water)	Biosphere
			Groundwater recharge	Groundwater recharge	Far-field
				Near-surface runoff processes: variable source area response	Biosphere
				Near-surface runoff processes: overland flow, interflow, return flow, macropore flow	Biosphere
				Capillary rise in soil	Biosphere
			Infiltration	Evaporation of soil moisture	Biosphere
	Changes in surface hydrology		Changes in groundwater recharge and discharge	Hydrological change	Geology/climate changes
				Variation in groundwater recharge	Geology/climate changes
			Lake formation	Lake infilling	Biosphere
			River flooding	Flooding	Geology/climate changes
				Flood (short-term)	Biosphere
Climatic				Insolation	Geology/climate changes
	Climate			Precipitation, temperature and soil water balance	Biosphere
				Precipitation, temperature and soil water balance	Geology/climate changes
				Convection, turbulence and diffusion (atmospheric)	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Wind	Biosphere
				Hurricanes	Geology/climate changes
				Seasons	Biosphere
			Precipitation	Precipitation (meteoric)	Biosphere
			Temperature		
	Climate change	Meteorological	Climate change	Global effects	Geology/climate changes
				Climate change	Geology/climate changes
				Drought	Geology/climate changes
				Drought	Biosphere
				Dust storms and desertification (massive)	Geology/climate changes
		Glaciation	Glaciation	No ice age	Geology/climate changes
				Erosion: glacial	Geology/climate changes
				Glaciation	Geology/climate changes
				Snow melt	Geology/climate changes
				Extreme erosion and denudation: glacial-induced (e.g. coastal/stream erosion)	Geology/climate changes
				Glacial/interglacial cycling effects (including sea level changes)	Geology/climate changes
			Permafrost	Accumulation of gases under permafrost	Geology/climate changes
				Permafrost	Geology/climate changes
				Accumulation of gases under permafrost	Near-field
Marine	Seas		Seas and oceans	Coastal waters: water transport, bottom and suspended sediment transport, effects of sea level change, estuarine development and coastal erosion	Biosphere
				Tsunamis	Geology/climate changes
				Seiches	Geology/climate changes

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Coastal waters: tidal mixing, residual current mixing, effects of sea level change	Biosphere
				Ocean waters: water exchange, effects of sea level change	Biosphere
			Estuaries	Estuaries: water flow, suspended sediments, bottom sediments, effects of salinity variation, effects on vegetation, estuarine development and sea level change	Biosphere
				Estuarine surface flow characteristics: tidal cycling, sediment transport, successional development, effects of sea level change	Biosphere
	Marine sedimentology		Coastal erosion	Coastal erosion due to sea level change	Geology/climate changes
			Marine sediment transport and deposition	Marine sediment transport and deposition	Geology/climate changes
	Sea level changes		Sea level changes	Sea level change	Geology/climate changes
				River incision/sedimentation due to sea level change	Geology/climate changes
				Surface flow characteristics: effects of sea level change	Biosphere
Ecological	Flora & fauna		Plants		
			Animals	Burrowing animals	Biosphere
			Microbes	Microbial activity	Biosphere
				Natural microbial activity	Near-field
	Changes in flora & fauna		Natural ecological development	Animals: Effects of relocation and migration	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Ecological change (e.g. forest fire cycles)	Biosphere
				Terrestrial ecological development: Estuarine	Biosphere
				Biogeochemical changes	Biosphere
				Terrestrial ecological development: natural and agricultural systems	Biosphere
				Biological evolution	Biosphere
				Terrestrial ecological development: Effects of succession	Biosphere
				Critical group - evolution	Biosphere
				Ecological response to climate, including glacial/interglacial cycling, (e.g. desert formation)	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Waste and repository characteristics	Repository characteristics		Disposal geometry	Disposal geometry	Near-field
				Retrievability	Near-field
	Waste characteristics		Waste inventory	Inventory: radionuclides	Waste
				Source terms	Waste
			Heterogeneity of waste forms	Channelling within the canister (preferential pathways)	Canister
				Role of eventual channelling within the canister	Waste
				Heterogeneity of waste forms (chemical, physical)	Waste
	Container characteristics		Container form		
			Container material inventory	Inventory	Canister
	Seal characteristics		Seal geometry		
			Seal physical properties	Seal characteristics (e.g. hydraulic conductivity)	Seals
				Swelling pressure	Seals
			Seal chemical composition	Concrete	Seals
	Backfill characteristics		Backfill physical properties	Backfill characteristics (e.g. hydraulic conductivity)	Backfill
				Swelling pressure	Backfill
			Backfill chemical composition	Buffer additives	Backfill
	Postclosure monitoring		Postclosure monitoring	Postclosure monitoring	Human influences
				Monitoring and remedial activities	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Radiological	Radioactive decay		Radionuclide decay and ingrowth	Waste: radionuclide decay and ingrowth	Waste
				Radioactive decay	Biosphere
			Heat from radioactive decay	Radioactive decay: heat	Waste
	Nuclear criticality		Nuclear criticality: heat	Nuclear criticality (preclosure)	Waste
				Nuclear criticality	Far-field
				Nuclear criticality: heat	Near-field
				Nuclear criticality: heat	Waste
				Nuclear criticality (postclosure)	Waste
				Nuclear criticality: heat	Backfill
				Nuclear criticality: heat	Seals
	Radiological effects on material properties		Radiological effects on waste		
			Radiological effects on containers	Radiation effects on canister	Canister
			Radiological effects on seals	Radiation effects on bentonite	Seals
Geological / mechanical	Excavation-induced fracturing		Disturbed rock zone	Rock property changes (hydraulic conductivity, fractures, pore blocking, channel formation/closure)	Near-field
				Disturbed zone (hydromechanical) effects	Near-field
				Formation of cracks	Near-field
				Differential elastic response	Near-field
				Blasting and vibration	Near-field
			Excavation-induced changes in stress	Excavation-induced stress/fracturing in host rock	Near-field
				Repository-induced seismicity	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Repository-induced seismicity	Far-field
	Rock creep		Salt creep	Non-elastic response	Near-field
				Non-elastic response	Far-field
				External stress	Canister
				External stress	Backfill
				Creeping of rock mass	Near-field
			Changes in the stress field	Changes in in-situ stress field	Near-field
	Roof falls		Roof falls	Caving/roof collapse	Near-field
	Subsidence		Subsidence	Subsidence	Far-field
			Large-scale rock fracturing		
	Effects of fluid pressure changes		Disruption due to gas effects	Gas effects: disruption	Seals
				Gas effects: disruption	Backfill
				Gas effects: disruption	Waste
				Gas effects: disruption	Canister
				Gas effects: disruption	Near-field
			Pressurization	Gas effects: pressurization	Seals
				Gas effects: pressurization	Backfill
				Gas effects: pressurization	Waste
				Gas effects: pressurization	Canister
				Gas effects: pressurization	Near-field
	Effects of explosions		Gas explosions	Gas effects: fire	Canister
				Gas effects: fire	Seals
				Gas effects: fire	Near-field
				Gas effects: fire	Backfill
				Gas effects: explosions	Backfill
				Explosion	Far-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Gas effects: explosions	Seals
				Gas effects: explosions	Waste
				Gas effects: explosions	Near-field
				Gas effects: fire	Waste
				Gas effects: explosions	Canister
			Nuclear explosions	Nuclear criticality: explosions	Seals
				Nuclear criticality: explosions	Backfill
				Nuclear criticality: explosions	Near-field
				Nuclear criticality: explosions	Waste
				Nuclear criticality: explosions	Canister
	Thermal effects		Thermal effects on material properties	Material property changes: heat	Waste
				Material property changes	Waste
				Hydrothermal alteration	Near-field
				Thermal effects on the seal material	Seals
				Hydrothermal alteration	Seals
				Hydrothermal alteration	Backfill
				Dehydration of salt minerals	Near-field
				Natural thermal effects	Backfill
				Natural thermal effects	Seals
				Thermal non-elastic response	Near-field
				Thermal non-elastic response	Far-field
			Thermally-induced stress changes	Thermal cracking	Waste
				Thermally-induced stress/fracturing in host rock	Near-field
				Thermal cracking	Canister
			Differing thermal expansion of repository components	Differing thermal expansion (canister-seal, buffer-host rock)	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Differing thermal expansion of host rock zones	Near-field
				Differing thermal expansion (canister-backfill, buffer-host rock)	Backfill
				Differing thermal expansion of canister and backfill	Canister
				Thermal effects on the backfill material	Backfill
				Thermal differential elastic response	Near-field
				Thermal differential elastic response	Far-field
	Mechanical effects on material properties		Consolidation of waste	External stress	Waste
			Movement of containers	Canister movement	Canister
				Movement of canister in backfill	Backfill
				Movement of canister	Seals
			Container integrity	Release of radionuclides from the failed canister	Canister
				Structural container metal corrosion: stress corrosion cracking	Canister
				Hydrostatic pressure on canister	Canister
				Uniform corrosion	Canister
				Structural container metal corrosion: localized	Canister
				Structural container metal corrosion: crevice	Canister

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Structural container metal corrosion: bulk	Canister
				Corrosion (including partial corrosion)	Canister
				Container failure (long term)	Canister
				Container failure (early)	Canister
				Mechanical canister damage (failure)	Canister
				Pitting	Canister
				Swelling of corrosion products	Canister
				Container corrosion products	Canister
			Mechanical effects of backfill	Erosion of backfill	Backfill
				Extreme channel flow of oxidants and nuclides (preferential pathways)	Backfill
				Long-term physical stability	Backfill
				Mechanical failure of backfill (preferential pathways)	Backfill
				Preferential pathways in the backfill	Backfill
				Swelling of corrosion products	Backfill
				Mechanical effects: local fractures/cracks (preferential pathways)	Backfill
			Consolidation of seals	Long-term physical stability	Seals
				External stress	Seals
			Mechanical degradation of seals	Mechanical effects: local fractures/cracks (preferential pathways)	Seals
				Mechanical failure of seals (preferential pathways)	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Erosion of seals	Seals
				Shaft seal failure/degradation	Seals
				Preferential pathways in the seals	Seals
				Swelling of corrosion products	Seals
				Sealing of cracks: concrete	Seals
				Cracking: concrete	Seals
				Physico-chemical degradation of concrete	Near-field
				Uneven swelling of bentonite	Near-field
				Uneven swelling of bentonite	Seals
				Coagulation of bentonite	Seals
			Investigation boreholes	Loss of integrity of borehole seals: seal failure or degradation	Biosphere
				Investigation borehole seal failure/degradation	Seals
			Underground boreholes		
Subsurface hydrological / fluid dynamical	Repository-induced flow		Brine inflow	Repository-induced changes in groundwater flow direction	Near-field
				Groundwater flow (saturated conditions, including fracture flow)	Near-field
				Cavitation	Near-field
				Saline (or fresh) groundwater intrusion	Near-field
				Backfill:resaturation/desaturation	Backfill
				Seals: resaturation/desaturation	Seals
				Cavitation	Far-field
				Resaturation	Near-field
				Saline groundwater intrusion	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Saline groundwater intrusion	Backfill
				Groundwater flow, effects of solution channels (preferential pathways)	Near-field
				Changes in moisture content due to stress relief	Near-field
			Wicking	Capillary action	Waste
				Capillary action	Backfill
				Unsaturated transport	Near-field
	Effects of gas generation		Fluid flow due to gas production	Groundwater flow due to gas production	Seals
				Gas transport into and through the far-field (gas phase and in solution)	Far-field
				Gas transport in the near field as gas phase and in solution	Backfill
				Groundwater flow due to gas production	Backfill
				Groundwater and gas flow	Backfill
				Gas transport in the near field as gas phase and in solution	Seals
				Gas transport in the waste container	Canister
				Gas-induced groundwater transport	Far-field
				Multiphase flow and gas-driven flow	Far-field
				Groundwater flow due to gas production	Near-field
				Groundwater and gas flow	Seals
				Groundwater and gas flow	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Gas transport in the near field as gas phase and in solution	Near-field
				Gas transport: gas phase and in solution	Biosphere
				Gas mediated transport	Far-field
				Gas-mediated transport	Biosphere
	Thermal effects			Thermo-hydro-mechanical effects	Near-field
			Convection	Repository thermally-induced groundwater transport	Near-field
				Variations in groundwater temperature	Backfill
				Variations in groundwater temperature	Seals
				Variations in groundwater temperature	Near-field
				Convection	Near-field
				Convection (contaminant transport)	Backfill
				Convection (contaminant transport)	Seals
Geochemical / chemical				Chemical changes due to sorption, complex formation, speciation, gas, solubility	Biosphere
	Gas generation			Gas generation from concrete	Waste
				Gas generation from concrete	Seals
		Microbial gas generation		Methane/CO2 production: Carbonate/bicarbonate exchange with concrete	Waste
				Canister: microbiological effects/microbial activity	Canister
			Degradation of organic material	Methane/CO2 production	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Methane/CO2 production: Inhibition due to the pressure of toxic materials	Waste
				Methane/CO2 production: anaerobic production	Waste
				Degradation of plastics and cellulosics	Waste
				Methane/CO2 production: aerobic degradation	Waste
				Methane and carbon dioxide by microbial degradation of cellulose and other organic wastes	Waste
				Backfill: microbiological effects/microbial activity	Backfill
				Microbiological effects due to cellulose degradation	Waste
			Effects of biofilms on microbial gas generation	Methane/CO2 production: energy and nutrient control of metabolism	Waste
				Methane and CO2 production: energy and nutrient control of metabolism	Near-field
				Methane/CO2 production: Effects of biofilms	Waste
			Effects of temperature on microbial gas generation	Methane/CO2 production: effects of temperature	Waste
			Effects of pressure on microbial gas generation	Methane/CO2 production: effects of lithostatic pressure	Waste
				Methane CO2 production: effects of lithostatic pressure	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Effects of radiation on microbial gas generation	Methane CO2 production: effects of radiation on microbial populations	Near-field
				Mutation	Near-field
				Methane/CO2 production: effects of radiation on microbial populations	Waste
		Corrosion	Gases from metal corrosion	Effects of hydrogen from metal corrosion	Seals
				Effects of hydrogen from metal corrosion	Backfill
				Hydrogen by metal corrosion	Waste
				Internal corrosion due to waste	Waste
				Hydrogen: corrosion of container steel	Canister
				Methane CO2 production: effects of hydrogen from metal corrosion	Near-field
				Metal corrosion: wastes	Waste
				Methane/CO2 production: effects of hydrogen from metal corrosion	Backfill
				Methane/CO2 production: effects of hydrogen from metal corrosion	Seals
				Dissolution	Canister
			Galvanic coupling	Galvanic coupling	Canister
			Chemical effects of corrosion		
		Radiolytic gas generation		Radiolysis	Seals
				Radiolysis	Backfill
			Radiolysis of brine		
			Radiolysis of cellulose	Radiolysis	Waste

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Helium gas production	Gas generation: He production	Waste
			Radioactive gas	Methane/CO2 production	Backfill
	Chemical speciation		Speciation	Speciation	Far-field
				Chemical effects: Interactions of waste canister and rock	Canister
				Speciation	Biosphere
				Thermochemical changes	Backfill
				Thermochemical changes	Seals
				Thermochemical changes	Near-field
				Chemical changes due to complex formation	Backfill
				Chemical changes due to complex formation	Seals
				Chemical changes due to waste degradation	Backfill
				Chemical changes due to waste degradation	Seals
				Thermal effects on hydrochemistry	Biosphere
				Speciation	Near-field
				Chemical changes due to speciation (chemical changes)	Near-field
				Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)	Near-field
				Chemical effects: interactions of waste canister and rock	Near-field
				Thermally induced chemical changes (water chemistry)	Waste
				Chemical effects: geochemical change	Waste

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Chemical changes due to speciation	Backfill
				Chemical changes due to speciation	Seals
				Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)	Far-field
				Speciation	Backfill
				Speciation	Seals
				Changes in pore water composition, pH, Eh: concrete	Near-field
				Chemical changes due to gas production	Waste
				Chemical changes due to gas production	Backfill
				Chemical changes due to gas production	Seals
				Speciation	Waste
				Biogeochemical changes	Backfill
				Biogeochemical changes	Near-field
				Effects of bentonite on groundwater chemistry	Seals
				Speciation of corrosion products (include in water chemistry)	Canister
				Interactions with corrosion products and waste	Waste
			Kinetics of speciation	Chemical kinetics	Seals
				Chemical kinetics	Backfill
				Chemical kinetics	Waste
				Chemical kinetics	Canister
				Chemical kinetics	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
	Precipitation / dissolution			Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	Near-field
				Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	Backfill
				Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	Seals
				Solubility	Waste
				Solubility effects (pH and Eh)	Biosphere
				Precipitation, dissolution, recrystallization, reconcentration	Far-field
				Precipitation, dissolution, recrystallization, reconcentration	Biosphere
				Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	Far-field
				Reconcentration	Near-field
			Dissolution of waste	Dissolution chemistry	Waste
				Dissolution	Waste
			Precipitation	Precipitation	Waste
				Precipitation	Canister
				Precipitation	Backfill
				Precipitation	Seals
				Recrystallization	Near-field
				Recrystallization	Backfill
				Recrystallization	Waste
				Recrystallization	Seals
				Precipitation, reconcentration	Seals
				Precipitation, reconcentration	Backfill

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Precipitation, reconcentration	Near-field
				Fracture mineralization	Near-field
			Kinetics of precipitation / dissolution	Leaching: wastes	Waste
	Sorption reactions		Actinide sorption	Chemical changes due to sorption	Seals
				Ionic exchange in soil	Biosphere
				Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)	Near-field
				Sorption (linear, nonlinear, irreversible)	Near-field
				Anion exchange	Backfill
				Anion exchange	Seals
				Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)	Far-field
				Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)	Backfill
				Sorption effects (pH and Eh, ionic strength, complexing agents, colloids)	Seals
				Sorption (linear, nonlinear, irreversible)	Backfill
				Sorption (linear, nonlinear, irreversible)	Seals
				Sorption (linear, nonlinear, irreversible)	Far-field
				Sorption (linear, nonlinear, irreversible)	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Chemical changes due to sorption	Backfill
				Chemical changes due to sorption (chemical changes)	Near-field
				Sorption effects (pH and Eh)	Biosphere
			Kinetics of sorption		
			Changes in sorptive surfaces	Changes in sorptive surfaces	Biosphere
				Changes in sorptive surfaces	Backfill
				Changes in sorptive surfaces	Near-field
				Changes in sorptive surfaces	Seals
				Saturation of sorption sites	Seals
				Saturation of sorption sites	Backfill
				Exchange capacity exceeded	Backfill
				Exchange capacity exceeded	Seals
				Changes in sorptive surfaces	Far-field
	Redox chemistry		Effect of metal corrosion	Redox potential	Waste
				Chemical changes due to metal corrosion	Waste
				Chemical changes due to metal corrosion	Canister
				Electrical effects of metal corrosion	Waste
				Chemical effects of rock reinforcement	Near-field
				Chemical changes due to corrosion	Backfill
				Chemical changes due to corrosion	Seals
			Redox fronts	Redox front	Backfill
				Redox front	Seals
			Redox kinetics		

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
			Localized reducing zones		
	Organic complexation		Organic complexation	Complex formation: wastes	Waste
				Complex formation: wastes	Waste
			Organic ligands	Methylation	Near-field
			Humic and fulvic acids	Complexation by organics (including humic and fulvic acids)	Biosphere
				Complexation by organics (including humic and fulvic acids)	Far-field
			Kinetics of organic complexation		
	Exothermic reactions			Thermal effects on hydrochemistry	Near-field
			Exothermic reactions	Thermochemical effects	Backfill
			Concrete hydration	Thermal effects (e.g. concrete hydration)	Near-field
				Thermal effects (e.g. concrete hydration)	Seals
				Thermochemical effects	Seals
	Chemical effects on material properties		Chemical degradation of seals	Chemical effects: gas generation	Seals
				Cement sulphate reaction	Seals
				Alkali-aggregate reaction	Seals
				Reactions with cement pore water (include in chemical degradation)	Seals
				Cement-sulphate reaction: concrete	Near-field
				Dissolution	Seals
				Degradation of the bentonite by chemical reactions	Seals

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
M			Chemical degradation of backfill	Chemical effects: gas generation	Backfill
				Dissolution	Backfill
				Reactions with cement pore water (include in chemical degradation	Backfill
			Microbial effects on concrete	Hydrogen: effects of microbial growth on concrete	Waste
				Biogeochemical changes	Seals
				Hydrogen: effects of microbial growth on concrete	Seals
				Seal: microbiological effects/microbial activity	Seals
				Methane/CO2 production: effects of microbial growth on properties of concrete	Near-field
Contaminant transport mode	Solute transport		Solute transport	Isotopic dilution	Seals
				Isotopic dilution	Backfill
				Transport of chemically active substances into the near-field	Seals
				Transport of chemically active substances into the near-field	Backfill
				Dilution (mass, isotopic, species)	Near-field
				Dilution (mass, isotopic, species)	Far-field
				Dilution (mass, isotopic, species)	Biosphere
	Colloid transport		Colloid transport	Colloid transport (inorganic and organic)	Seals
				Colloid transport (inorganic and organic)	Backfill
				Colloid transport	Near-field
			Colloid formation and stability	Colloid formation: wastes	Waste

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
M				Colloids	Near-field
				Colloids, complexing agents	Biosphere
				Colloids: formation & effects (including inorganic and organic colloid transport)	Far-field
				Chemical changes due to colloid production (chemical changes)	Near-field
				Colloids: formation and effects (including inorganic and organic colloid transport)	Biosphere
				Physico-chemical phenomena/effects (e.g. colloid formation)	Biosphere
				Chemical changes due to colloid production	Backfill
				Chemical changes due to colloid production	Seals
				Physico-chemical phenomena/effects (e.g. colloid formation)	Near-field
			Colloid filtration	Pore blockage: concrete	Near-field
			Colloid sorption		
	Particulate transport		Suspensions of particles		
			Rinse	Rinse	Waste
			Cuttings		
			Cavings		
			Spallings		
	Microbial transport		Microbial transport	Biogeochemical changes	Far-field
				Transport of radionuclides bound to microbes	Near-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Transport of radionuclides bound to microbes	Backfill
				Transport of radionuclides bound to microbes	Seals
				Transport of radionuclides bound to microbes	Far-field
				Transport of radionuclides bound to microbes	Biosphere
				Microbial activity	Far-field
				Transport of microbes into the near-field	Near-field
			Biofilms	Rock property changes: microbial pore blocking	Near-field
	Gas transport		Transport of radioactive gases	Transport of active gases: gas phase and in solution	Biosphere
				Active methane, carbon dioxide, radon, tritiated hydrogen and other active gases	Waste
				Transport of active gases	Near-field
				Transport of active gases	Far-field
				Radon emission	Biosphere
				Gas discharge	Biosphere
				Transport of active gases	Backfill
				Transport of active gases	Seals
Contaminant transport process	Advection		Advection	Advection/dispersion: radionuclides	Near-field
				Advection/dispersion: radionuclides	Backfill
				Groundwater flow, advection/dispersion (saturated conditions)	Far-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Extreme channel flow of oxidants and nuclides (preferential pathways)	Seals
				Extreme channel flow of oxidants and nuclides (preferential pathways)	Near-field
				Advection/dispersion: radionuclides	Seals
				Water flow: advection and dispersion	Biosphere
				Unsaturated transport	Backfill
				Unsaturated transport	Seals
				Unsaturated transport	Far-field
	Diffusion		Diffusion	Diffusion: radionuclides	Near-field
				Diffusion: radionuclides	Backfill
				Diffusion: radionuclides	Seals
				Diffusion (bulk, matrix, surface)	Biosphere
				Diffusion (bulk, matrix, surface)	Far-field
			Matrix diffusion		
	Thermochemical transport phenomena		Soret effect	Soret effect	Seals
				Soret effect	Backfill
				Soret effect	Far-field
				Soret effect	Near-field
				Thermal effects and transport (diffusion) properties	Near-field
	Electrochemical transport phenomena		Electrochemical effects	Electrochemical gradients	Waste
				Electrochemical cracking	Canister

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Natural telluric electrochemical reactions	Canister
				Electrochemical gradients	Canister
				Natural telluric electrochemical reactions	Backfill
				Natural telluric electrochemical reactions	Seals
			Galvanic coupling	Galvanic coupling	Waste
			Electrophoresis	Coupled effects (electrophoresis)	Canister
	Physicochemical transport phenomena		Chemical gradients	Chemical gradients	Near-field
				Chemical gradients (electrochemical effects and osmosis)	Biosphere
				Chemical gradients (electrochemical effects and osmosis)	Far-field
				Chemical gradients	Backfill
				Chemical gradients	Seals
				Chemical gradients (electrochemical effects and osmosis)	Canister
			Osmosis	Chemical gradients, osmosis	Waste
			Alpha recoil	Recoil of alpha-decay	Waste
				Radiolysis, radiation damage	Far-field
				Release of stored energy	Waste
				Sudden energy release	Waste
				Release of stored energy	Near-field
			Enhanced diffusion	Effects at saline-freshwater interface	Far-field

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Effects at saline-freshwater interface	Near-field
				Effects at saline-freshwater interface	Backfill
				Effects at saline-freshwater interface	Seals
	Plant, animal and soil uptake			Bioaccumulation and translocation	Biosphere
			Plant uptake	Plants: Cycling processes	Biosphere
				Plants: Internal translocation and retention	Biosphere
				Tree sap	Biosphere
				Houseplants	Biosphere
				Plants: Vapor uptake	Biosphere
				Plants: Leaf-fall and senescence	Biosphere
				Plants: Root uptake, including deep rooting species	Biosphere
				Plants: Washoff and leaching by rainfall	Biosphere
				Plants: Deposition on surfaces	Biosphere
			Animal uptake	Animal habits (grooming and fishing, soil ingestion, diets, scavengers/predators)	Biosphere
				Animals: Cycling processes	Biosphere
				Animals: Uptake by inhalation	Biosphere
				Critical group - pets	Biosphere
				Animals: Internal translocation and retention	Biosphere
				Intrusion (animal)	Biosphere
				Animals: Uptake by ingestion	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Intrusion in accumulation zone in the biosphere (animals)	Biosphere
			Accumulation in soils	Accumulation in soils and organic debris, including peat	Biosphere
				Accumulation in sediments	Biosphere
				Solid discharge via erosional processes	Biosphere
	Human uptake			Radiotoxic contaminants	Biosphere
				Cure for cancer	Human influences
				Critical group - agricultural labor,	Biosphere
				Critical group - individuality	Biosphere
				Sensitization to radiation	Biosphere
			Ingestion	Carcasses	Biosphere
				Ingestion and wild plants	Biosphere
				Human diet	Biosphere
				Ingestion and domestic animal products	Biosphere
				Ingestion and agricultural crops	Biosphere
				Ingestion and wild animals	Biosphere
				Human soil ingestion	Biosphere
				Ingestion and drinking water	Biosphere
				Ingestion and soils and sediments	Biosphere
			Inhalation	Outdoor spraying of water	Human influences
				Inhalation and salt particles	Biosphere
				Smoking	Biosphere
				Showers and humidifiers	Biosphere
				Radiological factors (smoking, transport agents)	Human influences
				Inhalation and biotic material	Biosphere

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Household dust and fumes	Biosphere
				Deposition (wet and dry)	Biosphere
				Inhalation and soils and sediments	Biosphere
				Inhalation and gases and vapors (indoor/outdoor)	Biosphere
				Suspension in air	Biosphere
			Irradiation	Building materials	Biosphere
				Critical group - clothing and home furnishings	Biosphere
				External exposure: land, sediments, water bodies	Biosphere
			Dermal sorption	Dermal sorption - nuclides other than tritium	Biosphere
				Food preparation	Biosphere
				Dermal sorption - tritium	Biosphere
			Injection	Inject/ingest/inhaling locally produced drugs	Human influences

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Geological	Drilling		Oil and gas exploration	Exploratory boreholes (oil, gas)	Human influences
				Undetected repository intrusions (boreholes, mining)	Human influences
				Exploratory boreholes (oil, gas): nonintrusive	Human influences
			Potash exploration	Exploratory boreholes (water, potash)	Human influences
			Water resources exploration		
			Oil and gas exploitation	Resource exploitation (e.g. hydrocarbon, geothermal)	Human influences
			Groundwater exploitation		
			Archeological investigations	Drilling: archeology: nonintrusive	Human influences
			Geothermal	Geothermal energy production	Human influences
				Geothermal energy exploration (and other unidentified resources)	Human influences
			Other resources		
			Enhanced oil and gas recovery	Drilling: enhanced oil/gas production: nonintrusive	Human influences
			Liquid waste disposal	Drilling: liquid waste disposal: nonintrusive	Human influences
			Hydrocarbon storage	Drilling: hydrocarbon storage: nonintrusive	Human influences
			Deliberate drilling intrusion	Intrusion (deliberate)	Human influences
				Sabotage	Human influences
				Sabotage	Near-field
				Intrusion (deliberate) - malicious (sabotage, act of war (nuclear))	Human influences
				Chemical sabotage	Human influences
	Excavation activities			Intrusion in accumulation zone in the biosphere	Human influences

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Resource exploitation (intersection of zone of contamination)	Human influences
			Potash mining	Potash mining	Human influences
			Other resources	Mining other than potash	Human influences
			Tunneling	Tunnelling	Human influences
			Construction of underground facilities	Gas leakage into underground living space	Biosphere
				Construction of underground storage/disposal facilities (e.g. gas storage)	Human influences
				Heat storage underground	Human influences
				Space heating	Biosphere
				Water leak into underground living space	Biosphere
				Near storage of other waste	Human influences
				Construction of underground dwellings/shelters	Human influences
			Archeological excavations	Archeological investigations	Human influences
			Deliberate mining intrusion	Unsuccessful attempt of site improvement	Human influences
				Intrusion (deliberate) - recovery of repository materials	Human influences
				Intrusion (deliberate) - recovery of wastes or associated materials (mining)	Human influences
	Subsurface explosions			Sudden energy release	Human influences
		Resource recovery	Resource recovery	Explosions (resource recovery)	Human influences
		Underground nuclear device testing	Underground nuclear device testing	Underground weapons testing (nuclear device)	Human influences

Human-initiated EPs

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Subsurface hydrological and geochemical	Borehole fluid flow	Drilling-induced flow	Drilling fluid flow		
			Drilling fluid loss		
			Blowouts		
			Drilling-induced geochemical changes		
		Fluid extraction	Oil and gas extraction	Resource exploitation following intrusion	Human influences
			Groundwater extraction	Industrial use of water	Human influences
				Intentional artificial groundwater recharge or withdrawal	Human influences
				Groundwater discharge (wells)	Biosphere
				Wells (high demand)	Human influences
				Groundwater extraction	Human influences
				Dewatering	Human influences
				Borehole - well	Far-field
				Wells	Human influences
		Fluid injection		Reuse of boreholes	Human influences
				Injection wells	Human influences
			Liquid waste disposal	Injection of liquid wastes: nonintrusive	Human influences
			Enhanced oil/gas production	Injection wells: enhanced oil/gas production, hydrocarbon storage: nonintrusive	Human influences
				Faulting/fracturing: change of properties - human-induced	Geology/climate changes
			Hydrocarbon storage		
			Fluid injection-induced geochemical changes		

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
		Flow through abandoned boreholes		Boreholes - unsealed	Biosphere
			Natural borehole fluid flow		
			Waste-induced borehole flow		
			Flow through undetected boreholes	Undetected boreholes (existing): nonintrusive	Human influences
			Borehole-induced solution and subsidence	Borehole-induced solution and subsidence	Human influences
			Borehole-induced mineralization		
			Borehole-induced geochemical changes		
	Excavation-induced flow		Changes in groundwater flow due to mining		
			Changes in geochemistry due to mining	Solution mining	Human influences
	Explosion-induced flow		Changes in groundwater flow due to explosions		
Geomorphological	Land use and disturbances		Land use changes	Charcoal production	Biosphere
				Peat and leaf litter harvesting	Human influences
				Land use changes	Biosphere
				Ashes and sewage sludge	Human influences
				Peat and leaf litter harvesting	Biosphere
			Surface disruptions	Explosions (act of war)	Human influences
				Quarrying, peat extraction	Human influences
				Quarrying, near surface extraction	Human influences
				Earth moving projects	Human influences
				Earthmoving	Human influences
				Blasting and vibration	Human influences

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
Surface hydrological	Water control and use			Human-induced changes in surface hydrology	Human influences
			Damming of streams or rivers	Hydrologic stresses: damming of streams or rivers	Human influences
				Dams	Biosphere
				Terrestrial water use (including wells and dams)	Biosphere
			Reservoirs	Reservoirs	Human influences
			Irrigation	Irrigation	Human influences
			Lake usage	Artificial lake mixing	Human influences
				Artificial lake mixing	Biosphere
				Heat storage in lakes	Human influences
				Lake infilling	Human influences
			Altered soil or surface water chemistry by human activities	Herbicides, pesticides, fungicides	Human influences
				Altered soil or surface water chemistry by human activities	Human influences
				Herbicides, pesticides, fungicides	Biosphere
				Crop fertilization	Biosphere
				Hydroponics	Biosphere
				Hydroponics	Human influences
				Far field hydrochemistry - acids, oxidants, nitrates	Far-field
				Crop fertilization	Human influences
Climatic	Anthropogenic climate change		Greenhouse gas effects	Anthropogenic climate change drought (greenhouse effect)	Geology/climate changes
				Greenhouse-induced effects (e.g. sea level change, precipitation, temp.)	Geology/climate changes

WIPP Categorization			CCA FEP List	DCCA FEP List	Sub-system
				Greenhouse-induced ecological effects (including food production)	Biosphere
				Greenhouse-induced storm surges	Geology/climate changes
			Acid rain	Acid rain	Biosphere
				Acid rain	Human influences
				Acid rain	Geology/climate changes
			Damage to ozone layer	Ozone layer (failure)	Geology/climate changes
				Ozone layer failure	Biosphere
Marine	Marine activities		Coastal water use	Coastal water use	Biosphere
			Sea water use	Sea water use	Biosphere
			Estuarine water use	Estuarine water use	Biosphere
Ecological	Agricultural activities		Ranching	Ranching	Human influences
			Arable farming	Biogas production	Human influences
				Crop storage	Biosphere
				Crop storage	Human influences
			Fish farming	Fish farming	Human influences
	Social and technological developments		Demographic change and urban development	Demographic change, urban development	Human influences
				Agricultural and fisheries practice changes	Human influences
				Critical group - leisure pursuits	Biosphere
				Demographic change, urban development	Biosphere
				Critical group - house location	Biosphere
				Technological advances in food production	Human influences
			Loss of records	Loss of records	Human influences

Appendix C: FEPs Excluded from the DCCA FEP List in the Development of the CCA FEP List

Table C-1. FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as modeling issues

DCCA FEP name	Sub-system
Boundary conditions	Backfill
Boundary conditions	Canister
Boundary conditions	Near-field
Boundary conditions	Seals
Boundary conditions	Waste
Correlation	Backfill
Correlation	Biosphere
Correlation	Canister
Correlation	Far-field
Correlation	Near-field
Correlation	Seals
Correlation	Waste
Groundwater flow: initial conditions	Backfill
Groundwater flow: initial conditions	Seals
Time dependence	Backfill
Time dependence	Canister
Time dependence	Seals
Time-dependence	Near-field
Uncertainties	Biosphere

Table C-2. FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as issues not regulated by 40 CFR Part 191

DCCA FEP name	Sub-system
Advection/dispersion: hazardous constituents	Backfill
Advection/dispersion: hazardous constituents	Near-field
Advection/dispersion: hazardous constituents	Seals
Biotoxicity	Biosphere
Carcinogenic contaminants	Biosphere
Chemical toxicity	Biosphere
Diffusion: hazardous constituents	Backfill
Diffusion: hazardous constituents	Near-field
Diffusion: hazardous constituents	Seals
Dissolution, speciation, sorption, precipitation; hazardous constituents	Backfill
Dissolution, speciation, sorption, precipitation; hazardous constituents	Near-field
Dissolution, speciation, sorption, precipitation; hazardous constituents	Seals
Inventory: hazardous constituents (e.g. VOCs, heavy metals)	Waste
Mutagenic contaminants	Biosphere
Release of hazardous constituents from the failed canister	Canister
Release of sorbed VOCs	Waste
Solubility, speciation, precipitation: hazardous constituents	Waste
Source terms (hazardous constituents)	Waste
Teratogenic contaminants	Waste
Toxicity of mined rock	Biosphere

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Table C-3 FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as issues relating to designs different to that forming the basis of the CCA

DCCA FEP name	Sub-system
Alkali-aggregate reaction	Backfill
Backfill material deficiencies	Backfill
Cement sulphate reaction	Backfill
Coagulation of bentonite	Backfill
Cracking: concrete	Backfill
Degradation of the bentonite by chemical reactions	Backfill
Design modifications: backfill	Backfill
Effects of bentonite on groundwater chemistry	Backfill
Faulty backfill emplacement	Backfill
Gas generation from concrete	Backfill
Hydrogen: effects of microbial growth on concrete degradation	Backfill
Inadequate backfill or compaction, voidage	Backfill
Radiation effects on bentonite	Backfill
Sealing of cracks: concrete	Backfill
Thermal effects (e.g. concrete hydration)	Backfill
Uneven swelling of bentonite	Backfill
Inadequate design: exploration borehole seal failure	Biosphere
Backfill effects on container corrosion	Canister
Chemical reactions (copper corrosion)	Canister
Common cause canister defects - quality control	Canister
Container healing	Canister
Corrosive agents, sulphides, oxygen, etc.	Canister
Cracking along welds	Canister
Creeping of copper	Canister
Design modifications: canister	Canister
Differing thermal expansion of materials (glass, canister)	Canister
Hydride cracking	Canister
Incomplete filling of canisters	Canister
Internal pressure	Canister
Loss of ductility	Canister
Material defects, e.g. early canister failure	Canister
Radiation damage to container (embrittlement)	Canister
Random canister defects - quality control	Canister
Role of chlorides in copper corrosion	Canister
Stress corrosion cracking	Canister
Boreholes unsealed	Far-field
Inadequate design: exploration borehole seal failure	Far-field
Incomplete vault closure	Far-field
Accidents during operation	Human influences

Table C-3 FEPs on the DCCA FEP list excluded from the development of the CCA FEP list as issues relating to designs different to that forming the basis of the CCA (Continued)

DCCA FEP name	Sub-system
Backfill/seal material deficiencies	Human influences
Decontamination materials left	Human influences
Design modifications	Human influences
Inadvertent inclusion of undesirable materials	Human influences
Other future uses of crystalline rock	Human influences
Poor quality construction	Human influences
Poorly designed repository	Human influences
Radioactive waste disposal error	Human influences
Stray materials left	Human influences
Abandonment of unsealed repository	Near-field
Accidents during operation	Near-field
Design modification: DRZ (e.g. grouting)	Near-field
Design modification: geometry	Near-field
Effects of phased operations	Near-field
Improper operation	Near-field
Inadequate design: shaft seal and exploration borehole seal failure	Near-field
Incomplete repository or borehole closure	Near-field
Open boreholes	Near-field
Poor quality construction	Near-field
Preclosure events	Near-field
Repository flooding during operations	Near-field
Unmodeled design features	Near-field
Buffer additives	Seals
Design modifications: seals	Seals
Faulty seal emplacement	Seals
Inadequate seal or compaction, voidage	Seals
Seal material deficiencies	Seals
Damaged or deviating waste contents	Waste
Design modifications: waste (e.g. buffer additives)	Waste
Differing thermal expansion of glass matrix and canister	Waste
Fracturing	Waste
I, Cs-migration to fuel surface	Waste
Long-term physical stability	Waste
Radiation damage of the matrix including embrittlement	Waste
Solubility within fuel matrix	Waste
Solubility with fuel matrix	Waste
Stability of glass	Waste
Waste incompatibility	Waste

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix SEAL

M

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Waste Isolation Pilot Plant
Shaft Sealing System
Compliance Submittal Design Report

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SANDIA REPORT

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Unlimited Release
Printed August 1996

Waste Isolation Pilot Plant Shaft Sealing System Compliance Submittal Design Report

Volume 1 of 2: Main Report
Appendices A, B, C, and D

Repository Isolation Systems Department

Prepared by
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Waste Isolation Pilot Plant Shaft Sealing System Compliance Submittal Design Report

Volume 1 of 2: Main Report Appendices A, B, C, and D

Repository Isolation Systems Department
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ABSTRACT

This report describes a shaft sealing system design for the Waste Isolation Pilot Plant (WIPP), a proposed nuclear waste repository in bedded salt. The system is designed to limit entry of water and release of contaminants through the four existing shafts after the WIPP is decommissioned. The design approach applies redundancy to functional elements and specifies multiple, common, low-permeability materials to reduce uncertainty in performance. The system comprises 13 elements that completely fill the shafts with engineered materials possessing high density and low permeability. Laboratory and field measurements of component properties and performance provide the basis for the design and related evaluations. Hydrologic, mechanical, thermal, and physical features of the system are evaluated in a series of calculations. These evaluations indicate that the design guidance is addressed by effectively limiting transport of fluids within the shafts, thereby limiting transport of hazardous material to regulatory boundaries. Additionally, the use or adaptation of existing technologies for placement of the seal components combined with the use of available, common materials assure that the design can be constructed.

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Acronyms

AIS	Air Intake Shaft
AMM	asphalt mastic mix
CFR	Code of Federal Regulations
DOE	Department of Energy
DRZ	disturbed rock zone
EPA	Environmental Protection Agency
HMAC	hot mix asphalt concrete
MDCF	Multimechanism Deformation Coupled Fracture
MD	Munson-Dawson
NMVP	No Migration Variance Petition
PA	performance assessment
PTM	Plug Test Matrix
QA	quality assurance
SMC	Salado Mass Concrete
SPVD	Site Preliminary Design Validation
SSSPT	Small Scale Seal Performance Test
SWCF	Sandia WIPP Central Files
TRU	transuranic
WIPP	Waste Isolation Pilot Plant

EXECUTIVE SUMMARY

Introduction

This report documents a shaft seal system design developed as part of a submittal to the Environmental Protection Agency (EPA) that will demonstrate regulatory compliance of the Waste Isolation Pilot Plant (WIPP) for disposal of transuranic waste. The shaft seal system limits entry of water into the repository and restricts the release of contaminants. Shaft seals address fluid transport paths through the opening itself, along the interface between the seal material and the host rock, and within the disturbed rock surrounding the opening. The entire shaft seal system is described in this report and its five appendices, which include seal material specifications, construction methods, rock mechanics analyses, fluid flow evaluations, and the design drawings. The design represents a culmination of several years of effort that has most recently focused on providing to the EPA a viable shaft seal system design. Sections of this report and the appendices explore function and performance of the WIPP shaft seal system and provide well documented assurance that such a shaft seal system could be constructed using available materials and methods.

The purpose of the shaft seal system is to limit fluid flow within four existing shafts after the repository is decommissioned. Such a seal system would not be implemented for several decades, but to establish that regulatory compliance can be achieved at that future date, a shaft seal system has been designed that exhibits excellent durability and performance and is constructable using existing technology. The design approach is conservative, applying redundancy to functional elements and specifying various common, low-permeability materials to reduce uncertainty in performance. It is recognized that changes in the design described here will occur before construction and that this design is not the only possible combination of materials and construction strategies that would adequately limit fluid flow within the shafts.

Site Setting

One of the Department of Energy's (DOE's) site selection criteria is a favorable geologic setting which minimizes fluid flow as a transport mechanism. Groundwater hydrology in the proximity of the WIPP site is characterized by geologic strata with low transmissivity and low hydrologic gradients, both very positive features with regard to sealing shafts. For purposes of performance evaluations, hydrological analyses divide lithologies and requirements into the Rustler Formation (and overlying strata) and the Salado Formation, comprised mostly of salt. The principal design concern is fluid transport phenomena of seal materials and lithologies within the Salado Formation.

The rock mechanics setting is an important consideration in terms of system performance. Rock properties affect hydrologic response of the shaft seal system. The stratigraphic section contains lithologies that exhibit brittle and ductile behavior. A zone of rock around the shafts is disturbed owing to the creation of the opening. The disturbed rock zone (DRZ) is an important design consideration because it possesses higher permeability than intact rock. Host rock response and its potential to fracture, flow, and heal around WIPP shaft openings are relevant to the performance of the shaft seal system.

Design Guidance

Use of both engineered and natural barriers to isolate wastes from the accessible environment is required by 40 CFR 191.14(d), and the use of engineered barriers to prevent or substantially delay movement of water or radionuclides toward the accessible environment is required by 40 CFR 194.44. Hazardous constituent release limits are specified in 40 CFR 191 for the entire repository system (EPA, 1996a; 1996b).

Design guidance for the shaft seal system addresses the need for the WIPP to comply with system requirements and to follow accepted engineering practices using demonstrated technology. Design guidance is categorized below:

- limit hazardous constituents reaching regulatory boundaries,
- restrict groundwater flow through the sealing system,
- use materials possessing mechanical and chemical compatibility,
- protect against structural failure of system components,
- limit subsidence and prevent accidental entry, and
- utilize available construction methods and materials.

Discussions of the design presented in the text of this report and the details presented in the appendices respond to these qualitative design guidelines. The shaft seal system design was completed under a Quality Assurance program that includes review by independent, qualified experts to assure the best possible information is provided to the DOE on selection of engineered barriers (40 CFR 194.27). Technical reviewers examined the complete design including conceptual, mathematical, and numerical models and computer codes (40 CFR 194.26). The design reduces the impact of uncertainty associated with any particular element by using multiple sealing system components and by using components constructed from different materials.

Design Description

The shaft sealing system comprises 13 elements that completely fill the shaft with engineered materials possessing high density and low permeability. Salado Formation components provide the primary regulatory barrier by limiting fluid transport along the shaft during and beyond the 10,000-year regulatory period. Components within the Rustler Formation limit commingling between brine-bearing members, as required by state regulations. Components from the Rustler to the surface fill the shaft with common materials of high density, consistent with good engineering practice. A synopsis of each component is given below.

Shaft Station Monolith. At the bottom of each shaft a salt-saturated concrete monolith supports the local roof. A salt-saturated concrete, called Salado Mass Concrete (SMC), is specified and is placed using a conventional slickline construction procedure where the concrete is batched at the surface. SMC has been tailored to match site conditions. The salt-handling shaft and the waste-handling shaft have sumps which also will be filled with salt-saturated concrete as part of the monolith.

Clay Columns. A sodium bentonite is used for three compacted clay components in the Salado and Rustler Formations. Although alternative construction specifications are viable, labor-

intensive placement of compressed blocks is specified because of proven performance. Clay columns effectively limit brine movement from the time they are placed to beyond the 10,000-year regulatory period. Stiffness of the clay is sufficient to promote healing of fractures in the surrounding rock salt near the bottom of the shafts, thus removing the proximal DRZ as a potential pathway. The Rustler clay column limits brine communication between the Magenta and Culebra Members of the Rustler Formation.

Concrete-Asphalt Waterstop Components. Concrete-asphalt waterstop components comprise three elements: an upper concrete plug, a central asphalt waterstop, and a lower concrete plug. Three such components are located within the Salado Formation. These concrete-asphalt waterstop components provide independent shaft cross-section and DRZ seals that limit fluid transport, either downward or upward. Concrete fills irregularities in the shaft wall, while use of the salt-saturated concrete assures good bonding with salt. Salt creep against the rigid concrete components establishes a compressive stress state and promotes early healing of the salt DRZ surrounding the concrete plugs. The asphalt intersects the shaft cross section and the DRZ.

Compacted Salt Column. Each shaft seal includes a column of compacted WIPP salt with 1.5 percent weight water added to the natural material. Construction demonstrations have shown that mine-run WIPP salt can be dynamically compacted to a density equivalent to approximately 90% of the average density of intact Salado salt. The remaining void space is removed through consolidation caused by creep closure. The salt column becomes less permeable as density increases. The location of the compacted salt column near the bottom of the shaft assures the fastest achievable consolidation of the compacted salt column after closure of the repository. Analyses indicate that the salt column becomes an effective long-term barrier in under 100 years.

Asphalt Column. An asphalt-aggregate mixture is specified for the asphalt column, which bridges the Rustler/Salado contact and provides a seal essentially impermeable to brine for the shaft cross-section and the shaft wall interface. All asphalt is placed with a heated slickline.

Concrete Plugs. A concrete plug is located just above the asphalt column and keyed into the surrounding rock. Mass concrete is separated from the cooling asphalt column with a layer of fibercrete, which permits work to begin on the overlying clay column before the asphalt has completely cooled. Another concrete plug is located near the surface, extending downward from the top of the Dewey Lake Redbeds.

Earthen Fill. The upper shaft is filled with locally available earthen fill. Most of the fill is dynamically compacted (the same method used to construct the salt column) to a density approximating the surrounding lithologies. The uppermost earthen fill is compacted with a sheepsfoot roller or vibratory plate compactor.

Structural Analysis

Structural issues pertaining to the shaft seal system have been evaluated. Mechanical, thermal, physical, and hydrological features of the system are included in a broad suite of structural calculations. Conventional structural mechanics applications would normally calculate load on system elements and compare the loads to failure criteria. Several such conventional calculations have been performed and show that the seal elements exist in a favorable, compressive stress state that is low in comparison to the strength of the seal materials. Thermal analyses have been

performed to examine the effects of concrete heat of hydration and heat transfer for asphalt elements. Coupling between damaged rock and fluid flow and between the density and permeability of the consolidating salt column is evaluated within the scope of structural calculations.

The appendices provide descriptions of various structural calculations conducted as part of the design study. The purpose of each calculation varies; however, the calculations generally address one or more of the following concerns: (1) stability of the component, (2) influences of the component on hydrological properties of the seal and surrounding rock, or (3) construction methods. Stability calculations address:

- potential for thermal cracking of concrete;
- structural loads on seal components resulting from salt creep, gravity, swelling clay, dynamic compaction, or possible repository-generated gas pressures.

Structural calculations defining input conditions to hydrological calculations include:

- spatial extent of the DRZ within the Salado Formation salt beds as a function of depth, time, and seal material;
- fracturing and DRZ development within Salado Formation interbeds;
- shaft-closure induced consolidation of compacted salt columns;
- impact of pore pressures on salt consolidation.

Construction analyses examine:

- placement and structural performance of asphalt waterstops,
- potential subsidence reduction through backfilling the shaft station areas.

Structural calculations model shaft features including representation of the host rock and its damaged zone as well as the seal materials themselves. Two important structural calculations discussed below are unique to shaft seal applications.

DRZ Behavior. The development and subsequent healing of a disturbed rock zone (DRZ) that forms in the rock mass surrounding the WIPP shafts is a significant concern in the seal design. It is well known that a DRZ will develop in rock salt adjacent to the shaft upon excavation. Placement of rigid components in the shaft promotes healing within the salt DRZ as seal elements restrain inward creep and reduce the stress difference. Two computer models to calculate development and extent of the salt DRZ are used. The first model uses a ratio of stress invariants to predict fracture; the second approach uses a damage stress criterion. The temporal and spatial extent of the DRZ along the entire shaft length is evaluated.

Several analyses are performed to examine DRZ behavior of the rock salt surrounding the shaft. The time-dependent DRZ development and subsequent healing in the Salado salt surrounding each of the four seal materials are considered. All seal materials below a depth of about 300 m provide sufficient rigidity to heal the DRZ, a phenomenon that occurs quickly around rigid components near the shaft bottom. An extensive calculation is made of construction effects on the DRZ during placement of the asphalt-concrete waterstops. The time-dependent development of the DRZ within anhydrite and polyhalite interbeds of the Salado Formation is calculated. For

all interbeds, the factor of safety against shear or tensile fracturing increases with depth into the rock surrounding the shaft wall. These results indicate that a continuous DRZ will not develop in nonsalt Salado rocks. Rock mechanics analysis also determines which of the near surface lithologies fracture in the proximity of the shaft. Results from these rock mechanics analyses are used as input conditions for the fluid-flow analyses.

Compacted Salt Behavior. Unique application of crushed salt as a seal component required development of a constitutive model for salt reconsolidation. The model developed includes a nonlinear elastic component and a creep consolidation component. The nonlinear elastic modulus is density-dependent, based on laboratory test data performed on WIPP crushed salt. Creep consolidation behavior of crushed salt is based on three candidate models whose parameters are obtained from model fitting to hydrostatic and shear consolidation test data gathered for WIPP crushed salt. The model for consolidating crushed salt is used to predict permeability of the salt column.

The seal system prevents fluid transport to the consolidating salt column to ensure that pore pressure does not unacceptably inhibit the reconsolidation process. Calculations made to estimate fractional density of the crushed salt seal as a function of time, depth, and pore pressure show consolidation time increases as pore pressure increases, as expected. At a constant pore pressure of one atmosphere, compacted salt will increase from its initial fractional density of 90% to 96% within 40, 80, and 120 years after placement at the bottom, middle, and top of the salt component, respectively. At a fractional density of 96%, the permeability of reconsolidating salt is approximately 10^{-18} m^2. A pore pressure of 2 MPa increases times required to achieve a fractional density of 96% to 92 years, 205 years, and 560 years at the bottom, middle, and top of the crushed salt column, respectively. A pore pressure of 4 MPa would effectively prevent reconsolidation of the crushed salt within 1,000 years. Fluid flow calculations show only minimal transport of fluids to the salt column, so pore pressure equilibrium in the consolidating salt does not occur before low permeabilities ($\sim 10^{-18}$ m^2) are achieved.

Hydrologic Evaluations

The ability of the shaft seal system to satisfy design guidance is determined by the performance of the actual seal components within the physical setting in which they are constructed. Important elements of the physical setting are hydraulic gradients of the region, properties of the lithologic units surrounding a given seal component, and potential gas generation within the repository. Hydrologic evaluations focus on processes that could result in fluid flow through the shaft seal system and the ability of the seal system to limit any such flow. Transport of radiological or hazardous constituents will be limited if the carrier fluids are similarly limited.

Physical processes that could impact seal system performance have been incorporated into four models. These models evaluate: (1) downward migration of groundwater from the Rustler Formation, (2) gas migration and reconsolidation of the crushed salt seal component, (3) upward migration of brines from the repository, and (4) flow between water-bearing zones in the Rustler Formation.

Downward Migration of Rustler Groundwater. The shaft seal system is designed to limit groundwater flowing into and through the shaft sealing system. The principal source of groundwater to the seal system is the Culebra Member of the Rustler Formation. No significant

sources of groundwater exist within the Salado Formation; however, brine seepage has been noted at a number of the marker beds and is included in the models. Downward migration of Rustler groundwater is limited to ensure that liquid saturation of the compacted salt column does not impact the consolidation process and to limit quantities of brine reaching the repository horizon.

Consolidation of the compacted salt column will be most rapid immediately following seal construction. Simulations conducted for the 200-year period following closure demonstrate that, during this initial period, downward migration of Rustler groundwater is insufficient to impact the consolidation process. Rock mechanics analyses show that this period encompasses the reconsolidation process. Lateral migration of brine through the marker beds is quantified in the analysis and shown to be inconsequential.

At steady-state, the flow rate is most dependent on permeability of the system. Potential flow paths within the seal system consist of the seal material, an interface with the surrounding rock, and the host rock DRZ. Low permeability is specified for the engineered materials, and construction methods ensure a tight interface. Thus the flow path most likely to impact performance is the DRZ. Effects of the DRZ and sensitivity of the seal system performance to both engineered and host rock barriers show that the DRZ is successfully mitigated by the proposed design.

Gas Migration and Salt Column Consolidation. A multi-phase flow model of the lower seal system evaluates the performance of components extending from the middle concrete-asphalt waterstop located at the top of the salt column to the repository horizon for 200 years following closure. During this time period, the principal fluid sources to the model consist of potential gas generated by the waste and lateral brine migration within the Salado Formation. The predicted downward migration of a small quantity of Rustler groundwater (discussed above) is included in this analysis.

Effects of gas generation are evaluated for three different repository repressurization scenarios, which simulate pressures as high as 14 MPa. Model results predict that high repository pressures do not produce appreciable differences in the volume of gas migration over the 200-year simulation period. Relatively low gas flow is a result of the low permeability and rapid healing of the DRZ around the lower concrete-asphalt waterstop.

Upward Migration of Brine. The Salado Formation is overpressurized with respect to the measured heads in the Rustler, and upward migration of contaminated brines could occur through an inadequately sealed shaft. Results from the model discussed above demonstrate that the crushed salt seal will reconsolidate to a very low permeability within 100 years following repository closure. Structural results show that the DRZ surrounding the long-term clay and crushed salt seal components will completely heal within the first several decades. Model calculations predict that very little brine flows from the repository to the Rustler/Salado contact.

Intra-Rustler Flow. Based on head differences between the various members of the Rustler Formation, nonhydrostatic conditions exist within the Rustler Formation. Therefore, the potential exists for vertical flow within water-bearing strata within the Rustler. The two units with the greatest transmissivity within the Rustler are the Culebra and the Magenta dolomites, which have the greatest potential for interflow. The relatively low undisturbed permeabilities of

the mudstone and anhydrite units separating the Culebra and the Magenta naturally limit crossflow. However, the construction and subsequent closure of the shaft provide a potentially permeable vertical conduit connecting water-bearing units.

The primary motivation for limiting formation crossflow within the Rustler is to prevent mixing of formation waters within the Rustler, as required by State of New Mexico statute. Commonly, such an undertaking would limit migration of higher dissolved solids (high-density) groundwater into lower dissolved solids groundwater. In the vicinity of the WIPP site, the Culebra has a higher density groundwater than the Magenta, and the potential for fluid migration between the two most transmissive units is from the unit with the lower total dissolved solids to the unit with the higher dissolved solids. This calculation shows that potential flow rates between the Culebra and the Magenta are insignificant. Under expected conditions, intra-Rustler flow is expected to be of such a limited quantity that (1) it will not affect either the hydraulic or chemical regime within the Culebra or the Magenta and (2) it will not be detrimental to the seal system itself.

Concluding Remarks

The principal conclusion is that an effective, implementable shaft seal system has been designed for the WIPP. Design guidance is addressed by limiting any transport of fluids within the shaft, thereby limiting transport of hazardous material to regulatory boundaries. The application or adaptation of existing technologies for placement of seal components combined with the use of available, common materials provide confidence that the design can be constructed. The structural setting for seal elements is compressive, with shear stresses well below the strength of seal materials. Because of the favorable hydrologic regime coupled with the low intrinsic permeability of seal materials, long-term stability of the shaft seal system is expected. Credibility of these conclusions is bolstered by the basic design approach of using multiple components to perform each sealing function and by using extensive lengths within the shafts to effect a sealing system. The shaft seal system adequately meets design requirements and can be constructed.

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1. INTRODUCTION

1.1 Purpose of Compliance Submittal Design Report

This report documents the detailed design of the shaft sealing system for the Waste Isolation Pilot Plant (WIPP). The design documented in this report builds on the concepts and preliminary evaluations presented in the Sealing System Design Report issued in 1995 (DOE, 1995). The report contains a detailed description of the design and associated construction procedures, material specifications, analyses of structural and fluid flow performance, and design drawings. The design documented in this report forms the basis for shaft sealing discussions in the Compliance Certification Application (CCA) to the Environmental Protection Agency (EPA), for shaft sealing simulations in the associated performance assessments, and for ongoing evaluations of the sealing system associated with the no-migration variance petition.

1.2 WIPP Description

The WIPP is designed as a full-scale, mined geological repository for the safe management, storage, and disposal of transuranic (TRU) radioactive wastes generated by US government defense programs. The facility is located near Carlsbad, New Mexico, in the southeastern portion of the state. The underground facility (Figure 1-1) consists of a series of shafts, drifts, panels, and disposal rooms. Four shafts, ranging in diameter from 3.5 to 6.1 m, connect the disposal horizon to the surface. Sealing of these four shafts is the focus of this report.

The disposal horizon is at a depth of approximately 655 m in bedded halite within the Salado Formation. The Salado is a sequence of bedded evaporites approximately 600 m thick that were deposited during the Permian Period, which ended about 225 million years ago. Salado salt has been identified as a good geologic medium to host a nuclear waste repository because of several favorable characteristics. The characteristics present at the WIPP site include very low permeability, vertical and lateral stratigraphic extent, tectonic stability, and the ability of salt to creep and ultimately entomb material placed in excavated openings. Creep closure also plays an important role in the shaft sealing strategy.

The WIPP facility must be determined to be in compliance with applicable regulations prior to the disposal of waste. After the facility meets the regulatory requirements, disposal rooms will be filled with containers holding TRU wastes of various forms. Wastes placed in the drifts and disposal rooms will be at least 150 m from the shafts. Regulatory requirements include use of both engineered and natural barriers to limit migration of hazardous constituents from the repository to the accessible environment. The shaft seals are part of the engineered barriers.

1.3 Performance Objective for WIPP Shaft Seal System

Each of the four shafts from the surface to the underground repository must be sealed to limit hazardous material release to the accessible environment and to limit groundwater flow into the repository. Although the seals will be permanent, the regulatory period applicable to the repository system analyses is 10,000 years.

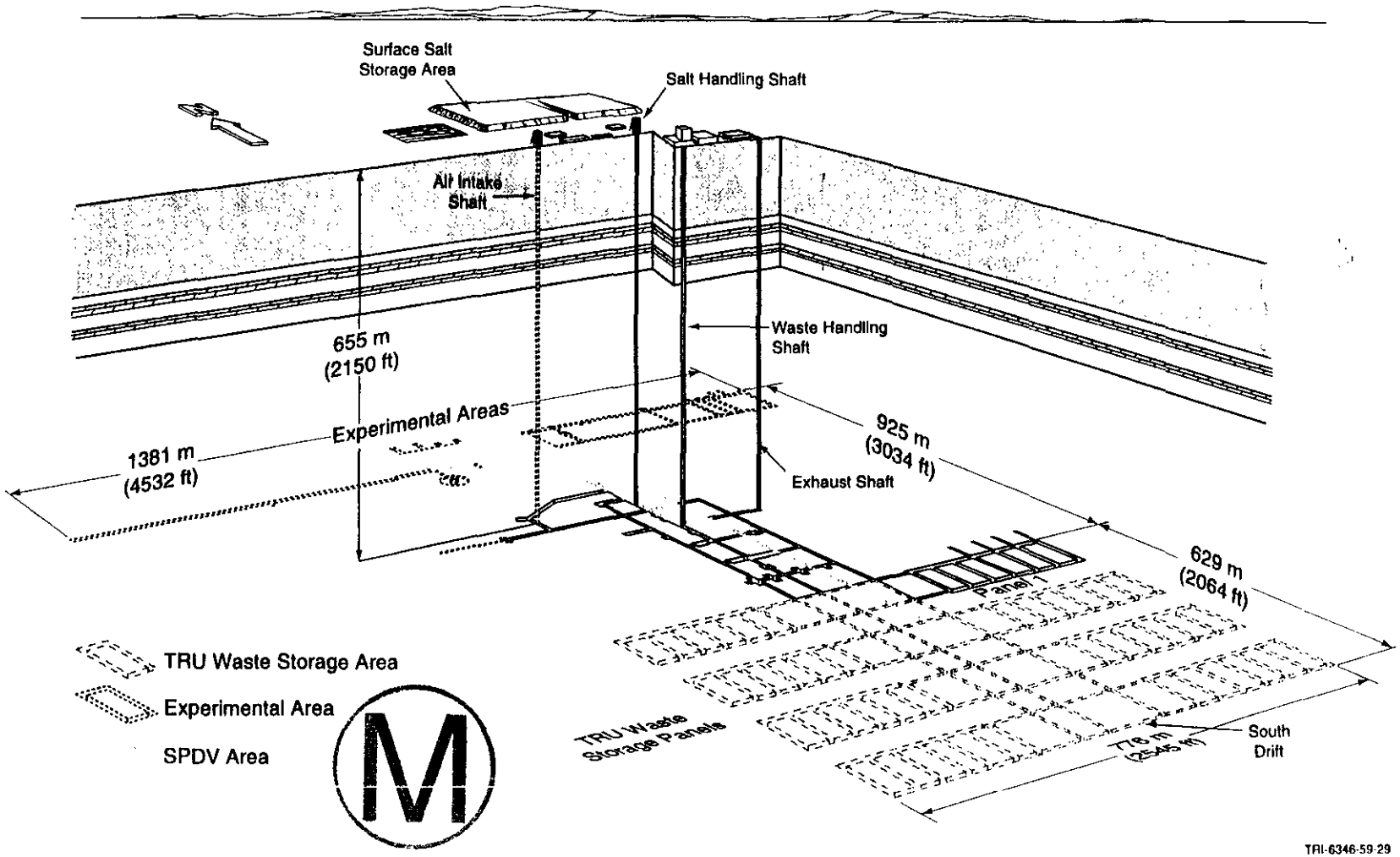

Figure 1-1. View of the WIPP facility.

1.4 Sealing System Design Development Process

This report presents a conservative approach to shaft sealing system design. Shaft sealing system performance plays a crucial role in meeting regulatory radionuclide and hazardous constituents release requirements. Although all engineering materials have uncertainties in properties, a combination of available, low-permeability materials can provide an effective sealing system. To reduce the impact of system uncertainties and to provide a high level of assurance of compliance, numerous components are used in this sealing system. Components in this design include long columns of clay, densely compacted crushed salt, a waterstop of asphaltic material sandwiched between massive low-permeability concrete plugs, a column of asphalt, and a column of earthen fill. Different materials perform identical functions within the design, thereby adding confidence in the system performance through redundancy.

The design is based on common materials and construction methods that utilize available technologies. When choosing materials, emphasis was given to permeability characteristics and mechanical properties of seal materials. However, the system is also chemically and physically compatible with the host formations, enhancing long-term performance.

Recent laboratory experiments, construction demonstrations, and field test results have been added to the broad and credible database and have supported advances in modeling capability. Results from a series of multi-year, in situ, small-scale seal performance tests show that bentonite and concrete seals maintain very low permeabilities and show no deleterious effects in the WIPP environment. A large-scale dynamic compaction demonstration established that crushed salt can be successfully compacted. Laboratory tests show that compacted crushed salt consolidates through creep closure of the shaft from initial conditions achieved in dynamic compaction to a dense salt mass with regions where permeability approaches that of in situ salt. These technological advances have allowed more credible analysis of the shaft sealing system.

The design was developed through an interactive process involving a design team consisting of technical specialists in the design and construction of underground facilities, materials behavior, rock mechanics analysis, and fluid flow analysis. The design team included specialists drawn from the staff of Sandia National Laboratories, Parsons Brinckerhoff Quade and Douglas, Inc. (contract number AG-4909), INTERA, Inc. (contract number AG-4910), and RE/SPEC Inc. (contract number AG-4911), with management by Sandia National Laboratories. The contractors developed a quality assurance program consistent with the Sandia National Laboratories Quality Assurance Program Description for the WIPP project. All three contractors received quality assurance support visits and were audited through the Sandia National Laboratories audit and assessment program. Quality assurance (QA) documentation is maintained in the Sandia National Laboratories WIPP Central Files. Access to project files for each contractor can be accomplished using the contract numbers specified above. In addition to the contractor support, technical input was obtained from consultants in various technical specialty areas.

Formal preliminary and final design reviews have been conducted on the technical information documented in the report. In addition, technical, management, and QA reviews have been performed on this report. Documentation is in the WIPP Central File.

It is recognized that additional information, such as on specific seal material or formation characteristics, on the sensitivity of system performance to component properties, on placement effectiveness, and on long-term performance, could be used to simplify the design and perhaps reduce the length or number of components. Such design optimization and associated simplifications are left to future research that may be used to update the compliance evaluations completed between now and the time of actual seal emplacement.

1.5 Organization of Document

This report contains an Executive Summary, 10 sections, and 5 appendices. The body of the report does not generally contain detailed backup information; this information is incorporated by reference or in the appendices.

The Executive Summary is a synopsis of the design and the supporting discussions related to seal materials, construction procedures, structural analyses, and fluid flow analyses. Introductory material in Section 1 sets the stage for and provides a "road map" to the remainder of the report.

Site characteristics that detail the setting into which the seals would be placed are documented in Section 2. These characteristics include the WIPP geology and stratigraphy for both the region and the shafts as well as a brief discussion of rock mechanics considerations of the site that impact the sealing system. Regional and local characteristics of the hydrologic and geochemical settings are also briefly discussed.

Section 3 presents the design guidance used for development of the shaft sealing system design. Seal-related guidance from applicable regulations is briefly described. The design guidance is then provided along with the design approach used to implement the guidance. The guidance forms the basis both for the design and for evaluations of the sealing system presented in other sections.

The shaft sealing system is documented in Section 4; detailed drawings for the design are provided in Appendix E. The seal components, their design, and their functions are discussed for the Salado, the Rustler, and the overlying formations.

The sealing materials are described briefly in Section 5, with more detail provided in the materials specifications (Appendix A). The materials used in the various seal components are discussed along with the reasons they are expected to function as intended. Material properties including permeability, strength, and mechanical constitutive response are given for each material. Brief discussions of expected compatibility, performance, construction techniques, and other characteristics relevant to the WIPP setting are also given.

Section 6 contains a brief description of the construction techniques proposed for use. General site and sealing preparation activities are discussed, including construction of a multi-deck stage for use throughout the placement of the components. Construction procedures to be used for the various types of components are then summarized based on the more detailed discussions provided in Appendix B.

Section 7 summarizes structural analyses performed to assess the ability of the shaft sealing system to function in accordance with the design guidance provided in Section 3 and to

provide input to hydrological calculations. The methods and computer programs, the models used to simulate the behavior of the seal materials and surrounding salt, and the results of the analyses are discussed. Particular emphasis is placed on the evaluations of the behavior of the disturbed rock zone. Details of the structural analyses are presented in Appendix D.

Section 8 summarizes fluid flow analyses performed to assess the ability of the shaft sealing system to function in accordance with the design guidance provided in Section 3. Hydrologic evaluations are focused on processes that could result in fluid flow through the shaft seal system and the ability of the seal system to limit such flow. Processes evaluated are downward migration of groundwater from the overlying formation, gas migration and reconsolidation of the crushed salt component, upward migration of brines from the repository, and flow between water-bearing zones in the overlying formation. Hydrologic models are described and the results are discussed as they relate to satisfying the design guidance, with extensive reference to Appendix C that documents details of the flow analyses.

Conclusions drawn about the performance of the WIPP shaft sealing system are described in Section 9. The principal conclusion that an effective, implementable design has been presented is based on the presentations in the previous sections. A reference list that documents principal references used in developing this design is then provided.

The five appendices that follow provide details related to the following subjects:

Appendix A — Material Specification

Appendix B — Shaft Sealing Construction Procedures

Appendix C — Fluid Flow Analyses

Appendix D — Structural Analyses

Appendix E — Design Drawings (separate volume)

1.6 Systems of Measurement

Two systems of measurement are used in this document and its appendices. Both the System International d'Unites (SI) and English Gravitational (*fps* units) system are used. This usage corresponds to common practice in the United States, where SI units are used for scientific studies and *fps* units are used for facility design, construction materials, codes, and standards. Dual dimensioning is used in the design description and other areas where this use will aid the reader.

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2. SITE GEOLOGIC, HYDROLOGIC, AND GEOCHEMICAL SETTING

The site characteristics relevant to the sealing system are discussed in this section. The location and geologic setting of the WIPP are discussed first to provide background. The geology and stratigraphy, which affect the shafts, are then discussed. The hydrologic and geochemical settings, which influence the seals, are described last.

2.1 Introduction

The WIPP site is located in an area of semiarid rangeland in southeastern New Mexico. The nearest major population center is Carlsbad, 42 km west of the WIPP. Two smaller communities, Loving and Malaga, are about 33 km to the southwest. Population density close to the WIPP is very low: fewer than 30 permanent residents live within a 16-km radius.

2.2 Site Geologic Setting

Geologically the WIPP is located in the Delaware Basin, an elongated depression that extends from just north of Carlsbad southward into Texas. The Delaware Basin is bounded by the Capitan Reef (see Figure 2-1). The basin covers over 33,000 km^2 and is filled with sedimentary rocks to depths of 7,300 m (Hills, 1984). Rock units of the Delaware Basin (representing the Permian System through the Quaternary System) are listed in Figure 2-2.

Minimal tectonic activity has occurred in the region since the Permian Period (Powers et al., 1978). Faulting during the late Tertiary Period formed the Guadalupe and Delaware Mountains along the western edge of the basin. The most recent igneous activity in the area occurred during the mid-Tertiary Period about 35 million years ago and is evidenced by a dike in the subsurface 16 km northwest of the WIPP. Major volcanic activity last occurred more than 1 billion years ago during Precambrian time (Powers et al., 1978). None of these processes affected the Salado Formation at the WIPP. Therefore, seismic-related design criteria are not included in the current seal systems design guidelines.

2.2.1 Regional WIPP Geology and Stratigraphy

The Delaware Basin began forming with crustal subsidence during the Pennsylvanian Period approximately 300 million years ago. Relatively rapid subsidence over a period of about 14 million years resulted in the deposition of a sequence of deep-water sandstones, shales, and limestones rimmed by shallow-water limestone reefs such as the Capitan Reef (see Figure 2-1). Subsidence slowed during the late Permian Period. Evaporite deposits of the Castile Formation and the Salado Formation (which hosts the WIPP underground workings) filled the basin and extended over the reef margins. The evaporites, carbonates, and clastic rocks of the Rustler Formation and the Dewey Lake Redbeds were deposited above the Salado Formation near the end of the Permian Period. The Santa Rosa and Gatuña Formations were deposited after the close of the Permian Period.

From the surface downward to the repository horizon the stratigraphic units are the Quaternary surface sand sediments, Gatuña Formation, Santa Rosa Formation, Dewey Lake Redbeds, Rustler Formation, and Salado Formation. Three principal stratigraphic units (the Dewey Lake Redbeds, the Rustler Formation, and the Salado Formation) comprise all but the upper 15 to 30 m (50 to 100 ft) of the geologic section above the WIPP facility.

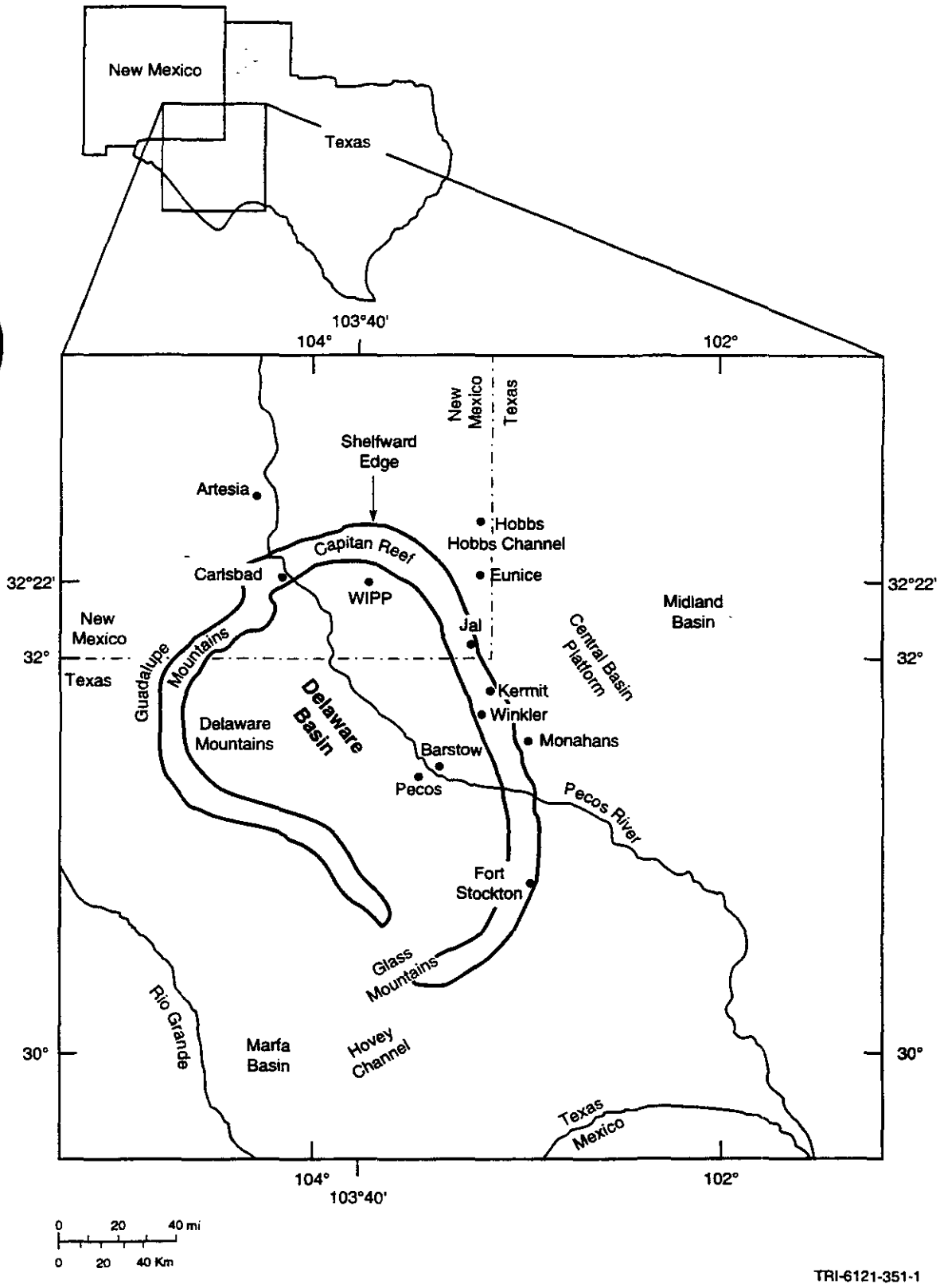

Figure 2-1. Location of the WIPP in the Delaware Basin.

Erathem	System	Series	Lithostratigraphic Unit	Age Estimate (yr)
Cenozoic	Quaternary	Holocene	Windblown sand	
		Pleistocene	Mescalero caliche	~500,000
			Gatuña Formation	~600,000
	Tertiary	Pliocene	Ogallala Formation	5.5 million
		Miocene		24 million
		Oligocene	Absent in southeastern New Mexico	
		Eocene		
		Paleocene		66 million
Mesozoic	Cretaceous	Upper	Absent in southeastern New Mexico	
		Lower	Detritus preserved	144 million
	Jurassic		Absent in southeastern New Mexico	208 million
	Triassic	Upper	Dockum Group	
		Lower	Absent in southeastern New Mexico	245 million
Paleozoic	Permian, Upper	Ochoan	Dewey Lake Redbeds	
			Rustler Formation	
			Salado Formation	
			Castile Formation	
		Guadalupian	Capitan Limestone and Bell Canyon Formation	
	Permian, Lower	Leonardian	Bone Springs	
		Wolfcampian	Wolfcamp (informal)	286 million

Modified from Bachman, 1987

Figure 2-2. Chart showing major stratigraphic divisions, southeastern New Mexico.

The Dewey Lake Redbeds consist of alternating layers of reddish-brown, fine-grained sandstone and siltstone cemented with calcite and gypsum (Vine, 1963). The Rustler Formation lies below the Dewey Lake Redbeds; this formation, the youngest of the Late Permian evaporite sequence, includes units that provide potential pathways for radionuclide migration from the WIPP. The five units of the Rustler, from youngest to oldest, are: (1) the Forty-niner Member, (2) the Magenta Dolomite Member, (3) the Tamarisk Member, (4) the Culebra Dolomite Member, and (5) an unnamed lower member.

The 250-million-year-old Salado Formation lies below the Rustler Formation. This unit is about 600 m thick and consists of three informal members. From youngest to oldest, they are: (1) an upper member (unnamed) composed of reddish-orange to brown halite interbedded with polyhalite, anhydrite, and sandstone, (2) a middle member (the McNutt Potash Zone) composed of reddish-orange and brown halite with deposits of sylvite and langbeinite; and (3) a lower member (unnamed) composed of mostly halite with lesser amounts of anhydrite, polyhalite, and glauberite, with some layers of fine clastic material. These lithologic layers are nearly horizontal at the WIPP, with a regional dip of less than one degree. The WIPP repository is located in the unnamed lower member of the Salado Formation, approximately 655 m (2150 ft) below the ground surface.

2.2.2 Local WIPP Stratigraphy

The generalized stratigraphy of the WIPP site, with the location of the repository, is shown in Figure 2-3. To establish the geologic framework required for the design of the WIPP facility shaft sealing system, an evaluation was performed to assess the geologic conditions existing in and between the shafts, where the individual shaft sealing systems will eventually be emplaced (DOE, 1995: Appendix A). The study evaluated shaft stratigraphy, regional groundwater occurrence, brine occurrence in the exposed Salado Formation section, and the consistency between recorded data and actual field data.

Four shafts connect the WIPP underground workings to the surface, the (1) Air Intake Shaft (AIS), (2) Exhaust Shaft, (3) Salt Handling Shaft, and (4) Waste Shaft. Stratigraphic correlation and evaluation of the unit contacts show that lithologic units occur at approximately the same levels in all four shaft locations. Some stratigraphic contact elevations vary because of regional structure and stratigraphic thinning and thickening of units. However, the majority of the stratigraphic contacts used to date are suitable for engineering design reference because they intersect all four shafts.

2.2.3 Rock Mechanics Setting

The WIPP stratigraphy includes rock types that exhibit both brittle and ductile behaviors. The majority of the stratigraphy intercepted by the shafts consists of the Salado Formation, which is predominantly halite. The primary mechanical behavior of halitic rocks is creep. Except near free surfaces (such as the shaft wall), the salt rocks will remain tight and undisturbed despite the long-term creep deformation they sustain. The other rock types within the Salado Formation are anhydrites and polyhalites. These two rock types are typically brittle, stiff, and exhibit high strength in laboratory tests. The structural strength of particular anhydritic rock layers, however, depends on the thickness of the layers, which range from thin (<1 m) to fairly

thick (10 m or more). Brittle failure of these noncreeping rocks can occur as they restrain, or attempt to restrain, the creep of the salt above and below the stiff layer. Although thick layers can resist the induced stresses, thin layers are fractured in tension by the salt creep. Because the deformation in the bounding salt is time dependent, the damage in the brittle rock is also time dependent.

Above the Salado Formation, the Rustler Formation stratigraphy consists of relatively strong limestones and siltstones. The shaft excavation is the only significant disturbance to these rocks. Any subsurface subsidence (deformation) or loading induced by the presence of the repository are negligible in a rock mechanics sense.

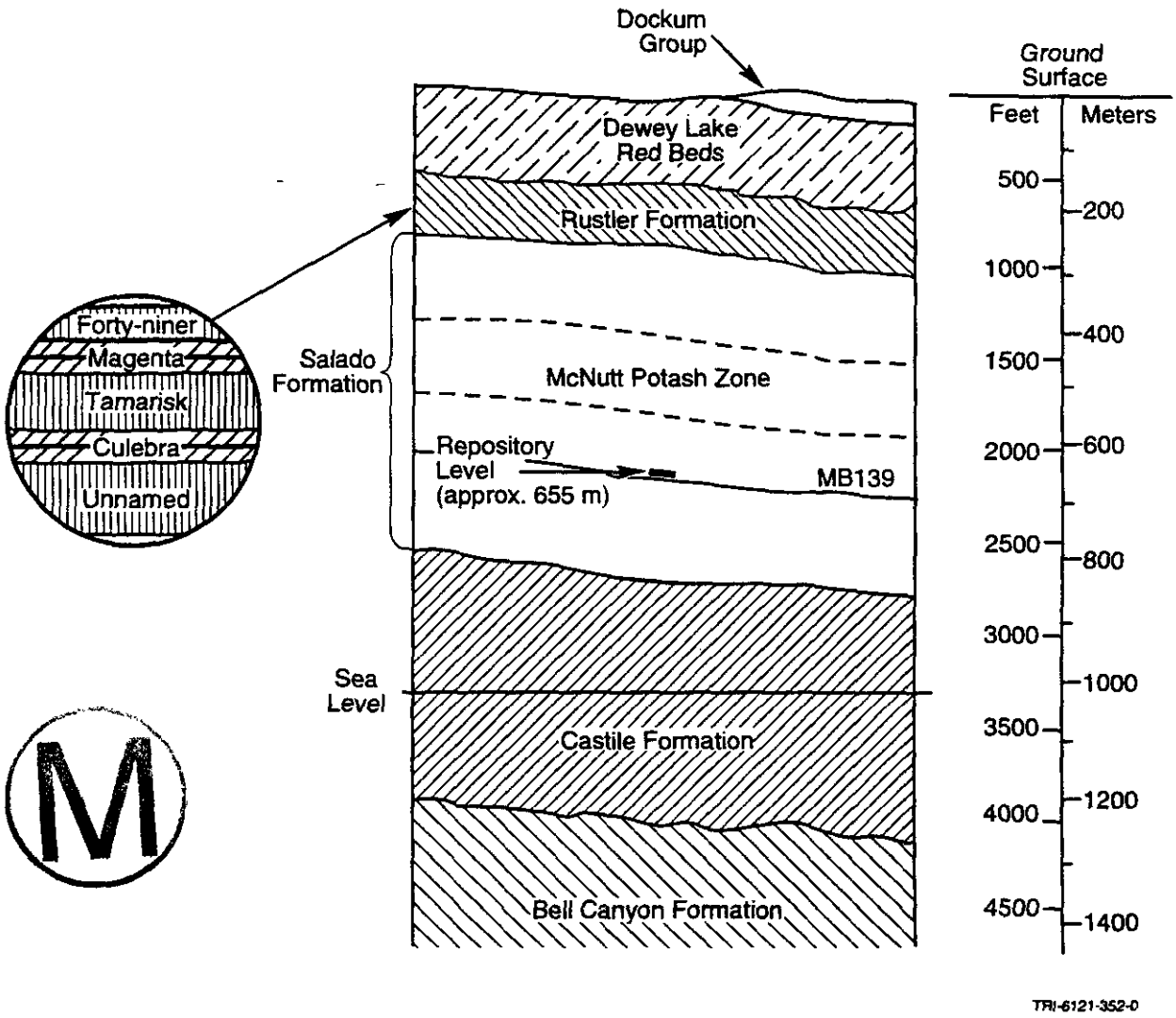

Figure 2-3. Generalized stratigraphy of the WIPP site showing repository level.

Regardless of rock type, the shafts create a disturbed zone in the surrounding rock. Microfracturing will occur in the rock adjacent to the shaft wall, where confining stresses are low or nonexistent. The extent of the zone depends on the rock strength and the prevailing stress state, which is depth dependent. In the salt rocks, microfracturing occurs to form the disturbed zone both at the time of excavation and later as dilatant creep deformations occur. In the brittle rocks, the disturbance occurs at the time of excavation and does not worsen with time. The extent of disturbed zones in the salt and brittle rocks can be calculated, as will be described in Section 7 and Appendix D.

Preventing the salt surrounding the shafts from creeping causes reintroduction of stresses that reverse the damage process and cause healing (Van Sambeek et al., 1993). The seal system design relies on this principle for sealing the disturbed zone in salt. In the brittle rocks, grouting of the damage is a viable means of reducing the interconnected fractures that increase the permeability of the rock.

2.3 Site Hydrologic Setting

The WIPP shafts penetrate approximately 655 m (2150 ft) of sediments and rocks. From a hydrogeologic perspective, relevant information includes the permeability of the water-bearing units, the thickness of the water-bearing units, and the observed vertical pressure (head) gradients expected to exist after shaft construction and ambient pressure recovery. This section will discuss these three aspects of the site hydrogeology. The geochemistry of the pore fluids adjacent to the shaft system is also important hydrogeologic information and will be provided in Section 2.4.

2.3.1 Hydrostratigraphy

The WIPP shafts penetrate Quaternary surface sediments, the Gatuña Formation, the Santa Rosa Formation, the Dewey Lake Redbeds, the Rustler Formation, and the Salado Formation. The Rustler Formation contains the only laterally-persistent water-bearing units in the WIPP vicinity. As a result, flow-field characterization, regional flow-modeling, and performance assessment off-site release scenarios focus on the Rustler Formation. The hydrogeology of the stratigraphic units in contact with the upper portion of the AIS sealing system is fairly well known from detailed hydraulic testing of the Rustler Formation at well H-16 located 17 m from the AIS (Beauheim, 1987). The H-16 borehole was drilled in July and August 1987 to monitor the hydraulic responses of the Rustler members to the drilling and construction of the AIS. During the drilling of H-16, each member of the Rustler Formation was cored. In addition, detailed drill-stem, pulse, and slug hydraulic tests were performed in H-16 on the members of the Rustler. Through the detailed testing program at H-16, the permeability of each of the Rustler members was estimated. Detailed mapping of the AIS by Holt and Powers (1990) and other investigators provided information on the location of wet zones and weeps within the Salado Formation. This information will be summarized below. The reader, unless particularly interested in this subject, should proceed to Section 2.3.2.

Water-bearing zones have been observed in units above the Rustler Formation in the WIPP site vicinity. However, drilling in the Dewey Lake Redbeds has not identified any continuous saturated units at the WIPP site. Water-bearing units within stratigraphic intervals

above the Rustler are typically perched saturated zones of very low yield. Thin perched groundwater intervals have been encountered in WIPP wells H-1, H-2, and H-3 (Mercer and Orr, 1979). The only Dewey Lake Redbed wells that have sufficient yields for watering livestock are the James Ranch wells, the Pocket well, and the Fairfield well (Brinster, 1991). These wells are located to the south of the WIPP and are not in the immediate vicinity of the WIPP shafts.

The Dewey Lake Redbeds overlie the Rustler Formation. The Rustler is composed of five members defined by lithology. These are, in ascending order, the unnamed lower member, the Culebra dolomite, the Tamarisk, the Magenta dolomite, and the Forty-niner (see Figure 2-3). Of these five members, the unnamed lower member, the Culebra, and the Magenta are the most transmissive units in the Rustler. The Tamarisk and the Forty-niner are aquitards within the Rustler and have very low permeabilities relative to the three members listed above.

To the east of the shafts in Nash Draw, the Rustler/Salado contact has been observed to be permeable and water-bearing. This contact unit has been referred to as the "brine aquifer" (Mercer, 1983). The brine aquifer is not reported to exist in the vicinity of the shafts. The hydraulic conductivity of the Rustler/Salado contact in the vicinity of the shafts is reported to be approximately 4×10^{-11} m/s, which is equivalent to a permeability of 6×10^{-18} m^2 using reference brine fluid properties (Brinster, 1991). The unnamed lower member was hydraulic tested at well H-16 in close proximity to the AIS. The maximum permeability of the unnamed lower member was interpreted to be 2.2×10^{-18} m^2 and was attributed to the unnamed lower member claystone by Beauheim (1987), which correlates to the transition and bioturbated clastic zones of Holt and Powers (1990).

The Culebra Dolomite Member is the most transmissive member of the Rustler Formation in the vicinity of the WIPP site and is the most transmissive saturated unit in contact with the shaft sealing system. The Culebra is an argillaceous dolomicrite which contains secondary porosity in the form of abundant vugs and fractures. The permeability of the Culebra varies greatly in the vicinity of the WIPP and is controlled by the condition of the secondary porosity (fractures). The permeability of the Culebra in the vicinity of the shafts is approximately 2.1×10^{-14} m^2.

The Tamarisk Member is composed primarily of massive, lithified anhydrite, including anhydrite 2, mudstone 3, and anhydrite 3. Testing of the Tamarisk at H-16 was unsuccessful. The estimated transmissivity of the Tamarisk at H-16 is one to two orders of magnitude lower than the least-transmissive unit successfully tested at H-16, which results in a permeability range from 4.6×10^{-20} to 4.6×10^{-19} m^2. Anhydrites in the Rustler have an approximate permeability of 1×10^{-19} m^2. The permeability of mudstone 3 is 1.5×10^{-19} m^2 (Brinster, 1991).

The Magenta is a dolomite that is typically less permeable than the Culebra. The Magenta Dolomite Member overlies the Tamarisk Member. The Magenta is an indurated, gypsiferous, arenaceous, dolomite that Holt and Powers (1990) classify as a dolarenite. The dolomite grains are primarily composed of silt to fine sand-sized clasts. Wavy to lenticular bedding and ripple cross laminae are prevalent through most of the Magenta. Holt and Powers (1990) estimate that inflow to the shaft from the Magenta during shaft mapping was less than 1 gal/min. The Magenta has a permeability of approximately 1.5×10^{-15} m^2 (Saulnier and Avis, 1988).

The Forty-niner Member is divided into three informal lithologic units. The lowest unit is anhydrite 4, a laminated anhydrite having a gradational contact with the underlying Magenta. Mudstone 4 overlies anhydrite 4 and is composed of multiple units containing mudstones, siltstones, and very fine sandstones. Anhydrite 5 is the uppermost informal lithologic unit of the Forty-niner Member. The permeability of mudstone 4, determined from the pressure responses in the Forty-niner interval of H-16 to the drilling of the AIS, is 3.9×10^{-16} m^2 (referred to as the Forty-niner claystone by Avis and Saulnier, 1990).

The Salado Formation is a very low permeability formation that is composed of bedded halite, polyhalite, anhydrite, and mudstones. Inflows in the shafts have been observed over select intervals during shaft mapping, but flows are below the threshold of quantification. In some cases these weeps are individual, lithologically distinct marker beds, and in some cases they are not. Directly observable brine flow from the Salado Formation into excavated openings is a short-lived process. Table 2-1 lists the brine seepage intervals identified by Holt and Powers (1990) during their detailed mapping of the AIS. Seepage could be indicated by a wet rockface or by the presence of precipitate from brine evaporation on the shaft rockface. The zones listed in Table 2-1 make up less than 10% of the Salado section that is intersected by the WIPP shafts.

Table 2-1. Salado Brine Seepage Intervals[1]

Stratigraphic Unit	Lithology	Thickness (m)
Marker Bed 103	Anhydrite	5.0
Marker Bed 109	Anhydrite	7.7
Vaca Triste	Mudstone	2.4
Zone A	Halite	2.9
Marker Bed 121	Polyhalite	0.5
Union Anhydrite	Anhydrite	2.3
Marker Bed 124	Anhydrite	2.7
Zone B	Halite	0.9
Zone C	Halite	2.7
Zone D	Halite	3.2
Zone E	Halite	0.6
Zone F	Halite	0.9
Zone G	Halite	0.6
Zone H	Halite	1.8
Marker Bed 129	Polyhalite	0.5
Zone I	Halite	1.7
Zone J	Halite	1.2

(1) After US DOE, 1995.

To gain perspective into the important stratigraphic units from a hydrogeologic view, the permeability and thickness of the units adjacent to the shafts can be compared. Table 2-2 lists the lithologic units in the Rustler and the Salado Formations with their best estimate permeabilities and their thickness as determined from the AIS mapping. The stratigraphy of the units overlying the Rustler is not considered in Table 2-2 because these units are typically not saturated in the vicinity of the WIPP shafts. The overlying sediments account for approximately 25% of the stratigraphy column adjacent to the shafts.

Because permeability varies over several orders of magnitude, the log of the permeability is also listed to simplify comparison between units. Table 2-2 shows that by far the two most transmissive zones occur in the Rustler Formation; these are the Culebra and Magenta dolomites. These units are relatively thin when compared to the combined Rustler and Salado thickness adjacent to the shafts (3% of Rustler and Salado combined thickness). The Magenta and the Culebra are the only two units that are known to possess permeabilities higher than 1×10^{-18} m^2.

Table 2-2. Permeability and Thickness of Hydrostratigraphic Units in Contact with Seals

Formation	Member/ Lithology	Undisturbed Permeability (m^2)	Thickness (m)
Rustler	Anhydrite(1)	1.0×10^{-19}	46.7
Rustler	Mudstone 4	3.9×10^{-16}	4.4
Rustler	Magenta	1.5×10^{-15}	7.8
Rustler	Mudstone 3	1.5×10^{-19}	2.9
Rustler	Culebra	2.1×10^{-14}	8.9
Rustler	Transition/ Bioturbated Clastics	2.2×10^{-18}	18.7
Salado	Halite	1.0×10^{-21}	356.6
Salado	Polyhalite	3.0×10^{-21}	10.9
Salado	Anhydrite	1.0×10^{-19}	28.2

(1) Anhydrite 5, Anhydrite 4, Anhydrite 3, and Anhydrite 2

The vast majority (97%) of the rocks adjacent to the shaft in the Rustler and the Salado Formations are low permeability ($<1\times10^{-18}$ m^2). The conclusion that can be drawn from reviewing Table 2-2 is that the shafts are located hydrogeologically in a low permeability, low groundwater flow regime. Inflow measurements have historically been made at the shafts, and observable flow is attributed to leakage from the Rustler Formation.

Flow modeling of the Culebra has demonstrated that depressurization has occurred as a result of the sinking of the shafts at the site. Maximum estimated head drawdown in the Culebra at the centroid of the shafts was estimated by Haug et al. (1987) to be 33 m in the mid-1980s. This drawdown in the permeable units intersected by the shafts is expected because the shafts act as long-term constant pressure (atmospheric) sinks. Measurements of fluid flow into the WIPP

shafts when they were unlined show a range from a maximum of 0.11 L/s (3,469 m^3/yr) measured in the Salt Handling Shaft on September 13, 1981 to a minimum of 0.008 L/s (252 m^3/yr) measured at the Waste Handling Shaft on August 6, 1987 (LaVenue et al., 1990).

The following summary of shaft inflow rates from the Rustler is based on a review of LaVenue et al. (1990) and Cauffman et al. (1990). Shortly after excavation and prior to grouting and liner installation, the inflow into the Salt Handling Shaft was 0.11 L/s (3,469 m^3/yr). The average flow rate measured after shaft lining for the period from mid-1982 through October 1992 was 0.027 L/s (851m^3/yr). The average flow rate into the Waste Handling Shaft during the time when the shaft was open and unlined was about 0.027 L/s (851 m^3/yr). Between the first and second grouting events (July 1984 to November 1987) the average inflow rate was 0.016 L/s (505 m^3/yr). No estimates were found after the second grouting. Inflow to the pilot holes for the Exhaust Shaft averaged 0.028 L/s (883 m^3/yr). In December 1984 a liner plate was grouted across the Culebra. After this time, a single measurement of inflow from the Culebra was 0.022 L/s (694 m^3/yr). After liner plate installation, three separate grouting events occurred at the Culebra. No measurable flow was reported after the third grouting event in the summer of 1987. Flow into the AIS when it was unlined and draining averaged 0.044 L/s (1,388 m^3/yr). Since the Rustler has been lined, flow into the AIS has been negligible.

The majority of the flow represented by these shaft measurements originates from the Rustler. This is clearly evident by the fact that lining of the WIPP shafts was found to be unnecessary in the Salado Formation below the Rustler/Salado contact. When the liners were installed, flow rates diminished greatly. Under sealed conditions, hydraulic gradients in rocks adjacent to the shaft will diminish as the far-field pressures approach ambient conditions. The low-permeability materials sealing the shaft combined with the reduction in lateral hydraulic gradients will likely result in flow rates into the shaft that are several orders of magnitude less than observed under open shaft or lined shaft conditions.

2.3.2 Observed Vertical Gradients

Hydraulic heads within the Rustler and between the Rustler and Salado Formations are not in hydrostatic equilibrium. Mercer (1983) recognized that heads at the Rustler Salado transition (referred to as the brine aquifer and not present in the vicinity of the WIPP shafts) indicate an upward hydraulic gradient from that zone to the Culebra. Later, with the availability of more head measurements within the Salado and Rustler members, Beauheim (1987) provided additional insight into the potential direction of vertical fluid movement within the Rustler. He reported that the hydraulic data indicate an upward gradient from the Salado to the Rustler.

Formation pressures in the Salado Formation have been decreased in the near vicinity of the WIPP underground facility. The highest, and thought to be least disturbed, estimated formation fluid pressure from hydraulic testing is 12.55 MPa estimated from interpretation of testing within borehole SCP01 in Marker Bed 139 (MB139) just below the underground facility horizon (Beauheim et al., 1993). The fresh-water head within MB139, based on the estimated static formation pressure of 12.55 MPa, is 1,663.6 m (5,458 ft) above mean sea level (msl).

Hydraulic heads in the Rustler have also been impacted by the presence of the WIPP shafts. Impacts in the Culebra were significant in the 1980s with a large drawdown cone extending away from the shafts in the Culebra (Haug et al., 1987). The undisturbed head of the

Rustler Salado contact in the vicinity of the AIS is estimated to be about 936.0 m (3,071 ft) msl (Brinster, 1991). The undisturbed head in the Culebra is estimated to be approximately 926.9 m (3,041 ft) msl in the vicinity of the AIS (LaVenue et al., 1990). The undisturbed head in the Magenta is estimated to be approximately 960.1 m (3,150 ft) msl (Brinster, 1991).

The disturbed and undisturbed heads in the Rustler are summarized in Table 2-3. Also included is the freshwater head of MB139 based on hydraulic testing in the WIPP underground. Consistent with the vertical flow directions proposed by previous investigators, estimated vertical gradients in the vicinity of the AIS before the shafts were drilled indicate a hydraulic gradient from the Magenta to the Culebra and from the Rustler/Salado contact to the Culebra. There is also the potential for flow from the Salado Formation to the Rustler Formation.

Table 2-3. Freshwater Head Estimates in the Vicinity of the Air Intake Shaft

Hydrologic Unit	Freshwater Head (m asl)		Reference
	Undisturbed	Disturbed	
Magenta Member	960.1[1]	948.8[2] (H-16)	Brinster (1991) Beauheim (1987)
Culebra Member	926.9[1]	915.0[2] (H-16)	LaVenue et al. (1990) Beauheim (1987)
Lower Unnamed Member	—	953.4[2] (H-16)	Beauheim (1987)
Rustler/Salado Contact	936.0 - 940.0[1]	—	Brinster (1991)
Salado MB139	1,663.6[2]	—	Beauheim et al. (1993)

1 Estimated from a contoured head surface plot based principally on well data collected prior to shaft construction.

2 Measured through hydraulic testing and/or long-term monitoring.

2.4 Site Geochemical Setting

2.4.1 Regional and Local Geochemistry in Rustler Formation and Shallower Units

The Rustler Formation, overlying the Salado Formation, consists of interbedded anhydrite/gypsum, mudstone/siltstone, halite east of the WIPP site, and two layers of dolomite. Principal occurrences of $NaCl/MgSO_4$ brackish to briny groundwater in the Rustler at the WIPP site and to the north, west, and south are found (1) at the lower member near its contact with the underlying Salado and (2) in the two dolomite members having a variable fracture-induced secondary porosity. The mineralogy of the Rustler Formation is summarized in Table 2-4.

The five members of the Rustler Formation are described as follows: (1) The Forty-niner Member is similar in lithology to the other non-dolomitic units but contains halite east of the WIPP site. (2) The Magenta Member is another variably fractured dolomite/sulfate unit containing sporadic occurrences of groundwater near and west of the WIPP site. (3) The Tamarisk Member is dominantly anhydrite (locally altered to gypsum) with subordinate fine-

grained clastics, containing halite to the east of the WIPP site. (4) The Culebra Dolomite Member is dominantly dolomite with subordinate anhydrite and/or gypsum, having a variable fracture-induced secondary porosity containing regionally continuous occurrences of groundwater at the WIPP site and to the north, west, and south. (5) An unnamed lower member consists of sandstone, siltstone, mudstone, claystone, and anhydrite locally altered to gypsum, and containing halite under most of the WIPP site and occurrences of brine at its base, mostly west of the WIPP site.

Table 2-4. Chemical Formulas, Distributions, and Relative Abundance of Minerals in the Rustler and Salado Formations (after Lambert, 1992)

Mineral	Formula	Occurrence/ Abundance
Amesite	$(Mg_4Al_2)(Si_2Al_2)O_{10}(OH)_8$	S, R
Anhydrite	$CaSO_4$	SSS, RRR
Calcite	$CaCO_3$	S, RR
Carnallite	$KMgCl_3 \cdot 6H_2O$	SS†
Chlorite	$(Mg,Al,Fe)_{12}(Si,Al)_8O_{20}(OH)_{16}$	S‡, R‡
Corrensite	Mixed-layer chlorite/smectite	S‡, R‡
Dolomite	$CaMg(CO_3)_2$	RR
Feldspar	$(K,Na,Ca)(Si,Al)_4O_8$	S‡, R‡
Glauberite	$Na_2Ca(SO_4)_2$	S
Gypsum	$CaSO_4 \cdot 2H_2O$	S, RRR
Halite	NaCl	SSS, RRR
Illite	$K_{1-1.5}Al_4(Si_{7-6.5}Al_{1-1.5}O_{20})(OH)_4$	S‡, R‡
Kainite	$KMgClSO_4 \cdot 3H_2O$	SS†
Kieserite	$MgSO_4 \cdot H_2O$	SS†
Langbeinite	$K_2Mg_2(SO_4)_3$	S*
Magnesite	$MgCO_3$	S, R
Polyhalite	$K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$	SS, R
Pyrite	FeS_2	S, R
Quartz	SiO_2	S‡, R‡
Serpentine	$Mg_3Si_2O_5(OH)_4$	S‡, R‡
Smectite	$(Ca_{1/2},Na)_{0.7}(Al,Mg,Fe)_4(Si,Al)_8O_{20}(OH)_4 \cdot nH_2O$	S‡, R‡
Sylvite	KCl	SS*

Key to Occurrence/Abundance notations:

S = Salado Formation; R = Rustler Formation; 3× = abundant, 2× = common, 1× = rare or accessory;

* = potash-ore mineral (never near surface); † = potash-zone non-ore mineral; ‡ = in claystone interbeds.

The Dewey Lake Redbeds, overlying the Rustler Formation, are the uppermost Permian unit; they consist of siltstones and claystones locally transected by concordant and discordant fractures that may contain gypsum. The Dewey Lake Redbeds contain sporadic occurrences of groundwater that may be locally perched, mostly in the area south of the WIPP site. The Triassic Dockum Group (undivided) rests on the Dewey Lake Redbeds in the eastern half of the WIPP site and thickens eastward; it is a locally important source of groundwater for agricultural and domestic use.

The Gatuña Formation, overlying the Dewey Lake Redbeds, occurs locally as channel and alluvial pond deposits (sands, gravels, and boulder conglomerates). The pedogenic Mescalero caliche is commonly developed on top of the Gatuña Formation and on many other erosionally truncated rock types. Surficial dune sand, which may be intermittently damp, covers virtually all outcrops at and near the WIPP site. Siliceous alluvial deposits southwest of the WIPP site also contain potable water. The geochemistry of groundwater found in the Rustler Formation and Dewey Lake Redbeds is summarized in Table 2-5.

Table 2-5. Major Solutes in Selected Representative Groundwater from the Rustler Formation and Dewey Lake Redbeds, in mg/L (after Lambert, 1992)

Well	Date	Zone	Ca	Mg	Na	K	SO_4	Cl
WIPP-30	July 1980	R/S	955	2770	121,000	2180	7390	192,000
WIPP-29	July 1980	R/S	1080	2320	36,100	1480	12,000	58,000
H-5B	June 1981	Cul	1710	2140	52,400	1290	7360	89,500
H-9B	November 1985	Cul	590	37	146	7	1900	194
H-2A	April 1986	Cul	743	167	3570	94	2980	5310
P-17	March 1986	Cul	1620	1460	28,300	782	6020	48,200
WIPP-29	December 1985	Cul	413	6500	94,900	23,300	20,000	179,000
H-3B1	July 1985	Mag	1000	292	1520	35	2310	3360
H-4C	November 1986	Mag	651	411	7110	85	7100	8460
Ranch	June 1986	DL	420	202	200	4	1100	418

Key to Zone:
R/S = "basal brine aquifer" near the contact between the Rustler and Salado Formations;
Cul = Culebra Member, Rustler Formation;
Mag = Magenta Member, Rustler Formation;
DL = Dewey Lake Redbeds.

2.4.2 Regional and Local Geochemistry in the Salado Formation

The Salado Formation consists dominantly of halite, interrupted at intervals of meters to tens of meters by beds of anhydrite, polyhalite, mudstone, and local potash mineralization (sylvite or langbeinite, with or without accessory carnallite, kieserite, kainite and glauberite, all in a halite matrix). Some uniquely identifiable non-halite units, 0.1 to 10 m thick, have been

numbered from the top down (100 to 144) for convenience as marker beds to facilitate cross-basinal stratigraphic correlation. The WIPP facility was excavated just above Marker Bed 139 in the Salado Formation at a depth of about 655 m.

Although the most common Delaware Basin evaporite mineral is halite, the presence of less soluble interbeds (dominantly anhydrite, polyhalite, and claystone) and more soluble admixtures (e.g. sylvite, glauberite, kainite) has resulted in chemical and physical properties significantly different from those of pure NaCl. Under differential stress produced near excavations, brittle interbeds (anhydrite, polyhalite, magnesite, dolomite) may fracture, whereas under a similar stress regime pure NaCl would undergo plastic deformation. Fracturing of these interbeds has locally enhanced the permeability, allowing otherwise nonporous rock to carry groundwater (e.g., the fractured polyhalitic anhydrite of Marker Bed 139 under the floor of the WIPP excavations).

Groundwater in evaporites represents the exposure of chemical precipitates to fluids that may be agents (as in the case of dissolution) or consequences of postdepositional alteration of the evaporites (as in the cases of dehydration of gypsum and diagenetic dewatering of other minerals). Early in the geological studies of the WIPP site, groundwater occurrences that could be hydrologically characterized were identified.

Since the beginning of conventional mining in the Delaware Basin, relatively short-lived seeps (pools on the floor, efflorescences on the walls, and stalactitic deposits on the ceiling) have been known to occur in the Salado Formation where excavations have penetrated. These brine occurrences are commonly associated with the non-halitic interbeds whose porosity is governed either by fracturing (as in brittle beds) or mineralogical discontinuities (as in "clay" seams).

The geochemistry of brines encountered in the Salado Formation is summarized in Table 2-6. The relative abundance of minerals was summarized in Table 2-4.

Table 2-6. Variations in Major Solutes in Brines from the Salado Formation, in mg/L (after Lambert, 1992)

Source of Brine	Date	Ca	Mg	K	Na	Cl	SO_4
Room G Seep							
	Sep-87	278	14800	15800	99000	188000	29500
	Nov-87	300	18700	15400	97100	190000	32000
	Feb-88	260	18200	17100	94100	186000	36200
	Mar-88	280	17000	16200	92100	187000	34800
	Jul-88	292	13000	14800	96600	188000	29300
	Sep-88	273	14700	13700	86500	185000	28000
	Apr-91	240	14400	12900	95000	189000	28000
	Jul-91	239	14100	13100	93000	190000	27700
	Oct-91	252	14700	14100	95000	189000	27100
Marker Bed 139							
(under repository)		300	18900	14800	67700	155900	14700
		300	17100	15600	72700	158900	13400
		300	17600	15800	71600	182200	14700
Room J							
		230	17700	13500	63600	167000	15100
		210	27400	22400	56400	168000	19600
		220	17900	15600	73400	165000	9300
		250	22200	18300	63000	165000	31100
		190	31000	19900	46800	170000	24600
		100	35400	27800	40200	173000	30000
		270	18900	14500	59900	166000	16200
		280	20200	17000	70400	165000	10600
Room Q							
		279	31500	22600	68000	205000	19400
		288	31100	24100	68000	203000	19200
		257	34000	26300	63000	205000	23500
AIS Sump							
(accumulation in	Jul-88	960	1040	1720	118000	187000	6170
bottom of sump)	May-89	900	500	600	83100	122700	7700
	May-89	1000	800	1100	82400	114200	8800
McNutt Potash Zone							
Duval mine		640	55400	30000	27500	236500	3650
Miss. Chem. mine		200	44200	45800	43600	226200	12050

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3. DESIGN GUIDANCE

3.1 Introduction

The WIPP is subject to regulatory requirements contained in 40 CFR 191 and 40 CFR 194. The use of both engineered and natural barriers to isolate wastes from the accessible environment is required by 40 CFR 191.14(d), and the use of engineered barriers to prevent or substantially delay the movement of water or radionuclides toward the accessible environment is required by 40 CFR 194.44. Quantitative requirements for potential releases of radioactive and other hazardous materials from the repository system are specified in 40 CFR 191 and 40 CFR 268. The regulations impose quantitative release requirements on the total repository system, not on individual subsystems of the repository system, for example, the shaft sealing subsystem.

3.2 Design Guidance and Design Approach

The guidance described for the design of the shaft sealing system addresses the need for the WIPP to comply with system requirements and to follow accepted engineering practices using demonstrated technology. The design guidance addresses the need to limit:

1. radiological or other hazardous constituents reaching the regulatory boundaries,
2. groundwater flow into and through the sealing system,
3. chemical and mechanical incompatibility,
4. structural failure of system components,
5. subsidence and accidental entry, and
6. development of new construction technologies and/or materials.

For each element of design guidance, a design approach has been developed. Table 3-1 contains qualitative design guidance and the design approach used to implement it.

Table 3-1. Shaft Sealing System Design Guidance

Qualitative Design Guidance	Design Approach
The shaft sealing system shall limit:	*The shaft sealing system shall be designed to meet the qualitative design guidance in the following ways:*
1. the migration of radiological or other hazardous constituents from the repository horizon to the regulatory boundary during the 10,000-year regulatory period following closure;	1. In the absence of human intrusion, brine migrating from the repository horizon to the Rustler Formation must pass through a low permeability sealing system.
2. groundwater flowing into and through the shaft sealing system;	2. In the absence of human intrusion, groundwater migrating from the Rustler Formation to the repository horizon must pass through a low permeability sealing system.

Table 3-1. Shaft Sealing System Design Guidance

Qualitative Design Guidance	Design Approach
3. chemical and mechanical incompatibility of seal materials with the seal environment;	3. Brine contact with seal elements is limited and materials possess acceptable mechanical properties.
4. the possibility for structural failure of individual components of the sealing system;	4. State of stress from forces expected from rock creep and other mechanical loads is favorable for seal materials.
5. subsidence of the ground surface in the vicinity of the shafts and the possibility of accidental entry after sealing;	5. The shaft is completely filled with low-porosity materials, and construction equipment would be needed to gain entry.
6. the need to develop new technologies or materials for construction of the shaft sealing system.	6. Construction of the shaft sealing system is feasible using available technologies and materials.

4. DESIGN DESCRIPTION

4.1 Introduction

The design presented in this section was developed based on (1) the design guidance outlined in Section 3.0, (2) past design experience, and (3) a desire to reduce uncertainties associated with the performance of the WIPP sealing system. The WIPP shaft sealing system design has evolved over the past decade from the initial concepts presented by Stormont (1984) to the design concepts presented in this document. The past designs are:

- the plugging and sealing program for the WIPP (Stormont, 1984),
- the initial reference seal system design (Nowak et al., 1990),
- the seal design alternative study (Van Sambeek et al., 1993),
- the WIPP sealing system design (DOE, 1995).

The present design changes were implemented to take advantage of knowledge gained from small-scale seals tests conducted at the WIPP (Knowles and Howard, 1996), advances in the ability to predict the time-dependent mechanical behavior of compacted salt rock (Callahan et al., 1996), large-scale dynamic salt compaction tests and associated laboratory determination of the permeability of compacted salt samples (Hansen and Ahrens, 1996; Brodsky et al., 1996), field tests to measure the permeability of the DRZ surrounding the WIPP AIS (Dale and Hurtado, 1996), and around seals (Knowles et al., 1996). A summary paper (Hansen et al., 1996) describing the design has been prepared.

The shaft sealing system is composed of seals within the Salado Formation, the Rustler Formation, and the Dewey Lake Redbeds and overlying units. All components of the sealing system are designed to meet Items 3, 4, and 6 of the Design Guidance (Table 3-1.); that is, all sealing system components are designed to be chemically and mechanically compatible with the seal environment, structurally adequate, and constructable using currently available technology and materials. The seals in the Salado Formation are also designed to meet Items 1 and 2 of the Design Guidance. These seals will limit fluid migration upward from the repository to the Rustler Formation and downward from the Rustler Formation to the repository. Migration of brine upward and downward is discussed in Sections 8.5 and 8.4 respectively. The seals in the Rustler Formation are designed to meet Item 2 in addition to Items 3, 4, and 6 of the Design Guidance. The seals in the Rustler Formation limit migration of Rustler brines into the shaft cross-section and also limit cross-flow between the Culebra and Magenta members. The principal function of the seals in the Dewey Lake Redbeds and overlying units is to meet Item 5 of the Design Guidance, that is, to limit subsidence of the ground surface in the vicinity of the shafts and to prevent accidental entry after repository closure. Entry of water (surface water and any groundwater that might be present in the Dewey Lake Redbeds and overlying units) into the sealing system is limited by restraining subsidence and by placing high density fill in the shafts.

4.2 Existing Shafts

The WIPP underground facilities are accessed by four shafts commonly referred to as the Waste, Air Intake, Exhaust, and Salt Handling Shafts. These shafts were constructed between 1981 and 1988. All four shafts are lined from the surface to just below the contact of the Rustler

and Salado Formations. The lined portion of the shafts terminates in a substantial concrete structure called the "key," which is located in the uppermost portion of the Salado Formation. Drawings showing the configuration of the existing shafts are included in Appendix E and listed below in Table 4-1. Table 4-2 contains a summary of information describing the existing shafts.

The upper portions of the WIPP shafts are lined. The Waste, Air Intake, and Exhaust shafts have concrete linings; the Salt Handling Shaft has a steel lining with grout backing. In addition, during shaft construction, steel liner plates, wire mesh, and pressure grouting were used to stabilize portions of the shaft walls in the Rustler Formation and overlying units. Seepage of groundwater into the lined portions of the shafts has been observed. This seepage was expected; in fact, the shaft keys (massive concrete structures located at the base of each shaft liner) were designed to collect the seepage and transport it through a piping system to collection points at the repository horizon. In general, the seepage originates in the Magenta and Culebra members of the Rustler Formation and in the interface zone between the Rustler and Salado formations. It flows along the interface between the shaft liner and the shaft wall and through the DRZ immediately adjacent to the shaft wall. In those cases where seepage through the liner occurred, it happened where the liner offered lower resistance to flow than the interface and DRZ, for example, at construction joints. Maintenance grouting, in selected areas of the WIPP shafts, has been utilized to reduce seepage.

Table 4-1. Drawings Showing Configuration of Existing WIPP Shafts
(Drawings are in Appendix E)

Shaft	Drawing Title	Sheet Number of Drawing SNL-007
Waste	Near-Surface/Rustler Formation Waste Shaft Stratigraphy & As-Built Elements	2 of 28
Waste	Salado Formation Waste Shaft Stratigraphy & As-Built Elements	3 of 28
AIS	Near-Surface/Rustler Formation Air Intake Shaft Stratigraphy & As-Built Elements	7 of 28
AIS	Salado Formation Air Intake Shaft Stratigraphy & As-Built Elements	8 of 28
Exhaust	Near-Surface/Rustler Formation Exhaust Shaft Stratigraphy & As-Built Elements	12 of 28
Exhaust	Salado Formation Exhaust Shaft Stratigraphy & As-Built Elements	13 of 28
Salt Handling	Near-Surface/Rustler Formation Salt Handling Shaft Stratigraphy & As-Built Elements	17 of 28
Salt Handling	Salado Formation Salt Handling Shaft Stratigraphy & As-Built Elements	18 of 28

Table 4-2. Summary of Information Describing Existing WIPP Shafts

	Shafts			
	Salt Handling	**Waste**	**Air Intake**	**Exhaust**
A. Construction Method				
i. Sinking method	Blind bored	Initial 6' pilot hole slashed by drill & blast (smooth wall blasting)	Raise bored	Initial 6' pilot hole slashed by drill & blast (smooth wall blasting)
ii. Dates of shaft sinking	7/81-10/81	Drilled 12/81-2/82 Slashed 10/83-6/84	12/87-8/88	9/83-11/84
iii. Ground treatment in water-bearing zone	Grout behind steel liner during construction	Grouted 1984 & 1988	Grouted 1993	Grouted 1985, 1986, & 1987
iv. Sump construction	Drill & blast	Drill & blast	No sump	No sump
B. Upper Portion of Shaft *				
i. Type of liner	Steel	Concrete	Concrete	Concrete
ii. Lining diameter (ID)	10'-0"	19'-0"	18'-0"/16'-7"	14'-0"
iii. Excavated diameter	11'-10"	20'-8" to 22'-4"	20'-3"	15'-8" to 16'-8"
iv. Installed depth of liner	838.5'	812'	816'	846'
C. Key Portion of Shaft *				
i. Construction material	Reinf. conc. w/chem. seals	Reinf. concrete w/chem. seals	Reinf. concrete w/chem. seals	Reinf. concrete w/chem. seals
ii. Liner diameter (ID)	10'-0"	19'-0"	16'-7"	14'-0"
iii. Excavated diameter	15'-0" to 18'-0"	27'-6" to 31'-0"	29'-3" to 35'-3"	21'-0" to 26'-0"
iv. Depth-top of Key	844'	836'	834'	846'
v. Depth-bottom of Key	883'	900'	897'	910'
vi. Dow Seal #1 depth	846' to 848'	846' to 849'	839' to 842'	853' to 856'
vii. Dow Seal #2 depth	853' to 856'	856' to 859'	854' to 857'	867' to 870'
viii. Dow Seal #3 depth	868 to 891'	NA	NA	NA
ix. Top of salt (Rustler/Salado contact)	851'	843'	841'	853'
D. Lower Shaft (Unlined) *				
i. Type of support	Unlined	Chain link mesh	Unlined	Chain link mesh
ii. Excavated diameter	11'-10"	20'-0"	20'-3"	15'-0"
iii. Depth-top of "unlined"	882'	900'	904'	913'
iv. Depth-bottom of "unlined"	2144'	2142'	2128'	2148'
E. Station *				
i. Type of support	Wire mesh		Wire mesh	Wire mesh
ii. Principal dimensions	21H × 31W	12H × 30W	25H × 36W	12H × 23W
iii. Depth-top of station	2144'	2142'	2128'	2148'
iv. Depth-floor of station	2162'	2160'	2150'	2160'
F. Sump *				
Depth-top of sump	2162'	2160'	No sump	No sump
Depth-bottom of sump	2272'	2286'		
G. Shaft Duty	Construction hoisting of excavated salt; personnel hoisting	Hoisting shaft for lowering waste containers; personnel hoisting until waste receipt	Ventilation shaft for intake (fresh) air; personnel hoisting	Exhaust air ventilation shaft

*This information is from the Westinghouse WID drawings identified on Sheets 2, 3, 7, 8, 12, 13, 17, and 18 of Drawing SNL-007 (see Appendix E).

4.3 Sealing System Design Description

This section describes the shaft sealing system design, components, and functions. The shaft sealing system consists of three essentially independent parts:

1. The seals in the Salado Formation provide the primary regulatory barrier. They will limit fluid flow into and out of the repository throughout the 10,000-year regulatory period.
2. The seals in the Rustler Formation will limit flow from the water-bearing members of the Rustler Formation and limit commingling of Magenta and Culebra groundwaters.
3. The seals in the Dewey Lake Redbeds and the near-surface units will limit infiltration of surface water and preclude accidental entry through the shaft openings.

The same sealing system is used in all four shafts. Therefore an understanding of the sealing system for one shaft is sufficient to understand the sealing system in all shafts. Only minor differences exist in the lengths of the components, and the component diameters differ to accommodate the existing shaft diameters.

The shaft liner will be removed in four locations in each shaft. All of these locations are within the Rustler Formation. Additionally, the upper portion of each shaft key will be eliminated. The portion of the shaft key that will be eliminated spans the Rustler/Salado interface and extends into the Salado Formation. The shaft liner removal locations are

1. from 10 ft above the Magenta Member to the base of the Magenta (removal distances vary from 34–39 ft because of different member thickness at shaft locations),
2. for a distance of 10 ft in the anhydrite of the Tamarisk Member,
3. through the full height of the Culebra (17–24 ft), and
4. from the top anhydrite unit in the unnamed lower member to the top of the key (67–85 ft).

Additionally, the concrete will be removed from the top of the key to the bottom of the key's lower chemical seal ring (23 to 29 ft). Drawing SNL-007, Sheets 4, 9, 14, and 19 in Appendix E show shaft liner removal plans, and Sheet 23 shows key removal plans.

The decision to abandon portions of the shaft lining and key in place is based on two factors. First, no improvements in the performance of the sealing system associated with removal of these isolated sections of concrete have been identified. Second, because the keys are thick and heavily reinforced, their removal would be costly and time consuming. No technical problems are associated with the removal of this concrete; thus, if necessary, its removal can be incorporated in any future design.

The DRZ will be pressure grouted throughout the liner and key removal areas and for a distance of 10 ft above and below all liner removal areas. The pressure grouting will stabilize the DRZ during liner removal and shaft sealing operations. The grouting will also control groundwater seepage during and after liner removal. The pressure grouting of the DRZ has not been assigned a sealing function beyond the construction period. It is likely that this grout will seal the DRZ for an extended period of time. However, past experience with grout in the mining and tunneling industries demonstrates that groundwater eventually opens alternative pathways through the media and reestablishes seepage patterns (maintenance grouting is common in both

mines and tunnels). Therefore, post-closure sealing of the DRZ in the Rustler Formation has not been assumed in the design.

The compacted clay sealing material (bentonite) will seal the shaft cross-section in the Rustler Formation. In those areas where the shaft liner has been removed, the compacted clay will confine the vertical movement of groundwater in the Rustler to the DRZ. Sealing the shaft DRZ is accomplished in the Salado Formation. It is achieved initially through the interruption of the halite DRZ by concrete-asphalt waterstops and on a long-term basis through the natural process of healing the halite DRZ. The properties of the compacted clay are discussed in Section 5.3.2. The concrete-asphalt waterstops and DRZ healing in the Salado are discussed in Sections 7.6.1 and 7.5.2 respectively.

Reduction of the uncertainty associated with long-term performance is addressed by replacing the upper and lower Salado Formation salt columns used in some of the earlier designs with compacted clay columns and by adding asphalt sealing components in the Salado Formation. Use of disparate materials for sealing components reduces the uncertainty associated with a common-mode failure.

The compacted salt column provides a seal with an initial permeability several orders of magnitude higher than the clay or asphalt columns; however, its long-term properties will approach those of the host rock. The permeability of the compacted salt, after consolidation, will be several orders of magnitude lower than that of the clay and comparable to that of the asphalt. The clay provides seals of known low permeability at emplacement, and asphalt provides an independent low permeability seal of the shaft cross-section and the shaft wall interface at the time of installation. Sealing of the DRZ in the Rustler Formation during the construction period is accomplished by grouting, and initial sealing of the DRZ in the Salado Formation is accomplished by three concrete-asphalt waterstops.

In the following sections, each component of each of the three shaft segments is identified by name and component number (see Figure 4-1 for nomenclature). Associated drawings in Appendix E are also identified. Drawings showing the overall system configurations for each shaft are listed in Table 4-3.

4.3.1 Salado Seals

The seals placed in the Salado Formation are composed of (1) consolidated salt, clay, and asphalt components that will function for very long periods, exceeding the 10,000-year regulatory period; and (2) salt saturated concrete components that will function for extended periods. The specific components that comprise the Salado seals are described below.

4.3.1.1 Compacted Salt Column

The compacted salt column (Component 10 in Figure 4-1, and shown in Drawing SNL-007, Sheet 25) will be constructed of crushed salt taken from the Salado Formation. The length of the salt column varies from 170 to 172 m (556 to 564 ft) in the four shafts. The compacted salt column is sized to allow the column and concrete-asphalt waterstops at either end to be placed between the Vaca Triste Unit and Marker Bed 136. The salt will be placed and

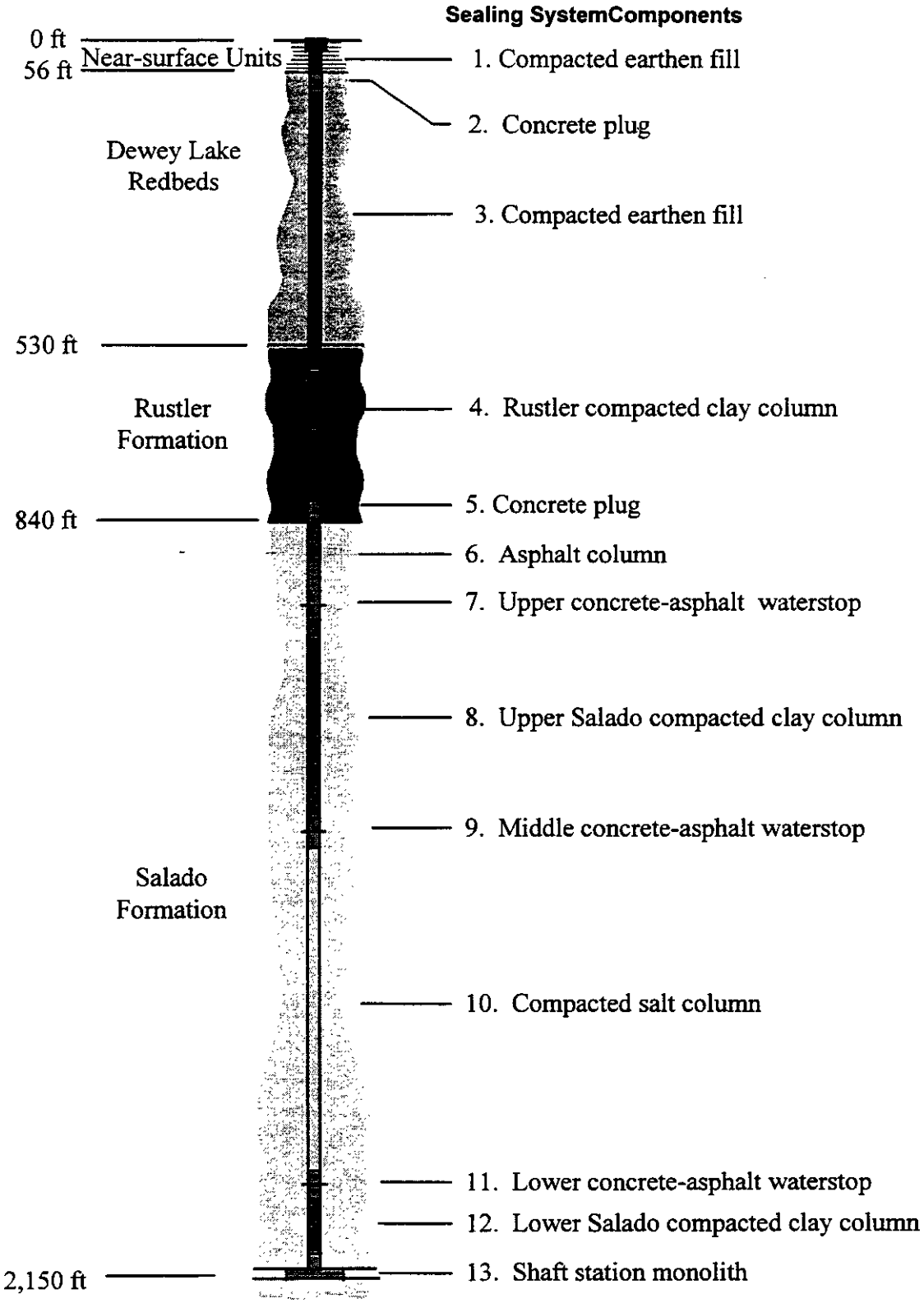

Figure 4-1. Arrangement of the Air Intake Shaft sealing system.

Table 4-3. Drawings Showing the Sealing System for Each Shaft
(Drawings are in Appendix E)

Shaft	Drawing Title	Sheet Number of Drawing SNL 007
Waste	Near-Surface/Rustler Formation Waste Shaft Stratigraphy & Sealing Subsystem Profile	4 of 28
Waste	Salado Formation Waste Shaft Stratigraphy & Sealing Subsystem Profile	5 of 28
AIS	Near-Surface/Rustler Formation Air Intake Shaft Stratigraphy & Sealing Subsystem Profile	9 of 28
AIS	Salado Formation Air Intake Shaft Stratigraphy & Sealing Subsystem Profile	10 of 28
Exhaust	Near-Surface/Rustler Formation Exhaust Shaft Stratigraphy & Sealing Subsystem Profile	14 of 28
Exhaust	Salado Formation Exhaust Shaft Stratigraphy & Sealing Subsystem Profile	15 of 28
Salt Handling	Near-Surface/Rustler Formation Salt Handling Shaft Stratigraphy & Sealing Subsystem Profile	19 of 28
Salt Handling	Salado Formation Salt Handling Shaft Stratigraphy & Sealing Subsystem Profile	20 of 28

compacted to a density approaching 90% of the average density of intact Salado salt. The effects of creep closure will cause this density to increase with time, further reducing permeability.

The salt column will offer limited resistance to fluid migration immediately after emplacement, but it will become less permeable as creep closure further compacts the salt. Salt creep increases rapidly with depth; therefore, at any time, creep closure of the shaft will be greater at greater depth. The location and initial compaction density of the compacted salt column were chosen to assure consolidation of the compacted salt column in the 100 years following repository closure. The state of salt consolidation, results of analyses predicting the creep closure of the shaft, consolidation and healing of the compacted salt, and healing of the DRZ surrounding the compacted salt column are presented in Sections 7.5 and 8.4 of this document. These results indicate that the salt column will become an effective long-term barrier within 100 years.

4.3.1.2 Upper and Lower Salado Compacted Clay Columns

The upper and lower Salado compacted clay columns (Components 8 and 12 respectively in Figure 4-1) are shown in detail on Drawing SNL-007, Sheet 24. A commercial well-sealing grade sodium bentonite will be used to construct the upper and lower Salado clay columns. These clay columns will effectively limit fluid movement from the time they are placed and will provide an effective barrier to fluid migration throughout the 10,000-year regulatory period and thereafter. The upper clay column ranges in length from 102 to 107 m (335 to 351 ft), and the lower clay column ranges in length from 29 to 33 m (94 to 107 ft) in the four shafts. The locations for the upper and lower clay columns were selected based on the need to limit fluid migration into the compacting salt column. The lower clay column stiffness is sufficient to promote early healing of the DRZ, thus removing the DRZ as a potential pathway for fluids (Appendix D, Section 5.2.1).

4.3.1.3 Upper, Middle, and Lower Concrete-Asphalt Waterstops

The upper, middle, and lower concrete-asphalt waterstops (Components 7, 9, and 11 respectively in Figure 4-1) are identical and are composed of three elements: an upper concrete plug, a central asphalt waterstop, and a lower concrete plug. These components are also shown on Drawing SNL-007, Sheet 22. The concrete specified is a specially developed salt-saturated concrete called Salado Mass Concrete (SMC). In all cases the component's overall design length is 15 m (50 ft).

The upper and lower concrete plugs of the concrete-asphalt waterstop are identical. They fill the shaft cross-section and have a design length of 7 m (23 ft). The plugs are keyed into the shaft wall to provide positive support for the plug and overlying sealing materials. The interface between the concrete plugs and the surrounding formation will be pressure grouted. The upper plug in each component will support dynamic compaction of the overlying sealing material if compaction is specified. Dynamic compaction of the salt column is discussed in Section 6.

The asphalt waterstop is located between the upper and lower concrete plugs. In all cases a kerf extending one shaft radius beyond the shaft wall is cut in the surrounding salt to contain the waterstop. The kerf is 0.3 m (1 ft) high at its edge and 0.6 m (2 ft) high at the shaft wall. The kerf, which cuts through the existing shaft DRZ, will result in the formation of a new DRZ along its perimeter. This new DRZ will heal shortly after construction of the waterstop, and thereafter the waterstop will provide a very low permeability barrier to fluid migration through the DRZ. The formation and healing of the DRZ around the waterstop are addressed in Section 7.6.1. The asphalt fill for the waterstop extends two feet above the top of the kerf to assure complete filling of the kerf. The construction procedure used assures that shrinkage of the asphalt from cooling will not result in the creation of voids within the kerf and will minimize the size of any void below the upper plug.

Concrete-asphalt waterstops are placed at the top of the upper clay column, the top of the compacted salt column, and the top of the lower clay column. The concrete-asphalt waterstops provide independent seals of the shaft cross-section and the DRZ. The SMC plugs (and grout) will fill irregularities in the shaft wall, bond to the shaft wall, and seal the interface. Salt creep against the rigid concrete components will place a compressive load on the salt and promote

early healing of the salt DRZ surrounding the SMC plugs. The asphalt waterstop will seal the shaft cross-section and the DRZ.

The position of the concrete components was first determined by the location of the salt and clay columns. The components were then moved upward or downward from their initial design location to assure the components were located in regions where halite was predominant. This positioning, coupled with variations in stratigraphy, is responsible for the variations in the lengths of the salt and clay columns.

4.3.1.4 Asphalt Column

An asphalt-aggregate mixture is specified for the asphalt column (Component 6 in Figure 4-1). This column is 42 to 44 m (138 to 143 ft) in length in the four shafts, as shown in Drawing SNL-007, Sheet 23. The asphalt column is located above the upper concrete-asphalt waterstop; it extends approximately 5 m (16 ft) above the Rustler/Salado interface. A 6-m (20-ft) long concrete plug (part of the Rustler seals) is located just above the asphalt column.

The existing shaft linings will be removed from a point well above the top of the asphalt column to the top of the shaft keys. The concrete shaft keys will be removed to a point just below the lowest chemical seal ring in each key. The asphalt column is located at the top of the Salado Formation and provides an essentially impermeable seal for the shaft cross section and along the shaft wall interface. The length of the asphalt column will decrease slightly as the column cools. The procedure for placing the flowable asphalt-aggregate mixture is described in Section 6.

4.3.1.5 Shaft Station Monolith

A shaft station monolith (Component 13) is located at the base of the each shaft. Because the configurations of each shaft differ, drawings of the shaft station monoliths for each shaft were prepared. These drawings are identified in Table 4-4. The shaft station monoliths will be constructed with SMC. The monoliths function to support the shaft wall and adjacent drift roof, thus preventing damage to the seal system as the access drift closes from natural processes.

Table 4-4. Drawings Showing the Shaft Station Monoliths (Drawings are in Appendix E)

Shaft	Drawing Title	Sheet Number of Drawing SNL-007
Waste	Waste Shaft Shaft Station Monolith	6 of 28
AIS	Air Intake Shaft Shaft Station Monolith	11 of 28
Exhaust	Exhaust Shaft Shaft Station Monolith	16 of 28
Salt Handling	Salt Handling Shaft Shaft Station Monolith	21 of 28

4.3.2 Rustler Seals

The seals in the Rustler Formation are composed of the Rustler compacted clay column and a concrete plug. The concrete plug rests on top of the asphalt column of the Salado seals. The clay column extends from the concrete plug through most of the Rustler Formation and terminates above the Rustler's highest water-bearing zone in the Forty-niner Member.

4.3.2.1 Rustler Compacted Clay Column

The Rustler compacted clay column (Component 4 in Figure 4-1) is shown on Drawing SNL-007, Sheet 27 for each of the four shafts. A commercial well-sealing-grade sodium bentonite will be used to construct the Rustler clay column, which will effectively limit fluid movement from the time of placement and provide an effective barrier to fluid migration throughout the 10,000-year regulatory period and thereafter. Design length of the Rustler clay column is about 71 m (234 to 235 ft) in the four shafts.

The location for the Rustler clay columns was selected to limit fluid migration into the shaft cross-section and along the shaft wall interface and to limit mixing of Culebra and Magenta waters. The clay column extends from above the Magenta Member to below the Culebra Member of the Rustler Formation. The Magenta and Culebra are the water-bearing units of the Rustler. The members above the Magenta (the Forty-niner), between the Magenta and Culebra (the Tamarisk), and below the Culebra (the unnamed lower member) are aquitards in the vicinity of the WIPP shafts.

4.3.2.2 Rustler Concrete Plug

The Rustler concrete plug (Component 5 in Figure 3-1) is constructed of SMC. The plugs for the four shafts are shown on Drawing SNL-007, Sheet 26. The plug is 6 m (20 ft) long and will fill the shaft cross-section. The plug is placed directly on top of the asphalt column of the Salado seals. The plug will be keyed into the surrounding rock and grouted. The plug permits work to begin on the overlying clay column before the asphalt has completely cooled. The option of constructing the overlying clay columns using dynamic compaction (present planning calls for construction using compressed clay blocks) is also maintained by keying the plug into the surrounding rock.

4.3.3 Near-Surface Seals

The near-surface region is composed of dune sand, the Mescalero caliche, the Gatuña Formation, the Santa Rosa Formation, and the Dewey Lake Redbeds. This region extends from the ground surface to the top of the Rustler Formation—a distance of about 160 m (525 ft). All but about 15 m (50 ft) of this distance is composed of the Dewey Lake Redbeds Formation. The near-surface seals are composed of two earthen fill columns and a concrete plug. The upper earthen fill column (Component 1) extends from the shaft collar through the surficial deposits downward to the top of the Dewey Lake Redbeds. The concrete plug (Component 2) is placed in the top portion of the Dewey Lake Redbeds, and the lower earthen fill column (Component 3) extends from the concrete plug into the Rustler Formation. These components are shown on Drawing SNL-007, Sheet 28.

This seal will limit the amount of surface water entering the shafts and will limit the potential for any future groundwater migration into the shafts. The near surface seals will also completely close the shafts and prevent accidental entry and excessive subsidence in the vicinity of the shafts. As discussed in Section 4.3.2, the existing shaft linings will be abandoned in place throughout the near-surface region.

4.3.3.1 Near-Surface Upper Compacted Earthen Fill

This component (Component 1 in Figure 3-1) will be constructed using locally available fill. The fill will be compacted to a density near that of the surrounding material to inhibit the migration of surface waters into the shaft cross-section. The length of this column varies from 17 to 28 m (56 to 92 ft) in the four shafts. In all cases, this portion of the WIPP sealing system may be modified as required to facilitate decommissioning of the WIPP surface facilities.

4.3.3.2 Near-Surface Concrete Plug

Current plans call for an SMC plug (Component 2 in Figure 4-1). However, freshwater concrete may be used if found to be desirable at a future time. The plug extends 12 m (40 ft) downward from the top of the Dewey Lake Redbeds. It is placed inside the existing shaft lining, and the interface is grouted.

4.3.3.3 Near-Surface Lower Compacted Earthen Fill

This component (Component 3 in Figure 4-1) will be constructed using locally available fill, which will be placed using dynamic compaction (the same method used to construct the salt column). The fill will be compacted to a density equal to or greater than the surrounding materials to inhibit the migration of surface waters into the shaft cross-section. The length of this column varies from 136 to 148 m (447 to 486 ft) in the four shafts.

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5. MATERIAL SPECIFICATION

Appendix A provides a body of technical information for each of the WIPP shaft seal materials. The materials specification characterizes each seal material, establishes the adequacy of its function, states briefly the method of component placement, and quantifies expected characteristics (particularly permeability) pertinent to a WIPP-specific shaft seal design. The goal of the materials specifications is to substantiate why materials used in this seal system design will limit fluid flow within the shafts and thereby limit releases of hazardous constituents from the WIPP site at the regulatory boundary.

This section summarizes materials characteristics for shaft seal system components designed for the WIPP. The shaft seal system will not be constructed for decades; however, if it were to be constructed in the near term, materials specified could be placed in the shaft and meet performance specifications without unreasonable advances in either material development or construction techniques. Construction methods are described in Appendix B. Materials specifications and construction specifications are not to be construed as the only materials or methods that would suffice to seal the shafts effectively. Undoubtedly, the design will be modified, perhaps simplified, and construction alternatives may prove to be advantageous during the years before seal construction proceeds. Nonetheless, a materials specification is necessary to establish a frame of reference for shaft seal design and analysis, to guide construction specifications, and to provide a basis for seal material parameters.

Design detail and other characteristics of the geologic, hydrologic, and chemical setting are provided in the text, appendices, and references. The four shafts will be entirely filled with dense materials possessing low permeability and other desirable engineering and economic attributes. Seal materials include concrete, clay, asphalt, and compacted salt. Other construction and fill materials include cementitious grout and earthen fill. Concrete, clay, and asphalt are common construction materials used extensively in sealing applications. Their descriptions, drawn from literature and site-specific references, are given in Appendix A. Compaction and natural reconsolidation of crushed salt are uniquely applied here. Therefore, crushed salt specification includes discussion of constitutive behavior and sealing performance, specific to WIPP applications. Cementitious grout is also specified in some detail. Only rudimentary discussion of earthen fill is given here and in Appendices A and B. Specifications for each material are discussed in the following order:

- functions,
- material characteristics,
- construction,
- performance requirements,
- verification methods.

Seal system components are materials possessing high durability and compatibility with the host rock. The system contains functional redundancy and uses differing materials to reduce uncertainty in performance. All materials used in the shaft seal system are expected to maintain their integrity for very long periods. Some sealing components reduce fluid flow soon after placement while other components are designed to function well beyond the regulatory period.

5.1 Longevity

A major environmental advantage of the WIPP locale is an overall lack of groundwater to seal against. Even though very little regional water is present in the geologic setting, the seal system reflects great concern for groundwater's potential influence on the shaft seal system. If the hydrologic system sustained considerable fluid flow, brine geochemistry could impact engineered materials. Brine would not chemically change the compacted salt column, but mechanical effects of pore pressure are of concern to reconsolidation. The geochemical setting, as further discussed in Section 2.4, will have little influence on concrete, asphalt, and clay shaft seal materials. Each material is durable because the potential for degradation or alteration is very low.

Materials used to form the shaft seals are the same as those identified in the scientific and engineering literature as appropriate for sealing deep geologic repositories for radioactive wastes. Durability or longevity of seal components is a primary concern for any long-term isolation system. Issues of possible degradation have been studied throughout the international community and within waste isolation programs in the USA. Specific degradation studies are not detailed in this document because longevity is one of the over-riding attributes of the materials selected and degradation is not perceived to be likely. However, it is acknowledged here that microbial degradation, seal material interaction, mineral transformation, such as silicification of bentonite, and effects of a thermal pulse from asphalt or hydrating concrete are areas of continuing investigations.

Among longevity concerns, degradation of concrete is the most recognized. At this stage of the design, it is established that only small volumes of brine ever reach the concrete elements (see Section C4). Further analysis concerned with borehole plugging using cementitious materials shows that at least 100 pore volumes of brine in an open system would be needed to begin degradation processes. In a closed system, such as the hydrologic setting in the WIPP shafts, phase transformations create a degradation product of increased volume. Net volume increase owing to phase transformation in the absence of mass transport would decrease rather than increase permeability of concrete seal elements.

Asphalt has existed for thousands of years as natural seeps. Longevity studies specific to DOE's Hanford site have utilized asphalt artifacts buried in ancient ceremonies to assess long-term stability (Wing and Gee, 1994). Asphalt used as a seal component deep in the shaft will inhabit a benign environment, devoid of ultraviolet light or an oxidizing atmosphere. Additional assurance against possible microbial degradation in asphalt elements is provided with addition of lime. For these reasons, it is believed that asphalt components will possess their design characteristics well beyond the regulatory period.

Natural bentonite is a stable material that generally will not change significantly over a period of ten thousand years. Bentonitic clays have been widely used in field and laboratory experiments concerned with radioactive waste disposal. As noted by Gray (1993), three internal mechanisms, illitization, silicification and charge change, could affect sealing properties of bentonite. Illitization and silicification are thermally driven processes and, following discussion by Gray (1993), are not possible in the environment or time-frame of concern at the WIPP. The naturally occurring Wyoming bentonite which is the specified material for the WIPP shaft seal is

well over a million years old. It is, therefore, highly unlikely that the metamorphism of bentonite enters as a design concern.

5.2 Materials

5.2.1 Mass Concrete

Concrete has low permeability and is widely used for hydraulic applications. The specification for mass concrete presents a special design mixture of a salt-saturated concrete called Salado Mass Concrete (SMC). Performance of SMC and similar salt-saturated mixtures has been established through analogous industrial applications and in laboratory and field testing. The documentation substantiates adequacy of SMC for concrete applications within the WIPP shafts.

The function of the concrete is to provide durable components with small void volume, adequate structural compressive strength, and low permeability. SMC is used as massive plugs, a monolith at the base of each shaft, and in tandem with asphalt waterstops. Concrete is a rigid material that will support overlying seal components while promoting natural healing processes within the salt DRZ. Concrete is one of the redundant components that protects the reconsolidating salt column. The salt column will achieve low permeabilities in fewer than 100 years, and concrete will no longer be needed at that time. However, concrete will continue to provide good sealing characteristics for a very long time.

Salt-saturated concrete contains sufficient salt as an aggregate to saturate hydration water with respect to NaCl. Salt-saturated concrete is required for all uses within the Salado Formation because fresh water concrete would dissolve part of the host rock. The concrete specified for the shaft seal system has been tailored for the service environment and includes all the engineering properties of high quality concrete, as described in Appendix A. Among these are low heat of hydration, high compressive strength, and low permeability. Because SMC provides material characteristics of high-performance concrete, it will likely be the concrete of choice for all seal applications at the WIPP.

Construction involves surface preparation and slickline placement. A batching and mixing operation on the surface will produce a wet mixture having low initial temperatures. Placement uses a tremie line, where the fresh concrete exits the slickline below the surface level of the concrete being placed. Placed in this manner, the SMC will have low porosity (about 5%) with or without vibration. Tremie line placement is a standard construction method in mining operations.

Specifications of concrete properties include mixture proportions and characteristics before and after hydration. SMC strength is much greater than required for shaft seal elements, and the state of stress within the shafts is compressional with little shear stress developing. Volume stability of the SMC is also excellent; this, combined with salt-saturation, assures a good bond with the salt. Permeability of SMC is very low, consistent with most concrete (Pfeifle et al., 1996). Because of a favorable state of stress and isothermal conditions, the SMC will remain intact. Because little brine is available to alter concrete elements, minimal degradation is possible. These favorable attributes combine to assure concrete elements within the Salado will remain structurally sound and possess very low permeability (between 2×10^{-21} and 1×10^{-17} m^2)

for exceedingly long periods. A permeability distribution function and associated discussion are given in Appendix A.

Standard ASTM specifications are made for the green and hydrated concrete properties. Quality control and a history of successful use in both civil construction and mining applications assure proper placement and performance.

5.2.2 Compacted Clay

Compacted clays are commonly proposed as primary sealing materials for nuclear waste repositories and have been extensively investigated against rigorous performance requirements. Advantages of clays for sealing purposes include low permeability, demonstrated longevity in many types of natural environments, deformability, sorptive capacity, and demonstrated successful utilization in practice for a variety of sealing purposes.

Compacted clay as a shaft sealing component functions as a barrier to brine flow and possibly to gas flow (see alternative construction methods in Appendix B). Compacted bentonitic clay can generate swelling pressure and clays have sufficient rigidity to promote healing of any DRZ in the salt. Wetted swelling clay will seal fractures as it expands into available space and will ensure tightness between the clay seal component and the shaft walls.

The Rustler and Salado compacted clay columns are specified to be constructed of dense sodium bentonite blocks. An extensive experimental data base exists for the permeability of sodium bentonites under a variety of conditions. Many other properties of sodium bentonite, such as strength, stiffness, and chemical stability, are established. Bentonitic clays heal when fractured and can penetrate small fractures or irregularities in the host rock. Further, bentonite is stable in the seal environment. These properties, noted by international waste isolation programs, make bentonite a widely accepted seal material.

From the bottom clay component to the top earthen fill, different methods will be used to place clay materials in the shaft. Seal performance within the Salado Formation is far more important to regulatory compliance of the seal system than is performance of clay and earthen fill in the overlying formations. Therefore, more time and effort will be expended on placement of Salado clay components. Three potential construction methods could be used to place clay in the shaft, as discussed in Appendix B: compacted blocks, vibratory roller, and dynamic compaction. Construction of Salado clay components specifies block assembly.

Required sealing performance of compacted clay elements varies with location. For example, Component 4 provides separation of water-bearing zones, while the lowest clay column (Component 12) limits fluid flow to the reconsolidating salt column. If liquid saturation in the clay column of 85% can be achieved, it would serve as a gas barrier. In addition, compacted clay seal components promote healing of the salt DRZ. To achieve low permeabilities, the dry density of the emplaced bentonite should be about 1.8 g/cm^3. A permeability distribution function for performance assessment and the logic for its selection are given in Appendix A.

Verification of specified properties such as density, moisture content, permeability, or strength of compacted clay seals can be determined by direct measurement during construction. However, indirect methods are preferred because certain measurements, such as permeability, are

likely to be time consuming and invasive. Methods used to verify the quality of emplaced seals will include quality of block production and field measurements of density.

5.2.3 Asphalt

Asphalt is used to prevent water migration down the shaft in two ways: as an asphalt column near the Rustler/Salado contact and as a "waterstop" sandwiched between concrete plugs at three locations within the Salado Formation. Asphalt components of the WIPP seal design add assurance that minimal transport of brine down the sealed shaft will occur.

Asphalt is a widely used construction material because of its many desirable engineering properties. Asphalt is a strong cement, readily adhesive, highly waterproof, and durable. Furthermore, it is a plastic substance that is readily mixed with mineral aggregates. A range of viscosity is achievable for asphalt mixtures. It is highly resistant to most acids, salts, and alkalis. These properties are well suited to the requirements of the WIPP shaft seal system.

Construction of the seal components containing asphalt can be accomplished using a slickline process where low-viscosity heated material is effectively pumped into the shaft. The technology to apply the asphalt in this manner is available as described in the construction procedures in Appendix B.

The asphalt components are required to endure for about 100 years and limit brine flow down the shaft to the compacted salt component. Since asphalt will not be subjected to ultraviolet light or an oxidizing environment, it is expected to provide an effective seal for centuries. Air voids less than 2% ensure low permeability. The permeability of the massive asphalt column is expected to have an upper limit 1×10^{-18} m^2.

Sufficient construction practice and laboratory testing information is available to assure performance of the asphalt component. Laboratory validation tests to optimize viscosity may be desirable before final installation specifications are prepared. In general, verification tests would add quantitative documentation to expected performance values and have direct application to WIPP.

5.2.4 Compacted Salt Column

A reconsolidated column of natural WIPP salt will seal the shafts permanently. If salt reconsolidation is unimpeded by fluid pore pressures, the material will eventually achieve extremely low permeabilities approaching those of the native Salado Formation. Recent developments in support of the WIPP shaft seal system have produced confirming experimental results, constitutive material models, and construction methods that substantiate use of a salt column to create a low permeability seal component. Reuse of salt excavated in the process of creating the underground openings has been advocated since its initial proposal in the 1950s. Replacing the natural material in its original setting ensures physical, chemical, and mechanical compatibility with the host formation.

The function of the compacted and reconsolidated salt column is to limit transmission of fluids into or out of the repository for the statutory period of 10,000 years. The functional period starts within a hundred years and lasts essentially forever. After a period of consolidation, the salt column will almost completely retard gas or brine migration within the former shaft opening.

A completely consolidated salt column will achieve flow properties indistinguishable from natural Salado salt.

The salt component is composed of crushed Salado salt with additional small amounts of water. The total water content of the crushed salt will be adjusted to 1.5 wt% before it is tamped into place. Field and laboratory tests have verified that natural salt can be compacted to significant fractional density ($\rho \geq 0.9$) with addition of these moderate amounts of water.

Dynamic compaction is the specified construction procedure to tamp crushed salt in the shaft. Deep dynamic compaction provides great energy to the crushed salt, is easy to apply, and has an effective depth of compactive influence greater than lift thickness. Dynamic compaction is relatively straightforward and requires a minimal work force in the shaft. Compaction itself will follow procedures developed in a large-scale compaction demonstration, as outlined in Appendix B.

Numerical models of the shaft provide density of the compacted salt column as a function of depth and time. Many calculations comparing models for consolidation of crushed salt were performed to quantify performance of the salt column, as discussed in Appendix D and the references (Callahan et al., 1996; Brodsky et al., 1996). From the density-permeability relationship of reconsolidating crushed salt, permeability of the compacted salt seal component is calculated. In general, results show that the bottom of the salt column consolidates rapidly, achieving permeability of 1×10^{-19} m^2 in about 50 years. By 100 years, the middle of the salt column reaches similar permeability.

Results of the large-scale dynamic compaction demonstration suggest that deep dynamic compaction will produce a sufficiently dense starting material. As with other seal components, testing of the material in situ will be difficult and probably not optimal to ensure quality of the seal element. This is particularly apparent for the compacted salt component because the compactive effort produces a finely powdered layer on the top of each lift. It was demonstrated (Hansen and Ahrens, 1996) that the fine powder is very densely compacted upon tamping the superincumbent lifts. The best means to ensure that the crushed salt element is placed properly is to establish performance through verification of quality assurance/quality control procedures. If crushed salt is placed with a reasonable uniformity of water and compacted with sufficient energy, long-term performance can be assured.

5.2.5 Cementitious Grout

Cementitious grouting is specified for all concrete members. Grouting is also used in advance of liner removal to stabilize the ground and to limit water inflow during shaft seal construction. Cementitious grout is specified because of its proven performance, nontoxicity, and previous use at the WIPP.

The function of grout is to stabilize the surrounding rock before existing concrete liners are removed. Grout will fill fractures within adjacent lithologies, thereby adding strength and reducing permeability and, hence, water inflow during shaft seal construction. Grout around concrete members of the concrete asphalt waterstop will be employed in an attempt to tighten the interface and fill microcracks in the DRZ. Efficacy of grouting will be determined during construction.

An ultrafine cementitious grout has been specifically developed for use at the WIPP (Ahrens and Onofrei, 1996). This grout consists of Type 5 portland cement, pumice as a pozollanic material, and superplasticizer. The average particle size is approximately 2 microns. The ultrafine grout is mixed in a colloidal grout mixer, with a water to components ratio (W:C) of 0.6:1.

Drilling and grouting sequences provided in Appendix B follow standard procedures. Grout will be mixed on the surface and transported by slickline to the middle deck on the multi-deck stage (galloway). Grout pressures are specified below lithostatic to prevent hydrofracturing.

Performance of grout is not a consideration for compliance issues. Grouting of concrete elements is an added assurance to tighten interfaces. Grouting is used to facilitate construction by stabilizing any loose rock behind the concrete liner.

No verification of the effectiveness of grouting is currently specified. If injection around concrete plugs is possible, an evaluation of quantities and significance of grouting will be made during construction. Procedural specifications will include measurements of fineness and determination of rheology in keeping with processes established during the WIPP demonstration grouting (Ahrens et al., 1996).

5.2.6 Earthen Fill

A brief description of the earthen fill is provided in Appendix A, and construction is summarized in Appendix B. Compacted fill can be obtained from local borrow pits, or material excavated during shaft construction can be returned to the shaft. There are minimal design requirements for earthen fill and none that are related to WIPP regulatory performance.

5.3 Concluding Remarks

Materials specifications in Appendix A provide descriptions of seal materials along with reasoning on their expected reliability in the WIPP setting. The specification follows a framework that states the function of the seal component, a description of the material, and a summary of construction techniques. The performance requirements for each material are detailed. Materials chosen for use in the shaft seal system have several common desirable attributes: low permeability, high density, compatibility, longevity, low cost, constructability, availability, and supporting documentation.

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6. CONSTRUCTION TECHNIQUES

Construction of the shaft sealing system is feasible. The described procedures utilize currently available technology, equipment, and materials to satisfy shaft sealing system design guidance. Although alternative methods are possible, those described satisfy the design guidance requirements listed in Table 3-1 and detailed in the appendices. Construction feasibility is established by reference to comparable equipment and activities in the mining, petroleum, and food industries and test results obtained at the WIPP. Equipment and procedures for emplacement of sealing materials are described below.

6.1 Multi-Deck Stage

A multi-deck stage (Figures 6-1 and 6-2) consisting of three vertically connected decks will be the conveyance utilized during the shaft sealing operation. Detailed sketches of the multi-deck stage appear in Appendix E. The stage facilitates installation and removal of utilities and provides a working platform for the various sealing operations. A polar crane attached to the lower deck provides the mechanism required for dynamic compaction and excavation of the shaft walls. Additionally, the header at the bottom of the slickline is supported by a reinforced steel shelf, which is securely bolted to the shaft wall during emplacement of sealing materials. The multi-deck stage can be securely locked in place in the shaft whenever desired (e.g., during dynamic compaction, excavation of the salt walls of the shaft, grouting, liner removal, etc.). The multi-deck stage is equipped with floodlights, remotely aimed closed-circuit television, fold-out floor extensions, a jib crane, and range-finding devices. Similar stages are commonly employed in shaft sinking operations.

The polar crane can be configured for dynamic compaction (Figure 6-1) or for excavation of salt (Figure 6-2); a man cage or bucket can be lowered through the stage to the working surface below. Controlled manually or by computer, the crane and its trolley utilize a geared track drive. The crane can swiftly position the tamper (required for dynamic compaction) in the drop positions required (Figure 6-3) or accommodate the undercutter required for excavation of the shaft walls. The crane incorporates a hoist on the trolley and an electromagnet, enabling it to position, hoist, and drop the tamper. A production rate of one drop every two minutes during dynamic compaction is possible.

6.2 Salado Mass Concrete (Shaft Station Monolith and Shaft Plugs)

Salado Mass Concrete, described in Appendix A, will be mixed on surface at 20°C and transferred to emplacement depth through a slickline (i.e., a steel pipe fastened to the shaft wall and used for the transfer of sealing materials from surface to the fill horizon) minimizing air entrainment and ensuring negligible segregation. Existing sumps will be filled to the elevation of the floor of the repository horizon, and emplacement of the shaft station monolith is designed to eliminate voids at the top (back) of the workings.

When excavating salt for waterstops or plugs in the Salado Formation, an undercutter attached to the trolley of the polar crane will be forced into the shaft wall by a combination of geared trolley and undercutter drives. Full circumferential cuts will be accomplished utilizing the torque developed by the geared polar crane drive.

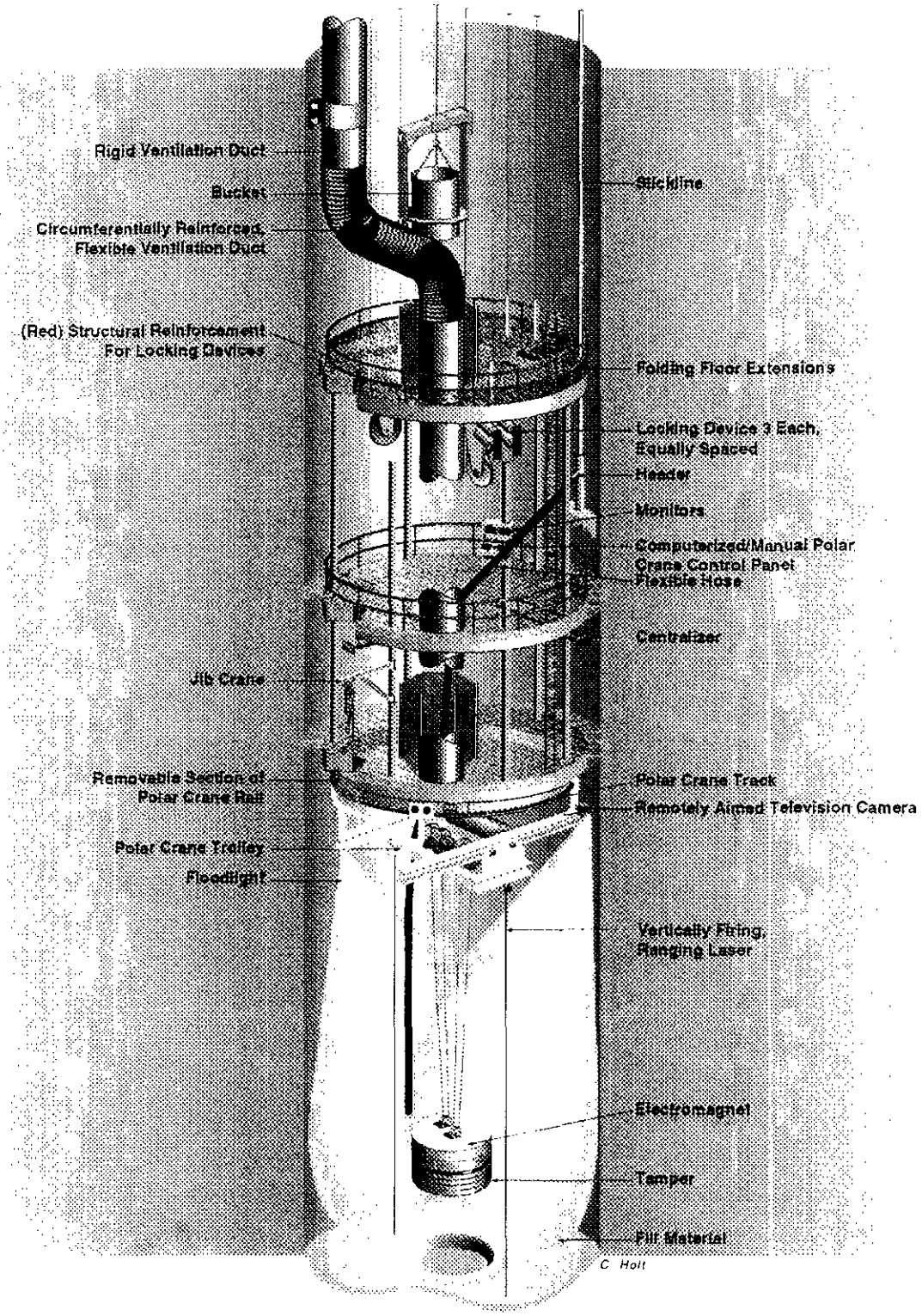

Figure 6-1. Multi-deck stage illustrating dynamic compaction.

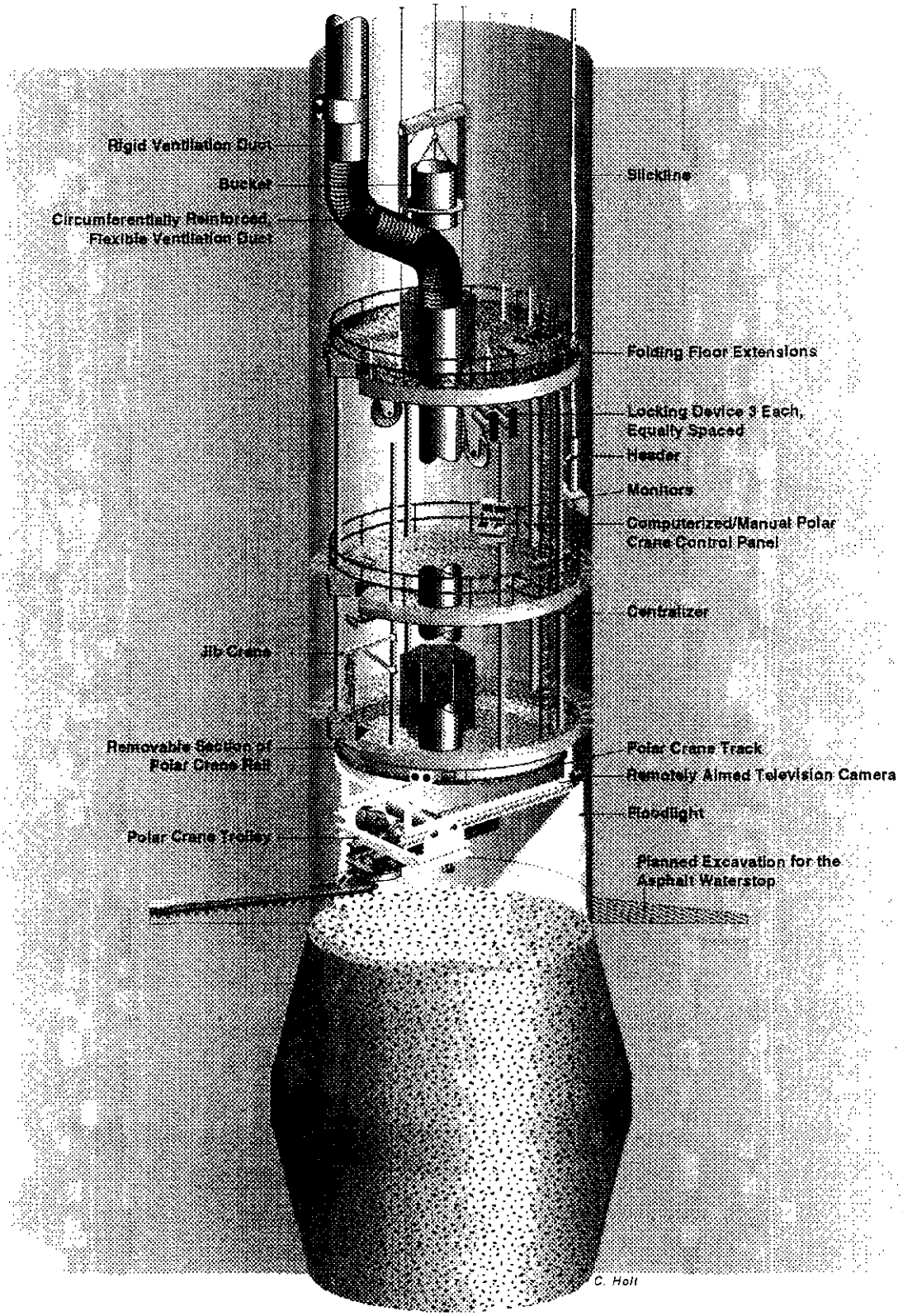

Figure 6-2. Multi-deck stage illustrating excavation for asphalt waterstop.

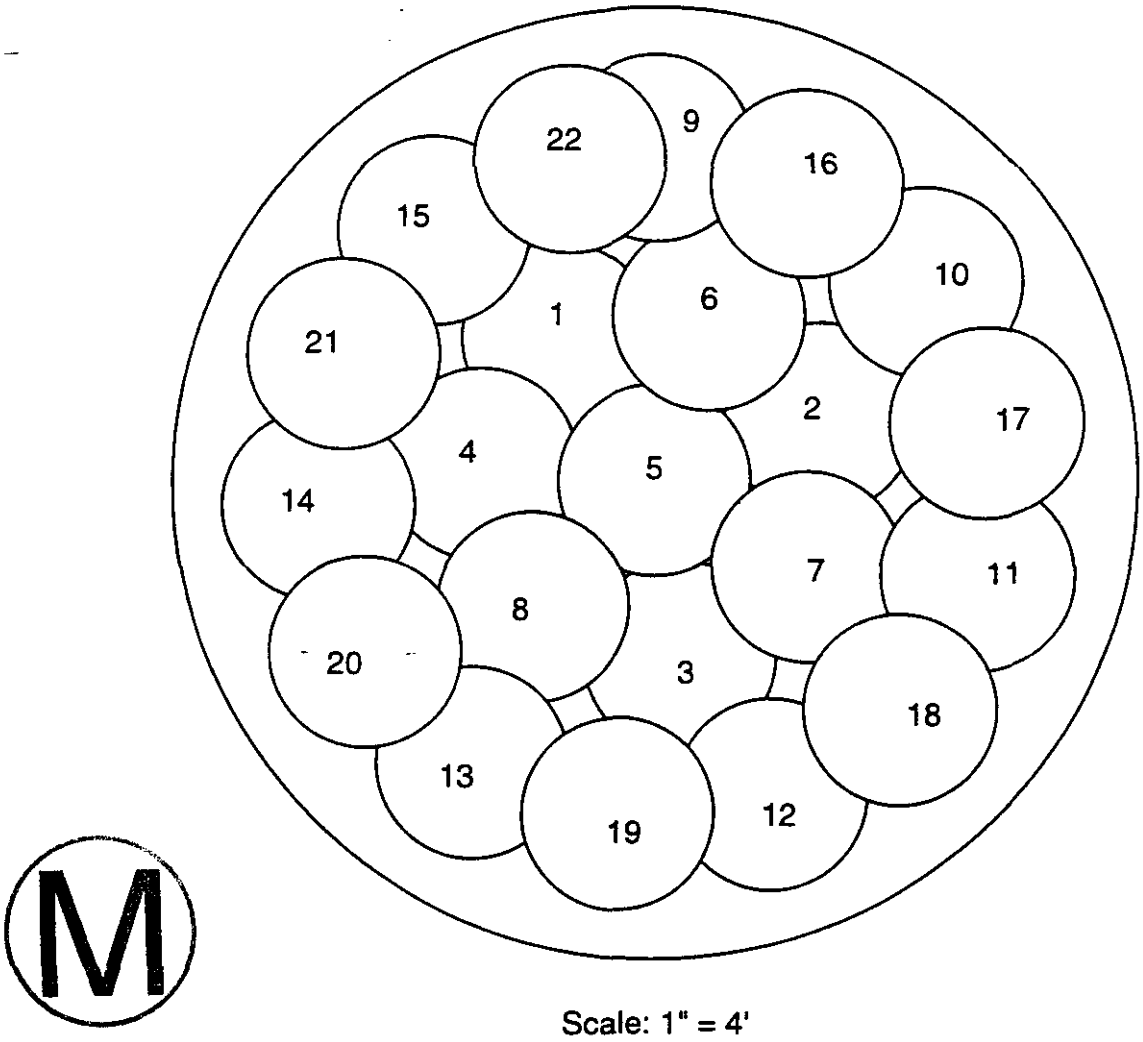

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Figure 6-3. Drop pattern for 6-m-diameter shaft using a 1.2-m-diameter tamper.

The undercutter proposed is a modified version of those currently in use in salt and coal mines, where their performance is proven. Such modifications and applications have been judged feasible by the manufacturer.

The concrete-salt interface and DRZ around concrete plugs in the Salado Formation (and the one at the base of the Rustler Formation) will be grouted with ultrafine grout. Injection holes will be collared in the top of the plug and drilled downward at 45° below horizontal. The holes will be drilled in a "spin" pattern describing a downward opening cone designed to intercept both vertical and horizontal fractures (Figure 6-4). The holes will be stage grouted (i.e., primary holes will be drilled and grouted, one at a time). Secondary holes will then be drilled and grouted, one at a time, on either side of primaries that accepted grout.

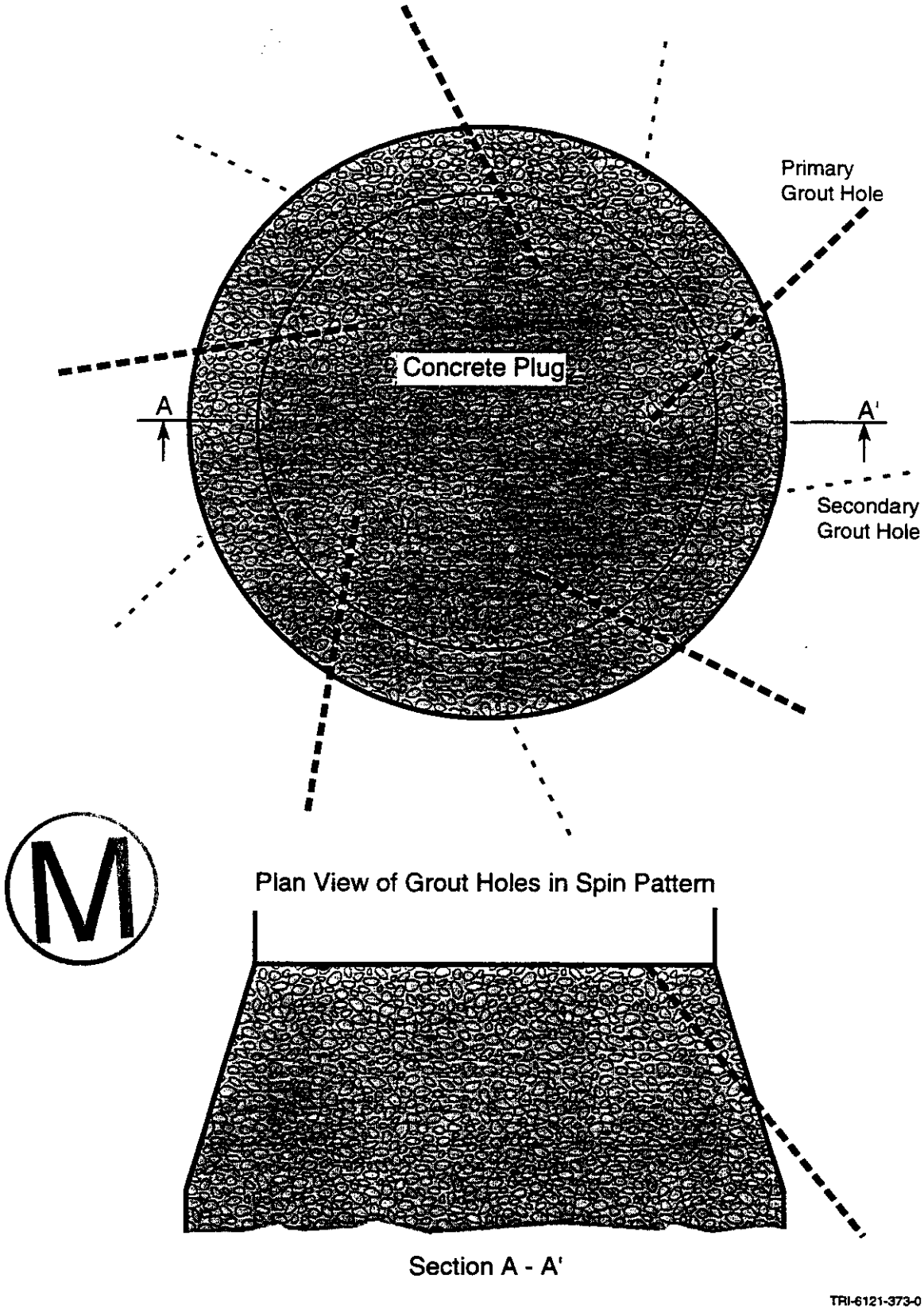

Figure 6-4. Plan and section views of downward spin pattern of grout holes.

6.3 Compacted Clay Columns (Salado and Rustler Formations)

Cubic blocks of sodium bentonite, 20.8 cm on the edge and weighing approximately 18 kg, will be precompacted on surface to a density between 1.8 and 2.0 gm/cm^3 and emplaced manually. The blocks will be transferred from surface on the man cage. Block surfaces will be moistened with a fine spray of potable water, and the blocks will be manually placed so that all surfaces are in contact. Peripheral blocks will be trimmed to fit irregularities in the shaft wall, and remaining voids will be filled with a thick mortar of sodium bentonite and potable water. Such blocks have been produced at the WIPP and used in the construction of 0.9-m-diameter seals, where they performed effectively (Knowles and Howard, 1996). Alternatives, which may be considered in future design evaluations, are discussed in Appendix B.

6.4 Asphalt Waterstops and Asphaltic Mix Columns

Neat asphalt is selected for the asphalt waterstops, and an asphaltic mastic mix (AMM) consisting of neat asphalt, fine silica sand, and hydrated lime will be the sealing material for the columns. Both will be fluid at emplacement temperature and remotely emplaced. Neat asphalt (or AMM, prepared in a pug mill near the shaft collar) will be heated to 180°C and transferred to emplacement depth via an impedance-heated, insulated tremie line (steel pipe) suspended from slips (pipe holding device) at the collar of the shaft.

This method of line heating is common practice in the mining and petroleum industries. This method lowers the viscosity of the asphalt so that it can be pumped easily. Remote emplacement by tremie line eliminates safety hazards associated with the high temperature and gas produced by the hot asphalt. Fluidity ensures that the material will flow readily and completely fill the excavations and shaft. Slight vertical shrinkage will result from cooling (calculations in Appendix D), but the material will maintain contact with the shaft walls and the excavation for the waterstop. Vertical shrinkage will be counteracted by the emplacement of additional material.

6.5 Compacted WIPP Salt

Dynamic compaction of mine-run WIPP salt has been demonstrated (Ahrens and Hansen, 1995). The surface demonstration produced salt compacted to 90% of in-place rock salt density, with a statistically averaged permeability of 1.65×10^{-15} m^2. Additional laboratory consolidation of this material at 5 MPa confining pressure (simulating creep closure of the salt) resulted in increased compaction and lower permeability (Brodsky, 1994). Dynamic compaction was selected because it is simple, robust, proven, has excellent depth of compaction, and is applicable to the vertical WIPP shafts.

The compactive effect expanded laterally and downward in the demonstration, and observation during excavation of the compacted salt revealed that the lateral compactive effect will fill irregularities in the shaft walls. Additionally, the depth of compaction, which was greater than that of the three lifts of salt compacted, resulted in the bottom lift being additionally compacted during compaction of the two overlying lifts. This cumulative effect will occur in the shafts.

Construction of the salt column will proceed in the following manner:

- Crushed and screened salt will be transferred to the fill elevation via slickline. Use of slicklines is common in the mining industry, where they are used to transfer backfill materials or concrete to depths far greater than those required at the WIPP. Potable water will be added via a fine spray during emplacement at the fill surface to adjust the moisture content to 1.5 ±0.3 wt%, accomplished by electronically coordinating the weight of the water with that of the salt exiting the hose.
- Dynamic compaction will then be used to compact the salt by dropping the tamper in specific, pre-selected positions such as those shown in Figure 6-3.

6.6 Grouting of Shaft Walls and Removal of Liners

The procedure listed below is a common mining practice which will be followed at each elevation where liner removal is specified. If a steel liner is present, it will be cut into manageable pieces and hoisted to the surface for disposal, prior to initiation of grouting.

Upward opening cones of diamond drill holes will be drilled into the shaft walls in a spin pattern (Figure 6-5) to a depth ensuring complete penetration of the Disturbed Rock Zone (DRZ) surrounding the shaft. For safety reasons, no major work will be done from the top deck; all sealing activities will be conducted from the bottom deck. The ends of the holes will be 3 m apart, and the fans will be 3 m apart vertically, covering the interval from 3 m below to 3 m above the interval of liner removal. Tests at the WIPP demonstrated that the ultrafine cementitious grout penetrated more than 2 m from the injection holes(Ahrens et al., 1996).

Injection holes will be drilled and grouted one at a time, as is the practice in stage grouting. Primary holes are grouted first, followed by the grouting of secondary holes on either side of primaries that accepted grout. Ultrafine grout will be injected below lithostatic pressure to avoid hydrofracturing the rock, proceeding from the bottom fan upward. Grout will be mixed on surface and transferred to depth via the slickline.

Radial, horizontal holes will then be drilled on a 0.3-m grid, covering the interval to be removed. These will be drilled to a depth sufficient to just penetrate the concrete liner. A chipping hammer will be used to break a hole through the liner at the bottom of the interval. This hole, approximately 0.3 m in diameter, will serve as "free face," to which the liner can be broken. Hydraulically-actuated steel wedges will then be used in the pre-drilled holes to break out the liner in manageable pieces, beginning adjacent to the hole and proceeding upward. Broken concrete will be allowed to fall to the fill surface, where it will be gathered and hoisted to the surface for disposal. Chemical seal rings will be removed as encountered.

6.7 Earthen Fill

Local soil, screened to produce a maximum particle dimension of approximately 15 mm, will be the seal material. This material will be transferred to the fill surface via the slickline and emplaced in the same manner as the salt. After adjusting the moisture content of the earthen fill below the concrete plug in the Dewey Lake Redbeds to achieve maximum compaction, the fill will be dynamically compacted, achieving a permeability as low as that of the enclosing formation.

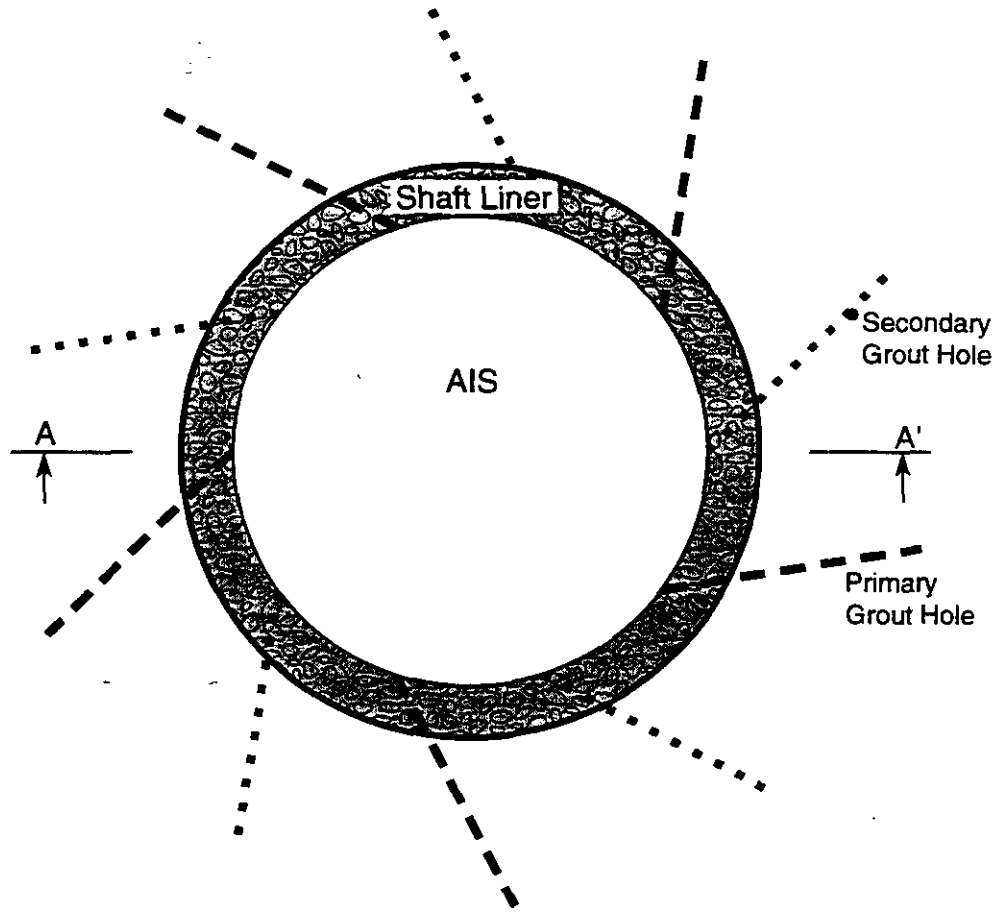

Plan View of Grout Holes in Spin Pattern

Section A - A'

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Figure 6-5. Plan and section views of upward spin pattern of grout holes.

The portion of the earthen fill above the plug will be compacted with a vibratory-impact sheepsfoot roller, a vibratory sheepsfoot roller, or a walk-behind vibratory plate compactor, because of insufficient height for dynamic compaction.

6.8 Schedule

For discussion purposes, it has been assumed that the shafts will be sealed two at a time. This results in the four shafts being sealed in approximately six and a half years. The schedules presented in Appendix B are based on this logic. Sealing the shafts sequentially would require approximately eleven and a half years.

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7. STRUCTURAL ANALYSES OF SHAFT SEALS

7.1 Introduction

The shaft seal system was designed in accordance with design guidance described in Section 3.2. To be successful, seal system components must exhibit desired structural behavior. The desired structural behavior can be as simple as providing sufficient strength to resist imposed loads. In other cases, structural behavior is critical to achieving desired hydrological properties. For example, permeability of compacted salt depends on the consolidation induced by shaft closure resulting from salt creep. In this example, results from structural analyses feed directly into fluid-flow calculations, which are described in Section 8, because structural behavior affects both time-dependent permeabilities of the compacted salt and pore pressures within the compacted salt. In other structural considerations, thermal effects are analyzed as they affect the constructability and schedule for the seal system. Thus a series of analyses, loosely termed structural analyses, were performed to accomplish three purposes:

1. to determine loads imposed on components and to assess both structural stability based on the strength of the component and mechanical interaction between components;
2. to estimate the influence of structural behavior of seal materials and surrounding rock on hydrological properties; and
3. to provide structural and thermal related information on construction issues.

For the most part, structural analyses rely on information and design details presented in the Design Description (Section 4), the Design Drawings (Appendix E), and Material Specification (Section 5 and Appendix A). Some analyses are generic, and calculation input and subsequent results are general in nature.

7.2 Analysis Methods

Finite-element modeling was the primary numerical modeling technique used to evaluate structural performance of the shaft seals and surrounding rock mass. Well documented finite-element computer programs, SPECTROM-32 and SPECTROM-41, were used in structural and thermal modeling, respectively. The computer program SALT_SUBSID was used in the subsidence modeling over the backfilled shaft-pillar area. Specific details of these computer programs as they relate to structural calculations are listed in Appendix D, Section D2.

7.3 Models of Shaft Seals Features

Structural calculations require material models to characterize the behavior of (1) each seal material (concrete, crushed salt, compacted clay, and asphalt); (2) the intact rock lithologies in the near-surface, Rustler, and Salado formations; and (3) any DRZ within the surrounding rock. A general description of the material models used in characterizing each of these materials and features is given below. Details of the models and specific values of model parameters are given in Appendix D, Section D3.

7.3.1 Seal Material Models

The SMC thermal properties required for the structural analyses (thermal conductivity, density, specific heat, and volumetric heat generation rate) were obtained from SMC test data. Concrete was assumed to behave as a viscoelastic material, based on experimental data, and the elastic modulus of SMC was modeled as age-dependent. Strength properties of SMC were specified in the design (see Appendix A).

For crushed salt, the deformational model included a nonlinear elastic component and a creep consolidation component. The nonlinear elastic modulus was assumed to be density-dependent, based on laboratory test data performed on WIPP crushed salt. Creep consolidation behavior of crushed salt was based on three candidate models whose parameters were obtained from model fitting to hydrostatic and shear consolidation test data performed on WIPP crushed salt. Creep consolidation models include functional dependencies on density, mean stress, stress difference, temperature, grain size, and moisture content.

Compacted clay was assumed to behave according to a nonlinear elastic model in which shear stiffness is negligible, and asphalt was assumed to behave as a weak elastic material. Thermal properties of asphalt were taken from literature.

7.3.2 Intact Rock Lithologies

Salado salt was assumed to be argillaceous salt that is governed by the Multimechanism Deformation Coupled Fracture (MDCF) model, which is an extension of the Munson-Dawson (M-D) creep model. A temperature-dependent thermal conductivity was necessary.

Salado interbeds were assumed to behave elastically. Their material strength was assumed to be described by a Drucker-Prager yield function, consistent with values used in previous WIPP analyses.

Deformational behavior of the near-surface and Rustler Formation rock types was assumed to be time-invariant, and their strength was assumed to be described by a Coulomb criterion, consistent with literature values.

7.3.3 Disturbed Rock Zone Models

Two different models were used to evaluate the development and extent of the DRZ within intact salt. The first approach used ratios of time-dependent stress invariants to quantify the potential for damage or healing to occur. The second approach used the damage stress criterion according to the MDCF model for WIPP salt.

7.4 Structural Analyses of Shaft Seal Components

7.4.1 Salado Mass Concrete Seals

Five analyses related to structural performance of SMC seals were performed, including (1) a thermal analysis, (2) a structural analysis, (3) a thermal stress analysis, (4) a dynamic compaction analysis, and (5) an analysis of the effects of clay swelling pressure. This section presents these analyses and evaluates the results in terms of the performance of the SMC seal. Details of these calculations are given in Appendix D, Section D4.

7.4.1.1 Thermal Analysis of Concrete Seals

The objective of this calculation was to determine expected temperatures within (and surrounding) an SMC emplacement resulting from its heat of hydration. Results indicate that the concrete component temperature increases from ambient (27°C) to a maximum of 53°C at 0.02 year after emplacement. The maximum temperature in the surrounding salt is 38°C at approximately the same time. The thermal gradient within the concrete is approximately 1.5°C/m. Most of the higher temperatures are contained within the concrete. At a radial distance of 2 m into the surrounding salt, the temperature rise is less than 1°C. These conditions are favorable for proper performance of the SMC components. A 26°C temperature rise and a 1.5°C/m temperature gradient are not large enough to cause thermal cracking as the concrete cools (Andersen et al., 1992).

7.4.1.2 Structural Analysis of Concrete Seals

The objectives of this calculation were to determine (1) expected stresses within the concrete components caused by restrained creep of the surrounding salt and (2) expected stresses in the concrete component from weight of overlying seal material.

In the upper concrete-asphalt waterstop, radial stresses increase (compression is positive) from zero at time of emplacement (t = 0) to 2.5 MPa at t = 50 years. Similarly, radial stresses in the middle concrete component range from 3.5 to 4.5 MPa at 50 years after emplacement. In the lower concrete-asphalt waterstop, radial stresses range from 4.5 to 5.5 MPa at t = 50 years. All the calculated stresses are well below the unconfined compressive strength of the concrete (30 MPa).

The upper, middle, and lower concrete-asphalt waterstops are located at depths of 300, 420, and 610 m, respectively. When performing these calculations, it was assumed that each concrete component must support the weight of the overlying materials between it and the next concrete component above it. Using an average overburden density of 0.02 MPa/m, stresses induced by the overlying material are significantly less than the strength of the concrete. The structural integrity of concrete components will not be compromised by either induced radial stress or imposed vertical stress.

7.4.1.3 Thermal Stress Analysis of Concrete Seals

The objectives of this calculation were (1) to determine thermal stresses in concrete components from the heat of hydration and (2) to determine thermal impact on the creep of the surrounding salt.

Thermoelastic stresses in the concrete were calculated based on a maximum temperature increase of 26°C and assuming a fully confined condition. Results of this calculation indicate that short-term compressive thermal stresses in the concrete will be less than 9.2 MPa. The temperature rise in the surrounding salt is insignificant in terms of producing either detrimental or beneficial effects. Based on these results, the structural integrity of concrete components will not be compromised by thermoelastic stresses caused by heat of hydration.

7.4.1.4 Effect of Dynamic Compaction on Concrete Seals

The objective of this calculation was to determine a required thickness of seal layers above concrete components to reduce the impact of dynamic compaction. Compaction depths for crushed salt and clay layers are 2.8 m and 2.2 m, respectively. Layers 3.7-m thick for crushed salt and 3-m thick for clay are to be emplaced before compaction begins, thus providing a layer about 30% thicker than the calculated compaction depths.

7.4.1.5 Effect of Clay Swelling Pressures on Concrete Seals

The objective of this calculation was to determine the increased stresses within concrete components as a result of clay swelling pressures. Test measurements on confined bentonite at an emplaced density of 1.8 g/cm^3 indicate that anticipated swelling pressures are on the order of 3.5 MPa. In order to fracture the salt surrounding the clay, the swelling pressures must exceed the lithostatic rock stress in the salt, which ranges from nominally 8.3 MPa at the upper clay seal to 14.4 MPa at the lower clay seal. The design strength of the concrete (31.0 MPa) is significantly greater than the swelling pressure of 3.5 MPa. Even in the unlikely event that the clay swelled to lithostatic pressures, the resulting state of stress in the concrete seal would lie well below any failure surface. Furthermore, the compressive tangential stress in the salt along the shaft wall, even after stress relaxation from creep, is always larger than lithostatic. Hence, radial fracturing from clay swelling pressure is not expected.

7.4.2 Crushed Salt Seals

Two analyses related to structural performance of crushed salt seals were performed, including (1) a structural analysis and (2) an analysis to determine effects of pore pressure on consolidation of crushed salt seals. This section presents the results of these analyses and evaluates the results in terms of performance of crushed salt seals. Details of these analyses are given in Appendix D, Section D4.

7.4.2.1 Structural Analysis of Compacted Salt Seal

The objectives of this calculation were (1) to determine the fractional density of the crushed salt seal as a function of time and depth and, using these results, (2) to determine permeability of the crushed salt as a function of time and depth.

Results indicate that compacted salt will increase from its emplaced fractional density of 90% to a density of 95% approximately 40, 80, and 120 years after emplacement at the bottom, middle, and top of the shaft seal, respectively. Using the modified Sjaardema-Krieg creep consolidation model, the times required to fully reconsolidate the crushed salt to 100% fractional density are 70 years, 140 years, and 325 years at the bottom, middle, and top of the salt column, respectively. Based on these results, the desired fractional densities (hence, permeability) can be achieved over a substantial length of the compacted salt seal in the range of 50 to 100 years.

7.4.2.2 Pore Pressure Effects on Reconsolidation of Crushed Salt Seals

The objective of this calculation was to determine the effect of pore pressure on the reconsolidation of the crushed salt seal. Fractional densities of the crushed salt seal were calculated using the modified Sjaardema-Krieg consolidation model for a range of pore pressures

(0, 2, and 4 MPa). Results indicate that times required to consolidate the crushed salt increase as the pore pressure increases, as expected. For example, for a pore pressure of 2 MPa, the times required to achieve a fractional density of 96% are about 90 years, 205 years, and 560 years at the bottom, middle, and top of the crushed salt column, respectively. A pore pressure of 4 MPa would effectively prevent reconsolidation of the crushed salt within a reasonable period (<1,000 years). The results of this calculation were used in the fluid flow calculations, and the impact of these pore pressures on the permeability of the crushed salt seal is described in Section 8 and Appendix C.

7.4.3 Compacted Clay Seals

One analysis was performed to determine the structural response of compacted clay seals. The objective of this calculation was to determine stresses in the upper Salado compacted clay component and the lower Salado compacted clay component as a result of creep of the surrounding salt. Details of this calculation are given in Appendix D, Section D4. Results of this calculation indicate that after 50 years the compressive stresses in the upper Salado compacted clay component are about 0.7 MPa, not including the effects of swelling pressures. Similarly, after 50 years the stresses in the lower Salado compacted clay component are approximately 2.6 MPa. Based on these results, the compacted clay component will provide some restraint to the creep of salt and induce a back (radial) stress in the clay seal, which will promote healing of the DRZ in the surrounding intact salt (see discussion about DRZ in Section 7.5.1).

7.4.4 Asphalt Seals

Three analyses were performed related to structural performance of the asphalt seals, including (1) a thermal analysis, (2) a structural analysis, and (3) a shrinkage analysis. This section presents the results of these analyses and evaluates the results in terms of the performance of the asphalt seal. Details of these analyses are given in Appendix D, Section D4.

7.4.4.1 Thermal Analysis

The objectives of this calculation were (1) to determine temperature histories within the asphalt seal and the surrounding salt and (2) to determine effects of the length of the waterstop.

Results indicate that the center of the asphalt column will cool from its emplaced temperature of 180°C to 83°C, 49°C, 31°C, and 26°C at times 0.1 year, 0.2 year, 0.5 year, and 1.0 year, respectively. Similarly, the asphalt/salt interface temperatures at corresponding times are 47°C, 38°C, 29°C, and 26°C. The time required for a waterstop to cool is significantly less than that required to cool the asphalt column. Based on these results, about 40 days are required for asphalt to cool to an acceptable working environment temperature. The thermal impact on enhanced creep rate of the surrounding salt is considered to be negligible.

7.4.4.2 Structural Analysis

The objective of this analysis was to calculate pressures in asphalt that result from restrained creep of the surrounding salt and to evaluate stresses induced on the concrete seal component by such pressurization.

Results indicate that pressures in the waterstops after 100 years are 1.8 MPa, 2.5 MPa, and 3.2 MPa for the upper, middle, and lower waterstops, respectively. Based on these results, the structural integrity of concrete components will not be compromised by imposed pressures, and the rock surrounding the asphalt will not be fractured by the pressure. The pressure from asphalt is enough to initiate healing of the DRZ surrounding the waterstop.

7.4.4.3 Shrinkage Analysis

The objective of this analysis was to calculate shrinkage of the asphalt column as it cools from its emplaced temperature to an acceptable working environment temperature. Results of this analysis indicate that the 42-m asphalt column will shrink 0.9 m in height as the asphalt cools from its emplaced temperature of 180°C to 38°C.

7.5 Disturbed Rock Zone Considerations

7.5.1 General Discussion of DRZ

Microfracturing leading to a DRZ occurs within salt whenever excavations are made. Laboratory and field measurements show that a DRZ has enhanced permeability. The body of evidence strongly suggests that induced fracturing is reversible and healed when deviatoric stress states created by the opening are reduced. Rigid seal components in the shaft provide a restraint to salt creep closure, thereby inducing healing stress states in the salt. A more detailed discussion of the DRZ is included in Appendix D.

7.5.2 Structural Analyses

Three analyses were performed to determine the behavior of the DRZ in the rock mass surrounding the shaft. The first analysis considered time-dependent DRZ development and subsequent healing of intact Salado salt surrounding each of the four seal materials. The second analysis considered time-dependent development of the DRZ within anhydrite and polyhalite interbeds within the Salado Formation. The last analysis considered time-independent DRZ development within the near-surface and Rustler formations. These analyses are discussed below and given in more detail in Appendix D, Section D5. Results from these analyses were used as input conditions for the fluid flow analysis presented in Section 8 and Appendix C.

7.5.2.1 Salado Salt

The objective of this calculation was to determine time-dependent extent of the DRZ in salt, assuming no pore pressure effects, for each of the four shaft seal materials (i.e., concrete, crushed salt, compacted clay, and asphalt. The seal materials below a depth of about 300 m provide sufficient rigidity to heal the DRZ within 100 years. Asphalt, modeled as a weak elastic material, will not create a stress state capable of healing the DRZ because it is located high in the Salado.

7.5.2.2 Salado Anhydrite Beds

The objective of this calculation was to determine the extent of the DRZ within the Salado anhydrite and polyhalite interbeds as a result of creep of surrounding salt.

For all interbeds, the factor of safety against failure (shear or tensile fracturing) increases with depth into the rock surrounding the shaft wall. These results indicate that, with the exception of Marker Bed 117 (MB117), the factor of safety is greater than 1 (no DRZ will develop) for all interbeds. For MB117, the potential for fracturing is localized to within 1 m of the shaft wall.

7.5.2.3 Near-Surface and Rustler Formations

The objective of this calculation was to determine the extent of the DRZ surrounding the shafts in the near-surface and Rustler formations.

Rock types in near-surface and Rustler formations are anhydrite, dolomite, and mudstone. These rock types exhibit time-independent behavior. Results indicate that no DRZ will develop in anhydrite and dolomite (depths between 165 and 213 m). For mudstone layers, the radial extent of the DRZ increases with depth, reaching a maximum of 2.6 shaft radii at a depth of 223 m.

7.6 Other Analyses

This section discusses two structural analyses performed in support of design concerns, namely (1) the asphalt waterstops constructability and (2) benefits from shaft station backfilling. Analyses performed in support of these efforts are discussed below and given in more detail in Appendix D, Section D6.

7.6.1 Asphalt Waterstops

The DRZ is a major contributor to fluid flows through a low permeability shaft seal system, regardless of the materials emplaced within the shaft. Therefore, to increase the confidence in the overall shaft seal, low permeability layers (termed radial waterstops) were included to intersect the DRZ surrounding the shaft. These waterstops are emplaced to alter the flow direction either inward toward the shaft seal or outward toward intact salt. Asphalt-filled waterstops will be effective soon after emplacement. The objectives of these structural calculations were to evaluate performance of the waterstops in terms of (1) intersecting the DRZ around the shaft, (2) inducing a new DRZ because of special excavation, and (3) promoting healing of the DRZ.

Results indicate that the DRZ from the shaft extends to a radial distance of less than one shaft radius (3.04 m). Waterstop excavation extends the DRZ radially to about 1.4 shaft radii (4.3 m). However, this extension is localized within the span of the concrete component and extends minimally past the waterstop edge. The DRZ extent reduced rapidly after the concrete and asphalt restrained creep of the surrounding salt. After 20 years, the spatial extent of the DRZ is localized near the asphalt-concrete interface, extending spatially into the salt at a distance of less than 2 m. Based on these results, construction of waterstops is possible without substantially increasing the DRZ. Furthermore, the waterstop extends well beyond the maximum extent of the DRZ surrounding the shaft and effectively blocks this flow path (within 2 years after emplacement), albeit over only a short length of the flow path.

7.6.2 Shaft Pillar Backfilling

The objective of this calculation was to assess potential benefits from backfilling a portion of the shaft pillar to reduce subsurface subsidence and thereby decrease the potential for inducing fractures along the shaft wall. The calculated subsidence without backfilling is less than one foot, due to the relatively low extraction ratio at the WIPP. Based on the results of this analysis, backfilling portions of the shaft pillar would result in only 10% to 20% reduction in surface subsidence. This reduction in subsidence from backfilling is not considered enough to warrant backfilling the shaft pillar area. The shaft seals within the Salado are outside the angle-of-draw for any horizontal displacements caused by the subsidence over the waste panels. Moreover, horizontal strains caused by subsidence induced by closures within the shaft pillar are compressive in nature and insignificant in magnitude to induce fracturing along the shaft wall.

8. HYDROLOGIC EVALUATION OF THE SHAFT SEAL SYSTEM

8.1 Introduction

The design guidance in Section 3 presented the rationale for sealing the shaft seal system with low permeability materials, but it did not provide specific performance measures for the seal system. This section compares the hydrologic behavior of the system to several performance measures that are directly related to the ability of the seal system to limit liquid and gas flows through the seal system. The hydrologic evaluation is focused on the processes that could result in fluid flow through the shaft seal system and the ability of the seal system to limit any such flow. Transport of radiological or hazardous constituents will be limited if the carrier fluids are similarly limited.

The hydrologic performance models are fully described in Appendix C. The analyses presented are deterministic. Quantitative values for those parameters that are considered uncertain and that may significantly impact the primary performance measures have been varied, and the results are presented in Appendix C. This section summarizes the seal system performance analyses and discusses results within the context of the design guidance of Section 3. The results demonstrate that (1) fluid flows will be limited within the shaft seal system and (2) uncertainty in the conceptual models and parameters for the seal system are mitigated by redundancy in component function and materials.

8.2 Performance Models

The physical processes that could impact seal system performance are presented in detail in Appendix C. These processes have been incorporated into four performance models. These models evaluate (1) downward migration of groundwater from the Rustler Formation, (2) gas migration and consolidation of the crushed salt seal component, (3) upward migration of brines from the repository, and (4) flow between water-bearing zones in the Rustler Formation. The first three are analyzed using numerical models of the Air Intake Shaft (AIS) seal system and the finite-difference codes SWIFT II and TOUGH28W. These codes are extensively used and well documented within the scientific community. A complete description of the models is provided in Appendix C. The fourth performance model uses a simple, analytical solution for fluid flow. Results from the analyses are summarized in the following sections and evaluated in terms of the design guidance presented in Section 3.

Material properties and conceptual models that may significantly impact seal system performance have been identified, and uncertainty in properties and models have been addressed through variation of model parameters. These parameters include (1) the effective permeability of the DRZ, (2) those describing salt column consolidation and the relationship between compacted salt density and permeability, and (3) repository gas pressure applied at the base of the shaft seal system.

8.3 Downward Migration of Rustler Groundwater

The shaft seal system is designed to limit groundwater flowing into and through the shaft sealing system (see Section 3). The principal source of groundwater to the seal system is the Culebra Member of the Rustler Formation. The Magenta Member of this formation is also

considered a groundwater source, albeit a less significant source than the Culebra. No significant sources of groundwater exist within the Salado Formation; however, brine seepage has been noted at a number of the marker beds. The modeling includes the marker beds, as discussed in Appendix C. Downward migration of Rustler groundwater must be limited so that liquid saturation of the compacted salt column salt column does not impact the consolidation process and to ensure that significant quantities of brine do not reach the repository horizon. Because it is clear that limitation of liquid flow into the salt column necessarily limits liquid flow to the repository, the volumetric flux of liquid into and through the salt column were selected as performance measures for this model.

Consolidation of the compacted salt column salt column will be most rapid immediately following seal construction. Simulations were conducted for the 200-year period following closure to demonstrate that, during this initial period, downward migration of Rustler groundwater will be insufficient to impact the consolidation process. Lateral migration of brine through the marker beds is also quantified in the analysis and shown to be nondetrimental to the function of the salt column.

8.3.1 Analysis Method

Seal materials will not, in general, be fully saturated with liquid at the time of construction. The host rock surrounding the shafts will also be partially desaturated at the time of seal construction. The analysis presented in this section assumes a fully saturated system. The effects of partial saturation of the shaft seal system are favorable in terms of system performance, as will be discussed in Section 8.3.2.

Seal material and host rock properties used in the analyses are discussed in Appendix C, Section C3. Appendix A contains a detailed discussion of seal material properties. A simple perspective on the effects of material and host rock properties may be obtained from Darcy's Law. At steady-state, the flow rate in a fully saturated system depends directly on the system permeability. The seal system consists of the component material and host rock DRZ. Low permeability is specified for the engineered materials; thus the system component most likely to impact performance is the DRZ. Rock mechanics calculations presented in Appendix D predict that the DRZ in the Salado Formation will not be vertically continuous because of the intermittent layers of stiff anhydrites (marker beds). Asphalt waterstops are included in the design to minimize DRZ impacts. The effects of the marker beds and the asphalt waterstops on limiting downward migration are explicitly simulated through variation of the permeability of the layers of Salado DRZ.

Initial, upper, and lateral boundary conditions for the performance model are consistent with field measurements for the physical system. At the base of the shaft a constant atmospheric pressure is assumed.

8.3.2 Summary of Results

The initial pore volumes in the filled repository and the AIS salt column are approximately 460,000 m^3 and 250 m^3, respectively. The performance model predicts a maximum cumulative flow of less than 5 m^3 through the sealed shafts for the 200 years following closure. If the marker beds have a disturbed zone immediately surrounding the shaft,

the maximum flow is less than 10 m^3 during the same period. Assuming the asphalt waterstops are not effective in interrupting the vertical DRZ, the volumetric flow increases but is still less than 30 m^3 for the 200 years following closure. These volumes are less than 1/100 of 1% of the pore volume in the repository and less than 20% of the initial pore volume of the salt column.

Two additional features of the model predictions should also be considered. The first of these is that flow rates fall from less than 1 m^3 / year in the first five years to negligible values within 10 years of seal construction. Therefore most of the cumulative flow occurs within a few years following closure. The second feature is the model prediction that the system returns to nearly ambient undisturbed pressures within two years. The repressurization occurs quickly within the model due to the assumption of a fully saturated flow regime because of brine incompressibility. As will be discussed in Section 8.4, the pore pressure in the compacted salt column is a critical variable in the analysis. The pressure profiles predicted by the model are an artifact of the assumption of full liquid saturation and do not apply to the pore pressure analysis of the salt column.

The magnitude of brine flow that can reach the repository through a sealed shaft is minimal and will not impact repository performance. The flow that reaches the salt column must be assessed with regard to the probable impacts on the consolidation process. Although the volume of flow to the salt column is a small percentage of the available pore volume, the saturation state and fluid pore pressure of this component are the variables of significance. These issues cannot be addressed by a fully saturated model. Instead it is necessary to include these findings in a multi-phase model that includes the salt column. This is the topic of Section 8.4.

The results of the fully saturated model will over-predict the flow rates through the sealed shaft. This analysis does not take credit for the time required for the system to resaturate, nor does it take credit for the sorptive capabilities of the clay components. The principal source of groundwater to the system is the Rustler Formation. The upper clay component is located below the Rustler and above the salt column and will be emplaced at a liquid saturation state of approximately 80%. Bentonite clays exhibit strong hydrophilic characteristics, and it is expected that the upper clay component will have these same characteristics. As a result, it is possible that a significant amount of the minimal Rustler groundwater that reaches the clay column will be absorbed and retained by this seal component. Although this effect is not directly included in the present analysis, the installation of a partially saturated clay component provides assurance that the flow rates predicted by the model are maximum values.

8.4 Gas Migration and Consolidation of Compacted Salt Column

The seal system is designed to limit the flow of gas from the disposal system through the sealed shafts. Migration of gas could impact performance if this migration substantially increases the fluid pore pressure of the compacted salt column. The initial pore pressure of the salt column will be approximately atmospheric. The sealed system will interact with the adjacent desaturated host rock as well as the far-field formation. Natural pressurization will occur as the system returns to an equilibrium state. This pressurization, coupled with seepage of brine through the marker beds, will also result in increasing fluid pore pressure within the compacted salt column. The analysis presented in this section addresses the issue of fluid pore pressure in the compacted salt column resulting from the effects of gas generation at the repository horizon

and natural repressurization from the surrounding formation. A brief discussion on the impedance to gas flow afforded by the lower compacted clay column is also presented.

8.4.1 Analysis Method

A multi-phase flow model of the lower seal system was developed to evaluate the performance of components extending from the middle SMC component to the repository horizon.

Rock mechanics calculations presented in Section 7 and Appendix D predict that the compacted salt column will consolidate for a period of approximately 400 years if the fluid-filled pores of the column do not produce a backstress. Within the physical setting of the compacted salt column, three processes have been identified which may result in a significant increase in pore pressure: groundwater flow from the Rustler Formation, gas migration from the repository, and natural fluid flow and repressurization from the Salado Formation. The first two processes were incorporated into the model as initial and boundary conditions, respectively. The third process was captured in all simulations through modeling of the lithologies surrounding the shaft. Simulations were conducted for 200 years following closure to evaluate any effects these processes might have on the salt column during this initial period.

As discussed in Section 8.3.1, the host rock DRZ is an important consideration in seal system performance. A vertically continuous DRZ could exist in both the Rustler and Salado Formations. Concrete-asphalt waterstops are included in the design to add assurance that a DRZ will not adversely impact seal performance. The significance of a continuous DRZ and waterstops will be evaluated based on results of the performance model.

A detailed description of the model grid, assumptions, and parameters is presented in Appendix C.

8.4.2 Summary of Results

The consolidation process is a function of both time and depth. The resultant permeability of the compacted salt column will similarly vary. To simplify the evaluation, an effective permeability of the salt component was calculated. This permeability is calculated by analogy to electrical circuit theory. The permeability of each model layer is equated to a resistor in a series of resistors. The equivalent resistance (i.e., permeability) of a homogeneous column of identical length is derived in this manner. Figure 8-1 illustrates this process.

Results of the performance model simulations are summarized in Table 8-1. The effective permeabilities were calculated by the model assuming that, as the salt consolidated, permeability was reduced pursuant to the best-fit line through the experimental data (Figure A-7). From Table 8-1 it is clear that, for all simulated conditions, the salt column consolidates to very low values in 200 years. Differences in the effective permeability because of increased repository gas pressure and a vertically continuous DRZ were negligible. The DRZ around concrete components is predicted to heal (Appendix D) within 25 years. If the asphalt waterstops do not function as intended, the DRZ in this region will still heal in 25 years, as compared to 2 years for effective waterstops. The effective permeability of the compacted salt column increases by about a factor of two for this condition. However, the resultant permeability is sufficiently

low that the compacted salt columns will comprise permanent effective seals within the WIPP shafts.

Table 8-1. Summary of Results from Performance Model

Repository Pressure	Rustler Flow (m^3)	Continuous DRZ (Yes/No)	Concrete-Asphalt Waterstop Healing Time (Years)	Effective Permeability at 200 Years (m^2)
7 MPa in 100 Years	0	No	2	3.3×10^{-20}
14 MPa in 200 Years	0	No	2	3.3×10^{-20}
7 MPa in 100 Years	2.7	Yes	2	3.4×10^{-20}
7 MPa in 100 Years	17.2	Yes	25	6.0×10^{-20}

The relationship between the fractional density (i.e., consolidation state) of the compacted salt column and permeability is uncertain, as discussed in Appendix A. Lines drawn through the experimental data (Figure A-7) provide a means to quantify this uncertainty but do not capture the actual physical process of consolidation. As observed through microscopy, consolidation is dominated by pressure solution and redeposition, a mechanism of mass movement facilitated by the presence of moisture on grain boundaries (Hansen and Ahrens, 1996). As this process continues, the connected porosity and hence permeability of the composite mass will reduce at a rate that has not been characterized by the data collected in WIPP experiments. The results of the multi-phase performance model presented in Table 8-1 used a best-fit line through the data. Additional simulations were conducted using a line that represents a 95% certainty that the permeability is less than or equal to values taken from this line. Model simulations that used the 95% line are not considered representative of the consolidation process. However, these results provide an estimation of the significance that this uncertainty may have on the seal system performance.

Figure 8-2 depicts the effective permeability of the salt column as a function of time using the 95% line. The consolidation process, and hence permeability reduction, essentially stopped at 75 years for this simulation. Although the model predicts that the fractional density at the base of the salt column will reach approximately 97% of the density of intact halite, the permeability remains several orders of magnitude higher than that of the surrounding host rock. As a result, repressurization occurs rapidly throughout the vertical extent of the compacted salt column, and consolidation ceases. Laboratory experiments have shown that permeability to brine should decrease to levels of 10^{-18} to 10^{-20} m^2 at the fractional densities predicted by the performance model. The transport of brine within the consolidating salt will reduce the permeability even further (Brodsky et al., 1995). The predicted permeability of 10^{-16} m^2 is still sufficiently low that brine migration would be limited (DOE, 1995). However, the results of this analysis are more valuable in terms of demonstrating the coupled nature of the mechanical and hydrological behavior of consolidating crushed salt.

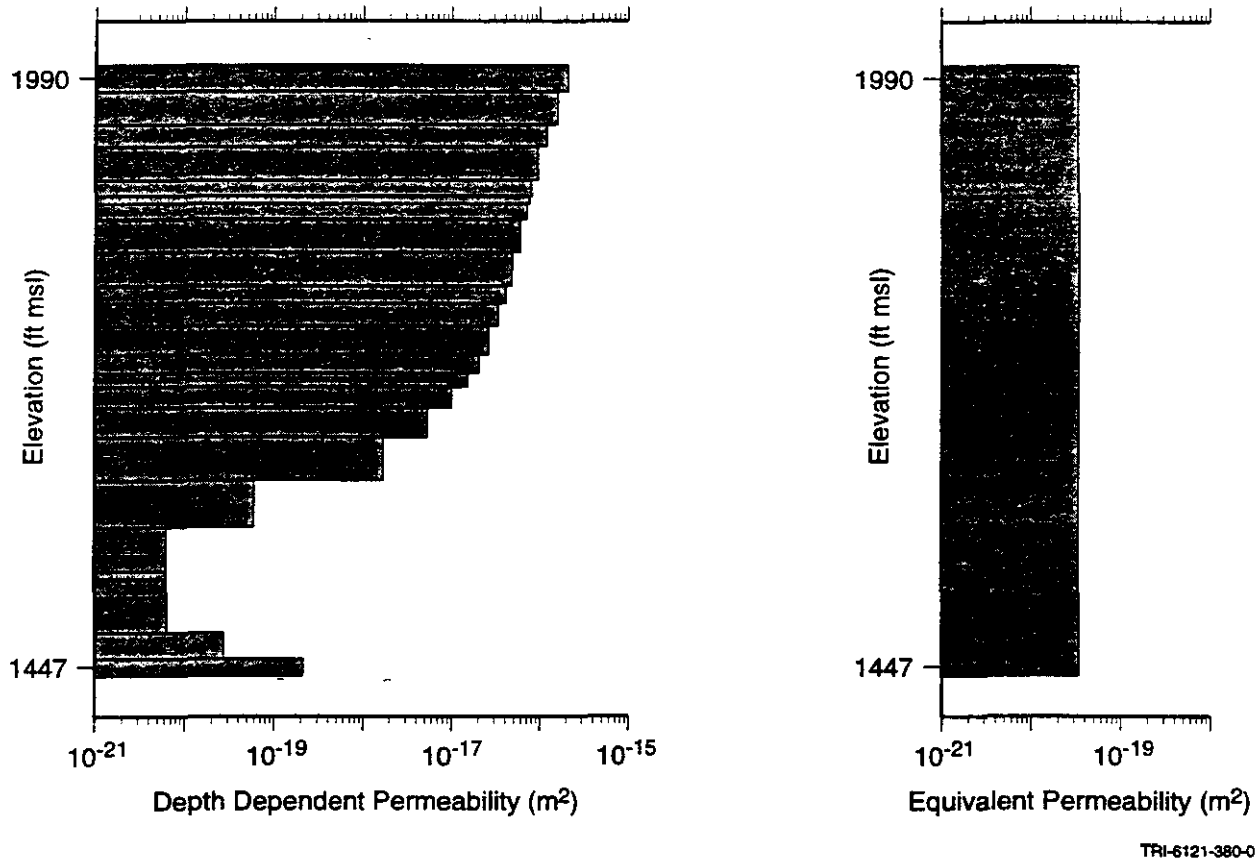

Figure 8-1. Calculation of an effective salt column permeability from the depth-dependent permeability at a point in time.

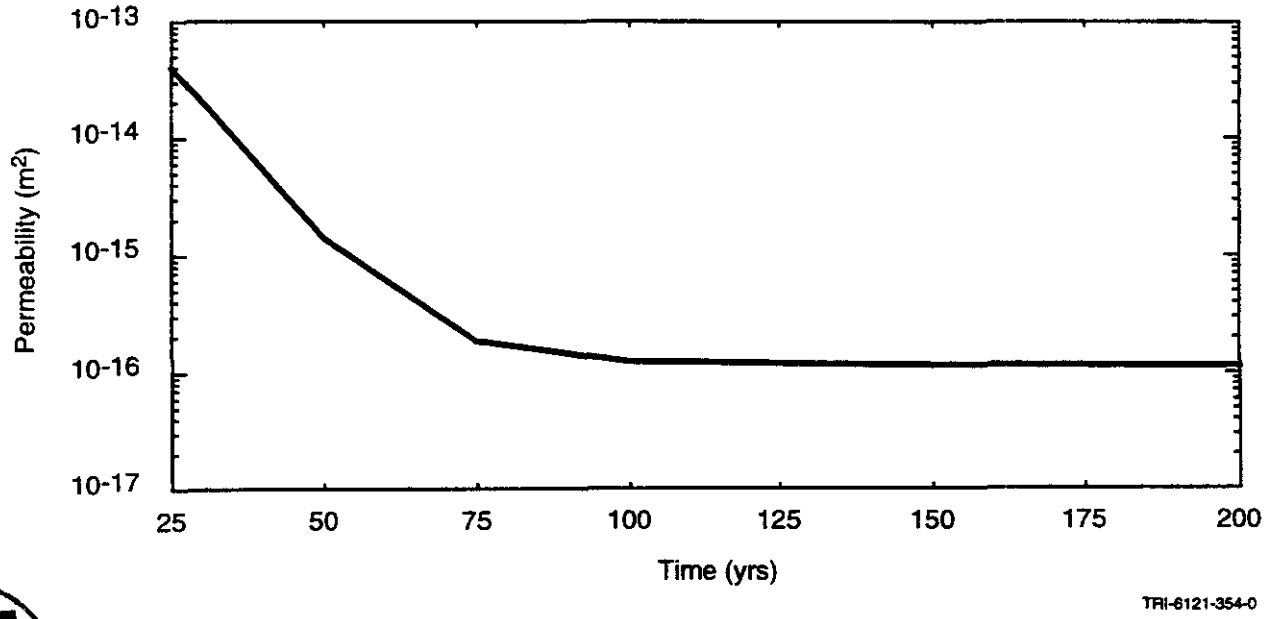

Figure 8-2. Effective permeability of the Salado salt column using the 95% certainty line.

A final consideration within this performance model relates to the lower compacted clay column. This clay column is included in the design to provide a barrier to both gas and brine migration from the repository horizon. The ability of the clay to prevent gas migration will depend upon its liquid saturation state (Section 5 and Appendix A). The lower clay component has an initial liquid saturation of about 80%, and portions of the column achieve brine saturations of nearly 100% during the 200 year simulation period. If the clay component performs as designed, gas migration through this component should be minimal. An examination of the model gas saturations indicates that, for all runs, gas flow occurs primarily through the DRZ prior to healing. These model predictions are consistent with field demonstrations that brine-saturated bentonite seals will prevent gas flow at differential pressures of up to 4 MPa (Knowles and Howard, 1996).

8.5 Upward Migration of Brine

The performance model discussed in Section 8.3 was modified to simulate undisturbed equilibrium pressures. As discussed in Appendix C, the Salado Formation is overpressurized with respect to the measured heads in the Rustler, and upward migration of contaminated brines could occur through an inadequately sealed shaft. Sections 8.3 and 8.4 demonstrated that the compacted salt column will consolidate to a low permeability following repository closure. Appendix D and Section 7 show that the DRZ surrounding the long-term clay and crushed salt seal components will completely heal within the first several decades. As a result, upward migration at the base of the Salado salt is predicted to be approximately 1 m^3 over the regulatory period. At the Rustler/Salado contact, a total of approximately 20 m^3 migrates through the sealed AIS over the regulatory period. The only brine sources between these two depths are the marker beds. It can therefore be concluded that most of the brine flow reaching the Rustler/Salado contact originates in marker beds above the repository horizon. The seal system effectively limits the flow of brine and gas from the repository through the sealed shafts throughout the regulatory period.

8.6 Intra-Rustler Flow

The potential exists for vertical flow within water-bearing strata of the Rustler Formation. Flow rates were estimated using a closed form solution of the steady-state saturated flow equation (Darcy's Law). The significance of the calculated flow rates can be assessed in terms of the width of the hydraulic disturbance (i.e., plume half-width) generated in the recipient flow field. The plume half-width was calculated to be minimal for all expected conditions (Section C7). Intra-Rustler flow is therefore concluded to be of such a limited quantity that (1) it will not affect either the hydraulic or chemical regime in the Rustler and (2) it will not be detrimental to the seal system.

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9. CONCLUSIONS

The principal conclusion drawn from discussions in the previous sections and details provided in the appendices is that an effective, implementable design has been documented for the WIPP shaft sealing system. Specifically, the six elements of the Design Guidance, Table 3-1, are implemented in the design in the following manner:

1. The shaft sealing system shall limit the migration of radiological or other hazardous constituents from the repository horizon to the regulatory boundary during the 10,000-year regulatory period following closure.

Based on the analysis presented in Section 8.5, it was determined that this shaft sealing system effectively limits the migration of radiological or other hazardous constituents from the repository horizon to the regulatory boundary during the 10,000-year regulatory period following closure.

2. The shaft sealing system shall limit groundwater flowing into and through the shaft sealing system.

The combination of the seal components in the Salado Formation, the Rustler Formation, and above the Rustler combine to produce a robust system. Based on analysis presented in Section 8.3, it was concluded that the magnitude of brine flow that can reach the repository through the sealed shaft is minimal and will not impact repository performance.

3. The shaft sealing system shall limit chemical and mechanical incompatibility of seal materials with the seal environment.

The sealing system components are constructed of materials possessing high durability and compatibility with the host rock. Engineered materials including salt-saturated concrete, bentonite, clays, and asphalt are expected to retain their design properties over the regulatory period.

4. The shaft sealing system shall limit the possibility for structural failure of individual components of the sealing system.

Analysis of components has determined that: (a) the structural integrity of concrete components will not be compromised by induced radial stress, imposed vertical stress, temperature gradients, dynamic compaction of overlying materials, or swelling pressure associated with bentonite (Section 7.4.1); (b) the thermal impact of asphalt on the creep rate of the salt surrounding the asphalt waterstops is negligible (Section 7.4.4); and (c) the pressure from the asphalt element of the concrete-asphalt waterstops is sufficient to initiate healing of the surrounding DRZ within two years of emplacement (Section 7.6.1). The potential for structural failure of sealing components is minimized by the favorable compressive stress state that will exist in the sealed WIPP shafts.

5. The shaft sealing system shall limit subsidence of the ground surface in the vicinity of the shafts and the possibility of accidental entry after sealing.

The use of high density sealing materials that completely fill the shafts eliminates the potential for shaft wall collapse, eliminates the possibility of accidental entry after closure, and assures that local surface depressions will not occur at shaft locations.

6. The shaft sealing system shall limit the need to develop new technologies or materials for construction of the shaft sealing system.

The shaft sealing system utilizes existing construction technologies (identified in Section 6) and materials (identified in Section 5).

The design guidance can be summarized as focusing on two principal questions: Can you build it, and will it work? The use or adaptation of existing technologies for the placement of the seal components combined with the use of available, common materials assure that the design can be constructed. Performance of the sealing system has been demonstrated in the hydrologic analyses that show very limited flows of gas or brine, in structural analyses that assure acceptable stress and deformation conditions, and in the use of low permeability materials that will function well in the environment in which they are placed. Confidence in these conclusions is bolstered by the basic design approach of using multiple components to perform each intended sealing function and by using extensive lengths within the shafts to effect a sealing system. Additional confidence is added by the results of field and lab tests in the WIPP environment that support the data base for the seal materials.

10. REFERENCES

Ahrens, E.H., and F.D. Hansen. 1995. *Large-Scale Dynamic Compaction Demonstration Using WIPP Salt: Fielding and Preliminary Results*. SAND95-1941. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM [SWCF] as WPO31104.)

Ahrens, E.H., and M. Onofrei. 1996. "Ultrafine Cement Grout for Sealing Underground Nuclear Waste Repositories," *2nd North American Rock Mechanics Symposium (NARMS 96), Montreal, Quebec, June 19-21, 1996*. SAND96-0195C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO31251.)

Ahrens, E.H., T.F. Dale, and R.S. Van Pelt. 1996. *Data Report on the Waste Isolation Pilot Plant Small-Scale Seal Performance Test, Series F Grouting Experiment*. SAND93-1000. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO37355.)

Andersen, P.J., M.E. Andersen, and D. Whiting. 1992. *A Guide to Evaluating Thermal Effects in Concrete Pavements*. SHRP-C/FR-92-101. Washington, DC: Strategic Highway Research Program, National Research Council. (Copy on file in the SWCF.)

Avis, J.D., and G.J. Saulnier, Jr. 1990. *Analysis of the Fluid-Pressure Responses of the Rustler Formation at H-16 to the Construction of the Air-Intake Shaft at the Waste Isolation Pilot Plant (WIPP) Site*. SAND89-7067. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24168.)

Bachman, G.O. 1987. *Karst in Evaporites in Southeastern New Mexico*. SAND86-7078. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24006.)

Beauheim, R.L. 1987. *Interpretations of Single-Well Hydraulic Tests Conducted at and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987*. SAND87-0039. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO27679.)

Beauheim, R.L., R.M. Roberts, T.F. Dale, M.D. Fort, and W.A. Stensrud. 1993. *Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report*. SAND92-0533. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO23378.)

Brinster, K.F. 1991. *Preliminary Geohydrologic Conceptual Model of the Los Medaños Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment*. SAND89-7147. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO27781.)

Brodsky, N.S. 1994. *Hydrostatic and Shear Consolidation Tests with Permeability Measurements on Waste Isolation Pilot Plant Crushed Salt*. SAND93-7058. Albuquerque, NM: Sandia National Laboratories.

Brodsky, N.S., D.H. Zeuch, and D.J. Holcomb. 1995. "Consolidation and Permeability of Crushed WIPP Salt in Hydrostatic and Triaxial Compression," *Rock Mechanics Proceedings of the 35th U.S. Symposium, University of Nevada, Reno, NV, June 5-7, 1995.* Eds. J.J.K. Daemen and R.A. Schultz. Brookfield, VT: A.A. Balkema. 497-502. (Copy on file in the SWCF as WPO22432.)

Brodsky, N.S., F.D. Hansen, and T.W. Pfeifle. 1996. "Properties of Dynamically Compacted WIPP Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996.* SAND96-0838C. Albuquerque, NM: Sandia National Laboratories. (Copy on file at the Technical Library, Sandia National Laboratories, Albuquerque, NM.)

Callahan, G.D., M.C. Loken, L.D. Hurtado, and F.D. Hansen. 1996. "Evaluation of Constitutive Models for Crushed Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996.* SAND96-0791C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO36449.)

Cauffman, T.L., A.M. LaVenue, and J.P. McCord. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume II: Data Base.* SAND89-7068/2. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO10551.)

Dale, T., and L.D. Hurtado. 1996. "WIPP Air-Intake Shaft Disturbed-Rock Zone Study," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996.* SAND96-1327C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

DOE (U.S. Department of Energy). 1995. *Waste Isolation Pilot Plant Sealing System Design Report.* DOE/WIPP-95-3117. Carlsbad, NM: U.S. Department of Energy, Waste Isolation Pilot Plant. (Copy on file in the SWCF as WPO29062.)

EPA (Environmental Protection Agency). 1996a. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Response to Comments Document for 40 CFR Part 194.* EPA 402-R-96-001. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM.)

EPA (Environmental Protection Agency). 1996b. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document for 40 CFR Part 194.* EPA 402-R-96-002. Washington, DC: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM.)

Gray, M.N. 1993. *OECD/NEA International Stripa Project. Overview Volume III: Engineered Barriers.* Stockholm, Sweden: SKB, Swedish Nuclear Fuel and Waste Management Company. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM as TD898.2 .G73 1993.)

Hansen, F.D., and E.H. Ahrens. 1996. "Large-Scale Dynamic Compaction of Natural Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND96-0792C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO39544.)

Hansen, F.D., E.H. Ahrens, A.W. Dennis, L.D. Hurtado, M.K. Knowles, J.R. Tillerson, T.W. Thompson, and D. Galbraith. 1996. "A Shaft Seal System for the Waste Isolation Pilot Plant," *Proceedings of SPECTRUM '96, Nuclear and Hazardous Waste Management, International Topical Meeting, American Nuclear Society/Department of Energy Conference, Seattle, WA, August 18-23, 1996*. SAND96-1100C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO39369.)

Haug, A., V.A. Kelley, A.M. LaVenue, and J.F. Pickens. 1987. *Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report*. SAND86-7167. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO28486.)

Hills, J.M. 1984. "Sedimentation, Tectonism, and Hydrocarbon Generation in [the] Delaware Basin, West Texas and Southeastern New Mexico," *American Association of Petroleum Geologists Bulletin*. Vol. 68, no. 3, 250-267. (Copy on file in the SWCF.)

Holt, R.M., and D.W. Powers. 1990. *Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant*. DOE-WIPP 90-051. Carlsbad, NM: Westinghouse Electric Corporation for U.S. Department of Energy. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM.)

Knowles, M.K., and C.L. Howard. 1996. "Field and Laboratory Testing of Seal Materials Proposed for the Waste Isolation Pilot Plant," *Proceedings of the Waste Management 1996 Symposium, Tucson, AZ, February 25-29, 1996*. SAND95-2082C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO30945.)

Knowles, M.K., D. Borns, J. Fredrich, D. Holcomb, R. Price, D. Zeuch, T. Dale, and R.S. Van Pelt. 1996. "Testing the Disturbed Zone Around a Rigid Inclusion in Salt," *4th Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND95-1151C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

Lambert, S.J. 1992. "Geochemistry of the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, U.S.A.," *Applied Geochemistry*. Vol. 7, no. 6, 513-531. (Copy on file in the SWCF as WPO26361.)

LaVenue, A.M., T.L. Cauffman, and J.F. Pickens. 1990. *Ground-Water Flow Modeling of the Culebra Dolomite. Volume I: Model Calibration*. SAND89-7068/1. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24085.)

Mercer, J.W. 1983. *Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area, Southeastern New Mexico*. Water-Resources Investigations Report 83-4016. Albuquerque, NM: U.S. Geological Survey, Water Resources Division. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM.) (Copy on file in the SWCF.)

Mercer, J.W., and B.R. Orr. 1979. *Interim Data Report on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico*. Water-Resources Investigations Report 79-98. Albuquerque, NM: U.S. Geological Survey, Water Resources Division. (Copy on file in the SWCF.)

Nowak, E.J., J.R. Tillerson, and T.M. Torres. 1990. *Initial Reference Seal System Design: Waste Isolation Pilot Plant*. SAND90-0355. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO23981.)

Pfeifle, T.W., F.D. Hansen, and M.K. Knowles. 1996. "Salt-Saturated Concrete Strength and Permeability," *4th Materials Engineering Conference, ASCE Materials Engineering Division, Washington, DC, November 11-18, 1996*. Albuquerque, NM: Sandia National Laboratories.)

Powers, D.W., S.J. Lambert, S-E. Shaffer, L.R. Hill, and W.D. Weart, eds. 1978. *Geological Characterization Report Waste Isolation Plant (WIPP) Site, Southeastern New Mexico*. SAND78-1596. Albuquerque, NM: Sandia National Laboratories. Vols. I-II. (Copy on file in the SWCF as WPO5448, WPO26829-26830.)

Saulnier, G.J., Jr., and J.D. Avis. 1988. *Interpretation of Hydraulic Tests Conducted in the Waste-Handling Shaft at the Waste Isolation Pilot Plant (WIPP) Site*. SAND88-7001. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24164.)

Stormont, J.C. 1984. *Plugging and Sealing Program for the Waste Isolation Pilot Plant (WIPP)*. SAND84-1057. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24698.)

Van Sambeek, L.L., D.D. Luo, M.S. Lin, W. Ostrowski, and D. Oyenuga. 1993. *Seal Design Alternatives Study*. SAND92-7340. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO23445.)

Vine, J.D. 1963. *Surface Geology of the Nash Draw Quadrangle, Eddy County, New Mexico*. Geological Survey Bulletin 1141-B. Washington, DC: U.S. Government Printing Office. (Copy on file in the SWCF as WPO39558.)

Wing, N.R., and G.W. Gee. 1994. "Quest for the Perfect Cap," *Civil Engineering*. Vol. 64, no. 10, 38-41. (Copy on file in the SWCF as WPO21158.)

Appendix A

Material Specification

Appendix A Abstract

This appendix specifies material characteristics for shaft seal system components designed for the Waste Isolation Pilot Plant. The shaft seal system will not be constructed for decades; however, if it were to be constructed in the near term, materials specified here could be placed in the shaft and meet performance specifications. A material specification is necessary today to establish a frame of reference for design and analysis activities and to provide a basis for seal material parameters. This document was used by three integrated working groups: (1) the architect/engineer for development of construction methods and supporting infrastructure, (2) fluid flow and structural analysis personnel for evaluation of seal system adequacy, and (3) technical staff to develop probability distribution functions for use in performance assessment. The architect/engineers provide design drawings, construction methods and schedules as appendices to the final shaft seal system design report, called the *Compliance Submittal Design Report*. Similarly, analyses of structural aspects of the design and fluid flow calculations comprise other appendices to the final design report. These products together are produced to demonstrate the adequacy of the shaft seal system to independent reviewers, the EPA, and stakeholders. It is recognized that actual placement of shaft seals is many years in the future, so design, planned construction method, and components will almost certainly change between now and the time that detailed construction specifications are prepared for the bidding process. Specifications provided here are likely to guide future work between now and the time of construction, perhaps benefiting from optimization studies, technological advancements, or experimental demonstrations.

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A1. INTRODUCTION

This appendix provides a body of technical information for each of the WIPP shaft seal system materials identified in the text of the *Compliance Submittal Design Report*. This material specification characterizes each seal material, establishes why it will function adequately, states briefly how each component will be placed, and quantifies expected characteristics, particularly permeability, pertinent to a WIPP-specific shaft seal design. Each material is first described from an engineering viewpoint, then appropriate properties are summarized in tables and figures which emphasize permeability parameter distribution functions used in performance calculations. Materials are discussed beyond limits normally found in conventional construction specifications. Descriptive elements focus on stringent shaft seal system requirements that are vital to regulatory compliance demonstration. Information normally contained in an engineering *performance specification* is included because more than one construction method, or even a completely different material, may function adequately. Content that would eventually be included contractually in *specifications for materials* or *specifications for workmanship* are not included in detail. The goal of these specifications is to substantiate why materials used in this seal system design will limit fluid flow and thereby adequately limit releases of hazardous constituents from the WIPP site at the regulatory boundary.

Figure A-1 is a schematic drawing of the proposed WIPP shaft sealing system. Design detail and other characteristics of the geologic, hydrologic and chemical setting are provided in the main body of the report, other appendices, and references. The four shafts will be entirely filled with dense materials possessing low permeability and other desirable engineering and economic attributes. Seal materials include concrete, clay, asphalt, and compacted salt. Other construction and fill materials include cementitious grout and earthen fill. The level of detail included for each material, and the emphasis of detail, vary among the materials. Concrete, clay, and asphalt are common construction materials used extensively in hydrologic applications. Their descriptions will be rather complete, and performance expectations will be drawn from the literature and site-specific references. Portland cement concrete is the most common structural material being proposed for the WIPP shaft seal system and its use has a long history. Considerable specific detail is provided for concrete because it is salt-saturated. Clay is used extensively in the seal system. Clay is often specified in industry as a construction material, and bentonitic clay has been widely specified as a low permeability liner for hazardous waste sites. Therefore, a considerable body of information is available for clay materials, particularly bentonite. Asphalt is a widely used paving and waterproofing material, so its specification here reflects industry practice. It has been used to seal shaft linings as a filler between the concrete and the surrounding rock, but has not been used as a full shaft seal component. Compaction and natural reconsolidation of crushed salt are uniquely applied here. Therefore, the crushed salt specification provides additional information on its constitutive behavior and sealing performance. Cementitious grout is also specified in some detail because it has been developed and tested for WIPP-specific applications and similar international waste programs. Earthen fill will be given only cursory specifications here because it has little impact on the shaft seal performance and placement to nominal standards is easily attained.

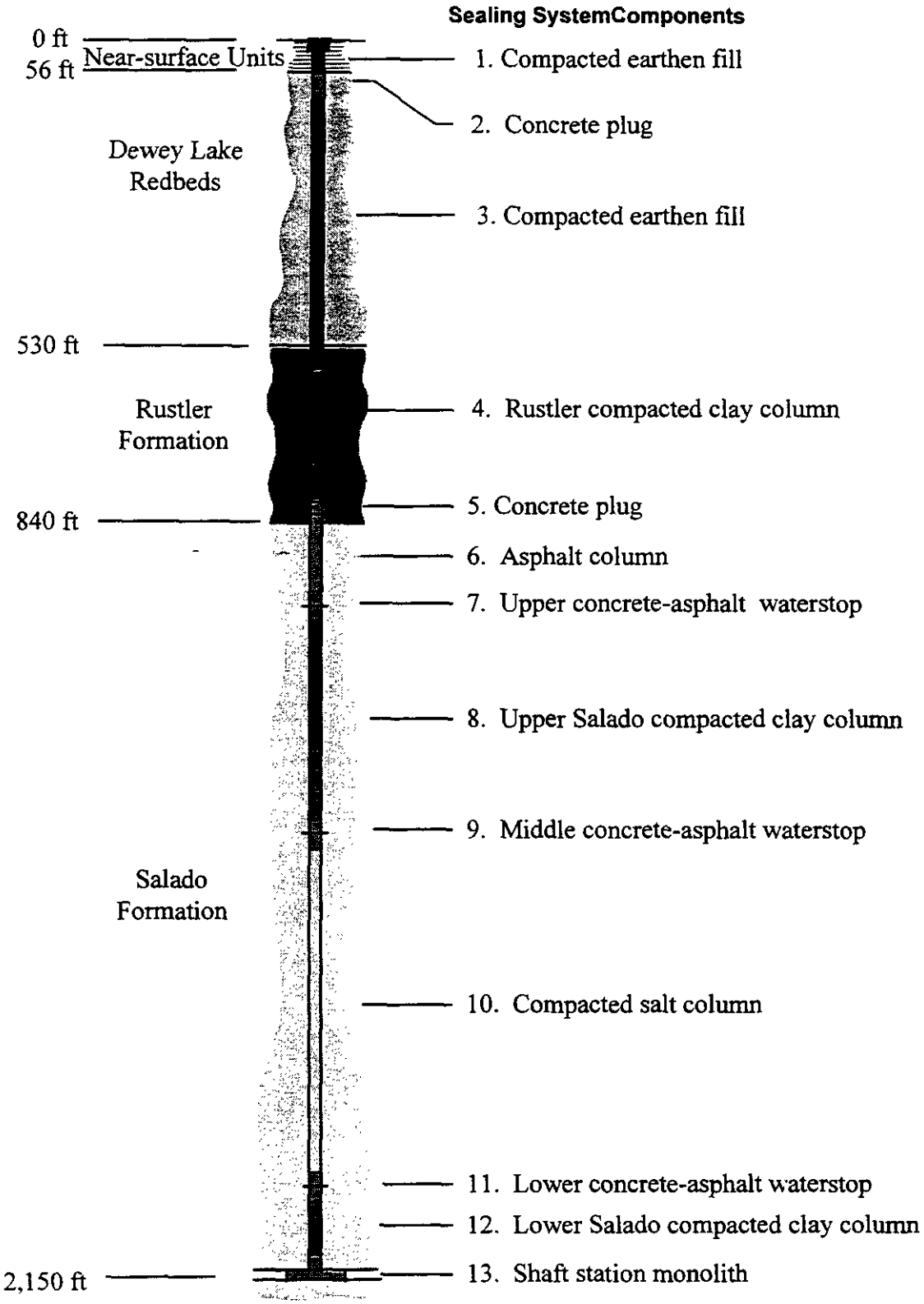

Figure A-1. Schematic of the WIPP shaft seal design.

Discussion of each material is divided into sections, which are described in the annotated bullets below:

- Functions

  A general summary of functions of specific seal components is presented. Each seal component must function within a natural setting, so design considerations embrace naturally occurring characteristics of the surrounding rock.

- Material Characteristics

  Constitution of the seal material is described and key physical, chemical, mechanical, hydrological, and thermal features are discussed.

- Construction

  A brief mention is made regarding construction, which is more thoroughly treated in Appendix B of the *Compliance Submittal Design Report*. Construction, as discussed in this section, is primarily concerned with proper placement of materials. A viable construction procedure that will attain placement specifications is identified, but such a specification does not preclude other potential methods from use when the seal system is eventually constructed.

- Performance Requirements

  Regulations to which the WIPP must comply do not provide quantitative specifications applicable to seal design. Performance of the WIPP repository is judged against potential releases of hazardous constituents at the regulatory boundary, which is a probabilistic calculation. To this end, probability distribution functions for permeabilities (referred to as PDFs) of each material have been derived for performance assessment of the WIPP system and are included within this subsection on performance requirements.

- Verification Methods

  It must be assured that seal materials placed in the shaft meet specifications. Both design and selection of materials reflect this principal concern. Assurance is provided by quality control procedures, quality assurance protocol, real-time testing, demonstrations of technology before construction, and personnel training. Materials and construction procedures are kept relatively simple, which creates robustness within the overall system. In addition, elements of the seal system often are extensive in length, and construction will require years to complete. If atypical placement of materials is detected, corrections can be implemented without impacting performance. These specifications limit in situ testing of seal material as it is constructed although, if it is later determined to be desirable, certain in situ tests can be amended in construction specifications. Invasive testing has the potential to compromise the material, add cost, and create logistic and safety problems. Conventional specifications are made for property testing and quality control.

- References

  These specifications draw on a wealth of information available for each material. Reference to literature values, existing data, anecdotal information, similar applications, laboratory and field testing, and other applicable supportive documentation is made.

A1.1 Sealing Strategy

The shaft seal system design is an integral part of compliance with 40 CFR 191. The EPA has also promulgated 40 CFR 194, entitled "Criteria for the Certification and Re-certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191," to which this design and these specifications are responsive. Other seal design requirements, such as State of New Mexico regulations, apply to stratigraphy above the Salado.

Compliance of the site with 40 CFR 191 will be determined in part by the ability of the seal system to limit migration of hazardous constituents to the regulatory boundary. Both natural and engineered barriers may combine to form the isolation system, with the shaft seal system forming an engineered barrier in a natural setting. Seal system materials possess high durability and compatibility with the host rock. All materials used in the shaft seal system are expected to maintain their integrity for very long periods. The system contains functional redundancy and uses differing materials to reduce uncertainty in performance. Some sealing components are used to retard fluid flow soon after placement, while other components are designed to function well beyond the regulatory period. International programs engaged in research and demonstration of sealant technology provide significant information on longevity of materials similar to those proposed for this shaft seal system (Gray, 1993). When this information is applied to the setting and context of the WIPP, there is strong evidence that the materials specified will maintain their positive attributes for defensibly long periods.

A1.2 Longevity

Longevity of materials is considered within the site geologic and hydrologic setting as summarized in the main body of this report and described in the Seal System Design Report (DOE, 1995). A major environmental advantage of the WIPP locality is an overall lack of groundwater to seal against. In terms of sealing the WIPP site, the stratigraphy can be conveniently divided into the Salado Formation and the superincumbent formations comprising primarily the Rustler Formation and the Dewey Lake Redbeds. The Salado Formation, composed mainly of evaporite sequences dominated by halite, is nearly impermeable. Transmissivity of engineering importance in the Salado Formation is lateral along anhydrite interbeds, basal clays, and fractured zones near underground openings. Neither the Dewey Lake Redbeds nor the Rustler Formation contains regionally productive sources of water, although seepage near the surface in the Exhaust Shaft has been observed. Permeability of materials placed in the Salado below the contact with the Rustler, and their effects on the surrounding disturbed rock zone, are the primary engineering properties of concern. Even though very little regional water is present in the geologic setting, the seal system reflects great concern for groundwater's potential influence on materials comprising the shaft seal system.

Shaft seal materials have been selected in part because of their exceptional durability. However, it is recognized that brine chemistry *could* impact engineered materials if conditions permitted. Highly concentrated saline solutions can, under severe circumstances, affect performance of cementitious materials and clay. Concrete has been shown to degrade under certain conditions, and clays can be more transmissive to brine than to potable water. Asphalt and compacted salt are essentially chemically inert to brine. Although stable in naturally occurring seeps such as those in the Santa Barbara Channel (California), asphalt can degrade

when subjected to ultraviolet light or through microbial activity. Brine would not chemically change the compacted salt column, but mechanical effects of pore pressure are of concern to reconsolidation. Mechanical influences of brine on the reconsolidating salt column are discussed in Sections 7 and 8 of the main report, which summarize Appendices D and C, respectively.

Because of limited volumes of brine, low hydraulic gradients, and low permeability materials, the geochemical setting will have little influence on shaft seal materials. Each material is durable, though the potential exists for degradation or alteration under extreme conditions. For example, the three major components of portland cement concrete, portlandite ($Ca(OH)_2$,) calcium-aluminate-hydrate (CAH) and calcium-silicate-hydrate (CSH), are not thermodynamically compatible with WIPP brines. If large quantities of high ionic strength brine were available and transport of mass was possible, degradation of cementitious phases would certainly occur. Such a localized phenomenon was observed on a construction joint in the liner of the Waste Handling Shaft at the WIPP site. Within the shaft seal system, however, the hydrologic setting does not support such a scenario. Locally brine will undoubtedly contact the surface of mass placements of concrete. A low hydrologic gradient will limit mass transport, although degradation of paste constituents is expected where brine contacts concrete.

Among longevity concerns, degradation of concrete is the most recognized. At this stage of the design, it is established that only small volumes of brine ever reach the concrete elements (see Section 8). Further analysis concerned with borehole plugging using cementitious materials shows that at least 100 pore volumes of brine in an open system would be needed to begin degradation processes. In a closed system, such as the hydrologic setting in the WIPP shafts, phase transformations create a degradation product of increased volume. Net volume increase owing to phase transformation in the absence of mass transport would decrease rather than increase permeability of concrete seal elements.

Mechanical and chemical stability of clays, in this case the emphasis is on bentonitic clay, is particularly favorable in the WIPP geochemical and hydrological environment. A compendium of recent work associated with the Stripa project in Sweden (Gray, 1993) provides field-scale testing results, supportive laboratory experimental data, and thermodynamic modeling that lead to a conclusion that negligible transformation of the bentonite structure will occur over the regulatory period of the WIPP. In fact, very little brine penetration into clay components is expected, based on intermediate-scale experiments at WIPP. Any wetting of bentonite will result in development of swelling pressure, a favorable situation that would accelerate return to a uniform stress state within the clay component.

Natural bentonite is a stable material that generally will not change significantly over a period of ten thousand years. Bentonitic clays have been widely used in field and laboratory experiments concerned with radioactive waste disposal. As noted by Gray (1993), three internal mechanisms, illitization, silicification and charge change, could affect sealing properties of bentonite. Illitization and silicification are thermally driven processes and, following discussion by Gray (1993), are not possible in the environment or time-frame of concern at the WIPP. The naturally occurring Wyoming bentonite which is the specified material for the WIPP shaft seal is well over a million years old. It is, therefore, highly unlikely that metamorphism of bentonite enters as a design concern.

Asphalt has existed for thousands of years as natural seeps. Longevity studies specific to DOE's Hanford site have utilized asphalt artifacts buried in ancient ceremonies to assess long-term stability (Wing and Gee, 1994). Asphalt used as a seal component deep in the shaft will inhabit a benign environment, devoid of ultraviolet light or an oxidizing atmosphere. Additional assurance against possible microbial degradation in asphalt elements is mitigated with addition of lime. For these reasons, it is thought that design characteristics of asphalt components will endure well beyond the regulatory period.

Materials being used to form the shaft seals are the same as those being suggested in the scientific and engineering literature as appropriate for sealing deep geologic repositories for radioactive wastes. This fact was noted during independent technical review. Durability or longevity of seal components is a primary concern for any long-term isolation system. Issues of possible degradation have been studied throughout the international community and within waste isolation programs in the USA. Specific degradation studies are not detailed in this document because longevity is one of the over-riding attributes of the materials selected and degradation is not perceived to be likely. However, it is acknowledged here that microbial degradation, seal material interaction, mineral transformation, such as silicification of bentonite, and effects of a thermal pulse from asphalt or hydrating concrete remain areas of continued study.

A2. MATERIAL SPECIFICATIONS

The WIPP shaft seal system plays an important role in meeting regulatory requirements. A combination of available, durable materials which can be emplaced with low permeability is proposed as the seal system. Components include mass concrete, asphalt waterstops sandwiched between concrete plugs, a column of asphalt, long columns of compacted clay, and a column of compacted crushed WIPP salt. The design is based on common materials and construction technologies that could be implemented using today's technology. In choosing materials, emphasis was given to permeability characteristics and mechanical properties. The function, constitution, construction, performance, and verification of each material are given in the following sections.

A2.1 Mass Concrete

Concrete has exceptionally low permeability and is widely used for hydraulic applications such as water storage tanks, water and sewer systems, and massive dams. Salt-saturated concrete has been used successfully as a seal material in potash and salt mining applications. Upon hydration, unfractured concrete is nearly impermeable, having a permeability less than 10^{-20} m^2. In addition, concrete is a primary structural material used for compression members in countless applications. Use of concrete as a shaft seal component takes advantage of its many attributes and the extensive documentation of its use.

This specification for mass concrete will discuss a special design mixture of a salt-saturated concrete called Salado Mass Concrete or SMC (Wakeley et al., 1995). Performance of SMC and similar salt-saturated mixtures is established and will be completely adequate for concrete applications within the WIPP shafts. Because concrete is such a widely used material, it has been written into specifications many times. Therefore, the specification for SMC contains

recognized standard practices, established test methods, quality controls, and other details that are not available at a similar level for other seal materials. Use of salt-saturated concrete, especially SMC, is backed by extensive laboratory and field studies that establish performance characteristics far exceeding requirements of the WIPP shaft seal system.

A2.1.1 Functions

The function of the concrete is to provide a durable component with small void volume, adequate structural compressive strength, and low permeability. Concrete components appear within the shaft seal system at the very bottom, the very top, and several locations in between where they provide a massive plug that fills the opening and a tight interface between the plug and host rock. In addition, concrete is a rigid material that will support overlying seal components while promoting natural healing processes within the salt disturbed rock zone (the DRZ is discussed further in Appendix D).

Concrete is one of the redundant components that protects the reconsolidating salt column. Since the salt column will achieve low permeabilities in fewer than 100 years (see Section 2.4.4 of this specification), concrete would no longer be needed after that time. For purposes of performance assessment calculations, a change in concrete permeability to degraded values is "allowed" to occur. However, concrete within the Salado Formation is likely to endure throughout the regulatory period with sustained engineering properties.

All concrete sealing elements, with the exception of a possible concrete cap, are unreinforced. In conventional civil engineering design, reinforcement is used to resist tensile stresses since concrete is weak in tension and reinforcement bar (rebar) balances tensile stresses in the steel with compressive stresses in concrete. However, concrete has exceptional compressive strength, and all the states of stress within the shaft will be dominated by compressive stress. Mass concrete, by definition, is related to any volume of concrete where heat of hydration is a design concern. SMC is tailored to minimize heat of hydration and overall differential temperature. An analysis of hydration heat distribution is included in Appendix D. Boundary conditions are favorable for reducing any possible thermally induced tensile cracking during the hydration process.

A2.1.2 Material Characteristics

Salt-saturated concrete contains sufficient salt as an aggregate to saturate hydration water with respect to NaCl. Salt-saturated concrete is required for all uses within the Salado Formation because fresh water concrete would dissolve part of the host rock. Dissolution would cause a poor bond and perhaps a more porous interface, at least initially.

Dry materials for SMC include cementitious materials, fine and coarse aggregates, and sodium chloride. Concrete mixture proportions of materials for one cubic yard of concrete appear in Table A-1.

Table A-1. Concrete Mixture Proportions

Material	lb/yd^3
Portland cement	278
Class F fly ash	207
Expansive cement	134
Fine aggregate	1292
Coarse aggregate	1592
Sodium chloride	88
Water	225

kg/m^3 = (lb/yd^3) * (0.59). Water : Cement Ratio is weight of water divided by all cementitious materials.

Table A-2 is a summary of standard specifications for concrete materials. Further discussion of each specification is presented in subsequent text, where additional specifications pertinent to particular concrete components are also given.

Table A-2. Standard Specifications for Concrete Materials

Material	Applicable Standard Tests and Specifications	Comments
Class H oilwell cement	American Petroleum Institute Specification 10	Chemical composition determined according to ASTM C 114
Class F fly ash	ASTM C 618, Standard Specification for Fly Ash	Composition and properties determined according to ASTM C 311
Expansive cement	Similar to ASTM C 845	Composition determined according to ASTM C 114
Salt	ASTM E 534, Chemical Analysis of Sodium Chloride	Batched as dry ingredient, not as an admixture
Coarse and fine aggregates	ASTM C 33, Standard Specification for Concrete Aggregates; ASTM C 294 and C 295 also applied	Moisture content determined by ASTM C 566

Portland cement shall conform to American Petroleum Institute (API) Specification 10 Class G or Class H. Additional requirements for the cement are that the fineness as determined according to ASTM C 204 shall not exceed 300 m^2/kg, and the cement must meet the requirement in ASTM C 150 for moderate heat of hydration.

Fly Ash shall conform to ASTM C 618, Class F, with the additional requirement that the percentage of Ca cannot exceed 10 %.

Expansive cement for shrinkage-compensation shall have properties so that, when used with portland cement, the resulting blend is shrinkage compensating by the mechanism described in ASTM C 845 for Type K cement. Additional requirements for chemical composition of the shrinkage compensating cement appear in Table A-3.

Table A-3. Chemical Composition of Expansive Cement

Chemical composition	Weight %
Magnesium oxide, max	1.0
Calcium oxide, min	38.0
Sulfur trioxide, max	28.0
Aluminum trioxide (AL_2O_3), min	7.0
Silicon dioxide, min	7.0
Insoluble residue, max	1.0
Loss on ignition, max	12.0

Sodium Chloride shall be of a technical grade consisting of a minimum of 99.0 % sodium chloride as determined according to ASTM E 534, and shall have a maximum particle size of 600 μm.

Aggregate proportions are reported here on saturated surface-dry basis. Specific gravity of coarse and fine aggregates used in these proportions were 2.55 and 2.58, respectively. Absorptions used in calculations were 2.25 (coarse) and 0.63 (fine) % by mass. Concrete mixture proportions will be adjusted to accommodate variations in the materials selected, especially differences in specific gravity and absorptions of aggregates. Fine aggregate shall consist of natural silica sand. Coarse aggregate shall consist of gravel. The quantity of flat and elongated particles in the separate size groups of coarse aggregates, as determined by ASTM D 4791, using a value of 3 for width-thickness ratio and length-width ratio, shall not exceed 25 % in any size group. Moisture in the fine and coarse aggregate shall not exceed 0.1 % when determined in accordance with ASTM C 566. Aggregates shall meet the requirements listed in Table A-4.

A2.1.3 Construction

Construction techniques include surface preparation of mass concrete and slickline (a drop pipe from the surface) placement at depth within the shaft. A batching and mixing operation on the surface will produce a wet mixture having initial temperatures not exceeding 20°C. Placement uses a tremie line, where the fresh concrete exits the slickline below the surface level of the concrete being placed. This procedure will minimize entrained air. Placement requires no vibration and, except for the large concrete monolith at the base of each shaft, no form work. No special curing is required for the concrete because its natural environment ensures retention of humidity and excellent hydration conditions. It is desired that each concrete pour be continuous, with the complete volume of each component placed without construction joints. However, no perceivable reduction in performance is anticipated if, for any reason,

concrete placement is interrupted. A free face or cold joint could allow lateral flow but would remain perpendicular to flow down the shaft. Further discussion of concrete construction is presented in Appendix B.

Table A-4. Requirements for Salado Mass Concrete Aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific Gravity (ASTM C 127, ASTM C 128)	2.65, max	2.80, max
Absorption (ASTM C 127, ASTM C 128)	1.5 percent, max	3.5 percent, max
Clay Lumps and Friable Particles (ASTM C 142)	3.0 percent, max	3.0 percent, max
Material Finer than 75-μm (No. 200) Sieve (ASTM C 117)	3.0 percent, max	1.0 percent, max
Organic Impurities (ASTM C 40)	No. 3, max	N/A
L.A. Abrasion (ASTM C 131, ASTM C 535)	N/A	50 percent, max
Petrographic Examination (ASTM C 295)	Carbonate mineral aggregates shall not be used	Carbonate rock aggregates shall not be used
Coal and Lignite, less than 2.00 specific gravity (ASTM C 123)	0.5 percent, max	0.5 percent, max

A2.1.4 Performance Requirements

Specifications of concrete properties include characteristics in the green state as well as the hardened state. Properties of hydrated concrete include conventional mechanical properties and projections of permeabilities over hundreds of years, a topic discussed at the end of this section. Table A-5 summarizes target properties for SMC. Attainment of these characteristics has been demonstrated (Wakeley et al., 1995). SMC has a strength of about 40 MPa at 28 days and continues to gain strength after that time, as is typical of hydrating cementitious materials. Concrete strength is naturally much greater than required for shaft seal elements because the state of stress within the shafts is compressional with little shear stress developing. In addition, compressive strength of SMC increases as confining pressure increases (Pfeifle et al., 1996). Volume stability of the SMC is also excellent, which assures a good bond with the salt.

Thermal and constitutive models for the SMC are described in Appendix D. Thermal properties are fit to laboratory data and used to calculate heat distribution during hydration. An isothermal creep law and an increasing modulus are used to represent the concrete in structural calculations. The resistance established by concrete to inward creep of the Salado Formation accelerates healing of microcracks in the salt. The state of stress impinging on concrete elements within the Salado Formation will approach a lithostatic condition.

Table A-5. Target Properties for Salado Mass Concrete

Property	Comment
Initial slump 10 ± 1.0 in. Slump at 2 hr 8 ± 1.5 in.	ASTM C 143, high slump needed for pumping and placement
Initial temperature ≤ 20°C	ASTM C 1064, using ice as part of mixing water
Air content ≤ 2.0%	ASTM C 231 (Type B meter), tight microstructure and higher strength
Self-leveling	Restrictions on underground placement may preclude vibration
No separately batched admixtures	Simple and reproducible operations
Adiabatic temperature rise ≤ 16°C at 28 days	To reduce thermally induced cracking
30 MPa (4500 psi) compressive strength	ASTM C 39, at 180 days after placement
Volume stability	ASTM C 157, length change between +0.05 and -0.02% through 180 days

Permeability of SMC is very low, consistent with most concretes. Owing to a favorable state of stress and isothermal conditions, the SMC will remain intact. Because little brine is available to alter concrete elements, minimal degradation is possible. Resistance to phase changes of salt-saturated concretes and mortars within the WIPP setting has been excellent. These favorable attributes combine to assure concrete elements within the Salado will remain structurally sound and possess very low permeability for exceedingly long periods.

Permeabilities of SMC and other salt-saturated concretes have been measured in Small-Scale Seal Performance Tests (SSSPT) and Plug Test Matrix (PTM) at the WIPP for a decade and are corroborated by laboratory measurements (e.g., Knowles and Howard, 1996; Pfeifle et al., 1996). From these tests, values and ranges of concrete permeability have been developed. For performance assessments calculations, permeability of SMC seal components is treated as a random variable defined by a log triangular distribution with a best estimator of 1.78×10^{-19} m^2 and lower and upper limits of 2.0×10^{-21} and 1.0×10^{-17} m^2, respectively.

The probability distribution function is shown in Figure A-2. Further, it is recognized that concrete function is required for only a relatively short-term period as salt reconsolidates. Concrete is expected to function adequately beyond its design life. For calculational expediency, a higher, very conservative permeability of 1.0×10^{-14} is assigned to concrete after 400 years. This abrupt change in permeability does not imply degradation, but rather reflects system redundancy and the fact that concrete is no longer relied on as a seal component.

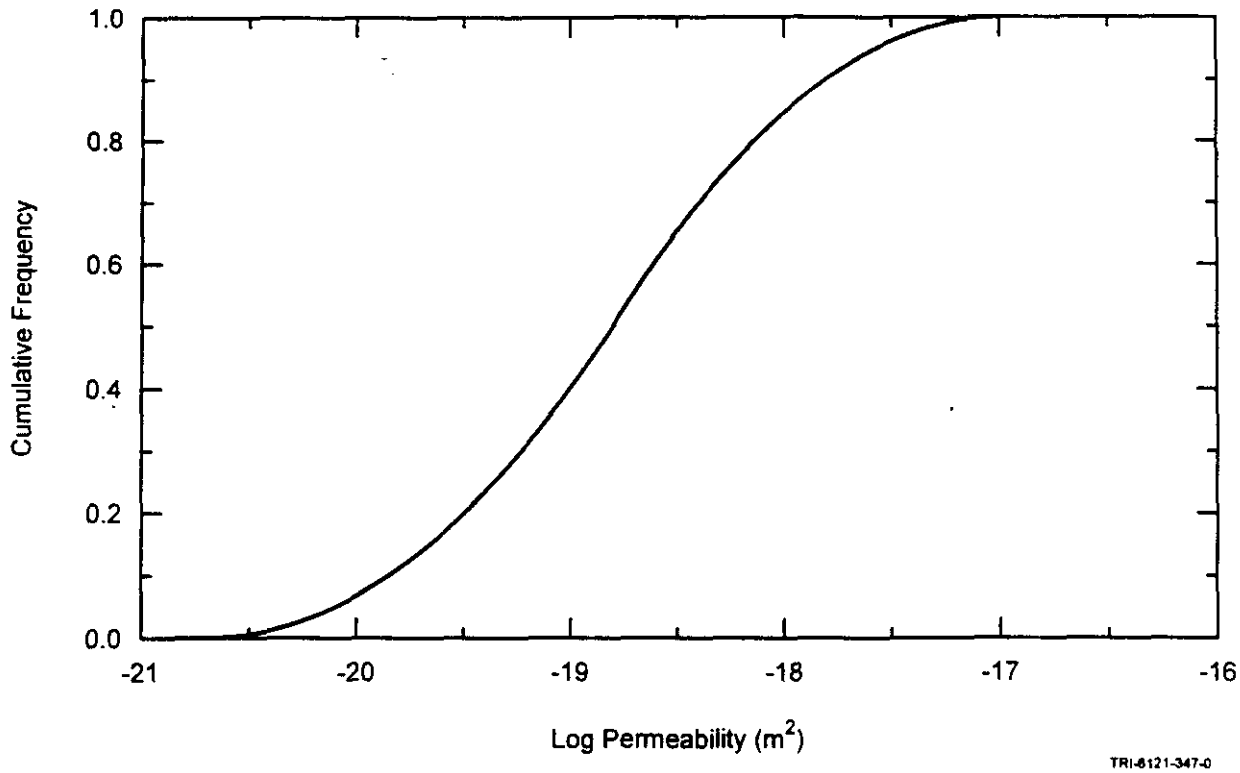

Figure A-2. Cumulative distribution function for SMC.

A2.1.5 Verification Methods

The concrete supplier shall perform the inspection and tests described below (Tables A-6 and A-7) and, based on the results of these inspections and tests, shall take appropriate action. The laboratory performing verification tests shall be on-site and shall conform with ASTM C 1077. Individuals who sample and test concrete or the constituents of concrete as required in this specification shall have demonstrated a knowledge and ability to perform the necessary test procedures equivalent to the ACI minimum guidelines for certification of Concrete Laboratory Testing Technicians, Grade I. The Buyer will inspect the laboratory, equipment, and test procedures for conformance with ASTM C 1077 prior to start of dry materials batching operations and prior to restarting operations.

A2.1.5.1 Fine Aggregate

(A) Grading. Dry materials will be sampled while the batch plant is operating; there shall be a sieve analysis and fineness modulus determination in accordance with ASTM C 136.

(B) Fineness Modulus Control Chart. Results for fineness modulus shall be grouped in sets of three consecutive tests, and the average and range of each group shall be plotted on a control chart. The upper and lower control limits for average shall be drawn 0.10 units above and below the target fineness modulus, and the upper control limit for range shall be 0.20 units above the target fineness modulus.

Table A-6. Test Methods Used for Measuring Concrete Properties During and After Mixing

Property	Test Method	Title
Slump	ASTM C 143	Slump of Portland Cement Concrete
Unit weight	ASTM C 138	Unit Weight, Yield, and Air Content (Gravimetric) of Concrete
Air content	ASTM C 231	Air Content of Freshly Mixed Concrete by the Pressure Method
Mixture temperature	ASTM C 1064	Temperature of Freshly Mixed Concrete

Table A-7. Test Methods Used for Measuring Properties of Hardened Concrete

Property	Test Method	Title
Compressive strength	ASTM C 39	Compressive Strength of Cylindrical Concrete Specimens
Modulus of elasticity	ASTM C 469	Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
Volume stability	ASTM C 157	Length Change of Hardened Cement Mortar and Concrete

(C) Corrective Action for Fine Aggregate Grading. When the amount passing any sieve is outside the specification limits, the fine aggregate shall be immediately resampled and retested. If there is another failure for any sieve, the fact shall be immediately reported to the Buyer. Whenever a point on the fineness modulus control chart, either for average or range, is beyond one of the control limits, the frequency of testing shall be doubled. If two consecutive points are beyond the control limits, the process shall be stopped and stock discarded if necessary.

(D) Moisture Content Testing. There shall be at least two tests for moisture content in accordance with ASTM C 566 during each 8-hour period of dry materials batch plant operation.

(E) Moisture Content Corrective Action. Whenever the moisture content of fine aggregate exceeds 0.1 % by weight, the fine aggregate shall be immediately resampled and retested. If there is another failure the batching shall be stopped.

A2.1.5.2 Coarse Aggregate

(A) Grading. Coarse aggregate shall be analyzed in accordance with ASTM C 136.

(B) Corrective Action for Grading. When the amount passing any sieve is outside the specification limits, the coarse aggregate shall be immediately resampled and retested. If the second sample fails on any sieve, that fact shall be reported to the Buyer. Where two consecutive averages of five tests are outside specification limits, the dry materials batch plant operation shall be stopped, and immediate steps shall be taken to correct the grading.

(C) Moisture Content Testing. There shall be at least two tests for moisture content in accordance with ASTM C 566 during each 8-hour period of dry materials batch plant operation.

(D) Moisture Content Corrective Action. Whenever the moisture content of coarse aggregate exceed 0.1 % by weight, the coarse aggregate shall be immediately resampled and retested. If there is another failure, batching shall be stopped.

A2.1.5.3 Batch-Plant Control

The measurement of all constituent materials including cementitious materials, each size of aggregate, and granular sodium chloride shall be continuously controlled. The aggregate batch weights shall be adjusted as necessary to compensate for their nonsaturated surface-dry condition.

A2.1.5.4 Concrete Products

Concrete products will be tested during preparation and after curing as summarized in Tables A-6 and A-7 for preparation and hydrated concrete, respectively.

A2.2 Compacted Clay

Compacted clays are commonly proposed as primary sealing materials for nuclear waste repositories and have been extensively investigated (e.g., Gray, 1993). Compacted clay as a shaft sealing component provides a barrier to brine and possibly to gas flow into or out of the repository and supports the shaft with a high density material to minimize subsidence. In the event that brine does contact the compacted clay columns, bentonitic clay can generate a beneficial swelling pressure. Swelling would increase internal supporting pressure on the shaft wall and accelerate healing of any disturbed rock zone. Wetted, swelling clay will seal fractures as it expands into available space and will ensure tightness between the clay seal component and the shaft walls.

A2.2.1 Functions

In general, clay is used to prevent fluid flow either down or up the shaft. In addition, clay will stabilize the shaft opening and provide a backstress within the Salado Formation that will enhance healing of microfractures in the disturbed rock. Bentonitic clays are specified for Components 4, 8, and 12. In addition to limiting brine migration down the shafts, a primary function of a compacted clay seal through the Rustler Formation (Component 4) is to provide separation of water bearing units. The primary function of the upper Salado clay column (Component 8) is to limit groundwater flow down the shaft, thereby adding assurance that the reconsolidating salt column is protected. The lower Salado compacted clay column (Component 12) will act as a barrier to brine and possibly to gas flow (see construction alternatives in Appendix B) soon after placement and remain a barrier throughout the regulatory period.

A2.2.2 Material Characteristics

The Rustler and Salado compacted clay columns will be constructed of a commercial well-sealing grade sodium bentonite blocks compacted to between 1.8 and 2.0 g/cm^3. An extensive experimental data base exists for the permeability of sodium bentonites under a variety

of conditions. Many other properties of sodium bentonite, such as strength, stiffness, and chemical stability also have been thoroughly investigated. Advantages of clays for sealing purposes include low permeability, demonstrated longevity in many types of natural environments, deformability, sorptive capacity, and demonstrated successful utilization in practice for a variety of sealing purposes.

A variety of clays could be considered for WIPP sealing purposes. For WIPP, as for most if not all nuclear waste repository projects, bentonite has been and continues to be a prime candidate as the clay sealing material. Bentonite clay is chosen here because of its overwhelming positive sealing characteristics. Bentonite is a highly plastic swelling clay material (e.g., Mitchell, 1993), consisting predominantly of smectite minerals (e.g., IAEA, 1990). Montmorillonite, the predominant smectite mineral in most bentonites, has the typical plate-like structure characteristic of most clay minerals.

The composition of a typical commercially available sodium bentonite (e.g. Volclay, granular sodium bentonite) contains over 90% montmorillonite and small portions of feldspar, biotite, selenite, etc. A typical sodium bentonite has the chemical composition summarized in Table A-8 (American Colloid Company, 1995). This chemical composition is close to that reported for MX-80 which was used successfully in the Stripa experiments (Gray, 1993). Sodium bentonite has a tri-layer expanding mineral structure of approximately $(Al\ Fe_{1.67}\ Mg_{0.33})\ Si_4O_{10}\ (OH_2)\ Na^{+}Ca^{++}{}_{0.33}$. Specific gravity of the sodium bentonite is about 2.5. The dry bulk density of granular bentonite is about 1.04 g/cm^3.

Densely compacted bentonite (of the order of 1.75g/cm^3), when confined, can generate a swelling pressure up to 20 MPa when permeated by water (IAEA, 1990). The magnitude of the swelling pressure generated depends on the chemistry of the permeating water. Laboratory and field measurements suggest that the bentonite specified for shaft seal materials in the Salado may achieve swell pressures of 3 to 4 MPa, and likely substantially less. Swelling pressure in the bentonite column is not expected to be appreciable because little contact with brine fluids is conceivable. Further considerations of potential swelling of bentonite within the Rustler Formation may be appropriate, however.

Table A-8. Representative Bentonite Composition.

Chemical Compound	Weight %
SiO_2	63.0
Al_2O_3	21.1
Fe_2O_3	3.0
FeO	0.4
MgO	2.7
Na_2O	2.6
CaO	0.7
H_2O	5.6
Trace Elements	0.7

Mixtures of bentonite and water can range in rheological characteristics from a virtually Newtonian fluid to a stiff solid, depending on water content. Bentonite can form stiff seals at low moisture content, and can penetrate fractures and cracks when it has a higher water content. Under the latter conditions it can fill void space in the seal itself and disturbed rock zones. Bentonite with dry density of 1.75 g/cm^3 has a cohesion of 5-50 kPa, and a friction angle of 5 to 15° (IAEA, 1990). At density greater than 1.6-1.7 g/cm^3, swelling pressure of bentonite is less affected by the salinity of groundwater providing better chemical and physical stabilities.

A2.2.3 Construction

Seal performance within the Salado Formation is far more important to regulatory compliance than is performance of earthen fill in the overlying formations. Three potential construction methods might be used to place clay in the shaft, as discussed in Appendix B. Construction of bentonite clay components specifies block assembly procedures demonstrated successfully at the WIPP site (Knowles and Howard, 1996) and in a considerable body of work by Roland Pusch (see summary in Gray, 1993). To achieve low permeabilities, dry density of the bentonite blocks should be about 2.0 g/cm^3, although a range of densities is discussed in Section 2.2.4. A high density of clay components is also desirable to carry the weight of overlying seal material effectively and to minimize subsidence.

Placement of clay in the shaft is one area of construction that might be made more cost and time effective through optimization studies. An option to construct clay columns using dynamic compaction will likely prove to be efficient, so it is specified for earthen fill in the Dewey Lake Redbeds (as discussed later) and may prove to be an acceptable placement method for other components. Dynamic compaction would use equipment developed for placement of crushed salt. The Canadian nuclear waste program has conducted extensive testing, both in situ and in large scale laboratory compaction of clay-based barrier materials with dynamic hydraulically powered impact hammers (e.g., Kjartanson et al, 1992). The Swedish program similarly has investigated field compaction of bentonite-based tunnel backfill by means of plate vibrators (e.g., Nilsson, 1985). Both studies demonstrated the feasibility of in situ compaction of bentonite-based materials to a high density. Near surface, conventional compaction methods will be used because insufficient space remains for dynamic compaction using the multi-deck work stage.

A2.2.4 Performance Requirements

The proven characteristics of bentonite assure attainment of very low permeability seals. It is recognized that the local environment contributes to the behavior of compacted clay components. Long-term material stability is a highly desired sealing attribute. Clay components located in brine environments will have to resist cation exchange and material structure alteration. Clay is geochemically mature, reducing likelihood of alteration and imbibition of brine is limited to isolated areas. Compacted clay is designed to withstand possible pressure gradients and to resist erosion and channeling that could conceivably lead to groundwater flow through the seal. Compacted clay seal components support the shaft walls and promote healing of the salt DRZ. Volume expansion or swelling would accelerate healing in the salt. A barrier to gas flow could be constructed if moisture content of approximately 85% of saturation could be achieved.

Permeability of bentonite is inversely correlated to dry density. Figure A-3 plots bentonite permeability as a function of reported sample density for sodium bentonite samples. The permeability ranges from approximately 1×10^{-21} to 1×10^{-17} m^2. In all cases, the data in Figure A-3 are representative of low ionic strength permeant waters. Data provided in this figure are limited to sodium bentonite and bentonite/sand mixtures with clay content greater than or equal to 50 %. Cheung et al. (1987) report that in bentonite/sand mixtures, sand acts as an inert fraction which does not alter the permeability of the mixture from that of a 100 % bentonite sample at the same equivalent dry density. Also included in Figure A-3 are the three point estimates of permeability at dry densities of 1.4, 1.8, and 2.1 g/cm^3 provided by Jaak Daemen of the University of Nevada, Reno, who is actively engaged in WIPP-specific bentonite testing.

A series of in situ tests (SSSPTs) that evaluated compacted bentonite as a sealing material at the WIPP site corroborate data shown in Figure A-3. Test Series D tested two 100 % bentonite seals in vertical boreholes within the Salado Formation at the repository horizon. The diameter of each seal was 0.91 m, and the length of each seal was 0.91 m. Cores of the two bentonite seals had initial dry densities of 1.8 and 2.0 g/cm^3. Pressure differentials of 0.72 and 0.32 MPa were maintained across the bentonite seals with a brine reservoir on the upstream (bottom) of the seals for several years.

Over the course of the seal test, no visible brine was observed at the downstream end of the seals. Upon decommissioning the SSSPT, brine penetration was found to be only 15 cm. Determination of the absolute permeability of the bentonite seal was not precise; however, a bounding calculation of 1×10^{-19} m^2 was made by Knowles and Howard (1996).

Beginning with a specified dry density of 1.8 to 2.0 g/cm^3 and Figure A-3, a distribution function for clay permeability was developed and is provided in Figure A-4. Parameter distribution reflects some conservative assumptions pertaining to WIPP seal applications. The following provide rationale behind the distribution presented in Figure A-4.

1. A practical minimum for the distribution can be specified at 1×10^{-21} m^2.
2. If effective dry density of the bentonite emplaced in the seals only varies from 1.8 to 2.0 g/cm^3, then a maximum expected permeability can be extrapolated from Figure A-3 as 1×10^{-19} m^2.
3. Uncertainty exists in being able to place massive columns of bentonite to design specifications. To address this uncertainty in a conservative manner, it is assumed that the compacted clay be placed at a dry density as low as 1.6 g/cm^3. At 1.6 g/cm^3, the maximum permeability for the clay would be approximately 5×10^{-19} m^2. Therefore, neglecting salinity effects, a range of permeability from 1×10^{-21} to 5×10^{-19} m^2 with a best estimate of less than 1×10^{-19} m^2 could be reasonably defined (assuming a best estimate emplacement density of 1.8 g/cm^3). It could be argued, based on Figure A-3, that a best estimate could be as low as 2×10^{-20} m^2.

Salinity increases bentonite permeability; however, these effects are greatly reduced at the densities specified for the shaft seal. At seawater salinity, Pusch et al. (1989) report the effects on permeability could be as much as a factor of 5 (one-half order of magnitude). To account for salinity effects in a conservative manner, the maximum permeability is increased from 5×10^{-19} to 5×10^{-18} m^2. The best estimate permeability is increased by one-half order of magnitude to

5×10^{-19} m^2. The lower limit is held at 1×10^{-21} m^2. Because salinity effects are greatest at lower densities, the maximum is adjusted one full order of magnitude while the best estimate (assumed to reside at a density of 1.8 g/cm^3) is adjusted one-half of an order.

The four arguments presented above give rise to the permeability cumulative frequency distribution plotted in Figure A-4, which summarizes the performance specification for bentonite columns.

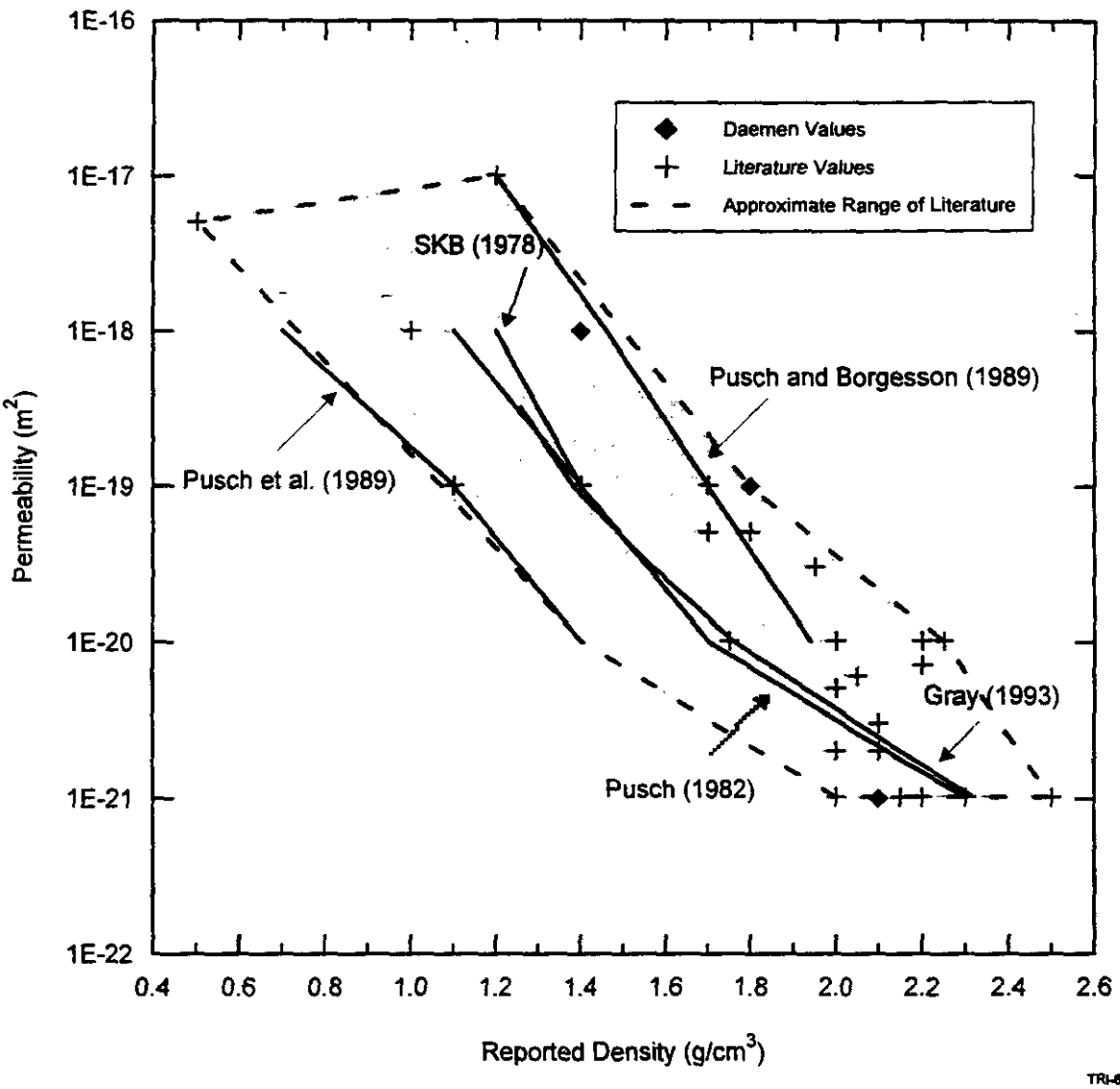

Figure A-3. Sodium bentonite permeability versus density.

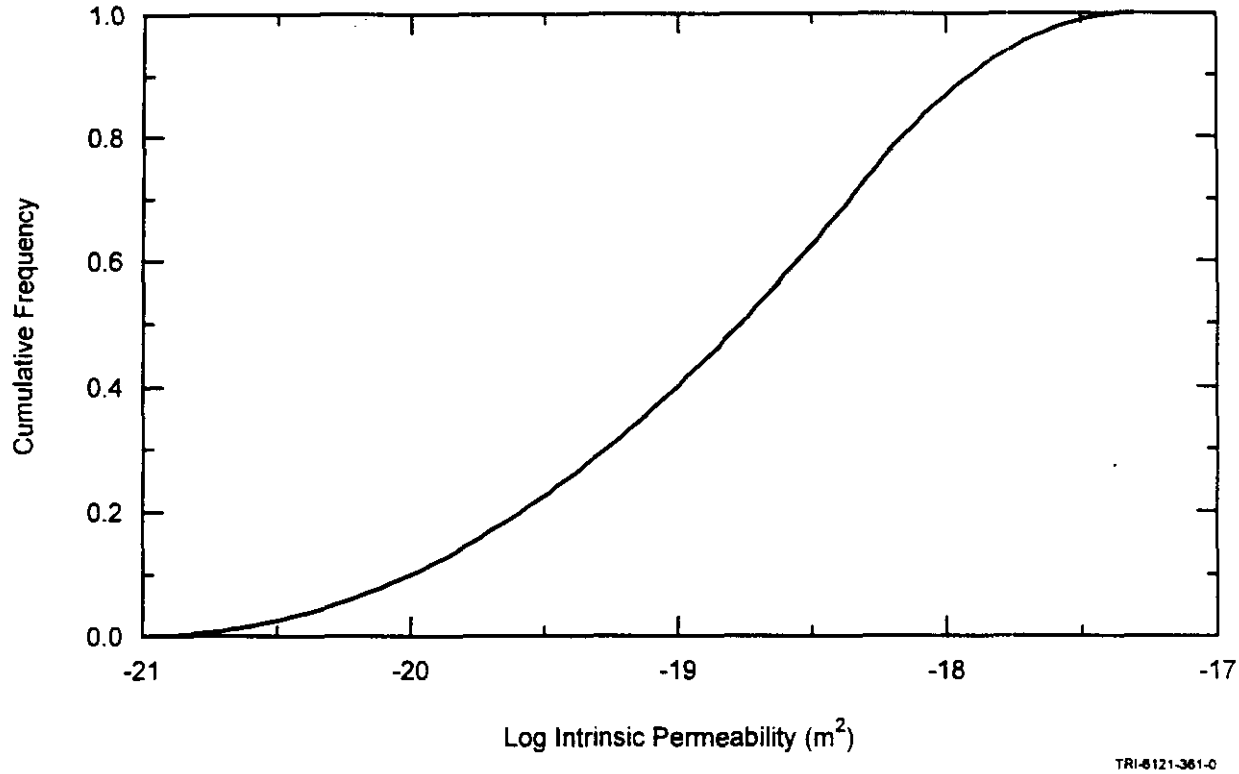

Figure A-4. Cumulative frequency distribution for compacted bentonite.

A2.2.5 Verification Methods

Verification of specified properties such as density, moisture content or strength of compacted clay seals can be determined by direct access during construction. However, indirect methods are preferred because certain measurements, such as permeability, are likely to be time consuming and invasive. Methods used to verify the quality of emplaced seals will include quality of block production and field measurements of density. As a minimum, standard quality control procedures recommended for compaction operations will be implemented including visual observation, in situ density measurements, and moisture content measurements. Visual observation accompanied by detailed record keeping will assure design procedures are being followed. In situ testing will confirm design objectives are accomplished in the field.

Density measurements of compacted clay shall follow standard procedures such as ASTM D 1556, D 2167, and D 2922. The moisture content of clay blocks shall be calculated based on the water added during mixing and can be confirmed by following ASTM Standard procedures D 2216 and D 3017. It is probable that verification procedures will require modifications to be applicable within the shaft. As a minimum, laboratory testing to certify the above referenced quality control measures will be performed to assure that the field measurements provide reliable results.

A2.3 Asphalt Components

Asphalt is used to prevent water migration down the shaft in two ways: an asphalt column bridging the Rustler/Salado contact and a "waterstop" sandwiched between concrete plugs at three locations within the Salado Formation, two above the salt column and one below the salt column. An asphalt mastic mix (AMM) that contains aggregate is specified for the column while the specification for the waterstop layer is pure asphalt.

Asphalt is a widely used construction material with many desirable properties. Asphalt is a strong cement, is readily adhesive, highly waterproof, and durable. Furthermore, it is a plastic substance that provides controlled flexibility to mixtures of mineral aggregates with which it is usually combined. It is highly resistant to most acids, salts, and alkalis. A number of asphalts and asphalt mixes are available that cover a wide range of viscoelastic properties which allows the properties of the mixture to be designed for a wide range of requirements for each application. These properties are well suited to the requirements of the WIPP shaft seal system.

A2.3.1 Functions

The generic purpose of asphalt seal components above the salt column is to eliminate water migration downward. The asphalt waterstops above the salt column are designed to intersect the DRZ and limit fluid flow. Asphalt is not the lone component preventing flow of brine downward; it functions in tandem with concrete and a compacted clay column. Waterstop Component # 11 located below the salt column would naturally limit upward flow of brine or gas. Concrete abutting the asphalt waterstops provides a rigid element that creates a backstress upon the inward creeping salt, promoting healing within the DRZ. Asphalt is included in the WIPP shaft seal system to reduce uncertainty of system performance by providing redundancy of function while using an alternative material type. The combination of shaft seal components restricts fluid flow up or down to allow time for the salt column to reconsolidate and form a natural fluid-tight seal.

The physical and thermal attributes of asphalt combine to reduce fluid flow processes. The placement fluidity permits asphalt to flow into uneven interstices or fractures along the shaft wall. Asphalt will self-level into a nearly voidless mass. As it cools, the asphalt will eventually cease flowing. The elevated temperature and thermal mass of the asphalt will enhance creep deformation of the salt and promote healing of the DRZ surrounding the shaft. Asphalt adheres tightly to most materials, eliminating flow along the interface between the seal material and the surrounding rock.

A2.3.2 Material Characteristics

The asphalt column specified for the WIPP seal system is an AMM commonly used for hydraulic structures. The AMM is a mixture of asphalt, sand, and hydrated lime. The asphalt content of AMM is higher than those used in typical hot mix asphalt concrete (pavements). High asphalt contents (10-20% by weight) and fine, well-graded aggregate (sand and mineral fillers) are used to obtain a near voidless mix. A low void content ensures a material with extremely low water permeability because there are a minimum number of connected pathways for brine migration.

A number of different asphaltic construction materials, including hot mix asphalt concrete (HMAC), neat asphalt, and AMMs, were evaluated for use in the WIPP seal design. HMAC was eliminated because of construction difficulty that might have led to questionable performance. An AMM is selected as a preferred alternative for the asphalt columns because it has economic and performance advantages over the other asphaltic options. Aggregate and mineral fines in the AMM increase rigidity and strength of the asphalt seal component, thereby enhancing the potential to heal the DRZ and reducing shrinkage relative to neat asphalt.

Viscosity of the AMM is an important physical property affecting construction and performance. The AMM is designed to have low enough viscosity to be pumpable at application temperatures and able to flow readily into voids. High viscosity of the AMM at operating temperatures prevents long-term flow, although none is expected. Hydrated lime is included in the mix design to increase the stability of the material, decrease moisture susceptibility, and act as an anti-microbial agent. Table A-9 details the mix design specifications for the AMM.

The asphalt used in the waterstop is AR-4000, a graded asphalt of intermediate viscosity. The waterstop uses pure, or neat, asphalt because it is a relatively small volume when compared to the column.

A2.3.3 Construction

Construction of asphalt seal components can be accomplished using a slickline process where the molten material is effectively pumped into the shaft. The AMM will be mixed at ground level in a pug mill at approximately 180°C. At this temperature the material is readily pourable. The AMM will be slicklined and placed using a heated and insulated tremie line. The AMM will easily flow into irregularities in the surface of the shaft or open fractures until the AMM cools. After cooling, flow into surface irregularities in the shaft and DRZ will slow considerably because of the sand and mineral filler components in the AMM and the temperature dependence of the viscosity of the asphalt. AMM requires no compaction in construction. Neat asphalt will be placed in a similar fashion.

The technology to pump AMM is available as described in the construction procedures in Appendix B. One potential problem with this method of construction is ensuring that the slickline remains heated throughout the construction phase. Impedance heating (a current construction technique) can be used to ensure the pipe remains at temperatures sufficient to promote flow. The lower section (say 10 m) of the pipe may not need to be heated, and it may not be desirable to heat it as it is routinely immersed in the molten asphalt during construction to minimize air entrainment. Construction using large volumes of hot asphalt would be facilitated by placement in sections. After several meters of asphalt are placed, the slickline would be retracted by two lengths of pipe and pumping resumed. Once installed, the asphalt components will cool; the column will require several months to approach ambient conditions. Calculations of cooling times and plots of isotherms for the asphalt column are given in Appendix D. It should be noted that a thermal pulse into the surrounding rock salt could produce positive rock mechanics conditions. Fractures will heal much faster owing to thermally activated dislocation motion and diffusion. Salt itself will creep inward at a much greater rate as well.

Table A-9. Asphalt Component Specifications

AMM Composition:	20 wt% asphalt (AR-4000 graded asphalt) 70 wt% aggregate (silicate sand) 10 wt% hydrated lime	
Aggregate (% passing by weight)		
US Sieve Size		Specification Limits
2.36 mm	(No. 8)	100
1.18 mm	(No. 16)	90
600	(No. 30)	55-75
300	(No. 50)	35-50
150	(No. 100)	15-30
75	(No. 200)	5-15

Mineral Filler: Hydrated Lime Chemical Composition:
Total active lime content (% by weight) ..... min. 90.0%
Unhydrated lime weight (% by weight CaO) ..... max. 5.0%
Free water (% by weight H_2O) ..... max. 4.0%

Residue Analysis:
Residue retained on No. 6 sieve ..... max. 0.1%
Residue retained on No. 30 sieve ..... max. 3.0%

A2.3.4 Performance Requirements

Asphalt components are required to endure for about 100 years as an interim seal while the compacted salt component reconsolidates to create a very low permeability seal component. Since asphalt will not be subjected to ultraviolet light or an oxidizing environment, it is expected to provide an effective brine seal for several centuries. Air voids should be less than 2% to ensure low permeability. Asphalt mixtures do not become measurably permeable to water until voids approach 8% (Brown, 1990).

At Hanford, experiments are ongoing on the development of a passive surface barrier designed to isolate wastes (in this case to prevent downward flux of water and upward flux of gases) for 1000 years with no maintenance. The surface barrier uses asphalt as one of many horizontal components because low-air-void, high-asphalt-content materials are noted for low permeability and improved mechanically stable compositions. The design objective of this asphalt concrete was to limit infiltration to 1.6×10^{-9} cm/s (1.6×10^{-11} m/s, or for fresh water, an intrinsic permeability of 1.6×10^{-18} m^2). The asphalt component of the barrier is composed of a 15 cm layer of asphaltic concrete overlain with a 5-mm layer of fluid-applied asphalt. The reported hydraulic conductivity of the asphalt concrete is estimated to be 1×10^{-9} m/s (equivalent

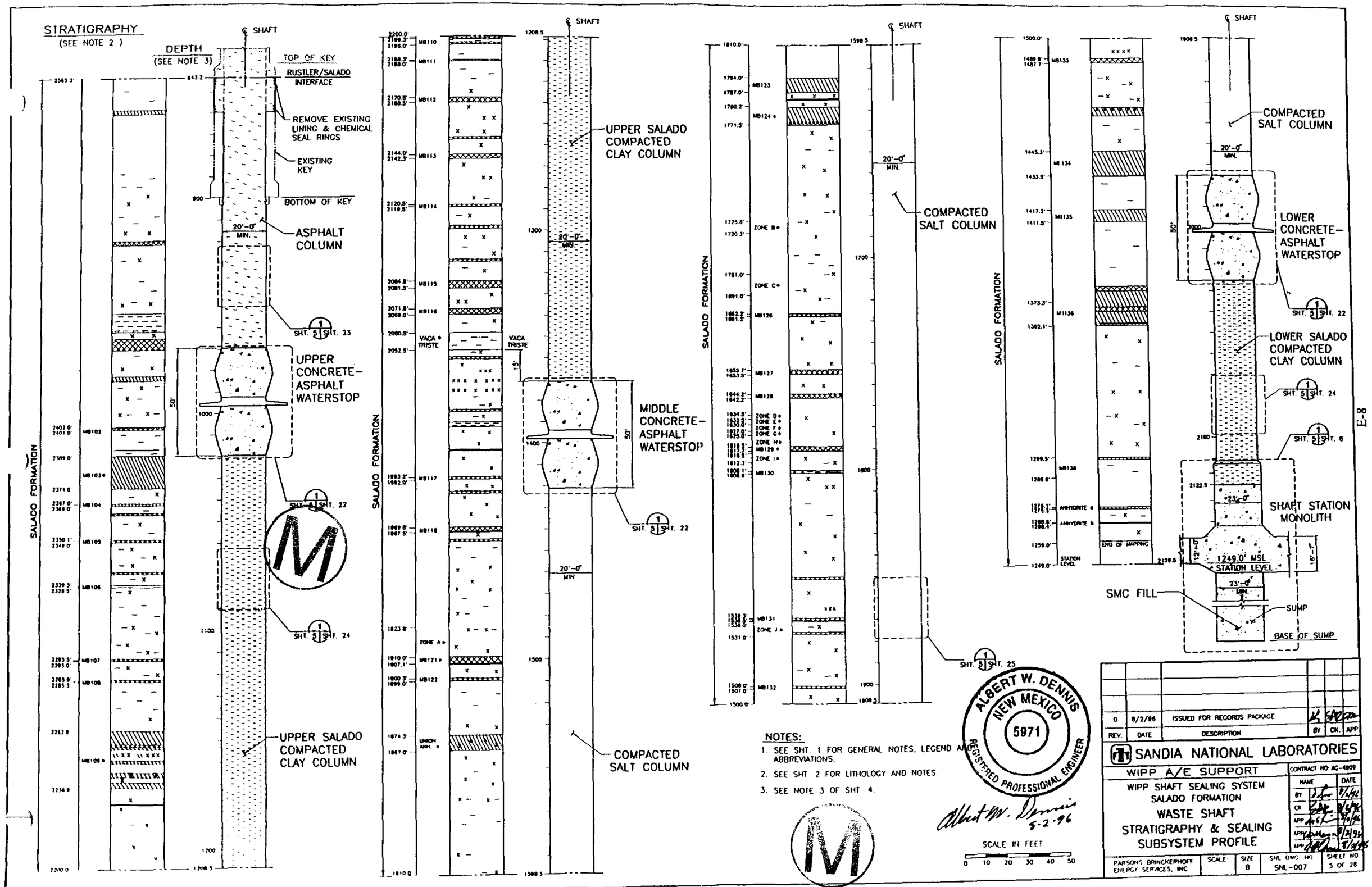
STRATIGRAPHY
(SEE NOTE 2)
DEPTH
(SEE NOTE 3)
SHAFT
TOP OF KEY
RUSTLER/SALADO INTERFACE
REMOVE EXISTING LINING & CHEMICAL SEAL RINGS
EXISTING KEY
BOTTOM OF KEY
ASPHALT COLUMN
20'-0" MIN.
SHT. 5 SHT. 23
UPPER CONCRETE-ASPHALT WATERSTOP
SHT. 5 SHT. 22
SHT. 5 SHT. 24
UPPER SALADO COMPACTED CLAY COLUMN
SALADO FORMATION
UPPER SALADO COMPACTED CLAY COLUMN
MIDDLE CONCRETE-ASPHALT WATERSTOP
COMPACTED SALT COLUMN
VACA TRISTE
COMPACTED SALT COLUMN
SHT. 5 SHT. 25
LOWER CONCRETE-ASPHALT WATERSTOP
SHT. 5 SHT. 22
LOWER SALADO COMPACTED CLAY COLUMN
SHT. 5 SHT. 24
SHT. 5 SHT. 6
SHAFT STATION MONOLITH
1249.0' MSL STATION LEVEL
SMC FILL
SUMP
BASE OF SUMP
END OF MAPPING
STATION LEVEL
ANHYDRITE a
ANHYDRITE b
ZONE A
ZONE B
ZONE C
ZONE D
ZONE E
ZONE F
ZONE G
ZONE H
ZONE I
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UNION ANH. b
NOTES:
1. SEE SHT. 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS.
2. SEE SHT 2 FOR LITHOLOGY AND NOTES.
3. SEE NOTE 3 OF SHT 4.
ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER
Albert W. Dennis 5-2-96
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0 8/2/96 ISSUED FOR RECORDS PACKAGE
REV. DATE DESCRIPTION BY CK. APP
SANDIA NATIONAL LABORATORIES
WIPP A/E SUPPORT
WIPP SHAFT SEALING SYSTEM
SALADO FORMATION
WASTE SHAFT
STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
CONTRACT NO: AC-4909
NAME DATE
BY
CK
APP
PARSONS BRINCKERHOFF ENERGY SERVICES, INC
SCALE
SIZE B
SNL DWG NO SNL-007
SHEET NO 5 OF 28

to an intrinsic permeability of approximately 1×10^{-16} m^2 assuming fresh water). Myers and Duranceau (1994) report that the hydraulic conductivity of fluid-applied asphalt is estimated to be 1.0×10^{-11} to 1.0×10^{-10} cm/s (equivalent to an intrinsic permeability of approximately 1.0×10^{-20} to 1.0×10^{-19} m^2 assuming fresh water).

Consideration of published values results in a lowest practical permeability of 1×10^{-21} m^2. The upper limit of the asphalt seal permeability is assumed to be 1×10^{-18} m^2. Intrinsic permeability of the asphalt column is defined as a log triangular distributed parameter, with a best estimate value of 1×10^{-20} m^2, a minimum value of 1×10^{-21} m^2, and a maximum value of 1×10^{-18} m^2, as shown in Figure A-5. It is recognized that the halite DRZ in the uppermost portion of the Salado Formation is not likely to heal because creep of salt is relatively slow.

These values are used in performance assessment of regulatory compliance analyses and in fluid flow calculations (Appendix C) pertaining to seal system functional evaluation. Other calculations pertaining to rock mechanics and structural considerations of asphalt elements are discussed in Appendix D.

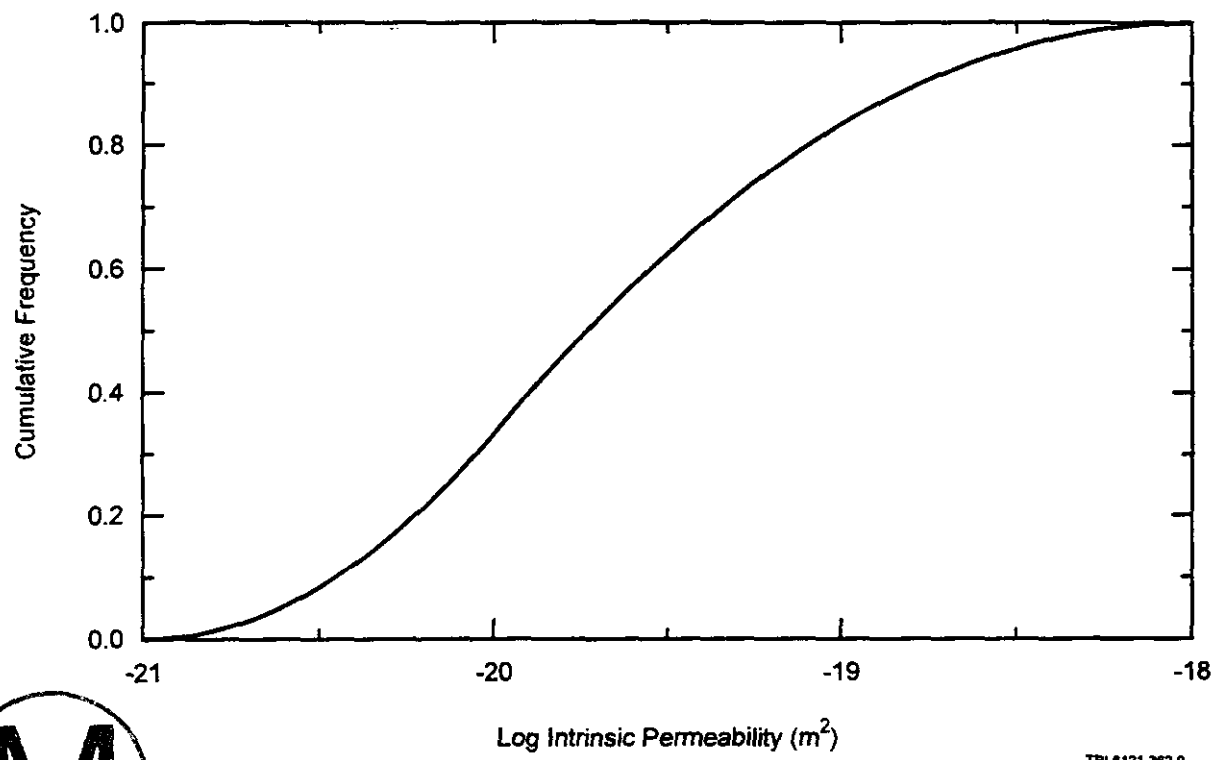

Figure A-5. Asphalt permeability cumulative frequency distribution function.

A2.3.5 Verification Methods

Viscosity of the AMM must be low enough for easy delivery through a heated slickline. Sufficient text book information is available to assure performance of the asphalt component; however, laboratory validation tests may be desirable before installation. There are no plans to test asphalt components after they are placed. With that in mind, some general tests identified below would add quantitative documentation to expected performance values and have direct application to WIPP. The types and objectives of the verification tests are:

Mix Design. A standard mix design which evaluates a combination of asphalt and aggregate mixtures would quantify density, air voids, viscosity, and permeability. Although the specified mixture will function adequately, studies could optimize the mix design.

Viscoelastic Properties at Service Temperatures. Viscoelastic properties over the range of expected service temperatures would refine the rheological model.

Accelerated Aging Analysis. Asphalt longevity issues could be further addressed by using the approach detailed in PNL-Report 9336 (Freeman and Romine, 1994).

Brine Susceptibility Analysis. The presumed inert nature of the asphalt mix can be demonstrated through exposure to groundwater brine solutions found in the Salado Formation. Potential for degradation will be characterized by monitoring the presence of asphalt degradation products in WIPP brine or brine simulant as a function of time. Effects on hydraulic conductivity can be measured during these experiments.

A2.4 Compacted Salt Column

A reconstituted salt column has been proposed as a primary means to isolate for several decades those repositories containing hazardous materials situated in evaporite sequences. Reuse of salt excavated in the process of creating the underground openings has been advocated since the initial proposal by the NAS in the 1950s. Replacing the natural material to its original setting ensures physical, chemical, and mechanical compatibility with the host formation. Recent developments in support of the WIPP shaft seal system have produced confirming experimental results, constitutive material laws, and construction methods that substantiate use of a salt column for a low permeability, perfectly compatible seal component.

Numerical models of the shaft and seal system have been used to provide information on the mechanical processes that affect potential pathways and overall performance of the seal system. Several of these types of analyses are developed in Appendix D. Simulations of the excavated shaft and the compacted salt seal element behavior after placement show that as time passes, the host salt creeps inward, the compacted salt is loaded by the host formation and consolidates, and a back pressure is developed along the shaft wall. The back pressure imparted to the host formation by the compacted salt promotes healing of any microcracks in the host rock. As compacted salt consolidates, density and stiffness increase and permeability decreases.

A2.4.1 Functions

The function of the compacted and reconsolidated salt column is to limit transmission of fluids into or out of the repository for the statutory period of 10,000 years. The functional period

starts within a hundred years and lasts essentially forever. After a period of consolidation, the salt column will almost completely retard gas or brine migration within the former shaft opening. A completely consolidated salt column will achieve flow properties indistinguishable from natural Salado salt.

A2.4.2 Material Characteristics

The salt component comprises crushed Salado salt with addition of small amounts of water. No admixtures other than water are needed to meet design specifications. Natural Salado salt (also called WIPP salt) is typical of most salts in the Permian Basin: it has an overall composition approaching 90-95 % halite with minor clays, carbonate, anhydrite, and other halite minerals. Secondary minerals and other impurities are of little consequence to construction or performance of the compacted salt column as long as the halite content is approximately 90 %.

The total water content of the crushed salt should be approximately 1.5 wt% as it is tamped into place. Field and laboratory testing verified that natural salt can be compacted to significant density ($\rho \geq 0.9$) with addition of these modest amounts of water. In situ WIPP salt contains approximately 0.5 wt% water. After it is mined, transported, and stored, some of the connate water is lost to evaporation and dehydration. Water content of the bulk material that would be used for compaction in the shaft is normally quite small, on the order of 0.25 wt%, as measured during compaction demonstrations (Hansen and Ahrens, 1996). Measurements of water content of the salt will be necessary periodically during construction to calibrate the proper amount of water to be added to the salt as it is placed.

Water added to the salt will be sprayed in a fine mist onto the crushed salt as it is cast in each lift. Methods similar to those used in the large-scale compaction demonstration will be developed such that the spray visibly wets the salt grain surfaces. General uniformity of spray is desired. The water has no special chemical requirements for purity. It can be of high quality (drinkable) but need not be potable. Brackish water would suffice because water of any quality would become brackish upon application to the salt.

The mined salt will be crushed and screened to a nominal maximum diameter of 5 mm. Gradation of particles smaller than 5 mm is not of concern because the crushing process will create relatively few fines compared to the act of dynamic compaction. Based on preliminary large-scale demonstrations, excellent compaction was achieved without optimization of particle sizes. It is evident from results of the large compaction demonstration coupled with laboratory studies that initial density can be increased and permeability decreased beyond existing favorable results. Further demonstrations of techniques, including crushing and addition of water may be undertaken in ensuing years between compliance certification and beginning of seal placement.

A2.4.3 Construction

Dynamic compaction is the specified procedure to tamp crushed salt in the shaft. Other techniques of compaction have potential, but their application has not been demonstrated. Deep dynamic compaction provides the greatest energy input to the crushed salt, is easy to apply, and has an effective depth of compactive influence far greater than lift thickness. Dynamic compaction is relatively straightforward and requires a minimal work force. If the number of drops remains constant, diameter and weight of the tamper increases in proportion to the

diameter of the shaft. The weight of the tamper is a factor in design of the infrastructure supporting the hoisting apparatus. Larger, heavier tampers require equally stout staging. The construction method outlined in Appendix B balances these opposing criteria. Compaction itself will follow the successful procedure developed in the large-scale compaction demonstration (Hansen and Ahrens, 1996).

Transport of crushed salt to the working level can be accomplished by dropping it down a slickline. As noted, additional water will be sprayed onto the crushed salt at the bottom of the shaft as it is placed. Lift heights of approximately 2 m are specified, though greater depths could be compacted effectively using dynamic compaction. Uneven piles of salt can be hand leveled.

A2.4.4 Performance Requirements

Compacted crushed salt is a unique seal material because it consolidates naturally as the host formation creeps inward. As the crushed salt consolidates, void space diminishes, density increases, and permeability decreases. Thus, sealing effectiveness of the compacted salt column will improve with time. Laboratory testing over the last decade has shown that pulverized salt specimens can be compressed to high densities and low permeabilities (Brodsky et al., 1996). In addition, consolidated crushed salt uniquely guarantees chemical and mechanical compatibility with the host salt formation. Therefore, crushed salt will provide a seal that will function essentially forever once the consolidation process is completed. Primary performance results of these analyses include plots of fractional density as a function of depth and time for the crushed salt column and permeability distribution functions that will be used for performance assessment calculations. These performance results are summarized near the end of this section, following a limited background discussion.

To predict performance, a constitutive model for crushed salt is required. To this end, a technical evaluation of potential crushed salt constitutive models was completed (Callahan et al., 1996). Ten potential crushed salt constitutive models were identified in a literature search to describe the phenomenological and micromechanical processes governing consolidation of crushed salt. Three of the ten potential models were selected for rigorous comparisons to a specially developed, although somewhat limited, database. The database contained data from hydrostatic and shear consolidation laboratory experiments. The experiments provide deformation (strain) data as a function of time under constant stress conditions. Based on volumetric strain measurements from experiments, change in crushed salt density and porosity are known. In some experiments, permeability was also measured, which provides a relationship between density and permeability of crushed salt. Models were fit to the experimental database to determine material parameter values and the model that best represents experimental data.

Modeling has been used to predict consolidating salt density as a function of time and position in the shaft. Position or depth of the calculation is important because creep rates of intact salt and crushed salt are strong functions of stress difference. Analyses made use of a "pineapple" slice structural model at the top (430 m), middle (515 m), and bottom (600 m) of the compacted salt column. Initial fractional density of the compacted crushed salt was 0.90 (1944 kg m^{-3}). The structural model, constitutive material models, boundary conditions, etc. are described in Appendix D. Modeling results coupled with laboratory-determined relationships

between density and permeability were used to develop distribution functions for permeability of the compacted crushed salt column for centuries after seal emplacement.

Analyses used reference engineering values for parameters in the constitutive models (e.g., the creep model for intact salt and consolidation models for crushed salt). Some uncertainty associated with model parameters exists in these constitutive models. Consolidating salt density was quantified by predicting density at specific times using parameter variations. Many of these types of calculations comparing three models for consolidation of crushed salt were performed to quantify performance of the salt column, and the reader is referred to Appendix D for more detail.

Predictions of fractional density as a function of time and depth are shown in Figure A-6. Performance calculations of the seal system require quantification of the resultant salt

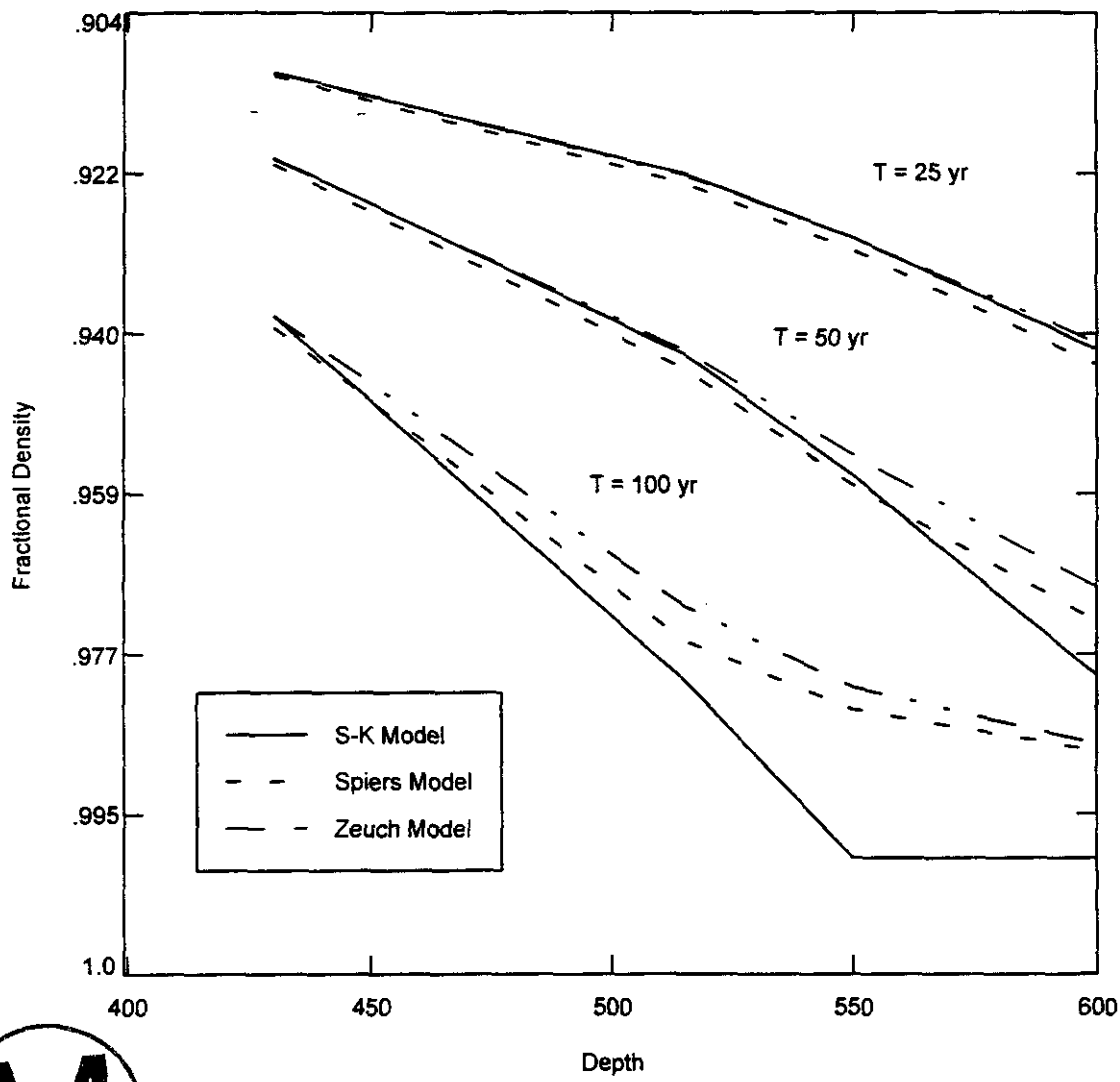

Figure A-6. Fractional density of the consolidating salt column.

permeability. The permeability can be derived from the experimental data presented in Figure A-7. This plot depicts probabilistic lines through the experimental data. From these lines,distribution functions can be derived. Permeability of the compacted salt column is treated as a transient random variable defined by a log triangular distribution. Distribution functions were provided for 0, 50, 100, 200, and 400 years after seal emplacement, assuming that fluids in the salt column pores spaces would not produce a backstress. The resultant cumulative frequency distribution for seal permeability at the seal mid-height is shown in Figure A-8. This method predicts permeabilities ranging from 1×10^{-23} m^2 to 1×10^{-16} m^2. Because crushed salt consolidation will be affected by both mechanical and hydrological processes, detailed calculations were performed. These calculations are presented in Appendices C and D.

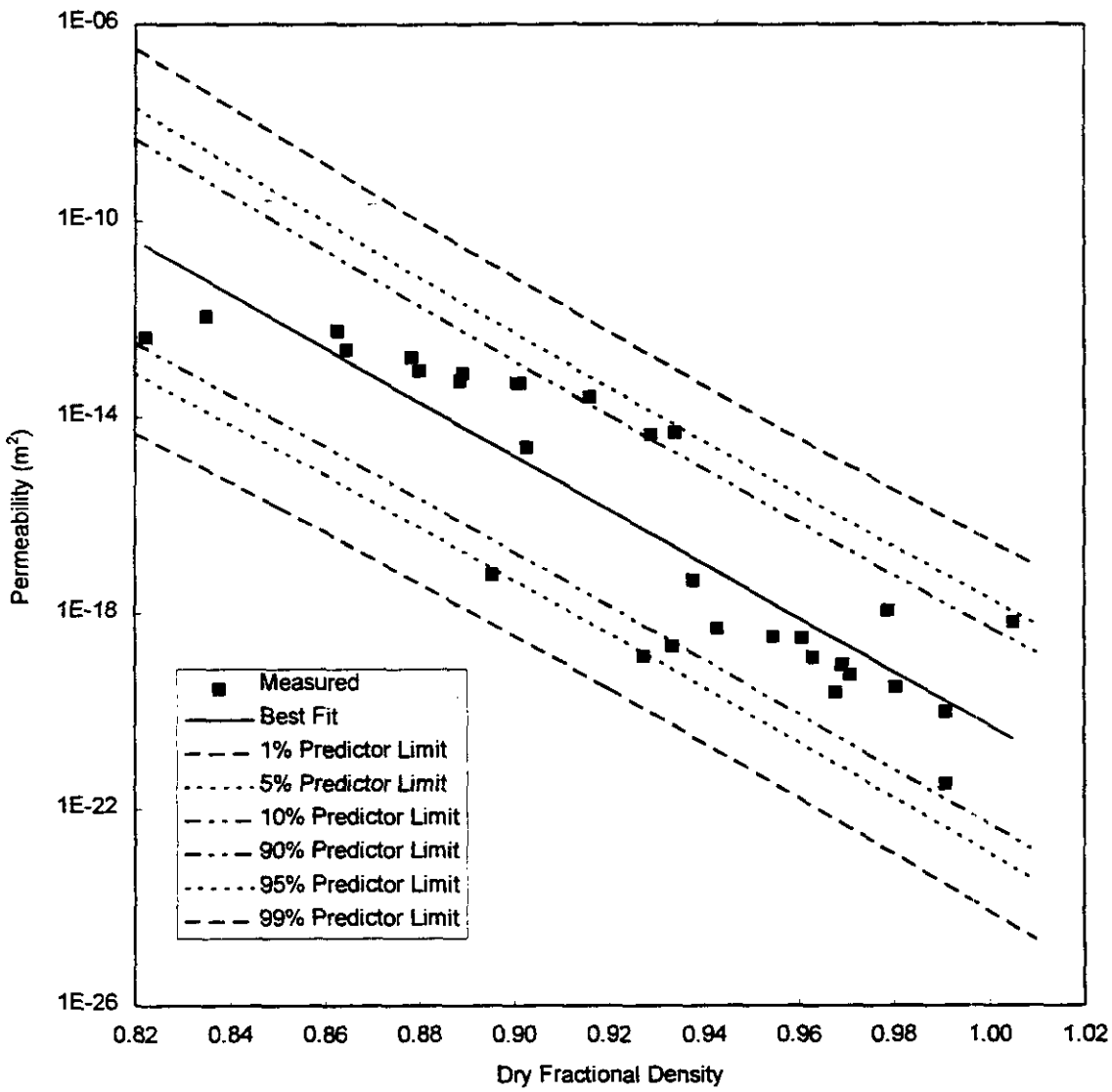

Figure A-7. Permeability of consolidated crushed salt as a function of fractional density.

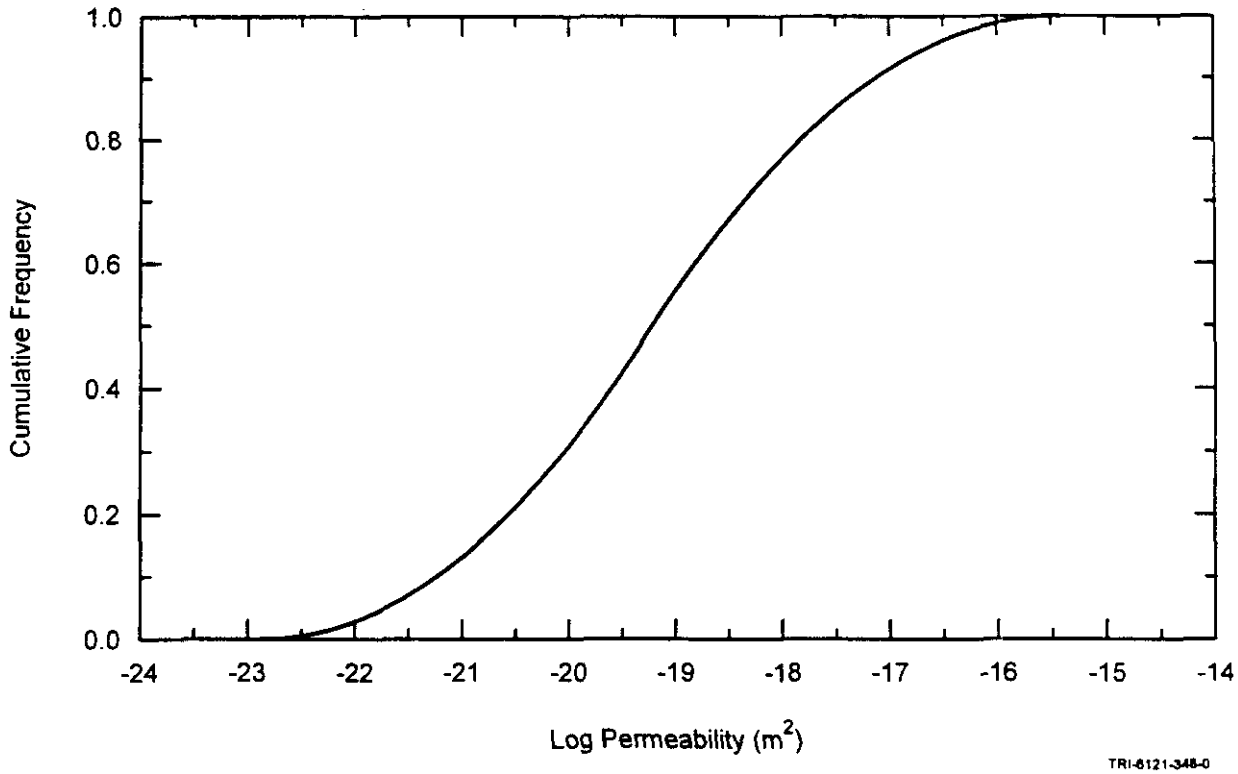

Figure A-8. Compacted salt column permeability cumulative frequency distribution function at seal midpoint 100 years following closure.

Numerical models of the shaft provide density of the compacted salt column as a function of depth and time. From the density-permeability relationship, permeability of the compacted salt seal component can be calculated. Similarly, the extent of the disturbed rock zone around the shaft is provided by numerical models. From field measurements of the halite DRZ, permeability of the DRZ is known as a function of depth and time. These spatial and temporal permeability values provide information required to assess the potential for brine and gas movement in and around the consolidating salt column.

A2.4.5 Verification Methods

Results of the large-scale dynamic compaction demonstration suggest that deep dynamic compaction will produce a dense starting material, and laboratory work and modeling show that compacted salt will reconsolidate within several decades to an essentially impermeable mass. As with other seal components, testing of the material in situ will be difficult and probably not the best way to ensure quality of the seal element. This is particularly apparent for the compacted salt component because the compactive effort produces a finely powdered layer on the top of each lift. It turns out that the fine powder compacts into a very dense material when the next lift is compacted. The best way to ensure that the crushed salt element functions properly is to establish performance through QA/QC procedures. If crushed salt is placed with a reasonable

uniformity of water and is compacted with sufficient energy, long-term performance can be assured.

Periodic measurements of the water content of loose salt as it is placed in lifts will be used for verification and quality control. Thickness of lifts will be controlled. Energy imparted to each lift will be documented by logging drop patterns and drop height. If deemed necessary, visual inspection of the tamped salt can be made by human access. The powder layer can be shoveled aside and hardness of underlying material can be qualitatively determined or tested. Overall geometric measurements made from the original surface of each lift could be used to approximate compacted density.

A2.5 Cementitious Grout

Cementitious grouting is specified for all concrete members in response to external review suggestions. Grouting is also used in advance of liner removal to stabilize the ground. Cementitious grout is specified because of its proven performance, nontoxicity, and previous use at the WIPP.

A2.5.1 Functions

The function of grout is to stabilize the surrounding rock before existing concrete liners are removed. Grout will fill fractures within adjacent lithologies, thereby adding strength and reducing permeability. Grout around concrete members of the concrete asphalt waterstop will be employed in an attempt to tighten the interface and fill microcracks in the DRZ. Efficacy of grouting will be determined during construction. In addition, reduction of local permeability will further limit groundwater influx into the shaft during construction. Concrete plugs are planned for specific elevations in the lined portion of each shaft. The formation behind the concrete liner will be grouted from approximately 3 m below to 3 m above the plug positions to ensure stability of any loose rock.

A2.5.2 Material Characteristics

The grout developed for use in the shaft seal system has the following characteristics:

- no water separation upon hydration,
- low permeability paste,
- fine particle size,
- low hydrational heat,
- no measurable agglomeration subsequent to mixing,
- two hours of injectability subsequent to mixing,
- short set time,
- high compressive strength, and
- competitive cost.

A cementitious grout developed by Ahrens and coworkers (Ahrens et al., 1996) is specified for application in the shaft seal design. This grout consists of portland cement, pumice

as a pozollanic material, and superplasticizer in the proportions listed in Table A-10. The ultrafine grout is mixed in a colloidal grout mixer, with a water to components ratio (W:C) of 0.6:1. Grout has been produced with 90 % of the particles smaller than 5 microns and an average particle size of 2 microns. The extremely small particle size enables the grout to penetrate fractures with apertures as small as 6 microns.

Table A-10. Ultrafine Grout Mix Specification

Component	Weight Percent (wt%)
Type 5 portland cement	45
Pumice	55
Superplasticizer	1.5

A2.5.3 Construction

Grout holes will be drilled in a spin pattern that extends from 3 m below to 3 m above that portion of the lining to be removed. The drilling and grouting sequence will be defined in the workmanship specifications prior to construction. Grout will be mixed on surface and transferred to thw work deck via the slick line. Maximum injection pressure will be lithostatic, less 50 psig. It is estimated that four holes can be drilled and grouted per shift.

A2.5.4 Performance Requirements

Performance of grout is not a consideration for compliance issues. Grouting is used to facilitate construction by stabilizing any loose rock behind the concrete liner. If the country rock is fractured, grouting will reduce the permeability of the DRZ significantly. Application at the WIPP demonstrated permeability reduction in an anhydrite marker bed of two to three orders of magnitude (Ahrens et al., 1996). Reduction of local permeability adds to longevity of the grout itself and reduces the possibility of brine contacting seal elements. Because grout does not influence compliance issues, a model for it is not used and has not been developed. General performance achievements are:

- filled fractures as small as 6 microns,
- no water separation upon hydration,
- no evidence of halite dissolution,
- no measurable agglomeration subsequent to mixing,
- one hour of injectability,
- initial Vicat needle set in 2.5 hours,
- compressive strength 40 MPa at 28 days, and
- competitive cost.

A2.5.5 Verification Methods

No verification of the effectiveness of grouting is currently specified. If injection around concrete plugs is possible, an evaluation of quantities and significance of grouting will be made during construction. Procedural specifications will include measurements of fineness and determination of rheology in keeping with processes established during the WIPP demonstration grouting (Ahrens et al., 1996).

A2.6 Earthen Fill

Compacted earthen fill comprise approximately 150 m of shaft fill in the Dewey Lake Redbeds and near surface stratigraphy.

A2.6.1 Functions

There are minimal performance requirements imposed for Components 1 and 3 and none that affect regulatory compliance of the site. Specifications for Components 1 and 3 are general: fill the shaft with relatively dense material to reduce subsidence.

A2.5.2 Material Characteristics

Fill can utilize material that was excavated during shaft sinking and stored at the WIPP site, or a borrow pit may be excavated to secure fill material. The bulk fill material may include bentonite additive, if deemed appropriate.

A2.5.3 Construction

Dynamic compaction is specified for the clay column in the Dewey Lake Formation because of its perceived expediency. Vibratory compaction will be used near surface when there is no longer space for the three stage construction deck.

A2.5.4 Performance Requirements

Care will be taken to compact the earthen fill with an energy of twice Modified Proctor energy, which has been shown to produce a dense, uniform fill.

A2.5.6 Verification

Materials placed will be documented, with density measurements as appropriate.

A3. CONCLUDING REMARKS

Material specifications in this appendix provide descriptions of seal materials along with reasoning about why they are expected to function well in the WIPP setting. The specification follows a framework that states the function of the seal component, a description of the material, and a summary of construction techniques that could be implemented without resorting to extensive development efforts. Discussion of performance requirements for each material is the most detailed section because design of the seal system requires analysis of performance to ascertain compliance with regulations. Successful design of the shaft seal system is

demonstrated by an evaluation of how well the design performs, rather than by comparison with a predetermined quantity.

Materials chosen for use in the shaft seal system have several common desirable attributes: low permeability, availability, high density, longevity, low cost, constructability, and supporting documentation. Functional redundancy using different materials provides an economically and technologically feasible shaft seal system that limits fluid transport.

A4. REFERENCES

Ahrens, E.H., T.F. Dale, and R.S. Van Pelt. 1996. *Data Report on the Waste Isolation Pilot Plant Small-Scale Seal Performance Test, Series F Grouting Experiment*. SAND93-1000. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM [SWCF] as WPO37355.)

American Colloid Company. 1995. "Technical Data Sheet. Volclay GPG 30." Arlington Heights, IL: Industrial Chemical Division, American Colloid Company. 1 p. (Copy on file in the SWCF as WPO39636.)

American Petroleum Institute. 1990. "Specification for Materials and Testing for Well Cements." API Specification 10. 5th ed. Washington, DC: American Petroleum Institute. (Available from American Petroleum Institute, 1220 L St. NW, Washington, DC 20005, 202/682-8375.)

ASTM C 33 - 93. "Specification for Concrete Aggregates," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 39 - 94. "Test Method for Compressive Strength of Cylindrical Concrete Specimens," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 40 - 92. "Test Method for Organic Impurities in Fine Aggregates for Concrete," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 114 - 94. "Test Methods for Chemical Analysis of Hydraulic Cement," *Annual Book of ASTM Standards, Volume 04.01, Cement; Lime; Gypsum*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 117 - 95. "Test Method for Material Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 123 - 94. "Test Method for Lightweight Pieces in Aggregate," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 127 - 88 (1993). "Test Method for Specific Gravity and Absorption of Coarse Aggregate," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 128 - 93. "Test Method for Specific Gravity and Absorption of Fine Aggregate," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 131 - 89. "Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 136 - 95a. "Test Method for Sieve Analysis of Fine and Coarse Aggregates," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 138 - 92. "Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 142 - 78 (1990). "Test Method for Clay Lumps and Friable Particles in Aggregates," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 143 - 90a. "Test Method for Slump of Hydraulic Cement Concrete," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 150 - 95. "Specification for Portland Cement," *Annual Book of ASTM Standards, Volume 04.01, Cement; Lime; Gypsum*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

M

ASTM C 157 - 93. "Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 204 - 94a. "Test Method for Fineness of Hydraulic Cement by Air Permeability Apparatus," *Annual Book of ASTM Standards, Volume 04.01, Cement; Lime; Gypsum*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 231 - 91b. "Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 294 - 86 (1991). "Descriptive Nomenclature for Constituents of Natural Mineral Aggregates," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 295 - 90. "Guide for Petrographic Examination of Aggregates for Concrete," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 311 - 94b. "Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 469 - 94. "Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 534 - 94. "Specification for Preformed Flexible Elastomeric Cellular Thermal Insulation in Sheet and Tubular Form," *Annual Book of ASTM Standards, Volume 04.06, Thermal Insulation; Environmental Acoustics*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

M

ASTM C 535 - 89. "Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 566 - 95. "Test Method for Total Moisture Content of Aggregate by Drying," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 618 - 95. "Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 845 - 90. "Specification for Expansive Hydraulic Cement," *Annual Book of ASTM Standards, Volume 04.01, Cement; Lime; Gypsum*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 1064 - 86 (1993). "Test Method for Temperature of Freshly Mixed Portland Cement Concrete," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM C 1077 - 95a. "Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation," *Annual Book of ASTM Standards, Volume 04.02, Concrete and Aggregates*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM D 1556 - 90. "Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method," *Annual Book of ASTM Standards, Volume 04.08, Soil and Rock*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM D 2167 - 94. "Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method," *Annual Book of ASTM Standards, Volume 04.08, Soil and Rock*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM D 2216 - 92. "Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock," *Annual Book of ASTM Standards, Volume 04.08, Soil and Rock.* Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM D 2922 - 91. "Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)," *Annual Book of ASTM Standards, Volume 04.08, Soil and Rock.* Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM D 3017 - 88 (1993). "Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)," *Annual Book of ASTM Standards, Volume 04.08, Soil and Rock.* Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM D 4791 - 95. "Test Method for Flat or Elongated Particles in Coarse Aggregate," *Annual Book of ASTM Standards, Volume 04.03, Road and Paving Materials; Pavement Management Technologies.* Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

ASTM E 534 - 91. "Test Methods for Chemical Analysis of Sodium Chloride," *Annual Book of ASTM Standards, Volume 15.05, Engine Coolants; Halogenated Organic Solvents; Industrial Chemicals.* Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

Brodsky, N.S., F.D. Hansen, and T.W. Pfeifle. 1996. "Properties of Dynamically Compacted WIPP Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996.* SAND96-0838C. Albuquerque, NM: Sandia National Laboratories. (Copy on file at the Technical Library, Sandia National Laboratories, Albuquerque, NM.)

Brown, E.R. 1990. "Density of Asphalt Concrete--How Much is Needed?," *Transportation Research Record No. 1282.* Washington, DC: Transportation Research Board. 27-32. (Copy on file in the SWCF.)

Callahan, G.D., M.C. Loken, L.D. Hurtado, and F.D. Hansen. 1996. "Evaluation of Constitutive Models for Crushed Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996.* SAND96-0791C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO36449.)

M

Cheung, S.C.H., M.N. Gray, and D.A. Dixon. 1987. "Hydraulic and Ionic Diffusion Properties of Bentonite-Sand Buffer Materials," *Coupled Processes Associated with Nuclear Waste Repositories, Proceedings of the International Symposium on Coupled Processes Affecting the Performance of a Nuclear Waste Repository, Berkeley, CA, September 18-20, 1985*. Ed. C-F. Tsang. Orlando, FL: Academic Press, Inc. 383-407. (Copy on file in the SWCF.)

CRD-C 38 - 73. "Method of Test for Temperature Rise in Concrete," *Handbook for Concrete and Cement*. Vicksburg, MS: U.S. Army Corps of Engineers, Waterways Experiment Station. (Copy on file in the SWCF as WPO39656.)

DOE (U.S. Department of Energy). 1995. *Waste Isolation Pilot Plant Sealing System Design Report*. DOE/WIPP-95-3117. Carlsbad, NM: U.S. Department of Energy, Waste Isolation Pilot Plant. (Copy on file in the SWCF as WPO29062.)

EPA (Environmental Protection Agency). 1996a. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Response to Comments Document for 40 CFR Part 194*. EPA 402-R-96-001. Washington, DC: Environmental Protection Agency, Office of Radiation and Indoor Air. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM.)

EPA (Environmental Protection Agency). 1996b. *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document for 40 CFR Part 194*. EPA 402-R-96-002. Washington, DC: Environmental Protection Agency, Office of Radiation and Indoor Air. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM.)

Freeman, H.D., and R.A. Romine. 1994. *Hanford Permanent Isolation Barrier Program: Asphalt Technology Test Plan*. PNL-9336. Richland, WA: Pacific Northwest Laboratories. (Copy available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA, 22161, 703/487-4650. Order number: DE94013454.)

Gray, M.N. 1993. *OECD/NEA International Stripa Project. Overview Volume III: Engineered Barriers*. Stockholm, Sweden: SKB, Swedish Nuclear Fuel and Waste Management Company. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM as TD898.2 .G73 1993.)

Hansen, F.D., and E.H. Ahrens. 1996. "Large-Scale Dynamic Compaction of Natural Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND96-0792C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO39544.)

IAEA (International Atomic Energy Agency). 1990. *Sealing of Underground Repositories for Radioactive Wastes*. STI/DOC/10/319. Technical Reports Series No. 319. Vienna, Austria: International Atomic Energy Agency; Lanham, MD: Unipub. (Copies on file at the Technical Library, Sandia National Laboratories, Albuquerque, NM and at Centennial Science and Engineering Library, University of New Mexico, Albuquerque, NM.)

Kjartanson, B.H., N.A. Chandler, A.W.L. Wan, C.L. Kohle, and P.J. Roach. 1992. "Use of a Method Specification for In Situ Compaction of Clay-Based Barrier Materials," *High Level Radioactive Waste Management, Proceedings of the Third International Conference, Las Vegas, NV, April 12-16, 1992.* La Grange Park, IL: American Nuclear Society, Inc.; New York, NY: American Society of Civil Engineers. Vol. 1, 1129-1136. (Copy on file in the SWCF.)

Knowles, M.K., and C.L. Howard. 1996. "Field and Laboratory Testing of Seal Materials Proposed for the Waste Isolation Pilot Plant," *Proceedings of the Waste Management 1996 Symposium, Tucson, AZ, February 25-29, 1996.* SAND95-2082C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO30945.)

Mitchell, J.K. 1993. *Fundamentals of Soil Behavior.* 2nd ed. New York, NY: John Wiley & Sons, Inc.

Myers, D.R., and D.A. Duranceau. 1994. *Prototype Hanford Surface Barrier: Design Basis Document.* BHI-00007, Rev. 00. Richland, WA: Bechtel Hanford, Inc. for the U.S. Department of Energy, Office of Environmental Restoration and Waste Management. (Copy on file at the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM.)

Nilsson, J. 1985. "Field Compaction of Bentonite-Based Backfilling," *Engineering Geology.* Vol. 21, no. 3-4, 367-376. (Copy on file in the SWCF.)

Onofrei, M., M.N. Gray, W.E. Coons, and S.R. Alcorn. 1992. "High Performance Cement-Based Grouts for Use in a Nuclear Waste Disposal Facility," *Waste Management.* Vol. 12, no. 2/3, 133-154. (Copy on file in the SWCF.)

Pfeifle, T.W., F.D. Hansen, and M.K. Knowles. 1996. "Salt-Saturated Concrete Strength and Permeability," *4th Materials Engineering Conference, ASCE Materials Engineering Division, Washington, DC, November 11-18, 1996.* Albuquerque, NM: Sandia National Laboratories.)

Pusch, R. 1982. "Mineral-Water Interactions and Their Influence on the Physical Behavior of Highly Compacted Na Bentonite," *Canadian Geotechnical Journal.* Vol. 19, no. 3, 381-387. (Copy on file in the SWCF.)

Pusch, R., and L. Börgesson. 1989. "Bentonite Sealing of Rock Excavations," *Sealing of Radioactive Waste Repositories, Proceedings of an NEA/CEC Workshop, Braunschweig, Germany, May 22-25, 1989.* EUR 12298. Paris: Organisation for Economic Co-Operation and Development. 297-308. (Copy on file in the SWCF.)

Pusch, R., M. Gray, F. Huertas, M. Jorda, A. Barbreau, and R. Andre-Jehan. 1989. "Sealing of Radioactive Waste Repositories in Crystalline Rock," *Sealing of Radioactive Waste Repositories, Proceedings of an NEA/CEC Workshop, Braunschweig, Germany, May 22-25, 1989.* EUR 12298. Paris: Organisation for Economic Co-Operation and Development. 214-228. (Copy on file in the SWCF.)

Wakeley, L.D., P.T. Harrington, and F.D. Hansen. 1995. *Variability in Properties of Salado Mass Concrete*. SAND94-1495. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO22744.)

Wing, N.R., and G.W. Gee. 1994. "Quest for the Perfect Cap," *Civil Engineering*. Vol. 64, no. 10, 38-41. (Copy on file in the SWCF as WPO21158.)

Appendix B

Shaft Sealing Construction Procedures

Appendix B Abstract

This appendix describes equipment and procedures used to construct the shaft seals as specified in the main report. Existing or reasonably modified construction equipment is specified, standard mining practices are applied, and a general schedule is provided at the end of this appendix. This appendix describes the following activities:

- pre-sealing activities for the sub-surface and surface,
- construction and operation of a multi-deck stage,
- installation of special concrete (sumps, shaft station monoliths, and concrete plugs),
- installation of compacted clay columns,
- emplacement and dynamic compaction of WIPP salt,
- installation of neat asphalt and asphaltic mastic mix,
- grouting of concrete plugs and the country rock behind existing shaft liners,
- removal of portions of the existing shaft liners, and
- emplacement of compacted earthen fill.

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B1. INTRODUCTION

This appendix describes construction specifications for placement of shaft seal materials. Flexibility is incorporated in construction specifications to facilitate placement of several different material types. Engineering materials used to seal the full length of the shaft include earthen fill, compacted clay, tamped crushed salt, asphalt, concrete, and a combination of concrete and asphalt in concrete-asphalt waterstops. Appendix A of this report provides details of the materials. A full-length shaft seal of this type has never before been constructed; however, application of available technology and equipment, standard construction practices, and common materials provides confidence that the system can be placed to satisfy the design requirements.

A primary feature of the construction specification is development of a work platform from which seal materials are placed. Although the proposed multi-deck stage (galloway) proposed here is engineered specifically for shaft sealing operations, it is similar to stages used for construction of shafts. Inherently flexible, the multi-deck stage facilitates several construction methods required for the various materials specified for the shaft seal system. It provides an assembly of a slickline and header for transport of flowable materials from the surface to the placement horizon. A crane device is attached to the base of the stage to facilitate compaction, and an avenue through the stage provides a means to transport bulk material. It is understood that procedures specified here may change during the tens of years preceding construction as a result of equipment development, additional testing, or design changes. Further, it is acknowledged that the construction methods specified are not the only methods that could place the seal materials successfully.

A few assumptions are made for purposes of evaluating construction activities. These assumptions are not binding, but are included to assist discussion of general operational scenarios. For example, four multi-deck stages are specified, one for each shaft. This specification is based on shaft-sinking experience, which indicates that because of the wear encountered, it is advisable to replace rather than rebuild stages. However, much of the equipment on the multi-deck stage is reused. For scheduling purposes, it is assumed that sealing operations are conducted in two of the four shafts simultaneously. The Air Intake and Exhaust Shafts are sealed first, and the Waste and Salt Handling Shafts are sealed last. With this approach, shaft sealing will require about six and a half years, excluding related work undertaken by the WIPP Operating Contractor. Sealing the shafts sequentially would require approximately eleven and a half years. To facilitate discussion of scheduling and responsibilities, it is assumed that sealing operations will be conducted by a contractor other than the WIPP Operating Contractor.

Years from now, when actual construction begins, it is probable that alternatives may be favored. Therefore, construction procedures note alternative methods in recognition that changes are likely and that the construction strategy is sufficiently robust to accommodate alternatives. This appendix contains both general and very specific information. It begins with a discussion of general mobilization in Section 2. Details of the multi-deck construction stage are provided in Section 3. Section 4 contains descriptions of the construction activities. Information presented here is supplemented by several engineering drawings and sketches contained in Appendix E. The topical information and the level of provided detail substantiate the theory that reliable shaft seal construction is possible using available technology and materials.

B2. PROJECT MOBILIZATION

The duty descriptions that follow are for discussion purposes. The discussions do not presuppose contractual arrangements, but simply identify tasks necessary for shaft seal construction.

B2.1 Subsurface

Prior to initiation of sealing activities, the WIPP Operating Contractor will remove installations and equipment on the repository level. A determination of items removed will be made before construction begins. Such removal would include, but is not limited to, gates and fences at the shaft; equipment such as winches, ventilation fans, pipelines; and communication and power cables. Additionally, the following items will be removed from the shafts:

- cables, counterweights, and sheaves;
- existing waterlines; and
- electrical cables not required for sealing operations.

The following equipment will be stored near the shaft on the repository level by the Sealing Contractor prior to initiation of sealing activities:

- a concrete header, hopper, and pump;
- a concrete pump line to distribute concrete; and
- an auxiliary mine fan and sufficient flexible ventilation tubing to reach work areas required for installation of the shaft station concrete monolith.

The subsurface will be prepared adequately for placement of the shaft station monolith. Determination of other preparatory requirements may be necessary at the time of construction.

B2.2 Surface

The Operating Contractor will remove surface facilities such as headframes, hoists, and buildings to provide clear space for the Sealing Contractor. Utilities required for sealing activities (e.g., air compressors, water, electrical power and communication lines) will be preserved. The Sealing Contractor will establish a site office and facilities required to support the construction crews, including a change house, lamp room, warehouse, maintenance shop, and security provisions. Locations will be selected and foundations constructed for headframes, multi-deck stage winches, man/equipment hoist, and exhaust fan. A drawing in Appendix E (Sketch E-4) depicts a typical headframe and associated surface facilities. The hoist and winches will be enclosed in suitable buildings; utilities and ventilation ducting will be extended to the shaft collar. The large ventilation fan located near the collar is designed to exhaust air through the rigid ventilation duct, resulting in the movement of fresh air down the shaft. Air flow will be sufficient to support eight workers to the depth of the repository level. The following facilities will be procured and positioned near the shaft collar:

- a concrete batch plant capable of weighing, batching, and mixing the concrete to design specifications;
- a crushing and screening plant to process WIPP salt and local soil;

- an insulated and heated pug mill, asphalt pump, asphalt storage tank, and other auxiliary equipment; and
- pads, silos, and structures to protect sealing materials from the weather.

The Sealing Contractor will construct a temporary structural steel bulkhead over the shaft at the surface. The bulkhead will be sufficiently strong to support the weight of the multi-deck stage, which will be constructed on it. When the multi-deck stage is completed, the headframe will be erected. The headframe (depicted in Appendix E, Sketch E-3) will be built around the multi-deck stage, and a mobile crane will be required during fabrication. When the headframe is completed, cables for hoisting and lowering the multi-deck stage will be installed. Cables will run from the three winches, over the sheaves in the headframe, down and under the sheaves on the multi-deck stage, and up to anchors in the headframe. The headframe will be sufficiently high to permit the multi-deck stage to be hoisted until the lowest component is 3.05 m (10 ft) above surface. This will facilitate slinging equipment below the multi-deck stage and lowering it to the work surface, as well as activities required at the collar during asphalt emplacement.

The multi-deck stage will be lowered to clear the collar, allowing the installation of compressed-air-activated steel shaft collar doors, which will serve as a safety device, permitting safe access to the man cage and bucket, while preventing objects from falling down the shaft. Following installation of these doors, workers will utilize the multi-deck stage to traverse the shaft from the collar to the repository horizon, inspecting it for safety hazards and making any necessary repairs. After this inspection, the multi-deck stage will return to the surface.

B2.3 Installation of Utilities

In preparation for placement of shaft seal materials, requisite utilities will be outfitted for operations. The multi-deck stage will descend from the collar to the repository horizon. As added assurance against unwanted water, a gathering system similar to the one currently in place at the bottom of the concrete liner will be installed and moved upward as seal emplacement proceeds. Water collected will be hoisted to the surface for disposal. Additionally, any significant inflow will be located and minimized by grouting. After installation of the water gathering system, the following utilities will be installed from surface to the repository horizon by securely fastening them to the shaft wall:

- 5.1-cm steel waterline with automatic shut-off valves every 60 m;
- 10.2-cm steel compressed-air line;
- power, signal, and communications cables;
- 15.2 cm steel slickline and header; and
- a rigid, cylindrical, ventilation duct, which would range from 107 cm in diameter in the three largest shafts to 91 cm in diameter in the Salt Handling Shaft.

B3. MULTI-DECK STAGE

The multi-deck stage (galloway) provides a work platform from which all sealing operations except placement of asphalt are conducted. The concept of using a multi-deck stage is derived from similar equipment commonly employed during shaft sinking operations. Plan and

section views of conceptual multi-deck stages are shown in Appendix E, Sketches E-1 and E-2. The construction decks specified here are modified from typical shaft sinking configurations in two important ways to facilitate construction. Conceptual illustrations of these two modifications are displayed in Figures B-1 and B-2. Figure B-1 illustrates the multi-deck performing dynamic compaction of salt. Figure B-2 illustrates the multi-deck stage configured for excavation of the kerf required for the asphalt waterstop in Salado salt.

A device called a polar crane mounted below the lower deck can be configured for either dynamic compaction or salt excavation. The crane can rotate 360° horizontally by actuating its geared track drive. Its maximum rotational speed will be approximately two revolutions per minute. The crane can be controlled manually or by computer (computerized control will swiftly position the tamper in the numerous drop positions required for dynamic compaction). When excavation for the concrete-asphalt waterstops is required, the tamper, electromagnet, and cable used for dynamic compaction will be removed, and a custom salt undercutter will be mounted on the polar crane trolley. Geared drives on the crane, trolley, and undercutter will supply the force required for excavation. In addition to the special features noted above and shown in Figures B-1 and B-2, the multi-deck stage has the following equipment and capabilities:

- Maximum hoisting/lowering speed is approximately 4.6 m (15 ft) per minute.
- A cable, electromagnet, and tamper will be attached to the polar crane during dynamic compaction. The cylindrical tamper consists of A-36 carbon steel plates bolted together with high-tensile-strength steel bolts. It is hoisted and dropped by the polar crane using the electromagnet. The tamper will be mechanically secured to the polar crane before personnel are allowed under it.
- Range-finding lasers will facilitate the accurate positioning of the multi-deck stage above the work surface and allow the operator to determine when the surface is sufficiently level. The distance indicated by each laser will be displayed on a monitor at the crane control station.
- Flood lights and remotely controlled closed-circuit television equipment will enable the crane operator to view operations below the multi-deck stage on a monitor.
- Fold-out floor extensions that accommodate the variance in shaft diameter between the unlined and lined portions of the shaft will be provided for safety.
- A cutout in each deck, combined with a removable section of the polar crane track, will permit stage movement without removal of the rigid ventilation duct (which is fastened to the shaft wall).

The multi-deck stage is equipped with many of the features found on conventional shaft sinking stages, such as:

- three independent hoisting/lowering cables,
- man and material conveyances capable of passing through the multi-deck stage and accessing the working surface below,
- a jib crane that can be used to service the working surface below,
- removable safety screens and railings, and
- centering devices.

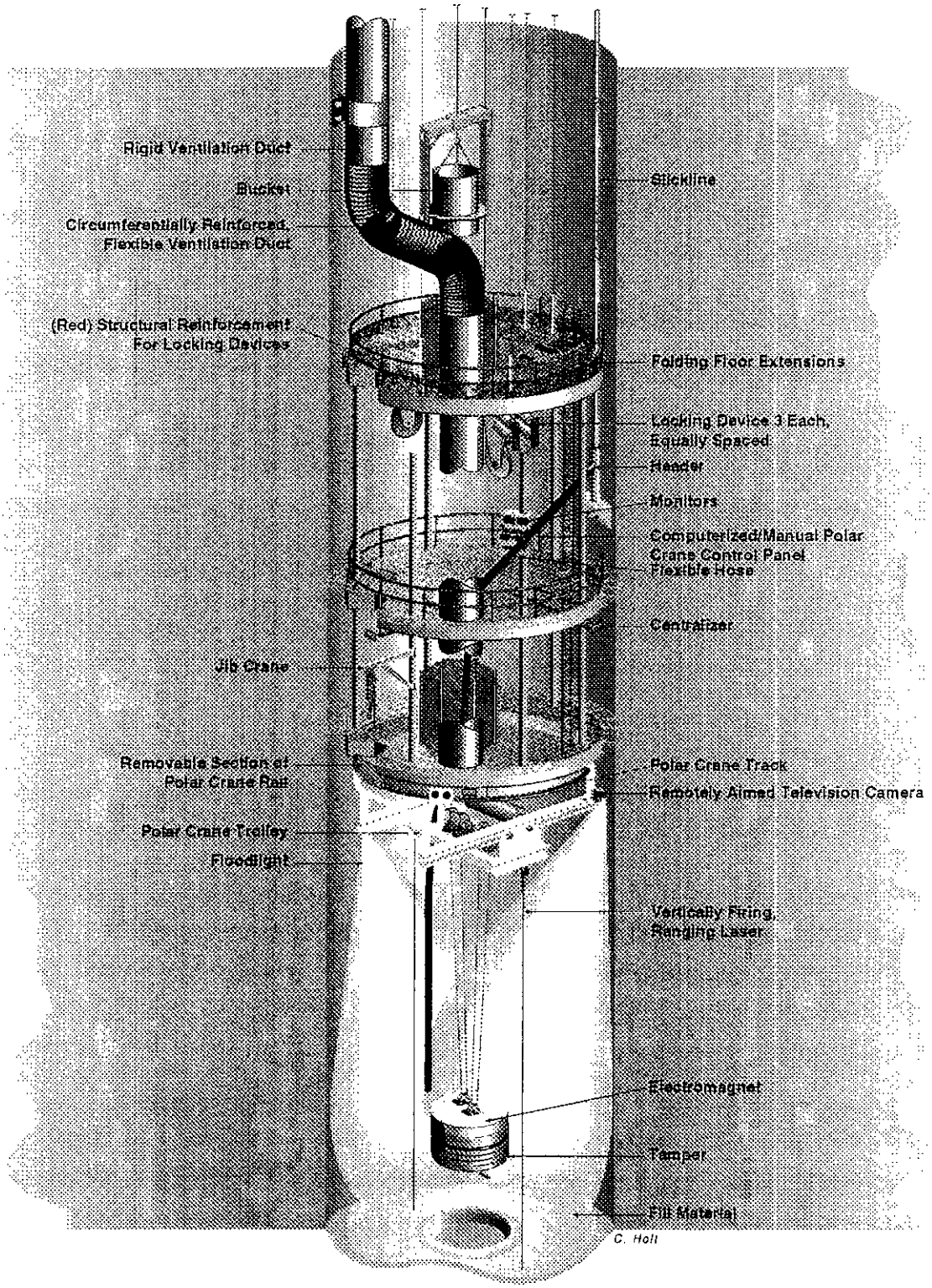

Figure B-1. Multi-deck stage illustrating dynamic compaction.

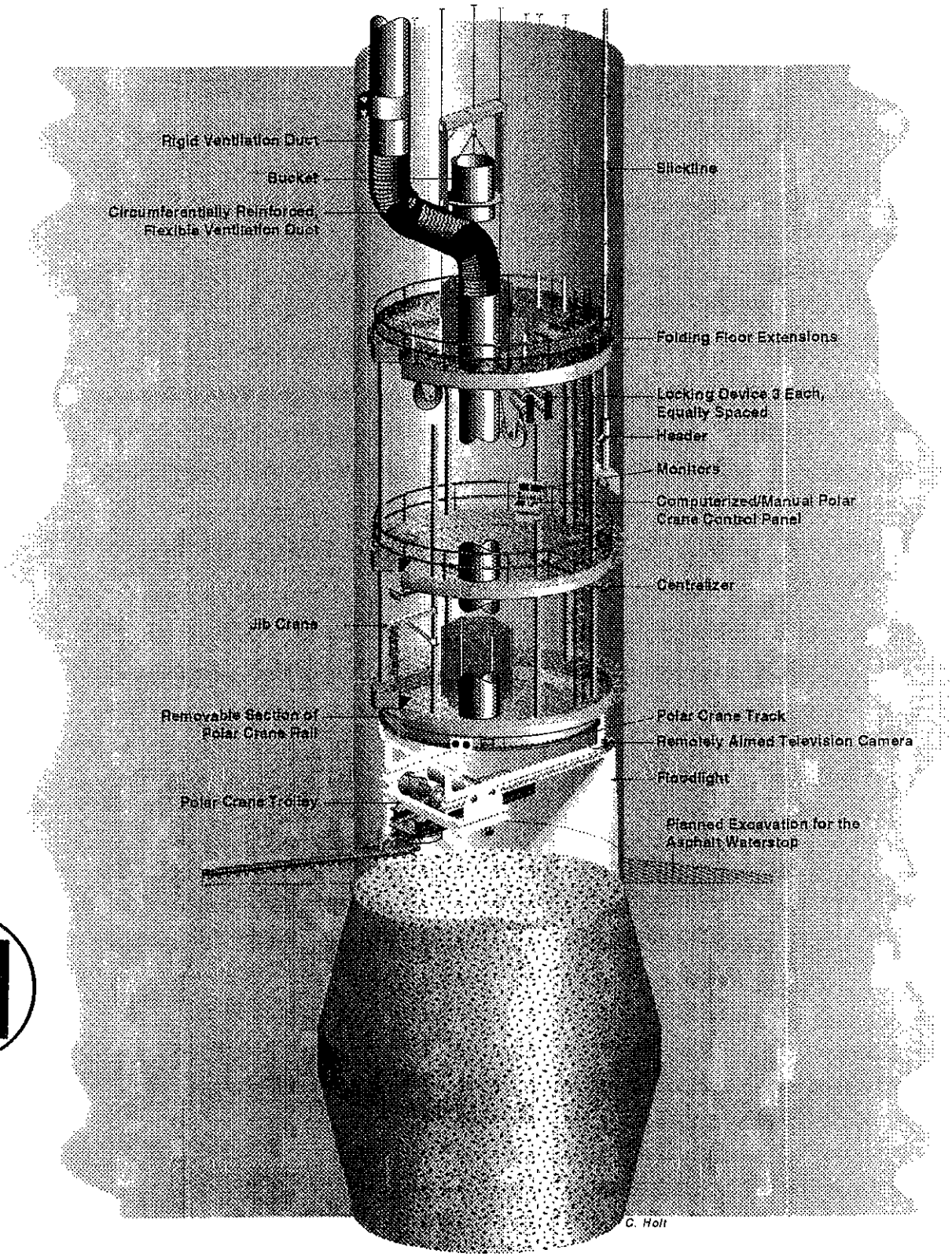

Figure B-2. Multi-deck stage illustrating excavation for asphalt waterstop.

Three sets of double locking devices are provided to secure the multi-deck stage to the shaft wall. A suitable factor of safety for these locking devices is judged to be 4. The area of the grips securing the deck is calculated from static principles:

$$FS = \mu\,(Co)\,(A)\,/\,W \qquad \text{(B-1)}$$

where:

FS	= factor of safety
μ	= steel/salt friction coefficient = 0.15 (see Table 20.1 in McClintock and Argon, 1966; and Van Sambeek, 1988)
Co	= compressive strength of WIPP salt, which varies from 172 kg/cm^2 to 262 kg/cm^2 (Van Sambeek, 1988)
W	= total vertical weight
A	= total gripper pad surface area.

Manipulating the equation to solve for required area, applying a factor of safety of 4, selecting the heaviest work stage (753,832 kg) and the minimum compressive strength value for salt (assuming that the locking pressure equals the minimum compressive strength of salt), the following gripper surface area (A) is:

A = 4(753,832 kg)/0.15(172 kg/cm^2) = 11,416.5 cm^2, and each of the six gripper pads would be 1902.8 cm^2.

As designed, each gripper pad area is 2167.2 cm^2, resulting in a factor of safety (FS) of 4.56. Additionally, although tension in the hoisting cables is relaxed while the multi-deck stage is in the locked configuration, the cables are still available to hold the work-deck, should the locking devices fail.

B4. PLACEMENT OF SEALING MATERIALS

Construction activities include placement of materials in three basic ways: (1) by slickline (e.g., concrete and asphalt), (2) by compaction (e.g., salt and earthen fill), and (3) by physical placement (e.g., clay blocks). Materials will be placed at various elevations using identical procedures. Because placement procedures generally are identical regardless of elevation, they will be described only once. Where differences occur, they will be identified and described. In general, placement of shaft seal elements is described from bottom to top.

B4.1 Concrete

Concrete is used as a seal material for several different components, such as the existing sumps in the Salt Handling Shaft and the Waste Shaft, the shaft station monoliths, concrete plugs, and concrete-asphalt waterstops. Existing sumps are shown in Appendix E, Drawings SNL-007, Sheets 6 and 21. Shaft station monoliths are shown in Drawings SNL-007, Sheets 6, 11, 16, and 21. Concrete plugs are depicted on Drawings SNL-007, Sheets 4, 5, 9, 10, 14, 15, 19, and 20. Lower, middle, and upper concrete-asphalt waterstops are shown in Drawing

SNL-007, Sheet 22. Construction material for all concrete members will be Salado Mass Concrete (SMC).

As specified, all SMC will be mixed on surface to produce a product possessing the characteristics defined in Appendix A. Concrete will be transferred to its placement location within the shaft via slickline and header. The slickline (shown in Figure B-1) is a steel pipe fastened to the shaft wall. Vertical drops as great as 656 m to the repository horizon are required. Such concrete transport and construction are common in mining applications. For example, a large copper mine in Arizona is placing concrete at a depth of 797 m using this procedure. A header attached to the bottom of the slickline is designed to absorb kinetic energy generated by the falling material. The header, a steel pipe slightly larger in diameter than the slickline and made of thicker steel, diverts the flow 45°, absorbing most of the impact. Because the drop generates considerable force, the header will be securely supported by a reinforced steel shelf bolted to the shaft wall. A flexible hose, in sections approximately 3 m long and joined by quick-connect fittings, will be attached to the header.

B4.1.1 Shaft Station Monolith

Construction of the shaft station monoliths is preceded by filling two existing sumps with SMC. Initially, sufficient hose will be used to convey the concrete to the bottom of the sump. The discharge will remain below the concrete surface during placement to minimize air entrainment. Sections of hose will be withdrawn and removed as the SMC rises to the floor of the repository horizon in a continuous pour. Subsequent to filling the sump, arrangements will be made to place the concrete monolith.

A small mine fan will be located above the rigid suction-duct inlet to ensure a fresh air base. Masonry block forms will be constructed at the extremities of the shaft station monolith in the drifts leading from the station. Temporary forms, partially filling the opening, will be erected at the shafts to facilitate the placement of the outermost concrete. These temporary forms will permit access necessary to ensure adequate concrete placement. SMC will be transported via the slickline to the header, which will discharge into a hopper feeding the concrete pump, and the pump will be attached to the pumpcrete line. The pumpcrete line, suspended in cable slings near the back of the drifts, will be extended to the outer forms. A flexible hose, attached to the end of the pumpcrete line, will be used by workers to direct emplacement. The pumpcrete line will be withdrawn as emplacement proceeds toward the shaft.

When the concrete has reached the top of the temporary forms, they will be extended to seal the openings completely, and two 5-cm-diameter polyvinyl chloride (PVC) pipes will be incorporated in the upper portion of each form. Both pipes will be situated in a vertical plane oriented on the long axis of the heading and inclined away from the station at approximately 70° to the horizontal. The upper end of the top pipe will extend to just below the back, and the upper end of the lower pipe will be located just below that of the top pipe. SMC will be injected through the lower pipe until return is obtained from the upper pipe, ensuring that the heading has been filled to the back. The header will then be moved to a position in the shaft above the designed elevation at the top of the shaft station monolith and supported by a bracket bolted to the shaft wall. After the outer concrete has achieved stability, the temporary interior forms may be removed. Equipment no longer required will be slung below the multi-deck stage and hoisted

to surface for storage and later use. The station and shaft will be filled to design elevation with concrete via the slickline, header, and flexible hose. The slickline is cleaned with spherical, neoprene swabs ("pigs") that are pumped through the slickline, header, and hose.

B4.1.2 Concrete-Asphalt Waterstops

Lower, middle, and upper concrete-asphalt waterstops in a given shaft are identical and consist of two SMC sections separated by an asphalt waterstop. Before the bottom member of the lower concrete component is placed, the multi-deck stage will be raised into the headframe; the polar crane will be mounted below the lower deck; and the salt undercutter will be mounted on the crane trolley. The multi-deck stage will then return to the elevation of the concrete component. Two undercutter bars will be used to make the necessary excavations for upper, middle, and lower asphalt-concrete waterstops and the concrete plug above the Salado Formation. Notches for the plugs will be excavated using a short, rigid cutter bar (length less than half the radius). The kerf for the asphalt waterstop will be excavated using a long cutter bar that can excavate the walls to a depth of one shaft radius. These operations will be conducted as required as seal placement proceeds upward.

The lower concrete member (and all subsequent concrete entities) will be placed via the slickline, header, and flexible hose, using the procedure outlined for the shaft station monolith. Construction of vertical shaft seals provides the ideal situation for minimizing interface permeability between the rock and seal materials. Concrete will flow under its own weight to provide intimate contact. A tight cohesive interface was demonstrated for concrete in the small-scale seal performance tests (SSSPTs). The SSSPT concrete plugs were nearly impermeable without grouting. However, interface grouting is usually performed in similar construction, and it will be done here in the appropriate locations.

B4.1.3 Concrete Plugs

An SMC plug, keyed into the shaft wall, is situated a few meters above the upper Salado contact in the Rustler Formation. A final SMC plug is located a few meters below surface in the Dewey Lake Redbeds. This plug is emplaced within the existing shaft liner using the same construction technique employed for the concrete-asphalt waterstops.

B4.2 Clay

B4.2.1 Salado and Rustler Compacted Clay Column

Blocks of sodium bentonite clay, precompacted to a density of 1.8 to 2.0 g/cm^3, will be the sealing material. This density has been achieved at the WIPP using a compaction pressure of 492.2 kg/cm^2 in a machine designed to produce adobe blocks (Knowles and Howard, 1996). Blocks are envisioned as cubes, 20.8 cm on the edge, weighing approximately 18 kg, a reasonable weight for workers to handle. The bentonite blocks will be compacted at the WIPP in a new custom block-compacting machine and will be stored in controlled humidity to prevent desiccation cracking. Blocks will be transported from surface in the man cage, which will be sized to fit through the circular "bucket hole" in the multi-deck stage. The conveyance will be stacked with blocks to a height of approximately 1.8 m.

Installation will consist of manually stacking individual blocks so that all interfaces are in contact. Block surfaces will be moistened with a spray of potable water as the blocks are placed to initiate a minor amount of swelling, which will ensure a tight fit and a decrease in permeability. Peripheral blocks will be trimmed to fit irregularities in the shaft wall and placed as close to the wall as possible. Trimmed material will be manually removed with a vacuum. Dry bentonite will be manually tamped into remaining voids in each layer of blocks. This procedure will be repeated throughout the clay column. The multi-deck stage will, in all cases, be raised and utilities removed to the surface as emplacement of sealing materials proceeds upward.

Dynamic compaction construction is an alternative method of clay emplacement that could be considered in the detailed design. Dynamic compaction materials being considered are:

- sodium bentonite/fine silica sand, and
- highly compressed bentonite pellets.

Boonsinsuk et al. (1991) developed and tested a dynamic (drop hammer) method for a relatively large diameter (0.5-m) hole, simulated with a steel cylinder, that gave very good results on 1 : 1 dry mass mixtures of sodium bentonite and sand, at a moisture content of 17% to 19%. The alternatives have the advantages of simplifying emplacement.

B4.3 Asphalt

Asphalt, produced as a distillate of petroleum, is selected as the seal material because of its longevity, extremely low permeability, history of successful use as a shaft lining material, and its ability to heal if deformed. Shielded from ultraviolet radiation and mixed with hydrated lime to inhibit microbial degradation, the longevity of the asphalt will be great. Emplaced by tremie line at the temperature specified, the material will be fluid and self-leveling, ensuring complete contact with the salt.

Construction of an asphalt column using heated asphalt will introduce heat to the surrounding salt. The thermal shock and heat dissipation through the salt has not been studied in detail. Performance of the asphalt column may be enhanced by the introduction of the heat that results from acceleration of creep and healing of microfractures. If, upon further study, the thermomechanical effects are deemed undesirable or if an alternative construction method is preferred at a later date, asphalt can readily be placed as blocks. Asphalt can "cold flow" to fill gaps, or the seams between blocks can be filled with low-viscosity material.

B4.3.1 Concrete-Asphalt Waterstops

Electrically insulated, steel grated flooring will be constructed over the shaft at the surface. A second, similar flooring will be built in the shaft 3 m below the first. These floors will be used only during the emplacement of asphalt and asphaltic mastic mix (AMM) and will be removed at all other times. A 12.7-cm ID/14-cm OD, 4130 steel pipe (tremie line) in 3-m lengths will be electrically equipped for impedance heating, then insulated and suspended in the shaft from slips (pipe holding devices) situated on the upper floor. The tremie line cross-sectional area is smallest at the shoulder of the top thread, where tensional yield is 50,000 kg; the

line weight is 20.8 kg/m. Heavier weights are routinely suspended in this manner in the petroleum and mining industries.

Neat, AR-4000-graded petroleum-based asphalt cement will be the sealing material for asphalt waterstops. Neat asphalt from the refinery will be delivered to the WIPP at approximately 80°C in conventional, insulated refinery trucks and pumped into a heated and insulated storage tank located near the shaft. The multi-deck stage will be hoisted into the headframe and mechanically secured for safety. Asphalt, heated to 180°C ±5°, will be pumped down the shaft to the fill elevation through the heated tremie line. Viscosity of the neat asphalt for the waterstops will be sufficiently low to allow limited penetration of the DRZ. Installation of asphalt in each of the concrete-waterstops is identical.

As the pipe is lowered, workers on the lower deck will attach the wiring required for heating circuits and apply insulation. Workers on the top deck will install flanged and electrically insulated couplings as required (the opening in the slip bowl will be large enough to permit the passage of these couplings). Properly equipping and lowering the pipe should progress at the rate of one section every 10 minutes. The lower asphalt waterstop requires approximately 607 m of pipe for a casing weight of 12,700 kg. Additionally, electrical wire and insulation will weigh about 7250 kg for a total equipped tremie line weight of 20,000 kg. Therefore, the safety factor for the tremie line is 50,000 kg/20,000 kg, or 2.5.

To minimize air entrainment, the lower end of the tremie line will be immersed as much as 1 m during hot asphalt emplacement. Therefore, the lower 3 m of casing will be left bare (to simplify cleaning when emplacement has been completed).

Initially the tremie line will be lowered until it contacts the concrete plug (immediately underlying the excavation for the waterstop) and then raised approximately 0.3 m. Asphalt emplacement will proceed as follows:

- The impedance heating system will be energized, heating the tremie line to 180°C ±5°, and the asphalt in the storage tank will be heated to approximately 180°C ±5°.
- Heated, neat asphalt will be pumped down the tremie line at a rate approximating 13 L/min. This low rate will ensure that the asphalt flows across the plug from the insertion point, completely filling the excavation and shaft to the design elevation.
- The tremie line will be raised 3 m and cleaned by pumping a neoprene swab through it with air pressure. Impedance heating will be stopped, and the line will be allowed to cool. When cool, the line will be hoisted, stripped, cleaned, disassembled, and stored for future use.

Sealing operations will be suspended until the air temperature at the top of the asphalt has fallen to approximately 50°C for the comfort of the workers when they resume activity at the fill horizon. Temperature will be determined by lowering a remotely read thermometer to an elevation approximately 3 m above the asphalt at the center of the shaft. The temperature of the asphalt at the center of the shaft will be 50°C in about a month, but active ventilation should permit work to resume in about two weeks (see calculations in Appendix D).

When sufficient cooling has occurred, workers will descend in the multi-deck stage and cover the hot asphalt with an insulating and structural material such as fiber-reinforced shotcrete,

as illustrated in Figure B-3. To accomplish this, they will spray cementitious shotcrete containing fibrillated polypropylene fibers (for added tensional strength), attaining a minimum thickness of approximately 0.6 m.

B4.3.2 Asphaltic Mastic Mix Column

Asphaltic mastic mix (AMM) for the column will be prepared on surface in a pug mill. Viscosity of the AMM can be tailored to provide desired properties such as limited migration into large fractures.

- AMM will be prepared by mixing the ingredients in the pug mill, which has been heated to 180°C ±5°. The mix will be pumped from the pug mill through the tremie line to the emplacement depth. AMM is self-leveling at this temperature, and its hydrostatic head will ensure intimate contact with the shaft walls.
- Pumping rate will be approximately 200 L/min for efficiency, because of the larger volume (approximately 1,224,700 L in the Air Intake Shaft). To facilitate efficient emplacement and avoid air entrainment, the tremie line will not be shortened until the mix has filled 6 vertical meters of the shaft. Back pressure (approximately 0.84 kg/cm^2) resulting from 6 m of AMM above the discharge point will be easily overcome from surface by the hydraulic head.

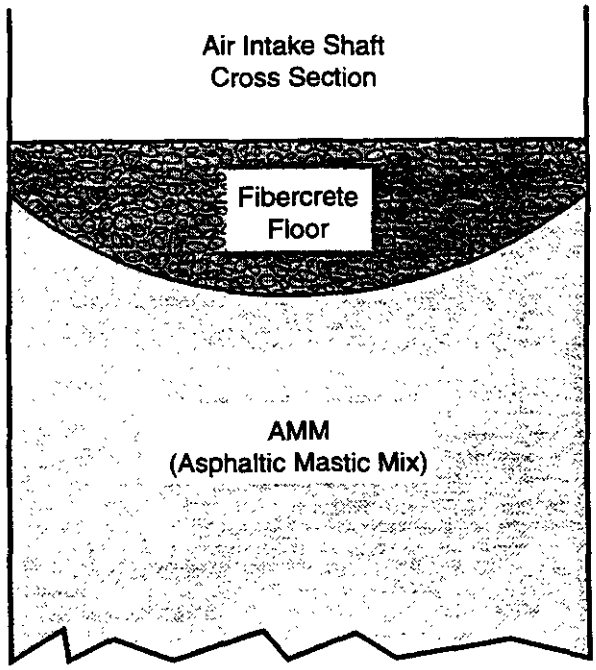

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Figure B-3. Typical fibercrete at top of asphalt.

After 6 vertical meters of AMM have been placed:

- Impedance heating current will be turned off and locked out (the hot line will drain completely).
- To prevent excessive back pressure resulting from AMM above the insertion point, the line will be disconnected from the pump and hoisted hot. Two sections will be stripped, removed, cleaned with a "pig," and stacked near the shaft.
- Electrical feed will be adjusted (because of the decreased resistance of the shortened line).
- The tremie line will be reconnected to the pump.
- The impedance heating system will be energized.
- When the temperature of the line has stabilized at 180°C ±5°, pumping will resume.

This procedure will be followed until the entire column, including the volume computed to counteract 0.9 m of vertical shrinkage (calculations in Appendix D), has been placed. The line will be disconnected from the pump and cleaned by pumping "pigs" through it with air pressure. It will then be hoisted, stripped, removed in 3-m sections, and stacked on surface for reuse.

Sealing operations will be suspended following removal of the tremie line, and ventilation will be continuous to speed cooling. The column will shrink vertically but maintain contact with the shaft walls as it cools. When the air temperature at 3 m above the asphalt has cooled sufficiently, workers will descend on the multi-deck stage and cover the hot asphalt with fibercrete as described for the concrete-asphalt waterstop (Section B4.3.1) and illustrated in Figure B-3.

Note: Near the top of the Salado Formation, portions of the concrete liner key, chemical seal rings, and concrete and steel shaft liners will be removed. Liner removal will occur before emplacement of AMM. For safety, exposed rock will be secured with horizontal, radial rock bolts and cyclone steel mesh. A range-finding device, fastened to the shaft wall approximately 3 m above the proposed top of the asphaltic column, will indicate when the hot AMM reaches the desired elevation. A remotely read thermometer, affixed to the shaft wall approximately 2 m above the proposed top of the column, will show when the air temperature has fallen sufficiently to resume operations. The intake of the rigid ventilation duct will be positioned approximately 3 m above the proposed top of the column, and ventilation will be continuous throughout emplacement and cooling of the asphaltic column. After the multi-deck stage has been hoisted into the headframe and mechanically secured for safety, emplacement of AMM will proceed.

B4.4 Compacted Salt Column

Crushed, mine-run salt, dynamically compacted against intact Salado salt, is the major long-term shaft seal element. As-mined WIPP salt will be crushed and screened to a maximum particle dimension of 5 mm. The salt will be transferred from surface to the fill elevation via the slickline and header. A flexible hose attached to the header will be used to emplace the salt, and a calculated weight of water will be added. After the salt has been nominally leveled, it will be dynamically compacted. Dynamic compaction consists of compacting material by dropping a tamper on it and delivering a specified amount of energy. The application of three times

Modified Procter Energy (MPE) to each lift (one MPE equals 2,700,000 Joules/m^3) will result in compacting the salt to 90% of the density of in-place rock salt.

Approximately 170 vertical meters of salt will be dynamically compacted. Dynamic compaction was validated in a large-scale demonstration at Sandia National Laboratories during 1995. As-mined WIPP salt was dynamically compacted to 90% density of in-place rock salt in a cylindrical steel chamber simulating the Salt Handling Shaft (Ahrens and Hansen, 1995). Depth of compaction is greater than that achieved by most other methods, allowing the emplacement of thicker lifts. For example, dropping the 4.69 metric ton tamper 18 m (as specified below) results in a compaction depth of approximately 4.6 m, allowing emplacement of lifts 1.5-m high. Most other compaction methods are limited to lifts of 0.3 m or less. Lift thickness will be increased and drop height decreased for the initial lift above the concrete plug at the base of the salt column to ensure that the concrete is not damaged. Drop height for the second and third lifts will be decreased as well. Although the tamper impact is thereby reduced, three MPE will be delivered to the entire salt column.

If lifts are 1.5-m thick, the third lift below the surface will receive additional densification during compaction of overlying lifts, and this phenomenon will proceed up the shaft. Construction will begin by hoisting the multi-deck stage to the surface and attaching the cable, electromagnet, and tamper to the hoist on the polar crane. The multi-deck assembly will be lowered to the placement elevation, and moisture content of the crushed and screened salt will be calibrated. Then the salt will be conveyed at a measured rate via a weighbelt conveyor to a vibrator-equipped hopper overlying the 15.2-cm ID slickline. The salt will pass down the slickline and exit a flexible hose connected to the header. A worker will direct the discharge so that the upper surface of the lift is nominally level and suitable for dynamic compaction. A second worker will add potable water, in the form of a fine spray, to the salt as it exits the hose. Water volume will be electronically controlled and coordinated with the weight of the salt to achieve the desired moisture content.

The initial lift above the SMC will be 4.6 m, and drop height will be 6 m. This increased lift thickness and reduced drop height are specified to protect the underlying SMC plug from damage and/or displacement from tamper impact. Compaction depth for a drop height of 6 m is approximately 3.7 m. Ultimately, the tamper will be dropped six times in each position, resulting in a total of 132 drops per lift in the larger shafts. The drop pattern is shown in Figure B-4. A salt lift 1.5 m high will then be placed and leveled. Following compaction of the initial lift, the multi-deck stage will be positioned so the base of the hoisted tamper is 10 m above the surface of the salt.

The multi-deck stage will then be secured to the shaft walls by activating hydraulically powered locking devices. Hydraulic pressure will be maintained on these units when they are in the locked position; in addition, a mechanical pawl and ratchet on each pair will prevent loosening. The safety factor for the locking devices has been calculated to be approximately 4.5. After locking, tension in the hoisting cables will be relaxed, and centering rams will be activated to level the decks. Prior to positioning the stage, tension will be applied to the hoisting cables; the centering rams will be retracted; and the locking devices will be disengaged.

The work deck will be hoisted until the base of the retracted tamper is 23 m above the surface of the salt, where it will be locked into position and leveled as described above. This

procedure, repeated throughout the salt column, allows emplacement and compaction of three lifts (1.5-m thick) per multi-deck stage move. Depth of compaction for a drop height of 18 m is approximately 4.6 m. Therefore the third lift below the fill surface will receive a total of 9 MPE (274,560 m kg/m^3), matching the energy applied in the successful, large-scale demonstration.

The compactive effect expands laterally as it proceeds downward from the base of the tamper and will effectively compact the salt into irregularities in the shaft wall, as demonstrated in the large-scale demonstration. Although other techniques could be used, dynamic compaction was selected because it is simple, can be used in the WIPP shafts, and has been demonstrated (Hansen and Ahrens, 1996).

The tamper will be dropped from the hoisted position by turning off the power to the electromagnet. Immediately upon release, the crane operator will "chase" the tamper by lowering the electromagnet at twice hoisting speed; the magnet will engage the tamper, allowing it to be hoisted for the subsequent drop. Initially, the tamper will be dropped in positions that avoid impact craters caused by preceding drops. The surface will then be leveled manually and the tamper dropped in positions omitted during the previous drop series.

Experience gained during the large-scale salt compaction demonstration indicated that a considerable volume of dust is generated during the emplacement of the salt, but not during dynamic compaction. However, because the intake of the rigid vent duct is below the multi-deck stage, workers below the stage will wear respirators during emplacement. They will be the only workers affected by dust during dynamic compaction.

The Air Intake Shaft will require 22 drop positions (Figure B-4). Application of one MPE requires six drops in each position, for a total of 132 drops per lift. Three MPE, a total of 396 drops per lift, will be applied to all salt. After each compaction cycle, the salt surface will be leveled manually and the tamper will be dropped in positions omitted in the preceding drop series. Two lifts, each 1.8 m high, will then be sequentially placed, leveled, and compacted with two MPE, using a 6-m drop height.

Dynamic compaction ensures a tight interface. Salt compacted during the large-scale dynamic compaction demonstration adhered so tenaciously to the smooth interior walls of the steel compaction chamber that grinders with stiff wire wheels were required for its removal.

B4.5 Grout

Ultrafine sulfate-resistant cementitious grout (Ahrens et al., 1996) is selected as the sealing material. Specifically developed for use at the WIPP, and successfully demonstrated in an in situ test, the hardened grout has a permeability of 1×10^{-21} m^2. It has the ability to penetrate fractures smaller than 6 microns and is being used for the following purposes:

- to seal many of the microfractures in the DRZ and ensure a tight interface between SMC and the enclosing rock, and
- to solidify fractured rock behind existing concrete shaft liners, prior to removal of the liner (for worker safety).

The interface between concrete plugs in the Salado Formation (and one in the Rustler Formation, a short distance above the Salado) will be grouted. A 45° downward-opening cone of

reverse circulation diamond drill holes will be collared in the top of the plugs, drilled in a spin pattern (see Figure B-5), and stage grouted with ultrafine cementitious grout at 3.5 kg/cm^2 below lithostatic pressure. Stage grouting consists of:

- drilling and grouting primary holes, one at a time;
- drilling and grouting secondary holes, one at a time, on either side of the primary holes that accepted grout; and
- (if necessary) drilling and grouting tertiary holes on either side of secondary holes that accepted grout.

Note: For safety, all liner removal tasks will be accomplished from the bottom deck. In areas where the steel liner is removed, it will be cut into manageable pieces with a cutting torch and hoisted to the surface for disposal. Mechanical methods will be employed to clean and roughen the existing concrete shaft liner before placing the Dewey Lake SMC plug in the shafts.

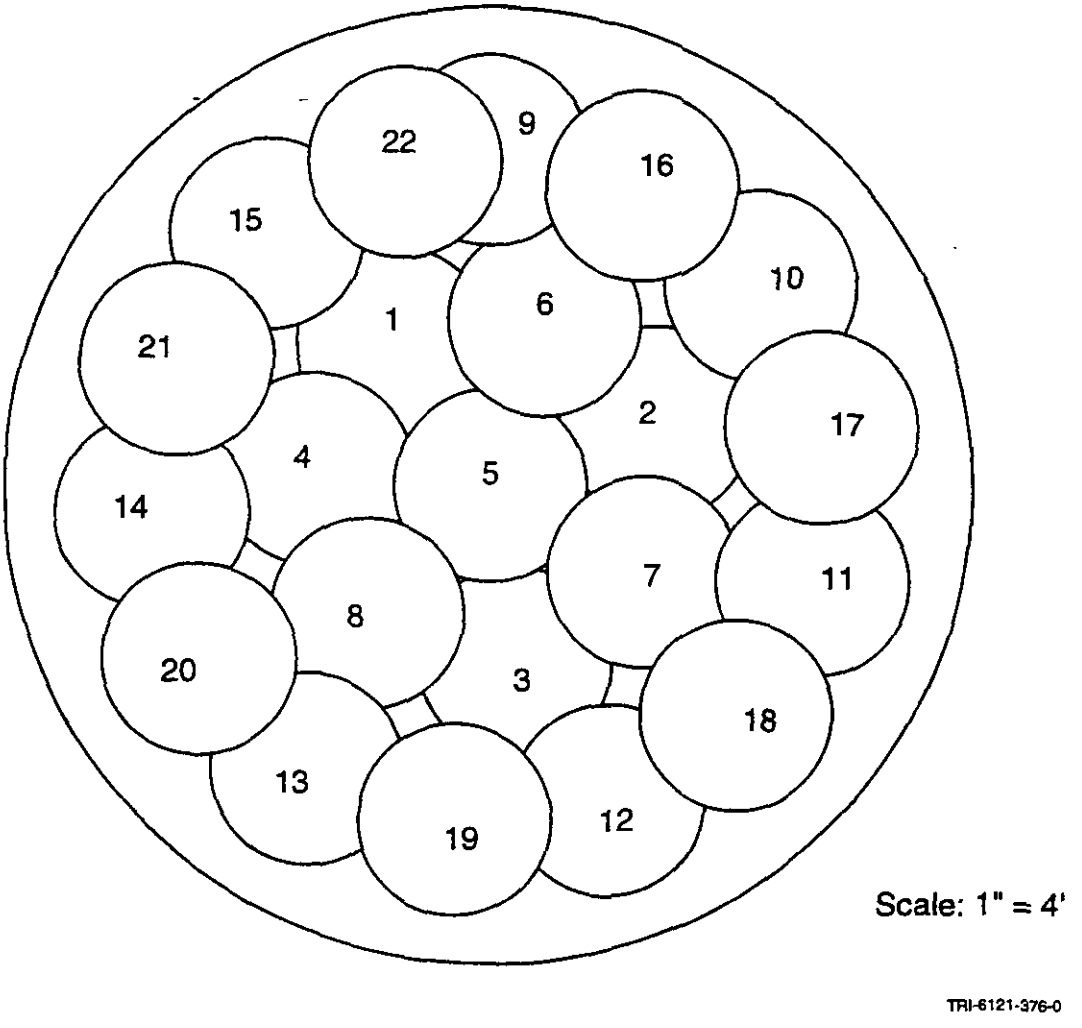

Figure B-4. Drop pattern for 6-m-diameter shaft using a 1.2-m-diameter tamper.

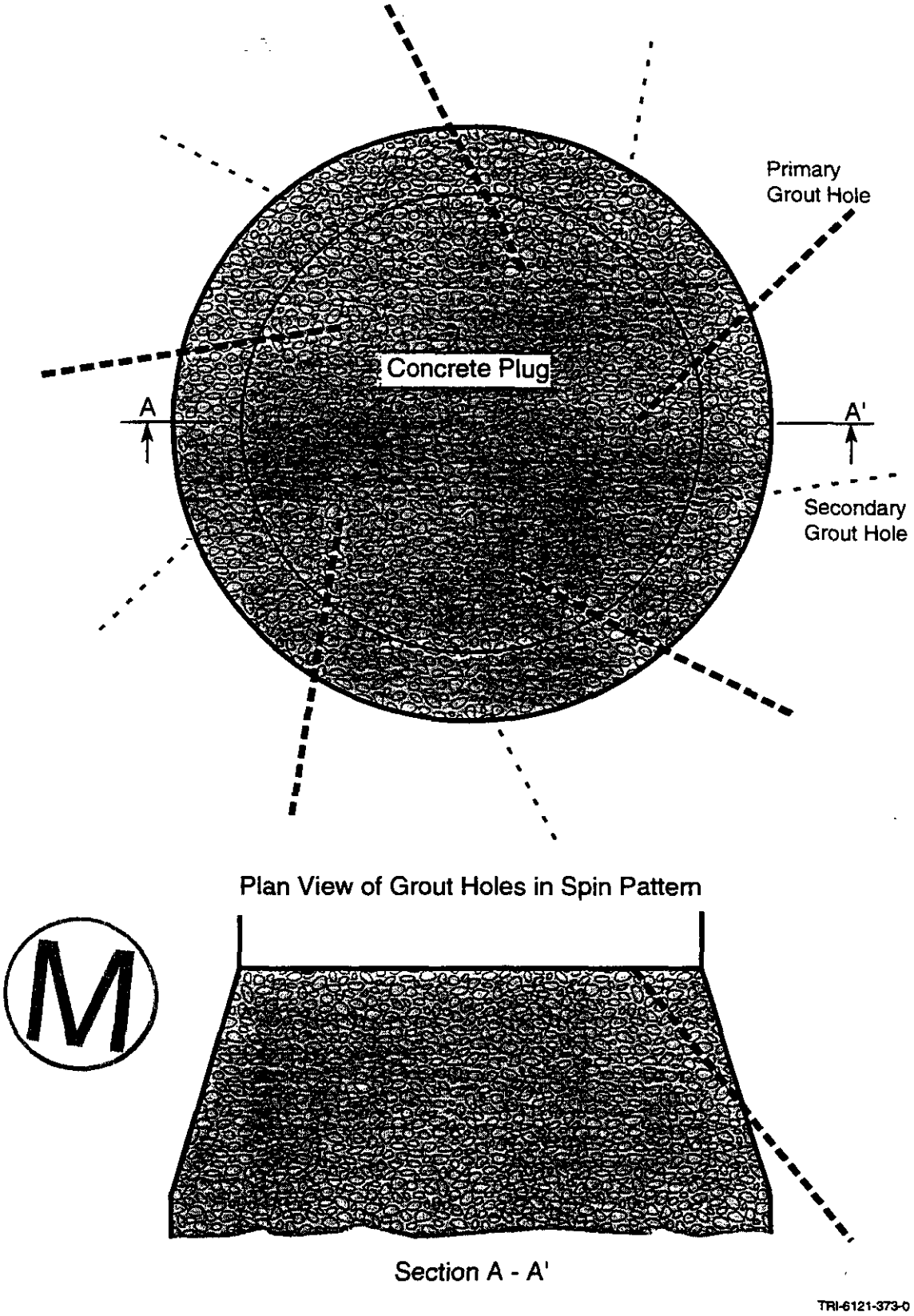

Figure B-5. Plan and section views of downward spin pattern of grout holes.

The work sequence will start 3 m below the lower elevation of liner removal. A 45° upward-opening cone of grout injection holes, drilled in a "spin" pattern (Figure B-6), will be drilled to a depth subtending one shaft radius on a horizontal plane. These holes will be stage grouted as described in Section 4.5. Noncoring, reverse circulation, diamond drill equipment will be used to avoid plugging fractures with fine-grained diamond drill cuttings. Ultrafine cementitious grout will be mixed on the surface, transferred via the slickline to the upper deck of the multi-deck stage, and injected at 3.5 kg/cm^2 gage below lithostatic pressure to avoid hydrofracturing the rock. Grout will be transferred in batches, and after each transfer, a "pig" will be pumped through the slickline and header to clean them. Grouting will proceed upward from the lowest fan to the highest. Recent studies conducted in the Air Intake Shaft (Dale and Hurtado, 1996) show that this hole depth exceeds that required for complete penetration of the Disturbed Rock Zone (DRZ). Maximum horizontal spacing at the ends of the holes will be 3 m.

The multi-deck stage will then be raised 3 m and a second fan, identical to the first, will be drilled and grouted. This procedure will continue, with grout fans 3 m apart vertically, until the highest fan, located 3 m above the highest point of liner removal, has been drilled and grouted. Ultrafine cementitious grout was observed to penetrate more than 2 m in the underground grouting experiment conducted at the WIPP in Room L-3 (Ahrens and Onofrei, 1996).

When grouting is completed, the multi-deck stage will be lowered to the bottom of the liner removal section and a hole will be made through the concrete liner. This hole, approximately 30 cm in diameter, will serve as "free-face" to which the liner will be broken. Similar establishment and utilization of free face is a common practice in hard rock mining (e.g., the central drill hole in a series drilled into the rock to be blasted is left empty and used as free-face to which explosives in adjacent holes break the rock). Radial, horizontal percussion holes will be drilled on a 30-cm grid (or less, if required), covering the liner to be removed. Hydraulic wedges, activated in these holes, will then break out the liner, starting adjacent to the free face and progressing away from it, from the bottom up. Broken fragments of the concrete liner will fall to the fill surface below.

A mucking "claw," suspended from the trolley of the polar crane, will collect the broken concrete and place it in the bucket for removal to the surface. As many as three buckets can be used to speed this work.

B4.6 Compacted Earthen Fill

Local soil, screened to a maximum particle dimension of 13 mm, will be placed and compacted to inhibit the migration of surficial water into the shaft cross section. Such movement is further decreased by a 12-m high SMC plug at the top of the Dewey Lake Redbeds.

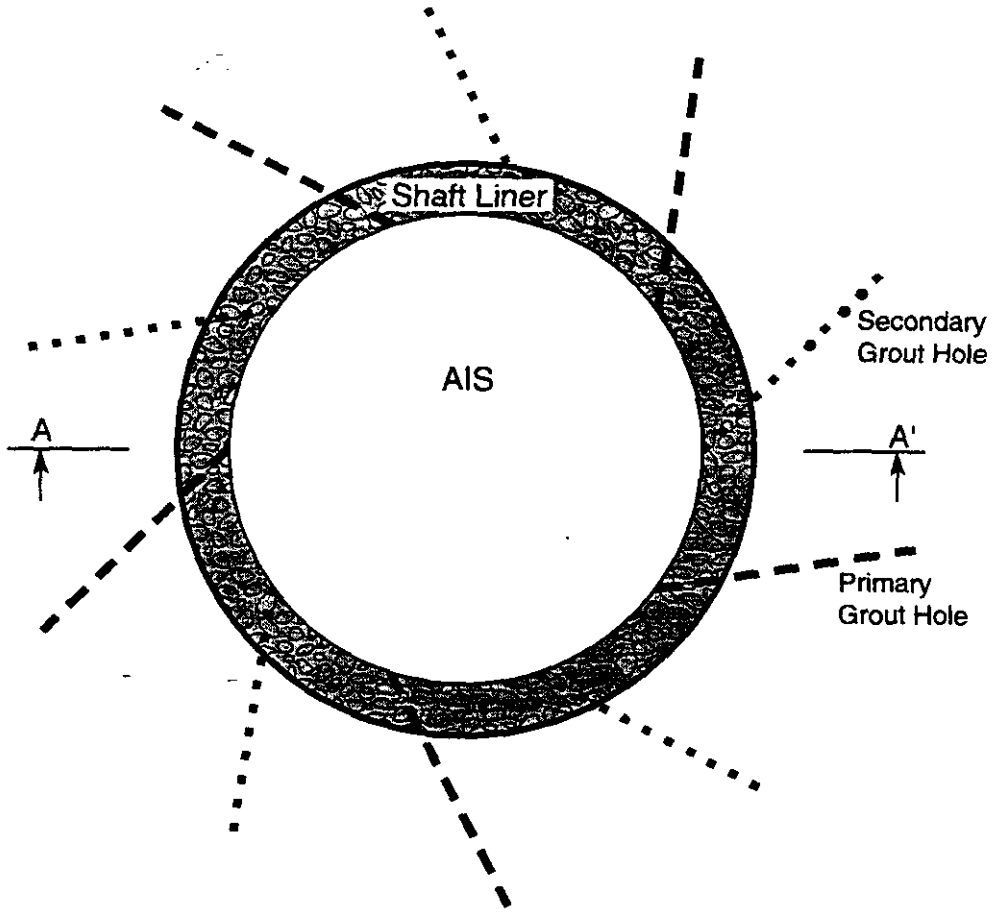

Plan View of Grout Holes in Spin Pattern

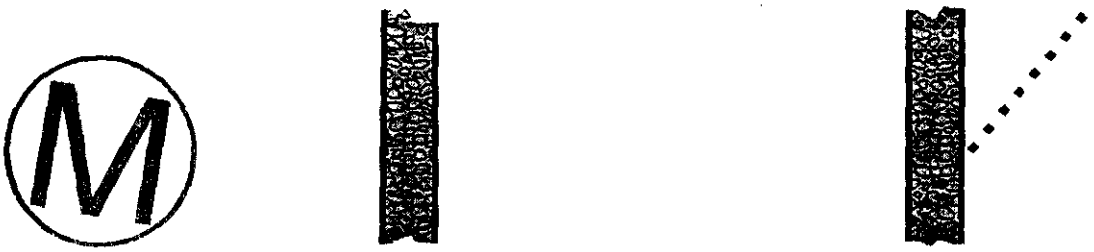

Section A - A'

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Figure B-6. Plan and section views of upward spin pattern of grout holes.

B4.6.1 Lower Section

Emplacement of the compacted earthen fill will proceed as follows:

- Moisture content of the screened soil will be determined.
- The soil will then be transferred via the slickline, header, and flexible hose from surface to the fill elevation. The moisture content optimal for compaction will be achieved using the same procedure as described for compacted salt (Section B4.4). The soil will be emplaced in lifts 1.2 m high (depth of compaction is approximately 3.7 m) and dynamically compacted using a drop height of 18.3 m.
- The fill will be dynamically compacted until its hydraulic conductivity to water is nominally equivalent to that of the surrounding formation.

This procedure will continue until the lower section has been emplaced and compacted. Care will be exercised at the top of the column to ensure that all soil receives sufficient compaction.

B4.6.2 Upper Section

The upper section contains insufficient room to employ dynamic compaction. Therefore the screened soil, emplaced as described above, will be compacted by vibratory-impact sheepsfoot roller, vibratory sheepsfoot roller, or a walk-behind vibratory-plate compactor. Because of the limited compaction depth of this equipment, lifts will be 0.3 m high. The top of the fill will be coordinated with the WIPP Operating Contractor to accommodate plans for decommissioning surface facilities and placing markers.

B4.7 Schedule

Preliminary construction schedules are included on the following pages. The first schedule is a concise outline of the total construction schedule. It is followed by individual schedules for each shaft. The first schedule in each shaft series is a truncated schedule showing the major milestones. The truncated schedules are followed by detailed construction schedules for each shaft. These schedules indicate that it will take approximately six and a half years to complete the shaft sealing operations, assuming two shafts are simultaneously sealed.

M

SEALING SCHEDULE--ALL SHAFTS

ID	Task Name	Duration
1	Project Mobilization	15w
2	Air Intake Shaft Shaft	159.85w
3	Salt Shaft	115.19w
4	Exhaust Shaft	129.23w
5	Waste Shaft	172.71w
6	Project Demobilization	8w

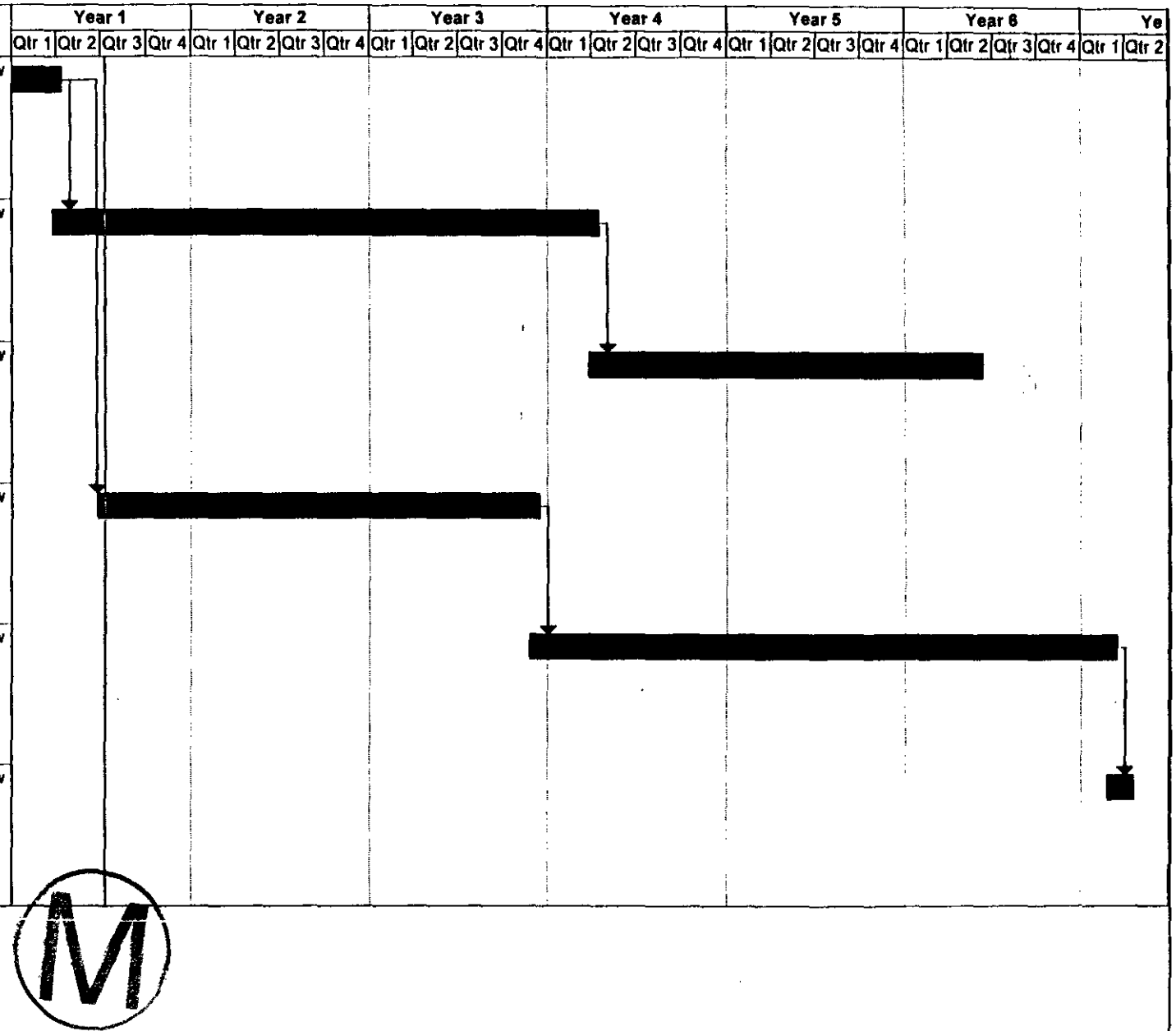

Project:SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task		Summary		Rolled Up Progress	
Progress		Rolled Up Task			
Milestone		Rolled Up Milestone			

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M

SEALING SCHEDULE--AIR INTAKE SHAFT

ID	Task Name	Duration
1	Mobilization	4w
3	Plant Set-up	12w
5	Inspect & Scale Shaft-2151'	1w
7	Install Construction Utilities	7.17w
9	Drill & Grout Lining	11.5w
11	Shaft Station Monolith-37'	4.78w
15	Lower Salado Compacted Clay Column-93.5'	4.96w
17	Lower Concrete-Asphalt Waterstop-50'	8.25w
26	Compacted Salt Column-563.5'	23.58w
28	Middle Concrete-Asphalt Waterstop-50'	8.25w
37	Upper Salado Compacted Clay Column-344'	18.24w
39	Upper Concrete-Asphalt Waterstop-50'	10.25w
48	Asphalt Column-138.3'	19.41w
56	Concrete Plug-20'	5.99w
61	Remove Concrete Shaft Lining	5.71w
63	Rustler Compacted Clay Column-234.7'	8.36w
65	Compacted Earthen Fill-473'	7.59w
67	Concrete Plug-40'	2.96w
71	Compacted Earthen Fill-57'	0.65w
73	Demobilization	3.2w

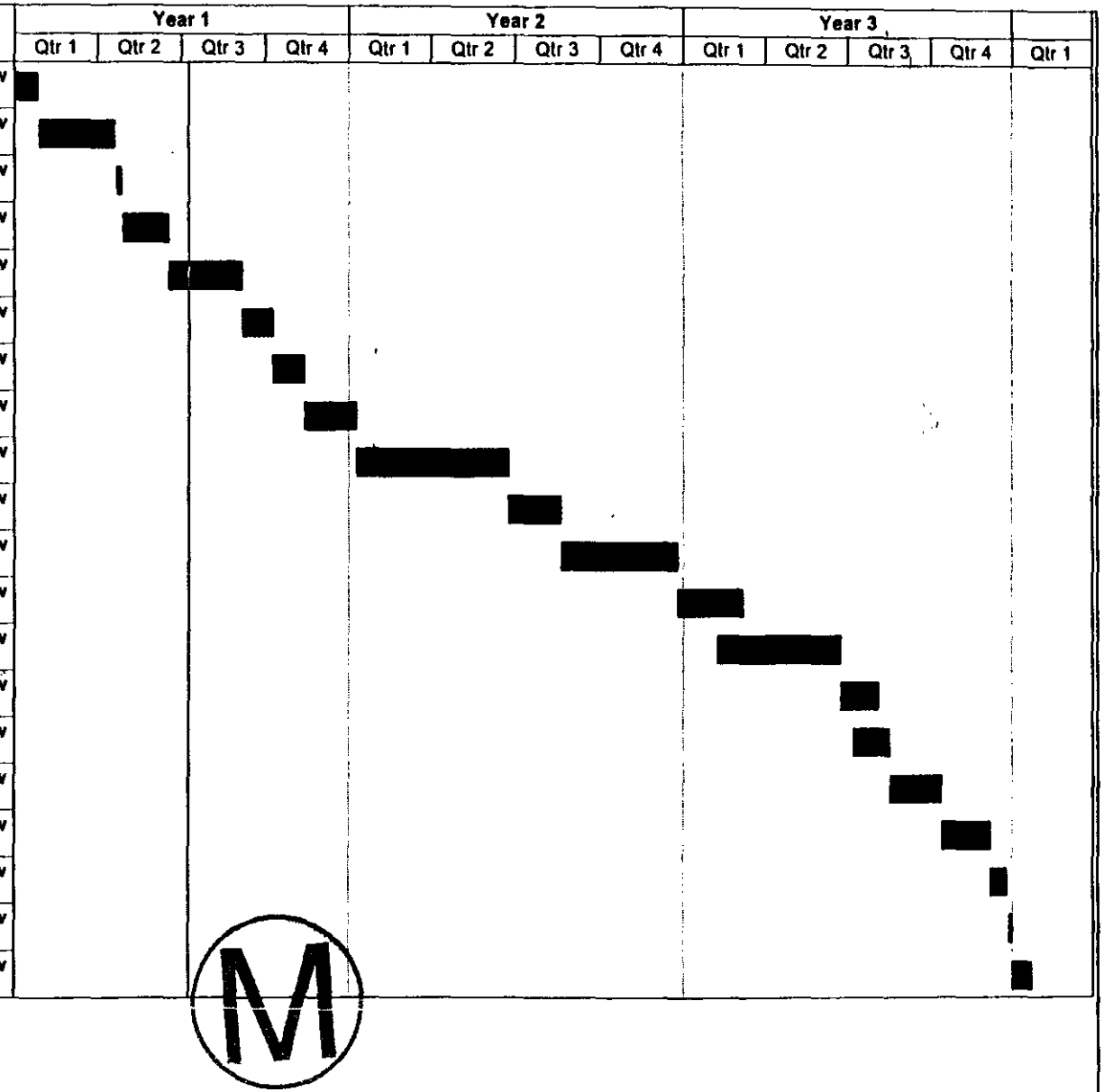

Project: AIR INTAKE SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
1	**Mobilization**	4w
2	Mobilize	4w
3	**Plant Set-up**	12w
4	Plant Set-up	12w
5	**Inspect & Scale Shaft-2151'**	1w
6	Inspect & Scale Shaft	1w
7	**Install Construction Utilities**	7.17w
8	Install Utilities	7.17w
9	**Drill & Grout Lining**	11.5w
10	Drill & Grout Lining	11.5w
11	**Shaft Station Monolith-37'**	4.78w
12	Construct Bulkheads	0.8w
13	Pour Concrete (37' high)	0.98w
14	Cure Concrete	3w
15	**Lower Salado Compacted Clay Column-93.5'**	4.96w
16	Emplace Bentonite Blocks (93.5' high)	4.96w
17	**Lower Concrete-Asphalt Waterstop-50'**	8.25w
18	Excavate for Lower Plug	1.67w
19	Pour Concrete-Lower Plug (23' high typ.)	0.28w
20	Excavate Waterstop	0.63w
21	Place Asphalt (4' high typ.)	0.72w
22	Cool-down Asphalt	1w

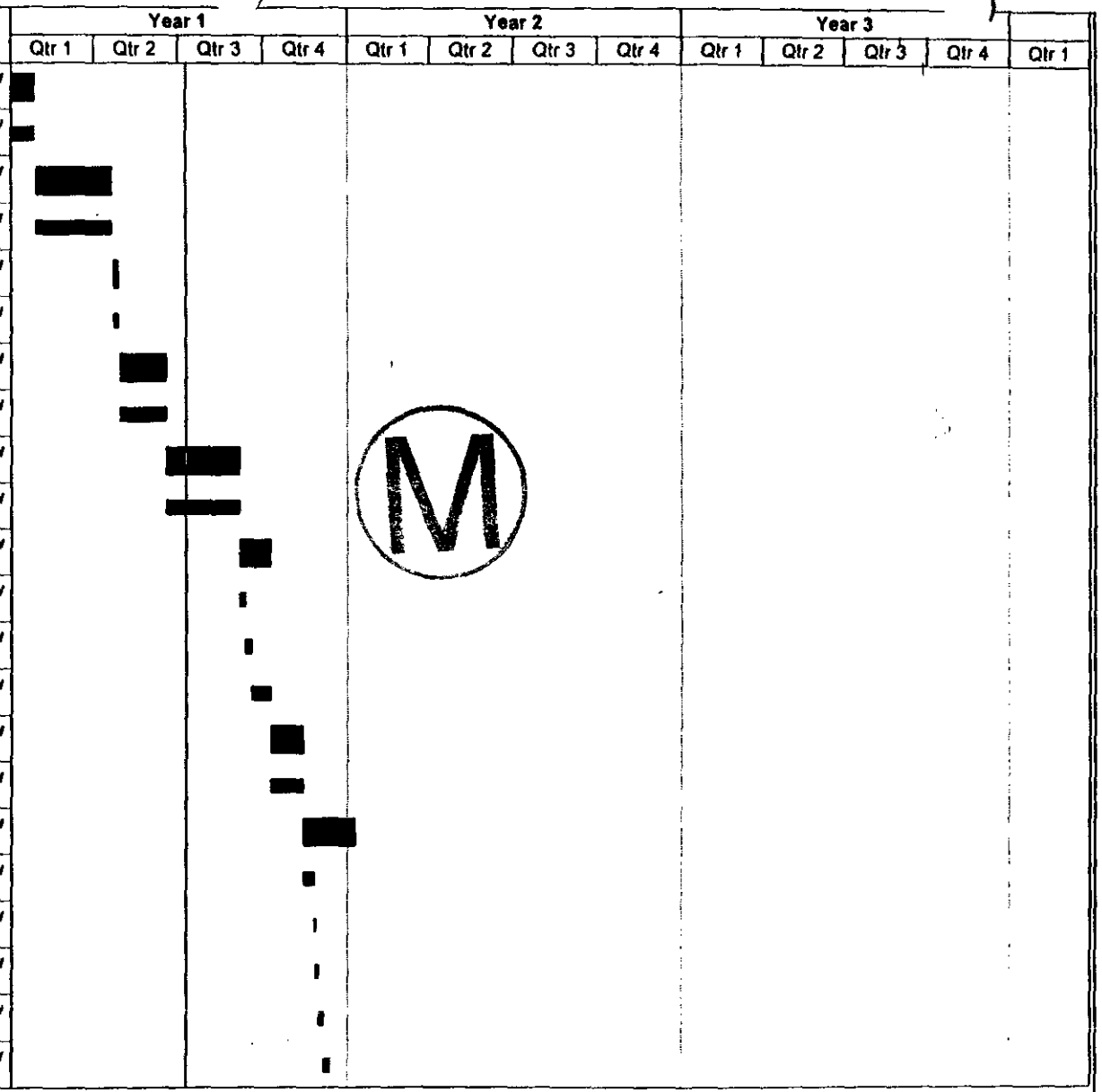

Project: AIR INTAKE SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
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Summary
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Rolled Up Progress

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ID	Task Name	Duration
23	Excavate for Upper Plug	1.67w
24	Pour Concrete-Upper Plug (23' high typ.)	0.28w
25	Cure Concrete	2w
26	**Compacted Salt Column-563.5'**	**23.58w**
27	Emplace & Compact Crushed/Screened Salt	23.58w
28	***Middle Concrete-Asphalt Waterstop-50'***	***8.25w***
29	Excavate for Lower Plug	1.67w
30	Pour Concrete-Lower Plug	0.28w
31	Excavate Waterstop	0.63w
32	Place Asphalt	0.72w
33	Cool-down Asphalt	1w
34	Excavate for Upper Plug	1.67w
35	Pour Concrete-Upper Plug	0.28w
36	Cure Concrete	2w
37	**Upper Salado Compacted Clay Column-344'**	**18.24w**
38	Emplace Bentonite Blocks	18.24w
39	***Upper Concrete-Asphalt Waterstop-50'***	**10.25w**
40	Excavate for Lower Plug	1.67w
41	Pour Concrete-Lower Plug	0.28w
42	Excavate Waterstop	0.63w
43	Place Asphalt	0.72w
44	Cool-down Asphalt	1w

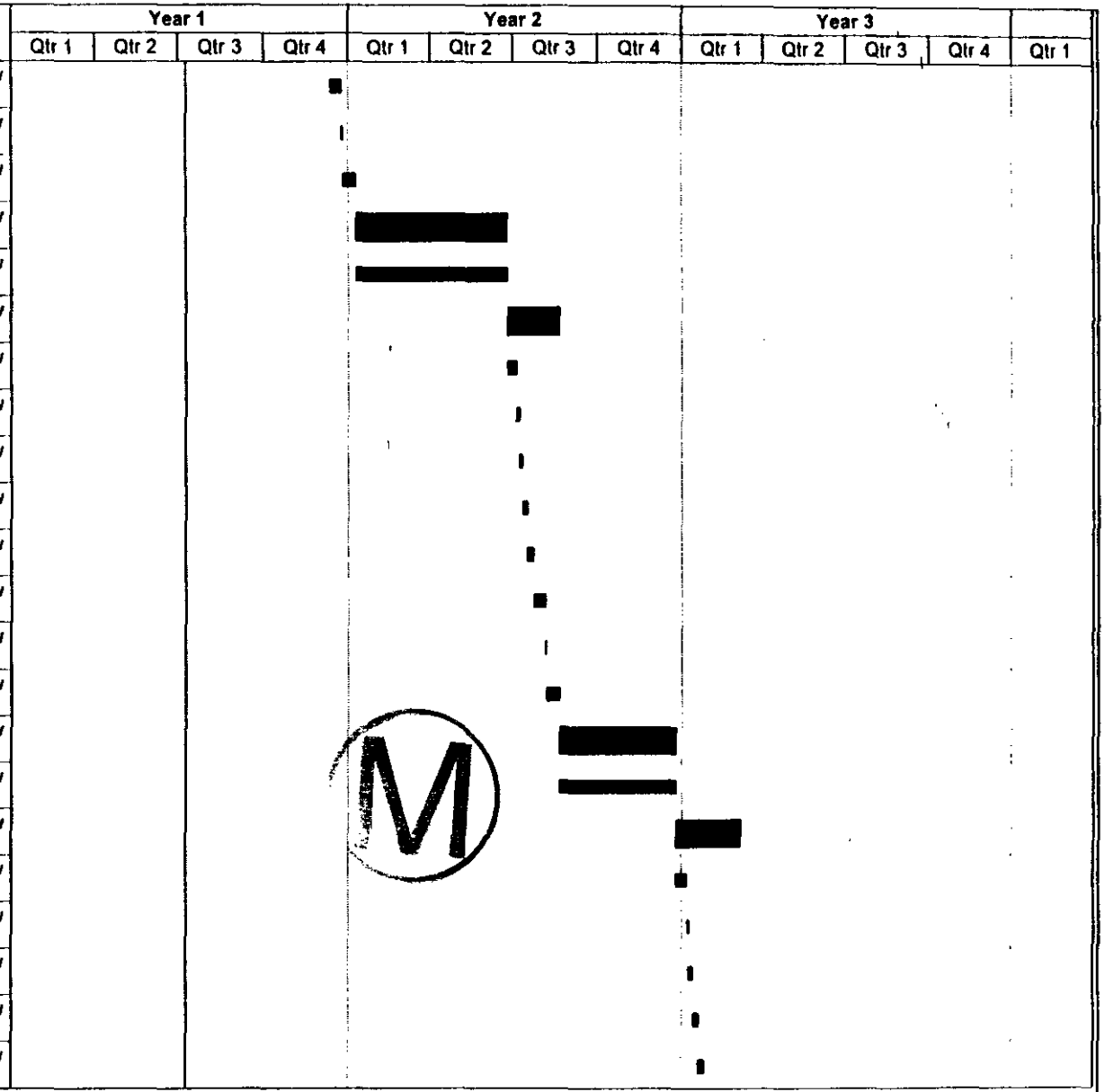

Project: AIR INTAKE SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
45	Excavate for Upper Plug	1.67w
46	Pour Concrete-Upper Plug	0.28w
47	Cure Concrete	4w
48	**Asphalt Column-138.3'**	**19.41w**
49	Remove Lining in Key	3.76w
50	Remove Chemical Seal Rings	0.6w
51	Mobilize to Emplace Asphalt	0.3w
52	Asphalt in Salt Section	3.62w
53	Asphalt in Lower Lined Section	1.93w
54	Complete Asphalt Emplacement	2.77w
55	Cool-down Asphalt	6.43w
56	**Concrete Plug-20'**	**5.99w**
57	Remove Concrete Lining & Rock	1.65w
58	Remove Liner Plate	0.13w
59	Pour Concrete(20' high)	0.21w
60	Cure Concrete	4w
61	**Remove Concrete Shaft Lining**	**5.71w**
62	Remove 86' of lining--4 zones	5.71w
63	**Rustler Compacted Clay Column-234.7'**	**8.36w**
64	Emplace & Compact Bentonite(234.7' high)	8.36w
65	**Compacted Earthen Fill-473'**	**7.59w**
66	Emplace & Compact Earthen Fill(473' high)	7.59w

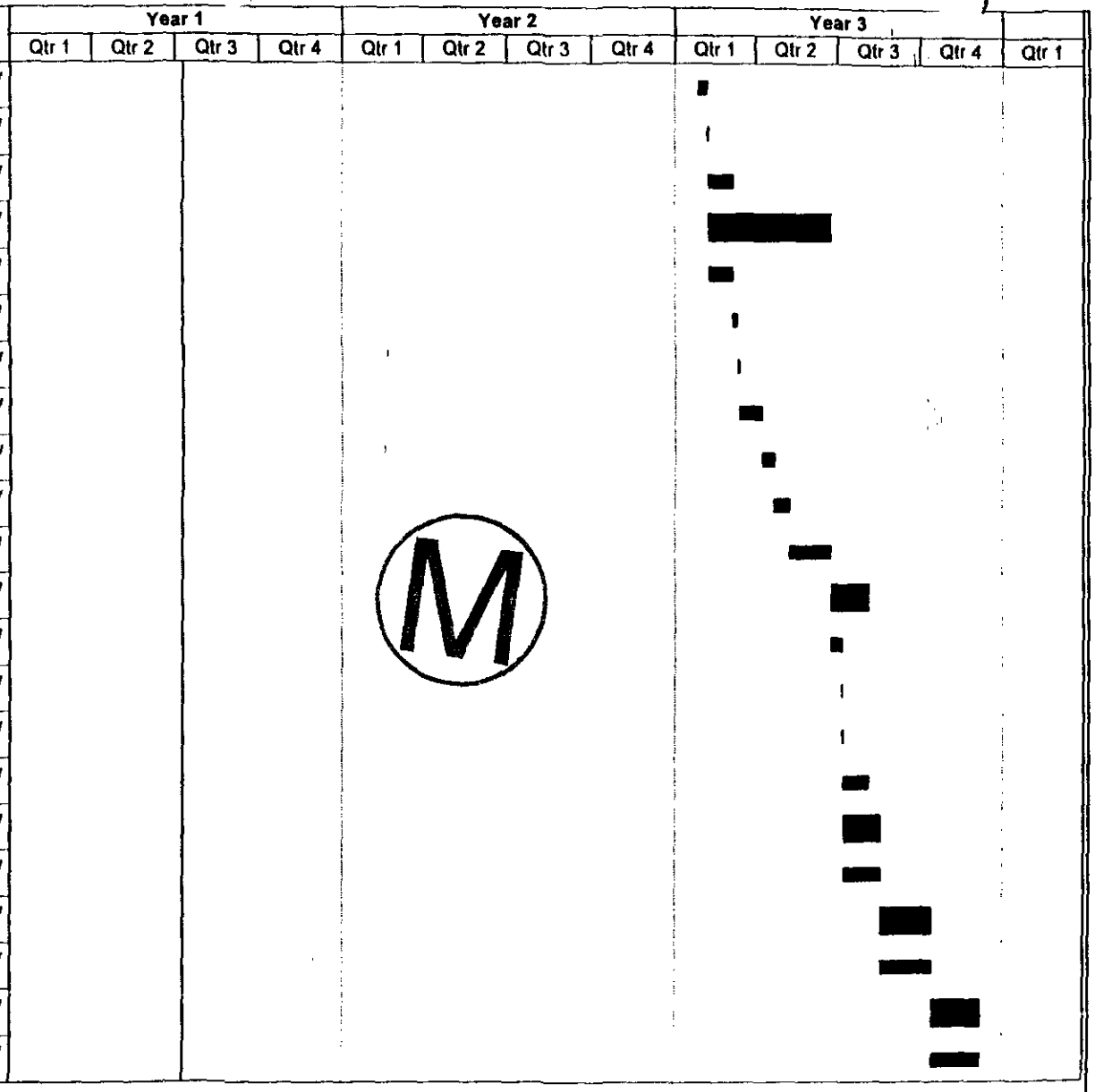

Project: AIR INTAKE SHAFT SEALING SCHEDULE
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Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

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ID	Task Name	Duration
67	**Concrete Plug-40'**	**2.96w**
68	Clean Existing Surface	0.6w
69	Pour Concrete(40' high)	0.36w
70	Cure Concrete	2w
71	**Compacted Earthen Fill-57'**	**0.65w**
72	Emplace & Compact Earthen Fill (57' high)	0.65w
73	**Demobilization**	**3.2w**
74	Demob	3.2w

Project: AIR INTAKE SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

SEALING SCHEDULE--SALT HANDLING SHAFT

M

ID	Task Name	Duration
1	Mobilization	4w
3	Plant Set-up	12w
5	Inspect & Scale Shaft-2164.5'	1.06w
7	Install Construction Utilities	7.6w
9	Drill & Grout Lining	5.35w
12	Shaft Station Monolith-37'	4.44w
16	Lower Salado Compacted Clay Column-107'	3.06w
18	Lower Concrete-Asphalt Waterstop-50'	8.74w
27	Compacted Salt Column-560'	12.67w
29	Middle Concrete-Asphalt Waterstop-50'	6.74w
38	Upper Salado Compacted Clay Column-335'	9.58w
40	Upper Concrete-Asphalt Waterstop-50'	8.74w
49	Asphalt Column-140'	15.33w
57	Concrete Plug-20'	5.32w
61	Remove Concrete Shaft Lining	1.9w
63	Rustler Compacted Clay Column-234'	4.81w
65	Compacted Earthen Fill-449'	3.65w
67	Concrete Plug-40'	2.45w
71	Compacted Earthen Fill-92.5'	0.65w
73	Demobilization	3w

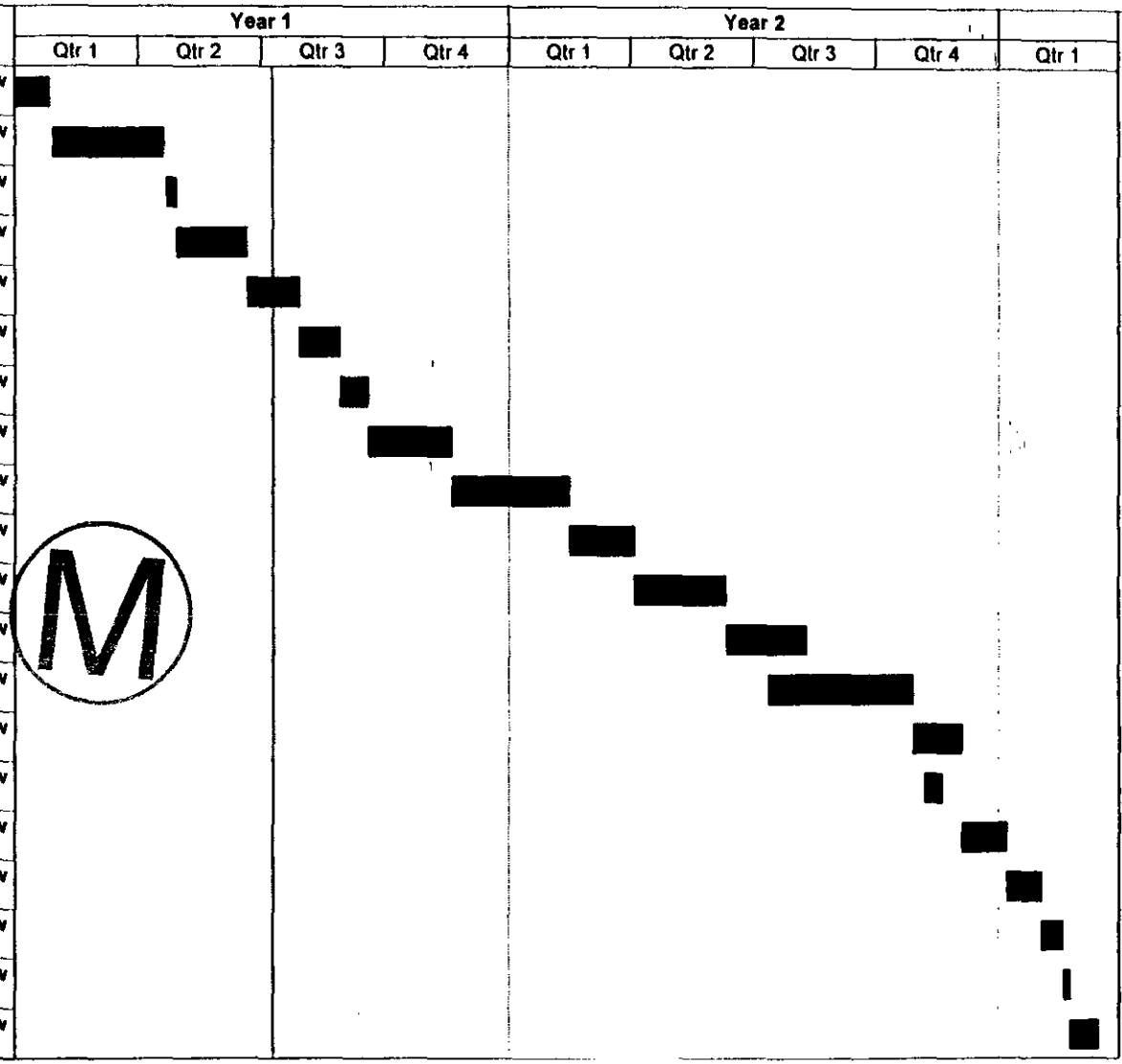

Project: SALT HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
1	**Mobilization**	4w
2	Mobilize	4w
3	**Plant Set-up**	12w
4	Plant Set-up	12w
5	**Inspect & Scale Shaft-2164.5'**	1.06w
6	Inspect & Scale Shaft	1.06w
7	**Install Construction Utilities**	7.6w
8	Install Utilities	7.6w
9	**Drill & Grout Lining**	5.35w
10	Drill Grout Holes	2.14w
11	Grout Lining	3.21w
12	**Shaft Station Monolith-37'**	4.44w
13	Construct Bulkheads	0.8w
14	Pour Concrete (37' high)	0.64w
15	Cure Concrete	3w
16	**Lower Salado Compacted Clay Column-107'**	3.06w
17	Emplace Bentonite Blocks (107.0 ' high)	3.06w
18	**Lower Concrete-Asphalt Waterstop-50'**	8.74w
19	Excavate for Lower Plug	1.38w
20	Pour Concrete-Lower Plug (23' high-typ)	0.17w
21	Excavate Waterstop	0.34w
22	Place Asphalt (4' high-typ)	0.3w

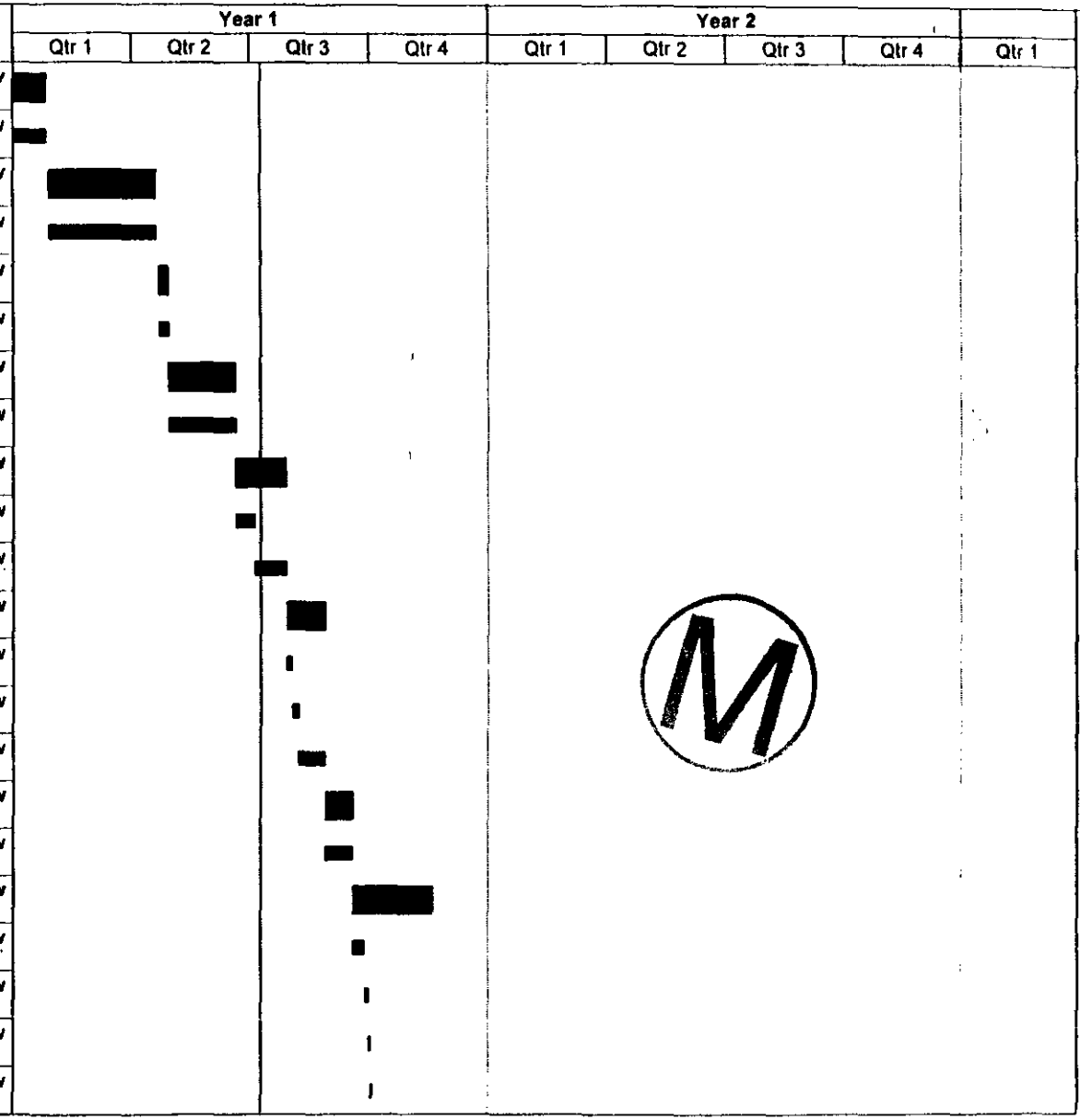

Project: SALT HANDLING SHAFT SEALING SCHEDULE
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Task
Progress
Milestone
Summary
Rolled Up Task
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Rolled Up Progress

Page 1

ID	Task Name	Duration
23	Cool-down Asphalt	1w
24	Excavate for Upper Plug	1.38w
25	Pour Concrete-Upper Plug (23' high-typ)	0.17w
26	Cure Concrete	4w
27	**Compacted Salt Column-560'**	**12.67w**
28	*Emplace & Compact Crushed/Screened Salt*	12.67w
29	**Middle Concrete-Asphalt Waterstop-50'**	**6.74w**
30	Excavate for Lower Plug	1.38w
31	Pour Concrete-Lower Plug	0.17w
32	Excavate Waterstop	0.34w
33	Place Asphalt	0.3w
34	Cool-down Asphalt	1w
35	Excavate for Upper Plug	1.38w
36	Pour Concrete-Upper Plug	0.17w
37	Cure Concrete	2w
38	**Upper Salado Compacted Clay Column-335'**	**9.58w**
39	Emplace Bentonite Blocks	9.58w
40	**Upper Concrete-Asphalt Waterstop-50'**	**8.74w**
41	Excavate for Lower Plug	1.38w
42	Pour Concrete-Lower Plug	0.17w
43	Excavate Waterstop	0.34w
44	Place Asphalt	0.3w

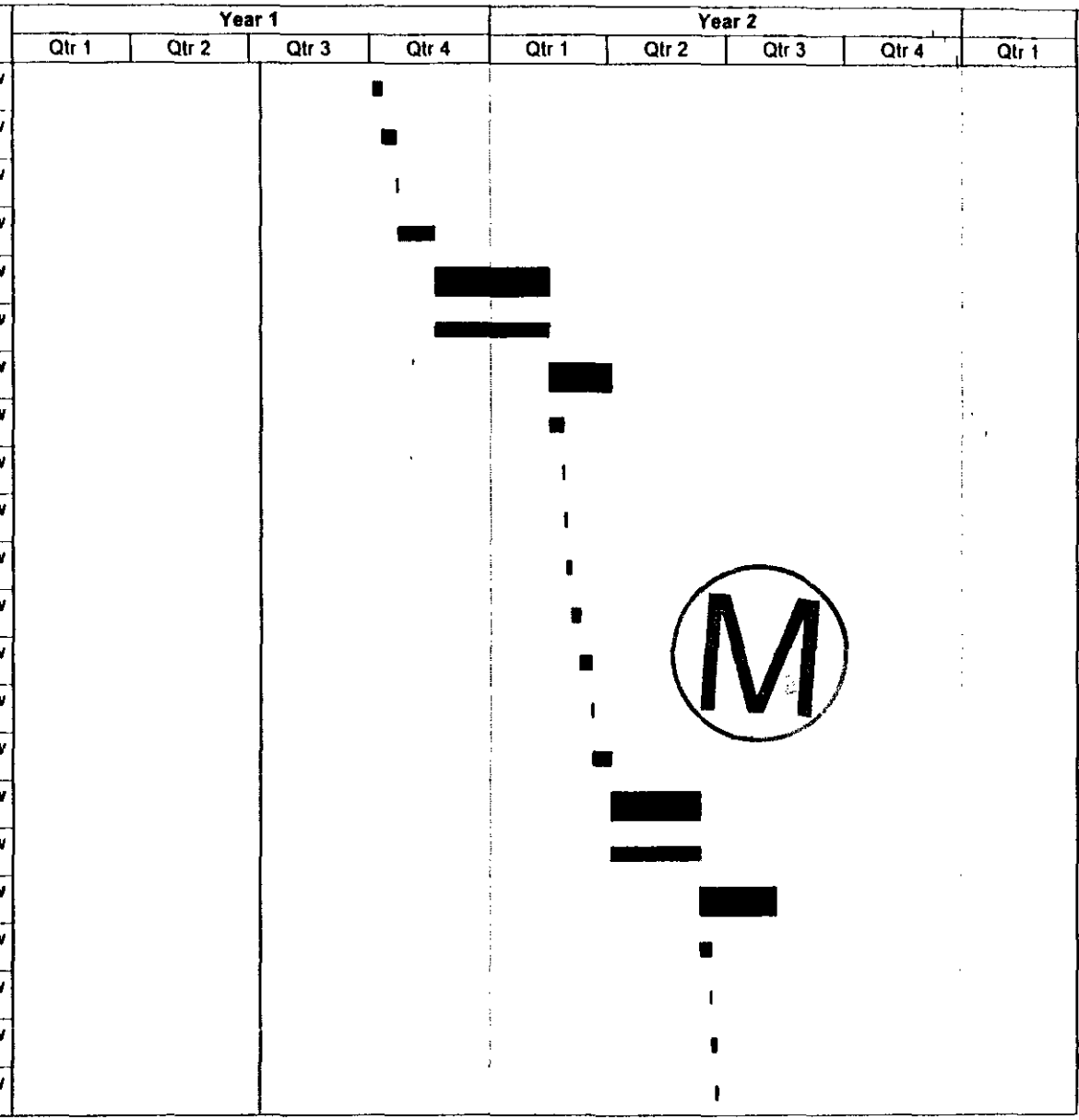

Project: SALT HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
45	Cool-down Asphalt	1w
46	Excavate for Upper Plug	1.38w
47	Pour Concrete-Upper Plug	0.17w
48	Cure Concrete	4w
49	**Asphalt Column-140'**	**15.33w**
50	Remove Lining in Key	2.02w
51	Remove Chemical Seal Rings	0.4w
52	Mobilize to emplace asphalt	2w
53	Asphalt in Salt Section	2.73w
54	Asphalt in Lower Lined Section	0.25w
55	Complete Asphalt Emplacement	1.5w
56	Cool-down Asphalt	6.43w
57	**Concrete Plug-20'**	**5.32w**
58	Remove Concrete Lining & Rock	1.11w
59	Pour Concrete (20' high)	0.21w
60	Cure Concrete	4w
61	**Remove Concrete Shaft Lining**	**1.9w**
62	Remove 72' of lining--4 zones	1.9w
63	***Rustler Compacted Clay Column-234'***	**4.81w**
64	Emplace & Compact Bentonite (234' high)	4.81w
65	***Compacted Earthen Fill-449'***	**3.65w**
66	Emplace & Compact Earthen Fill (449' high)	3.65w

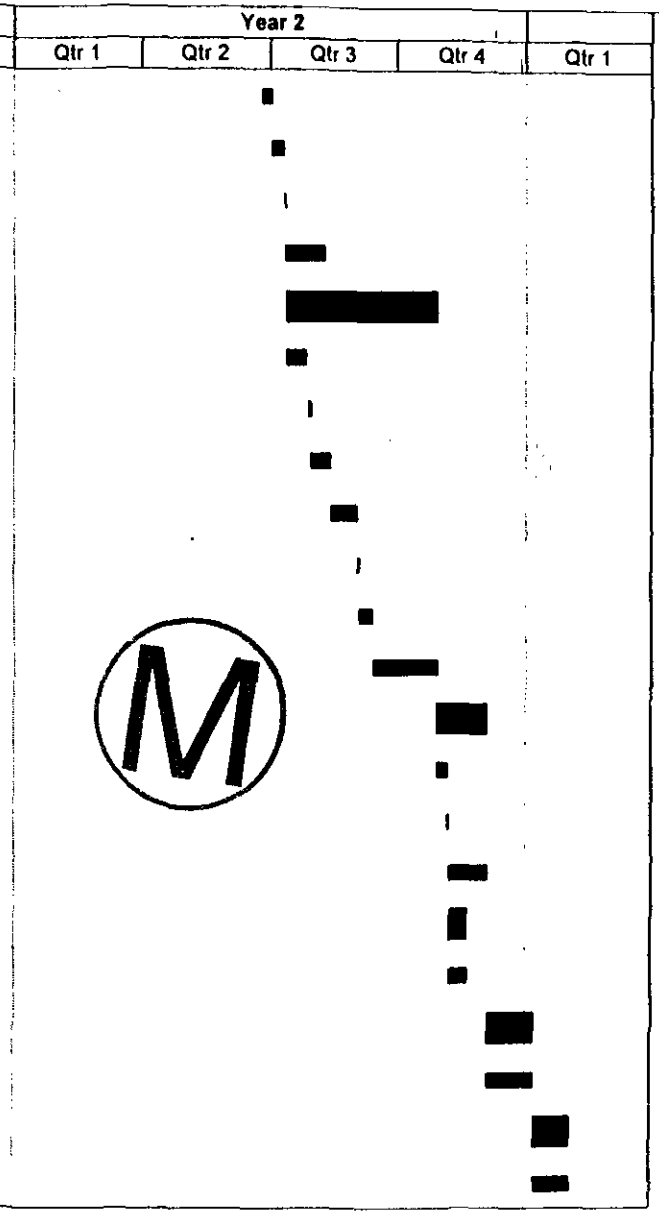

Project: SALT HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration	Year 1 Qtr 1	Year 1 Qtr 2	Year 1 Qtr 3	Year 1 Qtr 4	Year 2 Qtr 1	Year 2 Qtr 2	Year 2 Qtr 3	Year 2 Qtr 4	Qtr 1
67	**Concrete Plug-40'**	**2.45w**									
68	Clean Existing Surface	0.34w									
69	Pour Concrete	0.11w									
70	Cure Concrete	2w									
71	**Compacted Earthen Fill-92.5'**	**0.65w**									
72	*Emplace & Compact Earthen Fill (92.5'high)*	0.65w									
73	**Demobilization**	**3w**									
74	Demob	3w									

M

Project: SALT HANDLING SHAFT SEALING SCHEDULE
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Task
Progress
Milestone
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Rolled Up Milestone
Rolled Up Progress

SEALING SCHEDULE--EXHAUST SHAFT

M

ID	Task Name	Duration
1	Mobilization	4w
3	Plant Set-up	12w
5	Inspect & Scale Shaft-2159.5'	1w
7	Install Construction Utilities	7.2w
9	Drill & Grout Lining	8.26w
12	Shaft Station Monolith-33'	3.69w
16	Lower Salado Compacted Clay Column-98'	3.18w
18	Lower Concrete-Asphalt Waterstop-50'	9.19w
27	Compacted Salt Column-559'	14.37w
29	Middle Concrete-Asphalt Waterstop-50'	7.19w
38	Upper Salado Compacted Clay Column-340'	11.01w
40	Upper Concrete-Asphalt Waterstop-50'	9.19w
49	Asphalt Column-142.5'	18.43w
57	Concrete Plug-20'	5.87w
61	Remove Concrete Shaft Lining	3.23w
63	Rustler Compacted Clay Column-234.5'	6.62w
65	Compacted Earthen Fill-486.4'	5.44w
67	Concrete Plug-40'	2.69w
71	Compacted Earthen Fill-58.1'	0.44w
73	Demobilization	3w

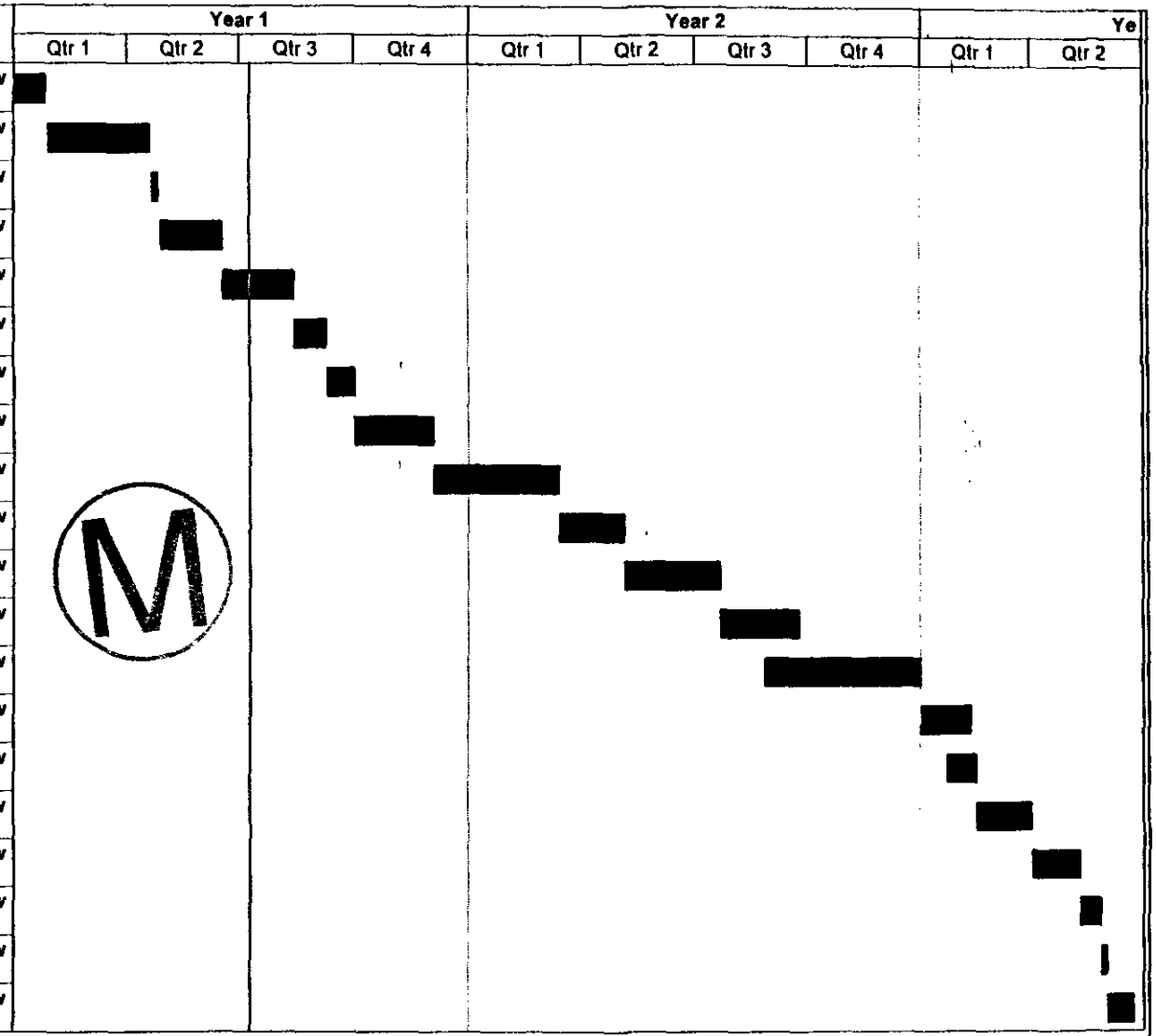

Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
1	**Mobilization**	4w
2	Mobilize	4w
3	**Plant Set-up**	12w
4	Plant Set-up	12w
5	**Inspect & Scale Shaft-2159.5'**	1w
6	Inspect & Scale Shaft	1w
7	**Install Construction Utilities**	7.2w
8	Install Utilities	7.2w
9	**Drill & Grout Lining**	8.26w
10	Drill Grout Holes	3.3w
11	Grout Lining	4.96w
12	**Shaft Station Monolith-33'**	3.69w
13	Construct Bulkheads	0.4w
14	Pour Concrete (33' high)	0.29w
15	Cure Concrete	3w
16	**Lower Salado Compacted Clay Column-98'**	3.18w
17	Emplace Bentonite Blocks (98 ' high)	3.18w
18	**Lower Concrete-Asphalt Waterstop-50'**	9.19w
19	Excavate for Lower Plug	1.45w
20	Pour Concrete-Lower Plug (23' high-typ)	0.22w
21	Excavate Waterstop	0.47w
22	Place Asphalt (4' high-typ)	0.38w

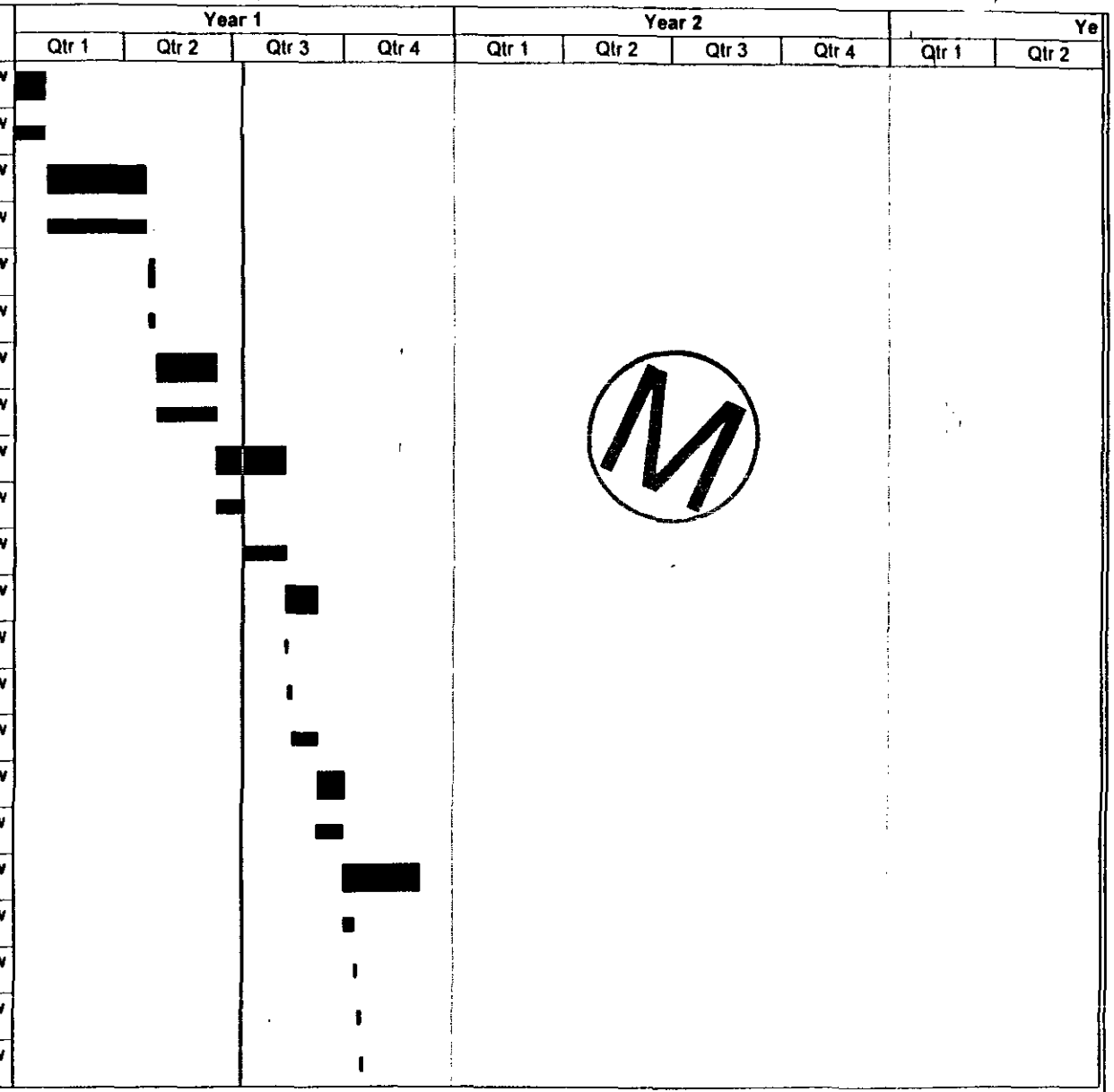

Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

Page 1

ID	Task Name	Duration
23	Cool-down Asphalt	1w
24	Excavate for Upper Plug	1.45w
25	Pour Concrete-Upper Plug (23' high-typ)	0.22w
26	Cure Concrete	4w
27	**Compacted Salt Column-559'**	**14.37w**
28	Emplace & Compact Crushed/Screened Salt	14.37w
29	**Middle Concrete-Asphalt Waterstop-50'**	**7.19w**
30	Excavate for Lower Plug	1.45w
31	Pour Concrete-Lower Plug	0.22w
32	Excavate Waterstop	0.47w
33	Place Asphalt	0.38w
34	Cool-down Asphalt	1w
35	Excavate for Upper Plug	1.45w
36	Pour Concrete-Upper Plug	0.22w
37	Cure Concrete	2w
38	**Upper Salado Compacted Clay Column-340'**	**11.01w**
39	Emplace Bentonite Blocks(340' high)	11.01w
40	**Upper Concrete-Asphalt Waterstop-50'**	**9.19w**
41	Excavate for Lower Plug	1.45w
42	Pour Concrete-Lower Plug	0.22w
43	Excavate Waterstop	0.47w
44	Place Asphalt	0.38w

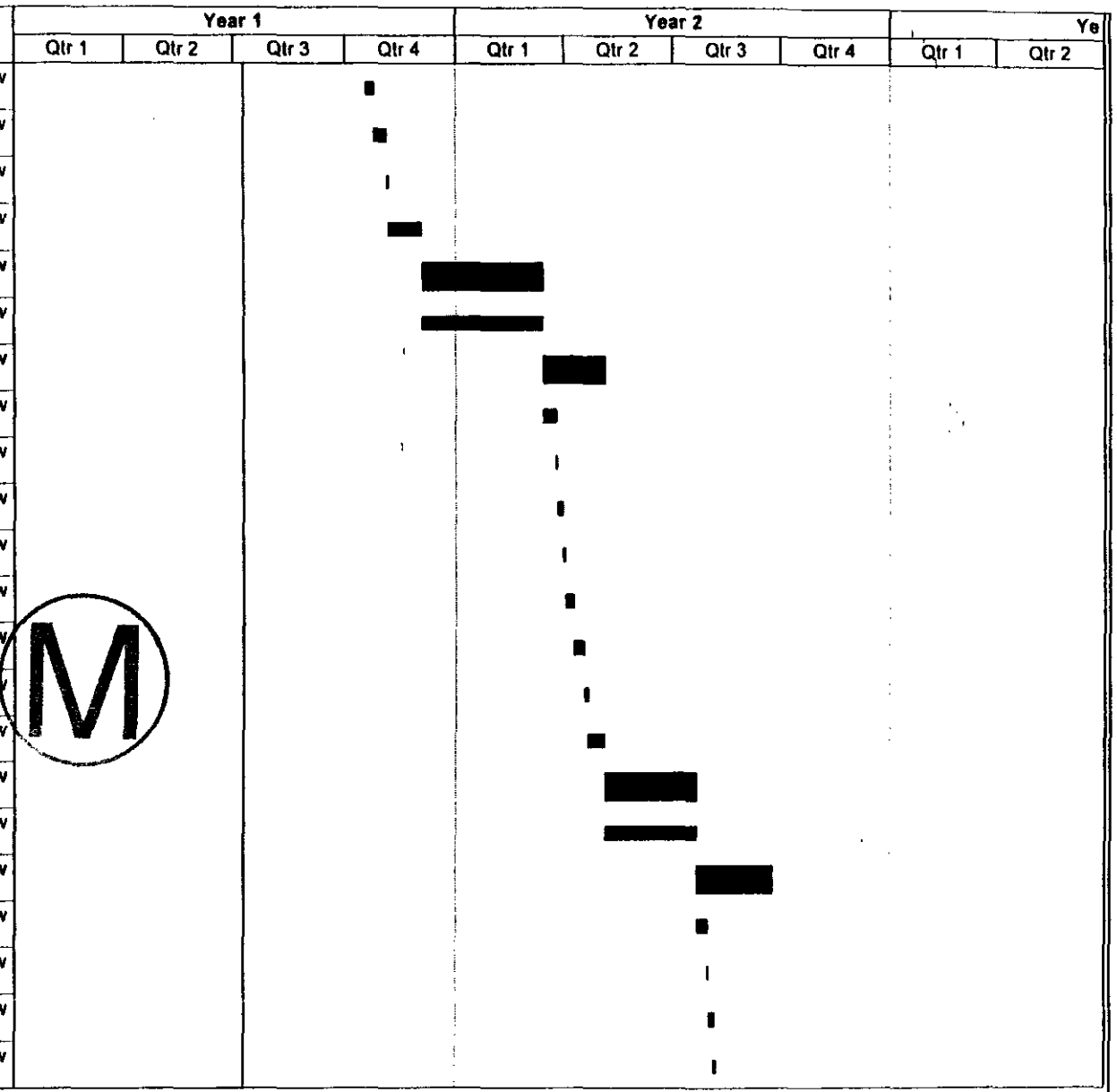

Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
45	Cool-down Asphalt	1w
46	Excavate for Upper Plug	1.45w
47	Pour Concrete-Upper Plug	0.22w
48	Cure Concrete	4w
49	**Asphalt Column-142.5'**	**18.43w**
50	Remove Lining in Key	3.15w
51	Remove Chemical Seal Rings	0.5w
52	Mobilize to Emplace Asphalt	2w
53	Asphalt in Salt Section	2.64w
54	Asphalt in Lower Lined Section	1.44w
55	Complete Asphalt Emplacement	2.27w
56	Cool-down Asphalt	6.43w
57	**Concrete Plug-20'**	**5.87w**
58	Remove Concrete Lining & Rock	1.7w
59	Pour Concrete (20' high)	0.17w
60	Cure Concrete	4w
61	**Remove Concrete Shaft Lining**	**3.23w**
62	Remove 84' of lining--4 zones	3.23w
63	**Rustler Compacted Clay Column-234.5'**	**6.62w**
64	Emplace & Compact Bentonite(234.5' high)	6.62w
65	**Compacted Earthen Fill-486.4'**	**5.44w**
66	Emplace & Compact Earthen Fill(486.4' high	5.44w

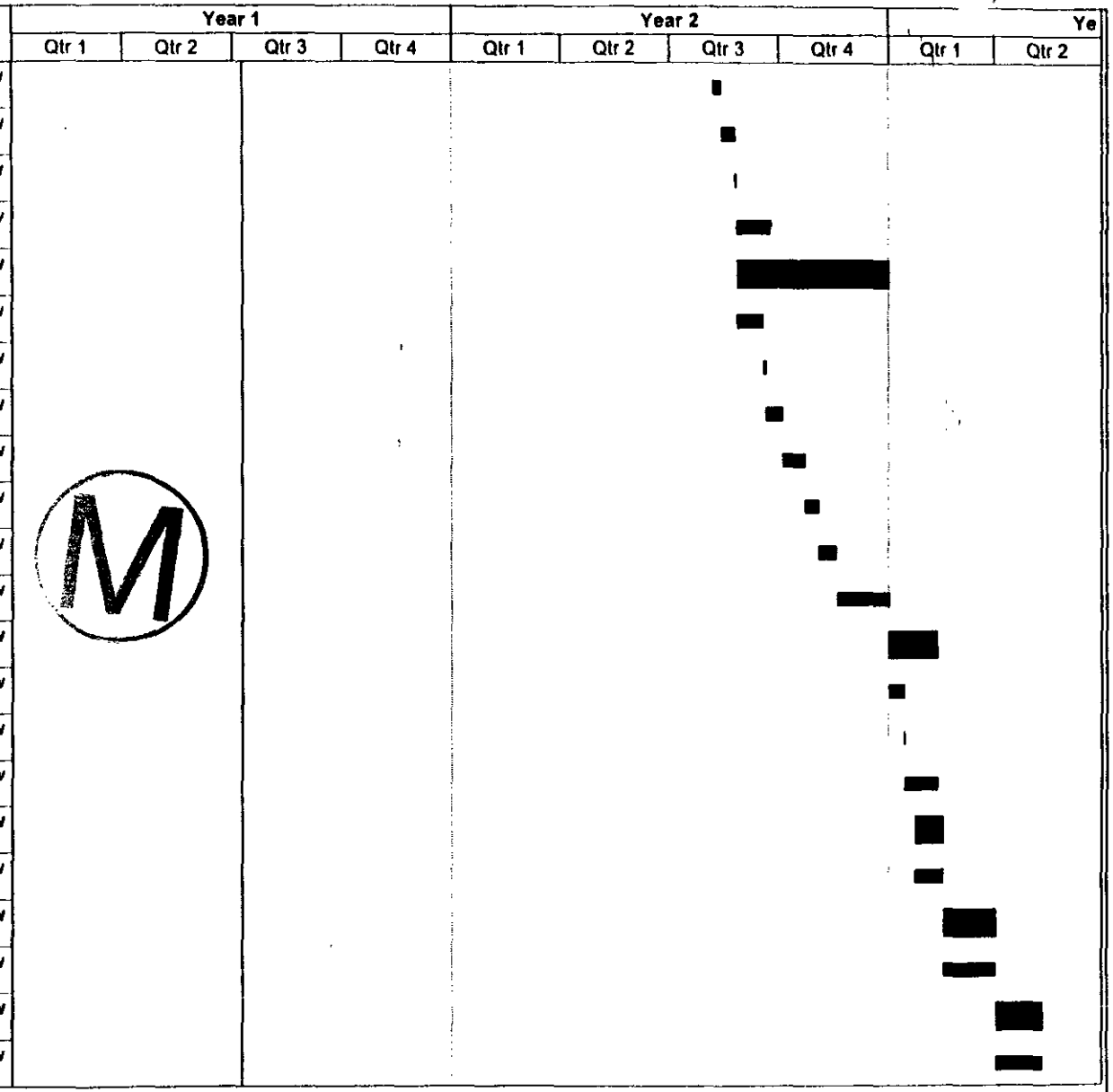

Project: EXHAUST SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration	Year 1				Year 2				Ye	
			Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2
67	**Concrete Plug-40'**	**2.69w**										
68	Clean Existing Surface	0.47w										
69	Pour Concrete	0.22w										
70	Cure Concrete	2w										
71	**Compacted Earthen Fill-56.1'**	**0.44w**										
72	Emplace & Compact Earthen Fill (56.1'high)	0.44w										
73	**Demobilization**	**3w**										
74	Demob	3w										

M

Project: EXHAUST SHAFT
SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

SEALING SCHEDULE--WASTE SHAFT

M

ID	Task Name	Duration
1	Mobilization	4w
3	Plant Set-up	12w
5	Inspect & Scale Shaft-2159.5'	1w
7	Install Construction Utilities	7.2w
9	Drill & Grout Lining	11.21w
12	Shaft Station Monolith-37'	5.17w
16	Lower Salado Compacted Clay Column-96'	5.01w
18	Lower Concrete-Asphalt Waterstop-50'	12.57w
27	Compacted Salt Column-555.5'	22.87w
29	Middle Concrete-Asphalt Waterstop-50'	10.57w
38	Upper Salado Compacted Clay Column-351.5'	17.86w
40	Upper Concrete-Asphalt Waterstop-50'	12.57w
49	Asphalt Column-142.3'	20.71w
57	Concrete Plug-20'	5.98w
61	Remove Concrete Shaft Lining	5.07w
63	Rustler Compacted Clay Column-234.7'	10.99w
65	Compacted Earthen Fill-447'	8.25w
67	Concrete Plug-40'	3.04w
71	Compacted Earthen Fill-61.5'	1.14w
73	Demobilization	3.5w

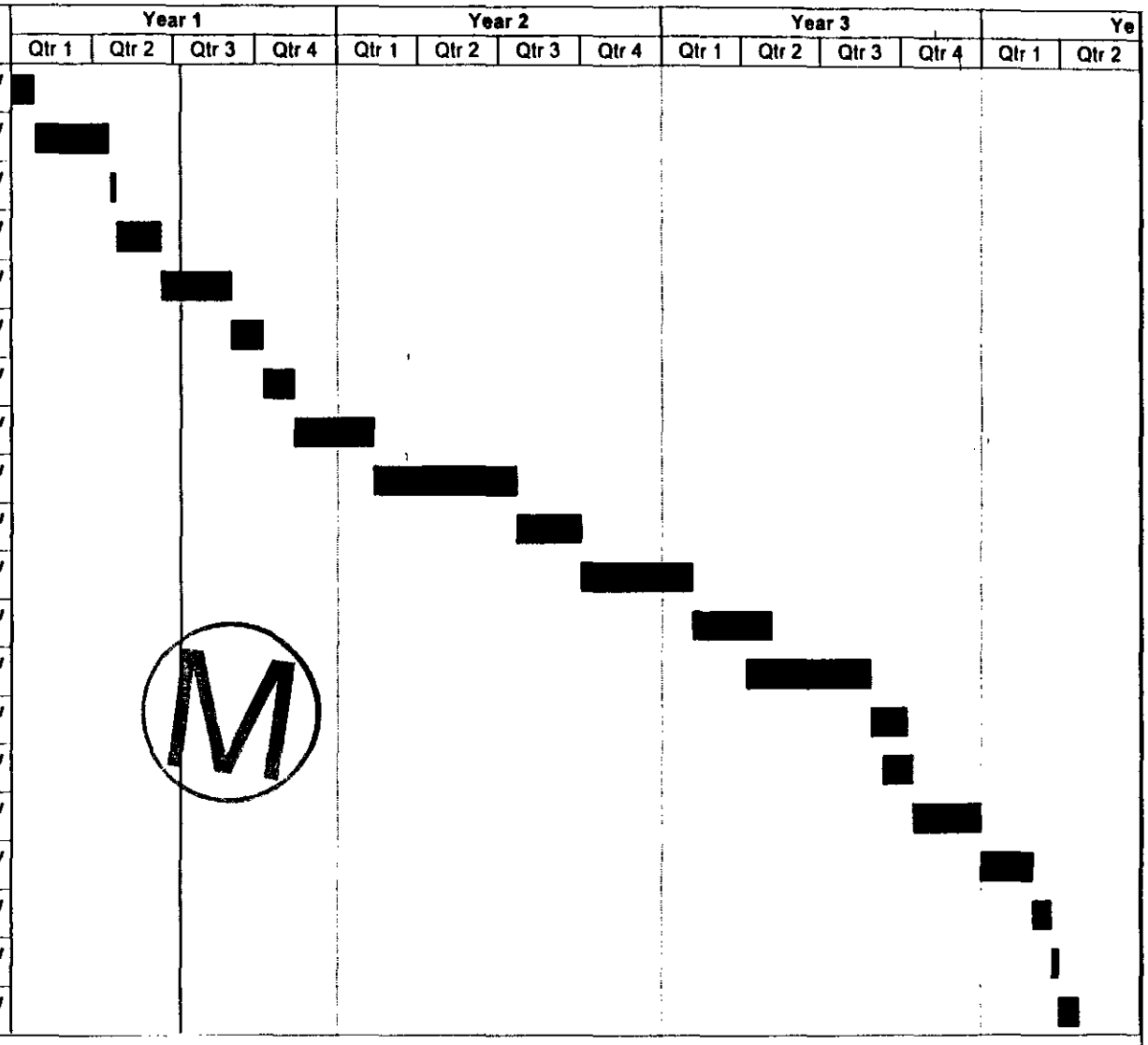

Project: WASTE HANDLING SHAFT SEALING SCHEDULE
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Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
1	**Mobilization**	4w
2	Mobilize	4w
3	**Plant Set-up**	12w
4	Plant Set-up	12w
5	**Inspect & Scale Shaft-2159.5'**	1w
6	Inspect & Scale Shaft	1w
7	**Install Construction Utilities**	7.2w
8	Install Utilities	7.2w
9	***Drill & Grout Lining***	11.21w
10	Drill Grout Holes	4.48w
11	Grout Lining	6.73w
12	**Shaft Station Monolith-37'**	5.17w
13	Construct Bulkheads	1w
14	Pour Concrete (37' high)	1.17w
15	Cure Concrete	3w
16	**Lower Salado Compacted Clay Column-96'**	5.01w
17	Emplace Bentonite Blocks (96 ' high)	5.01w
18	**Lower Concrete-Asphalt Waterstop-50'**	12.57w
19	Excavate for Lower Plug	2.72w
20	Pour Concrete-Lower Plug (23' high-typ)	0.27w
21	*Excavate Waterstop*	0.84w
22	Place Asphalt (4' high-typ)	0.75w

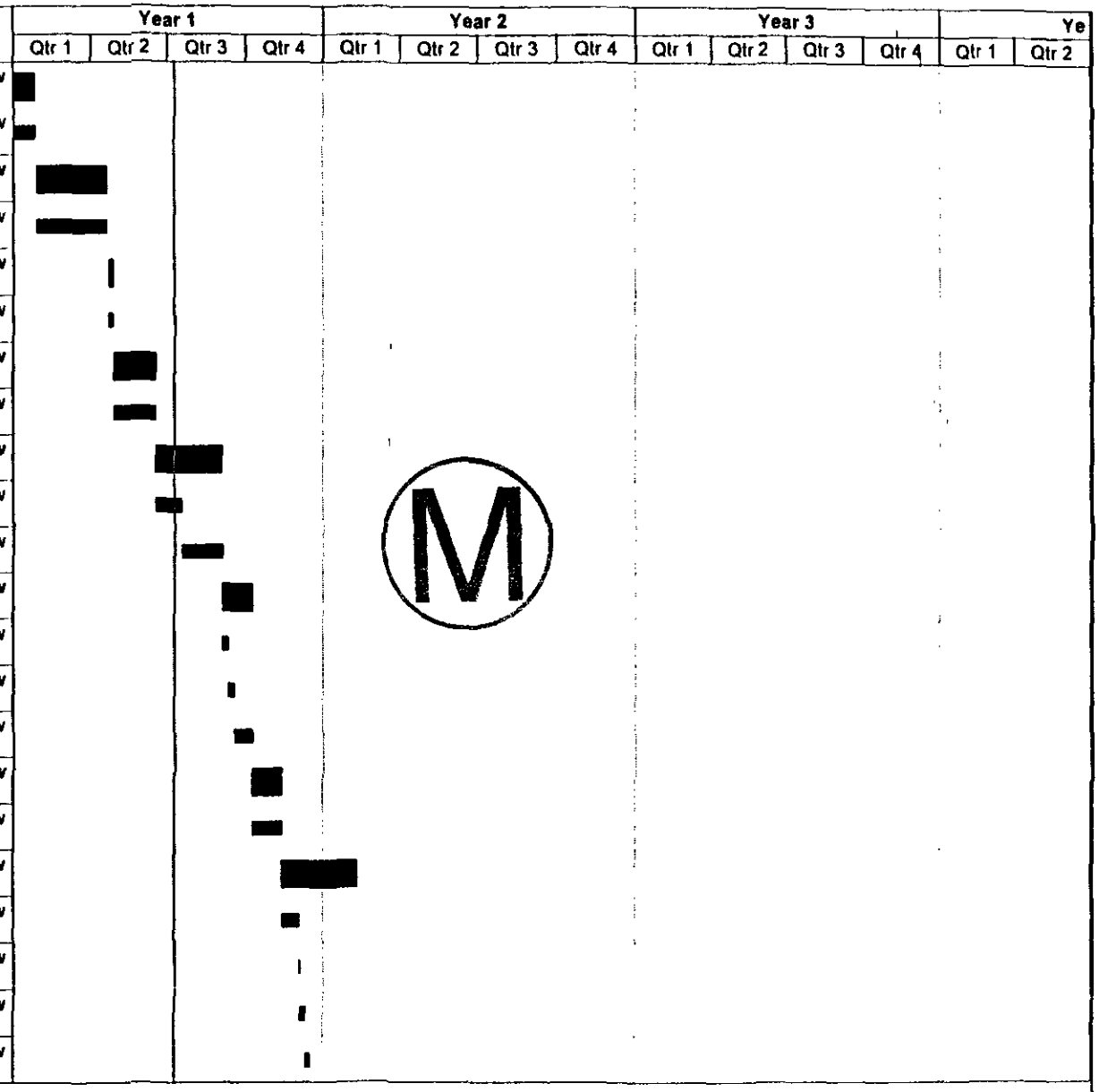

Project: WASTE HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
23	Cool-down Asphalt	1w
24	Excavate for Upper Plug	2.72w
25	Pour Concrete-Upper Plug (23' high-typ)	0.27w
26	Cure Concrete	4w
27	**Compacted Salt Column-555.5'**	**22.87w**
28	Emplace & Compact Crushed/Screened Salt	22.87w
29	**Middle Concrete-Asphalt Waterstop-50'**	**10.57w**
30	Excavate for Lower Plug	2.72w
31	Pour Concrete-Lower Plug	0.27w
32	Excavate Waterstop	0.84w
33	Place Asphalt	0.75w
34	Cool-down Asphalt	1w
35	Excavate for Upper Plug	2.72w
36	Pour Concrete-Upper Plug	0.27w
37	Cure Concrete	2w
38	**Upper Salado Compacted Clay Column-351.5'**	**17.86w**
39	Emplace Bentonite Blocks(351.5' high)	17.86w
40	**Upper Concrete-Asphalt Waterstop-50'**	**12.57w**
41	Excavate for Lower Plug	2.72w
42	Pour Concrete-Lower Plug	0.27w
43	Excavate Waterstop	0.84w
44	Place Asphalt	0.75w

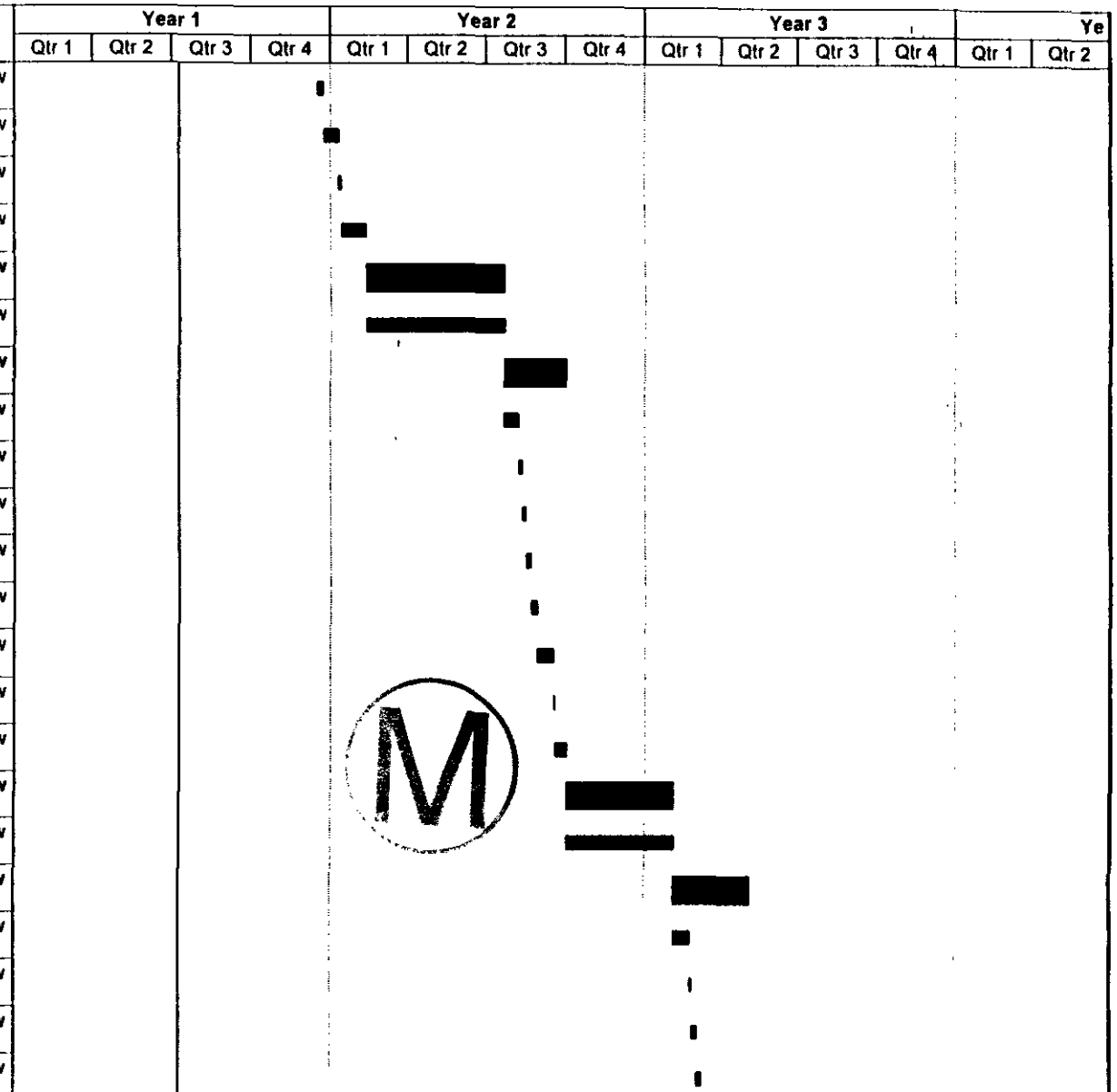

Project: WASTE HANDLING SHAFT SEALING SCHEDULE
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Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
45	Cool-down Asphalt	1w
46	Excavate for Upper Plug	2.72w
47	Pour Concrete-Upper Plug	0.27w
48	Cure Concrete	4w
49	**Asphalt Column-142.3'**	**20.71w**
50	Remove Lining in Key	3.8w
51	Remove Chemical Seal Rings	0.6w
52	Mobilize to emplace asphalt	0.3w
53	Asphalt in Salt Section	4.01w
54	Asphalt in Lower Lined Section	2.33w
55	Complete Asphalt Emplacement	3.24w
56	Cool-down Asphalt	6.43w
57	**Concrete Plug-20'**	**5.98w**
58	Remove Concrete Lining & Rock	1.73w
59	Pour Concrete (20' high)	0.25w
60	Cure Concrete	4w
61	**Remove Concrete Shaft Lining**	**5.07w**
62	Remove 84' of lining--4 zones	5.07w
63	**Rustler Compacted Clay Column-234.7'**	**10.99w**
64	Emplace & Compact Bentonite (234.7' high)	10.99w
65	**Compacted Earthen Fill-447'**	**8.25w**
66	Emplace & Compact Earthen Fill (447' high)	8.25w

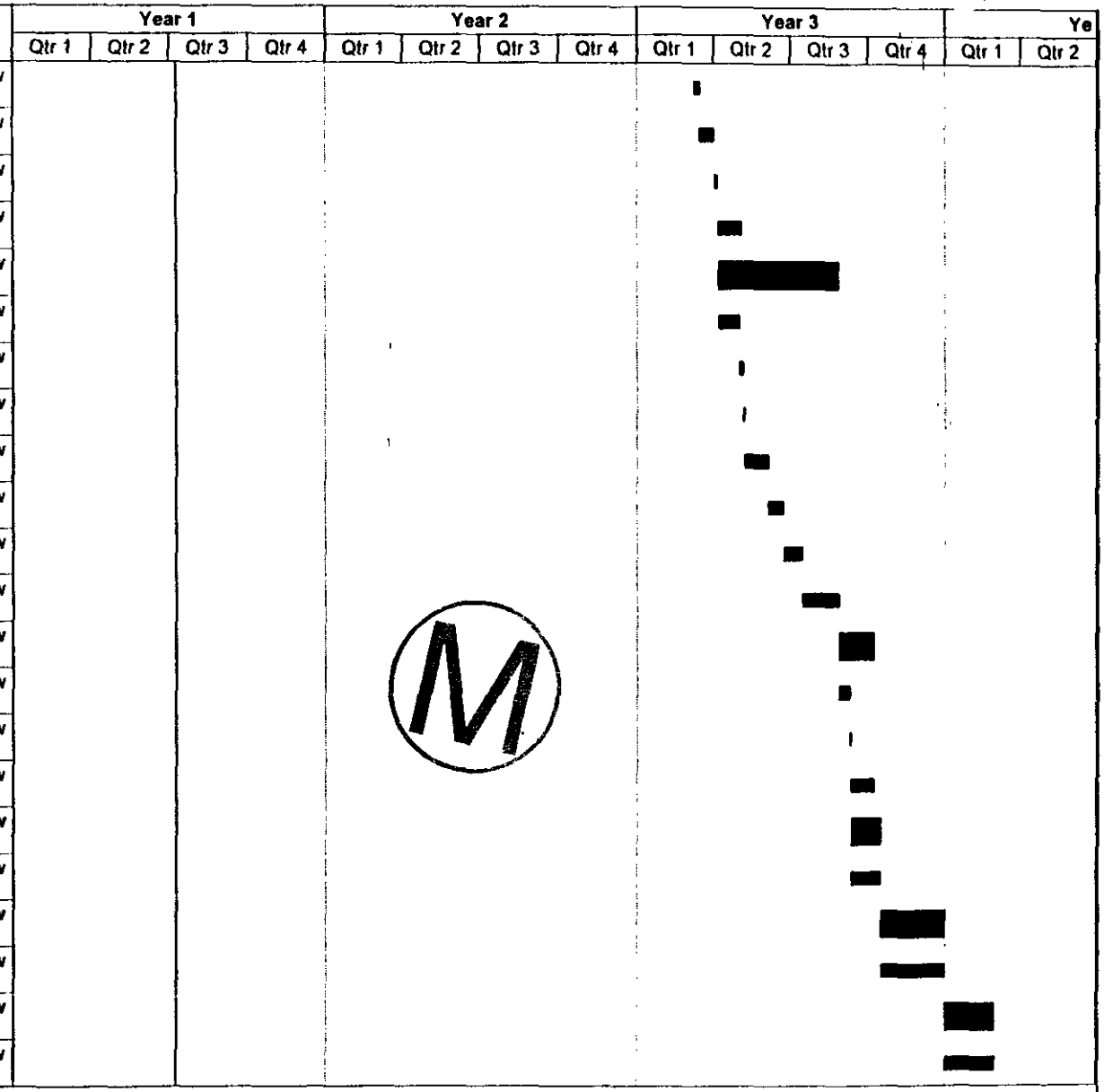

Project: WASTE HANDLING SHAFT SEALING SCHEDULE
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Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

ID	Task Name	Duration
67	**Concrete Plug-40'**	**3.04w**
68	Clean Existing Surface	0.64w
69	Pour Concrete	0.4w
70	Cure Concrete	2w
71	**Compacted Earthen Fill-61.5'**	**1.14w**
72	Emplace & Compact Earthen Fill (61.5' high)	1.14w
73	**Demobilization**	**3.5w**
74	Demob	3.5w

Project: WASTE HANDLING SHAFT SEALING SCHEDULE
Date: Tue 7/9/96

Task | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Milestone | Rolled Up Progress

B5. REFERENCES

Ahrens, E.H., and F.D. Hansen. 1995. *Large-Scale Dynamic Compaction Demonstration Using WIPP Salt: Fielding and Preliminary Results*. SAND95-1941. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM [SWCF] as WPO31104.)

Ahrens, E.H., and M. Onofrei. 1996. "Ultrafine Cement Grout for Sealing Underground Nuclear Waste Repositories," *2nd North American Rock Mechanics Symposium (NARMS 96), Montreal, Quebec, June 19-21, 1996*. SAND96-0195C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO31251.)

Ahrens, E.H., T.F. Dale, and R.S. Van Pelt. 1996. *Data Report on the Waste Isolation Pilot Plant Small-Scale Seal Performance Test, Series F Grouting Experiment*. SAND93-1000. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO37355.)

Boonsinsuk, P., B.C. Pulles, B.H. Kjartanson, and D.A. Dixon. 1991. "Prediction of Compactive Effort for a Bentonite-Sand Mixture," *44th Canadian Geotechnical Conference, Preprint Volume, Calgary, Alberta, September 29-October 2, 1991*. Paper No. 64. Waterloo, Ontario: Canadian Geotechnical Society. Pt. 2, 64/1 through 64/12. (Copy on file in the SWCF.)

Dale, T., and L.D. Hurtado. 1996. "WIPP Air-Intake Shaft Disturbed-Rock Zone Study," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND96-1327C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

Hansen, F.D., and E.H. Ahrens. 1996. "Large-Scale Dynamic Compaction of Natural Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND96-0792C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO39544.)

Knowles, M.K., and C.L. Howard. 1996. "Field and Laboratory Testing of Seal Materials Proposed for the Waste Isolation Pilot Plant," *Proceedings of the Waste Management 1996 Symposium, Tucson, AZ, February 25-29, 1996*. SAND95-2082C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO30945.)

McClintock, F.A., and A.S. Aragon. 1996. *Mechanical Behavior of Materials*. Reading MA: Addison-Wesley.

Van Sambeek, L.L. 1988. *Considerations for the Use of Quarried Salt Blocks in Seal Components at the WIPP*. Topical Report RSI-0340. Rapid City, SD: RE/SPEC Inc. (Copy on file in the SWCF as WPO9233.)

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Appendix C

Fluid Flow Analyses

Appendix C Abstract

This appendix documents four models that were used to evaluate the performance of the proposed WIPP shaft seal system design in terms of fluid-flow (gas and brine) within the seal system components and surrounding Disturbed Rock Zone (DRZ). The common hydrogeologic framework used by the models is described in terms of a radially symmetric system centered on the Air Intake Shaft and extending from the repository level upward through the Salado and Rustler Formations. Properties that govern fluid flow within porous media are defined for the seal system components, the host lithologic units, and the DRZ. Laboratory, field, and mechanical modeling studies are utilized to develop a conceptualization of the DRZ, which includes a time-varying permeability within the Salado Formation dependent on depth and rigidity of adjacent seal components. Model 1 is a completely saturated numerical flow model and is used to evaluate brine flow down the shaft from the Rustler Formation to the compacted salt column component during the 200-year period immediately after seal emplacement. Model 2 is a two-phase (gas and brine) numerical flow model used to evaluate gas flow up from the repository to the compacted salt column as well as pressure within the compacted salt column during the same 200-year period. A compacted salt reconsolidation submodel is incorporated, which predicts crushed salt permeability as a function of time, pressure, and depth within the column. Model 3 is a fully saturated numerical flow model and is used to evaluate brine flow upward within the seal system during the time period from 400 to 10,000 years after seal emplacement under ambient formation pressure conditions. Model 4 utilizes simple analytical relationships to analyze the potential brine flow through the shaft seals attributable to a range of nonhydrostatic natural head conditions between the Magenta and Culebra, the two primary water-bearing members of the Rustler Formation. The seal-system performance models were used to examined fluid-flow sensitivity to various assumptions of DRZ continuity, the existence of asphalt within concrete seal components, and different repository pressure loading scenarios.

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C1. INTRODUCTION

This appendix describes analyses conducted to quantify the fluid-flow performance of the WIPP shaft seal system design. The appendix is organized in the following manner. First, the statements of the problems to be solved are developed. The problem statements are introduced in terms of performance models. The analysis sections of this appendix are organized in terms of these performance models. For each performance model, the conceptual model is described along with a description of the quantitative method used. Each performance calculation is defined in terms of the relevant assumptions, parameters, and boundary conditions. Finally, results from each performance model are presented. The numerical codes SWIFT II (Version 2F) and TOUGH28W (Version 2.02) have been used in this appendix to quantitatively analyze fluid-flow performance for the WIPP shaft seal system.

The fluid-flow analyses presented in this appendix were performed using SI units. Dimensions, parameter values, and performance model results will be presented in SI units. However, graphical depiction of the models used will be presented in terms of feet above mean sea level (ft msl) to facilitate comparisons with seal system design drawings.

C2. DEFINITION OF PERFORMANCE MODELS

Evaluation of the fluid-flow performance of the shaft seal system is facilitated through definition of relevant performance models. Each performance model is derived from performance measures that quantify migration of fluids within and through the system. This approach differs in scope from that of the assessment of the WIPP repository. In the latter case, a general system model is developed in an iterative manner. Physical processes that may result in contaminant release are systematically identified and evaluated through results of the system model simulations. The performance models defined in this appendix are specific to performance measures applicable to the shaft seal system. These models were developed through assessment of the physical characteristics of the WIPP shaft sealing system, the surrounding media, and the sealing functions that are described in detail in Section 4 of the main report.

Qualitative design guidance has been developed for the shaft seal system based on the function of the shaft seal system. This guidance seeks (1) to limit the migration of radiological or other hazardous constituents from the repository horizon to the regulatory boundary over a 10,000-year regulatory period and (2) to limit groundwater flow into and through the shaft sealing system. Additional qualitative design guidance arises from special requirements of the compacted salt column. The salt column requires reconsolidation, a process that can be adversely affected by significant pore pressures within the column. This guidance seeks (3) to limit both groundwater and repository-generated gas from flowing into the compacted salt column.

The primary potential source of significant groundwater flow to the shaft sealing system comes from the Rustler Formation. Because of the low permeability of the Salado Formation, it is isolated from active groundwater circulation. However, because the Salado is significantly over-pressured relative to the Rustler Formation (Beauehim et al., 1993), the Salado Formation

represents a possible source of long-term upward flow from the repository horizon through the seal system.

The motivations for limiting brine migration in the seal system are: (1) to limit brine migration from the Rustler to the repository during repressurization of the seal system; (2) to prevent significant pore pressures from building in the compacted salt column and potentially affecting reconsolidation; (3) to limit the interconnection of water-bearing strata in the Rustler; and (4) to limit brine migration upward from the Salado. Likewise, the motivations for limiting gas and brine migration up the seal system from the repository are: (5) to limit upward fluid flow to the accessible environment; and (6) to prevent significant pore pressures from building in the compacted salt column.

These motivations, together with the features and processes that underlie them, can be synthesized into four flow-performance models:

Model 1: Flow Down from the Rustler

Model 2: Gas Migration and Compacted Salt Column Consolidation

Model 3: Flow up from the Salado

Model 4: Intra-Rustler Flow

These performance models are coupled or interdependent. For example, flow from the Rustler (Model 1) could be affected by the consolidation (permeability) of the compacted salt column (Model 2). Likewise, Model 2 performance could be affected by the flow from the Rustler (Model 1). Model 1 will be evaluated first, followed by the analysis of Model 2. Models 3 and 4 will be evaluated separately.

Several analysis assumptions are shared among all the performance models and are listed below.

- Each analysis uses the Air Intake Shaft (AIS) as the shaft analyzed. It is assumed that the AIS analysis is representative of the three other WIPP shafts.
- The stratigraphy used in these performance calculations is consistent with the AIS stratigraphy as presented by Holt and Powers (1990) and as summarized by DOE (1995).
- A radial model geometry is assumed.
- Isothermal conditions are considered. This means that fluid flow driven by temperature gradients is assumed to be negligible.
- Each shaft can be considered independently. This means that it is assumed that no hydraulic interference exists between shafts.
- Flow is considered through the intact rocks, the seal materials, and the disturbed rock zone (DRZ).
- The DRZ can appropriately be described as having its largest permeability at the shaft/DRZ contact and approaching intact permeabilities at its outer extent. The permeability is assumed to vary log-linearly from the shaft/DRZ interface to the outer extent of the DRZ (intact rock).

- For Models 1 and 2, a preclosure period of 50 years is assumed. During the preclosure period, the shaft is held at atmospheric conditions.

The analyses presented in this appendix are deterministic and do not account for the full-range of potential outcomes that may be expected by performing a stochastic analysis allowing parameters to randomly vary across their respective uncertainty ranges. A stochastic analysis of the complete disposal system was conducted by WIPP PA for the 40 CFR 191 Compliance Certification Application of the WIPP (DOE, 1996). This analysis addressed the ranges of seal system parameters as applicable to the behavior of the disposal system. The analyses presented in this report address those parameters that are considered the most uncertain and to which the primary performance measures (flow rates) are most sensitive. These parameters include (1) the permeability of the DRZ, (2) the relationship between compacted salt density and permeability, and (3) the repository gas pressure applied at the base of the shaft seal system. The prediction of brine-flow migration down the shaft system (Model 1) is performed with a saturated flow model, which estimates the flow. In addition, a limited sensitivity analysis was performed, which provided a range in model predictions for variations in what are considered to be important processes. These processes are incorporated in model parameters that address (1) the vertical continuity of the DRZ, (2) the healing rate against the concrete-asphalt waterstops, (3) the relationship between compacted salt density and permeability, and (4) the repository gas pressure applied at the base of the shaft sealing system.

C3. HYDROGEOLOGIC FRAMEWORK

This section discusses the hydrogeologic framework for the hydraulic analysis of the performance of the WIPP shaft seal system. The hydrogeologic framework includes (1) the stratigraphy of the host rocks and how it is conceptualized for the performance models; (2) the ambient fluid pressure profile within the host rocks; (3) and the hydraulic parameters describing the seal system, the host rocks, and the DRZ.

The properties that govern fluid flow within porous media are defined for the seal components, the host lithologic units, and the DRZ. Both single-phase (SWIFT II) and multi-phase (TOUGH28W) fluid flow codes were used in these calculations.

C3.1 Stratigraphy

The stratigraphy of the host rocks adjacent to the shaft from the repository horizon to the surface is composed of the Salado Formation, the Rustler Formation, the Dewey Lake Redbeds, and the surficial Santa Rosa and Gatuña Formations. Dune sand and caliche overlie the sediments at the surface. The primary water-bearing strata are confined to the Rustler and Salado Formations. Therefore, the discussion of stratigraphy will focus on the Salado and Rustler Formations.

The reference stratigraphy used to develop the performance models in this appendix is based on the shaft mapping of the AIS (Holt and Powers, 1990). The detailed stratigraphy of the Rustler and Salado Formations in the AIS is also summarized in Appendix A of DOE (1995). The detailed stratigraphy will not be discussed here.

The detailed modeling of the discrete stratigraphy present in the Rustler and Salado formations presents a challenge. Several Salado marker beds are very thin, with thicknesses less than 0.5 m in many instances. To reduce the total number of grid cells to a manageable level in the performance models, several individual stratigraphic units were merged into single model combined units. Units were merged together based on proximity, thickness, and lithology. Table C-1 lists the Salado Formation combined units and the individual beds that were merged to form them. Rock properties of the combined stratigraphic units were calculated based on the thickness-weighted arithmetic mean of the rock properties of individual beds composing the combined units. DRZ permeabilities of the combined stratigraphic units were calculated based on the thickness-weighted harmonic mean.

Table C-1. Summary of Salado Stratigraphic Units Merged into Salado Model Combined Units

Combined Unit Name	Combined Unit Thickness (m)	Stratigraphic Unit	Rock Type	Individual Unit Thickness (m)
Unit 1	5.79	MB103	Anhydrite(1) (2)	5.03
		MB104	Anhydrite	0.30
		MB105	Anhydrite	0.30
		MB106	Anhydrite	0.15
Unit 2	8.05	MB107	Polyhalite	0.15
		MB108	Polyhalite	0.15
		MB109	Anhydrite(1) (2)	7.74
Unit 3	3.57	MB110	Polyhalite	0.34
		MB111	Polyhalite	0.18
		MB112	Polyhalite	0.61
		MB113	Polyhalite	0.30
		MB114	Polyhalite	0.30
		MB115	Polyhalite	1.07
		MB116	Polyhalite	0.76
Unit 4	5.79	MB117	Polyhalite	0.46
		MB118	Polyhalite	0.79
		MB119	Polyhalite	0.61
		MB120	Polyhalite	0.27
		Zone A	Halite(1)	3.05

Table C-1. Summary of Salado Stratigraphic Units Merged into Salado Model Combined Units

Combined Unit Name	Combined Unit Thickness (m)	Stratigraphic Unit	Rock Type	Individual Unit Thickness (m)
		MB121	Polyhalite	0.30
		MB122	Polyhalite	0.30
Unit 5	4.72	MB123	Anhydrite	1.98
		MB124	Anhydrite(1)	2.74
Unit 6	3.96	Zone B	Halite(1)	0.91
		Zone C	Halite(1)	2.74
		MB126	Polyhalite	0.30
Unit 7	11.83	MB127	Polyhalite	0.79
		MB128	Polyhalite	1.07
		Zone D	Halite(1)	3.20
		Zone E	Halite(1)	0.61
		Zone F	Halite(1)	0.91
		Zone G	Halite(1)	0.61
		Zone H	Halite(1)	1.80
		MB129	Polyhalite(1)	0.46
		Zone I	Halite(1)	1.74
		MB130	Polyhalite	0.64
Unit 8	2.29	MB131	Polyhalite	0.30
		Zone J	Halite(1)	1.22
		MB132	Polyhalite	0.30
		MB133	Polyhalite	0.46
Unit 9	4.75	Unnamed	Anhydrite	0.76
		MB134	Anhydrite(2)	3.69
		MB135	Anhydrite	0.30

Table C-1. Summary of Salado Stratigraphic Units Merged into Salado Model Combined Units

Combined Unit Name	Combined Unit Thickness (m)	Stratigraphic Unit	Rock Type	Individual Unit Thickness (m)
Unit 10		MB136	Anhydrite(2)	4.30
		MB137	Anhydrite	0.40
Unit 11	0.49	MB138	Anhydrite	0.18
		Anhydrite A	Anhydrite	0.30

(1) Identified brine seepage interval.
(2) Anhydrite unit greater than 3 m in thickness.

C3.2 Observed Vertical Gradients

Heads within the Rustler and between the Rustler and Salado formations are not in hydrostatic equilibrium. Mercer (1983) recognized that heads at the Rustler/Salado transition (referred to as the brine aquifer and not present in the vicinity of the WIPP shafts) indicate an upward hydraulic gradient from that zone to the Culebra. Later, with the availability of more head measurements within the Salado and Rustler, Beauheim (1987) provided additional insight into the potential direction of vertical fluid movement within the Rustler. He reported that the hydraulic data indicate an upward gradient from the Salado to the Rustler.

Formation pressures in the Salado Formation have been decreased in the near vicinity of the WIPP underground facility. The highest, and thought to be least disturbed, estimated formation fluid pressure from hydraulic testing is 12.55 MPa estimated from interpretation of testing within borehole SCP01 in MB139 just below the underground facility horizon (Beauheim et al., 1993). The freshwater head within MB139, based on the estimated static formation pressure of 12.55 MPa, is 1663.6 m (5458 ft) above mean sea level (msl).

Heads in the Rustler have also been impacted by the presence of the WIPP shafts. These impacts in the Culebra were significant in the 1980s, with a large drawdown cone extending away from the shafts in the Culebra (Haug et al., 1987). The undisturbed head of the Rustler/ Salado contact in the vicinity of the AIS is estimated to be approximately 936.0 m (3071 ft) msl (Brinster, 1991). The undisturbed head in the Culebra is estimated to be approximately 926.9 m (3041 ft) msl in the vicinity of the AIS (LaVenue et al., 1990). The undisturbed head in the Magenta is estimated to be approximately 960.1 m (3150 ft) msl (Brinster, 1991).

The disturbed and undisturbed heads in the Rustler are summarized in Table C-2. Also included is the freshwater head of MB139 based on hydraulic testing in the WIPP underground. Consistent with the vertical flow directions proposed by previous investigators, estimated vertical gradients in the vicinity of the AIS before the shafts were drilled indicate a hydraulic gradient from the Magenta to the Culebra and from the Rustler/Salado contact to the Culebra. There is also the potential for flow from the Salado Formation to the Rustler Formation.

Table C-2. Freshwater Head Estimates in the Vicinity of the Air Intake Shaft

Hydrologic Unit	Freshwater Head (m asl) Undisturbed	Disturbed	Reference
Magenta Member	960.1(1)	948.8(2)	Brinster (1991)
		(H-16)	Beauheim (1987)
Culebra Member	926.9(1)	915.0(2)	LaVenue et al. (1990)
		(H-16)	Beauheim (1987)
Lower Unnamed Member	—	953.4(2) (H-16)	Beauheim (1987)
Rustler/Salado Contact	936.0 - 940.0(1)	—	Brinster (1991)
Salado MB139	1663.6(2)	—	Beauheim et al. (1993)

(1) Estimated from contoured head surface plot based primarily on well data collected before shaft construction.
(2) Measured through hydraulic testing and/or long-term monitoring.

C3.3 Shaft Seal Material Properties

The WIPP shaft seal system is composed of four primary materials: compacted clay, compacted salt, salt-saturated concrete, and asphalt. Eathern fill material is specified for the shafts in the near-surface regions. The performance models described in Section 2 require quantitative values for certain properties of the seal materials. These properties may be broadly divided into two categories: saturated flow parameters and two-phase flow parameters. Saturated flow parameters include intrinsic permeability, porosity, and compressibility of the materials, as well as the initial pore pressure of the components. Necessary parameters for two-phase flow will depend on the selection of an appropriate conceptual model for two-phase flow. The following sections describe the process used in the selection of saturated and two-phase flow parameters for the performance models presented in Sections C4, C5, and C6. Values for these parameters are summarized in Tables C-3 through C-8.

Table C-3. Bentonite Compacted Clay Parameters

Parameter	Value
Intrinsic Permeability (m^2)	5×10^{-19}
Porosity (m^3/m^3)	0.24
Pore compressibility (1/Pa) Upper Salado clay Lower Salado clay Rustler clay column	 1.81×10^{-9} 1.59×10^{-9} 1.96×10^{-9}
Initial Pressure (Pa)	101356.5
Initial Water Saturation	0.79

Table C-4. Asphalt Parameters

Parameter	Value
Intrinsic Permeability (m^2)	1×10^{-20}
Porosity (m^3/m^3)	0.01
Pore compressibility (1/Pa)	2.97×10^{-8}
Initial Pressure (Pa)	101356.5
Initial Water Saturation	0.0

Table C-5. Compacted Salt Parameters

Parameter	Value
Intrinsic Permeability (m^2)	7.9×10^{-13} to 6.3×10^{-21} (1)
Porosity (m^3/m^3)	0.05
Pore compressibility (1/Pa)	8.5×10^{-10}
Initial Pressure (Pa)	101356.5
Initial Water Saturation	0.32

(1) Section C5.3.

Table C-6. Concrete Parameters

Parameter	Value
Intrinsic Permeability (m^2) 0 to 400 years 400 to 10000 years	 1.78×10^{-19} 1.0×10^{-14}
Porosity (m^3/m^3)	0.0227
Pore compressibility (1/Pa)	2.64×10^{-9}
Initial Pressure (Pa)	101356.5
Initial Water Saturation	1.0

Table C-7. Earthen Fill Parameters

Parameter	Value
Intrinsic Permeability (m^2)	1×10^{-14}
Porosity (m^3/m^3)	0.32
Pore compressibility (1/Pa)	3.1×10^{-8}
Initial Pressure (Pa)	101356.5
Initial Water Saturation	0.8

Table C-8. Capillary Pressure and Relative Permeability Model Parameters for Compacted Clay, Concrete, Reconsolidated Salt, and Earthen Fill

Parameter	Value
Threshold Pressure (Pa)	$P_t = 5.6\times10^{-7}\ k^{-0.346}$
Lambda (λ)	0.94
Residual Water Saturation	0.2
Residual Gas Saturation	0.2

C3.3.1 Saturated Flow Parameters

The simplest approximation of flow can be derived from Darcy's Law, an empirical relationship that demonstrates that flow through a porous material depends directly on the hydraulic gradient, fluid viscosity, and material permeability. The hydraulic gradient will depend on the physical system, as will fluid viscosity. For an engineered system such as the WIPP shaft sealing system, it is possible to limit flow by specifying ver low material permeabilities. It is recognized that fluid flow through the WIPP shaft sealing system is complex and that a simple Darcy flow analysis will not suffice. Nonetheless, the importance of seal material permeability and the ability to engineer low-permeability materials can be justifiably retained in the performance analysis of the seal system. The specifications for seal materials are discussed in considerable detail in Appendix A. The analyses presented in this appendix focus on the expected behavior of the seal system within the context of each performance model. Because of uncertainty in the consolidation process for crushed salt, deterministic calculations are presented that capture this uncertainty. In all other cases, the selected permeability reflects confidence that the seal components will be constructed in a manner consistent with the specifications put forth in Appendix A. The most probable value for each material permeability was used for the analyses, except as noted otherwise in the text.

Unlike TOUGH28W, SWIFT II requires input of hydraulic conductivity rather than intrinsic permeability. The conversion from permeability to hydraulic conductivity in this report

will use a fluid density of 1230 kg/m^3, an acceleration of gravity of 9.792 m/s^2, and a fluid viscosity of 1.8×10^{-3} Pa • s. These fluid properties are representative of a WIPP saturated brine.

Material porosity and compressibility relate to the storage capacity of a porous media. Sensitivity studies conducted previously (WIPP PA, 1992–1993) have demonstrated that fluid flow is not significantly impacted by material storage capacity. With the exception of the crushed salt column permeability, the performance measures identified for the shaft seal system relate to fluid flow. As discussed in the previous paragraphs, the uncertainty in the salt column consolidation process is addressed in the relevant performance model. Variations in seal material porosity and compressibility were not included in these analyses. The most probable values for these parameters were selected for use in the performance models (DOE, 1996).

The pressure in the open shafts is atmospheric. It was assumed that the initial pore pressure for all seal materials was also atmospheric. Values for the saturated flow parameters and initial conditions for all seal materials are presented in Tables C-3 through C-7. These values are consistent with the most probable values listed in Appendix PAR of the WIPP Compliance Certification Application (DOE, 1996). Additional details regarding the uncertainty in these parameters are presented as appropriate later in the text.

C3.3.2 Two-Phase Flow Parameters

Two conditions necessitate consideration of two-phase flow within the shaft seal system. The first is that the seal system will be partially saturated with respect to brine at the time of construction. The second relates to the possibility that gas will be generated by the waste forms, and this gas could migrate to the base of the sealed shafts. Modeling a system that has two phases requires knowledge of the two-phase properties, which are characterized by capillary pressure and relative permeability curves for each phase. Ideally, each material will have a set of characteristic curves derived from experimental data. In practice, however, these curves rarely exist for the precise materials being modeled. The curves can be estimated using functional relationships found in the literature (Brooks and Corey, 1966; van Genuchten, 1980; Parker et al., 1987). Webb (1996) performed a literature review of the relationships for determining two-phase characteristic curves. Based on those comparisons, he concluded that no single model best fits all the data, and he further recommended the use of two models for future modeling activities at the WIPP. He referred to these two models as the mixed Brooks and Corey model and the van Genuchten/Parker model. The van Genuchten/Parker model was implemented in the two-phase calculations presented in this appendix.

Based on literature searches, two-phase parameters for the Brooks and Corey model were derived. These parameters were applied to all seal materials, with the exception of asphalt. Parameters necessary for the van Genuchten/Parker model can be derived from those specified for the Brooks and Corey model. The necessary parameters are the threshold pressure, pore size distribution index (λ), residual water saturation, and residual gas saturation. An empirically derived relationship between threshold pressure and permeability (Davies, 1991) is used for determining the threshold pressure. The values used for two-phase flow parameters are summarized in Table C-8.

The initial saturation condition must also be specified for the seal system. The initial liquid saturation state is derived from the following relationship:

$$S = w\gamma \frac{(1-\phi)}{\phi} \tag{C-1}$$

where

S = the liquid saturation

γ = the specific gravity of the material

w = the moisture content of the material

ϕ = the material porosity.

For all materials, the liquid was assumed to be brine. Porosity and moisture content are engineered parameters specified for each material (DOE, 1996).

The capillary pressure model for asphalt is the only exception to the parameters described above. Asphalt is a hydrophobic material. Using the parameters described for other seal materials and the low brine saturation of the asphalt, this seal component would develop a large suction pressure, attracting water. This behavior is not consistent with a hydrophobic material. Therefore, a linear capillary model is assumed for the asphalt. The model is defined by a zero capillary pressure at all brine saturations.

C3.4 Host-Rock Properties

Because the permeability (or hydraulic conductivity) of the host-rock formations is the most important parameter characterizing the host formations, emphasis will be given to it. Porosity and compressibility used for each rock type will be summarized in tables, but discussion of these parameters and their sources will be limited.

C3.4.1 Permeability and Hydraulic Conductivity

The following sections discuss the permeability and hydraulic conductivity of the Salado evaporites and each member of the Rustler Formation. The values assumed for both the undisturbed and disturbed formation are presented. Tables C-9 and C-10 summarize the values of permeability and hydraulic conductivity for the Rustler and Salado Formations.

The reported disturbed formation permeabilities represent the permeability of the DRZ at the shaft/DRZ interface. These permeabilities will later be used to calculate the effective DRZ permeability.

Table C-9. Summary of Permeability and Hydraulic Conductivity, Porosity, and Compressibility for the Rustler Modeled Lithologic Units

Lithology	Undisturbed Permeability (m^2)	Undisturbed Hydraulic Conductivity (m/s)	Disturbed Permeability (m^2)	Disturbed Hydraulic Conductivity (m/s)	Porosity (fraction)	Rock Compressibility (Pa^{-1})	Pore-Volume Compressibility (Pa^{-1})
Anhydrite(1)	1.00×10^{-19}	6.69×10^{-13}	1.00×10^{-19}	6.69×10^{-13}	0.01	2.2×10^{-11}	2.2×10^{-9}
Mudstone 4	3.89×10^{-16}	2.60×10^{-9}	3.89×10^{-13}	2.60×10^{-6}	0.30	9.8×10^{-10}	3.3×10^{-9}
Magenta	1.49×10^{-15}	1.00×10^{-8}	1.49×10^{-14}	1.00×10^{-7}	0.16	1.1×10^{-9}	6.9×10^{-9}
Mudstone 3	1.49×10^{-19}	1.00×10^{-12}	1.49×10^{-16}	1.00×10^{-9}	0.30	9.8×10^{-10}	3.3×10^{-9}
Culebra	2.09×10^{-14}	1.40×10^{-7}	2.09×10^{-13}	1.40×10^{-6}	0.16	1.1×10^{-9}	6.9×10^{-9}
Anhydrite 1/ Mudstone 1	1.00×10^{-19}	6.69×10^{-13}	1.00×10^{-19}	6.69×10^{-13}	0.05	200×10^{-11}	4.5×10^{-10}
Transition/ Bioturbated Clastics	2.24×10^{-18}	1.50×10^{-11}	2.24×10^{-15}	1.50×10^{-8}	0.20	7.9×10^{-11}	3.9×10^{-10}

(1) Anhydrite 5, Anhydrite 4, Anhydrite 3, and Anhydrite 2.

Table C-10. Summary of Permeability and Hydraulic Conductivity, Porosity, and Compressibility for the Salado Modeled Lithologic Units

Lithology	Undisturbed Permeability (m^2)	Undisturbed Hydraulic Conductivity (m/s)	Disturbed Permeability (m^2)	Disturbed Hydraulic Conductivity (m/s)	Porosity (fraction)	Rock Compressibility (Pa^{-1})	Pore-Volume Compressibility (Pa^{-1})
Anhydrite >3 m thick	1.00×10^{-19}	6.69×10^{-13}	1.00×10^{-19}	6.69×10^{-13}	0.01	2.23×10^{-11}	2.23×10^{-9}
Anhydrite <3 m thick	1.00×10^{-19}	6.69×10^{-13}	1.00×10^{-15}	6.69×10^{-9}	0.01	2.23×10^{-11}	2.23×10^{-9}
Halite	1.00×10^{-21}	6.69×10^{-15}	1.00×10^{-15}	6.69×10^{-9}	0.01	8.05×10^{-11}	8.05×10^{-9}
Polyhalite	3.00×10^{-21}	2.01×10^{-14}	1.00×10^{-15}	6.69×10^{-9}	0.01	2.23×10^{-11}	2.23×10^{-9}
Vaca Triste	1.49×10^{-19}	1.00×10^{-12}	1.49×10^{-16}	1.00×10^{-9}	0.20	6.6×10^{-10}	3.3×10^{-9}

Salado Formation

Table C-11 summarizes testing and analysis of test data for the Salado halite. In this appendix, the permeability of the undisturbed halite is assumed to have a value of 1×10^{-21} m^2, and the permeability of the disturbed halite is assumed to have a value of 1×10^{-15} m^2. The permeability for undisturbed halite is consistent with the cumulative probability distribution for the permeability of far field and depressurized halite given in Gorham et al. (1992). The permeability for disturbed halite was selected based on the probability density function for disturbed halite recommended to PA and included in Appendix D of this document. The basis for the disturbed halite permeability values is derived from field tests within the AIS (Dale and Hurtado, 1996) and other field test programs (Knowles et al., 1996; Stormont, 1990), which are discussed in Section C3.5. The disturbed halite distribution function recommended to PA is log-triangular with a maximum of 1×10^{-14} m^2 (6.7×10^{-8} m/s) and a minimum of 1×10^{-17} m^2. The permeability of 1×10^{-15} m^2 is consistent with the Salado disturbed permeability for halite previously used by PA.

The median permeability for undisturbed anhydrite, based on borehole testing, was 1.0×10^{-19} m^2 (DOE, 1996). The value for the disturbed permeability of the Salado anhydrites was assumed to be 1×10^{-15} m^2, which is consistent with the disturbed anhydrite permeability reported by Sandia WIPP Project (WIPP PA, 1992–1993).

The undisturbed polyhalite permeability of 3.0×10^{-21} m^2 was taken from Lappin et al. (1989) and Saulnier and Avis (1988). Because there was no specific information concerning polyhalite disturbed permeability, it was assumed to be the same as that for halite and anhydrite.

Table C-11. Testing and Analysis Summary for Salado Halite

Lithology	Reference(s)	Permeability (m^2)	Hydraulic Conductivity (m/s)	Comments
Undisturbed Halite	Beauheim et al., 1991 Beauehim et al., 1993	$3\times10^{-18} - 10^{-21}$	$2\times10^{-11} - 6.7\times10^{-15}$	Underground testing at the WIPP from 1988 to 1992
	Gorham et al., 1992	$10^{-19} - 10^{-24}$	$6.9\times10^{-13} - 6.7\times10^{-18}$	Values recommended for PA calculation
Disturbed Halite	Gorham et al., 1992	$10^{-13} - 10^{-18}$	$6.7\times10^{-7} - 6.7\times10^{-12}$	Values recommended for 1992 PA calculation
	WIPP PA, 1992–1993	$10^{-15} - 10^{-22}$	$6.9\times10^{-9} - 6.7\times10^{-16}$	Range used for 1992 PA calculations
	Dale and Hurtado, 1996	$10^{-14} - 10^{-17}$	$6.9\times10^{-8} - 6.7\times10^{-11}$	Testing in the AIS during 1995

The lithology of the Vaca Triste is a halitic siltstone and mudstone. No hydraulic conductivity information was available for the Vaca Triste. In the absence of any specific information, the undisturbed permeability and the disturbed permeability for the Vaca Triste were assumed to be 1.49×10^{-19} m^2 (1.0×10^{-12} m/s) and 1.49×10^{-16} m^2 (1.0×10^{-9} m/s), respectively. These values are the same as those used for Mudstone 3 in the Rustler, which has a similar lithology.

Within the Salado formation, several brine seepage intervals were noted. Permeabilities for these zones were assigned values of 10 times the base value for each rock type. Porosities and compressibilities were not modified for the brine seepage zones. Table C-12 identifies which Salado stratigraphic units were treated as brine seepage intervals.

Table C-12. Salado Brine Seepage Intervals(1)

Stratigraphic Unit
Marker Bed 103
Marker Bed 109
Vaca Triste
Zone A
Marker Bed 121
Union Anhydrite
Marker Bed 124
Zone B
Zone C
Zone D
Zone E
Zone F
Zone G
Zone H
Marker Bed 129
Zone I
Zone J

(1) After US DOE, 1995.

Rustler Formation

The Rustler Formation consists of five members, which from the oldest to youngest are: the unnamed lower member, the Culebra Dolomite Member, the Tamarisk Member, the Magenta Dolomite Member, and the Forty-niner Member. Many of the members are composed of informal lithologic units. The lower unnamed member has been hydraulically tested in the

vicinity of the AIS (see Table C-13) Because the tests reported in Beauheim (1987) most likely tested the most transmissive portions of the unnamed lower member (i.e., the transition and bioturbated clastic zones), the maximum measured hydraulic conductivity of 1.5×10^{-11} m/s was selected as the hydraulic conductivity for the transition and bioturbated zones units. The lower permeability units of the unnamed lower member, Anhydrite 1 and Mudstone 1, were assigned a permeability consistent with the anhydrite permeability of 1.0×10^{-19} m^2. Mudstone 2, which underlies the Culebra, was tested in H-16 in the test interval that included the Culebra (Beauheim, 1987). For this reason, the model considers Mudstone 2 and the Culebra as a single unit. The hydraulic conductivity of this unit is discussed with the Culebra.

A disturbed permeability 2.24×10^{-15} m^2 was selected for the bioturbated clastic zone and the transition zone. This value represents a three order of magnitude increase in hydraulic conductivity over the undisturbed value. A disturbed permeability of 1.0×10^{-15} m^2 was assigned to Anhydrite 1 and Mudstone 1, which were considered as a single unit in the model. Rock mechanics calculations presented in Appendix D of this report evaluate DRZ development in the clay units of the Rustler Formation.

The hydraulic conductivity of the Culebra dolomite varies over a wide range (four orders of magnitude) at the WIPP site. This wide variation is due to the presence of both open and filled fractures within the Culebra. The hydraulic conductivity is lowest in regions where the fractures in the Culebra are filled and highest in regions where the fractures are open. The location of the WIPP shafts is in a region of relatively lower hydraulic conductivity.

A value of 2.09×10^{-14} m^2 was selected as the permeability for the Culebra. This value represents the highest site-specific hydraulic conductivity estimated from testing the Culebra in the vicinity of the AIS. The disturbed permeability for the Culebra was assigned a value of 2.09×10^{-13} m^2. Mechanical calculations presented in Appendix D predict that Rustler dolomites will not develop a DRZ.

The Tamarisk Member of the Rustler Formation includes Anhydrite 2, which directly overlies the Culebra, Mudstone 3, and Anhydrite 3, which underlies the Magenta. Hydraulic testing of the Tamarisk was attempted at H-16 adjacent to the AIS but was unsuccessful (Beauheim, 1987). It was estimated that the transmissivity of the Tamarisk was one to two orders of magnitude lower than the least-transmissive unit successfully tested at H-16. This results in an estimated permeability ranging from 4.63×10^{-20} to 4.63×10^{-19} m^2.

A value of 1.0×10^{-19} m^2 was selected for the undisturbed permeability of the anhydrite units (Anhydrite 3 and Anhydrite 2) of the Tamarisk. The value for the disturbed permeability of the anhydrite units was taken as 1.0×10^{-15} m^2, which is consistent with the disturbed anhydrite permeability reported by Sandia WIPP Project (WIPP PA, 1992–1993). Rock mechanics calculations presented in Appendix D of this report predict that Rustler anhydrites do not develop a DRZ adjacent to the shaft. A value of 1.49×10^{-19} m^2 was selected for the undisturbed permeability of Mudstone 3, consistent with Brinster (1991). A disturbed permeability three orders of magnitude higher than the undisturbed value, or 1.49×10^{-16} m^2, was assumed for Mudstone 3.

Table C-13. Testing Summary for Rustler Formation

Lithology	Reference(s)	Range (m^2)	Conductivity (m/s)	Comments
Unnamed lower member: bioturbated clastic zone	Beauheim, 1987 Beauehim et al., 1993	2.24×10^{-18} – 1.84×10^{-18}	1.5×10^{-11} – 1.2×10^{-11}	Two build-up tests conducted over a 34.1-m interval
Silty mudstone at 238.4 m	Saulnier & Avis, 1988	1.49×10^{-20} – 1.49×10^{-21}	1.0×10^{-13} – 1.0×10^{-14}	Pulse testing in Waste Handling Shaft at discrete depth intervals
Silty claystone at 245.4 m	Saulnier & Avis, 1988	7.47×10^{-21} – 8.97×10^{-22}	5.0×10^{-14} – 6.0×10^{-13}	
Culebra Dolomite	Beauheim, 1987	2.09×10^{-14} – 1.18×10^{-14}	1.0×10^{-7} – 7.9×10^{-8}	Results of two drill-stem tests conducted in H-16
	Avis & Saulnier, 1990	1.49×10^{-14} – 2.84×10^{-15}	1.0×10^{-7} – 1.9×10^{-8}	Interpretation from fluid-pressure response in H-16 during drilling of AIS
Tamarisk Member	Avis & Saulnier, 1990	Response insufficient to estimate	Response insufficient to estimate	Interpretation from fluid-pressure response in H-16 during drilling of AIS
Magenta Member	Beauheim, 1987	5.68×10^{-16}	3.8×10^{-9}	Drill-stem test in H-16
	Avis & Saulnier, 1990	1.49×10^{-15}	1.0×10^{-8}	Interpretation from fluid-pressure response in H-16 during drilling of AIS
Forty-niner Member (Mudstone 4)	Beauheim, 1987	2.84×10^{-16} to 2.54×10^{-16}	1.9×10^{-9} – 1.7×10^{-9}	Testing at H-16
	Beauheim, 1987	2.39×10^{-15}	1.6×10^{-18}	Testing at H-14
	Avis & Saulnier, 1990	3.89×10^{-16}	2.6×10^{-9}	Interpretation from fluid-pressure response in H-16 during drilling of AIS

A value of 1.49×10^{-15} m^2 was selected as the undisturbed permeability for the Magenta. A value of 1.49×10^{-14} m^2 was selected for the disturbed permeability for the Magenta. This value is one order of magnitude greater than the undisturbed value.

The Forty-Niner member is composed of Anhydrite, Mudstone 4, and Anhydrite 6. At H-16, the permeability of the Forty-Niner Member is attached to Mudstone 4. Table C-3 summarizes hydraulic testing results for the Forty-Niner Member. Because the hydraulic conductivity value interpreted by Avis and Saulnier (1990) derived from a test that stressed a larger volume of rock, and because their hydraulic conductivity is larger than that determined for Mudstone 4 at H-16, a hydraulic conductivity of 3.89×10^{-16} m^2 was selected as the undisturbed permeability for Mudstone 4. The disturbed hydraulic conductivity for Mudstone 4 was assigned a value of 3.89×10^{-13} m^2, which is three orders of magnitude greater than the undisturbed value. The undisturbed and disturbed permeability for the anhydrite units in the Forty-niner (Anhydrite 4 and Anhydrite 5) were assigned values of 1.0×10^{-19} and 1.0×10^{-15} m^2, respectively.

C3.4.2 Porosity

Hydraulic test analyses have been performed on the members of the Rustler Formation (Beauheim, 1987; Saulnier and Avis, 1988; and Avis and Saulnier, 1990). These investigators assumed porosity values consistent with clays and dolomites, which are considered to be the most permeable units within the Rustler. The porosity values for anhydrite and halite were derived primarily from underground testing at the WIPP. The primary references for the anhydrites and halite porosities are Beauheim et al. (1991), Sandia WIPP Project (1992), and Beauheim et al. (1993). The ranges in porosity values used by WIPP investigators are listed in Table C-14. Selected values for the formation porosities fell within the ranges listed in this table (Tables C-9 and C-10).

Table C-14. Summary of Literature Values for Formation Porosities

Information/Lithology	Reference(s)	Porosity Range
Salado Halite and Anhydrite	Peterson et al., 1987 Beauheim et al., 1991 WIPP PA, 1992–1993 Beauheim et al., 1993	0.001 to 0.01
Rustler clays and dolomites	Beauheim, 1987 Saulnier & Avis, 1988 Brinster, 1991 Freeze & Cherry, 1979	0.05 to 0.3

C3.4.3 Formation Compressibility

The compressibility of the mudstone units and the transition/bioturbated clastic unit were calculated using Equation C-2 (Touloukian et al., 1981):

$$C_R = \frac{3(1-2v)}{E} \qquad \text{(C-2)}$$

where:

C_R = rock compressibility, Pa^{-1}

v = Poisson's ratio, dimensionless

E = Young's modulus, Pa^{-1}.

Touloukian et al. (1981) give a Young's modulus of 2.83 GPa and a Poisson's ratio of 0.04 for claystone. These values were assumed to be representative of the mudstones in the Rustler Formation. Substituting these values into Equation C-2 yields a rock compressibility of 9.8×10^{-10} Pa^{-1}. Dividing this value by the mudstone porosity of 0.30 results in a pore-volume compressibility of 3.3×10^{-9} Pa^{-1}.

The lithology of the transition/bioturbated clastic unit can be described as sandstone, siltstone, and halite-cemented sandstone and siltstone. Compressibility data for this unit are not available; therefore Young's modulus and Poisson's ratio for sandstones and siltstones were taken from Touloukian et al. (1981). The average Young's modulus and Poisson's ratio were 19.0 and 0.24 GPa respectively for sandstone, and 25.2 and 0.18 GPa respectively for siltstone. The values for the two rock types were then averaged to obtain a Young's modulus of 22.1 GPa and a Poisson's ratio of 0.21, assumed to be representative of the transition/bioturbated clastic unit. Using Equation C-2 and the assumed porosity of 0.20 yields a rock compressibility of 7.9×10^{-11} Pa^{-1} and a pore-volume compressibility of 3.9×10^{-10} Pa^{-1} for this unit.

LaVenue et al. (1990) assumed a rock compressibility of 1.1×10^{-9} Pa^{-1} for the Culebra in their regional groundwater flow model. This value was adopted for the rock compressibility of the Culebra and Magenta. Dividing this value by the assumed porosity of 0.16 yields a pore-volume compressibility of 6.9×10^{-9} Pa^{-1} for these two units.

The median rock compressibility for anhydrite interpreted from borehole testing was 2.23×10^{-11} Pa^{-1} (DOE, 1996), which converts to a pore-volume compressibility of 2.23×10^{-9} Pa^{-1} for a porosity of 0.01. Because no information about polyhalite compressibility was available, a value equal to that determined for anhydrite was assumed. A value of 8.05×10^{-9} Pa^{-1} was used for pore-volume compressibility for the Salado halite. Rock and pore-volume compressibilties for all lithologic units modeled are summarized in Tables C-9 and C-10.

C3.4.4 Two-Phase Properties of the Salado

Unsaturated flow properties for Salado halite and anhydrite marker beds were taken from Sandia WIPP Project (WIPP PA, 1992–1993) and are shown in Table C-15 in terms of parameter values for the Brooks-Corey equations for relative permeability and capillary pressure. The required parameters are threshold displacement pressure (P_t), residual wetting phase saturation (S_{lr}), residual gas saturation (S_{gr}), and the pore size distribution parameter (λ). Threshold displacement pressure (P_t) is specified by using the correlation with permeability, k, suggested by Davies (1991) and documented in Sandia WIPP Project (WIPP PA, 1992–1993). The same parameters were used for both disturbed and undisturbed rock. For the compacted salt column

performance model, it was found that greater numerical stability could be achieved if the TOUGH28W implementations of the Van Genuchten-Parker equations were used for relative permeability and capillary pressure instead of the Brooks-Corey equations. Pressure parameter P_o in the Van Genuchten-Parker equation for capillary pressure was derived from the Brooks-Corey parameter P_t in Table C-15 by equating the two formulas at an effective saturation of 0.5.

Table C-15. Salado Two-Phase Properties

Parameter	Salado Halite and Polyhalite	Salado Anhydrite
P_t (MPa)	$5.6\times10^{-7}[k(m^2)]^{-0.346}$	$2.6\times10^{-7}[k(m^2)]^{-0.346}$
S_{lr}	0.2	0.2
S_{gr}	0.0	0.0
λ	0.7	0.7

C3.5 DRZ Properties

A disturbed rock zone (DRZ) forms around excavations in the bedded halite of the Salado Formation immediately upon passage of the mining tools, and progressively develops over time with the unloading of the formation as it creeps into excavations (Stormont, 1990). Van Sambeek et al. (1993) refer to the DRZ that forms upon mining as the "initial DRZ" and the DRZ that forms as a result of creep deformation and stress redistribution as the "secondary DRZ." The DRZ extends radially out from the shaft wall into the host formation. The DRZ is expected to have the following characteristics: (1) increased porosity resulting from micro- or macro-fracturing, (2) increased fluid (gas or liquid) permeability, (3) decreased brine saturation, (4) decreased load-bearing capacity, and (5) decreased lithostatic pressure (Stormont, 1990; Van Sambeek et al., 1993). Because of these properties, the DRZ could act as a vertical flow path for brine and gas around a shaft seal. It is important to characterize the extent of the DRZ around the shaft excavations and its time-dependent properties (especially permeability).

Laboratory, field, and modeling studies have been performed to determine the mechanics of DRZ development. DRZ development has been documented in almost all horizontal rectangular excavations of the WIPP underground facility through gas permeability testing (Stormont et al., 1987; Stormont, 1990), visual observations (Borns and Stormont, 1988), and by other methodologies (Holcomb, 1988). Laboratory testing of salt cores has also provided significant insight into DRZ development. Hansen and Mellegard (1979) found that dilatancy is favored by conditions of low confining stress and high deviatoric stress, which characterize the region near an excavation. Laboratory testing has shown that a halite DRZ is self-healing given the proper stress conditions; Brodsky (1990) showed that artificially damaged cores could be healed with certain confining pressures and time.

Two hydraulic testing programs have been conducted within WIPP shafts. The earliest hydraulic testing program was conducted in the Waste Handling Shaft (Saulnier and Avis, 1988). More recently, hydraulic testing was performed to determine the extent of the DRZ in the AIS.

Six boreholes, three at each of two levels, were used to determine both gas and brine permeabilities (Dale and Hurtado, 1996).

Waste Handling Shaft Hydraulic Testing

The objective of the hydraulic testing conducted in the Waste Handling Shaft (Saulnier and Avis, 1988) was to identify the DRZ using permeability testing. This testing used a three-packer system capable of simultaneously testing the permeability in three zones at three different radial distances from the shaft. Four levels were tested, two in the unnamed lower member of the Rustler (depths 238.4 m [782 ft] and 245.4 m [805 ft] below ground surface [bgs], which coincide with the transition and bioturbated clastic zones), one just below the Rustler/Salado contact in halite (at a depth of 259.1 m [850 ft] bgs), and one in Salado halite, anhydrite, and polyhalite (at a depth of 402.3 m [1320 ft] bgs). The results from these tests showed no correlation between permeability and radial distance from the shaft at any level and did not identify the DRZ. A potential reason the DRZ was not clearly identified in the Waste Handling Shaft was the location of the test intervals. For three of the test intervals, the test closest to the shaft was located 1 m (3.2 ft) from the excavation. One test conducted in the Waste Handling Shaft (W850W) tested a zone located within 0.3 m (1 ft) of the shaft liner. The test zone closest to the shaft for test W850W extended from the outer edge of the shaft liner to a distance of 1.25 m (4.08 ft) from the shaft. This zone included the liner/DRZ interface and the DRZ. Saulnier and Avis (1988) report that testing of this zone proved futile because the zone could not be pressurized. They concluded that the test zone included an open fracture or a gap representing the liner/DRZ interface.

Air Intake Shaft Hydraulic Testing

Permeability testing was conducted to determine the radial extent of the DRZ in the Salado Formation surrounding the AIS. Testing was conducted at two levels within the AIS (Level A at 345.9 m [1135 ft] and Level C at 626.4 m [2,055 ft] bgs). At each of the two levels tested, three 10-cm (4-in.) diameter boreholes were drilled at a spacing of 120° into the formation at a 6° angle below the horizontal. The boreholes were drilled to a depth of approximately 6 m (20 ft). All six boreholes were gas-flow tested prior to the performance of brine testing. It is expected that the regions of the DRZ closest to the shaft wall have the greatest dilation and are likely the most desaturated (i.e., have brine saturations significantly less than 1.0). As the permeability of the DRZ approaches the intact permeability at greater radial distances, it is expected that the brine saturation of the DRZ approaches unity. Gas-flow tests were performed to determine the extent of the desaturated region (and, in so doing, define the radius where brine testing can be performed), to identify the relative permeability to gas of the DRZ, and to bracket the DRZ threshold pressure.

The distance within the boreholes at which the brine-permeability tests were conducted was based on the results of the gas-permeability testing. For gas-flow testing, a four-packer test tool was initially set so that the first test zone started at 6 in. from the shaft wall and extended an additional 15 in. into the formation. If gas flow was observed at that depth, the test tool was inserted an additional 2 to 4 in. and another test was performed. The process was repeated until a test with no observable gas flow was obtained. Brine-flow testing was performed approximately 5 to 6 in. beyond the distance at which no gas flow was observed. The objective of the brine-

permeability tests was to bracket the Salado permeability as a function of radial distance away from the shaft face in brine-saturated portions of the Salado. It was assumed that if the gas-permeability estimate was above 1.0×10^{-21} m^2, the formation was not completely saturated with respect to brine. Once the gas permeability decreased to less than or equal to 1.0×10^{-21} m^2, the formation was assumed to be at high brine saturations. The intact salt permeability was assumed (based on repository horizon testing) to be approximately 1.0×10^{-21} m^2. This order of magnitude value for intact permeability was confirmed with the brine testing in the AIS. The gas permeability testing system threshold was 1.0×10^{-23} m^2.

C3.5.1 Model for Calculating the Effective DRZ Permeability

From the results of the field testing in the AIS it was determined that the permeability of the Salado halite can vary over orders of magnitude across the DRZ. An effective permeability of the DRZ can be estimated through the definition of a functional relationship for the change in permeability as a function of radial distance in the DRZ. The AIS field data provide insight into the variation of permeability in the DRZ and the extent of the DRZ. Figure C-1 plots the AIS brine and gas permeability results along with several lines demonstrating potential relationships of DRZ permeability as a function of radial distance and the extent of the DRZ.

This interpretation is taken from Dale and Hurtado (1996); the details are not provided here. The AIS field data support the assumption that the DRZ permeability is greatest in the DRZ near the excavation face and decreases radially outward away from the shaft wall. Figure C-1 shows that a log-linear model of permeability as a function of radial distance is reasonable, based on the field results. A log-linear variation in permeability is also consistent with radial variation in dilatant strain predicted in the DRZ. Figure C-2 is a schematic of a shaft with a DRZ of inner radius r_i and outer radius r_o. It is assumed that the permeability k_i at r_i is several orders of magnitude higher than the intact undisturbed permeability k_o defined at r_o. A log-linear model is assumed to describe the DRZ permeability as a function of radial distance, and used to calculate an effective DRZ permeability. Field data are limited, and a precise functional relation for the radial change in permeability is not known. However, this model captures results of available field data and incorporates the largest calculated extent of the DRZ.

An equation was derived to calculate the effective DRZ permeability assuming that the change in permeability within the DRZ is log-linear. For a given r_i, k_i, r_o, and k_o, an effective DRZ permeability can be calculated that accounts for both the decrease in DRZ permeability and the increase in flow area as a function of radial distance away from the excavation. The equation for the effective DRZ permeability is:

$$k_{\mathrm{DRZ}} = \frac{2}{r_o + r_i}\left[\left(\frac{r_o\left[\ln(k_o)-\ln(k_i)\right]-\Delta r}{\left[\ln(k_o)-\ln(k_i)\right]^2}\right)k_o - \left(\frac{r_i\left[\ln(k_o)-\ln(k_i)\right]-\Delta r}{\left[\ln(k_o)-\ln(k_i)\right]^2}\right)k_i\right] \qquad \text{(C-3)}$$

where Δr is equal to the outer DRZ radius minus the inner DRZ radius.

Figure C-1 demonstrates that this relationship (dotted lines) provides a reasonable representation of the field permeability test results for both the upper and lower zones of the AIS.

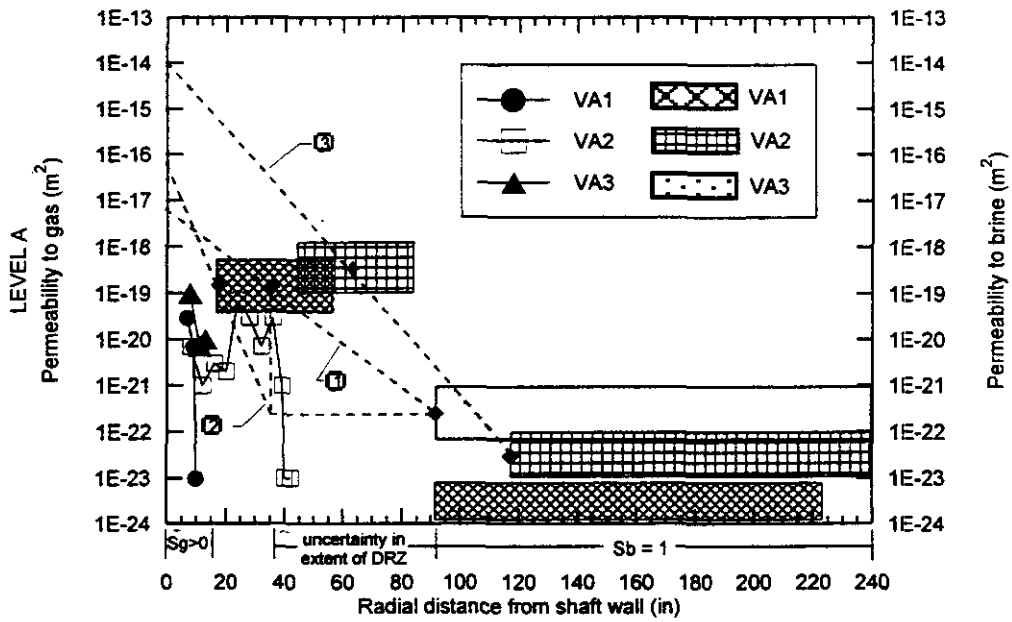

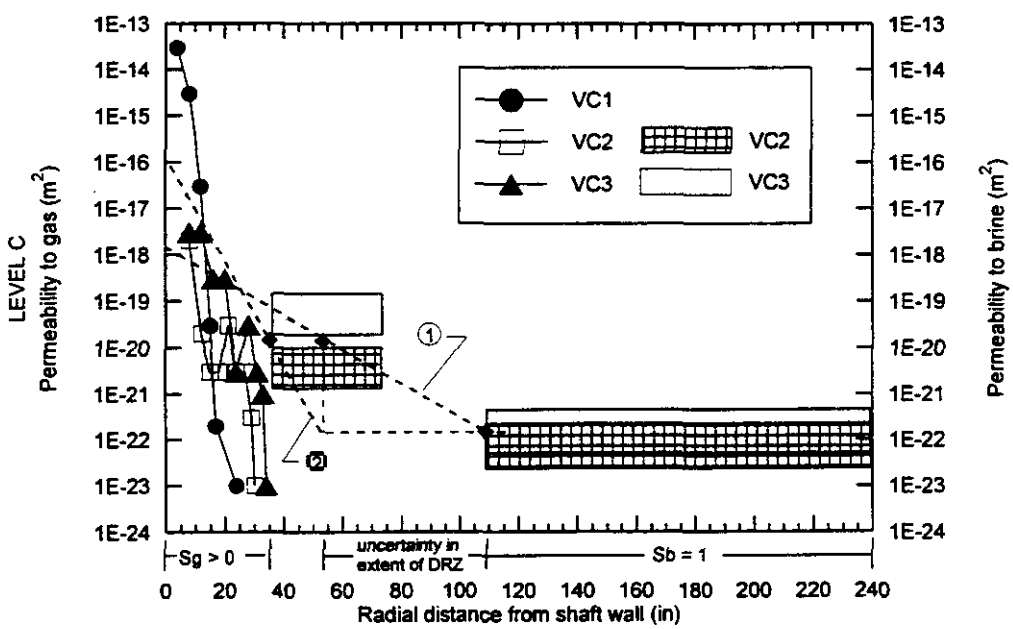

Figure C-1. AIS field permeability results.

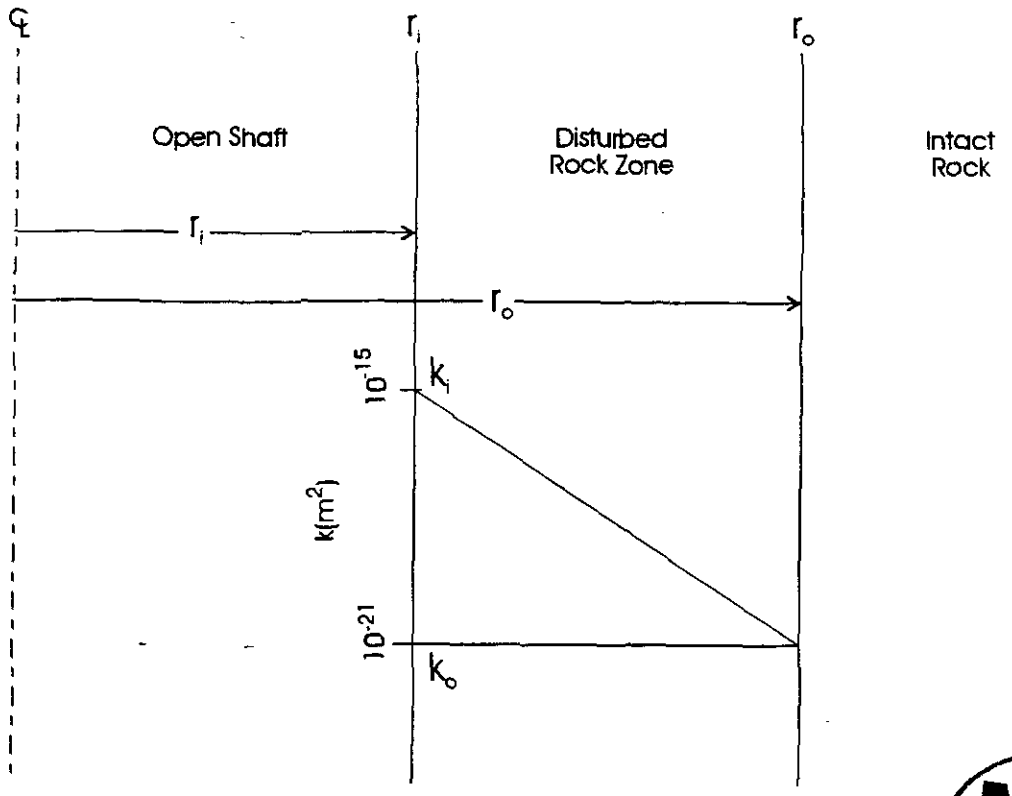

k_i Represents Maximum Dilation
k_o Represents Intact Conditions
r_i Excavation Face, Inner Radius of DRZ
r_o Outer Radius of DRZ

Figure C-2. Log-linear model for the calculation of an effective permeability of the DRZ.

C3.5.2 Model DRZ Effective Permeability

Rock mechanics calculations have been performed to predict the DRZ extent in both the Rustler and Salado formations. These calculations are presented in Appendix D of this report. The extent of the DRZ within the Rustler Formation is a function of rock type and depth. Mechanical calculations presented in Appendix D indicate no DRZ for anhydrites and dolomites, and a DRZ extent that increases with shaft depth for mudstones. The DRZ extent for the Rustler mudstones was interpolated from values given in Appendix D. For the base case assumption, the anhydrites were assumed to have no DRZ, consistent with the mechanical calculations presented in Appendix D. However, for the base-case model conceptualization, the Magenta and Culebra dolomites were assigned a DRZ. This was done to account for the fact that both of these dolomites are naturally fractured and the mechanical calculations did not account for the

presence of fractures. The extent of the DRZ for dolomite was set equal to one shaft radius. The DRZ in the Rustler is assumed not to heal as a function of time.

The DRZ extent within the Salado halite is calculated as a function of depth, shaft seal material, and time. In the Salado, the halite DRZ is at a maximum at closure and heals as a function of time. Healing occurs quickest with increased depth of burial and increased stiffness (bulk modulus) of the shaft seal material. Calculations of the radial extent of the halite DRZ for times 0, 10, 25, 50, and 100 years after shaft closure are provided in Appendix D. Plots of the halite DRZ extent adjacent to the various seal materials are also shown in Appendix D.

For halite, the effective DRZ permeability was calculated with Equation C-3 using the extent of the halite DRZ from Appendix D and the disturbed halite permeability at the shaft/DRZ interface. The effective permeability of the DRZ, as calculated using Equation C-3, is controlled by the permeability at the shaft/DRZ interface (k_i). For these calculations, k_i is assumed to remain constant and at its maximum value as long as a DRZ is predicted. In reality, it is expected that as the DRZ heals (halite), k_i will also decrease in magnitude. Therefore the calculation of the effective DRZ permeability is considered conservative.

Also presented in Appendix D are mechanical calculations that predict the DRZ in anhydrite Salado interbeds as a function of interbed thickness. These calculations show that for an anhydrite interbed thickness less than approximately 0.8 m, the anhydrite interbeds develop a DRZ approximately 1 m in extent. Previous estimates predicted that Salado anhydrite units with a thickness of less than 3 m have a DRZ extending 1 m from the shaft. For the base-case conceptualization, anhydrite units equal to or greater than 3 m in thickness were assigned no DRZ.

Because the anhydrite and polyhalite DRZs do not heal, the values calculated for DRZ extent do not change with time for these units. The DRZ extent for polyhalite for all times was assumed to be equal to the halite DRZ extent for the open shaft time period. Effective DRZ permeabilities based on Equation C-3 were adjusted for the difference between model DRZ areas, which do not vary (12% of shaft radius), and the variable DRZ areas described above.

Mechanical calculations predict that anhydrites within the Rustler and several within the Salado do not form a DRZ. These predictions do not account for damage induced during shaft construction, such as blasting damage. Because field data are not available for the DRZ in the Rustler members and Salado anhydrites, the models assume that the DRZ may be configured as "continuous" or "discontinuous." The discontinuous DRZ assumption utilizes only intact permeability values for Salado anhydrites and Rustler members. The continuous DRZ assumes these lithologies are damaged, and permeabilities are adjusted accordingly.

The model grids in this appendix do not include a discrete interface zone between shaft seal materials and the DRZ. This is because the model grids presented were based on the assumption that a continuous DRZ would be considered in all simulations. In the base-case conceptualization, a discontinuous DRZ is modeled consistent with mechanical predictions. However, in all cases the models are also run considering a continuous DRZ.

Mechanical calculations presented in Appendix D indicate that the DRZ surrounding the concrete-asphalt waterstops becomes discontinuous through healing of the salt within 2 years after emplacement. In the modeling in this appendix, it is assumed that the waterstops

effectively intersect the DRZ at 2 years after seal emplacement. Table C-16 gives the permeability values used for the base case conceptualization of the DRZ.

At the Rustler/Salado contact, unsaturated Rustler brine can potentially enter the Salado DRZ. Seepage of Rustler groundwater into the Salado DRZ could result in dissolution of Salado salt. It has been postulated that this type of dissolution would produce a direct conduit from the Rustler/ Salado contact to the lower Salado sealing system. Approximately 1.4×10^{-4} m^3 (0.3 kg) of salt are required to fully saturate 10^{-3} m^3 (1 kg) of Culebra groundwater (Siegel et al., 1991). The potential for creation of such a conduit will be treated within Performance Model 1.

C4. FLOW DOWN FROM THE RUSTLER (MODEL 1)

C4.1 Statement of Problem

The shaft seal system is designed to limit migration of fluids within the sealed shaft. Using the approximation of a completely saturated seal system, this calculation examined the potential for flow and quantity of flow that migrates from the Rustler and Salado down the shaft during early times. The performance measures (results) from this model are brine flow rate and cumulative brine volume over a 200-year time frame after repository closure. These performance measures are presented at (1) the Rustler/Salado interface, (2) the top of the compacted salt column, and (3) the base of the compacted salt column.

C4.2 Performance Model 1 Description

C4.2.1 Conceptual Model and Assumptions

To investigate the potential for vertical flow down from the Rustler through the shaft seal system, a full-shaft saturated-flow model was used. The focus of this calculation was to estimate the amount of brine flowing down through the shaft seal system to reach the top of the compacted salt column and, potentially, the repository.

Conceptually, flow down the seal system is an early-time issue. Over time, pressures at depth in the seal system will equilibrate to far-field pressures, which are significantly over-pressured with respect to the Rustler, and the downward driving force will reverse its direction. However, because the Rustler will repressurize more rapidly than the Salado, there is a potential for downward flow during the seal repressurization period. To characterize this period, the flow system has been conceptualized as a shaft seal system and an adjacent DRZ surrounded by host rocks. The primary assumptions are listed below:

- This calculation assumed that the primary water-producing zones above the Salado Formation are within the Rustler Formation. As a result, this calculation did not include supra-Rustler units.
- The calculation assumed brine-saturated flow conditions. This assumption (1) did not account for the time required or volume of liquid required to saturate the seal components and (2) overestimated brine transmissivities over the time period where the DRZ and seals would be variably saturated.

Table C-16. Model DRZ Permeability for Base-Case Conceptualization (Corrected for Model DRZ Area)

Row	Unit	Intrinsic Permeability (m^2)					
		Time=0 Yr	Time=2 Yr	Time=10 Yr	Time=25 Yr	Time=50 Yr	Time=100 Yr
1	Anhydrite5	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}
2	Anhydrite5	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}
3	Mudstone4	5.99×10^{-13}	5.99×10^{-13}	5.99×10^{-13}	5.99×10^{-13}	5.99×10^{-13}	5.99×10^{-13}
4	Mudstone4	5.99×10^{-13}	5.99×10^{-13}	5.99×10^{-13}	5.99×10^{-13}	5.99×10^{-13}	5.99×10^{-13}
5	Anhydrite4	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}
6	Magenta	6.06×10^{-14}	6.06×10^{-14}	6.06×10^{-14}	6.06×10^{-14}	6.06×10^{-14}	6.06×10^{-14}
7	Anhydrite3	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}
8	Anhydrite3	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}
9	Mudstone3	2.75×10^{-16}	2.75×10^{-16}	2.75×10^{-16}	2.75×10^{-16}	2.75×10^{-16}	2.75×10^{-16}
10	Anhydrite2	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}
11	Anhydrite2	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}
12	Culbera/Mudstone2	8.50×10^{-13}	8.50×10^{-13}	8.50×10^{-13}	8.50×10^{-13}	8.50×10^{-13}	8.50×10^{-13}
13	Anhydrite1/Mudstone1	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}	1.00×10^{-19}
14	Transition/Bioturbated Clastics	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}
15	Transition/Bioturbated Clastics	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}
16	Transition/Bioturbated Clastics	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}
17	Transition/Bioturbated Clastics	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}
18	Transition/Bioturbated Clastics	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}
19	Transition/Bioturbated Clastics	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}	4.94×10^{-15}
20	Salado Halite	3.64×10^{-16}	3.64×10^{-16}	3.62×10^{-16}	3.59×10^{-16}	3.55×10^{-16}	3.49×10^{-16}
21	Salado Halite	3.68×10^{-16}	3.68×10^{-16}	1.10×10^{-16}	4.05×10^{-17}	1.00×10^{-21}	1.00×10^{-21}

Table C-16. Model DRZ Permeability for Base-Case Conceptualization (Corrected for Model DRZ Area)

Row	Unit	Intrinsic Permeability (m^2)					
		Time=0 Yr	Time=2 Yr	Time=10 Yr	Time=25 Yr	Time=50 Yr	Time=100 Yr
22	Salado Halite	3.70×10^{-16}	3.70×10^{-16}	1.08×10^{-16}	3.88×10^{-17}	1.00×10^{-21}	1.00×10^{-21}
23	Salado Halite	3.72×10^{-16}	3.72×10^{-16}	1.07×10^{-16}	3.80×10^{-17}	1.00×10^{-21}	1.00×10^{-21}
24	Salado Halite	3.73×10^{-16}	3.73×10^{-16}	1.06×10^{-16}	3.72×10^{-17}	1.00×10^{-21}	1.00×10^{-21}
25	Salado Halite	3.74×10^{-16}	3.74×10^{-16}	3.72×10^{-16}	3.69×10^{-16}	3.65×10^{-16}	3.58×10^{-16}
26	Salado Halite	3.76×10^{-16}	3.76×10^{-16}	3.73×10^{-16}	3.70×10^{-16}	3.66×10^{-16}	3.60×10^{-16}
27	Salado Halite	3.78×10^{-16}	3.78×10^{-16}	3.76×10^{-16}	3.73×10^{-16}	3.69×10^{-16}	3.62×10^{-16}
28	Salado Halite	3.83×10^{-16}	3.83×10^{-16}	3.81×10^{-16}	3.78×10^{-16}	3.73×10^{-16}	3.66×10^{-16}
29	Salado Halite	3.86×10^{-16}	3.86×10^{-16}	9.75×10^{-17}	2.87×10^{-17}	1.00×10^{-21}	1.00×10^{-21}
30	Salado Halite	3.88×10^{-16}	3.88×10^{-16}	9.62×10^{-17}	2.74×10^{-17}	1.00×10^{-21}	1.00×10^{-21}
31	Salado Halite	3.90×10^{-16}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
32	Salado Halite	3.91×10^{-16}	3.91×10^{-16}	9.47×10^{-17}	2.60×10^{-17}	1.00×10^{-21}	1.00×10^{-21}
33	Salado Halite	3.93×10^{-16}	3.93×10^{-16}	9.33×10^{-17}	2.47×10^{-17}	1.00×10^{-21}	1.00×10^{-21}
34	Combined Unit 1	1.15×10^{-18}	1.15×10^{-18}	1.15×10^{-18}	1.15×10^{-18}	1.15×10^{-18}	1.15×10^{-18}
35	Combined Unit 1	1.15×10^{-18}	1.15×10^{-18}	1.15×10^{-18}	1.15×10^{-18}	1.15×10^{-18}	1.15×10^{-18}
36	Salado Halite	4.00×10^{-16}	4.00×10^{-16}	2.92×10^{-16}	1.97×10^{-16}	1.01×10^{-16}	2.56×10^{-17}
37	Salado Halite	4.05×10^{-16}	4.05×10^{-16}	2.90×10^{-16}	1.91×10^{-16}	9.13×10^{-17}	1.81×10^{-17}
38	Salado Halite	4.13×10^{-16}	4.13×10^{-16}	2.86×10^{-16}	1.81×10^{-16}	7.85×10^{-17}	7.76×10^{-18}
39	Combined Unit 2	1.04×10^{-18}	1.04×10^{-18}	1.04×10^{-18}	1.04×10^{-18}	1.04×10^{-18}	1.04×10^{-18}
40	Salado Halite	4.25×10^{-16}	4.25×10^{-16}	2.75×10^{-16}	1.63×10^{-16}	6.00×10^{-17}	1.00×10^{-21}
41	Salado Halite	4.32×10^{-16}	4.32×10^{-16}	2.66×10^{-16}	1.51×10^{-16}	5.04×10^{-17}	1.00×10^{-21}
42	Salado Halite	4.37×10^{-16}	4.37×10^{-16}	2.61×10^{-16}	1.42×10^{-16}	4.37×10^{-17}	1.00×10^{-21}
43	Combined Unit 3	4.79×10^{-16}	4.79×10^{-16}	4.79×10^{-16}	4.79×10^{-16}	4.79×10^{-16}	4.79×10^{-16}
44	Salado Halite	4.41×10^{-16}	4.41×10^{-16}	2.55×10^{-16}	1.34×10^{-16}	3.73×10^{-17}	1.00×10^{-21}
45	Salado Halite	4.44×10^{-16}	4.44×10^{-16}	2.52×10^{-16}	1.29×10^{-16}	3.35×10^{-17}	1.00×10^{-21}
46	Salado Halite	4.47×10^{-16}	4.47×10^{-16}	2.49×10^{-16}	1.25×10^{-16}	3.00×10^{-17}	1.00×10^{-21}
47	Vaca Triste	1.40×10^{-16}	1.40×10^{-16}	1.40×10^{-16}	1.40×10^{-16}	1.40×10^{-16}	1.40×10^{-16}

Table C-16. Model DRZ Permeability for Base-Case Conceptualization (Corrected for Model DRZ Area)

Row	Unit	Intrinsic Permeability (m^2)					
		Time=0 Yr	Time=2 Yr	Time=10 Yr	Time=25 Yr	Time=50 Yr	Time=100 Yr
48	Salado Halite	4.49×10^{-16}	4.49×10^{-16}	2.45×10^{-16}	1.20×10^{-16}	2.64×10^{-17}	1.00×10^{-21}
49	Salado Halite	4.50×10^{-16}	4.50×10^{-16}	2.45×10^{-16}	1.19×10^{-16}	2.55×10^{-17}	1.00×10^{-21}
50	Salado Halite	4.52×10^{-16}	4.52×10^{-16}	5.44×10^{-17}	2.94×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
51	Salado Halite	4.53×10^{-16}	4.53×10^{-16}	5.32×10^{-17}	2.64×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
52	Salado Halite	4.54×10^{-16}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
53	Salado Halite	4.55×10^{-16}	4.55×10^{-16}	5.19×10^{-17}	2.30×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
54	Salado Halite	4.57×10^{-16}	4.57×10^{-16}	5.07×10^{-17}	2.00×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
55	Salado Halite	4.60×10^{-16}	4.60×10^{-16}	9.88×10^{-17}	7.89×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
56	Salado Halite	4.65×10^{-16}	4.65×10^{-16}	9.40×10^{-17}	3.94×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
57	Combined Unit 4	5.46×10^{-16}	5.46×10^{-16}	1.73×10^{-16}	9.66×10^{-19}	1.90×10^{-20}	1.90×10^{-20}
58	Salado Halite	4.71×10^{-16}	4.71×10^{-16}	8.65×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
59	Salado Halite	4.73×10^{-16}	4.73×10^{-16}	8.36×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
60	Union Anhydrite	3.86×10^{-16}	3.86×10^{-16}	3.86×10^{-16}	3.86×10^{-16}	3.86×10^{-16}	3.86×10^{-16}
61	Salado Halite	4.76×10^{-16}	4.76×10^{-16}	8.08×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
62	Salado Halite	4.78×10^{-16}	4.78×10^{-16}	7.80×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
63	Salado Halite	4.81×10^{-16}	4.81×10^{-16}	7.42×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
64	Combined Unit 5	3.37×10^{-16}	3.37×10^{-16}	3.37×10^{-16}	3.37×10^{-16}	3.37×10^{-16}	3.37×10^{-16}
65	Salado Halite	4.85×10^{-16}	4.85×10^{-16}	6.91×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
66	Salado Halite	4.88×10^{-16}	4.88×10^{-16}	6.62×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
67	Salado Halite	4.90×10^{-16}	4.90×10^{-16}	6.34×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
68	Combined Unit 6	5.91×10^{-16}	5.91×10^{-16}	7.93×10^{-17}	1.08×10^{-20}	1.08×10^{-20}	1.08×10^{-20}
69	Salado Halite	4.93×10^{-16}	4.93×10^{-16}	5.96×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
70	Salado Halite	4.95×10^{-16}	4.95×10^{-16}	5.67×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
71	Combined Unit 7	5.94×10^{-16}	5.94×10^{-16}	8.12×10^{-17}	1.33×10^{-20}	1.33×10^{-20}	1.33×10^{-20}
72	Salado Halite	5.03×10^{-16}	5.03×10^{-16}	4.77×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
73	Salado Halite	5.05×10^{-16}	5.05×10^{-16}	4.38×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}

Table C-16. Model DRZ Permeability for Base-Case Conceptualization (Corrected for Model DRZ Area)

Row	Unit	Intrinsic Permeability (m^2)					
		Time=0 Yr	Time=2 Yr	Time=10 Yr	Time=25 Yr	Time=50 Yr	Time=100 Yr
74	Salado Halite	5.06×10^{-16}	5.06×10^{-16}	4.15×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
75	Combined Unit 8	5.85×10^{-16}	5.85×10^{-16}	8.42×10^{-17}	1.88×10^{-20}	1.88×10^{-20}	1.88×10^{-20}
76	Salado Halite	5.08×10^{-16}	5.08×10^{-16}	3.89×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
77	Salado Halite	5.09×10^{-16}	5.09×10^{-16}	3.61×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
78	Salado Halite	5.11×10^{-16}	5.11×10^{-16}	3.31×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
79	Combined Unit 9	1.29×10^{-19}	1.29×10^{-19}	1.29×10^{-19}	1.29×10^{-19}	1.29×10^{-19}	1.29×10^{-19}
80	Combined Unit 9	1.29×10^{-19}	1.29×10^{-19}	1.29×10^{-19}	1.29×10^{-19}	1.29×10^{-19}	1.29×10^{-19}
81	Salado Halite	5.13×10^{-16}	5.13×10^{-16}	2.99×10^{-17}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
82	Salado Halite	5.13×10^{-16}	5.13×10^{-16}	5.53×10^{-18}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
83	Salado Halite	5.13×10^{-16}	5.13×10^{-16}	5.25×10^{-18}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
84	Salado Halite	5.14×10^{-16}	5.14×10^{-16}	4.95×10^{-18}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
85	Salado Halite	5.14×10^{-16}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}	1.00×10^{-20}
86	Salado Halite	5.15×10^{-16}	5.15×10^{-16}	4.48×10^{-18}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
87	Salado Halite	5.16×10^{-16}	5.16×10^{-16}	4.08×10^{-18}	1.00×10^{-21}	1.00×10^{-21}	1.00×10^{-21}
88	Salado Halite	5.16×10^{-16}	5.16×10^{-16}	1.02×10^{-16}	1.91×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
89	Combined Unit 10	1.09×10^{-19}	1.09×10^{-19}	1.09×10^{-19}	1.09×10^{-19}	1.09×10^{-19}	1.09×10^{-19}
90	Combined Unit 10	1.09×10^{-19}	1.09×10^{-19}	1.09×10^{-19}	1.09×10^{-19}	1.09×10^{-19}	1.09×10^{-19}
91	Salado Halite	5.18×10^{-16}	5.18×10^{-16}	9.66×10^{-17}	1.43×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
92	Salado Halite	5.19×10^{-16}	5.19×10^{-16}	9.18×10^{-17}	1.01×10^{-18}	1.00×10^{-21}	1.00×10^{-21}
93	Salado Halite	5.21×10^{-16}	5.21×10^{-16}	8.76×10^{-17}	6.34×10^{-19}	1.00×10^{-21}	1.00×10^{-21}
94	Salado Halite	5.21×10^{-16}	5.21×10^{-16}	8.55×10^{-17}	4.47×10^{-19}	1.00×10^{-21}	1.00×10^{-21}
95	Salado Halite	5.22×10^{-16}	5.22×10^{-16}	8.44×10^{-17}	3.53×10^{-19}	1.00×10^{-21}	1.00×10^{-21}
96	Combined Unit 11	2.86×10^{-16}	2.86×10^{-16}	2.86×10^{-16}	2.86×10^{-16}	2.86×10^{-16}	2.86×10^{-16}
97	Salado Halite	5.22×10^{-16}	5.22×10^{-16}	5.22×10^{-16}	5.22×10^{-16}	5.22×10^{-16}	5.22×10^{-16}
98	Salado Halite	5.22×10^{-16}	5.22×10^{-16}	5.22×10^{-16}	5.22×10^{-16}	5.22×10^{-16}	5.22×10^{-16}
99	Salado Halite	5.23×10^{-16}	5.23×10^{-16}	5.23×10^{-16}	5.23×10^{-16}	5.23×10^{-16}	5.23×10^{-16}

- The model was initialized at hydrostatic conditions based on heads in the Rustler Formation.
- The base of the shaft, at the repository horizon, was held at atmospheric conditions. The pressure at the repository horizon will increase after closure in response to far-field pressures and waste-generated gas. This assumption maintains a large downward potential gradient.

Assumptions relevant to all numerical calculations in this appendix are listed in Section C2.

Except for isolated regions, the Rustler Formation will likely resaturate the DRZ and adjacent rock surrounding the shaft liner in a relatively short period. However, performance models show that the lower-shaft seal system will not resaturate with brine and repressurize to ambient pressures for at least 100 years. Under variably saturated conditions along the shaft, brine flow rates are expected to be less than those provided in this analysis.

C4.2.2 Numerical Method

The modeling for this investigation was conducted using SWIFT II (Sandia Waste Isolation, Flow, and Transport Code), Version 2F. SWIFT II is a fully transient three-dimensional, finite-difference code that solves the coupled equations for single-phase flow and transport in porous and fractured geologic media. SWIFT II was selected because it is versatile and has been extensively verified against analytical results.

SWIFT II is supported by comprehensive documentation and an extensive testing history. Reeves et al. (1986a) discuss the theory and implementation of the code and basic limitations of the methodology. A guide to the input data is provided by Reeves et al. (1986b). Comparisons of the results from SWIFT II to analytical solutions appear in Finley and Reeves (1981), Reeves et al. (1987), and Ward et al. (1984).

C4.2.3 Model Geometry and Boundary Conditions

The full-shaft model was implemented with the cylindrical grid shown in Figures C-3a and C-3b. This grid extends vertically from the shaft station monolith at elevation 387.4 m (1271.0 ft) msl up through the Rustler Formation to an elevation of 872.6 m (2862.7 ft) msl. The grid extends radially from the center of the shaft out to an outer radius of 30.9 m (101.4 ft). It is composed of 19 radial columns and 99 vertical layers. Tables C-14 and C-15 provide details of the grid representing various seal components and host rock units.

Layer thicknesses (Table C-17) and column widths (Table C-18) are chosen so that they will adequately resolve the flow field within each seal component and each unit of the host formation without unduly compromising computational efficiency. Consistent with the first-order analysis of Van Sambeek et al. (1993), the total DRZ width (0.370 m) represents approximately 12% of the shaft radius (3.09 m).

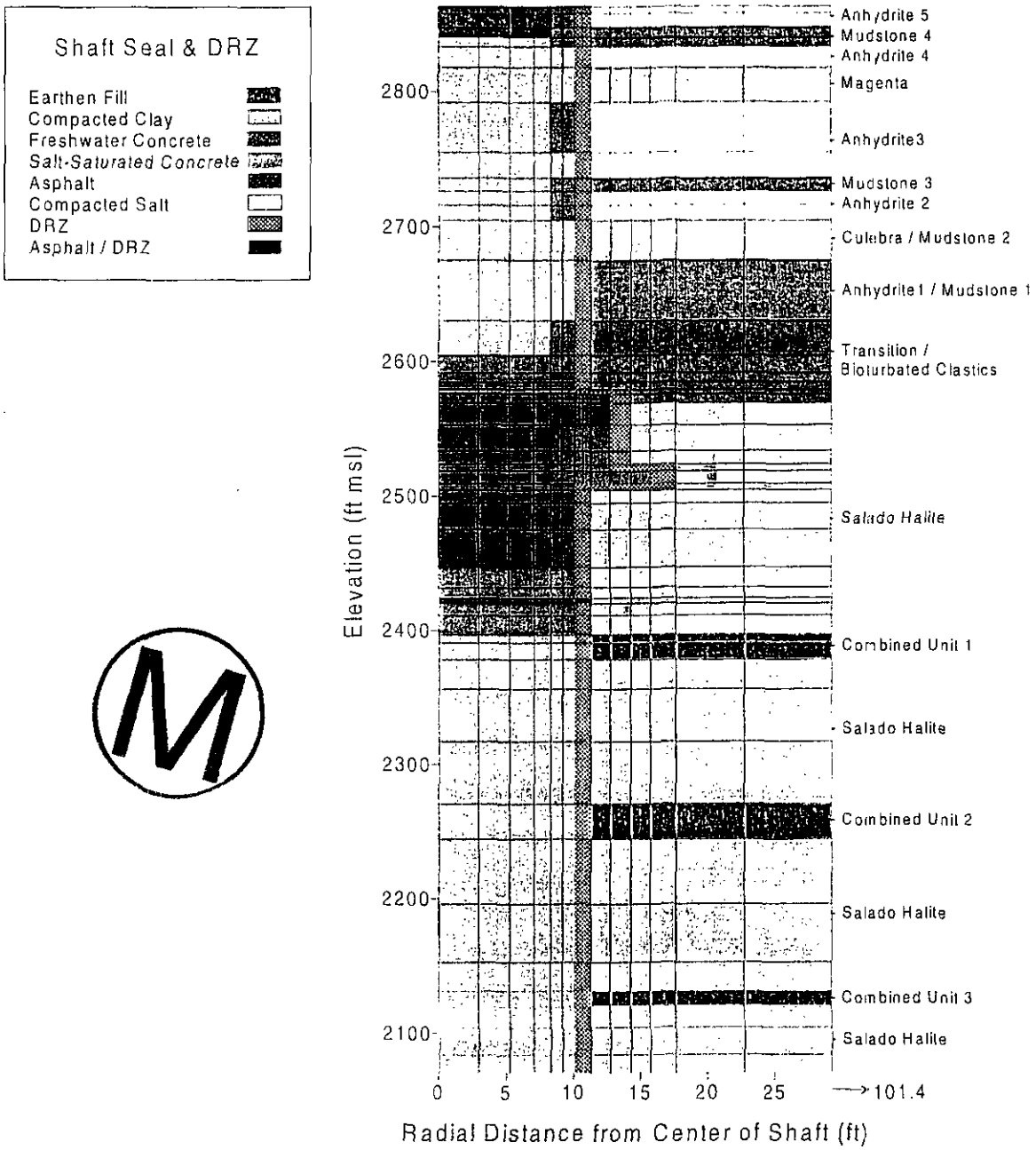

Figure C-3a. Full shaft model grid (top).

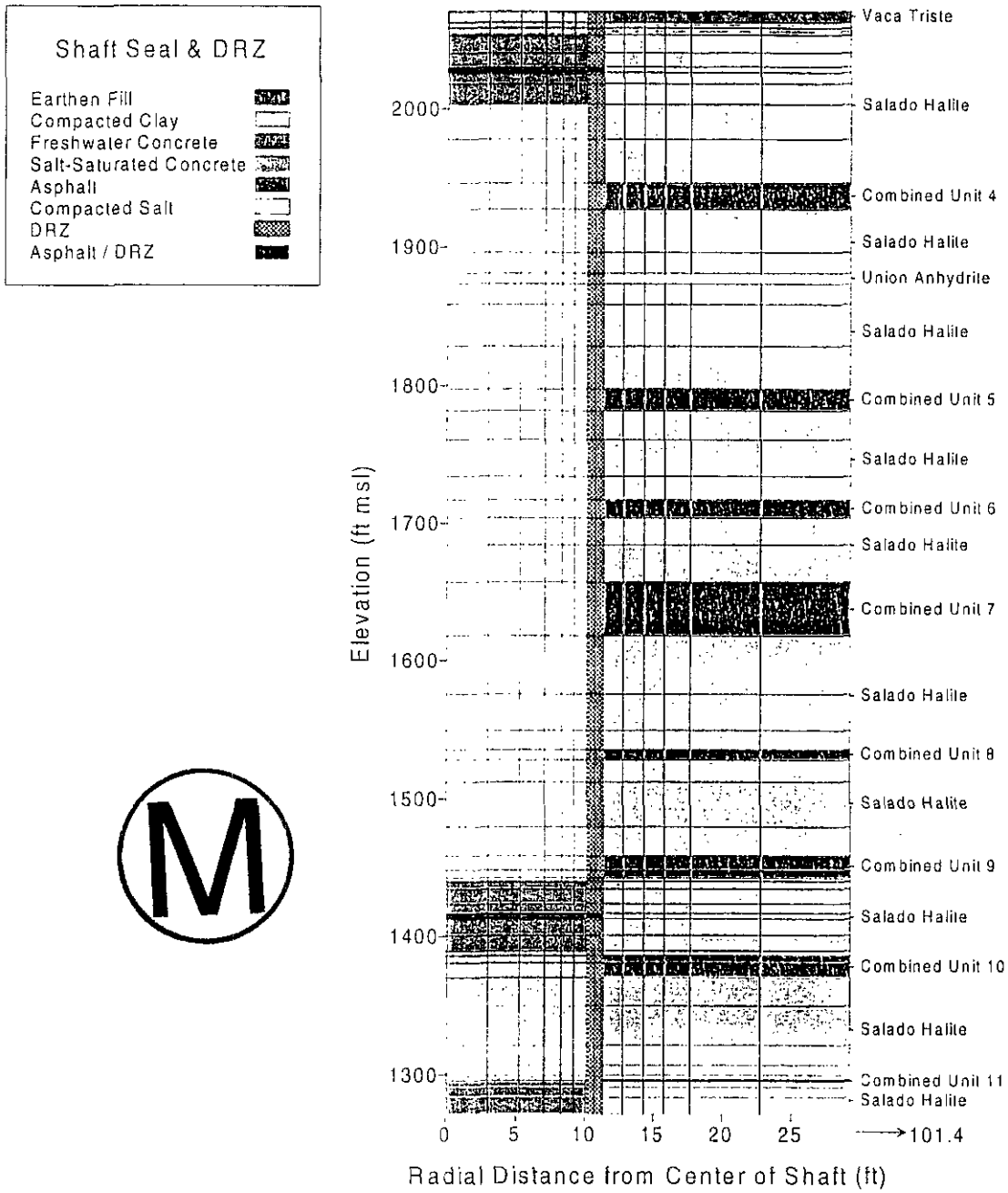

Figure C-3b. Full shaft model grid (bottom).

Table C-17. Full-Shaft Model Vertical Layers

Layer Number	Layer Thickness (m)	Shaft Seal Component	Host Formation Unit
1 (TOP)	1.52	Earthen Fill	Anhydrite 5
2	3.11	Earthen Fill	Anhydrite 5
3	2.29	Earthen Fill	Mudstone 4
4	2.13	Rustler Compacted Clay Column	Mudstone 4
5	4.69	Rustler Compacted Clay Column	Anhydrite 4
6	7.82	Rustler Compacted Clay Column	Magenta
7	11.26	Rustler Compacted Clay Column	Anhydrite 3
8	5.80	Rustler Compacted Clay Column	Anhydrite 3
9	2.90	Rustler Compacted Clay Column	Mudstone 3
10	3.15	Rustler Compacted Clay Column	Anhydrite 2
11	3.41	Rustler Compacted Clay Column	Anhydrite 2
12	8.99	Rustler Compacted Clay Column	Culbera/Mudstone 2
13	13.72	Rustler Compacted Clay Column	Anhydrite1/Mudstone 1
14	7.76	Rustler Compacted Clay Column	Transition/Bioturbated Clastics
15	4.02	Concrete Plug	Transition/Bioturbated Clastics
16	2.07	Concrete Plug	Transition/Bioturbated Clastics
17	1.72	Asphalt Column	Transition/Bioturbated Clastics
18	1.02	Asphalt Column	Transition/Bioturbated Clastics
19	2.04	Asphalt Column	Transition/Bioturbated Clastics
20	4.97	Asphalt Column	Salado Halite
21	5.86	Asphalt Column	Salado Halite

Table C-17. Full-Shaft Model Vertical Layers

Layer Number	Layer Thickness (m)	Shaft Seal Component	Host Formation Unit
22	3.00	Asphalt Column	Salado Halite
23	1.50	Asphalt Column	Salado Halite
24	2.90	Asphalt Column	Salado Halite
25	1.50	Asphalt Column	Salado Halite
26	3.00	Asphalt Column	Salado Halite
27	6.00	Asphalt Column	Salado Halite
28	8.55	Asphalt Column	Salado Halite
29	4.57	Upper Concrete Plug	Salado Halite
30	2.44	Upper Concrete Plug	Salado Halite
31	1.22	Asphalt Waterstop	Salado Halite
32	2.71	Upper Concrete Plug	Salado Halite
33	4.30	Upper Concrete Plug	Salado Halite
34	1.93	Upper Salado Compacted Clay Column	Combined Unit 1
35	3.86	Upper Salado Compacted Clay Column	Combined Unit 1
36	6.76	Upper Salado Compacted Clay Column	Salado Halite
37	11.92	Upper Salado Compacted Clay Column	Salado Halite
38	14.08	Upper Salado Compacted Clay Column	Salado Halite
39	8.05	Upper Salado Compacted Clay Column	Combined Unit 2
40	14.74	Upper Salado Compacted Clay Column	Salado Halite
41	13.00	Upper Salado Compacted Clay Column	Salado Halite
42	6.50	Upper Salado Compacted Clay Column	Salado Halite
43	3.57	Upper Salado Compacted Clay Column	Combined Unit 3

Table C-17. Full-Shaft Model Vertical Layers

Layer Number	Layer Thickness (m)	Shaft Seal Component	Host Formation Unit
44	4.87	Upper Salado Compacted Clay Column	Salado Halite
45	6.13	Upper Salado Compacted Clay Column	Salado Halite
46	4.27	Upper Salado Compacted Clay Column	Salado Halite
47	2.44	Upper Salado Compacted Clay Column	Vaca Triste
48	1.22	Upper Salado Compacted Clay Column	Salado Halite
49	1.52	Upper Salado Compacted Clay Column	Salado Halite
50	3.90	Middle Concrete Plug	Salado Halite
51	3.12	Middle Concrete Plug	Salado Halite
52	1.22	Asphalt Waterstop	Salado Halite
53	2.44	Middle Concrete Plug	Salado Halite
54	4.57	Middle Concrete Plug	Salado Halite
55	7.65	Compacted Salt Column	Salado Halite
56	9.69	Compacted Salt Column	Salado Halite
57	5.79	Compacted Salt Column	Combined Unit 4
58	9.49	Compacted Salt Column	Salado Halite
59	4.57	Compacted Salt Column	Salado Halite
60	2.29	Compacted Salt Column	Union Anhydrite
61	4.57	Compacted Salt Column	Salado Halite
62	9.17	Compacted Salt Column	Salado Halite
63	9.45	Compacted Salt Column	Salado Halite
64	4.72	Compacted Salt Column	Combined Unit 5
65	6.41	Compacted Salt Column	Salado Halite
66	8.17	Compacted Salt Column	Salado Halite
67	5.24	Compacted Salt Column	Salado Halite
68	3.96	Compacted Salt Column	Combined Unit 6
69	5.00	Compacted Salt Column	Salado Halite

M

Table C-17. Full-Shaft Model Vertical Layers

Layer Number	Layer Thickness (m)	Shaft Seal Component	Host Formation Unit
70	8.33	Compacted Salt Column	Salado Halite
71	11.83	Compacted Salt Column	Combined Unit 7
72	12.97	Compacted Salt Column	Salado Halite
73	8.00	Compacted Salt Column	Salado Halite
74	4.25	Compacted Salt Column	Salado Halite
75	2.29	Compacted Salt Column	Combined Unit 8
76	4.88	Compacted Salt Column	Salado Halite
77	9.95	Compacted Salt Column	Salado Halite
78	6.52	Compacted Salt Column	Salado Halite
79	3.11	Compacted Salt Column	Combined Unit 9
80	1.65	Compacted Salt Column	Combined Unit 9
81	0.82	Compacted Salt Column	Salado Halite
82	1.65	Lower Concrete Plug	Salado Halite
83	3.23	Lower Concrete Plug	Salado Halite
84	2.13	Lower Concrete Plug	Salado Halite
85	1.22	Asphalt Waterstop	Salado Halite
86	3.63	Lower Concrete Plug	Salado Halite
87	3.38	Lower Concrete Plug	Salado Halite
88	1.13	Lower Salado Compacted Clay Column	Salado Halite
89	1.52	Lower Salado Compacted Clay Column	Combined Unit 10
90	3.18	Lower Salado Compacted Clay Column	Combined Unit 10
91	6.33	Lower Salado Compacted Clay Column	Salado Halite
92	8.66	Lower Salado Compacted Clay Column	Salado Halite
93	4.39	Lower Salado Compacted Clay Column	Salado Halite
94	2.19	Lower Salado Compacted Clay Column	Salado Halite

Table C-17. Full-Shaft Model Vertical Layers

Layer Number	Layer Thickness (m)	Shaft Seal Component	Host Formation Unit
95	1.10	Lower Salado Compacted Clay Column	Salado Halite
96	0.49	Shaft Station Monolith	Combined Unit 11
97	1.16	Shaft Station Monolith	Salado Halite
98	2.19	Shaft Station Monolith	Salado Halite
99 (BOTTOM)	3.78	Shaft Station Monolith	Salado Halite

Table C-18. Full-Shaft Model Radial Gridding

Column Number	Radius to Outer Grid Column Boundary (m)	Model Component(s)
1	0.90	Seal
2	1.60	Seal
3	2.15	Seal
4	2.53	Seal
5	2.80	Liner, Seal
6	3.09	Liner, Seal
7	3.27	DRZ, Liner, Seal
8	3.46	DRZ, Liner, Seal
9	3.90	Host Rock, Liner, DRZ, Seal
10	4.37	Host Rock, Liner, DRZ
11	4.81	Host Rock, Liner, DRZ
12	5.39	Host Rock, DRZ
13	6.94	Host Rock
14	8.90	Host Rock
15	11.42	Host Rock
16	14.66	Host Rock
17	18.81	Host Rock
18	24.14	Host Rock
19	30.9	Host Rock

Because the outer boundary condition accurately characterizes an infinite aquifer, it is unnecessary to extend the radial grid to large distances. The radial boundary was fixed at 30.9 m (10 shaft radii), a distance sufficient to capture any vertical flow components that may arise in the host rock during the shaft resaturation process. Beyond the outermost extent of the seal components (4.81 m), a node-distributed grid is used because it is most appropriate for a radially converging flow field. Here coordinates of the nodal points increase in geometric progression, as recommended by Aziz and Settari (1979, p. 87).

Grid sensitivities are not expected. For liquid flow, flow rates are sufficiently small that the chosen level of refinement can resolve pressure gradients. It is important to resolve such gradients because they control the rates at which groundwater moves downward through seal components and radially inward through host rock.

For gas flow as simulated with a similar grid in Model 2, the situation is quite different. Within seal components lying below the lower seal, gas pressurization times are sufficiently small in comparison to the time required for salt-column reconsolidation that it is unnecessary to resolve gradients in the pressure front with either spatial or temporal discretization. Rather, grid refinement must be focused on the critical lower seal components and the DRZ that surrounds them. Here it is essential to resolve pressure gradients.

After DRZ healing, permeabilities of these components are sufficiently small so that long-term pressure gradients can be maintained, thus limiting gas pressurization of the salt columns as desired. Current results of two-phase simulations indicate that this grid is sufficiently refined to show substantially limited gas flows. Although some level of grid sensitivity could be present for gas flow within the lower seal components and surrounding DRZ, further refinement would yield only steeper pressure gradients and even smaller gas flow rates into the salt column.

For the model to accurately represent formation conditions at the time of closure, a pre-closure period was simulated. Therefore the modeling was conducted in two stages. The pre-closure period extended from the time of shaft excavation to the time of shaft closure. The duration was assumed to be 50 years. The shaft was considered to be instantaneously excavated, and development of the DRZ was considered to occur instantaneously after shaft excavation. The initial pressure conditions, in the portions of the system other than the open shaft, were represented by hydrostatic equilibrium based on an undisturbed head of 927 m msl at the center of the Culebra and a single-density fluid of 1230 kg/m^3. The pressure in the open shaft was held at 1 atm for the duration of the pre-closure simulation. No-flow boundary conditions were imposed at the top and bottom of the model. Infinite aquifer boundary conditions were set at the outer edge of the modeled region. The model components for the pre-closure simulation were the open shaft, the existing shaft liner, the DRZ, and the undisturbed formation.

The purpose of pre-closure modeling was to develop the pressure distribution in the formations created by the open shaft. For the post-closure period, the shaft was sealed and the initial grid-block pressures were set equal to the final grid-block pressures of the pre-closure simulation. Sealing of the shaft was considered to occur instantaneously. To maximize the driving force between the Rustler Formation and the bottom of the shaft, atmospheric pressure was maintained at the bottom of the shaft and DRZ. Otherwise, no-flow boundary conditions were imposed at the bottom and top of the model and along the vertical boundary at the center of

the shaft. Infinite aquifer boundary conditions were set at the outer edge of the modeled region. The model components for the post-closure simulation were the earthen fill, freshwater concrete, salt-saturated concrete, asphalt, compacted clay, crushed salt, the existing shaft liner, the DRZ, and the undisturbed formation. Freshwater concrete was assigned properties identical to those specified for salt-saturated concrete.

C4.2.4 Model Parameters

The model parameters were discussed in detail in Section C3. As reported in that section, permeabilities within the compacted salt column and within the Salado DRZ are transient (see Tables C-5 and C-16). Figures C-4 and C-5 illustrate the model permeabilities for the base-case simulation during the open-shaft period, at closure (t = 0 years), at 2 years (t = 2), and at 200 years (t = 200). These figures demonstrate the transient nature of the DRZ and compacted salt column permeabilities. These figures offer a method to integrate all of the permeability information provided in the tables in Section C3.

The base-case simulation assumed that the anhydrites in the Rustler Formation and anhydrites greater than 3 m thick in the Salado Formation had no DRZ (based on mechanical modeling results presented in Appendix D). This condition results in a discontinuous DRZ at the time of closure (see Figure C-4, second panel), as discussed in Section C3.5.1. Although this case could be realistic, a second case (Run 2) was considered to allow assessment of the impact of the discontinuous DRZ. The relationship developed for the Salado DRZ (Equation C-3) was applied to all lithologies for Run 2, resulting in a continuous DRZ along the shaft wall. Run 2 included concrete-asphalt waterstops that completely healed the adjacent DRZ after two years.

Run 3 was a sensitivity simulation to examine the impact of the concrete-asphalt waterstops. Run 3 incorporated a continuous DRZ at the time of shaft closure, as in Run 2. However, in contrast to Run 2, the DRZ adjacent to the concrete-asphalt waterstops was allowed to heal at the same rate as the DRZ adjacent to the concrete of the plugs, rather than in two years. Table C-19 summarizes the three simulations, highlighting the principal differences among them.

Table C-19. Performance Model 1 Simulations

Run	DRZ	Waterstops
1 (Base-Case)	Discontinuous	Yes
2	Continuous	Yes
3	Continuous	No

C4.3 Performance Model Results

Simulation results for Performance Model 1 are presented in terms of brine flow rates (m^3/yr), cumulative flow (m^3), and pressure distribution plots. Figure C-6 shows calculated brine flow rates for Runs 1 through 3 measured at the Rustler/Salado contact and at the top and bottom of the compacted salt column. Although the simulations continued out to 1000 years after shaft closure, the brine flow values were plotted to only 50 years because flow rates diminished to less than 0.03 m^3/yr by that time.

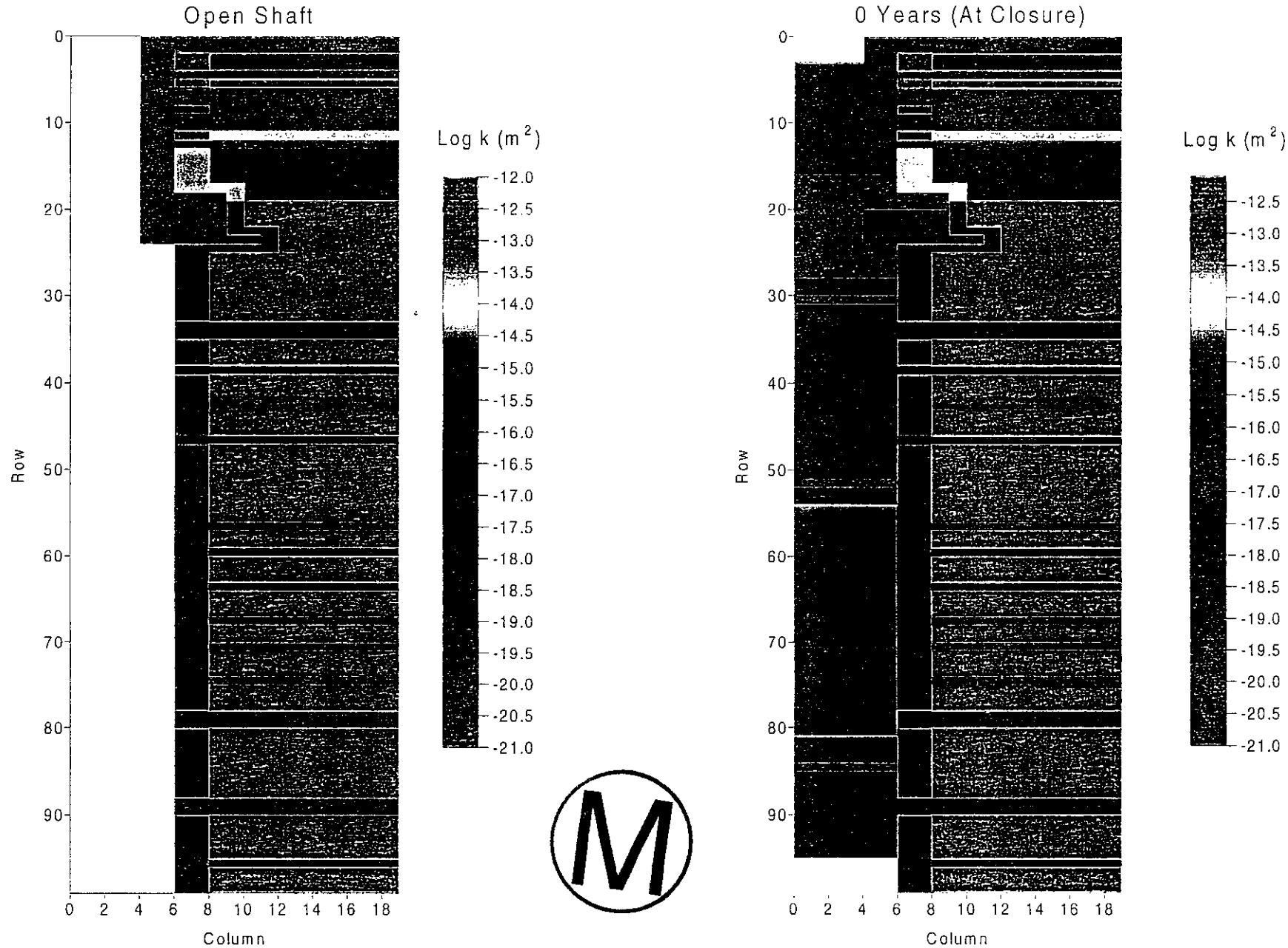

Figure C-4. Permeability fields for Run 1 (base case).

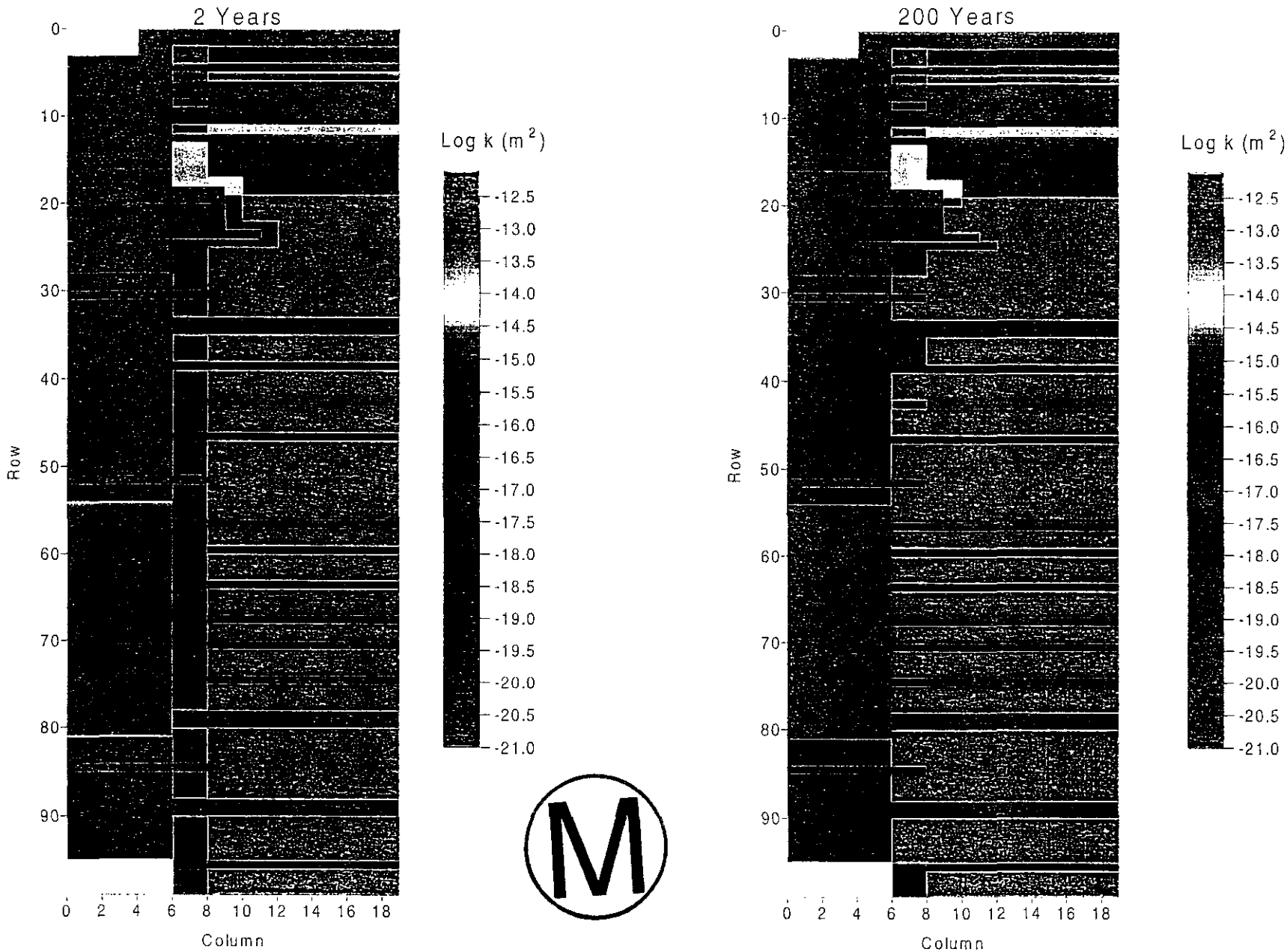

Figure C-5. Permeability fields for Run 1 (base case).

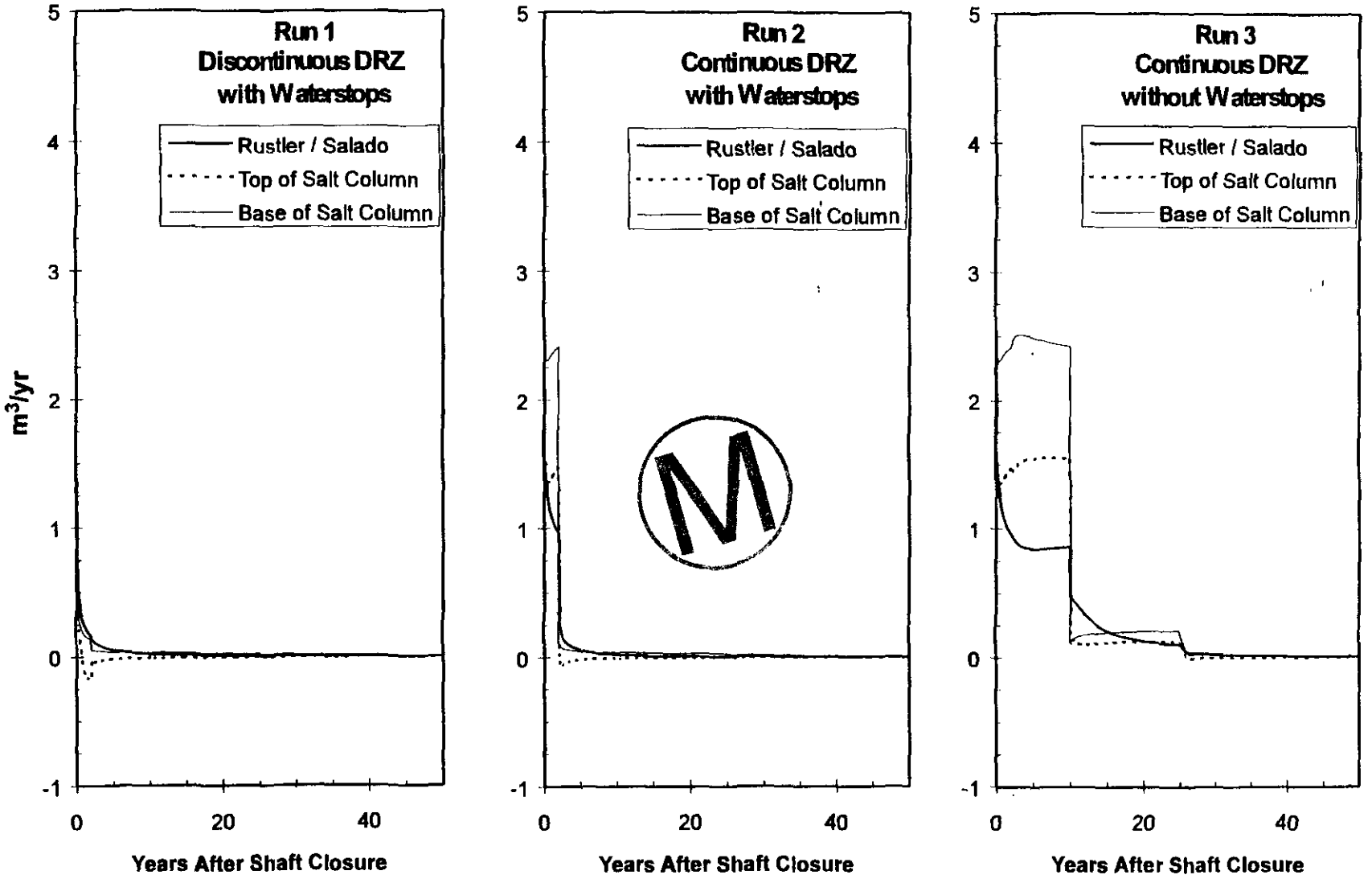

Figure C-6. Model 1 flow rates.

Figure C-7 shows the cumulative flow at 200 years measured at the Rustler/Salado contact and the top and bottom of the compacted salt column. Flow for each level for each run was divided into three components: flow through the shaft seal materials, flow through the DRZ, and flow through the intact host rock out to a radial distance of 10 shaft radii. As expected, flow through the intact rock was minimal for all cases. In Runs 2 and 3, where the DRZ is continuous, the amount of flow moving down through the seal system increased as a function of depth. This was a product of the model boundary conditions that direct formation fluids through the base of the shaft. In Run 1, the combination of a discontinuous DRZ and the waterstops created a pressure sink within and adjacent to the upper Salado compacted clay column. The small amount of flow moving down across the Rustler/Salado contact was used to repressurize the sink and did not migrate past the top of the compacted salt column.

The flow volumes predicted by Model 1 provided an estimate of the number of seal component pore-volumes that will pass through a given seal component. This exercise provides a useful method of quantifying flow estimates and is useful in the evaluation of seal material longevity. The total volume passing across the Rustler/Salado contact, the top of the compacted salt column, and the bottom of the compacted salt column was estimated for a 10,000-year period. Because the simulation did not extend for 10,000 years, the last simulated flow rate was used as a constant for times greater than the simulation time. As discussed in Section C4.2.1, the flow direction will reverse as the system equilibrates. The estimated flow volumes presented here are therefore maximum values.

The flow volumes were estimated for the top of the Salado concrete seal components and the compacted clay components. These flow volumes were then converted to total number of pore-volumes for a given seal component. The largest number of pore volumes predicted to flow through any Salado concrete component was 4. This calculation does not account for the volume of the asphalt waterstop. The largest number of pore volumes that flowed through any Salado compacted clay column was 0.4 for the lower Salado compacted clay column.

Figures C-8 and C-9 illustrate the change in pressure distribution with time for Run 1 (Discontinuous DRZ with Waterstops). All pressures are referenced to the elevation at the base of the model. The first panel of Figure C-8 shows the pressure drawdown at the end of the open shaft period just before shaft closure. The second panel shows the pressure profile just prior to activation of the waterstops. The first of the two panels shown in Figure C-9 illustrates the effect of the waterstops. The final panel in this sequence shows that most of the model has been repressurized by 200 years after shaft closure.

The potential for dissolution of salt in the Salado DRZ was introduced in Section C3.5. The results of Model 1 can be used to estimate the volume of salt that could be dissolved. Run 1 of the performance model predicts a maximum of about 1000 kg (1 m^3) of groundwater will migrate into the Salado DRZ. A maximum of about 0.14 m^3 of salt could be dissolved in this quantity of groundwater. The DRZ adjacent to the asphalt column contains approximately 1700 m^3 of salt. Dissolution of 0.14 m^3 of salt constitutes less than 0.01% of the DRZ volume. Therefore the probability that dissolutions will impact performance is exceedingly low.

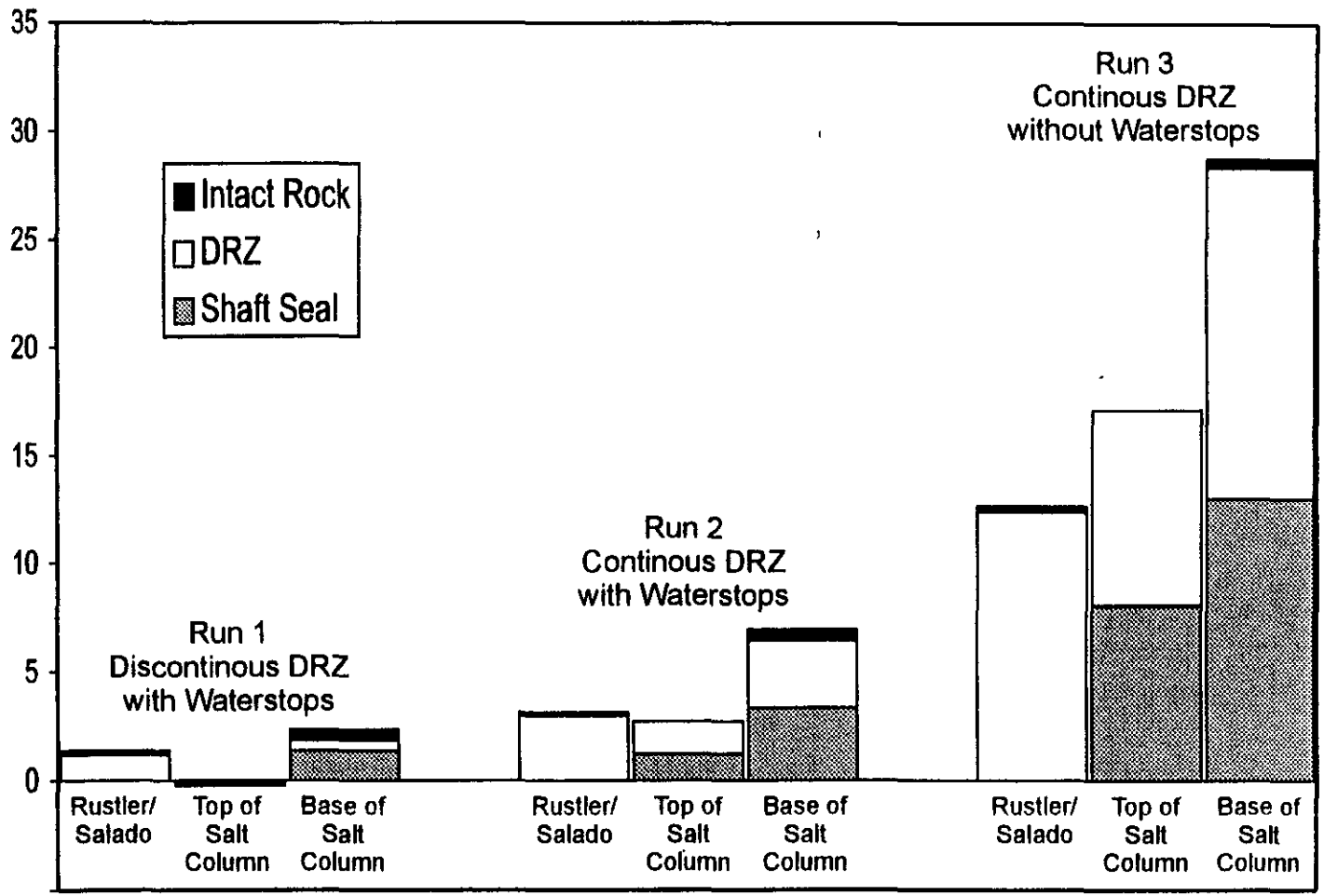

Figure C-7. Cumulative flow at 200 years.

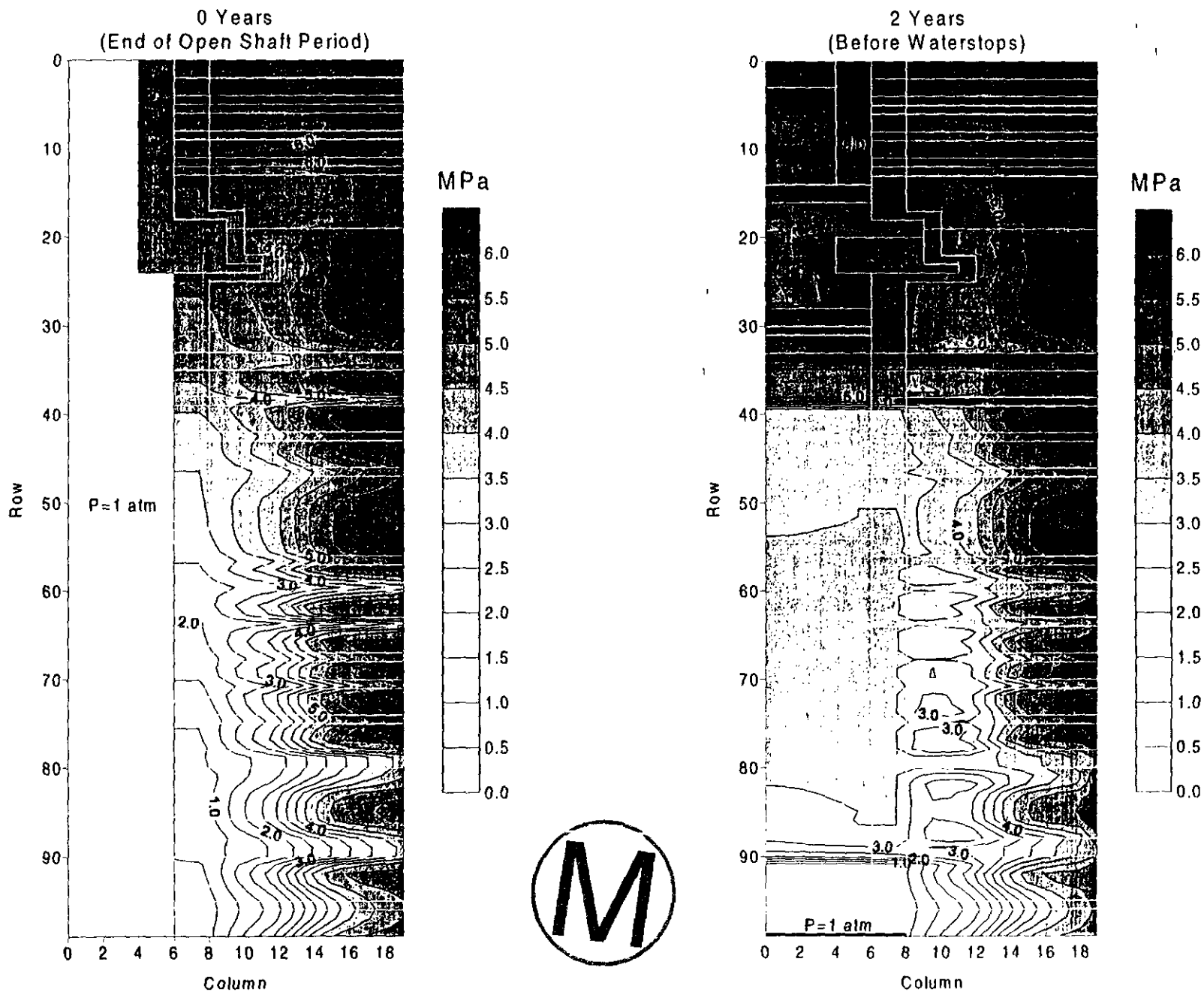

Figure C-8. Pressure distributions for Run 1 (base case).

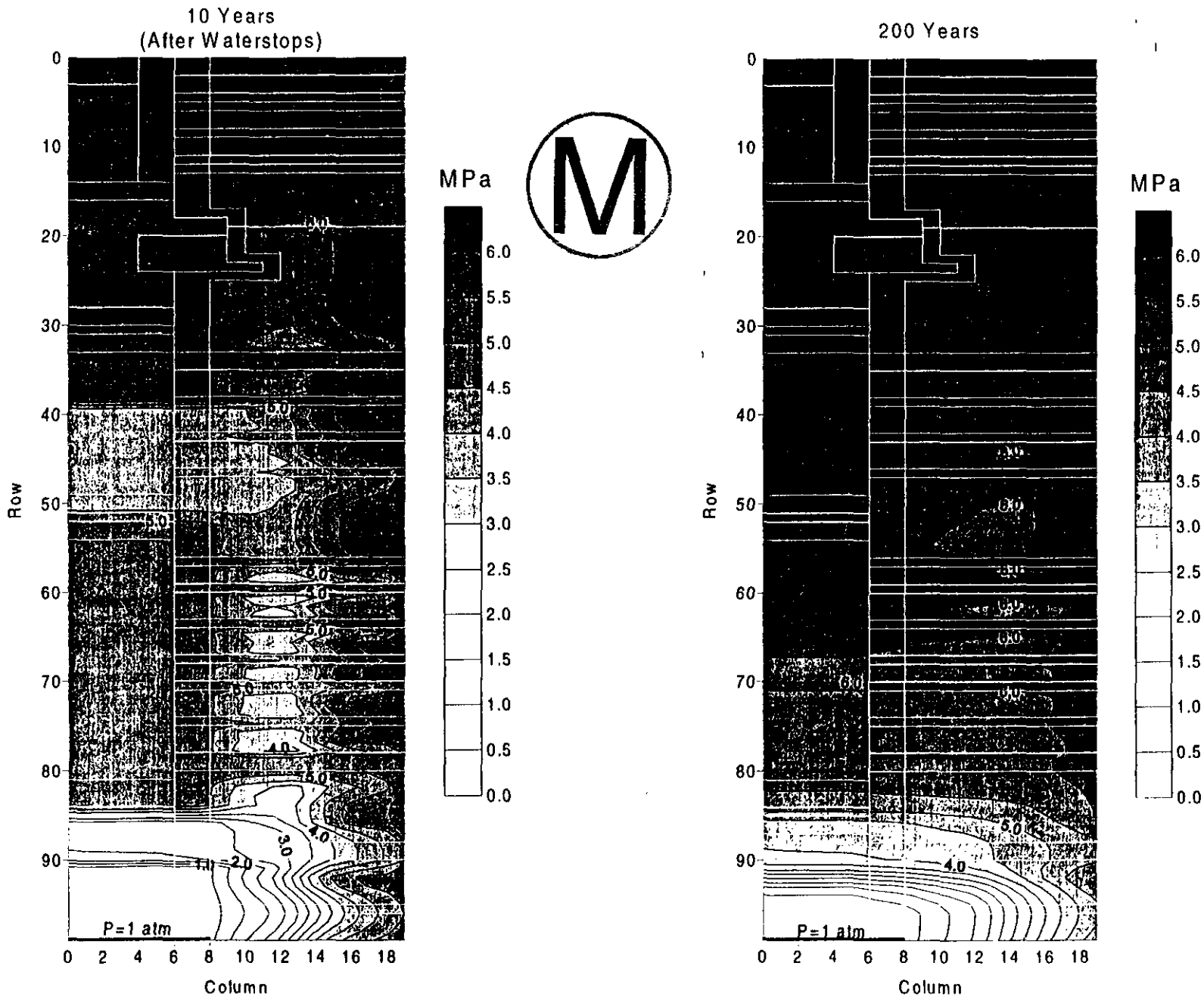

Figure C-9. Pressure distributions for Run 1 (base case).

C5. GAS MIGRATION AND CONSOLIDATION OF COMPACTED SALT COLUMN (MODEL 2)

C5.1 Statement of Problem

The compacted compacted salt column seal component is approximately 172 m (563 ft) long and located between elevations 439 m (1440 ft) msl and 611 m (2003 ft) msl in the proposed seal system design. This seal system component is composed of compacted crushed Salado salt, initially partially saturated with small amounts of water. After closure, as the host formation creeps inward, the crushed salt is expected to consolidate to a density and permeability condition comparable to that of the Salado host rock, thus creating a permanent, chemically compatible, low permeability seal component. The consolidation process can potentially be affected by pore pressures in the salt column. The purpose of this analysis was to predict the effect of pressure increases due to fluid (brine or gas) movement within the lower shaft seal system on compacted salt column permeability during the early time period when consolidation is occurring.

Fluid movement into the salt column could occur from three different sources: (1) brine flow down the shaft from the Rustler Formation above, (2) gas flow up the shaft from the repository below, and (3) brine flow towards the shaft from the host Salado formation due to pressure gradients created during the period the shaft is open to atmospheric pressure. Relationships developed for salt column fractional density (Appendix D) as a function of depth, pressure, and time were combined with estimates for crushed salt permeability as a function of fractional density and used in the analysis to provide an estimate of salt column permeability as a function of depth and time during the first 200 years after seal emplacement. In addition to salt column permeability, model outputs to be analyzed include pressure in the salt column and gas flow from the repository past the lower concrete component into the salt column.

C5.2 Performance Model 2 Description

C5.2.1 Conceptual Model and Assumptions

The schematic diagram in Figure C-10 shows the conceptualization of the flow system in the lower shaft region and the model components implemented by the compacted salt column performance model. The three sources of fluid flow that could contribute to pressure increases in the compacted salt column are shown in the diagram of the conceptual model (i.e., brine from the Rustler, brine from the host formation, and gas from the repository). Model components include the lower shaft seal components from the repository horizon to the top of the Vaca Triste interbed in the Salado Formation, a DRZ surrounding the shaft, and various anhydrite marker beds within the Salado Formation from the Vaca Triste to the repository horizon.

As discussed in Section C3, the DRZ was assumed to have progressively lower permeability as healing occurs with time after seal emplacement. The crushed salt of the compacted salt column was assumed to consolidate and achieve lower permeability with time at differing rates depending on depth within the column and the amount of pore-pressure back stress within the column.

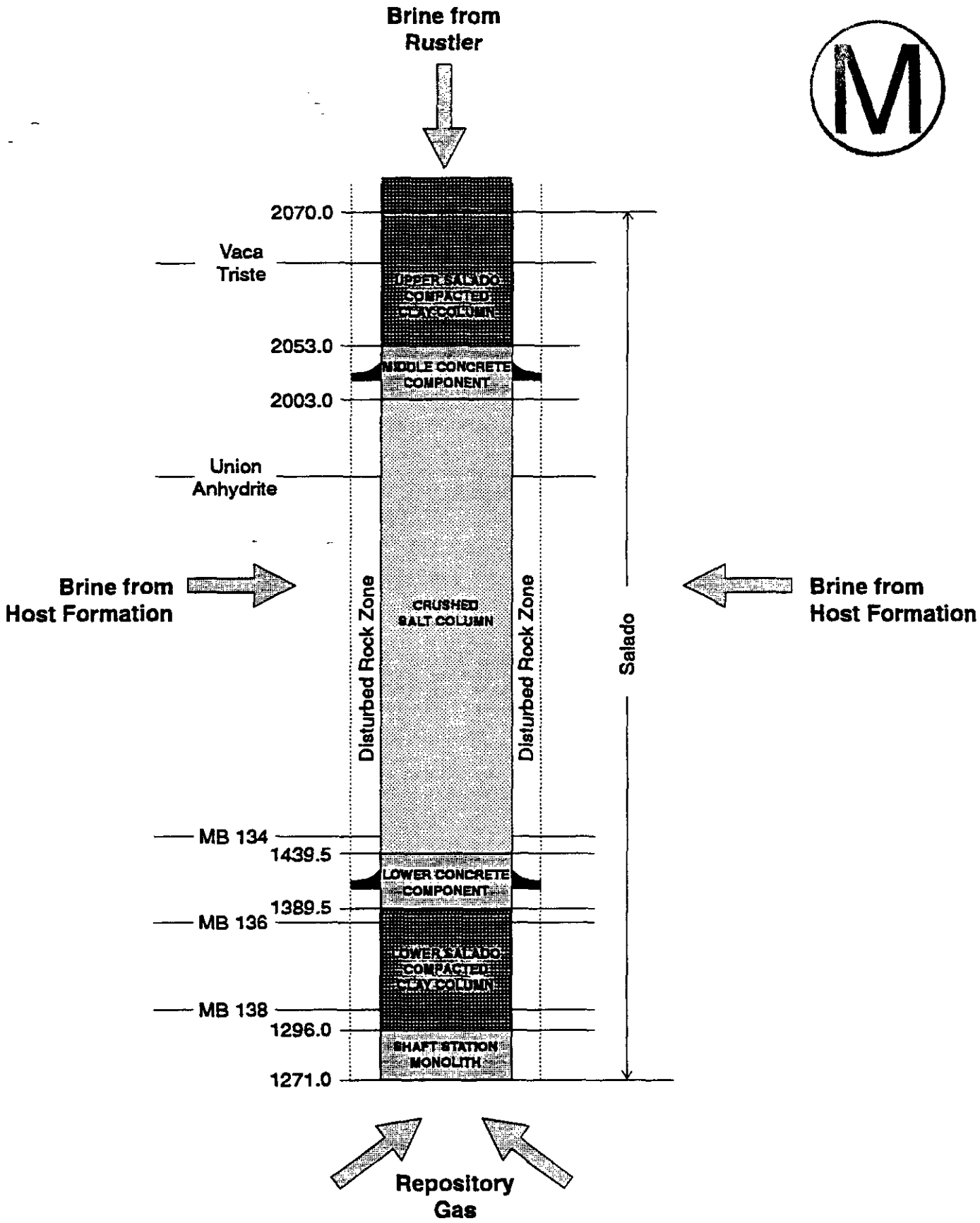

Figure C-10. Conceptual diagram of compacted salt column performance model components.

Results obtained from the full-shaft saturated flow model discussed in Section C4 indicate no brine flow down the shaft into the compacted salt column from the Rustler Formation for the case of a discontinuous DRZ, 2.7 m^3 for a continuous DRZ with waterstops, or 17.2 m^3 for the case of a continuous DRZ without waterstops. This volume of fluid was accounted for in the compacted salt column performance model by including it in the initial brine saturation of the crushed salt. The Rustler flow was distributed evenly throughout the entire pore space of the column by making an appropriate adjustment to initial salt column liquid saturation.

Pressure increase resulting from gas generation within the repository was simulated by applying an increasing gas pressure boundary condition at the base of the shaft. The repository pressure was assumed to increase to 7 MPa in 100 years in one case and 14 MPa in 200 years in a second case. Additional assumptions included in the compacted salt column performance model are discussed in Section C2.

C5.2.2 Numerical Model

The computer code used to implement the compacted salt column performance model is TOUGH28W, Version 2.02 (TOUGH2). TOUGH28W is a numerical simulation program for multi-dimensional coupled fluid and heat flows of multi-phase, multi-component fluid mixtures in porous and fractured media. This code was developed by Karsten Pruess at Lawrence Berkeley National Laboratory and has been used extensively in studies of high-level nuclear waste isolation in partially saturated geologic media (Pruess, 1991). TOUGH28W includes a number of fluid property equation-of-state modules. These modules make the code applicable to a variety of subsurface flow systems, including groundwater aquifers, unsaturated zones, and geothermal reservoirs. The version of the code used for this study incorporates the equation-of-state module EOS8W, which allows for simulation of the three phases water, air, and oil. This version includes a feature which optionally allows for specification of fluid properties representative of WIPP brine instead of water and hydrogen instead of air.

Version 2.02 includes a modification that permits specification of permeability as a function of time for specific model regions. This feature was included to simulate the reduction in permeability of the DRZ around the shaft attributable to healing after seal emplacement. The feature was implemented by allowing the user to provide as input a table specifying permeabilities at different values of the time variable and a rock type (i.e., region) to which the table applies. At each calculational time-step, the code will interpolate a permeability value from the table and apply that value to the specified region.

Version 2.02 also includes a modification to allow specification of permeability as a function of depth and pressure. This feature was included in order to simulate reconsolidation of the compacted salt column at differing rates depending on depth within the column and pore-pressure back stress. This feature was implemented by allowing the user to provide a table as input specifying the rate of change of permeability at different values of pore pressure and elevation for a specific rock type (i.e., region) to which the table applies. At each time-step for each grid element in the specified region, the rate of change in permeability obtained from the table is multiplied by the step size and applied to that grid element subject to specified minimum and maximum permeability values.

C5.2.3 Model Geometry and Boundary Conditions

The compacted salt column performance model was implemented with the radially symmetric cylindrical grid shown in Figure C-11. The modeled region extends in the vertical direction from the base of the shaft at elevation 387 m (1271 ft) up to the top of the Vaca Triste unit at elevation 631 m (2070 ft). The modeled region extends in the radial direction from the center of the shaft to the outer radial boundary at 282 m (925 ft).

The radial extent of Figure C-11 is truncated at 100 ft in order to show shaft detail. The grid contains 25 columns of grid cells in the radial direction and 59 layers in the vertical direction. The innermost four columns of grid cells represent the shaft and associated seal materials, and the next two columns radially outward represent a DRZ surrounding the shaft. Seal components represented in the model include, from top to bottom:

- a small portion of the upper Salado compacted clay column,
- the middle concrete component including asphalt waterstop,
- the compacted salt column,
- the lower concrete component including asphalt waterstop,
- the lower Salado compacted clay column, and
- the shaft station concrete monolith.

Although the last component is represented in the model grid, no "credit" is taken for its sealing properties; thus the model permeability of the shaft station monolith was set relatively high (1×10^{-14} m^2) when compared to other model permeabilities.

The host Salado Formation was modeled as layers of halite separated by several layers of anhydrite marker beds. Some of the interbeds that occur close together are combined in the model into single layers, as discussed in Section C3. Table C-20 provides details of the model grid layers representing the various seal components and host formation units. Table C-21 provides details of model gridding in the radial direction.

The leftmost model boundary was considered to be no-flow since this is the line of symmetry at the center of the shaft. The rightmost model boundary (i.e. the outer radial boundary) was assumed to be a constant pressure boundary at hydrostatic equilibrium relative to 12.5 MPa in MB139 near the base of the repository. A boundary radius of 282 m (926 ft) was determined by conducting a series of one-dimensional sensitivity runs to determine at what distance pressure response in the shaft was not sensitive to boundary location. The top and bottom model boundaries were assumed to be no-flow boundaries. This is a reasonable assumption for the time period considered in this model since pressure gradients are primarily directed radially inward because of the open-shaft condition during the repository operational period.

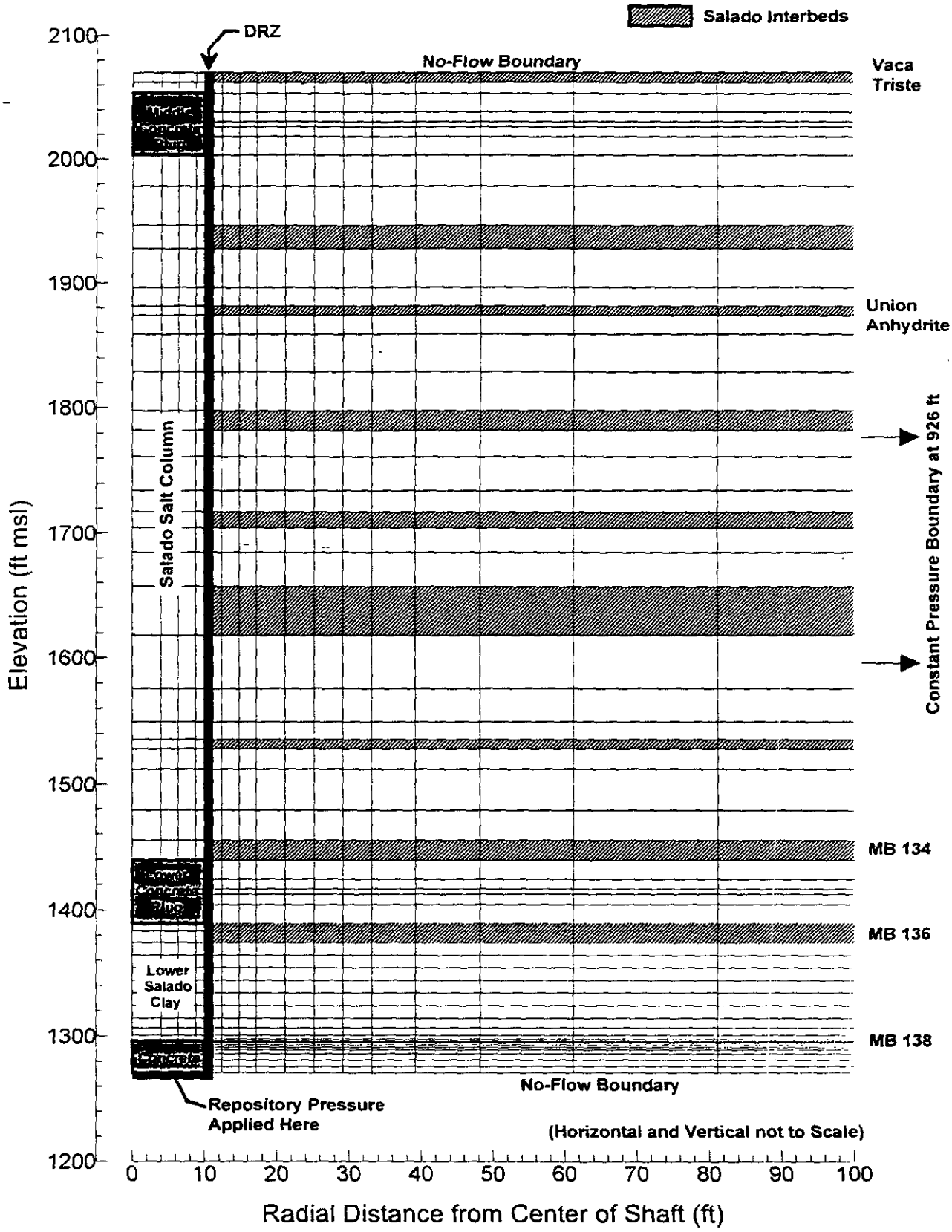

Figure C-11. Grid used by the compacted salt column performance model.

Table C-20. Vertical Layers of the Compacted Salt Column Performance Model

Layer Number	Layer Thickness (m)	Shaft Seal Component	Host Formation Unit
1 (TOP)	2.44	Upper Salado Compacted Clay Column	Vaca Triste
2	2.74	Upper Salado Compacted Clay Column	Salado Halite
3	4.57	Middle Concrete Plug	Salado Halite
4	2.44	Middle Concrete Plug	Salado Halite
5	1.22	Asphalt Waterstop	Salado Halite
6	2.44	Middle Concrete Plug	Salado Halite
7	4.57	Middle Concrete Plug	Salado Halite
8	7.65	Compacted Salt Column	Salado Halite
9	9.69	Compacted Salt Column	Salado Halite
10	5.79	Compacted Salt Column	Combined MB117 - MB122 and Zone A
11	9.49	Compacted Salt Column	Salado Halite
12	4.57	Compacted Salt Column	Salado Halite
13	2.29	Compacted Salt Column	Union Anhydrite
14	4.57	Compacted Salt Column	Salado Halite
15	9.17	Compacted Salt Column	Salado Halite
16	9.45	Compacted Salt Column	Salado Halite
17	4.72	Compacted Salt Column	Combined MB123 - MB124
18	6.41	Compacted Salt Column	Salado Halite
19	8.17	Compacted Salt Column	Salado Halite
20	5.24	Compacted Salt Column	Salado Halite
21	3.96	Compacted Salt Column	Combined Zone B - C and MB126
22	6.00	Compacted Salt Column	Salado Halite
23	8.33	Compacted Salt Column	Salado Halite
24	11.83	Compacted Salt Column	Combined MB127 - MB130 and Zones D - I
25	12.97	Compacted Salt Column	Salado Halite
26	8.00	Compacted Salt Column	Salado Halite

Table C-20. Vertical Layers of the Compacted Salt Column Performance Model

Layer Number	Layer Thickness (m)	Shaft Seal Component	Host Formation Unit
27	4.25	Compacted Salt Column	Salado Halite
28	2.29	Compacted Salt Column	Combined MB131 - MB133 and Zone J
29	4.88	Compacted Salt Column	Salado Halite
30	9.95	Compacted Salt Column	Salado Halite
31	7.35	Compacted Salt Column	Salado Halite
32	4.75	Compacted Salt Column	Combined MB134 - MB135
33	4.57	Lower Concrete Plug	Salado Halite
34	2.44	Lower Concrete Plug	Salado Halite
35	1.22	Asphalt Waterstop	Salado Halite
36	2.44	Lower Concrete Plug	Salado Halite
37	4.57	Lower Concrete Plug	Salado Halite
38	0.61	Lower Salado Compacted Clay Column	Combined MB136-MB137
39	1.22	Lower Salado Compacted Clay Column	Combined MB136-MB137
40	2.87	Lower Salado Compacted Clay Column	Combined MB136-MB137
41	3.05	Lower Salado Compacted Clay Column	Salado Halite
42	3.05	Lower Salado Compacted Clay Column	Salado Halite
43	3.05	Lower Salado Compacted Clay Column	Salado Halite
44	3.05	Lower Salado Compacted Clay Column	Salado Halite
45	3.05	Lower Salado Compacted Clay Column	Salado Halite
46	3.05	Lower Salado Compacted Clay Column	Salado Halite
47	2.32	Lower Salado Compacted Clay Column	Salado Halite
48	1.83	Lower Salado Compacted	Salado Halite

Table C-20. Vertical Layers of the Compacted Salt Column Performance Model

Layer Number	Layer Thickness (m)	Shaft Seal Component	Host Formation Unit
		Clay Column	
49	0.91	Lower Salado Compacted Clay Column	Salado Halite
50	0.46	Lower Salado Compacted Clay Column	Salado Halite
51	0.23	Shaft Station Monolith	Combined MB138 and Anhydrite A/B
52	0.23	Shaft Station Monolith	Combined MB138 and Anhydrite A/B
53	0.46	Shaft Station Monolith	Salado Halite
54	0.61	Shaft Station Monolith	Salado Halite
55	0.61	Shaft Station Monolith	Salado Halite
56	0.91	Shaft Station Monolith	Salado Halite
57	1.52	Shaft Station Monolith	Salado Halite
58	1.52	Shaft Station Monolith	Salado Halite
59 (BOTTOM)	1.52	Shaft Station Monolith	Salado Halite

Table C-21. Compacted Salt Column Performance Model Radial Gridding

Column Number	Radius to Outer Grid Column Boundary (m)	Model Component
1	1.22	Shaft
2	1.95	Shaft
3	2.68	Shaft
4	3.05	Shaft
5	3.23	DRZ
6	3.41	DRZ
7	3.78	Host Formation
8	4.51	Host Formation
9	5.24	Host Formation
10	6.46	Host Formation

Table C-21. Compacted Salt Column Performance Model Radial Gridding

Column Number	Radius to Outer Grid Column Boundary (m)	Model Component
11	7.68	Host Formation
12	8.90	Host Formation
13	10.12	Host Formation
14	11.95	Host Formation
15	14.69	Host Formation
16	18.65	Host Formation
17	24.75	Host Formation
18	33.89	Host Formation
19	47.61	Host Formation
20	68.95	Host Formation
21	99.43	Host Formation
22	145.15	Host Formation
23	190.87	Host Formation
24	236.59	Host Formation
25	282.31	Host Formation

Two exceptions to the no-flow top and bottom model boundaries were considered. First, the possibility of brine flow down the shaft from the Rustler Formation was considered by increasing the initial crushed-salt brine saturation as discussed above. Second, gas flow up from the repository was simulated by applying a time varying pressure boundary condition at the base of the shaft. The waste forms in the repository may generate gas (WIPP PA, 1992–1993). Model 2 does not explicitly model the generation of gas in the repository. Rather, it indirectly incorporates repository gas generation by applying a time-varying gas pressure boundary condition at the base of the shaft. Two pressure specifications were considered in the gas flow analysis. In one, the pressure increased to 7 MPa in 100 years and then remained constant for the remaining simulation time (200 years total). In the second, the pressure at the base of the shaft increased steadily for the 200-year simulation period to 14 MPa. These two specifications are representative of results obtained for pressure at the base of the shaft by WIPP PA in the No Migration Variance Petition (NMVP) simulations. The time-varying pressure boundary conditions were chosen to correspond to the quickest pressure increase (i.e., highest gas generation rates) simulated in the NMVP simulations. Figure C-12 shows the pressure condition applied at the base of the shaft in the model runs for these two specifications. Because of limitations in implementing the time-varying boundary condition at the base of the shaft in TOUGH28W, the pressure was "stepped up" to final values in a series of consecutive restarted simulations.

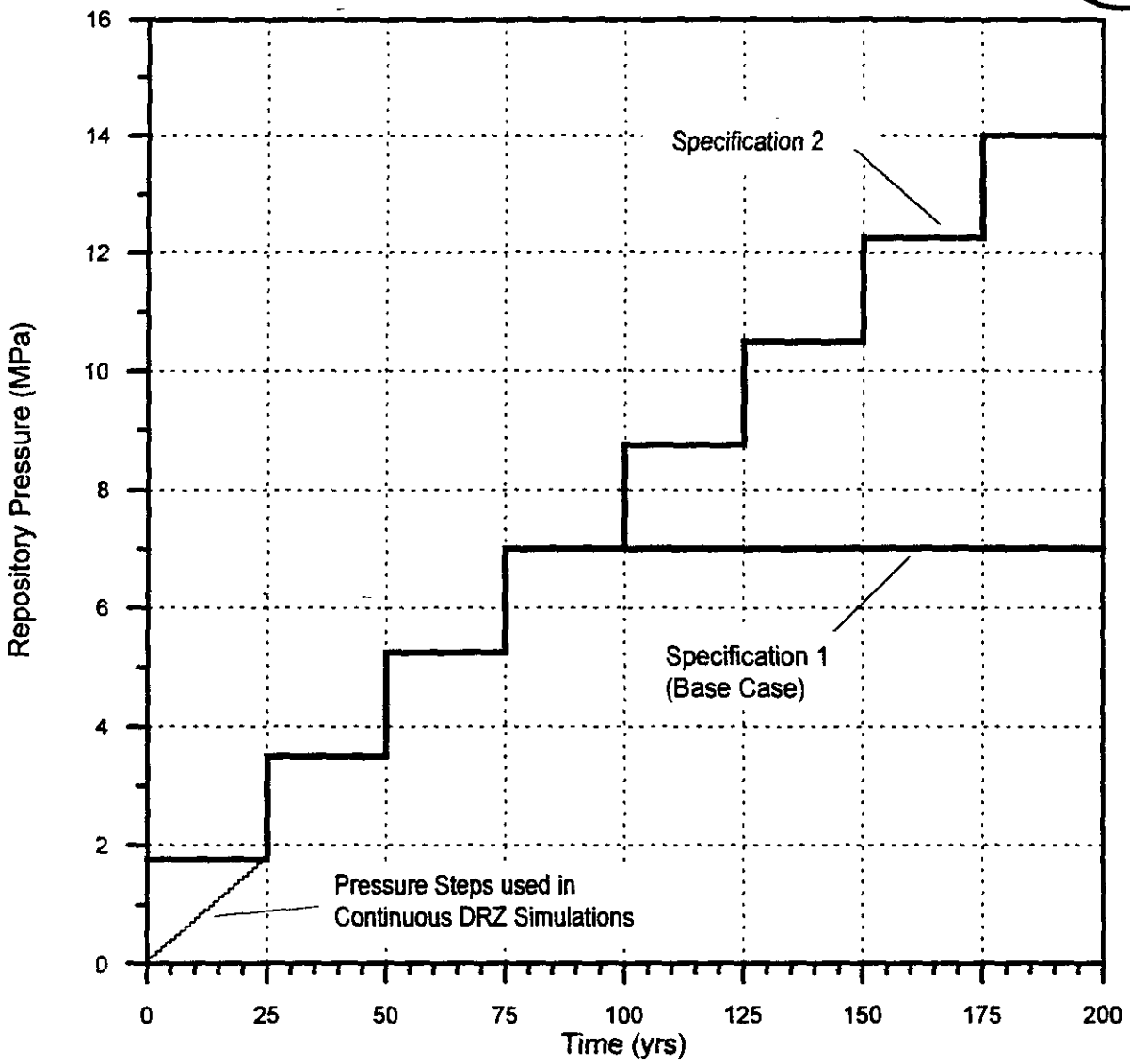

Figure C-12. Two specifications of pressure at the base of the shaft.

For most of the simulations presented here, the pressure was increased in 1.75-MPa steps at 25-year intervals. For continuous DRZ simulations, however, the 1.75 MPa repository pressure at time zero was considered an unrealistic boundary condition to apply to the pre-healed DRZ around the lower concrete component seal. For these cases, the boundary pressure was increased in 1-year steps of 0.07 MPa each. The lighter line between 0 and 25 years in Figure C-12 represents the repository pressure boundary condition used for continuous DRZ simulations.

C5.2.4 Model Parameters

Model parameters for the compacted salt column performance model include material properties for shaft seal components, fluid properties, two-phase flow properties, and material properties for Salado halite and anhydrite marker beds. The properties used in this model are discussed in detail in Section C3. Also discussed in Section C3 are the time-varying permeabilities of the DRZ zones surrounding the shaft.

An additional process that must be modeled for the compacted salt column performance model was the consolidation behavior of the crushed salt column. Curves showing salt column fractional density as a function of time at three different depths (430, 515, and 600 m) and three different pore pressures (0, 2, and 4 MPa) are presented in Appendices A and D. The data are replotted in Figure C-13 in terms of the average rate of change in fractional density (on the right axis) versus pressure for the three depths. A relationship has also been developed between crushed salt fractional density and permeability. To account for uncertainty in the permeability versus fractional density relationship, a best fit line through the data, as well as lines through 95th and 5th percentiles, were developed. Using the best fit line between fractional density and permeability, the left axis of Figure C-13 gives the average rate of change for the log of permeability as a function of pressure at the three depths. As shown in the figure, several points were extrapolated from the data to provide model data points up to 10 MPa. The consolidation rate at these higher pressures is not significant to model performance, but the data were required because it was anticipated that salt column pressures could reach these values during late model times.

The "consolidation surface" shown in Figure C-14 was developed by interpolating between the data points shown in Figure C-13. This surface provides the relationship between the rate of change in permeability and depth and pressure within the compacted salt column. In tabular form, this surface is required as input to the compacted salt column performance model. The general shape of this surface shows that the greatest magnitude of the rate of permeability change (i.e., the highest consolidation rate) occurs at the greatest depth (lowest elevation) and lowest pore pressure.

C5.3 Performance Model Results

Six simulations were run with the compacted salt column performance model, a base-case and five additional runs, to examine the sensitivity of the model to variations in repository pressure, the crushed-salt permeability-fractional density relationship, flow down the shaft from the Rustler Formation, and continuous DRZ with and without waterstops.

Table C-22 summarizes the six simulations and provides information about the combination of parameters used for each. The "Repository Pressure" column in the table refers the pressure specifications defined in Figure C-12. The "Permeability/Fractional Density Predictor" column in the table refers to either the best fit or the 95th percentile lines through the permeability versus fractional density data. The primary difference between these two permeability specifications is the starting and ending points for salt column permeability. For the best fit line, crushed salt permeability starts at 2.5×10^{-15} m^2 (90% fractional density) and achieves a minimum possible value of 6.3×10^{-21} m^2 (100% fractional density). For the "95%" predictor line, crushed salt permeability starts at 7.9×10^{-13} m^2 and achieves a minimum possible

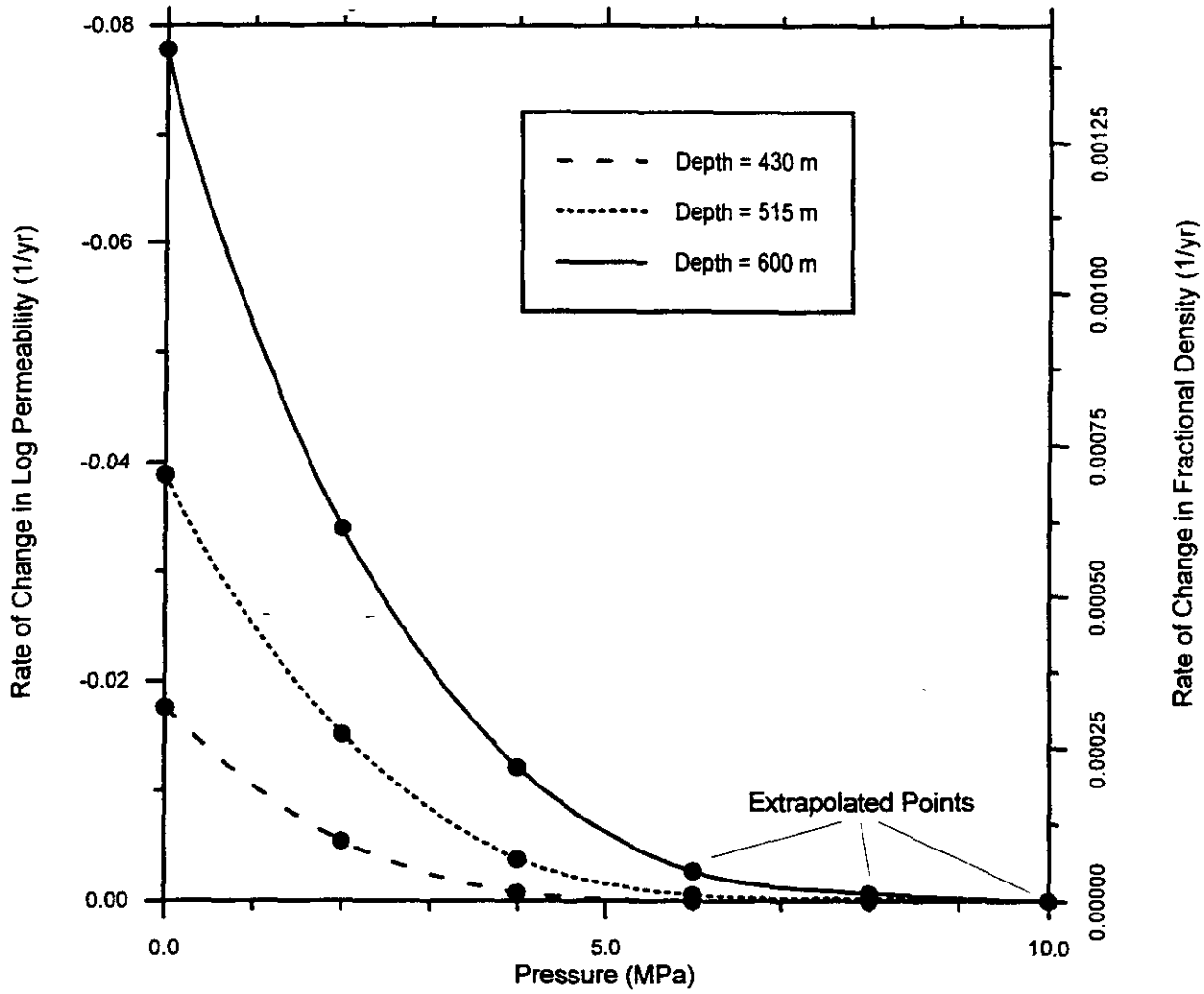

Figure C-13. Rate of change in log permeability (fractional density) with pressure and depth.

value of 2.0×10^{-18} m^2. The "Rustler Flow" column in the table indicates the amount by which the salt column initial liquid saturation was increased to account for brine flow down the shaft from the Rustler Formation, predicted by the full-shaft saturated flow model for the case of a continuous DRZ with and without waterstops.

Identical initial pressure conditions were used for each simulation and were established in two steps. First, all grid elements were assigned an initial pressure based on hydrostatic pressure referenced to 12.5 MPa at the elevation of MB139. Next, a conditioning simulation was run in which the shaft was considered to be open to atmospheric pressure for 50 years. Grid-element pressures were captured at the end of this 50-year simulation and used to initialize each of the performance calculations.

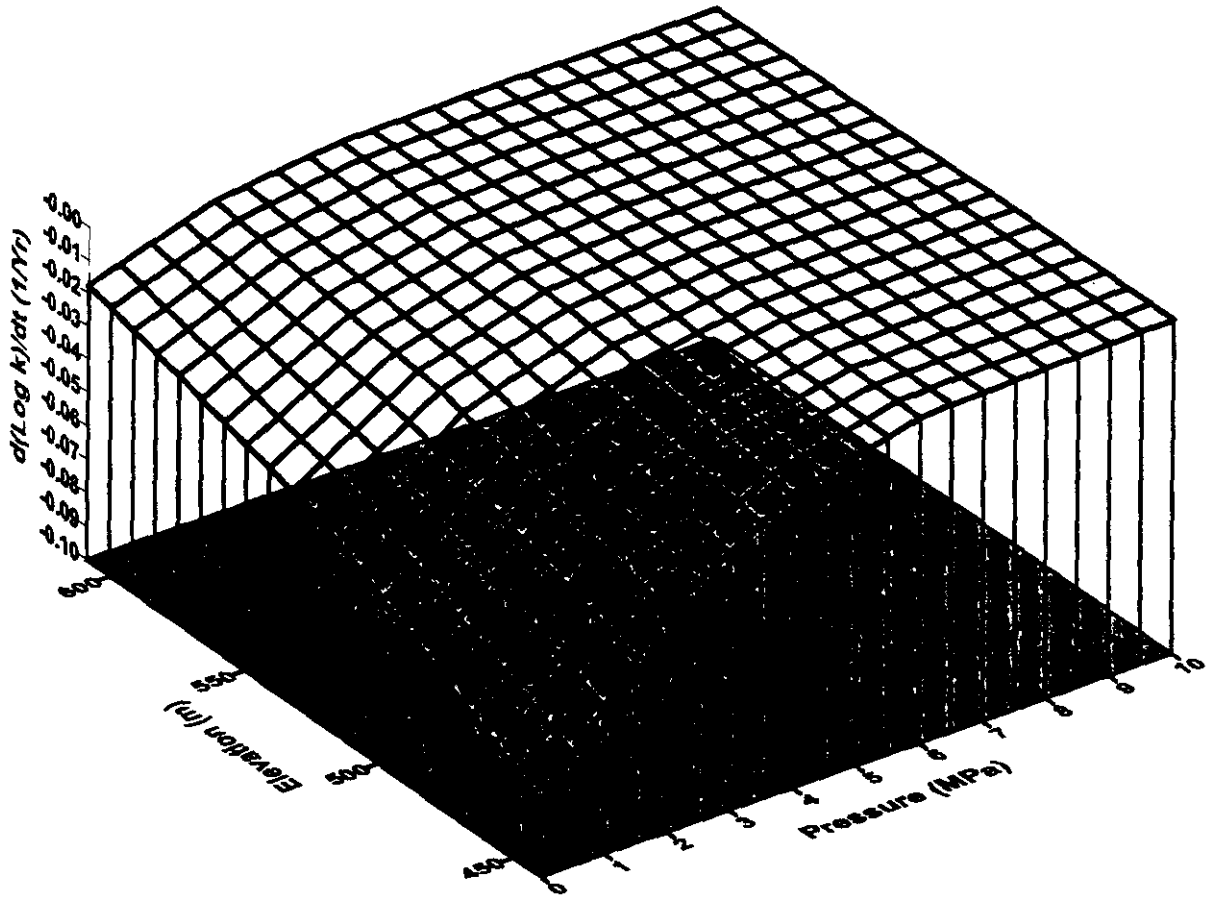

Figure C-14. Reconsolidation surface for the best-fit permeability/fractional density predictor.

Simulation results are presented here in terms of pressure in the compacted salt column, gas flow past the lower concrete component into the compacted salt column, and predicted permeability of the compacted salt column. For the base case of 7 MPa at the repository horizon, Figure C-15 shows calculated pressure in the compacted salt column versus time after seal emplacement at three locations near the top, middle, and bottom of the salt column. The figure shows pressure increased most rapidly at the bottom of the column. Pressure began to increase rapidly at the bottom of the salt column approximately 30 years after seal emplacement. The fact that the pressure in Figure C-15 increased to levels greater than the maximum pressure at the

Table C-22. Compacted Salt Column Performance Model Simulations

Run	Repository Pressure*	Permeability/ Fractional Density Predictor	Rustler Flow (m^3)	Continuous DRZ	Water Stops
1 (Base Case)	7 MPa in 100 Years	Best Fit	0.00	No	Yes
2	7 MPa in 100 Years	95%	0.00	No	Yes
3	14 MPa in 200 Years	Best Fit	0.00	No	Yes
4	14 MPa in 200 Years	95%	0.00	No	Yes
5	7 MPa in 100 Years (Linear First 25 Years)	Best Fit	2.70	Yes	Yes
6	7 MPa in 100 Years (Linear First 25 Years)	Best Fit	17.20	Yes	No

* Source: NMVP calculations.

base of the shaft (7 MPa) indicates that the far-field pressure boundary was the primary source driving the pressure increase. Figure C-16 shows calculated permeability profiles in the compacted salt column at several points in time following seal emplacement. This figure shows that permeability has decreased to a minimum value of 6.3×10^{-21} m^2 over a portion of the base of the salt column in 100 years and shows little further reduction of permeability over the period from 100 to 200 years. The figure generally shows lower permeability near the bottom of the salt column where the consolidation rate is higher, and relatively higher permeability near the top of the salt column where the consolidation rate is lower. After 100 years, pressure increases throughout the column have almost completely stopped the consolidation process.

A small region, from elevation 439 m (1440 ft) to about elevation 457 m (1500 ft), at the base of the salt column showed less reconsolidation at times ranging from 50 to 200 years than the region immediately above it due to the pressure influence of the repository. Figure C-16 also shows that for times greater than about 50 years, consolidation in the upper half of the salt column was significantly slowed because of repressurization through the relatively high permeability Union Anhydrite (1.0×10^{-18} m^2).

The results of Run 2, in terms of pressure and permeability in the compacted salt column, are shown in Figures C-17 and C-18, respectively. Parameter specification for this run was identical to Run 1 except that the 95% permeability-fractional density correlation was used (i.e., the assumed salt column permeability was higher for a given fractional density). These results show that pressurization in the salt column occured at later times than for the base case. The permeability profiles in Figure C-18 show that, in contrast to the base case, very little crushed salt reconsolidation occured in the lower half of the salt column after about 75 years. This outcome occurs because the pressure increased throughout the vertical extent of the salt column

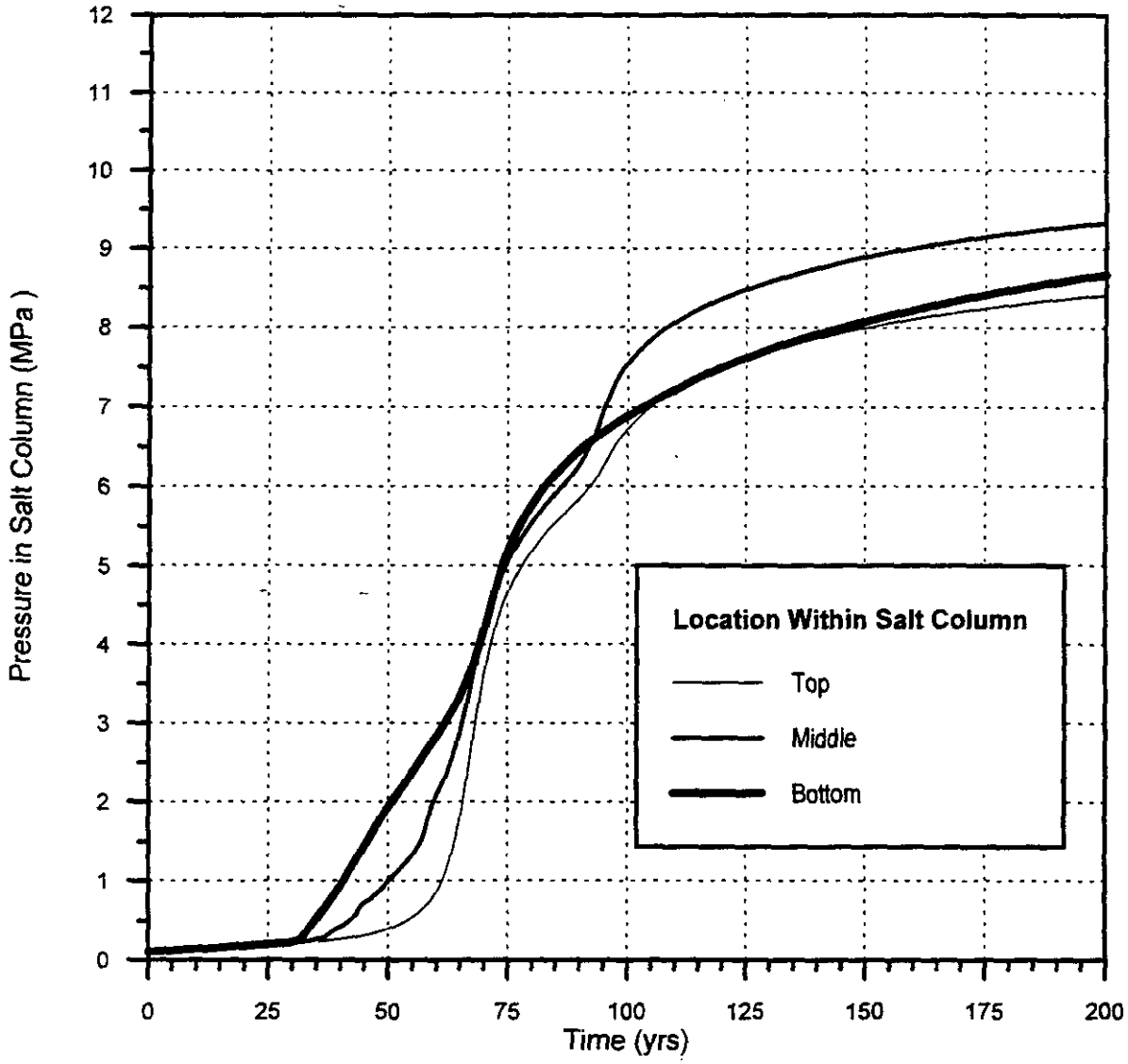

Figure C-15. Calculated pressure versus time after seal emplacement at the top, middle, and bottom of the compacted salt column (base case).

at 75 years in this case, whereas the base case, because of lower permeability of the salt column, retained a region of lower pressure near the base of the column. This can be seen in Figure C-19, which shows pressure contours at 75 years for the base case and for Run 2. In both cases, pressure increases in the salt column due to the influence of the outer pressure boundary through the Union Anhydrite (and to a lesser extent the other interbeds). In the base case, the lower permeability of the reconsolidating crushed salt isolated the area at the base of the column from the Union Anhydrite. For the base case, Figure C-19 shows an area near the base of the column where pressure remained less than 1 MPa at 75 years. In Run 2, the relatively higher permeability of the consolidating crushed salt allowed the pressure to equilibrate along the entire

length of the column, thereby inhibiting consolidation even in the lower half of the column after 75 years.

Runs 3 and 4 in Table C-22 are identical to Runs 1 and 2, respectively, except that the repository pressure was increased from 7 MPa to 14 MPa in the period from 100 to 200 years (see Figure C-12). The results of these two runs in terms of pressure and permeability in the salt column are nearly identical to the results of Runs 1 and 2, and additional plots are not shown. Like those of Runs 1 and 2, these results indicate that, after 100 years, the compacted salt column was sufficiently isolated that salt reconsolidation is not significantly affected by repository-pressure increases.

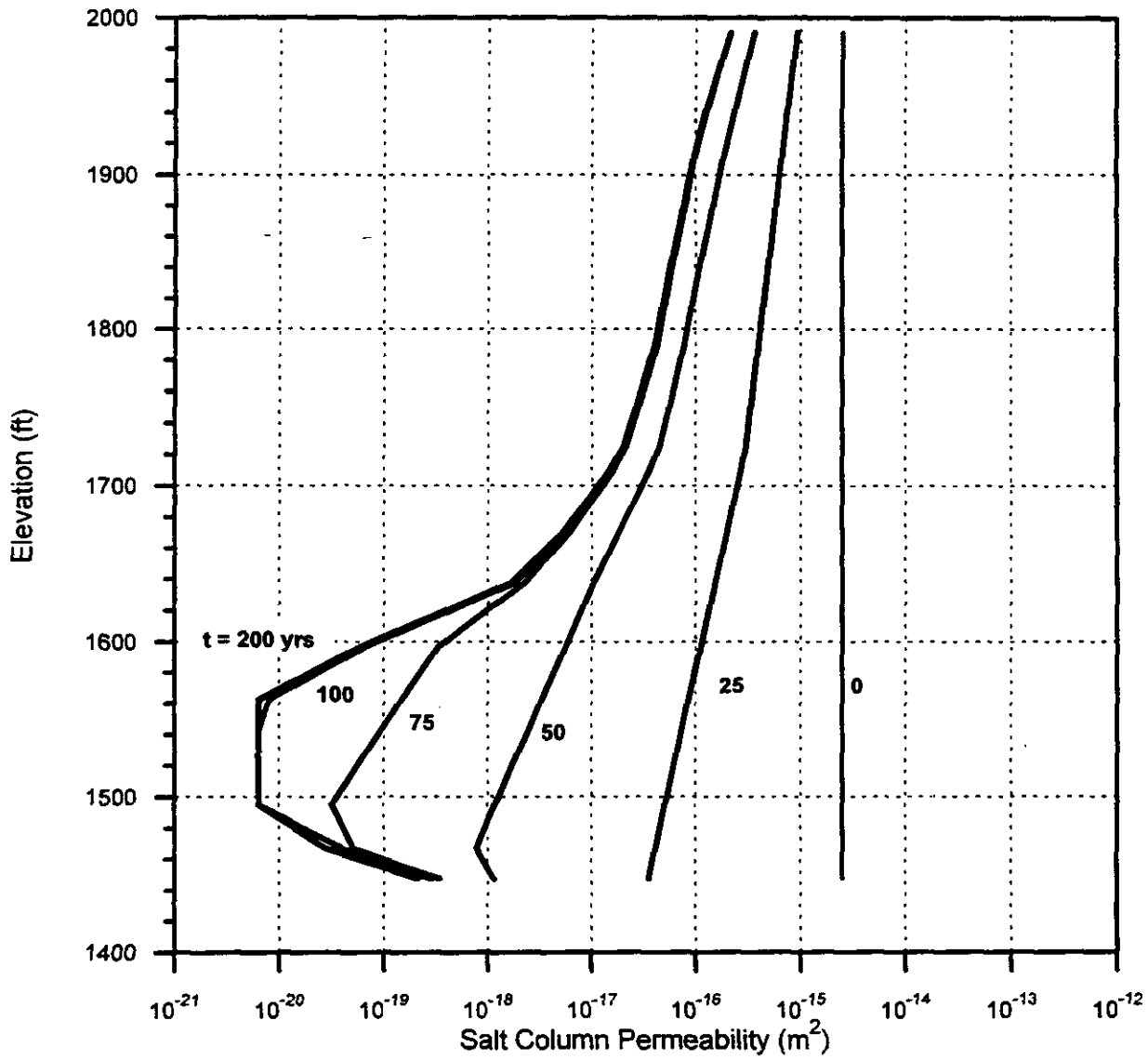

Figure C-16. Calculated salt column permeability versus elevation within the column for several times following seal emplacement (base case).

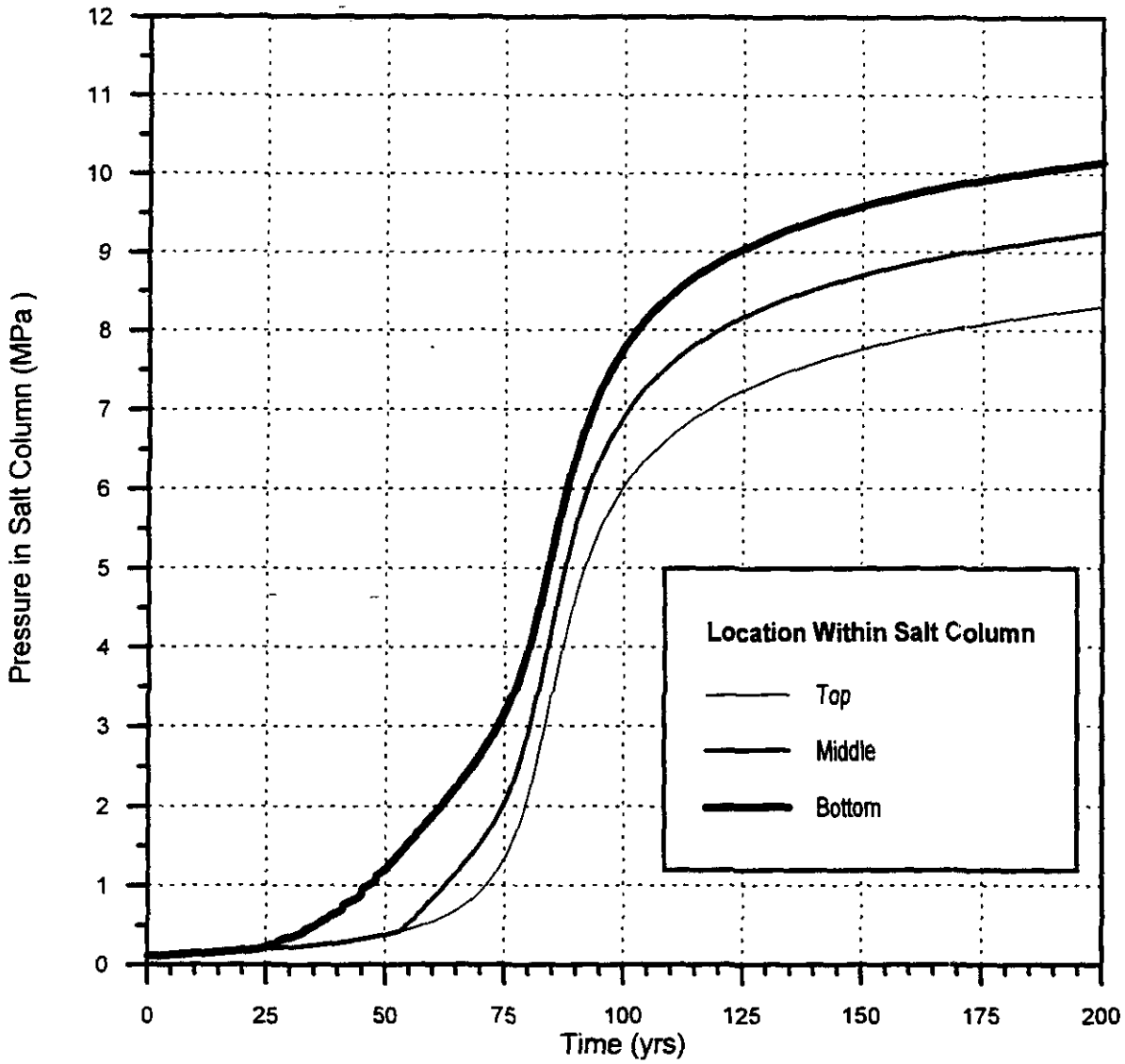

Figure C-17. Calculated pressure versus time after seal emplacement at the top, middle, and bottom of the compacted salt column (Run 2).

Two additional runs (Runs 5 and 6 in Table C-22) were made in which brine flow down the shaft from the Rustler Formation calculated by the full-shaft saturated flow model was included in the initial brine saturation of the compacted salt column. For these two simulations, the permeability of the DRZ adjacent to the shaft at the level of MB134, MB135, MB136, and MB137 was increased to 2.9×10^{-16} m^2, thus creating a continuous (prior to healing) DRZ from the gas source at the repository level to the salt column. In the previous simulations, these DRZ units were assumed to be mostly unfractured, with permeability more like the undisturbed host anhydrite of the associated marker beds (1.0×10^{-19} m^2).

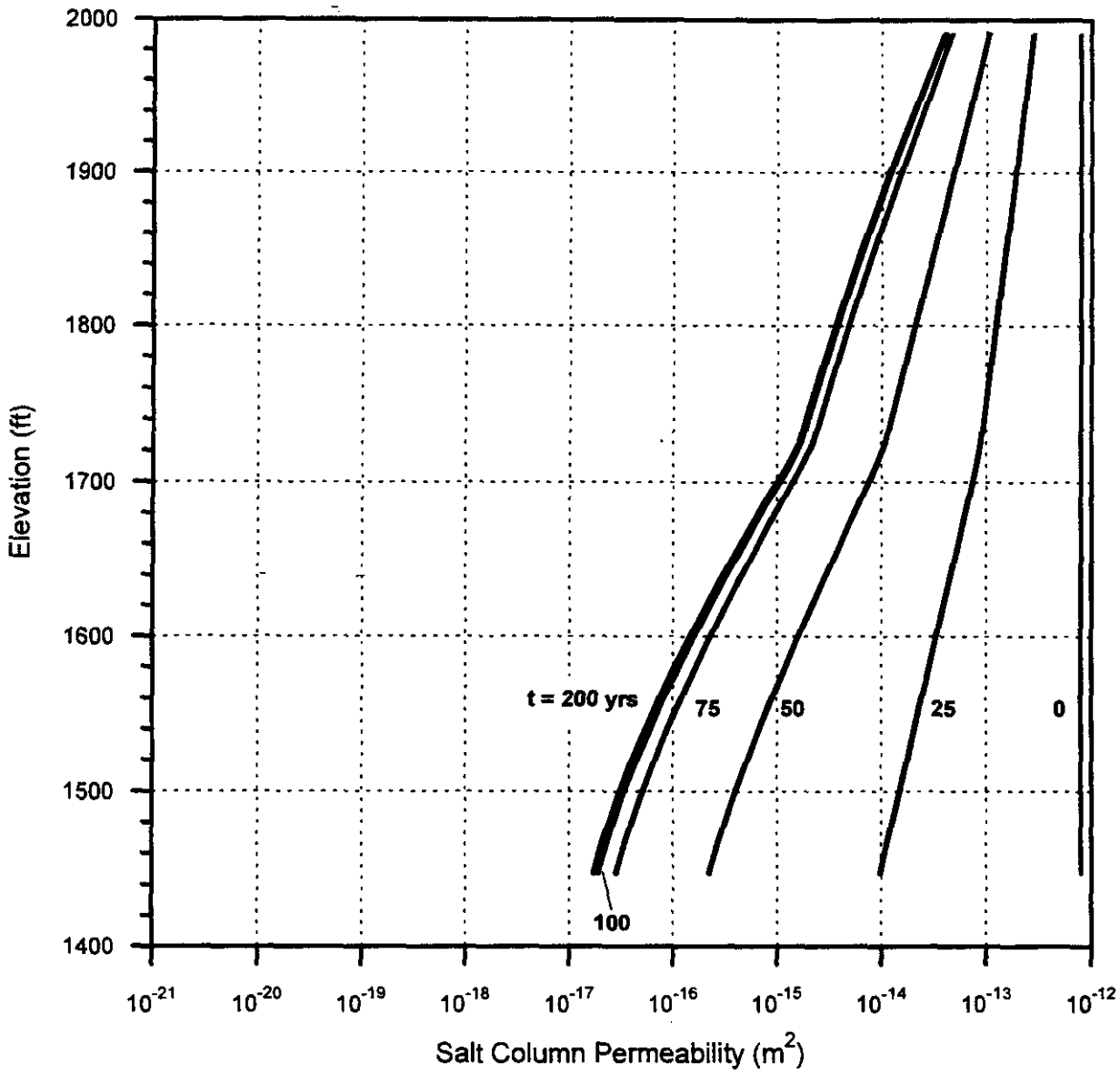

Figure C-18. Calculated salt column permeability versus elevation within the column for several times following seal emplacement (Run 2).

In Run 5 the asphalt waterstops were assumed to be in place as in the previous runs; however, in Run 6 the asphalt waterstops were excluded. The initial brine saturation of the salt column was increased by 2.7 m^3 and 17.2 m^3 for the two runs, respectively, to account for Rustler flow predicted by the full-shaft saturated flow model for these two cases. For the continuous DRZ assumption, with the increased communication between the base of the shaft and the compacted salt column prior to DRZ healing around the rigid concrete components, it was thought that stepping the repository pressure up to 1.75 MPa at time zero would provide unrealistic results. Therefore, for these two runs, the repository boundary pressure was

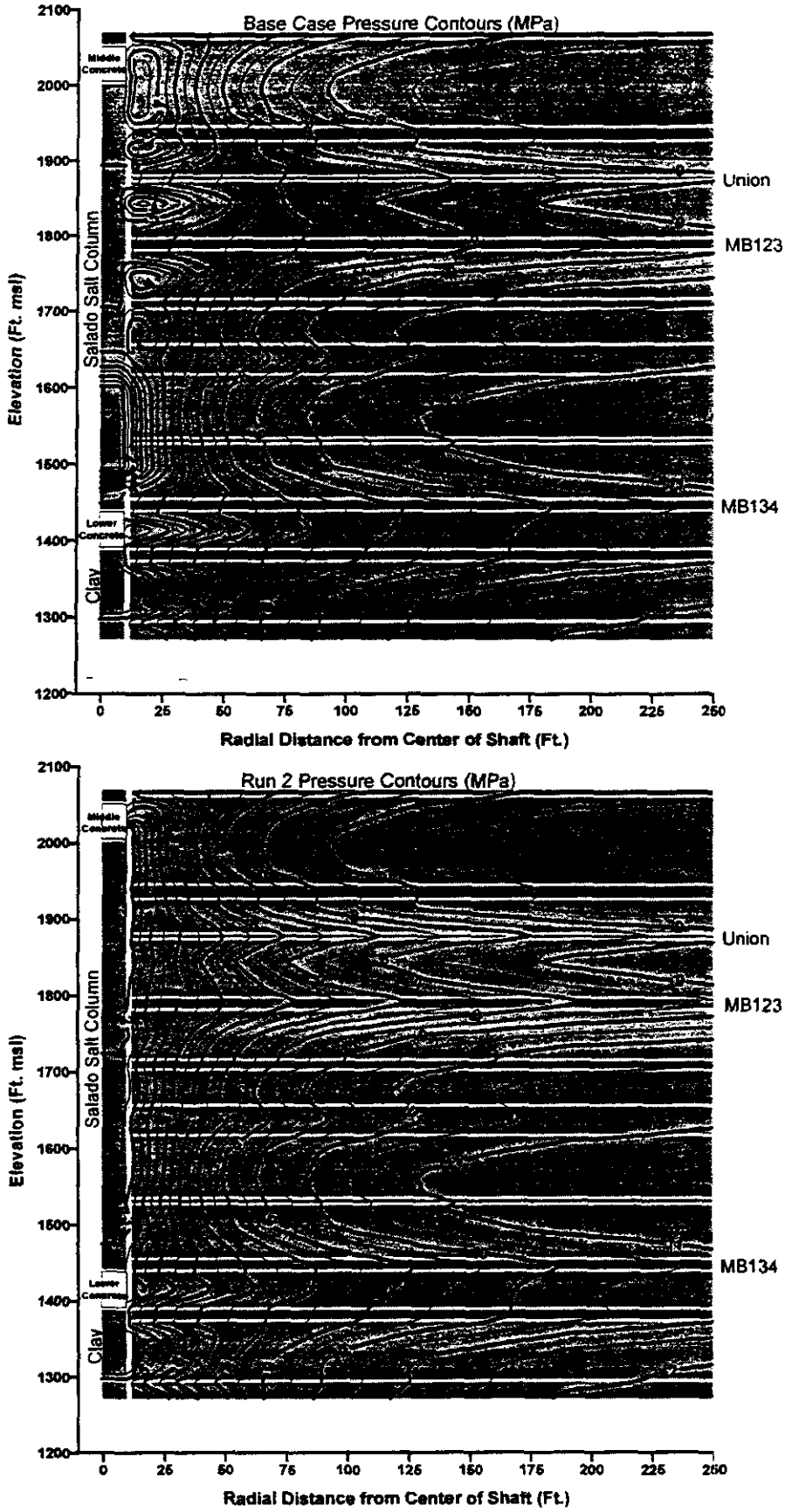

Figure C-19. Pressure contours at 75 years for base case and for 95% permeability/fractional density predictor (Run 2).

increased in 0.07-MPa increments at one-year time intervals (see Figure C-12). This rate of pressure increase is the same for all simulations; however, it is applied in smaller time increments in Runs 5 and 6.

The pressure and permeability results of Run 5 are nearly identical to the results of the base case (Run 1) shown in Figures C-15 and C-16, indicating no sensitivity to the inclusion of a DRZ adjacent to MB134 through MB137. The results of Run 6 do, however, show some sensitivity to the absence of the asphalt waterstops. Figure C-20 shows pressure versus time at the top, middle, and bottom of the salt column for the base case and for Run 6. This figure shows that pressure rose faster than for the base case at early times before the DRZ had fully healed around the lower concrete seal at 25 years. As a result of the faster pressure increase in the salt column, the calculated permeability profiles shown in Figure C-21 for this run show less crushed-salt reconsolidation at 100 years than in the base case shown in Figure C-16. Figure C-21 shows that, without concrete-asphalt waterstops, permeability at the bottom of the salt column for the case does not reach the minimum value of 6.3×10^{-21} m^2.

Figure C-22 shows cumulative gas flow up the shaft from the repository past the lower concrete seal for each run. The right axis in the figure gives cumulative mass of gas flow in kg and the left axis translates this mass to a cumulative volume of flow in m^3 at standard conditions (20°C and atmospheric pressure). This figure shows that cumulative gas flow up from the repository was less than 100 m^3 for all runs, except for Run 6 in which the concrete-asphalt waterstops were omitted. Run 6 predicted that approximately 600 m^3 of gas reached the salt column in the first 25 years.

The lower Salado compacted clay column provides an effective barrier in shaft cross-section because of its low permeability and its relatively high brine saturation, thus forcing most of the gas to flow through the DRZ. The compacted clay column was initialized at an initial brine saturation of nearly 80%. For all simulations performed, it resaturated to near 100% at top and bottom over the 200-year simulation time.

C6.0 FLOW UP FROM THE SALADO (MODEL 3)

C6.1 Statement of Problem

This calculation examined the potential for brine flow and quantity of brine flow that may be expected to migrate upward through the shaft seal system in response to the ambient pressure conditions that will be present several hundred years after closure. Pressures measured in the Salado at the repository horizon are significantly over-pressured with respect to hydrostatic conditions and to the Rustler (see Table C-2). Because the Salado is very impermeable, any natural component of vertical flow from the Salado upward must be very low. However, with the connection of the Salado and the Rustler Formations through the shaft seal system, the potential for upward flow exists. The performance measure (result) for this model is the steady-state brine flow rate. The performance measure will be provided for the Rustler/Salado contact, the top of the compacted salt column, and the top of combined Unit 8 (composed of MB131, Zone J, MB132, and MB133).

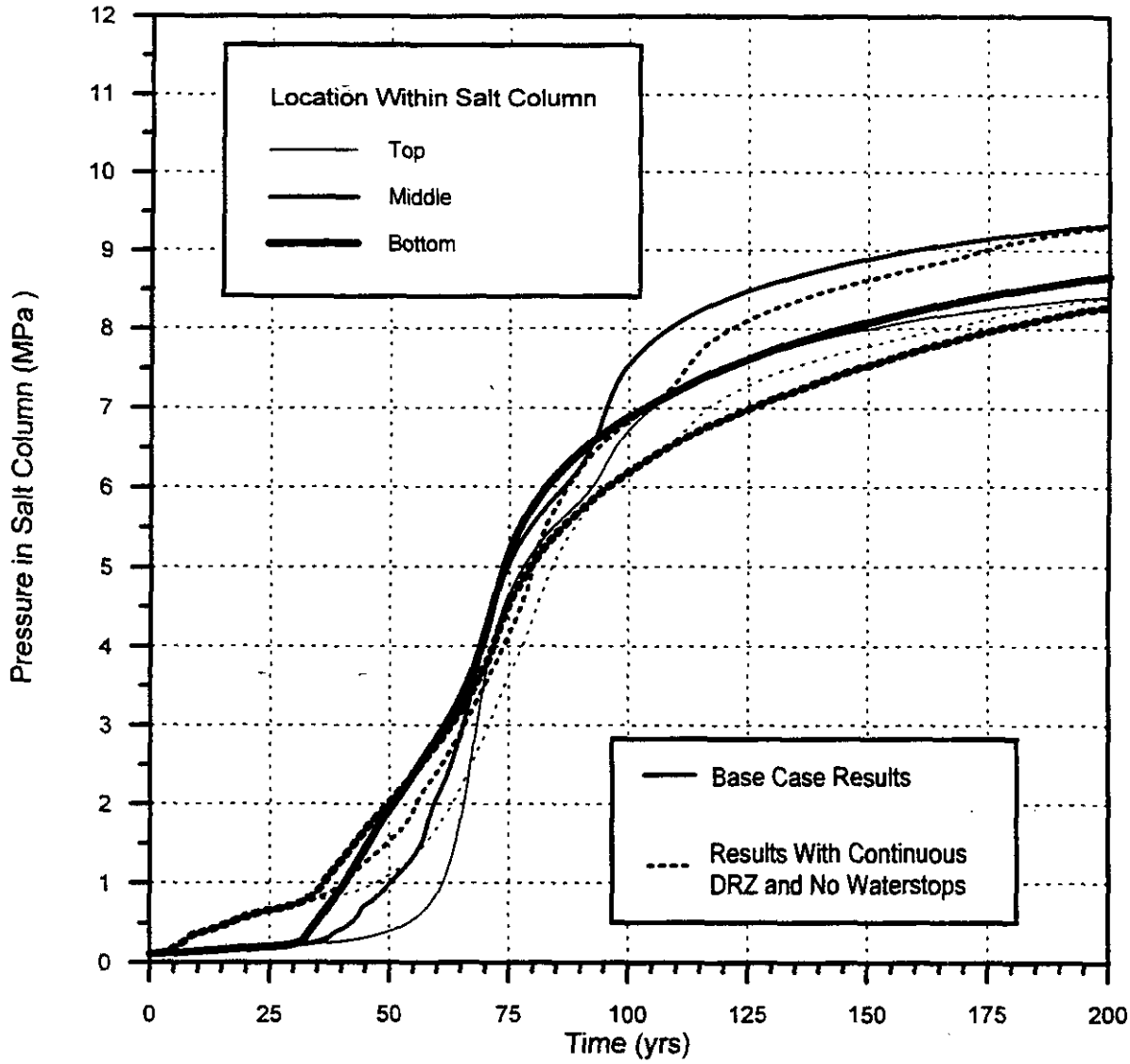

Figure C-20. Comparison of calculated pressure results for base case and continuous DRZ with no waterstops (Run 6).

C6.2 Performance Model Description

C6.2.1 Conceptual Model and Assumptions

The model grid and simulation code (SWIFT II) used in this model are identical to those used in Model 1. The primary difference in the conceptual model between Model 1 and Model 3 is the time frame over which this calculation is considered relevant. Model 1 predicted brine flow down the shaft. The Model 1 calculation is considered an early-time calculation before far-field pressures gradients reestablish in the vicinity of the shaft. The Model 1 calculation runs from shaft closure forward to 400 years post-closure. Model 3 assumed that equilibrium pressure gradients have reestablished in the vicinity of the shaft and DRZ healing has taken place within the Salado halite.

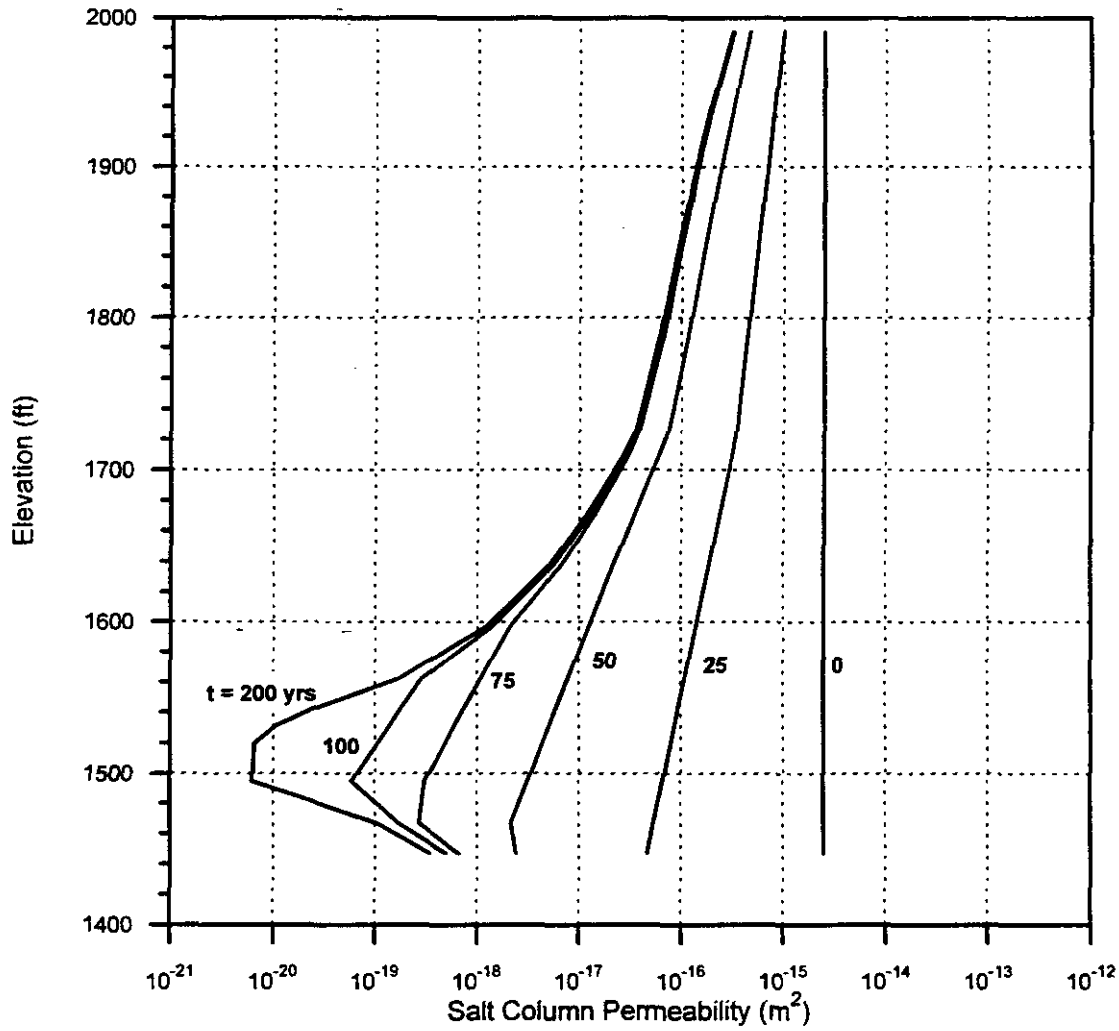

Figure C-21. Calculated salt column permeability versus elevation within the column for several times following seal emplacement (Run 6: Rustler flow included, continuous DRZ, no waterstops).

In Section C2, the primary assumptions common to all numerical calculations in this appendix are listed. In addition to those listed in Section C2, the following list summarizes the primary assumptions specific to Model 3:

- The calculation assumed brine-saturated flow conditions.
- The model is initialized at nonhydrostatic conditions based on undisturbed heads in the Rustler Formation and the maximum estimated formation pressure measured in the Salado Formation (see Table C-2).
- Seal system and DRZ permeabilities are representative of times greater than or equal to 400 years after closure.

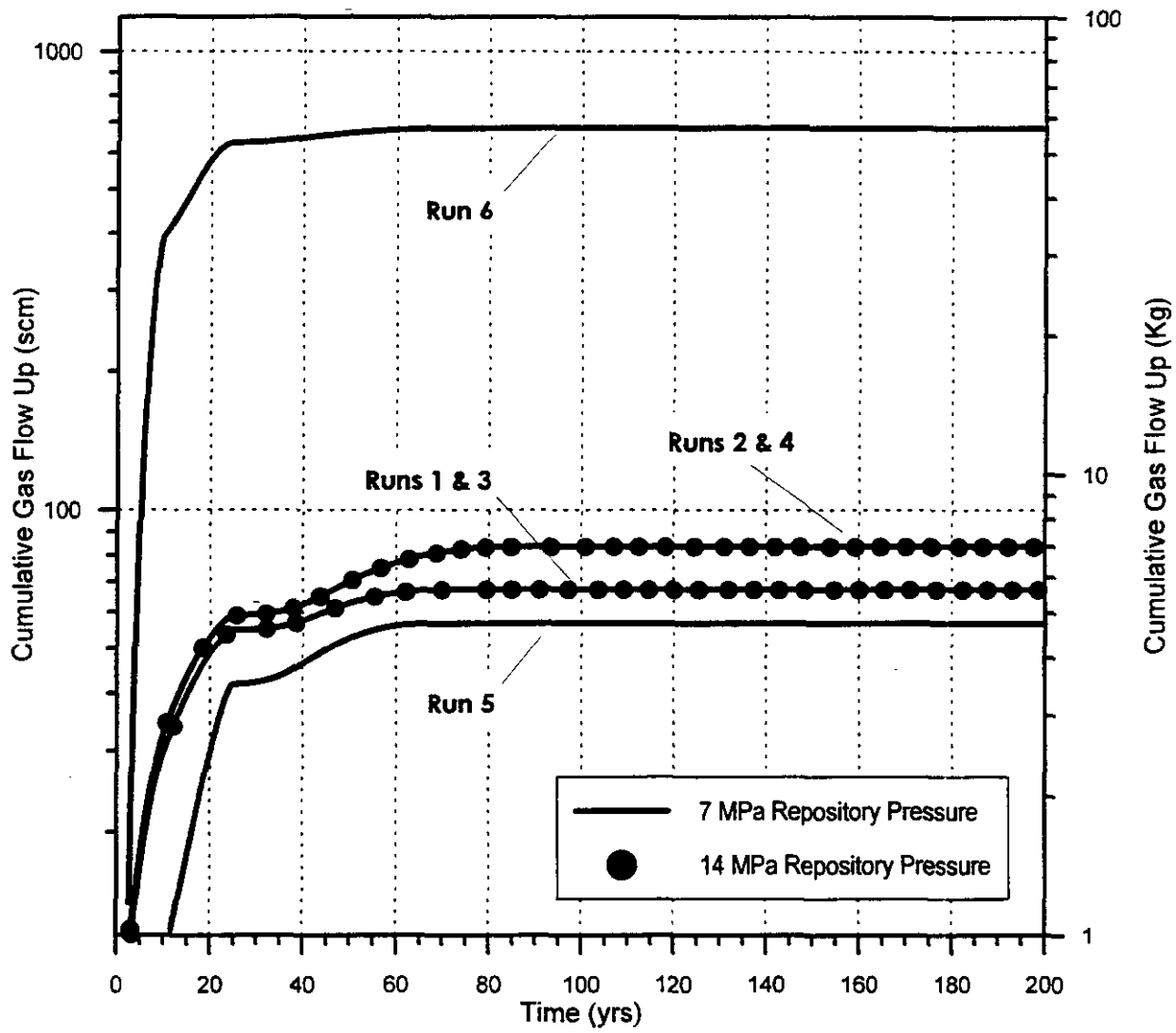

Figure C-22. Cumulative gas flow from the repository to the compacted salt column.

C6.2.2 Numerical Method

The numerical code used in Model 3 is SWIFT II. This code was also used in Model 1; see Section C4.2.2 for a complete description.

C6.2.3 Model Geometry and Boundary Conditions

The model geometry and grid are the same as that used in Model 1; see Section C4.2.3 for a complete description. However, the initial conditions and boundary conditions differ from those of Model 1. For Model 3, the shaft is completely sealed, and the DRZ and the compacted salt column permeabilities are no longer transient and have achieved their lowest values. This permeability field was held constant in Model 3.

The lateral boundary and initial grid-block pressures were initialized at nonhydrostatic conditions consistent with the undisturbed heads reported for the Magenta, the Culebra, the Rustler/Salado contact, and MB139 (see Table C-2). No-flow boundary conditions were imposed at the top and bottom of the model. Infinite aquifer boundary conditions were set at the outer edge of the modeled region. The model components for the simulation are concrete, asphalt, compacted clay, crushed salt, shaft liner, DRZ, and undisturbed formation.

C6.2.4 Model Parameters

Best case model parameters as specified for Model 1 for the host-rock and seal system have been used. Table C-23 summarizes the three simulations performed in Model 3, highlighting the principal differences among them. This suite of runs is similar to the runs simulated in Model 1.

The base-case simulation (Run 1) assumed that the anhydrites in the Rustler Formation, and anhydrites greater than 3 m thick in the Salado Formation, have no DRZ (based on mechanical modeling results presented in Appendix D). This condition results in a discontinuous DRZ, which is discontinuous initially and remains so throughout the simulations. The second simulation (Run 2) assumes that Rustler members and Salado anhydrites are damaged, and allows healing to occur only in the Salado halite. Runs 1 and 2 include waterstops. The third simulation (Run 3) is a sensitivity simulation to examine the impact of the asphalt waterstops. It is the same as Run 2 except that the concrete-asphalt waterstops were not incorporated into the model. Figure C-23 depicts the permeabilities used in these three simulations.

Table C-23. Performance Model 3 Simulations

Run	Rustler and Anhydrite DRZ	Waterstops
1 (Base-Case)	No	Yes
2	Yes	Yes
3	Yes	No

C6.3 Performance Model Results

Results are presented in terms of brine flow rates (m^3/s). Because the vertical gradient is directed upward, the flow rates reported are also upward. Table C-24 provides the steady-state upward flow rates measured at the Rustler/Salado contact, the top of the compacted salt column, and the top of combined Unit 8 of the model. The difference between the results of Runs 1 and 2 derives from the increased DRZ permeabilities assumed for the anhydrite units. The lack of a difference between the results of Runs 2 and 3 denotes the negligible effect of the waterstops on long-term saturated flow.

The waterstops were included in the seal system design as an immediate seal for the DRZ. Therefore, their inclusion in Runs 1 and 2 was not really appropriate. However, based on the results from Run 3, it can be concluded that their presence in Runs 1 and 2 did not affect the predicted performance measure of upward steady-state flow rate for these simulations.

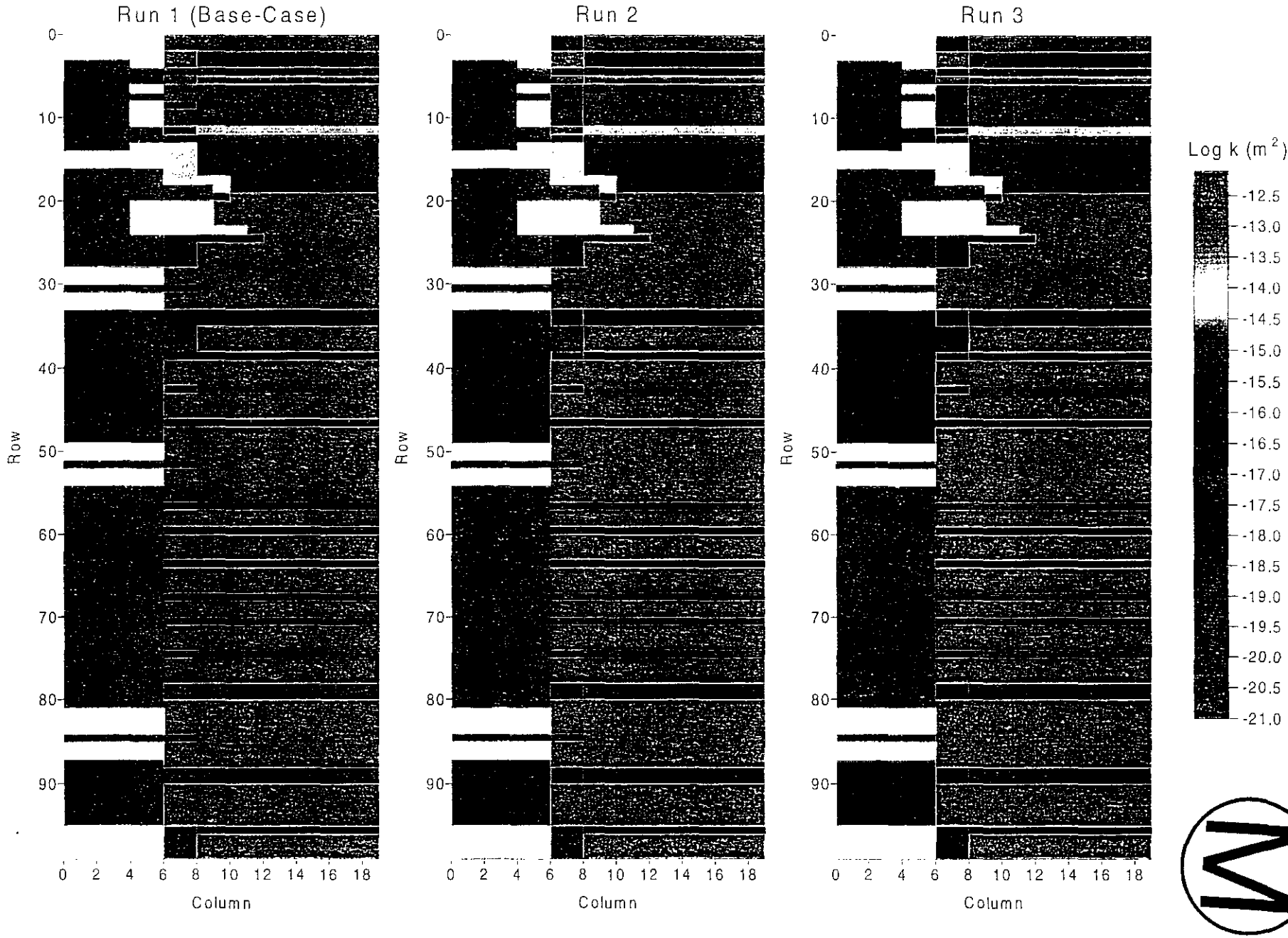

Figure C-23. Permeability fields for Runs 1 through 3 (t > 400 years).

Table C-24. Comparison of Flow Rates Up the Shaft/DRZ from Simulations that Incorporate the Measured Pressure Conditions

Run	Combined Unit 8	Top of Compacted Salt Column	Rustler/Salado Contact
	Flow Rate up the Shaft and DRZ (m^3/yr)		
1 (base-case)	4.76×10^{-5}	1.68×10^{-4}	8.27×10^{-4}
2	4.76×10^{-5}	1.71×10^{-4}	9.68×10^{-4}
3	4.76×10^{-5}	1.71×10^{-4}	9.68×10^{-4}

C7. INTRA-RUSTLER FLOW (MODEL 4)

C7.1 Statement of Problem

The shaft seal system is designed to limit migration of fluids within the sealed shaft. The natural heads within the Rustler Formation are nonhydrostatic indicating the potential for vertical flow (Beauheim, 1989). This calculation examined the potential for, and quantity of brine flow, which, after closure, could be expected to migrate between the Magenta and the Culebra, the two primary water-bearing members of the Rustler Formation.

C7.2 Performance Model Description

The previous models have used sophisticated numerical flow models. This performance model employed simple analytical relationships. The calculation assumptions yielded a relatively simple conceptual model and estimates of intra-Rustler flow rates. The conceptual model, relevant assumptions, and the analysis approach are discussed below.

C7.2.1 Conceptual Model and Assumptions

Non-hydrostatic conditions exist within the Rustler Formation based on estimated undisturbed or measured disturbed head differences between the various members of the Rustler Formation (see Table C-1). Relatively low undisturbed permeabilities of the mudstone and anhydrite units separating the Culebra and the Magenta naturally limit crossflow. However, the construction and subsequent closure of the shaft provide a potential permeable vertical conduit connecting water bearing units. In this calculation, the hydraulic conductance of the shaft seal system was used to estimate flow rates between the Magenta and Culebra under various assumptions. Figure C-24 schematically shows the conceptual model for calculating intra-Rustler flow rates. From Figure C-24 one can see that flow was considered through the seal and through the DRZ consistent with Models 1 through 3. The primary assumptions for this analysis are listed below:

- Saturated flow was assumed under isothermal and constant fluid-density conditions.
- Flow-rates were calculated using the steady-state version of Darcy's Law for saturated flow.

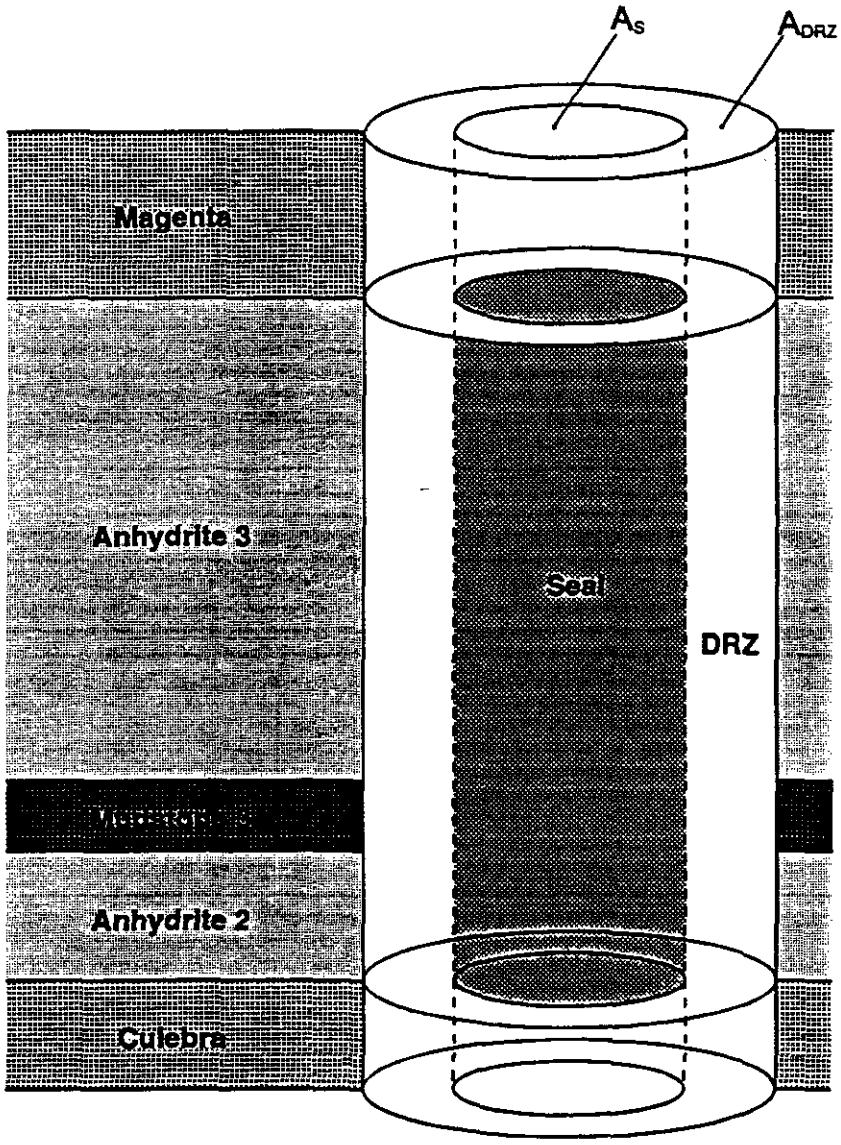

Hydraulic Conductance of the Seal

$$\frac{k_s A_s}{L}\left(\frac{\rho g}{\mu}\right)$$

Conbined Hydraulic Conductance of the Seal Plus DRZ

$$\frac{k_s A_s + k_{DRZ} A_{DRZ}}{L}\left(\frac{\rho g}{\mu}\right)$$

Figure C-24. Intra-Rustler flow conceptual model.

- Resistance to flow was assumed to be only a function of the seal material and DRZ permeabilities. The resistance provided by the geologic members is assumed to be much larger, and the resulting natural vertical crossflow was not considered.
- The driving force (head difference) between water-bearing strata was assumed to be constant and unchanged as a result of flow between units.

C7.2.2 Analytical Approach

A simple analytical model was used to estimate the potential for brine migration between Rustler members. When two hydraulic units are hydraulically connected and at different heads, flow will occur from the unit with the highest head to the unit with the lowest head. Flow is governed by Darcy's Law, which under the assumptions of single-phase steady-state fluid flow through a porous medium can be expressed as

$$Q = -kA \frac{\Delta h}{\Delta l} \frac{\rho g}{\mu} \tag{C-4}$$

where

Q = volumetric flow rate with units of (m^3)
k = the intrinsic permeability of the porous medium (m^2)
ρ = the fluid density (kg/m^3)
g = the acceleration of gravity (m/s^2)
μ = the fluid viscosity (Pa • s)
Δh = the head difference bertween these two units (m)
$\Delta 1$ = the separation of the Culebra and the Magenta (m)
A = the seal plus DRZ cross-sectional area normal to the flow direction (m^2).

Equation C-4 above can be simplified by using the concept of the hydraulic conductance of a porous medium. The hydraulic conductance of a porous medium is composed of area, length, intrinsic permeability, and the fluid viscosity and density. The hydraulic conductance is the inverse of the hydraulic resistance.

The hydraulic conductance defined in terms of intrinsic permeability can be expressed as

$$C = \frac{kA}{\Delta l} \frac{\rho g}{\mu} \tag{C-5}$$

where C is the hydraulic conductance (m^2/s).

In this case Darcy's Law above can be expressed as

$$Q = C \Delta h \tag{C-6}$$

where C is the effective hydraulic conductance of the seal and DRZ materials separating the Culebra and the Magenta.

Figure C-24 shows the conceptual model for intra-Rustler flow. An effective hydraulic conductance of the seal and DRZ system between the Magenta and the Culebra members can be calculated by analogy to electrical circuit theory. The effective hydraulic conductance is composed of the properties of the DRZ and the seal combined. The seal and DRZ act in parallel, and therefore the hydraulic conductance of these two regions can be directly added to get their combined conductance:

$$C = \frac{k_s A_s + k_{DRZ} A_{DRZ}}{\Delta l} \frac{\rho g}{\mu} \tag{C-7}$$

Because the DRZ permeability is a function of rock type, the effective seal plus DRZ hydraulic conductance must also be combined vertically in series between the Magenta and the Culebra. Using the hydraulic conductance of the seal system and the DRZ, a volumetric flow rate can be estimated from the potential head difference.

To put the calculated volumetric flow rates into perspective, the flow rate can be used to calculate the width of the hydraulic disturbance which is created in the water-bearing unit receiving the interflow. Figure C-25 depicts the case of a point injection into a linear flow field. The injected fluid displaces a certain volume of the receiving aquifer fluid and this volume can be expressed as the maximum plume width (measured in plan view, Figure C-25). Within this maximum plume width, the fluid in the receiving aquifer is composed entirely of injected fluid. Outside of this width, the fluid is composed of the resident aquifer fluid. The equation describing the half plume width is:

$$W = \frac{Q_w}{2 u_o b} \tag{C-8}$$

where

Q_w = the intra-Rustler fluid flow rate

u_o = the Darcy velocity of the stratigraphic unit being injected into

b = the thickness of the stratigraphic unit being injected into.

C7.2.3 Model Parameters

Model parameters having to do with the seal system and the Rustler rocks have been previously defined (Section C3). Using the base case seal and DRZ conceptualization and parameters, the flow rate between the Magenta and the Culebra was calculated considering a range of head differences. The calculated flow rates are used to estimate plume half widths in both the Culebra or the Magenta. The flow rate between the Magenta and the Culebra was also calculated considering a continuous DRZ of variable normalized radius and considering a constant head difference of similar magnitude to that which is currently estimated for undisturbed conditions (see Table C-2).

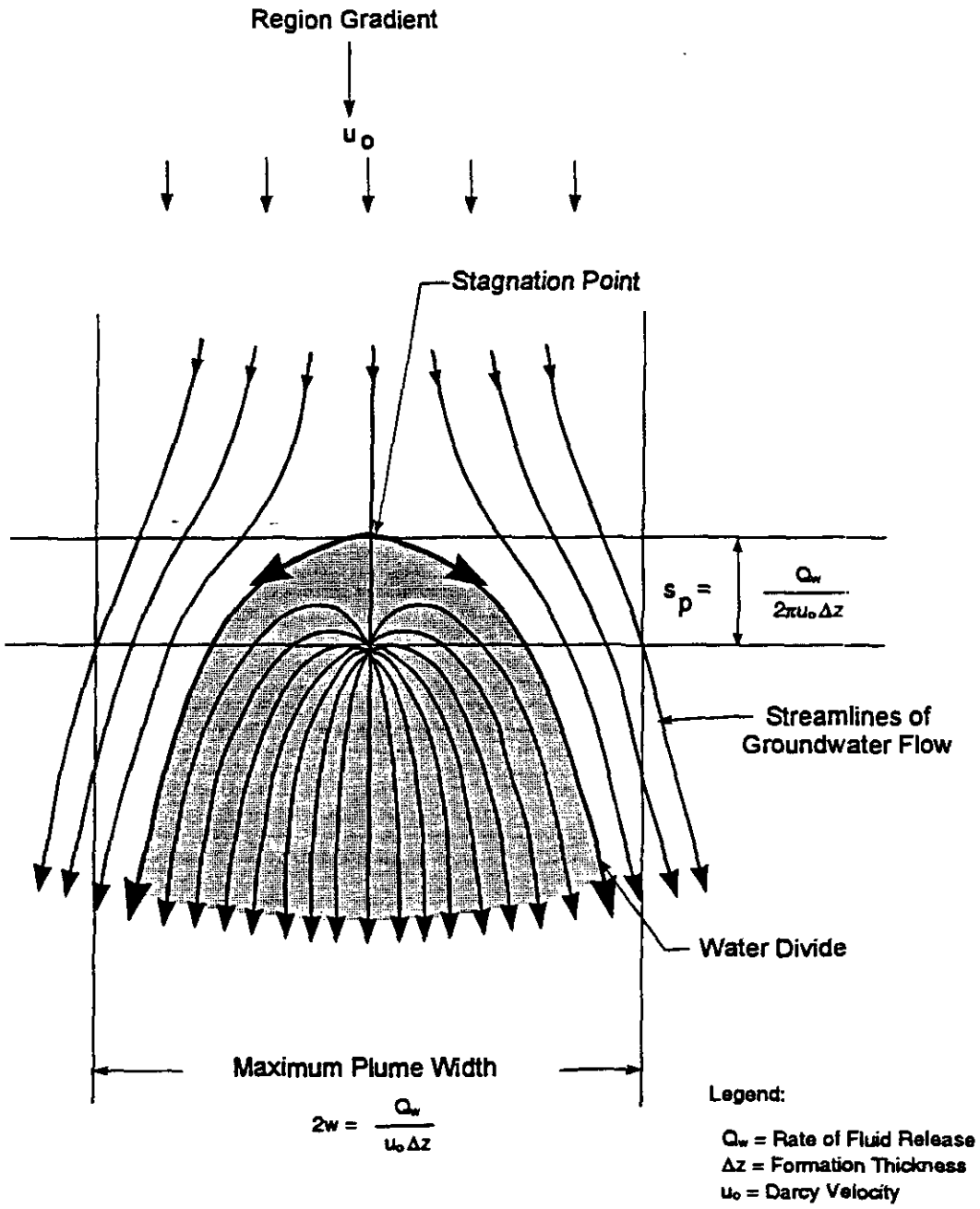

Figure C-25. Effect of an injection well on a unidirectional flow field.

The only parameters unique to Model 4 are the Darcy velocities in the Magenta and the Culebra. These velocities were calculated assuming steady-state Darcy flow and using the minimum regional hydraulic gradient for the Culebra and a regional hydraulic gradient for the Magenta reported by Lambert (1996). The Culebra Darcy velocity was chosen to predict the largest plume half width for a given flow rate (see Equation C-8 above). Table C-25 lists the gradients and Darcy velocities calculated from them using the Culebra and Magenta hydraulic conductivities reported in Section C3.

Table C-25. Regional Darcy Velocities for Culebra and Magenta Members of the Rustler Formation

Rustler Member	Hydraulic Gradient(1)	Darcy Velocity (m/s)
Magenta	0.003788	3.788×10^{-11}
Culebra	0.001894	2.652×10^{-10}

(1) After Lambert, 1996.

C7.3 Performance Model Results

Table C-2 shows that the approximate undisturbed head difference between the Magenta and the Culebra is 33.2 m (109 ft). Presently, this head difference would direct flow from the Magenta to the Culebra. However, the true head difference is uncertain, especially temporally. Using the base case conceptualization for the DRZ, the flow-rate between the Magenta and the Culebra was calculated for head differences ranging from 3.1 to 121.9 m (10 to 400 ft). Figure C-26 plots the resulting flow rates, which range from 0.002 to 0.096 m^3/yr. Figure C-27 plots the resulting plume-half width assuming flow was directed into either the Magenta or the Culebra. As can be seen in Figure C-27, the plume half width did not extend past one shaft radius for head differences less than approximately 76 m (250 ft).

The base-case conceptualization assumed that no anhydrite DRZ exists in the Rustler. The next calculation examined the sensitivity of interflow to a continuous DRZ (in both anhydrite and mudstone) for the estimated undisturbed head difference between the Magenta and Culebra.

Figure C-28 plots the flow rate between the Magenta and the Culebra assuming a head difference of 33.5 m (110 ft) and assuming the DRZ is continuous and has a normalized radius of extent varying from 1.0 (no DRZ) to 3.0 (three shaft radii). Flow rates range from 0.003 to 2.93 m^3/yr. Figure C-29 plots the calculated plume half-width for these flow rates assuming flow is directed into either the Magenta or the Culebra. For a continuous DRZ normalized radius of less than 1.5, the hydraulic disturbance caused by Culebra-Magenta interflow is minimal. Because the flow-rate and plume half-width are linearly correlated to the head difference, results from Figures C-28 and C-29 can be easily scaled to consider any head difference of interest.

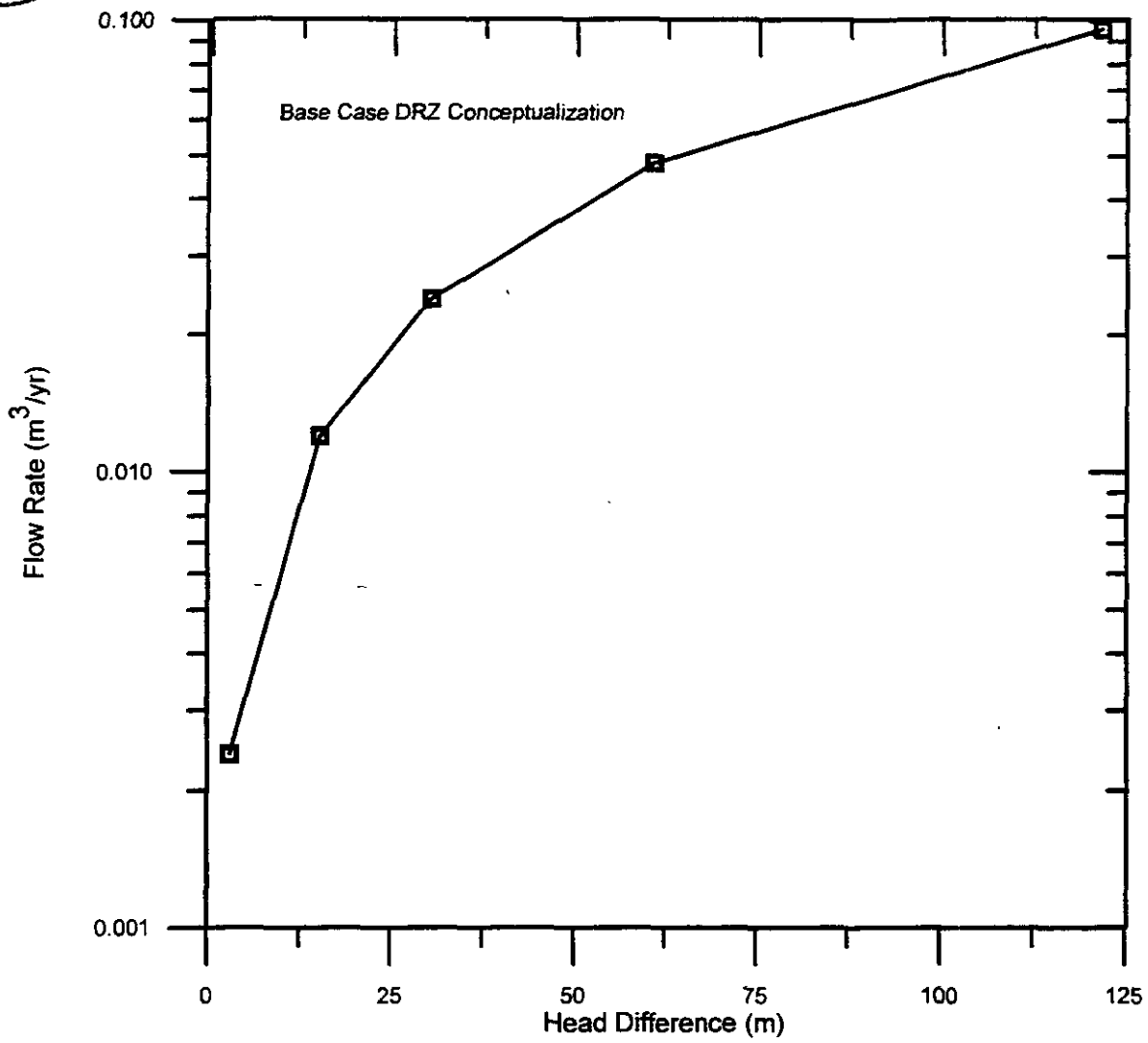

Figure C-26. Sensitivity of flow rate between Culebra and Magenta to head difference (base case).

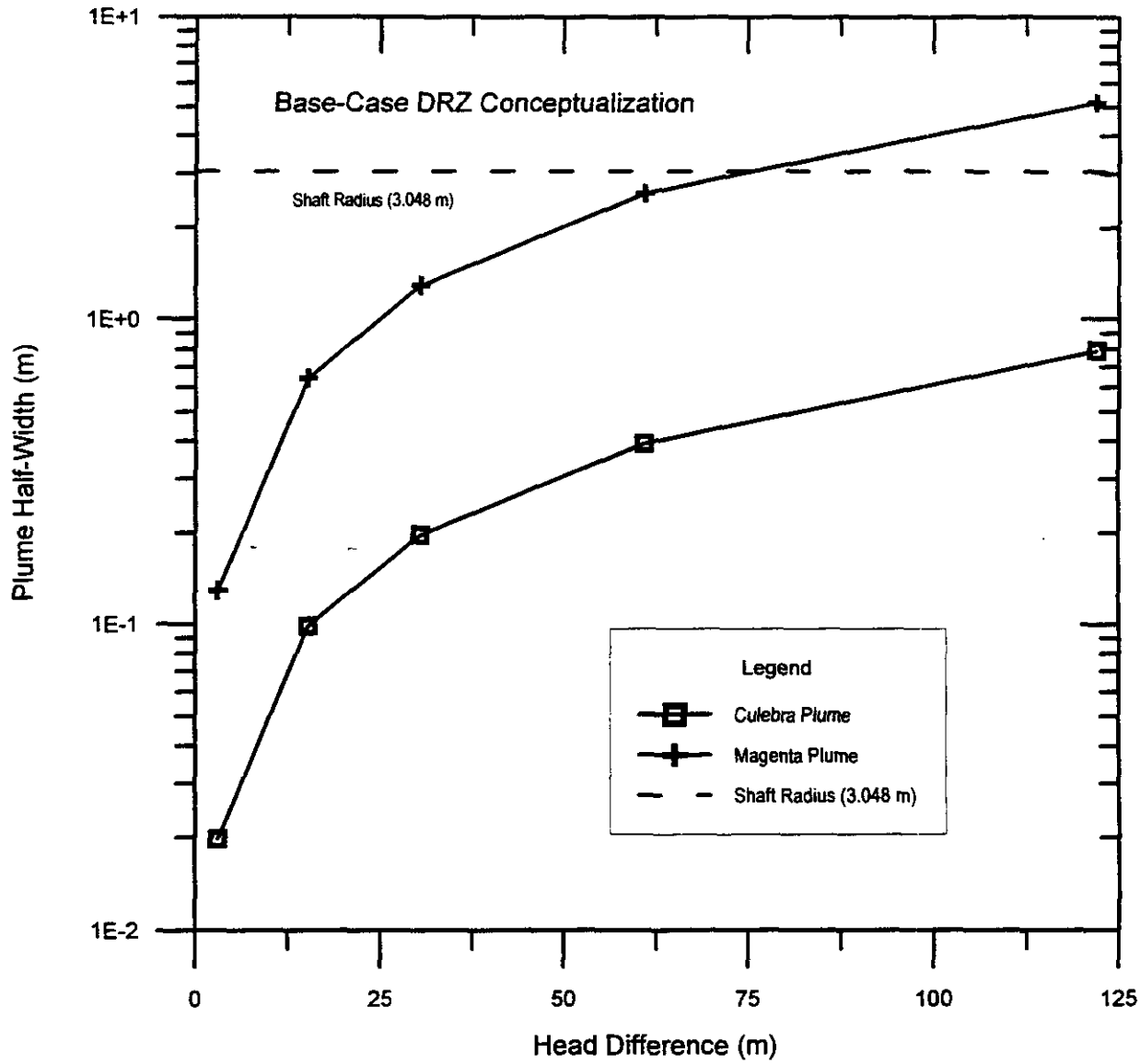

Figure C-27. Sensitivity of flow-field disturbance to head difference (base case).

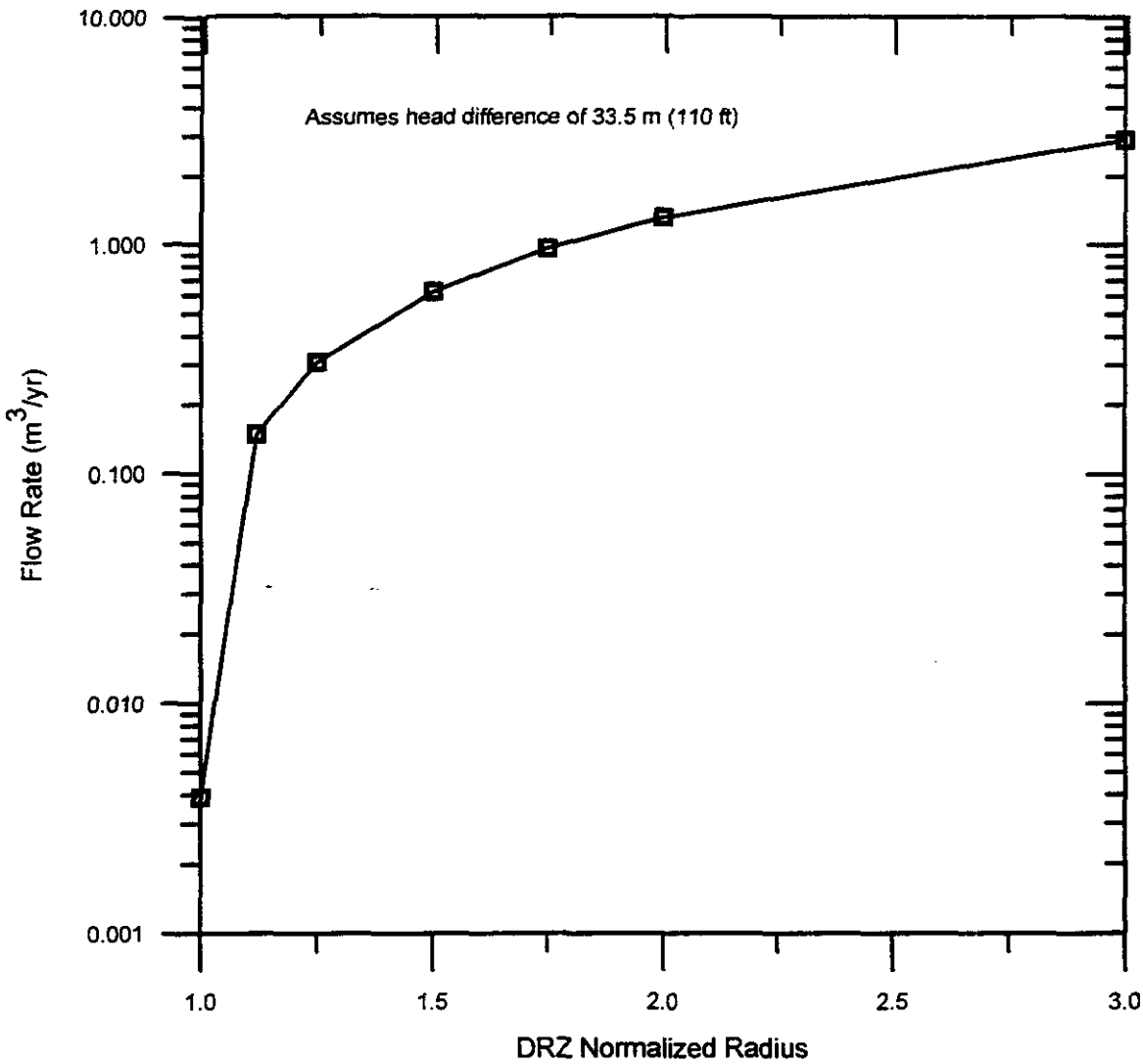

Figure C-28. Sensitivity of flow rate between Culebra and Magenta to DRZ radius (continuous DRZ).

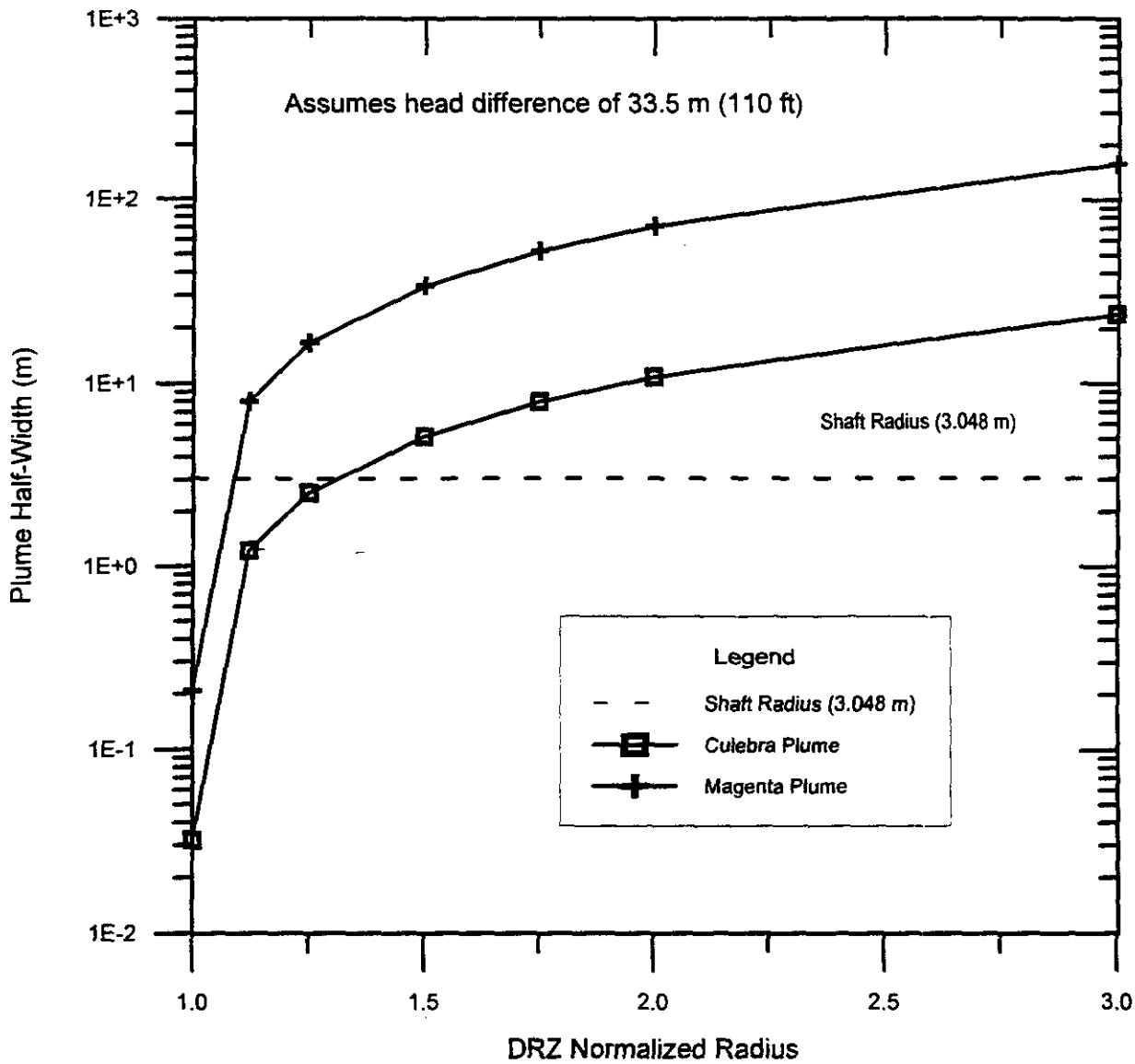

Figure C-29. Sensitivity of flow-field disturbance to DRZ radius (continuous DRZ).

C8. REFERENCES

Avis, J.D., and G.J. Saulnier, Jr. 1990. Analysis of the Fluid-Pressure Responses of the Rustler Formation at H-16 to the Construction of the Air-Intake Shaft at the Waste Isolation Pilot Plant (WIPP) Site. SAND89-7067. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM [SWCF] as WPO24168.)

Aziz, K., and A. Settari. 1979. Petroleum Reservoir Simulation. New York, NY: Elsevier Applied Science Publishers.

Beauheim, R.L. 1987. Interpretations of Single-Well Hydraulic Tests Conducted at and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987. SAND87-0039. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO27679.)

Beauheim, R.L. 1989. Interpretation of H-11b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site. SAND89-0536. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24154.)

Beauheim, R.L., G.J. Saulnier, Jr., and J.D. Avis. 1991. Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report. SAND90-0083. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO26003.)

Beauheim, R.L., R.M. Roberts, T.F. Dale, M.D. Fort, and W.A. Stensrud. 1993. Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report. SAND92-0533. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO23378.)

Borns, D.J., and J.C. Stormont. 1988. An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone. SAND87-1375. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24694.)

Brinster, K.F. 1991. Preliminary Geohydrologic Conceptual Model of the Los Medaños Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment. SAND89-7147. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO27781.)

Brodsky, N.S. 1990. Crack Closure and Healing Studies in WIPP Salt Using Compressional Wave Velocity and Attenuation Measurements: Test Methods and Results. SAND90-7076. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO25755.)

Brooks, R.H., and A.T. Corey. 1966. "Properties of Porous Media Affecting Fluid Flow," Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers (ASCE). Vol. 92, no. IR2, 61-88. (Copy on file in the SWCF.)

Dale, T., and L.D. Hurtado. 1996. "WIPP Air-Intake Shaft Disturbed-Rock Zone Study," 4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996. SAND96-1327C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

Davies, P.B. 1991. Evaluation of the Role of Threshold Pressure in Controlling Flow of Waste-Generated Gas into Bedded Salt at the Waste Isolation Pilot Plant. SAND90-3246. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO26169.)

DOE (U.S. Department of Energy). 1995. Waste Isolation Pilot Plant Sealing System Design Report. DOE/WIPP-95-3117. Carlsbad, NM: U.S. Department of Energy, Waste Isolation Pilot Plant. (Copy on file in the SWCF as WPO29062.)

DOE (U.S. Department of Energy). 1996. Compliance Certification Application for the Waste Isolation Pilot Plant. DOE/CAO-96-2184. Carlsbad, NM: U.S. Department of Energy, Carlsbad Area Office.

Finley, N.C., and M. Reeves. 1981. SWIFT Self-Teaching Curriculum: Illustrative Problems to Supplement the User's Manual for the Sandia Waste-Isolation Flow and Transport Model (SWIFT). SAND81-0410. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO30254.)

Freeze, R.A., and J.A. Cherry. 1979. Groundwater. Englewood Cliffs, NJ: Prentice-Hall, Inc. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM as GB1003.2 .F73 1979.)

Gorham, E., R. Beauheim, P. Davies, S. Howarth, and S. Webb. 1992. "Recommendations to PA on Salado Formation Intrinsic Permeability and Pore Pressure for 40 CFR 191 Subpart B Calculations," Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters. Sandia WIPP Project. SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories. A-47 through A-66. (In Appendix A of SAND92-0700/3, which is on file in the SWCF as WPO23529.)

Hansen, F.D., and K.D. Mellegard. 1979. Creep Behavior of Bedded Salt from Southeastern New Mexico at Elevated Temperature. SAND79-7030; RSI-0062. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO27369.)

Haug, A., V.A. Kelley, A.M. LaVenue, and J.F. Pickens. 1987. Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report. SAND86-7167. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO28486.)

Holcomb, D.J. 1988. "Cross-Hole Measurements of Velocity and Attenuation to Detect a Disturbed Zone in Salt at the Waste Isolation Pilot Plant," Key Questions in Rock Mechanics, Proceedings of the 29th U.S. Symposium, University of Minnesota, Minneapolis, MN, June 13-15, 1988. Eds. P.A. Cundall, R.L. Sterling, and A.M. Starfield. SAND87-3016C. Brookfield, VT: A.A. Balkema. 633-640. (Copy on file in the SWCF as WPO29992.)

Holt, R.M., and D.W. Powers. 1990. Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant. DOE-WIPP 90-051. Carlsbad, NM: Westinghouse Electric Corporation. (Copy on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM.)

Knowles, M.K., D. Borns, J. Fredrich, D. Holcomb, R. Price, D. Zeuch, T. Dale, and R.S. Van Pelt. 1996. "Testing the Disturbed Zone Around a Rigid Inclusion in Salt," 4th Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996. SAND95-1151C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

Lambert, S.J. In preparation. Sources of Natural Brines at the Waste Isolation Pilot Plant and Implications for the Seal System. SAND94-0091. Albuquerque, NM: Sandia National Laboratories(Copy on file in the SWCF.)

Lappin, A.R., R.L. Hunter, D.P. Garber, and P.B. Davies, eds. 1989. Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989. SAND89-0462. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24125.)

LaVenue, A.M., T.L. Cauffman, and J.F. Pickens. 1990. Ground-Water Flow Modeling of the Culebra Dolomite. Volume I: Model Calibration. SAND89-7068/1. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24085.)

Mercer, J.W. 1983. Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area, Southeastern New Mexico. Water-Resources Investigations Report 83-4016. Albuquerque, NM: U.S. Geological Survey, Water Resources Division. (Copy on file in the SWCF.)

Parker, J.C., R.L. Lenhard, and T. Kuppusamy. 1987. "A Parametric Model for Constitutive Properties Regarding Multiphase Flow in Porous Media," Water Resource Research, Vol. 23, no. 4.

Peterson, E.W., P.L. Lagus, and K. Lie. 1987. Fluid Flow Measurements of Test Series A and B for the Small Scale Seal Performance Tests. SAND87-7041. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24430.)

Pruess, K. 1991. TOUGH2 - A General-Purpose Numerical Simulator for Multiphase Fluid and Heat Flow. LBL-29400. Berkeley, CA: Earth Sciences Division, Lawrence Berkeley Laboratory. (Copy on file in the SWCF.)

Reeves, M., D.S. Ward, N.D. Johns, and R.M. Cranwell. 1986a. Theory and Implementation for SWIFT II, The Sandia Waste-Isolation Flow and Transport Model for Fractured Media, Release 4.84. SAND83-1159, NUREG/CR-3328. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO28363.)

Reeves, M., D.S. Ward, N.D. Johns, and R.M. Cranwell. 1986b. Data Input Guide for SWIFT II, The Sandia Waste-Isolation Flow and Transport Model for Fractured Media, Release 4.84. SAND83-0242, NUREG/CR-3162. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO29686.)

Reeves, M., D.S. Ward, P.A. Davis, and E.J. Bonano. 1987. SWIFT II Self-Teaching Curriculum: Illustrative Problems for the Sandia Waste-Isolation Flow and Transport Model for Fractured Media. SAND84-1586 Revision, NUREG/CR-3925. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO30179.)

Sandia WIPP Project. 1992. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 3: Model Parameters. SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO20910.)

Saulnier, G.J., Jr., and J.D. Avis. 1988. Interpretation of Hydraulic Tests Conducted in the Waste-Handling Shaft at the Waste Isolation Pilot Plant (WIPP) Site. SAND88-7001. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24164.)

Siegel, M.D., S.J. Lambert, and K.L. Robinson, eds. 1991. Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico. SAND88-0196. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO25624.)

Stormont, J.C. 1990. Summary of 1988 WIPP Facility Horizon Gas Flow Measurements. SAND89-2497. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24044.)

Stormont, J.C., E.W. Peterson, and P.L. Lagus. 1987. Summary of and Observations About WIPP Facility Horizon Flow Measurements Through 1986. SAND87-0176. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24698.)

Touloukian, Y.S., C.Y. Ho, W.R. Judd, and R.F. Roy. 1981. Physical Properties of Rocks and Minerals. McGraw-Hill/Cindas Data Series on Material Properties ; Vol. II-2. New York, NY: McGraw-Hill. (Copies available at Technical Library, Sandia National Laboratories, Albuquerque, NM and at Centennial Science and Engineering Library, University of New Mexico, Albuquerque, NM.)

van Genuchten, M. Th. 1980. "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils," Soil Science Society of America Journal. Vol. 44, no. 5, 892-898. (Copy on file in the SWCF.)

Van Sambeek,, L.L., D.D. Luo, M.S. Lin, W. Ostrowski, and D. Oyenuga. 1993. Seal Design Alternatives Study. SAND92-7340. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO23445.)

Ward, D.S., M. Reeves, and L.E. Duda. 1984. Verification and Field Comparison of the Sandia Waste-Isolation Flow and Transport Model (SWIFT). SAND83-1154, NUREG/CR-3316. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO29695.)

Webb, S. W. 1996. Review of Two-Phase Characteristic Curves for Porous Media and Application to the WIPP. SAND93-3912. Albuquerque, NM: Sandia National Laboratories. (WPO# 37539)

WIPP PA. 1992-1993. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. SAND92-0700. Albuquerque, NM: Sandia National Laboratories. (Vol. 1 on file in the SWCF as WPO20762; Vol. 2 filed as WPO20805; Vol. 3 filed as WPO20910; Vol. 4 filed as WPO20958; Vol. 5 filed as WPO20929.)

Appendix D

Structural Analyses

Appendix D Abstract

The seals for the shafts at the WIPP are comprised of columns of compacted earthen fill, compacted clay, asphalt, and compacted crushed salt, separated by concrete seals. The structural behavior of these columns and the concrete components is the primary focus of the calculations presented in this appendix. The development (and subsequent healing) of the disturbed rock zone that forms in the rock mass surrounding the shafts is a significant concern in the seal design, and these issues are also addressed in this appendix. In addition, several structural calculations are included that were used as input to the hydrological calculations reported in Section 8 and Appendix C. Complexity of the calculations ranged from solving a simple equation to rigorous finite-element modeling encompassing both thermal and structural elements.

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D1. INTRODUCTION

The seals for the shafts at the WIPP are comprised of columns of compacted earthen fill, compacted clay, asphalt, and compacted crushed salt, separated by concrete seals. Within the Salado Formation each shaft seal includes: (1) an asphalt column extending from above the Rustler/ Salado interface down into the Salado salt, (2) an upper Salado compacted clay column, (3) a long compacted crushed salt column, and (4) a lower Salado compacted clay column. Each of these columns is separated by specially designed salt-saturated concrete components. The structural behavior of the various columns and the concrete components is the initial focus of the calculations presented in this appendix.

The development (and subsequent healing) of a disturbed rock zone (DRZ) that forms in the rock mass surrounding the WIPP shafts is a significant concern in the seal design. It is well known that an initial DRZ will develop in the rock adjacent to the shaft immediately after excavation. Moreover, the DRZ within the Salado Formation continues to develop because of salt creep. Shaft seal emplacement will cause the DRZ to heal with time because of restraint to creep closure by the seal materials and the subsequent reduction in the stress differences in the surrounding intact salt. Within the formations above the Salado, the DRZ is assumed to be time-invariant, since the behavior of the rock masses encountered there is predominantly elastic. The calculation of the temporal and spatial extent of the DRZ along the entire shaft length is the second focus of this appendix.

This appendix provides a collection of calculations pertaining to the above mentioned structural concerns. The purpose of each calculation varied; however, the calculations generally addressed one or more of the following issues (1) stability of the component, (2) influences of the component on hydrological properties of the seal and surrounding rock, or (3) construction issues. Stability issues that were addressed in these calculations included:

- potential for thermal cracking of concrete seals, and.
- structural failure of concrete seal components because of loads resulting from (1) creep of surrounding salt, (2) dynamic compaction and gravity loads of overlying seal material, (3) repository generated gas pressures, and (4) clay swelling pressures.

Structural calculations were also used to define input conditions to the hydrological calculations reported in Section 8, including:

- spatial extent of the DRZ within the Salado Formation surrounding the shafts as a function of depth, time, and seal material type,
- fracturing and DRZ development within Salado Formation interbeds,
- compacted-salt fractional density as a function of depth and time,
- shaft-closure induced consolidation of compacted-salt seals, and
- impact of pore pressures on consolidation of compacted-salt seals.

The construction issues that were addressed included:

- emplacement and structural performance of asphalt waterstops, and
- potential benefits from backfilling shaft stations.

Complexity of the calculations ranged from solving a simple equation to rigorous finite-element modeling encompassing both thermal and structural elements. All calculations are presented in a similar format, having approximately the same detail. Each calculation is described in terms of its objectives, problem statement, assumptions, and results.

Calculations were performed concurrently with development of the shaft seal design. Consequently, in some instances calculations reported here do not exactly match particular component dimensions shown in the design drawings (Appendix E) because of later changes in the design. Conclusions drawn from the results of these earlier calculation would not, however, change simply because of dimensional changes or emplacement conditions. In some instances a single calculation (e.g., a finite-element analysis of the concrete seal) was used to evaluate the structural behavior of more than one seal component. For example, the finite-element analysis of the asphalt waterstops was used to calculate both the DRZ development in the Salado salt and the time-dependent stresses in the concrete seals. Additionally, some results are drawn from previous similar analyses that are still generally applicable to the current design.

For convenience, the presentation of structural analyses in this appendix is divided into five sections, describing:

- analyses methods,
- material models,
- structural behavior of the shaft seal components,
- DRZ development (and healing) in intact rock surrounding the shaft, and
- analyses related to construction issues.

More specifically, analyses methods and computer programs used in performing these analyses are presented in Section D2. The analyses methods include finite element modeling and analytical techniques. Section D3 describes the models used in characterizing material behavior of shaft seal components, the intact rock mass, and the DRZ. Material models included thermal properties, deformational behavior, and strength properties for the four shaft seal materials and the in situ materials. Also included is a description of the models used to characterize the DRZ. A summary of the structural analyses of the four shaft seal materials is presented in Section D4. Analyses of the shaft seal components are presented by material type, i.e., concrete, compacted crushed salt, compacted clay, and asphalt. The behavior of the DRZ within the intact rock mass surrounding the shaft is described in Section D5. The DRZ was evaluated within Salado salt, Salado interbeds, and overlying nonsalt formations. Finally, analyses of asphalt waterstops and shaft station backfilling are discussed in Section D6.

D2. ANALYSES METHODS

Finite-element modeling and subsidence modeling were the primary methodologies used in evaluating the structural performance of the shaft seals and the surrounding intact rock mass. The finite element programs SPECTROM-32 and SPECTROM-41 were used in the structural and thermal calculations, respectively. The program SALT_SUBSID was used in the subsidence modeling. These programs are described below.

D2.1 SPECTROM-32

The finite-element structural modeling program SPECTROM-32 (Callahan, 1994) was used in performing structural calculations. These calculations included creep deformation of the host rock, consolidation of shaft seal material, and development (and subsequent healing) of the DRZ within salt. This thermomechanical program was designed specifically for simulation of underground openings and structures. SPECTROM-32 has the capability to model the elastic-plastic response, commonly associated with brittle rock types, and has been used extensively to simulate the time-dependent viscoplastic behavior observed in intact salt. In addition, creep consolidation material behavior (e.g., crushed salt) can be modeled using SPECTROM-32. Specific features and capabilities of SPECTROM-32 required for numerical simulations include:

- capabilities for plane-strain and axisymmetric geometries,
- kinematic and traction boundary conditions,
- Multimechanism Deformation Coupled Fracture (MDCF) (Chan, 1993) constitutive model for modeling creep behavior of salt and estimating the DRZ in salt,
- creep consolidation models for time-dependent densification of crushed salt,
- nonlinear elastic behavior for modeling time-independent deformational behavior of crushed salt and compacted clay,
- capability to represent arbitrary in situ stress and temperature fields, and
- capability to simulate shaft excavation and seal material emplacements.

Most of the structural analyses were performed using Version 4.06 of this program. Analyses using recently developed creep consolidation models and for calculating the effects of pore pressure on consolidation of crushed-salt seal were performed using Version 4.08 of the program.

D2.2 SPECTROM-41

The finite-element program SPECTROM-41 (Svalstad, 1989) was used in performing thermal calculations. This program has been designed and used to solve heat transfer problems resulting from the storage of heat-generating material in geologic formations for the past 15 years. The program has been documented to satisfy the requirements and guidelines outlined in NUREG-0856 (Silling, 1983). Specific features and capabilities of SPECTROM-41 that were required for the numerical simulations include:

- capabilities for two-dimensional and axisymmetric geometries,
- multimaterial behavior,
- specified initial temperature conditions,
- specified temperature or flux boundary conditions,
- temperature-dependent thermal properties,
- time-dependent volumetric heat generation, and
- transient and/or steady-state solutions.

D2.3. SALT_SUBSID

SALT_SUBSID (Nieland, 1991) is a PC-based subsidence modeling software used to evaluate surface subsidence over underground openings in salt. The computer program has the capability of developing a site-specific subsidence model which can be used for predicting the future subsidence over a new or existing mining plan. The computer program can also predict stresses and strains along the shaft height resulting from subsidence. Subsidence calculations can be performed on either solution mines or dry mines in salt or potash. The analytical model is based on the solution for ground movement above a closing displacement discontinuity in an isotropic material and includes a time-dependent function to account for the viscoplastic nature of salt. SALT_SUBSID is commercially available software from the Solution Mining Research Institute (SMRI).

D3. MATERIAL CHARACTERIZATION

This section describes models used in characterizing material behavior of the WIPP shaft seal components, intact rock mass, and DRZ. Structural models used to characterize the four shaft seal materials are discussed in Section D3.1. The structural models include thermal properties, deformational behavior, and strength characteristics. Seal materials include concrete, crushed salt, compacted clay, and asphalt. Structural models for intact rock are presented in Section D3.2. These materials include Salado salt, Salado anhydrite and polyhalite, and the rock types encountered in the near-surface and Rustler Formations. Models used in characterizing the DRZ within the intact rock mass surrounding the shaft are presented in Section D3.3.

D3.1 Shaft Seal Components

The shaft seal components include Salado Mass Concrete (SMC), crushed salt, compacted clay, and asphalt. Thermal, deformational, and strength characteristics of these four materials that were required in the structural analyses are given in the following sections.

D3.1.1 Salado Mass Concrete

Thermal, deformational, and strength characteristics of SMC were required in these structural analyses. These properties are discussed in the following subsections.

Thermal Properties. Required thermal properties include thermal conductivity, specific heat, density, and volumetric heat generation rate (Table D-1). Values of thermal conductivity, specific heat, and density are based on laboratory tests performed at Waterways Experimental Station (WES) (Wakeley et al., 1994).

Heat of hydration of SMC is illustrated in Figure D-1 which shows heat generation (Btu/lb_{cem}) as a function of time (hr), where the subscript "cem" refers to the total weight of cementitious material. The curve was digitized and fit to the functional form,

$$Q(t) = Q_{\infty} \exp\left[-(\tau_e / t)^{\alpha}\right] \qquad \text{(D-1)}$$

which was suggested by the Andersen et al. (1992) for describing the heat of hydration for concrete pavements, where Q_∞, τ_e and α are the model parameters and t is time (hr).

These model parameters were determined using the statistical program BMDP/386 and are listed in Table D-2. The volumetric heat generation rate (dQ/dt) of the concrete is required in performing the thermal analyses. Differentiating Equation D-1 with respect to time results in:

$$dQ(t)/dt = Q(t)(\tau_e/t)^\alpha(\alpha/t) \qquad \text{(D-2)}$$

The conversion of units from Btu/lb_{cem} to $W\text{-}hr/m^3_{con}$, where m^3_{con} refers to cubic meters of concrete, is given as follows:

[1 Btu/lb_{cem}] [1055 J/Btu] [2.2 lb/kg] [2280 kg/m^3] [1 W-s/J] [1 hr/3600 s] [0.16 lb_{cem}/lb_{con}] = 235 $W\text{-}hr/m^3_{con}$.

Deformational Properties. SMC is assumed to behave as a viscoelastic material, based on experimental data for several mixes of SMC. The WES (Wakeley et al., 1994) creep data are summarized in Table D-3. An isothermal form of the Norton (power) creep law was fit to long-term laboratory creep-test data and resulted in the following:

$$\dot{\varepsilon}_{ss} = A\sigma^n \qquad \text{(D-3)}$$

where:

$\dot{\varepsilon}_{ss}$ = steady-state strain rate

σ = deviatoric stress

A = fitted model parameter = $0.11(10^{-6})$/day

n = fitted model parameter = 0.54.

Table D-1. Salado Mass Concrete Thermal Properties

Property	Units	Value
Thermal Conductivity	W/m-K	2.145
Specific Heat	J/kg-K	971.
Density	kg/m^3	2,280
Heat of Hydration Rate	W/m^3	(Equation D-2)

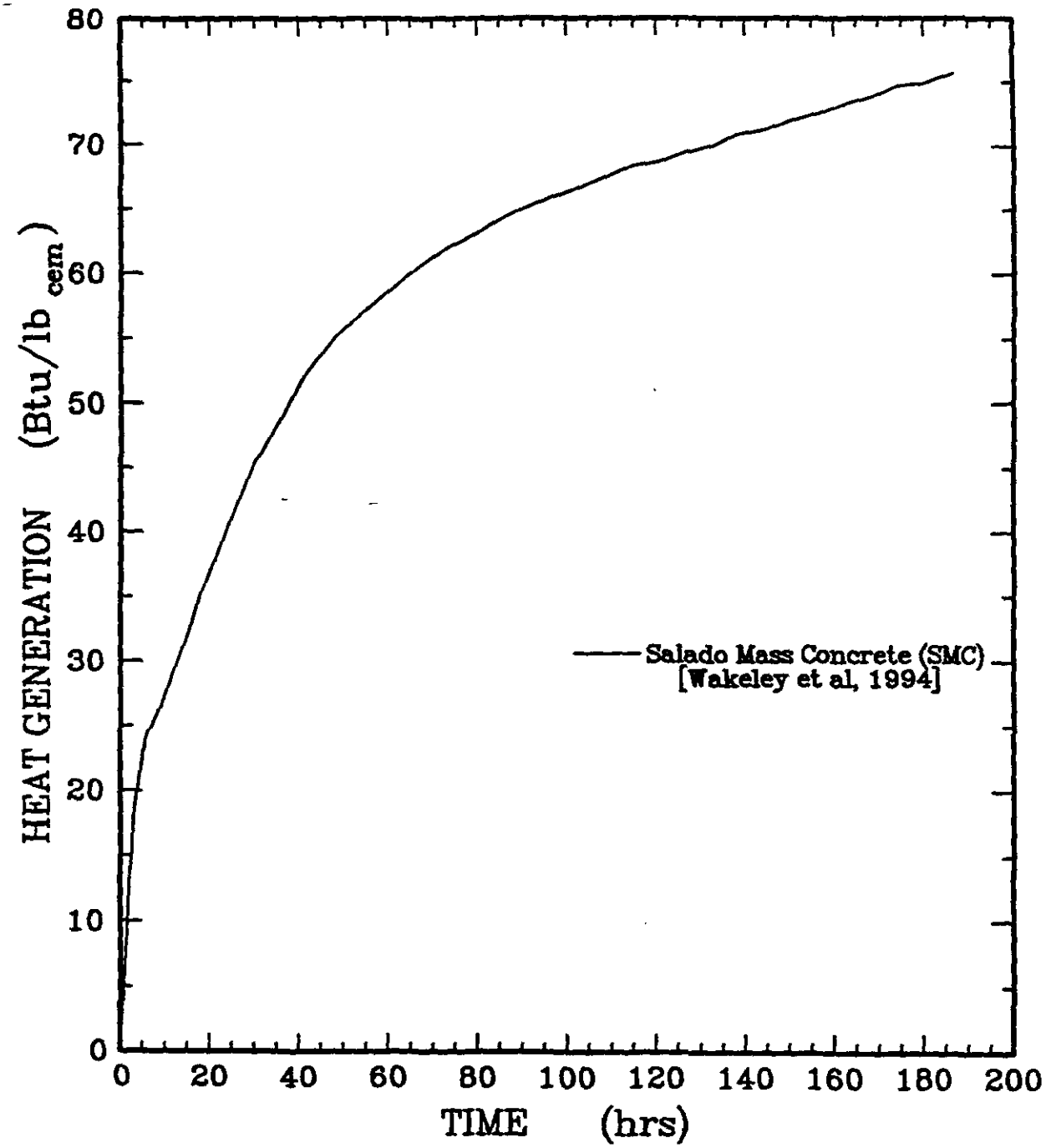

Figure D-1. Heat generation of Salado Mass Concrete mixture.

Table D-2. Heat of Hydration Model Parameters

Parameter	Units	SMC
Q_∞	Btu/lb_{cem} ($W\text{-}hr/m^3_{con}$)	173.7 (40,837)
τ_e	hr	89.8
α	—	0.264

Table D-3. Summary of Creep Data (from Wakeley et al., 1994)

Test Number	Uniaxial Stress (MPa)	Steady-State Strain Rate (10^{-6}/day)
1	2.5	0.175
2	5.9	0.265
3	7.8	0.333

The elastic modulus of SMC is assumed to be age-dependent, based on experimental data reported by WES (Wakeley et al., 1994). These data are given in Table D-4. A functional form shown in Equation D-4 was used to represent the age-dependence of the elastic modulus of SMC as it sets (increases in stiffness):

$$E(t) = E_{max}\left(\frac{t}{t + t_0}\right) \tag{D-4}$$

where:

$E(t)$ = modulus at time t

t = time (days)

E_{max} = ultimate stiffness.

Table D-4. Variation of Elastic Modulus of SMC as a Function of Time (from Wakeley et al., 1994)

Time (days)	Elastic Modulus 10^6 (psi)
0	0
28	4.00
90	5.77
230	6.34

The model parameters derived from experimental results given in Table D-4 are:

$E_{max} = 6.7\ (10^6)$ psi

$t_0 = 16.75$ days.

Poisson's ratio of SMC was assumed to be 0.19 and is consistent with literature values for concretes. The thermal expansion of SMC is 11.9 (10^{-6})/°C based on test data from WES (Wakeley et al., 1994).

Strength Properties. The design specification for concrete is a 28-day unconfined compressive strength of 4,500 psi (31 MPa) (Appendix A). Recent laboratory tests indicate that SMC has an unconfined compressive strength of about 6,000 psi (40 MPa) (Wakeley et al., 1994).

D3.1.2 Crushed Salt

The total strain rate for the crushed-salt constitutive model is assumed to consist of three components. These components include nonlinear elastic ($\dot{\varepsilon}_{ij}^{e}$), creep consolidation ($\dot{\varepsilon}_{ij}^{c}$), and creep ($\dot{\varepsilon}_{ij}^{i}$) contributions, and the total strain rate ($\dot{\varepsilon}_{ij}$) can be written as:

$$\dot{\varepsilon}_{ij} = \dot{\varepsilon}_{ij}^{e} + \dot{\varepsilon}_{ij}^{c} + \dot{\varepsilon}_{ij}^{i} \qquad \text{(D-5)}$$

Both the nonlinear elastic and creep consolidation portions of the model describe the material behavior in bulk (volumetric deformation) and in shear (deviatoric deformation). However, the creep portion of the crushed-salt model only describes deviatoric behavior. In fact, the creep portion of the crushed-salt model is the same as that of intact salt, i.e., the Munson-Dawson model described in Section D3.2.1. Nonlinear elastic and creep consolidation models used for crushed salt are described in the next sections.

Nonlinear Elastic Model for Crushed Salt. Elastic strain, ε_{ij}^{e}, is the contribution from the stress field given by Hooke's law, which, in terms of the bulk modulus and shear modulus, is written as:

$$\varepsilon_{ij}^{e} = \frac{\sigma_m}{3K}\delta_{ij} + \frac{S_{ij}}{2G} \qquad \text{(D-6)}$$

where:

σ_m	$= \frac{\sigma_{kk}}{3}$, mean stress
S_{ij}	$= \sigma_{ij} - \sigma_m \delta_{ij}$, deviatoric stress
δ_{ij}	= Kronecker delta
K	= bulk modulus
G	= shear modulus.

Sjaardema and Krieg (1987) propose bulk and shear moduli as exponential functions of the current density, ρ:

$$K = K_0 e^{K_1 \rho}$$
$$G = G_0 e^{G_1 \rho} \qquad \text{(D-7)}$$

where K_0, K_1, G_0, and G_1 are material constants. The current density (ρ) is written in terms of the total volumetric strain, ε_v, using the relation:

$$\rho = \frac{\rho_0}{1+\varepsilon_v} \qquad \text{(D-8)}$$

where ρ_0 is the density of the material before the volumetric strain is imposed. The moduli are capped at values consistent with moduli for intact salt when the current density equals intact salt's density.

Table D-5 lists material parameters of the nonlinear elastic model for WIPP crushed salt. The terms K_0 and G_0 are the leading coefficients defining the bulk and shear moduli, respectively as the density approaches zero. The terms K_1 and G_1 are identical in magnitude and describe the density dependence in Equation D-7. Exponential function parameters are from Sjaardema and Krieg (1987). Intact crushed-salt constants (K_f, G_f, and ρ_f) are based on recent measurements on WIPP salt.

Table D-5. Nonlinear Elastic Material Parameters for WIPP Crushed Salt

Parameter	Units	Value
K_0	MPa	0.01760
K_1	m^3/kg	0.00653
G_0	MPa	0.0106
G_1	m^3/kg	0.00653
K_f	MPa	23,504
G_f	MPa	14,156
ρ_f	kg/m^3	2,160

Creep Consolidation Models for Crushed Salt. Four constitutive laws were used to describe the creep consolidation portion of the crushed-salt model:

- Sjaardema-Krieg
- Revised Sjaardema-Krieg
- Zeuch
- Spiers.

The first model is based on the work of Sjaardema and Krieg (1987) with a deviatoric component added (Callahan and DeVries, 1991). In this study, this model is referred to as the original S-K model. This model can be expressed mathematically as:

$$\dot{\varepsilon}_{ij}^{c} = \frac{(1+\varepsilon_v)^2}{\rho_0} B_0\left(1-e^{-B_1\sigma_m}\right) e^{A\rho}\left\{\frac{\delta_{ij}}{3}-\frac{S_{ij}}{\sigma_e}\right\} \tag{D-9}$$

where:

ε_v = ε_{kk}, total volumetric strain

σ_e = average effective stress measure

B_0, B_1, A = material constants.

Because Equation D-9 allows for unlimited consolidation, a cap is introduced that eliminates further consolidation when the intact material density (ρ_f) is reached. Thus, when the condition

$$|\varepsilon_v| \geq \left|\frac{\rho_0}{\rho_f}-1\right| \tag{D-10}$$

is satisfied, no further creep consolidation occurs.

Table D-6 gives values of the crushed-salt parameters for the original S-K model.

Table D-6. Creep Consolidation Parameters for Crushed Salt (after Sjaardema and Krieg, 1987)

Parameter	Units	Value
B_0	$kg/m^3 \bullet s^{-1}$ $kg/m^3 \bullet yr^{-1}$	1.3×10^8 4.10×10^{15}
B_1	MPa^{-1}	0.82
A	m^3/kg	-1.73×10^{-2}

The second creep consolidation model used in this study is a revised Sjaardema-Krieg model, reported originally by Callahan et al. (1995) and recently updated to include a more general formulation and an updated database by Callahan et al. (1996). The mathematical form of this model is:

$$\dot{\varepsilon}_{ij}^{c} = \dot{\varepsilon}_{eq}^{c}\left(\sigma_{eq}^{f}\right)\frac{\partial\,\sigma_{eq}}{\partial\,\sigma_{ij}} \tag{D-11}$$

where $\dot{\varepsilon}_{eq}^{c}$ and σ_{eq}^{f} are the power-conjugate equivalent inelastic strain measure and equivalent stress measure for creep consolidation, respectively, and σ_{eq} is an equivalent stress measure that provides a nonassociative formulation in governing the magnitude of the volumetric strain.

With these considerations, the equivalent stress measures can be written as:

$$\sigma_{eq}^{f} = \eta\left|\sigma_m\right|^{\eta_2} - \frac{\left|\sigma_1 - \sigma_3\right|^{m_1}}{\sigma_{r_1}^{m_1-1}}$$
$$\sigma_{eq} = \kappa\left|\sigma_m\right|^{\kappa_2} - \frac{\left|\sigma_1 - \sigma_3\right|^{m_1}}{\sigma_{r_2}^{m_2-1}} \qquad \text{(D-12)}$$

where:

$$\eta = \eta_0(1-\Omega)^{\eta_1}$$
$$\kappa = \kappa_0(1-\Omega)^{\kappa_1}$$
$$\Omega = \begin{Bmatrix} D_t, 0 < D < D_t \\ D, D_t < D < 1 \end{Bmatrix}$$

D_t = transitional fractional density

D = fractional density

σ_1 and σ_3 = principal stresses

σ_{r_1} and σ_{r_2} = reference stresses

$\eta_0, \eta_1, \eta_2,$
$\kappa_0, \kappa_1, \kappa_2,$
m_1, m_2 = material parameters.

The kinetic equation as described by the revised Sjaardema-Krieg model can be written as:

$$\dot{\varepsilon}_{eq}^{c} = \frac{B_0\ (1 + \varepsilon_v)^2}{\rho_0\ d^p} \exp\left(\frac{A\rho_o}{1 + \varepsilon_v}\right)\left[1 + a_1\left(1 - e^{-a_2 w}\right)\right] e^{\frac{-Q_c}{RT}} \qquad \text{(D-13)}$$

where:

d = grain diameter

w = percent moisture by weight

T = absolute temperature

R = universal gas constant

$B_0, A, p,$
a_1, a_2, Q_c = material parameters.

The revised Sjaardema-Krieg creep consolidation model has a total of 17 parameters, which are listed in Table D-7.

Table D-7. Revised Sjaardema-Krieg, Zeuch, and Spiers Creep Consolidation Parameter Values

Parameter	Units	Modified Material Models			Reference Values
		Sjaardema-Krieg	Zeuch	Spiers	
η_0	$MPa^{1-\eta_2}$	-1.437	-42.33	$-2.91(10^{-6})$	—
η_1	—	2.594	2.740	0.108	—
η_2	—	3.623	3.049	5.523	—
m_1	—	0.731	0.605	0.174	—
σ_{r_1}	MPa	3.535	18.33	0.019	—
D_t	—	0.867	0.888	0.881	—
a_1	—	17.00	20.10	71.10	—
a_2	—	47.50	96.60	0.626	—
Q_c/R	K	$4.01(10^3)$	$9.26(10^{-17})$	$1.8(10^2)$	—
p	—	0.564	0.396	$3.22(10^{-5})$	—
B_0	$kg \cdot m^{p-3}/(MPa \cdot s)$	$6.459(10^7)$			—
A	m^3/kg	$-1.307(10^{-2})$			$-1.72(10^{-2})$
b_2	—		4.469		1/3
b_3	—		5.722		1/2
b_7	$m^p/(MPa \cdot s)$		$6.54(10^{-14})$		—
b_8	$m^p/(MPa \cdot s)$		$9.05(10^{-19})$		—
n	—		9.991		4.9
r_1	$m^p/(MPa \cdot s)$			$1.02(10^{-7})$	—
r_3	—			9.770	1/3
r_4	—			0.806	2
n	—			3.190	4.15

The third model used for the creep consolidation is the Zeuch model, which is based on the kinetics of isostatic pressing. Similar to the revised Sjaardema-Krieg model, the Zeuch model was modified to account for a more general formulation. The Zeuch model is divided into two stages, depending on the fractional density. The kinetic equation describing the modified Zeuch model is:

For Stage 1 ($D_0 \le D \le 0.9$):

$$\dot{\varepsilon}^c_{eq} = \frac{\rho_0 b_7}{\rho\, d^p} D_0^{b_2} D^{2(b_2-n)-1} \left(\frac{D-D_0}{1-D_0}\right)^{b_3-n} \left[1 + a_1(1-e^{-a_2 w})\right] \exp\left(-\frac{Q_c}{RT}\right) \qquad \text{(D-14)}$$

For Stage 2 ($0.9 < D \leq 1$):

$$\dot{\varepsilon}^{c}_{eq} = \frac{\rho_0 b_8}{\rho\, d^p} \frac{(1-D)}{\left\{1-(1-D)^{1/n}\right\}^n} \left[1 + a_1(1-e^{-a_2 w})\right] \exp\left(e - \frac{Q_c}{RT}\right) \tag{D-15}$$

where $D = D_0/(1+\varepsilon_v)$ and b_2, b_3, b_7, b_8, n, a_1, a_2, and Q_c are model parameters (Table D-7).

The fourth model was developed by Spiers and coworkers based on pressure solutioning as the consolidation mechanism. The Spiers model was also modified to account for a more general formulation and an updated database by Callahan et al. (1996). The modified Spiers model is:

$$\dot{\varepsilon}^{c}_{eq} = \frac{r_1}{d^p}\left[1 + a_1(1-e^{-a_2 w})\right] e^{\frac{-Q_c}{RT}} \left(\frac{(1+\varepsilon_v)^{r_2}}{|\varepsilon_v|^{r_3}}\right) \Gamma \tag{D-16}$$

where:

$$\Gamma = \begin{cases} 1 & \text{small strain } (\varepsilon_v > -15\%) \\ \left[\dfrac{\varepsilon_v + \phi_0}{\phi_0(\varepsilon_v + 1)}\right]^n & \text{large strain } (\varepsilon_v < -15\%) \end{cases} \tag{D-17}$$

and ϕ_0 is the initial porosity and r_1, r_2, r_3, n, a_1, a_2, p, and Q_c are material parameters (Table D-7).

D3.1.3 Compacted Clay

The clay used in the WIPP shaft seal design is assumed to behave according to a nonlinear elastic model. The form of this model is identical to the nonlinear elastic portion of the crushed-salt model, in which the bulk and shear moduli are expressed as exponential functions of the current density:

$$\begin{aligned} K &= K_0 e^{K_1 \rho} \\ G &= G_0 e^{G_1 \rho} \end{aligned} \tag{D-18}$$

The parameters for the volumetric (bulk) behavior of clay are based on consolidation data reported in Lambe and Whitman (1969). These parameters are listed in Table D-8. The intact shear modulus (G_f) was calculated from the bulk modulus, assuming a Poisson's ratio of 0.25.

D3.1.4 Asphalt

Thermal properties of solidified asphalt are given in Table D-9. These properties are taken from the literature (Yoder and Witczak, 1975). Asphalt was assumed to behave elastically. The elastic (primarily bulk) response of the asphalt is considered most important to seal application. Because the asphalt is emplaced in a confined volume and the expected stresses that develop (as a result of creep of the surrounding salt and weight of the overlying seal materials) are compressive in nature, the volumetric behavior of the material is important to characterize.

The shear and time-dependent behavior of the asphalt are secondary effects. Young's modulus and Poisson's ratio of asphalt are listed in Table D-10. These properties are taken from Yoder and Witczak (1975) and are highly sensitive to temperature. The values shown in Table D-10 are representative of the WIPP repository horizon temperature of 27°C. Asphalt stiffness is assumed to be zero before it solidifies; i.e., it behaves as a fluid.

Although it is recognized that the behavior of asphalt is certainly time-dependent, the creep effects of this material were not considered in this modeling effort. As noted above, the predominant structural behavior of the seals is highly dependent on the behavior of surrounding materials, primarily creep of surrounding salt. Elastic behavior is assumed to be the predominant behavior because the asphalt is confined and will be volumetrically compressed. Because of confinement, there is little opportunity for creep flow of asphalt. In addition, the primary mechanism for creep (shear stress) of the asphalt is not expected to occur.

Table D-8. Nonlinear Elastic Material Parameters for Compacted Clay

Parameter (Equation D-18)	**Units**	**Value**
K_0	MPa	$2.26(10^{-6})$
K_1	m^3/kg	0.0096
G_0	MPa	$1.36(10^{-8})$
G_1	m^3/kg	0.0096
K_f	MPa	20,824
G_f	MPa	12,494
ρ_f	kg/m^3	2,390

Table D-9. Asphalt Thermal Properties

Property	**Units**	**Value**
Thermal Conductivity	W/m-K	1.45
Specific Heat	J/kg-K	712
Density	kg/m^3	2000

Table D-10. Asphalt Elastic Properties

Property	**Units**	**Value**
Young's Modulus	MPa	3034
Poisson's Ratio	—	0.35

D3.2 In Situ Materials

The in situ materials include Salado salt, Salado interbeds (anhydrite and polyhalite), and rock types encountered in the near-surface and Rustler Formations. Thermal, deformational, and strength characteristics of these materials required for structural analyses are given in the following subsections.

D3.2.1 Salado Salt

Thermal Properties. Thermal properties of Salado salt are given in Table D-11. These values are reported by Krieg (1984). Thermal conductivity of Salado salt is temperature dependent, expressed mathematically as:

$$k(T) = k_{300}(300/T)^{\lambda} \tag{D-19}$$

where:

$k(T)$	= thermal conductivity of salt as a function of temperature
T	= temperature (K)
k_{300}	= thermal conduetivity at reference temperature (T = 300 K) = 5.0 W/m-K
λ	= exponent describing temperature dependence = 1.14.

Table D-11. Salado Salt Thermal Properties

Property	Units	Value
Thermal Conductivity	W/m-K	(Equation D-19)
Specific Heat	J/kg • K	971
Density	kg/m^3	2160

Deformational Characteristics. Intact salt was assumed to be argillaceous salt that is governed by the Multimechanism Deformation Coupled Fracture (MDCF) model (Chan et al., 1995a). This model is an extension of the well-documented Munson-Dawson (M-D) creep model (Munson et al., 1989) to include a calculation of damage. The evolutionary equations for the MDCF model are:

$$\dot{\varepsilon}_{ij}^{i} = \dot{\varepsilon}_{ij}^{c} + \dot{\varepsilon}_{ij}^{d} + \dot{\varepsilon}_{ij}^{h} \tag{D-20}$$

The first inelastic strain rate represents climb-controlled creep, which is described by the following kinetic equation:

$$\dot{\varepsilon}_{ij}^{c} = \dot{\varepsilon}_{eq}^{c} \frac{\partial \sigma_{eq}^{c}}{\partial \sigma_{ij}} \tag{D-21}$$

where σ_{eq}^{c} and $\dot{\varepsilon}_{eq}^{c}$ are power-conjugate equivalent stress measure and equivalent inelastic strain rate for the climb-controlled creep deformation mechanisms, respectively. The second inelastic

strain rate represents damage accumulation in the model. Two kinetic equations describe the damage model, one for shear-induced damage and one for cleavage fracture. These kinetic equations are additive to give the total inelastic damage strain rate as follows:

$$\dot{\varepsilon}_{ij}^{d} = \dot{\varepsilon}_{eq}^{\omega_s} \frac{\partial \sigma_{eq}^{\omega_s}}{\partial \sigma_{ij}} + \dot{\varepsilon}_{eq}^{\omega_t} \frac{\partial \sigma_{eq}^{\omega_t}}{\partial \sigma_{ij}} \tag{D-22}$$

where $\left\{\sigma_{eq}^{\omega_s} \text{ and } \sigma_{eq}^{\omega_t}\right\}$ and $\left\{\dot{\varepsilon}_{eq}^{\omega_s} \text{ and } \dot{\varepsilon}_{eq}^{\omega_t}\right\}$ are power-conjugate equivalent stress measures and equivalent inelastic strain rates for the damage mechanisms, respectively. The third inelastic strain rate represents healing in the model. For calculations performed in support of the shaft seal design, healing was not operative, i.e., $\dot{\varepsilon}_{ij}^{h} = 0$.

Climb-Controlled Creep

The equivalent inelastic strain rate is assumed to consist of a multiplicative transient function on the steady-state creep rate, viz.:

$$\dot{\varepsilon}_{eq}^{c} = F\dot{\varepsilon}_{s} \tag{D-23}$$

The steady-state strain rate consists of three mechanisms that describe dislocation climb, an undefined mechanism, and dislocation glide.

$$\dot{\varepsilon}_{s} = \sum_{i=1}^{3} \dot{\varepsilon}_{s_i} \tag{D-24}$$

$$\dot{\varepsilon}_{s_1} = A_1 \left(\frac{\sigma_{eq}^{c}}{(1-\omega)\mu} \right)^{n_1} \exp\left(-\frac{Q_1}{RT} \right) \tag{D-25}$$

$$\dot{\varepsilon}_{s_2} = A_2 \left(\frac{\sigma_{eq}^{c}}{(1-\omega)\mu} \right)^{n_2} \exp\left(-\frac{Q_2}{RT} \right) \tag{D-26}$$

$$\dot{\varepsilon}_{s_3} = \left[B_1 \exp\left(-\frac{Q_1}{RT} \right) + B_2 \exp\left(-\frac{Q_2}{RT} \right) \right] \times \sinh\left[q \frac{\left(\frac{\sigma_{eq}^{c}}{(1-\omega)} - \sigma_0 \right)}{\mu} \right] H\left(\frac{\sigma_{eq}^{c}}{(1-\omega)} - \sigma_0 \right) \tag{D-27}$$

The transient function, F, describes work-hardening, equilibrium, and recovery branches:

$$F = \begin{cases} \exp\left[\Delta\left(1-\dfrac{\zeta}{\varepsilon_t^*}\right)^2\right] & \zeta < \varepsilon_t^* \\ 1 & \zeta = \varepsilon_t^* \\ \exp\left[-\delta\left(1-\dfrac{\zeta}{\varepsilon_t^*}\right)^2\right] & \zeta > \varepsilon_t^* \end{cases} \tag{D-28}$$

with an internal variable, ξ, described in terms of an evolutionary equation as:

$$\dot{\zeta} = (F-1)\dot{\varepsilon}_s \tag{D-29}$$

and the transient strain limit is defined by:

$$\varepsilon_t^* = K_0 \exp(cT)\left(\frac{\sigma_{eq}^c}{(1-\omega)\mu}\right)^m \tag{D-30}$$

with the hardening parameter, Δ, given by:

$$\Delta = \alpha + \beta \log\left(\frac{\sigma_{eq}^c}{(1-\omega)\mu}\right) \tag{D-31}$$

where:

R	= universal gas constant
μ	= normalizing parameter
q	= activation volume
σ_0	= stress limit of dislocation slip mechanism
$A_1, A_2, B_1, B_2, n_1, n_2, Q_1, Q_2, q, K_0, c, m, \alpha, \beta, \delta$	= experimental constants
H(.)	= Heaviside step function.

The maximum shear stress (Tresca) is chosen as the conjugate stress measure for climb-controlled creep:

$$\sigma_{eq}^c = 2\sqrt{J_2}\psi \tag{D-32}$$

where:

$$J_2 = \frac{1}{2} s_{ij} s_{ji}$$

$$s_{ij} = \sigma_{ij} - \sigma_m \delta_{ij}$$

$$\sigma_m = \frac{\sigma_{kk}}{3}, \text{ mean stress}$$

$$\delta_{ij} = \text{Kronecker delta}$$

$$\Psi = \frac{1}{3}\sin^{-1}\left[\frac{-3\sqrt{3}J_3}{2J_2^{3/2}}\right] \left(-\frac{\pi}{6} \le \Psi \le \frac{\pi}{6}\right) \tag{D-33}$$

$$J_3 = \frac{1}{3} s_{ij} s_{jk} s_{ki}$$

Damage Induced Flow

The damage strain rate in Equation D-22 is examined next with the two terms representing shear-induced damage and tension-induced damage considered separately (Chan et al., 1992; Chan, 1994a, 1994b; Chan et al., 1995b):

$$\dot{\varepsilon}_{ij}^{\omega_s} = \dot{\varepsilon}_{eq}^{\omega_s} \frac{\partial \sigma_{eq}^{\omega_s}}{\partial \sigma_{ij}}, \text{ and } \dot{\varepsilon}_{ij}^{\omega_t} = \dot{\varepsilon}_{eq}^{\omega_t} \frac{\partial \sigma_{eq}^{\omega_t}}{\partial \sigma_{ij}} \tag{D-34}$$

The equations describing the shear-induced (s) and tension-induced (t) damage are similar in form. Thus, the subscript i is used to represent s and t. The equivalent inelastic strain rate is given by:

$$\dot{\varepsilon}_{eq}^{\omega_i} = F^{\omega_i} \dot{\varepsilon}_s^{\omega_i} \tag{D-35}$$

with:

$$F^{\omega_s} = F \exp\left[\frac{c_4\left(\sigma_{eq}^{\omega_s} - c_5\right)}{\sigma_0(1-\rho)}\right] \tag{D-36}$$

$$F^{\omega_t} = F \exp\left[\frac{c_4\left(\sigma_{eq}^{\omega_t} - c_5\right)}{\sigma_0(1-\rho)}\right] \tag{D-37}$$

and:

$$\dot{\varepsilon}_s^{\omega_i} = c_1 \omega_0 \exp(c_3 \omega) \left[\sinh\left(\frac{c_2 \sigma_{eq}^{\omega_i} H\left[\sigma_{eq}^{\omega_i}\right]}{[1-\omega][1-\rho]\mu}\right)\right]^{m_3} \tag{D-38}$$

and c_1 is defined by:

$$c_1 = c_0\left[B_1 \exp\left(-\frac{Q_1}{RT}\right) + B_2 \exp\left(-\frac{Q_2}{RT}\right)\right] \tag{D-39}$$

where c_0, c_2, c_3, c_4, c_5, and n_3 are material constants and ω_0 is the initial damage. The power-conjugate equivalent stress measures are given by:

$$\sigma_{eq}^{\omega_s} = |\sigma_1 - \sigma_3| + f_p\, x_2 x_7\, \mathrm{sgn}(I_1 - \sigma_3)\left(\frac{I_1 - \sigma_3}{3x_7\, \mathrm{sgn}(I_1 - \sigma_3)}\right)^{x_6} \tag{D-40}$$

$$\sigma_{eq}^{\omega_t} = x_1 \sigma_1 H(\sigma_1) \tag{D-41}$$

where x_1, x_2, x_6, and x_7 are material constants of the damage model, I_1 is the first stress invariant, and σ_1 and σ_3 are the maximum and minimum principal stresses, respectively, with compression assumed to be negative. The material parameter f_p is related to the impurity content by:

$$f_p = 1 - p_1 \rho \tag{D-42}$$

where ρ is the impurity (clay) content and p_1 is a material parameter, which is analogous to a local stress intensity factor.

The preceding equations include the damage (ω), which is described in terms of an evolutionary equation. The damage evolution equation is taken as:

$$\dot{\omega} = \dot{\omega}_s + \dot{\omega}_t - h(\omega, \sigma_{eq}^{h}) \tag{D-43}$$

where the damage rate components for the shear-induced and tension-induced damage are given by:

$$\dot{\omega}_s = \frac{x_4}{t_0}\omega\left[\ln\left(\frac{1}{\omega}\right)\right]^{\frac{x_4+1}{x_4}}\left[\frac{\sigma_{eq}^{\omega_s} H\left(\sigma_{eq}^{\omega_s}\right)}{(1-\rho)\xi_s}\right]^{x_{3_s}} \tag{D-44}$$

$$\dot{\omega}_t = \frac{x_4}{t_0}\omega\left[\ln\left(\frac{1}{\omega}\right)\right]^{\frac{x_4+1}{x_4}}\left[\frac{\sigma_{eq}^{\omega_t} H\left(\sigma_{eq}^{\omega_t}\right)}{(1-\rho)\xi_t}\right]^{x_{3_t}} \tag{D-45}$$

where x_4, x_{3_s}, x_{3_t}, ξ_s, ξ_t, and t_0 are material constants. The parameter ξ_s may have different values according to the magnitude of the effective shear-induced damage stress; i.e.,:

$$\begin{aligned} \xi_s &= \xi_s^1 \text{ for } \sigma_{eq}^{\omega_s}/(1-\omega) > \sigma_0 \\ \xi_s &= \xi_s^2 \text{ for } \sigma_{eq}^{\omega_s}/(1-\omega) \le \sigma_0 \end{aligned} \tag{D-46}$$

The healing term in Equation D-43, $h(\omega, \sigma_{eq}^{h})$, was assumed to be zero for these calculations.

The shear-induced inelastic damage flow is assumed to be nonassociative. The flow potential power-conjugate stress measure for shear-induced damage is given by (cf. Equation D-42):

$$\sigma_{eq}^{\omega_s} = |\sigma_1 - \sigma_3| + \frac{x_2 x_8}{3}(I_1 - \sigma_3) \tag{D-47}$$

where x_8 is a material constant.

The flow potential power-conjugate stress measure for tension-induced damage is given by:

$$\sigma_{eq}^{\omega_t} = x_1 \sigma_1 H(\sigma_1) \tag{D-48}$$

where x_1 is a material constant.

The Munson-Dawson creep parameter values for argillaceous WIPP salt are listed in Table D-12. The damage parameters are given in Table D-13.

D3.2.2 Salado Anhydrite and Polyhalite

Salado anhydrite and polyhalite interbeds were assumed to behave elastically. Elastic constants for anhydrite and polyhalite are given in Table D-14. These values have been used in previous similar WIPP analyses (Morgan et al., 1987).

DRZ development was assessed using a Drucker-Prager strength criterion. Damage to the interbeds is assumed to occur when the peak material strength of the rock is exceeded. The material strength of brittle rocks can be described by a Drucker-Prager type yield:

$$F = aI_1 + \sqrt{J_2} - C \tag{D-49}$$

where:

I_1	= first invariant of the total stress tensor
J_2	= second invariant of the deviatoric stress tensor
a and C	= material constants.

Values for the Drucker-Prager material constants presented by Morgan et al. (1987) for anhydrite and polyhalite are given in Table D-14. The material is elastic when $F < 0$ and will fracture and dilate if $F \geq 0$. The potential for fracture development can be expressed as a factor of safety given by the ratio of the strength measure to the stress measure. The factor of safety as used in this appendix is based on the following equation:

$$\text{Factor of Safety} = \frac{|aI_1 - C|}{\sqrt{J_2}} \tag{D-50}$$

Table D-12. Munson-Dawson Parameter Values for Argillaceous Salt
(after Munson et al., 1989)

Parameter	Units	Value
Elastic Parameter Values		
E	MPa	31,000
ν	—	0.25
Munson-Dawson Creep Parameter Values		
A_1	yr^{-1} s^{-1}	4.437×10^{30} 1.407×10^{23}
A_2	yr^{-1} s^{-1}	4.144×10^{20} 1.314×10^{13}
Q_1/R Q_1	K cal/mol	12,581 25,000
Q_2/R Q_2	K cal/mol	5032 10,000
n_1	—	5.5
n_2	—	5.0
B_1	yr^{-1} s^{-1}	2.838×10^{14} 8.998×10^{6}
B_2	yr^{-1} s^{-1}	1.353×10^{6} 4.289×10^{-2}
q	—	5.335×10^{3}
σ_0	MPa	20.57
m	—	3
K_0	—	2.47×10^{6}
c	K^{-1}	9.198×10^{-03}
α	—	-14.96
β	—	-7.738
δ	—	0.58

Table D-13. Damage Model Parameters for Argillaceous Salt

Parameter	Units	Value
x_1	—	0.0
x_2	—	9.0
x_3	—	5.5
x_4	—	3.0
x_5	$(\text{MPa})^{x_3-s}$	10^{13}; $\sigma_1 - \sigma_3 > \sigma_0$ 10^{14}; $\sigma_1 - \sigma_3 < \sigma_0$
x_6	—	0.75
x_7	MPa	1
x_8	—	0.1
c_0	—	34.0
c_2	—	850.0
c_3	—	10.0
c_4	—	6.0
n_3	—	3
ω_0	—	10^{-4}
p_1	—	28
ρ_0	—	0.029

Table D-14. Anhydrite and Polyhalite Elastic and Drucker-Prager Parameter Values

Material	*E* (MPa)	ν	*C* (MPa)	a
Anhydrite	75,100	0.35	1.35	0.450
Polyhalite	55,300	0.36	1.42	0.473

D3.2.3 Near Surface and Rustler Formations

Failure of the rock within the near-surface and Rustler formations is assumed to be time independent and can be estimated according to two common failure criteria: Tresca and Coulomb criteria. The Tresca criterion for failure is based strictly on the difference between minimum and maximum principal stresses:

$$\sigma_3 - \sigma_1 \geq C_0 \tag{D-51}$$

where C_0 is uniaxial compressive strength. The von Mises criterion is a modification of the Tresca criterion wherein C_0 is replaced by $2C_0/\sqrt{3}$.

The Coulomb criterion accounts for the beneficial effect of confinement and says failure occurs whenever:

$$\sigma_1 - \sigma_3 \geq C_0 + \sigma_3(\tan\beta - 1)$$
$$\tan\beta = \frac{1+\sin\phi}{1-\sin\phi} \tag{D-52}$$

where ϕ is the angle of internal friction.

Strength parameters of rock types encountered in near-surface and Rustler formations are given in Table D-15.

Table D-15. Rock Types and Properties

Rock Type	Depth (m)	Strength Properties		
		C_0 (MPa)	T_0 (MPa)	ϕ (Deg)
Mudstone	0-165, 223-260	16.8	1	34.4
Anhydrite	165-183, 192-213	92.6	5.72	44.8
Dolomite	183-192, 213-223	107.3	4	41.9

D3.3 Models for the Disturbed Rock Zone within Salt

Two different models were used to evaluate the development and extent of the DRZ within the intact salt. The first approach is based on the ratio between two stress invariants: i.e., $\sqrt{J_2}/I_1$. This criterion has been used to characterize the potential of salt damage or healing in related WIPP studies. The second approach uses the damage stress (σ_{eq}^{ω}) according to the MDCF constitutive model for WIPP salt. These criteria are discussed in the following subsections.

D3.3.1 Stress-Invariant Criterion

The stress-invariant criterion is based on the separation of stress conditions that do or do not cause dilatancy in WIPP salt when plotted in I_1 - $\sqrt{J_2}$ stress space. I_1 is the first invariant of the stress tensor and represents the mean stress. $\sqrt{J_2}$ is the second invariant of the deviatoric stress tensor and represents the shear stress. Taken together, I_1 and $\sqrt{J_2}$ provide a damage factor that indicates the potential for dilatancy and fracture. The functional form of the stress-invariant criterion is:

$$\frac{\sqrt{J_2}}{I_1}\begin{cases}\geq 0.27; \text{damage occurs} \\ < 0.27; \text{remains intact}\end{cases} \tag{D-53}$$

where:

$$\sqrt{J_2} = \sqrt{\frac{1}{6}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]}$$

$$I_1 = \sigma_1+\sigma_2+\sigma_3$$

$$\sigma_1,\sigma_2,\sigma_3 = \text{principal stresses}$$

This criterion is based on experimental evidence of dilation in tested samples of WIPP salt. Other investigators have observed similar stress-invariant criteria for dilatancy in other salts as documented by Van Sambeek et al. (1993b).

D3.3.2 Damage-Stress Criterion

Using the MDCF model (Chan, 1993), the potential level of damage can be evaluated by the power-conjugate equivalent-stress measure (the damage stress, σ_{eq}^{ω}). The damage stress for shear-induced damage is given by Chan (1993):

$$\sigma_{eq}^{\omega} = |\sigma_1-\sigma_3| + (1-p_1\,\rho)\;x_2 x_7\,\mathrm{sgn}(I_1-\sigma_3)\left[\frac{I_1-\sigma_3}{3x_7\,\mathrm{sgn}(I_1-\sigma_3)}\right]^{x_6}. \tag{D-54}$$

The MDCF damage model constants are given in Table D-13 for argillaceous halite.

D3.3.3 Evaluation of DRZ Models

An evaluation of the stress-invariant (Equation D-53) and damage-stress (Equation D-54) models was performed using the air intake shaft (AIS) permeability testing results reported in Section 3.5 of Appendix C. In this testing, permeability was measured as a function of radius into the surrounding intact salt at two depths (346 m and 626 m) within the Salado Formation. The results of this testing are shown in Figure C-1 of Appendix C. This figure was used to estimate the range in the radial extent of the DRZ. The minimum and maximum normalized DRZ radii at the two depths are given in Table D-16. The term "normalized DRZ radius" is defined as the radial extent of the DRZ into the Salado Formation divided by the AIS shaft radius.

Table D-16. Normalized DRZ Radius Surrounding the AIS

Depth (m)	Minimum	Maximum
346	1.31	1.77
626	1.45	1.92

An estimation of the state of stress surrounding the AIS can be made using the steady-state analytical solution for a circular opening in an infinite domain that has an initial lithostatic stress state (Van Sambeek, 1986). The material is assumed to be governed by a simple Norton creep law and a von Mises flow rule. The solution is given in terms of the radial (σ_{rr}) tangential ($\sigma_{\theta\theta}$), and axial (σ_{zz}) stresses as:

$$\begin{aligned}
\sigma_1 = \sigma_{rr} &= P_0\left[(a/r)^{2/n} - 1\right] \\
\sigma_3 = \sigma_{\theta\theta} &= P_0\left[(1-2/n)(a/r)^{2/n} - 1\right] \\
\sigma_2 = \sigma_{zz} &= (\sigma_{rr} + \sigma_{\theta\theta})/2 \\
&= P_0(a/r)^{2/n}\left[(1-1/n) - 1\right]
\end{aligned} \tag{D-55}$$

where:

$\sigma_1, \sigma_2, \sigma_3$	= maximum, intermediate, and minimum principal stresses, respectively
a	= radius of AIS = 3.05 [m]
r	= arbitrary raduis (note: $r \geq a$)
P_0	= magnitude of preesixting stress in surrounding salt = 5.8+0.0225 (d-250) [MPa]
d	= depth [m]
n	= exponent of effective stress in Norton creep law = 5.0 (steady-state, time = ∞) = 1.0 (elastic, time = 0).

The normalized DRZ radius (r/a) was calculated as a function of depth by substituting Equation D-55 into Equation D-53 (stress-invariant model) and Equation D-54 (damage-stress model). The results of these calculations are shown in Figure D-2. Superposed on this figure are the AIS field test results (Table D-16). The following conclusions can be made regarding this calculation:

- The stress-invariant model (Equation D-53) substantially underpredicts the measured DRZ.
- The damage-stress model (Equation D-54) provides a conservative estimate (overprediction) of the measured DRZ.

Based on the results of this simple exercise, the damage-stress model was used to estimate the behavior of the DRZ in all subsequent structural calculations.

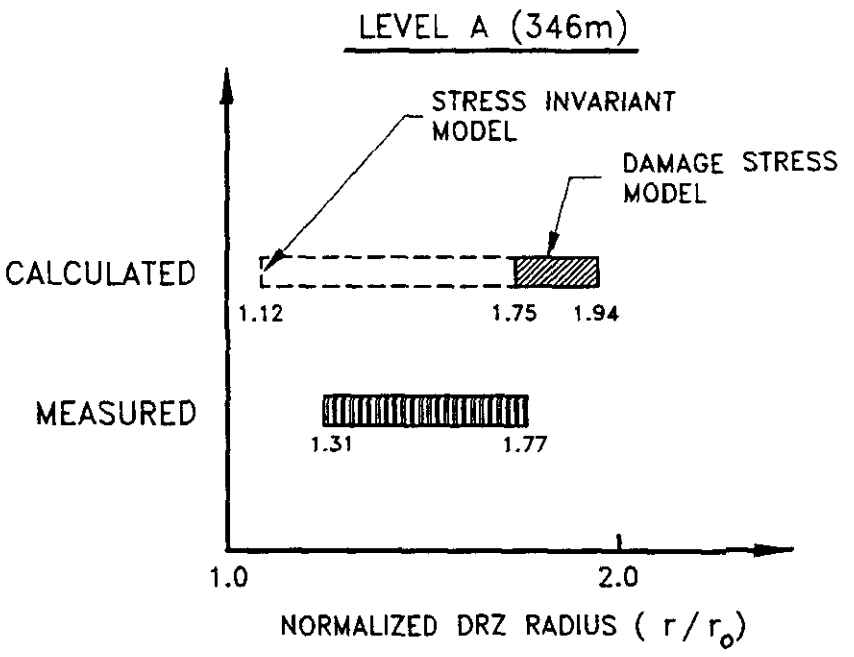

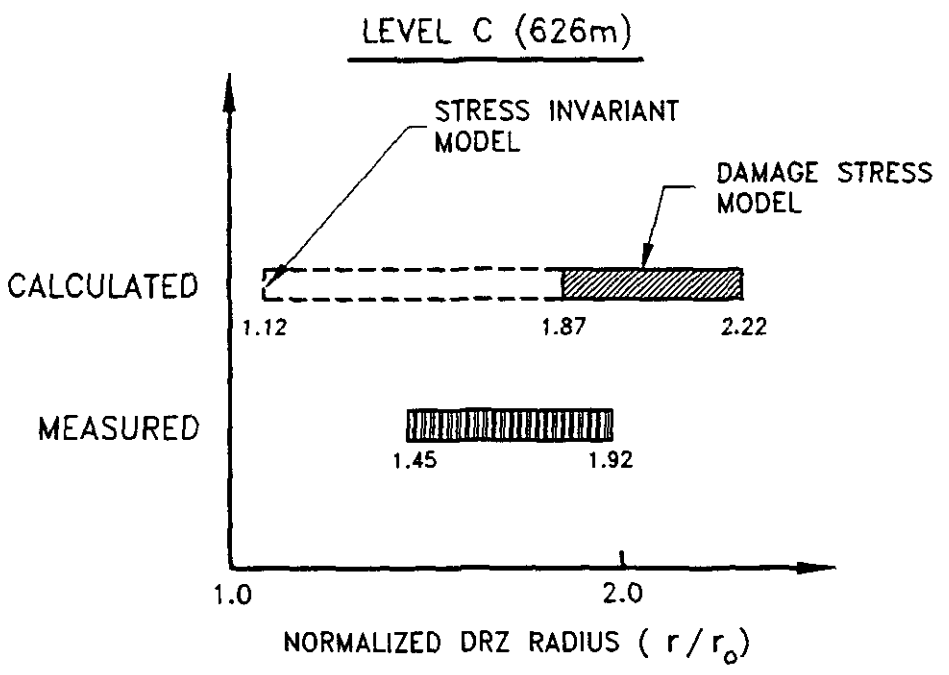

Figure D-2. Comparison of calculated results using damage-stress and stress-invariant DRZ models with measured AIS results.

D4. SHAFT SEAL COMPONENT ANALYSES

D4.1 Salado Mass Concrete Seals

D4.1.1 Thermal Analysis of Concrete Seals

Objective

The objective of this calculation was to determine the expected temperatures within (and surrounding) an SMC emplacement attributable to its heat of hydration.

Problem Description

An axisymmetric representation of the SMC seal, the open shaft, and the surrounding Salado salt is shown in Figure D-3. The left vertical boundary is the centerline of the shaft and is a line of symmetry. The lower horizontal boundary is a plane of symmetry located at the midheight of the SMC seal. The upper horizontal and right vertical boundaries are beyond the thermal influence of the heat-generating SMC seal throughout the simulation period of 1 year. The modeled height of the SMC seal was 6.08 m (20 ft). The radius of the shaft was modeled as 3.04 m. A simulation period of 1 year was determined to be of sufficient duration for the SMC and Salado salt temperatures to reach maximums.

Assumptions

- The SMC seal is placed instantaneously at time = 0 year and generates heat in accordance with Equation D-2.
- The initial temperature of the surrounding salt is 27°C.
- The variations in stratigraphy within the Salado Formation are ignored in this calculation. The in situ material surrounding the shaft was assumed to be entirely Salado salt.
- The seal and shaft are thermally isolated from other seals and other shafts; i.e., the domain surrounding the seal is assumed to be infinite in extent.

Results

Calculated temperatures from this analysis are shown in Figures D-4 and D-5. Figure D-4 shows that locations in the SMC increase in temperature from ambient (27°C) to a maximum of 53°C at 0.02 year after SMC placement. The maximum temperature in the surrounding salt is 38°C at approximately the same time. Figure D-5 shows isotherms within and surrounding the seal at 0.02 year. The thermal gradient within the concrete is approximately 1.5°C/m. This figure also shows that at a radial distance of 2.0 m into the surrounding salt, the temperature rise is less than 1°C.

D4.1.2 Structural Analysis of Concrete Seals

Objective

The objective of this calculation was to determine stresses within the concrete seals resulting from creep of the surrounding salt and the weight of the overlying seal material.

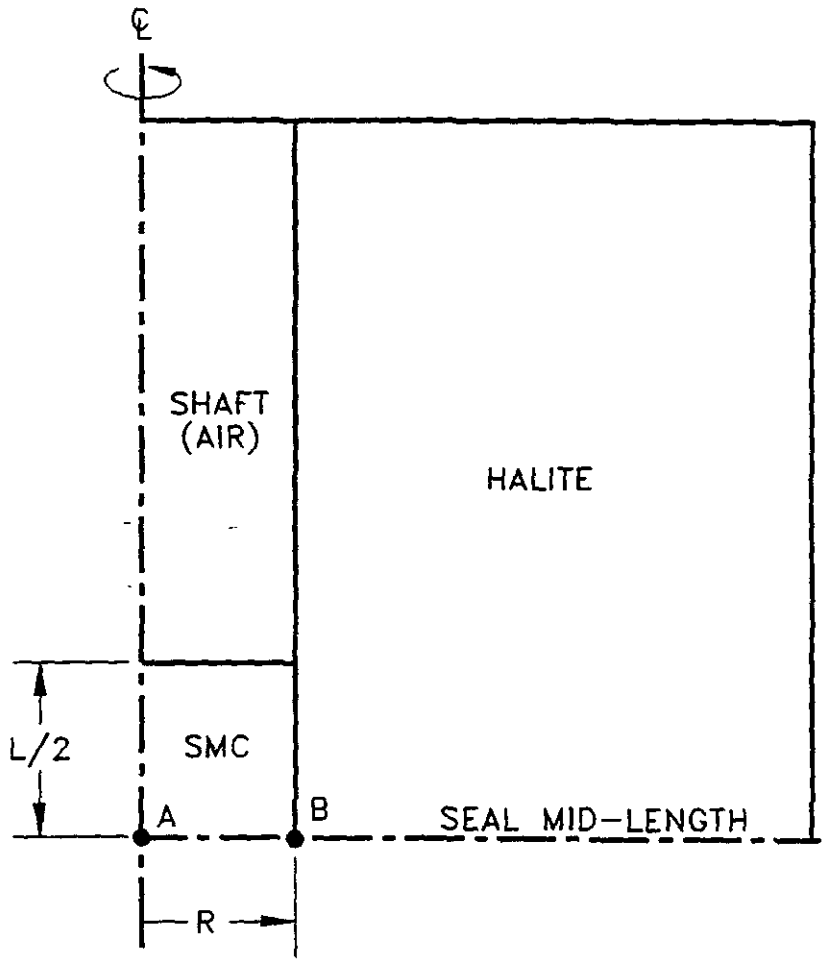

POINT A = SMC Midpoint
POINT B = SMC/Salt Interface
L = Seal Length (20 ft)
R = Shaft Radius = (10 ft)

Figure D-3. Axisymmetric model used in the SMC thermal analysis.

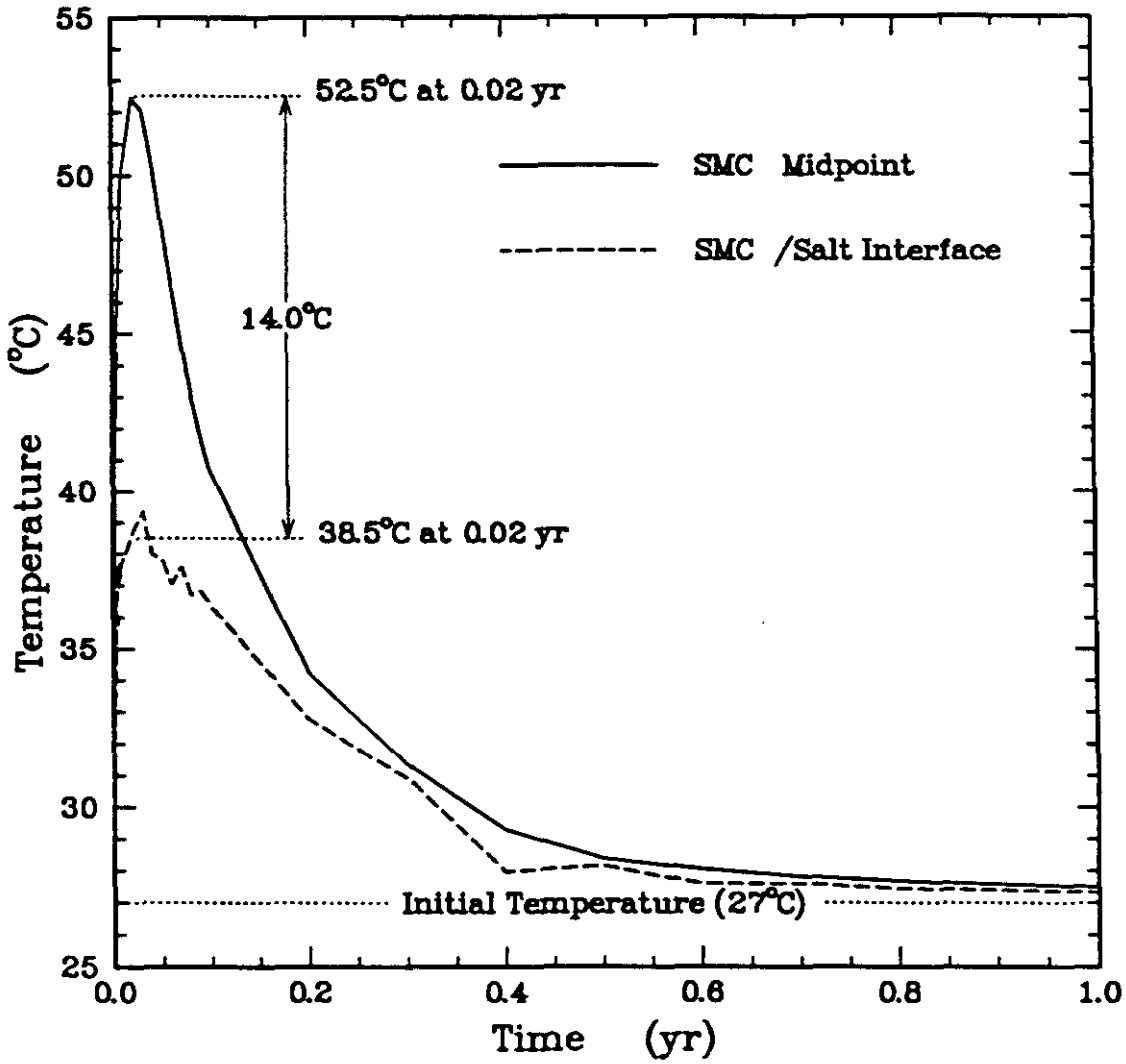

Figure D-4. Temperature histories of SMC center and SMC/salt interface.

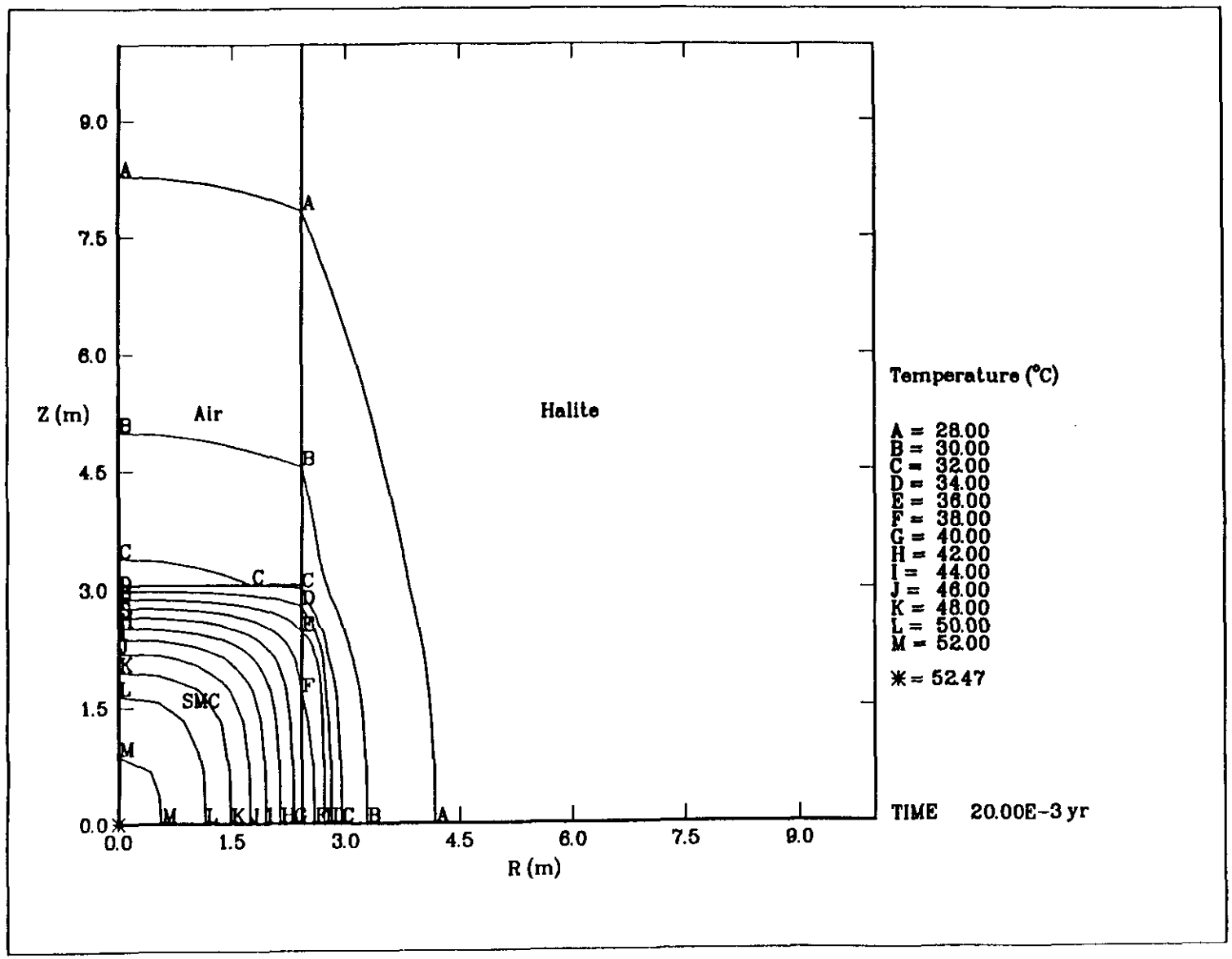

Figure D-5. Isotherms surrounding SMC seal at 0.02 year.

Problem Description

The concrete seal components in the shaft seal were modeled using the Air Intake Shaft (AIS) geometry (see Figure D-6). The bottoms of the concrete components are located in good quality halite at depths of 308 m, 429 m, and 616 m for the upper, middle, and lower concrete seals, respectively. Each of the three concrete components was analyzed independently.

As shown in Figures D-7 through D-9, sealing of the shaft and installation of seal system components were simulated from bottom to top of the modeled region in arbitrary increments of 0.1 year for each stage. The response of the seal components and extent of the DRZ were simulated to 100 years. The following marker beds (MBs) were included in the calculation model: MB101, MB103, MB115, MB116, MB117, MB134, MB136, and the Vaca Triste.

Assumptions

- Axisymmetric conditions are applicable, and a condition of axially restrained displacements exists with respect to the vertical direction at a moderate distance from the seal system.
- The shaft is instantaneously excavated at time $t = 0$. Excavations for the concrete seal wings and waterstop occur instantaneously at time $t = 50$ years.
- Each seal emplacement operation occurs instantaneously.
- The shaft has a uniform initial diameter of 6.1 m.
- The shaft is sufficiently isolated from other excavations that the response of the shaft is unaffected by other underground workings at the WIPP.
- Anhydrite, siltstone, and polyhalite beds exhibit elastic behavior only. Marker beds MB104, MB105, MB118, and MB137 were not modeled in this study because these relatively thin members are not structurally important and would not significantly affect the results.
- Beds comprised predominately of halite are assumed to be argillaceous salt, as defined by the MDCF model, with a clay content of 2.9%.
- Elastic properties of all materials are independent of temperature within the range of interest.
- Inelastic behavior, such as creep, yielding, or cracking, was not modeled for concrete.
- Tension-induced creep damage of salt is ignored.
- Damage stress can be used to indicate if a region within the salt is accumulating damage or healing.
- Initial temperature and stress conditions are listed in Table D-17.

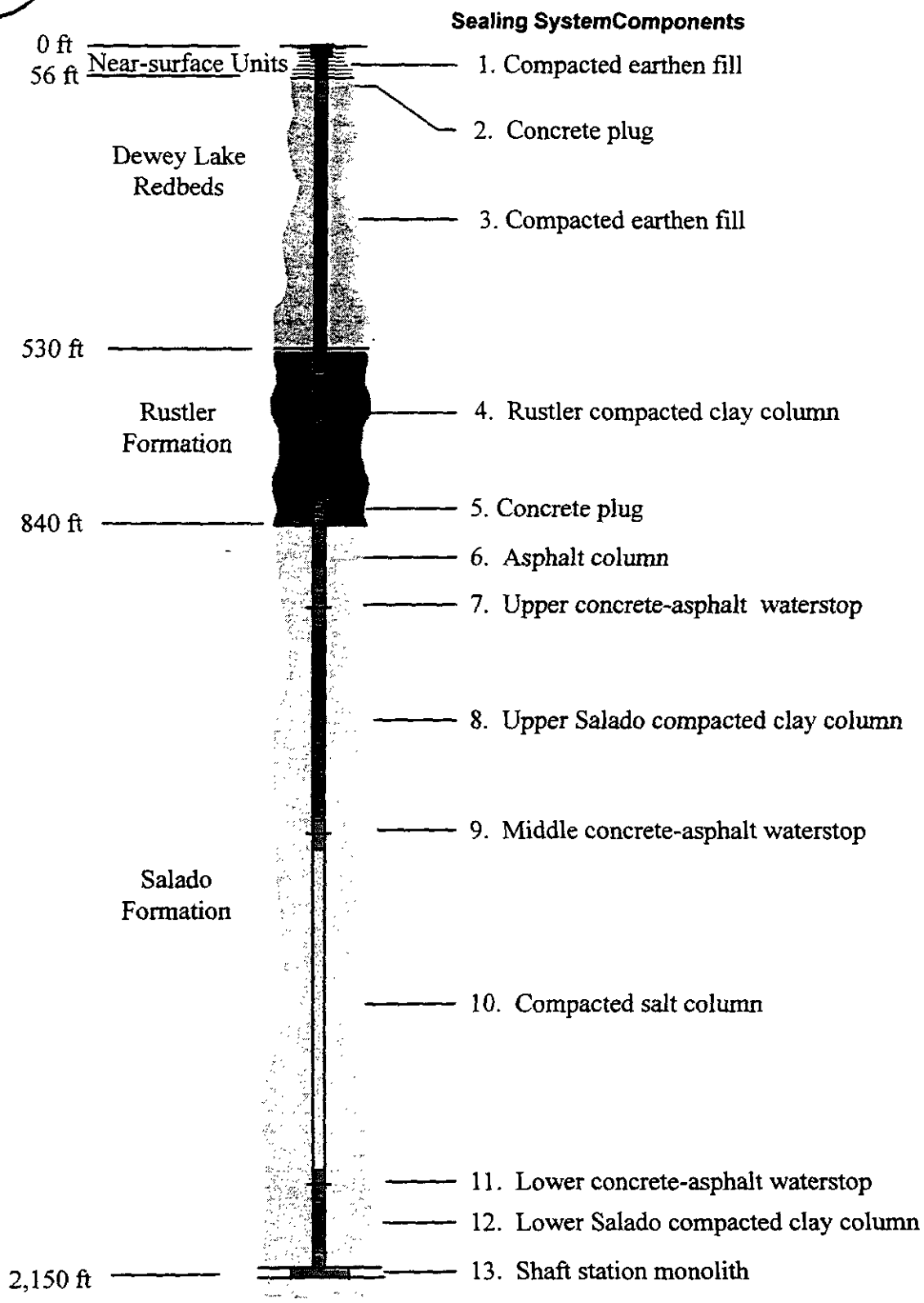

Figure D-6. Seal system conceptual design for the WIPP Air Intake Shaft (DOE, 1995).

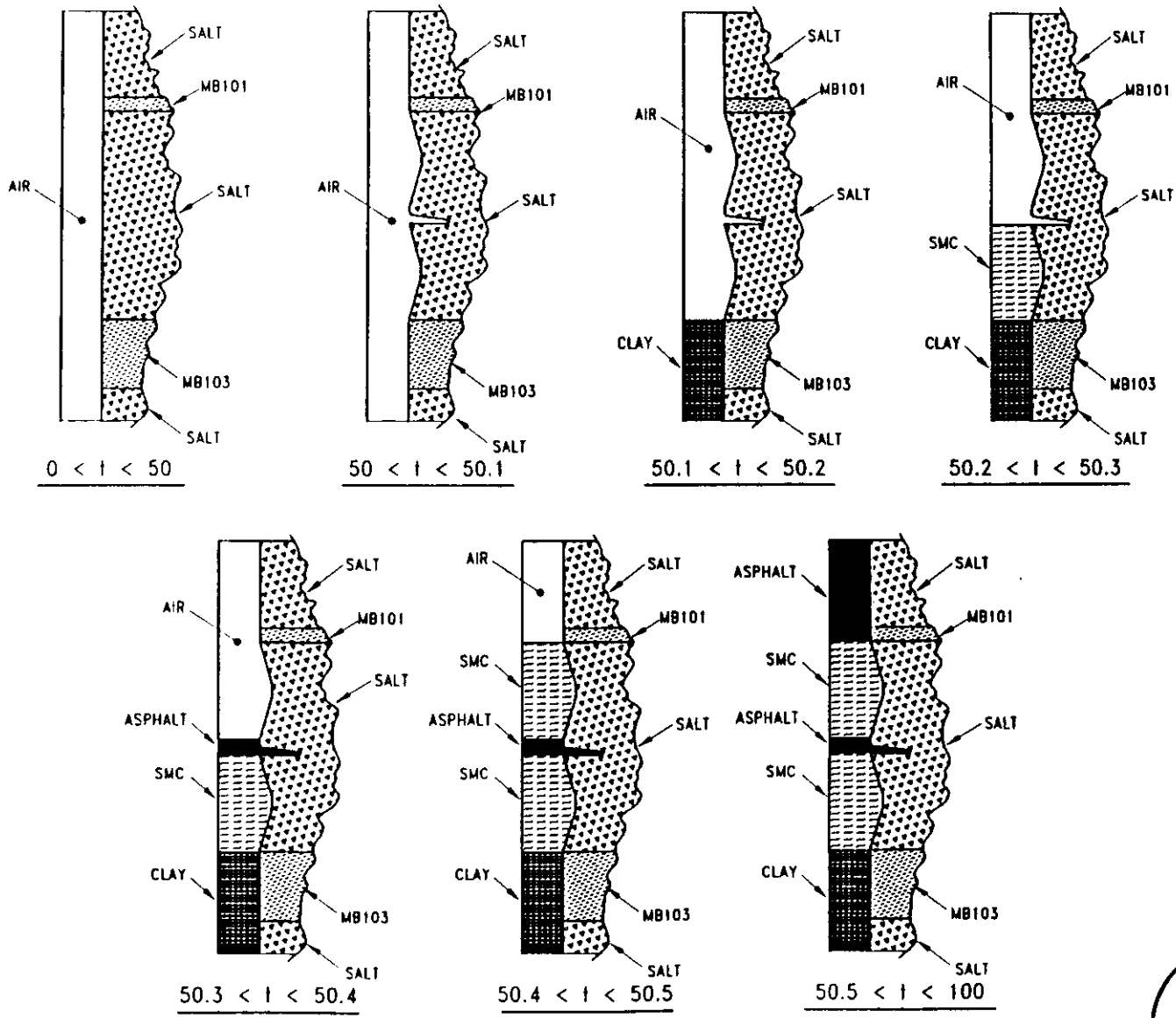

Figure D-7. Axisymmetric model configuration of upper concrete shaft seal.

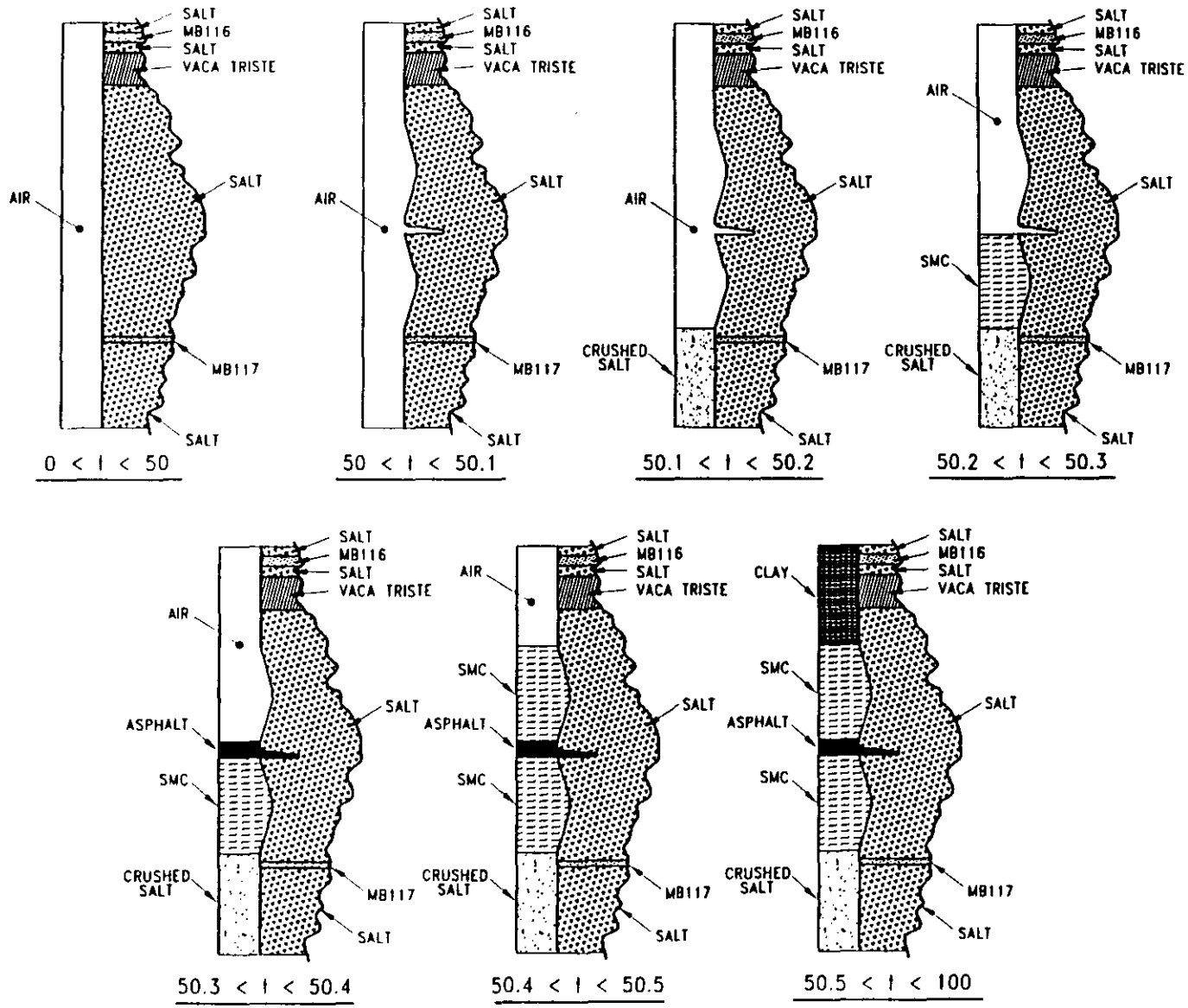

Figure D-8. Axisymmetric model configuration of middle concrete shaft seal.

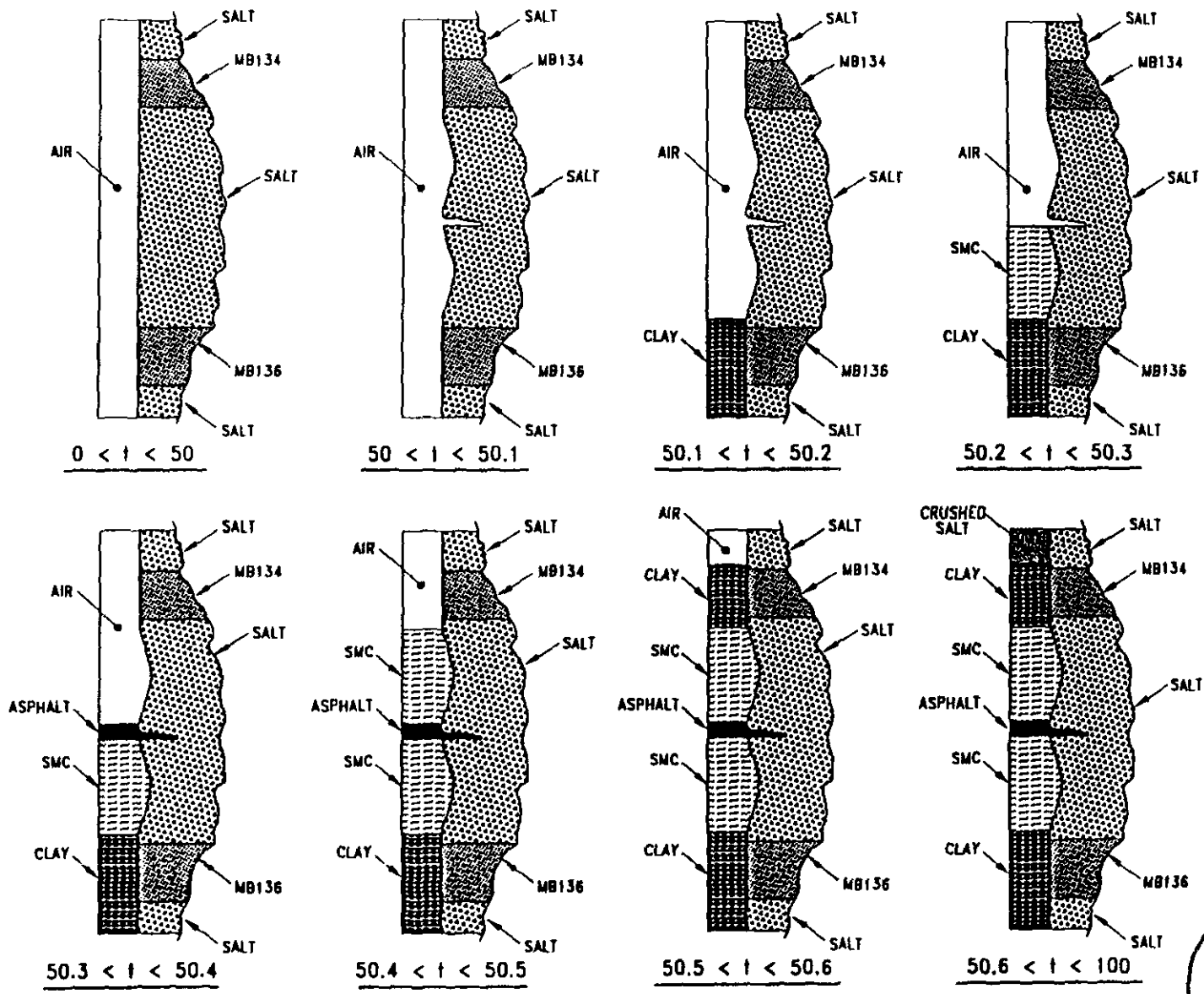

Figure D-9. Axisymmetric model configuration of lower concrete shaft seal.

Table D-17. Initial Temperature and Stress Conditions within Salado Formation

Location Within Salado Formation	Depth (m)	Initial Conditions	
		Temperature[1] (°C)	Stress[2] (MPa)
Upper	301	23.5	6.95
Middle	421	24.7	9.65
Lower	608	26.6	13.86

(1) Based on temperature of 27°C at 650-m depth and a geothermal gradient of 10°C/km (Sass et al., 1971).
(2) Based on in situ stress of 14.8 MPa at 650-m depth and an average overburden density of 2,300 kg/m^3 (Krieg, 1984, p. 14).

Results

Throughout the calculations, the salt surrounding the shaft creeps toward and into the shafts. This creep causes radial loading on the shaft components when the creep is restrained. In turn, the radial loading induces radial stress in the components. In the upper concrete component, the average radial stress increases from zero at time of emplacement ($t = 0$) to 2.5 MPa at $t = 50$ years. Similarly, the radial stress in the middle concrete component ranges from 3.5 to 4.5 MPa and in the lower concrete component the radial stress ranges from 4.5 to 5.5 MPa at $t = 50$ years.

To determine the axial loading on the shaft components, it was assumed that each concrete component must support the weight of the overlying seal material between it and the next concrete component. Using an average vertical stress gradient of 0.02 MPa/m, the calculated vertical stresses on the upper, middle, and lower concrete components from the weight of the overlying seal material are 7.0, 2.4, and 3.8 MPa, respectively. The specified design strength of the concrete material is 31.0 MPa.

D4.1.3 Thermal Stress Analysis of Concrete Seals

Objectives

The objectives of this calculation were (1) to determine the stresses in the concrete as a result of its heat of hydration and (2) to determine the thermal impact on the creep of the surrounding salt.

Problem Description

Compressive stresses develop within the concrete as a result of thermal expansion of the concrete and restrained creep of the surrounding salt. Thermal stresses within the concrete were calculated using the formula:

$$\sigma_T = E\,\alpha\,\Delta T \qquad \text{(D-56)}$$

where:

σ_T = thermal stress (for a fully confined condition)

E = Young's modulus

α = linear coefficient of thermal expansion

ΔT = temperature increase.

Thermal results indicate that the concrete will heat to approximately 53°C at approximately 0.02 year after placement (see Section D4.1.1) from an ambient temperature of 27°C. The surrounding salt heats to a maximum of 38°C at approximately the same time.

Results

The thermoelastic stresses in the concrete were calculated based on a maximum temperature increase of 26°C (Figure D-4) and assuming a fully confined condition. The calculation results indicate that short-term thermal stresses in the concrete are less than 9.2 MPa.

As shown in Figure D-4, the maximum salt temperature will be approximately 38°C at 0.02 year of the emplacement. While it is understood that elevated temperatures do increase the creep rate of salt, the small magnitude and short duration of the thermal pulse in the salt had negligible effect on increasing stresses in concrete through enhanced salt creep.

D4.1.4 Effect of Dynamic Compaction on Concrete Seals

Objective

The objective of this simple calculation was to determine a thickness of seal layer above each of the concrete components to reduce the impact of dynamic compaction.

Problem Description

As shown in Figure D-6, compacted clay and salt columns are included in the shaft seal design directly above the three concrete components. These seal materials may be dynamically compacted as they are emplaced.

The compacted depth (D) was calculated using the equation:

$$D = n\left(WH\right)^{1/2} \tag{D-57}$$

where:

W = tamper weight = 5.14 (metric tons)

H = drop height = 6.1 (m)

n = material coefficient.

This equation is taken from a construction reference manual and is based on a functional fit to field measurements. The material coefficient (n) is given as 0.5 for all soil deposits and was used in the calculation for crushed salt. For clay, this coefficient ranges from 0.35 to 0.40 for decreasing moisture content. A higher value of n results in a larger compactive depth.

Results

Using Equation D-57 and the design inputs, the compacted depths for crushed salt and clay are 9.2 feet and 7.2 feet, respectively. The calculations indicate that the provided thickness for crushed salt (12 ft) and clay (10 ft) are greater than the compacted depth.

D4.1.5 Effect of Clay Swelling Pressures on Concrete Seals

Objectives

The objectives of this analysis were to determine the potential for failing the concrete components as a result of clay swelling pressures and the potential for fracturing the salt where the swelling pressure acts directly on the shaft wall.

Problem Description and Results

In order to fail the concrete seals, the applied swelling pressures must exceed the compressive strength of the concrete (4,500 psi = 31.0 MPa). Test measurements on confined bentonite at a density of 1.8 g/c^3 (Pfeifle and Brodsky, 1991) indicate that the maximum swelling pressures are on the order of 3.5 MPa (Figure D-10). These test results were used to approximate the induced stresses on the concrete seals from clay swelling pressures.

D4.2 Crushed Salt Seal

D4.2.1 Structural Analysis of Crushed Salt Seal

Objective

The objective of this calculation was to determine the fractional density of the crushed salt seal as a function of time and depth within the shaft.

Problem Description

The analysis performed is illustrated schematically in Figure D-11, which also shows the model geometry. The model is an axisymmetric representation of the shaft and host rock at a prescribed depth. For time $t < -50$ years, the shaft is not present and a self-equilibrating initial lithostatic (hydrostatic) stress field exists in the salt such that the three principal stresses are identical. At time $t = -50$ years, the cylindrical shaft is "excavated," and the surrounding salt is allowed to creep for 50 years, i.e., the operational period. At time $t = 0$, crushed salt is compacted in the shaft with an initial density of 1.944 Mg/m^3 (90% of the intact salt density). Salt surrounding the shaft continues to creep inward and consolidates the crushed salt until the crushed-salt seal reaches the intact density of salt. At that time, the model describing crushed salt is changed to the model for intact salt. Crushed salt was modeled using the candidate models discussed in Section D3.1.2. A simulation time of 450 years after emplacement was used, which is sufficient to allow the compacted crushed salt, even at the shallowest depth, to achieve a fractional density greater than 99% of the density of intact salt for each of the three crushed-salt models.

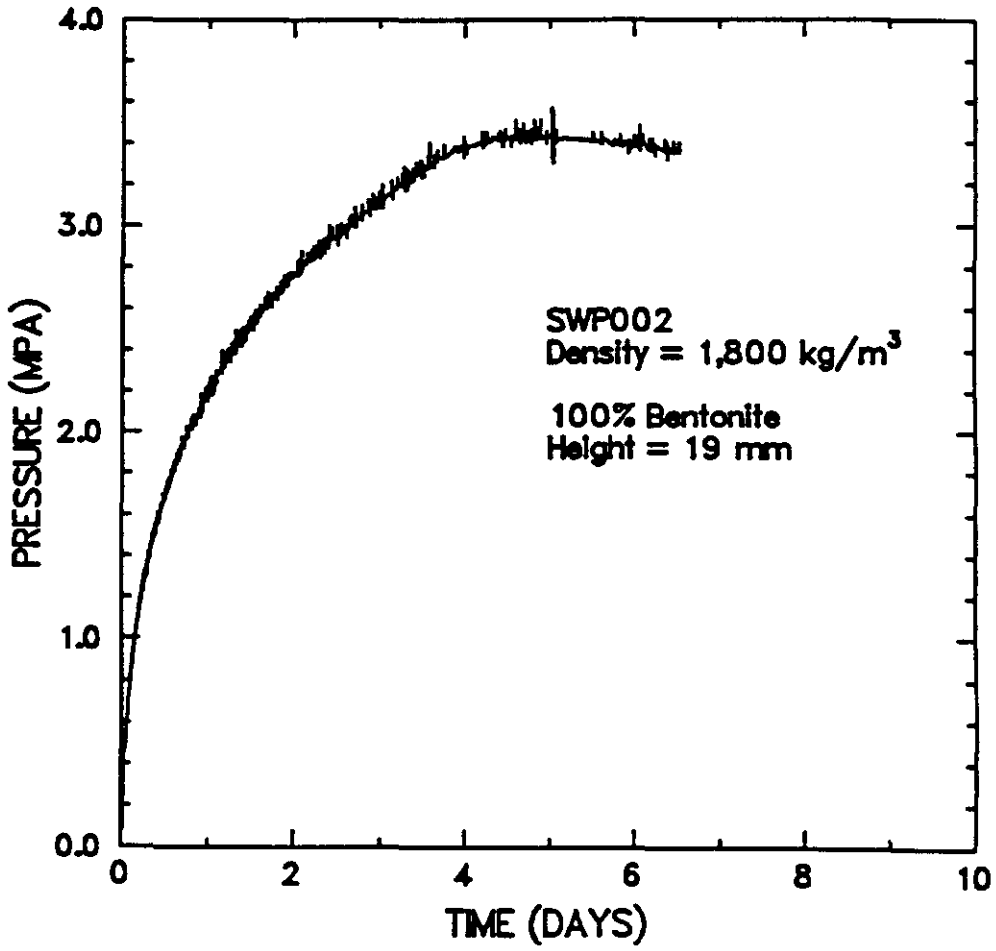

Figure D-10. Swelling pressures as a function of time for a brine-saturated bentonite specimen with a density of 1,800 kg/m^3.

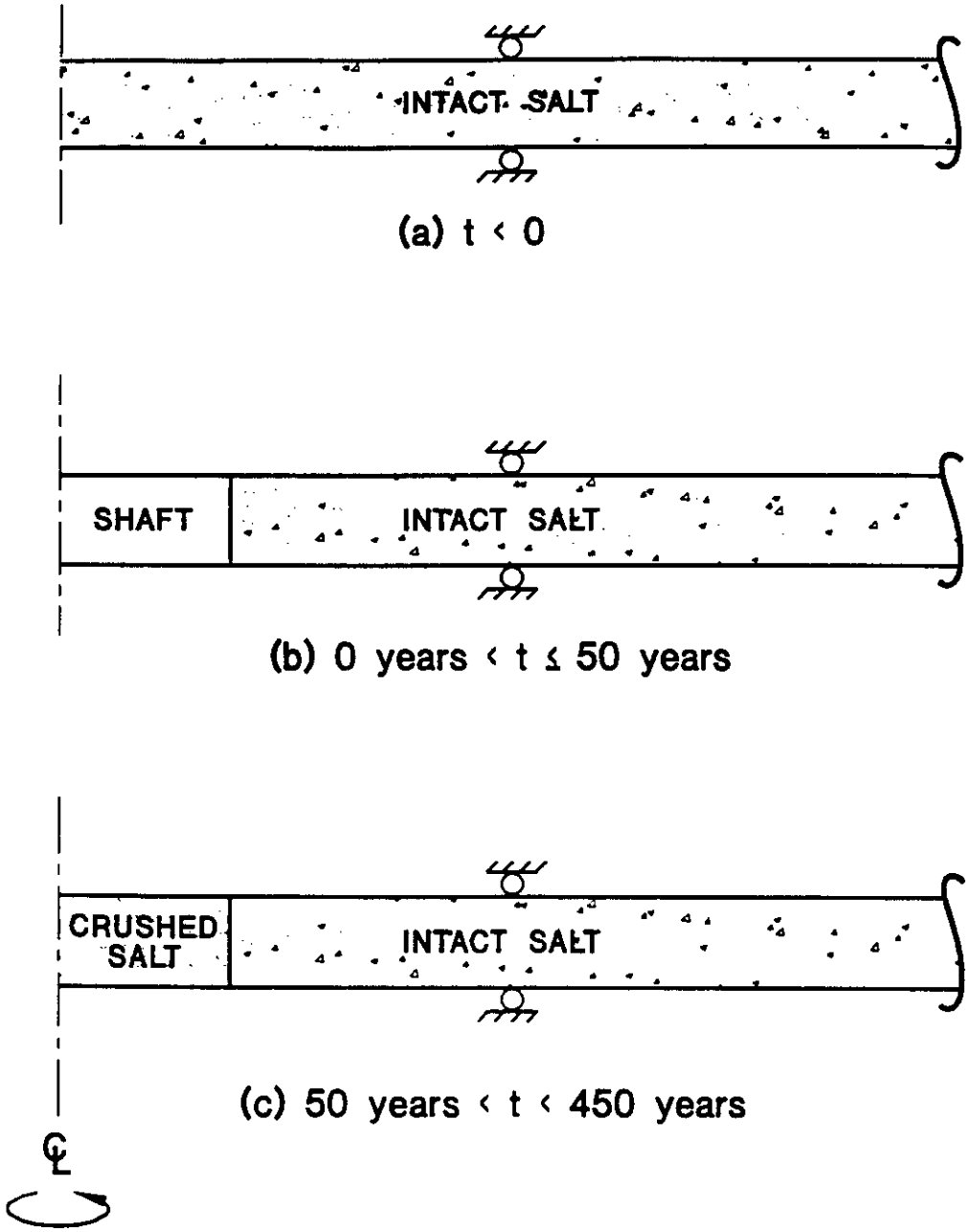

Figure D-11. "Pineapple slice" axisymmetric models.

Assumptions

- Axisymmetric conditions exist around the shaft, and plane-strain conditions are appropriate with respect to the axial (vertical) direction.
- Vertical variations in stratigraphy are ignored. Intact salt is modeled exclusively as argillaceous salt governed by the MDCF model.
- The initial stress state and temperature vary with depth within the Salado Formation as given in Table D-17.
- The modified creep consolidation models of Zeuch, Spiers, and Sjaardema-Krieg were used. These models include the development of mean stresses in the crushed salt and restraint to creep closure.

Results

The fractional densities of crushed-salt seal at the top (depth = 430 m), middle (depth = 515 m), and bottom (depth = 600 m) of the salt column are shown in Figure D-12 as a function of time for the three consolidation models. The models predict essentially the same behavior for fractional densities ranging from 90 to 95%. The times required to achieve a fractional density of 95% are approximately 40, 80, and 120 years at the bottom, middle, and top of the seal, respectively. Only the modified Sjaardema-Krieg creep consolidation model mathematically allows full consolidation. The times required to theoretically reconsolidate the crushed salt to 100% fractional density are 70 years, 140 years, and 325 years at the bottom, middle, and top of the salt column, respectively.

D4.2.2 Effect of Fluid Pressure on the Reconsolidation of Crushed Salt Seals

Objective

The objective of this calculation was to determine the effect of fluid pressure on the reconsolidation of the crushed-salt seal. The results of this calculation were used as input conditions to the fluid-flow analyses described in Appendix C. Because creep of intact salt is an exponential function of stress, fluid pressure applied to the shaft wall would significantly reduce the closure rate of the shaft and, consequently, the reconsolidation rate of the crushed salt.

Problem Description

In this analysis, three models representative of different depths were used. These models are axisymmetric representations of the AIS and the surrounding intact salt. The reconsolidation rate depends on the depth, fluid pressure, time, and creep rate of the surrounding intact salt. Representative models used in this analysis are shown schematically in Figure D-11. The initial stress and temperature conditions were obtained as described in the notes to Table D-17.

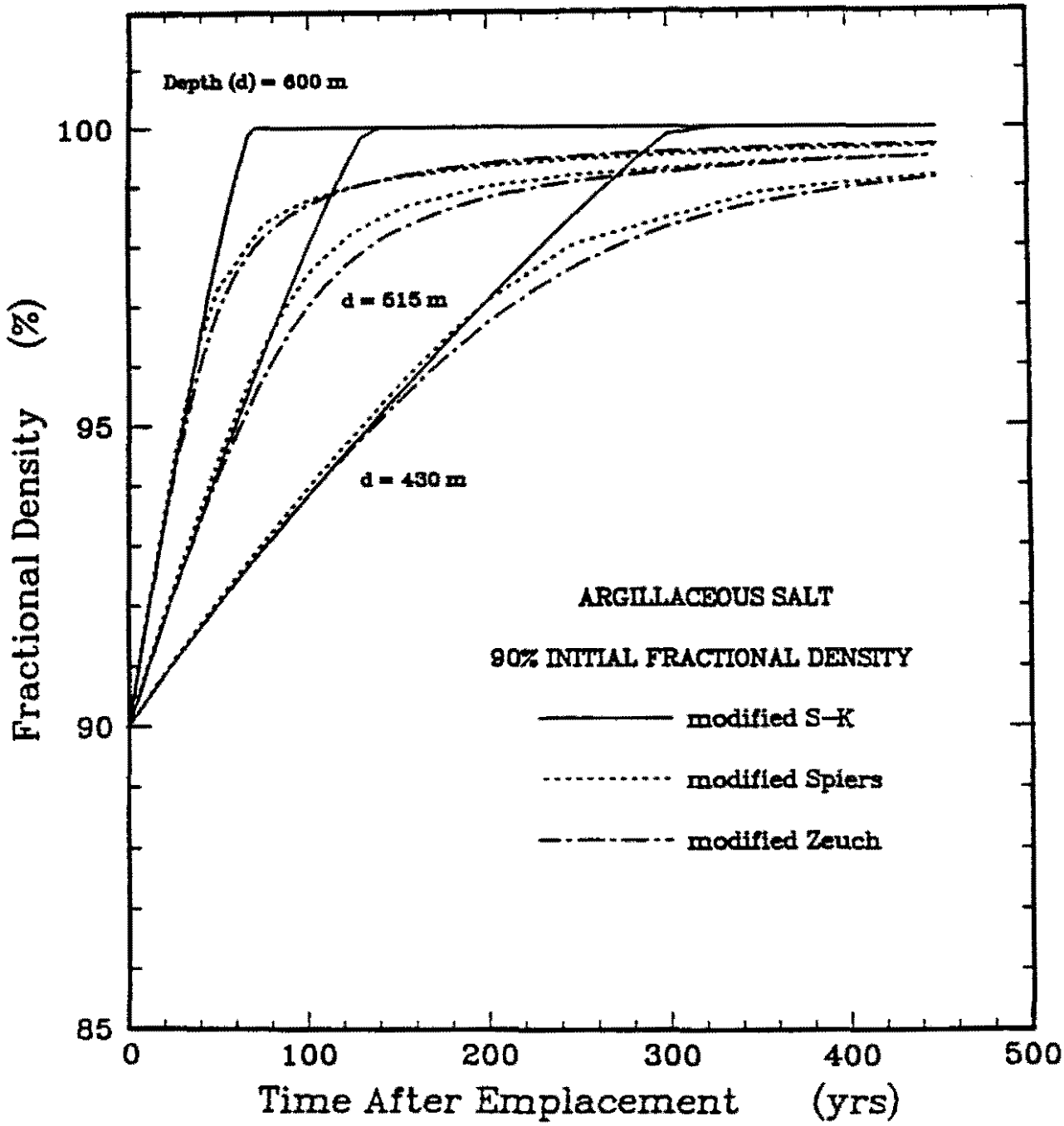

Figure D-12. Consolidation of crushed salt in a shaft at depths of 430, 515, and 600 m using the modified Sjaardema-Krieg, Spiers, and Zeuch models.

Three depths were considered: 430 m, 515 m, and 600 m, which are representative of the top, middle, and bottom of the compacted-salt seal. The fluid in the crushed salt was assumed to behave as a linear elastic material, in which the fluid pressure is related to the volumetric strain through the bulk modulus as:

$$P = MIN\left\{P_0 + K\left(1 - V / V_0\right), P_{\max}\right\} \tag{D-58}$$

where:

P	= fluid pressure
P_0	= initial fluid pressure
K	= fluid bulk modulus
V	= current volume of crushed salt
V_0	= initial volume (based on 90% fractional density)
$P_{\max}$	= maximum fluid pressure.

Maximum fluid pressures ($P_{\max}$) considered are 0, 2, and 4 MPa. These values encompass the allowable range in fluid pressures in terms of salt reconsolidation. Based on the results of this calculation, fluid pressures greater than 4 MPa effectively prevent reconsolidation over a 1000-year time frame.

Assumptions

- The fractional densities of the crushed-salt seal were calculated through 500 years using the modified Sjaardema-Krieg consolidation model.
- The fractional density of the crushed salt after compaction is 90%, i.e., $\rho_0 = 0.90$.
- The shaft remains open for 50 years, then is instantaneously filled with compacted crushed salt.
- The initial fluid pressures are applied instantaneously at time = 50 years. This is a conservative assumption because it provides an immediate restraint to creep closure and results in longer reconsolidation times.
- Vertical variations in stratigraphy and material properties are neglected. Intact salt is modeled exclusively as argillaceous salt governed by the MDCF model.

Results

Results for 0 MPa are shown in Figure D-12; results for 2 MPa are shown in Figure D-13. These results indicate that, as expected, the time required to consolidate the crushed salt increases substantially as the fluid pore pressure increases. For fluid pressures of 4 MPa or greater, reconsolidation times are increased to the point where the crushed salt does not achieve a fractional density of 96% until substantially beyond 1000 years. For zero fluid pressure, times of about 40 years, 70 years, and more than 150 years are required. For a fluid pressure of 2 MPa, the times required to achieve a fractional density of 96% are about 90 years, 200 years, and 560 years at the bottom, middle, and top of the crushed-salt column, respectively.

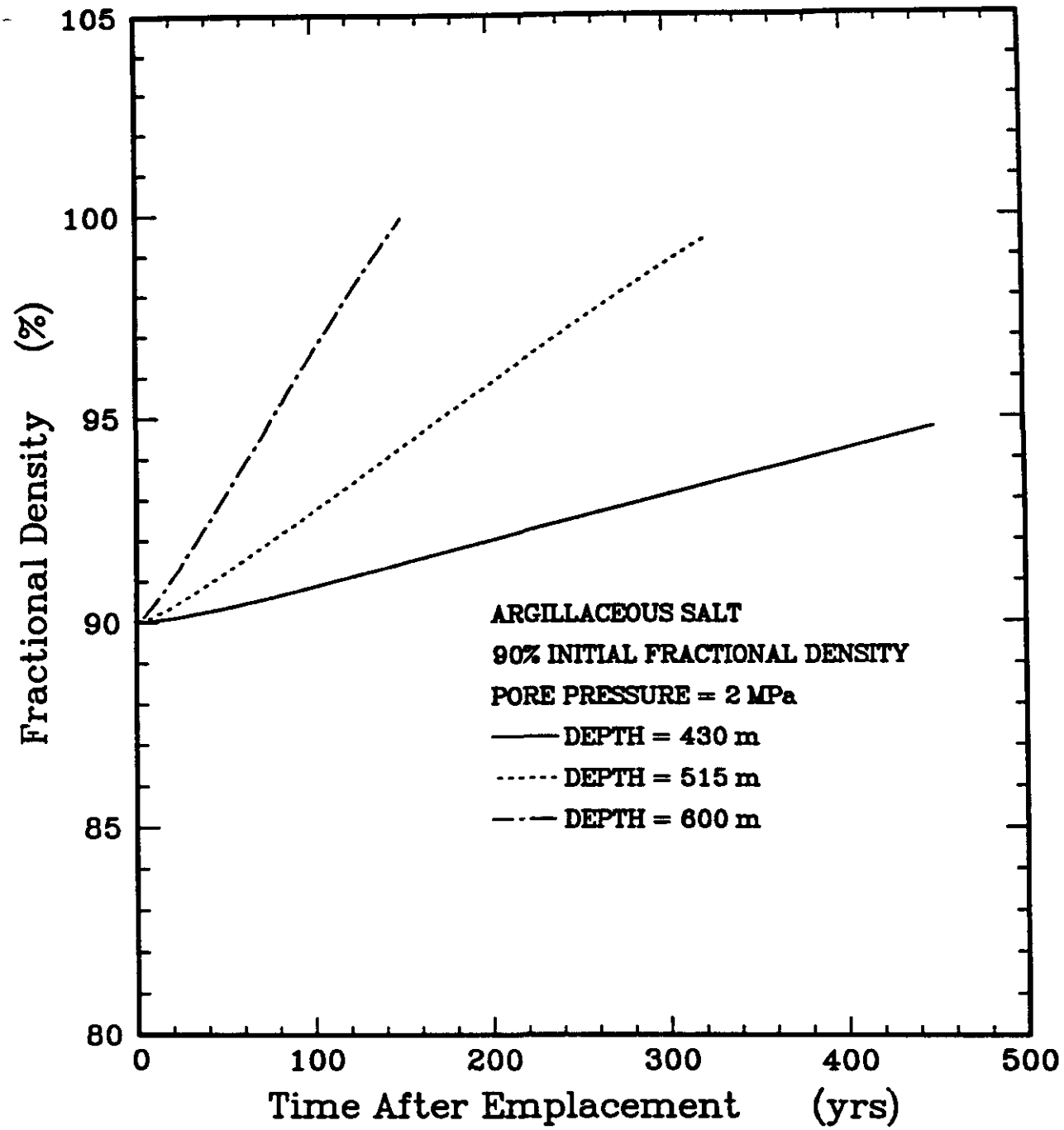

Figure D-13. Crushed-salt fractional density as a function of time for a fluid pressure of 2 MPa and using the modified Sjaardema-Krieg creep consolidation model.

D4.3 Compacted Clay Seals

D4.3.1 Structural Analysis of Compacted Clay Seals

Objective

The objective of this calculation was to determine the stresses in the upper and lower Salado compacted clay columns as a result of creep of the surrounding salt. These stresses may increase the loads imposed on the concrete seal components. The problem description and assumptions used in performing this calculation are the same as those presented in Section 4.1.2. The results of this calculation indicate that after 50 years the compressive stress in the upper Salado compacted clay column ranges from 0.6 MPa at the top to 0.8 MPa at the bottom of the column. Similarly, after 50 years, the mean stresses in the lower Salado compacted clay column are approximately 2.6 MPa.

D4.4 Asphalt Seals

D4.4.1 Thermal Analysis of Asphalt Seals

Objectives

The objectives of this calculation were (1) to determine the temperature histories within the asphalt seal and the surrounding salt and (2) to determine the thermal effects which depend on the length of the waterstop.

Problem Description

A schematic diagram of the AIS seal showing the asphalt components is given in Figure D-14. The AIS is approximately 6.1 m (20 feet) in diameter. The asphalt seal through the Rustler/Salado interface is more than 36 m (119 feet) in height (Figure D-6). The waterstops are 1.22 m (4 feet) in height and, as shown in Figure D-14, extend radially 3.05 m (10 feet) into the surrounding salt.

Two geometrical models were used to calculate thermal results. The first model, shown in Figure D-15(a), represents an asphalt seal of infinite length and can be used to approximate thermal conditions within the asphalt at the Rustler/Salado interface. This model was used to calculate the maximum asphalt (Point A) and salt (Point B) temperatures. The right boundary was extended laterally (100 shaft radii) to be beyond the thermal influence of the asphalt for 10 years. The left vertical boundary represents the shaft centerline and is a line of symmetry. The second model, shown in Figure D-15(b), is referred to as a "quarter-symmetry model." It is used to represent thermal conditions near the asphalt waterstops and to calculate the thermal effects of the radial extent of the waterstop into the salt. The left and lower boundaries are lines of symmetry located at the shaft centerlines and waterstop midheight, respectively. The modeled height of the asphalt is 0.61 m (2 ft). The radial extent of the waterstop as shown in Figure D-15(b) is 3.05 m (10 ft) or equivalently 1 shaft radius into the salt. The right and upper boundaries are extended 100 m from the waterstop center; beyond the thermal influence of the asphalt through 10 years following emplacement. The temperatures at the asphalt center (Point A in Figure D-15) were calculated as a function of time for two cases: (1) no waterstop and (2) full waterstop.

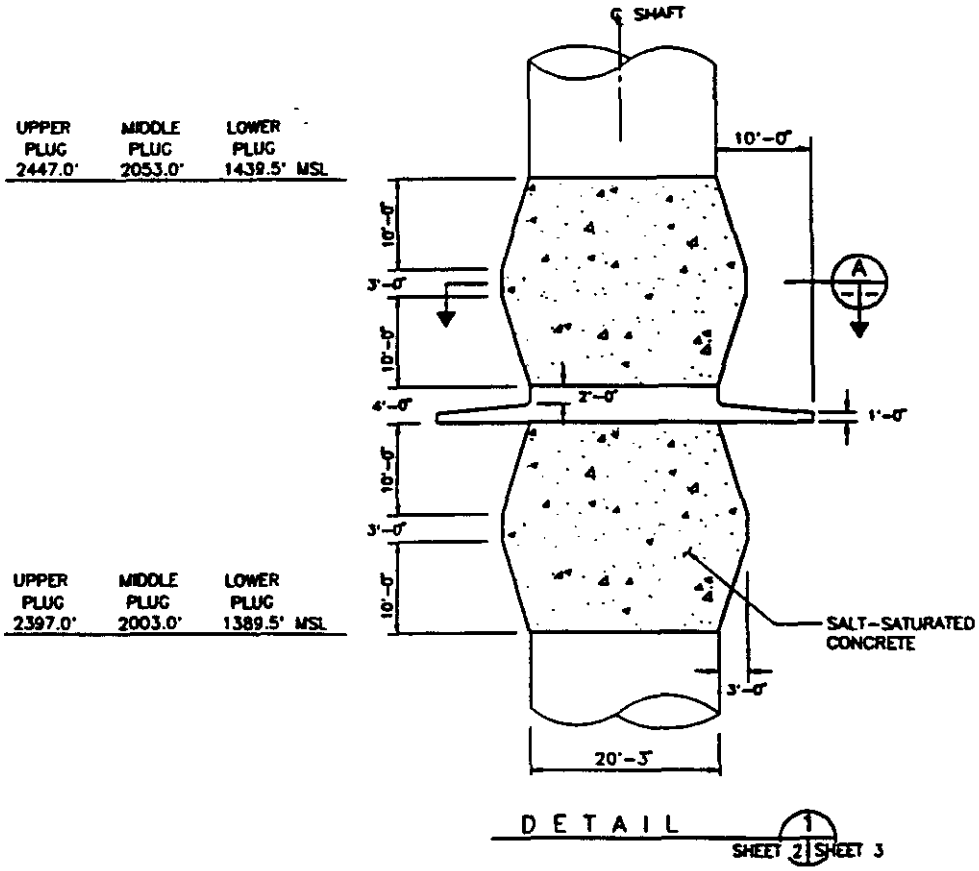

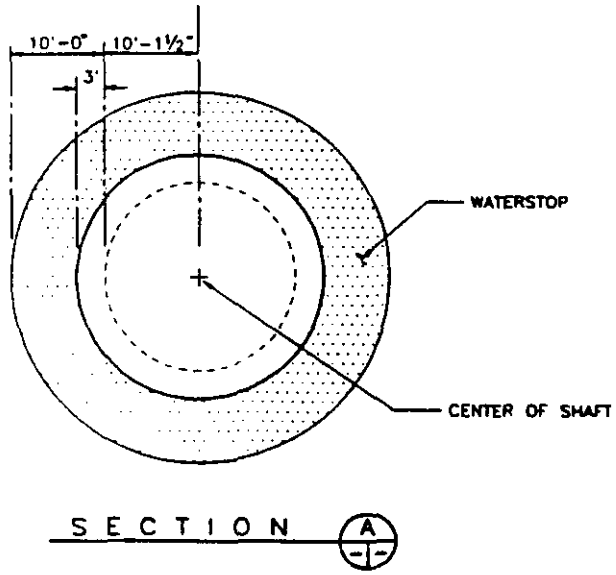

TYPICAL SALADO MASS CONCRETE PLUG
WITH WATERSTOP (3 LOCATIONS)

Figure D-14. WIPP shaft seal design showing asphalt components.

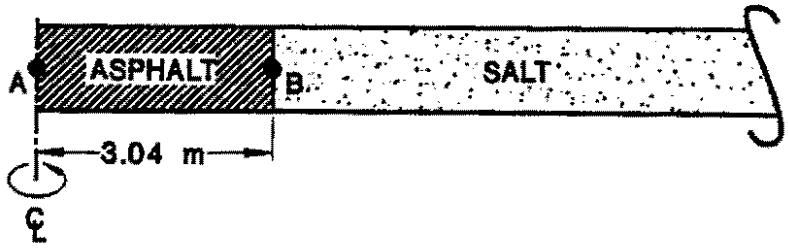

(a) Pineapple-Slice Model

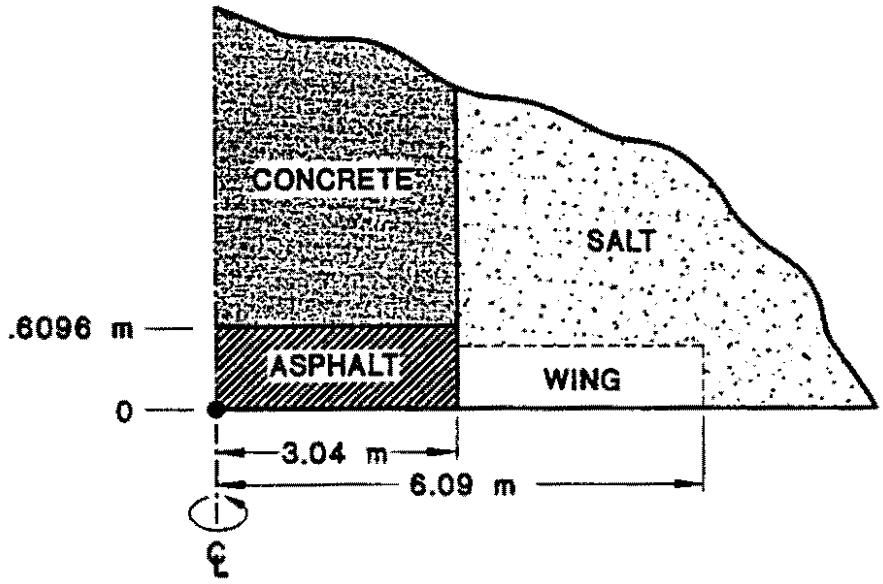

(b) Quarter-Symmetry Model

Figure D-15. Models used in thermal analysis of asphalt seal.

Assumptions

- The initial formation temperature is 23°C everywhere along the length of the seal.
- The AIS is thermally isolated from the remaining shafts; i.e., the domain surrounding the AIS is assumed to be infinite in extent.
- The stratigraphy can be neglected; i.e., the domain is assumed to be homogeneous (salt).
- The heat of hydration of the concrete is ignored.
- All seal materials are emplaced simultaneously at time = 0.
- All boundaries are adiabatic.
- The asphalt is emplaced at 180°C.

Results

The results of this analysis are shown in Figures D-16 through D-18. Figure D-16 shows temperature histories of the asphalt and surrounding salt near the seal midheight. These results indicate that the asphalt center cools from its emplaced temperature of 180°C to 83°C, 49°C, 31°C, and 26°C at times 0.1 year, 0.2 year, 0.5 year, and 1.0 year, respectively. Similarly, the asphalt/salt interface temperatures at the same times are 47°C, 38°C, 29°C, and 26°C.

Figure D-17 shows the temperature histories in the asphalt waterstop. The time required to cool the waterstop is significantly less than that required to cool the asphalt column. Specifically, the waterstop center has cooled to temperatures of 38°C, 29°C, 24°C, and 23°C at times 0.1 year, 0.2 year, 0.5 year, and 1.0 year, respectively.

D4.4.2 Structural Analysis of Asphalt Seals

The objective of this analysis was to calculate the pressures in the asphalt as a result of creep of surrounding salt to evaluate stresses induced on concrete seal components. The problem description and assumptions used in performing this calculation are the same as those presented in Section 4.1.2. The results of this calculation are shown in Figure D-19, which shows the calculated pressure in the upper, middle, and lower asphalt waterstops as a function of time after emplacement. These results indicate that after 100 years, the pressures in the waterstop are 1.8 MPa, 2.5 MPa, and 3.2 MPa for the upper, middle, and lower waterstops, respectively.

D4.4.3 Shrinkage Analysis of Asphalt Seals

Objective

The objective of this analysis was to determine the shrinkage of the asphalt column as it cools from its emplaced temperature to an acceptable working environment temperature.

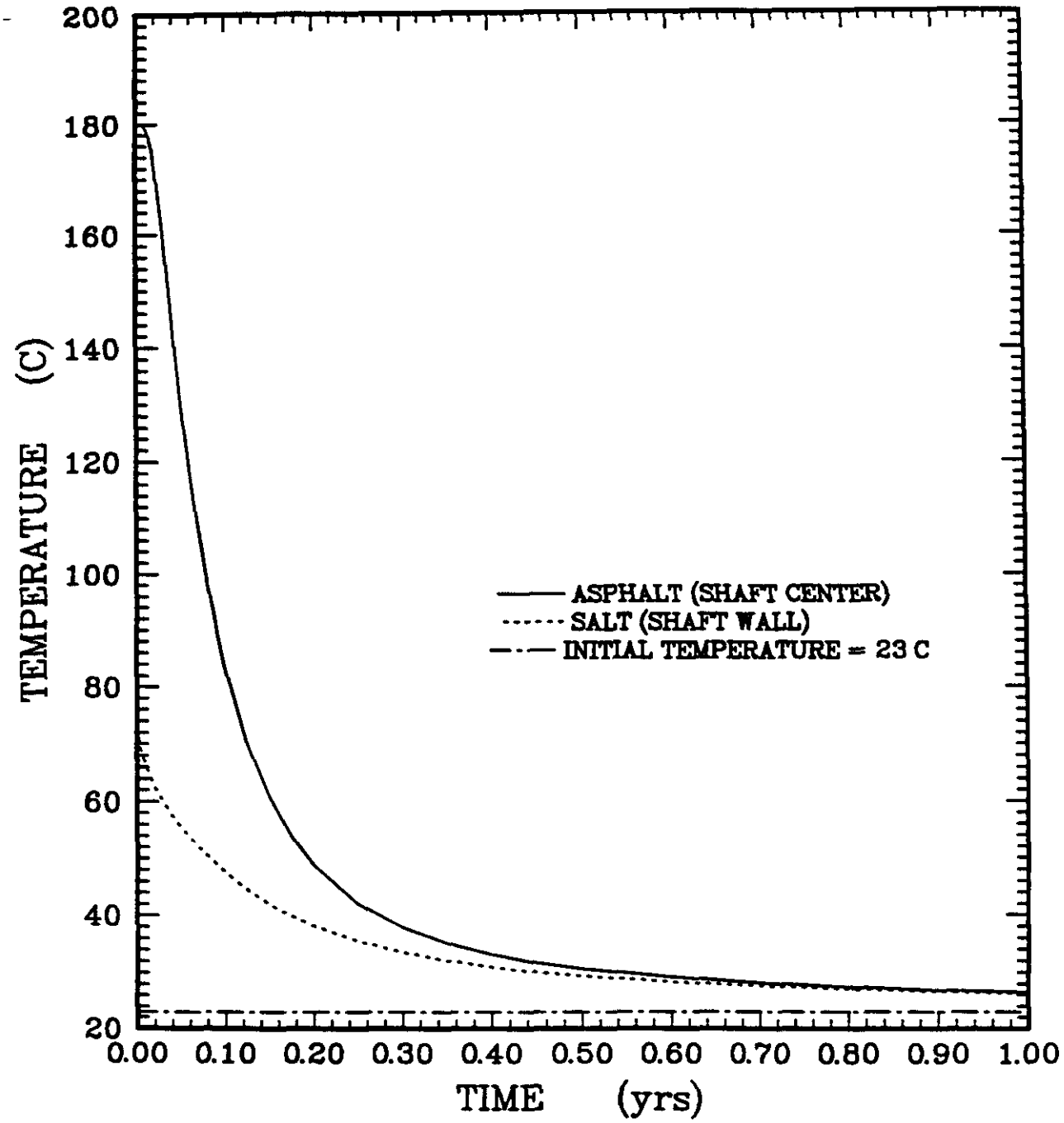

Figure D-16. Temperature histories in asphalt (Point A, Figure D-15a) and salt (Point B, Figure D-15a).

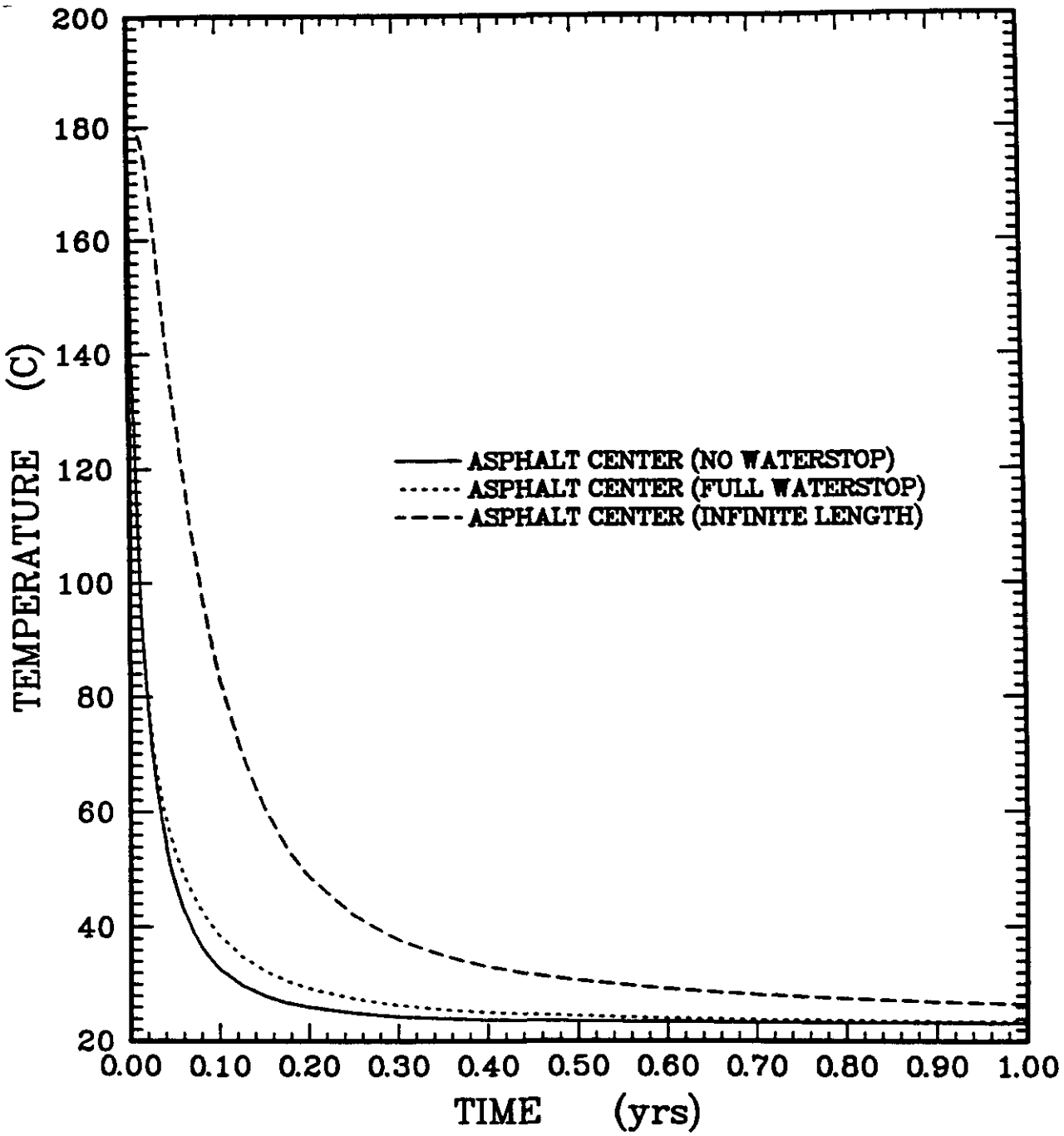

Figure D-17. Comparison of asphalt center temperatures for different waterstop configurations.

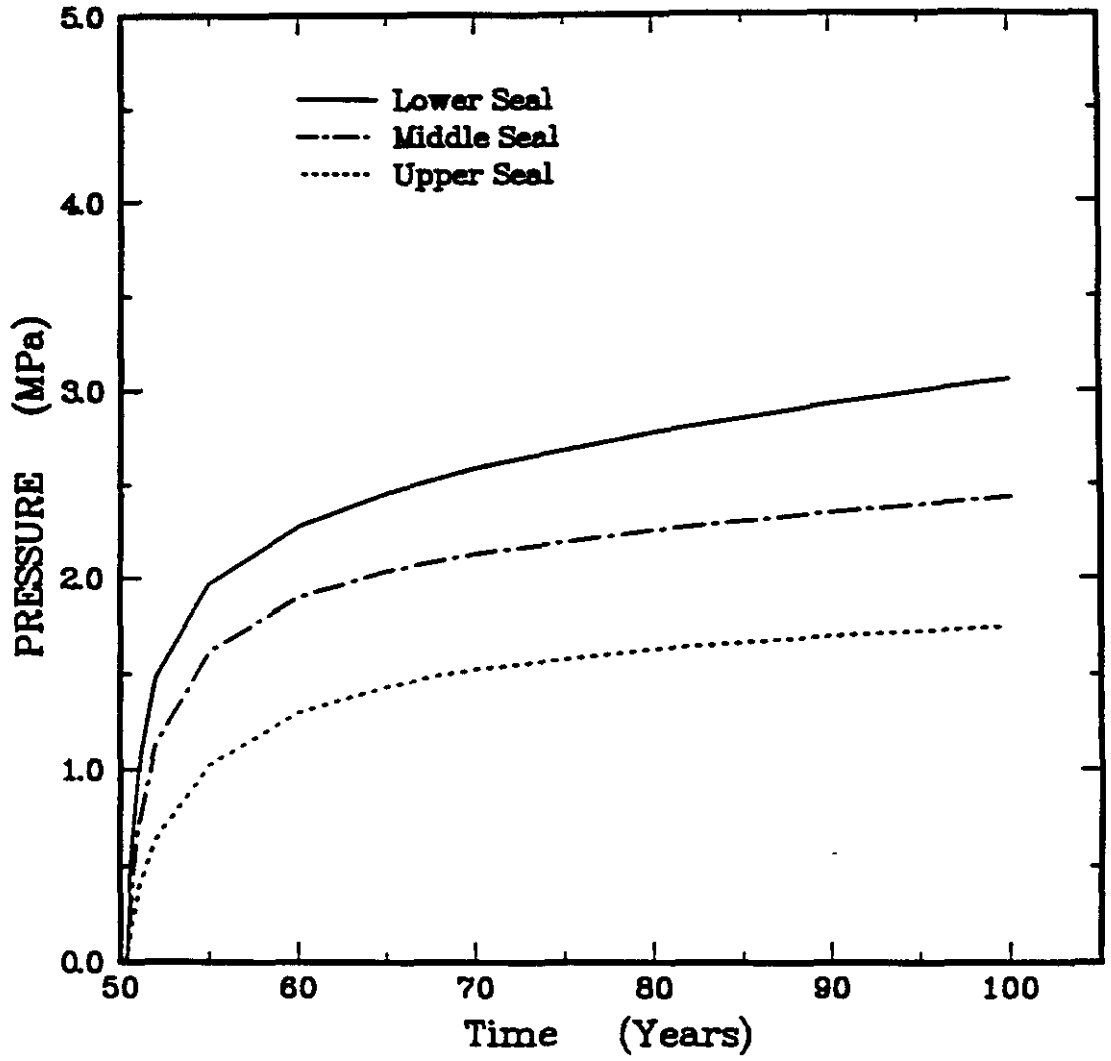

Figure D-18. Pressure buildup in the upper, middle, and lower shaft seal waterstops.

Problem Description

The height of the asphalt column is 138 ft. The volumetric coefficient of thermal expansion for asphalt is 0.00035/°F.[1] The linear coefficient of thermal expansion for sandstone aggregate is 0.000005/°F; the corresponding volume coefficient is about three times the linear coefficient, or 0.000015/°F. Within the column, sand and lime comprise 80% of the volume and asphalt comprises 20%. Thermal contraction can be calculated for each constituent or an equivalent coefficient can be calculated. The equivalent coefficient is:

$$\begin{aligned}\alpha_{mix} &= 0.8\alpha_{sand} + 0.2\alpha_{asphalt} \\ &= 0.8(0.000015) + 0.2(0.00035) \\ &= 0.00008/^{\circ}\end{aligned} \tag{D-59}$$

Assumptions

It is assumed that the asphalt mastic mixture will retain enough mobility that all "voids" caused by shrinkage will occur at the top of the emplacement only. That is, the mixture will flow downward as it shrinks. Accelerated creep closure of the shaft because of heating is ignored in calculating the shaft volume.

Results

The change in height of the asphalt column is given by:

$$\begin{aligned}\Delta h &= \frac{\Delta V}{\pi r^2} = \frac{V\alpha\Delta T}{\pi r^2} = \frac{H\pi r^2\alpha\Delta T}{\pi r^2} = h\alpha\Delta T \\ &= (42.09\,\text{m} \quad \times 10^{-4}/^{\circ}\text{C})(180 - 37.78^{\circ}\text{C}) \\ &= 0.89\,\text{m}\end{aligned} \tag{D-60}$$

where:

Δh	= change in height of asphalt column (m)
ΔV	= change in volume of asphalt column (m^3)
r	= shaft radius (m)
α	= volumetric coefficient of thermal expansion (/°C)
ΔT	= temperature change from emplacement (T = 180°F) to cooled state (T = 37.78°C).

[1] *Standard Practice for Determining Asphalt Volume Correction to a Base Temperature*, ASTM Designation: D 4311-83, Section 3.3.

D5. DISTURBED ROCK ZONE CONSIDERATIONS

D5.1 General Discussion

A DRZ develops around virtually every underground excavation. The DRZ can be defined as that region near an excavation (in salt or nonsalt rock) that experiences a change in hydrological or mechanical properties. The DRZ is generally assumed to have the following characteristics:

1. dilational deformation resulting from micro- or macrofracturing,
2. decreased load-bearing capacity (loss of strength), and
3. increased fluid permeability (increase in interconnected porosity).

Characterization of the DRZ in salt requires both spatial and temporal considerations. For that purpose, the DRZ can be divided into four regimes: (1) initial creation of the DRZ resulting from stress perturbations brought on by the excavation, (2) changes in rock properties caused by "weathering" of exposed rock, (3) later changes in the DRZ extent that may occur with time as the salt creeps, and (4) a decrease in the DRZ extent (and eventual elimination) that occurs through healing of the micro- and macrofracturing when salt creep is restrained. Remediation of the DRZ may also be possible by engineering fixes such as grouting.

In situ fluid flow and permeability measurements performed in boreholes drilled from excavations in the WIPP provide a geometrical delineation of the DRZ and a measure of the hydrological properties for the DRZ. In general, the disturbance, as reflected by enhanced permeability, is restricted to about one-half the effective radius of the excavation. Within this region the permeability will increase from 10^{-22} to 10^{-23} m^2 (undisturbed permeability) at the edge of the DRZ to about 10^{-14} to 10^{-15} m^2 near the excavation surface (Knowles et al., 1996). Although this discussion relates to underground measurements in the WIPP drifts, a similar delineation of the DRZ around the AIS was observed by Dale and Hurtado (1996).

Underground observations and measurements are consistent with the description of the DRZ extending to less than one excavation radius and having permeabilities that are largest near the excavation boundary and lowest (decreasing by several orders of magnitude to salt's undamaged value) at the edge of the DRZ. Stress states around excavations, whether the instantaneous elastic distributions or the creep-induced stationary distributions, follow a similar trend. Shear stresses are largest near the excavation and become smaller at greater distances from the excavation. This similarity in trends suggests a conclusion that the DRZ can be defined in terms of the stress states existing in the salt. Laboratory testing data from independent laboratories using three different test types also support a conclusion that the onset of damage in salt (dilatant behavior) is predictable based on the stress state imposed on the salt (Van Sambeek et al., 1993a). Other laboratory testing data support a conclusion that damage within a salt specimen can be healed (in fact, healed quite rapidly) by applying favorable stress states to the damaged specimen (e.g., Costin and Wawersik, 1980; Brodsky, 1990). From these results, a conceptual model for the DRZ is developed where (1) the maximum extent of the DRZ is strictly a function of the most severe stress state ever to exist around the excavation and (2) the current extent of the DRZ is defined by the current stress state around the excavation. Implicit is that the

disturbed salt will heal "instantaneously" as the stress state is slowly changed from unfavorable (damage inducing) to favorable.

D5.1.1 Salt Damage Models

Two salt damage models are used to define the DRZ for the WIPP seals design: the stress-invariant ratio and the damage stress criterion (Section D.3.2) model. The stress-invariant ratio states that salt will incur damage whenever the ratio between the shear stress (as measured by the second invariant of the deviatoric stress tensor) and the confining pressure (as measured by the first invariant of the stress tensor) exceeds a critical value of 0.27. Mathematically, this is:

$$\frac{\sqrt{J_2}}{I_1} \geq 0.27 \qquad \text{(D-61)}$$

where $\sqrt{J_2}$ is the shear stress measure and I_1 is the confining stress measure. The relationship is based on laboratory testing data from numerous creep and quasi-static tests on WIPP and Avery Island salts. In general, the relationship seems to represent both different salts and different test types as described by Van Sambeek et al. (1993b).

The MDCF model tracks the development of porosity as result of strain-induced damage within the salt, as described in Section D3.2.1. The dominant deformation mechanism governing the dilational behavior of salt is the time-dependent microfracturing mechanism (Chan et al., 1992). This mechanism is operable for a limited range in stress states (i.e., high shear stresses relative to a low mean stress). The stress states causing microfracturing are typically most severe in the salt immediately adjacent the excavation and less severe deeper into the salt. At some depth, the mean stress increases enough and the shear stresses decrease enough that microfracturing stops; this depth defines the DRZ boundary.

Definition of the DRZ by the MDCF model is preferred over the stress-invariant ratio from a scientific viewpoint because it directly connects the variables of stress, strain, and damage (including damage reversal or healing) in one relationship, albeit a complex relationship. The stress-invariant ratio can only indicate where damage is likely to occur and when healing can begin based on changes in the stress-invariant ratio. The stress-invariant ratio provides no quantitative information about the degree of damage or the significance of the damage in terms of enhanced permeability. The stress-invariant ratio is, however, simpler to apply to engineering problems.

D5.1.2 Salt Healing Models

Healing of damaged salt within the DRZ will occur whenever stress states no longer cause damage. This condition is reached by (1) reducing shear stress, (2) increasing the mean stress, or (3) doing both. The most practical way to achieve a more favorable stress state is to restrain the natural creep of salt by forming a barrier to closure at the free surface of the shaft. By doing so, the stress parallel to the creep deformation direction will increase in compressive magnitude. As this stress increases, the shear stress decreases and the mean stress increases, which is the situation required to reverse the damaging stress condition. Once the damaging stress state is reversed, healing of damage can begin.

Evidence for reversing damaging stress states into healing stress states can be found in (1) natural analogues, (2) laboratory tests (Costin and Wawersik, 1980), (3) in situ seal tests in the WIPP (Knowles et al., 1996), and (4) bulkheads in salt and potash mines. The physical process for healing the microfracture-damaged salt is primarily fluid-assisted pressure solution and redeposition. In addition, dislocation motion of the solid state allows further deformation of crystals to occupy space. Both mechanisms operate effectively at stresses and temperatures applicable to the DRZ around the WIPP shafts.

Natural Analogues. Salt formations are universally considered to have very low permeabilities, which is why salt formations are an ideal storage medium. The Salado salt formation originated as precipitate in oversaturated brines. The original porosity was huge because the salt mass was comprised of loose hopper crystals. With time and superincumbent pressure from additional salts and other sediments, the salt became impermeable, possessing essentially no voids. From this analog, suturing of grain boundaries under natural conditions is demonstrated. The geologic time available for healing is admittedly long; however, the natural stresses and temperatures for the healing process are similar to conditions expected around the WIPP shaft.

Laboratory Test Evidence. Brodsky (1990) and Brodsky and Munson (1994) present test results for the healing of damaged salt under isostatic stress. This work is particularly significant because the salt specimens used in the healing tests had been intentionally damaged in constant-strain-rate tests where the dilatant behavior (volumetric strain) was measured. Thus damage was quantified before the healing phase of the test. The ultrasonic velocity degradation and recovery were monitored during the damage and healing phases. The healing rate, as reflected by ultrasonic velocity recovery, depends on the original damage level, applied pressure, and temperature. The times to full recovery are short, based on the 20-day tests at a 20°C to 70°C range of test temperatures. Therefore, once the seal components restrain the creep of salt and cause confining stresses to develop in the salt, crack closure and healing in the DRZ will be rapid.

In Situ Seal Tests. Tests at the WIPP known as Small-Scale Seal Performance Tests (SSSPTs) have shown that large-diameter borehole seals constructed of bentonite and concrete provide nearly impermeable barriers to fluid flow. These seals were emplaced in boreholes drilled into the ribs and floor of a 5.5-m-square room. Thus the boreholes were drilled into a DRZ surrounding the room, and the borehole created a supplementary DRZ around itself. The time lapse between drilling the borehole and emplacing the seal was several months, so ample time was allowed for the DRZ to develop. Testing of the borehole seals 9 years after emplacement revealed no leakage through the DRZ. The DRZ must therefore have been healed because the borehole seal caused a stress state to reestablish that was conducive to healing.

Bulkheads in Salt and Potash Mines. The Rocanville potash mine in Saskatchewan provides one compelling case history for healing of a salt DRZ. An exploratory drift in the mine entered a barren salt zone (devoid of sylvite, so the surrounding rock was halite) and sustained a brine inflow. Within about a month, a concrete bulkhead was built in the drift, including construction grouting of the interface between the bulkhead and the salt. After sealing the drift, the brine pressure behind the bulkhead reached a near hydrostatic pressure greater than 8 MPa and remained at that pressure for more than 10 years. There is no evidence of leakage through either the bulkhead or the salt DRZ surrounding the drift. Although the drift was blocked at an early

age, a DRZ must have formed instantaneously with the excavation of the drift. To be consistent with the observations, this DRZ must have been healed to avoid leakage during a 10-year time span. This bulkhead remains accessible and continues to function perfectly.

D5.2 Disturbed Rock Zone Analyses

D5.2.1 Analysis of the Disturbed Rock Zone in Salado Salt

Objective

The objective of this calculation was to determine the spatial extent of the DRZ in the intact salt surrounding the shaft for each of the four shaft seal materials (i.e., concrete, crushed salt, compacted clay, and asphalt). This information was used to define the input parameters to the fluid-flow calculations reported in Section 8 of the main report.

Problem Description

The radial extent of the DRZ within the intact salt was determined using a series of "pineapple-slice" models. Each model corresponds to a depth (and its associated initial temperature and stress conditions). Figure D-11 shows the schematic model geometry, which includes an axisymmetric representation of the shaft and surrounding host rock at a fixed depth. The outer (right) boundary is located 50 shaft radii from the axis of symmetry, the shaft centerline. The boundary condition at the outer boundary is maintained at the initial stress magnitude, i.e., the lithostatic stress.

Five depths were chosen to be representative of conditions along the length of the shaft within the Salado Formation. Specifically, depths of 250, 350, 450, 550, and 650 m were considered in this analysis. The initial stress and temperature conditions for these depths were determined as shown by the notes to Table D-17. Four moduli of elasticity were considered to approximate the seal materials of asphalt, compacted clay, crushed salt, and salt-saturated concrete. Five depths are considered adequate to determine a functional relationship between the DRZ radial extent and depth for each seal material type.

In the analysis for times $t < 0$ year, the shaft is not present, and an initial lithostatic stress field exists in the salt. At time $t = 0$ year, the cylindrical shaft is excavated, and the surrounding salt is allowed to creep for 50 years, i.e., the operational period. At time $t = 50$ years, the shaft is sealed. In the analyses, salt surrounding the shaft continues to creep against the seal material and consolidates the seal material (if applicable) for an additional 100 years. The time-dependent radial extent of the DRZ was calculated for each model (depth) and seal material-type. The damage-stress criterion for argillaceous salt (see Section D3.3.2) was used to estimate the spatial extent of the DRZ as a function of time for each of the models considered.

Assumptions

- The stratigraphy surrounding the AIS is modeled as being entirely argillaceous salt.
- The initial stress state prior to excavation is lithostatic.
- The modeled region remains isothermal.

- The shaft excavation and seal material emplacement are performed instantaneously at times of 0 and 50 years, respectively.
- The shaft is sufficiently isolated from other excavations so that only the shaft is considered in the analysis. Axisymmetric conditions are, therefore, applicable and a condition of plane strain exists with respect to the axial (vertical) direction.
- The calculations are based on finite deformation solutions.
- The damage stress criterion can be used to define the spatial extent of the DRZ.
- Short-term thermally enhanced salt creep is ignored.
- Pore pressure effects are not incorporated.
- A Tresca flow rule was used for intact salt.

Results

The results of this calculation are shown in Figures D-19 through D-23 in terms of the normalized DRZ radius as a function of backfill stiffness (i.e., elastic modulus) at various depths within the Salado Formation at times 0, 10, 25, 50, and 100 years after emplacement, respectively. The normalized DRZ radius is defined as the ratio of the radius to the DRZ boundary and the shaft radius. The radius to the DRZ boundary is defined as the location where the damage stress (Equation D-54) is equal to zero. For all backfill types, the most conservative (i.e., largest) estimate of the extent of the DRZ was calculated using the minimum value of the material's stiffness.

The concrete seals are located at approximate depths of 301, 420, and 608 m. An elastic modulus of 30 GPa was used for concrete, corresponding to the 28-day stiffness according to Equation D-4. Using the results shown in Figures D-19 through D-23, the normalized DRZ radii surrounding the three concrete seals are summarized in Table D-18 for times of 0, 10, 25, 50, and 100 years after emplacement.

The compacted-salt column is located at depths ranging from 420 to 600 m. A minimum elastic modulus of 7.5 GPa was used for compacted crushed salt, corresponding to the emplaced fractional density of 90% using Equation D-7. Using the results shown in Figures D-19 through D-23, the normalized DRZ radii surrounding the compacted crushed salt seal are summarized in Table D-19 at the top (429 m), middle (515 m), and bottom (600 m) of the column at times 0, 10, 25, 50, and 100 years following emplacment.

Compacted clay is used as a shaft seal in two locations within the Salado Formation. The upper Salado compacted clay column is located at depths between 307 and 413 m. The lower Salado compacted clay column is located at depths between 617 and 643 m. An elastic modulus of 1.2 GPa was assumed for compacted clay, corresponding to a fractional density of 90% according to Equation D-18. Using the results shown in Figures D-19 through D-23, the normalized DRZ radii surrounding the compacted clay seals are summarized in Table D-20 at the top and bottom of the upper and lower Salado compacted clay columns at times 0, 10, 25, 50, and 100 years following emplacement.

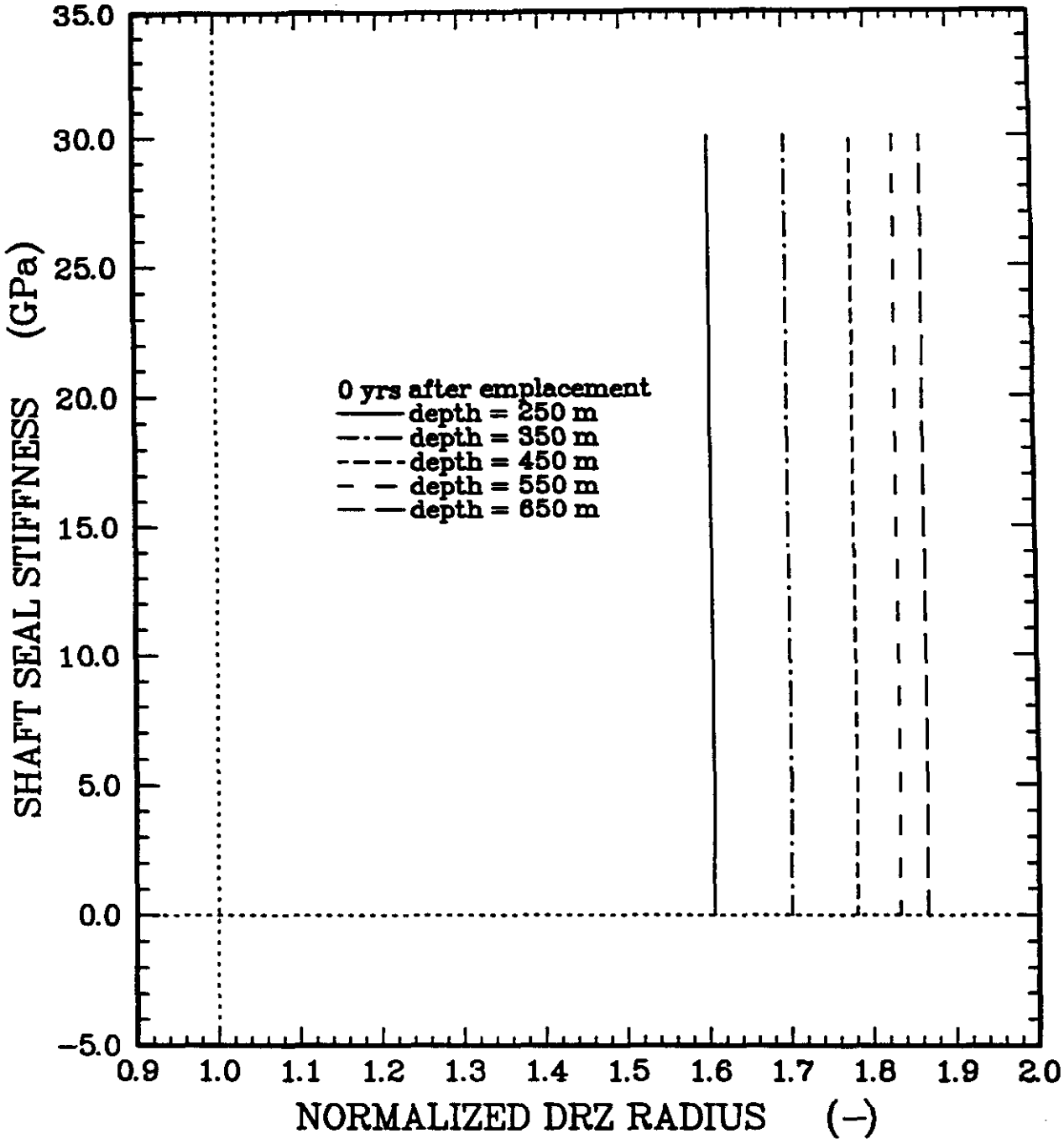

Figure D-19. Normalized DRZ radius as a function of shaft seal stiffness at various depths within the Salado Formation at time = 0 year after emplacement.

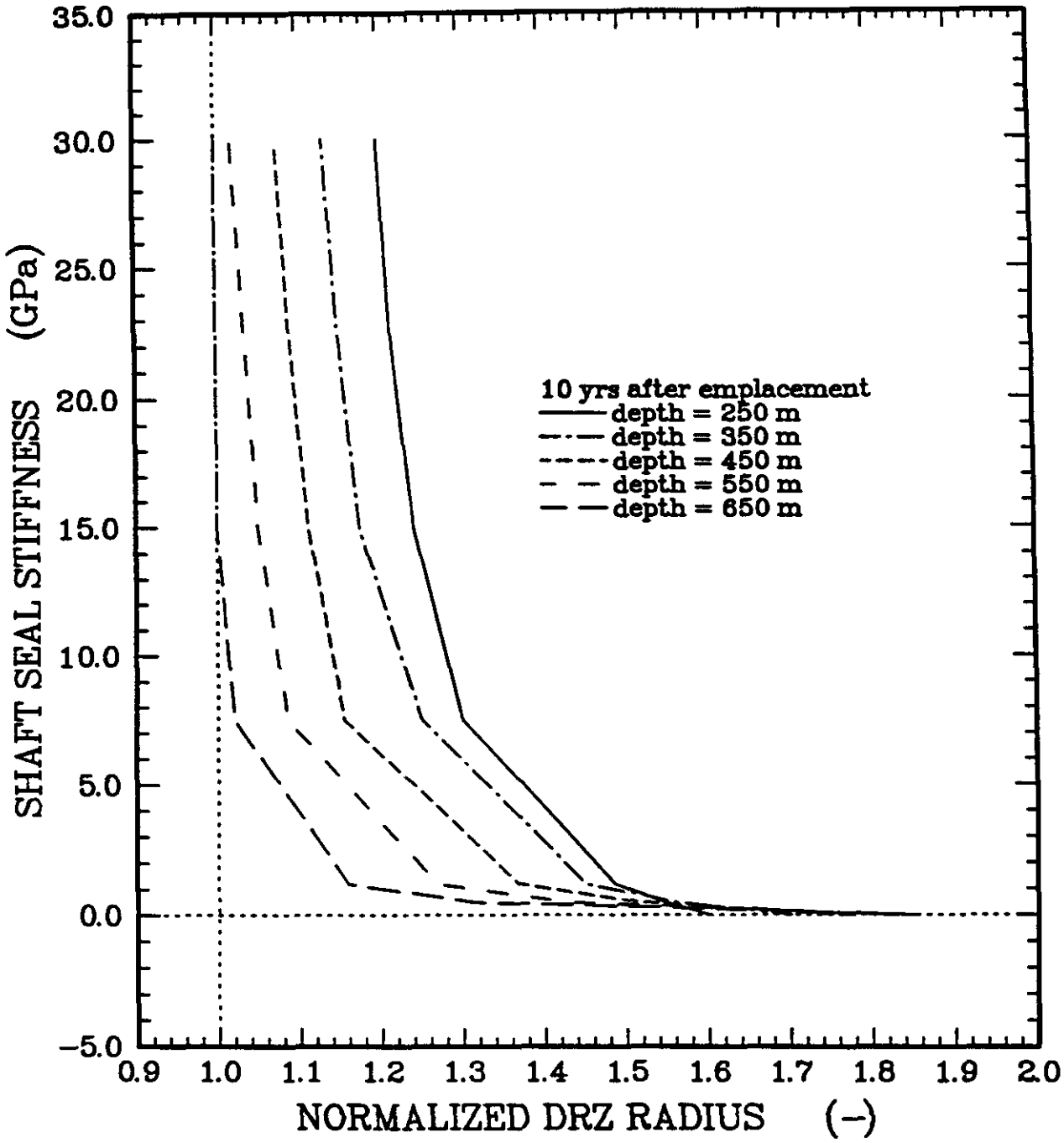

Figure D-20. Normalized DRZ radius as a function of shaft seal stiffness at various depths within the Salado Formation at time = 10 years after emplacement.

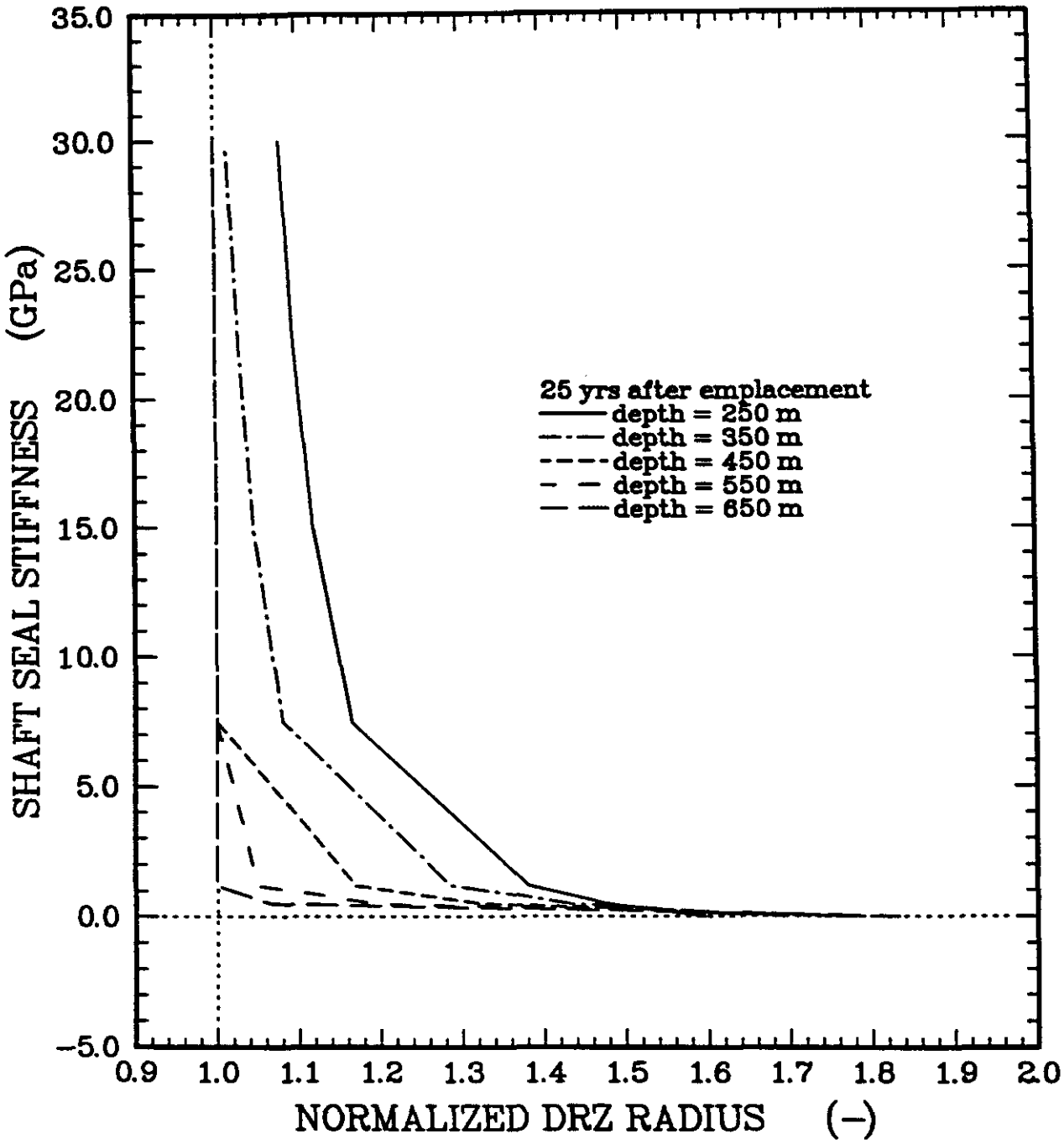

Figure D-21. Normalized DRZ radius as a function of shaft seal stiffness at various depths within the Salado Formation at time = 25 years after emplacement.

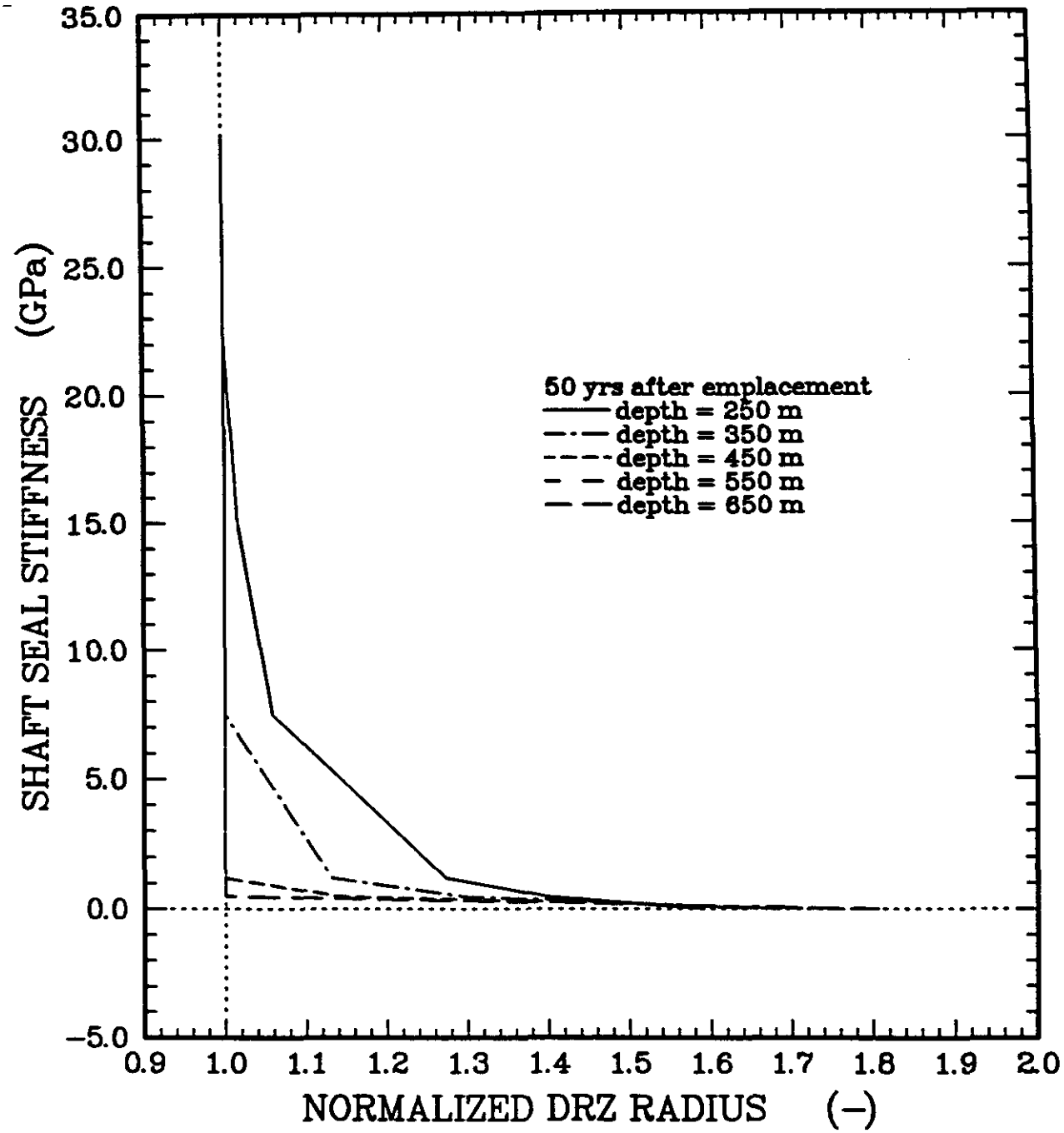

Figure D-22. Normalized DRZ radius as a function of shaft seal stiffness at various depths within the Salado Formation at time = 50 years after emplacement.

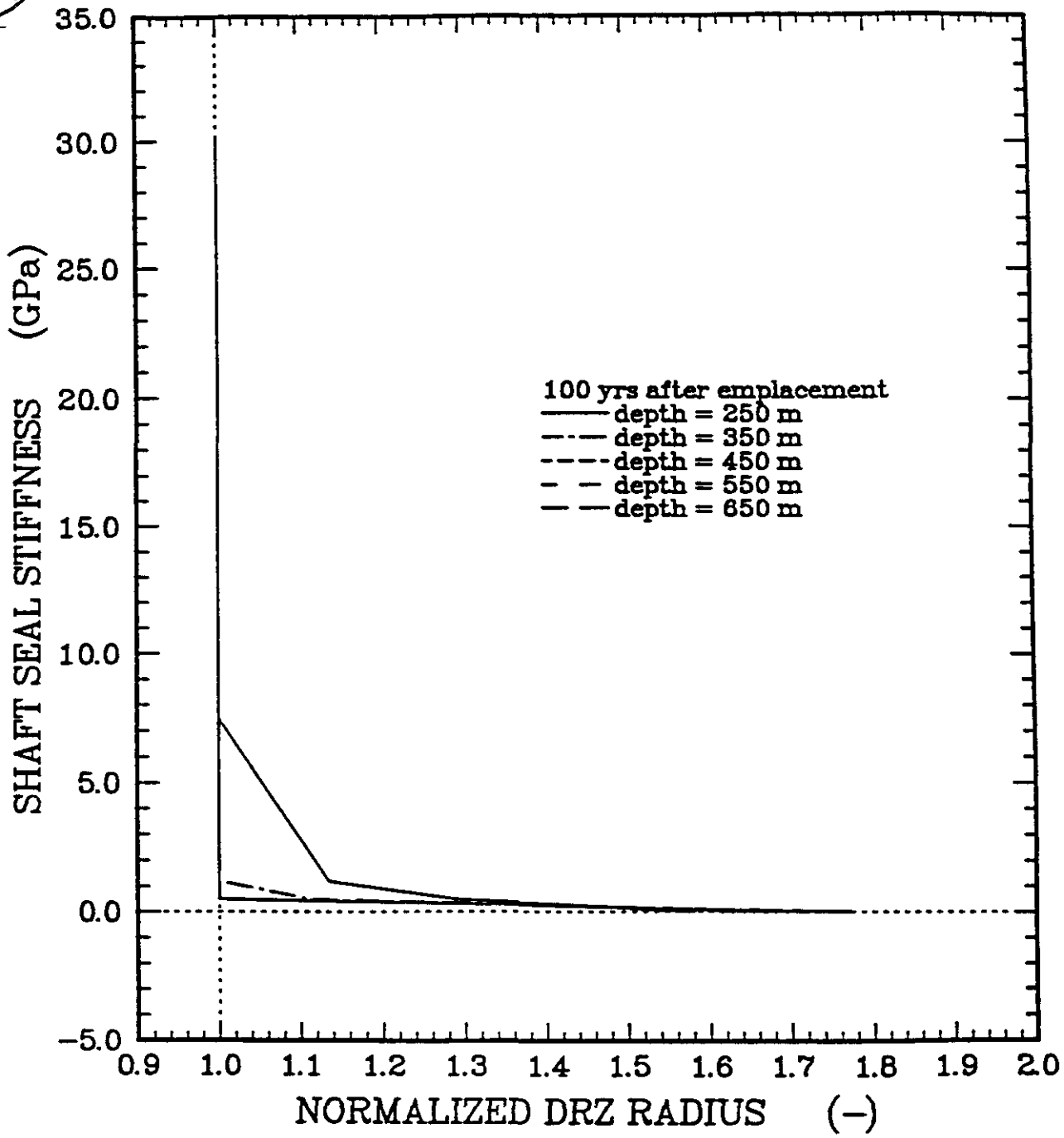

Figure D-23. Normalized DRZ radius as a function of shaft seal stiffness at various depths within the Salado Formation at time = 100 years after emplacement.

Table D-18. Normalized DRZ Radius—Concrete

Concrete Component	Time After Emplacement (yrs)				
	0	10	25	50	100
Upper (d = 301 m)	1.65	1.16	1.05	1.00	1.00
Middle (d = 421 m)	1.76	1.09	1.01	1.00	1.00
Lower (d = 608 m)	1.85	1.01	1.00	1.00	1.00

Table D-19. Normalized DRZ Radius—Crushed Salt

Depth	Time After Emplacement (yrs)				
	0	10	25	50	100
Upper (d = 429 m)	1.77	1.20	1.02	1.00	1.00
Middle (d = 510 m)	1.82	1.11	1.01	1.00	1.00
Lower (d = 600 m)	1.85	1.05	1.00	1.00	1.00

Table D-20. Normalized DRZ Radius—Compacted Clay

Depth	Time After Emplacement (yrs)				
	0	10	25	50	100
Top of USCCC (d = 308 m)	1.66	1.47	1.32	1.19	1.06
Bottom of USCCC (d = 413 m)	1.75	1.40	1.21	1.05	1.00
Top of LSCCC (d = 616 m)	1.85	1.22	1.03	1.00	1.00
Bottom of LSCCC (d = 643 m)	1.86	1.20	1.02	1.00	1.00

USCCC = upper Salado compacted clay column; LSCCC = lower Salado compacted clay column.

Asphalt is used as a shaft seal material from the Rustler/Salado interface to the top of the upper concrete component (depths between 256 and 293 m). A minimum elastic modulus of 0 GPa was assumed for asphalt, corresponding to its unsolidified stiffness.

Using the results shown in Figures D-19 through D-23, the normalized DRZ radii surrounding the asphalt seal are summarized in Table D-21 at the top and bottom of the column at times 0, 10, 25, 50, and 100 years after emplacement.

Table D-21. Normalized DRZ Radius—Asphalt

Depth	Time After Emplacement (yrs)				
	0	10	25	50	100
Top (d = 256 m)	1.61	1.61	1.60	1.59	1.58
Bottom (d = 293 m)	1.65	1.65	1.64	1.63	1.62

D5.2.2 Salado Anhydrite Beds

The material behavior of the interbeds within the Salado Formation is assumed to be elastic (time-invariant); in contrast, the salt creeps (time-dependent). Therefore the interbeds will tend to inhibit creep closure of the shaft. In addition, the salt creep that does occur will tend to increase the potential for fracturing within the interbeds because of shear tractions that develop along the interface. The thickness of the interbeds relative to the thickness of the salt above and below the interbeds determines which of the two behaviors will dominate. That is, the thicker the interbeds, the less salt creep will occur; and the thicker the salt bed layer, the greater the potential for fracturing the interbeds.

Objective

The objective of this calculation is to determine the extent of the DRZ within the Salado anhydrite and polyhalite interbeds as a result of the creep of the surrounding salt. The definition of the DRZ within these interbeds was used in the fluid-flow consolidations reported in Appendix C.

Problem Description

The problem description and assumptions used in performing this calculation are the same as those presented in Section D4.1.2. The marker bed locations relative to the concrete seal components are shown in Figures D-7 and D-9. The deformational and strength properties of the anhydrite and polyhalite materials are given in Table D-15.

Results

The results are summarized in Figures D-24 and D-25, which show a calculated factor of safety against failure for the various anhydrite and polyhalite layers as a function of radial distance from the shaft after the shaft has been left open for 50 years.

For all interbeds, the factor of safety increases as the distance from the shaft wall increases. Further, with the exception of MB117, the factor of safety is greater than one (no DRZ) for all interbeds. For MB117, the failure (DRZ) is localized to within 1 m of the shaft wall.

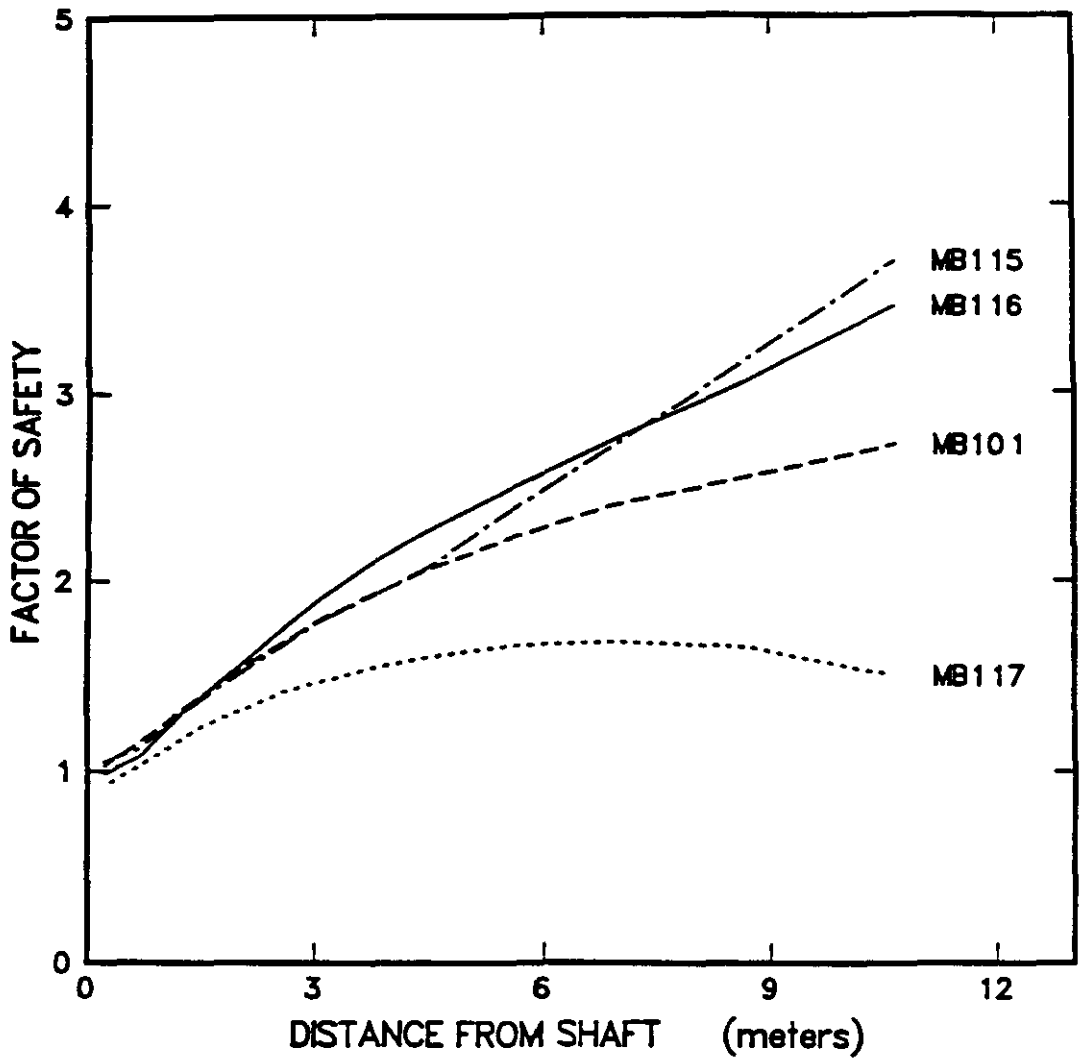

Figure D-24. Factor of safety in polyhalite beds at 50 years.

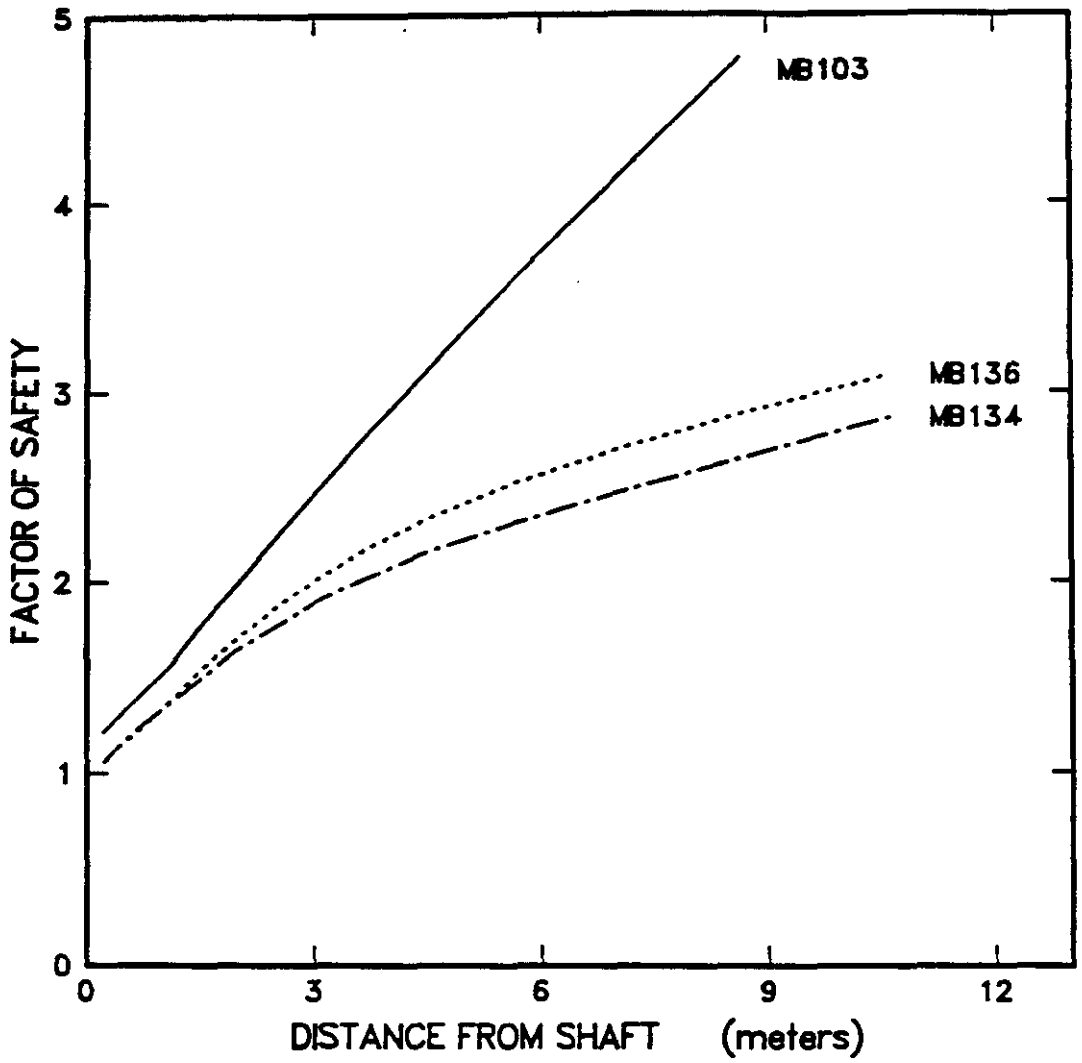

Figure D-25. Factor of safety in anhydrite beds at 50 years.

D5.2.3 Near Surface and Rustler Formations

The DRZ around a circular opening (such as a shaft) was estimated using analytical means. The extent of the DRZ in the formations above the Salado was calculated based on two criteria for rock failure. The shaft excavation superimposes an increment of damage or disturbance on any natural preexisting disturbance in the host rock. In the near-surface and Rustler formations at the WIPP, the development of the DRZ is assumed to be time-invariant; rock behavior is observed to be elastic.

Objective

The objective of this calculation is to determine the extent of the DRZ surrounding the shafts in the near-surface and Rustler formations. The rock types that compose these formations are anhydrite, dolomite, and mudstone and exhibit time-invariant behavior.

Problem Description

The rock surrounding the shafts can be divided into two regions: the DRZ region in which the rock fails (plastic region) and a region that behaves elastically. The geometry of the regions is defined as:

$$\begin{aligned} &\text{DRZ region:} \quad a \le r \le R \\ &\text{Elastic region:} \quad R \le r \le \infty \end{aligned} \tag{D-62}$$

where a is the shaft radius and R is the radius to the interface between the plastic and elastic regions. The radius R can be calculated so that the radial stress distribution is continuous across the interface and satisfies the boundary conditions at the shaft wall and the far field. Similarly, stress distributions in the plastic zone are assumed to just satisfy the failure criterion.

The Coulomb failure criterion accounts for the beneficial effect of confinement and says failures occur whenever:

$$\begin{aligned} &\sigma_1 - \sigma_3 \ge C_0 + \sigma_3(\tan\beta - 1) \\ &\tan\beta = \frac{1+\sin\phi}{1-\sin\phi} \end{aligned} \tag{D-63}$$

where ϕ is the angle of internal friction (Table D-16). The radius to the elastic/plastic interface based on the Coulomb failure criterion (Ladanyi, 1974) is:

$$\text{Coulomb:} \quad R/a = \left[\frac{P_0 + T_0 - mC_0}{T_0}\right]^{1/(\tan\beta - 1)} \tag{D-64}$$

where:

P_0 = far-field stress magnitude

T_0 = tensile strength = S_0 / tan ϕ (Table D-15)

C_0 = cohesion (Table D-15).

Because of scale effects, rock is seldom as strong in situ as laboratory strength tests indicate. This scale effect is shown, for example, by Goodman (1980), who suggests a factor of safety (strength reduction factor) of five for foundation designs. The in situ strength of the rock was determined by reducing the matrix strength (based on a literature survey of laboratory tested strengths) by a factor ranging from three to five. To span the uncertainty in the horizontal stress magnitude, the in situ (far-field) stress was taken to be a multiple of between one to two times the vertical stress. The intermediate value for each parameter was used as the likely parameter value for southeastern New Mexico. These parameters should result in a conservative estimate of the DRZ within these formations.

Results

The results of this calculation are shown in Figure D-26, which shows the radial extent of the DRZ as a function of depth. These results indicate that the DRZ is not present at depths less than 50 m and for the depth interval from 165 m to 213 m (principally, an anhydrite and dolomite interval). For the mudstones between 50 and 165 m and between 223 and 260 m, the radial extent of the DRZ increases with depth, reaching a maximum of 2.6 shaft radii at a depth of 260 m. The results of this analysis were used to define the initial conditions to the fluid-flow calculations predicted in Section 8.

D6. OTHER ANALYSES

This section discusses two supplementary analyses performed to support the shaft seal design: (1) the DRZ created by asphalt waterstops and (2) potential benefits from shaft station backfilling.

D6.1 Asphalt Waterstops

The DRZ is potentially a major contributor to fluid flows past a shaft seal, regardless of which seal materials are emplaced within the shaft. Therefore, to increase the confidence in the overall shaft seal system, low permeability layers (termed radial waterstops) intersect the DRZ surrounding the shaft to impede fluid flow. These waterstops are emplaced to alter the flow direction either inward toward the shaft seal or outward toward the intact salt. The waterstop effectively blocks the full cross section of the shaft and DRZ using a virtually impermeable material (asphalt). The waterstop is thin so that its height is small relative to its width (radius); a small ratio between height and width will concentrate the new DRZ at the edge of the waterstop. The extent of the new DRZ is small, so the area for fluid leakage past the waterstop is also small.

Objectives

The objectives of this calculation were (1) to estimate the additional damage introduced by excavating the radial slot in the shaft wall and (2) to analyze the potential for healing this induced DRZ.

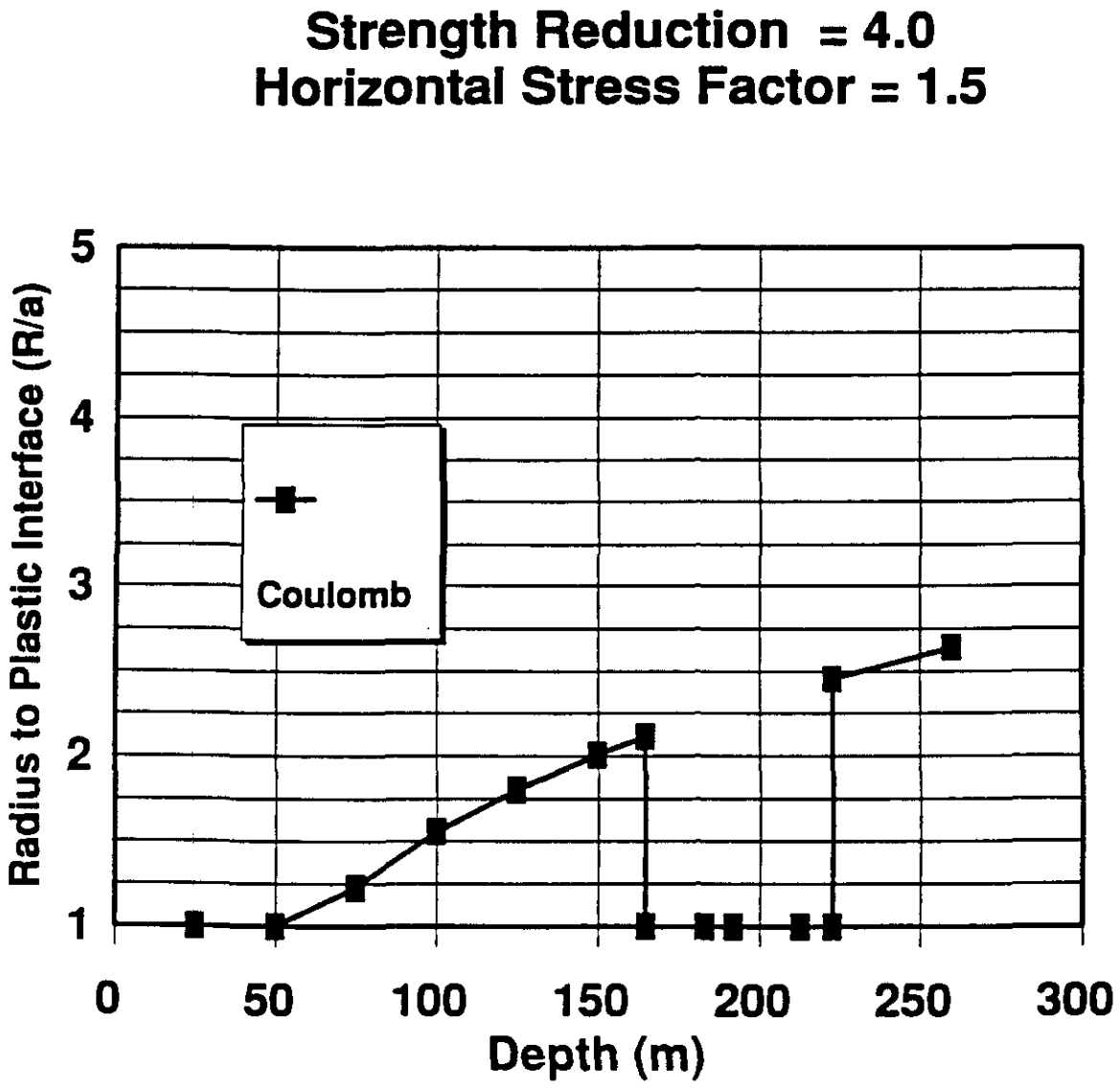

Figure D-26. Normalized DRZ radius for strength reduction factor of 4 and horizontal stress factor of 1.5.

Problem Description

The problem description and assumptions used in performing this calculation are the same as those presented in Section 4.1.2. The damage-stress criterion was used to indicate the spatial extent of the DRZ; i.e., zones with positive damage stress were assumed to be damaged and zones with negative damage stress were assumed to be either undamaged or healed. The rate of healing was assumed to be instantaneous; i.e., zones where the damage stress changed from positive to negative were assumed to be healed immediately.

Results

The results from analysis of the lower concrete component waterstop are presented here; the structural behavior of the other two waterstops is similar. Figures D-27, D-28, and D-29 show contours of damage stress surrounding the lower concrete component waterstop just before excavation of the waterstop, immediately after excavation, and 20 years after emplacement of the asphalt and concrete seals. Figure D-27 indicates that the DRZ before excavating the waterstop is contained spatially within the salt to a radial distance of less than one shaft radius (about 3 m). Figure D-28 indicates that the DRZ extends radially to approximately 1.4 shaft radii (4.3 m) into the salt as a result of the waterstop excavation. This extension of the DRZ is localized within the span of the concrete seals and approaches the waterstop kerf edge. The results shown in Figure D-29 indicate that the DRZ has reduced substantially in size as a result of emplacement of the concrete and asphalt seals and 20 years creep of the surrounding salt. After 20 years, the spatial extent of the DRZ is localized near the asphalt/concrete interface, extending spatially into the salt a distance of less than 2 m. For input to the fluid-flow calculations, a time of 2 years was estimated for the asphalt waterstop to become effective in terms of sealing off flow through the DRZ.

D6.2 Shaft Pillar Backfilling

The underground portion of the WIPP is quite small when compared to most salt and potash mines. Nonetheless, subsidence will occur as the underground openings close because of creep in the salt. The amount of subsidence depends on the volume of space remaining in the repository at the time of closure. The volume of space (void) will consist of empty access drifts, backfilled entries, and filled waste rooms. The waste rooms are expected to have a 63.8% porosity after accounting for the voids in the waste containers, voids between containers, and headspace in the room (Callahan and DeVries, 1991). Similarly, backfilled entries are expected to retain a porosity of about 40% following mechanical placement of salt backfill (backfill fractional density of 0.6). Subsidence of the ground around the shafts could conceivably disturb the shaft seals. Backfilling the entries in the shaft pillar would reduce the eventual subsidence.

Objective

The objective of this calculation was to assess the benefits of backfilling the shaft pillar in terms of reducing the subsidence of the shaft seal and therefore decreasing the potential for differential settlement within the seal.

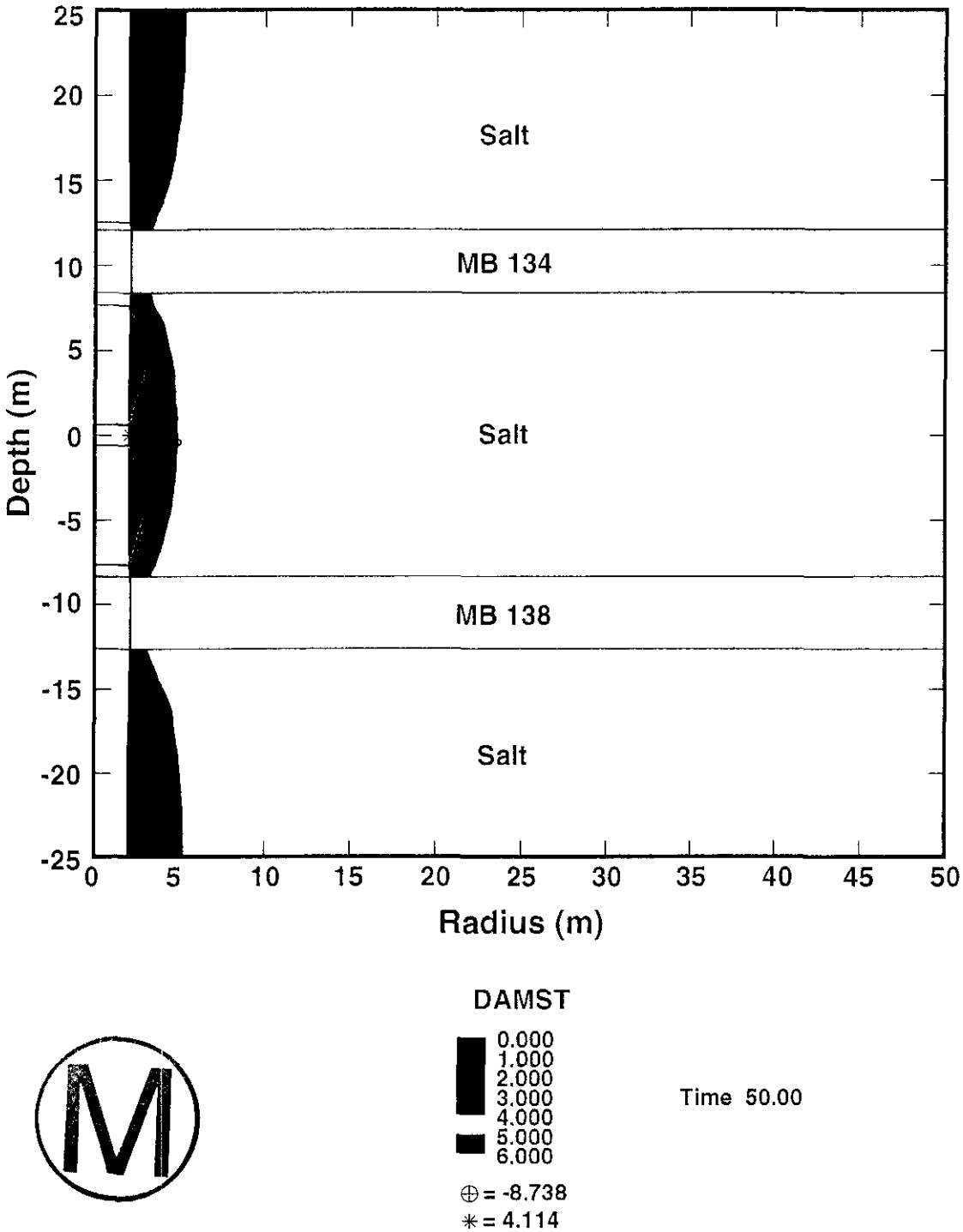

Figure D-27. Salt DRZ around the lower shaft seal at 50 years (prior to seal construction).

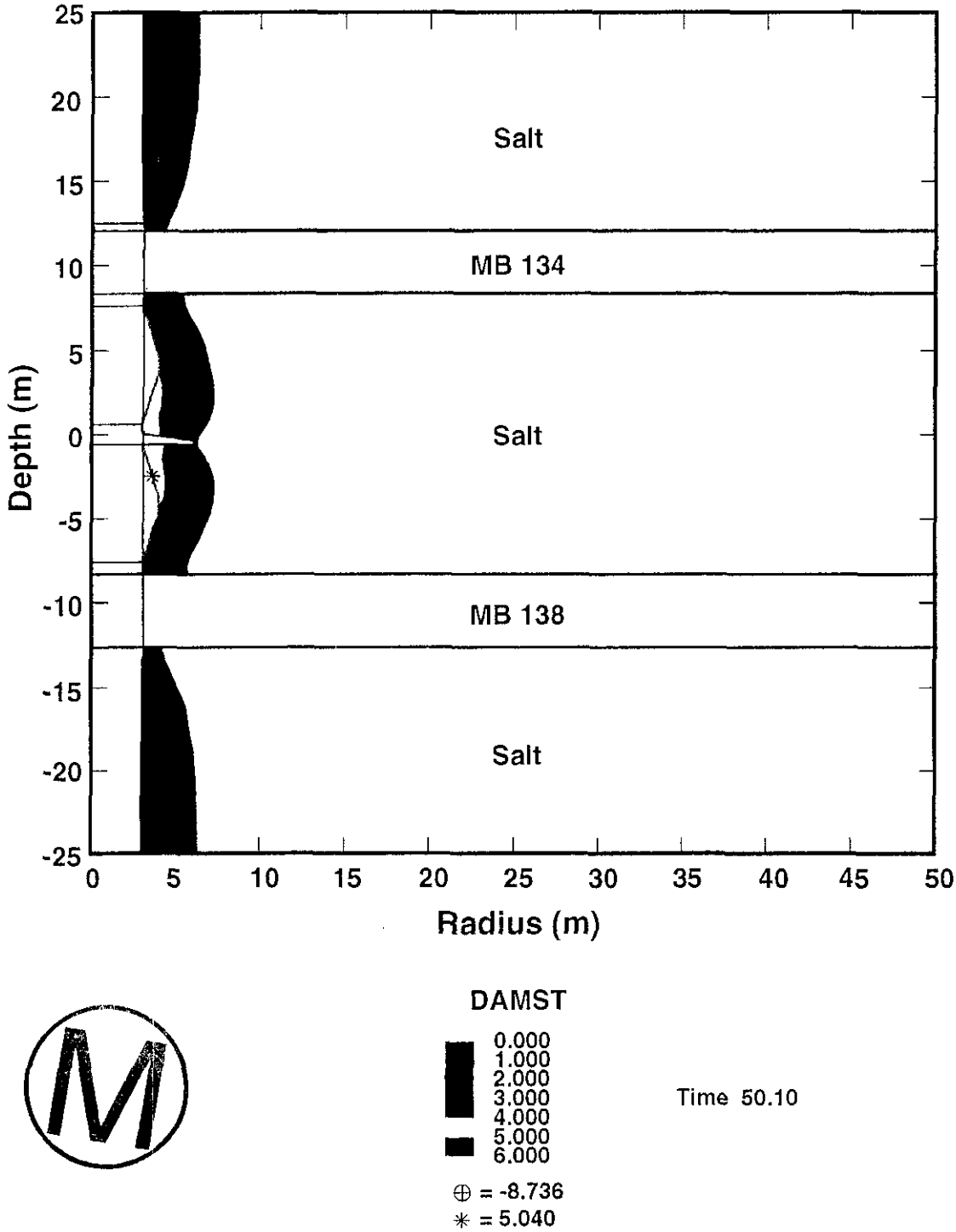

Figure D-28. Salt DRZ around the lower shaft seal at 50.1 years (after excavations but before seal construction).

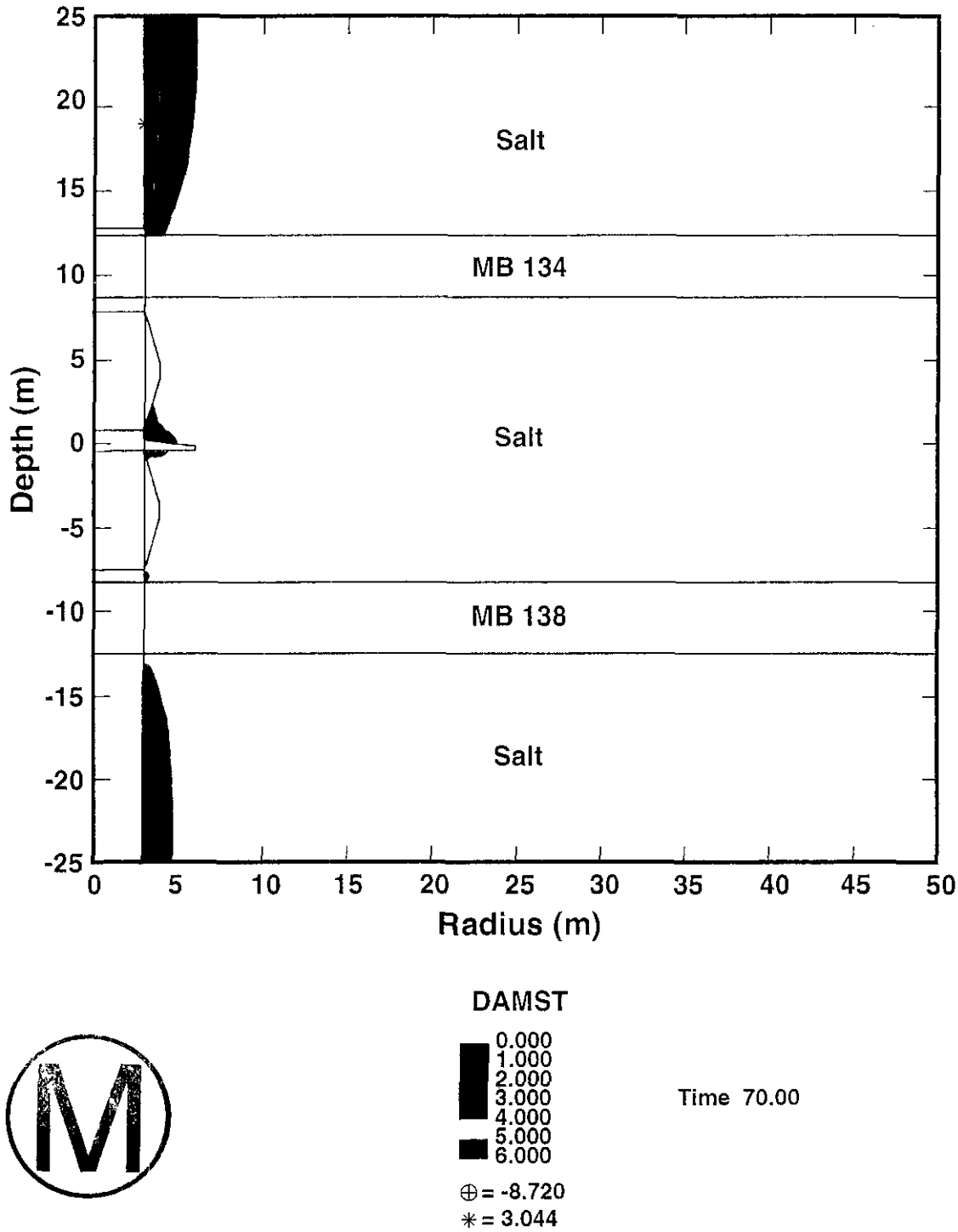

Figure D-29. Salt DRZ around the lower shaft seal at 20 years after seal construction.

Problem Description

The subsidence analysis for this calculation was performed using the computer program SALT_SUBSID, which is distributed by the Solution Mining Research Institute (Nieland, 1991). Mathematically, the numerical model is represented by:

$$S(x,y) = \sum_j F\left(x_j, y_j, D, A_j, V_j\right) \tag{D-65}$$

where S is the ultimate subsidence at the x, y coordinates of a point on the surface after total closure of the underground openings. The function $F(x_j, y_j, D, A, V_j)$ describes the spatial variation of ultimate subsidence for individual mining areas with centers at x_j, y_j, at depth D, of rectangular area A_j, and volume V_j. The spatial function, F, is based on the displacement discontinuity solution for the surface displacement after the closure of a rectangular prismatic opening in an elastic half space. The theoretical basis for the function was obtained from papers by Davis (1983).

The primary input to SALT_SUBSID is the underground opening geometries. The coordinates of the entries and rooms were taken from an AutoCad rendering of the WIPP site. The mining blocks used as input to the analysis are shown in Figure D-30. (The representation is sufficiently accurate for purposes of this calculation but not accurate to the extent that the individual coordinates can be relied on for any other purposes.)

Eight panels of waste rooms were represented in the subsidence model. The height of the waste rooms was set to 8.29 ft based on an excavated height of 13 ft and a filled waste-room porosity of 63.8%. The waste rooms are close enough to affect the surface subsidence at the shaft collars; they probably are not close enough to affect subsurface subsidence at the shaft seal locations.

Two backfilled areas were considered: backfilled areas of either 200 or 300-ft radius around each of the four shafts. To account for backfilling, the entry height was adjusted for any portion of the entries within the circular area around each shaft. The adjusted height was 4.33 ft based on an assumed backfill porosity of 30% and a nominal 1-ft headspace for the originally 12-ft-tall entries. For each scenario, the ultimate subsidence was calculated. This subsidence results from total closure of the shaft pillar workings.

Results

The ultimate subsidence was calculated for the three scenarios: no backfill in the shaft area, 61-m (200-ft) radius backfilled areas, and 91-m (300-ft) radius backfilled areas around the shafts. Over the shaft area, the ultimate surface subsidence is about 0.15 m (0.5 ft) or less depending on the backfill situation. Figure D-31 shows profiles of the ultimate subsidence over the shaft area; the profile is north-to-south, centered on the salt-handling shaft. The ultimate surface subsidence in the shaft area is reduced from 0.15 m (0.5 ft) for the no backfill condition to 0.13 m (0.44 ft) and 0.12 m (0.41 ft) by backfilling to 61 m and 91 m radii, respectively. As a matter of interest, the maximum subsidence for WIPP is centered over the waste panel area with a magnitude of 0.26 m (0.85 ft). The restriction in subsidence is not considered to be enough that it warrants backfilling the shaft pillar area.

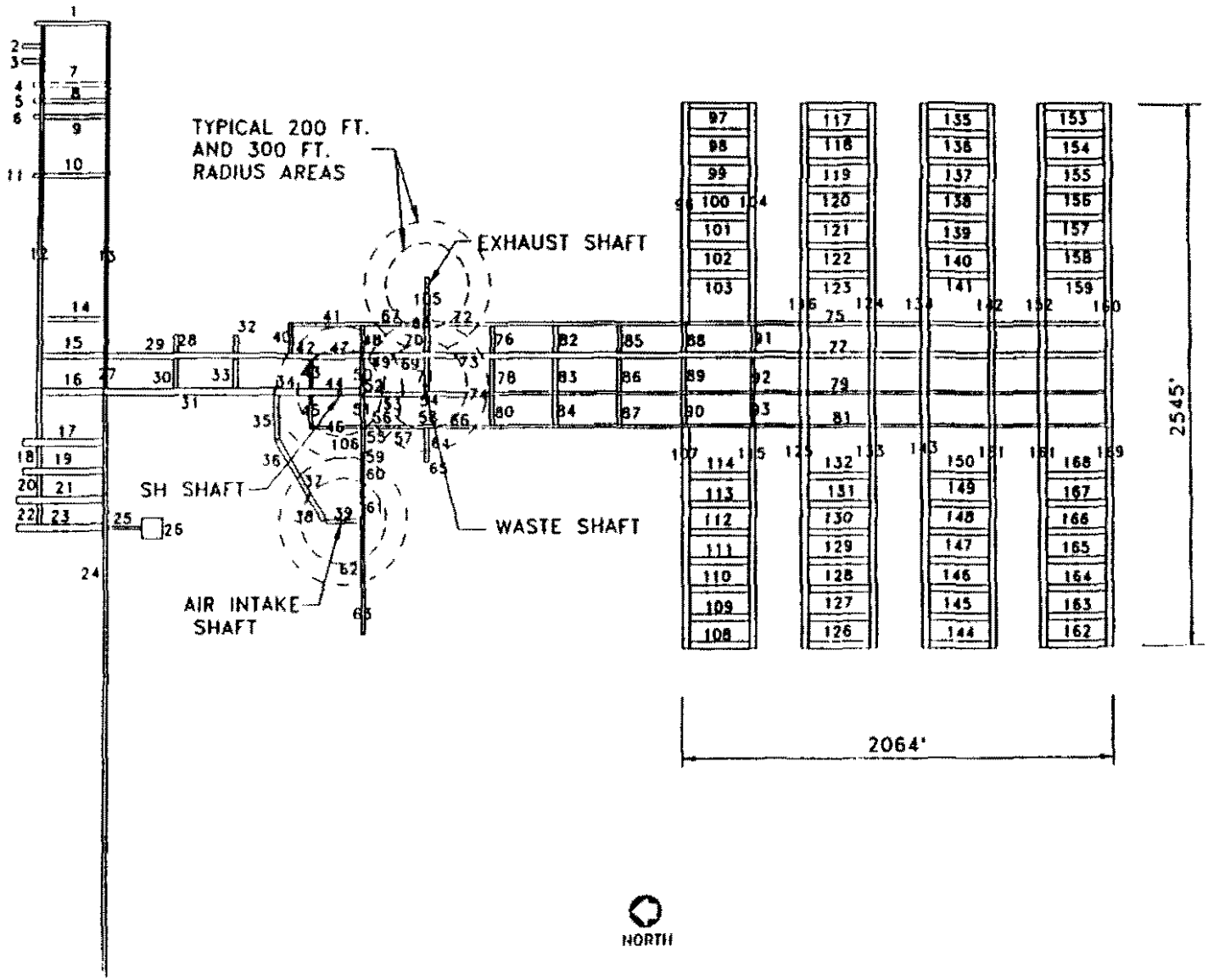

Figure D-30. Mining blocks used to represent WIPP underground workings.

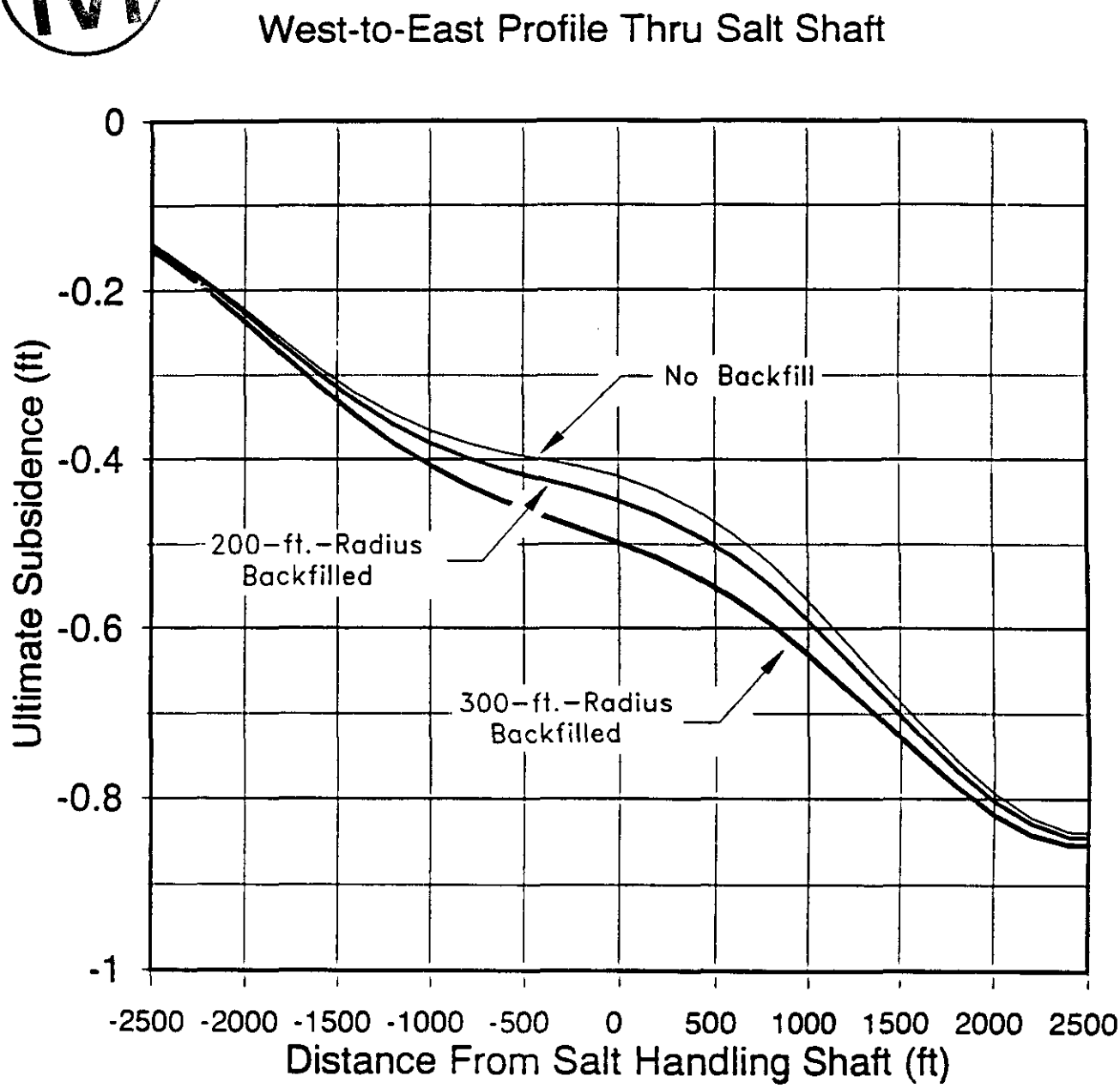

Figure D-31. Surface subsidence profiles over shaft area.

D7. REFERENCES

Andersen, P.J., M.E. Andersen, and D. Whiting. 1992. *A Guide to Evaluating Thermal Effects in Concrete Pavements*. SHRP-C/FR-92-101. Washington, DC: Strategic Highway Research Program, National Research Council.

ASTM D 4311 - 83 (R 1990). "Standard Practice for Determining Asphalt Volume Correction to a Base Temperature (R 1990)," *Annual Book of ASTM Standards, Volume 04.03, Road and Paving Materials; Pavement Management Technologies*. Philadelphia, PA: American Society for Testing and Materials. (Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, 215/299-5400.)

Brodsky, N.S. 1990. *Crack Closure and Healing Studies in WIPP Salt Using Compressional Wave Velocity and Attenuation Measurements: Test Methods and Results*. SAND90-7076. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM [SWCF] as WPO25755.)

Brodsky, N.S., and D.E. Munson. 1994. "Thermomechanical Damage Recovery Parameters for Rocksalt From the Waste Isolation Pilot Plant," *Rock Mechanics, Models and Measurements, Challenges from Industry: Proceedings of the 1st North American Rock Mechanics Symposium, University of Texas at Austin, Austin, TX, June 1-3, 1994*. Eds. P.P. Nelson and S.E. Laubach. Brookfield, VT: A.A. Balkema. 731-738. (Copy on file in the SWCF as WPO27175.)

Callahan, G.D. 1994. *SPECTROM-32: A Finite Element Thermomechanical Stress Analysis Program Version 4.06*. Topical Report RSI-0531. Rapid City, SD: RE/SPEC Inc. (Copy on file in the SWCF as WPO36814.)

Callahan, G.D., and K.L. DeVries. 1991. *Analyses of Backfilled Transuranic Wastes Disposal Rooms*. SAND91-7052. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO23990.)

Callahan, G.D., M.C. Loken, L.L. Van Sambeek, R. Chen, T.W. Pfeifle, J.D. Nieland, and F.D. Hansen. 1995a. *Evaluation of Potential Crushed-Salt Constitutive Models*. SAND95-2143. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO31068.)

Callahan, G.D., M.C. Loken, L.D. Hurtado, and F.D. Hansen. 1996. "Evaluation of Constitutive Models for Crushed Salt," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND96-0791C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO36449.)

Chan, K.S. 1993. "Time Dependent Interface of Bed Separation Fracture Process in Bedded Natural Salt Deposits," *Monthly Technical Report No. FY 93-6*. Prepared by Southwest Research Institute, San Antonio, TX for Sandia National Laboratories, Albuquerque, NM. (Copy on file in SWCF as WPO21030.)

Chan, K.S. 1994a. "Further Development of Fracture Constitutive Model for Rock Salt," *Monthly Technical Report No. FY 93-12*. Prepared by Southwest Research Institute, San Antonio, TX, for Sandia National Laboratories, Albuquerque, NM, January 15, 1993[sic]. (Copy on file in the SWCF as WPO21086.)

Chan, K.S. 1994b. "Further Development of Fracture Constitutive Model for Rock Salt," *Monthly Technical Report No. FY 94-1*. Prepared by Southwest Research Institute, San Antonio, TX, for Sandia National Laboratories, Albuquerque, NM, February 14, 1993[sic]. (Copy on file in the SWCF as WPO21087.)

Chan, K.S., S.R. Bodner, A.F. Fossum, and D.E. Munson. 1992. "A Constitutive Model for Inelastic Flow and Damage Evolution in Solids Under Triaxial Compression," *Mechanics of Materials*. Vol. 14, no. 1, 1-14. (Copy on file in the SWCF as WPO29289.)

Chan, K.S., S.R. Bodner, A.F. Fossum, and D.E. Munson. 1995a. "Constitutive Representation of Damage Healing in WIPP Salt," *Rock Mechanics, Proceedings of the 35th U.S. Symposium, University of Nevada, Reno, NV, June 5-7, 1995*. Eds. J.J.K. Daemen and R.A. Schultz. Brookfield, VT: A.A. Balkema. 485-490. (Copy on file in the SWCF as WPO23774.)

Chan, K.S., D.E. Munson, A.F. Fossum, and S.R. Bodner. 1995b. "Inelastic Flow Behavior of Argillaceous Salt," *International Journal of Damage Mechanics*. SAND94-3017J. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO22199.)

Costin, L.S., and W.R. Wawersik. 1980. *Creep Healing of Fractures in Rock Salt*. SAND80-0392. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO26748.)

Dale, T., and L.D. Hurtado. 1996. "WIPP Air-Intake Shaft Disturbed-Rock Zone Study," *4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND96-1327C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

Davis, P.M. 1983. "Surface Deformation Associated With a Dipping Hydrofracture," *Journal of Geophysical Research*. Vol. 88, no. B7, 5826-5834. (Copy on file in the SWCF.)

DOE (U.S. Department of Energy). 1995. *Waste Isolation Pilot Plant Sealing System Design Report*. DOE/WIPP-95-3117. Carlsbad, NM: U.S. Department of Energy, Waste Isolation Pilot Plant. (Copy on file in the SWCF as WPO29062.)

Goodman, R.E. 1980. *Introduction to Rock Mechanics*. New York, NY: John Wiley & Sons. 85-88, 310-311. (Copy on file in the SWCF as microfilm NNA.910315.0132.)

Knowles, M.K., D. Borns, J. Fredrich, D. Holcomb, R. Price, D. Zeuch, T. Dale, and R.S. Van Pelt. 1996. "Testing the Disturbed Zone Around a Rigid Inclusion in Salt," *4th Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996*. SAND95-1151C. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

Krieg, R.D. 1984. *Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project*. SAND83-1908. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24519.)

Ladanyi, B. 1974. "Use of the Long-Term Strength Concept in the Determination of Ground Pressure on Tunnel Linings," *Advances in Rock Mechanics, Proceedings of the Third Congress of the International Society for Rock Mechanics, Denver, CO, September 1-7, 1974*. Washington, DC: National Academy of Sciences. Vol. 2, pt. B, 1150–1156. (Copy on file in the SWCF.)

Lambe, T.W., and R.V. Whitman. 1969. *Soil Mechanics*. New York, NY: John Wiley & Sons. (Copy on file in the SNL Technical Library.)

Morgan, H.S., M. Wallner, and D.E. Munson. 1987. *Results of an International Parallel Calculations Exercise Comparing Creep Responses Predicted with Three Computer Codes for Two Excavations in Rock Salt*. SAND87-2125. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO24110.)

Munson, D.E., A.F. Fossum, and P.E. Senseny. 1989. *Advances in Resolution of Discrepancies Between Predicted and Measured In Situ WIPP Room Closures*. SAND88-2948. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO27882.)

Nieland, J.D. 1991. "SALT_SUBSID: A PC-Based Subsidence Model, User's Manual." Topical Report RSI-0389. Prepared for the Solution Mining Research Institute, Woodstock, IL. Rapid City, SD: RE/SPEC Inc. (Copy on file in the SWCF.)

Pfeifle, T.W., and N.S. Brodsky. 1991. *Swelling Pressure, Water Uptake, and Permeability of 70/30 Crushed Salt/Bentonite*. SAND91-7070. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO25438.)

Sass, J.H., A.H. Lachenbruch, R.J. Munroe, G.W. Greene, and T.H. Moses, Jr. 1971. "Heat Flow in the Western United States," *Journal of Geophysical Research*. Vol. 76, no. 26, 6376-6413. (Copy on file in the SWCF.)

Silling, S.A. 1983. *Final Technical Position on Documentation of Computer Codes for High-Level Waste Management*. NUREG-0856. Washington, D.C.: Division of Waste Management, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission. (Copy on file in the SWCF.)

Sjaardema, G.D., and R. D. Krieg. 1987. *A Constitutive Model for the Consolidation of WIPP Crushed Salt and Its Use in Analyses of Backfilled Shaft and Drift Configurations*. SAND87-1977. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO27693.)

Svalstad, D.K. 1989. *Documentation of SPECTROM-41: A Finite Element Heat Transfer Analysis Program; Revision 0*. DOE/CH/10378-1, RSI-0266. Prepared by RE/SPEC Inc., Rapid City, SD. Argonne, IL: U.S. Department of Energy, Chicago Operations Office. (Copy available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA, 22161, 703/487-4650. Order number: DE90000683/XAB.)

Van Sambeek, L.L. 1986. "Creep of Rock Salt Under Inhomogeneous Stress Conditions." Ph.D. dissertation. Golden, CO: Colorado School of Mines. (Dissertation available from Colorado School of Mines Library, Golden, CO.)

Van Sambeek, L.L., D.D. Luo, M.S. Lin, W. Ostrowski, and D. Oyenuga. 1993a. *Seal Design Alternatives Study*. SAND92-7340. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO23445.)

Van Sambeek, L.L., J.L. Ratigan, and F.D. Hansen. 1993b. "Dilatancy of Rock Salt in Laboratory Tests," *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, Rock Mechanics in the 1990s, 34th U.S. Symposium on Rock Mechanics, University of Wisconsin, Madison, WI,* June *27-30, 1993.* Vol. 30, no. 7, 735-738. (Copy on file in the SWCF.)

Wakeley, L.D., J.J. Ernzen, B.D. Neeley, and F.D. Hansen. 1994. *Salado Mass Concrete: Mixture Development and Preliminary Characterization.* SAND93-7066. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF as WPO10671.)

Yoder, E.J., and M.W. Witczak. 1975. *Principles of Pavement Design*. 2nd ed. New York, NY: John Wiley & Sons.

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Waste Isolation Pilot Plant Shaft Sealing System Compliance Submittal Design Report

Volume 2 of 2: Appendix E

Repository Isolation Systems Department

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-94AL85000

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Waste Isolation Pilot Plant Shaft Sealing System Compliance Submittal Design Report

Volume 2 of 2: Appendix E

Repository Isolation Systems Department
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

This is the second volume of a two-volume report describing a shaft sealing system design for the Waste Isolation Pilot Plant. This appendix contains detailed drawings of the shaft sealing system and its components.

WASTE ISOLATION PILOT PLANT

CARLSBAD, NM

SHAFT SEALING SYSTEM DESIGN

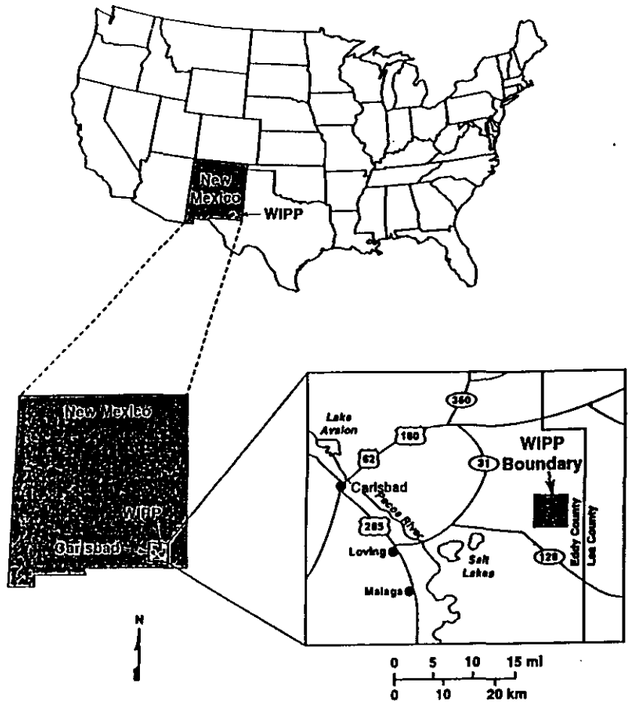

DESIGN DRAWINGS

DRAWING NUMBER	TITLE
SNL-007 1 OF 28	WIPP SHAFT SEALING SYSTEM SHAFT LOCATION PLAN, ABBREVIATIONS, GENERAL NOTES AND LEGEND
SNL-007 2 OF 28	WIPP SHAFT SEALING SYSTEM NEAR-SURFACE/RUSTLER FORMATIONS WASTE SHAFT STRATIGRAPHY & AS-BUILT ELEMENTS
SNL-007 3 OF 28	WIPP SHAFT SEALING SYSTEM SALADO FORMATION WASTE SHAFT STRATIGRAPHY & AS-BUILT ELEMENTS
SNL-007 4 OF 28	WIPP SHAFT SEALING SYSTEM NEAR-SURFACE/RUSTLER FORMATIONS WASTE SHAFT STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
SNL-007 5 OF 28	WIPP SHAFT SEALING SYSTEM SALADO FORMATION WASTE SHAFT STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
SNL-007 6 OF 28	WIPP SHAFT SEALING SYSTEM WASTE SHAFT SHAFT STATION MONOLITH
SNL-007 7 OF 28	WIPP SHAFT SEALING SYSTEM NEAR-SURFACE/RUSTLER FORMATIONS AIR INTAKE SHAFT STRATIGRAPHY & AS-BUILT ELEMENTS
SNL-007 8 OF 28	WIPP SHAFT SEALING SYSTEM SALADO FORMATION AIR INTAKE SHAFT STRATIGRAPHY & AS-BUILT ELEMENTS
SNL-007 9 OF 28	WIPP SHAFT SEALING SYSTEM NEAR-SURFACE/RUSTLER FORMATIONS AIR INTAKE SHAFT STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
SNL-007 10 OF 28	WIPP SHAFT SEALING SYSTEM SALADO FORMATION AIR INTAKE SHAFT STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
SNL-007 11 OF 28	WIPP SHAFT SEALING SYSTEM AIR INTAKE SHAFT SHAFT STATION MONOLITH
SNL-007 12 OF 28	WIPP SHAFT SEALING SYSTEM NEAR-SURFACE/RUSTLER FORMATIONS EXHAUST SHAFT STRATIGRAPHY & AS-BUILT ELEMENTS
SNL-007 13 OF 28	WIPP SHAFT SEALING SYSTEM SALADO FORMATION EXHAUST SHAFT STRATIGRAPHY & AS-BUILT ELEMENTS
SNL-007 14 OF 28	WIPP SHAFT SEALING SYSTEM NEAR-SURFACE/RUSTLER FORMATIONS EXHAUST SHAFT STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
SNL-007 15 OF 28	WIPP SHAFT SEALING SYSTEM SALADO FORMATION EXHAUST SHAFT STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
SNL-007 16 OF 28	WIPP SHAFT SEALING SYSTEM EXHAUST SHAFT SHAFT STATION MONOLITH
SNL-007 17 OF 28	WIPP SHAFT SEALING SYSTEM NEAR-SURFACE/RUSTLER FORMATIONS SALT HANDLING SHAFT STRATIGRAPHY & AS-BUILT ELEMENTS
SNL-007 18 OF 28	WIPP SHAFT SEALING SYSTEM SALADO FORMATION SALT HANDLING SHAFT STRATIGRAPHY & AS-BUILT ELEMENTS
SNL-007 19 OF 28	WIPP SHAFT SEALING SYSTEM NEAR-SURFACE/RUSTLER FORMATIONS SALT HANDLING SHAFT STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
SNL-007 20 OF 28	WIPP SHAFT SEALING SYSTEM SALADO FORMATION SALT HANDLING SHAFT STRATIGRAPHY & SEALING SUBSYSTEM PROFILE
SNL-007 21 OF 28	WIPP SHAFT SEALING SYSTEM SALT HANDLING SHAFT SHAFT STATION MONOLITH
SNL-007 22 OF 28	WIPP SHAFT SEALING SYSTEM CONCRETE-ASPHALT WATERSTOP IN SALADO FORMATION
SNL-007 23 OF 28	WIPP SHAFT SEALING SYSTEM ASPHALT COLUMN
SNL-007 24 OF 28	WIPP SHAFT SEALING SYSTEM UPPER AND LOWER SALADO COMPACTED CLAY COLUMNS
SNL-007 25 OF 28	WIPP SHAFT SEALING SYSTEM COMPACTED SALT COLUMN
SNL-007 26 OF 28	WIPP SHAFT SEALING SYSTEM CONCRETE PLUG
SNL-007 27 OF 28	WIPP SHAFT SEALING SYSTEM RUSTLER COMPACTED CLAY COLUMN
SNL-007 28 OF 28	WIPP SHAFT SEALING SYSTEM COMPACTED EARTHEN FILL AND CONCRETE PLUG

WIPP LAYOUT

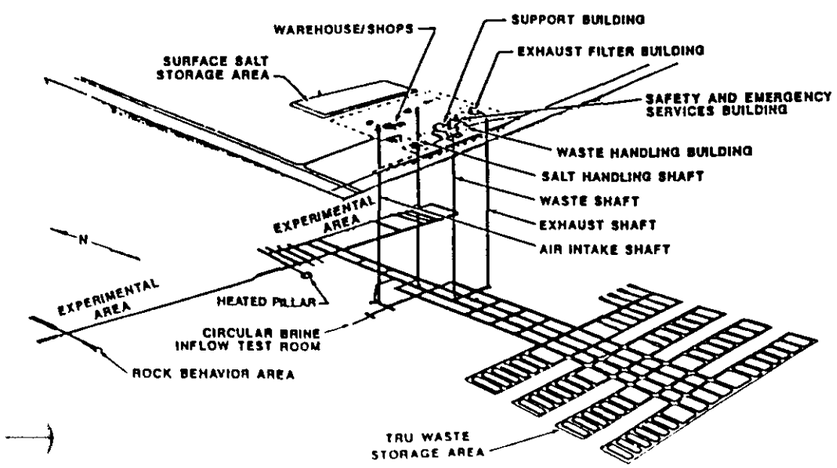

2-18-98
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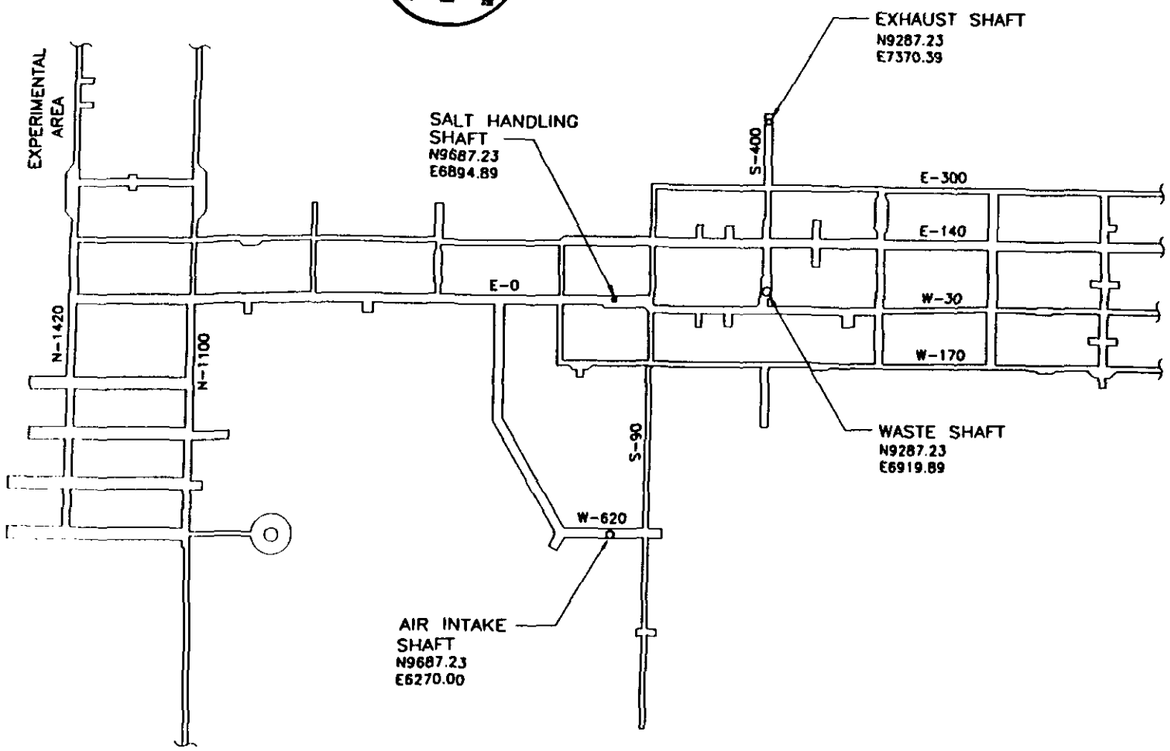

SHAFT SEALS LOCATION PLAN

N

SCALE IN FEET
0 100 200 300 400 500

GENERAL NOTES:

1. THE DRIFT NUMBERING SYSTEM (E-300, S-400, ETC.) IS BASED ON THE DIRECTION AND NOMINAL DISTANCE IN FEET THE DRIFT IS FROM THE SALT HANDLING SHAFT'S DESIGNATED CENTERLINE LOCATION OF N-000, E-000. THE WIPP PLANT COORDINATE SYSTEM CENTERLINE LOCATION FOR THE SALT HANDLING SHAFT IS N9687.23, AND E6894.89. THE PLANT COORDINATE SYSTEM IS DESCRIBED IN WESTINGHOUSE DRAWING NO. 51-W-109-W, UNDERGROUND EXCAVATIONS, DATED 6/15/92.

2. THE AS-BUILT DIMENSIONS AND DEPTHS AND/OR ELEVATIONS SHOWN IN THESE DRAWINGS ARE NOMINAL IN THAT DIMENSIONS MAY CHANGE DUE TO LOCAL VARIANCE OF THE STRATIFICATION, OPERATIONAL MODIFICATIONS MADE TO SUIT THE CREEP CLOSURE OF THE HALITE, AND OTHER OPERATIONAL REQUIREMENTS. THEREFORE THE AS-BUILT DIMENSIONS AND THE PERTINENT ELEVATIONS FOR SITING THE SEALING SYSTEM SHALL BE VERIFIED BY FIELD SURVEYING AND EXPLORATORY CORE DRILLING DURING SITE PREPARATION FOR THE FINAL CONSTRUCTION.

3. DRAWING NUMBERS:
   FOR CLARITY ON DETAIL AND SECTION DESIGNATIONS, AND NOTES, ONLY THE SHEET NUMBER IS SHOWN.

LEGEND FOR PROPOSED SHAFT SEALING SYSTEM:

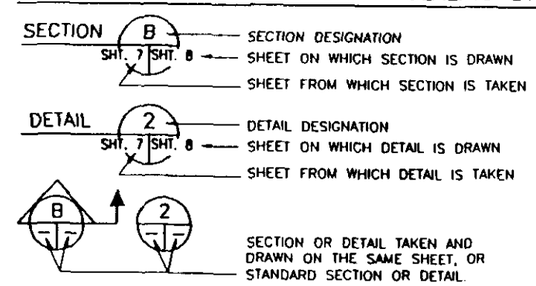

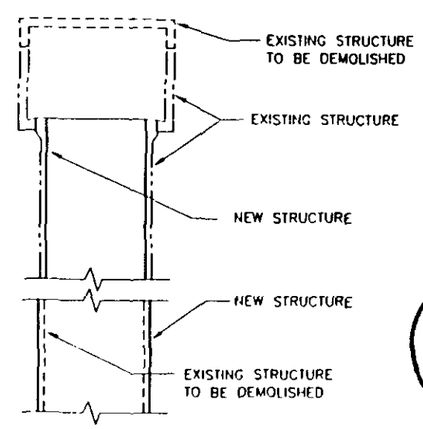

ABBREVIATIONS:

℄	CENTERLINE
ANH.	ANHYDRITE
CMP	CORRUGATED METAL PLATE
CONC.	CONCRETE
DOE	DEPARTMENT OF ENERGY
DWG.	DRAWING
E	EAST
EL.	ELEVATION
EXIST.	EXISTING
FT.	FOOT, FEET
HT.	HEIGHT
I.D.	INSIDE DIAMETER
IN.	INCHES
MB	MARKER BED
MIN.	MINIMUM
MSL	MEAN SEA LEVEL
N	NORTH
NO.	NUMBER
R	RADIUS
S	SOUTH
SHT.	SHEET NUMBER
SMC	SALADO MASS CONCRETE
TYP.	TYPICAL
USGS	UNITED STATES GEOLOGICAL SURVEY
W	WEST
WID	WESTINGHOUSE WASTE ISOLATION DIVISION
WIPP	WASTE ISOLATION PILOT PLANT

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

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WIPP A/E SUPPORT

CONTRACT NO: AC-4909

WIPP SHAFT SEALING SYSTEM

SHAFT LOCATION PLAN, ABBREVIATIONS, GENERAL NOTES AND LEGEND

	NAME	DATE
BY		8/2/96
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E4

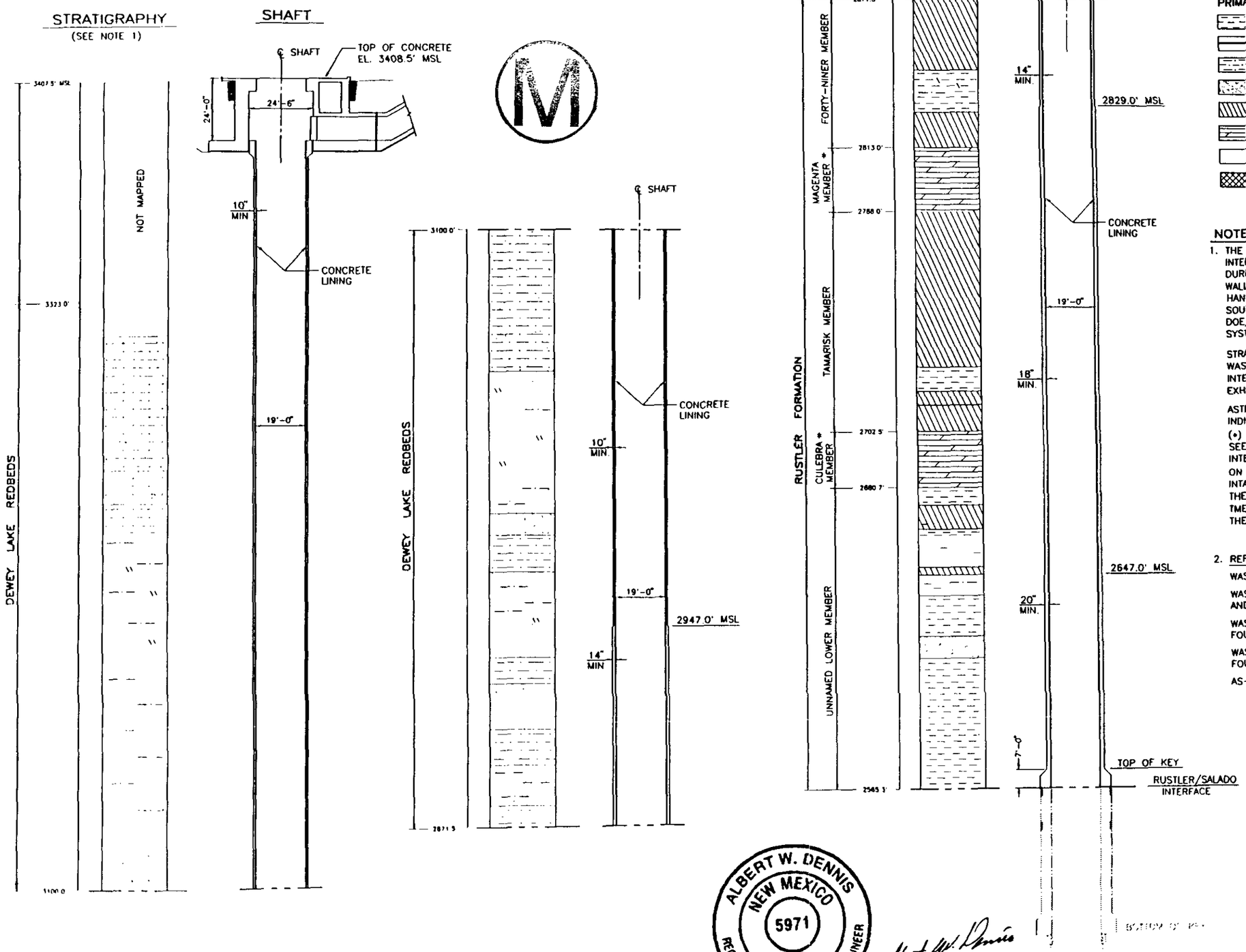

LITHOLOGY:

PRIMARY ROCK/SEDIMENT TYPES	SECONDARY CONSTITUENTS
MUDSTONE/CLAYSTONE	ARGILLACEOUS
CLAYSTONE BED	SILTY
SILTSTONE	SANDY
SANDSTONE	SULFATIC
ANHYDRITE/GYPSUM	DOLOMITIC
DOLOMITE	CALCAREOUS
HALITE	HALITIC
POLYHALITE	POLYHALITIC

NOTES:

1. THE STRATIGRAPHY AND GROUNDWATER BRINE SEEPAGE/WEEP INTERVALS ARE BASED ON THE LITHOLOGIC INFORMATION COMPILED DURING THE GEOLOGIC MAPPING OF THE WASTE HANDLING SHAFT WALLS, WTSD-TME 038, "GEOTECHNICAL ACTIVITIES IN THE WASTE HANDLING SHAFT WASTE ISOLATION PILOT PLANT (WIPP) PROJECT SOUTHEASTERN NEW MEXICO," 1984, AND APPENDIX A OF REPORT DOE/WIPP-95-3117, "WASTE ISOLATION PILOT PLANT SEALING SYSTEM DESIGN REPORT," 1995.

   STRATIGRAPHIC CONTACT AT THE TOP OF THE DEWEY LAKE REDBEDS WAS NOT RECORDED DURING MAPPING. ELEVATION SHOWN IS INTERPRETED FROM RECORDINGS OF THE SALT HANDLING AND EXHAUST SHAFTS.

   ASTERISK (*) WITHIN THE RUSTLER AND SUPRA RUSTLER FORMATIONS INDICATE GROUNDWATER OBSERVED DURING SHAFT MAPPING. ASTERISK (*) WITHIN THE SALADO FORMATION INDICATES A POTENTIAL BRINE SEEPAGE/WEEP INTERVAL. THESE POTENTIAL BRINE SEEPAGE/WEEP INTERVALS, LOCATED ABOVE THE SHAFT STATION LEVEL, ARE BASED ON OBSERVED INTERVALS OF BRINE SEEPAGE/WEEPS IN THE AIR INTAKE SHAFT THAT HAVE BEEN PROJECTED TO THE WASTE SHAFT. THE MAPPING OF THE WASTE SHAFT (HOLT & POWERS, 1984/WTSD-TME-038) DID NOT INDICATE OBSERVED SEEPAGE INTERVALS WITHIN THE SALADO FORMATION.

2. REFERENCE AS-BUILT DRAWINGS FROM WID:

WASTE SHAFT 311 SHAFT DEVELOPMENT SECTIONS	31-R-001-01D
WASTE SHAFT 311 SHAFT LINING & KEY SECTIONS AND DETAILS	31-R-002-01D
WASTE HANDLING BUILDING 411 HOIST TOWER FOUNDATION PLANS, ELEVATIONS, 76'-0" & 89'-0"	41-D-016-014
WASTE HANDLING BUILDING 411 HOIST TOWER FOUNDATION SECTIONS	41-D-018-014
AS-BUILT FOR WASTE SHAFT COLLAR	OGL A-001

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WIPP SHAFT SEALING SYSTEM
NEAR-SURFACE/RUSTLER FORMATIONS
WASTE SHAFT
STRATIGRAPHY &
AS-BUILT ELEMENTS

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 2 OF 28

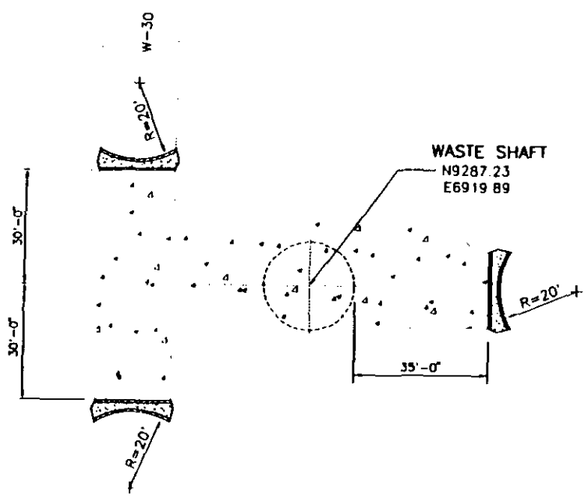

E-140

S-400

SECTION A

N

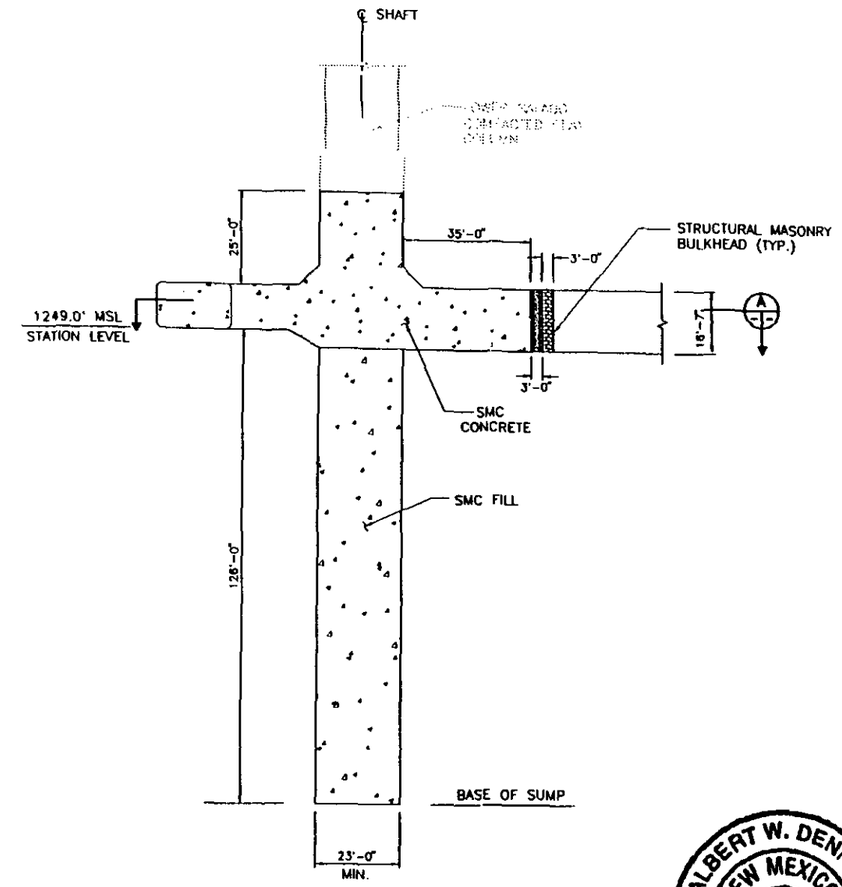

DETAIL 1

SHT. 5 SHT. 6

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REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

NOTES:

1 SEE SHT 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS

SCALE IN FEET

0 10 20 30 40 50

REV.	DATE	DESCRIPTION	BY	CK.	APP
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WIPP A/E SUPPORT

CONTRACT NO AC-4909

WIPP SHAFT SEALING SYSTEM

WASTE SHAFT
SHAFT STATION MONOLITH

	NAME	DATE
BY		8/1/96
CK		8/2/96
APP		8-2-96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 6 OF 28

E-9

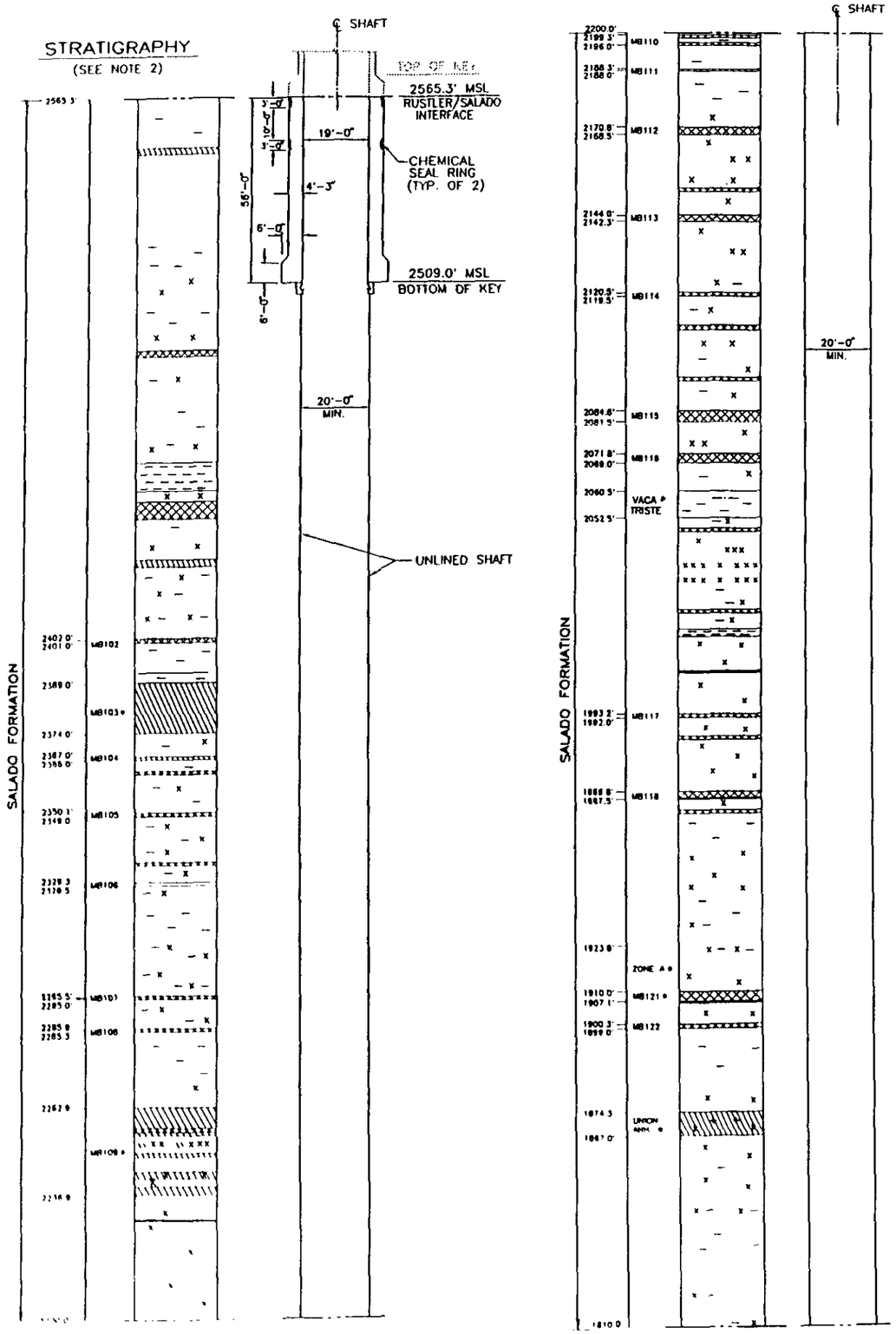

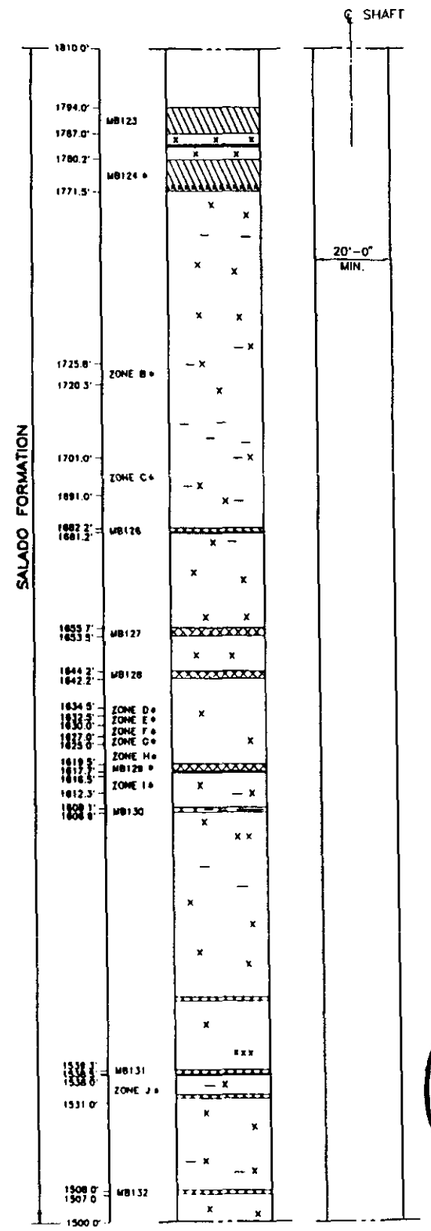

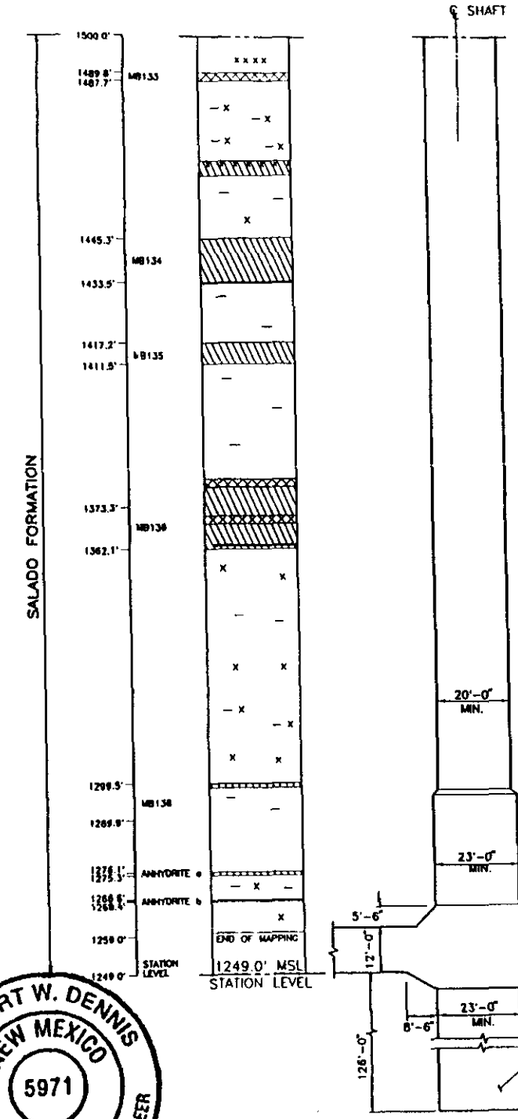

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8-2-96

NOTES:

1 SEE SHT 1 FOR GENERAL NOTES AND ABBREVIATIONS

2 SEE SHT 2 FOR LITHOLOGY AND NOTES

SCALE IN FEET
0 10 20 30 40 50

REV	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

WIPP SHAFT SEALING SYSTEM
SALADO FORMATION
WASTE SHAFT
STRATIGRAPHY &
AS-BUILT ELEMENTS

CONTRACT NO: AG-4909

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC | SCALE | SIZE B | DWG NO SNL-007 | SHEET NO 3 OF 28

E-6

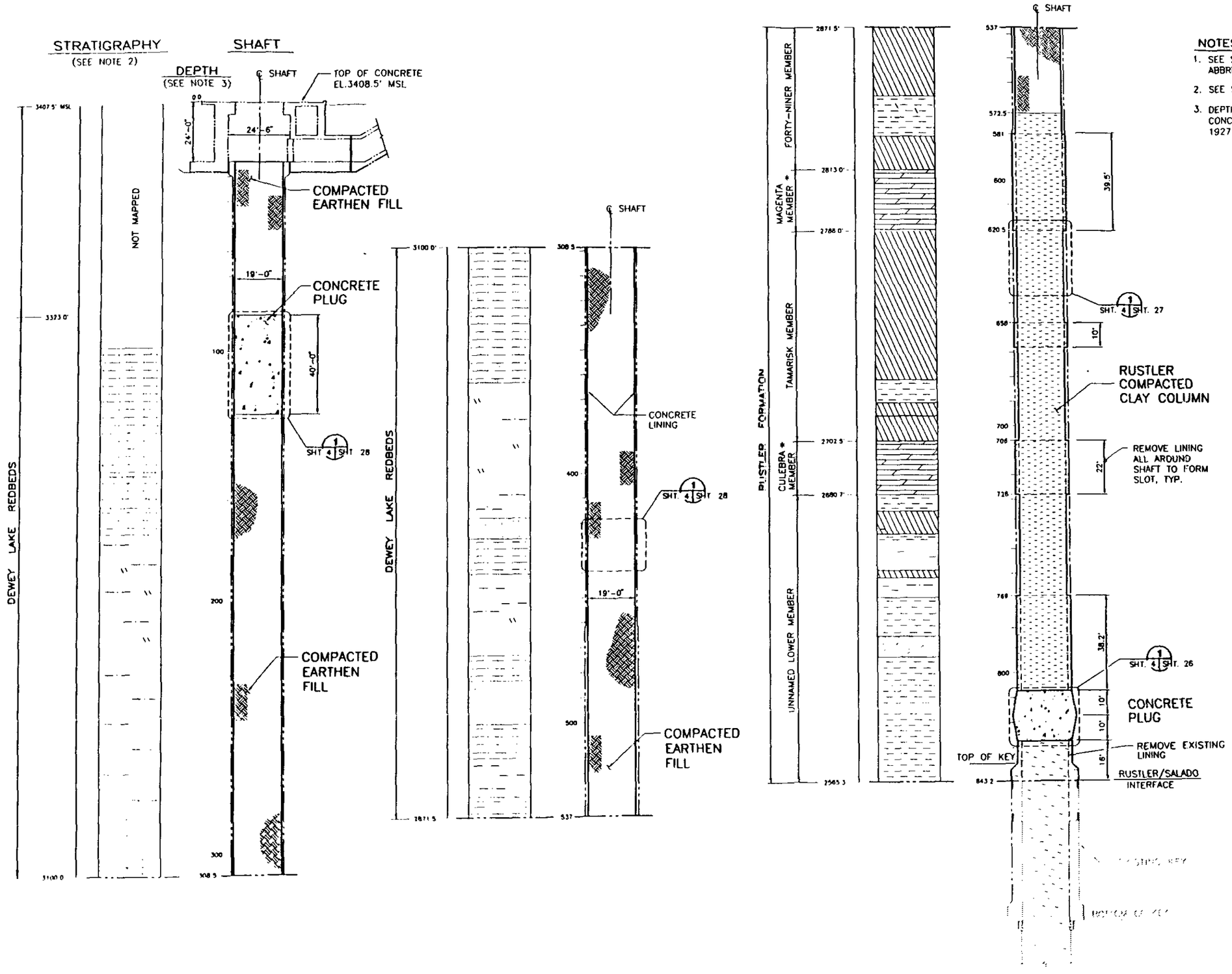

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS.
2. SEE SHT. 2 FOR LITHOLOGY AND NOTES.
3. DEPTHS SHOWN ARE DISTANCES BELOW THE TOP OF CONCRETE, LOCATED AT EL. 3408.5' ABOVE MSL USGS 1927 NORTH AMERICAN DATUM.

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

SCALE IN FEET
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WIPP A/E SUPPORT

WIPP SHAFT SEALING SYSTEM
NEAR-SURFACE/RUSTLER FORMATIONS
WASTE SHAFT
STRATIGRAPHY & SEALING
SUBSYSTEM PROFILE

CONTRACT NO AG-4909

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 4 OF 28

E-7

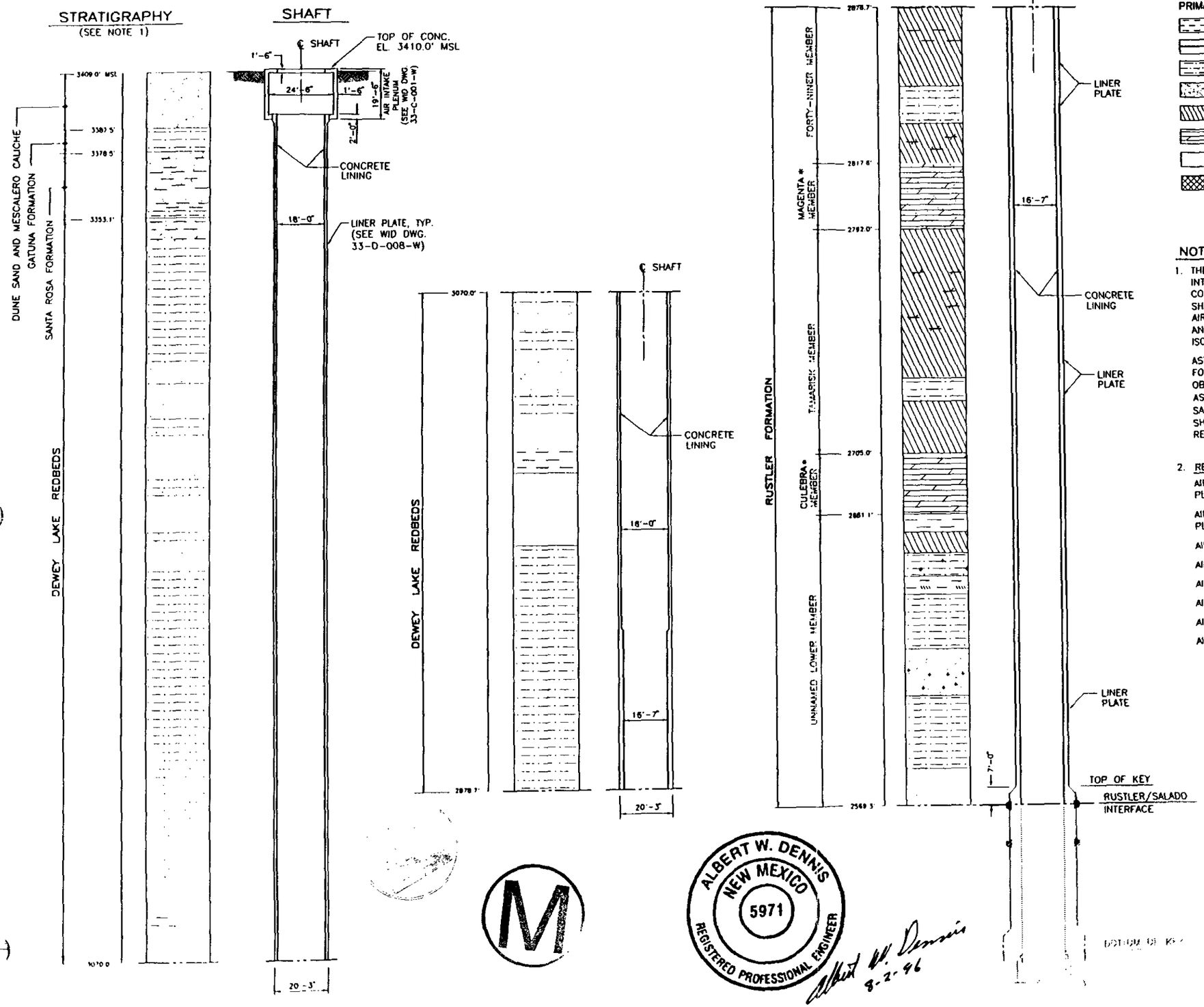

LITHOLOGY:

PRIMARY ROCK/SEDIMENT TYPES	SECONDARY CONSTITUENTS
MUDSTONE/CLAYSTONE	ARGILLACEOUS
CLAYSTONE BED	SILTY
SILTSTONE	SANDY
SANDSTONE	SULFATIC
ANHYDRITE/GYPSUM	DOLOMITIC
DOLOMITE	CALCAREOUS
HALITE	HALITIC
POLYHALITE	POLYHALITIC
	LANGBEINITE

NOTES:

1. THE STRATIGRAPHY AND GROUNDWATER BRINE SEEPAGE/WEEP INTERVALS ARE BASED ON THE LITHOLOGIC INFORMATION COMPILED DURING THE GEOLOGIC MAPPING OF THE AIR INTAKE SHAFT WALLS, DOE/WIPP-90-051, "GEOLOGIC MAPPING OF THE AIR INTAKE SHAFT AT THE WASTE ISOLATION PILOT PLANT", 1990, AND APPENDIX A OF REPORT DOE/WIPP-95-3117, "WASTE ISOLATION PILOT PLANT SEALING SYSTEM DESIGN REPORT", 1995.

   ASTERISK(*) INDICATES GROUNDWATER (RUSTLER/SUPRA RUSTLER FORMATIONS) OR BRINE SEEPAGE/WEEPS (SALADO FORMATION) OBSERVED DURING THE MAPPING OF THE AIR INTAKE SHAFT. AS OF 1994, ONLY MB103 SHOWED VISIBLE MOISTURE ON THE SALADO FORMATION SURFACE EXPOSED WITHIN THE AIR INTAKE SHAFT, "BRINE SAMPLING EVALUATION PROGRAM 1992-1993 REPORT," 1994, DOE-WIPP 94-011.

2. REFERENCE AS-BUILT DRAWINGS FROM WID:

AIR INTAKE SHAFT 331 SHAFT COLLAR / AIR INTAKE PLENUM PLAN, SECTIONS AND DETAILS.	33-C-001-W
AIR INTAKE SHAFT 331 SHAFT COLLAR / AIR INTAKE PLATFORM PLAN, SECTIONS AND DETAILS.	33-C-002-W
AIR INTAKE SHAFT 331 STRUCTURE PLAN, SECTIONS AND DETAILS	33-C-003-W1
AIR INTAKE SHAFT 331 SHAFT KEY PLAN, SECTIONS AND DETAILS	33-C-004-W1
AIR INTAKE SHAFT 331 LINING DETAILS	33-C-005-W
AIR INTAKE SHAFT 331 EXCAVATION AS-BUILT	33-D-002-W
AIR INTAKE SHAFT 331 GENERAL ARRANGEMENT	33-D-008-W
AIR INTAKE SHAFT 331 SHAFT STATION PLAN, SECTIONS AND DETAILS	51-W-212-W

SCALE IN FEET
0 10 20 30 40 50

REV.	DATE	DESCRIPTION	BY	CK.	APP.
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

WIPP SHAFT SEALING SYSTEM
NEAR-SURFACE/RUSTLER FORMATIONS
AIR INTAKE SHAFT
STRATIGRAPHY &
AS-BUILT ELEMENTS

CONTRACT NO: AC-4909

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS, BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE	SNL DWG NO	SHEET NO
	8		SNL-007	7 OF 28

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER
Albert W. Dennis
8-2-96

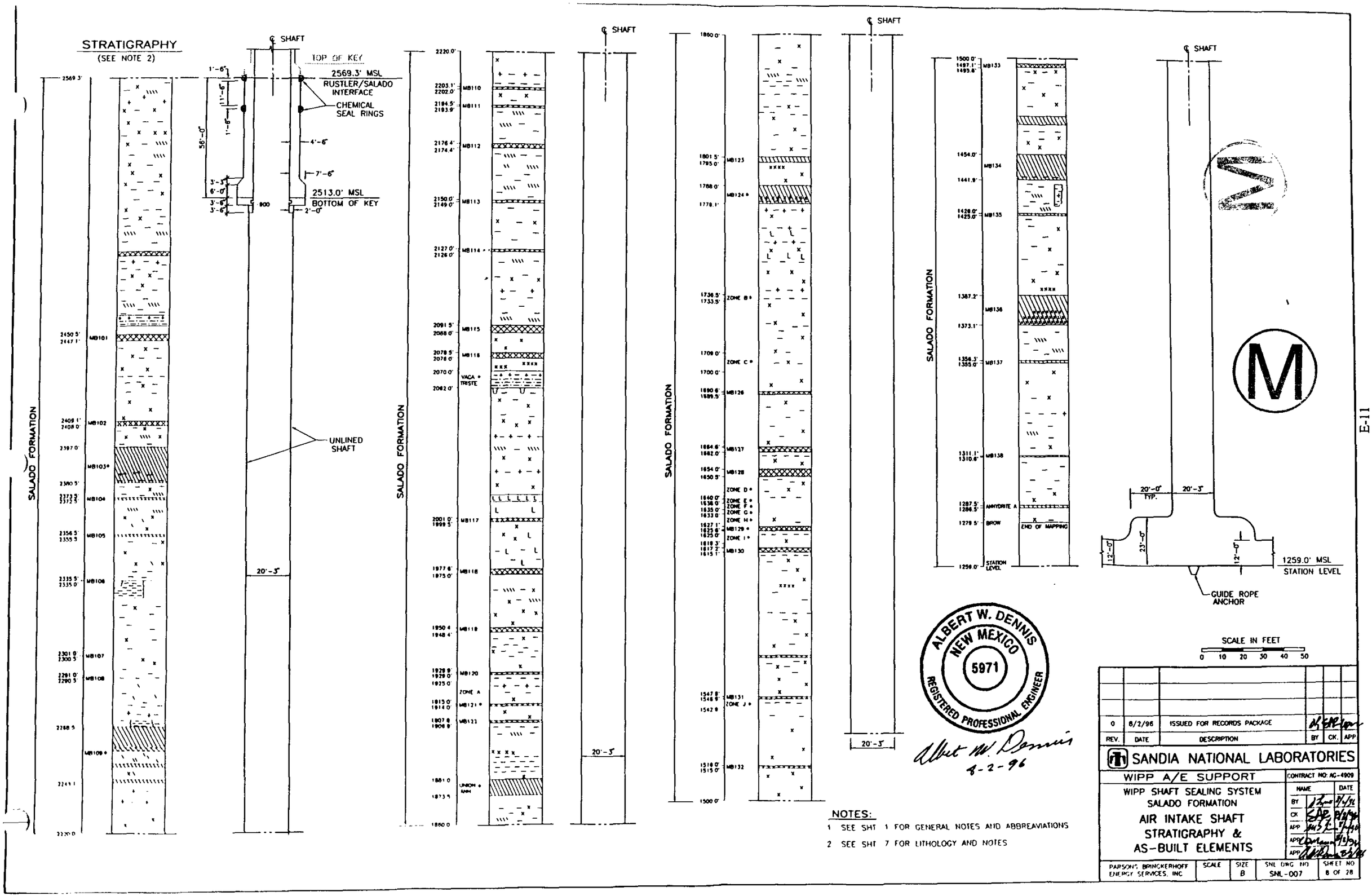
STRATIGRAPHY
(SEE NOTE 2)
SALADO FORMATION
℄ SHAFT
TOP OF KEY
2569.3' MSL
RUSTLER/SALADO INTERFACE
CHEMICAL SEAL RINGS
2513.0' MSL
BOTTOM OF KEY
UNLINED SHAFT
20'-3"
ZONE A
ZONE B
ZONE C
ZONE D
ZONE E
ZONE F
ZONE G
ZONE H
ZONE I
ZONE J
VACA TRISTE
UNION ANH
ANHYDRITE A
BROW
END OF MAPPING
STATION LEVEL
20'-0" TYP.
20'-3"
12'-0"
23'-0"
1259.0' MSL
STATION LEVEL
GUIDE ROPE ANCHOR
SCALE IN FEET
0 10 20 30 40 50
ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER
Albert W. Dennis
8-2-96
NOTES:
1 SEE SHT 1 FOR GENERAL NOTES AND ABBREAVIATIONS
2 SEE SHT 7 FOR LITHOLOGY AND NOTES
0 8/2/96 ISSUED FOR RECORDS PACKAGE
REV. DATE DESCRIPTION BY CK. APP
SANDIA NATIONAL LABORATORIES
WIPP A/E SUPPORT
CONTRACT NO: AC-4909
WIPP SHAFT SEALING SYSTEM
SALADO FORMATION
AIR INTAKE SHAFT
STRATIGRAPHY &
AS-BUILT ELEMENTS
NAME DATE
BY
CK
APP
PARSONS BRINCKERHOFF ENERGY SERVICES, INC
SCALE
SIZE B
SNL DWG NO SNL-007
SHEET NO 8 OF 28

E-11

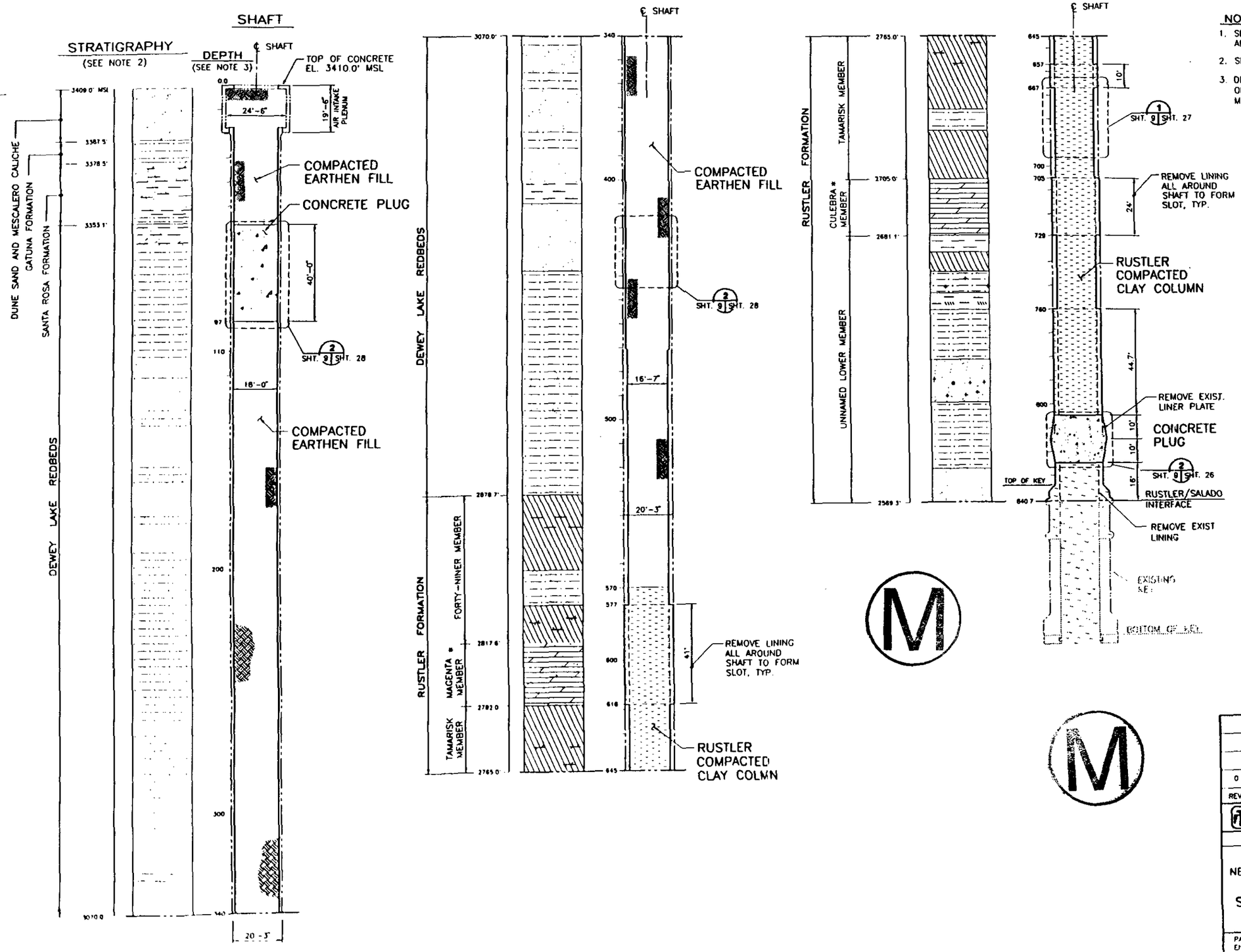

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS
2. SEE SHT. 7 FOR LITHOLOGY AND NOTES.
3. DEPTHS SHOWN ARE DISTANCES BELOW THE TOP OF CONCRETE, LOCATED AT EL. 3410.0' ABOVE MSL USGS 1927 NORTH AMERICAN DATUM

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

SCALE IN FEET
0 10 20 30 40 50

REV.	DATE	DESCRIPTION	BY	CK	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AC-4909

WIPP SHAFT SEALING SYSTEM
NEAR-SURFACE/RUSTLER FORMATIONS
AIR INTAKE SHAFT
STRATIGRAPHY AND SEALING
SUBSYSTEM PROFILE

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 9 OF 28

E-12

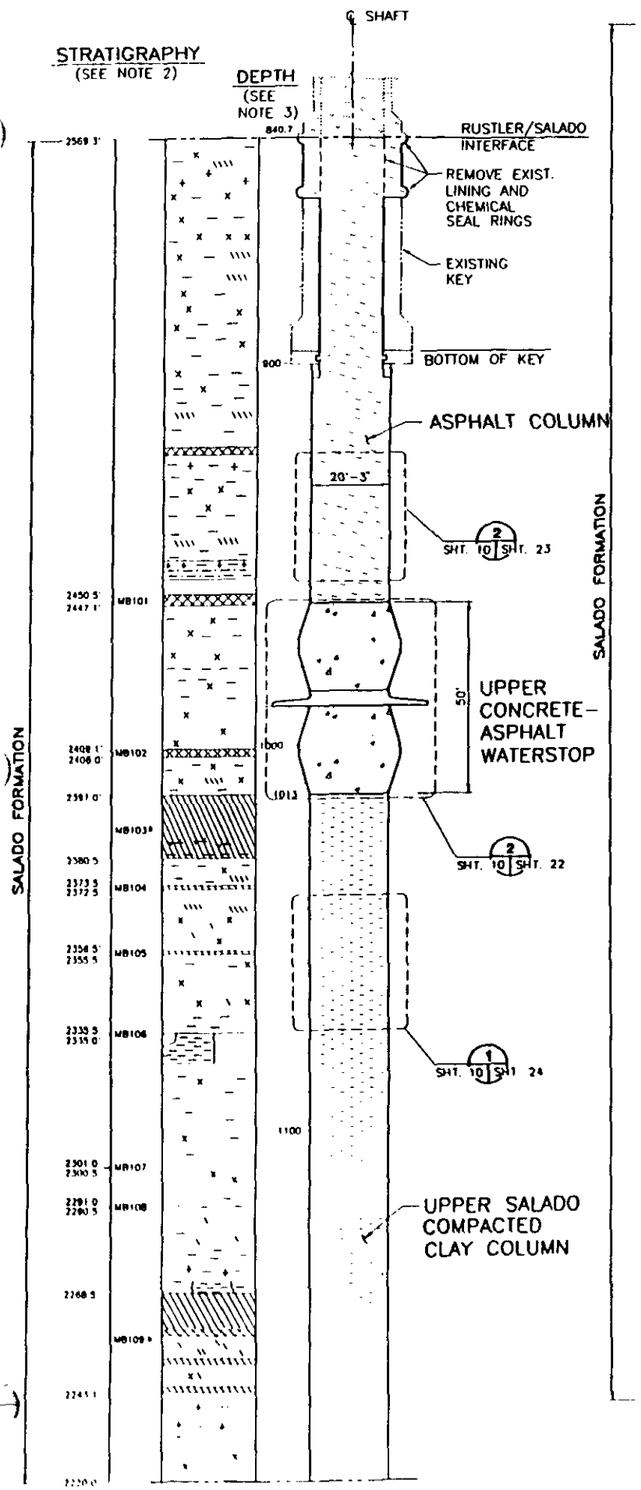

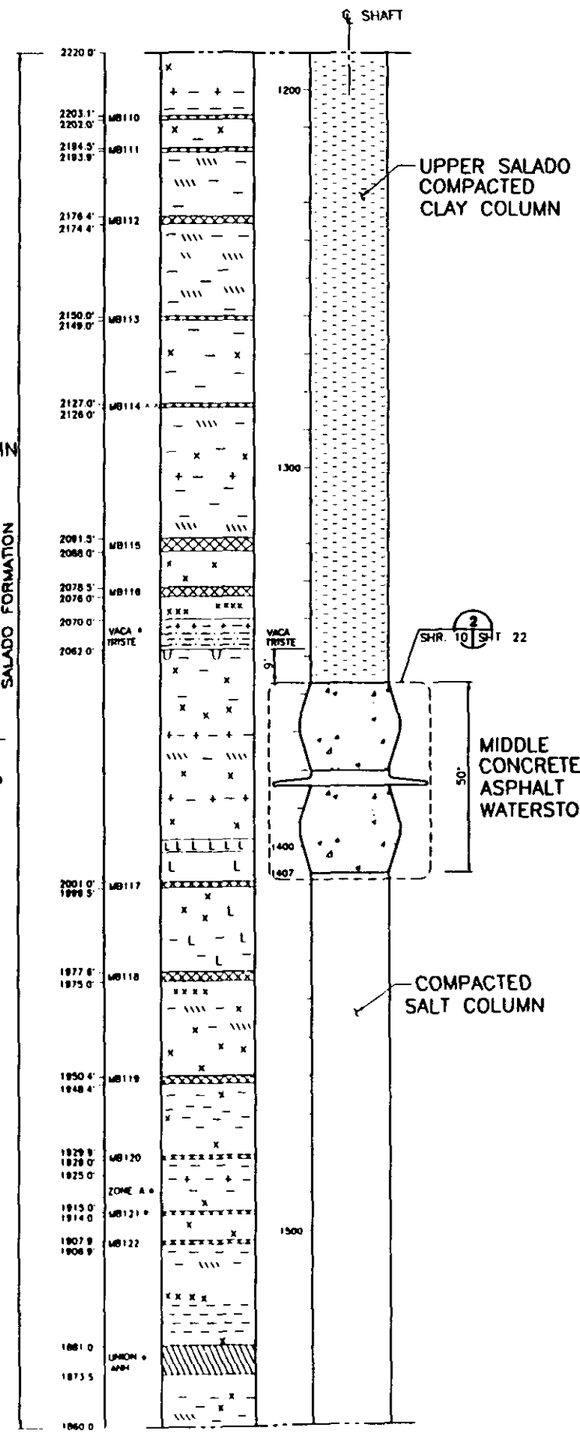

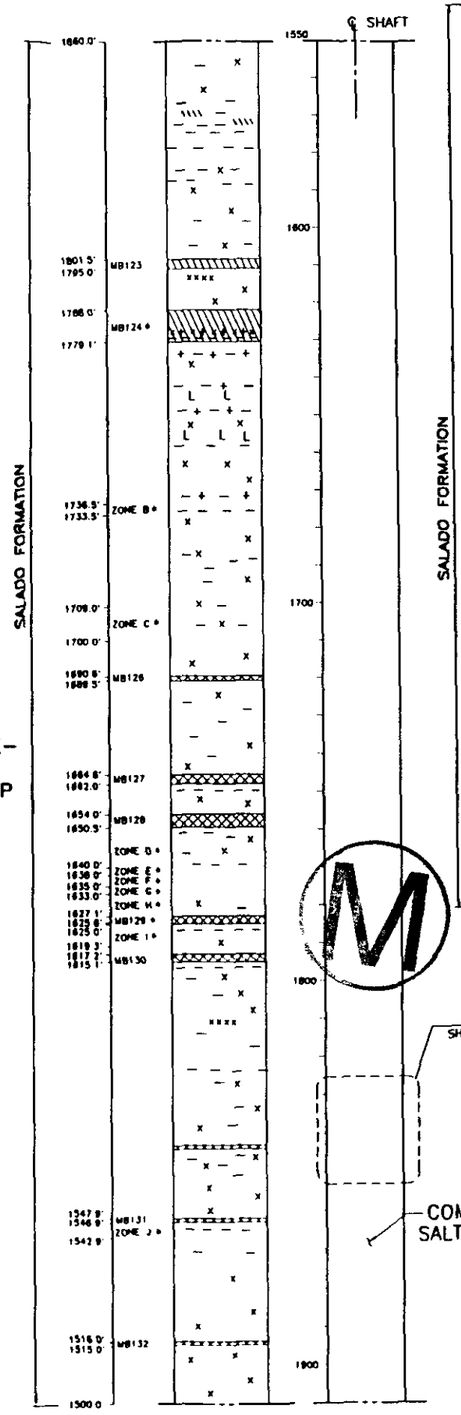

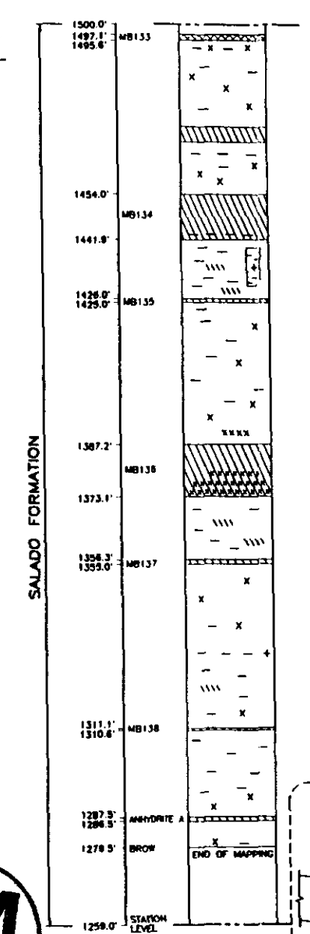

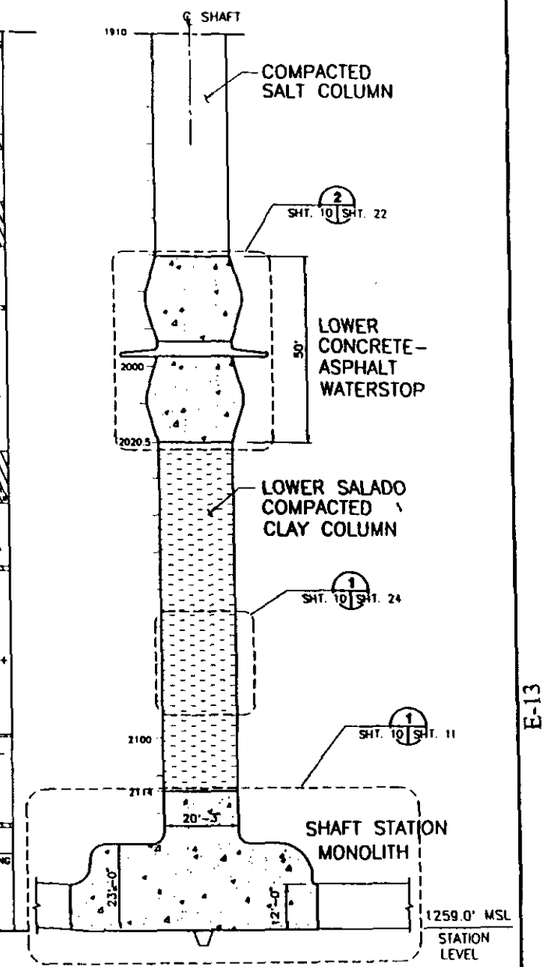

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS
2. SEE SHT. 7 FOR LITHOLOGY AND NOTES.
3. SEE NOTE 3 OF SHT. 9.

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

SCALE IN FEET
0 10 20 30 40 50

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AG-4909

WIPP SHAFT SEALING SYSTEM
SALADO FORMATION
AIR INTAKE SHAFT
STRATIGRAPHY AND SEALING SUBSYSTEM PROFILE

	NAME	DATE
BY		
CK		
APP		
APP		
APP		

PARSONS BRINCKERHOFF ENERGY SERVICES, INC | SCALE | SIZE B | SNL DWG NO SNL-007 | SHEET NO 10 OF 28

E-13

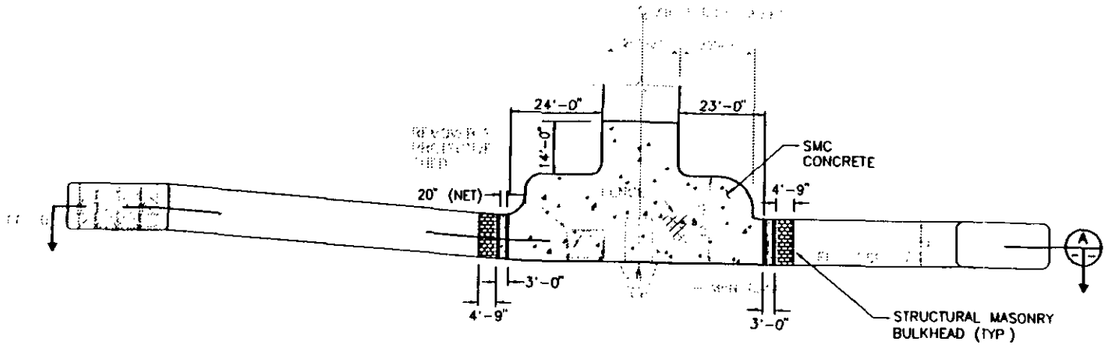

DETAIL 1 SHT. 10 SHT. 11

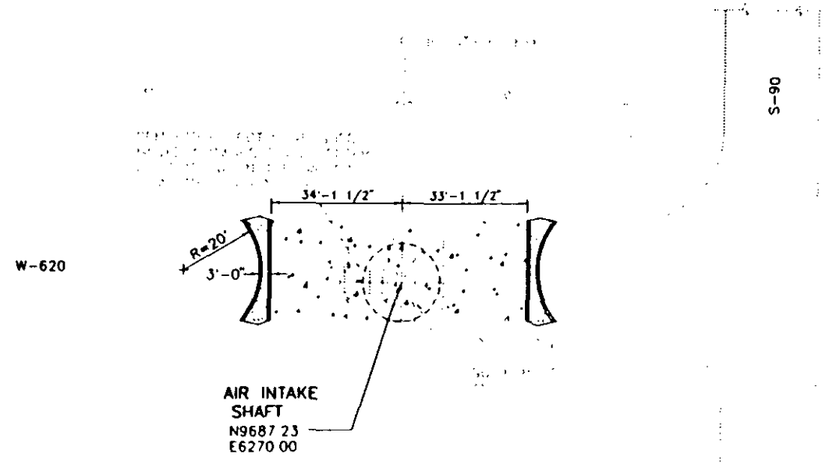

SECTION A

N

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS.

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A. W. Dennis
8-2-96

SCALE IN FEET
0 10 20 30 40 50

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO: AG-4909

WIPP SHAFT SEALING SYSTEM

AIR INTAKE SHAFT
SHAFT STATION MONOLITH

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 11 OF 28

E-14

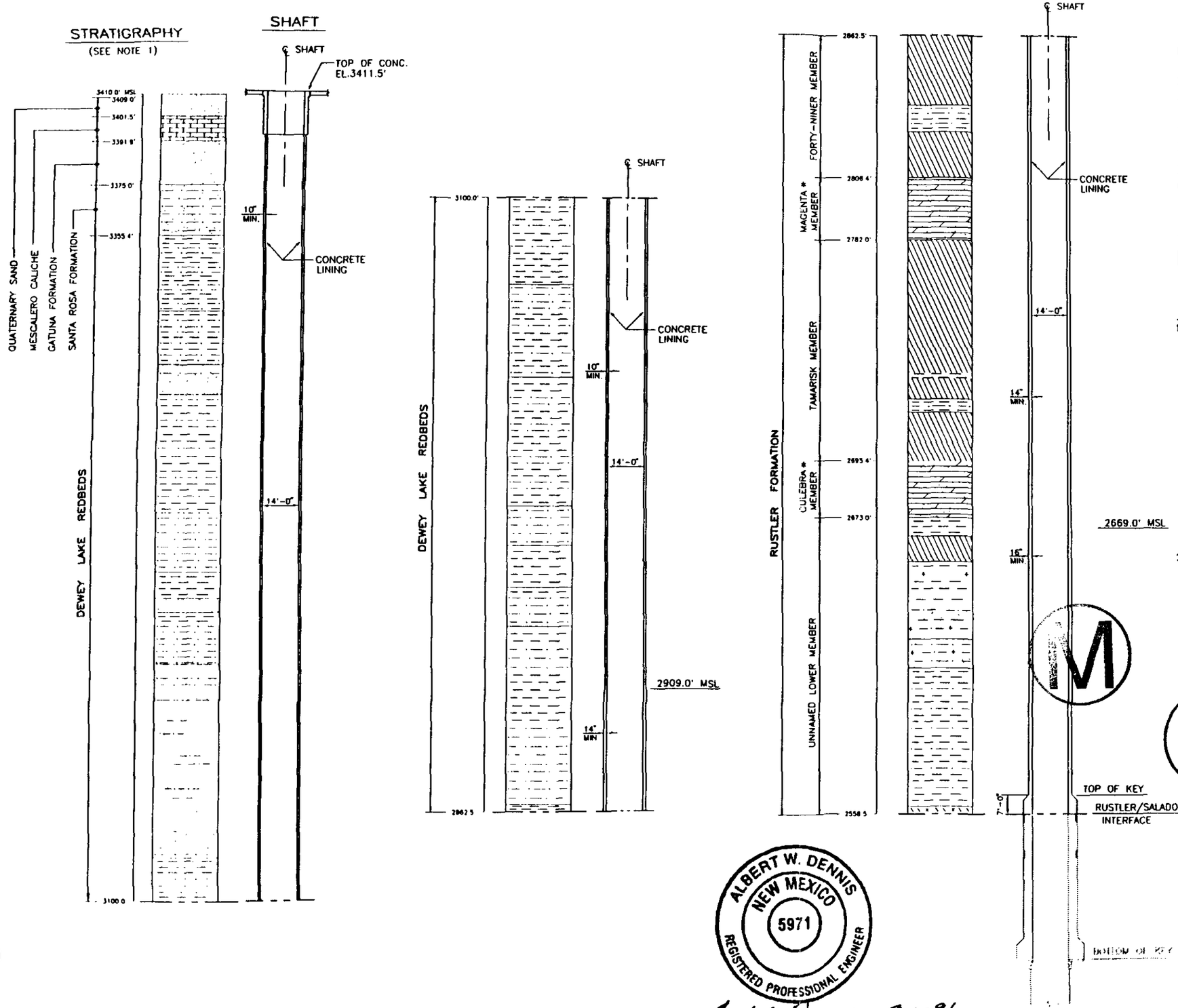

LITHOLOGY:

PRIMARY ROCK/SEDIMENT TYPES	SECONDARY CONSTITUENTS
MUDSTONE/CLAYSTONE	ARGILLACEOUS
CLAYSTONE BED	SILTY
SILTSTONE	SANDY
SANDSTONE	SULFATIC
ANHYDRITE/GYPSUM	DOLOMITIC
DOLOMITE	CALCAREOUS
HALITE	HALITIC
POLYHALITE	POLYHALITIC
CALICHE	

NOTE:

1. THE STRATIGRAPHY AND GROUNDWATER BRINE SEEPAGE/WEEP INTERVALS ARE BASED ON THE LITHOLOGIC INFORMATION COMPILED DURING THE GEOLOGIC MAPPING OF THE EXHAUST SHAFT WALLS DOE-WIPP-86-008, "GEOTECHNICAL ACTIVITIES IN THE EXHAUST SHAFT", AND APPENDIX A OF REPORT DOE/WIPP-95--3117, "WASTE ISOLATION PILOT PLANT SEALING SYSTEM DESIGN REPORT", 1995.

   ASTERISK (*) WITHIN THE RUSTLER AND SUPRA RUSTLER FORMATIONS INDICATE GROUNDWATER OBSERVED DURING SHAFT MAPPING. ASTERISK (*) WITHIN THE SALADO FORMATION INDICATES A POTENTIAL BRINE SEEPAGE/WEEP INTERVAL. THESE POTENTIAL BRINE SEEPAGE/WEEP INTERVALS ARE BASED ON OBSERVED INTERVALS OF BRINE SEEPAGE /WEEPS IN THE AIR INTAKE SHAFT THAT HAVE BEEN PROJECTED TO THE EXHAUST SHAFT. THE MAPPING OF THE EXHAUST SHAFT (HOLT & POWERS, 1986/DOE-WIPP 86-008) DID NOT INDICATE OBSERVED SEEPAGE INTERVALS WITHIN THE SALADO FORMATION.

2. REFENCE AS-BUILT DRAWINGS FROM WID:

EXHAUST SHAFT 351, SHAFT LINING AND KEY SECTION AND DETAILS	35-R-002-01D
EXHAUST SHAFT 351, GENERAL ARRRANGEMENT, PLANS AND SECTIONS	35-R-004-01D
EXHAUST SHAFT WINCH AND COLLAR LAYOUT - SHOWS PERMANENT COLLAR STRUCTURE	OGL-S-020-1FB
EXHAUST SHAFT, SHAFT DEVELOPMENT, PLAN, SECTIONS AND DETAIL	WTSD 390D064 (1 of 2)

SCALE IN FEET
0 10 20 30 40 50

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A. W. Dennis 8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO: AG-4909

WIPP SHAFT SEALING SYSTEM
NEAR-SURFACE/RUSTLER FORMATIONS
EXHAUST SHAFT
STRATIGRAPHY &
AS-BUILT ELEMENTS

	NAME	DATE
BY		8/1/96
CK.		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE:	SIZE B	SNL DWG NO SNL-007	SHEET NO 12 OF 28

E-15

NAME [illegible] DATE [illegible] 1996 TIME: 2:59 PM

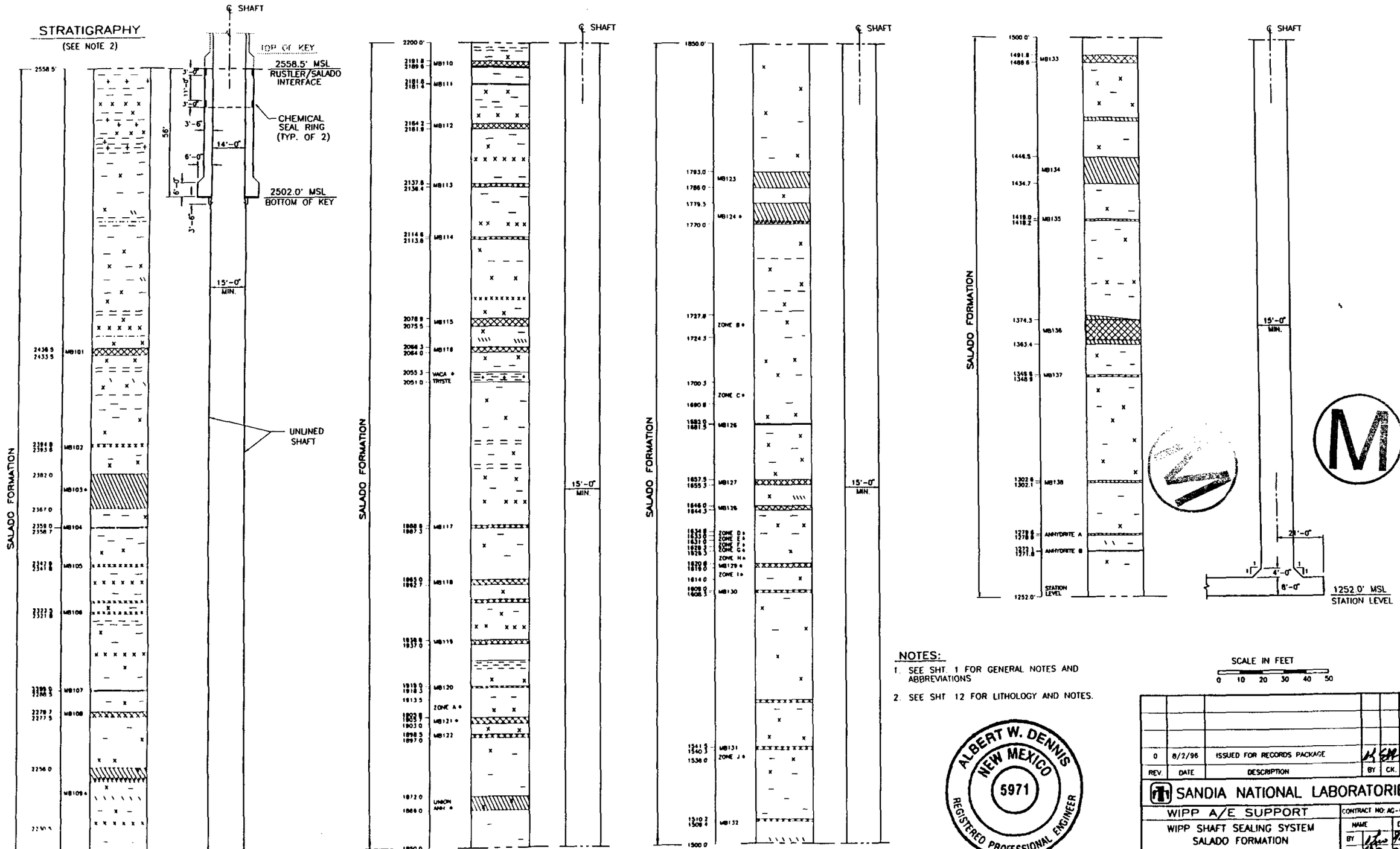

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTES AND ABBREVIATIONS
2. SEE SHT. 12 FOR LITHOLOGY AND NOTES.

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A. W. Dennis
8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP.
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO: AG-4909

WIPP SHAFT SEALING SYSTEM
SALADO FORMATION
EXHAUST SHAFT
STRATIGRAPHY &
AS-BUILT ELEMENTS

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		08/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE	SNL DWG NO	SHEET NO
		B	SNL-007	13 OF 28

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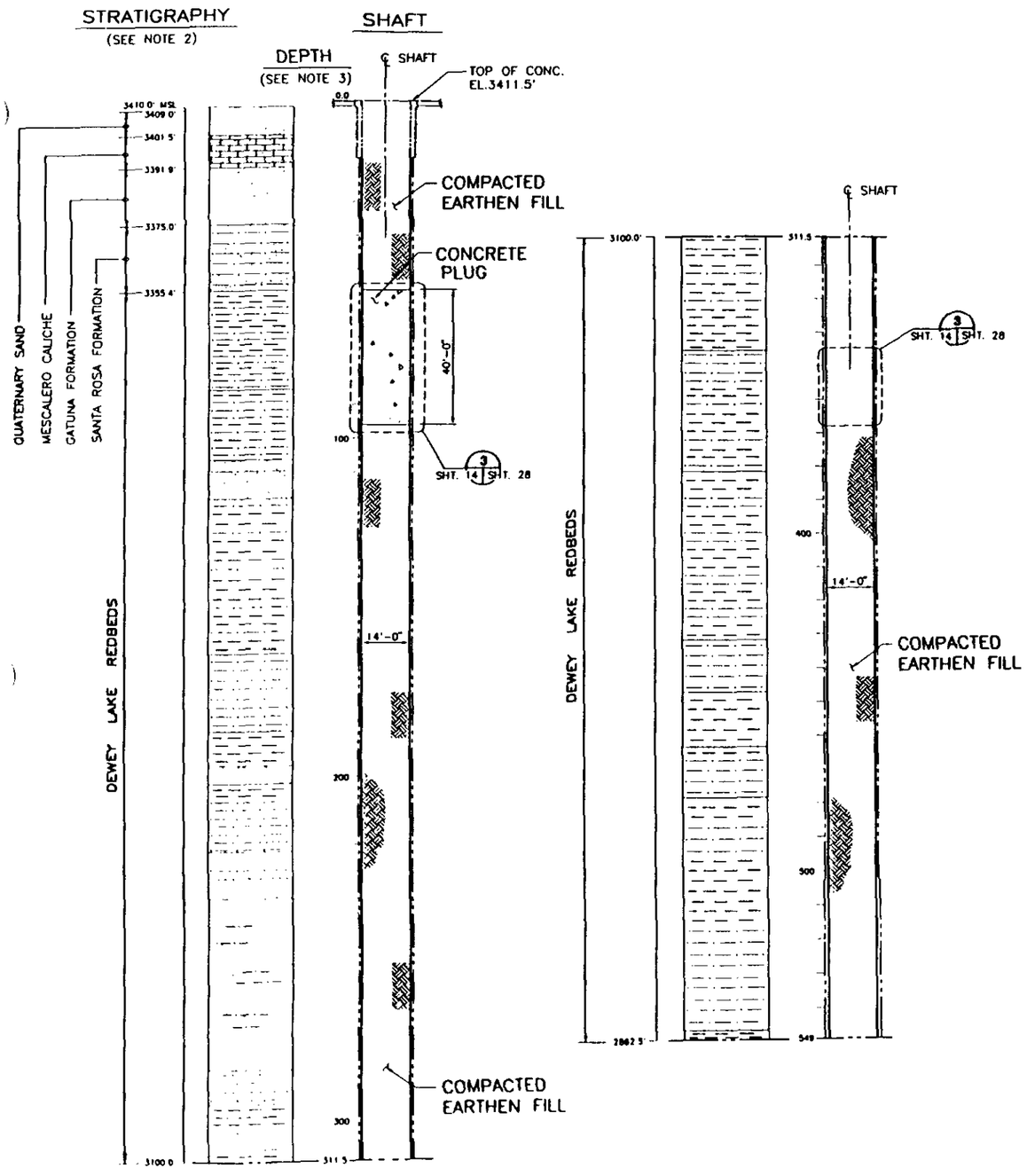

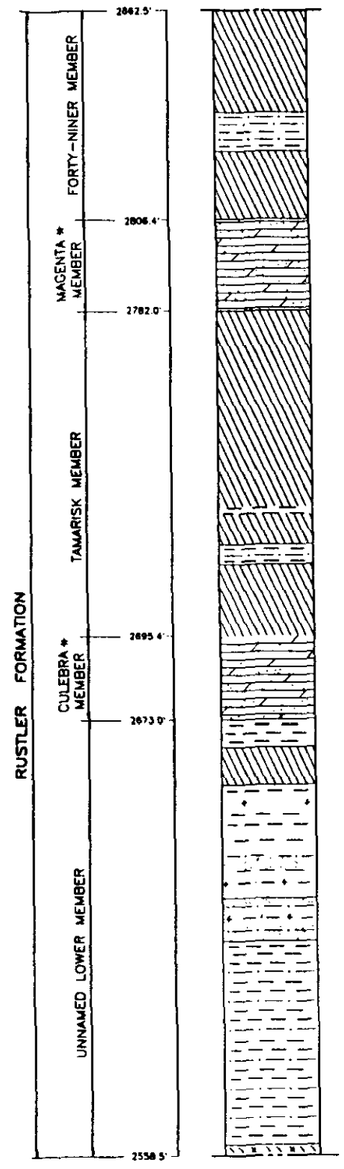

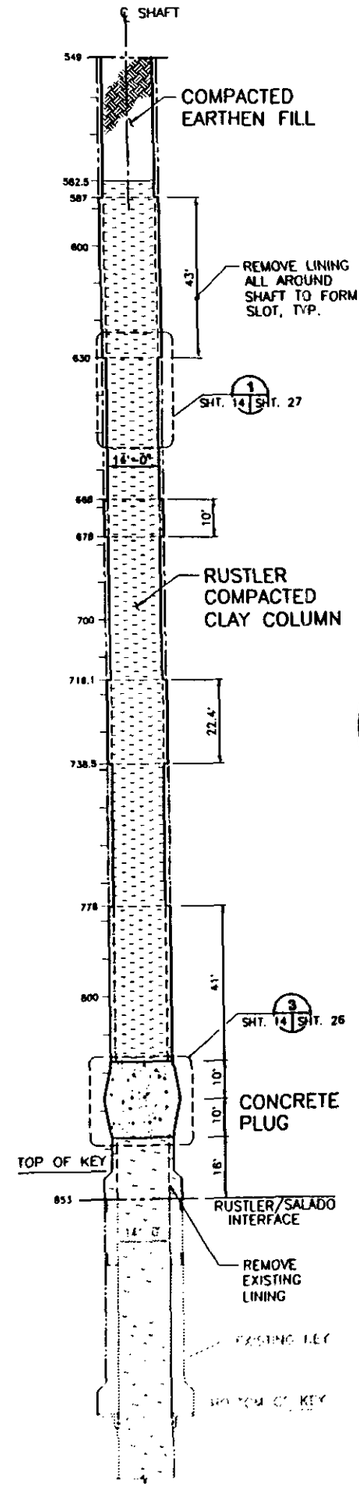

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTE, LEGEND AND ABBREVIATIONS
2. SEE SHT. 12 FOR LITHOLOGY AND NOTES.
3. DEPTHS SHOWN ARE DISTANCES BELOW THE TOP OF CONCRETE, LOCATED AT EL. 3411.5' ABOVE MSL USGS 1927 NORTH AMERICAN DATUM.

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A.W. Dennis 8-2-96

SCALE IN FEET
0 10 20 30 40 50

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AC-4909

WIPP SHAFT SEALING SYSTEM
NEAR-SURFACE/RUSTLER FORMATIONS
EXHAUST SHAFT
STRATIGRAPHY & SEALING
SUBSYSTEM PROFILE

	NAME	DATE
BY		8/1/96
CK		8/1/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE	SNL DWG NO	SHEET NO
		B	SNL-007	14 OF 28

E-17

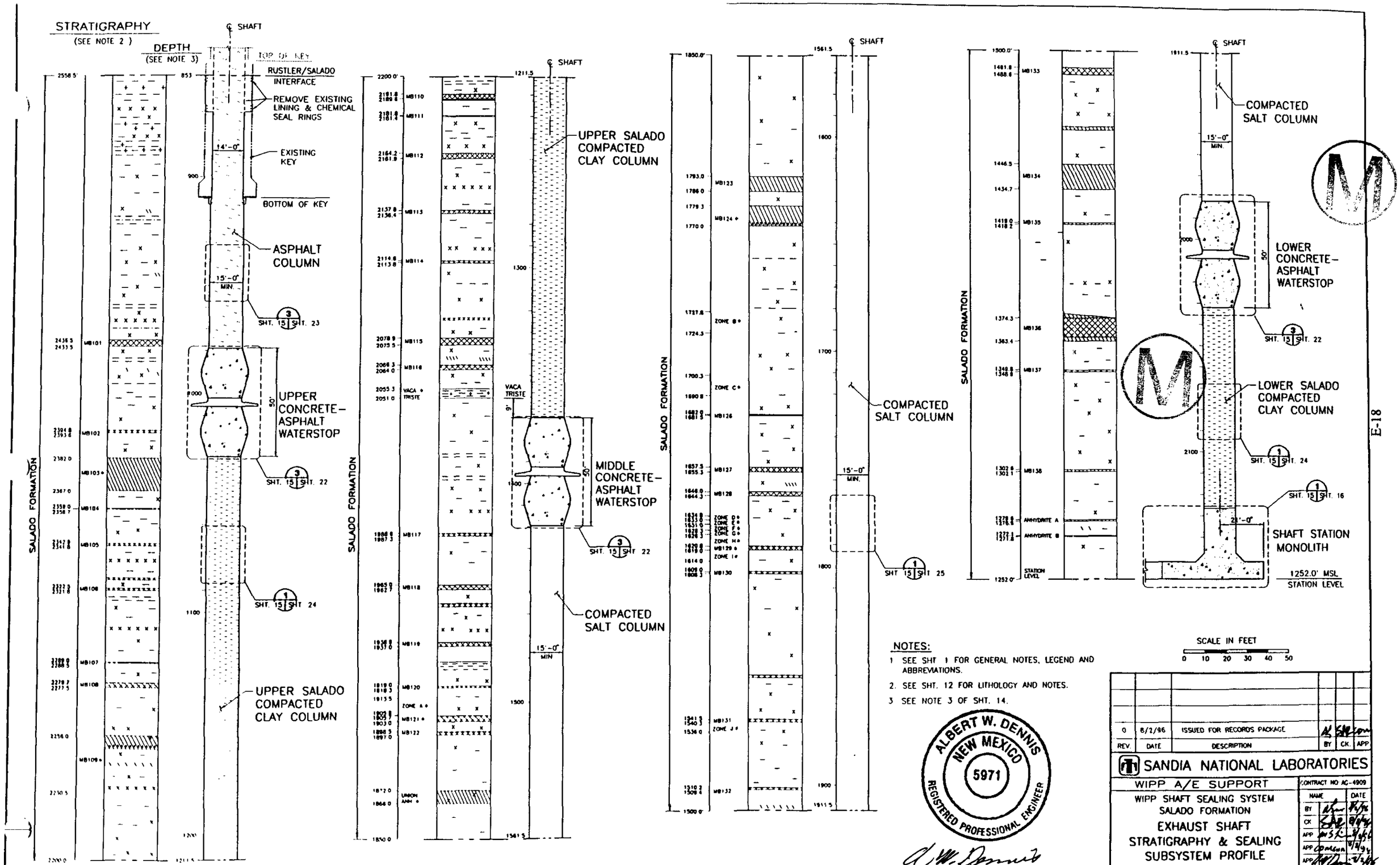

NOTES:

1. SEE SHT 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS.
2. SEE SHT. 12 FOR LITHOLOGY AND NOTES.
3. SEE NOTE 3 OF SHT. 14.

ALBERT W. DENNIS NEW MEXICO 5971 REGISTERED PROFESSIONAL ENGINEER

A. W. Dennis 8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AC-4909

WIPP SHAFT SEALING SYSTEM
SALADO FORMATION
EXHAUST SHAFT
STRATIGRAPHY & SEALING
SUBSYSTEM PROFILE

NAME	DATE
BY	
CK	
APP	
APP	
APP	

PARSONS BRINCKERHOFF ENERGY SERVICES, INC | SCALE | SIZE B | SNL DWG NO SNL-007 | SHEET NO 15 OF 28

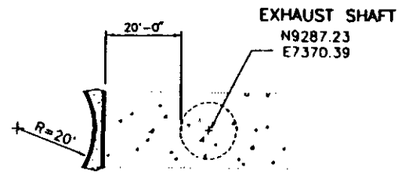

S-400

E-300

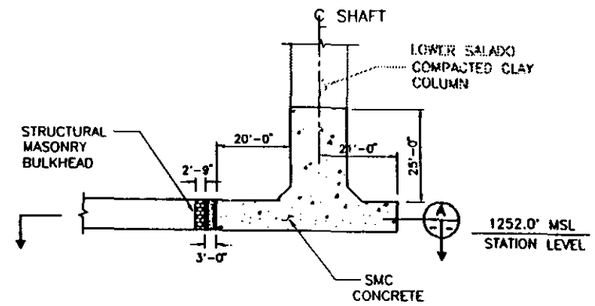

DETAIL 1
SHT. 15 SHT. 16

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS.

SECTION A

N

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A. W. Dennis 8-2-96

SCALE IN FEET
0 10 20 30 40 50

REV	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

WIPP SHAFT SEALING SYSTEM

EXHAUST SHAFT
SHAFT STATION MONOLITH

CONTRACT NO: AC-4909

	NAME	DATE
BY		8/1/96
CK		8/1/96
APP		8/1/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 16 OF 28

E-19

NAME [illegible] DATE [illegible] TIME 3:19 PM

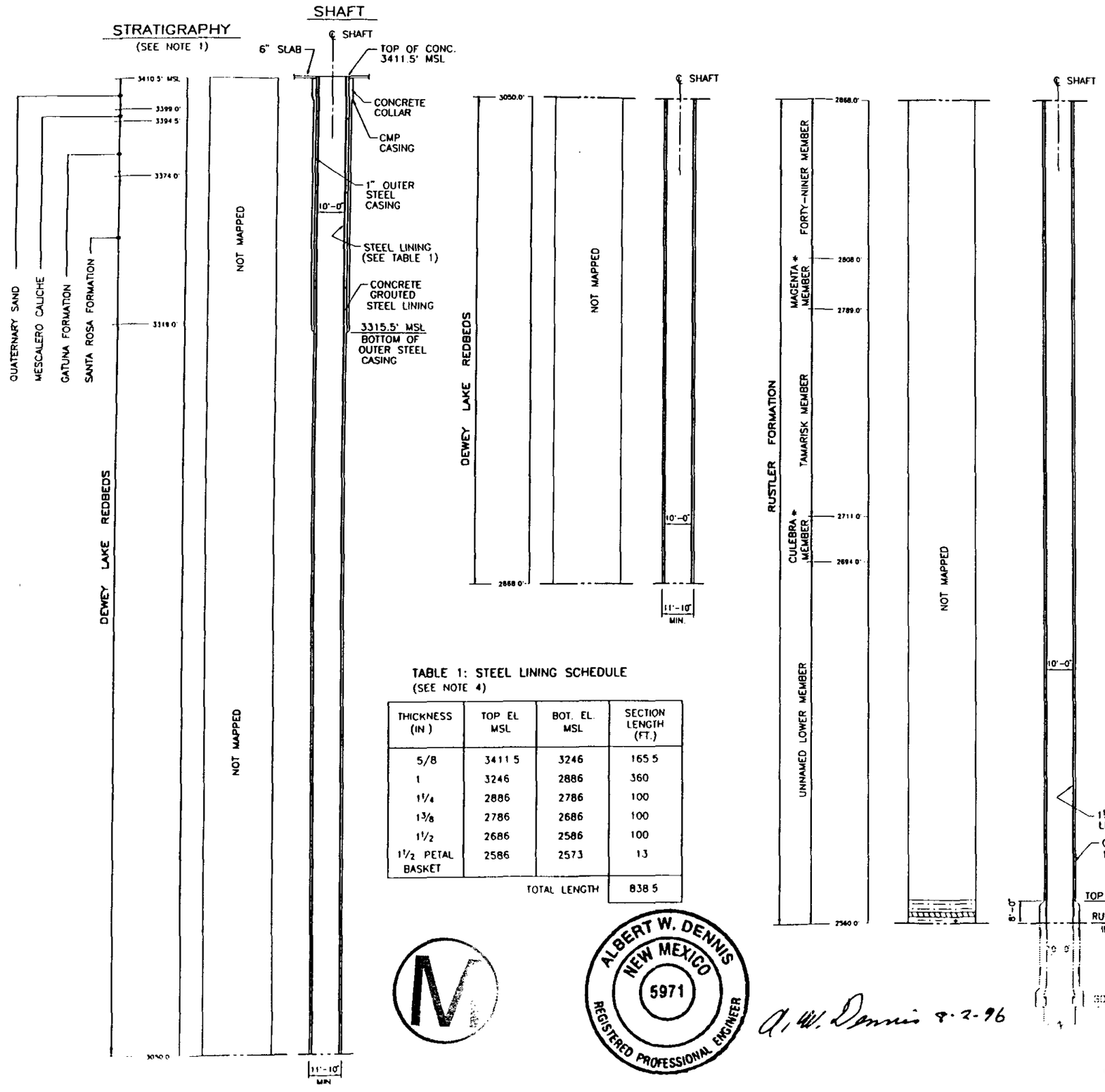

TABLE 1: STEEL LINING SCHEDULE
(SEE NOTE 4)

THICKNESS (IN.)	TOP EL MSL	BOT. EL. MSL	SECTION LENGTH (FT.)
5/8	3411.5	3246	165.5
1	3246	2886	360
1¼	2886	2786	100
1⅜	2786	2686	100
1½	2686	2586	100
1½ PETAL BASKET	2586	2573	13
		TOTAL LENGTH	838.5

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A. W. Dennis 8-2-96

LITHOLOGY:

PRIMARY ROCK/SEDIMENT TYPES
- MUDSTONE/CLAYSTONE
- CLAYSTONE BED
- SILTSTONE
- SANDSTONE
- ANHYDRITE/GYPSUM
- DOLOMITE
- HALITE
- POLYHALITE

SECONDARY CONSTITUENTS
- ARGILLACEOUS
- SILTY
- SANDY
- SULFATIC
- DOLOMITIC
- CALCAREOUS
- HALITIC
- POLYHALITIC

NOTES:

1. THE STRATIGRAPHY AND GROUNDWATER BRINE SEEPAGE/WEEP INTERVALS ARE BASED ON THE LITHOLOGIC INFORMATION COMPILED DURING THE GEOLOGIC MAPPING OF THE SALT HANDLING SHAFT WALLS, TME 3178; "GEOTECHNICAL ACTIVITIES IN THE EXPLORATORY SHAFT-SELECTION OF THE FACILITY INTERVAL"; AND APPENDIX A OF REPORT DOE/WIPP-95-3117, "WASTE ISOLATION PILOT PLANT SEALING SYSTEM DESIGN REPORT", 1995.

   ASTERISK (*) WITHIN THE RUSTLER AND SUPRA RUSTLER FORMATIONS AND THE RUSTLER/SALADO FORMATION CONTACT INDICATES GROUNDWATER OBSERVED PRIOR TO SHAFT LINING INSTALLATION. ASTERISK (*) WITHIN THE SALADO FORMATION INDICATES A POTENTIAL BRINE SEEPAGE/WEEP INTERVAL. THESE POTENTIAL BRINE SEEPAGE/WEEP INTERVALS, LOCATED ABOVE THE SHAFT STATION LEVEL, ARE BASED ON OBSERVED INTERVALS OF BRINE SEEPAGE/WEEPS IN THE AIR INTAKE SHAFT THAT HAVE BEEN PROJECTED TO THE SALT HANDLING SHAFT. THE MAPPING OF THE SALT HANDLING SHAFT (JAROLIMEK ET AL., 1983/TME-3178) DID NOT INDICATE OBSERVED SEEPAGE INTERVALS WITHIN THE SALADO FORMATION.

2. REFERENCE AS-BUILT DRAWINGS FROM WID:

EXPLORATORY SHAFT KEY SHAFT STATION LOCATION, SECTIONS	37-R-010
EXPLORATORY SHAFT KEY, SECTIONS AND DETAILS	37-R-012
EXPLORATORY SHAFT STATION DEVELOPMENT - EXPERIMENTAL LEVEL PLAN AND SECTIONS	37-R-019
UNDERGROUND BASE PLAN E-0 DRIFT FROM N-9900 TO N-9580	51-W-126-W5
WIPP EXHAUST SHAFT 120" I.D. CASING x 834'	FS-M3259-01
WIPP PROJECT 120" I.D. CASING LINER HOLE COMPLEX	FS M3259-02

3. HISTORICAL NOTE: SINCE ITS CONSTRUCTION, THE SALT HANDLING SHAFT HAS BEEN REFERRED TO AS THE EXHAUST SHAFT, THE EXPLORATORY SHAFT, THE CONSTRUCTION AND SALT HANDLING SHAFT, AND THE SALT HANDLING SHAFT.

4. THICKNESS OF STEEL LINING VARIES, LINING TYPE AND LENGTH ARE BASED ON FENIX AND SCISSON AS-BUILT DWGS. M3259-02, REV. 0, DATED 11/30/79, WIPP PROJECT 120" I.D. CASING LINER HOLE COMPLEX, AND M3259-01, REV. 1, DATED 10/13/80, WIPP EXHAUST SHAFT 120" I.D. CASING x 834'.

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO: AC-4909

WIPP SHAFT SEALING SYSTEM
NEAR-SURFACE/RUSTLER FORMATIONS
SALT HANDLING SHAFT
STRATIGRAPHY &
AS-BUILT ELEMENTS

	NAME	DATE
BY		
CK		
APP		
APP		
APP		

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 17 OF 28

NAME C:\SNL\DWG\SNL007.DWG DATE REV 24 1996 TIME 3:01 PM

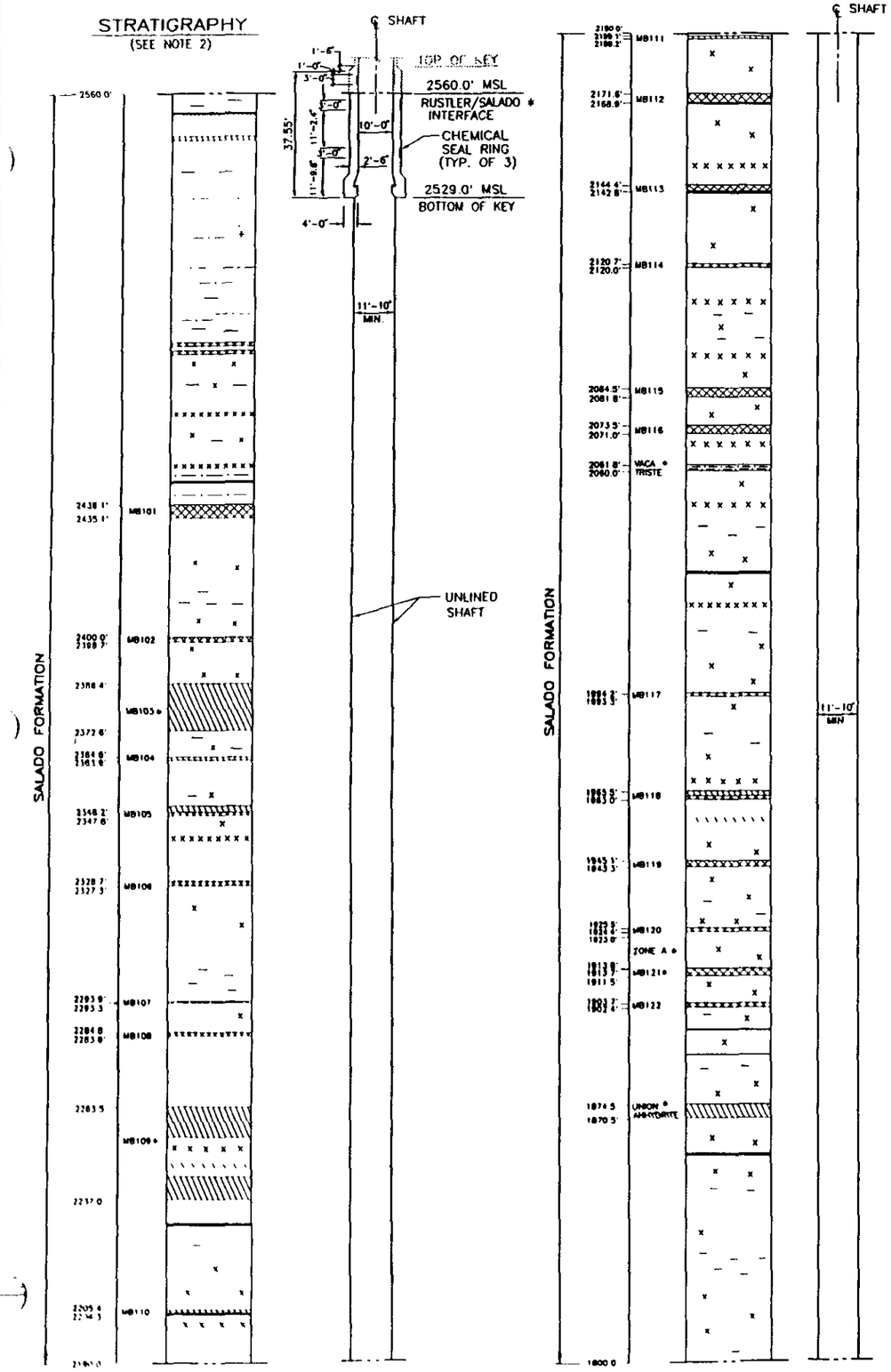

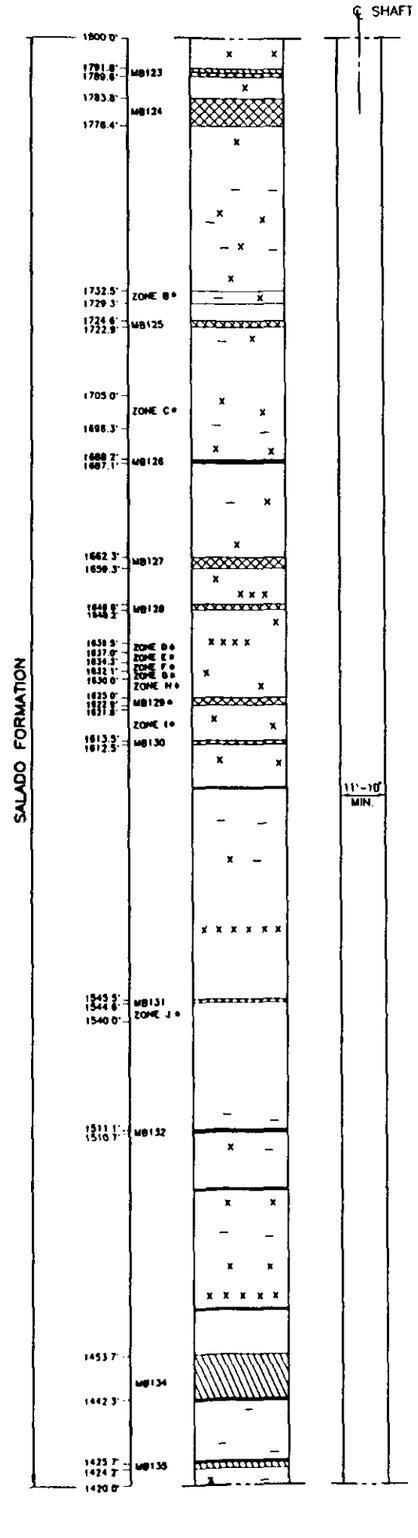

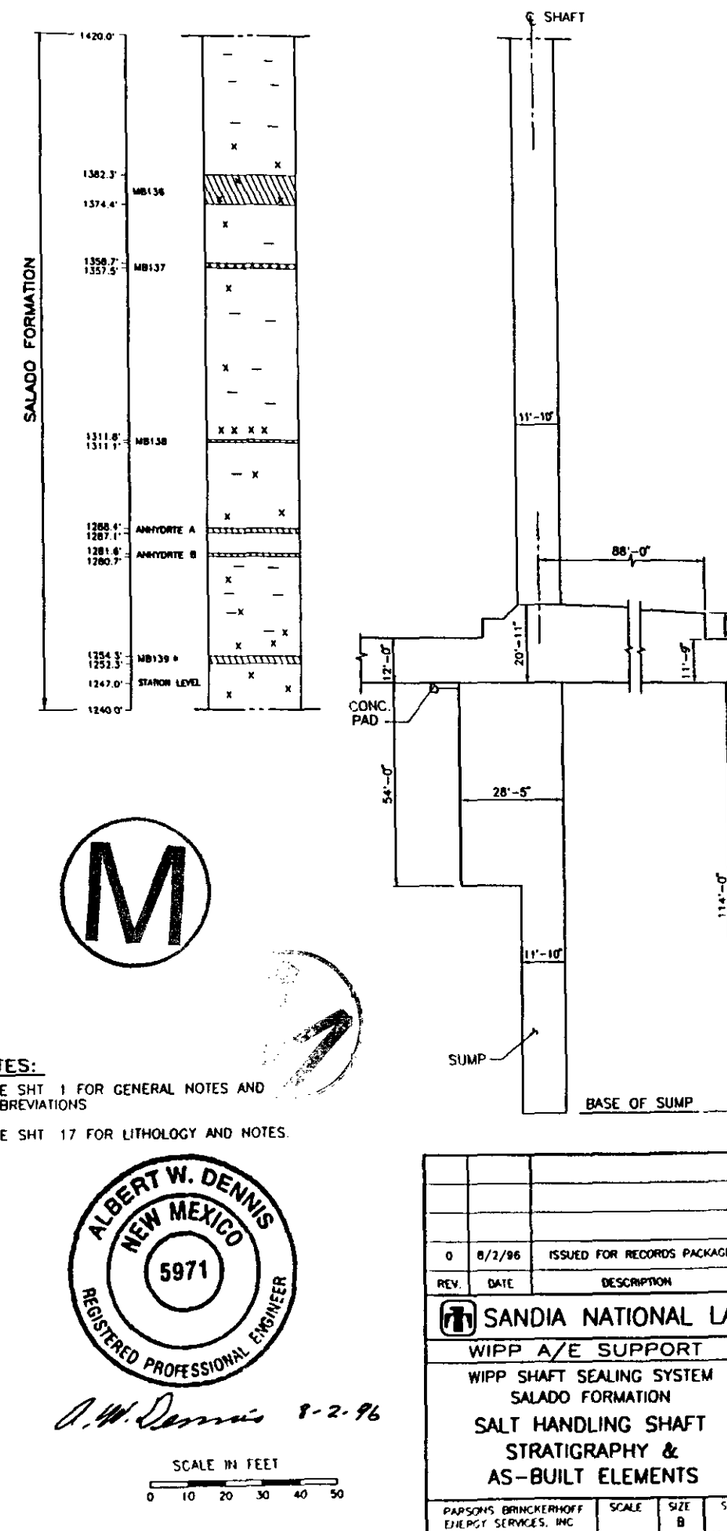

NOTES:

1. SEE SHT 1 FOR GENERAL NOTES AND ABBREVIATIONS
2. SEE SHT 17 FOR LITHOLOGY AND NOTES.

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A.W. Dennis 8-2-96

SCALE IN FEET
0 10 20 30 40 50

REV.	DATE	DESCRIPTION	BY	CK.	APP.
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AC-4909

WIPP SHAFT SEALING SYSTEM
SALADO FORMATION
SALT HANDLING SHAFT
STRATIGRAPHY &
AS-BUILT ELEMENTS

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP.		8/2/96
APP.		8/2/96
APP.		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 18 OF 28

E-21

NAME DATE TIME

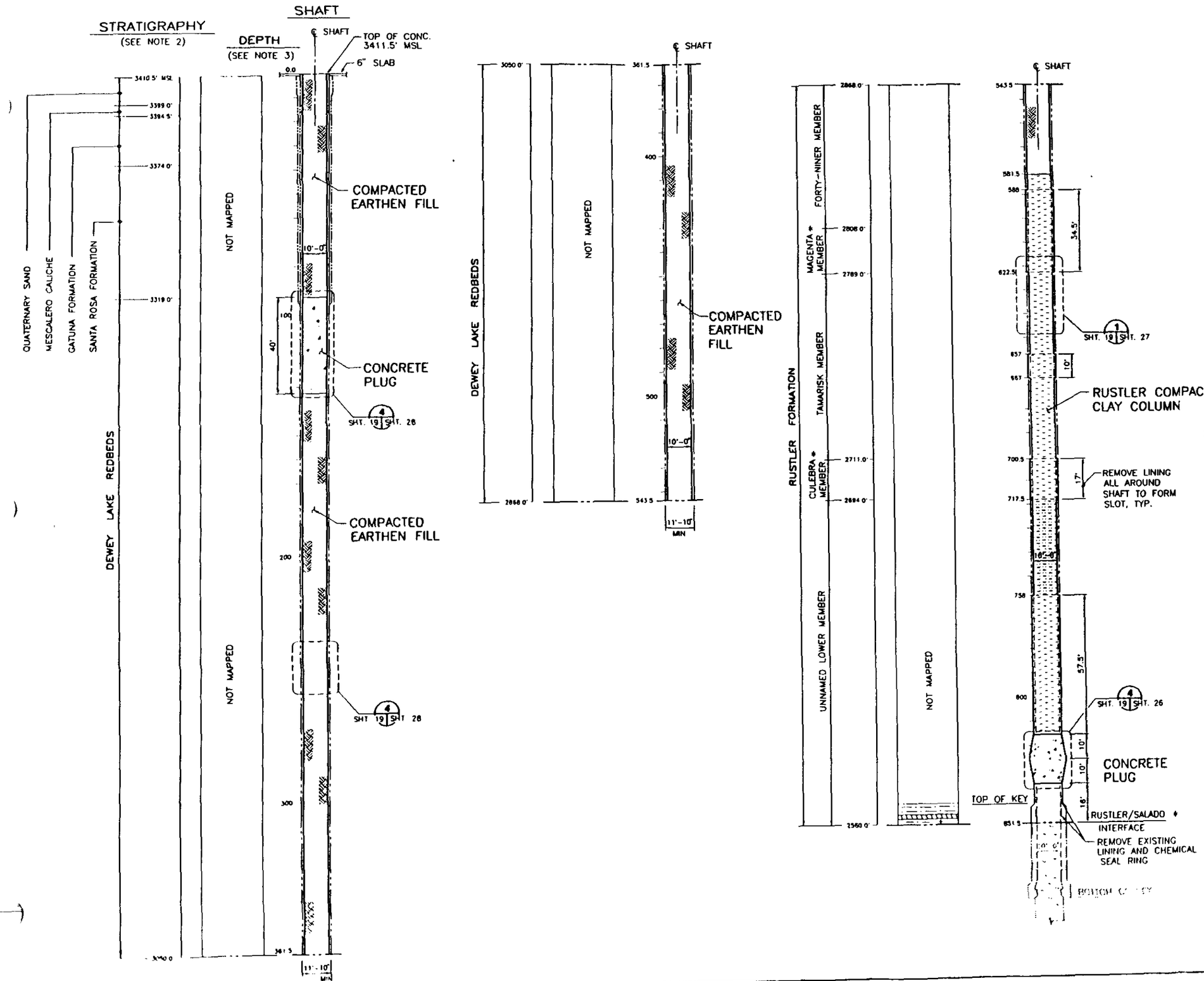

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS.
2. SEE SHT. 17 FOR LITHOLOGY AND NOTES.
3. DEPTHS SHOWN ARE DISTANCES BELOW THE TOP OF CONCRETE, LOCATED AT EL. 3411.5' ABOVE MSL USGS 1927 NORTH AMERICAN DATUM.

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A. W. Dennis 8-2-96

SCALE IN FEET
0 10 20 30 40 50

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

WIPP SHAFT SEALING SYSTEM
NEAR-SURFACE/RUSTLER FORMATIONS
SALT HANDLING SHAFT
STRATIGRAPHY & SEALING
SUBSYSTEM PROFILE

CONTRACT NO. AC-4909

	NAME	DATE
BY		7/1/96
CK.		8/1/96
APP		8/1/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 19 OF 28

E-22

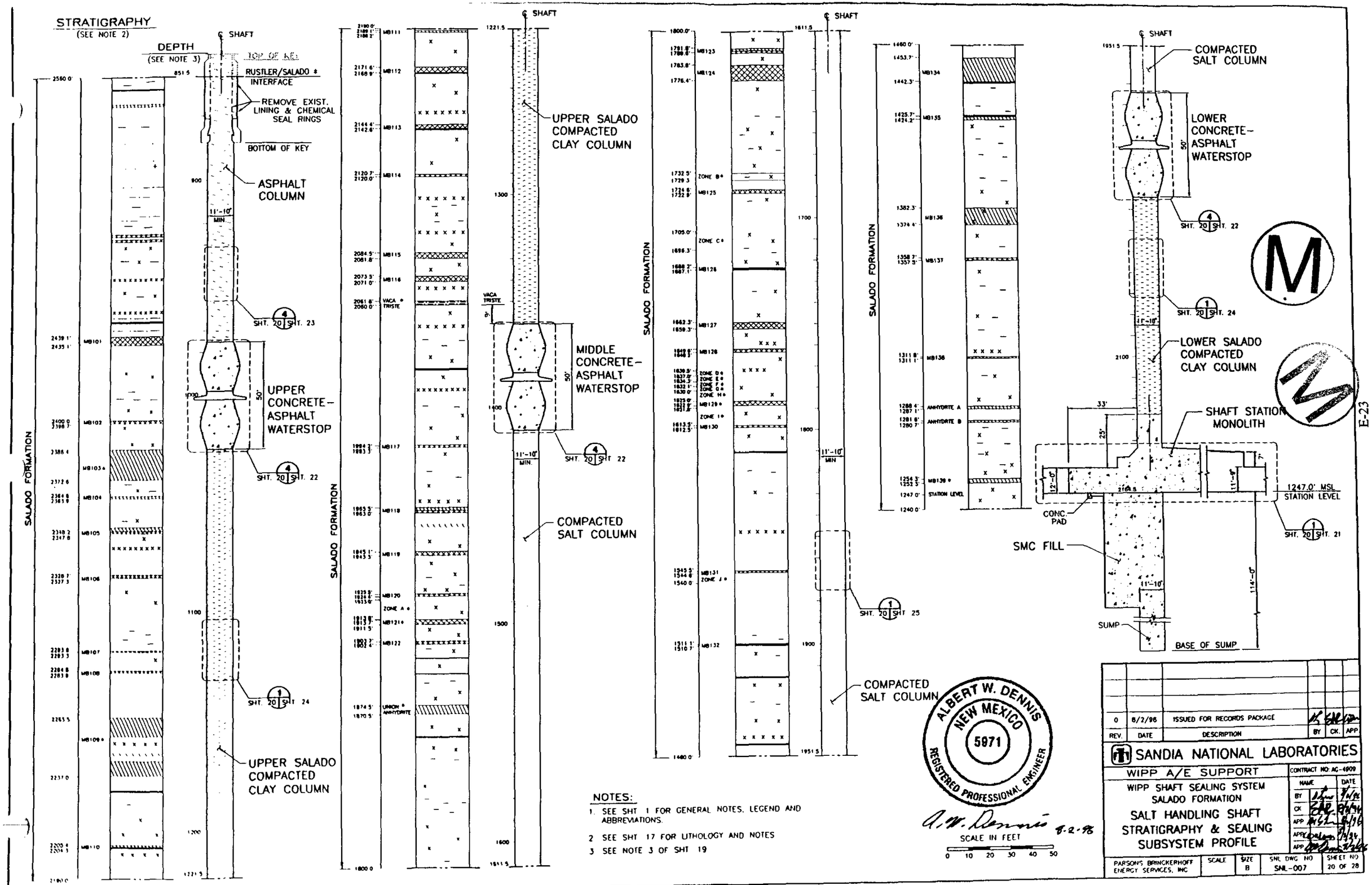

NOTES:

1. SEE SHT 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS.
2. SEE SHT 17 FOR LITHOLOGY AND NOTES
3. SEE NOTE 3 OF SHT 19

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

A.W. Dennis 8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO: AC-4909

WIPP SHAFT SEALING SYSTEM
SALADO FORMATION
SALT HANDLING SHAFT
STRATIGRAPHY & SEALING
SUBSYSTEM PROFILE

	NAME	DATE
BY		
CK		
APP		
APP		
APP		

PARSONS BRINCKERHOFF ENERGY SERVICES, INC | SCALE | SIZE B | SNL DWG NO SNL-007 | SHEET NO 20 OF 28

E-23

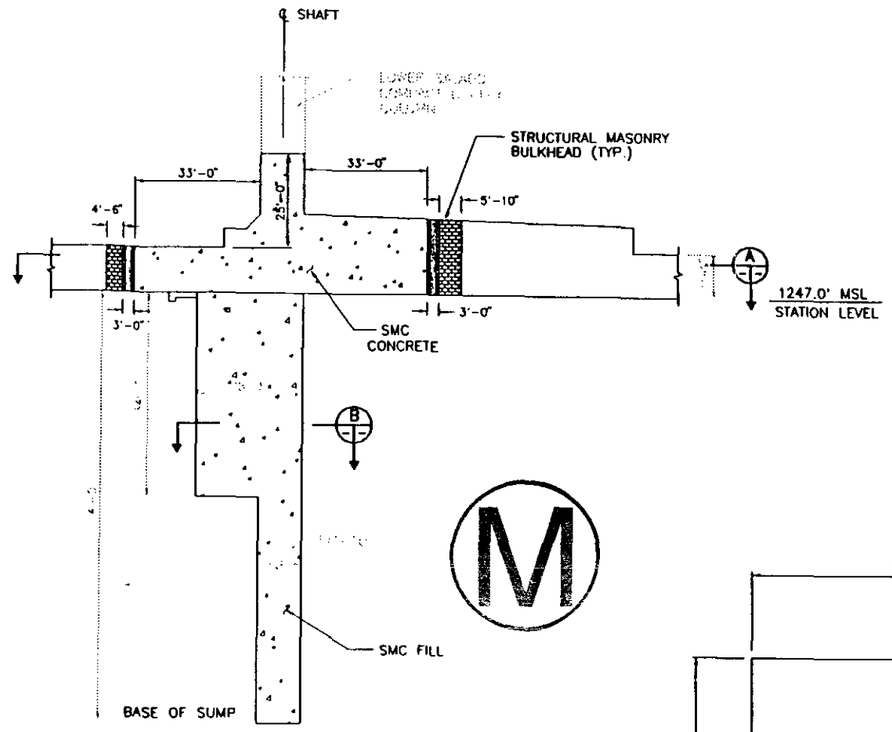

DETAIL 1

SHT. 20 SHT. 21

SCALE IN FEET

0 10 20 30 40 50

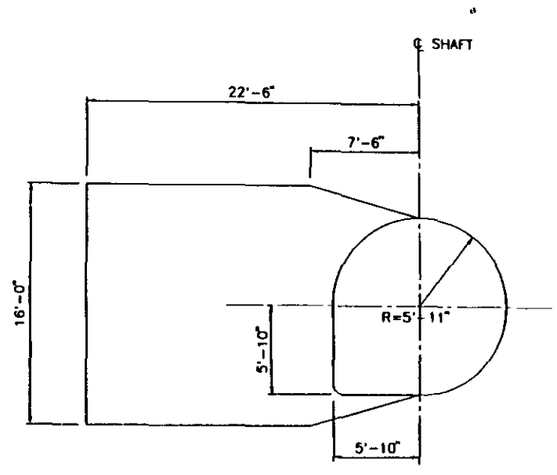

SECTION B

SCALE IN FEET

0 5 10 15 20

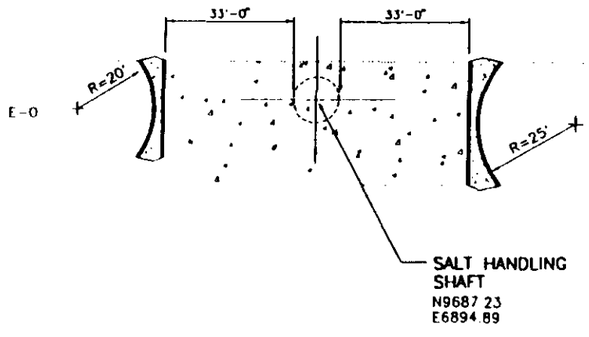

SECTION A

SCALE IN FEET

0 10 20 30 40 50

N

NOTES:

1. SEE SHT. 1 FOR GENERAL NOTES, LEGEND AND ABBREVIATIONS

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AC-4909

WIPP SHAFT SEALING SYSTEM

SALT HANDLING SHAFT
SHAFT STATION MONOLITH

	NAME	DATE
BY		8/4/96
CK		8/4/96
APP		8/4/96
APP		8/4/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 21 OF 28

E-24

NAME: [illegible] DATE: MAY 28 1996 TIME: 3:43 PM

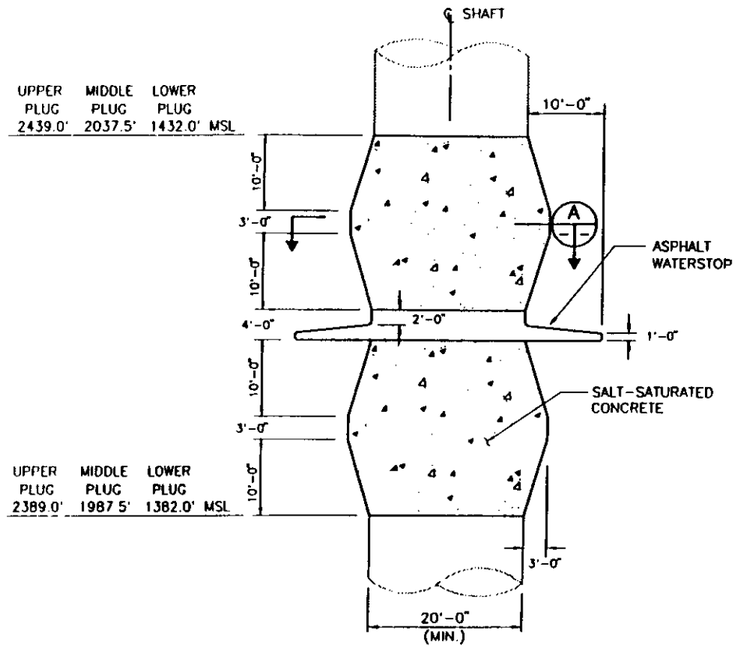

DETAIL 1
WASTE SHAFT SHT. 5 SHT 22

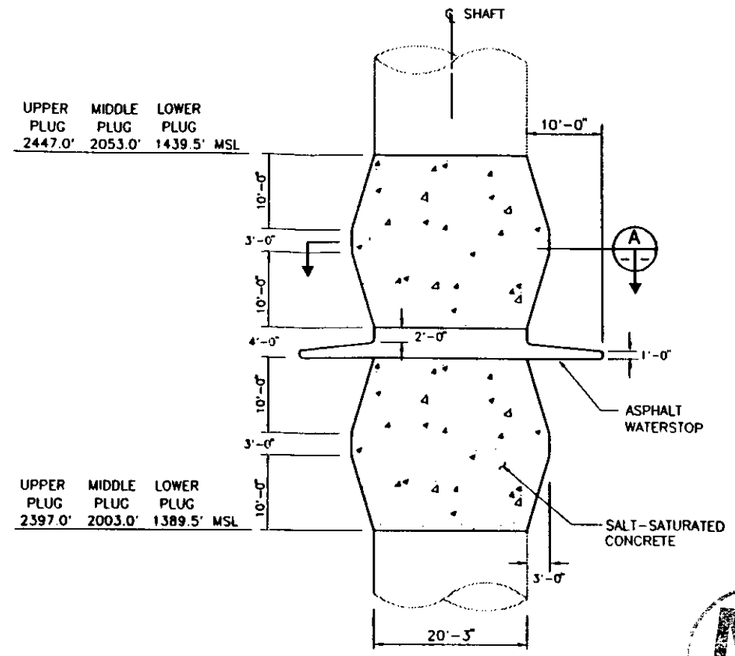

DETAIL 2
AIR INTAKE SHAFT SHT. 10 SHT 22

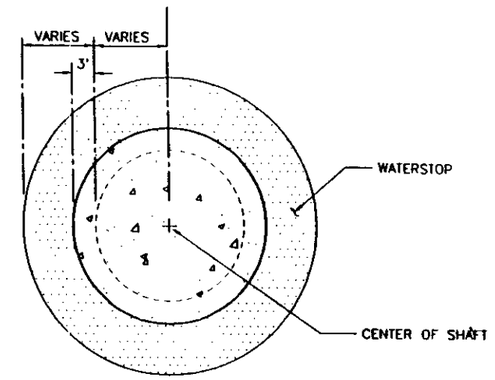

SECTION A
NO SCALE

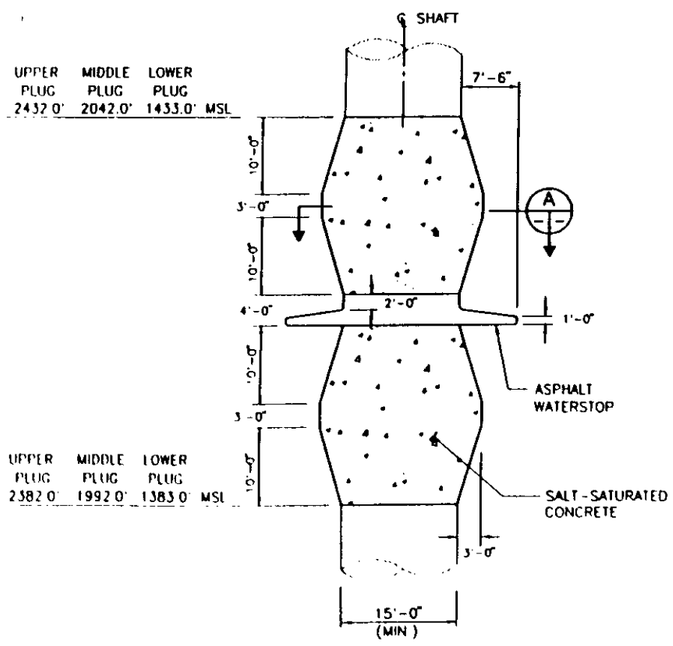

DETAIL 3
EXHAUST SHAFT SHT 15 SHT 22

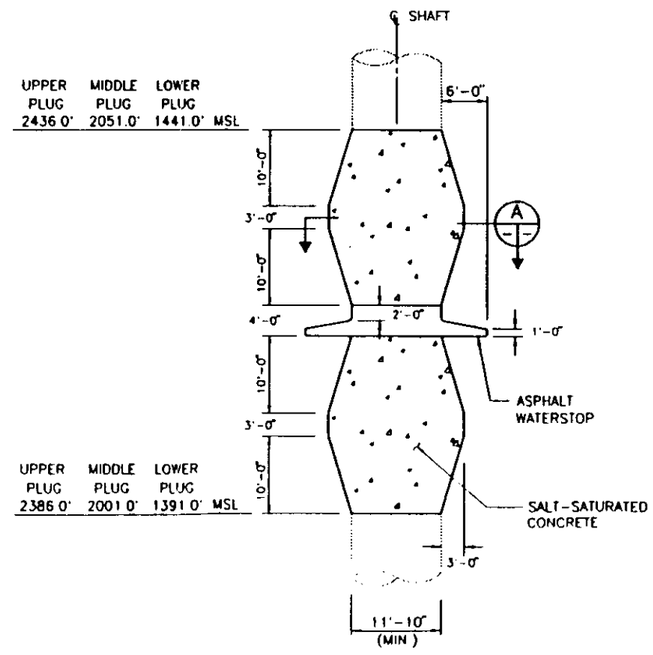

DETAIL 4
SALT HANDLING SHAFT SHT 20 SHT 22

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
9-2-96

SCALE IN FEET
0 5 10 15 20 25

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AG-4909

WIPP SHAFT SEALING SYSTEM

CONCRETE-ASPHALT WATERSTOP IN SALADO FORMATION

	NAME	DATE
BY		
CK		
APP		
APP		
APP		

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 22 OF 28

E-25

NAME [illegible] DATE MAY 06 1996 TIME 3:45 PM

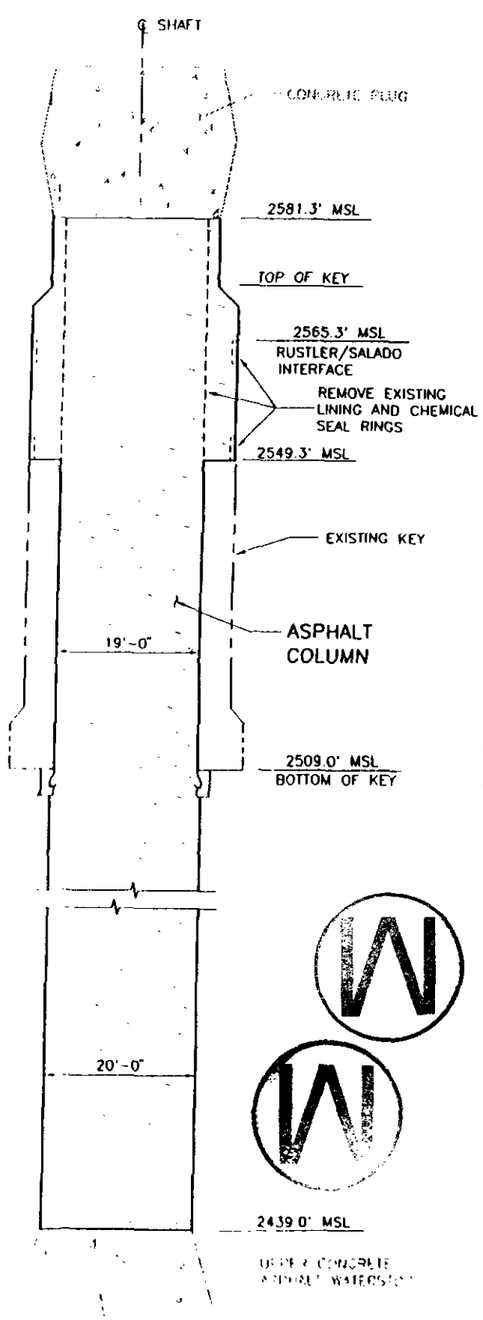

DETAIL 1
WASTE SHAFT SHT 5 SHT 23

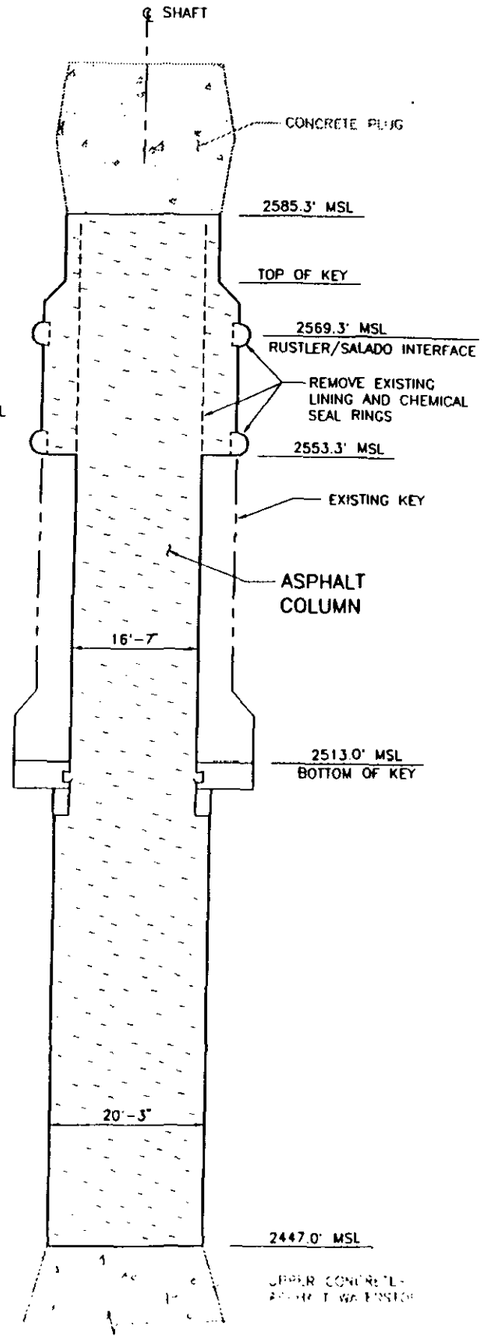

DETAIL 2
AIR INTAKE SHAFT SHT 10 SHT 23

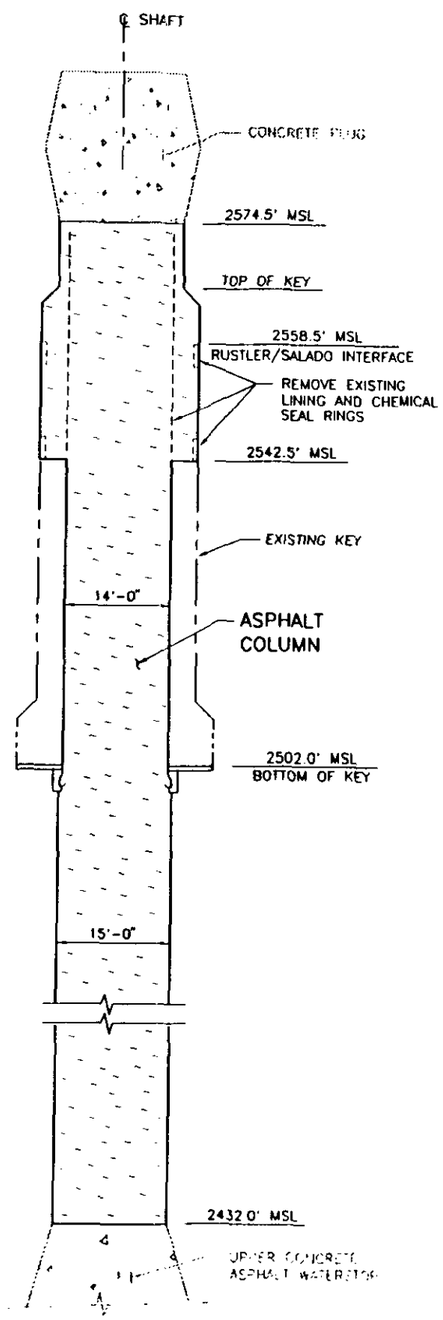

DETAIL 3
EXHAUST SHAFT SHT. 15 SHT 23

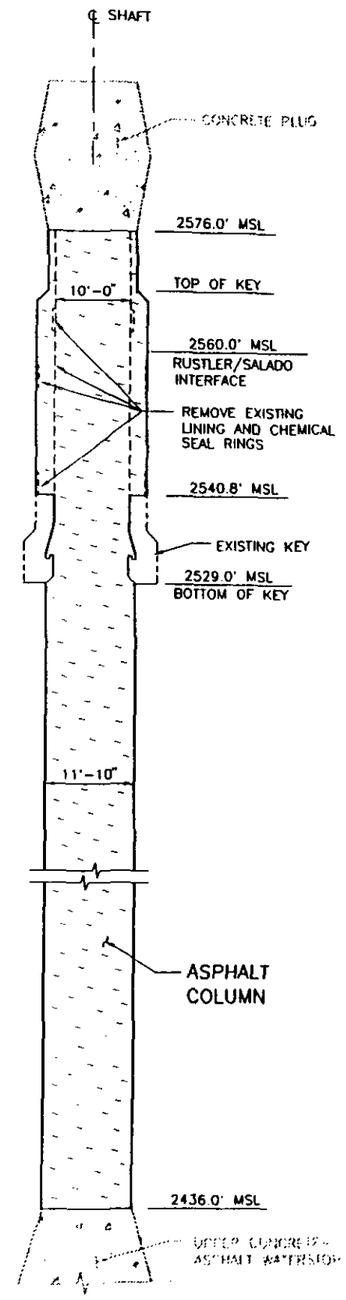

DETAIL 4
SALT HANDLING SHAFT SHT 20 SHT. 23

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

SCALE IN FEET
0 5 10 15 20 25

REV.	DATE	DESCRIPTION	BY	CK.	APP.
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO: AC-4909

WIPP SHAFT SEALING SYSTEM

ASPHALT COLUMN

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SML-007	SHEET NO 23 OF 28

E-26

NAME [illegible] DATE MAY 06 1996 TIME 4:09 PM

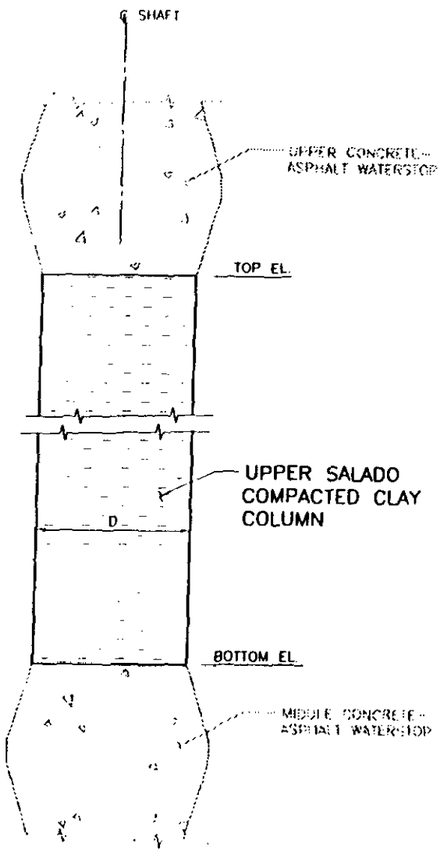

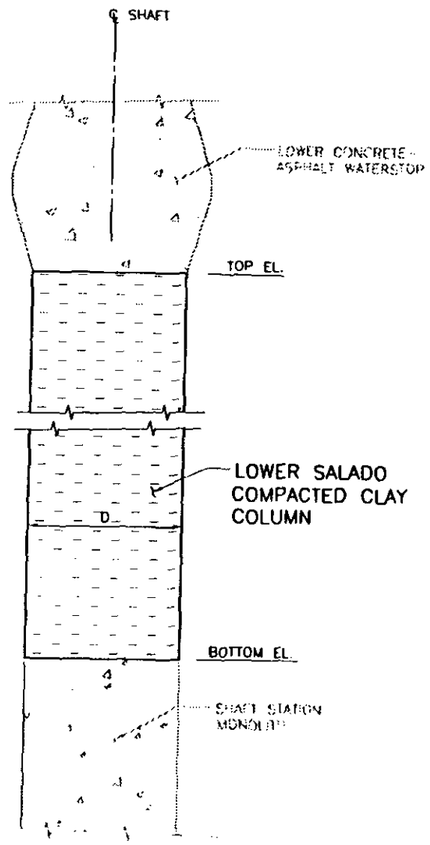

TABLE 1

SHAFT	NOMINAL SHAFT DIAMETER D	UPPER SALADO COMPACTED CLAY COLUMN			LOWER SALADO COMPACTED CLAY COLUMN		
		TOP EL. (FT. MSL)	BOTTOM EL. (FT. MSL)	TOTAL HT. (FT.)	TOP EL. (FT. MSL)	BOTTOM EL. (FT. MSL)	TOTAL HT. (FT.)
WASTE	20'-0"	2389.0	2037.5	351.5	1382.0	1286.0	96.0
AIR INTAKE	20'-3"	2397.0	2053.0	344.0	1389.5	1296.0	93.5
EXHAUST	15'-0"	2382.0	2042.0	340.0	1383.0	1285.0	98.0
SALT HANDLING	11'-10"	2386.0	2051.0	335.0	1391.0	1284.0	107.0

DETAIL 1

SEE TABLE 1 FOR DETAILS
NO SCALE

SHT. 5 | SHT. 24
SHT. 10
SHT. 15
SHT. 20

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
9-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP.
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO. AC-4909

WIPP SHAFT SEALING SYSTEM

UPPER AND LOWER SALADO COMPACTED CLAY COLUMNS

	NAME	DATE
BY		8/1/96
CK		8/2/96
APP		9/9/96
APP		9/9/96
APP		9/9/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 24 OF 28

E-27

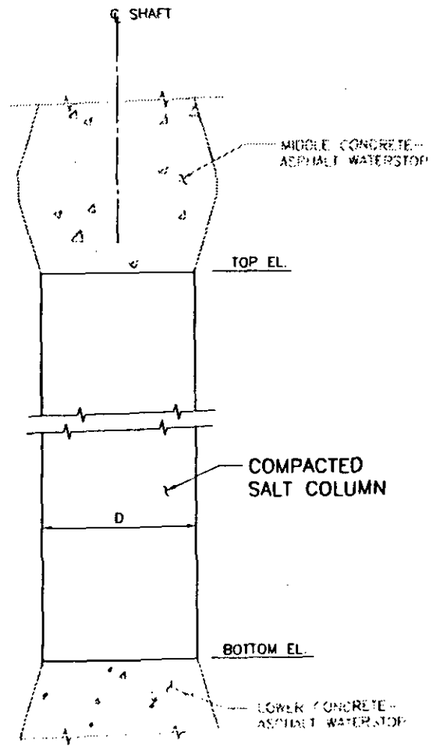

DETAIL 1
SEE TABLE 1 FOR DETAILS
NO SCALE
SHT. 5 SHT. 10 SHT. 15 SHT. 20 SHT. 25

TABLE 1

SHAFT	NOMINAL SHAFT DIAMETER D	COMPACTED SALT COLUMN		
		TOP EL. (FT. MSL)	BOTTOM EL. (FT. MSL)	TOTAL HT. (FT.)
WASTE	20'-0"	1987.5	1432.0	555.5
AIR INTAKE	20'-3"	2003.0	1439.5	563.5
EXHAUST	15'-0"	1992.0	1433.0	559.0
SALT HANDLING	11'-10"	2001.0	1441.0	560.0

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AC-4909

WIPP SHAFT SEALING SYSTEM

COMPACTED SALT COLUMN

	NAME	DATE
BY		8/1/96
CK		8/1/96
APP		8/1/96
APP		8/1/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC | SCALE | SIZE B | SNL DWG NO SNL-007 | SHEET NO 25 OF 28

E-28

NAME [illegible] DATE [illegible] TIME [illegible] PM

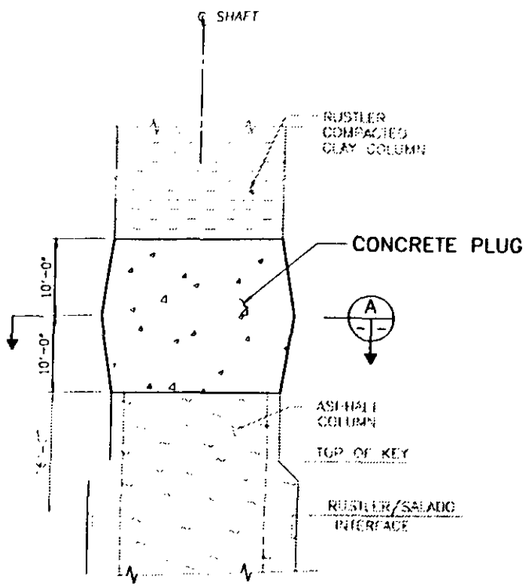

DETAIL 1
WASTE SHAFT SHT. 4 SHT. 26

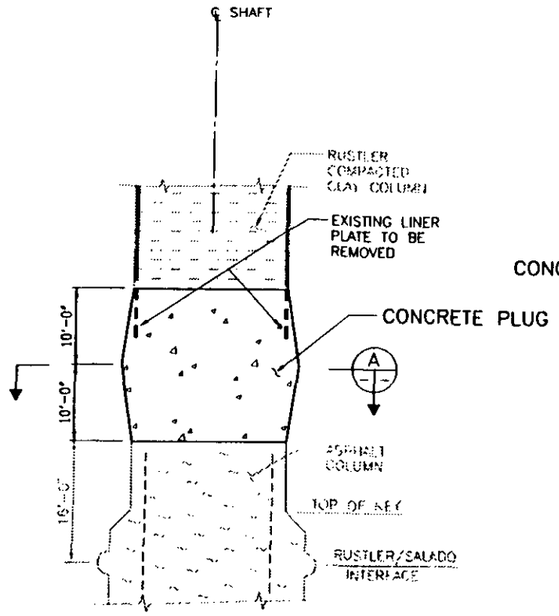

DETAIL 2
AIR INTAKE SHAFT SHT. 9 SHT. 26

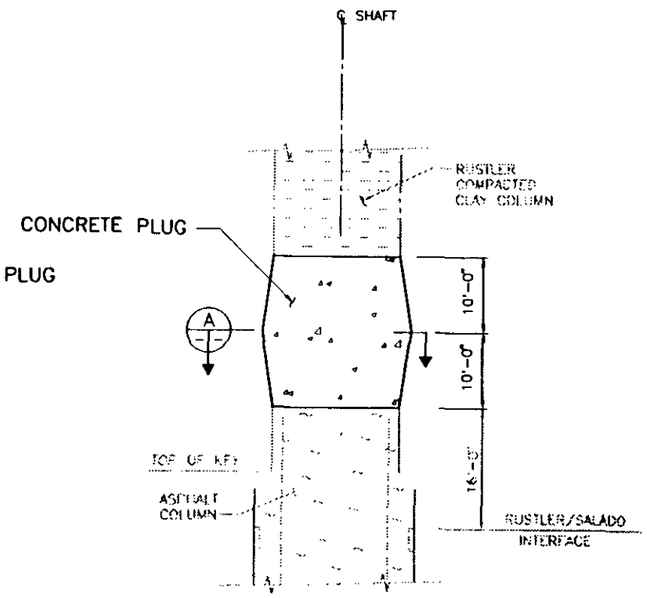

DETAIL 3
EXHAUST SHAFT SHT. 14 SHT. 26

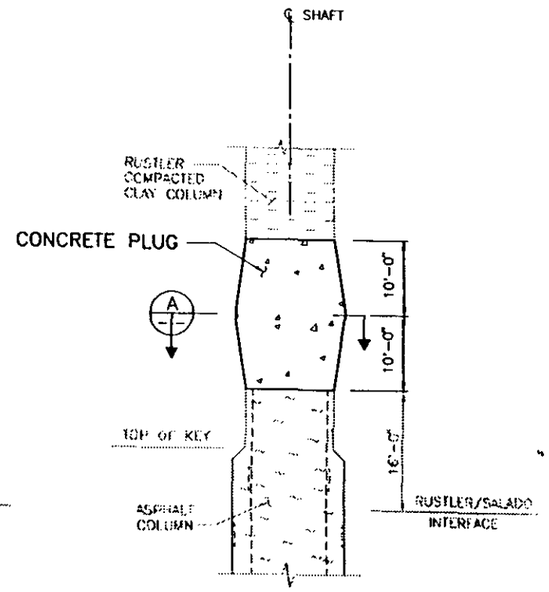

DETAIL 4
SALT HANDLING SHAFT SHT. 19 SHT. 26

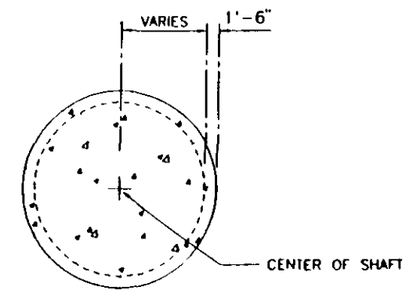

SECTION A
NO SCALE

SCALE IN FEET
0 5 10 15 20 25

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO AG-4909

WIPP SHAFT SEALING SYSTEM

CONCRETE PLUG

	NAME	DATE
BY		
CK		
APP		
APP		
APP		

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 26 OF 28

E-29

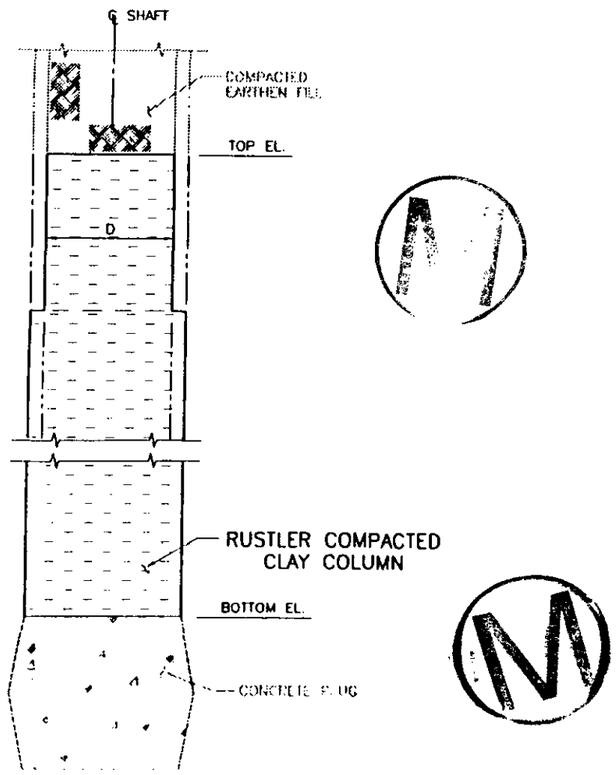

DETAIL 1
SEE TABLE 1 FOR DETAILS
NO SCALE
SHT. 4 | SHT. 27
SHT. 9
SHT. 14
SHT. 19

TABLE 1

SHAFT	NOMINAL SHAFT DIAMETER D	RUSTLER COMPACTED CLAY COLUMN		
		TOP EL. (FT. MSL)	BOTTOM EL. (FT. MSL)	TOTAL HT. (FT.)
WASTE	19'-0"	2836.0	2601.3	234.7
AIR INTAKE	16'-7"	2840.0	2605.3	234.7
EXHAUST	14'-0"	2829.0	2594.5	234.5
SALT HANDLING	10'-0"	2830.0	2596.0	234.0

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
9-2-96

REV	DATE	DESCRIPTION	BY	CK	APP
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

CONTRACT NO. AC-4909

WIPP SHAFT SEALING SYSTEM

RUSTLER COMPACTED CLAY COLUMN

	NAME	DATE
BY		8/2/96
CK.		8/2/96
APP		9/2/96
APP		9/2/96
APP		9/2/96

PARSONS, BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 27 OF 28

E-30

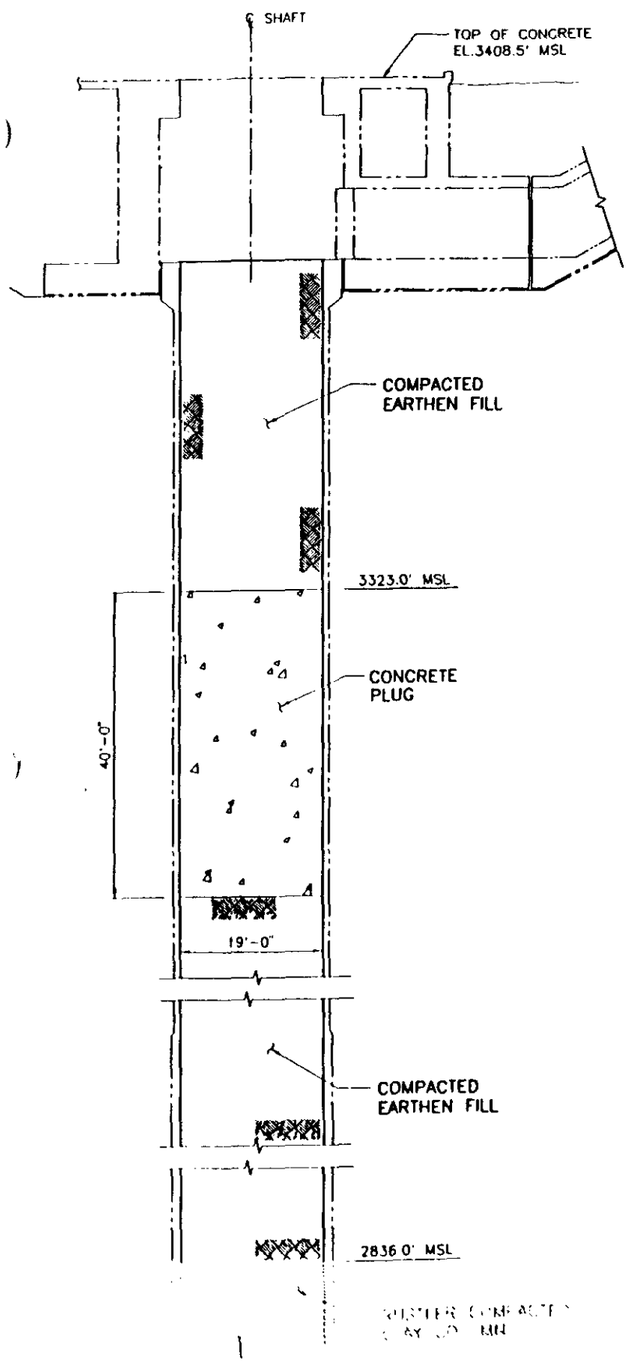

DETAIL
WASTE SHAFT SHT 4 SHT 28

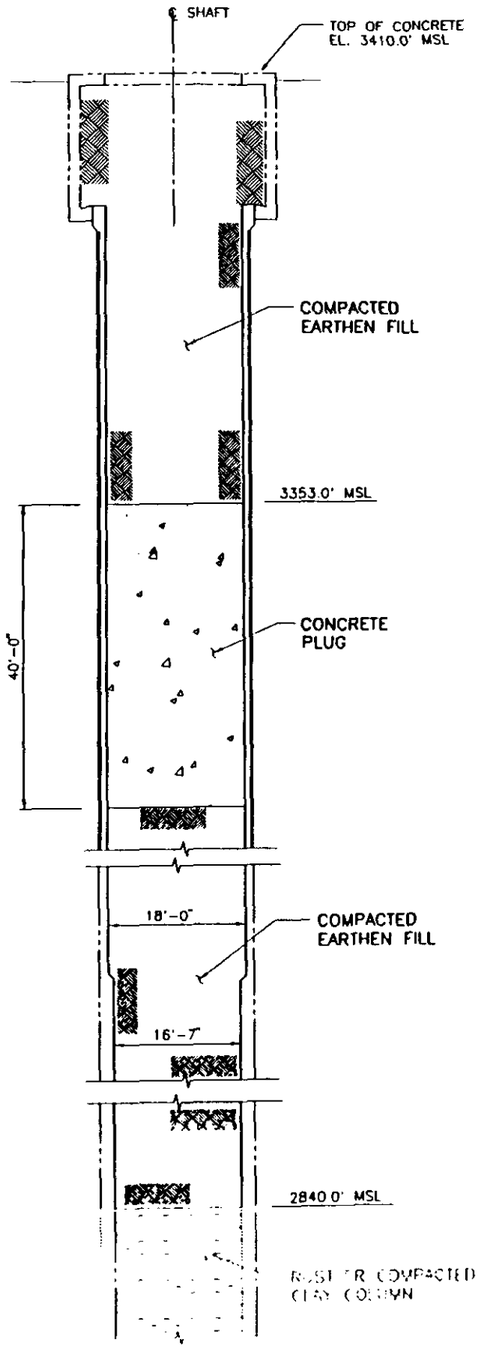

DETAIL
AIR INTAKE SHAFT SHT 9 SHT 28

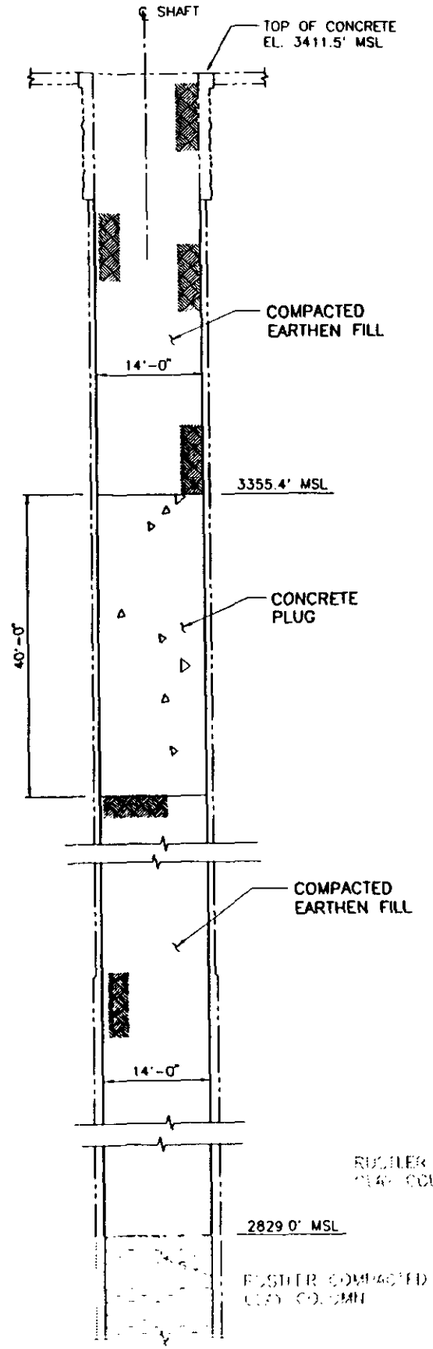

DETAIL
EXHAUST SHAFT SHT 14 SHT 28

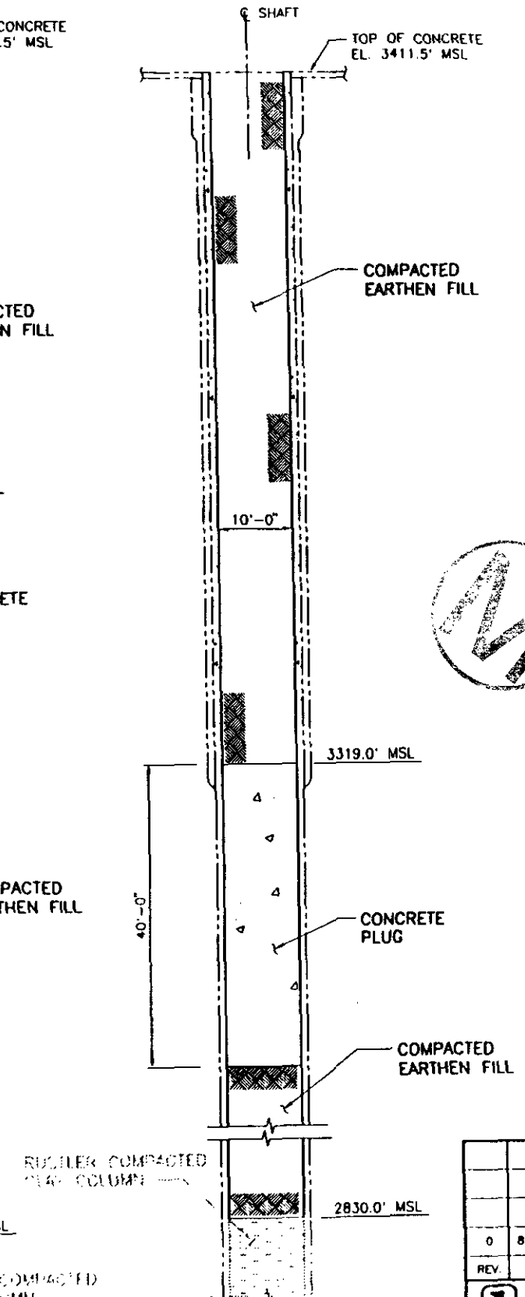

DETAIL
SALT HANDLING SHAFT SHT. 19 SHT. 28

SCALE IN FEET
0 5 10 15 20 25

ALBERT W. DENNIS
NEW MEXICO
5971
REGISTERED PROFESSIONAL ENGINEER

Albert W. Dennis
8-2-96

REV.	DATE	DESCRIPTION	BY	CK.	APP.
0	8/2/96	ISSUED FOR RECORDS PACKAGE			

SANDIA NATIONAL LABORATORIES

WIPP A/E SUPPORT

WIPP SHAFT SEALING SYSTEM

COMPACTED EARTHEN FILL AND CONCRETE PLUG

CONTRACT NO: AC-4909

	NAME	DATE
BY		8/2/96
CK		8/2/96
APP		8/2/96
APP		8/2/96
APP		8/2/96

PARSONS BRINCKERHOFF ENERGY SERVICES, INC	SCALE	SIZE B	SNL DWG NO SNL-007	SHEET NO 28 OF 28

E-31

WASTE ISOLATION PILOT PLANT

CARLSBAD, NM

SHAFT SEALING SYSTEM DESIGN

EQUIPMENT AND CONSTRUCTION SKETCHES

DRAWING NUMBER	TITLE
SKETCH E-1	WIPP SHAFT SEALING SYSTEM SMALLER GALLOWAY GENERAL ARRANGEMENT PLANS AND SECTIONS
SKETCH E-2	WIPP SHAFT SEALING SYSTEM LARGER GALLOWAY GENERAL ARRANGEMENT PLANS AND SECTIONS
SKETCH E-3	WIPP SHAFT SEALING SYSTEM TYPICAL HEADFRAME PLANS AND SECTIONS
SKETCH E-4	WIPP SHAFT SEALING SYSTEM PERSPECTIVE HEADFRAME AND ASSOCIATED SURFACE FACILITIES

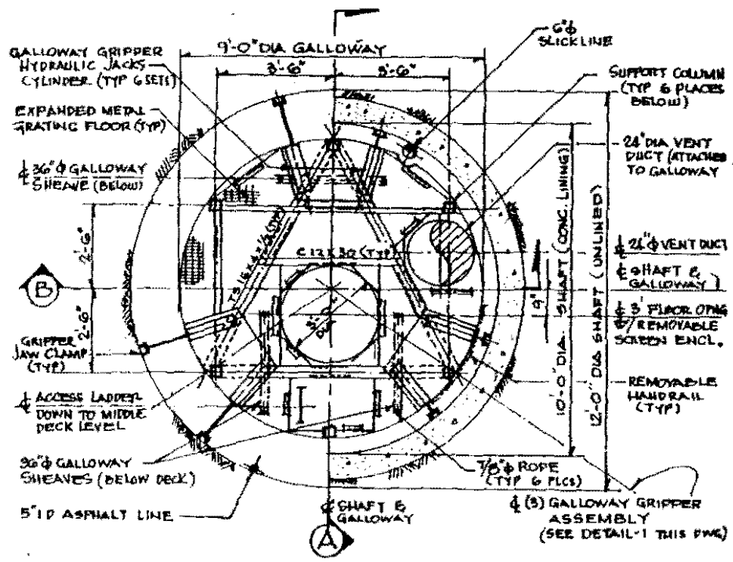

PLAN - TOP DECK

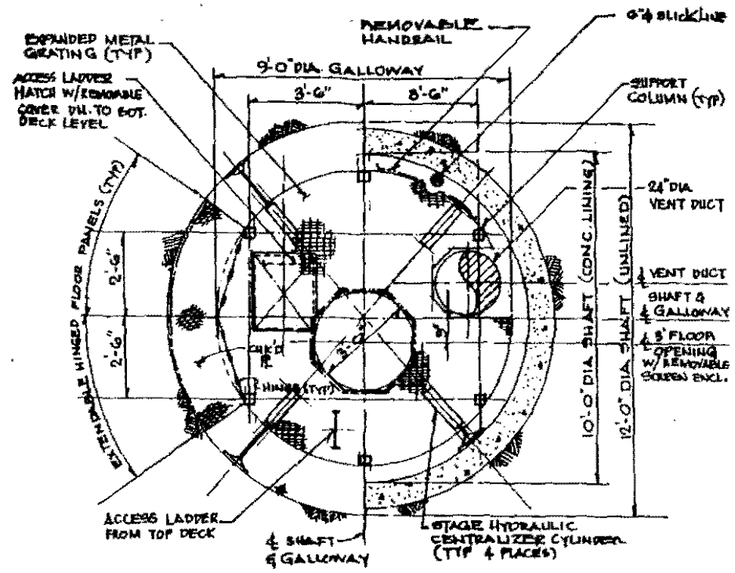

PLAN - MIDDLE DECK

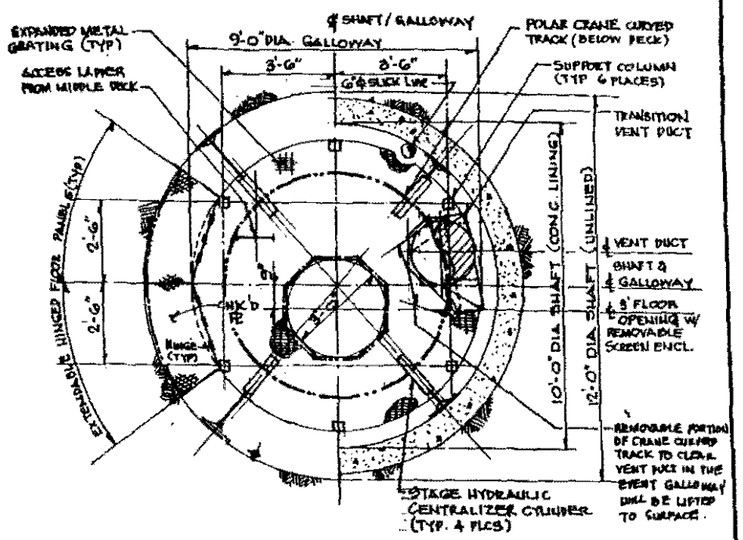

PLAN - BOTTOM DECK

10 FT DIA SHAFT

SCALE IN FEET

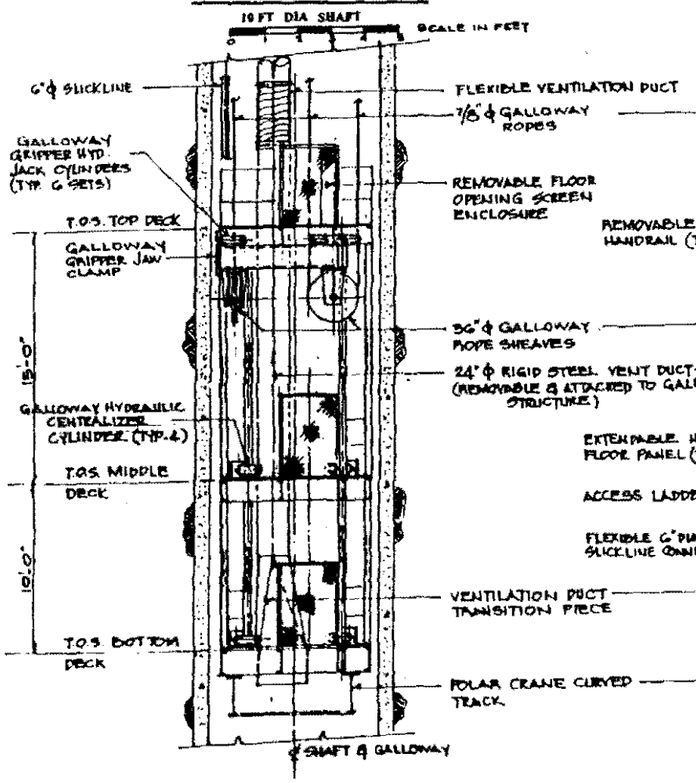

SECTION A

SCALE IN FEET

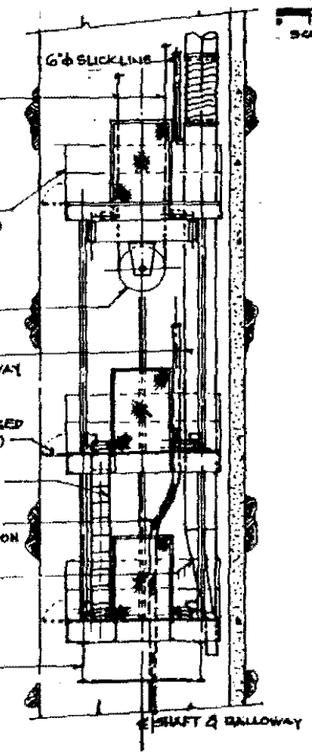

SECTION B

SCALE IN FEET

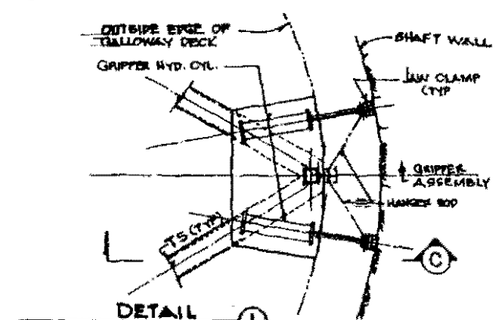

DETAIL 1
GALLOWAY GRIPPER

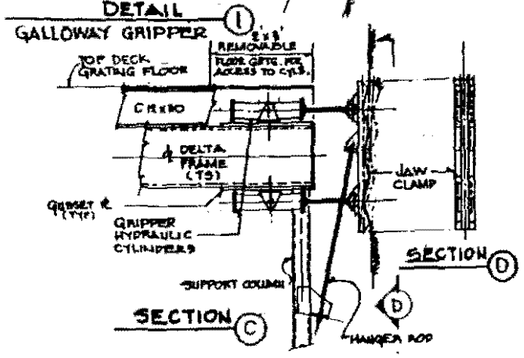

SECTION D

SECTION C

WIPP SHAFT SEALING SYSTEM

SMALLER GALLOWAY
GENERAL ARRANGEMENT
PLANS & SECTIONS

SKETCH E-1

E-33

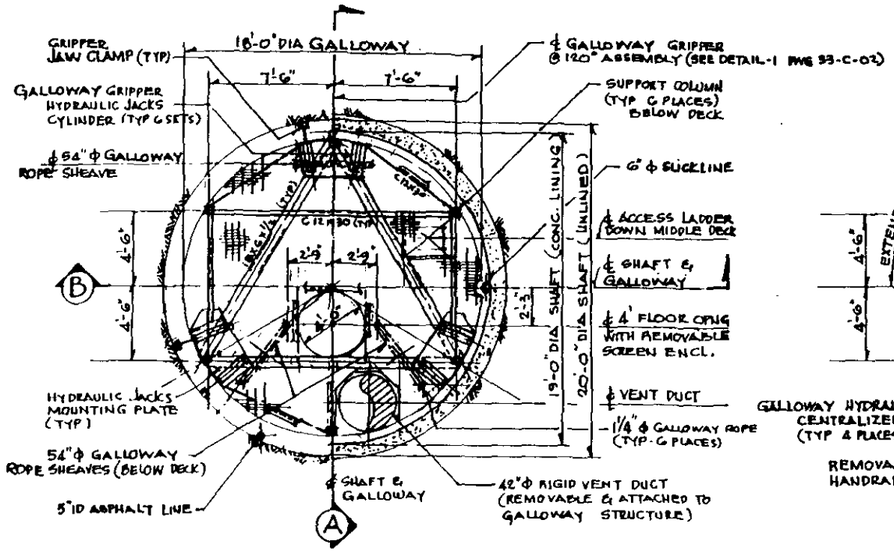

PLAN - TOP DECK

20 FT DIA SHAFT

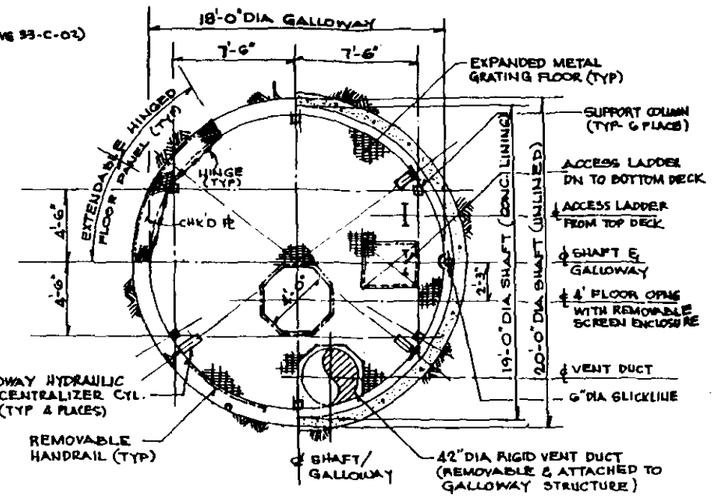

PLAN - MIDDLE DECK

20 FT DIA SHAFT

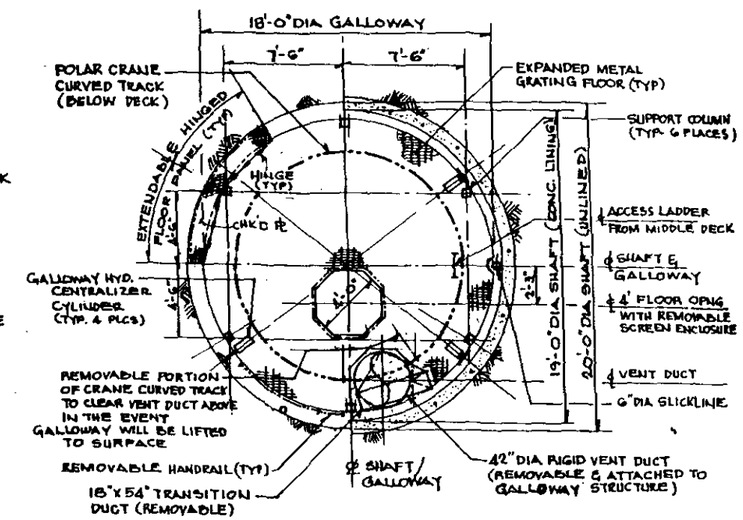

PLAN - BOTTOM DECK

20 FT DIA SHAFT

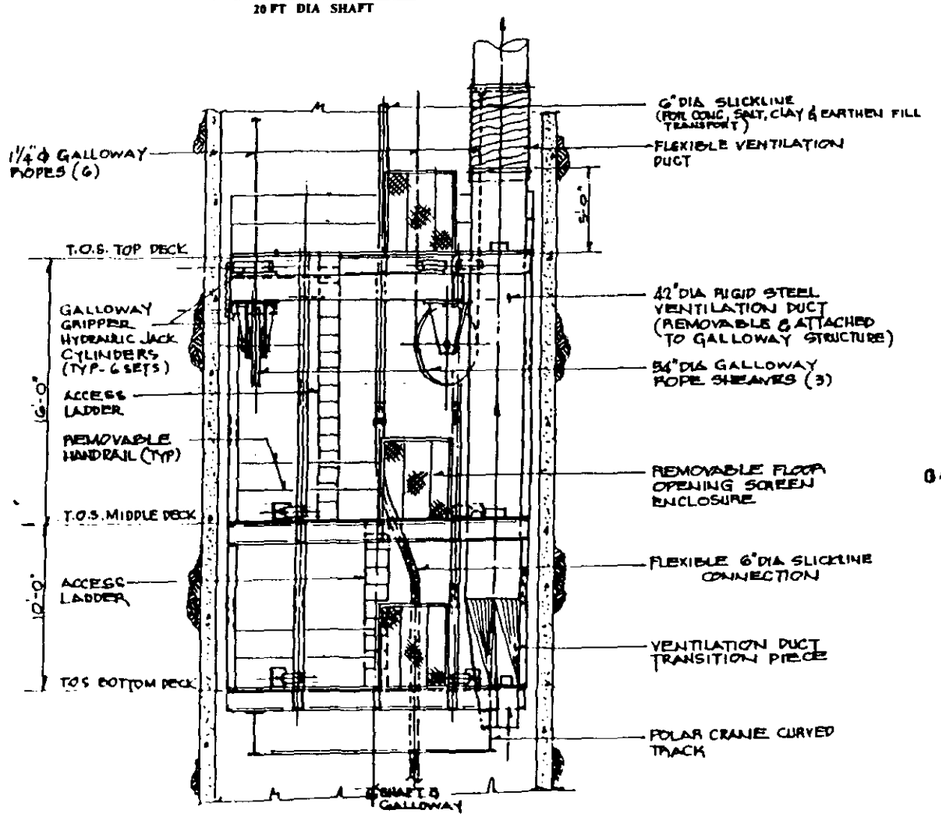

SECTION A

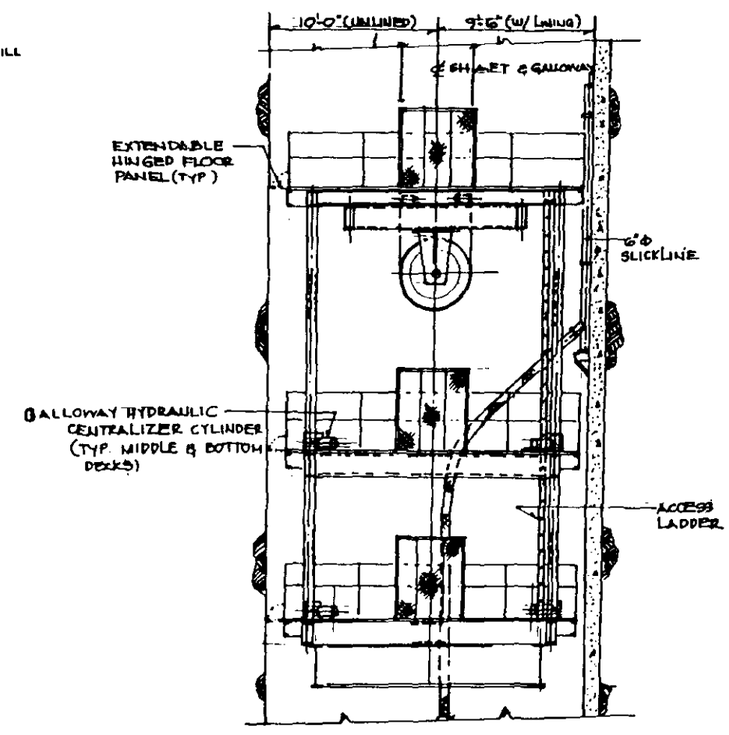

SECTION B

GALLOWAY DESIGN DATA

	SALT HANDLING SHAFT	EXHAUST SHAFT	AIR INTAKE SHAFT	WASTE SHAFT
Shaft Diameter	10'-0"(lined) 11'-10"(unlined)	14'(lined) 15'(unlined)	16'-7"(lined) 20'(unlined)	19'-0"(lined) 20'(unlined)
Dia of Galloway	9ft	13ft	15'-7"	18ft
Height of Galloway	25ft	25ft	26ft	26ft
Dia of Vent duct	24 inch	36 inch	42 inch	42 inch
No. of Galloway rope	6	6	6	6
No. of Galloway sheave	3	3	3	3
Dia of Galloway rope	7/8 inch	1 1/8 inch	1 1/4 inch	1 1/4 inch
Dia of Galloway sheaves	36 inch	36 inch	54 inch	54 inch
Wt. of Galloway(struct)	18000 lb	29000 lb	40200 lb	49600 lb
Polar crane wt.	58696 lb	48606 lb	58696 lb	58696 lb
Tamper weight	11394 lb	11394 lb	11394 lb	11394 lb
Total Wt. Galloway (live and dead load)	80409 lb	113816 lb	143622 lb	162622 lb

SCALE IN FEET
0 1 2 3 4 5 6

WIPP SHAFT SEALING SYSTEM

LARGER GALLOWAY
GENERAL ARRANGEMENT
PLANS & SECTIONS

SKETCH E-2

E-34

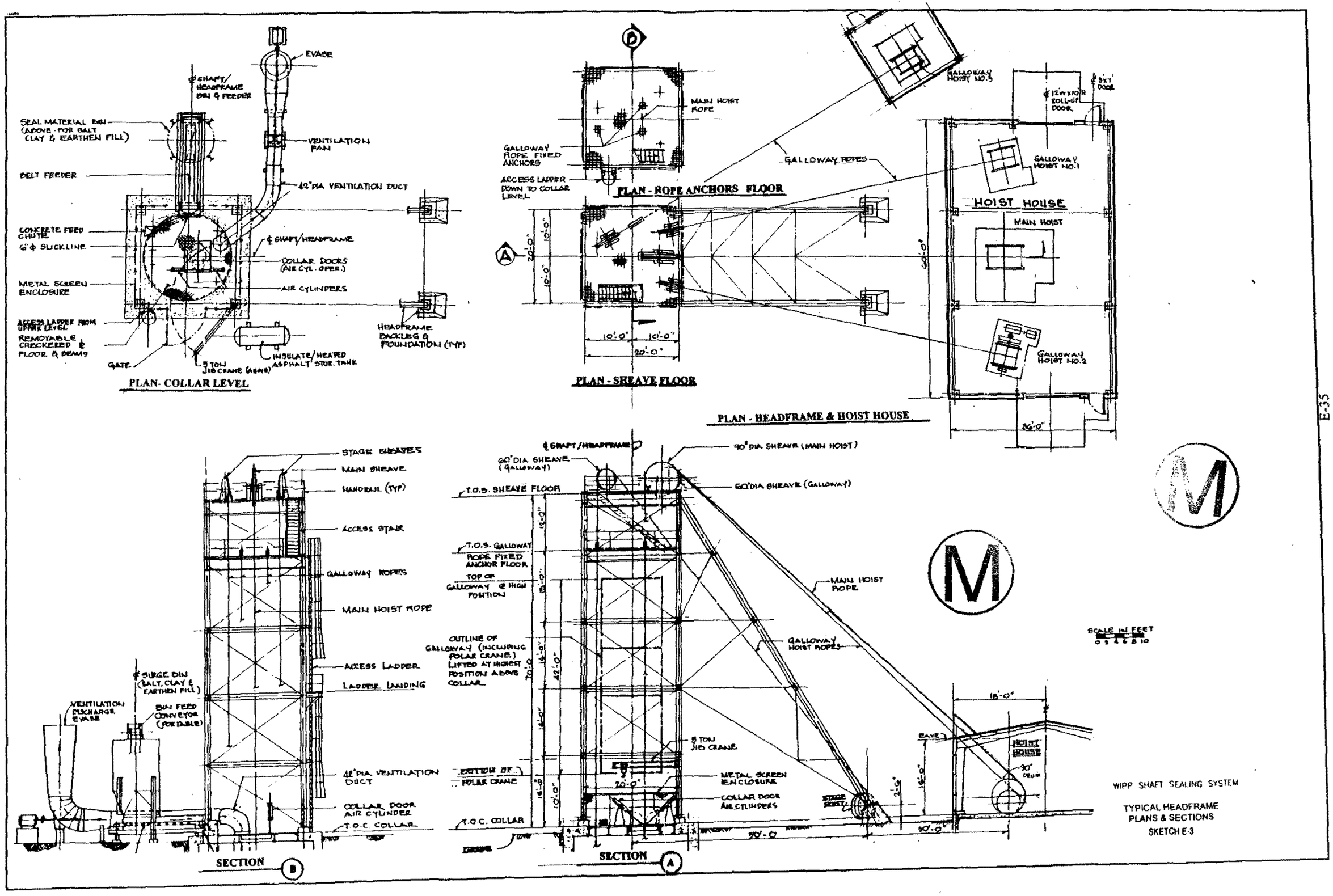
EVASE
℄ SHAFT/ HEADFRAME BIN & FEEDER
SEAL MATERIAL BIN (ABOVE - FOR SALT CLAY & EARTHEN FILL)
VENTILATION FAN
BELT FEEDER
42"DIA VENTILATION DUCT
CONCRETE FEED CHUTE
6" ϕ SLICKLINE
℄ SHAFT/HEADFRAME
COLLAR DOORS (AIR CYL. OPER.)
METAL SCREEN ENCLOSURE
AIR CYLINDERS
ACCESS LADDER FROM UPPER LEVEL
REMOVABLE CHECKERED ℄ FLOOR & BEAMS
GATE
5 TON JIB CRANE (ABOVE)
INSULATE/HEATED ASPHALT STOR. TANK
HEADFRAME BACKLEG & FOUNDATION (TYP)
PLAN- COLLAR LEVEL
MAIN HOIST ROPE
GALLOWAY ROPE FIXED ANCHORS
ACCESS LADDER DOWN TO COLLAR LEVEL
PLAN - ROPE ANCHORS FLOOR
PLAN - SHEAVE FLOOR
GALLOWAY HOIST NO.3
GALLOWAY ROPES
12'W x 10'H ROLL-UP DOOR
3'x7' DOOR
GALLOWAY HOIST NO.1
HOIST HOUSE
MAIN HOIST
GALLOWAY HOIST NO.2
PLAN - HEADFRAME & HOIST HOUSE
STAGE SHEAVES
MAIN SHEAVE
HANDRAIL (TYP)
ACCESS STAIR
GALLOWAY ROPES
MAIN HOIST ROPE
ACCESS LADDER
LADDER LANDING
SURGE BIN (SALT, CLAY & EARTHEN FILL)
VENTILATION DISCHARGE EVASE
BIN FEED CONVEYOR (PORTABLE)
42"DIA VENTILATION DUCT
COLLAR DOOR AIR CYLINDER
T.O.C. COLLAR
SECTION B
℄ SHAFT/HEADFRAME
60"DIA SHEAVE (GALLOWAY)
90"DIA SHEAVE (MAIN HOIST)
60"DIA SHEAVE (GALLOWAY)
T.O.S. SHEAVE FLOOR
T.O.S. GALLOWAY ROPE FIXED ANCHOR FLOOR
TOP OF GALLOWAY @ HIGH POSITION
MAIN HOIST ROPE
OUTLINE OF GALLOWAY (INCLUDING POLAR CRANE) LIFTED AT HIGHEST POSITION ABOVE COLLAR
GALLOWAY HOIST ROPES
5 TON JIB CRANE
BOTTOM OF POLAR CRANE
METAL SCREEN ENCLOSURE
COLLAR DOOR AIR CYLINDERS
T.O.C. COLLAR
SECTION A
SCALE IN FEET
0 2 4 6 8 10
WIPP SHAFT SEALING SYSTEM
TYPICAL HEADFRAME PLANS & SECTIONS
SKETCH E-3

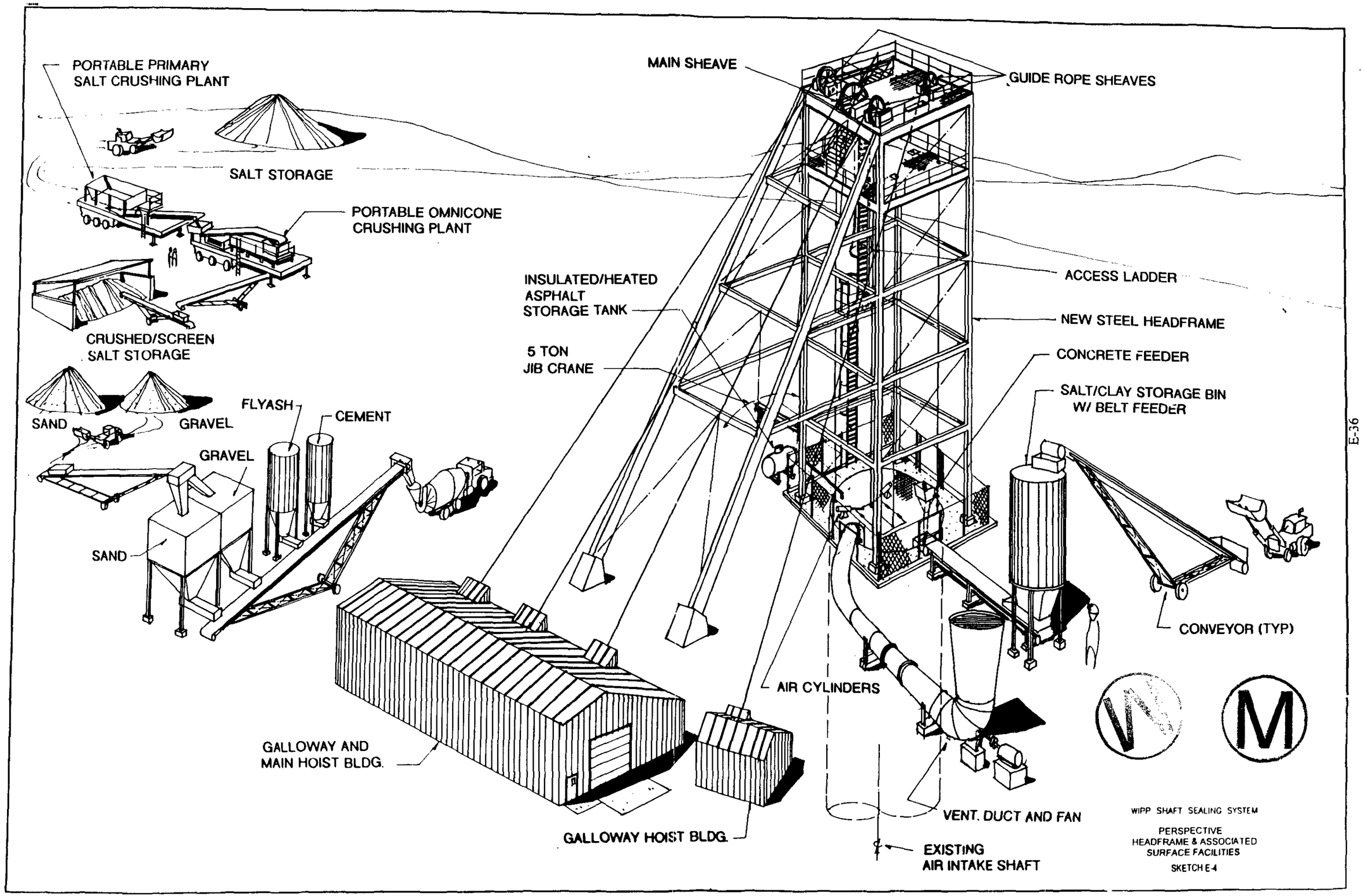
PORTABLE PRIMARY
SALT CRUSHING PLANT
SALT STORAGE
PORTABLE OMNICONE
CRUSHING PLANT
CRUSHED/SCREEN
SALT STORAGE
SAND
GRAVEL
FLYASH
CEMENT
GRAVEL
SAND
MAIN SHEAVE
GUIDE ROPE SHEAVES
INSULATED/HEATED
ASPHALT
STORAGE TANK
5 TON
JIB CRANE
ACCESS LADDER
NEW STEEL HEADFRAME
CONCRETE FEEDER
SALT/CLAY STORAGE BIN
W/ BELT FEEDER
CONVEYOR (TYP)
AIR CYLINDERS
GALLOWAY AND
MAIN HOIST BLDG.
GALLOWAY HOIST BLDG.
VENT. DUCT AND FAN
EXISTING
AIR INTAKE SHAFT
WIPP SHAFT SEALING SYSTEM
PERSPECTIVE
HEADFRAME & ASSOCIATED
SURFACE FACILITIES
SKETCH E-4

E-36

WIPP
UC721 Distribution List

Federal Agencies

US Department of Energy (4)
Office of Civilian Radioactive Waste Mgmt.
Attn: Deputy Director, RW-2
Acting Director, RW-10
Office of Human Resources & Admin.
Director, RW-30
Office of Program Mgmt. & Integ.
Director, RW-40
Office of Waste Accept., Stor., & Tran.
Forrestal Building
Washington, DC 20585

Attn: Project Director (2)
Yucca Mountain Site Characterization Office
Director, RW-3
Office of Quality Assurance
101 Convention Center Drive, Suite #P-110
Las Vegas, NV 89109

US Department of Energy
Albuquerque Operations Office
Attn: National Atomic Museum Library
P.O. Box 5400
Albuquerque, NM 87185-5400

US Department of Energy
Research & Waste Management Division
Attn: Director
P.O. Box E
Oak Ridge, TN 37831

US Department of Energy (8)
Carlsbad Area Office
Attn: G. Dials
D. Galbraith (3)
M. Matthews
M. McFadden
R. Lark
J. A. Mewhinney
P.O. Box 3090
Carlsbad, NM 88221-3090

US Department of Energy
Office of Environmental Restoration and
Waste Management
Attn: J. Lytle, EM-30
Forrestal Building
Washington, DC 20585-0002

US Department of Energy (3)
Office of Environmental Restoration and
Waste Management
Attn: M. Frei, EM-34, Trevion II
Washington, DC 20585-0002

US Department of Energy
Office of Environmental Restoration and
Waste Management
Attn: S. Schneider, EM-342, Trevion II
Washington, DC 20585-0002

US Department of Energy (2)
Office of Environment, Safety & Health
Attn: C. Borgstrom, EH-25
R. Pelletier, EH-231
Washington, DC 20585

US Department of Energy (2)
Idaho Operations Office
Fuel Processing & Waste Mgmt. Division
785 DOE Place
Idaho Falls, ID 83402

US Environmental Protection Agency (2)
Radiation Protection Programs
Attn: M. Oge
ANR-460
Washington, DC 20460

Boards

Defense Nuclear Facilities Safety Board
Attn: D. Winters
625 Indiana Ave. NW, Suite 700
Washington, DC 20004

Nuclear Waste Technical Review Board (2)
Attn: Chairman
S. J. S. Parry
1100 Wilson Blvd., Suite 910
Arlington, VA 22209-2297

State Agencies

Attorney General of New Mexico
P.O. Drawer 1508
Santa Fe, NM 87504-1508

Environmental Evaluation Group (3)
Attn: Library
7007 Wyoming NE, Suite F-2
Albuquerque, NM 87109

Metropolitan Water District of Southern Calif.
Attn: J. Narvaiz
P.O. Box 54153
Los Angeles, CA 90071-3123

NM Energy, Minerals, and Natural
Resources Department
Attn: Library
2040 S. Pacheco
Santa Fe, NM 87505

NM Environment Department (3)
Secretary of the Environment
Attn: Mark Weidler
1190 St. Francis Drive
Santa Fe, NM 87503-0968

NM Bureau of Mines & Mineral Resources
Socorro, NM 87801

NM Environment Department
WIPP Project Site
Attn: P. McCasland
P.O. Box 3090
Carlsbad, NM 88221

Laboratories/Corporations

Battelle Pacific Northwest Laboratories (2)
Attn: R. E. Westerman
R. Romine, MS P8-38
P.O. Box 999
900 Battelle Blvd.
Richland, WA 99352

Brookhaven National Laboratory
Attn: P. D. Moskowitz
Environmental & Waste Technology
Center
Building 830
Upton, NY 11973

Harnischfeger Corp.
Phonex Engineering Services
Attn: R. Luebke
2969 S. Chase Avenue
Milwaukee, WI 53207-6408

Ian Clelland
6656 N. Amdahl Dr.
Tucson, AZ 85704

INTERA, Inc.
Attn: G. A. Freeze
1650 University Blvd. NE, Suite 300
Albuquerque, NM 87102

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Austin, TX 78731

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1261 Town Center Drive
Las Vegas, NV 89134

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P.O. Box 2123
Carlsbad, NM 88221

Istasca Consulting Group, Inc.
Attn: John Tinucci
Thresher Square East
708 South Third Street, Suite 310
Minneapolis, MI 55415

Los Alamos National Laboratory
Attn: B. Erdal, INC-12
P.O. Box 1663
Los Alamos, NM 87544

Morton International, Morton Salt
Attn: H. W. Diamond
Morton International Building
100 N. Riverside Plaza,
Randolph Street at the River
Chicago, IL 60606-1597

Parsons Brinckerhoff Energy Services, Inc.
Attn: W. S. Roman
One Penn Plaza
New York, NY 10119

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Suite 850 North
San Francisco, CA 94107

Parsons Brinckerhoff International, Inc.
Attn: Mary Ann Novak
700 11th Street, NW, Suite 710
Washington, DC 20001

Phillips Mining, Geotechnical & Grouting
Attn: Stephen Phillips
8640 North Glenhurst Place
Tucson, AZ 85704

RE/SPEC, Inc. (5)
Attn: L. Van Sambeek (3)
G. Callahan
M. Loken
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3824 Jet Drive
P.O. Box 725
Rapid City, SD 57709

RE/SPEC, Inc
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4775 Indian School NE, Suite 300
Albuquerque, NM 87110-3927

Science Applications International Corp.
Attn: W. Thompson
15000 W. 6th Avenue, Suite 202
Golden, CO 80401

Tech Reps, Inc. (3)
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L. Robledo (2)
5000 Marble NE, Suite 222
Albuquerque, NM 87110

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B. A. Howard
R. Kehrman
P.O. Box 2078
Carlsbad, NM 88221

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1355 Beverly Road
McLean, VA 22101

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Bellevue, WA 98009-2050

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Murrysville, PA 15668

Universities

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Department of Engineering
Claremont, CA 91711

New Mexico State University
Waste-management Education & Research Corporation.
Attn: R. Bhada
P.O. Box 3001
Las Cruces, NM 88003-8001

University of California
Department of Mechanical and Environmental Engineering
Attn: E. Marschall
University of California
Santa Barbara, CA 93106

University of Nevada-Reno
Department of Mining Engineering
Mackay School of Mines
Attn: J. Daamen
Reno, NV 89557

University of New Mexico
Center for Radioactive Waste Management
Attn: W. Lutze
209 Faris Engineering Building
Albuquerque, NM 87131-1341

University of New Mexico
Department of Civil Engineering
Attn: J. C. Stormont
Albuquerque, NM 87131-1351

University of New Mexico
Geology Department
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Albuquerque, NM 87131

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College of Ocean & Fishery Sciences
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Seattle, WA 98195

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Martin Speere Memorial Library
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Carlsbad, NM 88220

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B. Goodwin
Malcolm Gray
Maria Onefrei
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Francois Chenevier (2)
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de la Vallee Rhone
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30205 Bagnols-Sur-Ceze, FRANCE

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Centre d'Etudes de Cadarache
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M. Wallner
Postfach 510 153
D-30631 Hannover, GERMANY

Bundesministerium fur Forschung und
Technologie
Postfach 200 706
5300 Bonn 2, GERMANY

Forschungszentrum Karlsruhe GmbH
Institut für Nukleare Entsorgungstechnik
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Postfach 3640, D-76021 Karlsruhe
Bundesrepublic Deutchland
GERMANY

Gesellschaft fur Anlagen und Reaktorsicherheit
(GRS)
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Schwertnergasse 1
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52072 Aachen, GERMANY

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Institut Für Tieflagerung
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D-3300 Braunschweig, GERMANY
Shingo Tashiro
Japan Atomic Energy Research Institute
Tokai-Mura, Ibaraki-Ken, 319-11
JAPAN

Netherlands Energy Research Foundation ECN
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3 Westerduinweg
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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix SER

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

WIPP Site Environmental Report

DOE/WIPP 96-2182

Waste Isolation Pilot Plant

Site Environmental Report

For Calendar Year 1995

U.S. Department of Energy
Prepared by Westinghouse Electric Corp.
Waste Isolation Division

Cover: **Kokopelli**

The Kokopelli or Flute Player appears in Anasazi rock drawings as early as 1000 A.D. It was believed that Kokopelli could summon the clouds and make the wind talk.

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1995 WIPP Site Environmental Report
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ACRONYMS AND ABBREVIATIONS

AA	Atomic Absorption
AEC	United States Atomic Energy Commission
AHPA	Archaeological and Historic Preservation Act
AMS	Ambient Air Monitoring Station
AQCR	Air Quality Control Regulation
ARA	Archaeological Recovery Act
ASER	Annual Site Environmental Report
ASME	American Society of Mechanical Engineers
BECR	Biennial Environmental Compliance Report
BMP	Best Management Practices
BLK	Blank
BLM	Bureau of Land Management
C and C	Consultation and Cooperation
CAA	Clean Air Act
CDC	Centers for Disease Control
CED	Committed Effective Dose
CEQ	Council on Environmental Quality

ACRONYMS AND ABBREVIATIONS

(continued)

CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CMS	Central Monitoring System
CRRMP	Cooperative Raptor Research and Management Program
CRA	Carlsbad Resource Area
CRF	Central Records Facility
CWA	Clean Water Act
CY	Calendar Year
DMR	Discharge Monitoring Report
DOE	United States Department of Energy
DOL	Department of Labor
DOI	United States Department of the Interior
DOT	Department of Transportation
DP	Discharge Plan
DUP	Duplicate Sample
ECAP	Environmental Compliance Assessment Program
EEG	Environmental Evaluation Group

ACRONYMS AND ABBREVIATIONS

(continued)

ELP	Environmental Leadership Program
EML	Environmental Measurements Lab
EMP	Environmental Monitoring Plan
EO	Executive Order
EPA	United States Environmental Protection Agency
EPCRA	Emergency Planning Community Right-to-Know Act
ESA	Endangered Species Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
ESH&RC	Environment, Safety, Health and Regulatory Compliance
FEIS	Final Environmental Impact Statement
FLPMA	Federal Land Policy and Management Act of 1976
FSAR	Final Safety Analysis Report
GSP	Groundwater Surveillance Program
HAP	Hazardous Air Pollutant
HEPA	High Efficiency Particulate Air
HMP	Habitat Management Plan

ACRONYMS AND ABBREVIATIONS

(continued)

HPIC	High Pressure Ionization Chamber
HSWA	Hazardous and Solid Waste Amendments of 1984 (to RCRA)
ICAP	Inductively Coupled Argon Plasma
LDR	Land Disposal Restrictions
LEPC	Local Emergency Planning Committee
LLCL	Low-Level Counting Laboratory
LMIP	Land Management Implementation Plan
LMP	Land Management Plan
LS	Liquid Scintillation
LWA	Land Withdrawal Act
MAP	Mitigation Action Plan
MBTA	Migratory Bird Treaty Act
MDC	Minimum Detectable Concentration
MET	Meteorological Station
MOC	Management and Operating Contractor
MOU	Memorandum of Understanding

ACRONYMS AND ABBREVIATIONS

(continued)

MSHA	Federal Mine Safety and Health Act
NAAQS	National Ambient Air Quality Standards
NCP	National Contingency Plan
NEPA	National Environmental Policy Act
NES	Nonradiological Environmental Surveillance
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NHPA	National Historic Preservation Act
NMD	No-Migration Determination
NMED	New Mexico Environment Department
NMIMT	New Mexico Institute of Mining Technology
NMVP	No-Migration Variance Petition
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission/National Response Center
NWPA	Nuclear Waste Policy Act
OSHA	Occupational Safety and Health Administration

ACRONYMS AND ABBREVIATIONS

(continued)

PCB	Poly-chlorinated Biphenyl
PESP	Performance Evaluation Study Program
PI	Principal Investigator
PPOA	Pollution Prevention Opportunity Assessment
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QAP	Quality Assurance Program
QC	Quality Control
QSL	Qualified Suppliers List
RBP	Radiological Baseline Program
RCRA	Resource Conservation and Recovery Act
REMP	Radioactive Effluent Monitoring Program
RES	Radiological Environmental Surveillance
RIDS	Records Inventory and Disposition Schedule
RL	Radiochemistry Laboratory
RMP	Resource Management Plan

ACRONYMS AND ABBREVIATIONS

(continued)

ROD	Record of Decision
RRMP	Raptor Research and Management Program
SAA	Satellite Accumulation Area
SARA	Superfund Amendments and Reauthorization Act
SERC	State Emergency Response Commission
SDWA	Safe Drinking Water Act
SEIS	Supplemental Environmental Impact Statement
SHPO	State Historic Preservation Officer
SNL	Sandia National Laboratories
SPDV	Site Preliminary Design and Validation
TDS	Total Dissolved Solids
TPY	Ton Per Year
TRU	Transuranic Waste
TRUPACT-II	Transuranic Package Transporter Model II
TSCA	Toxic Substances Control Act
TSDF	Treatment Storage Disposal Facility

ACRONYMS AND ABBREVIATIONS

(continued)

TSP	Total Suspended Particulates
USF&WS	United States Department of the Interior, Fish and Wildlife Service
USGS	United States Geological Survey
VOC	Volatile Organic Compound
VPP	Voluntary Protection Program
WAB	WIPP Air Blank
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plan
WQSP	WIPP Groundwater Quality Surveillance Program

Chapter 1
Executive Summary

The U.S. Department of Energy (DOE) Order 5400.1 *General Environmental Protection Program,* requires DOE facilities, that conduct environmental protection programs, to annually prepare a Site Environmental Report (SER). The purpose of the SER is to provide an abstract of environmental assessments conducted in order to characterize site environmental management performance, to confirm compliance with environmental standards and requirements, and to highlight significant programs and efforts of environmental merit. The content of this SER is not restricted to a synopsis of the required data, in addition, information pertaining to new and continued monitoring and compliance activities during the 1995 calendar year are also included.

Data contained in this report are derived from those monitoring programs directed by the Waste Isolation Pilot Plant (WIPP) *Environmental Monitoring Plan* (EMP) (DOE/WIPP 94-024). The EMP provides inclusive guidelines implemented to detect potential impacts to the environment and to establish baseline measurements for future environmental evaluations. Surface water, groundwater, air, soil, and biotic matrices are monitored for an array of radiological and nonradiological factors. The baseline radiological surveillance program encompasses a broader geographic area that includes nearby ranches, villages, and cities. Most elements of nonradiological assessments are conducted within the geographic vicinity of the WIPP site.

To date, the WIPP remains in a preoperational phase. Accordingly, certain operational requirements specified in DOE Order 5400.1 and in the *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (DOE/EH-0173T) do not apply. This report does not address program modifications, new program implementation, and activities that will be developed to meet future (operational) requirements such as radionuclide emissions and effluents and respective impacts upon the public and the environment.

1.1 Compliance Summary

A summary of significant compliance-related activities at the WIPP during Calendar Year (CY) 1995 is presented in this chapter. Chapter 3 will address environmental statutes and executive orders. These important statutes and orders will be comprehensively discussed in terms of compliance status, significant issues, actions, and accomplishments specific to WIPP.

On January 13, 1994, the DOE recommended that the New Mexico Environmental Department (NMED) allow the DOE to modify the Resource Conservation and Recovery Act (RCRA) permit

application to reflect disposal rather than test-phase operations. On September 2, 1994, the NMED rescinded the draft permit issued in August 1993 and ordered the submittal of a revised permit application. The revised permit was submitted during May of 1995.

The *No-Migration Determination Annual Report for the Period of September 1993 through August 1994* (DOE/WIPP 94-2029) was submitted to the Environmental Protection Agency (EPA) Region VI, and to EPA Headquarters on November 14, 1994. This report was prepared to satisfy the annual reporting requirements contained in the *Conditional No-Migration Determination for the U.S. Department of Energy Waste Isolation Pilot Plant* (NMD), published in the *Federal Register* on November 14, 1990. Although the NMD was written specifically for the WIPP test phase, compliance conditions mandated by the first WIPP NMD will continue until issuance of a Disposal Phase NMD. A No-Migration Variance Petition for the disposal phase is being developed, based on waste characterization data and applicable modeling results. It is expected to be submitted to the EPA in June 1996.

The Land Withdrawal Act (LWA), Section 8, requires the DOE to submit to EPA an application for certification of compliance with EPA's final disposal regulations. The EPA finalized disposal regulations (40 CFR 191) in December of 1993. Currently, the EPA is developing criteria for certifying compliance with these regulations. After EPA has finalized the compliance criteria, a compliance certification application, in accordance with the mandates of the WIPP LWA, will be developed.

1.1.1 The No-Migration Variance Petition

The *No-Migration Determination Annual Report for the Period of September 1994 through August 1995* (DOE/WIPP 95-2141) was submitted to the Environmental Protection Agency (EPA) Region VI, and to EPA Headquarters on November 6, 1995. This report was prepared to satisfy the annual reporting requirements contained in the *Conditional No-Migration Determination for the U.S. Department of Energy Waste Isolation Pilot Plant* (NMD), published in the *Federal Register* on November 14, 1990. Although the NMD was written specifically for the WIPP test phase, some of the compliance conditions mandated by the first WIPP NMD remain in effect until issuance of a Disposal Phase NMD. A Disposal Phase No-Migration Variance Petition is being developed, based on waste characterization data and applicable modeling results. It is expected to be submitted to the EPA in CY 1996.

1.1.2 NEPA Annual Mitigation Report

The *1995 Annual Mitigation Report for the Waste Isolation Pilot Plant* (NEPA ID# WIP:95:0002) was issued July 10, 1995, in accordance with the requirement of DOE Order 5440.1E, *National Environmental Policy Act Compliance Program*. On September 11, 1995, DOE Order 5440.1E was replaced with a revised NEPA Compliance Program and issued as DOE Order 0451.1. This order also requires DOE facilities to track and annually report progress in implementing a commitment for environmental impact mitigation that is essential to render the impacts of a proposed action not significant or that is made in a record of decision.

1.1.3 SARA Title III Emergency and Hazardous Chemical Inventory

On January 30, 1995, the WIPP submitted the *Emergency and Hazardous Chemical Inventory Report* for CY 1994 to the Carlsbad Area Office of the Department of Energy for distribution to the New Mexico State Emergency Response Commission, the Eddy County Local Emergency Planning Committee, and the local fire department with jurisdiction over the WIPP site, as required by Section 312 of the *Superfund Amendments and Reauthorization Act* (SARA) Title III. In March 1994, the WIPP submitted the Emergency and Hazardous Chemical Inventory Report for CY 1993 to appropriate organizations.

1.1.4 New Mexico Air Quality Permit 310-M-2

On February 26, 1994, the WIPP completed the emission monitoring requirements established in the New Mexico Air Quality Permit 310-M-2. With the submittal of the *Final Compliance Sampling Report* on March 28, 1994, the DOE has fulfilled all monitoring and reporting requirements identified in the permit. The permit was modified on September 1, 1994 to allow one diesel generator to operate under load while the second diesel generator is at idle speed, in a warm up or cool down mode. This allows for greater operational flexibility.

1.1.5 NEPA Training

A computer-based National Environmental Policy Act (NEPA) training module was issued in December 1994 and has continued to be a productive tool in providing NEPA guidance to employees. This program is updated, as necessary, to ensure employees are kept abreast of current NEPA guidelines so that proper steps are taken in the planning, coordination, and performance of their work.

1.1.6 Environmental Compliance Assessments

During 1995, 8 environmental compliance assessments were conducted. Thirty-five (35) improvements were identified and implemented as a result of these assessments. The assessed areas included: Satellite Accumulation Areas and Hazardous Waste Staging Area; Sandia National Laboratories - Culebra Transport Program; Air, Waste, and Water Program; Annual Hazardous Waste Fee Regulations; Dosimetry and Analytical Laboratory; National Pollutant Discharge Elimination System (NPDES); RCRA Equipment Inspections; and Environmental Monitoring.

1.1.7 ISO 14000

The International Standards Organization (ISO) is establishing a new philosophy for environmental management that goes beyond regulatory compliance. ISO 14000 is the system of international environmental management standards designed to give a common management approach for parties trading products or services having impact on the environment. While the ISO 14000 standards are completely voluntary, many companies and countries are adopting them because the standards are agreed upon internationally. The WID views early ISO 14000 compliance as an important step towards becoming an industry leader. Compliance efforts are already underway aimed at certification assessments in March 1997.

1.1.8 Voluntary Release Assessment Program at Selected Solid Waste Management Units at the WIPP

The U.S. Department of Energy, Carlsbad Area Office (DOE-CAO) has completed a voluntary release assessment sampling program at 11 selected Solid Waste Management Units (SWMUs) at the WIPP. Data generated by the release assessment sampling program are being used to document voluntary release assessment/corrective action commitments contained in the *Voluntary Release Assessment/Corrective Action Work Plan (DOE/WIPP Draft 2115)* submitted to the EPA and NMED in July, 1995. The CAO made the decision to complete a voluntary release assessment/corrective action program at selected SWMUs described in Chapter J of the RCRA Part B permit because the proposed rules provide incentives for facilities willing to complete voluntary corrective actions.

A total of 264 release assessment samples were collected to determine if a release had occurred from any of the 11 SWMUs described in the release assessment work plan. Release assessment sampling data, and proposed corrective actions have been compiled into three data summary reports.

Data summary reports were submitted to the EPA Region VI, Hazardous Waste Management Division and the NMED Hazardous and Radioactive Materials Bureau.

Based on the results of voluntary release assessment sampling, the CAO has formally requested that a determination of No Further Action be granted for each of the 11 SWMUs. In the event the No Further Action determination is approved by the agencies, each of the 11 sites will be replanted with native vegetation in accordance with the guideline provided in the *WIPP Land Management Plan* (DOE WIPP 93-004).

1.1.9 Site Environmental Awareness Program

The Site Environmental Awareness Program was established in December 1995 to educate, inform, and increase the awareness of environmental issues to all Waste Isolation Division employees. The program provides an overview of all applicable environmental drivers. This general environmental awareness, cultivated by the Environmental Awareness Campaign and the Managers' Environmental Handbook, will lead to the implementation of the Management Environmental Awareness Program (MEAP).

1.1.10 Executive Order 12873 - *Federal Acquisition, Recycling, and Waste Prevention*

In January 1996, the WID implemented an Affirmative Procurement (AP) program driven by the Resource Conservation and Recovery Act Section 6002(i), Executive Order 12873, *Federal Acquisition, Recycling, and Waste Prevention*, and the Environmental Protection Agency guidelines. 40 CFR 248-250 and 252-253. The purpose of AP is to implement a systematic and cost-effective program for promoting and procuring materials and products made from recycled materials. AP is designed to "close a loop" in the waste minimization recycling process by supporting the market of recycled materials.

The WIPP must implement the four affirmative procurement program elements in order to be in compliance with the RCRA and EPA guidelines. These elements include the following:

- A preference program to purchase recycled products when it is determined to be technically and economically feasible.
- Recycled product promotion.

- A system for supplier certification of recovered material content.
- Annual reporting and program evaluation.

In January 1996, the WID held a series of three training sessions for all requisitioners acquainting them with the AP and their responsibilities when procuring specific items.

1.2 Environmental Monitoring Program Information

Site characterization and environmental baseline measurements at the WIPP were initiated during 1975. Many of these elements continue to be maintained on radiological and nonradiological databases. When the WIPP becomes operational, baseline measurements will be transitioned to the "operational phase" and will be constantly monitored throughout the life of the project.

1.2.1 Environmental Monitoring Plan (EMP)

The WIPP's EMP provides schedules and guidelines for monitoring a comprehensive set of parameters to detect and quantify present or potential environmental impacts, both nonradiologically and radiologically. Most nonradiological surveillance is conducted in the geographic vicinity of the WIPP site. Radiological surveillance covers a broader geographic area that includes nearby ranches, villages, and cities. Sampling activities conducted during CY 1995 were performed at locations identified in the EMP. Monitoring protocol is dynamic and requires modifications from time-to-time to sustain a contemporary and technically sound program. Environmental Monitoring will continue at the WIPP site during project operations and throughout decommissioning activities.

1.3 Environmental Radiological Program Information

The following presents monitoring topics for the subprograms of the EMP. These subprograms are consistent with guidance provided in the *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, (DOE/EH-0173T).

DOE Order 5400.1 requires the establishment of a radiological baseline during the preoperational phase. Once a radiological baseline has been established, applicable radiological sampling programs can be maintained or can be modified to improve sampling efficiency. As radiological sampling protocol evolves to reflect program requirements (e.g., DOE Orders, EPA directives), the continuation of baseline sampling is necessary to provide adequate and timely measurements prior to

waste receipt. As specifically outlined in the EMP, five subprograms are being conducted to document the background levels of potential radionuclide pathways leading from the WIPP to the environment and the public. These five subprograms are presented in the *Statistical Summary of the Radiological Baseline Program (RBP) for the Waste Isolation Pilot Plant* (DOE/WIPP 92-037).

Results from the radiological analysis of environmental samples are provided in the attached appendices.

1.3.1 Airborne Particulate and Effluent Monitoring

The WIPP began sampling airborne aerosol particulates during 1985. This sampling activity continues to be an integral subprogram of the EMP. The *Safety Analysis Report* (SAR) (DOE/WIPP 95-2065) identifies the atmosphere pathway as the most credible exposure pathway for the public to radiation. To monitor this pathway, particulate aerosol samplers continuously operated at seven locations during 1995; three, within 1000 meters of the facility boundary; three, at local ranches and communities; and one, at a sample control site.

The continuous aerosol samplers employed to collect particulates, during 1995, maintain a regulated flow rate of 0.057 cubic meters per minute (approximately two cubic feet per minute) of air through a 47-millimeter (1.9 inch) fiber filter. Particulate filters are collected weekly (168 hour intervals) at all locations. Subsequent to collection, the filters are desiccated (or dried) for a minimum of 12 hours and transferred to the WIPP Site Low-Level Counting Laboratory (LLCL) for analysis of gross alpha and beta activity. Table 5-1 lists the quarterly alpha and beta concentrations for each sampling location. After samples are counted onsite, the filters are consolidated into 13-week or quarterly composites and transmitted to an offsite contract analytical laboratory for specific radionuclide analysis. These radionuclides with applicable data results, are provided in the attached appendices, and are presented as a calculated quarterly average.

1.3.2 Soil Sampling

Soil Samples were collected and analyzed in accordance with applicable guidance (e.g. DOE EH/0173T) and sampling procedures. Discussions pertaining to the radiological analysis of subject samples are provided in Chapter 5, *Environmental Radioactivity Monitoring*. Chapter 6, *Environmental Nonradiological Program Information*, discusses results from nonradiological analysis.

1.3.3 Groundwater

Groundwater surveillance activities during CY 1995 consisted of two separate programs: Groundwater Quality Sampling and Groundwater Level Surveillance Measurements. Groundwater quality samples were gathered from 10 well locations completed in the Culebra dolomite and one in the Dewey Lake. Sixty-nine groundwater level surveillance measurements were recorded quarterly at 64 well bores. Fifty-nine different measurements were recorded at 54 separate well bores. During CY 1994, seven new monitoring wells were drilled; six, in the Culebra dolomite; and one, into the Dewey Lake. Results and discussions pertaining to groundwater sampling activities are provided in Chapter 7, *Groundwater Surveillance.*

1.3.4 Surface Water and Sediment Sampling

Surface water was collected at 11 locations with concurrent sediment samples taken at 10. Analysis revealed no unusual levels of background radioactivity. Discussions pertaining to surface water and sediment sampling are provided in Chapter 5, *Environmental Radiological Program Information.*

1.3.5 Game Animals and Fish Samples

Because of profound drought conditions during CY 1995, quail and rabbit populations were drastically low. Quail sampling has been indefinitely postponed until the population increases to the capacity that sampling will not adversely affect the local population status. Sampling of rabbits was restricted to three individual road kills.

In prior years, sample matrices were restricted exclusively to single species (e.g., only desert cottontails as rabbit samples). During 1995, this restrictive sample protocol was revised to allow for the inclusion of a greater diversity of sample specimens. For example, rather than restricting the collection of "rabbit" to the desert cottontail (*Sylvilagus audoboni)*, blacktail jackrabbits (*Lepus californicus*) have been included as a sample matrix, due primarily to the frequency of sample availability (jackrabbits constitute a significant majority of road kills).

Discussions pertaining to the radiological analysis of game animals and fish are presented in Chapter 5, *Environmental Radiological Program Information*. Results from the laboratory analysis of tissue are contained in the attached appendices.

1.4 Nonradiological Environmental Monitoring Information

Nonradiological environmental surveillance was also conducted in accordance with the EMP. This program was preceded by the WIPP Biology Program (1975-1982). An extensive baseline of information describing the major ecological components of the Los Medaños, prior to the initiation of the WIPP site construction activities, was developed. Six universities participated in the initiation of the characterization and baseline surveillance programs.

A significant portion of the nonradiological surveillance investigated effects of fugitive salt dust, generated by the surface stockpiling activities, on the surrounding environment (e.g., Reith, et al., 1985). This study is described in the *Summary of the Salt Impact Studies at the Waste Isolation Pilot Plant 1984 to 1990* (DOE/WIPP 92-038).

1.4.1 Land Management

In accordance with Section 4 of the Waste Isolation Pilot Plant (WIPP) *Land Withdrawal Act* (LWA) (Public Law 102-579), the DOE prepared a Land Management Plan (LMP) as required by the Act. The development of this plan was in collaboration with the U.S. Department of Interior's (DOI) Bureau of Land Management (BLM) and the state of New Mexico. Changes or amendments to the LMP are done in consultation with the BLM, the state of New Mexico, and affected stakeholders, as appropriate.

The LMP, as required by LWA, was prepared to identify resource values, promote the concept of multiple-use management, and identify long-term goals for the management of DOE/WIPP lands until the culmination of the decommissioning phase. The Plan also provides the opportunity for participation in the land use planning process by the public, as well as local, state, and federal agencies.

During CY 1995, a reprint of the LMP, which incorporates elements of implementation previously provided in the WIPP *Land Management Implementation Plan* (LMIP) (DOE/WIPP 94-026), was developed. The reprint does not revise or amend the intent or scope of the original plan, but merges implementing actions from the LMIP to make the plan more helpful for those desiring to use WIPP lands. An additional reason for developing this reprint was to reduce document volume and redundancies in text, which results in the LMIP being superseded by the LMP. The new LMP was finalized for distribution and implementation on January 31, 1996.

The LMP was prepared through the integration of the WIPP *Land Withdrawal Act* of 1992 (Public Law 102-579), BLM planning regulations (43 CFR 1600) issued under the authority of the Federal Land Policy and Management Act (FLPMA) of 1976, the National Environmental Policy Act (NEPA) of 1969, as amended; and existing Memoranda of Understanding (MOU) among the DOE and local, state and/or federal agencies. The LMP is designed to provide a comprehensive framework for the management and coordination of WIPP land uses during the life of the project. The LMP, and any subsequent amendments, will continue through the decommissioning phase. Moreover, in accordance with section 13 of the WIPP *Land Withdrawal Act*, the DOE will develop, in consultation with the Secretary of the Interior and the State of New Mexico, a plan for the management and use of the WIPP Land Withdrawal Area following the decommissioning of WIPP. This plan must be developed by October 30, 1997.

The guidelines prescribed in the LMP provide for the management and oversight of WIPP lands under the jurisdiction of the DOE in addition to lands outside the WIPP boundary that are used in the operation of the WIPP (e.g., groundwater surveillance well pads outside the withdrawn area). Furthermore, this plan provides for multiagency involvement in the administration of DOE land management actions. Documents referenced in the LMP are available to any person and/or organization desiring to conduct activities on lands under the jurisdiction of the DOE/WIPP in addition to those involved in development and/or amending existing land management actions. Documents can be obtained from the U.S. Department of Energy, Carlsbad Area Office, P.O. Box 3090, Carlsbad, New Mexico 88221.

The LMP advocates direct communication among stakeholders, including federal and state agencies involved in managing the resources within, or activities impacting the areas adjacent to, the WIPP Land Withdrawal Area (WLWA). It sets forth cooperative arrangements and protocols for addressing WIPP-related land management actions. The DOE recognizes the guidelines for contemporary land management practices that pertain to rational adherence with edicts in the WIPP LWA and all applicable regulatory requirements contained therein. Commitments contained in current permits, agreements, or concurrent MOUs with other agencies (e.g., state of New Mexico, DOI), shall be adhered to when addressing/evaluating land use management activities and future amendments that affect the management of WIPP lands.

The LMP is reviewed on a biennial basis to assess the adequacy and effectiveness of the document, or as may be necessary to address emerging issues potentially affecting WIPP lands. Affected agencies, groups, and/or individuals may be involved in the review process.

Contents of the LMP focus on management protocols for the following issues: administration of the plan; environmental compliance; wildlife; cultural resources; grazing; recreation; energy and mineral resources; lands/realty; reclamation; security; industrial safety; emergency management; maintenance and work control. Each issue and its complementary planning/management criteria are described in respective document chapters.

1.4.2 Meteorology

The WIPP Nonradiological Environmental Surveillance (NES) includes a primary meteorological (MET) station that provides support for various programs at the WIPP. The primary function of the MET is to generate data to model atmospheric conditions for Radiological Environmental Surveillance (RES). The station records standard meteorological measurements for wind speed, wind direction, and temperatures at a radius of 3, 10, and 40 meters (10, 30, and 130-feet respectively) with dew point and precipitation monitored at ground level. These parameters are measured continuously, and the data are logged, at fifteen minute intervals, in the Central Monitoring System (CMS).

In 1995, the annual rate of precipitation at the WIPP site was 23.27 cm (9.16 inches), which is 6.68 cm (2.63 inches) above last year's rate. The cumulative precipitation for 1995 remains well below normal.

The wind direction at the WIPP site is predominately from the southeast vector. In CY 1995, the data collected on wind direction in the WIPP area were consistent with data previously collected on wind direction in the same area. Discussions pertaining to meteorological monitoring are contained in Chapter 6, *Environmental Nonradiological Program Information*.

1.4.3 Air Quality Monitoring

Weekly measurements of Total Suspended Particulates (TSP) were collected by the low-volume continuous air samplers at seven field locations.

1.4.4 Wildlife Population Monitoring

Population density measurements of various species of wildlife are performed annually to assess the effects of the WIPP's activities on transient and resident wildlife populations.

1.4.4.1 Raptor Research and Management Program

During CY 1995, data were collected on resident birds of prey within an area of approximately 870 square miles in the vicinity of the WIPP, with the WIPP Site as the epicenter of the study area. The majority of this sector is managed under the authority of the U.S. Department of the Interior's Bureau of Land Management (BLM) Carlsbad Resource Area (CRA) with WIPP lands comprising the nucleus of the research area. This cooperative enterprise between the BLM and the DOE was commissioned through the bilateral development of an Interagency Agreement. The Agreement defines commitments on behalf of each respective agency to include deliverables and itemized timelines for the completion of each element.

The CY 1995 survey period was characterized by a severe drought that had dramatic ramifications throughout the study area. Observations indicate the drought suppressed population densities of both predators and prey, affected the number of inhabited territories, and brought about declines in nesting and production. The 1995 data contains descriptive information on the social hierarchy of the Harris' Hawk (*Parabuteo unicinctus*), physiognomy of the study area, research protocol, territorial fidelity (to include territorial trials), sex ratios, prey base determinations, capture and banding results, and habitat preferences. In addition, an inventory of other raptor inhabitants of the area was conducted. Result comparisons between 1995 and 1992 (the last calendar year of normal to above-normal precipitation) data were conducted to evaluate responses of resident raptors to the prolonged drought (currently in its fourth year).

1.4.5 Reclamation of Disturbed Lands

Reclamation activities during CY 1995 consisted of the periodic inspections, supplemental seedings, and exclosure maintenance of several reclamation sites. During 1995, reclamation equipment was purchased that includes a 4-wheel drive tractor, a ten-foot tandem disk, a ripper, and a hole auger. In addition to post holes, the auger is also used to access different soil horizons for sample arrays.

1.4.6 Vegetation Monitoring

During CY 1995 ecological vegetation monitoring was postponed because the data indicated negligible effects of salt tailings on the peripheral environment. A pattern was observed from the 1989-1992 data which was repeated in the 1993 data. The pattern confirms an increased progression in shrub cover near salt tailings. This increase is a result of the colonization of more saline-tolerant species (e.g. 4-winged saltbush, *Atriplex canescens*) in close proximity to the salt piles. Cursory

observations of peripheral effects resulting from salt-induced physiological stress near the salt tailings was not observed during 1993, 1994, or 1995. Responses of these plots to seasonal precipitation rates should reveal whether this pattern is reflecting the beginning of significant changes in the structure of the plant community or whether it is only a short-term effect caused by seasonal conditions. Successional dry conditions during CY 1995 (Figure 6-1) prohibited any validation of assumptions regarding repercussions of salt migration from the tailings piles into the adjacent environment.

1.5 Quality Assurance

Programs described in this document adhere to policies set forth by Quality Assurance (QA) guidance criteria including: American Society of Mechanical Engineers (ASME) NQA-1, Quality Assurance Program (QAP) Requirements for Nuclear Facilities (ASME, 1989) and EPA, QAMS-005/80, Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans (EPA, 1980), and fulfills the requirements of the QA plans specified in DOE Orders 5400.1 (DOE, 1988d), 5400.3 (DOE, 1988e), 5700.6C (DOE, 1991) and the Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance (DOE/EH-0173T).

Chapter 2
Introduction

This 1995 Site Environmental Report (SER) is prepared in accordance with the guidance contained in the 1990 DOE Order 5400.1, *General Environmental Protection Program*; DOE/WIPP 91-054, *Environmental Protection Implementation Plan*, and DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*. The above orders and guidance documents require that DOE facilities submit a SER to DOE Headquarters, Office of the Assistant Secretary for Environment, Safety and Health.

The SER provides a comprehensive description of operational environmental monitoring activities at the WIPP during CY 1995. This report also discusses the Quality Assurance (QA) and Quality Control (QC) programs. QA/QC programs provide the oversight necessary to maintain sample integrity to include:

- Proceduralized (to industry standards) sample collection methodology
- Personnel training
- Scrutiny of analytical data.

These criteria ensure that data derived from environmental samples provide an accurate representation of environmental conditions at the WIPP site. The requirements and goals driving these activities are more fully described in the *Environmental Monitoring Plan for the Waste Isolation Pilot Plant* (DOE/WIPP 94-024).

The Environmental Monitoring Plan (EMP) was drafted in accordance with the guidelines contained in the *General Environmental Protection Program* (DOE Order 5400.1). The EMP defines the scope and extent of the WIPP Environmental Monitoring Programs and ensures that all appropriate sampling efforts are in place to generate the following: (1) The amount and type of naturally occurring radioactivity in the WIPP area prior to operational status. These quantitative data will support comparisons between preoperational and operational environmental conditions, once the WIPP site is operating as a waste repository for TRU waste; and (2) A comparison between preoperational and operational radiological emissions, once the WIPP site is operating as a waste repository for TRU waste.

Since waste has not yet been received, certain elements of DOE Order 5400.1 are not relevant to the WIPP Environmental Monitoring Program. For example, no discussion is included in this report of radionuclide emissions with subsequent calculation of doses to the public. The EMP is reviewed annually and updated every three years, as required by DOE Order 5400.1. The revisions/updates address general changes, improvements, and enhancements to be implemented based upon the data generated from the monitoring programs.

2.1 Description of the WIPP Project

The WIPP project is authorized by the DOE, National Security, and Military Applications of Nuclear Energy Authorization Act of 1980 (i.e., Public Law 96-164). The legislative mandate is to demonstrate the safe disposal of transuranic wastes resulting from national defense activities and programs. To fulfill this mandate, the WIPP has been designed to scientifically investigate: (1) the behavior of bedded salt and the interactions between the salt and radioactive wastes and (2) to demonstrate safe and efficient handling, transport, and emplacement of transuranic (TRU) waste in a fully operational disposal site.

The first radioactive wastes will be emplaced once permitting activities are completed. Subsequent to successful permit completion, the WIPP site will be designated as an operational facility. TRU wastes will then be transported from generator/storage sites throughout the United States to the WIPP site.

The TRU waste received from the generator sites will be transported to the WIPP site via tractor-trailer trucks. Each truck can carry up to three TRU Package Transporters (TRUPACT IIs), and each transporter may contain fourteen 55-gallon drums or two standard waste boxes. The TRUPACT II is a durable, reusable container that has been certified by the Nuclear Regulatory Commission (NRC) to transport contact-handled (waste containers that can be handled without additional shielding) transuranic waste to the WIPP.

Once TRU wastes have arrived at the WIPP, they are transported into the Waste Handling Building. The waste containers will be removed from the TRUPACT IIs, placed on the waste hoist, and lowered to the repository level of 655 m (2150 feet) below the surface. During the disposal phase, waste drums will be removed from the hoist and emplaced in excavated storage rooms in the Salado formation, a thick sequence of salt beds deposited approximately 250 million years ago in the Permian Age. After the disposal areas have been filled, specially designed closures will be placed in the excavated disposal rooms and seals will be placed in the shafts. The self-healing nature of the salt formation will aid in gradual closure causing encapsulation and isolation of the waste within the Salado formation.

During site operations, the underground area will be ventilated with ambient air that enters the Air Intake Shaft, the Salt Handling Shaft, the Waste Handling Shaft, and exits through the Exhaust Shaft. In the event of an underground accident involving radioactivity, exhaust air can be circulated at a reduced flow rate through the Exhaust Filter Building. This building contains banks of High Efficiency Particulate Air (HEPA) filters that remove contaminated particulates.

2.2 Affected Environment

The WIPP Site is located in Eddy County in Southeastern New Mexico (Figure 2.1). The site is 26 miles east of Carlsbad, New Mexico, in a region known as the Los Medaños, that represents the initial intergradation between the Llano Estacado and the Chihuahuan Desert. This region displays an exceptional diversity of plant and animal inhabitants.

Geographically, the region is regarded as a relatively flat, sparsely inhabited plateau with little surface water. The region is popular for recreation, providing opportunities for hunting, camping, hiking, and bird watching.

The majority of the lands outside the WIPP site boundary, are managed under the jurisdiction of the U.S. Department of the Interior's (DOI) Bureau of Land Management (BLM) Carlsbad Resource Area (CRA) local office. Land uses in the surrounding area include livestock grazing, potash mining, oil and gas exploration and production (including support services), and recreational uses.

The WIPP site boundary extends at least 1.6 kilometers or one mile beyond any of the WIPP underground developments and is defined on the surface by the 16-section (4,146 ha) Land Withdrawal Area. On October 30, 1992, the WIPP Land Withdrawal Act, Public Law 102-579, was signed into law, transferring the land from the Department of Interior (DOI) to the DOE. In accordance with edicts contained in the Land Withdrawal Act, a WIPP Land Management Plan (DOE/WIPP 93-004), was prepared and submitted to Congress.

Consisting of 16 sections (4,146 ha or 10,240 acres) of federal land, the WIPP site is located in Eddy County, New Mexico in Township 22 South, Range 31 East. With the exception of properties located within the boundaries of the posted 1454 acre (589 ha) Off Limits Area, the surface land uses remain largely unchanged and are managed in accordance with accepted practices for multiple land use. Mining and drilling for purposes other than those which support the WIPP project are prohibited within the 16-section (4,146 ha) area.

2.2.1 WIPP Property Areas

The WIPP site is divided into defined areas as represented in Figure 2.1. Descriptions of these WIPP areas are as follows:

2.2.1.1 Property Protection Area

The interior core area of the facility (Figure 2.1) is a land area of approximately 34.16 surface acres surrounded by a chain link fence. This sector, formerly identified as "Zone I," is designated as the "Property Protection Area." All access control features are maintained with uniformed security personnel on duty 24 hours a day.

2.2.1.2 Exclusive Use Area

The Exclusive Use Area (Figure 2.1) is comprised of approximately 277.14 acres within Sections 20, 21, 28, and 29 of Township 22 South, Range 31 East. It is surrounded by a five-strand barbed wire fence and is restricted exclusively for the use of the DOE, its contractors and subcontractors in support of the project. In addition, this area is defined as the point of closest public access for the purposes of performing accident consequences to the general public in the WIPP Safety Analysis Report (SAR). This area is marked by DOE "No Trespassing" signs and will be patrolled by WIPP security personnel to prevent unauthorized activities or uses.

2.2.1.3 Off Limits Area

The Off Limits Area (Figure 2.1) is a sector comprised of 1453.9 acres, or 2.2 square miles (more or less), within Sections 20, 21, 28, and 29 of Township 22 South, Range 31 East. This sector is managed as an area wherein unauthorized entry and the unauthorized introduction of weapons and/or dangerous materials (as provided in 10 CFR 860.3 and 860.4) is prohibited. Pertinent prohibitions and subsequent penalties (10 CFR 860.5) are posted at consistent intervals along the perimeter as directed in 10 CFR 860.6. Grazing and public thoroughfare continue until such time that these activities present a threat to the security, safety, and/or environmental quality of the WIPP. This sector will be patrolled by WIPP security personnel to prevent unauthorized activity or use. While the subject sector is posted, the area is not fenced.

2.2.1.4 Waste Isolation Pilot Plant Land Withdrawal Area

The WIPP Site Boundary distinguishes the perimeter of the 16 section (or 10,240 acres) WIPP Land Withdrawal Area (WLWA). This tract includes properties outlying the Property Protection Area, the Exclusive Use Area, and the Off Limits Area. This sector is designated at points of ingress and egress, as a Multiple Land Use Area, and is managed accordingly. Certain restrictions however do apply. Information regarding land use restrictions is available from the DOE on request.

2.2.1.5 Special Management Areas

There are property sectors used in the operation of the WIPP (e.g., reclamation sites, well pads, roads, etc.) that are (and may be) identified as Special Management Areas (SMA). A SMA designation is due to values, resources, and/or circumstances that meet criteria for protection and management under special management designations. Unique resources of value that are in danger of being lost or damaged, sectors wherein ongoing construction is occurring, fragile plant and/or animal communities, sites of archaeological significance, sectors containing imminent risks (safety hazards), or a sector(s) that may receive an unanticipated elevated security status would be suitable for designation as a SMA. Accordingly, the subject sector would receive special management emphasis under this stipulation. SMAs will be posted against trespass and shall be safeguarded commensurate with applicable laws governing property protection. WIPP security personnel will patrol these areas to prevent unauthorized access or use.

The first two aforementioned sectors are posted against trespass under the authority of Section 229 of the Atomic Energy Act, 42 U.S.C. 2278a, and pursuant to the regulations set forth in 10 CFR 860 and DOE Order 5632.6, *Physical Protection of DOE Property and Unclassified Facilities*. These sectors are patrolled by the WIPP security and regulations are enforced commensurate with laws pertaining to property protection. The WIPP site boundary (4 miles x 4 miles) provides a functional barrier of intact salt between the underground region defined by the Off Limits Area and the accessible environment.

2.2.2 Demographics Within the Affected Environment

There are approximately 26 residents at various locations within 10 miles of the WIPP site. The majority of the local population within 50 miles of the WIPP are concentrated in and around the communities of Carlsbad, Hobbs, Eunice, Jal, and Artesia, New Mexico. The nearest community is the village of Loving, New Mexico, 18 miles west-southwest of the WIPP. The population of Loving decreased from an estimated 1600 in 1980 to 1240 in 1990 with a current population estimate of 1291. The nearest major populated area is Carlsbad, New Mexico, 26 miles west of the WIPP. The population of Carlsbad decreased from an estimated 25,496 in 1980 to an estimated 24,952 in 1990 with a current estimated population of 26,974. [Population estimates are calculated by subtracting the number of deaths from the number of births and adding net migration.] The transient population within 10 miles of the WIPP is associated with ranching, oil and gas exploration/production, and potash mining.

The two nearby ranch residences (Smith Ranch and Mills Ranch) are continuously monitored as part of the Environmental Monitoring Program.

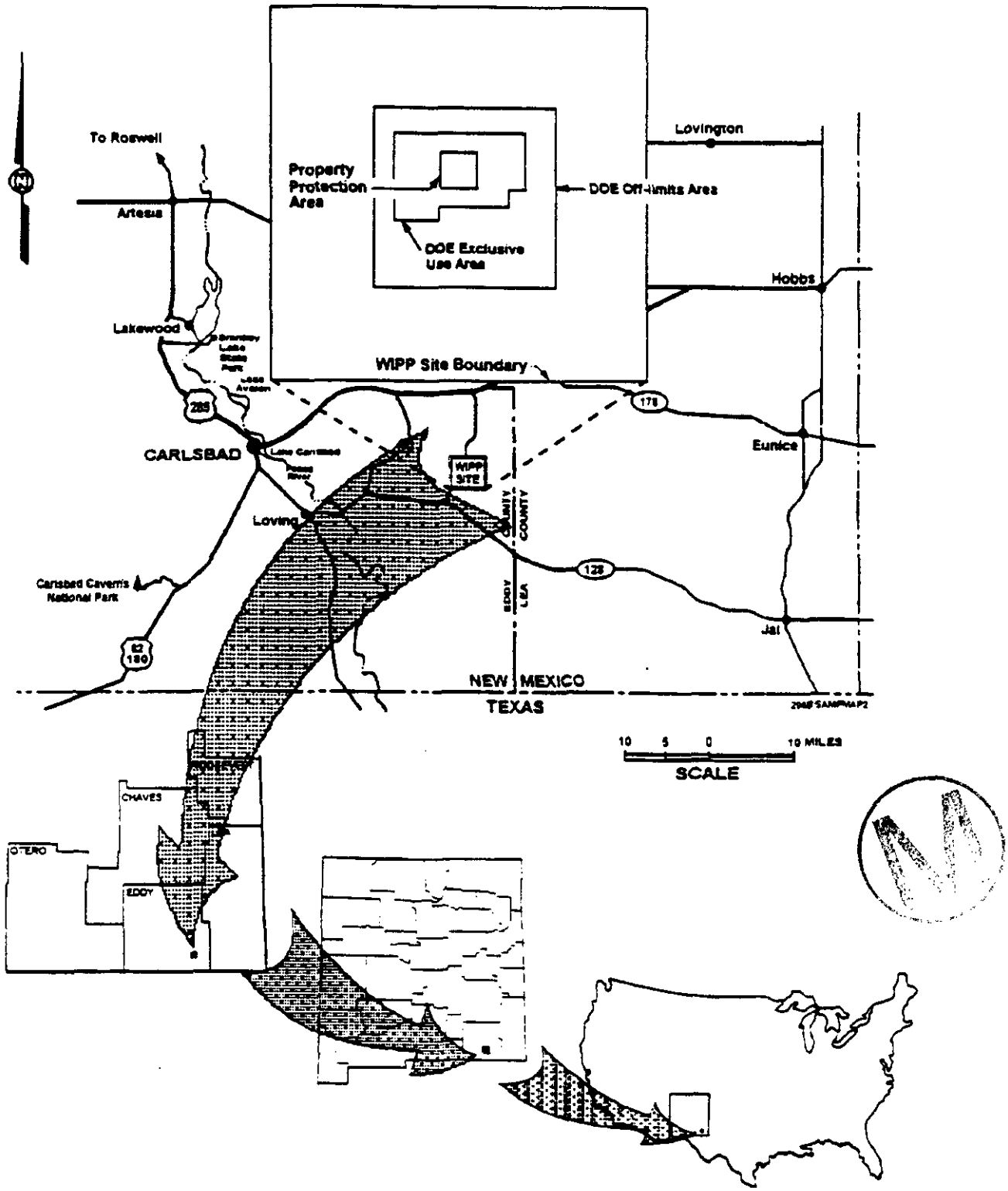

Figure 2-1
Regional Location Of The WIPP Site
including WIPP Property Areas

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Chapter 3
Compliance Summary

The WIPP is required to comply with all applicable federal laws, state laws, and DOE Orders. Documentation of requisite federal and state permits, notifications, and applications for approval is maintained by the Environment, Safety, and Health (ES&H) Department of the current Managing and Operating Contractor. Regulatory requirements are incorporated in the facility plans and implementing procedures.

3.1 Compliance Assessment for Calendar Year 1995

In 1995 the WIPP maintained compliance with applicable federal and state environmental regulations. Section 3.2 lists the compliance status of each major environmental statute and executive order applicable to the WIPP, including significant issues generated by, and actions and accomplishments driven by these statutes and orders. Section 3.3 describes other significant compliance accomplishments at the WIPP facility in CY 1995.

3.2 Compliance Status

This section documents compliance with the following regulatory requirements at the WIPP:

- Atomic Energy Act of 1954 (AEA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (includes the Superfund Amendments and Reauthorization Act of 1986)
- Resource Conservation and Recovery Act (RCRA)
- National Environmental Policy Act (NEPA)
- Clean Air Act (CAA)
- Clean Water Act (CWA)
- Safe Drinking Water Act (SDWA)
- Toxic Substances Control Act (TSCA)
- Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
- Endangered Species Act (ESA)
- National Historic Preservation Act (NHPA)
- Floodplain Management Executive Order
- Protection of Wetlands Executive Order
- Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes

- Hazardous Materials Transportation Act (HMTA)
- Packaging and Transportation of Radioactive Materials
- Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980
- Waste Isolation Pilot Plant Land Withdrawal Act (LWA)
- Taylor Grazing Act
- Federal Land Policy and Management Act (FLPMA)
- Public Rangelands Improvement Act
- Grazing Fees Executive Order
- Materials Act of 1947
- Federal Mine Safety and Health Act of 1977 (MSHA)
- Occupational Safety and Health Administration Regulations (OSHA)
- Noise Control Act of 1972
- Bald and Golden Eagle Protection Act
- Migratory Bird Treaty Act (MBTA)
- National Defense Authorization Act - Fiscal Year 1989
- Protection and Enhancement of Environmental Quality Executive Orders
- Federal Compliance with Pollution Control Standards Executive Order
- Executive Order 12873 "Federal Acquisition, Recycling, and Waste Prevention"

3.2.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 U.S.C. § 9601 et seq.), (including the Superfund Amendments and Reauthorization Act of 1986)

The CERCLA, or "Superfund," and the Superfund Amendments and Reauthorization Act (SARA) establish a comprehensive federal strategy for responding to, and establishing liability for, releases of hazardous substances from a facility to the environment. Hazardous substance cleanup procedures are specified in the National Contingency Plan (NCP). 40 CFR 300. No release sites have been identified at the WIPP that would require cleanup under the provisions of the CERCLA. Any spill of hazardous substances that exceeds a reportable quantity, must be reported to the National Response Center (NRC) under the provisions of Section 103 of CERCLA and 40 CFR 302.

3.2.1.1 Accidental Releases of Reportable Quantities of Hazardous Substances

On July 2, 1995, there was one spill at the WIPP that exceeded the reportable quantity limits. Approximately 75 gallons of 35/65 Ethylene Glycol solution was spilled inside a diesel generator building. Of the 75 gallons, approximately 40 gallons was contained inside the building and on a

concrete pad. The spill was immediately reported to the National Response Center (NRC), the State Emergency Response Commission (SERC), and the Local Emergency Planning Committee (LEPC). A follow-up report was sent to the SERC, the LEPC, and the NMED Hazardous and Radioactive Materials Bureau, NMED Groundwater Protection and Remediation Bureau, and the EPA Region 6. The spill was contained immediately, and clean-up was completed in a short period of time with containment of the contaminated soil and absorbant material accomplished by placing it in drums. Subsequent sampling of the containerized contaminated material was conducted on July 7,1995, in order to characterize the waste prior to disposal at an offsite disposal facility.

The WIPP facility is required to report such events under Sections 311 and 312 of SARA Title III, also known as the *Emergency Planning and Community Right-to-Know Act* (EPCRA). Reports required by these two sections are submitted to the SERC, the LEPC, and the local fire department. The WIPP also submits Section 311 data and Section 312 annual reports to the Carlsbad Fire Department, the Hobbs Fire Department, and the Otis Fire Department. For emergency response purposes, the DOE maintains Memoranda of Understanding (MOU) with each of these agencies.

The WIPP facility is currently exempt from the reporting requirements in Section 313 of the EPCRA. Section 313 lists the following toxic chemicals, currently in use at WIPP, that exceed the 10,000 pound threshold level: ethylene glycol, sulfuric acid, toluene, and xylene. Ethylene glycol and sulfuric acid meet the 10,000 pound reporting threshold, however, these chemicals are used as a structural component of the facility and are subject to the use exemption. Toluene and xylene are contained in unleaded gasoline and are subject to the vehicle maintenance exemption. Documentation of this exempt status is reviewed annually.

3.2.1.2 Waste Minimization and Pollution Prevention Programs

In April, 1995, the WIPP hosted the Seventh Semiannual DOE Defense Programs' Technology Workshop. The focus of the workshop was "Hands-on Pollution Prevention". Approximately 90 people from various DOE sites attended the three day workshop. Workshop attendees participated in two days of benchmarking pollution prevention processes and a one day tour of the WIPP site facility.

The WIPP Project and the WIPP Waste Minimization Committee sponsored two "Waste-In-Place" Teachers' Workshops for area educators. Thirty teachers from the Artesia and Carlsbad school districts participated in a day-long workshop that enchanced awareness on environmental issues such as litter control, recycling, and waste prevention. It is anticipated that additional workshops will be scheduled in the future.

The WIPP celebrated the week of "Earth Day 1995" with a variety of employee awareness activities. Each day of the week of April 17-21 the WIPP Waste Minimization Committee presented recycling techniques, processes, possibilities and alternatives for plastic, paper, glass and aluminum.

The WIPP recycling programs continue to be a success. In 1995 the WIPP donated approximately 50 tons of paper and corrugated cardboard for recycling. All project participants, including the DOE, Westinghouse, Sandia National Laboratories, and minor subcontractors are involved in this recycling effort.

In 1995, the WIPP recharged 260 printer toner cartridges for a savings of almost $15,000. The WIPP printer toner cartridge recharging program recharges toner cartridges for a cost of $40 per recharge, instead of discarding them and purchasing new cartridges for $70-$130. After the cartridges have been recharged three times, they are sent for recycling.

In December, 1994, the aerosol can puncturing program began with surface operations, and in April, 1995, the program was expanded to include underground operations. This program allows cans to be punctured and emptied thereby reducing the amount of hazardous waste and saving on disposal costs. Since the program's inception, approximatley $6,800 has been saved on disposal costs.

3.2.2 Executive Order 12873 - *Federal Acquisition, Recycling, and Pollution Prevention*

The WIPP adopted a systematic and cost-effective Affirmative Procurement Plan for the promotion and procurement of certain products containing recovered materials in July 1995. Affirmative Procurement is designed to "close a loop" in the waste minimization recycling process by supporting the market for materials collected through recycling and salvage operations.

Affirmative procurement programs are mandated by RCRA Section 6002(i), which requires federal agencies and their procuring agencies to establish material preference programs targeted to purchase recycled materials. Executive Order (EO) 12873, *Federal Acquisition, Recycling, and Waste Prevention*, and the Enviromental Protection Agency 40 CFR 248-250; 252-253 provide additional guidance for implementing affirmative procurement programs at federal facilities.

Affirmative procurement programs must include four elements: (1) a preference program; (2) a promotion program; (3) estimation, certification, and verification procedures; and (4) procedures for annual review and monitoring. The purchase and use of recycled products at the WIPP will help

foster markets for recovered materials and reduce the amount of solid waste requiring disposal through the purchase and use of products containing recovered materials.

3.2.3 Resource Conservation and Recovery Act (RCRA)
(42 U.S.C. § 3251 et seq.)

The RCRA was enacted in 1976, and implementing regulations were promulgated in May 1980. This body of regulations ensures that hazardous wastes are managed and disposed in an environmentally safe manner. Facilities that store, treat, or dispose of hazardous waste also must protect human health and the environment. The Hazardous and Solid Waste Amendments (HSWA) of 1984 prohibit land disposal of hazardous wastes unless certain treatment standards are satisfied or unless the EPA approves a petition to receive a variance from Land Disposal Restriction (LDR) standards. The HSWA also places increased emphasis on waste minimization activities and serves as a mechanism to enforce the RCRA cleanup requirements.

The WIPP facility is subject to the permitting requirements under the RCRA and the New Mexico Hazardous Waste Act. Title 40 CFR 264 outlines the technical standards for Treatment, Storage, and Disposal facilities that must be addressed in a permit application (as applicable). Title 40 CFR 270 outlines the requirements of the RCRA permitting program with respect to general format and content for applications, and the administrative aspects of the permitting and modification processes. The WIPP RCRA permit application addresses TRU mixed waste management activities for surface facilities and in the repository as required for disposal operations. This application was submitted to the NMED in May 1995. In general, programmatic changes reflected in this application center on the DOE decision to forego test phase activities at the WIPP. The RCRA permit is expected to be issued by the NMED in August 1996.

In order to permanently dispose of TRU mixed waste, the DOE has petitioned the EPA for a variance from the LDR of the RCRA, codified in 40 CFR 268. As defined in the provisions of 40 CFR § 268.6, the DOE must demonstrate "to a reasonable degree of certainty" that hazardous constituents will not migrate from the disposal unit in concentrations exceeding health-based levels. The WIPP is currently developing the final No Migration Variance Petition (NMVP) for the disposal phase. The Draft NMVP was submitted to the EPA in May 1995 and addresses a no-migration demonstration within the WIPP operational time frame (waste emplacement). The Final NMVP, which is near completion, all-inclusive of the first submittal, will demonstrate no migration after closure of the facility. The Final NMVP will be submitted to the EPA in June 1996, and a No-Migration Determination is expected to be issued by June 1997.

3.2.3.1 Mixed-Waste Management

In August 1993, the New Mexico Environment Department (NMED) issued, for public comment, a draft permit for the WIPP facility. In October 1993, the DOE made the decision not to conduct tests with radioactive wastes at the WIPP. At that time the DOE also requested an extension to the public comment period. On January 13, 1994, the DOE submitted a request to modify the RCRA permit application to reflect disposal, rather than test-phase operations. The NMED granted an extension to the public comment period until January 15, 1994. On September 2, 1994, NMED requested that a revised permit application be submitted by May 31, 1995, to accurately reflect future WIPP activities. Subject revisions were prepared and submitted to the NMED in phases as Revision 4 of the RCRA Part B permit application, and in May 1995, the revised permit application was submitted in its entirety as Revision 5. Revision 5 was determined to be administratively complete in July 1995. The NMED is currently conducting a technical review of the permit application.

3.2.3.2 Hazardous Waste Generator Compliance

Nonradioactive hazardous waste is currently generated through normal facility operations. These wastes are managed in Satellite Accumulation Areas (SAA) and "less than 90-day" storage areas. In addition, hazardous waste generated at the WIPP is characterized, packaged, labeled, and manifested prior to shipment to an offsite Treatment Storage Disposal Facility (TSDF) in accordance with those requirements as codified in 40 CFR 262. Various waste minimization activities have been implemented at the site. One such activity is the Aerosol Can Puncturing Program. Once a can is punctured and drained of the contents, it is then classified as RCRA "empty" and managed as nonhazardous. The remaining residual liquids are the only portion of the waste managed as hazardous, which substantially reduces the volume of this particular waste stream.

3.2.3.3 Voluntary Release Assessment Program at Selected Solid Waste Management Units at the WIPP

The U. S. Department of Energy, Carlsbad Area Office (DOE-CAO) has completed a voluntary release assessment sampling program at 11 selected Solid Waste Management Units (SWMUs) at the WIPP. Solid Waste Management Units are defined in the proposed Subpart S regulations as, "Any discernible unit at which solid waste has been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous waste. Such units include any area at a facility at which solid wastes have been routinely and systematically released", *Federal Register, Vol. 55, No. 145; July 27, 1990, VI (B) (3).*

The CAO made the decision to complete a voluntary release assessment/corrective action program at selected SWMUs described in Chapter J of the RCRA Part B permit because the proposed rules provide incentives for facilities willing to complete voluntary corrective actions. The Subpart S rules state: "The Agency intends to remove regulatory disincentives to independent action by facility owner/operators, and will encourage voluntary cleanups. EPA recognizes that it is important to allow willing and responsible owner/operators to begin corrective action promptly without unnecessary procedural delay."

The Voluntary Release Assessment/Corrective Action Program is intended to be the first phase in implementing the RCRA Facility Investigation corrective action process at the WIPP. The results of voluntary facility investigations will be used to focus on plausible concerns and expedite cleanup decisions as defined in the preamble of the proposed Subpart S Rule.

Data generated by the release assessment sampling program are being used to document voluntary release assessment/corrective action commitments contained in the *Voluntary Release Assessment/ Corrective Action Work Plan (DOE/WIPP Draft 2115)* submitted to the EPA and NMED in July, 1995. These data are also being used to update SWMU information contained in the 1994 RCRA Facility Assessment (RFA) for the WIPP (*Assessment of Solid Waste Management Units at the Waste Isolation Pilot Plant), NMED/DOE/AIP 94/1.*

A total of 264 release assessment samples were collected to determine if a release had occurred from any of the 11 SWMUs described in the release assessment work plan. Release assessment sampling data, and proposed corrective actions have been compiled into three data summary reports. Data summary reports were submitted to the EPA Region VI, Hazardous Waste Management Division and the NMED Hazardous and Radioactive Materials Bureau. Summary reports were submitted to the agencies as validated data became available. These "tiered" data submittals are designed to provide the agencies with the opportunity to review release assessment data prior to the issuance of the RCRA Part B permit for public review and comment.

Using the criteria provided in proposed *40 CFR § 264.514 FR Vol. 55, No. 145, VI(D), p. 30813*, and the October 1995, *EPA Region III Risk-Based Concentration Table, July - December 1995*, the analytical data collected at each of the 11 SWMUs demonstrates that no release of hazardous constituents has occurred. Thus, there is no potential for impacts to human health or the environment.

Based on these results the DOE-CAO has formally requested that a determination of No Further Action be granted for each of the 11 SWMUs. Because it is the EPA's intent to encourage

voluntary corrective actions, the CAO has requested that after appropriate public review and agency approval, a No Further Action determination be granted for the each of the 11 SWMUs prior to the issuance of the RCRA Part B Permit for the WIPP. If this No Further Action determination is approved by the agencies, each of the 11 sites will be replanted with native vegetation in accordance with the guideline provided in the *WIPP Land Management Plan* (DOE/WIPP 93-004).

3.2.4 National Environmental Policy Act (NEPA)
(42 U.S.C. § 4321 et seq.)

The NEPA requires the federal government to use all practicable means to consider potential environmental impacts of proposed projects as part of the decision-making process. NEPA dictates that the public shall be allowed to review and comment on proposed projects that have the potential to significantly affect the environment. The NEPA also directs the federal government to use all practicable means to improve and coordinate federal plans, functions, programs, and resources relating to human health and the environment.

NEPA procedural objectives and public involvement requirements are detailed in the Council on Environmental Quality (CEQ) regulations implementing the NEPA in 40 CFR 1500-1508. DOE codified its requirements for implementing CEQ's regulations in 10 CFR 1021. Further procedural NEPA compliance guidance is provided in DOE Order O 451.1, *National Environmental Policy Act Compliance Program*. DOE Order O 451.1 superseded DOE Order 5440.1E on September 11, 1995.

Title 10 CFR 1021.331 requires that "...following the completion of each environmental impact statement and its associated Record of Decision (ROD), the DOE shall prepare a Mitigation Action Plan (MAP) that addresses mitigation commitments expressed in the ROD." DOE Order O 451.1 further requires DOE facilities to track and annually report progress in implementing a commitment for environmental impact mitigation that is essential to render the impacts of a proposed action not significant or that is made in a ROD. The *1995 Annual Mitigation Report for the Waste Isolation Pilot Plant* (NEPA ID# WIP:95:0002) was issued July 10, 1995.

In December 1994, a computer-based NEPA training module was released for use at the WIPP. The training module provides specific instructions to workers for completing environmental checklists which assess the impacts of their proposed actions.

In 1980, the DOE prepared the *Final Environmental Impact Statement for the Waste Isolation Pilot Plant* (FEIS). The objective of the FEIS was to assess the potential impacts of developing WIPP in

addition to the alternatives for the disposal and management of TRU waste. By 1990, following construction of the WIPP facilities, the DOE decided to prepare the *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant* (SEIS-I) to update the environmental record established in the FEIS (DOE 1990).

The preparation of the second Supplemental Environmental Impact Statement (SEIS-II) is underway. The DOE is now proposing to continue the phased development of WIPP by beginning the disposal of defense-related TRU waste. The SEIS-II document originated from new information relevant to environmental concerns and a commitment made in the Final Supplemental Environmental Impact Statement (FSEIS) to prepare another environmental impact statement prior to the decision to proceed with waste disposal activities at the WIPP site. Scoping meetings were held in Carlsbad, NM; Albuquerque, NM; Santa Fe, NM; Denver, CO; and Boise, ID. An implementation plan was prepared and made available to the public in DOE reading rooms. The Record of Decision for the SEIS-II is scheduled for March 1997.

3.2.5 Clean Air Act (CAA)
(42 U.S.C. § 7401 et seq.)

The CAA provides for the preservation, protection, and enhancement of air quality, particularly at locations of special interest such as areas of natural, recreational, scenic, or historic value. Under Section 109 of the Clean Air Act, the EPA established the National Ambient Air Quality Standards (NAAQS) for six "criteria" pollutants: sulfur dioxide, total suspended particulates, carbon monoxide, ozone, nitrogen oxide, and lead. These standards establish primary and secondary standards for ambient air quality that the EPA considers necessary to protect public health and welfare.

In 1993, Westinghouse Electric Corporation, Waste Isolation Division (WID), completed the WIPP Hazardous Air Pollutant (HAP) Emission Inventory. The 1993 HAPs inventory was developed as a baseline document to calculate maximum potential hourly and annual emissions of both hazardous and criteria air pollutants. In 1995 the HAPs inventory was repeated and compared to the baseline data. Emission estimates were used to determine if the WIPP is required to obtain an air permit as specified in the following regulations:

- Clean Air Act § 112 National Emission Standards for Hazardous Air Pollutants
- Clean Air Act Part C (Prevention of Significant Deterioration - Criteria Pollutants)
- New Mexico Air Quality Control Regulation 752
- New Mexico Air Quality Control Regulation 702.

The CAA. Section 112 establishes emission standards for Hazardous Air Pollutants. The 1990 Clean Air Act Amendments (CAAA) increased to 189 the number of hazardous air pollutants regulated under the CAA. Hazardous air pollutant emissions are regulated under 40 CFR 61, the *National Emission Standards for Hazardous Air Pollutants* (NESHAP). The NESHAP establishes permitting and reporting requirements for facilities that have the potential to emit hazardous air pollutants. At the WIPP, the majority of hazardous air pollutants are regulated in Subpart A of the NESHAP. Radionuclide emissions other than radon are regulated in Subpart H of the NESHAP.

Based on an MOU with the EPA, the DOE committed to compliance with the requirements of 40 CFR 61, Subpart H, through the disposal phase of operations at the WIPP. A revised standard for radionuclide emissions was promulgated by the EPA in a final ruling published in the *Federal Register*, effective December 15, 1989 (54 FR 51654).

The *1995 Safety Analysis Report* (SAR) establishes the adequacy of the WIPP safety bases regarding plant response to conditions considered to be "extremely unlikely." Waste containers accepted for disposal at the WIPP are expected to meet the WIPP *Radiological Control Manual* external contamination limits. Waste container contamination levels are thus at undetectable levels. WIPP normal operations do not involve or entail any planned or expected releases of airborne radioactive materials, therefore, no hazards exist to the public, worker, or environment for the airborne pathway as a result of normal operations. Radiological consequences to the offsite public from normal operations will therefore meet the criteria in 40 CFR 191, Subpart A in addition to 40 CFR 61. External doses to workers from the handling of contact handled waste containers were estimated to be well within DOE ALARA or "as low as reasonably achievable" goals. Moreover, consequences to the public and worker as a result of the release of volatile organic compounds (VOCs) during disposal phase normal operations were shown to be many orders of magnitude below health based limits.

A revised data package will be submitted to the EPA prior to waste receipt. An emissions monitoring system was installed to comply with the periodic confirmatory monitoring compliance requirements established in NESHAP. On November 21, 1994, the EPA approved the use of a single-point source shrouded probe for compliance sampling. The shrouded probe will be used to conduct periodic confirmatory monitoring at the WIPP.

Based on the HAP's inventory, WIPP operations do not exceed the 10 ton per year (tpy) emission limit for any individual HAP or the 25-tpy limit for any combination of HAPs emissions established in Subpart A. The WIPP does not have any NESHAP Subpart A permitting or reporting requirement at this time. However, 40 CFR 61, Subpart A, Section 61.09(a)(1), requires that the

WIPP facility notify the EPA of its anticipated date of initial startup (i.e., receipt of wastes) not more than 60 days and not less than 30 days before actual startup date. In addition, the EPA required that notification of the actual date of initial startup must be made within 15 days after startup.

Based on emission estimates generated in the HAPs inventory, the WIPP site is not required to obtain any federal CAA permits. The WIPP, in consultation with the NMED Air Quality Bureau, working in concert with data provided in the first HAP's inventory, was required to obtain a New Mexico Air Quality Control Regulation (AQCR) 702 Operating Permit for two primary backup, diesel generators at the site. The only emission points where the WIPP site exceeds state threshold criteria is with the WIPP backup diesel generators. On June 18, 1993, the DOE submitted an AQCR 702 permit application for the WIPP backup diesel generators. On December 7, 1993, the New Mexico Air Quality Bureau issued Air Quality Permit 310-M-2. On February 26, 1994, the WIPP completed the emission monitoring requirements established in the permit. With the submittal of the *Final Compliance Sampling Report* on March 28, 1994, the DOE has fulfilled all monitoring and reporting requirements identified in the permit. The permit was modified on September 1, 1994 to allow one diesel generator to operate under load while the second diesel generator is at idle speed in a warm up or cool down mode. This allows for greater operational flexibility.

3.2.6 Clean Water Act (CWA)

Section 402 of the CWA, establishes provisions for the issuance of permits for discharges into waters of the United States. Regulations promulgated to define this permitting process are contained in 40 CFR 122. Subpart A, Section (b)(1), and state that ". . . National Pollutant Discharge Elimination System (NPDES) program requires permits for the discharge of "pollutants" from any "point source" into "waters of the United States." The WIPP has no pollutant discharges from point sources and is currently exempted from obtaining a standard NPDES permit.

On September 9, 1992, the EPA issued the final requirements for NPDES *General Permits for Storm Water Discharges Associated with Industrial Activity*. The storm water regulations establish requirements for managing industrial storm water runoff that has the potential to discharge into waters of the United States. The WIPP submitted a Notice of Intent (NOI) to the EPA to obtain a NPDES Storm Water General Permit on December 31, 1992. The NOI describes how the WIPP site mitigates the discharge of contaminated storm water through the use of Best Management Practices (BMPs). These BMPs include engineering controls such as storm water retention basins, the covering of materials storage areas, and the reclamation of disturbed areas. The EPA issued a

New Mexico NPDES Storm Water General Permit (NMR00A021) on January 31, 1992. As part of the Nationwide General Permit Program, the WIPP is included in the New Mexico General Permit.

No sampling is required to demonstrate compliance with the WIPP Storm Water Permit unless a release occurs from one of the BMPs. Operational permit compliance activities are limited to quarterly inspections of retention basins, spill containment devices, reclamation sites, and site housekeeping practices.

The NPDES sewage sludge regulations promulgated in 40 CFR 122.21 require all facilities that generate or dispose of sewage sludges to submit an information package describing sewage sludge management and disposal practices. This information is reviewed by the EPA to determine if a NPDES permit will be required for the disposal of sewage sludges at a facility.

On February 14, 1994, the DOE submitted an information package to the EPA Water Management Division and requested a written determination whether a NPDES permit would be required for sewage sludges generated at the WIPP. On March 31, 1994, the EPA Region VI Permits Issuance Section notified the DOE that they had received the information package. The agency determined that the information package was complete and stated they would notify the DOE if a full and complete sewage sludge permit application would be required at a future date.

On January 16, 1992, the NMED issued the Discharge Plan (DP-831) for the WIPP sewage facility. The approved Discharge Plan superseded an Emergency Discharge Permit issued on September 18, 1991. In addition to sewage effluent, the Discharge Plan allows for the disposal of a maximum of 1500 gallons a day of nonhazardous brines generated by seepage into shaft sumps and from pumping of observation wells at the site. [Note: Exceptions to the classification of "nonhazardous" are brine waters with lead concentrations exceeding regulatory levels, collected in the waste shaft sump and boreholes OH 224, 225, and 226, located between the waste shaft and the exhaust shaft. Subject waters were disposed of as RCRA hazardous waste in an approved and permitted treatement storage and disposal (TSD) facility. No brine from the exhaust shaft has shown a hazardous lead content.] Brine waters are collected in portable tanks and transported to the north sewage system evaporation basin. Characterization samples were collected throughout 1995 to demonstrate that site-generated brines are nonhazardous and can be disposed in the sewage evaporation pond. On August 28, 1995, the WID submitted a request to the NMED requesting a minor amendment to DP-831 increasing the amount of nonhazardous brine for disposal to 2000 gallons per day. On October 4, 1995, the NMED approved the amendment to the Discharge Plan. The increase was required, not because additional brine was being generated but, because on days the observation wells were pumped,

greater than 1500 gallons was produced necessitating that the brine be disposed of over two days time.

The DOE submits quarterly Discharge Monitoring Reports (DMR) to the NMED to demonstrate compliance with the inspection, monitoring, and reporting requirements identified in the plan.

3.2.7 Safe Drinking Water Act (SDWA)
(42 U.S.C. § 300f et seq.)

The SDWA of 1974 provides the regulatory strategy for protecting public water supply systems and underground sources of drinking water. The NMED notified the WIPP in a September 9, 1992, letter that the WIPP Public Water Supply was categorized as a nontransient, noncommunity system for reporting and testing requirements. At that time, the NMED determined that the WIPP was required to sample drinking water for total coliform bacteria, lead, copper, nitrate and nitrite. In a March 11, 1994, letter the NMED again modified compliance sampling requirements, stating that only lead, copper, and bacteriological samples are required. The modification was based upon New Mexico Water Supply Regulations which mandate that when a public water supply system supplements other systems, that water system is treated as a single system for compliance sampling purposes.

The Carlsbad Municipal Public Water Supply System is contracted to provide raw water to the WIPP from city-owned wells located 31 miles north of the site. Because of this contractual agreement, the city of Carlsbad completes the source or point-of-entry samples for the various chemical constituents at each well field source.

On June 2, 1994, lead and copper samples were collected from 20 locations to demonstrate compliance with the newly identified SDWA sampling requirements. Five of the 20 samples exceeded the SDWA lead action levels. At the direction of the NMED, these five locations were resampled on June 30, 1994. Based on the results of these five samples, three locations (site drinking fountains) were permanently taken out of service and the faucets at the two remaining locations were replaced. Follow-up sampling was conducted at each of these locations and all were below the SDWA action levels.

In January and again in July of 1995, lead and copper compliance samples were collected and submitted for analysis. All samples were below action levels with the exception of one sample that exceeded action levels for lead. This location was resampled and the sample analysis was returned significantly below action levels. It was determined that just prior to sampling this location.

maintenance had been performed on the foot-operated valve for the faucet. Based on previous samples at this location and subsequent confirmatory sampling, it was decided that the maintenance activity had been the cause of the sample being above action levels.
On August 17, 1995 a request was submitted to the NMED requesting a reduction of lead and copper sampling activity. The request was based upon sampling results, in conjunction with administrative actions and resampling, that demonstrated the WIPP water supply system met the criteria for reduced sampling status. The number of samples was reduced from twenty to ten, and the period was increased from every six months to annually. The request was granted on August 23, 1995.

Bacterial samples were collected and reported monthly throughout 1995. All bacteriological/analytical results were below the SWDA regulatory limits.

3.2.8 National Historic Preservation Act (NHPA)
(16 U.S.C. § 470 et seq.)

The NHPA was enacted to protect the nation's cultural resources and to establish the National Register of Historic Places. Federal agencies are required to coordinate NEPA compliance with the responsibilities of the NHPA to ensure that historic and cultural properties are given proper consideration in the preparation of environmental assessments (EAs) and environmental impact statements (EIS's). Agency obligations, however, under the NHPA are independent from NEPA and must be complied with even when an EA or EIS is not required. That is, for proposed projects that are not classified as major federal actions with significant environmental impacts, DOE must still consider impacts to historic properties and sites. Where both NEPA and the NHPA are applicable, draft EIS's must integrate NHPA considerations along with other environmental impact analyses and studies (see 40 CFR 1502.25)

3.2.8.1 Summary

From man's first arrival in the Southwest about 10,000 B.C. to the late 1800s, southeastern New Mexico was inhabited by aboriginal hunters and gatherers who subsisted on various wild plants and animals. These people would have found a number of edible plants throughout the region, including mesquite beans, hackberries, walnuts, acorns, seed-producing grasses, agave and a variety of other succulents. Big and small game, including bison, deer, antelope, rabbits, reptiles, birds, and various invertebrates, could have been hunted or collected in the region.

From approximately 600 A.D. onward, as trade networks were established with Puebloan people to the west, domesticated plant foods and materials, including corn (or maize), beans, squash, and cotton, were acquired in exchange for dried meat, hides, and other products from the Pecos Valley and Plains. The indigenous population may also have practiced horticulture at favorable locales in the area, but only on an intermittent basis, since water for crops would have been scarce and unpredictable much of the time.

In the mid-1500s, the Spanish Conquistadors encountered Jumano and Apachean peoples in the region practicing hunting and gathering and engaging in trade with Puebloans. Later, as the natives acquired horses, and as Europeans began settling the land, this traditional way of life evolved into specialized bison hunting on the Llano Estacado and raiding both Spanish and Puebloan settlements to the west. In the late 1800s, the region was settled by ranchers and farmers.

The WLWA is situated in dune-covered, rolling-plains terrain in the eastern part of the BLM's Carlsbad Resource Area. Known archaeological sites within the area are primarily the remains of prehistoric camps and short-term settlements. These localities are generally marked by hearth features, scattered burned rock, flaked stone projectile points, and cutting and scraping tools, pottery fragments, and groundstone implements. Locations generally represent short-term, seasonal occupations by small, nomadic groups of hunters and gatherers who utilized the plants and animals in the dune lands east of the Pecos River. In a few cases within the WLWA, sites with evidence of structures have been reported. These sites probably hosted occupations of perhaps several weeks or months.

Many known historical sites in southeastern New Mexico consist primarily of early twentieth century homesteads that failed, or isolated features from late nineteenth and early twentieth century cattle or sheep ranching and military activities. Although the region was part of the Spanish and Mexican colonial empires, no related conquest or settlement sites have yet been identified.

Historic components (more than 50 years old) are rare, but are occasionally noted within the WLWA. These include features and debris related to ranching in the early years of the twentieth century. In addition, more modern ranching debris and facilities such as fence lines are present in the area, including some which are likely still in use. Ranch-related sites which date to the 1940s and 1950s are common in parts of the WLWA. These will be considered historical properties within the next several years and under current law, will have to be treated as such. The majority of the several sites recorded in the area typically include elements which can contribute to their eligibility for the National Register of Historic Places. With few exceptions, cultural properties

known or anticipated for the WLWA are significant; they must be identified, recorded, assessed through inventory, and considered in any plan of development for the area.

Compared with most other parts of southeastern New Mexico, the locations and nature of cultural resources within the WLWA can be described relatively well, based on intensive inventory of portions of the area, along with limited excavation and some other work on some sites.

In 1976 four sections comprising the WIPP core area (Sections 20, 21, 28, and 29), along with associated rights-of-way and drilling pads within and outside the WLWA (Nielson 1976) were inventoried by the Agency for Conservation Archaeology (ACA) of Eastern New Mexico University. Additional rights-of-way within and outside the WLWA were inventoried in 1978 and 1979 by ACA (Schermer 1978; MacLennan and Schermer 1979). Sites identified in the core area were relocated and evaluated in 1980 by ACA, and management recommendations for those sites were prepared (Schermer 1980). Subsequently, in accordance with the ACA's recommendations, a number of sites within the WIPP core area were tested for eligibility and/or were excavated as mitigation (Lord and Reynolds 1985).

In 1987 Mariah Associates conducted an intensive study of portions of 45 sections surrounding the WIPP facility. Mariah's study included an inventory of 2,460 acres in 15 quarter-section units. Inventoried units were selected so as to be representative of the area as a whole. Within each of the sample units, all cultural resource sites encountered were recorded, certain selected sites were tested, and management recommendations were prepared (Mariah Associates, 1987).

Between 1989 and 1992, several seismic projects associated with oil and gas development provided cultural resource clearances within the WLWA. Numerous inventories have been conducted outside the withdrawal area, primarily for oil and gas exploration and ranching.

Inventories conducted to date within the withdrawal area have located 60 archaeological sites, along with 91 isolated occurrences (single or few artifacts, or isolated features which can be fully recorded in the field). Sites and isolates identified are almost exclusively prehistoric. Only one site with both prehistoric and historic components has been noted.

Of a total of 10,240 acres in the WLWA, 3,380 acres (37 percent) have been inventoried for cultural resources. The results have been the discovery of one site for every 65 acres surveyed, and one isolate in every 42 acres. Based on this information, and assuming environmental homogeneity and a fairly even distribution of sites, the remaining 6,410 uninventoried acres could contain approximately 99 sites and 153 isolates. The combined results of the several inventories conducted

within the WLWA compare well with those from Mariah's 1987 inventory of selected units over a much larger area. Mariah's results show only a slightly higher frequency of cultural resources per acre. In 2,460 acres, 40 sites and 75 isolates were recorded, or one site for every 62 acres and one isolate in every 33 acres.

Of the 40 sites identified and evaluated on the Mariah inventory, 14 are eligible for the National Register of Historic Places, 24 are potentially eligible, and two are not eligible. [Note: A determination of eligibility can be made only after the site has been archaeologically tested.] None of the 75 isolates are considered eligible. While the data from the various researchers cited above are not always consistent with Mariah's explicit data on site significance, it appears that within the WLWA, the majority of sites either are or have the potential to be eligible for the National Register of Historic Places and will require consideration in future land disturbing activities.

Site significance is contingent on the number of manifestations encountered, their diversity in composition, the total number of each type of manifestation, and existing evidence suggesting whether or not a given site is datable. Previous limited cultural inventories indicate that WIPP represents a potentially significant cultural resource contributor to the discipline of archeology and shall be regarded as such when deliberating land management decisions.

The objectives of the DOE are to protect and preserve representatives of the full array of cultural resources, within the WLWA, for the benefit of scientific and socio-cultural use by present and future generations. This guidance will ensure that cultural resources are given full consideration in land use planning and management decisions.

On June 21, 1995, an investigation was conducted of a previously known site as several previously buried artifacts emerged at the surface. No regulatory actions were required following the investigation, since no surface disturbing activities are planned for the area in question. During 1995, no new archaeological sites were discovered. Avoidance remains to be the WIPP's primary mitigation measure for archaeological sites.

3.2.9 Federal Compliance with Pollution Control Standards (Executive Order 12088)

Executive Order (EO) 12088 advises the director of each federal agency to ensure that all necessary actions are taken for the prevention, control, and abatement of environmental pollution. Each agency is responsible for compliance with applicable pollution control standards established by such statutes as the CWA, the CAA, the AEA of 1954, and others. Each agency must submit an annual

plan for the control of environmental pollution at its facilities. This EO mandates that the DOE control pollution at the WIPP facility.

The *Waste Minimization and Pollution Prevention Awareness Plan* was updated on May 31, 1994. This plan is reviewed annually and updated at least every three years. Pollution prevention awareness guidance is contained in the *Resource Conservation and Recovery Act Compliance Manual* (WP 02-6, 02-7) and its implementing procedures, as well as in the *Environmental Compliance Manual* (WP 02-5). These environmental compliance manuals are currently being revised to incorporate elements of the Waste Minimization and Pollution Prevention Awareness Program.

3.2.10 Hazardous Materials Transportation Act (HMTA)
(49 App. U.S.C. 1801 et seq.; 49 CFR 106-179)

The HMTA is the major transportation-related statute that affects the Department of Energy at the WIPP. It provides for safe intra and inter-state transportation of hazardous materials (including radioactive materials). The HMTA allows states to regulate the transport of hazardous/radioactive materials if regulations are consistent with the HMTA or U.S. Department of Transportation (DOT) regulations. In the second modification to the Agreement for Consultation and Cooperation, dated August 4, 1987, the DOE agreed to comply with all applicable DOT regulations and the corresponding NRC regulations. Therefore, the following regulations are applicable or potentially applicable to the WIPP.

The DOT regulations for hazardous/radioactive materials are contained in 49 CFR 171-177. Specifications for the kinds and designs of packages to be used for the transport of various types of radionuclides are contained in 49 CFR 173, Subpart I (and parallel Nuclear Regulatory Commission regulations in 10 CFR 71). The DOT regulations in 49 CFR 174 addresses the shipment of radioactive material by rail. 49 CFR 177 provides routing and training requirements for highway shipments of nuclear material.

3.2.11 Packaging and Transportation of Radioactive Materials
(10 CFR 71)

Regulations for shipping containers and safe packaging and transportation of radioactive materials are under the authority of the Nuclear Regulatory Commission (NRC) and the Department of Transportation (DOT). Packaging requirements for radioactive materials, including the Type B packages to be used to transport waste to the WIPP facility, are detailed in the DOT regulations (49 CFR 173, Subpart I). This citation also references the NRC regulations. Generally, the NRC does

not have regulatory authority over the DOE. The only portion of the NRC's implementing regulations that applies to the WIPP is 10 CFR 71, Packaging and Transportation of Radioactive Material. These regulations pertain to the NRC's certification of packaging such as the TRUPACT-II shipping container designed to transport TRU waste from the generator sites to the WIPP. The NRC certified the TRUPACT-II container August 30, 1989, after compliance with the 10 CFR 71 requirements for Type B packaging were demonstrated. On April 22, 1994, DOE submitted a subsequent application to the NRC requesting a revision to the existing Certificate of Compliance (C of C). Thus, on March 30, 1995, the NRC issued C of C No. 9218, Revision No. 6 to the DOE for the continued use of TRUPACT-IIs to ship radioactive material. Revision 6 supersedes in its entirety, C of C No. 9218, Revision No. 5, dated June 9, 1994.

3.3 Other Significant Accomplishments and Ongoing Compliance Activities for Calendar Year 1995

3.3.1 Environmental Compliance Assessment Program (ECAP)

The ECAP plays a major role in the overall program for environmental protection activities at the WIPP. The ECAP was developed to determine if impactive or potentially impactive facility activities protect human health and the environment and if these activities are in compliance with applicable federal, state, and local requirements; with permit condition/requirements; and with best management practices. This program provides a comprehensive system, not only to assess compliance with applicable environmental statutes and requirements at the WIPP, but also to identify operationally feasible and environmentally sound corrective action measures for nonconformances or observations identified. The ECAP is designed to address five compliance assessment processes: (1) environmental compliance appraisals; (2) environmental audits; (3) independent review group evaluations; (4) environmental event evaluations; and (5) environmental compliance status tracking and reporting process.

During 1995, eight environmental compliance assessments were conducted. Thirty-five (35) improvements were identified and implemented as a result of these assessments. The assessed areas included: Satellite Accumulation Areas and Hazardous Waste Staging Area; Sandia National Laboratories - Culebra Transport Program; Air, Waste, and Water Program; Annual Hazardous Waste Fee Regulations; Dosimetry and Analytical Labortatory; NPDES; RCRA Equipment Inspections; and Environmental Monitoring.

3.3.2 Site Environmental Management Program

In December 1995, the Site Environmental Awareness Program was initiated in order to increase employee awareness of environmental issues. The program has a three-phased approach and is aimed at WID Managers and Supervisors. However, many program elements target all WID Employees. The three phases include:

- Environmental Awareness Campaign
- Manager's Environmental Handbook
- Management Environmental Accountability Program (MEAP)

3.3.3 Environmental Awareness Campaign

The purpose of the Environmental Awareness Campaign is to increase the visibility of environmental issues for the employees. The campaign consists of various tools, forums, and educational opportunities for managers, supervisors, and the general employee.

3.3.4 Manager's Environmental Handbook

The purpose of the Manager's Environmental Handbook is to provide a brief overview of Corporate Charters and Policies; WIPP policies and procedures; DOE Orders; and the major environmental laws and regulations that directly apply to the WIPP. The Handbook will also contain segments on ISO 14000 Standards and the Environmental Leadership Program.

3.3.5 Management Environmental Accountability Program (MEAP)

The purpose of the MEAP is to educate employees and managers about current environmental issues and to encourage individual and line-management accountability. The program will consists of 12 training elements on a variety of environmental subjects. A managers training packet ensures that current environmental information is conveyed correctly and consistently. The packet contains appendices, exercises and incident/events that are applicable to the particular lesson.

3.3.5.1 Benefits of the MEAP

- Establishes the WIPP as a proactive, environmentally responsible citizen;
- Promotes individual responsibility;

- Aligns with the Westinghouse and the Department of Energy's Carlsbad Area Office's mission to protect human health and the environment;

- Enhances the WID's application to one of the Environmental Protection Agency's environmental management programs;

- Fulfills one of the elements for the implementation of ISO 14000.

3.3.6 ISO 14000 - STANDARDS FOR ENVIRONMENTAL MANAGEMENT

The *Organization de Standards International*, formed in Amsterdam in 1947, sets standards for a wide range of products and management operations. Following the success of the International Standards Organization (ISO) 9000 series for quality management, ISO introduced the 14000 series, which is a set of environmental management standards now under development. These environmental management standards will promote international trade and will foster economic growth.

ISO 14000 certifies that those businesses conducting worldwide trade have met internationally agreed upon policies and regulatory standards. These policies and regulatory standards prescribe a common baseline approach to environmental and managerial problem solving, system evaluation, product quality, and product labeling. Should differences arise among or between trade partners, the ISO 14000 will serve as a standardized methodology for solving problems or remediating differences.

All ISO standards are voluntary. However, governments and industries are adopting ISO standards, making them necessary to conduct business. ISO 14000 standards address the following five areas:

- Environmental Management Systems

- Environmental Performance Evaluations

- Environmental Auditing

- Life-Cycle Assessment

- Environmental Labeling

3.3.6.1 Environmental Management Systems (EMS)

An EMS consists of three parts: a written statement; education and training; and knowledge of relevant government environmental regulations. The statement commits the company to seek the highest product quality with the lowest environmental impact. All employees will have access to the EMS through education and training. The EMS incorporates relevant government environmental regulations.

3.3.6.2 Environmental Performance Evaluations

Environmental Performance Evaluations measure the impact a business is having on the environment. An inventory of air and waste discharges establishes a baseline. A business may then measure performance improvements over time.

3.3.6.3 Environmental Auditing

An evaluation conducted by an independent third party constitutes an environmental audit. The results of the audit are provided to management to permit integration of changes and improvements in procedures and processes. Typically, audits are conducted yearly.

3.3.6.4 Life-Cycle Assessment

A Life-Cycle Assessment is an analysis of the environmental effects of process inputs and wastes during the operational life of the company's product or service.

3.3.6.5 Environmental Labeling

Environmental labeling identifies "environmentally friendly" products to consumers. ISO 14000 defines the characteristics of environmentally friendly products through standardized international product labeling. Companies planning to identify their products through labeling obtain a competitive advantage over nonlabeled competitors, attract new customers, and reduce liability.

3.3.7 Descriptive Titles of the ISO 14000 Series

The following is a list of descriptive titles of the ISO 14000 Series, which is divided into two categories: organizational evaluation and product evaluation. Only ISO 14001 is a specification standard. All others are guidance standards.

3.3.7.1 Organizational Evaluation Standards

14001: Environmental Management Systems - Specifications
14010: General Principles of Environmental Auditing
14011: Audit Procedures
14012: Qualification Criteria for Environmental Auditors
14015: Environmental Site Assessments
14031: The Management System and Its Relationship to the Environment

3.3.7.2 Product Evaluation Standards

14020: Goals and Principles of All Environmental Labeling
14021: Self-Declaration Environmental Claims
14024: Environmental Labeling - Guiding Principles
14040: Life-Cycle Assessment - Principles and Practices
14041: Life-Cycle Inventory Analysis
14042: Life-Cycle Impact Assessment
14043: Life-Cycle Improvement Assessment
14060: Guide for the Inclusion of Environmental Impacts in the Product Standards

3.3.8 Waste Minimization Committee

The Waste Minimization Committee was formed in 1993 with representatives from groups generating or working with hazardous and/or large volumes of waste. The Committee prepared a Waste Minimization Charter, which outlines the Committee's responsibilities.

The Waste Minimization Committee is split into separate subcommittees to concentrate on different areas of pollution prevention. These subcommittees are the Employee Awareness, Community Outreach, Waste Assessments, and Hazardous Solvent Substitution.

In January 1996, the Employee Awareness Subcommittee began its' Employee Awareness Campaign. Waste Minimization suggestion/nomination/idea forms were distributed by Subcommittee members the first week of January. Employees with waste minimization or pollution prevention ideas or suggestions can submit them to the subcommittee and receive a prize. Employees can also nominate others who practice waste minimization or pollution prevention in their day-to-day activities. Drawings are held each Friday for t-shirts with the waste minimization slogan printed on them. Articles are printed in the *TRU-News* periodically to educate employees on the importance of waste minimization and to announce prize winners in the awareness campaign.

A Pollution Prevention Opportunity Assessment (PPOA) was conducted in 1995 by the Waste Assessments Subcommittee. The PPOA Subcommittee investigated cafeteria operations for potential waste minimization and pollution prevention opportunities. The PPOA was completed in October, 1995 and concerns are being addressed by the subcommittee.

In 1994 a PPOA was performed on the process of disposing of fluorescent tubes onsite and alternatives to their disposal as hazardous waste. As a result of this PPOA, a contract was put into place with a fluorescent tube recycling company to recycle WIPP's spent fluorescent tubes.

Other waste minimization activities for 1995 include:

- Recycling of white bond paper, corrugated cardboard, and aluminum cans
- Recharging of toner cartridges
- Puncturing of aerosol cans to reduce hazardous waste volumes
- Recycling of waste oil offsite
- Reusing cold-degreasing solvents at six solvent stations used for cleaning parts
- Reclaiming cold-degreasing solvents offsite
- Using recycled janitorial paper products exclusively
- Recycling of lead-acid batteries offsite

3.3.9 Environmental Training

Environmental training was provided to personnel associated with environmental operations at the WIPP. Training courses ranged from technical topics (e.g. RCRA sampling), basic ES&H training, and general site-wide training such as the required General Employee training module. These courses were conducted both onsite by WIPP personnel and offsite by various contractors.

Table 3-1
Compliance Status with Major Environmental Regulations
Applicable to the WIPP Project

Statute/Regulation	Status
Atomic Energy Act	No radioactive waste was received during CY 1995.
Clean Air Act	NESHAP data package and letter of notification submitted. No monitoring/reporting required until after receipt of waste.
Clean Water Act	Quarterly inspections of best management practices to comply with (stormwater retention basins) NPDB storm water general permit (NMR00A021).
Comprehensive Environmental Response, Compensation, and Liability Act/Superfund Amendments and Reauthorization Act	No Land Disposal Units (LDUs) exist at the site. No CERCLA site cleanup required. Reports filed as required under SARA for hazardous substances are maintained onsite.
Endangered Species Act	Individual permits to collect biological samples and to band nonendangered species of raptors are maintained.
Federal Land Policy and Management Act	An MOU between the DOE and the BLM was issued in July 1994. This MOU outlines the responsibilities the BLM and the DOE have with regard to land use management for the withdrawal area.
Federal Insecticide, Fungicide, and Rodenticide Act	All use of pesticides is approved by Industrial Safety and is performed by subcontractors.
Hazardous Materials Transportation Act	Hazardous wastes to be sent offsite are reviewed to ensure compliance with HMTA.

Table 3-1
Compliance Status with Major Environmental Regulations
Applicable to the WIPP Project

Statute/Regulation	Status
National Environmental Policy Act (as supplemented by DOE Order O 451.1, and 10 CFR 1021)	The 1995 *Annual Mitigation Report for the Waste Isolation Pilot Plant* (NEPA ID# WIP:95:0002) was issued July 1995. This provides a status of the commitments made in the WIPP's Records of Decision. Purchase requisitions and engineering work packages which initiate changes and modifications to the WIPP facility, continue to be reviewed for potential environmental impacts.
National Historic Preservation Act	Activities requiring excavation in previously undisturbed areas are surveyed by licensed, permitted archaeologists. Required reports are submitted to the New Mexico State Historic Preservation Officer.
New Mexico Air Quality Control Act	The New Mexico Air Quality Bureau issued Air Quality Permit 310-M-2 on December 7, 1993. On February 26, 1994, the WIPP completed the emission monitoring requirements established in the permit. With the submittal of the *Final Compliance Sampling Report* on March 28, 1994, the DOE has fulfilled all monitoring and reporting requirements identified in the permit. New Mexico does not yet have primacy for NESHAP for radionuclide emissions from DOE facilities. New Mexico Hazardous Waste Management Regulations See "Resource Conservation and Recovery Act." NMED does not yet have primacy for all areas by the RCRA.
New Mexico Radioactive Materials Act	No radioactive wastes had been received at the WIPP in CY 1995.
New Mexico Water Quality Act	The DOE submits quarterly discharge monitoring reports to the NMED Groundwater Quality Bureau to comply with the requirements of the WIPP Discharge Plan. DP-831.

Table 3-1
Compliance Status with Major Environmental Regulations
Applicable to the WIPP Project

Statute/Regulation	Status
New Mexico Wildlife Conservation Act	See "Endangered Species Act."
Resource Conservation and Recovery Act	*Hazardous-waste generator compliance:* All site-generated hazardous wastes were transported off-site within the 90-day accumulation period. *No-Migration Determination compliance:* The fourth annual report was submitted to EPA on November 14, 1994. *Mixed-waste management:* On January 13, 1994, the DOE formally requested that the NMED allow the DOE to modify the RCRA permit application to reflect disposal operations. In September 1994, the NMED ordered the submittal of a complete revised permit application by May 31, 1995. DOE has submitted Chapters B, D, E, F, G, H, I, J & K to the NMED for their review. *Underground Storage Tanks:* Annual registration fee paid.
Toxic Substances Control Act	Procurement of asbestos-/PCB-containing materials not allowed. Other portions of TSCA not applicable.

Table 3-2

DOE Orders Affecting the WIPP Environmental Program

ORDER NO.	DATE	TITLE	ANNOTATION
DOE 5400.1	11/09/88 Change 1-06/29/90	General Environmental Protection Program	Establishes environmental protection program requirements, authorities, and responsibilities for DOE operations for ensuring compliance with federal and state environmental protection laws and regulations, federal executive orders, and internal department policies.
DOE 5400.5	02/08/90 Change 2-01/07/93	Radiation Protection of the Public and the Environment	Establishes standards and requirements for operations of the DOE and DOE contractors with respect to protection of the public and the environment against undue risk from radiation.
DOE O 451.1.	09/11/95	National Environmental Policy Act Compliance Program	Establishes DOE policy for implementation of the National Environmental Policy Act of 1969 (PL 91-190).
DOE O 460.1	09/27/95	Packaging and Transportation Safety	Establishes safety requirements for the proper packaging and transportation of DOE offsite shipments and onsite transfers of hazardous materials and for model transportation.
DOE 5484.1 Paragraphs 1-5, 6a(1)-(10),6f(1)-(8), and the second misnumbered 6f, and Ch I and Ch II are cancelled and replaced by DOE O 225	09/29/95	Accident Investigation	Prescribes requirements for conducting investigations of certain accidents occurring at DOE operations and sites, and to prevent recurrence of such accidents.

AL 5484.1	08/23/82 Change 1-10/24/86	Environmental Protection, Safety and Health Protection Information Reporting Requirements	Albuquerque Operations Office implementation of 5484.1.1E
DOE 5480.23	04/30/92 Change-1 3/10/94	Nuclear Safety Analysis Reports	To establish uniform requirements for the preparation and review of safety analyses of DOE operations which include the following: identification of hazards, their elimination or control, assessment of the risk, and documented management authorization of their operation.
DOE 5482.1B	9/23/86 Change-5 05/10/93	Environmental, Safety and Health Appraisal Program	To establish the Environmental Protection, Safety, and Health (ES&H) appraisal program for the DOE.
DOE O 151.1.	Change 1 10/26/95	Comprehensive Emergency Management System	Establishes requirements for comprehensive planning, preparedness, response, and recovery activities of emergency management programs for DOE or for programs requiring DOE assistance.
DOE 5700.6C	08/21/91	Quality Assurance	To provide DOE policy, set forth principles, and assign responsibilities for establishing, implementing, and maintaining programs of plans and actions to ensure quality achievement in DOE programs.
DOE 5820.2A	09/26/88	Radioactive Waste Management	Establishes policies and guidelines by which DOE manages radioactive waste, waste byproducts, and radioactively contaminated surplus facilities.
DOE O 430.1 Life-Cycle Assessment Management	08/24/95	Life-Cycle Assessment Management	To plan, acquire, operate, maintain, and dispose of physical assets as valuable national resources

Table 3-3

Summary of Agreements Between the DOE and the State of New Mexico That Affect the WIPP Environmental Program

Stipulated Agreement on Civil Action No. 81-0363 JB - This agreement, approved by the U.S. District Court proceedings, held in abeyance in the lawsuit against the DOE by the State of New Mexico, was executed on July 1, 1981. The eight-page agreement assures that a binding, enforceable "consultation and cooperation" agreement will be entered into by the DOE and the state, and that the DOE will make a "good faith effort" to resolve certain state offsite concerns (which are covered in the Supplemental Stipulated Agreement). The Stipulated Agreement also addresses a number of additional studies and experiments to be conducted by the DOE for the Site Preliminary and Design Validation Phase of the WIPP facility. This agreement was signed by Jeff Bingaman (Attorney General, State of New Mexico) and Myles Flint (Attorney, U.S. Department of Justice), and was issued July 1, 1981, by Juan G. Burciaga (U.S. District Judge, District of New Mexico).

Agreement for Consultation and Cooperation -- Usually referred to as the "C&C Agreement," this agreement is contained in Appendix A to the Stipulated Agreement. It affirms the intent of the Secretary of Energy to consult and cooperate with New Mexico with respect to state public health and safety concerns. It was signed in July 1981 by Bruce King (Governor, State of New Mexico) and James B. Edwards (Secretary, U.S. Department of Energy).

Working Agreement for Consultation and Cooperation, Appendix B, Article IV, Revision I -- This agreement, Appendix B to the Stipulated Agreement, identifies in Article IV over 60 "key events" and "milestones" in the construction and operation of the WIPP facility that must be reviewed by the state before they are commenced. Many environmental items are included. It was signed in March 1983 by Robert McNeill (Chairman, Radioactive Waste Task Force), and R. G. Romotowski, (Manager, Albuquerque Operations Office, U.S. Department of Energy). (Article IV of the Working Agreement was revised on April 8, 1983).

Supplemental Stipulated Agreement Resolving Certain State Off-Site Concerns Over WIPP -- This agreement dated December 27, 1982, addresses five state concerns including the need for state "verification" of the WIPP Environmental Monitoring Program. The concerns addressed are: state liability for a nuclear incident, emergency response preparedness, transportation monitoring of the WIPP facility waste, the WIPP facility environmental monitoring by the state, and upgrading of state highways. It was signed in December 1982 by Bruce King (Governor, State of New Mexico) et al., and R. G. Romotowski (Manager, Albuquerque Operations Office, U.S. Department of Energy).

First Modification to the July 1, 1981, Agreement for Consultation and Cooperation on WIPP by the State of New Mexico and the U.S. Department of Energy -- This modification was signed November 30, 1984, wherein the DOE and the state agree to address certain concerns of the state regarding: (1) the specific mission of the WIPP Project, (2) a demonstration of retrievability prior to waste emplacement, (3) post-closure control and responsibility, (4) completion of certain additional scientific testing and reports, (5) compliance with applicable federal regulatory standards for waste repositories, and (6) a program for encouraging and reporting on the hiring of New Mexico residents at the WIPP Project. It was signed in November 1984 by Joseph Goldberg (Secretary, Health and Environment Department, State of New Mexico), and R. G. Romotowski (Manager, Albuquerque Operations Office, U.S. Department of Energy).

Second Modification to the July 1, 1981, Agreement for Consultation and Cooperation on the WIPP by the State of New Mexico and the U.S. Department of Energy -- Signed August 4, 1987, wherein the DOE and the state agree to address certain concerns of the state regarding: (1) surface and subsurface mining and drilling after closure of the WIPP site, (2) the disposal of salt tailings at the WIPP site, and (3) compliance with U.S. Environmental Protection Agency, U.S. Department of Transportation, and U.S. Nuclear Regulatory Commission regulations. It was signed in August 1987 by Garrey Carruthers (Governor, State of New Mexico) et al., and R.G. Romotowski, (Manager, Albuquerque Operations Office, U.S. Department of Energy).

1988 Modification to the Working Agreement of the Consultation and Cooperation Agreement Between the U.S. Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant -- This modification deleted the sorbing tracer test from the list of required reports and substituted additional tests. In addition, the state is allowed to operate a fixed-air sampler in the mine ventilation effluent air stream. It was signed in March 1988 by Kirkland Jones Deputy Director, New Mexico Environmental Improvement Division, State of New Mexico) et al., and R. G. Romotowski (Manager, Albuquerque Operations Office, U.S. Department of Energy).

Environmental Oversight and Monitoring Agreement -- This agreement states that the DOE will provide additional technical and financial support for state activities in environmental oversight, monitoring, access, and emergency response to ensure compliance with applicable federal, state, and local laws at several DOE facilities including the WIPP facility. It was signed in October 1990 by Garrey Carruthers (Governor, State of New Mexico; Dennis Boyd (Secretary, Health and Environment Department), and Bruce G. Twining (Manager, Albuquerque Operations Office, U.S. Department of Energy).

Site-Specific Protocol for Implementation of the Environmental Oversight and Monitoring Agreement -- Signed October 23, 1992, this protocol describes the site-specific protocol for day-to-day activities involving the NMED and the DOE contract personnel stationed at the WIPP. This protocol is a result of the "Environmental Oversight and Monitoring Agreement of 1990" between the State of New Mexico and the DOE. It is designed within the context of the unique nature and purpose of the WIPP.

Table 3-4

Active/Pending Permits for the Waste Isolation Pilot Plant During 1995

Granting Agency	Type of Permit	Permit Number	Granted/ Submitted	Expiration	1995 Permit Status
Department of the Interior, Bureau of Land Management	Right-of-Way for Water Pipeline	NM53809	8/17/83	None	Active
Department of the Interior, Bureau of Land Management	Right-of-Way for the North Access Road	NM55676	8/24/83	None	Active
Department of the Interior, Bureau of Land Management	Right-of-Way for Railroad	NM55699	9/27/83	None	Active
Department of the Interior, Bureau of Land Management	Right-of-Way for Dosimetry and Aerosol Sampling Sites	NM63136	7/31/86	None	Active
Department of the Interior, Bureau of Land Management	Right-of-Way for Seven Subsidence Monuments	NM65801	11/7/86	None	Active
Department of the Interior, Bureau of Land Management	Right-of-Way for Aerosol Sampling Site	NM77921	8/18/89	8/18/2019	Active
Department of the Interior, Bureau of Land Management	Right-of-Way for Ten Raptor Nesting Platforms	NM82212	9/12/89	12/13/2019	Active
Department of the Interior, Bureau of Land Management	Right-of-Way for Survey Monument Installation	NM82245	12/13/89	12/13/2019	Active
Department of the Interior, Bureau of Land Management	Approval to Drill 2 new test wells on existing pads at P-1 and P-2	None	9/18/86	None	Active
Department of the Interior, Bureau of Land Management	Free Use Permit for Caliche	NM-FU5-94405	6/6/95	5/12/98	Active

Table 3-4

Active/Pending Permits for the Waste Isolation Pilot Plant During 1995

Granting Agency	Type of Permit	Permit Number	Granted/ Submitted	Expiration	1995 Permit Status
New Mexico Environment Department	Open Burning Permit to train fire control Crews	None	2/20/95	10/25/95	Cancelled Open burn training no longer conducted on site.
New Mexico Environment Department	Operating Permit for two backup generators	310-M-2	12/7/93	None	Active
New Mexico Environment Department	Submittal of Part B RCRA Permit Application		Submitted to the NMED and EPA Region VI on 2/26/92 and on 2/27/92. Revisions were delivered to the NMED on 3/4/92 and 1/27/93.		NMED declared permit administratively complete 7/22/92. Draft permit issued 8/24/93. Public comment period was held open to 7/14/94.
New Mexico Environment Department	Acknowledgement of Notification of Hazardous Waste Activity	NM4890139088	1/88 Latest report delivered on 2/28/92	None - Contingent upon delivery of biennial report	Active
New Mexico Department of Game and Fish	Individual Banding	#1961	4/1/94	3/31/95	Active
New Mexico Department of Game and Fish	Master Collecting	#1894	4/5/94	3/31/95	Active
New Mexico Department of Game and Fish	Concurrence that WIPP construction activities will have no significant impact on State-listed threatened or endangered species	None 7/25/83 None Active	5/26/89	None	Active
U.S. Department of the Interior, Fish and Wildlife Service	Master Personal Banding	#22478	5/19/93	6/30/95	Active

Table 3-4

Active/Pending Permits for the Waste Isolation Pilot Plant During 1995

Granting Agency	Type of Permit	Permit Number	Granted/ Submitted	Expiration	1995 Permit Status
U.S. Department of the Interior, Fish and Wildlife Service	Concurrence that WIPP construction activities will have no significant impact on Federally-listed threatened or endangered species	None	5/29/80	None	Active
New Mexico Department of Finance and Administrative Planning Division, Historic Preservation Bureau	Concurrence that the DOE Archaeological Resources Protection Plan is adequate to mitigate any adverse impacts upon cultural resources resulting from construction of the WIPP facility				
Protection Agency	Notification of the presence of 2 Underground Storage Tanks	None	4/15/86	None	Active
U.S. Environmental Protection Agency	New Mexico NPDES Storm Water General Permit	NMR00 A021	12/31/92	12/31/97	Active
New Mexico Commissioner of Public Lands	Right-of-Way for High Volume Air Sampler	RW-22789	10/3/85	10/3/2020	Active

Chapter 4
Environmental Program Information

The WIPP's policy is to conduct its operations in a manner commensurate with all applicable environmental laws and regulations.

4.1 Environmental Monitoring Plan (EMP)

The WIPP's Environmental Monitoring Plan outlines a program that monitors a comprehensive set of parameters to detect and quantify present and future environmental impacts. Nonradiological portions of the plan focus on the immediate area surrounding the site.

The goal of the EMP is to identify what impacts may exist from the WIPP on the local ecosystem. Evaluation of the severity, geographic extent, and environmental significance of these impacts is important to the mission of the facility and future research. Although the WIPP has performed a detailed study of these impacts, additional samples will be collected and analyzed to investigate and explain trends or anomalies that may have a bearing on environmental impacts. The EMP sampling schedule is provided in Table 4-1.

As recommended in DOE/EP-0023 (i.e., Corley et al. 1981) and DOE/EH-0173T, the EMP describes the monitoring of naturally occurring and specific anthropogenic radionuclides. This surveillance has included the monitoring of world-wide fallout. The geographic scope of radiological sampling is based on projections of potential release pathways (see Figure 5-1, Primary Pathway Exposure model) from the stored waste at the WIPP. Surrounding population centers are also monitored. Future radionuclide monitoring will be confirmed to transuranic elements only, since these are the radionuclides of concern from the standpoint of a potential release.

Results and discussions pertaining to respective monitoring programs prescribed by the EMP are provided in Chapter 5 *Environmental Radiological Program Information,* and Chapter 6, *Environmental Nonradiological Program Information.*

As required by DOE Order 5400.1, the EMP is to be reviewed annually and updated every three years. The most recent EMP was updated in March 1994 (DOE/WIPP 94-024).

4.2 Baseline Data

Within the WIPP Environmental Monitoring section there are four programs currently in place: the Nonradiological Environmental Surveillance (NES) (Chapter 6), the Radiological Environmental Surveillance (RES) (Chapter 5), Land Management (to include the Cooperative Raptor Research and Management Program), and the WIPP Groundwater Surveillance Programs (Chapter 7). The purpose of these programs is to collect the data needed to detect and quantify possible impacts that construction and operational activities at the WIPP may have on the surrounding ecosystem and, when necessary, provide technical support for issues that require technical expertise in the disciplines of environmental science or land management. The data are used to assess impacts of WIPP operations on the environment and to demonstrate compliance with applicable standards for radiological and nonradiological programs.

Preliminary studies must be considered during environmental evaluations. These preliminary assessments have contributed to baseline data gathered during the construction phase, as well as provided much of the foundation for long-term monitoring programs. Examples of such investigations include the following:

- WIPP Site Characterization Program - instituted in 1976 by Sandia National Laboratories (SNL) to monitor air quality, background radiation levels, and groundwater quality (Pocalujka et al., 1979; 1980a, b, c; 1981a, b; Powers et al., 1978; Lappin, 1989).

- WIPP Biology Program - began in 1975 with site characterization studies of climate, soils, vegetation, arthropods, and vertebrates (Best, 1980).

- Investigations of the Site Geohydrology - conducted by the U.S. Geological Survey (USGS) at the request of the DOE. In addition, the Nuclear Regulatory Commission issued a contract to Columbia University to perform a study of radionuclide mobility in the highly saline groundwaters of the Delaware Basin (USGS, 1983).

- Radiological Monitoring of Air, Water, and Biological media - conducted by the Atomic Energy Commission (AEC) before and after the Project Gnome nuclear detonation (U.S. AEC, 1962a, b, c, d).

4.3 Land Management Programs

On October 30, 1992, the WIPP *Land Withdrawal Act* (P.L. 102-579) became law. This Act transferred the responsibility for the management of the WIPP Land Withdrawal Area from the Secretary of the Interior to the Secretary of Energy. In accordance with sections 3(a)(1) and (3) of the Act, these lands

> ". . . are withdrawn from all forms of entry, appropriation, and disposal under the public land laws . . ." and are reserved for the use of the Secretary of Energy ". . . for the construction, experimentation, operation, repair and maintenance, disposal, shutdown, monitoring, decommissioning, and other activities, associated with the purposes of WIPP as set forth in Section 213 of the Department of Energy National Security and Military Applications of Nuclear Energy Act of 1980 (P.L. 96-164; 93 Stat. 1259, 1265) and this Act."

In accordance with Section 4 of the WIPP *Land Withdrawal Act* (LWA) (Public Law 102-579), the DOE developed a Land Management Plan (LMP) as required by the Act. The development of this plan was in consultation and cooperation with the U.S. Department of Interior's (DOI) Bureau of Land Management (BLM) and the state of New Mexico. Changes or amendments to the plan require the involvement of the BLM, the state of New Mexico, and affected stakeholders, as appropriate.

The LMP, as required by LWA, was developed to identify resource values, promote the concept of multiple-use management, and identify long-term goals for the management of WIPP lands until the culmination of the decommissioning phase. The plan also provides the opportunity for participation in the land use planning process by the public, as well as local, state, and federal agencies.

The most recent version of the LMP, completed on January 31, 1996, is a reprint which incorporates elements of implementation previously provided in the WIPP *Land Management Implementation Plan* (LMIP) (DOE/WIPP 94-026). The reprint does not revise or amend the intent or scope of the original plan, but merges implementing actions from the LMIP to make the plan more helpful for those desiring to use WIPP lands. An additional reason for developing the reprint was to reduce document volume and redundancies in text, which results in the LMIP being superseded by the latest version of the LMP.

The LMP is prepared through the integration of the WIPP *Land Withdrawal Act* of 1992 (Public Law 102-579). BLM planning regulations (43 CFR 1600) issued under the authority of the Federal

Land Policy and Management Act (FLPMA) of 1976, the National Environmental Policy Act (NEPA) of 1969, as amended; and existing Memoranda of Understanding (MOU) among the DOE and local, state and/or federal agencies. The LMP is designed to provide a comprehensive framework for the management and coordination of WIPP land uses during the life of the project. The LMP, and any subsequent amendments, will continue through the decommissioning phase. Moreover, in accordance with section 13 of the WIPP *Land Withdrawal Act*, the DOE will develop, in consultation with the Secretary of the Interior and the State of New Mexico, a plan for the management and use of the WIPP Land Withdrawal Area following the decommissioning of WIPP. This plan must be developed by October 30, 1997.

Guidelines prescribed in the LMP provide for the management and oversight of WIPP lands under the jurisdiction of the DOE in addition to lands outside the WIPP boundary that are used in the operation of the WIPP (e.g., groundwater surveillance well pads outside the withdrawn area). Furthermore, this plan provides for multiagency involvement in the administration of DOE land management actions. The LMP, in addition to any documents referenced therein, are available to person(s) and/or organization(s) desiring to conduct activities on lands under the jurisdiction of the WIPP in addition to those involved in development and/or amending existing land management actions. These documents can be obtained from the U.S. Department of Energy, Carlsbad Area Office, P.O. Box 3090, Carlsbad, New Mexico 88221.

The LMP envisions and encourages direct communication among stakeholders, including federal and state agencies involved in managing the resources within, or activities impacting the areas adjacent to, the WIPP WLWA. It sets forth cooperative arrangements and protocols for addressing WIPP-related land management actions. The DOE recognizes the guidelines for contemporary land management practices that pertain to rational adherence with edicts in the WIPP LWA and all applicable regulatory requirements contained therein. Commitments contained in current permits, agreements, or concurrent MOUs with other agencies (e.g., state of New Mexico, DOI), shall be adhered to when addressing/evaluating land use management activities and future amendments that affect the management of WIPP lands.

The LMP is reviewed on a biennial basis to assess the adequacy and effectiveness of the document, or as may be necessary to address emerging issues potentially affecting WIPP lands. Affected agencies, groups, and/or individuals may be involved in the review process. Components of the LMP emphasize management protocols for the following issues: administration of the plan; environmental compliance; wildlife; cultural resources; grazing; recreation; energy and mineral resources; lands/realty; reclamation; security; industrial safety; emergency management;

maintenance and work control. Each issue and its complementary planning/management criteria are described in respective chapters of the document.

4.3.1 Land Management and Environmental Compliance

Parties who desire to conduct activities that impact lands under the jurisdiction of the WIPP, outside the inner core of the facility designated as the Property Protection Area, are required to prepare a Land Use Request (LUR). A LUR consists of a narrative description of the project, a completed Environmental Review, and a map depicting the location of the proposed activity. The LUR is used to determine if applicable regulatory requirements have been met prior to the approval of a proposed project. A LUR is submitted by any WIPP organization or outside entity wishing to complete any construction, rights-of-way, pipeline easements, or similar actions within the WIPP Site Boundary and on lands used in the operation of the WIPP, under the jurisdiction of the DOE.

During CY 1995, four LURs for construction were submitted to the WIPP LUC for review and determination. LURs submitted for the year received approval with contingencies (e.g. archeological clearance reports) as appropriate.

4.3.2 Grazing

The *Land Withdrawal Act* provides for the continuation of grazing practices, within the WLWA, in accordance with applicable grazing laws and policies, including the Act described as:

> "An Act to stop injury to public grazing lands by preventing overgrazing and soil deterioration, to provide for their orderly use, improvement, and development, to stabilize the livestock industry dependent upon the public range, and for other purposes..."

approved June 28, 1934 (43 U.S.C. 315 et seq., commonly referred to as the *Taylor Grazing Act*); title IV of the *Federal Land Policy and Management Act* of 1976 (43 U.S.C. 1751 et seq.); and the *Public Rangelands Improvement Act* of 1978 (43 U.S.C. 1901 et seq., and 43 CFR 4100).

The principles of multiple-use and sustained-yield are basic to the management of this program. Rangelands comprise a substantial portion of the WLWA and provide forage for livestock and valuable wildlife habitats.

The WLWA affects two grazing allotments administered by the BLM: the Livingston Ridge Allotment (No. 77027) and the Antelope Ridge Allotment (No. 77032).

The Livingston Ridge allotment begins 17 miles east of Carlsbad, New Mexico. The allotment is comprised of 55,581 acres in size and permitted to a livestock rancher operating a year-round cow/calf business. Land ownership is divided between federal, state, and private lands. Acreage distributed by ownership are as follows: (1) 41,608 acres of Federal ownership (2,880 acres within the WLWA), (2) 13,063 acres of State Trust lands, and (3) 910 acres of private (deeded) land. Although the allotment is 55,581 acres in size, only 5.18 percent of the allotment is situated within the WLWA.

Pasture rotation with some of the pastures being rested for at least a portion of the growing season is standard management practice for this allotment. Vegetative monitoring studies to collect data on the utilization of the land, and the amount of precipitation by pasture from each study allotment are conducted annually to compare production with consumption. Should vegetative monitoring studies indicate a need for an allotment management plan, a plan will be developed in consultation with the BLM. The allotment is permitted for 6,483 Animal Unit Months (AUMs), which converts to 6.3 acres per AUM. (An AUM is the amount of forage necessary for the sustenance of a cow, or its equivalent, for a period of one month.)

The Antelope Ridge allotment begins 23 miles east of Carlsbad, New Mexico, and contains 77,574 acres. This allotment is permitted to a livestock rancher operating a year-round cow/calf business. Approximately 300 acres (more or less) within the Antelope Ridge allotment contain the WIPP facilities and are posted against trespass and fenced to prevent grazing. Land ownership of the subject allotment is divided between federal, state, and private (deeded) lands. Acreage distributed by ownership are as follows: (1) 66,757 acres of federal land (7,360 acres within the WLWA), (2) 8,749 acres of State Trust lands, and (3) 2,068 acres of private land. Of the 77,574 acres contained in this allotment, 9.49 percent is within the WLWA.

An allotment management plan has been developed for this allotment by the BLM. The plan includes a seven-pasture rotation system, with some pastures being rested for full years and others receiving growing season rest. The allotment is permitted for 13,236 AUMs which translates to 7.0 acres per AUM.

Both allotments consist of sandy and deep sand range sites. These sites have combined shin-oak/dune (SOD) and grassland (SG) aspects and include grasses such as Gramas (*Bouteloua* spp.), Bluestems (*Andropogon* spp.), and Dropseeds (*Sporobolus* spp.). Other key forage plant species include Havard Shin Oak (*Quercus havardii*) and Fourwing Salt-bush (or Chamiza) (*Atriplex canescens*).

During CY 1995, no incidents of non-compliance involving grazing allottees on WIPP lands were noted.

4.3.3 Wildlife Population Monitoring

The WIPP is involved in the planning of wildlife investigation and management projects. Recommendations for approaches, potential prospectuses, and proposed investigational plans are evaluated. Tools, techniques, and personnel available for conducting investigations and achieving management objectives are examined. These criteria are essential to wildlife objectives for effective planning as it relates to choice, between alternatives, establishment of realistic constraints (e.g., time, funding, manpower), practicality, and expediency in the development of efficient research methodology.

Wildlife within the WLWA are provided consideration during planning stages of projects involving the disturbance or encroachment of wildlife habitat inside DOE lands by way of the LUR process. Monitoring and research of specific wildlife populations occur in accordance with applicable laws. agreements, and regulations subject to funding and personnel constraints.

The WIPP conducts a number of general wildlife management activities. Each activity is mandated and/or supported by state and federal guidelines or by way of commitments created through interagency agreements (e.g., *Raptor Research and Monitoring Interagency Agreement)* and/or MOUs.

Examinations of wildlife species in the area reveals significant diversity and complexity. Management of indigenous wildlife incorporates the development of a logical sequence when programming activities. Solutions for problems (e.g., home-range, territoriality) serve the implementation of conservation and resource management objectives as they pertain to the management and operation of the WIPP site.

4.3.3.1 Affected Biological and Wildlife Environment

The wildlife habitat around the WIPP is categorized in accordance with the BLM's standardized habitat sites subsequent to a detailed Integrated Habitat Inventory Classification System. WIPP lands comprise a small part of those lands grouped into major habitat types as described in Appendix L-2 of the *East Roswell Grazing Environmental Impact Statement*. Moreover, habitat types and species inventories were conducted for the DOE during initial site characterization studies as described in the WIPP Biology Program, the *Final Environmental Impact Statement* (FEIS)

(DOE/EIS-0026-FS), the Site and Preliminary Design Validation studies, and the *Environmental Monitoring Plan* (DOE/WIPP 92-040). Wildlife in the vicinity of the WIPP is characterized by a wide variety of insects, amphibians, reptiles, birds, and mammals.

The Chihuahuan desert has long been regarded for its extraordinary diversity of plant and animal communities. The location of the WIPP, situated in the Los Medaños region of the Chihuahuan desert, exemplifies this unusual array of biotic factors. The Los Medaños is located in an area of intergradation between the northern region of the Chihuahuan Desert and the Llano Estacado or Staked Plains. The region is characterized by aeolian and alluvial sedimentation on upland plains that form hummocks, dunes, sand ridges, and swales with the presence of Havard Shin Oak (or shinnery oak) as a prominent foliar factor. Although the abundance of Shin Oak has aided in the stabilization of the dunes, a number of them remain unstable and exhibit distinct signs of shifting. An additional predominant shrub is Honey Mesquite which has invaded what at one time was a short-grass, shinnery oak-dominated landscape.

As with many areas, the shinnery oak community has shifted from a dominant bluestem/grama grassland with varying amounts of shinnery oak, sand sage, and yucca to a composition dominated by Dropseeds, three-awns, and Gramas, with high densities of Plains Yucca, annual forbs, and Mesquite.

According to the BLM's Resource Management Plan, 15 percent of the wildlife species identified in the Resource Area utilize the Shin Oak habitat with 30 percent occupying areas consisting primarily of grass compositions with greater than 75 percent grasses in the description of the potential plant community.

The subtle blend of plant communities with Shin Oak/Dune habitat (SOD) that somewhat dominates Grassland (SG) affords a composition of factors that results in the diverse wildlife population of the Los Medaños.

Wildlife populations are characterized by numerous species of arthropods, amphibians, reptiles, birds, and mammals. Now and then, aquatic mollusks, inhabitants of local stock ponds and livestock drinking units, are observed. Jerusalem crickets (*Stenopelmatus fuscus*) are an example of one order of insects that occupy the locality of the WIPP.

Red-Spotted Toads (*Bufo punctatus*) and New Mexico Spadefoot Toads (*Spea hammondi*) are two examples of no fewer than ten different species of indigenous amphibians. Their significance is

seldom recognized until spring or summer rains, at which time they appear in extraordinary numbers.

Reptiles comprise more conspicuous inhabitants due to the diurnal nature of numerous species. Ornate Box Turtles (*Terapene ornata*), Desert Side-Blotched Lizards (*Uta stansburiana*), and Texas Horned Lizards (*Phrynosoma cornutum*, a federal notice-of-review species listed under the Endangered Species Act) represent three of approximately 35 distinct species of indigenous reptiles. Moreover, three species of rattlesnake can be encountered in the area.

Bird densities vary according to preferable food and habitat availability. The habitat heterogeneity of the Los Medaños accounts for a wide assortment of bird species that inhabit the area either as seasonal transients or permanent residents. Large numbers of Mourning Dove (*Zenaida macroura*), Pyrrhuloxias (*Cardinalis sinuata*), and Black-Throated Sparrows (*Amphispiza bilineata*) are frequently observed. A unique desert subspecies of the Northern Bobwhite (*Colinus virginianus*), Scaled Quail (*Callipepla squamata*), and an occasional Lesser Prairie Chicken (*Typanuchus pallidicinctus*) depict the gallinaceous inhabitants. Due to a scarcity of surface waters in the immediate vicinity of the WIPP, migrating or breeding waterfowl are not considered common.

The area supports a particularly abundant and diverse population of Raptors, or birds of prey. Harris' Hawks (*Parabuteo unicinctus*), Swainson's Hawks (*Buteo swainsoni*), and Great Horned Owls (*Bubo virginianus*) illustrate species commonly found nesting in the area. The density of large avian-predator nests is generally regarded as a predominant raptor breeding population.

As is common in desert biomes, Black-Tailed Jackrabbits (*Lepus californicus*) and Desert Cottontails (*Sylvilagus audoboni*) are the most conspicuous mammals. Three species of Ground Squirrel (*Spermophilus spp.*) and numerous other rodents such as Kangaroo Rats (*Dipodomys spp.*) and Cactus Mice (*Peromyscus eremicus*) also occupy the area. Large piles of debris, that may consist of aluminum cans, cow dung and other rubbish (sometimes to a height of nearly five feet), clustered at the base of cactus or large mesquites characterize the houses (or "middens") of the Southern Plains Woodrat (*Neotoma micropus*). Although specimens rarely exceed weights of 300 grams, several Woodrats that weighed nearly 500 grams have been captured, by WIPP biologists, near the WIPP. Big-game species, such as Desert Mule Deer (*Odocoileus hemionus*) and carnivores such as Coyotes (*Canis latrans*) and Badgers (*Taxidea taxis*) also frequent the area.

The DOE consulted with the United States Fish and Wildlife Service (USF&WS) in 1979 to determine the presence of threatened or endangered species at or near the WIPP site. At that time, the USF&WS listed the Lee Pincushion Cactus (*Coryphantha sneedi* var. *leei*), the Black-Footed

Ferret (*Mustela nigripes*), the American Peregrine Falcon (*Falco peregrinus anatum*), and the Bald Eagle (*Haliaeetus leucocephalus*) as threatened or endangered that could occur on lands within or outlying the WIPP site. However, no critical habitat for endangered species was identified at the WIPP. In 1989, the DOE again consulted with the USF&WS to update the list of threatened and endangered species. The agency has advised the DOE that the list of species provided in 1979 is still valid.

During 1989, the DOE consulted with the NMDG&F regarding the state-listed endangered species in the vicinity of the WIPP. Based on NMDG&F Regulation 657, dated January 9, 1988, the NMDG&F listed seven birds and one reptile in one of two endangerment categories that occur or are likely to occur at the site.

During 1995, the USF&WS transmitted the April 24, 1995, updated list of threatened and endangered species (to include Notice of Review) for Eddy and Lea Counties, New Mexico. Inclusive were approximately 18 species that occur or are likely to occur on WIPP lands. Accordingly, the list was disseminated to pertinent WIPP departments for consideration and incorporation into applicable documents. The DOE currently operates under the assumption that activities associated with the operation of the WIPP will have no impact on any threatened or endangered species. Considerations pertaining to protected species are implemented in accordance with this management plan, during the deliberation and administration of projects conducted on WIPP lands.

Population density measurements of birds and small nocturnal mammals, initiated in 1985, were performed annually to assess the effects of WIPP surface activities (e.g. construction, salt piles) on wildlife populations. Customary protocol involved comparative data analysis between two outlying or "control" plots and two experimental plots situated in proximity to WIPP operations. A Hantavirus investigation during CY 1994, prompted the temporary postponement of small nocturnal mammal surveys. As previous years' investigations revealed no detectable detrimental impacts from salt encroachment on the peripheral environment, annual appraisals of small mammal populations have been discontinued indefinitely.

4.3.3.2 Cooperative Raptor Research and Management Program

During CY 1995, data were collected on resident birds of prey within an area of approximately 870 square miles in the vicinity of the WIPP. The majority of this sector is managed under the authority of the BLM Carlsbad Resource Area (CRA) with WIPP lands comprising the nucleus of the research area. This cooperative enterprise between the BLM and the DOE was commissioned through the

bilateral development of an Interagency Agreement. The Agreement defines commitments on behalf of each respective agency to include deliverables and itemized timelines for the completion of each element.

Raptor inhabitants have long been regarded as useful "environmental barometers ." Populations oscillate in response to changes in environmental conditions that include human caused or "anthropogenic" influences (e.g. habitat loss to industrial development, persecution), and non-anthropogenic limiting factors (e.g. climatic conditions, parasitism, predation, fratricide, prey availability).

The CY 1995 survey period represented the fourth consecutive year of drought that has had dramatic ramifications throughout the study area. Observations indicate the drought probably suppressed population densities in both predators and prey, effected the number of inhabited territories, and brought about declines in nesting and production. Data collected during this study includes descriptive information on the social behavior of the Harris' Hawk (*Parabuteo unicinctus*), physiognomy of the study area, territorial fidelity, sex ratios, nesting data, prey base determinations, capture and banding results, research protocol, phlebotomy data, results of territorial trials, habitat preferences and results from the inventory of other common raptors in the vicinity of the WIPP.

Significant changes occurred during CY 1995 in tenant raptor populations of the Los Medaños as compared to prior years' assessments, most notably, those years experiencing normal or above normal precipitation (e.g. CY 1992). For example, the ratio of immature hawks to breeding adults during 1992 (the last year of recorded near-normal precipitation) was approximately 1:1. Breeding proficiency during CY 1995, however, exhibited a significant reduction in fledging success as the ratio declined to less than four nestlings fledged per 45 adults observed. It can be presumed that these skewed age ratios are in correlation to an unusually high percentage of nest failures (91.1 percent) in the study area. Data correlation indicates that these failures are one of many repercussions of low prey densities; likely the result of the regional drought conditions.

In addition to nest observations, data were also collected to evaluate Harris' Hawk territories. The emphasis in this feature of the investigation was to evaluate territorial tenancy, territorial configuration, and territorial fidelity. Prior to 1990, Harris' Hawks in the Los Medaños had been assumed to be non-territorial (Bednarz 1987). Snyder and Snyder (1990), however disputed this assumption, asserting that such a conclusion resulted from the observer's inability to recognize related individuals of the same group or of peripheral groups in the near vicinity. The supposition of non-territoriality in Harris Hawks of the Los Medaños was also diametric to observations

conducted on geographically segregated populations, most notably in Arizona (Dawson and Manaan 1990).

Numerous incidents of aggression were observed by WIPP researchers, between Harris' Hawks and other species of raptors, such as Red Tailed Hawks (*Buteo jamaicensis*). Although this type of interaction was common, the controversial intraspecific territorial behavior of the resident Harris' Hawks remained shrouded as conjecture. The first indication that the Los Medaños population was in fact, innately territorial, was in 1993 when an immature female who, as a nestling, fell from the nest during a windstorm and was remanded to a wildlife rehabilitator for rehabilitation. Subsequently, she was released into her original group after spending nearly a year in rehabilitation. The dominant or "alpha" male (most likely her father) and a subordinate "beta" male (both of whom were readily recognizable as they were color-banded) immediately drove the female to the ground and perched above her with arched necks, vocalizing for nearly an hour. She was ousted from the territory in less than one day. This incident prompted WIPP researchers to more closely examine territoriality in the Los Medaños Harris' Hawks.

In order to accurately evaluate territoriality, researchers released a non-related Harris' Hawk, trained as falconry bird, into sectors known to be occupied by Harris' Hawk clans. The degree of intraspecific territoriality, or the defense of preferred sectors from intruders of the same species, was measured by the number of incidents wherein residents would supplant intruders and the amour of time before those intruders would be driven from the territorial proximity. In addition, interactions between intruder and residents were observed and noted. Without exception, the intraspecific intruder was repeatedly supplanted and driven from territories within a brief period of time (usually less than an hour).

Posturing and vocalizations precluded any physical interaction but, if the intruder failed to leave the area, more aggressive reactions such as shoulder bumping, flogging with wings, or simply knocking the intruder from perches usually followed. Seldom do Harris' Hawks grab or mortally wound members of their own species, therefore, there was little, if any danger, of wounding the released bird. In one recorded event, the intruder was repeatedly displaced, or supplanted, from trees and other perches, six different times (with no injuries sustained to the released bird) before being called back to the handler.

This high degree of territorial demeanor provides a significant management aspect of the species. Dimensional assessments of territories are integrated into land management practices by diverting construction and other invasive practices into land sectors unoccupied by territorial species, or away from territorial epicenters (e.g. nests and/or nest trees) so as not to displace resident clans or create

aberrant limiting factors that may adversely influence prey densities, loafing coverts, or potential nest substrates.

4.3.4 Reclamation of Disturbed Lands

The DOE recognizes responsibilities pursuant to applicable federal, state, and local environmental regulations to enhance and restore areas affected by the WIPP activities, to include areas disturbed prior to WIPP activities that were accepted as part of the land transfer from the BLM to the DOE. These obligations include protocols designed to be revised as needed and are no way limited, except by law, to revisions based on new techniques for reclamation and new plans which the WIPP may incorporate in the future.

WIPP reclamation activities are conducted in accordance with the *Environmental Protection Implementation Plan* (DOE/WIPP 90-050); DOE Order 5400.1, *General Environmental Protection Program Requirements*; the DOE *Organization Act* (42 U.S.C. 7112); *the Federal Land Policy and Management Act* of 1976 (Public Law 94-579); the *Final Supplement to the Environmental Impact Statement* (SEIS) WIPP (DOE/EIS-0026-FS, January 1990); the *Final Environmental Impact Statement,* (DOE/EIS-0026); and all applicable reclamation requirements by federal laws and regulations, Executive Orders, MOUs, DOE Orders, and state and local laws. These commitments encompass any unforeseeable future mandates or amendments to existing regulations.

In accordance with the LMP, the WIPP implements a contemporary reclamation program and corresponding long-range reclamation plans. As locations are identified for reclamation, WIPP personnel reclaim these areas by using the best acceptable reclamation practices. Seed mixes used reflect those species indigenous to the vicinity with priority given to those plant species which are conducive to soil stabilization, wildlife, and livestock needs.

Without an active reclamation program, the establishment of stable ecological conditions in arid environments may require decades or centuries to achieve, depending on natural and unnatural disturbance and environmental conditions present during the entirety of the reclamation process. Reclamation activities are intended to reduce soil erosion, increase the rate of plant colonization and succession, and provide habitat for wildlife in disturbed areas. In addition to maintaining the compliance posture of the WIPP with respective external entities, reclamation ultimately serves to mitigate the effects of WIPP-related activities on affected plant and animal communities.

The objective of the DOE reclamation program is to return lands used in the operation of the WIPP that are no longer commissioned for WIPP operations, to a stable ecological condition. Plant

species and topography of the reclaimed area are indicative of the vicinity. It is the intent of the DOE to establish reclamation guidelines for land use requestors.

Reclamation activities during CY 1995 consisted of the continuation of decommissioning numerous existing fenced areas that had been constructed during much of the initial site characterization studies in the late 1970s. In addition to the exclosures, activities initiated during CY 1994, regarding the removal of re-bar (emplaced within numerous study areas to delineate sampling points) to alleviate safety hazards to personnel and livestock, were continued. Problem areas (e.g. drainages, eroded slopes, etc.) in existing reclamation sites received additional stabilization measures which include seeding and the spreading of straw. Existing fences left in place, were repaired as necessary. Roads, under the jurisdiction of the WIPP were evaluated to assess the usefulness of respective roads in the operation of the facility. One road in particular, the East Link Road, was regarded as having merit as an access route for emergency vehicles to the east. This road was closed due to safety concerns. Land management personnel administered the fabrication of a gate, warning signs, and requisite road surface repair to secure the road and make it functional for WIPP use only.

4.3.5 Oil and Gas Surveillance

Surveillances of oil and gas activities within one mile of the WIPP boundary, were conducted throughout the calendar year for 1995 in accordance with the BLM/DOE MOU. Oil and gas activities within the defined land sectors are monitored twice monthly to identify new activities associated with oil and gas exploration/production to include:

- drilling
- survey staking
- geophysical exploration
- pipeline construction
- work-overs
- changes in well status
- anomalous occurrences (e.g., leaks, spills, accidents, etc.)

The oil and gas industry is well established in the Los Medaños region of New Mexico (the vicinity of the WIPP), with producing oil and gas fields, support services, and compressor stations. Nearly all phases of oil and gas activities have occurred in the locality. These phases include seismic exploration, exploratory drilling, field development (comprised of production and injection wells) and other sundry activities associated with hydrocarbon extraction.

As identified in the BLM's *Oil and Gas Potential Occurrence Zones*, the Los Medaños region is located in a region designated as having a "high potential for oil and gas occurrence." This region, part of the Delaware Basin, is bordered by the Capitan Reef. The majority of hydrocarbon extraction has occurred outside the Basin, within the reef. Although the Delaware Basin accounts for approximately 32 percent of lands in Eddy County, only 17 percent of oil and gas wells are located within its boundaries.

During 1995, oil and gas reserves in the immediate vicinity of the WLWA were evaluated by the New Mexico Bureau of Mines and Mineral Resources. Results from this evaluation were compiled in a report, *Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site*, March 31, 1995.

During CY 1995, WIPP surveillance teams conducted a total of 24 routine surveillances, four reciprocate inspections, and additional surveillances performed as required. One well, for example, designated as James Ranch Unit No. 16, was drilled by Enron Oil and Gas within 330 feet of the WIPP Site Boundary. In addition to Land Management personnel conducting onsite visits to the well location, customary stipulations for approval were requested on behalf of the DOE. Accordingly, Enron provided daily drilling records to the WIPP Office of Land Management. These records included all of the elements required to drill the subject well (e.g., date of well spudding, drilling rates, depths, degree of deviation, perforation horizons, initial production rates, etc.). These records were used as a means of correlating the horizontal displacement of the well bore with the WIPP Site Boundary. The subject well was drilled to a depth of 11,250 feet with a total maximum deviation from vertical of 196.57 feet.

To date, no wells drilled in the vicinity have exceeded the acceptable distance between bottom hole location and the WIPP Site Boundary. Routine oil and gas surveillance activities continue on a bi-monthly basis with supplementary oversight conducted as conditions warrant.

4.3.6 Recreation and Land Management

Recreational opportunities on WIPP lands continue in accordance with most traditional land uses. Examples of such land use concepts can be found in the *Carlsbad Resource Area Resource Management Plan and Environmental Impact Statement* (BLM-NM-PT-86-004-4410). Traditional land uses that conflict with the mission of responsible land management practices are restricted on WIPP lands at the discretion of the DOE in consultation with the LMC and affected stakeholders. Properties posted with DOE "no trespassing" signs are excluded from public use and are routinely

patrolled by WIPP personnel to prevent unauthorized use. Violators are subject to prosecution in accordance with applicable laws and regulations governing property protection.

Due to the topography, climatic conditions, and wildlife in the area of the WIPP site, an extensive (non-facility based) variety of recreational opportunities are available to include: hunting for both big and small game animals; camping; horseback riding; hiking; watching wildlife (e.g., bird watching); and sightseeing. The WIPP area contains significant biodiversity in addition to historic and prehistoric sites. These offer rewarding opportunities for scientific study and interpretive recreation.

The objective of the DOE is to support a range of recreational outdoor activities for all segments of the public, commensurate with demand, access, safety, regulatory requirements, environmental protection, and liability. Visitors have a freedom of choice with minimal regulatory constraint regarding activities outside the boundary of the "Off Limits Area." Personnel from the WIPP office of Land Management routinely monitor recreational activities on WIPP lands to provide assistance to land users, interpretive programs, and as a matter of general policy.

4.3.7 Lands and Realty

Land use management responsibilities of the DOE pertain to general realty issues, access corridors, rights-of-way, and avoidance areas that affect, but are not solely contained within, the WLWA.

WIPP Lands are relatively well consolidated within the boundaries of the 10,240 acre WLWA. There are, however, additional properties outlying the WLWA boundary, used in the operation of the WIPP, that are managed under the custodial auspices of right-of-way reservations granted (typically) by the BLM or the state of New Mexico. Groundwater monitoring well pads, their access roads, and environmental monitoring sampling stations predominate this property category for lands under the jurisdiction of the WIPP.

Access to the WIPP site is from U.S. Highway 62/180, 13 miles to the north (North Access Road), and from Highway 128, four miles to the south (South Access Road). Rail access to the WIPP site is provided by a rail line connecting with a spur of the Atchison, Topeka, and Santa Fe railroad near the Western Ag-Minerals Nash Draw mine six miles southwest of the site.

WIPP lands may be designated, at the discretion of the Land Management Council (LMC), as right-of-way corridors or as avoidance areas to protect environmental and social values while optimizing economic efficiency for utilities and transportation facilities. The LMC will identify which lands

will be avoided when routing future rights-of-way in order to protect sensitive resource values, and which areas may be designated as corridors. Major rights-of-way used in the operation of the WIPP, in addition to those that existed prior to land withdrawal, were acquired from the BLM. Existing rights-of-way are commonly associated with linear facility development (e.g., power lines, gas lines, water lines). Development and/or maintenance of adequate access routes within the WLWA represent significant concerns.

The objective of the DOE is to ensure proper management and maintenance of DOE/WIPP lands and realty (e.g., rights-of-way and access routes), in addition to providing safe and adequate access to the WIPP site while protecting the security of WIPP personnel, lands and realty (e.g., facilities). The DOE consults with BLM and the State of New Mexico, as appropriate, on future rights-of-way actions needed outside the WLWA.

4.3.7.1 Proposals for New Access Routes, Easements, and Rights-of-Way

The DOE examines, by way of the LMC and in accordance with applicable laws and regulations, proposals from land users (WIPP and non-WIPP) that impact lands/realty, under the jurisdiction of the DOE to include: new access routes; easements; and rights-of-way when such access will not cause significant adverse impacts to other resources. In addition, the DOE:

1. Reviews and comments on applications or proposals received from the BLM for access routes, easements, and rights-of-way affecting, but not solely contained within, the WLWA.

2. Forwards to the New Mexico Environment Department (NMED) Hazardous and Radioactive Materials Bureau/DOE Oversight Bureau, within 30 days of receipt from or submittal to the BLM:

   A. Applications or proposals for any access routes, easements, and rights-of-way affecting, but not solely contained within, the WLWA; and

   B. Any DOE comments developed on such applications or proposals.

4.3.7.2 Utility Development

In general, WIPP lands are available for utility and transportation facility development; however, applicants are encouraged to locate any new facilities within existing right-of-way corridors. Deviations from existing corridors may be permitted on the basis of the need of the proposal and lack of conflicts with other resource values and uses.

4.3.7.3 Avoidance Areas

Right-of-way avoidance areas are defined as areas where future rights-of-way may be granted only when no feasible alternative route or designated right-of-way corridor is available. Terms and conditions of right-of-way grants depend on the sensitivity of the affected resources and existing laws and regulations established as protective measures for the area in question.

4.3.7.4 Access Permits

The DOE does not grant permits for access when reasonable access already exists. Exceptions may be considered by the LMC only if the requestor presents, to the satisfaction of the LMC, a compelling need.

4.3.7.5 Advertising

No commercial advertising signs are allowed on WIPP lands. Violations will result in prosecution of the violator commensurate with laws governing property protection. Directional and road signs are authorized by the DOE and conform with DOE specifications and configurations.

4.3.7.6 Rights-of-Way, Rights-of-Way Corridors, and Realty Components

Realty components constructed, maintained, and/or utilized in the operation of WIPP, under existing custodial right-of-way reservations include, but are not limited to, the following:

I. North Access Road

The North Access Road is a private road granted, for perpetuity, under right-of-way reservation NM 55676 on August 24, 1983. The North Access Road is approximately 13 miles in length with an easement width of 120 feet. This road is restricted for use by the personnel, agents, and contractors of the DOE on official business related to the WIPP Project, or to personnel, permittees, licensees,

or lessees of the BLM. Signs are placed and will be maintained at the turnout of Highway 62/180 stating the restrictions on access. Persons desiring access to Highway 128 should use the Lea County Line Road immediately to the east. Right-of-way NM 55676 was amended on April 22, 1988, to facilitate the construction of livestock fencing along either side of the subject road.

II. South Access Road

Eddy County Road 802 is designated as the South Access Road. This road originates at the turnout of Highway 128 and terminates as the pavement ends at the confluence of Sections 28 and 29 in T.22 South, R.31 East. This is a county road constructed in accordance with BLM Right-of-Way permit NM 46130. Terms for the right-of-way are for ". . . 50 years after the date of grant." The road configuration consists of a right-of-way width of 80 feet, two 12 foot driving lanes, two-to-four foot shoulders, and parallel "bar" ditches. Multiple-use access will be allowed unless it is determined that access by industry or the general public represents a significant safety risk to WIPP personnel. Upon determination, general access on Eddy County Road 802 may be restricted at the boundary of the 1454-acre Off-Limits Area in accordance with DOE Order 5632.6, *Physical Protection of DOE Property and Unclassified Facilities.*

III. Water Service Pipeline

Water service for the WIPP facility is furnished by a water line that originates 31 miles north of the facility. Maintenance and operation of the water line is performed in accordance with the conditions of Contract DE-AC04-86AL24138-M002 between the City of Carlsbad and the DOE under right-of-way reservation NM 53809 issued to the U.S. Army Corps of Engineers acting on behalf of the DOE. The volume capacity of the water line is such that it meets all water requirements for the operation of the WIPP facility, as well as provides the City of Carlsbad with untreated water.

The initial 16-mile segment of the line is a 24 inch diameter line that accommodates the city of Carlsbad deliveries in excess of that required by the WIPP facility. The city of Carlsbad is authorized to use capacity in the initial 16-mile segment that is in excess of 500 gallons per minute, provided that:

- Any such use of the excess capacity by the city of Carlsbad will be without any cost or liability to the DOE.

- The city of Carlsbad will notify the DOE not less than 30 days in advance of the installation of each new tap and/or service capacity commitment which the city of Carlsbad intends to serve from the DOE's line.

- Upon request by the DOE Contracting Officer, the city of Carlsbad will provide a monthly tabulation of deliveries by tap point for the preceding 24 months.

In the final 15-mile (10 inch diameter) segment, the DOE has authorized the 3/4 inch water tap lines to supply water to livestock drinking tanks. Additional tap points may be added from time to time with advance approval of the DOE. Water delivered at such tap points are metered and billed by the city of Carlsbad consistent with the city of Carlsbad's rates and procedures for providing service to its regular customers. Future use of the water pipeline within the WLWA will be determined at the time of decommissioning of the WIPP facility.

As specified in Contract DE-AC04-86AL24138-M002, the city of Carlsbad provides the DOE's water requirements free of consumption charge and maintain the water line, at its expense, during the initial term of the contract and any optional extension terms thereafter. Single maintenance projects involving repairs or replacements that cost in excess of $10,000 are considered abnormal and thus are funded by the DOE, provided that such repairs or replacements are not the result of the fault or negligence of the city of Carlsbad or its customers, and provided further that the city of Carlsbad first obtains the advance approval of the DOE Contracting Officer for any maintenance project requiring the DOE funding. This contract is renegotiated between the DOE and the city of Carlsbad every five years.

An operating committee, comprised of (no fewer than) two representatives from the DOE and other affected city, county, state, and federal agencies, has been formed. The responsibilities of the operating committee will be:

- To establish standard procedures and practices for the operation and maintenance of the water line.

- To review any technical studies that may be conducted during the term of the contract and keep the DOE Contracting Officer and the city of Carlsbad currently advised as to matters needing attention.

IV. Access Railroad

Rail access to the WIPP site is provided by a rail line connecting with a spur of the Atchison, Topeka, and Santa Fe railroad near the Western-Ag Minerals Nash Draw Mine six miles southwest of the site. This section of rail was constructed under the auspices of right-of-way reservation NM 55699 granted on September 27, 1983, is approximately five miles in length and consists of an adjacent frontage road, in addition to the rail. Both railroad and service road were constructed on an easement width of 150 feet. The railroad and the concurrent easement road is inspected and maintained, in accordance with provisions in the WIPP Land Management Plan, until such time as the determination is made that the rail spur is identified for decommissioning.

V. Transmission Line

The WIPP is serviced by an overhead electrical transmission line that traverses the WLWA for two miles to the north (right-of-way reservation NM 43203) and an additional two miles to the south (right-of-way reservation NM 91163). The southern terminal of the line is approximately five miles south of the WIPP at a location identified as the Southwest Public Service Company's Sand Dune Substation. Access to the power line easement is restricted to WIPP employees and SPS employees. Unauthorized access to the easement is prohibited and may result in DOE response commensurate with property protection.

VI. High-Pressure Gas Line

A 12 inch, high-pressure, interstate gas line with a corresponding easement road traverses portions of Sections 15, 16, 17, 19, and 20 of the WLWA. Maintenance and operation of the line and the easement road are the proprietary responsibility of the El Paso Natural Gas Company (the owner/operator of the line) under right-of-way reservation LC 060762. The WIPP periodically uses the easement road for access to the east and, therefore, conducts inspections and maintenance activities (as needed and in accordance with WIPP maintenance protocol) to the road in order to provide adequate and safe access for WIPP vehicles (e.g., emergency response vehicles). Anomalous occurrences (e.g. spills, leaks) are addressed by way of mutual determination between the lessee and the WIPP Land Use Coordinator.

VII. Salt Tailings Stockpiles

Salt from the underground mining operations is brought to the surface and stored in a bermed salt pile just north of the surface facilities. The salt storage pile contains approximately 408,000 cubic

yards of material, with a capacity to store the estimated 2,116,400 cubic yards of material projected to be excavated during the lifetime of the WIPP project. There is also an inactive storage pile containing roughly 162,000 cubic yards within the DOE Exclusive Use Area, east of the Property Protection Area fence. This pile, referred to as the Site and Preliminary Design Validation (SPDV) pile, resulted from accumulation of material(s) extracted during the drilling of one 12-foot diameter and one 6-foot diameter shaft to the repository depth of 2,150 feet and the initial excavations underground.

Salt from the north stockpile, which is not needed for decommissioning will be disposed of under sections 2 and 3 of the Act of July 31, 1947 (30 U.S.C. 602, 603; commonly referred to as the "Materials Act of 1947"). After disposal of the salt, the stockpile area will be reclaimed in accordance with stipulations for reclamation contained in the WIPP LMP.

Daniel B. Stephens and Associates (1995) performed a field characterization of the SPDV salt pile from July 31, 1995 through September 8, 1995. The characterization employed a multiphase approach to identify and quantify potentially hazardous constituents within the pile. Nonintrusive reconnaissance sampling methods included a magnetometer and passive soil gas survey. Areas of concern identified during the nonintrusive surveys were investigated further by intrusive means. The location-specific sampling included trenching, drilling, and sampling for confirmatory chemical analysis.

The reconnaissance magnetometer survey discovered four magnetic anomalies below ground surface. Three of the magnetic anomalies corresponded with an area where elevated measurements of total petroleum hydrocarbons (TPH) were determined by the passive PETREX soil gas reconnaissance survey. The PETREX soil gas analysis identified responses above background in the eastern portion of the salt pile, characteristic off degraded waste oils and fuels.

The intrusive, location-specific investigation focused on areas identified as potential areas of concern during the areal reconnaissance surveys. Trenching operations determined that the identified magnetic anomalies resulted from miscellaneous pieces of scrap iron. No drums or containers that may have contained fuels and spent lubricants were encountered. The 10 soil borings advanced through the pile encountered uncontained salt and sand material.

Samples collected from field and laboratory analyses during the trenching and drilling program did not have detectable concentrations of volatile and semivolatile organic compounds, with the exception of one sample analyzed by field methods. TPH concentrations for the samples analyzed in the laboratory ranged from less than 10 mg/kg to 43 mg/kg. TPH concentrations were below

regulatory guidelines set by the NMED. Metal concentrations in analyzed soils were also below applicable regulatory guidelines. Accordingly, no remedial measures are required according to NMED requirements.

Table 4-1

EMP SAMPLING SCHEDULE

TYPE OF SAMPLE	SAMPLING LOCATIONS	SAMPLING FREQUENCY
Liquid Effluent	1	Annual
Liquid Effluent	1	Quarterly
Meteorology	2	Continuous
Atmospheric Particulates @ CBD (Carlsbad) MLR (Mills Ranch) SMR (Smith Ranch) WEE (WIPP East) WFF (WIPP Far Field) SEC (Southeast Control) WSS (WIPP South)	7	Weekly
Vegetation	4	Annual
Beef/Deer/Game Birds/Rabbits	as available	Annually (as available)
Soil	7	Annual
Surface Water	13	Annually (as available)
Groundwater	7	Annual
Fish	2	Annual
Sediment	10	Annual
Aerial Photography	1	Annual

Table 4-2

EMP Analytical Array

Type of Sample	Analysis
Liquid Influent	Specific Radionuclides
Liquid Effluent	Specific Radionuclides, Chemical Constituents
Airborne Effluent	Gross α, Gross β, Specific Radionuclides
Meteorology	Temperature, Wind Speed, Wind Direction, Precipitation, Dew Point, Barometric Pressure
Atmospheric Particulates	Gross α, Gross β, TSP, Specific Radionuclide
Vegetation	Specific Radionuclides
Beef	Specific Radionuclides
Game Birds	Specific Radionuclides
Rabbits	Specific Radionuclides
Soil	Specific Radionuclides
Surface Water	Specific Radionuclides
Groundwater	Specific Radionuclides
Fish	Specific Radionuclides
Sediment	Specific Radionuclides
Aerial Photography	Area of Land Disturbed
Salt Impact Study Soil Chemistry	pH, Na, Cl, Mg, Ca, K
Ecology Investigations Wildlife Survey	Cooperative Raptor Research and Management Program

TSS = Total Suspended Solids
TSP = Total Suspended Particulates
EC = Electrical Conductivity
pH = Hydrogen - Ion Activity

Specific Radionuclides = ^{238}Pu, $^{239/240}Pu$, ^{241}Pu, ^{233}U, ^{235}U, ^{241}Am, ^{232}Th, ^{226}Ra, ^{228}Ra, ^{210}Po, ^{210}Pb, ^{137}Cs, ^{90}Sr, ^{40}K, ^{7}Be, ^{60}Co, U_{nat} TH_{nat}

Chemical Constituents = Chloride, iron, magnesium, phenols, sodium, sulfate, pH, specific conductance, total organic carbon, total organic halogen, arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, silver, alkalinity, bromide, iodide, orthophosphate, beryllium, calcium, boron, lithium, potassium, silica, carbon tetrachloride, methalene chloride, trichloroethylene, 1,1,1 trichloroethane, freon-113, TSS, TDS

Chapter 5
Environmental Radiological Program Information

The following subsections provide a description of the various radiological programs constituting the Environmental Monitoring Program at the WIPP. The media that are analyzed radiologically are airborne particulates, soil, sediment, surface water, groundwater, and biotics.

5.1 Radioactive Effluent Monitoring

The Radioactive Effluent Monitoring Program is described in the WIPP Environmental Monitoring Plan (EMP). This plan defines the scope of the WIPP's effluent and environmental monitoring programs during the operational life of the facility. Figure 5-1 illustrates the primary pathways to the public for radioactive releases from the WIPP site.

The Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance (DOE/EH-0173T), (DOE, 1991), establishes elements for radiological effluent monitoring and environmental surveillance programs considered acceptable to the DOE, and in support of DOE Order 5400.1, *General Environmental Protection Program.* These guidelines incorporate and expand the requirements embodied in germane DOE guidance (e.g. 5400.1). In CY 1995 no radioactive waste was received at the WIPP site, and as a result, no effluent sampling or release data are reported in this document.

5.2 Environmental Radioactivity Monitoring

The following subsections present the monitoring results of the EMP for CY 1995. These results include monitored subprograms such as air particulate, background radiation, soil, sediment, surface and groundwater, and biotic radioactivity. Table 5-1 and figures 5-2 through 5-9 illustrate gross alpha and beta analysis and locations of WIPP air filters conducted at the WIPP Radiochemistry Laboratory (RL). Table 5-2 lists the minimum detectable concentration (MDC) for each element as they pertain to a specific sample medium. Reported analytical values that are less than the calculated MDC's should not be used in the determination of baseline activity levels. The subject MDC's provide the minimum level at which there is a degree of confidence that activity is present in measurable concentrations.

The attached appendices (A1-A6) provide radiological analytical results from an offsite contract laboratory in tabular and graphical form. Sample results coded with an asterisk indicate the nuclide

was not identified by the Canberra Nuclear Nuclide Identification Program. Nuclide activity values reported in this data summary were calculated using industry standard criteria (e.g., Canberra Nuclear minimum activity or MINACT program) by the contract analytical laboratory.

Other values of interest within the Environmental Monitoring data are the paired-duplicate data results. These samples are denoted "DUP" within the graphs. The paired-duplicate samples are collected coincidentally with the routine sample at a specific location, and are subject to the same sources of error as the reference samples (Keith, 1988).

Also of note are data results listed as "BLK". These results are derived from blank's such as deionized water that were sent to the contract laboratory as a QA check. These values provide insight on the laboratory's sample handling and analytical processes. There are "BLK's" noted in the surface and groundwater data results. Blank air samples are denoted as "WAB".

On the graphs, data values below the minimum detectable concentration have not been graphed or used in the standard deviation calculations. The mean for each of the graphs was determined by dividing the sum of the data points above the MDC by the total number of data points. The blank filter data were not included in the standard deviation and mean calculations. There is also not a graph produced for every analyte corresponding to each matrix. Those matrices with less than four data points at or above the minimum detectable concentration were not deemed appropriate to graph. However, all the data values are available for review in the tabular data tables relative to the matrix types.

Only the data values above the MDC were used to plot the graphs in the appendices. Data anomalies (a significant outlier) or data values below the MDC have been excluded from the graphical data representation in order to maintain a reasonable scale on the graphs.

5.2.1 Atmospheric Radiation Baseline

The WIPP, in alignment with virtually every nuclear facility, collects and analyzes air samples. Frame (1987) explains that the most commonly encountered airborne radionuclides are detectable by way of this sample medium.

Levels of these radionuclides in the environment may be so low that the activity collected over a period of approximately 168 hours (one week) will be insufficient for determination of the individual radionuclides. Therefore, it is standard practice at the WIPP to analyze filters first for gross

alpha/beta activity as an indicator measurement. Subsequently, the filters are compiled into quarterly composites for analysis of specific radionuclides.

Performing a gross alpha/beta analysis requires a minimum of 12 hours desiccation to provide a time period (post sampling) for the decay of natural radionuclides (e.g., radon daughters, 0.5 hour effective half-life).

During CY 1995, continuous particulate aerosol filtration samplers operated at seven locations; three, within 1000 meters of the facility; three, at local ranches and communities; and one, as a sample control site (Figure 5-10).

The continuous aerosol samplers presently in use maintain a regulated flow rate of approximately 0.056 cubic meters per minute (two cubic feet per minute) of air through a 47-millimeter (1.9-inch) glass fiber filter. Table 5-1 depicts the 1995 quarterly average concentrations of the alpha and beta activity on the low-volume aerosol filters from each location and illustrates the mean gross alpha concentrations for all seven sampling locations. Mean gross alpha concentration shows limited fluctuation throughout the year, as illustrated in Table 5-1. These fluctuations, graphically depicted in Figures 5-2 through 5-8, appear to be consistent among all sampling locations.

Gross alpha and beta measurements provide an indication of naturally occurring or man-made radionuclide concentrations or changes in a specific radionuclide concentration. These measurements are screened to ensure that important radionuclides are not overlooked when measurements are performed.

Airborne particulate sampling was initiated in July 1985. Weekly filter collections and subsequent radiochemical analyses began in early 1986, except at the WIPP Far Field location where data collection began in October 1986. Particulate filters were collected weekly at all locations in CY 1995. These filters were analyzed at WIPP's radiochemistry laboratory where a weekly gross alpha and beta count of each filter was completed.

As an additional QA function instituted during 1995, blank air filters were incorporated into the analytical processes. Since the blank filters have no sampled air passed through them, a standardized air volume has been entered into the calculation to allow for a comparison between the field samples and the blank filters. The standardized air volume was determined by using a two cubic feet/minute flow rate. This equates to a 7417 m^3 flow volume per calendar quarter for each quarterly composite. This provides a reasonable correlation between the field air samples and the blank air filters when both data units are in Bq/m^3.

In the appendices the blank filter data values are denoted on the graphs as "WAB" WIPP air blank. This provides a comparison between the field sample and blank filter for the air sampling program.

Appendix A1 provides a tabular and graphical data listing for the radiological analysis of CY 1995 air filters.

5.2.2 Background Radiation Baseline

During 1995, it was concluded that sufficient baseline data had been obtained from the Reuter/Stokes. An assessment of the capabilities of the Reuter-Stokes with regard to the gamma source term of the WIPP-bound transuranic waste indicates that such a dose-rate instrument would be ineffective for detecting a radiological release. A determination was made that the likelihood of detecting a release with the transuranic alpha emitters from air samplers far exceeded the real-time dose rate capability of the Reuter-Stokes. Therefore, the Reuter-Stokes High Pressure Ion Chamber was permanently removed from service.

5.2.3 Radiological Soil Monitoring

Radiological soil samples were collected, during CY 1995, at six separate locations. A template inserted into the soil allows for the collection of samples at three depths per location that include:

1. 0 - 2 centimeters TS-(surface soil)
2. 2 - 5 centimeters TI-(intermediate soil)
3. 5 - 10 centimeters TD-(deep soil)

Each complete sample was a composite of 10 randomly selected subsamples. Appendix A2 provides a data listing for the radiological analysis of CY 1995 soil samples.

5.2.4 Hydrologic Radioactivity

The hydrologic radioactivity subprogram is designed to establish characteristic radioactivity levels in surface water bodies, bottom sediments, and groundwater. The following discussion of the hydrologic program pertains to samples collected during 1995. It also details refinements made to the program since the publication of the *Radiological Baseline Program Sampling Plan* (Reith and Daer, 1985).

5.2.4.1 Radiological Surface Water and Sediment Monitoring

Surface water samples were collected at 11 of the 12 standard sampling locations during CY 95. There was not a sample collected at the Red Tank location in CY 95, as this location was dry due to the drought conditions experienced in southeastern New Mexico in 1995. Of these locations, sediment samples were collected at 10 of the 12. The data from the analysis of these samples does not indicate any unusual levels of environmental radioactivity. Analytical results from surface water and sediment samples are presented in Appendix A3 and A4 respectively.

5.2.4.2 Radiological Groundwater Characterization

Groundwater samples were collected in accordance with the Water Quality Sampling Program (WQSP). The primary objective of the WQSP is to obtain, using rigorous field and laboratory procedures and protocols, representative groundwater data from selected wells. At each well site, the well is purged and the groundwater is serially analyzed for specific field parameters. Once the field parameters have stabilized denoting a chemical steady state with respect to those parameters analyzed, a final groundwater sample is collected and analyzed for radionuclides. The controlling document for the WQSP is the *WIPP Water Quality Sampling Plan and Procedures Manual* (WP 02-1, Rev 2).

The primary water-bearing formations being evaluated in accordance with the WQSP are the Culebra and Magenta Dolomite members of the Rustler Formation. In 1995, groundwater data were gathered at 10 well locations completed in the Culebra dolomite and one in the Dewey Lake. Contrary to preceding years no water quality data were collected from privately owned wells in the area near the WIPP site. An in-depth discussion of groundwater hydrology and a figure showing well locations is presented in Chapter 7, *Groundwater Surveillance*. Results from the radiological analyses of groundwater are provided in Appendix A5.

5.2.5 Biotic Radioactivity

Keith (1991) asserts that sampling biota for radiological analysis provides diverse challenges due to variations between species, dissimilarities within given populations, species mobility, and tissue differentiation. WIPP environmental monitoring programs implement proceduralized protocols to ensure that samples collected are representative, random, and homogeneous for the particular matrix being sampled. Examples of available biotic media used for radiologic analysis are vegetation, fish, quail, rabbit, beef, and deer. Results for the biotic radiological analysis are presented in Appendix A6.

5.2.5.1 Vegetation

Vegetation was collected at six locations. Native plants are universally accepted as a readily accessible and reliable sample medium for the evaluation of radionuclides. Vascular plants, in general, have distinctly different physiological characteristics, therefore it is imperative that individual sample location selection is random, in order to acquire a true representation of the plant community being sampled. Sparrow (1958) documented variables in the effect of ionizing radiation on plant communities by exposing tracts of densely vegetated lands to a known quantity from a stationary radioactive source. Results were profound and illustrated the predicted dissimilarities in responses of woody and herbaceous (soft tissue) plants to ionizing radiation. Investigations of this nature were precursors to contemporary standards of radiological vegetative evaluations.

The diversity in plant composition and the potential plant community of the region provides for an ample variety of vegetative medium from which to sample. Composite samples collected at predetermined locations include, but are not limited to, woody plants such as Harvard Shin Oak (*Quercus havardii)* and Sand Sage (*Artemesia filifolia)* in addition to a variety of soft tissue plants consisting of grasses such as Mesa Dropseed (*Sporobolus flexuosus)* and forbes like Prairie Spurge (*Euphorbia missourica).*

5.2.5.2 Quail and Rabbits

Data pertaining to radionuclide body-burdens in the muscular tissue of quail and rabbits has been collected, by WIPP biologists, since 1985. The popularity of these animals with local hunters prompted the inclusion of quail and rabbit as viable pathways to the local population (Figure 5.1). Quail species accessed for radiological appraisals are Scaled Quail (*Callipepla squamata)* and a desert subspecies of the Northern Bobwhite (*Colinus virginianus var. taylori)* (Robbins 1981). Prior to 1995, the use of rabbit as a biomonitor, was restricted to Desert Cottontails (*Sylvilagus auduboni).* During 1995, however, population numbers of Desert Cottontails, like quail, sustained a drastic population decline. Accordingly, WIPP biologists incorporated the inclusion of tissue from Blacktail Jackrabbits (*Lepus californicus).* Blacktail Jackrabbits are readily available as they constitute the vast majority of road kills in the vicinity of the WIPP. Three rabbits samples were collected and analyzed during CY 1995.

Unusually low numbers of resident quail precluded the capture of specimens for sampling. The collection of quail as a sample medium, has been indefinitely postponed until such time that the resident population can provide and sustain the numbers necessary to yield the amount of tissue necessary for analysis.

5.2.5.3 Fish

Fish samples were collected at two locations; Brantley Lake and the Pecos River. The target species for fish samples are catfish, primarily of the genus *Ictalurus* (channel catfish) although several large specimens of the more predatory flathead catfish *(Pylodictis olivaris)* have been caught and sampled. Of the variety of indigenous fishes, catfish were selected as the preferable sample matrix due to their popularity with local fisherman. Moreover, catfish represent a multi-media feeder. Multi-media feeder refers to organisms which access a wide variety of food sources. Within an ecosystem, most catfish species serve as scavenger and predator, therefore, provide one of the most reliable values when assessing for the presence of background radionuclide concentrations in biota.

Two collection methods for fish were employed for the duration of the sample period. One method, utilizing trammel nets, was implemented for a period of approximately three weeks. Although the trammel nets are extremely efficient, the mechanics of capture are indiscriminate and usually fatal to smaller fish even though WIPP personnel inspect the nets every four hours. Deployment and supervision of trammel nets is labor intensive. However, the use of trammel nets is of merit and will be considered during future sampling deliberations.

The alternate, and preferred, method of collection was the utilization of trot lines. Trot lines or "long lines" employ lengths of small diameter cord, up to 100 feet in length, with hooks suspended approximately every two-to-three feet. Each hook is baited with, beef liver, bait shrimp, or other forage preferred by catfish. Protocol was to inspect lines morning and evening. The use of trot lines provided the requisite sample aliquot of catfish tissue in approximately one week per sample location.

5.3 Assessment of Potential Dose to the Public

In 1995, no waste was received at the WIPP; therefore, the public could not be exposed to radiation due to WIPP operations. Documentation of naturally occurring background radiation is discussed in Chapter 5, *Environmental Radiological Program Information* and Chapter 7, *Ground Water Surveillance*, of this report.

ENVIRONMENTAL RADIOLOGICAL PROGRAM INFORMATION

TABLE 5-1

ACTIVITY CONCENTRATIONS IN QUARTERLY AVERAGES OF THE LOW VOLUME AEROSOL FILTERS (Bq/ml)

FIRST QUARTER 1995

LOCATION	ALPHA	BETA
Carlsbad	9.10E-11	8.63E-10
Smith Ranch	8.28E-11	8.87E-10
Mills Ranch	8.98E-11	8.05E-10
WIPP Far Field	8.58E-11	8.03E-10
WIPP South	9.21E-11	8.45E-10
WIPP East	9.62E-10	8.45E-10
South East Control	7.51E-11	7.92E-10

SECOND QUARTER 1995

LOCATION	ALPHA	BETA
Carlsbad	1.19E-10	7.67E-10
Smith Ranch	1.19E-10	7.69E-10
Mills Ranch	1.31E-10	7.45E-10
WIPP Far Field	1.24E-10	7.64E-10
WIPP South	1.28E-10	7.63E-10
WIPP East	1.34E-10	7.38E-10
South East Control	1.32E-10	6.77E-10

THIRD QUARTER 1995

LOCATION	ALPHA	BETA
Carlsbad	1.28E-10	8.85E-10
Smith Ranch	1.40E-10	8.83E-10
Mills Ranch	1.34E-10	8.82E-10
WIPP Far Field	1.52E-10	8.48E-10
WIPP South	1.49E-10	8.53E-10
WIPP East	1.32E-10	8.57E-10
South East Control	1.47E-10	8.91E-10

TABLE 5-1
(CONTINUED)

FOURTH QUARTER 1995

LOCATION	ALPHA	BETA
Carlsbad	1.18E-10	1.48E-09
Smith Ranch	1.00E-10	1.34E-09
Mills Ranch	1.19E-10	1.34E-09
WIPP Far Field	1.26E-10	1.42E-09
WIPP South	1.11E-10	1.36E-09
WIPP East	1.10E-10	1.36E-09
South East Control	1.03E-10	1.29E-09

ENVIRONMENTAL RADIOLOGICAL PROGRAM INFORMATION
TABLE 5-2

RADIOLOGICAL ANALYTICAL CONTRACT REQUIRED DETECTION LIMITS

ANALYTES FOR AIR SAMPLES	MINIMUM DETECTABLE CONCENTRATION (Bq/m^3)
Americium-241	7.00E-06
Beryllium-7	1.00E+01
Cesium-137	1.00E-01
Cobalt-60	3.00E-02
Lead-210	3.00E-04
Plutonium-238	1.00E-05
Plutonium-241	4.00E-04
Plutonium-239/240	7.00E-06
Polonium-210	4.00E-04
Potassium-40	3.00E-01
Radium-228	1.00E-03
Radium-226	4.00E-04
Strontium-90	3.00E-03
Thorium-228	1.00E-05
Thorium-230	1.00E-05
Thorium-232	3.00E-06
Uranium-233/234	3.00E-05
Uranium-238	4.00E-05
Uranium-235/236	4.00E-05

TABLE 5-2

(CONTINUED)

ANALYTES FOR BIOTIC SAMPLES	MINIMUM DETECTABLE CONCENTRATION (Bq/g)
Americium-241	4.00E-03
Cesium-137	4.00E-03
Cobalt-60	4.00E-03
Lead-210	7.00E-02
Plutonium-238	1.00E-02
Plutonium-241	4.00E-01
Plutonium-239/240	7.00E-03
Polonium-210	7.00E-02
Potassium-40	4.00E-03
Radium-228	7.00E-02
Radium-226	7.00E-03
Strontium-90	7.00E-02
Thorium-228	4.00E-03
Thorium-230	4.00E-03
Thorium-232	4.00E-03
Uranium-233/234	4.00E-03
Uranium-238	4.00E-03
Uranium-235/236	4.00E-02

TABLE 5-2

(CONTINUED)

ANALYTES FOR SEDIMENT SAMPLING	MINIMUM DETECTABLE CONCENTRATION (Bq/g)
Americium-241	4.00E-03
Cesium-137	4.00E-03
Cobalt-60	4.00E-03
Lead-210	7.00E-02
Plutonium-238	1.00E-02
Plutonium-241	4.00E-01
Plutonium-239/240	7.00E-03
Polonium-210	7.00E-02
Potassium-40	4.00E-03
Radium-228	7.00E-02
Radium-226	7.00E-03
Strontium-90	7.00E-02
Thorium-228	4.00E-03
Thorium-230	4.00E-03
Thorium-232	4.00E-03
Uranium-233/234	4.00E-02
Uranium-238	4.00E-03
Uranium-235/236	4.00E-02

TABLE 5-2

(CONTINUED)

ANALYTES FOR SURFACE AND GROUNDWATER	MINIMUM DETECTABLE CONCENTRATION (Bq/l)
Americium-241	1.00E-02
Cesium-137	1.00E+00
Cobalt-60	2.00E+00
Lead-210	4.00E-01
Plutonium-238	1.00E-02
Plutonium-241	7.00E-01
Plutonium-239/240	1.00E-02
Polonium-210	3.00E-02
Potassium-40	3.00E+00
Radium-228	4.00E-02
Radium-226	4.00E-02
Strontium-90	4.00E-01
Thorium-228	1.00E-01
Thorium-230	1.00E-01
Thorium-232	2.00E-02
Uranium-233/234	2.00E-01
Uranium-238	2.00E-01
Uranium-235/236	2.00E-01

TABLE 5-2

(CONTINUED)

ANALYTES FOR SOIL SAMPLING	MINIMUM DETECTABLE CONCENTRATION (Bq/g)
Americium-241	4.00E-03
Cesium-137	4.00E-03
Cobalt-60	4.00E-03
Lead-210	7.00E-02
Plutonium-238	1.00E-02
Plutonium-241	4.00E-01
Plutonium-239/240	7.00E-03
Polonium-210	7.00E-02
Potassium-40	4.00E-03
Radium-228	7.00E-02
Radium-226	7.00E-03
Strontium-90	7.00E-02
Thorium-228	4.00E-03
Thorium-230	4.00E-03
Thorium-232	4.00E-03
Uranium-233/234	4.00E-03
Uranium-238	4.00E-03
Uranium-235/236	4.00E-02

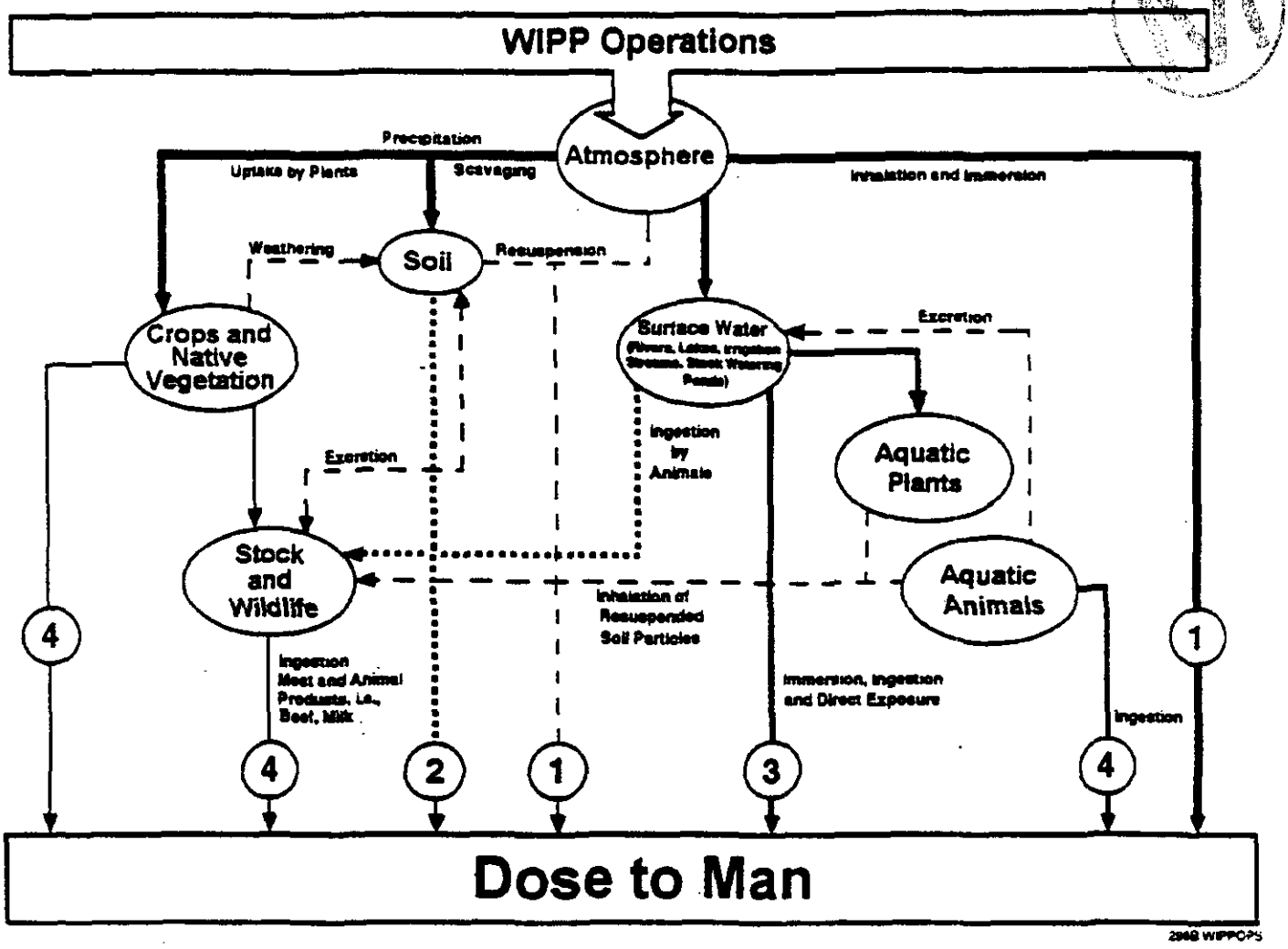

Possible radionuclide pathways leading from the WIPP Site to man:

The width of each line is proportional to the importance of the pathway in the Los Medanos ecosystem. The numbers in the pathways leading to man indicate which monitoring programs will intercept that pathway.

1. Airborne particulate and effluent monitoring
2. Soil and sediment sampling
3. Surface water and groundwater monitoring
4. Vegetation, beef, game animals and aquatic foodstuffs sampling

Figure 5-1
Primary Pathways to Man for Radioacitive Releases from the WIPP Site

Carlsbad

1995 Gross Alpha / Gross Beta

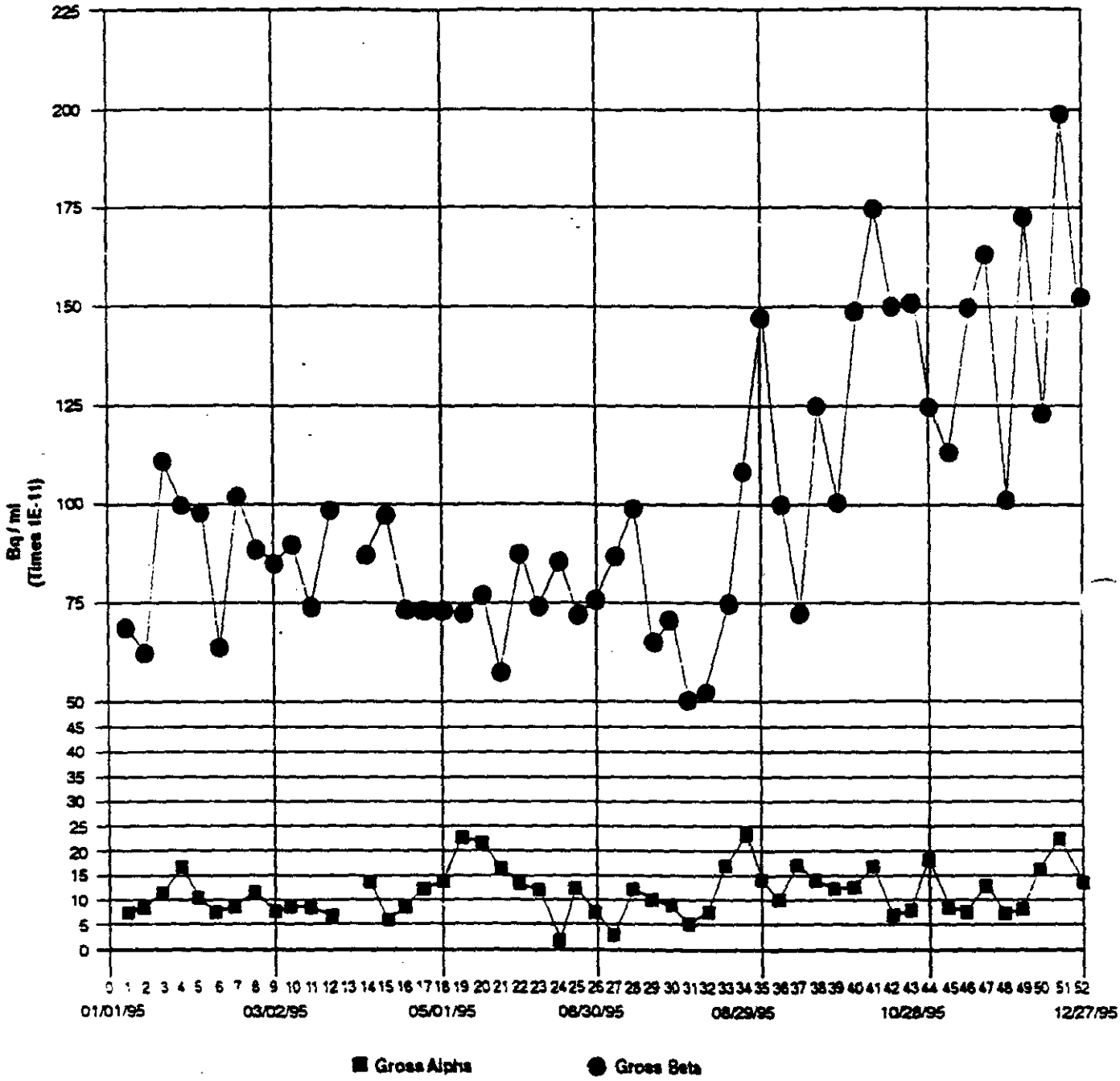

Figure 5-2
1995 Gross Alpha/Beta
Carlsbad

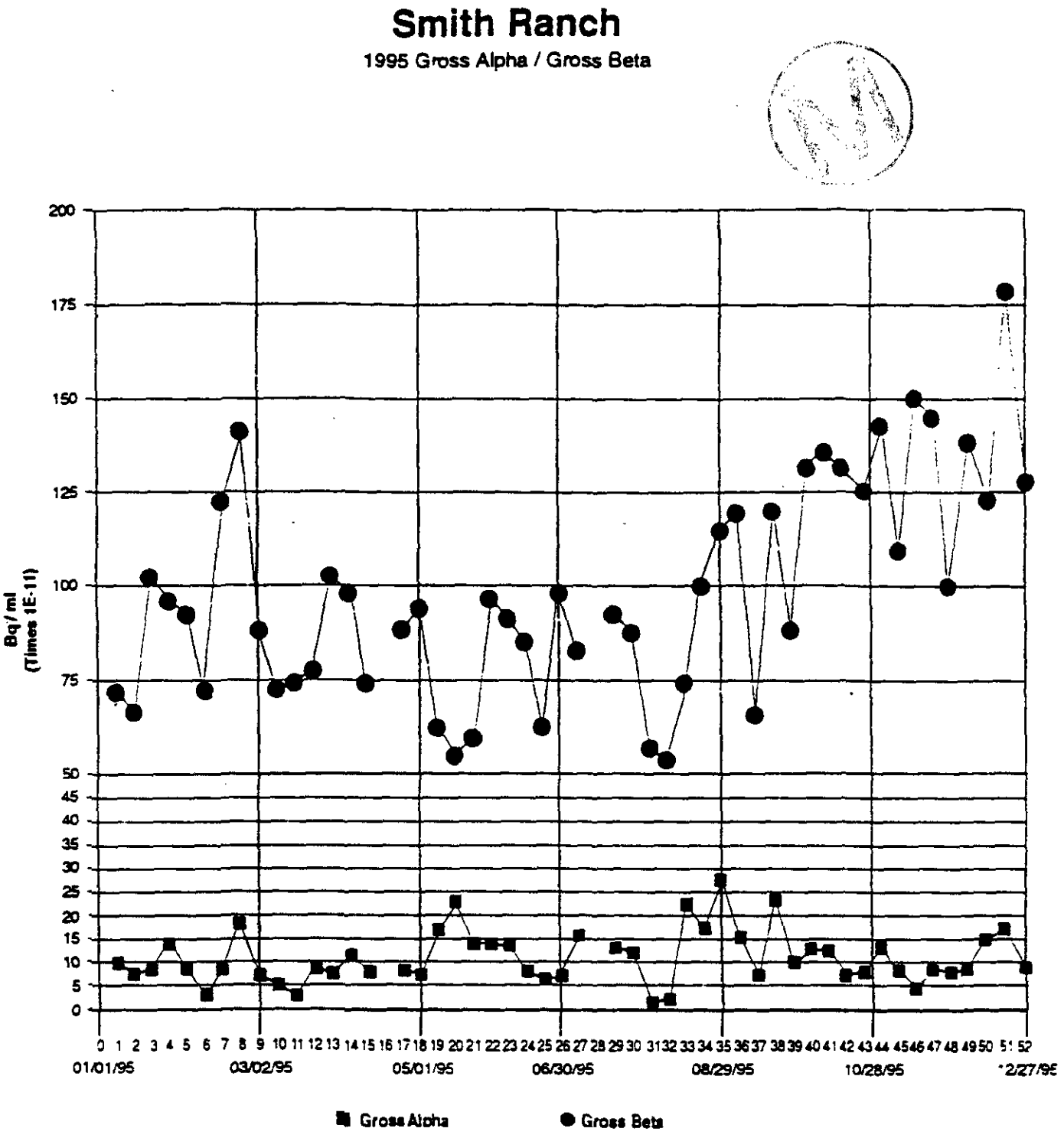

Figure 5-3
1995 Gross Alpha/Beta
Smith Ranch

WIPP Far Field

1995 Gross Alpha / Gross Beta

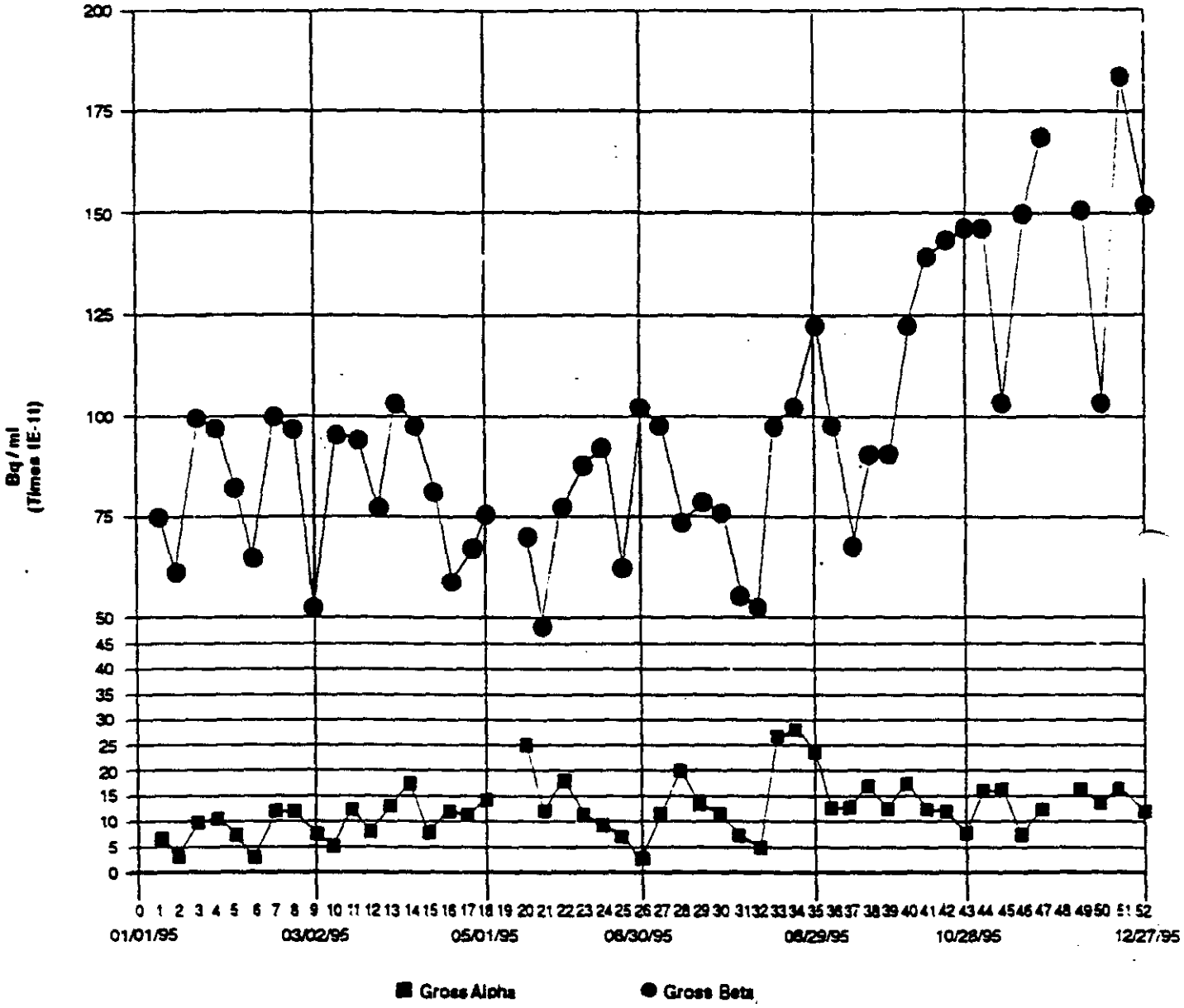

Figure 5-4
1995 Gross Alpha/Beta
WIPP Far Field

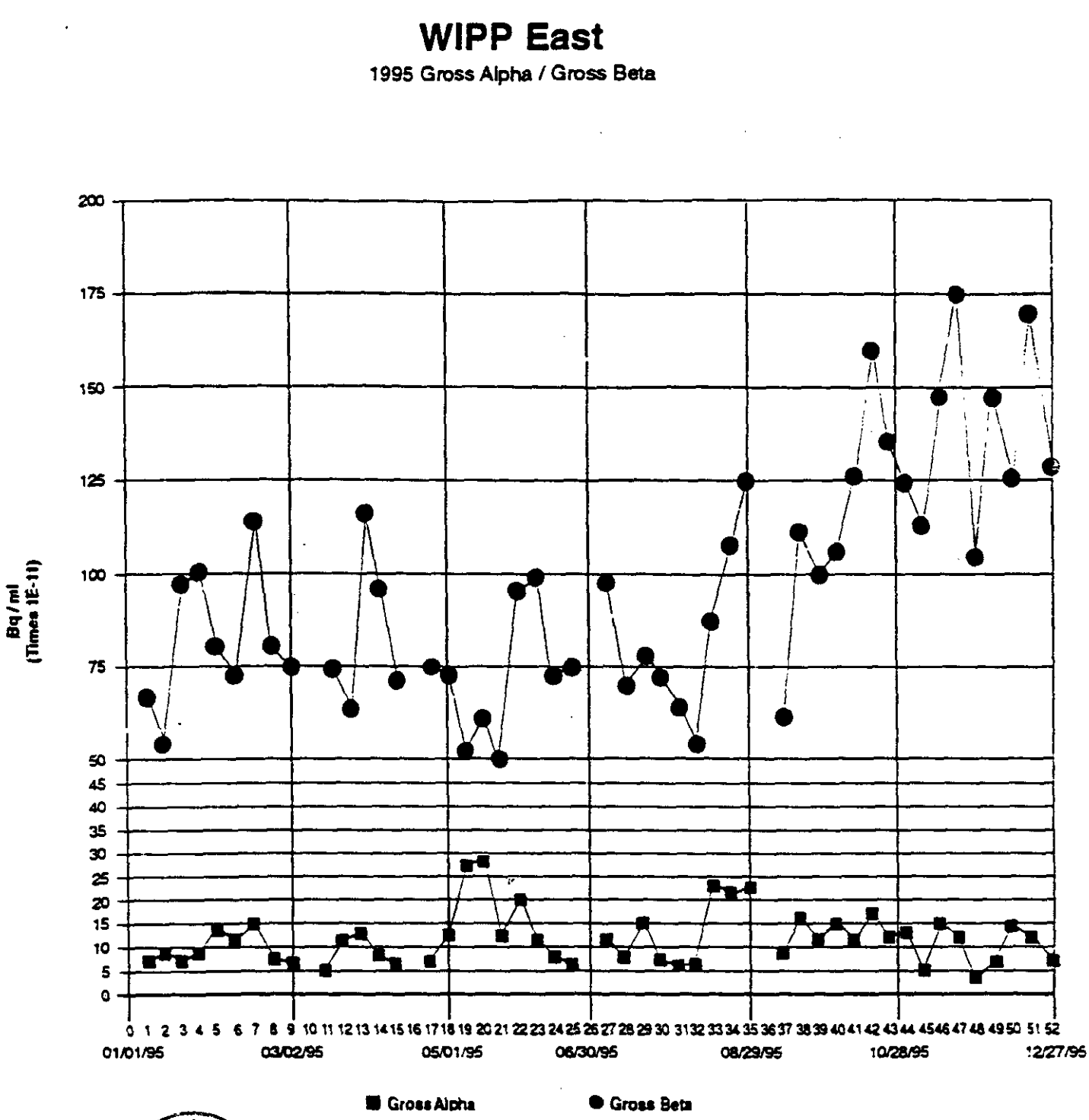

Figure 5-5
1995 Gross Alpha/Beta
WIPP East

WIPP South

1995 Gross Alpha / Gross Beta

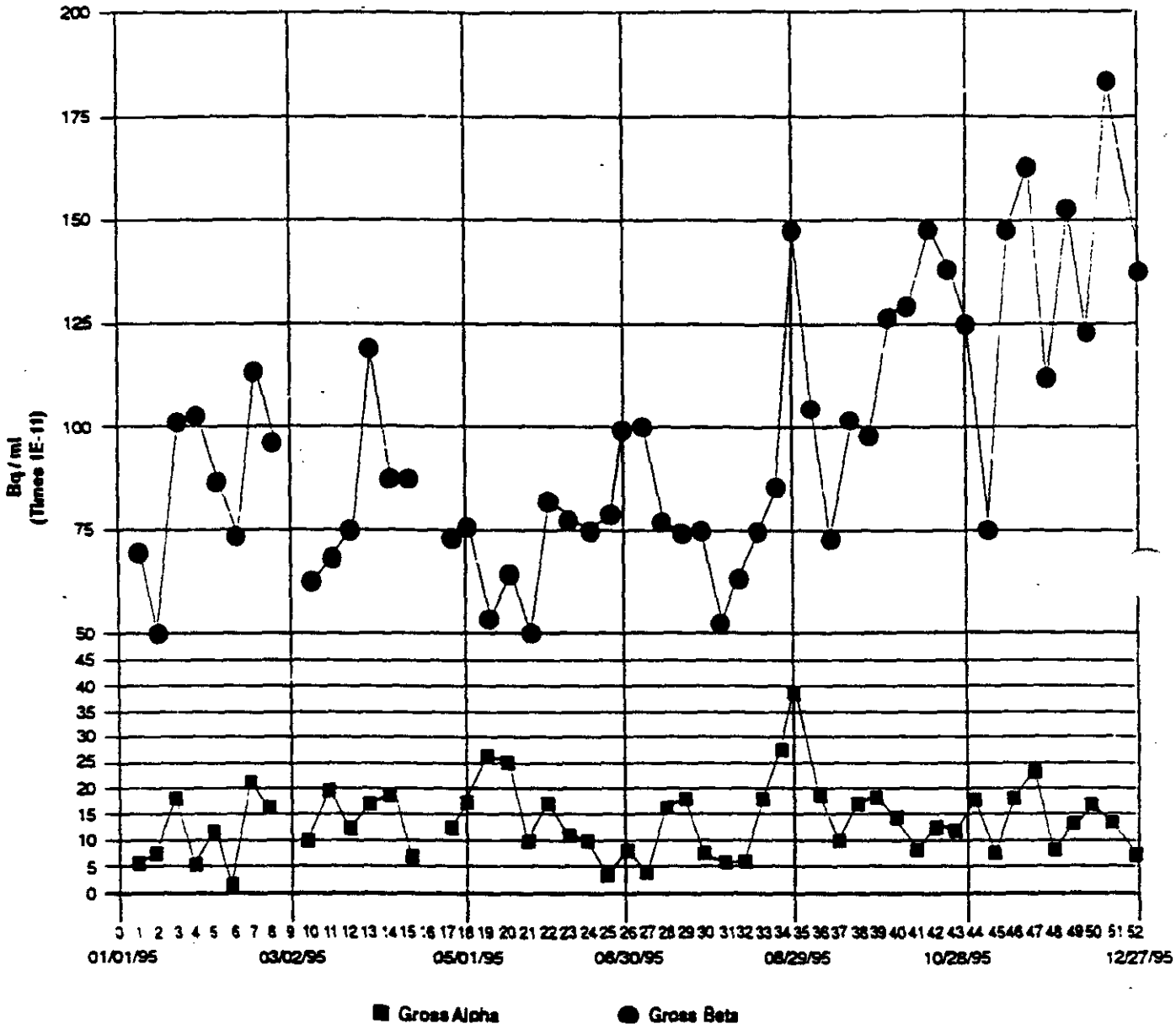

Figure 5-6
1995 Gross Alpha/Beta
WIPP South

Mills Ranch

1995 Gross Alpha / Gross Beta

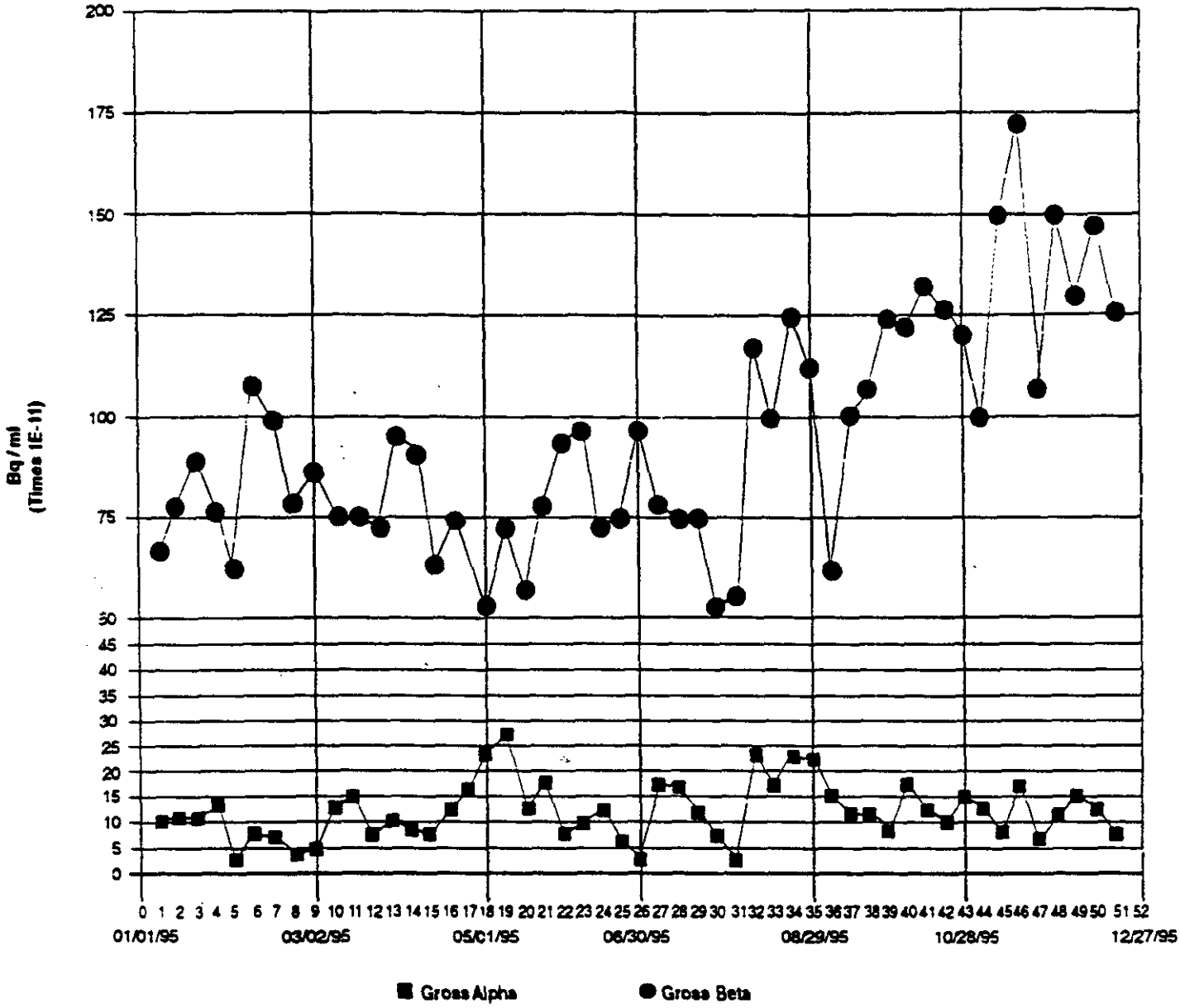

Figure 5-7
1995 Gross Alpha/Beta
Mills Ranch

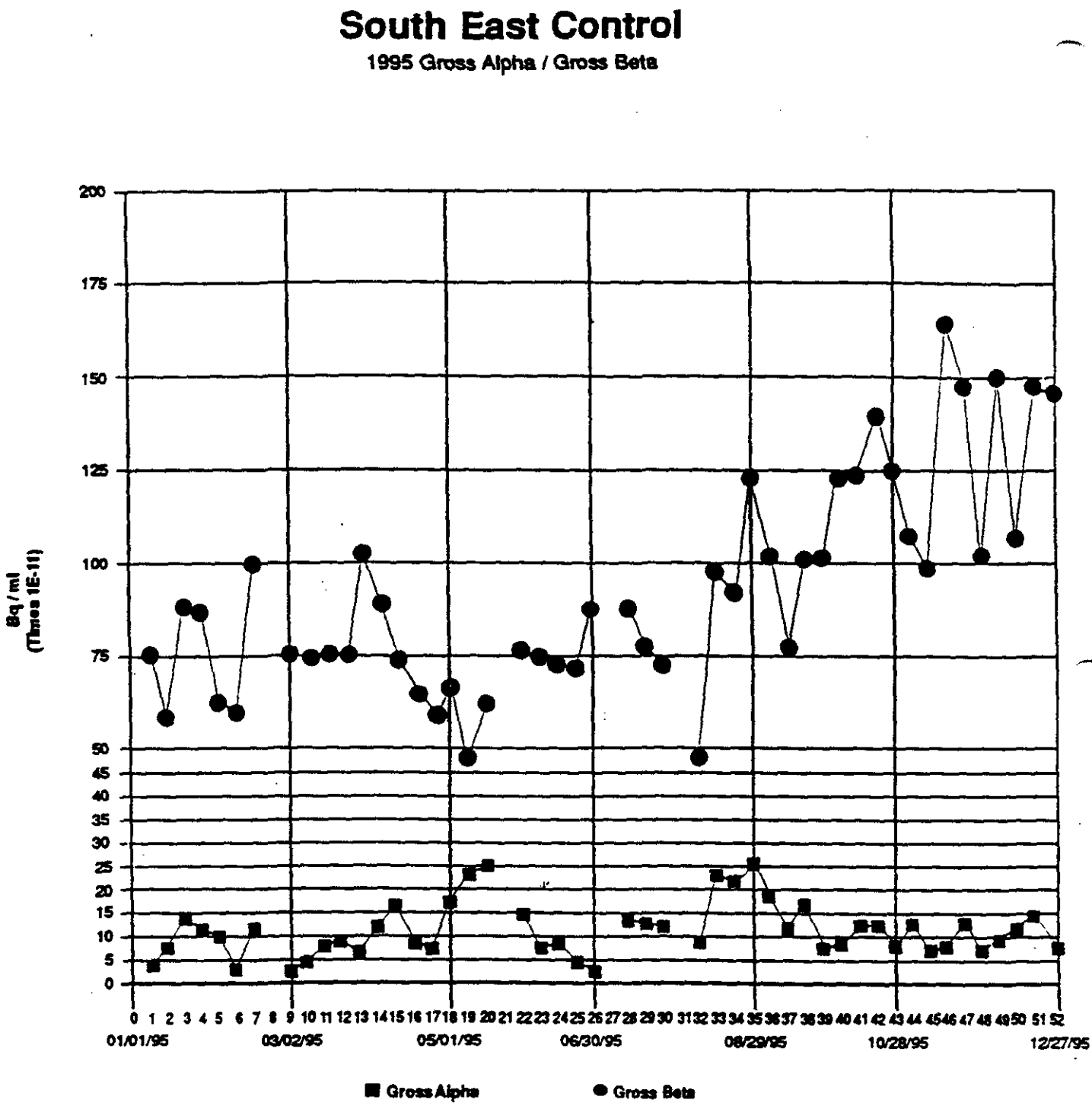

Figure 5-8
1995 Gross Alpha/Beta
Southeast Control

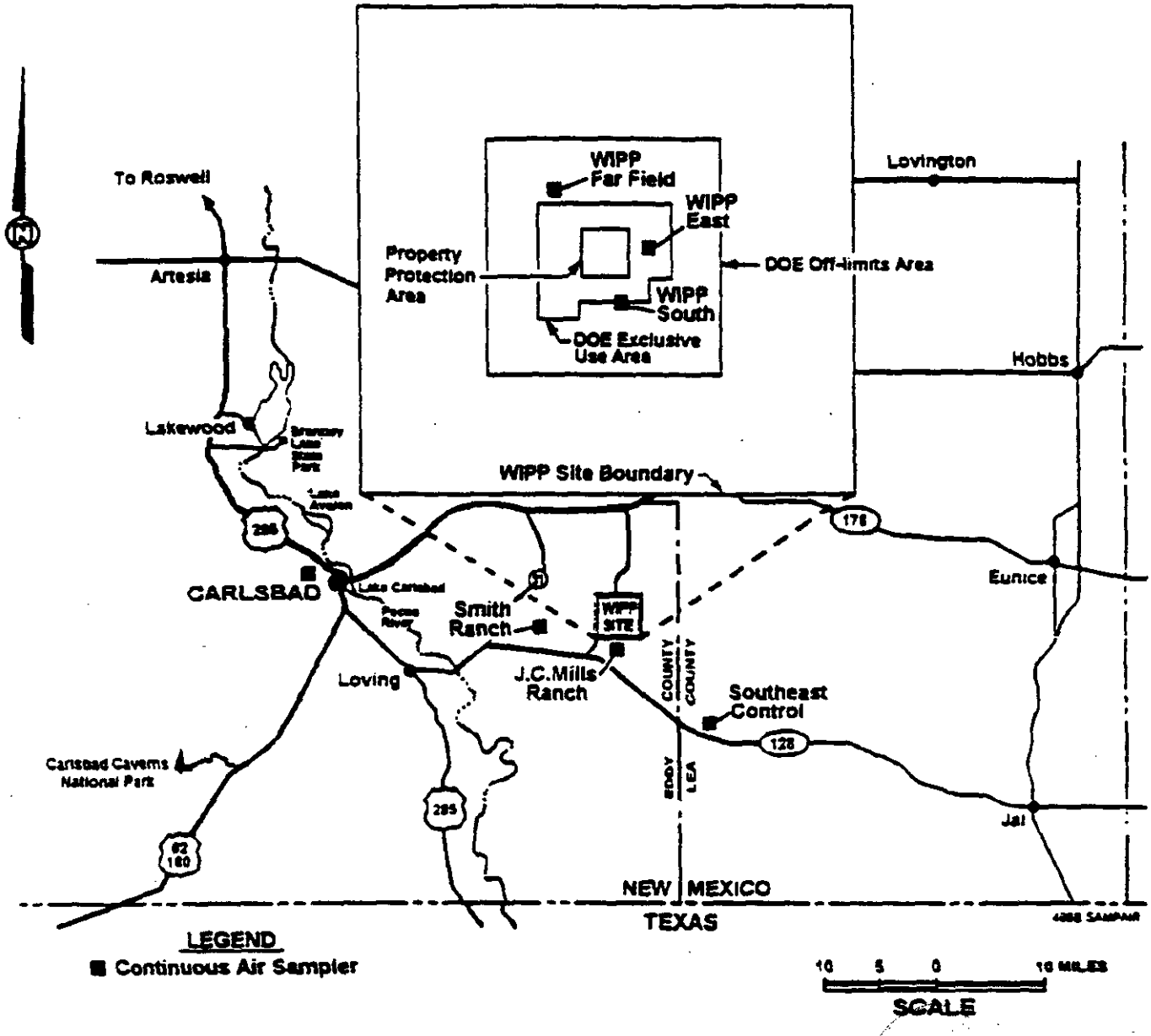

Figure 5-9
Continuous Air/Radiological Soil Sampling Locations

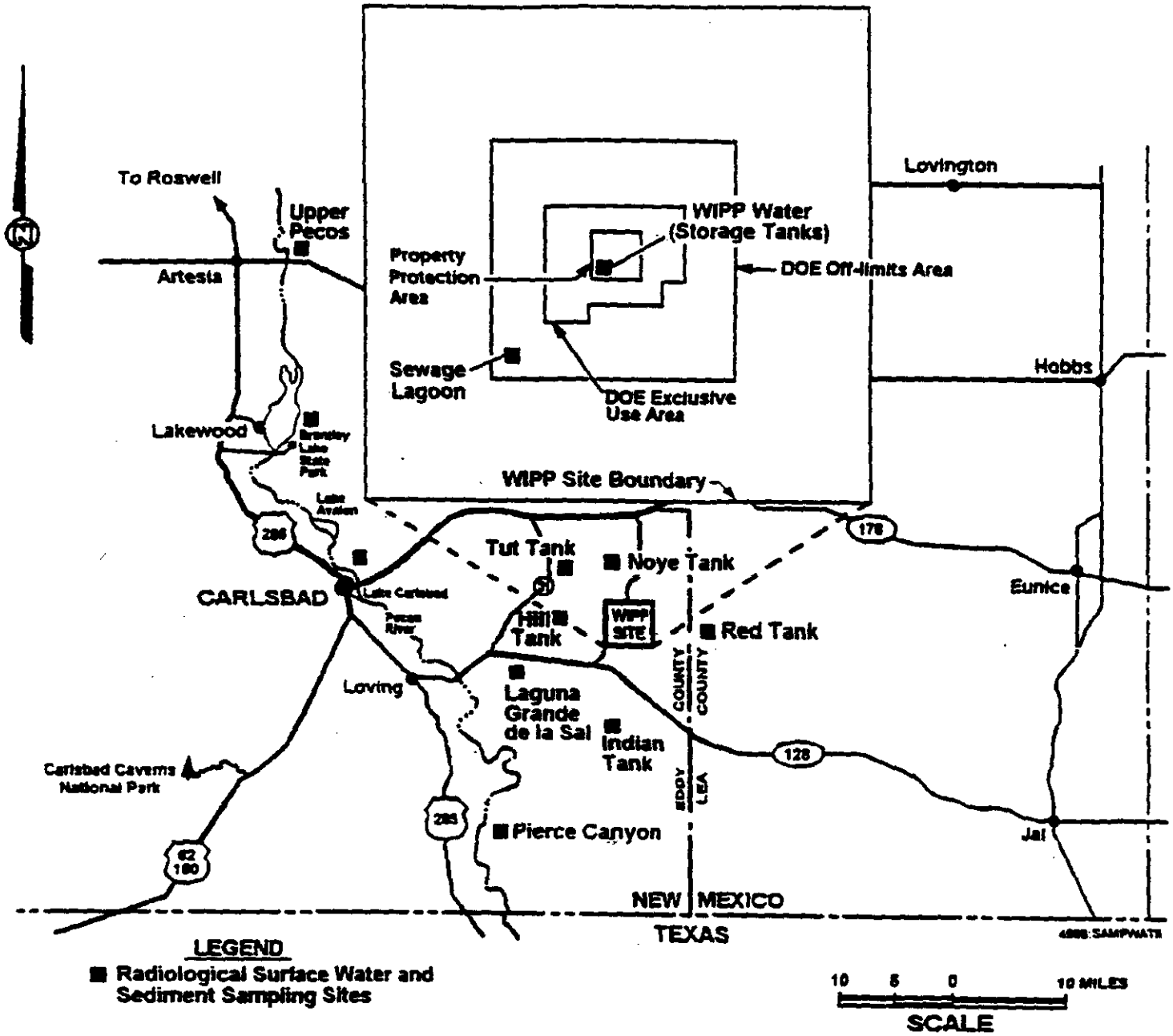

Figure 5-10
Radiological Surface Water and/or Bottom Sediment Sampling Sites

Chapter 6
Environmental Nonradiological Program Information

This chapter of the SER presents and discusses Nonradiological Environmental Sampling (NES) data collected between January 1, 1995, and December 31, 1995. Nonradiological programs at the WIPP include the following subprograms: land management to include reclamation/restoration of disturbed lands, oil and gas surveillance, and wildlife population monitoring (see Chapter 4 *Environmental Program Information*) and meteorological monitoring. In addition to the NES programs, Volatile Organic Compounds (VOCs) were monitored to comply with provisions of the WIPP's current No Migration Determination (NMD) and liquid effluent monitoring is conducted in accordance with *Sewage Systems Discharge Monitoring and Compliance* (DP-831) criteria. The results of the environmental monitoring activities and discussions of significant findings are presented in this report.

6.1 Principal Functions of Nonradiological Sampling

The principal functions of the NES are to:

- Assess the impacts of construction and operational activities from the WIPP on the surrounding ecosystem.
- Monitor ecological conditions in the Los Medaños Area.
- Investigate unusual or unexpected elements in the ecological databases.
- Provide environmental data that are important to the mission of the WIPP project, but which have not or will not be acquired by other programs.
- Comply with applicable commitments identified with existing agreements (e.g. BLM/DOE MOU, Interagency Agreements, Agreements in Principal, etc.)

6.2 Meteorology

A principle component of the NES is a primary meteorological (MET) station located 600 meters northeast of the Waste Handling Building. The main function of the MET is to generate data for

modeling atmospheric conditions. The station documents standard meteorological measurements of wind speed, wind direction, and temperatures, with dew point and precipitation monitored at ground level. These parameters are measured continuously and the data are stored in the Central Monitoring System (CMS).

In addition to the primary meteorological station, the WIPP Far Field Station (WFF) is located 1000 meters northwest of the Waste Handling Building. At the WFF a secondary meteorological station measures and records temperature and barometric pressure at ground level and wind speed and wind direction at 10 meters (30 feet).

6.2.1 Climatic Data

The mean annual temperature for the WIPP area in 1995 was 17°C (63°F). The mean monthly temperatures for the WIPP area ranged from 6°C (42°F) during January to 28°C (83°F) in June. Generally, maximum temperatures occur in June through September, while minimum temperatures occur in December through February as illustrated in Figure 6-3, page 6-9.

The first freezing day of the 1995-96 winter season occurred November 11, with 0°C (32°F). The last freezing day of the 1995-96 winter season was April 4, with a temperature of 0°C (32°F). The maximum temperature recorded was 42°C (107°F) on July 26.

The annual rate of precipitation at the WIPP site for 1995 was 23.27 cm (9.16 in), which is 6.7 cm (2.63 in) above last year's rate. The annual precipitation for 1995 was 29 percent greater than that recorded for 1994 and 71 percent less than CY 1992, the last year of normal to above-normal precipitation. Profound drought conditions persisted during CY 1995, the conspicuous effects evident in tenant vegetative and wildlife communities. Figure 6-1, page 6-7, displays the monthly precipitation at the WIPP.

6.2.2 Wind Direction and Wind Speed

The predominate wind direction in the WIPP area was from the southeast sector (135°). However, winds occurring in late spring were primarily from the west. Various weather systems move through this area briefly altering the predominant southeasterly winds and sometimes resulting in violent convectional storms. Wind speed noted as calm (less than 0.5 meters per second [mps]) occurred 8.3 percent of the time. Winds of 1.4 through 2.8 mps were the most prevalent over 1995, accounting for 25.5 percent of the time. Figure 6-2, page 6-8, displays the annual wind data at the WIPP for CY 1995.

6.3 Air Quality Monitoring

Weekly measurements of Total Suspended Particulates (TSPs) (milligrams per cubic meter) are calculated from the particulates collected onto glass fiber filters, by the low-volume continuous air samplers at seven air sampling locations. These filters can load with dust particles due to the arid climate of this area; however, this poses no health concern.

6.4 Surface and Subsurface Soil Monitoring

Surface and subsurface soil monitoring was conducted during CY 1995. A detailed discussion of the nonradiological soil monitoring program is available in the report titled *Summary of the Salt Impact Studies at the WIPP, 1984 to 1990* (DOE/WIPP 92-038). Analytical results from the nonradiological soil sampling program are presented in Appendix B.

6.5 Vegetation Monitoring

Because of continuing drought conditions during CY 1995, the plant community of the Los Medaños globally exhibited distinctive signs of physiological stress (e.g. stem and leaf necrosis, chlorosis). As no discernable variations in stress could be identified, delineating subtle variations in plants growing near salt tailings piles in comparison to plants growing varying distances from the tailings, evaluations of the effects of salt on proximal plant communities has been indefinitely postponed. Data collected to date indicate "marginal" to "no negative" impacts on the surrounding plant communities in the form of eolian salt deposition from the mine tailings. The nature of the salt is to become compacted and solidified by the heavy machinery and moisture.

Runoff is collected in the catchment basin, where it evaporates into the atmosphere or is absorbed into the soil. Any resulting salt crust is then weathered and partially dispersed to the surrounding area. This represents only a minimal deposit. Interestingly, wildlife has been observed using the salt tailings as a source of salt, similar to cattle using salt licks.

6.6 Volatile Organic Compounds (VOC) Monitoring

As stated in Section 3.2.3, **Resource Conservation and Recovery Act (RCRA) page 3-7,** the WIPP has developed and implemented a VOC monitoring program to satisfy the air monitoring requirements of the NMD for the WIPP (55 FR 47700). The data resulting from this program are reported in the NMD annual reports submitted to the EPA.

The WIPP VOC Monitoring Program is referenced in the EMP for the WIPP (DOE/WIPP 94-024). Implementing documents specific to the VOC monitoring program include the *VOC Monitoring Plan* (WP 12-6) and *Volatile Organic Compounds Monitoring Quality Assurance Program Plan* (WP 12-7). The *VOC Monitoring Plan* (WP 12-6) is currently under revision. These revisions will reflect present VOC Monitoring activities to support the No-Migration Variance Petition for the Disposal Phase.

6.7 Seismic Activity

Geologic structures and tectonism of the Permian Basin are associated with large-scale basin, inter-basin, and basin-margin subsidence or emergence that occurred during the Paleozoic era. The WIPP facility is about 60 miles from the western margin of the Permian Basin. The basin is a broad structural feature made up of a series of Paleozoic sedimentary basins whose last episodes of major subsidence occurred during late Permian time. The area today is characterized by the basin filled with thick evaporite layers and bordered by the Amarillo uplift to the north, the Marathon thrust belt to the south, and the Diablo Platform, Sacramento and Guadalupe Mountain orogenies to the west.

All major tectonic elements of the Permian Basin were completely formed before deposition of the Permian salt-bearing rocks, and the region has been relatively stable since that time. Deep-seated faults are rare, except along the west margin of the basin and no indications of younger deep-seated faults are noted. On June 16, 1978, an earthquake near Snyder, Texas lead researchers to conclude that the earthquake may have been induced from secondary oil recovery operations and hydrocarbon production. The depth of the earthquake closely approximated the bottom of the relatively shallow drillholes located in the oil and gas-producing area.

Historically, the seismic information for the WIPP facility region before 1962 was based on chronicles of the effects of those tremors on people, structures, and land forms. Seismicity, prior to 1962, reported in New Mexico, occurred in the Rio Grande area between Albuquerque and Socorro and was associated with a structure known as the Rio Grande Rift. These earthquakes had intensities of Modified Mercalli V or greater, based upon the perceptions of people experiencing these quakes.

Since 1962, virtually all seismic information is based on instrumental data recorded at various seismograph stations. Currently, seismicity is being monitored at the New Mexico Institute of Mining and Technology (NMIMT), Socorro, using data from a seven-station network approximately centered on the WIPP site (Figure 6-4). Station signals are telemetered to the

NMIMT Seismological Observatory in Socorro. When appropriate, readings from the WIPP network stations are combined with readings from an additional New Mexico Tech network which is located in Socorro in the central Rio Grande rift. Occasionally, data are exchanged with the University of Texas at El Paso and Texas Tech, both of whom operate stations in West Texas. The annual mean for the operational efficiency of seismic monitoring stations during CY 1995 is approximately 88.2 percent.

From January 1, 1995 through December 31, 1995 locations for 108 seismic events were recorded within 300 kilometers of the WIPP. These data include origin times, epicenter coordinates, and magnitudes. During 1995, the strongest recorded event (with a magnitude of 5.3) was located approximately 241 km south of the WIPP site. This shock was the largest on record, within 300 km of the WIPP, since the Valentine, Texas earthquake on August 16, 1931. The Valentine quake registered an estimated magnitude of 6.4.

6.8 Liquid Effluent Monitoring

The WIPP sewage lagoon system is a zero-discharge facility consisting of two primary settling lagoons, two polishing lagoons, a chlorination system, and three evaporation basins. The entire facility is lined with 30 mil synthetic liners. The facility is designed to dispose of domestic sewage and site-generated brine waters from observation well pumping and from underground dewatering activities at the site.

The WIPP sewage facility is operated under the New Mexico Discharge Plan (DP-831) and managed in accordance with the EPA sewage sludge regulations (40 CFR 503), the New Mexico Solid Waste Management Regulations (Part 700), the New Mexico Water Quality Control Regulations (3-100), and the WIPP Sewage Sampling Procedure, WP 02-EM1001. These requirements provide guidance for disposal of domestic sewage, site generated brine waters, and site generated non hazardous waste waters.

A determination is made on a case-by-case basis to determine regulatory requirements for onsite or offsite disposal of sewage sludge. Sludges are useful as fertilizers and soil stabilizers when applied to reclamation areas, however, this particular technique has not been employed at the WIPP (although it remains one of many viable reclamation alternatives). In the event that sludges are considered for reclamation, they will be analyzed in accordance with regulatory requirements of 40 CFR 503 prior to application.

On January 16, 1992, the NMED issued the Discharge Plan (DP-831) for the WIPP sewage facility. The approved Discharge Plan superseded an Emergency Discharge Permit issued in January, 1992. In addition to sewage effluent, the Discharge Plan allows for the disposal of 1500 gallons a day of nonhazardous brines generated by seepage into shaft sumps and from the pumping of observation wells at the site. Characterization samples were collected throughout 1995 to demonstrate that site-generated brines are nonhazardous and can be disposed in the sewage evaporation pond. The DOE submits quarterly Discharge Monitoring Reports to the NMED to demonstrate compliance with the inspection, monitoring, and reporting requirements identified in the plan. No effluent limits were established in DP-831. The NMED Groundwater Protection and Remediation Bureau established a list of analytes to be sampled on a quarterly basis to be used as indicators of sewage system performance. Analytical results from DP-831 sampling activities are provided in Appendix B.

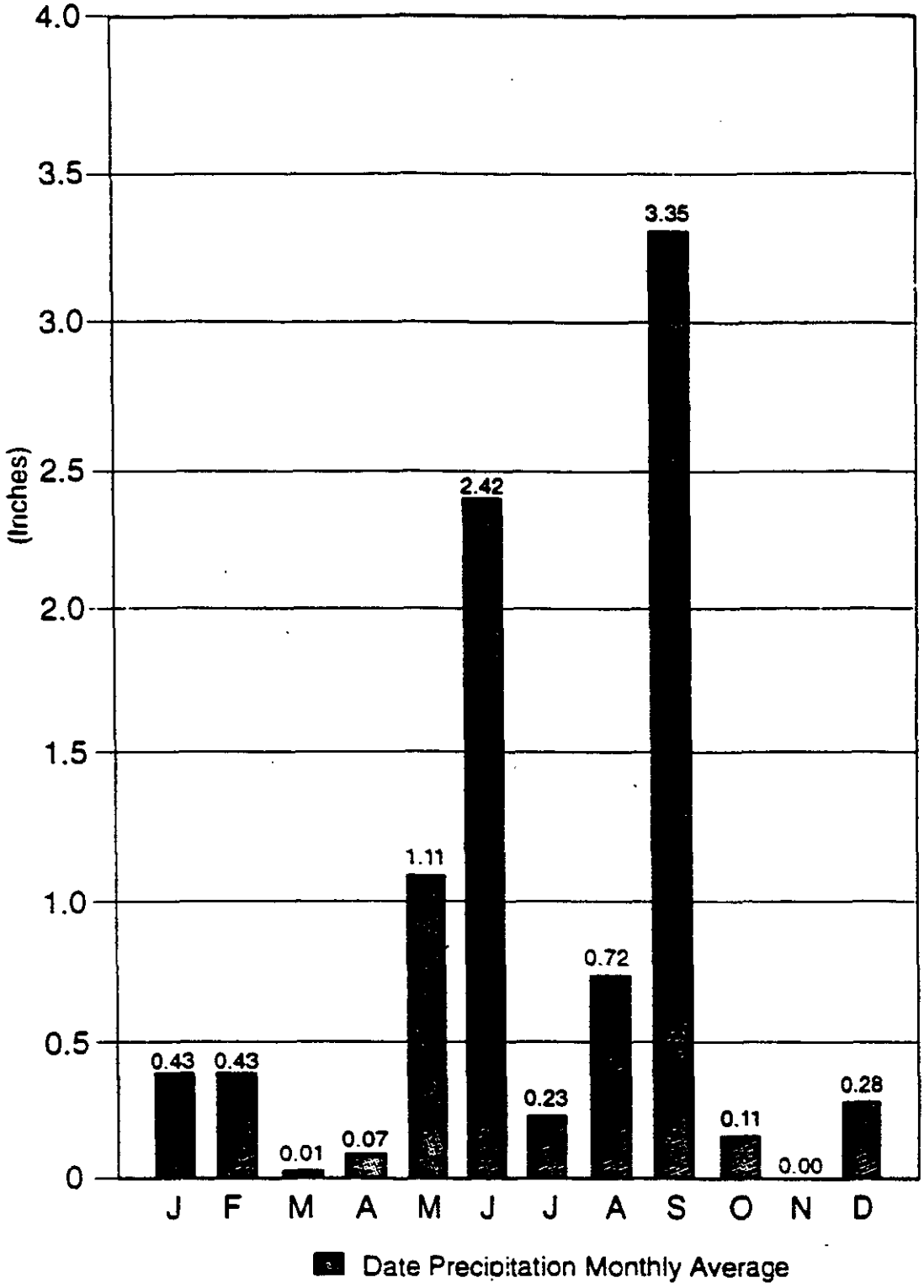

Figure 6-1
1995 Precipitation

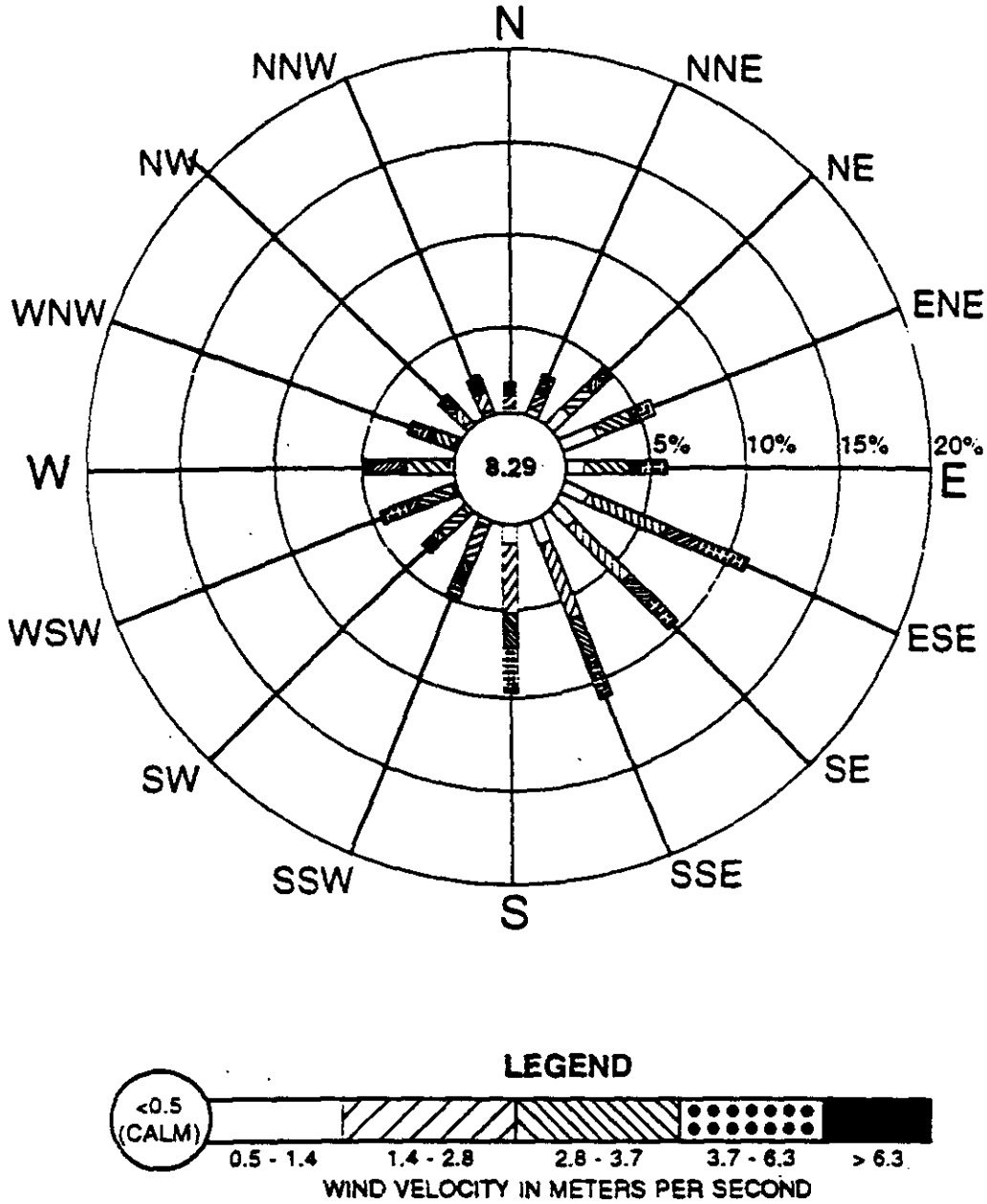

Figure 6-2
Annual Windrose

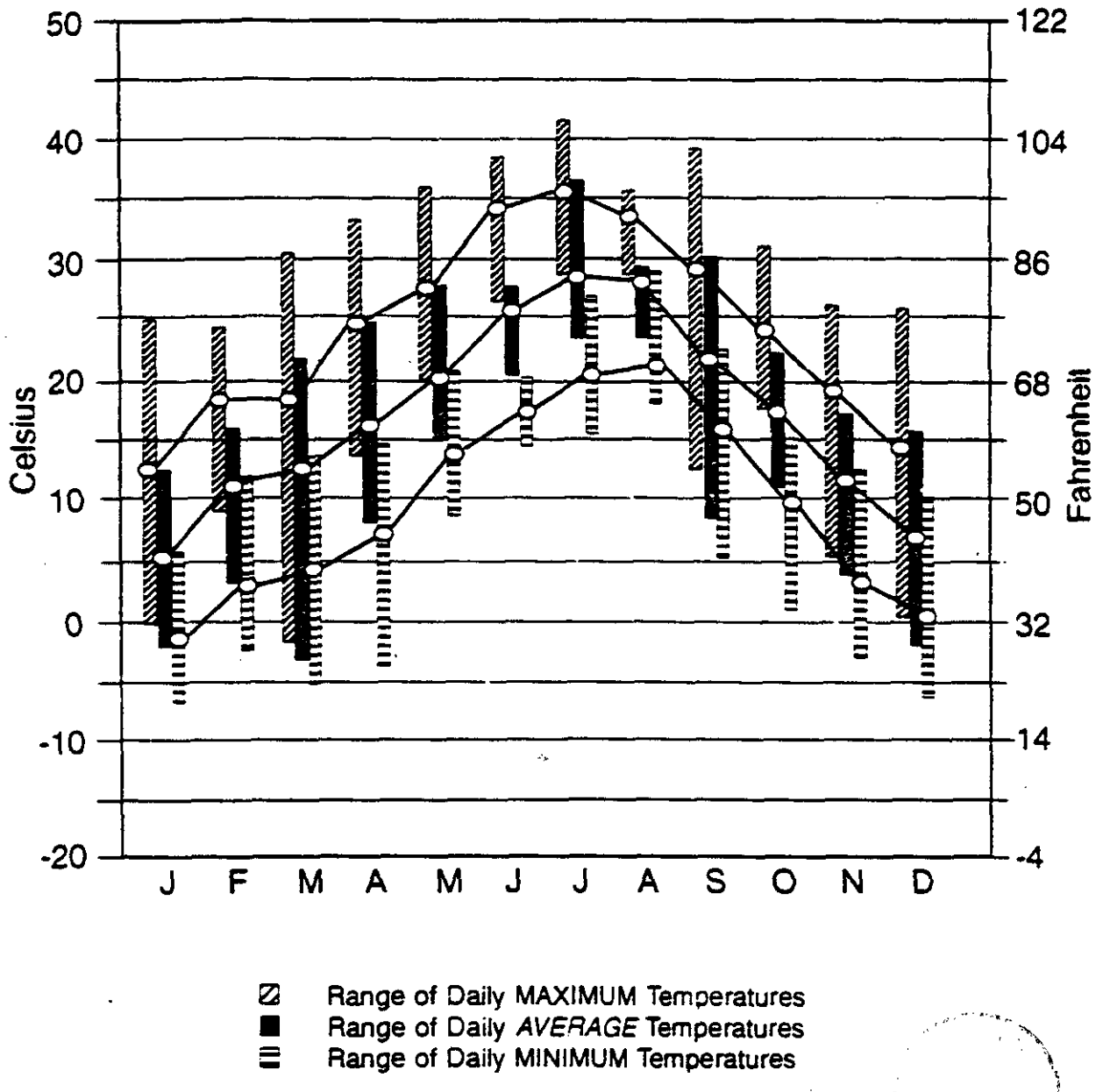

Figure 6-3
1995
Average Monthly Temperatures

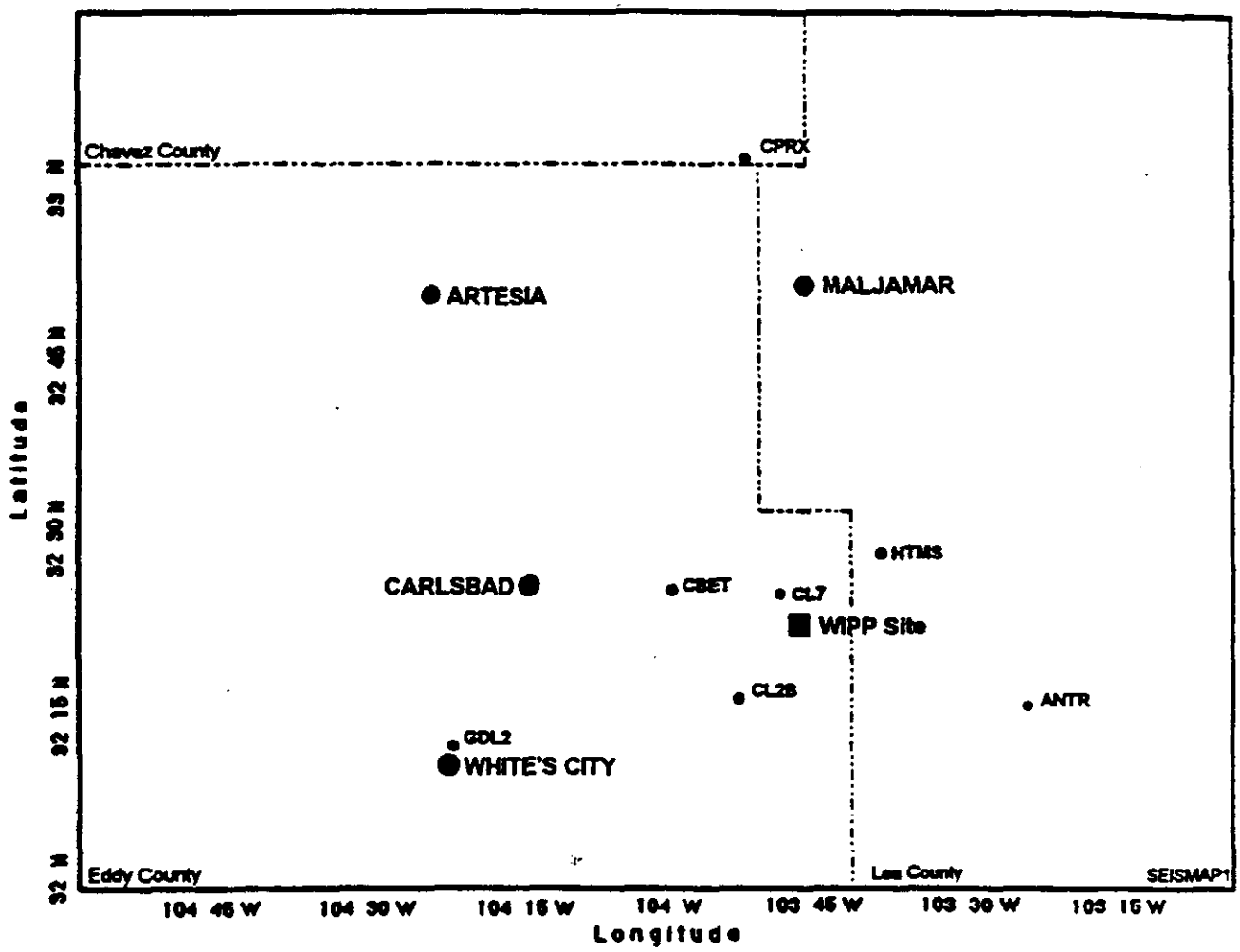

Definitions of Acronyms

ANTR-Antelope Ridge
CPRX-Caprock
CBET-Carlsbad East Tower
GDL2-Guadalupe Mountains
CL2B-Carlsbad Station
2BHTMS-Hat Mesa
CL7-Carlsbad Station 7

Figure 6-4
WIPP Seismograph Station Locations

Chapter 7
Groundwater Surveillance

Current groundwater surveillance activities at the WIPP are outlined in the WIPP *Groundwater Monitoring Program Plan and Procedure Manual* (WP 02-1 Rev 2). This monitoring plan is a Quality Assurance (QA) document that contains program plans for each of the activities performed by groundwater surveillance personnel. In addition, WP 02-1, Rev 2 provides detailed procedures for performing specific activities such as pumping system installations, field parameter analysis and document, and QA records management. Groundwater surveillance activities are also defined in the EMP.

The objective of the Groundwater Surveillance Program (GSP) is to determine the physical and chemical characteristics of groundwater, maintain surveillance of groundwater levels surrounding the WIPP facility, both before and throughout the operational lifetime of the facility, and fulfill the requirements set forth in DOE order 5400.1, *General Environmental Protection Program.*

Background water quality data were collected from 1985 through the 1990 sampling period as reported in DOE/WIPP 92-013, *Background Water Quality Characterization Report for the Waste Isolation Pilot Plant.* This background data will be compared to water quality data collected throughout the operational life of the facility. Pre-operational data gathered in the interim period will be used to strengthen the background data, to evaluate the need to make adjustments to comparison criteria, and to determine future regulatory needs and land-use decisions.

The data obtained by the Water Quality Sampling Program (WQSP) in 1995 supported two major programs at the WIPP: Site Characterization and Performance Assessment in compliance with 40 CFR 191. Each of these programs requires a unique set of analyses and data. Particular sample needs are defined by each program. In addition to the characterization of groundwater, the WQSP supported radionuclide monitoring for the Environmental Analysis and Compliance Section of WIPP. Results of radionuclide sampling are discussed in Chapter 5, *Environmental Radiological Program Information,* pages 5-3 through 5-4. The NMED and the EEG were on hand at each sampling event to collect samples for independent evaluation.

The WIPP is located within the Pecos Valley section of the Southern Great Plains physiographic province (Powers et al., 1978). Geologic and lithologic descriptions of the area surrounding the WIPP site can be found in documents such as the EMP, DOE/WIPP 90-008 *Groundwater Protection Management Program Plan*, and USGS 83-4016 (Mercer, 1983). Industries in the vicinity which

could potentially contribute to the pollution of the groundwater are potash mining, oil and gas exploration/production, and agriculture.

The Culebra is the most significant water-bearing unit within the vicinity of the WIPP. No known hydrologic connection exists between the repository horizon and the Culebra. Surveillance of hydrological characteristics in the Culebra provides data which can be used to detect changes in water characterization. It also provides additional data for use in hydrologic models designed to predict long term performance of the repository. Data is gathered from 64 well bores; five of which are equipped with production-inflated packers to allow groundwater level surveillance of more than one producing zone through the same well bore.

Groundwater Quality data were gathered from ten wells completed in the Culebra member of the Rustler formation and one well completed in the Dewey Lake formation. The water quality sampling process has been developed using logistics from groundwater wells originally constructed for characterization, not intended for groundwater monitoring activities. Seven wells were drilled in the latter part of 1994 constructed for the explicit purpose of gathering water quality data. These wells are constructed with fiberglass casing and screens that will not bias sample collection. In 1995 samples were collected from old as well as new wells.

By virtue of a Groundwater Monitoring Waiver, prepared under 40 CFR 265, the WIPP Project is not required to monitor groundwater to comply with the U.S. Environmental Protection Agency (EPA) RCRA. The WIPP GSP provides a basis for future compliance to the RCRA, as well as any other groundwater protection-related regulations, should the need arise.

The original wells are constructed with J-55 or K-55 iron casing. In order to decrease the sampling bias created by well construction deficiencies, combined with the low transmissibilities of the formations involved, a labor intensive sampling process has been initiated.

Sampling episodes are referred to as a "sampling round". Each sampling round consists of the collection of two types of samples: (1) serial samples and (2) final samples. Serial samples are taken periodically while the well is being purged. Key physical and chemical parameters (known as field parameters) are analyzed and compared with past serial sampling data, when available, until a chemical steady state has been reached. A chemical steady state is usually defined as $\pm$ 5 percent of the average of the three to five preceding parameter measurements made on the final day of serial sampling from preceeding sampling rounds. Stabilization of these field parameters is a function of purging and is used as an indicator to determine if the groundwater is representative of the zone being sampled. A final sample is collected when it has been determined that the pumped

groundwater has achieved a representative state. The sample is then sent off site to a contract laboratory for analysis.

Groundwater surveillance activities during CY 1995 consisted of two separate programs: Groundwater Quality Sampling and Groundwater Level Measurements.

7.1 Groundwater Quality

Sampling for groundwater quality was performed at 11 well sites during CY 1995 (Figure 7-1, page 7-6). Each of the iron cased wells were purged a minimum of 24 hours prior to the commencement of the serial sampling phase. The fiber glass cased wells were serially sampled as soon as possible after the pump was turned on to better observe early chemical reactions to pumping. Field analysis for Eh, pH, Specific Gravity, Specific Conductance, Alkalinity, Chloride, Divalent Cations, and Total Iron were performed on a periodic basis during the serial sampling. These field parameters were used as indicators, during the purging process to better determine when the formation water being pumped had reached a representative state. Normally this process required seven to ten days to complete for the iron cased wells and four-to-seven days for the fiber glass cased wells. Following the field analysis of the final serial sample, samples were collected and shipped to an independent, contracted, laboratory for analysis. Parameters of analysis by the contracted laboratory are listed in Table 7-1, page 7-10.

The total gallons of water removed from the Culebra as a result of groundwater surveillance activity was approximately 47,145 gallons throughout the year. The results of final sample analysis show relative consistency when compared to background data. Where background data are not available, analytical results are presented in tabular form. Tables 7-1.1 through 7-1.4, pages 7-11 through 7-14, contain average results of data collected from the Culebra dolomite during 1995 as compared to background data for major constituents of the background matrix. Tables 7-1.5 through 7-1.11, pages 7-15 through 7-28 contain first round data as reported by the contract laboratory. None of the waste stream Volatile Organic Compounds for which analysis were run showed any detectable concentrations.

Water quality of the Culebra in the vicinity of the WIPP is naturally poor and is not suitable for human consumption or for agricultural purposes. The water contains naturally high concentrations of total dissolved solids (TDS) and mineral constituents primarily of chloride, calcium, magnesium, sodium and potassium (Mercer, 1983). The high concentration of TDS results in water of

generally poor quality. This has historically posed problems for laboratories performing analysis because the water interferes with the normal operation of standard laboratory equipment such as Atomic Absorption or Iductively Coupled Argon Plasma, causing detection limits to be inconsistent

7.2 Groundwater Level Surveillance

In October 1988, WIPP was tasked with conducting a Groundwater Level Surveillance Program. Sixty four well bores were utilized to perform surveillance of seven water bearing zones in the WIPP area. The two zones of primary interest are the Culebra and Magenta. Fifty one measurements are taken in the Culebra; and ten, in the Magenta. Three measurements were taken in the Dewey Lake, two in the Rustler/Salado contact, one measurement each is taken in Bell Canyon, Forty-niner, and unnamed lower member. Locations of groundwater level surveillance sites are pictured in Figure 7-2, page 7-7.

Five wellbores are configured to allow monitoing of more than one formation. These are; H-01 Culebra/Magenta, H-03d Dewey Lake/Forty Niner, H-16 Dewey Lake/Unnamed Lower Member, Wipp-25 Culebra/Magenta, and WIPP-27 Culebra/Magenta.

Groundwater pump tests conducted by Sandia National Laboratories in support of the Culebra Transport Program have influenced groundwater level elevations for 1995. The pump tests primarily conducted southwest of the center of the site near WQSP-4 and DOE-1 have influenced groundwater elevations for virtually all Culebra wells located in the southwestern quadrant of the WIPP Land Withdrawal Area.

Groundwater elevation measurements in the Culebra indicate that the generalized directional flow of groundwater is north to south in the vicinity of WIPP (Figure 7-3, page 7-8). However, caution should be used when making assumptions based on groundwater level data alone. One should also be aware that the fractured media of the Culebra, coupled with variable fluid densities, can cause localized flow patterns to have little or no relationship to general flow patterns (Mercer 1983, Crawley 1988).

Regional groundwater levels taken in the Culebra show no significant increase or decrease in the water level elevation over the period of January 1995 through December 1995. Groundwater level elevations within the WIPP site boundaries were affected by groundwater quality sampling activities and the Culebra transport program pumping tests currently being conducted by Sandia National Laboratories.

Groundwater flow directions in the Magenta appear to be generally from an east to west direction across the WIPP site (Figure 7-4, page 7-9). No studies have been performed in the Magenta to determine spacial variations in the fluid densities of the magnitude studied in the Culebra. It is probable that density variations do occur in the Magenta; therefore, the potential may exist that flow patterns in the Magenta may be affected by variations in fluid density. Also, flow through the fractured media of the Magenta may dictate the behavior of localized flow patterns.

Regional groundwater level measurements taken in the Magenta dolomite indicate that water levels are increasing in wells located near the center of the site. While water levels near or outside the WIPP boundary appear to be relatively stable.

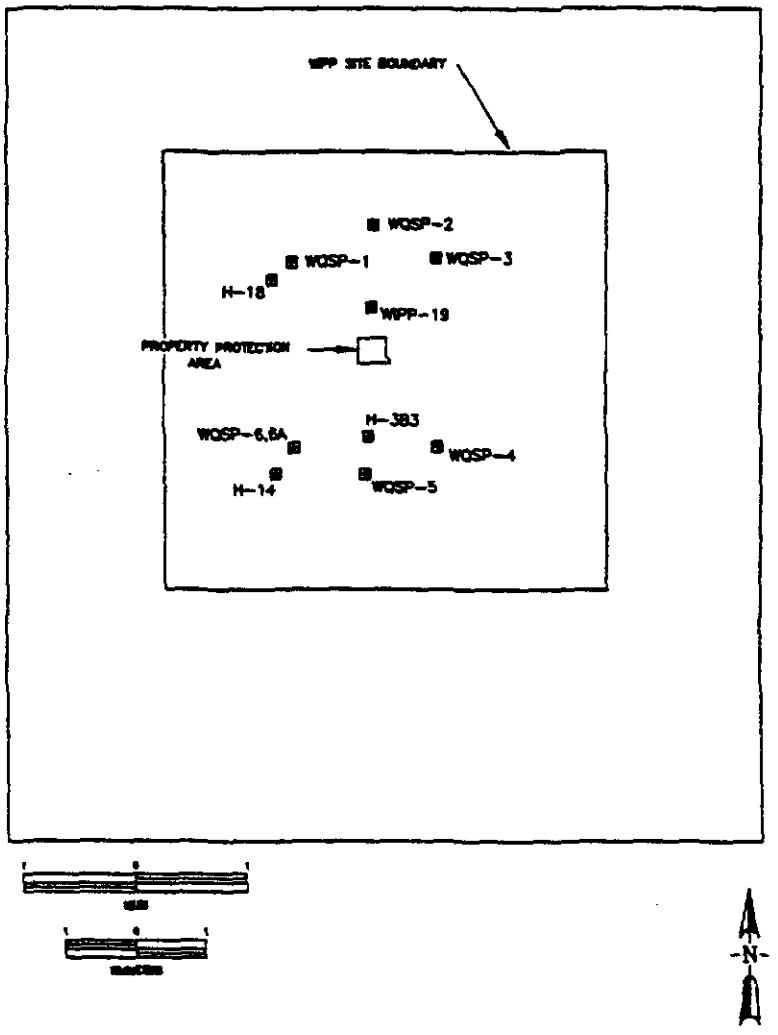

FIGURE 7-1 WATER QUALITY SAMPLING PROGRAM SAMPLE WELLS 1995

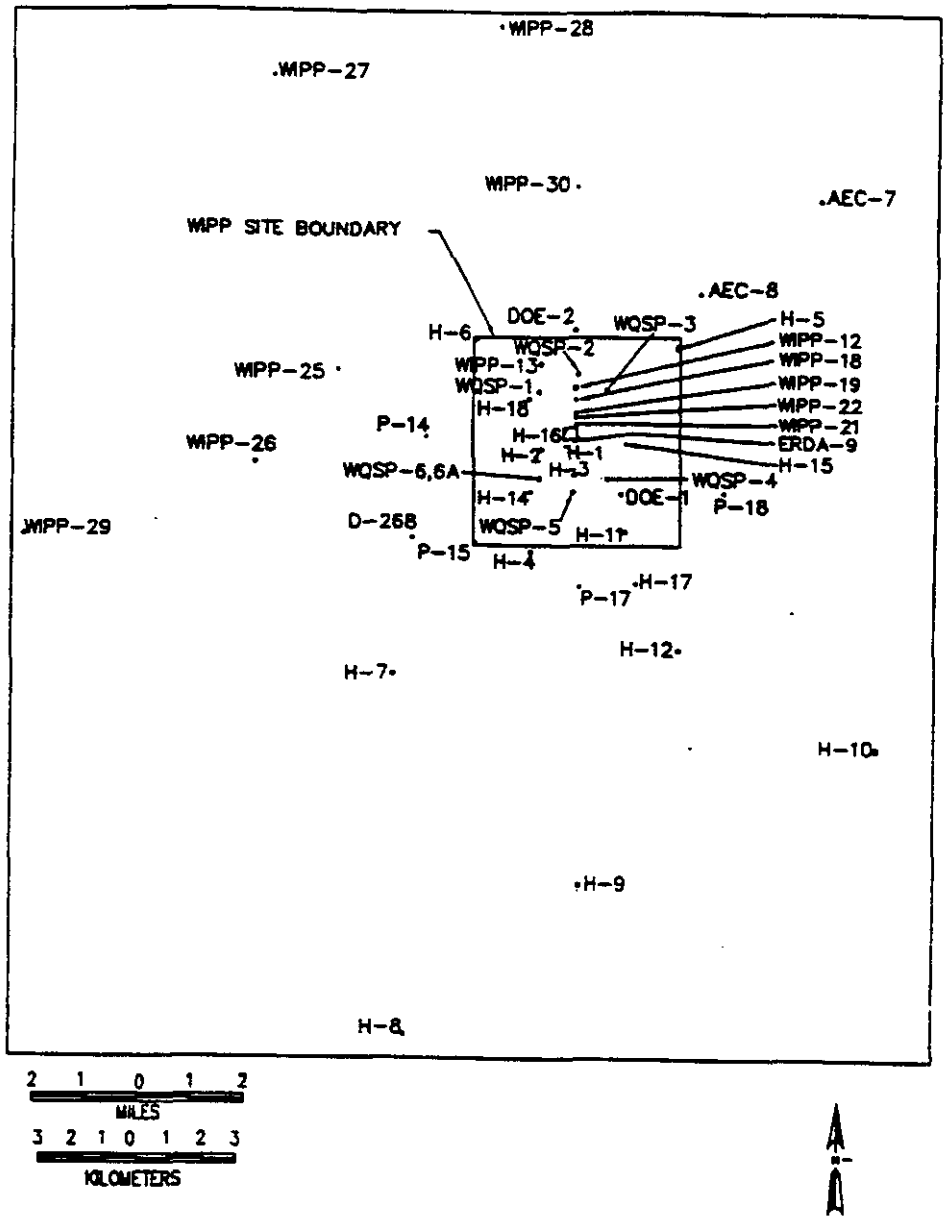

FIGURE 7-2 GROUND WATER LEVEL SURVEILLANCE WELLS

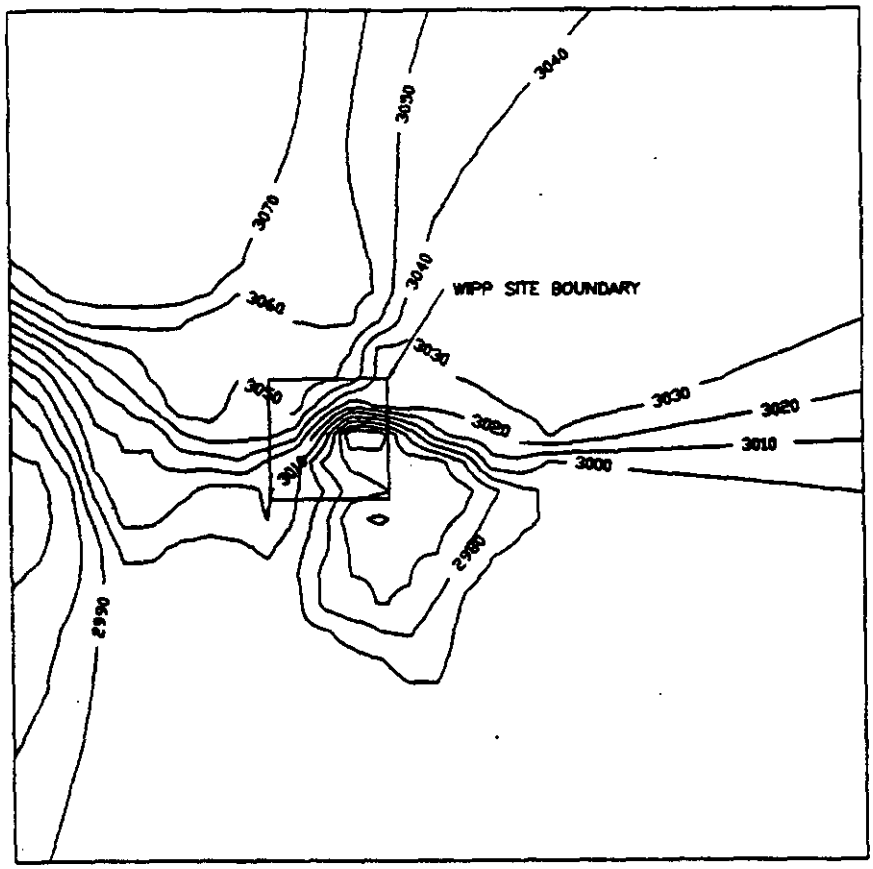

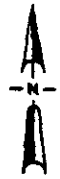

FIGURE 7-3 POTENTIOMETRIC SURFACE OF THE CULEBRA DOLOMITE MEMBER OF THE RUSTLER FORMATION NEAR THE WIPP SITE AS OF 12/95

NOTE: CONTOUR LINE ELEVATION IN FEET ABOVE MEAN SEA LEVEL

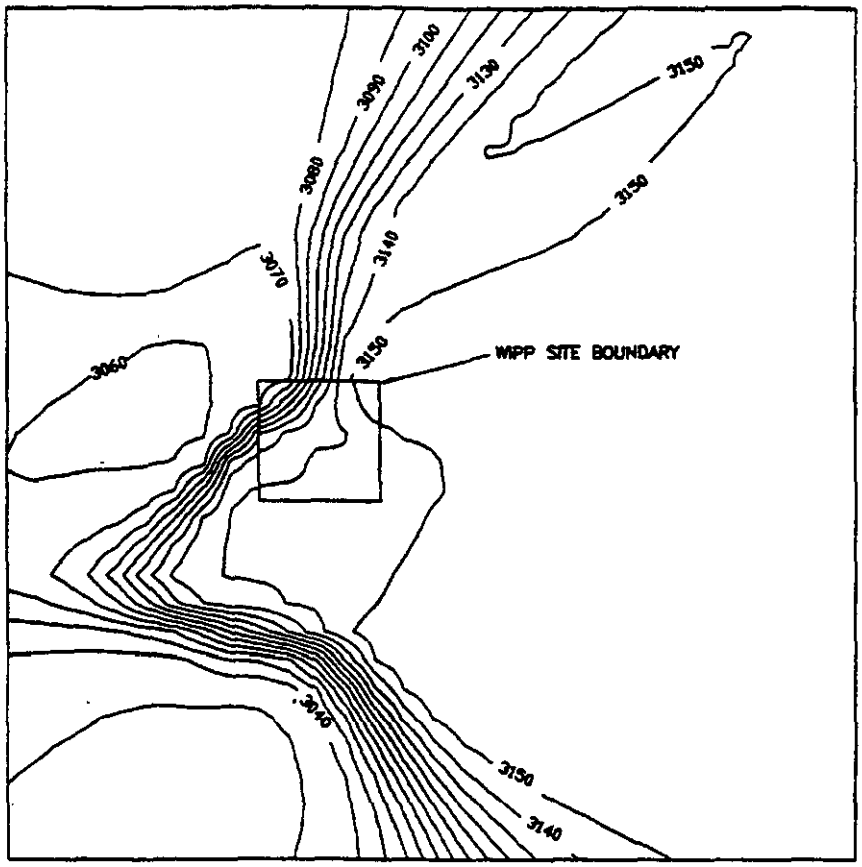

FIGURE 7-4 POTENTIOMETRIC SURFACE OF THE MAGENTA DOLOMITE MEMBER OF THE RUSTLER FORMATION NEAR THE WIPP SITE AS OF 12/95

NOTE: CONTOUR LINE ELEVATION IN FEET ABOVE MEAN SEA LEVEL

TABLE 7-1
PARAMETERS ANALYZED
DURING
CALENDAR YEAR 1995

SPECIFIC CONDUCTANCE	BORON
SULFATE	CADMIUM
TOTAL DISSOLVED SOLIDS	CALCIUM
TOTAL SUSPENDED SOLIDS	CHROMIUM
DENSITY	IRON
pH	LEAD
ALKALINITY	LITHIUM
BROMIDE	MAGNESIUM
CHLORIDE	MERCURY
FLUORIDE	POTASSIUM
IODIDE	SELENIUM
NITROGEN, NO3 (AS N)	SILICA
TOTAL ORGANIC CARBON	SILVER
TOTAL ORGANIC HALOGENS	SODIUM
PHENOL, TOTAL	CARBON TETRACHLORIDE
ORTHOPHOSPHATE (AS P)	METHYLENE CHLORIDE
ARSENIC	TRICHLOROETHYLENE
BARIUM	1,1,1-TRICHLOROETHANE
BERYLLIUM	FREON-113

TABLE 7-1.1
H-03b3, CULEBRA
ROUND 10 COMPARISON TO BACKGROUND CHARACTERIZATION

PARAMETER	1995 AVERAGE CONCENTRATION mg/l	BACKGROUND CONCENTRATION INTERVAL mg/l
BORON	24.05	19-32
CALCIUM	1.345	1,193-1,527
IRON	<1.00	0.14-0.47
LITHIUM	0.356	0.15-0.82
MAGNESIUM	685	710-826
POTASSIUM	364	372-534
SODIUM	15.000	16,140-17,900
ALKALINITY	43.3	46-54
BROMIDE	26.15	7-41
CHLORIDE	28,950	26,742-30,838
FLUORIDE	<3.00	1.5-1.6
pH	7.46	6.85-7.66
SULFATE	5,408	4,537-4,823
TOTAL DISSOLVED SOLIDS	55,600	53,130-55,170
ARSENIC	<0.006	<0.10
BARIUM	<0.02	≤0.06
BERYLLIUM	<0.01	≤0.15
CADMIUM	<0.0057	≤0.07
CHROMIUM	<0.0025	0.007-0.4
LEAD	<0.013	≤0.50
MERCURY	<0.002	<0.001
SELENIUM	<0.006	<0.50
SILICA	16.5	4.5-13
SILVER	0.035	≤0.10
IODIDE	<2.00	<2.0
NITRATE AS (N)	0.22	<0.20
PHENOLICS	<0.10	≤0.033
PHOSPHATE AS (P)	<0.02	≤0.06
TOTAL ORGANIC CARBON	0.98	≤2.0
TOTAL ORGANIC HALOGEN	0.079	0.14-0.42

TABLE 7-1.2
H-14, CULEBRA
ROUND 8 COMPARISON TO BACKGROUND CHARACTERIZATION

PARAMETER	1995 AVERAGE CONCENTRATION mg/l	BACKGROUND CONCENTRATION INTERVAL mg/l
BORON	11.7	11
CALCIUM	1,770	1,504-2,129
IRON	1.12	0.1-0.8
LITHIUM	0.389	.039-0.56
MAGNESIUM	527	451-613
POTASSIUM	217	233-257
SODIUM	3,200	2,750-4,184
ALKALINITY	29.9	35-43
BROMIDE	9.59	9-18
CHLORIDE	9,997	6,954-9,779
FLUORIDE	<3.00	0.1-2.6
pH	7.59	5.89-8.50
SULFATE	2,112	1,209-2,291
TOTAL DISSOLVED SOLIDS	18,217	14,066-19,867
ARSENIC	<0.002	<0.05
BARIUM	0.024	<0.05
BERYLLIUM	<0.04	<0.05
CADMIUM	<0.0013	≤0.06
CHROMIUM	<0.0025	0.2-0.4
LEAD	<0.0125	≤0.5
MERCURY	<0.0002	≤0.0004
SELENIUM	<0.002	<0.05
SILICA	10.08	5.5-14
SILVER	<0.0025	≤0.1
IODIDE	<2.00	<2.0
NITRATE AS (N)	<.10	≤0.40
PHENOLICS	<0.10	0.068-0.14
PHOSPHATE AS (P)	<0.2	≤0.05
TOTAL ORGANIC CARBON	1.58	≤2.0
TOTAL ORGANIC HALOGEN	0.106	0.08-1.1

TABLE 7-1.3
H-18, CULEBRA
ROUND 4 COMPARISON TO BACKGROUND CHARACTERIZATION

PARAMETER	1995 AVERAGE CONCENTRATION mg/l	BACKGROUND CONCENTRATION INTERVAL mg/l
BORON	16.95	14-18
CALCIUM	1,180	820-1,367
IRON	<1.0	0-0.7
LITHIUM	0.28	0.04-0.44
MAGNESIUM	511	452-555
POTASSIUM	192.5	207-270
SODIUM	7,420	5,967-9,266
ALKALINITY	53.9	46-61
BROMIDE	13.0	11-19
CHLORIDE	14,650	11,258-13,742
FLUORIDE	<3.0	1.4-2.1
pH	7.67	4.87-8.98
SULFATE	4,035	2,150-6,317
TOTAL DISSOLVED SOLIDS	29,300	18,919-36,347
ARSENIC	<0.001	<0.05
BARIUM	<0.04	<0.05
BERYLLIUM	<0.02	<0.05
CADMIUM	<0.0022	<0.05
CHROMIUM	0.0036	≤0.2
LEAD	<0.013	<0.5
MERCURY	<0.002	<0.0002
SELENIUM	<0.001	<0.5
SILICA	9.98	5.1-13
SILVER	0.0063	<0.1
IODIDE	<2.00	<2.0
NITRATE AS (N)	<0.10	≤0.2
PHENOLICS	<0.10	≤0.12
PHOSPHATE AS (P)	<0.02	≤0.03
TOTAL ORGANIC CARBON	0.93	≤5.0
TOTAL ORGANIC HALOGEN	0.063	≤0.42

TABLE 7-1.4
WIPP-19, CULEBRA
ROUND 10 COMPARISON TO BACKGROUND CHARACTERIZATION

PARAMETER	1995 AVERAGE CONCENTRATION mg/l	BACKGROUND CONCENTRATION INTERVAL mg/l
BORON	28.5	27-34
CALCIUM	1,440	1,441-1,919
IRON	1.76	≤2.0
LITHIUM	0.43	0.3-1.1
MAGNESIUM	900	961-2,239
POTASSIUM	486	565-913
SODIUM	23,000	23,962-32,658
ALKALINITY	43.3	51-70
BROMIDE	46.2	22-126
CHLORIDE	34,750	33,201-54,520
FLUORIDE	<3.00	0.8-1.1
pH	7.60	6.75-7.33
SULFATE	6,590	5,097-5,763
TOTAL DISSOLVED SOLIDS	65,800	68,389-103,151
ARSENIC	<0.005	<0.5
BARIUM	<0.04	<0.50
BERYLLIUM	<0.02	<0.50
CADMIUM	<0.0013	<0.50
CHROMIUM	<0.0025	≤2.0
LEAD	<0.013	<5.0
MERCURY	<0.0002	<0.002
SELENIUM	<0.005	<0.50
SILICA	9.20	≤4.40
SILVER	0.0035	<1.0
IODIDE	<2.00	<2.0
NITRATE AS (N)	<0.10	≤0.12
PHENOLICS	<0.1	≤0.019
PHOSPHATE AS (P)	<0.02	≤0.03
TOTAL ORGANIC CARBON	1.07	2-7
TOTAL ORGANIC HALOGEN	0.67	0.57-3.2

TABLE 7-1.5
WQSP-1, CULEBRA
ROUND ONE ANALYTICAL RESULTS

PARAMETER	VALUE	DUPLICATE	UNIT	AVERAGE
SPECIFIC CONDUCTANCE	83400.0000	83800.0000	umhos/cm	83600.0000
SULFATE	5230.0000	5490.0000	mg/l	5360.0000
TOTAL DISS SOLIDS	77400.0000	77600.0000	mg/l	77500.0000
TOTAL SUSP SOLIDS	<10.0000	<10.0000	mg/l	<10.0000
DENSITY	1.0530	1.0530	g/mL	1.0530
pH	7.0900	7.1100	SU	7.1000
ALKALINITY	46.5000	47.5000	mg/l	47.0000
BROMIDE	44.9000	45.1000	mg/l	45.0000
CHLORIDE	34500.0000	35000.0000	mg/l	34750.0000
FLUORIDE	<2.0000	<2.0000	mg/l	<2.0000
IODIDE	<2.0000	<2.0000	mg/l	<2.0000
NITROGEN, NO3 (AS N)	<0.0100	<0.0100	mg/l	<0.0100
TOTAL ORGANIC CARBON	1.4900	1.4700	mg/l	1.4800
TOTAL ORGANIC HALOGENS	0.0290	0.0220	mg/l	0.0255
PHENOL, TOTAL	<0.0100	<0.0100	mg/l	<0.0100
ORTHOPHOSPHATE (AS P)	0.0200	0.0200	mg/l	0.0200
ARSENIC	<0.0100	<0.0010	mg/l	<0.0055
BARIUM	<0.0400	<0.0400	mg/l	<0.0400
BERYLLIUM	<0.0200	<0.0200	mg/l	<0.0200
BORON	14.0000	13.6000	mg/l	13.8000
CADMIUM	<0.0013	<0.0013	mg/l	<0.0013
CALCIUM	1700.0000	1670.0000	mg/l	1685.0000
CHROMIUM	<0.0025	<0.0025	mg/l	<0.0025
IRON	<1.0000	<1.0000	mg/l	<1.0000
LEAD	<0.0130	<0.0130	mg/l	<0.0130
LITHIUM	0.4170	0.4140	mg/l	0.4155
MAGNESIUM	1110.0000	1080.0000	mg/l	1095.0000
MERCURY	<0.0002	<0.0002	mg/l	<0.0002
POTASSIUM	497.0000	474.0000	mg/l	485.5000
SELENIUM	<0.0100	<0.0100	mg/l	<0.0100

TABLE 7-1.5
WQSP-1, CULEBRA
ROUND ONE ANALYTICAL RESULTS

SILICA	9.1800	9.4900	mg/l	9.3350
SILVER	<0.0025	<0.0025	mg/l	<0.0025
SODIUM	20100.0000	19800.0000	mg/l	19950.0000
CARBON TETRACHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
METHYLENE CHLORIDE	0.0170	0.0160	mg/l	0.0165
TRICHLOROETHYLENE	<0.0050	<0.0050	mg/l	<0.0050
1,1,1-TRICHLOROETHANE	<0.0050	<0.0050	mg/l	<0.0050
FREON-113	<0.0050	<0.0050	mg/l	<0.0050

TABLE 7-1.6
WQSP-2, CULEBRA
ROUND ONE ANALYTICAL RESULTS

PARAMETER	VALUE	DUPLICATE	UNIT	AVERAGE
SPECIFIC CONDUCTANCE	80100.0000	79900.0000	umhos/cm	80000.0000
SULFATE	5540.0000	5470.0000	mg/l	5505.0000
TOTAL DISS SOLIDS	67600.0000	67600.0000	mg/l	67600.0000
TOTAL SUSP SOLIDS	38.0000	44.0000	mg/l	41.0000
DENSITY	1.0600	1.0500	g/mL	1.0550
pH	7.3300	7.3300	SU	7.3300
ALKALINITY	52.5000	5.2500	mg/l	28.8750
BROMIDE	33.3000	33.8000	mg/l	33.5500
CHLORIDE	38500.0000	38500.0000	mg/l	38500.0000
FLUORIDE	<2.0000	<2.0000	mg/l	<2.0000
IODIDE	<2.0000	<2.0000	mg/l	<2.0000
NITROGEN, NO3 (AS N)	<0.1000	<0.1000	mg/l	<0.1000
TOTAL ORGANIC CARBON	<4.0000	<4.0000	mg/l	<4.0000
TOTAL ORGANIC HALOGENS	24.4000	63.8000	mg/l	44.1000
PHENOL, TOTAL	<0.1000	<0.1000	mg/l	<0.1000
ORTHOPHOSPHATE (AS P)	<0.0200	<0.0200	mg/l	<0.0200
ARSENIC	<0.0100	<0.0100	mg/l	<0.0100
BARIUM	<0.0400	<0.0400	mg/l	<0.0400
BERYLLIUM	<0.0200	<0.0200	mg/l	<0.0200
BORON	17.2000	17.2000	mg/l	17.2000
CADMIUM	<0.0013	<0.0013	mg/l	<0.0013
CALCIUM	1460.0000	1450.0000	mg/l	1455.0000
CHROMIUM	<0.0025	<0.0025	mg/l	<0.0025
IRON	<1.0000	<1.0000	mg/l	<1.0000
LEAD	<0.0130	<0.0130	mg/l	<0.0130
LITHIUM	<0.3910	<0.3870	mg/l	<0.3890
MAGNESIUM	966.0000	960.0000	mg/l	963.0000
MERCURY	<0.0010	<0.0010	mg/l	<0.0010
POTASSIUM	450.0000	446.0000	mg/l	448.0000
SELENIUM	<0.0100	<0.0100	mg/l	<0.0100

TABLE 7-1.6
WQSP-2, CULEBRA
ROUND ONE ANALYTICAL RESULTS

SILICA	7.3500	7.9700	mg/l	7.6600
SILVER	<0.0025	<0.0025	mg/l	<0.0025
SODIUM	19100.0000	18400.0000	mg/l	18750.0000
CARBON TETRACHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
METHYLENE CHLORIDE	<0.0050	0.0050	mg/l	<0.0050
TRICHLOROETHYLENE	<0.0050	<0.0050	mg/l	<0.0050
1,1,1-TRICHLOROETHANE	<0.0050	<0.0050	mg/l	<0.0050
FREON-113	<0.0050	<0.0050	mg/l	<0.0050

TABLE 7-1.7
WQSP-3, CULEBRA
ROUND ONE ANALYTICAL RESULTS

PARAMETER	VALUE	DUPLICATE	UNIT	AVERAGE
SPECIFIC CONDUCTANCE	193000.0000	194000.0000	umhos/cm	193500.0000
SULFATE	6710.0000	6700.0000	mg/l	6705.0000
TOTAL DISS SOLIDS	218000.0000	219000.0000	mg/l	218500.0000
TOTAL SUSP SOLIDS	71.0000	74.0000	mg/l	72.5000
DENSITY	1.1400	1.1300	g/mL	1.1350
pH	7.1200	7.1100	SU	7.1150
ALKALINITY	44.0000	44.0000	mg/l	44.0000
BROMIDE	100.0000	105.0000	mg/l	102.5000
CHLORIDE	130000.0000	138000.0000	mg/l	134000.0000
FLUORIDE	<2.0000	<2.0000	mg/l	<2.0000
IODIDE	<2.0000	<2.0000	mg/l	<2.0000
NITROGEN, NO3 (AS N)	<0.1000	<0.1000	mg/l	<0.1000
TOTAL ORGANIC CARBON	1.3800	1.3400	mg/l	1.3600
TOTAL ORGANIC HALOGENS	0.1660	0.1470	mg/l	0.1565
PHENOL, TOTAL	<0.1000	<0.1000	mg/l	<0.1000
ORTHOPHOSPHATE (AS P)	<0.0200	<0.0200	mg/l	<0.0200
ARSENIC	<0.0100	<0.0100	mg/l	<0.0100
BARIUM	<0.1600	<0.1600	mg/l	<0.1600
BERYLLIUM	<0.0800	<0.0800	mg/l	<0.0800
BORON	50.1000	48.5000	mg/l	49.3000
CADMIUM	<0.0013	<0.0013	mg/l	<0.0013
CALCIUM	1420.0000	1350.0000	mg/l	1385.0000
CHROMIUM	0.0027	0.0025	mg/l	0.0026
IRON	<4.0000	<4.0000	mg/l	<4.0000
LEAD	<0.0130	<0.0130	mg/l	<0.0130
LITHIUM	<0.8000	<0.8000	mg/l	<0.8000
MAGNESIUM	2210.0000	2110.0000	mg/l	2160.0000
MERCURY	<0.0010	<0.0010	mg/l	<0.0010
POTASSIUM	1380.0000	1310.0000	mg/l	1345.0000
SELENIUM	<0.0100	<0.0100	mg/l	<0.0100

TABLE 7-1.7
WQSP-3, CULEBRA
ROUND ONE ANALYTICAL RESULTS

SILICA	4.4600	4.6800	mg/l	4.5700
SILVER	<0.0025	<0.0025	mg/l	<0.0025
SODIUM	79100.0000	76700.0000	mg/l	77900.0000
CARBON TETRACHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
METHYLENE CHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
TRICHLOROETHYLENE	<0.0050	<0.0050	mg/l	<0.0050
1,1,1-TRICHLOROETHANE	<0.0050	<0.0050	mg/l	<0.0050
FREON-113	<0.0050	<0.0050	mg/l	<0.0050

TABLE 7-1.8
WQSP-4, CULEBRA
ROUND ONE ANALYTICAL RESULTS

PARAMETER	VALUE	DUPLICATE	UNIT	AVERAGE
SPECIFIC CONDUCTANCE	107000.0000	106000.0000	umhos/cm	106500.0000
SULFATE	7100.0000	7050.0000	mg/l	7075.0000
TOTAL DISS SOLIDS	108000.0000	108000.0000	mg/l	108000.0000
TOTAL SUSP SOLIDS	55.0000	59.0000	mg/l	57.0000
DENSITY	1.0800	1.0800	g/mL	1.0800
pH	7.1600	7.1700	SU	7.1650
ALKALINITY	40.0000	42.0000	mg/l	41.0000
BROMIDE	55.7000	52.6000	mg/l	54.1500
CHLORIDE	61200.0000	60700.0000	mg/l	60950.0000
FLUORIDE	<2.0000	<2.0000	mg/l	<2.0000
IODIDE	<2.0000	<2.0000	mg/l	<2.0000
NITROGEN, NO3 (AS N)	<0.1000	<0.1000	mg/l	<0.1000
TOTAL ORGANIC CARBON	1.2000	1.1700	mg/l	1.1850
TOTAL ORGANIC HALOGENS	0.0590	0.0200	mg/l	0.0395
PHENOL, TOTAL	<0.1000	<0.1000	mg/l	<0.1000
ORTHOPHOSPHATE (AS P)	<0.0200	<0.0200	mg/l	<0.0200
ARSENIC	<0.0080	<0.0080	mg/l	<0.0080
BARIUM	<0.1600	<0.1600	mg/l	<0.1600
BERYLLIUM	<0.0800	<0.0800	mg/l	<0.0800
BORON	33.7000	33.4000	mg/l	33.5500
CADMIUM	<0.1300	<0.0013	mg/l	<0.0657
CALCIUM	1710.0000	1650.0000	mg/l	1680.0000
CHROMIUM	<0.0025	<0.0025	mg/l	<0.0025
IRON	<4.0000	<4.0000	mg/l	<4.0000
LEAD	<0.0130	<0.0130	mg/l	<0.0130
LITHIUM	<0.8000	<0.8000	mg/l	<0.8000
MAGNESIUM	1270.0000	1230.0000	mg/l	1250.0000
MERCURY	<0.0010	<0.0010	mg/l	<0.0010
POTASSIUM	764.0000	732.0000	mg/l	748.0000
SELENIUM	<0.0100	<0.0100	mg/l	<0.0100

TABLE 7-1.8
WQSP-4, CULEBRA
ROUND ONE ANALYTICAL RESULTS

SILICA	6.0500	6.1000	mg/l	6.0750
SILVER	<0.0025	<0.0025	mg/l	<0.0025
SODIUM	35900.0000	34400.0000	mg/l	35150.0000
CARBON TETRACHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
METHYLENE CHLORIDE	0.0100	0.0100	mg/l	0.0100
TRICHLOROETHYLENE	<0.0050	<0.0050	mg/l	<0.0050
1,1,1-TRICHLOROETHANE	<0.0050	<0.0050	mg/l	<0.0050
FREON-113	<0.0050	<0.0050	mg/l	<0.0050

TABLE 7-1.9
WQSP-5, CULEBRA
ROUND ONE ANALYTICAL RESULTS

PARAMETER	VALUE	DUPLICATE	UNIT	AVERAGE
SPECIFIC CONDUCTANCE	43100.0000	43200.0000	umhos/cm	43150.0000
SULFATE	5370.0000	5380.0000	mg/l	5375.0000
TOTAL DISS SOLIDS	43800.0000	44100.0000	mg/l	43950.0000
TOTAL SUSP SOLIDS	<10.0000	<10.0000	mg/l	<10.0000
DENSITY	1.0300	1.0280	g/mL	1.0290
pH	7.8000	7.8000	SU	7.8000
ALKALINITY	52.0000	50.0000	mg/l	51.0000
BROMIDE	21.3000	21.7000	mg/l	21.5000
CHLORIDE	15000.0000	14800.0000	mg/l	14900.0000
FLUORIDE	<3.0000	<3.0000	mg/l	<3.0000
IODIDE	<2.0000	<2.0000	mg/l	<2.0000
NITROGEN, NO3 (AS N)	<0.1000	<0.1000	mg/l	<0.1000
TOTAL ORGANIC CARBON	1.8700	2.0200	mg/l	1.9450
TOTAL ORGANIC HALOGENS	0.0549	0.0526	mg/l	0.0538
PHENOL, TOTAL	<0.1000	<0.1000	mg/l	<0.1000
ORTHOPHOSPHATE (AS P)	<0.0200	<0.0200	mg/l	<0.0200
ARSENIC	<0.0130	<0.0130	mg/l	<0.0130
BARIUM	<0.0400	<0.0400	mg/l	<0.0400
BERYLLIUM	<0.0200	<0.0200	mg/l	<0.0200
BORON	30.3000	30.1000	mg/l	30.2000
CADMIUM	<0.0025	<0.0025	mg/l	<0.0025
CALCIUM	987.0000	982.0000	mg/l	984.5000
CHROMIUM	<0.0130	<0.0130	mg/l	<0.0130
IRON	<1.0000	<1.0000	mg/l	<1.0000
LEAD	<0.0130	<0.0130	mg/l	<0.0130
LITHIUM	0.3500	0.3640	mg/l	0.3570
MAGNESIUM	434.0000	432.0000	mg/l	433.0000
MERCURY	<0.0010	<0.0010	mg/l	<0.0010
POTASSIUM	286.0000	286.0000	mg/l	286.0000
SELENIUM	<0.0130	<0.0130	mg/l	<0.0130

TABLE 7-1.9
WQSP-5, CULEBRA
ROUND ONE ANALYTICAL RESULTS

SILICA	11.0000	10.9000	mg/l	10.9500
SILVER	<0.0130	<0.0130	mg/l	<0.0130
SODIUM	8880.0000	8900.0000	mg/l	8890.0000
CARBON TETRACHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
METHYLENE CHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
TRICHLOROETHYLENE	<0.0050	<0.0050	mg/l	<0.0050
1,1,1-TRICHLOROETHANE	<0.0050	<0.0050	mg/l	<0.0050
FREON-113	<0.0050	<0.0050	mg/l	<0.0050

TABLE 7-1.10
WQSP-6, CULEBRA
ROUND ONE ANALYTICAL RESULTS

PARAMETER	VALUE	DUPLICATE	UNIT	AVERAGE
SPECIFIC CONDUCTANCE	27200.0000	27100.0000	umhos/cm	27150.0000
SULFATE	5590.0000	5340.0000	mg/l	5465.0000
TOTAL DISS SOLIDS	21600.0000	21600.0000	mg/l	21600.0000
TOTAL SUSP SOLIDS	15.0000	14.5000	mg/l	14.7500
DENSITY	0.9990	1.0000	g/mL	0.9995
pH	7.8100	7.8000	SU	7.8050
ALKALINITY	52.5000	52.5000	mg/l	52.5000
BROMIDE	11.2000	10.7000	mg/l	10.9500
CHLORIDE	15800.0000	15800.0000	mg/l	15800.0000
FLUORIDE	<2.0000	<2.0000	mg/l	<2.0000
IODIDE	1.4300	1.5900	mg/l	1.5100
NITROGEN, NO3 (AS N)	<0.1000	<0.1000	mg/l	<0.1000
TOTAL ORGANIC CARBON	1.1100	1.1600	mg/l	1.1350
TOTAL ORGANIC HALOGENS	0.0600	0.0310	mg/l	0.0455
PHENOL, TOTAL	<0.1000	<0.1000	mg/l	<0.1000
ORTHOPHOSPHATE (AS P)	<0.0200	<0.0200	mg/l	<0.0200
ARSENIC	<0.0040	<0.0040	mg/l	<0.0040
BARIUM	<0.0400	<0.0400	mg/l	<0.0400
BERYLLIUM	<0.0200	<0.0200	mg/l	<0.0200
BORON	16.6000	16.9000	mg/l	16.7500
CADMIUM	<0.0013	<0.0013	mg/l	<0.0013
CALCIUM	719.0000	731.0000	mg/l	725.0000
CHROMIUM	<0.0025	<0.0027	mg/l	<0.0026
IRON	<1.0000	<1.0000	mg/l	<1.0000
LEAD	<0.0130	<0.0130	mg/l	<0.0130
LITHIUM	0.2490	0.2720	mg/l	0.2605
MAGNESIUM	250.0000	253.0000	mg/l	251.5000
MERCURY	<0.0010	<0.0010	mg/l	<0.0010
POTASSIUM	182.0000	184.0000	mg/l	183.0000
SELENIUM	<0.0040	<0.0040	mg/l	<0.0040

TABLE 7-1.10
WQSP-6, CULEBRA
ROUND ONE ANALYTICAL RESULTS

SILICA	10.3000	10.6000	mg/l	10.4500
SILVER	<0.0025	<0.0032	mg/l	<0.0029
SODIUM	6070.0000	6050.0000	mg/l	6060.0000
CARBON TETRACHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
METHYLENE CHLORIDE	<0.0050	<0.0080	mg/l	<0.0065
TRICHLOROETHYLENE	<0.0050	<0.0050	mg/l	<0.0050
1,1,1-TRICHLOROETHANE	<0.0050	<0.0050	mg/l	<0.0050
FREON-113	<0.0050	<0.0050	mg/l	<0.0050

TABLE 7-1.11
WQSP-6a, DEWEY LAKE
ROUND ONE ANALYTICAL RESULTS

PARAMETER	VALUE	DUPLICATE	UNIT	AVERAGE
SPECIFIC CONDUCTANCE	4968.0000	4968.0000	umhos/cm	4968.0000
SULFATE	1905.0000	1905.0000	mg/l	1905.0000
TOTAL DISS SOLIDS	11000.0000	11000.0000	mg/l	11000.0000
TOTAL SUSP SOLIDS	91.0000	91.0000	mg/l	91.0000
DENSITY	0.9772	0.9772	g/ml	0.9772
pH	7.6600	7.6600	SU	7.6600
ALKALINITY	111.0000	111.0000	mg/l	111.0000
BROMIDE	<2.0000	<2.0000	mg/l	<2.0000
CHLORIDE	1040.0000	1040.0000	mg/l	1040.0000
FLUORIDE	<3.0000	<3.0000	mg/l	<3.0000
IODIDE	<2.0000	<2.0000	mg/l	<2.0000
NITROGEN, NO3 (AS N)	7.6200	7.6200	mg/l	7.6200
TOTAL ORGANIC CARBON	1.1000	1.1000	mg/l	1.1000
TOTAL ORGANIC HALOGENS	0.0880	0.0880	mg/l	0.0880
PHENOL, TOTAL	<0.1000	<0.1000	mg/l	<0.1000
ORTHOPHOSPHATE (AS P)	<0.0200	<0.0200	mg/l	<0.0200
ARSENIC	<0.0060	<0.0060	mg/l	<0.0060
BARIUM	<0.0200	<0.0200	mg/l	<0.0200
BERYLLIUM	<0.0100	<0.0100	mg/l	<0.0100
BORON	0.4290	0.4290	mg/l	0.4290
CADMIUM	<0.0013	<0.0013	mg/l	<0.0013
CALCIUM	681.0000	681.0000	mg/l	681.0000
CHROMIUM	<0.0025	<0.0025	mg/l	<0.0025
IRON	<0.4000	<0.4000	mg/l	<0.4000
LEAD	<0.0125	<0.0125	mg/l	<0.0125
LITHIUM	0.0950	0.0950	mg/l	0.0950
MAGNESIUM	181.0000	181.0000	mg/l	181.0000
MERCURY	<0.0002	<0.0002	mg/l	<0.0002
POTASSIUM	4.8200	4.8200	mg/l	4.8200
SELENIUM	<0.0060	<0.0060	mg/l	<0.0060

TABLE 7-1.11
WQSP-6a, DEWEY LAKE
ROUND ONE ANALYTICAL RESULTS

SILICA	24.2700	24.2700	mg/l	24.2700
SILVER	0.0028	0.0028	mg/l	0.0028
SODIUM	347.0000	347.0000	mg/l	347.0000
CARBON TETRACHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
METHYLENE CHLORIDE	<0.0050	<0.0050	mg/l	<0.0050
TRICHLOROETHYLENE	<0.0050	<0.0050	mg/l	<0.0050
1,1,1-TRICHLOROETHANE	<0.0050	<0.0050	mg/l	<0.0050
FREON-113	<0.0050	<0.0050	mg/l	<0.0050

Chapter 8
Quality Assurance

The purpose of the Quality Assurance/Quality Control (QA/QC) program is to ensure that processes. activities, and products that potentially impact health, safety, and the environment are appropriately planned, implemented, and assessed. The goal of the QA/QC program is twofold: (1) to provide confidence that the data used in demonstrating regulatory compliance are adequate and (2) to promote continuous improvement in WIPP's operations. The QA program is successful when risks and environmental impacts are identified and minimized, and when safety, reliability, and performance are maximized.

This chapter outlines the QA processes applicable to the radiological and nonradiological environmental monitoring programs. The QA Program is used to monitor the reliability, accuracy. and precision of environmental data, and to detect and correct problems in the sample collection, preparation, analysis, and the data evaluation phases.

A comprehensive QA program has been implemented to ensure that the data collected reflect selected parameters of the environment. The data have been obtained prior to commencement of operations, providing a sound baseline for comparison with operational-phase data. The data will be evaluated to determine future impacts of the WIPP on the environment.

The focus of this program includes the following areas:

- Sample collection at specified locations in accordance with approved procedures. These procedures are based on established and accepted practices.

- Procedure review and revision to minimize uncertainties introduced through sampling and analysis, while maintaining comparability and continuity between past and future data.

- Verification of data through a continuing program of analytical laboratory quality control, including the performance of interlaboratory cross-checks, duplicate and split sample radiological analysis, and sample splits provided to the EEG, and to the NMED.

Requirements and guidance sources for QA Program content include the following: Title 10 CFR 830.120, *Nuclear Safety Management, Quality Assurance*; (CAO-94-1012), *DOE Carlsbad Area Office Quality Assurance Program Description*; (ASME NQA-1), *Quality Assurance Program Requirements for Nuclear Facilities*; (DOE Order 5700.6C), *Quality Assurance*, (DOE/EH-0173T), *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, and SW-846, *Test Methods for Evaluating Solid Waste*.

8.1 Sample Collection Methodologies

The WID follows approved sampling plans and procedures in the collection and handling of samples used in environmental monitoring. The sampling plans and procedures specify proper sampling techniques for the particular sample medium.

Elements of sample QA include specifying the following:

- Method used to select sampling sites
- Specific sampling methods to be used
- Containers, preservatives, transportation, and storage requirements
- Labeling requirements
- Preparatory measures for sampling equipment and containers
- Preservation methods and allowable hold times, including transportation
- Sample chain-of-custody
- Documentation used to record sample history, sampling conditions, and analyses

Sampling procedures are contained in the following documents:

- *WIPP Groundwater Monitoring Program Plan and Procedure Manual* (WP 02-1)
- *WIPP Environmental Procedures Manual* (WP 02-3)
- *Nonradioactive Hazardous Materials Environmental Compliance Manual* (WP 02-5)
- *Quality Assurance Project Plan for WIPP Site Effluent and Hazardous Materials Sampling* (WP 02-EM1)
- *WIPP Site Effluent and Hazardous Materials Sampling Plan* (WP 02-EM2)
- *WIPP VOC Operating Procedures Manual* (WP 12-VC)
- *Quality Assurance Project Plan for Sampling Emissions of Radionuclides to the Ambient Air at the WIPP* (DOE-WIPP 93-042)

Chapter 11 of the EMP defines the policies and practices that are followed to ensure the data are accurate, complete, representative, and comparable. The data collected in the Nonradiological Environmental Surveillance monitoring programs are analyzed as stated in DOE/EH-0023 (Corley et al., 1981). Section 8.0 of the EMP discusses, at length, the statistical procedures used to analyze the data.

8.2 Revision of Procedures

Written procedures are essential in providing instruction to field personnel for sample collection. As data are collected, and records are generated, these procedures form the basis for an auditable program. The Q&RA Department and the Environmental Compliance Assessment Program (ECAP) periodically conduct assessments of environmental monitoring activities to determine the degree of compliance and effectiveness in implementation of the procedures.

In addition to independent assessment, one of the responsibilities of data collection personnel is to assess collection and analysis methodologies on a routine and ongoing basis. Field procedures, analytical procedures, and laboratory methodologies are periodically assessed for adequacy and effectiveness. Processes that require improvement are modified according to established document control procedures. The EEG and the NMED act as the performance based check-point to ensure that radiological sampling procedures are adequately implemented and that data are comparable among the WIPP, EEG, and the NMED samples.

8.3 Interlaboratory Comparisons

In 1995 the WIPP completed installation of a radiochemistry laboratory to perform sample preparation and chemical separations. Currently members of the radiochemistry laboratory are in the process of validating sample preparation and chemical separation methods.

The WIPP Radiochemistry Laboratory (RL) participated in both the DOE Environmental Measurements Laboratory Quality Assessment Program (DOE-EML QAP) and the Environmental Protection Agency's Performance Evaluation Study Program (EPA PESP) during 1995. Participation in these programs provides a means for the RL staff to upgrade analytical methodology, as well as provide hands-on experience in analysis of environmental samples for radionuclides. These programs provide simulated environmental samples which contain known amounts of one or more radionuclides. The samples are prepared and distributed to participating laboratories by the sponsoring agencies. Each laboratory performs the analysis for which they have the capabilities. Using standard analytical methods specific to that laboratory, the samples are

analyzed and the results are reported electronically. The results for each laboratory participating in the programs are compared with known values then statistically analyzed. Results from the statistical analysis and the known values are then made available to participating laboratories.

Because the installation of the RL was not completed until the middle of 1995 the RL staff was unable to complete validation sample preparation and chemical separations methods during 1995. For this reason the capability of the RL to perform a wide variety of analysis on differing sample matrices was limited.

The WIPP RL submitted analysis results to DOE-EML for both rounds of the QAP in 1995. Results reported were from the analysis for gamma emitting radionuclides in a simulated air filter and in a water sample.

The WIPP RL used evaluation criteria from ANSI N13.30, "Performance Criteria for Radiobioassay", as a reference. The criteria is:

$$-0.25 \leq Br \leq 0.5$$

where Br is the relative bias and is defined as:

$$Br = (\text{reported result} - \text{known value}) \div (\text{known value})$$

The EML has recently established evaluation criteria based on historical reported values for each nuclide/matrix. Three ranges have been established for judging a laboratories performance. These ranges are "acceptable", "acceptable with warning", and "not acceptable". The criteria for acceptable performance has been chosen to be between the 15th and the 85th percentile of the cumulative normalized distribution. This can be viewed as the middle 70% of all measurements reported to EML. The acceptable interval is an analog to the one sigma interval of a normal distribution. The "acceptable with warning" criterium, is between the 5th and the 15th percentile on the low end. On the high end, it is between the 85th and 95th percentile. The "not acceptable" criteria is established at less than the 5th percentile or greater than the 95th percentile.

Acceptable performance ranges for each matrix and the WIPP Radiochemistry Laboratory analysis are not available from DOE-EML at this time. However, as shown in Table 2, the WIPP analytical results are well within the acceptance criteria listed in ANSI N13.30.

As in the DOE-EML QAP the WIPP RL used evaluation criteria from ANSI N13.30, "Performance Criteria for Radiobioassay" to evaluate its performance. The Br values are well within the limits of the reference criteria with the exception of the gross alpha/beta in water. This was the RL's first attempt at performing the analysis for gross alpha/beta in water. After the results were obtained from the EPA an extensive review of the analysis methods was performed and the root cause of the RL's poor performance were identified. Measures are being implemented to prevent a reoccurrence of the problem.

Table 8-1. WIPP Analytical Results for DOE-EML QAP, 1st Round CY-95

Evaluation Using EML Criteria

Matrix	Nuclide	EML Known Value	WIPP Reported Value	WIPP Performance	Acceptable Performance	WIPP Performance (Acceptable yes/no)
Air Filter	^{54}Mn	4.71 Bq/filter	3.88 Bq/filter	0.82	0.74 to 1.36	yes
Air Filter	^{57}Co	12.70 Bq/filter	10.11 Bq/filter	0.80	0.64 to 1.45	yes
Air Filter	^{60}Co	3.76 Bq/filter	3.22 Bq/filter	0.86	0.71 to 1.29	yes
Air Filter	^{125}Sb	9.42 Bq/filter	8.72 Bq/filter	0.93	0.50 to 1.50	yes
Air Filter	^{134}Cs	5.75 Bq/filter	5.78 Bq/filter	1.01	0.65 to 1.22	yes
Air Filter	^{137}Cs	5.28 Bq/filter	4.39 Bq/filter	0.83	0.69 to 1.32	yes
Air Filter	^{144}Ce	91.20 Bq/filter	67.49 Bq/filter	0.74	0.59 to 1.36	yes
Water	^{54}Mn	43.50 Bq/liter	46.7 Bq/liter	1.07	0.81 to 1.25	yes
Water	^{60}Co	196.0 Bq/liter	212.0 Bq/liter	1.08	0.79 to 1.18	yes
Water	^{134}Cs	83.5 Bq/liter	93.6 Bq/liter	1.12	0.74 to 1.29	yes
Water	^{137}Cs	76.8 Bq/liter	84.9 Bq/liter	1.11	0.82 to 1.29	yes

Notes: 1. $\text{WIPP Performance} = \frac{\text{WIPP Reported Value}}{\text{EML Known Value}}$

Table 8-2. WIPP Analytical Results for DOE-EML QAP 2nd Round CY 1995

Evaluation Using Draft ANSI 13.30 Criteria

Nuclide	Matrix	Reported Result	Known Value	BR
^{54}Mn	Air Filter	5.27 Bq/filter	5.34 Bq/filter	-0.01
^{57}Co	Air Filter	14.91 Bq/filter	14.70 Bq/filter	0.01
^{60}Co	Air Filter	34.72 Bq/filter	32.60 Bq/filter	-0.07
^{125}Sb	Air Filter	11.42 Bq/filter	11.40 Bq/filter	-0.00
^{134}Cs	Air Filter	17.30 Bq/filter	17.90 Bq/filter	-0.03
^{137}Cs	Air Filter	6.74 Bq/filter	7.25 Bq/filter	-0.07
^{144}Ce	Air Filter	52.66 Bq/filter	52.10 Bq/filter	0.01
^{54}Mn	Water	55.58 Bq/liter	44.90 Bq/liter	0.24
^{60}Co	Water	233.77 Bq/liter	196.00 Bq/liter	0.19
^{137}Cs	Water	88.94 Bq/liter	75.20 Bq/liter	0.18

Table 8-3. WIPP Analytical Results for EPA PESP, 1st Quarter CY-95

Matrix	Analysis Performed	Reported Result	Known Value	Relative Bias (Br)
Water	^{131}I	106.2 pCi/liter	100.0 pCi/liter	0.06

Table 8-4. WIPP Analytical Results for EPA PESP, 2nd Quarter CY-95

Matrix	Analysis Performed	Reported Result	Known Value	Relative Bias (Br)
Water	^{3}H	7913.67 pCi/liter	7435.0 pCi/liter	0.06

Table 8-5. WIPP Analytical Results for EPA PESP, 3rd Quarter CY-95

Matrix	Analysis Performed	Reported Result	Known Value	Relative Bias (Br)
Water	^{60}Co	40.19 pCi/liter	40.00 pCi/liter	0.00
Water	^{65}Zn	80.62 pCi/liter	76.00 pCi/liter	0.06
Water	^{134}Cs	47.23 pCi/liter	50.00 pCi/liter	-0.06
Water	^{137}Cs	37.59 pCi/liter	35.00 pCi/liter	0.07
Water	^{133}Ba	75.22 pCi/liter	79.00 pCi/liter	-0.05
Water	^{3}H	5049.85 pCi/liter	4872.00 pCi/liter	-0.04

Table 8-6. WIPP Analytical Results for EPA PESP, 4th Quarter CY-95

Matrix	Analysis Performed	Reported Result	Known Value	Relative Bias (Br)
Air Filter	gross alpha	26.11 pCi/filter	25.00 pCi/liter	0.04
Air Filter	Gross beta	93.59 pCi/filter	86.00 pCi/liter	0.09
Air Filter	^{137}Cs	25.00 pCi/filter	25.00 pCi/liter	0.00
Water	^{131}I	155.90 pCi/liter	148.00 pCi/liter	0.05
Water	Gross alpha	8.53 pCi/liter	51.20 pCi/liter	-0.83
Water	gross beta	19.15 pCi/liter	24.80 pCi/liter	-0.23

8.4 Analytical Laboratory Quality Assurance and Quality Control

During CY 1995 the WIPP extended contracts to the following analytical laboratories: Ross Analytical Services Inc. in Strongsville, Ohio; Accu-Labs in Golden, Colorado; and Datachem Laboratories in Salt Lake City, Utah. The contract laboratories are required to follow established QA/QC procedures as specified in the contract statement of work. Successful bidders performing environmental analyses are required to be on the Qualified Suppliers List and must undergo program reviews and assessments.

Laboratory QA/QC includes the following:

- Reviewing and approving of the laboratory QA plan
- Qualifying and training staff
- Specifying acceptable tolerances in data quality
- Performing internal laboratory QC
- Analyzing blind samples
- Calibrating and maintaining analytical equipment
- Reporting on the performance of measurement systems and data quality
- Reporting the performance of demonstration programs

8.5 Data Handling

Field data are collected and recorded in data books, organized by sample location and sampling round. Separate data books are prepared for sampling, field notes, and contract laboratory data. If samples are sent to more than one laboratory for analysis, then each lab has its own data book. Samples are collected and sent to the laboratory for analysis, accompanied by QC samples. Analytical results are verified through specifying method blanks, duplicates, spikes, and trip blanks. The Principle Investigator reviews the QC data against specified limits to determine whether the data set is suitable for inclusion in the report. The data are reported in the ASER.

8.6 Records Management

Documents and records generated under the CAO QA program are specified, prepared, reviewed, approved, controlled, and maintained in accordance with the *Carlsbad Area Office Quality Assurance Program Description* (QAPD) (CAO 94-1012). The QAPD provides a single reference for all WIPP project participants in meeting records management requirements as specified in DOE orders and

regulations. Further records management requirements and procedures are provided in the *Carlsbad Area Office Information Management Plan* (CAO-94-1001).

All original records are maintained in fire resistant file cabinets until they are transmitted to the CAO Central Records Facility for permanent filing. All records, including raw data, calculations, computer programs, or other data manipulation media are subject to review and verification under the WIPP QAP and the ECAP. The Environmental Monitoring Section is responsible for validating these records before transmitting them to the CAO Central Records Facility in accordance with an approved Records Inventory Disposition Schedule.

Records (i.e., reports of analyses and sample receipt forms transmitted by contract analytical laboratories) are dated upon receipt and a copy made for QC review. Specific record and data management procedures including those referencing data manipulations are implemented according to the approved quality assurance project plan or work plan.

The WIPP complies with the *National Emission Standards for Hazardous Air Pollutants* record-keeping requirements issued under 40 CFR 61, Subpart H, which addresses atmospheric radionuclide emissions. Unless regulations are amended in the future, records developed pursuant to these criteria (i.e., Medical, Health and Safety Records) will be maintained at least 30 years as specified in DOE Order 1324.2A, *Records Disposition* (DOE, 1992), Chapter V, Attachment 1, Schedule 25.

Consistent record keeping for all aspects of the Environmental Monitoring Programs is a part of QA requirements. The EMP lists the required records, reports, and laws, regulations, or DOE Orders that contain the requirements.

Chapter 9
References

American National Standards Institute/American Society of Mechanical Engineers (ASME/NQA-1), 1986, Revised 1989, *Quality Assurance Program Requirements for Nuclear Facilities*, NQA-1-1989.

Atomic Energy Commission, *Project Gnome: Project Manager's Report*, Washington, D. C., 1962a.

Atomic Energy Commission, *Project Gnome Final Report*: Weather and Surface Radiation Prediction Activities, PNE-126F, Washington, D. C., 1962b.

Atomic Energy Commission, *Project Gnome Final Report: Off-Site Radiological Safety Report*, PNE-132F, Washington, D. C., 1962c.

Atomic Energy Commission, *Project Gnome Final Report*: On-Site Radiological Safety Report, PNE-133F, Washington, D. C., 1962d.

Bednarz, J. C., 1987. *Pair and Group Reproductive Success, Polyandry, and Cooperative Breeding in Harris' Hawks.* Auk 104:393-404

Dawson, J.W., and R.W. Manaan. 1989. *A Comparison of Two Methods of Estimating Breeding Group Size in the Harris' Hawk* Auk 106:480-483

Dawson, J.W., and R.W. Manaan. 1991b *The Role of Territoriality in the Social Organization of Harris' Hawk.* Auk 106:661-672

Frame, P.W., *Environmental Air Sampling: Collection and Analysis of Specific Radionuclides*, Professional Training Programs Training and Management Systems Division of Oak Ridge Associated Universities, Oak Ridge, Tennessee, 1987.

Hart, J. S., and L. M. Brausch, *Plan to Mitigate Effects on Archeological Resources; Site and Preliminary Design Validation (SPDV), Waste Isolation Pilot Plant, Eddy County, New Mexico*, International Technology Corporation, Albuquerque, New Mexico, 1980.

Keith, L.H., *Principles of Environmental Sampling*, American Chemical Socitey, 1988.

Keith. L.H., *Environmental Sampling and Analysis: A Practical Guide*, Lewis Publishers Inc., 1991

Lord, K.J. and W.E. Reynolds, ed., 1985. *Archeological Investigations of Three Sites within the WIPP Core Area, Eddy County, New Mexico*, Chambers Consultants and Planners, Albuquerque, New Mexico, prepared for the U.S. Army Corps of Engineers.

MacLennan, R.B., and S.C. Shermer, 1979. *An Archeological Survey for the Waste Isolation Pilot Plant: Access Roads and Railroad Right-of-Way*, Agency for Conservation Archeology, Eastern New Mexico University, Portales, New Mexico.

Mariah Associates, Inc., 1987. *Report of Class II Survey and Testing of Cultural Resources at the WIPP Site at Carlsbad, New Mexico*, Prepared for the U.S. Army Corps of Engineers, Albuquerque District.

Mercer, J. W., 1983. "Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medaños Area, Southeastern New Mexico," *U.S. Geological Survey, Water Resources Investigations Report* 83-4016, U.S. Geologic Survey, Albuquerque, New Mexico.

Neilson, J., 1976. *An Archeological Reconnaissance of Sandia Laboratories' Los Medaños Nuclear Waste Disposal Facility, Eddy County, New Mexico*, SAND 77-7024, Sandia Laboratories, Albuquerque, New Mexico.

Powers, D. W., et al., (eds.), *Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, SAND 78-1596*, Sandia National Laboratories, Albuquerque, New Mexico., 1978.

Reith, C. C. and G. Daer, *Radiological Baseline Program for the Waste Isolation Pilot Plant: Program Plan*, WTSD-TME-057, Waste Isolation Pilot Plant, Carlsbad, New Mexico, 1985.

Reith, C. C., et al., *Ecological Monitoring Program for the Waste Isolation Pilot Plant, Semi-Annual Report*: July-December 1984, WTSD-TME-058, Waste Isolation Pilot Plant, Carlsbad. New Mexico., 1985.

Snyder, Noel F.R., and H.A. Snyder, *BIRDS OF PREY; Natural History and Conservation of North American Raptors*; Voyageur Press Inc., 1991

U. S. Department of Energy, DOE/EH-0349, *Environmental Management Assessment of the WIPP*, Carlsbad, NM, July 1993.

U. S. Department of Energy, DOE/WIPP 88-008, *Ecological Monitoring Program at the Waste Isolation Pilot Plant, Annual Report, Calendar Year 1987*, 1988.

U. S. Department of Energy, DOE/WIPP 88-009, *Annual Site Environmental Monitoring Report for the Waste Isolation Pilot Plant, Calendar Year 1987*, 1988.

U. S. Department of Energy, DOE/WIPP-89-001, *Annual Water Quality Data Report for the Waste Isolation Pilot Plant*, 1989.

U. S. Department of Energy, DOE/WIPP 89-005, *Annual Site Environmental Report For the Waste Isolation Pilot Plant, Calendar Year 1988*, 1989.

U. S. Department of Energy, DOE/WIPP 88-025, *Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant*, Waste Isolation Pilot Plant, Carlsbad New Mexico., 1989.

U. S. Department of Energy, *Final Safety Analysis Report, Waste Isolation Pilot Plant*, WP 02-9, Waste Isolation Pilot Plant, Carlsbad, New Mexico, 1990.

U. S. Department of Energy, DOE/WIPP 90-003, *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year* 1989, 1990.

U. S. Department of Energy, DOE/WIPP 90-008, *Waste Isolation Pilot Plant Groundwater Protection Management Plan*, 1990.

U. S. Department of Energy, DOE/WIPP 89-003, *DOE, Waste Isolation Pilot Plant No-Migration Variance Petition*, Revision 1, 1990d.

U. S. Department of Energy, DOE/WIPP 91-008, *Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1990*, 1991.

U. S. Department of Energy, DOE/WIPP 91-025, *1990 Annual Water Quality Data Report for the Waste Isolation Pilot Plant*, WIPP Project, Carlsbad, New Mexico, 1991.

U. S. Department of Energy, DOE/WIPP 91-054, *Environmental Protection Implementation Plan for the Waste Isolation Pilot Plant*, 1991.

U. S. Department of Energy, DOE/WIPP 91-059, *Waste Isolation Pilot Plant No-Migration Determination Annual Report for the Period November 1990 through September 1991*, Waste Isolation Pilot Plant, Carlsbad, New Mexico, 1991.

U. S. Department of Energy, 1992, *Resource Conservation and Recovery Act Part B Permit Application*, DOE/WIPP 91-005, Revision 1.0, Waste Isolation Pilot Plant, Carlsbad, NM.

U. S. Department of Energy, DOE/WIPP 92-013, *Background Water Quality Characterization Report for the WIPP*, 1992.

U. S. Department of Energy, DOE/WIPP 92-037, *Statistical Summary of the Radiological Baseline Program for the WIPP*, 1992.

U. S. Department of Energy, DOE/WIPP 92-038, *Summary of the Salt Impact Studies at the WIPP, 1984 to 1990*, 1992.

U. S. Department of Energy, DOE/WIPP 92-039, *A Study of Disturbed Land Reclamation Techniques for the WIPP*, 1992.

U. S. Department of Energy, WP 02-3, *Environmental Procedures Manual, 1988*.

U. S. Department of Energy, WP 02-1, Rev. 2, *Groundwater Monitoring Program Plan and Procedures Manual*, 1990.

U. S. Department of Energy, Environmental Measurements Laboratory, HASL-300, *Environmental Measurement Laboratory Procedures Manual*, (revised annually).

U. S. Department of Energy, *Implementation of the National Environmental Policy Act (NEPA)*, DOE Order AL 5440.1E, Albuquerque Operations Office, Albuquerque, New Mexico.

U. S. Department of Energy, 1981, *Department of Energy/Waste Isolation Pilot Plant, Record of Decision*, Federal Register, Vol. 46, No. 18, pp. 9162-9164.

U. S. Department of Energy, *Final Environmental Impact Statement, Waste Isolation Pilot Plant*, DOE/EIS-0026, Vols. 1 and 2, Washington, D.C., 1980.

U. S. Department of Energy, DOE/EH-0023, *A Guide for Environmental Radiological Surveillance at U.S. Department of Energy Installations*, U.S. Department of Energy, Washington, D. C., 1981.

U. S. Department of Energy, *Quality Assurance*, DOE Order 5700.6C, Washington, D.C., 1986.

U. S. Department of Energy, *General Environmental Protection Program*, DOE Order 5400.1, Washington, D.C., 1988a.

U. S. Department of Energy, *Radiation Protection of the Public and the Environment*, DOE Order 5400.5, Washington, D.C., 1988b.

U. S. Department of Energy, *Radioactive Waste Management*, DOE Order 5820.2A, Washington, D.C., 1988d.

U. S. Department of Energy, *Hazardous and Radioactive Mixed Waste Program*, DOE Order 5400.3, Washington, D.C., 1989.

U. S. Department of Energy and U.S. Department of Labor (DOL), 1987, *Memorandum of Understanding Between the U.S. Department of Energy and the U.S. Department of Labor*, signed June 1987 by Roy L. Bernard, Administrator for Metal and Nonmetal Mine Safety and Health, U.S. Department of Labor, and R. G. Romotowski, Manager, Albuquerque Operations Office, U.S. Department of Energy.

U. S. Department of Energy 1990a, *Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant*, DOE/EIS-0026-FS, U.S. Department of Energy, Office of Environmental Restoration and Waste Management, Washington, D.C.

U. S. Department of Energy, 1990c, *Record of Decision, Waste Isolation Pilot Plant*, Federal Register, Vol. 55, No. 121, pp. 25689-25692.

U. S. Department of Energy, 1991a, *Final Safety Analysis Report Addendum, Dry Bin Scale Test*, WP 02-9, Revision 0, Waste Isolation Pilot Plant, Carlsbad, NM.

U. S. Department of Energy, 1991b, *Waste Isolation Pilot Plant RCRA Part A Permit Application*, Waste Isolation Pilot Plant, Carlsbad, NM.

U. S. Department of Energy, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, DOE/EH-0173T, January 1991.

U. S. Department of Energy, *Records Description*, DOE Order 1324.2A, Washington D.C., 1992

U. S. Environmental Protection Agency, 1990b, *Notice Proposing to Grant a Conditional Variance to the Department of Energy Waste Isolation Pilot Plant (WIPP) from Land Disposal Restrictions*, Federal Register, Vol. 55, No. 67, pp. 13068-13094.

U. S. Environmental Protection Agency 1990c, *Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP)*, Federal Register, Vol. 55, No. 220, pp. 47700-47721.

U. S. Environmental Protection Agency, *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*, EPA Publication QAMS-005/80, December 29, 1980.

U. S. Environmental Protection Agency, 1986, *State Authorization to Regulate the Hazardous Components of Radioactive Mixed Wastes Under the Resource Conservation and Recovery Act*, Federal Register, Vol. 51, No. 128, pp. 24504-24505.

U. S. Geological Survey, *Geohydrology of the Proposed Waste Isolation Pilot Plant Site*, Los Medaños Area, Southeastern New Mexico. USGS 83-4016., 1983.

U. S. Nuclear Regulatory Commission, 1990, *Certificate of Compliance for Radioactive Materials Packaging*, No. 9218, U.S. Nuclear Regulatory Commission, Washington, D.C.

Westinghouse Electric Corporation, 1991, *VOC Monitoring Plan for Bin-Room Tests*, WP 12-6, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

Westinghouse Electric Corporation, 1992, *Volatile Organic Compounds Monitoring Quality Assurance Program Plan*, Revision 1, WP 12-7, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

Westinghouse Electric Corporation, 1992, *WID Quality Assurance Manual*, WP 13, Rev. 14,.

APPENDIX A1
RADIOLOGICAL ANALYSIS
AIR

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SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^-3	COUNTING ERROR
AC-CBD 1.1 Air Sampling 1st Quarter Carlsbad	Americium-241	3.59E-05	1.07E-05
	Beryllium-7	2.70E-04	1.50E-04
	Cesium-137	-5.80E-06	1.00E-05
	Cobalt-60	-4.90E-06	8.50E-06
	Lead-210	9.10E-04	2.10E-04
	Plutonium-238	-7.05E-07	4.15E-06
	Plutonium-241	1.15E-03	2.44E-04
	Plutonium-239/240	7.04E-07	2.39E-06
	Polonium-210	4.11E-04	1.21E-05
	Potassium-40	3.50E-04	1.20E-04
	Radium-228	2.90E-05	3.40E-05
	Radium-226	8.00E-04	2.70E-04
	Strontium-90	-1.40E-05	1.10E-05
	Thorium-228	6.37E-06	6.62E-06
	Thorium-230	2.52E-05	8.81E-06
	Thorium-232	5.75E-06	4.45E-06
	Uranium-233/234	1.62E-05	7.68E-06
	Uranium-238	9.88E-06	5.53E-06
	Uranium-235/236	-8.70E-07	3.81E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT $Bq/m^{\wedge 3}$	COUNTING ERROR
AC-CBD 2.1 Air Sampling 2nd Quarter Carlsbad	Americium-241	4.43E-05	1.20E-05
	Beryllium-7	8.40E-04	2.10E-04
	Cesium-137	3.30E-06	1.10E-05
	Cobalt-60	5.60E-06	9.30E-06
	Lead-210	1.50E-04	1.70E-04
	Plutonium-238	2.35E-06	4.61E-06
	Plutonium-241	2.13E-03	2.45E-04
	Plutonium-239/240	-7.82E-07	2.66E-06
	Polonium-210	7.03E-05	5.78E-06
	Potassium-40	2.80E-04	1.10E-04
	Radium-228	5.00E-05	3.70E-05
	Radium-226	8.40E-04	2.90E-04
	Strontium-90	6.10E-06	1.40E-05
	Thorium-228	8.29E-06	7.44E-06
	Thorium-230	1.91E-05	9.08E-06
	Thorium-232	1.66E-06	3.26E-06
	Uranium-233/234	1.63E-05	7.34E-06
	Uranium-238	1.31E-05	5.73E-06
	Uranium-235/236	4.03E-06	5.24E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-CBD 3.1 Air Sampling 3rd Quarter Carlsbad	Americium-241	3.20E-06	1.34E-06
	Beryllium-7	6.90E-04	1.80E-04
	Cesium-137	2.50E-07	8.70E-06
	Cobalt-60	1.90E-06	7.30E-06
	Lead-210	9.70E-04	2.10E-04
	Plutonium-239/240	3.24E-07	4.50E-07
	Plutonium-241	-7.17E-04	8.22E-05
	Plutonium-238	3.25E-07	1.19E-06
	Polonium-210	3.12E-04	8.01E-06
	Potassium-40	3.20E-05	1.70E-04
	Radium-226	1.10E-04	1.70E-04
	Radium-228	7.90E-05	3.20E-05
	Strontium-90	2.40E-06	1.10E-05
	Thorium-230	7.32E-06	1.93E-06
	Thorium-228	3.21E-06	1.48E-06
	Thorium-232	3.97E-06	1.44E-06
	Uranium-238	9.03E-06	2.19E-06
	Uranium-233/234	7.67E-06	2.09E-06
	Uranium-235/236	9.98E-07	1.13E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-CBD 4.1 Air Sampling 4th Quarter Carlsbad	Americium-241	2.56E-06	1.15E-06
	Beryllium-7	2.90E-03	4.30E-04
	Cesium-137	4.20E-06	8.50E-06
	Cobalt-60	-1.40E-06	7.40E-06
	Lead-210	1.70E-03	2.70E-04
	Plutonium-238	0.00E+00	5.15E-07
	Plutonium-241	-5.73E-04	6.79E-05
	Plutonium-239/240	5.25E-07	6.30E-07
	Polonium-210	2.92E-04	6.49E-06
	Potassium-40	1.60E-04	1.70E-04
	Radium-226	1.70E-05	1.70E-04
	Radium-228	2.00E-05	3.00E-05
	Strontium-90	1.10E-05	1.10E-05
	Thorium-228	2.10E-06	1.11E-06
	Thorium-230	6.15E-06	1.85E-06
	Thorium-232	1.55E-06	9.07E-07
	Uranium-233/234	4.96E-06	1.80E-06
	Uranium-235/236	1.66E-07	5.63E-07
	Uranium-238	2.55E-06	1.32E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-SMR 1.1 Air Sampling 1st Quarter Smith Ranch	Americium-241	3.95E-05	1.12E-05
	Beryllium-7	4.00E-04	1.60E-04
	Cesium-137	4.90E-06	8.10E-06
	Cobalt-60	2.80E-07	6.60E-06
	Lead-210	9.20E-04	2.20E-04
	Plutonium-238	6.32E-06	6.86E-06
	Plutonium-241	1.35E-03	2.73E-04
	Plutonium-239/240	3.61E-06	5.00E-06
	Polonium-210	4.09E-04	1.17E-05
	Potassium-40	7.30E-05	1.80E-04
	Radium-228	5.80E-05	3.00E-05
	Radium-226	3.60E-04	1.50E-04
	Strontium-90	1.40E-06	1.10E-05
	Thorium-228	1.14E-05	9.75E-05
	Thorium-230	1.78E-05	8.42E-06
	Thorium-232	7.48E-06	6.35E-06
	Uranium-233/234	1.34E-05	6.89E-06
	Uranium-238	4.23E-06	5.17E-06
	Uranium-235/236	8.69E-07	2.95E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-SMR 2.1 Air Sampling 2nd Quarter Smith Ranch	Americium-241	4.04E-05	1.13E-05
	Beryllium-7	8.70E-04	2.10E-04
	Cesium-137	3.10E-06	8.30E-06
	Cobalt-60	-4.60E-06	7.80E-06
	Lead-210	1.90E-04	1.50E-04
	Plutonium-238	-8.45E-07	4.38E-06
	Plutonium-241	2.62E-03	2.87E-04
	Plutonium-239/240	8.44E-07	3.70E-06
	Polonium-210	9.54E-05	5.37E-06
	Potassium-40	1.00E-04	1.60E-04
	Radium-228	7.50E-05	6.00E-05
	Radium-226	7.00E-05	1.80E-04
	Strontium-90	1.90E-06	1.20E-05
	Thorium-228	1.28E-05	1.02E-05
	Thorium-230	3.23E-05	1.04E-05
	Thorium-232	1.90E-05	8.74E-06
	Uranium-233/234	2.35E-05	8.48E-06
	Uranium-238	1.78E-05	7.26E-06
	Uranium-235/236	7.03E-06	4.87E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-SMR 3.1 Air Sampling 3rd Quarter Smith Ranch	Americium-241	9.29E-06	2.17E-06
	Beryllium-7	7.90E-04	1.70E-04
	Cesium-137	2.50E-06	7.60E-06
	Cobalt-60	-4.80E-06	6.70E-06
	Lead-210	9.90E-04	1.90E-04
	Plutonium-239/240	1.53E-05	2.88E-06
	Plutonium-241	-6.26E-04	6.76E-05
	Plutonium-238	5.56E-07	8.62E-07
	Polonium-210	1.98E-04	6.81E-06
	Potassium-40	1.60E-04	1.30E-04
	Radium-226	1.90E-04	1.60E-04
	Radium-228	5.60E-05	4.00E-05
	Strontium-90	-3.50E-06	8.90E-06
	Thorium-230	2.13E-04	9.77E-06
	Thorium-228	4.85E-06	1.78E-06
	Thorium-232	4.18E-06	1.40E-06
	Uranium-238	3.08E-04	1.24E-05
	Uranium-233/234	5.24E-05	5.27E-06
	Uranium-235/236	7.89E-06	2.30E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^-3	COUNTING ERROR
AC-SMR 4.1 Air Sampling 4th Quarter Smith Ranch	Americium-241	1.33E-06	1.13E-06
	Beryllium-7	2.40E-03	4.00E-04
	Cesium-137	-7.10E-07	7.80E-06
	Cobalt-60	-8.50E-07	5.90E-06
	Lead-210	1.60E-03	2.60E-04
	Plutonium-238	-4.17E-07	7.21E-07
	Plutonium-241	-4.53E-04	7.30E-05
	Plutonium-239/240	8.33E-07	8.61E-07
	Polonium-210	2.18E-04	6.60E-06
	Potassium-40	2.10E-04	1.60E-04
	Radium-226	1.10E-04	1.70E-04
	Radium-228	1.70E-05	4.70E-05
	Strontium-90	6.50E-06	9.20E-06
	Thorium-228	2.80E-06	1.21E-06
	Thorium-230	1.02E-05	2.25E-06
	Thorium-232	2.03E-06	1.08E-06
	Uranium-233/234	1.77E-06	1.36E-06
	Uranium-235/236	0.00E+00	6.12E-07
	Uranium-238	3.29E-06	1.49E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WFF 1.1 Air Sampling 1st Quarter WIPP Far Field	Americium-241	3.76E-05	9.84E-06
	Beryllium-7	3.80E-04	1.50E-04
	Cesium-137	-1.10E-05	9.40E-06
	Cobalt-60	5.20E-06	8.01E-06
	Lead-210	9.50E-04	2.20E-04
	Plutonium-238	2.13E-06	3.11E-06
	Plutonium-241	1.25E-03	2.35E-04
	Plutonium-239/240	1.42E-06	1.97E-06
	Polonium-210	3.86E-04	1.08E-05
	Potassium-40	2.30E-05	1.70E-04
	Radium-228	3.60E-05	3.30E-05
	Radium-226	7.70E-04	2.60E-04
	Strontium-90	1.60E-05	1.40E-05
	Thorium-228	1.26E-05	6.55E-06
	Thorium-230	2.85E-05	9.05E-06
	Thorium-232	4.27E-06	3.90E-06
	Uranium-233/234	2.83E-05	1.21E-05
	Uranium-238	-1.57E-06	6.90E-06
	Uranium-235/236	0.00E+00	6.59E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WFF 1.2 1st Quarter Air Sampling WIPP Far Field	Americium-241	5.64E-05	1.43E-05
	Beryllium-7	5.40E-04	2.30E-04
	Cesium-137	-8.40E-08	1.10E-05
	Cobalt-60	1.50E-05	9.30E-06
	LEad-210	9.90E-04	2.60E-04
	Plutonium-238	-1.79E-06	4.31E-06
	Plutonium-241	1.85E-03	3.01E-04
	Plutonium-239/240	1.79E-06	3.51E-06
	Polonium-210	3.54E-04	1.28E-05
	Potassium-40	6.40E-05	2.40E-04
	Radium-228	7.20E-05	3.80E-05
	Radium-226	5.30E-04	2.00E-04
	Strontium-90	-4.40E-05	1.60E-05
	Thorium-228	5.11E-06	9.17E-06
	Thorium-230	2.68E-05	1.07E-05
	Thorium-232	3.68E-06	4.42E-06
	Uranium-233/234	1.18E-05	9.63E-06
	Uranium-238	6.75E-06	6.19E-06
	Uranium-235/236	-2.08E-06	5.77E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WFF 2.1 2nd Quarter Air Sampling WIPP Far Field	Americium-241	3.51E-05	1.09E-05
	Beryllium-7	5.90E-04	2.00E-04
	Cesium-137	6.50E-06	1.10E-05
	Cobalt-60	-4.90E-06	1.10E-05
	Lead-210	3.60E-04	2.00E-04
	Plutonium-238	-2.90E-06	4.01E-06
	Plutonium-241	2.79E-03	2.54E-04
	Plutonium-239/240	-2.17E-06	3.75E-06
	Polonium-210	1.13E-04	6.44E-06
	Potassium-40	4.60E-04	1.40E-04
	Radium-228	7.50E-05	5.30E-05
	Radium-226	9.00E-04	3.10E-04
	Strontium-90	1.40E-05	1.20E-05
	Thorium-228	9.42E-06	7.22E-06
	Thorium-230	5.75E-05	1.25E-05
	Thorium-232	6.38E-06	5.01E-06
	Uranium-233/234	3.33E-05	1.20E-05
	Uranium-238	1.51E-05	8.39E-06
	Uranium-235/236	7.85E-06	6.08E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WFF 2.2 Air Sampling 2nd Quarter WIPP Far Field -	Americium-241	1.22E-04	4.20E-05
	Beryllium-7	-3.40E-05	3.90E-04
	Cesium-137	8.80E-05	5.50E-05
	Cobalt-60	1.10E-05	3.10E-05
	Lead-210	3.20E-03	5.40E-04
	Plutonium-238	0.00E+00	1.76E-05
	Plutonium-241	1.11E-02	1.07E-03
	Plutonium-239/240	6.35E-06	1.52E-05
	Polonium-210	2.48E-05	6.26E-06
	Potassium-40	1.20E-05	7.30E-04
	Radium-228	3.60E-04	1.30E-04
	Radium-226	1.80E-03	6.80E-04
	Strontium-90	-1.30E-05	4.00E-05
	Thorium-228	1.88E-05	2.86E-05
	Thorium-230	1.94E-04	5.13E-05
	Thorium-232	2.04E-05	1.89E-05
	Uranium-233/234	1.12E-04	4.01E-05
	Uranium-238	9.48E-05	3.78E-05
	Uranium-235/236	1.77E-05	2.08E-05

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WFF 3.1 Air Sampling 3rd Quarter WIPP Far Field	Americium-241	2.06E-06	1.24E-06
	Beryllium-7	8.10E-04	1.90E-04
	Cesium-137	-2.00E-06	7.70E-06
	Cobalt-60	-5.00E-07	6.70E-06
	Lead-210	3.40E-03	8.00E-04
	Plutonium-239/240	-1.39E-07	8.16E-07
	Plutonium-241	-5.99E-04	6.93E-05
	Plutonium-238	0.00E+00	6.67E-07
	Polonium-210	2.50E-04	8.00E-06
	Potassium-40	8.70E-05	1.30E-04
	Radium-226	1.30E-03	3.70E-04
	Radium-228	2.80E-05	2.80E-05
	Strontium-90	-4.40E-06	9.90E-06
	Thorium-230	8.49E-06	2.33E-06
	Thorium-228	3.81E-06	1.62E-06
	Thorium-232	5.18E-06	1.63E-06
	Uranium-238	3.57E-05	4.21E-06
	Uranium-233/234	2.19E-05	3.36E-06
	Uranium-235/236	1.25E-06	9.72E-07

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WFF 4.1 Air Sampling 4th Quarter WIPP Far Field	Americium-241	1.48E-07	1.20E-06
	Beryllium-7	2.40E-03	3.80E-04
	Cesium-137	-1.60E-06	9.10E-06
	Cobalt-60	-2.90E-06	7.70E-06
	Lead-210	1.40E-03	2.50E-04
	Plutonium-238	-1.45E-07	6.35E-07
	Plutonium-241	-3.31E-04	7.86E-05
	Plutonium-239/240	7.23E-07	8.51E-07
	Polonium-210	2.40E-04	7.71E-06
	Potassium-40	1.80E-04	1.50E-04
	Radium-226	7.10E-04	2.30E-04
	Radium-228	3.40E-06	3.30E-05
	Strontium-90	2.60E-06	1.20E-05
	Thorium-228	3.07E-06	1.59E-06
	Thorium-230	6.38E-06	2.09E-06
	Thorium-232	3.49E-06	1.36E-06
	Uranium-233/234	6.29E-06	2.10E-06
	Uranium-235/236	1.24E-06	1.04E-06
	Uranium-238	2.58E-06	1.43E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WEE 1.1 Air Sampling 1st Quarter WIPP East	Americium-241	5.35E-05	1.25E-05
	Beryllium-7	4.50E-04	1.60E-04
	Cesium-137	-4.80E-06	8.10E-06
	Cobalt-60	4.40E-07	7.60E-06
	Lead-210	9.00E-04	2.00E-04
	Plutonium-238	0.00E+00	2.25E-06
	Plutonium-241	2.00E-03	2.86E-04
	Plutonium-239/240	8.11E-07	4.77E-06
	Polonium-210	3.68E-04	1.05E-05
	Potassium-40	1.30E-04	1.70E-04
	Radium-228	2.70E-05	3.10E-05
	Radium-226	3.90E-05	1.70E-04
	Strontium-90	8.60E-06	1.10E-05
	Thorium-228	9.09E-07	6.42E-06
	Thorium-230	3.04E-05	1.06E-05
	Thorium-232	4.10E-06	5.33E-06
	Uranium-233/234	1.47E-05	8.12E-06
	Uranium-238	8.07E-06	6.59E-06
	Uranium-235/236	-5.43E-06	4.35E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-WEE 1.2 Air Sampling 1st Quarter WIPP East	Americium-241	6.46E-04	1.64E-04
	Beryllium-7	7.30E-04	1.20E-03
	Cesium-137	-5.40E-05	1.10E-04
	Cobalt-60	8.00E-05	8.20E-05
	Lead-210	1.70E-03	2.40E-03
	Plutonium-238	-1.83E-05	4.40E-05
	Plutonium-241	2.20E-02	3.06E-03
	Plutonium-239/240	4.57E-05	4.01E-05
	Polonium-210	4.37E-04	5.05E-05
	Potassium-40	1.20E-02	2.50E-03
	Radium-228	9.80E-04	3.90E-04
	Radium-226	5.40E-03	2.00E-03
	Strontium-90	-6.40E-05	1.50E-04
	Thorium-228	0.00E+00	4.63E-05
	Thorium-230	1.92E-04	9.04E-05
	Thorium-232	8.70E-06	3.81E-05
	Uranium-233/234	3.07E-04	1.18E-04
	Uranium-238	4.99E-05	6.91E-05
	Uranium-235/236	3.08E-05	4.49E-05

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WEE 2.1 Air Sampling 2nd Quarter WIPP East	Americium-241	3.47E-05	1.10E-05
	Beryllium-7	2.60E-04	1.60E-04
	Cesium-137	3.20E-05	1.60E-05
	Cobalt-60	-3.40E-07	8.70E-06
	Lead-210	1.40E-04	1.50E-04
	Plutonium-238	-1.65E-06	3.95E-06
	Plutonium-241	2.45E-03	2.89E-04
	Plutonium-239/240	0.00E+00	3.94E-06
	Polonium-210	5.28E-05	4.83E-06
	Potassium-40	2.00E-04	1.10E-04
	Radium-226	6.30E-05	1.80E-04
	Radium-228	3.30E-05	3.70E-05
	Strontium-90	-4.00E-06	1.60E-05
	Thorium-230	4.55E-05	1.30E-05
	Thorium-228	8.39E-06	7.54E-06
	Thorium-232	5.05E-06	4.66E-06
	Uranium-233/234	2.92E-05	1.09E-05
	Uranium-238	2.25E-05	8.31E-06
	Uranium-235/236	4.62E-06	4.05E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^-3	COUNTING ERROR
AC-WEE 2.2 Air Sample 2nd Quarter WIPP East	Americium-241	4.11E-05	1.21E-05
	Beryllium-7	5.20E-04	1.70E-04
	Cesium-137	1.10E-05	1.00E-05
	Cobalt-60	-2.40E-06	9.10E-06
	Lead-210	5.90E-05	2.10E-04
	Plutonium-238	-2.27E-06	3.92E-06
	Plutonium-241	1.00E-03	2.55E-04
	Plutonium-239/240	1.51E-06	2.96E-06
	Polonium-210	7.08E-05	5.71E-06
	Potassium-40	2.20E-04	1.10E-04
	Radium-228	4.20E-06	3.60E-05
	Radium-226	8.90E-04	3.00E-04
	Strongium-90	-1.10E-05	1.30E-05
	Thorium-228	6.02E-06	7.72E-06
	Thorium-230	3.65E-05	1.13E-05
	Thorium-232	0.00E+00	3.04E-06
	Uranium-233/234	2.23E-05	9.83E-06
	Uranium-238	1.24E-05	8.41E-06
	Uranium-235/236	1.02E-06	2.00E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WEE 3.1 Air Sample 3rd Quarter WIPP East	Americium-241	3.05E-06	1.42E-06
	Beryllium-7	8.20E-04	2.20E-04
	Cesium-137	-4.30E-06	9.60E-06
	Cobalt-60	-9.70E-06	8.70E-06
	Lead-210	8.30E-04	2.10E-04
	Plutonium-239/240	4.97E-07	1.08E-06
	Plutonium-241	-8.45E-04	8.52E-05
	Plutonium-238	0.00E+00	6.50E-07
	Polonium 210	2.81E-04	9.33E-06
	Potassium-40	5.20E-05	1.70E-04
	Radium-226	1.40E-06	1.80E-04
	Radium-228	3.40E-05	3.50E-05
	Strontium-90	-2.20E-06	1.40E-05
	Thorium-230	1.28E-05	2.58E-06
	Thorium-228	3.47E-06	1.51E-06
	Thorium-232	2.92E-06	1.38E-06
	Uranium-238	1.21E-04	8.25E-06
	Uranium-233/234	7.83E-05	6.63E-06
	Uranium-235/236	6.44E-06	2.16E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WEE 3.2 Air Sample 3rd Quarter WIPP East	Americium-241	1.11E-06	9.35E-07
	Beryllium-7	6.00E-04	1.80E-04
	Cesium-137	2.90E-07	1.00E-05
	Cobalt-60	2.00E-06	8.60E-06
	Lead-210	9.80E-04	2.50E-04
	Plutonium-239/240	3.68E-07	8.83E-07
	Plutonium-241	-9.98E-04	9.36E-05
	Plutonium-238	3.68E-07	7.21E-07
	Polonium 210	3.16E-04	8.97E-06
	Potassium-40	1.00E-04	2.10E-04
	Radium-226	8.50E-05	2.00E-04
	Radium-228	7.30E-05	5.50E-05
	Stronnum-90	5.00E-06	1.30E-05
	Thorium-230	9.79E-06	2.48E-06
	Thorium-228	5.69E-06	1.87E-06
	Thorium-232	3.77E-06	1.42E-06
	Uranium-238	5.76E-05	6.13E-06
	Urannum-233/234	4.69E-05	5.55E-06
	Uranium-235/236	3.75E-06	1.83E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WEE 4.1 Air Sample 4th Quarter WIPP East	Americium-241	5.39E-07	9.87E-07
	Beryllium-7	2.60E-03	4.40E-04
	Cesium-137	7.60E-06	8.00E-06
	Cobalt-60	1.10E-06	6.30E-06
	Lead-210	1.70E-03	2.70E-04
	Plutonium-238	3.89E-07	6.73E-07
	Plutonium-241	-3.15E-04	6.61E-05
	Plutonium-239/240	5.19E-07	6.23E-07
	Polonium 210	2.16E-04	5.30E-06
	Potassium-40	1.10E-04	1.50E-04
	Radium-226	6.30E-05	1.70E-04
	Radium-228	5.00E-05	2.90E-05
	Strontium-90	-5.30E-07	2.00E-06
	Thorium-228	2.75E-06	1.35E-06
	Thorium-230	6.55E-06	1.86E-06
	Thorium-232	2.67E-06	1.09E-06
	Uranium-233/234	3.50E-06	1.51E-06
	Uranium-235/236	0.00E+00	7.70E-07
	Uranium-238	2.21E-06	1.27E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WEE 4.2 Air Sample 4th Quarter WIPP East	Americium-241	9.30E-07	1.13E-06
	Beryllium-7	2.40E-03	3.80E-04
	Cesium-137	-2.60E-06	8.10E-06
	Cobalt-60	-3.90E-06	7.50E-06
	Lead-210	1.50E-03	2.60E-04
	Plutonium-238	-2.63E-07	5.15E-07
	Plutonium-241	-4.20E-03	6.84E-04
	Plutonium-239/240	5.25E-07	6.31E-07
	Polonium 210	3.56E-04	7.22E-06
	Potassium-40	1.50E-04	1.60E-04
	Radium-226	9.50E-05	1.70E-04
	Radium-228	4.80E-05	3.10E-05
	Strontium-90	-4.40E-07	9.20E-06
	Thorium-228	2.87E-06	1.28E-06
	Thorium-230	4.91E-06	1.56E-06
	Thorium-232	2.90E-06	1.18E-06
	Uranium-233/234	3.81E-06	1.58E-06
	Uranium-235/236	-1.57E-07	1.11E-06
	Uranium-238	4.58E-06	1.54E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-WSS 1.1 Air Sampling 1st Quarter WIPP South	Americium-241	4.96E-05	1.17E-05
	Beryllium-7	3.20E-04	1.60E-04
	Cesium-137	-6.90E-06	8.10E-06
	Cobalt-60	-5.50E-06	7.60E-06
	Lead-210	8.90E-04	2.00E-04
	Plutonium-238	1.49E-06	2.92E-06
	Plutonium-241	1.84E-03	2.56E-04
	Plutonium-239/240	0.00E+00	5.06E-06
	Polonium-210	4.03E-04	1.39E-05
	Potassium-40	1.40E-04	1.60E-04
	Radium-228	4.30E-05	3.10E-05
	Radium-226	5.40E-05	1.70E-04
	Stronnum-90	-4.30E-06	1.30E-05
	Thorium-228	1.45E-05	8.67E-06
	Thorium-230	3.28E-05	1.04E-05
	Thorium-232	4.37E-06	4.04E-06
	Uranium-233/234	2.07E-05	9.36E-06
	Uranium-238	7.85E-06	6.10E-06
	Uranium-235/236	2.64E-06	3.86E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WSS 2.1 Air Sampling 2nd Quarter WIPP South	Americium-241	3.33E-05	1.01E-05
	Beryllium-7	2.00E-04	1.60E-04
	Cesium-137	-2.60E-06	8.70E-06
	Cobalt-60	1.20E-05	8.30E-06
	Lead-210	6.80E-05	2.10E-04
	Plutonium-238	0.00E+00	3.37E-06
	Plutonium-241	7.28E-04	2.33E-04
	Plutonium-239/240	3.51E-06	3.07E-06
	Polonium-210	4.34E-05	4.72E-06
	Potassium-40	1.00E-03	2.20E-04
	Radium-228	7.60E-05	6.10E-05
	Radium-226	3.50E-04	1.50E-04
	Strontium-90	-6.80E-06	1.20E-05
	Thorium-228	5.77E-06	5.36E-06
	Thorium-230	3.36E-05	1.04E-05
	Thorium-232	5.95E-06	4.61E-06
	Uranium-233/234	1.87E-05	1.32E-05
	Uranium-238	7.89E-06	7.23E-06
	Uranium-235/236	1.22E-06	5.33E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WSS 3.1 Air Sampling 3rd Quarter WIPP South	Americium-241	1.83E-06	1.46E-06
	Beryllium-7	8.20E-04	1.90E-04
	Cesium-137	4.30E-06	8.10E-06
	Cobalt-60	-9.10E-06	7.30E-06
	Lead-210	8.70E-04	1.80E-04
	Plutonium-239/240	6.59E-07	6.46E-07
	Plutonium-241	-9.01E-04	8.50E-05
	Plutonium-238	1.65E-07	5.60E-07
	Polonium 210	2.80E-04	1.01E-05
	Potassium-40	2.40E-04	1.60E-04
	Radium-226	7.00E-04	2.40E-04
	Radium-228	4.50E-05	2.90E-05
	Strontium-90	-5.70E-06	1.20E-05
	Thorium-230	1.07E-05	2.54E-06
	Thorium-228	5.34E-06	1.88E-06
	Thorium-232	4.40E-06	1.69E-06
	Uranium-238	8.28E-06	2.28E-06
	Uranium-233/234	6.64E-06	2.07E-06
	Uranium-235/236	0.00E+00	8.76E-07

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WSS 3.2 Air Sampling 3rd Quarter WIPP South	Americium-241	1.88E-06	1.24E-06
	Beryllium-7	9.30E-05	8.80E-05
	Cesium-137	2.90E-06	7.70E-06
	Cobalt-60	1.70E-06	6.70E-06
	Lead-210	3.10E-03	8.50E-04
	Plutonium-239/240	1.07E-06	8.99E-07
	Plutonium-241	-8.18E-04	7.96E-05
	Plutonium-238	-4.59E-07	5.19E-07
	Polonium 210	2.78E-04	9.90E-06
	Potassium-40	-5.70E-05	5.60E-05
	Radium-226	6.10E-05	7.40E-04
	Radium-228	-2.40E-05	2.80E-05
	Strontium-90	2.70E-06	8.90E-06
	Thorium-230	1.06E-05	2.29E-06
	Thorium-228	5.02E-06	1.73E-06
	Thorium-232	4.80E-06	1.58E-06
	Uranium-238	5.99E-06	1.77E-06
	Uranium-233/234	7.61E-06	2.13E-06
	Uranium-235/236	3.36E-07	9.32E-07

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-WSS 4.1 Air Sampling 4th Quarter WIPP South	Americium-241	1.40E-07	7.28E-07
	Beryllium-7	2.60E-03	4.40E-04
	Cesium-137	4.40E-06	7.90E-06
	Cobalt-60	1.80E-06	6.40E-06
	Lead-210	1.40E-03	2.40E-04
	Plutonium-238	3.70E-07	5.40E-07
	Plutonium-241	-6.95E-03	6.30E-04
	Plutonium-239/240	3.69E-07	6.39E-07
	Polonium 210	2.95E-04	7.27E-06
	Potassium-40	1.30E-04	1.80E-04
	Radium-226	8.50E-05	1.70E-04
	Radium-228	5.20E-05	3.00E-05
	Strontium-90	-5.80E-07	7.70E-06
	Thorium-228	2.90E-06	1.23E-06
	Thorium-230	6.24E-06	1.71E-06
	Thorium-232	2.14E-06	1.10E-06
	Uranium-233/234	2.08E-05	3.22E-06
	Uranium-235/236	1.66E-06	1.07E-06
	Uranium-238	2.78E-05	3.67E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^-3	COUNTING ERROR
AC-MLR 1.1 Air Sampling 1st Quarter Mills Ranch	Americium-241	3.57E-05	1.01E-05
	Beryllium-7	5.40E-04	2.10E-04
	Cesium-137	3.80E-07	1.10E-05
	Cobalt-60	-8.00E-06	1.10E-05
	Lead-210	1.00E-03	2.20E-04
	Plutonium-238	-7.63E-07	2.59E-06
	Plutonium-241	1.13E-03	2.48E-04
	Plutonium-239/240	7.62E-07	4.48E-06
	Polonium-210	3.47E-04	1.48E-05
	Potassium-40	3.80E-04	1.30E-04
	Radium-228	6.10E-05	3.50E-05
	Radium-226	8.20E-04	2.80E-04
	Strontium-90	-8.40E-06	1.10E-05
	Thorium-228	7.16E-06	7.15E-06
	Thorium-230	2.88E-05	9.35E-06
	Thorium-232	3.59E-06	3.15E-06
	Uranium-233/234	8.50E-05	2.04E-05
	Uranium-238	1.06E-05	8.36E-06
	Uranium-235/236	5.84E-06	5.72E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^-3	COUNTING ERROR
AC-MLR 2.1 Air Sampling 2nd Quarter Mills Ranch	Americium-241	3.69E-05	1.09E-05
	Beryllium-7	4.40E-04	1.50E-04
	Cesium-137	1.10E-05	7.80E-06
	Cobalt-60	5.80E-07	7.00E-06
	Lead-210	9.00E-05	1.50E-04
	Plutonium-238	6.64E-07	3.44E-06
	Plutonium-241	1.01E-03	2.19E-04
	Plutonium-239/240	1.33E-06	2.60E-06
	Polonium-210	4.23E-05	3.86E-06
	Potassium-40	2.40E-05	1.40E-04
	Radium-228	3.10E-05	2.80E-05
	Radium-226	3.60E-05	1.90E-04
	Strontium-90	-4.10E-05	1.40E-05
	Thorium-228	3.99E-06	5.19E-06
	Thorium-230	2.74E-05	9.80E-06
	Thorium-232	2.88E-06	3.46E-06
	Uranium-233/234	1.89E-05	8.76E-06
	Uranium-238	8.50E-06	5.58E-06
	Uranium-235/236	1.61E-06	2.23E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-MLR 2.2 Air Sampling 2nd Quarter Mills Ranch	Americium-241	2.88E-05	8.49E-06
	Beryllium-7	3.20E-04	1.90E-04
	Cesium-137	2.80E-06	9.70E-06
	Cobalt-60	-3.10E-06	8.20E-06
	Lead-210	1.00E-04	1.90E-04
	Plutonium-238	-1.31E-06	2.57E-06
	Plutonium-241	1.51E-03	2.21E-04
	Plutonium-239/240	-6.54E-07	1.28E-06
	Polonium-210	4.86E-05	7.57E-06
	Polonium-210	1.54E-02	9.15E-03
	Potassium-40	2.30E-04	9.80E-05
	Radium-226	7.20E-04	2.50E-04
	Radium-228	5.60E-05	3.90E-05
	Strontium-90	-2.60E-06	1.10E-05
	Thorium-230	2.47E-05	1.01E-05
	Thorium-228	1.07E-05	7.89E-06
	Thorium-232	6.17E-06	5.73E-06
	Uranium-233/234	1.36E-05	7.82E-06
	Uranium-238	1.13E-05	7.10E-06
	Uranium-235/236	9.32E-07	4.08E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^-3	COUNTING ERROR
AC-MLR 3.1 Air Sampling 3rd Quarter Mills Ranch	Americium-241	1.05E-06	7.31E-07
	Beryllium-7	9.60E-04	2.10E-04
	Cesium-137	-2.80E-06	8.60E-06
	Cobalt-60	-2.80E-06	7.80E-06
	Lead-210	9.50E-04	2.310E-04
	Plutonium-239/240	1.40E-07	7.28E-07
	Plutonium-241	-8.75E-04	7.09E-05
	Plutonium-238	0.00E+00	6.74E-07
	Polonium 210	3.72E-04	9.40E-06
	Potassium-40	4.00E-05	1.50E-04
	Radium-226	8.20E-05	1.60E-04
	Radium-228	6.30E-05	3.20E-05
	Stronnum-90	7.80E-06	9.70E-06
	Thorium-230	7.67E-05	7.08E-06
	Thorium-228	6.47E-06	2.50E-06
	Thorium-232	7.70E-06	2.27E-06
	Uranium-238	4.93E-06	1.71E-06
	Uranium-233/234	6.52E-06	1.97E-06
	Uranium-235/236	8.22E-07	9.67E-07

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-MLR 4.1 Air Sampling 4th Quarter Mills Ranch	Americium-241	1.80E-06	1.23E-06
	Beryllium-7	2.50E-03	4.10E-04
	Cesium-137	1.40E-06	6.90E-06
	Cobalt-60	4.70E-07	6.40E-06
	Lead-210	1.50E-03	2.30E-04
	Plutonium-238	-6.64E-07	8.63E-07
	Plutonium-241	-7.85E-03	6.88E-04
	Plutonium-239/240	6.64E-07	1.96E-06
	Polonium 210	3.28E-04	7.76E-06
	Potassium-40	8.40E-05	1.10E-04
	Radium-226	3.60E-05	1.50E-04
	Radium-228	2.50E-05	2.70E-05
	Strontium-90	1.20E-05	9.20E-06
	Thorium-228	4.08E-06	1.35E-06
	Thorium-230	1.14E-05	2.30E-06
	Thorium-232	2.94E-06	1.25E-06
	Uranium-233/234	5.14E-06	1.76E-06
	Uranium-235/236	-4.53E-07	6.62E-07
	Uranium-238	5.76E-06	1.75E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-SEC 1.1 Air Sampling 1st Quarter South East Control	Americium-241	3.55E-05	1.06E-05
	Beryllium-7	4.00E-04	1.60E-04
	Cesium-137	1.70E-06	9.60E-06
	Cobalt-60	1.20E-05	8.40E-06
	Lead-210	9.60E-04	2.40E-04
	Plutonium-238	0.00E+00	3.57E-06
	Plutonium-241	2.32E-03	3.28E-04
	Plutonium-239/240	0.00E+00	2.65E-06
	Polonium-210	3.54E-04	1.45E-05
	Potassium-40	2.00E-04	2.20E-04
	Radium-228	7.40E-05	3.40E-05
	Radium-226	5.60E-04	2.00E-04
	Strontium-90	1.80E-06	1.30E-05
	Thorium-228	7.64E-06	4.99E-06
	Thorium-230	3.15E-05	1.01E-05
	Thorium-232	3.06E-06	4.75E-06
	Uranium-233/234	1.38E-05	7.93E-06
	Uranium-238	7.30E-06	6.16E-06
	Uranium-235/236	-1.00E-06	1.96E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-SEC 1.2 Air Sampling 1st Quarter South East Control	Americium-241	5.07E-05	1.20E-05
	Beryllium-7	4.30E-04	1.50E-04
	Cesium-137	4.90E-06	8.10E-06
	Cobalt-60	1.30E-06	7.80E-06
	Lead-210	9.60E-04	2.00E-04
	Plutonium-238	-1.51E-06	4.19E-06
	Plutonium-241	2.56E-03	2.71E-04
	Plutonium-239/240	0.00E+00	3.62E-06
	Polonium-210	3.95E-04	1.09E-05
	Potassium-40	1.50E-04	1.60E-04
	Radium-228	3.70E-05	3.10E-05
	Radium-226	3.70E-05	6.40E-04
	Strontium-90	1.90E-05	1.50E-05
	Thorium-228	7.79E-07	4.04E-06
	Thorium-230	2.18E-05	7.69E-06
	Thorium-232	2.11E-06	3.08E-06
	Uranium-233/234	1.74E-05	9.00E-06
	Uranium-238	5.82E-06	6.37E-06
	Uranium-235/236	8.97E-07	4.65E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-SEC 2.1 Air Sampling 2nd Quarter South East Control	Americium-241	2.56E-05	9.66E-06
	Beryllium-7	5.90E-04	2.10E-04
	Cesium-137	3.20E-06	1.00E-05
	Cobalt-60	4.20E-06	9.30E-06
	Lead-210	1.10E-04	2.30E-04
	Plutonium-238	-1.57E-06	3.78E-06
	Plutonium-241	2.81E-03	2.73E-04
	Plutonium-239/240	1.57E-06	3.77E-06
	Polonium-210	5.60E-05	3.95E-06
	Potassium-40	1.20E-03	2.50E-04
	Radium-228	7.90E-05	4.30E-05
	Radium-226	7.40E-05	2.50E-04
	Strontium-90	-1.30E-05	1.50E-05
	Thorium-228	7.98E-06	7.58E-06
	Thorium-230	2.89E-05	9.68E-06
	Thorium-232	2.40E-06	3.51E-06
	Uranium-233/234	3.05E-05	1.10E-05
	Uranium-238	1.80E-05	7.38E-06
	Uranium-235/236	9.68E-07	3.29E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-SEC 3.1 Air Sampling 3rd Quarter South East Control	Americium-241	2.38E-06	1.37E-06
	Beryllium-7	8.50E-04	2.10E-04
	Cesium-137	9.70E-06	9.50E-06
	Cobalt-60	8.90E-06	7.80E-06
	Lead-210	9.70E-04	2.20E-04
	Plutonium-239/240	1.46E-06	9.07E-07
	Plutonium-241	-9.32E-04	7.09E-05
	Plutonium-238	-2.93E-07	7.03E-07
	Polonium 210	3.99E-04	9.92E-06
	Potassium-40	1.20E-04	1.90E-04
	Radium-226	9.10E-05	1.80E-04
	Radium-228	5.90E-05	5.90E-05
	Strontium-90	3.70E-06	9.50E-06
	Thorium-230	1.03E-05	2.40E-06
	Thorium-228	4.90E-06	2.04E-06
	Thorium-232	5.50E-06	1.88E-06
	Uranium-238	6.53E-06	2.16E-06
	Uranium-233/234	3.10E-06	1.97E-06
	Uranium-235/236	7.67E-07	1.06E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-SEC 4.1 Air Sampling 4th Quarter South East Control	Americium-241	2.72E-06	1.35E-06
	Beryllium-7	2.80E-03	4.10E-04
	Cesium-137	6.60E-06	7.90E-06
	Cobalt-60	-5.90E-06	7.00E-06
	Lead-210	5.90E-03	1.10E-03
	Plutonium-238	-4.09E-07	4.63E-07
	Plutonium-241	-6.13E-03	7.29E-04
	Plutonium-239/240	8.18E-07	6.55E-07
	Polonium 210	3.26E-04	7.51E-06
	Potassium-40	2.10E-04	1.50E-04
	Radium-226	1.30E-03	3.70E-04
	Radium-228	4.00E-05	2.80E-05
	Strontium-90	2.70E-06	9.90E-06
	Thorium-228	2.93E-06	1.40E-06
	Thorium-230	7.55E-06	2.06E-06
	Thorium-232	3.06E-06	1.20E-06
	Uranium-233/234	1.06E-05	2.45E-06
	Uranium-235/236	7.79E-07	6.83E-07
	Uranium-238	5.10E-05	4.99E-06

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-WAB 1.1 Air Sampling 1st Quarter Blank Filter Analysis	Americium-241	5.58E-05	1.08E-01
	Beryllium-7	-1.48E-04	7.00E-01
	Cesium-137	1.48E-06	6.70E-02
	Cobalt-60	-1.75E-06	6.80E-02
	Lead-210	7.69E-05	1.10E+00
	Plutonium-238	6.70E-07	9.75E-03
	Plutonium-241	2.21E-03	1.78E+00
	Plutonium-239/240	4.02E-06	2.75E-02
	Polonium-210	6.77E-07	5.80E-03
	Potassium-40	2.56E-04	8.30E-01
	Radium-228	2.16E-05	2.80E-01
	Radium-226	7.86E-04	2.00E+00
	Strontium-90	1.08E-05	9.60E-02
	Thorium-228	2.16E-06	2.34E-02
	Thorium-230	6.50E-07	6.14E-02
	Thorium-232	2.35E-05	2.50E-02
	Uranium-233/234	6.50E-07	5.85E-02
	Uranium-238	1.53E-05	4.29E-02
	Uranium-235/236	0.00	3.91E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT UNIT Bq/m^{3}	COUNTING ERROR
AC-WAB 1.2 Air Sampling 1st Quarter Blank Filter Anlaysis	Americium-241	3.61E-05	7.36E-02
	Beryllium-7	2.70E-05	6.80E-01
	Cesium-137	8.22E-07	5.80E-02
	Cobalt-60	6.88E-06	5.00E-02
	Lead-210	7.42E-04	9.00E-01
	Plutonium-238	0.00E+00	4.28E-02
	Plutonium-241	4.15E-03	3.19E+00
	Plutonium-239/240	2.40E-06	3.49E-02
	Polonium-210	2.70E-07	6.26E-03
	Potassium-40	9.71E-04	1.50E+00
	Radium-228	4.31E-05	2.00E-01
	Radium-226	3.64E-04	1.10E+00
	Stronnum-90	-2.16E-05	9.30E-02
	Thorium-228	2.98E-06	3.42E-02
	Thorium-230	1.82E-05	5.79E-02
	Thorium-232	2.01E-06	2.18E-02
	Uranium-233/234	1.02E-05	5.66E-02
	Uranium-238	4.76E-06	3.56E-02
	Uranium-235/236	0.00E+00	2.99E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^{-3}	COUNTING ERROR
AC-WAB 2.1 Air Sampling 2nd Quarter Blank Filter Analysis	Americium-241	3.60E-05	7.34E-02
	Beryllium-7	2.97E-05	5.80E-01
	Cesium-137	-5.26E-07	5.40E-02
	Cobalt-60	2.70E-06	5.20E-02
	Lead-210	5.66E-05	1.00E+00
	Plutonium-238	-6.84E-07	2.22E-02
	Plutonium-241	4.26E-04	1.66E+00
	Plutonium-239/240	6.82E-07	2.22E-02
	Polonium-210	-2.72E-07	8.40E-03
	Potassium-40	1.19E-04	1.10E+00
	Radium-228	2.83E-05	2.10E-01
	Radium-226	6.61E-04	1.80E+00
	Strontium-90	-3.64E-06	7.10E-02
	Thorium-228	4.00E-06	4.20E-02
	Thorium-230	2.02E-05	5.76E-02
	Thorium-232	0.00E+00	2.97E-02
	Uranium-233/234	1.86E-05	5.78E-02
	Uranium-238	7.95E-06	4.09E-02
	Uranium-235/236	-1.63E-06	2.91E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WAB 2.2 Air Sampling WIPP 2nd Quarter Blank Filter Analyis	Americium-241	4.41E-05	8.08E-02
	Beryllium-7	6.34E-05	7.30E-01
	Cesium-137	4.45E-06	6.30E-02
	Cobalt-60	1.89E-06	4.90E-02
	Lead-210	7.28E-04	8.70E-01
	Plutonium-238	-6.66E-07	2.17E-02
	Plutonium-239/240	3.99E-06	2.73E-02
	Plutonium-241	6.23E-04	1.66E+00
	Polonium-210	2.08E-06	9.15E-03
	Potassium-40	9.44E-04	1.50E+00
	Radium-228	6.88E-05	2.90E-01
	Radium-226	1.29E-04	1.50E+00
	Strontium-90	-3.64E-06	7.50E-02
	Thorium-228	-8.05E-07	3.10E-02
	Thorium-230	2.25E-05	6.43E-02
	Thorium-232	2.90E-06	2.59E-02
	Uranium-238	4.54E-06	3.89E-02
	Uranium-235/236	1.60E-06	2.33E-02
	Uranium-233/234	1.43E-05	5.16E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/m^3	COUNTING ERROR
AC-WAB 3.1 Air Sampling 3rd Quarter Blank Filter Anslysis	Amencium-241	6.47E-07	8.20E-03
	Beryllium-7	2.83E-05	5.10E-01
	Cesium-137	-2.16E-06	5.60E-02
	Cobalt-60	-1.17E-06	5.80E-02
	Lead-210	2.97E-05	1.00E+00
	Plutonium-239/240	5.54E-07	4.03E-03
	Plutonium-241	-1.00E-03	5.20E-01
	Plutonium-238	-2.78E-07	5.71E-03
	Polonium 210	6.44E-07	2.39E-03
	Potassium-40	2.70E-05	5.30E-01
	Radium-226	1.89E-04	1.40E+00
	Radium-228	7.28E-06	2.20E-01
	Strontium-90	-3.64E-06	8.10E-02
	Thorium-230	5.62E-06	1.40E-02
	Thorium-228	1.58E-06	1.04E-02
	Thorium-232	2.74E-07	4.88E-03
	Uranium-238	3.06E-06	1.14E-02
	Uranium-233/234	3.45E-06	1.44E-02
	Uranium-235/236	8.21E-07	1.19E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT UNIT Bq/m³	COUNTING ERROR
AC-WAB 4.1 Air Sampling WIPP 4th Quarter Blank Filter Anlaysis	Americium-241	2.39E-06	8.91E-03
	Beryllium-7	-2.02E-05	6.10E-01
	Cesium-137	-6.34E-06	6.20E-02
	Cobalt-60	-3.51E-06	5.60E-02
	Lead-210	8.67E-04	1.00E+00
	Plutonium-238	2.71E-07	4.83E-03
	Plutonium-241	-4.77E-04	5.12E-01
	Plutonium-239/240	3.92E-06	1.16E-02
	Polonium-210	1.30E-06	2.07E-03
	Potassium-40	2.83E-04	1.20E+00
	Radium-226	3.24E-06	1.30E+00
	Radium-228	3.37E-05	2.20E-01
	Strontium-90	1.32E-05	8.90E-02
	Thorium-228	1.97E-06	9.47E-03
	Thorium-230	7.94E-06	1.49E-02
	Thorium-232	4.06E-06	1.07E-02
	Uranium-233/234	4.76E-06	1.49E-02
	Uranium-235/236	0.00E+00	4.75E-03
	Uranium-238	8.47E-06	1.59E-02

1995
Am-241 IN AIR

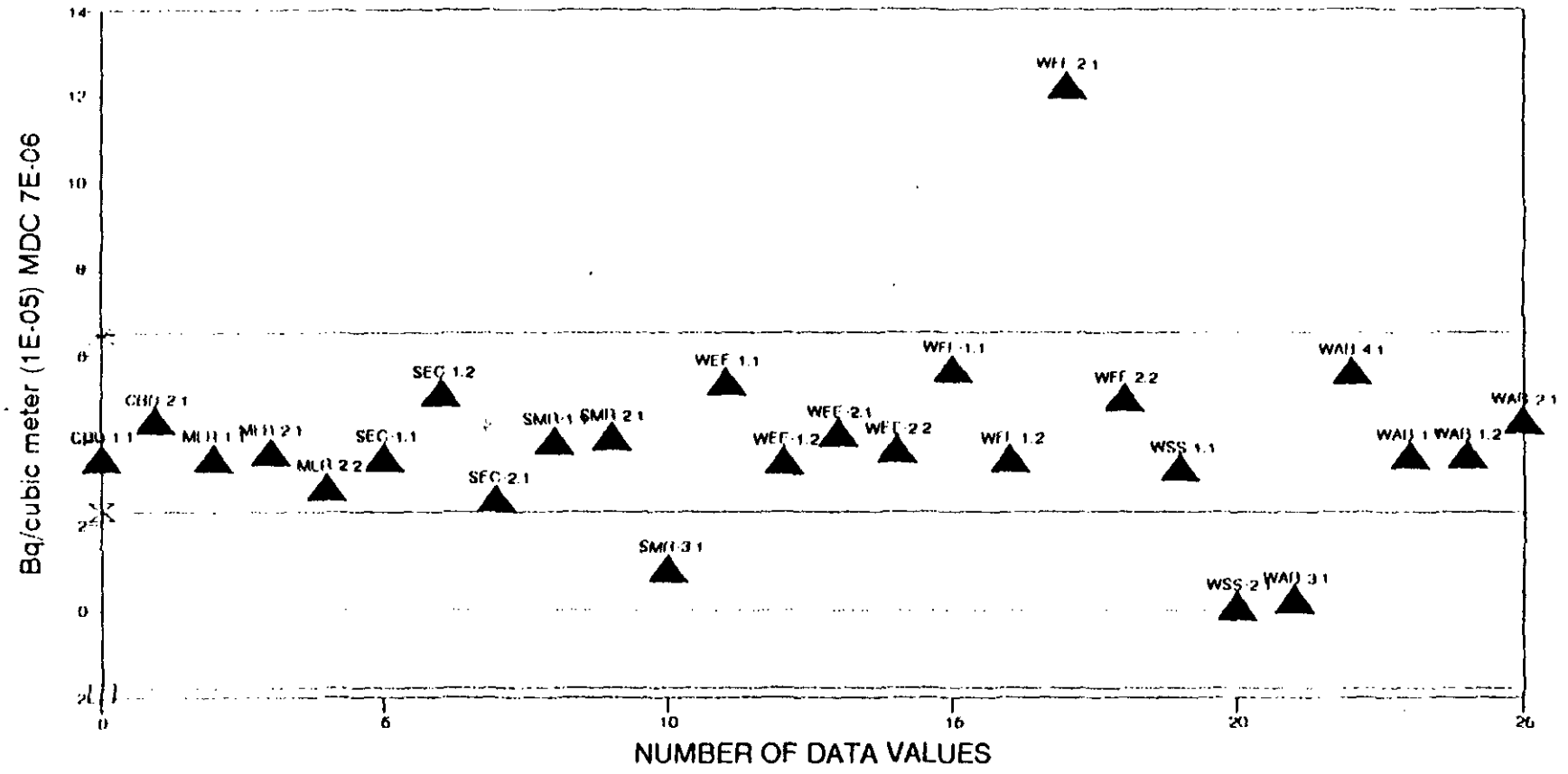

▲ ANALYTICAL VALUE ⊠ MEAN ✳ +2 STD. DEV ⊟ -2 STD. DEV.

1995
Pb-210 IN AIR

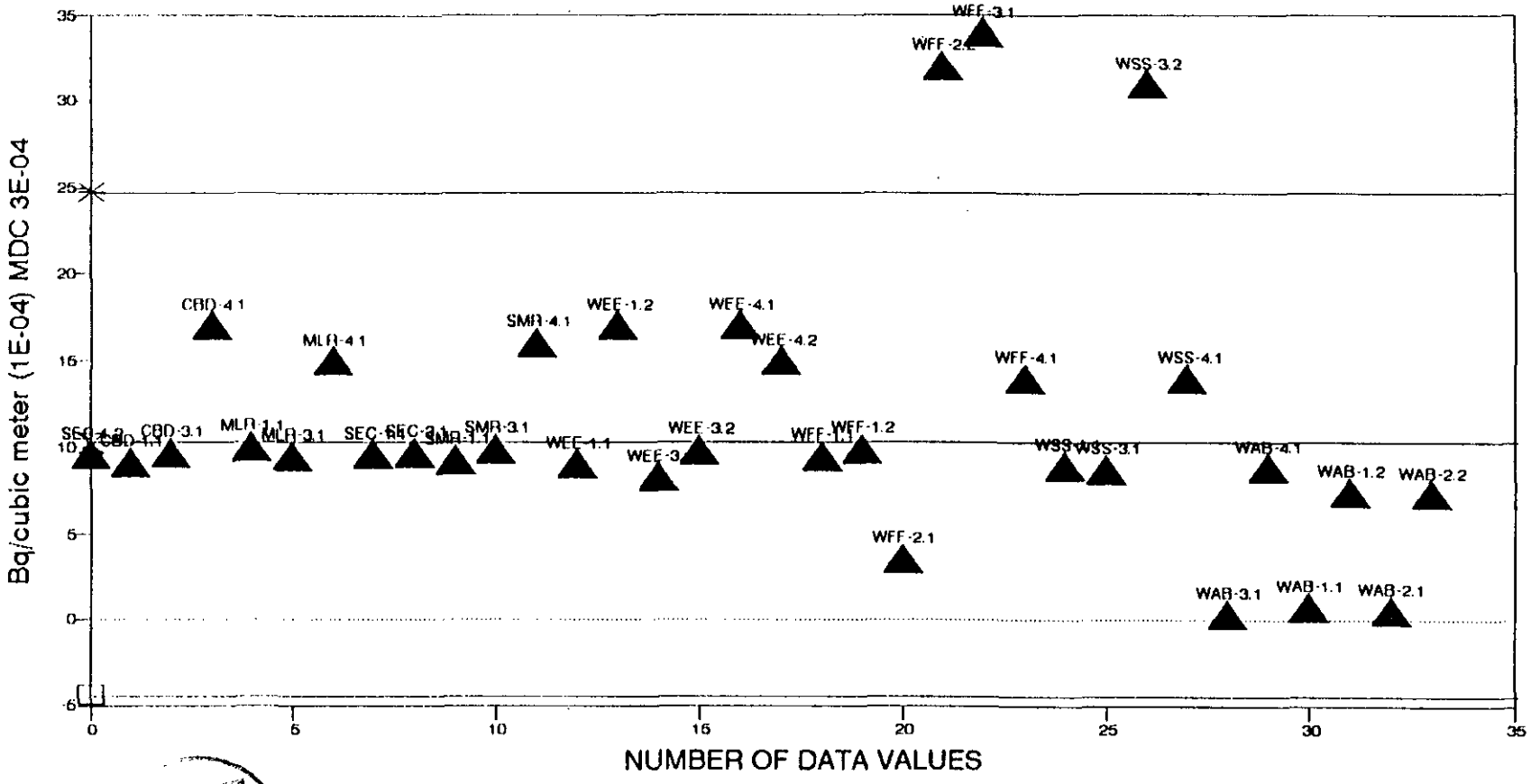

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Po-210 IN AIR

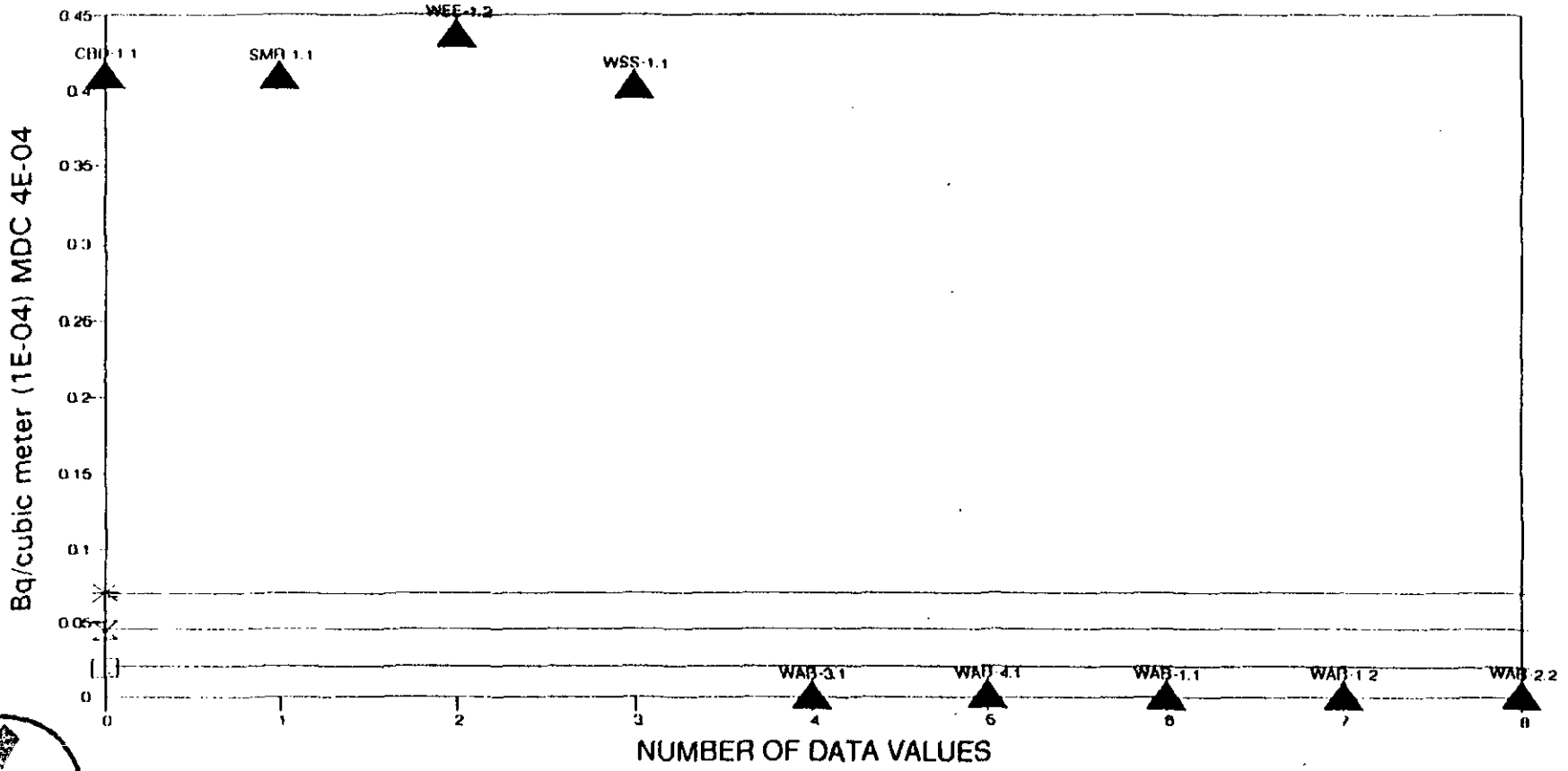

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Pu-241 IN AIR

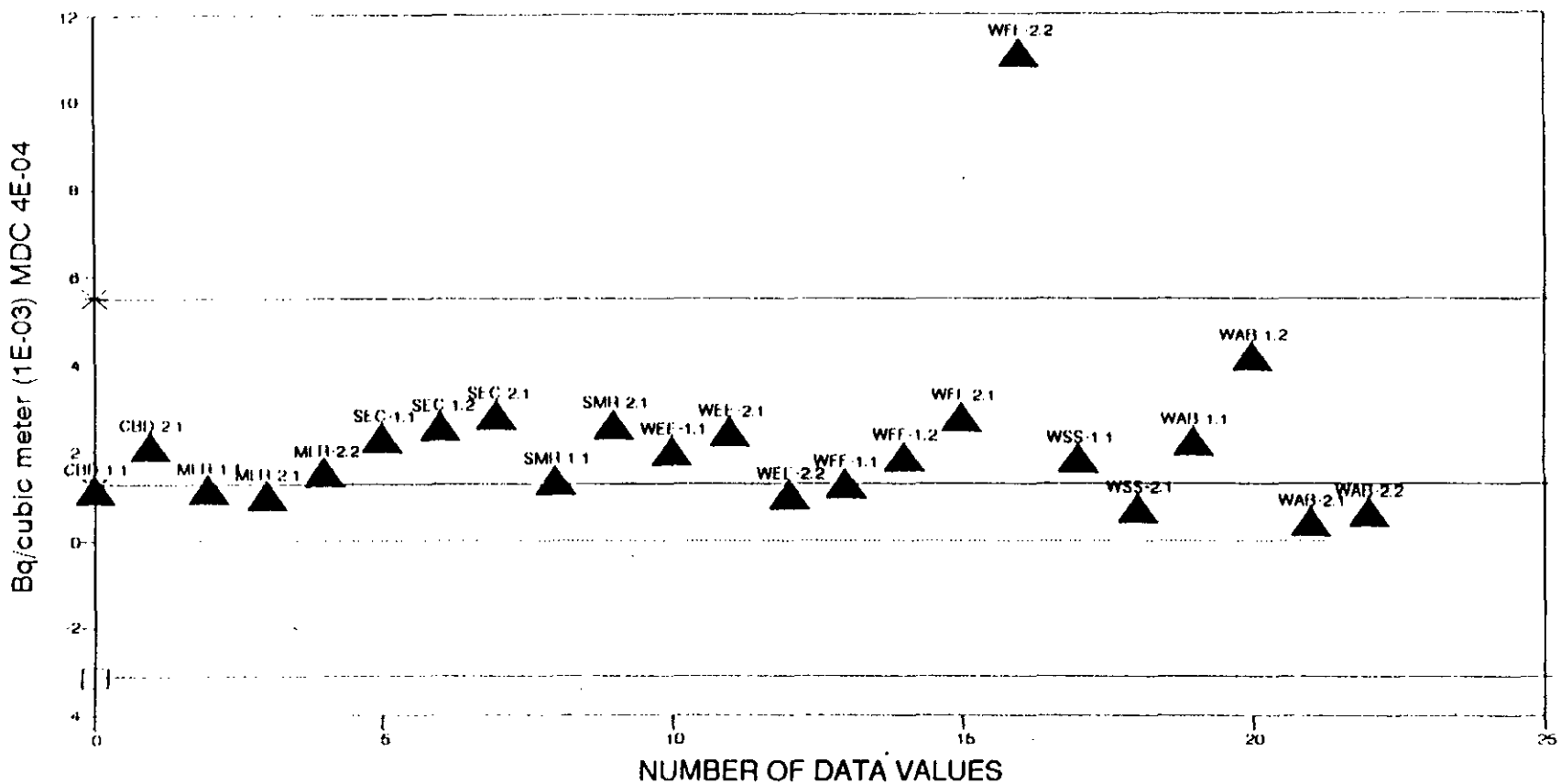

▲ ANALYTICAL VALUE ✕ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Ra-226 IN AIR

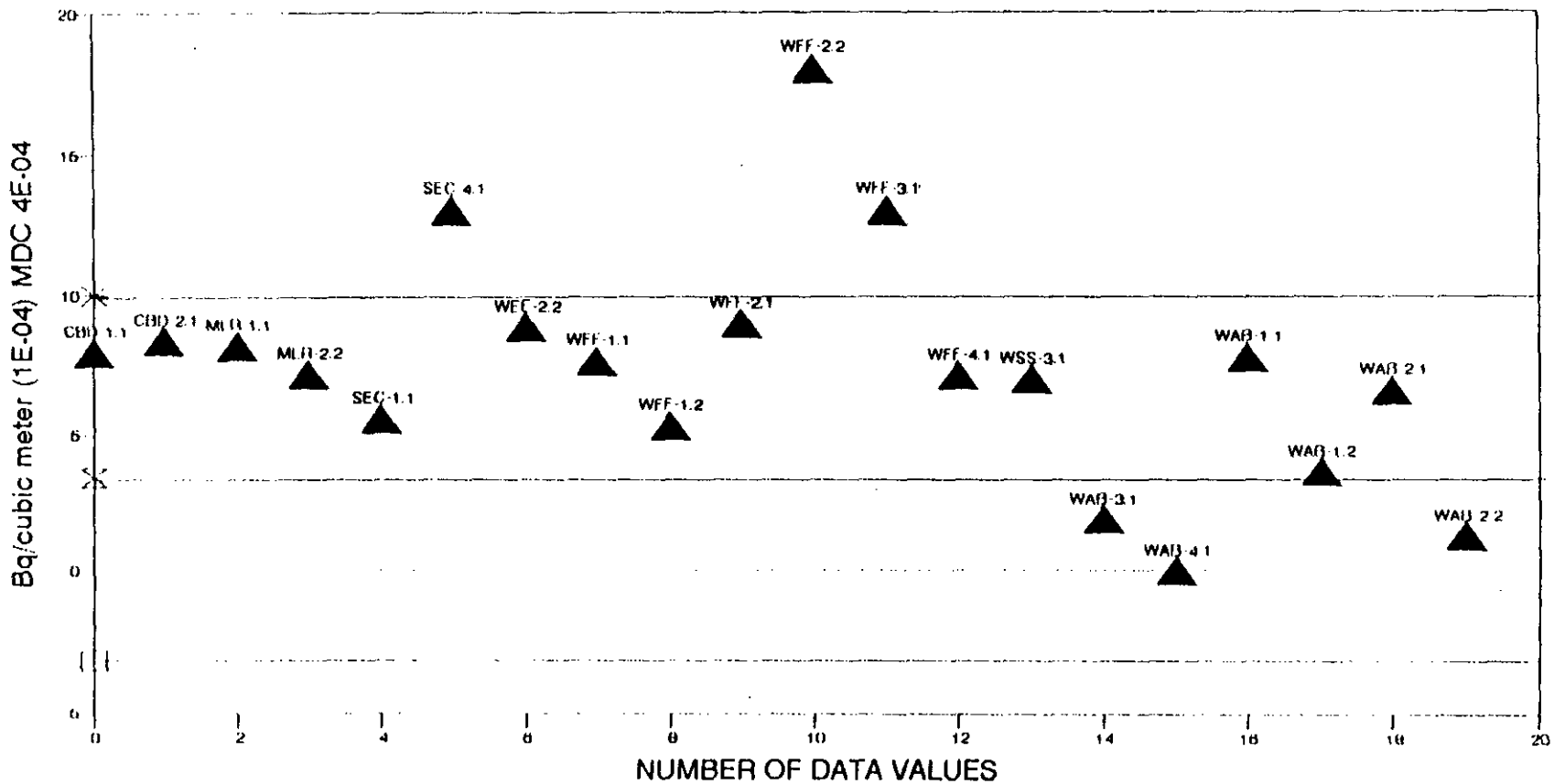

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Th-228 IN AIR

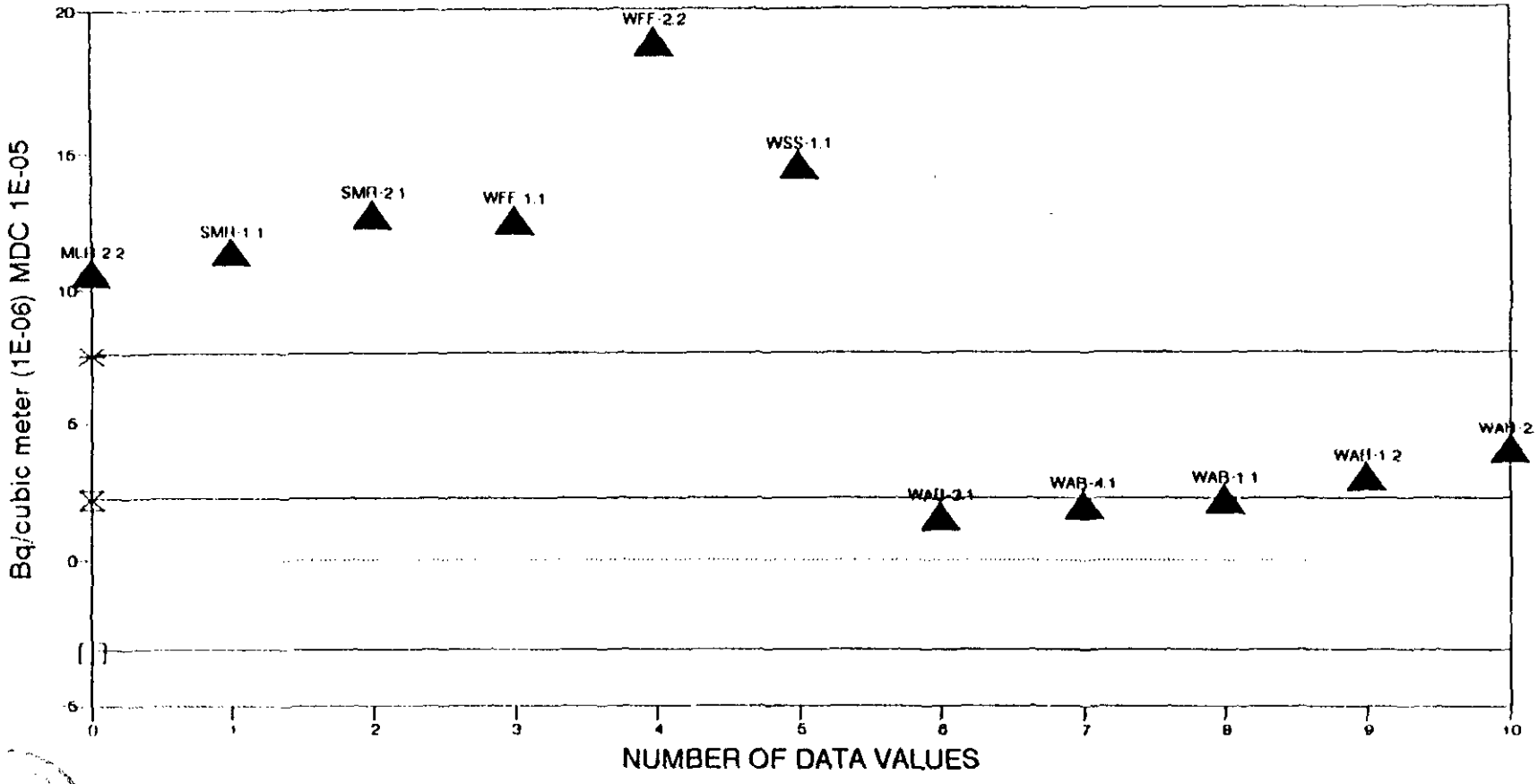

ANALYTICAL VALUE MEAN +2 STD. DEV. -2 STD. DEV.

1995

Th-230 IN AIR

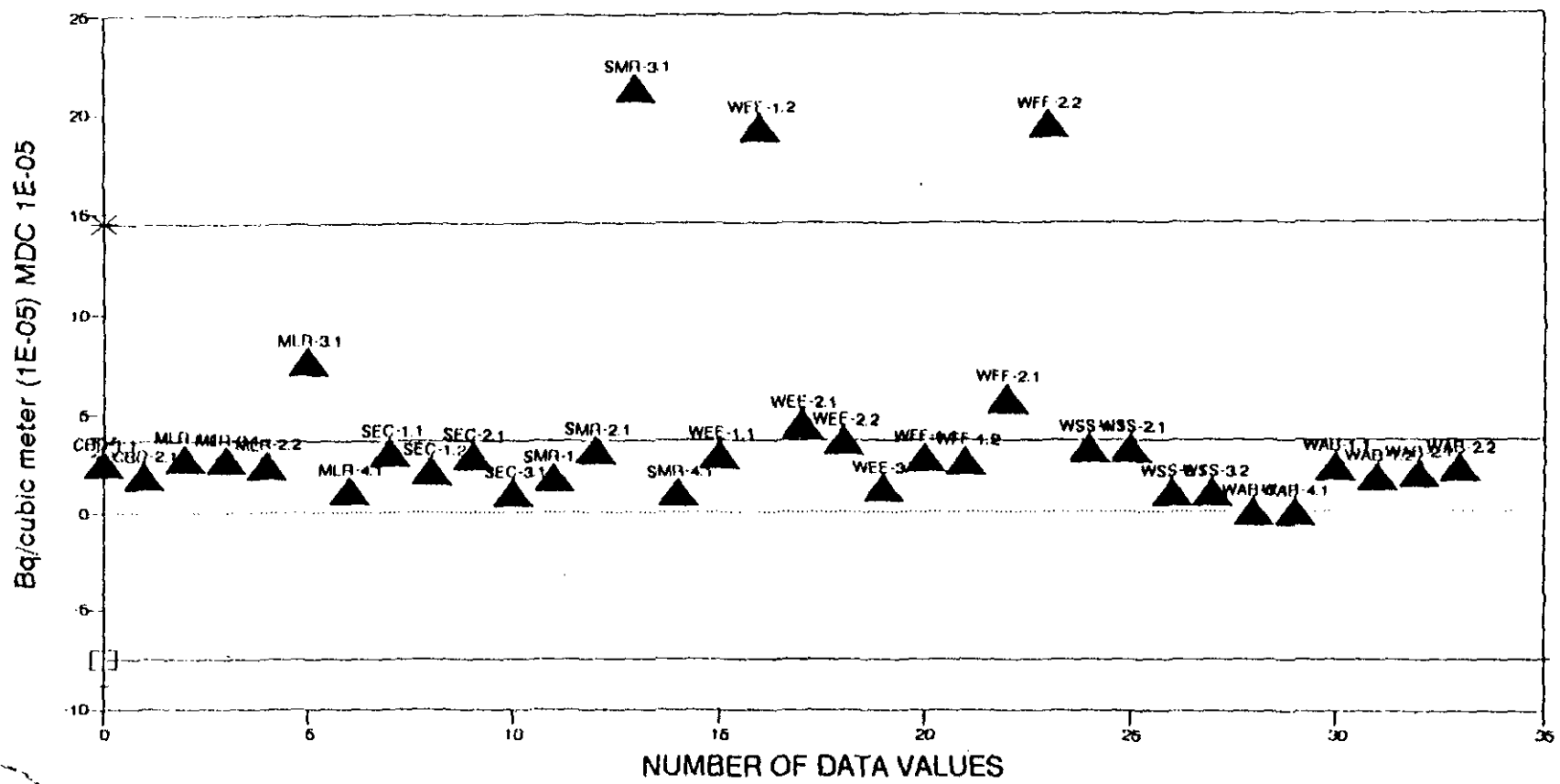

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Th-232 IN AIR

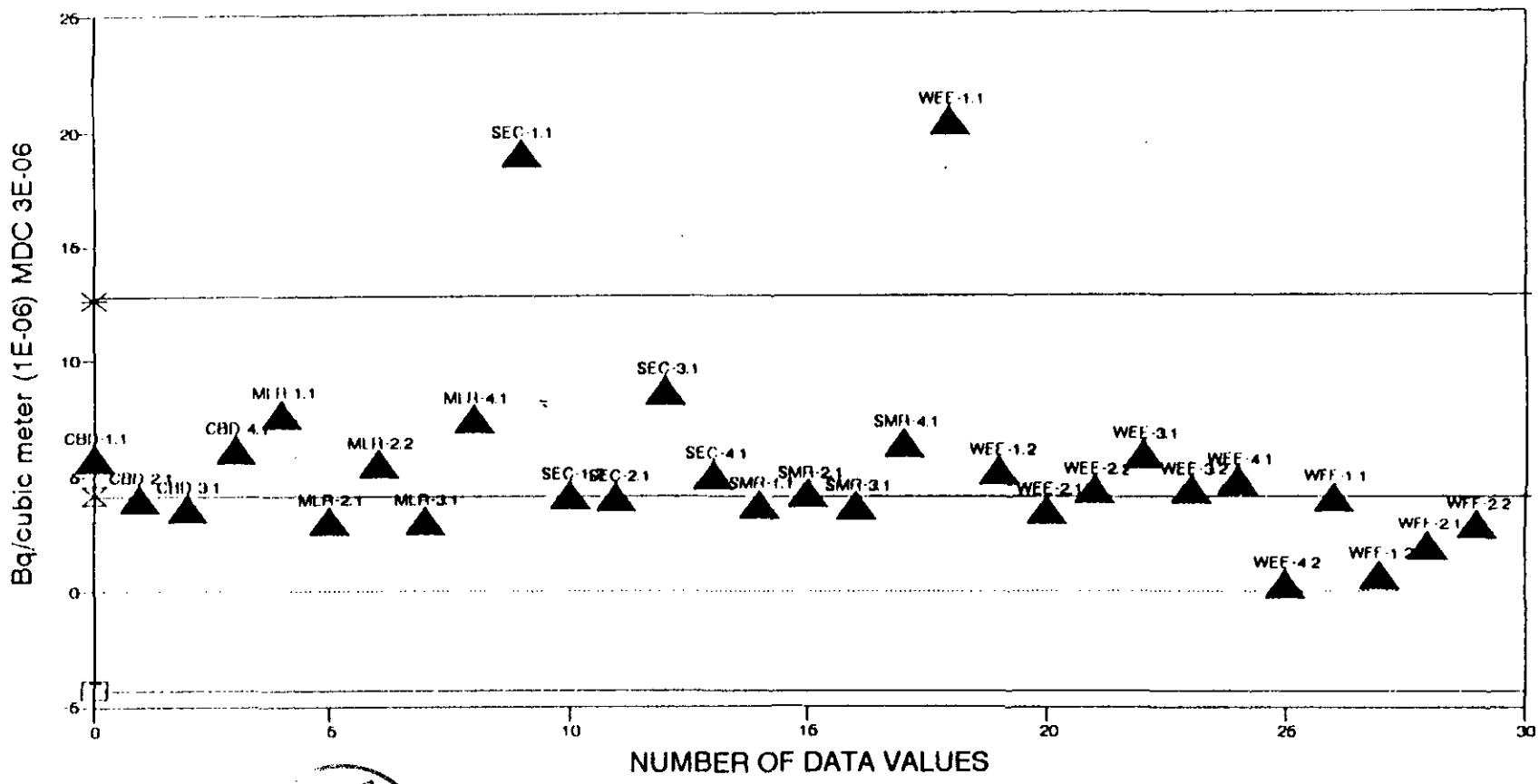

ANALYTICAL VALUE | MEAN | +2 STD. DEV. | -2 STD. DEV.

1995
U-233/234 IN AIR

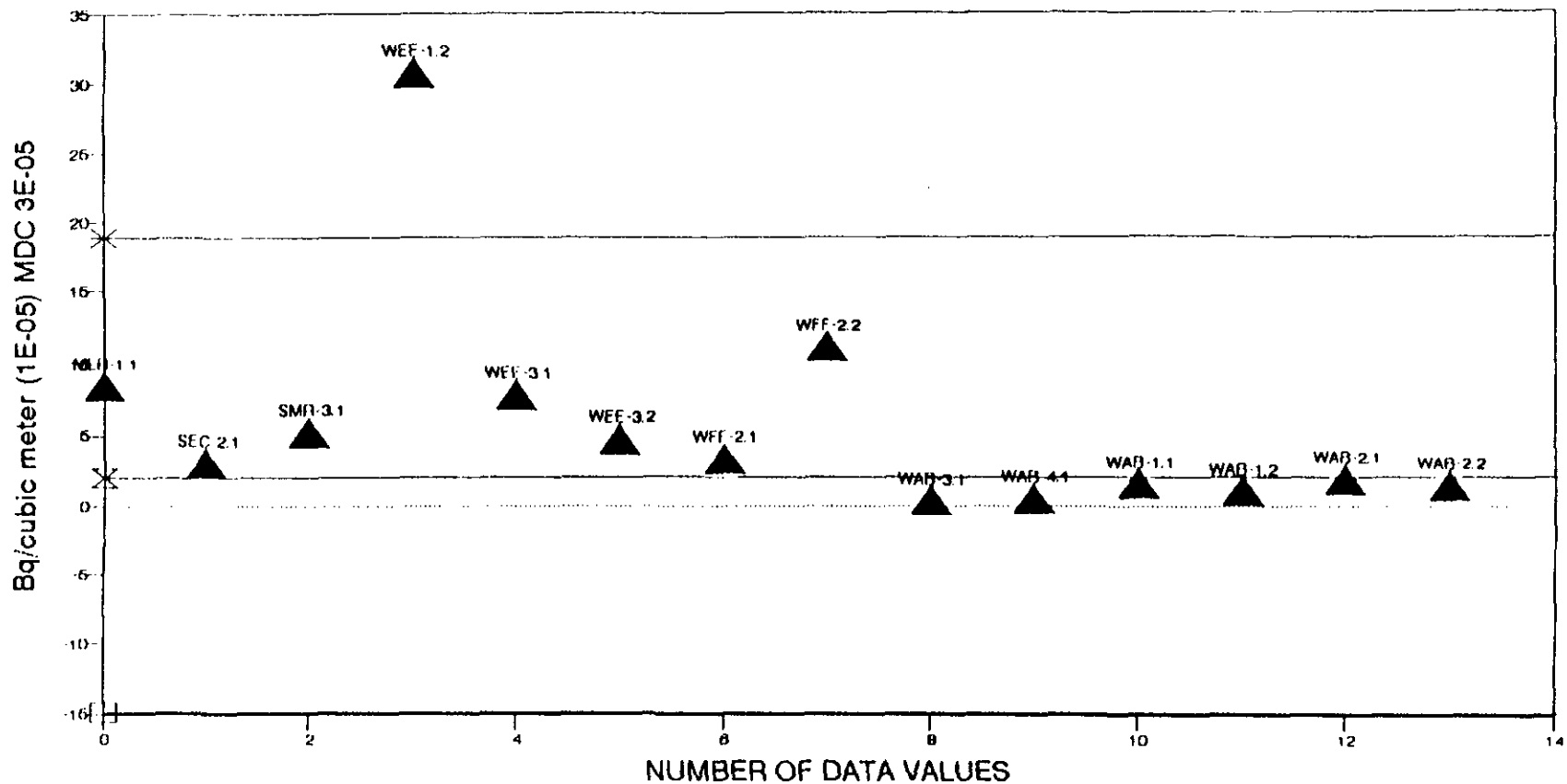

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
U-238 IN AIR

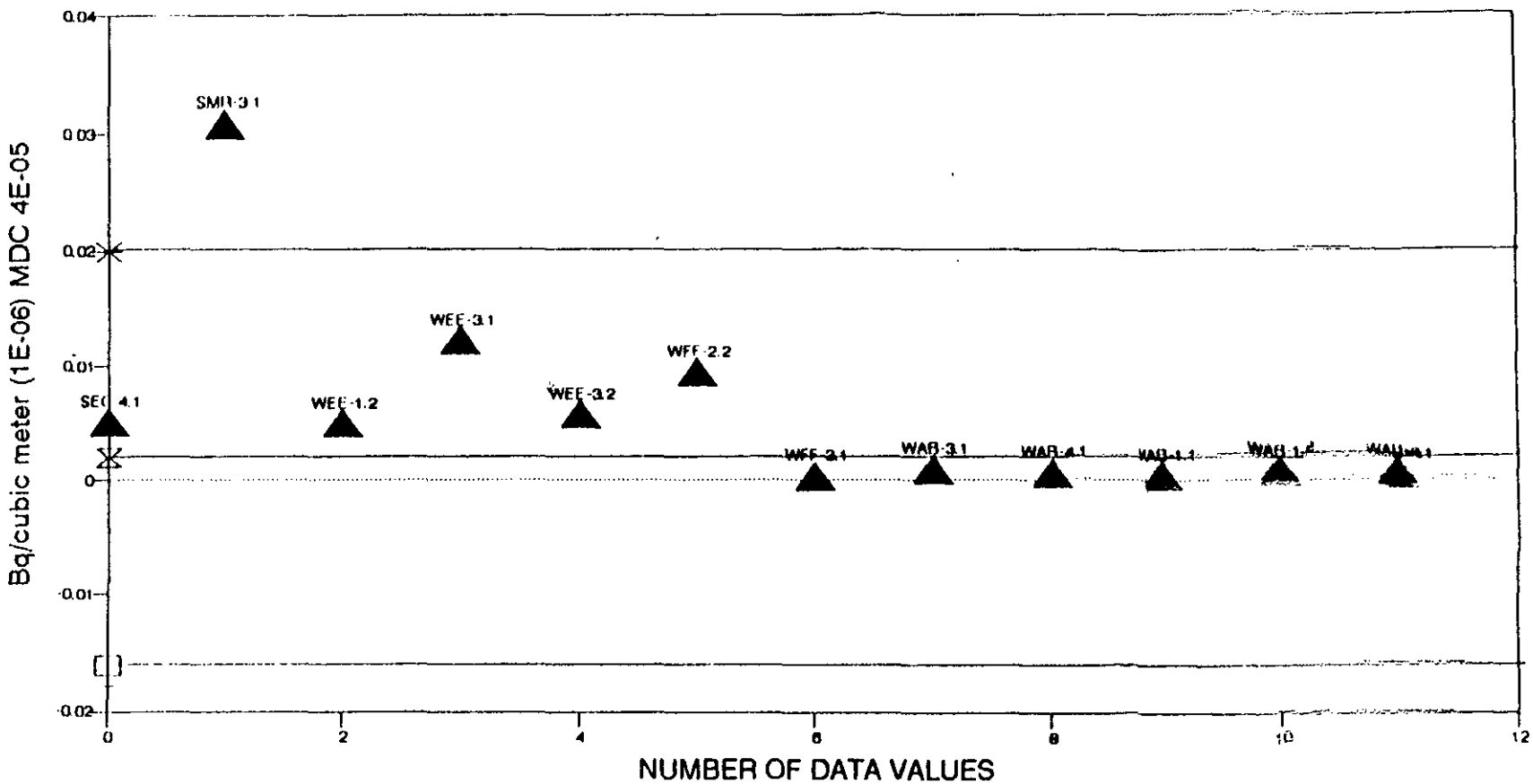

▲ ANALYTICAL VALUE ⊠ MEAN +2 STD. DEV. -2 STD. DEV.

APPENDIX A2
RADIOLOGICAL ANALYSIS
SOILS

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TS-MLR Terrestrial Surface Mills Ranch	Americium-241	6.36E-03	1.67E-03
	Cesium-137	1.10E-02	2.40E-03
	Cobalt-60	*-2.30E-05	3.60E-04
	Lead-210	5.20E-02	4.20E-02
	Plutonium-241	5.63E-02	3.22E-02
	Plutonium-238	1.09E-03	7.02E-04
	Plutonium-239/240	2.98E-04	5.15E-04
	Polonium-210	3.20E-02	1.20E-02
	Potassium-40	4.50E-01	6.40E-02
	Radium-226	1.10E-02	4.00E-02
	Radium-228	2.40E-02	4.50E-03
	Strontium-90	1.30E-03	1.40E-03
	Thorium-232	1.73E-02	2.50E-03
	Thorium-228	1.68E-01	7.76E-03
	Thorium-230	2.58E-02	3.04E-03
	Uranium-233/234	2.48E-02	5.71E-03
	Uranium-238	2.08E-02	5.09E-03
	Uranium-235/236	1.89E-03	1.66E-03
TI-MLR Terrestrial Intermediate Mills Ranch	Americium-241	5.55E-03	1.67E-03
	Cesium-137	5.40E-03	9.50E-04
	Cobalt-60	*-2.00E-04	3.20E-04
	Lead-210	2.90E-02	9.20E-03
	Plutonium-241	6.16E-02	3.18E-02
	Plutonium-238	7.86E-04	6.09E-04
	Plutonium-239/240	5.89E-04	6.09E-04
	Polonium-210	2.00E-02	1.20E-02
	Potassium-40	4.30E-01	9.60E-02
	Radium-226	3.40E-02	1.80E-02
	Radium-228	2.40E-02	4.40E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TI-MLR Terrestrial Intermediate Mills Ranch (continued)	Strontium-90	1.10E-03	1.30E-03
	Thorium-232	1.41E-02	2.25E-03
	Thorium-228	1.69E-01	7.78E-03
	Thorium-230	2.34E-02	2.87E-03
	Uranium-233/234	1.22E-01	7.37E-03
	Uranium-238	9.25E-02	6.40E-03
	Uranium-235/236	1.59E-02	3.11E-03
TD-MLR Terrestrial Deep Mills Ranch	Americium-241	7.37E-03	1.73E-03
	Cesium-137	6.60E-03	1.80E-03
	Cobalt-60	*-1.5E-04	3.80E-04
	Lead-210	*5.80E-02	4.90E-02
	Plutonium-241	2.48E-02	3.23E-02
	Plutonium-238	7.15E-04	7.22E-04
	Plutonium-239/240	9.19E-04	7.22E-04
	Polonium-210	1.70E-02	1.10E-02
	Potassium-40	4.80E-01	7.40E-02
	Radium-226	4.10E-02	1.10E-02
	Radium-228	2.60E-02	4.80E-03
	Strontium-90	1.90E-03	1.40E-03
	Thorium-232	1.96E-02	2.68E-03
	Thorium-228	1.67E-01	7.82E-03
	Thorium-230	2.32E-02	2.90E-03
	Uranium-233/234	1.71E-02	3.12E-03
	Uranium-238	1.76E-02	3.09E-03
	Uranium-235/236	1.55E-03	1.30E-03
TS-SEC Terrestrial Surface South East Control	Americium-241	6.97E-03	1.63E-03
	Cesium-137	4.40E-03	1.20E-03
	Cobalt-60	*4.30E-05	2.70E-04
	Lead-210	1.50E-02	4.30E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TS-SEC Terrestrial Surface South East Control (continued)	Plutonium-241	4.83E-02	3.43E-02
	Plutonium-238	3.00E-03	1.17E-03
	Plutonium-239/240	1.00E-03	7.23E-04
	Polonium-210	1.20E-02	1.30E-02
	Potassium-40	2.10E-01	3.40E-02
	Radium-226	1.90E-02	8.30E-03
	Radium-228	1.30E-02	2.90E-03
	Strontium-90	1.10E-04	1.30E-03
	Thorium-232	7.41E-03	1.68E-03
	Thorium-228	1.50E-01	7.48E-03
	Thorium-230	1.43E-02	2.34E-03
	Uranium-233/234	1.59E-02	3.39E-03
	Uranium-238	8.72E-03	2.34E-03
	Uranium-235/236	7.55E-04	9.06E-04
TI-SEC Terrestrial Intermediate South East Control	Americium-241	6.07E-03	1.63E-03
	Cesium-137	4.20E-03	1.10E-03
	Cobalt-60	*1.30E-04	2.90E-04
	Lead-210	*3.70E-02	3.50E-02
	Plutonium-241	6.99E-02	3.95E-02
	Plutonium-238	7.84E-04	1.20E-03
	Plutonium-239/240	-1.31E-04	6.77E-04
	Polonium-210	2.10E-02	1.10E-02
	Potassium-40	2.30E-01	3.30E-02
	Radium-226	2.10E-02	7.50E-03
	Radium-228	1.10E-02	2.60E-03
	Strontium-90	3.30E-03	1.80E-03
	Thorium-232	6.40E-03	1.96E-03
	Thorium-228	1.57E-01	7.90E-03
	Thorium-230	1.16E-02	2.34E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TI-SEC Terrestrial Intermediate South East Control (continued)	Uranium-233/234	9.40E-03	2.23E-03
	Uranium-238	1.02E-02	2.32E-03
	Uranium-235/236	6.46E-04	7.75E-04
TD-SEC Terrestrial Deep South East Control	Americium-241	7.58E-03	1.71E-03
	Cesium-137	4.70E-03	7.80E-04
	Cobalt-60	*1.20E-05	2.80E-04
	Lead-210	1.80E-02	6.70E-03
	Plutonium-239/240	1.01E-04	4.42E-04
	Plutonium-241	-8.53E-03	3.16E-02
	Plutonium-238	9.08E-04	7.13E-04
	Polonium-210	1.10E-02	1.00E-02
	Potassium-40	2.10E-01	4.60E-02
	Radium-226	2.20E-02	1.20E-02
	Radium-228	1.20E-02	2.90E-03
	Strontium-90	4.70E-04	1.40E-03
	Thorium-230	1.29E-02	2.23E-03
	Thorium-232	8.72E-03	1.85E-03
	Thorium-228	1.61E-01	7.67E-03
	Uranium-233/234	1.01E-02	2.36E-03
	Uranium-238	6.12E-03	1.88E-03
	Uranium-235/236	8.20E-04	7.19E-04
TS-SMR Terrestrial Surface Smith Ranch	Americium-241	7.28E-03	1.77E-03
	Cesium-137	3.20E-03	1.10E-03
	Cobalt-60	*2.20E-04	3.70E-04
	Lead-210	*1.20E-02	4.70E-02
	Plutonium-241	1.01E-01	3.55E-02
	Plutonium-238	1.07E-04	9.59E-04
	Plutonium-239/240	1.28E-03	7.83E-04
	Polonium-210	1.60E-02	1.20E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TS-SMR Terrestrial Surface Smith Ranch (continued)	Potassium-40	4.50E-01	7.00E-02
	Radium-226	4.30E-02	1.20E-02
	Radium-228	2.10E-02	4.10E-03
	Strontium-90	1.60E-04	1.60E-03
	Thorium-232	1.41E-02	2.28E-03
	Thorium-228	1.66E-01	7.72E-03
	Thorium-230	2.15E-02	2.80E-03
	Uranium-233/234	1.36E-02	2.65E-03
	Uranium-238	1.06E-02	2.38E-03
	Uranium-235/236	1.46E-03	9.54E-04
TI-SMR Terrestrial Intermediate Smith Ranch	Americium-241	6.25E-03	1.61E-03
	Cesium-137	2.90E-03	7.70E-04
	Cobalt-60	*5.80E-05	2.90E-04
	Lead-210	2.90E-02	8.00E-03
	Plutonium-241	-2.60E-03	3.37E-02
	Plutonium-238	1.27E-03	7.77E-04
	Plutonium-239/240	3.18E-04	6.22E-04
	Polonium-210	1.10E-02	1.40E-02
	Potassium-40	4.20E-01	7.90E-02
	Radium-226	7.30E-03	3.40E-02
	Radium-228	2.00E-02	4.00E-03
	Strontium-90	-9.60E-05	1.50E-03
	Thorium-232	1.31E-02	2.17E-03
	Thorium-228	1.60E-01	7.65E-03
	Thorium-230	2.06E-02	2.73E-03
	Uranium-233/234	1.29E-02	2.91E-03
	Uranium-238	1.36E-02	2.76E-03
	Uranium-235/236	4.90E-04	8.47E-04

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TD-SMR Terrestrial Deep Smith Ranch	Americium-241	8.38E-03	1.92E-03
	Cesium-137	4.90E-03	1.20E-03
	Cobalt-60	*-1.50E-04	3.80E-04
	Lead-210	*4.30E-02	4.20E-02
	Plutonium-241	3.39E-02	3.28E-02
	Plutonium-238	1.23E-03	1.06E-03
	Plutonium-239/240	5.11E-04	6.65E-04
	Polonium-210	1.30E-02	1.00E-02
	Potassium-40	4.90E-01	7.00E-02
	Radium-226	4.50E-02	1.20E-02
	Radium-228	2.40E-02	4.60E-03
	Strontium-90	9.60E-05	2.00E-03
	Thorium-232	1.81E-02	2.59E-03
	Thorium-228	1.62E-01	7.82E-03
	Thorium-230	2.16E-02	2.85E-03
	Uranium-233/234	5.17E-02	5.07E-03
	Uranium-238	3.89E-02	4.38E-03
	Uranium-235/236	5.84E-03	2.12E-03
TS-WEE Terrestrial Surface WIPP East	Americium-241	7.06E-03	1.68E-03
	Cesium-137	6.90E-03	1.50E-03
	Cobalt-60	*-2.60E-04	2.90E-04
	Lead-210	*2.80E-02	3.40E-02
	Plutonium-241	-9.79E-03	3.38E-02
	Plutonium-238	0.00E+00	4.21E-04
	Plutonium-239/240	1.07E-03	7.29E-04
	Polonium-210	2.70E-02	1.20E-02
	Potassium-40	2.90E-01	4.10E-02
	Radium-226	*2.50E-02	9.00E-03
	Radium-228	1.20E-02	3.00E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TS-WEE Terrestrial Surface WIPP East (continued)	Strontium-90	6.10E-04	1.40E-03
	Thorium-232	7.13E-03	1.62E-03
	Thorium-228	1.55E-01	7.61E-03
	Thorium-230	1.16E-02	2.10E-03
	Uranium-233/234	2.78E-02	3.70E-03
	Uranium-238	1.45E-02	2.66E-03
	Uranium-235/236	2.49E-03	1.30E-03
TI-WEE Terrestrial Intermediate WIPP East	Americium-241	5.63E-03	1.42E-03
	Cesium-137	6.60E-03	1.10E-03
	Cobalt-60	*-1.20E-04	2.90E-04
	Lead-210	2.20E-02	6.90E-03
	Plutonium-241	4.91E-02	3.35E-02
	Plutonium-238	3.16E-04	3.58E-04
	Plutonium-239/240	7.37E-04	5.46E-04
	Polonium-210	1.70E-02	1.10E-02
	Potassium-40	2.60E-01	5.80E-02
	Radium-226	2.00E-02	1.20E-02
	Radium-228	1.20E-02	2.70E-03
	Strontium-90	2.60E-04	1.30E-03
	Thorium-232	7.96E-03	1.70E-03
	Thorium-228	1.57E-01	7.52E-03
	Thorium-230	1.32E-02	2.26E-03
	Uranium-233/234	2.12E-02	3.50E-03
	Uranium-238	1.97E-02	3.25E-03
	Uranium-235/236	4.31E-03	1.69E-03
TD-WEE Terrestrial Deep WIPP East	Americium-241	5.95E-03	1.60E-03
	Cesium-137	1.10E-02	2.10E-03
	Cobalt-60	*3.50E-04	1.80E-03
	Lead-210	4.50E-02	1.40E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TD-WEE Terrestrial Deep WIPP East (continued)	Plutonium-241	4.17E-02	3.04E-02
	Plutonium-238	4.86E-04	6.87E-04
	Plutonium-239/240	4.86E-04	5.04E-04
	Polonium-210	1.50E-02	1.10E-02
	Potassium-40	3.70E-01	6.90E-02
	Radium-226	3.60E-02	1.90E-02
	Radium-228	1.80E-02	3.80E-03
	Strontium-90	1.40E-04	1.50E-03
	Thorium-232	9.42E-03	1.83E-03
	Thorium-228	1.58E-01	7.54E-03
	Thorium-230	1.43E-02	2.29E-03
	Uranium-233/234	2.33E-02	3.32E-03
	Uranium-238	1.65E-02	2.77E-03
	Uranium-235/236	1.00E-03	8.42E-04
TS-WFF Terrestrial Surface WIPP Far Field	Americium-241	7.60E-03	1.69E-03
	Cesium-137	5.60E-03	9.50E-04
	Cobalt-60	*7.80E-5	2.70E-04
	Lead-210	2.90E-02	7.40E-03
	Plutonium-241	1.91E-02	3.32E-02
	Plutonium-238	4.33E-04	8.49E-04
	Plutonium-239/240	9.74E-04	7.65E-04
	Polonium-210	1.50E-02	1.60E-02
	Potassium-40	2.10E-01	4.80E-02
	Radium-228	9.80E-03	2.50E-03
	Radium-226	*1.90E-02	1.10E-02
	Strontium-90	2.7E-04	1.40E-03
	Thorium-232	6.68E-03	1.72E-03
	Thorium-228	1.52E-01	8.08E-03
	Thorium-230	1.20E-02	2.25E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TS-WFF Terrestrial Surface WIPP Far Field (continued)	Uranium-233/234	9.25E-03	2.29E-03
	Uranium-238	9.00E-03	2.24E-03
	Uranium-235/236	1.18E-03	9.89E-04
TI-WFF Terrestrial Intermediate WIPP Far Field	Americium-241	8.44E-03	1.80E-03
	Cesium-137	5.40E-03	1.10E-03
	Cobalt-60	*2.40E-05	2.40E-04
	Lead-210	1.80E-02	6.80E-03
	Plutonium-241	3.04E-02	3.18E-02
	Plutonium-238	4.15E-04	6.43E-04
	Plutonium-239/240	2.07E-04	6.42E-04
	Polonium-210	1.70E-02	1.40E-02
	Potassium-40	2.00E-01	3.90E-02
	Radium-226	5.20E-03	2.00E-02
	Radium-228	8.90E-03	2.20E-03
	Strontium-90	-2.20E-04	1.40E-03
	Thorium-232	5.96E-03	1.50E-03
	Thorium-228	1.52E-01	7.50E-03
	Thorium-230	1.22E-02	2.12E-03
	Uranium-233/234	6.63E-03	2.08E-03
	Uranium-238	9.13E-03	2.07E-03
	Uranium-235/236	1.02E-03	9.51E-04
TD-WFF Terrestrial Deep WIPP Far Field	Americium-241	5.72E-03	1.41E-03
	Cesium-137	5.80E-03	1.30E-03
	Cobalt-60	*2.50E-04	3.10E-04
	Lead-210	*1.20E-02	2.90E-02
	Plutonium-241	4.83E-02	3.29E-02
	Plutonium-238	1.47E-03	9.21E-04
	Plutonium-239/240	-1.05E-04	3.57E-04
	Polonium-210	1.10E-02	1.30E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TD-WFF Terrestrial Deep WIPP Far Field (continued)	Potassium-40	2.50E-01	3.70E-02
	Radium-226	1.30E-02	8.30E-03
	Radium-228	9.90E-03	2.70E-03
	Strontium-90	1.00E-03	1.40E-03
	Thorium-232	6.37E-03	1.55E-03
	Thorium-228	1.62E-01	7.86E-03
	Thorium-230	1.09E-02	2.03E-03
	Uranium-233/234	1.37E-02	3.53E-03
	Uranium-238	7.06E-03	3.03E-03
	Uranium-235/236	-1.78E-04	1.67E-03
TS-WSS Terrestrial Surface WIPP South	Americium-241	4.63E-03	1.35E-03
	Cesium-137	4.00E-03	7.50E-04
	Cobalt-60	*-3.80E-05	2.80E-04
	Lead-210	2.50E-02	7.20E-03
	Plutonium-241	2.59E-02	3.08E-02
	Plutonium-238	1.07E-03	6.32E-04
	Plutonium-239/240	6.80E-04	5.71E-04
	Polonium-210	2.10E-02	9.40E-03
	Potassium-40	2.30E-01	5.20E-02
	Radium-226	1.40E-02	8.60E-03
	Radium-228	9.50E-03	2.60E-03
	Strontium-90	8.50E-04	1.40E-03
	Thorium-232	9.20E-03	1.87E-03
	Thorium-228	1.65E-01	7.76E-03
	Thorium-230	1.32E-02	2.20E-03
	Uranium-233/234	1.16E-02	2.66E-03
	Uranium-238	9.84E-03	2.45E-03
	Uranium-235/236	3.42E-04	1.06E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TI-WSS Terrestrial Intermediate WIPP South	Americium-241	6.41E-03	1.74E-03
	Cesium-137	5.80E-03	1.60E-03
	Cobalt-60	*1.10E-04	3.00E-04
	Lead-210	7.60E-03	3.90E-02
	Plutonium-241	7.01E-02	3.27E-02
	Plutonium-238	4.01E-04	3.93E-04
	Plutonium-239/240	3.01E-04	4.40E-04
	Polonium-210	1.80E-02	1.10E-02
	Potassium-40	2.60E-01	4.10E-02
	Radium-226	2.50E-02	8.90E-03
	Radium-228	1.10E-02	2.50E-03
	Strontium-90	8.60E-04	1.50E-03
	Thorium-232	8.79E-03	1.77E-03
	Thorium-228	1.57E-01	7.60E-03
	Thorium-230	1.30E-02	2.18E-03
	Uranium-233/234	6.85E-03	2.13E-03
	Uranium-238	6.60E-03	2.04E-03
	Uranium-235/236	1.14E-03	8.44E-04
TD-WSS Terrestrial Deep WIPP South	Americium-241	6.22E-03	1.66E-03
	Cesium-137	4.80E-03	1.10E-03
	Cobalt-60	*2.70E-05	2.70E-04
	Lead-210	1.50E-02	6.70E-03
	Plutonium-241	2.48E-02	3.41E-02
	Plutonium-238	5.32E-04	7.52E-04
	Plutonium-239/240	-2.13E-04	5.10E-04
	Polonium-210	1.40E-02	9.80E-03
	Potassium-40	2.60E-01	4.90E-02
	Radium-226	2.70E-02	1.40E-02
	Radium-228	1.30E-02	2.80E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TD-WSS Terrestrial Deep WIPP South (continued)	Strontium-90	7.10E-04	1.30E-03
	Thorium-232	1.05E-02	1.94E-03
	Thorium-228	1.65E-01	7.78E-03
	Thorium-230	1.10E-02	2.01E-03
	Uranium-233/234	3.94E-02	4.57E-03
	Uranium-238	3.01E-02	4.01E-03
	Uranium-235/236	2.84E-03	1.43E-03
TS-WNW Terrestrial Surface Note: Acronym WNW denotes duplicate sample collected at WIPP Far Field	Americium-241	7.82E-03	1.71E-03
	Cesium-137	6.20E-03	1.30E-03
	Cobalt-60	*1.80E-05	2.40E-04
	Lead-210	2.40E-02	7.30E-03
	Plutonium-241	2.47E-02	3.58E-02
	Plutonium-238	2.29E-04	7.76E-04
	Plutonium-239/240	3.43E-04	5.92E-04
	Polonium-210	1.70E-02	1.60E-02
	Potassium-40	2.30E-01	4.40E-02
	Radium-226	1.80E-02	1.10E-02
	Radium-228	1.10E-02	2.50E-03
	Strontium-90	-1.70E-03	1.40E-03
	Thorium-232	5.62E-03	1.55E-03
	Thorium-228	1.65E-01	7.92E-03
	Thorium-230	1.23E-02	2.17E-03
	Uranium-233/234	1.12E-02	2.67E-03
	Uranium-238	7.52E-03	2.27E-03
	Uranium-235/236	1.89E-04	9.82E-04
TI-WNW Terrestrial Intermediate Note: Acronym WNW denotes duplicate sample collected at WIPP Far Field	Americium-241	7.10E-03	1.61E-03
	Cesium-137	5.30E-03	1.20E-03
	Cobalt-60	*3.30E-05	2.70E-04

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TI-WNW Terrestrial Intermediate Note: Acronym WNW denotes duplicate sample collected at WIPP Far Field (continued)	Lead-210	2.50E-02	3.60E-02
	Plutonium-241	4.44E-02	3.47E-02
	Plutonium-238	8.07E-04	7.50E-04
	Plutonium-239/240	3.46E-04	5.05E-04
	Polonium-210	1.50E-02	1.20E-02
	Potassium-40	2.30E-01	3.30E-02
	Radium-226	2.10E-02	8.50E-03
	Radium-228	8.90E-03	2.30E-03
	Strontium-90	5.60E-04	1.40E-03
	Thorium-232	7.57E-03	1.67E-03
	Thorium-228	1.56E-01	7.40E-03
	Thorium-230	1.38E-02	2.20E-03
	Uranium-233/234	1.64E-02	3.18E-03
	Uranium-238	9.59E-03	2.38E-03
	Uranium-235/236	7.17E-04	1.11E-03
TD-WNW Terrestrial Deep Note: Acronym WNW denotes duplicate sample collected at WIPP Far Field	Americium-241	3.04E-01	9.90E-03
	Cesium-137	4.90E-03	7.90E-04
	Cobalt-60	*1.30E-04	2.60E-04
	Lead-210	1.60E-02	6.20E-03
	Plutonium-239/240	0.00E+00	5.89E-04
	Plutonium-241	-1.77E-02	3.67E-02
	Plutonium-238	3.68E-04	7.22E-04
	Polonium-210	8.30E-03	1.90E-02
	Potassium-40	1.90E-01	4.40E-02
	Radium-226	*1.40E-02	9.80E-03
	Radium-228	6.90E-03	2.10E-03
	Strontium-90	-4.90E-04	1.30E-03
	Thorium-232	5.08E-03	1.50E-03
	Thorium-228	1.53E-01	7.78E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS/UNIT Bq/g	COUNTING ERROR
TD-WNW Terrestrial Deep Note: Acronym WNW denotes duplicate sample collected at WIPP Far Field (continued)	Thorium-230	8.49E-03	1.85E-03
	Uranium-233/234	6.62E-03	2.11E-03
	Uranium-238	6.11E-03	1.86E-03
	Uranium-235/236	1.44E-03	9.44E-04

1995
Am-241 IN SOIL

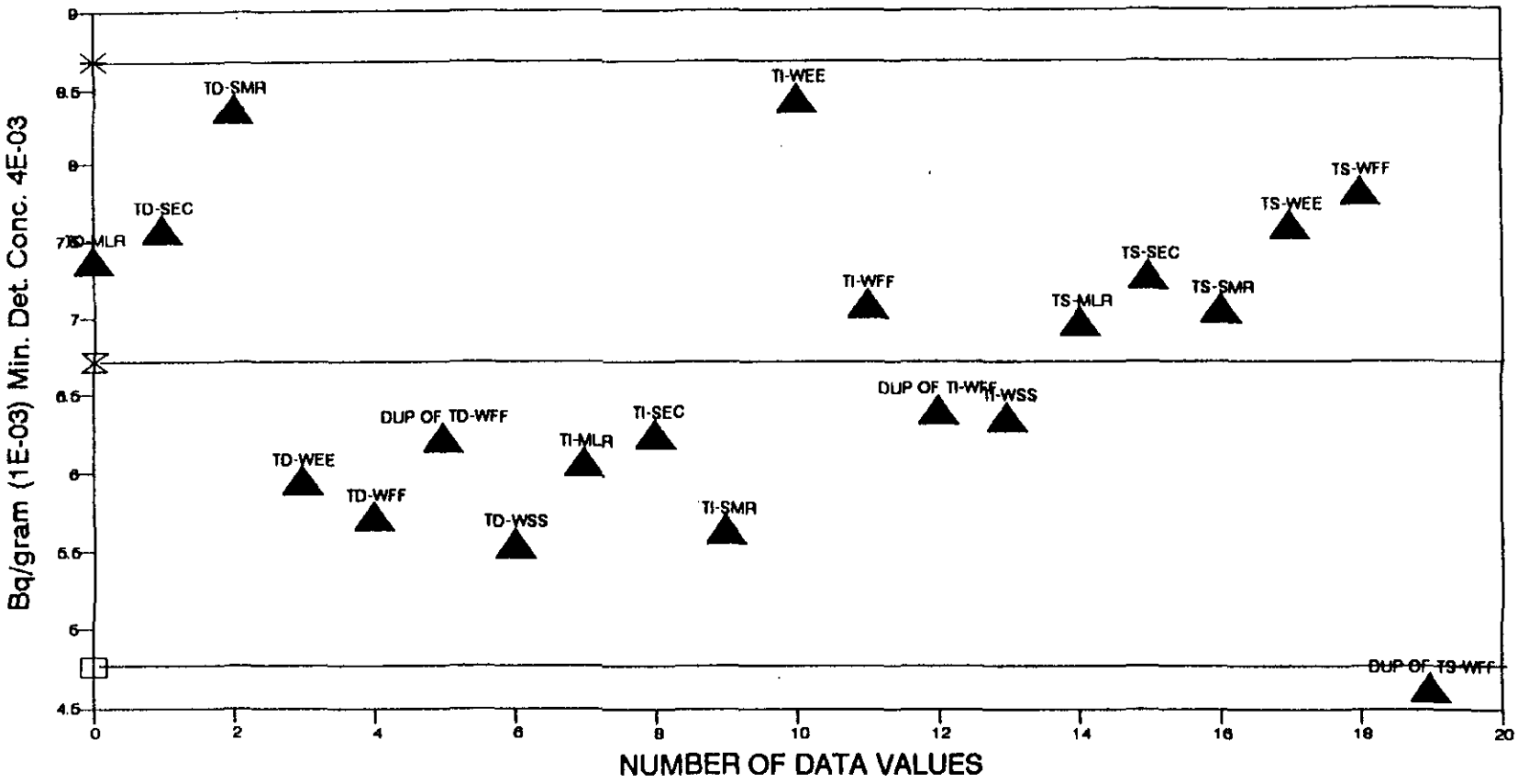

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Cs-137 IN SOIL

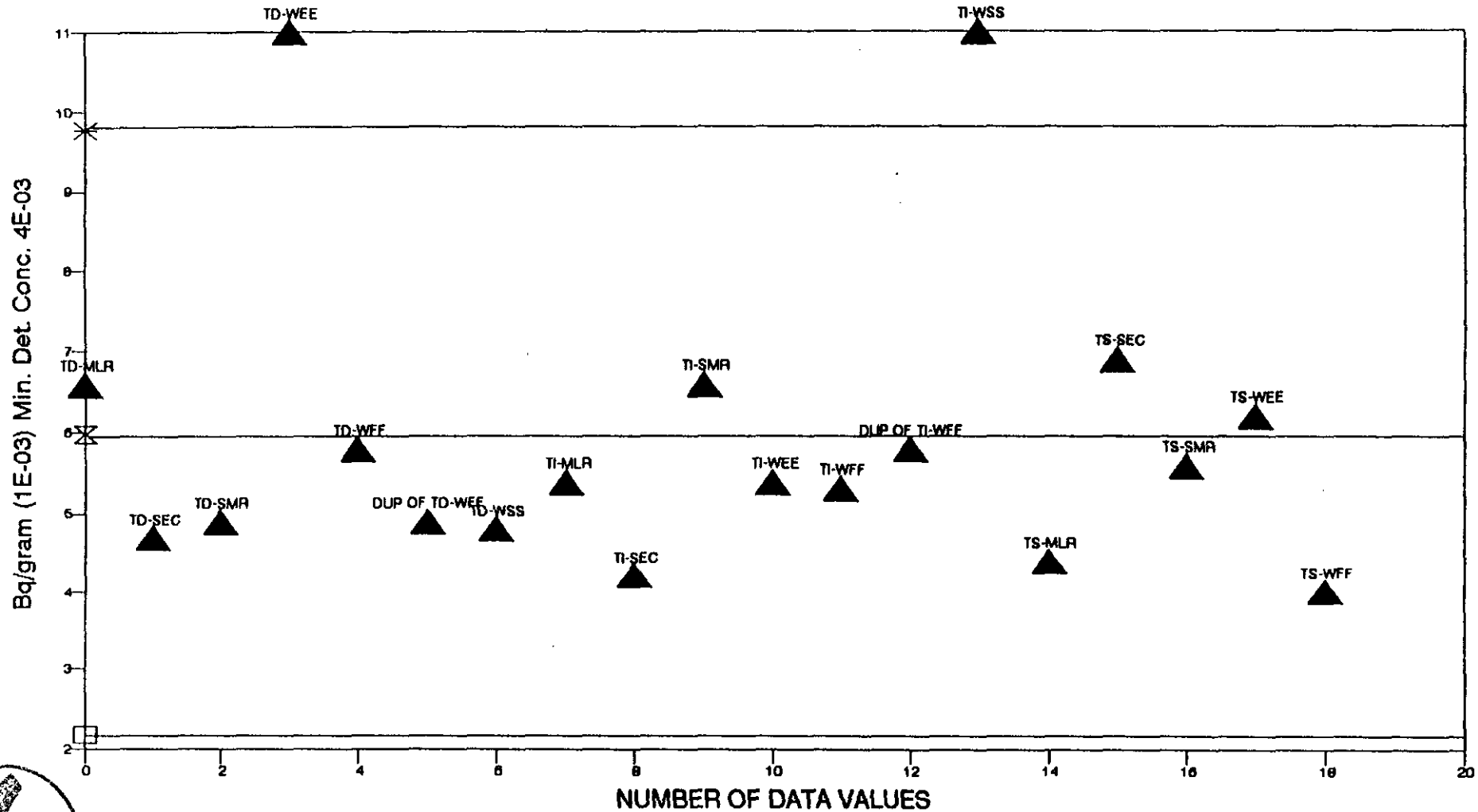

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
K-40 IN SOIL

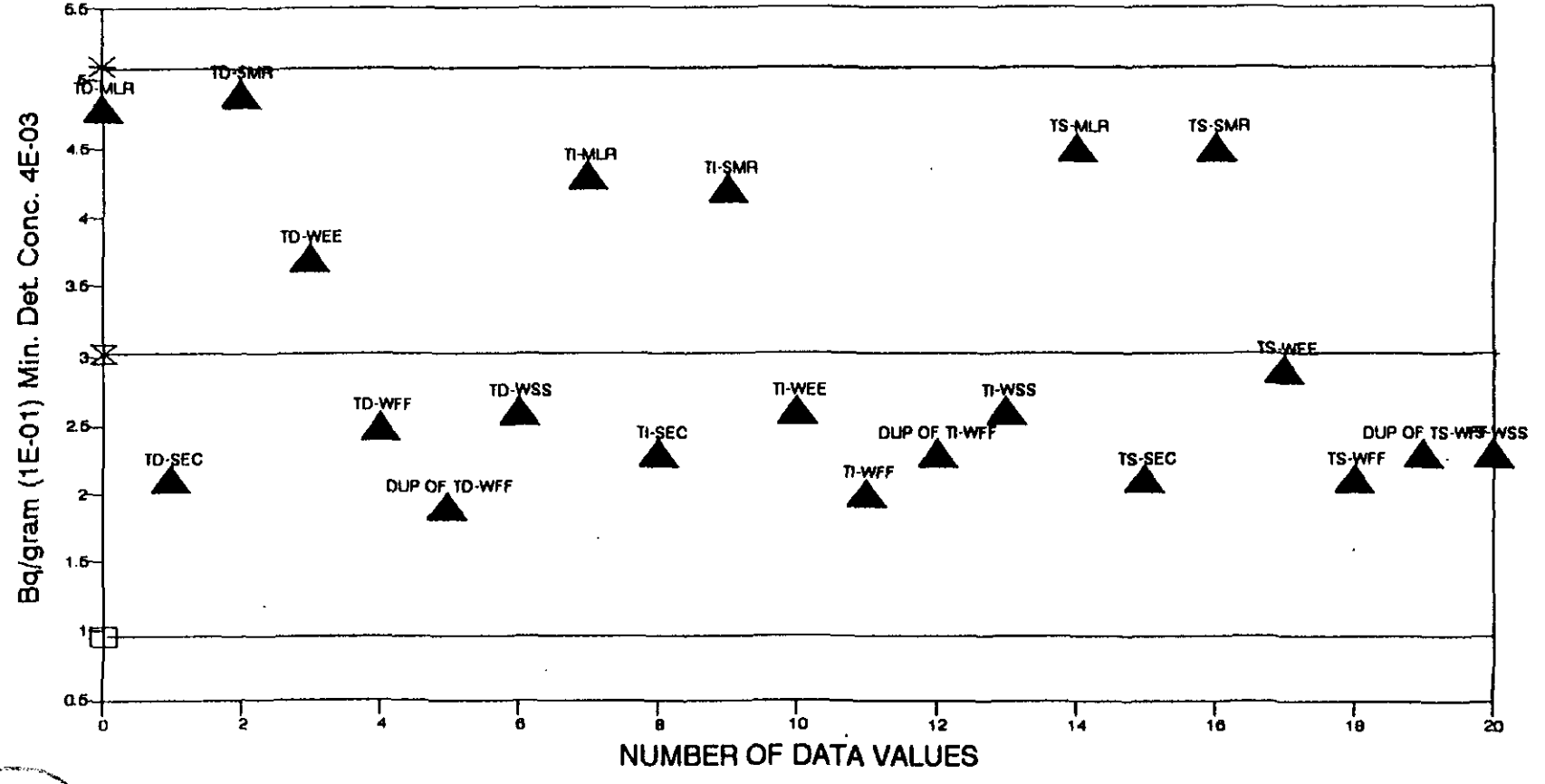

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Ra-226 IN SOIL

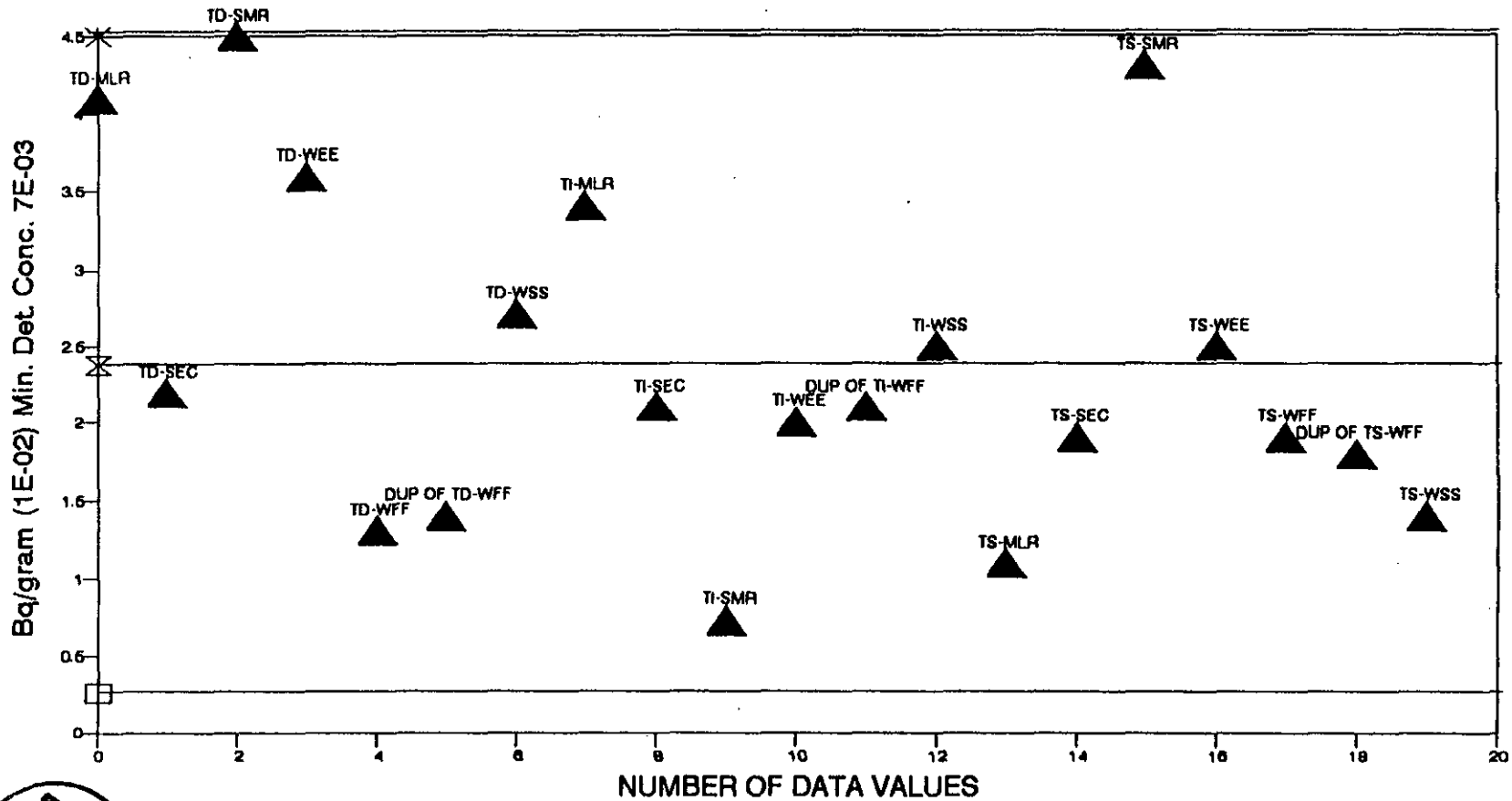

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Th-228 IN SOIL

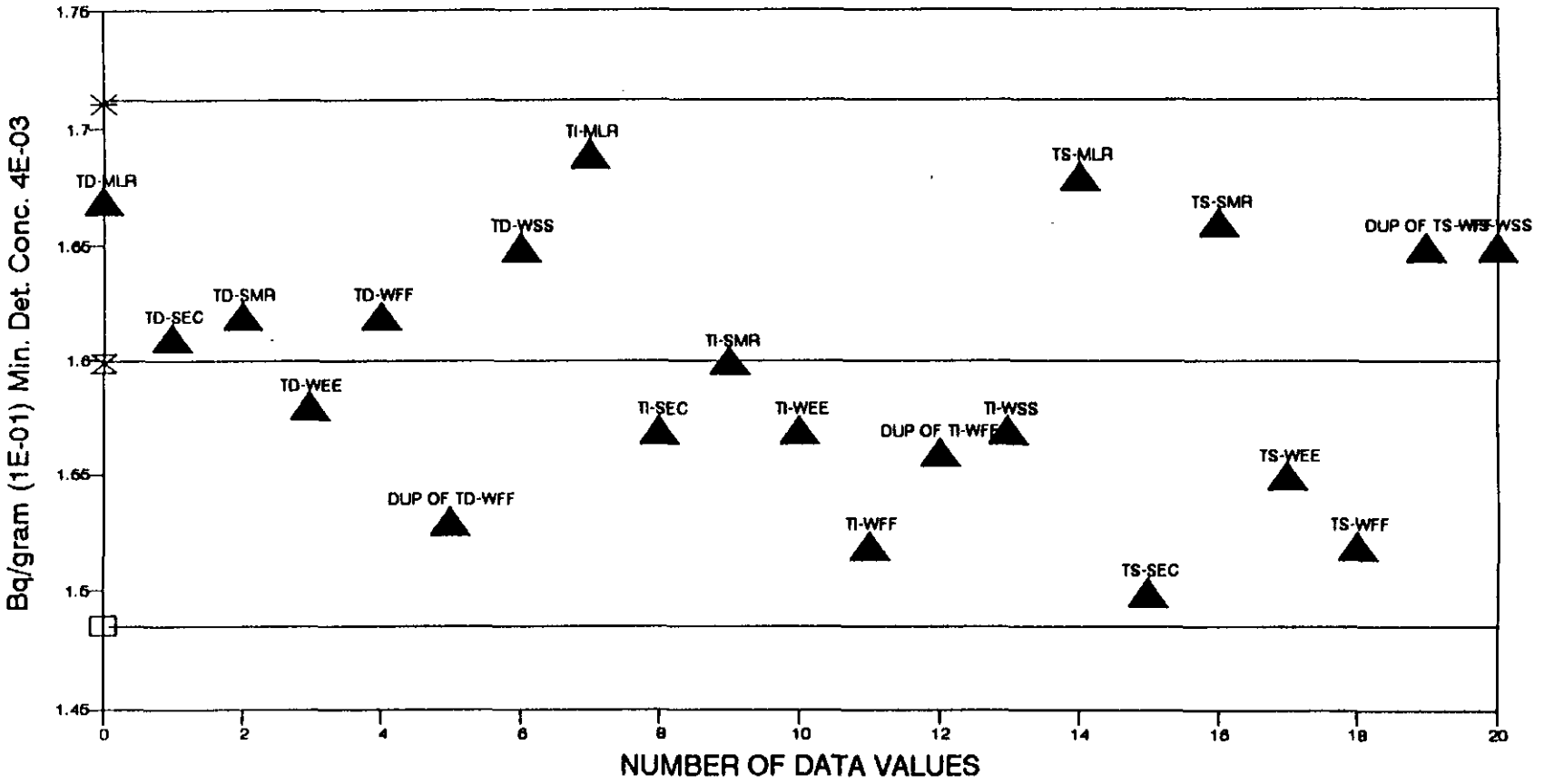

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Th-230 IN SOIL

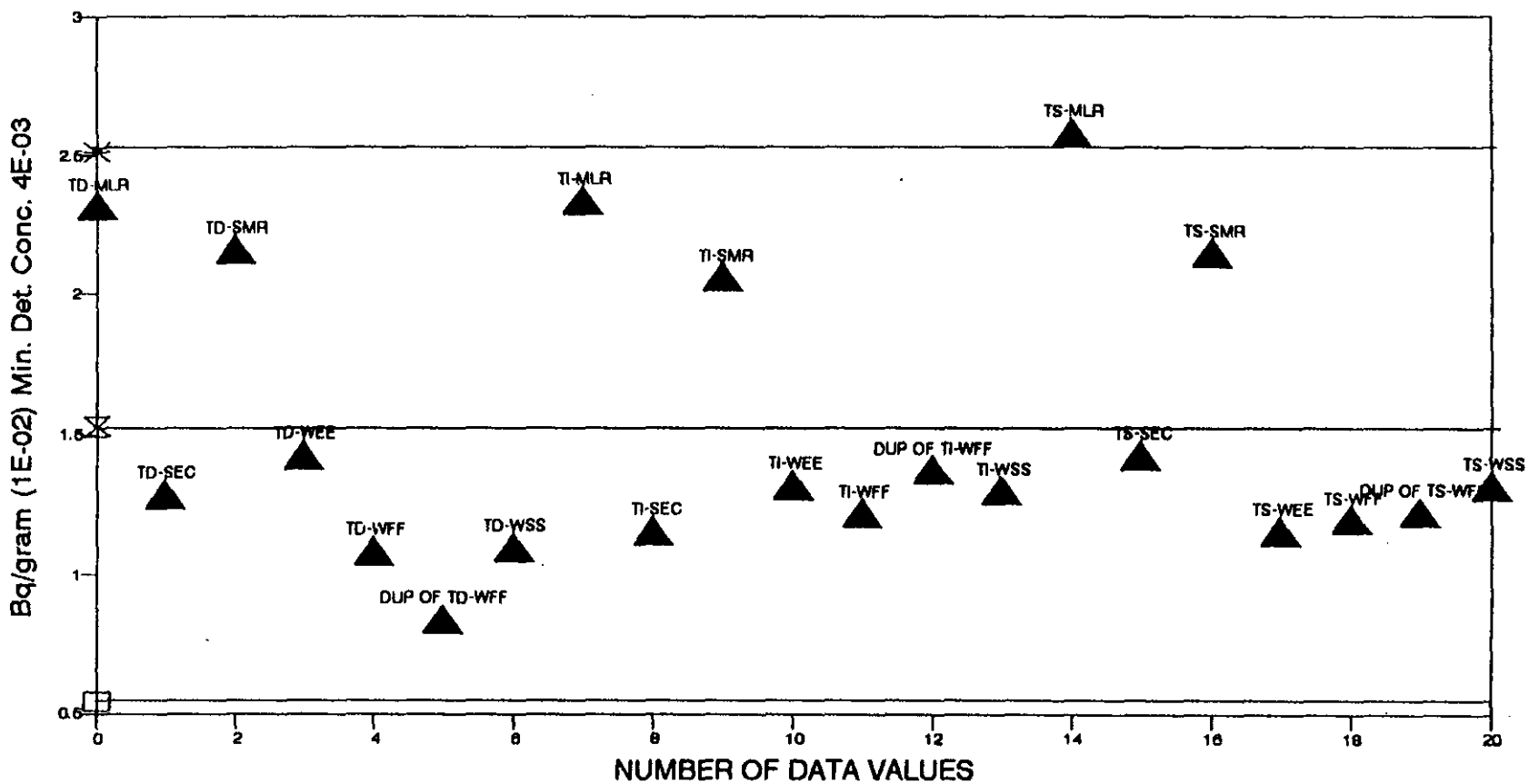

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Th-232 IN SOIL

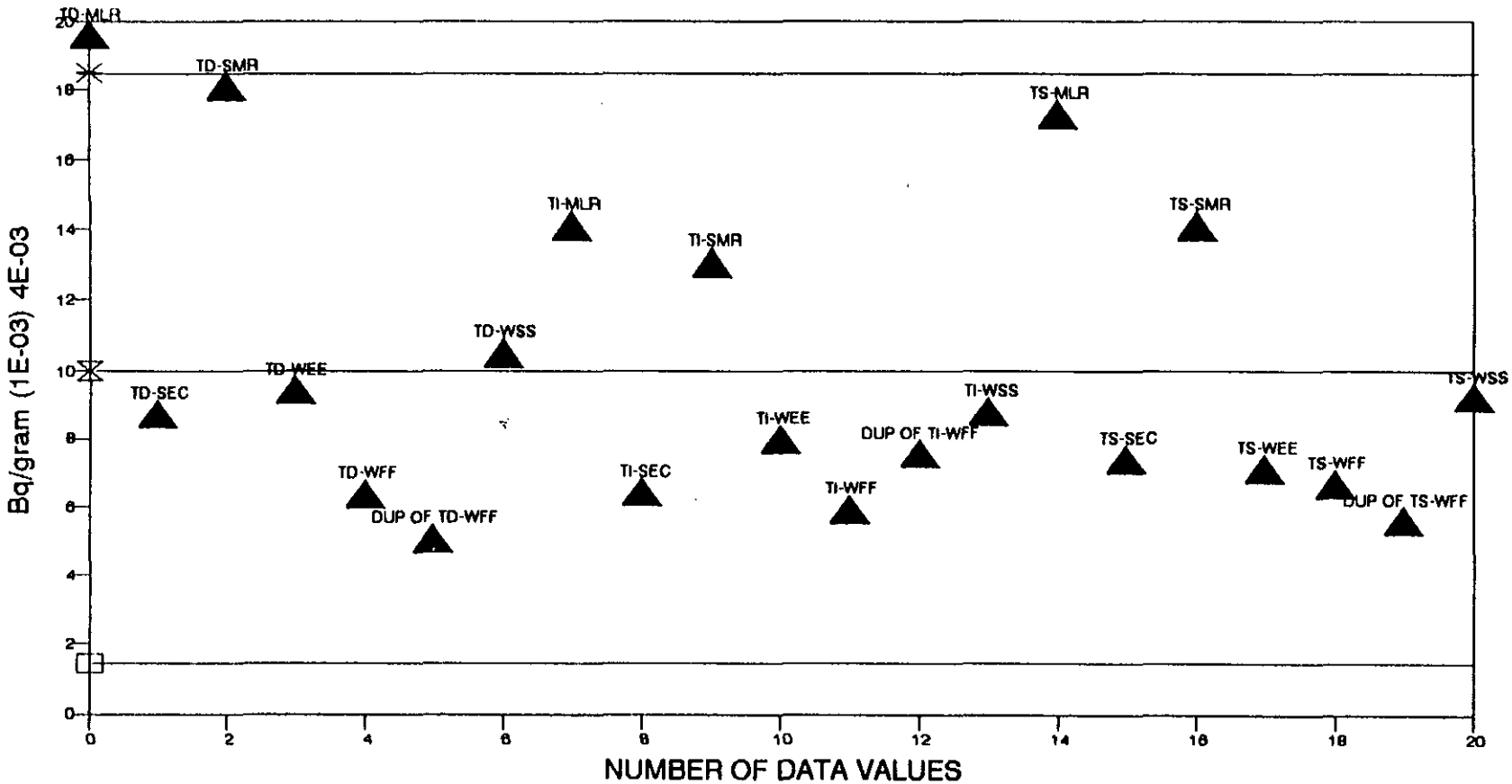

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
U-233/234 IN SOIL

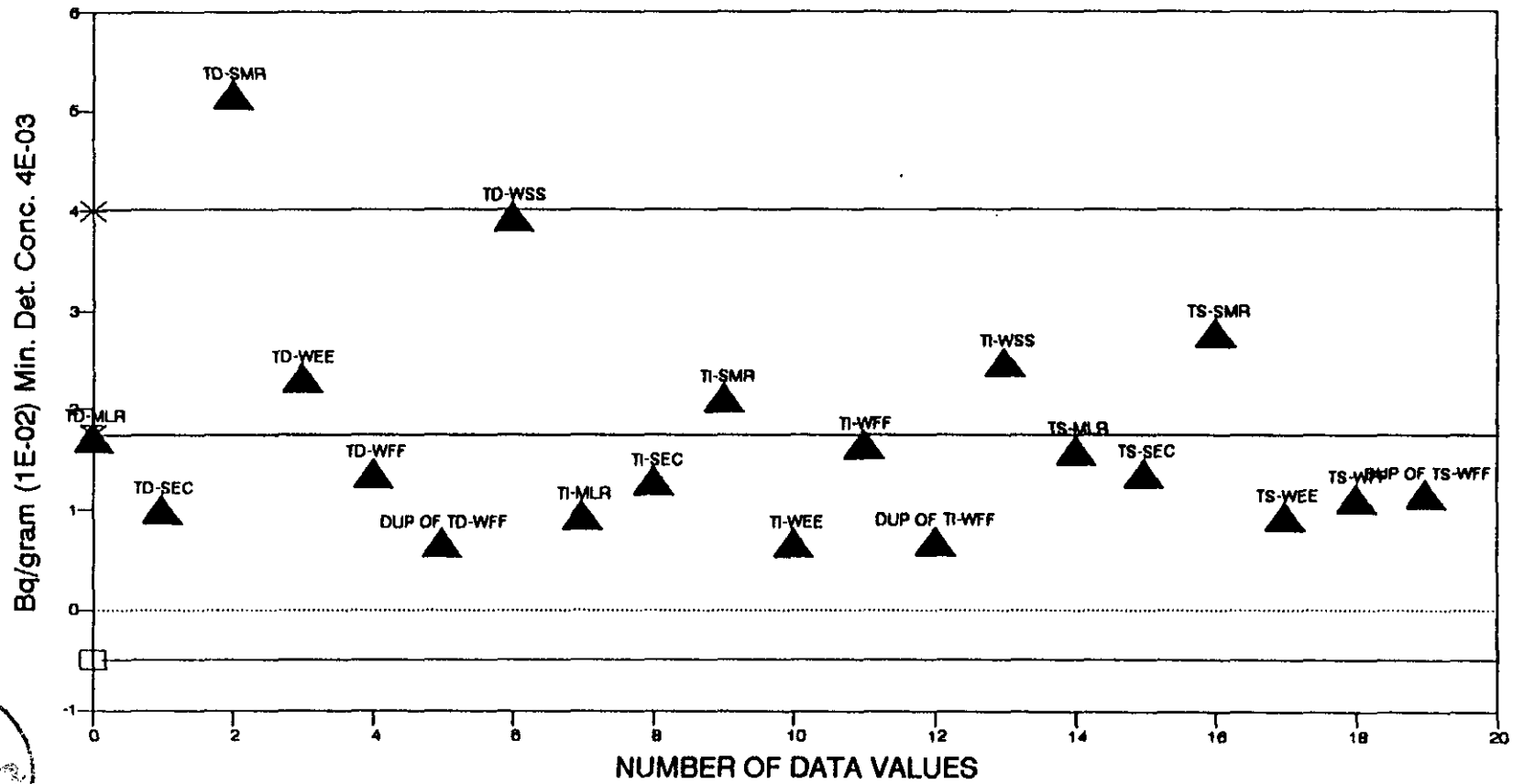

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
U-238 IN SOIL

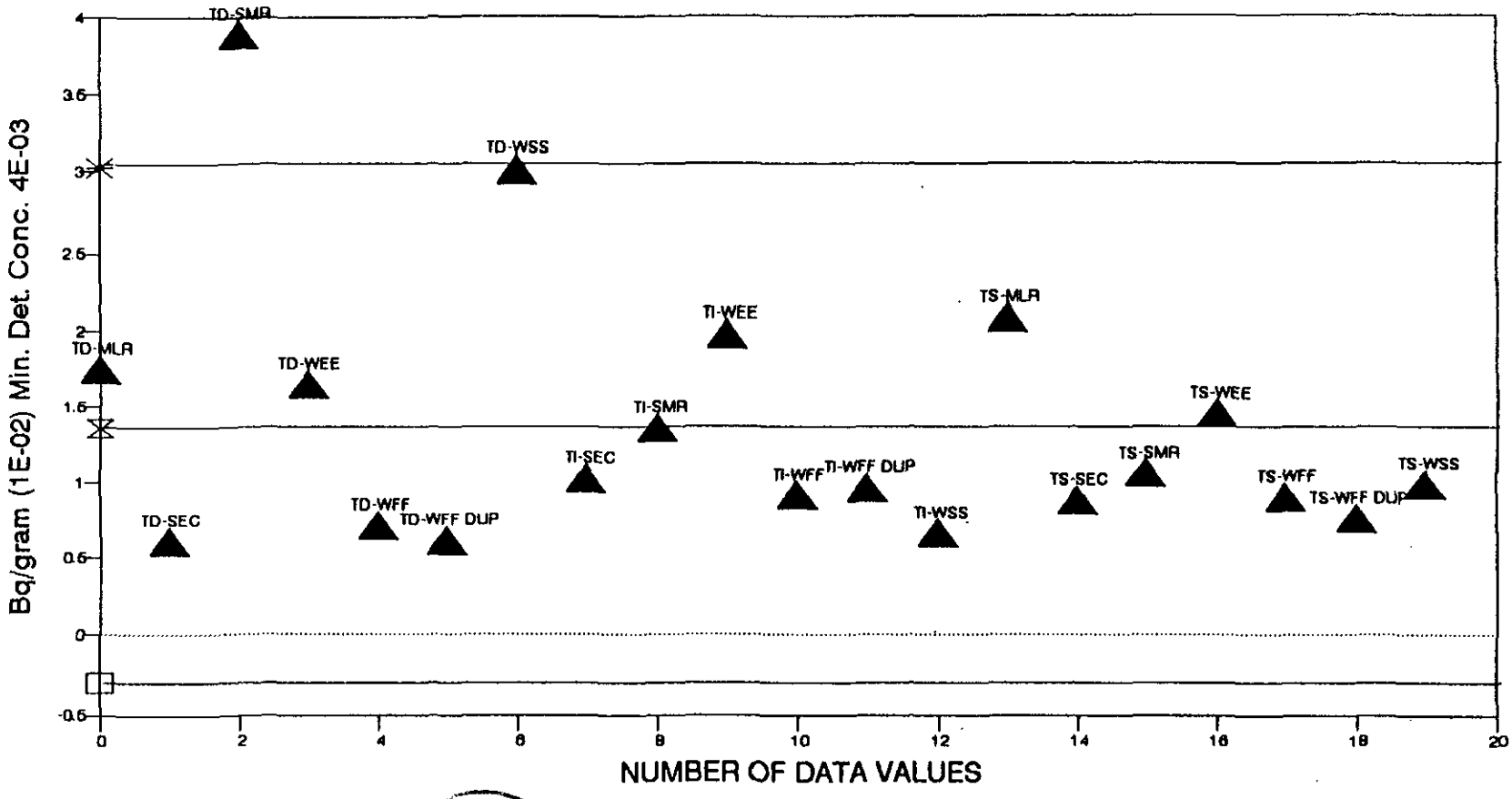

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

APPENDIX A3
RADIOLOGICAL ANALYSIS
SURFACE WATER

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-UPR Surface Water Upper Pecos River	Americium-241	1.75E-02	5.82E-03
	Cesium-137	*-9.30E-2	1.60E-01
	Cobalt-60	*-7.40E-2	1.70E-01
	Lead-210	6.30E-01	3.10E+00
	Plutonium-239/240	2.66E-03	2.33E-03
	Plutonium-241	-7.90E-01	3.57E-01
	Plutonium-238	0.00E+00	1.48E-03
	Polonium-210	2.20E-03	7.50E-02
	Potassium-40	*3.60E0	1.90E+00
	Radium 228	8.60E-03	2.60E-02
	Radium 226	1.74E-02	3.10E-03
	Strontium-90	-2.10E-02	2.00E-02
	Thorium-230	3.63E-02	8.77E-03
	Thorium-232	1.98E-03	2.75E-03
	Thorium-228	6.71E-03	3.92E-03
	Uranium-238	3.25E-02	7.95E-03
	Uranium-235/236	4.86E-03	3.76E-03
	Uranium-234	6.83E-02	1.15E-02
	Uranium-233	6.83E-02	1.15E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-PCN Surface Water Pierce Canyon	Americium-241	2.48E-02	7.25E-03
	Cesium-137	*3.30E-2	1.50E-01
	Cobalt-60	*1.70E-2	1.60E-01
	Lead-210	*5.10E0	2.20E+00
	Plutonium-239/240	3.94E-03	4.55E-03
	Plutonium-238	1.13E-03	2.21E-03
	Plutonium-241	-4.87E-01	3.76E-01
	Polonium-210	5.10E-03	8.30E-02
	Potassium-40	1.60E+00	3.40E+00
	Radium 228	-1.01E-02	2.70E-02
	Radium 226	8.67E-03	2.20E-03
	Strontium-90	-4.10E-03	2.20E-02
	Thorium-230	3.52E-02	8.41E-03
	Thorium-228	5.29E-04	3.44E-03
	Thorium-232	2.54E-03	2.64E-03
	Uranium-233	2.51E-01	2.20E-02
	Uranium-235/236	1.10E-02	5.89E-03
	Uranium-238	1.11E-01	1.47E-02
	Uranium-234	2.51E-01	2.20E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-IDN Surface Water Indian Tank	Americium-241	2.59E-02	7.03E-03
	Cesium-137	*-1.40E-1	1.70E-01
	Cobalt-60	*6.90E-2	1.50E-01
	Lead-210	*6.40E0	2.10E+00
	Plutonium-238	-7.10E-04	3.68E-03
	Plutonium-241	1.33E-02	5.00E-01
	Plutonium-239/240	2.13E-03	3.11E-03
	Polonium-210	2.00E-02	1.20E-01
	Potassium-40	*3.10E0	1.90E+00
	Radium 228	1.97E-03	2.50E-02
	Radium 226	1.69E-02	3.00E-03
	Strontium-90	2.50E-02	2.40E-02
	Thorium-228	4.94E-03	3.87E-03
	Thorium-230	1.81E-02	6.04E-03
	Thorium-232	9.49E-04	2.63E-03
	Uranium-238	1.35E-02	5.49E-03
	Uranium-235/236	5.93E-04	1.16E-03
	Uranium-234	1.97E-02	6.45E-03
	Uranium-233	1.97E-02	6.45E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-HIL Surface Water Hill Tank	Americium-241	2.15E-02	6.26E-03
	Cesium-137	*1.30E-1	1.40E-01
	Cobalt-60	*1.80E-2	1.60E-01
	Lead-210	2.50E+00	3.30E+00
	Plutonium-238	-9.33E-03	7.16E-03
	Plutonium-239/240	-6.66E-03	5.22E-03
	Plutonium-241	-4.07E-01	4.42E-01
	Polonium-210	2.80E-02	1.10E-01
	Potassium-40	*4.00E0	1.80E+00
	Radium 226	6.85E-03	2.40E-03
	Radium 228	2.18E-02	2.90E-02
	Strontium-90	3.40E-02	2.20E-02
	Thorium-230	2.73E-02	7.97E-03
	Thorium-228	6.30E-03	4.94E-03
	Thorium-232	1.21E-03	2.91E-03
	Uranium-234	2.02E-02	6.86E-03
	Uranium-233	2.02E-02	6.86E-03
	Uranium-235/236	2.70E-03	2.65E-03
	Uranium-238	6.02E-03	3.87E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-FWT Surface Water Fresh Water Tanks	Americium-241	2.13E-02	6.53E-03
	Cesium-137	*9.70E-03	1.70E-01
	Cobalt-60	*1.10E-02	1.60E-01
	Lead-210	1.30E+00	3.50E+00
	Plutonium-238	-1.28E-03	3.55E-03
	Plutonium-241	-7.29E-01	3.89E-01
	Plutonium-239/240	2.56E-03	3.55E-03
	Polonium-210	6.60E-03	8.90E-02
	Potassium-40	*2.00E0	2.00E+00
	Radium 228	3.03E-02	2.60E-02
	Radium 226	3.74E-03	1.70E-03
	Strontium-90	-2.20E-02	2.50E-02
	Thorium-228	3.39E-03	3.15E-03
	Thorium-230	2.38E-02	6.91E-03
	Thorium-232	9.32E-04	1.29E-03
	Uranium-238	2.42E-02	7.53E-03
	Uranium-235/236	2.49E-03	3.45E-03
	Uranium-234	6.24E-02	1.14E-02
	Uranium-233	6.24E-02	1.14E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-SEW Surface Water Sewage Lagoon	Americium-241	2.39E-02	7.92E-03
	Cesium-137	*2.90E-02	1.30E-01
	Cobalt-60	*-8.90E-02	1.70E-01
	Lead-210	1.10E+00	3.10E+00
	Plutonium-238	5.16E-04	1.01E-03
	Plutonium-241	-5.45E-01	3.46E-01
	Plutonium-239/240	6.70E-03	4.17E-03
	Polonium-210	4.60E-03	9.50E-02
	Potassium-40	6.10E+00	3.30E+00
	Radium 228	1.44E-02	2.70E-02
	Radium 226	3.85E-02	4.70E-03
	Strontium-90	3.50E-02	2.30E-02
	Thorium-228	-1.47E-03	4.54E-03
	Thorium-230	1.00E-01	1.68E-02
	Thorium-232	-2.82E-03	2.76E-03
	Uranium-238	3.77E-03	3.80E-03
	Uranium-235/236	-1.33E-03	1.84E-03
	Uranium-234	3.22E-02	8.55E-03
	Uranium-233	3.22E-02	8.55E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-BRA Surface Water Brantley Lake	Americium-241	2.20E-02	6.72E-03
	Cesium-137	*-2.30E-02	1.60E-01
	Cobalt-60	*-6.20E-02	1.70E-01
	Lead-210	*6.09E00	2.10E+00
	Plutonium-238	5.99E-04	2.03E-03
	Plutonium-241	-8.59E-01	4.11E-01
	Plutonium-239/240	2.99E-03	3.10E-03
	Polonium-210	3.70E-03	8.90E-02
	Potassium-40	*2.20E00	2.10E+00
	Radium 228	2.88E-02	2.60E-02
	Radium 226	9.11E-03	2.50E-03
	Strontium-90	1.80E-02	2.50E-02
	Thorium-228	6.41E-03	3.79E-03
	Thorium-230	2.24E-02	6.95E-03
	Thorium-232	2.24E-03	3.10E-03
	Uranium-238	4.12E-02	8.97E-03
	Uranium-235/236	2.51E-03	3.01E-03
	Uranium-234	1.00E-01	1.43E-02
	Uranium-233	1.00E-01	1.43E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-NOY Noya Tank Surface Water	Americium-241	2.13E-02	7.38E-03
	Cesium-137	*5.80E-02	1.60E-01
	Cobalt-60	*9.50E-02	1.70E-01
	Lead-210	1.40E+00	3.20E+00
	Plutonium-238	5.26E-04	3.09E-03
	Plutonium-241	-6.23E-01	3.71E-01
	Plutonium-239/240	2.63E-03	3.09E-03
	Polonium-210	8.10E-03	8.70E-02
	Potassium-40	*2.70E00	2.00E+00
	Radium 226	9.07E-03	2.50E-03
	Radium 228	3.23E-02	2.60E-02
	Strontium-90	4.00E-02	2.20E-02
	Thorium-230	1.73E-02	7.31E-03
	Thorium-228	7.76E-03	4.83E-03
	Thorium-232	2.30E-03	2.76E-03
	Uranium-238	1.47E-02	5.43E-03
	Uranium-235/236	1.29E-03	3.10E-03
	Uranium-234	2.77E-02	8.51E-03
	Uranium-233	2.77E-02	8.51E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-LGS Surface Water Laguna Grande de la Sol	Americium-241	7.42E-02	5.45E-02
	Cesium-137	*1.20E-01	2.70E-01
	Cobalt-60	*9.80E-02	3.80E-01
	Lead-210	*4.60E00	4.00E+00
	Plutonium-238	-5.94E-04	2.60E-03
	Plutonium-239/240	3.56E-03	3.29E-03
	Plutonium-241	-4.92E-01	3.94E-01
	Polonium-210	6.00E-02	1.40E-01
	Potassium-40	1.40E+03	1.60E+02
	Radium 228	1.51E-01	5.20E-02
	Radium 226	2.99E-01	1.50E-03
	Strontium-90	5.20E-02	2.60E-02
	Thorium-232	2.36E-03	3.44E-03
	Thorium-228	8.17E-03	6.79E-03
	Thorium-230	1.73E-02	8.16E-03
	Uranium-238	1.11E+00	5.40E-02
	Uranium-235/236	7.52E-02	1.58E-02
	Uranium-233	2.34E+00	7.86E-02
	Uranium-234	2.34E+00	7.86E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-COY Surface Water Note: Acronym COY denotes duplicate sample collected at Pierce Canyon	Americium-241	1.98E-02	6.64E-03
	Cesium-137	*4.30E-02	1.30E-01
	Cobalt-60	*3.10E-02	1.60E-01
	Lead-210	1.10E+00	2.70E+00
	Plutonium-238	1.99E-03	3.90E-03
	Plutonium-241	-3.87E-01	4.43E-01
	Plutonium-239/240	1.98E-03	2.25E-03
	Polonium-210	6.70E-03	9.00E-02
	Potassium-40	1.20E+00	3.20E+00
	Radium 228	2.19E-02	4.30E-02
	Radium 226	5.96E-03	2.60E-03
	Strontium-90	-1.20E-02	2.00E-02
	Thorium-228	1.64E-03	4.41E-03
	Thorium-230	4.26E-02	9.50E-03
	Thorium-232	-1.05E-03	1.46E-03
	Uranium-238	9.84E-02	1.38E-02
	Uranium-235/236	1.28E-02	5.73E-03
	Uranium-234	2.13E-01	2.04E-02
	Uranium-233	2.13E-01	2.04E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-COW Surface Water Note: Acronym COW denotes sample blank	Americium-241	5.22E-02	1.12E-02
	Cesium-137	*-1.30E-02	1.40E-01
	Cobalt-60	*-2.10E-02	1.70E-01
	Lead-210	*6.60E00	2.10E00
	Plutonium-238	-2.10E-03	2.51E-03
	Plutonium-241	-6.12E-01	3.44E-01
	Plutonium-239/240	1.10E-02	5.33E-03
	Polonium-210	3.30E-02	7.90E-02
	Potassium-40	*2.40E00	2.00E00
	Radium 228	-1.87E-02	2.50E-02
	Radium 226	6.85E-03	1.90E-03
	Strontium-90	2.20E-02	2.20E-02
	Thorium-228	1.06E-03	2.53E-03
	Thorium-230	3.35E-02	8.45E-03
	Thorium-232	-1.01E-03	1.41E-03
	Uranium-238	4.05E-03	3.14E-03
	Uranium-235/236	1.25E-03	1.73E-03
	Uranium-234	1.01E-02	5.05E-03
	Uranium-233	1.01E-02	5.05E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-CBD Surface Water Carlsbad	Americium-241	2.25E-02	6.43E-03
	Cesium-137	*1.10E-02	1.50E-01
	Cobalt-60	*1.0E-01	1.50E-01
	Lead-210	3.60E-01	3.20E00
	Plutonium-238	0.00E+00	1.66E-03
	Plutonium-241	-8.35E-01	4.15E-01
	Plutonium-239/240	-1.80E-03	2.03E-03
	Polonium-210	3.10E-03	7.80E-02
	Potassium-40	*2.40E00	1.90E00
	Radium 228	6.20E-03	2.50E-02
	Radium 226	4.48E-03	1.70E-03
	Strontium-90	-1.20E-02	2.20E-02
	Thorium-228	1.57E-03	3.40E-03
	Thorium-230	2.27E-02	7.19E-03
	Thorium-232	2.01E-03	1.97E-03
	Uranium-238	6.51E-02	1.17E-02
	Uranium-235/236	4.39E-03	4.08E-03
	Uranium-234	1.52E-01	1.75E-02
	Uranium-233	1.52E-01	1.75E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
HS-TUT Surface Water Tut Tank	Americium-241	2.07E-02	6.13E-03
	Cesium-137	*-3.0E-2	1.6E-1
	Cobalt-60	*9.9E-2	1.4E-1
	Lead-210	9.2E-1	2.9E0
	Plutonium-238	-5.79E-4	3.40E-03
	Plutonium-241	-5.04E-1	3.98E-01
	Plutonium-239/240	-2.31E-3	2.27E-03
	Polonium-210	3.0E-2	1.5E-1
	Potassium-40	*3.5E0	2.0E0
	Radium 228	2.47E-2	2.9E-2
	Radium 226	4.67E-2	5.0E-3
	Strontium-90	4.2E-2	2.1E-2
	Thorium-232	3.21E-03	2.98E-03
	Thorium-230	3.27E-02	8.11E-03
	Thorium-228	1.10E-02	4.68E-03
	Uranium-235/236	2.49E-03	3.86E-03
	Uranium-234	1.36E-02	8.99E-03
	Uranium-238	1.41E-02	5.59E-03
	Uranium-233	1.36E-02	8.99E-03

1995
Am-241 IN SURFACE WATER

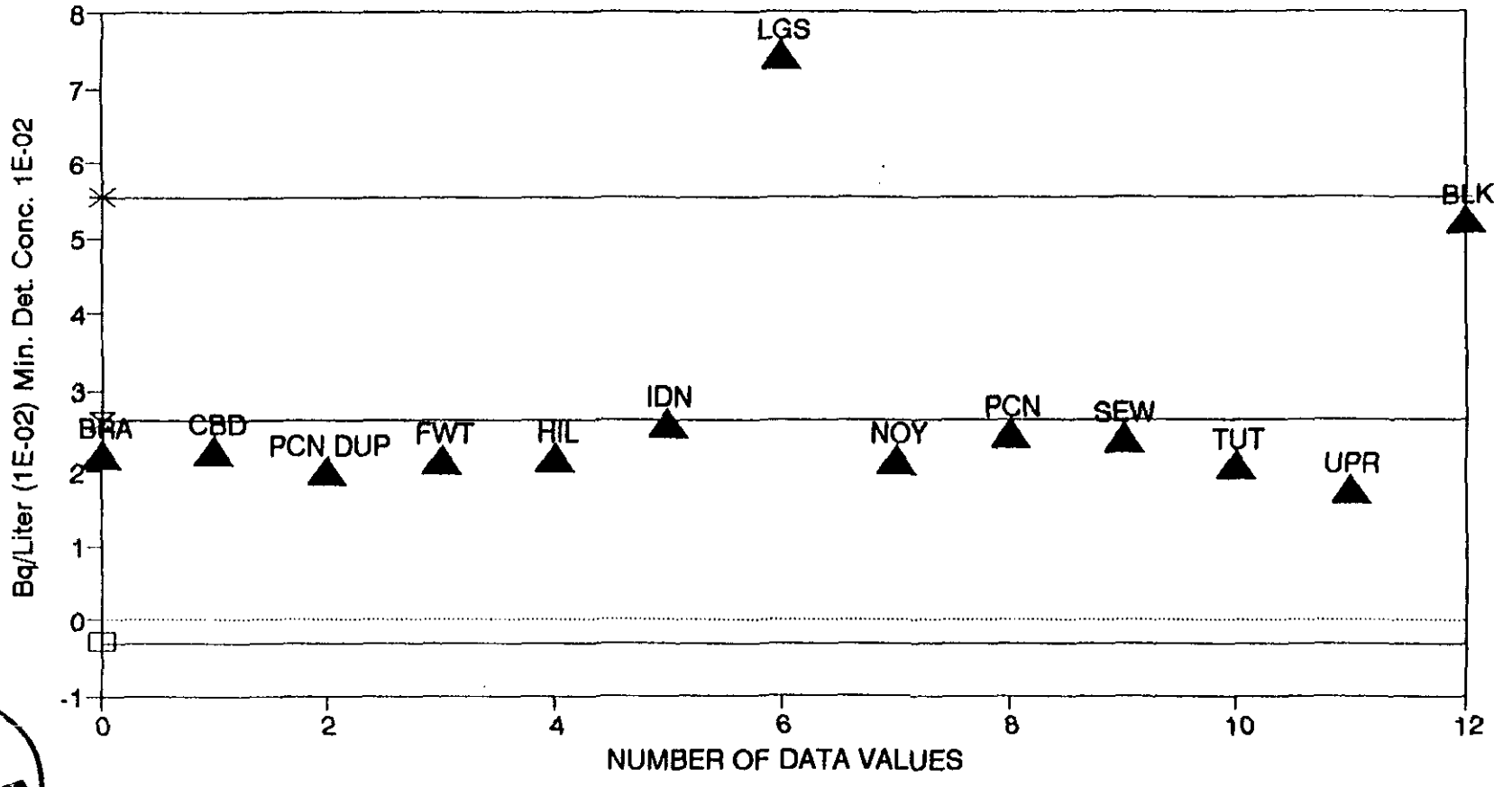

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
K-40 IN SURFACE WATER

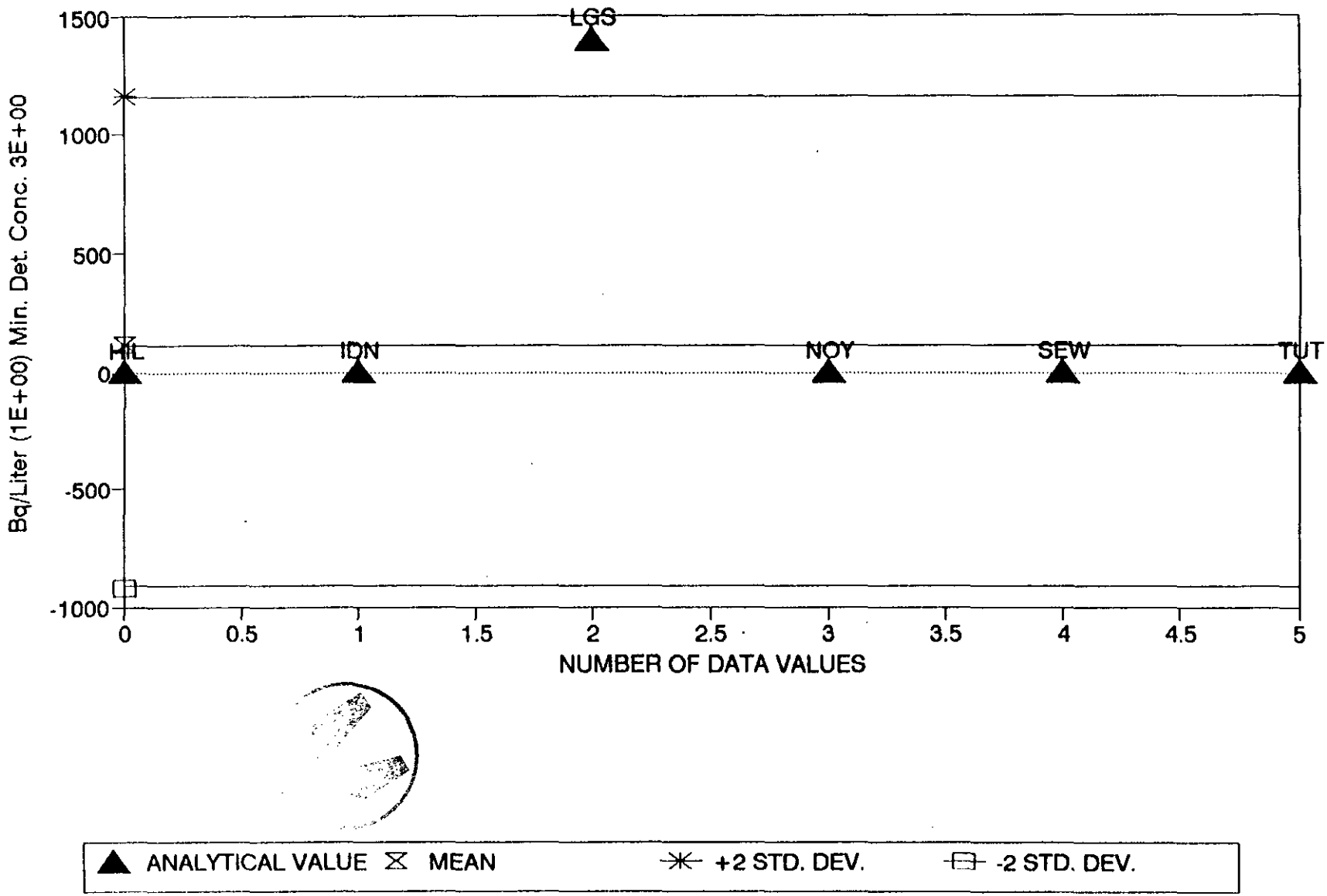

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Pb-210 IN SURFACE WATER

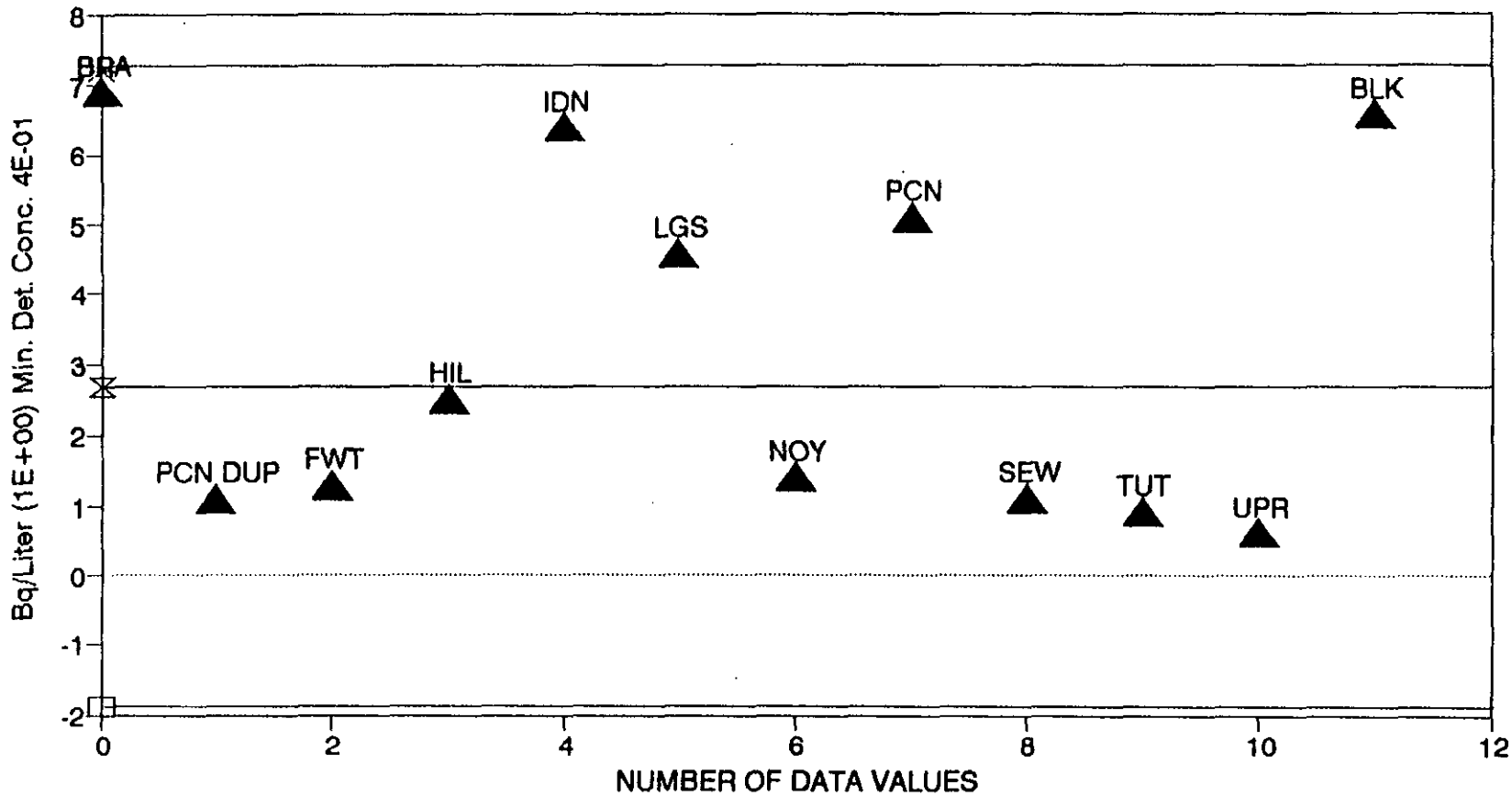

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV ⊟ -2 STD. DEV.

APPENDIX A4
RADIOLOGICAL ANALYSIS
BOTTOM SEDIMENT

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
HB-UPR Bottom Sediment Upper Pecos River	Americium-241	2.46E-02	3.12E-03
	Cesium-137	1.20E-03	1.20E-03
	Cobalt-60	*3.80E-04	6.40E-04
	Lead-210	2.60E-02	1.50E-02
	Plutonium-238	-1.22E-04	4.15E-04
	Plutonium-241	1.93E-01	6.91E-02
	Plutonium-239/240	6.11E-04	5.36E-04
	Polonium-210	1.55E-02	1.96E-03
	Potassium-40	3.60E-01	6.80E-02
	Radium-226	3.60E-02	1.80E-02
	Radium-228	2.30E-02	5.80E-03
	Strontium-90	3.40E-02	4.40E-03
	Thorium-228	3.28E-02	3.79E-03
	Thorium-232	2.95E-02	3.47E-03
	Thorium-230	6.62E-02	5.19E-03
	Uranium-238	3.33E-02	3.56E-03
	Uranium-235/236	2.82E-03	1.15E-03
	Uranium-234	4.53E-02	4.20E-03
	Uranium-233	4.53E-02	4.20E-03
HB-PCN Bottom Sediment Pierce Canyon	Americium-241	1.64E-02	2.64E-03
	Cesium-137	*-1.80E-04	6.80E-04
	Cobalt-60	*2.70E-04	5.90E-04
	Lead-210	1.50E-02	1.20E-02
	Plutonium-238	0.00E+00	3.89E-04
	Plutonium-241	-2.10E-02	8.85E-02
	Plutonium-239/240	4.20E-04	4.76E-04
	Polonium-210	1.07E-02	2.27E-03
	Potassium-40	1.90E-01	3.90E-02
	Radium-226	2.40E-02	1.50E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
HB-PCN Pierce Canyon Bottom Sediment (continued)	Radium-228	*1.30E-02	4.10E-03
	Strontium-90	4.80E-03	3.10E-03
	Thorium-228	2.05E-02	2.97E-03
	Thorium-232	1.67E-02	2.59E-03
	Thorium-230	5.39E-02	4.68E-03
	Uranium-238	2.96E-02	3.42E-03
	Uranium-235/236	3.35E-03	1.31E-03
	Uranium-234	3.62E-02	3.79E-03
	Uranium-233	3.62E-02	3.79E-03
HB_IDN Bottom Sediment Indian Tank	Americium-241	5.50E-02	5.41E-03
	Cesium-137	1.20E-02	2.30E-03
	Cobalt-60	*7.10E-04	7.70E-04
	Lead-210	6.20E-02	1.70E-02
	Plutonium-238	1.23E-04	4.18E-04
	Plutonium-241	6.41E-02	8.06E-02
	Plutonium-239/240	4.92E-04	6.82E-04
	Polonium-210	5.31E-02	3.90E-03
	Potassium-40	4.90E-01	9.30E-02
	Radium-226	3.30E-02	1.90E-02
	Radium-228	3.60E-02	8.80E-03
	Strontium-90	5.80E-03	2.90E-03
	Thorium-228	2.05E-02	2.91E-03
	Thorium-232	1.91E-02	2.72E-03
	Thorium-230	3.43E-02	3.63E-03
	Uranium-238	2.80E-02	3.16E-03
	Uranium-235/236	1.14E-03	9.48E-04
	Uranium-234	3.14E-02	3.39E-03
	Uranium-233	3.14E-02	3.39E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
HB-HIL Bottom Sediment Hill Tank	Americium-241	5.57E-02	6.45E-03
	Cesium-137	1.30E-02	2.80E-03
	Cobalt-60	*4.90E-05	7.60E-04
	Lead-210	5.90E-02	1.70E-02
	Plutonium-239/240	1.12E-03	6.93E-04
	Plutonium-241	9.44E-02	7.27E-02
	Plutonium-238	-1.12E-04	3.80E-04
	Polonium-210	5.00E-02	2.98E-03
	Potassium-40	7.20E-01	1.30E-01
	Radium-228	3.50E-02	7.80E-03
	Radium-226	4.80E-02	2.50E-02
	Strontium-90	8.90E-03	2.70E-03
	Thorium-228	4.19E-02	4.50E-03
	Thorium-232	3.89E-02	4.20E-03
	Thorium-230	5.09E-02	4.85E-03
	Uranium-238	2.51E-02	3.04E-03
	Uranium-235/236	2.22E-03	1.14E-03
	Uranium-234	3.04E-02	3.37E-03
	Uranium-233	3.04E-02	3.37E-03
HB-CBD Bottom Sediment Carlsbad	Americium-241	1.56E-02	2.39E-03
	Cesium-137	4.20E-03	1.60E-03
	Cobalt-60	*2.70E-02	2.10E-02
	Lead-210	4.80E-02	2.00E-02
	Plutonium-238	2.37E-04	4.65E-04
	Plutonium-241	1.82E-02	7.44E-02
	Plutonium-239/240	4.73E-04	4.64E-04
	Polonium-210	2.97E-02	7.46E-03
	Potassium-40	2.90E-01	5.80E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
HB-CBD Bottom Sediment Carlsbad (continued)	Radium-226	2.90E-02	2.20E-02
	Radium-228	*2.50E-02	6.90E-03
	Strontium-90	2.30E-03	1.90E-03
	Thorium-228	1.81E-02	2.76E-03
	Thorium-232	1.80E-02	2.67E-03
	Thorium-230	5.50E-02	4.66E-03
	Uranium-238	2.86E-02	3.45E-03
	Uranium-235/236	2.08E-03	1.02E-03
	Uranium-234	3.74E-02	3.96E-03
	Uranium-233	3.74E-02	3.96E-03
HB-TUT Bottom Sediment Tut Tank	Americium-241	5.68E-02	7.24E-03
	Cesium-137	3.40E-03	1.50E-03
	Cobalt-60	*2.90E-03	2.30E-02
	Lead-210	5.70E-02	2.00E-02
	Plutonium-238	-4.10E-04	4.02E-04
	Plutonium-239/240	1.02E-04	3.48E-04
	Plutonium-241	2.56E-02	6.38E-02
	Polonium-210	3.40E-02	2.96E-03
	Potassium-40	7.00E-01	1.80E-01
	Radium-226	3.70E-02	2.10E-02
	Radium-228	3.90E-02	1.10E-02
	Strontium-90	3.30E-03	2.80E-03
	Thorium-230	3.43E-02	3.64E-03
	Thorium-232	2.43E-02	3.07E-03
	Thorium-228	2.51E-02	3.21E-03
	Uranium-235/236	5.23E-03	1.74E-03
	Uranium-234	5.14E-02	4.64E-03
	Uranium-238	4.88E-02	4.48E-03
	Uranium-233	5.14E-02	4.64E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
HB -NOY Bottom Sediment Noya Tank	Americium-241	1.65E-02	2.45E-03
	Cesium-137	1.00E-03	1.10E-03
	Cobalt-60	*4.50E-04	9.50E-04
	Lead-210	2.70E-02	1.30E-02
	Plutonium-238	4.43E-04	4.34E-04
	Plutonium-241	3.87E-02	6.97E-02
	Plutonium-239/240	5.53E-04	4.84E-04
	Polonium-210	1.13E-02	1.42E-03
	Potassium-40	3.20E-01	6.20E-02
	Radium-226	1.70E-02	1.40E-02
	Radium-228	1.80E-02	4.50E-03
	Strontium-90	4.90E-03	2.70E-03
	Thorium-228	1.33E-02	2.32E-03
	Thorium-232	1.42E-02	2.37E-03
	Thorium-230	4.20E-02	4.04E-03
	Uranium-238	1.30E-02	2.43E-03
	Uranium-235/236	1.72E-03	1.05E-03
	Uranium-234	1.31E-02	2.54E-03
	Uranium-233	1.31E-02	2.54E-03
HB_LGS Bottom Sediment Laguna Grande de la Sol	Americium-241	9.49E-03	2.48E-03
	Cesium-137	*8.20E-05	7.10E-04
	Cobalt-60	*7.10E-05	5.40E-04
	Lead-210	1.10E-02	1.00E-02
	Plutonium-238	2.27E-04	4.46E-04
	Plutonium-241	6.15E-02	7.37E-02
	Plutonium-239/240	4.54E-04	5.45E-04
	Polonium-210	1.95E-02	1.76E-03
	Potassium-40	2.70E-01	5.20E-02
	Radium-226	2.80E-02	1.80E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
HB_LGS Bottom Sediment Laguna Grande de la Sol (continued)	Radium-228	*5.90E-03	4.20E-03
	Strontium-90	2.70E-03	1.90E-03
	Thorium-228	1.45E-02	2.53E-03
	Thorium-232	4.08E-03	1.29E-03
	Thorium-230	4.86E-02	4.40E-03
	Uranium-238	3.66E-02	3.80E-03
	Uranium-235/236	5.14E-03	1.61E-03
	Uranium-234	6.06E-02	4.91E-03
	Uranium-233	6.06E-02	4.91E-03
HB-COY Note: Acronym COY denotes duplicate sample collected at Pierce Canyon	Americium-241	3.51E-02	3.75E-03
	Cesium-137	*2.10E-04	6.00E-04
	Cobalt-60	*1.40E-04	5.10E-04
	Lead-210	1.10E-02	9.80E-03
	Plutonium-238	3.51E-04	6.07E-04
	Plutonium-241	1.13E-01	7.53E-02
	Plutonium-239/240	5.84E-04	5.12E-04
	Polonium-210	1.48E-02	2.17E-03
	Potassium-40	2.00E-01	3.90E-02
	Radium-226	3.60E-02	1.40E-02
	Radium-228	*1.30E-02	7.70E-03
	Strontium-90	1.00E-02	2.90E-03
	Thorium-228	1.69E-02	2.76E-03
	Thorium-232	1.69E-02	2.68E-03
	Thorium-230	4.49E-02	4.38E-03
	Uranium-238	1.88E-02	2.84E-03
	Uranium-235/236	0.00E+00	1.18E-03
	Uranium-234	2.30E-02	3.22E-03
	Uranium-233	2.30E-02	3.22E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
HB-RED Bottom Sediment Red Tank	Americium-241	1.68E-02	2.52E-03
	Cesium-137	5.30E-03	2.00E-03
	Cobalt-60	*4.50E-04	7.40E-04
	Lead-210	6.20E-02	1.80E-02
	Plutonium-238	0.00E+00	5.12E-04
	Plutonium-241	6.21E-02	6.82E-02
	Plutonium-239/240	7.46E-04	5.53E-04
	Polonium-210	3.59E-02	2.54E-03
	Potassium-40	3.90E-01	7.60E-02
	Radium-226	3.10E-02	1.90E-02
	Radium-228	3.00E-02	7.40E-03
	Strontium-90	6.90E-03	2.90E-03
	Thorium-228	3.82E-02	4.11E-03
	Thorium-232	3.26E-02	3.69E-03
	Thorium-230	5.50E-02	4.79E-03
	Uranium-238	2.47E-02	3.11E-03
	Uranium-235/236	1.08E-03	8.46E-04
	Uranium-234	2.81E-02	3.32E-03
	Uranium-233	2.81E-02	3.32E-03
HB-BRA Bottom Sediment Brantley Lake	Americium-241	1.82E-02	2.89E-03
	Cesium-137	*-1.20E-05	7.50E-04
	Cobalt-60	*5.30E-04	5.50E-04
	Lead-210	1.70E-02	1.30E-02
	Plutonium-238	2.22E-04	3.07E-04
	Plutonium-241	5.60E-02	6.96E-02
	Plutonium-239/240	6.64E-04	6.14E-04
	Polonium-210	6.84E-03	1.22E-03
	Potassium-40	2.90E-01	5.60E-02
	Radium-226	3.00E-02	1.70E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
HB-BRA Bottom Sediment Brantley Lake	Radium-228	1.90E-02	5.40E-03
	Strontium-90	4.10E-03	2.50E-03
	Thorium-228	2.80E-02	3.61E-03
	Thorium-232	2.29E-02	3.16E-03
	Thorium-230	7.37E-02	5.61E-03
	Uranium-238	6.21E-02	4.77E-03
	Uranium-235/236	8.05E-03	1.95E-03
	Uranium-234	9.10E-02	5.78E-03
	Uranium-233	9.10E-02	5.78E-03

1995
Am-241 IN SEDIMENT

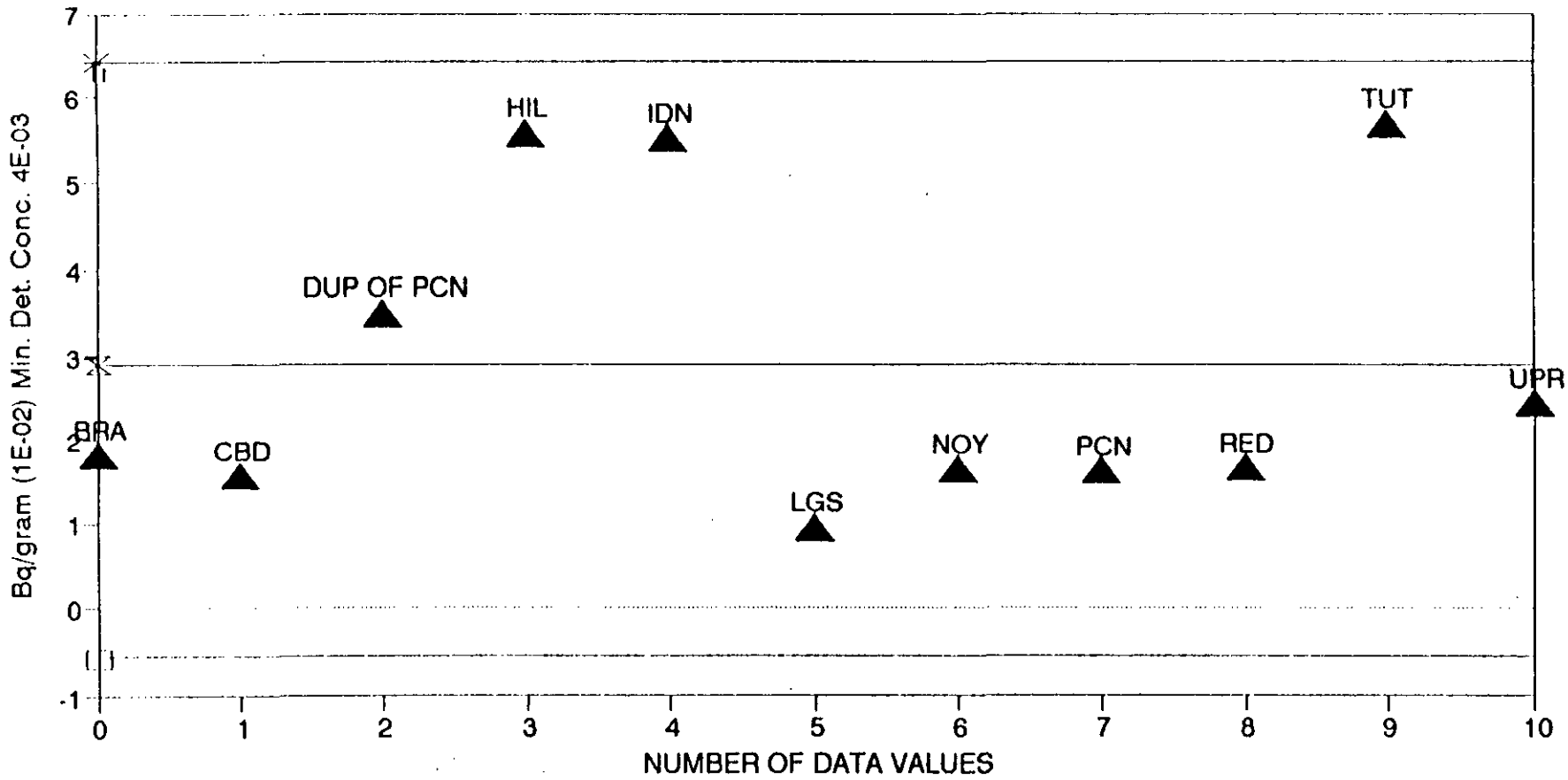

▲ ANALYTICAL VALUE ✕ MEAN +2 STD. DEV. -2 STD. DEV.

1995
Cs-137 IN SEDIMENT

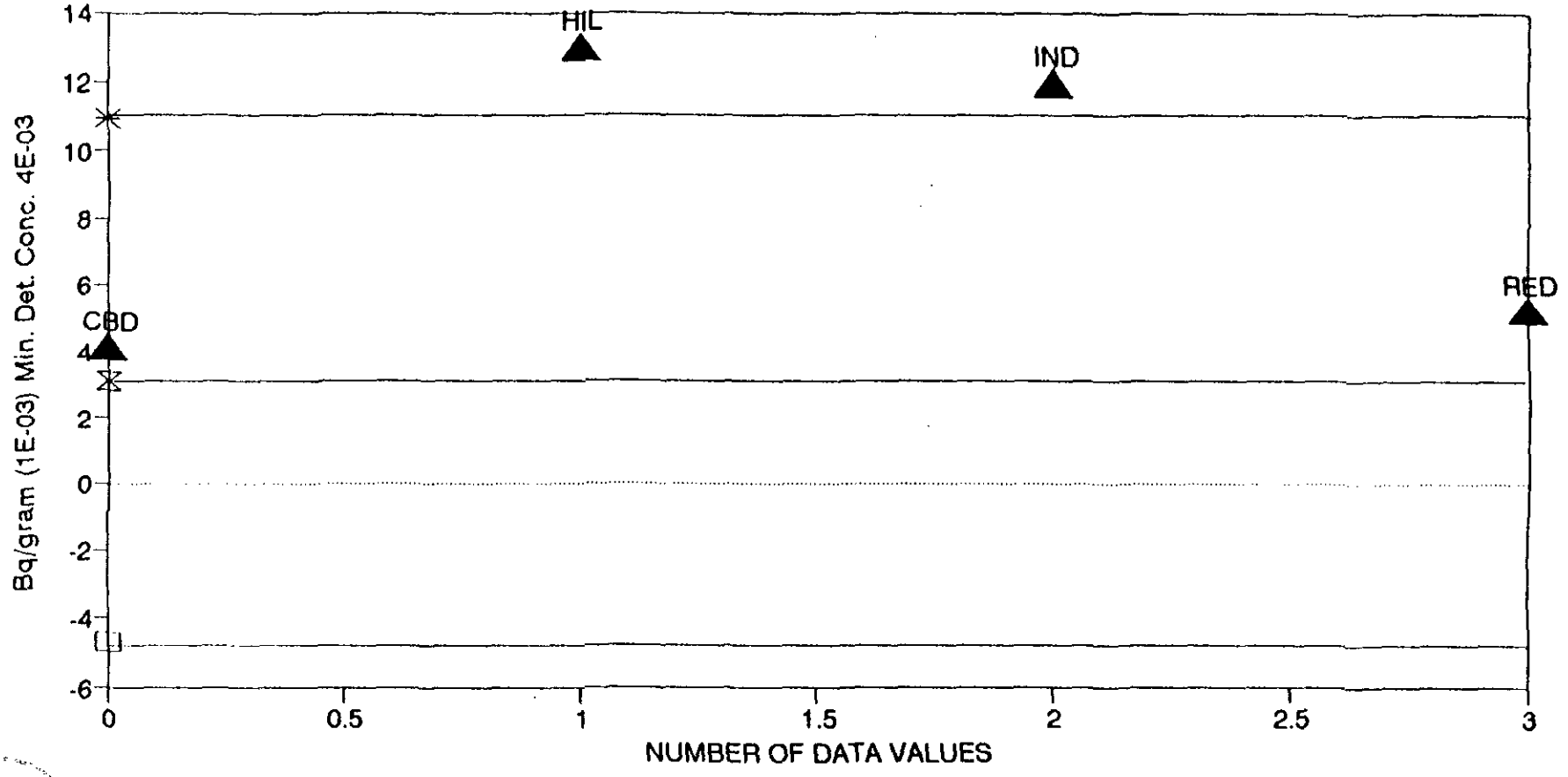

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
K-40 IN SEDIMENT

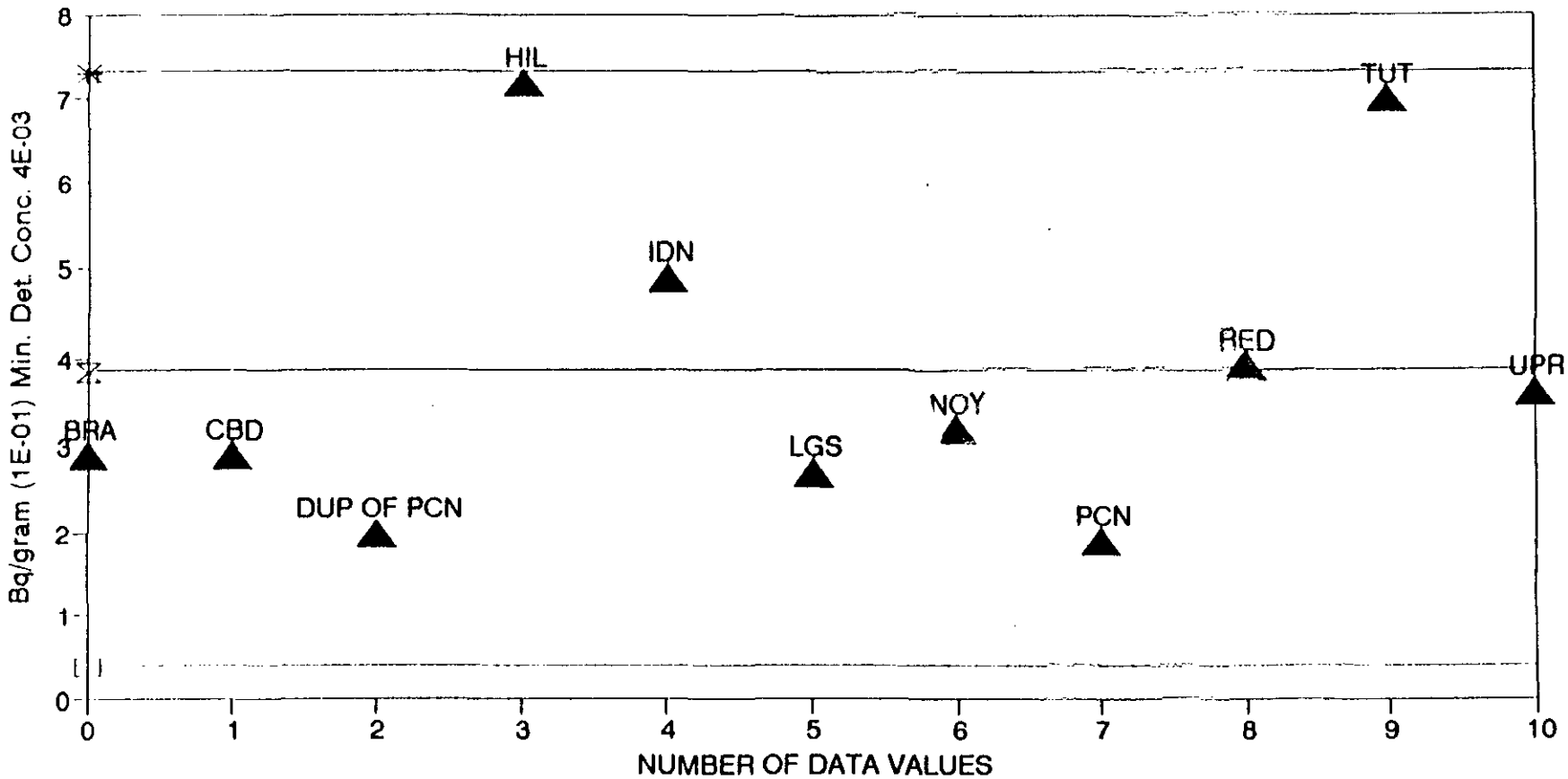

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Ra-226 IN SEDIMENT

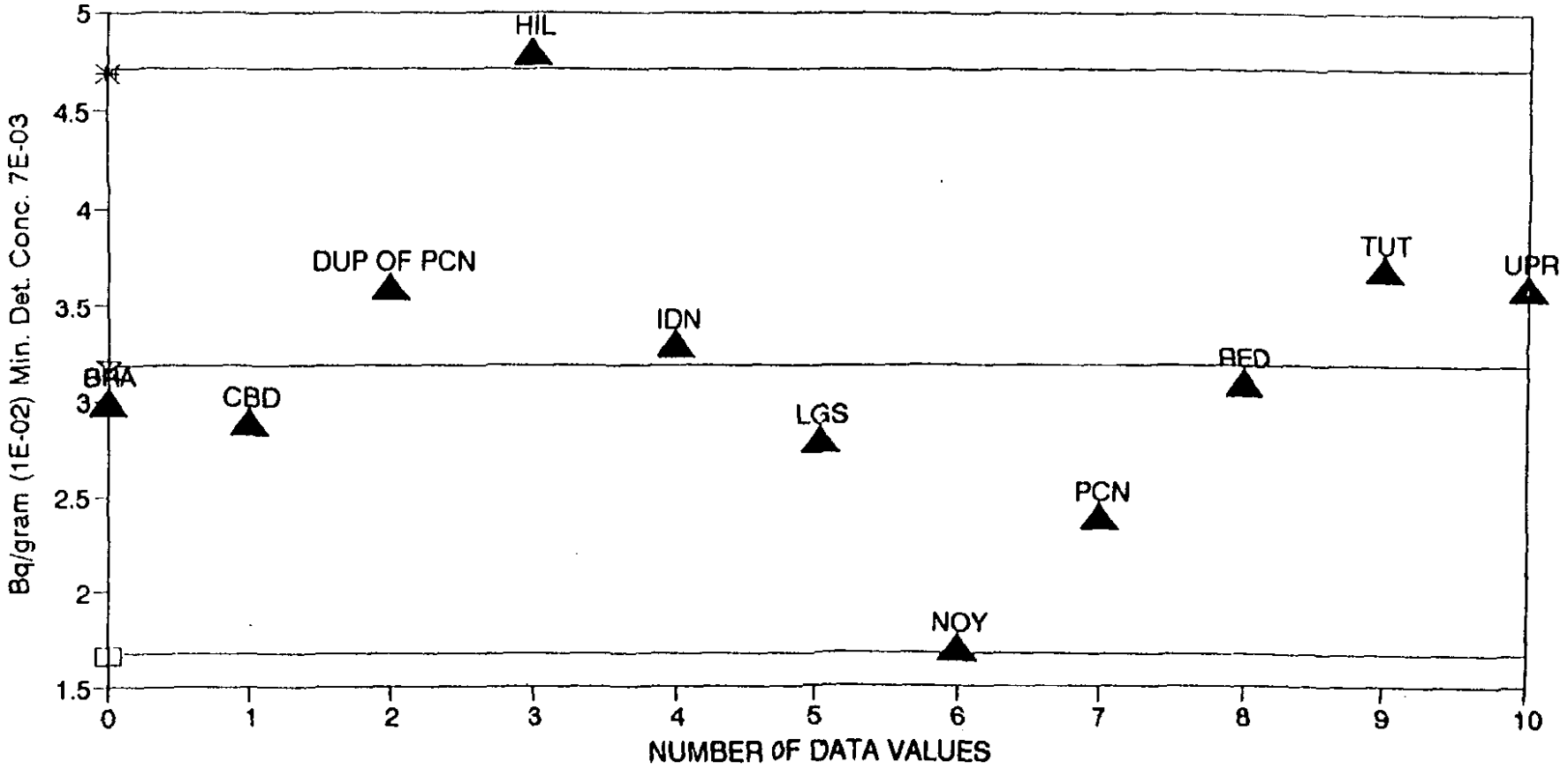

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
Th-228 IN SEDIMENT

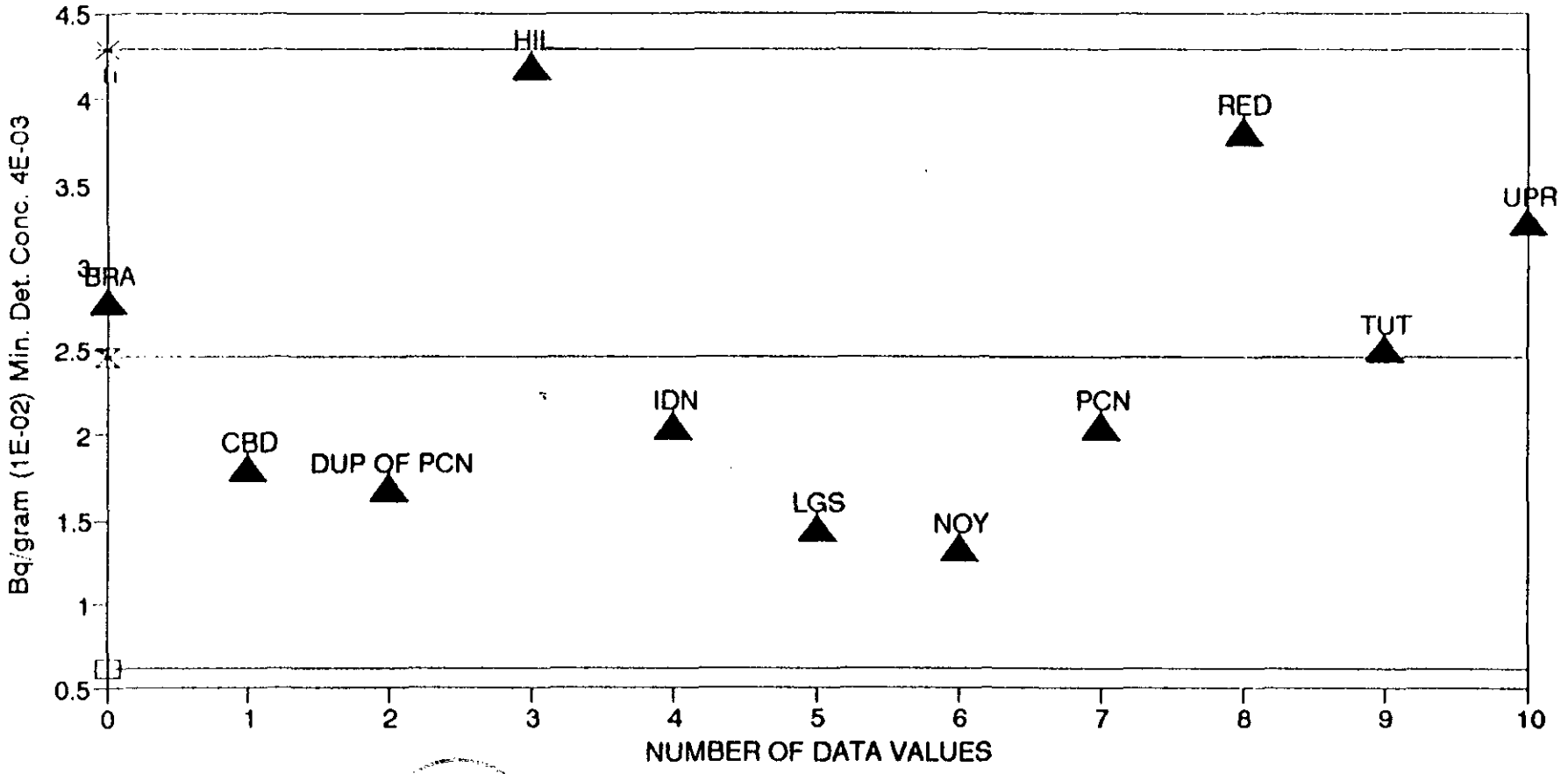

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊡ -2 STD. DEV.

1995
Th-230 IN SEDIMENT

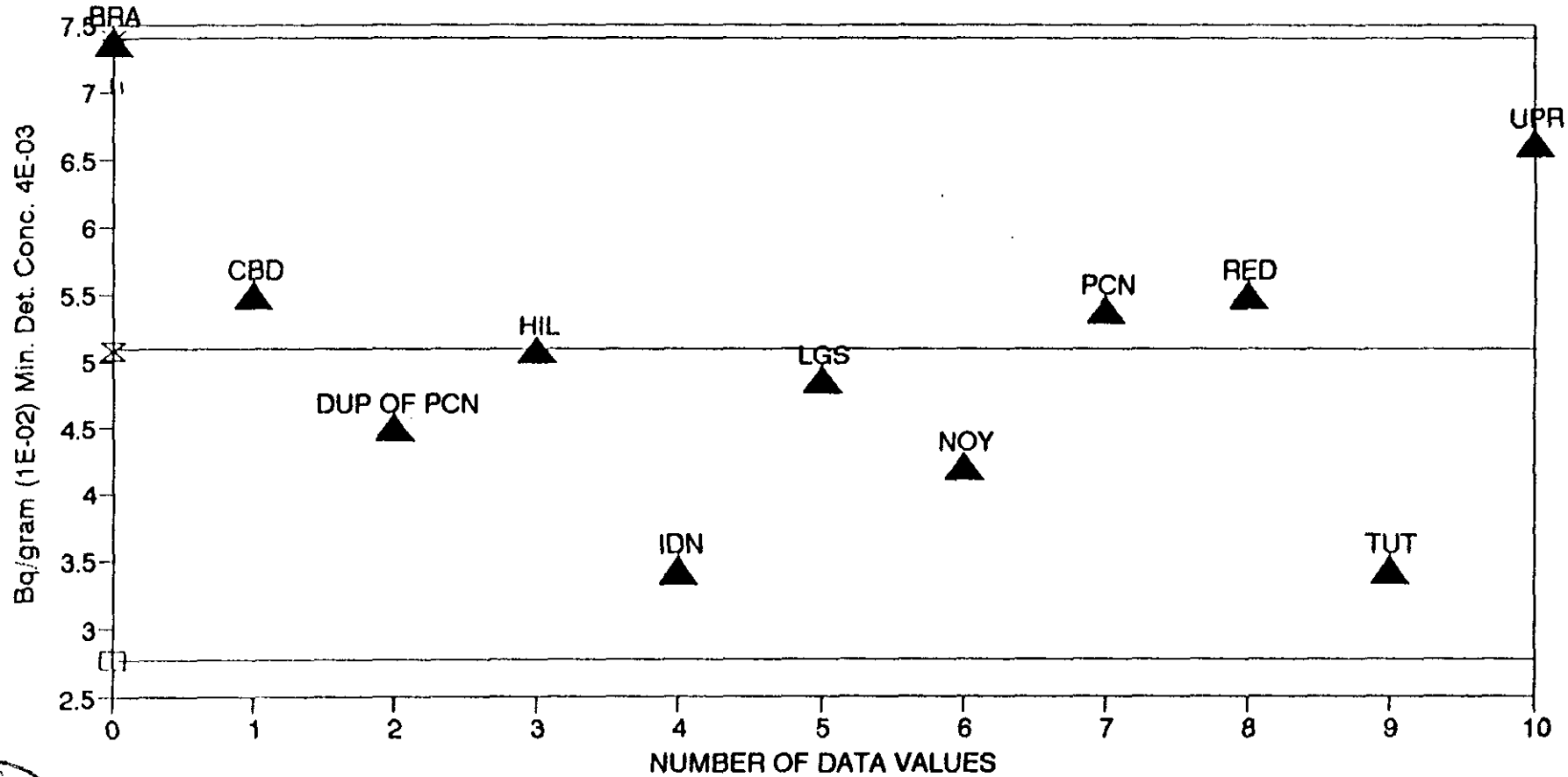

ANALYTICAL VALUE MEAN +2 STD. DEV. -2 STD. DEV.

1995
Th-232 IN SEDIMENT

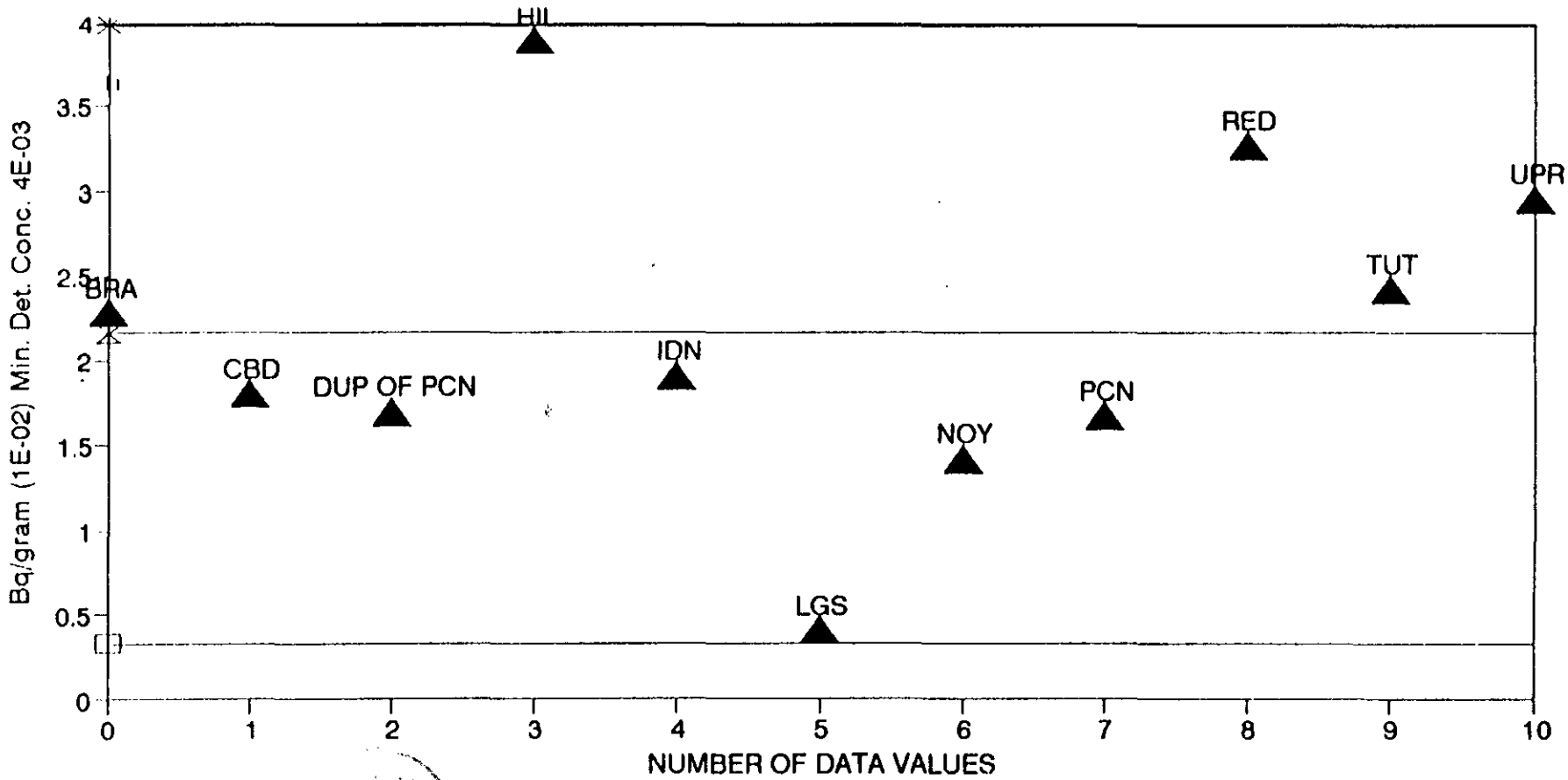

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
U-233/234 IN SEDIMENT

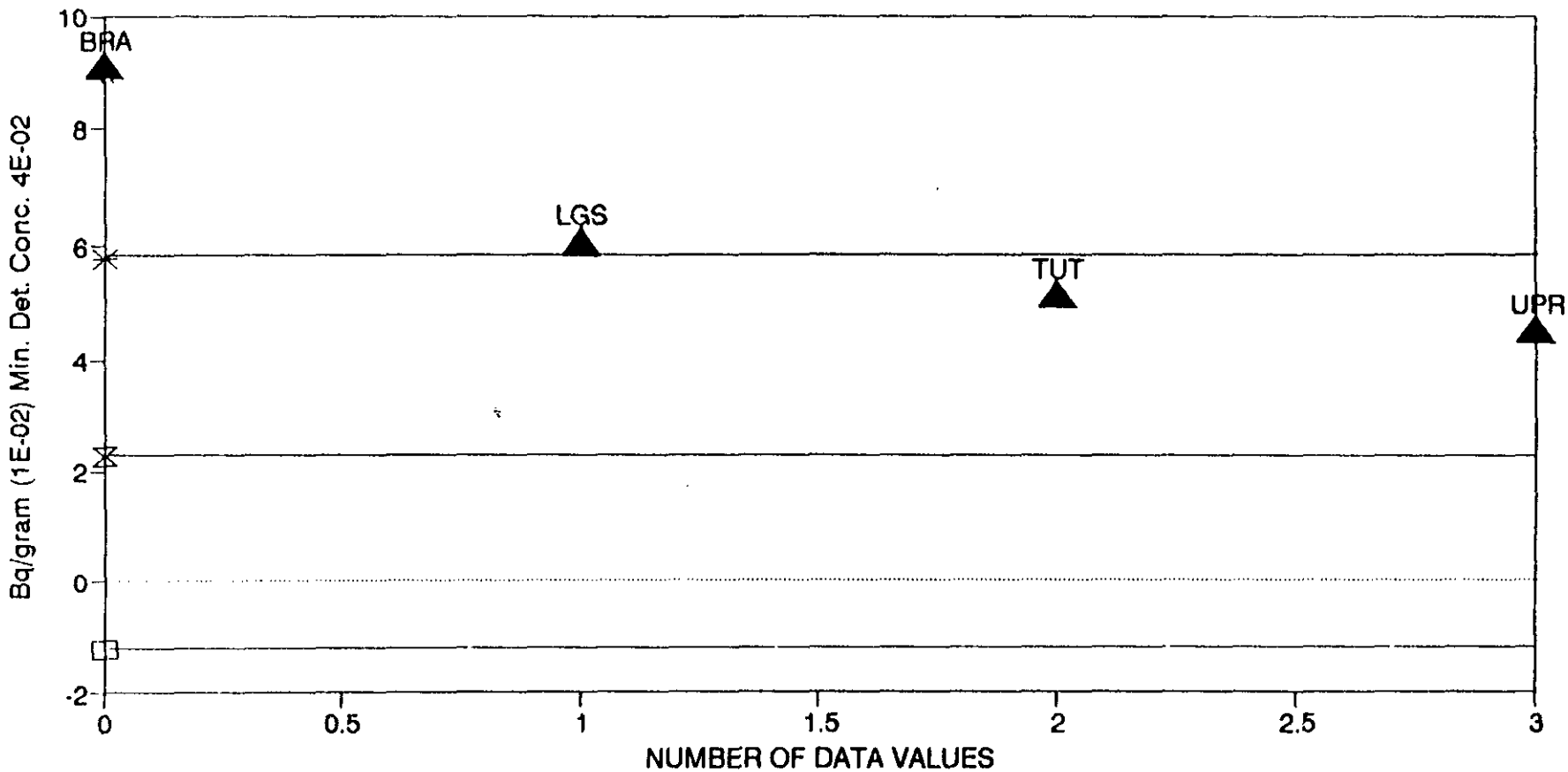

ANALYTICAL VALUE MEAN +2 STD. DEV. -2 STD. DEV.

1995
U-238 IN SEDIMENT

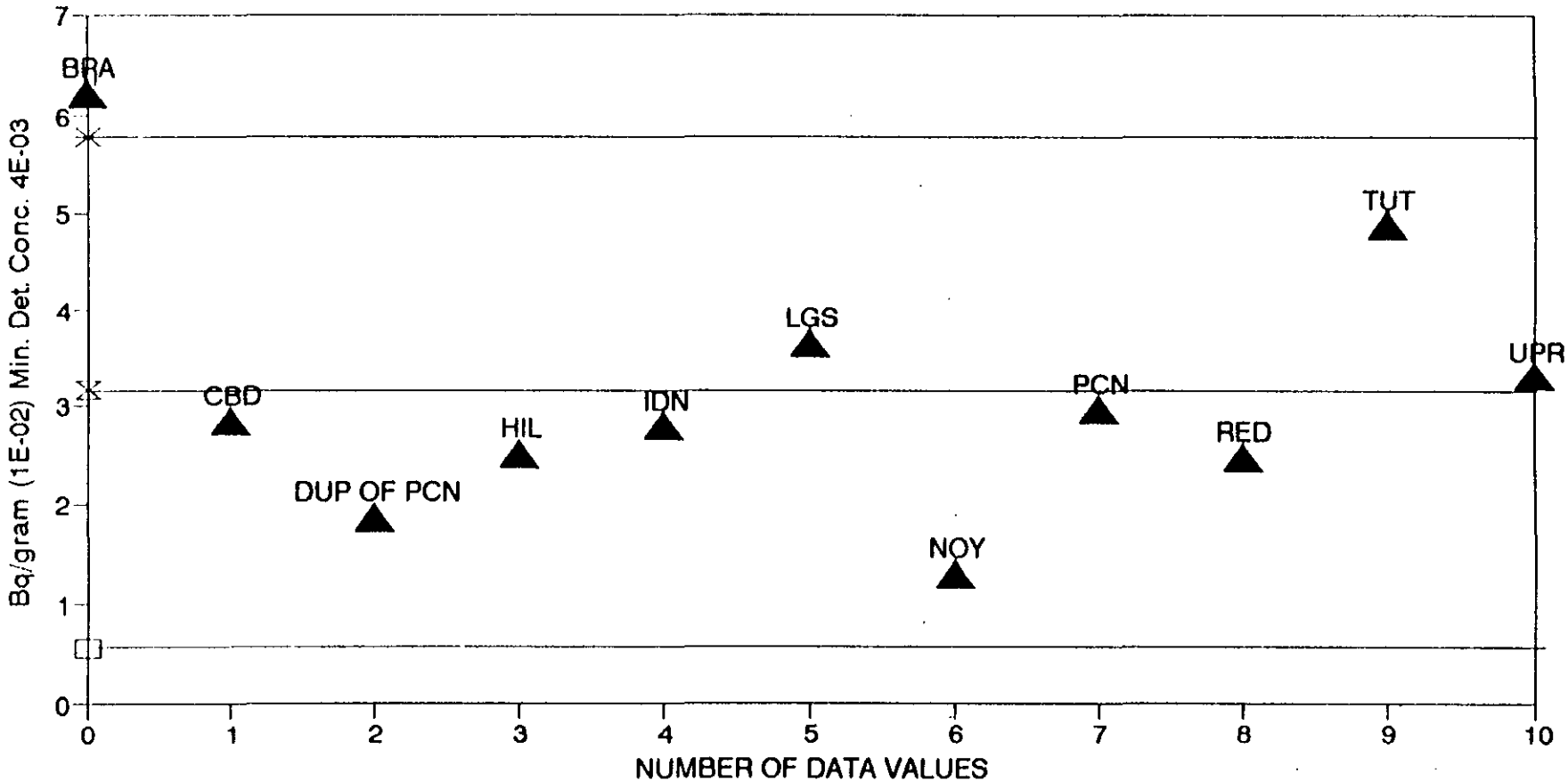

▲ ANALYTICAL VALUE ⧖ MEAN +2 STD. DEV. -2 STD. DEV.

APPENDIX A5
RADIOLOGICAL ANALYSIS
GROUND WATER

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
H-03B3 Ground Water Round 10	Americium-241	3.51E-02	7.29E-31
	Cesium-137	-3.90E-03	7.10E-02
	Cobalt-60	-1.90E-02	8.10E-02
	Lead-210	5.60E+00	1.30E+00
	Plutonium-239/240	2.69E-03	2.28E-33
	Plutonium-241	-6.02E-02	1.16E-11
	Plutonium-238	2.03E-03	2.09E-33
	Polonium-210	1.63E-02	7.71E-36
	Potassium-40	1.50E+01	2.70E+00
	Radium-226	4.40E+00	4.70E-02
	Radium-228	5.67E-01	7.00E-02
	Strontium-90	-6.90E-03	3.10E-02
	Thorium-228	1.27E-01	1.44E-24
	Thorium-232	1.00E-03	2.17E-34
	Thorium-230	2.55E-02	5.95E-33
	Uranium-235/236	1.16E-02	4.82E-33
	Uranium-238	7.62E-02	1.10E-25
	Uranium-233/234	4.82E-01	2.70E-25
H14 Ground Water Round 8	Americium-241	1.30E-02	4.22E-33
	Cesium-137	-6.20E-02	7.00E-02
	Cobalt-60	5.90E-02	8.10E-02
	Lead-210	1.10E+00	1.80E+00
	Plutonium-241	-1.88E-01	1.38E-12
	Plutonium-238	-8.30E-04	1.99E-34
	Plutonium-239/240	1.24E-03	1.40E-31
	Polonium-210	8.63E-03	9.92E-31
	Potassium-40	7.80E+00	2.10E+00
	Radium-228	8.04E-01	7.80E-02
	Radium-226	3.10E+00	3.90E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
H14 Ground Water Round 8 (continued)	Strontium-90	-6.40E-04	1.70E-02
	Thorium-230	1.61E-02	4.87E-33
	Thorium-228	6.52E-02	1.02E-23
	Thorium-232	-9.85E-04	1.11E-33
	Uranium-233/234	3.27E-01	2.26E-25
	Uranium-238	3.88E-02	8.10E-35
	Uranium-235/236	3.94E-03	3.06E-33
H18 Ground Water Round 4	Americium-241	1.91E-02	5.31E-31
	Cesium-137	1.00E-02	7.00E-02
	Cobalt-60	4.20E-02	7.60E-02
	Lead-210	6.80E+00	1.40E+00
	Plutonium-241	-1.17E-01	1.17E-11
	Plutonium-238	0.00E+00	1.98E-34
	Plutonium-239/240	1.43E-03	1.40E-39
	Polonium-210	N/A	N/A
	Potassium-40	7.70E+00	2.10E+00
	Radium-228	5.07E-01	6.70E-02
	Radium-226	3.70E+00	4.30E-02
	Strontium-90	-2.10E-02	2.70E-02
	Thorium-230	2.18E-02	6.54E-34
	Thorium-228	1.18E-01	1.63E-27
	Thorium-232	1.81E-03	2.51E-34
	Uranium-233/234	6.20E-01	2.99E-27
	Uranium-238	9.97E-02	1.20E-23
	Uranium-235/236	1.32E-02	4.97E-33
WIPP19 Ground Water Round 10	Americium-241	2.00E-02	6.03E-33
	Cesium-137	-7.90E-02	7.60E-02
	Cobalt-60	9.40E-02	8.40E-02
	Lead-210	1.80E-01	1.90E+00

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
WIPP19 Ground Water Round 10 (continued)	Plutonium-241	-2.29E-01	1.24E-12
	Plutonium-238	0.00E+00	1.41E-33
	Plutonium-239/240	0.00E+00	9.94E-42
	Polonium-210	1.40E-02	1.09E-21
	Potassium-40	1.90E+01	3.30E+00
	Radium-228	1.59E+00	1.10E-01
	Radium-226	5.00E+00	5.00E-02
	Strontium-90	1.60E-03	1.80E-02
	Thorium-230	3.76E-02	1.16E-21
	Thorium-228	2.14E-01	2.88E-21
	Thorium-232	3.68E-03	3.81E-35
	Uranium-233/234	6.36E-01	4.57E-21
	Uranium-238	9.92E-02	1.85E-21
	Uranium-235/236	3.32E-02	1.19E-27
WQSP-1 Ground Water Round 1	Americium-241	1.98E-02	8.91E-32
	Cesium-137	-1.90E-02	7.30E-02
	Cobalt-60	1.70E-01	8.00E-02
	Lead-210	9.20E+00	1.60E+00
	Plutonium-241	-2.99E-01	1.55E-12
	Plutonium-238	1.44E-03	3.12E-35
	Plutonium-239/240	-9.55E-04	2.65E-36
	Polonium-210	-5.47E-03	1.47E-22
	Potassium-40	1.60E+01	2.80E+00
	Radium-228	1.46E+00	1.00E-01
	Radium-226	6.00E+00	5.50E-02
	Strontium-90	2.70E-02	2.70E-02
	Thorium-230	3.65E-02	7.80E-33
	Thorium-228	1.02E-01	1.45E-24
	Thorium-232	8.47E-04	1.66E-33

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
WQSP-1 Ground Water Round 1 (continued)	Uranium-233/234	1.42E+00	4.79E-25
	Uranium-238	2.36E-01	1.96E-23
	Uranium-235/236	2.60E-02	7.90E-36
WQSP-2 Ground Water Round 1	Americium-241	2.09E-02	5.46E-33
	Cesium-137	-1.10E-01	7.60E-02
	Cobalt-60	1.20E-01	8.20E-02
	Lead-210	4.10E-01	2.20E+00
	Plutonium-241	-2.73E-01	1.72E-12
	Plutonium-238	-5.71E-04	3.36E-37
	Plutonium-239/240	-5.68E-04	2.95E-36
	Polonium-210	8.79E-03	7.71E-31
	Potassium-40	1.70E+01	3.10E+00
	Radium-228	7.52E-01	9.30E-02
	Radium-226	3.70E+00	4.40E-02
	Strontium-90	-3.10E-02	2.40E-02
	Thorium-230	4.02E-02	7.74E-34
	Thorium-228	3.97E-02	8.38E-34
	Thorium-232	-3.20E-03	2.87E-36
	Uranium-233/234	1.21E+00	4.06E-23
	Uranium-238	1.91E-01	1.64E-25
	Uranium-235/236	3.24E-02	8.50E-38
WQSP-3 Ground Water Round 1	Americium-241	4.40E-02	1.03E-21
	Cesium-137	-1.00E-01	7.90E-02
	Cobalt-60	-1.60E-02	7.80E-02
	Lead-210	1.50E-01	2.10E+00
	Plutonium-241	-1.34E-01	1.26E-12
	Plutonium-238	7.72E-04	2.62E-35
	Plutonium-239/240	1.54E-03	1.84E-32
	Polonium-210	9.56E-02	2.06E-28

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
WQSP-3 Ground Water Round 1 (continued)	Potassium-40	4.90E+01	6.40E+00
	Radium-228	1.71E+00	1.10E-01
	Radium-226	7.80E+00	6.00E-02
	Strontium-90	2.40E-03	3.30E-02
	Thorium-230	1.85E-02	7.34E-36
	Thorium-228	6.47E-02	1.48E-28
	Thorium-232	6.60E-04	2.24E-34
	Uranium-233/234	3.21E-01	2.64E-26
	Uranium-238	3.75E-02	9.86E-38
	Uranium-235/236	6.90E-03	5.06E-36
WQSP-4 Ground Water Round 1	Americium-241	2.47E-02	5.32E-32
	Cesium-137	-3.30E-02	7.80E-02
	Cobalt-60	8.60E-02	8.40E-02
	Lead-210	5.40E-01	2.10E+00
	Plutonium-241	-2.17E-01	1.29E-12
	Plutonium-238	0.00E+00	1.09E-32
	Plutonium-239/240	3.91E-04	2.03E-34
	Polonium-210	0.00E+00	4.72E-31
	Potassium-40	2.50E+01	4.00E+00
	Radium-228	2.03E+00	1.30E-01
	Radium-226	9.10E+00	7.00E-02
	Strontium-90	-1.20E-02	2.20E-02
	Thorium-230	2.14E-02	9.23E-31
	Thorium-228	5.96E-02	1.65E-21
	Thorium-232	3.05E-03	4.73E-38
	Uranium-233/234	6.83E-01	5.02E-21
	Uranium-238	1.07E-01	2.07E-21
	Uranium-235/236	1.77E-02	8.93E-33

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
WQSP-6A Ground Water Round 1	Americium-241	1.67E-02	5.36E-34
	Cesium-137	1.40E-02	7.00E-02
	Cobalt-60	6.50E-02	8.40E-02
	Lead-210	7.00E+00	1.30E+00
	Plutonium-241	-8.18E-03	1.11E-11
	Plutonium-238	-6.70E-04	2.63E-35
	Plutonium-239/240	1.33E-03	1.31E-39
	Polonium-210	N/A	N/A
	Potassium-40	2.70E+00	9.30E-01
	Radium-228	1.84E-02	3.30E-02
	Radium-226	9.00E-02	6.90E-03
	Strontium-90	-2.10E-02	3.20E-02
	Thorium-230	3.16E-02	6.59E-33
	Thorium-228	1.62E-02	5.59E-35
	Thorium-232	-3.35E-04	1.14E-33
	Uranium-233/234	2.32E-01	1.74E-22
	Uranium-238	1.28E-01	1.30E-23
	Uranium-235/236	1.46E-02	5.11E-33
B-2 Ground Water Note: Acronym B-2 denotes sample blank	Americium-241	2.00E-02	5.59E-33
	Cesium-137	-6.60E-02	8.00E-02
	Cobalt-60	-3.00E-03	7.60E-02
	Lead-210	7.10E+00	1.50E+00
	Plutonium-241	5.85E-02	1.18E-11
	Plutonium-238	-1.70E-03	1.49E-34
	Plutonium-239/240	1.02E-03	1.48E-32
	Polonium-210	-2.02E-03	5.59E-31
	Potassium-40	2.50E+01	3.80E+00
	Radium-228	1.89E+00	1.10E-01

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
B-2 Ground Water Note: Acronym B-2 denotes sample blank (continued)	Radium-226	8.60E+00	6.30E-02
	Strontium-90	-1.50E-02	2.00E-02
	Thorium-230	3.07E-02	8.11E-35
	Thorium-228	5.57E-02	1.21E-28
	Thorium-232	0.00E+00	1.94E-34
	Uranium-233/234	6.21E-01	4.86E-21
	Uranium-238	8.60E-02	1.88E-21
	Uranium-235/236	1.21E-02	8.19E-38
WQSP-5 Ground Water Round 1	Americium-241	2.05E-02	6.44E-03
	Cesium-137	-6.20E-02	1.30E-01
	Cobalt-60	2.50E-02	1.50E-01
	Lead-210	8.00E+00	2.40E+00
	Plutonium-238	5.51E-04	1.87E-03
	Plutonium-241	-5.92E+00	2.78E-01
	Plutonium-239/240	3.84E-03	3.22E-03
	Polonium-210	4.54E-02	9.96E-03
	Potassium-40	1.20E+01	3.20E+00
	Radium-226	2.70E+00	4.00E-02
	Radium-228	2.90E-01	5.00E-02
	Strontium-90	2.50E-01	6.00E-02
	Thorium-228	7.22E-02	1.32E-02
	Thorium-232	4.94E-04	1.68E-03
	Thorium-230	1.53E-02	6.21E-03
	Uranium-233/234	5.64E-01	4.09E-02
	Uranium-235/236	1.04E-02	7.17E-03
	Uranium-238	8.57E-02	1.60E-02
WQSP-6 Ground Water Round 1	Americium-241	1.59E-02	5.61E-03
	Cesium-137	1.40E-02	7.00E-02
	Cobalt-60	6.50E-02	8.40E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/L	COUNTING ERROR
WQSP-6 Ground Water Round 1 (continued)	Lead-210	7.00E+00	1.30E+00
	Plutonium-239/240	6.26E-03	4.85E-03
	Plutonium-238	7.86E-04	2.66E-03
	Plutonium-241	-6.90E+00	3.95E-01
	Polonium-210	N/A	N/A
	Potassium-40	2.70E+00	9.30E-01
	Radium-228	1.84E-02	3.30E-02
	Radium-226	9.00E-02	6.90E-03
	Strontium-90	1.80E-01	4.50E-02
	Thorium-228	3.24E-02	9.11E-03
	Thorium-232	0.00	2.22E-03
	Thorium-230	2.32E-02	7.15E-03
	Uranium-238	7.80E-02	1.44E-02
	Uranium-233/234	6.05E-01	4.04E-02
	Uranium-235/236	5.96E-03	6.02E-03

1995
Am-241 IN GROUNDWATER

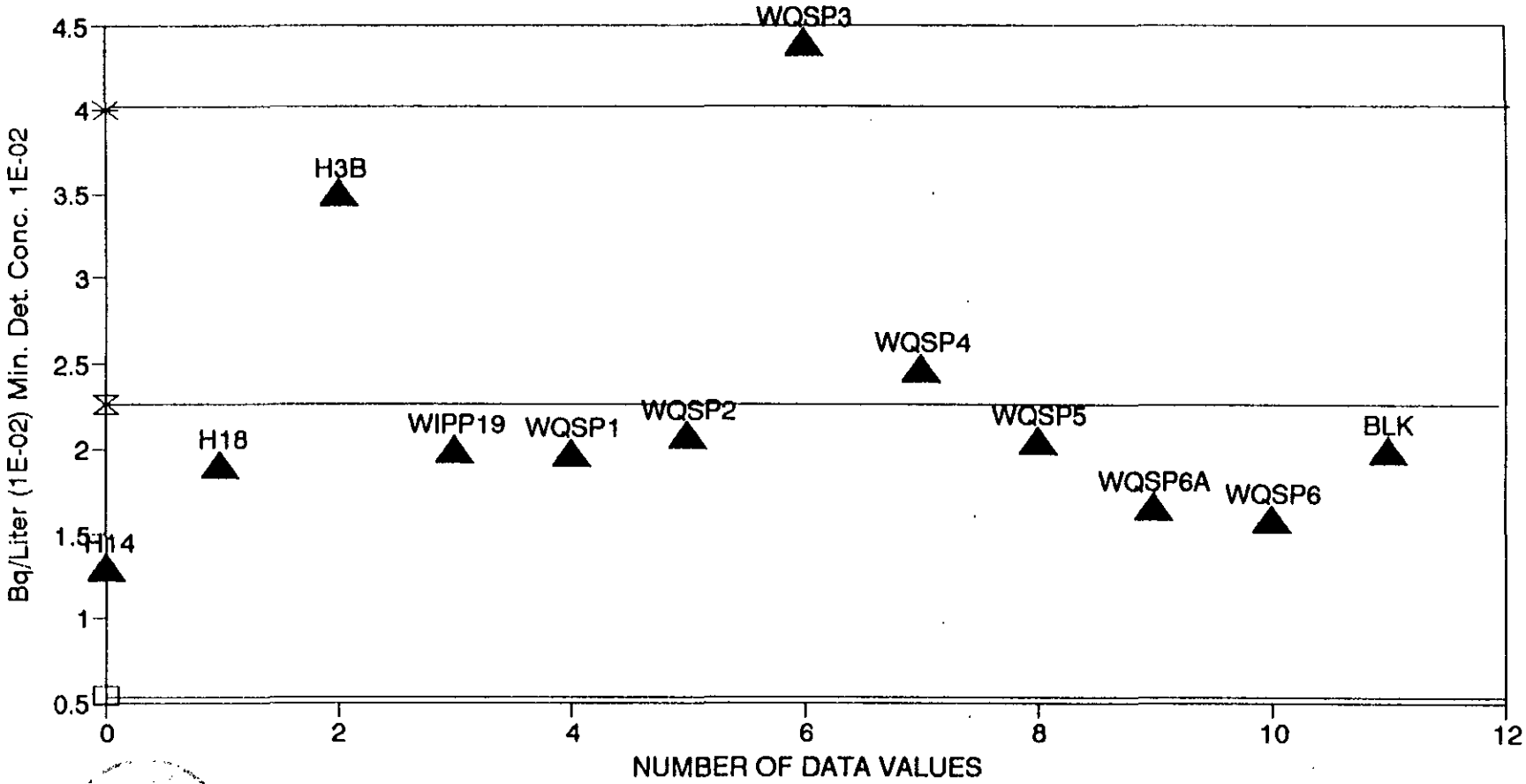

ANALYTICAL VALUE MEAN +2 STD. DEV. -2 STD. DEV.

1995
Pb-210 IN GROUNDWATER

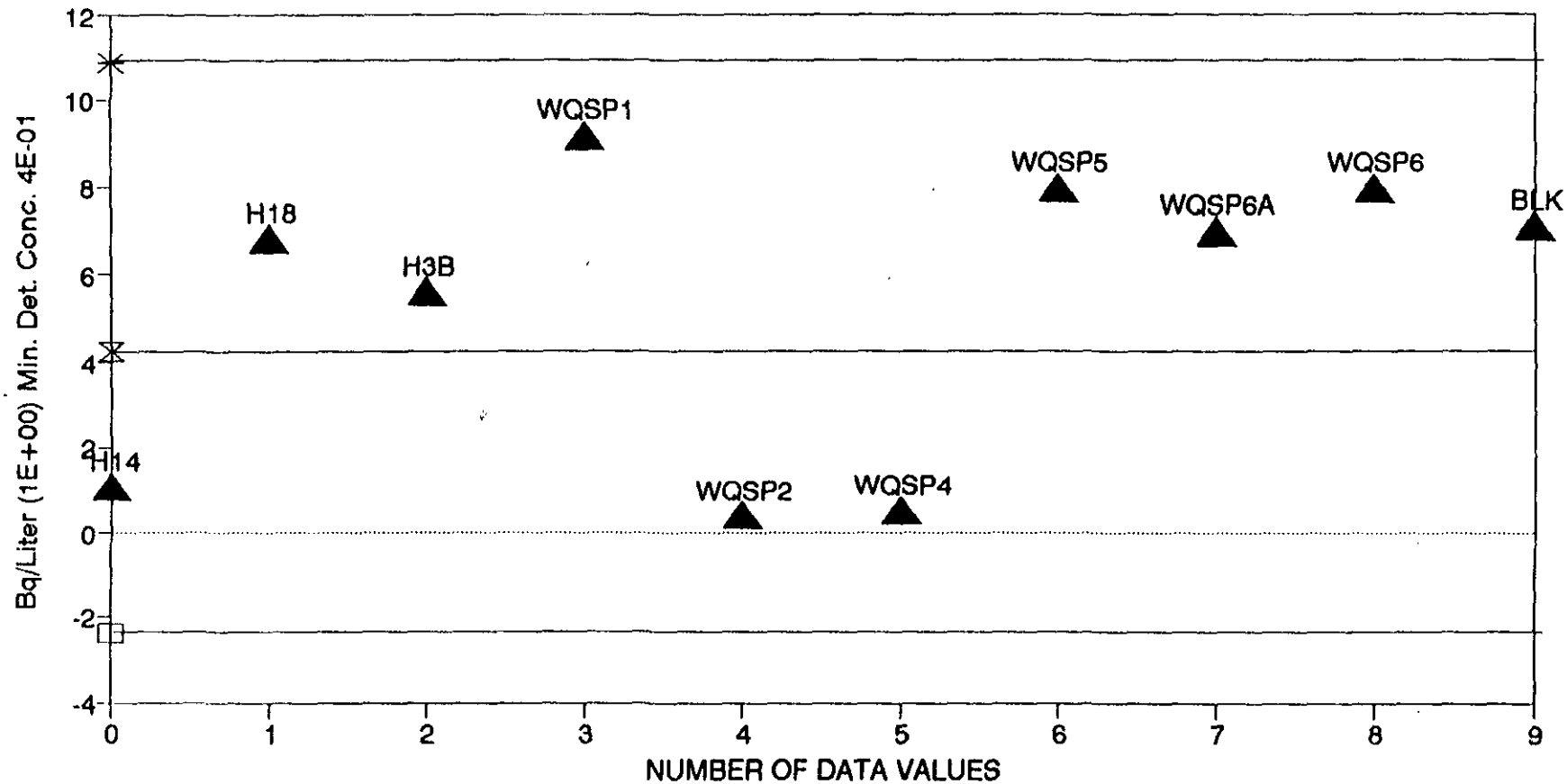

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
K-40 IN GROUNDWATER

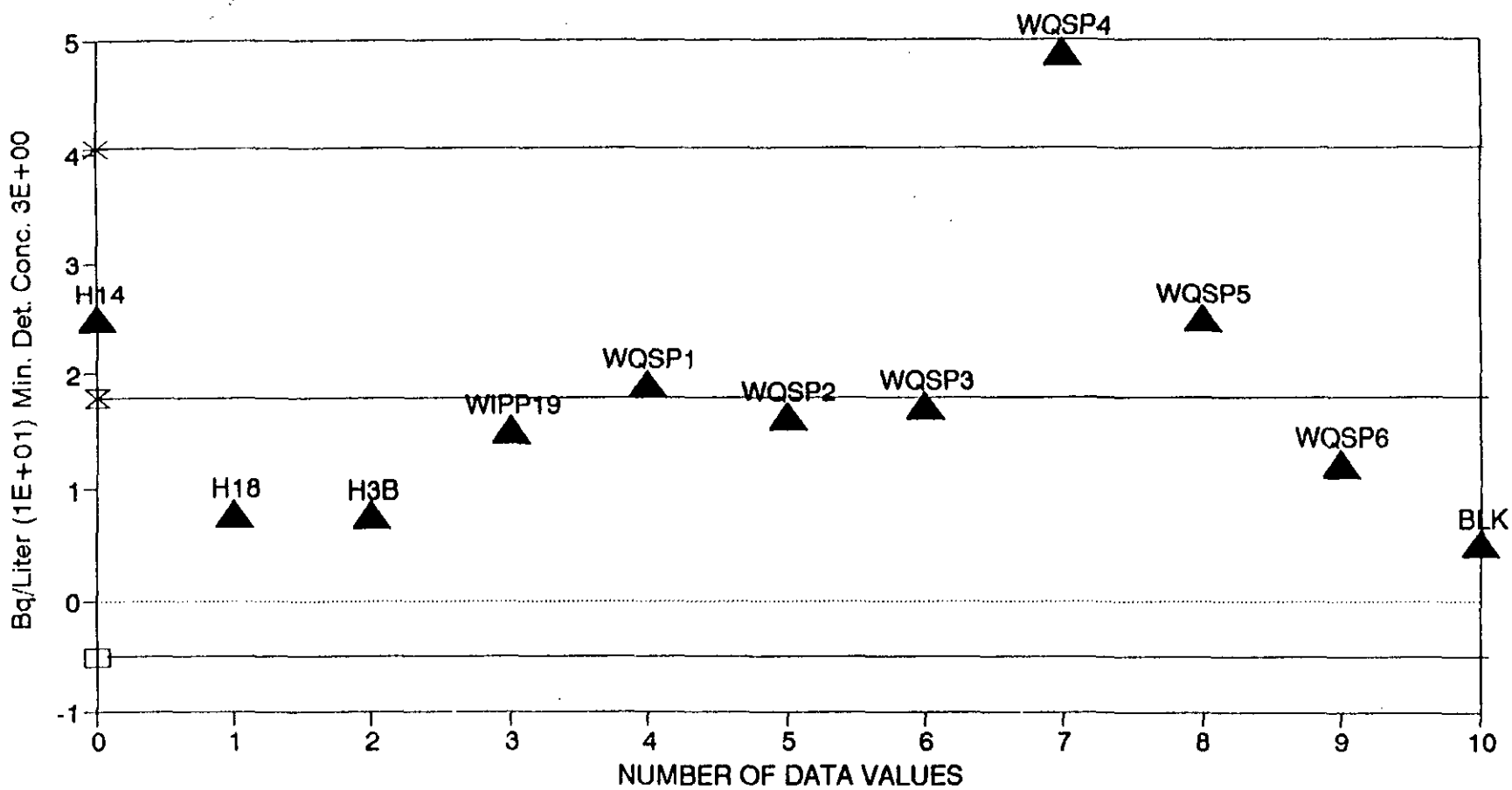

ANALYTICAL VALUE MEAN +2 STD. DEV -2 STD. DEV.

1995
Ra-226 IN GROUNDWATER

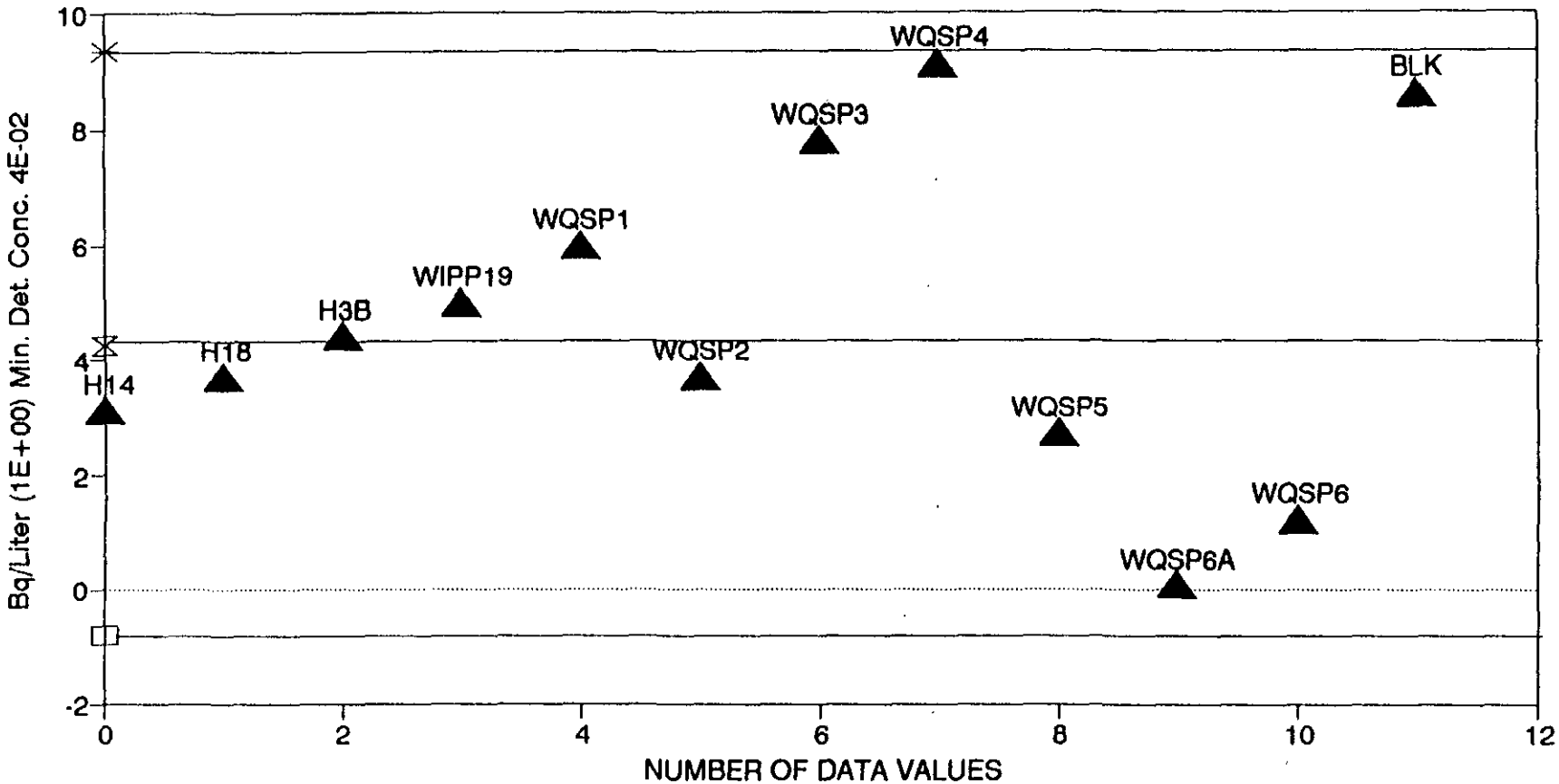

▲ ANALYTICAL VALUE ⧖ MEAN +2 STD. DEV. -2 STD. DEV.

1995
Ra-228 IN GROUNDWATER

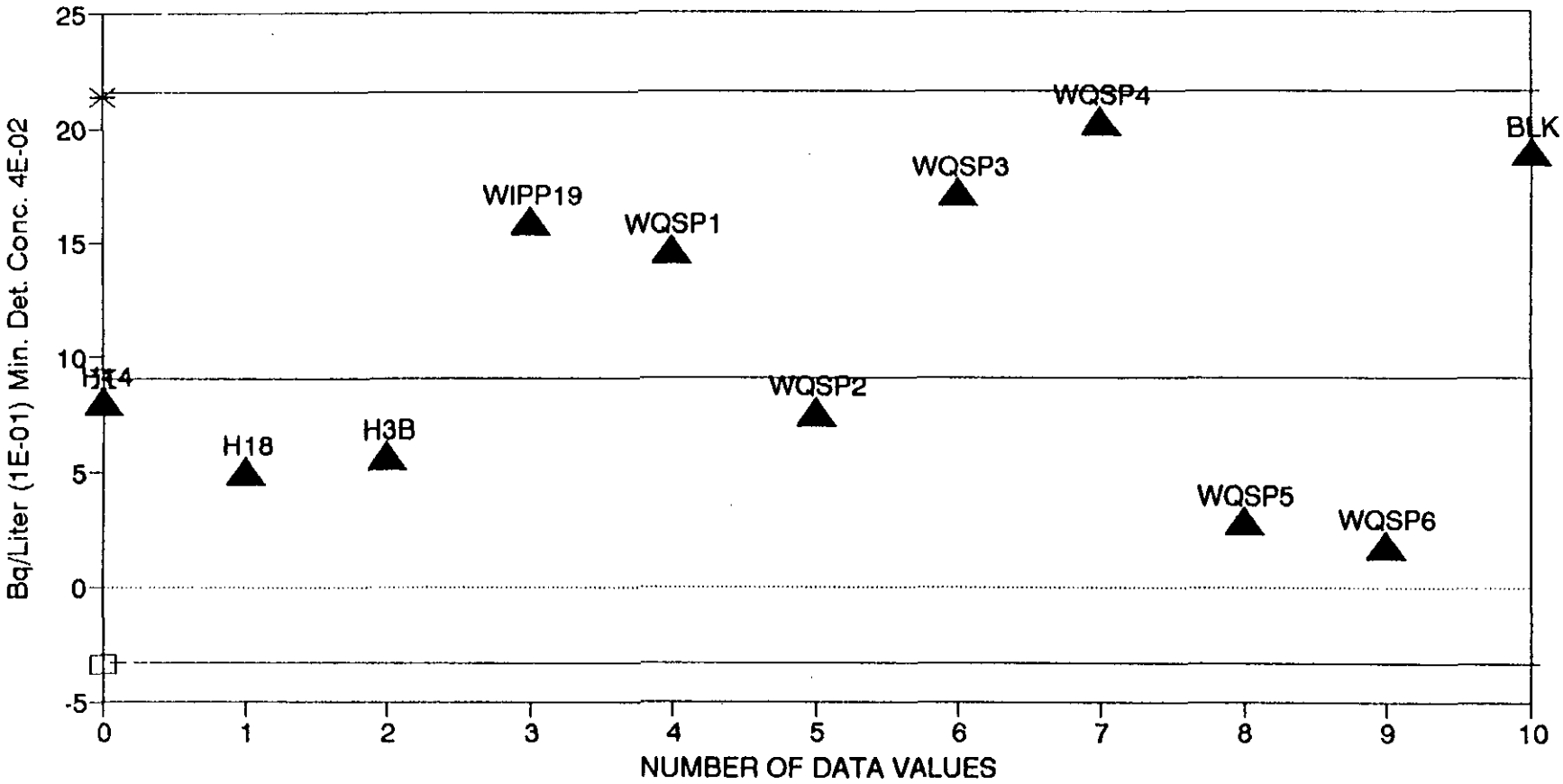

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995 WIPP
Th-228 IN GROUNDWATER

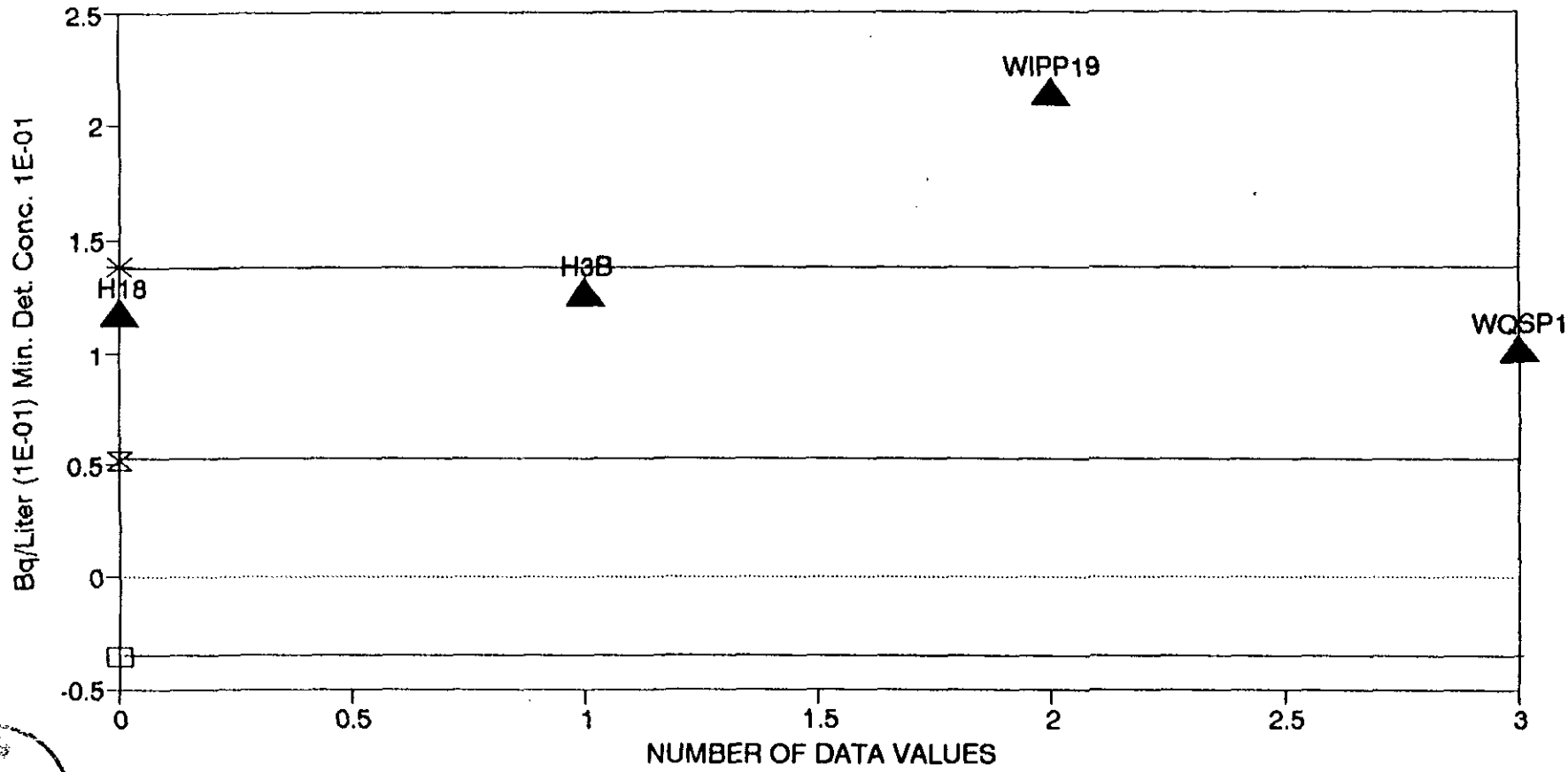

▲ ANALYTICAL VALUE ⧖ MEAN +2 STD. DEV. -2 STD. DEV.

1995
U-233/234 IN GROUNDWATER

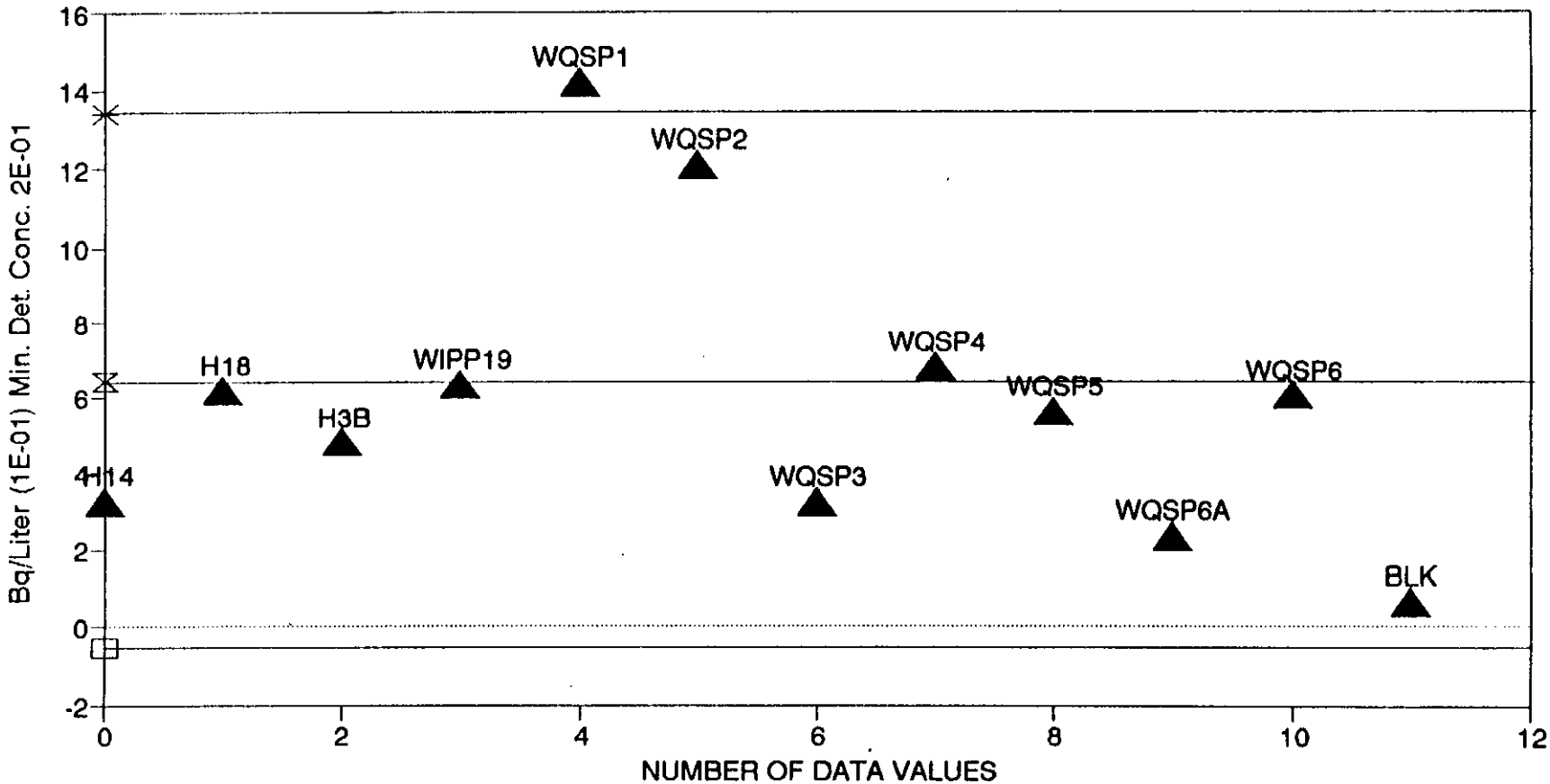

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

APPENDIX A6
RADIOLOGICAL ANALYSIS
BIOTICS

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BV-WE1 Biotic Vegetation WIPP East	Americium-241	7.16E-03	1.81E-03
	Cesium-137	2.90E-04	5.10E-04
	Cobalt-60	3.10E-04	5.60E-04
	Lead-210	2.20E-02	1.20E-02
	Plutonium-241	-9.96E-02	3.89E-02
	Plutonium-238	2.26E-04	4.42E-04
	Plutonium-239/240	-2.25E-04	3.12E-04
	Polonium-210	7.90E-03	2.57E-03
	Potassium-40	3.80E-01	4.70E-02
	Radium-228	7.70E-03	2.80E-03
	Radium-226	1.90E-02	1.60E-02
	Strontium-90	8.86E-04	2.86E-03
	Thorium-232	2.89E-03	1.19E-03
	Thorium-228	1.16E-02	2.26E-03
	Thorium-230	8.38E-03	1.86E-03
	Uranium-233/234	4.60E-03	1.77E-03
	Uranium-238	3.64E-03	1.54E-03
	Uranium-235/236	5.98E-04	5.86E-04
BV-SE1 Biotic Vegetation South East 1	Americium-241	5.08E-03	1.48E-03
	Cesium-137	-1.70E-04	7.60E-04
	Cobalt-60	4.30E-04	1.40E-03
	Lead-210	2.10E-02	2.00E-02
	Plutonium-241	-1.74E-01	3.89E-02
	Plutonium-238	2.31E-04	4.53E-04
	Plutonium-239/240	5.76E-04	8.15E-04
	Polonium-210	1.17E-02	2.69E-03
	Potassium-40	5.40E-01	6.70E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BV-SE1 Biotic Vegetation South East 1 (continued)	Radium-228	6.30E-03	2.90E-03
	Radium-226	3.10E-03	2.40E-02
	Strontium-90	3.45E-03	2.64E-03
	Thorium-230	7.53E-03	1.71E-03
	Thorium-228	1.20E-02	2.16E-03
	Thorium-232	3.85E-03	1.21E-03
	Uranium-233/234	5.04E-03	1.65E-03
	Uranium-238	4.74E-03	1.41E-03
	Uranium-235/236	3.74E-04	4.23E-04
BV-SE2 Biotic Vegetation South East 2	Americium-241	1.10E-02	2.29E-03
	Cesium-137	2.00E-04	6.10E-04
	Cobalt-60	2.20E-04	6.90E-04
	Lead-210	2.60E-02	1.70E-02
	Plutonium-241	-1.59E-01	3.34E-02
	Plutonium-238	-9.94E-05	5.15E-04
	Plutonium-239/240	0.00E+00	3.89E-04
	Polonium-210	5.21E-03	2.15E-03
	Potassium-40	4.00E-01	5.20E-02
	Radium-228	5.80E-05	2.30E-03
	Radium-226	7.90E-02	1.40E-02
	Strontium-90	9.71E-04	2.02E-03
	Thorium-230	1.04E-02	2.09E-03
	Thorium-228	3.03E-02	3.57E-03
	Thorium-232	5.69E-03	1.48E-03
	Uranium-233/234	5.05E-03	1.83E-03
	Uranium-238	4.94E-03	1.63E-03
	Uranium-235/236	1.45E-04	7.52E-04
BV-NW1 Biotic Vegetation North West 1	Americium-241	8.49E-03	1.87E-03
	Cesium-137	-3.80E-06	7.20E-04

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BV-NW1 Biotic Vegetation North West 1 (continued)	Cobalt-60	3.90E-05	7.60E-04
	Lead-210	4.60E-02	1.70E-02
	Plutonium-241	-1.49E-01	3.83E-02
	Plutonium-238	1.09E-04	3.69E-04
	Plutonium-239/240	-2.17E-04	4.25E-04
	Polonium-210	1.03E-02	2.54E-03
	Potassium-40	3.90E-01	5.00E-02
	Radium-228	3.10E-03	2.60E-03
	Radium-226	2.30E-02	2.10E-02
	Strontium-90	5.46E-03	2.65E-03
	Thorium-230	9.33E-03	2.10E-03
	Thorium-228	9.72E-03	2.43E-03
	Thorium-232	3.58E-03	1.56E-03
	Uranium-233/234	5.50E-03	1.63E-03
	Uranium-238	4.61E-03	1.42E-03
	Uranium-235/236	3.71E-04	4.19E-04
BV-NW2 Biotic Vegetation North West 2	Americium-241	6.82E-03	1.88E-03
	Cesium-137	-3.70E-05	1.10E-03
	Cobalt-60	-7.10E-04	1.20E-03
	Lead-210	2.20E-02	3.00E-02
	Plutonium-241	-7.12E-02	3.65E-02
	Plutonium-238	-5.30E-04	4.64E-04
	Plutonium-239/240	1.06E-04	4.64E-04
	Polonium-210	1.05E-02	2.85E-03
	Potassium-40	3.90E-01	5.70E-02
	Radium-228	5.40E-03	4.40E-03
	Radium-226	1.50E-01	2.60E-02
	Strontium-90	9.56E-04	2.55E-03
	Thorium-230	8.95E-03	2.01E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BV-NW2 Biotic Vegetation North West 2 (continued)	Thorium-228	1.75E-02	2.78E-03
	Thorium-232	2.58E-03	1.20E-03
	Uranium-233/234	7.25E-03	1.82E-03
	Uranium-238	3.99E-03	1.31E-03
BV-CT1 Biotic Vegetation Control 1	Uranium-235/236	1.01E-03	7.82E-04
	Americium-241	6.40E-03	1.93E-03
	Cesium-137	2.20E-04	6.60E-04
	Cobalt-60	-3.80E-04	7.70E-04
	Lead-210	2.80E-02	1.60E-02
	Plutonium-241	-1.84E-01	4.09E-02
	Plutonium-238	-5.88E-04	6.10E-04
	Plutonium-239/240	-1.17E-04	6.90E-04
	Polonium-210	1.83E-02	3.99E-03
	Potassium-40	5.90E-01	7.10E-02
	Radium-228	2.30E-03	3.10E-03
	Radium-226	6.60E-03	2.20E-02
	Strontium-90	4.85E-03	2.67E-03
	Thorium-230	1.04E-02	2.01E-03
	Thorium-228	6.68E-03	1.75E-03
	Thorium-232	3.35E-03	1.23E-03
	Uranium-233/234	8.97E-03	3.08E-03
	Uranium-238	9.63E-03	3.05E-03
	Uranium-235/236	1.85E-03	1.55E-03
BV-CT2 Biotic Vegetation Control 2	Americium-241	2.04E-02	4.06E-03
	Cesium-137	-1.10E-05	7.80E-04
	Cobalt-60	-1.80E-04	9.20E-04
	Lead-210	2.10E-02	2.10E-02
	Plutonium-241	-1.45E-01	3.17E-02
	Plutonium-238	0.00E+00	2.69E-04

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BV-CT2 Biotic Vegetation Control 2 (continued)	Plutonium-239/240	1.94E-04	3.81E-04
	Polonium-210	8.60E-03	2.01E-03
	Potassium-40	4.90E-01	6.50E-02
	Radium-228	2.60E-03	3.10E-03
	Radium-226	8.40E-03	2.60E-02
	Strontium-90	3.56E-03	2.94E-03
	Thorium-230	1.15E-02	2.47E-03
	Thorium-228	2.20E-03	1.75E-03
	Thorium-232	-1.43E-03	1.63E-03
	Uranium-233/234	5.65E-03	1.77E-03
	Uranium-238	3.20E-03	1.32E-03
	Uranium-235/236	6.07E-04	5.95E-04
BR-NAR Biotic Rabbit North Access 12081.1	Americium-241	5.15E-05	1.75E-04
	Cesium-137	1.50E-04	3.90E-04
	Cobalt-60	1.00E-04	3.60E-04
	Lead-210	2.50E-02	4.80E-03
	Plutonium-241	-1.77E-02	8.36E-03
	Plutonium-238	1.00E-04	1.41E-04
	Plutonium-239/240	1.60E-04	1.36E-04
	Polonium-210	3.10E-03	4.75E-03
	Potassium-40	1.10E-01	2.90E-02
	Radium-228	1.60E-03	1.50E-03
	Radium-226	1.40E-03	6.80E-03
	Strontium-90	3.90E-03	4.40E-03
	Thorium-230	5.31E-04	2.41E-04
	Thorium-228	1.03E-04	1.35E-04
	Thorium-232	-1.90E-05	8.30E-05
	Uranium-233/234	2.44E-04	1.77E-04
	Uranium-238	1.13E-04	1.04E-04

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BR-NAR Biotic Rabbit North Access 12081.1 (continued)	Uranium-235/236	4.65E-05	1.12E-04
BR-NAR Biotic Rabbit North Access 11141.1	Americium-241	2.57E-04	1.30E-04
	Cesium-137	7.60E-05	3.80E-04
	Cobalt-60	-5.00E-04	3.30E-04
	Lead-210	6.20E-03	2.50E-02
	Plutonium-241	-2.46E-02	6.93E-03
	Plutonium-238	1.72E-05	3.37E-05
	Plutonium-239/240	1.72E-05	7.52E-05
	Polonium-210	2.50E-03	2.29E-03
	Potassium-40	9.60E-02	2.90E-02
	Radium-228	2.00E-03	1.30E-03
	Radium-226	5.60E-02	1.60E-02
	Strontium-90	5.30E-03	4.20E-03
	Thorium-230	5.52E-04	2.12E-04
	Thorium-228	1.95E-05	8.51E-05
	Thorium-232	5.33E-05	7.79E-05
	Uranium-233/234	3.19E-04	2.06E-04
	Uranium-238	-7.98-05	1.11E-04
	Uranium-235/236	1.23E-04	1.28E-04
BR-LWA Biotic Rabbit Land Withdrawl Area 12121.2	Americium-241	1.92E-04	1.51E-04
	Cesium-137	-5.60E-04	1.40E-03
	Cobalt-60	-1.30e-04	1.20E-03
	Lead-210	1.50E-01	2.30E-02
	Plutonium-241	-2.74E-02	8.30E-03
	Plutonium-238	-2.19E-04	1.61E-04
	Plutonium-239/240	0.00E+00	9.52E-05
	Polonium-210	3.97E-03	2.87E-03

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BR-LWA Biotic Rabbit Land Withdrawl Area 12121.2 (continued)	Potassium-40	1.20E-01	4.10E-02
	Radium-228	2.80E-03	4.80E-03
	Radium-226	1.20E-01	3.80E-02
	Strontium-90	3.60E-04	3.60E-03
	Thorium-230	1.11E-03	2.90E-04
	Thorium-228	2.11E-05	2.20E-04
	Thorium-232	-3.79E-05	1.98E-04
	Uranium-233/234	4.36E-04	2.06E-04
	Uranium-238	-5.96E-05	1.17E-04
	Uranium-235/236	-7.35E-05	8.32E-05
BR-LWA Biotic Rabbit Land Withdrawl Area 12122.2	Americium-241	3.41E-04	1.77E-04
	Cesium-137	3.60E-04	5.60E-04
	Cobalt-60	4.30E-04	4.60E-04
	Lead-210	5.30E-02	8.70E-03
	Plutonium-241	-4.18E-02	7.51E-03
	Plutonium-238	3.73E-05	1.16E-04
	Plutonium-239/240	1.12E-04	1.03E-04
	Polonium-210	4.98E-03	3.82E-03
	Potassium-40	1.20E-01	3.70E-02
	Radium-228	1.30E-03	3.70E-03
	Radium-226	9.60E-03	1.30E-02
	Stronnum-90	6.10E-03	4.10E-03
	Thorium-230	1.20E-03	3.26E-04
	Thorium-228	1.51E-04	1.74E-04
	Thorium-232	-1.98E-05	1.16E-04
	Uranium-233/234	2.85E-04	2.14E-04
	Uranium-238	5.72E-05	1.12E-04
	Uranium-235/236	7.06E-05	1.22E-04

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BF-PEC Biotic Fish Pecos River	Americium-241	6.90E-05	8.29E-05
	Cesium-137	9.20E-05	4.20E-04
	Cobalt-60	1.30E-04	4.10E-04
	Lead-210	2.90E-02	5.10E-03
	Plutonium-241	-2.32E-02	3.31E-03
	Plutonium-238	1.97E-05	4.74E-05
	Plutonium-239/240	0.00E+00	3.86E-05
	Polonium-210	1.72E-03	9.37E-04
	Potassium-40	1.10E-01	3.30E-02
	Radium-228	1.40E-03	1.50E-03
	Radium-226	3.80E-03	8.00E-03
	Strontium-90	-1.72E-03	2.27E-03
	Thorium-230	7.37E-04	1.73E-04
	Thorium-228	2.20E-05	4.32E-05
	Thorium-232	-2.04E-05	2.83E-05
	Uranium-233/234	3.63E-04	1.30E-04
	Uranium-238	1.59E-04	9.50E-05
	Uranium-235/236	1.15E-05	6.76E-05
BF-BRA Biotic Fish Brantley Lake	Americium-241	0.00E+00	4.67E-05
	Cesium-137	-3.40E-04	4.30E-04
	Cobalt-60	7.90E-04	4.10E-04
	Lead-210	3.80E-02	6.30E-03
	Plutonium-241	-2.03E-02	3.15E-03
	Plutonium-238	0.00E+00	5.46E-05
	Plutonium-239/240	-9.84E-06	4.31E-05
	Polonium-210	5.34E-03	1.69E-03
	Potassium-40	8.80E-02	1.80E-02
	Radium-228	3.40E-04	2.90E-03
	Radium-226	8.80E-03	1.00E-02

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULT/UNIT Bq/g	COUNTING ERROR
BF-BRA Biotic Fish Brantley Lake (continued)	Strontium-90	1.19E-03	2.41E-03
	Thorium-230	7.31E-04	1.70E-04
	Thorium-228	-4.19E-05	5.81E-05
	Thorium-232	2.92E-05	4.26E-05
	Uranium-234	8.04E-04	1.80E-04
	Uranium-238	9.33E-04	1.92E-04
	Uranium-235/236	6.06E-05	6.28E-05

1995
Am-241 IN VEGETATION

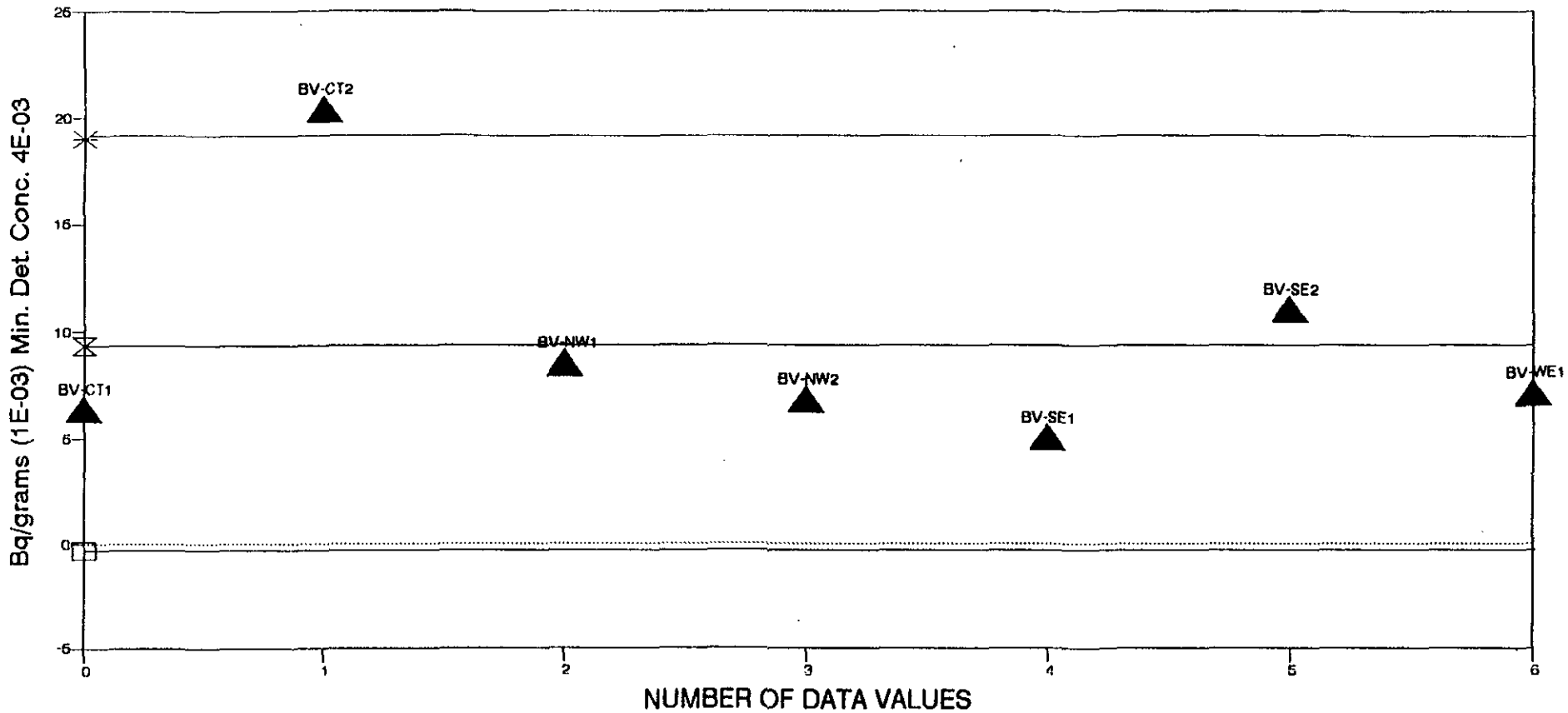

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
K-40 IN RABBIT

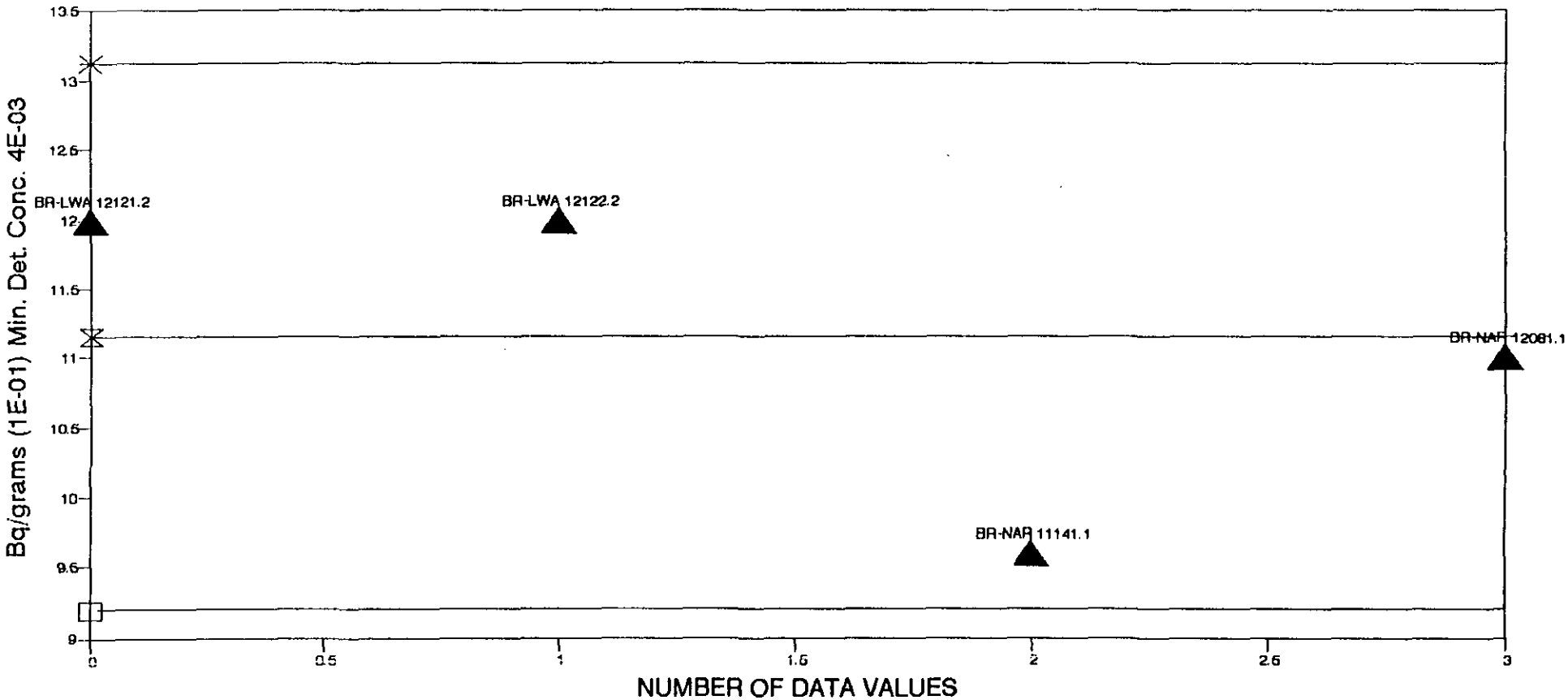

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

1995
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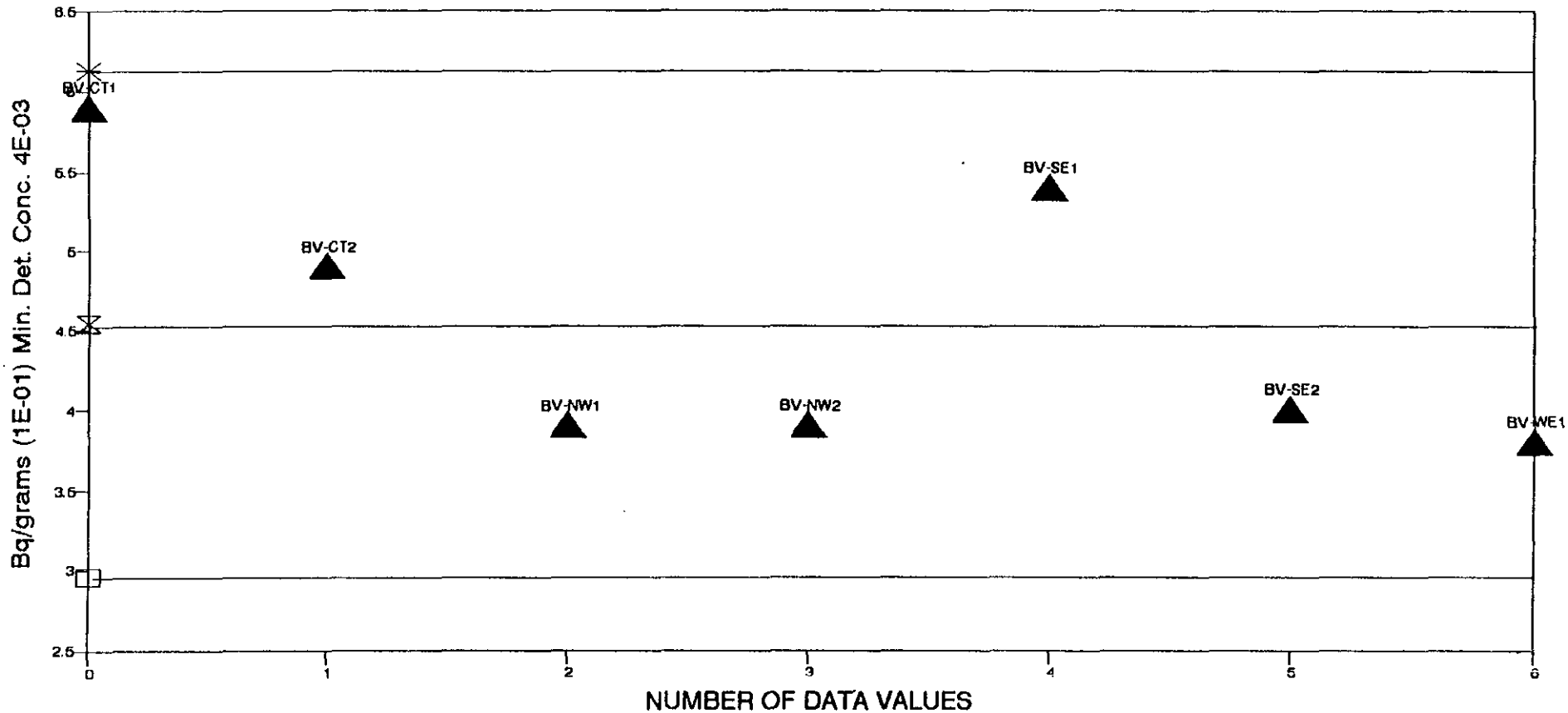

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1995

Ra-226 IN VEGETATION

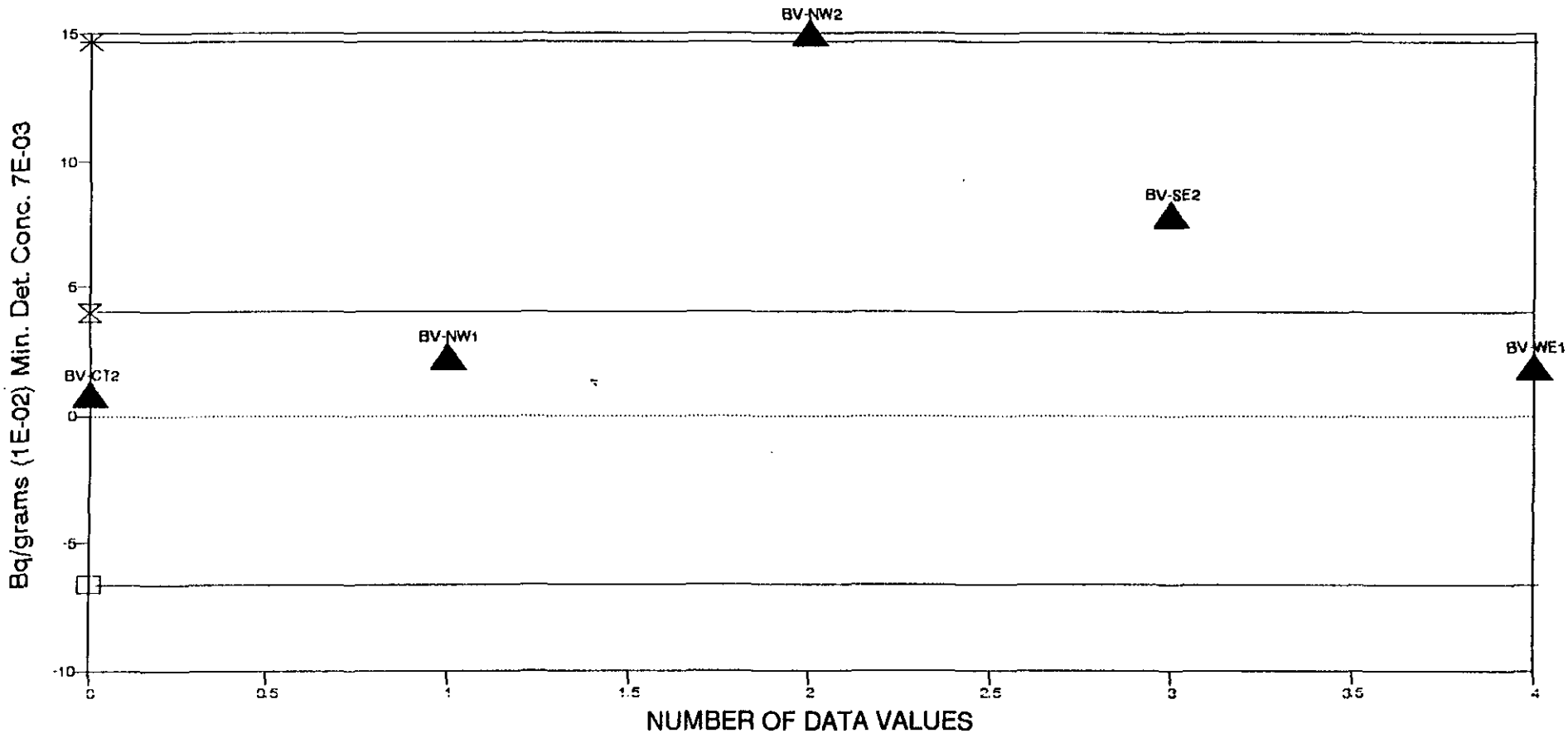

▲ ANALYTICAL VALUE ⧖ MEAN +2 STD. DEV. -2 STD. DEV.

1995
Th-228 IN VEGETATION

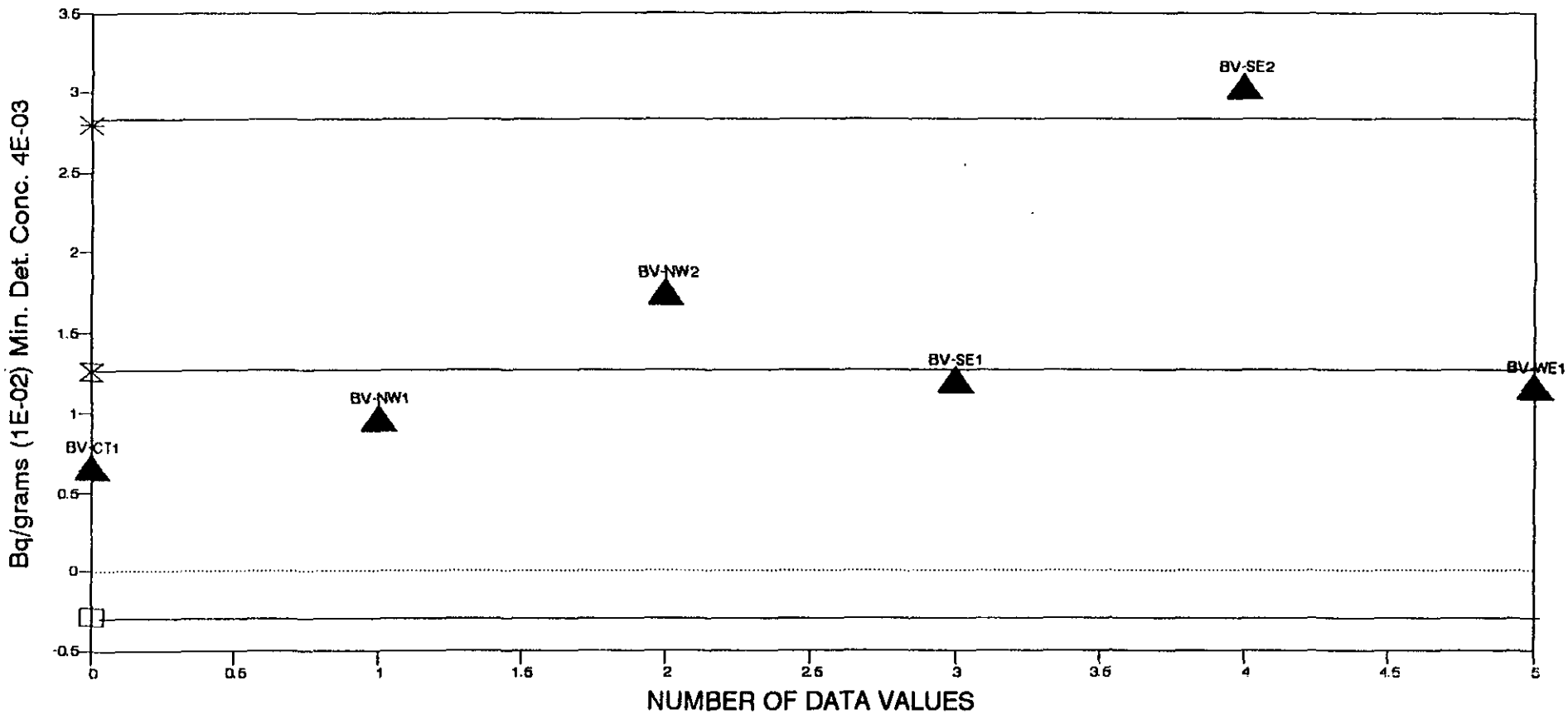

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

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Th-230 IN VEGETATION

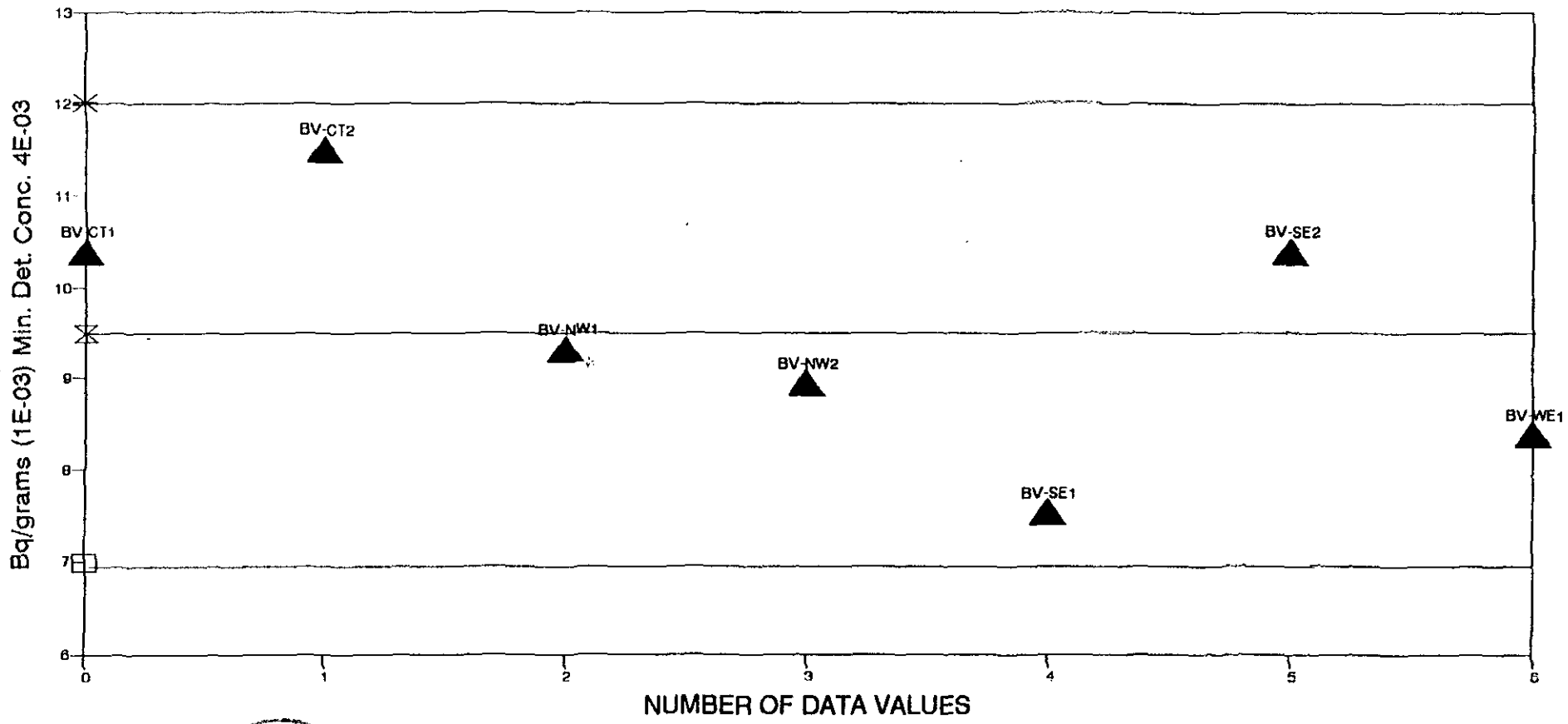

▲ ANALYTICAL VALUE ⧖ MEAN +2 STD. DEV. -2 STD. DEV.

1995
U-233/234 IN VEGETATION

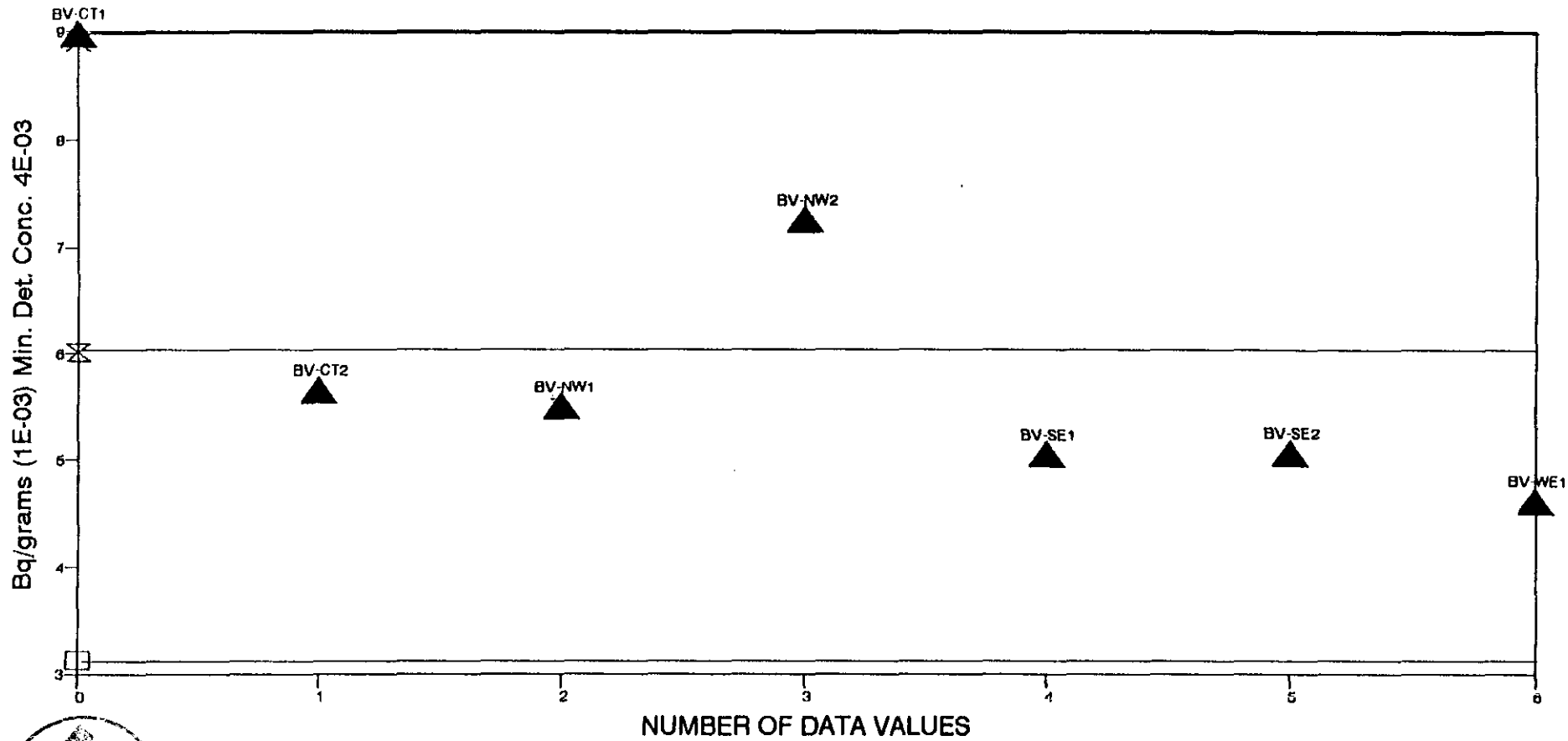

▲ ANALYTICAL VALUE ⧖ MEAN ✳ +2 STD. DEV. ⊟ -2 STD. DEV.

APPENDIX B1
DP-831
LIQUID EFFLUENT ANALYSIS

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
HE-COM DP-831 1st quarter Sewage Samples	Radium 226	< 0.3	pCi/L
	Radium 228	< 2	pCi/L
	Nitrate/Nitrite	1.0	mg/L
	Nitrogen/Kjeldahl	76	mg/L
	Total Dissolved Solids	1600	mg/L
	Total Dissolved Solids	16000	mg/L
	Total Dissolved Solids	15000	mg/L
HE-COM DP-831 2nd quarter Sewage Samples	Radium 226	< 0.6	pCi/L
	Radium 228	2.7+/-1.0	pCi/L
	Nitrate/Nitrite	0.2	mg/L
	Nitrogen/Kjeldahl	46	mg/L
	Total Dissolved Solids	1700	mg/L
	Total Dissolved Solids	12000	mg/L
	Total Dissolved Solids	12000	mg/L
HE-COM DP-831 3rd quarter Sewage Samples	Radium 226	4.0+/-0.6	pCi/L
	Radium 228	< 2	pCi/L
	Nitrate/Nitrite	< 0.1	mg/L
	Nitrogen/Kjeldahl	48	mg/L
	Total Dissolved Solids	30000	mg/L
	Total Dissolved Solids	31000	mg/L
	Total Dissolved Solids	5500	mg/L
HE-COM DP-831 4th quarter Sewage Samples	Radium 226	< 0.6	pCi/L
	Radium 228	1.1+/-0.6	pCi/L
	Nitrate/Nitrite	0.1	mg/L
	Nitrogen/Kjeldahl	71	mg/L
	Total Dissolved Solids	2400	mg/L
	Total Dissolved Solids	16000	mg/L
	Total Dissolved Solids	15000	mg/L

APPENDIX B2
NONRADIOLOGICAL SOIL ANALYSIS

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-NW1 Terrestrial Surface Non-Radiological North West 1	Saturation Percent	27	%
	Conductivity	.19	mmhos/cm
	Chloride	8	mg/kg
	pH	8.5	pH
	Calcium, total	58	mg/kg
	Potassium, total	26	mg/kg
	Magnesium, total	6	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.10	SAR
	Saturation Percent	30	%
	Conductivity	.22	mmhos/cm
	Chloride	24	mg/kg Dry
	pH	8.2	pH
	Calcium, total	60	mg/kg
	Potassium, total	32	mg/kg
	Magnesium, total	7	mg/kg
	Sodium, total	9	mg/kg
	Sodium Absorption Ratio	.29	SAR
	Saturation Percent	27	%
	Conductivity	.13	mmhos/cm
	Chloride	28	mg/kg Dry
	pH	8.0	pH
	Calcium, total	32	mg/kg
	Potassium, total	14	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.13	SAR
	Saturation Percent	29	%
	Conductivity	.15	mmhos/cm

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-NW1 Terrestrial Surface Non-Radiological North West 1 (continued)	Chloride	20	mg/kg Dry
	pH	7.7	pH
	Calcium, total	37	mg/kg
	Potassium, total	27	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	4	mg/kg
	Sodium Absorption Ratio	.17	SAR
	Saturation Percent	15	%
	Conductivity	.1	mmhos/cm
	Chloride	11	mg/kg Dry
	pH	8.2	pH
	Calcium, total	23	mg/kg
	Potassium, total	12	mg/kg
	Magnesium, total	3	mg/kg
	Sodium, total	7	mg/kg
	Sodium Absorption Ratio	.36	SAR
	Saturation Percent	28	%
	Conductivity	.15	mmhos/cm
	Chloride	6	mg/kg Dry
	pH	8.8	pH
	Calcium, total	36	mg/kg
	Potassium, total	22	mg/kg
	Magnesium, total	9	mg/kg
	Sodium, total	4	mg/kg
	Sodium Absorption Ratio	.15	SAR
TS-NW2 Terrestrial Surface Non-Radiological North West 2	Saturation Percent	32	%
	Conductivity	.10	mmhos/cm
	Chloride	8	mg/kg Dry
	pH	7.0	pH
	Calcium, total	21	mg/kg

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-NW2 Terrestrial Surface Non-Radiological North West 2 (continued)	Potassium, total	18	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.16	SAR
	Saturation Percent	33	%
	Conductivity	.12	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	6.9	pH
	Calcium, total	25	mg/kg
	Potassium, total	25	mg/kg
	Magnesium, total	5	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.14	SAR
	Saturation Percent	34	%
	Conductivity	.09	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	6.6	pH
	Calcium, total	21	mg/kg
	Potassium, total	16	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.16	SAR
	Saturation Percent	30	%
	Conductivity	.07	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	6.8	pH
	Calcium, total	16	mg/kg
	Potassium, total	14	mg/kg
	Magnesium, total	3	mg/kg
	Sodium, total	2	mg/kg

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-NW2 Terrestrial Surface Non-Radiological North West 2 (continued)	Sodium Absorption Ratio	.12	SAR
	Saturation Percent	30	%
	Conductivity	.11	mmhos/cm
	Chloride	6	mg/kg Dry
	pH	7.1	pH
	Calcium, total	24	mg/kg
	Potassium, total	20	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.15	SAR
	Saturation Percent	30	%
	Conductivity	.06	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.0	pH
	Calcium, total	11	mg/kg
	Potassium, total	11	mg/kg
	Magnesium, total	2	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.15	SAR
TS-SE1 Terrestrial Surface Non-Radiological South East 1	Saturation Percent	27	%
	Conductivity	.14	mmhos/cm
	Chloride	10	mg/kg Dry
	pH	8.1	pH
	Calcium, total	42	mg/kg
	Potassium, total	13	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.12	SAR
	Saturation Percent	30	%
	Conductivity	.13	mmhos/cm

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-SE1 Terrestrial Surface Non-Radiological South East 1 (continued)	Chloride	6	mg/kg Dry
	pH	7.3	pH
	Calcium, total	31	mg/kg
	Potassium, total	16	mg/kg
	Magnesium, total	5	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.13	SAR
	Saturation Percent	27	%
	Conductivity	.10	mmhos/cm
	Chloride	<6	mg/kg Dry
	pH	7.7	pH
	Calcium, total	27	mg/kg
	Potassium, total	12	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.14	SAR
	Saturation Percent	31	%
	Conductivity	.17	mmhos/cm
	Chloride	6	mg/kg Dry
	pH	8	pH
	Calcium, total	58	mg/kg
	Potassium, total	23	mg/kg
	Magnesium, total	6	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.10	SAR
	Saturation Percent	29	%
	Conductivity	.10	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.5	pH
	Calcium, total	24	mg/kg

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-SE1 Terrestrial Surface Non-Radiological South East 1 (continued)	Potassium, total	13	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.10	SAR
	Saturation Percent	30	%
	Conductivity	.11	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.5	pH
	Calcium, total	30	mg/kg
	Potassium, total	13	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	4	mg/kg
	Sodium Absorption Ratio	.18	SAR
TS-SE2 Terrestrial Surface Non-Radiological South East 2	Saturation Percent	29	%
	Conductivity	.09	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	6.9	pH
	Calcium, total	21	mg/kg
	Potassium, total	15	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.10	SAR
	Saturation Percent	31	%
	Conductivity	.11	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	6.9	pH
	Calcium, total	28	mg/kg
	Potassium, total	14	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	2	mg/kg

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-SE2 *Terrestrial Surface* Non-Radiological South East 2 (continued)	Sodium Absorption Ratio	.09	SAR
	Saturation Percent	27	%
	Conductivity	.06	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.3	pH
	Calcium, total	16	mg/kg
	Potassium, total	7	mg/kg
	Magnesium, total	2	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.12	SAR
	Saturation Percent	31	%
	Conductivity	.10	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.0	pH
	Calcium, total	24	mg/kg
	Potassium, total	21	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.09	SAR
	Saturation Percent	28	%
	Conductivity	.09	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.0	pH
	Calcium, total	21	mg/kg
	Potassium, total	12	mg/kg
	Magnesium, total	3	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.11	SAR
	Saturation Percent	27	%
	Conductivity	.07	mmhos/cm

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-SE2 Terrestrial Surface Non-Radiological South East 2 (continued)	Chloride	< 6	mg/kg Dry
	pH	6.8	pH
	Calcium, total	16	mg/kg
	Potassium, total	11	mg/kg
	Magnesium, total	3	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.12	SAR
TS-CT1 Terrestrial Surface Non-Radiological Control 1	Saturation Percent	27	%
	Conductivity	.06	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	6.9	pH
	Calcium, total	11	mg/kg
	Potassium, total	13	mg/kg
	Magnesium, total	2	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.15	SAR
	Saturation Percent	33	%
	Conductivity	.11	mmhos/cm
	Chloride	7	mg/kg Dry
	pH	6.7	pH
	Calcium, total	25	mg/kg
	Potassium, total	13	mg/kg
	Magnesium, total	5	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.10	SAR
	Saturation Percent	31	%
	Conductivity	.12	mmhos/cm
	Chloride	12	mg/kg Dry
	pH	6.9	pH
	Calcium, total	16	mg/kg

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-CT1 Terrestrial Surface Non-Radiological Control 1 (continued)	Potassium, total	8	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.12	SAR
	Saturation Percent	32	%
	Conductivity	.08	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	6.6	pH
	Calcium, total	15	mg/kg
	Potassium, total	19	mg/kg
	Magnesium, total	3	mg/kg
	Sodium, total	1	mg/kg
	Sodium Absorption Ratio	.62	SAR
	Saturation Percent	32	%
	Conductivity	.10	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	6.3	pH
	Calcium, total	21	mg/kg
	Potassium, total	36	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.10	SAR
	Saturation Percent	29	%
	Conductivity	.06	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7	pH
	Calcium, total	13	mg/kg
	Potassium, total	23	mg/kg
	Magnesium, total	2	mg/kg
	Sodium, total	2	mg/kg

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-CT1 Terrestrial Surface Non-Radiological Control 1 (continued)	Sodium Absorption Ratio	.14	SAR
TS-CT2 Terrestrial Surface Non-Radiological Control 2	Saturation Percent	25	%
	Conductivity	.07	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.9	pH
	Calcium, total	18	mg/kg
	Potassium, total	6	mg/kg
	Magnesium, total	3	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.11	SAR
	Saturation Percent	32	%
	Conductivity	.19	mmhos/cm
	Chloride	9	mg/kg Dry
	pH	7.1	pH
	Calcium, total	52	mg/kg
	Potassium, total	24	mg/kg
	Magnesium, total	10	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.10	SAR
	Saturation Percent	29	%
	Conductivity	.12	mmhos/cm
	Chloride	9	mg/kg Dry
	pH	7.0	pH
	Calcium, total	32	mg/kg
	Potassium, total	17	mg/kg
	Magnesium, total	6	mg/kg
	Sodium, total	3	mg/kg

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-CT2 Terrestrial Surface Non-Radiological Control 2 (continued)	Sodium Absorption Ratio	.13	SAR
	Saturation Percent	25	%
	Conductivity	.09	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.5	pH
	Calcium, total	23	mg/kg
	Potassium, total	8	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.10	SAR
	Saturation Percent	17	%
	Conductivity	.13	mmhos/cm
	Chloride	7	mg/kg Dry
	pH	7.2	pH
	Calcium, total	30	mg/kg
	Potassium, total	24	mg/kg
	Magnesium, total	6	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.09	SAR
	Saturation Percent	32	%
	Conductivity	.11	mmhos/cm
	Chloride	13	mg/kg Dry
	pH	7.2	pH
	Calcium, total	30	mg/kg
	Potassium, total	13	mg/kg
	Magnesium, total	5	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.09	SAR

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-WE1 Terrestrial Surface Non-Radiological WIPP East 1	Saturation Percent	27	%
	Conductivity	.10	mmhos/cm
	Chloride	9	mg/kg Dry
	pH	7.4	pH
	Calcium, total	28	mg/kg
	Potassium, total	10	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	4	mg/kg
	Sodium Absorption Ratio	.19	SAR
	Saturation Percent	27	%
	Conductivity	.09	mmhos/cm
	Chloride	7	mg/kg Dry
	pH	7.8	pH
	Calcium, total	23	mg/kg
	Potassium, total	9	mg/kg
	Magnesium, total	3	mg/kg
	Sodium, total	4	mg/kg
	Sodium Absorption Ratio	.21	SAR
	Saturation Percent	29	%
	Conductivity	.12	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.6	pH
	Calcium, total	32	mg/kg
	Potassium, total	12	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	2	mg/kg
	Sodium Absorption Ratio	.09	SAR
	Saturation Percent	33	%
	Conductivity	.10	mmhos/cm
	Chloride	< 6	mg/kg Dry

SAMPLE ANALYSIS BY LOCATION	PARAMETER	RESULTS	UNIT
TS-WE1 Terrestrial Surface Non-Radiological WIPP East 1 (continued)	pH	8.0	pH
	Calcium, total	30	mg/kg
	Potassium, total	9	mg/kg
	Magnesium, total	3	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.14	SAR
	Saturation Percent	29	%
	Conductivity	.15	mmhos/cm
	Chloride	6	mg/kg Dry
	pH	7.9	pH
	Calcium, total	44	mg/kg
	Potassium, total	15	mg/kg
	Magnesium, total	5	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.11	SAR
	Saturation Percent	25	%
	Conductivity	.09	mmhos/cm
	Chloride	< 6	mg/kg Dry
	pH	7.8	pH
	Calcium, total	22	mg/kg
	Potassium, total	10	mg/kg
	Magnesium, total	4	mg/kg
	Sodium, total	3	mg/kg
	Sodium Absorption Ratio	.15	SAR

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix SMP

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Subsidence Monitoring Plan

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ACRONYMS

DOE	Department of Energy
GPS	Global Positioning System
NGS	National Geodetic Survey
QA	Quality Assurance
WID	Waste Isolation Division
WIPP	Waste Isolation Pilot Plant

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APPENDIX SMP

SMP.1 Introduction

Subsidence monitoring was chosen by the Department of Energy (DOE) as the basic long-term monitoring tool. Subsidence monitoring is a non-intrusive technique that can related to numerical predictions as a means of detecting substantial and detrimental deviations from expected repository performance by allowing a comparison of actual subsidence to that calculated numerically. Subsidence monitoring meets the regulatory requirements for long-term monitoring as stated in 40 CFR Part 191 (EPA 1993) as follows:

- It can be implemented without dependence on site utilities.
- It can provide useful data at reasonable cost over a long time period.
- It requires minimum maintenance.

This plan provides the following information with respect to subsidence monitoring:

- Subsidence Theory and Measurement
- Subsidence Baseline
- Monitoring Activities
- Equipment
- Quality Assurance

SMP.2 Subsidence Theory and Measurement

Subsidence is defined as vertical movement of the land surface anywhere in the subsidence basin. Subsidence monitoring is defined as the measurement of relative vertical movement of the land surface. This movement can be up (uplift) or down (subsidence) and is relative to an assumed fixed reference. This reference is assumed fixed, even though it may be subject to the same factors that cause the surface movement and may also be moving. The techniques used to monitor subsidence measure the vertical height difference between an array of markers on the surface and is typically done with a leveling survey. Usually, one reference benchmark (ideally outside the potential subsidence basin) is used as the standard and the relative movement of other stations or benchmarks are measured to detect vertical movement over time.

The error in subsidence measurements is determined by the equipment and distances between the stations. A first-order survey has an error of one part in 100,000 and a second-order

survey has an error of one part in 20,000. With current technology, several thousandths of an inch vertical movement can be measured to this precision.

Subsidence can be caused by a variety of factors. Mining, hydrocarbon extraction, water injection and extraction, geological deformation, and dissolution are potential factors that may cause subsidence in the Waste Isolation Pilot Plant (WIPP) vicinity. Major subsidence features in the vicinity of the WIPP include Nash Draw, caused by dissolution of evaporites in the upper Salado and lower Rustler and localized mine-induced subsidence associated with areas in the potash mines in the vicinity of the WIPP where pillars have been removed as a portion of the mine is abandoned (second-mined areas).

Several documents related to subsidence in the vicinity of the WIPP have been completed. Several documents describing particular aspects of the WIPP include estimates of subsidence related directly to the excavations of the repository. These include the following:

1. *Final Environmental Impact Statement (FEIS), Waste Isolation Pilot Plant,* DOE/EIS-0026, DOE, 1980, (DOE 1980).

2. *Final Safety Analysis Report (FSAR), Waste Isolation Pilot Plant,* WP 02-09, WEC, 1990, (DOE 1990).

3. *Preliminary Comparison with 40 CFR §191, Part B for the Waste Isolation Pilot Plant, December 1991,* SAND91-0893, "Vol 1, Methodology and Results," SNL, 1991, (WIPP PA Division 1991).

4. *Backfill Engineering Analysis Report (BEAR),* (WEC 1994).

Those reports evaluate the potential for, and predict subsidence caused by the mining of the WIPP repository's shafts, drifts, and waste disposal rooms. These calculations account for a range of emplaced waste volumes, waste densities, and backfill types. Subsidence was also calculated for conditions where no backfill would be used. The calculated results from these reports are summarized in Table SMP-1.

The studies listed above predict the maximum subsidence expected. These studies were not specifically performed to estimate subsidence for long-term repository performance monitoring and do not account for other factors that may influence subsidence such as local hydrocarbon extraction and local potash mining.

The *Backfill Engineering Analysis Report (BEAR)* (WEC 1994) contains the most recent and detailed analysis of subsidence. Contour maps are included in this report that detail subsidence predictions using influence function and National Coal Board method for scenarios with and without backfill. The maximum subsidence was also calculated using the mass conservation method.

Table SMP-1. Maximum Subsidence Predictions for the WIPP Site

CONDITION/AREA	PREDICTED SUBSIDENCE
FEIS	
70-percent backfill density	1-foot (0.3-meter) subsidence
50-percent backfill density	1.6-foot (0.5-meter) subsidence
No backfill	3.28-foot (1.0-meter) subsidence
FSAR	
Shaft pillar area (backfill type and amount not specified)	1- to 1.2-foot (0.3- to 0.38-meter) subsidence
SNL	
35° angle	0.3-foot (0.09-meter) subsidence
25° angle	0.4-foot (0.13-meter) subsidence
BEAR	
No backfill	1.3- to 2-foot (0.40- to 0.60-meter) subsidence
Highly compacted backfill	1- to 1.7-foot (0.30- to 0.52-meter) subsidence

SMP.3 Subsidence Baseline

During the initial site selection process, 195 miles (314 kilometers) of first order, Class 1 leveling survey was performed by the National Geodetic Survey (NGS) in 1977. Later, new survey lines were established that connected the previous first-order benchmarks through Carlsbad, to second-order survey lines through Eunice and Hobbs. Benchmarks were placed over the Nash Draw from the north end to the Remuda Basin, over potash mines, the WIPP site, and the San Simon Sink (Powers 1993). Independent of the National Geodetic Survey benchmarks, an additional 52 benchmarks were installed over the WIPP site and surrounding area.

The National Geodetic Survey network was resurveyed in 1981 and the relative movement between Carlsbad and the WIPP site was measured to be about 0.8 inches (2 centimeters). Relative motion across the network was down to the east and up to the west (Powers 1993).

The relationships between subsidence and potash mining in the WIPP vicinity are discussed in Powers (1993). From data in this report, potash mining was shown to have caused significant subsidence at mines close to the WIPP. Two benchmarks over the Mississippi Chemical

Corporation mine measured relative to Carlsbad show 10- and 40-inch (25.4- and 102.7-centimeter) movement downward from 1977 to 1981. Powers (1993) also discusses mining effects on surface subsidence at other mines and correlated a relationship between mining and the surface area effects. This work allows the possible effects of potash mining to be taken into account when evaluating WIPP-induced subsidence. Powers (1993) also includes an assessment of the effects resulting from the production of brine from WIPP 12.

SMP.4 Monitoring Activities

The WIPP Subsidence Monitoring Program is performed annually and then allows for a comparison of the data, development of a database, and analysis of subsidence characteristics at the WIPP Site. The program includes surface subsidence monitoring involving twenty (20) miles of leveling loops through approximately fifty (50) monuments (S-Caps). Subsidence monitoring surveys include the Global Positioning Satellite (GPS) and surveys of the S-Caps. Figure SMP-1 identifies approximately 50 benchmarks (those designated "S" and "PT") distributed throughout the area of influence of the repository. The annual survey is completed so as to achieve closures better than the minimum standard of Second Order Class II for verticle control surveys. State-of-the-art digital leveling technology is employed for all subsidence surveys.

A National Geodetic Survey was performed in 1996, however the final report has not yet been published. The current plan is to resurvey about every 10 years. The last National Geoditic Survey was performed in 1981.

Subsidence data are currently being compiled into a database that will be evaluated as part of this monitoring plan and will include a comparison with subsidence predictions such as those in the BEAR (WEC 1994). The subsidence monitoring study will also investigate factors that influence subsidence to the extent that these factors are identified in the failure scenarios considered in the performance assessment. The goal of the study is to document the most reliable subsidence predictions for the repository and to define the bounding limits of measurement that will indicate poor repository performance.

Additional benchmarks will be added, as necessary, to ensure adequate coverage of the subsidence basin.

SMP.5 Instrumentation

State-of-the-art leveling equipment is specified for subsidence measurement. The following is a list of technical specifications for typical leveling equipment used for subsidence monitoring:

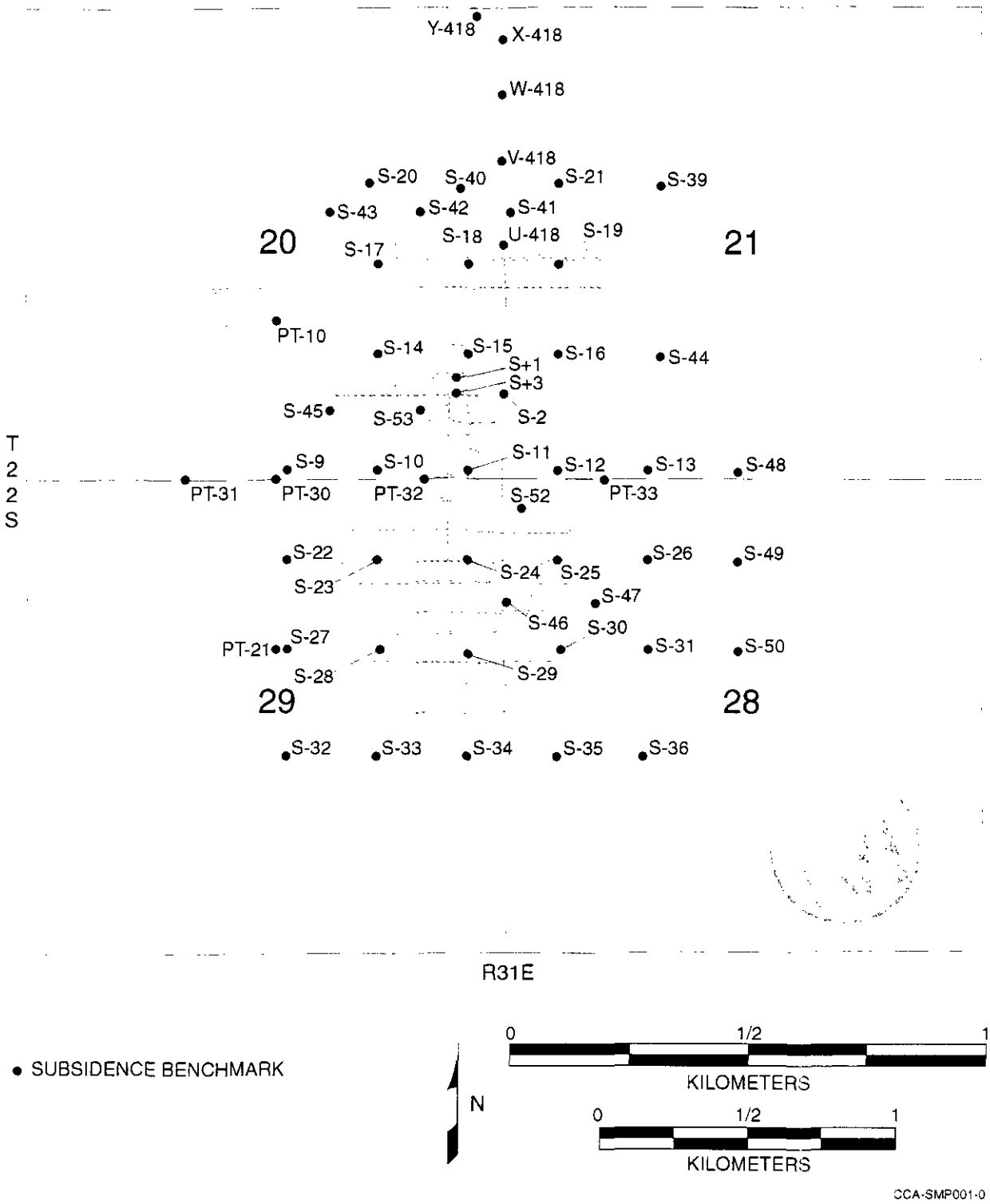

Figure SMP-1. Subsidence Monitoring Benchmarks

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Standard deviation	
(1kilometer double-run leveling)	
Electronically	1.5 millimeters
Optically	2.0 millimeters
Range	
Electronically	1.8 meters to 100 meters
Optically	0.6 meters upwards
Distance measurements	
Electronically	3 millimeters - 5 millimeters/10
Optically	0.2 meters - 0.5 meters
Temperature range	
Measurement	-20°C to + 50°C
Storage	-40°C to + 70°C
Compensator	Pendulum compensator with electronic range check.
Working range	±12 feet
Setting accuracy	±0.8 inches
Sensitivity of circular bubble	8feet/2 millimeters
Horizontal circle	rotable
Diameter	108 millimeters
Units	400 gon or 360°
Graduation interval	1 gon or 1°
Estimate to	~ 0.2 interval

SMP.6 Quality Assurance

Subsidence surveying is performed by a qualified contractor under the supervision of the Waste Isolation Division (WID) Site Survey Group. Vendors who perform surveying work must meet the following minimum standards:

- Five years experience in surveying field
- Proficient in using the precision leveling equipment specified for the program
- Proficient in using related surveying software
- Proficient in using global positioning satellite equipment and software

Quality Assurance (QA) requirements for Procurement of outside vendors to perform quality affecting work are in Section 2.3 of the CAO Quality Assurance Program Document (QAPD) (see Appendix QAPD).

Maintenance and calibration of equipment used for monitoring is addressed in Section 2.4.3 of the CAO QAPD (see Appendix QAPD). For subsidence measurements, maintenance and calibration are performed by the equipment vendor in accordance with national standards. Equipment is only procured from, maintained by, and calibrated by vendors on the WIPP approved Qualified Supplier's List.

Operational tests to verify that leveling instruments are in calibration are performed daily when equipment is in use.

Data, plots, graphics, and reports generated as a result of the subsidence surveys are reviewed by cognizant technical engineering personnel to ensure their adequacy and accuracy in accordance with DOE and DOE/WIPP Quality Assurance/Review procedures.

REFERENCES

DOE (U.S. Department of Energy). 1980. *Final Environmental Impact Statement, Waste Isolation Pilot Plant.* DOE/EIS-0026. Vols. 1 and 2. Assistant Secretary for Defense Programs. Washington, D.C. WPO 38835, WPO 38838, WPO 38839.

DOE (U.S. Department of Energy). 1990. *Final Safety Analysis Report.* WP 02-9, Rev. 0, May 1990. Westinghouse Electric Corporation, Waste Isolation Pilot Plant, Carlsbad, NM.

EPA, 1993. 40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. *Federal Register,* Vol. 58, No. 242, p. 66398. December 20, 1993. Office of Radiation and Air, Washington, D.C.

Powers, D.W. 1993. *Background Report on Subsidence Studies for the Potash Mines and WIPP Site Area, Southeastern New Mexico,* in Sandia National Laboratories' Nuclear Waste Management Library, UN02678.

Westinghouse Electric Corporation (WEC). 1994. *Backfill Engineering Analysis Report, Waste Isolation Pilot Plant.* Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM. WPO 37909.

WIPP PA (Performance Assessment) Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B, for the Waste Isolation Pilot Plant, December 1991, Vol. 1, Methodology and Results.* SAND91-0893/1. Albuquerque, NM: Sandia National Laboratories.

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Appendix SOTERM

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Source Term

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ACRONYMS

BNL	Brookhaven National Laboratory
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
EDTA	ethylene diamine tetra-acetate
ERDA	U.S. Energy Research and Development Administration
HMW/FW	Harvie-Møller-Weare/Felmy and Weare
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
NIST	National Institute of Standards and Technology
SIT	Specific-ion Interaction Theory
SPC	Salado Primary Constituent
SWCF	Sandia National Laboratories WIPP Central File
TRU	transuranic
TWBIR	Transuranic Waste Baseline Inventory Report
WIPP	Waste Isolation Pilot Plant

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APPENDIX SOTERM

SOTERM.1 Introduction

The actinide source term at the Waste Isolation Pilot Plant (WIPP) represents the mobile concentration of select actinide elements in the WIPP repository. The source term is the sum of contributions from dissolved actinide species and mobile colloidal actinide species existing in the repository. The actinide source term establishes the mobile concentration of actinides that may move from the repository in brine. Release to the accessible environment in brine may follow a pathway up the sealed operational shafts, out through possible intrusion boreholes, and/or out laterally through Salado Formation interbeds. For a discussion of release scenarios and pathways, see Chapter 6.0 (Section 6.3). Quantification of the impact of these releases contributes directly to assessing compliance with Title 40 Code of Federal Regulations (CFR) Part 191. Direct release to the surface of actinides entrained as particulates with solid waste stemming from drilling, cuttings, and spallings, is not part of the actinide source term as described herein.

The actinide source term is limited to those radionuclides that may significantly impact the performance of the WIPP. Consequently, the actinide source term provides a quantification of mobile concentrations of thorium, uranium, neptunium, plutonium, americium, and curium. Other radionuclides, such as strontium, cesium, and radium, are not included in the actinide source term because of their relatively short half-lives or limited waste inventory (Appendix WCA, Sections WCA.3.2 and WCA.8.3).

Appendix SOTERM (SOurce TERM) focuses on the development of actinide source term parameter values and the implementation of those values in performance assessment calculations. In Section SOTERM.2, an overview of the repository system is presented, including a review of relevant geochemical and chemical constraints on the repository system, the conceptual framework on which the actinide source term is based, simplifications required to develop parameter values, and assumptions made. Sections SOTERM.3 and SOTERM.4 focus on the development of the dissolved actinide solubility parameters and oxidation state distribution, respectively. Section SOTERM.5 focuses on the impact of organic ligands on dissolved actinide concentration. The mobile colloidal actinide source term is described in Section SOTERM.6. In Section SOTERM.7 the performance assessment implementation of the dissolved actinide and colloidal actinide components of the actinide source term is described.

Appendix SOTERM is a supplement to information presented in Sections 6.4.3.4, 6.4.3.5, and 6.4.3.6 of this application.

SOTERM.2 Conceptual Framework of Chemical Conditions

In this section, an overview of the chemistry of the repository system is presented. The ambient geochemical conditions are described first. The effects of human intrusion and waste are then described. Emphasis is placed on how various components and processes within the repository will affect the dissolution and colloidal suspension of actinides. Excess MgO will be added to the repository for assurance purposes, so the effect of MgO is included in this discussion. Simplifications and assumptions used to model the components and processes are discussed in each section.

SOTERM.2.1 Ambient Geochemical Conditions

The Salado is predominantly halite (NaCl), but also contains accessory evaporite minerals such as anhydrite ($CaSO_4$), gypsum ($CaSO_4 \bullet 2H_2O$), polyhalite ($K_2MgCa_2(SO_4)_4 \bullet 2H_2O$), and magnesite ($MgCO_3$). Small quantities of intergranular and intragranular brines are associated with the salt at the repository horizon. These brines are highly concentrated solutions (up to 8 molar) of predominantly Na-Mg-K-Cl-SO_4 with smaller amounts of Ca, CO_3, and B. These brines have been in contact with the evaporite salts for geologic time and are saturated with respect to the evaporite minerals.

Underlying the Salado is the Castile, composed of bedded anhydrite. The Castile in the vicinity of the WIPP site is known to contain localized brine reservoirs under sufficient pressure to force brine to the land surface if penetrated by a borehole. Castile brines are predominantly saturated sodium chloride solutions containing calcium and sulfate, and small concentrations of other elements, and are about eight times more concentrated than sea water. Overlying the Salado in the vicinity of the WIPP site is the Culebra, a fractured dolomite ($CaMg(CO_3)_2$) layer. It is significant because it is expected to be the most transmissive geologic pathway to the accessible environment. Culebra brines are generally more dilute than the Salado and Castile brines, and are predominantly sodium chloride with potassium, magnesium, calcium, sulfate, and carbonate. See Chapter 2.0 (Section 2.4.2) of this application for information on the distribution of Culebra brine salinity.

SOTERM.2.2 Repository Chemical Conditions

Three aspects of the repository chemical environment can have a major impact on the dissolution and colloidal suspension of actinides. These are

- brine composition,
- the microbial degradation of organic waste, and
- corrosion of metallic waste.

For each of these, the effect, the range of possible behavior, and the simplifications used in modeling are discussed.

SOTERM.2.2.1 Brine

Brine required for mobilization of actinides and its composition will affect the quantity of actinide that may be dissolved or suspended. For example, high ionic strength brines have been shown to increase the solubility of actinides and also to increase the coagulation and settling rate of mineral fragment colloids.

In human intrusion scenarios, Salado and/or Castile brine will enter the repository, depending on whether the intrusion penetrates a brine reservoir in the Castile. However, in addition to Salado and Castile brines, brines from the Rustler and Dewey Lake can flow down the borehole to the repository, mix with the waste, and then be forced back up a borehole. Rustler and Dewey Lake brines are considerably less concentrated than Salado and Castile brines. As the Rustler and Dewey Lake brines flow into the repository, they would dissolve Salado halite until they attain compositions between that of Salado and Castile brines (see Section SOTERM.7.1.2). Under any intrusion scenario, therefore, the brine dissolving actinides would have the composition of Salado, Castile, or a mixture of Salado and Castile brines.

The Salado and Castile brine compositions bracket the range of possibilities within the repository, so experiments and modeling of repository chemistry were performed using the end member brines only. Modeling of brine mixing within the performance assessment was considered and rejected because it was not sufficiently accurate to reduce the uncertainty associated with brine mixing and related brine chemistry compared to bracketing this uncertainty with end-member brines. Brine mixing is addressed in Section SOTERM.7.1.2.

Several synthetic brines that simulate brines collected from the Salado, the Castile, and the Culebra were used in the experimental program. Brine A is a synthetic brine often used to simulate the upper range in Salado brine, magnesium concentration and ionic strength, as is SPC (Salado Primary Constituent) Brine, a version of Brine A with the trace elements removed. Synthetic ERDA-6 brine represents Castile brine. The primary chemical components of these brines are given in Table SOTERM-1 (from Brush 1990, pp. 20-22). As is evident in Table SOTERM-1, Salado brine contains high concentrations of magnesium chloride, whereas Castile brine is dominated by sodium chloride and contains bicarbonate.

In addition to using the end member brines, several other simplifying assumptions were made, including the following:

- Brine that may be in the repository is well-mixed with waste.
- Equilibrium with the more available minerals (halite, anhydrite, magnesite) is established. (Reduction-oxidation equilibrium with waste materials is not assumed.)
- For modeling purposes, brine composition is constant in time.

Table SOTERM-1. Some Chemical Components of WIPP Brines (from Brush 1990).

Ion or Chemical Property	Brine A	ERDA-6
Alkalinity (HCO_3^- equivalent, mM)	--	43
B^{3+} (mM)	20	63
Br^- (mM)	10	11
Ca^{2+} (mM)	20	12
Cl- (mM)	5,350	4,800
K^+ (mM)	770	97
Mg^{2+} (mM)	1,440	19
Na^+ (mM)	1,830	4,870
pH	6.5	6.17
SO_4^{2-} (mM)	40	170
TDS (mg/liter)	306,000	330,000

SOTERM.2.2.2 Microbial Degradation of Organic Materials

A large quantity of organic materials, including cellulosics, plastics, and rubber, will be emplaced in the WIPP, and will potentially be degraded by microbes.

There is considerable uncertainty whether significant microbial colonies will be viable in the WIPP for 10,000 years. As discussed in Appendix PAR, the U.S. Department of Energy (DOE) represents that uncertainty by assigning a 50 percent probability of significant microbial gas generation. It is further assumed that, in the event of significant microbial gas generation, there is a 50 percent chance that plastics and rubbers will be biodegraded (Wang and Brush 1996). Microbial degradation of organic carbon may influence actinide mobilization in four ways:

(1) fast reduction of oxidized actinide species, which in most cases are more soluble,

(2) consumption of solubilizing organic ligands,

(3) production of humic and microbial colloids, thereby increasing the amount of actinide sorbed on colloidal surfaces, and

(4) generation of CO_2, which in the absence of added MgO, would increase acidity and carbonate concentrations in the brine and thereby increase actinide solubility.

The first three of these are considered in the analyses that studied the oxidation state distributions (Section SOTERM.4), the effects of organic ligands (Section SOTERM.5), and the effects of colloids (Section SOTERM.6). The effect of CO_2 production is discussed further in this section. The simplifications used in the performance assessment calculations for all four of these effects are discussed at the end of this section.

The inventory of organic material, which includes cellulosics, plastics, and rubbers, is about 10^9 moles of carbon (DOE 1996, 3–13). At the maximum degradation rate of 0.3 mole carbon/kilogram of organic-materials/year in the inundated repository (Wang and Brush 1996), this inventory will be entirely biodegraded within about 200 years after closure. It is expected that the maximum time for complete degradation would be about 2000 years in cases where significant microbial action occurs.

The primary reaction for CO_2 production from organic carbon biodegradation is expected to be

$$C_6H_{10}O_5 + H_2O = 3CH_4 + 3CO_2 \qquad (2\text{-}1)$$

Two other reactions can also contribute, although because of the limited amount of nitrate and sulfate relative to organic carbon in the waste (Wang and Brush 1996), the potential amount of CO_2 generated is much less:

$$C_6H_{10}O_5 + 4.8\ HNO_3 = 7.4\ H_2O + 6\ CO_2 + 2.4\ N_2 \qquad (2\text{-}2)$$

$$C_6H_{10}O_5 + 3\ H_2SO_4 = 5\ H_2O + 6\ CO_2 + 3\ H_2S \qquad (2\text{-}3)$$

The pmH ($-\log_{10}$ of the hydrogen ion molality) of the brine in the repository is a function of the amount of CO_2 dissolved in the brine (in high ionic strength solutions, the pmH is a better indication of acidity than pH, $-\log_{10}$ of the hydrogen ion activity). Figures SOTERM-1 and SOTERM-2 show the dependence of pmH on carbon dioxide fugacity [$f(CO_2)$] for Brine A (Salado brine) and ERDA-6 (Castile brine), respectively, calculated by Wang (1996a and 1996b) using the code EQ3/6 (Wolery 1992; Wolery and Daveler 1992). The range shown in these figures is the range expected only when significant CO_2 generation takes place, and when MgO is not added to the repository. As can be seen in these figures, the pmH may approach 4.5 as the CO_2 fugacity exceeds 50 atm. At these pmH and $f(CO_2)$ conditions, the solubilities of actinides are much higher than at neutral or slightly basic pmH and low $f(CO_2)$. Excess MgO, however, will be emplaced with the waste for assurance purposes, and will buffer the pmH and $f(CO_2)$ of the repository brine to values where the solubility of actinides is minimized. Figures SOTERM-3 and SOTERM-4 show the major minerals and pH obtained with titration of $Mg(OH)_2$ into each of the end member brines.

Hydrated MgO, $Mg(OH)_2$, will react with CO_2 by the reaction

$$Mg(OH)_2 + CO_2 = MgCO_3 + H_2O. \qquad (2\text{-}4)$$

This reaction will buffer the CO_2 fugacity at approximately 10^{-7} atm. However, CO_2 can also react with $Ca(OH)_2$ present as cementitious material in the waste by the reaction

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O. \quad (2\text{-}5)$$

If the reaction in Equation 2-5 buffered the hydrogen ion molality (pmH) of the repository, the pmH would be high. However, the effect of $Ca(OH)_2$ is minimal, because it will be quickly consumed by reactions 2.5 and 2.6 (reaction with $MgCl_2$ in Salado brine):

$$Ca(OH)_2 + MgCl_2 = CaCl_2 + Mg(OH)_2 \quad (2\text{-}6)$$

Figures SOTERM-5a and 5b show the amounts of generated CO_2, dissolved $Mg(OH)_2$ and $Ca(OH)_2$ that are expected within the repository and the corresponding buffers for each end member brine (Salado and Castile). It is estimated that $2x10^9$ moles of MgO will be added to the repository for assurance and $8x10^6$ moles of $Ca(OH)_2$ will be present as a cementious material in the waste (Storz 1996). Because the quantities of MgO and $Ca(OH)_2$ are fixed, the pH and $f(CO_2)$ will be a function only of the amount of CO_2 produced by microbial reaction, the volume of brine in the repository, and the type of brine. Figures 5a and 5b were constructed from the titration calculations with computer code EQ3/6 (Wolery 1992; Wolery and Daveler 1992). In the calculations, 0.004 moles $Ca(OH)_2$ were added for each mole of $Mg(OH)_2$. The figure indicates that, for Castile brine ERDA-6 (Figure SOTERM-5b), the transition from one buffer to another is very sharp whereas, for Salado brine Brine-A, a transition region (III) exists (Figure SOTERM-5a) (Wang 1996a, Figure 26). The existence of region (III) is due to the formation of Mg-oxychlorite. The transition region and region I have very similar pH values. Furthermore, the figure shows that the chemical conditions in the repository will be dominantly controlled by $Mg(OH_2)$ and carbonate minerals, because $Ca(OH)_2$ in the waste will be consumed easily by reaction with microbially-generated CO_2 or $MgCl_2$ in the Salado brine. (Note that even if there is no CO_2 generation, the Mg buffers will apply if more than 5000 cubic meters of Salado brine enter the repository. The amount of 5000 cubic meters is a small fraction of the repository pore volume.) The dashed line is included to show that the CO_2 produced from degradation of only 8 percent of the cellulosics is enough to react with all the $Ca(OH)_2$ in the waste.

Therefore, under all situations where repository performance may be affected, the brine pmH and $f(CO_2)$ will be controlled by the $Mg(OH)_2 + MgCO_3$ buffer.

Four effects of microbial degradation of organic materials are recognized in modeling system performance. A simplification has been made that the effects will be time independent after 100 years. The effects are

(1) Reduction-oxidation effects. After 100 years, the repository will have a reducing environment. Even though significant microbial action is only 50 percent likely, the corrosion of steel will also produce a reducing environment (Section SOTERM.2.2.3).

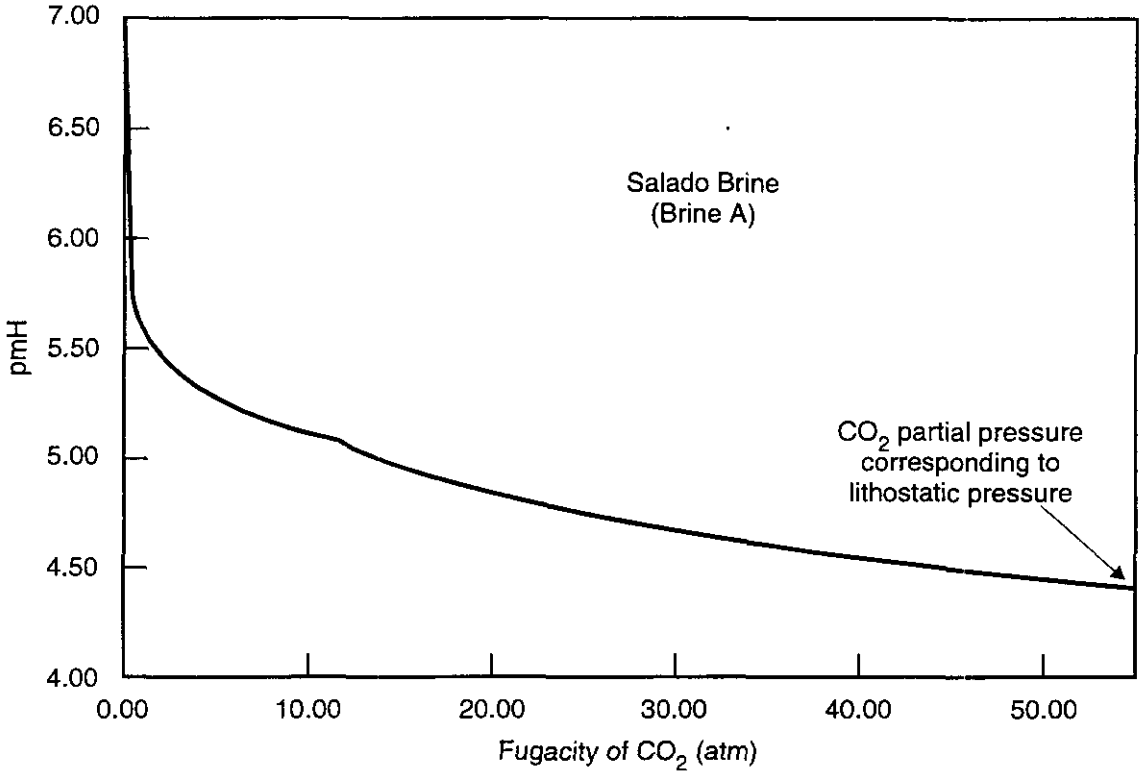

NOTE: It is assumed that CO_2 production by microbial reactions will be the dominant factor lowering brine pmH. Because of the difficulty in estimating the maximum CO_2 pressure in the repository, it is further assumed that the CO_2 pressure is limited by lithostatic pressure (approximately 150 atm), corresponding to approximately 55 atm CO_2 fugacity, according to a real-gas model developed by Duan et al. (1992) for a pure CO_2 system.

CCA-SOT002-0

Figure SOTERM-1. The pmH Changes of Salado Brine in the Absence of Added MgO as the Disposal Room is Pressurized with CO_2 Generated by Microbial Reactions

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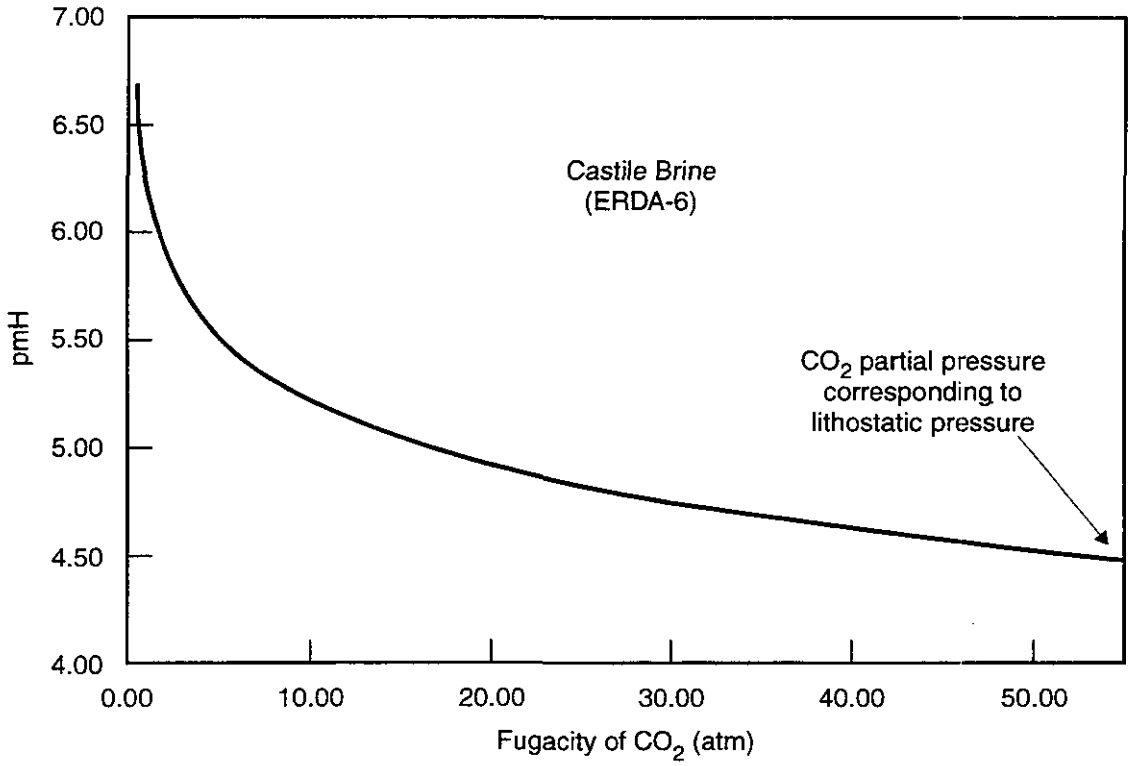

NOTE: It is assumed that CO_2 production by microbial reactions will be the dominant factor lowering brine pmH. Because of the difficulty in estimating the maximum CO_2 pressure in the repository, it is further assumed that the CO_2 pressure is limited by lithostatic pressure (approximately 150 atm), corresponding to approximately 55 atm CO_2 fugacity, according to a real-gas model developed by Duan et al. (1992) for a pure CO_2 system.

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Figure SOTERM-2. The pmH Changes of Castile Brine in the Absence of Added MgO as the Disposal Room is Pressurized with CO_2 Generated by Microbial Reactions

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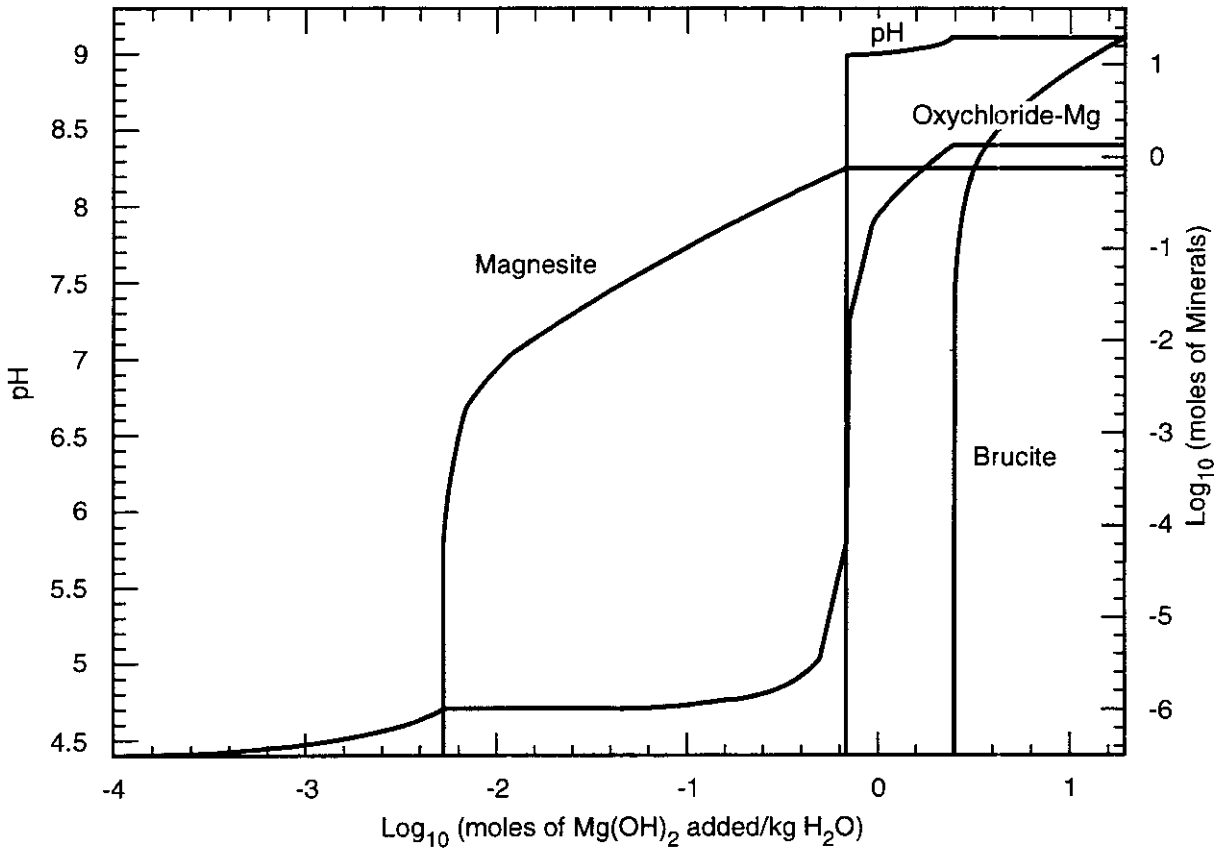

NOTE: The brine chemical composition used in the calculation is from Brush (1990, Table 2-2).

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Figure SOTERM-3. EQ3/6 Titration of Hydrated MgO into Salado Brine (Brine A)

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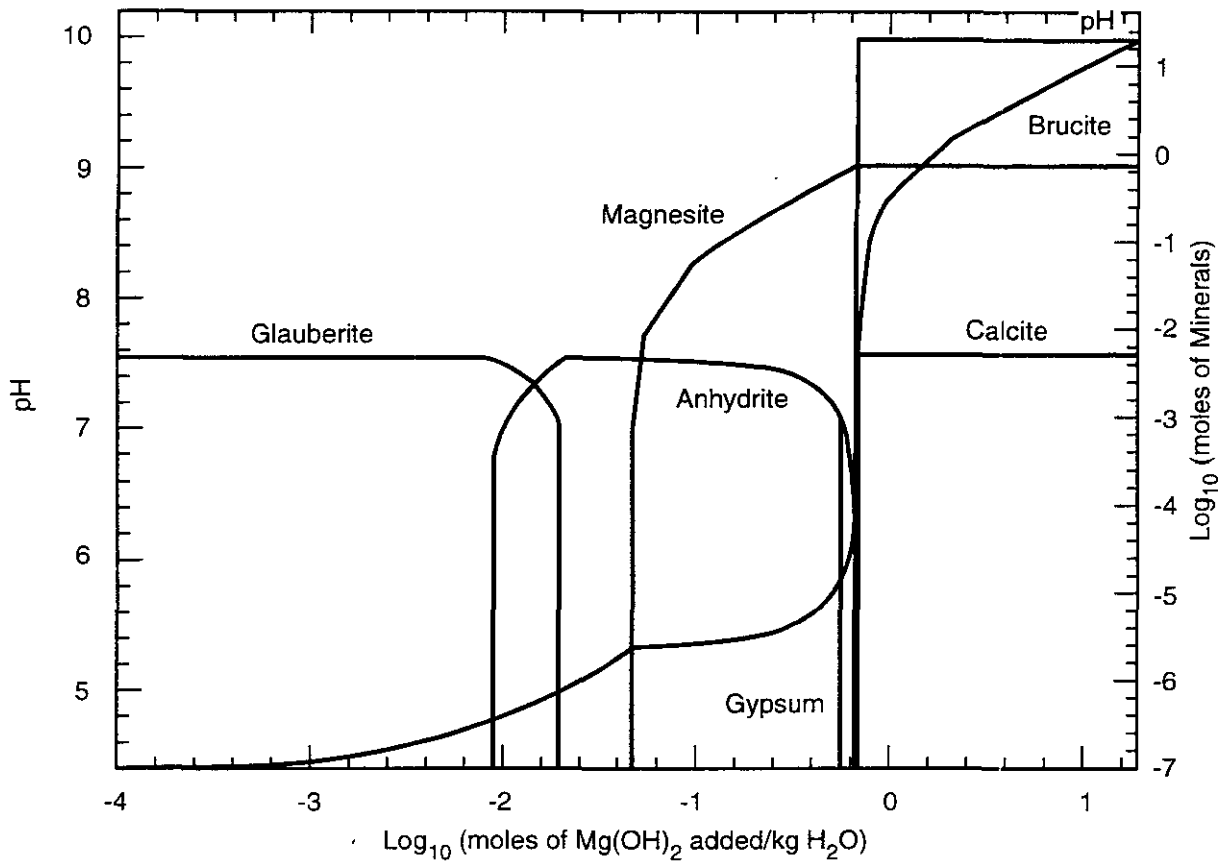

NOTE: The brine chemical composition used in the calculation is from Brush (1990, Table 2-3).

CCA-SOT005-0

Figure SOTERM-4. EQ3/6 Titration of Hydrated MgO into Castile Brine (ERDA-6)

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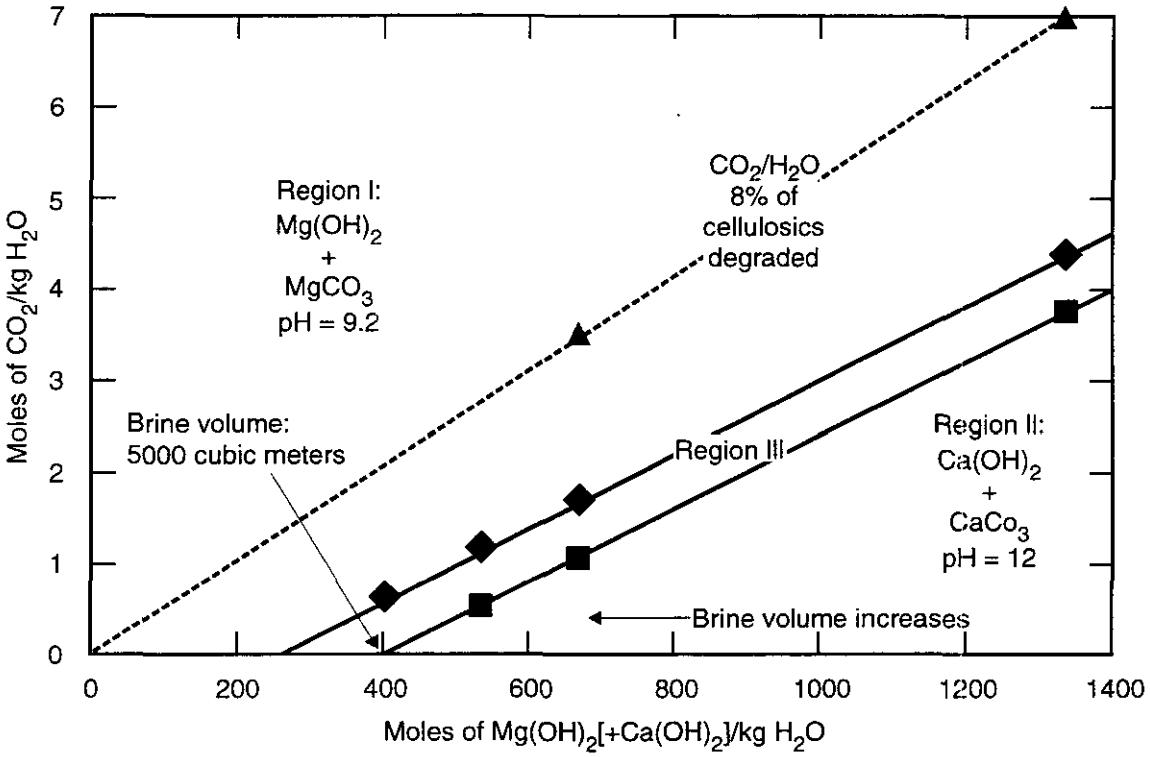

NOTE: Since MgO and $Ca(OH)_2$ are fixed, the ratio of $Mg(OH)_2/H_2O = 2 \times 10^9$ moles/kg of total water in the repository. The ratio of $Ca(OH)_2$/kg H_2O = 0.004*$Mg(OH)_2$/kg H_2O. The dashed line is the CO_2/H_2O ratio corresponding to 8% of cellulosics biodegraded. Region III can be combined into region I, because they have similar pH values.

CCA-SOT006-0

Figure SOTERM-5a. Chemical-Buffer Distribution for Salado Brine (Brine-A) as a Function of CO_2 Produced and $Mg(OH)_2$[+$Ca(OH)_2$] Added per Kilogram of Water

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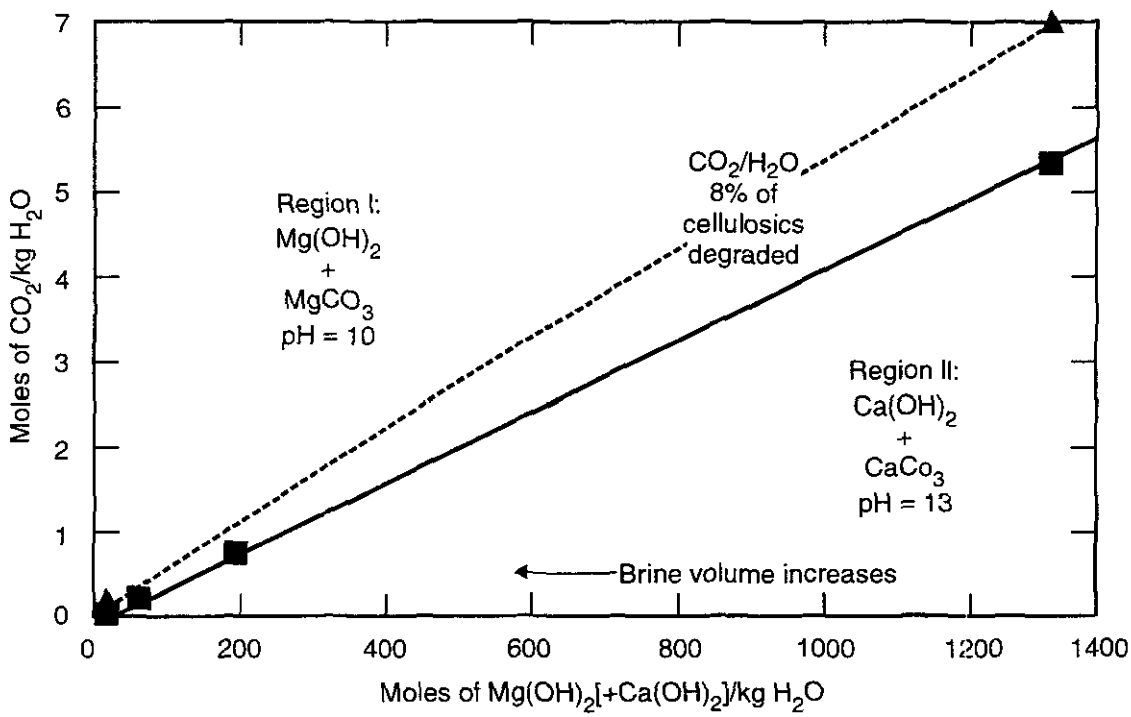

NOTE: Since MgO and $Ca(OH)_2$ are fixed, the ratio of $Mg(OH)_2/H_2O = 2 \times 10^9$ moles/kg of total water in the repository. The ratio of $Ca(OH)_2$/kg H_2O = 0.004*$Mg(OH)_2$/kg H_2O. The dashed line is the CO_2/H_2O ratio corresponding to 8% of cellulosics biodegraded.

CCA-SOT007-0

Figure SOTERM-5b. Chemical-Buffer Distribution for Salado Brine (ERDA-6) as a Function of CO_2 Produced and $Mg(OH)_2$[+$CA(OH)_2$] Added per Kilogram of Water

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(2) Consumption of organic ligands. While some microbes are known to consume some organic ligands, there is uncertainty as to the presence or viability of these particular microbes within the repository environment. Therefore, no credit has been taken for the microbial degradation of organic ligands. Other mechanisms for reducing the effect of organic ligands are discussed in Section SOTERM.5.

(3) Production of humic and microbe colloids. Even though microbes are modeled with only a 50 percent chance of significant growth, it is assumed that there are enough suspended microbes (viable or lysed) to increase the suspended actinide concentration. This is further discussed in Section SOTERM.6.

(4) CO_2 generation. With the addition of excess MgO backfill, the effects of CO_2 generation are minimized, and it is assumed that the system may be modeled using the $Mg(OH)_2 + MgCO_3$ buffer.

SOTERM.2.2.3 Corrosion of Steels and Other Metals

The corrosion of steels and other metals within the repository will have several effects on the dissolution and suspension of actinides. Corrosion is expected to

- reduce the oxidation states of some actinides, affecting their solubility and binding constants (Section SOTERM.4),
- release metal ions such as iron and nickel into solution. These metal ions can then bind organic ligands, thus reducing the ability of the ligands to increase actinide solubility (Section SOTERM.5),
- produce colloidal corrosion products on which actinides may sorb (Section SOTERM.6).

It is expected that the oxic corrosion of steels and aerobic biodegradation of organic materials will quickly consume the limited amount of O_2 trapped within the repository at emplacement. After the O_2 is consumed, anoxic corrosion of the metals will occur (Brush 1990, 30 et seq.). There will be about 2×10^9 moles of iron in the repository (DOE 1996, 2-5, 2-6) which is expected to corrode at a rate between 0.005 and 6.5 microns/year when inundated with brine but is immeasurably slow when in unsaturated conditions (Wang and Brush 1996). If the ferrous metals corroded at the maximum rate, they would be corroded within approximately 6,000 years after closure. In most cases, however, it is expected that there will be significant amounts of uncorroded metal in the repository throughout the 10,000-year regulatory period. In addition, WIPP specific experiments (Wang and Brush 1996) show that the steels will corrode by the following reaction:

$$Fe(O) + H_2O = Fe(OH)_2 + H_2 . \qquad (2\text{-}7)$$

Metal hydroxides such as $Fe(OH)_2$ are more soluble in the WIPP high ionic strength brines than in dilute waters, and significant amounts of Fe(II) may dissolve. Refait and Genin (1994) estimated Fe(II) solubilities between 10^{-4} and 10^{-6} M for pH between 8.5 and 10.5 at reduction-oxidation conditions expected for the repository. Sagoe-Crentsil and Glasser (1993) observed even higher solubilities at pH 13 with electrolytic dissolution of iron.

Corrosion of metals will produce reducing conditions within the repository, but the effective reduction-oxidation state of the system is unknown. The repository system is not described using Eh, because in low temperature systems reduction-oxidation equilibrium between the many reduction-oxidation couples may not necessarily be obtained and no unique Eh is defined. For this reason the reduction-oxidation states of the actinides have been determined experimentally as described in Section SOTERM.4.

SOTERM.2.2.4 Other Effects

High pressure in the repository after closure is expected to have an insignificant effect on actinide solubility and the association of actinides with colloids and therefore its effect is eliminated from performance assessment calculations. Temperature within the repository is not expected to change by more than a few degrees from ambient (α) (Sanchez and Trellue 1996; Wang and Brush 1996). Because the effect on solubility of a few degrees is insignificant compared to uncertainty of the measurements and modeling of solubility, temperature effects were also discounted (Section SOTERM.3.3).

Radiolysis of brine may change the effective reduction-oxidation state. When energy from radioactive decay is absorbed by water, the water is broken into energetic fragments that reassemble into oxidized and reduced species. Depending on the chemical reactivity of these species, the system may be effectively more oxidizing or more reducing as a result of the radiolysis. For example, radiolysis often occurs by the following reaction:

$$2\ H_2O + \text{radiation} = H_2(g) + H_2O_2\ . \qquad (2\text{-}8)$$

Peroxide (H_2O_2) is more reactive than $H_2(g)$ at low temperature, and peroxide reduction-oxidation reactions will affect the system more than the slow H_2 reactions. If the system is initially very oxidized, the H_2O_2 will cause a reduction in the effective reduction-oxidation state, but if the system is initially very reduced, the peroxide will cause oxidation in the effective reduction-oxidation state. In the WIPP, it is expected that the repository will be quite reducing due to the large amount of iron metal and dissolved Fe(II) species. Any oxidized species such as peroxide generated from radiolysis are expected to quickly react with the iron metal and Fe(II) thus negating any oxidizing effect of radiolysis. Therefore, radiolysis is not expected to affect the reduction-oxidation state of the repository.

Other components of the waste may have a potential to influence the concentration of dissolved actinides within the repository. These include, for example, organic ligands (Section SOTERM.5); other salts such as $CaCl_2$, which may raise the ionic strength of the

brine; vermiculite, which may sorb actinides; and phosphate, which may precipitate insoluble actinide phosphates. The effects of most of these components are assumed beneficial and are unquantifiable, so they were not included in performance assessment modeling.

SOTERM.2.2.5 Summary

The chemical environment in the brine-inundated repository is a function of brine composition (Salado or Castile); microbial degradation of organic materials, which will produce various gases and colloidal particles; the MgO additive, which will control the pmH and the CO_2 fugacity; and corrosion of the large quantity of metals in the repository, which will cause reducing conditions and release ions that will bind with and sequester organic ligands.

SOTERM.3 Prediction of Dissolved Actinide Solubility

This section describes the basic approach to predicting dissolved actinide solubility for this application. Surveys of different possible conceptual and mathematical descriptions of the system are presented, followed by a more detailed discussion of the method selected.

The material in this section is intended to provide an overview of the modeling methods. More detailed descriptions of particular points or issues can be found in the indicated references.

SOTERM.3.1 Previous Approaches to Estimating Actinide Solubility in the WIPP

Brine flow through the repository was not considered early in the WIPP project history because none was expected (see Appendix Mass, Section MASS.2). As it was realized that brine may enter the waste disposal region from a variety of sources, scenarios involving brine flow were developed. These scenarios required investigation of potential mobilization of actinides, including actinide solubility in brine.

The solubility of actinides in the WIPP was initially estimated by an expert panel that reviewed the existing literature on actinide solubilities (Trauth et al. 1992). The range of solubilities obtained was about 14 orders of magnitude because the chemical conditions surveyed included extremes of acidity and other conditions. With the addition of MgO backfill and the demonstrated reducing conditions, these extremes will not occur in the WIPP. The expert panel also estimated the effect of high carbonate concentrations (which are known to increase actinide solubility significantly) on the actinide solubility despite the paucity of data for carbonate solutions. Median solubilities developed by the panel were Th, 10^{-10} M; U, 10^{-3} M; Np, 10^{-7} M; Pu, 10^{-9} M; and Am and Cm, 10^{-9} M (Trauth et al. 1992, p. 4-5; Hobart et al. 1996). Published studies of actinides under environmental conditions (that is, neutral or basic pH) have focused on actinides in surface waters and ground waters that are considerably more dilute than WIPP brines, which contributed to the wide range of concentration estimates because more pertinent data were unavailable.

Experimental investigations for other radioactive-waste projects (for example, Nitsche 1987) have approached the question of potential actinide solubility by measuring the solubility of the actinides in the waste directly. Although this is possible for well-characterized and homogeneous waste and ground waters, the waste intended for the WIPP is heterogeneous, and a relatively wide range of chemical conditions would be possible in the repository without the MgO backfill. Measuring solubility directly in experiments using transuranic (TRU) waste and ensuring that the measurements reflect steady-state WIPP conditions would entail an extremely large number of measurements and considerable uncertainty. This approach was determined to be neither practical nor feasible. The DOE therefore decided to estimate actinide solubilities by using an equilibrium thermodynamics model based on experimental parameterization.

SOTERM.3.2 Selection of the Pitzer Activity Coefficient Model

The thermodynamic activity of a dissolved species in solution is expressed as an activity coefficient multiplier of its analytical concentration. In dilute aqueous solutions, the activity coefficient is close to unity, but in high ionic strength brines such as encountered in the WIPP, the activity coefficient may be quite different than unity.

The calculation of activity coefficients is the central feature of thermodynamic models in concentrated electrolyte systems. Activity coefficients represent the deviation from the nearly ideal behavior that is observed or assumed in dilute electrolyte systems. Aqueous electrolyte activity coefficient models generally include the Debye-Hückel limiting law (see, for example, Pitzer 1991, 59 et seq.) to describe behavior in the dilute region (<0.1 molal), and often include one or more adjustable parameters to reproduce measured behavior in more concentrated solutions.

Numerous activity coefficient models for concentrated electrolytes have been proposed, including the Pitzer formalism (Pitzer 1991, Chapter 3), the Harned's Rule approach (Wood 1975), and the Specific-ion Interaction Theory (SIT) approach (Grenthe and Wanner 1992), given in order of approximately decreasing mathematical complexity. The Pitzer formalism contains parameters that explicitly represent the contributions to the excess free energy from every two-moiety and three-moiety interaction, where a moiety is a cationic, anionic, or neutral aqueous species. The Harned's Rule approach asserts that the "logarithm of the activity coefficient of one electrolyte in a mixture of constant total molality is directly proportional to the molality of the other component" (Robinson and Stokes 1959, 438), and thus by extension to multicomponent systems containing parameters for two-moiety interactions. The SIT formalism contains parameters for two-moiety cation-anion interactions.

A primary consideration for selecting an activity coefficient model for the WIPP actinide solubility data base was the demonstrated applicability of existing models and data bases to the brine and evaporite systems at the WIPP site. The Pitzer formalism, especially as parameterized by Harvie et al. (1980a), Harvie et al. (1984), and Felmy and Weare (1986),

includes an established data base describing solubility in the Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-B-H_2O system; this system includes the significant inorganic constituents of WIPP brines. The Harned's Rule approach has been parameterized for the NaCl-KCl-$MgCl_2$-$CaCl_2$ and NaCl-$MgSO_4$ systems (Wood 1975) but does not include the carbonate ion, which is one of the most important complexants for actinides in aqueous systems. The SIT formalism (Grenthe and Wanner 1992) is most commonly used for extrapolating apparent stability constants to zero ionic strength. No demonstrations that the SIT formalism has been applied to multicomponent concentrated electrolytes such as brine-evaporite systems have been identified in the literature.

The chemical behavior of the concentrated electrolytes that occur in evaporites like those at the WIPP site has been extensively studied and documented. The applications of the Harvie et al. (1980a), Harvie et al. (1984), and Felmy and Weare (1986) parameterization of the Pitzer formalism include: prediction of the mineral precipitation sequence accompanying sea water evaporation (Eugster et al. 1980; Harvie et al. 1980b); the formation of borate minerals in Searles Lake, CA (Felmy and Weare 1986); and an analysis of Permian sea water compositions based in part on fluid inclusion data from the Salado (Horita et al. 1991). Additional applications are given in Pitzer (1991, Chapters 6 and 7).

Brines in the WIPP system range from about 0.8 molal to 8 molal ionic strength. The Pitzer model is developed for and has been shown to work for electrolytes as concentrated as those in the WIPP system, and has been applied successfully to evaporite systems with concentrations greater than 10 molal (Felmy and Weare 1986). Rather than develop a new description of the chemical behavior of the nonactinide chemical constituents in WIPP brines, it was decided to use the Harvie et al. (1984)/Felmy and Weare (1986) (HMW/FW) parameterization of the Pitzer model as the reference activity coefficient formalism and thermodynamic data base for further WIPP application. The WIPP actinide solubility research focused on extending the data base to include the actinides of interest to the WIPP and the organic waste constituents that may impact actinide dissolved concentrations.

SOTERM.3.3 The FMT Computer Code

The FMT code (Novak 1995; WIPP Performance Assessment 1995) implements the Pitzer formalism, and is used to calculate the solubility of the actinide elements in equilibrium with the appropriate solubility-controlling solid(s) in WIPP brines through the minimization of the Gibbs free energy of the system. Where appropriate parameters already existed in the HMW/FW data base, they have been used in FMT calculations for the WIPP. Additional parameters, most notably those for the actinide ions, have been taken from the literature or determined from experimental data (see Section SOTERM.3.4) using the NONLIN code (Novak 1995; WIPP Performance Assessment 1996). NONLIN calculates the Pitzer parameters using a non-linear least squares fitting program.

The FMT calculations were done for three actinides: Am(III), Th(IV), and Np(V), that are chemical analogs for the actinide III, IV, and V oxidation states, respectively. Because

actinides in the same oxidation state exhibit similar chemical behavior, these FMT model calculations are applied to all actinides in that particular oxidation state; for example, the Am(III) FMT model applies to Pu(III) and Cm(III), and the Np(V) model applies to Pu(V).

The dissolved concentrations of the actinides Am, Cm, Np, Pu, Th, and U will be limited by solubility-controlling solids for each of the actinides in the brines. The important ions in WIPP brines are H^+, Na^+, K^+, Mg^{2+}, OH^-, Cl^-, CO_3^{2-} SO_4^{2-}, and Ca^{2+}. Other ions (for example, PO_4^{3-},F^-, Al^{3+}, and Fe^{2+}/Fe^{3+}, may be important at influencing dissolved actinide concentrations both by influencing solubility and by influencing reduction-oxidation reactions. Pitzer parameters for these other ions were not quantitatively included in the dissolved species source term model, but are qualitatively included in the understanding of the chemical environment. For example, phosphates are known to precipitate actinides (Cotton and Wilkinson 1988), but this effect has conservatively been ignored due to the uncertainty of the phosphate inventory in the WIPP and the lack of a complete set of Pitzer parameters for its inclusion. The existence of Fe(II) from the anoxic corrosion of iron is accounted for in the oxidation state distribution (see Section SOTERM.4), but is expected to have an insignificant effect on the solubility of an individual actinide oxidation state.

The expected temperature of the WIPP disposal rooms during the regulatory time frame is not expected to change by more than a few degrees from ambient (Sanchez and Trellue 1996; Wang and Brush 1996). The small differences in thermodynamic properties caused by these changes are well within acceptable uncertainty for the WIPP system. For these reasons, the small differences in properties over this temperature range are not significant for the WIPP, and all information was developed for 25°C. Literature information taken at approximately 20°C was deemed acceptable for model parameterization as well.

The development of the dissolved actinide concentration model was largely the development of a data base that includes the standard chemical potentials of the aqueous and solid chemical species containing actinides, and the specific ion interaction parameters required to describe the interactions between these species and other constituents of brines in WIPP scenarios. The following subsections describe briefly how these data bases were built and how the needed parameters were obtained. The development of the oxidation state distribution reflected in these sections is discussed in Section SOTERM.4.

Section SOTERM.3.4 provides a guide to the information that is needed for predicting dissolved actinide concentrations. The FMT data base used in this application is documented in Novak and Moore (1996). The user's manuals for the FMT and NONLIN codes are contained in Attachments 1 and 2 respectively to this appendix.

SOTERM.3.4 Overview of the Experimental Data

SOTERM.3.4.1 The III Actinides: Am(III), Pu(III), Cm (III) and the Lanthanide Analog Nd(III)

The III actinides of interest to the WIPP are Am(III), Pu(III), and Cm(III). The lanthanide analog Nd(III) has been shown to exhibit the same chemical properties as the III actinides. The An(III)* model has been demonstrated to describe the chemical behavior of both Am(III) and Pu(III) accurately, by a combination of comparisons with existing literature information and comparisons with additional experiments designed specifically to perform this demonstration. For the III system, working with Nd(III) provides a particular advantage because Nd is not radioactive, which simplifies the laboratory work, and is stable in the III state.

The dissolved concentration model was used to predict the behavior of the III actinides in the WIPP system, as is shown for the simple example of the solubility of Am(III) in a closed system of SPC brine as a function of pmH (Appendix E of Novak 1995).

Data for the III actinides and lanthanides are the most extensive of all the oxidation states of interest. The An(III) model was developed simultaneously from individual data for the Pu(III), Am(III), Nd(III), and Cm(III) systems. Cm(III) may be presumed to behave virtually identically with Am(III) (see, for example, Katz et al. 1986, 1498). The An(III) model has been parameterized in the Pitzer formalism for the Na, Cl, SO_4, CO_3, and PO_4 systems; Pu^{3+}-Na^+-Cl^- in Felmy et al. (1989); Am^{3+}-Na^+-HCO_3^--OH^--H_2O in Felmy et al. (1990); Am^{3+}-Na^+-SO_4^{2-} - PO_4^{3-} in Rai et al. (1995); and Nd^{3+}-Na^+ -CO_3^{2-}-HCO_3^--H_2O in Rao et al. (1996). Some of the aqueous species required are Am^{3+}, $AmCO_3^+$, $Am(CO_3)_2^-$, $Am(CO_3)_3^{3-}$, and the solid species $AmOHCO_3(s)$. These are represented by the following reactions, as written for Am(III):

$$Am^{3+} + CO_3^{2-} = AmCO_3^+$$

$$Am^{3+} + 2\,CO_3^{2-} = Am(CO_3)_2^-$$

$$Am^{3+} + 3\,CO_3^{2-} = Am(CO_3)_3^{3-}$$

$$Am^{3+} + OH^- = AmOH^{2+}$$

$$Am^{3+} + 2OH^- = Am(OH)_2^+$$

$$Am^{3+} + 3OH^- = Am(OH)_3(s)$$

$$Am^{3+} + OH^- + CO_3^{2-} = AmOH\,CO_3(s)$$

*The symbol An is used to designate any actinide element.

These reactions represent one set of orthogonal reactions for americium(III) species.

The An(III) data base has been extended to mixed Na^+-Cl^--CO_3^{2-} media, and has been shown to reproduce the independently measured solubility of $NaAm(CO_3)_2(s)$ in 5.6 M NaCl (Runde and Kim 1994) and Nd^{3+} solubility in WIPP brines.

SOTERM.3.4.2 <u>The IV Actinides: Th (IV), U(IV), Pu(IV), Np(IV)</u>

The IV actinides important to WIPP performance are Th (IV), U(IV), Pu(IV), and Np(IV). The variation in charge to radius ratio for the tetravalent actinides is greater than for actinides in other oxidation states (Cotton and Wilkinson 1988), and larger differences in the chemical behavior among the IV actinides is expected. The application of the Th(IV) model to the other IV species is more uncertain, yet still conservative because Th(IV) is the most soluble among these elements under WIPP conditions. The model was evaluated against data for Pu(IV) and Np(IV) solubility, and demonstrated to predict the chemical behavior of these actinides conservatively.

The Th(IV) dissolved concentration model is parameterized in the Pitzer formalism for interactions in the Na^+-K^+-Mg^{2+}-Cl^-- SO_4^{2-}-CO_3^{2-}-HCO_3^- -OH^--H_2O system. This model requires the species Th^{4+}, $Th(OH)_2SO_4$ (s), $Th(SO_4)_3^{2-}$, $Th(SO_4)_2$ (aq), ThO_2, $Th(OH)_4$(aq), $Th(OH)_3CO_3^-$, and $Th(CO_3)_5^{6-}$ to describe the data pertinent to the WIPP (Felmy et al. 1991; Felmy and Rai 1992; Felmy et al. 1996). The principal reactions required are (as written for Th(IV)):

$$ThO_2\ (am) + 2H_2O = Th(OH)_4(aq)$$

$$Th^{4+} + 4OH^- = Th(OH)_4\ (aq)$$

$$Th^{4+} + 3OH^- + CO_3^{2-} = Th(OH)_3CO_3^-$$

$$Th^{4+} + 5CO_3^{2-} = Th(CO_3)_5^{6-}$$

$$Th^{4+} + 2SO_4^{2-} = Th(SO_4)_2\ (aq)$$

$$Th^{4+} + 3SO_4^{2-} = Th(SO_4)_3^{2-}$$

$$Th^{4+} + 2OH^- + SO_4^{2-} = Th(OH)_2SO_4\ (s)$$

These reactions represent one set of orthogonal reactions for actinide(IV) species.

The Th(IV) model has been extended to concentrated NaCl, $MgCl_2$, $NaHCO_3$ and Na_2CO_3 solutions. In addition, Th(IV) solubility has been measured in WIPP brines.

SOTERM.3.4.3 The V Actinides: Np(V)

The only V actinide of interest to the WIPP is Np(V), which exists as the neptunyl ion, NpO_2^+. The base model for Np(V) comes from Fanghänel et al. (1995), constructed for the German repository program. The Np(V) model was parameterized for the elements Na, Cl, CO_3, and ClO_4 (the last of which is not important for the WIPP but is invaluable for interpreting data in the literature). The model requires the aqueous species NpO_2^+, $NpO_2OH(aq)$, $NpO_2(OH)_2^-$, $NpO_2CO_3^-$, $NpO_2(CO_3)_2^{3-}$, and $NpO_2(CO_3)_3^{5-}$, and the solid species $NpO_2OH(am)$, $NpO_2OH(aged)$, $Na_3NpO_2(CO_3)_2$ (s), $KNpO_2CO_3 \cdot 2H_2O(s)$, $K_3NpO_2(CO_3)_2 \cdot 0.5H_2O(s)$ and $NaNpO_2CO_3\ 3.5H_2O(s)$ to explain the available data. These are represented by the reactions

$$NpO_2^+ + OH^- = NpO_2OH(aq)$$

$$NpO_2^+ + 2\ OH^- = NpO_2(OH)_2^-$$

$$NpO_2^+ + CO_3^{2-} = NpO_2CO_3^-$$

$$NpO_2^+ + 2CO_3^{2-} = NpO_2(CO_3)_2^{3-}$$

$$NpO_2^+ + 3CO_3^{2-} = NpO_2(CO_3)_3^{5-}$$

$$NpO_2OH(am) = NpO_2^+ + OH^-$$

$$NpO_2OH(s) = NpO_2^+ + OH^-$$

$$NaNpO_2CO_3 \cdot 3.5H_2O(s) = Na^+ + NpO_2^+ + CO_3^{2-} + 3.5H_2O$$

$$Na_3NpO_2(CO_3)_2\ (s) = 3Na^+ + NpO_2^+ + 2CO_3^{2-}$$

$$KNpO_2CO_3 \cdot 2H_2O(s) = K^+ + NpO_2^+ + CO_3^{2-} + 2H_2O$$

$$K_3NpO_2(CO_3)_2 \cdot 0.5H_2O(s) = 3K^+ + NpO_2^+ + 2CO_3^{2-} + 0.5H_2O$$

These represent a set of orthogonal reactions for neptunium(V) species. The Np(V) solubility model is being extended to potassium systems, including $K_3NpO_2\ (CO_3)_2(s)$.

SOTERM.3.4.4 The VI Actinides: U(VI)

The An(VI) FMT model has not been developed sufficiently for reliable use in predicting concentrations of this oxidation state in WIPP brines under various solution conditions. Although uranyl carbonate can be successfully modeled, the hydrolysis behavior of U(VI) is quite complicated and no satisfactory predictive models applicable to WIPP-like conditions are yet available. Because the implementation of an MgO backfill limits the pmH and fCO_2 to

discrete values, empirical measurement of the solubility of U(VI) in WIPP and/or WIPP like brines became practical. As documented in Hobart and Moore (1996), the solubility of U(VI) at pH 10, in the absence of carbonate, was determined to be 8.8 x 10^{-5} molal. The incorporation of U(VI) data into performance assessment is discussed in Section SOTERM.7.

SOTERM.3.5 Calculations of Actinide Solubility Using the FMT Computer Code

Details of the implementation of FMT and an early version of the CHEMDAT data base are given in Appendix D of Novak (1995), and in the FMT User's Manual. FMT calculated chemical equilibrium for user-specified total element amounts for aqueous or aqueous/mineral geochemical systems. The set of FMT calculations of actinide solubility in the WIPP system performed for the performance assessment included establishing equilibrium with halite, anhydrite, brucite, and magnesite (Novak et al. 1996), the minerals present in large quantities in the repository system. The effects of the MgO backfill are realized through the establishment of equilibrium of brine with brucite and magnesite.

SOTERM.3.6 Use of FMT Results in Performance Assessment

Table SOTERM-2 gives the solubilities for each actinide oxidation state analog as calculated with the thermodynamic model and FMT.

Table SOTERM-2. Solubilities of the Oxidation State Analogs, in moles/liter, with MgO Backfill

		Solubilities for PA Material Name and Oxidation State			
Brine	**PA Parameter Name**	**SOLMOD3 (III)**	**SOLMOD4 (IV)**	**SOLMOD5 (V)**	**SOLMOD6 (VI*)**
Salado	SOLSIM	5.82 x 10^{-7}	4.4 x 10^{-6}	2.3 x 10^{-6}	8.7 x 10^{-6}
Castile	SOLCIM	6.52 x 10^{-8}	6.0 x 10^{-9}	2.2 x 10^{-6}	8.8 x 10^{-6}

*Not calculated with the FMT model

Uncertainties in the solubility data and uncertainty in the NONLIN least squares refinement result in uncertainty in the model predictions. This is also evident when the data of Runde and Kim (1994) are compared with FMT model results. A measure of uncertainty was obtained by Bynum (1996) by examining the difference between the modeled solubilities for each oxidation state analog and comparing these to the experimental data used to generate the respective Pitzer parameters. The results of Bynum's analysis is given in Figure SOTERM-6. These results were combined as shown in Figure SOTERM-7 for entry into the parameter database as a cumulative distribution. This distribution was sampled in performance assessment as discussed in Section SOTERM.7.1.3. Note that the median of this distribution is -0.09 and not zero, indicating that slightly more experimental values were below the model

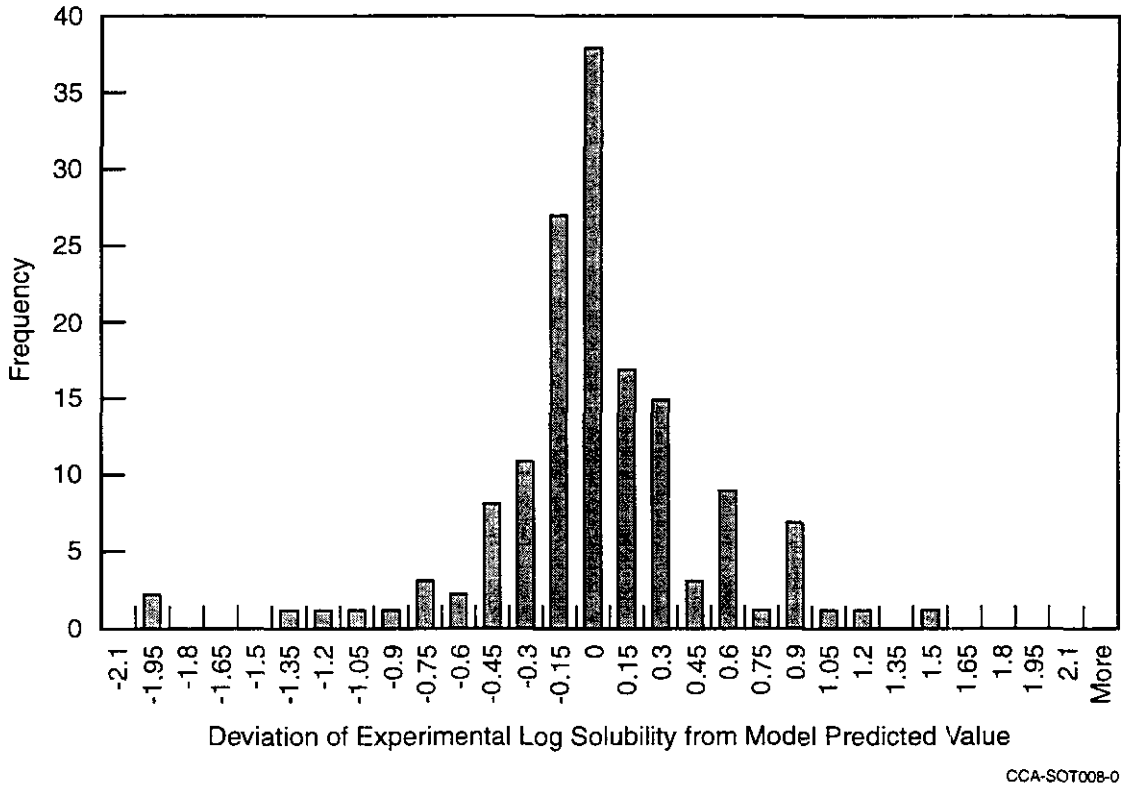

Figure SOTERM-6. Deviation of 150 Experimental Log Solubilities from the Model-Predicted Values

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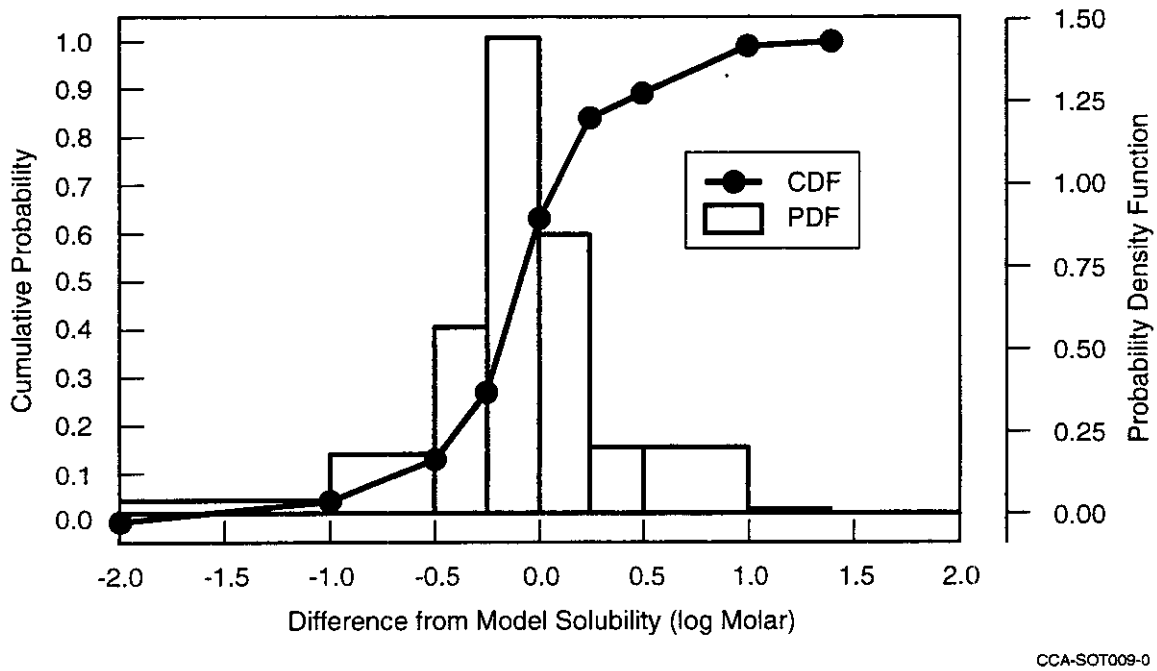

Figure SOTERM-7. Distribution of Actinide Solubility Uncertainty Utilized by Performance Assessments

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prediction than above. Table 6-11 in Chapter 6.0 of this application reports the median values, which are 10^{-9} (0.8128) times the model values shown in Table SOTERM-2, for those actinides assigned a distribution of solubilities rather than a constant value.

SOTERM.4 Oxidation State Distribution of the Actinides in Solution

This section describes the literature investigation and experimental program that resulted in identification of the oxidation states of the actinides that may be stable under expected repository conditions. The large quantities of iron in the repository, which will corrode to produce hydrogen and dissolved iron, provide a chemically reducing environment, thereby stabilizing reduced valence states. Microbial metabolism and the presence of organic material will add to this reducing environment.

SOTERM.4.1 Thorium

Thorium is known to exist only in the IV oxidation state in the natural environment (Hobart 1990; Katz et al. 1986, 1135, and following; 1486). The standard reduction potential for the Th(IV)/Th(III) couple is very low at -3.8 V. (with the standard hydrogen electrode potential = 0). Therefore, conditions in the inundated WIPP are not expected to produce any other valence state of thorium, nor has one been observed in any of the experiments done in connection with the WIPP Project. Thorium will be stable in the WIPP in oxidation state IV.

SOTERM.4.2 Uranium

Uranium can exist in aqueous solution in the III, IV, V, and VI oxidation states (Hobart 1990; Keller 1971; Clark et al. 1995). The dominant valence states for uranium in the natural environment are IV and VI. U(III) is metastable in aqueous solution but is easily oxidized (Katz et al. 1986, 1139, and following), and is difficult to isolate without traces of U(IV). In uranium, with open electronic shell structure $5f^3 6d 7s^2$, the shielding of the 5f electrons is not sufficiently effective for the trivalent state to dominate as it does in the transamericium actinides (Hobart 1990).

U(V) disproportionates rapidly in aqueous solution by the reaction

$$2U(V) = U(IV) + U(VI)\,, \qquad (4\text{-}1)$$

and the reduction-oxidation potential for the U(VI)/U(V) couple is only +0.16 V. U(V) (UO_2^+) is most stable in the pH region 2-4 (Katz et al. 1986, 1144), which is considerably more acidic than anticipated WIPP conditions. U(VI) (UO_2^{2+}), on the other hand, is quite stable and difficult to reduce. However, in the highly reducing conditions expected in the WIPP, U(VI) may be reduced to U(IV). In experiments in simulated WIPP brines, Reed et al. (1996) have found that at pH 10 under anoxic conditions, U(VI) as a carbonate complex is quite stable. The stable oxidation states of uranium in the WIPP are IV and VI.

SOTERM.4.3 Neptunium

In the natural environment, neptunium may exist in oxidation states IV, V, and VI (Hobart 1990; Keller 1971; Clark et al. 1995). In the WIPP environment, Np(IV) is expected to be present (Rai and Strickert 1980; Rai et al. 1982; Kim et al. 1985; Pryke and Rees 1986). Np(V) appears to be the dominant oxidation state in natural groundwater (Hobart 1990). Nitsche and Edelstein (1985) have observed that Np(V) is the most stable state in Yucca Mountain well water. Studies of the solubility of NpO_2OH in 1 M and 5 M NaCl solutions at pH 6.5 suggest that Np(V) may be reduced to Np(IV) under these conditions (Kim et al. 1985; Neck et al. 1992). Np(VI) may be introduced into the WIPP or be produced by radiolysis, but its long-term stability is unlikely in the presence of the reducing agents that are expected to be present in the WIPP. The reduction-oxidation potential for the Np(VI)/Np(V) couple in basic solution is +0.6 V (Katz et al. 1986, 470); in neutral solution, +1.24V. (Martinot and Fuger 1985, 651 et seq.). Reed et al. (1996) have found spectroscopic evidence for reduction of Np(VI) to Np(V) in ERDA-6 (Castile) brine at pH 10, and have observed total reduction of Np(VI) to Np(V) in G-Seep (Salado) brine at pH 7. In the presence of oxalate, citrate, and ethylene diamine tetra-acetate (EDTA), Reed et al. (1996) have observed rapid and complete reduction of Np(VI) to Np(V). Neck et al. (1995) have shown Np(V) carbonate complexes to be stable in 5 M NaCl. The stable oxidation states of neptunium in the WIPP are IV and V.

SOTERM.4.4 Americium

The trivalent state of americium (AmIII) is the most stable aqueous oxidation state (Katz et al. 1986, 912), and it is quite difficult to oxidize in aqueous solution (Hobart et al. 1982). Am(IV) is unstable, but Am(V) and Am(VI) are accessible under highly oxidizing conditions. These higher oxidation states are not stable in natural waters and can be readily reduced by action of reductants naturally present in those waters. Reduction-oxidation potentials for americium couples (Martinot and Fuger 1985, 660 et seq.) are 2.62 V., 1.20 V. and 1.59 V. for the (IV)/(III), (V)/(IV), and (VI)/(V) couples, respectively.

As is evident from the relatively high values of the reduction-oxidation potentials, all of the americium oxidation states higher than III can oxidize water and are thermodynamically unstable. The report of Am(V) resulting from radiolytic oxidation of Am(III) in NaCl solution (Runde and Kim 1994) may occur in micro-environments within the WIPP disposal rooms, but would not be stable in the homogeneous mixture of waste and brine. Solubility studies carried out by Pryke and Rees (1986) and Felmy et al. (1990) indicate that Am(V) is unstable in brine above pH 9 and reduces to Am(III). These studies showed significant instability of Am(V) even at pH 7. The large quantities of iron in the repository, as well as the presence of microbes, will result in a highly reducing environment. The MgO backfill in the WIPP will keep the pH in brine that may be in the repository between 9 and 10 (Wang 1996a). The stable oxidation state of americium in brine that may be in the repository is III.

SOTERM.4.5 Curium

Curium is distinguished by the relatively great stability of the III oxidation state with respect to oxidation or reduction (Katz et al. 1986, 970). The stability of Cm(III) may be attributed to the half-filled f-shell electronic configuration ($5f^7$). The oxidation of Cm(III) is achieved only with the strongest oxidizing agents, and only one report claims evidence for an oxidation state higher than IV (Korpusov et al. 1975). The Cm(III) to Cm(IV) transition has not been successfully induced by ozone or electrochemically, and the Cm(IV) phosphotungstate produced by oxidizing with peroxysulfate is considerably less stable than the Am(IV) analog (Katz et al. 1986, 971). In the reducing environment of the WIPP repository, any Cm(IV) produced radiolytically would be unstable. The oxidation state of curium therefore expected to be stable in the repository brine is III.

SOTERM.4.6 Plutonium

Plutonium can exist in oxidation states III, IV, V, VI, and VII (Katz et al. 1986, 781). Pu(VII) is very unstable and exists only in extremely basic solutions (for example, 7 M NaOH). Thus, Pu(VII) will not be stable in the WIPP environment. Pu(VI) has been shown to form stable chloride complexes (albeit under oxic conditions) in high-ionic strength NaCl solutions (Clark and Tait 1996). However, Clark and Tait (1996) and Reed et al. (1996) have shown the complete reduction of Pu(VI) under expected WIPP repository conditions to Pu(IV), with a transient Pu(V) intermediate, by iron and other reductants.

Massive quantities of iron metal (approximately 10^9 moles), an effective reductant, will be placed within the repository. An estimate of the amount of iron with respect to the amount of plutonium, for example, can be made on the scale of an average drum; all repository solution chemistry is presumed to occur under average conditions and at equilibrium. Each drum contains on the average about 60 millimoles of Pu. Each drum contains about 170 moles of iron in the container alone—potentially about a 2800-fold excess of iron. The reaction rate of iron with the brine is very fast (Appendix PAR, Parameter 1). Therefore, as any brine moves into the repository it will react with the iron and establish a highly reducing environment, leading to the reduction of plutonium to one of the lower oxidation states.

As brine enters the repository, iron will undergo anoxic corrosion, producing Fe^{2+}. Both metallic iron (Fe^0) and Fe^{2+} have been shown to quantitatively reduce Pu(VI) in WIPP brines to either Pu(IV) or Pu(III). Clark and Tait (1996) and Felmy et al. (1996) have experimentally observed the reduction of Pu(VI) carbonates by either Fe^0 or Fe^{2+} to Pu(IV). In the absence of carbonates, a quantitative reduction of Pu(VI) is also observed but the determination of the oxidation state of the resulting species cannot be definitively determined due to its concentration being below the lower limit of detection of the oxidation state analytical process (about 10^{-9} molar). However, since the concentration should have been above the analytical detection limit if the plutonium had been in the V state, it is reasonably assumed that the plutonium must have been reduced to either the IV or III oxidation state. Neretnieks (1982)

has shown that when dissolved actinides in moving groundwater came in contact with Fe(II), the actinides were reduced to a much less soluble oxidation state and precipitated.

Pu(III) is not very stable under expected WIPP conditions, but Felmy et al. (1989) have observed Pu(III) in PBB1 and PBB3 brines at neutral and slightly basic conditions. Under highly basic conditions, the plutonium concentration is below the lower limit of detection, and it cannot be conclusively demonstrated that the plutonium remains in the III oxidation state.

The DOE has determined (Weiner 1996) that Pu(IV) will be the dominant oxidation state under WIPP conditions. Because the existence of Pu (III) cannot be conclusively excluded, it too has been included in the performance assessment.

SOTERM.4.7 Summary of Oxidation State Distribution

Table SOTERM-3 presents the oxidation states of the actinides as they are used in performance assessment of the WIPP.

Table SOTERM-3. Oxidation States of the Actinides in the WIPP As Used in PA

Actinide Element	Oxidation States			
thorium		IV		
uranium		IV		VI
neptunium		IV	V	
plutonium	III	IV		
americium	III			
curium	III			

SOTERM.5 The Role of Organic Ligands

Organic ligands may be a component of the wastes to be disposed of in the WIPP. Because organic ligands may complex with actinides and increase dissolved actinide concentrations, the effect of organic liquids was evaluated. Organic ligands also complex strongly with multivalent metal cations. The multivalent metal cations thereby compete with the actinides, and an assessment of this effect was performed. The analysis, summarized here, demonstrates that organic ligands will not be available to complex the actinides and thus will not impact dissolved actinide concentrations in the WIPP.

A number of organic compounds are capable of forming strong complexes with actinide ions, thereby stabilizing the actinide in solution. In general, the reactions that take place for one-to-one complexes are

$$An^{n+} + L^{m-} \leftrightarrow AnL^{(n+m)}, \quad (5\text{-}1)$$

where An is a general symbol for any actinide, with charge n, and L is a general symbol for an organic ligand with charge m. The apparent stability constant for this reaction is

$$\beta = [AnL^{(n+m)}]/[An^{n+}][L^{m-}]. \quad (5\text{-}2)$$

The square brackets indicate concentration. This constant is sometimes referred to as an association constant.

The TWBIR (DOE 1996, Appendix B4) initially identified about 60 organic compounds among the non-radioactive constituents of TRU waste to be emplaced in the WIPP (Drez 1991; Brush 1990). Ten of these compounds have the potential to increase radionuclide solubility (Choppin 1988). Screening studies of these compounds have been conducted by Florida State University. Deprotonation and complexation experiments have been performed with five of these: acetate, citrate, oxalate, lactate, and EDTA. Four of these (acetate, citrate, oxalate, and EDTA) were identified in the waste inventory of the WIPP (DOE 1996, 3–12) as the only water-soluble organic ligands present in significant quantities. Lactate was not included because none was identified in the initial inventory, and estimating its concentration resulting from both production and consumption by microbes is not possible. These organic ligands are capable of significantly enhancing dissolved actinide concentrations, are potentially present in the repository, and are generally representative of any organic ligand that could be present in the WIPP.

Ligand concentrations in the repository were estimated using inventory amounts of ligands and a brine volume of 29,841 m^3, the smallest quantity of brine required to be in the repository which will support transport away from the repository (Larson 1996). As per the TWBIR, Rev. 2, Page 3-1, a scaling factor of 2.05 was applied to all values. The results are listed in Table SOTERM-4.

Table SOTERM-4. Organic Ligand Concentrations in Inundated Repository

Organic Ligand	Inventory Amount (g)	Organic Concentration (molality)	Organic Concentration (scaled)
acetate	1.3×10^6	5.2×10^{-4}	1.1×10^{-3}
oxalate	1.6×10^6	2.3×10^{-4}	4.7×10^{-4}
citrate	1.4×10^8	3.6×10^{-3}	7.4×10^{-3}
EDTA	2.3×10^4	2.0×10^{-6}	4.2×10^{-6}

Apparent stability constants for organic ligand-actinide complexation and deprotonation constants for the organic acids were determined at Florida State University using

potentiometric titration and a solvent extraction technique. The results of these studies are summarized in Table SOTERM-5.

Complexation constants for each organic-actinide binding reaction were determined using the Pitzer formalism. The NONLIN computer code was used to calculate Pitzer interaction parameters and standard chemical potentials (Moore 1996). The parameters were added to the existing FMT data base for inorganic compounds and equilibrium calculations were performed. In FMT modeling calculations including organic ligands, all four of the water-soluble organic ligands identified in the WIPP inventory were included together at the expected concentrations so that competition among complexing sites could be examined (Novak et al. 1996). Calculations were done separately for Salado and Castile brines, using the brine formulations given by Brush (1990, 17-28). Complexation constants for magnesium with the organic ligands were measured at Florida State University and the results are listed in Table SOTERM-6. These results were included in the calculations so that magnesium (backfill component) competition with the actinides for ligand complexation could be evaluated. The FMT output is the calculated equilibrium solubility of the actinide as a function of the repository conditions.

As the iron and steel in the repository corrode, additional transition metal ions will dissolve. These ionic species include iron (Fe), nickel (Ni), chromium (Cr), vanadium (V), and manganese (Mn), because the steels used for the waste drums contain on average at least 0.001 weight percent of Ni, Cr, V, and Mn as minor constituents (National Institute of Standards and Technology 1995). Because at least 1.9×10^9 moles of steels will be disposed of in the WIPP, there should be at least 1×10^4 moles of Ni, Cr, V, and Mn in the repository. There are also expected to be $> 6 \times 10^7$ moles of Pb. Additionally, these and other metals will be present in some of the waste forms; however, these additional quantities in the waste were not considered in this evaluation because insufficient data were available.

The complexation constants for the various metals cited above with the four representative organic ligands are listed in Table SOTERM-7. To assess the ability of these metals to complex with the organic ligands, competition calculations with EDTA (selected because it is the most strongly complexing of the four organic ligands under consideration) in low ionic strength NaCl solution saturated with iron hydroxide, nickel hydroxide and magnesium oxide (backfill) were performed. The calculations showed that under these conditions 99.8 percent of the EDTA was complexed by Ni, thus effectively rendering the EDTA unavailable for complexation with the actinides and rendering complexation of actinides by organic ligands inconsequential. Although these results are approximate because complexation constants for low ionic strength media were used, the fact that a single metal cation could bind more than 99 percent of the EDTA strongly suggests that the full range of metals that will be present will readily overwhelm the complexation sites of the organic ligands. Additionally, at higher ionic strength, iron and nickel have much higher solubility than in dilute solutions. Variation in ionic strength is not expected to change the complexation constants sufficiently to reduce this effect on the organics.

Table SOTERM-5. Apparent Stability Constants for Organic Ligands and Actinides in NaCl Media

Organic Ligand	Actinide Ion	NaCl (molality)	log_{10} of Apparent Stability Constant (β)
Acetate	Am^{3+}	0.3 to 5	1.44 - 2.2
	Th^{4+}	0.3 to 5	3.68 - 4.18
	NpO_2^+	0.3 to 5	1.05 - 1.8
	UO_2^{2+}	0.3 to 4	2.23 - 3.09
Lactate	Am^{3+}	0.3 to 5	1.75 - 2.55
	Th^{4+}	0.3 to 5	3.83 - 4.28
	NpO_2^+	0.2 to 5	1.43- 1.95
	UO_2^{2+}	0.3 to 5	2.45 - 2.73
Oxalate	Am^{3+}	0.3 to 5	4.17 - 4.63
	Th^{4+}	0.3 to 5	7.04 - 7.47
	NpO_2^+	1.0 to 5.0	3.62 - 4.63
	UO_2^{2+}	0.3 to 5	5.82 - 6.7
Citrate	Am^{3+}	0.3 to 5	4.84 - 5.9
	Th^{4+}	0.1 to 5	9.31 - 10.18
	NpO_2^+	0.1 to 5	2.39 - 2.56
	UO_2^{2+}	0.3 to 5	7.07 - 7.32
EDTA	Am^{3+}	0.3 to 5	13.76 - 15.1
	Th^{4+}	0.3 to 5	15.56 - 16.94
	NpO_2^+	0.3 to 5	5.45 - 6.7
	UO_2^{2+}	0.3 to 4	10.75 - 12.16

Table SOTERM-6. Apparent Stability Constants for Magnesium Complexation with Organic Ligands at High Ionic Strength

Organic Ligand	NaCl (Molality)	log_{10} of Apparent Stability Constant
acetate	5	0.690
oxalate	5	2.20
citrate	3	2.02
EDTA	5	6.66

Table SOTERM-7. Apparent Stability Constants for Organic Ligands with Metals (Martell and Smith 1982, 75, 284, 307, 328).

Organic Ligand	Metal	Ionic Strength (molality)	$\log_{10}$ of Apparent Stability Constant
EDTA	Fe^{2+}	0.1	14.3
	Ni^{2+}	0.1	13.6
	Cr^{2+}	0.1	18.4
	Mn^{2+}	0.1	13.9
	V^{2+}	0.1	12.7
	Cu^{2+}	0.1	18.9
	Pb^{2+}	0.1	18
Citrate	Fe^{2+}	0.1	4.4
	Ni^{2+}	0.1	5.4
	Mn^{2+}	0.1	4.15
	Cu^{2+}	0.1	5.9
	Pb^{2+}	0.1	4.08
Oxalate	Fe^{2+}	1.0	3.05
	Ni^{2+}	0.0	5.16
	Cr^{2+}	0.1	3.85
	Cu^{2+}	0.1	4.84
	Pb^{2+}	0.16	4.00
Acetate	Fe^{2+}	0	1.4
	Ni^{2+}	0	1.43
	Cr^{2+}	0.3	1.25
	Mn^{2+}	0.16	0.8
	Cu^{2+}	0	2.22
	Pb^{2+}	0.1	2.15

In addition to the calculations using the HYDRAQL code, simple scoping type equilibrium calculations were performed including several of the expected transition metals. The following equations were solved simultaneously:

$$\beta_{Fe(II)} = [EDTA\text{-}Fe^{2-}] / [EDTA^{4-}][Fe^{2+}]$$

$$\beta_{Ni(II)} = [EDTA\text{-}Ni^{2-}] / [EDTA^{4-}][Ni^{2+}]$$

$$\beta_{Mg(II)} = [EDTA\text{-}Mg^{2-}] / [EDTA^{4-}][Mg^{2+}]$$

$$\beta_{Th(IV)} = [EDTA\text{-}Th] / [EDTA^{4-}][Th^{4+}]$$

along with mass balance equations for each metal. The nickel concentration of 3.65×10^{-4} used in the calculations was determined by taking the minimum number of moles of nickel expected in the repository, dividing by the available repository volume reported by Weiner (1996) and converting the value to molality. An approximation of 1×10^{-4} molal was chosen for the iron concentration. All other values for component concentrations and apparent

stability constants are reported above. To approximate the effect of ionic strength on the apparent stability constants for nickel and iron the values used were an order of magnitude lower than those reported in Table WCA-10. These calculations do not include all possible metal ions expected under repository conditions, for example calcium and chromium are not included. Therefore, these results are considered conservative. The results indicate more than 97 percent of the total EDTA is complexed by the transition metals. Thus the excess of nonradioactive metals present in the repository will overwhelm the complexation sites of the organic ligands and complexation of the organic ligands with actinides will be negligible.

SOTERM.6 Mobile Colloidal Actinide Source Term

Colloidal particles will be generated in the repository environment as a result of microbial degradation of cellulosics, corrosion of steel waste containers and waste constituents, by the hydrodynamic entrainment of colloidal-sized mineral fragments, and several other mechanisms. Those colloidal particles may sorb dissolved actinides or the dissolved actinides themselves may form colloidal-sized particles. In an intrusion scenario, actinide-bearing colloidal particles, together with dissolved actinides, may be transported to the Culebra by Castile or Salado brines that are present in the repository. Additional colloidal particles may be present in natural Culebra groundwater and could form additional actinide-bearing colloidal particles. After introduction to the Culebra, the dissolved actinides and actinide-bearing colloidal particles are transported by Culebra ground waters. Colloidal actinides may also be transported through the fractured anhydrite interbeds of the Salado.

The actinide source term at the WIPP is defined as the sum of contributions from dissolved actinide species and mobile colloidal actinide species. Colloidal actinides that are not suspended in the aqueous phase (that is, not mobile) are not included in the colloidal actinide source term. Sorption of colloidal actinides onto fixed substrates will also reduce the mobile colloidal actinide source term, but no credit is currently being taken for reduction by that means.

In this section, the quantification of the mobile actinide-bearing colloid component of the actinide source term is described. The quantification of colloid-facilitated transport of actinides in the overlying Culebra, in the event of an intrusion into the repository, is described in Chapter 6.0 (Section 6.4.6.2.2) and Appendix MASS (Section MASS.15.3).

SOTERM.6.1 Introduction

Colloidal particles are generally defined as particles with at least one dimension between 1 nm and 1 μm, suspended in a liquid, and maintained in suspension for very long periods of time by Brownian (random thermal) motion (Hiemenz 1986; Buddemeier and Hunt 1988; Stumm 1992, 1993). Those size boundaries are approximately defined on the basis of physical phenomena. Particles larger than about 1 μm are too large for Brownian motion to overcome gravitational forces, and the particles will rather quickly settle by gravity. An exception is the case of microbes, which are considered to be colloidal, but may exceed 1 μm. The specific

gravities of microbes are typically quite close to that of the dispersant, and so they may not settle by gravitational forces. Generally, particles smaller than approximately 1 nm behave in transport like dissolved ionic species.

SOTERM.6.1.1 Formation and Behavior of Colloidal Particles

Inorganic colloidal particles have been reported to form by a variety of processes. Colloidal particles may form by condensation or homogenous nucleation from dissolved species when a mineral phase is supersaturated or as hydrolyzed precipitates of mixed metal ions (Kim 1992). Colloidal particles may also form by release of particles from bulk material due to disruption of fragile aggregates by changes in ionic strength or hydrodynamic forces, dissolution of a more soluble surrounding matrix (Buddemeier and Hunt 1988; Kim 1994), mechanical grinding of mineral surfaces, or mechanical disruption of secondary minerals present at mineral surfaces (McCarthy and Zachara 1989).

Organic colloidal particles may form from microbial degradation of materials, condensation reactions of organic molecules to form humic substances, or microbe activity. A variety of naturally occurring organic materials, such as viruses, microbes, and pollen, are colloidal-sized particles (McCarthy and Zachara 1989; Stumm 1992, 243).

Colloidal particles may interact with actinides to form radiocolloids in two ways (see, for example, Lieser et al. 1986a,b, 1990; Kim et al. 1984a,b; Buddemeier and Hunt 1988; Kim 1992, 1994). First, radiocolloids may form as a result of chemical reactions involving dissolved polyvalent actinide ions. Hydrolysis and condensation reactions have been shown to form actinide macromolecules in which the actinide ions are bridged with hydroxyl ions to form polymers. Those radiocolloids are termed "actinide intrinsic colloids," "true colloids," "real colloids," "Eigenkolloide," or "type I colloids."

A second means to form radiocolloids is by sorption of actinides by ordinarily non-radioactive colloidal particles. In the actinide environmental geochemistry literature, the non-radioactive colloidal particle has been called a "ground-water colloid." Once actinide sorption has occurred, the resulting radiocolloids may be called "pseudo-colloids," "carrier colloids," "Fremdkolloide," or "type II colloids." The colloidal substrate for sorption may be a mineral fragment, a microbial cell, or a humic substance. Bates et al. (1992) recently described radiocolloids, which they called "primary colloids," forming in situ at the surfaces of vitrified radioactive waste as it reacts chemically with water. Considering that coprecipitation is a continuum with adsorption (see, for example, Comans and Middleburg 1987; Stumm 1992, 253 et seq.), the "primary colloid" can be included in the carrier colloid category, and more specifically, a mineral fragment type colloidal particle. A similar sort of colloid would form by isomorphous lattice substitution of actinide ions during mineral precipitation (that is, coprecipitation) or precipitation of actinide minerals.

In the traditional colloid chemistry literature, two types of colloidal particles are defined on the basis of how they interact with the dispersant (see, for example, Alexander and Johnson

1949, 114; Vold and Vold 1983; Hirtzel and Rajagopalan 1985; Hiemenz 1986; Ross and Morrison 1988; Hunter 1991-1992). Hydrophobic colloids are stabilized by electrostatic forces, whereas hydrophilic colloids are stabilized by solvation forces. In light of increased knowledge of aqueous surface chemistry gained over the past two decades, the terms hydrophilic and hydrophobic must be used cautiously, because even hydrophobic surfaces have hydrophilic surface functional groups. It is important, however, to make the distinction between how those two types of colloidal particles behave, because they exhibit different kinetic stability behaviors in electrolytes.

Kinetic stability differs from thermodynamic stability. Thermodynamic stability refers to the chemical equilibrium between the colloidal particles and the dispersant, whereas kinetic stability refers to the rate at which colloidal particles in a colloidal dispersion are removed from suspension due to agglomeration followed by gravitational settling. Thermodynamic stability may be most important for actinide intrinsic colloids, because that type of colloid forms directly from solution by chemical reactions. Kinetic stability is inversely related to the rate of particle aggregation, which is dependent on the frequency and efficiency (the fraction resulting in permanent joining) of collisions between colloidal particles. The behavior of colloidal particle types as a function of ionic strength is probably the single most important phenomenon affecting the importance of colloid-facilitated actinide transport at the WIPP.

Hydrophobic colloidal particles are kinetically stabilized and destabilized by electrostatic forces. In an aqueous dispersant, hydrophobic colloidal particles are attracted to one another by van der Waals forces. That electrostatic attraction is countered by repulsive forces generated by a cloud of counterions surrounding each particle (Lyklema 1978; Hiemenz 1986). In a kinetically-stable colloidal dispersion, colloidal particles are usually repelled from one another before they get close enough to become agglomerated. However, as the ionic strength of the dispersion is increased, the thickness of the cloud of counterions is compressed, allowing closer particle-particle interaction. The net effect is that as colloidal particles come into proximity with one another in the dispersion, a greater chance for sticking exists, and so the rate of agglomeration increases. That phenomenon is very effective at removing colloidal particles from suspension even at fairly low ionic strengths over periods of hours to days. Mineral fragments, which are a hydrophobic colloid type, are affected by ionic strength in this way.

Hydrophilic colloidal particles are stabilized by solvation forces, which are largely independent of the ionic strength of the dispersant (Alexander and Johnson 1949). This type of colloidal particle is essentially a dissolved macromolecule. Humic materials are an example of the traditional hydrophilic colloid type. Two major categories of hydrophilic colloidal particles are recognized. Micelles are aggregates of dissolved monomers, that are in thermodynamic equilibrium with those monomers. Polyelectrolytes are charged polymers that are not in thermodynamic equilibrium with a monomeric species (examples of polyelectrolytes include gum arabic, gelatin, pectin, and proteins). An important distinction, therefore, is that micelles require a minimum threshold concentration of monomers (the critical micellization concentration, or c.m.c.) to form. In contrast, the formation of

polyelectrolytes is not dependent on monomer concentration. Polyelectrolytes may act as an association colloid by adsorbing on hydrophobic colloidal particles. The resulting dispersions may be extremely kinetically stable (Hiemenz 1986, 659).

The kinetic stability of hydrophobic colloidal particles may be modified by coatings of steric stabilizing compounds, which themselves are essentially hydrophilic materials (also referred to as protective or association colloids) which modify the surface behavior to inhibit close interaction of particles. Such colloidal systems are rendered kinetically stable. Particles stabilized by organic compounds in seawater are an example of a sterically stabilized colloidal system. Microbes can be considered as stabilized in a similar manner, except that the stability is imparted by molecules (for example, polysaccharides), attached to the surface of the microbe, which have hydrophilic parts extending into the dispersant.

Colloidal particles may have rigid or flexible structures, which may affect the way in which they interact with the host rock during transport. "Hard-sphere" colloidal particles, such as mineral fragments, have discrete well-defined boundaries at the particle-water interface, and are rigid. "Soft-sphere" colloidal particles, such as humic substances, have less distinct boundaries at the particle-water interface, are flexible and may undergo conformational changes in response to environmental variations. "Soft-sphere" colloids are essentially dissolved macromolecules and are closest in form and behavior to particles referred to as hydrophilic colloids in the traditional colloid chemistry literature (Lyklema 1978; Hiemenz 1986).

SOTERM.6.1.2 Definition of Colloidal Particle Types

On the basis of the phenomena described in the previous section, several classification schemes have been proposed by various workers, and a large number of descriptive terms have evolved and been propagated in the literature. For actinide environmental geochemistry, most of the classification schemes are based on how the colloidal particle interacts with radionuclides. Colloidal particles are classified into the following four types for evaluation of the impact of colloidal particles at the WIPP site:

(1) Mineral fragments are hydrophobic, hard-sphere particles, that are kinetically stabilized or destabilized by electrostatic forces, and may consist of crystalline or amorphous solids. Mineral fragments may be made kinetically stable by coatings with steric stabilizers that prevent close contact. Mineral fragments may act as substrates for sorption of actinides or they may consist of precipitated or coprecipitated actinide solids.

(2) Actinide intrinsic colloids are macromolecules of actinides that, at least in some cases, may mature into a mineral fragment type colloidal particle. When immature, they are hydrophilic; when mature, they become hydrophobic.

(3) Humic substances are hydrophilic, soft-sphere particles, that are stabilized by solvation forces. They are often powerful substrates for uptake of metal cations and are relatively small (less than 100,000 atomic mass units).

(4) Microbes are relatively large colloidal particles that are stabilized by hydrophilic coatings on their surfaces, which behave as steric stabilizing compounds. They may act as substrates for extracellular actinide sorption or they may actively bioaccumulate actinides intracellularly.

SOTERM.6.2 Performance Assessment Implementation

Results of the colloidal actinide investigation were used in performance assessment in three types of parameter values: (1) constant concentration values; (2) concentration values proportional to the dissolved actinide concentration; and (3) maximum concentration values. The parameter types are summarized below and are described in parameter record packages (Papenguth 1996a,b,c,d).

For actinide intrinsic colloids and mineral fragment colloids, actinide concentrations associated with them were described as constant values. Table SOTERM-8 summarizes the material and parameter names and descriptions. As discussed in Appendix PAR (Section PAR.3), IDMTRL is the material name in the INGRES data base, and IDPRAM is the parameter name.

Experiments conducted to quantify actinide concentrations associated with humic substances and microbes provided the basis for a more sophisticated representation, in which colloidal actinide concentations were related to the dissolved actinide concentration by proportionality constants. For microbes, the proportionality relationship was made by element. For humic actinides, however, the relationship was made by oxidation state rather than by element. For microbes and humic substances, the experiments also provided a basis to define upper limits for the concentration of actinide that could be associated with each of those colloid types. For both humic and microbial actinides, the upper limit parameter was defined by element rather than oxidation state, and is in units of molarity. The use of the two upper limit parameters is slightly different, and is described in the sections below discussing humic substances and microbes.

SOTERM.6.3 Development of Parameter Values

In this section, the experimental basis for the parameter values is described. For each of the four colloidal particle types, the characteristics of the colloidal particle type are described, the experimental program is outlined, methods of interpretation are described, and results are summarized.

Table SOTERM-8. Material and Parameter Names for Colloids

IDMTRL	IDPRAM	Brief Description of Parameter
Th, U, Np, Pu, Am	CONCMIN	concentration of actinide associated with mobile mineral fragment colloids
Th, U, Np, Pu, Am	CONCINT	concentration of actinide associated with mobile actinide intrinsic colloids
Th, U, Np, Pu, Am	PROPMIC	proportionality constant for concentration of actinides associated with mobile microbes.
PHUMOX3* PHUMOX4 PHUMOX5 PHUMOX6	PHUMCIM	proportionality constant for concentration of actinides associated with mobile humic colloids, in Castile brine, actinide solubilities are inorganic only (complexes with man-made organic ligands are not important), solubilities were calculated assuming equilibrium with Mg-bearing minerals (brucite and magnesite);
PHUMOX3* PHUMOX4 PHUMOX5 PHUMOX6	PHUMSIM	proportionality constant for concentration of actinides associated with mobile humic colloids, in Salado brine, actinide solubilities are inorganic only (complexes with man-made organic ligands are not important), solubilities were calculated assuming equilibrium with Mg-bearing minerals (brucite and magnesite).
Th, U, Np, Pu , Am	CAPMIC	maximum (cap) concentration of actinide associated with mobile microbes;
Th, U, Np, Pu, Am	CAPHUM	maximum (cap) concentration of actinide associated with mobile humic colloids.

* Proportionality constant for concentration of actinides associated with mobile humic substances, for PHUMOX3, for actinide elements with oxidation state 3 [that is, Pu(III) and Am(III)]; PHUMOX4, oxidation state 4 [that is, Th(IV), U(IV), Np(IV), and Pu(IV)]; PHUMOX5, oxidation state 5 [that is, Np(V)]; and PHUMOX6, oxidation state 6 [that is, U(VI)].

SOTERM.6.3.1 Mineral Fragment Colloids

Mineral fragment type colloidal particles may be present in naturally occurring groundwaters, and they may be released from the host rock due to disruption of fragile aggregates by changes in ionic strength or hydrodynamic forces, dissolution of a more soluble surrounding matrix, mechanical grinding of mineral surfaces, or mechanical disruption of secondary minerals present at mineral surfaces. Under certain conditions, such as extreme changes in ionic strength of the groundwater or by physical disruption due to natural or human-induced events, mineral fragment type colloidal particles could also be produced within the Culebra. In an intrusion scenario at the WIPP, mixing of repository brines with Culebra brines may result in mineral precipitation that may include coprecipitation of actinide-bearing mineral fragment type colloidal particles. Within the repository, mineral fragment type colloidal particles may form from corrosion of iron-bearing waste and the steel packaging materials. In addition,

Portland cement based matrixes will be attacked and will produce mineral fragment type colloidal particles. Bentonite, which may be a constituent of drilling mud is itself a potential source of mineral fragment type colloidal material that should be considered for actinide transport.

In terms of colloidal actinide transport, mineral fragment type colloids act as carriers, in that actinide ions sorb onto the surfaces of the colloids. Because each mineral substrate has a different affinity for actinides, quantification of actinide concentrations associated with the wide range of mineralogies likely to be present at the WIPP is insurmountable. Instead, a bounding approach was used based on residual concentrations of colloidal particles in WIPP-relevant brines coupled with estimates of reasonable maximum concentrations of actinides that could be sorbed onto the colloid surfaces. That approach requires three pieces of information: (1) the number of mineral fragment type colloidal particles in the aqueous phase; (2) the geometric surface area of individual colloidal particles; and (3) the site-binding capacity of the mineral surface. In the remainder of this section, descriptions of the determination of items (1) through (3), the interpretation of that information, and the development of parameter values are provided.

SOTERM.6.3.1.1 *Description of Experiments*

Hydrophobic colloidal particles, such as mineral fragments, are kinetically stabilized and destabilized by electrostatic forces (refer to detailed discussion in Papenguth and Behl 1996, Sections 2.5.1 and 2.6). In an aqueous dispersant, hydrophobic colloidal particles are attracted to one another by van der Waals forces. That electrostatic attraction is countered by repulsive forces generated by a cloud of counterions surrounding each particle. In a kinetically stable colloidal dispersion, colloidal particles are usually repelled from one another before they get close enough to become agglomerated. However, as the ionic strength of the dispersion is increased, the thickness of the cloud of counterions is compressed, allowing closer particle-particle interaction. The net effect is that as colloidal particles come into proximity with one another in the dispersion, a greater chance for sticking exists, and so the rate of agglomeration increases. That phenomenon is very effective at removing colloidal particles from suspension even at fairly low ionic strengths over periods of hours to days.

The kinetic stability of the mineral-fragment-type colloids in WIPP-relevant brines was evaluated in coagulation series experiments. Colloidal dispersions of mineral fragments were prepared by mechanical disaggregation of representative mineral, rock samples, and other materials or by chemical precipitation from laboratory reagents. Brine simulants were prepared that covered the ranges of ionic strengths observed in WIPP brines. The brines were sequentially diluted with deionized water by factors of 10 and adjusted to acidic, neutral, and basic pH conditions to evaluate the effects of ionic strength and pH on kinetic stability. At the ionic strength referred to as the critical coagulation concentration (c.c.c.), colloidal particles will rapidly coagulate, forming agglomerates large enough to settle by gravitational forces. The number population of colloidal particles remaining in suspension in the various

dispersions was measured over time to assess their stability as a function of solution ionic strength and time.

Colloidal dispersions were prepared for the following minerals or materials: bentonite, kaolinite, montmorillonite, vermiculite, illite, anhydrite, calcium carbonate, magnesite, hematite (mechanically disaggregated), hematite (chemical precipitate), limonite, goethite, magnetite, quartz, siderite, brucite, strontianite, diatomaceous earth, pyrite, and cellulosic materials (Masslinn paper towels and Scott paper towels). The brine solutions used included a Salado-like brine simulant (SPC brine) and a Culebra brine simulant (H-17). For c.c.c. experiments, sequential dilutions of those brines were made that spanned approximately five orders-of-magnitude. Brine simulants consisting of 0.5 M NaCl or $CaCl_2$ were also used. For the residual concentration measurements which were used as the basis for the performance assessment deliverables described herein, the one order-of-magnitude dilution (that is, 10 percent of original strength) of the Salado-like brine and the Culebra brine simulants were used. That reduction in ionic strength provides a degree of conservatism in the results.

The c.c.c. experiments for the various concentrations of WIPP brine simulants were conducted under acidic (observed pH generally ranging from 3 to 4), neutral (pH 6 to 8), and basic (pH 9 to 12) conditions. Following the introduction of an aliquot of dispersed colloidal particles to a series of test tubes containing the sequentially diluted brine, colloidal particle concentrations remaining near the top of the fluid columns (residual concentration) were measured as a function of time. The degree of coagulation and settling was quantified using an inductively coupled argon-plasma atomic emission spectrophotometer, nephelometry, and direct particle counting.

Most of the experiments conducted relating to the kinetic stability of mineral fragment colloidal particles were qualitative to semi-quantitative, and were focused on evaluating whether a c.c.c. existed. For the final experiments, however, a state-of-the-art particle spectrometer was used with significantly greater sensitivity. That device was designed for semiconductor fabrication plants, which require extremely pure processing water, and use a similar instrument to ascertain purity. The final experiments were conducted over an extended period of time using the more sensitive analytical technique to determine the number and size of colloids in the brine suspensions. Those experiments were conducted in a similar fashion to previous experiments for bentonite (supplied by the Aldrich Chemical Co.), goethite, and hematite (mechanically disaggregated), but in a relatively dilute (and therefore conservative) brine simulant consisting of 0.1 M NaCl. Residual particle concentrations made with the particle spectrometer compared favorably with measurements made with spectroscopic techniques made at similar experiment times. Generally after the first day of the c.c.c. experiments, the majority (greater than 99 percent) of the colloidal particles had already settled out of suspension. With the more sensitive particle spectrometer, however, residual concentrations of colloidal particles were observed to continue to decrease. For experiments analyzed by spectroscopic or light-scattering techniques, final residual colloid number populations remaining suspended in the test vessels were determined by multiplying the initial colloid number populations determined at the start of the experiments by the fraction of

suspended colloids remaining at the final reading. Using the particle spectrometer, final number populations were measured directly.

SOTERM.6.3.1.2 *Interpretation and Discussion*

Parameter values (CONCMIN) describing the amount of actinide element bound by mineral fragment type colloidal particles were determined from the information described above, combined with estimates of adsorption site densities.

Actinides sorbed to the surfaces of colloidal particles can be estimated using ranges of values for adsorption site densities taken from published surface complexation modeling research. The actinide concentration contained by a single mineral fragment type colloidal particle is calculated by considering the geometrical surface area of a spherical particle:

$$[An]_p = \frac{\pi D^2 N_s}{N_A} \quad , \qquad (6\text{-}1)$$

where:

$[An]_p$	=	concentration of an adsorbed actinide element (moles/particle)
D	=	spherical colloidal particle diameter (nm)
N_S	=	adsorption site density (sites/nm^2)
N_A	=	Avogadro constant

An adsorption site density of 1 site/nm^2 was used for N_S in the above equation, a value which is realistic, but probably conservative. With that site density, 1 nm and 1 μm diameter particles could have a maximum of about 10^{-24} and 10^{-18} moles actinide per particle, respectively. To obtain an estimate of the maximum actinide concentrations that could be associated with the colloids, the estimates of residual colloid number populations (particles per liter of dispersion) were multiplied by the estimated maximum actinide transport capacity described by Equation 6-1. The use of a uniform adsorption site density is a conservative approach, because the actual sorption on mineral surfaces should be described by some kind of isotherm which will result in less than 100 percent coverage. Further, if multivalent adsorbates are present [for example, U(VI)], multiple adsorption sites may be required for one adsorbate ion, reducing the net adsorption capacity of the surface.

Final residual colloid number populations quantified by spectrophotometry or nephelometry showed that mineral fragment type colloidal particles are kinetically destabilized by brines similar in composition to those present at the WIPP site. Colloid number population values were, with a few exceptions, reduced to less than 5 percent of the initial values within 1 day. Conservative estimates of maximum actinide concentrations associated with those residual colloid populations are on the order of 10^{-7} to 10^{-9} moles actinide per liter of dispersion.

The final experiments, which utilized the particle spectrometer to measure the quantity of colloids remaining in suspension offered the most sensitive estimates. Moreover, those experiments were conducted for substantially longer periods of time than the semi-quantitative c.c.c. experiments. Those experimental results are shown in Table SOTERM-9.

Table SOTERM-9. Experimental Results for Mineral Fragment Colloids

Mineral	Time of Final Reading (days)	Estimated Actinide Concentration (moles/liter dispersion)
hematite	12.8	1.6×10^{-8}
goethite	12.9	9.5×10^{-10}
bentonite	12.8	1.6×10^{-10}
geometric mean		1.3×10^{-9}

The DOE believes that the experimental results using the particle spectrometer with the three distinct colloids (hematite, goethite, and bentonite), are representative of other mineral fragment type colloidal particles in terms of their behavior in brine solutions. The geometric mean was assumed to be a more representative average of the final colloid concentrations than the arithmetic mean because of the very small final colloid concentrations (which, for this particular case, is also conservative).

Mineral fragment type colloidal particles are unique among the four colloidal particle types addressed for the WIPP, because their concentrations are not generally linked to solubility, as are actinide intrinsic colloids and humic substances, or to a maximum supportable population in the case of microbes. Consequently, in an intrusion scenario at the WIPP, as dissolved actinide elements are introduced to the Culebra, it is possible that those dissolved actinides could sorb onto a separate population of indigenous mineral fragments, producing a supplemental source term. To account for that possibility, the geometric mean value listed above was multiplied by a factor of two, producing a final "most-likely value" of 2.6×10^{-9} moles actinide per liter of dispersion.

To capture uncertainty, mainly stemming from knowledge of the adsorption site density value, a triangular distribution with "minimum values" and "maximum values" spanning one order of magnitude about the geometric mean was provided for performance assessment calculations. Additional conservatism is incorporated into the mineral fragment parameter values in that the total concentration of actinides carried by mineral fragment colloidal particles have essentially been multiplied by a factor of five, because a separate population of colloidal particles has been assumed for each actinide element. No consideration of competition for sorption sites is incorporated into the calculation approach. The value used for adsorption site density is conservative, but reasonable. For the performance assessment calculations, however, the triangular distribution was not sampled. Instead, the maximum parameter values were used as constant values, which essentially results in a site density of 10

sites/nm^2. Parameter values for CONCMIN are summarized in Section SOTERM.6.3.5. Section SOTERM.7 discusses details on performance assessement implementation.

SOTERM.6.3.2 Actinide Intrinsic Colloids

Actinide intrinsic colloids (also known as true colloids, real colloids, type I colloids, and Eigenkolloide) form by condensation reactions of hydrolyzed actinide ions and consist solely of actinide cations linked by anions. There are several stages in the development of actinide intrinsic colloids at which they have significantly different behaviors. When immature, actinide intrinsic colloids display physiochemical properties that are similar to ionized humic substances. With age, they become more similar to mineral-fragment type colloidal particles.

The experimental approach used was strongly influenced by reviews of published literature on actinide intrinsic colloids. Pertinent literature is discussed below (see also Papenguth and Behl 1996).

SOTERM.6.3.2.1 Intrinsic Colloids of Plutonium

The most well-known and well-studied actinide intrinsic colloid is the Pu(IV) intrinsic colloid, which has been used as a basis of comparison for investigating intrinsic colloids of other actinides. Most of the knowledge about the Pu(IV) intrinsic colloid comes from research at high Pu concentrations in highly acidic solutions, which was conducted to help improve the efficiency of processing techniques. The Pu(IV) intrinsic colloid is notorious in its propensity to polymerize to form a gel-like material, which can even plug process lines.

A conclusive demonstration of the mechanisms of formation of the Pu(IV) intrinsic colloid has not yet been made, but there is a preponderance of evidence that suggests that polymerization is strongly linked to hydrolysis, and that the initial polymerization, or condensation, produces a macromolecule that becomes progressively more crystalline with time. The final mature colloid has a composition between $Pu(OH)_4$ (am) and PuO_2 (c), although the latter compound may be only partly crystalline and both may include interstitial water molecules.

The most convincing and consistent explanation for the chemistry of the Pu(IV) intrinsic colloid is presented by Johnson and Toth (1978). Those authors developed a conceptual model to explain the solution chemistry of a variety of metal cations and a variety of oxidation states. The conceptual model involves processes referred to as "olation" and "oxolation" in which metal cations become bridged with hydroxyl groups, which in turn undergo irreversible elimination of water and concurrent formation of oxygen bridges. Johnson and Toth demonstrate that the model is consistent with the observed behavior of the Pu(IV) intrinsic colloid.

Hydrolysis reactions for metal cations such as plutonium may be written as follows:

first: $Pu^{4+} + H_2O$ Ö $PuOH^{3+} + H^+$ (6-2)

second: $PuOH^{3+} + H_2O$ Ö $Pu(OH)_2^{2+} + H^+$ (6-3)

third: $Pu(OH)_2^{2+} + H_2O$ Ö $Pu(OH)_3^{+} + H^+$ (6-4)

fourth: $Pu(OH)_3^{+} + H_2O$ Ö $Pu(OH)_4\ (aq) + H^+$ (6-5)

Johnson and Toth (1978) point out, however, that in interpreting the formation of the Pu(IV) intrinsic colloid, it makes better sense to include the implied waters of hydration that surround metal cations in solution. Hydrolysis Equations 6-2 through 6-5 can be rewritten as follows, where n equals 4:

first: $[Pu(H_2O)_m]^{n+}$ Ö $[Pu(OH)(H_2O)_{m-1}]^{n-1} + H^+$ (6-6)

second: $[Pu(H_2O)_{m-1}]^{n-1}$ Ö $[Pu(OH)(H_2O)_{m-2}]^{n-2} + H^+$ (6-7)

third: $[Pu(H_2O)_{m-2}]^{n-2}$ Ö $[Pu(OH)(H_2O)_{m-3}]^{n-3} + H^+$ (6-8)

fourth: $[Pu(H_2O)_{m-3}]^{n-3}$ Ö $[Pu(OH)(H_2O)_{m-4}]^{n-4} + H^+$ (6-9)

From the literature, it is clear that polymerization occurs nearly immediately after the first hydrolysis (Equation 6-6) occurs. Johnson and Toth (1978) suggest the following reaction involving polymerization of two hydrolyzed species by loss of water (oxolation):

$$2\{[(H_2O)_{d-2}Pu(OH)(H_2O)]^{+(y-1)}\}\ \text{Ö}\ [(H_2O)_{d-2}Pu(OH)(OH)Pu(H_2O)_{d-2}]^{+2(y-1)} + 2H_2O \quad (6\text{-}10)$$

Aging or maturation of polymer then occurs by loss of water (olation) as follows:

$$[Pu(OH)(OH)Pu(OH)(OH)Pu(OH)(OH)...]\ \text{Ö}\ [Pu(O)Pu(O)Pu(O)...]_n + 3nH_2 \quad (6\text{-}11)$$

Maiti et al. (1989) and Laul et al. (1985) describe similar reactions, but it appears that they believe that the third hydrolysis reaction occurs, because they use the $Pu(OH)_3^+$ ion in their proposed polymerization reaction. Use of that ion does not appear to be consistent with observations by many workers that polymerization occurs immediately after the first hydrolysis reaction.

As the actinide polyelectrolytes mature through the olation process to become closer in composition to an actinide-oxide mineral, they will be kinetically destabilized by the high ionic strengths of the WIPP brines and will not be mobile. Further, the solubilities of the mature solid phase cannot be exceeded. In fairly long-term experiments, Nitsche et al. (1992, 1994) showed that the concentration of Pu(IV) intrinsic colloid stabilized at about 10^{-8} M. It is not known whether the form was Pu(IV) polyelectrolyte or Pu(IV) mineral fragment type colloid.

SOTERM.6.3.2.2 *Intrinsic Colloids of other Actinides*

Reference is made to a variety of intrinsic colloids of other actinides, but no systematic investigations of their formation and behaviors appear to have been made. Plutonium is

apparently unique in its propensity to form an intrinsic colloid. No mention is made in the literature of maturation of polyelectrolytes of other actinides to form mineral fragment type colloidal particles as plutonium does.

In general, the tendency of actinides to hydrolyze and to polymerize to form intrinsic colloids follows the order:

$$An^{4+} >> An(VI)O_2^{2+} > An^{3+} > An(V)O_2^{+} \qquad (6\text{-}12)$$

(Cleveland 1979a,b; Choppin 1983; Kim 1992; Lieser et al. 1991, 119). The order of oxidation states in the equation above results from the ionic charge to ionic radius ratios. The tendency for hydrolysis of $An(VI)O_2^{2+}$ is greater than for An^{3+} because the effective charge on the central cation on the linear $[O\text{-}An\text{-}O]^{2+}$ ion is 3.3±0.1, slightly greater than 3. This trend generally holds true for the actinide elements in general, because of the very small changes in ionic radii among the actinide elements (this is the oxidation state analogy; refer to Novak 1996). There are differences in the behaviors of the actinides from element to element that stem from very subtle changes in the charge to radius ratio and the nature of the configuration of the f molecular orbital.

Considering Pu as an example, hydrolysis becomes significant for Pu^{4+}, $Pu(VI)O_2^{2+}$, Pu^{3+}, and $Pu(V)O_2^{+}$ at pH values of <1, 4-5, 6-8, and 9-10, respectively (Choppin 1983). On the basis of the hydrolysis trend, it is not likely that An(III) and An(V) actinides will form actinide intrinsic colloids. There are suggestions in the literature, however, that Am^{3+} may form an intrinsic colloid, which is surprising because it does not undergo hydrolysis until relatively high pH. Thorium does not follow the trend described by Equation 6-12 because its large size makes it resistant to hydrolysis (Cotton and Wilkinson 1988). Nevertheless, thermodynamic data suggest that in almost all environments (near neutral or higher pH) thorium exists as $Th(OH)_4$ (aq). Moreover, thorium has been reported to form a polymer (Kraus 1956; Johnson and Toth 1978), although as discussed below, this species should be referred to as an oligomer.

Examples can be found in the literature of polymeric species of many of the actinides of importance to the WIPP (see, for example, Baes and Mesmer 1976; Kim 1992). It is important, however, to note the sizes of polymers described in the literature. It is well known that as polyvalent metals, the actinides can form polynuclear species, but they are largely lower polymers (that is, oligomers) such as dimers, trimers, tetramers, and hexamers (see, for example, Choppin 1983, 46). However, in terms of physical transport behavior, lower polymers will behave no differently than dissolved monomeric species. In contrast, the higher polymers, such as the Pu(IV)-polymer, may reach colloidal sizes (1 nm to 1 μm) and will have different hydrodynamic properties than the sub-colloidal-sized dissolved species. Johnson and Toth (1978) reported a molecular weight of 4000 for a Th polymer. Assuming that it consisted of $Th(OH)_4$, that polymer would consist of about 13 thorium metal ions (that is, the degree of polymerization number, N). That observation is consistent with Kraus (1956), in which he quotes an N value of about 9 for Th polyelectrolyte.

Empirical evidence published in the literature does not always support the suggestion that Am, as a trivalent cation, will form an intrinsic colloidal particle. Avogadro and de Marsily (1984) suggested that, like Pu, Am is a likely candidate to form an insoluble hydroxide. Buckau et al. (1986) reported the formation of Am(III) intrinsic colloids at near neutral pH conditions, with a particle size greater than 1 nm. In their study of the hydrolysis of Am(III) over a pH range from 3 to 13.5, however, Kim et al. (1984a) found only monomers of Am. Regardless of whether Am(III) intrinsic colloids will form under highly idealized laboratory environments, it would be highly unlikely that they would form in a geologic system, because of the tremendously strong sorption properties of the Am(III) ion.

SOTERM.6.3.2.3 *Experimental*

The focus of experiments, conducted at Lawrence Livermore National Laboratory (LLNL), were to test phenomena described in the published literature, under WIPP-relevant conditions:

- critical coagulation concentration for mature Pu(IV) mineral fragment type colloid (refer to description of experiment AIC-1 in Papenguth and Behl [1996]),
- formation of Pu(IV) colloid, from oversaturation and undersaturation in the absence of carbon dioxide (AIC-8 and AIC-9, respectively),
- inhibition of Pu(IV) polymerization due to organic complexants (AIC-2),
- depolymerization of Pu-colloid due to organic complexants (AIC-2b),
- polyelectrolyte chain termination by non-actinide metal cations (AIC-4), and
- sorption effects of WIPP repository substrates on Pu(IV) colloid (AIC-5).

The last four experiments listed above provide evidence that, under some conditions at the WIPP, the Pu(IV)-colloid is less likely to form or is sorbed. To parameterize the WIPP performance assessment calculations, however, the first two experiments listed above were used. Both sets of experiments (AIC-1, AIC-8/9) can essentially be viewed as solubility experiments. The critical coagulation experiments are solubility experiments conducted from undersaturation conditions, in which the in-growth of free Pu(IV) is observed (and are therefore equivalent to AIC-9). In both sets of experiments (AIC-1, AIC-8/9), the Pu solution concentration is measured as a function of time for as long as five weeks, as steady-state concentration is being reached. The two sets of experiments were anticipated to provide information to resolve the question of kinetic versus thermodynamic stability control on the formation and development of the Pu(IV) colloid. That question was not resolved, but the data still provide the necessary information for parameterizing the WIPP performance assessment calculations. The values for the parameters submitted for calculations were derived from the experiments listed in Table SOTERM-10.

The data from those experiments are plotted in Figure SOTERM-8 along with regression lines for data collected by Rai et al. (1980) for $Pu(OH)_4$ (am) and PuO_2 and Rai and Swanson (1981) for Pu(IV)-polymer under acidic pH conditions. With MgO backfill, the pcH of the

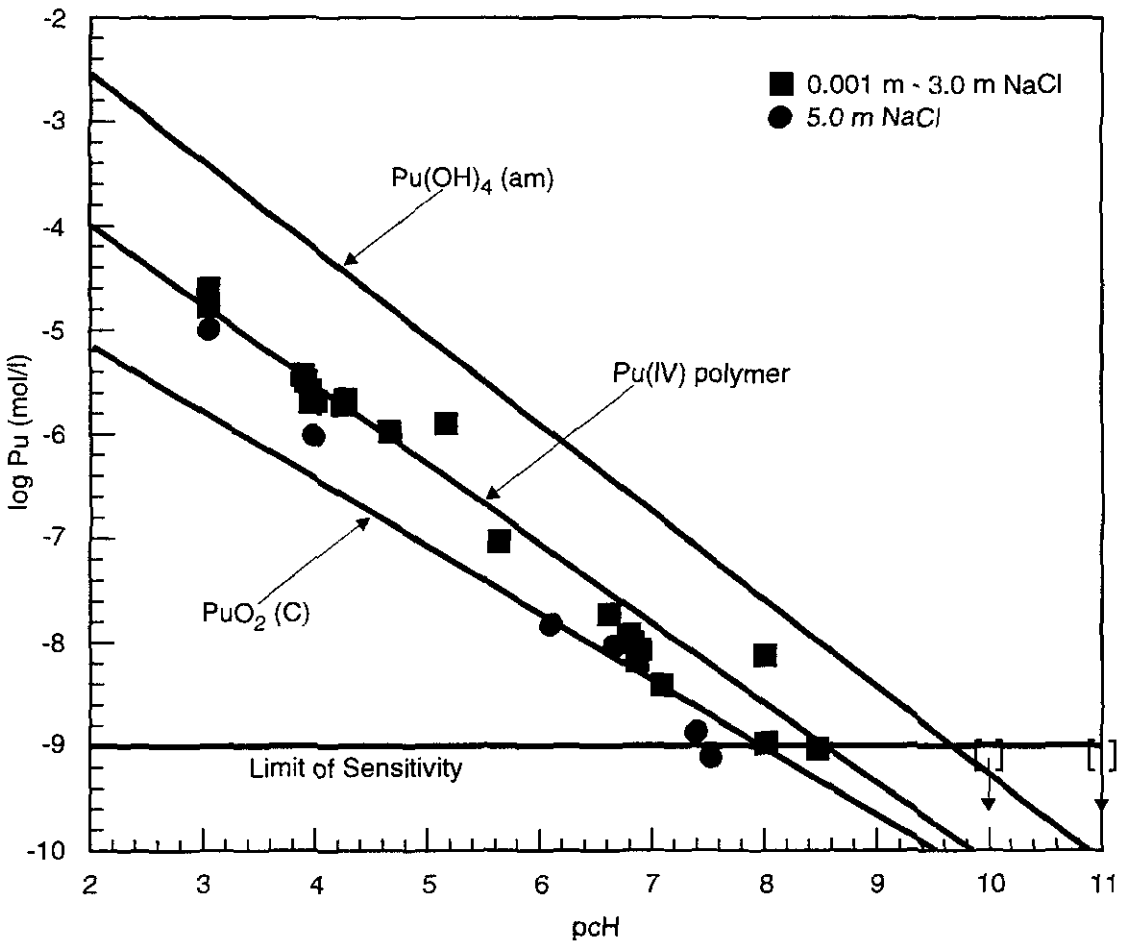

NOTE 1: Open brackets with arrows pointing down indicate Pu concentration is below the minimum analytical detection limit. Solubility lines for $Pu(OH)_{4amorphous}$ and $PuO_{2crystalline}$ are extrapolated from Rai et al. (1980). The solubility line for Pu(IV)-polymer is extrapolated from Rai and Swanson (1981). Plotted values were collected at LLNL as part of the WIPP colloid research program.

NOTE 2: Note that under basic pH conditions fixed by MgO, the solubility of the Pu(IV)-polymer is below the minimum analytical detection limit of 10^{-9} M.

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Figure SOTERM-8. Solubility of Pu(IV)-Polymer in NaCl Media as a Function of pcH

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Table SOTERM-10. Plutonium Intrinsic Colloid Experiments

Number	Experiment	Starting Material	pcH approx.	NaCl (molality)	Duration
AIC-1	c.c.c. (equivalent to undersaturation experiment AIC-9)	Pu(IV) colloid: aged 1 month: about 2 x 10^{-4} M	4 7 10	0.001 0.01 0.1 0.8 3.0 5.0	3 to 5 weeks
AIC-8	oversaturation	Pu(IV) aquo ion: about 1 x 10^{-4} M	3 7 10	0.05 0.5 1.0 5.0	4 weeks

repository brine is expected to be about 9.3 (refer to Wang 1996a; also see Novak and Moore 1996; Siegel 1996). As shown in Figure SOTERM-8, the regression line calculated from the LLNL data suggests that at a pcH of 9.3 the solubility of Pu(IV)-polymer is approximately 5 x 10^{-10} M. Because the extrapolated solubility is less than the minimum analytical detection limit of 1 x 10^{-9} M, the minimum analytical detection limit value was selected for use in WIPP performance assessment calculations. The LLNL results are consistent with the extrapolated relationships based on published results of Rai et al. (1980) and Rai and Swanson (1981).

SOTERM.6.3.2.4 *Interpretation and Discussion*

Parameter values (CONCINT) describing the amount of actinide element bound by actinide intrinsic colloidal particles were determined from the information described above. For the Pu(IV)-polymer, the minimum analytical detection limit was selected. In the absence of conclusive evidence that intrinsic colloids of other actinides form, or form polymers rather than oligomers, the concentration of Th-, U-, Np-, and Am-intrinsic colloids was set to zero.

Geochemical conditions in the Culebra are not conducive to the formation of a new supplementary population of actinide intrinsic colloids. In particular, the concentration of actinide ions is reduced. Therefore, the source term for actinide intrinsic colloids reflects what would form in the WIPP repository, under most favorable conditions for the formation of the Pu(IV)-polymer.

Parameter values for CONCINT are summarized in Section SOTERM.6.3.5.

SOTERM.6.3.3 Humic Substances

Humic substances are defined as high-molecular-weight organic compounds generally present as anions in natural waters. Humic substances may consist of humic acids, which may be aliphatic or aromatic, or fulvic acids. The difference between humic acids and fulvic acids is largely an operational distinction; humic acids can be precipitated at pH values below about 2, whereas fulvic acids are soluble over the entire pH range. Fulvic acids generally have lower molecular weights than humic acids. The dominant functional group that may react with dissolved actinides are carboxyl groups, but phenolic hydroxyl and alcoholic hydroxyl groups also contribute to complexation. At the WIPP, humic substances may be introduced to the repository as a constituent of soil-bearing waste or may be a constituent of the organic carbon component of Castile, Salado, or Culebra groundwaters. Probably more importantly, humic substances may form from condensation reactions between microbial metabolites (for example, carboxylic acids), cellulosic degradation products, and the extracellular polymers associated with microbes. Because of the general lack of knowledge in the scientific community regarding the formation of humic substances, as well as very slow kinetics of formation, a direct attempt has not been made to quantify the amounts of humic substances that would form in situ. Instead, the contribution of humic-bound actinides was bounded through quantification of humic-actinide complexation behavior coupled with quantification of solubilities of humic substances in WIPP-relevant brines. Regardless of the source of humic substances, the total concentration of humic substance available to mobilize actinides is limited by the solubility of humic substances in WIPP brines. The chemical nature of humic substances generated in situ cannot be predicted either, but can be bounded by the three types of humic substances.

To determine the concentration of actinides associated with humic substances, four pieces of information are required: (1) the concentration of reactive humic substance in the aqueous phase (humic solubility); (2) the binding capacity of the humic substance; (3) actinide uptake (that is, actinide complexation constants); and (4) concentrations of actinide ions in the aqueous phase (that is, actinide solubility). The quantification of actinide solubilities (4) is described in Novak and Moore (1996) and results are summarized in Siegel (1996). In the remainder of this document, the focus is on the determination of items (1) through (3), the interpretation of that information, and the development of parameter values suitable for performance assessment calculations.

SOTERM.6.3.3.1 Experimental

In general, humic substances encompass a broad variety of high-molecular-weight organic compounds. The range of their chemical behaviors, however, is covered by consideration of three types: aliphatic humic acid (generally terrestrial); aromatic humic acid (generally marine); and fulvic acid. The following humic substances were used:

FA-Suw: fulvic acid isolated from the Suwannee River acquired from the International Humic Substances Society, Golden, Colorado;

HAal-LBr: aliphatic humic acid isolated from sediments collected from Lake Bradford, Florida, prepared by Florida State University;

HAal-Ald: aliphatic humic acid purchased from Aldrich Chemical Co., purified by Florida State University;

HAar-Gor: aromatic humic acid isolated from groundwaters near Gorleben, Germany, obtained from Professor J.-I. Kim, Institut für Radiochemie, München; and

HAar-Suw: aromatic humic acid isolated from the Suwannee River acquired from the International Humic Substances Society, Golden, Colorado.

Solubilities were measured in experiments that were conducted over periods of several weeks. The solubilities of humic substances remaining in the fluid column were determined using a scanning fluorometer, carbon coulometer, and UV/Visible light spectrophotometer, in WIPP-relevant brine simulants with FA-Suw, HAal-LBr, HAal-Ald, and HAar-Suw. In addition to spectroscopic data, visible inspection proved valuable. In oversaturation experiments, humic substances were dissolved in deionized water under basic pH conditions to enhance dissolution and then added as a spike to a brine solution. In undersaturation experiments, humic substances were added directly to brine solutions and allowed to dissolve until an equilibrium was reached. In either case, an equilibrium was reached between dissolved (that is, ionic) and precipitated humic substances. The precipitated humic substances coagulated and settled by gravity. The kinetics of precipitation were sufficiently slow that several weeks were required for equilibrium to be reached. Brine solutions consisted of a NaCl matrix with various concentrations of Ca^{2+} and Mg^{2+}. The concentration of Na^{+} in the brine had little effect on solubility except at very high concentrations, but the concentration of the divalent cations had a significant impact on humic substance solubilities. Consequently, experiments were conducted with a NaCl background electrolyte concentration with concentrations of Ca and Mg ranging from 10 mM each (representative of natural WIPP brines) to 500 mM each (representative of a MgO backfill scenario). At Sandia National Laboratories, solubilities between approximately 1.5 mg/L and 2.0 mg/L were observed in systems containing 10 mM or greater Ca^{2+} and Mg^{2+}. For the calculations described below, the higher solubility value of 2.0 mg/L was used.

Site-binding capacity values were determined by titration at Florida State University for two humic substances (HAal-LBr and HAal-Ald). Those values were supplemented with values for a variety of humic substances compiled from published literature. In general, site-binding capacities for humic substances are between 3 and 6 meq OH^{-}/g, but in isolated cases are as low as about 1.5 and as high as about 9.5 meq OH^{-}/g. For the calculations described below, values of 4.65, 5.38, and 5.56 meq OH^{-}/g were used for aliphatic humic acid, aromatic humic acid, and fulvic acid, respectively. The aliphatic humic acid value was determined from HAal-LBr at Florida State University. The aromatic humic acid value was from Gorleben

(Gohy-573). The fulvic acid value represents the mean of 11 published values for fulvic acids collected in Europe (Ephraim et al. 1995).

Actinide complexation factors for Am(III) and U(VI) binding on three humic substances (FA-Suw, HAal-LBr, and HAar-Gor) were measured at Florida State University. Complexation measurements were made at measured pH_{obs} values of approximately 4.8 and 6, conditions at which the humic substances are highly deprotonated, and actinides U and Am have not undergone extensive hydrolysis reactions. Those conditions were chosen to maximize complexation between the humic substances and those actinide elements. Measurements were made in NaCl media with ionic strengths of approximately 3 and 6 molal. These experiments were completed prior to the DOE establishing the position that MgO backfill would be emplaced to sequester CO_2 and fix pcH at about 9.3. The experiments conducted at Florida State University represent conservative conditions designed to provide high-end estimates of actinide uptake by humic substances. Actinide complexation by humic substances generally decreases at basic pH values because of the reduction in actinide-complex charges due to hydrolysis reactions. In addition, the high concentrations of Mg^{2+} in solution due to the presence of MgO backfill will compete with actinides for binding sites on humic substances and reduce the actinide uptake. Florida State University reported the first and second stability constants defined as follows (square brackets represent concentration):

$$An + HS \leftrightarrow AnHS;\ \beta_{1:An} = [AnHS]/[An][HS] \qquad (6\text{-}13)$$

$$An + 2(HS) \leftrightarrow An(HS)_2;\beta_{2:An} = [An(HS)_2]/[An][HS]^2 \qquad (6\text{-}14)$$

where:

HS	=	humic substance (eq OH-/L, that is, site-binding capacity incorporated)
An	=	actinide element
$\beta_{1:An}$	=	first stability constant, for 1:1 An:humic binding
$\beta_{2:An}$	=	second stability constant, for 1:2 An:humic binding

For the calculations described below, complexation constants were selected from the most relevant experimental conditions, which were pH_{obs} 6 and 6 molal NaCl. The following stability constants reported by Florida State University were used (reported as log values), as shown in Table SOTERM-11.

Table SOTERM-11. Humic Substances Experimental Results

Humic Substance	Am^{3+} : β_1	Am^{3+} : β_2	$U(VI)O_2^{2+}$: β_1	$U(VI)O_2^{2+}$: β_2
HAal-LBr	6.09 +/- 0.05	10.46 +/- 0.12	5.91 +/- 0.16	10 43 +/- 0.19
HAal-Gor	6.02 +/- 0.04	10.40 +/- 0.10	5.35+/- 0.15	8.98 +/- 0.26
FA-Suw	4.6 +/-0.3	8.95 +/- 0.45	not measured	not measured

The Florida State University results show that there is little difference in Am(III) and $U(VI)O_2^{2+}$ uptake by aliphatic and aromatic humic acids, but that uptake by fulvic acid is significantly less. The Florida State University results also show that an increase of NaCl ionic strength from 3 to 6 has little effect on actinide uptake. Those observations aid in justifying the use of published stability constants for other actinide elements experimentally determined at lower ionic strengths and for other humic substances. On the basis of the similarities in stability constants for Am(III) and $U(VI)O_2^{2+}$ for the humic acids, Sandia National Laboratories has used the Am(III) stability constant for FA-Suw for $U(VI)O_2^{2+}$ on FA-Suw.

Stability constants for Th(IV) with several humic and fulvic acids were reported by Nash and Choppin (1980). In NaCl media at pH values between 3.95 and 5.03, those authors reported log stability constants between 9.7 and 13.2. Under basic conditions expected in the WIPP repository, it is likely that complexation of Th(IV) will be markedly less, because the dominant Th(IV)-bearing aqueous species will be $Th(OH)_4$ (aq) (Novak and Moore 1996). No reports of direct investigations of Th-complex binding on humic substances were found. For the calculations described herein, the published results from Baskaran et al. (1992) describing the distribution of Th(IV) in sea water were used. From that work, a ratio of dissolved versus colloidal Th(IV) of 6.349 was calculated, assuming that the solubility of colloidal organic material in sea water is equivalent to our measured value of humic substances in WIPP-relevant brines (that is, 2.0 mg/liter). The nature of the humic substances is likely to be dominated by aromatic humic acid, but may also contain fulvic acid.

For the calculations described herein, a log stability constant for $Np(V)O_2^+$ of 3.67 measured at pH 9 for a Gorleben humic acid (Gohy-573; Kim and Sekine 1991) was used. Results presented in Rao and Choppin (1995) for Lake Bradford humic acid and a Gorleben humic acid (Gohy-573) show little effect of pH on Np(V) stability constants, presumably because of the lack of hydrolysis of reactions for Np(V) over the pH range those authors studied. The Gorleben humic acid is aromatic in nature.

No published stability constants were found for plutonium. For the calculations described herein, an oxidation state analogy was used for the plutonium oxidation species, an approach that is conservative. Allard et al. (1980) have shown that at pH 9, Pu(IV) undergoes hydrolysis reactions to a greater extent than Th(IV), which should result in reduced complexation of Pu(IV).

An oxidation state analogy was used to develop parameter values for elements expected to have multiple oxidation states in the WIPP repository. Oxidation speciation of the actinide elements was evaluated as part of the dissolved actinide source term program. Weiner (1996) has concluded that in the WIPP repository, the following species will be present: Th(IV); U(IV) and U(VI); Np(IV) and Np(V); Pu(III) and Pu(IV); and Am(III). The relative concentrations of oxidation species of a particular element are designated by their respective solubility values. The substitutions made following the oxidation state analogy are summarized in Table SOTERM-12.

Table SOTERM-12. Oxidation State Analogy Substitutions

Required Binding Constant	Substitute	Source of Data
Th(IV)	none required	Baskaran et al. (1992)
U(IV)	Th(IV)	Baskaran et al. (1992)
U(VI)	none required	WIPP-specific data, Florida State University
Np(IV)	Th(IV)	Baskaran et al. (1992)
Np(V)	none required	Kim and Sekine (1991)
Pu(III)	Am(III)	WIPP-specific data, Florida State University
Pu(IV)	Th(IV)	Baskaran et al. (1992)
Am(III)	none required	WIPP-specific data, Florida State University

To compensate for the effects of competition for actinide complexation by the high concentrations of calcium and magnesium in repository brines in the presence of MgO backfill, stability constants for Ca^{2+} and Mg^{2+} were used in simultaneously solved equations (described below). Stability constants for Ca^{2+} and Mg^{2+} at basic pH values are not available, but several published reports provide values in the acidic range. Choppin and Shanbhag (1981) reported log stability constants of 2.25 to 3.32 for Ca^{2+} in 0.1 M NaClO4 at pH 3.9 and 5.0 for an aliphatic humic acid (Aldrich humic acid). Schnitzer and Skinner (1967) reported log binding constants ranging from 2.2 to 3.72 for Ca^{2+} in low ionic strength solutions over a pH range of 3.5 to 5.0 for fulvic acid. For Mg^{2+}, Schnitzer and Skinner (1967) reported log stability constants ranging from 1.23 to approximately 2.0 under the same experimental conditions. For the calculations, a log stability constant of 2.0 for the sum of Ca^{2+} and Mg^{2+} concentrations was used, which is a conservative value.

Binding of Ca^{2+} and Mg^{2+} to humic substances is described in the same way as Equation 6-13 above:

$$(Ca+Mg) + HS \leftrightarrow (CaMg)HS; \quad \beta_{1;Ca,Mg} = [(CaMg)HS]/[Ca+Mg][HS] \qquad (6\text{-}15)$$

where:

$\beta_{1;CaMg}$ = first stability constant, for 1:1 (Ca+Mg):humic binding (note that no second stability constants exist for divalent cation binding)

SOTERM.6.3.3.2 *Interpretation and Discussion*

Proportionality constants (PHUMCIM and PHUMSIM) describing the amount of actinide element bound to humic substances were determined from the data listed above, coupled with dissolved actinide concentrations. In addition, maximum theoretical concentrations of actinides that could be associated with humic substances (CAPHUM) were calculated from the data above.

The concentration of an actinide element of a given oxidation state was calculated by simultaneous solution of Equations 6-13 and 6-15, combined with a mass-balance expression:

$$[HS_{tot}] = [AnHS] + [(CaMg)HS] + [HS] \tag{6-16}$$

where:

$[HS_{tot}]$	=	total concentration of humic substance
$[HS]$	=	concentration of uncomplexed humic substance
$[AnHS]$	=	concentration of humic complexed with an actinide element
$[(CaMg)HS]$	=	concentration of humic complexed with divalent cations

Equation 6-13 describing the effect of two humic substances binding with one actinide ion was disregarded for these calculations, because its contribution to the total humic-bound actinide concentrations was negligible.

Rearranging Equations 6-13 and 6-15 provides:

$$[AnHS] = \beta_{1;An}\,[An]\,[HS]\,, \tag{6-17}$$

$$[(CaMg)HS] = \beta_{1;CaMg}\,[Ca+Mg]\,[HS]\,. \tag{6-18}$$

Substituting Equations 6-17 and 6-18 into Equation 6-16 results in:

$$[HS_{tot}] = \beta_{1;An}\,[An]\,[HS] + \beta_{1;\,CaMg}\,[Ca+Mg]\,[HS] + [HS]\,. \tag{6-19}$$

Rearranging Equation 6-19 provides:

$$[HS] = \frac{[HS_{tot}]}{\beta_{1;An}[An] + \beta_{1;CaMg}[Ca+Mg] + 1}\,. \tag{6-20}$$

Equations 6-17, 6-18, and 6-20 were used to calculate humic-bound actinide concentrations ([AnHS]). The resulting AnHS concentration values were then summed for actinide elements with multiple oxidation states, and then divided by the dissolved concentration of the respective actinide element. The final forms of the parameter values PHUMCIM and PHUMSIM are proportionality constants in units of "moles humic-bound colloidal actinide per mole of dissolved actinide." The proportionality values may be multiplied by the dissolved actinide concentration expressed in molarity or molality, depending on the desired final unit.

Depending on the intrusion scenario, the WIPP repository may be dominated by Castile brine or by intergranular Salado brine, resulting in different actinide solubilities, but also different

solubilities of Ca^{2+} and Mg^{2+}. Under MgO backfill conditions, solubility parameters calculated for a system buffered by brucite and magnesite were used (Siegel 1996).

Equations 6-17, 6-18, and 6-20 were used to determine humic-bound actinide concentrations ([AnHS]) for one or more humic substance types for Am(III), Th(IV), Np(V), and U(VI). The oxidation state analogy is most heavily utilized for plutonium, because stability constants for Pu(III) or Pu(IV) are not available. Concentrations of Ca^{2+} and Mg^{2+} in the Salado and Castile brines with MgO backfill were obtained from Novak and Moore (1996). In the performance assessment calculations, the humic-bound actinide concentration in the III oxidation state in Castile brine was sampled. All other humic-bound actinide concentrations were held constant.

The PHUMCIM and PHUMSIM parameters, used in conjunction with materials (idmtrls) PHUMOX3, PHUMOX4, PHUMOX5, or PHUMOX6, provide the means to calculate actinide-humic concentrations by actinide oxidation state and for intrusion scenarios involving different brines. For example, in an E1 scenario under "more reducing" conditions in the WIPP repository, PHUMCIM would be used with the following materials (idmtrls) to determine actinide-humic concentrations: thorium = PHUMOX4; uranium = PHUMOX4; neptunium = PHUMOX4; plutonium = PHUMOX3; and americium = PHUMOX3. For an E2 scenario under less reducing conditions in the WIPP repository, PHUMSIM would be used with the following idmtrls to determine actinide-humic concentrations: thorium = PHUMOX4; uranium = PHUMOX6; neptunium = PHUMOX5; plutonium = PHUMOX4; and americium = PHUMOX3.

Uncertainties due to analytical precision are small compared to uncertainties in knowledge of the dominant humic substance type, site binding densities, and actinide solubilities. The proportionality factor approach coupled with the actinide solubility model uncertainty results in an adequate representation of the uncertainty in the concentration of actinides bound by mobile humic substances.

The CAPHUM parameter simply represents the theoretical maximum concentration of actinides that can be bound by a humic substance. Based on a solubility limit concentration of humic substances of 2.0 mg/liter, and the highest site-binding capacity (for fulvic acids) of 5.56 meq OH^-/g, the theoretical maximum is 1.1×10^{-5} eq/liter. Assuming the conservative case in which actinide species are monovalent, the maximum theoretical concentration of actinides that can be bound by humic substances is 1.1×10^{-5} molar. That number is conservative, because it assumes a pool of humic substances is available for each actinide element, when in reality, actinide elements will compete for the same pool of humic substances. CAPHUM is used in an expression such as the following:

$$[\text{AnHS}] = \text{MIN}(\text{AnHS value calculated with proportionality constant}, 1.1 \times 10^{-5}) \quad (6\text{-}21)$$

in which the calculated concentration of a particular actinide is compared to the upper limit value. Parameter values for PHUMCIM, PHUMSIM, and CAPHUM are found in Appendix PAR (Table PAR-39) and Appendix SOTERM (Section SOTERM.6.3.5).

SOTERM.6.3.4 Microbes

Potentially important colloidal-sized microorganisms include bacteria, fungi, yeast, and protozoa. For the WIPP site, the focus is on the halophilic and halotolerant microbes that have been identified at the site (Brush 1990; Francis and Gillow 1994). Microbes are important to consider in performance assessments of the WIPP because they may significantly affect the characteristics of the waste stored at the WIPP, and also participate in transport of actinides. Microbes are known to actively bioaccumulate actinides intracellularly as well as act as substrates for passive extracellular sorption.

At the WIPP site, concentrations of naturally occurring microbes are on the order of 10^4 to 10^7 cells per milliliter (Francis and Gillow 1994, Table 1). In the presence of nutrients provided by WIPP waste constituents, including nitrates, sulfates, and cellulosic materials such as protective clothing and wood, the population of microbes is likely to increase. Lysis, a natural phenomenon whereby cells die and release their cell constituents to the solution, also provides a source of nutrients to microbes.

When introduced to nutrient, microbes typically follow a predictable growth curve (defined by the population number of microbes plotted as a function of time), consisting of an initial period of inactivity (very early log phase) ranging up to several days, followed by a sharp increase in growth (early log phase). That level of growth is sustained for one or more days (log phase) during which time microbial metabolites, including carboxylic acids, enzymes, and exocellular polymers, are generated. The growth rate eventually begins to decline (late log phase) due to the effects of those metabolites, limitations in nutrients or substrates, or population dynamics, and reaches a steady-state population (stationary phase). Viable microbes may aggregate to form clusters.

SOTERM.6.3.4.1 Description of Experiments

Several types of experiments were conducted to evaluate the impact of microbes in support of the WIPP colloid research program (refer to descriptions in Papenguth and Behl 1996): (1) evaluation of indigenous concentrations of microbes; (2) quantification of mobile concentrations under nutrient- and substrate-rich conditions; (3) quantification and characterization of actinide bioaccumulation by microbes; and (4) evaluation of toxicity effects of actinide elements on microbe growth.

Experiments were conducted at Brookhaven National Laboratory (BNL) and as a collaborative effort between BNL and Los Alamos National Laboratory (LANL). Evaluation of indigenous concentrations was a collaborative effort between BNL and LANL. Quantification of mobile concentrations was conducted at BNL. The bioaccumulation and

toxicity work was conducted at BNL or LANL depending on actinide element. Thorium and uranium were investigated at BNL. The other actinide elements of interest, neptunium, plutonium, and americium, were investigated at LANL under the guidance of BNL personnel.

Experiments to determine the mobile concentrations of microbes remaining suspended in the fluid column were conducted similarly to experiments previously conducted in support of the WIPP gas generation program (Brush 1990; Francis and Gillow 1994). Bacterial cultures were introduced to a solution containing nutrient and substrate, and sealed. Bacteria population was monitored over periods of several weeks or more using measurements of optical density or by direct counting of aliquots of fixed cells. An important change in protocol from previous experiments, however, is that instead of filtering the entire contents of the vessels, only the mobile cells remaining suspended in the fluid column were counted. Results of the experiments showed that the mobile concentration of microbes was a couple orders-of-magnitude less than the total concentration of microbes. The existence of indigenous microbes in Salado groundwaters has been demonstrated in previous work (Francis and Gillow 1994). As part of the WIPP colloid research program, samples of Culebra groundwater were carefully collected from the H-19 hydropad, processed, and characterized for indigenous microbes. Concentrations of naturally occurring microbes were on the order of 10^5 cells per milliliter, determined using direct counting methods.

The evaluation of indigenous concentrations of microbes and quantification of mobile concentrations provided important supporting evidence for quantifying the microbial actinide source term and for evaluating microbe-facilitated transport of actinides in the Culebra. However, the basis for developing the actual parameter values to be used in performance assessment calculations was established with bioaccumulation and toxicity experiments, referred to herein as filtration experiments. Those experiments were conducted by combining microbe cultures with various concentrations and complexes of ^{232}Th, ^{238}U, ^{237}Np, ^{239}Pu, or ^{243}Am. The actinide reagents used were thorium nitrate, thorium EDTA, uranyl(VI) nitrate, uranyl(VI) citrate, neptunyl(V) EDTA, plutonyl(V) perchlorate, plutonyl(V) EDTA, and americium EDTA. For those experiments, a pure bacterial culture (WIPP-1A) and a mixed bacterial culture (BAB) were used. Most of the experiments were conducted with the WIPP-1A culture, because of the fast growth of that pure culture. The WIPP-1A mixed culture typically reaches steady-state concentration within several days, whereas the BAB mixed culture requires several weeks. Because of the rapid response of the WIPP-1A culture, most of the experiments were conducted with that culture to expedite the research program. A complementary set of experiments were repeated with the BAB mixed culture, to evaluate the representativeness of the pure culture. Experiments were conducted over periods of 11 to 15 days for the WIPP-1A microbe culture, and up to 21 days for the BAB culture. Each experiment consisted of a subset of two or three replicate test vessels, that were sampled during the overall test interval, to provide time sequence data. In addition, replicate test vessels that were not innoculated with microbes were included in each experiment to provide a control. Sequential filtration with 0.03 μm, 0.4 μm, and 10 μm filter pore sizes was conducted on each vessel. The following size fractions were obtained as shown in Table SOTERM-13.

Table SOTERM-13. Microbe Experimental Results

Fluid Column Sample	Particle Size	Actinide Association with
not filtered	all	all forms listed below
0.22 m syringe filter, filtrate	< 0.22 μm	dissolved; lysed microbes
10 m filter, filter retentate	> 10 μm	clumped microbes
10 m filter, filtrate	< 10 μm	dissolved; dispersed microbes; lysed microbes
0.4 m filter, filter retentate	= 0.4 to 10 μm	dispersed microbes
0.4 m filter, filtrate	<0.4 μm	dissolved; lysed microbes
0.03 m filter, filter retentate	= 0.03 to 0.4 μm	lysed microbes
0.03 m filter, filtrate	< 0.03 μm	dissolved; lysed microbes

In addition to the potential actinide associations listed above, there was some evidence of the formation of inorganic precipitates in some of the experiments. The nutrient used in many experiments was phosphate (1 g PO_4^{3-} /liter), which is known to coprecipitate actinide cations. The inoculated control samples provided the means to evaluate the extent of that experimental artifact. The control samples also provided the means to assess the extent of sorption of actinides onto test vessels, sampling, and filtration equipment. All sequential filters were composed of the same material, which simplifies assessment of sorption on the filtration equipment.

The toxicity experiments were conducted as a component of the filtration experiments described above, by varying the actinide concentration, and comparing growth curves measured by optical density and/or by direct cell counting. To increase the total concentration of actinides in solution, EDTA was added in some experiments in a one-to-one molar ratio with the actinide element. That approach was taken for some Pu experiments, and all of the Th, Np, and Am experiments.

SOTERM.6.3.4.2 Interpretation and Discussion

Proportionality constants (PROPMIC) describing the amount of actinide element bound to mobile microbes were determined from the data listed above. In addition, maximum concentrations of actinides that could be associated with microbes (CAPMIC) were determined from the experimental data. Those two parameters are suitable for use in performance assessment calculations, when coupled with dissolved actinide solubility values (refer to Section SOTERM.7.2 for details).

The 0.4 μm filter retentate and 0.03 μm filtrate (acquired from the inoculated vessels, not the uninoculated control vessels) were selected to represent the microbial actinide and dissolved

actinide concentrations, respectively. The ratio between the microbial actinide and dissolved actinide, both expressed in molarity, represents the proportionality constant value used for the PROPMIC parameter. The 0.4 μm filter retentate was selected to represent the microbial fraction because nearly all of the bacteria biomass was associated with that filter. A small concentration of actinides was associated with suspected biomass trapped on the 10 μm filter, as clumped microbes, and on the 0.03 μm filter, as lysed microbes. The contribution of actinides-associated biomass consisting of clumped and lysed microbes was typically at least one order-of-magnitude less than the actinide concentration associated with the dispersed microbes collected on the 0.4 μm filter. The concentration of dissolved actinides measured from the 0.03 μm filter filtrate was used in the ratio because it provides the best indication of final dissolved actinide concentration. Representative values for PROPMIC were developed on an element-by-element basis. Results of experiments using the BAB culture were disregarded, because of their lower uptake of actinides (especially plutonium), and because of the limited number of experiments conducted with that culture. For the WIPP-1A culture, the first sampling period (2 to 4 days, but generally 3 days) was disregarded in determining proportionality constants because steady state population had not yet been reached. The remaining values were averaged arithmetically.

The filtration experiments discussed above also provided the basis for determining CAPMIC values. Final cell population numbers in the test vessels were estimated using measurements of optical density at a wavelength of 600 nm or by direct counting with epifluorescent microscopy. The magnitude of the toxicity effects was estimated by comparing final cell numbers obtained from a series of test vessels with varying actinide concentration. The direct counting technique provided the most dependable measure of cell number and was used where available. The CAPMIC value is defined as the actinide concentration in molarity at which no growth was observed. For cases where growth clearly diminished as actinide concentration increased, but the actinide concentration was not great enough to stop growth, CAPMIC values were determined by linear extrapolation of population numbers, and then adding an order-of-magnitude to account for uncertainty. On the basis of WIPP experimental results (Papenguth 1996b), it appears that the toxicity effects are due to chemical toxicity rather than radiotoxicity. Because of the high radiation levels of americium and safety considerations in the laboratory facility used, the molar concentration could not be increased to the point at which toxicity effects could be observed. Consequently no CAPMIC value is currently available for americium. CAPMIC values are used similarly to the CAPHUM values (see Equation 6-21), except that the upper limit for microbe concentration is due to toxicity rather than geometric limitations imposed by the colloid itself. Consequently, for microbes, the total concentration of mobile actinides in a performance assessment realization is used in the comparison, rather than the amount of actinides associated with the microbes.

The experiments conducted do not provide sufficient information to enable us to formulate a distribution of values for PROPMIC and CAPMIC. Therefore, single values for PROPMIC and CAPMIC are used in the performance assessment. Uncertainties due to analytical precision are small compared to uncertainties in knowledge of the microbe culture that might predominate in the WIPP repository or in the Culebra in an intrusion scenario. The

proportionality factor approach coupled with the actinide solubility model uncertainty results in an adequate description of the uncertainty in the concentration of actinides bound by mobile microbes.

Parameter values for PROPMIC and CAPMIC are summarized in Section SOTERM.6.3.5.

SOTERM.6.3.5 Summary of Parameter Values

Parameter values for CONCMIN, CONCINT, PROPMIC, CAPMIC, PHUMSIM, PHUMCIM, and CAPHUM are summarized in Table SOTERM-14.

Table SOTERM-14. Colloid Concentration Factors

	CONCMIN Concentration on Mineral Fragments[a]	CONCINT Concentration as Intrinsic Colloid[a]	PROPMIC Proportion Sorbed on Microbes[b]	CAPMIC Maximum Sorbed on Microbes[c]	Proportion Sorbed on Humics[b]		CAPHUM Maximum Sorbed on Humics[a]
					PHUMSIM Salado	PHUMCIM Castile	
Th(IV)	2.6×10^{-8}	0.0	3.1	0.0019	6.3	6 3	1.1×10^{-5}
U(IV)	2.6×10^{-8}	0.0	0.0021	0.0021	6.3	6 3	1.1×10^{-5}
U(VI)	2.6×10^{-8}	0.0	0.0021	0.0023	0.12	0.51	1.1×10^{-5}
Np(IV)	2.6×10^{-8}	0.0	12.0	0.0027	6.3	6.3	1.1×10^{-5}
Np(V)	2.6×10^{-8}	0.0	12.0	0.0027	9.1×10^{-4}	7.4×10^{-3}	1.1×10^{-5}
Pu(III)	2.6×10^{-8}	0.0	0.3	6.8×10^{-5}	0.19	1.37[d]	1.1×10^{-5}
Pu(IV)	2.6×10^{-8}	1.0×10^{-9}	0.3	6.8×10^{-5}	6.3	6.3	1.1×10^{-5}
Am(III)	2.6×10^{-8}	0.0	3.6	NA	0.19	1.37[d]	1.1×10^{-5}

[a]In units of moles colloidal actinide per liter
[b]In units of moles colloidal actinide per mole dissolved actinide
[c]In units of moles total mobile actinide per liter
[d]A cumulative distribution from 0.065 to 1.60 with a mean value of 1.1 was used
NOTE: The colloidal source term is added to the dissolved source term to arrive at a total source term. Mineral fragments were provided with distributions, but the maximum was used as described in SOTERM.7.1.3. Humic proportionality constants for III, IV, and V were provided with distributions, but only the Castile Am(III) and Pu(III) were sampled.

SOTERM.6.4 Summary

Results of the colloidal actinide investigation are used in performance assessment in three types of parameter values: (1) constant concentration values for actinides associated with mineral fragment and actinide intrinsic colloids; (2) concentration values proportional to the dissolved actinide concentration for actinides associated with microbes and humic substances;

and (3) maximum concentration values providing an upper limit for actinide concentrations associated with microbes and humic substances. The parameter values are summarized in Table SOTERM-14. Given the actinide solubilities calculated for Salado and Castile brines in the presence of MgO backfill material, the largest contributors to the mobile colloidal actinide source term are actinides associated with humic substances and microbes. The contribution from mineral fragment and actinide intrinsic colloids is comparatively small. More details can be found in the SWCF parameter record packages describing the determination of the mobile colloidal actinide source term (Papenguth 1996a,b,c,d).

SOTERM.7 Use of the Actinide Source Term in Performance Assessment

As described in the preceding sections, the actinide source term program provided the parameters that were needed to construct maximum dissolved and suspended colloidal actinide concentrations for use in modeling the mobilization and transport of actinides in the disposal system, as modeled by NUTS and PANEL. Prior to these transport calculations, however, some simplifications and manipulations (using ALGEBRA) were required as discussed in the following sections.

SOTERM.7.1 Simplifications

The DOE has concentrated on those processes that are most likely to have a significant impact on system performance. Therefore, several simplifications were used in the modeling of radionuclide mobilization in performance assessment calculations. These include

(1) using constant solubility and colloid parameters throughout the repository and regulatory period for a given realization as described in Section SOTERM.2.2,

(2) limiting the number of isotopes modeled to the ones most important to compliance (see Appendix WCA, Section WCA.3),

(3) using the chemistries of Castile and Salado brines—the end member brines—to bracket the behavior of mixed brines within the repository,

(4) sampling only the uncertain parameters having the most significant effect on repository performance

(5) combining dissolved and colloidal species for transport within the disposal system, as modeled by NUTS and PANEL.

SOTERM.7.1.1 Elements and Isotopes Modeled

Selection of isotopes for modeling transport in the disposal system with NUTS and PANEL is described in Appendix WCA, Section WCA.3. PANEL model runs included nearly all isotopes of the 6 actinides studied in the AST program: Am, Cm, Np, Pu, Th, and U. NUTS

model runs included 5 isotopes: ^{238}Pu, ^{239}Pu, ^{241}Am, ^{234}U, and ^{230}Th. The rationale for use of these isotopes is also reported by Garner (1996).

SOTERM.7.1.2 Use of Brine End Members

Brine from three sources may enter the repository, depending on the nature of future human intrusion. The general scenarios described in Chapter 6.0 (Section 6.3), and considered in the source term calculations may be categorized into three groups: (1) undisturbed performance (UP), (2) intrusion through the repository and into the Castile intersecting a pressurized brine reservoir (E1 and E1E2); and (3) intrusion through the repository but not into a pressurized brine reservoir (E2).

Under all scenarios, brine may flow from the surrounding Salado through the disturbed rock zone (DRZ), and into the repository in response to the hydraulic head difference between the repository and the surrounding formation. In scenarios where a borehole is drilled into the repository, brine may flow down the borehole from the Rustler and Dewey Lake. In scenarios where a pressurized Castile brine reservoir is intercepted, brine from the Castile may flow up the borehole into the repository. As mentioned in Section SOTERM.2.2.1, the brines in these three formations have considerably different compositions and the solubility of actinides are significantly different in each of these end member compositions. The composition of the more dilute brines of the Rustler and Dewey Lake, however, are expected to change rapidly upon entering the repository due to fast dissolution of host Salado minerals (about 93.2 percent halite and about 1.7 percent each of polyhalite, gypsum, anhydrite, and magnesite; Brush 1990) from the walls and floor of the repository. EQ3/6 calculations titrating Salado rock into dilute brines show that gypsum, anhydrite and magnesite saturate before halite. When halite saturates, the brine composition is very similar to that of Castile brine. One hundred times as much polyhalite must be added to the system before the resulting brine has a composition similar to Salado brines. These calculations indicate that if dilute brines dissolve away only the surfaces of the repository, they will obtain Castile-like compositions, but if they circulate through the Salado after saturating with halite, they may obtain compositions similar to Salado brine. Similarly, if Castile brine circulates through enough host rock, it may also approach Salado brine composition. In either case, the actual brine within the repository may be described as a mixture of the two concentrated brine end members—Salado and Castile. This mixture, however, is very hard to quantify, because it is both temporally and spatially variable. Only in the undisturbed scenario is the mixture well defined as 100 percent Salado brine over the 10,000-year regulatory period.

For a panel intersected by a borehole, the BRAGFLO calculations show that in the 10 percent of the repository represented by the BRAGFLO panel computational cells, the ratio of brine inflow that enters by the borehole versus inflow from the repository walls varies through time and depends on the sampled parameter values and scenario being considered. This ratio was the only measure of brine mixing available to the source term ALGEBRA runs in the performance assessment calculations. This ratio was quite crude because it (1) did not account for brine composition changes that occur when water was consumed by corrosion

reactions, (2) did not resolve the details of flow, diffusion and brine interaction with internal pillars and the disturbed rock zone (DRZ), and (3) was an average over one tenth of the repository. It is expected that the fraction of Salado brine will be quite high in areas of the repository distant from the borehole and the fraction will be much lower near the borehole. Because radionuclide travel up the borehole is required for significant release, it is the solubility of radionuclides near the borehole that is most important. Given these uncertainties, the DOE decided to calculate radionuclide solubilities using the Castile end member composition for scenarios in which a borehole penetrates a brine reservoir and Salado end member composition for scenarios where it does not.

SOTERM.7.1.3 Sample Uncertain Parameters

Distributions of parameter values for up to 30 source-term parameters are available, but many of these are expected to have very limited impact on disposal system performance. The most important parameters are expected to be the oxidation state parameter and the solubilities of Pu(III), Pu(IV), and Am(III) in the two brine end members.

A single distribution (Figures SOTERM-6 and SOTERM-7) was provided for modeling the solubility of all oxidation states of all actinides in both brines. However, the amount of correlation between the solubilities of the actinides was uncertain. Some factors that cause uncertainty in the solubility affect all oxidation states of all actinides similarly and some factors will affect only some actinides or some oxidation states. For example, uncertainties in the sulfate concentrations will have more effect in the uncertainty of the solubility of the actinides in the IV oxidation state, while uncertainties in the ionic strength has a more generalized effect of increasing the uncertainty in the stability of any highly charged species. In nature, solubilities show correlation due to reduction-oxidation effects as well as compositional effects. It is therefore expected that solubilities within the WIPP should show some correlation, but not 100 percent correlation.

The use of the end member brines in the calculations results in a correlation of solubilities due to ionic strength and major ion effects, and the use of the oxidation state parameter results in a correlation due to reduction-oxidation effects. The DOE assumes these effects (that is, ionic strength, major ions, and reduction-oxidation state) encompass the major correlations and therefore impose no further correlations. A better estimate of this correlation would be necessary for more detailed chemical modeling, but for use in performance assessment, this decision is not very important. With nine possible element-oxidation state combinations (Am(III), Cm(III), Np(IV), Np(V), Pu(III), Pu(IV), Th(IV), U(IV), and U(VI)), and two brines, a 0 percent correlation implies 18 independent samples of the distribution.

The parameters to be sampled were selected based on expectations of their significance of effect on disposal system performance.

- A 100 percent correlation was made between Am and Cm dissolved solubilities. Only the parameters for Am were sampled, and these were copied for Cm.

- Np solubilities were not sampled because Np does not have a very large EPA unit during the 10,000-year regulatory period (see Appendix WCA, Section WCA.3, for discussion of EPA unit and the relative importance of Np).
- The solubilities of U(IV) and Th(IV) in Castile brine were not sampled because (1) the EPA units of U and Th are only a little larger than the EPA unit of Np during the regulatory period (Garner 1996), and (2) the solubility of the IV oxidation state in Castile brine is low enough that it cannot adversely affect system performance.
- The actinide concentration on mineral fragment parameters was not sampled because the concentrations of actinides that may be mobilized on mineral fragments were in most cases much lower that the possible concentrations of dissolved actinides.
- Of the humic acid proportionality constants, only the one for the III oxidation state in Castile brine was sampled because it was high and it applied to significant elements (Pu and Am).

Parameters not sampled were fixed at a maximum reasonable value during the calculations.

Twelve parameters were sampled in the performance assessment for the source term (see Appendix PAR):

Material Name	Parameter Name
SOLAM3	SOLSIM, SOLCIM
SOLPU3	SOLSIM, SOLCIM
SOLPU4	SOLSIM, SOLCIM
SOLU4	SOLSIM
SOLU6	SOLSIM, SOLCIM
SOLTH4	SOLSIM
GLOBAL	OXSTAT
PHUMOX3	PHUMCIM

where
SOLAM3 = distribution parameter for SOLubility of AM(III),
SOLSIM = SOLubility in Salado brine, Inorganic only, $Mg(OH)_2/MgCO_3$ buffer,
SOLCIM = SOLubility in Castile brine, Inorganic only, $Mg(OH)_2/MgCO_3$ buffer,
OXSTAT = OXidation STATe parameter,
PHUMOX3 = the Proportionality constant for HUMic colloids and actinides in the +3 OXidation state,
PHUMCIM = the Proportionality constant for HUMic colloids in Castile brine, Inorganic only, $Mg(OH)_2/MgCO_3$ buffer.

SOTERM.7.1.4 Combining the Transport of Dissolved and Colloidal Species in the Salado Formation

Dissolved and colloidal species may transport differently because of different diffusion rates, sorption onto stationary materials, and size exclusion effects (filtration and hydrodynamic

chromatography). With maximum molecular diffusion coefficients of about 4 x 10^{-10} meters squared per second, actinides are estimated to diffuse about 10 meters in 10,000 years, a negligible distance. Sorption and filtration have beneficial but unquantifiable effects on performance. Hydrodynamic chromatography may increase colloid transport over dissolved transport by at most a factor of 2 for theoretically perfect colloid transport conditions. In real situations, the increase is much less. Given the small or beneficial nature of these effects, the DOE did not model them in the performance assessment calculations of radionuclide transport.

Because there was no modeled mechanism to differentiate dissolved from colloidal species, the DOE combined them for transport within the Salado. In the modeling of transport within the Culebra, however, these simplifications were not appropriate. While transport within the repository is through at most hundreds of meters of poorly defined waste that is undergoing decomposition, transport through the Culebra is over kilometers in a relatively homogeneous (as compared to waste) fractured dolomite. Diffusion of radionuclides into, and sorption on, a dolomite matrix have been shown by sensitivity analysis (WIPP Performance Assessment Department 1992) to be processes important in performance assessment. Therefore, the mobilized actinide delivered to the Culebra by Salado transport codes was separated into its five species (dissolved, humic, microbe, mineral fragment, intrinsic colloid).

SOTERM.7.2 Construction of Source Term

The parameters required for constructing the source term were (1) modeled solubilities for four oxidation states in each brine end member, (2) a distribution to be used around the modeled solubility values, (3) a scheme for assigning sampled dominant oxidation states, (4) colloidal concentrations or proportionality constants for the 5 actinides or the 4 oxidation states for each of four colloid types, and (5) caps on the actinide concentrations that may be carried on two colloid types. Use of these parameters in the performance assessment calculations required combining these into a single effective solubility or maximum concentration for each modeled actinide. The term effective solubility is used for the maximum combined mobilized actinide concentration due to dissolved and colloidal species, because the NUTS and PANEL codes use these numbers for each actinide as if they were solubilities. The maximum is not the maximum of the distribution, but is called the maximum because the concentration may be lower due to inventory limits. Both NUTS and PANEL assume that the actinides instantly mobilize up to this effective solubility limit as long as sufficient inventory is available in the computational cell for this to occur. When the inventory is not sufficient, the actual mobilized concentration will be lower and is said to be inventory limited. The calculation of the effective solubilities was performed prior to NUTS and PANEL using ALGEBRA, for each of 100 sampled realizations, as shown in Figure SOTERM-9.

All the source term parameter values and their distributions were entered into the performance assessment parameter database. For the sampled parameters, the LHS code read the distribution information from the performance assessment parameter database and created 100

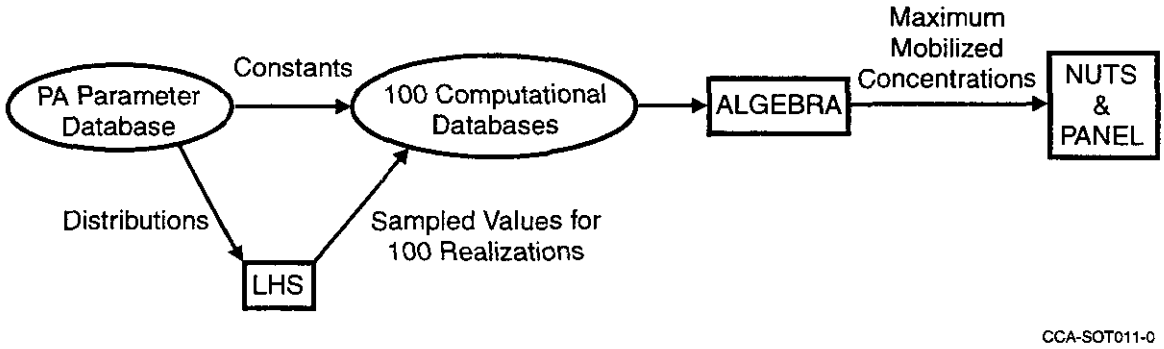

Figure SOTERM-9. Calculations Performed by ALGEBRA for Each Replicate of 100 Realizations to Produce Effective Solubilities for Each Modeled Actinide

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sampled values for each. These values were combined with the constant value parameters and stored in computational databases for each of the 100 realizations, which comprised one replicate. For each realization, ALGEBRA read both the constant and sampled values for all the source term parameters, and constructed effective solubilities for NUTS and PANEL, as shown below. This process was repeated for scenarios using Salado end-member effective solubilities and for scenarios using Castile end-member effective solubilities. (Parameters that are sampled and values derived from them are indicated by italics. Parameters read by ALGEBRA are in bold.)

Dissolved = **Model Solubility** * $10^{\textit{Sampled from Solubility Distribution}}$

Humic = *Dissolved* * ***Proportionality Constant***
if *Dissolved* * ***Prop. Const.*** < **Humic Cap**, otherwise
Humic = **Humic Cap**

Microbe = *Dissolved* * **Proportionality Constant**
if the *Total Mobile* < **Microbe Cap**, otherwise
Microbe = **Microbe Cap**

Mineral = **Database Concentration**

Intrinsic = **Database Concentration**

Total Mobile = *Dissolved* + *Humic* + *Microbe* + Mineral + Intrinsic

For actinides with more than one oxidation state, the above procedure is performed for each oxidation state, and the final total mobile concentration is set based on the oxidation state parameter:

Total Mobile = Total Mobile (lower oxidation state) if OXSTAT $\leq$ 0.5
= Total Mobile (higher oxidation state) if OXSTAT > 0.5

where OXSTAT is the oxidation state parameter that is sampled uniformly from 0 to 1.

For example, for one realization, in Salado brine, the sampled value for OXSTAT was 0.9 so Pu would be present in the IV state. The sample of the solubility distribution was 0.8 for the modeled solubility for the IV state, which has a model solubility of 4.4×10^{-6}. The humic proportionality constant for the IV oxidation state in Salado brine is 6.3, the microbe proportionality constant for Pu is 0.3, the humic cap is 1.1×10^{-5} M, the microbe cap for Pu is 2.1×10^{-3}, the actinide on mineral fragment concentration is 2.6×10^{-8}, and the Pu intrinsic colloid concentration is 1×10^{-9}.

For this realization, the maximum concentration of dissolved plutonium used by performance assessment would be:

Maximum concentration of dissolved Pu: $C_{Pu} = (4.4 \times 10^{-6})(10^{0.8}) = 2.8 \times 10^{-5}$ mole/liter

(This example has been rounded to two significant figures, although performance assessment would not round at this intermediate point.) C_{Pu} is the maximum concentration of all combined isotopes of Pu.

The maximum humic complexed plutonium would be:

$$(2.8 \times 10^{-5} \text{ mole/liter})(6.3 \text{ moles adsorbed per mole}) = 1.8 \times 10^{-4} \text{ moles/liter}$$

This value, however, exceeds the cap for humic-mobilized plutonium, 1.1×10^{-5} mole/liter. Therefore, in this case, the cap would be used for the maximum humic mobilized actinide concentration.

The maximum microbial mobilized plutonium would be:

$$(2.8 \times 10^{-5} \text{ mole/liter})(0.3 \text{ moles bioaccumulated per mole}) = 8.3 \times 10^{-6} \text{ moles/liter}$$

which is less than the cap.

The total maximum plutonium concentration or effective solubility for this realization would then be the sum of the dissolved and colloidal actinides:

Dissolved + *Humic* + *Microbe* + Mineral + Intrinsic

$$2.8 \times 10^{-5} + 1.1 \times 10^{-5} + 8.3 \times 10^{-6} + 2.6 \times 10^{-8} + 1.0 \times 10^{-9} = 4.7 \times 10^{-5} \text{ moles/liter}$$

ALGEBRA also calculates the fraction of each actinide that is mobilized by the 5 different mechanisms as follows:

Fraction dissolved = Dissolved/Total Mobile
Fraction on humics = Humic/Total Mobile
Fraction in/on microbes = Microbe/Total Mobile
Fraction on mineral fragments = Mineral/Total Mobile
Fraction as intrinsic colloid = Intrinsic/Total Mobile

The total mobile concentration and mobile fractions are then copied from Am to Cm. In addition, the ALGEBRA run also combines isotopes (Section WCA.3.2; Garner 1996) for the NUTS and SECOTP2D transport codes. For example, the curies of ^{233}U are added to the curies of ^{234}U and the uranium solubility is decreased by a factor of 100 to account for the shared solubility with the low activity ^{238}U, which is not modeled, enabling NUTS to properly model the effect of the uranium isotopes on compliance using the single "lumped" isotope ^{234}U.

The output of the ALGEBRA calculations are computational databases that contain the effective solubilities and effective inventories. NUTS and PANEL both assume instantaneous dissolution and colloidal mobilization up to the effective solubility limit when sufficient inventory is present, as discussed in Chapter 6.0 (Section 6.4.13). Table SOTERM-15 shows the total effective solubilities obtained when median parameter values are used.

Table SOTERM-15. Log Molar Total Maximum Mobilized Concentrations Using Median Parameter Values

Brine	Am(III)	Pu(III)	Pu(IV)	U(IV)	U(VI)	Th(IV)	Np(IV)	NP(V)
Salado	-5.64	-6.14	-4.80	-4.84	-5.10	-4.59	-4.17	-4.52
Castile	-6.47	-6.77	-7.19	-7.16	-4.96	-7.05	-6.85	-4.54

REFERENCES

Alexander, A.E., and P. Johnson. 1949. *Colloid Science*. New York, NY: Oxford University Press. Vol. 1.

Allard, B., H. Kipatsi, and J. O. Liljenzin. 1980. "Expected Species of Uranium, Neptunium and Plutonium in Neutral Aqueous Solutions," *Journal of Inorganic Nuclear Chemistry*. Vol. 42, no. 7, 1015-1027.

Avogadro, A., and G. de Marsily. 1984. "The Role of Colloids in Nuclear Waste Disposal," *Scientific Basis for Nuclear Waste Management VII, Materials Research Society Symposia Proceedings, Boston, MA, November 14-17, 1983*. Ed. G.L. McVay. New York, NY: North-Holland. Vol. 26, 495-505.

Baes, C.F., Jr., and R.E. Mesmer. 1976. *The Hydrolysis of Cations*. New York, NY: Wiley Interscience.

Baskaran, M., P. H. Santschi, G. Benoit, and B. D. Honeyman. 1992. "Scavenging of Thorium Isotopes by Colloids in Seawater of the Gulf of Mexico," *Geochimica et Cosmochimica Acta*. Vol. 56, no. 9, 3375-3388.

Bates, J.K., J.P. Bradley, A. Teetsov, C.R. Bradley, and M. Buchholtz. 1992. "Colloid Formation During Waste Form Reaction: Implications for Nuclear Waste Disposal," *Science*. Vol. 256, no. 5057, 649-561.

Brush, L.H. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant*. SAND90-0266. Albuquerque, NM: Sandia National Laboratories. WPO 26015.

Buckau, G., R. Stumpe, and J.I. Kim. 1986. "Americium Colloid Generation in Groundwaters and Its Speciation by Laser-Induced Photoacoustic Spectroscopy," *Journal of the Less-Common Metals*. Vol. 122, 555-562.

Buddemeier, R.W., and J.R. Hunt. 1988. "Transport of Colloidal Contaminants in Groundwater: Radionuclide Migration at the Nevada Test Site," *Applied Geochemistry*. Vol. 3, no. 5, 535-548.

Bynum, R. V. May 23, 1996. Memo to M. S. Tierney and C. Stockman. "Update of Uncertainty Range and Distribution for Actinide Solubilities to be Used in CCA NUTS Calculation." WPO 35835.

Choppin, G.R. 1983. "Solution Chemistry of the Actinides," *Radiochimica Acta*. Vol. 32, no. 1-3, 43-53.

Choppin, G. R. 1988. Unpublished Letter to L. H. Brush, December 29, 1988, Tallahassee, FL. (Copy on file at Sandia WIPP Central Files.)

Choppin, G. R., and P. M. Shanbhag. 1981. "Binding of Calcium by Humic Acid," *Journal of Inorganic and Nuclear Chemistry*. Vol. 43, no. 5, 921–922.

Clark, D. L. and Tait, C. D. 1996. Monthly Reports Under SNL Contract AP2274, Sandia WIPP Central File A:WBS 1.1.10.1.1. These data are qualified under LANL QAPjP CST-OSD-QAP1-001/0. WPO 31106.

Clark, D.L., D.E. Hobart, and M.P. Neu. 1995. "Actinide Carbonate Complexes and Their Importance in Actinide Environmental Chemistry," *Chemical Reviews*. Vol. 95, no. 1, 25-48.

Cleveland, J.M. 1979a. *The Chemistry of Plutonium*. La Grange Park, IL: American Nuclear Society.

Cleveland, J.M. 1979b. "Critical Review of Plutonium Equilibria of Environmental Concern," *Chemical Modeling in Aqueous Systems: Speciation, Sorption, Solubility, and Kinetics, 176th Meeting of the American Chemical Society, Miami Beach, FL, September 11-13, 1978*. Ed. E.A. Jenne. Washington, DC: American Chemical Society. 321-338.

Comans, R.N.J., and J.J. Middelburg. 1987. "Sorption of Trace Metals on Calcite: Applicability of the Surface Precipitation Model," *Geochimica et Cosmochimica Acta*. Vol. 51, no. 9, 2587-2591.

Cotton, F.A., and G. Wilkinson. 1988. *Advanced Inorganic Chemistry*. 5th ed. New York, NY: John Wiley & Sons.

DOE (U.S. Department of Energy). 1996. *Transuranic Waste Baseline Inventory Report (Revision 3)*. DOE/CAO-95-1121. Carlsbad, NM: U.S. Department of Energy.

Drez, P.E. 1991. "Preliminary Nonradionuclide Inventory of CH-TRU Waste,"*Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 3: Reference Data*. WIPP Performance Assessment Division Eds. R.P. Rechard, A.C. Peterson, J.D. Schreiber, H.J. Iuzzolino, M.S. Tierney, and J.S. Sandha. SAND91-0893/3. Albuquerque, NM: Sandia National Laboratories, A-43 through A-53.

Duan, Z., N. Møller, J. Greenberg, and J.H. Weare. 1992. "The Prediction of Methane Solubility in Natural Waters to High Ionic Strengths from 0 to 250°C and from 0 to 1600 bar," *Geochimica et Cosmochimica Acta*. Vol. 56, no. 4, 1451-1460.

Ephraim, J. H., C. Petersson, M. Norden, and B. Allard. 1995. "Potentiometric Titrations of Humic Substances: Do Ionic Strength Effects Depend on the Molecular Weight?" *Environmental Science and Technology*. Vol. 29, no. 3, 622-628.

Eugster, H.P., C.E. Harvie, and J.H. Weare. 1980. "Mineral Equilibria in the Six-component Seawater System, Na-K-Mg-Ca-SO_4-Cl-H_2O, at 25°C," *Geochimica et Cosmochimica Acta*. Vol. 44, no. 9, 1335-1347. WPO 30424.

Fanghänel, Th., V. Neck, and J.I. Kim. 1995. "Thermodynamics of Neptunium(V) in Concentrated Salt Solutions: II. Ion Interaction (Pitzer) Parameters for Np(V) Hydrolysis Species and Carbonate Complexes," *Radiochimica Acta*. Vol. 69, no. 3, 169-176. WPO 40233.

Felmy, A.R., and J.H. Weare. 1986. "The Prediction of Borate Mineral Equilibria in Natural Waters, Application to Searles Lake, California," *Geochimica et Cosmochimica Acta*. Vol. 50, no. 12, 2771-2783. WPO 30421.

Felmy, A.R., and D. Rai. 1992. "An Aqueous Thermodynamic Model for a High Valence 4:2 Electrolyte Th^{4+}-SO in the System Na^+-K^+-Li^+-NH-SO-HSO-H_2O to High Concentration," *Journal of Solution Chemistry*. Vol. 21, no. 5, 407-423. WPO 40224.

Felmy, A. R., D. Rai, J. A. Schramke, and J. L. Ryan. 1989. "The Solubility of Plutonium Hydroxide in Dilute Solution and in High-Ionic-Strength Chloride Brines," *Radiochimica Acta*. Vol. 48, no. 112, 29-35.

Felmy, A. R., D. Rai, and R. W. Fulton. 1990. "The Solubility of $AmOHCO_3$(c) and the Aqueous Thermodynamics of the System Na^+-H CO_3--$(CO_3)^{2-}$-OH-H_2O," *Radiochimica Acta*. Vol. 50, no. 4, 193-204.

Felmy, A.R., D. Rai, and M.J. Mason. 1991. "The Solubility of Hydrous Thorium(IV) Oxide in Chloride Media: Development of an Aqueous Ion-Interaction Model," *Radiochimica Acta*. Vol. 55, no. 4, 177-185. WPO 40225.

Felmy, A.R., D. Rai, S.M. Sterner, M.J. Mason, N.J. Hess, and S.D. Conradson. 1996. "Thermodynamic Models for Highly Charged Aqueous Species: The Solubility of Th(IV) Hydrous Oxide in Concentrated $NaHCO_3$ and Na_2CO_3 Solutions." In preparation. (Copy on file in the Sandia WIPP Central Files. A:1.1.10.1.1: TO: QA: Inorganic (IV) Actinide Thermodynamic Data, WPO 40226, 8/14/96).

Francis, A.J., and J.B. Gillow. 1994. *Effects of Microbial Processes on Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions. Progress Report through 1992*. SAND93-7036. Albuquerque, NM: Sandia National Laboratories. WPO 26555.

Garner, J. March 15, 1996. "Radioisotopes to Be Used in the 1996 CCA Calculations." Memorandum to Christine Stockman. WPO 35202.

Grenthe, I., and H. Wanner. 1992. *Guidelines for the Extrapolation to Zero Ionic Strength.* NEA-TBD-2, Revision 2, Gif-sur-Yvette, France: OECD Nuclear Energy Agency, Data Bank. WPO 21109.

Harvie, C.E., N. Møller, and J.H. Weare. 1980a. "The Prediction of Mineral Solubilities in Natural Waters, The Na-K-Mg-Ca-Cl-SO_4-H_2O System from Zero to High Concentration at 25°C," *Geochimica et Cosmochimica Acta.* Vol. 44, no. 7, 981-997. WPO 30423.

Harvie, C.E., J.H. Weare, L.A. Hardie, and H.P. Eugster. 1980b. "Evaporation of Seawater: Calculated Mineral Sequences," *Science.* Vol. 208, no. 4443, 498-500.

Harvie, C.E., N. Møller, and J.H. Weare. 1984. "The Prediction of Mineral Solubilities in Natural Waters, The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_2-H_2O System to High Ionic Strengths at 25°C," *Geochimica et Cosmochimica Acta.* Vol. 48, no. 4, 723-751. WPO 30422.

Hiemenz, P.C. 1986. *Principles of Colloid and Surface Chemistry.* 2nd ed. New York, NY: Marcel Dekker, Inc.

Hirtzel, C.S., and R. Rajagopalan. 1985. *Colloidal Phenomena. Advanced Topics.* Park Ridge, NJ: Noyes Publications.

Hobart, D.E. 1990. "Actinides in the Environment," *Proceedings of the Robert A. Welch Foundation Conference on Chemical Research, No., XXXIV: 50 Years With Transuranium Elements, Houston, TX, October 22-23, 1990.* Vol. 34, 378-436.

Hobart, D.E., and R. Moore. 1996. "Analysis of Uranium (VI) Solubility Data for WIPP Performance Assessment: Implementation of Analysis Plan AP-028." Copy on file in Sandia WIPP Central File. WPO 39856 (5/28/96).

Hobart, D. E., K. Samhoun, and J. R. Peterson. 1982. "Spectroelectrochemical Studies of the Actinides: Stabilization of Americium (IV) in Aqueous Carbonate Solution," *Radiochimica Acta.* Vol. 31, no. 3/4, 139-145.

Hobart, D.E., C.J. Bruton, F.J. Millero, I-Ming Chou, K.M. Trauth, and D.R. Anderson. 1996. *Estimates of the Solubilities of Waste Element Radionuclides in Waste Isolation Pilot Plant Brines: A Report by the Expert Panel on the Source Term.* SAND96-0098. Albuquerque, NM: Sandia National Laboratories.

Horita, J., T. J. Friedman, B. Lazar, and H.D. Holland. 1991. "The Composition of Permian Seawater," *Geochimica et Cosmochimica Acta.* Vol. 55, no. 2, 417-432.

Hunter, R.J. 1991-1992. *Foundations of Colloid Science*. Reprinted. New York, NY: Oxford University Press. Vols. I-II.

Johnson, G.L., and L.M. Toth. 1978. *Plutonium(IV) and Thorium(IV) Hydrous Polymer Chemistry*. ORNL/TM-6365. Oak Ridge, TN: Oak Ridge National Laboratory, Chemistry Division.

Katz, J.J., G.T. Seaborg, and L.R. Morss, eds. 1986. *The Chemistry of the Actinide Elements*. 2nd ed. New York, NY: Chapman and Hall. Vols. 1-2.

Keller, C. 1971. *The Chemistry of the Transuranium Elements*. Weinheim, Germany: Verlag Chemie, GmbH.

Kim, J.I. 1992. "Actinide Colloid Generation in Groundwater," *Radiochimica Acta*. Vol. 52/53, pt. 1, 71-81.

Kim, J.I. 1994. "Actinide Colloids in Natural Aquifer Systems," *MRS Bulletin, A Publication of the Materials Research Society*. Vol. 19, no. 12, 47-53.

Kim, J.-I., and T. Sekine. 1991. "Complexation of Neptunium(V) with Humic Acid," *Radiochimica Acta*. Vol. 55, no. 4, 187-192.

Kim, J.I., M. Bernkopf, Ch. Lierse, and F. Koppold. 1984a. "Hydrolysis Reactions of Am(III) and Pu(VI) Ions in Near-Neutral Solutions," *Geochemical Behavior of Disposed Radioactive Waste*. Eds. G.S. Barney, J.D. Navratil, and W.W. Schulz. ACS Symposium Series 246. Washington, DC: American Chemical Society. 115-134.

Kim, J.I., G. Buckau, F. Baumgärtner, H.C. Moon, and D. Lux. 1984b. "Colloid Generation and the Actinide Migration in Gorleben Groundwaters," *Scientific Basis for Nuclear Waste Management VII, Materials Research Society Symposia Proceedings, Boston, MA, November 14-17, 1983*. Ed. G.L. McVay. New York, NY: North-Holland. Vol. 26, 31-40.

Kim, J.I., Ch. Apostolidis, G. Buckau, K. Bueppelmann, B. Kanellakopulos, Ch. Lierse, S. Magirius, R. Stumpe, I. Hedler, Ch. Rahner, and W. Stoewer. 1985. *Chemisches Verhalten von Np, Pu und Am in verschiedenen knozentrierten Salzloesunger = Chemical Behaviour of Np, Pu, and Am in Various Brine Solutions*. RCM 01085. Munich, Germany: Institut für Radiochemie der Technische Universitaet Muenchen. (Available from National Technical Information Service, 555 Port Royal Road, Springfield, VA 22161, 703/487-4650 as DE857 2334.)

Korpusov, G.V., E.N. Patrusheva, and M.S. Dolidze. 1975. "The Study of Extraction Systems and the Method of Separation of Trivalent Transuranium Elements Cm, Bk, and Cf," *Soviet Radiochemistry*. Vol 17, no. 1-6, 230-236.

Kraus, K.A. 1956. "Hydrolytic Behavior of the Heavy Elements," *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, August 8-20, 1955.* New York, NY: United Nations. Vol. 7, 245-257.

Larson, K.L., March 13, 1996. "Brine Waste Contact Volumes for Scoping Analysis of Organic Ligand Concentration." Memorandum to R. V. Bynum. WPO 30644.

Laul, J.C., M.R. Smith, and N. Hubbard. 1985. "Behavior of Natural Uranium, Thorium and Radium Isotopes in the Wolfcamp Brine Aquifers, Palo Duro Basin, Texas," *Scientific Basis for Nuclear Waste Management, Materials Research Society Symposia Proceedings, Boston, MA, November 26-29, 1984.* Eds. C.M. Jantzen, J.A. Stone, and R.C. Ewing. Pittsburgh, PA: Materials Research Society. Vol. 44, 475-482.

Lieser, K., B. Gleitsmann, S. Peschke, and T. Steinkopff. 1986a. "Colloid Formation and Sorption of Radionuclides in Natural Systems," *Radiochimica Acta.* Vol. 40, no. 1, 39-47.

Lieser, K., B. Gleitsmann, and T. Steinkopff. 1986b. "Sorption of Trace Elements or Radionculides in Natural Systems Containing Groundwater and Sediments," *Radiochimica Acta.* Vol. 40, no. 1, 33-37.

Lieser, K.H., A. Ament, R. Hill, R.N. Singh, U. Stingl, and B. Thybusch. 1990. "Colloids in Groundwater and Their Influence on Migration of Trace Elements and Radionuclides," *Radiochimica Acta.* Vol. 49, no. 2, 83-100.

Lieser, K.H., R. Hill, U. Mühlenweg, R.N. Singh, T. Shu-De, and Th. Steinkopff. 1991. "Actinides in the Environment," *Journal of Radioanalytical and Nuclear Chemistry, Articles.* Vol. 147, no. 1, 117-131.

Lyklema, J. 1978. "Surface Chemistry of Colloids in Connection with Stability," T*he Scientific Basis of Flocculation.* Ed. K.J. Ives. NATO Advanced Study Institute Series, Series E, Volume E27. Alphen aan den Rijn: Sijthoff & Noordhoff. 3-36.

Maiti, T.C., M.R. Smith, and J.C. Laul. 1989. "Colloid Formation Study of U, Th, Ra, Pb, Po, Sr, Rb, and Cs in Briny (High Ionic Strength) Groundwaters: Analog Study for Waste Disposal," *Nuclear Technology.* Vol. 84, no. 1, 82-87.

Martell, A.E., and R.M. Smith. 1982. *Critical Stability Constants, Volume 5: First Supplement.* New York, NY: Plenum Press.

Martinot, L. and J. Fuger. 1985. "The Actinides," *Standard Potentials in Aqueous Solution.* Eds. A.J. Bard, R. Parsons, and J. Jordan. New York, NY: Marcel Dekker. 631-674.

McCarthy, J.F., and J.M. Zachara. 1989. "Subsurface Transport of Contaminants," *Environmental Science & Technology*. Vol. 23, no. 5, 496-502.

Moore, R.C. Feburary 22, 1996. "Model Parameters for Deprotonation of Lactic Acid, Citric Acid, Oxalic Acid, and EDTA and Complexation of Acetate, Lactate, Citrate, Oxalate, and EDTA with Mg^{2+}, NpO_2^{+}, Am^{3+}, Th^{4+}, and UO_2^{2+} in NaCl Media." Memorandum to C.F. Novak. (Copy on file in the Sandia WIPP Central Files A:1.1.1.1.4: TD:QA; WPO 35307).

Nash, K.L., and G.R. Choppin. 1980. "Interaction of Humic and Fulvic Acids with TH(IV)," *Journal of Inorganic and Nuclear Chemistry*. Vol. 42, no. 7, 1045–1050.

National Institute of Standards and Technology. 1995. *NIST Standard Reference Materials Catalog, 1995-1996*. Washington, DC: Commerce Department, Technology Administration, National Institute of Standards and Technology. 25-38.

Neck, V., J.I. Kim, and B. Kanellakopulos. 1992. "Solubility and Hydrolysis Behavior of Neptunium (V)," *Radiochimica Acta*. Vol. 56, no. 1, 25-30.

Neck, V., W. Runde, and J.I. Kim. 1995. "Solid-Liquid Equilibria of Np(V) in Carbonate Solutions at Different Ionic Strengths: II," *Journal of Alloys and Compounds*. Vol. 225, 295-302.

Neretnieks, I. 1982. *The Movement of a Redox Front Downstream From a Repository for Nuclear Waste*. KBS Report TR 82-16. Stockholm: Svensk Kärnbränsleforsorjning AB.

Nitsche, H. 1987. "Effects of Temperature on the Solubility and Speciation of Selected Actinides in Near-Neutral Solution," *Inorganica Chimica Acta*. Vol. 127, no. 1, 121-128.

Nitsche, H., and N.M. Edelstein. 1985. "Solubilities and Speciation of Selected Transuranium Ions. A Comparison of a Non-complexing Solution with a Groundwater from the Nevada Tuff Site," *Radiochimica Acta*. Vol. 39, no. 1, 23-33.

Nitsche, H., K. Roberts, R.C. Gatti, T. Prussin, K. Becraft, S.C. Leung, S.A. Carpenter, and C.F. Novak. 1992. *Plutonium Solubility and Speciation Studies in a Simulant of Air Intake Shaft Water from the Culebra Dolomite at the Waste Isolation Pilot Plant*. SAND92-0659. Albuquerque, NM: Sandia National Laboratories. WPO 23480.

Nitsche, H., K. Roberts, R. Xi, T. Prussin, K. Becraft, I. Al Mahamid, H.B. Silber, S.A. Carpenter, R.C. Gatti, and C.F. Novak. 1994. "Long Term Plutonium Solubility and Speciation Studies in a Synthetic Brine," *Radiochimica Acta, Special Issue: Chemistry and Migration Behaviour of Actinides and Fission Products in the Geosphere, Proceedings of the Fourth International Conference, Charleston, SC, December 12-17, 1993*. Munich: R. Oldenbourg Verlag. Vol. 66/67, 3-8. WPO 21107.

Novak, C.F. 1995. *The WIPP Actinide Source Term: Test Plan for the Conceptual Model and the Dissolved Concentration Submodel.* SAND95-1985. Albuquerque, NM: Sandia National Laboratories. WPO 27860.

Novak, C.F., and R.C. Moore, March 28, 1996. "Estimates of Dissolved Concentrations for III, IV, V, and VI Actinides in Salado and Castile Brine Under Anticipated Repository Conditions." SNL Tech Memo. (Copy on file in the Sandia WIPP Central File A: WBS 1.2.0.7.1; WBS 1.1.10.1.1: WPO 36207.)

Novak, C.F., R.C. Moore, and R.V. Bynum. 1996. "Prediction of Dissolved Actinide Concentrations in Concentrated Electrolyte Solutions: A Conceptual Model and Model Results for the Waste Isolation Pilot Plant (WIPP)," *Proceedings of the International Conference on Deep Geological Disposal of Radioactive Waste, Winnipeg, Manitoba, Canada, September 16-19, 1996.*

Papenguth, H.W. 1996a: H.W. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7, 1996: Attachment A: Rationale for Definition of Parameter Values for Actinide Intrinsic Colloids." WPO 35852.

Papenguth, H.W. 1996b: H.W. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7, 1996: Attachment A: Rationale for Definition of Parameter Values for Microbes." WPO 35856.

Papenguth, H.W. 1996c: H.W. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7, 1996: Attachment A: Rationale for Definition of Parameter Values for Humic Substances." WPO 35855.

Papenguth, H.W. 1996d: H.W. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7, 1996: Attachment A: Rationale for Definition of Parameter Values for Mineral Fragment Type Colloids." WPO 35850.

Papenguth, H.W., and Y.K. Behl. 1996. "Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant." SNL Test Plan TP 96-01. (Copy on file in the Sandia WIPP Central File A:1.1.10.2.1. PUB:QA; WPO 31337.)

Pitzer, K.S., ed. 1991. *Activity Coefficients in Electrolyte Solutions.* 2nd ed. Boca Raton, FL: CRC Press.

Pryke, D.C., and J.H. Rees. 1986. "Understanding the Behaviour of the Actinides Under Disposal Conditions: A Comparison between Calculated and Experimental Solubilities," *Radiochimica Acta.* Vol. 40, no. 1, 27-32.

Rai, D., and R.G. Strickert. 1980. "Chemical Aspects of Medium- and Long-Term Radioactive Waste Disposal," *Transactions of the American Nuclear Society and the European Nuclear Society.* Vol. 35, 185-186.

Rai, D., and J.L. Swanson. 1981. "Properties of Plutonium(IV) Polymer of Environmental Importance," *Nuclear Technology.* Vol. 54, no. 1, 107-111. WPO 30420.

Rai, D., R.J. Serne, and D.A. Moore. 1980. "Solubility of Plutonium Compounds and Their Behavior in Soils," *Soil Science Society of America Journal.* Vol. 44, no. 3, 490-495.

Rai, D., R.G. Strickert, and G.L. McVay. 1982. "Neptunium Concentrations in Solutions Contacting Actinide-Doped Glass," *Nuclear Technology.* Vol. 58, no. 1, 69-76.

Rai, D., A.R. Felmy, and R.W. Fulton. 1995. "Nd^{3+} and Am^{3+} Ion Interactions with Sulfate Ion," *Journal of Solution Chemistry.* Vol 24, no. 9, 879-895.

Rao, L., and G.R. Choppin. 1995. "Thermodynamic Study of the Complexation of Neptunium(V) with Humic Acids," *Radiochimica Acta.* Vol. 69, no. 2, 87-95.

Rao, L., D. Rai, A.R. Felmy, R.W. Fulton, and C.F. Novak. 1996. "Solubility of $NaNd(CO_3)_2 \cdot 6H_2O$ in Concentrated Sodium Carbonate and Sodium Bicarbonate Solutions." *Radiochimica Acta.* In press. WPO 36484.

Reed, D.T., D.G. Wygmans, and M.K. Richman. 1996. "Actinide Stability/Solubility in Simulated WIPP Brines." Interim Report under SNL WIPP Contract AP-2267. (Copy on file in the Sandia WIPP Central files.)

Refait, Ph. and J.-M.R. Génin. 1994. "The Transformation of Chloride-Containing Green Rust One Into Sulphated Green Rust Two by Oxidation in Mixed Cl^- and SO_4^{2-} Aqueous Media," *Corrosion Science.* Vol. 36, no. 1, 55-65.

Robinson, R.A., and R.H. Stokes. 1959. *Electrolyte Solutions, The Measurement and Interpretation of Conductance, Chemical Potential, and Diffusion in Solutions of Simple Electrolytes.* 2nd ed. (revised). London, England: Butterworths.

Ross, S., and I.D. Morrison. 1988. *Colloidal Systems and Interfaces.* New York. NY: John Wiley & Sons.

Runde, W. and J.I. Kim. 1994. *Untersuchungen der Übertragbarkeit von Labordaten natürliche Verhältnisse. Chemisches Verhalten von drei- und fünfwertigem Americium in salinen NaCl-Lösungen.* Report RCM-01094, Munich: Institut für Radiochemie, Technische Universität München. (Available from National Technical Information Service, 555 Port Royal Road, Springfield, VA, 22161, 703/487-4650 as DE 95752244.)

Sagoe-Crentsil, K.K., and F.P. Glasser. 1993. " 'Green Rust', Iron Solubility and the Role of Chloride in the Corrosion of Steel at High pH," *Cement and Concrete Research.* Vol. 23, no. 4, 785-791.

Sanchez, L.C., and H.R. Trellue. January 17, 1996. "Estimation of Maximum RH-TRU Thermal Heat Load for WIPP." WPO 31165.

Schnitzer, M., and S. I. M. Skinner. 1967. "Organo-Metallic Interactions in Soils: 7 Stability Constants of Pb^{++}, Ni^{++}, Mn^{++}, Co^{++}, Ca^{++}, and Mg^{++} - Fulvic Acid Complexes," *Soil Science*. Vol. 103, no. 4, 247-252.

Siegel, M.D. 1996. "Solubility Parameters for Use in the CCA NUTS and GRIDFLOW Calculations." SNL Technical memorandum dated 29 March 1996 to Martin S. Tierney. (Copy on file in the Sandia WIPP Central File A:WBS 1.2.0.7.1; WBS 1.1.10.61: WPO 35835.) Also WPO 37314.

Storz, L. June 24, 1996. "Estimate of the Amount of $Ca(OH)_2$ Contained in the Portland Cement Fraction of the Waste for Disposal in the WIPP," Memorandum to Yifeng Wang. (Copy on file in Sandia WIPP Central File A: WBS 1.1.09.1.1: WPO 40351.)

Stumm, W. 1992. *Chemistry of the Solid-Water Interface.* New York, NY: John Wiley & Sons, Inc.

Stumm, W. 1993. "Aquatic Colloids as Chemical Reactants: Surface Structure and Reactivity," *Colloids in the Aquatic Environment.* Ed. T.F. Tadros and J. Gregory. New York, NY: Elsevier Applied Science. (Reprinted from Colloids and Surfaces. Vol. 73, 1-18.)

Trauth, K.M., S.C. Hora, R.P. Rechard, and D.R. Anderson. 1992. *The Use of Expert Judgment to Quantify Uncertainty in Solubility and Sorption Parameters for Waste Isolation Pilot Plant Performance Assessment.* SAND92-0479. Albuquerque, NM: Sandia National Laboratories. WPO 23526

Vold, R.D., and M.J. Vold. 1983. *Colloid and Interface Chemistry.* Reading, MA: Addison-Wesley.

Wang, Y. March 18, 1996a. "Define Chemical Conditions for FMT Actinide Solubility Calculations," Memorandum to Malcolm D. Siegel, Sandia WIPP Central File A:WBS 1.1.09.1.1. WPO 37038.

Wang, Y. July 19, 1996b. "Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment," memorandum to Richard Vann Bynum and Laurence H. Brush. (Copy on file in the Sandia WIPP Central File A:1.1.0.9.1.1.CO/COM:QA; WPO 39871.)

Wang, Y. and L. Brush. January 26, 1996. "Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance Assessment." WPO 31943.

Weiner, R. 1996. "Documentation Package For: Oxidation State Distribution of Actinides in the Repository." SNL Technical memorandum dated 27 March 1996 to SWCF-A: Records Center, SWCF-A: WBS 12.1.10.1.1:PDD: QA: Dissolved Species: Oxidation State Distribution: Actinides: OX3: OX4: OX5: OX6 (WPO 35194).

WIPP Performance Assessment Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 2: Technical Basis.* SAND92-0700/2. Albuquerque, NM: Sandia National Laboratories. WPO 20805.

WIPP Performance Assessment Department. 1995. *User's Manual for FMT, Version 2.0,* WPO 28119.

WIPP Performance Assessment Department. 1996. *User's Manual for NONLIN, Version 2.0,* WPO 30740.

Wolery, T.J. 1992. *EQ3/6, A Software Package for Geochemical Modeling of Aqueous Systems: Package Overview and Installation Guide (Version 7.0).* UCRL-MA-110662 PT 1. Livermore, CA: Lawrence, CA: Lawrence Livermore National Laboratory.

Wolery, T.J., and S.A. Daveler. 1992. *EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0).* UCRL-MA-110662-Pt. 4. Livermore, CA: Lawrence Livermore National Laboratory.

Wood, J.R. 1975. "Thermodynamics of Brine-Salt Equilibria. I. The Systems NaCl-KCl-$MgCl_2$-$CaCl_2$-H_2O and NaCl-$MgSO_4$-H_2O at 25°C," *Geochimica et Cosmochimica Acta.* Vol. 39, no. 8, 1147-1163.

ATTACHMENTS

Attachment 1: WIPP Performance Assessment, User's Manual for FMT, Version 2.0. WPO 28119

Attachment 2: WIPP Performance Assessment, User's Manual for NONLIN, Version 2.0. WPO 20740

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WIPP PA

User's Manual

for

FMT, Version 2.0

Document Version 1.00

WPO # 28119

November 17, 1995

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1.0 INTRODUCTION

The program FMT (Fracture-Matrix Transport) solves chemical equilibrium problems using the Pitzer activity coefficient formalism (Pitzer, 1991). Although, as the name implies, this code was originally intended for transport calculations, this feature is not supported in this release of FMT (Version 2.0).

FMT is used to compute the concentrations, expressed in terms of molality (moles of solute per kilogram of solvent), of chemical species using a thermodynamic model for concentrated electrolyte systems (brines). FMT is used to simulate the solubility behavior of radionuclides in brines found in the Castile, Rustler, and Salado Formations near the WIPP site. FMT is based on the Harvie-Møller-Weare (HMW) data base (Harvie et al., 1984; Felmy and Weare, 1986) enhanced with radioactive elements such as americium(III) and neptunium(V). The purpose of the calculation is to find the detailed distribution of chemical species when the solution is at equilibrium.

FMT solves both single and multiple equilibrium problems:

- The single equilibrium problem (also known as the flash problem) uses the "batch" mode of FMT. In this mode, the user specifies the total element abundances and FMT calculates the equilibrium concentrations of dissolved components and solids.

- For multiple equilibrium problems a "titration" mode is available, in which FMT mechanizes repetitive flash calculations required to compute the composition of a solution results from titrating one solution with another solution or a solution containing minerals. For titration problems, the user specifies the compositions of both solutions and the volumes of the titrant solution to be added.

For the 1996 WIPP PA calculation, FMT will be used to generate tables of solubilities for generalized actinide (referred to here as "An") oxidation states An(III), An(IV), An(V), and An(VI). These tables will be converted into equations of surfaces that will be used by the WIPP PA codes PANEL and NUTS to calculate actinide solubility values as a function of CO_2 fugacity, hydrogen ion concentration, brine composition, and organic chelator concentrations.

This document serves as a User's Manual for FMT, as used to support the 1996 WIPP Performance Assessment calculations. As such, it describes the code's purpose and function, the user's interaction with the code, and the equations and numerical methods employed by the code. Examples of user-accessible input files, output files, and screen displays are appended to this manual for the user's convenience.

1.1 Software Identifier

Code Name: FMT
WIPP Prefix: FMT_
Version Number: 2.0 11/03/95
Platforms: FORTRAN 77 for OpenVMS AXP, versions 1.5 and 6.1, on DEC Alpha and Power Macintosh 7100

1.2 Points of Contact

1.2.1 *Code Sponsor*

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2.0 FUNCTIONAL REQUIREMENTS

R.1: FMT simulates solubility behavior of radionuclides in brines found in Castile, Rustler, and Salado Formations near the WIPP site.

R.2: FMT calculates chemical equilibrium using aqueous thermodynamics. It is based on the Harvie-Møller-Weare (HMW) database enhanced with radioactive elements.

R.3: FMT additionally mechanizes repetitive calculations, e.g., titrating a solution of one chemical composition with a solution of another chemical composition.

R.4: The element enhancements FMT supports include Americium (III) and Neptunium (V).

R.5: The "batch" simulation mode, also known as flash problems, calculates equilbrium abundances for one set of element abundances.

R.6: The "titrate" mode shall support explicit specification, i.e. adding user specified volumes for each titration increment.

R.7: The "titrate" mode shall support linear increments, i.e., adding the same constant volume for each titration increment.

R.8: The "titrate" mode shall support logarithmic increments, i.e. adding a logarithmically increasing volume for each titration.

R.9: The parameters in the actinide series used in the FMT database are calculated by NONLIN or other equivalent means.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

In order to run the FMT code successfully, the user will need a basic knowledge of

- Open VMS and Digital Equipment Co.'s (DEC's) Digital Command Language (DCL), if running the code on the DEC platform
- Power Macintosh 7100 operation, if running the code on a Macintosh platform

To interpret the results of FMT, a chemistry background is required. A user should have a

- BS in Chemistry, or the equivalent
- sound understanding of chemical reaction equilibrium analysis.

To understand how the FMT code works and the theory and algorithms upon which FMT is based, the user should also have a basic understanding of

- thermodynamics
- partial differential equations
- linear algebra (through senior undergraduate level)
- numerical methods (graduate or senior level undergraduate level).

4.0 DESCRIPTION OF THE MODELS AND METHODS

4.1 Mathematical Model and Numerical Methods

FMT solves chemical equilibrium problems, as defined by linear material balance equations and nonlinear reaction equilibrium equations as given in standard chemical thermodynamics texts such as Denbigh (1981) and Smith and Van Ness (1975). An extensive survey of numerical methods developed specifically to solve these problems is given in Smith and Missen (1991). In particular, FMT uses the "Villars-Cruise-Smith" (VCS) algorithm, which is explained in Section 6.4.4 of Smith and Missen (1991). A brief overview of the VCS algorithm, as presented in Smith and Missen (1991) follows. Interested readers are referred to Smith and Missen (1991) for a more detailed discussion.

If the Gibbs free-energy function G is viewed as a function of the reaction-extent variables $\vec{\xi}$, then the chemical equilibrium problem is that of minimizing $G(\vec{\xi})$; i.e.,

$$\frac{\partial G}{\partial \vec{\xi}} = \mathbf{0}. \tag{1}$$

Equation 1 is equivalent to the classical chemical formulation of the equilibrium conditions

$$\Delta \mathbf{G} \equiv \mathbf{N}^T \vec{\mu}\left(\vec{\xi}\right) = 0, \tag{2}$$

where

$\mathbf{N}^T$ = the complete, transposed stoichiometric matrix: the $(N \times R)$ matrix whose columns are the R stoichiometric vectors; that is, $\mathbf{N} = (\vec{\nu}_1, \vec{\nu}_2, \ldots, \vec{\nu}_R)$; entry (i,j) of $\mathbf{N}$ is ν_{ij}, and

$\vec{\mu}$ = chemical-potential vector with entries μ_i.

A first-order algorithm approach for minimizing $G(\vec{\xi})$ requires that the variables $\vec{\xi}$ be adjusted at each iteration by amounts $\delta\vec{\xi}$:

$$\begin{aligned} \delta\xi_j^{(m)} &= -\left(\frac{\partial G}{\partial \xi_j}\right)^{(m)} = -\Delta G_j^{(m)} \\ &= -\sum_{i=1}^{N'} \nu_{ij} \mu_i^{(m)}; \qquad j = 1, 2, \ldots R \,, \end{aligned} \tag{3}$$

where

m = iteration index,

ν_{ij} = stoichiometric coefficient of species i in stoichiometric vector (equation) j,

N' = number of species excluding inert species,

μ_i = chemical potential of species i, and

R = maximum number of linearly independent chemical equations.

The mole numbers are adjusted by means of

$$\delta n_i^{(m)} = \sum_{j=1}^{R} \nu_{ij} \delta \xi_j^{(m)}; \quad i = 1,2,\ldots N', \tag{4}$$

where n_i = the number of moles of species i.

As with first-order optimization methods in general, this algorithm has been found to converge rather slowly, and therefore is not widely used.

In a second-order algorithm approach for minimizing $G(\bar{\xi})$, the Newton-Raphson method can be applied to equations 2, which yields

$$\delta \bar{\xi}^{(m)} = -\left(\frac{\partial^2 G}{\partial \bar{\xi}^2}\right)^{-1}_{\mathbf{n}^{(m)}} \left(\frac{\partial G}{\partial \bar{\xi}}\right)_{\mathbf{n}^{(m)}}, \tag{5}$$

where $\mathbf{n}$ = species-abundance vector with entries n_i. This approach requires the solution of a set of $R = (N' - M)$ linear equations on each iteration (where M is the number of elements). Because N' is usually large compared with M, the numerical solution of these linear equations can be very time consuming and this approach is not widely used.

The VCS algorithm, an intermediate between the above first- and second-order methods, provides a way to essentially reduce the labor involved in the solution of the linear equations.

The VCS algorithm begins with equation 5, the Hessian matrix $(\partial^2 G / \partial \bar{\xi}^2)$ for which, in the case of a single ideal phase, can be expressed as

$$\begin{aligned} \frac{\partial^2 G}{\partial \xi_i \partial \xi_j} &= \frac{\partial}{\partial \xi_j}\left(\sum_{k=1}^{N'} \nu_{ki} \mu_k\right) \\ &= RT \sum_{k=1}^{N'} \sum_{l=1}^{N'} \nu_{ki} \nu_{lj} \left(\frac{\delta_{kl}}{n_k} - \frac{1}{n_t}\right); \qquad j = 1,2,\ldots R, \end{aligned} \tag{6}$$

where

R = the gas constant, 8.3143 J mole^{-1} K^{-1},

T = absolute temperature (K)

δ_{kl} = the Kronecker delta function; $\delta_{kl} = 1$, if $k = l$; $\delta_{kl} = 0$, if $k \neq l$,

n_k = number of moles of species k, and

n_t = total number of moles.

Smith and Missen (1991) explain in Section 6.4.4 how the Hessian matrix in equation 6 can be expressed as

$$RT\left(\frac{\partial^2 G}{\partial \xi_i \partial \xi_j}\right)^{-1} \approx \left(\frac{1}{n_{i+M}} + \sum_{k=1}^{M} \frac{\nu_{ki}^2}{n_k} - \frac{\bar{\nu}_i^2}{n_t}\right)^{-1} \delta_{ij}\,, \tag{7}$$

where $\bar{\nu}_i$ is the sum of the stoichiometric coefficients in stoichiometric equation i., i.e. $\bar{\nu}_i = \sum_{k=1}^{N'} \nu_{ki}$

The VCS algorithm for a single ideal phase uses equation 5 with equation 7 and iteratively adjusts each stoichiometric equation by an amount

$$\delta\xi_j^{(m)} = -\left(\frac{1}{n_{j+M}^{(m)}} + \sum_{k=1}^{M} \frac{\nu_{kj}^2}{n_k^{(m)}} - \frac{\bar{\nu}_j^2}{n_t}\right)^{-1} \frac{\Delta G_j^{(m)}}{RT}; \qquad j=1,2,\ldots R \tag{8}$$

As is explained in Section 4.4, FMT replaces one of the R element balances in Equation 8 with the charge balance, which not only specifies the material balance of the "replaced" element but also constrains the solution to be charge neutral.

The thermodynamics of concentrated electrolyte solutions (brines) requires consideration of the chemical nonidealities of the system. FMT uses the activity coefficient model of Pitzer (1991) and the development of this model with a consistent data base as described by Harvie et al. (1984) and Felmy and Weare (1986) as the basis for modeling chemical nonidealities. These references provide extensive detail about this Pitzer activity coefficient formalism used in FMT. A brief discussion of the Pitzer activity coefficient model follows in Section 4.2.

4.2 The Pitzer Activity Coefficient Formalism

The Pitzer activity coefficient formalism is a set of mathematical equations for calculating activity coefficients for aqueous species, and is valid from dilute systems through the concentrated brines observed at the WIPP Site. The theoretical and historical development of this formalism can be traced though Pitzer (1991), particularly Chapter 3, and references therein.

The implementation of the Pitzer activity coefficient formalism within FMT is based on the forms of the equations as presented in Harvie and Weare (1980), Harvie et al. (1984), and Felmy and Weare (1986). Because there is no difference in the mathematical formulation from these references and FMT, only the equations in Felmy and Weare (1986) are presented below. The interested reader will find a comprehensive presentation of these equations in the three cited publications.

The activities of the species a_i can be defined by the following equation:

$$\left(\frac{\partial G}{\partial n_i}\right)_{T,P,n} = \mu_i = \mu_i^0 + RT\ln a_i, \qquad \text{(A.1a*)}$$

where μ_i^0 = the standard chemical potential for species i. Activity is defined for each solute species i by

$$a_i = \gamma_i m_i \qquad \text{(A.1b)}$$

and, for the solvent, by

$$\ln a_{H_2O} = \frac{-W}{1000}\left(\sum_i m_i\right)\phi \qquad \text{(A.1c)}$$

where

γ_i = the activity coefficient of the solute species,

m_i = the molality of the solute species,

W = the molecular weight of water,

$\sum_i m_i$ = the sum over all solutes (cations, anions, and neutrals), and

ϕ = the osmotic coefficient.

While the chemical potentials for pure phases (e.g., minerals) are constant at fixed temperature and pressure, the fugacity of gas-phase species, f_i, is defined as follows:

$$\frac{\mu_i}{RT} = \frac{\mu_i^0}{RT} + \ln(f_i). \qquad \text{(A.1d)}$$

The remaining variables lacking explicit definition are the excess functions γ_i and $(\phi - 1)$. These functions, rewritten below, are modeled using the semiempirical equations of Pitzer (1973) and co-workers. (Note that, in the Pitzer equations presented below, I = ionic strength, and that subscripts M, X, and N refer to cations, anions, and neutrals, respectively. The remaining terms are explained following the presentation of the Pitzer equations.)

---

* Equation numbering scheme in Felmy and Weare (1986) duplicated for this discussion.

$$(\phi-1)=\frac{2}{\left(\sum_i m_i\right)}\left\{-\frac{A^{\phi}I^{3/2}}{1+bI^{1/2}}+\sum_c\sum_a m_c m_a\left(B^{\phi}_{ca}+ZC_{ca}\right)+\sum_{c<c'}\sum m_c m_{c'}\left(\Phi^{\phi}_{cc'}+\sum_a m_a\psi_{cc'a}\right)\right.$$

$$+\sum_{a<a'}\sum m_a m_{a'}\left(\Phi^{\phi}_{aa'}+\sum_c m_c\psi_{aa'c}\right)+\sum_n\sum_c m_n m_c\lambda_{nc} \tag{A.2a}$$

$$\left.+\sum_n\sum_a m_n m_a\lambda_{na}+\sum_n\sum_c\sum_a m_n m_c m_a\zeta_{nca}\right\}$$

$$\ln\gamma_M=z_M^2F+\sum_a m_a\left(2B_{Ma}+ZC_{Ma}\right)+\sum_c m_c\left(2\Phi_{Mc}+\sum_a m_a\psi_{Mca}\right)$$

$$+\sum_{a<a'}\sum m_a m_{a'}\psi_{aa'M}+|z_M|\sum_c\sum_a m_c m_a C_{ca}+\sum_n m_n\left(2\lambda_{nM}\right)+\sum_n\sum_a m_n m_a\zeta_{naM} \tag{A.2b}$$

$$\ln\gamma_X=z_M^2F+\sum_c m_c\left(2B_{Xc}+ZC_{Xc}\right)+\sum_a m_a\left(2\Phi_{Xa}+\sum_c m_c\psi_{Xca}\right)$$

$$+\sum_{c<c'}\sum m_c m_{c'}\psi_{cc'X}+|z_X|\sum_c\sum_a m_c m_a C_{ca}+\sum_n m_n\left(2\lambda_{nX}\right)+\sum_n\sum_c m_n m_c\zeta_{ncX} \tag{A.2c}$$

$$\ln\gamma_N=\sum_c m_c\left(2\lambda_{Nc}\right)+\sum_a m_a\left(2\lambda_{Na}\right)+\sum_c\sum_a m_c m_a\zeta_{Nca} \tag{A.2d}$$

$$F=-A^{\phi}\left(\frac{I^{1/2}}{1+bI^{1/2}}+\frac{2}{b}\ln\left(1+bI^{1/2}\right)\right)+\sum_c\sum_a m_c m_a B'_{ca}$$

$$+\sum_{c<c'}\sum m_c m_{c'}\Phi'_{cc'}+\sum_{a<a'}\sum m_a m_{a'}\Phi'_{aa'} \tag{A.2e}$$

$$C_{MX}=\frac{C^{\phi}_{MX}}{2\left|Z_M Z_X\right|^{1/2}} \tag{2b}$$

$$Z=\sum_i |z_i| m_i \tag{2c}$$

A^{ϕ} is one third of the Debye-Hückel limiting slope (A in the following empirical equation):

$$\ln\gamma_i = -\frac{A\sqrt{I}}{1+Ba_i\sqrt{I}} + \dot{B}_i I,$$

as presented on page 981 of Harvie and Weare [1980].) Here A^{ϕ} equals 0.39 at 25°C. The second virial coefficients, B, are given the following ionic strength dependence:

$$B^{\phi}_{MX} = \beta^{(0)}_{MX} + \beta^{(1)}_{MX} e^{-\alpha_1\sqrt{I}} + \beta^{(2)}_{MX} e^{-\alpha_2\sqrt{I}} \tag{3a}$$

$$B_{MX} = \beta^{(0)}_{MX} + \beta^{(1)}_{MX} g\left(\alpha_1\sqrt{I}\right) + \beta^{(2)}_{MX} g\left(\alpha_2\sqrt{I}\right) \tag{3b}$$

$$B'_{MX} = \beta^{(1)}_{MX} \frac{g'\left(\alpha_1\sqrt{I}\right)}{I} + \beta^{(2)}_{MX} \frac{g'\left(\alpha_2\sqrt{I}\right)}{I} \tag{3c}$$

The functions g and g' are defined by

$$g(x) = 2\frac{\left(1-(1+x)e^{-x}\right)}{x^2} \tag{4a}$$

$$g'(x) = -2\frac{\left(1-\left(1+x+\frac{x^2}{2}\right)e^{-x}\right)}{x^2} \tag{4b}$$

with $x = \alpha_1\sqrt{I}$ or $= \alpha_2\sqrt{I}$. When either cation M or anion X is univalent, $\alpha_1 = 2.0$ and $\alpha_2 = 12$. For 2 - 2 pairs, $\alpha_1 = 1.4$ and $\alpha_2 = 12$. For all electrolyes, $b = 1.2$. For 2 - 3 and higher pairs, $\alpha_1 = 1.4$ and $\alpha_2 = 50$. The dimensions of α_1 and α_2 are $kg^{1/2}mole^{-1/2}$. The virial coefficients, Φ, which depend upon ionic strength, are given the following form:

$$\Phi_{ij}^{\phi}=\theta_{ij}+{}^{E}\theta_{ij}(I)+I{}^{E}\theta'_{ij}(I) \tag{5a}$$

$$\Phi_{ij}=\theta_{ij}+{}^{E}\theta_{ij}(I) \tag{5b}$$

$$\Phi'_{ij}={}^{E}\theta'_{ij}(I) \tag{5c}$$

The functions ${}^{E}\theta_{ij}(I)$ and ${}^{E}\theta'_{ij}(I)$ are functions only of ionic strength and the electrolyte pair type.

The activity coefficient parameters, λ_{ni} and ζ_{nij}, representing the interactions between ions and neutral species, are taken to be constant. The third virial coefficients, C_{MX}^{ϕ} and ψ_{ijk}, are also assumed to be independent of ionic strength.

The complete set of parameters defining the model for nonideal behavior of electrolyte solutions are as follows:

- $\beta_{MX}^{(0)}$, $\beta_{MX}^{(1)}$, $\beta_{MX}^{(2)}$, and C_{MX}^{ϕ} for each cation-anion pair
- θ_{ij} for each cation-cation and anion-anion pair
- ψ_{ijk} for each cation-cation-anion and anion-anion-cation triplet
- λ_{ni} and ζ_{nij} *for ion-neutral and ion-ion-neutral interactions.*

Many of these parameters can be assigned a value of zero. The above parameters are tabulated in the CHEMDAT data base (Section 7.3, Appendices I and J).

4.3 Inclusion of Pitzer Activity Coefficients

The activity coefficients are included within FMT according to the "Indirect Methods Based on Algorithms for Ideal Systems" documented in Section 7.3.1 of Smith and Missen (1991). A brief overview of the discussion provided in Section 7.3.1 of Smith and Missen (1991) follows.

The following is an expression for the chemical potential:

$$\mu_i(T,P,\mathbf{x})=\mu_i^*(T,P)+RT\ln\gamma_i(T,P,\mathbf{x})x_i, \tag{9}$$

and

$$\lim_{x_i \to 1} \gamma_i = 1 \qquad \text{(Raoult convention)}$$

or

$$\lim_{x_i \to 0} \gamma_i = 1 \qquad \text{(Henry convention)}$$

where

$\mathbf{x}$ = mole-fraction vector with entries x_i,

T = temperature,

P = pressure, and

μ_i^* = standard chemical potential of species i.

Equation 9 may be rewritten as

$$\mu_i = \mu_i^* + \mathrm{R}T \ln \gamma_i(T,P,\mathbf{n}) + \mathrm{R}T \ln x_i, \tag{10}$$

where $\mathbf{n}$ = species-abundance vector with entries n_i.

When the first two terms on the right-hand side of equation 10 are combined, the equation can be formally rewritten as

$$\mu_i = \mu_i^*\left[T,P,\mathbf{n}^*,(T,P)\right] + \mathrm{R}T \ln x_i \tag{11}$$

where μ_i^* is now a function of T and P through the unknown equilibirum solution $\mathbf{n}^*$.

The calculation procedure is iterative, in which the first step is to compute the equilibrium composition assuming ideality ($\gamma_i = 1$), yielding a first approximation to the system mole numbers $\mathbf{n}^{(1)}$. Then the activity coefficients $\bar{\gamma}$ for the nonideal system are computed from a known chemical potential expression at the $\mathbf{n}^{(1)}$ composition. In the next step, the equilibrium composition in the "ideal" system is computed from equation 11, with μ_i^* replaced by

$$\mu_i^{*(1)} = \mu_i^* + \mathrm{R}T \ln \gamma_i\left(T,P,\mathbf{n}^{(1)}\right). \tag{12}$$

This process is repeated until the composition on successive iterations remains constant to within some specified tolerance. FMT uses this procedure in conjunction with the VCS algorithm described in Section 4.1.

4.4 Charge Neutrality

Charge neutrality is maintained within FMT in order to best represent the charge neutral state of aqueous solutions that occurs in the laboratory and the environment. It has been shown (see for example Smith and Missen, 1991) that a linear combination of the element material balances produces the charge balance equation. FMT replaces one of the element balances with the charge balance, which both specifies the material balance on the "replaced" element and constrains the solution to be charge neutral. The element to be replaced with the charge balance, FORTRAN variable RPLWCHG, can be any element, but is usually set to Oxygen because it will be present in all aqueous chemical systems. FMT cannot calculate a charge imbalanced solution composition. However, should one wish to specify a charge imbalance, fictitious aqueous species such as "PosIon+" and "NegIon-" made up of the pseudoelements PosIon:EL and NegIon:El and the appropriate charges can be used to do so. For example, entering a concentration of PosIon+ at 0.1m will cause the solution to have a net negative charge of 0.1m due to the nonfictitious species.

4.5 Pseudoelements

Pseudoelement is the name given to mathematical constructs that are not actual chemical elements but mathematically are treated the same as an element. Some of the pseudoelements used within FMT in the past have been Electron:EL, PosIon:EL, NegIon:EL, ClO4:EL, and Charge:EL. Perchlorate, ClO_4, is a pseudoelement because it is a combination of elements treated as an element. That is, the unit ClO4:EL cannot be divided into its constituent elements during simulations with FMT. Organic ligands are treated as pseudoelements, including Oxalate:EL, Citrate:EL, Acetate:EL, Lactate:EL, and EDTA:EL. This prevents these moieties from undergoing chemical reactions that alter the organic species, while allowing the organic ligands to complex with protons and other aqueous species.

5.0 CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

FMT calculates chemical equilibrium for user-specified total element amounts for aqueous or aqueous/mineral geochemical systems. All chemical elements specified by the user must be included in the data base used by FMT in order for calculations to proceed correctly. The current FMT data base, HMW_NP_AM.CHEMDAT (described in Section 7.3), is limited to the elements H, O, Na, K, Mg, Ca, Cl, B, and Br, and the pseudoelements "SO4," "CO3," "Am(III)," "Np(V)," "ClO4," and "Charge." (Element names contained in quotes are not strictly chemical elements, and are therefore called "pseudoelements." Pseudoelements are treated in the FMT data base as indivisible units, and thus behave numerically as though they were chemical elements.) The species that can be formed from these elements, aqueous and solid, are only those that are included in the data base. The data base documentation (Appendix I) gives the sources of parameters contained in the data base. The user is responsible for determining whether the data base included in FMT is appropriate for his/her chemical system.

It is important to note that FMT does not model gas phases explicitly. However, the effects of imposing chemical equilibrium between a solution and a gas phase with constant fugacities for all soluble gas phase constituents can be modeled by creating hypothetical but thermodynamically viable solid phases in the solution. These fictitious solids should have standard chemical potentials that are calculated from the gas fugacities.

Several scenarios for WIPP disposal rooms suggest there will be CO_2 gas present. It is therefore desirable to calculate the effects of CO_2 gas on the aqueous and solid chemistry in the disposal room, and in turn on dissolved actinide concentrations. While FMT cannot explicitly model the gas phase, it can model a system with constant CO_2 gas fugacity by proper declaration of a CO_2 solid phase, as discussed below.

Thermodynamics allows the declaration of a hypothetical CO_2 "solid" phase to mimic the effects of constant CO_2 gas fugacity:

$$CO_2(g) \leftrightarrow CO_2(\text{"solid"}). \tag{13}$$

At equilibrium, this reaction is described by the relationship

$$\frac{\mu^0_{CO_2(\text{"solid"})}}{RT} = \frac{\mu^0_{CO_2(g)}}{RT} + \ln f_{CO_2}, \tag{14}$$

where f_{CO_2} is the $CO_2(g)$ fugacity, which can be thought of as an effective partial pressure for $CO_2(g)$. Equation 14 , which makes use of the standard convention that the activity of a pure solid phase is unity, allows one to simulate a system with a constant $CO_2(g)$ fugacity as long as the CO_2 "solid" phase is present. See Novak (1995k) for details.

Other particular items to note are listed below:

- Oxidation-reduction (redox) reactions are not supported by the HMW_NP_AM data base.

- The "Am(III)" and "Np(V)" models in HMW_NP_AM are preliminary and provisional, and may be changed in further versions of the data base associated with FMT as more information becomes available. An example of this additional information is complexation with dissolved organic ligands such as the organic-acid anions acetate, lactate, oxalate, and citrate. Updated versions of the CHEMDAT data base for use with FMT will be issued as they are developed.

- The radioactive elements thorium(IV), uranium(IV), uranium(VI) and other elements may be added in future versions of the FMT data base. These additions will be modifications to the data base only (CHEMDAT) and will not require code changes. However, it is possible that several sections of code, particularly for calculating activity coefficients, may not be accessed until thorium(IV) is incorporated into the data base.

6.0 USER INTERACTIONS WITH THE SOFTWARE

6.1 Overview

FMT requires three input data files—INPUT, INGUESS, and CHEMDAT. An additional input file RHOMIN is required for titrate problems. In the INPUT file the user sets the problem parameters and specifies the solution composition by providing the *total element* abundances.

Note that "abundance" means the total amount, an extrinsic quantity, e.g., 3 moles of Na, 2 moles of Cl, 1 mole of Br. The intrinsic quantity, commonly moles per kg H_2O within FMT, is calculated based on the extrinsic amount of water that can be formed from the specified element abundances. This is the technical definition for the abundance entries. In practice, it is convenient to specify about 1 kg of water (about 55.5 moles of O and 111.0 moles of H) to allow the abundances in the INPUT and INGUESS files to be looked at on a molal (or approximately, molar) basis. (A convenient way to put all species concentrations in the INGUESS file on a nearly exact molal basis is through use of the FOR088 file, which contains a column of species concentrations in molal units. These concentrations can be copied to an INGUESS file to put all species in the INGUESS file on a molal basis, although technically it is still the extrinsic species abundances that are given. This merely "normalizes" all extrinsic abundances to a "per kg H_2O" basis.)

Optionally, the user could specify the same solution composition by setting the *species* abundances in the INGUESS file. The CHEMDAT file is a data base that contains species names, characteristics, and Pitzer parameters. RHOMIN, another data base file, contains mineral densities. FMT input files are discussed in detail in Section 7.0.

*****WARNING*****

The user should not and is not expected to change the CHEMDAT and RHOMIN files which are provided with the FMT code.

FMT generates a primary file OUTPUT and secondary file(s), depending on the problem. FOR088 is the secondary file for batch problems. TITRATE and MOLES are the secondary files for titrate problems. Both the FOR088 and TITRATE files are subsets of their respective OUTPUT files, reordered by chemical species for user convenience. Because the format of FOR088 is the same as that of INGUESS, FOR088 output can be used as input for INGUESS. Output files are discussed in detail in Section 9.0.

Figures 1 and 2 illustrate the input and output files for batch and titrate problems respectively. The input files labeled as static are the data base files.

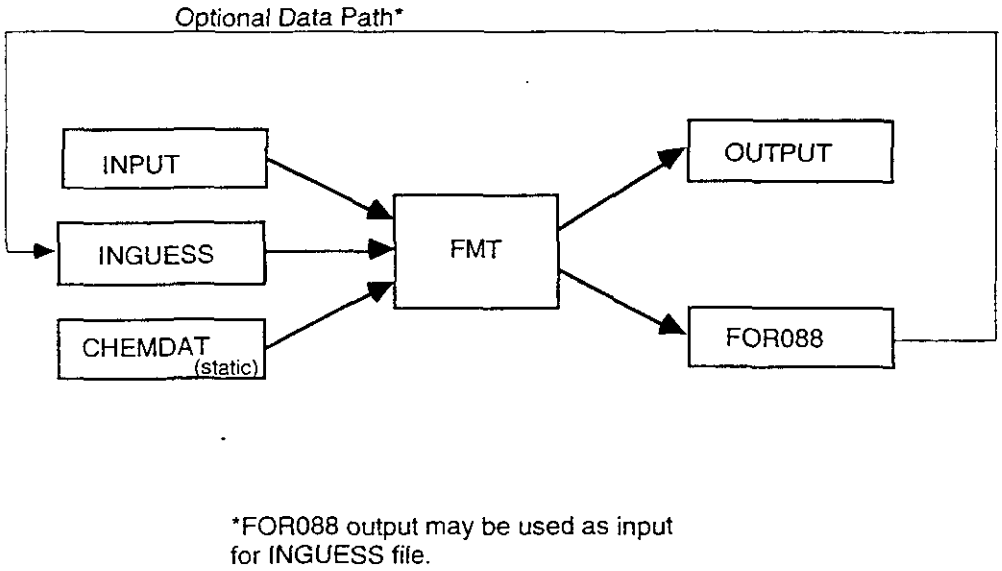

Figure 1. Input and Output Files for BATCH

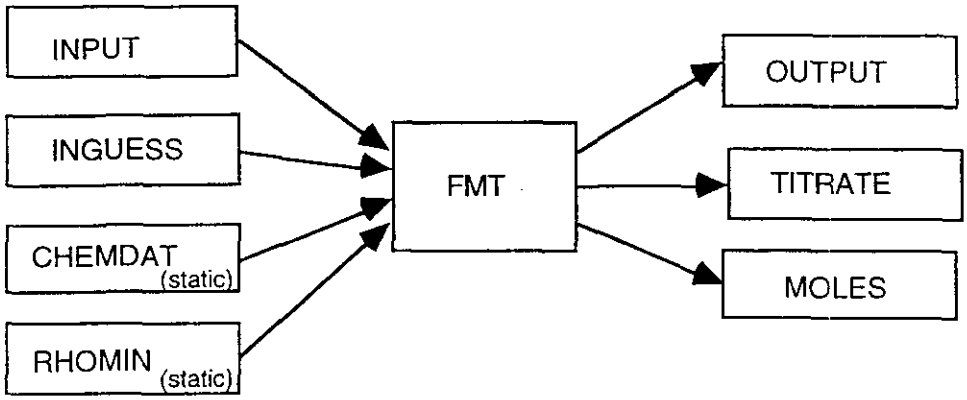

Figure 2. Input and Output Files for TITRATE

6.2 User-Supplied Input Files

Using a convenient editor, the user creates and modifies parameters in the INPUT and INGUESS files. After specifying a title for identifying the problem (usually naming the solution composition) and setting character flags in the INPUT file, the user quantifies the elemental amounts required for a specific solution. The user must specify the amounts in the same order as the elements are listed in the CHEMDAT file, starting with hydrogen.

The INGUESS file, if FMT is instructed to read it, provides molar amounts for each species in the CHEMDAT file. All amounts must be specified as total abundances, i.e., number of moles in the (unspecified) control volume. The user must state the moles for each species in the same order as

the species are listed in the CHEMDAT file, starting with H_2O. FMT converts these extrinsic quantities to molality using the mass of water that can form given the solution composition.

FMT reads the entire INPUT file. If the character strings 'MOLES' and 'EXACT' are set in the INPUT file, then FMT reads the moles for each species from the INGUESS file and calculates the molal amounts of all the elements. If 'nMOLES' and 'nEXACT' strings are set, then FMT uses the elemental mole amounts as stated in the INPUT file. In this case, the INGUESS file must exist although it may be an empty file, i.e., a file containing no data.

6.3 Executing FMT

6.3.1 DEC Environment

The user can use the command file FMT_FMTC.COM to run FMT on the Sandia NWER network with Digital's Alpha machine BEATLE. This file is located in the FMT library. All files in the library are under control of Digital's Configuration Management System (CMS). This library contains FMT data base files, source code and command files. The user can retrieve the command file FMT_FMTC.COM from the FMT library using the CMS "fetch" command. For ease in executing FMT, the command file should be in the same directory where the input files reside.

6.3.1.1 Fetching the Command File FMT_FMTC.COM from CMS

To retrieve the command file FMT_FMTC.COM, the user logs into BEATLE and types in the symbol "nonpa_cms_syms" to define other CMS symbols, and the command "libfmt" to specify the FMT library. Then the user locates the directory/subdirectory where his/her input files reside by typing in a "set default (sd)" command. The command "cfe fmt_fmtc.com" copies the command file into the user's current directory. The lines are:

```
$nonpa_cms_syms
$libfmt
$sd [username.user_inputfile_directory]
$cfe fmt_fmtc.com
```

The command file can be copied from directory to directory. The user does not need to fetch the file each time. FMT_FMTC.COM also issues the lines "nonpa_cms_syms" and "libfmt" so the user does not need to type those two lines for each login.

6.3.1.2 Running FMT_FMTC.COM

To execute "@FMT_FMTC" the user must always be logged into BEATLE. The user should be in the directory that contains the .IN and .INGUESS files before starting FMT_FMTC. To execute the command the user types in:

```
$@FMT_FMTC
```

The user will be prompted to supply a **substring** for the CHEMDAT and RHOMIN files and the input file's name. To retrieve a list of all CHEMDAT and RHOMIN files, the user can simply type in "FMT" since all database files are prefixed with the "FMT_HMW_" string. Any

substring of the database file name can be typed in if the user knows the valance states or the date of the files desired. The input file name must not contain the extensions (".IN" or ".INGUESS") and file names of IN and INGUESS must be the same.

After listing the CHEMDAT files that match the substring specified, the user is prompted to select a CHEMDAT file. The user can select a file by either double clicking on the file name, copying the file name and pasting it to the waiting request, or typing the entire name. Then a listing of all RHOMIN files matching the substring is displayed and the user is prompted to select a RHOMIN file.

WARNING: The FMT_FMTC command deletes all chemdat and rhomin files with the "FMT_" prefix from the user's current directory before fetching any CHEMDAT or RHOMIN file.

6.3.1.3 Examples

The following examples show what (in boldface) a user types in response to a "$" prompt line or FMT's request. All other lines are BEATLE's operating system response, CMS's response, or FMT's response. FMT_FMTC.COM generates the log file with the time and date stamp in the file's name. The log file records all the screen output, including explicit information on the build of the executable "FMT_FMT2P0" and the complete input and output file names used in the runs.

Example #1 - Running the batch problem BATCH_DOC

The input file names and extensions for the BATCH_DOC problem are BATCH_DOC.IN and BATCH_DOC.INGUESS. Referring to the directory listing after the run, the program FMT generated the files BATCH_DOC.OUT and BATCH_DOC.FOR088, CMS fetched the files FMT_HMW_NP_AM.CHEMDAT and FMT_HMW_NP_AM.RHOMIN, and FMT_FMTC.COM recorded the screen output from FMT in the file BATCH_DOC_JAN08_1519.LOG. A listing of the log file follows the directory listing.

```
$ dir

Directory U1:[SCBABB.FMT.CMS_TESTFILES]

BATCH_DOC.IN;1       BATCH_DOC.INGUESS;1 FMT_FMTC.COM;1

Total of 3 files.
$ @fmt_fmtc
Enter chemdat file name to search on: fmt
Enter rhomin file name to search,on: fmt
Enter input file name (without .extension): batch_doc
%CMS-I-LIBIS, library is WP$NONPA_CMSROOT:[FMT]
%CMS-S-LIBSET, library set

Elements in CMS Library WP$NONPA_CMSROOT:[FMT]

FMT_HMW35_951213.CHEMDAT "K+ INTERACTIONS TO NP(V) SOLUBILITY DB"
FMT_HMW_35.CHEMDAT "Initial load"
FMT_HMW_35_951213.CHEMDAT "K+INTERACTIONS TO NP(V) SOLUBILITY W/O CMS HISTORY"
FMT_HMW_35_951213_F-1.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-10.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-11.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-12.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-13.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-14.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-2.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-3.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-4.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-5.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-6.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-7.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-8.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F-9.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F1.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_35_951213_F10.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
```

```
FMT_HMW_35_951213_F60.CHEMDAT "CO2 FUGACITY FILES CREATED FROM FMT_HMW_35_951213.CHEMDAT MASTER FILE FROM CFNOVAK."
FMT_HMW_NP_AM.CHEMDAT "Initial load"
FMT_HMW_NP_AM_F60.CHEMDAT "Initial load"
Select CHEMDAT name from list above: FMT_HMW_NP_AM.CHEMDAT
Your CMS library list consists of:
   WP$NONPA_CMSROOT:[FMT]

%CMS-S-FETCHED, generation 1 of element WP$NONPA_CMSROOT:[FMT]FMT_HMW_NP_AM.CHEMDAT fetched

Elements in CMS Library WP$NONPA_CMSROOT:[FMT]

FMT_HMW_35.RHOMIN "Initial load"
FMT_HMW_NP_AM.RHOMIN "Initial load"
Select RHOMIN name from list above: FMT_HMW_NP_AM.RHOMIN
Your CMS library list consists of:
   WP$NONPA_CMSROOT:[FMT]

%CMS-S-FETCHED, generation 1 of element WP$NONPA_CMSROOT:[FMT]FMT_HMW_NP_AM.RHOMIN fetched

                image name: "FMT_FMT2P0"
                image file identification: "PROD PA96"
                image file build identification: ""
                link date/time: 21-DEC-1995 11:36:28.86
                linker identification: "A11-14"

Entering Subroutine READDAT
reading chemical species data from CHEMDAT file
DG_BYPASS flag set to nDG_BYPASS
[.FD.TITRATE]BATCH_DOC.in; to illustrate/document "BATCH" runs                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

Accuracy of reactions is              1.0000E-06
Minimum elemental abundance is        1.0000E-18
Number of Aqueous Species is            50

ACTIVITY COEF. FLAG PITZACT
using PITZER ACTIVITY COEFFICIENT model
Charge Balance replaces element Oxygen

Exiting Subroutine READDAT
Char Flags: FLOW/BATCH/TITRATE BATCH      UNUSED
this is a BATCH problem

Echo of Mole Specifications:  nMOLES     nEXACT
ECHO PRINT OF ELEMENT ABUNDANCES IN ONEFLSH
  110.222364000000       Hydrogen
  55.1654821000000       Oxygen
 0.200000000000000       Sodium
 1.000000000000000E-002 Potassium
 1.000000000000000E-003 Magnesium
 1.000000000000000E-004 Calcium
 0.110000000000000       Chlorine
 1.000000000000000E-003 Sulfur
 1.000000000000000E-004 Carbon
 0.000000000000000E+000 PosIon
 0.000000000000000E+000 NegIon
 0.000000000000000E+000 Air
 1.000000000000000E-007 Boron
 0.000000000000000E+000 Bromine
 0.000000000000000E+000 TracerEl
 0.000000000000000E+000 Th(IV)
 0.000000000000000E+000 Am(III)
 0.000000000000000E+000 U(VI)
 0.000000000000000E+000 Np(V)
 0.000000000000000E+000 ClO4-(EL)
 0.000000000000000E+000 Phosphorus
 0.000000000000000E+000 Electron
 4.906053920000000E-017 Charge
.LT. (MINABU*1.d-6) moles NaBO2.NaCl.2H2O___Teepleite_(20_C); del&switch
.LT. (MINABU*1.d-6) moles NaB5O8.5H2O_____Sodium_Pentaborate; del&switch
.LT. (MINABU*1.d-6) moles NaOH(aq).....to.titrate.base.only; del&switch
.LT. (MINABU*1.d-6) moles HCl(aq).......to.titrate.acid.only; del&switch
.LT. (MINABU*1.d-6) moles K2B4O7.4H2O___K-Tetraborate_(30_C); del&reopt
.LT. (MINABU*1.d-6) moles B4O5(OH)4=              B4O5(OH)4=; del&reopt
.LT. (MINABU*1.d-6) moles K8H6(SO4)7_______________Misenite; del&reopt
.LT. (MINABU*1.d-6) moles K8H4(CO3)6.3H2O___K-Sequicarbonate; del&switch
.LT. (MINABU*1.d-6) moles B3O3(OH)4-              B3O3(OH)4-; del&switch
.LT. (MINABU*1.d-6) moles Ca4Cl2(OH)6.13H2O__CaOxychloride'A; del&switch

************SOLUBILITY PRODUCT VIOLATION*************
** Mg(OH)2_____________________Brucite **  1.00E+01 **

************SOLUBILITY PRODUCT VIOLATION*************
** Mg2Cl(OH)3.4H2O_______MgOxychloride **  6.69E+00 **

          2 Solubility Product Violations
Adding solid Mg(OH)2_____________________Brucite
pmH = -log[m(H+)]                  =     12.7140
pH = -log[a(H+)]     =     12.8532
Total Diagonal Inversions           85
```

```
Total Stoichiometric Reoptimizations          10
SINGLE BATCH EQUILIBRATION COMPLETED
$ dir

Directory U1:[SCBABB.FMT.CMS_TESTFILES]

BATCH_DOC.FOR088;1  BATCH_DOC.IN;1       BATCH_DOC.INGUESS;1 BATCH_DOC.OUT;1
BATCH_DOC_JAN08_1519.LOG;1               FMT_FMTC.COM;1      FMT_HMW_NP_AM.CHEMDAT;1
FMT_HMW_NP_AM.RHOMIN;1

Total of 8 files.
$ type batch_doc_jan08_1519.log

                image name: "FMT_FMT2P0"
                image file identification: "PROD PA96"
                image file build identification: ""
                link date/time: 21-DEC-1995 11:36:28.86
                linker identification: "A11-14"

Entering Subroutine READDAT
reading chemical species data from CHEMDAT file
DG_BYPASS flag set to nDG_BYPASS
[.FD.TITRATE]BATCH_DOC.in; to illustrate/document "BATCH" runs                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

Accuracy of reactions is              1.0000E-06
Minimum elemental abundance is        1.0000E-18
Number of Aqueous Species is            50

ACTIVITY COEF. FLAG PITZACT
using PITZER ACTIVITY COEFFICIENT model
Charge Balance replaces element Oxygen

Exiting Subroutine READDAT
Char Flags: FLOW/BATCH/TITRATE BATCH      UNUSED
this is a BATCH problem

Echo of Mole Specifications:  nMOLES     nEXACT
ECHO PRINT OF ELEMENT ABUNDANCES IN ONEFLSH
  110.222364000000      Hydrogen
  55.1654821000000      Oxygen
 0.200000000000000      Sodium
 1.000000000000000E-002 Potassium
 1.000000000000000E-003 Magnesium
 1.000000000000000E-004 Calcium
 0.110000000000000      Chlorine
 1.000000000000000E-003 Sulfur
 1.000000000000000E-004 Carbon
 0.000000000000000E+000 PosIon
 0.000000000000000E+000 NegIon
 0.000000000000000E+000 Air
 1.000000000000000E-007 Boron
 0.000000000000000E+000 Bromine
 0.000000000000000E+000 TracerEl
 0.000000000000000E+000 Th(IV)
 0.000000000000000E+000 Am(III)
 0.000000000000000E+000 U(VI)
 0.000000000000000E+000 Np(V)
 0.000000000000000E+000 ClO4-(EL)
 0.000000000000000E+000 Phosphorus
 0.000000000000000E+000 Electron
 4.906053920000000E-017 Charge
.LT. (MINABU*1.d-6) moles NaBO2.NaCl.2H2O___Teepleite_(20_C); del&switch
.LT. (MINABU*1.d-6) moles NaB5O8.5H2O_____Sodium_Pentaborate; del&switch
.LT. (MINABU*1.d-6) moles NaOH(aq).......to.titrate.base.only; del&switch
.LT. (MINABU*1.d-6) moles HCl(aq)........to.titrate.acid.only; del&switch
.LT. (MINABU*1.d-6) moles K2B4O7.4H2O___K-Tetraborate_(30_C); del&reopt
.LT. (MINABU*1.d-6) moles B4O5(OH)4=                B4O5(OH)4=; del&reopt
.LT. (MINABU*1.d-6) moles K8H6(SO4)7_______________Misenite; del&reopt
.LT. (MINABU*1.d-6) moles K8H4(CO3)6.3H2O___K-Sequicarbonate; del&switch
.LT. (MINABU*1.d-6) moles B3O3(OH)4-                B3O3(OH)4-; del&switch
.LT. (MINABU*1.d-6) moles Ca4Cl2(OH)6.13H2O__CaOxychloride A; del&switch

************SOLUBILITY PRODUCT VIOLATION*************
** Mg(OH)2_____________________Brucite **  1.00E+01 **

************SOLUBILITY PRODUCT VIOLATION*************
** Mg2Cl(OH)3.4H2O_______MgOxychloride **  6.69E+00 **

          2 Solubility Product Violations
Adding solid Mg(OH)2_____________________Brucite
pmH = -log[m(H+)]                    =      12.7140
pH = -log[a(H+)]     =      12.8532
Total Diagonal Inversions          85
Total Stoichiometric Reoptimizations          10
SINGLE BATCH EQUILIBRATION COMPLETED
```

Example #2 - Running the titrate problem NP_NACL_BM

For a titrate problem such as NP_NACL_BM, the input files are NP_NACL_BM.IN and NP_NACL_BM.INGUESS. FMT generates NP_NACL_BM.OUT, NP_NACL_BM.TITRATE, and NP_NACL_BM.MOLES.

```
$ dir

Directory U1:[SCBABB.FMT.CMS_TESTFILES]

FMT_FMTC.COM;1       FMT_HMW_NP_AM.CHEMDAT;1                    FMT_HMW_NP_AM.RHOMIN;1
NP_NACL_BM.IN;5      NP_NACL_BM.INGUESS;2

Total of 5 files.
$ @fmt_fmtc
Enter chemdat file name to search on: np
Enter rhomin file name to search on: np
Enter input file name (without .extension): np_nacl_bm
%CMS-I-LIBIS, library is WP$NONPA_CMSROOT:[FMT]
%CMS-S-LIBSET, library set
-CMS-I-SUPERSEDE, library list superseded

Elements in CMS Library WP$NONPA_CMSROOT:[FMT]

FMT_HMW_NP_AM.CHEMDAT "Initial load"
FMT_HMW_NP_AM_F60.CHEMDAT "Initial load"
Select CHEMDAT name from list above: FMT_HMW_NP_AM.CHEMDAT
Your CMS library list consists of:
   WP$NONPA_CMSROOT:[FMT]

%CMS-S-FETCHED, generation 1 of element WP$NONPA_CMSROOT:[FMT]FMT_HMW_NP_AM.CHEMDAT fetched

Elements in CMS Library WP$NONPA_CMSROOT:[FMT]

FMT_HMW_NP_AM.RHOMIN "Initial load"
Select RHOMIN name from list above: FMT_HMW_NP_AM.RHOMIN
Your CMS library list consists of:
   WP$NONPA_CMSROOT:[FMT]

%CMS-S-FETCHED, generation 1 of element WP$NONPA_CMSROOT:[FMT]FMT_HMW_NP_AM.RHOMIN fetched

                 image name: "FMT_FMT2P0"
                 image file identification: "PROD PA96"
                 image file build identification: ""
                 link date/time: 21-DEC-1995 11:36:28.86
                 linker identification: "A11-14"

Entering Subroutine READDAT
reading chemical species data from CHEMDAT file
DG_BYPASS flag set to nDG_BYPASS
Benchmark TITRATE Problem; Np(V)O2 with CO3 in 5.61molal NaCl                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

Accuracy of reactions is              1.0000E-06
Minimum elemental abundance is        1.0000E-18
Number of Aqueous Species is            50

ACTIVITY COEF. FLAG PITZACT
using PITZER ACTIVITY COEFFICIENT model
Charge Balance replaces element Oxygen

Exiting Subroutine READDAT
Char Flags: FLOW/BATCH/TITRATE TITRATE    EXPLICIT
this is a TITRATION problem

Character Flags:  J.C. nMOLES     nEXACT
Character Flags:  I.C. nMOLES     nEXACT
TEMP is an unused local variable    180000.100000000

TITRATION option requires delta(x)=0.01 meters
  Defining delta(x) as such

DIFFUS  Parameter UNUSED= nDIFFUS
CONVEC  Parameter UNUSED= CONVEC
SSDIFF  Parameter UNUSED= nSSDIFF
RESTART Parameter Value Read = nRESTART
UNUSED Parameters nPUSHPULL nMULTINJ
UNUSED parameter FRAC FLO

TITRATION Problem:
 -) Assigning all delta(y) to 0.1 m
 -) Setting # of nodes in Y-direction to 3
 -) Setting NONREACTIVE Porosity to 0.0

Char Flags UNUSED UNUSED RHSFDIF    LHSFDIF
Char Flags UNUSED UNUSED nMOLES     nEXACT
```

```
TEMP is an unused local variable   9.999999999999999E-021
Character Flags:  VPOROS FRFLASH VPOROS     FRFLASH

Specifying VARIABLE POROSITY for TITRATION Problem

Character Flags:  VAR_AQ_RHO VAR_AQ_RHO FRFLASH

Aqueous Density is a Function of Composition

Char Flag is UNUSED:  NO X DIFF nNO X DIFF
Char Flag is UNUSED:  UNIFORM UNIFORM              0

MINERAL DENSITIES, KG/M^3, IN FILE "RHOMIN"

pmH = -log[m(H+)]                    =     11.6199
pH = -log[a(H+)]     =      11.7497
pmH = -log[m(H+)]                    =      5.9141
pH = -log[a(H+)]     =       5.3205
TITRATION Character Flags
  cdum1= TITRATE       cdum2= ASREAD
reading titrant volumes from input file
  First Volume Added =          0.10 mL
  Final Volume Added =         10.00 mL

pmH = -log[m(H+)]                    =      5.9141
pH = -log[a(H+)]     =       5.3205
pmH = -log[m(H+)]                    =      6.2386
pH = -log[a(H+)]     =       5.6451
pmH = -log[m(H+)]                    =      6.5870
pH = -log[a(H+)]     =       5.9936
pmH = -log[m(H+)]                    =      6.8286
pH = -log[a(H+)]     =       6.2353
pmH = -log[m(H+)]                    =      7.2930
pH = -log[a(H+)]     =       6.6996
pmH = -log[m(H+)]                    =      8.5359
pH = -log[a(H+)]     =       7.9427
pmH = -log[m(H+)]                    =      8.9250
pH = -log[a(H+)]     =       8.3317
pmH = -log[m(H+)]                    =      9.1587
pH = -log[a(H+)]     =       8.5655
pmH = -log[m(H+)]                    =      9.3098
pH = -log[a(H+)]     =       8.7166
pmH = -log[m(H+)]                    =      9.4653
pH = -log[a(H+)]     =       8.8722
pmH = -log[m(H+)]                    =      9.8154
pH = -log[a(H+)]     =       9.2225
pmH = -log[m(H+)]                    =     10.0620
pH = -log[a(H+)]     =       9.4695
pmH = -log[m(H+)]                    =     10.4406
pH = -log[a(H+)]     =       9.8493
pmH = -log[m(H+)]                    =     10.8825
pH = -log[a(H+)]     =      10.2955
pmH = -log[m(H+)]                    =     11.2341
pH = -log[a(H+)]     =      10.6594
End of AutoTitration Problem
$ dir

Directory U1:[SCBABB.FMT.CMS_TESTFILES]

FMT_FMTC.COM;1       FMT_HMW_NP_AM.CHEMDAT;1        FMT_HMW_NP_AM.RHOMIN;1
NP_NACL_BM.IN;5      NP_NACL_BM.INGUESS;2           NP_NACL_BM.MOLES;1
NP_NACL_BM.OUT;1     NP_NACL_BM.TITRATE;1           NP_NACL_BM_JAN08_1523.LOG;1

Total of 9 files.
```

6.3.2 Macintosh Environment

The user double clicks with a mouse or track ball on the Macintosh executable icon for FMT, named PMacFmt. A screen titled "Output from PMacFmt" displays the file prompts and writes each file name on the screen after the user selects or names a file. The user makes a selection through a window display by navigating the folders or directory tree and double clicking on a file name.

The user can set a folder or directory before selecting or naming any file. The order of prompts in a batch problem directs the user to:

1. Select CHEMDAT File
2. Select RHOMIN File*
3. Select INPUT File
4. Select INGUESS File
5. Enter OUTPUT File Name
6. Enter FOR088 File Name

A titrate problem directs the user to:

1. Select CHEMDAT File
2. Select RHOMIN File
3. Select INPUT File
4. Select INGUESS File
5. Enter OUTPUT File Name
6. Enter TITRATE File Name
7. Enter MOLES File Name

6.3.3 Organization of Files

A suggested method for organizing folders or directories while running FMT on the DEC Alpha, Macintosh, or PC platforms is shown in Figures 3 and 4. Using this approach, the user groups

- all data base files (CHEMDAT and RHOMIN) in one folder. Beneath a major folder labeled "HMW_DB," Figure 3 shows two subfolders, labeled "HMW_NP_AM" and "HMW_35," which each contain unique CHEMDAT and RHOMIN data base files.
- the IN and INGUESS files in another folder. Beneath a major folder labeled "Test Cases," Figure 4 shows two problem-labeled folders, "BATCH_DOC" and "NP_NACL_BM," which each contain separate sets of input files. The "BATCH_DOC" input files are located under each version number folder.

* Although the RHOMIN file is not used for batch calculations, the user must still provide a file name for it when operating in a Macintosh environment.

- the ouput files in either the same problem-labeled folder or another folder (beneath the problem-labeled folder) labeled with version numbers "V1," "V2," and so on. Both options are shown in Figure 4.

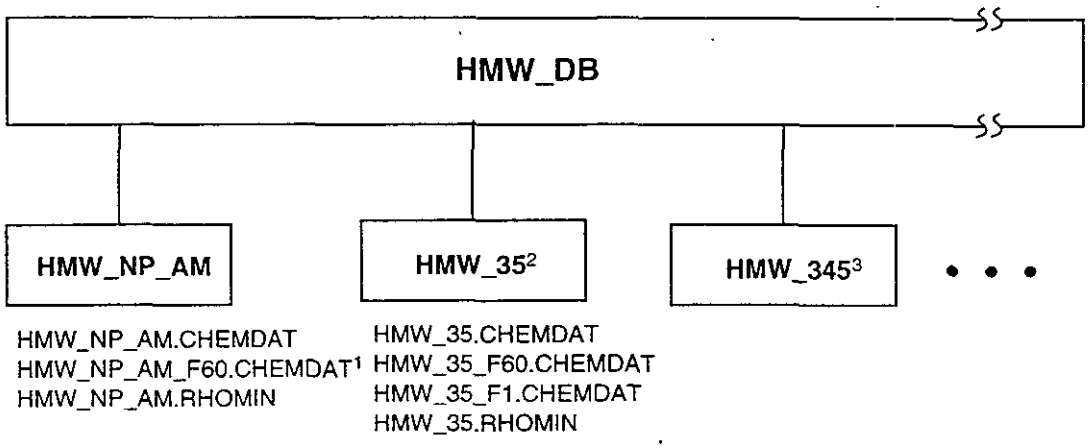

Notes
1. Same as *HMW_NP_AM.CHEMDAT*, except a declaration of CO_2 *"solid" fugacity = 60.0 atm* was added.
2. Contains updates on thermodynamic parameter values and complexation data for Np(V) and Np(V); F1 and F60 designate modifications to CHEMDAT file to reflect CO_2 "solid" fugacity at 1 and 60 atm.
3. Folder for future CHEMDAT data bases for Actinides in III, IV, V oxidation states.

Figure 3. Suggested data base organization.

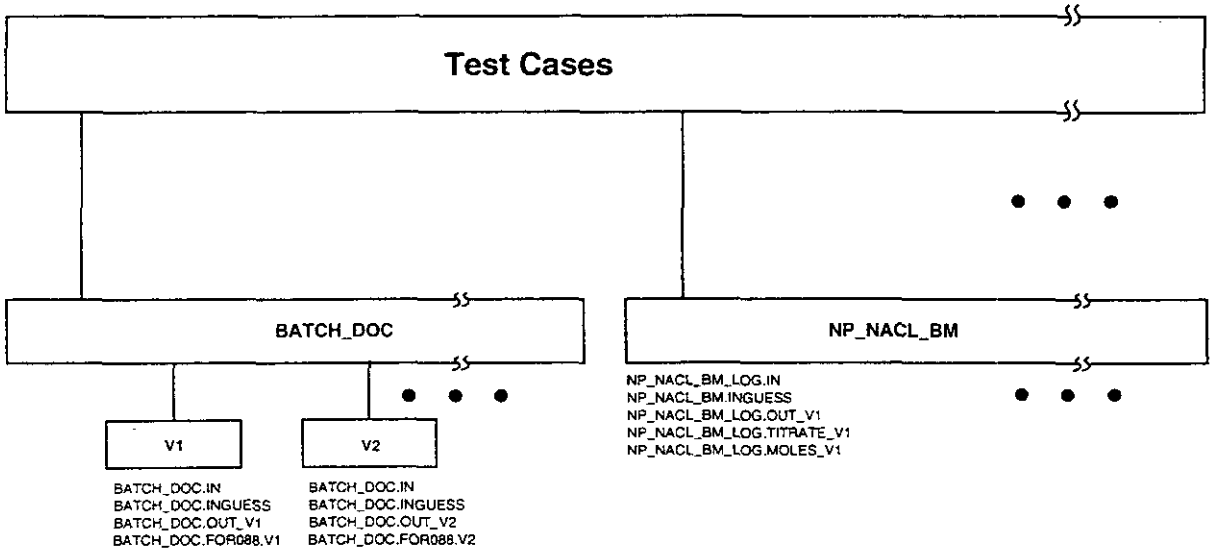

Figure 4. Suggested input/output file organization.

6.4 Setting up and Running a Batch (Flash) Problem

The input files for batch problems are INPUT, INGUESS, and CHEMDAT. The user supplies the INPUT and INGUESS files. CHEMDAT is provided as a standard data base file.

In batch problems, FMT generates two output files: OUTPUT and FOR088.

6.4.1 Screen Display Descriptions

The lines displayed on the screen during the execution of batch problems are frequently repeated in the OUTPUT file, including the CHEMDAT portion of that file. Any error messages will be displayed on the screen and printed in the OUTPUT file. The user can refer to Section 8.0 for explanations of errors and other messages; the OUTPUT file is documented in Section 9.1.

Table 1 explains the lines displayed to the user's screen during FMT execution. The "Line" column refers to the line numbers listed in a display of the screen during execution of a sample problem called "BATCH_DOC." If applicable, the "Variable Name" column shows FMT program variables.

Table 1. Batch Problem Screen Display Description (See Appendix A for sample listing.)

Line	Variable Name	Description
1	CHEMDAT_NAME	A partial string of a CHEMDAT filename to search on.
2	RHOMIN_NAME	A partial string of a RHOMIN filename to search on.
3	FILE_NAME	The full file name without the ".xxx" extension.
4-6		notation; setting pointers to FMT CMS library
8-11		list of CHEMDAT files with their comments in FMT CMS library that correspond to search string in line 1
12	CHEMDAT_NAME	user double clicks or cuts and pastes with a mouse or types in appropriate CHEMDAT filename
13-16		notation indicating that the CHEMDAT filename in line 12 has been copied to the user's current directory
18-20		list of RHOMIN files with their comments in FMT CMS library that correspond to search string in line 2
21	RHOMIN_NAME	user double clicks or cuts and pastes with a mouse or types in appropriate RHOMIN filename

22-25		notation indicating that the RHOMIN filename in line 21 has been copied to the user's current directory
27-31		linker and identity information on the FMT2P0 executable in CMS
33		notation; FMT will begin reading problem description from INPUT file (BATCH_DOC.IN, Appendix E) and chemical data from CHEMDAT file (HMW_NP_AM.CHEMDAT, Appendix I)
34		notation; FMT read 'CHEMFILE' from INPUT file (BATCH_DOC.IN, Appendix E)
35	DUMMY2	FMT read 'nDG_BYPASS' from CHEMDAT file (HMW_NP_AM.CHEMDAT, Appendix I)
36		notation; repeat of line 1 of INPUT file (BATCH_DOC.IN, Appendix E)
37-42	DBASE1, DBASE2, ACCURACY, MINABU,NAQ	repeat of lines 3-8 OUTPUT file for CHEMDAT (Appendix J)
44-45	DUMMY2	FMT read 'PITZACT' from CHEMDAT file (HMW_NP_AM.CHEMDAT, Appendix I) and notation (repeat of line 1273 from OUTPUT file for CHEMDAT [Appendix J])
46	ELNAMES (RPLWCHG)	repeat of line 1274 from OUTPUT file for CHEMDAT (Appendix J)
48		notation; FMT finished reading CHEMDAT file (HMW_NP_AM.CHEMDAT, Appendix I)
49	CDUM1,CDUM2	character strings read from INPUT file (BATCH_DOC.IN, Appendix E) to set batch mode
50		notation that FMT has a BATCH problem
51	DUMMY, DUMMY1	character strings read from INPUT file (BATCH_DOC.IN, Appendix E) to *not* read species amounts from INGUESS
52-76		notation; listing of elemental abundances
	ABUND(i), ELNAMES(i)	i^{th} mole amount from INPUT file (BATCH_DOC.IN, Appendix E) and i^{th} element name from CHEMDAT file (HMW_NP_AM.CHEMDAT, Appendix I)
77-86	NAMES(i)	species deleted from equilibrium algorithm because their total number of moles NMOLES(i) became negligible($<$MINABU$\times 1\times 10^{-6}$)

88-95		repeat of lines 17-24 in OUTPUT file for Batch (BATCH_DOC.OUT, *Appendix M)*
96-97		repeat of lines 163-164 in OUTPUT file for Batch (BATCH_DOC.OUT, Appendix M)
98-99		repeat of lines 180-181 in OUTPUT file for Batch (BATCH_DOC.OUT, Appendix M)
100		notation; normal exit from batch mode

6.4.2 Using FOR088 File as INGUESS File

The secondary output file FOR088 is produced from batch problems. Using the FOR088 as an INGUESS file provides the user with an easy way to adjust the solution composition.

Suppose the user ran a batch problem and generated the output files OUTPUT and FOR088. The FOR088 file contains the number of moles of each species calculated from the equilibrium run. The user could rename the FOR088 file to INGUESS, change the flags to 'MOLES' 'EXACT' in INPUT, and recalculate the equilibrium solution using the species concentrations (total mole amounts) read from the renamed INGUESS file. In this scenario, the calculated results would be the same.

If a user wanted to use the calculated concentrations from BATCH_DOC as a starting point but, for example, wanted the solution to be less basic, one could take the new INGUESS file, and increase the moles of one or several acids (or whatever else one desired to change) and run the problem again. Because the total mole amounts would be calculated from the INGUESS file, this would change the equilibrium system.

The process of running FMT, renaming the FOR088 file as the INGUESS file, modifying the INGUESS file, and rerunning FMT, can be used to fine tune the composition to whatever the user desires.

6.5 Setting up and Running a Titrate Problem

In addition to running in batch mode, FMT can calculate equilibrium concentrations resulting from titrating one solution with another solution or solution containing minerals ("a slurry"). For titrate problems, the user defines two solution compositions, the solution to titrate with, called the titrant or the "buret" solution, and the solution to be titrated, or the "Erlenmeyer" solution. The user must also specify the volumes of buret solution to add to the Erlenmeyer solution, and the number of additions.

Titration can be conceptualized as a series of N_s beakers each containing 1 liter of the Erlenmeyer solution. A volume of titrant solution in milliliters ΔV_i, $i=1,\ldots,N_s$, is added to each beaker. The first volume addition is always zero, that is, $\Delta V_1 \equiv 0$. At each titration step the specified volume is

added to each of the N_s beakers containing 1 liter of Erlenmeyer solution, and each beaker is reequilibrated. This volume addition assumes that the density of the titrant is 1000 grams per liter.

6.5.1 Using Volume Options (LOG10, LINEAR, and ASREAD)

FMT provides the user three different methods for specifying the titrant volume. Table 2 shows each option, a description of each option, and the mathematical method used to calculate the volumes to be titrated with each of the N_s Erlenmeyer solutions.

Table 2. Titrate Options

Option	Description	Method
LINEAR	add the same constant titrant volume for each iteration increment	$\Delta V_i = DV(2) \times (i-1)$, $i=2,\ldots,N_s$, where DV(2) is read from the INPUT file
LOG10	add titrant volumes that increase exponentially from the user specified minimum to maximum volumes	$\Delta V_i = DV(2) \times e^{(i-2)R}$, $i=2,\ldots,N_s$, with $R = \frac{\ln(DV(N_s)) - \ln(DV(2))}{N_s - 2}$, where DV(2) and $DV(N_s)$ are read from the INPUT file
ASREAD	add user specified titrant volumes	$\Delta V_i = DV(i)$, $i=2,\ldots,N_s$, where DV(i) values are read from the INPUT file

A problem called "Np_NaCl_BM" is used to illustrate the input and output files as an example problem. All three methods are demonstrated below using the same buret and Erlenmeyer solution compositions and same number of beakers, $N_s = 15$. For the example Np_NaCl_BM problem the initial volumes are

DV(1) = 0.0 mL for all three options

DV(2) = 0.1 mL for all three options.

The incremental volume is

$\Delta V_i = 0.1 \times (i-1)$ mL for 'LINEAR'

$\Delta V_i = 0.1 \times e^{(i-2)R}$ with $R = (\ln(10.0) - \ln(0.1))/13.0$,

$i = 2, \ldots, 15$ for 'LOG10'

and user-specified increments for 'ASREAD'.

The final volume is

`DV(15) = 1.4 mL` for 'LINEAR' option

`DV(15) = 10.0 mL` for 'LOG10' and 'ASREAD' options.

Figure 5 illustrates the LINEAR option. In the example shown in the figure, 15 different solutions are considered. The first beaker is a 1-L Erlenmeyer solution with no titrant volume added, the second is a l-L Erlenmeyer solution with 0.1 mL of titrant added, the third is a 1-L Erlenmeyer solution with 0.2 mL of titrant added, and so on up to the last beaker, a 1-L Erlenmeyer solution with 1.4 mL of titrant added.

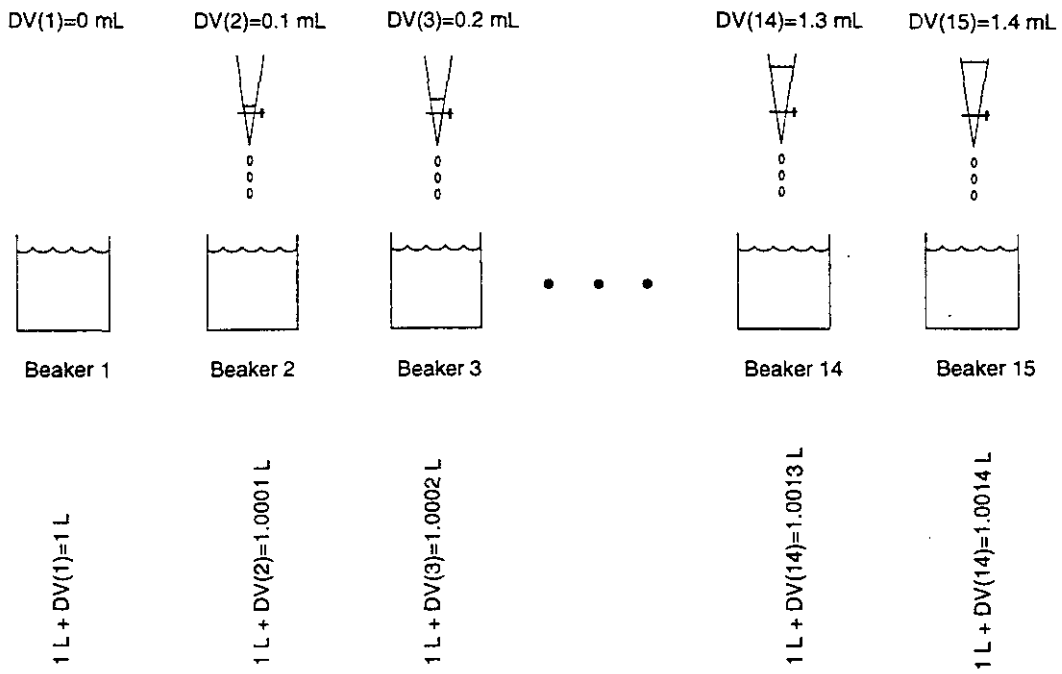

Figure 5. Titration problem using LINEAR option.

The user can use the above options in the following order:

1. use the LOG10 option to rapidly find the full extent of pH response possible
2. use the LINEAR option to locate regions of slow and rapid pH changes
3. use the ASREAD option to show the minimum number of points of pH changes

All options use NSPACE, the number of Erlenmeyer solutions. The LINEAR option requires an initial volume DV(2). The LOG10 option requires initial and last volumes DV(2) and DVMAX. The ASREAD option requires DV(i) amounts defined by the user

where i=2, . . ., NSPACE.

The flag for titrating (or "injecting") solids 'INJSOLIDS' is turned on so that FMT will add both the aqueous phase and solid phase portions of the titrant solution as a slurry mixture.

6.5.2 Screen Display Descriptions

Table 3 explains the lines displayed to the user's screen while executing FMT for the titrate problem. The "Line" column refers to the lines listed in screen displays of the Np_NaCl_BM_LOG, Np_NaCl_BM_LIN, and Np_NaCl_BM, the LOG10, LINEAR, and ASREAD runs of the titrate problem, which are described in detail later in this manual. "Variable Name" column shows FMT's program variables.

Table 3. Titrate Problem Screen Display Description (See Appendices B, C, and D for sample screen displays of Np_NaCl_BM_LOG, Np_NaCl_BM_LIN, and Np_NaCl_BM, respectively.)

Line	Variable Name	Description
1-48		repeat of variable names and descriptions in Table 1 for Batch
49	CDUM1,CDUM2	character strings read from INPUT (Np_NaCl_BM_LOG.IN [Appendix F], Np_NaCl_BM_LIN.IN [Appendix G], or Np_NaCl_BM.IN [Appendix H]) to set titrate mode
50		notation that FMT has a TITRATION problem
52	CDUM1,CDUM2	character strings read from INPUT (Appendices F, G, or H) to *not* read species amounts from INGUESS for the injected or buret solution
53	CDUM1,CDUM2	character strings read from INPUT (Appendices F, G, or H) to *not* read species amounts from INGUESS for the initial or Erlenmeyer solution
54		unused number read from INPUT (Appendices F, G, or H) line 56
56-57		notation; repeated in OUTPUT file for CHEMDAT (Appendix J)
59-64		unused character strings read from INPUT (Appendices F, G, or H) lines 57-61,65
66-69		repeat of lines 17-20 in OUTPUT file for Titrate (Np_NaCl_BM_LOG.OUT [Appendix N], Np_NaCl_BM_LIN.OUT [Appendix O], or Np_NaCl_BM.OUT [Appendix P])

71-72		unused character strings read from INPUT (Appendices F, G, or H) line 68-69
74-75		unused variables read from INPUT (Appendices F, G, or H) line 94-95
77		notation; repeat of line 18 in OUTPUT file for Titrate (Appendices N, O, or P)
79		unused variables read from INPUT (Appendices F, G, or H) lines 95-96
81		notation; repeat of line 24 in OUTPUT file for Titrate (Appendices N, O, or P)
83-84		unused character string read from INPUT (Appendices F, G, or H) line 97-98
86		notation; repeat of line 27 in OUTPUT file for Titrate (Appendices N, O, or P)
88-89		pmH (negative base 10 logarithm of hydrogen ion molality) and pH (negative base 10 logarithm of hydrogen ion activity) of the titrant solution
90-91		pmH and pH of the Erlenmeyer solution
93	CDUM1,CDUM2	character strings read from INPUT (Appendices F, G, or H) to set titrate method
94-95	DV(2), DV(NSPACE)	initial titrant volume as read from INPUT (Appendices F, G, or H) and final titrant volume; for example, 0.1 mL and 1.4 mL in Figure 5
97-126		pmH and pH of resulting solutions following titrant additions DV(i), i=1, . . ., N_S to 1 liter of the Erlenmeyer solution, with no additions to the first beaker; see Figure 5.
127		notation; normal exit from titrate mode

6.5.3 Titrate Sample Problem: Solubility Calculation

*****NOTE*****

The user should be familiar with the input and output files for the 'ASREAD' titration calculation (see Section 6.5.1) before reading this section.

The following example Np(V)/CO_3/NaCl problem illustrates a typical way in which FMT is used. This calculation is designed to show how the solubility of $NaNpO_2CO_3(s)$ varies as a function of CO_3^{2-} concentration in 5.61 molal NaCl media. This is the simulation used to generate Figure 7 of Novak and Roberts (1995). Because it is not possible to vary the carbonate concentration while keeping the concentrations of both Na^+ and Cl^- constant, the simulation was designed to keep the Na^+ concentration constant.

Referring to Appendix P, the listing for Np_NaCl_BM.OUT (an output file for the titrate calculation using the 'ASREAD' option), the flash calculation output for the titrant shows 5.61 molal sodium on Lines 58 and 102, approximately 2 molal CO_3^{2-} on Line 103, with 1.61 molal Cl^- (Lines 62 and 104) to create a charge-neutral solution. The titrant was designed to have a very high carbonate concentration. The solution could not have been made much more concentrated in carbonate because it is nearly saturated with respect to $Na_2CO_3 \cdot 7H_2O(s)$ as indicated by the Saturation Index of –0.251 listed in the Descriptor column on Line 114. The flash calculation output for the Erlenmeyer solution shows 5.61 molal sodium and 5.61 molal chloride (Lines 198 and 197), in equilibrium with a large excess of $NaNpO_2CO_3(s)$ at a relatively high pmH of 5.91 on Line 222. This solution was designed to have a very low carbonate concentration, 3.09×10^{-8} molal (Line 204). A large excess of $NaNpO_2CO_3(s)$ was specified because we are investigating the solubility behavior of this solid as conditions vary, and the large excess allows the amount of solid to change with changing aqueous conditions while keeping the solid phase present.

Examining the TITRATE file, Appendix T, the listing for Np_NaCl_BM.TITRATE on Lines 26-41, shows that the Na^+ concentration remains constant at 5.61 molal, while the Cl^- concentration changes slightly from 5.61 to 5.51 molal. More importantly, the CO_3^{2-} concentration varies widely, from 3.09×10^{-8} to 4.84×10^{-2} molal (Lines 43-58), as was intended. The $NaNpO_2CO_3(s)$ concentrations confirm that this solid is present across this aqueous composition range (Lines 79-94), and all other solid phases are absent. The concentrations of the Np(V) species NpO_2^+, $NpO_2OH(aq)$, $NpO_2(OH)_2^-$, $NpO_2CO_3^-$, $NpO_2(CO_3)_2^{3-}$, and $NpO_2(CO_3)_3^{5-}$, given in Lines 62-77 are the desired information from this simulation; these are plotted in Figure 6, along with the total Np(V) in solution (the sum of the individual species concentrations) and experimental measurements of this system from Neck et al. (1994).

The data from Neck et al. (1994) plotted in Figure 6 are:

mCO_3^{2-}	mNp(V) total		mCO_3^{2-}	mNp(V) total
9.49E-4	5.13E-6		3.61E-3	1.07E-5
3.61E-4	4.17E-6		6.27E-3	2.24E-5
7.20E-5	4.47E-6		1.50E-2	8.51E-5
9.93E-6	1.15E-5		1.98E-2	1.38E-4
2.38E-6	3.39E-5		2.74E-2	2.57E-4
1.25E-6	6.17E-5		1.09E-3	4.47E-6
3.78E-7	2.04E-4		3.29E-4	3.55E-6
1.73E-7	4.37E-4		2.50E-4	3.63E-6
1.57E-7	4.90E-4		2.28E-5	6.46E-6
9.06E-6	1.29E-5		6.27E-7	1.41E-4
2.74E-5	6.17E-6		5.72E-8	1.10E-3
1.19E-3	4.90E-6			

Figure 6 is comparable to Figure 7 from Novak and Roberts (1995), the main difference being the axis ranges. This figure shows that the hydrolysis species $NpO_2OH(aq)$ and $NpO_2(OH)_2^-$ are unimportant under these conditions, with concentrations always at least three orders of magnitude smaller than the total Np(V). This example shows the comparison between model calculations and experimental data, and also shows that the values calculated with FMT Version 1.0, used in

Novak and Roberts (1995), agree with values calculated with FMT Version 2.0, used in this user's guide. The symbols in the calculated curves serve both to identify the individual curves and show the positions of the flash calculations used to define the curves. If desired, one could trace these calculated species concentrations to values in Appendix T.

Figure 6 also shows how the 'ASREAD' option for titration problems lets the user specify exactly where values for the independent variable, in this case CO_3^{2-} concentration, will be. The modeling points were spaced relatively far apart in regions with linear behavior and closer together in regions of curvature.

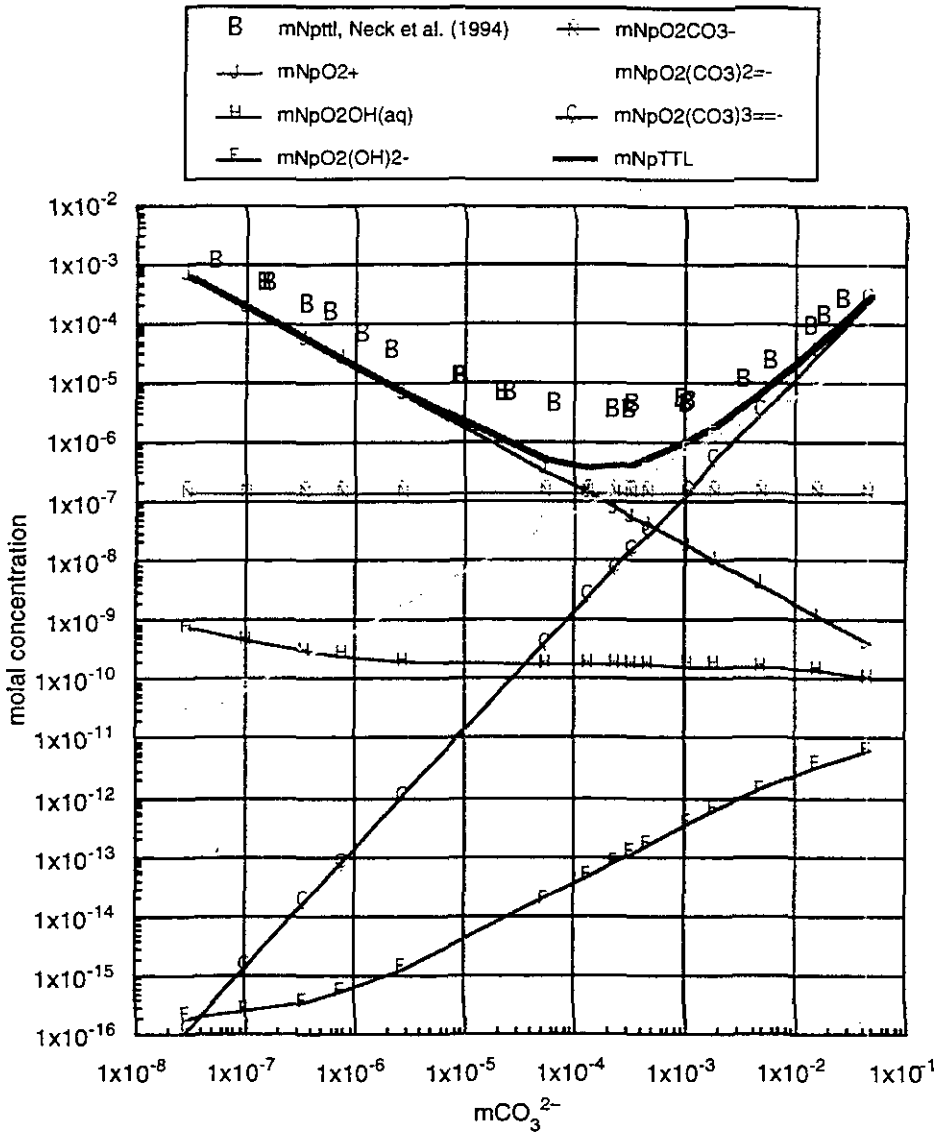

Figure 6. Calculated Total Np(V) and Np(V) Concentrations as a function of CO_3^{2-} concentration in 5.61 molal (5M) NaCl, and comparison with experimental measurements from Neck et al. (1994).

7.0 DESCRIPTION OF INPUT FILES

Of the four input files for FMT (see Figures 1 and 2), the user provides two files (INPUT and INGUESS) The other two files (CHEMDAT and RHOMIN) are the input data base files and are supplied by the code authors. INPUT and INGUESS can be edited by the user using a convenient text editor.

The input data files are read using standard FORTRAN free-field format read conventions. All character data must be enclosed in single quotes. Data are separated by either a space or a comma. Blank lines may be inserted anywhere in the input files to improve readability.

Comments are interspersed throughout the input files. These are not read by FMT and they are placed at the end of a line. They are used to:

- identify the element or species on a line, or
- document the reference source of data on a line.

FMT uses character strings to set options or flags in the INPUT and CHEMDAT files. The following options are considered:

- "on" when the character string equals a specific set of upper case letters, such as 'MOLES' or 'BATCH', or
- "off" when the character string equals any other set of letters.

The code developer of FMT chose to indicate turning "off" options by placing a lower case "n" before the specific string that turns an option "on," e.g., 'nMOLES' or 'nBATCH'. This offers the advantage of keeping the meaningful value of the flag close at hand for easy interpretation of the individual flags.

Batch problems require the input files INPUT, INGUESS, and CHEMDAT to run, and an additional file RHOMIN is required for titrate problems. A description of all four input files, for both Batch and Titrate calculations, follows.

7.1 INPUT

7.1.1 *Batch Problem*

The batch INPUT (.IN) file is used to specify the molar abundances of the elements for the batch problem. The bulk of the lines in this file (Figure 7) specifies element abundances. The flags on Line 6 indicate if the INGUESS file should be read for species abundances. A line-by-line description of this file is provided below in Table 4, and a sample listing of BATCH_DOC.IN is provided in Appendix E.

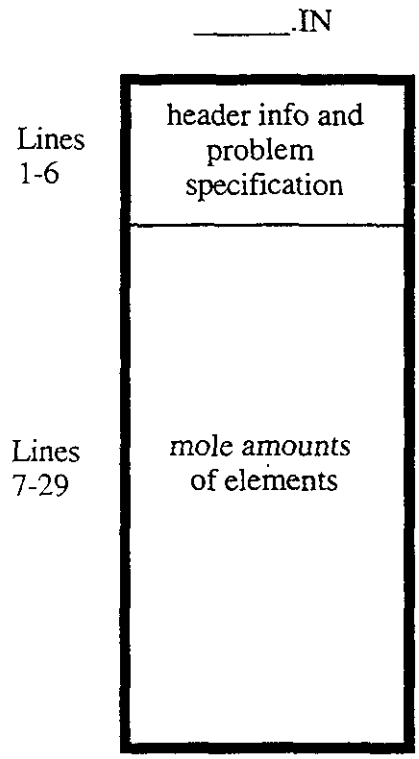

Figure 7. Batch INPUT file.

Table 4 lists the INPUT file parameters for a batch problem. The "LINE" column refers to the line numbers listed in the BATCH_DOC.IN file. The "Variable Name" column corresponds to the FMT program variables. "Permissible Value" column is the only set of values permitted for use with this program. Any other values have unknown consequences.

Table 4. INPUT File Parameters for Batch (See Appendix E for sample listing.)

Line	Variable Name	Permissible Value	Description
1	TITLE78	any character string (maximum 78 characters)	character string that identifies or describes the user's problem
2	DUMMY	'CHEMFILE'	character string used as a flag for reading the CHEMDAT file (Appendix I)
4	CDUM1, CDUM2	'BATCH' 'UNUSED'	the first string indicates this is a batch problem with the second string's value being irrelevant

6	DUMMY, DUMMY1		2 character strings used as flags for calculating the equilibrium state using either:
		'MOLES' 'EXACT'	species abundances read from INGUESS from which FMT calculates element abundances
		or	
		'nMOLES' 'nEXACT'	element abundances from INPUT (does not read INGUESS)
7-29	ABUND (i)	nonnegative real number	mole amount of ith element in the order listed in CHEMDAT (Appendix I, lines 8-10), one elemental amount per line

As shown in BATCH_DOC.IN file on lines 7-29, each amount is followed by an element or a psuedo element name. The names are not read by FMT and are included for human readability only.

7.1.2 Titrate Problem

The titrate INPUT (.IN) file, a required input file for running a titrate calculation (Section 6.1), is used to specify the molar abundances of the elements for both the buret and Erlenmeyer solutions, along with the number of titrant volumes ("burets") that are to be added for the titrate problem. (See Section 6.5 for explanation of titration problem.) The bulk of the lines in this file (Figure 8) specifies the molar abundances of the elements in the buret and Erlenmeyer ("beaker") solutions. Line 6 or Line 31 allows the user to set flags that force a read of the INGUESS file for species abundances. Line 100 in the file allows the user to specify that the titration method — adding equal volumes of the titrant successively (LINEAR), adding titrant volumes that increase exponentially (LOG10), or adding user-specified titrant volumes (ASREAD). A line-by-line description of this file is provided in Table 5, and sample listings are provided in Appendix F (LOG10 method), Appendix G (LINEAR method), and Appendix H (ASREAD).

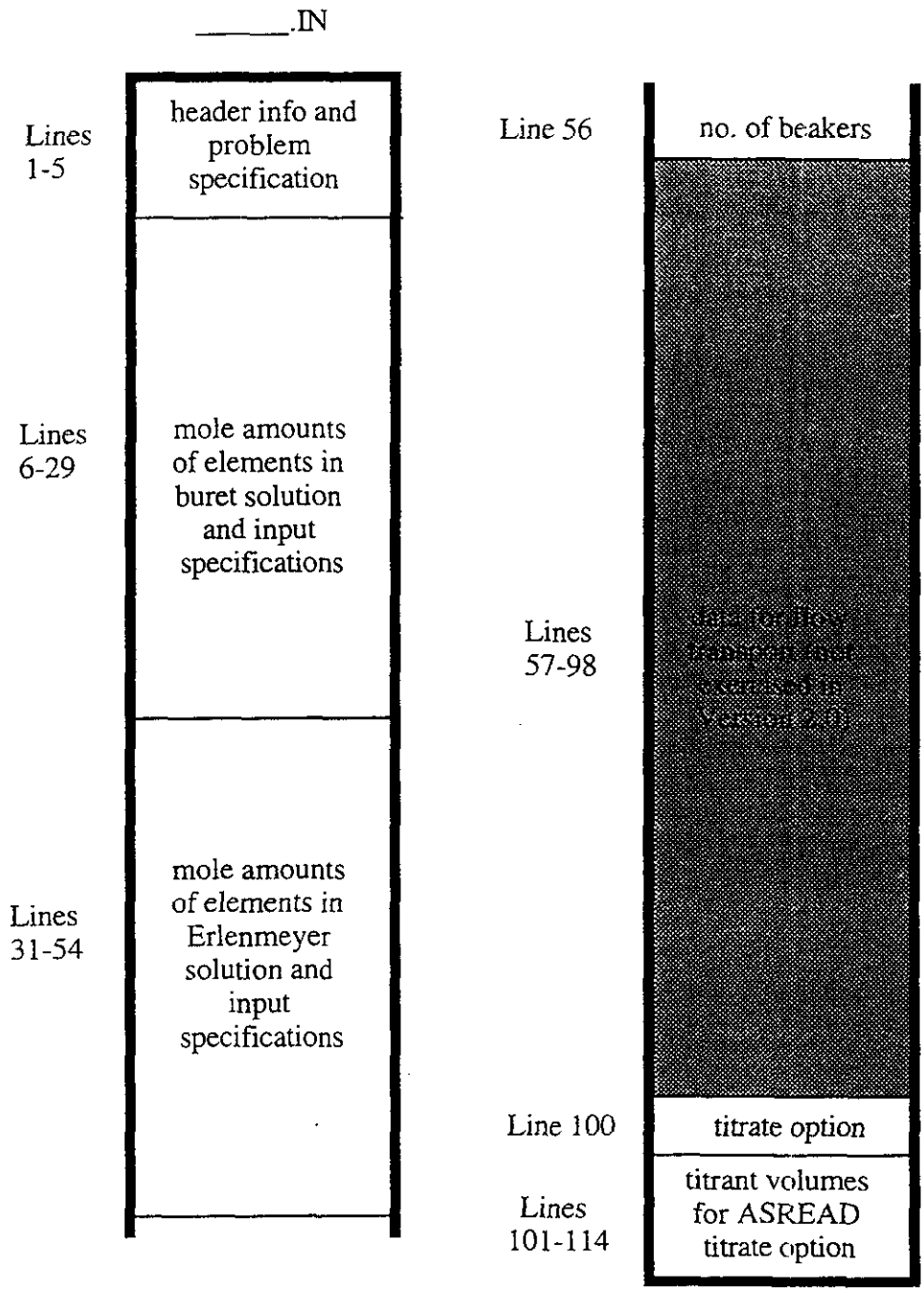

Figure 8. Titrate INPUT file.

The INPUT file parameters for a titrate problem are shown in Table 5. The "LINE" column in Table 5 refers to the lines listed in the Np_NaCl_BM_LOG.IN, Np_NaCl_BM_LIN.IN, and Np_NaCl_BM.IN files.

Table 5. INPUT File Parameters for Titrate (See Appendices F, G, and H for sample listings of Np_NaCl_BM_LOG.IN, Np_NaCl_BM_LIN.IN, and Np_NaCl_BM.IN, respectively.)

Line	Variable Names	Permissible Values	Description
1	TITLE78	any character string (maximum 78 characters)	character string that identifies or describes the user's problem
2	DUMMY	'CHEMFILE'	character string used as a flag for reading the CHEMDAT file (Appendix I)
4	CDUM1,CDUM2	'TITRATE' 'EXPLICIT'	the first and second strings are required to indicate that this is a titrate problem
6	CDUM1,CDUM2		2 character strings used as flags for the titrant or buret solution for calculating the equilibrium state using either:
		'MOLES' 'EXACT'	species abundances read from INGUESS from which FMT calculates element abundances
		or	
		'nMOLES' 'nEXACT'	element abundances from INPUT (does not read INGUESS)
7-29	ELTOTAL (i,1)	nonnegative real number*	mole amount of ith element in buret solution, one elemental amount per line
31	CDUM1,CDUM2		2 character strings used as flags for the solution to be titrated or Erlenmeyer solution for calculating the equilibrium state using either:
		'MOLES' 'EXACT'	species abundances read from INGUESS from which FMT calculates element abundances
		or	
		'nMOLES' 'nEXACT'	element abundances from INPUT (does not read INGUESS)

* The value on line 29, though negative, is essentially zero since it is so small (order of magnitude: 10^{-15})

32-54	ELTOTAL (i,2)	nonnegative real number**	mole amount of ith element in Erlenmeyer solution, one elemental amount per line
56	NSPACE, TEMP,TEMP, TEMP, CDUM1	2 < integer number < 66 2.25d3 0.0025d0 1.800001d5 'nDXVARIABLE'	the first number in this line specifies the total number of beakers, N_S. Recall that the first beaker gets zero addition of titrant solution, so N_S-1 volumes are added. The three remaining numbers and character string should be specified as indicated, but these values are not used for titration problems.
57-98		exactly as specified in the INPUT (.IN) file	none of these values are used for titrate problems, but must be included
100			The following five values on this line set one of the titrate options:
	CDUM1	'TITRATE'	'TITRATE' must always read 'TITRATE'
	CDUM2		Specifies the method of adding volume amounts to each beaker:
		'LINEAR' or	add equal sequential volumes
		'LOG10' or	add exponentially increasing volumes
		'ASREAD'	read volume amounts from the INPUT file
	DV(2)		initial volume, in mL, to add to the second beaker, valid for LINEAR or LOG10 options. A value must exist but not used for ASREAD option.
	DVMAX		volume added to the last beaker, valid only for LOG10 option. A value must exist but not used for ASREAD or LINEAR options.

** The value on line 54, though negative, is essentially zero since it is so small (order of magnitude: 10^{-15})

	CDUM3	'nINJSOLIDS' or 'INJSOLIDS'	By default, FMT will add only the aqueous phase part of the titrant to the Erlenmeyer solution. However, if the user wishes to add both the aqueous phase and solid phase portions of the titrant solution, which can be conceptualized as a slurry, this option for titrating (or "injecting") solids is turned on with the flag 'INJSOLIDS'
101-114	DV(i)	nonnegative real number	read titrant volumes, in mL, to be added for each of the N_S-1 additions where N_S value is set on line 56. For the ASREAD option; see Appendix H for illustration. For the LINEAR and LOG10 options, the INPUT file is not read after line 100.

In the input files referenced in the above table, lines 6-29 state the composition of the titrant or buret solution. Lines 31-54 define the composition of the titrated or Erlenmeyer solution. Line 56 states the number of beakers, N_S, for titration. Lines 57 through 98 are read but not used.

The INPUT file structure accommodates the three titration methods:

- Line 100 in the file Np_NaCl_BM_LOG.IN demonstrates using the 'LOG10' option with the initial and final volumes. FMT disregards any lines following line 100.

- Line 100 in the file Np_NaCl_BM_LIN.IN sets the 'LINEAR' option and the initial volume, and FMT disregards the final volume number. FMT stops reading the file and disregards any further lines.

- Line 100 in the file Np_NaCl_BM.IN sets the 'ASREAD' option, and FMT disregards the initial and final volume numbers. In lines 100-114 of the Np_NaCl_BM.IN file, FMT reads the 14 user-specified volumes for the 'ASREAD' option.

7.2 INGUESS

The INGUESS file is an input file for both the batch and titrate options that allows the user to specify the species abundances, from which FMT calculates the element abundances. The user must set the appropriate flags 'MOLES' and 'EXACT' in the INPUT file (Section 7.1). (If the INGUESS file is not used, the element abundances provided in the INPUT file are used.)

7.2.1 Batch Problem

The user can rename the FOR088 output file from a batch calculation and modify the species amounts as desired to build a solution composition for the INGUESS file (see Section 6.4.2). A line-by-line description of the INGUESS file, whose structure is identical to that of the FOR088 file (Appendix Q), is provided below in Table 6.

Table 6. INGUESS File Parameters for Batch Problem

Line	Variable Name	Permissible Value	Description
1-115	NMOLES (i)	nonnegative real number	mole amount of ith species in the order listed in CHEMDAT (Appendix I, lines 14-140), one species amount per line

On each line of an INGUESS (or FOR088) file, the total moles is followed by a species name and molality value. The order of the species listed follows that of the CHEMDAT file (Appendix I, Lines 14-140). HMW_NP_AM.CHEMDAT file has 115 species. FMT does not read the names or molality values from an INGUESS file, which were derived from a renamed FOR088 file.

7.2.2 Titrate Problem

When running a titrate problem, a user could direct FMT to compute the total element abundances for either the buret or Erlenmeyer solution by setting one set of species abundances in the INGUESS file and 'MOLES' 'EXACT' in either line 6 or 31 in the INPUT file as listed in Table 5. 'MOLES' and 'EXACT' set on line 6 would use INGUESS for buret solution; MOLES' and 'EXACT' set on line 31 would use INGUESS for the Erlenmeyer solution.

Table 7. INGUESS File Parameters for Titrate Problem

Line	Variable Name	Permissible Value	Description
1-115	NMOLES (i)	nonnegative real number	mole amount of ith species listed in CHEMDAT (Appendix I, lines 14-140), one species amount per line, for buret or Erlenmeyer solution

7.3 Standard CHEMDAT Input File

FMT is capable of evaluating the HMW model as defined in the CHEMDAT file, which contains the thermodynamic parameters necessary to model the chemical behavior of actinide elements in brines. HMW stands for Harvie-Møller-Weare/Felmy-Weare (Harvie et al., 1984; Felmy and Weare, 1986); it represents a thermodynamic model for evaporite systems using the Pitzer activity coefficient formalism (Section 4.2).

The term HMW_NP_AM.CHEMDAT as used throughout this document refers to version 95.01.31 of the file (a copy and output list of which are provided in Appendices I and J, respectively) where:

- HMW stands for Harvie-Møller-Weare/Felmy-Weare

- NP stands for neptunium(V)
- AM stands for americium(III).

The elemental list in the CHEMDAT file contains the physical elements as found on the periodic table and "psuedo elements" as required for solving chemical equilibrium problems. The psuedo elements in the HMW_NP_AM.CHEMDAT file are PosIon, NegIon, Air, Boron, Bromine, TracerEl, ClO4-(EL), Electron and Charge. These psuedo elements are treated exactly like the physical elements in the mathematical sense, regardless of their identity. See Section 4.5.

The CHEMDAT file illustrated throughout this document is HMW_NP_AM.CHEMDAT, version date 95.01.31.

*****NOTE*****

HMW_NP_AM.CHEMDAT is not necessarily the CHEMDAT file that will be used to support the WIPP 1996 PA calculations. Additional species and elements will be added to the HMW_NP_AM.CHEMDAT that will be used to support the 1996 WIPP PA calculations.

This data base contains the thermodynamic parameters necessary to model the chemical behavior of Np(V) and Am(III) in brines. Note that the extension of the Pitzer model to higher electrolyte types than in Harvie et al. (1984) and Felmy and Weare (1986) is necessary for Am(III); this is discussed in Pitzer and Silvester (1978).

*****WARNING*****

The user should not and is not expected to change the CHEMDAT file. To do so invalidates the QA performed on this data base.

7.3.1 CHEMDAT Data Flow

Both the FMT subroutines READDAT and RDPITZR read from the CHEMDAT file. Parameters read from CHEMDAT are echoed or printed to the OUTPUT file. Some parameters are also displayed on the user's screen.

The FMT control flow is illustrated with a Nassi-Schneiderman (N-S) chart (Figure 9). This shows the data flow of the CHEMDAT file in the READDAT subroutine. FMT program variables, TTLELEM and TTLSPEC in the diagram are the total number of elements and the total number of species respectively.

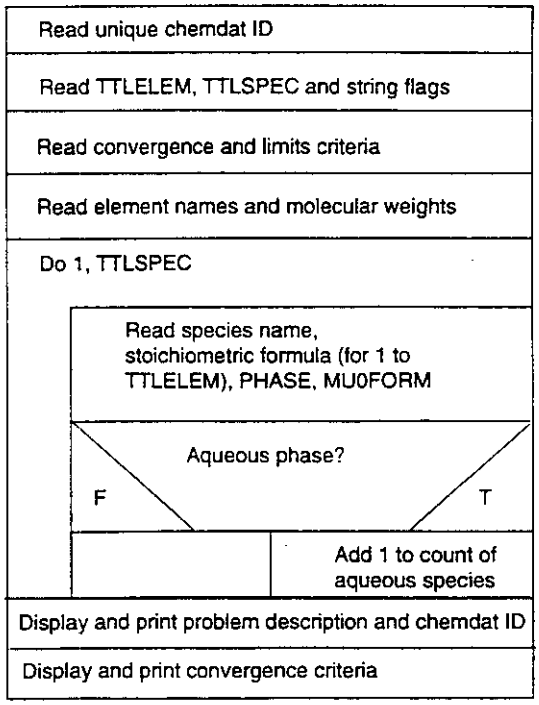

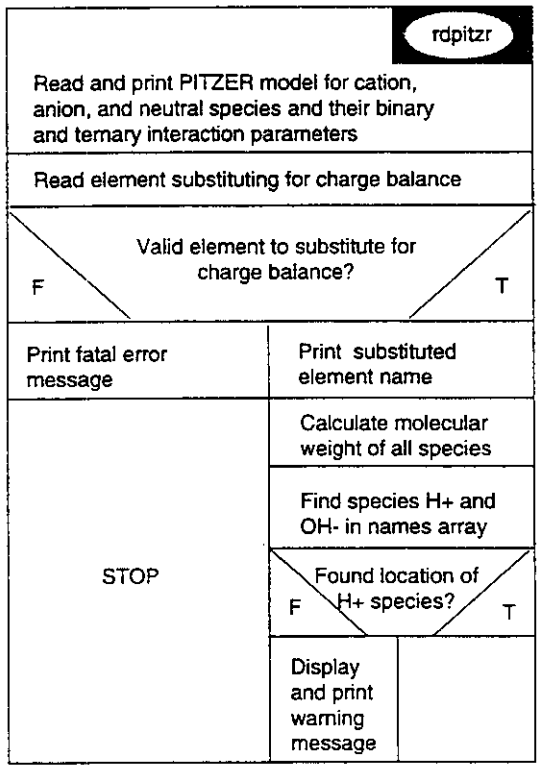

Figure 9. Nassi-Schneiderman (N-S) chart showing FMT control flow.

7.3.2 CHEMDAT Data Sources

The temperature range of the thermodynamic data is specified at 25 ° C with a few species at 20°C and 30°C.

The data for HMW_NP_AM.CHEMDAT can be grouped into three types: parameters for the brine (evaporite) electrolytes, parameters for Np(V) interactions with evaporite electrolytes, and parameters for Am(III) interactions with evaporite electrolytes. There is some overlap among these groups, but this categorization scheme will be used.

7.3.2.1 Brine Model

Parameters for brine electrolytes come primarily from Harvie et al. (1984) and Felmy and Weare (1986), called Harvie-Møller-Weare/Felmy-Weare, or HMW/FW or simply HMW for short. Harvie et al. (1984) presents a model for the Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O system, and Felmy and Weare (1986) extends this model to include boron species. Also included in this category are data from Pitzer (1991) for ion interactions with perchlorate, ClO_4^-. Perchlorate data are included in HMW_NP_AM.CHEMDAT not because perchlorate is important for the WIPP, but because much actinide chemistry was measured in the presence of perchlorate, and therefore parameters are needed to interpret these data. Parameters from Harvie et al. (1984) and Felmy and Weare (1986) were taken directly with no modification, and are not reproduced here. Parameters from Pitzer (1991) were scaled as necessary from the forms in which they were reported to the forms needed for use by FMT. These parameters are documented in Table 8.

7.3.2.2 Np(V) Model

Parameters for Np(V) interactions in NaCl, $NaClO_4$, and Na_2CO_3 media are taken from Novak and Roberts (1995). This model for Np(V) chemistry in brines is limited to predominantly NaCl, $NaClO_4$, or Na_2CO_3 media, and has not been shown to apply to other media. However, it can provide a first estimate of the solubility behavior of neptunium(V) in predominantly sodium chloride groundwaters containing carbonate, such as brines from the Castile and Rustler Formations in the vicinity of the WIPP Site. Parameters for Np(V) were taken directly from Novak and Roberts (1995) with no modification, as given in Tables 9 and 10. Since the publication of Novak and Roberts (1995), several alternative sets of parameters for Np(V) in concentrated electrolytes have been released in draft form. These will be included in future releases of the CHEMDAT data base for the purpose of WIPP PA calculations.

7.3.2.3 Am(III) Model

Parameters for Am(III) interactions with chloride, sulfate, phosphate, and carbonate anions, including interactions with several groundwater cations, are taken from Felmy et al. (1990), Felmy et al. (1989), Rai et al. (1992a, 1992b, 1994), and Rao et al. (1994). Although these parameters were developed for Am(III), Pu(III), or Nd(III), we have used the oxidation state analogy for f-elements (Novak and Dhooge, 1995) to apply these parameters to Am(III) as shown here. Although we call it the Am(III) model, this model should apply equally well to Pu(III) and Nd(III).

Felmy et al. (1990) provide the values of standard chemical potential for the americium species shown in Table 11, and the ion interaction parameters shown in Table 12. These parameters were developed from relatively dilute, i.e., less than 0.1 molal, solutions, so they do not necessarily apply to more concentrated solutions, as this discussion of Rao et al. (1994) below shows.

Rai et al. (1992b) use Nd(III) and Am(III) data from Felmy et al. (1990) and Rai et al. (1983) to develop the Nd(III) standard chemical potentials shown in Table 13. These values were converted to standard chemical potentials for the analogous Am(III) species for use within HMW_NP_AM.CHEMDAT as follows. One can write a general chemical reaction Nd^{3+} with a ligand Y^n, where n can be positive or negative, and the analogous reaction for Am^{3+}:

$$Nd^{3+} + yY^n \leftrightarrow NdY_y^{3+yn} \qquad \mu^o_{rxn1} = \mu^o_{NdY_y^{3+yn}} - \mu^o_{Nd^{3+}} - y\,\mu^o_{Y^n} \tag{15}$$

$$Am^{3+} + yY^n \leftrightarrow AmY_y^{3+yn} \qquad \mu^o_{rxn2} = \mu^o_{AmY_y^{3+yn}} - \mu^o_{Am^{3+}} - y\,\mu^o_{Y^n} \tag{16}$$

Because we are assuming identical chemical behavior for Am(III) and Nd(III), we must have $\mu^o_{rxn1} = \mu^o_{rxn2}$. Therefore, the standard chemical potential for the complex americium species is given by

$$\mu^o_{AmY_y^{3+yn}} = \mu^o_{NdY_y^{3+yn}} + \left[\mu^o_{Am^{3+}} - \mu^o_{Nd^{3+}}\right] \tag{17}$$

Analogous expressions hold for Pu(III). The dimensionless standard chemical potentials for the second and third americium hydrolysis species, calculated using the above equation, are given in Table 13.

Felmy et al. (1989) gives ion interaction parameters between Pu(III) and Cl^-, as well as the standard chemical potential for $Pu(OH)_3(s)$. The ion interaction parameters are given in Table 14; these are assumed to apply equally well to Am(III) by analogy. The standard chemical potential for $Pu(OH)_3(s)$ is converted to that for $Am(OH)_3(s)$ in Table 15.

Rao et al. (1994) parameterized ion interactions for Nd(III) in concentrated $NaHCO_3$ and Na_2CO_3 media, extending the work for Felmy et al. (1990) to the large carbonate concentrations that could occur in WIPP under disposal scenarios with large $CO_2(g)$ pressures. They identified an additional Nd(III) solid phase that forms under concentrated conditions, and had to modify one of the ion interaction parameters determined in Felmy et al. (1990). The parameters from Rao et al. (1994), converted to apply to Am(III) species, are given in Tables 16 and 17.

Interactions for Nd(III) or Am(III) with phosphate species are discussed in Rai et al. (1992a, 1992b) and Rai et al. (1994). These papers present the standard chemical potentials for H_3PO_4, $H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}, as shown in Table 18. The reported standard chemical potentials for

H_3PO_4 and $H_2PO_4^-$, taken from Pitzer and Silvester (1976) as the original source. are the same. However, there are slight differences in the standard chemical potentials given for HPO_4^{2-}, and PO_4^{3-}, even though these are all reported as having been taken from Wagman et al. (1982). The differences in these reported values are slight and will have no significant impact on calculations using these numbers. We have gone back to the original Wagman et al. (1982) reference to arrive at the selected values indicated in Table 18. Ion interaction parameters for phosphoric acid, taken from Pitzer and Silvester (1976), are given in Table 19.

The standard chemical potentials for three different Am(III)-phosphate or analogous Nd(III)-phosphate phases are reported in Rai et al. (1992a, 1992b) and Rai et al. (1994). These values, along with conversion from Nd(III) to Am(III) where necessary, are given in Table 20. The difference among the calculated values for the standard chemical potentials for the americium phosphate solid phase is less than 0.9 units; all values are effectively the same. However, because the value from Rai et al. (1992a) was determined for Am directly, not for Nd, this value was selected for use in HMW_NP_AM.CHEMDAT.

Table 21 contains the ion interaction parameters developed for Nd(III) or Am(III) in Rai et al. (1994). The publication of Novak et al. (1995) provides a comprehensive description of the sources for and the rationale for selection of the Am(III) thermodynamic parameters that will be incorporated into future versions of the CHEMDAT file.

Table 8. Ion interaction parameters from Pitzer (1991), converted to values needed for FMT.

1-1 electrolytes	$\beta^{(0)}$	$\beta^{(1)}$	C^{ϕ}
Na^+-ClO_4^-	0.0554	0.2755	–0.00118
Na^+-$H_2PO_4^-$	–0.0533	0.0396	0.00795
K^+-$H_2PO_4^-$	–0.0678	–0.1042	0
H^+-ClO_4^-	0.1747	0.2931	0.00819

2-1 electrolytes	$\frac{4}{3}\beta^{(0)}$	$\frac{4}{3}\beta^{(1)}$	$\frac{2^{5/2}}{3}C^{\phi}$	$\beta^{(0)}$	$\beta^{(1)}$	C^{ϕ}
Na^{+}-HPO_4^{2-}	–0.0777	1.954	0.0554	–0.0583	1.466	0.0294
K^{+}-HPO_4^{2-}	0.0330	1.699	0.0309	0.0248	1.274	0.0164
Ca^{2+}-ClO_4^{-}	0.6015	2.342	–0.00943	0.4511	1.756	–0.00500
Mg^{2+}-ClO_4^{-}	0.6615	2.678	0.01806	0.4961	2.008	0.009578
UO_2^{2+}-Cl^{-}	0.5698	2.192	–0.06951	0.4274	1.644	–0.03686
UO_2^{2+}-ClO_4^{-}	0.8151	2.859	0.04089	0.6113	2.144	0.02168

3-1 electrolytes	$\frac{3}{2}\beta^{(0)}$	$\frac{3}{2}\beta^{(1)}$	$\frac{3^{3/2}}{2}C^{\phi}$	$\beta^{(0)}$	$\beta^{(1)}$	C^{ϕ}
Na^{+}-PO_4^{3-}	0.2672	5.777	–0.1339	0.1781	3.851	–0.05154
K^{+}-PO_4^{3-}	0.5594	5.958	–0.2255	0.3729	3.972	–0.08680

2-2 electrolytes	$\beta^{(0)}$	$\beta^{(1)}$	C^{ϕ}
UO_2^{2+}-SO_4^{2-}	0.322	1.827	–0.0176

Table 9. Standard chemical potentials for neptunyl(V) species, from Novak and Roberts (1995).

Species	μ_f^o/RT	Species	μ_f^o/RT
NpO_2^+	–369.127	$NaNpO_2CO_3(s)$	–713.707
$NpO_2OH(am)$	–452.642	$NpO_2CO_3^-$	–594.492
$NpO_2OH(aged)$	–454.010	$NpO_2(CO_3)_2^{3-}$	–808.403
$NpO_2OH(aq)$	–438.518	$NpO_2(CO_3)_3^{5-}$	–1019.918
$NpO_2(OH)_2^-$	–505.829		

Table 10. Ion interaction parameters for neptunyl(V) species, from Novak and Roberts (1995).

$\beta^{(0)}_{NpO_2^+-ClO_4^-}$	0.312	$\beta^{(0)}_{Na^+-NpO_2CO_3^-}$	0.161	β\s((0),Na^+-$NpO_2(CO_3)_3^{5-}$)	1.97
$\beta^{(0)}_{NpO_2^+-Cl^-}$	0.169	β\s((0),Na^+-$NpO_2(CO_3)_2^{3-}$)	0.407	β\s((1),Na^+-$NpO_2(CO_3)_3^{5-}$)	16

Table 11. Dimensionless standard chemical potentials for Am(III) species from Felmy et al. (1990)

Species	μ_i^o / RT
Am^{3+}	–241.694
$AmCO_3^+$	–472.06
$Am(CO_3)_2^-$	–695.88
$Am(CO_3)_3^{3-}$	–915.46
$AmOHCO_3(c)$	–569.98

Table 12. Specific ion interaction parameters for Am(III) species from Felmy et al. (1990).

	$\beta^{(0)}$	$\beta^{(1)}$	$\beta^{(2)}$	C^{ϕ}
Na^{+} - ClO_4^{-}	0.80	5.35	0	–0.0048
Na^{+} - $Am(CO_3)_3^{3-}$	0.24*	8.1	0	0

* this value is modified in Table 17

Table 13. Dimensionless standard chemical potentials for Nd(III) species from Rai et al. (1992b), with calculated values for analogous Am(III) species.

Nd Species	μ_i^o / RT	Am Species	μ_i^o / RT
Nd^{3+}	–270.926	Am^{3+}	–241.694
$Nd(OH)_2^{+}$	–422.879	$Am(OH)_2^{+}$	–393.647*
$Nd(OH)_3^{0}$	–492.182	$Am(OH)_3^{0}$	–462.950*
$Nd(OH)_3(gl)$	–527.259	$Am(OH)_3(gl)$	–498.027*

*calculated by equation 17

Table 14. Specific ion interaction parameters for Am(III) species from Felmy et al. (1989), and, by analogy, for Am(III).

	$\beta^{(0)}$	$\beta^{(1)}$	$\beta^{(2)}$	C^{ϕ}
Pu^{+++} - Cl^{-}	0.6117	5.403	0	–0.0284
Am^{+++} - Cl^{-}	0.6117	5.403	0	–0.0284

Table 15. Dimensionless standard chemical potentials for Pu(III) species from Felmy et al. (1989), with calculated values for analogous Am(III) species.

Pu Species	μ_i^o / RT	Am Species	μ_i^o / RT
Pu^{3+}	–233.4	Am^{3+}	–241.694
$Pu(OH)_3(s)$	–484.0	$Am(OH)_3(s)$	–492.294*

*calculated by equation 17

Table 16. Dimensionless standard chemical potentials for Nd(III) species from Rao et al. (1994), with calculated values for analogous Am(III) species.

Nd Species	μ_i^o / RT	Am Species	μ_i^o / RT
Nd^{3+}	–270.926	Am^{3+}	–241.694
$NaNd(CO_3)_2 \cdot 6H_2O(c)$	–1425.726	$NaAm(CO_3)_2 \cdot 6H_2O(c)$	–1396.494*

*calculated by equation 17

Table 17. Specific ion interaction parameters for Nd(III) species from Rao et al. (1994), and, by analogy, for Am(III).

	$\beta^{(0)}$	$\beta^{(1)}$	$\beta^{(2)}$	C^{ϕ}
$Na^+ - Nd(CO_3)_2^-$	0	–8.37	0	0
$Na^+ - Nd(CO_3)_3^{3-}$	–0.94*	8.1	0	0.418
$Na^+ - Am(CO_3)_2^-$	0	–8.37	0	0
$Na^+ - Am(CO_3)_3^{3-}$	–0.94*	8.1	0	0.418

*this value was changed from that given in Felmy et al. (1990)

Table 18. Standard chemical potentials for phosphate species, with selected values for HMW_NP_AM.CHEMDAT data base.

name	Rai et al. (1992a)	Rai et al. (1992b)	Rai et al. (1994)	selected value
$H_3PO_4(aq)$	–460.90	–460.90	–460.90	–460.90
$H_2PO_4^-$	–455.96	–455.960	–455.960	–455.960
HPO_4^{2-}	–439.404	–439.354	–439.354	–439.367
PO_4^{3-}	–410.98	–410.947	–410.947	–410.947

Table 19. Specific ion interaction parameters for $H_3PO_4(aq)$ from Pitzer and Silvester (1976).

	λ
H^+ - $H_3PO_4(aq)$	0.290
K^+ - $H_3PO_4(aq)$	–0.070
HPO_4^{2-} - $H_3PO_4(aq)$	–0.400

Table 20. Standard chemical potentials for Am(III)- or Nd(III)-phosphate solid phases.

Nd Solid Phase	μ_i^o / RT	Am Solid Phase	μ_i^o / RT
Nd^{3+}	–270.926	Am^{3+}	–241.694
		AmPO4•xH2O(am), Rai et al. (1992a)	–709.75
NdPO4(c), Rai et al. (1992b)	–738.166	AmPO4(c)	–708.934*
NdPO4(c), Rai et al. (1994)	–738.63	AmPO4(c)	–709.398•

*calculated by equation 17

Table 21. Specific ion interaction parameters for Nd(III) species from Rai et al. (1994), and, by analogy, for Am(III).

	$\beta^{(0)}$	$\beta^{(1)}$	$\beta^{(2)}$	C^{ϕ}
Nd^{3+} - SO_4^{2-}	3.0398	0	–2500	0
Nd^{3+} - $H2PO_4^{-}$	0	0	–92.9	0
Am^{3+} - SO_4^{2-}	3.0398	0	–2500	0
Am^{3+} - $H2PO_4^{-}$	0	0	–92.9	0

7.3.3 Description of HMW_NP_AM.CHEMDAT

The standard chemical potentials for most species are values obtained from a reference source, as explained in Section 7.3.2. At the end of a line shown in the listing of HMW_NP_AM.CHEMDAT in Appendix I, the character strings FRSR89, FRF90, PS76, P91, RFF92, RFFR92, RFF94, RRFF94, NR94, HMW84, and FW86 indicate the source of the data. The key to citations is listed at the end of the file in Appendix I. These indicators are not read by FMT, but serve merely to help with human interpretation of the file.

Some of the standard chemical potentials for species, i.e., lines 39-49 and 70-72 in Appendix I, are described as "arbitrary." The Table 22 lists the value, the lines where instances occurred, and the definition of the value.

Table 22. Arbitrary values used for standard chemical potentials

Arbitrary Values	**Example in Lines**	**Definition**
–999.99	39, 40, 70, 72	physical species but represent the only occurrence for that element that have no chemical reactions in solution
0	45, 46, 49	nonphysical species that are included to facilitate the running of certain types of problems
500.	42, 43, 44, 47, 48	species included for adjusting the hydrogen ion concentration when setting up an input file and are designed to completely dissociate within an equilibrium problem

999.99	77	species that may be added in future, but which are not allowed to form in a solution (the character string DISABLED is appended to their name)

The nonphysical species are included for convenience only. They facilitate, e.g., addition of HCl(aq) to adjust the pH, insuring complete dissociation. To make sure these species are never calculated as being present, they were arbitrarily assigned the large positive value 500 for dimensionless standard chemical potential.

In Table 23 the "Variable Name" column is for the FMT program variables. Input parameters that are described as unused are not supported in this version of FMT.

Table 23. CHEMDAT input parameters (Listing of HMW_NP_AM.CHEMDAT provided in Appendix I.)

Line	Variable Name	Description
1-2	DBASE1, DBASE2	unique identification of the data base
4	TTLELEM, TTLSPEC, DUMMY, DUMMY2, DUMMY1, DUMMY3	number of elements (positive integer); number of species (positive integer); unused flag; unused flag; extra echo printing flag (if user specifies 'ECHO,' then extra information will be printed); unused flag;
5	MAXIT, ACCURCY, MINABU	maximum number of iterations for each equilibrium calculation (positive integer); convergence tolerance on equilibrium problem (positive, real); minimum element abundance, abundances below which elements are considered not to be there (positive, real)
6	DUMMY, TEMPERA, P(1), P(2)	character flag indicating the units for standard chemical potentials ('NONE' means dimensionless); temperature in degrees Kelvin (real, positive); unused pressure in atmospheres, unused pressure in atmospheres. Note: TEMPERA is always set to 298.15 by FMT.
8-10	ELNAMES(i)	name of ith element
11-12	MWELEM(i)	molecular weight of ith element

14-140	NAMES(j), FORMULA(i,j), PHASE(j), MU0FORM(j)	name of jth chemical species; stoichiometric number of each element in the species and charge of species (last number); phase of the species (1=aqueous, 2=solid, 3=gas, but gasses are unsupported); standard chemical potential of the species (in the units indicated by the flag in line 6). Entries in the formula vector usually are, but need not be, integers, and can be positive or negative. H_2O must always be the first species declared. All aqueous species must be declared before any solid species is declared.
142	DUMMY2, ITEMP	character flag that, when set to 'DG_BYPASS' allows alternate values for the standard chemical potentials to be read from file "bypass" for the first ITEMP species.
143	DUMMY2	character flag that enables the use of the Pitzer activity coefficient model when equal to 'PITZACT'. Any other character string will disable the Pitzer activity coefficient model.
144	NCATION	number of cations for which Pitzer activity coefficient model is used (positive integer) See note below Line 855 for a discussion of the order of cations, anions, and neutral species.
145	NANION	number of anions for which Pitzer activity coefficient model is used (positive integer)
146	NNEUTRL	number of neutral species for which Pitzer activity coefficient model is used (positive integer)
148-419	SE(i,j,1)	array of single electrolyte parameters The notation for charges on each cation-anion interaction is 1 when either cation or anion has a charge of 1 2 when both cation and anion have a charge of 2 3 for all other cases.
	SE(i,j,2)	$\beta^{(0)}$ parameter for each cation-anion interaction
	SE(i,j,3)	$\beta^{(1)}$ parameter for each cation-anion interaction
	SE(i,j,4)	$\beta^{(2)}$ parameter for each cation-anion interaction
	SE(i,j,5)	C^{ϕ} parameter, but this is later converted to C_{MX} (see equation A.4b, Harvie et al. [1984] or equation 2b, Felmy and Weare [1986], which is reproduced in Section 4.3).

		Note on cation-anion interactions: the parameters for SE are read in order - the first cation for all anions, then the second cation for all anions, etc. The character strings at the end of the numbers indicate the cation-anion pair specified on each line, for ease of human interpretation only.
422-433	ME(i,j,1)	for i>j, i and j are cation indices, cation-cation ternary interactions, θ_{ij}
436-454	ME(i,j,1)	for i<j, i and j are anion indices, anion-anion ternary interactions, θ_{ij}
456-544	PSI(i,j,k)	for i>j, i and j are cation indices, k is the anion index, cation-cation-anion ternary interactions, Ψ_{ijk}
546-753	PSI(i,j,k)	for i<j, i and j are anion indices, k is the cation index, anion-anion-cation ternary interactions, Ψ_{ijk}
755-760	NEUCAT(i,j)	neutral-cation binary ion interaction parameters, i=neutral species index, j=cation index, λ_{ij}
762-767	NEUANI(i,j)	neutral-anion binary ion interaction parameters i=neutral species index, j=anion index, λ_{ij}
769-851	PTZTSI(i,j,k)	neutral-cation-anion ternary ion interaction parameters, i=neutral species index, j=cation index, k=anion index, ζ_{ijk}
853	ELMAP(1,i)	maps the location in the species list to the order the Pitzer parameters were entered: cation map
854	ELMAP(2,i)	anion map
855	ELMAP(3,i)	neutral species map

		Note on species order: cationic, anionic, and neutral species are referenced by the order given in ELMAP(,). This is determined as follows: the cations are the second, third, fourth, fifth, sixth, seventh, twenty-second, etc., species entered in the species list, i.e., Na+, K+, Ca+, Mg+, MgOH+, H+, $MgB(OH)_4^+$, etc. Similar patterns are used for anions and cations. This allows additional flexibility in reorganizing and rearranging the data input files without having to reenter all of the ion interaction parameters. Although the order is arbitrary, it is very important that a consistent order is maintained throughout the CHEMDAT file. Because all parameters are clearly labeled, the echo printing of the ion interaction parameters makes is easy to determine whether errors were made when changing the CHEMDAT file. *****CAUTION***** ***THE USER SHOULD NOT ALTER THE CHEMDAT FILE.***
857	DUMMY, NEQACT	character flag that, when equal to 'EQUALACT', indicates that NEQACT (positive integer) activity coefficients of "nonPitzer" species will be set equal to activity coefficients of Pitzer species. For example, one could run calculations using both 22Na and 23Na (which would have to be declared as separate elements in the element list), but instead of repeating all the 23Na parameters for 22Na, use the 'EQUALACT' flag. When DUMMY='EQUALACT' this line would be followed by NEQACT pairs of positive integers, one pair per line, corresponding to species position in the species list. The activity coefficient of the first species in the pair will be set equal to the activity coefficient of the second species of the pair.
859	RPLWCHG	positive integer indicating the element to RePLace With CHarGe. Used to implement the constraint of solution charge neutrality. The 2nd element corresponds to oxygen.
860	DUMMY, NEHRXN	character flag indicating whether redox reactions are specified (they are when the flag is 'REDOX'). When this flag is used, it will be followed by specifications of NEHRXN (positive integer) redox reactions. This feature is unsupported in FMT V2.0.
861	DUMMY, NSBSTPM, NSBSTRX, DUMMY1	flags and parameters for specifying ion exchange reactions. The value 'IONEX' means that ion exchange reactions are specified on NSBSTPM permanent substrates and NSBSTRX reactive (soluble) substrates. The value for DUMMY1 indicates what type of mass-action model to use for ion exchange calculations. This feature is unsupported in FMT V2.0.

7.3.4 Description of OUTPUT File "BATCH.DOC" for HMW_NP_AM.CHEMDAT

The output file "BATCH_DOC.OUT," provided in Appendix J, is used to illustrate the lines echoing the CHEMDAT file. Table 24 explains this file. The OUTPUT file for a titrate problem will have an extra 5 lines after line 1277. The additional lines are described on line 1277 of Table 24. Line 1280 for the batch problem would be line 1285 for a titrate problem.

Table 24. OUTPUT file description of CHEMDAT input parameters (See listing provided in Appendix J.)

Line	Variable Name	Description
1		notation; FMT sets temperature to 298.15 Kelvin
2	TITLE99	problem title specified on line 1 of INPUT file with 'FMT' and version number appended
3-4	DBASE1, DBASE2	unique identification specified on lines 1 and 2 of CHEMDAT file
6	ACCURCY	convergence tolerance for equilibrium calculations, specified on line 5 of CHEMDAT file
7	MINABU	minimum elemental abundances for equilibrium calculations, specified on line 5 of CHEMDAT file. If the total number of moles of an element falls below this value, the element is considered to be absent (see Novak, 1995a).
8	NAQ	number of aqueous species in CHEMDAT
11		notation; species listed in order for Pitzer parameters
13-18	NAMES (ELMAP(1,i))	ordered list of cation species
20-26	NAMES (ELMAP(2,i))	ordered list of anion species
29-32	NAMES (ELMAP(3,i))	ordered list of neutral species
34-296		table of cation-anion binary interactions and parameters
	NAMES (ELMAP(1,i))	"Cation" species column
	NAMES (ELMAP(2,j))	"Anion" species column

	SE(i,j,2)	"Beta(0)" column, $\beta^{(0)}$ parameter for i^{th} cation, j^{th} anion interaction
	SE(i,j,3)	"Beta(1)" column, $\beta^{(1)}$ parameter for i^{th} cation, j^{th} anion interaction
	SE(i,j,4)	"Beta(2)" column, $\beta^{(2)}$ parameter for i^{th} cation, j^{th} anion interaction
	SE(i,j,5)	"Cphi" column, C^{ϕ} parameter for i^{th} cation, j^{th} anion interaction
	ALPHACH (SE(i,j,1))	"Alpha-Values" column (α_1, α_2) string that states electrical charges on the ith cation, j^{th} anion interaction (see Table 23, lines 148-419)
298-338		table of cation-cation ternary interactions and parameters
	NAMES (ELMAP(1,j))	up to 10 columns of cation names on a line after leading cation
	NAMES (ELMAP(1,i))	name of leading i^{th} cation in the order listed on lines 15-18
	ME(i,j,1)	cation-cation ternary interaction parameter, θ_{ij}
341-416		table of anion-anion ternary interaction and parameters
	NAMES (ELMAP(2,j))	up to 10 columns of anion names on a line after leading anion
	NAMES (ELMAP(2,i))	name of leading i^{th} anion on ordered list
	ME(i,j,1)	anion-anion ternary interaction parameters, θ_{ij}
419-579		table of cation-cation-anion ternary interaction and parameters
	NAMES (ELMAP(2,k))	up to 10 columns of anion names on a line
	NAMES (ELMAP(1,i)), NAMES (ELMAP(1,j))	two cation names
	PSI(i,j,k)	cation-cation-anion ternary interaction parameter, Ψ_{ijk}
581-965		table of anion-anion-cation ternary interaction and parameters

	NAMES (ELMAP(1,k))	up to 10 columns of cation names on a line
	NAMES (ELMAP(2,i)), NAMES (ELMAP(2,j))	two anion names
	PSI(j,i,k)	anion-anion-cation ternary interaction parameter, ψ_{ijk}
967-982		table of neutral-cation binary interaction and parameters
	NAMES (ELMAP(3,i))	up to 10 columns of neutral species names on a line
	NAMES (ELMAP(1,j)), NEUCAT(i,j)	j^{th} cation name and up to 10 binary interaction values. λ_{ij}
985-1007		table of neutral-anion binary interaction and parameters
	NAMES (ELMAP(3,i))	up to 10 columns of neutral species names on a line
	NAMES (ELMAP(2,j)), NEUANI(i,j)	j^{th} anion name and up to 10 binary interaction values, λ_{ij}
		table of neutral-cation-anion ternary interaction and parameters
1009-1272	NAMES (ELMAP(3,i))	up to 10 neutral species names in columns on a line
	NAMES (ELMAP(1,j)), NAMES (ELMAP(2,k))	j^{th} cation and k^{th} anion names
	PTZTSI(i,j,k)	up to 10 ternary interaction values, ζ_{ijk}
1273		notation that Pitzer activity coefficient model is used
1274	ELNAME (RPLWCHG)	states name of element replaced by charge balance (see Table 23, line 859)
1277		notation that the problem is BATCH (If this were a titration problem, notation would be that the problem is TITRATION.)

	CDUM1,CDUM2	5 extra lines for a TITRATION problem: notation defining delta(x) echoing character flags set by INPUT file in line 64 Note: Line count will be off by +5 for titrate problems
1280		notation that FMT uses dimensionless gas constant
1281	TKELVIN	temperature in degrees Kelvin, same as TEMPERA
1284	ALLSPEC, TTLELEM	number of species, number of elements
1286-1309	ELNAMES(i), MWELEM(i)	name and molecular weight of ith element
1312-1427		listing of each species' chemical properties
	i, NAMES(i)	number and name of ith chemical species
	PSNAME (PHASE(i))	string notation for the phase of the ith species
	MWSPEC(i)	molecular weight of ith species; computed as: ΣFORMULA(j,i)*MWELEM(j), where FORMULA(j,i) is the stoichiometric number of jth element in the ith species, MWELEM(j) is the molecular weight of the jth element, index j runs through all elements, and index i runs through all species
	MU0FORM(i)	standard chemical potential of the ith species
1430-1545		table showing relationship of species to elements
	i,NAMES(i)	number and name of ith chemical species
	FORMULA(j,i), j=1,ttlelem	stoichiometric number of each element in the ith species

7.4 Standard RHOMIN Input File

The input file RHOMIN, another data base, contains mineral densities. The RHOMIN file is required for titrate problems. It is not used for batch problems. RHOMIN contains the density of each of the solid species or minerals in the CHEMDAT file.

The RHOMIN input file, HMW_NP_AM.RHOMIN, contains mineral densities in units of kg/m^3 or equivalently in g/L, $\rho_{MINERALS}$, for all of the minerals contained in the CHEMDAT file. The numerical values for mineral densities were taken from Weast (1980) when available, otherwise the minerals were arbitrarily assigned a value of 2000 g/L. Mineral densities are not needed to calculate the chemical equilibrium problems that FMT 2.0 solves. However, they were needed for transport calculations that explicitly accounted for the volumes of solid phases and the changes in porosity caused by mineral dissolution and precipitation, a feature incorporated in earlier versions of FMT (Novak, 1994) that is no longer supported. The only place this information is used within FMT 2.0 is in calculating the volumes of the initial "Erlenmeyer" solution for titrate problems. Thus, the particulars of titrate problems may be different if mineral densities in RHOMIN are altered. The RHOMIN file is an atavism that will be removed from the next extensive update of FMT.

Changing the values in RHOMIN will change the aqueous volume to solid volume ratio, which will change the response of the Erlenmeyer solution to the titrant volume. The titration curve will not change, but the points used to plot the titration curve will change.

*****WARNING*****

The user should not and is not expected to change the RHOMIN file.

In Table 25, which describes the input parameters for HMW_NP_AM.RHOMIN, the "Variable Name" column is for the FMT program variables. FMT reads only the number on each line of HMW_NP.RHOMIN. The species name on the line is for human readability and is not read by FMT.

Table 25. RHOMIN input parameters (See Appendix K for listing, and Appendix L for output file listing.)

Line	Variable Name	Description
1-66	RHOSPEC(i)	density of the ith mineral species

8.0 ERROR MESSAGES

FMT has three types of messages - fatal error messages, warning messages, and informational messages. A system error message pertaining to divide by zero is also described after the section on fatal error messages.

8.1 Fatal Error Messages

A normal FMT run will terminate with a message displayed at the user's screen of either "SINGLE BATCH EQUILIBRATION COMPLETED" or "End of Autotitration Problem" for a batch or titrate problem respectively. Fatal errors terminate the execution of FMT abnormally. These errors are always printed on the user's screen and unit 6* that is usually defaulted the user's screen. The same and/or additional messages may be printed in the OUTPUT file.

Each error can generate one or more messages as shown below between lines of asterisks. A bracketed line preceding messages indicates where messages are printed. A pair of single quotes enclosing a phrase starting with 'value ...' indicate that the run time value in FMT will be listed.

The errors are listed in alphabetic order as they appear on the screen.

8.1.1 "Charge" abundance is not . . .

```
****************************************
[on unit 6]
"Charge" abundance is not numerically zero

[on screen]
"Charge" abundance is not numerically zero
or
"Charge" abundance is not numerically zero, INJECTED
or
"Charge" abundance is not numerically zero, INITIAL

[in OUTPUT file]
"Charge" abundance is not numerically zero
****************************************
```

8.1.1.1 Explanation

This error occurs when the last elemental amount in the INPUT file is greater than a numeric zero, that is, plus or minus 1.0×10^{-13}. The last line printed to the screen differs for batch and titration problems. If the last word in the line following "numerically zero" states:

- no word, it is a batch problem; the last line in element list does not have a zero charge balance
- "INJECTED," the first or titrant solution does not have a zero charge balance

* By default, unit 6 is the user's screen. The user could define a file = 6. If unit 6 is the user's screen, the message sent to 6 is printed first, followed by the [on screen] messages.

- "INITIAL," the second or titrated solution does not have a zero charge balance

8.1.1.2 Suggested Solution

Change the charge amount in the INPUT file to zero.

8.1.2 check problem type . . .

```
****************************************
[on unit 6]
check problem type option:  BATCH or TITRATE

[on screen]
CHECK PROBLEM TYPE SPECIFICATIONS

[in OUTPUT file]
check problem type option:  BATCH or TITRATE
****************************************
```

8.1.2.1 Explanation

On line 4 of the INPUT file (the CDUM1 variable), the character string must be exactly 'BATCH' or 'TITRATE'.

8.1.2.2 Suggested Solution

Check that all the characters in the word are capitalized and the word is immediately surrounded by a pair of the single quote character. No spaces, tabs, or unprintable characters are permitted in the word.

8.1.3 ERROR IN INITIAL ESTIMATE . . .

```
****************************************
[on screen]
ERROR IN INITIAL ESTIMATE DETERMINATION, INITGES

[on unit 6]
LINEAR SYSTEM INCONSISTENT [or] NO SOLUTION IS FEASIBLE

[in OUTPUT file]
ERROR IN RESULTS OF FEASBL
Results of call to FEASBL, IER= 2 [or] Results of call to FEASBL, IER= 3
****************************************
```

8.1.3.1 Explanation

The initial guess routine could not find an estimated solution for the given input. The initial guess algorithm is the weakest part of the code. The input could still represent a physical problem, but it may be a difficult combination of input values for the optimizing algorithm to find a solution.

8.1.3.2 Suggested Solution

Set up the initial solution desired in the INGUESS file and force FMT to read INGUESS with the flags 'MOLES' 'EXACT' set in the INPUT file. The objective is to develop a reasonable set of species values to give to the initial guess algorithm.

8.1.4 INPUT ERROR to . . .

```
****************************************
[on unit 6]
INPUT ERROR to FEASBL
NEQ.gt.IDIM .or. IDIMP1.lt.IDIM+1 [or] NEQ.ge.NVAR

[on screen]
ERROR IN INITIAL ESTIMATE DETERMINATION, INITGES

[in OUTPUT file]
ERROR IN RESULTS OF FEASBL
Results of call to FEASBL, IER= 1
****************************************
```

8.1.4.1 Explanation

NEQ, the number of linear equations must be greater than the first dimension of the coefficient array or the dimensions of the working arrays must be greater than NEQ+1 [or] NEQ must be greater than the number of variables, NVAR.

8.1.4.2 Suggested Solution

Contact the code sponsors. This message indicates programming errors.

8.1.5 MAXELEM= 'value for . . .

```
****************************************
[on unit 6]
MAXELEM= 'value for MAXELEM'
TTLELEM= 'value for TTLELEM
Parameter Dimensions Too Small for this Problem
Must Increase MAXELEM to   MAXELEM='value for TTLELEM+1'

[on screen]
MAXELEM DIMENSION IS TOO SMALL
****************************************
```

8.1.5.1 Explanation

This error occurs when the number of elements in the CHEMDAT file exceeds MAXELEM, a programmatic value which is set to 30.

8.1.5.2 Suggested Solution

Contact the code sponsors to set a higher limit for MAXELEM.

8.1.6 MAXSPEC= 'value for . . .

```
****************************************
[on unit 6]
MAXSPEC= 'value for MAXSPEC'
TTLELEM= 'value for TTLELEM'
TTLSPEC= 'value for  TTLSPEC'
Parameter Dimensions Too Small for this Problem'
Must Increase MAXSPEC to   MAXSPEC= 'value for TTLELEM+TTLSPEC'

[on screen]
MAXSPEC DIMENSION IS TOO SMALL
****************************************
```

8.1.6.1 Explanation

This error occurs when the number of species plus the number of elements in the CHEMDAT file exceeds MAXSPEC, a programmatic value which is set to 250.

8.1.6.2 Suggested Solution

Contact the code sponsors to set a higher limit for MAXSPEC.

8.1.7 MUST PUT ALL AQUEOUS . . .

```
****************************************
[on screen]
MUST PUT ALL AQUEOUS SPECIES BEFORE MINERALS

[in OUTPUT file]
MUST PUT ALL AQUEOUS SPECIES BEFORE MINERALS
****************************************
```

8.1.7.1 Explanation

This error occurs in the CHEMDAT file when a solid phase of a species is erroneously listed before an aqueous phase of a species.

8.1.7.2 Suggested Solution

In the CHEMDAT file, ensure that all aqueous species are declared before solid species.

8.1.8 Negative Element or Species Abundance . . .

```
***************************************
[on screen]
Negative Element Abundance Entered
  or
Negative Species Abundance Entered

[in OUTPUT file for batch option]
Negative element abundance in input file
'element name'  'abund value'
STOPPING EXECUTION in ROUTINE ONEFLSH
  or
Negative species abundance in inguess file
'species name'  'abund value'
STOPPING EXECUTION in ROUTINE ONEFLSH

[in OUTPUT file for titration option]
Negative element abundance given, INJECTED
'element name'  'abund value'
STOPPING EXECUTION in ROUTINE FMT2P0
  or
Negative element abundance given, INITIAL
'element name'  'abund value'
STOPPING EXECUTION in ROUTINE FMT2P0
  or
Negative species abundance in inguess file
'species name'  'abund value'
STOPPING EXECUTION in ROUTINE FLASHIJ
***************************************
```

8.1.8.1 Explanation

The error "Negative Element Abundance Entered" is generated when an element amount in the INPUT file is negative. The OUTPUT file contains the element name (from the CHEMDAT file) and the negative amount read from the INPUT file that caused this fatal error. For

- 'BATCH' problem: If the last line in the OUTPUT file states "ROUTINE ONEFLSH", the 'BATCH' flag was set in the INPUT file.

- 'TITRATE' problem: If the last line in the OUTPUT file states "ROUTINE FMT2P0", the 'TITRATE' flag was set in the INPUT file. The first line of the error message "Negative element ..." in the OUTPUT file tells which solution the fatal error is in - the INJECTED solution is the first solution or titrant solution while the INITIAL is the second solution or the titrated solution. The amount for a titrated solution could be essentially zero which is less than -1.0×10^{-12}.

The other error "Negative Species Abundance Entered" is generated when a species amount in the INGUESS file is negative. The OUTPUT file contains the species name (from the CHEMDAT file) and the negative amount read from the INGUESS file that caused this fatal error. For

- 'BATCH' problem: If the last line in the OUTPUT file states "ROUTINE ONEFLSH", the 'BATCH' flag was set in the INPUT file.

- 'TITRATE' problem: If the last line in the OUTPUT file states "ROUTINE FLASHIJ", the 'TITRATE' flag and the 'MOLES' 'EXACT' flags were set for either the titrant or titrated solution by the INPUT file

8.1.8.2 Suggested Solution

Change the negative amount in the INPUT or INGUESS file to zero or positive amount. Check the rest of the INPUT or INGUESS file for any negative amounts and change to zero or positive amounts.

8.1.9 NEW T" option . . .

```
****************************************
[on screen]
"NEW T" option for non 298.15K discontinued
****************************************
```

8.1.9.1 Explanation

This error occurs in the CHEMDAT file when the character string 'NEW T' is set.

8.1.9.2 Suggested Solution

Notify the code sponsors and change the character string to 'nNEW T' in CHEMDAT.

8.1.10 No Convergence on Equi . . .

```
****************************************
[on screen]
No Convergence on Equi Solid Suite

[in OUTPUT file]
EXITED SOLID ITERATION LOOP, MAXIMUM REACHED
diagnostics, no solid convergence achieved
list of element abundances follows:
'value for ABUND(i)' 'values for ELNAMES(i)'
list of species abundances follows:
'value for NMOLES(i)' 'values for NAMES(i)'
****************************************
```

8.1.10.1 Explanation

This error occurs when there is no convergence in the equilibrium root finding algorithm after 20 iterations. (The number 20 is hard coded in the program).

8.1.10.2 Suggested Solution

Contact the code sponsors. The algorithm has checked at least 20 different sets of solids and found no equilibrium solution. Either the problem is incredibly complex or the particular set of element abundances represents a condition for which no solution can be found. In more than nine years experience with this equilibrium algorithm, this error has never occurred.

8.1.11 PROBLEM TOO LARGE FOR . . .

```
***************************************
[on screen]
PROBLEM TOO LARGE FOR SPATIAL ARRAY DIMENSIONS

[in OUTPUT file]
TOO MANY NODES IN THE X AND Y DIRECTION
  NSPACE set to        'value for NSPACE'
  MWIDTH set to        'value for MWIDTH'
  MUST CONFORM TO THE FOLLOWING
  NSPACE .LE.          'value for MXSPACE'
  MWIDTH .LE.          'value for MXWIDTH'
  MWIDTH*NSPACE+2 .LE. 'value for MXANDY'
***************************************
```

8.1.11.1 Explanation

This error appears in titrate problems when NSPACE, the number of Erlenmeyer solutions, is greater than 66.

8.1.11.2 Suggested Solution

Reduce the NSPACE parameter in the INPUT file to 66 or less and adjust the ASREAD volumes to 66 or less if using 'ASREAD.'

8.1.12 Species "H2O" must be first . . .

Reduce the NSPACE parameter in the INPUT file to 66 or less.

```
***************************************
[on unit 6]
Species "H2O" must be first species in list
  Also, the first 3 chars. must be "H2O"

[on screen]
FIRST SPECIES NAME IS NOT H2O
***************************************
```

8.1.12.1 Explanation

This error occurs in CHEMDAT when the variable NAME(1) does not contain the character string H2O as the first 3 characters. The NAME variable is read on line 14 as printed in Appendix I listing of HMW_NP_AM.CHEMDAT.

8.1.12.2 Suggested Solution

Check that there are no spaces in the string H2O and that the string immediately follows the single quote mark.

8.1.13 To use TITRATE option . . .

```
****************************************
[on unit 6]
To use TITRATE option, specify:
      'TITRATE' 'LINEAR or LOG10' DVMIN DVMAX
  where DVMIN and DVMAX are the minimum and maximum titrant volumes.
  When LINEAR is used, multiples of DVMIN (mL) are added to each beaker.
  When LOG10 is used, volumes from DVMIN (mL) to DVMAX (mL) are added to
    each beaker on a logarithmic scale.

[on screen]
Check Specifications for TITRATE Option

[in OUTPUT file]
To use TITRATE option, specify:
      'TITRATE' 'LINEAR or LOG10' DVMIN DVMAX
  where DVMIN and DVMAX are the minimum and maximum titrant volumes.
  When LINEAR is used, multiples of DVMIN (mL) are added to each beaker.
  When LOG10 is used, volumes from DVMIN (mL) to DVMAX (mL) are added to
    each beaker on a logarithmic scale.
****************************************
```

8.1.13.1 Explanation

This error occurs when the INPUT file does not contain the one of the strings 'LINEAR', 'LOG10', or 'ASREAD' following the required 'TITRATE' string after the section of unused values (See line 100 in Table 5).

8.1.13.2 Suggested Solution

Check that one of the permissible character strings LINEAR, LOG10, or ASREAD is enclosed in single quotes and listed after the TITRATE string in the line.

8.1.14 Trying to shift reaction . . .

```
****************************************
[in OUTPUT file]
Trying to shift reaction to the left, but
   SMLPRD is .LE. 0.d0
```

```
[or]
Trying to shift reaction to the right, but
   SMLRCT is .LE. 0.d0
****************************************
```

8.1.14.1 Explanation

FMT is attempting to eliminate one of the species involved in a solids-only reaction but there is no more product (top message) or there are no more reactants (bottom message).

8.1.14.2 Suggested Solution

Increase the amounts of elements in the INPUT file or amounts of species in the INGUESS file.

8.1.15 VALID CHARGE BALANCE ELEMENT NOT . . .

```
****************************************
[on screen]
VALID CHARGE BALANCE ELEMENT NOT SPECIFIED

[in OUTPUT file]
Need to specify the charge balance element
****************************************
```

8.1.15.1 Explanation

This error occurs in the CHEMDAT file when the variable RPLWCHG is negative or zero. The RPLWCHG variable is read on line 859 as a 2 (the element Oxygen) in Appendix I listing of HMW_NP_AM.CHEMDAT.

8.1.15.2 Suggested Solution

Notify the code sponsors.

8.1.16 Was expecting the "TITRATE" . . .

```
****************************************
[on unit 6]
Was expecting the "TITRATE" flag

To use TITRATE option, specify:
      'TITRATE' 'LINEAR or LOG10' DVMIN DVMAX
  where DVMIN and DVMAX are the minimum and maximum titrant volumes.
  When LINEAR is used, multiples of DVMIN (mL) are added to each beaker.
  When LOG10 is used, volumes from DVMIN (mL) to DVMAX (mL) are added to
    each beaker on a logarithmic scale.

[on screen]
second TITRATE flag incorrectly specified

[in OUTPUT file]
```

```
To use TITRATE option, specify:
      'TITRATE' 'LINEAR or LOG10' DVMIN DVMAX
  where DVMIN and DVMAX are the minimum and maximum titrant volumes.
  When LINEAR is used, multiples of DVMIN (mL) are added to each beaker.
  When LOG10 is used, volumes from DVMIN (mL) to DVMAX (mL) are added to
    each beaker on a logarithmic scale.
****************************************
```

8.1.16.1 Explanation

This error occurs when the INPUT file does not contain the 'TITRATE' string after the section of unused values (See INPUT file description for titrate problems, line 100 in Table 5).

8.1.16.2 Suggested Solution

Check that the character string TITRATE is enclosed in single quotes and listed first in the line. There could also be missing lines or values prior to this line. In the unused values section, the variables and their permissible values must be present.

8.2 System Error Messages

There is one system error message "divide by zero" that occurs because of insufficient water in the INGUESS file to support the chemical reactions. The water is used up in the chemical reactions, so that when the amount of water (which is now zero) is used in the denominator of a divide operation, a "divide by zero" system error results, halting FMT execution. The FOR088 file was not generated due to the abnormal termination. A suggested solution is to increase the amount of water to the INGUESS file or decrease species amounts.

8.3 Warning Messages

There are warning messages that indicate the solution is not a valid one.

One or more messages are shown between lines of asterisks. A bracket line preceding any messages indicates where messages are printed. A pair of single quotes enclosing a phrase indicate that the run time value in FMT will be listed.

The errors are listed in alphabetic order as they appear on the screen.

8.3.1 BATCH CALCULATION ERRORS . . .

```
****************************************
[on unit 6]
BATCH CALCULATION ERRORS, L2 norm 'value for L2 norm'
SEE OUTPUT FOR MASS BALANCE ERROR INSTRUCTIONS

[in OUTPUT file]
BATCH CALCULATION ERRORS, L2 norm 'value for L2 norm'
{a listing of the initial and final abundances, element names and the absolute
value of the differences between the initial and final abundances}
MASS BALANCE ERROR INSTRUCTIONS
```

```
1) Check to see how much abundances have changed
   Should only happen in batch problems, or when
   flashing initial or injected conditions

2) This problem occurs when the diagnostic
   "Trying to get Internal Initial Guess"
   has been printed, and means that the initial
   guess provided by /MOLES/ is inadequate

3) Try flashing with /nMOLES/-- this is the
   easiest way to try to fix the problem
****************************************
```

8.3.1.1 Explanation

This message warns that material balance errors are present during the flash calculation. This message occurs when material and charge balances exceed 1.0×10^{-6}. FMT prints the above message and continues on to the next flash in a titration problem.

8.3.1.2 Suggested Solution

None, but answer (if any) is invalid.

8.3.2 CANNOT FIND LOCATION OF . . .

```
****************************************
[on unit 6]
CANNOT FIND LOCATION OF "H+" INVALIDATING pH VALUE

[in OUTPUT file]
CANNOT FIND LOCATION OF "H+" INVALIDATING pH VALUE
****************************************
```

8.3.2.1 Explanation

This message occurs in the CHEMDAT file when the exact species name of 'H+' is missing from the species list or a space or unprintable character precedes the H+. The HMW_NP_AM.CHEMDAT has 115 species.

8.3.2.2 Suggested Solution

Verify that H+ species is not in the CHEMDAT file and notify the code sponsors.

8.3.3 "EXACT" mole amounts . . .

```
****************************************
[in OUTPUT file]
"EXACT" mole amounts not charge balanced
   CHARGE= 'value of charge ABUND'
****************************************
```

8.3.3.1 Explanation

FMT has calculated the elemental abundances using the mole amounts given in the INGUESS file. The solution must be charge neutral otherwise FMT will modify the abundance. This error occurs when the species amounts in the INGUESS file do not maintain charge neutrality. The absolute value of the charge must equal or exceed 1.0×10^{-12} for this error to occur.

8.3.3.2 Suggested Solution

Check the species amounts in the INGUESS file, being sure to maintain charge neutrality. For example, if you are increasing the amount of a positively charged species, then add the necessary amount of a negatively charged species, observing stoichiometric rules.

8.3.4 MASS BALANCE ERRORS . . .

```
****************************************
[on unit 6]
MASS BALANCE ERRORS at ISPACE= 'value of Erlenmeyer solution'
****************************************
```

8.3.4.1 Explanation

This message warns that material balance errors were detected during the flash calculation. FMT prints the above message and continues to the next Erlenmeyer solution in a titration problem.

8.3.4.2 Suggested Solution

None, but answer (if any) is invalid.

8.4 Informational Messages

There are informational messages that indicate where the code is during execution or what it is doing. These messages, presented in alphabetical order, are described below.

8.4.1 AQ vio 'value of mu' . . .

```
****************************************
[in OUTPUT file]
AQ  vio 'value of mu'  'species name' 'name index number'
****************************************
```

This message occurs in a batch problem when the mu value or concentration of aqueous/sorbed species exceeds 1.0×10-24 as specified by minabu×1.0×10-6, the convergence tolerance read from CHEMDAT. This message refers to FMT's normal algorithmic attempts to adjust the stoichiometric equation for the lack of species. These messages appear during execution of a batch problem as indicators of normal computational progress.

8.4.2 DONT HAVE ANY REACTIONS . . .

```
****************************************
[on unit 6]
 ************************************************
 ************************************************
 **** DONT HAVE ANY REACTIONS TO EQUILIBRATE ***
 ****** BUT CONTINUING CALCULATION ANYWAY ******
 ************************************************
 ************************************************

[in OUTPUT file]
 ************************************************
 ************************************************
 **** DONT HAVE ANY REACTIONS TO EQUILIBRATE ***
 ****** BUT CONTINUING CALCULATION ANYWAY ******
 ************************************************
 ************************************************
****************************************
```

This message occurs when there are no chemical reactions to equilibrate, which by definition means the system is at equilibrium.

8.4.3 MU(ttl)= 'value of mu' . . .

```
****************************************
[on unit 6]
MU(ttl)= 'value of mu' x 'value of Erlenmeyer solution'

[in OUTPUT file]
nonconvergent elemental abundances
MU(ttl)= 'value of mu' x 'value of Erlenmeyer solution'
table of element abundance
'value for abund(i)' 'value for elnames(i)'
****************************************
```

This is not a fatal error, but it is more than a run-time message. This message occurs when one or more reactions are not at equilibrium after MAXIT iterations. MAXIT is the number of iterations for minimizing free energy and set by the CHEMDAT file. The output from the runs in which this message occurs must be checked carefully by the user to see if they are suitable to use.

8.4.4 SOLUBILITY PRODUCT VIOLATION . . .

```
****************************************
[on unit 6]
 ************SOLUBILITY PRODUCT VIOLATION*************
'species name' ** 'value of mu'  **

[in OUTPUT file]
 ************SOLUBILITY PRODUCT VIOLATION*************
'species name' ** 'value of mu'  **
****************************************
```

This message occurs during execution of a batch problem when the mu value or concentration of a solid species exceeds 1.0×10^{-6} as specified by accuracy, the convergence tolerance read from CHEMDAT. This message refers to FMT's normal algorithmic attempts to adjust the stoichiometric equation for the lack of species.

8.4.5 'count of ' Solubility Product Violations . . .

```
****************************************
[on unit 6]
'count of ' Solubility Product Violations
 Adding solid 'name of solid species most oversaturated'

[in OUTPUT file]
'count of ' Solubility Product Violations
 Adding solid 'name of solid species most oversaturated'
****************************************
```

This message occurs during execution of a batch problem whenever a solid species needs to be included in a solution. A count of the number of solubility violations found during the equilibrium process. The largest mu value of a solid species is listed.

8.4.6 Switching Routine Hung . . .

```
****************************************
[on unit 6]
Switching Routine Hung, Ending Batch Calculation
*** Flash Calculation Terminated ***
***   Infinite Loop Encountered  ***
*** spacepoint='value of Erlenmeyer solution'

[in OUTPUT file]
Flash-Terminated (sp) 'value of Erlenmeyer solution'
*** Flash Calculation Terminated ***
***   Infinite Loop Encountered  ***
*** spacepoint= 'value of Erlenmeyer solution'
****************************************
```

A species has a calculated concentration right on the border between existing and not existing (MINABU value multiplied by 1.0×10^{-6}) and FMT cannot decide whether to include it or not. This message is triggered when FMT adds the same species three times in a row but the species gets deleted in the equilibrium root finding algorithm. Because the boundary between "existing" and "not existing" is very low (1.0×10^{-22}), this message has no consequences unless the user is looking at very trace species.

9.0 DESCRIPTION OF OUTPUT FILES

FMT generates a primary OUTPUT (.OUT) file and the secondary output files shown in Figures 1 and 2. Secondary output files vary according the whether a batch (single flash) calculation or titrate (multiple flash) calculation is performed. (A batch problem has one flash calculation. A titrate problem has a user-specified number of flash calculations.) FOR088 is the secondary file for batch problems; TITRATE and MOLES are the secondary files for titrate problems.

9.1 OUTPUT

For both batch and titration calculations, the primary file OUTPUT (.OUT) file lists the problem identity, echoes the CHEMDAT file, and contains a summary of element concentrations, species concentrations, and equilibrium parameters for each flash calculation performed.

Note that while the user is printing the OUTPUT file, page breaks will occur. The listings appended to this guide do not emulate the page break as a separate page but show such a line as a Fortran page break, i.e., the line is prefixed with the character "1."

9.1.1 Batch Problem

Table 26 explains the OUTPUT (.OUT) file generated from a batch problem called BATCH_DOC. The "Line" column refers to the line numbers listed in BATCH_DOC.OUT. "Variable Name" column shows applicable FMT program variables and some formulas.

Table 26. OUTPUT File Description for Batch (See Appendix M for sample listing.)

Line	Variable Name	Description
1	INFNM	INPUT filename.
2	INGFNM	INGUESS filename.
3	OUFNM	OUTPUT filename.
4	CHFNM	CHEMDAT filename.
5		notation; FMT sets temperature to 298.15 Kelvin
6	TITLE99	problem title specified on line 1 of INPUT file with 'FMT' and version number appended
7-8	DBASE1, DBASE2	unique data base identification specified on lines 1 and 2 of CHEMDAT file

11-14		this location would normally be filled with an echo print of ion interaction parameters and chemical species definitions, as read from the CHEMDAT input file (Appendix I). This information is reproduced in the OUTPUT file listing in Appendix J and is described in Section 7.3.
17-25		this section contains computation status indicators printed during calculations to find the equilibrium system.
17-21	NAMES(i), MU(i)	at the end of the first convergence loop, the solids brucite and magnesium oxychloride "MgOxychloride," were oversaturated, and thus the system was not at equilibrium.
23	NKSPVIO	number of solubility product violations for solids (minerals)
24	NAMES(i)	postulated that brucite was present in the equilibrium system, and thus added to the equilibrium calculations
25	ALLITER	number of times the diagonalized Hessian matrix system of equations was solved to reach the calculated equilibrium state
26		Note: a page break occurs; the first character "1" indicates a Fortran page break and is deleted before printing the remaining line
26-28	TITLE99, DBASE1, DBASE2	problem title and CHEMDAT input file (Appendix I) identification
29	PRESSUR, TEMPERA	pressure and temperature for batch problem
31-58		table of Elemental Abundances
	ABUND(i)	"Total Moles" column contains the exact number of moles for each element as read from the INPUT file, or as calculated from species abundances as read from the INGUESS file
	AQMOLES(i)/ KGH2O	"Aq. Molality" column is the total molality for each element in the aqueous phase
	AQMOLES(i)/ SOLNVOL	"Aq. Molarity" column is the total molarity for each element in the aqueous phase. This number is calculated from the solution density, as discussed on lines 54-67.
	AQMOLES(i)/ SOLNVOL× MWELEM(i) ×1000	"Aq. mg/liter" column is the total aqueous element concentration in milligrams per liter
	ELNAMES(i)	identifies the element name corresponding to the row of values in the table

60-73		this section documents the calculation of solution density, a quantity that is required only for converting molal units to Molar units. In batch problems, the density is used only to produce the volume based concentration units (Molar, mg/liter) printed in the OUTPUT file. The actual calculation of equilibrium is conducted using mass-based, i.e., molal, units. FMT uses a correlation based on NaCl solutions (as noted on line 35) to calculate solution density from total dissolved solids (TDS).
61-63	SOLMASS, KGH2O×1000, TDSGPKG	values calculated from equilibrium compositions
66	SPRHO	density specified in the INPUT file for titrate problems. For BATCH problems the solution density from the NaCl correlation is automatically used.
69-70	SOLNVOL, TDS	calculated values based on specified density on line 66
72	DENSITY(2, TDSGPKG)	*density calculated by FMT using the NaCl correlation*
73	(DENSITY(2, TDSGPKG)/ SPRHO-1.)×100	difference between the specified density (line 66) and the density calculated by FMT which will always be zero for BATCH problems
77-161		table listing detailed information about the species in the equilibrium problem. Note that only species that can be formed from elements with nonzero concentrations are included. Species are sorted approximately in order of decreasing concentration. For example, the total phosphorus element concentration on line 56 is zero, so no detailed information is given for phosphorus species.
	NAMES(i)	"Species Name" column
	MOLALTY(i) or for solids: NMOLES(i)/ NMOLES(1)/ MWH2O	"Molality" column contains the species molality, moles per kg H_2O, for all species including solids. However, the entry for water is not molality of water, which is invariant, but the mole fraction H_2O in the aqueous phase, as noted on line 170.
	LNGAMA(i)× MOLALTY(i)	"Activity" column is the product of the "Molality" and "Act Coef" columns or is defined to be 1 for solids
	LNGAMA(i) or 1.0 for solids	"Act Coef" column is the calculated activity coefficient for the species, which is 1 by definition for solids
	NMOLES(i)	"Total Moles" column is the total number of moles for the ith species
	NMOLES(i)/ SOLNVOL	"Molarity" column is the volume-based concentrations calculated from the "Molality" column using the solution density described above on lines 60-73

	NMOLES(i)/ SOLNVOL× MWSPEC(i)× 1000	"mg/liter" is the volume-based concentrations calculated from the "Molality" column
	MU(i)/LN10	"descriptor" column has various meanings, as stated in the notes on lines 172-176
163	-(NMOLES (NPROTON)/ NMOLES(1)/ MWH2O)	pmH: the negative base 10 logarithm of hydrogen ion molality
164	PHVECT	pH: the negative base 10 logarithm of hydrogen ion activity
165	OSM	osmotic coefficient, a value related to the activity of water; a value calculated from the Pitzer equations
166	LNGAMA(1)×100	equilibrium relative humidity, equal to 100% times the water activity
167	IONICST	ionic strength, in molal units, defined as $\sum_{i=2}^{Nspec} z_i^2 m_i$, where z_i is the charge on the ith species, m_i is the molality of the ith species, and index i runs from species 2 through all aqueous species, with species 1 defined as H_2O
168	SPRHO	solution density, calculated as described on lines 60-73
170-171		notes defining water and gas molality
172-176		notes describing the descriptor column in table of concentrations for batch system
178	ΣCHEMPOT(i)× NMOLES(i)	the total dimensionless Gibbs free energy for the solution; the quantity that is minimized to find the equilibrium composition
180	NINVERS	total number of times the diagonalized Hessian matrix system of equations was solved; for batch problem, this value is the same as ALLITER on line 25
181	ICNT	number of times the species list was changed for computational purposes in the minimization algorithm

In the BATCH_DOC.OUT file on lines 31-58, the first table gives the elemental abundances in various units, the first column being the number of total moles, and the second being the aqueous molality. The "Total Moles" column provides the basis for computation, i.e., the amount of each element, independent of phase, including hydrogen and oxygen. It is convenient to specify

material on an approximately 1 kg H_2O basis (~55.5 moles H_2O). The "Aq. Molality" column given the aqueous phase totals; it is this portion of the output that corresponds to the aqueous phase element totals listed above. The "Aq. Molarity" and "Aq. mg/liter" columns are provided for the convenience of those users who prefer these units. However, these units depend on the value used for solution density, which is approximated by FMT from a correlation based on the density of NaCl solutions.

Lines 77-161 which comprise the second table, Table of Concentrations for Batch System, list molality, activity, activity coefficient, and a descriptor for each chemical species that can be made from the elements with nonzero concentrations. For example, note that there are no species containing "Air", "TracerEl", "Th(IV)", etc. in this list. These species are sorted in approximate order of decreasing molality.

The descriptor serves several functions. First, it is the value that is actually tested for convergence (note that all values of the descriptor are less than the 10^{-6} as specified in line 6 of the output file listing for the CHEMDAT file; see Appendix J). The *component* species, lines 81-90, do not have descriptors because these are species from which all other species are formed by chemical reaction. (This quickly leads into an arcane discussion of the algorithm used to calculate equilibrium. The interested user should refer to Smith and Missen (1991), particularly Chapter 6.) The descriptor values given for noncomponent species, lines 91-101, all have absolute values less than 10^{-6}, thus indicating convergence. The remaining species, lines 102-161, all have zero concentration. Most of these species are solids, and the descriptor is the saturation index, $SI=\log_{10}(Q/K_{sp})$, an indication of how saturated the solution is with respect to that solid. A saturation index of 0.0 indicates the solution is exactly saturated. A saturation index less than zero indicates undersaturation. FMT does not allow solutions to be oversaturated.

Lines 157-158 show that the species NaOH(aq) and HCl(aq) have zero concentrations, and descriptors of –293 and –254 respectively. As the note in line 175 indicates, the descriptor value for aqueous species with zero concentrations is approximately equal to the $\log_{10}$ concentration of that aqueous species in this solution. (For comparison, one atom in 1 kg H_2O would have a molal concentration of 1.6×10^{-24} molal, corresponding to a descriptor value of –23.8.) These values are a consequence of the choice of values for the standard chemical potentials of these species. As discussed in the CHEMDAT data base documentation (Section 7.3 and Appendices I and J), these species are nonphysical and included for convenience only.

9.1.2 Titrate Problem

Table 27 explains the printout for a titrate problem using the OUTPUT file generated from executing Np_NaCl_BM_LOG. (It also explains the printout of the OUTPUT file generated from executing Np_NaCL_BM_LIN and Np_NaCl_BM.) The "Line" column refers to the line numbers listed in Np_NaCl_BM_LOG.OUT. "Variable Names" column shows FMT's program names and some formulas.

Table 27. OUTPUT File Description for Titrate (See Appendices N, O, and P for sample listings of Np_NaCl_BM_LOG.OUT, Np_NaCl_BM_LIN.OUT, and Np_NaCl_BM.OUT, respectively.)

Line	Variable Name	Description
1	INFNM	INPUT filname
2	INGFNM	INGUESS filname
3	OUFNM	OUTPUT filname
4	CHFNM	CHEMDAT filname
5		notation that temperature is set to 298.15 Kelvin by FMT
6	TITLE99	problem title specified on line 1 of INPUT file with 'FMT' and version number appended
7-8	DBASE1, DBASE2	unique data base identification specified on lines 1 and 2 of CHEMDAT file
11-14		this location would normally be filled with an echo print of ion interaction parameters and chemical species definitions, as read from the CHEMDAT. This information is reproduced in the OUTPUT file listing provided in Appendix J and is described therein.
17-20		notation of parameters set for fracture/matrix transport
24		notation of porosity
27		notation of aqueous density
29	RHFNM	RHOMIN filename
31-34		this location would normally be filled with an echo print of mineral species and their densities, as read from RHOMIN. This information is reproduced in the OUTPUT file listing provided in Appendix L and is described therein.
36-44	GBV(i)	unused 3 sets of grid blocks in fracture/matrix transport each containing N_S solutions
46-139		summary information for the titrant solution flash calculation
140-237		summary information for the Erlenmeyer solution flash calculation
238		notation; first beaker of Erlenmeyer solution

238-336		summary information for the first beaker (same as Erlenmeyer solution when corrected for different volumes)
337		notation; second beaker of Erlenmeyer solution
337-435		summary information for addition of DV(2)* to 1 liter of the Erlenmeyer solution
436		notation; third beaker of Erlenmeyer solution
436-534		summary information for addition of DV(3)* to 1 liter of the Erlenmeyer solution
535		notation; fourth beaker of Erlenmeyer solution
535-633		summary information for addition of DV(4)* to 1 liter of the Erlenmeyer solution
634		notation; fifth beaker of Erlenmeyer solution
634-732		summary information for addition of DV(5)* to 1 liter of the Erlenmeyer solution
733		notation; sixth beaker of Erlenmeyer solution
733-831		summary information for addition of DV(6)* to 1 liter of the Erlenmeyer solution
832		notation; seventh beaker of Erlenmeyer solution
832-930		summary information for addition of DV(7)* to 1 liter of the Erlenmeyer solution
931		notation; eighth beaker of Erlenmeyer solution
931-1029		summary information for addition of DV(8)* to 1 liter of the Erlenmeyer solution
1030		notation; ninth beaker of Erlenmeyer solution
1030-1128		summary information for addition of DV(9)* to 1 liter of the Erlenmeyer solution

* Summary information for DV(2) through DV(14) not shown in listings for Np_NaCl_BM_LIN.OUT and Np_NaCl_BM.OUT.

1129		notation; 10th beaker of Erlenmeyer solution
1129-1227		summary information for addition of DV(10)* to 1 liter of the Erlenmeyer solution
1228		notation; 11th beaker of Erlenmeyer solution
1228-1326		summary information for addition of DV(11)* to 1 liter of the Erlenmeyer solution
1327		notation; 12th beaker of Erlenmeyer solution
1327-1425		summary information for addition of DV(12)* to 1 liter of the Erlenmeyer solution
1426		notation; 13th beaker of Erlenmeyer solution
1426-1524		summary information for addition of DV(13)* to 1 liter of the Erlenmeyer solution
1525		notation; 14th beaker of Erlenmeyer solution
1525-1623		summary information for addition of DV(14)* to 1 liter of the Erlenmeyer solution
1624		notation; 15th (last) beaker of Erlenmeyer solution
1624-1722		summary information for addition of DV(15)** to 1 liter of the Erlenmeyer solution
1723	TIFNM	TITRATE filename***
1724	MOFNM	MOLES filename****

** Summary information for DV(15) in listings for Np_NaCl_BM_LIN.OUT and Np_NaCl_BM.OUT are from lines 343-441.

*** On line 442 in listings for Np_NaCl_BM_LIN.OUT and Np_NaCl_BM.OUT.

**** On line 443 in listings for Np_NaCl_BM_LIN.OUT and Np_NaCl_BM.OUT.

9.2 FOR088

The batch-generated secondary file FOR088 contains three columns from the "Table of Concentration for Batch System" in the OUTPUT file. The columns are total species moles, species name, and species molality with the species reordered as listed in the CHEMDAT file. FOR088 and the input file INGUESS have the same format, and are designed to facilitate creation of a specific solution composition. FOR088 can be renamed and used as a template for an INGUESS file which the user can edit. Table 28 explains the FOR088 file generated from a batch problem. The "Line" column refers to the line numbers listed in BATCH_DOC.FOR088.

Table 28. FOR088 File Description for Batch (See Appendix Q for sample listing.)

Line	Variable Name	Description
1-115	NMOLES(i)	total number of moles for the ith species
	NAMES(i)	the ith species names
	NMOLES(i)/ NMOLES(1)/ MWH2O	the ith species molality, moles per kg H_2O (see line 77-161 "Molality" column in Table 26 and Appendix M)

9.3 TITRATE

The TITRATE file, a secondary output file for the titrate problem, contains the titrant volumes and the equilibrated concentrations of all species, and the pH and ionic strength of each flash calculation from the OUTPUT file. The concentrations from each flash calculation have been reorganized by species for easy transfer to a graphics program for plotting.

Table 29 describes a TITRATE file generated by FMT. The "Line" column refers to the line numbers listed in Np_NaCl_BM_LOG.TITRATE. Np_NaCl_BM_LIN.TITRATE and Np_NaCl_BM_LIN.TITRATE have similar sample listings in Appendices S and T, respectively.

Table 29. TITRATE File Description (Appendix R)

Line	Variable Name	Description
1-3	TITLE99, DBASE1, DBASE2	problem title and CHEMDAT identification
5-20	j, DV(j)*1.d3	j^{th} beaker and titrant volume added to j^{th}beaker

23-245		table of all species molal concentrations
	NAMES(i)	up to 9 columns of species names on a line
	j, *SPMOLES(i,j)*/ ACONST(i)	j^{th} beaker and species molal concentration
247-262	j, IONICST(J)	j^{th} beaker and ionic strength
	EH(j)	the Eh (an option which is not supported in FMT 2.0)
	DV(j)*1.d3	titrant volume
	PHVECT(j)	pH of solution

9.4 MOLES

The titrate secondary output files are TITRATE and MOLES.

Available for diagnostic purpose, the MOLES file, a secondary output file for the titrate problem, contains the equilibrated concentrations of the initial solution. The MOLES file should be deleted after each execution of FMT.

Table 30 describes a MOLES file generated by FMT. The "Line" column refers to the line numbers listed in Np_NaCl_BM_LOG.MOLES. (No printouts for Np_NaCl_BM_LIN.MOLES and Np_NaCl_BM.MOLES are appended to this manual.)

Table 30. MOLES File Description (See Appendix U for sample listing of Np_NaCl_BM_LIN.MOLES.)

Line	Variable Name	Description
1-3	TITLE99, DBASE1, DBASE2	problem title and CHEMDAT identification
5-28	ELNAMES(i), ELTOTAL(i,1), ELTOTAL(i,2)	listing of the elements, elemental abundances for injected solution (buret) and initial solution (Erlenmeyer) as read from the INPUT file
30-53	ELNAMES(i), ELTOTAL(i,1), ELTOTAL(i,2)	after reading the INGUESS file for species abundances, if requested, and equilibrating both solutions the listing of elements, elemental abundances of the injected solution and the initial solution before any titration begins

55-170	NAMES(i), IJCONCS(i,1), IJCONCS(i,2)	listing of the species, the injected concentrations and the initial concentrations

10.0 REFERENCES

Denbigh, K. 1981. *The Principles of Chemical Equilibrium.* Cambridge: Cambridge University Press.

Felmy, A.R., D. Rai, and R.W. Fulton. 1990. "The Solubility of $AmOHCO_3(c)$ and the Aqueous Thermodynamics of the System Na^+-Am^{3+}-HCO_3^--OH^--H_2O." *Radiochimica Acta* vol. 50: 193-240.

Felmy, A.R., D. Rai, J.A. Schramke, and J.L. Ryan. 1989. "The Solubility of Plutonium Hydroxide in Dilute Solution and in High-Ionic-Strength Chloride Brines." *Radiochimica Acta* vol. 48: 29-35.

Felmy, A.R., and J.H. Weare. 1986. "The Prediction of Borate Mineral Equilibria in Natural Waters: Application to Searles Lake, California." *Geochimica et Cosmochimica Acta* vol. 50: 2771-2783.

Harvie, C.E., N. Møller, and J.H. Weare. 1984. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O System to High Ionic Strength at 25°C." *Geochimica et Cosmochimica Acta* vol. 48: 723-751.

Harvie, C.E., and J.H. Weare. 1980. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-Cl-SO_4-H_2O System from Zero to High Concentration at 25°C." *Geochimica et Cosmochimica Acta* vol. 44: 981-997.

Moore, R.C. "Validation of data entries in computer data file HMW_NP_AM.CHEMDAT," memorandum to C.F. Novak. 20 March 1995. Copy on file at Sandia WIPP Central Files.

Neck, V., J.I. Kim, and B. Kanellakopulos. 1994. Thermodynamic Behavior of Neptunium(V) in Concentrated NaCl and $NaClO_4$ Solutions. translated from Thermodynamisches Verhalten von Neptunium(V) in konzentrierten NaCl- und $NaClO_4$ Lösungen. KfK 5301. Institut für Nukleare Entsorgungstechnik, Institut für Heiße Chemie, Kernforschungszentrum Karlsruhe.

Novak, C.F. 1995a. "Creation and Definition of the Database for FMT called "HMW_NP_AM.CHEMDAT," version date 94.01.17." memorandum to N.J. Dhooge. 18 January 1995. Copy on file at Sandia WIPP Central Files.

Novak, C.F. 1995b. "Correction to the Database for FMT called "HMW_NP_AM.CHEMDAT," to create version date 95.01.31." memorandum to N.J. Dhooge. 31 January 1995. Copy on file at Sandia WIPP Central Files.

Novak, C.F. 1995c. "Input/Output Files for FMT Version 1.2." memorandum to Sandra C. Babb and Chris C. Crafts. 13 February 1995. Copy on file at Sandia WIPP Central Files.

Novak, C.F. 1995d. "'BATCH' Benchmark Problem for FMT: WIPP SPC Brine." memorandum to Ellen S. Dombroski. 14 February 1995. Copy on file at Sandia WIPP Central Files.

Novak, C.F. 1995e. "Input/Output Files for 'TITRATE' Problems; Benchmark Problem for FMT: The Solubility of $NaNpO_2CO_3(s)$ in 5.61 molal NaCl as a Function of Carbonate Concentration." memorandum to Ellen S. Dombroski and Sandra C. Babb. 15 February 1995. Copy on file at Sandia WIPP Central Files.

Novak, C.F. 1995k. "Performing FMT Simulations with Fixed $CO_2(g)$ Fugacity ("Partial Pressure")." memorandum to Chris C. Crafts and Sandra C. Babb. 20 March 1995. Copy on file at Sandia WIPP Central Files.

Novak, C.F. 1994. "Development of the FMT Chemical Transport Simulator: Coupling Aqueous Density and Mineral Volume Fraction to Phase Composition." *Proceedings of the Fourth International Conference on the Chemistry and Migration Behaviour of Actinides and Fission Products in the Geosphere* . Special Issue of Radiochimica Acta. R. Oldenbourg Verlag: München, Germany.

Novak, C.F., and K.E. Roberts. 1995. "Thermodynamic Modeling of Neptunium(V) Solubility in $Na\text{-}CO_3\text{-}HCO_3\text{-}Cl\text{-}ClO_4\text{-}H\text{-}OH\text{-}H_2O$ Electrolytes," *Materials Research Society Symposium Proceedings, Volume 353. International Symposium on the Scientific Basis for Nuclear Waste Management (18th: 1994: Kyoto, Japan).* pp. 1119-1128.

Novak, C.F., C.C. Craft, and N.J. Dhooge. 1995. *Thermodynamic modeling of +III Actinide solubility in concentrated Na-Cl-SO4-CO3-PO4 electrolytes: predicted phase diagrams and comparison with experiment.* SAND95-0258. Albuquerque, New Mexico: Sandia National Laboratories.

Pitzer, K.S. 1991. *Activity Coefficients in Electrolyte Solutions.* Boca Raton, Florida: CRC Press.

Pitzer, K.S. 1973. "Thermodynamics of electrolytes I: Theoretical basis and general equations." *J. Phys. Chem.* vol. 77, 268-277.

Pitzer, K.S., and L.F. Silvester. 1976. "Thermodynamics of Electrolytes. VI. Weak Electrolytes Including H_3PO_4." *Journal of Solution Chemistry* vol. 5: 269-278.

Pitzer, K.S., and L.F. Silvester. 1978. "Thermodynamics of Electrolytes. 11. Properties of 3:2, 4:2, and Other High-Valence Types." *Journal of Physical Chemistry* vol. 82: 1239-1242.

Rai, D., A.R. Felmy, and R.W. Fulton. 1994. "The Nd^{3+} and Am^{3+} Ion Interactions with SO_4^{2-} and their Influence on $NdPO_4(c)$ Solubility." *Journal of Solution Chemistry.* submitted June 1994.

Rao, L., D. Rai, A.R. Felmy, and RW. Fulton. 1994. "Solubility of $NaNd(CO_3)_2 \cdot 6H_2O$ in Concentrated Sodium Carbonate and Sodium Bicarbonate Solutions." *Radiochimica Acta* vol. ___: ___-___. SAND94-1948J.

Rai, D., A.R. Felmy, and R.W. Fulton. 1992a. "Solubility and Ion Activity Product of $AmPO_4 \cdot xH_2O$(am)." *Radiochimica Acta* vol. 56: 7-14.

Rai, D., A.R. Felmy, R.W. Fulton, and J.L. Ryan. 1992b. "Aqueous Chemistry of Nd in Borosilicate-Glass/Water Systems." *Radiochimica Acta* vol. 58/59: 9-16.

Rai, D., R.G. Strickert, D.A. Moore, and J.L. Ryan. 1983. "Am(III) Hydrolysis Constants and Solubility of Am(III) Hydroxide." *Radiochimica Acta* vol. 33: 201-206.

Smith, W.R., and R.W. Missen. 1991. Chemical Reaction Equilibrium Analysis: Theory and Algorithms. New York: John Wiley and Sons.

Smith, J.M., and H.C. Van Ness. 1975. *Introduction to Chemical Engineering Thermodynamics*. New York: McGraw-Hill.

Wagman, D.D., W.H. Evans, V.B. Parker, R.H. Schumm, I. Halow, S.M. Bailey, K.L Churney, R.L. Nuttall. 1982. The NBS Tables of Chemical Thermodynamic Properties. Selected Values for Inorganic and C_1 and C_2 Organic Substances in SI Units. *Journal of Physical and Chemical Reference Data* vol. 11, Supplement 2.

Weast, R.C. 1980. *CRC Handbook of Chemistry and Physics* 60th ed. Chemical Rubber Publishing Company, Boca Raton, Florida.

11.0 APPENDICES

Note

The numbers to the left of each line in Appendices A through U are not actually present in the files and screen displays; they are used solely to reference the lines in this guide

Note

The sample files and displays provided in Appendices A through U are examples *only*. They *are not* necessarily representative of files used to support the 1996 WIPP PA regulatory calculation.

Appendix A: Sample Screen Display of BATCH_DOC

See Table 1 for explanation of this screen display.

```
Enter chemdat file name to search on: np_am
Enter rhomin file name to search on: np_am
Enter input file name (without extension): batch_doc
%CMS-I-LIBIS, library is WP$NONPA_CMSROOT:[FMT]
%CMS-S-LIBSET, library set
%CMS-I-SUPERSEDE, library list superseded

Elements in CMS Library WP$NONPA_CMSROOT:[FMT]

FMT_HMW_NP_AM.CHEMDAT "Initial load"
FMT_HMW_NP_AM_F60.CHEMDAT "Initial load"
Select CHEMDAT name from list above: FMT_HMW_NP_AM.CHEMDAT
Your CMS library list consists of:
   WP$NONPA_CMSROOT:[FMT]

%CMS-S-FETCHED, generation 1 of element WP$NONPA_CMSROOT:[FMT]FMT_HMW_NP_AM.CHEMDAT fetched

Elements in CMS Library WP$NONPA_CMSROOT:[FMT]

FMT_HMW_NP_AM.RHOMIN "Initial load"
Select RHOMIN name from list above: FMT_HMW_NP_AM.RHOMIN
Your CMS library list consists of:
   WP$NONPA_CMSROOT:[FMT]

%CMS-S-FETCHED, generation 1 of element WP$NONPA_CMSROOT:[FMT]FMT_HMW_NP_AM.RHOMIN fetched

                 image name: "FMT_FMT2P0"
                 image file identification: "PROD PA96"
                 image file build identification: ""
                 link date/time: 21-DEC-1995 11:36:28.86
                 linker identification: "A11-14"

Entering Subroutine READDAT
reading chemical species data from CHEMDAT file
DG_BYPASS flag set to nDG_BYPASS
[.FD.TITRATE]BATCH_DOC.in; to illustrate/document "BATCH" runs                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

Accuracy of reactions is              1.0000E-06
Minimum elemental abundance is        1.0000E-18
Number of Aqueous Species is            50

ACTIVITY COEF. FLAG PITZACT
using PITZER ACTIVITY COEFFICIENT model
Charge Balance replaces element Oxygen

Exiting Subroutine READDAT
Char Flags: FLOW/BATCH/TITRATE BATCH      UNUSED
this is a BATCH problem

Echo of Mole Specifications:  nMOLES     nEXACT
ECHO PRINT OF ELEMENT ABUNDANCES IN ONEFLSH
  110.222364000000      Hydrogen
  55.1654821000000      Oxygen
 0.200000000000000      Sodium
 1.000000000000000E-002 Potassium
 1.000000000000000E-003 Magnesium
 1.000000000000000E-004 Calcium
 0.110000000000000      Chlorine
 1.000000000000000E-003 Sulfur
 1.000000000000000E-004 Carbon
 0.000000000000000E+000 PosIon
 0.000000000000000E+000 NegIon
 0.000000000000000E+000 Air
 1.000000000000000E-007 Boron
 0.000000000000000E+000 Bromine
 0.000000000000000E+000 TracerEl
 0.000000000000000E+000 Th(IV)
 0.000000000000000E+000 Am(III)
 0.000000000000000E+000 U(VI)
 0.000000000000000E+000 Np(V)
 0.000000000000000E+000 ClO4-(EL)
 0.000000000000000E+000 Phosphorus
 0.000000000000000E+000 Electron
 4.906053920000000E-017 Charge
.LT. (MINABU*1.d-6) moles NaBO2.NaCl.2H2O___Teepleite_(20_C); del&switch
.LT. (MINABU*1.d-6) moles NaB5O8.5H2O_____Sodium_Pentaborate; del&switch
.LT. (MINABU*1.d-6) moles NaOH(aq).......to.titrate.base.only; del&switch
.LT. (MINABU*1.d-6) moles HCl(aq).......to.titrate.acid.only; del&switch
.LT. (MINABU*1.d-6) moles K2B4O7.4H2O___K-Tetraborate_(30_C); del&reopt
.LT. (MINABU*1.d-6) moles B4O5(OH)4=              B4O5(OH)4=; del&reopt
```

Appendix A: Sample Screen Display of BATCH_DOC

```
.LT. (MINABU*1.d-6) moles K8H6(SO4)7_______________Misenite; del&reopt
.LT. (MINABU*1.d-6) moles K8H4(CO3)6.3H2O___K-Sequicarbonate; del&switch
.LT. (MINABU*1.d-6) moles B3O3(OH)4-              B3O3(OH)4-; del&switch
.LT. (MINABU*1.d-6) moles Ca4Cl2(OH)6.13H2O__CaOxychloride A; del&switch

************SOLUBILITY PRODUCT VIOLATION*************
** Mg(OH)2_____________________Brucite **  1.00E+01 **

************SOLUBILITY PRODUCT VIOLATION*************
** Mg2Cl(OH)3.4H2O______MgOxychloride **  6.69E+00 **

          2 Solubility Product Violations
Adding solid Mg(OH)2_____________________Brucite
pmH = -log[m(H+)]                  =     12.7140
pH = -log[a(H+)]     =     12.8532
Total Diagonal Inversions            85
Total Stoichiometric Reoptimizations           10
SINGLE BATCH EQUILIBRATION COMPLETED
```

Appendix B: Sample Screen Display of Np_NaCl_BM_LOG

See Table 3 for explanation of this screen display.

```
Enter chemdat file name to search on: np_am
Enter rhomin file name to search on: np_am
Enter input file name (without extension): np_nacl_bm_log
%CMS-I-LIBIS, library is WP$NONPA_CMSROOT:[FMT]
%CMS-S-LIBSET, library set
-CMS-I-SUPERSEDE, library list superseded

Elements in CMS Library WP$NONPA_CMSROOT:[FMT]

FMT_HMW_NP_AM.CHEMDAT "Initial load"
FMT_HMW_NP_AM_F60.CHEMDAT "Initial load"
Select CHEMDAT name from list above: FMT_HMW_NP_AM.CHEMDAT
Your CMS library list consists of:
   WP$NONPA_CMSROOT:[FMT]

%CMS-S-FETCHED, generation 1 of element WP$NONPA_CMSROOT:[FMT]FMT_HMW_NP_AM.CHEMDAT fetched

Elements in CMS Library WP$NONPA_CMSROOT:[FMT]

FMT_HMW_NP_AM.RHOMIN "Initial load"
Select RHOMIN name from list above: FMT_HMW_NP_AM.RHOMIN
Your CMS library list consists of:
   WP$NONPA_CMSROOT:[FMT]

%CMS-S-FETCHED, generation 1 of element WP$NONPA_CMSROOT:[FMT]FMT_HMW_NP_AM.RHOMIN fetched

                image name: "FMT_FMT2P0"
                image file identification: "PROD PA96"
                image file build identification: ""
                link date/time: 21-DEC-1995 11:36:28.86
                linker identification: "A11-14"

Entering Subroutine READDAT
reading chemical species data from CHEMDAT file
DG_BYPASS flag set to nDG_BYPASS
Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

Accuracy of reactions is              1.0000E-06
Minimum elemental abundance is        1.0000E-18
Number of Aqueous Species is            50

ACTIVITY COEF. FLAG PITZACT
using PITZER ACTIVITY COEFFICIENT model
Charge Balance replaces element Oxygen

Exiting Subroutine READDAT
Char Flags: FLOW/BATCH/TITRATE TITRATE    EXPLICIT
this is a TITRATION problem

Character Flags:  J.C. nMOLES     nEXACT
Character Flags:  I.C. nMOLES     nEXACT
TEMP is an unused local variable    180000.100000000

TITRATION option requires delta(x)=0.01 meters
  Defining delta(x) as such

DIFFUS  Parameter UNUSED= nDIFFUS
CONVEC  Parameter UNUSED= CONVEC
SSDIFF  Parameter UNUSED= nSSDIFF
RESTART Parameter Value Read = nRESTART
UNUSED Parameters nPUSHPULL nMULTINJ
UNUSED parameter FRAC FLO

TITRATION Problem:
 -) Assigning all delta(y) to 0.1 m
 -) Setting # of nodes in Y-direction to 3
 -) Setting NONREACTIVE Porosity to 0.0

Char Flags UNUSED UNUSED RHSFDIF    LHSFDIF
Char Flags UNUSED UNUSED nMOLES     nEXACT

TEMP is an unused local variable   9.9999999999999999E-021
Character Flags:  VPOROS FRFLASH VPOROS     FRFLASH

Specifying VARIABLE POROSITY for TITRATION Problem

Character Flags:  VAR_AQ_RHO VAR_AQ_RHO FRFLASH

Aqueous Density is a Function of Composition
```

Appendix B: Sample Screen Display of Np_NaCl_BM_LOG

```
Char Flag is UNUSED:  NO X DIFF nNO X DIFF
Char Flag is UNUSED:  UNIFORM UNIFORM              0

MINERAL DENSITIES, KG/M^3, IN FILE 'RHOMIN'

pmH = -log[m(H+)]                    =     11.6199
pH = -log[a(H+)]     =     11.7497
pmH = -log[m(H+)]                    =      5.9141
pH = -log[a(H+)]     =      5.3205
TITRATION Character Flags
  cdum1= TITRATE      cdum2= LOG10
  First Volume Added =          0.10 mL
  Final Volume Added =         10.00 mL

pmH = -log[m(H+)]                    =      5.9141
pH = -log[a(H+)]     =      5.3205
pmH = -log[m(H+)]                    =      6.2386
pH = -log[a(H+)]     =      5.6451
pmH = -log[m(H+)]                    =      6.5870
pH = -log[a(H+)]     =      5.9936
pmH = -log[m(H+)]                    =      8.5360
pH = -log[a(H+)]     =      7.9427
pmH = -log[m(H+)]                    =      9.4653
pH = -log[a(H+)]     =      8.8722
pmH = -log[m(H+)]                    =      9.8154
pH = -log[a(H+)]     =      9.2225
pmH = -log[m(H+)]                    =     10.0620
pH = -log[a(H+)]     =      9.4695
pmH = -log[m(H+)]                    =     10.2640
pH = -log[a(H+)]     =      9.6719
pmH = -log[m(H+)]                    =     10.4406
pH = -log[a(H+)]     =      9.8493
pmH = -log[m(H+)]                    =     10.6002
pH = -log[a(H+)]     =     10.0098
pmH = -log[m(H+)]                    =     10.7468
pH = -log[a(H+)]     =     10.1578
pmH = -log[m(H+)]                    =     10.8825
pH = -log[a(H+)]     =     10.2955
pmH = -log[m(H+)]                    =     11.0086
pH = -log[a(H+)]     =     10.4243
pmH = -log[m(H+)]                    =     11.1257
pH = -log[a(H+)]     =     10.5454
pmH = -log[m(H+)]                    =     11.2341
pH = -log[a(H+)]     =     10.6594
End of AutoTitration Problem
```

Appendix C: Sample Screen Display of Np_NaCl_BM_LIN

Note

Lightened text same as screen display provided in Appendix B.

See Table 3 for explanation of this screen display.

```
Enter input file name (without extension): np_nacl_bm_lin
Benchmark TITRATE Problem, LINEAR option: Np(V)O2 with CO3 in 5.61molal NaCl  FMT V2.0
```

Appendix C Sample Screen Display of Np_NaCl_BM_LIN

```
TITRATION Character Flags
   cdum1= TITRATE      cdum2= LINEAR
   First Volume Added =          0.10 mL
   Final Volume Added =          1.40 mL

pmH = -log[m(H+)]                    =      5.9141
pH = -log[a(H+)]     =       5.3205
pmH = -log[m(H+)]                    =      6.2386
pH = -log[a(H+)]     =       5.6451
pmH = -log[m(H+)]                    =      8.4116
pH = -log[a(H+)]     =       7.8183
pmH = -log[m(H+)]                    =      9.5098
pH = -log[a(H+)]     =       8.9167
pmH = -log[m(H+)]                    =      9.7906
pH = -log[a(H+)]     =       9.1977
pmH = -log[m(H+)]                    =      9.9569
pH = -log[a(H+)]     =       9.3641
pmH = -log[m(H+)]                    =     10.0747
pH = -log[a(H+)]     =       9.4821
pmH = -log[m(H+)]                    =     10.1656
pH = -log[a(H+)]     =       9.5733
pmH = -log[m(H+)]                    =     10.2395
pH = -log[a(H+)]     =       9.6473
pmH = -log[m(H+)]                    =     10.3015
pH = -log[a(H+)]     =       9.7095
pmH = -log[m(H+)]                    =     10.3548
pH = -log[a(H+)]     =       9.7631
pmH = -log[m(H+)]                    =     10.4016
pH = -log[a(H+)]     =       9.8100
pmH = -log[m(H+)]                    =     10.4431
pH = -log[a(H+)]     =       9.8517
pmH = -log[m(H+)]                    =     10.4804
pH = -log[a(H+)]     =       9.8892
pmH = -log[m(H+)]                    =     10.5142
pH = -log[a(H+)]     =       9.9232
End of AutoTitration Problem
```

Appendix D: Sample Screen Display of Np_NaCl_BM

Note

Lightened text same as screen display provided in Appendix B.

See Table 3 for explanation of this screen display.

```
Enter input file name (without extension): np_nacl_bm
Benchmark TITRATE Problem; Np(V)O2 with CO3 in 5.61molal NaCl                FMT V2.0
```

Appendix D Sample Screen Display of Np_NaCl_BM

```
TITRATION Character Flags
  cdum1= TITRATE      cdum2= ASREAD
reading titrant volumes from input file
  First Volume Added =        0.10 mL
  Final Volume Added =       10.00 mL

pmH = -log[m(H+)]                  =      5.9141
pH = -log[a(H+)]     =      5.3205
pmH = -log[m(H+)]                  =      6.2386
pH = -log[a(H+)]     =      5.6451
pmH = -log[m(H+)]                  =      6.5870
pH = -log[a(H+)]     =      5.9936
pmH = -log[m(H+)]                  =      6.8286
pH = -log[a(H+)]     =      6.2353
pmH = -log[m(H+)]                  =      7.2930
pH = -log[a(H+)]     =      6.6996
pmH = -log[m(H+)]                  =      8.5359
pH = -log[a(H+)]     =      7.9427
pmH = -log[m(H+)]                  =      8.9250
pH = -log[a(H+)]     =      8.3317
pmH = -log[m(H+)]                  =      9.1587
pH = -log[a(H+)]     =      8.5655
pmH = -log[m(H+)]                  =      9.3098
pH = -log[a(H+)]     =      8.7166
pmH = -log[m(H+)]                  =      9.4653
pH = -log[a(H+)]     =      8.8722
pmH = -log[m(H+)]                  =      9.8154
pH = -log[a(H+)]     =      9.2225
pmH = -log[m(H+)]                  =     10.0620
pH = -log[a(H+)]     =      9.4695
pmH = -log[m(H+)]                  =     10.4406
pH = -log[a(H+)]     =      9.8493
pmH = -log[m(H+)]                  =     10.8825
pH = -log[a(H+)]     =     10.2955
pmH = -log[m(H+)]                  =     11.2341
pH = -log[a(H+)]     =     10.6594
End of AutoTitration Problem
```

Appendix E: Sample Input File "BATCH_DOC.IN"

See Table 4 for explanation of this listing.

```
'[.FD.TITRATE]BATCH_DOC.in; to illustrate/document "BATCH" runs'
'CHEMFILE'

'BATCH', 'UNUSED'

'nMOLES', 'nEXACT',
  1.10222364E+02   Hydrogen
  5.51654821E+01   Oxygen
  2.00000000E-01   Sodium
  1.00000000E-02   Potassium
  1.00000000E-03   Magnesium
  1.00000000E-04   Calcium
  1.10000000E-01   Chlorine
  1.00000000E-03   Sulfur
  1.00000000E-04   Carbon
  0.00000000E+00   PosIon
  0.00000000E+00   NegIon
  0.00000000E+00   Air
  1.00000000E-07   Boron
  0.00000000E+00   Bromine
  0.00000000E+00   TracerEl
  0.00000000E+00   Th(IV)
  0.00000000E+00   Am(III)
  0.00000000E+00   U(VI)
  0.00000000E+00   Np(V)
  0.00000000E+00   ClO4-(EL)
  0.00000000E+00   Phosphorus
  0.00000000E+00   Electron
  4.90605392E-17   Charge
```

Appendix F: Sample Input File "Np_NaCl_BM_LOG.IN"

See Table 5 for explanation of this listing.

```
'Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl'
'CHEMFILE'

'TITRATE', 'EXPLICIT',

'nMOLES', 'nEXACT',
  1.11017363E+02   Hydrogen
  6.15086815E+01   Oxygen
  5.61000000E+00   Sodium
  0.00000000E+00   Potassium
  0.00000000E+00   Magnesium
  0.00000000E+00   Calcium
  1.61000000E+00   Chlorine
  0.00000000E+00   Sulfur
  2.00000001E+00   Carbon
  0.00000000E+00   PosIon
  0.00000000E+00   NegIon
  0.00000000E+00   Air
  0.00000000E+00   Boron
  0.00000000E+00   Bromine
  0.00000000E+00   TracerEl
  0.00000000E+00   Th(IV)
  0.00000000E+00   Am(III)
  0.00000000E+00   U(VI)
  0.00000000E+00   Np(V)
  0.00000000E+00   ClO4-(EL)
  0.00000000E+00   Phosphorus
  0.00000000E+00   Electron
 -2.22044605E-15  Charge

'nMOLES','nEXACT',
  1.11018363E+02   Hydrogen
  1.05508682E+02   Oxygen
  1.56100000E+01   Sodium
  0.00000000E+00   Potassium
  0.00000000E+00   Magnesium
  0.00000000E+00   Calcium
  5.61100000E+00   Chlorine
  0.00000000E+00   Sulfur
  1.00000000E+01   Carbon
  0.00000000E+00   PosIon
  0.00000000E+00   NegIon
  0.00000000E+00   Air
  0.00000000E+00   Boron
  0.00000000E+00   Bromine
  0.00000000E+00   TracerEl
  0.00000000E+00   Th(IV)
  0.00000000E+00   Am(III)
  0.00000000E+00   U(VI)
  1.00000000E+01   Np(V)
  0.00000000E+00   ClO4-(EL)
  0.00000000E+00   Phosphorus
```

```
  0.00000000E+00   Electron
 -2.37316632E-15  Charge

 15  2.25d3  0.0025d0  1.800001d5 'nDXVARIABLE'
'nDIFFUS',
'CONVEC',
'nSSDIFF',
'nRESTART',
'nPUSHPULL','nMULTINJ',

 20 1 20 'nLOTS' 10
'nTGRAD' 'LINEAR'
'FRAC FLO' 'nTWO PHASE' 'nMASS TR'
 3
 0.1d0 0.2d0 0.3d0
 1.d-7 0.d0 0.18291d0 0.2d0 0.d0 'RHSFDIF' 'LHSFDIF'
'nMOLES' 'nEXACT' Plain old pure H2O
  1.11017364E+02   Hydrogen
  5.55086820E+01   Oxygen
  0.00000000E+00   Sodium
  0.00000000E+00   Potassium
  0.00000000E+00   Magnesium
  0.00000000E+00   Calcium
  0.00000000E+00   Chlorine
  0.00000000E+00   Sulfur
  0.00000000E+00   Carbon
  0.00000000E+00   PosIon
  0.00000000E+00   NegIon
  0.00000000E+00   Air
  0.00000000E+00   Boron
  0.00000000E+00   Bromine
  0.00000000E+00   TracerEl
  0.00000000E+00   Pu(III)
  0.00000000E+00   Am(III)
  0.00000000E+00   U(VI)
  0.00000000E+00   Np(V)
  0.00000000E+00   ClO4-(EL)
  0.00000000E+00   Phosphorus
  0.00000000E+00   Electron
  0.00000000E+00   Charge

 1.d-12 1.d-20 (fracture, matrix permeabilities)
'VPOROS' 'FRFLASH' (NOFLASH or FRFLASH, default is all flash)
'VAR_AQ_RHO' 1074.9d0
'nNO X DIFF',
'UNIFORM',0

'TITRATE','LOG10',0.1d0,10.d0,'nINJSOLIDS'
```

Appendix G: Sample Input File "Np_NaCl_BM_LIN.IN"

Note

Lines 2 through 98 in this file (lightened text) same as lines 2 through 98 in file provided in Appendix F (NP_NaCl_BM_LOG.IN).

See Table 5 for explanation of this listing.

```
1 'Benchmark TITRATE Problem, LINEAR option; Np(V)O2 with CO3 in 5.61molal NaCl'
2 'NUMERIC'
3
4 'TITRATE', 'EXPLICIT',
5
6 'nMOLES', 'nEXACT',
7    1.11017463E+02    Hydrogen
8    1.15058815E+01    Oxygen
9    5.61000000E+00    Sodium
10   1.00000000E+00    Potassium
11   1.00000000E+00    Magnesium
12   0.00000000E+00    Calcium
13   1.01000000E+00    Chlorine
14   1.00000000E+00    Sulfur
15   3.00000001E+00    Carbon
16   0.00000000E+00    Positon
17   0.00000000E+00    Negion
18   0.00000000E+00    Air
19   0.00000000E+00    Boron
20   0.00000000E+00    Bromine
21   0.00000000E+00    TracerEl
22   0.00000000E+00    Th(IV)
23   0.00000000E+00    Am(III)
24   0.00000000E+00    U(VI)
25   0.00000000E+00    Np(V)
26   0.00000000E+00    ClO4-(EL)
27   0.00000000E+00    Phosphorus
28   0.00000000E+00    Electron
29  -2.22044605E-15    Charge
30
31 'nMOLES','nEXACT',
32   1.11018363E+02    Hydrogen
33   1.05508682E+02    Oxygen
34   1.55100000E+01    Sodium
35   0.00000000E+00    Potassium
36   0.00000000E+00    Magnesium
37   0.00000000E+00    Calcium
38   5.61000000E+00    Chlorine
39   0.00000000E+00    Sulfur
40   1.00000000E+01    Carbon
41   0.00000000E+00    Positon
42   0.00000000E+00    Negion
43   0.00000000E+00    Air
44   0.00000000E+00    Boron
```

Appendix G: Sample Input File "NP_NaCl_BM_LIN.IN"

```
   0.000000000E+00   Bromine
   0.000000000E+00   TracerEl
   0.000000000E+00   Tl(IV)
   0.000000000E+00   Am(III)
   0.000000000E+00   U(VI)
   1.000000000E+01   Np(V)
   0.000000000E+00   ClO4-(EL)
   0.000000000E+00   Phosphorus
   0.000000000E+00   Electron
  -0.000000000E+00   Charge

  15  0.2583  0.002500  1.80000185 'nDIVARIABLE'
 'nDIFFLG',
 'CONDEC',
 'nSSDIFF',
 'nRESTART',
 'nFILEHTOIL','nMULTIMT',

  20 1 20 'nLOTS' 10
 'nTORAD' 'LINEAR'
 'FRAC FLO' 'nTWO PHASE'  'nMASS TF'
  5
  0.140 0.160 0.340
  1.8-7 0.80 0.1929100 0.200 0.8. 'RHSFDIF' 'LHSFDIF'
 'nMOLES' 'nEXACT' Plain old pure H2O
   1.110175745E+02   Hydrogen
   5.550268210E+01   Oxygen
   0.000000000E+00   Sodium
   0.000000000E+00   Potassium
   0.000000000E+00   Magnesium
   0.000000000E+00   Calcium
   0.000000000E+00   Chlorine
   0.000000000E+00   Sulfur
   0.000000000E+00   Carbon
   0.000000000E+00   Proton
   0.000000000E+00   NegIon
   0.000000000E+00   Air
   0.000000000E+00   Boron
   0.000000000E+00   Bromine
   0.000000000E+00   TracerEl
   0.000000000E+00   Pu(III)
   0.000000000E+00   Am(III)
   0.000000000E+00   U(VI)
   0.000000000E+00   Np(V)
   0.000000000E+00   ClO4-(EL)
   0.000000000E+00   Phosphorus
   0.000000000E+00   Electron
   0.000000000E+00   Charge

  1.E-12 1.E-20 (fracture, matrix permeabilities)
 'VPORUS' 'FRFLASH' (nOFLASH or FRFLASH, default is all flash)
 'VAR_AQ_RHO' 1074.961
 'TWO X DIFF',
'UNIFORM',0

'TITRATE','LINEAR',.1,10,'nINJSOLIDS'
```

Appendix H: Sample Input File "Np_NaCl_BM.IN"

Note

Lines 2 through 98 in this file (lightened text) same as lines 2 through 98 in file provided in Appendix F (NP_NaCl_BM_LOG.IN).

See Table 5 for explanation of this listing.

```
1 'Benchmark TITRATE Problem, LINEAR option; Np(V)O2 with CO3 in 5.61molal NaCl'
2 'CHEMFILE'
3
4 'TITRATE', 'EXPLICIT',
5
6 'TMOLES', 'TEXACT',
7    1.11017363E-02    Hydrogen
8    1.15956512E-02    Oxygen
9    5.61000000E-01    Sodium
10   0.00000000E-00    Potassium
11   0.00000000E-00    Magnesium
12   0.00000000E-00    Calcium
13   1.81000000E-01    Chlorine
14   0.00000000E-00    Sulfur
15   2.00000001E-00    Carbon
16   0.00000001E-00    Boron
17   1.00000000E-00    Neutron
18   0.00000000E-00    Air
19   0.00000000E+00    Boron
20   0.00000000E-00    Bromine
21   0.00000000E-00    Uranium
22   0.00000001E-00    Th(IV)
23   0.00000000E-00    As(III)
24   0.00000000E-00    U(VI)
25   0.00000000E+00    Np(V)
26   0.00000000E+00    Cl04-(EL)
27   0.00000000E-00    Phosphorus
28   0.00000000E-00    Electron
29  -2.22044605E-16    Charge
30
31 'TMOLES','TEXACT',
32   1.11018303E-02    Hydrogen
33   1.15956642E-02    Oxygen
34   1.56100000E-01    Sodium
35   0.00000000E-00    Potassium
36   0.00000000E-00    Magnesium
37   0.00000000E-00    Calcium
38   5.61100000E-00    Chlorine
39   0.00000000E-00    Sulfur
40   1.00000002E-01    Carbon
41   0.00000000E-00    Boron
42   0.00000000E-00    Nagium
43   0.00000000E-00    Air
44   0.00000000E-00    Boron
```

Appendix H: Sample Input File "Np_NaCl_BM.IN"

```
   0.000000000E+00   Bromine
   0.000000000E+00   Tracer-El
   0.000000000E+00   Pu(III)
   0.000000000E+00   Am(III)
   0.000000000E+00   U(VI)
   1.000000000E-01   Np(V)
   0.000000000E+00   ClO4-(EL)
   0.000000000E+00   Phosphorus
   0.000000000E+00   Fluoride
  -0.000000000E-15   Charge

  15  9.1583  0.0025E0  1.0000000E0 'nDNVARIABLE'
  'nDENSITY',
  'CONTROL',
  'nDOUBLE',
  'nREDIALT',
  'nPHSHFULL','nMULTIPN',

  20 1 20 'nLOTS' 10
 'nLOGRAD' 'LINEAR'
 'PRIO PIO' 'nTWO PHASE' 'nMASS TR'
  3
  0.140 0.240 0.360
  1.0-7 0.0E 0.1829180 0.230 0.0E 'RESFDIF' 'DRSFDIF'
 'nMOLES' 'nEXACT' Plain old pure H2O
   1.110173944E+02   Hydrogen
   5.550868210E-01   Oxygen
   0.000000000E+00   Sodium
   0.000000000E+00   Potassium
   0.000000000E+00   Magnesium
   0.000000000E+00   Calcium
   0.000000000E+00   Chlorine
   0.000000000E+00   Sulfur
   0.000000000E+00   Carbon
   0.000000000E+00   NomIon
   0.000000000E+00   MagIon
   0.000000000E+00   Air
   0.000000000E+00   Boron
   0.000000000E-00   Bromine
   0.000000000E+00   Tracer-El
   0.000000000E+00   Pu(III)
   0.000000000E+00   Am(III)
   0.000000000E-00   U(VI)
   0.000000000E-00   Np(V)
   0.000000000E+00   ClO4-(EL)
   0.000000000E-00   Phosphorus
   0.000000000E-00   Electron
   0.000000000E-00   Charge

  1.0-12 1.0-20 (fracture, matrix permeabilities)
 'PROFOD' 'PRFLASH' (NOFLASH or PRFLASH, default is all flash)
 'AAR_A2_RHO' 1074.9d0
 'nNO 2 DEFT',
 'UNIFORM',3

 'TITRATE','ASREAD',0.1d0,10.d0,'nINJSOLIDS'
  0.10000
```

Appendix H: Sample Input File "Np_NaCl_BM.IN"

```
0.14251
0.16
0.18
0.20309
0.22
0.24
0.26
0.28943
0.41246
0.58780
1.1938
3.4551
10.000
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

I.1 Listing

See Table 23 for explanation of this listing.

```
'DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);'
'95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)'

23 115 'nNEW T' 'nACTCOEF' 'nECHO' 'nABCD'
200 1.d-6 1.d-18
'NONE' 298.15 1.d0 1.d0

'Hydrogen' 'Oxygen' 'Sodium' 'Potassium' 'Magnesium' 'Calcium' 'Chlorine' 'Sulfur' 'Carbon' 'PosIon'
   'NegIon' 'Air' 'Boron' 'Bromine' 'TracerEl' 'Th(IV)' 'Am(III)' 'U(VI)' 'Np(V)' 'ClO4-(EL)'
   'Phosphorus' 'Electron' 'Charge'
1.0079 15.9994 22.98977 39.0983 24.305 40.08 35.453 32.06 12.011 0.0 0.0
   28.84 10.81 79.904 0.0 232.0381 243.0 238.029 237.0482 99.4506 30.974 0.0 0.0

'H2O                          WATER' 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0   1 -95.6635     HMW84
'Na+                            Na+' 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  1   1 -105.651     HMW84
'K+                              K+' 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  1   1 -113.957     HMW84
'Ca++                          Ca++' 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  2   1 -223.30      HMW84
'Mg++                          Mg++' 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  2   1 -183.468     HMW84
'MgOH+                        MgOH+' 1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  1   1 -251.94      HMW84
'H+                              H+' 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  1   1  0.         HMW84

'Cl-                            Cl-' 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1   1 -52.955      HMW84
'SO4=                          SO4=' 0 4 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 -2   1 -300.386    HMW84
'HSO4-                        HSO4-' 1 4 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 -1   1 -304.942    HMW84
'OH-                            OH-' 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -1   1 -63.435     HMW84
'HCO3-                        HCO3-' 1 3 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 -1   1 -236.751    HMW84
'CO3=                          CO3=' 0 3 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 -2   1 -212.944    HMW84

'CO2(aq)                    CO2(aq)' 0 2 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0  0   1 -155.68      HMW84
'CaCO3(aq)                CaCO3(aq)' 0 3 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0  0   1 -443.5       HMW84
'MgCO3(aq)                MgCO3(aq)' 0 3 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0  0   1 -403.155     HMW84

'B(OH)3(aq)               B(OH)3(aq)' 3 3 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0  0   1 -390.81      FW86
'B(OH)4-                    B(OH)4-' 4 4 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 -1   1 -465.20     FW86
'B3O3(OH)4-               B3O3(OH)4-' 4 7 0 0 0 0 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 -1   1 -963.77     FW86
'B4O5(OH)4=               B4O5(OH)4=' 4 9 0 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 -2   1 -1239.10    FW86
'CaB(OH)4+                CaB(OH)4+' 4 4 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0  1   1 -692.30     FW86
'MgB(OH)4+                MgB(OH)4+' 4 4 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0  1   1 -651.89     FW86
'Br-                            Br-' 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 -1   1 -999.99     arbitrary
'ClO4-            perchlorate ClO4-' 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 -1   1 -999.99     arbitrary

'NaOH(aq)......to.titrate.base.only' 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0   1  500.       arbitrary
'HCl(aq).......to.titrate.acid.only' 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0  0   1  500.       arbitrary
'HClO4(aq).....to.titrate.acid.only' 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0  0   1  500.       arbitrary
'PosIon................POSITIVE.ION' 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0  1   1  0.         arbitrary
'NegIon................NEGATIVE.ION' 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 -1   1  0.         arbitrary
'PosIon(OH)(aq).....to.titrate.base' 1 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0  0   1  500.       arbitrary
'HNegIon(aq)........to.titrate.acid' 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0  0   1  500.       arbitrary
'Tracer(aq).....conservative.tracer' 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0  0   1  0.         arbitrary

'H3PO4(aq)                H3PO4(aq)' 3 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0  0   1 -460.90      RFF92
'H2PO4-                     H2PO4-' 2 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 -1   1 -455.96      RFF92
'HPO4=                        HPO4=' 1 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 -2   1 -439.367     RFF94
'PO4=-                        PO4=-' 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 -3   1 -410.947     RFF94

'NpO2+                         NpO2+' 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0  1   1 -369.127     N&R94
'NpO2OH(aq)                NpO2OH(aq)' 1 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0  0   1 -438.518     N&R94
'NpO2(OH)2-               NpO2(OH)2-' 2 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 -1   1 -505.829     N&R94
'NpO2CO3-                   NpO2CO3-' 0 5 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 -1   1 -594.492     N&R94
'NpO2(CO3)2=-            NpO2(CO3)2=-' 0 8 0 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 1 0 0 -3   1 -808.403     N&R94
'NpO2(CO3)3==-          NpO2(CO3)3==-' 0 11 0 0 0 0 0 0 3 0 0 0 0 0 0 0 0 0 1 0 0 -5   1 -1019.918    N&R94

'Am+++                         Am+++' 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0  3   1 -241.694     FRF90
'AmCO3+                       AmCO3+' 0 3 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0  1   1 -472.060     FRF90
'Am(CO3)2-                 Am(CO3)2-' 0 6 0 0 0 0 0 0 2 0 0 0 0 0 0 0 1 0 0 0 0 -1   1 -695.880     FRF90
'Am(CO3)3=-               Am(CO3)3=-' 0 9 0 0 0 0 0 0 3 0 0 0 0 0 0 0 1 0 0 0 0 -3   1 -915.460     FRF90
'Am(OH)2+                   Am(OH)2+' 2 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0  1   1 -393.647     RFFR92
'Am(OH)3(aq)              Am(OH)3(aq)' 3 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0  0   1 -462.950     RFFR92

'Th++++                       Th++++' 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0  4   1 -999.99      arbitrary

'UO2++                     U(VI)O2++' 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0  2   1 -999.99      arbitrary

'NpO2OH(aged)_________NpO2OH(aged)' 1 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0  0   2 -454.010     N&R94
'NpO2OH(amor)_________NpO2OH(amor)' 1 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0  0   2 -452.642     N&R94
'NaNpO2CO3(s)_________NaNpO2CO3(s)' 0 5 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0  0   2 -713.707     N&R94
'Na3NpO2(CO3)2(s)_DISABLED_DISABLED' 0 8 3 0 0 0 0 0 2 0 0 0 0 0 0 0 0 1 0 0 0  0   2  999.99     arbitrary
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
'AmOHCO3(c)_____________AmOHCO3(c)' 1 4 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0  0   2 -569.980     FRF90
'Am(OH)3(s)_____________Am(OH)3(s)' 3 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0  0   2 -492.294     FRSR89
'NaAm(CO3)2.6H2O(c)_____________' 12 12 1 0 0 0 0 0 2 0 0 0 0 0 0 0 1 0 0 0 0 0  0   2 -1396.494    RRFF94
'AmPO4(c)_______________AmPO4(c)' 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0  0   2 -709.750     RFF94

'CaSO4__________________Anhydrite' 0 4 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -533.73      HMW84
'NaK3(SO4)2__Aphthitalite/Glaserite' 0 8 1 3 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1057.05     HMW84
'CaCl2.6H2O_____________Antarcticite' 12 6 0 0 0 1 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -893.65     HMW84
'CaCO3__________________Aragonite' 0 3 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -455.17     HMW84
'K2SO4__________________Arcanite' 0 4 0 2 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -532.39     HMW84
'MgCl2.6H2O_____________Bischofite' 12 6 0 0 1 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -853.1      HMW84
'Na2Mg(SO4)2.4H2O_______Bloedite' 8 12 2 0 1 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1383.6     HMW84
'Mg(OH)2________________Brucite' 2 2 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -335.4      HMW84
'Na6CO3(SO4)2___________Burkeite' 0 11 6 0 0 0 0 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1449.4     HMW84
'CaCO3__________________Calcite' 0 3 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -455.6      HMW84
'CaCl2.4H2O_____CaCl2_Tetrahydrite' 8 4 0 0 0 1 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -698.7      HMW84
'Ca4Cl2(OH)6.13H2O__CaOxychloride A' 32 19 0 0 0 4 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -2658.45    HMW84
'Ca2Cl2(OH)2.H2O____CaOxychloride B' 4 3 0 0 0 0 2 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -778.41     HMW84
'KMgCl3.6H2O____________Carnallite' 12 6 0 1 1 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1020.3     HMW84
'MgSO4.7H2O_____________Epsomite' 14 11 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1157.83    HMW84
'CaNa2(CO3)2.5H2O_______Gaylussite' 10 11 2 0 0 1 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1360.5     HMW84
'Na2Ca(SO4)2____________Glauberite' 0 8 2 0 0 1 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1047.45    HMW84
'CaSO4.2H2O_____________Gypsum' 4 6 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -725.56     HMW84
'NaCl___________________Halite' 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -154.99     HMW84
'MgSO4.6H2O_____________Hexahydrite' 12 10 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1061.60    HMW84
'KMgClSO4.3H2O__________Kainite' 6 7 0 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -938.2      HMW84
'KHCO3__________________Kalicinite' 1 3 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -350.06     HMW84
'MgSO4.H2O_____________ Kieserite' 2 5 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -579.80     HMW84
'K2Mg(SO4)2.4H2O________Leonite' 8 12 0 2 1 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1403.97    HMW84
'Na4Ca(SO4)3.2H2O_______Labile_Salt' 4 14 4 0 0 1 0 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1751.45    HMW84
'MgCO3__________________Magnesite' 0 3 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -414.45     HMW84
'Mg2Cl(OH)3.4H2O_____MgOxychloride' 11 7 0 0 2 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1029.6     HMW84
'KHSO4__________________Mercallite' 1 4 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -417.57     HMW84
'Na2SO4.10H2O___________Mirabilite' 20 14 2 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1471.15    HMW84
'K8H6(SO4)7_____________Misenite' 6 28 0 8 0 0 0 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -3039.24    HMW84
'NaHCO3_________________Nahcolite' 1 3 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -343.33     HMW84
'Na2CO3.10H2O___________Natron' 20 13 2 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1382.78    HMW84
'MgCO3.3H2O_____________Nesquehonite' 6 6 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -695.3      HMW84
'K2Mg(SO4)2.6H2O Picromerite/Schoen' 12 14 0 2 1 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1596.1     HMW84
'Na2Ca(CO3)2.2H2O_______Pirssonite' 4 8 2 0 0 1 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1073.1     HMW84
'K2MgCa2(SO4)4.2H2O_____Polyhalite' 4 18 0 2 1 2 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -2282.5     HMW84
'Ca(OH)2________________Portlandite' 2 2 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -362.12     HMW84
'K2CO3.3/2H2O___Potassium_Carbonate' 3 4.5 0 2 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -577.37     HMW84
'K8H4(CO3)6.3H2O___K-Sequicarbonate' 10 21 0 8 0 0 0 0 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -2555.4     HMW84
'KNaCO3.6H2O_________K-Na-Carbonate' 12 9 1 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1006.8     HMW84
'K2NaH(CO3)2.2H2O___Potassium_Trona' 5 8 1 2 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -971.74     HMW84
'K3H(SO4)2__Sesquipotassium_Sulfate' 1 8 0 3 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -950.8      HMW84
'Na3H(SO4)2____Sesquisodium_Sulfate' 1 8 3 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -919.6      HMW84
'Na2CO3.7H2O____Na2CO3-Heptahydrate' 14 10 2 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1094.95    HMW84
'KCl____________________Sylvite' 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -164.84     HMW84
'K2Ca(SO4)2.H2O_________Syngenite' 2 9 0 2 0 1 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -1164.8     HMW84
'Mg2CaCl6.12H2O_________Tachyhydrite' 24 12 0 0 2 1 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -2015.9     HMW84
'Na2SO4_________________Thenardite' 0 4 2 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -512.35     HMW84
'Na2CO3.H2O_____________Thermonatrite' 2 4 2 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -518.8      HMW84
'Na3H(CO3)2.2H2O________Trona' 5 8 3 0 0 0 0 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 -960.38     HMW84
'Na2B4O7.10H2O__________ Borax' 20 17 2 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 2 -2224.16    FW86
'B(OH)3_____________Borix_Acid_Solid' 3 3 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 2 -390.88     FW86
'KB5O8.4H2O____K-Pentaborate_(30_C)' 8 12 0 1 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 2 -1770.26    FW86
'K2B4O7.4H2O___K-Tetraborate_(30_C)' 8 11 0 2 0 0 0 0 0 0 0 4 0 0 0 0 0 0 0 0 0 0 0 2 -1663.47    FW86
'NaBO2.4H2O_______Sodium_Metaborate' 8 6 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 2 -761.42     FW86
'NaB5O8.5H2O_____Sodium_Pentaborate' 10 13 1 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 2 -1854.80    FW86
'NaBO2.NaCl.2H2O___Teepleite_(20_C)' 4 4 2 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 2 -725.77     FW86

'nDG_BYPASS' 0
'PITZACT'
 13 #Cat  Na,K,Ca,Mg,MgOH,H,MgB(OH)4+,CaB(OH)4+,Am+++,AmCO3+,Th++++,UO2++,NpO2+
 20 #Ani  Cl,SO4,HSO4,OH,HCO3,CO3,B(OH)4,B3O3(OH)4,B4O5(OH)4,Br,Am(CO3)2-,Am(CO3)3=-,ClO4-,NpO2(OH)2-,NpC,NpC2,NpC3,H2PO4,HPO4,PO4
  6 #Neu  CO2,CaCO3,MgCO3,B(OH)3,H3PO4

  1  .0765     .2644    .0     .00127   Na+ Cl-          HMW84 (beta0, beta1, beta2, cphi)
  1  .01958   1.113     .0     .00497   Na+ SO4=         HMW84
  1  .0454     .398     .0     .0       Na+ HSO4-        HMW84
  1  .0864     .253     .0     .0044    Na+ OH-          HMW84
  1  .0277     .0411    .0     .0       Na+ HCO3-        HMW84
  1  .0399    1.389     .0     .0044    Na+ CO3=         HM284
  1 -.0427     .089     .0     .0114    Na+ B(OH)4-      FW86
  1 -.056     -.910     .0     .0       Na+ B3O3(OH)4-   FW86
  1 -.11      -.40      .0     .0       Na+ B4O5(OH)4=   FW86
  1  .0        .0       .0     .0       Na+ Br-
  1  .0      -8.37      .0     .0       Na+ Am(CO3)2-    RRFF94
  1 -.94      8.1       .0     .418     Na+ Am(CO3)3=-   RRFF94,FRF90
  1  .0554     .2755    .0    -.00118   Na+ ClO4-        P91
  1  .0        .0       .0     .0       Na+ NpO2(OH)2-   NR94
  1  .161      .0       .0     .0       Na+ NpO2CO3-     NR94
  1  .407      .0       .0     .0       Na+ NpO2(CO3)2=- NR94
  1  1.97     16.       .0     .0       Na+ NpO2(CO3)3==- NR94
  1 -.0533     .0396    .0     .00795   Na+ H2PO4-       P91
  1 -.0583    1.466     .0     .0294    Na+ HPO4=        P91
  1  .1781    3.851     .0    -.05154   Na+ PO4=-        P91
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
1  .04835    .2122    .0    -.00084   K+ Cl-          HMW84
1  .04995    .7793    .0     .0       K+ SO4=         HMW84
1 -.0003     .1735    .0     .0       K+ HSO4-        HMW84
1  .1298     .320     .0     .0041    K+ OH-          HMW84
1  .0296    -.013     .0    -.008     K+ HCO3-        HMW84
1  .1488    1.43      .0    -.0015    K+ CO3=         HMW84
1  .035      .14      .0     .0       K+ B(OH)4-      FW86
1 -.13       .0       .0     .0       K+ B3O3(OH)4-   FW86
1 -.022      .0       .0     .0       K+ B4O5(OH)4=   FW86
1  .0        .0       .0     .0       K+ Br-
1  .0        .0       .0     .0       K+ Am(CO3)2-
1  .0        .0       .0     .0       K+ Am(CO3)3=-
1  .0        .0       .0     .0       K+ ClO4-
1  .0        .0       .0     .0       K+ NpO2(OH)2-
1  .0        .0       .0     .0       K+ NpO2CO3-
1  .0        .0       .0     .0       K+ NpO2(CO3)2=-
1  .0        .0       .0     .0       K+ NpO2(CO3)3==-
1 -.0678    -.1042    .0     .0       K+ H2PO4-       P91
1  .0248    1.274     .0     .0164    K+ HPO4=        P91
1  .3729    3.972     .0    -.08680   K+ PO4=-        P91

1  .3159    1.614     .0    -.00034   Ca++ Cl-        HMW84
2  .20      3.1973   -54.24  .0       Ca++ SO4=       HMW84
1  .2145    2.53      .0     .0       Ca++ HSO4-      HMW84
1 -.1747    -.2303   -5.72   .0       Ca++ OH-        HMW84
1  .4       2.977     .0     .0       Ca++ HCO3-      HMW84
2  .0        .0       .0     .0       Ca++ CO3=       HMW84
1  .0        .0       .0     .0       Ca++ B(OH)4-    FW86
1  .0        .0       .0     .0       Ca++ B3O3(OH)4- FW86
1  .0        .0       .0     .0       Ca++ B4O5(OH)4= FW86
1  .0        .0       .0     .0       Ca++ Br-
1  .0        .0       .0     .0       Ca++ Am(CO3)2-
3  .0        .0       .0     .0       Ca++ Am(CO3)3=-
1  .4511    1.756     .0    -.00500   Ca++ ClO4-      P91
1  .0        .0       .0     .0       Ca++ NpO2(OH)2-
1  .0        .0       .0     .0       Ca++ NpO2CO3-
3  .0        .0       .0     .0       Ca++ NpO2(CO3)2=-
3  .0        .0       .0     .0       Ca++ NpO2(CO3)3==-
1  .0        .0       .0     .0       Ca++ H2PO4-
2  .0        .0       .0     .0       Ca++ HPO4=
3  .0        .0       .0     .0       Ca++ PO4=-

1  .35235   1.6815    .0     .00519   Mg++ Cl-        HMW84
2  .2210    3.343   -37.23   .025     Mg++ SO4=       HMW84
1  .4746    1.729     .0     .0       Mg++ HSO4-      HMW84
1  .0        .0       .0     .0       Mg++ OH-        HMW84
1  .329      .6072    .0     .0       Mg++ HCO3-      HMW84
2  .0        .0       .0     .0       Mg++ CO3=       HMW84
1  .0        .0       .0     .0       Mg++ B(OH)4-    FW86
1  .0        .0       .0     .0       Mg++ B3O3(OH)4- FW86
1  .0        .0       .0     .0       Mg++ B4O5(OH)4= FW86
1  .0        .0       .0     .0       Mg++ Br-
1  .0        .0       .0     .0       Mg++ Am(CO3)2-
3  .0        .0       .0     .0       Mg++ Am(CO3)3=-
1  .4961    2.008     .0     .009578  Mg++ ClO4-      P91
1  .0        .0       .0     .0       Mg++ NpO2(OH)2-
1  .0        .0       .0     .0       Mg++ NpO2CO3-
3  .0        .0       .0     .0       Mg++ NpO2(CO3)2=-
3  .0        .0       .0     .0       Mg++ NpO2(CO3)3==-
1  .0        .0       .0     .0       Mg++ H2PO4-
2  .0        .0       .0     .0       Mg++ HPO4=
3  .0        .0       .0     .0       Mg++ PO4=-

1 -.10      1.658     .0     .0       MgOH+ Cl-       HMW84
1  .0        .0       .0     .0       MgOH+ SO4=      HMW84
1  .0        .0       .0     .0       MgOH+ HSO4-     HMW84
1  .0        .0       .0     .0       MgOH+ OH-       HMW84
1  .0        .0       .0     .0       MgOH+ HCO3-     HMW84
1  .0        .0       .0     .0       MgOH+ CO3=      HMW84
1  .0        .0       .0     .0       MgOH+ B(OH)4-
1  .0        .0       .0     .0       MgOH+ B3O3(OH)4-
1  .0        .0       .0     .0       MgOH+ B4O5(OH)4=
1  .0        .0       .0     .0       MgOH+ Br-
1  .0        .0       .0     .0       MgOH+ Am(CO3)2-
1  .0        .0       .0     .0       MgOH+ Am(CO3)3=-
1  .0        .0       .0     .0       MgOH+ ClO4-
1  .0        .0       .0     .0       MgOH+ NpO2(OH)2-
1  .0        .0       .0     .0       MgOH+ NpO2CO3-
1  .0        .0       .0     .0       MgOH+ NpO2(CO3)2=-
1  .0        .0       .0     .0       MgOH+ NpO2(CO3)3==-
1  .0        .0       .0     .0       MgOH+ H2PO4-
1  .0        .0       .0     .0       MgOH+ HPO4=
1  .0        .0       .0     .0       MgOH+ PO4=-

1  .1775    .2945     .0     .0008    H+ Cl-          HMW84
1  .0298    .0        .0     .0438    H+ SO4=         HMW84
1  .2065    .5556     .0     .0       H+ HSO4-        HMW84
1  .0        .0       .0     .0       H+ OH-          HMW84
1  .0        .0       .0     .0       H+ HCO3-        HMW84
1  .0        .0       .0     .0       H+ CO3=         HMW84
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
1  .0        .0        .0        .0        H+ B(OH)4-          FW86
1  .0        .0        .0        .0        H+ B3O3(OH)4-       FW86
1  .0        .0        .0        .0        H+ B4O5(OH)4=       FW86
1  .0        .0        .0        .0        H+ Br-
1  .0        .0        .0        .0        H+ Am(CO3)2-
1  .0        .0        .0        .0        H+ Am(CO3)3=-
1  .1747     .2931     .0        .00819    H+ ClO4-            P91
1  .0        .0        .0        .0        H+ NpO2(OH)2-
1  .0        .0        .0        .0        H+ NpO2CO3-
1  .0        .0        .0        .0        H+ NpO2(CO3)2=-
1  .0        .0        .0        .0        H+ NpO2(CO3)3==-
1  .0        .0        .0        .0        H+ H2PO4-
1  .0        .0        .0        .0        H+ HPO4=
1  .0        .0        .0        .0        H+ PO4=-

1  .16       .0        .0        .0        MgB(OH)4+ Cl-       HMW84
1  .0        .0        .0        .0        MgB(OH)4+ SO4=      HMW84
1  .0        .0        .0        .0        MgB(OH)4+ HSO4-     HMW84
1  .0        .0        .0        .0        MgB(OH)4+ OH-       HMW84
1  .0        .0        .0        .0        MgB(OH)4+ HCO3-     HMW84
1  .0        .0        .0        .0        MgB(OH)4+ CO3=      HMW84
1  .0        .0        .0        .0        MgB(OH)4+ B(OH)4-
1  .0        .0        .0        .0        MgB(OH)4+ B3O3(OH)4-
1  .0        .0        .0        .0        MgB(OH)4+ B4O5(OH)4=
1  .0        .0        .0        .0        MgB(OH)4+ Br-
1  .0        .0        .0        .0        MgB(OH)4+ Am(CO3)2-
1  .0        .0        .0        .0        MgB(OH)4+ Am(CO3)3=-
1  .0        .0        .0        .0        MgB(OH)4+ ClO4-
1  .0        .0        .0        .0        MgB(OH)4+ NpO2(OH)2-
1  .0        .0        .0        .0        MgB(OH)4+ NpO2CO3-
1  .0        .0        .0        .0        MgB(OH)4+ NpO2(CO3)2=-
1  .0        .0        .0        .0        MgB(OH)4+ NpO2(CO3)3==-
1  .0        .0        .0        .0        MgB(OH)4+ H2PO4-
1  .0        .0        .0        .0        MgB(OH)4+ HPO4=
1  .0        .0        .0        .0        MgB(OH)4+ PO4=-

1  .12       .0        .0        .0        CaB(OH)4+ Cl-
1  .0        .0        .0        .0        CaB(OH)4+ SO4=      HMW84
1  .0        .0        .0        .0        CaB(OH)4+ HSO4-     HMW84
1  .0        .0        .0        .0        CaB(OH)4+ OH-       HMW84
1  .0        .0        .0        .0        CaB(OH)4+ HCO3-     HMW84
1  .0        .0        .0        .0        CaB(OH)4+ CO3=      HMW84
1  .0        .0        .0        .0        CaB(OH)4+ B(OH)4-
1  .0        .0        .0        .0        CaB(OH)4+ B3O3(OH)4-
1  .0        .0        .0        .0        CaB(OH)4+ B4O5(OH)4=
1  .0        .0        .0        .0        CaB(OH)4+ Br-
1  .0        .0        .0        .0        CaB(OH)4+ Am(CO3)2-
1  .0        .0        .0        .0        CaB(OH)4+ Am(CO3)3=-
1  .0        .0        .0        .0        CaB(OH)4+ ClO4-
1  .0        .0        .0        .0        CaB(OH)4+ NpO2(OH)2-
1  .0        .0        .0        .0        CaB(OH)4+ NpO2CO3-
1  .0        .0        .0        .0        CaB(OH)4+ NpO2(CO3)2=-
1  .0        .0        .0        .0        CaB(OH)4+ NpO2(CO3)3==-
1  .0        .0        .0        .0        CaB(OH)4+ H2PO4-
1  .0        .0        .0        .0        CaB(OH)4+ HPO4=
1  .0        .0        .0        .0        CaB(OH)4+ PO4=-

1  .6117     5.403     .0        -0.0284   Am+++ Cl-           FRSR89
3  3.0398    .0        -2500     .0        Am+++ SO4=          RFF94
1  .0        .0        .0        .0        Am+++ HSO4-
1  .0        .0        .0        .0        Am+++ OH-
1  .0        .0        .0        .0        Am+++ HCO3-
3  .0        .0        .0        .0        Am+++ CO3=
1  .0        .0        .0        .0        Am+++ B(OH)4-
1  .0        .0        .0        .0        Am+++ B3O3(OH)4-
1  .0        .0        .0        .0        Am+++ B4O5(OH)4=
1  .0        .0        .0        .0        Am+++ Br-
1  .0        .0        .0        .0        Am+++ Am(CO3)2-
3  .0        .0        .0        .0        Am+++ Am(CO3)3=-
1  .80       5.35      .0        -0.0048   Am+++ ClO4-         FRF90
1  .0        .0        .0        .0        Am+++ NpO2(OH)2-
1  .0        .0        .0        .0        Am+++ NpO2CO3-
3  .0        .0        .0        .0        Am+++ NpO2(CO3)2=-
3  .0        .0        .0        .0        Am+++ NpO2(CO3)3==-
1  .0        .0        -92.9     .0        Am+++ H2PO4-        RFF94
3  .0        .0        .0        .0        Am+++ HPO4=
3  .0        .0        .0        .0        Am+++ PO4=-

1  .0        .0        .0        .0        AmCO3+ Cl-
1  .0        .0        .0        .0        AmCO3+ SO4=
1  .0        .0        .0        .0        AmCO3+ HSO4-
1  .0        .0        .0        .0        AmCO3+ OH-
1  .0        .0        .0        .0        AmCO3+ HCO3-
1  .0        .0        .0        .0        AmCO3+ CO3=
1  .0        .0        .0        .0        AmCO3+ B(OH)4-
1  .0        .0        .0        .0        AmCO3+ B3O3(OH)4-
1  .0        .0        .0        .0        AmCO3+ B4O5(OH)4=
1  .0        .0        .0        .0        AmCO3+ Br-
1  .0        .0        .0        .0        AmCO3+ Am(CO3)2-
1  .0        .0        .0        .0        AmCO3+ Am(CO3)3=-
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
1  .0        .0        .0      .0        AmCO3+ ClO4-
1  .0        .0        .0      .0        AmCO3+ NpO2(OH)2-
1  .0        .0        .0      .0        AmCO3+ NpO2CO3-
1  .0        .0        .0      .0        AmCO3+ NpO2(CO3)2=-
1  .0        .0        .0      .0        AmCO3+ NpO2(CO3)3==-
1  .0        .0        .0      .0        AmCO3+ H2PO4-
1  .0        .0        .0      .0        AmCO3+ HPO4=
1  .0        .0        .0      .0        AmCO3+ PO4=-

1  .0        .0        .0      .0        Th++++ Cl-
3  .0        .0        .0      .0        Th++++ SO4=
1  .0        .0        .0      .0        Th++++ HSO4-
1  .0        .0        .0      .0        Th++++ OH-
1  .0        .0        .0      .0        Th++++ HCO3-
3  .0        .0        .0      .0        Th++++ CO3=
1  .0        .0        .0      .0        Th++++ B(OH)4-
1  .0        .0        .0      .0        Th++++ B3O3(OH)4-
1  .0        .0        .0      .0        Th++++ B4O5(OH)4=
1  .0        .0        .0      .0        Th++++ Br-
1  .0        .0        .0      .0        Th++++ Am(CO3)2-
3  .0        .0        .0      .0        Th++++ Am(CO3)3=-
1  .0        .0        .0      .0        Th++++ ClO4-
1  .0        .0        .0      .0        Th++++ NpO2(OH)2-
1  .0        .0        .0      .0        Th++++ NpO2CO3-
3  .0        .0        .0      .0        Th++++ NpO2(CO3)2=-
3  .0        .0        .0      .0        Th++++ NpO2(CO3)3==-
1  .0        .0        .0      .0        Th++++ H2PO4-
3  .0        .0        .0      .0        Th++++ HPO4=
3  .0        .0        .0      .0        Th++++ PO4=-

1  .4274     1.644     .0     -.03686    UO2++ Cl-            P91
2  .322      1.827     .0     -.0176     UO2++ SO4=           P91
1  .0        .0        .0      .0        UO2++ HSO4-
1  .0        .0        .0      .0        UO2++ OH-
1  .0        .0        .0      .0        UO2++ HCO3-
2  .0        .0        .0      .0        UO2++ CO3=
1  .0        .0        .0      .0        UO2++ B(OH)4-
1  .0        .0        .0      .0        UO2++ B3O3(OH)4-
1  .0        .0        .0      .0        UO2++ B4O5(OH)4=
1  .0        .0        .0      .0        UO2++ Br-
1  .0        .0        .0      .0        UO2++ Am(CO3)2-
3  .0        .0        .0      .0        UO2++ Am(CO3)3=-
1  .6113     2.144     .0      .02168    UO2++ ClO4-          P91
1  .0        .0        .0      .0        UO2++ NpO2(OH)2-
1  .0        .0        .0      .0        UO2++ NpO2CO3-
3  .0        .0        .0      .0        UO2++ NpO2(CO3)2=-
3  .0        .0        .0      .0        UO2++ NpO2(CO3)3==-
1  .0        .0        .0      .0        UO2++ H2PO4-
2  .0        .0        .0      .0        UO2++ HPO4=
3  .0        .0        .0      .0        UO2++ PO4=-

1  0.169     .0        .0      .0        NpO2+ Cl-            NR94
1  .0        .0        .0      .0        NpO2+ SO4=
1  .0        .0        .0      .0        NpO2+ HSO4-
1  .0        .0        .0      .0        NpO2+ OH-
1  .0        .0        .0      .0        NpO2+ HCO3-
1  .0        .0        .0      .0        NpO2+ CO3=
1  .0        .0        .0      .0        NpO2+ B(OH)4-
1  .0        .0        .0      .0        NpO2+ B3O3(OH)4-
1  .0        .0        .0      .0        NpO2+ B4O5(OH)4=
1  .0        .0        .0      .0        NpO2+ Br-
1  .0        .0        .0      .0        NpO2+ Am(CO3)2-
1  .0        .0        .0      .0        NpO2+ Am(CO3)3=-
1  0.312     .0        .0      .0        NpO2+ ClO4-          NR94
1  .0        .0        .0      .0        NpO2+ NpO2(OH)2-
1  .0        .0        .0      .0        NpO2+ NpO2CO3-
1  .0        .0        .0      .0        NpO2+ NpO2(CO3)2=-
1  .0        .0        .0      .0        NpO2+ NpO2(CO3)3==-
1  .0        .0        .0      .0        NpO2+ H2PO4-
1  .0        .0        .0      .0        NpO2+ HPO4=
1  .0        .0        .0      .0        NpO2+ PO4=-


-.012 .07  .07   0.   .036 0.   0.  0.  0.  0.  0.  0.   Na:       (cations  2 thru 13)
 .032  0.   0.   .005 0.   0.   0.  0.  0.  0.  0.  0.   K:        (cations  3 thru 13)
 .007  0.  .092  0.   0.   0.   0.  0.  0.  0.            Ca:       (cations  4 thru 13)
   0. .10   0.   0.   0.   0.   0.  0.  0.                Mg:       (cations  5 thru 13)
   0.  0.   0.   0.   0.   0.   0.  0.                    MgOH:     (cations  6 thru 13)
   0.  0.   0.   0.   0.   0.   0.                        H :       (cations  7 thru 13)
   0.  0.   0.   0.   0.   0.                             MgB(OH)4: (cations  8 thru 13)
   0.  0.   0.   0.   0.                                  CaB(OH)4: (cations  9 thru 13)
   0.  0.   0.   0.                                       Am+++:    (cations 10 thru 13)
   0.  0.   0.                                            AmCO3+:   (cations 11 thru 13)
   0.  0.                                                 Th++++:   (cations 12 thru 13)
   0.                                                     UO2++:    (cations 13 thru 13)


 .02  -.006  -.050  .03  -.02  -.065 .12 .074 0. 0. 0. 0. 0. 0. 0. 0. 0. .1  0. 0. Cl:        (anions  2-20)
 0.   -.013  .01   .02  -.012  .10  .12  0.  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  0.    SO4:       (anions  3-20)
 0.    0.    0.    0.   0.     0.   0.   0.  0. 0. 0. 0. 0. 0. 0. 0. 0. 0.        HSO4:      (anions  4-20)
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
 0.    .10    0.    0.    0.     0.    0.    0.  0. 0. 0. 0. 0. 0. 0. 0.          OH:          (anions  5-20)
-.04    0.   -.10  -.087  0.     0.    0.    0.  0. 0. 0. 0. 0. 0. 0.             HCO3:        (anions  6-20)
 0.     0.    0.    0.    0.     0.    0.    0.  0. 0. 0. 0. 0. 0.                CO3:         (anions  7-20)
 0.     0.    0.    0.    0.     0.    0.    0.  0. 0. 0. 0. 0.                   B(OH)4:      (anions  8-20)
 0.     0.    0.    0.    0.     0.    0.    0.  0  0. 0. 0.                       B3O3(OH)4:   (anions  9-20)
 0.     0.    0.    0.    0.     0.    0.    0.  0. 0. 0.                          B4O5(OH)4:   (anions 10-20)
 0.     0.    0.    0.    0.     0.    0.    0.  0. 0.                             Br:          (anions 11-20)
 0.     0.    0.    0.    0.     0.    0.    0.  0.                                Am(CO3)2-:   (anions 12-20)
 0.     0.    0.    0.    0.     0.    0.    0.                                    Am(CO3)3=-:  (anions 13-20)
 0.     0.    0.    0.    0.     0.    0.                                          ClO4-:       (anions 14-20)
 0.     0.    0.    0.    0.     0.                                                NpO2(OH)2-:  (anions 15-20)
 0.     0.    0.    0.    0.                                                        NpO2CO3-:    (anions 16-20)
 0.     0.    0.    0.                                                              NpO2(CO3)2=-:(anions 17-20)
 0.     0.    0.                                                                    NPC3==-:     (anions 18-20)
 0.     0.                                                                          H2PO4-:      (anions 19-20)
 0.                                                                                 HPO4=:       (anions 20-20)

-.0018 -.010     .0   .0 -.003 .003 .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-K:20anions
 -.007 -.055     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-Ca:
 -.012 -.015     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-Mg:
    .0    .0     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-MgOH:
 -.004    .0 -.0129   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-H:
    .0    .0     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-MgB(OH)4+
    .0    .0     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-CaB(OH)4+
    .0    .0     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-Am+++
    .0    .0     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-AmCO3+
    .0    .0     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-Th++++
    .0    .0     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-UO2++
    .0    .0     .0   .0   .0   .0  .0 .0 .0    .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Na-NpO2++

-.025     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -Ca:
-.022  -.048     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -Mg:
    .0     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -MgOH:
-.011   .197 -.0265   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -H :
    .0     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -MgB(OH)4+
    .0     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -CaB(OH)4+
    .0     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -Am+++
    .0     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -AmCO3+
    .0     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -Th++++
    .0     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -UO2++
    .0     .0     .0   .0   .0   .0  .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  K -NpO2++

-.012 .024  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-Mg:
    .0   .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-MgOH:
-.015    .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-H :
    .0   .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-MgB(OH)4+
    .0   .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-CaB(OH)4+
    .0   .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-Am+++
    .0   .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-AmCO3+
    .0   .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-Th++++
    .0   .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-UO2++
    .0   .0  .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Ca-NpO2++

 .028 .0     .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-MgOH:
-.011 .0 -.0178  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-H :
    .0 .0     .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-MgB(OH)4+
    .0 .0     .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-CaB(OH)4+
    .0 .0     .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-Am+++
    .0 .0     .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-AmCO3+
    .0 .0     .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-Th++++
    .0 .0     .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-UO2++
    .0 .0     .0  .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  Mg-NpO2++

 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgOH-H :
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgOH-MgB(OH)4+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgOH-CaB(OH)4+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgOH-Am+++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgOH-AmCO3+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgOH-Th++++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgOH-UO2++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgOH-NpO2++

 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  H-MgB(OH)4+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  H-CaB(OH)4+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  H-Am+++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  H-AmCO3+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  H-Th++++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  H-UO2++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  H-NpO2++

 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgB(OH)4-CaB(OH)4+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgB(OH)4-Am+++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgB(OH)4-AmCO3+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgB(OH)4-Th++++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgB(OH)4-UO2++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  MgB(OH)4-NpO2++

 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  CaB(OH)4-Am+++
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  CaB(OH)4-AmCO3+
 .0   .0   .0   .0   .0   .0   .0   .0  .0  .0   .0  .0   .0   .0   .0 0 0 0 0 0 0 0  CaB(OH)4-Th++++
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  CaB(OH)4-UO2++
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  CaB(OH)4-NpO2++

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  Am+++-AmCO3+
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  Am+++-Th++++
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  Am+++-UO2++
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  Am+++-NpO2++

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  AmCO3+-Th++++
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  AmCO3+-UO2++
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  AmCO3+-NpO2++

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  Th++++-UO2++
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  Th++++-NpO2++

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0 0 0 0 0  UO2++-NpO2++

 .0014    .0 -.018 -.004 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-SO4:(Na,K,Ca,Mg,
-.006     .0    .0    .0 .0 .013 .0 .0    .0    .0    .0    .0    .0  Cl-HSO4:  MgOH,H,MgB(OH)3,
-.006 -.006 -.025    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-OH:    CaB(OH)4,Am+++,
-.015    .0    .0 -.096 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-HCO3:  AmCO3+,Th++++,
 .0085  .004    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-CO3:   UO2++,NpO2+)
-.0073    .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-B(OH)4:
-.024     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-B3O3(OH)4:
 .026     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-B4O5(OH)4:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-Br:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-Am(CO3)2:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-Am(CO3)3:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-ClO4-:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-NpO2(OH)2-:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-NpO2CO3-:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-NpO2(CO3)2=-:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-NpO2(CO3)3==-:
   .0   -.01    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-H2PO4-:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-HPO4=:
   .0     .0    .0    .0 .0    .0 .0 .0    .0    .0    .0    .0    .0  Cl-PO4=-:

-.0094 -.0677 .0 -.0425 .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-HSO4:
-.009 -.050 .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-OH:
-.005 .0    .0   -.161 .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-HCO3:
-.005 -.009 .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-CO3:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-B(OH)4:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-B3O3(OH)4:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-B4O5(OH)4:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-Br:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-Am(CO3)2:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-Am(CO3)3:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-ClO4-:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-NpO2(OH)2-:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-NpO2CO3-:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-NpO2(CO3)2=-:
 .0    .0    .0    .0    .0 .0    .0    .0    .0    .0    .0    .0    .0  SO4-NpO2(CO3)3==-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  SO4-H2PO4-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  SO4-HPO4=:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  SO4-PO4=-:

 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-OH:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-HCO3-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-CO3=:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-B(OH)4-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-B3O3(OH)4:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-B4O5(OH)4:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-Br-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-Am(CO3)2-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-Am(CO3)2=-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-ClO4-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-NpO2(OH)2-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-NpO2CO3-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-NpO2(CO3)2=-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-NpO2(CO3)3==-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-H2PO4-:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-HPO4=:
 .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0  HSO4-PO4=-:

   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-HCO3:
-.017 -.01   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-CO3:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-B(OH)4:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-B3O3(OH)4:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-B4O5(OH)4:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-Br:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-Am(CO3)2:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-Am(CO3)3:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-ClO4-:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-NpO2(OH)2-:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-NpO2CO3-:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-NpO2(CO3)2=-:
   .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-NpO2(CO3)3==-:
 .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-H2PO4-:
 .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-HPO4=:
 .0   .0   .0   .0   .0    .0    .0    .0    .0    .0    .0    .0    .0  OH-PO4=-:
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
.002 .012 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-CO3:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-B(OH)4:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-B3O3(OH)4:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-B4O5(OH)4:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-Br:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-Am(CO3)2:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-Am(CO3)3:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-ClO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-NpO2(OH)2-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-NpO2CO3-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-NpO2(CO3)2=-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-NpO2(CO3)3==-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-H2PO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-HPO4=:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HCO3-PO4=-:

.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-B(OH)4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-B3O3(OH)4:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-B4O5(OH)4:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-Br:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-Am(CO3)2:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-Am(CO3)3:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-ClO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-NpO2(OH)2-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-NpO2CO3-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-NpO2(CO3)2=-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-NpO2(CO3)3==-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-H2PO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-HPO4=:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   CO3-PO4=-:

.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-B3O3(OH)4:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-B4O5(OH)4:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-Br:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-Am(CO3)2:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-Am(CO3)3:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-ClO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-NpO2(OH)2-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-NpO2CO3-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-NpO2(CO3)2=-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-NpO2(CO3)3==-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-H2PO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-HPO4=:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)4-PO4=-:

.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-B4O5(OH)4:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-Br:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-Am(CO3)2:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-Am(CO3)3:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-ClO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-NpO2(OH)2-
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-NpO2CO3-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-NpO2(CO3)2=-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-NpO2(CO3)3==-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-H2PO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-HPO4=:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B3O3(OH)4-PO4=-:

.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=Br:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=Am(CO3)2:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=Am(CO3)3:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=ClO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=NPO2(OH)2-
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=NpO2CO3-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=NpO2(CO3)2=-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=NpO2(CO3)3==-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=H2PO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=HPO4=:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   B4O5(OH)4=PO4=-:

.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-Am(CO3)2:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-Am(CO3)3:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-ClO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-NpO2(OH)2-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-NpO2CO3-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-NpO2(CO3)2=-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-NpO2(CO3)3==-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-H2PO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-HPO4=:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Br-PO4=-:

.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-Am(CO3)3:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-ClO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-NpO2(OH)2-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-NpO2CO3-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-NpO2(CO3)2=-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-NpO2(CO3)3==-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-H2PO4-:
.0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-HPO4=:
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)2-PO4=-:

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)3-ClO4-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)3-NpO2(OH)2-
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)3-NpO2CO3-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)3-NpO2(CO3)2=-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)3-NpO2(CO3)3==-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)3-H2PO4-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)3-HPO4=:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   Am(CO3)3-PO4=-:

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   ClO4-NpO2(OH)2-
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   ClO4-NpO2CO3-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   ClO4-NpO2(CO3)2=-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   ClO4-NpO2(CO3)3==-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   ClO4-H2PO4-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   ClO4-HPO4=:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   ClO4-PO4=-:

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(OH)2--NpO2CO3-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(OH)2--NpO2(CO3)2=-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(OH)2--NpO2(CO3)3==-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(OH)2-H2PO4-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(OH)2-HPO4=:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(OH)2-PO4=-:

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2CO3-NpO2(CO3)2=-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2CO3-NpO2(CO3)3==-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2CO3-H2PO4-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2CO3-HPO4=:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2CO3-PO4=-:

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpC2-NpO2(CO3)3==-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpC2-H2PO4-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpC2-HPO4=:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpC2-PO4=-:

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(CO3)3-H2PO4-:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(CO3)3-HPO4=:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2(CO3)3-PO4=-:

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   H2PO4-HPO4=:
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   H2PO4-PO4=-:

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   HPO4-PO4=-:

 .100 .051  .183 .183 .0   .0   .0   .0   .0   .0   .0   .0   .0   CO2-Cations      HMW84
  .0   .0    .0   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   CaCO3-Cations    HMW84
  .0   .0    .0   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   MgCO3-Cations    HMW84
-.097 -.14   .0   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   B(OH)3-Cations   FW86
  .0   .0    .0   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   NpO2OH-Cations
  .0 -.07    .0   .0  .0  .29   .0   .0   .0   .0   .0   .0   .0   H3PO4-Cations    PS76

-.005 .097 -.003   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   0 0 0 0   0 0 0  CO2-Anions     HMW84
  .0   .0    .0   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   0 0 0 0   0 0 0  CaCO3-Anions   HMW84
  .0   .0    .0   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   0 0 0 0   0 0 0  MgCO3-Anions   HMW84
 .091 .018   .0   .0  .0   .0   .0 -.20   .0   .0   .0   .0   .0   0 0 0 0   0 0 0  B(OH)3-Anions  FW86
  .0   .0    .0   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   0 0 0 0   0 0 0  NpO2OH-Anions
  .0   .0    .0   .0  .0   .0   .0   .0   .0   .0   .0   .0   .0   0 0 0 0 -.4 0 0  H3PO4-Anions   PS76

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0  CO2-Cation-Anion
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0  (Cations down, Anions across)
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0  CaCO3-Cation-Anion
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0

 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0  MgCO3-Cation-Anion
 .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0 0 0 0
```

Appendix I: Listing of HMW_NP_AM.CHEMDAT and References Cited in Listing

```
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0

 .0   .046 .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0   B(OH)3-Cation-Anion FW86
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0   (Cations down, Anions across)
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
-.0102 .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0    .0   .0 .0 .0 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0

 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0   NpO2OH(aq)-Cation-Anion
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0

 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0   H3PO4-Cation-Anion
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0
 .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0 0 0 0

 2  3  4  5  6  7 22 21 43 44 49 50 37                    cation  mapping for ELMAP(1,)
 8  9 10 11 12 13 18 19 20 23 45 46 24 39 40 41 42 34 35 36  anion   mapping for ELMAP(2,)
14 15 16 17 38 33                                          neutral mapping for ELMAP(3,)

'nEQUALACT' 0

2 (Oxygen)
'nREDOX' 0
'nIONEX' 0 0 'nMF'
```

```
FRSR89 ==  Felmy, Rai, Schramke, and Ryan (1989) RCA 48 pp.29-35
FRF90  ==  Felmy, Rai, and Fulton (1990) RCA 50 pp.193-204
FS76   ==  Pitzer and Silvester (1976) J Soln Chem 5#4 pp.269-278
P91    ==  Pitzer (1991) CRC Handbook, Activity Coef in Electrolyte Solns
RFF92  ==  Rai, Felmy, and Fulton (1992)  RCA 56 pp.7-14
RFFR92 ==  Rai, Felmy, Fulton, and Ryan (1992) RCA 58/59 pp.9-16
RFF94  ==  Rai, Felmy, and Fulton (1994)
RRFF94 ==  Rao, Rai, Felmy, and Fulton (1994) SAND94-1948J for RCA

NR94   ==  Novak and Roberts (1994) SAND94-xxxx MRS/Kyoto
HMW84  ==  Harvie, Moller, Weare (1984) GCA 48 pp.723-751
PW86   ==  Felmy and Weare (1986) GCA 50 pp.2771-2783
```

I.2 References Cited in Listing

Felmy, A.R., D. Rai, and R.W. Fulton. 1990. "The Solubility of AmOHCO3(c) and the Aqueous Thermodynamics of the System Na+-Am3+-HCO_3^--OH—H2O." Radiochimica Acta vol. 50: 193-240.

Felmy, A.R., D. Rai, J.A. Schramke, and J.L. Ryan. 1989. "The Solubility of Plutonium Hydroxide in Dilute Solution and in High-Ionic-Strength Chloride Brines." *Radiochimica Acta* vol. 48: 29-35.

Felmy, A.R., and J.H. Weare. 1986. "The Prediction of Borate Mineral Equilibria in Natural Waters: Application to Searles Lake, California." *Geochimica et Cosmochimica Acta* vol. 50: 2771-2783.

Harvie, C.E., N. Møller, and J.H. Weare. 1984. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O System to High Ionic Strength at 25°C." *Geochimica et Cosmochimica Acta* vol. 48: 723-751.

Novak, C.F., and K.E. Roberts. 1994. *Thermodynamic Modeling of Neptunium(V) Solubility in Na-CO_3-HCO_3-Cl-ClO_4-H-OH-H_2O Electrolytes*. SAND94-0805C. Albuquerque, New Mexico: Sandia National Laboratories.

Pitzer, K.S. 1991. *Activity Coefficients in Electrolyte Solutions*. Boca Raton, Florida: CRC Press.

Pitzer, K.S., and L.F. Silvester. 1976. "Thermodynamics of Electrolytes. VI. Weak Electrolytes Including H_3PO_4." *Journal of Solution Chemistry* vol. 5: 269-278.

Rai, D., A.R. Felmy, and R.W. Fulton. 1992a. "Solubility and Ion Activity Product of $AmPO_4 \cdot xH_2O$(am)." *Radiochimica Acta* vol. 56: 7-14.

Rai, D., A.R. Felmy, and R.W. Fulton. 1994. "The Nd^{3+} and Am^{3+} Ion Interactions with SO_4^{2-} and their Influence on $NdPO_4$(c) Solubility." *Journal of Solution Chemistry*. submitted June 1994.

Rai, D., A.R. Felmy, R.W. Fulton, and J.L. Ryan. 1992b. "Aqueous Chemistry of Nd in Borosilicate-Glass/Water Systems." *Radiochimica Acta* vol. 58/59: 9-16.

Rao, L., D. Rai, A.R. Felmy, and RW. Fulton. 1994. "Solubility of $NaNd(CO_3)_2 \cdot 6H_2O$ in Concentrated Sodium Carbonate and Sodium Bicarbonate Solutions." *Radiochimica Acta* vol. ___: ___-___. SAND94-1948J.

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

See Table 24 for explanation of this listing.

```
Temperature is Hard Coded as 298.15K
[.FD.TITRATE]BATCH_DOC.in; to illustrate/document "BATCH" runs                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFP94)

Accuracy of reactions is              1.0000E-06
Minimum elemental abundance is        1.0000E-18
Number of Aqueous Species is            50


Species Order for Pitzer Parameters

Cations

Na+                 K+                  Ca++                Mg++
MgOH+               H+                  MgB(OH)4+           CaB(OH)4+
Am+++               AmCO3+              Th++++              UO2++
NpO2+

Anions

Cl-                 SO4=                HSO4-               OH-
HCO3-               CO3=                B(OH)4-             B3O3(OH)4-
B4O5(OH)4=          Br-                 Am(CO3)2-           Am(CO3)3=-
ClO4-            pe NpO2(OH)2-          NpO2CO3-            NpO2(CO3)2=-
NpO2(CO3)3==-       H2PO4-              HPO4=               PO4=-


Neutral

CO2(aq)             CaCO3(aq)           MgCO3(aq)           B(OH)3(aq)
NpO2OH(aq)          H3PO4(aq)

Cation-Anion Binary Interaction Parameters

Cation          Anion              Beta(0)     Beta(1)     Beta(2)     Cphi     Alpha-Values
Na+             Cl-                0.07650     0.26440     0.00000     0.00127  (2.0,12) 1-1,1-2,1-3
Na+             SO4=               0.01958     1.11300     0.00000     0.00497  (2.0,12) 1-1,1-2,1-3
Na+             HSO4-              0.04540     0.39800     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             OH-                0.08640     0.25300     0.00000     0.00440  (2.0,12) 1-1,1-2,1-3
Na+             HCO3-              0.02770     0.04110     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             CO3=               0.03990     1.38900     0.00000     0.00440  (2.0,12) 1-1,1-2,1-3
Na+             B(OH)4-           -0.04270     0.08900     0.00000     0.01140  (2.0,12) 1-1,1-2,1-3
Na+             B3O3(OH)4-        -0.05600    -0.91000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             B4O5(OH)4=        -0.11000    -0.40000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             Br-                0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             Am(CO3)2-          0.00000    -8.37000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             Am(CO3)3=-        -0.94000     8.10000     0.00000     0.41800  (2.0,12) 1-1,1-2,1-3
Na+             ClO4-              0.05540     0.27550     0.00000    -0.00118  (2.0,12) 1-1,1-2,1-3
Na+             NpO2(OH)2-         0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             NpO2CO3-           0.16100     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             NpO2(CO3)2=-       0.40700     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             NpO2(CO3)3==-      1.97000    16.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Na+             H2PO4-            -0.05330     0.03960     0.00000     0.00795  (2.0,12) 1-1,1-2,1-3
Na+             HPO4=             -0.05830     1.46600     0.00000     0.02940  (2.0,12) 1-1,1-2,1-3
Na+             PO4=-              0.17810     3.85100     0.00000    -0.05154  (2.0,12) 1-1,1-2,1-3
K+              Cl-                0.04835     0.21220     0.00000    -0.00084  (2.0,12) 1-1,1-2,1-3
K+              SO4=               0.04995     0.77930     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              HSO4-             -0.00030     0.17350     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              OH-                0.12980     0.32000     0.00000     0.00410  (2.0,12) 1-1,1-2,1-3
K+              HCO3-              0.02960    -0.01300     0.00000    -0.00800  (2.0,12) 1-1,1-2,1-3
K+              CO3=               0.14880     1.43000     0.00000    -0.00150  (2.0,12) 1-1,1-2,1-3
K+              B(OH)4-            0.03500     0.14000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              B3O3(OH)4-        -0.13000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              B4O5(OH)4=        -0.02200     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              Br-                0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              Am(CO3)2-          0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              Am(CO3)3=-         0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              ClO4-              0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              NpO2(OH)2-         0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              NpO2CO3-           0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              NpO2(CO3)2=-       0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              NpO2(CO3)3==-      0.00000     0.00000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              H2PO4-            -0.06780    -0.10420     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
K+              HPO4=              0.02480     1.27400     0.00000     0.01640  (2.0,12) 1-1,1-2,1-3
K+              PO4=-              0.37290     3.97200     0.00000    -0.08680  (2.0,12) 1-1,1-2,1-3
Ca++            Cl-                0.31590     1.61400     0.00000    -0.00034  (2.0,12) 1-1,1-2,1-3
Ca++            SO4=               0.20000     3.19730   -54.24000     0.00000  (1.4,12) 2-2
Ca++            HSO4-              0.21450     2.53000     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Ca++            OH-               -0.17470    -0.23030    -5.72000     0.00000  (2.0,12) 1-1,1-2,1-3
Ca++            HCO3-              0.40000     2.97700     0.00000     0.00000  (2.0,12) 1-1,1-2,1-3
Ca++            CO3=               0.00000     0.00000     0.00000     0.00000  (1.4,12) 2-2
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Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

Ca++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Ca++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Ca++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Ca++	Br-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Ca++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Ca++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
Ca++	ClO4-	0.45110	1.75600	0.00000	-0.00500	(2.0,12)	1-1,1-2,1-3
Ca++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Ca++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Ca++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
Ca++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
Ca++	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Ca++	HPO4=	0.00000	0.00000	0.00000	0.00000	(1.4,12)	2-2
Ca++	PO4=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
Mg++	Cl-	0.35235	1.68150	0.00000	0.00519	(2.0,12)	1-1,1-2,1-3
Mg++	SO4=	0.22100	3.34300	-37.23000	0.02500	(1.4,12)	2-2
Mg++	HSO4-	0.47460	1.72900	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	OH-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	HCO3-	0.32900	0.60720	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	CO3=	0.00000	0.00000	0.00000	0.00000	(1.4,12)	2-2
Mg++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	Br-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
Mg++	ClO4-	0.49610	2.00800	0.00000	0.00958	(2.0,12)	1-1,1-2,1-3
Mg++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
Mg++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
Mg++	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
Mg++	HPO4=	0.00000	0.00000	0.00000	0.00000	(1.4,12)	2-2
Mg++	PO4=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
MgOH+	Cl-	-0.10000	1.65800	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	SO4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	HSO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	OH-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	HCO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	CO3=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	Br-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	ClO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	HPO4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgOH+	PO4=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	Cl-	0.17750	0.29450	0.00000	0.00080	(2.0,12)	1-1,1-2,1-3
H+	SO4=	0.02980	0.00000	0.00000	0.04380	(2.0,12)	1-1,1-2,1-3
H+	HSO4-	0.20650	0.55560	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	OH-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	HCO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	CO3=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	Br-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	ClO4-	0.17470	0.29310	0.00000	0.00819	(2.0,12)	1-1,1-2,1-3
H+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	HPO4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
H+	PO4=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	Cl-	0.16000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	SO4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	HSO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	OH-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	HCO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	CO3=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	Br-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	ClO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
MgB(OH)4+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

[illegible]	MgB(OH)4+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	MgB(OH)4+	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	MgB(OH)4+	HPO4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	MgB(OH)4+	PO4=-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	Cl-	0.12000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	SO4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	HSO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	OH-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	HCO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	CO3=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	Br-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	ClO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	HPO4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	CaB(OH)4+	PO4=-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	Cl-	0.61170	5.40300	0.00000	-0.02840	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	SO4=	3.03980	0.00000	-2500.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Am+++	HSO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	OH-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	HCO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	CO3=	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Am+++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	Br-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Am+++	ClO4-	0.80000	5.35000	0.00000	-0.00480	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Am+++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Am+++	H2PO4-	0.00000	0.00000	-92.90000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Am+++	HPO4=	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Am+++	PO4=-	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	AmCO3+	Cl-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	SO4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	HSO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	OH-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	HCO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	CO3=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	Br-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	ClO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	HPO4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	AmCO3+	PO4=-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	Cl-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	SO4=	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Th++++	HSO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	OH-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	HCO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	CO3=	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Th++++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	Br-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Th++++	ClO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Th++++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Th++++	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	Th++++	HPO4=	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	Th++++	PO4=-	0.00000	0.00000	0.00000	0.00000	(1,4,50)	2-(n>2)
[illegible]	UO2++	Cl-	0.42740	1.64400	0.00000	-0.03686	(2,0,12)	1-1,1-2,1-3
[illegible]	UO2++	SO4=	0.32200	1.82700	0.00000	-0.01760	(1,4,12)	2-2
[illegible]	UO2++	HSO4-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	UO2++	OH-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	UO2++	HCO3-	0.00000	0.00000	0.00000	0.00000	(2,0,12)	1-1,1-2,1-3
[illegible]	UO2++	CO3=	0.00000	0.00000	0.00000	0.00000	(1,4,12)	2-2

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

UO2++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
UO2++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
UO2++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
UO2++	Br-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
UO2++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
UO2++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
UO2++	ClO4-	0.61130	2.14400	0.00000	0.02168	(2.0,12)	1-1,1-2,1-3
UO2++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
UO2++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
UO2++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
UO2++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
UO2++	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
UO2++	HPO4=	0.00000	0.00000	0.00000	0.00000	(1.4,12)	2-2
UO2++	PO4=-	0.00000	0.00000	0.00000	0.00000	(1.4,50)	2-(n>2)
NpO2+	Cl-	0.16900	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	SO4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	HSO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	OH-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	HCO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	CO3=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	Br-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	ClO4-	0.31200	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	H2PO4-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	HPO4=	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3
NpO2+	PO4=-	0.00000	0.00000	0.00000	0.00000	(2.0,12)	1-1,1-2,1-3

Cation-Cation Ternary Interactions: theta(c1,c2)

	K+	Ca++	Mg++	MgOH+	H+	MgB(OH)4+	CaB(OH)4+	Am+++	AmCO3+	Th++++
Na+	-0.01200	0.07000	0.07000	0.00000	0.03600	0.00000	0.00000	0.00000	0.00000	0.00000

	UO2++	NpO2+
Na+	0.00000	0.00000

	Ca++	Mg++	MgOH+	H+	MgB(OH)4+	CaB(OH)4+	Am+++	AmCO3+	Th++++	UO2++
K+	0.03200	0.00000	0.00000	0.00500	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	NpO2+
K+	0.00000

	Mg++	MgOH+	H+	MgB(OH)4+	CaB(OH)4+	Am+++	AmCO3+	Th++++	UO2++	NpO2+
Ca++	0.00700	0.00000	0.09200	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	MgOH+	H+	MgB(OH)4+	CaB(OH)4+	Am+++	AmCO3+	Th++++	UO2++	NpO2+
Mg++	0.00000	0.10000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	H+	MgB(OH)4+	CaB(OH)4+	Am+++	AmCO3+	Th++++	UO2++	NpO2+
MgOH+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	MgB(OH)4+	CaB(OH)4+	Am+++	AmCO3+	Th++++	UO2++	NpO2+
H+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	CaB(OH)4+	Am+++	AmCO3+	Th++++	UO2++	NpO2+
MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	Am+++	AmCO3+	Th++++	UO2++	NpO2+
CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000

	AmCO3+	Th++++	UO2++	NpO2+
Am+++	0.00000	0.00000	0.00000	0.00000

	Th++++	UO2++	NpO2+
AmCO3+	0.00000	0.00000	0.00000

	UO2++	NpO2+
Th++++	0.00000	0.00000

	NpO2+
UO2++	0.00000

Anion-Anion Ternary Interactions: theta(a1,a2)

	SO4=	HSO4-	OH-	HCO3-	CO3=	B(OH)4-	B3O3(OH)4-	B4O5(OH)4=	Br-	Am(CO3)2-
Cl-	0.02000	-0.00600	-0.05000	0.03000	-0.02000	-0.06500	0.12000	0.07400	0.00000	0.00000

	Am(CO3)3=-	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-
Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.10000	0.00000	0.00000

	HSO4-	OH-	HCO3-	CO3=	B(OH)4-	B3O3(OH)4-	B4O5(OH)4=	Br-	Am(CO3)2-	Am(CO3)3=-
SO4=	0.00000	-0.01300	0.01000	0.02000	-0.01200	0.10000	0.12000	0.00000	0.00000	0.00000

	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-
SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Appendix J: *OUTPUT File Listing of HMW_NP_AM.CHEMDAT*

	OH-	HCO3-	CO3=	B(OH)4-	B3O3(OH)4-	B4O5(OH)4=	Br-	Am(CO3)2-	Am(CO3)3=-	ClO4-
HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-			
HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000			
	HCO3-	CO3=	B(OH)4-	B3O3(OH)4-	B4O5(OH)4=	Br-	Am(CO3)2-	Am(CO3)3=-	ClO4-	NpO2(OH)2-
OH-	0.00000	0.10000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-				
OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
	CO3=	B(OH)4-	B3O3(OH)4-	B4O5(OH)4=	Br-	Am(CO3)2-	Am(CO3)3=-	ClO4-	NpO2(OH)2-	NpO2CO3-
HCO3-	-0.04000	0.00000	-0.10000	-0.08700	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-					
HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000					
	B(OH)4-	B3O3(OH)4-	B4O5(OH)4=	Br-	Am(CO3)2-	Am(CO3)3=-	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2
CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-						
CO3=	0.00000	0.00000	0.00000	0.00000						
	B3O3(OH)4-	B4O5(OH)4=	Br-	Am(CO3)2-	Am(CO3)3=-	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3
B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	H2PO4-	HPO4=	PO4=-							
B(OH)4-	0.00000	0.00000	0.00000							
	B4O5(OH)4=	Br-	Am(CO3)2-	Am(CO3)3=-	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-
B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	HPO4=	PO4=-								
B3O3(OH)4-	0.00000	0.00000								
	Br-	Am(CO3)2-	Am(CO3)3=-	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=
B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	PO4=-									
B4O5(OH)4=	0.00000									
	Am(CO3)2-	Am(CO3)3=-	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-
Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	Am(CO3)3=-	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-	
Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	
	ClO4-	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-		
Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000		
	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-			
ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000			
	NpO2CO3-	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-				
NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
	NpO2(CO3)2	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-					
NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000					
	NpO2(CO3)3	H2PO4-	HPO4=	PO4=-						
NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000						
	H2PO4-	HPO4=	PO4=-							
NpO2(CO3)3==-	0.00000	0.00000	0.00000							
	HPO4=	PO4=-								
H2PO4-	0.00000	0.00000								
	PO4=-									
HPO4=	0.00000									

Cation-Cation-Anion Ternary Interactions: psi(,,,)

		Cl-	SO4=	HSO4-	OH-	HCO3-	CO3=	B(OH)4-	B3O3(OH)4	B4O5(OH)4	Br-
Na+	K+	-0.00180	-0.01000	0.00000	0.00000	-0.00300	0.00300	0.00000	0.00000	0.00000	0.00000
Na+	Ca++	-0.00700	-0.05500	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Mg++	-0.01200	-0.01500	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	MgOH+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	H+	-0.00400	0.00000	-0.01290	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Ca++	-0.02500	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Mg++	-0.02200	-0.04800	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	MgOH+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	H+	-0.01100	0.19700	-0.02650	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

K+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Mg++	-0.01200	0.02400	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	MgOH+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	H+	-0.01500	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	MgOH+	0.02800	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	H+	-0.01100	0.00000	-0.01780	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	H+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am+++	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am+++	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am+++	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am+++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
AmCO3+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
AmCO3+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
AmCO3+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Th++++	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Th++++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
UO2++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

		Am(CO3)2-	Am(CO3)3=	ClO4-	NpO2(OH)2	NpO2CO3-	NpO2(CO3)	NpO2(CO3)	H2PO4-	HPO4=	PO4=-
Na+	K+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Ca++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Mg++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	MgOH+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	H+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Ca++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Mg++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	MgOH+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	H+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Mg++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	MgOH+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	H+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

Ca++	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	MgOH+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	H+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Mg++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	H+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgOH+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	MgB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	CaB(OH)4+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MgB(OH)4+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	Am+++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CaB(OH)4+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am+++	AmCO3+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am+++	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am+++	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am+++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
AmCO3+	Th++++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
AmCO3+	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
AmCO3+	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Th++++	UO2++	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Th++++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
UO2++	NpO2+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Anion-Anion-Cation Ternary Interactions: psi(,,,)

		Na+	K+	Ca++	Mg++	MgOH+	H+	MgB(OH)4+	CaB(OH)4+	Am+++	AmCO3+
Cl-	SO4=	0.00140	0.00000	-0.01800	-0.00400	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	HSO4-	-0.00600	0.00000	0.00000	0.00000	0.00000	0.01300	0.00000	0.00000	0.00000	0.00000
Cl-	OH-	-0.00600	-0.00600	-0.02500	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	HCO3-	-0.01500	0.00000	0.00000	-0.09600	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	CO3=	0.00850	0.00400	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	B(OH)4-	-0.00730	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	B3O3(OH)4-	-0.02400	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	B4O5(OH)4=	0.02600	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	H2PO4-	0.00000	-0.01000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Cl-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	HSO4-	-0.00940	-0.06770	0.00000	-0.04250	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	OH-	-0.00900	-0.05000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	HCO3-	-0.00500	0.00000	0.00000	-0.16100	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	CO3=	-0.00500	-0.00900	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
SO4=	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

HSO4-	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HSO4-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	CO3=	-0.01700	-0.01000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	CO3=	0.00200	0.01200	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B4O5(OH)4=	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B4O5(OH)4=	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B4O5(OH)4=	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B4O5(OH)4=	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B4O5(OH)4=	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

713	B4O5(OH)4=	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
714	B4O5(OH)4=	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
715	B4O5(OH)4=	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
716	B4O5(OH)4=	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
717	B4O5(OH)4=	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
718	B4O5(OH)4=	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
719	Br-	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
720	Br-	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
721	Br-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
722	Br-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
723	Br-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
724	Br-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
725	Br-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
726	Br-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
727	Br-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
728	Br-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
729	Am(CO3)2-	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
730	Am(CO3)2-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
731	Am(CO3)2-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
732	Am(CO3)2-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
733	Am(CO3)2-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
734	Am(CO3)2-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
735	Am(CO3)2-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
736	Am(CO3)2-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
737	Am(CO3)2-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
738	Am(CO3)3=-	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
739	Am(CO3)3=-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
740	Am(CO3)3=-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
741	Am(CO3)3=-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
742	Am(CO3)3=-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
743	Am(CO3)3=-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
744	Am(CO3)3=-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
745	Am(CO3)3=-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
746	ClO4-	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
747	ClO4-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
748	ClO4-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
749	ClO4-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
750	ClO4-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
751	ClO4-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
752	ClO4-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
753	NpO2(OH)2-	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
754	NpO2(OH)2-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
755	NpO2(OH)2-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
756	NpO2(OH)2-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
757	NpO2(OH)2-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
758	NpO2(OH)2-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
759	NpO2CO3-	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
760	NpO2CO3-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
761	NpO2CO3-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
762	NpO2CO3-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
763	NpO2CO3-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
764	NpO2(CO3)2=-	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
765	NpO2(CO3)2=-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
766	NpO2(CO3)2=-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
767	NpO2(CO3)2=-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
768	NpO2(CO3)3==-	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
769	NpO2(CO3)3==-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
770	NpO2(CO3)3==-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
771	H2PO4-	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
772	H2PO4-	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
773	HPO4=	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
774												
775			Th++++	UO2++	NpO2+							
776	Cl-	SO4=	0.00000	0.00000	0.00000							
777	Cl-	HSO4-	0.00000	0.00000	0.00000							
778	Cl-	OH-	0.00000	0.00000	0.00000							
779	Cl-	HCO3-	0.00000	0.00000	0.00000							
780	Cl-	CO3=	0.00000	0.00000	0.00000							
781	Cl-	B(OH)4-	0.00000	0.00000	0.00000							
782	Cl-	B3O3(OH)4-	0.00000	0.00000	0.00000							
783	Cl-	B4O5(OH)4=	0.00000	0.00000	0.00000							
784	Cl-	Br-	0.00000	0.00000	0.00000							
785	Cl-	Am(CO3)2-	0.00000	0.00000	0.00000							
786	Cl-	Am(CO3)3=-	0.00000	0.00000	0.00000							
787	Cl-	ClO4-	0.00000	0.00000	0.00000							
788	Cl-	NpO2(OH)2-	0.00000	0.00000	0.00000							
789	Cl-	NpO2CO3-	0.00000	0.00000	0.00000							
790	Cl-	NpO2(CO3)2=-	0.00000	0.00000	0.00000							
791	Cl-	NpO2(CO3)3==-	0.00000	0.00000	0.00000							
792	Cl-	H2PO4-	0.00000	0.00000	0.00000							
793	Cl-	HPO4=	0.00000	0.00000	0.00000							
794	Cl-	PO4=-	0.00000	0.00000	0.00000							
795	SO4=	HSO4-	0.00000	0.00000	0.00000							
796	SO4=	OH-	0.00000	0.00000	0.00000							
797	SO4=	HCO3-	0.00000	0.00000	0.00000							
798	SO4=	CO3=	0.00000	0.00000	0.00000							
799	SO4=	B(OH)4-	0.00000	0.00000	0.00000							
800	SO4=	B3O3(OH)4-	0.00000	0.00000	0.00000							
801	SO4=	B4O5(OH)4=	0.00000	0.00000	0.00000							
802	SO4=	Br-	0.00000	0.00000	0.00000							

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

SO4=	Am(CO3)2-	0.00000	0.00000	0.00000
SO4=	Am(CO3)3=-	0.00000	0.00000	0.00000
SO4=	ClO4-	0.00000	0.00000	0.00000
SO4=	NpO2(OH)2-	0.00000	0.00000	0.00000
SO4=	NpO2CO3-	0.00000	0.00000	0.00000
SO4=	NpO2(CO3)2=-	0.00000	0.00000	0.00000
SO4=	NpO2(CO3)3==-	0.00000	0.00000	0.00000
SO4=	H2PO4-	0.00000	0.00000	0.00000
SO4=	HPO4=	0.00000	0.00000	0.00000
SO4=	PO4=-	0.00000	0.00000	0.00000
HSO4-	OH-	0.00000	0.00000	0.00000
HSO4-	HCO3-	0.00000	0.00000	0.00000
HSO4-	CO3=	0.00000	0.00000	0.00000
HSO4-	B(OH)4-	0.00000	0.00000	0.00000
HSO4-	B3O3(OH)4-	0.00000	0.00000	0.00000
HSO4-	B4O5(OH)4=	0.00000	0.00000	0.00000
HSO4-	Br-	0.00000	0.00000	0.00000
HSO4-	Am(CO3)2-	0.00000	0.00000	0.00000
HSO4-	Am(CO3)3=-	0.00000	0.00000	0.00000
HSO4-	ClO4-	0.00000	0.00000	0.00000
HSO4-	NpO2(OH)2-	0.00000	0.00000	0.00000
HSO4-	NpO2CO3-	0.00000	0.00000	0.00000
HSO4-	NpO2(CO3)2=-	0.00000	0.00000	0.00000
HSO4-	NpO2(CO3)3==-	0.00000	0.00000	0.00000
HSO4-	H2PO4-	0.00000	0.00000	0.00000
HSO4-	HPO4=	0.00000	0.00000	0.00000
HSO4-	PO4=-	0.00000	0.00000	0.00000
OH-	HCO3-	0.00000	0.00000	0.00000
OH-	CO3=	0.00000	0.00000	0.00000
OH-	B(OH)4-	0.00000	0.00000	0.00000
OH-	B3O3(OH)4-	0.00000	0.00000	0.00000
OH-	B4O5(OH)4=	0.00000	0.00000	0.00000
OH-	Br-	0.00000	0.00000	0.00000
OH-	Am(CO3)2-	0.00000	0.00000	0.00000
OH-	Am(CO3)3=-	0.00000	0.00000	0.00000
OH-	ClO4-	0.00000	0.00000	0.00000
OH-	NpO2(OH)2-	0.00000	0.00000	0.00000
OH-	NpO2CO3-	0.00000	0.00000	0.00000
OH-	NpO2(CO3)2=-	0.00000	0.00000	0.00000
OH-	NpO2(CO3)3==-	0.00000	0.00000	0.00000
OH-	H2PO4-	0.00000	0.00000	0.00000
OH-	HPO4=	0.00000	0.00000	0.00000
OH-	PO4=-	0.00000	0.00000	0.00000
HCO3-	CO3=	0.00000	0.00000	0.00000
HCO3-	B(OH)4-	0.00000	0.00000	0.00000
HCO3-	B3O3(OH)4-	0.00000	0.00000	0.00000
HCO3-	B4O5(OH)4=	0.00000	0.00000	0.00000
HCO3-	Br-	0.00000	0.00000	0.00000
HCO3-	Am(CO3)2-	0.00000	0.00000	0.00000
HCO3-	Am(CO3)3=-	0.00000	0.00000	0.00000
HCO3-	ClO4-	0.00000	0.00000	0.00000
HCO3-	NpO2(OH)2-	0.00000	0.00000	0.00000
HCO3-	NpO2CO3-	0.00000	0.00000	0.00000
HCO3-	NpO2(CO3)2=-	0.00000	0.00000	0.00000
HCO3-	NpO2(CO3)3==-	0.00000	0.00000	0.00000
HCO3-	H2PO4-	0.00000	0.00000	0.00000
HCO3-	HPO4=	0.00000	0.00000	0.00000
HCO3-	PO4=-	0.00000	0.00000	0.00000
CO3=	B(OH)4-	0.00000	0.00000	0.00000
CO3=	B3O3(OH)4-	0.00000	0.00000	0.00000
CO3=	B4O5(OH)4=	0.00000	0.00000	0.00000
CO3=	Br-	0.00000	0.00000	0.00000
CO3=	Am(CO3)2-	0.00000	0.00000	0.00000
CO3=	Am(CO3)3=-	0.00000	0.00000	0.00000
CO3=	ClO4-	0.00000	0.00000	0.00000
CO3=	NpO2(OH)2-	0.00000	0.00000	0.00000
CO3=	NpO2CO3-	0.00000	0.00000	0.00000
CO3=	NpO2(CO3)2=-	0.00000	0.00000	0.00000
CO3=	NpO2(CO3)3==-	0.00000	0.00000	0.00000
CO3=	H2PO4-	0.00000	0.00000	0.00000
CO3=	HPO4=	0.00000	0.00000	0.00000
CO3=	PO4=-	0.00000	0.00000	0.00000
B(OH)4-	B3O3(OH)4-	0.00000	0.00000	0.00000
B(OH)4-	B4O5(OH)4=	0.00000	0.00000	0.00000
B(OH)4-	Br-	0.00000	0.00000	0.00000
B(OH)4-	Am(CO3)2-	0.00000	0.00000	0.00000
B(OH)4-	Am(CO3)3=-	0.00000	0.00000	0.00000
B(OH)4-	ClO4-	0.00000	0.00000	0.00000
B(OH)4-	NpO2(OH)2-	0.00000	0.00000	0.00000
B(OH)4-	NpO2CO3-	0.00000	0.00000	0.00000
B(OH)4-	NpO2(CO3)2=-	0.00000	0.00000	0.00000
B(OH)4-	NpO2(CO3)3==-	0.00000	0.00000	0.00000
B(OH)4-	H2PO4-	0.00000	0.00000	0.00000
B(OH)4-	HPO4=	0.00000	0.00000	0.00000
B(OH)4-	PO4=-	0.00000	0.00000	0.00000
B3O3(OH)4-	B4O5(OH)4=	0.00000	0.00000	0.00000
B3O3(OH)4-	Br-	0.00000	0.00000	0.00000
B3O3(OH)4-	Am(CO3)2-	0.00000	0.00000	0.00000
B3O3(OH)4-	Am(CO3)3=-	0.00000	0.00000	0.00000
B3O3(OH)4-	ClO4-	0.00000	0.00000	0.00000

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

```
B3O3(OH)4-      NpO2(OH)2-      0.00000  0.00000  0.00000
B3O3(OH)4-      NpO2CO3-        0.00000  0.00000  0.00000
B3O3(OH)4-      NpO2(CO3)2=-    0.00000  0.00000  0.00000
B3O3(OH)4-      NpO2(CO3)3==-   0.00000  0.00000  0.00000
B3O3(OH)4-      H2PO4-          0.00000  0.00000  0.00000
B3O3(OH)4-      HPO4=           0.00000  0.00000  0.00000
B3O3(OH)4-      PO4=-           0.00000  0.00000  0.00000
B4O5(OH)4=      Br-             0.00000  0.00000  0.00000
B4O5(OH)4=      Am(CO3)2-       0.00000  0.00000  0.00000
B4O5(OH)4=      Am(CO3)3=-      0.00000  0.00000  0.00000
B4O5(OH)4=      ClO4-           0.00000  0.00000  0.00000
B4O5(OH)4=      NpO2(OH)2-      0.00000  0.00000  0.00000
B4O5(OH)4=      NpO2CO3-        0.00000  0.00000  0.00000
B4O5(OH)4=      NpO2(CO3)2=-    0.00000  0.00000  0.00000
B4O5(OH)4=      NpO2(CO3)3==-   0.00000  0.00000  0.00000
B4O5(OH)4=      H2PO4-          0.00000  0.00000  0.00000
B4O5(OH)4=      HPO4=           0.00000  0.00000  0.00000
B4O5(OH)4=      PO4=-           0.00000  0.00000  0.00000
Br-             Am(CO3)2-       0.00000  0.00000  0.00000
Br-             Am(CO3)3=-      0.00000  0.00000  0.00000
Br-             ClO4-           0.00000  0.00000  0.00000
Br-             NpO2(OH)2-      0.00000  0.00000  0.00000
Br-             NpO2CO3-        0.00000  0.00000  0.00000
Br-             NpO2(CO3)2=-    0.00000  0.00000  0.00000
Br-             NpO2(CO3)3==-   0.00000  0.00000  0.00000
Br-             H2PO4-          0.00000  0.00000  0.00000
Br-             HPO4=           0.00000  0.00000  0.00000
Br-             PO4=-           0.00000  0.00000  0.00000
Am(CO3)2-       Am(CO3)3=-      0.00000  0.00000  0.00000
Am(CO3)2-       ClO4-           0.00000  0.00000  0.00000
Am(CO3)2-       NpO2(OH)2-      0.00000  0.00000  0.00000
Am(CO3)2-       NpO2CO3-        0.00000  0.00000  0.00000
Am(CO3)2-       NpO2(CO3)2=-    0.00000  0.00000  0.00000
Am(CO3)2-       NpO2(CO3)3==-   0.00000  0.00000  0.00000
Am(CO3)2-       H2PO4-          0.00000  0.00000  0.00000
Am(CO3)2-       HPO4=           0.00000  0.00000  0.00000
Am(CO3)2-       PO4=-           0.00000  0.00000  0.00000
Am(CO3)3=-      ClO4-           0.00000  0.00000  0.00000
Am(CO3)3=-      NpO2(OH)2-      0.00000  0.00000  0.00000
Am(CO3)3=-      NpO2CO3-        0.00000  0.00000  0.00000
Am(CO3)3=-      NpO2(CO3)2=-    0.00000  0.00000  0.00000
Am(CO3)3=-      NpO2(CO3)3==-   0.00000  0.00000  0.00000
Am(CO3)3=-      H2PO4-          0.00000  0.00000  0.00000
Am(CO3)3=-      HPO4=           0.00000  0.00000  0.00000
Am(CO3)3=-      PO4=-           0.00000  0.00000  0.00000
ClO4-           NpO2(OH)2-      0.00000  0.00000  0.00000
ClO4-           NpO2CO3-        0.00000  0.00000  0.00000
ClO4-           NpO2(CO3)2=-    0.00000  0.00000  0.00000
ClO4-           NpO2(CO3)3==-   0.00000  0.00000  0.00000
ClO4-           H2PO4-          0.00000  0.00000  0.00000
ClO4-           HPO4=           0.00000  0.00000  0.00000
ClO4-           PO4=-           0.00000  0.00000  0.00000
NpO2(OH)2-      NpO2CO3-        0.00000  0.00000  0.00000
NpO2(OH)2-      NpO2(CO3)2=-    0.00000  0.00000  0.00000
NpO2(OH)2-      NpO2(CO3)3==-   0.00000  0.00000  0.00000
NpO2(OH)2-      H2PO4-          0.00000  0.00000  0.00000
NpO2(OH)2-      HPO4=           0.00000  0.00000  0.00000
NpO2(OH)2-      PO4=-           0.00000  0.00000  0.00000
NpO2CO3-        NpO2(CO3)2=-    0.00000  0.00000  0.00000
NpO2CO3-        NpO2(CO3)3==-   0.00000  0.00000  0.00000
NpO2CO3-        H2PO4-          0.00000  0.00000  0.00000
NpO2CO3-        HPO4=           0.00000  0.00000  0.00000
NpO2CO3-        PO4=-           0.00000  0.00000  0.00000
NpO2(CO3)2=-    NpO2(CO3)3==-   0.00000  0.00000  0.00000
NpO2(CO3)2=-    H2PO4-          0.00000  0.00000  0.00000
NpO2(CO3)2=-    HPO4=           0.00000  0.00000  0.00000
NpO2(CO3)2=-    PO4=-           0.00000  0.00000  0.00000
NpO2(CO3)3==-   H2PO4-          0.00000  0.00000  0.00000
NpO2(CO3)3==-   HPO4=           0.00000  0.00000  0.00000
NpO2(CO3)3==-   PO4=-           0.00000  0.00000  0.00000
H2PO4-          HPO4=           0.00000  0.00000  0.00000
H2PO4-          PO4=-           0.00000  0.00000  0.00000
HPO4=           PO4=-           0.00000  0.00000  0.00000

Neutral-Cation Binary Interactions:  lambda(n,c)

                CO2(aq)   CaCO3(aq)  MgCO3(aq)  B(OH)3(aq)  NpO2OH(aq)  H3PO4(aq)
Na+             0.10000   0.00000    0.00000    -0.09700    0.00000     0.00000
K+              0.05100   0.00000    0.00000    -0.14000    0.00000    -0.07000
Ca++            0.18300   0.00000    0.00000     0.00000    0.00000     0.00000
Mg++            0.18300   0.00000    0.00000     0.00000    0.00000     0.00000
MgOH+           0.00000   0.00000    0.00000     0.00000    0.00000     0.00000
H+              0.00000   0.00000    0.00000     0.00000    0.00000     0.29000
MgB(OH)4+       0.00000   0.00000    0.00000     0.00000    0.00000     0.00000
CaB(OH)4+       0.00000   0.00000    0.00000     0.00000    0.00000     0.00000
Am+++           0.00000   0.00000    0.00000     0.00000    0.00000     0.00000
AmCO3+          0.00000   0.00000    0.00000     0.00000    0.00000     0.00000
Th++++          0.00000   0.00000    0.00000     0.00000    0.00000     0.00000
UO2++           0.00000   0.00000    0.00000     0.00000    0.00000     0.00000
NpO2+           0.00000   0.00000    0.00000     0.00000    0.00000     0.00000
```

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

Neutral- Anion Binary Interactions: lambda(n,a)

	CO2(aq)	CaCO3(aq)	MgCO3(aq)	B(OH)3(aq)	NpO2OH(aq)	H3PO4(aq)
Cl-	-0.00500	0.00000	0.00000	0.09100	0.00000	0.00000
SO4=	0.09700	0.00000	0.00000	0.01800	0.00000	0.00000
HSO4-	-0.00300	0.00000	0.00000	0.00000	0.00000	0.00000
OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B3O3(OH)4-	0.00000	0.00000	0.00000	-0.20000	0.00000	0.00000
B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	-0.40000
HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Neutral-Cation-Anion Ternary Interactions: zeta(n,c,a)

		CO2(aq)	CaCO3(aq)	MgCO3(aq)	B(OH)3(aq	NpO2OH(aq	H3PO4(aq)
Na+	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	SO4=	0.00000	0.00000	0.00000	0.04600	0.00000	0.00000
Na+	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Na+	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
K+	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ca++	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

[illegible]	Mg++	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Mg++	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgOH+	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	Cl-	0.00000	0.00000	0.00000	-0.01020	0.00000	0.00000
[illegible]	H+	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	H+	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	MgB(OH)4+	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

[illegible]	CaB(OH)4+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	CaB(OH)4+	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Am+++	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	AmCO3+	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	Th++++	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	Cl-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	SO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	HSO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	OH-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	HCO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	CO3=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	B(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	B3O3(OH)4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	B4O5(OH)4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	Br-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	Am(CO3)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	Am(CO3)3=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	ClO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	NpO2(OH)2-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	NpO2CO3-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	NpO2(CO3)2=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	NpO2(CO3)3==-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	H2PO4-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	HPO4=	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
[illegible]	UO2++	PO4=-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

```
NpO2+          Cl-            0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          SO4=           0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          HSO4-          0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          OH-            0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          HCO3-          0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          CO3=           0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          B(OH)4-        0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          B3O3(OH)4-     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          B4O5(OH)4=     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          Br-            0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          Am(CO3)2-      0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          Am(CO3)3=-     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          ClO4-          0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          NpO2(OH)2-     0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          NpO2CO3-       0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          NpO2(CO3)2=-   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          NpO2(CO3)3=-   0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          H2PO4-         0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          HPO4=          0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
NpO2+          PO4=-          0.00000  0.00000  0.00000  0.00000  0.00000  0.00000
using PITZER ACTIVITY COEFFICIENT model
Charge Balance replaces element Oxygen


this is a BATCH problem


Ideal Gas Constant is Unity (Dimensionless)
Temperature =       298.15 [=] degree Kelvin


 115 Species                        23 Elements

          Element Name        Molecular Weight
          Hydrogen                 1.00790
          Oxygen                  15.99940
          Sodium                  22.98977
          Potassium               39.09830
          Magnesium               24.30500
          Calcium                 40.08000
          Chlorine                35.45300
          Sulfur                  32.06000
          Carbon                  12.01100
          PosIon                   0.00000
          NegIon                   0.00000
          Air                     28.84000
          Boron                   10.81000
          Bromine                 79.90400
          TracerEl                 0.00000
          Th(IV)                 232.03810
          Am(III)                243.00000
          U(VI)                  238.02900
          Np(V)                  237.04820
          ClO4-(EL)               99.45060
          Phosphorus              30.97400
          Electron                 0.00000
          Charge                   0.00000


   Species Name                          Phase        Mol.Wt.    Std Chemical Potential, u/RT
 1 H2O                          WATER    aqueous      18.015      -95.663
 2 Na+                            Na+    aqueous      22.990     -105.651
 3 K+                              K+    aqueous      39.098     -113.957
 4 Ca++                          Ca++    aqueous      40.080     -223.300
 5 Mg++                          Mg++    aqueous      24.305     -183.468
 6 MgOH+                        MgOH+    aqueous      41.312     -251.940
 7 H+                              H+    aqueous       1.008        0.000
 8 Cl-                            Cl-    aqueous      35.453      -52.955
 9 SO4=                          SO4=    aqueous      96.058     -300.386
10 HSO4-                        HSO4-    aqueous      97.066     -304.942
11 OH-                           OH-     aqueous      17.007      -63.435
12 HCO3-                        HCO3-    aqueous      61.017     -236.751
13 CO3=                          CO3=    aqueous      60.009     -212.944
14 CO2(aq)                    CO2(aq)    aqueous      44.010     -155.680
15 CaCO3(aq)                CaCO3(aq)    aqueous     100.089     -443.500
16 MgCO3(aq)                MgCO3(aq)    aqueous      84.314     -403.155
17 B(OH)3(aq)               B(OH)3(aq)   aqueous      61.832     -390.810
18 B(OH)4-                    B(OH)4-    aqueous      78.839     -465.200
19 B3O3(OH)4-               B3O3(OH)4-   aqueous     148.457     -963.770
20 B4O5(OH)4=               B4O5(OH)4=   aqueous     191.266    -1239.100
21 CaB(OH)4+                CaB(OH)4+    aqueous     118.919     -692.300
22 MgB(OH)4+                MgB(OH)4+    aqueous     103.144     -651.890
23 Br-                            Br-    aqueous      79.904     -999.990
24 ClO4-             perchlorate ClO4-   aqueous      99.451     -999.990
25 NaOH(aq).......to.titrate.base.only    aqueous      39.997      500.000
26 HCl(aq)........to.titrate.acid.only    aqueous      36.461      500.000
27 HClO4(aq)......to.titrate.acid.only    aqueous     100.459      500.000
28 PosIon................POSITIVE.ION    aqueous       0.000        0.000
29 NegIon................NEGATIVE.ION    aqueous       0.000        0.000
30 PosIon(OH)(aq).....to.titrate.base     aqueous      17.007      500.000
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Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

31	HNegIon(aq).....to.titrate.acid		aqueous	1.008	500.000
32	Tracer(aq).....conservative.tracer		aqueous	0.000	0.000
33	H3PO4(aq)	H3PO4(aq)	aqueous	97.995	-460.900
34	H2PO4-	H2PO4-	aqueous	96.987	-455.960
35	HPO4=	HPO4=	aqueous	95.980	-439.367
36	PO4=-	PO4=-	aqueous	94.972	-410.947
37	NpO2+	NpO2+	aqueous	269.047	-369.127
38	NpO2OH(aq)	NpO2OH(aq)	aqueous	286.054	-438.518
39	NpO2(OH)2-	NpO2(OH)2-	aqueous	303.062	-505.829
40	NpO2CO3-	NpO2CO3-	aqueous	329.056	-594.492
41	NpO2(CO3)2=-	NpO2(CO3)2=-	aqueous	389.065	-808.403
42	NpO2(CO3)3==-	NpO2(CO3)3==-	aqueous	449.075	-1019.918
43	Am+++	Am+++	aqueous	243.000	-241.694
44	AmCO3+	AmCO3+	aqueous	303.009	-472.060
45	Am(CO3)2-	Am(CO3)2-	aqueous	363.018	-695.880
46	Am(CO3)3=-	Am(CO3)3=-	aqueous	423.028	-915.460
47	Am(OH)2+	Am(OH)2+	aqueous	277.015	-393.647
48	Am(OH)3(aq)	Am(OH)3(aq)	aqueous	294.022	-462.950
49	Th++++	Th++++	aqueous	232.038	-999.990
50	UO2++	U(VI)O2++	aqueous	270.028	-999.990
51	NpO2OH(aged)	NpO2OH(aged)	solid	286.054	-454.010
52	NpO2OH(amor)	NpO2OH(amor)	solid	286.054	-452.642
53	NaNpO2CO3(s)	NaNpO2CO3(s)	solid	352.046	-713.707
54	Na3NpO2(CO3)2(s)	DISABLED_DISABLED	solid	458.035	999.990
55	AmOHCO3(c)	AmOHCO3(c)	solid	320.017	-569.980
56	Am(OH)3(s)	Am(OH)3(s)	solid	294.022	-492.294
57	NaAm(CO3)2.6H2O(c)		solid	494.099	-1396.494
58	AmPO4(c)	AmPO4(c)	solid	337.972	-709.750
59	CaSO4	Anhydrite	solid	136.138	-533.730
60	NaK3(SO4)2	Aphthitalite/Glaserite	solid	332.400	-1057.050
61	CaCl2.6H2O	Antarcticite	solid	219.077	-893.650
62	CaCO3	Aragonite	solid	100.089	-455.170
63	K2SO4	Arcanite	solid	174.254	-532.390
64	MgCl2.6H2O	Bischofite	solid	203.302	-853.100
65	Na2Mg(SO4)2.4H2O	Bloedite	solid	334.461	-1383.600
66	Mg(OH)2	Brucite	solid	58.320	-335.400
67	Na6CO3(SO4)2	Burkeite	solid	390.063	-1449.400
68	CaCO3	Calcite	solid	100.089	-455.600
69	CaCl2.4H2O	CaCl2_Tetrahydrite	solid	183.047	-698.700
70	Ca4Cl2(OH)6.13H2O	CaOxychloride A	solid	567.467	-2658.450
71	Ca2Cl2(OH)2.H2O	CaOxychloride B	solid	203.096	-778.410
72	KMgCl3.6H2O	Carnallite	solid	277.854	-1020.300
73	MgSO4.7H2O	Epsomite	solid	246.469	-1157.830
74	CaNa2(CO3)2.5H2O	Gaylussite	solid	296.154	-1360.500
75	Na2Ca(SO4)2	Glauberite	solid	278.175	-1047.450
76	CaSO4.2H2O	Gypsum	solid	172.168	-725.560
77	NaCl	Halite	solid	58.443	-154.990
78	MgSO4.6H2O	Hexahydrite	solid	228.454	-1061.600
79	KMgClSO4.3H2O	Kainite	solid	248.960	-938.200
80	KHCO3	Kalicinite	solid	100.115	-350.060
81	MgSO4.H2O	Kieserite	solid	138.378	-579.800
82	K2Mg(SO4)2.4H2O	Leonite	solid	366.678	-1403.970
83	Na4Ca(SO4)3.2H2O	Labile_Salt	solid	456.242	-1751.450
84	MgCO3	Magnesite	solid	84.314	-414.450
85	Mg2Cl(OH)3.4H2O	MgOxychloride	solid	207.146	-1029.600
86	KHSO4	Mercallite	solid	136.164	-417.570
87	Na2SO4.10H2O	Mirabilite	solid	322.189	-1471.150
88	K8H6(SO4)7	Misenite	solid	991.237	-3039.240
89	NaHCO3	Nahcolite	solid	84.007	-343.330
90	Na2CO3.10H2O	Natron	solid	286.141	-1382.780
91	MgCO3.3H2O	Nesquehonite	solid	138.360	-695.300
92	K2Mg(SO4)2.6H2O	Picromerite/Schoen	solid	402.708	-1596.100
93	Na2Ca(CO3)2.2H2O	Pirssonite	solid	242.108	-1073.100
94	K2MgCa2(SO4)4.2H2O	Polyhalite	solid	602.922	-2282.500
95	Ca(OH)2	Portlandite	solid	74.095	-362.120
96	K2CO3.3/2H2O	Potassium_Carbonate	solid	165.229	-577.370
97	K8H4(CO3)6.3H2O	K-Sequicarbonate	solid	730.919	-2555.400
98	KNaCO3.6H2O	K-Na-Carbonate	solid	230.188	-1006.800
99	K2NaH(CO3)2.2H2O	Potassium_Trona	solid	258.243	-971.740
100	K3H(SO4)2	Sesquipotassium_Sulfate	solid	310.418	-950.800
101	Na3H(SO4)2	Sesquisodium_Sulfate	solid	262.092	-919.600
102	Na2CO3.7H2O	Na2CO3-Heptahydrate	solid	232.095	-1094.950
103	KCl	Sylvite	solid	74.551	-164.840
104	K2Ca(SO4)2.H2O	Syngenite	solid	328.407	-1164.800
105	Mg2CaCl6.12H2O	Tachyhydrite	solid	517.590	-2015.900
106	Na2SO4	Thenardite	solid	142.037	-512.350
107	Na2CO3.H2O	Thermonatrite	solid	124.004	-518.800
108	Na3H(CO3)2.2H2O	Trona	solid	226.026	-960.380
109	Na2B4O7.10H2O	Borax	solid	381.367	-2224.160
110	B(OH)3	Borix_Acid_Solid	solid	61.832	-390.880
111	KB5O8.4H2O	K-Pentaborate_(30_C)	solid	293.204	-1770.260
112	K2B4O7.4H2O	K-Tetraborate_(30_C)	solid	305.493	-1663.470
113	NaBO2.4H2O	Sodium_Metaborate	solid	137.859	-761.420
114	NaB5O8.5H2O	Sodium_Pentaborate	solid	295.111	-1854.800
115	NaBO2.NaCl.2H2O	Teepleite_(20_C)	solid	160.272	-725.770

	Truncated Name	Formula Matrix																					
1	H2O	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Na+	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

3	K+	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	Ca++	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
5	Mg++	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
6	MgOH+	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7	H+	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
8	Cl-	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
9	SO4=	0	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2
10	HSO4-	1	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
11	OH-	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
12	HCO3-	1	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
13	CO3=	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	-2
14	CO2(aq)	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	CaCO3(aq)	0	3	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	MgCO3(aq)	0	3	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	B(OH)3(aq)	3	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
18	B(OH)4-	4	4	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	-1
19	B3O3(OH)4-	4	7	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	-1
20	B4O5(OH)4=	4	9	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	-2
21	CaB(OH)4+	4	4	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
22	MgB(OH)4+	4	4	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
23	Br-	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	-1
24	ClO4- pe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	-1
25	NaOH(aq).....to.ti	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	HCl(aq).....to.ti	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	HClO4(aq).....to.ti	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
28	PosIon.....	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
29	NegIon.....	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	-1
30	PosIon(OH)(aq).....	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
31	HNegIon(aq).....	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
32	Tracer(aq).....cons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
33	H3PO4(aq)	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
34	H2PO4-	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1
35	HPO4=	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-2
36	PO4=-	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-3
37	NpO2+	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
38	NpO2OH(aq)	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
39	NpO2(OH)2-	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	-1
40	NpO2CO3-	0	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	-1
41	NpO2(CO3)2=-	0	8	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	-3
42	NpO2(CO3)3==-	0	11	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	-5
43	Am+++	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3
44	AmCO3+	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1
45	Am(CO3)2-	0	6	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	-1
46	Am(CO3)3=-	0	9	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	-3
47	Am(OH)2+	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
48	Am(OH)3(aq)	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
49	Th++++	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4
50	UO2++	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
51	NpO2OH(aged)_____	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
52	NpO2OH(amor)_____	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
53	NaNpO2CO3(s)_____	0	5	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
54	Na3NpO2(CO3)2(s)_DI	0	8	3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0
55	AmOHCO3(c)_____	1	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
56	Am(OH)3(s)_____	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
57	NaAm(CO3)2.6H2O(c)_	12	12	1	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0
58	AmPO4(c)_____	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
59	CaSO4_____	0	4	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	NaK3(SO4)2__Aphthit	0	8	1	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	CaCl2.6H2O_____	12	6	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	CaCO3_____	0	3	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	K2SO4_____	0	4	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	MgCl2.6H2O_____	12	6	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	Na2Mg(SO4)2.4H2O___	8	12	2	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	Mg(OH)2_____	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	Na6CO3(SO4)2_____	0	11	6	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	CaCO3_____	0	3	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	CaCl2.4H2O_____CaC	8	4	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	Ca4Cl2(OH)6.13H2O__	32	19	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	Ca2Cl2(OH)2.H2O____	4	3	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	KMgCl3.6H2O_____	12	6	0	1	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	MgSO4.7H2O_____	14	11	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	CaNa2(CO3)2.5H2O___	10	11	2	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	Na2Ca(SO4)2_____	0	8	2	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	CaSO4.2H2O_____	4	6	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	NaCl_____	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	MgSO4.6H2O_____	12	10	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	KMgClSO4.3H2O_____	6	7	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	KHCO3_____	1	3	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	MgSO4.H2O_____	2	5	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	K2Mg(SO4)2.4H2O____	8	12	0	2	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	Na4Ca(SO4)3.2H2O___	4	14	4	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	MgCO3_____	0	3	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	Mg2Cl(OH)3.4H2O____	11	7	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86	KHSO4_____	1	4	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
87	Na2SO4.10H2O_____	20	14	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	K8H6(SO4)7_____	6	28	0	8	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	NaHCO3_____	1	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	Na2CO3.10H2O_____	20	13	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
91	MgCO3.3H2O_____	6	6	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	K2Mg(SO4)2.6H2O Pic	12	14	0	2	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix J: OUTPUT File Listing of HMW_NP_AM.CHEMDAT

93	Na2Ca(CO3)2.2H2O___	4	8	2	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	K2MgCa2(SO4)4.2H2O_	4	18	0	2	1	2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	Ca(OH)2_____	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	K2CO3.3/2H2O___Pota	3	4	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	K8H4(CO3)6.3H2O___K	10	21	0	8	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
98	KNaCO3.6H2O_____	12	9	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99	K2NaH(CO3)2.2H2O___	5	8	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	K3H(SO4)2__Sesquipo	1	8	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
101	Na3H(SO4)2____Sesqu	1	8	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102	Na2CO3.7H2O____Na2C	14	10	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
103	KCl_____	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
104	K2Ca(SO4)2.H2O_____	2	9	0	2	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
105	Mg2CaCl6.12H2O_____	24	12	0	0	2	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
106	Na2SO4_____	0	4	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107	Na2CO3.H2O_____	2	4	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
108	Na3H(CO3)2.2H2O____	5	8	3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
109	Na2B4O7.10H2O_____	20	17	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
110	B(OH)3_____B	3	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
111	KB5O8.4H2O____K-Pen	8	12	0	1	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
112	K2B4O7.4H2O___K-Tet	8	11	0	2	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
113	NaBO2.4H2O_____So	8	6	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
114	NaB5O8.5H2O_____Sod	10	13	1	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
115	NaBO2.NaCl.2H2O___T	4	4	2	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

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Appendix K: Listing of HMW_NP_AM.RHOMIN and References Cited in Listing

K.1 Listing

See Table 25 for explanation of this listing.

```
     2.d3   'Np(V)O2OH(aged)....Np(V)O2OH(aged)'
     2.d3   'Np(V)O2OH(amor)....Np(V)O2OH(amor)'
     2.d3   'NaNp(V)O2CO3(s)....NaNp(V)O2CO3(s)'
     2.d3   'NaNpO2CO3Na2CO3(s)Na3NpO2(CO3)2(s)'
     2.d3    AmOHCO3(c)
     2.d3    Am(OH)3(s)
     2.d3    NaAm(CO3)2.6H2O(c)
     2.d3    AmPO4(c)

  2980.d0   CaSO4                      Anhydrite  CRC p.B-181:185
     2.d3   NaK3(SO4)2  Aphthitalite/Glaserite
     2.d3   CaCl2.6H2O              Antarcticite
  2940.d0   CaCO3                       Aragonite  CRC p.B-181:185
  2663.d0   K2SO4                        Arcanite  CRC p.B-181:185
     2.d3   MgCl2.6H2O               Bischofite
  2250.d0   Na2Mg(SO4)2.4H2O           Bloedite  CRC p.B-181:185
  2390.d0   Mg(OH)2                     Brucite  CRC p.B-181:185
     2.d3   Na6CO3(SO4)2               Burkeite
  2828.d0   CaCO3                       Calcite  CRC p.B-181:185
     2.d3   CaCl2.4H2O       CaCl2 Tetrahydrite
     2.d3   Ca4Cl2(OH)6.13H2O  CaOxychloride A
     2.d3   Ca2Cl2(OH)2.H2O    CaOxychloride B
  1602.d0   KMgCl3.6H2O              Carnallite  CRC p.B-181:185
  1677.d0   MgSO4.7H2O                 Epsomite  CRC p.B-181:185
  1991.d0   CaNa2(CO3)2.5H2O         Gaylussite  CRC p.B-181:185
  2800.d0   Na2Ca(SO4)2              Glauberite  CRC p.B-181:185
  2335.d0   CaSO4.2H2O                    Gypsum  CRC p.B-181:185
  2165.d0   NaCl                         Halite  CRC p.B-181:185
     2.d3   MgSO4.6H2O              Hexahydrite
  2150.d0   KMgClSO4.3H2O               Kainite  CRC p.B-181:185
     2.d3   KHCO3                    Kalicinite
  2571.d0   MgSO4.H2O                 Kieserite  CRC p.B-181:185
     2.d3   K2Mg(SO4)2.4H2O              Leonite
     2.d3   Na4Ca(SO4)3.2H2O        Labile Salt
  3210.d0   MgCO3                     Magnesite  CRC p.B-181:185
     2.d3   Mg2Cl(OH)3.4H2O       MgOxychloride
     2.d3   KHSO4                    Mercallite
  1490.d0   Na2SO4.10H2O             Mirabilite  CRC p.B-181:185
     2.d3   K8H6(SO4)7                 Misenite
     2.d3   NaHCO3                   Nahcolite
     2.d3   Na2CO3.10H2O                 Natron
     2.d3   MgCO3.3H2O             Nesquehonite
     2.d3   K2Mg(SO4)2.6H2O Picromerite/Schoen
     2.d3   Na2Ca(CO3)2.2H2O         Pirssonite
     2.d3   K2MgCa2(SO4)4.2H2O       Polyhalite
     2.d3   Ca(OH)2                  Portlandite
     2.d3   K2CO3.3/2H2O   Potassium Carbonate
     2.d3   K8H4(CO3)6.3H2O   K-Sequicarbonate
     2.d3   KNaCO3.6H2O          K-Na-Carbonate
     2.d3   K2NaH(CO3)2.2H2O   Potassium Trona
     2.d3   K3H(SO4)2  Sesquipotassium Sulfate
     2.d3   Na3H(SO4)2    Sesquisodium Sulfate
     2.d3   Na2CO3.7H2O    Na2CO3-Heptahydrate
  1990.d0   KCl                         Sylvite  CRC p.B-181:185
     2.d3   K2Ca(SO4)2.H2O            Syngenite
     2.d3   Mg2CaCl6.12H2O         Tachyhydrite
     2.d3   Na2SO4                   Thenardite
  2255.d0   Na2CO3.H2O            Thermonatrite  CRC p.B-181:185
  2140.d0   Na3H(CO3)2.2H2O               Trona  CRC p.B-181:185
  1715.d0   Na2B4O7.10H2O                 Borax  CRC p.B-181:185
     2.d3   B(OH)3             Borix Acid Solid
     2.d3   KB5O8.4H2O    K-Pentaborate (30 C)
     2.d3   K2B4O7.4H2O   K-Tetraborate (30 C)
     2.d3   NaBO2.4H2O       Sodium Metaborate
     2.d3   NaB5O8.5H2O     Sodium Pentaborate
     2.d3   NaBO2.NaCl.2H2O   Teepleite (20 C)
```

K.2 References Cited in Listing

Novak, C.F. 1994. "Development of the FMT Chemical Transport Simulator: Coupling Aqueous Density and Mineral Volume Fraction to Phase Composition." *Proceedings of the*

Fourth International Conference on the Chemistry and Migration Behaviour of Actinides and Fission Products in the Geosphere . Special Issue of Radiochimica Acta. R. Oldenbourg Verlag: München, Germany.

Weast, R.C. 1980. *CRC Handbook of Chemistry and Physics* 60th ed. Chemical Rubber Publishing Company, Boca Raton, Florida.

Appendix L: Output File Listing of HMW_NP_AM.RHOMIN

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MINERAL DENSITIES, KG/M^3, IN FILE 'RHOMIN'

NpO2OH(aged)__________NpO2OH(aged)     2000.00000000000
NpO2OH(amor)__________NpO2OH(amor)     2000.00000000000
NaNpO2CO3(s)__________NaNpO2CO3(s)     2000.00000000000
Na3NpO2(CO3)2(s)_DISABLED_DISABLED     2000.00000000000
AmOHCO3(c)____________AmOHCO3(c)       2000.00000000000
Am(OH)3(s)____________Am(OH)3(s)       2000.00000000000
NaAm(CO3)2.6H2O(c)____________         2000.00000000000
AmPO4(c)______________AmPO4(c)         2000.00000000000
CaSO4_________________Anhydrite        2980.00000000000
NaK3(SO4)2__Aphthitalite/Glaserite     2000.00000000000
CaCl2.6H2O____________Antarcticite     2000.00000000000
CaCO3_________________Aragonite        2940.00000000000
K2SO4_________________Arcanite         2663.00000000000
MgCl2.6H2O____________Bischofite       2000.00000000000
Na2Mg(SO4)2.4H2O______Bloedite         2250.00000000000
Mg(OH)2_______________Brucite          2390.00000000000
Na6CO3(SO4)2__________Burkeite         2000.00000000000
CaCO3_________________Calcite          2828.00000000000
CaCl2.4H2O_____CaCl2_Tetrahydrite      2000.00000000000
Ca4Cl2(OH)6.13H2O__CaOxychloride A     2000.00000000000
Ca2Cl2(OH)2.H2O____CaOxychloride B     2000.00000000000
KMgCl3.6H2O___________Carnallite       1602.00000000000
MgSO4.7H2O____________Epsomite         1677.00000000000
CaNa2(CO3)2.5H2O______Gaylussite       1991.00000000000
Na2Ca(SO4)2___________Glauberite       2800.00000000000
CaSO4.2H2O____________Gypsum           2335.00000000000
NaCl__________________Halite           2165.00000000000
MgSO4.6H2O____________Hexahydrite      2000.00000000000
KMgClSO4.3H2O_________Kainite          2150.00000000000
KHCO3_________________Kalicinite       2000.00000000000
MgSO4.H2O_____________ Kieserite       2571.00000000000
K2Mg(SO4)2.4H2O_______Leonite          2000.00000000000
Na4Ca(SO4)3.2H2O______Labile_Salt      2000.00000000000
MgCO3_________________Magnesite        3210.00000000000
Mg2Cl(OH)3.4H2O_____MgOxychloride      2000.00000000000
KHSO4_________________Mercallite       2000.00000000000
Na2SO4.10H2O__________Mirabilite       1490.00000000000
K8H6(SO4)7____________Misenite         2000.00000000000
NaHCO3________________Nahcolite        2000.00000000000
Na2CO3.10H2O__________Natron           2000.00000000000
MgCO3.3H2O____________Nesquehonite     2000.00000000000
K2Mg(SO4)2.6H2O Picromerite/Schoen     2000.00000000000
Na2Ca(CO3)2.2H2O______Pirssonite       2000.00000000000
K2MgCa2(SO4)4.2H2O____Polyhalite       2000.00000000000
Ca(OH)2_______________Portlandite      2000.00000000000
K2CO3.3/2H2O___Potassium_Carbonate     2000.00000000000
K8H4(CO3)6.3H2O___K-Sequicarbonate     2000.00000000000
KNaCO3.6H2O_____K-Na-Carbonate         2000.00000000000
K2NaH(CO3)2.2H2O___Potassium_Trona     2000.00000000000
K3H(SO4)2__Sesquipotassium_Sulfate     2000.00000000000
Na3H(SO4)2____Sesquisodium_Sulfate     2000.00000000000
Na2CO3.7H2O____Na2CO3-Heptahydrate     2000.00000000000
KCl___________________Sylvite          1990.00000000000
K2Ca(SO4)2.H2O_________Syngenite       2000.00000000000
Mg2CaCl6.12H2O_____Tachyhydrite        2000.00000000000
Na2SO4________________Thenardite       2000.00000000000
Na2CO3.H2O_________Thermonatrite       2255.00000000000
Na3H(CO3)2.2H2O_______________Trona    2140.00000000000
Na2B4O7.10H2O_________________ Borax   1715.00000000000
B(OH)3_____________Borix_Acid_Solid    2000.00000000000
KB5O8.4H2O____K-Pentaborate_(30_C)     2000.00000000000
K2B4O7.4H2O___K-Tetraborate_(30_C)     2000.00000000000
NaBO2.4H2O_____Sodium_Metaborate       2000.00000000000
NaB5O8.5H2O_____Sodium_Pentaborate     2000.00000000000
NaBO2.NaCl.2H2O___Teepleite_(20_C)     2000.00000000000
```

Appendix M: Sample Output File "BATCH_DOC.OUT"

See Table 26 for explanation of this listing.

```
INPUT    file name is U1:[SCBABB.FMT.USERGUIDE]BATCH_DOC.IN;1
INGUESS  file name is U1:[SCBABB.FMT.USERGUIDE]BATCH_DOC.INGUESS;1
OUTPUT   file name is U1:[SCBABB.FMT.USERGUIDE]BATCH_DOC.OUT;1
CHEMDAT  file name is U1:[SCBABB.FMT.USERGUIDE]FMT_HMW_NP_AM.CHEMDAT;1
Temperature is Hard Coded as 298.15K
[.FD.TITRATE]BATCH_DOC.in; to illustrate/document "BATCH" runs                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

*****************************************************************************************************************
*** ECHO PRINT OF "CHEMDAT" FILE WOULD BE HERE ***
***              SEE APPENDIX J                 ***
*****************************************************************************************************************


************SOLUBILITY PRODUCT VIOLATION*************
** Mg(OH)2____________________Brucite **  1.00E+01 **

************SOLUBILITY PRODUCT VIOLATION*************
** Mg2Cl(OH)3.4H2O_____MgOxychloride **  6.69E+00 **

          2 Solubility Product Violations
Adding solid Mg(OH)2____________________Brucite
# inversions for batch pblm            85
1[.FD.TITRATE]BATCH_DOC.in; to illustrate/document "BATCH" runs               FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

Using NaCl Density Correlation
  1.10222364E+02   1.11116160E+02   1.10794086E+02   1.11669359E+05  Hydrogen
  5.51654821E+01   5.56118135E+01   5.54506206E+01   8.87176659E+05  Oxygen
  2.00000000E-01   2.01625464E-01   2.01041045E-01   4.62188739E+03  Sodium
  1.00000000E-02   1.00812732E-02   1.00520523E-02   3.93018155E+02  Potassium
  1.00000000E-03   4.64673729E-08   4.63326856E-08   1.12611592E-03  Magnesium
  1.00000000E-04   1.00812732E-04   1.00520523E-04   4.02886254E+00  Calcium
  1.10000000E-01   1.10894005E-01   1.10572575E-01   3.92012950E+03  Chlorine
  1.00000000E-03   1.00812732E-03   1.00520523E-03   3.22268795E+01  Sulfur
  1.00000000E-04   1.00812732E-04   1.00520523E-04   1.20735200E+00  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  1.00000000E-07   1.00812732E-07   1.00520523E-07   1.08662685E-03  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
  4.90605392E-17   4.94592698E-17   4.93159103E-17   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     1002.59976105542      grams
    H2O MASS          991.938201296740      grams
    TDS(g/kg)         10.7482096613917      g/kgH2O

  Specified Solution Density
    DENSITY           1007.81851904202      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL     0.994821728428285      liters
    TDS               10.7170555829388      g/l

  Density based on TDS and NaCl solutions    1007.81851904202      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    9.92444E-01  9.93023E-01   1.001       5.50612E+01  5.53478E+01  9.97101E+05
Na+                            Na+    2.01625E-01  1.47085E-01  0.7295       2.00000E-01  2.01041E-01  4.62189E+03
```

Appendix M: Sample Output File "BATCH_DOC.OUT"

Cl-	Cl-	1.10894E-01	7.98916E-02	0.7204	1.10000E-01	1.10573E-01	3.92013E+03	
OH-	OH-	9.87965E-02	7.13753E-02	0.7224	9.80001E-02	9.85102E-02	1.67539E+03	
K+	K+	1.00813E-02	7.34149E-03	0.7282	1.00000E-02	1.00521E-02	3.93018E+02	
SO4=	SO4=	1.00813E-03	2.24998E-04	0.2232	1.00000E-03	1.00521E-03	9.65576E+01	
Mg(OH)2	Brucite	1.00808E-03	1.00000E+00	1.000	9.99954E-04	1.00516E-03	5.86205E+01	
Ca++	Ca++	1.00115E-04	2.00966E-05	0.2007	9.93083E-05	9.98252E-05	4.00099E+00	
CO3=	CO3=	1.00005E-04	2.44915E-05	0.2449	9.91991E-05	9.97155E-05	5.98385E+00	
B(OH)4-	B(OH)4-	1.00709E-07	6.61270E-08	0.6566	9.98971E-08	1.00417E-07	7.91680E-03	
CaCO3(aq)	CaCO3(aq)	6.97236E-07	6.97236E-07	1.000	6.92615E-07	6.95215E-07	6.95835E-02	1.36E-10
HCO3-	HCO3-	1.10094E-07	7.49923E-08	0.6812	1.09206E-07	1.09775E-07	6.69815E-03	1.60E-10
MgOH+	MgOH+	3.54268E-08	2.81647E-08	0.7950	3.51412E-08	3.53241E-08	1.45932E-03	-2.47E-07
Mg++	Mg++	1.09873E-08	2.56221E-09	0.2332	1.08988E-08	1.09555E-08	2.66273E-04	2.36E-10
CaB(OH)4+	CaB(OH)4+	8.72370E-11	5.94047E-11	0.6810	8.65337E-11	8.69841E-11	1.03441E-05	3.87E-11
MgCO3(aq)	MgCO3(aq)	5.32206E-11	5.32206E-11	1.000	5.27915E-11	5.30663E-11	4.47424E-06	3.15E-10
B(OH)3(aq)	B(OH)3(aq)	1.65411E-11	1.61858E-11	0.9785	1.64077E-11	1.64931E-11	1.01980E-06	1.62E-10
H+	H+	1.93212E-13	1.40201E-13	0.7256	1.91654E-13	1.92652E-13	1.94173E-10	1.36E-10
CO2(aq)	CO2(aq)	2.21142E-14	2.30277E-14	1.041	2.19360E-14	2.20501E-14	9.70422E-10	3.16E-10
MgB(OH)4+	MgB(OH)4+	6.18470E-15	4.24905E-15	0.6870	6.13484E-15	6.16677E-15	6.36066E-10	2.98E-10
HSO4-	HSO4-	4.06799E-15	3.00314E-15	0.7382	4.03519E-15	4.05620E-15	3.93717E-10	2.03E-10
Ca4Cl2(OH)6.13H2O	CaOxychloride A	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.27E+01
K8H6(SO4)7	Misenite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.09E+02
K2B4O7.4H2O	K-Tetraborate_(30_C)	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-3.56E+01
KB5O8.4H2O	K-Pentaborate_(30_C)	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-4.79E+01
B(OH)3	Borix_Acid_Solid	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.08E+01
Na2B4O7.10H2O	Borax	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-3.16E+01
Na3H(CO3)2.2H2O	Trona	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.32E+01
Na2CO3.H2O	Thermonatrite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-6.76E+00
Na2SO4	Thenardite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-5.03E+00
Mg2CaCl6.12H2O	Tachyhydrite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-4.59E+01
K2Ca(SO4)2.H2O	Syngenite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-8.82E+00
KCl	Sylvite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-4.13E+00
Na2CO3.7H2O	Na2CO3-Heptahydrate	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-5.84E+00
Na3H(SO4)2	Sesquisodium_Sulfate	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-2.18E+01
K3H(SO4)2	Sesquipotassium_Sulfate	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-2.30E+01
K2NaH(CO3)2.2H2O	Potassium_Trona	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.81E+01
KNaCO3.6H2O	K-Na-Carbonate	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-7.48E+00
K2CO3.3/2H2O	Potassium_Carbonate	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.19E+01
Ca(OH)2	Portlandite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.80E+00
K2MgCa2(SO4)4.2H2O	Polyhalite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-2.31E+01
Na2Ca(CO3)2.2H2O	Pirssonite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-6.35E+00
K2Mg(SO4)2.6H2O	Picromerite/Schoen	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.58E+01
MgCO3.3H2O	Nesquehonite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-8.04E+00
Na2CO3.10H2O	Natron	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-5.48E+00
NaHCO3	Nahcolite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-7.55E+00
NaBO2.4H2O	Sodium_Metaborate	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-8.35E+00
Na2SO4.10H2O	Mirabilite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-4.12E+00
KHSO4	Mercallite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.72E+01
Mg2Cl(OH)3.4H2O	MgOxychloride	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-5.77E+00
MgCO3	Magnesite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-5.37E+00
Na4Ca(SO4)3.2H2O	Labile_Salt	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.33E+01
K2Mg(SO4)2.4H2O	Leonite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.62E+01
MgSO4.H2O	Kieserite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.21E+01
KHCO3	Kalicinite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-9.54E+00
KMgClSO4.3H2O	Kainite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.53E+01
MgSO4.6H2O	Hexahydrite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.06E+01
NaCl	Halite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-3.50E+00
CaSO4.2H2O	Gypsum	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-3.77E+00
Na2Ca(SO4)2	Glauberite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-8.41E+00
CaNa2(CO3)2.5H2O	Gaylussite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-6.18E+00
MgSO4.7H2O	Epsomite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.04E+01
KMgCl3.6H2O	Carnallite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.84E+01
Ca2Cl2(OH)2.H2O	CaOxychloride B	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.24E+01
CaCl2.4H2O	CaCl2_Tetrahydrite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.26E+01
CaCO3	Calcite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-9.02E-01
Na6CO3(SO4)2	Burkeite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.61E+01
Na2Mg(SO4)2.4H2O	Bloedite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.52E+01
MgCl2.6H2O	Bischofite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.53E+01
K2SO4	Arcanite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-6.14E+00
CaCO3	Aragonite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.09E+00
CaCl2.6H2O	Antarcticite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.11E+01
NaK3(SO4)2	Aphthitalite/Glaserite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.07E+01
CaSO4	Anhydrite	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-3.98E+00
NaBO2.NaCl.2H2O	Teepleite_(20_C)	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-1.15E+01
NaB5O8.5H2O	Sodium_Pentaborate	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-4.78E+01
NaOH(aq).....to.titrate.base.only		0.00000E+00	0.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-2.93E+02
HCl(aq).....to.titrate.acid.only		0.00000E+00	0.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-2.54E+02
B4O5(OH)4=	B4O5(OH)4=	0.00000E+00	0.00000E+00	0.1519	0.00000E+00	0.00000E+00	0.00000E+00	-3.36E+01
K8H4(CO3)6.3H2O	K-Sequicarbonate	0.00000E+00	1.00000E+00	1.000	0.00000E+00	0.00000E+00	0.00000E+00	-6.18E+01
B3O3(OH)4-	B3O3(OH)4-	0.00000E+00	0.00000E+00	0.5412	0.00000E+00	0.00000E+00	0.00000E+00	-2.70E+01

pmH = -log[m(H+)] = 12.7140
pH = -log[a(H+)] = 12.8532
Osmotic Coefficient= 0.919612
Equilibrium RH (%) = 99.302313
Ionic Strength (m) = 0.213115
Density, kg/m3 = 1007.82

NOTES: - Water "molality" is mole fraction H2O in aqueous phase
- Gas "molality" and "activity" are gas partial pressures
- "Descriptor" means:

Appendix M: Sample Output File "BATCH_DOC.OUT"

```
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=     -5.30370149E+03

Total Diagonal Inversions          85
Total Stoichiometric Reoptimizations          10
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

See Table 27 for explanation of this listing.

```
INPUT    file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LOG.IN;1
INGUESS  file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LOG.INGUESS;1
OUTPUT   file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LOG.OUT;1
CHEMDAT  file name is U1:[SCBABB.FMT.USERGUIDE]FMT_HMW_NP_AM.CHEMDAT;1
Temperature is Hard Coded as 298.15K
Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

*****************************************************************************************************
*** ECHO PRINT OF "CHEMDAT" FILE WOULD BE HERE ***
***                SEE APPENDIX J                ***
*****************************************************************************************************


TITRATION Problem:
 -) Assigning all delta(y) to 0.1 m
 -) Setting # of nodes in Y-direction to 3
 -) Setting NONREACTIVE Porosity to 0.0



Specifying VARIABLE POROSITY for TITRATION Problem


Aqueous Density is a Function of Composition

RHOMIN   file name is U1:[SCBABB.FMT.USERGUIDE]FMT_HMW_NP_AM.RHOMIN;1

*****************************************************************************************************
*** TABLE OF MINERAL DENSITIES, KG/M^3 WOULD BE HERE ***
***                SEE APPENDIX L                ***
*****************************************************************************************************

GRID BLOCK VOLUMES, in liters
 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

# inversions for batch pblm          50
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles       Aq. Molality      Aq. Molarity      Aq. mg/liter

  1.11017363E+02    1.11029658E+02    1.00100314E+02    1.00891107E+05  Hydrogen
  6.15086815E+01    6.15154934E+01    5.54601388E+01    8.87328944E+05  Oxygen
  5.61000000E+00    5.61062129E+00    5.05833276E+00    1.16289907E+05  Sodium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Potassium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Magnesium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Calcium
  1.61000000E+00    1.61017830E+00    1.45167838E+00    5.14663538E+04  Chlorine
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Sulfur
  2.00000001E+00    2.00022150E+00    1.80332719E+00    2.16597629E+04  Carbon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  PosIon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  NegIon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Air
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Boron
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Bromine
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  TracerEl
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Th(IV)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Am(III)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  U(VI)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Np(V)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  ClO4-(EL)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Phosphorus
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Electron
 -2.22044605E-15   -2.22069196E-15   -2.00209536E-15    0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     1306.07033909890      grams
    H2O MASS          999.889265717486      grams
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
    TDS(g/kg)          306.214981877726      g/kgH2O

  Specified Solution Density
    DENSITY            1177.63607439302      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL       1.10906108219560      liters
    TDS                276.072326670473      g/l

  Density based on TDS and NaCl solutions    1177.63607439302      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    8.57464E-01  8.59843E-01   1.003       5.55025E+01  5.00446E+01  9.01564E+05
Na+                            Na+    5.61062E+00  3.69881E+00  0.6593       5.61000E+00  5.05833E+00  1.16290E+05
CO3=                          CO3=    1.99407E+00  4.09214E-02  2.0522E-02   1.99385E+00  1.79778E+00  1.07884E+05
Cl-                            Cl-    1.61018E+00  1.06477E+00  0.6613       1.61000E+00  1.45168E+00  5.14664E+04
HCO3-                        HCO3-    6.14734E-03  1.59044E-03  0.2587       6.14666E-03  5.54222E-03  3.38170E+02
OH-                            OH-    6.14733E-03  4.86901E-03  0.7921       6.14665E-03  5.54221E-03  9.42580E+01   2.00E-11
CO2(aq)                    CO2(aq)    2.36876E-09  7.15913E-09   3.022       2.36850E-09  2.13559E-09  9.39868E-05  -2.12E-07
H+                              H+    2.39954E-12  1.77959E-12  0.7416       2.39927E-12  2.16334E-12  2.18043E-09  -8.58E-08
Na3H(CO3)2.2H2O_____________Trona    0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -1.57E+00
HCl(aq).......to.titrate.acid.only    0.00000E+00  0.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -2.52E+02
NaOH(aq)......to.titrate.base.only    0.00000E+00  0.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -2.92E+02
NaCl_________________________Halite  0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -9.75E-01
NaHCO3_______________________Nahcolite 0.00000E+00 1.00000E+00  1.000       0.00000E+00  0.00000E+00  0.00000E+00  -1.83E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -2.51E-01
Na2CO3.H2O___________Thermonatrite    0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -7.99E-01
Na2CO3.10H2O_________________Natron   0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -8.30E-02

pmH = -log[m(H+)]                  =      11.6199
pH = -log[a(H+)]     =      11.7497
Osmotic Coefficient=     0.908418
Equilibrium RH (%) =    85.984284
Ionic Strength (m) =     7.604695
Density, kg/m3     =      1177.64

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=     -6.42133776E+03

Reaction #            1 sldsum    2.00000000000000
This is a solid-only reaction

shifting left by     4.64434654478256
calling makenuv for allomorphic reactions
# inversions for batch pblm          75
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/PW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles       Aq. Molality      Aq. Molarity      Aq. mg/liter

  1.11018363E+02    1.11017591E+02    9.93838868E+01    1.00169020E+05  Hydrogen
  1.05508682E+02    5.55113597E+01    4.96942389E+01    7.95078006E+05  Oxygen
  1.56100000E+01    5.61057382E+00    5.02263316E+00    1.15469181E+05  Sodium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Potassium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Magnesium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Calcium
  5.61100000E+00    5.61096098E+00    5.02297975E+00    1.78079701E+05  Chlorine
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Sulfur
  1.00000000E+01    6.12839261E-04    5.48618892E-04    6.58946152E+00  Carbon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  PosIon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  NegIon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Air
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Boron
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Bromine
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  TracerEl
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Th(IV)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Am(III)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  U(VI)
  1.00000000E+01    6.12839261E-04    5.48618892E-04    1.30049121E+02  Np(V)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  ClO4-(EL)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Phosphorus
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Electron
 -2.37316632E-15   -2.37314981E-15   -2.12446380E-15    0.00000000E+00  Charge
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
Solution Parameters, Calculated
  SOLUTION MASS     1328.11614865142      grams
  H2O MASS          1000.00695466819      grams
  TDS(g/kg)         328.106912108529      g/kgH2O

Specified Solution Density
  DENSITY           1188.93254605477      kg/m^3 = g/l

Solution Parameters Based on Specified Density
  SOLUTION VOL      1.11706602116201      liters
  TDS               293.724084134187      g/l

Density based on TDS and NaCl solutions    1188.93254605477      g/l
Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31822E-01   7.77959E-01   0.9352        5.55091E+01   4.96918E+01   8.95208E+05
NaNpO2CO3(s)_____NaNpO2CO3(s)         9.99932E+00   1.00000E+00   1.000         9.99939E+00   8.95147E+00   3.15133E+06
Cl-                            Cl-    5.61096E+00   5.29329E+00   0.9434        5.61100E+00   5.02298E+00   1.78080E+05
Na+                            Na+    5.61057E+00   5.29268E+00   0.9433        5.61061E+00   5.02263E+00   1.15469E+05
NpO2+                        NpO2+    6.12705E-04   1.21978E-03   1.991         6.12709E-04   5.48499E-04   1.47572E+02
CO2(aq)                    CO2(aq)    3.86103E-04   1.12115E-03   2.904         3.86106E-04   3.45643E-04   1.52117E+01
HCO3-                        HCO3-    2.26571E-04   8.38810E-05   0.3702        2.26573E-04   2.02829E-04   1.23760E+01   4.26E-09
NpO2CO3-                   NpO2CO3-   1.33526E-07   2.42971E-07   1.820         1.33527E-07   1.19534E-07   3.93334E-02  -1.99E-11
H+                             H+     1.21872E-06   4.78095E-06   3.923         1.21873E-06   1.09101E-06   1.09962E-03  -4.38E-08
CO3=                          CO3=    3.09384E-08   8.03342E-10   2.5966E-02    3.09386E-08   2.76963E-08   1.66203E-03  -1.62E-07
OH-                            OH-    3.01685E-09   1.63977E-09   0.5435        3.01687E-09   2.70071E-09   4.59318E-05   2.55E-08
NpO2OH(aq)                 NpO2OH(aq) 7.72186E-10   7.72186E-10   1.000         7.72191E-10   6.91267E-10   1.97740E-04   1.87E-07
NpO2(CO3)2=-             NpO2(CO3)2=- 1.98384E-11   5.13354E-16   2.5877E-05    1.98385E-11   1.77595E-11   6.90960E-06  -1.62E-07
NpO2(OH)2-                 NpO2(OH)2- 2.04382E-16   6.10703E-17   0.2988        2.04383E-16   1.82964E-16   5.54494E-11   2.13E-07
NpO2(CO3)3==-           NpO2(CO3)3==- 1.25197E-16   9.87896E-26   7.8908E-10    1.25198E-16   1.12077E-16   5.03310E-11  -3.23E-07
NpO2OH(aged)_____NpO2OH(aged)         0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.38E+00
NaOH(aq).......to.titrate.base.only   0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.99E+02
HCl(aq).......to.titrate.acid.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.45E+02
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -9.36E+02
NaCl_____________________Halite       0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -1.23E-01
NaHCO3_____________Nahcolite          0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.95E+00
Na2CO3.10H2O_____________Natron       0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -7.91E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -7.95E+00
Na2CO3.H2O___________Thermonatrite    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -8.24E+00
Na3H(CO3)2.2H2O_____________Trona     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -1.02E+01
NpO2OH(amor)_____NpO2OH(amor)         0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.98E+00

pmH = -log[m(H+)]                 =      5.9141
pH = -log[a(H+)]     =      5.3205
Osmotic Coefficient=     1.241871
Equilibrium RH (%) =    77.795863
Ionic Strength (m) =     5.611188
Density, kg/m3     =      1188.93

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -1.33323084E+04
Flashing Titration #          1
# inversions for batch pblm          11
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.85857174E+01   1.11017591E+02   9.93838868E+01   1.00169020E+05  Hydrogen
  3.66707638E+01   5.55113597E+01   4.96942389E+01   7.95078006E+05  Oxygen
  5.42543623E+00   5.61057382E+00   5.02263316E+00   1.15469181E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95016801E+00   5.61096098E+00   5.02297975E+00   1.78079701E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47561578E+00   6.12839260E-04   5.48618892E-04   6.58946151E+00  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   6.12839260E-04   5.48618892E-04   1.30049121E+02  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -6.94525850E-16  -1.99826754E-15  -1.78886601E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     461.602144251012      grams
    H2O MASS          347.563995068956      grams
    TDS(g/kg)         328.106912108175      g/kgH2O

  Specified Solution Density
    DENSITY           1188.93254605459      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL     0.388249228926247      liters
    TDS               293.724084133903      g/l

  Density based on TDS and NaCl solutions    1188.93254605459      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    8.31822E-01  7.77959E-01  0.9352       1.92928E+01  4.96918E+01  8.95208E+05
NaNpO2CO3(s)_____________NaNpO2CO3(s) 9.99932E+00  1.00000E+00  1.000        3.47540E+00  8.95147E+00  3.15133E+06
Cl-                             Cl-  5.61096E+00  5.29329E+00  0.9434       1.95017E+00  5.02298E+00  1.78080E+05
Na+                             Na+  5.61057E+00  5.29268E+00  0.9433       1.95003E+00  5.02263E+00  1.15469E+05
NpO2+                         NpO2+  6.12705E-04  1.21978E-03  1.991        2.12954E-04  5.48499E-04  1.47572E+02
CO2(aq)                     CO2(aq)  3.86103E-04  1.12115E-03  2.904        1.34196E-04  3.45643E-04  1.52117E+01
HCO3-                         HCO3-  2.26571E-04  8.38810E-05  0.3702       7.87481E-05  2.02829E-04  1.23760E+01  -6.17E-15
H+                               H+  1.21872E-06  4.78095E-06  3.923        4.23582E-07  1.09101E-06  1.09962E-03   6.17E-15
NpO2CO3-                   NpO2CO3-  1.33526E-07  2.42971E-07  1.820        4.64090E-08  1.19534E-07  3.93334E-02   1.85E-14
CO3=                            CO3=  3.09384E-08  8.03343E-10  2.5966E-02   1.07531E-08  2.76963E-08  1.66203E-03   0.00E+00
OH-                             OH-   3.01685E-09  1.63977E-09  0.5435       1.04855E-09  2.70071E-09  4.59318E-05  -6.17E-15
NpO2OH(aq)                NpO2OH(aq)  7.72186E-10  7.72186E-10  1.000        2.68384E-10  6.91267E-10  1.97740E-04   0.00E+00
NpO2(CO3)2=-            NpO2(CO3)2=-  1.98384E-11  5.13355E-16  2.5877E-05   6.89511E-12  1.77595E-11  6.90960E-06   0.00E+00
NpO2(OH)2-               NpO2(OH)2-   2.04381E-16  6.10703E-17  0.2988       7.10356E-17  1.82964E-16  5.54494E-11   1.23E-14
NpO2(CO3)3==-          NpO2(CO3)3==-  1.25197E-16  9.87897E-26  7.8908E-10   4.35139E-17  1.12077E-16  5.03310E-11  -3.53E-10
HCl(aq).......to.titrate.acid.only    0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.45E+02
NpO2OH(aged)_________NpO2OH(aged)     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.38E+00
NpO2OH(amor)_________NpO2OH(amor)     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.98E+00
NaOH(aq)......to.titrate.base.only    0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.99E+02
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.36E+02
NaCl_____________________Halite       0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.23E-01
NaHCO3___________________Nahcolite    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.95E+00
Na2CO3.10H2O_____________Natron       0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -7.91E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -7.95E+00
Na2CO3.H2O___________Thermonatrite    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -8.24E+00
Na3H(CO3)2.2H2O______________Trona    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.02E+01

pmH = -log[m(H+)]                 =      5.9141
pH = -log[a(H+)]     =      5.3205
Osmotic Coefficient=    1.241871
Equilibrium RH (%) =   77.795863
Ionic Strength (m) =    5.611188
Density, kg/m3     =     1188.93

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -4.63379813E+03
Flashing Titration #          2
# inversions for batch pblm          13
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.85957275E+01   1.11017746E+02   9.93891116E+01   1.00174286E+05  Hydrogen
  3.66763098E+01   5.55107903E+01   4.96962723E+01   7.95110540E+05  Oxygen
  5.42594206E+00   5.61014105E+00   5.02250276E+00   1.15466183E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95031318E+00   5.60993114E+00   5.02231483E+00   1.78056128E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47579611E+00   6.90932337E-04   6.18560128E-04   7.42952570E+00  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   1.72218651E-04   1.54179484E-04   3.65479691E+01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -7.46806759E-16  -2.14813422E-15  -1.92312635E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     461.665999617224      grams
    H2O MASS          347.653675849716      grams
    TDS(g/kg)         327.947988724253      g/kgH2O

  Specified Solution Density
    DENSITY           1188.85111378691      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.388329534508870       liters
    TDS               293.596838859300      g/l

  Density based on TDS and NaCl solutions    1188.85111378691      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    8.31845E-01  7.78011E-01  0.9353       1.92978E+01  4.96944E+01  8.95254E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.99718E+00  1.00000E+00  1.000        3.47556E+00  8.95002E+00  3.15082E+06
Na+                            Na+    5.61014E+00  5.29140E+00  0.9432       1.95039E+00  5.02250E+00  1.15466E+05
Cl-                            Cl-    5.60993E+00  5.29139E+00  0.9432       1.95031E+00  5.02231E+00  1.78056E+05
HCO3-                        HCO3-    3.82212E-04  1.41513E-04  0.3702       1.32878E-04  3.42177E-04  2.08787E+01
CO2(aq)                    CO2(aq)    3.08476E-04  8.95671E-04  2.904        1.07243E-04  2.76165E-04  1.21539E+01
NpO2+                        NpO2+    1.72085E-04  3.42481E-04  1.990        5.98258E-05  1.54059E-04  4.14492E+01  -1.64E-12
H+                             H+     5.77346E-07  2.26410E-06  3.922        2.00716E-07  5.16872E-07  5.20955E-04  -1.59E-11
NpO2CO3-                   NpO2CO3-   1.33573E-07  2.43030E-07  1.819        4.64370E-08  1.19581E-07  3.93490E-02  -2.47E-14
CO3=                          CO3=    1.10196E-07  2.86188E-09  2.5971E-02   3.83099E-08  9.86531E-08  5.92010E-03   2.55E-11
OH-                            OH-    6.37029E-09  3.46282E-09  0.5436       2.21466E-09  5.70303E-09  9.69932E-05   1.64E-11
NpO2OH(aq)               NpO2OH(aq)   4.57851E-10  4.57851E-10  1.000        1.59174E-10  4.09893E-10  1.17252E-04  -1.01E-11
NpO2(CO3)2=-           NpO2(CO3)2=-   7.06677E-11  1.82925E-15  2.5885E-05   2.45679E-11  6.32656E-11  2.46144E-05   2.65E-11
NpO2(CO3)3==-          NpO2(CO3)3==-  1.58546E-15  1.25406E-24  7.9097E-10   5.51192E-16  1.41939E-15  6.37413E-10  -8.77E-11
NpO2(OH)2-               NpO2(OH)2-   2.55903E-16  7.64679E-17  0.2988       8.89657E-17  2.29098E-16  6.94309E-11   6.38E-12
Na3H(CO3)2.2H2O_____________Trona     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.40E+00
Na2CO3.H2O__________Thermonatrite     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -7.69E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -7.40E+00
Na2CO3.10H2O_________________Natron   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -7.36E+00
NaHCO3_____________________Nahcolite  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.72E+00
NaCl_________________________Halite   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.23E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.36E+02
NaOH(aq).......to.titrate.base.only   0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.98E+02
NpO2OH(amor)_________NpO2OH(amor)     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.21E+00
NpO2OH(aged)_________NpO2OH(aged)     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.61E+00
HCl(aq).......to.titrate.acid.only    0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.45E+02

pmH = -log[m(H+)]                 =      6.2386
pH = -log[a(H+)]     =      5.6451
Osmotic Coefficient=    1.241740
Equilibrium RH (%) =   77.801108
Ionic Strength (m) =    5.620114
Density, kg/m3     =     1188.85

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          "dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          "Saturation Index for minerals, SI=log10(IAP/Ksp)
          "log10(activity) for aqueous species with very small concentrations
          "log10(partial pressure) for gases

Total G/RT=     -4.63438031E+03
Flashing Titration #            3
# inversions for batch pblm          22
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,F91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
Elemental Abundances for Flash Problem

  Total Moles       Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.85999827E+01   1.11017943E+02   9.93906557E+01   1.00175842E+05  Hydrogen
  3.66786675E+01   5.55109442E+01   4.96970938E+01   7.95123682E+05  Oxygen
  5.42615710E+00   5.61002979E+00   5.02247225E+00   1.15465482E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95037489E+00   5.60950015E+00   5.02199808E+00   1.78044898E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47587277E+00   7.90126088E-04   7.07373490E-04   8.49626299E+00  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   5.09860080E-05   4.56460697E-05   1.08203186E+01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -1.85281271E-15  -5.32890020E-15  -4.77078632E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     461.701224245777      grams
    H2O MASS          347.691387660720      grams
    TDS(g/kg)         327.905264930832      g/kgH2O

  Specified Solution Density
    DENSITY           1188.82922071361      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.388366315532383       liters
    TDS               293.562628954494      g/l

  Density based on TDS and NaCl solutions     1188.82922071361      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31852E-01   7.78030E-01   0.9353        1.92999E+01   4.96951E+01   8.95267E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.99622E+00   1.00000E+00   1.000         3.47560E+00   8.94928E+00   3.15056E+06
Na+                            Na+    5.61003E+00   5.29080E+00   0.9431        1.95056E+00   5.02247E+00   1.15465E+05
Cl-                            Cl-    5.60950E+00   5.29073E+00   0.9432        1.95037E+00   5.02200E+00   1.78045E+05
HCO3-                        HCO3-    5.79856E-04   2.14695E-04   0.3703        2.01611E-04   5.19125E-04   3.16755E+01
CO2(aq)                     CO2(aq)   2.09763E-04   6.09044E-04   2.903         7.29329E-05   1.87794E-04   8.26478E+00
NpO2+                         NpO2+   5.08519E-05   1.01191E-04   1.990         1.76808E-05   4.55260E-05   1.22486E+01   -9.95E-12
CO3=                           CO3=   3.72979E-07   9.68710E-09   2.5972E-02    1.29682E-07   3.33916E-07   2.00380E-02   -1.22E-10
H+                               H+   2.58813E-07   1.01480E-06   3.921         8.99871E-08   2.31707E-07   2.33537E-04    8.21E-11
NpO2CO3-                   NpO2CO3-   1.33591E-07   2.43057E-07   1.819         4.64484E-08   1.19600E-07   3.93550E-02   -1.23E-14
OH-                             OH-   1.42123E-08   7.72603E-09   0.5436        4.94149E-09   1.27238E-08   2.16397E-04   -8.04E-11
NpO2(CO3)2=-            NpO2(CO3)2=-   2.39201E-10   6.19248E-15   2.5888E-05    8.31683E-11   2.14149E-10   8.33180E-05   -1.14E-10
NpO2OH(aq)                NpO2OH(aq)   3.01826E-10   3.01826E-10   1.000         1.04942E-10   2.70215E-10   7.72962E-05    3.40E-11
NpO2(CO3)3==-           NpO2(CO3)3==-  1.81540E-14   1.43698E-23   7.9155E-10    6.31199E-15   1.62527E-14   7.29866E-09   -3.65E-07
NpO2(OH)2-                NpO2(OH)2-   3.76383E-16   1.12471E-16   0.2988        1.30865E-16   3.36963E-16   1.02121E-10   -4.63E-11
Na3H(CO3)2.2H2O_____________Trona      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -8.68E+00
Na2CO3.H2O__________Thermonatrite      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -7.16E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -6.87E+00
Na2CO3.10H2O_______________Natron      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -6.83E+00
NaHCO3_____________________Nahcolite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.54E+00
NaCl_______________________Halite      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.23E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.35E+02
NaOH(aq).......to.titrate.base.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.98E+02
NpO2OH(amor)_________NpO2OH(amor)      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.39E+00
NpO2OH(aged)_________NpO2OH(aged)      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.79E+00
HCl(aq).......to.titrate.acid.only     0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.45E+02

pmH = -log[m(H+)]                 =      6.5870
pH = -log[a(H+)]     =      5.9936
Osmotic Coefficient=     1.241681
Equilibrium RH (%) =    77.803013
Ionic Strength (m) =     5.610081
Density, kg/m3     =     1188.83

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
Total G/RT=     -4.63462770E+03
Flashing Titration #            4
# inversions for batch pblm            14
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
     Pressure=      1.00000E+00 [=] ATM      Temperature=      2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles       Aq. Molality      Aq. Molarity      Aq. mg/liter

  3.86060470E+01   1.11018357E+02   9.93915462E+01   1.00176739E+05  Hydrogen
  3.66820273E+01   5.55118409E+01   4.96981566E+01   7.95140687E+05  Oxygen
  5.42646354E+00   5.61000023E+00   5.02247206E+00   1.15465478E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95046284E+00   5.60889282E+00   5.02148063E+00   1.78026553E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47598202E+00   1.05369370E-03   9.43341702E-04   1.13304772E+01  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine .
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   5.04731450E-07   4.51871569E-07   1.07115342E-01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -8.05334972E-16  -2.31587983E-15  -2.07334069E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     461.766388131816       grams
    H2O MASS          347.744715353115       grams
    TDS(g/kg)         327.889016696973       g/kgH2O

  Specified Solution Density
    DENSITY           1188.82089442743       kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL     0.388423849459858       liters
    TDS               293.549618380179       g/l

  Density based on TDS and NaCl solutions     1188.82089442743       g/l
  Percent relative error vs NaCl density     0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31857E-01   7.78050E-01   0.9353        1.93029E+01   4.96953E+01   8.95271E+05
NaNpO2CO3(s)__________NaNpO2CO3(s)    9.99473E+00   1.00000E+00   1.000         3.47562E+00   8.94800E+00   3.15011E+06
Na+                            Na+    5.61000E+00   5.29000E+00   0.9430        1.95085E+00   5.02247E+00   1.15465E+05
Cl-                            Cl-    5.60889E+00   5.28999E+00   0.9431        1.95046E+00   5.02148E+00   1.78027E+05
HCO3-                        HCO3-    9.92660E-04   3.67543E-04   0.3703        3.45192E-04   8.88700E-04   5.42259E+01
CO3=                          CO3=    5.67888E-05   1.47494E-06   2.5972E-02    1.97480E-05   5.08414E-05   3.05095E+00
CO2(aq)                     CO2(aq)   4.03745E-06   1.17227E-05   2.903         1.40400E-06   3.61461E-06   1.59078E-01   -4.23E-08
OH-                            OH-    1.26397E-06   6.87170E-07   0.5437        4.39540E-07   1.13160E-06   1.92454E-02   -9.18E-08
NpO2+                        NpO2+    3.34101E-07   6.64703E-07   1.990         1.16182E-07   2.99111E-07   8.04750E-02    1.79E-07
NpO2CO3-                   NpO2CO3-   1.33613E-07   2.43094E-07   1.819         4.64631E-08   1.19620E-07   3.93616E-02    3.21E-13
NpO2(CO3)2=-            NpO2(CO3)2=-   3.64205E-08   9.43001E-13   2.5892E-05    1.26650E-08   3.26062E-08   1.26859E-02   -1.15E-07
H+                             H+     2.91065E-09   1.14100E-08   3.920         1.01216E-09   2.60582E-09   2.62641E-06    1.26E-07
NpO2(CO3)3=--         NpO2(CO3)3=--   4.20660E-10   3.33181E-19   7.9204E-10    1.46282E-10   3.76605E-10   1.69124E-04   -2.16E-07
NpO2OH(aq)                NpO2OH(aq)  1.76339E-10   1.76339E-10   1.000         6.13211E-11   1.57872E-10   4.51598E-05   -2.06E-08
NpO2(OH)2-                 NpO2(OH)2- 1.95583E-14   5.84438E-15   0.2988        6.80128E-15   1.75100E-14   5.30660E-09   -1.50E-07
Na3H(CO3)2.2H2O_______________Trona   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -6.27E+00
Na2CO3.H2O___________Thermonatrite    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -4.98E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -4.69E+00
Na2CO3.10H2O_________________Natron   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -4.65E+00
NaHCO3_____________________Nahcolite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.31E+00
NaCl_________________________Halite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.23E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.33E+02
NaOH(aq).......to.titrate.base.only   0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.96E+02
NpO2OH(amor)__________NpO2OH(amor)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.62E+00
NpO2OH(aged)__________NpO2OH(aged)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.03E+00
HCl(aq).......to.titrate.acid.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.47E+02

pmH = -log[m(H+)]                 =       8.5360
pH = -log[a(H+)]     =       7.9427
Osmotic Coefficient=     1.241601
Equilibrium RH (%) =    77.805007
Ionic Strength (m) =     5.610057
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Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

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Density, kg/m3      =      1188.82

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          "dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          "Saturation Index for minerals, SI=log10(IAP/Ksp)
          "log10(activity) for aqueous species with very small concentrations
          "log10(partial pressure) for gases

Total G/RT=     -4.63497997E+03
Flashing Titration #            5
# inversions for batch pblm            16
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.86146891E+01   1.11018383E+02   9.93917155E+01   1.00176910E+05  Hydrogen
  3.66868155E+01   5.55131961E+01   4.96994430E+01   7.95161268E+05  Oxygen
  5.42690025E+00   5.61000156E+00   5.02248064E+00   1.15465675E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95058817E+00   5.60799916E+00   5.02068795E+00   1.77998450E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47613771E+00   1.50108527E-03   1.34388050E-03   1.61413487E+01  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   5.18420811E-07   4.64127943E-07   1.10020694E-01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -1.02828867E-15  -2.95636061E-15  -2.64674862E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     461.868060856175      grams
    H2O MASS          347.822478666651      grams
    TDS(g/kg)         327.884450213538      g/kgH2O

  Specified Solution Density
    DENSITY           1188.81855435140      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.388510138208740       liters
    TDS               293.545961799972      g/l

  Density based on TDS and NaCl solutions    1188.81855435140      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    8.31862E-01  7.78067E-01  0.9353       1.93072E+01  4.96954E+01  8.95273E+05
NaNpO2CO3(s)_____________NaNpO2CO3(s) 9.99250E+00  1.00000E+00  1.000        3.47562E+00  8.94601E+00  3.14941E+06
Na+                            Na+   5.61000E+00  5.28971E+00  0.9429       1.95128E+00  5.02248E+00  1.15466E+05
Cl-                            Cl-   5.60800E+00  5.28867E+00  0.9431       1.95059E+00  5.02069E+00  1.77998E+05
HCO3-                        HCO3-   1.00903E-03  3.73572E-04  0.3702       3.50963E-04  9.03356E-04  5.51202E+01
CO3=                          CO3=   4.90717E-04  1.27445E-05  2.5971E-02   1.70682E-04  4.39325E-04  2.63636E+01
OH-                            OH-   1.07447E-05  5.84190E-06  0.5437       3.73726E-06  9.61946E-06  1.63601E-01  -4.59E-08
CO2(aq)                     CO2(aq)  4.82702E-07  1.40153E-06  2.904        1.67895E-07  4.32150E-07  1.90188E-02  -8.67E-08
NpO2(CO3)2=-          NpO2(CO3)2=-   3.14571E-07  8.14859E-12  2.5904E-05   1.09415E-07  2.81627E-07  1.09571E-01   2.59E-08
NpO2CO3-                 NpO2CO3-   1.33630E-07  2.43107E-07  1.819        4.64794E-08  1.19635E-07  3.93666E-02   4.47E-12
NpO2+                        NpO2+  3.86807E-08  7.69314E-08  1.989        1.34540E-08  3.46298E-08  9.31704E-03  -2.13E-08
NpO2(CO3)3==-        NpO2(CO3)3==-   3.13656E-08  2.48770E-17  7.9313E-10   1.09097E-08  2.80808E-08  1.26104E-02   4.49E-08
H+                             H+    3.42512E-10  1.34216E-09  3.919        1.19134E-10  3.06642E-10  3.09064E-07  -2.55E-08
NpO2OH(aq)               NpO2OH(aq)  1.73507E-10  1.73507E-10  1.000        6.03495E-11  1.55336E-10  4.44344E-05   4.70E-09
NpO2(OH)2-               NpO2(OH)2-  1.63614E-13  4.88873E-14  0.2988       5.69085E-14  1.46479E-13  4.43921E-08   2.99E-08
Na3H(CO3)2.2H2O_______________Trona  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -5.33E+00
Na2CO3.H2O____________Thermonatrite  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -4.04E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.75E+00
Na2CO3.10H2O_________________Natron  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.71E+00
NaHCO3_______________________Nahcolite 0.00000E+00 1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.30E+00
NaCl_________________________Halite  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.24E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.32E+02
NaOH(aq).....to.titrate.base.only    0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.95E+02
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
NpO2OH(amor)_________NpO2OH(amor)      0.00000E+00   1.00000E+00    1.000       0.00000E+00   0.00000E+00   0.00000E+00   -3.63E+00
NpO2OH(aged)_________NpO2OH(aged)      0.00000E+00   1.00000E+00    1.000       0.00000E+00   0.00000E+00   0.00000E+00   -3.03E+00
HCl(aq)........to.titrate.acid.only    0.00000E+00   0.00000E+00    1.000       0.00000E+00   0.00000E+00   0.00000E+00   -2.48E+02

pmH = -log[m(H+)]                  =      9.4653
pH = -log[a(H+)]     =      8.8722
Osmotic Coefficient=    1.241539
Equilibrium RH (%) =   77.806749
Ionic Strength (m) =    5.610494
Density, kg/m3     =     1188.82

NOTES:- Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -4.63548129E+03
Flashing Titration #          6
# inversions for batch pblm          17
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.86270051E+01   1.11018410E+02   9.93919460E+01   1.00177142E+05   Hydrogen
  3.66936391E+01   5.55151239E+01   4.97012721E+01   7.95190533E+05   Oxygen
  5.42752260E+00   5.61000344E+00   5.02249276E+00   1.15465953E+05   Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Calcium
  1.95076678E+00   5.60672579E+00   5.01955836E+00   1.77958403E+05   Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Sulfur
  3.47635958E+00   2.13880634E-03   1.91481868E-03   2.29988871E+01   Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   U(VI)
  3.47561578E+00   1.02583551E-06   9.18404325E-07   2.17706092E-01   Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00   Electron
 -9.45337050E-16  -2.71700630E-15  -2.43246632E-15   0.00000000E+00   Charge

  Solution Parameters, Calculated
    SOLUTION MASS     462.013014691340      grams
    H2O MASS          347.933330580303      grams
    TDS(g/kg)         327.877998698107      g/kgH2O

  Specified Solution Density
    DENSITY           1188.81524828657      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.388633149984603       liters
    TDS               293.540795775029      g/l

  Density based on TDS and NaCl solutions    1188.81524828657      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31870E-01   7.78092E-01   0.9354        1.93133E+01   4.96955E+01   8.95274E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.98931E+00   1.00000E+00   1.000         3.47562E+00   8.94318E+00   3.14841E+06
Na+                            Na+    5.61000E+00   5.28932E+00   0.9428        1.95191E+00   5.02249E+00   1.15466E+05
Cl-                            Cl-    5.60673E+00   5.28679E+00   0.9429        1.95077E+00   5.01956E+00   1.77958E+05
CO3=                          CO3=    1.11398E-03   2.89293E-05   2.5969E-02    3.87591E-04   9.97318E-04   5.98482E+01
HCO3-                        HCO3-    1.02256E-03   3.78536E-04   0.3702        3.55784E-04   9.15475E-04   5.58596E+01
OH-                            OH-    2.40684E-05   1.30873E-05   0.5438        8.37419E-06   2.15478E-05   3.66470E-01   -4.86E-09
NpO2(CO3)2=-          NpO2(CO3)2=-    7.13649E-07   1.84983E-11   2.5921E-05    2.48302E-07   6.38912E-07   2.48578E-01   9.95E-09
CO2(aq)                     CO2(aq)   2.18328E-07   6.33927E-07   2.904         7.59637E-08   1.95464E-07   8.60232E-03   -3.58E-08
NpO2CO3-                   NpO2CO3-   1.33654E-07   2.43125E-07   1.819         4.65026E-08   1.19657E-07   3.93738E-02   1.56E-12
NpO2(CO3)3==-        NpO2(CO3)3==-    1.61312E-07   1.28193E-16   7.9469E-10    5.61257E-08   1.44418E-07   6.48546E-02   1.97E-08
NpO2+                        NpO2+    1.70494E-08   3.38938E-08   1.988         5.93207E-09   1.52639E-08   4.10671E-03   -9.14E-09
H+                             H+     1.52979E-10   5.99129E-10   3.916         5.32265E-11   1.36958E-10   1.38040E-07   -1.97E-08
NpO2OH(aq)                NpO2OH(aq)  1.71249E-10   1.71249E-10   1.000         5.95833E-11   1.53315E-10   4.38564E-05   1.06E-08
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
NpO2(OH)2-                NpO2(OH)2-      3.61806E-13   1.08095E-13   0.2988      1.25884E-13   3.23915E-13   9.81663E-08   3.03E-08
Na3H(CO3)2.2H2O_____________Trona        0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -4.96E+00
Na2CO3.H2O__________Thermonatrite         0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -3.68E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate        0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -3.39E+00
Na2CO3.10H2O_________________Natron       0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -3.36E+00
NaHCO3_____________________Nahcolite      0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -2.30E+00
NaCl_______________________Halite         0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -1.24E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED        0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -9.32E+02
NaOH(aq).......to.titrate.base.only       0.00000E+00   0.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -2.95E+02
NpO2OH(amor)__________NpO2OH(amor)        0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -3.63E+00
NpO2OH(aged)__________NpO2OH(aged)        0.00000E+00   1.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -3.04E+00
HCl(aq)........to.titrate.acid.only       0.00000E+00   0.00000E+00   1.000       0.00000E+00   0.00000E+00   0.00000E+00   -2.49E+02

pmH = -log[m(H+)]                    =      9.8154
pH = -log[a(H+)]     =      9.2225
Osmotic Coefficient=    1.241451
Equilibrium RH (%) =   77.809217
Ionic Strength (m) =    5.611121
Density, kg/m3     =     1188.82

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -4.63619544E+03
Flashing Titration #          7
# inversions for batch pblm          17
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.86445565E+01   1.11018446E+02   9.93922712E+01   1.00177470E+05  Hydrogen
  3.67033634E+01   5.55178692E+01   4.97038762E+01   7.95232197E+05  Oxygen
  5.42840953E+00   5.61000623E+00   5.02251004E+00   1.15466351E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95102131E+00   5.60491242E+00   5.01794966E+00   1.77901369E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47667578E+00   3.04711826E-03   2.72801516E-03   3.27661900E+01  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   1.94421849E-06   1.74061427E-06   4.12609480E-01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -1.06779239E-15  -3.06756405E-15  -2.74631980E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     462.219612785916      grams
    H2O MASS          348.091311120339      grams
    TDS(g/kg)         327.868860898172      g/kgH2O

  Specified Solution Density
    DENSITY           1188.81056561769      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.388808466339423       liters
    TDS               293.533478681879      g/l

  Density based on TDS and NaCl solutions    1188.81056561769      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31881E-01   7.78127E-01   0.9354        1.93221E+01   4.96957E+01   8 95277E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.98478E+00   1.00000E+00   1.000         3.47562E+00   8.93914E+00   3 14699E+06
Na+                            Na+    5.61001E+00   5.28876E+00   0.9427        1.95279E+00   5.02251E+00   1 15466E+05
Cl-                            Cl-    5.60491E+00   5.28411E+00   0.9428        1.95102E+00   5.01795E+00   1 77901E+05
CO3=                          CO3=    2.00201E-03   5.19857E-05   2.5967E-02    6.96883E-04   1.79236E-03   1 07558E+02
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
HCO3-                          HCO3-      1.04073E-03  3.85192E-04  0.3701       3.62268E-04  9.31738E-04  5.68519E+01
OH-                            OH-        4.24988E-05  2.31125E-05  0.5438       1.47935E-05  3.80482E-05  6.47098E-01  -6.18E-08
NpO2(CO3)2=-           NpO2(CO3)2=-       1.28137E-06  3.32447E-11  2.5945E-05   4.46032E-07  1.14718E-06  4.46327E-01   4.81E-08
NpO2(CO3)3==-          NpO2(CO3)3==-      5.19502E-07  4.13999E-16  7.9692E-10   1.80834E-07  4.65098E-07  2.08864E-01   1.06E-07
CO2(aq)                        CO2(aq)    1.25799E-07  3.65269E-07  2.904        4.37894E-08  1.12625E-07  4.95659E-03  -3.39E-07
NpO2CO3-               NpO2CO3-           1.33688E-07  2.43151E-07  1.819        4.65356E-08  1.19688E-07  3.93840E-02   1.10E-12
NpO2+                          NpO2+      9.49498E-09  1.88634E-08  1.987        3.30512E-09  8.50064E-09  2.28707E-03  -4.03E-08
H+                             H+         8.66954E-11  3.39269E-10  3.913        3.01779E-11  7.76164E-11  7.82296E-08  -1.47E-07
NpO2OH(aq)             NpO2OH(aq)         1.68316E-10  1.68316E-10  1.000        5.85892E-11  1.50689E-10  4.31052E-05   1.04E-07
NpO2(OH)2-             NpO2(OH)2-         6.28105E-13  1.87627E-13  0.2987       2.18638E-13  5.62328E-13  1.70420E-07   2.44E-07
Na3H(CO3)2.2H2O_____________Trona         0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -4.70E+00
Na2CO3.H2O__________Thermonatrite          0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.43E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate         0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.14E+00
Na2CO3.10H2O_________________Natron        0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.10E+00
NaHCO3_____________________Nahcolite       0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.29E+00
NaCl_______________________Halite          0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.24E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED         0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.31E+02
NaOH(aq).......to.titrate.base.only        0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.94E+02
NpO2OH(amor)_________NpO2OH(amor)          0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.64E+00
NpO2OH(aged)_________NpO2OH(aged)          0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.05E+00
HCl(aq).......to.titrate.acid.only         0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.49E+02

pmH = -log[m(H+)]                    =      10.0620
pH = -log[a(H+)]     =       9.4695
Osmotic Coefficient=     1.241325
Equilibrium RH (%) =    77.812731
Ionic Strength (m) =     5.612017
Density, kg/m3     =      1188.81

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=     -4.63721298E+03
Flashing Titration #            8
# inversions for batch pblm            23
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
     Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.86695692E+01   1.11018496E+02   9.93927291E+01   1.00177932E+05  Hydrogen
  3.67172215E+01   5.55217779E+01   4.97075822E+01   7.95291491E+05  Oxygen
  5.42967348E+00   5.61001045E+00   5.02253469E+00   1.15466917E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95138405E+00   5.60233091E+00   5.01565935E+00   1.77820171E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47712639E+00   4.34048558E-03   3.88595344E-03   4.66741868E+01  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   3.60501967E-06   3.22750493E-06   7.65074233E-01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -4.02027671E-16  -1.15420235E-15  -1.03333521E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     462.514079623513      grams
    H2O MASS          348.316456438668      grams
    TDS(g/kg)         327.855951316366      g/kgH2O

  Specified Solution Density
    DENSITY           1188.80395005085      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.389058330100373       liters
    TDS               293.523141261063      g/l

  Density based on TDS and NaCl solutions     1188.80395005085      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    8.31897E-01  7.78177E-01  0.9354       1.93346E+01  4.96959E+01  8.95281E+05
NaNpO2CO3(s)_____________NaNpO2CO3(s) 9.97832E+00  1.00000E+00  1.000        3.47561E+00  8.93340E+00  3.14497E+06
Na+                             Na+   5.61001E+00  5.28798E+00  0.9426       1.95406E+00  5.02253E+00  1.15467E+05
Cl-                             Cl-   5.60233E+00  5.28028E+00  0.9425       1.95138E+00  5.01566E+00  1.77820E+05
CO3=                            CO3=  3.26656E-03  8.48095E-05  2.5963E-02   1.13780E-03  2.92449E-03  1.75496E+02
HCO3-                           HCO3- 1.06541E-03  3.94227E-04  0.3700       3.71098E-04  9.53837E-04  5.82004E+01
OH-                             OH-   6.77337E-05  3.68439E-05  0.5440       2.35928E-05  6.06407E-05  1.03133E+00  -3.65E-10
NpO2(CO3)2=-            NpO2(CO3)2=-  2.08796E-06  5.42434E-11  2.5979E-05   7.27272E-07  1.86931E-06  7.27286E-01   2.37E-09
NpO2(CO3)3==-           NpO2(CO3)3==- 1.37733E-06  1.10201E-15  8.0011E-10   4.79745E-07  1.23309E-06  5.53751E-01   4.86E-09
CO2(aq)                     CO2(aq)   8.07635E-08  2.34511E-07  2.904        2.81313E-08  7.23060E-08  3.18217E-03  -1.78E-08
NpO2CO3-                  NpO2CO3-    1.33737E-07  2.43187E-07  1.818        4.65827E-08  1.19732E-07  3.93986E-02   1.23E-12
NpO2+                         NpO2+   5.82643E-09  1.15644E-08  1.985        2.02944E-09  5.21629E-09  1.40343E-03  -2.34E-09
H+                              H+    5.44489E-11  2.12840E-10  3.909        1.89655E-11  4.87471E-11  4.91322E-08  -9.88E-09
NpO2OH(aq)                NpO2OH(aq)  1.64493E-10  1.64493E-10  1.000        5.72955E-11  1.47267E-10  4.21264E-05   7.54E-09
NpO2(OH)2-                NpO2(OH)2-  9.78743E-13  2.92306E-13  0.2987       3.40912E-13  8.76250E-13  2.65558E-07   1.74E-08
Na3H(CO3)2.2H2O_______________Trona   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -4.48E+00
Na2CO3.H2O___________Thermonatrite    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.22E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.93E+00
Na2CO3.10H2O_________________Natron   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.89E+00
NaHCO3_______________________Nahcolite 0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.28E+00
NaCl_________________________Halite   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.24E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.31E+02
NaOH(aq).......to.titrate.base.only   0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.94E+02
NpO2OH(amor)__________NpO2OH(amor)    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.65E+00
NpO2OH(aged)__________NpO2OH(aged)    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.06E+00
HCl(aq).......to.titrate.acid.only    0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.49E+02

pmH = -log[m(H+)]                 =     10.2640
pH = -log[a(H+)]     =      9.6719
Osmotic Coefficient=    1.241147
Equilibrium RH (%) =   77.817733
Ionic Strength (m) =    5.613297
Density, kg/m3     =     1188.80

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -4.63866284E+03
Flashing Titration #          9
# inversions for batch pblm          23
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.87052148E+01   1.11018564E+02   9.93933709E+01   1.00178579E+05  Hydrogen
  3.67369708E+01   5.55273411E+01   4.97128537E+01   7.95375832E+05  Oxygen
  5.43147475E+00   5.61001696E+00   5.02256990E+00   1.15467727E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95190099E+00   5.59865759E+00   5.01240002E+00   1.77704618E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47776855E+00   6.18147537E-03   5.53418864E-03   6.64711398E+01  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   6.66349238E-06   5.96573175E-06   1.41416597E+00  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -1.13087115E-15  -3.24368928E-15  -2.90402975E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     462.933810446950      grams
    H2O MASS          348.637323019311      grams
    TDS(g/kg)         327.837784084031      g/kgH2O

  Specified Solution Density
    DENSITY           1188.79464008680      kg/m^3 = g/l
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
Solution Parameters Based on Specified Density
  SOLUTION VOL     0.389416449591688      liters
  TDS              293.508593601194       g/l

Density based on TDS and NaCl solutions     1188.79464008680      g/l
Percent relative error vs NaCl density     0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                                Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                                WATER    8.31919E-01  7.78249E-01  0.9355       1.93524E+01  4.96961E+01  8.95286E+05
NaNpO2CO3(s)_____________NaNpO2CO3(s)       9.96914E+00  1.00000E+00  1.000        3.47561E+00  8.92523E+00  3.14209E+06
Na+                                 Na+     5.61002E+00  5.28690E+00  0.9424       1.95586E+00  5.02257E+00  1.15468E+05
Cl-                                 Cl-     5.59866E+00  5.27483E+00  0.9422       1.95190E+00  5.01240E+00  1.77705E+05
CO3=                               CO3=     5.06627E-03  1.31507E-04  2.5957E-02   1.76629E-03  4.53576E-03  2.72187E+02
HCO3-                             HCO3-     1.09867E-03  4.06389E-04  0.3699       3.83037E-04  9.83623E-04  6.00178E+01
OH-                                 OH-     1.01865E-04  5.54263E-05  0.5441       3.55141E-05  9.11987E-05  1.55104E+00  -1.77E-10
NpO2(CO3)2=-            NpO2(CO3)2=-        3.23222E-06  8.41283E-11  2.6028E-05   1.12687E-06  2.89376E-06  1.12586E+00   8.12E-10
NpO2(CO3)3==-           NpO2(CO3)3==-       3.29354E-06  2.65024E-15  8.0468E-10   1.14825E-06  2.94866E-06  1.32417E+00   1.75E-09
CO2(aq)                         CO2(aq)     5.53405E-08  1.60697E-07  2.904        1.92938E-08  4.95456E-08  2.18049E-03  -9.24E-09
NpO2CO3-                       NpO2CO3-     1.33806E-07  2.43236E-07  1.818        4.66498E-08  1.19795E-07  3.94192E-02   5.06E-13
NpO2+                             NpO2+     3.76324E-09  7.45944E-09  1.982        1.31200E-09  3.36917E-09  9.06466E-04  -7.98E-10
H+                                  H+      3.62550E-11  1.41496E-10  3.903        1.26398E-11  3.24586E-11  3.27150E-08  -4.95E-09
NpO2OH(aq)                   NpO2OH(aq)     1.59617E-10  1.59617E-10  1.000        5.56486E-11  1.42903E-10  4.08781E-05   4.15E-09
NpO2(OH)2-                   NpO2(OH)2-     1.42919E-12  4.26699E-13  0.2986       4.98268E-13  1.27953E-12  3.87777E-07   9.11E-09
Na3H(CO3)2.2H2O_______________Trona         0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -4.28E+00
Na2CO3.H2O____________Thermonatrite         0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.03E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate          0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.74E+00
Na2CO3.10H2O_________________Natron         0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.70E+00
NaHCO3_____________________Nahcolite        0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.26E+00
NaCl_______________________Halite           0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.25E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED          0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.31E+02
NaOH(aq).......to.titrate.base.only         0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.94E+02
NpO2OH(amor)__________NpO2OH(amor)          0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.66E+00
NpO2OH(aged)__________NpO2OH(aged)          0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.07E+00
HCl(aq).......to.titrate.acid.only          0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.49E+02

pmH = -log[m(H+)]                    =      10.4406
pH = -log[a(H+)]     =       9.8493
Osmotic Coefficient*     1.240893
Equilibrium RH (%) =    77.824850
Ionic Strength (m) =     5.615126
Density, kg/m3     =     1188.79

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=     -4.64072873E+03
Flashing Titration #          10
# inversions for batch pblm          22
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.6lmolal NaCl   FMT V2.0
DATABASE:  MMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.87560135E+01   1.11018653E+02   9.93942650E+01   1.00179480E+05  Hydrogen
  3.67651156E+01   5.55352555E+01   4.97203463E+01   7.95495709E+05  Oxygen
  5.43404174E+00   5.61002728E+00   5.02262026E+00   1.15468885E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95263769E+00   5.59343408E+00   5.00776448E+00   1.77540274E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47868370E+00   8.80060113E-03   7.87911990E-03   9.46361091E+01  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   1.23872216E-05   1.10901974E-05   2.62891134E+00  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -6.72313767E-16  -1.92587840E-15  -1.72422617E-15   0.00000000E+00  Charge
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
Solution Parameters, Calculated
  SOLUTION MASS     463.532138924454      grams
  H2O MASS          349.094609954685      grams
  TDS(g/kg)         327.812362913952      g/kgH2O

Specified Solution Density
  DENSITY           1188.78161259327      kg/m^3 = g/l

Solution Parameters Based on Specified Density
  SOLUTION VOL    0.389922029424127       liters
  TDS               293.488236965687      g/l

Density based on TDS and NaCl solutions    1188.78161259327      g/l
Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    8.31951E-01  7.78350E-01  0.9356       1.93778E+01  4.96966E+01  8.95293E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.95607E+00  1.00000E+00  1.000        3.47561E+00  8.91361E+00  1.13800E+06
Na+                            Na+    5.61003E+00  5.28539E+00  0.9421       1.95843E+00  5.02262E+00  1.15469E+05
Cl-                            Cl-    5.59343E+00  5.26704E+00  0.9416       1.95264E+00  5.00776E+00  1.77540E+05
CO3=                          CO3=    7.62562E-03  1.97880E-04  2.5949E-02   2.66206E-03  6.82717E-03  4.09693E+02
HCO3-                        HCO3-    1.14291E-03  4.22533E-04  0.3697       3.98983E-04  1.02324E-03  6.24350E+01
OH-                            OH-    1.47379E-04  8.02242E-05  0.5443       5.14493E-05  1.31948E-04  2.24408E+00  -2.23E-08
NpO2(CO3)2=-          NpO2(CO3)2=-    4.85191E-06  1.26624E-10  2.6098E-05   1.69378E-06  4.34388E-06  1.69005E+00   1.77E-08
NpO2(CO3)3==-        NpO2(CO3)3==-    7.39875E-06  6.00222E-15  8.1125E-10   2.58286E-06  6.62405E-06  2.97469E+00   3.56E-08
CO2(aq)                     CO2(aq)   3.97510E-08  1.15435E-07  2.904        1.38769E-08  3.55888E-08  1.56626E-03  -3.82E-07
NpO2CO3-                   NpO2CO3-   1.33905E-07  2.43306E-07  1.817        4.67454E-08  1.19884E-07  3.94486E-02   2.95E-11
NpO2+                         NpO2+   2.50641E-09  4.95882E-09  1.978        8.74975E-10  2.24398E-09  6.03735E-04  -1.78E-08
H+                              H+    2.51081E-11  9.77709E-11  3.894        8.76512E-12  2.24792E-11  2.26567E-08  -1.28E-07
NpO2OH(aq)                NpO2OH(aq)  1.53583E-10  1.53583E-10  1.000        5.36149E-11  1.37502E-10  3.93329E-05   1.10E-07
NpO2(OH)2-               NpO2(OH)2-   1.99131E-12  5.94256E-13  0.2984       6.95155E-13  1.78281E-12  5.40300E-07   2.38E-07
Na3H(CO3)2.2H2O_____________Trona     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -4.08E+00
Na2CO3.H2O__________Thermonatrite     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.85E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.56E+00
Na2CO3.10H2O_______________Natron     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.52E+00
NaHCO3_____________________Nahcolite  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.25E+00
NaCl_______________________Halite     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.26E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.31E+02
NaOH(aq).......to.titrate.base.only   0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.94E+02
NpO2OH(amor)_________NpO2OH(amor)     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.68E+00
NpO2OH(aged)_________NpO2OH(aged)     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.09E+00
HCl(aq).......to.titrate.acid.only    0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.49E+02

pmH = -log[m(H+)]                 =     10.6002
pH = -log[a(H+)]     =     10.0098
Osmotic Coefficient=    1.240532
Equilibrium RH (%) =   77.834968
Ionic Strength (m) =    5.617741
Density, kg/m3     =    1188.78

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -4.64367246E+03
Flashing Titration #          11
# inversions for batch pblm          22
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.88284068E+01   1.11018771E+02   9.93954996E+01   1.00180724E+05  Hydrogen
  3.68052248E+01   5.55465070E+01   4.97309848E+01   7.95665918E+05  Oxygen
  5.43769997E+00   5.61004415E+00   5.02269243E+00   1.15470544E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95368755E+00   5.58601315E+00   5.00117739E+00   1.77306742E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47998788E+00   1.25239828E-02   1.12127662E-02   1.34676535E+02  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   2.32128943E-05   2.07825866E-05   4.92647476E+00  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -8.43194194E-16  -2.41087366E-15  -2.15846374E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     464.385150217386       grams
    H2O MASS          349.746321818902       grams
    TDS(g/kg)         327.777080834729       g/kgH2O

  Specified Solution Density
    DENSITY           1188.76353136245       kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.390645521977908        liters
    TDS               293.459983409119       g/l

  Density based on TDS and NaCl solutions    1188.76353136245      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


  TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

  Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

  H2O                          WATER    8.31997E-01   7.78493E-01   0.9357        1.94140E+01   4.96971E+01   8.95304E+05
  NaNpO2CO3(s)_____________NaNpO2CO3(s) 9.93751E+00   1.00000E+00   1.000         3.47561E+00   8.89709E+00   3.13218E+06
  Na+                            Na+    5.61004E+00   5.28333E+00   0.9418        1.96209E+00   5.02269E+00   1.15471E+05
  Cl-                            Cl-    5.58601E+00   5.25591E+00   0.9409        1.95369E+00   5.00118E+00   1.77307E+05
  CO3=                          CO3=    1.12609E-02   2.92079E-04   2.5937E-02    3.93846E-03   1.00819E-02   6.05009E+02
  HCO3-                        HCO3-    1.20082E-03   4.43607E-04   0.3694        4.19981E-04   1.07510E-03   6.55992E+01
  OH-                            OH-    2.07123E-04   1.12810E-04   0.5447        7.24404E-05   1.85438E-04   3.15380E+00   -2.25E-09
  NpO2(CO3)2=-          NpO2(CO3)2=-    7.13717E-06   1.86975E-10   2.6197E-05    2.49620E-06   6.38993E-06   2.48610E+00    4.21E-09
  NpO2(CO3)3==-         NpO2(CO3)3==-   1.59398E-05   1.30821E-14   8.2072E-10    5.57490E-06   1.42710E-05   6.40874E+00    8.72E-09
  CO2(aq)                     CO2(aq)   2.96765E-08   8.61856E-08   2.904         1.03792E-08   2.65695E-08   1.16932E-03   -9.22E-08
  NpO2CO3-                   NpO2CO3-   1.34044E-07   2.43401E-07   1.816         4.68815E-08   1.20010E-07   3.94902E-02    8.14E-12
  NpO2+                         NpO2+   1.70329E-09   3.36086E-09   1.973         5.95718E-10   1.52496E-09   4.10285E-04   -4.25E-09
  NpO2OH(aq)             NpO2OH(aq)     1.46370E-10   1.46370E-10   1.000         5.11925E-11   1.31046E-10   3.74863E-05    4.11E-08
  H+                             H+     1.79163E-11   6.95424E-11   3.882         6.26615E-12   1.60405E-11   1.61672E-08   -4.53E-08
  NpO2(OH)2-            NpO2(OH)2-      2.67040E-12   7.96388E-13   0.2982        9.33963E-13   2.39082E-12   7.24565E-07    8.64E-08
  Na3H(CO3)2.2H2O_______________Trona   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.89E+00
  Na2CO3.H2O___________Thermonatrite    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.68E+00
  Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.39E+00
  Na2CO3.10H2O_________________Natron   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.35E+00
  NaHCO3_____________________Nahcolite  0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.23E+00
  NaCl_________________________Halite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.27E-01
  Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.31E+02
  NaOH(aq).....to.titrate.base.only     0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.94E+02
  NpO2OH(amor)__________NpO2OH(amor)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.70E+00
  NpO2OH(aged)__________NpO2OH(aged)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.11E+00
  HCl(aq).......to.titrate.acid.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.50E+02

  pmH = -log[m(H+)]                 =     10.7468
  pH = -log[a(H+)]     =     10.1578
  Osmotic Coefficient=    1.240021
  Equilibrium RH (%) =   77.849336
  Ionic Strength (m) =    5.621486
  Density, kg/m3     =     1188.76

  NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
          - Gas "molality" and "activity" are gas partial pressures
          - "Descriptor" means:
            *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
            *Saturation Index for minerals, SI=log10(IAP/Ksp)
            *log10(activity) for aqueous species with very small concentrations
            *log10(partial pressure) for gases

  Total G/RT=    -4.64786705E+03
  Flashing Titration #          12
  # inversions for batch pblm           22
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
  DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
  95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
      Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

  Elemental Abundances for Flash Problem

    Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

    3.89315747E+01   1.11018923E+02   9.93971848E+01   1.00182423E+05  Hydrogen
    3.68623846E+01   5.55624877E+01   4.97460679E+01   7.95907238E+05  Oxygen
    5.44291331E+00   5.61007250E+00   5.02279611E+00   1.15472927E+05  Sodium
    0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
    0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95518372E+00   5.57548446E+00   4.99182884E+00   1.76975308E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.48184647E+00   1.78114648E-02   1.59469162E-02   1.91538411E+02  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   4.37690919E-05   3.91872342E-05   9.28926332E+00  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -1.32033463E-15  -3.76512199E-15  -3.37097962E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     465.601420606269      grams
    H2O MASS          350.675126352096      grams
    TDS(g/kg)         327.728674256700      g/kgH2O

  Specified Solution Density
    DENSITY           1188.73872346794      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.391676834795082       liters
    TDS               293.421218832869      g/l

  Density based on TDS and NaCl solutions    1188.73872346794      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.32061E-01   7.78697E-01   0.9359        1.94655E+01   4.96979E+01   8.95318E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.91117E+00   1.00000E+00   1.000         3.47560E+00   8.87364E+00   3.12393E+06
Na+                            Na+    5.61007E+00   5.28057E+00   0.9413        1.96731E+00   5.02280E+00   1.15473E+05
Cl-                            Cl-    5.57548E+00   5.24002E+00   0.9398        1.95518E+00   4.99183E+00   1.76975E+05
CO3=                          CO3=    1.64154E-02   4.25480E-04   2.5920E-02    5.75648E-03   1.46970E-02   8.81956E+02
HCO3-                        HCO3-    1.27533E-03   4.70618E-04   0.3690        4.47227E-04   1.14183E-03   6.96709E+01
OH-                            OH-    2.84255E-04   1.54942E-04   0.5451        9.96812E-05   2.54499E-04   4.32833E+00   -1.42E-09
NpO2(CO3)2=-          NpO2(CO3)2=-    1.03463E-05   2.72515E-10   2.6339E-05    3.62818E-06   9.26320E-06   3.60399E+00    2.42E-09
NpO2(CO3)3==-         NpO2(CO3)3==-   3.32873E-05   2.77756E-14   8.3442E-10    1.16730E-05   2.98027E-05   1.33836E+01    5.14E-09
CO2(aq)                     CO2(aq)   2.29199E-08   6.65707E-08   2.904         8.03744E-09   2.05206E-08   9.03107E-04   -7.40E-08
NpO2CO3-                   NpO2CO3-   1.34242E-07   2.43528E-07   1.814         4.70755E-08   1.20190E-07   3.95491E-02    6.18E-12
NpO2+                         NpO2+   1.17432E-09   2.30833E-09   1.966         4.11805E-10   1.05139E-09   2.82874E-04   -2.46E-09
NpO2OH(aq)               NpO2OH(aq)   1.38078E-10   1.38078E-10   1.000         4.84205E-11   1.23624E-10   3.53631E-05    3.39E-08
H+                             H+     1.31074E-11   5.06455E-11   3.864         4.59643E-12   1.17353E-11   1.18280E-08   -3.64E-08
NpO2(OH)2-               NpO2(OH)2-   3.46327E-12   1.03185E-12   0.2979        1.21448E-12   3.10073E-12   9.39711E-07    7.04E-08
Na3H(CO3)2.2H2O_____________Trona     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.70E+00
Na2CO3.H2O__________Thermonatrite     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.52E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.23E+00
Na2CO3.10H2O_________________Natron   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.19E+00
NaHCO3_________________Nahcolite      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.20E+00
NaCl_________________________Halite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.28E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.30E+02
NaOH(aq).......to.titrate.base.only   0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.94E+02
NpO2OH(amor)__________NpO2OH(amor)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.73E+00
NpO2OH(aged)__________NpO2OH(aged)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.13E+00
HCl(aq).......to.titrate.acid.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.50E+02

pmH = -log[m(H+)]                 =     10.8825
pH = -log[a(H+)]     =     10.2955
Osmotic Coefficient=     1.239297
Equilibrium RH (%) =    77.869707
Ionic Strength (m) =     5.626852
Density, kg/m3     =     1188.74

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=     -4.65384406E+03
Flashing Titration #          13
# inversions for batch pblm          22
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin
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Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

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Elemental Abundances for Flash Problem

  Total Moles       Aq. Molality      Aq. Molarity      Aq. mg/liter

  3.90785996E+01    1.11019115E+02    9.93994493E+01    1.00184705E+05  Hydrogen
  3.69438430E+01    5.55851538E+01    4.97674088E+01    7.96248680E+05  Oxygen
  5.45034287E+00    5.61012129E+00    5.02294553E+00    1.15476363E+05  Sodium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Potassium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Magnesium
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Calcium
  1.95731591E+00    5.56057489E+00    4.97858483E+00    1.76505768E+05  Chlorine
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Sulfur
  3.48449515E+00    2.53082323E-02    2.26593804E-02    2.72161818E+02  Carbon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  PosIon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  NegIon
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Air
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Boron
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Bromine
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  TracerEl
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Th(IV)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Am(III)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  U(VI)
  3.47561578E+00    8.26620364E-05    7.40103261E-05    1.75440146E+01  Np(V)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  ClO4-(EL)
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Phosphorus
  0.00000000E+00    0.00000000E+00    0.00000000E+00    0.00000000E+00  Electron
 -1.25055944E-15   -3.55273740E-15   -3.18089495E-15    0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     467.335943430028      grams
    H2O MASS          351.998839687459      grams
    TDS(g/kg)         327.663306631854      g/kgH2O

  Specified Solution Density
    DENSITY           1188.70522197651      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL      0.393147043346010     liters
    TDS               293.368869726079      g/l

  Density based on TDS and NaCl solutions    1188.70522197651      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.32153E-01   7.78985E-01   0.9361        1.95390E+01   4.96989E+01   8.95336E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.87386E+00   1.00000E+00   1.000         3.47559E+00   8.84042E+00   3.11224E+06
Na+                            Na+    5.61012E+00   5.27693E+00   0.9406        1.97476E+00   5.02295E+00   1.15476E+05
Cl-                            Cl-    5.56057E+00   5.21732E+00   0.9383        1.95732E+00   4.97858E+00   1.76506E+05
CO3=                          CO3=    2.37058E-02   6.13801E-04   2.5892E-02    8.34440E-03   2.12246E-02   1.27367E+03
HCO3-                        HCO3-    1.36956E-03   5.04583E-04   0.3684        4.82083E-04   1.22622E-03   7.48201E+01
OH-                            OH-    3.82200E-04   2.08552E-04   0.5457        1.34534E-04   3.42198E-04   5.81986E+00   -1.17E-09
NpO2(CO3)2=-          NpO2(CO3)2=-    1.48219E-05   3.93404E-10   2.6542E-05    5.21729E-06   1.32706E-05   5.16313E+00    1.59E-09
NpO2(CO3)3==-        NpO2(CO3)3==-    6.77047E-05   5.78442E-14   8.5436E-10    2.38320E-05   6.06184E-05   2.72222E+01    3.46E-09
CO2(aq)                    CO2(aq)    1.82542E-08   5.30275E-08   2.905         6.42544E-09   1.63436E-08   7.19279E-04   -6.83E-08
NpO2CO3-                  NpO2CO3-    1.34522E-07   2.43696E-07   1.812         4.73516E-08   1.20442E-07   3.96323E-02    5.31E-12
NpO2+                        NpO2+    8.18986E-10   1.60121E-09   1.955         2.88282E-10   7.33267E-10   1.97283E-04   -1.64E-09
NpO2OH(aq)              NpO2OH(aq)    1.28920E-10   1.28920E-10   1.000         4.53797E-11   1.15427E-10   3.30183E-05    3.16E-08
H+                             H+    9.80463E-12   3.76405E-11   3.839         3.45122E-12   8.77844E-12   8.84779E-09   -3.32E-08
NpO2(OH)2-              NpO2(OH)2-    4.35852E-12   1.29676E-12   0.2975        1.53420E-12   3.90234E-12   1.18265E-06    6.48E-08
Na3H(CO3)2.2H2O_______________Trona   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.51E+00
Na2CO3.H2O___________Thermonatrite    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.36E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.07E+00
Na2CO3.10H2O_________________Natron   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.03E+00
NaHCO3_____________________Nahcolite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.17E+00
NaCl________________________Halite    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.31E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.30E+02
NaOH(aq).......to.titrate.base.only   0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.94E+02
NpO2OH(amor)__________NpO2OH(amor)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.76E+00
NpO2OH(aged)__________NpO2OH(aged)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.16E+00
HCl(aq).......to.titrate.acid.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.50E+02

pmH = -log[m(H+)]                 =     11.0086
pH = -log[a(H+)]     =     10.4243
Osmotic Coefficient=    1.238276
Equilibrium RH (%) =   77.898521
Ionic Strength (m) =    5.634549
Density, kg/m3     =     1188.71

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
Total G/RT=    -4.66236092E+03
Flashing Titration #          14
# inversions for batch pblm          22
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.92881252E+01   1.11019354E+02   9.94024309E+01   1.00187710E+05  Hydrogen
  3.70599297E+01   5.56172351E+01   4.97975186E+01   7.96730419E+05  Oxygen
  5.46093075E+00   5.61020635E+00   5.02316152E+00   1.15481328E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.96035450E+00   5.53951836E+00   4.95987023E+00   1.75842279E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.48826979E+00   3.59127333E-02   3.21548707E-02   3.86212152E+02  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   1.55346593E-04   1.39091324E-04   3.29713479E+01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -8.00005678E-16  -2.26063508E-15  -2.02408511E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     469.810029265032      grams
    H2O MASS          353.885368468197      grams
    TDS(g/kg)         327.576868460594      g/kgH2O

  Specified Solution Density
    DENSITY           1188.66091947607      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL     0.395243102189405      liters
    TDS               293.299643066972      g/l

  Density based on TDS and NaCl solutions    1188.66091947607      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    8.32282E-01  7.79391E-01  0.9365       1.96437E+01  4.97003E+01  8.95361E+05
NaNpO2CO3(s)_____________NaNpO2CO3(s)  9.82115E+00  1.00000E+00  1.000        3.47556E+00  8.79348E+00  3.09571E+06
Na+                             Na+    5.61021E+00  5.27230E+00  0.9398       1.98537E+00  5.02316E+00  1.15481E+05
Cl-                             Cl-    5.53952E+00  5.18493E+00  0.9360       1.96035E+00  4.95987E+00  1.75842E+05
CO3=                           CO3=    3.39812E-02  8.78458E-04  2.5851E-02   1.20255E-02  3.04255E-02  1.82581E+03
HCO3-                         HCO3-    1.48672E-03  5.46468E-04  0.3676       5.26128E-04  1.33115E-03  8.12230E+01
OH-                             OH-    5.04619E-04  2.75741E-04  0.5464       1.78577E-04  4.51816E-04  7.68417E+00  -1.22E-09
NpO2(CO3)2=-          NpO2(CO3)2=-     2.10028E-05  5.63525E-10  2.6831E-05   7.43260E-06  1.88051E-05  7.31643E+00   1.18E-09
NpO2(CO3)3==-        NpO2(CO3)3==-     1.34208E-04  1.18584E-13  8.8359E-10   4.74943E-05  1.20165E-04  5.39629E+01   2.62E-09
CO2(aq)                      CO2(aq)   1.49488E-08  4.34356E-08  2.906        5.29018E-09  1.33846E-08  5.89054E-04  -7.17E-08
NpO2CO3-                    NpO2CO3-   1.34916E-07  2.43910E-07  1.808        4.77447E-08  1.20798E-07  3.97494E-02   5.29E-12
NpO2+                          NpO2+   5.77122E-10  1.11979E-09  1.940        2.04235E-10  5.16733E-10  1.39025E-04  -1.25E-09
NpO2OH(aq)                NpO2OH(aq)   1.19205E-10  1.19205E-10  1.000        4.21850E-11  1.06732E-10  3.05311E-05   3.27E-08
H+                              H+     7.48733E-12  2.84836E-11  3.804        2.64966E-12  6.70386E-12  6.75682E-09  -3.39E-08
NpO2(OH)2-                NpO2(OH)2-   5.33952E-12  1.58534E-12  0.2969       1.88958E-12  4.78080E-12  1.44888E-06   6.67E-08
Na3H(CO3)2.2H2O_______________Trona    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.32E+00
Na2CO3.H2O___________Thermonatrite     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.20E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.91E+00
Na2CO3.10H2O_________________Natron    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.87E+00
NaHCO3_____________________Nahcolite   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.14E+00
NaCl_________________________Halite    0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.34E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.30E+02
NaOH(aq).......to.titrate.base.only    0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.93E+02
NpO2OH(amor)__________NpO2OH(amor)     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.79E+00
NpO2OH(aged)__________NpO2OH(aged)     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.20E+00
HCl(aq).......to.titrate.acid.only     0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.50E+02

pmH = -log[m(H+)]                 =     11.1257
pH = -log[a(H+)]     =     10.5454
Osmotic Coefficient=     1.236838
Equilibrium RH (%) =    77.939147
Ionic Strength (m) =     5.645593
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
Density, kg/m3      =      1188.66

NOTES:  - Water 'molality' is mole fraction H2O in aqueous phase
        - Gas 'molality' and 'activity' are gas partial pressures
        - 'Descriptor' means:
          'dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          'Saturation Index for minerals, SI=log10(IAP/Ksp)
          'log10(activity) for aqueous species with very small concentrations
          'log10(partial pressure) for gases

Total G/RT=     -4.67449693E+03
Flashing Titration #            15
# inversions for batch pblm            22
1Benchmark TITRATE Problem, LOG10 option; Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles       Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.95867206E+01   1.11019649E+02   9.94062599E+01   1.00191569E+05  Hydrogen
  3.72253652E+01   5.56624986E+01   4.98398335E+01   7.97407433E+05  Oxygen
  5.47601956E+00   5.61035435E+00   5.02347422E+00   1.15488517E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.96468480E+00   5.50989354E+00   4.93352227E+00   1.74908165E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.49364905E+00   5.08618173E-02   4.55413352E-02   5.46996977E+02  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   2.88102498E-04   2.57965074E-04   6.11501564E+01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -1.86320143E-15  -5.22528680E-15  -4.67868728E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     473.339684533635      grams
    H2O MASS          356.574003417592      grams
    TDS(g/kg)         327.465491025424      g/kgH2O

  Specified Solution Density
    DENSITY           1188.60383111845      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL      0.398231666549681     liters
    TDS               293.210437350984      g/l

  Density based on TDS and NaCl solutions     1188.60383111845      g/l
  Percent relative error vs NaCl density     0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM ,

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.32465E-01   7.79962E-01   0.9369        1.97930E+01   4.97021E+01   8.95393E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.74696E+00   1.00000E+00   1.000         3.47551E+00   8.72736E+00   3.07243E+06
Na+                             Na+   5.61035E+00   5.26665E+00   0.9387        2.00051E+00   5.02347E+00   1.15489E+05
Cl-                             Cl-   5.50989E+00   5.13884E+00   0.9327        1.96468E+00   4.93352E+00   1.74908E+05
CO3=                           CO3=   4.83971E-02   1.24807E-03   2.5788E-02    1.72571E-02   4.33344E-02   2.60046E+03
HCO3-                         HCO3-   1.63010E-03   5.97114E-04   0.3663        5.81251E-04   1.45958E-03   8.90593E+01
OH-                             OH-   6.55397E-04   3.58792E-04   0.5474        2.33698E-04   5.86839E-04   9.98054E+00   -1.54E-09
NpO2(CO3)2=-          NpO2(CO3)2=-    2.94209E-05   8.01487E-10   2.7242E-05    1.04907E-05   2.63433E-05   1.02493E+01    9.68E-10
NpO2(CO3)3=*-        NpO2(CO3)3=*-    2.58546E-04   2.39623E-13   9.2681E-10    9.21906E-05   2.31500E-04   1.03961E+02    2.18E-09
NpO2CO3-                   NpO2CO3-   1.35468E-07   2.44172E-07   1.802         4.83043E-08   1.21297E-07   3.99135E-02    6.09E-12
CO2(aq)                     CO2(aq)   1.25492E-08   3.64751E-08   2.907         4.47472E-09   1.12365E-08   4.94515E-04   -8.67E-08
NpO2+                         NpO2+   4.11022E-10   7.89015E-10   1.920         1.46560E-10   3.68027E-10   9.90165E-05   -1.07E-09
NpO2OH(aq)                NpO2OH(aq)   1.09291E-10   1.09291E-10   1.000         3.89705E-11   9.78589E-11   2.79929E-05    3.69E-08
H+                              H+    5.83272E-12   2.19064E-11   3.756         2.07980E-12   5.22258E-12   5.26384E-09   -3.80E-08
NpO2(OH)2-            NpO2(OH)2-      6.38945E-12   1.89128E-12   0.2960        2.27831E-12   5.72107E-12   1.73384E-06    7.50E-08
Na3H(CO3)2.2H2O_____________Trona     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.13E+00
Na2CO3.H2O__________Thermonatrite     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.05E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.76E+00
Na2CO3.10H2O_______________Natron     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.72E+00
NaHCO3_____________________Nahcolite  0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.10E+00
NaCl_______________________Halite     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.38E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.30E+02
NaOH(aq).....to.titrate.base.only     0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.93E+02
```

Appendix N: Sample Output File "Np_NaCl_BM_LOG.OUT"

```
NpO2OH(amor)__________NpO2OH(amor)     0.00000E+00   1.00000E+00   1.000     0.00000E+00   0.00000E+00   0.00000E+00   -3.83E+00
NpO2OH(aged)__________NpO2OH(aged)     0.00000E+00   1.00000E+00   1.000     0.00000E+00   0.00000E+00   0.00000E+00   -3.23E+00
HCl(aq).......to.titrate.acid.only     0.00000E+00   0.00000E+00   1.000     0.00000E+00   0.00000E+00   0.00000E+00   -2.50E+02

pmH = -log[m(H+)]          .          =     11.2341
pH = -log[a(H+)]     =      10.6594
Osmotic Coefficient=     1.234823
Equilibrium RH (%) =    77.996177
Ionic Strength (m) =     5.661425
Density, kg/m3     =      1188.60

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=     -4.69179003E+03
TITRATE  file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LOG.TITRATE;1
MOLES    file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LOG.MOLES;1
```

Appendix O: Sample Output File "Np_NaCl_BM_LIN.OUT"

See Table 27 for explanation of this listing.

```
INPUT    file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LIN.IN;1
INGUESS  file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LIN.INGUESS;1
OUTPUT   file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LIN.OUT;2
CHEMDAT  file name is U1:[SCBABB.FMT.USERGUIDE]FMT_HMW_NP_AM.CHEMDAT;1
Temperature is Hard Coded as 298.15K
Benchmark TITRATE Problem, LINEAR option; Np(V)O2 with CO3 in 5.61molal NaCl  FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)


*****************************************************************************************************
*** ECHO PRINT OF "CHEMDAT" FILE WOULD BE HERE ***
***                SEE APPENDIX J                ***
*****************************************************************************************************


TITRATION Problem:
 -) Assigning all delta(y) to 0.1 m
 -) Setting # of nodes in Y-direction to 3
 -) Setting NONREACTIVE Porosity to 0.0



Specifying VARIABLE POROSITY for TITRATION Problem


Aqueous Density is a Function of Composition

RHOMIN   file name is U1:[SCBABB.FMT.USERGUIDE]FMT_HMW_NP_AM.RHOMIN;1

*****************************************************************************************************
*** TABLE OF MINERAL DENSITIES, KG/M^3 WOULD BE HERE ***
***                SEE APPENDIX L                ***
*****************************************************************************************************

GRID BLOCK VOLUMES, in liters
 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

# inversions for batch pblm          50
1Benchmark TITRATE Problem, LINEAR option; Np(V)O2 with CO3 in 5.61molal NaCl  FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles       Aq. Molality      Aq. Molarity      Aq. mg/liter

  1.11017363E+02   1.11029658E+02   1.00100314E+02   1.00891107E+05  Hydrogen
  6.15086815E+01   6.15154934E+01   5.54601388E+01   8.87328944E+05  Oxygen
  5.61000000E+00   5.61062129E+00   5.05833276E+00   1.16289907E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.61000000E+00   1.61017830E+00   1.45167838E+00   5.14663538E+04  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  2.00000001E+00   2.00022150E+00   1.80332719E+00   2.16597629E+04  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -2.22044605E-15  -2.22069196E-15  -2.00209536E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     1306.07033909890      grams
    H2O MASS          999.889265717486      grams
```

Appendix O: Sample Output File "Np_NaCl_BM_LIN.OUT"

```
  TDS(g/kg)          306.214981877726      g/kgH2O

 Specified Solution Density
  DENSITY            1177.63607439302      kg/m^3 = g/l

 Solution Parameters Based on Specified Density
  SOLUTION VOL       1.10906108219560      liters
  TDS                276.072326670473      g/l

 Density based on TDS and NaCl solutions    1177.63607439302      g/l
 Percent relative error vs NaCl density    0.000000000000000E+000 %


 TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

 Species Name                              Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

 H2O                            WATER      8.57464E-01  8.59843E-01   1.003       5.55025E+01  5.00446E+01  9.01564E+05
 Na+                              Na+      5.61062E+00  3.69881E+00  0.6593       5.61000E+00  5.05833E+00  1.16290E+05
 CO3=                            CO3=      1.99407E+00  4.09214E-02  2.0522E-02   1.99385E+00  1.79778E+00  1.07884E+05
 Cl-                              Cl-      1.61018E+00  1.06477E+00  0.6613       1.61000E+00  1.45168E+00  5.14664E+04
 HCO3-                          HCO3-      6.14734E-03  1.59044E-03  0.2587       6.14666E-03  5.54222E-03  3.38170E+02
 OH-                              OH-      6.14733E-03  4.86901E-03  0.7921       6.14665E-03  5.54221E-03  9.42580E+01   2.00E-11
 CO2(aq)                       CO2(aq)     2.36876E-09  7.15913E-09   3.022       2.36850E-09  2.13559E-09  9.39868E-05  -2.12E-07
 H+                                H+      2.39954E-12  1.77959E-12  0.7416       2.39927E-12  2.16334E-12  2.18043E-09  -8.58E-08
 Na3H(CO3)2.2H2O_____________Trona         0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -1.57E+00
 HCl(aq).......to.titrate.acid.only         0.00000E+00  0.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -2.52E+02
 NaOH(aq)......to.titrate.base.only         0.00000E+00  0.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -2.92E+02
 NaCl_________________________Halite        0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -9.75E-01
 NaHCO3_______________________Nahcolite     0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -1.83E+00
 Na2CO3.7H2O____Na2CO3-Heptahydrate         0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -2.51E-01
 Na2CO3.H2O___________Thermonatrite         0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -7.99E-01
 Na2CO3.10H2O_________________Natron        0.00000E+00  1.00000E+00   1.000       0.00000E+00  0.00000E+00  0.00000E+00  -8.30E-02

 pmH = -log[m(H+)]                    =     11.6199
 pH = -log[a(H+)]     =     11.7497
 Osmotic Coefficient=    0.908418
 Equilibrium RH (%) =   85.984284
 Ionic Strength (m) =    7.604695
 Density, kg/m3     =    1177.64

 NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
         - Gas "molality" and "activity" are gas partial pressures
         - "Descriptor" means:
           *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
           *Saturation Index for minerals, SI=log10(IAP/Ksp)
           *log10(activity) for aqueous species with very small concentrations
           *log10(partial pressure) for gases

 Total G/RT=    -6.42133776E+03

 Reaction #            1 sldsum    2.00000000000000
 This is a solid-only reaction

 shifting left by    4.64434654478256
 calling makenuv for allomorphic reactions
 # inversions for batch pblm          75
1Benchmark TITRATE Problem, LINEAR option; Np(V)O2 with CO3 in 5.6lmolal NaCl  FMT V2.0
 DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
 95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

 Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  1.11018363E+02   1.11017591E+02   9.93838868E+01   1.00169020E+05  Hydrogen
  1.05508682E+02   5.55113597E+01   4.96942389E+01   7.95078006E+05  Oxygen
  1.56100000E+01   5.61057382E+00   5.02263316E+00   1.15469181E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  5.61100000E+00   5.61096098E+00   5.02297975E+00   1.78079701E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  1.00000000E+01   6.12839261E-04   5.48618892E-04   6.58946152E+00  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  1.00000000E+01   6.12839261E-04   5.48618892E-04   1.30049121E+02  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -2.37316632E-15  -2.37314981E-15  -2.12446380E-15   0.00000000E+00  Charge
```

Appendix O: Sample Output File "Np_NaCl_BM_LIN.OUT"

```
Solution Parameters, Calculated
  SOLUTION MASS      1328.11614865142      grams
  H2O MASS           1000.00695466819      grams
  TDS(g/kg)          328.106912108529      g/kgH2O

Specified Solution Density
  DENSITY            1188.93254605477      kg/m^3 = g/l

Solution Parameters Based on Specified Density
  SOLUTION VOL       1.11706602116201      liters
  TDS                293.724084134187      g/l

Density based on TDS and NaCl solutions    1188.93254605477      g/l
Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31822E-01   7.77959E-01   0.9352        5.55091E+01   4.96918E+01   8.95208E+05
NaNpO2CO3(s)_____________NaNpO2CO3(s)  9.99932E+00   1.00000E+00   1.000         9.99939E+00   8.95147E+00   3.15133E+06
Cl-                             Cl-    5.61096E+00   5.29329E+00   0.9434        5.61100E+00   5.02298E+00   1.78080E+05
Na+                             Na+    5.61057E+00   5.29268E+00   0.9433        5.61061E+00   5.02263E+00   1.15469E+05
NpO2+                         NpO2+    6.12705E-04   1.21978E-03   1.991         6.12709E-04   5.48499E-04   1.47572E+02
CO2(aq)                     CO2(aq)    3.86103E-04   1.12115E-03   2.904         3.86106E-04   3.45643E-04   1.52117E+01
HCO3-                         HCO3-    2.26571E-04   8.38810E-05   0.3702        2.26573E-04   2.02829E-04   1.23760E+01   4.26E-09
NpO2CO3-                    NpO2CO3-   1.33526E-07   2.42971E-07   1.820         1.33527E-07   1.19534E-07   3.93334E-02  -1.99E-11
H+                              H+     1.21872E-06   4.78095E-06   3.923         1.21873E-06   1.09101E-06   1.09962E-03  -4.38E-08
CO3=                           CO3=    3.09384E-08   8.03342E-10   2.5966E-02    3.09386E-08   2.76963E-08   1.66203E-03  -1.62E-07
OH-                             OH-    3.01685E-09   1.63977E-09   0.5435        3.01687E-09   2.70071E-09   4.59318E-05   2.55E-08
NpO2OH(aq)                 NpO2OH(aq)  7.72186E-10   7.72186E-10   1.000         7.72191E-10   6.91267E-10   1.97740E-04   1.87E-07
NpO2(CO3)2=-             NpO2(CO3)2=-  1.98384E-11   5.13354E-16   2.5877E-05    1.98385E-11   1.77595E-11   6.90960E-06  -1.62E-07
NpO2(OH)2-                NpO2(OH)2-   2.04382E-16   6.10703E-17   0.2988        2.04383E-16   1.82964E-16   5.54494E-11   2.13E-07
NpO2(CO3)3==-           NpO2(CO3)3==-  1.25197E-16   9.87896E-26   7.8908E-10    1.25198E-16   1.12077E-16   5.03310E-11  -3.23E-07
NpO2OH(aged)_________NpO2OH(aged)      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.38E+00
NaOH(aq).......to.titrate.base.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.99E+02
HCl(aq).......to.titrate.acid.only     0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.45E+02
Na3NpO2(CO3)2(s)_DISABLED_DISABLED     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -9.36E+02
NaCl_____________________Halite        0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -1.23E-01
NaHCO3___________________Nahcolite     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.95E+00
Na2CO3.10H2O_____________Natron        0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -7.91E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -7.95E+00
Na2CO3.H2O_____________Thermonatrite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -8.24E+00
Na3H(CO3)2.2H2O_______________Trona    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -1.02E+01
NpO2OH(amor)_________NpO2OH(amor)      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.98E+00

pmH = -log[m(H+)]                 =      5.9141
pH = -log[a(H+)]     =      5.3205
Osmotic Coefficient=     1.241871
Equilibrium RH (%) =    77.795863
Ionic Strength (m) =     5.611188
Density, kg/m3     =      1188.93

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -1.33323084E+04
Flashing Titration #          1
# inversions for batch pblm          11
1Benchmark TITRATE Problem, LINEAR option; Np(V)O2 with CO3 in 5.61molal NaCl  FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.85857174E+01   1.11017591E+02   9.93838868E+01   1.00169020E+05  Hydrogen
  3.66707638E+01   5.55113597E+01   4.96942389E+01   7.95078006E+05  Oxygen
  5.42543623E+00   5.61057382E+00   5.02263316E+00   1.15469181E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95016801E+00   5.61096098E+00   5.02297975E+00   1.78079701E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47561578E+00   6.12839260E-04   5.48618892E-04   6.58946151E+00  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
```

Appendix O: Sample Output File "Np_NaCl_BM_LIN.OUT"

```
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   6.12839260E-04   5.48618892E-04   1.30049121E+02  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -6.94525850E-16  -1.99826754E-15  -1.78886601E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     461.602144251012      grams
    H2O MASS          347.563995068956      grams
    TDS(g/kg)         328.106912108175      g/kgH2O

  Specified Solution Density
    DENSITY           1188.93254605459      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.388249228926247       liters
    TDS               293.724084133903      g/l

  Density based on TDS and NaCl solutions    1188.93254605459      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31822E-01   7.77959E-01   0.9352        1.92928E+01   4.96918E+01   8.95208E+05
NaNpO2CO3(s)__________NaNpO2CO3(s)    9.99932E+00   1.00000E+00   1.000         3.47540E+00   8.95147E+00   3.15133E+06
Cl-                             Cl-   5.61096E+00   5.29329E+00   0.9434        1.95017E+00   5.02298E+00   1.78080E+05
Na+                             Na+   5.61057E+00   5.29268E+00   0.9433        1.95003E+00   5.02263E+00   1.15469E+05
NpO2+                          NpO2+  6.12705E-04   1.21978E-03   1.991         2.12954E-04   5.48499E-04   1.47572E+02
CO2(aq)                      CO2(aq)  3.86103E-04   1.12115E-03   2.904         1.34196E-04   3.45643E-04   1.52117E+01
HCO3-                          HCO3-  2.26571E-04   8.38810E-05   0.3702        7.87481E-05   2.02829E-04   1.23760E+01   -6.17E-15
H+                                 H+  1.21872E-06   4.78095E-06   3.923         4.23582E-07   1.09101E-06   1.09962E-03    6.17E-15
NpO2CO3-                     NpO2CO3-  1.33526E-07   2.42971E-07   1.820         4.64090E-08   1.19534E-07   3.93334E-02    1.85E-14
CO3=                            CO3=   3.09384E-08   8.03343E-10   2.5966E-02    1.07531E-08   2.76963E-08   1.66203E-03    0.00E+00
OH-                             OH-    3.01685E-09   1.63977E-09   0.5435        1.04855E-09   2.70071E-09   4.59318E-05   -6.17E-15
NpO2OH(aq)                 NpO2OH(aq)  7.72186E-10   7.72186E-10   1.000         2.68384E-10   6.91267E-10   1.97740E-04    0.00E+00
NpO2(CO3)2=-             NpO2(CO3)2=-  1.98384E-11   5.13355E-16   2.5877E-05    6.89511E-12   1.77595E-11   5.90960E-06    0.00E+00
NpO2(OH)2-               NpO2(OH)2-    2.04381E-16   6.10703E-17   0.2988        7.10356E-17   1.82964E-16   5.54494E-11    1.23E-14
NpO2(CO3)3==-          NpO2(CO3)3==-   1.25197E-16   9.87897E-26   7.8908E-10    4.35139E-17   1.12077E-16   3.03310E-11   -3.53E-10
HCl(aq).......to.titrate.acid.only     0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.45E+02
NpO2OH(aged)__________NpO2OH(aged)     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.38E+00
NpO2OH(amor)__________NpO2OH(amor)     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.98E+00
NaOH(aq).......to.titrate.base.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.99E+02
Na3NpO2(CO3)2(s)_DISABLED_DISABLED     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.36E+02
NaCl_______________________Halite      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.23E-01
NaHCO3_____________________Nahcolite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.95E+00
Na2CO3.10H2O_______________Natron      0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -7.91E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -7.95E+00
Na2CO3.H2O_____________Thermonatrite   0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -8.24E+00
Na3H(CO3)2.2H2O_______________Trona    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.02E+01

pmH = -log[m(H+)]                 =      5.9141
pH = -log[a(H+)]     =      5.3205
Osmotic Coefficient=    1.241871
Equilibrium RH (%) =   77.795863
Ionic Strength (m) =    5.611188
Density, kg/m3     =     1188.93

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -4.63379813E+03

*****************************************************************************************
*** SUMMARY INFORMATION FOR ADDITION OF DV(2)...DV(14) WOULD BE HERE ***
*****************************************************************************************


Flashing Titration #          15
# inversions for batch pblm          23
1Benchmark TITRATE Problem, LINEAR option: Np(V)O2 with CO3 in 5.61molal NaCl  FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter
```

Appendix O: Sample Output File "Np_NaCl_BM_LIN.OUT"

```
  3.87258579E+01   1.11018601E+02   9.93937371E+01   1.00178948E+05  Hydrogen
  3.67484080E+01   5.55305592E+01   4.97159013E+01   7.95424591E+05  Oxygen
  5.43251790E+00   5.61002101E+00   5.02259034E+00   1.15468197E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95220036E+00   5.59653330E+00   5.01051495E+00   1.77637786E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47814044E+00   7.24644343E-03   6.48766141E-03   7.79233012E+01  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   8.79854005E-06   7.87723651E-06   1.86728474E+00  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -9.13270924E-16  -2.61814885E-15  -2.34399998E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     463.176929136630      grams
    H2O MASS          348.823147935362      grams
    TDS(g/kg)         327.827387253719      g/kgH2O

  Specified Solution Density
    DENSITY           1188.78931208719      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.389620704381517       liters
    TDS               293.500268120485      g/l

  Density based on TDS and NaCl solutions    1188.78931208719      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                              Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                              WATER    8.31932E-01   7.78290E-01   0.9355        1.93627E+01   4.96963E+01   8.95289E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)         9.96382E+00   1.00000E+00   1.000         3.47561E+00   8.92050E+00   3.14043E+06
Na+                               Na+     5.61002E+00   5.28628E+00   0.9423        1.95691E+00   5.02259E+00   1.15468E+05
Cl-                               Cl-     5.59653E+00   5.27166E+00   0.9420        1.95220E+00   5.01051E+00   1.77638E+05
CO3=                             CO3=     6.10711E-03   1.58505E-04   2.5954E-02    2.13030E-03   5.46763E-03   3.28108E+02
HCO3-                            HCO3-    1.11706E-03   4.13103E-04   0.3698        3.89655E-04   1.00009E-03   6.10225E+01
OH-                               OH-     1.20768E-04   6.57227E-05   0.5442        4.21267E-05   1.08122E-04   1.83887E+00   -1.39E-10
NpO2(CO3)2=-          NpO2(CO3)2=-        3.89199E-06   1.01411E-10   2.6056E-05    1.35762E-06   3.48446E-06   1.35568E+00    5.14E-10
NpO2(CO3)3==-         NpO2(CO3)3==-       4.76942E-06   3.85055E-15   8.0734E-10    1.66368E-06   4.27001E-06   1.91755E+00    1.15E-09
CO2(aq)                         CO2(aq)   4.74407E-08   1.37761E-07   2.904         1.65484E-08   4.24731E-08   1.86923E-03   -7.11E-09
NpO2CO3-                       NpO2CO3-   1.33846E-07   2.43265E-07   1.817         4.66887E-08   1.19831E-07   3.94312E-02    3.15E-13
NpO2+                             NpO2+    3.12502E-09   6.18962E-09   1.981         1.09008E-09   2.79779E-09   7.52738E-04   -5.05E-10
H+                                 H+      3.06048E-11   1.19335E-10   3.899         1.06757E-11   2.74002E-11   2.76166E-08   -3.76E-09
NpO2OH(aq)                    NpO2OH(aq)   1.57050E-10   1.57050E-10   1.000         5.47826E-11   1.40605E-10   4.02206E-05    3.26E-09
NpO2(OH)2-                    NpO2(OH)2-   1.66773E-12   4.97826E-13   0.2985        5.81743E-13   1.49310E-12   4.52501E-07    7.03E-09
Na3H(CO3)2.2H2O_______________Trona        0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -4.19E+00
Na2CO3.H2O____________Thermonatrite        0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.94E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate         0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.66E+00
Na2CO3.10H2O_________________Natron        0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.62E+00
NaHCO3_____________________Nahcolite       0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.26E+00
NaCl_______________________Halite          0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.25E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED         0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.31E+02
NaOH(aq).......to.titrate.base.only        0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.94E+02
NpO2OH(amor)__________NpO2OH(amor)         0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.67E+00
NpO2OH(aged)__________NpO2OH(aged)         0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -3.08E+00
HCl(aq).......to.titrate.acid.only         0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.49E+02

pmH = -log[m(H+)]                  =      10.5142
pH = -log[a(H+)]     =       9.9232
Osmotic Coefficient=     1.240746
Equilibrium RH (%) =    77.828965
Ionic Strength (m) =     5.616187
Density, kg/m3     =      1188.79

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          "dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          "Saturation Index for minerals, SI=log10(IAP/Ksp)
          "log10(activity) for aqueous species with very small concentrations
          "log10(partial pressure) for gases

Total G/RT=     -4.64192502E+03
TITRATE  file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LIN.TITRATE;2
```

Appendix O: Sample Output File "Np_NaCl_BM_LIN.OUT"

```
MOLES    file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM_LIN.MOLES;1
```

Appendix P: Sample Output File "Np_NaCl_BM.OUT"

See Table 27 for explanation of this listing.

```
INPUT    file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM.IN;1
INGUESS  file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM.INGUESS;1
OUTPUT   file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM.OUT;1
CHEMDAT  file name is U1:[SCBABB.FMT.USERGUIDE]FMT_HMW_NP_AM.CHEMDAT;1
Temperature is Hard Coded as 298.15K
Benchmark TITRATE Problem; Np(V)O2 with CO3 in 5.61molal NaCl                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

*****************************************************************************************************
*** ECHO PRINT OF "CHEMDAT" FILE WOULD BE HERE ***
***                SEE APPENDIX J                ***
*****************************************************************************************************


TITRATION Problem:
 -) Assigning all delta(y) to 0.1 m
 -) Setting # of nodes in Y-direction to 3
 -) Setting NONREACTIVE Porosity to 0.0



Specifying VARIABLE POROSITY for TITRATION Problem


Aqueous Density is a Function of Composition

RHOMIN   file name is U1:[SCBABB.FMT.USERGUIDE]FMT_HMW_NP_AM.RHOMIN;1

*****************************************************************************************************
*** TABLE OF MINERAL DENSITIES, KG/M^3 WOULD BE HERE ***
***                SEE APPENDIX L                ***
*****************************************************************************************************

GRID BLOCK VOLUMES, in liters
 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

 1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00
 1.00E+00  1.00E+00

# inversions for batch pblm          50
1Benchmark TITRATE Problem; Np(V)O2 with CO3 in 5.61molal NaCl                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  1.11017363E+02   1.11029658E+02   1.00100314E+02   1.00891107E+05  Hydrogen
  6.15086815E+01   6.15154934E+01   5.54601388E+01   8.87328944E+05  Oxygen
  5.61000000E+00   5.61062129E+00   5.05833276E+00   1.16289907E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.61000000E+00   1.61017830E+00   1.45167838E+00   5.14663538E+04  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  2.00000001E+00   2.00022150E+00   1.80332719E+00   2.16597629E+04  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -2.22044605E-15  -2.22069196E-15  -2.00209536E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     1306.07033909890      grams
    H2O MASS          999.889265717486      grams
```

Appendix P: Sample Output File "Np_NaCl_BM.OUT"

```
    TDS(g/kg)          306.214981877726      g/kgH2O

  Specified Solution Density
    DENSITY            1177.63607439302      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL       1.10906108219560      liters
    TDS                276.072326670473      g/l

  Density based on TDS and NaCl solutions    1177.63607439302      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.57464E-01   8.59843E-01    1.003        5.55025E+01   5.00446E+01   9.01564E+05
Na+                            Na+    5.61062E+00   3.69881E+00   0.6593        5.61000E+00   5.05833E+00   1.16290E+05
CO3=                          CO3=    1.99407E+00   4.09214E-02   2.0522E-02    1.99385E+00   1.79778E+00   1.07884E+05
Cl-                            Cl-    1.61018E+00   1.06477E+00   0.6613        1.61000E+00   1.45168E+00   5.14664E+04
HCO3-                        HCO3-    6.14734E-03   1.59044E-03   0.2587        6.14666E-03   5.54222E-03   3.38170E+02
OH-                            OH-    6.14733E-03   4.86901E-03   0.7921        6.14665E-03   5.54221E-03   9.42580E+01   2.00E-11
CO2(aq)                     CO2(aq)   2.36876E-09   7.15913E-09    3.022        2.36850E-09   2.13559E-09   9.39868E-05  -2.12E-07
H+                             H+     2.39954E-12   1.77959E-12   0.7416        2.39927E-12   2.16334E-12   2.18043E-09  -8.58E-08
Na3H(CO3)2.2H2O_____________Trona     0.00000E+00   1.00000E+00    1.000        0.00000E+00   0.00000E+00   0.00000E+00  -1.57E+00
HCl(aq).......to.titrate.acid.only     0.00000E+00   0.00000E+00    1.000        0.00000E+00   0.00000E+00   0.00000E+00  -2.52E+02
NaOH(aq)......to.titrate.base.only     0.00000E+00   0.00000E+00    1.000        0.00000E+00   0.00000E+00   0.00000E+00  -2.92E+02
NaCl_______________________Halite     0.00000E+00   1.00000E+00    1.000        0.00000E+00   0.00000E+00   0.00000E+00  -9.75E-01
NaHCO3_____________________Nahcolite  0.00000E+00   1.00000E+00    1.000        0.00000E+00   0.00000E+00   0.00000E+00  -1.83E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00    1.000        0.00000E+00   0.00000E+00   0.00000E+00  -2.51E-01
Na2CO3.H2O__________Thermonatrite     0.00000E+00   1.00000E+00    1.000        0.00000E+00   0.00000E+00   0.00000E+00  -7.99E-01
Na2CO3.10H2O_______________Natron     0.00000E+00   1.00000E+00    1.000        0.00000E+00   0.00000E+00   0.00000E+00  -8.30E-02

pmH = -log[m(H+)]                  =     11.6199
pH = -log[a(H+)]     =     11.7497
Osmotic Coefficient=    0.908418
Equilibrium RH (%) =   85.984284
Ionic Strength (m) =    7.604695
Density, kg/m3     =     1177.64

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          "dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          "Saturation Index for minerals, SI=log10(IAP/Ksp)
          "log10(activity) for aqueous species with very small concentrations
          "log10(partial pressure) for gases

Total G/RT=    -6.42133776E+03

Reaction #            1 sldsum    2.00000000000000
This is a solid-only reaction

shifting left by    4.64434654478256
calling makenuv for allomorphic reactions
# inversions for batch pblm          75
1Benchmark TITRATE Problem; Np(V)O2 with CO3 in 5.61molal NaCl                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem'

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  1.11018363E+02   1.11017591E+02   9.93638868E+01   1.00169020E+05  Hydrogen
  1.05508682E+02   5.55113597E+01   4.96942389E+01   7.95078006E+05  Oxygen
  1.56100000E+01   5.61057382E+00   5.02263316E+00   1.15469181E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  5.61100000E+00   5.61096098E+00   5.02297975E+00   1.78079701E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  1.00000000E+01   6.12839261E-04   5.48618892E-04   6.58946152E+00  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  1.00000000E+01   6.12839261E-04   5.48618892E-04   1.30049121E+02  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -2.37316632E-15  -2.37314981E-15  -2.12446380E-15   0.00000000E+00  Charge
```

Appendix P: Sample Output File "Np_NaCl_BM.OUT"

```
  Solution Parameters, Calculated
    SOLUTION MASS      1328.11614865142      grams
    H2O MASS           1000.00695466819      grams
    TDS(g/kg)          328.106912108529      g/kgH2O

  Specified Solution Density
    DENSITY            1188.93254605477      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL       1.11706602116201      liters
    TDS                293.724084134187      g/l

  Density based on TDS and NaCl solutions     1188.93254605477      g/l
  Percent relative error vs NaCl density     0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31822E-01   7.77959E-01   0.9352        5.55091E+01   4.96918E+01   8.95208E+05
NaNpO2CO3(s)__________NaNpO2CO3(s)    9.99932E+00   1.00000E+00   1.000         9.99939E+00   8.95147E+00   3.15133E+06
Cl-                            Cl-    5.61096E+00   5.29329E+00   0.9434        5.61100E+00   5.02298E+00   1.78080E+05
Na+                            Na+    5.61057E+00   5.29268E+00   0.9433        5.61061E+00   5.02263E+00   1.15469E+05
NpO2+                        NpO2+    6.12705E-04   1.21978E-03   1.991         6.12709E-04   5.48499E-04   1.47572E+02
CO2(aq)                    CO2(aq)    3.86103E-04   1.12115E-03   2.904         3.86106E-04   3.45643E-04   1.52117E+01
HCO3-                        HCO3-    2.26571E-04   8.38810E-05   0.3702        2.26573E-04   2.02829E-04   1.23760E+01   4.26E-09
NpO2CO3-                   NpO2CO3-   1.33526E-07   2.42971E-07   1.820         1.33527E-07   1.19534E-07   3.93334E-02  -1.99E-11
H+                             H+     1.21872E-06   4.78095E-06   3.923         1.21873E-06   1.09101E-06   1.09962E-03  -4.38E-08
CO3=                         CO3=     3.09384E-08   8.03342E-10   2.5966E-02    3.09386E-08   2.76963E-08   1.66203E-03  -1.62E-07
OH-                           OH-     3.01685E-09   1.63977E-09   0.5435        3.01687E-09   2.70071E-09   4.59318E-05   2.55E-08
NpO2OH(aq)               NpO2OH(aq)   7.72186E-10   7.72186E-10   1.000         7.72191E-10   6.91267E-10   1.97740E-04   1.87E-07
NpO2(CO3)2=-           NpO2(CO3)2=-   1.98384E-11   5.13354E-16   2.5877E-05    1.98385E-11   1.77595E-11   6.90960E-06  -1.62E-07
NpO2(OH)2-               NpO2(OH)2-   2.04382E-16   6.10703E-17   0.2988        2.04383E-16   1.82964E-16   5.54494E-11   2.13E-07
NpO2(CO3)3==-          NpO2(CO3)3==-  1.25197E-16   9.87896E-26   7.8908E-10    1.25198E-16   1.12077E-16   5.03310E-11  -3.23E-07
NpO2OH(aged)__________NpO2OH(aged)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.38E+00
NaOH(aq).......to.titrate.base.only   0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.99E+02
HCl(aq).......to.titrate.acid.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.45E+02
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -9.36E+02
NaCl_____________________________Halite 0.00000E+00 1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -1.23E-01
NaHCO3_____________________Nahcolite  0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.95E+00
Na2CO3.10H2O_____________Natron       0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -7.91E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -7.95E+00
Na2CO3.H2O___________Thermonatrite    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -8.24E+00
Na3H(CO3)2.2H2O_____________Trona     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -1.02E+01
NpO2OH(amor)__________NpO2OH(amor)    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00  -2.98E+00

pmH = -log[m(H+)]                 =      5.9141
pH = -log[a(H+)]     =      5.3205
Osmotic Coefficient=     1.241871
Equilibrium RH (%) =    77.795863
Ionic Strength (m) =     5.611188
Density, kg/m3     =     1188.93

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -1.33323084E+04
Flashing Titration #          1
# inversions for batch pblm          11
1Benchmark TITRATE Problem; Np(V)O2 with CO3 in 5.61molal NaCl                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter

  3.85857174E+01   1.11017591E+02   9.93838868E+01   1.00169020E+05  Hydrogen
  3.66707638E+01   5.55113597E+01   4.96942389E+01   7.95078006E+05  Oxygen
  5.42543623E+00   5.61057382E+00   5.02263316E+00   1.15469181E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.95016801E+00   5.61096098E+00   5.02297975E+00   1.78079701E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.47561578E+00   6.12839260E-04   5.48618892E-04   6.58946151E+00  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
```

Appendix P: Sample Output File "Np_NaCl_BM.OUT"

```
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   6.12839260E-04   5.48618892E-04   1.30049121E+02  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -6.94525850E-16  -1.99826754E-15  -1.78886601E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     461.602144251012      grams
    H2O MASS          347.563995068956      grams
    TDS(g/kg)         328.106912108175      g/kgH2O

  Specified Solution Density
    DENSITY           1188.93254605459      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL     0.388249228926247      liters
    TDS               293.724084133903      g/l

  Density based on TDS and NaCl solutions    1188.93254605459      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality      Activity      Act Coef      Total Moles   Molarity      mg/liter      Descriptor

H2O                          WATER    8.31822E-01   7.77959E-01   0.9352        1.92928E+01   4.96918E+01   8.95208E+05
NaNpO2CO3(s)_________NaNpO2CO3(s)     9.99932E+00   1.00000E+00   1.000         3.47540E+00   8.95147E+00   3.15133E+06
Cl-                            Cl-    5.61096E+00   5.29329E+00   0.9434        1.95017E+00   5.02298E+00   1.78080E+05
Na+                            Na+    5.61057E+00   5.29268E+00   0.9433        1.95003E+00   5.02263E+00   1.15469E+05
NpO2+                        NpO2+    6.12705E-04   1.21978E-03   1.991         2.12954E-04   5.48499E-04   1.47572E+02
CO2(aq)                    CO2(aq)    3.86103E-04   1.12115E-03   2.904         1.34196E-04   3.45643E-04   1.52117E+01
HCO3-                        HCO3-    2.26571E-04   8.38810E-05   0.3702        7.87481E-05   2.02829E-04   1.23760E+01   -6.17E-15
H+                             H+     1.21872E-06   4.78095E-06   3.923         4.23582E-07   1.09101E-06   1.09962E-03    6.17E-15
NpO2CO3-                   NpO2CO3-   1.33526E-07   2.42971E-07   1.820         4.64090E-08   1.19534E-07   3.93334E-02    1.85E-14
CO3=                          CO3=    3.09384E-08   8.03343E-10   2.5966E-02    1.07531E-08   2.76963E-08   1.66203E-03    0.00E+00
OH-                            OH-    3.01685E-09   1.63977E-09   0.5435        1.04855E-09   2.70071E-09   4.59318E-05   -6.17E-15
NpO2OH(aq)               NpO2OH(aq)   7.72186E-10   7.72186E-10   1.000         2.68384E-10   6.91267E-10   1.97740E-04    0.00E+00
NpO2(CO3)2=-           NpO2(CO3)2=-   1.98384E-11   5.13355E-16   2.5877E-05    6.89511E-12   1.77595E-11   6.90960E-06    0.00E+00
NpO2(OH)2-               NpO2(OH)2-   2.04381E-16   6.10703E-17   0.2988        7.10356E-17   1.82964E-16   5.54494E-11    1.23E-14
NpO2(CO3)3==-          NpO2(CO3)3==-  1.25197E-16   9.87897E-26   7.8908E-10    4.35139E-17   1.12077E-16   5.03310E-11   -3.53E-10
HCl(aq).......to.titrate.acid.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.45E+02
NpO2OH(aged)_________NpO2OH(aged)     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.38E+00
NpO2OH(amor)_________NpO2OH(amor)     0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.98E+00
NaOH(aq)......to.titrate.base.only    0.00000E+00   0.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.99E+02
Na3NpO2(CO3)2(s)_DISABLED_DISABLED    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -9.36E+02
NaCl_____________________Halite       0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.23E-01
NaHCO3___________________Nahcolite    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -2.95E+00
Na2CO3.10H2O_____________Natron       0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -7.91E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate    0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -7.95E+00
Na2CO3.H2O_____________Thermonatrite  0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -8.24E+00
Na3H(CO3)2.2H2O_________________Trona 0.00000E+00   1.00000E+00   1.000         0.00000E+00   0.00000E+00   0.00000E+00   -1.02E+01

pmH = -log[m(H+)]                 =      5.9141
pH = -log[a(H+)]     =      5.3205
Osmotic Coefficient=     1.241871
Equilibrium RH (%) =    77.795863
Ionic Strength (m) =     5.611188
Density, kg/m3     =      1188.93

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=    -4.63379813E+03

*****************************************************************************************
*** SUMMARY INFORMATION FOR ADDITION OF DV(2)...DV(14) WOULD BE HERE ***
*****************************************************************************************


Flashing Titration #          15
# inversions for batch pblm          22
1Benchmark TITRATE Problem; Np(V)O2 with CO3 in 5.61molal NaCl                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)
    Pressure=     1.00000E+00 [=] ATM     Temperature=     2.98E+02 [=] Kelvin

Elemental Abundances for Flash Problem

  Total Moles      Aq. Molality     Aq. Molarity     Aq. mg/liter
```

Appendix P: Sample Output File "Np_NaCl_BM.OUT"

```
  3.95867206E+01   1.11019649E+02   9.94062599E+01   1.00191569E+05  Hydrogen
  3.72253652E+01   5.56624986E+01   4.98398335E+01   7.97407433E+05  Oxygen
  5.47601956E+00   5.61035435E+00   5.02347422E+00   1.15488517E+05  Sodium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Potassium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Magnesium
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Calcium
  1.96468480E+00   5.50989354E+00   4.93352227E+00   1.74908165E+05  Chlorine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Sulfur
  3.49364905E+00   5.08618173E-02   4.55413352E-02   5.46996977E+02  Carbon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  PosIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  NegIon
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Air
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Boron
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Bromine
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  TracerEl
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Th(IV)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Am(III)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  U(VI)
  3.47561578E+00   2.88102498E-04   2.57965074E-04   6.11501564E+01  Np(V)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  ClO4-(EL)
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Phosphorus
  0.00000000E+00   0.00000000E+00   0.00000000E+00   0.00000000E+00  Electron
 -1.85235941E-15  -5.19488071E-15  -4.65146187E-15   0.00000000E+00  Charge

  Solution Parameters, Calculated
    SOLUTION MASS     473.339684533635      grams
    H2O MASS          356.574003417592      grams
    TDS(g/kg)         327.465491025424      g/kgH2O

  Specified Solution Density
    DENSITY           1188.60383111845      kg/m^3 = g/l

  Solution Parameters Based on Specified Density
    SOLUTION VOL    0.398231666549681       liters
    TDS               293.210437350984      g/l

  Density based on TDS and NaCl solutions     1188.60383111845      g/l
  Percent relative error vs NaCl density    0.000000000000000E+000 %


TABLE OF CONCENTRATIONS FOR BATCH SYSTEM

Species Name                          Molality     Activity     Act Coef     Total Moles   Molarity     mg/liter     Descriptor

H2O                          WATER    8.32465E-01  7.79962E-01  0.9369       1.97930E+01  4.97021E+01  8.95393E+05
NaNpO2CO3(s)_____________NaNpO2CO3(s) 9.74696E+00  1.00000E+00  1.000        3.47551E+00  8.72736E+00  3.07243E+06
Na+                             Na+  5.61035E+00  5.26665E+00  0.9387       2.00051E+00  5.02347E+00  1.15489E+05
Cl-                             Cl-  5.50989E+00  5.13884E+00  0.9327       1.96468E+00  4.93352E+00  1.74908E+05
CO3=                           CO3=  4.83971E-02  1.24807E-03  2.5788E-02   1.72571E-02  4.33344E-02  2.60046E+03
HCO3-                         HCO3-  1.63010E-03  5.97114E-04  0.3663       5.81251E-04  1.45958E-03  8.90593E+01
OH-                             OH-  6.55397E-04  3.58792E-04  0.5474       2.33698E-04  5.86839E-04  9.98054E+00  -1.54E-09
NpO2(CO3)2=-          NpO2(CO3)2=-   2.94209E-05  8.01487E-10  2.7242E-05   1.04907E-05  2.63433E-05  1.02493E+01   9.68E-10
NpO2(CO3)3===-        NpO2(CO3)3===- 2.58546E-04  2.39623E-13  9.2681E-10   9.21906E-05  2.31500E-04  1.03961E+02   2.18E-09
NpO2CO3-                 NpO2CO3-    1.35468E-07  2.44172E-07  1.802        4.83043E-08  1.21297E-07  3.99135E-02   6.09E-12
CO2(aq)                   CO2(aq)    1.25492E-08  3.64751E-08  2.907        4.47472E-09  1.12365E-08  4.94515E-04  -8.67E-08
NpO2+                       NpO2+    4.11022E-10  7.89015E-10  1.920        1.46560E-10  3.68027E-10  9.90165E-05  -1.07E-09
NpO2OH(aq)             NpO2OH(aq)    1.09291E-10  1.09291E-10  1.000        3.89705E-11  9.78589E-11  2.79929E-05   3.69E-08
H+                              H+   5.83272E-12  2.19064E-11  3.756        2.07980E-12  5.22258E-12  5.26384E-09  -3.80E-08
NpO2(OH)2-            NpO2(OH)2-     6.38945E-12  1.89128E-12  0.2960       2.27831E-12  5.72107E-12  1.73384E-06   7.50E-08
Na3H(CO3)2.2H2O_______________Trona  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.13E+00
Na2CO3.H2O___________Thermonatrite   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.05E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.76E+00
Na2CO3.10H2O_________________Natron  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.72E+00
NaHCO3_________________Nahcolite     0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.10E+00
NaCl___________________________Halite 0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -1.38E-01
Na3NpO2(CO3)2(s)_DISABLED_DISABLED   0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -9.30E+02
NaOH(aq).....to.titrate.base.only    0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.93E+02
NpO2OH(amor)___________NpO2OH(amor)  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.83E+00
NpO2OH(aged)___________NpO2OH(aged)  0.00000E+00  1.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -3.23E+00
HCl(aq).......to.titrate.acid.only   0.00000E+00  0.00000E+00  1.000        0.00000E+00  0.00000E+00  0.00000E+00  -2.50E+02

pmH = -log[m(H+)]                 =     11.2341
pH = -log[a(H+)]     =     10.6594
Osmotic Coefficient=     1.234823
Equilibrium RH (%) =    77.996177
Ionic Strength (m) =     5.661425
Density, kg/m3     =     1188.60

NOTES:  - Water "molality" is mole fraction H2O in aqueous phase
        - Gas "molality" and "activity" are gas partial pressures
        - "Descriptor" means:
          *dG/RT/ln10 for species with nonzero concs. (convergence criterion)
          *Saturation Index for minerals, SI=log10(IAP/Ksp)
          *log10(activity) for aqueous species with very small concentrations
          *log10(partial pressure) for gases

Total G/RT=     -4.69179003E+03
TITRATE  file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM.TITRATE;1
```

Appendix P: Sample Output File "Np_NaCl_BM.OUT"

```
MOLES    file name is U1:[SCBABB.FMT.USERGUIDE]NP_NACL_BM.MOLES;1
```

Appendix Q: Sample Output File "BATCH_DOC.FOR088"

See Table 28 for explanation of this listing.

```
5.506118174079332E+01 H2O                                  WATER 5.550868155779565E+01
2.000000000000000E-01 Na+                                    Na+ 2.016254639034410E-01
1.000000000000001E-02 K+                                      K+ 1.008127319517206E-02
9.930829876074504E-05 Ca++                                   Ca++ 1.001154090354837E-04
1.089876985084734E-08 Mg++                                   Mg++ 1.098734763576966E-08
3.514119485249377E-08 MgOH+                                 MgOH+ 3.542679857127635E-08
1.916539289681380E-13 H+                                      H+ 1.932115616855898E-13
1.099999999999999E-01 Cl-                                    Cl- 1.108940051468925E-01
9.999999999959653E-04 SO4=                                  SO4= 1.008127319513137E-03
4.035191240945192E-15 HSO4-                                HSO4- 4.067986529473380E-15
9.800006626741904E-02 OH-                                    OH- 9.879654411868162E-02
1.092064419243065E-07 HCO3-                                 HCO3- 1.100939975711625E-07
9.919912603905744E-05 CO3=                                   CO3= 1.000053490322044E-04
2.193596324564590E-14 CO2(aq)                            CO2(aq) 2.211424382786093E-14
6.916147055733898E-07 CaCO3(aq)                         CaCO3(aq) 6.972356792683824E-07
5.279149790754905E-11 MgCO3(aq)                         MgCO3(aq) 5.322055127883555E-11
1.640770852300863E-11 B(OH)3(aq)                       B(OH)3(aq) 1.654105921272029E-11
9.989705247502765E-08 B(OH)4-                             B(OH)4- 1.007089477393192E-07
0.000000000000000E+00 B3O3(OH)4-                        B3O3(OH)4- 0.000000000000000E+00
0.000000000000000E+00 B4O5(OH)4=                        B4O5(OH)4= 0.000000000000000E+00
8.653368448896738E-11 CaB(OH)4+                          CaB(OH)4+ 8.723697139181022E-11
6.134836150886349E-15 MgB(OH)4+                          MgB(OH)4+ 6.184695924470303E-15
0.000000000000000E+00 Br-                                     Br- 0.000000000000000E+00
0.000000000000000E+00 ClO4-                   perchlorate ClO4- 0.000000000000000E+00
0.000000000000000E+00 NaOH(aq).....to.titrate.base.only 0.000000000000000E+00
0.000000000000000E+00 HCl(aq).......to.titrate.acid.only 0.000000000000000E+00
0.000000000000000E+00 HClO4(aq).....to.titrate.acid.only 0.000000000000000E+00
0.000000000000000E+00 PosIon...............POSITIVE.ION 0.000000000000000E+00
0.000000000000000E+00 NegIon...............NEGATIVE.ION 0.000000000000000E+00
0.000000000000000E+00 PosIon(OH)(aq).....to.titrate.base 0.000000000000000E+00
0.000000000000000E+00 HNegIon(aq)........to.titrate.acid 0.000000000000000E+00
0.000000000000000E+00 Tracer(aq).....conservative.tracer 0.000000000000000E+00
0.000000000000000E+00 H3PO4(aq)                     H3PO4(aq) 0.000000000000000E+00
0.000000000000000E+00 H2PO4-                         H2PO4- 0.000000000000000E+00
0.000000000000000E+00 HPO4=                           HPO4= 0.000000000000000E+00
0.000000000000000E+00 PO4=-                           PO4=- 0.000000000000000E+00
0.000000000000000E+00 NpO2+                           NpO2+ 0.000000000000000E+00
0.000000000000000E+00 NpO2OH(aq)                   NpO2OH(aq) 0.000000000000000E+00
0.000000000000000E+00 NpO2(OH)2-                   NpO2(OH)2- 0.000000000000000E+00
0.000000000000000E+00 NpO2CO3-                       NpO2CO3- 0.000000000000000E+00
0.000000000000000E+00 NpO2(CO3)2=-               NpO2(CO3)2=- 0.000000000000000E+00
0.000000000000000E+00 NpO2(CO3)3==-             NpO2(CO3)3==- 0.000000000000000E+00
0.000000000000000E+00 Am+++                           Am+++ 0.000000000000000E+00
0.000000000000000E+00 AmCO3+                         AmCO3+ 0.000000000000000E+00
0.000000000000000E+00 Am(CO3)2-                     Am(CO3)2- 0.000000000000000E+00
0.000000000000000E+00 Am(CO3)3=-                    Am(CO3)3=- 0.000000000000000E+00
0.000000000000000E+00 Am(OH)2+                       Am(OH)2+ 0.000000000000000E+00
0.000000000000000E+00 Am(OH)3(aq)                   Am(OH)3(aq) 0.000000000000000E+00
0.000000000000000E+00 Th++++                           Th++++ 0.000000000000000E+00
0.000000000000000E+00 UO2++                         U(VI)O2++ 0.000000000000000E+00
0.000000000000000E+00 NpO2OH(aged)_____________NpO2OH(aged) 0.000000000000000E+00
0.000000000000000E+00 NpO2OH(amor)_____________NpO2OH(amor) 0.000000000000000E+00
0.000000000000000E+00 NaNpO2CO3(s)_____________NaNpO2CO3(s) 0.000000000000000E+00
0.000000000000000E+00 Na3NpO2(CO3)2(s)_DISABLED_DISABLED 0.000000000000000E+00
0.000000000000000E+00 AmOHCO3(c)_______________AmOHCO3(c) 0.000000000000000E+00
0.000000000000000E+00 Am(OH)3(s)________________Am(OH)3(s) 0.000000000000000E+00
0.000000000000000E+00 NaAm(CO3)2.6H2O(c)_______________ 0.000000000000000E+00
0.000000000000000E+00 AmPO4(c)_____________________AmPO4(c) 0.000000000000000E+00
0.000000000000000E+00 CaSO4_____________________Anhydrite 0.000000000000000E+00
0.000000000000000E+00 NaK3(SO4)2__Aphthitalite/Glaserite 0.000000000000000E+00
0.000000000000000E+00 CaCl2.6H2O_______________Antarcticite 0.000000000000000E+00
0.000000000000000E+00 CaCO3_____________________Aragonite 0.000000000000000E+00
0.000000000000000E+00 K2SO4_____________________Arcanite 0.000000000000000E+00
0.000000000000000E+00 MgCl2.6H2O________________Bischofite 0.000000000000000E+00
0.000000000000000E+00 Na2Mg(SO4)2.4H2O__________Bloedite 0.000000000000000E+00
9.999539072376642E-04 Mg(OH)2_____________________Brucite 1.008080852144262E-03
0.000000000000000E+00 Na6CO3(SO4)2_______________Burkeite 0.000000000000000E+00
0.000000000000000E+00 CaCO3_____________________Calcite 0.000000000000000E+00
0.000000000000000E+00 CaCl2.4H2O_____CaCl2_Tetrahydrite 0.000000000000000E+00
0.000000000000000E+00 Ca4Cl2(OH)6.13H2O__CaOxychloride A 0.000000000000000E+00
0.000000000000000E+00 Ca2Cl2(OH)2.H2O____CaOxychloride B 0.000000000000000E+00
0.000000000000000E+00 KMgCl3.6H2O_______________Carnallite 0.000000000000000E+00
0.000000000000000E+00 MgSO4.7H2O_________________Epsomite 0.000000000000000E+00
0.000000000000000E+00 CaNa2(CO3)2.5H2O_________Gaylussite 0.000000000000000E+00
0.000000000000000E+00 Na2Ca(SO4)2_______________Glauberite 0.000000000000000E+00
0.000000000000000E+00 CaSO4.2H2O_____________________Gypsum 0.000000000000000E+00
0.000000000000000E+00 NaCl_______________________Halite 0.000000000000000E+00
0.000000000000000E+00 MgSO4.6H2O_________________Hexahydrite 0.000000000000000E+00
0.000000000000000E+00 KMgClSO4.3H2O_____________Kainite 0.000000000000000E+00
0.000000000000000E+00 KHCO3_____________________Kalicinite 0.000000000000000E+00
0.000000000000000E+00 MgSO4.H2O_____________ Kieserite 0.000000000000000E+00
0.000000000000000E+00 K2Mg(SO4)2.4H2O___________Leonite 0.000000000000000E+00
```

Appendix Q: Sample Output File "BATCH_DOC.FOR088"

```
0.000000000000000E+00 Na4Ca(SO4)3.2H2O_______Labile_Salt 0.000000000000000E+00
0.000000000000000E+00 MgCO3_____________________Magnesite 0.000000000000000E+00
0.000000000000000E+00 Mg2Cl(OH)3.4H2O_____MgOxychloride 0.000000000000000E+00
0.000000000000000E+00 KHSO4_____________________Mercallite 0.000000000000000E+00
0.000000000000000E+00 Na2SO4.10H2O_____________Mirabilite 0.000000000000000E+00
0.000000000000000E+00 K8H6(SO4)7_________________Misenite 0.000000000000000E+00
0.000000000000000E+00 NaHCO3_____________________Nahcolite 0.000000000000000E+00
0.000000000000000E+00 Na2CO3.10H2O_________________Natron 0.000000000000000E+00
0.000000000000000E+00 MgCO3.3H2O_____________Nesquehonite 0.000000000000000E+00
0.000000000000000E+00 K2Mg(SO4)2.6H2O Picromerite/Schoen 0.000000000000000E+00
0.000000000000000E+00 Na2Ca(CO3)2.2H2O________Pirssonite 0.000000000000000E+00
0.000000000000000E+00 K2MgCa2(SO4)4.2H2O______Polyhalite 0.000000000000000E+00
0.000000000000000E+00 Ca(OH)2_________________Portlandite 0.000000000000000E+00
0.000000000000000E+00 K2CO3.3/2H2O___Potassium_Carbonate 0.000000000000000E+00
0.000000000000000E+00 K8H4(CO3)6.3H2O___K-Sequicarbonate 0.000000000000000E+00
0.000000000000000E+00 KNaCO3.6H2O________K-Na-Carbonate 0.000000000000000E+00
0.000000000000000E+00 K2NaH(CO3)2.2H2O___Potassium_Trona 0.000000000000000E+00
0.000000000000000E+00 K3H(SO4)2__Sesquipotassium_Sulfate 0.000000000000000E+00
0.000000000000000E+00 Na3H(SO4)2____Sesquisodium_Sulfate 0.000000000000000E+00
0.000000000000000E+00 Na2CO3.7H2O____Na2CO3-Heptahydrate 0.000000000000000E+00
0.000000000000000E+00 KCl_______________________Sylvite 0.000000000000000E+00
0.000000000000000E+00 K2Ca(SO4)2.H2O___________Syngenite 0.000000000000000E+00
0.000000000000000E+00 Mg2CaCl6.12H2O________Tachyhydrite 0.000000000000000E+00
0.000000000000000E+00 Na2SO4_____________________Thenardite 0.000000000000000E+00
0.000000000000000E+00 Na2CO3.H2O___________Thermonatrite 0.000000000000000E+00
0.000000000000000E+00 Na3H(CO3)2.2H2O_____________Trona 0.000000000000000E+00
0.000000000000000E+00 Na2B4O7.10H2O_____________ Borax 0.000000000000000E+00
0.000000000000000E+00 B(OH)3____________Borix_Acid_Solid 0.000000000000000E+00
0.000000000000000E+00 KB5O8.4H2O____K-Pentaborate_(30_C) 0.000000000000000E+00
0.000000000000000E+00 K2B4O7.4H2O___K-Tetraborate_(30_C) 0.000000000000000E+00
0.000000000000000E+00 NaBO2.4H2O_______Sodium_Metaborate 0.000000000000000E+00
0.000000000000000E+00 NaB5O8.5H2O_____Sodium_Pentaborate 0.000000000000000E+00
0.000000000000000E+00 NaBO2.NaCl.2H2O___Teepleite_(20_C) 0.000000000000000E+00
```

Appendix R: Sample Output File "Np_NaCl_BM_LOG.TITRATE"

See Table 29 for explanation of this listing.

```
Benchmark TITRATE Problem, LOG10 option: Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

Titrant Volumes per Grid Block, in milliliters
  1            0.000000 mL
  2            0.100000 mL
  3            0.142510 mL
  4            0.203092 mL
  5            0.289427 mL
  6            0.412463 mL
  7            0.587802 mL
  8            0.837678 mL
  9            1.193777 mL
 10            1.701254 mL
 11            2.424462 mL
 12            3.455107 mL
 13            4.923883 mL
 14            7.017038 mL
 15           10.000000 mL


Titration Results, molal

      H2O          Na+          K+           Ca++         Mg++         MgOH+        H+           Cl-          SO4=
 1)  1.92928E+01  5.61057E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.21872E-06  5.61096E+00  0.00000E+00
 2)  1.92978E+01  5.61014E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  5.77346E-07  5.60993E+00  0.00000E+00
 3)  1.92999E+01  5.61003E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  2.58813E-07  5.60950E+00  0.00000E+00
 4)  1.93029E+01  5.61000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  2.91065E-09  5.60889E+00  0.00000E+00
 5)  1.93072E+01  5.61000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  3.42512E-10  5.60800E+00  0.00000E+00
 6)  1.93133E+01  5.61000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.52979E-10  5.60673E+00  0.00000E+00
 7)  1.93221E+01  5.61001E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  8.66954E-11  5.60491E+00  0.00000E+00
 8)  1.93346E+01  5.61001E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  5.44489E-11  5.60233E+00  0.00000E+00
 9)  1.93524E+01  5.61002E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  3.62550E-11  5.59866E+00  0.00000E+00
10)  1.93778E+01  5.61003E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  2.51081E-11  5.59343E+00  0.00000E+00
11)  1.94140E+01  5.61004E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.79163E-11  5.58601E+00  0.00000E+00
12)  1.94655E+01  5.61007E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.31074E-11  5.57548E+00  0.00000E+00
13)  1.95390E+01  5.61012E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  9.80463E-12  5.56057E+00  0.00000E+00
14)  1.96437E+01  5.61021E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  7.48733E-12  5.53952E+00  0.00000E+00
15)  1.97930E+01  5.61035E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  5.83272E-12  5.50989E+00  0.00000E+00

      HSO4-        OH-          HCO3-        CO3=         CO2(aq)      CaCO3(aq)    MgCO3(aq)    B(OH)3(aq)   B(OH)4-
 1)  0.00000E+00  3.01685E-09  2.26571E-04  3.09384E-08  3.86103E-04  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 2)  0.00000E+00  6.37029E-09  3.82212E-04  1.10196E-07  3.08476E-04  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 3)  0.00000E+00  1.42123E-08  5.79856E-04  3.72979E-07  2.09763E-04  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 4)  0.00000E+00  1.26397E-06  9.92660E-04  5.67888E-05  4.03745E-06  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 5)  0.00000E+00  1.07447E-05  1.00903E-03  4.90717E-04  4.82702E-07  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 6)  0.00000E+00  2.40684E-05  1.02256E-03  1.11398E-03  2.18328E-07  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 7)  0.00000E+00  4.24988E-05  1.04073E-03  2.00201E-03  1.25799E-07  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 8)  0.00000E+00  6.77337E-05  1.06541E-03  3.26656E-03  8.07635E-08  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 9)  0.00000E+00  1.01865E-04  1.09867E-03  5.06627E-03  5.53405E-08  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
10)  0.00000E+00  1.47379E-04  1.14291E-03  7.62562E-03  3.97510E-08  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
11)  0.00000E+00  2.07123E-04  1.20082E-03  1.12609E-02  2.96765E-08  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
12)  0.00000E+00  2.84255E-04  1.27533E-03  1.64154E-02  2.29199E-08  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
13)  0.00000E+00  3.82200E-04  1.36956E-03  2.37058E-02  1.82542E-08  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
14)  0.00000E+00  5.04619E-04  1.48672E-03  3.39812E-02  1.49488E-08  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
15)  0.00000E+00  6.55397E-04  1.63010E-03  4.83971E-02  1.25492E-08  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

      B3O3(OH)4-   B4O5(OH)4=   CaB(OH)4+    MgB(OH)4+    Br-          ClO4-        NaOH(aq)..... HCl(aq)...... HClO4(aq)....
 1)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 2)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 3)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 4)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 5)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 6)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 7)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 8)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 9)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
10)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
11)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
12)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
13)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
14)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
15)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

      PosIon....... NegIon....... PosIon(OH)(aq HNegIon(aq).. Tracer(aq)... H3PO4(aq)   H2PO4-       HPO4=        PO4=-
 1)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 2)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 3)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 4)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
 5)  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
```

Appendix R: Sample Output File "Np_NaCl_BM_LOG.TITRATE"

6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

	NpO2+	NpO2OH(aq)	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2=-	NpO2(CO3)3===-	Am+++	AmCO3+	Am(CO3)2-
1)	6.12705E-04	7.72186E-10	2.04381E-16	1.33526E-07	1.98384E-11	1.25197E-16	0.00000E+00	0.00000E+00	0.00000E+00
2)	1.72085E-04	4.57851E-10	2.55903E-16	1.33573E-07	7.06677E-11	1.58546E-15	0.00000E+00	0.00000E+00	0.00000E+00
3)	5.08519E-05	3.01826E-10	3.76383E-16	1.33591E-07	2.39201E-10	1.81540E-14	0.00000E+00	0.00000E+00	0.00000E+00
4)	3.34101E-07	1.76339E-10	1.95583E-14	1.33613E-07	3.64205E-08	4.20660E-10	0.00000E+00	0.00000E+00	0.00000E+00
5)	3.86807E-08	1.73507E-10	1.63614E-13	1.33630E-07	3.14571E-07	3.13656E-08	0.00000E+00	0.00000E+00	0.00000E+00
6)	1.70494E-08	1.71249E-10	3.61806E-13	1.33654E-07	7.13649E-07	1.61312E-07	0.00000E+00	0.00000E+00	0.00000E+00
7)	9.49498E-09	1.68316E-10	6.28105E-13	1.33688E-07	1.28137E-06	5.19502E-07	0.00000E+00	0.00000E+00	0.00000E+00
8)	5.82643E-09	1.64493E-10	9.78743E-13	1.33737E-07	2.08796E-06	1.37733E-06	0.00000E+00	0.00000E+00	0.00000E+00
9)	3.76324E-09	1.59617E-10	1.42919E-12	1.33806E-07	3.23222E-06	3.29354E-06	0.00000E+00	0.00000E+00	0.00000E+00
10)	2.50641E-09	1.53583E-10	1.99131E-12	1.33905E-07	4.85191E-06	7.39875E-06	0.00000E+00	0.00000E+00	0.00000E+00
11)	1.70329E-09	1.46370E-10	2.67040E-12	1.34044E-07	7.13717E-06	1.59398E-05	0.00000E+00	0.00000E+00	0.00000E+00
12)	1.17432E-09	1.38078E-10	3.46327E-12	1.34242E-07	1.03463E-05	3.32873E-05	0.00000E+00	0.00000E+00	0.00000E+00
13)	8.18986E-10	1.28920E-10	4.35852E-12	1.34522E-07	1.48219E-05	6.77047E-05	0.00000E+00	0.00000E+00	0.00000E+00
14)	5.77122E-10	1.19205E-10	5.33952E-12	1.34916E-07	2.10028E-05	1.34208E-04	0.00000E+00	0.00000E+00	0.00000E+00
15)	4.11022E-10	1.09291E-10	6.38945E-12	1.35468E-07	2.94209E-05	2.58546E-04	0.00000E+00	0.00000E+00	0.00000E+00

	Am(CO3)3=-	Am(OH)2+	Am(OH)3(aq)	Th++++	UO2++	NpO2OH(aged)_	NpO2OH(amor)_	NaNpO2CO3(s)_	Na3NpO2(CO3)2
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99932E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99718E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99622E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99473E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99250E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.98931E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.98478E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.97832E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.96914E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.95607E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.93751E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.91117E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.87386E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.82115E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.74696E+00	0.00000E+00

	AmOHCO3(c)___	Am(OH)3(s)___	NaAm(CO3)2.6H	AmPO4(c)_____	CaSO4_____	NaK3(SO4)2__A	CaCl2.6H2O___	CaCO3_____	K2SO4_____
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

	MgCl2.6H2O___	Na2Mg(SO4)2.4	Mg(OH)2_____	Na6CO3(SO4)2_	CaCO3_____	CaCl2.4H2O___	Ca4Cl2(OH)6.1	Ca2Cl2(OH)2.H	KMgCl3.6H2O__
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

	MgSO4.7H2O___	CaNa2(CO3)2.5	Na2Ca(SO4)2__	CaSO4.2H2O___	NaCl_____	MgSO4.6H2O___	KMgClSO4.3H2O	KHCO3_____	MgSO4.H2O____
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

Appendix R: Sample Output File "Np_NaCl_BM_LOG.TITRATE"

11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

	K2Mg(SO4)2.4H	Na4Ca(SO4)3.2	MgCO3_____	Mg2Cl(OH)3.4H	KHSO4_____	Na2SO4.10H2O_	K8H6(SO4)7___	NaHCO3_____	Na2CO3.10H2O_
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

	MgCO3.3H2O___	K2Mg(SO4)2.6H	Na2Ca(CO3)2.2	K2MgCa2(SO4)4	Ca(OH)2_____	K2CO3.3/2H2O_	K8H4(CO3)6.3H	KNaCO3.6H2O__	K2NaH(CO3)2.2
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

	K3H(SO4)2__Se	Na3H(SO4)2___	Na2CO3.7H2O__	KCl_____	K2Ca(SO4)2.H2	Mg2CaCl6.12H2	Na2SO4_____	Na2CO3.H2O___	Na3H(CO3)2.2H
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

	Na2B4O7.10H2O	B(OH)3_____	KB5O8.4H2O___	K2B4O7.4H2O__	NaBO2.4H2O___	NaB5O8.5H2O__	NaBO2.NaCl.2H
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

	IonicStreng	Eh(=)Volts	TitrVol,ml	pH
1)	5.61119E+00	0.00000E+00	0.00000E+00	5.3205
2)	5.61031E+00	0.00000E+00	0.10000	5.6451
3)	5.61008E+00	0.00000E+00	0.14251	5.9936
4)	5.61006E+00	0.00000E+00	0.20309	7.9427
5)	5.61049E+00	0.00000E+00	0.28943	8.8722
6)	5.61112E+00	0.00000E+00	0.41246	9.2225
7)	5.61202E+00	0.00000E+00	0.58780	9.4695
8)	5.61330E+00	0.00000E+00	0.83768	9.6719
9)	5.61513E+00	0.00000E+00	1.1938	9.8493
10)	5.61774E+00	0.00000E+00	1.7013	10.010
11)	5.62149E+00	0.00000E+00	2.4245	10.158
12)	5.62685E+00	0.00000E+00	3.4551	10.295
13)	5.63455E+00	0.00000E+00	4.9239	10.424
14)	5.64559E+00	0.00000E+00	7.0170	10.545
15)	5.66143E+00	0.00000E+00	10.000	10.659

Appendix S: Sample Output File "Np_NaCl_BM_LIN.TITRATE"

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Benchmark TITRATE Problem, LINEAR option; Np(V)O2 with CO3 in 5.61molal NaCl  FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

Titrant Volumes per Grid Block, in milliliters
  1            0.000000 mL
  2            0.100000 mL
  3            0.200000 mL
  4            0.300000 mL
  5            0.400000 mL
  6            0.500000 mL
  7            0.600000 mL
  8            0.700000 mL
  9            0.800000 mL
 10            0.900000 mL
 11            1.000000 mL
 12            1.100000 mL
 13            1.200000 mL
 14            1.300000 mL
 15            1.400000 mL


Titration Results, molal
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	H2O	Na+	K+	Ca++	Mg++	MgOH+	H+	Cl-	SO4=
1)	1.92928E+01	5.61057E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.21872E-06	5.61096E+00	0.00000E+00
2)	1.92978E+01	5.61014E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	5.77346E-07	5.60993E+00	0.00000E+00
3)	1.93027E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.87609E-09	5.60892E+00	0.00000E+00
4)	1.93077E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.09202E-10	5.60789E+00	0.00000E+00
5)	1.93127E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.61951E-10	5.60685E+00	0.00000E+00
6)	1.93177E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.10445E-10	5.60582E+00	0.00000E+00
7)	1.93227E+01	5.61001E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	8.42049E-11	5.60479E+00	0.00000E+00
8)	1.93277E+01	5.61001E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	6.82959E-11	5.60375E+00	0.00000E+00
9)	1.93327E+01	5.61001E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	5.76161E-11	5.60272E+00	0.00000E+00
10)	1.93377E+01	5.61001E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	4.99485E-11	5.60169E+00	0.00000E+00
11)	1.93427E+01	5.61001E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	4.41741E-11	5.60066E+00	0.00000E+00
12)	1.93477E+01	5.61002E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.96673E-11	5.59962E+00	0.00000E+00
13)	1.93527E+01	5.61002E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.60509E-11	5.59859E+00	0.00000E+00
14)	1.93577E+01	5.61002E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.30838E-11	5.59756E+00	0.00000E+00
15)	1.93627E+01	5.61002E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.06048E-11	5.59653E+00	0.00000E+00

	HSO4-	OH-	HCO3-	CO3=	CO2(aq)	CaCO3(aq)	MgCO3(aq)	B(OH)3(aq)	B(OH)4-
1)	0.00000E+00	3.01685E-09	2.26571E-04	3.09384E-08	3.86103E-04	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	6.37029E-09	3.82212E-04	1.10196E-07	3.08476E-04	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	9.49137E-07	9.89705E-04	4.25167E-05	5.36072E-06	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	1.19027E-05	1.01025E-03	5.44263E-04	4.36260E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	2.27338E-05	1.02124E-03	1.05085E-03	2.30850E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	3.33488E-05	1.03174E-03	1.55739E-03	1.58957E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	4.37579E-05	1.04196E-03	2.06377E-03	1.22321E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	5.39719E-05	1.05196E-03	2.56997E-03	1.00104E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	6.40010E-05	1.06176E-03	3.07597E-03	8.51877E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	7.38545E-05	1.07138E-03	3.58175E-03	7.44762E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	8.35411E-05	1.08082E-03	4.08730E-03	6.64082E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	9.30687E-05	1.09010E-03	4.59262E-03	6.01101E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	1.02445E-04	1.09923E-03	5.09770E-03	5.50552E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	1.11676E-04	1.10821E-03	5.60253E-03	5.09071E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	1.20768E-04	1.11706E-03	6.10711E-03	4.74407E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

(missing species have zero amounts)

	NpO2+	NpO2OH(aq)	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2=-	NpO2(CO3)3==-	Am+++	AmCO3+	Am(CO3)2-
1)	6.12705E-04	7.72186E-10	2.04381E-16	1.33526E-07	1.98384E-11	1.25197E-16	0.00000E+00	0.00000E+00	0.00000E+00
2)	1.72085E-04	4.57851E-10	2.55903E-16	1.33573E-07	7.06677E-11	1.58546E-15	0.00000E+00	0.00000E+00	0.00000E+00
3)	4.46247E-07	1.76865E-10	1.47303E-14	1.33612E-07	2.72677E-08	2.35800E-10	0.00000E+00	0.00000E+00	0.00000E+00
4)	3.48770E-08	1.73300E-10	1.81034E-13	1.33632E-07	3.48878E-07	3.85776E-08	0.00000E+00	0.00000E+00	0.00000E+00
5)	1.80727E-08	1.71468E-10	3.42173E-13	1.33651E-07	6.73247E-07	1.43575E-07	0.00000E+00	0.00000E+00	0.00000E+00
6)	1.22005E-08	1.69754E-10	4.97012E-13	1.33671E-07	9.97249E-07	3.14830E-07	0.00000E+00	0.00000E+00	0.00000E+00
7)	9.21138E-09	1.68120E-10	6.45975E-13	1.33690E-07	1.32081E-06	5.51937E-07	0.00000E+00	0.00000E+00	0.00000E+00
8)	7.40067E-09	1.66553E-10	7.89467E-13	1.33710E-07	1.64391E-06	8.54484E-07	0.00000E+00	0.00000E+00	0.00000E+00
9)	6.18630E-09	1.65046E-10	9.27855E-13	1.33729E-07	1.96653E-06	1.22205E-06	0.00000E+00	0.00000E+00	0.00000E+00
10)	5.31533E-09	1.63595E-10	1.06147E-12	1.33749E-07	2.28868E-06	1.65423E-06	0.00000E+00	0.00000E+00	0.00000E+00
11)	4.66017E-09	1.62195E-10	1.19063E-12	1.33768E-07	2.61033E-06	2.15059E-06	0.00000E+00	0.00000E+00	0.00000E+00
12)	4.14945E-09	1.60844E-10	1.31559E-12	1.33788E-07	2.93150E-06	2.71072E-06	0.00000E+00	0.00000E+00	0.00000E+00
13)	3.74015E-09	1.59537E-10	1.43661E-12	1.33807E-07	3.25216E-06	3.33418E-06	0.00000E+00	0.00000E+00	0.00000E+00
14)	3.40480E-09	1.58274E-10	1.55392E-12	1.33827E-07	3.57233E-06	4.02056E-06	0.00000E+00	0.00000E+00	0.00000E+00
15)	3.12502E-09	1.57050E-10	1.66773E-12	1.33846E-07	3.89199E-06	4.76942E-06	0.00000E+00	0.00000E+00	0.00000E+00

	Am(CO3)3=-	Am(OH)2+	Am(OH)3(aq)	Th++++	UO2++	NpO2OH(aged)_	NpO2OH(amor)_	NaNpO2CO3(s)_	Na3NpO2(CO3)2
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99932E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99718E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99481E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99222E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.98964E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.98705E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.98446E+00	0.00000E+00

Appendix S: Sample Output File "Np_NaCl_BM_LIN.TITRATE"

8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.98188E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.97930E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.97672E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.97413E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.97156E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.96898E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.96640E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.96382E+00	0.00000E+00

(missing species have zero amounts)

	IonicStreng	Eh[=]Volts	TitrVol,ml	pH
1)	5.61119E+00	0.00000E+00	0.00000E+00	5.3205
2)	5.61031E+00	0.00000E+00	0.10000	5.6451
3)	5.61004E+00	0.00000E+00	0.20000	7.8183
4)	5.61055E+00	0.00000E+00	0.30000	8.9167
5)	5.61106E+00	0.00000E+00	0.40000	9.1977
6)	5.61157E+00	0.00000E+00	0.50000	9.3641
7)	5.61208E+00	0.00000E+00	0.60000	9.4821
8)	5.61259E+00	0.00000E+00	0.70000	9.5733
9)	5.61310E+00	0.00000E+00	0.80000	9.6473
10)	5.61362E+00	0.00000E+00	0.90000	9.7095
11)	5.61413E+00	0.00000E+00	1.0000	9.7631
12)	5.61464E+00	0.00000E+00	1.1000	9.8100
13)	5.61516E+00	0.00000E+00	1.2000	9.8517
14)	5.61567E+00	0.00000E+00	1.3000	9.8892
15)	5.61619E+00	0.00000E+00	1.4000	9.9232

Appendix T: Sample Output File "Np_NaCl_BM.TITRATE"

```
Benchmark TITRATE Problem; Np(V)O2 with CO3 in 5.61molal NaCl                FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31   Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

Titrant Volumes per Grid Block, in milliliters
  1            0.000000 mL
  2            0.100000 mL
  3            0.142510 mL
  4            0.160000 mL
  5            0.180000 mL
  6            0.203090 mL
  7            0.220000 mL
  8            0.240000 mL
  9            0.260000 mL
 10            0.289430 mL
 11            0.412460 mL
 12            0.587800 mL
 13            1.193800 mL
 14            3.455100 mL
 15           10.000000 mL


Titration Results, molal
```

	H2O	Na+	K+	Ca++	Mg++	MgOH+	H+	Cl-	SO4=
1)	1.92928E+01	5.61057E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.21872E-06	5.61096E+00	0.00000E+00
2)	1.92978E+01	5.61014E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	5.77346E-07	5.60993E+00	0.00000E+00
3)	1.92999E+01	5.61003E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	2.58815E-07	5.60950E+00	0.00000E+00
4)	1.93007E+01	5.61001E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.48381E-07	5.60933E+00	0.00000E+00
5)	1.93017E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	5.09374E-08	5.60913E+00	0.00000E+00
6)	1.93029E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	2.91107E-09	5.60889E+00	0.00000E+00
7)	1.93037E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.18855E-09	5.60872E+00	0.00000E+00
8)	1.93047E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	6.93877E-10	5.60851E+00	0.00000E+00
9)	1.93057E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	4.89995E-10	5.60830E+00	0.00000E+00
10)	1.93072E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.42501E-10	5.60800E+00	0.00000E+00
11)	1.93133E+01	5.61000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.52981E-10	5.60673E+00	0.00000E+00
12)	1.93221E+01	5.61001E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	8.66958E-11	5.60491E+00	0.00000E+00
13)	1.93524E+01	5.61002E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	3.62542E-11	5.59866E+00	0.00000E+00
14)	1.94655E+01	5.61007E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	1.31074E-11	5.57548E+00	0.00000E+00
15)	1.97930E+01	5.61035E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	5.83272E-12	5.50989E+00	0.00000E+00

	HSO4-	OH-	HCO3-	CO3=	CO2(aq)	CaCO3(aq)	MgCO3(aq)	B(OH)3(aq)	B(OH)4-
1)	0.00000E+00	3.01685E-09	2.26571E-04	3.09384E-08	3.86103E-04	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
2)	0.00000E+00	6.37029E-09	3.82212E-04	1.10196E-07	3.08476E-04	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3)	0.00000E+00	1.42122E-08	5.79854E-04	3.72976E-07	2.09764E-04	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
4)	0.00000E+00	2.47909E-08	7.06447E-04	7.92644E-07	1.46506E-04	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
5)	0.00000E+00	7.22202E-08	8.74979E-04	2.86004E-06	6.22872E-05	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
6)	0.00000E+00	1.26379E-06	9.92658E-04	5.67805E-05	4.03803E-06	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
7)	0.00000E+00	3.09556E-06	9.99205E-04	1.39997E-04	1.65938E-06	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
8)	0.00000E+00	5.30281E-06	1.00274E-03	2.40670E-04	9.72059E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
9)	0.00000E+00	7.50984E-06	1.00546E-03	3.41763E-04	6.88224E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
10)	0.00000E+00	1.07451E-05	1.00903E-03	4.90734E-04	4.82685E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
11)	0.00000E+00	2.40681E-05	1.02256E-03	1.11397E-03	2.18331E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
12)	0.00000E+00	4.24987E-05	1.04073E-03	2.00200E-03	1.25799E-07	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
13)	0.00000E+00	1.01868E-04	1.09867E-03	5.06639E-03	5.53385E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
14)	0.00000E+00	2.84255E-04	1.27533E-03	1.64154E-02	2.29199E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
15)	0.00000E+00	6.55397E-04	1.63010E-03	4.83971E-02	1.25492E-08	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

(missing species have zero amounts)

	NpO2+	NpO2OH(aq)	NpO2(OH)2-	NpO2CO3-	NpO2(CO3)2=-	NpO2(CO3)3==-	Am+++	AmCO3+	Am(CO3)2-
1)	6.12705E-04	7.72186E-10	2.04381E-16	1.33526E-07	1.98384E-11	1.25197E-16	0.00000E+00	0.00000E+00	0.00000E+00
2)	1.72085E-04	4.57851E-10	2.55903E-16	1.33573E-07	7.06677E-11	1.58546E-15	0.00000E+00	0.00000E+00	0.00000E+00
3)	5.08524E-05	3.01827E-10	3.76382E-16	1.33591E-07	2.39199E-10	1.81536E-14	0.00000E+00	0.00000E+00	0.00000E+00
4)	2.39307E-05	2.47753E-10	5.38926E-16	1.33598E-07	5.08355E-10	8.19789E-14	0.00000E+00	0.00000E+00	0.00000E+00
5)	6.63303E-06	2.00045E-10	1.26769E-15	1.33606E-07	1.83431E-09	1.06720E-12	0.00000E+00	0.00000E+00	0.00000E+00
6)	3.34150E-07	1.76340E-10	1.95555E-14	1.33613E-07	3.64151E-08	4.20537E-10	0.00000E+00	0.00000E+00	0.00000E+00
7)	1.35537E-07	1.75190E-10	4.75887E-14	1.33616E-07	8.97771E-08	2.55580E-09	0.00000E+00	0.00000E+00	0.00000E+00
8)	7.88495E-08	1.74579E-10	8.12402E-14	1.33620E-07	1.54320E-07	7.55070E-09	0.00000E+00	0.00000E+00	0.00000E+00
9)	5.55313E-08	1.74113E-10	1.14749E-13	1.33624E-07	2.19119E-07	1.52213E-08	0.00000E+00	0.00000E+00	0.00000E+00
10)	3.86794E-08	1.73507E-10	1.63619E-13	1.33630E-07	3.14582E-07	3.13678E-08	0.00000E+00	0.00000E+00	0.00000E+00
11)	1.70496E-08	1.71249E-10	3.61801E-13	1.33654E-07	7.13640E-07	1.61308E-07	0.00000E+00	0.00000E+00	0.00000E+00
12)	9.49502E-09	1.68316E-10	6.28103E-13	1.33688E-07	1.28136E-06	5.19497E-07	0.00000E+00	0.00000E+00	0.00000E+00
13)	3.76315E-09	1.59617E-10	1.42922E-12	1.33806E-07	3.23230E-06	3.29369E-06	0.00000E+00	0.00000E+00	0.00000E+00
14)	1.17432E-09	1.38078E-10	3.46327E-12	1.34242E-07	1.03462E-05	3.32871E-05	0.00000E+00	0.00000E+00	0.00000E+00
15)	4.11022E-10	1.09291E-10	6.38945E-12	1.35468E-07	2.94209E-05	2.58546E-04	0.00000E+00	0.00000E+00	0.00000E+00

	Am(CO3)3=-	Am(OH)2+	Am(OH)3(aq)	Th++++	UO2++	NpO2OH(aged)_	NpO2OH(amor)_	NaNpO2CO3(s)_	Na3NpO2(CO3)2
1)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99932E+00	0.00000E+00
2)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99718E+00	0.00000E+00
3)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99622E+00	0.00000E+00
4)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99580E+00	0.00000E+00
5)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99531E+00	0.00000E+00
6)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99473E+00	0.00000E+00
7)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99430E+00	0.00000E+00

Appendix T: Sample Output File "Np_NaCl_BM.TITRATE"

8)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99378E+00	0.00000E+00
9)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99326E+00	0.00000E+00
10)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.99250E+00	0.00000E+00
11)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.98931E+00	0.00000E+00
12)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.98478E+00	0.00000E+00
13)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.96914E+00	0.00000E+00
14)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.91117E+00	0.00000E+00
15)	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	9.74696E+00	0.00000E+00

(missing species have zero amounts)

	IonicStreng	Eh(=)Volts	TitrVol,ml	pH
1)	5.61119E+00	0.00000E+00	0.00000E+00	5.3205
2)	5.61031E+00	0.00000E+00	0.10000	5.6451
3)	5.61008E+00	0.00000E+00	0.14251	5.9936
4)	5.61003E+00	0.00000E+00	0.16000	6.2353
5)	5.61001E+00	0.00000E+00	0.18000	6.6996
6)	5.61006E+00	0.00000E+00	0.20309	7.9427
7)	5.61014E+00	0.00000E+00	0.22000	8.3317
8)	5.61024E+00	0.00000E+00	0.24000	8.5655
9)	5.61034E+00	0.00000E+00	0.26000	8.7166
10)	5.61049E+00	0.00000E+00	0.28943	8.8722
11)	5.61112E+00	0.00000E+00	0.41246	9.2225
12)	5.61202E+00	0.00000E+00	0.58780	9.4695
13)	5.61513E+00	0.00000E+00	1.1938	9.8493
14)	5.62685E+00	0.00000E+00	3.4551	10.295
15)	5.66143E+00	0.00000E+00	10.000	10.659

Appendix U: Sample Output File "Np_NaCl_BM_LOG.MOLES"

See Table 30 for explanation of this listing.

```
Benchmark TITRATE Problem, LOG10 option: Np(V)O2 with CO3 in 5.61molal NaCl   FMT V2.0
DATABASE:  HMW84/FW86; Np(V)-Na-CO3-OH-Cl-ClO4 (NR94);
95.01.31      Am(III)-Na-Cl-CO3-SO4-PO4 (FRSR89,FRF90,P91,RFFR92,RFF94,RRFF94)

   INITIAL and INJECTED Abundances BEFORE Flashing
   Hydrogen       1.1101736300E+02    1.1101836300E+02
   Oxygen         6.1508681500E+01    1.0550868200E+02
   Sodium         5.6100000000E+00    1.5610000000E+01
   Potassium      0.0000000000E+00    0.0000000000E+00
   Magnesium      0.0000000000E+00    0.0000000000E+00
   Calcium        0.0000000000E+00    0.0000000000E+00
   Chlorine       1.6100000000E+00    5.6110000000E+00
   Sulfur         0.0000000000E+00    0.0000000000E+00
   Carbon         2.0000000100E+00    1.0000000000E+01
   PosIon         0.0000000000E+00    0.0000000000E+00
   NegIon         0.0000000000E+00    0.0000000000E+00
   Air            0.0000000000E+00    0.0000000000E+00
   Boron          0.0000000000E+00    0.0000000000E+00
   Bromine        0.0000000000E+00    0.0000000000E+00
   TracerEl       0.0000000000E+00    0.0000000000E+00
   Th(IV)         0.0000000000E+00    0.0000000000E+00
   Am(III)        0.0000000000E+00    0.0000000000E+00
   U(VI)          0.0000000000E+00    0.0000000000E+00
   Np(V)          0.0000000000E+00    1.0000000000E+01
   ClO4-(EL)      0.0000000000E+00    0.0000000000E+00
   Phosphorus     0.0000000000E+00    0.0000000000E+00
   Electron       0.0000000000E+00    0.0000000000E+00
   Charge        -2.2204460500E-15   -2.3731663200E-15

   INITIAL and INJECTED Abundances AFTER Flashing
   Hydrogen       1.1101736300E+02    1.1101836300E+02
   Oxygen         6.1508681520E+01    1.0550868150E+02
   Sodium         5.6100000000E+00    1.5610000000E+01
   Potassium      0.0000000000E+00    0.0000000000E+00
   Magnesium      0.0000000000E+00    0.0000000000E+00
   Calcium        0.0000000000E+00    0.0000000000E+00
   Chlorine       1.6100000000E+00    5.6110000000E+00
   Sulfur         0.0000000000E+00    0.0000000000E+00
   Carbon         2.0000000100E+00    1.0000000000E+01
   PosIon         0.0000000000E+00    0.0000000000E+00
   NegIon         0.0000000000E+00    0.0000000000E+00
   Air            0.0000000000E+00    0.0000000000E+00
   Boron          0.0000000000E+00    0.0000000000E+00
   Bromine        0.0000000000E+00    0.0000000000E+00
   TracerEl       0.0000000000E+00    0.0000000000E+00
   Th(IV)         0.0000000000E+00    0.0000000000E+00
   Am(III)        0.0000000000E+00    0.0000000000E+00
   U(VI)          0.0000000000E+00    0.0000000000E+00
   Np(V)          0.0000000000E+00    1.0000000000E+01
   ClO4-(EL)      0.0000000000E+00    0.0000000000E+00
   Phosphorus     0.0000000000E+00    0.0000000000E+00
   Electron       0.0000000000E+00    0.0000000000E+00
   Charge        -2.2204460493E-15   -2.3731663190E-15

   INITIAL and INJECTED Concs AFTER Flashing, molal
   H2O                          WATER  5.5502535E+01  5.5509068E+01
   Na+                            Na+  5.6100000E+00  5.6106128E+00
   K+                              K+  0.0000000E+00  0.0000000E+00
   Ca++                          Ca++  0.0000000E+00  0.0000000E+00
   Mg++                          Mg++  0.0000000E+00  0.0000000E+00
   MgOH+                        MgOH+  0.0000000E+00  0.0000000E+00
   H+                              H+  2.3992707E-12  1.2187250E-06
   Cl-                            Cl-  1.6100000E+00  5.6110000E+00
   SO4=                          SO4=  0.0000000E+00  0.0000000E+00
   HSO4-                        HSO4-  0.0000000E+00  0.0000000E+00
   OH-                            OH-  6.1466486E-03  3.0168704E-09
   HCO3-                        HCO3-  6.1466639E-03  2.2657297E-04
   CO3=                          CO3=  1.9938533E+00  3.0938611E-08
   CO2(aq)                    CO2(aq)  2.3684969E-09  3.8610605E-04
   CaCO3(aq)                CaCO3(aq)  0.0000000E+00  0.0000000E+00
   MgCO3(aq)                MgCO3(aq)  0.0000000E+00  0.0000000E+00
   B(OH)3(aq)              B(OH)3(aq)  0.0000000E+00  0.0000000E+00
   B(OH)4-                   B(OH)4-  0.0000000E+00  0.0000000E+00
   B3O3(OH)4-              B3O3(OH)4-  0.0000000E+00  0.0000000E+00
   B4O5(OH)4=              B4O5(OH)4=  0.0000000E+00  0.0000000E+00
   CaB(OH)4+                CaB(OH)4+  0.0000000E+00  0.0000000E+00
   MgB(OH)4+                MgB(OH)4+  0.0000000E+00  0.0000000E+00
   Br-                            Br-  0.0000000E+00  0.0000000E+00
   ClO4-            perchlorate ClO4-  0.0000000E+00  0.0000000E+00
   NaOH(aq).......to.titrate.base.only  0.0000000E+00  0.0000000E+00
   HCl(aq)........to.titrate.acid.only  0.0000000E+00  0.0000000E+00
   HClO4(aq)......to.titrate.acid.only  0.0000000E+00  0.0000000E+00
```

Appendix U: Sample Output File "Np_NaCl_BM_LOG.MOLES"

```
PosIon................POSITIVE.ION  0.0000000E+00  0.0000000E+00
NegIon................NEGATIVE.ION  0.0000000E+00  0.0000000E+00
PosIon(OH)(aq).....to.titrate.base  0.0000000E+00  0.0000000E+00
HNegIon(aq)........to.titrate.acid  0.0000000E+00  0.0000000E+00
Tracer(aq).....conservative.tracer  0.0000000E+00  0.0000000E+00
H3PO4(aq)                 H3PO4(aq)  0.0000000E+00  0.0000000E+00
H2PO4-                       H2PO4-  0.0000000E+00  0.0000000E+00
HPO4=                         HPO4=  0.0000000E+00  0.0000000E+00
PO4=-                         PO4=-  0.0000000E+00  0.0000000E+00
NpO2+                         NpO2+  0.0000000E+00  6.1270920E-04
NpO2OH(aq)               NpO2OH(aq)  0.0000000E+00  7.7219130E-10
NpO2(OH)2-               NpO2(OH)2-  0.0000000E+00  2.0438298E-16
NpO2CO3-                   NpO2CO3-  0.0000000E+00  1.3352733E-07
NpO2(CO3)2=-           NpO2(CO3)2=-  0.0000000E+00  1.9838516E-11
NpO2(CO3)3==-         NpO2(CO3)3==-  0.0000000E+00  1.2519757E-16
Am+++                         Am+++  0.0000000E+00  0.0000000E+00
AmCO3+                       AmCO3+  0.0000000E+00  0.0000000E+00
Am(CO3)2-                 Am(CO3)2-  0.0000000E+00  0.0000000E+00
Am(CO3)3=-               Am(CO3)3=-  0.0000000E+00  0.0000000E+00
Am(OH)2+                   Am(OH)2+  0.0000000E+00  0.0000000E+00
Am(OH)3(aq)             Am(OH)3(aq)  0.0000000E+00  0.0000000E+00
Th++++                       Th++++  0.0000000E+00  0.0000000E+00
UO2++                     U(VI)O2++  0.0000000E+00  0.0000000E+00
NpO2OH(aged)_____________NpO2OH(aged)  0.0000000E+00  0.0000000E+00
NpO2OH(amor)_____________NpO2OH(amor)  0.0000000E+00  0.0000000E+00
NaNpO2CO3(s)_____________NaNpO2CO3(s)  0.0000000E+00  9.9993872E+00
Na3NpO2(CO3)2(s)_DISABLED_DISABLED  0.0000000E+00  0.0000000E+00
AmOHCO3(c)_______________AmOHCO3(c)  0.0000000E+00  0.0000000E+00
Am(OH)3(s)_______________Am(OH)3(s)  0.0000000E+00  0.0000000E+00
NaAm(CO3)2.6H2O(c)_______________  0.0000000E+00  0.0000000E+00
AmPO4(c)_________________AmPO4(c)  0.0000000E+00  0.0000000E+00
CaSO4____________________Anhydrite  0.0000000E+00  0.0000000E+00
NaK3(SO4)2__Aphthitalite/Glaserite  0.0000000E+00  0.0000000E+00
CaCl2.6H2O_______________Antarcticite  0.0000000E+00  0.0000000E+00
CaCO3____________________Aragonite  0.0000000E+00  0.0000000E+00
K2SO4____________________Arcanite  0.0000000E+00  0.0000000E+00
MgCl2.6H2O_______________Bischofite  0.0000000E+00  0.0000000E+00
Na2Mg(SO4)2.4H2O_________Bloedite  0.0000000E+00  0.0000000E+00
Mg(OH)2__________________Brucite  0.0000000E+00  0.0000000E+00
Na6CO3(SO4)2_____________Burkeite  0.0000000E+00  0.0000000E+00
CaCO3____________________Calcite  0.0000000E+00  0.0000000E+00
CaCl2.4H2O_____CaCl2_Tetrahydrite  0.0000000E+00  0.0000000E+00
Ca4Cl2(OH)6.13H2O__CaOxychloride A  0.0000000E+00  0.0000000E+00
Ca2Cl2(OH)2.H2O____CaOxychloride B  0.0000000E+00  0.0000000E+00
KMgCl3.6H2O______________Carnallite  0.0000000E+00  0.0000000E+00
MgSO4.7H2O_______________Epsomite  0.0000000E+00  0.0000000E+00
CaNa2(CO3)2.5H2O_________Gaylussite  0.0000000E+00  0.0000000E+00
Na2Ca(SO4)2______________Glauberite  0.0000000E+00  0.0000000E+00
CaSO4.2H2O_______________Gypsum  0.0000000E+00  0.0000000E+00
NaCl_____________________Halite  0.0000000E+00  0.0000000E+00
MgSO4.6H2O_______________Hexahydrite  0.0000000E+00  0.0000000E+00
KMgClSO4.3H2O____________Kainite  0.0000000E+00  0.0000000E+00
KHCO3____________________Kalicinite  0.0000000E+00  0.0000000E+00
MgSO4.H2O________________Kieserite  0.0000000E+00  0.0000000E+00
K2Mg(SO4)2.4H2O__________Leonite  0.0000000E+00  0.0000000E+00
Na4Ca(SO4)3.2H2O_________Labile_Salt  0.0000000E+00  0.0000000E+00
MgCO3____________________Magnesite  0.0000000E+00  0.0000000E+00
Mg2Cl(OH)3.4H2O_____MgOxychloride  0.0000000E+00  0.0000000E+00
KHSO4____________________Mercallite  0.0000000E+00  0.0000000E+00
Na2SO4.10H2O_____________Mirabilite  0.0000000E+00  0.0000000E+00
K8H6(SO4)7_______________Misenite  0.0000000E+00  0.0000000E+00
NaHCO3___________________Nahcolite  0.0000000E+00  0.0000000E+00
Na2CO3.10H2O_____________Natron  0.0000000E+00  0.0000000E+00
MgCO3.3H2O_______________Nesquehonite  0.0000000E+00  0.0000000E+00
K2Mg(SO4)2.6H2O Picromerite/Schoen  0.0000000E+00  0.0000000E+00
Na2Ca(CO3)2.2H2O_________Pirssonite  0.0000000E+00  0.0000000E+00
K2MgCa2(SO4)4.2H2O_______Polyhalite  0.0000000E+00  0.0000000E+00
Ca(OH)2__________________Portlandite  0.0000000E+00  0.0000000E+00
K2CO3.3/2H2O___Potassium_Carbonate  0.0000000E+00  0.0000000E+00
K8H4(CO3)6.3H2O___K-Sequicarbonate  0.0000000E+00  0.0000000E+00
KNaCO3.6H2O__________K-Na-Carbonate  0.0000000E+00  0.0000000E+00
K2NaH(CO3)2.2H2O___Potassium_Trona  0.0000000E+00  0.0000000E+00
K3H(SO4)2__Sesquipotassium_Sulfate  0.0000000E+00  0.0000000E+00
Na3H(SO4)2____Sesquisodium_Sulfate  0.0000000E+00  0.0000000E+00
Na2CO3.7H2O____Na2CO3-Heptahydrate  0.0000000E+00  0.0000000E+00
KCl______________________Sylvite  0.0000000E+00  0.0000000E+00
K2Ca(SO4)2.H2O___________Syngenite  0.0000000E+00  0.0000000E+00
Mg2CaCl6.12H2O________Tachyhydrite  0.0000000E+00  0.0000000E+00
Na2SO4___________________Thenardite  0.0000000E+00  0.0000000E+00
Na2CO3.H2O_____________Thermonatrite  0.0000000E+00  0.0000000E+00
Na3H(CO3)2.2H2O__________Trona  0.0000000E+00  0.0000000E+00
Na2B4O7.10H2O____________Borax  0.0000000E+00  0.0000000E+00
B(OH)3___________Borix_Acid_Solid  0.0000000E+00  0.0000000E+00
KB5O8.4H2O____K-Pentaborate_(30_C)  0.0000000E+00  0.0000000E+00
K2B4O7.4H2O___K-Tetraborate_(30_C)  0.0000000E+00  0.0000000E+00
NaBO2.4H2O_____Sodium_Metaborate  0.0000000E+00  0.0000000E+00
NaB5O8.5H2O_____Sodium_Pentaborate  0.0000000E+00  0.0000000E+00
NaBO2.NaCl.2H2O___Teepleite_(20_C)  0.0000000E+00  0.0000000E+00
```

Appendix V: Command File FMT_FMTC.COM

```
$   SET noverify
$!   SET verify
$!         FMT_FMTC.COM assigns and fetches user-selected
$!         chemdat and rhomin data base file names,
$!         assign user-specified input/output file names,
$!         executes fmt2p0 in CMS 1996 nonPA (Performance
$!         Asssessment) production area
$!
$!          Author:   K. M. Aragon
$!          Date:     11/17/95
$!
$!          Modifier: S. C. Babb
$!          Date:     12/13/95
$!
$!          Modifier: S. C. Babb
$!          Date:     12/18/95
$!          Reason:    use fmt executable in production area
$!                     print identity of fmt executable
$!                     add log file and mail facility
$!                     decided not to use mail facility
$!
$!          Modifier: S. C. Babb
$!          Date:     12/21/95
$!          Reason:   name of fmt executable changed to prefix
$!                    "fmt_" full name is fmt_fmt2p0_pa96.exe
$!
$!*********************************************************************
$!  INPUTS:
$!
$!     P1 - Substring chemdat file name search on valance states, dates,
$!              and/or fugacity
$!
$!     P2 - Substring rhomin file name search on valance states and/or dates
$!
$!     P3 - Input File Name (no extension)
$!
$!---------------------------------------------------------------------
$!
$! Turn on error handling; exit on any error.
$!
$   ON error then goto error_exit
$   mode = f$mode()
$!
$! Logic flow
$!
$   GOSUB check_filename
$   GOSUB define_cms_library
$   GOSUB delete_files
$   GOSUB get_database_files
$   GOSUB define_inputs
$   GOSUB define_outputs
$   GOSUB start_log
$!   GOSUB start_mail
$   GOSUB run_fmt
$   GOSUB undefine_symbols
$   goto  terminate
$   EXIT
$!---------------------------------------------------------------------
$CHECK_FILENAME:
$! Determine if any or all file names are passed as parameters. If not,
$! prompt for one if this is an interactive session;
$! otherwise flag an error and exit
$!
$!  Check for P1 - this is the CHEMDAT name field
$!
$  IF mode .eqs. "BATCH" .and. p1 .eqs. ""
$  THEN
$      WRITE sys$output -
      "Can not run in batch without a chemdat file name (P1). exiting."
$      GOTO error_exit
$  ENDIF
$!
$!
$  IF p1 .eqs. ""
$   THEN
$       INQUIRE chemdat_name  -
                "Enter chemdat file name to search on"
$       IF chemdat_name .eqs. "" THEN goto error_exit
$  ELSE
$       chemdat_name = p1
$  ENDIF
$!
$!  Check for P2 - this is the RHOMIN name field
$!
$  IF mode .eqs. "BATCH" .and. p2 .eqs. ""
$  THEN
```

Appendix V: Command File FMT_FMTC.COM

```
$      WRITE sys$output -
      "Can not run in batch without a rhomin file name (P2). exiting."
$      GOTO error_exit
$  ENDIF
$!
$!
$  IF p2 .eqs. ""
$   THEN
$       INQUIRE rhomin_name  -
                "Enter rhomin file name to search on"
$       IF rhomin_name .eqs. "" THEN goto error_exit
$   ELSE
$       rhomin_name = p2
$   ENDIF
$!
$!  Check for P3 - this is the file name field
$!
$  IF mode .eqs. "BATCH" .and. p3 .eqs. ""
$  THEN
$      WRITE sys$output -
      "Can not run in batch without a file name (P3). exiting."
$      GOTO error_exit
$  ENDIF
$!
$!
$  IF p3 .eqs. ""
$   THEN
$       INQUIRE file_name  "Enter input file name (without .extension)"
$       IF file_name .eqs. "" THEN goto error_exit
$  ELSE
$       file_name = p3
$  ENDIF
$   RETURN
$!-----------------------------------------------------------------------
$DEFINE_CMS_LIBRARY:
$! Define non-pa cms symbols and point to fmt library
$!
$!  set noverify
$  nonpa_cms_syms
$!
$! Set CMS library to FMT
$!
$   cms_library_name = "fmt"
$   lib'cms_library_name
$!  set verify
$!
$   RETURN
$!-----------------------------------------------------------------------
$DEFINE_INPUTS:
$! Define the input files needed.
$!
$   DEFINE input 'file_name'.in
$   DEFINE inguess 'file_name'.inguess
$!
$! Define a logical that points to the database files just fetched
$!
$   DEFINE chemdat 'chemdat_name'
$   DEFINE rhomin 'rhomin_name'
$!
$   RETURN
$!-----------------------------------------------------------------------
$DEFINE_OUTPUTS:
$! Define the output files needed.
$!
$   DEFINE output 'file_name'.out
$   DEFINE for088 'file_name'.for088
$   DEFINE titrate 'file_name'.titrate
$   DEFINE moles 'file_name'.moles
$!
$   RETURN
$!-----------------------------------------------------------------------
$DELETE_FILES:
$!
$! Turn off warning messages for no files to delete
$!
$   SET noon
$   SET message/nofac/nosev/notext/noid
$! Delete all 'file_name'.moles files; do not accumulate them.
$!
$   DELETE  'file_name'.moles;*
$! Delete all fmt prefixed files of chemdat and rhomin files
$!
$   DELETE  fmt_*.chemdat;*
$   DELETE  fmt_*.rhomin;*
$   SET message/fac/sev/text/id
$   SET on
$!
$   RETURN
$!-----------------------------------------------------------------------
$ERROR_EXIT:
```

```
$! Exit routine when a severe error is encountered
$!
$   Write sys$output "Executing error exit, ''$status'."
$   EXIT
$!-----------------------------------------------------------------------
$GET_DATABASE_FILES:
$!
$! If interactive, allow user to select/pick from a list of chemdat file names
$!
$  IF mode .nes. "BATCH"
$  THEN
$    cse "*''chemdat_name'*.chemdat"
$!
$    INQUIRE chemdat_name "Select CHEMDAT name from list above"
$  ENDIF
$!
$! Fetch chemdat from FMT CMS
$!
$!   set noverify
$   cfe 'chemdat_name'
$!  set verify
$!
$! If interactive allow user to select/pick from a list of rhomin file names
$!
$  IF mode .nes. "BATCH"
$  THEN
$   cse "*''rhomin_name'*.rhomin"
$!
$    INQUIRE rhomin_name "Select RHOMIN name from list above"
$  ENDIF
$!
$! Fetch chemdat from FMT CMS
$!   set noverify
$   cfe 'rhomin_name'
$!   set verify
$!
$   RETURN
$!-----------------------------------------------------------------------
$RUN_FMT:
$! Define the run symbols needed.
$   define /nolog exe_dir                wp$nonpa_prodroot:[fmt.exe]
$   fmt2p0      :== "$exe_dir:fmt_fmt2p0_pa96.exe"
$!
$! Run the utility that shows image information from the exe. (mandatory!)
$! This is part of the documentation required while doing a calculation.
$   @wp$ref:wp_get_image_id.com          exe_dir:fmt_fmt2p0_pa96.exe
$! Run the code
$!
$   fmt2p0
$   RETURN
$!-----------------------------------------------------------------------
$START_LOG:
$!
$   month   == f$cvtime("'''f$time()'", "absolute", "month" )
$   day             ==  f$cvtime("'''f$time()'", "comparison", "day" )
$   hour    == f$cvtime("'''f$time()'", "absolute", "hour" )
$   min             ==  f$cvtime("'''f$time()'", "absolute", "minute" )
$!
$   log_file_name :== "'''file_name'_''month'''day'_''hour'''min'.log"
$!  mike williamson's log file definition:
$!      "sys$login:fmt_''file_name'_''month'''day'_''hour'''min'.log"
$!
$   DEFINE/proc sys$output 'log_file_name
$!
$   RETURN
$!-----------------------------------------------------------------------
$START_MAIL:
$! Open a file where we can write a message that can be sent to the
$! user upon completion.
$!
$   mail_error_flag = 0
$   mail_file_name :== "sys$Login:fmt_mail.msg"
$   mail_subject   :== "FMT ''file_name' run."
$   mail_list == f$getjpi( "", "username")
$!
$   OPEN/write mail_file 'mail_file_name
$!
$   RETURN

$!-----------------------------------------------------------------------
$TERMINATE:
$! If there was no previously flagged error or problem, search the log files
$! for any fatal, error, or warning messages.
$!
$! Deassign sys$output so the "log" file closes.
$   deassign sys$output
$!
$! Show the run output to the user
$   TYPE 'log_file_name
$!
```

Appendix V: Command File FMT_FMTC.COM

```
$! Skip sending the mail message
$   goto end_terminate
$!
$! If there was not a previous error recorded, search the log file for
$! common error indicators.
$   search_status = 0
$   IF mail_error_flag .ne. 1
$   THEN
$!      Turn off informational messages from search command
$       SET message/nofac/nosev/notext/noid
$       SEARCH 'log_file_name' "-F-","-E-","-W-" / match=or
$       search_status = $status
$!      Turn on messages
$       SET message/fac/sev/text/id
$   ENDIF
$!
$   IF search_status .eq. 1 .or. mail_error_flag .eq. 1
$   THEN
$       WRITE mail_file  "The run log contains an error or warning. "
$       WRITE mail_file  "Please examine ''log_file_name'."
$       mail_subject    == "''mail_subject' ERROR"
$   ELSE
$       WRITE mail_file  "The FMT run has completed."
$   ENDIF
$!
$   CLOSE/nolog mail_file
$   MAIL/subject="''mail_subject'" 'mail_file_name' 'mail_list
$!
$END_TERMINATE:
$   EXIT
$!-----------------------------------------------------------------------------
$UNDEFINE_SYMBOLS:
$! Deassign input files
$!
$   DEASSIGN input
$   DEASSIGN inguess
$   DEASSIGN chemdat
$   DEASSIGN rhomin
$   DEASSIGN output
$   DEASSIGN for088
$   DEASSIGN titrate
$   DEASSIGN moles
$!
$   RETURN
$!-----------------------------------------------------------------------------
$! CMS REPLACEMENT HISTORY, Element FMT_FMTC.COM
$! *2    21-DEC-1995 12:58:57 SCBABB "FMT EXECUTABLE NAME CHANGED"
$! *1    19-DEC-1995 12:26:54 SCBABB "USER COMMAND FILE FOR EXECUTING FMT_FMT2P0 FROM CMS"
$! CMS REPLACEMENT HISTORY, Element FMT_FMTC.COM
```

Appendix W: Review Forms

This Appendix contains the review forms for the FMT User's Manual.

NOTE: Copies of the User's Manual Reviewer's Forms are available in the Sandia WIPP Central Files.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

SOTERM Attachment 2

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WIPP PA

User's Manual

for

NONLIN, Version 2.0

Document Version 1.0

WPO #30740

January 31, 1996

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1.0 INTRODUCTION

The program NONLIN fits parameters for a designated aqueous electrolyte model to experimental data on osmotic coefficients, mineral solubility, emf, or solvent extraction. Although NONLIN has two aqueous electrolyte models for excess free energy available, the Davies equations (Davies, 1962) and Pitzer's aqueous electrolyte model (Pitzer [1973] and coworkers), this document will discuss only the Pitzer model, which is used to support the 1996 WIPP Performance Assessment (PA) calculations.

For the 1996 WIPP PA calculation, NONLIN is used to calculate Pitzer parameters and standard chemical potentials of actinide chemical species. The calculated values will be added to the CHEMDAT data base used by a program called FMT. CHEMDAT contains the Harvie-Møller-Weare (HMW) database (Harvie et al., 1984; Felmy and Weare, 1986) for nonradioactive electrolyte systems and the actinide series of radioactive elements, such as americium(III) and neptunium(V). FMT is a chemical equilibrium modeling code, also used to support the 1996 WIPP PA calculations. The FMT User's Manual, WPO 28119, documents both the CHEMDAT data base and the FMT code.

1.1 Software Identifier

Code Name: NONLIN
WIPP Prefix: NL_
Version Number: 2.0 08/23/96
Platforms: FORTRAN 77 for Open VMS AXP, version 6.1, on DEC Alpha machines and Power Macintosh 7100

1.2 Points of Contact

1.2.1 Code Sponsor

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2.0 FUNCTIONAL REQUIREMENTS

R.1 NONLIN fits parameters for Pitzer's aqueous electrolyte model to experimental data on mineral solubility.

R.2 NONLIN fits parameters for Pitzer's aqueous electrolyte model to experimental data on solvent extraction.

R.3 NONLIN fits parameters for Pitzer's aqueous electrolyte model to experimental data for apparent stability.

3.0 REQUIRED USER TRAINING AND/OR BACKGROUND

In order to run the NONLIN code successfully, the user will need a basic knowledge of one of the following platforms:

- Open VMS and Digital Equipment Co.'s (DEC's) Digital Command Language (DCL), if running the code on the DEC platform
- Power Macintosh 7100 operation, if running the code on a Macintosh platform.

To interpret the results of NONLIN, a chemistry background is required. A user should have a:

- BS in Chemistry, or the equivalent
- familiarity with the Pitzer model for activity coefficient of electrolytes
- sound understanding of chemical reaction equilibrium analysis.

To understand how the NONLIN code works and the theory and algorithms upon which NONLIN is based, the user should also have a basic understanding of:

- equilibrium thermodynamics and solution chemistry
- linear algebra (through senior undergraduate level)
- numerical methods (graduate or senior level undergraduate level).

4.0 DESCRIPTION OF THE MODELS AND METHODS

NONLIN solves chemical equilibrium problems, as defined by the linear material balance equations and the nonlinear reaction equilibrium equations as given in standard chemical thermodynamics texts such as Denbigh (1981) and Smith and Van Ness (1975).

More specifically, NONLIN couples the GMIN free-energy chemical equilibrium program with the MINPACK least squares minimization routines. NONLIN can be used to interpret (i.e., fit) experimental concentration data such as

- solubility (i.e., the total dissolved concentration of element X in aqueous electrolyte of composition Y)

- electromotive force (emf)
- isopiestic data
- solvent extraction data (i.e., the distribution of element X between an aqueous and an organic phase)
- ion exchange data
- apparent stability constant data (i.e., the molal ion quotients for intra-aqueous reactions).

4.1 GMIN Chemical Equilibrium Model

The GMIN chemical equilibrium program is explained in detail by Felmy (1990) and Felmy (1995). Sections 4.1.1 and 4.1.3 of the following discussion are largely excerpted from that source. Section 4.1.2, which explains the Pitzer activity coefficient formalism, is excerpted from Felmy and Weare (1986).

4.1.1 Thermodynamic Model

The mathematical basis of GMIN is based on the development of an algorithm for solving the chemical equilibrium problem that is based on a constrained minimization of the Gibbs free energy.

NONLIN, as used in support of the 1996 WIPP PA calculation, makes use of the following general equations that GMIN can solve:

- chemical potential for water solvent in aqueous phase:

$$\frac{\mu_{H_2O}}{RT} = \frac{\mu^0_{H_2O}}{RT} - \frac{W}{1000}\left(\sum_{i=1}^{ns} m_i\right)\phi \tag{4-1}$$

- chemical potential for solute species in aqueous phase:

$$\frac{\mu_i}{RT} = \frac{\mu_i^0}{RT} + \ln m_i + \ln \gamma_i \tag{4-2}$$

where

μ_i = chemical potential of species i

μ_i^0 = standard chemical potential of species i

R = the gas constant

T = absolute temperature

W = molecular weight of water

ns = the total number of chemical species

m_i = molality of species i

ϕ = osmotic coefficient

γ_i = activity coefficient of species i.

While GMIN contains two formulations for activity coefficients for aqueous species, only one formulation is used in support of the WIPP PA calculation. This model is based on the work by Pitzer (1979) and coworkers. In this model, the activity coefficients are expressed in a virial-type expansion.

4.1.2 The Pitzer Activity Coefficient Formalism

The Pitzer activity coefficient formalism is a set of mathematical equations for calculating activity coefficients for aqueous species, and is valid from dilute systems through the concentrated brine concentrations observed at the WIPP Site. The theoretical and historical development of this formalism can be traced though Pitzer (1991), particularly Chapter 3, and references therein.

The implementation of the Pitzer activity coefficient formalism within NONLIN is based on the forms of the equations as presented in Harvie and Weare (1980), Harvie et al. (1984), and Felmy and Weare (1986). Because there is no difference in the mathematical formulation provided by these references, only the equations in Felmy and Weare (1986) are presented below. The interested reader will find a comprehensive presentation of these equations in the three cited publications.

The activities of the species a_i can be defined by the following equation:

$$\left(\frac{\partial G}{\partial n_i}\right)_{T,P,n} = \mu_i = \mu_i^0 + RT\ln a_i. \tag{4-3}$$

where G = Gibbs free-energy function, P = pressure, n_i = number of moles of species i, and activity is defined for each solute species i by

$$a_i = \gamma_i m_i \tag{4-4}$$

and, for the solvent, by

$$\ln a_{H_2O} = \frac{-W}{1000}\left(\sum_i m_i\right)\phi, \tag{4-5}$$

where

m_i = the molality of the solute species,

W = the molecular weight of water,

$\sum_i m_i$ = the sum over all solutes (cations (c), anions (a), and neutrals(n)), and

ϕ = the osmotic coefficient.

While the chemical potentials for pure phases (e.g., minerals) are constant at fixed temperature and pressure, the fugacity of gas-phase species, f_i, is defined as follows:

$$\frac{\mu_i}{RT} = \frac{\mu_i^0}{RT} + \ln(f_i). \tag{4-6}$$

The remaining variables that lack explicit definition are the excess functions γ_i and $(\phi - 1)$. These functions, rewritten below, are modeled using the semiempirical equations of Pitzer (1973) and co-workers. (Note that, in the Pitzer equations presented below, I = ionic strength, and that subscripts *M*, *X*, and *N* refer to cations, anions, and neutrals, respectively. The remaining terms are explained following the presentation of the Pitzer equations.)

$$\begin{aligned}(\phi-1) = \frac{2}{\left(\sum_i m_i\right)} \Bigg\{ & -\frac{A^\phi I^{3/2}}{1+bI^{1/2}} + \sum_c \sum_a m_c m_a \left(B^\phi_{ca} + ZC_{ca}\right) + \sum_{c<c'} \sum m_c m_{c'} \left(\Phi^\phi_{cc'} + \sum_a m_a \Psi_{cc'a}\right) \\ & + \sum_{a<a'} \sum m_a m_{a'} \left(\Phi^\phi_{aa'} + \sum_c m_c \Psi_{aa'c}\right) + \sum_n \sum_c m_n m_c \lambda_{nc} \\ & + \sum_n \sum_a m_n m_a \lambda_{na} + \sum_n \sum_c \sum_a m_n m_c m_a \zeta_{nca} \Bigg\}\end{aligned} \tag{4-7}$$

$$\begin{aligned}\ln\gamma_M = {} & z_M^2 F + \sum_a m_a \left(2B_{Ma} + ZC_{Ma}\right) + \sum_c m_c \left(2\Phi_{Mc} + \sum_a m_a \Psi_{Mca}\right) \\ & + \sum_{a<a'} \sum m_a m_{a'} \Psi_{aa'M} + |z_M| \sum_c \sum_a m_c m_a C_{ca} + \sum_n m_n \left(2\lambda_{nM}\right) + \sum_n \sum_a m_n m_a \zeta_{naM}\end{aligned} \tag{4-8}$$

$$\ln\gamma_X = z_M^2 F + \sum_c m_c\left(2B_{Xc} + ZC_{Xc}\right) + \sum_a m_a\left(2\Phi_{Xa} + \sum_c m_c \psi_{Xca}\right) + \sum_{c<c'}\sum m_c m_{c'} \psi_{cc'X} + |z_X| \sum_c \sum_a m_c m_a C_{ca} + \sum_n m_n\left(2\lambda_{nX}\right) + \sum_n \sum_c m_n m_c \zeta_{ncX} \tag{4-9}$$

$$\ln\gamma_N = \sum_c m_c\left(2\lambda_{Nc}\right) + \sum_a m_a\left(2\lambda_{Na}\right) + \sum_c \sum_a m_c m_a \zeta_{Nca} \tag{4-10}$$

$$F = -A^{\phi}\left(\frac{I^{1/2}}{1+bI^{1/2}} + \frac{2}{b}\ln\left(1+bI^{1/2}\right)\right) + \sum_c \sum_a m_c m_a B'_{ca} + \sum_{c<c'}\sum m_c m_{c'} \Phi'_{cc'} + \sum_{a<a'}\sum m_a m_{a'} \Phi'_{aa'} \tag{4-11}$$

where $b = 1.2$ for all electrolyes.

$$C_{MX} = \frac{C^{\phi}_{MX}}{2\left|Z_M Z_X\right|^{1/2}} \tag{4-12}$$

$$Z = \sum_i |z_i| m_i \tag{4-13}$$

A^{ϕ} is one third of the Debye-Hückel limiting slope (A in the following empirical equation):

$$\ln\gamma_i^{DH} = -\frac{A\sqrt{I}}{1+Ba_i\sqrt{I}} + \dot{B}_i I, \tag{4-14}$$

as presented on page 981 of Harvie and Weare [1980].) Here A^{ϕ} is a function of temperature and equals 0.39 at 25°C. The second virial coefficients, B, are empirical expansions and are given the following ionic strength dependence:

$$B^{\phi}_{MX} = \beta^{(0)}_{MX} + \beta^{(1)}_{MX} e^{-\alpha_1\sqrt{I}} + \beta^{(2)}_{MX} e^{-\alpha_2\sqrt{I}} \tag{4-15}$$

$$B_{MX} = \beta^{(0)}_{MX} + \beta^{(1)}_{MX} g\left(\alpha_1\sqrt{I}\right) + \beta^{(2)}_{MX} g\left(\alpha_2\sqrt{I}\right) \tag{4-16}$$

$$B'_{MX} = \beta^{(1)}_{MX} \frac{g'(\alpha_1 \sqrt{I})}{I} + \beta^{(2)}_{MX} \frac{g'(\alpha_2 \sqrt{I})}{I} \tag{4-17}$$

The functions g and g' are defined by

$$g(x) = 2\frac{(1-(1+x)e^{-x})}{x^2} \tag{4-18}$$

$$g'(x) = -2\frac{\left(1-\left(1+x+\frac{x^2}{2}\right)e^{-x}\right)}{x^2} \tag{4-19}$$

with $x = \alpha_1\sqrt{I}$ or $= \alpha_2\sqrt{I}$. When either cation M or anion X is univalent, $\alpha_1 = 2.0$ and $\alpha_2 = 12$. For 2 - 2 pairs, $\alpha_1 = 1.4$ and $\alpha_2 = 12$. For 2 - 3 and higher pairs, $\alpha_1 = 1.4$ and $\alpha_2 = 50$. The dimensions of α_1 and α_2 are $kg^{1/2}mole^{-1/2}$. The virial coefficients, Φ, which depend upon ionic strength, are given the following form:

$$\Phi^{\phi}_{ij} = \theta_{ij} + {}^{E}\theta_{ij}(I) + I\,{}^{E}\theta'_{ij}(I) \tag{4-20}$$

$$\Phi_{ij} = \theta_{ij} + {}^{E}\theta_{ij}(I) \tag{4-21}$$

$$\Phi'_{ij} = {}^{E}\theta'_{ij}(I) \tag{4-22}$$

The functions, ${}^{E}\theta_{ij}(I)$ and ${}^{E}\theta'_{ij}(I)$, are functions only of ionic strength and the electrolyte pair type.

The activity coefficient parameters, λ_{ni} and ζ_{nij}, represent the interactions between ions and neutral species. The third virial coefficients, C^{ϕ}_{MX} and ψ_{ijk}, are also assumed to be independent of ionic strength.

The following is the complete set of parameters that define the model for nonideal behavior of electrolyte solutions:

- $\beta^{(0)}_{MX}$, $\beta^{(1)}_{MX}$, $\beta^{(2)}_{MX}$, and C^{ϕ}_{MX} for each cation-anion pair
- θ_{ij} for each cation-cation and anion-anion pair
- ψ_{ijk} for each cation-cation-anion and anion-anion-cation triplet
- λ_{ni} and ζ_{nij} for ion-neutral and ion-ion-neutral interactions.

NONLIN minimizes the sum of the errors squared for the standard chemical potential of user-specified species by adjusting the values of the thermodynamic parameters specified by the user.

These are the Pitzer parameters NONLIN solves for using thermodynamic data.

4.1.3 Free-Energy Minimization Approach

The free-energy minimization problem in GMIN is formulated as

$$\text{minimize}\, G = \sum_{j=1}^{ns} \mu_j n_j \tag{4-23}$$

subject to the following mass-balance constraint

$$\sum_{j=1}^{ns} a_{ji} n_j = b_i, \qquad i = 1, \ldots, m_c \tag{4-24}$$

and the following charge-balance constraint

$$\sum_{j=1}^{nas} z_j n_j = 0 \tag{4-25}$$

and

$$n_j \geq 0 \qquad \text{for all species } j \tag{4-26}$$

where

ns = the total number of chemical species

n_j = mole number of species j

a_{ji} = number of moles of component i in species j

b_i = total number of moles of element i

m_c = number of linearly independent mass-balance constraints

nas = total number of aqueous species j

z_j = charge on species j

The free-energy minimization approach is fully documented in Harvie, Greenberg, and Weare (1987).

4.2 NONLIN Parameter Calculation

NONLIN calculates the Pitzer ion interaction parameters by using a non-linear least squares fitting algorithm. The code calculates values for user-specified aqueous solution and solid thermodynamic parameters, including the standard chemical potentials for ion pairs. NONLIN calculates the function to be minimized; i.e., the difference between solid and solution chemical potentials, and the Jacobian (the derivative of the chemical potential difference with respect to the adjustable parameters). The adjustable parameters, discussed in detail in Section 7.1, are the Pitzer parameters and the standard chemical potential of the chemical species to be fitted. Andrew R. Felmy is the code author of both NONLIN and GMIN, a chemical equilibrium code called by NONLIN. Pacific Northwest Laboratory maintains MINPACK, a set of matrix routines called by GMIN.

5.0 CAPABILITIES AND LIMITATIONS OF THE SOFTWARE

The chemical data base files and the problem definition files must be compatible; i.e., the species must be characterized in the data base before it is referenced in the problem. NONLIN capabilities are discussed at the beginning of Section 1.

6.0 USER INTERACTIONS WITH THE SOFTWARE

6.1 Overview

NONLIN requires six input data files— GMIN, INPUT, COMP, BINARYP, TERNARYP, and LAMBDA. The problem is defined by the GMIN and INPUT files. The GMIN file defines the chemical species to be considered. The INPUT file contains the experimental data and initial estimates for the Pitzer parameters or standard chemical potentials to be fitted. The last four files COMP, BINARYP, TERNARYP, and LAMBDA are the chemical data base files. These files contain species names and unique ID numbers, chemical characteristics, and Pitzer parameters. All the input files are discussed in detail in Section 7.0.

NONLIN generates one file OUTPUT. This file lists the problem definition as read from the GMIN and INPUT files, chemical species considered, and the best fit to the experimental data set(s).

Figure 6-1 illustrates all the input and output files used by NONLIN.

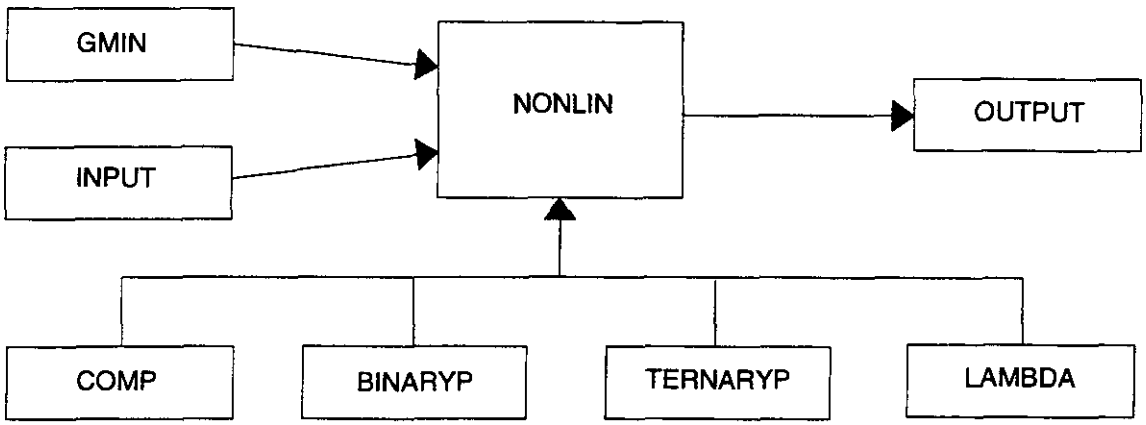

Figure 6-1. Input and Output Files for NONLIN.

6.2 User-Supplied Input Files

Using a convenient editor, the user creates the GMIN file and the INPUT file for a problem. The user should check the COMP, BINARYP, TERNARYP, and LAMBDA files to be sure that the required species and Pitzer parameters are included there.

6.3 Executing NONLIN

6.3.1 DEC Environment

The user can access the command file NL_NONLINC.COM to run NONLIN on the Sandia NWER network, using Digital's Alpha machine BEATLE. This file is located in the NL library. All files in the library are under control of Digital's Configuration Management System (CMS). This library contains NONLIN data base files, source code, and command files. The user can retrieve the command file NL_NONLINC.COM from the NL library using the CMS "fetch" command. For ease in executing NONLIN, the command file should be in the same directory where the input files reside.

6.3.1.1 Fetching the Command File NL_NONLINC.COM from CMS

To retrieve the command file NL_NONLINC.COM, the user logs into BEATLE and types the symbol "nonpa_cms_syms" to define other CMS symbols, followed by the command "libnl" to specify the NL library. Then the user locates the directory/subdirectory where his/her input files reside by typing in a "set default (sd)" command. The command "cfe nl_nonlinc.com" copies the command file into the user's current directory. The lines are:

```
$nonpa_cms_syms
$libnl
$sd [username.user_inputfile_directory]
$cfe nl_nonlinc.com
```

The command file can be copied from directory to directory. The user does not need to fetch the file each time. NL_NONLINC.COM also issues the lines "nonpa_cms_syms" and "libnl" automatically, making typing them unnecessary.

6.3.1.2 Running NL_NONLINC.COM

To execute "@NL_NONLINC" the user must always be logged into BEATLE. The user should be in the directory that contains the .IN and .GMIN files before starting NL_NONLINC. To execute the command, the user types:

```
$@ NL_NONLINC
```

The user will be prompted to supply a **substring** for the COMP, BINARYP, TERNARYP, and LAMBDA files and the GMIN and INPUT file names. To retrieve a list of all data base files, the user can simply type in ".DAT" since all of the NONLIN data base files have the string ".DAT" as the extension. Or, the user can type in any substring of the data base file name (e.g., COMP_960130). The GMIN and INPUT filestem names can be independent (e.g., SOLUB_01.IN and SOLUB_00.GMIN) or the same (e.g., AM_ACET.IN and AM_ACET.GMIN).

After listing the data base files that match the substring specified, the user is prompted to select each data base file. The user may select a file by copying and pasting the file name to the waiting request, by double clicking on one of the file names listed, or by typing the entire name.

WARNING: The NL_NONLINC command deletes all data base files with the "NL_" prefix and ".DAT" extension from the user's current directory before fetching any of the four data base files.

6.3.2 Macintosh Environment

The Macintosh executable icon for NONLIN is called PMacNonlin. To start the code, the user double clicks, either with a mouse or track ball, on the PMacNonlin icon. The chemical data base files must be located in the same folder that contains the executable icon. After starting the icon, the program will use the files explicitly labeled BINARYP, COMP, TERNARYP, and LAMBDA in the icon's folder.

A suggested method for organizing folders or directories while running NONLIN on the Macintosh is shown in Figure 6-2 and Figure 6-3. Using this approach, files are grouped as follows:

- all chemical data base files (BINARYP, COMP, TERNARYP and LAMBDA) and the PMacNonlin icon in one folder labeled "HMW_ACTINIDE_DB," as shown in Figure 6-2. New species can be added to these existing chemical database files without affecting the results of calculations performed using previous versions of these database files, as long as a consistent ID numbering scheme is maintained (Sections 7.3 through 7.6).

- the GMIN and INPUT files in another folder. Beneath a major folder labeled "TEST CASES," Figure 6-3 shows two problem-labeled folders, "Am_Acet" and "SOLUB," each containing the GMIN and INPUT files for the solvent extraction and mineral solubility problems, respectively. By default, the OUTPUT file will be placed in the same folder that contains the GMIN and INPUT files.

A screen titled "Output from PMacNonlin" displays the file prompts and writes the file names on the screen after the user has responded to all prompts. The user makes a selection through a window display by navigating the folders or directory tree and double clicking on a file name.

The user can set a folder or directory before selecting or naming any file. The prompts direct the user to:

1. Select INPUT File

2. Select GMIN File

3. Enter OUTPUT File Name

6.4 Setting up and Running Solubility Problem

The user supplies the GMIN and INPUT files. The HMW_ACTINIDE_DB chemical data base files are defined in COMP, BINARYP, TERNARYP, and LAMBDA. The INPUT file has a variable named "ndtyp," which defines the type of experimental data. Solubility data is denoted by setting the "ndtyp" variable to -1.

6.5 Setting up and Running Apparent Stability Constant Problem

NONLIN may be used to fit apparent stability constant data by setting up the problem as a solubility calculation. A detailed discussion and an example problem are provided in Appendix A.

6.6 Setting up and Running Extraction Problem

For a solvent extraction problem, the input files are the same as those for an solubility problem (as listed in Section 6.4). Solvent extraction data is denoted by setting the "ndtyp" variable to -4 in the INPUT file.

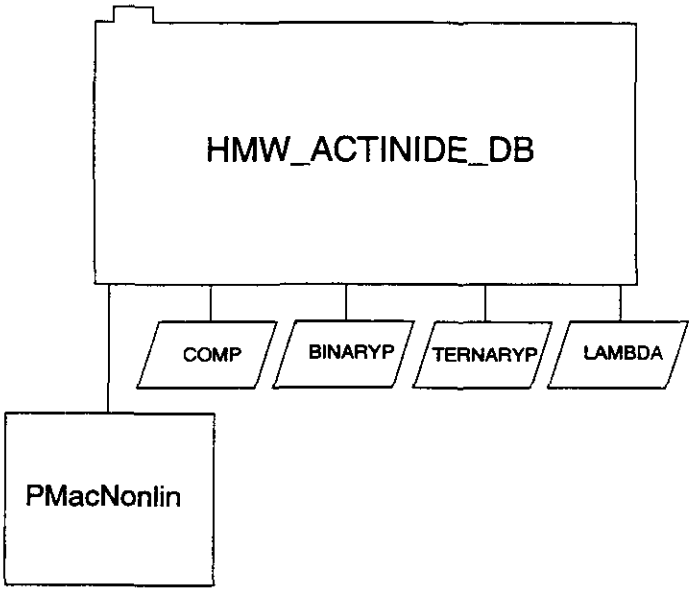

Figure 6-2. Suggested data base folder organization for Macintosh environment.

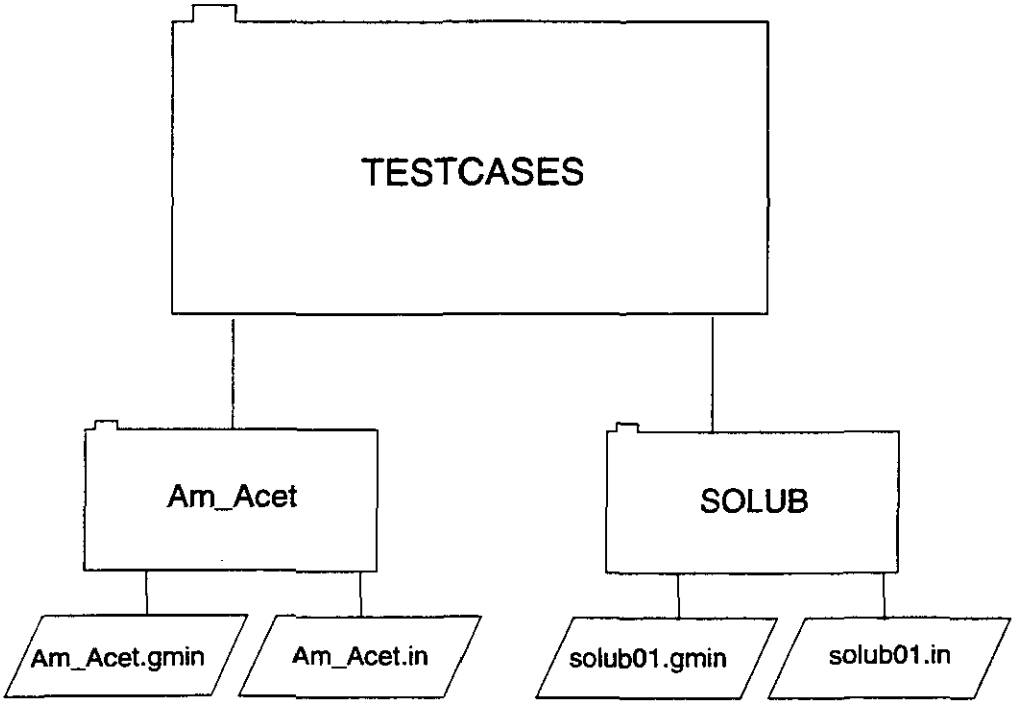

Figure 6-3. Suggested problem folder organization for Macintosh environment.

7.0 DESCRIPTION OF INPUT FILES

Of the six input files for NONLIN (see Figure 6-1), the user sets up the problem in the two files GMIN and INPUT. The other four files COMP, BINARYP, TERNARYP, and LAMBDA are the input chemical data base files. All files are text-based files and can be edited by the user using a convenient text editor.

Although NONLIN reads the INPUT file with both fixed-field and free field-formats[1], it reads all other data files using fixed-field formats only. There are two distinct independent numbers - the parameter key number and the species ID number. Although both numbers have six digits, they are not related in any way. The parameter key number is used only in the INPUT file while the species ID number is used in the other five files. To allow a species to be added or deleted easily, files are terminated by either a zero or a minus one in the ID number field. Blank lines and comments can be inserted with caution. Comments may be placed at the bottom of the file, or, in some cases, at the end of a line where NONLIN does not read them. Comments are used throughout the chemical data base files and the sample files to help the human reader identify the species on a line and document the source of the data or the fields in the file.

A description of all six input files follows.

7.1 GMIN

The GMIN file species are the chemical species to be considered in a particular computer run. The species ID numbers used in GMIN must correspond to species definitions in the COMP file. In addition, aqueous species may have ion interaction parameters specified in BINARYP, TERNARYP, or LAMBDA, but these are not required.

The six-digit ID number is assigned by the user. The first digit is the phase indicator, and can be 0, 1, 2, 3, or 4 for aqueous, solid, solid solution, and two types of adsorbed species, respectively. Only aqueous and solid species are relevant to WIPP use of this code, so only phase types 0 and 1 will be considered henceforth.

The assignment of the remaining five digits is arbitrary, with the only constraint being that each six-digit combination must be unique. The following conventions are suggested to help provide a method to assign ID numbers. Let the second and third digits correspond to the atomic number of the metallic portion of the species (if any) and the fourth and fifth digits correspond to the nonmetallic portion (if any). Use the final digit is used to break redundancies. These scheme is illustrated in Figure 7-1.

For example, the species IDs could be 012000 for aqueous Mg^{++}, 000170 for aqueous Cl^{-}, and 012170 for the $MgCl^{+}$ pair.

---

[1] "Fixed-field format" means that input data is read precisely in the columns specified by the code; "free-field format" means that the input numbers are independent of column formatting (i.e., the numbers in the input file are simply separated by spaces, tabs, or carriage returns). For example, in the sample INPUT file provided in Appendix C, lines 1 through 3, only the first 16 columns are read using a fixed-field format; lines 6 - 37 are read using the free-field format. However, the sample GMIN file provided in Appendix B must be read in its entirety using a fixed-field format input specification.

The order of the species in the file is important. The first species must be water, followed by cations, anions, and neutral species. The solid species are listed last.

The mole numbers for the species are read from the INPUT file. The mole numbers in GMIN file should be set to zero for aqueous species, and nonzero for solid species.

Table 7-1 lists the GMIN file parameters. The "LINE" column refers to the line numbers listed in the EXTR_00.GMIN file. The "Variable Name" column corresponds to the NONLIN program variables. "Permissible Value" column is the only set of values permitted for use with this program. Any other values have unknown consequences.

The EXTR_07.GMIN listing shows a "-1" on line 11 denoting the end of all species. NONLIN will ignore any lines that follow line 11. On lines 3-8 and line 10, NONLIN ignores the comment at the end of the lines following the species ID and mole number.

In Appendix D the sample input file SOLUB_00.GMIN lists six aqueous species and one solid species. NONLIN ignores any lines after line 11.

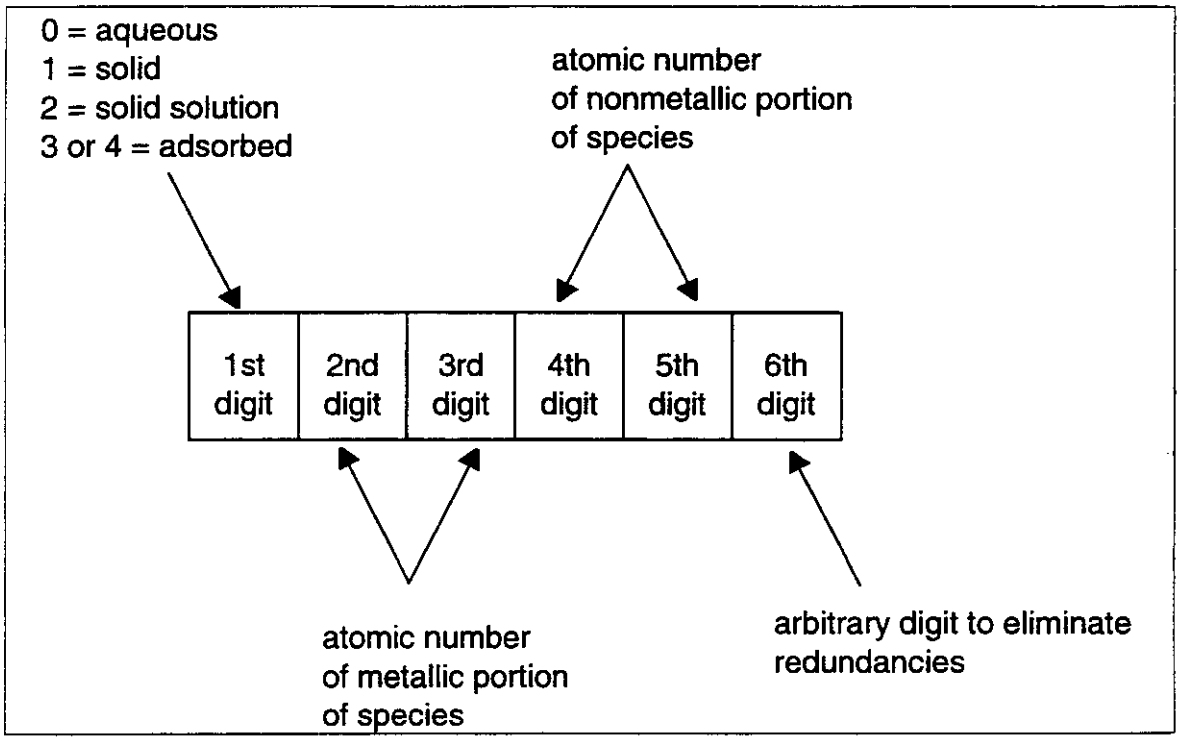

Figure 7-1. Format for six-digit species ID number.

Table 7-1. GMIN File Parameters (Line Numbers Correspond to Sample Listing in Appendix B)

Line	Frmt	Col	Variable Name	Permissible Value	Description
1	1x,I5	1-6	idebg1	0 or 1	normal mode or debug mode, prints intermediate calculations while iterating
	I5	7-11	isopt	0	flag setting the Pitzer ion interaction model
	I5	12-16	idopt	0	flag setting the non-ideal free energy model
	I5	17-21	iphopt	0 or 1	flag for printing species concentrations at end of iterative cycle print after each iteration
2	I3	1-3	iads	0	no adsorption option
3	I6	1-6	id(1)	001080	species ID number for water (water must be listed first)
	F15.3	7-21	x(1)	0.0	unused mole number (read from INPUT file)
4-8	I6	1-6	id(i)		list of aqueous species
	F15.3	7-21	x(i)	0.0	unused mole number (read from INPUT file)
9	I6	1-6	id(i)	000000	end of aqueous species
10	I6	1-6	id(i)	200000-299999	list of solid species
	F15.3	7-21	x(i)	0.0	unused mole number (read from INPUT file)
11	I6	1-6	id(i)	-1	end of all species
12					comment line

7.2 INPUT

The INPUT file is used to specify the experimental data and the thermodynamic parameter(s) to be fitted to the data. The first section lists the parameters to be fitted. In the first two columns, a "-1" is used to signal the end of the parameter list. The next section contains one or two data sets that are used to fit the parameters. Figure 7-2 illustrates the sectioning of an INPUT file using the lines in EXTR_07_EXACT.IN, Appendix C as an example. If there were another experimental data set, it would start on line 22.

In the first section the parameter key is a six-digit number whose structure is divided into three fields where

first and second digits	=	type of parameter
third and fourth digits	=	first ion number
fifth and sixth digits	=	second ion number

The parameter key index table relevant to WIPP use of NONLIN is shown in Table 7-2.

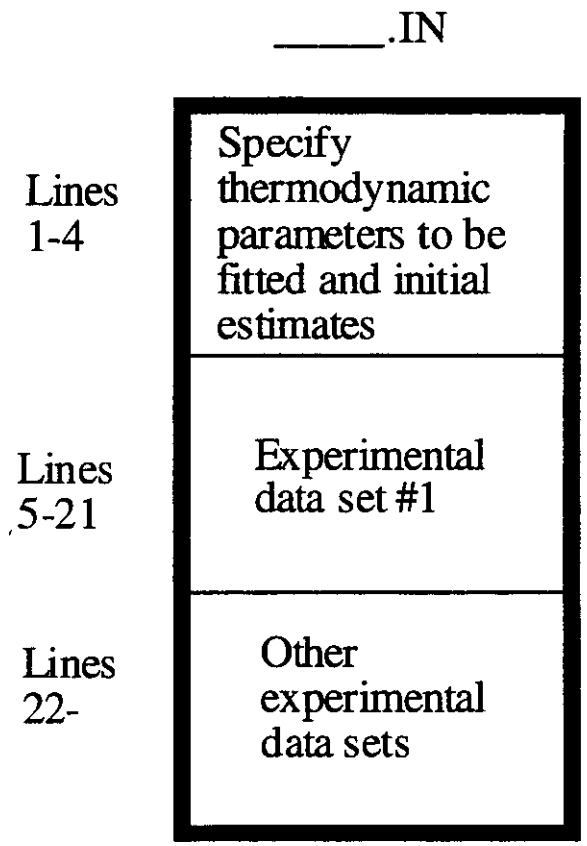

Figure 7-2. Sections of the INPUT file.

Table 7-2. Parameter Key Index Table

1st digit	2nd digit	3rd digit	4th digit	5th digit	6th digit

Adjustable parameter	Type	First Ion	Second Ion
$\mu°/RT$ (standard chemical potential)	00	00	species position number
$\beta^{(0)}$ (cation-anion pair)	01	cation number	anion number
$\beta^{(1)}$ (cation-anion pair)	02	cation number	anion number
$\beta^{(2)}$ (cation-anion pair)	03	cation number	anion number
C_{MX} (cation-anion pair)*	04	cation number	anion number
θ_{ij} (cation-cation pair)	05	00	cation-cation number
θ_{ij} (anion-anion pair)	06	00	anion-anion number
ψ_{ijk} (cation-cation-anion triplet)	07	cation-cation number	anion number
ψ_{ijk} (anion-anion-cation triplet)	08	anion-anion number	cation number
λ (cation-neutral)	09	neutral number	cation number
λ (anion-neutral)	10	neutral number	anion number
λ (neutral-neutral)	11	neutral number	neutral number
ζ_{ijk} (ion-ion-neutral)	12	neutral-cation number	anion number

*C^{ϕ}_{MX} may be computed from C_{MX} by using equation 12 (Section 4.1.2).

To illustrate, consider the species list in Appendix C, i.e.,

	Cation Number	Anion Number	Species Position Number
H_20			01
Na^+	01		02
Th^{++++}	02		03
H^+	03		04
OH^-		01	05
ClO_4^-		02	06

Na^+, Th^{++++}, and H^+ have cation numbers 01, 02, and 03, respectively; OH^- and ClO_4^- have anion numbers 01 and 02, respectively. (The number must be 2 digits.) Neutral species follow the same pattern.

Cation-cation, anion-anion, and neutral-cation numbers are more complicated to specify. These are assigned as follows, illustrated for the cations above. The first cation (Na+) is taken pairwise with the other cations (Th++++, H+) in the order in the list; i.e., Na+ - Th++++ is pairwise interaction 01, Na+ - H+ is pairwise interaction 02. With these, all Na+- cation interactions are specified. The next cation (Th++++) is then taken pairwise with the remaining cations, which in this case is only H+; i.e., Th++++ - H+ is pairwise interaction 03. (Th++++ - Na+ is the same as Na+ - Th++++). Anion-anion and neutral-cation numbers are handled similarly. If the above illustration contained a neutral aqueous species, here called NeuSpec#1, the numbering would be as given in the table below:

	Cation-Cation Number	Anion-Anion Number	Neutral-Cation Number
Na^+ - Th^{++++}	01		
Na^+ - H^+	02		
Th^{++++} - H^+	03		
OH^- - ClO_4^-		01	
NeuSpec#1 - Na^+			01
NeuSpec#1 - Th^{++++}			02
NeuSpec#1 - H^+			03

Therefore, for this illustration, $\theta_{Na^+-Th^{++++}}$ is represented by 050001, and $\psi_{H^+-Th^{++++}-ClO_4^-}$ is represented by 070302.

The OUTPUT file in the section titled "ADJUSTED PARAMETERS" echo prints the parameters that are being fitted by listing the parameters and the species names. This section should be examined to verify that the parameter numbers were selected correctly. This section is listed in Appendix J, lines 102-105; Appendix K, lines 94-95; and Figure A-5, lines 99-103.

When a species parameter is to be fitted, NONLIN ignores the value assigned to that species in the appropriate data base file(s).

The second section of the INPUT file lists an experimental data set, the number of data points, and the data type on one line followed by the data points. A "-1", "0", or a blank line may be used to signal the end of all experimental data sets. A line-by-line description of the INPUT file is provided below in Table 7-3, using the sample listing of EXTR_07_EXACT.IN in Appendix C.

Table 7-3 lists the INPUT file parameters. The "LINE" column refers to the line numbers listed in the EXTR_07_EXACT.IN file. The "Variable Name" column corresponds to the NONLIN program variables. The "Permissible Value" column is the only set of values permitted for use with this program. Any other values have unknown consequences.

Table 7-3. INPUT File Parameters (Line Numbers Correspond to Sample Listing in Appendix C)

Line	Frmt	Col	Variable Name	Permissible Value	Description
1-3	3I2	1-6	ipar1(i), ipar2(i), ipar3(i)	000000-999999	ID of the ith parameter to adjust
	F10.4	7-16	parv(i)	real number	estimate of the ith parameter value (best guess)
4	I2	1-2	ipar1(i)	-1	end of parameters to fit
5	I5	1-5	ndata(k)	1-99999	number of data points in the kth data set
	I5	6-10	ndtyp(k)	1,0,-1,-2,-3, or -4	type of experimental data (1=emf data, 0=osmotic data, -1=solubility data or solid solution data, -2=solid solution data in stoichiometric saturation, -3=adsorption data, -4=solvent extraction data)
6-21	free field		y(i)	positive real number	molar concentration in organic phase for extraction data otherwise set to 0.0 for all other data types
	free field		pph(i)	positive real number	target ph value if a fixed ph value is desired otherwise set to 0.0
	free field		mole(i, j), j=2,nas	positive real number>0	mole numbers for all species except water where water as mole(i,1) is set to 55.508373 within the code
22	I5	1-5	ndata(k)	0 or -1	end of all data sets
23					comment line (not read by NONLIN)

The next data set, if any, would begin on line 22 and would include the number of data points, the type of data, and all of its data points, following the format provided in lines 5 through 21. However, the EXTR_07_EXACT.IN listing shows a "-1" on line 22, which denotes the end of all data sets. NONLIN will ignore any lines that follow line 22. On lines 1-3 NONLIN also ignores the comment following each estimate. The EXTR_07_EXACT.IN shows that the user has

specified three parameters to be fitted (the standard chemical potential $\mu°/RT$, $\beta^{(0)}$, and C_{MX}) with an experimental extraction data set of 16 points.

Line 25 in the IN file of Appendix C, included only for the benefit of the user, shows the value type in each column for data specification. The first column, for extraction problems, is the concentration of the extracted species in the organic phase, here represented by mORG. The second column represents the pH ($= -\log_{10} a_{H^+}$) in all problem types, but is used only when the pH is to remain fixed, which is not the case in either Appendix C or E. The remaining columns give initial estimate molalities for all the aqueous species (except H_2O) from the GMIN file, and in the same order. (By definition, water is always 55.5 moles H_2O/kg H_2O.) These initial estimates should be charge balanced to best represent the chemical system.

In Appendix E the sample input file SOLUB_01.IN shows one parameter, $\mu°/RT$, to be fitted with an experimental solubility data set of 7 data points. On line 3 the data type is set to "-1" for solubility data. NONLIN ignores lines 12-15.

The file SOLUB_01.IN in Appendix E is similar to EXTR_07_EXACT.IN in Appendix C. The first two entries on line 1 indicate that the standard chemical potential of species number 6 (199001 in the GMIN file, corresponding to $H_2Ox \bullet 2\ H_2O(s)$) is to be fitted. The -1 (line 2) terminates the list of parameters to be fitted. Line 3 indicates that there are seven data points of type -1 (solubility data). Lines 4 - 10 provide the following data:

- The first column is zero by definition in solubility problems.
- The second column is pH, which is only used when pH is fixed (not in this run).
- The remaining columns correspont to (charge-balanced) species molalities.

These are illustrated in comment line 15 in Appendix E.

The apparent constant stability sample input file AM_ACET.IN in Appendix A, Figure A-2 shows four parameters to be fitted ($\mu°/RT$, $\beta^{(0)}$, $\beta^{(1)}$ and C_{MX}) using the solubility data set of 6 data points. On line 6 the data type is set to "-1" for solubility data.

7.3 COMP Data Base File

Table 7-4 lists the COMP file parameters. The COMP file contains a list of chemical species, the species stoichiometry and charge, and the dimensionless standard chemical potential. The temperature of the thermodynamic data is specified at 25 ° C. The COMP file contains all the species that could be considered by NONLIN in its calculations. The species list must begin with water, followed by other aqueous species, and then the solid species. The list of all chemical species must end with a "-1".

*****NOTE*****

The COMP file listed in Appendix F is not necessarily the file that will be used to support the WIPP 1996 PA calculations. Additional species and elements may be added to the file that will be used to support the 1996 WIPP PA calculations.

Table 7-4. COMP File Parameters (Line Numbers Correspond to Sample Lising in Appendix F)

Line	Frmt	Col	Variable Name	Permissible Value	Description
1-40	I6	1-6	idtmp	000000-999999	six digit species ID number where H_2O must always be the first species declared
	A12	7-16	intmp		name of species
	1x	18			
	I2	19-20	iztmp		charge of species
	F15.3	21-35	u0tmp		standard chemical potential of the species (μ_i°/RT)
	1x	36			
	10(I2, F4.1)	37-96	nt(j),v(j), j=1,10	0-99, 0.0-9999.	atomic number and stoichiometric coefficients for elements comprising the species (i.e. H =1, O = 8, Np = 93, etc.)
41	I6	1-6	idtmp	000000	blank line (species ID = 0)
42	I6	1-6	idtmp	-1	denotes the end of species list

A blank line may be inserted anywhere in the COMP file and the species ID will be assigned the value 0. In this file, the blank line can be used to separate groups of species to improve file readability, e.g., lines 6, 11, and 13. A "-1" on line 42 denotes the end of all species. NONLIN will ignore any comments that follow after the end of species list.

7.4 BINARYP Data Base File

The BINARYP file contains the species ID number in each binary interaction considered (e.g., Na^+-Cl^-, K^+-Cl^-) and the Pitzer ion-interaction parameters ($\beta^{(0)}$, $\beta^{(1)}$, $\beta^{(2)}$, and C_{MX}) for binary systems. The binary interaction list must end with a "000000". A cation anion pair and their Pitzer parameters may be inserted anywhere in this file. Blank lines are not allowed in this file until the end of the list.

In Table 7-5, which describes the input parameters for BINARYP, the "Variable Name" column lists the NONLIN program variables.

*****NOTE*****

The BINARYP file listed in Appendix G is not necessarily the file that will be used to support the WIPP 1996 PA calculations. Additional species and elements may be added to the file that will be used to support the 1996 WIPP PA calculations.

Table 7-5. BINARYP File Parameters (Line Numbers Correspond to Sample Listing in Appendix G)

Line	Frmt	Col	Variable Name	Permissible Value	Description
1-20	I6	1-6	id1	000000-999999	ID of the cation species
	1x	7			
	I6	8-13	id2	000000-999999	ID of the anion species
	F7.3	14-20	tb0		$\beta^{(0)}$ parameter for the cation-anion interaction
	F7.3	21-27	tb1		$\beta^{(1)}$ parameter for the cation-anion interaction
	F7.3	28-34	tb2		$\beta^{(2)}$ parameter for the cation-anion interaction
	F7.3	35-41	tcmx		C_{MX} parameter
21	I6	1-6	id1	000000	end of binary interactions
22-23					comments

NONLIN will ignore any lines following a blank line or a species ID number of "000000".

7.5 TERNARYP Data Base File

The TERNARYP file contains Pitzer ion-interaction parameters θ_{ij} for anion-anion and cation-cation systems and ψ_{ijk} for anion-anion-cation and cation-cation-anion systems. Species can be inserted in any order. For the file listed in Appendix I, the same species ID numbers in the first column were grouped together. Blank lines are not allowed in this file until the end of the list.

In Table 7-6, which describes the parameters in the TERNARYP file, the "Variable Name" column lists the NONLIN program variables.

NONLIN will ignore any comments that follow after species ID number 000000, the end of all ternary species parameters.

*****NOTE*****

The TERNARYP file listed in Appendix H is not necessarily the file that will be used to support the WIPP 1996 PA calculations. Additional species and elements may be added to the file that will be used to support the 1996 WIPP PA calculations.

Table 7-6. TERNARYP File Parameters (Line Numbers Correspond to Sample Listing in Appendix H)

Line	Frmt	Col	Variable Name	Permissible Value	Description
1-5, 10-11	I6	1-6	id1	000000-999999	ID of cation species
	1x	7			
	I6	8-13	id2	000000-999999	ID of cation species
	F7.3	14-20	ttc		θ_{ij} for cation-cation species
	1x	21			
	20(I6,1x,F7.3,1x)	22-320	id3(j1), tpsic(j1), j1=1,20		ID of anion species and ψ_{ijk} for cation-cation-anion species
6-9	I6 1x	1-6 7	id1	000000-999999	ID of anion species
	I6	8-13	id2	000000-999999	ID of anion species
	F7.3	14-20	ttc		θ_{ij} for anion-anion species
	1x	21			
	20(I6,1x,F7.3,1x)	22-320	id3(j1), tpsic(j1), j1=1,20		ID of cation species and ψ_{ijk} for anion-anion-cation species
12	I6	1-6		000000	end of all neutral parameters

7.6 LAMBDA Data Base File

The LAMBDA file (described in Table 7-7) contains Pitzer ion-interaction lambda parameters for neutral species. The species interactions include: neutral-cation, neutral-cation-anion, neutral-anion, and neutral-neutral.

*****NOTE*****

The LAMBDA file listed in Appendix I is not necessarily the file that will be used to support the WIPP 1996 PA calculations. Additional species and elements may be added to the file that will be used to support the 1996 WIPP PA calculations.

Table 7-7. LAMBDA File Parameters (Line Numbers Correspond to Sample Listing in Appendix I)

Line	Frmt	Col	Variable Name	Permis-sible Value	Description
1-2	I6	1-6	id1	000000-999999	ID of the neutral species
	1x	7			
	I6	8-13	id2	000000-999999	ID of cation species
	F7.3	14-20	tlambda		λ parameter for neutral-cation species
	1x	21			
	20(I6,1x,F7.3,1x)	22-27	id3(j1), thol(j1), j1=1,20		for neutral-cation species, ID of anion species and λ parameter for neutral-cation-anion species; a neutral-cation pair may have from zero to twenty anion species and lambda values
None[2]	I6	1-6	id1	000000-999999	ID of the neutral species
	1x,I6	7-13	id2	000000-999999	ID of anion species
	F7.3	14-20	tlambda		λ parameter for neutral-anion species
None[3]	I6	1-6	id1	000000-999999	ID of the neutral species
	1x,I6	7-13	id2	000000-999999	ID of neutral species
	F7.3	14-20	tlambda		λ parameter for neutral-neutral pair
3	I6	1-6		000000	end of neutral species list

[2] No corresponding line numbers in Appendix I since there are no neutral-anion species in the file.

[3] No corresponding line numbers in Appendix I since there are no neutral-neutral species in the file.

In Table 7-7, the "Variable Name" column lists the NONLIN program variables. The neutral species can be inserted in any order. A value for a neutral-cation pair, even if it is zero, must be assigned in order to specify a triplet neutral-cation-anion interaction. For the file in Appendix H, the same neutral species were grouped together with the cations first, and then the anions. There are no neutral-neutral parameters considered in NONLIN. Blank lines are not allowed in this file until the end of the list.

NONLIN will ignore any lines that follow after species ID number 000000, the end of all lambda parameters.

8.0 ERROR MESSAGES

NONLIN is not a particularly user-friendly code. NONLIN will detect errors in species ID numbers and in counting the total number of allowed species. The code will not automatically detect all errors in preparing the GMIN or INPUT files, or the interaction of these input files with the chemical model data files. Therefore, care should be taken to avoid errors. It is important that output from NONLIN be examined to see if it makes sense.

At the end of the OUTPUT file, a successful NONLIN run will display a set of lines with the header "FINAL APPROXIMATE SOLUTION" and the species ID with the converged parameter value. However, the presence of these lines may not necessarily indicate a set of valid values. There may still be errors in any of the files and the entire OUTPUT listing should be scanned carefully.

Error messages are usually listed at the end of the OUTPUT file before NONLIN terminates. A pair of single quotes within a message enclosing a phrase starting with 'value of ...' indicates that the run time value in NONLIN will be listed. A listing of the error messages follows.

- The following messages are printed when the nonlinear routine does not converge:

```
********** ITERATION DID NOT CONVERGE *******
**** MATRIX WITH ZERO ROW IN DECOMP
NO CONVERGENCE IN IMPROV MATRIX NEARLY SINGULAR
**** SINGULAR MATRIX IN DECOMP, ZERO DIVIDE IN SOLVE
********** ITERATION DID NOT CONVERGE *******
```

  If any of the above messages are displayed, the user should start with another set of initial estimates in the INPUT file. If the second message "MATRIX WITH ZERO ROW IN DECOMP" is displayed, the charge balance may be incorrect.

- The following messages are printed when there are more than two solid solution data sets in the INPUT file:

```
**  MORE THAN TWO SOLID SOLUTION DATA SETS  ***
***** ONLY TWO DATA SETS WITH EQUAL POINTS ALLOWED **
```

  If any of the above messages are displayed, the user should limit the number of solubility data sets to two in the INPUT file. In addition, for a data type of -2, the number of data points must be the same in both sets. However, this mode of running NONLIN is not used for the WIPP.

- The following message is printed when a species is listed in the GMIN file and is not in the chemical model data files:

  ```
  SPECIES 'value for ID' NOT FOUND IN DATA FILE
  ```

  If the above message is displayed, the user may have an incorrect species ID in the GMIN file or may need to add the species and its Pitzer parameters to the chemical model data files, i.e., the COMP, BINARYP, LAMBDA, and TERNARYP files.

- The following message is printed when the species listed in the GMIN file exceeds 16:

  ```
  TOO MANY AQUEOUS AND ADSORBED SPECIES
  ```

  If the above message is displayed in the GMIN file, the user should verify that the "000000" species or a blank line separates the aqueous from the solid species or the user should reduce the number of aqueous and adsorbed species.

9.0 DESCRIPTION OF OUTPUT FILE

NONLIN generates an OUTPUT (.OUT) file. The OUTPUT file lists the problem identity, echo prints the input data, computes the goodness of fit using the initial estimates (before any adjustments are made to the key parameters), continues to iterate until the absolute value of the error tolerance test converges to a value $\leq 10^{-5}$, and then prints the final solution.

Table 9-1 explains the OUTPUT (.OUT) file generated from the problem called EXTR_07_EXACT. The "Line" column refers to the line numbers listed in EXTR_07_EXACT.OUT. "Variable Name" column shows applicable NONLIN program variables and some formulas.

Table 9-1. OUTPUT File Description (Line Numbers Correspond to Sample Listing in Appendix J)

Line	Variable Name	Description
1	versn	notation; program name 'NONLIN' and version number
3		notation; code author
5-7	infnm, gmfnm, oufnm	user-supplied input file name, GMIN file name and output file name
9-21		table of aqueous and solid species and characteristics
	id(i), name(i), a(i,j), j=1,ncomp	species from GMIN, name from COMP, mole number from GMIN, charge and standard chemical potential from COMP
23		title for table of constraint equations

24	ncol(j), j=1,ncomp	column labels where 0 is charge and all others are elemental atomic numbers
25-31	name(i), a(i,j) j=1,ncomp	for each species--name, charge, and number of atoms in one molecule or ion
33		notation; closed two files
35-38	cofnm, bifnm, tefnm, lafnm	chemical data base file names
40		notation; Pitzer activity coefficient model used
42-48	name(jpc(i)), name(jpa(j)), b0(i,j), b1(i,j), b2(i,j),cmx(i,j)	table of single electrolyte parameters; listing cation-anion binary interactions, $\beta^{(0)}$, $\beta^{(1)}$,$\beta^{(2)}$, and C_{MX} parameters for i^{th} cation, j^{th} anion interactions
50-58		table of ternary electrolyte parameters; listing cation-cation-anion, if any; anion-anion-cation, if any
52	name(jpa(k)), k=1,na	column labels of anion species
53-55	name(jpc(i), name(jpc(j), tc(nt), (psic(nt,k), k=1,na)	cation-cation ternary interaction parameter, θ_{ij} and any cation-cation-anion ternary interaction parameters, ψ_{ijk}
57	name(jpc(k)), k=1,nc	column labels of cation species
58	name(jpa(i), name(jpa(j), ta(nt), (psia(nt,k), k=1,nc)	anion-anion ternary interaction parameters, θ_{ij} and any anion-anion-cation ternary interaction parameters, ψ_{ijk}
None[4]		table of neutral ion parameters, if any
	name(jpn(k), k=1,nn	column labels of neutral species
	name(jpc(i)), (clamb(j,i), j=1,nn)	neutral-cation species and binary interaction values, λ_{ij}
	name(jpa(i)), (alamb(j,i), j=1,nn)	neutral-anion species and binary interaction values, λ_{ij}

[4] No corresponding line numbers in Appendix J since there are no neutral ion parameters in the file.

	name(jpn(i)), (nlamb(j,i), j=1,nn)	neutral-neutral species and binary interaction values, λ_{ij}
None[5]		table of higher order lambdas, if any
	name(jpa(k)), k=1,na	column labels of anion species
	name(jpn(i), name(jpc(j), (holamb(nt,k), k=1,na)	neutral-cation-anion species and ternary interaction values, ζ_{ijk}
60-62	ns, ncomp, irank	count of species, components and independent constraints
64	ndtyp(k)	type of experimental data for data set #1
66-85		table listing the experimental data points
69	name(i),i=2,nas	column labels of species
70-85	mole(i,j),j=2,nas	input molality of each species
		type of experimental data for data set #k with table #k, where k=2...ndataset
87-99	parv(j),j=1,npar, fnorm	solution vector and norm from evaluating function at the initial estimates and each subsequent adjustment to the estimates
102-106	ipar1(i), name1, name2, name3, parv(i)	table of adjusted parameters: the parameter, species either (name1) or (name1 and name2) or (name1, name2 and name3) of first and second ions, and final fit value
107-125	y(m),sigma	calculated difference for data set #1, using the initial estimates
127-129	adev,sdev	adev = $\sum$abs(sigma)/ndatat; sdev = $(\sum(\text{sigma*sigma})/\text{ndatat})^{0.5}$
		calculated difference for data set #k, where k=2...ndataset; adev,sdev
131-149		table of final molalities
133	names(i),i=2,nas	column labels of species names

[5] No corresponding line numbers in Appendix J since there are no higher order lambdas in the file.

134-149	mole(i,j),j=2,nas	calculated molality for each species
151-169		table of final log activities
153	names(i),i=2,nas	column labels of species names
154-169	tloga(i,j),j=2,nas	calculated log activity for each species
171-189		table of calculated log activity coefficients
173	names(i),i=2,nas	column labels of species names
174-189	(tloga(i,j)-log10(mole(i,j)), j=2,nas	calculated log activity coefficients for each species
191		notation; system at equilibrium
192-278		standard chemical potential, $\beta^{(0)}$, and C_{MX}
280	fnorm	norm of the solution vector
283	info	exit parameter
286 - 291	ipar1(i), ipar2(i), ipar3(i), parv(i)	table of approximate solutions

10.0 REFERENCES

References from this manual (NONLIN)

Davies, C.W. 1962. *Ion Association*. Butterworths, London.

Denbigh, K. 1981. *The Principles of Chemical Equilibrium*. Cambridge: Cambridge University Press.

Dongarra, J.J., C.B. Moler, J.R. Bunch, and G.W. Stewart. 1979. *LINPACK User's Guide*. The Society for Industrial and Applied Mathematics, Philadelphia.

Felmy, A.R. 1990. *GMIN: A Computerized Chemical Equilibrium Model Using A Constrained Minimization of the Gibbs Free Energy*. PNL-7281. Richland, Washington: Pacific Northwest Laboratory.

Felmy, A.R. 1995. "GMIN, A Computerized Chemical Equilibrium Program Using a Constrained Minimization of the Gibbs Free Energy: Summary Report," *Chemical Equilibrium and Reaction Models*, SSSA Special Publication 42, Soil Science Society of America, American Society of Agronomy, 677 S. Segoe Rd., Madison WI 53611, USA., pp. 377-407

Felmy, A.R., and J.H. Weare. 1986. "The Prediction of Borate Mineral Equilibria in Natural Waters: Application to Searles Lake, California." *Geochimica et Cosmochimica Acta*, Vol. 50: pp. 2771-2783.

Gill, P.E., and W. Murray. 1974. "Newton-Type Methods for Unconstrained and Linearly Constrained Optimization." *Mathematical Programming*, Vol. 7: pp. 311-350.

Greenberg, J.P., J.H. Weare, and C.E. Harvie. 1985. "An Equilibrium Computation Algorithm for Complex Highly Nonideal Systems: Application to Silicate Phase Equilibria." *High Temperature Science*, Vol. 20: pp. 141-162.

Harvie, C.E., J.P. Greenberg, and J.H. Weare. 1987. "A Chemical Equilibrium Algorithm for Highly Non-ideal Multiphase Systems: Free Energy Minimization." *Geochimica et Cosmochimica Acta*, Vol. 51 #5: pp. 1045-1057.

Harvie, C.E., N. Møller, and J.H. Weare. 1984. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O System to High Ionic Strength at 25°C." *Geochimica et Cosmochimica Acta*, Vol. 48: pp. 723-751.

Harvie, C.E., and J.H. Weare. 1980. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-Cl-SO_4-H_2O System from Zero to High Concentration at 25°C." *Geochimica et Cosmochimica Acta*, Vol. 44: pp. 981-997.

Novak, C.F., and S.C. Babb. 1996. "WIPP PA User's Manual for FMT, Version 2.0". WPO # 28119, Albuquerque, New Mexico: Sandia National Laboratories.

Novak, C.F., and K.E. Roberts. 1994. *Thermodynamic Modeling of Neptunium(V) Solubility in Na-CO_3-HCO_3-Cl-ClO_4-H-OH-H_2O Electrolytes*. SAND94-0805C. Albuquerque, New Mexico: Sandia National Laboratories.

Pitzer, K.S. 1991. *Activity Coefficients in Electrolyte Solutions*. Boca Raton, Florida: CRC Press. Second Edition.

Pitzer, K.S. 1973. "Thermodynamics of Electrolytes I: Theoretical Basis and General Equations." *Journal of Physical Chemistry*, Vol. 77: pp. 268-277.

Pytkowicz, R. M. 1979. *Activity Coefficients in Electrolyte Solutions*. Boca Raton, Florida: CRC Press. First Edition.

Smith, J.M., and H.C. Van Ness. 1975. *Introduction to Chemical Engineering Thermodynamics*. New York: McGraw-Hill.

References from GMIN user's manual and technical reference (i.e., Felmy, 1990):

Davies, C.W. 1962. *Ion Association* . Butterworths, London.

Davis, J.A., R.O. James, and J.O. Leckie. 1978. "Surface Ionization and Complexation at the Oxide/Water Interface: I. Computation of Electrical Double Layer Properties in Simple Electrolytes." *Journal of Colloid and Interface Science*, Vol. 63: pp. 480-499.

Dongarra, J.J., C.B. Moler, J.R. Bunch, and G.W. Stewart. 1979. *LINPACK User's Guide*. The Society for Industrial and Applied Mathematics, Philadelphia.

Felmy, A.R. 1988. *Equilibrium and Nonequilibrium Transformations in Evaporites: Development and Application of Thermodynamic Models*.. PhD Dissertation, The University of California, San Diego, La Jolla, California.

Felmy, A.R., and J.H. Weare. 1986. "The Prediction of Borate Mineral Equilibria in Natural Waters: Application to Searles Lake, California." *Geochimica et Cosmochimica Acta*, Vol. 50: pp. 2771-2783.

Felmy, A.R., D.C. Girvin, and E.A. Jenne. 1984. *MINTEQ - A Computer Program for Calculating Aqueous Geochemical Equilibria*. EPA 600/3-84-032, U.S. Environmental Protection Agency, Office of Research and Development, Athens, Georgia.

Gill, P.E., and W. Murray. 1974. "Newton-Type Methods for Unconstrained and Linearly Constrained Optimization." *Mathematical Programming*, Vol. 7: pp. 311-350.

Greenberg, J.P., J.H. Weare, and C.E. Harvie. 1985. "An Equilibrium Computation Algorithm for Complex Highly Nonideal Systems: Application to Silicate Phase Equilibria." *High Temperature Science*, Vol. 20: pp. 141-162.

Guggenheim, E.A. 1967. *Thermodynamics*. North Holland, New York.

Harvie, C.E., J.P. Greenberg, and J.H. Weare. 1987. "A Chemical Equilibrium Algorithm for Highly Non-ideal Multiphase Systems: Free Energy Minimization." *Geochimica et Cosmochimica Acta*, Vol. 51 #5: pp. 1045-1057.

Parkhurst, D.L., D.C. Thorstenson, and L.N. Plummer. 1980. *PHREEQE - A Computer Program for Geochemical Calculations.* Water Resources Investigations 80-96, U.S. Geological Survey, Washington, D.C.

Pitzer, K.S. 1973. "Thermodynamics of Electrolytes I: Theoretical Basis and General Equations." *Journal of Physical Chemistry*, Vol. 77: pp. 268-277.

Pitzer, K.S. 1991. *Activity Coefficients in Electrolyte Solutions.* Boca Raton, Florida: CRC Press.

Plummer, L.N., and E. Busenberg. 1987. "Thermodynamics of Aragonite-Strontianite Solid Solutions: Results from Stoichiometric Solubility at 25 and 76°C." *Geochimica et Cosmochimica Acta*, Vol. 51: pp. 1393-1411.

Strang, G. 1980. *Linear Algebra and Its Applications.* Academic Press, New York.

Van Zeggeren, F., and S.H. Storey. 1970. *The Computation of Chemical Equilibria.* Cambridge University Press, London.

Westall, J. 1979. *MICROQLII. Computation of Adsorption Equilibria in BASIC.* EAWAG, CH-8600, Swiss Federal Institute, Duebendorf, Switzerland.

Wolery, T.J. 1979. Calculation of Chemical Equilibrium between Aqueous Solutions and Minerals. The EQ3/6 Software Package. UCRL-52658, Lawrence Livermore Laboratory, Livermore, California.

Zachara, J.M., D.L. Girvin, R.L. Schmidt, and C.T, Resch. 1987. "Chromate Adsorption on Amorphous Iron Oxyhydroxide in the Presence of Major Groundwater Ions." *Environmental Science and Technology*, Vol. 21(6): pp. 589-594.

Journal articles that provide data for use in NONLIN:

Felmy, A.R., and D. Rai. 1992. "An Aqueous Thermodynamic Model for a High Valence 4:2 Electrolyte Th^{4+}-SO_4^{2-} in the System Na^+-K^+-Li^+-NH_4^+ -SO_4^{2-} -HSO_4^- -H_2O to High Concentration." *Journal of Solution Chemistry*, Vol. 21 #5: pp. 407-423.

Felmy, A.R., D. Rai, and R.W. Fulton. 1990. "The Solubility of $AmOHCO_3$(c) and the Aqueous Thermodynamics of the System Na^+-Am^{3+}-HCO_3^- -OH^--H_2O." *Radiochimica Acta*, Vol. 50: pp. 193-240.

Felmy, A.R., D. Rai, and M.J. Mason. 1991. "The Solubility of Hydrous Thorium(IV) Oxide in Chloride Media: Development of an Aqueous Ion-Interaction Model." *Radiochimica Acta*, Vol. 55: pp. 177-185.

Felmy, A.R., D. Rai, J.A. Schramke, and J.L. Ryan. 1989. "The Solubility of Plutonium Hydroxide in Dilute Solution and in High-Ionic-Strength Chloride Brines." *Radiochimica Acta*, Vol. 48: pp. 29-35.

Harvie, C.E., and J.H. Weare. 1980. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-Cl-SO_4-H_2O System from Zero to High Concentration at 25°C." *Geochimica et Cosmochimica Acta*, Vol. 44: pp. 981-997.

Harvie, C.E., N. Møller, and J.H. Weare. 1984. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O System to High Ionic Strength at 25°C." *Geochimica et Cosmochimica Acta*, Vol. 48: pp. 723-751.

Novak, C.F., and K.E. Roberts. 1994. *Thermodynamic Modeling of Neptunium(V) Solubility in Na-CO_3-HCO_3-Cl-ClO_4-H-OH-H_2O Electrolytes*, SAND94-0805C. Albuquerque, New Mexico: Sandia National Laboratories.

Rai, D., A.R. Felmy, and R.W. Fulton. 1994. "The Nd^{3+} and Am^{3+} Ion Interactions with SO_4^{2-} and their Influence on $NdPO_4$(c) Solubility." *Journal of Solution Chemistry*, submitted June 1994.

Rao, L., D. Rai, A.R. Felmy, and RW. Fulton. 1994. "Solubility of $NaNd(CO_3)_2 \cdot 6H_2O$ in Concentrated Sodium Carbonate and Sodium Bicarbonate Solutions." *Radiochimica Acta*, Vol. ___: ___-___. SAND94-1948J.

Roy, R.N., K.M. Vogel, C.E. Good, W.B. Davis, L.N. Roy, D.A. Johnson, A.R. Felmy, and K.B. Pitzer. 1992. "Activity Coefficients in Electrolyte Mixtures: HCl + $ThCl_4$ + H_2O for 5°–55°C." *Journal of Physical Chemistry*, Vol. 96: pp. 11065-11072.

11.0 APPENDICES

Note

The numbers to the left of each line in Appendices A through K are not actually present in the files and screen displays; they are used solely to reference the lines in this guide

Note

The sample files and displays provided in Appendices A through K are examples *only*. They *are not* necessarily representative of files used to support the 1996 WIPP PA regulatory calculation.

Appendix A - Example for Calculating Thermodynamic Parameters from Apparent Stability Constants

NONLIN was not originally designed to fit apparent stability constant data. However, because of the flexibility of thermodynamics, apparent stability constant data can be rewritten to look like a system of solubility data, and these data can then be fitted in the usual way with NONLIN. This section describes and illustrates this process for the 1:1 americium acetate complex.

The complexation of Am(III) with acetate ion proceeds according to the reaction

$$Am^{3+} + Ac^{-} \leftrightarrow AmAc^{2+} \tag{A-1}$$

with the corresponding equilibrium expression

$$\beta^{\circ} = \frac{\gamma_{AmAc^{2+}}}{\gamma_{Am^{3+}}\,\gamma_{Ac^{-}}}\,\frac{m_{AmAc^{2+}}}{m_{Am^{3+}}\,m_{Ac^{-}}} \tag{A-2}$$

or

$$\beta^{app} = \beta^{\circ}\frac{\gamma_{Am^{3+}}\,\gamma_{Ac^{-}}}{\gamma_{AmAc^{2+}}} = \frac{m_{AmAc^{2+}}}{m_{Am^{3+}}\,m_{Ac^{-}}} \tag{A-3}$$

where β° is the thermodynamic stability constant and β^{app} is the apparent stability constant. We can define a fictitious solid AmAc/Am/Ac(s) based on reaction A-1, giving

$$AmAc/Am/Ac(s) \leftrightarrow AmAc^{2+} - Am^{3+} - Ac^{-} \tag{A-4}$$

which has the corresponding solubility product expression

$$K_{sp} = \frac{\gamma_{AmAc^{2+}}}{\gamma_{Am^{3+}}\,\gamma_{Ac^{-}}}\,\frac{m_{AmAc^{2+}}}{m_{Am^{3+}}\,m_{Ac^{-}}} \tag{A-5}$$

Note that the solubility expression in Equation A-5 is identical to that for the stability constant in Equation A-2. For this reason, by declaring the fictitious solid in Equation A-4, we can fit apparent stability constant data as if it were solubility data.

At equilibrium, the change in Gibbs free energy of reaction A-4 is zero by definition. Using this fact, we can rearrange the condition for equilibrium of Equation A-4 to the expression

$$\left[\left(\frac{\mu^\circ}{RT}\right)_{AmAc^{2+}} - \left(\frac{\mu^\circ}{RT}\right)_{AmAc/Am/Ac(s)}\right] + \ln\left(\gamma_{AmAc^{2+}}\, m_{AmAc^{2+}}\right) = \left(\frac{\mu}{RT}\right)_{Am^{3+}} + \left(\frac{\mu}{RT}\right)_{Ac^-} \qquad \text{(A-6)}$$

In Equation A-6 we will generally know the quantities on the right hand side of the equation, i.e., the dimensionless standard chemical potentials and the appropriate activity coefficient parameters for the uncomplexed species; all unknown quantities are on the left hand side. Thus, this method can be used to fit both the standard chemical potential of the aqueous complex, in this case $AmAc^{2+}$, and the activity coefficient parameters that contribute to $\gamma_{AmAc^{2+}}$. This method fits the standard chemical potential for the linear combination shown in square brackets in Equation A-6. Because we are not interested in the value for $\left(\frac{\mu^\circ}{RT}\right)_{AmAc/Am/Ac(s)}$ we can specify that $\left(\frac{\mu^\circ}{RT}\right)_{AmAc/Am/Ac(s)} = 0$ for the calculation and fit a value for $\left(\frac{\mu^\circ}{RT}\right)_{AmAc^{2+}}$ directly. Alternatively, we can arbitrarily assign a value $\left(\frac{\mu^\circ}{RT}\right)_{AmAc^{2+}} = 0$ and fit the linear combination in the brackets above, which will yield a fitted value equal to $-\left(\frac{\mu^\circ}{RT}\right)_{AmAc^{2+}}$.

An additional subtlety must be addressed in fitting apparent stability constant data. These data provide information on the molality quotients of the various species in solution, which in the illustration are Am^{3+}, Ac^-, and $AmAc^{2+}$. In order to fit these apparent stability constant values, the individual concentrations of the species Am^{3+}, Ac^-, and $AmAc^{2+}$ must be constrained to be constant throughout the computer run. This can be accomplished by adding "constraint" elements, called "CE" for short, to the species in question. Consider the following table of stoichiometries.

	0 (charge)	95 (Am(III))	89 (Acetate)	71 (CE#1)	72 (CE#2)	73 (CE#3)
Am3+	3	1	0	0	1	0
Ac–	–1	0	1	1	0	0
AmAc2+	2	1	1	0	0	1
AmAc/Am/Ac(s)	0	0	0	–1	–1	1

One can see by inspection that the linear combination of the stoichiometries as specified in Equation A-1 holds. By declaring the stoichiometries of the species in this way, the molality values, as specified in the INPUT file, are constrained to remain constant throughout the fitting run. This means that the input values of $m_{Am^{3+}}$, m_{Ac^-}, and $m_{AmAc^{2+}}$ will remain the same throughout the run.

The final step is specifying input concentrations $m_{Am^{3+}}$, m_{Ac^-}, and $m_{AmAc^{2+}}$ that correspond to the apparent stability constant data. A simple way to accomplish this would be to arbitrarily assign values to $m_{Am^{3+}}$ and m_{Ac^-} and then calculate the values for $m_{AmAc^{2+}}$ from the apparent stability constant data and Equation A-3.

The required NONLIN files for this example are given below. This problem calculates the dimensionless standard chemical potential of the fictitious solid AmAc/Am/Ac(s) (which is equal to the dimensionless standard chemical potential of $AmAc^{2+}$) and the ion interaction parameters $\beta^{(0)}_{AmAc^{2+}-Cl^-}$, $\beta^{(1)}_{AmAc^{2+}-Cl^-}$, and $C^{\phi}_{AmAc^{2+}-Cl^-}$. Figure A-1 is the GMIN file. Figure A-2 is the INPUT file, giving the parameters to be fitted and the initial estimates for those parameter values on lines 1 to 4, terminated with the –1 on line 5. Line 6 indicates that there are six data

points of solubility type data, and lines 7 through 12 give the species concentrations. Data input is terminated with the –1 on line 13.

The COMP file is given in Figure A-3. Note that the fictitious solid phase AmAc/Am/Ac(s) is included (line 34) and that the stoichiometries of Am^{3+}, Ac^{-}, and $AmAc^{2+}$ (lines 16, 22, and 19, respectively) have been modified by the addition of constraint elements as discussed above.

The BINARYP file is given in Figure A-4. The default value of ion interaction parameters is zero if they are not explicitly included in the BINARYP, TERNARYP, or LAMBDA files.

The results of the NONLIN run are given in the OUTPUT file of Figure A-5. The following are some points to note here: lines 9 to 33 echo print the input species names and IDs and the specified stoichiometries, as read from COMP; lines 44 to 65 echo print the ion interaction parameters read from BINARYP, TERNARYP, and LAMBDA; lines 71-82 echo print the input molalities read from INPUT; lines 84-95 print the estimates of parameter values in each fitting iteration (and the initial set, line 84, are the values given in lines 1 to 4 of the INPUT file); and lines 99 to 103 present the best-fit parameter values along with specification of what those parameters are (in human, not computer, symbology). Finally, note that the "equilibrated" molalities, i.e., lines 165 to 173, are identical to the input molalities because of the constraint elements that were added.

To compare the input values to the model-calculated values, perform the following steps:

1. Remove the fictitious elements from the COMP file.

2. Add the newly regressed parameters to the data base and run NONLIN without fitting any parameters. (Note that in this sample problem the fictitious elements 71, 72, and 73 have been removed from the COMP file. See lines 17, 20, 23, and 34 in Figure A-3 and compare with corresponding line numbers in Appendix F.)

3. Add the newly regressed standard chemical potential, as shown on line 20 in Appendix F.

4. Add the Pitzer parameters to the BINARYP file (see line 21 in Figure A-4). Note that C^{ϕ} is calculated using Equation 4-12 (on page 10); i.e.,

$$C^{\phi}_{AmAc^{2+}\,Cl^{-}} = C_{AmAc^{2+}\,Cl^{-}} \cdot 2 \cdot \left|Z_{AmAc^{2+}} Z_{Cl^{-}}\right|^{1/2} \tag{A-7}$$

substituting in the values provided at the end of Figure A-5, one gets

$$\begin{aligned} C^{\phi}_{AmAc^{2+}\,Cl^{-}} &= -3.5943059 \times 10^{-2} \cdot 2 \cdot |2 \cdot 1|^{1/2} \\ &= -1.02 \times 10^{-1} \end{aligned} \tag{A-8}$$

5. Run NONLIN without fitting any parameters, using the GMIN file in Figure A-6, the input file shown in Figure A-7, and the COMP database file shown in Figure A-8 (the same binary database file is used as before; see Figure A-4). The final output is shown in Figure A-9.

Figure A-10 contrasts the β_{app} calculated using Equation A-3 from the input molalitities (lines 75 to 80 in Figure A-9) with the β_{app} line using the curve-fitted final molalities (lines 101 to 106 in Figure A-9).

Note that in this sample problem NONLIN reports an abnormal termination condition because there is no solid phase to equilibrate with. This outcome is logical because NONLIN equilibrated the aqueous phase and then realized there was no solid phase (i/e., no AmAc/Am/Ac(s)) present.

The problem could be run by treating the solid phase as if it existed by adding the following species to the COMP file: AmAc/Am/Ac(s). The resulting GMIN file is shown in Figure A-11. The COMP database and output files are shown in Figures A-12 and A-13, respectively. WHEN the above species is added, NONLIN terminates normally. However, this calculation really has no

meaning. The new solid species AmAc/Am/Ac(s) is a solid with no chemical element in it, which can be thought of as an "empty" or "virtual" solid that solely satisfies NONLIN's need for a solid phase to equilibrate with.

See Table 7-1 for explanation of this listing.

```
0     0     0     0
0
001080      0.00000000      1  0 H2O
011000      0.00000000      2  1 Na+
001000      0.00000000      3  2 H+
095001      0.00000000      4  3 Am+++F
095891      0.00000000      5  4 AmAc++F
000170      0.00000000      6  1 Cl-
000891      0.00000000      7  2 Ac-F
000000
195890      0.00000000      8 AmAc/Am/Ac(s)
-1
-1
```

Figure A-1. Sample Input File: AM_ACET.GMIN

See Table 7-3 for explanation of this listing.

See Key Below

```
000005   -300.0      u0      AmAc/Am/Ac(s)
010401     .1        b(0)    AmAc++ Cl-
020401     .1        b(1)    AmAc++ Cl-
040401     .1        cphi    AmAc++ Cl-
-1
     6    -1
0    0     .30    1.4273e-5   1.010e-6   5.426e-7   .3   1.010e-2
0    0    1.0     1.4422e-5   1.021e-6   3.304e-7    1   1.021e-2
0    0    2.0     1.4648e-5   1.039e-6   2.856e-7    2   1.039e-2
0    0    3.0     1.4883e-5   1.054e-6   4.706e-7    3   1.054e-2
0    0    4.0     1.5127e-5   1.071e-6   7.240e-7    4   1.071e-2
0    0    5.0     1.5378e-5   1.089e-6   1.725e-6    5   1.089e-2
-1
```

Comments; not read by NONLIN

Unused columns

Na^+ molality

H^+ molality

Am^{3+} molality

$AmAc^{++}$ molality

Cl^- molality

Ac^- molality

Key (see Table 7-2)	
$u0 = \mu°/RT$	Am/AmAc solid
$b(0) = \beta^{(0)}$	AmAc++ Cl-
$b(1) = \beta^{(1)}$	AmAc++ Cl-
$cphi = C^{\phi}_{MX}$	AmAc++ Cl-

Figure A-2. Sample Input File: AM_ACET.IN

See Table 7-4 for explanation of this listing.

```
001080H2O            0        -95.6635  1 2.0 8 1.0

001000H+             1         000.000  1 1.0
011000Na+            1        -105.651 11 1.0
019000K+             1        -113.957 19 1.0

000080OH-           -1         -63.435  1 1.0 8 1.0
000161HSO4-         -1        -304.942 16 1.0 8 4.0 1 1.0
000170Cl-           -1        -52.9550 17 1.0
017080ClO4-         -1          -73.81 17 1.0 8 4.0

000050B(OH)3(aq)     0        -390.810  5 1.0 8 3.0 1 3.0

090000Th++++         4        -284.227 90 1.0
093080Np(V)O2+       1        -369.109 93 1.0 8 2.0
095000Am+++          3        -241.694 95 1.0
095001Am+++F         3        -241.694 95 1.072 1.0

095890AmAc++         2        -395.358 95 1.089 1.0
095891AmAc++F        2         999.999 95 1.089 1.073 1.0

000890Ac-           -1        -147.347 89 1.0
000891Ac-F          -1        -147.347 89 1.071 1.0

000990Ox=           -2          -272.2 99 1.0
001990HOx-          -1         -281.94 99 1.0 1 1.0
001991H2Ox(aq)       0         -284.99 99 1.0 1 2.0

093890NpO2Ac(aq)     0        -519.800 93 1.0 8 2.089 1.0

101990H2Ox.2H2O(s)   0         999.999 99 1.0 1 6.0 8 2.0
111990Na2Ox(s)       0         999.999 99 1.011 2.0

195890AmAc/Am/Ac(s)  0           0.000 73 1.071-1.072-1.0

199002Na+/NpO2+EX              999.999 93-1.011 1.0 8-2.0
199003Na+/Th++++EX             999.999 90-1.011 4.0

111170       Halite           -154.990 17 1. 11 1.
119172      Sylvite           -164.840 19 1. 17 1.

    -1
```

Figure A-3. Listing of AM_ACET_COMP.DAT

See Table 7-5 for explanation of this listing.

```
011000 000170  .0765  .2664   .000 .00127   Na+ - Cl-
011000 000161  .0454   .398   .000  .0000   Na+ - HSO4-
011000 000080  .0864   .253   .000  .0044   Na+ - OH-
011000 017080  .0554 0.2755   .000-.00118   Na+ - ClO4-
011000 001990 -.0307  .000    .000   .000   Na+ - HOx-
011000 000990  .0028  1.661   .000   .027   Na+ - Ox=
011000 000890  .1426  .22     .000-.00629   Na+ - Ac-
011000 000891  .1426  .22     .000-.00629   Na+ - Ac-F
019000 000170 .04835  .2122   .000-.00084   K+ - Cl-
019000 000161 -.0003  .1735   .000   .000   K+ - HSO4-
019000 000080  .1298   .320   .000  .0041   K+ - OH-
001000 000170  .1775  .2945   .000  .0008   H+ - Cl-
001000 000161  .2065  .5556   .000   .000   H+ - HSO4-
001000 017080  .1747 0.2931   .000 .00819   H+ - ClO4-
090000 000170 1.092   13.7   -160.  -.112   Th++++ - Cl-  Roy et al. 1992
090000 017080 1.186   27.3    .000 -.0566   Th++++ - ClO4-  GRC Extr Data
093080 000170  .1415  .281    .000   .000   NpO2+ - Cl-   NFRK95
093080 017080  .257   .180    .000  .0081   NpO2+ - ClO4- NFRK95
095000 000170  .6117 5.403    .000 -.0284   Am+++ - Cl-
095001 000170  .6117 5.403    .000 -.0284   Am+++F - Cl-
095890 000170  .2270 2.154    .000 -.102    AmAc++ - Cl-
000000

cation anion   beta0 beta1   beta2  cphi
```

Figure A-4. Sample listing of AM_ACET_BINARYP.DAT

See Table 9-1 for explanation of this listing.

```
NONLIN   V2.0

 NONLIN was developed by A.R. Felmy

 INPUT      file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET.IN;1
 GMIN       file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET.GMIN;1
 OUTPUT     file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET.OUT;1

            AQUEOUS SPECIES

     ID       NAME              MOLES        Z    u0rt
   1080H2O                 0.000000000000   0.    -95.663
  11000Na+                 0.000000000000   1.   -105.651
   1000H+                  0.000000000000   1.      0.000
  95001Am+++F              0.000000000000   3.   -241.694
  95891AmAc++F             0.000000000000   2.    999.999
    170Cl-                 0.000000000000  -1.    -52.955
    891Ac-F                0.000000000000  -1.   -147.347
            SOLID PHASES

     ID       NAME              MOLES        Z    u0rt
195890AmAc/Am/Ac(s     0.000000000000   0.       0.000

            CONSTRAINT EQUATIONS
                     0      1      8     11     95     72     89     73     17     71
H2O                 0.0    2.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
Na+                 1.0    0.0    0.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0
H+                  1.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
Am+++F              3.0    0.0    0.0    0.0    1.0    1.0    0.0    0.0    0.0    0.0
AmAc++F             2.0    0.0    0.0    0.0    1.0    0.0    1.0    1.0    0.0    0.0
Cl-                -1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    1.0    0.0
Ac-F               -1.0    0.0    0.0    0.0    0.0    0.0    1.0    0.0    0.0    1.0
AmAc/Am/Ac(s        0.0    0.0    0.0    0.0    0.0   -1.0    0.0    1.0    0.0   -1.0

 Closed input files GMIN and COMP

 COMP       file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_COMP.DAT;1
 BINARYP    file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_BINARYP.DAT;1
 TERNARYP   file name is U1:[SCBABB.NONLIN.INPUTFILES]TERNARYP.DAT;1
 LAMBDA     file name is U1:[SCBABB.NONLIN.INPUTFILES]LAMBDA.DAT;1

          non-ideal electrolyte parameters

          single electrolyte parameters
Na+          Cl-          0.07650    0.26640    0.00000    0.00127
Na+          Ac-F         0.14260    0.22000    0.00000   -0.00629
H+           Cl-          0.17750    0.29450    0.00000    0.00080
H+           Ac-F         0.00000    0.00000    0.00000    0.00000
Am+++F       Cl-          0.61170    5.40300    0.00000   -0.02840
Am+++F       Ac-F         0.00000    0.00000    0.00000    0.00000
AmAc++F      Cl-          0.00000    0.00000    0.00000    0.00000
AmAc++F      Ac-F         0.00000    0.00000    0.00000    0.00000

          ternary electrolyte parameters

                                       Cl-        Ac-F
Na+          H+           0.03600   -0.00400    0.00000
Na+          Am+++F       0.00000    0.00000    0.00000
Na+          AmAc++F      0.00000    0.00000    0.00000
H+           Am+++F       0.00000    0.00000    0.00000
H+           AmAc++F      0.00000    0.00000    0.00000
Am+++F       AmAc++F      0.00000    0.00000    0.00000

                                     Na+        H+         Am+++F     AmAc++F
Cl-          Ac-F        -0.09000    0.01029    0.00000    0.00000    0.00000

 TOTAL NUMBER OF SPECIES =  8
 NUMBER OF COMPONENTS    = 10
 INDEPENDENT CONSTRAINTS =  7

          SOLUBILITY DATA

          input molalities


     Na+          H+           Am+++F       AmAc++F      Cl-          Ac-F
   3.000E-01    1.427E-05    1.010E-06    5.426E-07    3.000E-01    1.010E-02
   1.000E+00    1.442E-05    1.021E-06    3.304E-07    1.000E+00    1.021E-02
   2.000E+00    1.465E-05    1.039E-06    2.856E-07    2.000E+00    1.039E-02
   3.000E+00    1.488E-05    1.054E-06    4.706E-07    3.000E+00    1.054E-02
   4.000E+00    1.513E-05    1.071E-06    7.240E-07    4.000E+00    1.071E-02
   5.000E+00    1.538E-05    1.089E-06    1.725E-06    5.000E+00    1.089E-02
```

Figure A-5. Sample Output File: AM_ACET.OUT (1 of 3)

```
 -3.0000E+02   1.0000E-01   1.0000E-01   1.0000E-01
              L2 NORM OF THE RESIDUALS   2.3449283E+02



 -3.9536E+02   2.2701E-01   2.1540E+00  -3.5943E-02
              L2 NORM OF THE RESIDUALS   1.4263862E-01



 -3.9536E+02   2.2701E-01   2.1540E+00  -3.5943E-02
              L2 NORM OF THE RESIDUALS   1.4263862E-01



            ADJUSTED PARAMETERS
  u0rt(                          AmAc++F      )  -3.9535830E+02
    b0(              AmAc++F     Cl-          )   2.2700551E-01
    b1(              AmAc++F     Cl-          )   2.1540417E+00
   cmx(              AmAc++F     Cl-          )  -3.5943059E-02

 DATA SET( 1)

  input     calc       diff
 0.000000000000000E+000   6.896275256025319E-003
 0.000000000000000E+000  -3.441260316461126E-002
 0.000000000000000E+000   8.104134361121851E-002
 0.000000000000000E+000  -9.661210626001093E-002
 0.000000000000000E+000   5.533810069229617E-002
 0.000000000000000E+000  -1.225101013483254E-002

 AVERAGE DEVIATION   =   4.7759E-02

 STANDARD DEVIATION =   5.8232E-02

FINAL MOLALITIES

Na+          H+           Am+++F       AmAc++F      Cl-          Ac-F
   3.000E-01   1.427E-05   1.010E-06   5.426E-07   3.000E-01   1.010E-02
   1.000E+00   1.442E-05   1.021E-06   3.304E-07   1.000E+00   1.021E-02
   2.000E+00   1.465E-05   1.039E-06   2.856E-07   2.000E+00   1.039E-02
   3.000E+00   1.488E-05   1.054E-06   4.706E-07   3.000E+00   1.054E-02
   4.000E+00   1.513E-05   1.071E-06   7.240E-07   4.000E+00   1.071E-02
   5.000E+00   1.538E-05   1.089E-06   1.725E-06   5.000E+00   1.089E-02

FINAL LOG ACTIVITIES

Na+          H+           Am+++F       AmAc++F      Cl-          Ac-F
  -6.728E-01  -4.958E+00  -7.403E+00  -6.823E+00  -6.758E-01  -2.160E+00
  -1.827E-01  -4.901E+00  -7.718E+00  -7.167E+00  -1.853E-01  -2.207E+00
   1.261E-01  -4.771E+00  -7.834E+00  -7.338E+00   1.237E-01  -2.212E+00
   3.310E-01  -4.625E+00  -7.836E+00  -7.244E+00   3.287E-01  -2.194E+00
   4.960E-01  -4.472E+00  -7.775E+00  -7.215E+00   4.938E-01  -2.160E+00
   6.408E-01  -4.315E+00  -7.671E+00  -7.038E+00   6.385E-01  -2.116E+00

Calculated Log Activity Coefficients

Na+          H+           Am+++F       AmAc++F      Cl-          Ac-F
      -0.1500      -0.1130      -1.4077      -0.5573      -0.1529      -0.1643
      -0.1827      -0.0602      -1.7272      -0.6858      -0.1853      -0.2161
      -0.1749       0.0630      -1.8505      -0.7936      -0.1773      -0.2290
      -0.1461       0.2022      -1.8589      -0.9171      -0.1485      -0.2168
      -0.1060       0.3484      -1.8043      -1.0750      -0.1083      -0.1901
      -0.0582       0.4981      -1.7082      -1.2750      -0.0604      -0.1529

SOLID PHASE NOW IN EQUILIBRIUM

 DATA SET( 1)

  input     calc       diff
 0.000000000000000E+000   0.000000000000000E+000
 0.000000000000000E+000   0.000000000000000E+000
 0.000000000000000E+000   0.000000000000000E+000
 0.000000000000000E+000   0.000000000000000E+000
 0.000000000000000E+000   0.000000000000000E+000
 0.000000000000000E+000   0.000000000000000E+000

 AVERAGE DEVIATION   =   0.0000E+00

 STANDARD DEVIATION =   0.0000E+00
```

Figure A-5. Sample Output File: AM_ACET.OUT (2 of 3)

```
FINAL  MOLALITIES

 Na+          H+           Am+++F       AmAc++F      Cl-          Ac-F
    3.000E-01   1.427E-05   1.010E-06   5.426E-07   3.000E-01   1.010E-02
    1.000E+00   1.442E-05   1.021E-06   3.304E-07   1.000E+00   1.021E-02
    2.000E+00   1.465E-05   1.039E-06   2.856E-07   2.000E+00   1.039E-02
    3.000E+00   1.488E-05   1.054E-06   4.706E-07   3.000E+00   1.054E-02
    4.000E+00   1.513E-05   1.071E-06   7.240E-07   4.000E+00   1.071E-02
    5.000E+00   1.538E-05   1.089E-06   1.725E-06   5.000E+00   1.089E-02

 FINAL  LOG  ACTIVITIES

 Na+          H+           Am+++F       AmAc++F      Cl-          Ac-F
   -6.728E-01  -4.958E+00  -7.403E+00  -6.823E+00  -6.758E-01  -2.160E+00
   -1.827E-01  -4.901E+00  -7.718E+00  -7.167E+00  -1.853E-01  -2.207E+00
    1.261E-01  -4.771E+00  -7.834E+00  -7.338E+00   1.237E-01  -2.212E+00
    3.310E-01  -4.625E+00  -7.836E+00  -7.244E+00   3.287E-01  -2.194E+00
    4.960E-01  -4.472E+00  -7.775E+00  -7.215E+00   4.938E-01  -2.160E+00
    6.408E-01  -4.315E+00  -7.671E+00  -7.038E+00   6.385E-01  -2.116E+00

 Calculated Log Activity Coefficients

 Na+          H+           Am+++F       AmAc++F      Cl-          Ac-F
      -0.1500      -0.1130      -1.4077      -0.5573      -0.1529      -0.1643
      -0.1827      -0.0602      -1.7272      -0.6858      -0.1853      -0.2161
      -0.1749       0.0630      -1.8505      -0.7936      -0.1773      -0.2290
      -0.1461       0.2022      -1.8589      -0.9171      -0.1485      -0.2168
      -0.1060       0.3484      -1.8043      -1.0750      -0.1083      -0.1901
      -0.0582       0.4981      -1.7082      -1.2750      -0.0604      -0.1529

       FINAL L2 NORM OF THE RESIDUALS   1.4263862E-01


      EXIT PARAMETER                          3


       FINAL APPROXIMATE SOLUTION


      0 0 5   -3.9535830E+02
      1 4 1    2.2700551E-01
      2 4 1    2.1540417E+00
      4 4 1   -3.5943059E-02
```

Figure A-5. Sample Output File: AM_ACET.OUT (3 of 3)

```
0     0     0     0
0
001080      0.00000000        1  0 H2O
011000      0.00000000        2  1 Na+
001000      0.00000000        3  2 H+
095000      0.00000000        4  3 Am+++
095890      0.00000000        5  4 AmAc++
000170      0.00000000        6  1 Cl-
000890      0.00000000        7  2 Ac-
000000
-1
-1
```

Figure A-6. Sample Input File: AM_ACET_POST_ABN.GMIN

```
-1
     6   -1
0    0     .30    1.4273e-5    1.010e-6     5.426e-7     .3    1.010e-2
0    0     1.0    1.4422e-5    1.021e-6     3.304e-7      1    1.021e-2
0    0     2.0    1.4648e-5    1.039e-6     2.856e-7      2    1.039e-2
0    0     3.0    1.4883e-5    1.054e-6     4.706e-7      3    1.054e-2
0    0     4.0    1.5127e-5    1.071e-6     7.240e-7      4    1.071e-2
0    0     5.0    1.5378e-5    1.089e-6     1.725e-6      5    1.089e-2
-1
```

Figure A-7. Sample Input File: AM_ACET_POST.IN

```
001080H2O            0        -95.6635  1 2.0 8 1.0

001000H+             1         000.000  1 1.0
011000Na+            1        -105.651 11 1.0
019000K+             1        -113.957 19 1.0

000080OH-           -1         -63.435  1 1.0 8 1.0
000161HSO4-         -1        -304.942 16 1.0 8 4.0 1 1.0
000170Cl-           -1        -52.9550 17 1.0
017080ClO4-         -1          -73.81 17 1.0 8 4.0

000050B(OH)3(aq)     0        -390.810  5 1.0 8 3.0 1 3.0

090000Th++++         4        -284.227 90 1.0
093080Np(V)O2+       1        -369.109 93 1.0 8 2.0
095000Am+++          3        -241.694 95 1.0
095001Am+++F         3        -241.694 95 1.072 1.0

095890AmAc++         2        -395.358 95 1.089 1.0
095891AmAc++F        2         999.999 95 1.089 1.073 1.0

000890Ac-           -1        -147.347 89 1.0
000891Ac-F          -1        -147.347 89 1.071 1.0

000990Ox=           -2          -272.2 99 1.0
001990HOx-          -1         -281.94 99 1.0 1 1.0
001991H2Ox(aq)       0         -284.99 99 1.0 1 2.0

093890NpO2Ac(aq)     0        -519.800 93 1.0 8 2.089 1.0

101990H2Ox.2H2O(s)   0         999.999 99 1.0 1 6.0 8 2.0
111990Na2Ox(s)       0         999.999 99 1.011 2.0

195890AmAc/Am/Ac(s) 0            0.000 73 1.071-1.072-1.0

199002Na+/NpO2+EX              999.999 93-1.011 1.0 8-2.0
199003Na+/Th++++EX             999.999 90-1.011 4.0

111170      Halite           -154.990 17 1. 11 1.
119172     Sylvite           -164.840 19 1. 17 1.

    -1
```

Figure A-8. Sample Input File: AM_ACET_COMP_POST_ABN.DAT

```
NONLIN   V2.0

 NONLIN was developed by A.R. Felmy

 INPUT     file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_POST.IN;1
 GMIN      file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_POST_ABN.GMIN;
 OUTPUT    file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_POST_ABN.OUT;1

           AQUEOUS SPECIES

    ID       NAME            MOLES        Z   u0rt
   1080H2O              0.000000000000   0.   -95.663
  11000Na+              0.000000000000   1.  -105.651
   1000H+               0.000000000000   1.     0.000
  95000Am+++            0.000000000000   3.  -241.694
  95890AmAc++           0.000000000000   2.  -395.358
    170Cl-              0.000000000000  -1.   -52.955
    890Ac-              0.000000000000  -1.  -147.347
           SOLID PHASES

    ID       NAME            MOLES        Z   u0rt

           CONSTRAINT EQUATIONS
                    0      1      8     11     95     89     17
 H2O              0.0    2.0    1.0    0.0    0.0    0.0    0.0
 Na+              1.0    0.0    0.0    1.0    0.0    0.0    0.0
 H+               1.0    1.0    0.0    0.0    0.0    0.0    0.0
 Am+++            3.0    0.0    0.0    0.0    1.0    0.0    0.0
 AmAc++           2.0    0.0    0.0    0.0    1.0    1.0    0.0
 Cl-             -1.0    0.0    0.0    0.0    0.0    0.0    1.0
 Ac-             -1.0    0.0    0.0    0.0    0.0    1.0    0.0

 Closed input files GMIN and COMP

 COMP      file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_COMP_POST_ABN.
 BINARYP   file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_BINARYP.DAT;1
 TERNARYP  file name is U1:[SCBABB.NONLIN.INPUTFILES]TERNARYP.DAT;1
 LAMBDA    file name is U1:[SCBABB.NONLIN.INPUTFILES]LAMBDA.DAT;1

        non-ideal electrolyte parameters

        single electrolyte parameters
Na+          Cl-            0.07650    0.26640    0.00000    0.00127
Na+          Ac-            0.14260    0.22000    0.00000   -0.00629
H+           Cl-            0.17750    0.29450    0.00000    0.00080
H+           Ac-            0.00000    0.00000    0.00000    0.00000
Am+++        Cl-            0.61170    5.40300    0.00000   -0.02840
Am+++        Ac-            0.00000    0.00000    0.00000    0.00000
AmAc++       Cl-            0.22700    2.15400    0.00000   -0.10200
AmAc++       Ac-            0.00000    0.00000    0.00000    0.00000

        ternary electrolyte parameters

                                         Cl-        Ac-
Na+          H+             0.03600   -0.00400    0.00000
Na+          Am+++          0.00000    0.00000    0.00000
Na+          AmAc++         0.00000    0.00000    0.00000
H+           Am+++          0.00000    0.00000    0.00000
H+           AmAc++         0.00000    0.00000    0.00000
Am+++        AmAc++         0.00000    0.00000    0.00000

                                         Na+        H+         Am+++      AmAc++
Cl-          Ac-           -0.09000    0.01029    0.00000    0.00000    0.00000

 TOTAL NUMBER OF SPECIES =  7
 NUMBER OF COMPONENTS    =  7
 INDEPENDENT CONSTRAINTS =  6
```

Figure A-9. Sample Output File: AM_ACET_POST_ABN.OUT (1 of 2)

```
SOLUBILITY DATA

          input molalities


     Na+          H+           Am+++        AmAc++       Cl-          Ac-
     3.000E-01    1.427E-05    1.010E-06    5.426E-07    3.000E-01    1.010E-02
     1.000E+00    1.442E-05    1.021E-06    3.304E-07    1.000E+00    1.021E-02
     2.000E+00    1.465E-05    1.039E-06    2.856E-07    2.000E+00    1.039E-02
     3.000E+00    1.488E-05    1.054E-06    4.706E-07    3.000E+00    1.054E-02
     4.000E+00    1.513E-05    1.071E-06    7.240E-07    4.000E+00    1.071E-02
     5.000E+00    1.538E-05    1.089E-06    1.725E-06    5.000E+00    1.089E-02

          ADJUSTED PARAMETERS

  DATA SET( 1)

   input     calc       diff
  0.000000000000000E+000   0.000000000000000E+000
  0.000000000000000E+000   0.000000000000000E+000
  0.000000000000000E+000   0.000000000000000E+000
  0.000000000000000E+000   0.000000000000000E+000
  0.000000000000000E+000   0.000000000000000E+000
  0.000000000000000E+000   0.000000000000000E+000

  AVERAGE DEVIATION  =  0.0000E+00

  STANDARD DEVIATION =  0.0000E+00

FINAL MOLALITIES

Na+          H+           Am+++        AmAc++       Cl-          Ac-
  3.000E-01  1.427E-05  1.008E-06  5.449E-07  3.000E-01  1.010E-02
  1.000E+00  1.442E-05  1.030E-06  3.219E-07  1.000E+00  1.021E-02
  2.000E+00  1.465E-05  1.020E-06  3.043E-07  2.000E+00  1.039E-02
  3.000E+00  1.488E-05  1.084E-06  4.404E-07  3.000E+00  1.054E-02
  4.000E+00  1.513E-05  1.045E-06  7.496E-07  4.000E+00  1.071E-02
  5.000E+00  1.538E-05  1.093E-06  1.721E-06  5.000E+00  1.089E-02

FINAL LOG ACTIVITIES

Na+          H+           Am+++        AmAc++       Cl-          Ac-
 -6.728E-01 -4.958E+00 -7.404E+00 -6.821E+00 -6.758E-01 -2.160E+00
 -1.827E-01 -4.901E+00 -7.715E+00 -7.178E+00 -1.853E-01 -2.207E+00
  1.261E-01 -4.771E+00 -7.842E+00 -7.311E+00  1.237E-01 -2.212E+00
  3.310E-01 -4.625E+00 -7.824E+00 -7.274E+00  3.287E-01 -2.194E+00
  4.960E-01 -4.472E+00 -7.785E+00 -7.202E+00  4.938E-01 -2.160E+00
  6.408E-01 -4.315E+00 -7.669E+00 -7.042E+00  6.385E-01 -2.116E+00

Calculated Log Activity Coefficients

Na+          H+           Am+++        AmAc++       Cl-          Ac-
     -0.1500      -0.1130      -1.4077      -0.5573      -0.1529      -0.1643
     -0.1827      -0.0602      -1.7272      -0.6859      -0.1853      -0.2161
     -0.1749       0.0630      -1.8505      -0.7941      -0.1773      -0.2290
     -0.1461       0.2022      -1.8589      -0.9181      -0.1485      -0.2168
     -0.1060       0.3484      -1.8043      -1.0767      -0.1083      -0.1901
     -0.0582       0.4981      -1.7082      -1.2776      -0.0604      -0.1529

SOLID PHASE NOW IN EQUILIBRIUM

 DATA SET( 1)

   input     calc       diff
**** SINGULAR MATRIX IN DECOMP, ZERO DIVIDE IN SOLVE
```

Figure A-9. Sample Output File: AM_ACET_POST_ABN.OUT (2 of 2)

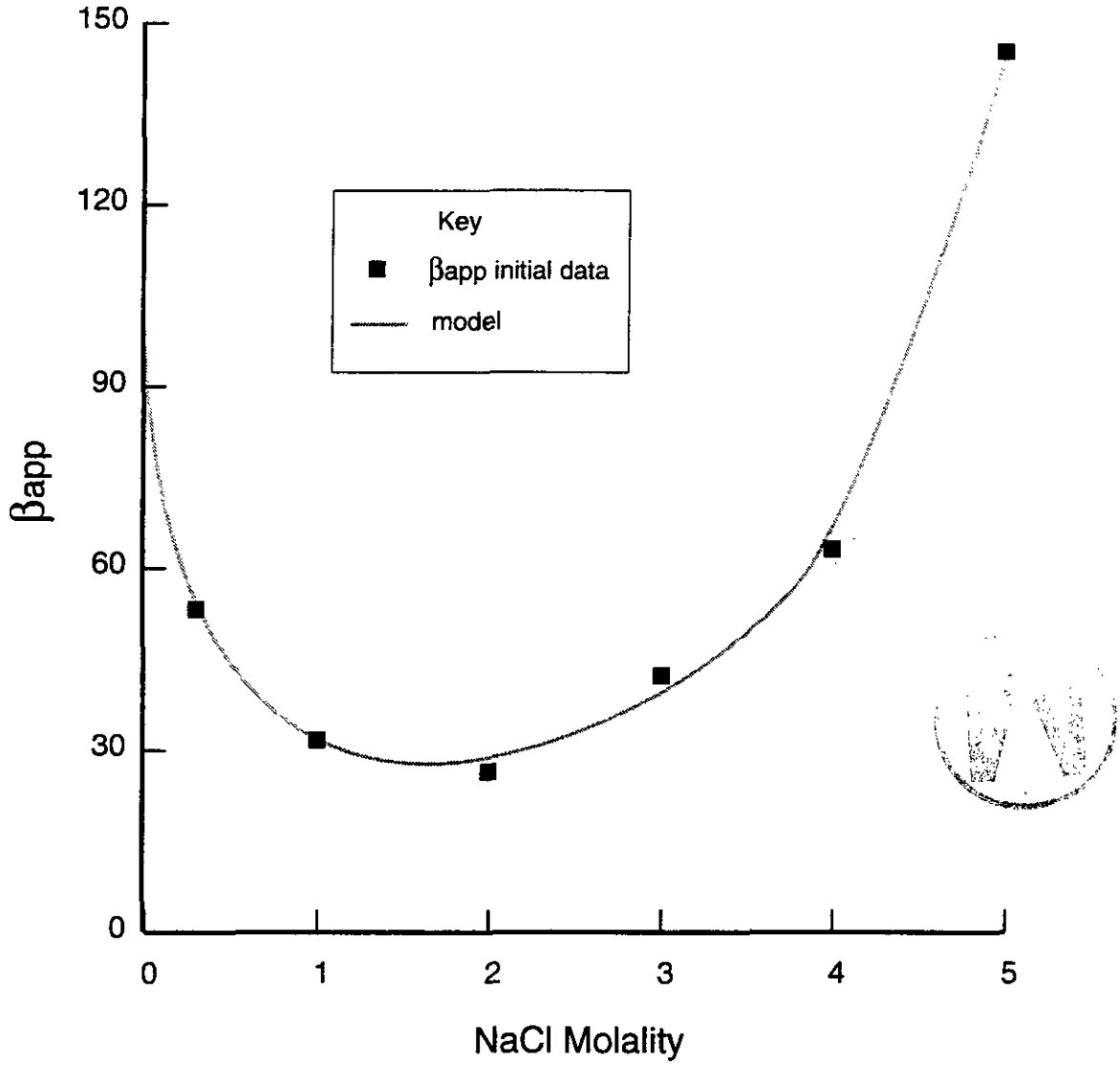

Figure A-10. Apparent stability constant for AmAc in NaCl media: comparison of the model with data.

```
0     0     0     0
0
001080      0.00000000        1  0 H2O
011000      0.00000000        2  1 Na+
001000      0.00000000        3  2 H+
095000      0.00000000        4  3 Am+++
095890      0.00000000        5  4 AmAc++
000170      0.00000000        6  1 Cl-
000890      0.00000000        7  2 Ac-
000000
195891      0.00000000
-1
-1
```

Figure A-11. Sample Input File: AM_ACET_POST_NORM.GMIN.

```
001080H2O            0        -95.6635  1 2.0 8 1.0

001000H+             1         000.000  1 1.0
011000Na+            1        -105.651 11 1.0
019000K+             1        -113.957 19 1.0

000080OH-           -1         -63.435  1 1.0 8 1.0
000161HSO4-         -1        -304.942 16 1.0 8 4.0 1 1.0
000170Cl-           -1        -52.9550 17 1.0
017080ClO4-         -1          -73.81 17 1.0 8 4.0

000050B(OH)3(aq)     0        -390.810  5 1.0 8 3.0 1 3.0

090000Th++++         4        -284.227 90 1.0
093080Np(V)O2+       1        -369.109 93 1.0 8 2.0
095000Am+++          3        -241.694 95 1.0
095001Am+++F         3        -241.694 95 1.072 1.0

095890AmAc++         2        -395.358 95 1.089 1.0
095891AmAc++F        2         999.999 95 1.089 1.073 1.0

000890Ac-           -1        -147.347 89 1.0
000891Ac-F          -1        -147.347 89 1.071 1.0

000990Ox=           -2          -272.2 99 1.0
001990HOx-          -1         -281.94 99 1.0 1 1.0
001991H2Ox(aq)       0         -284.99 99 1.0 1 2.0

093890NpO2Ac(aq)     0        -519.800 93 1.0 8 2.089 1.0

101990H2Ox.2H2O(s)   0         999.999 99 1.0 1 6.0 8 2.0
111990Na2Ox(s)       0         999.999 99 1.011 2.0

195890AmAc/Am/Ac(s)  0           0.000 73 1.071-1.072-1.0
195891AmAc/Am/Ac(s)  0           0.000 89 0.095 0.0

199002Na+/NpO2+EX             999.999 93-1.011 1.0 8-2.0
199003Na+/Th++++EX            999.999 90-1.011 4.0

111170       Halite          -154.990 17 1. 11 1.
119172      Sylvite          -164.840 19 1. 17 1.

     -1
```

Figure A-12. Sample Input File: AM_ACET_COMP_POST_NORM.DAT

```
NONLIN   V2.0

 NONLIN was developed by A.R. Felmy

 INPUT      file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_POST.IN;1
 GMIN       file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_POST_NORM.GMIN
 OUTPUT     file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_POST_NORM.OUT;

            AQUEOUS SPECIES

     ID       NAME            MOLES        Z    u0rt
   1080H2O              0.000000000000   0.    -95.663
  11000Na+              0.000000000000   1.   -105.651
   1000H+               0.000000000000   1.      0.000
  95000Am+++            0.000000000000   3.   -241.694
  95890AmAc++           0.000000000000   2.   -395.358
    170Cl-              0.000000000000  -1.    -52.955
    890Ac-              0.000000000000  -1.   -147.347
            SOLID PHASES

     ID       NAME            MOLES        Z    u0rt
195891AmAc/Am/Ac(s    0.000000000000   0.       0.000

            CONSTRAINT EQUATIONS
                    0      1      8     11     95     89     17
H2O               0.0    2.0    1.0    0.0    0.0    0.0    0.0
Na+               1.0    0.0    0.0    1.0    0.0    0.0    0.0
H+                1.0    1.0    0.0    0.0    0.0    0.0    0.0
Am+++             3.0    0.0    0.0    0.0    1.0    0.0    0.0
AmAc++            2.0    0.0    0.0    0.0    1.0    1.0    0.0
Cl-              -1.0    0.0    0.0    0.0    0.0    0.0    1.0
Ac-              -1.0    0.0    0.0    0.0    0.0    1.0    0.0
AmAc/Am/Ac(s      0.0    0.0    0.0    0.0    0.0    0.0    0.0

 Closed input files GMIN and COMP

 COMP       file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_COMP_POST_NORM
 BINARYP    file name is U1:[SCBABB.NONLIN.USERGUIDE]AM_ACET_BINARYP.DAT;1
 TERNARYP   file name is U1:[SCBABB.NONLIN.INPUTFILES]TERNARYP.DAT;1
 LAMBDA     file name is U1:[SCBABB.NONLIN.INPUTFILES]LAMBDA.DAT;1

          non-ideal electrolyte parameters

          single electrolyte parameters
Na+          Cl-          0.07650    0.26640    0.00000    0.00127
Na+          Ac-          0.14260    0.22000    0.00000   -0.00629
H+           Cl-          0.17750    0.29450    0.00000    0.00080
H+           Ac-          0.00000    0.00000    0.00000    0.00000
Am+++        Cl-          0.61170    5.40300    0.00000   -0.02840
Am+++        Ac-          0.00000    0.00000    0.00000    0.00000
AmAc++       Cl-          0.22700    2.15400    0.00000   -0.10200
AmAc++       Ac-          0.00000    0.00000    0.00000    0.00000

          ternary electrolyte parameters

                                       Cl-        Ac-
Na+          H+           0.03600   -0.00400    0.00000
Na+          Am+++        0.00000    0.00000    0.00000
Na+          AmAc++       0.00000    0.00000    0.00000
H+           Am+++        0.00000    0.00000    0.00000
H+           AmAc++       0.00000    0.00000    0.00000
Am+++        AmAc++       0.00000    0.00000    0.00000

                                       Na+        H+         Am+++      AmAc++
Cl-          Ac-         -0.09000    0.01029    0.00000    0.00000    0.00000

 TOTAL NUMBER OF SPECIES =  8
 NUMBER OF COMPONENTS    =  7
 INDEPENDENT CONSTRAINTS =  6

            SOLUBILITY DATA

            input molalities

     Na+          H+          Am+++       AmAc++      Cl-         Ac-
   3.000E-01   1.427E-05   1.010E-06   5.426E-07   3.000E-01   1.010E-02
   1.000E+00   1.442E-05   1.021E-06   3.304E-07   1.000E+00   1.021E-02
   2.000E+00   1.465E-05   1.039E-06   2.856E-07   2.000E+00   1.039E-02
   3.000E+00   1.488E-05   1.054E-06   4.706E-07   3.000E+00   1.054E-02
   4.000E+00   1.513E-05   1.071E-06   7.240E-07   4.000E+00   1.071E-02
   5.000E+00   1.538E-05   1.089E-06   1.725E-06   5.000E+00   1.089E-02
```

Figure A-13. Sample Output File: AM_ACET_POST_NORM.OUT (1 of 3)

```
ADJUSTED  PARAMETERS

  DATA SET( 1)

   input     calc       diff
   0.000000000000000E+000   0.000000000000000E+000
   0.000000000000000E+000   0.000000000000000E+000
   0.000000000000000E+000   0.000000000000000E+000
   0.000000000000000E+000   0.000000000000000E+000
   0.000000000000000E+000   0.000000000000000E+000
   0.000000000000000E+000   0.000000000000000E+000

  AVERAGE DEVIATION   =   0.0000E+00

  STANDARD DEVIATION =   0.0000E+00

 FINAL MOLALITIES

Na+          H+           Am+++        AmAc++       Cl-          Ac-
   3.000E-01  1.427E-05  1.008E-06  5.449E-07  3.000E-01  1.010E-02
   1.000E+00  1.442E-05  1.030E-06  3.219E-07  1.000E+00  1.021E-02
   2.000E+00  1.465E-05  1.020E-06  3.043E-07  2.000E+00  1.039E-02
   3.000E+00  1.488E-05  1.084E-06  4.404E-07  3.000E+00  1.054E-02
   4.000E+00  1.513E-05  1.045E-06  7.496E-07  4.000E+00  1.071E-02
   5.000E+00  1.538E-05  1.093E-06  1.721E-06  5.000E+00  1.089E-02

 FINAL LOG ACTIVITIES

Na+          H+           Am+++        AmAc++       Cl-          Ac-
  -6.728E-01 -4.958E+00 -7.404E+00 -6.821E+00 -6.758E-01 -2.160E+00
  -1.827E-01 -4.901E+00 -7.715E+00 -7.178E+00 -1.853E-01 -2.207E+00
   1.261E-01 -4.771E+00 -7.842E+00 -7.311E+00  1.237E-01 -2.212E+00
   3.310E-01 -4.625E+00 -7.824E+00 -7.274E+00  3.287E-01 -2.194E+00
   4.960E-01 -4.472E+00 -7.785E+00 -7.202E+00  4.938E-01 -2.160E+00
   6.408E-01 -4.315E+00 -7.669E+00 -7.042E+00  6.385E-01 -2.116E+00

Calculated Log Activity Coefficients

Na+          H+           Am+++        AmAc++       Cl-          Ac-
      -0.1500      -0.1130      -1.4077      -0.5573      -0.1529      -0.1643
      -0.1827      -0.0602      -1.7272      -0.6859      -0.1853      -0.2161
      -0.1749       0.0630      -1.8505      -0.7941      -0.1773      -0.2290
      -0.1461       0.2022      -1.8589      -0.9181      -0.1485      -0.2168
      -0.1060       0.3484      -1.8043      -1.0767      -0.1083      -0.1901
      -0.0582       0.4981      -1.7082      -1.2776      -0.0604      -0.1529

SOLID PHASE NOW IN EQUILIBRIUM

 DATA SET( 1)

  input     calc       diff
projected hessian indefinite
  0.000000000000000E+000   0.000000000000000E+000
projected hessian indefinite
  0.000000000000000E+000   0.000000000000000E+000
projected hessian indefinite
  0.000000000000000E+000   0.000000000000000E+000
projected hessian indefinite
  0.000000000000000E+000   0.000000000000000E+000
projected hessian indefinite
  0.000000000000000E+000   0.000000000000000E+000
projected hessian indefinite
  0.000000000000000E+000   0.000000000000000E+000

 AVERAGE DEVIATION   =   0.0000E+00

 STANDARD DEVIATION =   0.0000E+00
```

Figure A-13. Sample Output File: AM_ACET_POST_NORM.OUT (2 of 3)

```
FINAL  MOLALITIES

 Na+          H+           Am+++        AmAc++       Cl-          Ac-
    3.000E-01   1.427E-05   1.008E-06   5.449E-07   3.000E-01   1.010E-02
    1.000E+00   1.442E-05   1.030E-06   3.219E-07   1.000E+00   1.021E-02
    2.000E+00   1.465E-05   1.020E-06   3.043E-07   2.000E+00   1.039E-02
    3.000E+00   1.488E-05   1.084E-06   4.404E-07   3.000E+00   1.054E-02
    4.000E+00   1.513E-05   1.045E-06   7.496E-07   4.000E+00   1.071E-02
    5.000E+00   1.538E-05   1.093E-06   1.721E-06   5.000E+00   1.089E-02

 FINAL  LOG  ACTIVITIES

 Na+          H+           Am+++        AmAc++       Cl-          Ac-
   -6.728E-01  -4.958E+00  -7.404E+00  -6.821E+00  -6.758E-01  -2.160E+00
   -1.827E-01  -4.901E+00  -7.715E+00  -7.178E+00  -1.853E-01  -2.207E+00
    1.261E-01  -4.771E+00  -7.842E+00  -7.311E+00   1.237E-01  -2.212E+00
    3.310E-01  -4.625E+00  -7.824E+00  -7.274E+00   3.287E-01  -2.194E+00
    4.960E-01  -4.472E+00  -7.785E+00  -7.202E+00   4.938E-01  -2.160E+00
    6.408E-01  -4.315E+00  -7.669E+00  -7.042E+00   6.385E-01  -2.116E+00

 Calculated  Log  Activity  Coefficients

 Na+          H+           Am+++        AmAc++       Cl-          Ac-
      -0.1500      -0.1130      -1.4077      -0.5573      -0.1529      -0.1643
      -0.1827      -0.0602      -1.7272      -0.6859      -0.1853      -0.2161
      -0.1749       0.0630      -1.8505      -0.7941      -0.1773      -0.2290
      -0.1461       0.2022      -1.8589      -0.9181      -0.1485      -0.2168
      -0.1060       0.3484      -1.8043      -1.0767      -0.1083      -0.1901
      -0.0582       0.4981      -1.7082      -1.2776      -0.0604      -0.1529

      FINAL  L2  NORM  OF  THE  RESIDUALS   0.0000000E+00


     EXIT  PARAMETER                          0


      FINAL  APPROXIMATE  SOLUTION
```

Figure A-13. Sample Output File: AM_ACET_POST_NORM.OUT (3 of 3)

Appendix B - Sample Input File: EXTR_00.GMIN

See Table 7-1 for explanation of this listing.

```
0     0     0     0
0
001080      0.00000000        H2O
011000      0.00000000        Na+
090000      0.00000000        Th++++
001000      0.00000000        H+
000080      0.00000000        OH-
017080      0.00000000        ClO4-
000000
199003      0.00000000        Th++++/Na+ extracted
-1
-1
```

Appendix C - Sample Input File: EXTR_07_EXACT.IN

See Table 7-3 for explanation of this listing.

See key in Figure A-1.

```
000007    -120.65      uo[ Th++++/Na+ extracted]
010202      1.186      b(0)  Th+++/ClO4-
040202    -0.0141      cphi  Th+++/ClO4-
-1
   16    -4
1.00E-05        0.000   0.307   2.12E-05        1.00E-07        1.00E-07        0.307
1.00E-05        0.000   0.307   2.12E-05        1.00E-07        1.00E-07        0.307
1.00E-05        0.000   1.035   5.94E-05        1.00E-07        1.00E-07        1.035
1.00E-05        0.000   1.035   5.81E-05        1.00E-07        1.00E-07        1.035
1.00E-05        0.000   2.129   1.69E-04        1.00E-07        1.00E-07        2.129
1.00E-05        0.000   2.129   1.69E-04        1.00E-07        1.00E-07        2.129
1.00E-05        0.000   3.322   3.15E-04        1.00E-07        1.00E-07        3.322
1.00E-05        0.000   3.322   3.39E-04        1.00E-07        1.00E-07        3.322
1.00E-05        0.000   4.657   9.45E-04        1.00E-07        1.00E-07        4.657
1.00E-05        0.000   4.657   9.45E-04        1.00E-07        1.00E-07        4.657
1.00E-05        0.000   6.176   1.26E-03        1.00E-07        1.00E-07        6.176
1.00E-05        0.000   6.176   1.45E-03        1.00E-07        1.00E-07        6.176
1.00E-05        0.000   9.929   1.93E-03        1.00E-07        1.00E-07        9.929
1.00E-05        0.000   9.929   2.19E-03        1.00E-07        1.00E-07        9.929
1.00E-05        0.000   14.916  2.33E-03        1.00E-07        1.00E-07        14.916
1.00E-05        0.000   14.916  2.29E-03        1.00E-07        1.00E-07        14.916
-1
-1

mORG            pH      mNa+    mTh++++         mH+             mOH-            mClO4-
```

Appendix D - Sample Input File: SOLUB_00.GMIN

See Table 7-1 for explanation of this listing.

```
0     0     0     0
0
001080      0.00000000        H2O
001000      0.00000000        H+
000080      0.00000000        OH-
000161      0.00000000        HSO4-
001991      0.00000000        H2Ox(aq)
000000
101990      .000000000        H2Ox.2H2O(s)
-1
-1
```

Appendix E - Sample Input File: SOLUB_01.IN

See Table 7-3 for explanation of this listing.

```
000006      -10.0          u0 H2C2O4.2H2O(s))
-1
   07    -1
0.0      0.0      1.168    8.56E-15        1.168    0.875
0.0      0.0      1.965    5.09E-15        1.965    0.653
0.0      0.0      2.927    3.42E-15        2.927    0.534
0.0      0.0      4.450    2.25E-15        4.450    0.476
0.0      0.0      6.660    1.50E-15        6.660    0.432
0.0      0.0      9.548    1.05E-15        9.548    0.574
0.0      0.0      13.941   7.17E-16        13.941   1.268
-1
-1


0.0       pH        mH+      mOH-            mHSO4-     mH2Ox
```

See key in Figure A-1.

Appendix F - Listing of COMP.DAT

See Table 7-4 for explanation of this listing.

```
001080H2O            0       -95.6635  1 2.0 8 1.0

001000H+             1        000.000  1 1.0
011000Na+            1       -105.651 11 1.0
019000K+             1       -113.957 19 1.0

000080OH-           -1        -63.435  1 1.0 8 1.0
000161HSO4-         -1       -304.942 16 1.0 8 4.0 1 1.0
000170Cl-           -1       -52.9550 17 1.0
017080ClO4-         -1         -73.81 17 1.0 8 4.0

000050B(OH)3(aq)     0       -390.810  5 1.0 8 3.0 1 3.0

090000Th++++         4       -284.227 90 1.0
093080Np(V)O2+       1       -369.109 93 1.0 8 2.0
095000Am+++          3       -241.694 95 1.0
095001Am+++F         3       -241.694 95 1.072 1.0

095890AmAc++         2        999.999 95 1.089 1.0
095891AmAc++F        2        999.999 95 1.089 1.073 1.0

000890Ac-           -1       -147.347 89 1.0
000891Ac-F          -1       -147.347 89 1.071 1.0

000990Ox=           -2         -272.2 99 1.0
001990HOx-          -1        -281.94 99 1.0 1 1.0
001991H2Ox(aq)       0        -284.99 99 1.0 1 2.0

093890NpO2Ac(aq)     0       -519.800 93 1.0 8 2.089 1.0

101990H2Ox.2H2O(s)   0        999.999 99 1.0 1 6.0 8 2.0
111990Na2Ox(s)       0        999.999 99 1.011 2.0

195890AmAc/Am/Ac(s)  0          0.000 73 1.071-1.072-1.0

199002Na+/NpO2+EX             999.999 93-1.011 1.0 8-2.0
199003Na+/Th++++EX            999.999 90-1.011 4.0

111170       Halite          -154.990 17 1. 11 1.
119172      Sylvite          -164.840 19 1. 17 1.

    -1
```

Appendix G - Listing of BINARYP.DAT

See Table 7-5 for explanation of this listing.

```
011000 000170  .0765  .2664   .000 .00127   Na+ - Cl-
011000 000161  .0454   .398   .000  .0000   Na+ - HSO4-
011000 000080  .0864   .253   .000  .0044   Na+ - OH-
011000 017080  .0554 0.2755   .000-.00118   Na+ - ClO4-
011000 001990 -.0307  .000    .000   .000   Na+ - HOx-
011000 000990  .0028  1.661   .000   .027   Na+ - Ox=
011000 000890  .1426  .22     .000-.00629   Na+ - Ac-
011000 000891  .1426  .22     .000-.00629   Na+ - Ac-F
019000 000170 .04835  .2122   .000-.00084   K+ - Cl-
019000 000161 -.0003  .1735   .000   .000   K+ - HSO4-
019000 000080  .1298   .320   .000  .0041   K+ - OH-
001000 000170  .1775  .2945   .000  .0008   H+ - Cl-
001000 000161  .2065  .5556   .000   .000   H+ - HSO4-
001000 017080  .1747 0.2931   .000 .00819   H+ - ClO4-
090000 000170 1.092   13.7   -160.  -.112   Th++++ - Cl-  Roy et al. 1992
090000 017080 1.186   27.3    .000 -.0566   Th++++ - ClO4-  GRC Extr Data
093080 000170  .1415  .281    .000   .000   NpO2+ - Cl-   NFRK95
093080 017080  .257   .180    .000  .0081   NpO2+ - ClO4- NFRK95
095000 000170  .6117 5.403    .000 -.0284   Am+++ - Cl-
095001 000170  .6117 5.403    .000 -.0284   Am+++F - Cl-
000000

cation anion   beta0 beta1   beta2  cphi
```

Appendix H - Listing of TERNARYP.DAT

See Table 7-6 for explanation of this listing.

```
011000 019000  -.012 000170  -.0018
011000 001000   .036 000170   -.004 000161  -.0129 017080  -.0160
019000 001000   .005 000170   -.011 000160    .197 000161  -.0265
000170 000161  -.006 011000   -.006 001000   .0130
000170 000080   -.05 011000   -.006 019000   -.006
000170 000890  -.090 011000  .01029
000170 000891  -.090 011000  .01029
000080 017080 -.0320
017080 000890  0.064 011000  -.0072
090000 001000   .600
090000 011000   .420
000000
```

Appendix I - Listing of LAMBDA.DAT

See Table 7-7 for explanation of this listing.

```
000050 001000   .000 000170  -.0102
000050 019000   -.14
000000
```

Appendix J - Sample Output File: EXTR_07_EXACT.OUT

See Table 9-1 for explanation of this listing.

```
NONLIN  V2.0

 NONLIN was developed by A.R. Felmy

 INPUT     file name is U1:[ SCBABB.NONLIN.USERGUIDE] EXTR_07_EXACT.IN;1
 GMIN      file name is U1:[ SCBABB.NONLIN.USERGUIDE] EXTR_00.GMIN;1
 OUTPUT    file name is U1:[ SCBABB.NONLIN.USERGUIDE] EXTR_07_EXACT.OUT;1

           AQUEOUS SPECIES

    ID       NAME            MOLES        Z    u0rt
  1080H2O              0.000000000000   0.    -95.663
 11000Na+              0.000000000000   1.   -105.651
 90000Th++++           0.000000000000   4.   -284.227
  1000H+               0.000000000000   1.      0.000
    80OH-              0.000000000000  -1.    -63.435
 17080ClO4-            0.000000000000  -1.    -73.810
           SOLID PHASES

    ID       NAME            MOLES        Z    u0rt
199003Na+/Th++++EX    0.000000000000   0.    999.999

           CONSTRAINT EQUATIONS
                    0      1      8     11     90     17
H2O               0.0    2.0    1.0    0.0    0.0    0.0
Na+               1.0    0.0    0.0    1.0    0.0    0.0
Th++++            4.0    0.0    0.0    0.0    1.0    0.0
H+                1.0    1.0    0.0    0.0    0.0    0.0
OH-              -1.0    1.0    1.0    0.0    0.0    0.0
ClO4-            -1.0    0.0    4.0    0.0    0.0    1.0
Na+/Th++++EX      0.0    0.0    0.0    4.0   -1.0    0.0

 Closed input files GMIN and COMP

 COMP      file name is U1:[ SCBABB.NONLIN.INPUTFILES] COMP.DAT;3
 BINARYP   file name is U1:[ SCBABB.NONLIN.INPUTFILES] BINARYP.DAT;2
 TERNARYP  file name is U1:[ SCBABB.NONLIN.INPUTFILES] TERNARYP.DAT;1
 LAMBDA    file name is U1:[ SCBABB.NONLIN.INPUTFILES] LAMBDA.DAT;1

        non-ideal electrolyte parameters

        single electrolyte parameters
Na+          OH-            0.08640    0.25300    0.00000    0.00440
Na+          ClO4-          0.05540    0.27550    0.00000   -0.00118
Th++++       OH-            0.00000    0.00000    0.00000    0.00000
Th++++       ClO4-          1.18600   27.30000    0.00000   -0.05660
H+           OH-            0.00000    0.00000    0.00000    0.00000
H+           ClO4-          0.17470    0.29310    0.00000    0.00819

        ternary electrolyte parameters

                                         OH-        ClO4-
Na+          Th++++         0.42000    0.00000    0.00000
Na+          H+             0.03600    0.00000   -0.01600
Th++++       H+             0.60000    0.00000    0.00000

                                         Na+        Th++++      H+
OH-          ClO4-         -0.03200    0.00000    0.00000    0.00000

 TOTAL NUMBER OF SPECIES =  7
 NUMBER OF COMPONENTS    =  6
 INDEPENDENT CONSTRAINTS =  5

           SOLVENT EXTRACTION DATA
```

```
            input molalities


      Na+          Th++++       H+           OH-          ClO4-
      3.070E-01    2.120E-05    1.000E-07    1.000E-07    3.070E-01
      3.070E-01    2.120E-05    1.000E-07    1.000E-07    3.070E-01
      1.035E+00    5.940E-05    1.000E-07    1.000E-07    1.035E+00
      1.035E+00    5.810E-05    1.000E-07    1.000E-07    1.035E+00
      2.129E+00    1.690E-04    1.000E-07    1.000E-07    2.129E+00
      2.129E+00    1.690E-04    1.000E-07    1.000E-07    2.129E+00
      3.322E+00    3.150E-04    1.000E-07    1.000E-07    3.322E+00
      3.322E+00    3.390E-04    1.000E-07    1.000E-07    3.322E+00
      4.657E+00    9.450E-04    1.000E-07    1.000E-07    4.657E+00
      4.657E+00    9.450E-04    1.000E-07    1.000E-07    4.657E+00
      6.176E+00    1.260E-03    1.000E-07    1.000E-07    6.176E+00
      6.176E+00    1.450E-03    1.000E-07    1.000E-07    6.176E+00
      9.929E+00    1.930E-03    1.000E-07    1.000E-07    9.929E+00
      9.929E+00    2.190E-03    1.000E-07    1.000E-07    9.929E+00
      1.492E+01    2.330E-03    1.000E-07    1.000E-07    1.492E+01
      1.492E+01    2.290E-03    1.000E-07    1.000E-07    1.492E+01

    -1.2065E+02  1.1860E+00 -1.4100E-02
                L2 NORM OF THE RESIDUALS  2.3701936E+01



    -1.2065E+02  7.6650E-01 -1.4134E-02
                L2 NORM OF THE RESIDUALS  5.8867175E-01



    -1.2065E+02  7.6650E-01 -1.4134E-02
                L2 NORM OF THE RESIDUALS  5.8867175E-01



            ADJUSTED PARAMETERS
     u0rt(                          Na+/Th++++EX)  -1.2065375E+02
       b0(            Th++++       ClO4-        )   7.6649537E-01
      cmx(            Th++++       ClO4-        )  -1.4134295E-02

    DATA SET( 1)

     input     calc       diff
    1.000000000000000E-005   0.101481694490094
    1.000000000000000E-005   0.101481694490094
    1.000000000000000E-005  -0.220537193518512
    1.000000000000000E-005  -0.242559039934136
    1.000000000000000E-005   6.301298267648374E-002
    1.000000000000000E-005   6.301298267648374E-002
    1.000000000000000E-005  -0.108251784934691
    1.000000000000000E-005  -3.611739799594871E-002
    1.000000000000000E-005   0.242939165971691
    1.000000000000000E-005   0.242939165971691
    1.000000000000000E-005  -5.398818272699338E-002
    1.000000000000000E-005   8.004321603990713E-002
    1.000000000000000E-005  -0.229546862144291
    1.000000000000000E-005  -0.108708180248774
    1.000000000000000E-005   6.078330869018109E-002
    1.000000000000000E-005   4.401442682556691E-002

    AVERAGE DEVIATION  =  1.2496E-01

    STANDARD DEVIATION =  1.4717E-01

   FINAL MOLALITIES

   Na+          Th++++       H+           OH-          ClO4-
      3.070E-01  2.120E-05  1.367E-07  1.367E-07  3.070E-01
      3.070E-01  2.120E-05  1.367E-07  1.367E-07  3.070E-01
      1.035E+00  5.940E-05  1.346E-07  1.346E-07  1.035E+00
```

```
  1.035E+00  5.810E-05  1.346E-07  1.346E-07  1.035E+00
  2.129E+00  1.690E-04  1.157E-07  1.157E-07  2.129E+00
  2.129E+00  1.690E-04  1.157E-07  1.157E-07  2.129E+00
  3.322E+00  3.150E-04  9.326E-08  9.326E-08  3.322E+00
  3.322E+00  3.390E-04  9.327E-08  9.327E-08  3.322E+00
  4.657E+00  9.450E-04  7.150E-08  7.150E-08  4.657E+00
  4.657E+00  9.450E-04  7.150E-08  7.150E-08  4.657E+00
  6.176E+00  1.260E-03  5.191E-08  5.191E-08  6.176E+00
  6.176E+00  1.450E-03  5.194E-08  5.194E-08  6.176E+00
  9.929E+00  1.930E-03  2.303E-08  2.303E-08  9.929E+00
  9.929E+00  2.190E-03  2.303E-08  2.303E-08  9.929E+00
  1.492E+01  2.330E-03  8.007E-09  8.007E-09  1.492E+01
  1.492E+01  2.290E-03  8.007E-09  8.007E-09  1.492E+01

FINAL LOG ACTIVITIES

Na+          Th++++       H+           OH-          ClO4-
 -6.693E-01 -5.330E+00 -6.977E+00 -7.024E+00 -6.689E-01
 -6.693E-01 -5.330E+00 -6.977E+00 -7.024E+00 -6.689E-01
 -1.884E-01 -3.547E+00 -6.933E+00 -7.078E+00 -1.879E-01
 -1.884E-01 -3.556E+00 -6.933E+00 -7.078E+00 -1.879E-01
  1.102E-01 -2.229E+00 -6.875E+00 -7.153E+00  1.112E-01
  1.102E-01 -2.229E+00 -6.875E+00 -7.153E+00  1.112E-01
  3.088E-01 -1.509E+00 -6.820E+00 -7.227E+00  3.102E-01
  3.087E-01 -1.478E+00 -6.820E+00 -7.227E+00  3.103E-01
  4.719E-01 -7.038E-01 -6.769E+00 -7.302E+00  4.754E-01
  4.719E-01 -7.038E-01 -6.769E+00 -7.302E+00  4.754E-01
  6.210E-01 -2.366E-01 -6.724E+00 -7.376E+00  6.247E-01
  6.207E-01 -1.795E-01 -6.724E+00 -7.376E+00  6.251E-01
  9.022E-01  8.118E-01 -6.669E+00 -7.511E+00  9.062E-01
  9.019E-01  8.633E-01 -6.669E+00 -7.511E+00  9.065E-01
  1.172E+00  2.017E+00 -6.719E+00 -7.581E+00  1.176E+00
  1.172E+00  2.010E+00 -6.719E+00 -7.581E+00  1.175E+00

Calculated Log Activity Coefficients

Na+          Th++++       H+           OH-          ClO4-
     -0.1564      -0.6565      -0.1129      -0.1593      -0.1561
     -0.1564      -0.6565      -0.1129      -0.1593      -0.1561
     -0.2034       0.6797      -0.0622      -0.2074      -0.2028
     -0.2034       0.6797      -0.0622      -0.2074      -0.2028
     -0.2180       1.5430       0.0622      -0.2164      -0.2170
     -0.2180       1.5430       0.0622      -0.2164      -0.2170
     -0.2126       1.9927       0.2105      -0.1970      -0.2112
     -0.2127       1.9919       0.2105      -0.1971      -0.2111
     -0.1962       2.3207       0.3769      -0.1560      -0.1927
     -0.1962       2.3207       0.3769      -0.1560      -0.1927
     -0.1697       2.6630       0.5611      -0.0912      -0.1660
     -0.1700       2.6592       0.5609      -0.0914      -0.1657
     -0.0948       3.5263       0.9687       0.1267      -0.0907
     -0.0950       3.5229       0.9686       0.1266      -0.0904
     -0.0017       4.6499       1.3780       0.5156       0.0019
     -0.0016       4.6503       1.3781       0.5156       0.0018

SOLVENT EXTRACTION SYSTEM EQUILIBRATED
  u0rt(                          Na+/Th++++EX)  -1.2065375E+02
    b0(              Th++++      ClO4-        )   7.6649537E-01
   cmx(              Th++++      ClO4-        )  -1.4134295E-02

 DATA SET( 1)

  input     calc       diff
 1.000000000000000E-005  0.000000000000000E+000
 1.000000000000000E-005  0.000000000000000E+000
 1.000000000000000E-005  0.000000000000000E+000
 1.000000000000000E-005  0.000000000000000E+000
 1.000000000000000E-005  0.000000000000000E+000
 1.000000000000000E-005  0.000000000000000E+000
 1.000000000000000E-005  0.000000000000000E+000
 1.000000000000000E-005  0.000000000000000E+000
 1.000000000000000E-005  0.000000000000000E+000
```

```
  1.000000000000000E-005   0.000000000000000E+000
  1.000000000000000E-005   0.000000000000000E+000
  1.000000000000000E-005   0.000000000000000E+000
  1.000000000000000E-005   0.000000000000000E+000
  1.000000000000000E-005   0.000000000000000E+000
  1.000000000000000E-005   0.000000000000000E+000
  1.000000000000000E-005   0.000000000000000E+000

 AVERAGE DEVIATION   =  0.0000E+00

 STANDARD DEVIATION =  0.0000E+00

FINAL MOLALITIES

Na+          Th++++       H+           OH-          ClO4-
  3.070E-01  1.916E-05  1.367E-07  1.367E-07  3.070E-01
  3.070E-01  1.916E-05  1.367E-07  1.367E-07  3.070E-01
  1.035E+00  7.409E-05  1.346E-07  1.346E-07  1.035E+00
  1.035E+00  7.409E-05  1.346E-07  1.346E-07  1.035E+00
  2.129E+00  1.586E-04  1.157E-07  1.157E-07  2.129E+00
  2.129E+00  1.586E-04  1.157E-07  1.157E-07  2.129E+00
  3.322E+00  3.514E-04  9.328E-08  9.328E-08  3.322E+00
  3.322E+00  3.516E-04  9.328E-08  9.328E-08  3.322E+00
  4.658E+00  7.374E-04  7.145E-08  7.145E-08  4.657E+00
  4.658E+00  7.374E-04  7.145E-08  7.145E-08  4.657E+00
  6.176E+00  1.332E-03  5.192E-08  5.192E-08  6.176E+00
  6.176E+00  1.336E-03  5.192E-08  5.192E-08  6.176E+00
  9.927E+00  2.443E-03  2.305E-08  2.305E-08  9.929E+00
  9.928E+00  2.449E-03  2.304E-08  2.304E-08  9.929E+00
  1.492E+01  2.190E-03  8.006E-09  8.006E-09  1.492E+01
  1.492E+01  2.190E-03  8.006E-09  8.006E-09  1.492E+01

FINAL LOG ACTIVITIES

Na+          Th++++       H+           OH-          ClO4-
 -6.693E-01 -5.374E+00 -6.977E+00 -7.024E+00 -6.690E-01
 -6.693E-01 -5.374E+00 -6.977E+00 -7.024E+00 -6.690E-01
 -1.885E-01 -3.451E+00 -6.933E+00 -7.078E+00 -1.878E-01
 -1.885E-01 -3.451E+00 -6.933E+00 -7.078E+00 -1.878E-01
  1.102E-01 -2.256E+00 -6.875E+00 -7.153E+00  1.112E-01
  1.102E-01 -2.256E+00 -6.875E+00 -7.153E+00  1.112E-01
  3.087E-01 -1.462E+00 -6.820E+00 -7.227E+00  3.103E-01
  3.087E-01 -1.462E+00 -6.820E+00 -7.227E+00  3.103E-01
  4.724E-01 -8.077E-01 -6.769E+00 -7.302E+00  4.750E-01
  4.724E-01 -8.077E-01 -6.769E+00 -7.302E+00  4.750E-01
  6.209E-01 -2.136E-01 -6.724E+00 -7.376E+00  6.249E-01
  6.209E-01 -2.135E-01 -6.724E+00 -7.376E+00  6.249E-01
  9.016E-01  9.094E-01 -6.669E+00 -7.511E+00  9.067E-01
  9.016E-01  9.095E-01 -6.669E+00 -7.511E+00  9.067E-01
  1.172E+00  1.991E+00 -6.719E+00 -7.581E+00  1.175E+00
  1.172E+00  1.991E+00 -6.719E+00 -7.581E+00  1.175E+00

Calculated Log Activity Coefficients

Na+          Th++++       H+           OH-          ClO4-
     -0.1564      -0.6565      -0.1129      -0.1593      -0.1561
     -0.1564      -0.6565      -0.1129      -0.1593      -0.1561
     -0.2034       0.6791      -0.0623      -0.2075      -0.2027
     -0.2034       0.6792      -0.0623      -0.2075      -0.2027
     -0.2180       1.5433       0.0622      -0.2163      -0.2170
     -0.2180       1.5433       0.0622      -0.2163      -0.2170
     -0.2127       1.9918       0.2104      -0.1971      -0.2111
     -0.2127       1.9916       0.2104      -0.1971      -0.2111
     -0.1958       2.3246       0.3772      -0.1557      -0.1931
     -0.1958       2.3246       0.3772      -0.1557      -0.1931
     -0.1698       2.6620       0.5611      -0.0913      -0.1659
     -0.1698       2.6609       0.5610      -0.0913      -0.1658
     -0.0952       3.5215       0.9684       0.1263      -0.0902
     -0.0952       3.5205       0.9684       0.1264      -0.0902
     -0.0016       4.6508       1.3781       0.5157       0.0017
     -0.0016       4.6509       1.3781       0.5157       0.0017
```

```
 FINAL L2 NORM OF THE RESIDUALS  5.8867175E-01


EXIT PARAMETER                          3


 FINAL APPROXIMATE SOLUTION


0 0 7  -1.2065375E+02
1 2 2   7.6649537E-01
4 2 2  -1.4134295E-02
```

Appendix K - Sample Output File: SOLUB_01.OUT

See Table 9-1 for explanation of this listing.

```
NONLIN  V2.0

 NONLIN was developed by A.R. Felmy

 INPUT     file name is U1:[ SCBABB.NONLIN.USERGUIDE] SOLUB_01.IN;1
 GMIN      file name is U1:[ SCBABB.NONLIN.USERGUIDE] SOLUB_00.GMIN;1
 OUTPUT    file name is U1:[ SCBABB.NONLIN.USERGUIDE] SOLUB_01.OUT;1

           AQUEOUS SPECIES

     ID      NAME            MOLES        Z    u0rt
   1080H2O              0.000000000000   0.    -95.663
   1000H+               0.000000000000   1.      0.000
     80OH-              0.000000000000  -1.    -63.435
    161HSO4-            0.000000000000  -1.   -304.942
   1991H2Ox(aq)         0.000000000000   0.   -284.990
           SOLID PHASES

     ID      NAME            MOLES        Z    u0rt
 101990H2Ox.2H2O(s)    0.000000000000   0.    999.999

           CONSTRAINT EQUATIONS
                    0      1      8     16     99
 H2O              0.0    2.0    1.0    0.0    0.0
 H+               1.0    1.0    0.0    0.0    0.0
 OH-             -1.0    1.0    1.0    0.0    0.0
 HSO4-           -1.0    1.0    4.0    1.0    0.0
 H2Ox(aq)         0.0    2.0    0.0    0.0    1.0
 H2Ox.2H2O(s)     0.0    6.0    2.0    0.0    1.0

 Closed input files GMIN and COMP

 COMP      file name is U1:[ SCBABB.NONLIN.INPUTFILES] COMP.DAT;3
 BINARYP   file name is U1:[ SCBABB.NONLIN.INPUTFILES] BINARYP.DAT;2
 TERNARYP  file name is U1:[ SCBABB.NONLIN.INPUTFILES] TERNARYP.DAT;1
 LAMBDA    file name is U1:[ SCBABB.NONLIN.INPUTFILES] LAMBDA.DAT;1

        non-ideal electrolyte parameters

        single electrolyte parameters
H+          OH-             0.00000    0.00000    0.00000    0.00000
H+          HSO4-           0.20650    0.55560    0.00000    0.00000

        ternary electrolyte parameters

                                          H+
OH-         HSO4-           0.00000     0.00000

        neutral ion parameters
            H2Ox(aq)
H+              0.0000
OH-             0.0000
HSO4-           0.0000
H2Ox(aq)        0.0000

         higher order lambdas

                        OH-          HSO4-
H2Ox(aq)    H+              0.00000     0.00000

 TOTAL NUMBER OF SPECIES =  6
 NUMBER OF COMPONENTS    =  5
 INDEPENDENT CONSTRAINTS =  4

           SOLUBILITY DATA
```

```
              input molalities


        H+          OH-         HSO4-       H2Ox(aq)
        1.168E+00   8.560E-15   1.168E+00   8.750E-01
        1.965E+00   5.090E-15   1.965E+00   6.530E-01
        2.927E+00   3.420E-15   2.927E+00   5.340E-01
        4.450E+00   2.250E-15   4.450E+00   4.760E-01
        6.660E+00   1.500E-15   6.660E+00   4.320E-01
        9.548E+00   1.050E-15   9.548E+00   5.740E-01
        1.394E+01   7.170E-16   1.394E+01   1.268E+00

      -1.0000E+01
                L2 NORM OF THE RESIDUALS  1.2378927E+03



      -4.7788E+02
                L2 NORM OF THE RESIDUALS  2.7255679E+00



      -4.7788E+02
                L2 NORM OF THE RESIDUALS  2.7255679E+00



              ADJUSTED PARAMETERS
       u0rt(                          H2Ox.2H2O(s))   -4.7787833E+02

      DATA SET( 1)

       input     calc       diff
      0.000000000000000E+000  -1.30103480373751
      0.000000000000000E+000 -0.932205339571694
      0.000000000000000E+000 -0.611447612394127
      0.000000000000000E+000 -0.249916679321500
      0.000000000000000E+000  0.325209375816246
      0.000000000000000E+000  0.889641981011270
      0.000000000000000E+000   1.87975307818427

      AVERAGE DEVIATION   =   8.8417E-01

      STANDARD DEVIATION =   1.0302E+00

     FINAL MOLALITIES

     H+          OH-         HSO4-       H2Ox(aq)
       1.168E+00  1.845E-14  1.168E+00  8.750E-01
       1.965E+00  9.859E-15  1.965E+00  6.530E-01
       2.927E+00  5.247E-15  2.927E+00  5.340E-01
       4.450E+00  7.000E-15  4.450E+00  4.760E-01
       6.660E+00  7.000E-15  6.660E+00  4.320E-01
       9.548E+00  7.000E-15  9.548E+00  5.740E-01
       1.394E+01  7.000E-15  1.394E+01  1.268E+00

     FINAL LOG ACTIVITIES

     H+          OH-         HSO4-       H2Ox(aq)
       7.007E-02 -1.409E+01  7.007E-02 -5.799E-02
       3.985E-01 -1.444E+01  3.985E-01 -1.851E-01
       7.056E-01 -1.477E+01  7.056E-01 -2.725E-01
       1.114E+00 -1.471E+01  1.114E+00 -3.224E-01
       1.636E+00 -1.477E+01  1.636E+00 -3.645E-01
       2.265E+00 -1.482E+01  2.265E+00 -2.411E-01
       3.168E+00 -1.487E+01  3.168E+00  1.031E-01

     Calculated Log Activity Coefficients

     H+          OH-         HSO4-       H2Ox(aq)
```

```
          0.0026      -0.3603       0.0026       0.0000
          0.1051      -0.4330       0.1051       0.0000
          0.2392      -0.4922       0.2392       0.0000
          0.4657      -0.5552       0.4657       0.0000
          0.8128      -0.6145       0.8128       0.0000
          1.2849      -0.6654       1.2849       0.0000
          2.0238      -0.7168       2.0238       0.0000

    SOLID PHASE NOW IN EQUILIBRIUM

     DATA SET( 1)

      input     calc       diff
     0.000000000000000E+000   0.000000000000000E+000
     0.000000000000000E+000   0.000000000000000E+000
     0.000000000000000E+000   0.000000000000000E+000
     0.000000000000000E+000   0.000000000000000E+000
     0.000000000000000E+000   0.000000000000000E+000
     0.000000000000000E+000   0.000000000000000E+000
     0.000000000000000E+000   0.000000000000000E+000

     AVERAGE DEVIATION   =   0.0000E+00

     STANDARD DEVIATION =   0.0000E+00

    FINAL MOLALITIES

    H+            OH-           HSO4-         H2Ox(aq)
      1.168E+00   1.777E-14   1.168E+00   2.280E-01
      1.965E+00   9.589E-15   1.965E+00   2.506E-01
      2.927E+00   7.000E-15   2.927E+00   2.857E-01
      4.450E+00   7.000E-15   4.450E+00   3.691E-01
      6.660E+00   7.000E-15   6.660E+00   5.992E-01
      9.548E+00   7.000E-15   9.548E+00   1.353E+00
      1.394E+01   7.000E-15   1.394E+01   5.061E+00

    FINAL LOG ACTIVITIES

    H+            OH-           HSO4-         H2Ox(aq)
      8.371E-02  -1.410E+01   8.371E-02  -6.319E-01
      4.087E-01  -1.445E+01   4.087E-01  -5.947E-01
      7.133E-01  -1.464E+01   7.133E-01  -5.402E-01
      1.118E+00  -1.471E+01   1.118E+00  -4.312E-01
      1.627E+00  -1.477E+01   1.627E+00  -2.250E-01
      2.210E+00  -1.483E+01   2.210E+00   1.194E-01
      2.828E+00  -1.491E+01   2.828E+00   6.486E-01

    Calculated Log Activity Coefficients

    H+            OH-           HSO4-         H2Ox(aq)
          0.0163      -0.3532       0.0163       0.0102
          0.1153      -0.4288       0.1153       0.0063
          0.2469      -0.4897       0.2469       0.0039
          0.4700      -0.5541       0.4700       0.0017
          0.8038      -0.6163       0.8038      -0.0026
          1.2296      -0.6736       1.2296      -0.0120
          1.6841      -0.7552       1.6841      -0.0556

         FINAL L2 NORM OF THE RESIDUALS   2.7255679E+00


        EXIT PARAMETER                          3


         FINAL APPROXIMATE SOLUTION


         0 0 6  -4.7787833E+02
```

Appendix L - Review Forms

This Appendix contains the review forms for the NONLIN User's Manual.

NOTE: Copies of the User's Manual Reviewer's Forms are available in the Sandia WIPP Central Files.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix SUM

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Summary of Site-Characterization Studies Conducted from 1983 through 1987 at WIPP

SANDIA REPORT
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Summary of Site-Characterization Studies Conducted From 1983 Through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico

A. R. Lappin

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
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SUMMARY OF SITE-CHARACTERIZATION STUDIES CONDUCTED FROM 1983 THROUGH 1987 AT THE WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

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WIPP Earth Sciences Division, 6331
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

The Waste Isolation Pilot Plant (WIPP) is being constructed at a depth of 650 m in bedded halites of the Salado Formation. The geologic setting of the WIPP site has been active for at least 250 million years, and is presently responding to the end of the last pluvial period, within the 10,000-year time scale of regulatory interest. Both construction of the WIPP facility and WIPP site-characterization activities impose additional transient effects, some of which will last until the hydrologic and structural closure of the facility.

The Bell Canyon Formation beneath the WIPP facility contains shales, siltstones, and sandstones. Studies suggest that no channel sandstone is present in the Bell Canyon beneath the WIPP site. Fluid movement would be downward if drilling interconnected the Bell Canyon with the Rustler Formation, the first water-bearing zone above the WIPP facility.

The Salado and Castile Formations contain abundant bedded halites and anhydrites, and deform in response to gravity. Fluids play a major role in this deformation, although the regional permeabilities of both units are extremely low. Pressurized brines may be present within the Castile Formation 200 m or more beneath the WIPP waste-emplacement panels. The hydrologic and structural characteristics of the Salado change within an altered zone extending a few meters from the WIPP underground workings.

The permeability within this altered zone is enhanced, and deformation includes local opening of preexisting fractures in anhydrite and formation of new fractures in halite. Within a few meters of the facility the Salado characteristics become those of the far field, in which permeability is extremely low and deformation is dominated by creep. Brine seepage into the WIPP facility is extremely slow, and involves transient behavior resulting from the combined effects of deformation, low permeability, and ventilation.

At the WIPP site, the hydrology and geochemistry of the Rustler Formation and younger units overlying the Salado are dominated by confined flow within the Culebra dolomite. Rustler karst is not present at the WIPP site, but is present in and near Nash Draw. The combination of modern heads and transmissivities of units other than the Culebra indicates the potential for limited vertical flow within the Rustler, and from the Salado into the Rustler, but is not consistent with infiltration of water from the surface to the Rustler carbonates at the WIPP site. Isotopic studies indicate that surficial water was required for formation of secondary gypsum veins within the Dewey Lake Red Beds overlying the Rustler. The distribution of hydrochemical facies in Culebra groundwaters and the results of stable-isotope, radiocarbon, and uranium-disequilibrium studies are all consistent with the interpretation that there is no modern recharge to the Rustler at the WIPP site, and that a change of flow directions in the Culebra dolomite has occurred over approximately the last 10,000 years.

The transmissivity of the Culebra dolomite varies by approximately 6 orders of magnitude at and near the WIPP site. The transmissivity in the central portion of the site, including the locations of all four WIPP shafts, is low (less than 10^{-6} m^2/s). Higher Culebra transmissivities are found south, northwest, and west of the site, especially in Nash Draw. Fracturing within the Culebra affects local hydrology and contaminant transport, but is not significant in regional-scale behavior at and near the site, at least so long as the present distribution of head potentials is not significantly disturbed.

SUMMARY

The Waste Isolation Pilot Plant (WIPP), which is designed for receipt, handling, storage, and permanent isolation of defense-generated transuranic wastes, is being excavated at a depth of approximately 655 m in bedded halites of the Permian Salado Formation of southeastern New Mexico. Site-characterization activities at the present WIPP site began in 1976. Full construction of the facility began in 1983, after completion of "Site and Preliminary Design Validation" (SPDV) activities and reporting. Site-characterization activities since 1983 have had the objectives of updating or refining the overall conceptual model of the geologic, hydrologic, and structural behavior of the WIPP site and providing data adequate for use in WIPP performance assessment.

This report has four main objectives:

1. Summarize the results of WIPP site-characterization studies carried out since the spring of 1983 as a result of specific agreements between the U.S. Department of Energy and the State of New Mexico.

2. Summarize the results and status of site-characterization and facility-characterization studies carried out since 1983, but not specifically included in mandated agreements.

3. Compile the results of WIPP site-characterization studies into an internally consistent conceptual model for the geologic, hydrologic, geochemical, and structural behavior of the WIPP site. This model includes some consideration of the effects of the WIPP facility and shafts on the local characteristics of the Salado and Rustler Formations.

4. Discuss the present limitations and/or uncertainties in the conceptual geologic model of the WIPP site and facility.

The objectives of this report are limited in scope, and do not include determination of whether or not the WIPP Project will comply with repository-performance criteria developed by the U.S. Environmental Protection Agency (40CFR191). When combined, the results of recent and previous geologic studies of the WIPP site form a conceptual model, summarized below. The model presented is limited to aspects relevant to WIPP site characterization and, ultimately, performance assessment.

The overall geologic and hydrologic setting of the WIPP site area has been transient (not steady-state) since before the beginning of deposition of the Bell Canyon Formation, approximately 250 million years ago, and will continue to be transient after effective closure of the WIPP facility. Some events, such as crystallization of secondary minerals within the Salado Formation approximately 200 million years ago and formation of the Mescalero caliche 400,000 to 500,000 years ago, have taken place on a very long time scale relative to WIPP performance assessment, which must consider only a 10,000-year time frame. Two types of transient response

have occurred or are occurring at and near the WIPP site within the 10,000-year time frame of regulatory interest. These are: a) the continuing natural response of the geologic and hydrologic systems to the end of the last pluvial period (period of decreased temperatures and increased precipitation) in southeast New Mexico; and b) the continuing responses to hydrologic, geochemical, and structural transients resulting from WIPP site characterization and facility construction. The transient responses induced by the presence of the WIPP underground workings will continue until reequilibration following effective structural and hydrologic closure of the facility.

The Bell Canyon Formation, consisting largely of shales, siltstones, and sandstones, contains the first relatively continuous water-bearing zone beneath the WIPP facility. In some parts of the northern Delaware Basin, the unit contains permeable channel sandstones that are targets for hydrocarbon exploration. Recent studies suggest that the upper Bell Canyon at the WIPP site does not contain any major channel sandstone. This decreases the probability of the Bell Canyon serving as a source of fluids for dissolution of overlying evaporites at the WIPP. These same studies indicate that the final direction of fluid flow following interconnection of the Bell Canyon, Salado, and Rustler Formations within a drillhole would be downward into the Bell Canyon, after accounting for density increases in the fluids due to dissolution of halite within the Salado. It is assumed here that the measured hydrologic characteristics of the Bell Canyon Formation are more significant to WIPP performance assessment than those of underlying units. The head distribution within the upper Bell Canyon near the WIPP site indicates flow towards the northeast.

Both regional studies and studies within the WIPP facility indicate that the Castile and Salado Formations, both of which are made up predominantly of layered anhydrites and halites, should be considered as low-permeability units that deform regionally in response to gravity. In general, permeabilities and fluid-flow rates in both units are very low and are insensitive to stratigraphy. Formation permeabilities in the Castile and Salado Formations remote from the WIPP excavations are generally less than 0.1 microdarcy, and the regional water content of Salado halites is up to 2 weight percent. Exceptions include local brine occurrences in Castile anhydrites and gas occurrences in the Salado Formation, both of which are fracture-controlled, can be large in volume, and can be under pressures high enough to cause fluid flow to the surface. No major gas occurrence within the Salado Formation has been encountered at the WIPP site. In fact, where it has been possible to measure far-field brine pressures within the Salado, the pressures, permeabilities, and available brine volumes combine to indicate the potential for only very limited fluid flow upwards into the overlying Rustler Formation. It is not certain that the Castile and Salado Formations are hydrologically saturated regionally.

Pressurized Castile brines have been encountered in Castile anhydrite in hole WIPP-12, approximately 1.5 km north of the center of the WIPP site. Geophysical studies indicate that Castile brines may be present beneath a portion of the WIPP waste-emplacement panels, consistent with earlier assumptions. These brines are stratigraphically 200 m or more below the

WIPP facility horizon and are not of concern except in the case of human-intrusion breach of the facility.

In the western part of the Delaware Basin, extensive halite dissolution has apparently taken place in both the Castile and Salado Formations. However, much of the variability in structure and internal stratigraphic thicknesses within the Castile and Salado Formations results from deformation and original depositional variability, rather than from evaporite dissolution. Regional or far-field deformation of the Castile and Salado Formations involves pressure solution as a major mechanism, due to the presence of intergranular fluids, but occurs too slowly to be of future concern to the WIPP Project. Structures within hole DOE-2 result from deformation rather than dissolution.

The hydrologic and structural characteristics of the Salado Formation in the disturbed zone generated by the presence of the WIPP facility are different than those in the far field. Formation permeability within a couple of meters of the underground workings at the facility horizon increases significantly. Near-field deformation of the Salado Formation involves both the opening of preexisting fractures in anhydrite beneath the facility horizon (Marker Bed 139) and generation of new fractures in halite. Fluid contents in the disturbed zone at the facility horizon decrease in response to facility ventilation and/or deformation. Within a few meters of the underground workings, both hydrologic and structural behavior of the Salado Formation become essentially those of the far field. Brine seepage into the WIPP facility includes a significant transient phase, which will probably last until effective facility closure. The results of preliminary hydrologic testing in the Salado Formation adjacent to the WIPP air-intake shaft indicate extremely low permeabilities, with no apparent stratigraphic variability. The results also indicate that development of a disturbed zone around the WIPP shafts is less extensive than at the facility horizon. The extent, characteristics, and importance of the disturbed-rock zones around the WIPP shafts and at the facility horizon remain to be determined in detail.

At and near the WIPP site, the Rustler Formation should be considered as a layered unit of anhydrites, siltstones, and halites, containing a thin and variably fractured carbonate unit, the Culebra dolomite. The Culebra dolomite is the first continuous water-bearing unit above the WIPP facility and, at the WIPP site, is at least an order of magnitude more permeable than other members of the Rustler Formation, including the Magenta dolomite. The transmissivities of Rustler anhydrites at the WIPP site are too low to measure. As a result, the Culebra dominates fluid flow within the Rustler Formation at the WIPP site and is the most significant pathway to the accessible environment from the WIPP facility, except for direct breach to the surface by human intrusion. The transmissivity of the Culebra varies by approximately six orders of magnitude in the region containing the WIPP site. The Culebra transmissivity in the central portion of the site, including the locations of all four WIPP shafts, is low. Higher Culebra transmissivities are found in areas southeast and northwest of the central part of the site. Fluid flow rates within the Culebra are very low at the site center and in regions to the east, but

relatively high within Nash Draw. Modern flow in the Culebra is confined and largely north-south in the area of the WIPP site.

Fluid flow and geochemistry within the Culebra dolomite and shallower units are in continuing transient response to the marked decrease or cessation of local recharge at approximately the end of the last pluvial period. Both bulk chemistry and isotopic relations within Culebra fluids are inconsistent with modern flow directions if steady-state confined flow is assumed. Because of the relative head potentials within the Rustler Formation at and near the WIPP site, there must be a small amount of vertical fluid flow between its members, even though the permeabilities of Rustler members other than the Culebra dolomite are quite low. Where measured successfully, the modern head potentials within the Rustler prevent fluid flow from the surface downward into the Rustler carbonates. These results do not prohibit either the modern movement of fluids from the underlying Salado Formation upwards into the Rustler Formation or the downward movement of Dewey Lake waters into the Rustler Formation during or even after the cessation of local recharge at the end of the last pluvial period. They do, however, suggest that recharge from the surface to the Rustler Formation is not now occurring at the WIPP site. The results of stable-isotope, radiocarbon, and uranium-disequilibrium studies are also consistent with the interpretation that there is no measurable modern recharge to the Culebra dolomite from the surface at and near the WIPP site. The transient hydrologic response of the Rustler Formation to the end of the last pluvial period has involved at least some change in flow directions in the Culebra dolomite. Although the modern flow is largely north-south, the results of uranium-disequilibrium studies suggest that flow was more easterly during previous recharge.

Within and near Nash Draw, evaporite karst is operative within the Rustler, as evidenced by the continuing development of small caves and sinkholes in near-surface anhydrites and gypsums of the Forty-niner and Tamarisk Members. There is no evidence of karstic hydrology in the Rustler at and near the WIPP site. However fracturing of some portions of the Culebra dolomite is sufficient at the site to strongly affect both hydraulic and transport behavior on the hydropad scale, i.e., over distances of approximately 30 m. Interpretation of multipad interference tests conducted both north and south of the center of the WIPP site indicates that this fracturing need not be incorporated into numerical modeling of the regional-scale hydraulic behavior of the Culebra east of Nash Draw. Similarly, detailed transport calculations indicate that effects due to fracturing are not significant in regional-scale transport within the Culebra dolomite at and near the WIPP site, at least as long as the modern head distribution is not significantly disturbed and the calculated flow directions and transport properties are representative.

The Dewey Lake Red Beds overlying the Rustler Formation consist largely of siltstones and claystones, with subordinate sandstones. In tested locations, the Dewey Lake may be hydrologically unsaturated, but is too low in permeability for successful hydrologic testing. South of the WIPP site, near an area where the unit may be receiving modern recharge, sandstones within the Dewey Lake locally produce potable water. In general, water

levels within the Dewey Lake Red Beds, like those in the underlying Rustler Formation, must be in transient response to the end of the last pluvial period. Isotopic relations suggest that surficial waters have been involved in the formation of secondary gypsum veins within the Dewey Lake, but that the Dewey Lake and Rustler hydrologic systems are largely separate.

The major near-surface units at the WIPP site are the Gatuna Formation and Mescalero caliche. The sandstones and stream-channel conglomerates within the Gatuna indicate that major changes in local climate have occurred over (at least) the last 600,000 years. The widespread preservation of the Mescalero caliche indicates not only the relative structural stability of the Livingston Ridge surface (on which the WIPP surface facilities are sited) over the last 400,000 years, but also that infiltration over this same time period has not been sufficient to dissolve a layer of carbonate 1 to 2 m thick.

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SUMMARY OF SITE-CHARACTERIZATION STUDIES CONDUCTED FROM 1983 THROUGH 1987 AT THE WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico (Figure 1.1) is designed for the receipt, handling, storage, and disposal of defense-generated transuranic (TRU) wastes. The WIPP underground facilities are currently being constructed at a depth of approximately 655 m in bedded halites in the lower portion of the Salado Formation (Table 1.1). First receipt of waste is scheduled for October 1988.

WIPP site-characterization activities began in 1976 with the drilling of hole ERDA-9 near the center of the site (Sandia National Laboratories and United States Geologic Survey, 1983) (Figure 1.2). As used here, the term "WIPP site" specifically refers to the sixteen square miles of T22S, R31E contained within WIPP Zone 3 and shown in Figure 1.2. This terminology is used for internal consistency within the report. Construction of the WIPP facility and monitoring of its underground structural and hydrologic behavior began in 1981, with construction of two shafts and limited underground workings.

WIPP site-characterization and facility-characterization studies through March 1983 are documented in several reports, including: 1) the WIPP Geologic Characterization Report (Powers et al., 1978); 2) the WIPP Final Environmental Impact Statement (FEIS) (U.S. Department of Energy, 1980); and 3) both summary and topical reports completed as part of the WIPP Site and Preliminary Design Validation (SPDV) effort (e.g., Beauheim et al., 1983a; Borns et al., 1983; Lambert, 1983; Popielak et al., 1983; Weart, 1983; Wood et al., 1982).

After the SPDV studies were completed and documented, the U.S. Department of Energy and the State of New Mexico agreed to several additional site-characterization activities, which, with one exception, were scheduled for completion by January 1988. The specific studies are described in Appendices I and II to the "Agreement for Consultation and Cooperation Between [the U.S.] Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant" (1981), and are referred to here as "C&C studies." Some non-C&C studies, such as a major regional-scale interference test of the Culebra dolomite, have also been carried out since 1983. A reactive-tracer experiment in the Culebra dolomite, originally a C&C study, was deleted during 1987, by agreement between DOE and the State of New Mexico. Studies agreed to in lieu of the reactive-tracer experiment should, with a few exceptions, be completed and reported by approximately December 1988.

Thus, formal WIPP site-characterization activities will end approximately December 1988. However, understanding of the geologic, hydrologic, and geochemical behavior of the WIPP facility (and site) will continue to

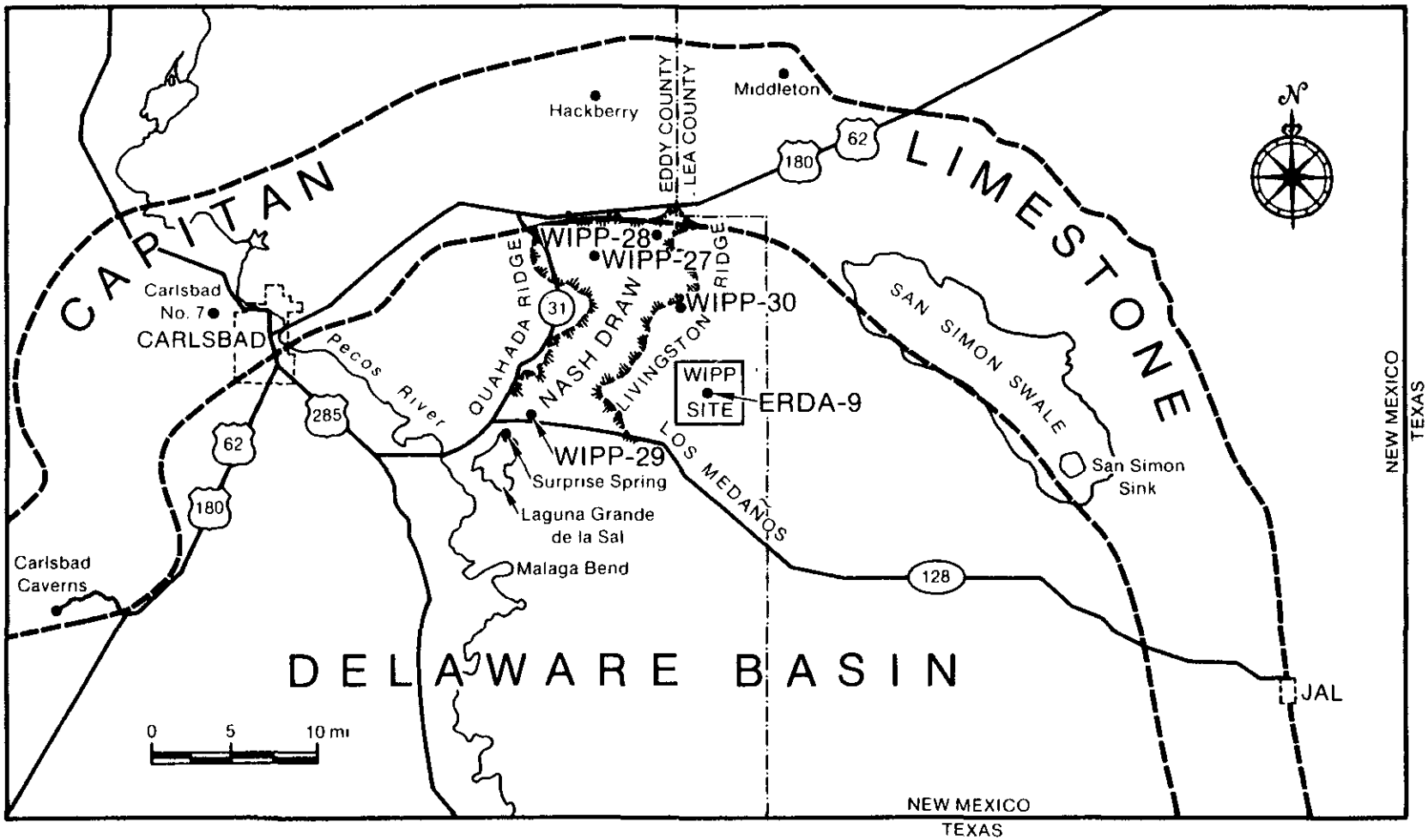

Figure 1.1: Setting of the WIPP site relative to the northern Delaware Basin. Selected geomorphic features and some holes referred to in text but not shown in Figure 1.2 are also included. Modified from Figure VI-1 of Lambert (1983).

Table 1.1: Generalized stratigraphic column of the Delaware Mountain Group and younger sedimentary rocks at and near the WIPP site. Figure 2-1 of Beauheim (1987c).

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATER-NARY	PLEISTO-CENE		MESCALERO CALICHE	
			GATUNA	
TRIASSIC		DOCKUM	UNDIVIDED	
PERMIAN	OCHOAN		DEWEY LAKE RED BEDS	
			RUSTLER	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				unnamed
			SALADO	
			CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON	
			CHERRY CANYON	
			BRUSHY CANYON	

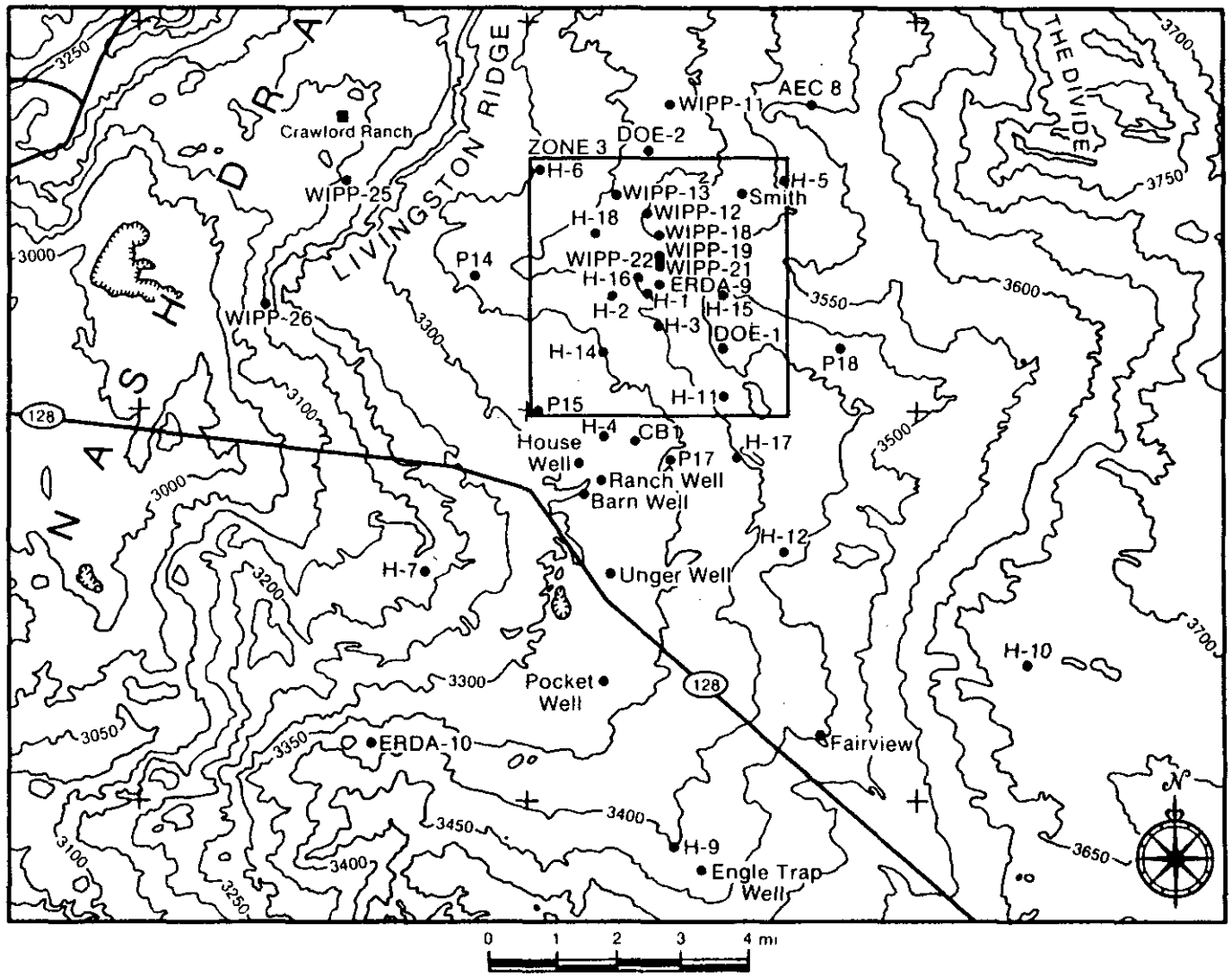

Figure 1.2: Boreholes at and near the WIPP site referred to in text. Holes were drilled as part of the site-characterization of the WIPP, as ranchers' wells, or as potash or hydrocarbon exploration holes. Only exploration holes which have been hydrologically tested are included.

develop after that time. Geotechnical work in and near the WIPP facility will extend into the period of operational demonstration, especially to complete characterization of the hydrologically and structurally disturbed zones around the underground workings and access shafts, in direct support of WIPP performance assessment. Data collected during these studies must support a full evaluation of expected facility performance against criteria developed by the U.S. Environmental Protection Agency (40CFR191) in their present or revised form. The structural, hydrologic, and nuclide-containment behavior of the WIPP facility, including potential far-field paths of nuclide release to the accessible environment, will be monitored throughout the WIPP operational period.

1.1 Report Objectives

This report has four main objectives. These are to:

1. Summarize the results of C&C studies carried out since the Spring of 1983.

2. Summarize the results and/or status of site-characterization and facility-characterization studies carried out since 1983 but not mandated by the C&C Agreement.

3. Compile the results of WIPP site-characterization studies into an internally consistent conceptual model for the geologic, hydrologic, geochemical, and structural behavior of the WIPP site. This model includes preliminary consideration of the local effects of the WIPP facility and shafts on the Salado and Rustler Formations.

4. Discuss the present limitations and/or uncertainties in the conceptual geologic model of the WIPP site and facility.

The objectives of the report are limited in scope and do not include determination of whether or not the WIPP Project will comply with repository-performance criteria developed by the U.S. Environmental Protection Agency (40CFR191). Whether or not the WIPP will comply with 40CFR191 must be demonstrated by the WIPP performance-assessment activity within five years following first emplacement of waste. The objective of this report is to develop as complete a conceptual model as possible for use in the required performance assessment.

1.2 Structure of Report

The remaining parts of this section (1.0) contain:

1. A general discussion of the stratigraphic setting and variability of sedimentary rocks within the northern Delaware Basin that have been of interest during WIPP site characterization (Section 1.3).

2. A general discussion of the technical issues of interest in WIPP site (and facility) characterization (Section 1.4). Emphasis in this discussion is on technical areas of site characterization which have been actively pursued since 1983.

The sections making up the body of the report (2.0 through 4.0) are generally ordered in stratigraphically upward sequence. This structure is a matter of convenience, and is not intended to imply relative priorities of the different issues and units discussed.

Within each technical section, recent studies in the formation(s) of interest are discussed in relation to the topics or issues outlined in Section 1.4. The final section of the report, Section 5.0, attempts to compile the results of the three preceding sections into an internally consistent conceptual model for the geologic, hydrologic, structural, and geochemical behavior of the WIPP site.

1.3 General Stratigraphic Setting of the WIPP Site and Facility

As shown in Figure 1.1, the WIPP site is located in southeastern New Mexico, in the northern portion of the Delaware Basin. The generalized stratigraphy in the vicinity of the WIPP is summarized in Table 1.1. Regional stratigraphic relationships and characteristics are discussed in detail in Powers et al. (1978).

The Delaware Basin became a distinct structure by the late Pennsylvanian Period to early Permian Period, approximately 280 million years ago. Approximately 250 million years ago, the reef now represented by the Capitan limestone began to grow around the margins of the developing basin, and the sandstones, shales, and carbonates now making up the Delaware Mountain Group (DMG) were deposited within the basin. Most of the Capitan limestone is relatively massive. Some portions of the unit are hydrologically active and support local karst hydrology, including the formation of large cavities such as Carlsbad Caverns. The Delaware Mountain Group, which is limited to the basin, contains three major subdivisions, the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations (in ascending stratigraphic order). Only the Bell Canyon Formation is considered here, as it is the first regionally continuous water-bearing formation beneath the WIPP facility. The hydraulic behavior of the Bell Canyon Formation is assumed to be more significant than that of any underlying units in WIPP breach scenarios.

The Bell Canyon Formation is divided into five informal members, the Hays sandstone, Olds sandstone, Ford shale, Ramsey sandstone, and Lamar limestone (in ascending stratigraphic order). The individual members vary in thickness and lithology. As shown in Figure 1.3, the upper Bell Canyon sandstones tend to be elongated and laterally discontinuous, in the nature of "channel sands." Individual sands are separated laterally by stratigraphically equivalent siltstones and/or shales. Near the WIPP site, the Bell Canyon Formation consists of a layered sequence of sandstones, shales/siltstones, and limestone 300 m or more in thickness (Powers et al., 1978).

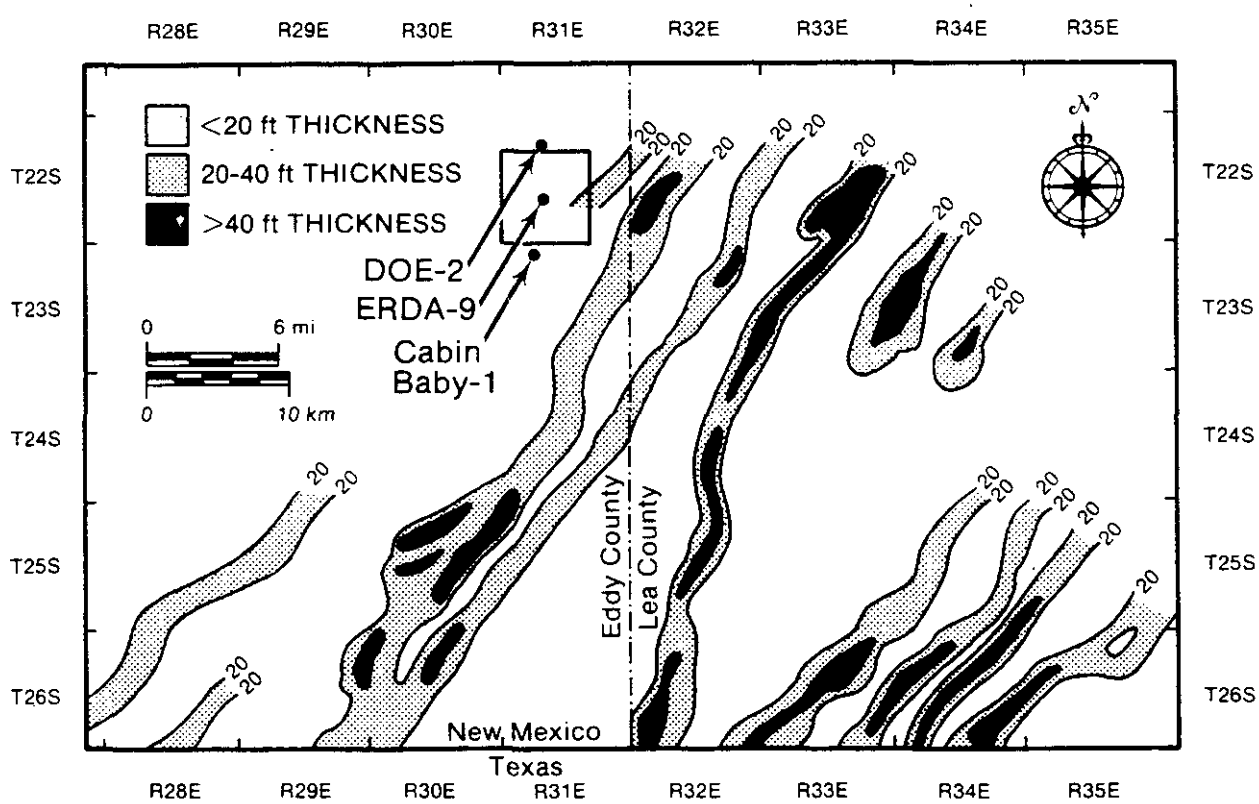

Figure 1.3: Lateral distribution and thicknesses of channel sands in the informal Ramsey member of the Bell Canyon Formation in the northern Delaware Basin, including holes DOE-2 and Cabin Baby-1. Simplified from Figure 2-2 of Davies (1983).

Within the northern Delaware Basin, the sandstones and shales of the Bell Canyon Formation are overlain by the thick-bedded sequence of anhydrites and halites of the Castile Formation, also of Permian age. As shown in Table 1.1, the Castile Formation near the WIPP site normally contains three relatively thick anhydrite/carbonate units and two thick halites. Both anhydrites and halites contain abundant anhydrite and/or carbonate laminae, may be strongly deformed internally, and are variable in local thickness. The thickness of the Castile Formation near the WIPP site is approximately 400 m.

The Salado Formation, of Late Permian (Ochoan) age, is 530 to 610 m thick at and near the WIPP site, and is generally bedded on a scale of 0.1 m to 1 m. It contains 45 numbered "anhydrite" marker beds of variable thickness (MB101 through MB145 with increasing depth). Between marker beds, the Salado consists of layered halites of varying purity and accessory mineralogy; anhydrite ($CaSO_4$), clays, and polyhalite ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$) are dominant accessory minerals. The WIPP facility horizon is between MB138 and MB139.

The Salado Formation is overlain by the Rustler Formation, also of Ochoan age. As shown in Table 1.2, the Rustler contains five members. Two, the Magenta and Culebra dolomites, are somewhat variable gypsiferous dolomites. The Culebra and Magenta dolomites vary mainly in the concentration of fractures and the local occurrence of silty zones. The other three members of the Rustler (unnamed lower member, Tamarisk Member, and Forty-niner Member in upward succession) consist of varying proportions of anhydrite, siltstone/claystone, and halite. The major mineralogical variability within the Rustler Formation as a whole is in the degree of alteration of anhydrite to gypsum and the presence or absence of halite, both generally interpreted to result from evaporite dissolution. Some of this variability, however, may reflect original depositional patterns. The Rustler ranges from 83 m to 130 m in thickness at the WIPP site, depending on the extent of evaporite dissolution and/or depositional variability.

The Culebra dolomite is the first laterally continuous unit above the WIPP facility to display significant permeability. Barring direct breach to the surface, the Culebra dolomite provides the most direct pathway between the WIPP facility and the accessible environment. The hydrology and fluid geochemistry of the Culebra dolomite are quite complex. The unit displays wide ranges in hydraulic properties, local flow and transport mechanisms, and geochemistry. As a result of these factors, the Culebra has received a great deal of study in WIPP site characterization, both before and since 1983.

The Rustler Formation at the WIPP is overlain by the Dewey Lake Red Beds (the uppermost unit of the Ochoan Series) consisting largely of siltstones and claystones, with subordinate sandstones. The unit is approximately 30 m to 170 m thick at and near the WIPP site, varying at least in part due to post-depositional erosion. Where relatively thick and hydraulically unsaturated, the Dewey Lake Red Beds form a low-permeability buffer zone between the surface and relatively soluble carbonates and/or sulfates in the underlying Rustler Formation. In some areas, however, the unit is

thinned by local erosion and/or is hydraulically saturated. Where sufficiently thin, the Dewey Lake may not present an effective barrier to vertical fluid movement from the surface into the Rustler, depending on the local fluid pressures within and above the Rustler Formation. Where saturated, the Dewey Lake may, in some areas, serve as a source of fluids to the underlying Rustler Formation. The depositional age of the Castile, Salado, and Rustler Formations, as well as the Dewey Lake Red Beds, ranges approximately from 245 million to 230 million years. Over approximately the eastern half of the WIPP site, the Dewey Lake Red Beds are overlain by the (undivided) Dockum Group of sandstones and shales of Triassic age.

Table 1.2: Generalized stratigraphy of the Rustler Formation at and near the WIPP site. Adapted from Snyder (1985).

Age	Member	Approximate Thickness (m)	Generalized Character in "Unaltered" Sections
Permian/ Ochoan	Forty-Niner	45±	Anhydrite Halite and Siltstone Anhydrite
	Magenta Dolomite	6-9	Thinly Laminated Gypsiferous Dolomite; Local Anhydrite
	Tamarisk	65±	Anhydrite Halite and Siltstone Anhydrite
	Culebra Dolomite	6-10	Finely Crystalline, Vuggy, Gypsiferous Dolomite; Local Siltstone
	Unnamed	44±	Alternating Halite, Siltstone, Anhydrite Laminated Siltstone

The shallowest and youngest stratigraphic units at the WIPP site proper, except for recent surficial sands, are the Gatuna Formation, the Mescalero caliche, and the Berino soil. The Gatuna Formation, the upper part of which is approximately 600,000 years in age, consists of siltstones, sands, and stream-laid conglomerates, deposited in a wetter climate than is now present in southeast New Mexico. The Mescalero caliche, 410,000 to 510,000 years in age, is relatively continuous in the vicinity of the WIPP site and supports the Livingston Ridge surface on which the site is located (Figure 1.1). The Berino soil, approximately 250,000 years old, is a thin horizon, and is much less widespread than either the Gatuna or the Mescalero. Together, the Gatuna Formation, Mescalero caliche, and Berino soil indicate

some of the variability of the climate in southeastern New Mexico over the last 600,000 years and the relative structural stability of the Livingston Ridge surface over the last 400,000 to 500,000 years.

Localized gypsite-spring deposits, approximately 25,000 years in age, occur along the eastern flank of Nash Draw, but are not currently active. Around the northwest margin of the Delaware Basin, packrat middens indicate that the climate approximately 10,500 years ago was significantly wetter than that at present. The recent surficial windblown sands at and near the WIPP site are almost all stabilized by vegetation. South of the site, however, there is an area in which surficial dunes appear to be active. It is from these dunes that the area has derived its name, "Los Medanos."

1.4 Technical Issues of Interest in WIPP Site and Facility Characterization

This section contains brief discussions of several technical issues of general interest in site characterization of the WIPP, including some consideration of the WIPP facility itself. The most general issues are discussed first. After that, the approach is generally stratigraphic, in parallel with the structure of the report as a whole. Detailed referencing of individual technical studies is not included here, but is included in Sections 2.0 through 4.0, where appropriate.

1.4.1 Transient Versus Steady-State Geologic, Hydrologic, and Geochemical Setting of the WIPP

In order for the expected behavior of the WIPP facility to be evaluated against the EPA's repository-performance guidelines (40CFR191), it must be demonstrated that the structural, hydrologic, geochemical, and transport behavior of the WIPP facility and environs are adequately understood to provide satisfactory predictions over at least the 10,000-year time frame of regulatory interest. "Structural behavior," as the term is used here, includes both far-field and near-field mechanical deformation of stratigraphic units. Far-field structural behavior is behavior independent of the presence of the WIPP facility, especially the underground workings. Near-field behavior is the behavior of the portions of the Salado and Rustler Formations that have been disturbed by the presence of the WIPP facility. "Hydrologic behavior" includes description of the distribution of hydrologic properties, fluid pressures, and directions of fluid flow. As the term is used here, however, it does not include investigation of chemical equilibrium between fluid and rock. "Geochemical behavior" includes both bulk chemistry and isotopic relations resulting from rock-water interaction, but is largely limited to consideration of natural chemical transport and reactions between rocks and fluids, independent of waste. "Transport behavior" includes consideration of the mechanisms of contaminant transport in Rustler groundwaters and the relative importance of different transport mechanisms; it does not include consideration of any specific radionuclides that will or will not be a part of the WIPP radionuclide inventory.

Two basic assumptions are possible concerning the overall geologic setting of the WIPP site. The simplest assumption, implicitly made in the WIPP FEIS (U.S. Department of Energy, 1980), is that the entire geologic system at the WIPP is at steady state on the time scale of regulatory interest. Under this assumption, the geology, hydrology, and geochemistry of the WIPP site should be constant with (or independent of) time for at least the period of regulatory concern to waste isolation.

However, the overall geologic and hydrologic settings of the WIPP site have been transient (not steady-state) since before the beginning of deposition of the Bell Canyon Formation, approximately 250 million years ago, and will continue to be transient long after effective closure of the WIPP facility. Some events, such as crystallization of secondary minerals within the Salado Formation approximately 200 million years ago and formation of the Mescalero caliche 400,000 to 500,000 years ago, have taken place on a very long time scale. Two types of transient response are occurring at and near the WIPP site within the 10,000-year time frame of regulatory interest. These are: a) the continuing natural response of the geologic and hydrologic systems to the end of the last pluvial period (period of decreased temperatures and increased precipitation) in southeast New Mexico; and b) the responses to man-induced hydrologic, geochemical, and structural transients resulting from site characterization and facility construction.

Thus, there is abundant evidence that the overall setting and behavior of the WIPP site are transient on at least three geologic and two human-induced time scales. The time scales of transient behavior range from at least tens of millions of years in the cases of secondary mineralization and fracture formation within the Salado Formation (independent of the WIPP facility) to tens of years in the case of pressure transients imposed on the Rustler Formation by shaft construction and hydrologic testing. The evidence for transient behavior of the WIPP site comes from a broad range of geologic, hydrologic, geochemical, and structural studies. The WIPP performance-assessment activity will ultimately determine which transient phenomena are significant to the long-term performance of the WIPP facility.

1.4.2 Dissolution of Evaporitic Rocks at and near the WIPP Site

Evaporite dissolution, i.e., dissolution or alteration of halite, anhydrite/gypsum, and/or the sulfatic carbonates of the Rustler, Salado, or Castile Formations by groundwaters, has been an issue of major interest in WIPP site characterization. The fundamental reason for this has been the need to evaluate the possibility that, although the Permian evaporites at the WIPP site have been in existence for approximately 240 million years, they might be regionally or locally dissolved on the 10,000-year time scale of regulatory interest. If this occurred, then evaporite dissolution could play a major role in breach of the WIPP facility, by short-circuiting the transport of radionuclides from the facility to the accessible environment.

There are four settings in which evaporite dissolution is or has been of interest in WIPP site characterization. These include:

1. Regional-scale stratabound dissolution of evaporites, especially halite, within the Castile and Salado Formations. In stratabound dissolution, fluid movement is predominantly parallel to bedding. Stratabound dissolution has probably taken place in the western part of the Delaware Basin, as indicated by the absence of halite from both the Castile and Salado Formations in Figure 1.4. If stratabound dissolution within the Castile reached the WIPP site, mechanical collapse of the overlying Salado Formation would occur, possibly resulting in direct breach of the facility. If stratabound dissolution within the Salado reached the WIPP, direct breach of the facility might result.

The possibility of stratabound dissolution reaching the WIPP site itself on the 10,000-year time scale of interest was evaluated as part of site-characterization activities prior to 1983. There is general agreement that stratabound dissolution of the Castile and/or Salado Formations will not reach the WIPP facility in the 10,000-year time frame of interest. In addition, recent interpretations indicate that much of the variability in the thicknesses of the Castile and Salado Formations is due to deformation and original depositional variability, rather than to evaporite dissolution. This should result in slower estimated dissolution rates.

2. Dissolution of Castile and/or Salado halites by localized upward intrusion of halite-unsaturated fluids from the upper portion of the Bell Canyon Formation into the overlying units. If such dissolution occurred immediately beneath the WIPP site, the resulting mechanical subsidence might directly breach the WIPP facility. If this dissolution mechanism is in fact feasible, the locations at which it might occur in the future are not predictable with the present understanding of hydrology in the northern Delaware Basin.

At the WIPP site, one basinal structure within the Salado Formation was proposed in 1983 as a possible result of subsidence resulting from point-source dissolution of Castile and/or Salado halites. This structure has since been investigated by the drilling, coring, and hydrologic testing of hole DOE-2 (Figure 1.2). No evidence of evaporite dissolution was found in hole DOE-2. The DOE-2 structure is the result of syndepositional and postdepositional deformation of the Castile and Salado Formations, rather than of evaporite dissolution. This conclusion, together with earlier studies indicating that the only proven "breccia pipes" in the northern Delaware Basin result from dissolution within the Capitan limestone and occur only directly above this unit (Snyder and Gard, 1982), indicates that point-source dissolution of Castile and/or Salado evaporites is not operative either within the main part of the basin or at the WIPP site.

3. Dissolution of halite from within the Rustler Formation by stratabound flow. East of the WIPP site, the Rustler Formation contains abundant halite (salt) in the Forty-niner, Tamarisk, and unnamed members. West of the WIPP site, for example in Nash Draw, the Rustler

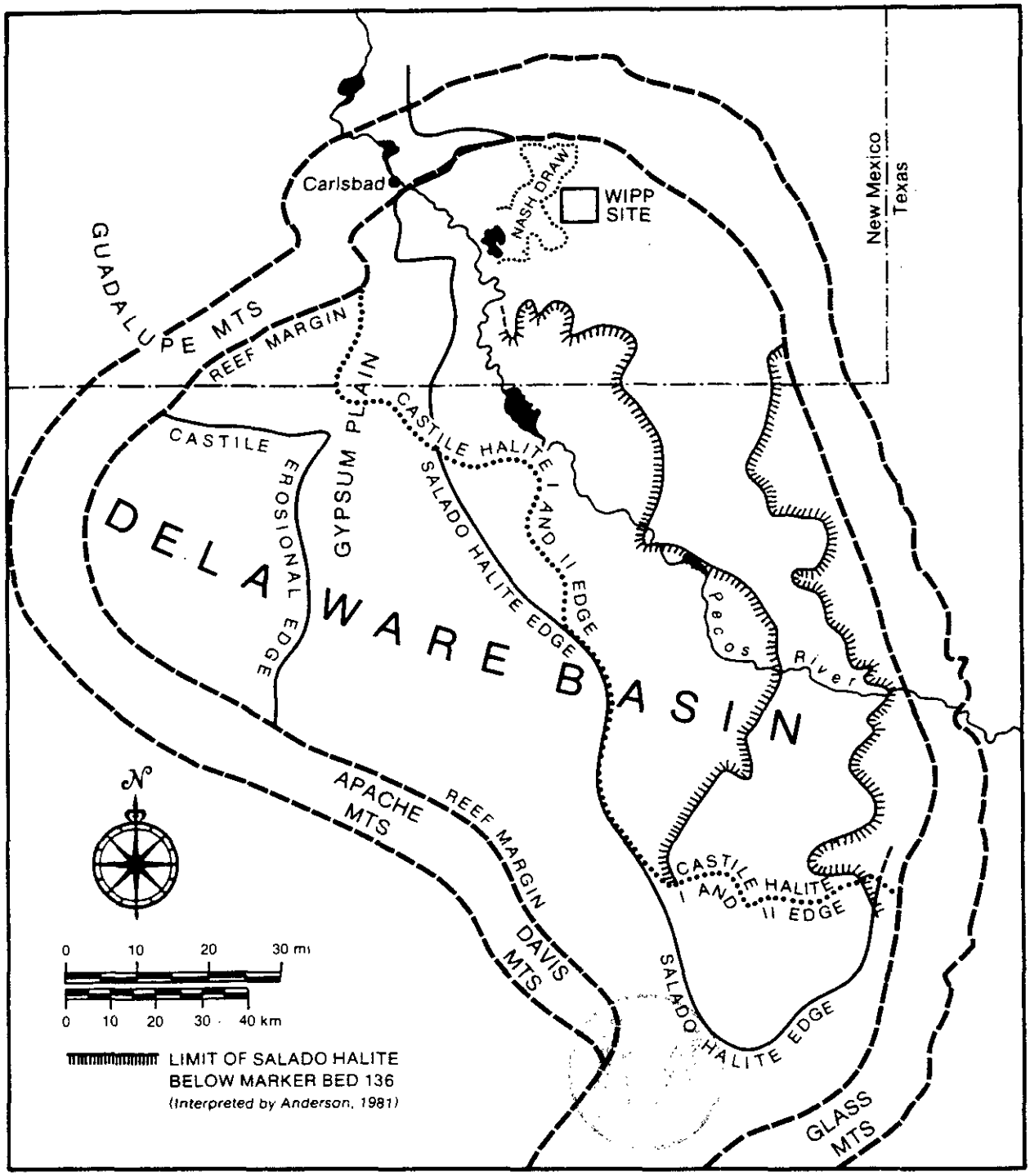

Figure 1.4: Generalized distribution of the Castile and Salado Formations in the Delaware Basin, with emphasis on distribution of halites. Slightly modified from Figure VII-1A of Lambert (1983) and including, in part, the interpretation of Anderson (1981).

Formation is totally devoid of halite (Figure 1.5). If Rustler variability is due to evaporite dissolution and if stratabound dissolution reached the WIPP site within 10,000 years, the overburden at the WIPP would be significantly reduced, perhaps leading to breach.

The variability within the Rustler Formation has conventionally been thought to result from regional-scale stratabound evaporite dissolution, based on the assumption that the distribution of halite was originally uniform. It has also traditionally been assumed that dissolution of Rustler evaporites was a recent phenomenon, linked to the growth of Nash Draw over the last 600,000 years. These two assumptions maximize both the total amount of halite dissolved from the Rustler and the rate at which this dissolution occurs. There is considerable disagreement concerning the uniformity and amount of stratabound evaporite dissolution within the Rustler Formation. However, even with the two "conservative" assumptions outlined above, i.e., assumptions thought to maximize the potential impact to the WIPP, it does not appear feasible for the Nash Draw structure to extend to the WIPP site on the time scale of regulatory interest.

4. Evaporite dissolution within the Rustler Formation as a result of vertical fluid flow. This second potential evaporite-dissolution mechanism involving the Rustler Formation at and near the WIPP site requires local recharge, from the surface to the Rustler Formation, of waters unsaturated in halite and anhydrite/gypsum. If this vertical movement of unsaturated fluids occurs to a significant degree, the resulting local evaporite dissolution within the Rustler might result in local high-permeability channels or pathways within the Rustler Formation. The final result of such dissolution would be the generation of a "karstic" hydrologic system. In such a system, the hydrology and transport behavior would be dominated by relatively narrow high-permeability pathways or channels, even though most of the unit would consist of low-permeability "blocks." The hydrology of at least part of the Rustler Formation within Nash Draw, where the Rustler is exposed at the surface, is known to be karstic, and includes the continuing formation of small caves and sinkholes in anhydrites of the Forty-niner and Tamarisk Members. Such a hydrologic and transport system within the Rustler Formation at the WIPP site itself might provide a means for rapid transport of nuclides from the WIPP facility to the accessible environment.

A comprehensive approach has been taken to the question of Rustler karst at the WIPP site. Field studies have evaluated the surface-geological evidence for and against significant surface infiltration and possible development of karstic cavities below. Hydrologic measurements, including regional-scale pumping tests, have characterized the present distribution of hydraulic properties and relative head potentials within the Rustler at and near the WIPP. Isotopic studies have estimated the isolation or residence times of Rustler waters, estimated the relative importance of vertical and stratabound fluid flow within the Rustler and Dewey Lake, and evaluated the extent to which the entire Rustler hydrologic setting is transient.

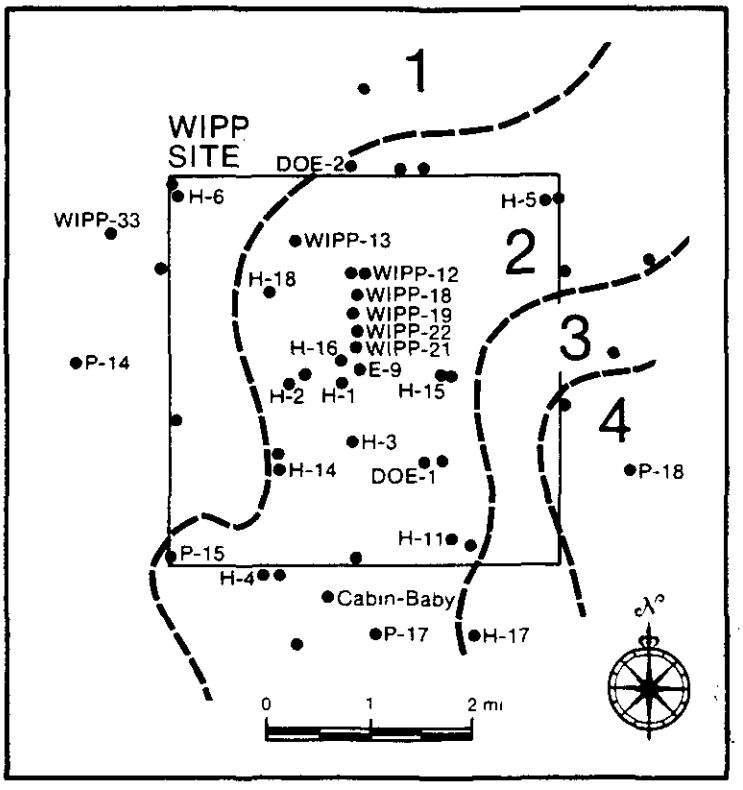

Figure 1.5: Generalized halite distribution within the Rustler Formation at and near the WIPP site. Slightly modified from Figure 9 of Chaturvedi and Channell (1985). Zone 1: no halite present within the Rustler Formation; Zone 2: halite present only below the Culebra Member; Zone 3: halite present between Culebra and Magenta Members; Zone 4: halite present above the Magenta Member.

The combined results of these studies indicate that vertical recharge from the surface to the Rustler is not active at the WIPP site. Where measured successfully, the calculated residence or isolation time of Rustler groundwaters at the WIPP site is greater than 10,000 years. There must have been changes in flow directions within the Culebra dolomite within the last (approximately) 10,000 years. The isotopic results do indicate that some vertical fluid flow has taken place, especially within the Dewey Lake Red Beds. In addition, local development of karstic channels or porosity within Rustler anhydrites does appear to have been a consequence of vertical infiltration of fluids from the surface in the WIPP-33 structure, approximately 1 km west of the western boundary of Zone 3. However, the WIPP-33 structure is unique at and near the WIPP site and is not now significantly active. Regional-scale pumping tests of the Culebra dolomite have not identified any major or dramatic high-transmissivity structures similar to those expected if Rustler karst involving the Culebra were present at the WIPP site.

1.4.3 Directions of Fluid Flow to Be Expected if the Rustler and Bell Canyon Formations Are Interconnected

In the effort to be "conservative," i.e., to not underestimate the impact of breaches of the WIPP facility, it was assumed in the WIPP FEIS (U.S. Department of Energy, 1980) that fluid flow in the event of interconnection of the Rustler and Bell Canyon Formations would be upward into the Rustler. This issue, as well as the distribution of hydrologic properties within the Bell Canyon Formation, has since been investigated in testing of the holes Cabin Baby-1 and DOE-2, near the southern and northern boundaries of the WIPP site, respectively (Figure 1.2).

The results of hydrologic testing in both Cabin Baby-1 and DOE-2 suggest that the WIPP site is not directly underlain by a high-permeability channel sand in the upper part of the Bell Canyon (Figure 1.3). If such a sand is present, it must be more narrow than those shown in Figure 1.3. This decreases the potential, already concluded by Wood et al. (1982) to be negligible, for any significant upward migration of Bell Canyon fluids into overlying evaporites in the absence of a drillhole. In addition, the fluid pressures and brine densities measured in both Cabin Baby-1 and DOE-2 indicate that, in the event of interconnection of the Bell Canyon, Salado, and Rustler Formations within a drillhole, the final direction of fluid flow would be downward into the Bell Canyon Formation. This conclusion assumes that both Bell Canyon and Rustler fluids become saturated as a result of local halite dissolution within the Salado Formation.

1.4.4 Distribution and Origin of Brine Occurrences within Castile Anhydrites

In the northern Delaware Basin, highly pressurized brines have been encountered locally in fractured anhydrites of the Castile Formation during drilling from the surface. The known distribution of these Castile brine occurrences as of 1983 is shown in Figure 1.6. Castile brines have been

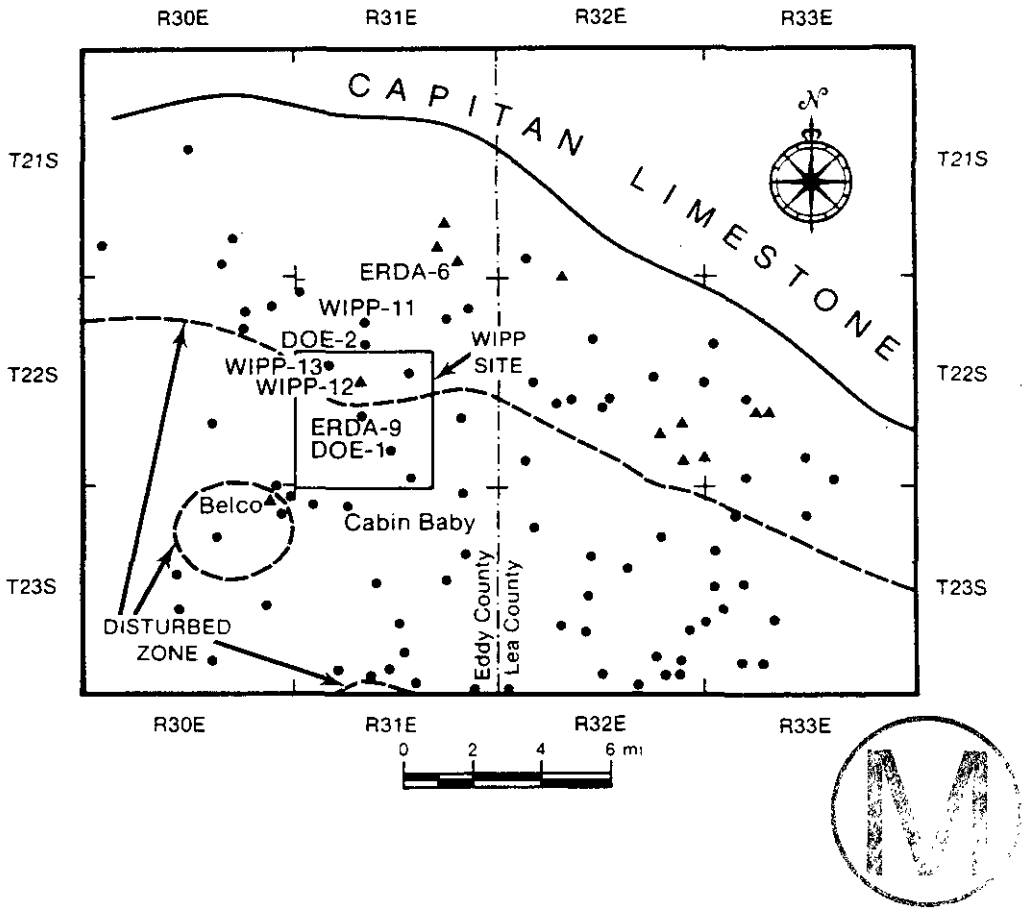

Figure 1.6: Generalized distribution of Castile brine occurrences and approximate extent of the Castile "Disturbed Zone" in the northern Delaware Basin. Distribution of Castile brines is simplified from Figure G-11 of Popielak et al. (1983). Approximate boundaries of Castile "Disturbed Zone" are from Figure 1-1 of Borns et al. (1983). Closed triangles represent holes in which Castile brines have been encountered. ERDA-9 is included for reference, but does not penetrate Castile Anhydrite III completely.

encountered largely in hydrocarbon-exploration drillholes both north and northeast of the WIPP site (i.e., between the WIPP site and the margin of the basin). However, brine was also encountered southwest of the WIPP site, at the Belco well. During WIPP site characterization, Castile brines have been encountered in hole WIPP-12, approximately 1.6 km north of the site center, and in ERDA-6, approximately 8 km northeast of the site center.

Two basic hypotheses have been put forward to explain the origin of Castile brines, namely that the occurrences are due to:

1. Migration of connate Castile fluids from halites into anhydrites fractured as a result of local deformation.

2. Isolation of meteoric waters within the fractured Castile anhydrites, following episodic lateral hydrologic connection of the Castile Formation and the Capitan limestone.

Because of the localized but widely distributed occurrence of Castile brines in the vicinity of the WIPP site, it has previously been assumed for purposes of performance assessment that Castile brine is present beneath the WIPP facility itself. Since the upper Castile anhydrite is stratigraphically 200 m or more beneath the WIPP facility horizon, this brine is of concern only in the event of a drilling intrusion which connects the brine occurrence with the facility. A recent surface-geophysical survey over an area including the WIPP waste-emplacement panels is consistent with the presence of Castile brines beneath a portion of the panels.

1.4.5 Deformation of the Castile and Salado Formations

Borns et al. (1983) define a structurally "Disturbed Zone" (DZ) (Figure 1.6) within the Castile Formation, based largely on the systematic loss of coherent seismic response. The deformation of the Castile Formation within the DZ involves both anhydrites and halites, and is associated with the known occurrences of Castile brines. Although the overall mineralogies of the Salado and Castile Formations are similar, the two units are layered on different scales. Regional deformation of the Salado Formation is largely in response to regional deformation of the underlying Castile Formation.

Recent results indicate that fluids and pressure-solution mechanisms play a major role in far-field deformation of both the Castile and Salado Formations. This has been investigated both theoretically and by examination of core collected in hole DOE-2. The time scale of regional deformation of the Salado and Castile Formations is from thousands to millions of years, too long to be of concern in evaluation of the future performance of the WIPP facility.

Construction of the underground WIPP facility, resulting in generation of a large void space at a depth of 650 m within a stratigraphic section that is predominantly halite, results in a strong local mechanical response within the Salado Formation. The near-field mechanical response of the Salado

Formation around the WIPP facility involves both higher stresses and deformation rates than expected in natural or far-field deformation. At least during early closure, near-field creep deformation appears to involve mechanisms such as dislocation climb. It is presently not known when, or if, pressure solution will become a dominant mechanism in creep closure of the WIPP facility.

Creep, however, is not the only near-field process involved in closure of the WIPP facility. Marker Bed 139 (MB139), approximately 1 m below the WIPP facility horizon, is fractured from pre-excavation processes, i.e., processes not related to excavation of the WIPP facility. The opening of these fractures, in addition to formation of fractures within Salado halites, plays a significant role in the near-field structural response to excavation of the WIPP facility.

Monitoring of these structural "excavation effects" is ongoing, and will continue through the operational phase of the WIPP. The time scale of near-field mechanical effects began with the beginning of construction of the WIPP facility and will continue until structural reequilibration following complete closure of the facility. Therefore, the time of interest may be 100 years or more, depending on both the long-term behavior of the facility and the types and amounts of both waste and backfill that are emplaced.

1.4.6 Fluid Flow within the Salado Formation

Salado halites were assumed to be anhydrous at the time of the WIPP FEIS and SPDV activities, with the exception of small amounts of fluid inclusions and water bound up in hydrous minerals. Fluid flow into the WIPP facility under this assumption would be very small in volume, directly stress-related, and transient. Long-term steady-state fluid flow would be zero.

Recent hydrologic measurements from the surface and within the WIPP facility, combined with geochemical studies within the facility, indicate that grain-boundary fluids are present within the Salado Formation, and that the unit should be considered as a very low-permeability material in which fluid residence times in the far field are on the order of millions of years. There are, however, major increases in both permeability and fluid-pressure gradients within the Salado Formation within a few meters of the WIPP facility at and near the facility horizon. The recent results suggest that, while there are major stress-related transient effects, long-term fluid flow into the facility will reach some very low but non-zero steady-state rate, and will continue until effective hydrologic closure of the facility. On the basis of preliminary hydrologic testing results, the development of an altered or disturbed zone around the WIPP shafts appears to be much more limited than at the facility horizon.

1.4.7 Present-Day Hydrology, Transport Behavior, and Geochemistry of the Rustler Formation

The Culebra Dolomite Member of the Rustler Formation is the first laterally continuous water-bearing zone above the WIPP facility. Transport within the Culebra dolomite constitutes the major transport mechanism from the WIPP facility to the accessible environment, except for direct transport to the surface. Therefore, there is great interest in determining the modern distribution of hydraulic and nuclide-transport properties within the Culebra.

The hydrologic characteristics of the Culebra dolomite are complex. The transmissivity of the unit varies by approximately four orders of magnitude at and near the WIPP site, with relatively high-transmissivity regions both southeast and northwest of the site center. However, the center of the WIPP site, including all four shaft locations, is in a region of low Culebra transmissivity (permeability). The relatively transmissive parts of the Culebra contain fractures that dominate both hydraulic and transport behavior on the scale of individual three-hole hydropads (approximately 30 m between holes). If these fractures were to dominate flow and transport behavior on the "regional" scale considered here, i.e., over the 3.2-kilometer distance between the center of the WIPP site and the boundary of WIPP Zone 3 (Figure 1.2), nuclide-transport times to the accessible environment would be greatly decreased relative to times estimated without considering fractures.

Numerical modeling of Rustler hydrology through 1983 was based on testing only at single holes and individual three-hole hydropads, and ignored possible fracturing. Since 1983, two regional-scale interference tests have been conducted in the Culebra, one centered at the H-3 pad and one at hole WIPP-13 (Figure 1.2). Hydraulic effects of fracturing have been evaluated in detail at the H-3 and H-11 hydropads. The interpretation of the regional-scale multipad interference tests indicates that fracturing need not be included in modeling simulation of Culebra hydrologic behavior at this scale, since test calculations with and without fractures have produced very similar results.

In addition, detailed calculations completed in 1987 indicate that although fracturing plays a major role in local or pad-scale contaminant transport within parts of the Culebra, radionuclide transport to the accessible environment can realistically be modeled using the porous-medium approximation, at least so long as the present pattern of head distributions within the Culebra is not significantly perturbed and the transport properties and flow paths assumed in the calculations are representative. This conclusion may or may not be valid in the case of a breach involving a Castile brine reservoir at high fluid pressures.

Through 1983, numerical modeling of Rustler hydrology also ignored both the geochemical variability of Rustler fluids and possible effects of variable fluid density on directions of fluid flow. Both numerical methods and data bases for evaluation of groundwater flow in the region of the WIPP site have developed significantly since that time. Recent groundwater-flow calculations, which include effects of variable brine density, indicate

that modern fluid flow within the Culebra dolomite is generally north-south in the vicinity of the WIPP site. Flow rates vary greatly, being rapid down the axis of Nash Draw, but extremely slow across the WIPP site proper. While the assumption of hydrologic steady state appears adequate for modeling of head potentials within the Culebra dolomite, groundwater flow across the WIPP site within the Culebra is sufficiently slow to make the assumption of hydrologic steady-state inadequate for detailed modeling of long-term flow directions and rates. However, the changes in flow rates and directions as a function of time appear not to be dramatic at the WIPP site itself. Groundwater flow is quite slow in this area.

As noted, Culebra fluids are quite variable. Recent work indicates that they can be broken into four distinct geochemical facies. The general distribution of fluid compositions is inconsistent with steady-state confined fluid flow in the present flow directions. The mineralogy of the Culebra dolomite is widely variable, but without sharp regional distinctions, since dolomite, clays, and gypsum/anhydrite are all widespread. Halite has not been reliably identified in Culebra core, except for that which may have been introduced during drilling. The analyzed Culebra fluid compositions form a variable but continuous population, all of which reflect exposure to evaporitic rocks.

2.0 BELL CANYON FORMATION

The Delaware Mountain Group is divided into the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations, all of which are predominantly of shales, siltstones, and sandstones. Only the Bell Canyon is considered here, since it is the first regionally continuous water-bearing zone beneath the WIPP facility. The hydraulic behavior of the Bell Canyon is assumed here to be more significant than that of underlying units in WIPP breach scenarios.

There have historically been two reasons for interest in the Bell Canyon Formation in WIPP site characterization. First, the Bell Canyon has been proposed by some as a source of fluids for local or point-source dissolution of halite in the overlying Castile and Salado Formations. This mechanism and general conclusions regarding its validity at the WIPP site are summarized in general terms in Section 2.1, based on work completed through 1983. Second, it must be assumed for purposes of performance assessment that at least one drillhole from the surface will penetrate the WIPP facility. It may then be important to estimate the distribution of permeable zones within the Bell Canyon at the WIPP site and to estimate directions of fluid flow that might result from an open borehole penetration that connected the Bell Canyon with fluid-bearing zones within the Rustler Formation, especially the Culebra dolomite. The character of the Bell Canyon and expected directions of fluid flow between the Culebra and the Bell Canyon at the WIPP site are discussed in Section 2.2.

2.1 Potential for the Bell Canyon Formation to Serve as a Source of Fluids for Dissolution of Evaporites in the Castile and Salado Formations

Anderson (1978, 1981) and Davies (1983) have proposed a major role for the Bell Canyon Formation in point-source dissolution of overlying evaporites. The proposed mechanism involves: 1) recharge of halite-unsaturated fluids to the Bell Canyon Formation from the Capitan limestone; 2) upward movement of these fluids into (at least) the lower halite of the Castile Formation; 3) halite dissolution within the Castile Formation; 4) subsidence and disruption of the Castile and overlying Salado Formations as a result of halite dissolution; 5) downward flow of halite-saturated brines back into the Bell Canyon Formation; and 6) removal of brines through the Bell Canyon Formation. An important characteristic of this hypothesis proposal is that it is not possible to predict localities of future point-source evaporite dissolution.

Wood et al. (1982), as part of the WIPP SPDV studies, addressed the potential for fluids within the upper Bell Canyon Formation to dissolve evaporites within the Castile Formation. For this evaluation, it is assumed that: 1) a permeable sandstone is present at the top of the Bell Canyon Formation, i.e., a Ramsey channel sand (Figure 1.3); 2) the effective thickness of the sandstone is 30 m; and 3) the transmissivity of the sandstone ranges from 1.0×10^{-6} to 2.8×10^{-6} m^2/s. Any decrease in sandstone permeability or shifting of the sandstone to positions below the

top of the Bell Canyon would reduce the potential for dissolution of overlying evaporites.

For the range of hydraulic properties and gradients considered, and assuming the Ramsey sand is at the top of the Bell Canyon, Wood et al. (1982) conclude that:

1. Except at locations adjacent to the Capitan limestone, only diffusional dissolution is possible directly above the Bell Canyon. Salt directly above the top of the Bell Canyon, assuming diffusional processes, is calculated to dissolve at a vertical rate of approximately 0.003 m per 10,000 years. This would have negligible effect on the WIPP facility.

2. Allowing for an order-of-magnitude increase in flow velocities within the Bell Canyon Formation, dissolution would still be too slow to maintain open cavities within Castile halites at depth. Such cavities are required to maintain the high-permeability pathways necessary for dissolution due to the density-flow mechanism outlined above.

3. Even allowing for the maximum potential dissolution rates at the top of the Bell Canyon from both diffusive and convective mechanisms, no significant evaporite dissolution as a result of fluid flow from within the Bell Canyon should be observed at the WIPP facility for at least 10,000 years.

In addition, Lambert (1983) concludes that the Bell Canyon Formation itself shows no evidence of either modern hydraulic connection with a source of halite-unsaturated fluids (such as the Capitan limestone) or any effective path for brines to exit the Delaware Basin. Instead, Lambert interprets the Bell Canyon fluids as having very long residence times and concludes that their compositions reflect extensive rock-water interaction, evolving isotopically and geochemically away from compositions representative of meteoric recharge.

Thus, studies at the end of the WIPP SPDV phase indicated that the Bell Canyon Formation was not dissolving evaporites near the WIPP site. As discussed in Section 3.0, however, this question was later investigated directly by the drilling, coring, and hydrologic testing of hole DOE-2 near the northern boundary of WIPP Zone 3 (Figure 1.2).

2.2 Expected Directions of Fluid Flow Between the Bell Canyon and Rustler Formations

The information on freshwater-equivalent heads in the Rustler and Bell Canyon Formations available through 1983 is summarized in Mercer (1983). At that time, the freshwater head within the Bell Canyon Formation at the center of the WIPP site, approximately 1040 m AMSL, was 120 m greater than the expected freshwater head in the Culebra dolomite at the same location,

approximately 920 m AMSL. (All elevations here are given relative to mean sea level.) This is consistent with the assumption made in the WIPP FEIS (U.S. Department of Energy, 1980) that fluid flow would be upwards into the Rustler if the Bell Canyon and Rustler were interconnected in an open hole. However, this "conservative" assumption, i.e., the assumption with most apparent impact to WIPP performance assessment, neglects: a) the original density of fluids in the Bell Canyon and Culebra; b) possible increases in both Bell Canyon and Culebra fluid densities due to dissolution of halite within the Salado Formation; c) possible effects of fluid potentials within the Salado Formation or elsewhere within the Rustler Formation; and d) possible changes in fluid density as a result of entrainment of waste from within the WIPP facility.

In the event of a drillhole breach interconnecting the Bell Canyon, Castile, Salado, and Rustler Formations, it is reasonable to assume that local dissolution of halite within the Salado Formation would take place, resulting in an average fluid density of approximately 1.2 g/cm^3, the approximate density of saturated NaCl brine. Under this assumption, Bell Canyon brine at the center of the WIPP site would stand to an elevation of approximately 835 m in an open hole, some 445 m above the WIPP facility, but approximately 210 m below land surface, and more than 200 m lower than the Bell Canyon freshwater-equivalent head of approximately 1040 m. Assuming that local halite dissolution within the Rustler or upper portion of the Salado Formations led to a final density of Culebra brine of 1.2 g/cm^3, the Culebra near the center of the WIPP site would support a column of brine to an elevation of approximately 900 m, 20 meters below the freshwater-equivalent head within the Culebra, but some 65 m higher than supported by the underlying Bell Canyon Formation.

Therefore, if brine saturation by halite dissolution is considered, the data available as of 1983 are consistent with the interpretation that interconnection of the Bell Canyon Formation and the Culebra dolomite in an open drillhole through the WIPP facility should result in downward movement of contaminated brine into the Bell Canyon Formation. However, the calculated direction of fluid flow depends on assumed fluid densities. Fluid might move upward until the Bell Canyon and Culebra fluids were saturated with halite, at which time downward flow would begin. In addition, these results depend on the assumption that no significant fluid or gas pressures are generated within the Salado Formation or WIPP facility. As of 1983, however, predicted directions of fluid flow were limited in reliability, because heads and fluid densities in the Culebra dolomite and Bell Canyon Formation had not been measured together in the same hole. Two holes penetrating the Bell Canyon Formation very near the WIPP site have since been drilled and/or hydrologically tested. The results from hole Cabin Baby-1 are discussed in Section 2.2.1, and those from hole DOE-2 in Section 2.2.2.

2.2.1 Results from Hole Cabin Baby-1

Cabin Baby-1, a hydrocarbon exploration hole, was originally drilled through the Castile Formation and the upper 35 m of the Bell Canyon

Formation in 1974 and 1975. At that time, all of the Ramsey and part of the Olds members of the Bell Canyon were penetrated. The hole depth at that time was 1265 m below land surface. As described in Beauheim et al. (1983b), the hole was deepened to a total depth of 1308 m in 1983 to allow hydrologic testing, fluid sampling, and monitoring of Bell Canyon fluid levels. The deepening allowed testing of most of the Hays sandstone member underlying the Olds, in addition to all of the Olds and Ramsey members.

The results of hydrologic testing of the Bell Canyon in Cabin Baby-1 and DOE-2 are summarized in Table 2.1. Only the lowermost "sand" member of the Bell Canyon, the Hays, is significantly permeable in Cabin Baby-1, with an interpreted transmissivity of between 1.7×10^{-7} and 5.1×10^{-7} m^2/s. The description of the Hays member by Beauheim et al. (1983b) indicates that it is siltstone. The estimated transmissivities of the overlying Olds and Ramsey members are less than 10^{-8} m^2/s. Core from the Ramsey member is not available from Cabin Baby-1.

Table 2.1: Summary of hydrologic test results from the Bell Canyon Formation in Cabin Baby-1 and DOE-2. Data from Table 6 of Beauheim et al. (1983b) and Table 7-2 of Beauheim (1986).

Effective Test Interval (m blg)	Unit	K(md)	T(m^2/s)
Cabin Baby			
1230-1246	Lamar	6×10^{-4}	5.7×10^{-11}
1247-1257	Ramsey	2.3×10^{-2} - 8.7×10^{-2}	1.7×10^{-9} - 6.3×10^{-9}
1259-1269	Olds	2.2×10^{-2} - 8.2×10^{-2}	2.1×10^{-9} - 7.9×10^{-9}
1271-1308	Hays	0.57 - 1.7	1.7×10^{-7} - 5.1×10^{-7}
DOE-2			
1263-1272	Ramsey	8.4×10^{-2} - 9.4×10^{-2}	5.8×10^{-9} - 6.5×10^{-9}
1276-1285	Olds	9.8×10^{-2} - 0.11	7.1×10^{-9} - 8.2×10^{-9}
1297-1318	Hays	2.3 - 2.4	5.7×10^{-7} - 6.0×10^{-7}

Fluid samples were successfully collected from the Hays and Olds members of the Bell Canyon in Cabin Baby-1, as was a mixed sample from the entire exposed Bell Canyon. The presence of the tracer added to the drilling

fluid indicates that all of the water samples are slightly contaminated with drilling fluid. Therefore, the reported specific gravity of fluid from the Hays sandstone (1.120 - 1.134) may be slightly too high (Beauheim et al., 1983b).

At the end of operations in 1983, the penetrated portion of the Bell Canyon in Cabin Baby-1 was isolated by a packer emplaced in the lower anhydrite of the Castile Formation, and a monitoring tube was installed to the surface to allow long-term monitoring of a composite Bell Canyon fluid level. As of October 1986, the composite Bell Canyon fluid level in Cabin Baby-1 was stabilized at an elevation of approximately 920 m (Saulnier et al., 1987). Assuming that a specific gravity of 1.12 represents Bell Canyon fluids in the hole, and that the fluid column is supported by the effective pressure at the top of the Hays member at an elevation of -255 m, the calculated pressure at this elevation is 12.81 MPa. This pressure in the Bell Canyon in Cabin Baby-1 would support a column of brine having a density of 1.20 g/cm^3 to an elevation of 842 m.

Culebra fluid pressures and properties in Cabin Baby-1 are contained in LaVenue et al. (1988). These results indicate a Culebra freshwater-equivalent head of approximately 913 m. At the elevation of the base of the Culebra in this hole, approximately 856 m, this requires a fluid pressure of approximately 0.55 MPa. Assuming a final brine density of 1.2 g/cm^3 after halite dissolution, this is equivalent to a brine column supported to an elevation of 903 m.

The expected saturated-brine head in the Culebra in Cabin Baby-1, 903 m, is 61 m higher than the composite saturated-brine head in the Bell Canyon in the same hole, 842 m. Thus, under the assumptions used here and consistent with extrapolations from regional data available as of 1983, the final direction of fluid flow in the event of an open drillhole interconnecting the Bell Canyon and Salado Formations with the Culebra dolomite at Cabin Baby-1 would be downward.

2.2.2 Results from Hole DOE-2

Hole DOE-2, located near the center of the northern boundary of WIPP Zone 3 (Figure 1.2), was drilled in two stages to a total depth of 1318 m, between August 1984 and June 1985 (Mercer et al., 1987). In addition to the shallower units in the hole, the Ramsey, Olds, and Hays "sandstone" members of the Bell Canyon Formation were hydrologically tested (Table 2.1), as described by Beauheim (1986).

The results of testing in DOE-2 are similar to those in Cabin Baby-1, in which the lower "sand," the Hays, is the only unit with appreciable permeability or transmissivity. Estimated transmissivities for the Hays in DOE-2 range from 5.7×10^{-7} to 6.0×10^{-7} m^2/s, similar to the upper estimate of transmissivity for the same zone in Cabin Baby-1. Estimated transmissivities of the Ramsey and Olds members in DOE-2 range only from 5.8×10^{-9} to 8.2×10^{-9} m^2/s, similar to the upper range of estimated transmissivities for the same members in Cabin Baby-1. The lithologic log

contained in Mercer et al. (1987) indicates that all three members are *fine-grained sandstones, rather than siltstone.*

After hydrologic testing, the Bell Canyon in DOE-2 was isolated for monitoring of a composite fluid level (Beauheim, 1986). As of March 1986, the composite fluid level had "stabilized" at an elevation of approximately 925 m. Assuming that the measured specific gravity of 1.10 (Mercer et al., 1987) is representative for the Bell Canyon fluids, and that the composite Bell Canyon head is controlled by fluid pressures at the top of the Hays member at an elevation of -243 m, this requires a fluid pressure of 12.5 MPa at this elevation. This pressure would support a column of brine having a density of 1.2 g/cm^3 to an elevation of approximately 827 m.

The Culebra freshwater-equivalent head in DOE-2 is approximately 934 m (LaVenue et al., 1988). Using the measured fluid density of 1.04 g/cm^3 (Uhland et al., 1987) for the Culebra in DOE-2, a freshwater-equivalent head of 934 m requires a pressure of 1.47 MPa at the base of the Culebra, at an elevation of 784 m. Assuming a final Culebra brine density of 1.2 g/cm^3 following halite dissolution, the Culebra fluid pressure at DOE-2 would support a brine column of density 1.2 g/cm^3 to an elevation of approximately 909 m, 82 m higher than supported by the composite Bell Canyon head in the same hole. Under the assumptions used here, the final direction of fluid flow in the event of an open hole interconnecting the Bell Canyon, Salado, and Culebra at DOE-2 would be downward.

Wood et al. (1982) estimate that the transmissivities of sandstones within the Bell Canyon Formation normally range from 1.0×10^{-6} to 2.8×10^{-6} m^2/s, although they report a maximum value of 1.7×10^{-5} m^2/s. This range is approximately one order of magnitude greater than the transmissivity of the Hays member in Cabin Baby-1 and DOE-2, and more than two orders of magnitude greater than the transmissivities measured in the Olds and Ramsey members in the same holes. Therefore, the Ramsey member in Cabin Baby-1 and DOE-2 does not appear to be part of one of the channel sands shown in Figure 1.3. Given that Cabin Baby-1 and DOE-2 are the only two holes very near to WIPP Zone 3 that penetrate the Bell Canyon, this result does not guarantee that no channel sandstone is present in the Bell Canyon beneath the WIPP site. Given the general trend of the channel sands shown in Figure 1.3, it does suggest that any channel sand present would have to be at least as narrow as the sand shown at the eastern edge of the WIPP site. Cabin Baby-1 lies along the trend of this sand, however, indicating that this channel is not continuous towards the southwest.

The recent results in both DOE-2 and Cabin Baby-1 are consistent with the conclusion that the final direction of fluid flow resulting from interconnection of the Bell Canyon Formation and the Culebra dolomite at or near the WIPP site would be downwards into the Bell Canyon, contrary to assumptions maintained in the WIPP FEIS. There are some limitations to this conclusion. There might be upward fluid movement until the Bell Canyon and Culebra fluids became essentially saturated with halite, at which time downward flow would begin. In addition, these results depend on the assumption that flow rates within the Bell Canyon and Culebra dominate any fluid pressures generated within the Salado Formation. This assumption appears generally valid, however, given the low fluid-flow rates normally encountered within the Salado Formation (Section 3.0).

3.0 CASTILE AND SALADO FORMATIONS

The major halite-bearing units at and near the WIPP site are the Castile and Salado Formations. Both units contain halites of varying purity and thickness. The two halites within the Castile Formation are normally thick, contain abundant sulfate/carbonate laminae, and are separated by two relatively thick anhydrites. The bedded halites within the Salado Formation contain accessory minerals such as polyhalite, clay, and anhydrite, and are separated by numerous anhydritic marker beds and related clay seams. Locally the middle portion of the Salado Formation contains commercial potash mineralization, at a level some 300 m stratigraphically above the WIPP facility horizon. The underground workings in the WIPP facility are being developed at a depth of approximately 655 m within bedded halites and anhydrites in the lower Salado. The halitic interval containing the WIPP facility horizon is approximately 8 m thick, and is situated between anhydrite marker beds MB138 and MB139. The Castile and Salado Formations are discussed together here, since halite is a major component of both, and many of the processes of interest involve both units.

The Castile Formation overlies the Bell Canyon Formation (Delaware Mountain Group). Near the WIPP site, the Castile normally contains a sequence of three thick anhydrites (Anhydrite I at the bottom and Anhydrite III at the top), separated by two thick halites (Halites I and II). The thickness of the Castile Formation at and near the WIPP site is approximately 400 m. Anderson et al. (1972) provide a general stratigraphic description of the Castile, including the more than 200,000 sulfate/carbonate laminae that occur throughout both halites and anhydrites within the unit. Bedding within Castile anhydrites ranges from massive (approximately 30 m) to laminar (see, for example, Mercer et al., 1987). Individual beds in the Salado are often 1 m thick or less. The unit nominally contains 45 anhydrite marker beds, numbered from Marker Bed 101 (MB101) to MB145 with increasing depth. The Salado Formation is about 600 m thick at the WIPP site.

In some areas, both total thickness and the thickness of stratigraphic intervals within the Castile and Salado Formations are variable. The origin and timing of this variability are discussed in Section 3.1. This variability has played a significant role in WIPP site characterization, since variable halite (and anhydrite) thicknesses could have at least three origins:

1. Initial depositional variability (e.g., Lambert, 1983; Borns and Shaffer, 1985).

2. Gravity-driven deformation, in which dense anhydrites sink into less dense halites, with compensating formation of salt-cored domes or anticlines (Borns et al., 1983; Borns and Shaffer, 1985).

3. Evaporite dissolution, by which halites are preferentially dissolved by contact with unsaturated groundwaters (Anderson, 1978; Davies, 1983).

Significant volumes of fluid are not normally encountered in drilling either the Castile or Salado. There are exceptions, however. Highly pressurized brines have been encountered in the uppermost Castile anhydrite in some hydrocarbon-exploration and stratigraphic test holes near the WIPP site (Figure 1.6). These fluids are under sufficient pressure to flow to the land surface. The origin and distribution of Castile brines at and near the WIPP site is discussed in Section 3.2.

As mentioned previously, the WIPP facility is presently being developed within the bedded halites and anhydrites of the lower Salado Formation. In order to place the WIPP facility within a proper regional perspective, it is necessary to characterize the behavior of the Salado Formation on both the regional scale and adjacent to the WIPP facility itself. The characteristics of the Salado are locally different as a result of "excavation effects" from construction of the WIPP facility. These transient effects demonstrably occur on time scales of interest in performance assessment. Recent studies examining the structural, hydrologic, and geochemical characteristics of the Salado Formation in and near the WIPP facility are discussed in Section 3.3. These studies are progressing, and will play a critical part in monitoring the behavior of the WIPP facility during the operational phase. The discussion of these activities is preliminary.

3.1 Regional and Local Variability, Deformation, and Dissolution of the Castile and Salado Formations

3.1.1 Regional Relationships and Behavior

As mentioned above, both aggregate and internal thicknesses within the Castile and Salado Formations vary locally. The variability near the WIPP site is shown in Figure 3.1. Holes WIPP-12, DOE-2, and WIPP-11 lie within the southern part of the Castile "Disturbed Zone" (DZ) shown in Figure 1.6, while hole Cabin Baby-1 lies outside this zone. Since ERDA-9 penetrates only the upper portion of the Castile Formation, the possible extension of the DZ beneath the WIPP facility has not been determined by drilling. The Castile and Salado Formations in hole Cabin Baby-1 are assumed here to represent the "undisturbed" character of these units near the WIPP site.

In the cross section shown in Figure 3.1, the total thickness of the Castile is known only in holes Cabin Baby-1 and DOE-2. The Castile is 409 m thick in Cabin Baby-1 and 302 m thick in DOE-2. The apparent thickness of Anhydrite I is 72 m in Cabin Baby-1 and 80 m in DOE-2. Therefore, we assume here that the thickness of Anhydrite I is not significantly variable on the scale of the WIPP site, and that, south of DOE-2, Anhydrite I is not strongly involved in structures within the Castile and overlying Salado. Apparent stratigraphic thicknesses from the top of the Castile to the top of Anhydrite I range from 222 m at DOE-2 to 372 m at WIPP-11. The assumed undisturbed thickness, that at Cabin Baby-1, is 337 m.

Much of the variability within the Castile Formation in Figure 3.1 is in halite thickness. For example, the anomalously thick Castile at WIPP-11 includes a thickness of 311 m for Halites I and II, compared with a

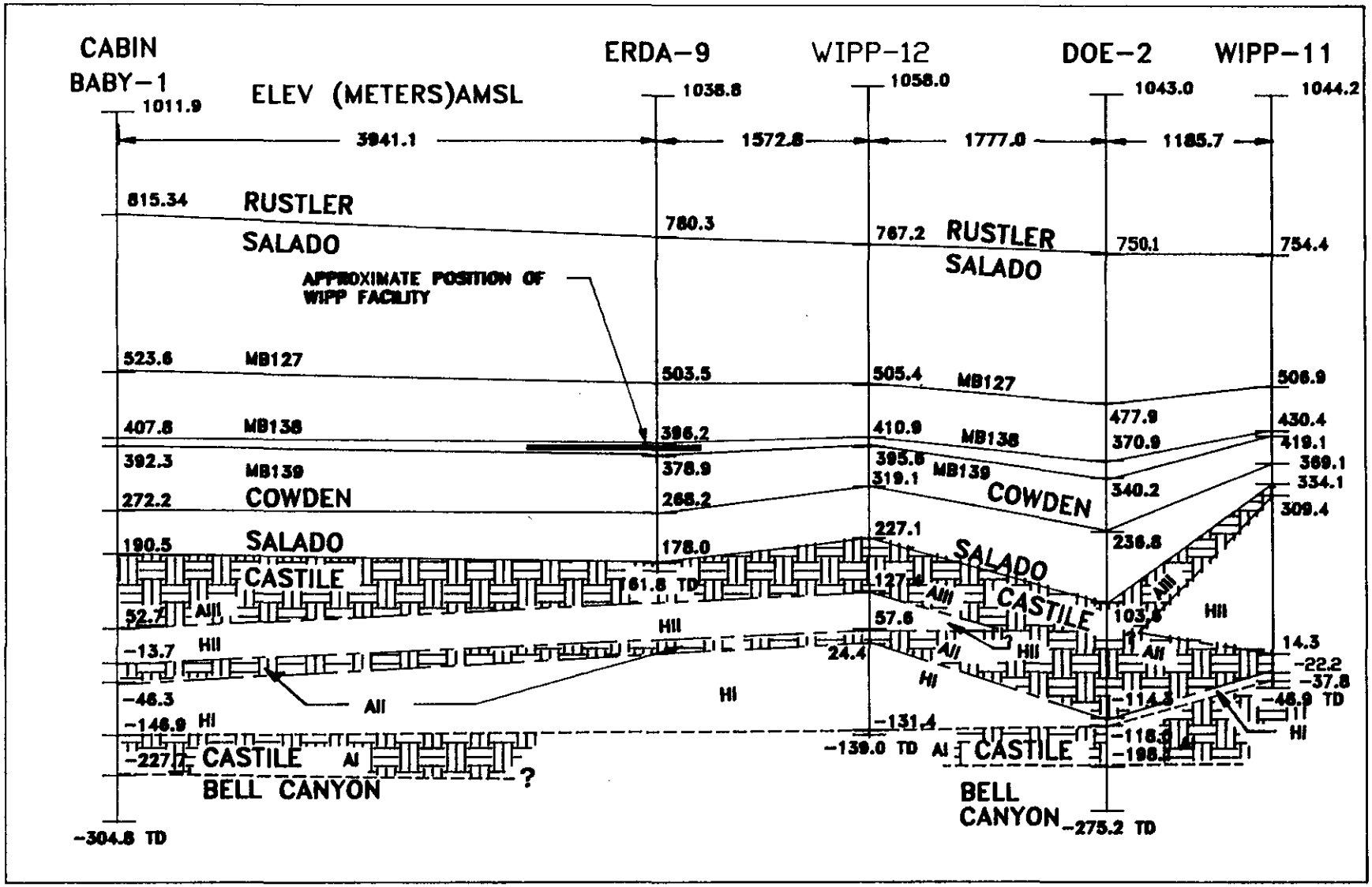

Figure 3.1: Generalized stratigraphic cross section of the Salado and Castile Formations between holes Cabin Baby-1 and WIPP-11. Hole locations used are shown in Figure 3.2. Elevations and hole spacings are in meters.

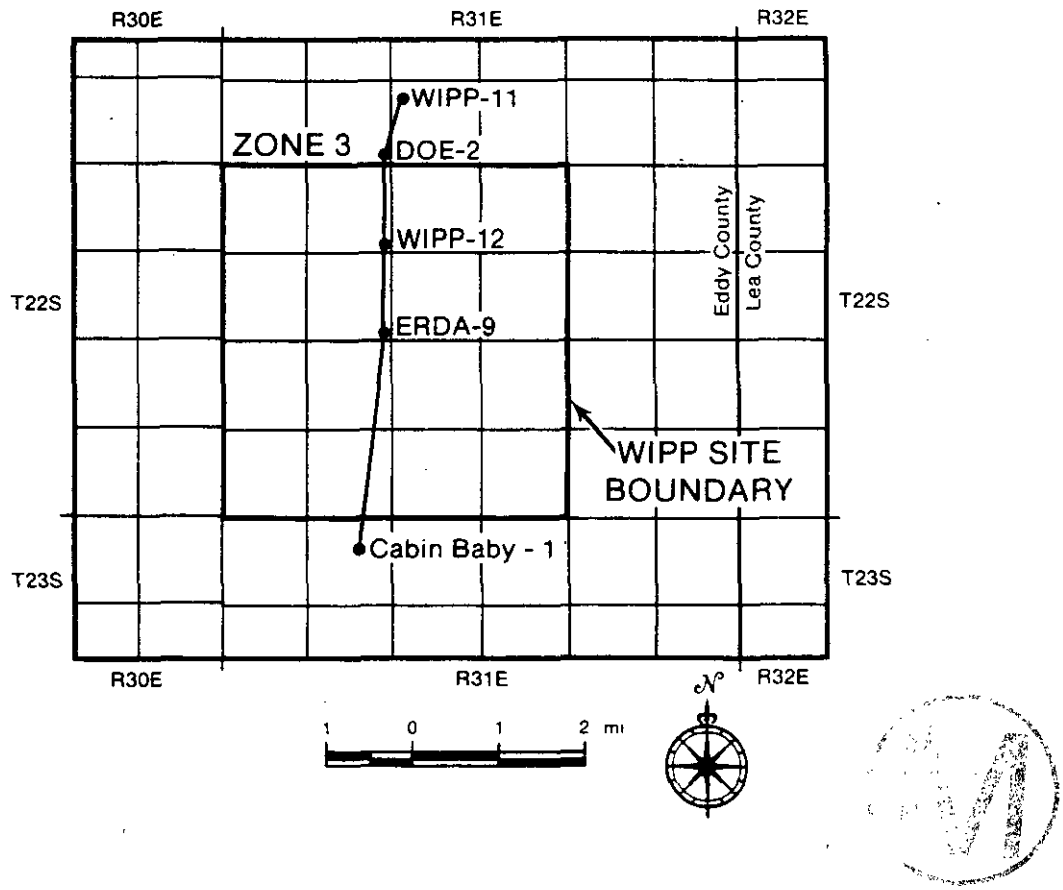

Figure 3.2: Hole locations used in Figure 3.1.

thickness of 167 m for the same units in Cabin Baby-1. At the other extreme, a total of only 2 m of Castile halite is present in DOE-2; Halite II is completely missing.

However, Anhydrites II and III also vary in thickness. Their total apparent thickness (drilled thickness, ignoring dip) in WIPP-11 is 61 m, compared to 219 m in DOE-2. Both values differ significantly from the total thickness of the two units in Cabin Baby-1, 170 m. These relationships indicate that, at least locally, anomalously thick halites within the Castile Formation are combined with anomalously thin anhydrites. Conversely, anomalously thin Castile halite, as in DOE-2, is combined with anomalously thick anhydrite. These results are inconsistent with halite dissolution being the only cause of variability in the thickness of the Castile Formation at the WIPP site.

Locally, the antithetic relations between anhydrite and halite thicknesses within the Castile are consistent with a similar relationship between overall thicknesses of the Salado and Castile Formations. The Salado is 625 m thick at Cabin Baby-1 and 602 m thick in ERDA-9. However, at WIPP-11 and WIPP-12, where the underlying Castile is anomalously thick, the Salado is unusually thin, 420 and 540 m, respectively. On the other hand, the Castile is relatively thin at DOE-2, and the apparent thickness of the Salado at DOE-2 is 647 m, greater than at either Cabin Baby-1 or ERDA-9.

Thus, the variable thicknesses of the combined Salado and Castile Formations at and near the WIPP site appear due to internally compensating variations in thicknesses of both anhydrites and halites. The origin of compensating anhydrite and halite thicknesses may be either depositional, as suggested by Lambert (1983) and Borns and Shaffer (1985), or a consequence of later gravity-driven deformation, as discussed in Borns et al. (1983). The Castile and Salado variability considered here at the WIPP site proper is very similar to that considered by Borns and Shaffer (1985) at the Poker Lake structures well south of the WIPP.

There is considerable evidence for both syndepositional and postdepositional deformation within the Castile Formation, as summarized by Borns et al. (1983) and Borns (1983). These authors distinguish three stages of deformation, listed in the sequence of development:

1. Formation of discontinuous isoclinal folds interpreted to be approximately syndepositional in age, i.e., to have occurred in soft sediments. These structures include displacive crystal growth in both anhydrites and carbonate laminae. Characteristically, the syndepositional structures are confined to a single layer, and may include disruption of the affected layer.

2. Asymmetric folding, including formation of crenulation cleavage, boudinage (separation) of carbonates, and convolute folding of anhydrite stringers within halites. Borns (1983) attributes a widespread subhorizontal fabric within Castile halites to folding at this stage. The axial planes of convolute folds in anhydrite stringers within Halites I and II are also subhorizontal. Borns (1983) interprets these relations to indicate that major deformation within the Castile often involves lateral movement of halite.

3. Late-stage near-vertical fractures and veins, which cross-cut earlier structures. These fractures may be either open, or filled with halite, anhydrite, and/or gypsum.

Syndepositional deformation was probably driven by gravity acting on original depositional slopes, or by responses to density contrasts within still-soft sediments. Borns et al. (1983) attribute later deformation to some combination of direct gravity-driven deformation resulting from deposition of dense anhydrites over less-dense halites and regional tilting of the Delaware Basin. On the large scale, the gravitic driving force for internal deformation of the Castile and overlying Salado Formations is clear. Above Anhydrite I, the Castile includes two thick anhydrites, with densities of approximately 2.95 g/cm^3. Each unit was deposited above thick halite with a density of 2.2 to 2.25 g/cm^3. Modeling discussed in Borns et al. (1983) indicates that, for the relatively thick-bedded Castile, these density contrasts should be sufficient to drive deformation in which the anhydrites effectively sink into underlying halites. Layering within the Salado is too thin to support such deformation; the Salado structures appear essentially to follow those in the underlying Castile as a relatively passive marker.

However, a driving force for deformation can be effective only if there are appropriate deformation mechanisms operating in the rocks involved. There have been three major studies into possible deformation mechanisms within the halites of the Castile and Salado. Munson (1979) assumed that deformation within the units is anhydrous. Munson concludes (Figure 3.3) that deformation under generic conditions for either a high-level-waste or TRU facility in halite would occur by an undefined mechanism, except at relatively high stress levels. At high stress levels, deformation would be dominated by creep mechanisms involving dislocation climb.

In contrast, Borns et al. (1983) associate structures within deformed portions of the Castile and Salado with the presence of fluids, and conclude that pressure solution plays a major role in controlling the regional deformation of both units. During pressure solution, deformation proceeds as a result of the migration of mineral constituents from regions of high stress to regions of low stress by means of diffusion through grain-boundary fluids. In the interpretation of Borns et al. (1983), the participation of fluids during deformation of the Castile and Salado Formations is indicated by veins containing both halite and anhydrite, as well as by anhydrite recrystallization in stress shadows. Recent studies of fluid contents within Salado halites indicate contents of as high as 2 weight percent (see Section 3.3), more than required for pressure solution to be operative (Borns, 1987b).

Borns (1987b) estimates deformation fields for halite, including pressure solution as a deformation mechanism (Figure 3.4). Field "C" in this figure includes the temperature and stress regimes estimated for regional deformation at and near the WIPP site by Borns et al. (1983), while field "B" is an analogous field for natural deformation of halites estimated by Carter and Hansen (1983) and Heard (1972). Pressure solution plays a major role in halite deformation within the conditions of both fields and assumed

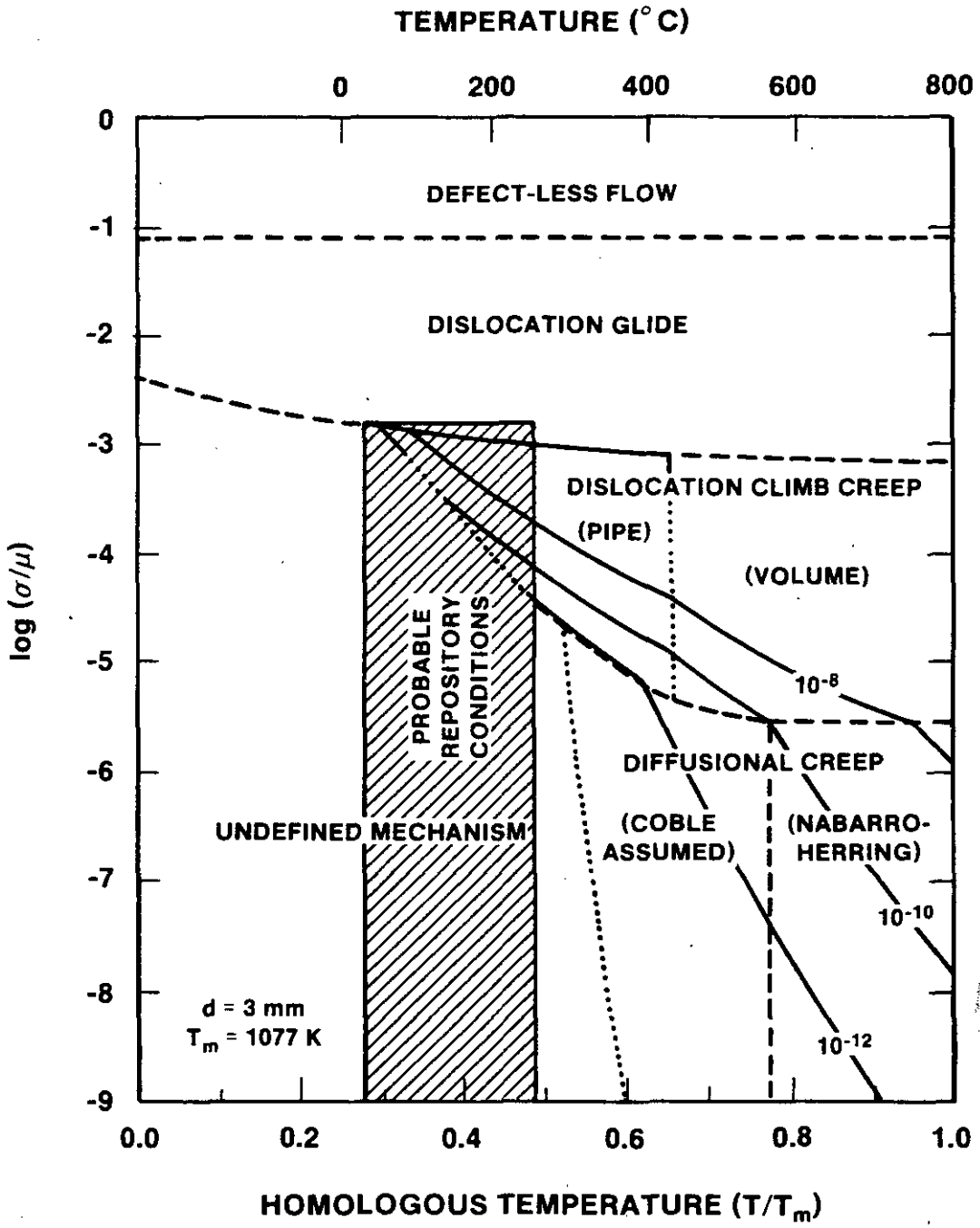

Figure 3.3: Deformation map for halite, assuming all deformation is anhydrous. Figure 2 of Borns (1987b). Homologous temperature (T/T_m) is the ratio between temperature and the dry melting temperature of halite. The stress axis is the log ratio of differential stress to halite shear modulus.

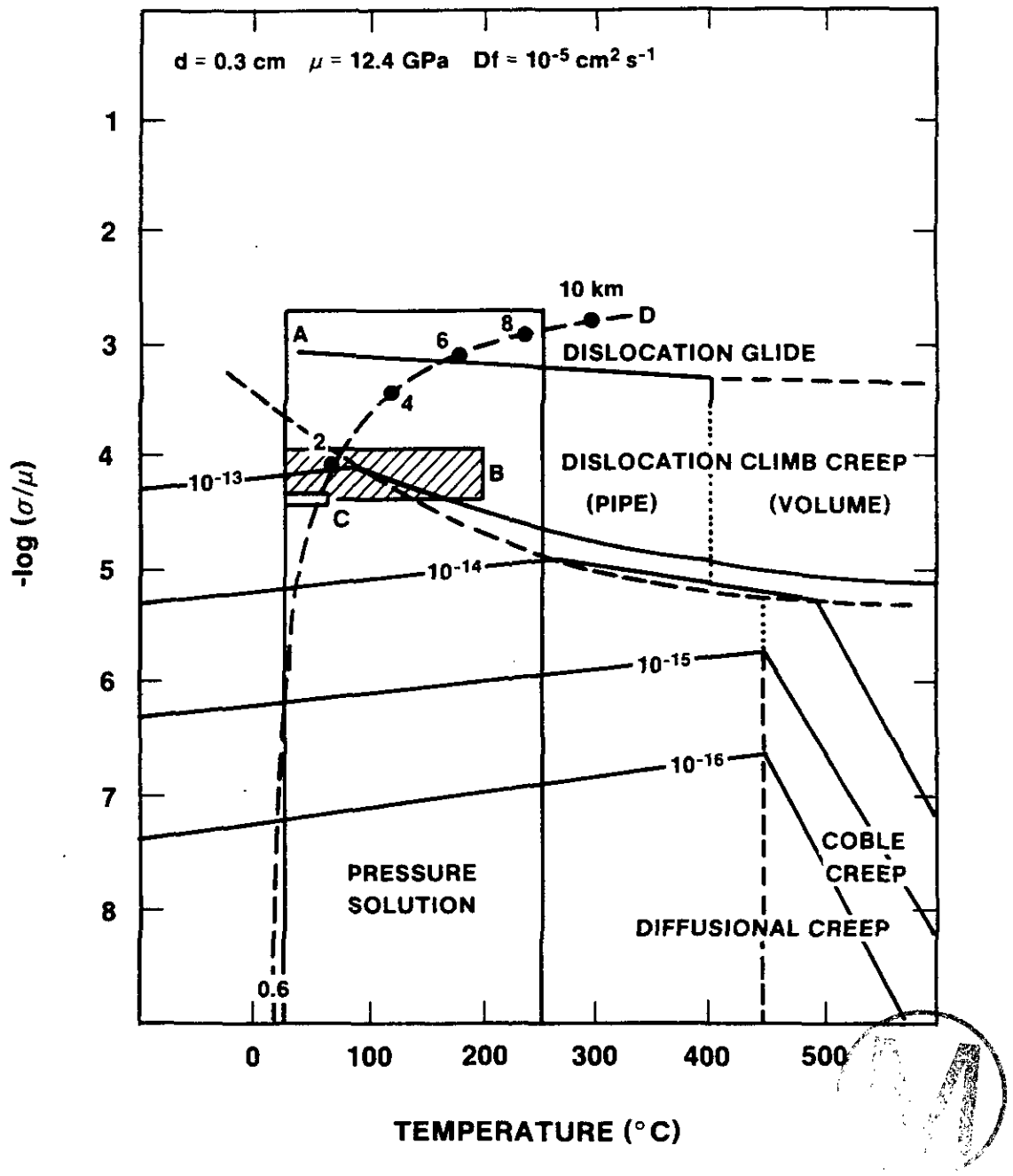

Figure 3.4: Deformation map for halite, assuming fluids present and considering pressure solution as a major deformation mechanism. Figure 4 of Borns (1987b). In this figure, viscous effects on grain boundaries are ignored. Field A is the field of "probable repository conditions" shown in Figure 3.3. Field B is the range of stress and temperature conditions estimated for natural rock-salt deformation (Carter and Hansen, 1983; Heard, 1972). Field C is the range of stress and temperature conditions for gravity-driven deformation at the WIPP site (Borns et al., 1983). Curve D is the estimated stress and temperature path for a Gulf Coast salt dome at the indicated depths (Carter and Heard, 1970).

material properties, so long as the volumetric strain rate is not greater than approximately 10^{-13} s^{-1}. As discussed by Borns (1987b), the maximum strain rates at which pressure solution is a dominant deformation mechanism depend on the character and thickness of the grain-boundary fluids.

The estimated strain rates for far-field deformation at the WIPP site, not including near-field deformation around the WIPP facility itself, are consistent with pressure solution. Based on a range of estimated strain rates of between 3 x 10^{-14} and 10^{-16} s^{-1}, the range of times calculated for formation of the WIPP-12 anticlinal structure, estimated to have undergone 1% volumetric strain, is 1.1 x 10^4 to 10^6 years (Borns et al., 1983). Near an underground facility such as the WIPP facility, however, early-time strain rates are probably too rapid for pressure solution to be a major deformation mechanism. Reported volumetric strain rates in such a setting are as high as 10^{-11} s^{-1} (Borns, 1987b), and may be even higher during initial transient closure.

In summary, the understanding of far-field deformation within the Castile and Salado Formations is consistent with the interpretations that:

1. Pressure solution, in which deformation results from mineral constituents being transported from high-stress to low-stress domains by means of an intergranular fluid or film, plays a major role in regional deformation of evaporites at and near the WIPP site. Since only approximately 0.2 volume percent (0.1 weight percent) fluid is required for pressure solution to be operative in halite, more than enough fluid is present within the Salado and Castile Formations at and near the WIPP site.

2. Much of the deformation within the DZ may have been effectively syndepositional (i.e., Permian) in age, although this is not the last period of deformation that has taken place.

3. The driving force behind regional-scale evaporite deformation at and near the WIPP is gravitational, due to the depositional emplacement of dense anhydrites over less dense halites. There is, however, a regional overprinting due to Pleistocene tilting of the entire northern Delaware Basin.

4. Deformation such as that known to occur within the DZ, even if it does progress toward the WIPP, is unlikely to reach the WIPP site within 10^4 years, the minimum estimated time required for formation of the WIPP-12 structure.

5. It is not known whether or when pressure solution will become an important mechanism in closure of the WIPP facility itself. At early times close to the facility, i.e., at relatively high stresses and deformation rates, mechanisms involving dislocation climb (and fracturing) should dominate. At later times and/or at greater distances from the underground workings, i.e., at lower stresses and deformation rates, pressure solution may dominate.

3.1.2 The DOE-2 Structure

The recognition of gravity as a driving force for regional-scale deformation of the Castile and Salado Formations and the probable role of pressure solution in such deformation does not rule out the possibility of halite removal by dissolution. The absence of halite within the Castile in the western part of the Delaware Basin (Figure 1.4) is interpreted as partly due to halite dissolution in response to regional tilting and uplift of the basin. However, as summarized by Neill et al. (1983), there is generally agreement that blanket or stratabound dissolution within the Castile and Salado Formations is not a feasible mechanism for breach of the WIPP facility on the regulatory time frame. Regional-scale evaporite dissolution within the Castile and Salado Formations is not discussed further here.

Both Anderson (1978, 1981) and Davies (1983) proposed that evaporites in the Castile and/or Salado Formations may be locally dissolved by halite-unsaturated fluids moving upwards from the Bell Canyon Formation (see Section 2.0). Subsidence of the overlying evaporites, especially the Salado Formation, would result. Hole DOE-2 was drilled specifically to investigate a depression in MB124 in the middle portion of the Salado Formation (Figure 3.1; see also Figure 2-2 of Mercer et al., 1987). However, the DOE-2 structure is interpreted as being due to lateral and vertical deformation of the Castile and Salado Formations, rather than evaporite dissolution.

The expected position of the top of the Castile Formation (Anhydrite III) in DOE-2 was at an elevation of between 230 and 260 m. However, the top of the Castile in DOE-2 was actually at an elevation of 102 m, more than 120 m lower. The base of the Castile in DOE-2, at an elevation of -199 m, is consistent with regional trends, indicating that the structure does not extend below the top of Anhydrite I.

Laminae within the upper Castile anhydrite in DOE-2 are strongly deformed, with vertical bedding and discontinuous folds at various depths (Mercer et al., 1987; Borns, 1987a). These structures are consistent with syndepositional deformation. Other structures seen in the Salado and Castile Formations in DOE-2, such as pull-apart structures and fibrous vein infillings, are interpreted by Borns as postdepositional. As noted by Borns (1987a), removal of Castile halite from DOE-2 by dissolution should have left in place many of the anhydrite "laminae" originally present in Halites I and II. No such dissolution residues were identified in core collected in hole DOE-2. The very thin Castile halite in DOE-2 (approximately 2 m) is compensated by unusually thick halites within the overlying Salado Formation. As shown in Figure 3.1 and noted in Table 3-3 of Mercer et al. (1987), halites within the informal lower member of the Salado Formation (from MB126 to the top of the Castile) in hole DOE-2 are 96 m thicker than in the same stratigraphic interval in hole WIPP-12, and 204 m thicker than in WIPP-11.

The DOE-2 structure is interpreted as being due to both lateral and vertical deformation of the Castile and Salado Formations, rather than to evaporite dissolution. The structural understanding of the Salado and

Castile does not allow prediction of where such a structure might develop in the future. Drilling and testing of hole DOE-2 indicates that no such structure remains unexamined at and near the WIPP site. Estimated times required for 1% strain in the structure at WIPP-12 indicates, however, that the time required for generation of a significant structure as a result of gravitationally driven deformation probably exceeds the 10,000-year time frame of regulatory interest.

3.2 Occurrence and Origin of Pressurized Brines within Anhydrites of the Castile Formation

Uncertainties about the original thicknesses, rates of gravity-driven deformation, and regional and local dissolution rates of Castile halites relate to natural phenomena affecting the reliability of long-term extrapolations of WIPP performance. One issue, the possible presence of pressurized Castile brines beneath the WIPP facility itself, plays a direct role in evaluation of the possible consequences of human intrusion into the WIPP facility. This is because, when encountered in drillholes, such brines can rise to the land surface; they would be capable of directly transmitting entrained waste to both the Rustler and the land surface. A geophysical survey conducted in 1987 indicates that Castile brines may be present beneath a portion of the WIPP waste-emplacement panels, consistent with previous assumptions made in WIPP performance assessment.

The known occurrences of Castile brines in the northern Delaware Basin as of 1983 (Figure 1.6) are taken from Popielak et al. (1983). Brines have been encountered in fractured Castile anhydrites in several hydrocarbon-exploration drillholes both north and northeast of the WIPP site, between the WIPP site and the margin of the Delaware Basin. In addition, Castile brines were encountered southwest of WIPP in the Belco well, approximately 6.5 km from the center of the site. During WIPP site characterization, pressurized Castile brines have been encountered in holes WIPP-12, approximately 1.6 km north of the site center, and ERDA-6, approximately 8 km northeast of the site center.

Brine volumes in the two occurrences have been estimated on the basis of flow tests and drillstem testing, but remain somewhat uncertain because of limited early flow data and the assumptions necessary concerning both fracture porosity and rock-mass compressibility in the absence of observation holes. Estimated brine volumes in the two occurrences range between 9.5×10^3 and 10^5 barrels for ERDA-6 and between 5×10^6 and 17×10^6 barrels for the WIPP-12 occurrence (Popielak et al., 1983; Neill et al., 1983).

Because of the apparent large volume of the WIPP-12 reservoir, it is reasonable to postulate that this reservoir extends beneath all or part of the WIPP facility. However, geophysical studies prior to 1983 were unsuccessful in determining whether or not Castile brines were present beneath the WIPP facility (Borns et al., 1983). Nonetheless, as a result of the occurrence of Castile brine in WIPP-12, it was assumed through 1983 that these brines were present beneath the WIPP facility (Channell, 1982; Bard, 1982; Case et al., 1982). A geophysical survey using transient

electromagnetic methods was made directly over the WIPP waste-emplacement panels in 1987 (Earth Technology, 1987), to determine the presence or absence of Castile brines beneath the facility. The results contained in Earth Technology (1987) are summarized in Figures 3.5 and 3.6.

As discussed in Section 2.0, the WIPP is underlaid by the Bell Canyon Formation. While the permeability of the upper portion of the Bell Canyon Formation is variable, the entire unit appears to be a good electrical conductor. Therefore, the dominant conductive layer beneath the WIPP facility appears to be the Bell Canyon. However, the apparent variations in depth to the first major conductor appear to exceed the estimated depth uncertainty for the geophysical method used, 75 m (Figure 3.6). At some of the locations, the interpreted depth to the first major conductor lies significantly above the depth of the top of the Bell Canyon Formation, i.e., within the Castile Formation. On the basis of this interpretation, brine may be present within the Castile Formation under part of the area outlined by the WIPP waste-emplacement panels (Earth Technology, 1987).

However, the combination of the depths to the first major conductor indicated in Figure 3.5 and stratigraphic depths indicated in Figure 3.1 suggests that the brine occurrence is limited. The depth to the top of the Bell Canyon is 1230 m in Cabin Baby-1 and approximately 1250 m in ERDA-9 (assuming linear variation between Cabin Baby-1 and DOE-2). Therefore, conductor depths greater than 1300 m in Figure 3.5 almost certainly reflect the Bell Canyon Formation. At the other limit, the depth to the bottom of the Salado is 861 m in ERDA-9 and 821 m in Cabin Baby-1. Since the minimum interpreted depth to the conductor is 988 m, the conductor does not appear to be within the Salado Formation anywhere in the surveyed area. The depth to the bottom of Anhydrite III is 959 m in Cabin Baby-1, and is assumed to be approximately 950 m in ERDA-9. Assuming 75 m vertical uncertainty in the geophysical soundings, this implies that apparent conductor depths of less than approximately 1025 m are consistent with brine occurrence within Anhydrite III. This interpretation suggests that brine is present within Anhydrite III under only the furthest northern and northeastern parts of the waste-emplacement panels. To date, pressurized Castile brines have been found only within fractured portions of the uppermost anhydrite present, Anhydrite II in ERDA-6 and Anhydrite III in WIPP-12.

The results shown in Figure 3.5 are based on one-dimensional modeling. Preliminary attempts at three-dimensional interpretation of the results indicate that the lateral resolution of the interpretation cannot be improved by more complex modeling approaches. Therefore, the "conservative" interpretation is that Castile brines are present beneath at least the northern portion of the WIPP waste-emplacement panels, consistent with both the most recent work and earlier assumptions.

Two basic hypotheses have been put forward to account for the occurrences of Castile brines:

1. Migration of connate Castile fluids into fractured anhydrites as a result of local deformation (Borns et al., 1983; Popielak et al., 1983).

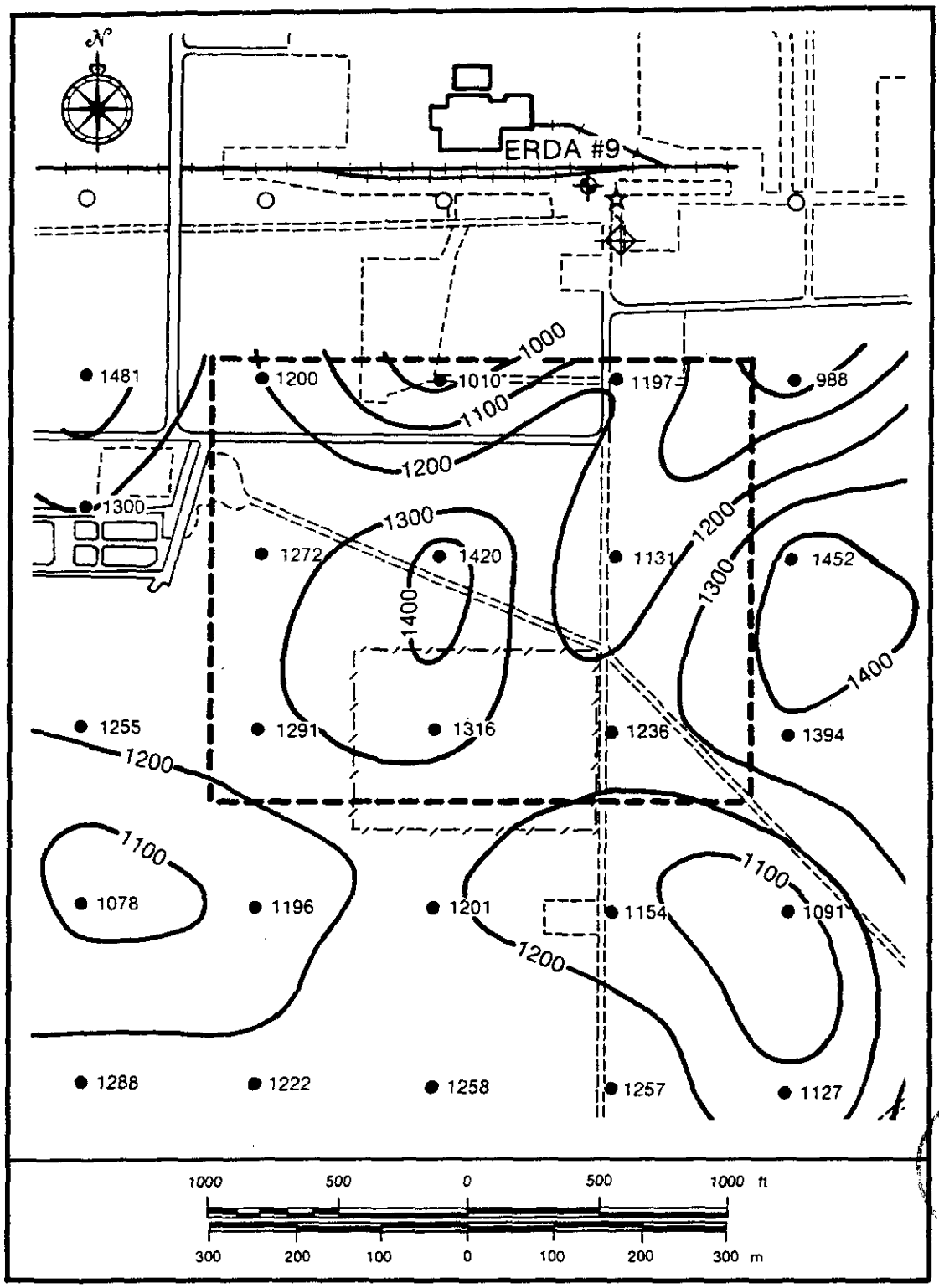

Figure 3.5: Contour map of apparent depth to first major deep conductor in survey including area of WIPP waste-emplacement panels, in meters. The heavily dashed rectangle outlines the surface projection of the WIPP waste-emplacement panels. Simplified from Figure 3-3 of Earth Technology (1987).

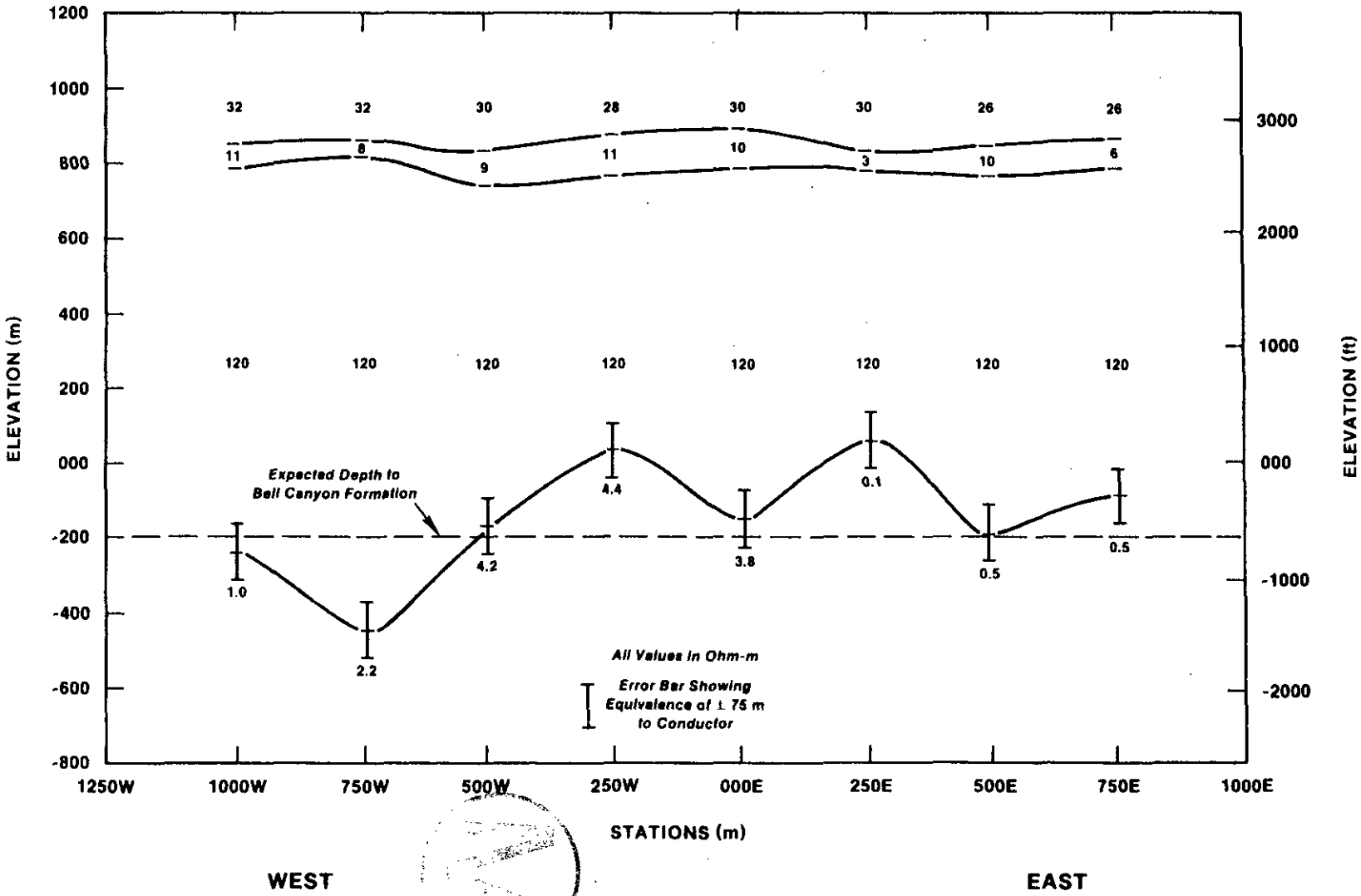

Figure 3.6: Cross section of apparent depth to first major deep conductor, showing brine locally present in both the Bell Canyon and Castile Formations. Line of section is along the north side of the WIPP waste-emplacement panels. Figure 4-11 of Earth Technology (1987).

2. Isolation of meteoric waters within fractured anhydrites following episodic hydrologic connection of the Castile with the Capitan limestone (Lambert and Carter, 1984).

According to the first hypothesis, the brines would be localized by deformation of the Castile Formation. The brines would occur in relatively low-pressure areas, such as the crests of domal or anticlinal structures similar to those encountered at WIPP-12 and ERDA-6. Such brines might continue to be generated by slow gravitationally driven deformation during and after the WIPP operational phase. Borns (1983) estimated that the reduction of porosity of the Castile halites by 0.2% required to generate the volumes of brine encountered in the WIPP-12 domal structure would likely be indistinguishable in bulk-property measurements. As pointed out by Borns (1987b), mechanical displacement and/or fluid movement during gravity-driven deformation need not be continuous. From a mechanical point of view, the emplacement of Castile brines appears consistent with either continuous or episodic deformation, and would result in indistinguishable changes in the properties of surrounding Castile halites. However, as discussed in Section 3.1, regional deformation within the Castile Formation is probably too slow to be of concern in the performance of the WIPP facility.

Lambert and Carter (1984) conclude, on the basis of uranium-disequilibrium studies, that the Castile brine occurrences were neither in-place nor remobilized connate Castile fluids. They conclude that the brine occurrences are the result of isolation of waters resulting from intermittent or episodic lateral hydraulic connection of the Capitan limestone and Castile anhydrites. Local fracturing of the Castile anhydrites is still required. Lambert and Carter (1984) specifically conclude that:

1. The residence or isolation times for the Castile brines at ERDA-6 and WIPP-12 are between 360,000 and 880,000 years.

2. The extent of buildup in $^{234}U/^{238}U$ ratios expected to result from continuous exposure of fresh rock to fluids during gravity-driven deformation is not seen.

3. Therefore, the mode of emplacement of the Castile brines must be episodic in character. The relevant episodic feature of the system is interpreted by Lambert and Carter (1984) to be hydraulic connection between the Castile anhydrites and the Capitan limestone. Any future brine generation, according to this interpretation, would require hydrologic reconnection of the Capitan and Castile.

In summary, recent geophysical studies indicate that brines are probably present within Castile anhydrites under a portion of the WIPP waste-emplacement panels. The brines are 250 m or more stratigraphically below the WIPP facility horizon. Although the detailed distribution of the brines remains unknown, this is not of special concern, since the presence of Castile brines beneath at least a portion of the WIPP facility has been and will continue to be assumed in WIPP performance assessment. The

mechanism(s) giving rise to Castile brine occurrences are not completely known. However, both mechanisms proposed, fluid migration in response to episodic deformation and isolation of fluids resulting from episodic interconnection of the Capitan limestone and Bell Canyon Formation, are unlikely to generate significant additional brine beneath the WIPP facility in the 10,000-year time scale of regulatory interest.

3.3 Recent Hydrologic, Geochemical, and Structural Studies of the Salado Formation

As mentioned above, the WIPP facility is presently being developed within bedded halites and anhydrites of the Salado Formation, at an average depth of approximately 655 m. This section attempts to place the WIPP facility within a proper perspective relative to both local and regional-scale hydrologic and structural behavior of the Salado Formation. Differences in Salado behavior as a result of the presence of the WIPP facility are considered as "excavation effects."

Section 3.3.1 discusses the hydrologic behavior of the Salado Formation as interpreted from testing conducted from the surface and within the WIPP facility. Section 3.3.2 describes the present understanding of the fluid geochemistry and mineralogy of the Salado Formation, based on recent and ongoing studies within the WIPP facility. Section 3.3.3 discusses the interim results of ongoing investigations into the structural behavior of the Salado Formation adjacent to the WIPP facility, with emphasis on Marker Bed 139 (MB139), a relatively thick anhydritic marker bed approximately 1 m below the WIPP facility horizon.

3.3.1 Regional-Scale and Near-Facility Hydrology of the Salado Formation

3.3.1.1 Hydrologic Testing from the Surface and at the Facility Horizon--Unlike the case in the Castile Formation, significant brine flows have not been encountered in hydrologic testing of the Salado Formation from the surface. However, two anomalous phenomena have been encountered in the Salado. First, pressurized gas has been encountered in some holes drilled from the surface and near the mining face in WIPP excavations. In the most dramatic case, nitrogen gas was encountered in the upper portion of the Salado in hole AEC-8, at a depth between 335 m and 391 m, during reworking of the hole approximately one year after original drilling (Table 3.1; Mercer, 1987). The gas pressure was sufficient to partially remove the drillstem from the borehole. A large volume of gas, approximately 6 x 10^5 m^3, was allowed to flow to the surface without apparent depletion of the reservoir (Mercer, 1987). Gas has also been locally encountered during construction of the WIPP facility, as described in Deal and Case (1987). To date, all gas occurrences within the WIPP facility have been small, although the largest such occurrence did result in a 0.4-m diameter disk being blown out of the face being mined. Second, as shown in Table 3.1, long-term monitoring at some holes penetrating the Salado Formation indicates a slow buildup of fluid pressure. The maximum pressure measured to date is 3.3 MPa (472 psig) at WIPP-12. This pressure is generated within the Salado, since it was measured before the hole was deepened into

Table 3.1: Summary of known Salado gas occurrences and measured wellhead pressures from surface drilling. Gas-occurrence data are modified from Table 2 of Mercer (1987). Fluid-pressure data are from the text of Mercer (1987).

A. *Gas Occurrences*

Hole	Comments
ERDA-9	At 430 m; trace of H_2S
ERDA-6	At 561 m; blew for 30 min.
AEC-7	At 491 m; blew for 1 hour
AEC-8	At 335-391 m; blew for several months
P-7	Many kicks
P-12	Hole unloaded fluid over weekend
P-20	Slight blow at TD of 608 m

B. Pressures Measured at Surface

Hole	Comments
Cabin Baby	1.4 MPa
WIPP-12	2.94 MPa, <u>before</u> deepening
WIPP-13	2.93 MPa, hole open to Castile and Salado
WIPP-11	0.12 MPa
DOE-2	0
AEC-7	0

the Castile Formation and intersected Castile brines (Section 3.2). The rate at which Salado brine pressures build up is very slow and, as noted by Mercer (1987), the pressures appear to be supported by only very small volumes of fluid. Complete reduction of the 1.6 Mpa (228 psig) pressure at the WIPP-12 wellhead in 1985 was achieved by release of approximately 5 gallons of brine. In some holes, for example DOE-2 and AEC-7, no long-term pressure buildup has been observed.

The published results of "successful" hydrologic tests of the Salado from the surface (Table 3.2) indicate permeabilities from approximately 0.01 microdarcy to a high of 25 microdarcies. Ongoing evaluation indicates that, as a result of instrumentation limitations, testing-time limitations or problems with pressure or flow stabilization, data from the Salado in DOE-2 are the most reliable, indicating a maximum permeability of 0.3 microdarcies. It has not been possible in testing from the surface to identify any discrete sources for this fluid or to determine any stratigraphic effects.

Table 3.2: Summary of Salado hydrologic properties interpreted in hydrologic testing from surface. Modified from Tables 3 through 9 of Mercer (1987). Ongoing interpretation indicates that only results from hole DOE-2 are reliable.

Hole	Comments
AEC-7	550.8-581-3 m; MB 126; gas perm. 3 x 10^{-6} D
AEC-7	672.7-703.2 m; MB 139; gas perm. 12-21 x 10^{-6} D
ERDA-9	436.8-452.9 m; MB 118, 119; perm. 0.1-0.7 x 10^{-6} D
ERDA-9	613.9-638.3 m; MB 136, 137; perm. 0.6-3.2 x 10^{-6} D
ERDA-9	765.7-798 m; Cowden, lower Salado; perm. 1.6-2.2 x 10^{-6} D
ERDA-9	799.5-876 m; lower Salado; perm 0.4-6.5 x 10^{-6} D
ERDA-9	799.5-826.9 m; lower Salado; perm. 0.7-25 x 10^{-6} D
Cabin Baby	230.7-828.2 m; entire Salado; perm. 0.01-0.1 x 10^{-6} D
DOE-2	669-703.8 m; MB 138, 139; perm. $\leq$0.3 x 10^{-6} D

However, there has been only limited "success" in field testing of the Salado from the surface. There appear to be two causes for this. First, the formation permeability appears in many cases to be below the testable minimum for the equipment used, approximately 0.01 to 0.1 microdarcy. For example, testing of all intervals in holes AEC-8, ERDA-10, and WIPP-12 was unsuccessful due to the low permeability and limitations to the test equipment. The most recent results included in Table 3.2, based on testing in Cabin Baby-1 in 1983 and DOE-2 in 1985, suggest an upper permeability

limit of approximately 0.3 microdarcies. As noted by Mercer (1987), it is not clear that any of the successful tests indicate the permeability of undisturbed halite, since the test intervals almost always include one or more interbeds. Second, in the case of hole WIPP-12, hole "ageing" during the seven years between hole completion and attempted testing of the Salado made it extremely difficult to find locations in the borehole that allowed successful setting of packers to isolate intervals for drillstem testing. The tentative interpretation is that this ageing involves loosening of grain boundaries in halites, with a concomitant increase in local permeability around the borehole.

Flow testing of the Salado Formation within the WIPP facility is still in its early stages. Preliminary results indicate that the presence of the WIPP facility has a strong impact on the hydrologic behavior of nearby portions of the Salado Formation. The results of initial gas-flow testing in the WIPP facility are described by Stormont et al. (1987). Interpretation of this testing indicated that apparent gas permeabilities are very low at distances of greater than approximately 2 m from the underground workings, with no distinguishable stratigraphic variability. Stormont et al. (1987) calculate a "far-field" permeability of less than 1 microdarcy for the Salado.

Stormont et al. (1987) identify a zone of markedly increased permeability within approximately 2 m of the underground workings, on the basis of marked increases in gas flow rates at constant injection pressure. The apparent increases in permeability are especially dramatic near room center lines, in both room roofs and floors. In addition, the magnitude of the local increases in permeability appear to be a function of both time and room width. Stormont et al. (1987) note that their measurements are consistent with time-dependent development of a dilatant or "damaged" zone around the underground workings, and that this zone may well be only partially saturated. Finally, Stormont et al. (1987) indicate that the interpretation of their tests was complicated by uncertainties in the degree of saturation of the Salado, pressure-threshold effects inherent in gas-flow testing in either a partially or fully saturated medium, and local flow inhomogeneities due to fracturing in the disturbed or altered zone near the facility.

Recent brine-flow testing within the WIPP facility described by Peterson et al. (1987) has eliminated some of the problems inherent in gas-flow testing. Peterson et al. (1987) describe the results of long-term (240-day) shut-in brine-flow tests in two holes. One hole penetrated "intact" halite and the other "intact" anhydrite in MB139, both at a distance of 8 to 9 m from the underground workings. Assuming complete saturation within the tested zones, the results indicate far-field permeabilities of approximately 0.001 microdarcy for intact halite, and 0.01 microdarcy for MB139. In addition, apparent steady-state "pore" pressures of 8.3 MPa and 10.3 MPa were measured in the two holes. Peterson et al. (1987) note that there is some uncertainty in both estimated permeabilities and fluid pressures, due to the long test times required.

Gas-flow testing of the same two holes prior to brine-flow testing, at a gas-injection injection pressure of 2.1 MPa, indicated halite and marker-bed permeabilities approximately one order of magnitude greater than

indicated in the later brine-flow testing. These higher permeabilities are similar to those reported by Stormont et al. (1987). Gas-flow testing after brine-flow testing indicated effectively zero permeability. The reasons for this complexity are not clear. It may well be that initial gas-flow testing utilized unsaturated flow paths resulting from near-hole dilatancy, and that these flow paths were later saturated during brine-flow testing.

However, it is not clear that the Salado Formation is completely saturated, even in the far-field. For example, the gas "blows" locally encountered in drilling the Salado from the surface (see Table 3.1) indicate that high-pressure gases occur locally within the unit. Unfortunately, it cannot be determined whether the initial pressures in these occurrences represent regional partial saturation or are a result of exsolution of dissolved gases as a result of stress release around drilled holes. The large gas flow in the Salado in hole AEC-8 occurred approximately one year after initial hole completion. Experience during the development of the WIPP facility also indicates the local occurrence of gas within the Salado at high pressure, perhaps approaching the local lithostatic pressure of 16 MPa. Release of gas concentrated along a fracture nearly parallel to the facility working face resulted in a small blowout during mining operations, as described by Deal and Case (1987). Later drilling in front of the same working face encountered gas at a depth of approximately 3 m. However, because gas occurrences within the WIPP facility have all been near faces being actively mined, it cannot be demonstrated that they were at lithostatic pressure before release. They may result from exsolution of dissolved gases during stress release near the excavation. Other observations by Deal and Case, such as the widespread exsolution of gas from brines collected within the WIPP facility and local bubbling of brine seeps on ribs within the facility, further suggest that gas may play a major role in at least the near-field hydrologic behavior of the Salado Formation.

Thus, the results of recent permeability testing within the Salado Formation, both within the WIPP facility and from the surface, are generally consistent with a far-field permeability of approximately 0.001 to 0.1 microdarcy. It is not certain whether the Salado is saturated or partially saturated regionally; in the altered zone near the WIPP facility, it appears to be partially saturated. There are marked near-field increases in Salado permeability near the WIPP facility, resulting from fracturing and possibly matrix dilatancy. The development of a hydrologically altered zone around workings at the WIPP facility horizon appears to depend on both time and geometry. The ultimate extent of this zone and the rate or extent of its elimination or reduction during the final stages of facility closure remain unknown at present, but will be examined carefully during the early operational phase.

3.3.1.2 Hydrologic Testing Adjacent to the WIPP Air-Intake Shaft--Barring a direct breach of the WIPP as a result of human intrusion, the successful long-term performance of the facility largely depends on the success with which the facility shafts are plugged or sealed. Present planning calls for emplacement of shaft seals in both the Salado Formation and the unnamed

lower member of the Rustler Formation. Therefore, it is important to know the distribution of hydrologic properties within both units adjacent to the WIPP shafts. A preliminary series of hydrologic tests was conducted at several levels in the WIPP waste-handling shaft during 1987. Additional testing and monitoring of the hydrologic characteristics of both the Rustler and Salado Formations adjacent to the WIPP air-intake shaft is planned.

The objectives of the preliminary hydrologic testing adjacent to the WIPP waste-handling shaft, results of which are described in Saulnier and Avis (1988), were to:

1. Determine if a significant fractured or altered zone had developed around the concrete shaft liner in the shaft since its completion.

2. Estimate the radial extent of the hydrologic cone of depression resulting from construction of the waste-handling shaft.

3. Determine "far-field" hydrologic properties for previously untested zones in the lower unnamed member of the Rustler Formation and levels in the Salado Formation at which it is anticipated that plugs might be placed at the end of the WIPP operational phase.

Testing in the waste-handling shaft was carried out in subhorizontal drillholes, using three distinct test zones. The detailed experimental instrumentation is described in Stensrud et al. (1988). Zone 1 extended from the hole "bottom" approximately 7.9 m outside the shaft to a depth of some 5.7 m, Zone 2 from approximately 4.8 m to 3.7 m, and Zone 3 from approximately 2.9 to 1.6 m. There was, however, some variability in both test-zone depths and the relationship between Zone 3 and the shaft liner. No shaft liner was present below the 850-foot level. The shaft liner was thin enough in the lower Rustler for Zone 3 to test entirely within the rock mass. At the 850 level, however, the thickened shaft liner in the keyway dictated that Zone 3 in one hole included the interface between rock and shaft liner. (English depth units are used here for consistency with depth records within the shaft).

The results of the preliminary testing in the waste-handling shaft are summarized in Table 3.3 and Figures 3.7 and 3.8. Tested lithologies include mudstone and claystone in the unnamed lower member of the Rustler (at the 782 and 805-foot depths, respectively) and halites, an anhydrite, and a polyhalite within the Salado Formation (850 and 1320-foot depths). All of the tested intervals are extremely low in permeability. Hydraulic conductivities listed in Table 3.3 range only from 10^{-14} to 10^{-13} m/s. This corresponds to an approximate range in permeability of one order of magnitude, from 0.001 to 0.01 microdarcy. There is no consistent increase in conductivity towards the shaft (from Zone 1 to Zone 3) in any of the rock types tested, except at the 850-ft level. In the 850W hole, pressurized fluids flowed into the borehole at the liner/rock interface. The precise origin of these fluids remains to be determined.

Table 3.3: Summary of results of 1987 hydrologic testing in the WIPP waste-handling shaft. From Saulnier and Avis (1988).

Borehole	Lithology	Test Zone Depth Int. (Feet from Shaft Wall)	Test Period	Pressure Pulse (psi)	Hydraulic Conductivity (m/s)	Formation Pressure (psi)
W782W	Silty Mudstone	1) 18.6-26.0	07/18-22/87	113.3	1.0 E-13	90
		2) 12.3-15.9	07/20-22/87	108.3	1.0 E-14	140
		3) 5.4- 9.5	07/21-22/87	99.4	1.0 E-14	140
W805W	Silty Claystone	1) 18.6-26.0	07/11-15/87	94.5	5.0 E-14	225
		2) 12.3-15.9	07/13-15/87	105.1	1.0 E-14	140
		3) 5.4- 9.5	07/14-15/87	97.8	1.0 E-14	110
W805SW	Silty Claystone	1) 18.6-26.5	08/28-31/87	102.9	6.0 E-15	275
		2) 12.3-15.9	Not Tested		1.0 E-14*	90*
		3) 5.4- 9.5	08/29-31/87	92.6	2.0 E-14	70
W850W	Halite	1) 18.6-26.0	07-30/08-03/87	97.6	1.0 E-13	40
		2) 12.3-15.9	08/2-3/87	116.5	1.0 E-13	40
		3) 5.4-9.5	07-31/08-3/87	90.39	Not Analyzable*	
W850SE	Halite	1) 23.2-36.0	08/19-24/87	103.5	3.0 E-14	50
		2) 16.8-20.5	08/21-24/87	103.1	3.0 E-14	30
		3) 10.0-14.1	08/22-24/87	100.7	2.0 E-14	90
W1320E	Halite/ Anhydrite Polyhalite	1) 18.6-41.8	08/11-17/87	173.3	2.0 E-14	550
		2) 12.3-15.9	08/14-17/87	52.6	3.0 E-14	450
		3) 5.4- 9.5	08/15-17/87	53.0	3.0 E-14	100

*Zone 2 analysis from pressure buildup after shut-in, August 28 to 31, 1987.

Physical limitations to the testing system dictated that Zone 3 not extend any closer than approximately 1.6 m from the inside of the shaft. Therefore, even if the one or two holes tested at each level are representative and adequately characterize the permeability at the tested levels, it can only be argued that the results indicate that no damaged zone presently extends more than 2 m into the rock mass. This includes any damage zone resulting from blasting during construction of the shaft. In addition, because of scheduling constraints, all of the testing was relatively short-term. Longer-term testing might identify changes in hydraulic properties near the shaft.

The permeabilities listed in Table 3.3 indicate no significant stratigraphic variability. All of the tests indicate extremely low permeability, roughly one order of magnitude less than estimated from measurements from the surface. One reason for this may be that the holes tested here were nearly horizontal; as a result, at least part of the fluid flow was vertical, perpendicular to layering. The results may imply that vertical

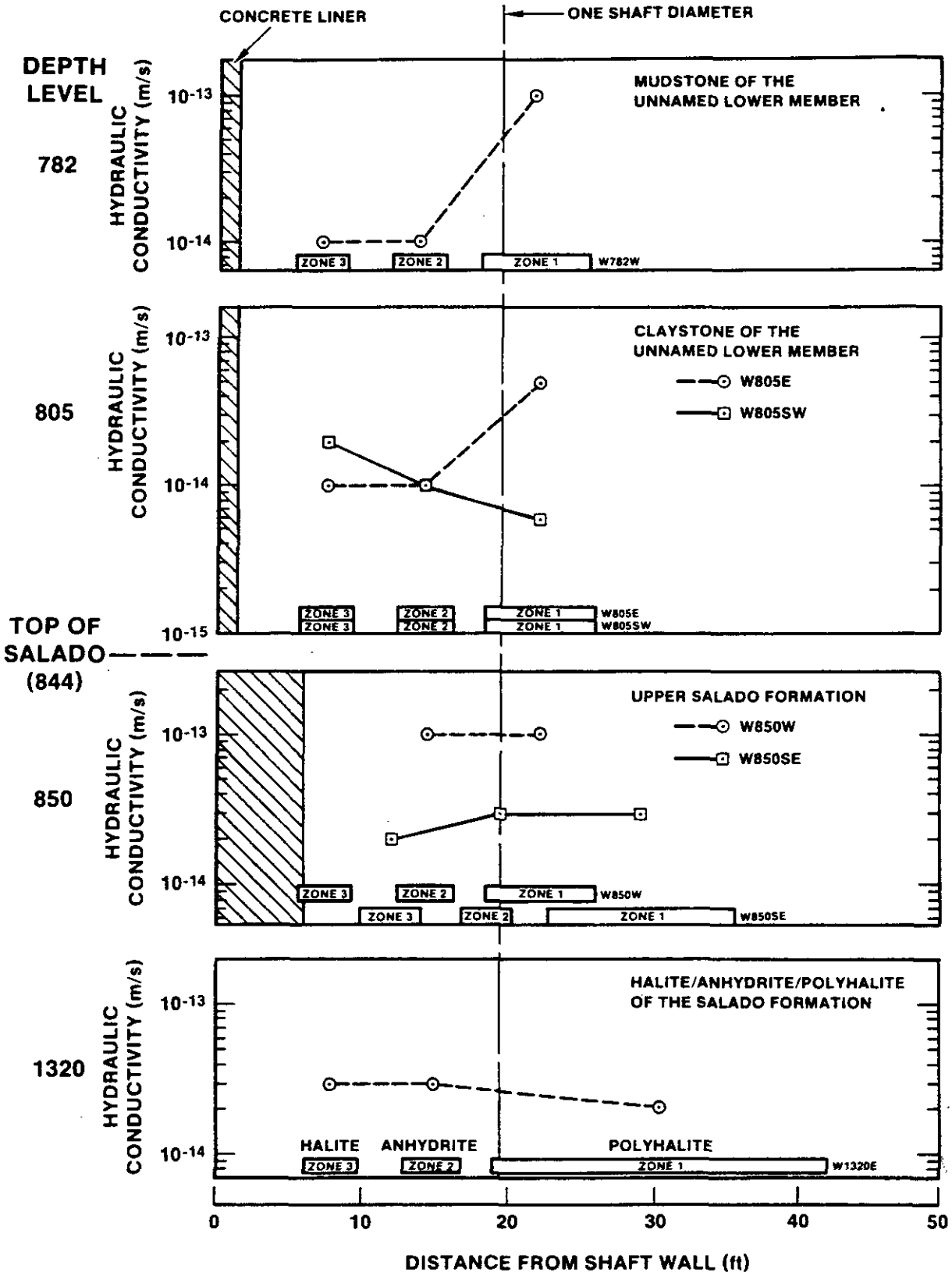

Figure 3.7: Summary of formation conductivities determined in 1987 testing in the WIPP waste-handling shaft. Figure 6.3 of Saulnier and Avis (1988).

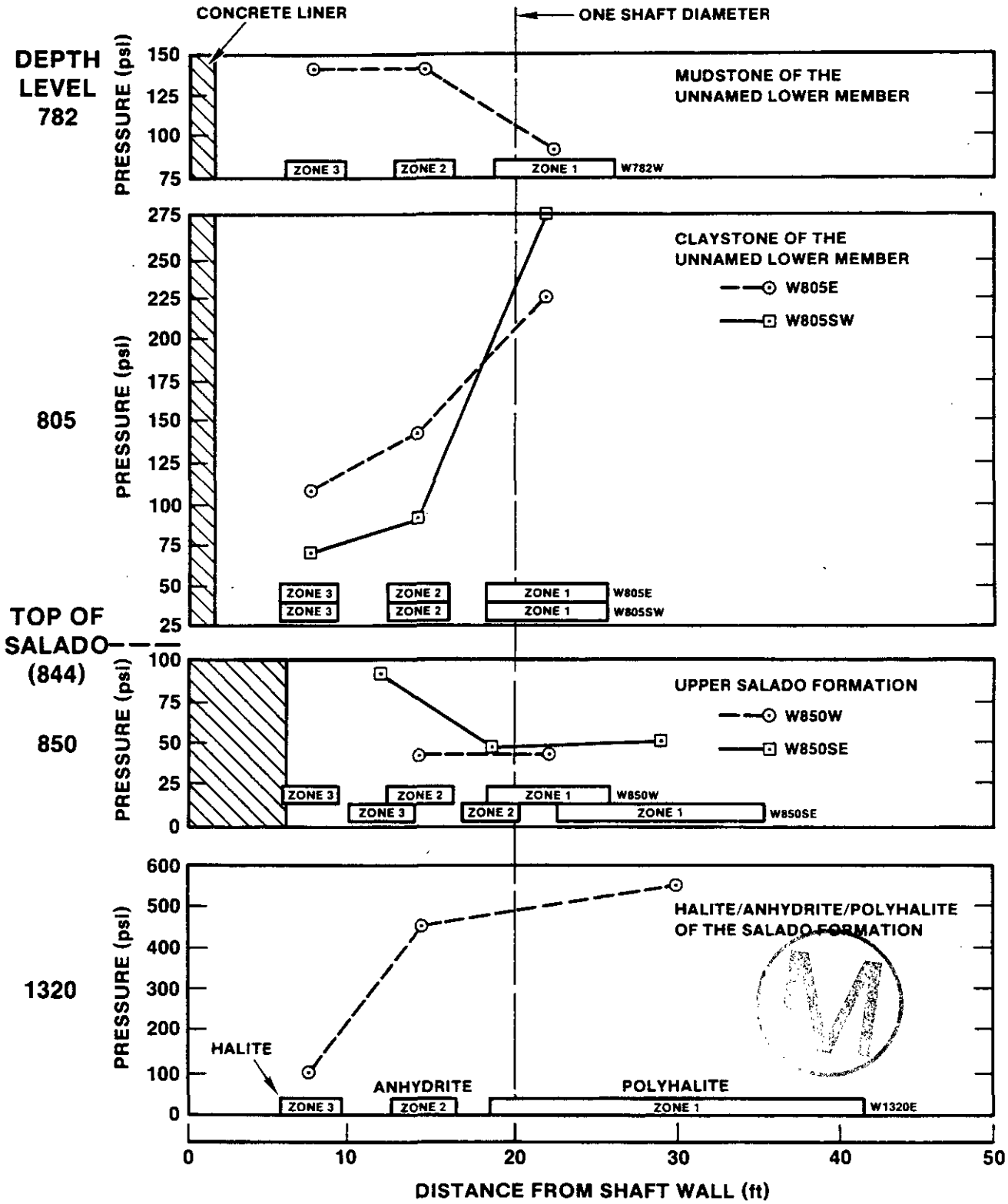

Figure 3.8: Summary of fluid formation pressures determined in 1987 testing in the WIPP waste-handling shaft. Figure 6.1 of Saulnier and Avis (1988).

permeability in both the lower part of the Rustler Formation and the Salado Formation is less than horizontal permeability, consistent with experience in other layered rock types.

Testing adjacent to the waste-handling shaft did indicate a distinct zone of decreased fluid pressures around the shaft at the 805-foot and 1320-foot levels, in claystone and halite/anhydrite/polyhalite, respectively (Figure 3.8). The cone of fluid-pressure depression apparently extends outward to greater than one shaft diameter at these levels. The fluid-pressure profiles at the 782-foot and 850-foot levels may be indeterminate because of effects of equipment compliance (Saulnier and Avis, 1988). The generation of a hydraulic cone of depression around the shaft was expected, consistent with responses noted earlier in the Culebra dolomite to construction of the WIPP exploratory shafts (see Haug et al., 1987). The behavior of this zone outside the Culebra as a function of time remains unknown.

Interpretation or prediction of long-term flow behavior into the shaft would require an observation hole, so that fluid storativities within affected units could be estimated. A nearby observation hole does not exist for the waste-handling shaft. However, hole H-16 was drilled and instrumented in 1987, approximately 17 m from the centerline of the WIPP air-intake shaft, specifically to investigate the near-field hydraulic response of all members of the Rustler Formation to construction of the shaft, and to provide monitoring data adequate for long-term predictions.

The hydrologic testing completed to date adjacent to the waste-handling shaft is preliminary, as is the interpretation of test results. The results to date allow limited fracturing, since only one or two holes was tested at each level. To better determine the presence or absence of fracturing by direct hydrologic measurement, arrays of three or more holes would be needed at each level. The fact that fluids were encountered at the liner/rock interface in one hole at the 850-foot level demonstrates that fluid movement at the shaft-liner/rock interface is possible locally, and that a single drillhole is not sufficient to characterize the source or behavior of these fluids. Non-intrusive geophysical methods similar to those described in Section 3.3.1.3 may aid in characterization of any altered zone around the WIPP shafts.

3.3.1.3 Brine Contents and Brine Seepage into the WIPP Facility--Geophysical studies within the WIPP facility aimed at characterization of the near-field disturbed rock zone are interim, and will continue during the early part of the WIPP operational phase. The presently available results, summarized in Borns and Stormont (1987) and Pfeifer (1987), indicate both that there is near-field variability in the water content and hydrologic properties of the Salado Formation and that water contents of Salado halites in the far-field are approximately twice that estimated at the time of the WIPP SPDV studies.

The results of a series of electrical conductivity measurements within the WIPP underground workings (Pfeifer, 1987) are shown in Figure 3.9. Two

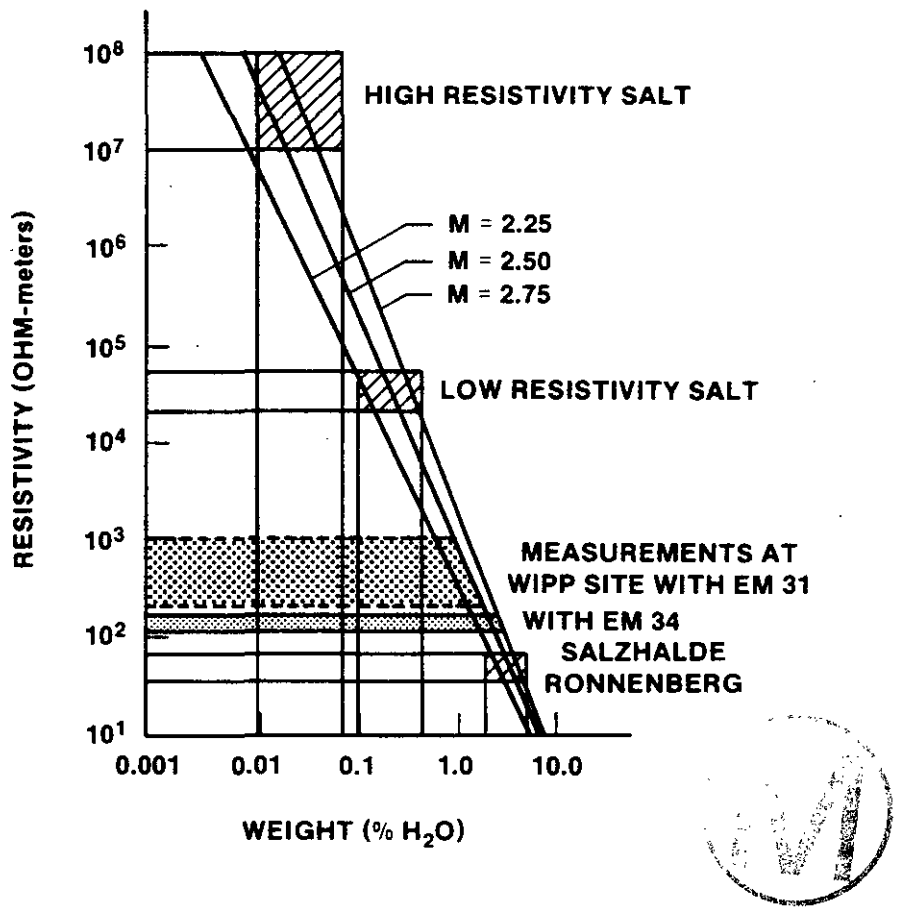

Figure 3.9: Apparent variation in water content of Salado halite at the WIPP facility horizon with depth into the wall. The EM31 survey investigates conductivity up to approximately 2 m depth and the EM34 survey to a depth up to 20 m. Figure 9 of Pfeifer (1987).

different instrumentation systems were used in these measurements. The EM31 system investigates the effective electrical conductivity to a depth of approximately 2 m, the EM34 system to a depth of up to 20 m into the adjacent rock mass. The apparent conductivity near the underground workings, measured with the EM31 system, is lower (resistivity is higher) than that measured at greater depth with the EM34 system. In Figure 3.9 this variation in resistivity is compared with a published correlation between water contents and resistivities of halites. The results are consistent with a water content of approximately 1% (by weight) near the mine opening and 2% or greater in the far field. Recent geophysical moisture and density measurements within the WIPP facility (Hudson, 1987) also are consistent with water contents of approximately 2 weight percent in Salado halite in the far field.

The recent results indicate that far-field water contents within the Salado Formation, estimated to average approximately 2 weight percent, are greater than previously expected. For example, estimated water contents of samples analyzed during SPDV activities ranged from a mean of 0.6 weight percent to a maximum of 1.8 weight percent, compared to mean and maximum values of 0.22 and 1.06 weight percent estimated from measurements on core from hole ERDA-9 (Beauheim et al., 1983a). The earlier estimates were made either on core material or on hand specimens collected during mining.

The combination of significant interconnected fluid contents and non-zero permeabilities within the Salado Formation in both the far-field and near the WIPP facility dictates that there be some fluid flow into the facility until effective hydrologic closure of the facility takes place. Two studies, both in their early stages, investigate the amounts and characteristics of fluid flow into the facility. One study, summarized in Deal and Case (1987), is a long-term study to characterize flow into the WIPP facility (exclusive of shafts) at ambient temperature. The second study, summarized in Nowak and McTigue (1987), is part of an experimental program using electrical heaters to simulate emplacement of defense-generated high-level waste (DHLW). A knowledge of ambient-temperature behavior is required in this study as a baseline for interpretation of later superimposed thermal effects.

Two lines of evidence summarized by Deal and Case (1987) indicate the complexity of ambient-temperature fluid flow into the WIPP facility from the Salado Formation. First, brine "seeps" often form within a few days on mined faces, and are indicated by the development of localized salt crusts or efflorescences on the walls. The seeps often appear to stop flowing after approximately one month. However, investigation of the salt deposits indicates that fluid flow may only decrease rather than ceasing entirely, and that the rate at which mine ventilation removes water locally exceeds the inflow rate at long times. Second, highly variable amounts of both brine and dissolved gas are intersected in drillholes within the WIPP facility. Minimum flow rates are apparently zero. The maximum flow rate was approximately 0.5 liter per day. One hole has produced approximately 235 liters of brine, and produced at a roughly steady-steady rate of 0.2 liters per day (Deal and Case, 1987). However, this hole apparently intersects numerous near-field fractures in MB139 related to the construction of the WIPP facility, and is unusual. Most of the measured

flow rates range from a few hundredths to a few tenths of a liter per day. Deformation near the facility strongly influences fluid flow. Deal and Case (1987) note that fluid flow into most holes within the WIPP facility is initially zero or nearly zero. This phase is normally followed by a relatively rapid rise to some maximum flow rate, after which flow slowly reduces to some relatively steady-state but decreasing value.

Work summarized in Nowak and McTigue (1987) investigates flow into one 0.9-m (36-inch) and three 0.76-m (30-inch) diameter holes emplaced as part of experiments simulating and overtesting emplacement of DHLW. Water was continuously removed from the holes by use of dry nitrogen. A baseline ambient-temperature flow of 5 to 15 grams/day was collected in each hole after an initial transient phase. The average flow of 10 grams per day extrapolates to a steady-state flux of approximately 1.6 $cm^3/day/m^2$ of excavation wall. After the heaters were turned on, there was a rapid increase in flow rate to some peak value, followed by a reduction to near steady-state flow. Apparent steady-state flow rates were 50 to 80 g/day in the two holes containing 1.5 kW heaters, and 8 to 10 g/day in the two holes containing 470 W heaters. The integrated fluid flow into the most strongly heated holes was 36 to 38 kg of fluid after 600 days. This mass is significantly greater than the 0.1 kg collected after two years in similar experiments conducted in domal salts at the Asse Mine, Germany (Nowak and McTigue, 1987). The difference suggests a significant difference between fluid flow in domal salts and in bedded salts, such as those at the WIPP.

Parametric numerical modeling described by Nowak and McTigue (1987) indicates that:

1. Pore-pressure measurements in both the near-field and far-field domains of the Salado Formation are needed to determine far-field and near-field flow behavior, since the observed transient effects resulting from seepage appear at present to be limited to the very near-field domain.

2. The transient stage of flow into the WIPP waste-emplacement rooms will last until connected pore space in both the rooms and any altered zone around the facility is either effectively eliminated or comes to pore-pressure equilibrium with the surrounding Salado. The calculations indicate that transient flow, ignoring closure, might last for more than 5000 years.

3. The rock volume effectively involved in flow within the Salado may be limited, rather than a significant portion of the formation. However, the affected volume must increase with time.

In summary, recent hydrologic results in the Salado Formation indicate that the unit has a far-field permeability of less than 0.1 microdarcy. It has not been possible to determine either stratigraphic effects or the presence of effective fracturing in the far-field environment. The brine content of Salado halites appears to be up to 2 weight percent in the far-field, roughly twice that previously expected. Where it has been possible to measure Salado brine pressures, the calculated heads indicate very limited fluid flow upwards into the overlying Rustler Formation. The permeability

of the Salado locally increases markedly within two meters of excavations at the WIPP facility horizon. The increase in permeability appears to be both time-dependent and geometry-dependent, and to involve significant fracturing. The Salado Formation may be only partially saturated in both the near-field and far-field environments. The low permeability of the Salado Formation, mine ventilation, and rapid mechanical deformation near the WIPP facility result in markedly transient fluid flow into the underground workings. At present, the time-scale of transient flow, volume of the Salado involved in flow, and final fluid volumes to be expected within the WIPP facility remain to be precisely determined.

3.3.2 Geochemical and Mineralogical Studies of the Salado Formation Near the Facility Horizon

The mineralogy and stratigraphy of the Salado Formation are somewhat complex. The general mineralogy of the units is summarized by Bodine (1978), and mineralogy near the WIPP facility horizon by Stein (1985). Bodine (1978) noted that Salado clays were unusually depleted in aluminum and enriched in magnesium. The recent work by Stein (1985) does not include detailed clay mineralogy, but does indicate the nearly ubiquitous occurrence of authigenic quartz and magnesite near the WIPP facility horizon, in addition to widespread occurrence of anhydrite, gypsum, and polyhalite as accessory minerals within halites.

As mentioned in Section 3.3.1, it has not been possible to sample Salado fluids during drilling or testing from the surface. However, Salado fluids have been sampled within the WIPP facility, and are continuing to be collected, as described in Deal and Case (1987). The compositional results available to date for Salado fluids collected within the WIPP facility are described in Stein and Krumhansl (1986), and directly address both the character of fluids within the Salado Formation and the validity of assumptions held through 1983 concerning the types of fluids within the unit.

It was assumed through 1983 that Salado halites were anhydrous, with the exception of fluid inclusions and the water of hydration of hydrated minerals such as clays and polyhalites. Both the compositions and ages of fluid inclusions within Salado halites were poorly constrained. The compositional results for Salado fluid inclusions and macroscopic brine occurrences within the WIPP facility, summarized by Stein and Krumhansl (1986), are shown in Figure 3.10. The open and half-open squares in Figure 3.10 represent the compositions of individual fluid inclusions extracted from crystals of halite. The circles and crosses represent the compositions of macroscopic fluids collected from the WIPP facility, respectively from brine "seeps" on the walls and holes in the floor.

The fluid-inclusion compositions and compositions of fluids from seeps and holes form two distinct populations in terms of their respective Na/Cl and K/Mg weight ratios. Therefore, fluids encountered within the WIPP facility cannot primarily arise from the migration of fluid inclusions. Stein and Krumhansl (1986) relate the compositions of fluid-inclusion Groups I (half-open squares in Figure 3.10) and II (open squares) to alteration of brines

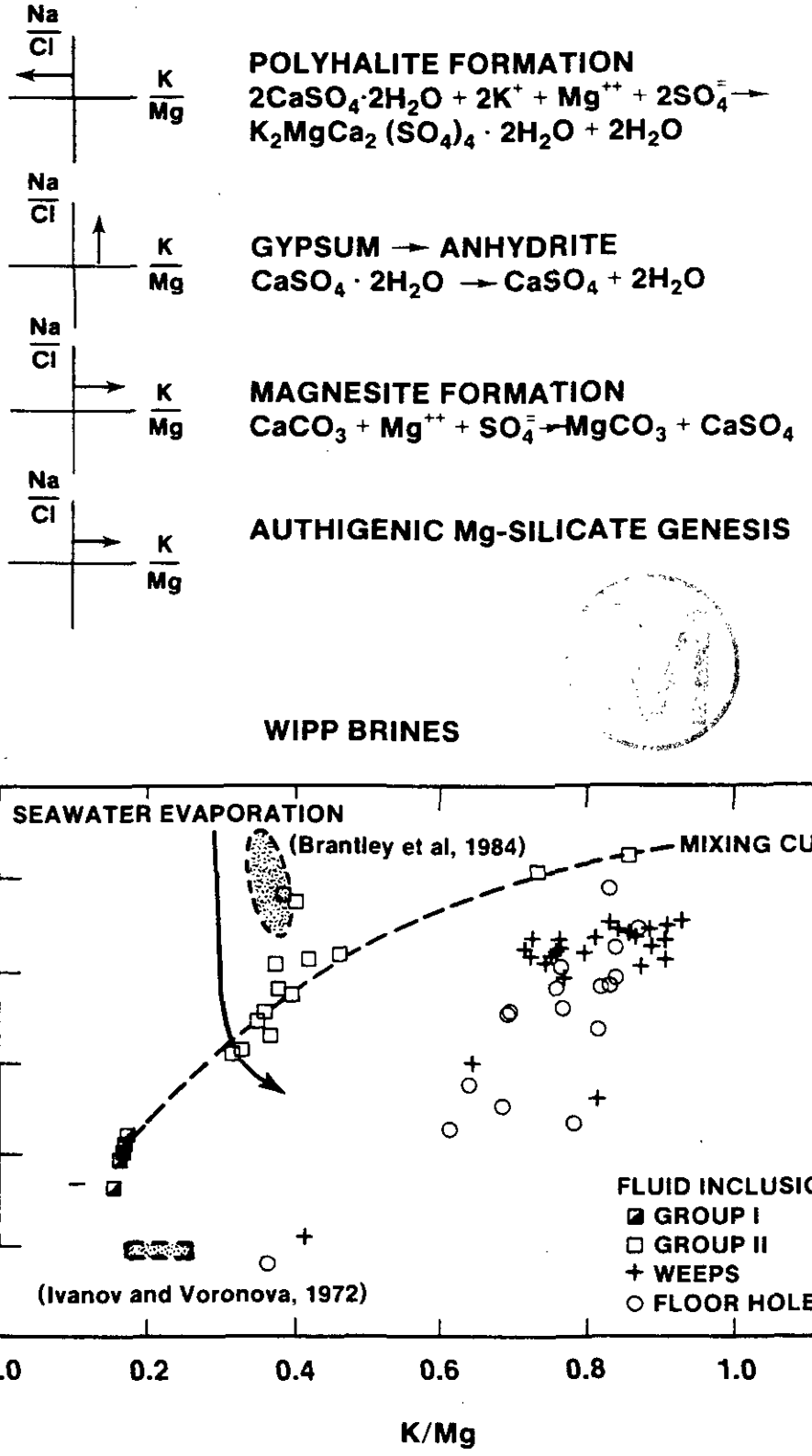

Figure 3.10: Compositional variability of Salado fluids from fluid inclusions and macroscopic brine occurrences in the WIPP facility. Figure 9 of Stein and Krumhansl (1986). Effects of individual reactions on fluid composition are also indicated.

originally resulting from evaporation of seawater. They interpret the controlling mechanisms to be crystallization of polyhalite and magnesite. Polyhalite formation drives fluid compositions to the left of the seawater-evaporation line in K/Mg space (Group I), while formation of magnesite drives fluid compositions to the right (Group II). The compositional effects of these reactions are summarized in the reactions included as part of Figure 3.10.

Both polyhalite and magnesite are widespread accessory minerals within Salado halites (Stein, 1985). Radiometric age dating of polyhalites from the WIPP (Brookins and Lambert, 1987) indicates crystallization ages of from 195 to 216 million years, i.e., from approximately 25 to 45 million years after deposition. The age of magnesite formation is unknown, but is assumed to be similar to that of polyhalite. On this basis, Stein and Krumhansl (1986) conclude that brines contained in fluid inclusions from samples near the WIPP facility horizon are roughly 200 million years old.

The fluids from weeps and seeps in the WIPP facility are enriched in potassium relative to both fluid inclusions and fluids expected from seawater evaporation (Figure 3.10). As discussed by Stein and Krumhansl and noted by Bodine (1978), the Salado clay-mineral assemblage is unusually Mg-rich. Stein and Krumhansl (1986) conclude that the relatively K-rich composition of fluids from weeps and seeps reflects the effects of the growth of these Mg-enriched silicates on grain-boundary fluids. While it is not possible to place a specific age on the grain-boundary fluids, it is known that the kinetics of such reactions are very slow. Therefore, Stein and Krumhansl (1986) conclude that the residence time of grain-boundary fluids within the Salado Formation must be at least several million years. The marked variability of fluids as a function of stratigraphy near the WIPP facility horizon, noted by Stein and Krumhansl, is consistent with there being little or no vertical fluid movement.

There is additional geochemical evidence for both the presence and timing of rock-water interactions involving fluids from the Rustler/Salado contact and deeper evaporite horizons at and near the WIPP. As summarized by Lambert and Harvey (1987), there is a body of consistent radiochronological evidence indicating the absence of any pervasive recrystallization of the evaporite section in approximately the last 200 million years. The internally consistent evidence consists of: a) K-Ar dating of polyhalites ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$); b) Rb/Sr isochrons on sylvites (KCl); and c) both Rb-Sr and K-Ar ages on langbeinite ($K_2Mg_2(SO_4)_3$). Apparent ages on leonite ($K_2Mg(SO_4)_2 \cdot 4H_2O$) are younger than ages on other minerals. Both Rb-Sr and K-Ar ages of clay minerals are significantly greater than the depositional age of the enclosing evaporites, suggesting that secondary reactions involving the clays have not completely altered their compositions. Thus, while the accessory magnesite near the WIPP facility horizon has not been dated, there is abundant radiometric evidence that the last major recrystallization of the Salado Formation occurred approximately 200 million years ago.

Available isotopic evidence for strong rock-water interactions in evaporitic rocks at and below the Rustler/Salado contact is summarized in Figure 3.11. These data and their implications for fluid flow are

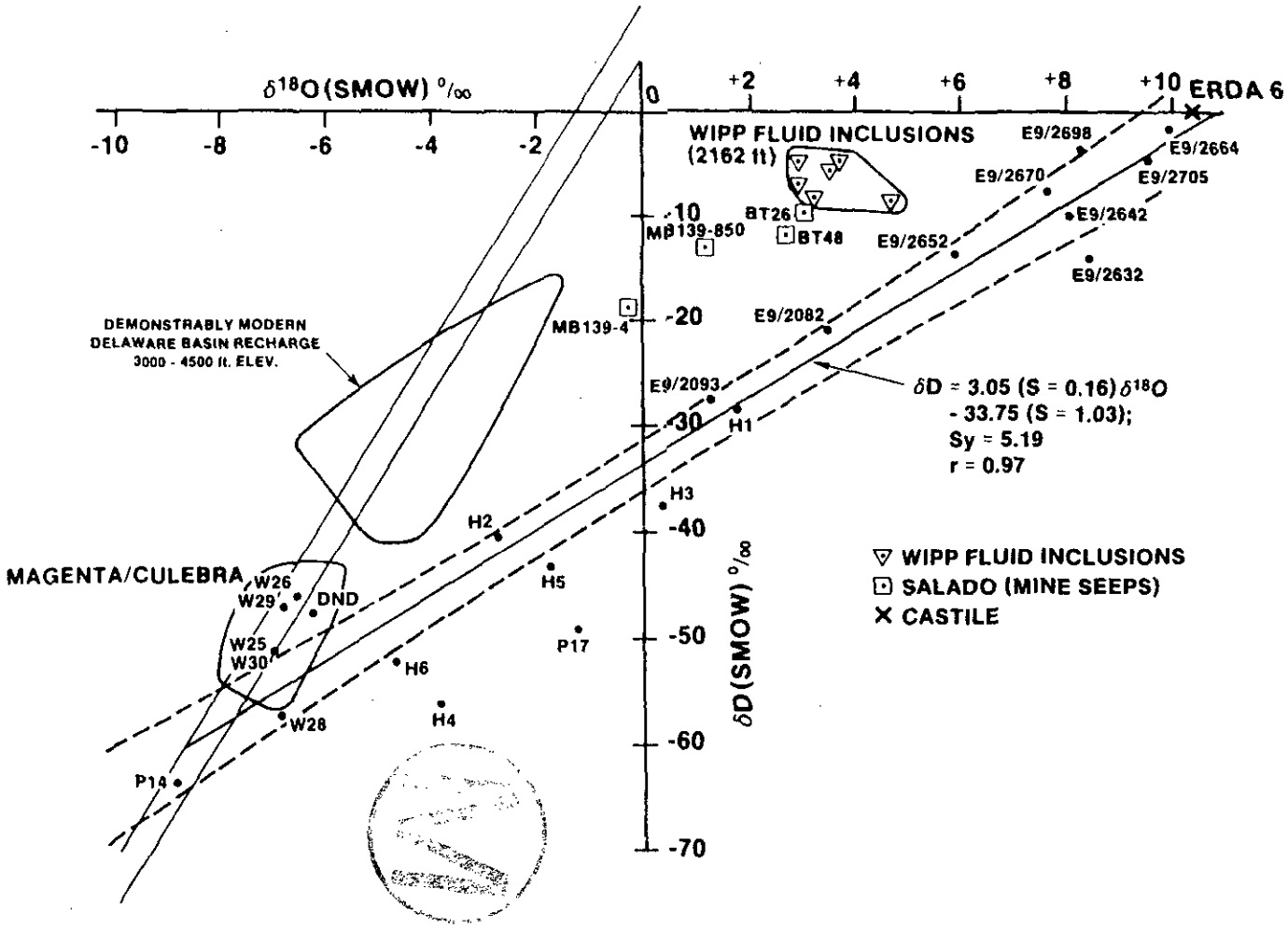

Figure 3.11: Stable-isotope composition of fluids from the Rustler/Salado contact and deeper evaporite zones at the WIPP site. Figure 25 of Lambert and Harvey (1987). Figure includes data from hole ERDA-9 (E9) of O'Neil et al. (1986) and fluid-inclusion data from the WIPP facility horizon (Knauth and Beeunas, 1986), in addition to original data from Lambert and Harvey. Lambert and Harvey data from the Rustler/Salado contact are indicated by hole designations, and those from MB139 by the appropriate prefix. Samples from seeps within the Duval Mine are indicated by the prefix BT (see Lambert and Harvey, 1987, for additional detail).

discussed by Lambert and Harvey (1987) relative to interpretations made by both O'Neil et al. (1986) and Knauth and Beeunas (1986).

O'Neil et al. (1986) consider the linear relationship between the isotopic composition of Castile brines (represented by brines from ERDA-6), fluid inclusions from the lower Salado in hole ERDA-9, and "modern meteoric water" (represented by fluids from Nash Draw and the western part of the WIPP site). They conclude that the trend reflects varying amounts of (vertical) mixing of Castile brines and modern near-surface waters. Lambert and Harvey (1987) conclude that large-scale mixing of fluids should involve major recrystallization of the evaporite section. They conclude, based on the radiometric-dating results discussed above, that such recrystallization has not taken place in the last 200 million years. Since they also concluded that large-scale mixing of fluids within an evaporite section would require recrystallization, the lack of significant recrystallization within the Salado is taken to indicate that there is no significant modern vertical mixing of Castile and surface fluids (Lambert and Harvey, 1987).

Instead, Lambert and Harvey (1987) consider the Castile fluids from ERDA-6, ERDA-9 fluid inclusions, and numerous fluids sampled from the Rustler/Salado contact as a single group (Figure 3.11). They conclude that these fluids form a variable population reflecting a mechanism by which increasing deviation of fluids from the meteoric compositional field results from increasing rock/water ratios, with resulting increasing interaction of fluids with hydrous minerals, especially clays, gypsum, and polyhalite. However, the isotopic character of rock-water reactions involving both gypsum and polyhalite are partially undefined at present.

One group of data shown in Figure 3.11 is not consistent with any single mechanism or trend of rock-water interaction within the Salado Formation. As noted, the trend including data from ERDA-6 brines, ERDA-9 fluid inclusions, and Rustler/Salado fluids appears to be continuous. However, fluids sampled directly in holes penetrating MB139 (samples MB139-850 and MB139-4) and in weeps within the nearby Duval Potash Mine (samples BT26 and BT48) are quite distinct. The isotopic composition of Salado fluid inclusions at the WIPP facility horizon reported by Knauth and Beeaunas (1986) are distinct and different from the character of inclusions from the Salado in ERDA-9. The reasons for the distinctions in fluid-inclusion analyses are not known, but may, as noted by Lambert and Harvey (1987), involve the different fluid-extraction techniques used by the different authors. The reason for the apparently distinct isotopic character of fluids from MB139 is not known at present. The available data indicate only a small isotopic distinction between fluid inclusions and macroscopic fluids collected at the WIPP horizon, in spite of the significant compositional differences between the two types of fluids noted by Stein and Krumhansl (1986).

In summary, the recent geochemical and hydrologic studies of the Salado Formation are generally internally consistent, but are incomplete at the present time. Hydrologic measurements indicate a far-field Salado permeability of less than 0.1 microdarcy. This indicates that, independent of local complications caused by the presence of the WIPP facility itself, fluid flow within the Salado is non-zero but extremely slow. The work by

Stein and Krumhansl indicates that the brine in fluid inclusions within Salado halites is on the order of 200 million years old, and is not the major source of fluid in the WIPP facility. Rather, the variable fluids in the WIPP underground workings appear to be grain-boundary fluids which have residence times within the Salado Formation of at least several million years. The variability in fluid compositions near the WIPP facility horizon is consistent with there being little or no vertical fluid movement. The isotope systematics and radiometric age dating of the Salado brines and minerals, considered together, are not consistent with derivation of Salado brines by modern large-scale vertical mixing of Castile and surficial waters.

3.3.3 Marker Bed 139 and the Structural Behavior of the Salado Formation near the WIPP Facility

Marker Bed 139, an anhydritic marker bed about 1 m in average thickness, occurs approximately 1 m or less below the WIPP facility horizon. Detailed study of MB139 began in 1983, because of concern that undulations on the top of the unit might be the result of deformation at some time after deposition or diagenesis (Jarolimek et al., 1983). If this were true, it is conceivable that such deformation might impact the WIPP facility during either the operational or regulatory time frames. The results of both Jarolimek et al. (1983) and Borns (1985) indicate, however, that the undulations on the upper surface of MB139 are depositional in origin.

Recent interest has focused on the mechanical and hydrologic fluid-flow behavior of MB139 near the WIPP underground workings. Observed behavior in room closure to date, especially in the oldest or "SPDV" rooms, indicates time-dependent opening of fractures in both MB139 and the halitic interval between MB139 and the room floors. It may be necessary to excavate MB139 in some areas before the end of operations, to provide an unaltered locality for emplacement of seals at the facility level. The mineralogy and structure of MB139 also provide information concerning long-term mechanical and fluid behavior within anhydritic portions of the Salado Formation, independent of the WIPP facility. Work examining MB139 and its role in excavation effects near the WIPP facility horizon is progressing; therefore, the discussion here is preliminary.

Borns (1985) investigated the stratigraphy and structure of MB139 in some detail, using core from a five-hole array drilled specifically for this purpose. The general level of internal complexity within MB139 is shown in Figure 3.12. The unit is bounded above and below by irregular contact zones. The lower contact zone (Zone V), often referred to informally as a "clay seam," is clay-rich and locally indicates some erosion and embayment of the top of the underlying polyhalitic halite. The upper contact zone (Zone I) is quite irregular in thickness, and contains structures indicative of shallow water deposition, such as mounds of halite hopper crystals. Borns (1985) concludes that the irregularities on the upper surface of MB139 are primary or depositional in origin, resulting from shallow-water depositional processes such as wave traction. This conclusion is in agreement with conclusions originally reached by Jarolimek et al. (1983).

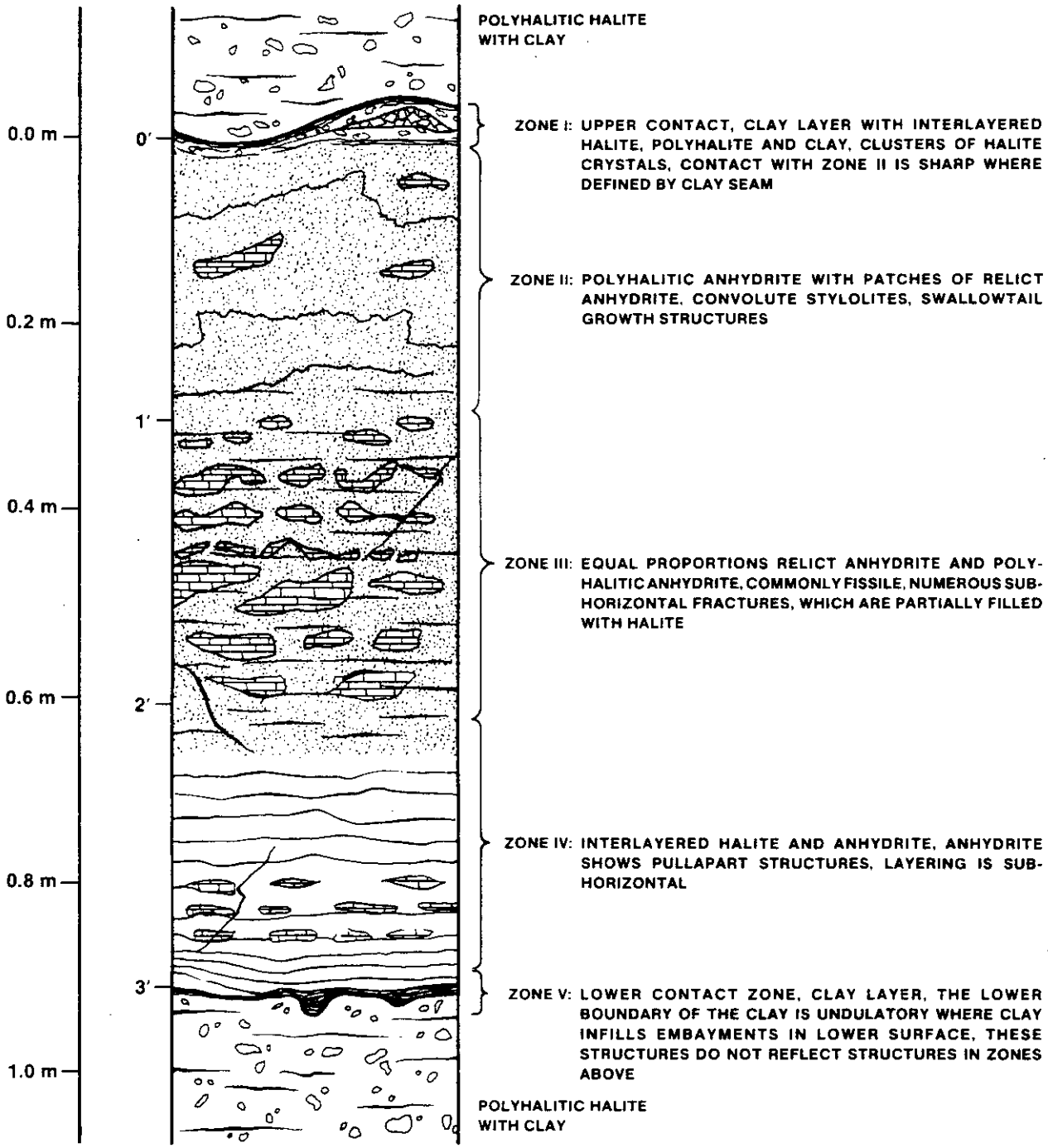

Figure 3.12: Generalized stratigraphic and structural cross section of MB139. The figure demonstrates the internal variability of the unit and the character of both upper and lower contacts. Figure 3 of Borns (1985).

The detailed investigations by Borns also revealed significant internal zonation and variability within the body of MB139. An upper zone within the unit (Zone II) is characterized by extensive replacement of original anhydrite by polyhalite (Figure 3.12), and by the presence of convoluted stylolites. Both features are interpreted to result from fluid movement after deposition. Based on the available radiometric ages on Salado polyhalites (Section 3.3.2), it may be that the formation of polyhalite MB139 occurred as much as 45 million years after deposition. However, polyhalites from within MB139 have not yet been dated. Zone IV, the internal zone directly above the basal contact, contains interlayered halite and anhydrite, with some replacement of anhydrite by later halite, again indicating fluid movement at some time. Anhydritic laminae in this zone show pull-apart structures with horizontal extension.

Within Zone III, the central portion of MB139, replacement of anhydrite by polyhalite is less complete than in Zone II. This zone also contains numerous sub-horizontal fractures, which are partially filled with halite and polyhalite. In some cases, inclined fractures extend from Zone III into or across the overlying Zones I and II. The cores investigated by Borns (1985) were drilled with air; halite was probably not removed from the fractures in Zone III during drilling. On this basis, Borns (1985) concludes that the partially healed subhorizontal fractures in the central part of MB139 predate the construction of the WIPP facility.

The time of formation of the fractures in MB139 is not known in detail. Borns (1985) suggests that they may have formed in response to long-term variations in the overburden pressure at the stratigraphic level of the WIPP facility. Alternatively, as noted by Borns (1985), the fractures may be a response to previous and/or ongoing gravity-driven deformation of the underlying Castile Formation. The horizontal orientation of most of the partially healed fractures favors an origin related to unloading.

An estimate of the variations in overburden pressure at the WIPP facility horizon, extrapolated from estimated variations in overburden at the contact between the Rustler and the Dewey Lake, is shown in Figure 3.13. The overburden pressure at the WIPP facility horizon is estimated to have varied between approximately 16 and 42 MPa since the end of deposition of the Dewey Lake Red Beds. The estimated overburden pressure at the end of the Cretaceous period, 42 MPa, is 2.6 times that at present. Based on stratigraphic interpretations, the reductions in overburden near the ends of the Cretaceous and Tertiary Periods appear to have been relatively sudden. If the interpretations of Borns (1985) are correct, and the sub-horizontal fractures within Zone III of MB139 formed by unloading in response to rapid erosion and removal of overburden, it follows that the formation of the fractures and at least initial movement of the halite-saturated fluids which resulted in their partial healing are probably either early Tertiary or early Pleistocene in age, i.e., that both fracture formation and fluid movement occurred either approximately 60 million or approximately 2 million years ago.

The mineralogical variability of MB139 and the occurrence of partially healed fractures within the central part of the unit have implications for both fluid flow and structural behavior of the unit. The widespread

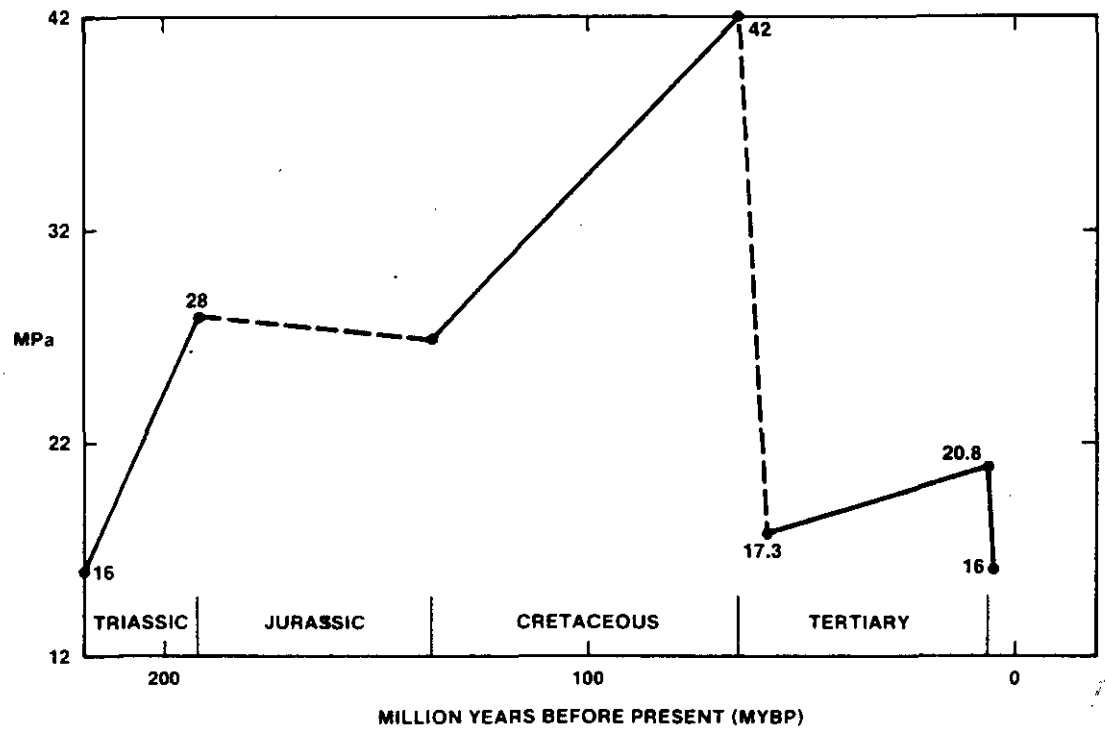

Figure 3.13: Variations in approximate overburden pressure at the WIPP facility horizon as a function of time. Overburden estimates (in MPa, 1 MPa = 145 psi) derived from Figure 10 of Borns (1985) by addition of constant 12 MPa overburden resulting from assumed constant thickness of interval between WIPP facility horizon and Rustler-Dewey Lake contact.

replacement of anhydrite by polyhalite indicates significant fluid movement, possibly some 45 million years after deposition. The replacement of anhydrite and partial healing of fractures by halite may indicate a second period of fluid movement at least 2 million years ago. The available hydrologic information for the Salado Formation at the WIPP site indicates that the far-field permeability within MB139 (and other anhydrite marker beds) is not significantly greater than that of the Salado halites themselves.

Pre-existing fractures within MB139 provide pre-existing planes of weakness that control or influence the near-field mechanical response around the WIPP excavation. Ongoing studies indicate that these fractures open locally in response to excavation. In the near-field altered zone, the resulting permeability is quite high. In the far-field, the permeability of MB139 appears no greater than that of surrounding halites. For confidence in plugging or sealing at the level of the WIPP facility horizon, it must ultimately be demonstrated either that fractures in MB139 will eventually reheal as a result of facility closure, or that damaged portions of the unit have been removed or grouted before seal emplacement. Characterization and delineation of the hydrologically and/or structurally altered zones around the WIPP facility horizon and shafts are ongoing, and will continue into the early operational phase of the facility.

4.0 RUSTLER FORMATION AND YOUNGER UNITS

As noted previously, much effort in WIPP site characterization has been focused on the Culebra Dolomite Member of the Rustler Formation, because this unit is the first laterally continuous water-bearing zone above the WIPP facility. The Culebra has continued to receive attention since 1983. However, work since 1983 has included other members of the Rustler Formation as well as shallower units. Section 4.0 discusses all units above the Salado as a group. Section 4.1 discusses hydrologic testing of the Rustler Formation and Dewey Lake Red Beds, and Section 4.2 discusses both field and numerical studies of the transport properties of the Culebra dolomite. Together, Sections 4.1 and 4.2 constitute a conceptual model of the modern flow and transport behavior within the shallow part of the WIPP stratigraphy, with emphasis on the Culebra dolomite. Section 4.3 discusses geochemical studies addressing both bulk-compositional and isotopic variability within the Rustler Formation and Dewey Lake Red Beds. Section 4.4 discusses studies into the overall geologic behavior of the Rustler and shallower formations at and near the WIPP site. Together, Sections 4.3 and 4.4 summarize available evidence concerning the transient geologic behavior in the region of the WIPP site for units above the Salado Formation.

4.1 Hydrologic Testing of the Rustler Formation and Dewey Lake Red Beds

The Rustler Formation at and near the WIPP site has been hydrologically tested and interpreted at three geometric scales, which are discussed sequentially from the smallest to the largest scale in this section. The smallest-scale of testing is conducted in single holes. Recent single-hole hydrologic testing has provided: 1) local or point transmissivity values for all members of the Rustler Formation except the Tamarisk Member, but with emphasis on the Culebra dolomite; 2) indications of the presence or absence of local hydraulically effective fracturing and wellbore damage within the Culebra; 3) information on relative head potentials within the Rustler; and 4) some indication of the distribution of properties and degree of hydraulic saturation within the Dewey Lake Red Beds. As discussed by Beauheim (1987b), single-hole testing is carried out by means of pumping, drillstem, slug-injection, slug-withdrawal, or pressure-pulse tests, depending on the local permeability or transmissivity. Single-hole testing is interpreted here in terms of transmissivities (in units of m^2/s). Use of this term assumes that the unit being tested is homogeneous across the tested interval. This assumption has been examined directly at hole H-14, in which two separate but overlapping intervals were tested in the Culebra dolomite. The results at H-14 indicate a factor of about 2 in vertical variability in transmissivity within the Culebra within a given hole. Recent single-hole testing of the Rustler Formation and Dewey Lake Red Beds is discussed in Section 4.1.1.

Single-hole tests do not indicate the extent to which either point transmissivity values or fracturing effects can be extrapolated laterally. Hydraulic behavior within the Culebra dolomite is, therefore, also examined at the "hydropad" scale. WIPP hydropads nominally contain three holes, located at the corners of an equilateral triangle 30 m on a side. Hydrologic information at the pad scale is collected by "interference"

testing. During this type of testing, at least two of the three holes on the pad are pumped sequentially in separate tests; the two unpumped holes in each test are used for observation. The objectives of interference hydrologic testing at the pad scale are to collect average or effective hydrologic-property data over distances of some 30 m, and to determine if fracturing effects are significant at this scale.

In the region of the WIPP site, single-pad hydraulic interference tests have been completed at the H-2, H-3, H-4, H-5, H-6, H-7, H-9, and H-11 hydropads. Detailed interpretation including evaluation of the effects of fracturing has been completed only for tests at the H-3 and H-11 hydropads, discussed in Section 4.1.2. Interference testing at the H-3 and H-11 pads has been interpreted using a "dual-porosity" approach, in which the Culebra is assumed to consist of an array of matrix blocks (primary porosity), separated by regularly spaced fractures (secondary porosity).

At some "large" scale, assuming that fracture spacing and properties are not too irregular, the effects of fracturing should become insignificant, i.e., it should become possible to model the flow and/or contaminant-transport behavior of a fractured rock unit such as the Culebra adequately using the porous-medium assumption. The scale at which this simplification is valid, however, may vary significantly with different rock types in different geologic or hydrologic settings. During WIPP site characterization, possible regional hydraulic effects of fracturing have been investigated by "multipad interference testing" of the Culebra dolomite. In this type of testing, one hole is pumped for a relatively long period of time, generally a month or more, while surrounding holes are used to observe hydraulic responses over an area of several square miles. Depending on the distances and extent of fracturing involved, effects due to fracturing may or may not be evident between the pumped hole and some of the observation holes.

Interpretation of multipad interference testing allows estimation of transmissivities and storativities within the tested area, provides information concerning the regional relationship between fluid densities and flow directions, and has allowed investigation of the interaction between WIPP shafts and the Culebra. Two major multipad interference tests, centered at the H-3 hydropad and at hole WIPP-13, have been carried out to date at the WIPP. Additionally, regional hydraulic information has been collected by observing hydrologic responses to WIPP shaft-sinking and shaft-sealing operations. Regional-scale hydrologic interpretation of the Rustler Formation, with emphasis on the Culebra dolomite, is discussed in Section 4.1.3. Interpretation on the regional scale indicates that fracturing need not be incorporated into regional-scale simulation of fluid pressures (head potentials) within the Culebra at and near the WIPP site, because pressure responses are relatively rapid, even on this scale. The assumption of steady state is adequate in modeling the modern Culebra head potentials. However, groundwater flow times are slow enough in the vicinity of the WIPP site to make the assumption of steady-state confined flow within the Culebra inadequate for simulation of long-term flow paths and flow times.

4.1.1 Single-Hole Hydraulic Testing and Interpretation

4.1.1.1 Transmissivity Distribution within Individual Units--Prior to 1985, hydrologic testing at and near the WIPP site was either interpreted using the porous-medium assumption or did not identify significant effects due to fracturing (e.g., Barr et al., 1983). More recently, Beauheim (1986, 1987b) has identified significant fracture effects in hydraulic testing of several holes, using the code INTERPRET. As described in detail by Beauheim (1986, 1987b), INTERPRET utilizes a "pressure-derivative" technique to determine whether or not significant pressure responses due to fracturing are present. In this approach, hydraulically effective fracturing is indicated by a flexure in the plot of dimensionless pressure derivative or drawdown versus dimensionless time (Figure 4.1.1). This flexure reflects a transition from "early" times, in which fluids are effectively produced only from within the fractures, to "late" times, in which fluid is produced from both fractures and matrix, but in which fluid release from the matrix to the fractures is generally the rate-limiting process. The transmissivity interpreted from behavior after this transition is referred to as "system" transmissivity.

At the time of the WIPP FEIS (U.S. Department of Energy, 1980) the suitability of the WIPP site was evaluated largely on the basis of possible releases from the site to Malaga Bend, on the Pecos River approximately 26 km from the WIPP site (Figure 1.1). Requirements for repository performance developed by the Environmental Protection Agency (40CFR191) were released in 1985. Although they may not be in their final form, these requirements place increased emphasis on evaluation of possible releases of radionuclides to the "accessible environment" near the facility. The definition of the accessible environment is not yet final. The WIPP Project has greatly increased the size and reliability of the hydrologic data base for the Rustler Formation since 1985, especially for the Culebra dolomite at and near the WIPP site. Table 4.1 contains the best local estimates of transmissivity used in modeling the hydrology of the Culebra dolomite from 1983 through 1987 and demonstrates the growth in this data base. Table 4.2 summarizes the results of recent single-hole testing in the Culebra dolomite.

Estimated Culebra transmissivities at the WIPP site area and within Nash Draw range over approximately six orders of magnitude, from 2.15 x 10^{-9} m^2/s at P-18 to 1.34 x 10^{-3} m^2/s at WIPP-26 (Tables 4.1 and 4.2). In addition to the growth in the Culebra data base evident in Table 4.1, many of the holes have been retested over the last five years. In some cases recent testing and interpretation have significantly changed earlier estimated transmissivities. However, the more recently estimated Culebra transmissivities are not consistently higher or lower than older values. At H-1 and DOE-2, recent data and interpretation indicate a significantly higher Culebra transmissivity. At H-3 and DOE-1, recent work indicates a lower local transmissivity than estimated earlier. In cases such as P-15, P-17, H-4, and WIPP-30, retesting and/or reinterpretation of earlier results has not resulted in any significant change in estimated Culebra transmissivity. In all cases, however, the more recent data and interpretations are better documented than older work, as a result of the

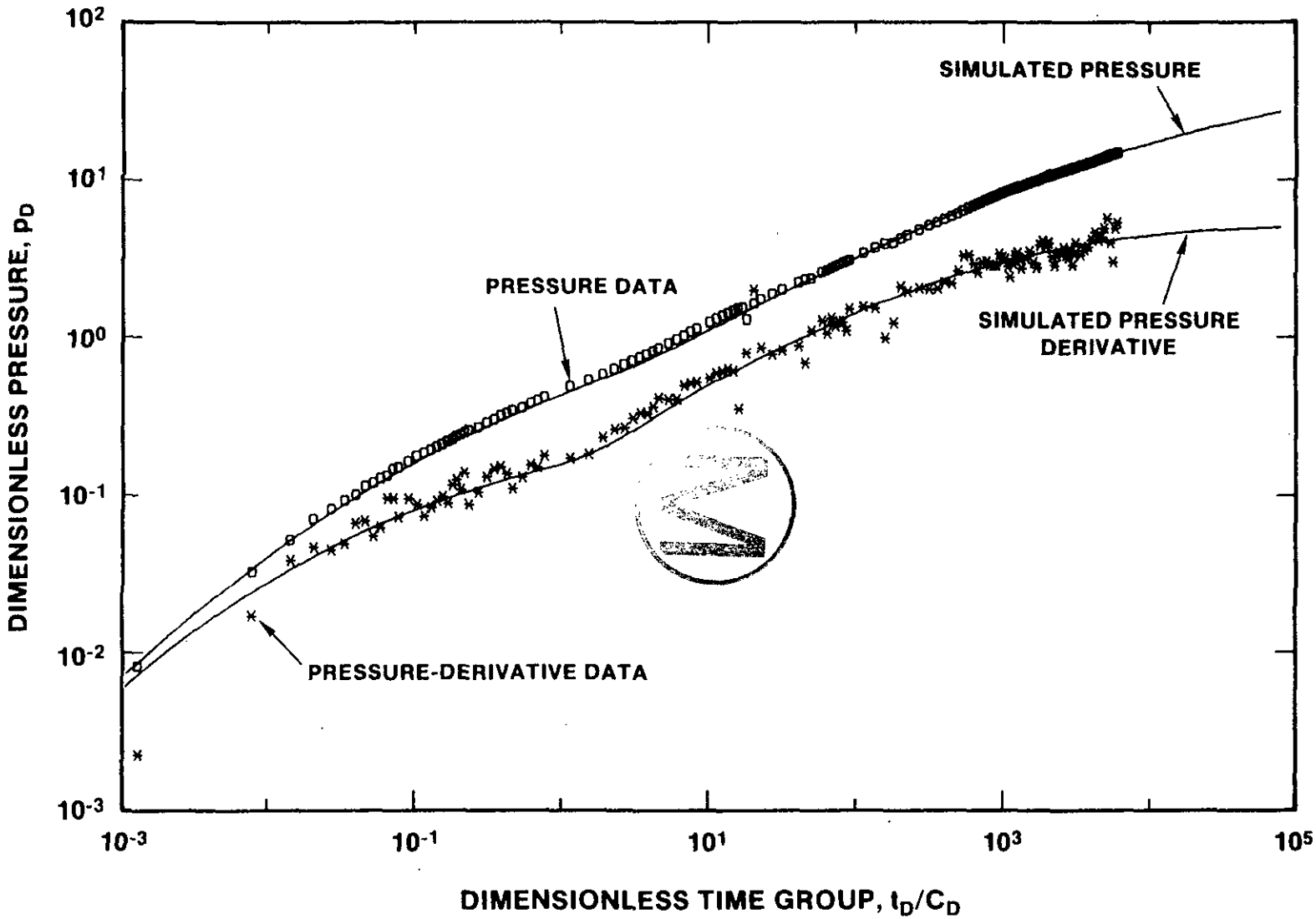

Figure 4.1.1: Measured and simulated response of H-3b1 to pumping of hole H-3b2. The presence of dual-porosity effects due to fracturing is indicated by the inflection in both measured and simulated pressure-derivative curves, in this case at a value of the dimensionless time group of approximately one. Simplified from Figure 6-11 of Beauheim (1987*a*).

Table 4.1: Transmissivity data bases used in numerical modeling of the Culebra dolomite in Barr et al. (1983), Haug et al. (1987), and LaVenue et al. (1988).

Well	Barr et al. (1983) Transmissivity (ft^2/day)	Haug et al. (1987) Transmissivity (ft^2/day)	LaVenue et al. (1988) Transmissivity (ft^2/day)	Transmissivity (m^2/sec)
H-1	0.07	0.07	0.8	8.60×10^{-7}
H-2	0.4	0.56	0.52	5.59×10^{-7}
H-3	19	3.7	2.3	2.47×10^{-6}
H-4	0.9	1.1	0.95	1.02×10^{-6}
H-5	0.2	0.16	0.14	1.51×10^{-7}
H-6	73	74	74	7.96×19^{-5}
H-7	>1000	1120	1030	1.11×10^{-3}
H-8	16	6.7	8.2	8.82×10^{-6}
H-9	230	170	160	1.72×10^{-4}
H-10	0.07	0.07	0.07	7.53×10^{-8}
H-11	--	10	26	2.80×10^{-5}
H-12	--	0.04	0.18	1.94×10^{-7}
H-14	--	--	0.31	3.33×10^{-7}
H-15	--	--	0.12	1.29×10^{-7}
H-16	--	--	0.7	7.53×10^{-7}
H-17	--	--	0.2	2.15×10^{-7}
H-18	--	--		
WIPP-12	--	--	0.03	3.23×10^{-8}
WIPP-13	--	--	69	7.42×10^{-5}
WIPP-18	--	--	0.3	3.23×10^{-7}
WIPP-19	--	--	0.6	6.45×10^{-7}
WIPP-21	--	--	0.25	2.69×10^{-7}
WIPP-22	--	--	0.37	3.98×10^{-7}
WIPP-25	270	270	270	2.90×10^{-4}
WIPP-26	1250	1250	1250	1.34×10^{-3}
WIPP-27	650	650	650	6.99×10^{-4}
WIPP-28	18	18	18	1.94×10^{-5}
WIPP-29	1000	1000	1000	1.08×10^{-3}
WIPP-30	0.3	0.3	0.3	3.22×10^{-7}
P-14	140	233	214	2.30×10^{-4}
P-15	0.07	0.08	0:09	9.68×10^{-8}
P-17	1	1.7	1.3	1.40×10^{-6}
P-18	0.001	0.002	0.002	2.15×10^{-9}
DOE-1	--	33	11	1.18×10^{-6}
DOE-2	--	36	89	9.57×10^{-6}
ERDA-9	--	--	0.47	5.06×10^{-7}
CABIN BABY	--	--	0.28	3.01×10^{-7}
ENGLE	--	--	43	4.62×10^{-5}
USGS-1	515	515	515	5.54×10^{-4}
	21 Values	25 Values	38 Values	38 Values

Table 4.2: Detailed summary of recent single-well test results in the Culebra dolomite. Slightly modified from Table 5-3 of Beauheim (1987b).

Well	Culebra Interval m (ft)	Interval Tested m (ft)*	Test Type	Transmissivity (ft^2/day)	Transmissivity (m^2/s)	Skin Factor
H-1	206-213.1 (676-699)	205.7-214.3 675-703)	slug #1	1.0	1.1×10^{-6}	--
			slug #2	0.83	8.9×10^{-7}	--
			slug #3	0.83	8.9×10^{-7}	--
			slug #4	0.83	8.9×10^{-7}	--
H-4c	149.4-157.3 (490-516)	150.6-158.5 (494-520)	slug	0.65	7.0×10^{-7}	--
H-8b	179.2-187.1 (588-614)	175.0-190.2 (574-624)	pumping	8.2	8.8×10^{-6}	-7.2
H-12	250.9-259.1 (823-850)	249.9-271.3 (820-890)	slug #1	0.18	1.9×10^{-7}	--
			slug #2	0.18	1.9×10^{-7}	--
H-14	166.1-174.3 (545-572)	162.5-167.9 (533-550.7)	DST/FBU	0.096	1.0×10^{-7}	-0.8
			DST/SFL	0.10	1.1×10^{-7}	--
			DST/SBU	0.10	1.1×10^{-7}	-1.3
H-14	166.1-174.3 (545-572)	162.5-175.0 (533-574)	DST/FBU	0.30	3.2×10^{-7}	-1.1
			DST/SBU	0.31	3.3×10^{-7}	-1.8
			slug	0.30	3.2×10^{-7}	--
H-15	262-4-269.1 (861-883)	260.0-271.3 (853-890)	DST/FBU	0.15	1.6×10^{-7}	2.6
			DST/SBU	0.15	1.6×10^{-7}	2.9
			slug	0.10	1.1×10^{-7}	--
H-16	213.4-221.0 (700-725)	212.4-223.7 (697-734)	DST/FBU	0.85	9.1×10^{-7}	0.0
			DST/SBU	0.85	9.1×10^{-7}	-0.3
			slug	0.69	7.4×10^{-7}	--
H-17	215.2-222.8 (706-731)	214.3-224.0 (703-735)	DST/FBU	0.21	2.3×10^{-7}	-1.5
			DST/SBU	0.22	2.4×10^{-7}	-1.2
			slug	0.22	2.4×10^{-7}	--

Table 4.2: Detailed summary of recent single-well test results in the Culebra dolomite. Slightly modified from Table 5-3 of Beauheim (1987b). (Continued)

Well	Culebra Interval m (ft)	Interval Tested m (ft)*	Test Type	Transmissivity (ft^2/day)	Transmissivity (m^2/s)	Skin Factor
H-18	210.3-217.3 (690-713)	208.8-217.6 (685-714)	DST/FBU	2.2	2.4×10^{-6}	-0.2
			DST/SBU	2.2	2.4×10^{-6}	-1.0
			slug	1.7	1.8×10^{-6}	--
WIPP-12	246.9-254.5 (810-835)	248.4-256.0 (815-840)	slug #1	0.10	1.1×10^{-7}	--
			slug #2	0.097	1.0×10^{-7}	--
WIPP-18	239.9-246-3 (787-808)	239.0-245-7 (784-806)	slug	0.30	3.2×10^{-7}	--
WIPP-19	230.4-237.4 (756-779)	229.8-237.7 (754-780)	slug	0.60	6.5×10^{-7}	--
WIPP-21	222.2-229.5 (729-753)	221.6-228.9 (727-751)	slug	0.25	2.7×10^{-7}	--
WIPP-22	226.2-232.9 (742-764)	228.0-234.7 (748-770)	slug	0.37	4.0×10^{-7}	--
WIPP-30	192.3-199.0 (631-653)	191.7-199.6 (629-655)	slug #1	0.18	1.9×10^{-7}	--
			slug #2	0.17	1.8×10^{-7}	--
P-15	125.9-132.6 (413-435)	125.0-133.5 (410-438)	slug #1	0.090	9.7×10^{-8}	--
			slug #2	0.092	9.9×10^{-8}	--
P-17	170.1-177.7 (558-583)	170.1-178.6 (558-586)	slug #1	1.0	1.1×10^{-6}	--
			slug #2	1.0	1.1×10^{-6}	--
P-18	277.1-285.9 (909-938)	277.1-286.5 (909-940)	slug	4×10^{-3}/	7×10^{-5}	--
ERDA-9	214.6-221.6 (704-727)	214.9-221.9 (705-728)	slug #1	0.45	4.8×10^{-7}	--
			slug #2	0.47	5.1×10^{-7}	--

Table 4.2: Detailed summary of recent single-well test results in the Culebra dolomite. Slightly modified from Table 5-3 of Beauheim (1987b). (Concluded)

Well	Culebra Interval m (ft)	Interval Tested m (ft)*	Test Type	Transmissivity (ft^2/day)	Transmissivity (m^2/s)	Skin Factor
Cabin baby-1	153.3-161.2 (503-529)	153.3-161.2 (503-529)	slug #1	0.28	3.0×10^{-7}	--
			slug #2	0.28	3.0×10^{-7}	--
DOE-1	250.2-256.9 (821-843)	249.9-256.9 (820-843)	pumping/ drawndown	28	3.0×10^{-5}	-5.1
			recovery	11	1.2×10^{-5}	-6.0
Engle	200.9-207.6 (659-681)	197.5-208.2 (648-683)	pumping	43	4.6×10^{-5}	4.2

*Actual intervals open to the wells.

increase in documentation requirements over the ten-year span of WIPP site characterization. The interpreted test data from recent single-hole testing at and near the WIPP site are included in Beauheim (1987b). Raw data, test histories, and test instrumentation for all hydrologic testing at the WIPP for approximately the last five years are contained in a series of six hydrologic data reports: Hydro Geo Chem (1985); INTERA and Hydro Geo Chem (1985); INTERA (1986); Saulnier et al. (1987); Stensrud et al. (1987); and Stensrud et al. (1988).

Transmissivities listed in Tables 4.1 and 4.2 are not identical in all cases. Transmissivity estimates included in Table 4.1 from three-hole hydropads, such as the H-4 pad, are effective transmissivities. In single-hole tests, this is the same as the measured value. In the case of three-hole hydropads, however, the effective transmissivity is the square root of the product of the estimated maximum and minimum transmissivities on the pad. The calculated effective transmissivity, which is used in regional-scale modeling (Section 4.1.3), generally does not correspond directly to any of the measured single-hole values on the same pad.

As mentioned above, Culebra transmissivities at and near the WIPP site and within Nash Draw range over approximately six orders of magnitude, from more than 10^{-3} m^2/s to less than 10^{-8} m^2/s. However, this variability is not random. A large area of low transmissivities (less than approximately 10^{-6} m^2/s) is present near the center of the WIPP site, extending to the east, southeast, and southwest (Figure 4.1.2). This zone includes holes WIPP-12, 18, 19, 21, and 22; H-1, 2, 4, 5, 10, 12, 14, 15, 16, and 17;

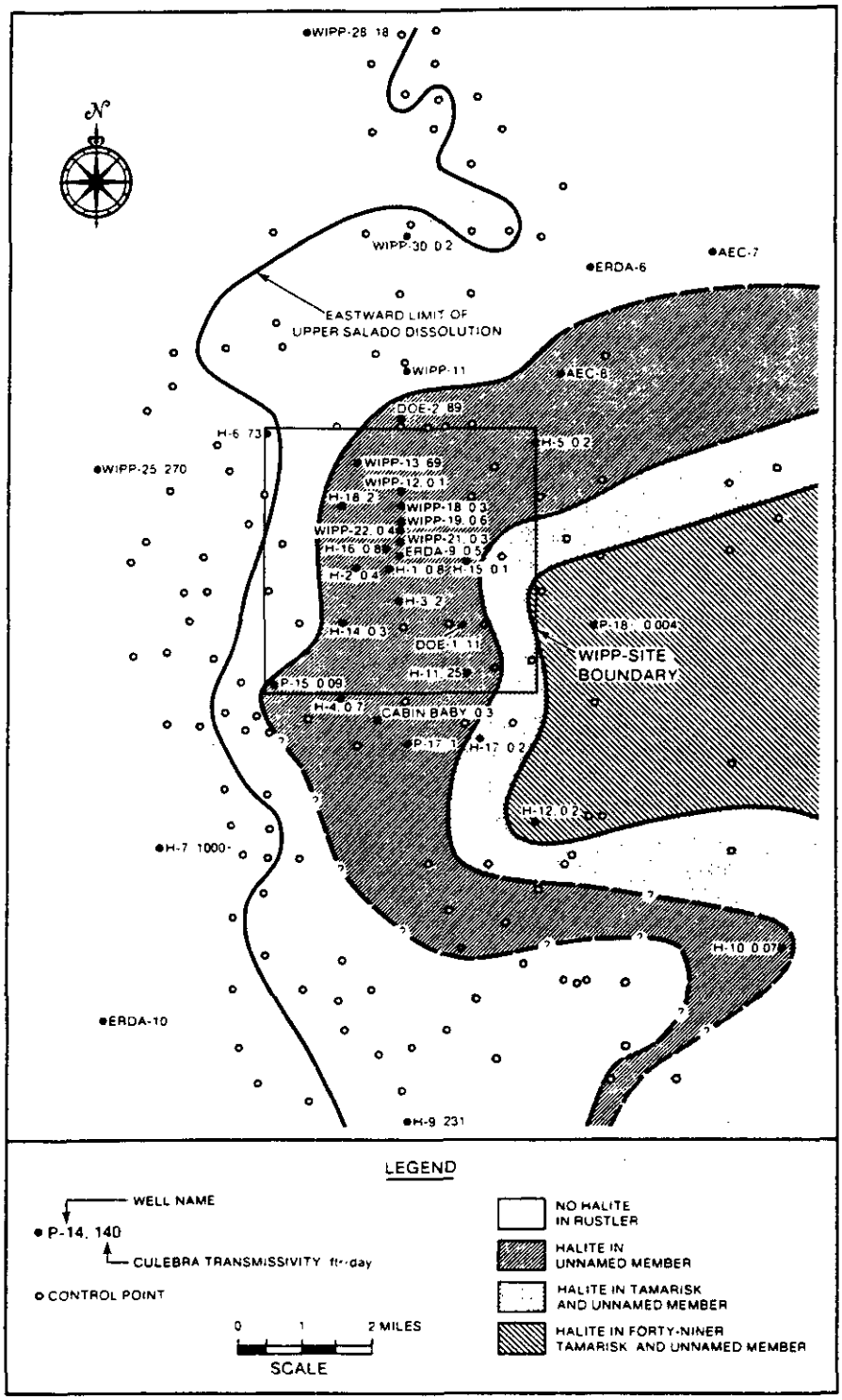

Figure 4.1.2: Transmissivity of the Culebra dolomite in relation to the distribution of halite within the Rustler Formation. Figure 6-2 of Beauheim (1987b). Halite distribution modified from Snyder (1985). Transmissivities in this figure are given in units of ft^2/day. Multiply by 1.075×10^{-6} to get transmissivities listed in Table 4.1 in m^2/s.

P-15, 17, and 18; ERDA-9, and Cabin Baby-1 (see also Figure 1.2). Within this low-transmissivity region, relatively high Culebra transmissivities (greater than approximately 10^{-5} m^2/s) have been measured southeast of the site center, in holes DOE-1 and H-11. The transmissivity measured on the H-3 pad (2.0×10^{-6} m^2/s) is transitional between transmissivities at H-11 and DOE-1 and those in the low-transmissivity domain north and southwest of H-3.

A continuous zone of variable but high Culebra transmissivity appears to be present northwest, west, and south of the site center. This zone includes holes H-6, 7, and 9; WIPP-13, 25, 26, 27, 28, and 29; DOE-2 and P-14; and the Engle well (see Figures 1.1 and 1.2). The Culebra transmissivity in hole H-18 (1.8×10^{-6} to 2.4×10^{-6} m^2/s) is transitional between those in adjacent higher-transmissivity and lower-transmissivity domains.

There are some limitations in the Culebra data base, in spite of the fact that Culebra transmissivities have now been estimated at 39 separate localities at and near the WIPP site and within Nash Draw. For example, although the low-transmissivity zone near the site center is interpreted here to be continuous to the southwest, there is no direct measurement of Culebra transmissivity in the interval between holes H-14 and H-2. At present there is also no direct field evidence of connection between the region containing holes DOE-1 and H-11 and the region to the south containing hole H-9. Quantitative integration of point data into a regional transmissivity pattern for the Culebra and evaluation of some of the uncertainties mentioned here are discussed in Section 4.1.3.

Single-hole Culebra tests in which the system transmissivity is less than 10^{-6} m^2/s generally do not show signs of fracturing, while holes with higher transmissivity do. To a first approximation, fracturing within the Culebra (and the Rustler as a whole) appears to be related to the removal of halite. As discussed by Mercer (1983), Snyder (1985), and Beauheim (1987b), there is a general correlation between the distribution of halite within the Rustler Formation (Figures 1.5 and 4.1.2) and transmissivity of Rustler members, especially the Culebra dolomite. The distribution of halite within the Rustler Formation is briefly discussed in Section 4.4.2.

However, the correlation between halite distribution and Culebra transmissivity is neither unique nor completely reliable. With the exception of WIPP-30 and possibly H-10, the Culebra in holes in which there is no halite in the unnamed lower member of the Rustler are highly transmissive. In WIPP-30, there is no halite within the Rustler, and the Culebra transmissivity is quite low. Without exception, the Culebra transmissivity is low if Rustler halite is present above the Culebra. Where there is Rustler halite present only beneath the Culebra, the correlation is not completely reliable, perhaps because of complications involving the response of the Culebra to evaporite dissolution in the upper part of the Salado Formation. For example, holes DOE-2 and WIPP-13, in the western part of the region in which halite is present beneath the Culebra (Figure 4.1.2), are highly transmissive, but hole H-18 is not. In the southeastern part of the WIPP site, holes P-17 and H-3 are relatively low in transmissivity, but the transmissivity at H-11 and DOE-1 is greater than 10^{-5} m^2/s. As discussed by Beauheim (1987b), examination of the detailed

Rustler isopachs summarized in Snyder (1985) does not indicate any consistent reason for the high transmissivities at H-11 and DOE-1.

The significance of the distinction between dual-porosity (fractured) and porous-medium behavior in single-hole hydraulic testing is not completely straightforward. The apparent absence of fracturing in a test does not indicate a total absence of fractures, nor does fracturing in single-hole hydraulic testing indicate that far-field or long-term hydraulic or transport behavior near a given hole is or would be dominated by fracture effects. At one extreme, very local fracturing in a very low-transmissivity test interval may play a role in the very early pressure responses, but may not be evident because of wellbore-storage and fluid-flow surge effects at the beginning of a test. Any low-transmissivity hole listed in Tables 4.1 and 4.2 may contain fractures which are not apparent because of the testing techniques and instrumentation used. However, the effects of these fractures should be extremely localized. At the other extreme, intense fracturing may lead to high transmissivity, but result in such small block sizes that fluid flow from the matrix blocks is "immediately" the rate-limiting step. Dual-porosity effects would not be evident during testing at such a site, and the tested interval would behave hydraulically as an equivalent porous medium. This type of behavior may be applicable, for example, in the highly-transmissive portions of the Culebra within Nash Draw; however, testing results in Nash Draw have not yet been investigated using INTERPRET. The hydraulic behavior of the highly-transmissive Culebra in the Engle well (4.6×10^{-5} m^2/s) does not show dual-porosity effects. However, this behavior is tentatively attributed by Beauheim (1987b) to wellbore and near-wellbore conditions, rather than to extreme fracturing of the test interval.

In addition, the fact that testing at a given hole does not indicate local fracturing does not guarantee that there is not fracturing nearby. Single-hole testing at WIPP-21 indicates a Culebra transmissivity of 2.7×10^{-7} m^2/s, with no dual-porosity effects. This hole responded strongly and rapidly to both the H-3 multipad interference test and activities in both the waste-handling and exhaust shafts. This behavior probably reflects the presence of a "low-storativity" structure, which could be a single fracture or fracture zone connecting the region near WIPP-21 with the two WIPP shafts, but not intersecting WIPP-21 itself.

Single-hole testing may also be strongly affected by drilling-induced near-well effects, which can make the test hole appear either more or less transmissive than the surrounding rock mass. As discussed by Beauheim (1986, 1987b), marked examples of such "skin" effects were found in testing in holes DOE-2 and WIPP-13. In the extreme example of hole DOE-2, the initial estimate of minimum transmissivity was 2.4×10^{-5} m^2/s. The calculated "skin factor" was +31 (Beauheim, 1986). For comparison, a hole so badly damaged that it would not produce fluid at all would have a skin factor of plus infinity. At the WIPP, positive skin factors have, in some cases, been reduced by acid treatment. Treatment of hole DOE-2 with hydrochloric acid removed the near-hole damage effects, and increased the interpreted transmissivity by a factor of 4, from 2.4×10^{-5} m^2/s, to 9.6×10^{-5} m^2/s (Table 4.1). The calculated skin factor at DOE-2 decreased from +31 to -4.7. A skin factor of less than zero indicates good connection of

the physical wellbore with fractures within the rock mass and results in an apparent well radius greater than that of the physical diameter of the hole. The Culebra in several holes listed in Table 4.2 exhibits negative skin factors, indicating good connection of the test hole with the surrounding rock mass.

As mentioned above, the presentation of data in terms of transmissivity explicitly assumes that the tested interval is vertically homogeneous. Data included in Table 4.2 indicate that Culebra transmissivity at H-14 varies with vertical position within the unit. While drilling this hole, it was possible to find a packer seat within the Culebra. Testing of the upper Culebra was then followed by testing of the entire unit. The calculated transmissivity of the upper 1.7 m of the Culebra is 1.1×10^{-7} m^2/s, while that of the entire 8.2 m thickness of the unit is 3.3×10^{-7} m^2/s. This indicates that the transmissivity of the lower 6.5 m of the Culebra in hole H-14 is approximately 2.2×10^{-7} m^2/s. The results at H-14 indicate that the Culebra cannot be assumed to be vertically homogeneous, since the transmissivity of individual zones within the unit vary by a factor of about 2. The results at H-14 are in qualitative agreement with the variability indicated by results of tracer-injection tests at holes H-1, H-2c, H-3, and P-14 (Mercer and Orr, 1979).

Because the Culebra dolomite is generally more permeable than the Magenta dolomite at and near the WIPP site, less testing of the Magenta has been completed at the WIPP. Older transmissivity data for the Magenta dolomite are contained in Mercer (1983) and Gonzalez (1983a). The results of recent testing of the Magenta dolomite in H-14, H-16, and DOE-2 are included in Table 4.3. Overall, reported Magenta transmissivities range from approximately 5.9×10^{-9} m^2/s in hole H-14 to 4.0×10^{-4} m^2/s in WIPP-25. Magenta transmissivities greater than approximately 10^{-6} m^2/s are known only in and near Nash Draw and the small valley south of the WIPP site (Figure 1.2).

As mentioned in Section 1.0, modeling of Rustler hydrology through 1983 assumed that the Culebra and Magenta dolomites were completely confined. This is equivalent to assuming that the unnamed lower, Tamarisk, and Forty-niner members of the Rustler have zero permeability. Indeed, standard hydrologic testing techniques are inapplicable to these units at the WIPP site because of their low permeabilities. Recent advances in testing, data-collection, and interpretation techniques have allowed meaningful examination of these units at three locations: DOE-2, H-14, and H-16 (Table 4.3). Even in the recent testing, however, it has only been possible to test the transmissivities of claystones and siltstones within the non-carbonate members of the Rustler. The claystones and siltstones in the Tamarisk and Forty-niner Members occur near the center of each unit, and are separated from the Magenta or Culebra by a zone of anhydrite/gypsum (Table 1.2). The anhydrites within the Rustler still cannot be tested from the surface, since their in situ transmissivities are less than approximately 10^{-11} m^2/s (Beauheim, 1986; 1987b). In addition, it still has not been possible to measure the transmissivity of the Tamarisk claystone, due to its low transmissivity.

Table 4.3: Summary of available transmissivity information for members of the Rustler Formation in holes H-14, H-16, and DOE-2. Slightly modified from data contained in Tables 5-2 and 5-3 of Beauheim (1987b) and Table 7-2 of Beauheim (1986).

	Zone depth (m)	Test interval (m)	Transmissivity (m^2/s)
H-14			
Forty-niner "claystone"	118.9 - 123.4	116.1 - 124.7	3.2×10^{-8} - 7.6×10^{-8}
Magenta	129.2 - 136.6	128.0 -136.6	5.7×10^{-9} - 6.0×10^{-9}
Culebra	166.1 - 174.3	162.5 - 175.0	3.2×10^{-7} - 3.3×10^{-7}
H-16			
Forty-niner "claystone"	171.6 - 175.0	170.7 - 177.1	2.4×10^{-10} - 6.0×10^{-9}
Magenta	179.8 - 187.8	179.5 - 189.3	2.6×10^{-8} - 3.0×10^{-8}
Culebra	213.4 - 221.0	212.4 - 223.7	7.4×10^{-7} - 9.1×10^{-7}
Unnamed member siltstone	237.1 - 256.6	225.2 - 259.4	2.4×10^{-10} - 2.9×10^{-10}
DOE-2			
Forty-niner "claystone"	204.2 - 207.5	202.4 - 209.1	2.7×10^{-9} - 1.2×10^{-8}
Magenta	213.1 - 220.1	213.4 - 220.1	1.1×10^{-9}
Culebra	251.2 - 257.9	251.2 - 257.9	9.6×10^{-5}

The transmissivity of the Magenta at H-14, H-16, and DOE-2 is 1.1×10^{-9} to 3.0×10^{-8} m^2/s (Table 4.3). The transmissivity of the claystone in the overlying Forty-niner in the same holes is comparable, 5.6×10^{-9} to 1.2×10^{-8} m^2/s. The siltstone within the unnamed lower member of the Rustler has been successfully tested only in hole H-16, in which it has an estimated transmissivity of between 2.4×10^{-10} and 2.9×10^{-10} m^2/s. The transmissivity of the Culebra in DOE-2, H-14, and H-16 ranges from 1.1×10^{-7} to 9.6×10^{-5} m^2/s, at least one order of magnitude greater than that of any of the surrounding units.

The results at H-14, H-16, and DOE-2 indicate that the Culebra is the most significant water-bearing unit within the Rustler at and near the WIPP site, consistent with earlier assumptions, although in some holes (H-10, WIPP-12, P-15) the Culebra transmissivity is similar to the Magenta transmissivities measured at H-14, H-16, and DOE-2. However, the recent results are inconsistent with previous assumptions, in that they suggest that stratabound fluid flow within the portion of the Rustler above the Culebra dolomite may occur as much through the Forty-niner claystone as through the Magenta, except where the Magenta is significantly fractured. At and near the WIPP site, both the Magenta and the Forty-niner claystone are more transmissive than the bounding anhydrites; no data are available concerning the transmissivity of the Tamarisk claystone. There must be a qualitative increase in the transmissivities of the Tamarisk and Forty-niner anhydrites somewhere between the WIPP site and Nash Draw, however, since evaporite karst in and near Nash Draw involves formation of small caverns and sinkholes within the Tamarisk and Forty-niner Members, as briefly discussed in Section 4.4.

4.1.1.2 Head Distribution within the Rustler Formation and between the Rustler, Dewey Lake, and Salado--As mentioned previously, numerical modeling of Rustler hydrology through 1983 assumed the Culebra and Magenta were completely confined, and that the transmissivities of other units within the Rustler were negligible. The results discussed in the preceding section indicate that the transmissivities of claystones or siltstones within the Rustler are locally measurable at the WIPP site, and are similar in magnitude to that of the Magenta dolomite, except where the Magenta is fractured. However, the transmissivity of the Culebra dolomite is normally at least one order of magnitude greater than that of other units within the Rustler at and near the WIPP site, and the transmissivities of Rustler anhydrites at and near the WIPP site are too low to measure. These results suggest that flow within the Culebra dolomite, parallel to layering, is the dominant factor in the hydrology of the Rustler Formation at the WIPP site. However, as discussed briefly in this section, fluid pressures and densities have been measured locally in units both above and below the Culebra.

Therefore, unless the Rustler anhydrites and/or Tamarisk claystone have absolutely zero permeability, there must be some vertical fluid flow within the Rustler. The amount of this flow is not known quantitatively, and cannot be measured directly in the field. At one extreme, vertical fluid flow may be completely negligible relative to stratabound flow within the Culebra dolomite. At the other extreme, "karstic" hydrology might occur within the Rustler Formation at the WIPP site, involving surficial recharge from the surface to the Rustler carbonates and/or anhydrites. In order for fluid flow to take place from the surface to the carbonate members of the Rustler Formation, the head potential within the Forty-niner must be greater than that within the underlying Magenta dolomite, regardless of the head potential or state of saturation within the Dewey Lake Red Beds. The relationships among the effective hydraulic heads of the various members of the Rustler Formation, the Salado, and the Dewey Lake in the central portion of the WIPP site are shown in Figure 4.1.3. The flow directions indicated include the expected effects due to variable brine densities.

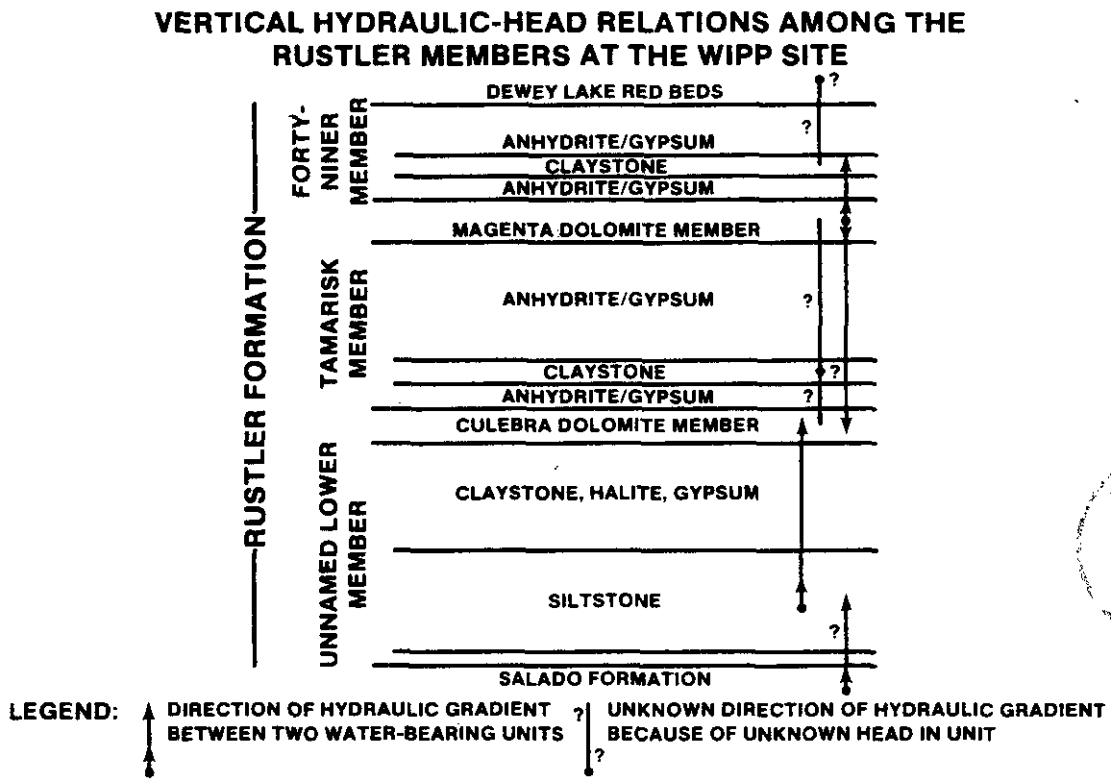

Figure 4.1.3: Head relations among units in the Rustler Formation and between the Rustler, Dewey Lake Red Beds, and Salado at the WIPP site. Figure 6-3 of Beauheim (1987b).

Figure 4.1.3 is based, in part, on testing of the Rustler and lower Dewey Lake Red Beds at H-14, H-16, and DOE-2. The transmissivity of the lower Dewey Lake was too low for successful testing, i.e., less than approximately 10^{-11} m^2/s. In fact, testing was unable to determine whether the Dewey Lake is hydraulically saturated. The regional pattern of hydrologic saturation within the Dewey Lake is not well known (Mercer, 1983); only very limited evidence has been found for local saturation at the WIPP site. South of the WIPP site, water is locally produced from the Dewey Lake, perhaps from lenticular sands within the unit (Mercer, 1983). Wells probably producing from within the Dewey Lake include the Pocket, Fairview, and Ranch wells indicated in Figure 1.2. As noted by Mercer (1983) the region east of the Ranch well includes thick active dune sands, and may serve as a location for local recharge to the Dewey Lake (see also Section 4.3.2).

In holes H-14 and H-16, consistent with the relationships shown in Figure 4.1.3, the Magenta head is greater than the head in the Forty-niner claystone (Beauheim,. 1987b). Therefore, modern fluid flow between these two members is upward, rather than downward. Since water at these two holes is not moving from the top of the Rustler downwards into the Magenta, it cannot be moving from the surface down into the Magenta dolomite.

The Dewey Lake Red Beds at H-14 and H-16 may not be saturated. If not, fluid flow from the surface to the Forty-niner claystone is not likely. Given the uncertainty in regional saturation and head potentials within the Dewey Lake Red Beds the results at H-14 and H-16 do not rule out fluid movement from the surface downward into the Forty-niner claystone or the upper anhydrite in the Forty-niner and/or into the Magenta dolomite in some areas; i.e., where the Dewey Lake is saturated. Also, these results do not eliminate the possibility of flow between the Dewey Lake Red Beds and the Rustler carbonates in the past, if heads within the Dewey Lake Red Beds and Forty-niner were higher at that time relative to heads within the Magenta.

Magenta heads near the center of the WIPP site are greater than Culebra heads (Figure 4.1.3), consistent with downward flow between these two units. As indicated in Figures 17 and 18 of Mercer (1983), the difference in heads between the two units tends to increase towards the east and decrease towards the west, primarily due to a general east-to-west decrease in Magenta heads. Within and near Nash Draw, the heads within the two units are similar; in some places in and near Nash Draw, (H-7a, WIPP-26, WIPP-28), the Magenta is unsaturated (Mercer, 1983).

Vertical flow from the Magenta to the Culebra has been considered in regional-scale modeling of Culebra hydrology (Section 4.1.3.1). However, as noted above and indicated in Figure 4.1.3, it has not been possible to measure either transmissivities or head potentials within either the claystone or anhydrites in the Tamarisk at or near the WIPP site. Vertical flow between the Magenta and Culebra is discussed further by Mercer (1983) and Beauheim (1987b). The possible consequences of such flow, as considered in numerical modeling of Culebra hydrology (Haug et al., 1987), are briefly considered in Section 4.1.3.1.

As noted by Mercer (1983) and Beauheim (1987b), the head potentials in the silty portion of the unnamed lower member of the Rustler are greater than within the Culebra over much of the area of the WIPP site. Thus, fluid flow into the Culebra from the underlying unnamed member and possibly the Salado Formation is possible at both of these locations. However, as indicated in Figure 4.1.3, it has not been possible to measure either transmissivities or head potentials within the claystone, halite, or gypsum/anhydrite in the upper part of the unnamed lower member. The possible implications of vertical fluid flow from the unnamed member into the Culebra in numerical modeling of Culebra hydrology are briefly discussed in Section 4.1.3.1.

4.1.2 Single-Pad Interference Testing

Interference testing at the scale of a single hydropad is designed to provide data concerning the hydrologic effects of both fracturing and "anisotropy" at a geometric scale of some 30 m. If the test interval behaves as a porous medium at the hydropad scale, interference testing yields an "anisotropy tensor," which indicates local directions of maximum and minimum transmissivities. If, however, the porous-medium assumption is not valid at this scale, i.e., if fracturing effects are significant, testing at this scale normally provides average system transmissivities and storativities along the independent pairs of flow paths. Section 4.1.2.1 describes the detailed results of single-pad interference testing at the H-3 hydropad, and Section 4.1.2.2 the detailed results of testing at the H-11 pad. Detailed interpretation of pad-scale interference testing has only been completed to date for these two locations. Interpretation of results obtained at the H-2, H-4, H-5, H-6, H-7, and H-9 pads is ongoing.

4.1.2.1 Interference Testing at the H-3 Hydropad--Beauheim (1987a) interprets hydraulic data collected at the H-3 hydropad (Figure 4.1.4) during single-hydropad testing in 1984 and the H-3 multipad interference test conducted in 1985 and 1986. Hole H-3b3 was the pumped hole during the 1984 test, and H-3b2 the pumped hole during the H-3 multipad test.

The characteristic drawdown response in both pumped and observation holes at the H-3 pad is shown in Figure 4.1.1. As noted in Section 4.1.1, the inflection in dimensionless pressure at early dimensionless times indicates fracturing at H-3. In fact, the responses of observation holes on the H-3 pad to the beginning of pumping during both single-pad and multi-pad testing tests were practically instantaneous. Observation holes H-3b1 and H-3b3 responded within five seconds to the beginning of pumping in H-3b2 during the multipad test. The peak drawdowns in the observation holes were 90% or more of the drawdown in the pumped hole, even in the relatively short 1984 test. As a result, it was necessary to interpret the responses of observation holes on the H-3 pad as if these holes were a part of the pumped hole. This conclusion is supported by the fact that the calculated effective hydraulic radius of the pumped well in the 1984 testing (H-3b3) is approximately 146 m (Beauheim, 1987a). This interpretation, however, makes it impossible to determine storativities along the flow paths at the H-3 pad.

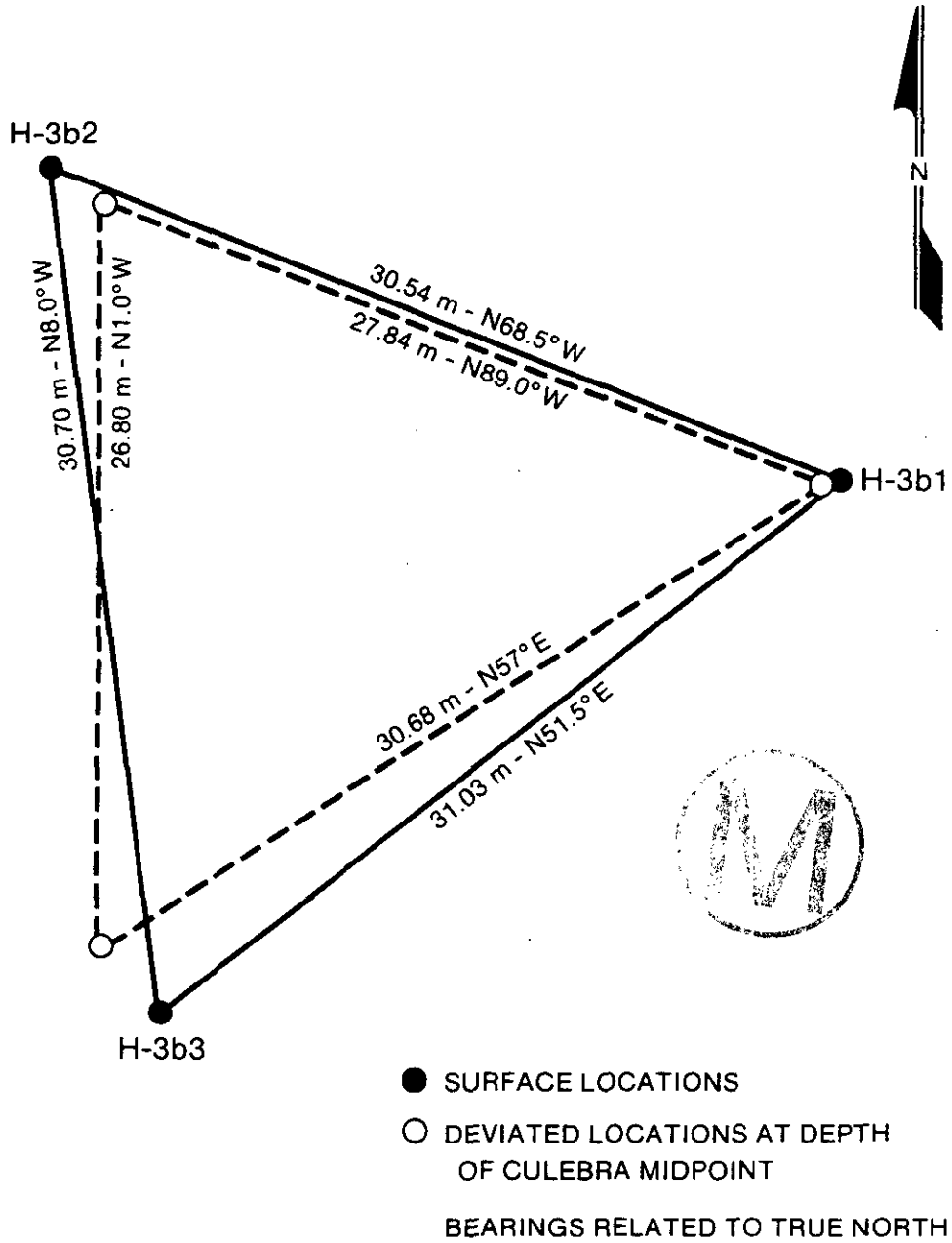

Figure 4.1.4: Physical layout of the H-3 hydropad. The figure is a plan view, showing positions and distances between wells both at the surface and where penetrating the Culebra dolomite. Figure 4.1 of Kelley and Pickens (1986).

The results of interference testing on the H-3 pad are summarized in Table 4.4. There is no significant difference between the interpreted transmissivities of the three holes on the H-3 pad, since the range in values is only from 3.1 to 3.2 x 10^{-6} m^2/s for the 1984 testing and 1.8 to 1.9 x 10^{-6} m^2/s for the multipad test. Therefore, there is no apparent anisotropy in the hydraulic properties at H-3. There is, however, a decrease of approximately 50% between the average transmissivity at H-3 interpreted from the 1984 testing, in which the pumping phase lasted 14 days at an average pumping rate of 4.0 gpm, and that interpreted from the H-3 multipad interference test, in which the pumping phase lasted 62 days, at an average rate of 4.8 gpm. Beauheim (1987a) attributes this difference to either a real difference in transmissivity between holes H-3b3 and H-3b2, the specific wells pumped in the two tests, and/or to the fact that the average transmissivity of the relatively large volume investigated during the long-term H-3 multipad test is lower than the average transmissivity of the volume investigated in the shorter-term 1984 testing. Consistent with this latter interpretation, the original H-3(b1) transmissivity of 2.0 x 10^{-5} m^2/s reported by Mercer (1983) is based on a combination of bailing/recovery and slug tests, both of short duration.

Table 4.4 includes estimates of both "skin factor" and the "storativity ratio" for individual holes on the H-3 pad. Calculated skin factors range from -7.3 to -8.1. As discussed by Beauheim (1987a), the strongly negative skin factors indicate direct connection of all three wellbores with fractures, consistent with the interpreted effective radius of 146 m for hole H-3b3. Although the storativities of the observation holes on the H-3 pad could not be calculated, Beauheim (1987a) does calculate "storativity ratios" (omegas), the ratio of fluid storativity within the fractures (secondary porosity) to that of the entire system of matrix plus fractures (primary plus secondary porosity). The calculated values range from 0.03 to 0.25. As noted by Saulnier (1987), most fractured-rock systems have a storativity ratio less than 0.1. The storativity ratios at the H-3 pad indicate unusually high storage within fractures, perhaps due to the vugginess of the Culebra.

4.1.2.2 Interference Testing at the H-11 Hydropad and Comparison with Results at the H-3 Pad--Saulnier (1987) summarizes the interpretation of pad-scale interference testing carried out at the H-11 hydropad (Figure 4.1.5) in 1984 and 1985. During 1984, holes H-11b1, H-11b2, and H-11b3 were each pumped in individual tests lasting from 12 to 21 hours. The 1985 test, in which H-11b3 was the pumped hole, lasted for 32 days. However, complications with instrumentation during the 1985 testing resulted in four distinct pumping and recovery periods. The resulting superposition of effects complicates interpretation of the 1985 results.

The results of interference testing at H-11 are included in Table 4.4. The interpreted transmissivities for pumped holes and for flow paths between pumped and observation holes on the H-11 pad range from 1.2 x 10^{-5} to 3.0 x 10^{-5} m^2/s. With the exception of the interpreted transmissivity of H-11b1 during 1984 pumping the range is only 2.5 x 10^{-5} to 3.0 x 10^{-5} m^2/s.

Table 4.4: Summary of single-pad interference testing results for the Culebra dolomite at the H-3 and H-11 hydropads. Slightly modified from data contained in Tables 6-1 and 6-3 of Beauheim (1987a) and Table 6.1 of Saulnier (1987).

	Transmissivity (m^2/s)	Skin Factor	Storativity	Storativity Ratio (ω)	Flow Ratio(λ)
H-3(1)					
H-3b3 (1984) pump	3.1×10^{-6}	-7.8	-	0.07	-
H-3b1 (obs.)	3.2×10^{-6}	-7.3	-	0.25	-
H-3b2 (obs.)	3.2×10^{-6}	-7.6	-	0.04	-
H-3b2 (1986) pump	1.8×10^{-6}	-8.1	-	0.03	-
H-3b1 (obs.)	1.9×10^{-6}	-7.7	-	0.25	-
H-3b3 (obs.)	1.9×10^{-6}	-8.0	-	0.10	-
H-11(2)					
H-11b1 (1984) pump	1.2×10^{-5}	-3.3	-	0.01	1.3×10^{-9}
H-11b2 (obs.)	2.5×10^{-5}	-	8×10^{-4}	0.35	2.0×10^{-6}
H-11b3 (obs.)	2.8×10^{-5}	-	5.5×10^{-4}	0.35	1.3×10^{-6}
H-11b2 (1984) pump	-	-	-	-	-
H-11b1 (obs.)	2.7×10^{-5}	-	6.1×10^{-4}	0.43	2.0×10^{-6}
H-11b3 (obs.)	2.6×10^{-5}	-	4.5×10^{-4}	0.40	3.8×10^{-6}
H-11b3 (1984) pump	2.8×10^{-5}	-4.4	-	0.01	2.3×10^{-6}
H-11b1 (obs.)	2.7×10^{-5}	-	6.3×10^{-4}	0.30	1.3×10^{-6}
H-11b2 (obs.)	2.6×10^{-5}	-	7.2×10^{-4}	0.30	1.3×10^{-6}
H-11b3 (1985) pump	3.0×10^{-5}	-4.6	-	0.01	3.7×10^{-7}
H-11b1 (obs.)	2.7×10^{-5}	-	2.9×10^{-3}	0.07	5.0×10^{-6}
H-11b2 (obs.)	2.8×10^{-5}	-	2.6×10^{-3}	0.07	5.8×10^{-6}

(1) All holes H-3 pad interpreted as part of pumped hole; therefore, storativities not available, but skin factors and point transmissivities available for all holes.

(2) Observation holes on H-11 pad well-behaved; therefore, transmissivities, except for pumped hole, are averages between observation and pumped hole.

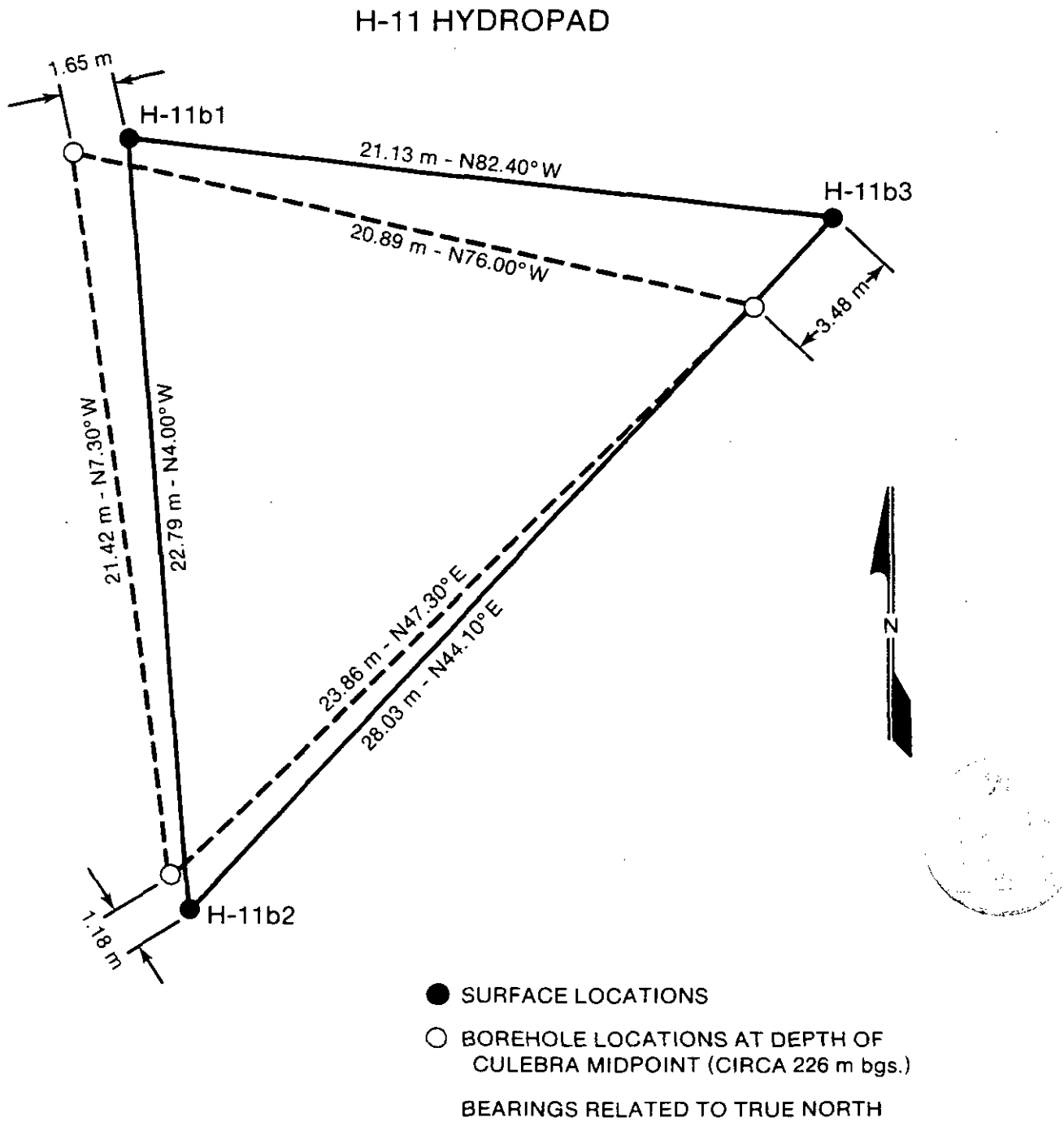

Figure 4.1.5: Physical layout of the H-11 hydropad. The figure is a plan view, showing positions and distances between wells both at the surface and where penetrating the Culebra dolomite. Modified from Figure 3.1 of Saulnier (1987).

The behavior of observation holes on the H-11 pad is consistently different than that observed on the H-3 pad. Although the observation holes on the H-11 pad displayed dual-porosity behavior, their response to the beginning and ending of pumping was sufficiently delayed to allow interpretation as observation holes, rather than as part of the pumped well. The calculated effective hydraulic radius of H-11b3, consistent with the behavior of the observation holes, is 4.9 m (Saulnier, 1987), as compared to an effective radius of 146 m at the H-3 pad (Beauheim, 1987a).

Comparison of the hydrologic behaviors at the H-3 and H-11 pads indicates that the hydraulic effectiveness of fracturing at a given site need not be proportional to the transmissivity. The interpreted transmissivity of H-11b3 during pumping of this hole in 1984 is 2.8×10^{-5} m^2/s, as compared to a transmissivity of 3.1×10^{-6} m^2/s for hole H-3b3 in 1984 testing at the H-3 pad. However, the effective radius of H-3b3 is 146 m, while that of H-11b3 is 5 m. In addition, the observation holes at the H-3 pad had to be treated as part of the pumped well, while observation holes at the H-11 pad behaved properly as observation wells. As shown in Table 4.3, the calculated skin factors at the H-3 pad, which range from -7.3 to -8.1, are consistently more negative than those at the H-11 pad, which range from -3.3 to -4.6.

Interpretation of behavior along the assumed radial flow paths between observation and pumped wells on the H-11 pads indicates average hydraulic storativities between 4.5×10^{-4} and 2.9×10^{-3}, with the higher values interpreted from testing in 1985. These storativities are higher than regional storativities calculated by Beauheim (1987a) from multipad testing at the H-3 pad (7.4×10^{-6} to 3.0×10^{-5}, see Table 4.6). As at the H-3 pad, calculated storativity ratios at H-11 range from 0.01 to 0.43, higher than normal for fractured media.

Calculated interporosity-flow parameters (lambdas) at H-11 range from 1.3×10^{-9} to 5.8×10^{-6} (Table 4.4). As noted by Saulnier (1987), the definition of the parameter lambda includes the ratio of the matrix permeability (permeability of the primary-porosity system) to permeability of the fractures (secondary-porosity system). Therefore, the calculated results indicate that there is a strong contrast between matrix and fracture permeabilities at the H-11 pad. As also indicated by Saulnier (1987), interpretation of the calculated lambda values at the H-11 pad is consistent with effective block or slab dimensions of 0.3 to 1.0 m. The available information on the effective block size in fractured portions of the Culebra dolomite is discussed further in Section 4.2, based on the results of testing with conservative tracers at the H-3 hydropad.

Using the system transmissivities interpreted from 1984 testing and an average storativity of 6.3×10^{-4}, Saulnier (1987) estimates the extent and orientation of hydraulic "anisotropy" at H-11. The calculated maximum transmissivity vector of 3.3×10^{-5} m^2/s is oriented 5.8 degrees north of east, and the calculated minimum transmissivity vector of 2.1×10^{-5} m^2/s 5.8 degrees west of north (Table 4.5). The calculated ratio of 1.6:1 between maximum and minimum transmissivities at H-11 indicates only a small degree of anisotropy. However, the presence of fractures at this site indicates that these results are only qualitative; because of the

fractures, directional variations in properties are almost certainly not continuous. Also, since the indicated directions of maximum and minimum transmissivity do not coincide with any direct flow paths on the H-11 pad, there is no guarantee that either the maximum or minimum values are reliable.

Table 4.5: Summary of apparent hydraulic anisotropy of the Culebra dolomite. Compiled from results contained in Saulnier (1987) and Gonzalez (1983b).

	T_{MAX} (m^2/s)	T_{MIN} (m^2/s)	T_{MAX}/T_{MIN}	Orientation of T_{MAX}
Site				
H-4(1)	2.9×10^{-6}	1.1×10^{-6}	2.6	N76W
H-5	2.4×10^{-7}	9.7×10^{-8}	2.5	N25W
H-6	1.1×10^{-4}	5.2×10^{-5}	2.1	N29W
H-11(2)	3.3×10^{-5}	2.1×10^{-5}	1.6	N84E

(1) Data for H-4, H-5, and H-6 from Gonzales (1983b).
(2) Data for H-11 from Saulnier (1987).

The available interpretations of anisotropy within the Culebra dolomite are summarized in Table 4.5. Earlier interpretations at the H-4, H-5, and H-6 pads all explicitly make the porous-medium assumption (Gonzalez, 1983b). The interpretation of Saulnier (1987) is based on the calculated system transmissivities. The available interpretations indicate transmissivity ratios between 1.6:1 and 2.6:1, with a direction of between N84E and N76W for the major transmissivity vector. For calculated major Culebra transmissivities between 2.4×10^{-7} m^2/s and 1.1×10^{-4} m^2/s and minor transmissivities between 9.7×10^{-8} and 5.2×10^{-5} m^2/s there appears to be less than a factor of three hydraulic anisotropy. The available results indicate that there is no consistent orientation of maximum Culebra transmissivity.

4.1.3 Multipad Interference Testing

As noted in the introduction to Section 4.0, the best method of estimating the regional distribution of properties within a variable hydrologic unit is by regional-scale testing and interpretation. At the WIPP site, two regional-scale multipad interference tests of the Culebra dolomite have been completed, centered at the H-3 hydropad and at hole WIPP-13. The H-3

multipad interference test and related analytical interpretation and regional-scale modeling of Culebra hydrology are discussed in Section 4.1.3.1. The WIPP-13 test and related interpretative and modeling studies are discussed in Section 4.1.3.2.

4.1.3.1 The H-3 Multipad Interference Test and the Regional Culebra Model of Haug et al. (1987)--The pumping phase of the H-3 multipad interference test (Figure 4.1.6) extended from October 15, 1985, to December 16, 1985. Recovery monitoring continued until April 16, 1986, when the data-acquisition system at the H-3 pad was turned off. Raw data from the test are included in INTERA (1986). Analytical interpretations of both detailed results at the H-3 pad and average or apparent transmissivities and storativities between H-3b2 (the pumped hole) and the numerous observation holes are reported by Beauheim (1987a). Analytical interpretation of regional flow patterns generated in response to the test, with emphasis on evaluation of a linear-flow regime at holes H-3, H-11, and DOE-1, is reported by Tomasko and Jensen (1987). Numerical calculation or simulation of Culebra transmissivities, heads, and fluid densities on the regional scale are reported by Haug et al. (1987), as well as modeling of the transient pressure responses to the H-3 multipad test.

Beauheim (1987a) describes the analytical (as opposed to numerical) interpretation of hydraulic data collected during the H-3 multipad interference test. Results on the H-3 pad itself are discussed in Section 4.1.2. The regional distribution of Culebra properties, based on Beauheim's analytical interpretation, is summarized in Table 4.6. The analytical approach used to interpret responses at observation holes necessarily assumes both radial flow into the pumped hole and homogeneous or average properties between pumped hole and individual observation holes (Beauheim, 1987a). Therefore, transmissivity values listed in Table 4.6 are apparent average values for an assumed radial flow path between H-3b2 and the listed observation hole. Beauheim (1987a) found it necessary to correct both pre-test and post-test heads for the relatively long-term transient behavior of some water levels at and near the WIPP site (Table 4.6). This transient behavior is in response to some combination of hydrologic testing, shaft sinking and sealing operations, and a possible regional transient.

Observation-hole responses to the H-3 multipad test fall into three general categories. First, on the H-3 pad itself, hydraulic fracturing was sufficient to require that Observation holes H-3b1 and H-3b3 be considered as part of the pumped hole (Section 4.1.2). Second, Observation holes DOE-1 and H-11b1, respectively 1606 and 2423 m southeast of H-3b2 (Figure 4.1.6), responded rapidly to both the beginning and ending of pumping. Drawdown in DOE-1 began 48 hours into the test, and that in H-11b1 only three hours later (Table 4.6). The average transmissivities interpreted along flow paths between H-3b2 and DOE-1 and H-11b1 are 5.9×10^{-6} m^2/s between DOE-1 and H-3b2 and 7.3×10^{-6} m^2/s between H-11b1 and H-3b2. Calculated apparent storativities along the same flow paths are 1.0×10^{-5} and 7.4×10^{-6}, respectively. Beauheim (1987a) concludes that the rapid responses at DOE-1 and H-11b1 and relatively high calculated transmissivities along flow paths between these holes and H-3b2 indicate a

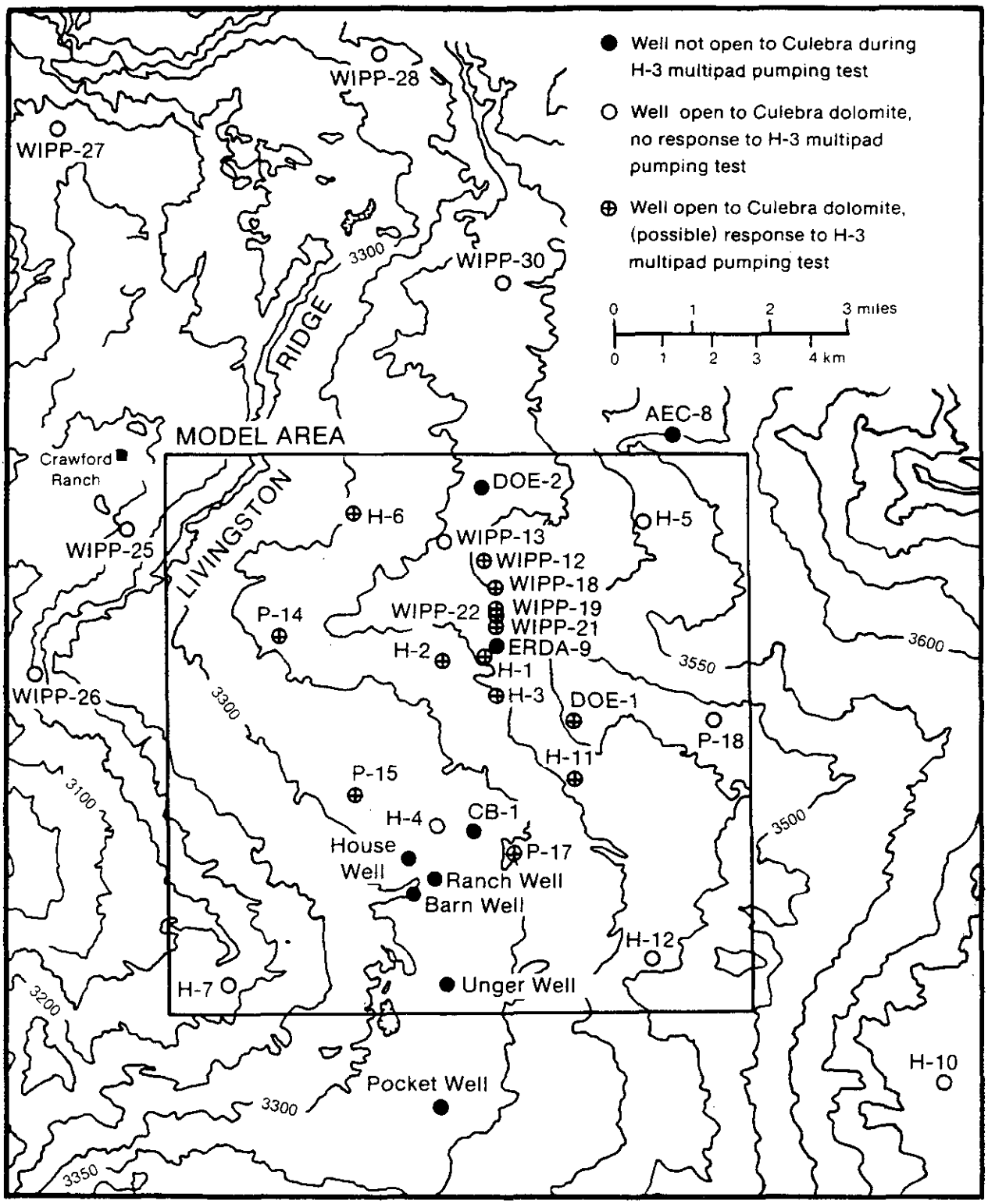

Figure 4.1.6: Pumping and observation wells for the H-3 multipad interference test. Figure 3.2 of Haug et al. (1987).

Table 4.6: Summary of results of analytical interpretation of H-3 multipad interference test. Slightly modified from data contained in Tables 3-1, 5-1, and 6-4 of Beauheim (1987a).

Well	Distance(m)(1)	Direction	First Obs.(2) Drawdown (hrs)	Delay in Max. Drawdown (hr)	Unmodified Interpretation		Modified Interpretation		
					$T(m^2/s)$(3)	S	$T(m^2/s)$	S	Head Modification (m/day)
H-11b1	2423	S42E	79	51	1.4×10^{-5}	6.6×10^{-6}	7.3×10^{-6}	7.4×10^{-6}	8.6×10^{-3}
DOE-1	1606	S68E	57	48	9.9×10^{-6}	9.2×10^{-6}	5.9×10^{-6}	1.0×10^{-5}	5.5×10^{-3}
H-1	815	N19W	488	1423	8.9×10^{-7}	3.9×10^{-5}	4.9×10^{-7}	2.7×10^{-5}	2.64×10^{-2}
H-2b2	1270	N54W	433	1393	2.7×10^{-6}	4.5×10^{-5}	1.3×10^{-6}	3.0×10^{-5}	1.16×10^{-2}
WIPP-19	1875	N2E	1207	1855	3.1×10^{-6}	2.9×10^{-5}	-	-	-
WIPP-21	1437	N3E	437	678	1.2×10^{-6}	9.0×10^{-6}	-	-	-
WIPP-22	1739	N2E	990	727	1.7×10^{-6}	1.7×10^{-5}	-	-	-

(1) Distances and directions measured from H-3b2 to the indicated well.
(2) First drawdown and delay in maximum drawdown are given relative to times at which pump was turned on and off, respectively.
(3) Unmodified and modified transmissivities (T) and storativities (S) are apparent average values between H-3b2 and indicated well, assuming radial flow to H-3b2.

preferential connection between the H-3 pad and the southeast portion of the WIPP site. He further concludes, consistent with single-pad interference testing at both H-3 and H-11 (see Section 4.1.2), that this connection is related to fractures. Third, holes north and northwest of H-3b2 were much slower to respond to the H-3 multipad test, indicating relatively poor and variable hydraulic connection in this direction. Hole H-1, 815 m from H-3b2, did not respond to pumping until approximately 488 hours into the test. The best estimate of the average transmissivity between H-3b2 and H-1 is 4.9 x 10^{-7} m^2/s. H-2b2, slightly further from H-3b2 than hole H-1, responded earlier (433 hours). The slightly higher apparent transmissivity between H-2b2 and H-3b2 (1.3 x 10^{-6} m^2/s) than between H-1 and H-3b2 indicates local variability within the Culebra dolomite, even in the low-transmissivity domain containing H-1, H-2, and H-3. In contrast to behavior at and southeast of the H-3 pad, there is no indication that regional-scale flow or pressure response between H-3 and either H-2b2 or H-1 involved fractures. Holes WIPP-19, 21, and 22 are north of the WIPP facility (Figure 4.1.6). Therefore, their response to any pumping test at H-3 will be influenced by the intervening WIPP shafts, unless the sealing of these shafts is perfect. There was, in fact, considerable uncertainty about the rates of leakage from the Culebra into the WIPP exhaust and waste-handling shafts during the H-3 test. As a result, interpreted transmissivities for flow paths extending north of the center of the WIPP site, i.e., between H-3b2 and holes WIPP-19, 21, and 22, may be inaccurate (Beauheim, 1987a).

Several observation holes did not respond measurably during the H-3 multipad test, including H-4, P-14, P-15, and P-17. Therefore, only minimal transmissivities could be calculated for areas south and southwest of H-3, based on the lack of response. Beauheim (1987a) estimates that the average transmissivity between H-4 and H-3b2 would need to be less than 1.0 x 10^{-6} m^2/s. As indicated in Table 4.2, drilling and testing of hole H-14 has since yielded results consistent with this bounding interpretation.

Tomasko and Jensen (1987) note a strikingly linear relationship between the observed drawdowns and the square root of time in holes H-3b2, H-11b1, and DOE-1 during the H-3 multipad test, and conclude from this that much of the response to the test in this area was a result of "linear flow," in which flow is largely confined to a linear high-transmissivity structure between less-permeable boundaries. Their interpretation is a second line of evidence for a high-transmissivity structure in the southeastern part of WIPP Zone 3. Figure 4.1.7 shows the nearly linear response of H-3b2 versus the square root of time during the pumping phase of the H-3 multipad test. Tomasko and Jensen (1987) interpret the limited curvature shown in Figure 4.1.7 to reflect the fact that the high-transmissivity structure containing H-3b2 is finite in width.

Figure 4.1.8 compares observed drawdowns and recoveries at H-11 and DOE-1 with those calculated assuming linear flow in a high-transmissivity structure oriented N29W. There is good agreement during the pumped phase, even with a model that used a simplified transmissivity distribution. Although calculated drawdowns exceed those measured, the shape of both drawdown and recovery curves agree well. This linear-flow approach yielded average transmissivities of 2.2 x 10^{-6}, 9.7 x 10^{-6}, and 2.0 x 10^{-5} m^2/s for

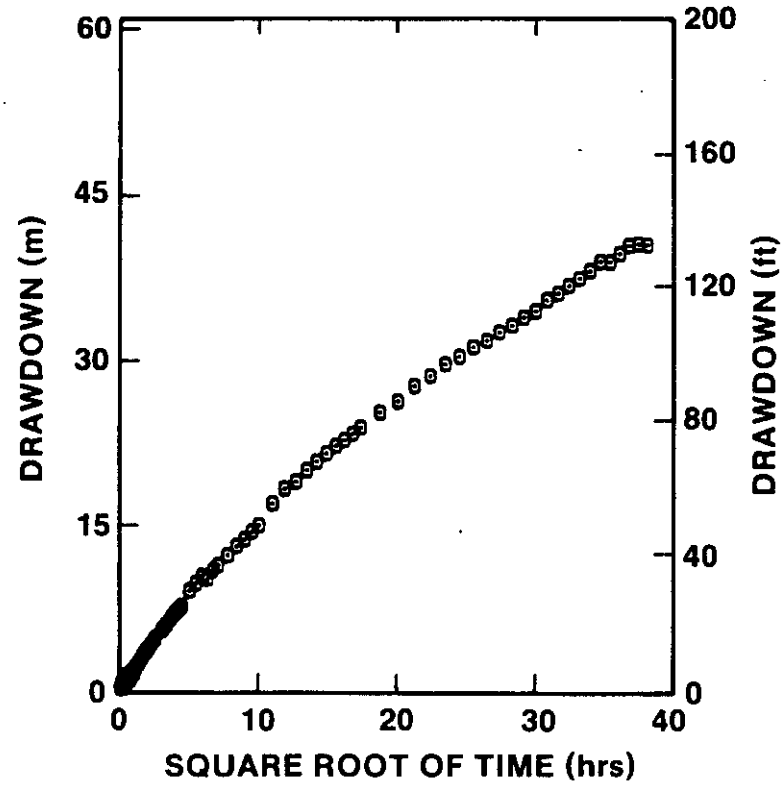

Figure 4.1.7: Observed drawdown versus the square root of time in hole H-3b2 during the H-3 multipad interference test. Slightly modified from Figure 15 of Tomasko and Jensen (1987).

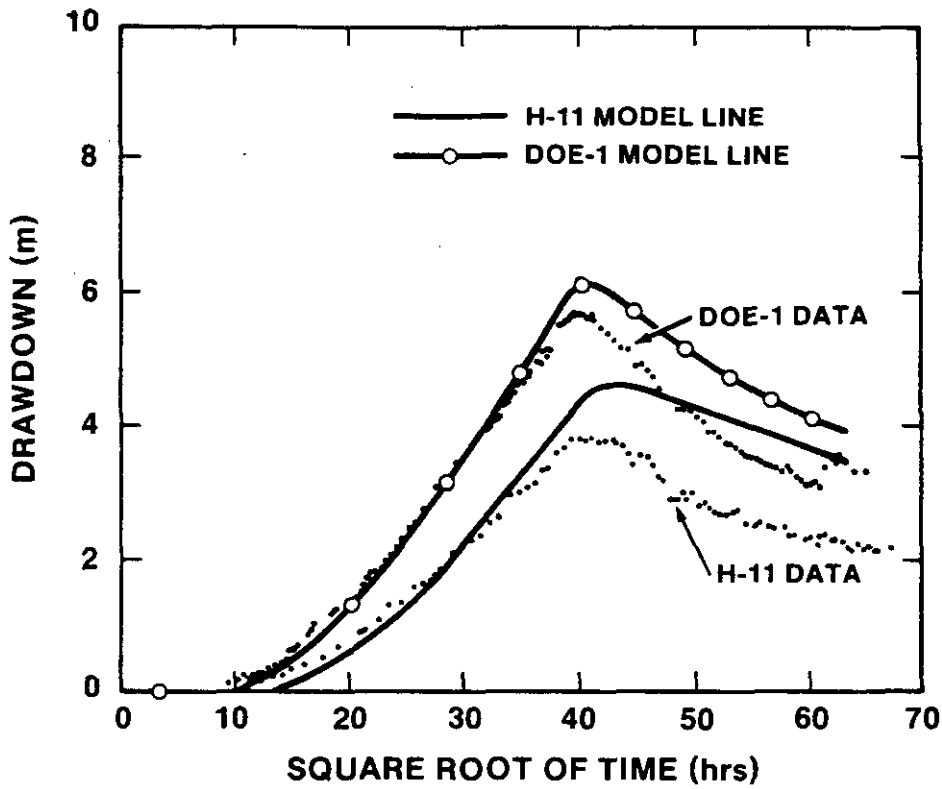

Figure 4.1.8: Comparison of measured and simulated responses at H-11 and DOE-1 during the H-3 multipad interference test, assuming perfectly linear flow. Figure 25 of Tomasko and Jensen (1987).

the H-3 pad and between H-3 and DOE-1 and H-11, respectively. These results are in qualitative agreement with the results of Beauheim (1987a) discussed above (2.0×10^{-6}, 5.9×10^{-6}, 7.3×10^{-6} m^2/s, respectively).

The analytical approaches discussed thus far involve specific assumptions, some of which pose real limitations in interpretation of testing on this geometric scale within a unit as complex as the Culebra dolomite. These include:

1. Regional-scale flow is assumed to be either perfectly radial or perfectly linear.

2. Transmissivities are either assumed uniform between pumped hole and observation hole, or a simplified transmissivity distribution is assumed.

3. Constant fluid density is assumed.

4. The Culebra dolomite is assumed to be completely confined.

In contrast, the approach taken by Haug et al. (1987), using the code SWIFT II (Reeves et al., 1986a; Reeves et al., 1986b), is fully numerical, and includes consideration of: a) a more complex pattern of regional flow, based on calculation of transmissivities between measurement points; b) variable fluid densities; and c) vertical fluid flux into or out of the Culebra. The modeling approach of Haug et al. (1987) assumes steady-state boundary conditions.

The results of non-directional kriging of the April 1986 Culebra-transmissivity data base (Figures 4.1.9 and 4.1.10) provide a quantitative indication of the statistical reliability of the data base at that time, independent of geologic and hydrologic judgement. The limited size of the data base resulted in the kriged transmissivity pattern consisting largely of "circles" around measured data points (Figure 4.1.9). The roughly circular areas within which the uncertainty in transmissivity (defined here as one standard deviation) was less than one order of magnitude were centered on individual hydro holes and approximately one kilometer in diameter (Figure 4.1.10). The only regions in which the areas of one-order-of-magnitude uncertainty overlapped was in the regions H-1 - H-2 - H-3 and H-11 - DOE-1. This finding provided strong impetus for testing of additional holes within WIPP Zone 3, as indicated by the large number of holes in Table 4.1 for which data have been collected or revised since April 1986.

One major emphasis of Haug et al. (1987) is consideration of the regional hydrologic behavior of the Culebra, independent of transient effects imposed by the WIPP facility. This required estimation of Culebra head potentials as they existed prior to the sinking of the WIPP shafts (Figure 4.1.11). Figure 4.1.12 shows the simulated or calculated Culebra transmissivity distribution resulting from calibration of downhole pressures within the Culebra against the "measured" pre-shaft freshwater-equivalent head potentials shown in Figure 4.1.11. The calibration effort

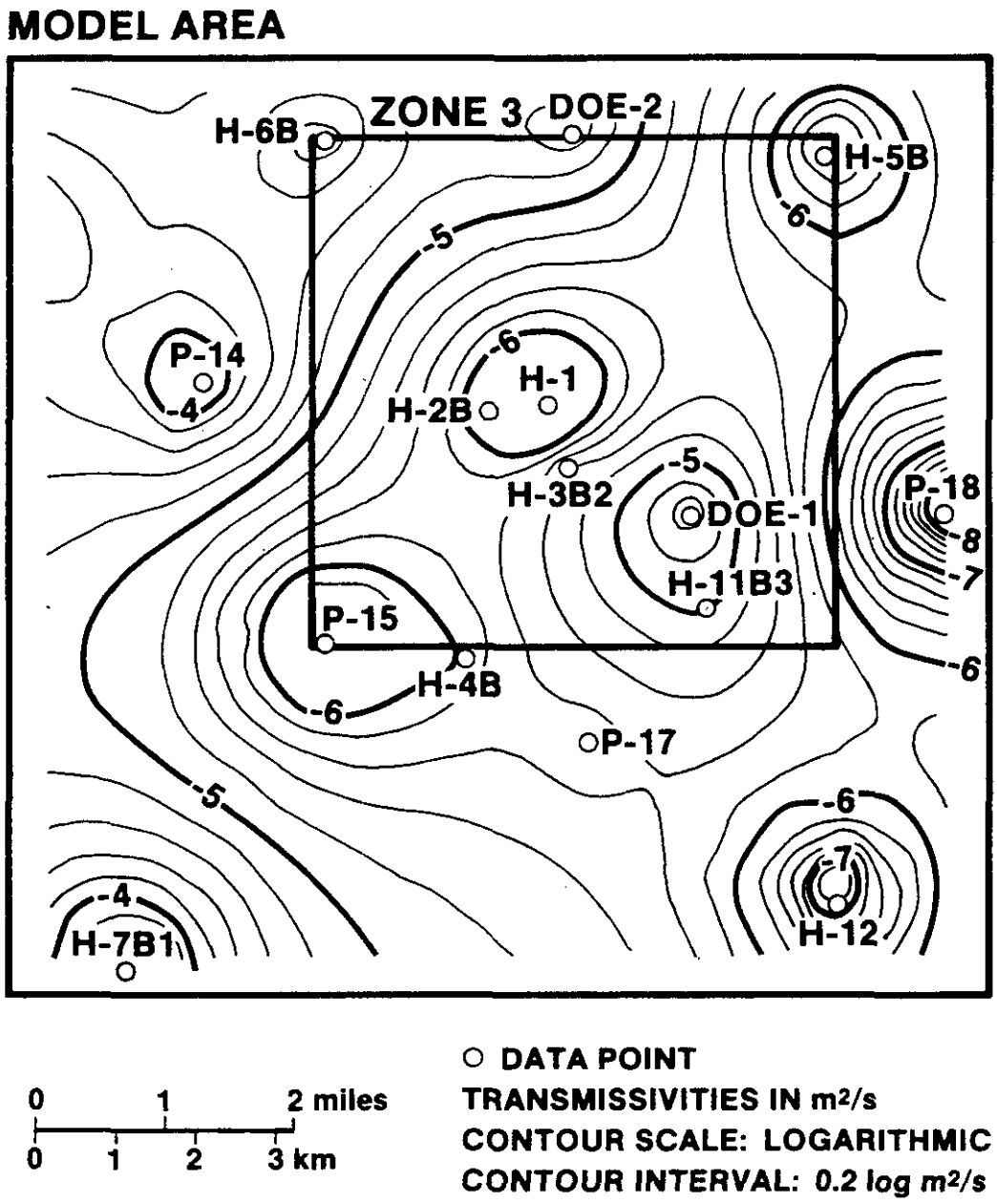

Figure 4.1.9: Initial kriged Culebra transmissivities, based on data available as of April 1986. Slightly modified from Figure 3.7 of Haug et al. (1987).

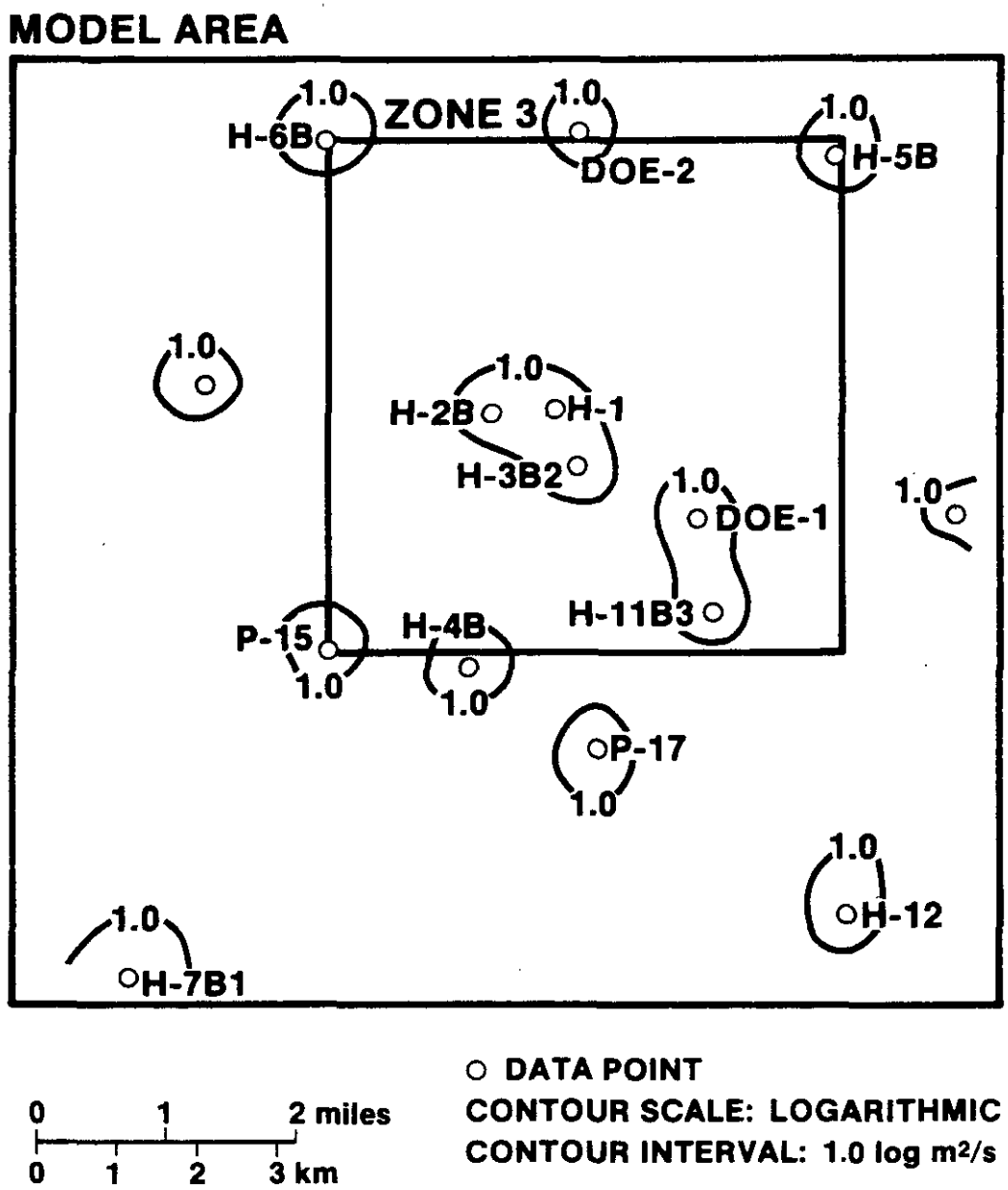

Figure 4.1.10: Estimation error in initial kriged Culebra transmissivities, based on data available as of April 1986. Slightly modified from Figure 3.8 of Haug et al. (1987).

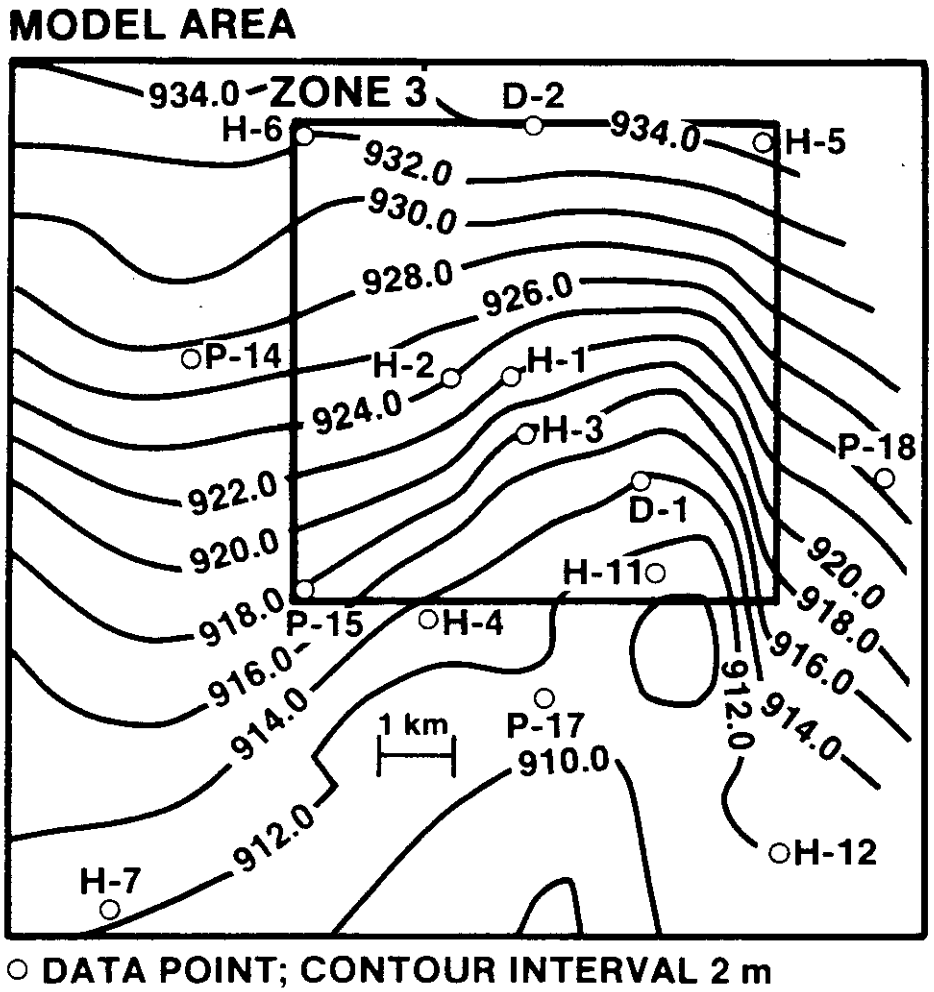

Figure 4.1.11: Best estimate of pre-shaft Culebra freshwater equivalent heads, based on data available as of April 1986. Slightly modified from Figure 3.9 of Haug et al. (1987).

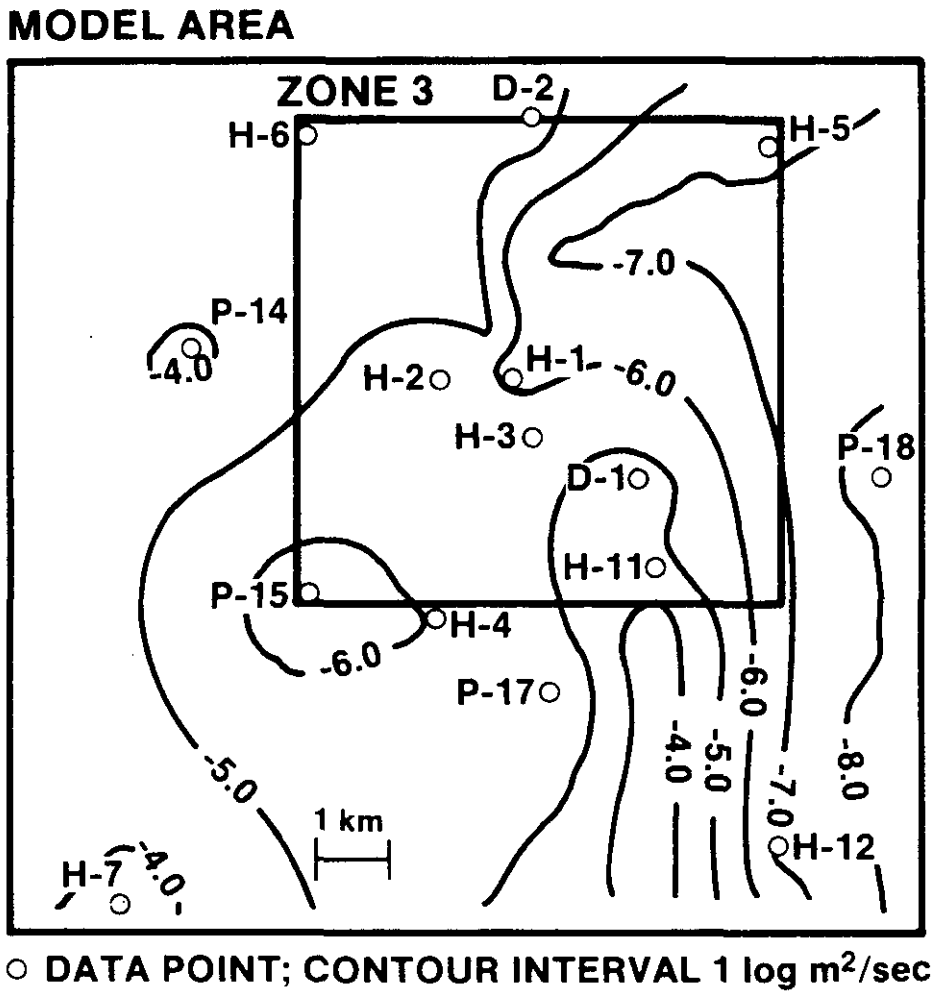

Figure 4.1.12: Best calculated distribution of Culebra transmissivities, based on pressure calibration to head distribution shown in Figure 4.1.11. Slightly modified from Figure 4.4 of Haug et al. (1987).

involved use of "pilot points" in some locations between measured data. At the pilot points, transmissivities were assigned, consistent with the uncertainty in initial kriged values. Evaluation of the statistical properties of the expanded data base including the pilot-point transmissivities indicated that the statistical properties of this data base were consistent with those of the measured data.

The transmissivity distribution in Figure 4.1.12 is marked by four main features:

1. A large and apparently continuous zone of relatively low transmissivity ($T<10^{-6}$ m^2/s) including the site center, the locations of the WIPP shafts, and extending to the east and northeast.

2. An apparently isolated region of low transmissivity in and near the southeastern portion of the site, in the region P-15 - H-4 - P-17. As noted in Section 4.1.1, it is not clear from existing point data whether or not this zone is connected to the low-transmissivity zone closer to the site center.

3. A narrow high-transmissivity zone ($T>10^{-5}$ m^2/s) in the region containing H-11 and DOE-1, and extending to the south. This zone was largely required in the model to account for the relatively low heads observed at H-11 and DOE-1 (Figure 4.1.11).

   The central portion of the high-transmissivity zone is defined in Haug et al. (1987) only by several pilot points, since no data from within the zone were available as of April 1986. The zone is consistent with results of both Beauheim (1987a) and Tomasko and Jensen (1987). Model transmissivities in the central part of the zone, approximately 3.0×10^{-4} m^2/s, are similar to the transmissivities at H-9b (1.7×10^{-4} m^2/s) and P-14 (2.3×10^{-4} m^2/s), but lower than the transmissivity at H-7b (1.1×10^{-3} m^2/s) (Table 4.1). The assigned value was chosen in the effort to be reasonably "conservative," i.e., to have the zone contain as high a transmissivity as was reasonable.

4. A relatively large and apparently continuous high-transmissivity zone in the western part of the modeled area. As of April 1986, the high-transmissivity zone included measured data only at holes H-6, DOE-2, P-14, and H-7. The need to define the relationship of this high-transmissivity zone to the low-transmissivity zone containing the center of the WIPP site was a major driving force behind multipad interference testing at WIPP-13 (Section 4.1.3.2).

The calculated transmissivity distribution (Figure 4.1.12) served as a basis for further model calibration (Haug et al., 1987). The distribution of Culebra fluid densities measured as of April 1986 is shown in Figure 4.1.13. Culebra fluids in the vicinity of the WIPP site range in density from approximately 1.00 to greater than 1.10 g/cm^3 (see Section 4.1.3.2). Two main features of Figure 4.1.13 are of note:

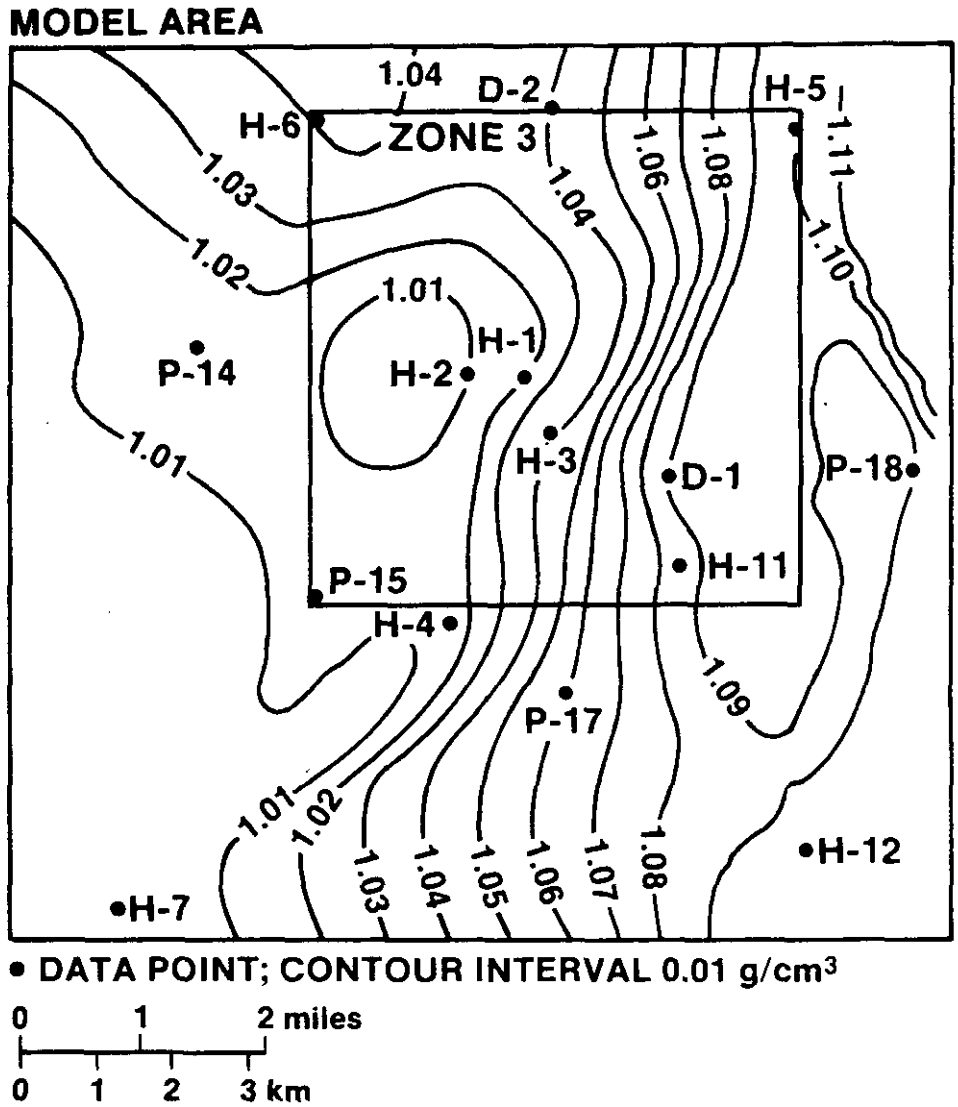

Figure 4.1.13: Best estimate of density distribution of Culebra fluids, based on information available as of April 1986. Figure 3.10 of Haug et al. (1987).

1. A linear zone of steep gradient in fluid density separates a large area of high fluid density (1.08 g/cm^3 or greater) east of the site center from an analogous area of relatively low fluid density (1.04 g/cm^3 or less) west of the site center.

2. Major curvature in the lines of fluid densities 1.01 through 1.04 g/cm^3 in the northwest part of the modeled area. As of April 1986, only measured density data from H-6, DOE-2, H-2, and P-14 provided control for this curvature.

During calibration of Culebra transmissivities against fluid densities, the interpolated brine densities near the boundaries of Figure 4.1.13 were first used as initial boundary conditions in simulation of assumed variable-density steady-state confined flow within the Culebra (Haug et al., 1987). The results of this approach were not satisfactory (Figures 4.1.14 and 4.1.15). Calculated brine densities at steady state are too low in the eastern portion of the model. The density contrasts in the eastern portion of the model (with the exception of the region near P-17) were adjusted successfully by slightly increasing the transmissivity in the northeastern portion of the model, without significantly changing fluid densities assigned at the boundaries. Over the western portion of the model, the problem was more severe. At steady state, a large area, including holes H-1, H-2, P-17, P-15, and P-14, was calculated to have fluid densities between 1.04 and 1.05 g/cm^3, compared to measured densities of 1.06 g/cm^3 at P-17 and less than 1.03 g/cm^3 at the other holes. The high calculated brine densities over the western portion of the site reflect the southward movement of the relatively dense brines at H-6 and DOE-2 required by steady-state confined flow (Haug et al., 1987).

These results are taken by Haug et al. (1987) to be consistent with at least three possibilities:

1. The interpolated brine densities along the northern boundary of the model are incorrect, except for the measured value at H-6. This possibility is considered in detail by Haug et al. (1987). Because of the recent increase in brine-density data in the northwest portion of the modeled area, the possibility is not considered further here (see Section 4.1.3.2).

2. There is enough vertical fluid leakage into and/or out of the Culebra to significantly affect fluid densities within the unit. This possibility is considered further by Haug et al. (1987), and is discussed below (see also Section 4.1.1).

3. The Culebra hydrologic regime is not at steady state on the time scale required for water flow across the modeled area. Transient boundary conditions for the hydrology of the Rustler Formation are consistent with recent geologic and isotopic results discussed in Sections 4.3 and 4.4, but have not yet been modeled directly, and are not considered further here.

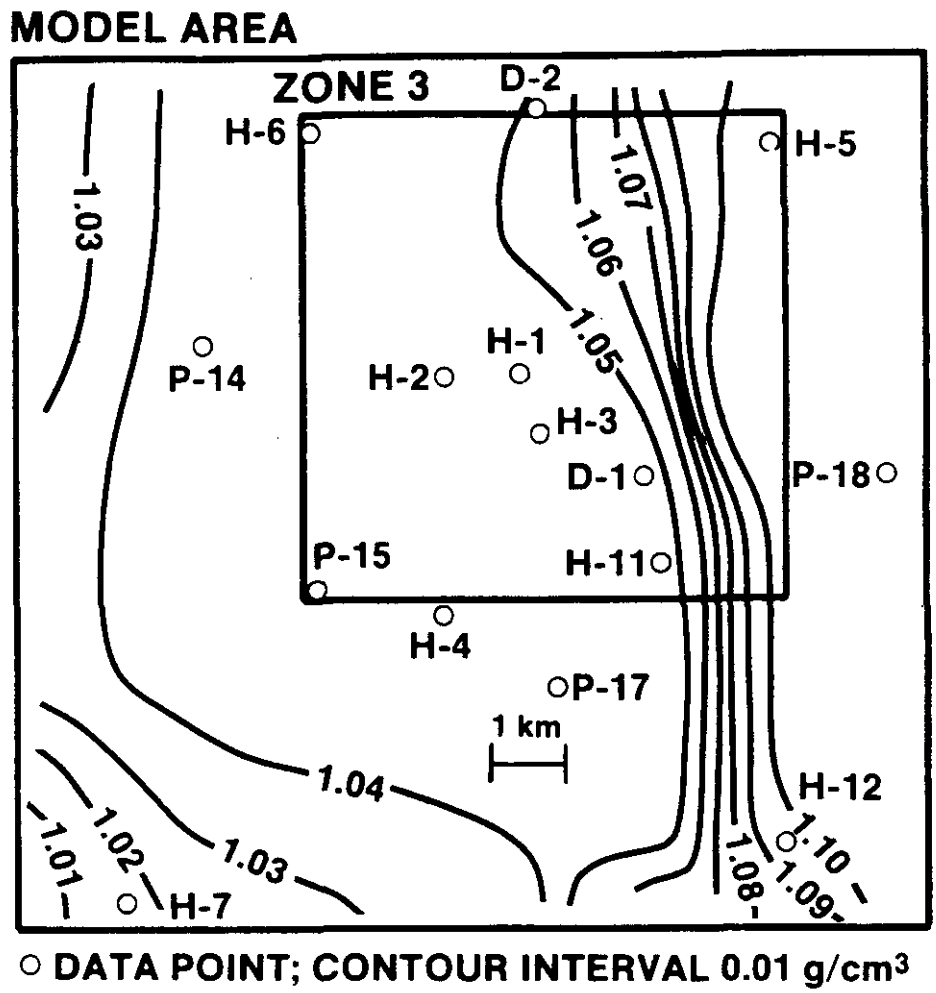

Figure 4.1.14: Calculated steady-state, brine-density distribution within the Culebra dolomite, based on data available as of April 1986. Slightly modified from Figure 4.7 of Haug et al. (1987).

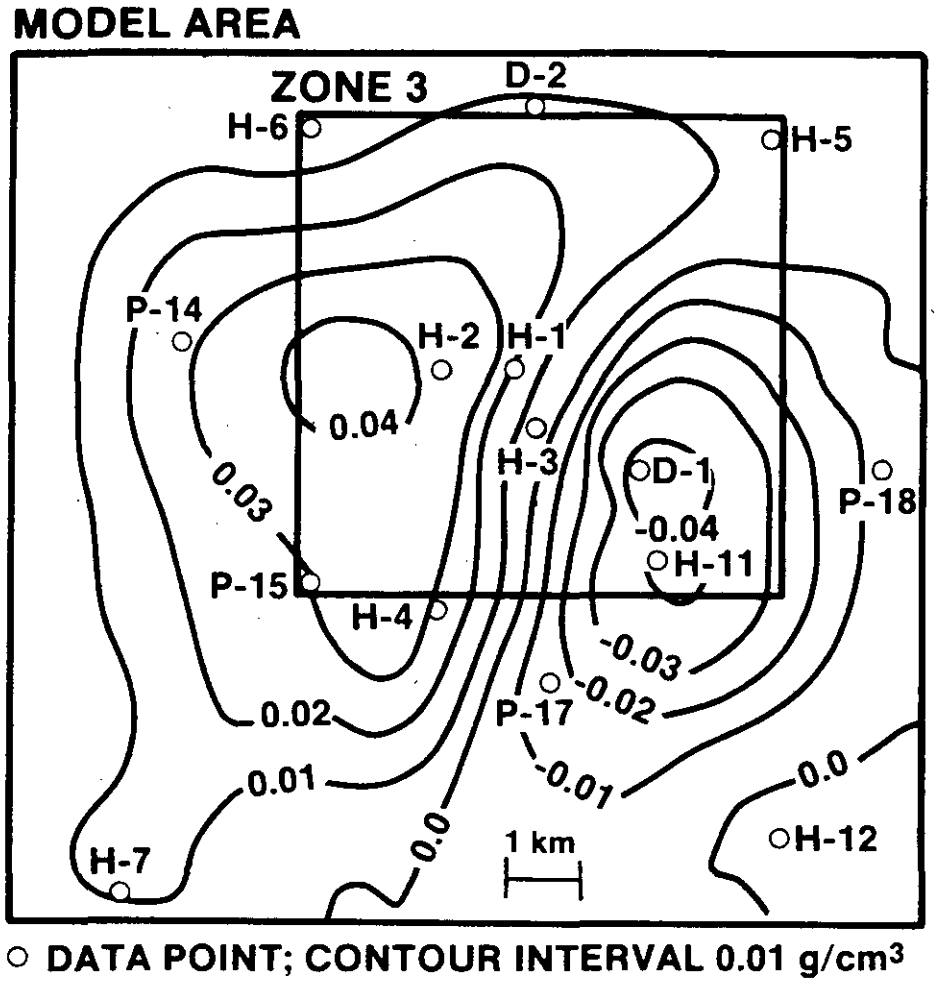

Figure 4.1.15: Difference between calculated steady-state brine density distribution within the Culebra (Figure 4.1.14) and the measured estimated distribution shown in Figure 4.1.13. Slightly modified from Figure 4.8 of Haug et al. (1987).

Haug et al. (1987) initially addressed the density contrast over the western portion of the modeled area by assuming that brine densities along the northern boundary of the model were incorrect; therefore, calibration against fluid density did not change interpolated transmissivities in this area. In the vicinity of hole P-17, however, better agreement between calculated and measured fluid densities was obtained by shifting the location of the southern high-transmissivity zone in Figure 4.1.12 closer to P-17.

Haug et al. (1987) then considered the possibility of vertical fluid flow into and/or out of the Culebra dolomite in two areas:

1. At and near P-17, where measured brine densities were 0.04 g/cm^3 higher than those calculated. Upward flow of relatively dense brine from the Rustler/Salado contact zone, through the unnamed lower member of the Rustler, into the Culebra dolomite was considered at this location, consistent with known head relationships (see Section 4.1.1).

2. Over the western and southwestern part of the modeled area, in which measured fluid densities are significantly less than modeled densities. Uniform downward flow of relatively fresh (low-density) fluids from the Magenta into the Culebra was considered in this area.

Assuming a brine density of 1.19 g/cm^3 for the Rustler/Salado contact zone and/or unnamed lower member of the Rustler in the region near P-17, Haug et al. (1987) estimate that a vertical flux of 10^{-12} m^3/m^{2}s would be sufficient to result in a calculated brine density within the Culebra of 1.06 g/cm^3, the measured value. Given the approximate vertical gradient of 0.18 m/m at this location, based on head relations shown in Mercer (1983), this flux would require a vertical hydraulic conductivity of 5.7 x 10^{-12} m/s in the unnamed member. This is within the range thought reasonable (Haug et al., 1987), but slightly higher than recently measured adjacent to the WIPP waste-handling shaft (Section 3.3.1.2). Thus, a very small upward flux into the Culebra in the vicinity of P-17 appears to be largely consistent with known data, and improves agreement between measured and calculated brine densities in the area. However, it is not feasible to measure the small flux in a reasonable time in the field.

In considering fluid flow from the Magenta dolomite downward into the Culebra over the western portion of the modeled area, Haug et al. (1987) assumed a brine density of 1.00 g/cm^3 for the Magenta. Addition of a small but constant vertical flux of 5 x 10^{-12} m^3/m^{2}s over the western portion of the model led to two qualitatively different responses:

1. In areas of low Culebra transmissivity, the resulting freshwater-equivalent heads were increased significantly, causing unacceptable disagreement between calculated and observed heads. In these areas, however, the assumed flux did significantly decrease the calculated brine densities within the Culebra.

2. In areas of high Culebra transmissivity, addition of the vertical flux did not significantly harm the agreement between calculated and

measured freshwater heads, nor did it significantly improve the agreement between measured and calculated brine densities within the Culebra.

Vertical flux from the Magenta downward into the Culebra dolomite over the western portion of the modeled area is consistent with known head and fluid-density relationships in some areas (Section 4.1.1.2). However, the flux, if real, must be laterally variable rather than constant, and the vertical conductivity of the Tamarisk claystone and anhydrites between the Magenta and Culebra may simply be too low at and near the site. The modeling results of Haug et al. (1987) suggest that vertical flow rates must be higher in regions in which the Culebra is more transmissive, and lower in regions where it is less transmissive. This amount of coupling of Culebra transmissivity with that of the overlying Tamarisk and Magenta members has not been identified in the regional variations in transmissivities of the different members of the Rustler at and near the WIPP site. For example, the transmissivity of the Tamarisk claystone, between the Magenta and Culebra, is too low for measurement at and near the site; the transmissivity of the Tamarisk anhydrites may be even lower. Given enough modeling time and effort, it appears that excellent agreement between measured and calculated brine densities within the Culebra dolomite could be obtained by calibration against both transmissivity distribution in the Magenta, Tamarisk, and Culebra and vertical flux, assuming steady-state boundary conditions. However, this agreement would not in any way be unique, and might not be consistent with the inability to measure properties within the Tamarisk. This is not to say that vertical flow is not occurring within the Rustler Formation (see Sections 4.1.1 and 4.4), simply that data are not adequate to model it precisely. The extremely low transmissivity of the Tamarisk claystone and anhydrites, relatively high transmissivity of the Culebra, and geochemical relationships within the Rustler (Section 4.4) suggest that transient confined flow within the Culebra dominates Rustler hydrology at and near the WIPP site.

In summary, model calibration to the Culebra pre-shaft head distribution by Haug et al. (1987) largely met with success, but also indicated uncertainties in the understanding of Culebra and Rustler hydrology. Calibration to the freshwater head distribution was successful to within one meter of measured values. Assuming steady-state confined flow, however, the resulting Culebra transmissivity distribution was not successful in simulating the measured brine-density distribution. In the eastern portion of the model, the required adjustment in transmissivity was minor. Over the western portion of the model, the results of Haug et al. (1987) indicated that: 1) the April 1986 understanding of brine densities may be qualitatively incorrect; 2) there may be regional-scale vertical flow within the Rustler Formation; and/or 3) the hydrologic setting of the Rustler Formation may be transient on the time scale required for groundwater flow across the modeled area.

The next step in model calibration by Haug et al. (1987) was simulation of transient stresses within the modeled area, assuming steady-state boundary conditions. Several transient activities were simulated, including: 1) sinking and grouting of the three existing WIPP shafts; 2) three pumping

tests and slug tests at H-2; 3) convergent-flow tracer testing at H-3; 4) a step-drawdown hydraulic test at H-3; and 5) the multipad interference test at H-3.

Responses to shaft sinking and grouting (both occurring before the H-3 multipad test) were well simulated using the density-calibrated transmissivity distribution estimated by calibration to the pre-shaft head distribution. From this, Haug et al. (1987) concluded that the transmissivity distribution in the region containing H-1, H-2, H-3, DOE-1, and H-11 was approximately correct.

Responses in the WIPP shafts and in holes WIPP-19, 21, and 22 during and after the H-3 multipad test could not be simulated closely unless additional leakage in the shafts was assumed to have occurred during the test. This conclusion, while coincidental, is supported by the fact that the hydraulic responses to sinking and initial grouting of the shafts were well simulated using the "steady-state" transmissivity distribution, while the later H-3 test itself was not.

The final calculated Culebra transmissivity distribution and fluid-flow velocities estimated on the basis of data available as of April 1986 and including adjustment for fluid-density effects in the eastern half of the model are shown in Figure 4.1.16. Four features are of note in this figure:

1. Fluid flow (presented as Darcy velocities) is extremely slow in the area H-12 - H-5 - WIPP-12. Calculated Darcy velocities in this area are 10^{-9} m/s or less.

2. Fluid flow in the southeastern portion of the model is strongly dominated by the high-transmissivity zone in the area H-11 - DOE-1 - P-17. Flow in this area is largely north-south, with Darcy velocities of approximately 10^{-8} m/s.

3. Flow in the northwest and western portions of the modeled area is rapid and largely north-south. Darcy velocities in this area range approximately from 5×10^{-9} to 1×10^{-8} m/s.

4. The region near the center of the WIPP site (WIPP-12 - P-15 - P-17) has relatively low Darcy velocities, approximately 1×10^{-9} to 3×10^{-9} m/s. The high-transmissivity zone to the southeast forces fluid flow in the region between H-4 and the center of the site to be northwest-southeast, in effect connecting the two high-transmissivity zones southeast and northwest of the site center. The control for this flow at the time of the H-3 multipad test was limited, since hole H-14 did not exist at that time.

As discussed in Section 4.1.2, interference testing at the H-3 and H-11 hydropads indicates the strong local influence of fracturing on hydraulic response. Haug et al. (1987) investigate whether or not a dual-porosity formalism is required to model regional-scale responses within the Culebra dolomite by examining times required for pressure equilibration between matrix blocks and fractures.

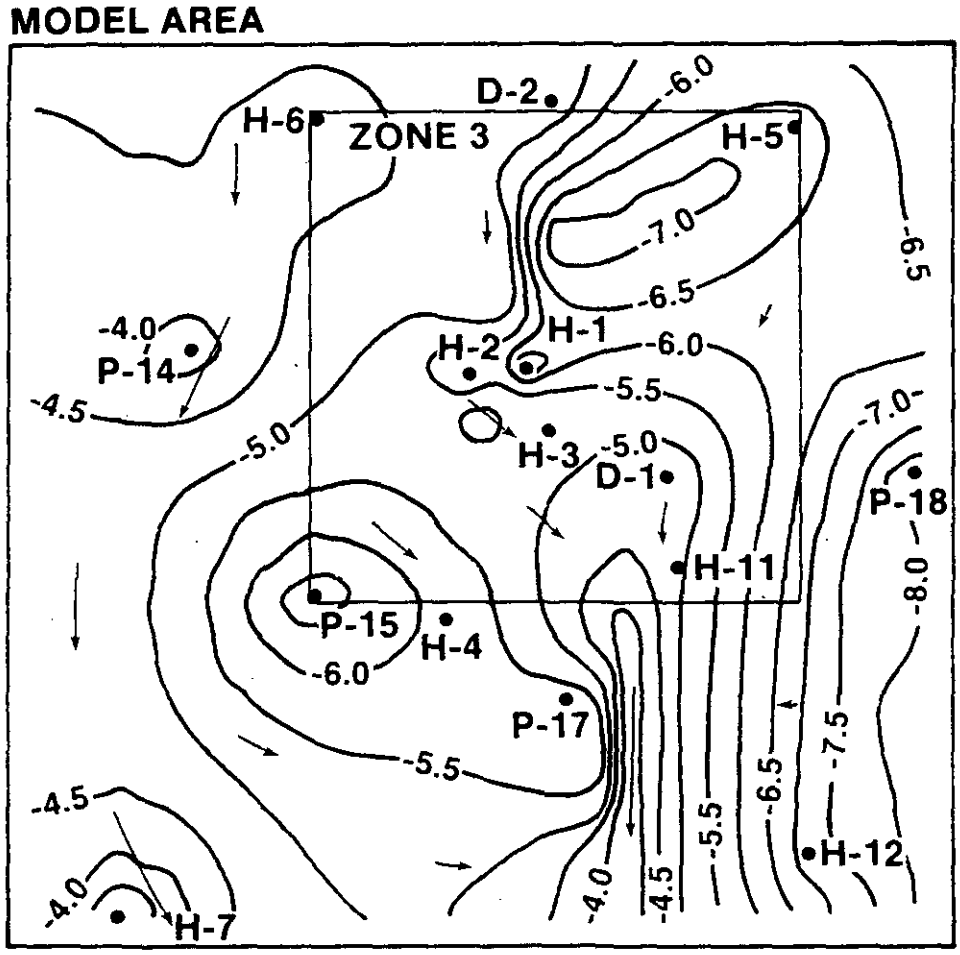

UNITS: LOG m^2/s; • DATA POINT;
CONTOUR INTERVAL: 0.5 UNITS

0 1 2 miles
0 1 2 3 km

Figure 4.1.16: Final calculated Culebra transmissivities and flow directions, based on data available as of April 1986. Slightly modified from Figure 4.11 of Haug et al. (1987).

The time required for pressures in the fracture and matrix in a fractured medium to equilibrate to within 1% is proportional to the square of matrix block size and linearly proportional to the fluid diffusivity within the matrix. For a range of Culebra matrix block sizes (fracture spacings) between 1 and 8 m and a representative range of matrix compressibilities, matrix porosities, and matrix conductivities, Haug et al. (1987) calculate a maximum pressure-response time of 26 days. For the base-case properties interpreted from conservative-tracer testing at the H-3 pad (Section 4.2) the calculated pressure response time is only six hours. Based on these preliminary calculations, Haug et al. (1987) conclude that a dual-porosity formalism is not needed in modeling the regional-scale hydraulic responses within the Culebra dolomite at and near the WIPP site. Haug et al. (1987) modeled the transient hydraulic responses at the H-3 hydropad to both shaft sinking and sealing and the H-3 multipad interference test using both dual-porosity and porous-medium formalisms to examine this conclusion further. Consistent with their conclusion that use of the dual-porosity formalism is not needed at a regional scale, the maximum difference between the transient freshwater heads calculated using the two approaches is 0.02 m.

However, the validity of this conclusion is somewhat limited by the range of fracture spacings considered. The correlation between fracturing and transmissivity within the Culebra discussed in Section 4.1.1 indicates that fracturing is significant in areas of transmissivity greater than approximately 10^{-6} m^2/s. The approximate fracture spacing at the H-3 pad, with a transmissivity of 2 x 10^{-6} m^2/s, is 0.25 to 1 m (Section 4.2). Zones of higher transmissivity presumably have smaller effective block sizes. The preliminary calculations of Haug et al. (1987) indicate that it is in zones of otherwise low transmissivity, in which fracturing is not evident in single-hole testing, and in which fracture spacings may significantly exceed the thickness of the Culebra, that hydraulic behavior on something approaching the regional scale might be controlled by fracturing. However, there is no evidence of any discrete fracture structures within low-transmissivity portions of the Culebra dolomite at or near the WIPP site.

In summary, fielding and interpretation of the H-3 multipad interference greatly increased the understanding of the hydrology of the Culebra Dolomite Member of the Rustler Formation. It emphasized the role of fracturing and lack of hydraulic anisotropy within the H-3 hydropad. The analytical interpretation by Beauheim (1987a) indicated the presence of a high-transmissivity region in the vicinity of H-11 and DOE-1, suggested strong directional dependence of responses to the test, and suggested that transmissivities between H-3 and H-4 were probably less than 10^{-6} m^2/s, an interpretation later confirmed by drilling and testing of hole H-14. The interpretation of Tomasko and Jensen (1987) indicated that regional-scale flow in the southeastern portion of the WIPP site was probably controlled by a linear high-transmissivity zone. Numerical modeling of the site area by Haug et al. (1987) yielded a more complete estimate of the lateral distribution of Culebra transmissivities, qualitatively consistent with the interpretations of Beauheim (1987a) and Tomasko and Jensen (1987). A high-transmissivity region in the vicinity of H-11 and DOE-1 was interpreted to be present, in addition to a largely separate high-transmissivity zone west and northwest of the site center. Large areas northeast, east, and

southwest of the site center appeared to have low transmissivity. The interpretation of Haug et al. (1987) indicated both that fluid flow on the WIPP site proper was largely controlled by the high-transmissivity zone containing holes H-11 and DOE-1, and that the effects of this zone included northwest to southeast flow across the area including H-4 and the site center itself. Consideration of discrete fractures or inclusion of dual-porosity formalism appears not to be required to model the regional-scale hydrologic behavior of the Culebra dolomite at and near the WIPP site.

Limitations to interpretation of the H-3 multipad test strongly influenced hydrologic field activities in 1986 and 1987. On a regional scale, the information gained through the H-3 test supported fielding and interpretation of a test centered at WIPP-13, which is discussed in the next section. In preparation for this test, updated and more-reliable data on the Culebra were collected at DOE-2, and a series of WIPP holes (13, 18, 19, 21, and 22). The paucity of reliable data in the southern half of Zone 3 led to the drilling and testing of H-14 and H-15, as well as to reentry and testing of the Culebra in P-17, H-4c, P-14, P-15, Cabin Baby-1, and ERDA-9. The scarcity of head-potential and hydraulic-property data from members of the Rustler other than the Culebra led to testing of all members in holes H-14, and H-16. H-16 itself was sited primarily to address the problem of linkage between all five members of the Rustler Formation and the WIPP air-intake shaft.

4.1.3.2 <u>The WIPP-13 Multipad Interference Test and the Regional Culebra Model of LaVenue et al. (1988)</u>--The second regional-scale or multipad interference test of the Culebra dolomite was centered at hole WIPP-13 (Figures 1.2 and 4.1.17). The pumping phase of the WIPP-13 test lasted from January 12, 1987, to February 17, 1987. Water levels were monitored continuously in 17 surrounding wells, at distances ranging from 1280 to 6248 m. Analytical interpretation of the WIPP-13 multipad test is discussed by Beauheim (1987c). Numerical simulation of Culebra transmissivities and pre-shaft heads in an area including that examined in the WIPP-13 test is the primary focus of LaVenue et al. (1988). This effort includes evaluation of long-term transient hydrologic data at and near the WIPP site. Detailed modeling of transient effects of the WIPP-13 multipad test will be combined during 1988 with calibration of the transient effects of a planned multipad interference test at the H-11 hydropad and emplacement of the WIPP air-intake shaft.

The effects of dual-porosity behavior were quite strong in WIPP-13 during the pumping phase of the WIPP-13 test (Figure 4.1.18). The Culebra in WIPP-13 has an estimated transmissivity of 7.4×10^{-5} m^2/s (Beauheim, 1987c). The Culebra in and near WIPP-13 is best thought of as a double-porosity medium with unrestricted interporosity flow (Beauheim, 1987c).

The analytical interpretation by Beauheim (1987c) indicates that WIPP-13 lies within a relatively homogeneous fractured region, which includes WIPP-13 and DOE-2, as well as the H-6 hydropad (both H-6a and H-6b were monitored during the WIPP-13 test). DOE-2, at a distance of 1475 m from WIPP-13, responded within one hour to the beginning of pumping, while H-6b, at a distance of 2188 m, responded within 8 hours (Table 4.7). The

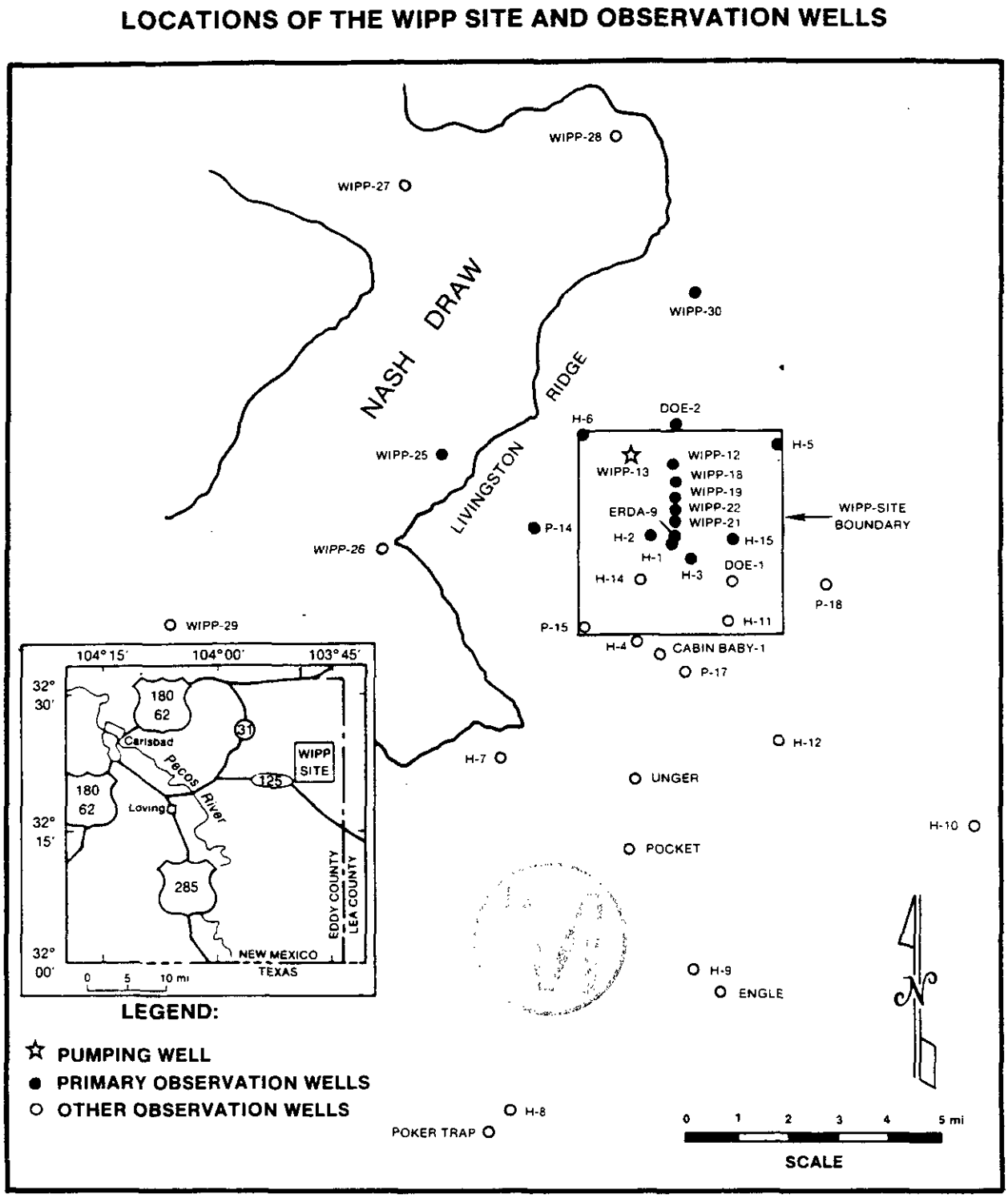

Figure 4.1.17: Pumped and observation wells for the WIPP-13 multipad interference test. Figure 1-1 of Beauheim (1987c).

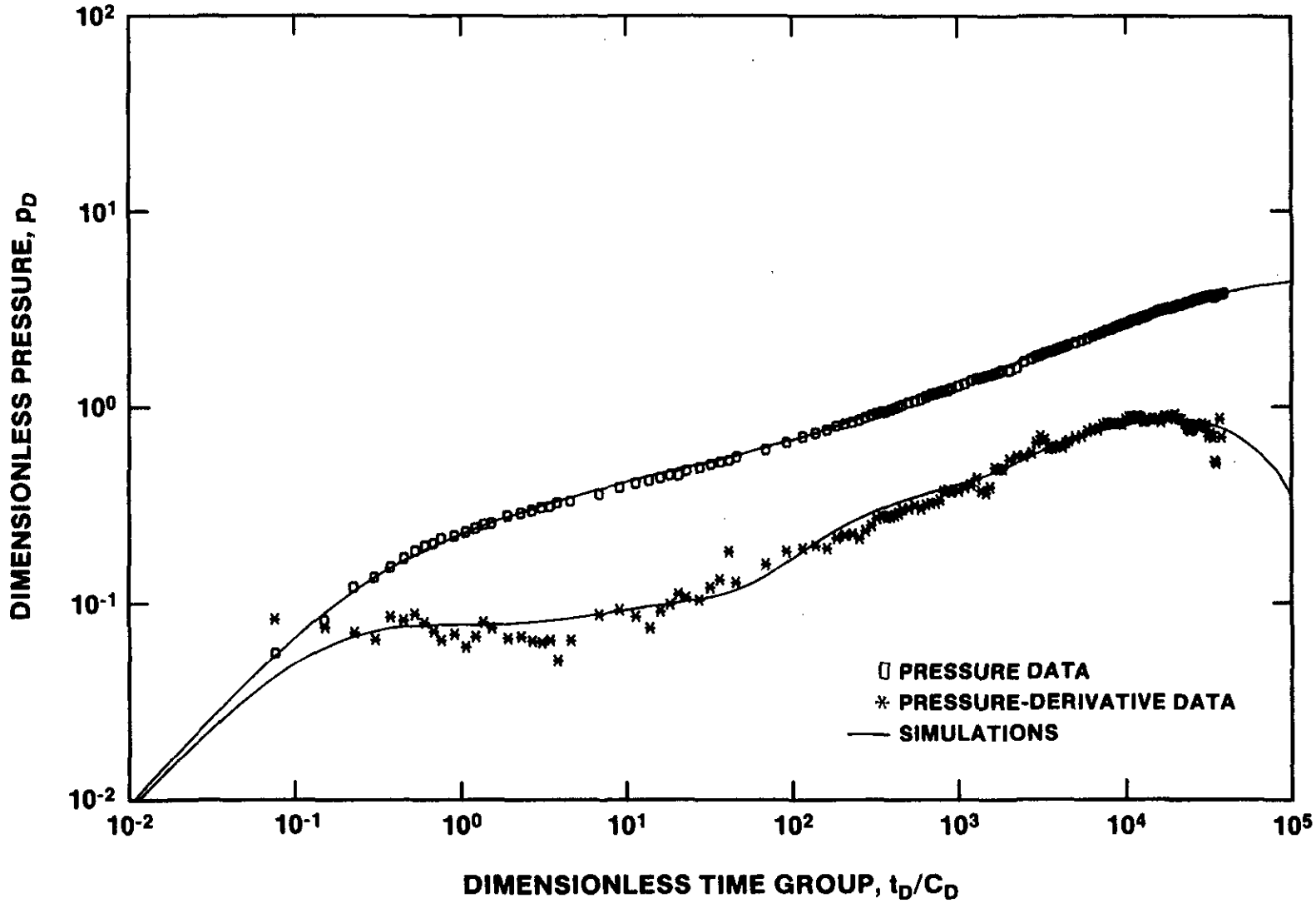

Figure 4.1.18: Measured and simulated hydrologic response of WIPP-13 during the pumping phase of the WIPP-13 multipad interference test. Slightly simplified from Figure 6-1 of Beauheim (1987c).

Table 4.7: Summary of analytical interpretation of results of the WIPP-13 multipad interference test. Slightly modified from data conatined in Tables 3-1, 5-1, and 6-1 of Beauheim (1987c).

Well	Distance(m)(1)	Direction	First (2) Drawdown (hrs)	Delay in Max. Drawdown (hr)	Maximum Drawdown (Psi)	T(m^2/s)(3)	S	Water-Level Modification (m/day)
WIPP-13	0	-	0	0		7.4×10^{-5}	-	-
DOE-2	1475	N45E	1	1	17.3	6.1×10^{-5}	5.1×10^{-6}	-
H-6a	2192	N20W	8	5	7.7	7.6×10^{-5}	8.2×10^{-6}	-
H-6b	2189	N20W	8	5	7.9	7.4×10^{-5}	7.9×10^{-6}	-
WIPP-30	5587	N12E	61	136	4.9	3.0×10^{-5}	5.6×10^{-6}	5.3×10^{-3}
WIPP-12	1283	S55E	74	186	11.9	8.5×10^{-6}	3.6×10^{-5}	4.5×10^{-3}
WIPP-18	1521	S45E	74	86	9.3	2.5×10^{-5}	4.0×10^{-5}	3.6×10^{-3}
WIPP-19	1823	S37E	102	186	7.2	2.6×10^{-5}	4.0×10^{-5}	7.6×10^{-3}
WIPP-21	2216	S29E	133	396	3.6	2.4×10^{-5}	5.3×10^{-5}	1.7×10^{-2}
WIPP-22	1933	S34E	102	286	5.7	2.0×10^{-5}	4.7×10^{-5}	8.2×10^{-3}
H-1	2676	S16E	600	2086(?)	1.1	2.2×10^{-5}	1.3×10^{-4}	1.4×10^{-2}
H-2b2	2597	S0W	445	986	1.4	1.7×10^{-5}	7.3×10^{-5}	6.0×10^{-3}
ERDA-9	2518	S24E	550	396	2.0	2.4×10^{-5}	5.4×10^{-5}	1.6×10^{-2}
Exhaust shaft	2414	S26E	400	336	3	3.0×10^{-5}	5.5×10^{-5}	2.9×10^{-2}
P-14	4228	S58W	71	56	0.8	2.8×10^{-4}	5.2×10^{-5}	-
WIPP-25	6264	S88W	76	26	0.3	7.0×10^{-4}	6.4×10^{-5}	-

(1) Distance and direction from WIPP-13.
(2) Time relative to beginning and ending of pumping phase.
(3) Apparent and effective transmissivity (T) and storativity (S) assume homogenous properties between WIPP-13 and given well, as well as radial flow into WIPP-13.

apparent average transmissivities between WIPP-13 and holes DOE-2 and H-6b are 6.1 x 10^{-5} m^2/s and 7.4 x 10^{-5} m^2/s, respectively. The rapid responses at DOE-2 and H-6b and the low apparent storativities between these holes and WIPP-13, 5.1 x 10^{-6} and 7.9 x 10^{-6}, respectively, suggest that the hydraulic response in this region is strongly affected by fracturing (Beauheim, 1987c).

The boundaries of the zone containing WIPP-13, DOE-2, and H-6 are complex. To the north, the zone appears to extend nearly to hole WIPP-30 (Beauheim, 1987c). This interpretation is based largely on the fact that WIPP-30, with a reported transmissivity of only 3.2 x 10^{-7} m^2/s (Beauheim, 1987b; Mercer, 1983) and at a distance of 5587 m from WIPP-13, responded within 61 hours to the beginning of pumping. In addition, the apparent average storativity between WIPP-13 and WIPP-30, 5.6 x 10^{-6}, is similar to that calculated between WIPP-13 and both DOE-2 and H-6b. Analytical interpretation of the response of DOE-2 to pumping of WIPP-13 requires addition of a low-permeability boundary; i.e., the response at DOE-2 shows the effects of a low-permeability region nearby. A change from high to low Culebra transmissivities must occur somewhere between DOE-2 and WIPP-12, as well as between DOE-2 and H-5.

Results contained in Beauheim (1987b) indicate a Culebra transmissivity of approximately 1.0 x 10^{-7} m^2/s in WIPP-12 (Table 4.2). The apparent average transmissivity between WIPP-13 and WIPP-12 is 8.5 x 10^{-6} m^2/s (Beauheim, 1987c). WIPP-12, only 1283 m from WIPP-13, did not respond to pumping of WIPP-13 until 74 hours into the test. Thus, by analogy with arguments concerning the response of WIPP-30, the boundary between the high-transmissivity zone containing WIPP-13 and the low-transmissivity zone containing WIPP-12 must lie relatively close to WIPP-13.

South of WIPP-12, the boundary between high-transmissivity and low-transmissivity domains probably lies further away from WIPP-13. Holes WIPP-18, 19, 21, 22; H-1, 2; and ERDA-9 all have estimated Culebra transmissivities of 1.0 x 10^{-6} m^2/s or less (Table 4.1). The apparent effective average transmissivities between WIPP-13 and these holes range from 1.7 x 10^{-5} to 2.6 x 10^{-5} m^2/s (Table 4.7), while that between WIPP-13 and the WIPP exhaust shaft is 3.0 x 10^{-5} m^2/s. Times required for the first response to pumping of WIPP-13 range from 74 to 600 hours, including the exhaust shaft. The high-transmissivity zone containing WIPP-13 is consistently represented as a high-permeability boundary in interpretation of the response of these observation holes (Beauheim, 1987c). The apparent behavior between WIPP-13 and the WIPP exhaust shaft is consistent with that between WIPP-13 and nearby observation holes. Beauheim (1987c) notes that the responses in both ERDA-9 and the exhaust shaft appear to be complicated by activities within the shaft.

The relatively homogeneous zone containing WIPP-13, DOE-2, and H-6 appears to be bounded on the west by a zone of higher transmissivity extending into the main portion of Nash Draw (Beauheim, 1987c). Apparent transmissivities between WIPP-13 and holes P-14 and WIPP-25 are 2.8 x 10^{-4} and 7.0 x 10^{-4} m^2/s, respectively. Hole WIPP-25, at a distance of 6264 m from WIPP-13, was the most distant monitoring hole used in the test (Figure 4.1.17).

The presence of both higher-transmissivity and lower-transmissivity domains outside the WIPP-13 - DOE-2 - H-6 region is consistent with the fact the analytical interpretation of the hydrologic behavior at WIPP-13 required the addition of both low-permeability and high-permeability boundaries (Beauheim, 1987c). In addition, a linear-flow interpretation of the flow near WIPP-13 analogous to that completed for the H-3 multipad test by Tomasko and Jensen (1987) was not successful.

The numerical simulation of Culebra hydrology over a large area, including the region stressed in the WIPP-13 test, is discussed and summarized in LaVenue et al. (1988). The emphasis in LaVenue et al. (1988) is on simulation of the Culebra hydrology as it existed before construction of the WIPP shafts, i.e., prior to 1981. Detailed numerical interpretation of the transient hydrologic stresses imposed by the WIPP-13 multipad test, sinking of the WIPP air-intake shaft, and a combined multipad interference test and conservative-tracer test at the H-11 pad will be conducted in 1988.

As noted in Section 4.1.1, there has been a significant increase in the Culebra transmissivity, head, and fluid-density data base since April 1986. In addition, as evident in Figure 4.1.19, the area included in modeling described in LaVenue et al. (1988), 24 x 25 km, is significantly larger than that included in Haug et al. (1987) (see Figure 4.1.6). As a result, the total data base considered in LaVenue et al. (1988) is much larger than that considered only 1.5 years earlier. Culebra transmissivity data from 38 individual wells or hydropads are considered in the 1988 report, as opposed to 24 locations in the 1987 report (Table 4.1). Compilation of the data base used by LaVenue et al. (1988) was significantly more complex for the data base used by Haug et al. (1987), both because of the increased number of holes and because of the increased awareness and concern about transient phenomena in Rustler hydrology. For example, development of the baseline water-level data required consideration of long-term transients, even in holes not directly affected by hydraulic testing at and near the WIPP site. In addition, some well locations were resurveyed (LaVenue et al., 1988); most Culebra fluid densities were revised as a result of recent sampling (Uhland et al., 1987), and were evaluated by detailed pressure-density surveys (Crawley, 1987).

The initial kriged Culebra transmissivities of LaVenue et al. (1988) are shown in Figure 4.1.19, based on data available as of November 1987. The general pattern is different from that indicated in Haug et al. (1987) (Figure 4.1.9). The increase in the available data base results in the initial kriged distribution in Figure 4.1.19 varying smoothly across much of the site area. The kriged transmissivities tend to be higher towards the west and lower towards the east, with an isolated zone of higher transmissivities at H-11 and DOE-1. In Figure 4.1.9, with the exception of the hole pairs H-1 - H-2 and H-11 - DOE-1, each data point tends to define a separate transmissivity zone.

The effects of the increased number of measurements on the Culebra transmissivity data base are demonstrated more clearly by comparison of Figure 4.1.10 with Figures 4.1.20 and 4.1.21. Kriging of the transmissivity data base available as of April 1986 (Figure 4.1.10) indicated that regions of

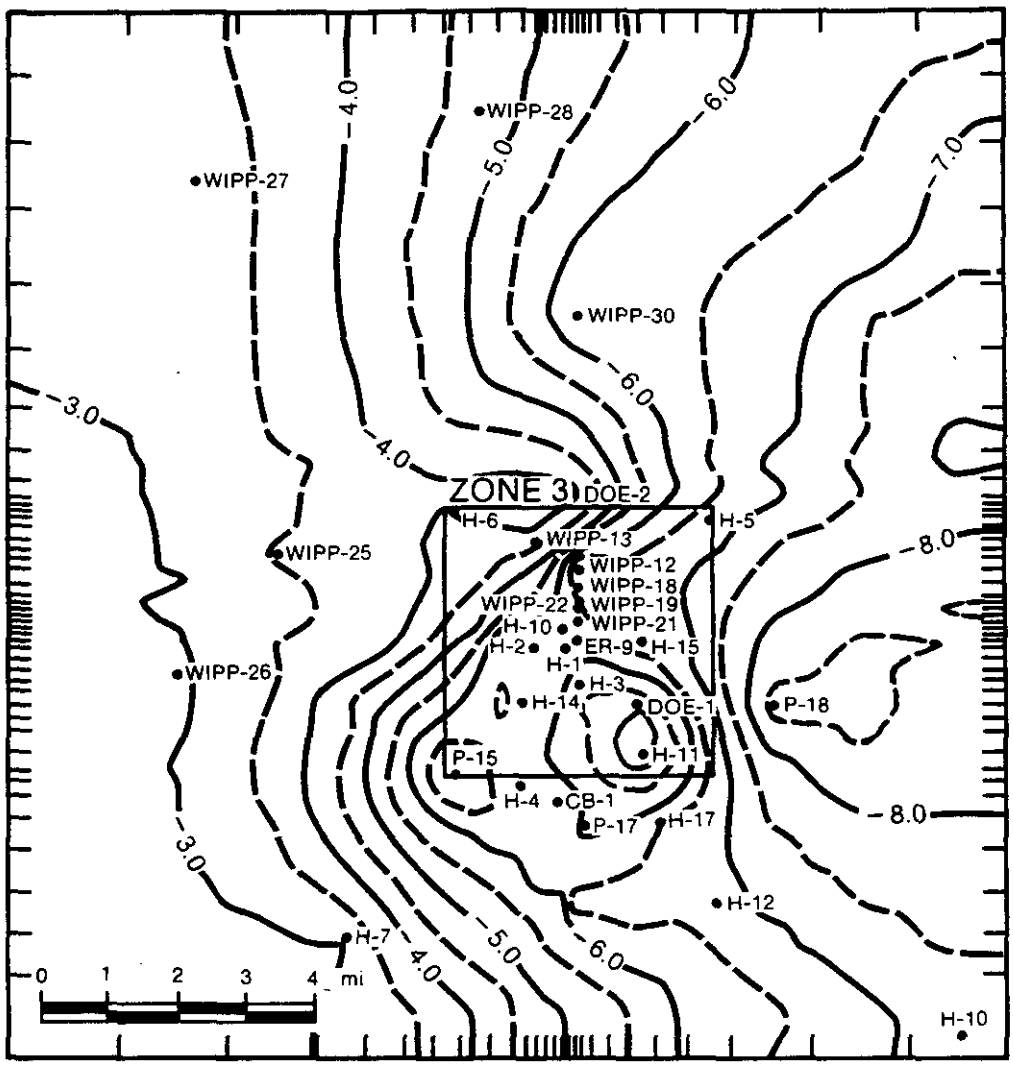

Figure 4.1.19: Initial kriged Culebra transmissivities, based on data available as of November, 1987. Values kriged with code AKRIP. Figure 3.12A of LaVenue et al. (1988).

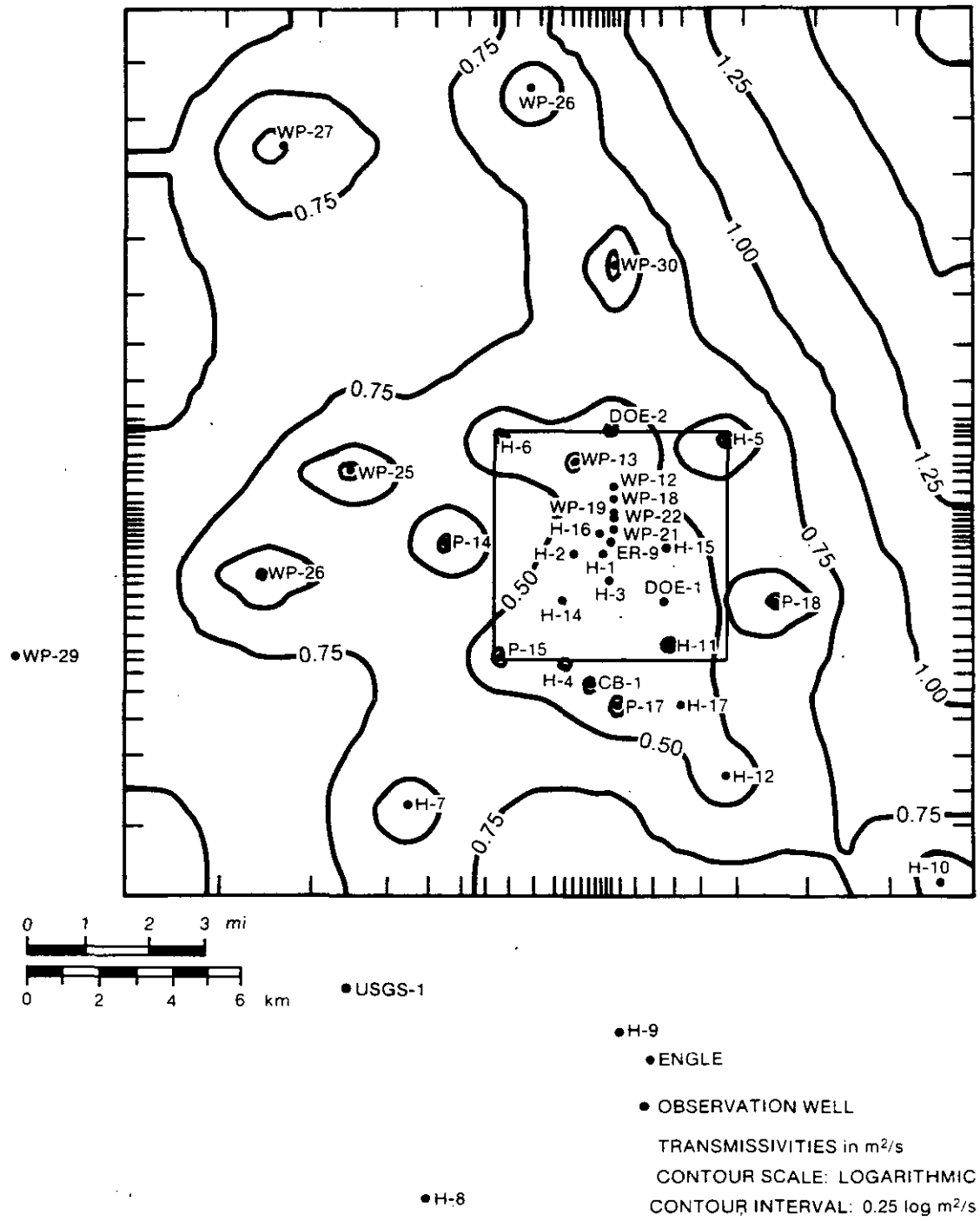

Figure 4.1.20: Estimation error in initial kriged Culebra transmissivities (one standard deviation), based on data available as of November 1987, assuming no uncertainty in individual measurements. Values kriged using code AKRIP. Figure 3.12B of LaVenue et al. (1988).

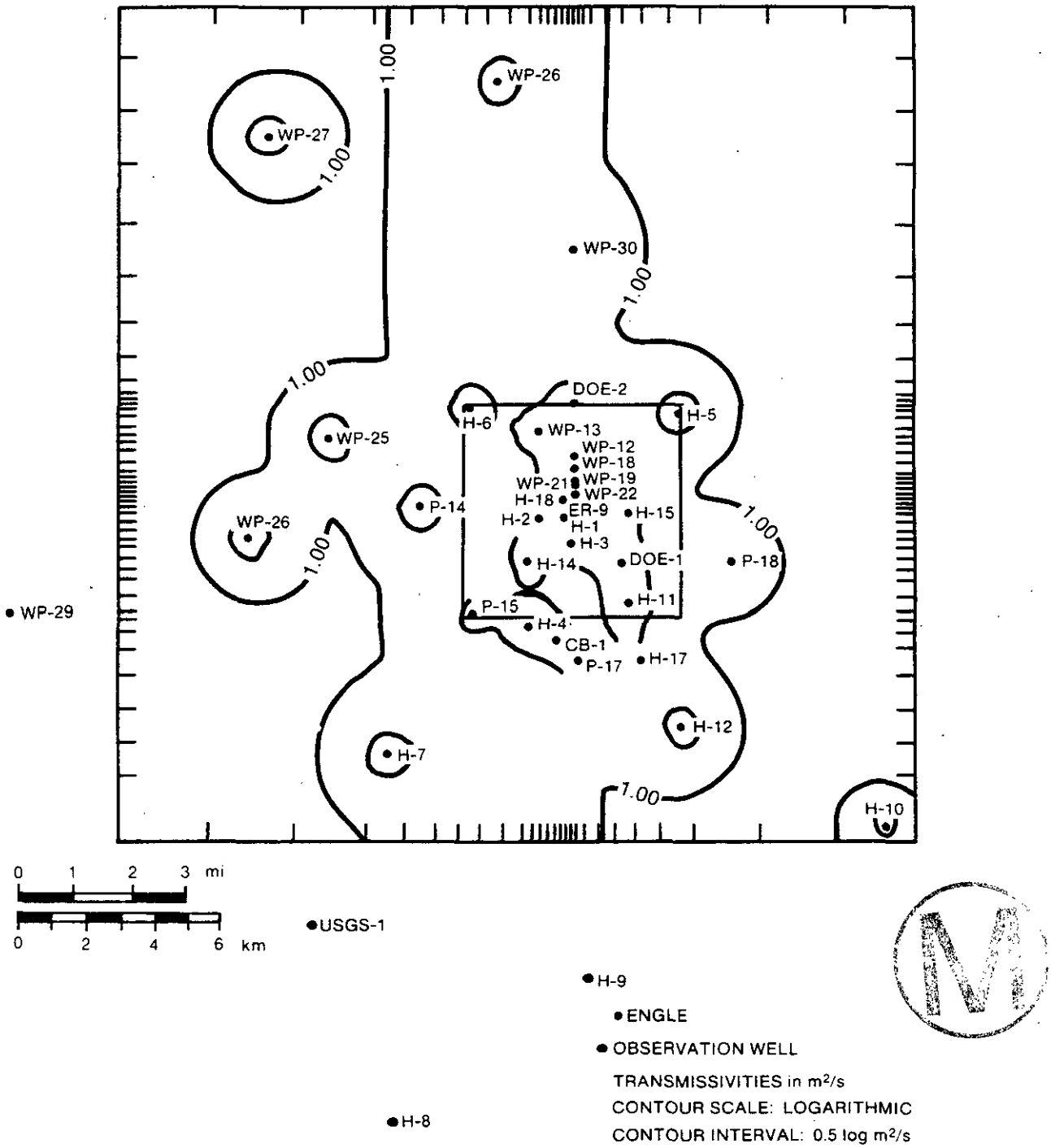

Figure 4.1.21: Estimation error in initial kriged Culebra transmissivities (one standard deviation), including estimated uncertainty in individual measurements. Values kriged using code K603. Figure 3.11B of LaVenue et al. (1988).

one order of magnitude uncertainty (defined at one standard deviation) did not overlap, except in very limited areas. Because of the limited data base available at that time, it was not possible for Haug et al. (1987) to consider either an underlying regional trend in the data or uncertainty in the measured data.

LaVenue et al. (1988) apply two kriging techniques to the Culebra transmissivity data in order to consider both the regional west-to-east decrease in transmissivities (Figure 4.1.19) and uncertainties in the measured data. Kriging of the enlarged data base using the AKRIP code, which fits a polynomial surface to the regional trend, but does not consider uncertainty in the measured data (LaVenue et al., 1988), indicates that the uncertainty in Culebra transmissivities over a large area, including most of Zone 3, should be less than 0.5 log unit at one standard deviation and less than one order of magnitude (1.0 log unit) at two standard deviations (Figure 4.1.20). Within the smaller area including both the center of the WIPP site and the locations the WIPP shafts, the uncertainty at two standard deviations is 0.5 log units or less; i.e., Culebra transmissivities should be estimated to within a factor of approximately three in this region, if it is assumed that field measurements are precise.

Results analogous to those in Figure 4.1.20, calculated by LaVenue et al. (1988) using the K603 code, which applies a linear trend surface to regional data, but allows consideration of uncertainty in measured data, are shown in Figure 4.1.21. LaVenue et al. (1988) estimate the uncertainty in measurements of Culebra transmissivities to be 0.25 log unit when transmissivity is estimated from pumping tests and 0.5 log units when estimated from other tests. Inclusion of these estimated uncertainties in individual measurements, combined with a simplified regional trend surface, suggests (Figure 4.1.21) an estimation error (one standard deviation) of 0.5 log unit or less within most of Zone 3. These results indicate that the uncertainty in Culebra transmissivities at two standard deviations within much of Zone 3, i.e., in a region extending from DOE-2 in the north to beyond H-11 in the south, is less than an order of magnitude, even including the estimated uncertainties in field measurements.

Such statistical approaches must not be overinterpreted, because they include no direct consideration of geologic processes. However, comparison of Figures 4.1.20 and 4.1.21 with Figure 4.1.10 provides a direct impression of the qualitative increase in both the size and reliability of the Culebra data base since April 1986.

The present distribution of measured Culebra fluid densities (LaVenue et al., 1988) is shown in Figure 4.1.22. Although the overall pattern is similar to that estimated on the basis of data available in April 1986 (Figure 4.1.13), with a general west-to-east increase in density, there are two significant differences. The density distribution in the west half of Zone 3 in Figure 4.1.13 is strongly non-linear, due to relatively high densities at H-6 and/or DOE-2. The variation in fluid densities in the region H-1 - DOE-2 - H-6 - P-14, based on data available as of November 1987 (Figure 4.1.22), is less irregular, and the regional trend is more consistent with the general west-to-east increase in density. Fluid

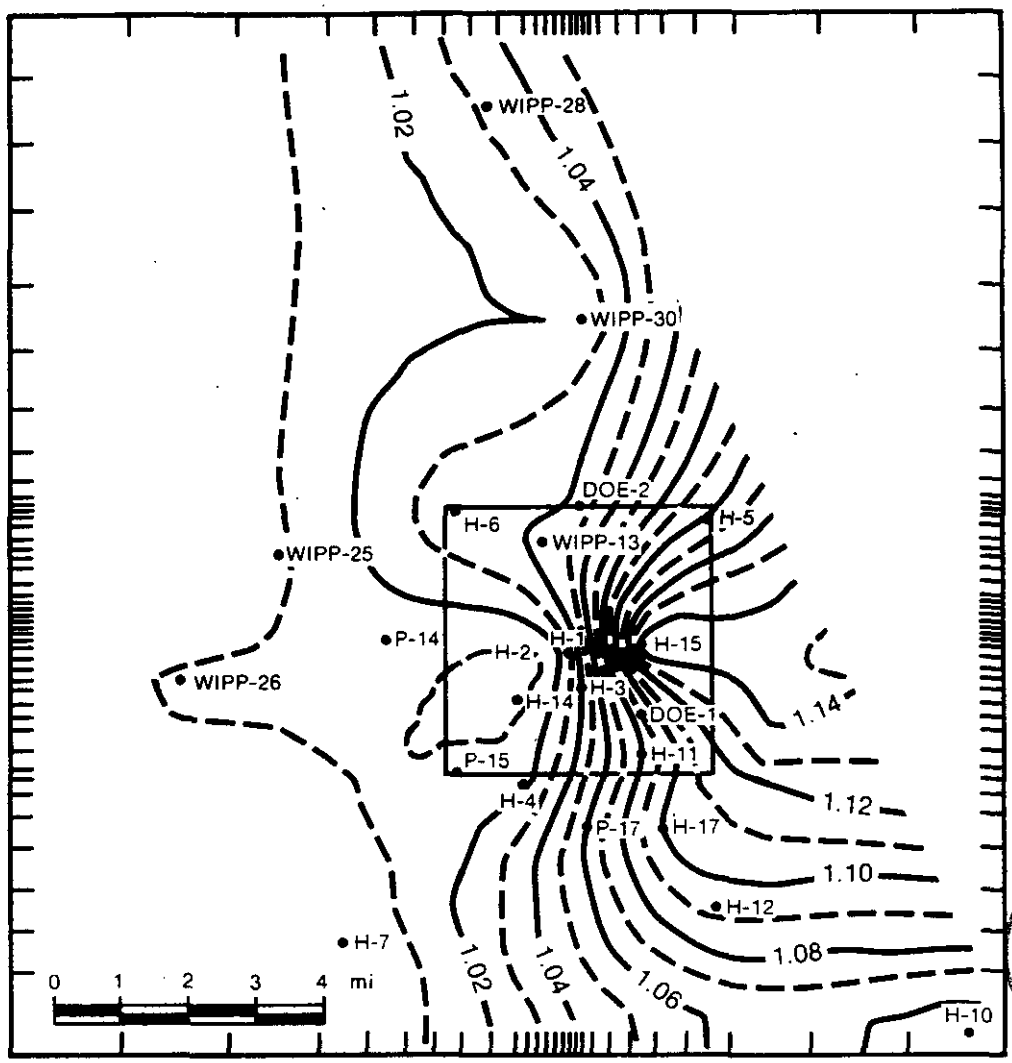

Figure 4.1.22: Measured density distribution of Culebra fluids, based on information available as of November 1987. Figure 3.15 of LaVenue et al. (1988).

densities in the region H-14 - H-2 - P-14 still appear to be anomalously low. The brine density distribution in the eastern part of Zone 3 (Figure 4.1.22) is also somewhat different than in Figure 4.1.13. In Figure 4.1.13, a general north-south trend of constant-density lines extends largely across the WIPP site west of holes DOE-1 and H-11. The distribution is more complex east of these holes. In Figure 4.1.22, the estimated brine density of approximately 1.14 g/cm^3 at hole H-15 causes significant curvature in the density distribution in the eastern portion of Zone 3. Nonetheless, the overall pattern of the distribution of Culebra brine densities based on data available as of November 1987 is simpler than previously estimated.

The present understanding of the distribution of pre-shaft freshwater-equivalent heads within the Culebra dolomite is shown in Figure 4.1.23. The general pattern is similar to that estimated by Haug et al. (1987), with a north-south head gradient of approximately 10^{-3} m/m across the area of the WIPP site. Gradients within the Culebra both south and north of the site are lower, approximately 10^{-4} m/m.

There is, however, one significant difference between the head distributions shown in Figures 4.1.23 and 4.1.11. Head contours form a sharp embayment in the southeastern portion of Zone 3 in Figure 4.1.11, extending at least as far north as the east-center of the site. Interpretation of water-level and fluid-density data available to November 1987 indicates (Figure 4.1.23) that there is little evidence of an embayment in Culebra freshwater-equivalent heads within WIPP Zone 3, except for the 913-m contour in the extreme southern part of the zone. Within the modeled area, head contours up to 919 m elevation do define a broad embayment south and east of the WIPP site. Expansion and improvement of the data base for calculation of Culebra freshwater-equivalent heads during 1986 and 1987 has resulted in significant smoothing of the estimated head distribution, especially within Zone 3.

In calibration efforts by Haug et al. (1987), it was assumed that Culebra fluid pressures and fluid densities were at steady state before construction of the WIPP shafts. As discussed in Section 4.1.3.1, assumption of steady state is adequate for simulation of pre-shaft Culebra heads or fluid pressures. The results in Haug et al. (1987), however, indicated problems with the assumption of steady-state confined flow in simulation of Culebra brine densities. The calibration approach taken by LaVenue et al. (1988) differed from that taken earlier. LaVenue et al. (1988) assumed that the fluid-density distribution remains fixed on the time scale required for pressure equilibration, and no calibration against the brine-density distribution was attempted. The calculations do take account of the variable fluid density at each point within the Culebra; they assume that effects of variable brine density on the modern flow directions can be estimated reliably fixing the modern fluid-density distribution in place. The results of calibration of Culebra transmissivities against the freshwater-equivalent head distribution shown in Figure 4.1.23, assuming that the fluid-density distribution shown in Figure 4.1.22 remains fixed (LaVenue et al., 1988), are shown in Figure 4.1.24.

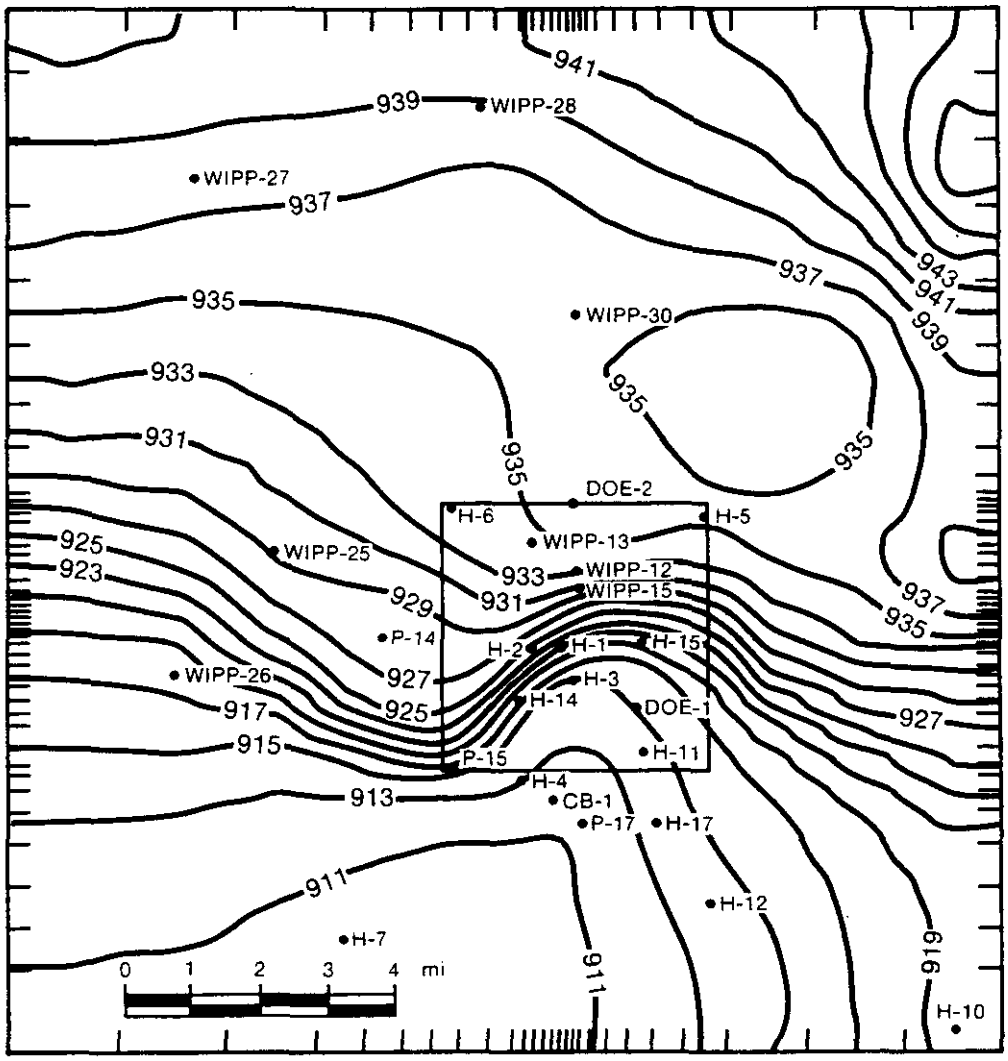

Figure 4.1.23: Estimate of pre-shaft, freshwater-equivalent heads in the Culebra dolomite, based on data available as of November 1987. Figure 3.14 of LaVenue et al. (1988).

The overall distribution of calibrated transmissivities (Figure 4.1.24) is not greatly different from the initial kriged distribution (Figure 4.1.19). The general trend of decreasing transmissivities from west to east is preserved. During calibration, transmissivities west of WIPP-30 and WIPP-28 were increased. Transmissivities in the area containing H-6, P-14, and WIPP-25 were generally decreased slightly, while those in the southern part of Nash Draw were increased. The low-transmissivity domain in WIPP Zone 3 ($T < 10^{-6}$ m^2/s) is expanded in the more recent interpretation (Figure 4.1.24). This region, including the center of the WIPP site, is now expected to be continuous from H-5 in the northeast to P-15, H-4, and Cabin Baby-1 to the southwest.

Calibration in the region between holes H-17, H-11, P-17, and extending to the south, required significant adjustment to the kriged distribution. Transmissivities in this region were increased from kriged values, similar to changes required during calibration by Haug et al. (1987). In order to simulate the low heads at H-11 and DOE-1 and the sharp head embayment in the southern part of Zone 3 expected on the basis of April 1986 data (Figure 4.1.11), Haug et al. (1987) included a narrow high-transmissivity zone east of P-17 (Figure 4.1.16). During calibration by Haug et al., a maximum transmissivity of approximately 3×10^{-4} m^2/s was assigned in this zone. The calibrated transmissivity distribution of LaVenue et al. (1988) in this region does not include as marked a high-transmissivity structure (Figure 4.1.24). Relatively high transmissivities are still required in the area, because of both the relatively low heads at H-11 and DOE-1 and the low gradients south of the WIPP site. However, the maximum transmissivity assigned at the pilot points shown in Figure 4.1.24 is approximately 5×10^{-5} m^2/s, only a factor of two greater than the effective transmissivity of 2.8×10^{-5} m^2/s calculated at the H-11 pad (Table 4.1).

LaVenue et al. (1988) investigate the need for the high-transmissivity zone by making calibration runs in which the increase in transmissivities south of H-11 was not incorporated, as well as runs in which the assigned heads along the southwestern part of the model were increased slightly. In all cases, the fit between calculated and estimated heads was worse than when increased transmissivities south of H-11 were included. Thus, a region of relatively high transmissivities is still expected to be present south of H-11. Transmissivities within this zone may be approximately twice as great as those measured at H-11. Both the lateral extent of the zone and the contrast between the high-transmissivity zone and surrounding regions are expected to be smaller than estimated in Haug et al. (1987). The zone is still expected to connect with the high-transmissivity region further to the south.

The changes in estimated transmissivities within and near the WIPP site are a direct result of the increase in the Culebra data base since April 1986 (Table 4.1). For example, hole H-14 was drilled and tested in 1986, specifically to examine transmissivities southwest of the site center (Section 4.1.1). Holes P-15, H-4, H-15, H-16, P-17, Cabin Baby-1, ERDA-9, and WIPP-12 have all been tested or retested since April 1986 (Table 4.2). Hole H-17 was drilled and tested specifically to evaluate the high-transmissivity zone east of P-17. Transmissivities at both DOE-1 and H-11 have been interpreted in detail since 1986, as discussed in Section 4.1.1.

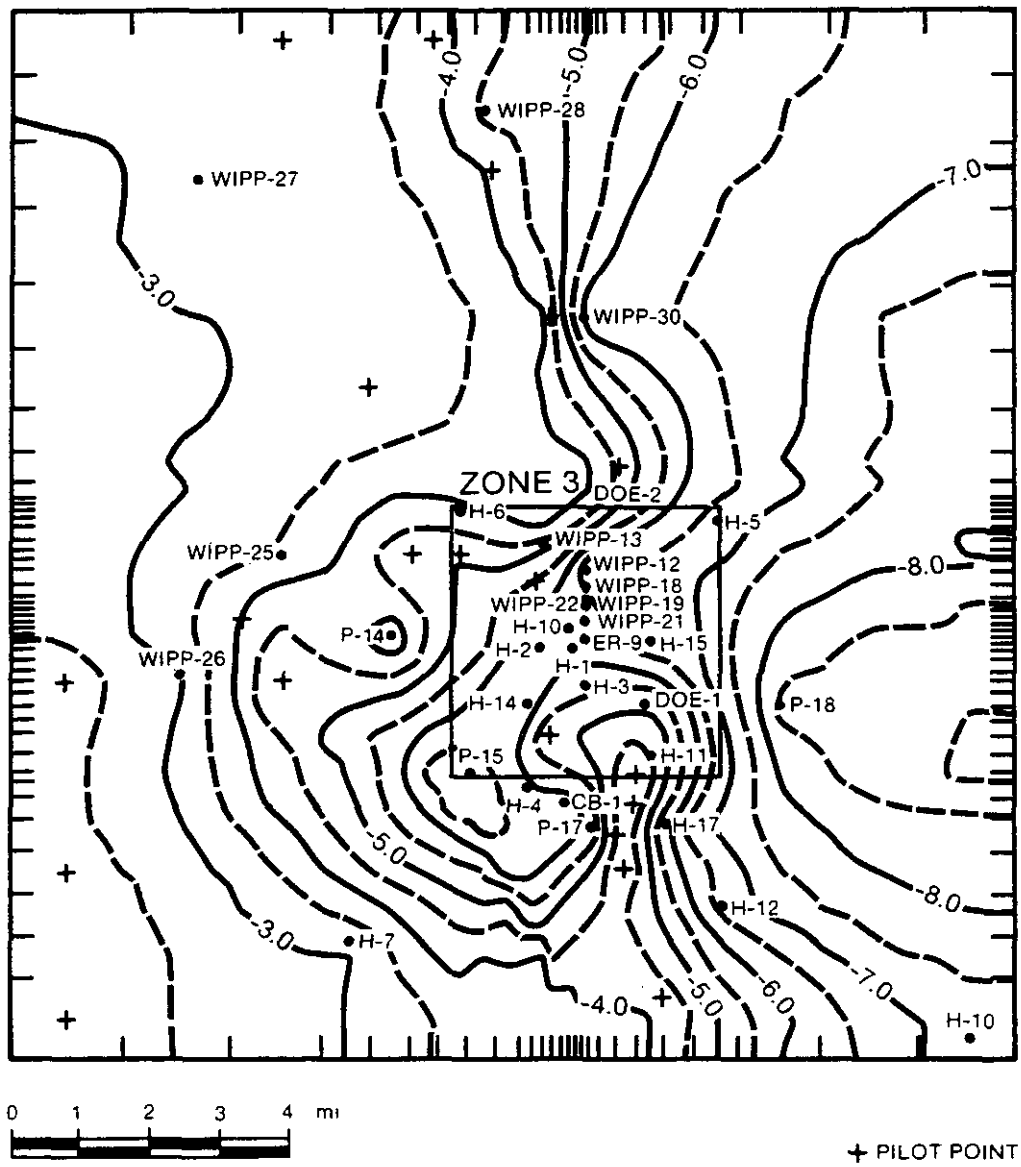

Figure 4.1.24: Calculated Culebra transmissivities at and near the WIPP site, based on steady-state calibration against freshwater-equivalent head distribution shown in Figure 4.1.23, fixing in place the fluid-density distribution shown in Figure 4.1.22. Figure 4.3 of LaVenue et al. (1988).

The distribution of Culebra pre-shaft head potentials calculated using the calibrated transmissivity distribution shown in Figure 4.1.24, is shown in Figure 4.1.25. Differences between calculated heads and those estimated on the basis of field data (Figure 4.1.23) are shown in Figure 4.1.26. The agreement is excellent, generally to within 1 m. This is less than the estimated uncertainty in freshwater-equivalent heads at individual wells, approximately 2 meters (LaVenue et al., 1988).

The modern flow directions and Darcy velocities within the Culebra dolomite at and near the WIPP site calculated by LaVenue et al. (1988) are shown in Figure 4.1.27. Darcy velocities do not include consideration of effective porosity; therefore, they do not represent actual groundwater particle velocities. Flow within the Culebra at and near the WIPP site is largely north-south, except in relatively low-transmissivity areas directly affected by either the high-transmissivity zone south of H-11 or by Nash Draw. Calculated Darcy velocities vary by six orders of magnitude, from 10^{-12} m/s (m^3/m^2s) east of the WIPP site to as high as 10^{-6} m/s along the axis of Nash Draw. In the region between WIPP-12 and the WIPP shafts, calculated Darcy velocities range from 2.5 to 7.5 x 10^{-10} m/s, and flow is north-south. LaVenue et al. (1988) note that calculated flow directions in the vicinity of DOE-2 appear unreliable due to local irregularities in the structure of the Culebra. As a result of the high-transmissivity zone south of H-11, flow in the vicinity of H-14 is towards the southeast, with a Darcy velocity of less than 10^{-9} m/s. Flow within the zone south of H-11 is to the south, with a Darcy velocity of approximately 2.5 x 10^{-9} m/s. The Darcy velocities shown in Figure 4.1.27 assume completely confined flow within the Culebra, and also assume steady-state heads and fixed brine-density distribution (LaVenue et al., 1988). They provide a realistic indication of modern flow directions.

Particle flowpaths and flowtimes calculated within the modelled area, assuming that the effective porosity of the Culebra is uniform at 16% are shown in Figure 4.1.28. As noted in Section 4.2, measured porosities within the Culebra range from 0.07 to 0.30. The effective in situ porosity is not known, but must be variable. It is not clear that assumption of confined flow within Nash Draw is valid. In addition, as discussed in Sections 4.3 and 4.4, Culebra hydrology is not at steady state, and there has probably been at least some change in flow directions within the Culebra within the last 10,000 years; the magnitude of the change remains uncertain. The travel times shown in Figure 4.1.28 must be taken only as an indication of the effects of relative variability in estimated particle flow rates.

Calculated particle velocities within Nash Draw are quite high, and calculated flow times across the entire modeled area are quite short in this region. Calculated travel times along paths A, B, and C (Figure 4.1.28) increase from west to east, from a low of 450 years to a high of 2800 years. Changes in Rustler water levels within Nash Draw since the beginning of potash mining approximately 50 years ago, described by Hunter (1985), indicate that the steady-state assumption is not realistic in this region, even on this relatively short time scale. At the other extreme, flow of a groundwater particle from H-5 to the southern boundary of the modeled area of LaVenue et al. (1988) is calculated to take more than one

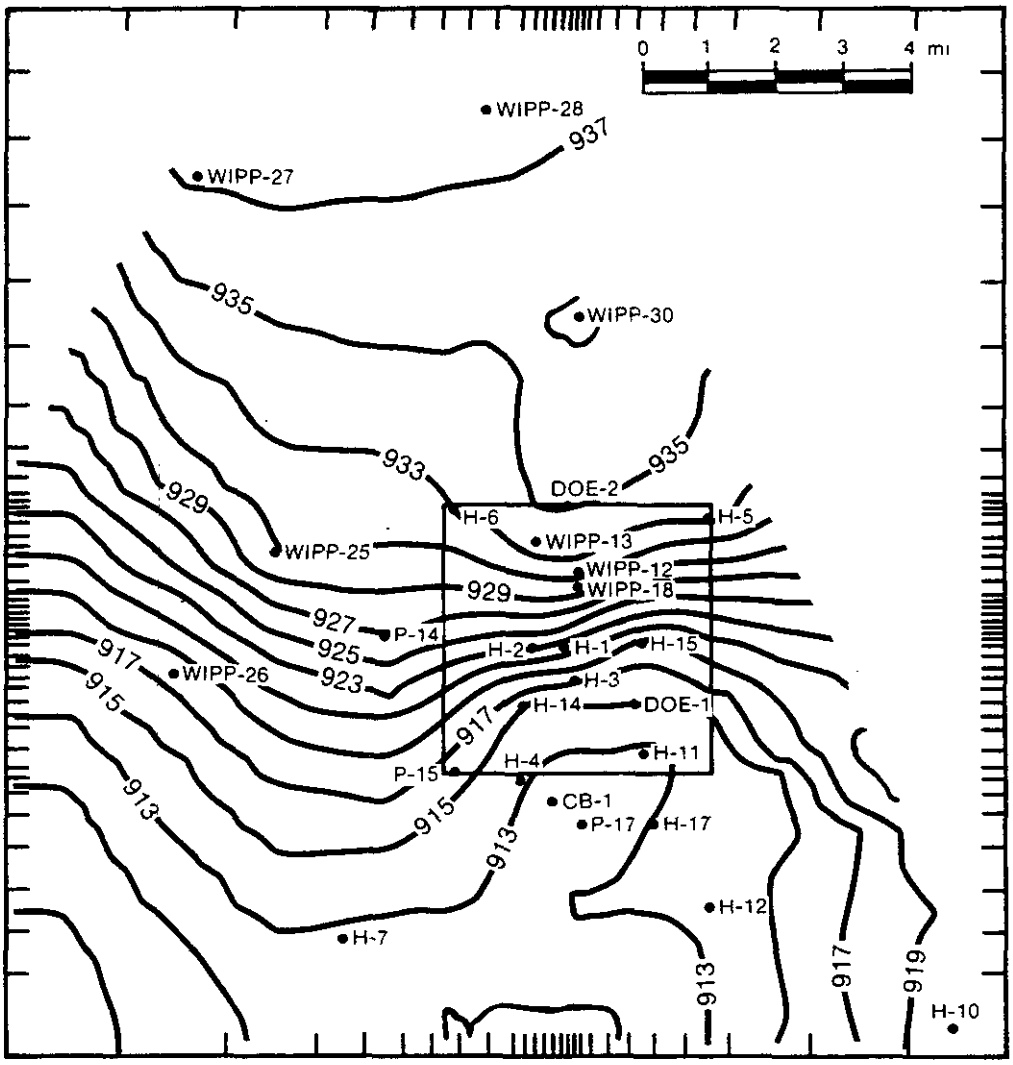

Figure 4.1.25: Calculated pre-shaft, freshwater-equivalent head distribution in the Culebra dolomite, based on calibrated transmissivity distribution shown in Figure 4.1.24. Figure 4.5A of LaVenue et al. (1988).

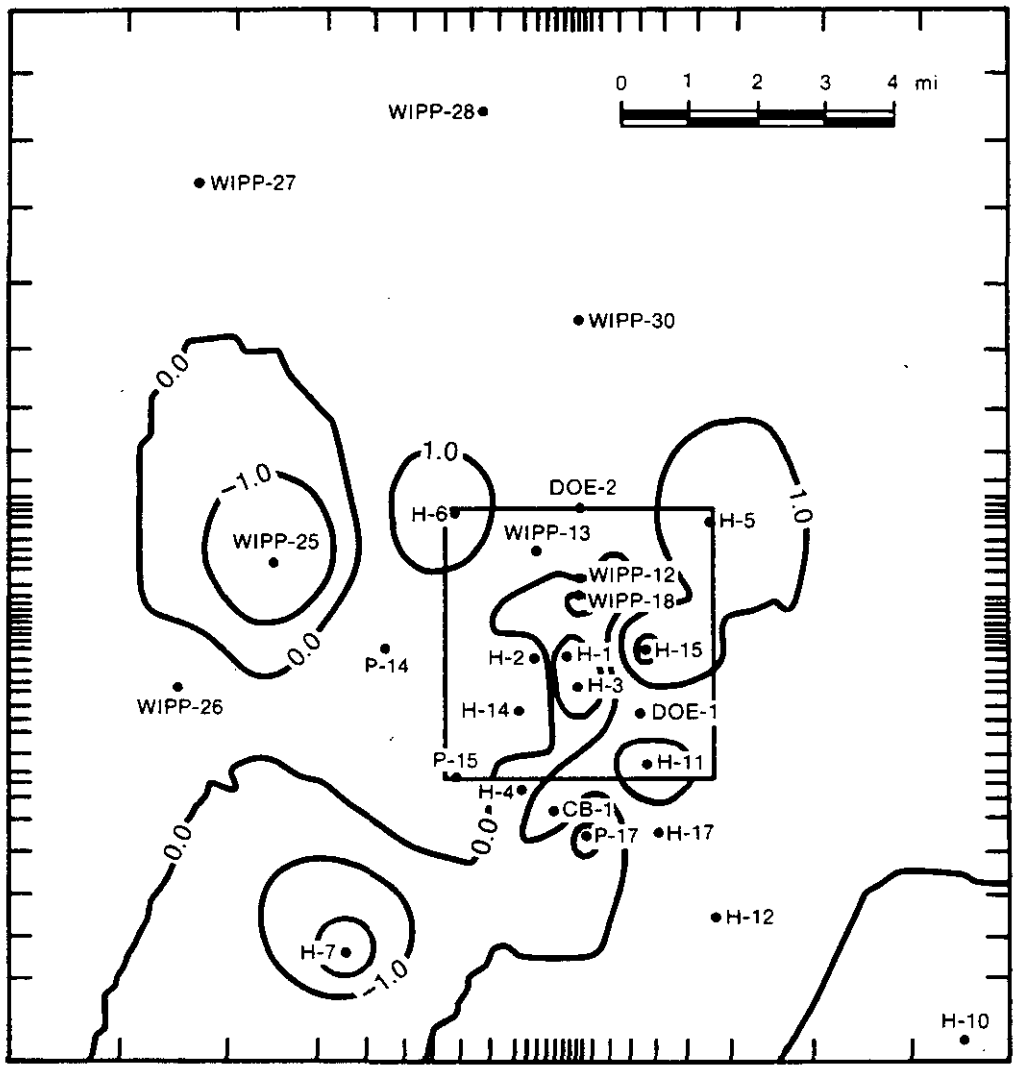

Figure 4.1.26: Difference between calculated Culebra head distribution (Figure 4.1.25) and measured pre-shaft head distribution (Figure 4.1.23). Figure 4.6 of LaVenue et al. (1988).

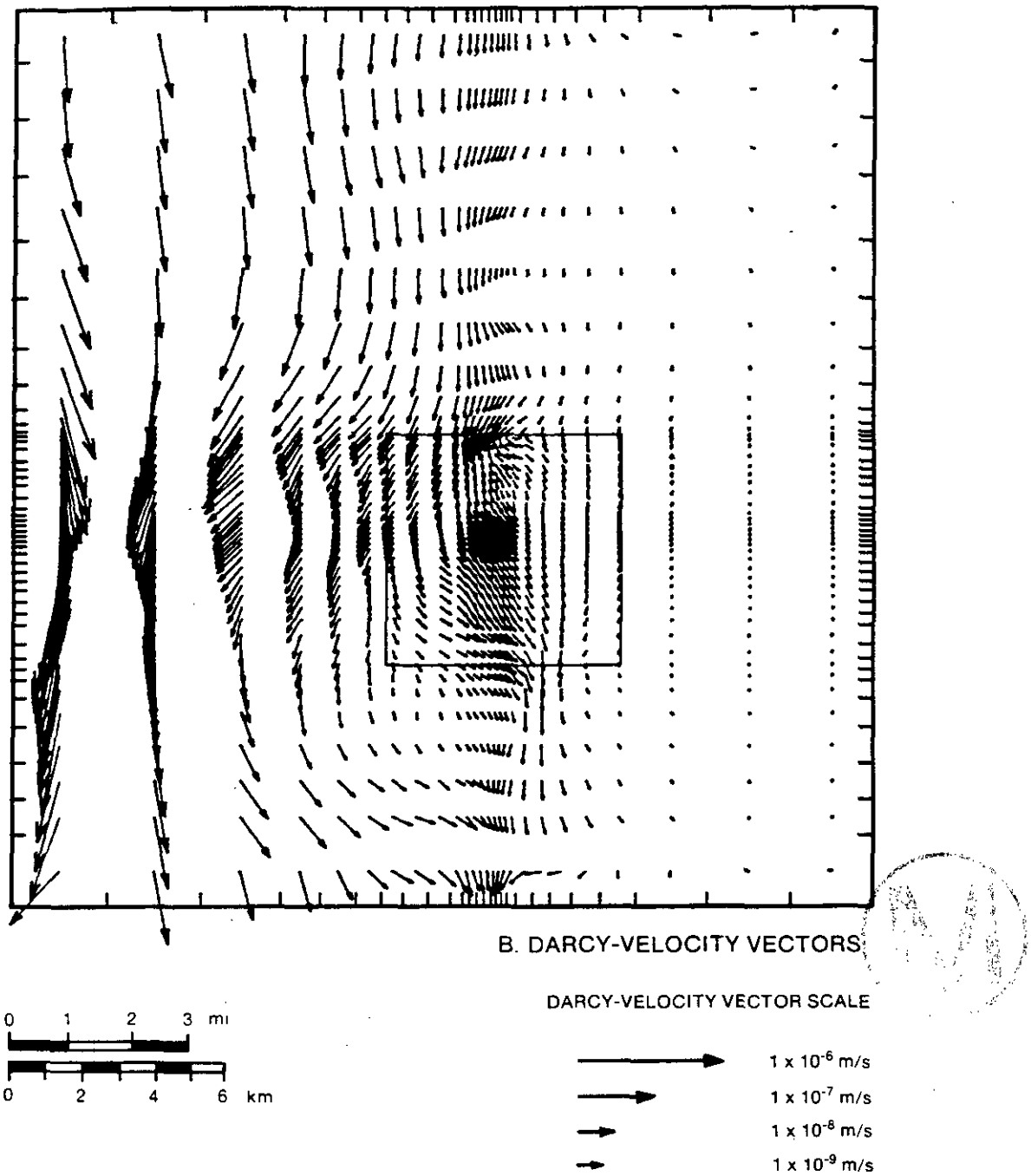

Figure 4.1.27: Calculated Darcy-velocity vectors in the Culebra dolomite, assuming the transmissivity distribution shown in Figure 4.1.24 and head distribution shown in Figure 4.1.25. Figure 4.5B of LaVenue et al. (1988).

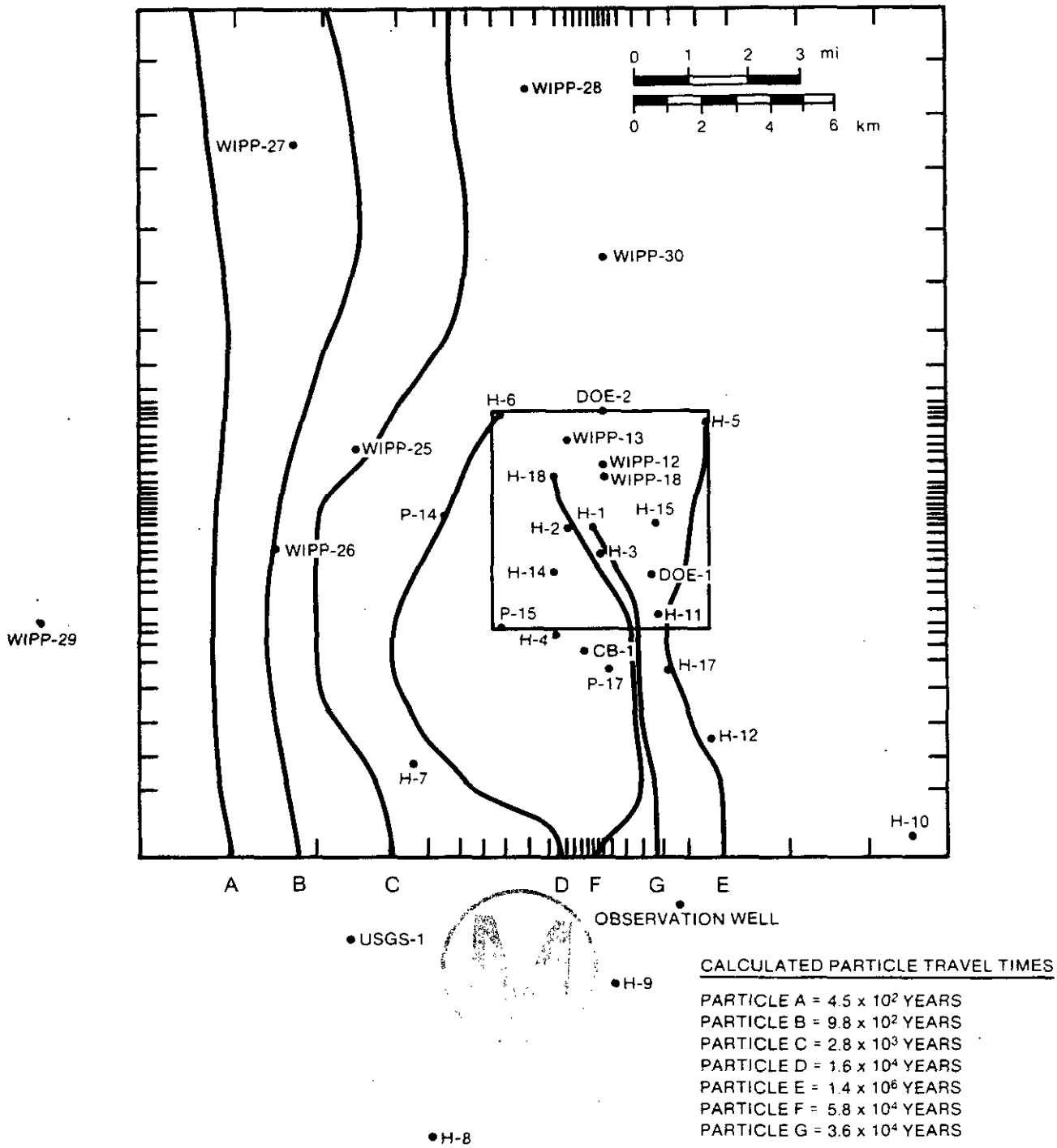

Figure 4.1.28: Calculated particle flowpaths and flow times within the Culebra dolomite, assuming steady-state and the transmissivity and head distributions shown in Figures 4.1.24 and 4.1.25. Figure 4.17 of LaVenue at al. (1988).

million years. Given that Culebra hydrology is in transient response to the end of the last pluvial period, it is not realistic to expect steady-state flow within the unit on a time scale of 106 years (LaVenue et al., 1988). The result indicates, however, that groundwater flow within the Culebra on the eastern part of the WIPP site is extremely slow.

Figure 4.1.28 also demonstrates an important consequence of the recent changes in the understanding of the distribution of Culebra transmissivities. Path G represents assumed steady-state flow from a position above the center of the WIPP waste-emplacement panels, analogous to the flowpath used in the detailed generic transport calculations contained in Reeves et al. (1987) (Section 4.2). Reeves et al. (1987) used the Culebra transmissivity distribution calculated by Haug et al. (1987), which included higher transmissivities south of H-11 than estimated by LaVenue et al. (1988) (Figure 4.1.24). The groundwater travel time calculated by LaVenue et al. (1988) for flow from directly above the center of the waste-emplacement panels to the southern boundary of the model shown in Figure 4.1.24 is 36,000 years. The calculated flow time from the release point of path G to the southern boundary of the WIPP site (Zone 3) is approximately 13,000 years, roughly 2.5 times that estimated by Reeves et al. (1987) along an analogous flowpath, but assuming the transmissivity distribution shown in Figure 4.1.16. The changes in interpreted Culebra transmissivities and head potentials since April 1986 have significantly increased expected groundwater flow times across the WIPP site within the Culebra dolomite. However, given the uncertainties in effective porosities, flowpaths, and transmissivities within the Culebra dolomite, the recent results must be considered approximate.

4.2 Pad-Scale and Regional-Scale Studies of Contaminant Transport within the Culebra Dolomite

For purposes of WIPP performance assessment, contaminant (radionuclide) transport within the Culebra dolomite is of concern in two general types of breach scenario. Section 4.2 discusses contaminant-transport results at both the hydropad and regional scale, under "low-pressure," relatively undisturbed conditions. Low-pressure conditions correspond to a release of fluids from the WIPP facility that does not disturb the pre-existing head distribution in the Culebra. "High-pressure" conditions, for which studies have not yet been completed, represent a breach involving effective connection of the Culebra dolomite with a pressurized brine in the Castile Formation beneath the WIPP facility (see Section 3.2) for a long enough period of time to significantly change the head gradients within the Culebra.

Detailed field testing of transport properties in the Culebra dolomite has been carried out only at the hydropad scale and is discussed in Section 4.2.1. Recent interpretation of conservative-tracer testing at the H-3 hydropad indicates that fracturing plays a major role in pad-scale contaminant transport in the transmissive (fractured) portions of the Culebra. In low-transmissivity areas, such as at the H-4 pad, pad-scale transport within the Culebra is best modelled using the equivalent-porous-medium assumption.

For purposes of performance assessment, however, the critical scale for transport within the Culebra dolomite is not the hydropad, but rather the distance between the point of breach into the Culebra and the boundary to the accessible environment. For purposes of consistency within this report, the boundary of WIPP Zone 3 is assumed to represent the boundary to the accessible environment. Contaminant transport over the 3.2 km from the center of the WIPP site to the boundary of Zone 3 is not amenable to field testing on a reasonable time scale. It is thus necessary to estimate the "regional-scale" transport behavior within the Culebra by numerical modeling. Section 4.2.2 discusses the regional-scale transport behavior of the Culebra dolomite at and near the WIPP site. The results in Section 4.2.2 indicate that, at least as long as the Culebra heads are not significantly disturbed and the assumed flow paths and material properties within the Culebra are reasonably representative, numerical simulation of regional-scale transport within the Culebra at and near the WIPP site need not include effects due to fracturing.

4.2.1 Hydropad-Scale Transport of Conservative Tracers at the H-3 and H-4 Hydropads

Convergent-flow tracer tests operated at the H-3 hydropad in May and June 1984 and at the H-4 hydropad between October 1982 and October 1984 are interpreted by Kelley and Pickens (1986). The interpretations are summarized here, with the objectives of examining the relative importance of dual-porosity or fracture-flow effects on the hydropad scale at two separate locations and discussing the ranges of transport parameters at the two locations.

The first stage of a convergent-flow tracer test is to establish approximate steady-state gradients between the observation holes and the pumped well. Tracers are then injected into the observation wells and their transport to the pumped well monitored. The fluorinated organic tracers meta-trifluoromethylbenzoate (m-TFMB) and pentafluorobenzoate (PFB) were used in testing at the H-3 pad. These same tracers were used at the H-4 pad, in addition to para-fluorobenzoate (p-FB) and thiocyanate (SCN). It is generally assumed that the tracers are chemically stable throughout a test, and that they do not interact with the surrounding rock mass except by diffusion (Kelley and Pickens, 1986).

The interpretation of the H-3 and H-4 tracer tests was done using the code SWIFT II (Reeves et al., 1986a; 1986b). SWIFT II handles the hydraulic and transport behavior of fractured media by means of a "dual-porosity" formalism, in which the composite medium is assumed to consist of an array of porous matrix blocks (primary porosity) and regularly spaced fractures (secondary porosity). The fractures and matrix are allowed to interact. The matrix-block geometry is idealized as either uniform slabs (parallel non-intersecting fractures) or cubes (three orthogonal fracture sets). In interpretation, radial flow towards the pumped hole was assumed.

Interpretation assuming the presence of three orthogonal sets of fractures and the assumption of radial flow are both equivalent to the assumption of isotropy. As mentioned in Section 4.1.2, however, interpretation of

hydraulic interference testing at the H-4, H-5, H-6, and H-11 hydropads indicates some directional dependence of Culebra hydraulic properties. In contrast, interpretation of the hydraulic behavior on the H-3 pad (Beauheim, 1987a) indicates effectively isotropic behavior. The results contained in Kelley and Pickens (1986) must be considered approximate.

4.2.1.1 Conservative-Tracer Tests at the H-3 Hydropad--The observed tracer behavior during convergent-flow testing at H-3 is shown in Figure 4.2.1, and is summarized in Table 4.8. Hole H-3b3 was the pumped hole in this test. Meta-trifluoromethylbenzoate (m-TFMB) injected in hole H-3b1 was first detected in hole H-3b3 ("breakthrough") approximately 0.92 days (22 hrs) after injection, and reached a well-defined peak concentration approximately 2.6 days (62.4 hrs) after injection. After this time, tracer concentration decreased rapidly towards a relatively steady-state value. In contrast, the pentafluorobenzoate (PFB) injected into hole H-3b2 travelled to the sampling hole much more slowly, was first detected approximately 3.76 days (90.2 hrs) after injection, reaching a very broadly defined peak concentration (if any) after approximately 23 days (552 hrs).

Thus, there is a marked difference between the apparent directional dependence of hydraulic behavior and transport behavior at the H-3 pad. Hydraulic anisotropy at the H-3 pad is negligible. However, m-TFMB breakthrough along the H-3b1 - H-3b3 path was four times more rapid than PFB breakthrough along the H-3b2 - H-3b3 path. The preliminary interpretation of a convergent-flow conservative-tracer test at the H-6 pad (Gonzalez, 1983b) also indicates a discrepancy between the directional dependence of hydraulic and transport behavior within the Culebra. In testing at H-6, PFB injected into H-6b arrived at H-6c 16 times more rapidly than did m-TFMB injected into H-6a (Gonzalez, 1983b). These results suggest that the apparent difference between the behaviors of m-TFMB and PFB at the H-3 pad reflects differences in transport behavior along the two flow paths, rather than inherent differences in the behavior of the two tracers.

Parameters resulting from calibration to the observed behavior of the H-3 test are shown in Table 4.9. In calibration, varying input parameters are used to simulate the observed tracer behavior until satisfactory agreement is reached. Because these same parameters were used in regional-scale transport calculations (Section 4.2.2), it is important to understand the character of the parameters listed in Table 4.9.

Three parameters, solute free-water diffusion coefficient, matrix tortuosity, and longitudinal dispersivity, were taken by Kelley and Pickens (1986) from ranges of published values, not based on WIPP-specific information. Specifically, values of 0.15 and 0.45 for matrix tortuosity were used as variable input to calculations. The matrix porosity value shown in Table 4.9 (0.20) is the approximate average of a series of six helium-pycnometer measurements made on Culebra core from holes H-3b2 and H-3b3.

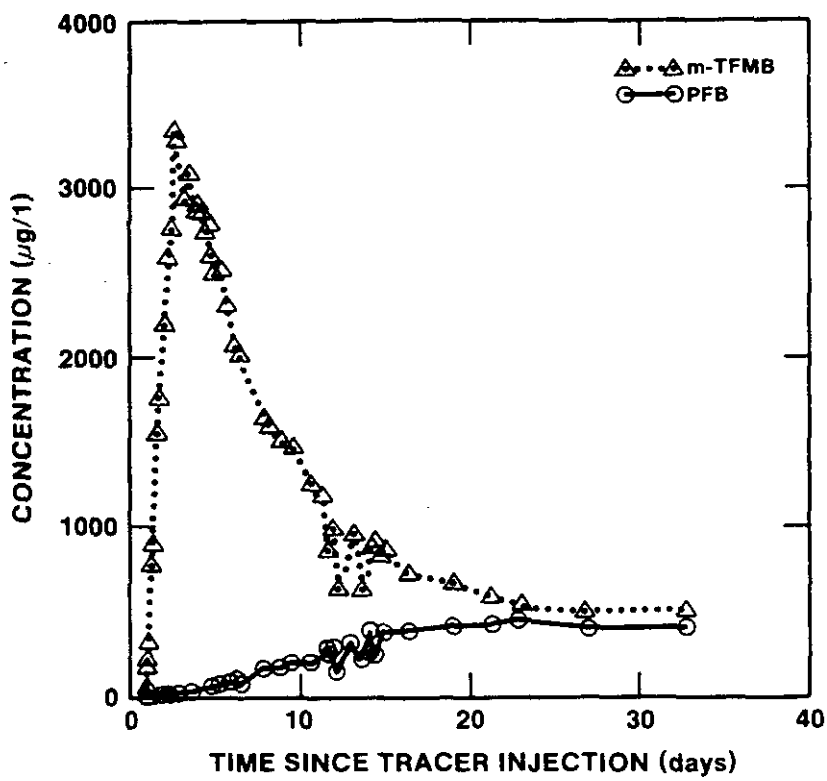

Figure 4.2.1: Observed tracer behavior during the convergent-flow test at the H-3 hydropad. Figure 4.5 of Kelley and Pickens (1986).

Table 4.8: Summary of observed tracer behavior during the convergent-flow test at the H-3 hydropad. Slightly modified from Table 4.2 of Kelley and Pickens (1986).

Parameter	Tracer	
	m-TFMB	PFB
1. Flow path	H-3b1 to H-3b3	H3b2 to H-3b3
2. First detection (days)	0.92	3.76
3. First reported concentration (mg/ℓ)	56	20
4. Time of peak concentration (days)	2.59	23.04
5. Peak concentration (mg/ℓ)	3379	444
6. Relative Peak Concentration (m/m_o)	3.3×10^{-6}	4.3×10^{-7}
7. Total tracer mass recovered (m/m_o)	0.53	0.15
8. Apparent fracture porosity	0.0019	0.019

Fracture porosity and matrix block length are specific outputs of the calculations, for the specific input values of other variables. Thus, in extrapolation of H-3 transport properties to other locations, only matrix block lengths and fracture porosities are based on the results of the H-3 tracer test; other values were input to interpretation of the H-3 testing based on either literature review or laboratory measurements.

The calculated fracture porosity of 0.19% along the H-3b1 - H-3b3 flow path (Table 4.9) was estimated directly from the relationship among pumping rate, H-3b1 - H-3b3 path length assuming direct radial flow, Culebra thickness, and time required for m-TFMB to reach peak concentration (22 hrs). Similar analysis along the H-3b2 - H-3b3 path yields an estimated fracture porosity of 1.9%. A fracture porosity of .19% was used in sensitivity studies, and was assumed to be applicable along both flowpaths on the H-3 pad (Kelley and Pickens, 1986).

Figures 4.2.2 and 4.2.3 show the best-fit simulations of transport behavior along the H-3b1 - H-3b3 flow path as a function of the specified input parameters. There is excellent agreement between measured and simulated results, with two different effective block sizes (1.2 and 2.1 m) being

Table 4.9: Input and best-fit calibration parameters from interpretation of the conservative-tracer test at the H-3 hydropad. Slightly modified from Table 4.3 of Kelley and Pickens (1986).

	Tracer	
	m-TFMB	PFB
Flow path	H-3b1 to H-3b3	H-3b2 to H-3b3
Input Parameters		
1. Diffusion coefficient for solute-free water (m^2/s)	7.4×10^{-10}	7.4×10^{-10}
2. Matrix tortuosity	0.15, 0.45	0.15, 0.45
3. Longitudinal disporsivity (m)	3.0	1.5
4. Matrix porosity	0.20	0.20
5. Fracture porosity	-	1.9×10^{-3}
Output Parameters		
1. Fracture porosity	1.9×10^{-3}	(1.9×10^{-2})
2. Matrix-block length (m)	1.2, 2.1	0.25, 0.44

calculated as a function of two different input matrix tortuosities (0.15 and 0.45, respectively). Figure 4.2.4 shows the analogous best-fit simulation for the H-3b2 - H-3b3 flowpath, assuming a matrix tortuosity of 0.15. The calculated effective block size along the H-3b2 - H-3b3 flowpath, 0.25 to 0.44 m, is smaller than along the path H-3b1 - H-3b3. As mentioned earlier, the calculated block sizes are only qualitative although, as noted by Kelley and Pickens (1986) they are consistent with observation of both Culebra core and exposures within the WIPP shafts. Thus, conservative-tracer testing at the H-3 pad indicates both the strong role of fracturing in transport at this scale (at least in some directions) and the strong directional dependence of estimated transport parameters such as effective block size.

The role of both matrix and fractures in pad-scale contaminant transport of conservative (non-sorbing) trace contaminants in the Culebra dolomite at the H-3 pad is emphasized in Figures 4.2.5 and 4.2.6. If dual-porosity and single-porosity simulations are both adjusted to match the time of peak

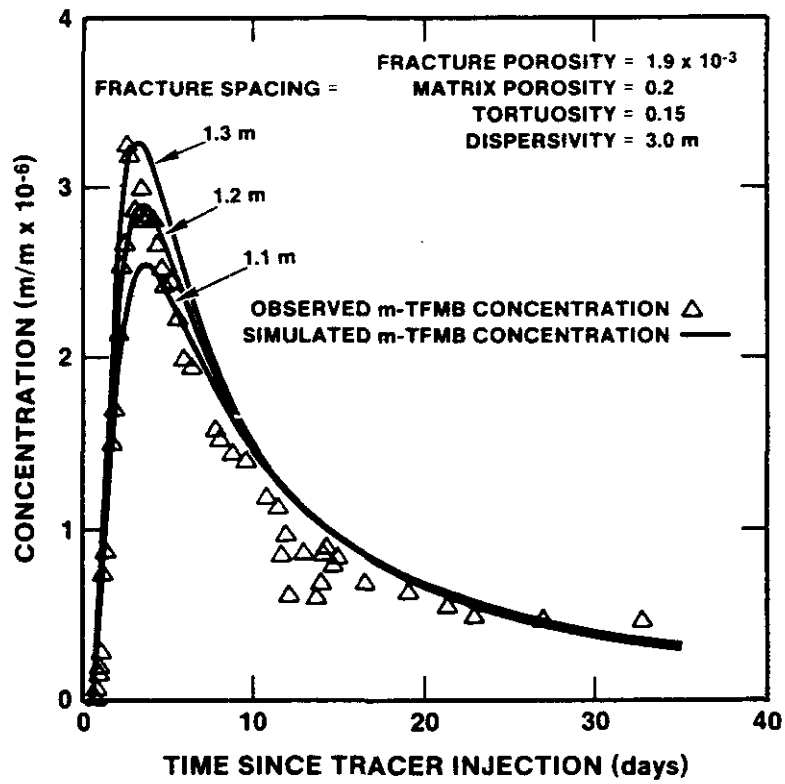

Figure 4.2.2: Best-fit simulation of measured transport behavior along the H-3b1 - H-3b3 flow path, assuming matrix tortuosity of 0.15. It is assumed that 1 kg of m-TFMB was successfully injected, and remained stable throughout the test. Figure 4.10a of Kelley and Pickens (1986).

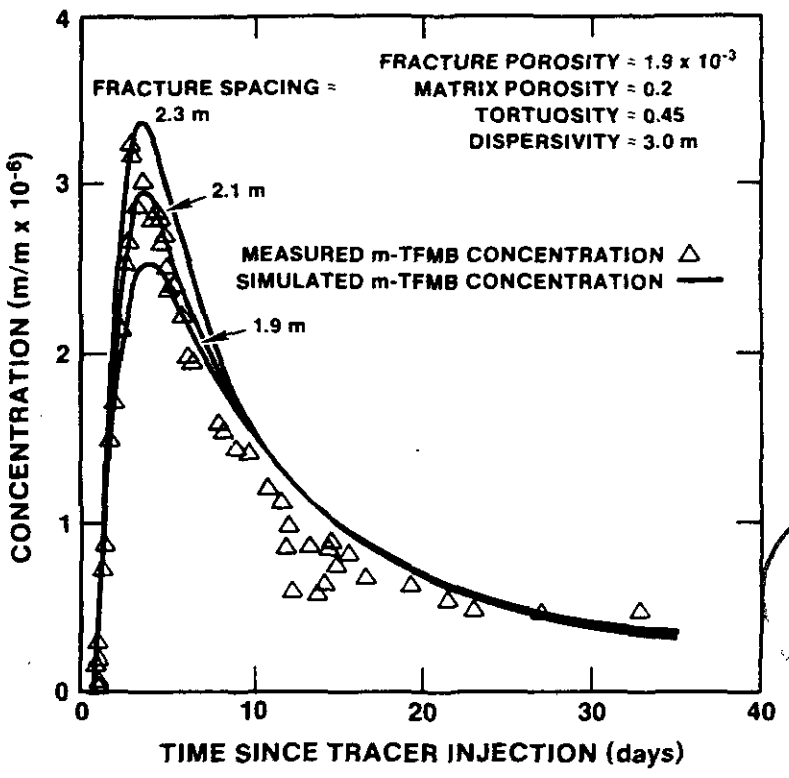

Figure 4.2.3: Best-fit simulation of measured transport behavior along the H-3b1 - H-3b3 flow path, assuming matrix tortuosity of 0.45. Figure 4.10b of Kelley and Pickens (1986).

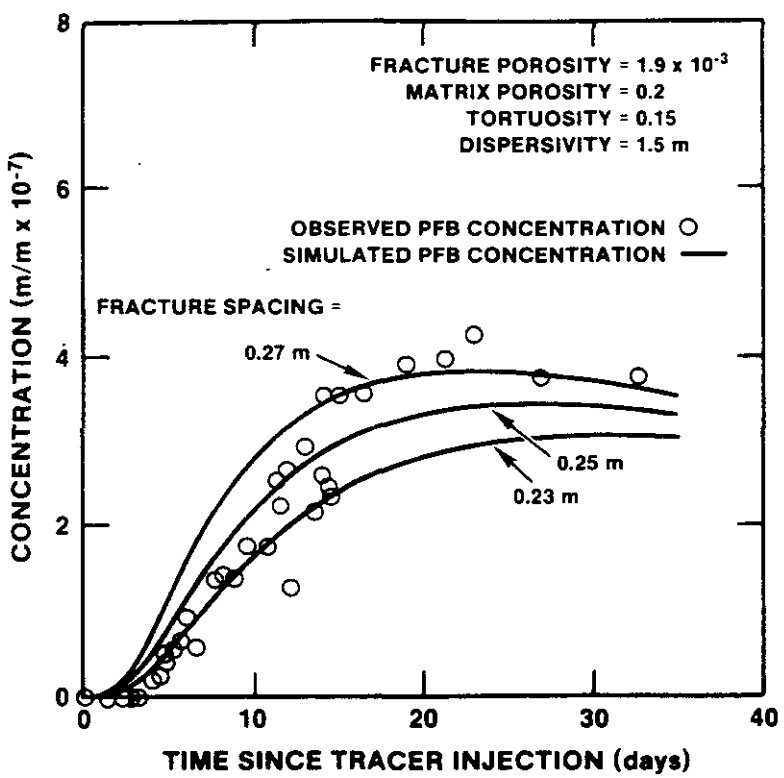

Figure 4.2.4: Best-fit simulation of measured transport behavior along the H-3b2 - H-3b3 flow path, assuming matrix tortuosity of 0.15. Fracture porosity is assumed to be the same as calculated for the flow path H-3b1 to H-3b3. Figure 4.11a of Kelley and Pickens (1986).

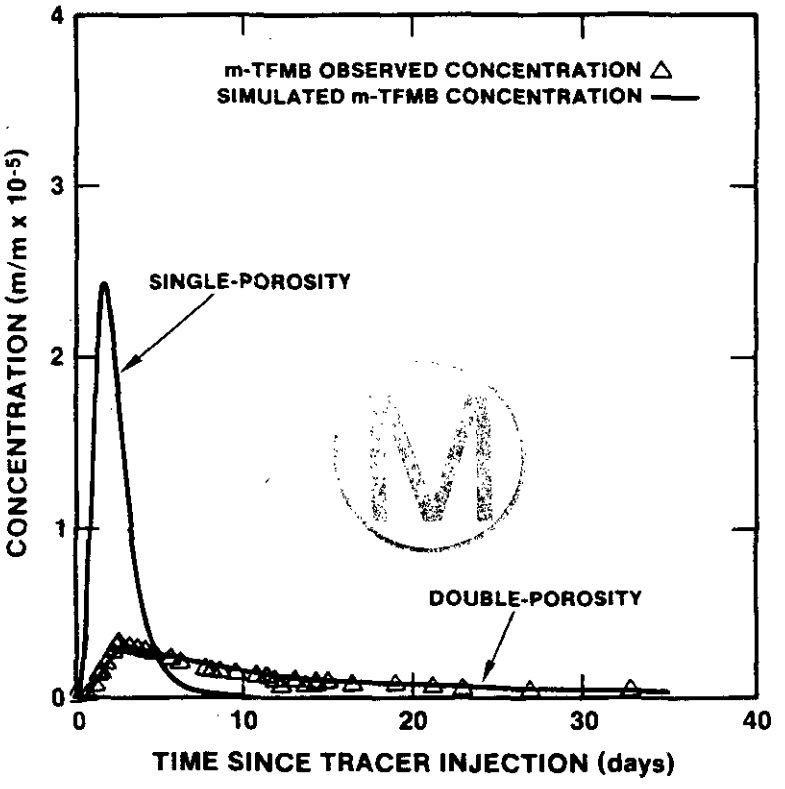

Figure 4.2.5: Best-fit single-porosity and dual-porosity simulations of tracer behavior along the H-3b1 - H-3b3 flow path when both simulations are forced to match the time of peak concentration. Figure 4.12 of Kelley and Pickens (1986).

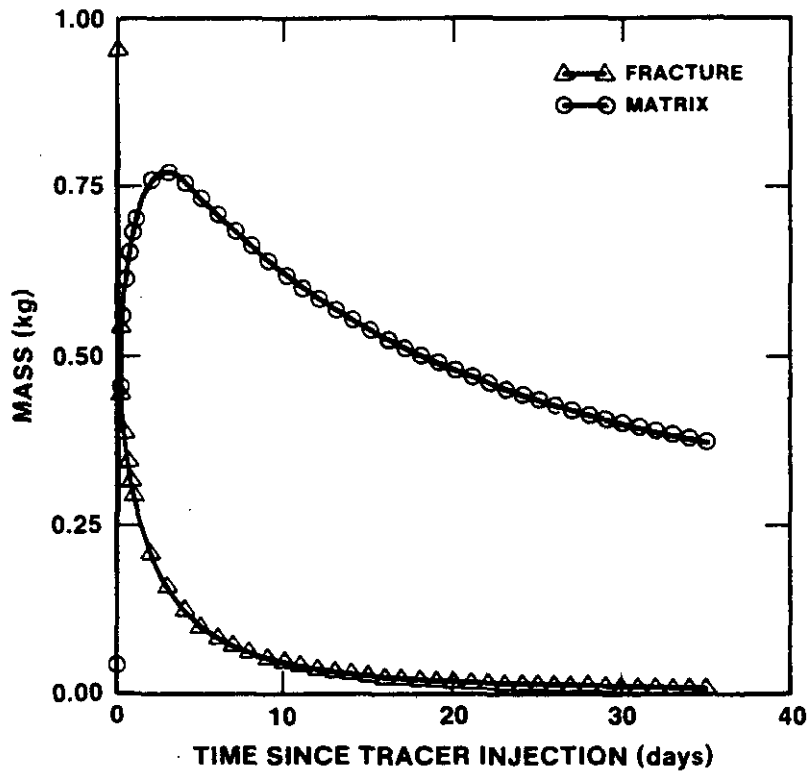

Figure 4.2.6: Calculated total masses of tracer m-TFMB in matrix and fractures as a function of time after injection. The fact that the total mass is less than 1 kg after approximately 2.5 days into the test reflects removal of tracer at the sampling hole, H-3b3. Figure 4.13 of Kelley and Pickens (1986).

concentration for m-TFMB transport along the path H-3b1 - H-3b3 (Figure 4.2.5), the post-peak behavior of the two simulations is qualitatively different. In the single-porosity simulation, the effective rock-mass porosity required to match the time of peak concentration is 0.0019, equivalent to the estimated fracture porosity in the dual-porosity simulation. The single-porosity simulation is thus equivalent to assuming no interaction between fractures and matrix, i.e., it is a "discrete-fracture" simulation, in which interaction between fractures and matrix is negligible. The peak concentration in the single-porosity simulation, which is overestimated by a factor of approximately eight, drops off very quickly, approaching zero, eight days after tracer injection. In contrast, the best-fit dual-porosity simulation matches both the time and magnitude of the tracer peak concentration well. In addition, both the observed tracer concentrations and those calculated with the best-fit dual-porosity parameters are above the detection limit more than 30 days after injection.

The conclusion by Kelley and Pickens (1986) that both the short-term and long-term transport behavior at the H-3 pad are affected by interaction of fractures and matrix is also supported by Figure 4.1.26. This figure indicates the total masses of m-TFMB calculated to be present in the matrix and fractures as a function of time since tracer injection. Initially, all of the injected tracer is contained in the fractures, and the total tracer mass in the matrix is zero. After approximately 0.5 days, however, tracer storage within the matrix blocks dominates as a result of diffusion from the fractures. At early times, storage within the matrix decreases both the concentration and the total mass of tracer in the fractures, consistent with the lower peak concentration calculated using the dual-porosity formalism (Figure 4.2.5). At longer times, the concentration of material within the matrix is greater than that within the fractures. Therefore, material diffuses from the matrix into the fractures, effectively keeping the concentration within the fractures from rapidly decreasing to zero as it does in the single-porosity simulation.

Interpretation of the H-3 conservative-tracer experiment provided the first estimates of Culebra transport parameters (fracture porosity and effective matrix block size) in fractured portions of the Culebra dolomite. There are unavoidable uncertainties in these estimates, however, due to both the need to assume radial flow in the interpretation and uncertainties in parameters such as effective matrix porosity. Regardless of these limitations, the conservative-tracer test at the H-3 pad provides direct evidence of the role of matrix diffusion in contaminant transport in fractured portions of the Culebra dolomite. This evidence is critical in supporting assumptions made in calculation of regional-scale transport within the Culebra (Section 4.2.2).

4.2.1.2 Conservative-Tracer Tests at the H-4 Hydropad--Conservative-tracer testing at H-3 investigated pad-scale contaminant transport where the Culebra is known to be effectively fractured (transmissivity approximately 2×10^{-6} m^2/s). At the H-4 pad, however, the transmissivity is lower (10^{-6} m^2/s or less; Tables 4.1 and 4.2), and there is no evidence of dual-porosity behavior in hydraulic testing.

The physical layout of the H-4 hydropad is shown in Figure 4.2.7. During steady-state, convergent-flow tracer testing at the pad between October 27, 1982, and October 15, 1984, H-4c was the pumped hole (at nominal rates of 1.66×10^{-2} and 3.33×10^{-2} l/s), and tracers were injected into holes H-4a and H-4b. Due to the very long test time at the H-4 pad, detailed interpretation of tracer behavior is hampered by pumping-rate fluctuations and pump breakdowns, as well as by questionable tracer stability (Kelley and Pickens, 1986).

The observed tracer behavior during testing at H-4 is summarized in Table 4.10. The first tracer detected in H-4c was m-TFMB travelling along the path H-4b to H-4c. However, the tracer was not detected until 262 days after injection. Tracer recovery was very limited during the test, the greatest being 37% of the total mass of m-TFMB injected. Because of the limited tracer recovery, the emphasis here is on m-TFMB behavior.

The calculated effective matrix or fracture porosities controlling first arrival of m-TFMB and PFB (Table 4.9), analyzed in the same method as in testing at the H-3 pad, are 0.033 and 0.053, respectively. Lab-measured total porosity for samples from the H-2, H-3, H-4, and H-6 pads range from 0.07 to 0.30, with an average value of 0.16 (Reeves et al., 1987). The two Culebra samples from hole H-4b have reported total porosities of 0.20 and 0.30. Therefore, the apparent porosities calculated from peak-concentration behavior in the H-4 tracer test may indicate that the hydraulically effective porosity of the Culebra at H-4 is significantly less than total porosity, that the tracers used did not remain stable and non-reactive for the two-year duration of the test, and/or that the Culebra core samples from H-4 are not representative.

Kelley and Pickens (1986) applied three different interpretative models to the behavior of m-TFMB at the H-4 pad: 1) a single-porosity model; 2) a dual-porosity model; and 3) a layered porous-medium model. The first two models are analogous to those used in interpretation of conservative-tracer testing at the H-3 pad. The third model is different in that it assumes that the Culebra consists of a specified number of parallel high-permeability and low-permeability porous layers. In this approach, unlike the dual-porosity approach, the total surface area available for diffusive transport between high-permeability and low-permeability zones is fixed by the specified number of high-permeability zones.

The simulation of m-TFMB behavior shown in Figure 4.2.8 assumes specified numbers of high-permeability zones and stability of 1 kg of tracer for the duration of the test. The time of peak concentration (388 days) is matched with an effective porosity of 0.04. However, the peak concentration is overestimated by a factor of approximately two if the Culebra is assumed to be uniform (one high-permeability zone). Kelley and Pickens (1986) note that improved agreement between observed and calculated behavior resulted if it was assumed that only 0.5 kg of tracer was effectively injected, rather than the nominal 1.0 kg.

A dual-permeability formalism was also used by Kelley and Pickens (1986), assuming that both low-permeability and high-permeability zones had an

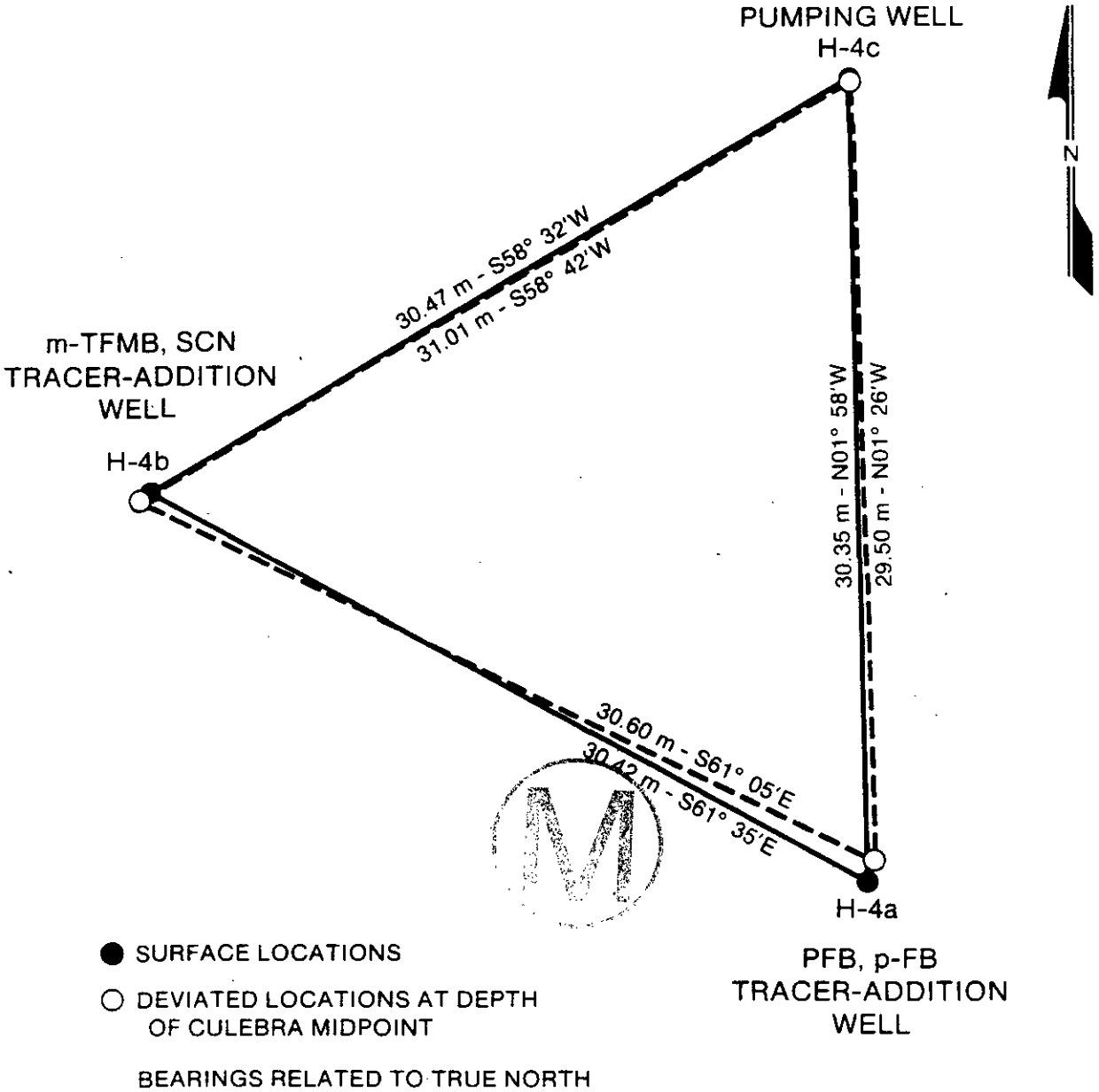

Figure 4.2.7: Physical layout of the H-4 hydropad. The figure includes orientations and spacings between holes, both at the surface and at the depth of the Culebra dolomite. Figure 6.1 of Kelley and Pickens (1986).

Table 4.10: Summary of observed tracer behavior during the convergent-flow, conservative-tracer test at the H-4 hydropad. Slightly modified from Table 6.2 of Kelley and Reeves (1986).

Parameter	Tracer	
	m-TFMB	PFB
1. Flow path	H-4b to H-4c	H-4a to H-4c
2. First detection (days)	262.2	501.1
3. First reported concentration (mg/ℓ)	78	48
4. Time of peak concentration (days)	388.2	507
5. Peak concentration (mg/ℓ)	723	54
6. Relative peak concentration (m/m_o)	7.1×10^{-7}	5.3×10^{-8}
7. Tracer Mass recovered (m/m_o)	0.37	0.022
8. Apparent fracture porosity from peak concentration	0.033	0.053(1)

(1) Apparent porosities for SCN = 0.024; p-FB = 0.064.

effective porosity of 0.20. The number of high-permeability zones was allowed to vary. It was assumed that 1.0 kg of m-TFMB remained stable throughout the test. The presence of increasing numbers of interfaces between high-permeability zones and "matrix" zones, in which only diffusive transport is allowed, effectively decreases the simulated peak concentration (Figure 4.2.8). The best fit was obtained for five or six high-permeability zones, although none of the fits were satisfactory (Kelley and Pickens, 1986), in part because they overestimate tracer concentrations at longer times. In order to improve the long-term fit, it would have to be assumed that there was some tracer degradation at longer times.

In summary, interpretation of the conservative-tracer test at the H-4 pad, while not successful in developing detailed estimates of transport parameters in unfractured portions of the Culebra, does indicate important considerations in both tracer testing at the pad scale and interpretation of regional-scale modeling of transport behavior. Both tracer and hydraulic behavior during the test are consistent with porous-medium behavior, indicating that fracturing need not be considered in evaluation of pad-scale or regional-scale transport in areas of relatively low Culebra

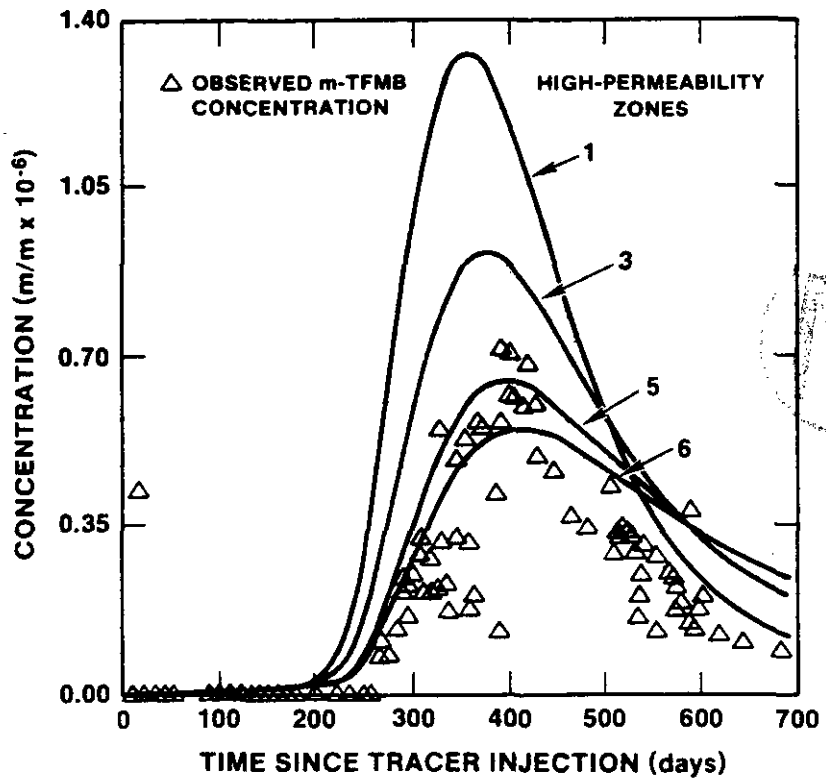

Figure 4.2.8: Best-fit simulation of m-TFMB behavior during testing at the H-4 hydropad, assuming effective injection and stability of 1 kg of tracer and control of behavior by the specified numbers of multiple high-permeability zones. Figure 6.11 of Kelley and Pickens (1986).

transmissivity ($T \leq$ approximately 10^{-6} m^2/s). If it is assumed that the Culebra at H-4 is vertically homogeneous and that the tracers used were stable and non-reactive for the duration of the test, then the hydraulically effective matrix porosity of the Culebra may be significantly less than the total porosity. Given the long duration of the H-4 test, however, it is probable that the tracers degraded during the test.

4.2.2 Regional-Scale Contaminant Transport in the Culebra Dolomite under Low-Pressure Conditions

Regional-scale contaminant transport within the Culebra dolomite under the low-pressure type of breach scenario, i.e., under conditions which do not disturb the head distribution within the Culebra, has been examined by Reeves et al. (1987). Significant transport under these conditions might be expected in the event of failure of the WIPP shaft seals in the absence of human intrusion, or in the event of an imperfectly plugged human-intrusion breach involving a high-pressure brine source within the Castile Formation. Calculations are ongoing to investigate behavior following a second type of breach, in which fluids are assumed to be injected at high pressures into the Culebra for long enough to dominate the local head potentials and flow rates.

The calculations in Reeves et al. (1987) investigate: 1) the significance of the interactions between matrix and fractures seen in tracer and hydraulic testing at the H-3 pad in regional-scale transport within fractured portions of the Culebra dolomite; and 2) the relative importance of several transport and material parameters of the Culebra in regional transport within fractured portions of the Culebra. The calculations in Reeves et al. (1987) were made using the following approach and/or assumptions:

1. Contaminants were assumed to be continuously injected into the Culebra dolomite at points directly above the WIPP waste-emplacement panels at a constant rate after time zero. The injection was slow enough not to disturb the "natural" (pre-WIPP-shaft) gradient or transmissivity distribution.

2. The boundary of WIPP Zone 3 was assumed to represent the boundary of the accessible environment.

3. Effects of radioactive decay and lateral dispersion were assumed negligible, and were not included. If lateral dispersion were included in the calculations, it would effectively slow down transport. The effects of lateral dispersivity on total integrated release to the accessible environment have not been quantified.

4. Material properties and flow velocity were assumed homogeneous between the point of entry into the Culebra and the accessible environment. The analysis was done in terms of an average Darcy velocity yielding groundwater travel times equivalent to those calculated from the flow model described in Haug et al. (1987). Fluid

flow and contaminant transport were controlled by the transmissivity and head distributions estimated by Haug et al. (1987), and were calculated along the flow paths shown in Figure 4.2.9.

5. As a result of the strong interactions between fractures and matrix observed in the conservative-tracer test conducted at the H-3 hydropad (Section 4.2.1), the double-porosity formalism was initially assumed to be appropriate for modeling of transport within fractured portions of the Culebra. However, a major objective of the report was to examine the consequences of both the "discrete-fracture" and "equivalent-porous-medium" end-member behaviors in regional transport.

6. The base-case values and ranges of properties shown in Table 4.11 were assumed to be representative for fractured portions of the Culebra dolomite. The Culebra transport properties estimated in conservative-tracer testing at the H-3 pad were taken as the base-case properties.

7. "Breakthrough," defined by Reeves et al. (1987) as the time at which the calculated contaminant concentration at the boundary to WIPP Zone 3 equaled 10% of the injected concentration, was assumed to provide a meaningful measure of transport behavior. Conclusions in the report are specifically evaluated on the basis of this assumption.

8. It was assumed that retardation effects within the Culebra dolomite can be realistically modeled as a linear process, i.e., that chemical reactions are "fast" relative to flow times within fractures, are reversible, and reflect local equilibrium within the matrix. Thus, it was assumed that chemical retardation within the matrix of the Culebra dolomite can be represented realistically by using an appropriate "matrix distribution coefficient," k_d.

9. The possible presence of mineralogical "skins" on matrix blocks was ignored, as were advective transport within the matrix and sorption on fracture surfaces. These assumptions appear to be generally "conservative," i.e., they should bias the calculations towards greater fracture flow, except for the case of mineralogical skins inhibiting diffusion into the matrix.

Figure 4.2.10 compares the average calculated travel times for a conservative contaminant from positions above the WIPP facility to the southern boundary of WIPP Zone 3, along the flow paths shown in Figure 4.2.9, according to three different assumptions. Using the dual-porosity formalism and assuming uniform distribution of the base-case material properties estimated at the H-3 pad, the time predicted for "breakthrough" of a conservative (non-sorbing) contaminant at the boundary of WIPP Zone 3 is 3490 years after the beginning of continuous injection. This is approximately 90% of the 3730 years predicted by single-porosity calculations in which the porosity is set equal to the sum of the base-case matrix and fracture porosities, 16.2%. In the absence of chemical retardation of the contaminant, the role of the matrix in transport is largely one of storage due to diffusion from fractures into/out of matrix blocks (Section 4.2.1).

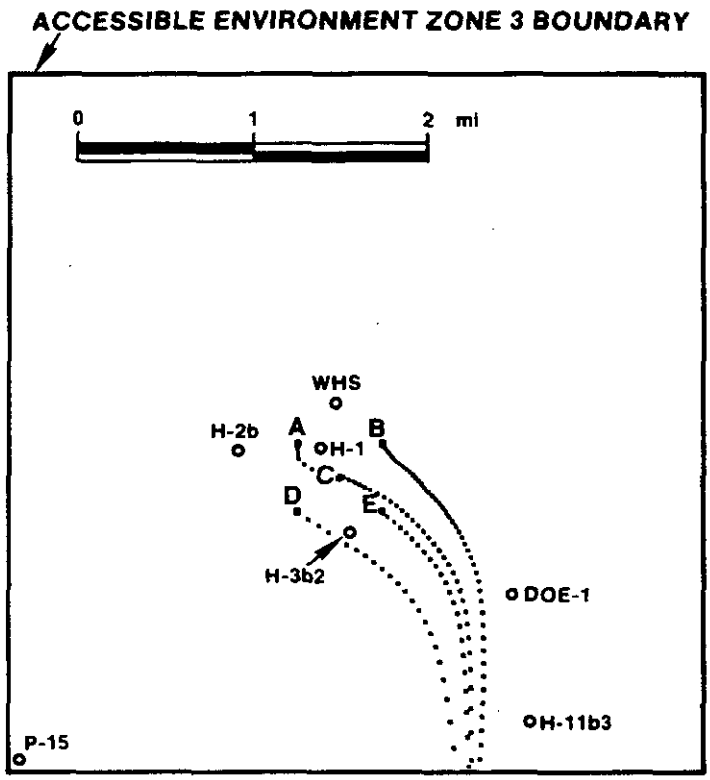

Figure 4.2.9: Release points into the Culebra dolomite and flow paths to the accessible environment considered by Reeves et al. (1987). Points A-E are vertical projections of the corners and center of the WIPP waste-emplacement panels upwards onto the Culebra dolomite. The small crosses extending from points A-E to the southern boundary of Zone 3 are equal-time marks along the flow paths. Slightly modified from Figure 1.7 of Reeves et al. (1987).

Table 4.11: Base-case Culebra transport properties and ranges of properties considered in regional-scale transport within Culebra dolomite. Slightly modified from Table 2.2 of Reeves et al. (1987).

Parameter	Units	Symbol	Base-Case	Range in Values	Relative Range (2)
1. Free-water diffusivity	cm^2/s	D'	2×10^{-5}	4×10^{-6} to 9×10^{-5}	4.30
2. Matrix tortuosity	-	θ'	0.15	0.05 to 0.50	3.00
3. Matrix-block length	2L'	m	2.4	0.25 to 7.0	2.81
4. Matrix porosity	-	ϕ'	0.16	0.07 to 0.30	1.44
5. Fracture porosity	-	ϕ	2×10^{-3}	2×10^{-4} to 2×10^{-2}	9.90
6. Longitudinal dispersivity	m	α	100	50 to 300	2.50
7. Specific matrix flux	m^3/m^2s	u	3.2×10^{-9}	2.2×10^{-9} to 4.7×10^{-9}	0.78
8. Matrix distribution coefficient	$m\ell/g$	k_d	(1)	(1)	-
9. Fraction distribution coefficient	$m\ell/g$	k_d	0	0	-

(1) Calculations done with fixed values of $k_d' = 0.0, 10, 10^2, 10^4\ m\ell/g$.
(2) Range divided by base-case value.

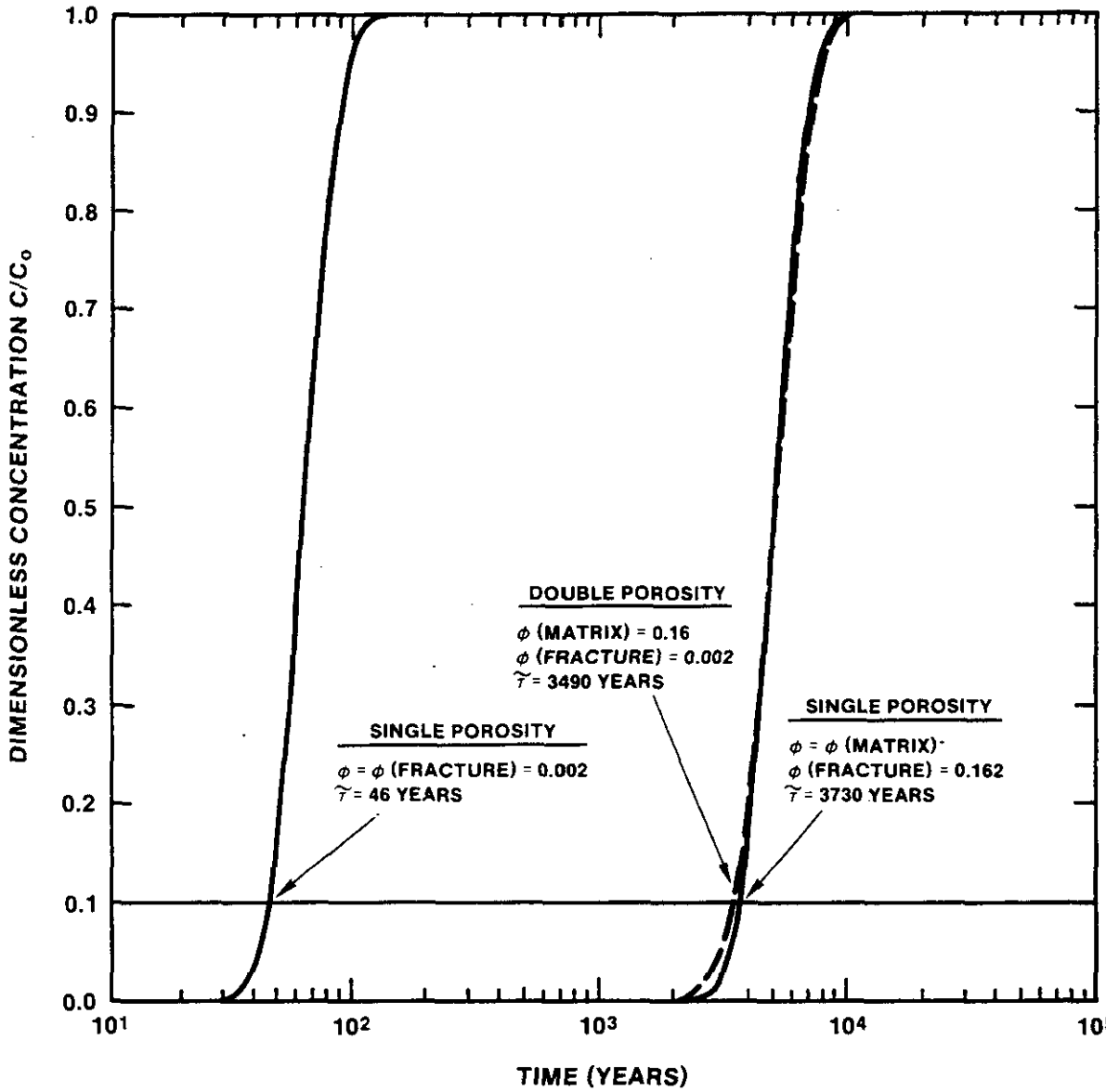

Figure 4.2.10: Comparison of base-case, regional-scale transport behavior of a conservative contaminant in the Culebra dolomite under discrete-fracture, dual-porosity, and porous-medium assumptions. Breakthrough is defined here as the time at which the concentration at the boundary of WIPP Zone 3 equals 10% of the injected concentration. Figure 5.1 of Reeves et al. (1987).

In effect, the single-porosity curve on the right-hand side of Figure 4.2.10 assumes instantaneous diffusion into and equilibration with the matrix.

At the other extreme, diffusion time into the matrix is infinite in fracture flow if it is assumed that fractures and matrix do not interact. The breakthrough time calculated (Figure 4.2.10) assuming that transport occurs only within fractures, assuming a fracture porosity of 0.2%, is 46 years (Reeves et al., 1987).

The experimental results at the H-3 hydropad (Section 4.2.1.1) and the calculated variations in breakthrough time at the boundary of WIPP Zone 3 shown in Figure 4.2.11 indicate the importance of matrix diffusion in both pad-scale and regional-scale transport in the Culebra dolomite. As described by Reeves et al. (1987), a diffusion time means that 1000 years is required for contaminant concentration in the center of matrix blocks to reach approximately 68% of the concentration at fracture surfaces. The base-case diffusion time (Figure 4.2.11) is 152 years. Even for diffusion times significantly greater than the base case value, a large benefit is gained from diffusion of non-sorbing contaminants into matrix blocks (Figure 4.2.11). Base-case transport properties were assumed in the calculations summarized in Figure 4.2.11, except for diffusion into matrix blocks.

Thus, the effective transport behavior within the Culebra dolomite for transport between any breach point directly above the WIPP emplacement panels and the boundary of Zone 3, assuming the breach does not disturb the head distribution within the Culebra, appears to be nearly that of an equivalent porous medium having a porosity equal to the sum of matrix plus fracture porosities. Inclusion of the dual-porosity formalism at this scale, given the assumed properties and flow paths, does not change calculated travel times by more than approximately 10%.

The conclusions supported by results shown in Figures 4.2.10 and 4.2.11 only apply directly to calculations assuming the base-case transport and material properties for the Culebra, which are based largely on interpretation of the conservative-tracer test at the H-3 pad (Section 4.2.1.1). Therefore, Reeves et al. (1987) examined the sensitivity of the results to variations in parameters. The relative importance of several transport parameters in regional-scale transport in the Culebra estimated by Reeves et al. (1987) is summarized in Table 4.12. Reeves et al. (1987) define importance in terms of both the sensitivity of calculated behavior to uncertainty in a given parameter and the estimated range of uncertainty of that parameter in the Culebra dolomite at and near the WIPP site. Thus, a highly sensitive parameter that was known with perfect precision would have zero importance. In contrast, a relatively insensitive parameter could be very important if its range of uncertainty was large.

Reeves at al. (1987) conclude that five parameters are most important in controlling "breakthrough" time to the southern boundary of WIPP Zone 3 in the Culebra dolomite. These are: 1) the matrix retardation (K'), where K' is proportional to $(1 + k_d')$ and k_d' is the matrix distribution

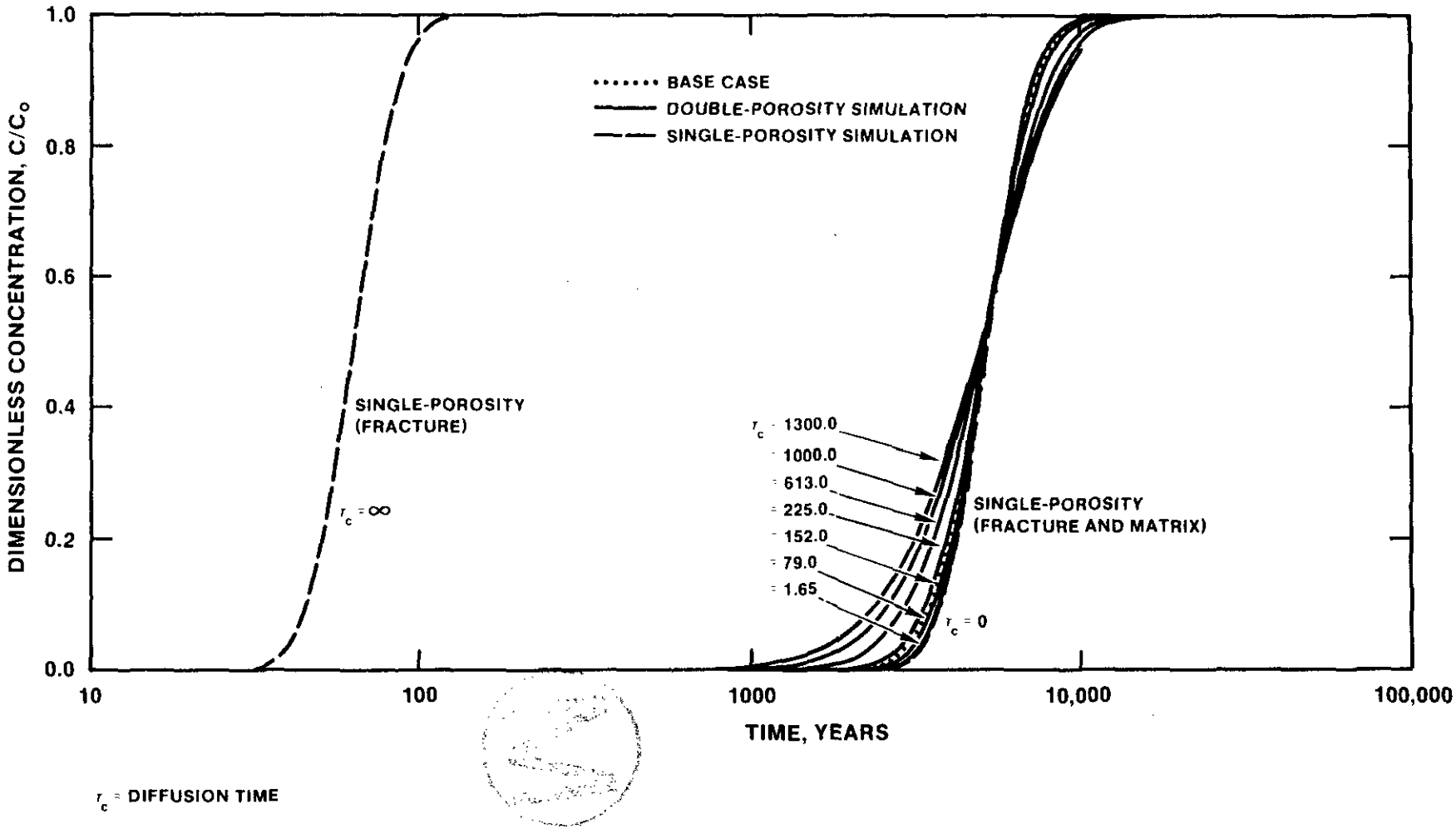

Figure 4.2.11: Estimated effect of variations in diffusion time on breakthrough, otherwise assuming base-case Culebra properties. The diffusion time is the time required for contaminant concentration at the center of matrix blocks to equal approximately 68% of the concentration in fractures. Modified from Figure 4.3 of Reeves et al. (1987).

Table 4.12: Estimated importance of different parameters in regional-scale contaminant transport within the Culebra dolomite. Table 4.5 of Reeves et al. (1987).

Parameter	Symbol	Sensitivity[a]	Importance Coefficient[a]	Importance Ranking
Free water diffusivity	D'	0.064	0.28	5
Matrix tortuosity	θ'	0.064	0.19	6
Matrix-block length	$2L'$	-0.13	0.36	4
Matrix porosity	ϕ'	1.1	1.58	1
Fracture porosity	ϕ	0.013[b]	0.13	7
Fracture dispersivity	α	-0.17	0.43	3
Fracture flux	u	-1.1	0.86	2

(a) Results are valid for retardations $K' = 1$, 1.50×10^2, 1.49×10^3, and 1.49×10^5.
(b) Upper-bound estimate.

coefficient; 2) the effective matrix porosity; 3) the Darcy flux within the fractures (defined as a specific flux m^3/m^2s); 4) the dispersivity in the fractures; and 5) the effective matrix-block size. Reeves et al. (1987) conclude that four parameters are relatively unimportant in controlling regional transport within the Culebra. These include: 1) free-water diffusivity; 2) matrix tortuosity; 3) fracture porosity; and 4) retardation in the fractures (not shown in Table 4.12).

The linear dependence of calculated breakthrough time on matrix retardation (K') is indicated in Figure 4.2.12. This behavior also indicates the effective porous-medium behavior on the regional scale, since for an ideal porous medium the dependence of breakthrough time on retardation is strictly linear. Breakthrough to the southern boundary of Zone 3 should not occur within 10,000 years after release for any matrix distribution coefficient (k_d) greater than approximately 0.2 mL/g for the assumed base-case Culebra material properties.

Valid use or extrapolation of the results contained in Reeves at al. (1987) depends on the assumptions listed at the beginning of this section, especially the representative character of the base-case transport properties and range of properties used in the calculations. The validity of the results is also dependent on the validity of the transmissivity and head distribution within the Culebra dolomite between the calculated

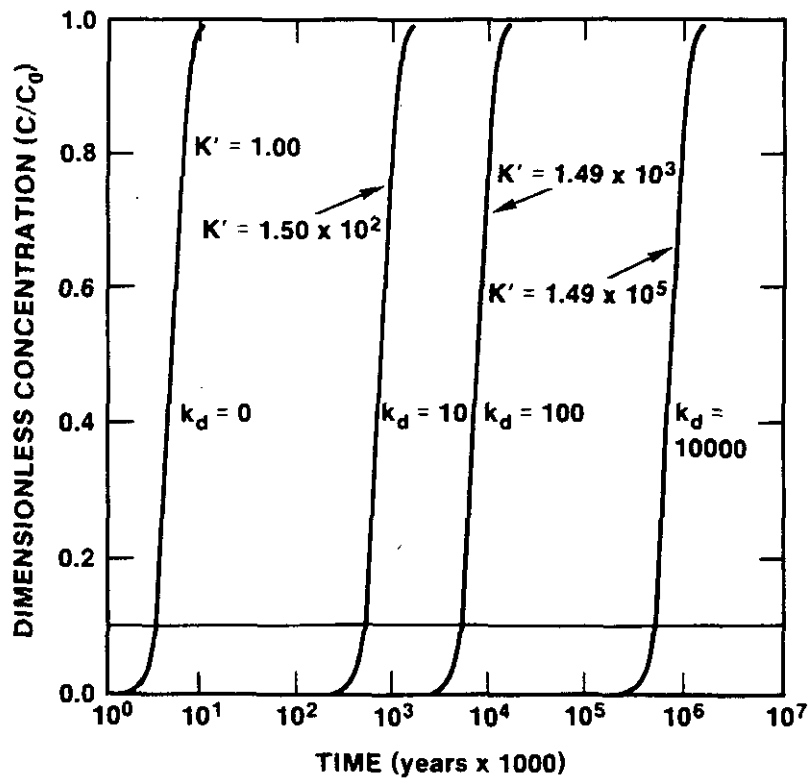

Figure 4.2.12: Variations in calculated breakthrough times to the boundary of WIPP zone 3 as a function of assumed matrix retardation, otherwise assuming base-case material properties. Matrix retardation (K') is proportional to $1 + k_d'$. Therefore, for a matrix distribution coefficient (k_d') of 0, K'=1.0. Slightly modified from Figure 4.1 of Reeves et al. (1987).

release points and the southern boundary of Zone 3. The results of LaVenue et al. (1988) discussed in Section 4.1.3.2 indicate that groundwater and contaminant travel times in the southern part of WIPP Zone 3 may be even slower than calculated by Reeves et al. (1988), so long as flow directions and rates within the Culebra are not affected too greatly by the continuing transient response of the Culebra to the end of the last pluvial period.

Effective matrix diffusion within fractured portions of the Culebra may be possible only because of the relatively slow flow velocities calculated assuming an undisturbed Culebra head distribution. In the event of a brine-reservoir breach of the WIPP facility, the volumes of brine injected from the Castile Formation into the Culebra dolomite might be sufficient to redefine the head distribution within the Culebra, greatly increase hydraulic gradients, and decrease flow times to the accessible environment. Calculations are underway to determine if the dual-porosity formalism is required to evaluate transport within the Culebra under these conditions.

4.3 Geochemical Studies in the Rustler Formation and Shallower Units

The hydrologic studies discussed in Section 4.1 and transport studies discussed in Section 4.2 largely ignore both geochemical behavior within the Rustler Formation and the overall geologic behavior of the WIPP site, except for interaction between the Culebra dolomite and trace contaminants. The status and present conclusions of geochemical studies within the Rustler Formation and shallower units are discussed in this section. The results of these studies, summarized by Siegel et al. (1988a), help place constraints on the relationship between the modern geochemistry and flow directions within both the Culebra dolomite and the Rustler Formation as a whole.

Section 4.3.1 describes the status of geochemical studies of major and minor solutes, in which Culebra groundwaters have been divided into four hydrochemical facies that may be diagnostic of natural interactions between Culebra waters and the matrix of the Culebra dolomite. The results, when compared with modern flow directions within the Culebra, indicate that the geochemistry of Culebra fluids is inconsistent with steady-state confined flow.

Section 4.3.2 discusses the expansion of the stable-isotope results and interpretations contained in Lambert (1983) to interpretations contained in Lambert (1987b) and Lambert and Harvey (1987). Stable-isotope studies themselves do not provide any information concerning the absolute ages of groundwaters. The studies can, in some cases, indicate whether different bodies of water were recharged under similar or different climatic conditions. The results of the recent stable-isotope studies indicate that the isotopic composition of Rustler groundwaters at and near the WIPP site is distinct from that of modern meteoric precipitation at similar elevations in the northern Delaware Basin.

Section 4.3.3 summarizes studies examining the lengths of time groundwaters in the Rustler/Salado contact zone, Rustler Formation, and Dewey Lake Red

Beds in the region of the WIPP site may have been isolated from contact with atmospherically derived components such as radiocarbon, tritium, and chlorine-36 (Lambert, 1987a). At the WIPP site, the applicability of such "environmental isotopes," which occur in ultratrace amounts, is unavoidably limited by the variability of the rock types present, as well as by the ages of both rocks and groundwaters. Specifically, no detectable ^{36}Cl above background has been detected in Rustler fluids, because of the large chlorine background inherent in fluids which have been involved in dissolution of halite from within the Rustler Formation. Nor have tritium levels significantly above background been identified in Rustler fluids, except in hole WIPP-29, interpreted on other grounds to be contaminated by potash mining. Radiocarbon studies met with only limited success, because the normal techniques used in drilling hydrocarbon-exploration and hydrologic test holes at and near the WIPP have resulted, in many cases, in some contamination with organic materials. The limited number of minimally contaminated radiocarbon results, however, indicate that the Culebra dolomite and part of the Dewey Lake Red Beds at the WIPP site have been isolated from atmospheric carbon sources for at least 12,000 years.

Section 4.3.4 discusses fluid-flow directions and rates within the Culebra dolomite, as interpreted from uranium-disequilibrium studies (Lambert and Carter, 1987). The results provide an effectively independent check of conceptual models derived from other studies. Although the present uranium-disequilibrium data base is limited, allowing considerable uncertainty in flow directions, the results indicate that there must have been a significant change in flow directions within the Culebra dolomite, on a time scale generally consistent with the end of local recharge indicated by radiocarbon studies.

4.3.1 Solute Geochemistry and Delineation of Hydrochemical Facies within the Culebra Dolomite

This section summarizes the currently available data and hypotheses (Siegel et al., 1988a) concerning the origin and compositions of waters in the Culebra dolomite. These authors delineate Culebra fluids into various hydrochemical facies, consider the compatibility of these facies with modern flow patterns derived from stratigraphic and hydrologic studies, and examine the interactions of Culebra solutes and host-rock mineralogies. Although Siegel et al. (1988a) emphasize the Culebra, relevant preliminary results of work on fluids from the Magenta dolomite, Rustler/Salado contact zone, and Dewey Lake Red Beds are included. One section of Siegel et al. (1988a), Bodine et al. (1988), was prepared as a summary interpretation of a separate study (Bodine and Jones, 1988), based on an independent data base. Data used in estimation of oxidation potentials (Eh) (Myers et al., 1988) were collected as part of the WIPP Water-Quality Sampling Program.

4.3.1.1 Hydrochemical Facies--The analytical ranges of compositions of Culebra waters and compositions used in calculations contained in Siegel et al. (1988a) are included in Table 4.13; major solutes are listed in Table 4.13a, minor and trace solutes in Table 4.13b. Individual data sets

Table 4.13a: Major solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b).

Well(s)	Collection Date(1)	Lab(2)	Total Dissolved Solids (mg/L)(7)	Ionic Strength (molal)(8)	Bromide (mg/L as Br)	Fluoride (mg/L as F)	Iodide (mg/L as I)	Boron (mg/L as B)	Lithium (mg/L as Li)	Strontium (mg/L as Sr)	Silica (mg/L as SiO_2)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)
Culebra													
DOE-1	4/85	UNC	131200	2.53	56	-	-	37	0.64	26	8.4	0.28	-
DOE-1	(2)	avg			60	1.2	-	36	0.64	21	-	-	-
DOE-1	(2)	rng			56-64	1.0-1.7	-	35-37	(1)	16-26	8-24	-	-
DOE-2	3/85	UNC	60400	1.19	34	1.7	0.22	16	0.47	38	17	0.036	0.30
DOE-2	(2)	avg			35	1.6	0.22	18	0.47	29	-	-	-
DOE-2	(2)	rng			34-36	1.2-2.2	(1)	14-24	(1)	22-38	17-24	-	-
H-2A	4/86	UNC	12900	0.27	5.6	2.2	0.081	10	0.22	9.5	13	1.1	0.055
H-3B3	6/84	UNC	55000	1.08	29	2.1	0.13	30	0.53	23	9.8	0.57	0.13
H-3B3	2/85	UNC	55800	1.08	26	1.9	0.14	26	0.40	30	11	0.20	0.12
H-3B2, H3B3	(4)	avg			31	1.8	0.14	28	0.41	25	-	-	-
H-3B2, H3B3	(4)	rng			26-39	1.5-2.1	0.13-0.14	21-34	0.30-0.53	23-30	9-20	-	-
H-4B	5/81	UNC	21700	0.46	42	-	-	18	0.39	14	11	-	-
H-4C	8/84	UNC	21200	0.45	48	2.1	0.23	20	0.49	18	13	2.2	0.20
H-4B	7/85	UNC	20200	0.42	43	2.7	-	14	0.40	14	14	0.32	0.11
H-4B, H-4C	(4)	avg			44	2.2	0.23	18	0.42	15	-	-	-
H-4B, H-4C	(4)	rng			43-48	1.7-2.7	(1)	14-23	0.39-0.49	13-18	11-30	-	-
H-5B	6/81	UNC	154400	2.99	62	-	-	33	0.77	32	6.2	-	-
H-5C	10/81	UNC	154500	3.00	64	-	-	35	0.77	31	5.8	-	-
H-5B	8/85	UNC	152600	2.97	49	2.0	0.19	34	0.81	29	7.1	2.9	0.29
H-5B, H-5C	(4)	avg			58	1.3	0.19	33	0.78	31	-	-	-
H-5B, H-5C	(4)	rng			49-64	0.8-2.0	(1)	29-35	0.77-0.81	29-32	5-36	-	-
H-6B	5/81	UNC	59300	1.18	34	-	-	11	0.44	32	20	-	-
H-6B	9/85	UNC	57400	1.13	34	1.9	0.096	10	0.45	30	18	0.094	0.13
H-6B	(3)	avg			34	1.6	0.096	9.5	0.44	28	-	-	-
H-6B	(3)	rng			34-35	1.3-1.9	(1)	7-11	0.44-0.45	24-32	18-43	-	-

Table 4.13a: Major solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Continued)

Well(s)	Collection Date(1)	Lab(2)	Total Dissolved Solids (mg/L)(7)	Ionic Strength (molal)(8)	Bromide (mg/L as Br)	Fluoride (mg/L as F)	Iodide (mg/L as I)	Boron (mg/L as B)	Lithium (mg/L as Li)	Strontium (mg/L as Sr)	Silica (mg/L as SiO_2)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)
H-7B1	3/86	UNC	3220	0.089	0.57	1.5	0.052	0.76	0.10	8.5	47	0.056	0.050
H-7B1	(3)	avg			0.57	1.4	0.052	0.77	0.11	7.7	-	-	-
H-7B1	(3)	rng			(1)	1.2-1.5	(1)	0.34-0.80	0.10-0.12	5.8-8.7	47-92	-	-
H-8B	1/86	UNC	2830	0.083	0.085	2.5	0.14	0.48	0.12	6.9	29	0.036	0.021
H-8B	(2)	avg			0.085	2.4	0.14	0.49	0.12	6.7	-	-	-
H-8B	(2)	rng			(1)	2.1-2.5	(1)	0.48-0.50	0.12	5.9-7.4	29-56	-	-
H-9B	11/85	UNC	3080	0.087	0.24	3.3	0.11	0.63	0.18	7.5	27	0.032	0.015
H-9B	(2)	avg			0.24	3.0	0.11	0.66	0.18	7.2	-	-	-
H-9B	(2)	rng			(1)	2.6-3.3	(1)	0.63-0.70	0.17-0.18	7.0-7.5	27-39	-	-
H-10B	3/80	GS	65700	1?	-	1.3	-	13	-	-	1.5	-	-
H-11B3	6/85	UNC	117400	2.23	47	-	-	32	0.62	25	-	0.14	0.22
H-11B3	(2)	avg			48	1.3	-	31	0.50	20	-	-	-
H-11B3	(2)	rng			47-48	1.0-1.6	-	30-32	0.38-0.62	18-25	25-32	-	-
H-12	8/85	UNC	140500	2.72	76	-	-	39	1.2	31	7.2	0.22	0.087
H-12	(2)	avg			76	1.5	-	38	0.85	29	-	-	-
H-12	(2)	rng			76-77	1.1-2.3	-	35-39	0.61-1.2	18-38	7-96	-	-
P-14	2/86	UNC	24900	0.58	72	1.7	0.42	0.72	0.28	51	30	2.0	0.18
P-14	(2)	avg			72	1.5	0.42	0.72	0.28	50	-	-	-
P-14	(2)	rng			(1)	1.2-1.7	(1)	(1)	(1)	48-51	30-69	-	-
P-17	3/86	UNC	86500	1.67	72	1.9	0.18	38	0.87	29	8.5	4.0	0.87
P-17	(2)	avg			70	1.6	0.18	35	0.87	31	-	-	-
P-17	(2)	rng			69-72	1.2-1.9	(1)	32-38	(1)	28-36	0-8.5	-	-
P-18	10/77	GS	118300	2.5?	-	1.2	-	100	-	-	1.0	-	-

Table 4.13a: Major solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Continued)

Well(s)	Collection Date(1)	Lab(2)	Total Dissolved Solids (mg/L)(7)	Ionic Strength (molal)(8)	Bromide (mg/L as Br)	Fluoride (mg/L as F)	Iodide (mg/L as I)	Boron (mg/L as B)	Lithium (mg/L as Li)	Strontium (mg/L as Sr)	Silica (mg/L as SiO_2)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)
WIPP-13	2/87	avg	-	-	39	1.4	-	11	0.35	25	-	-	-
WIPP-25	8/80	UNC	12100	0.26	2.6	-	-	1.5	0.20	12	34	-	-
WIPP-25	8/80	avg			2.6	-	-	1.5	0.20	12	-	-	-
WIPP-25	8/80	rng			(2)	-	-	(1)	(1)	(1)	(1)	-	-
WIPP-25	2/86	UNC	13600	-	3.4	1.7	0.042	1.7	0.22	17	33	0.50	0.11
WIPP-25	2/86	avg			3.8	1.6	0.042	1.7	0.22	17	-	-	-
WIPP-25	2/86	rng			3.4-4.2	1.6-1.7	(1)	1.7	(1)	(1)	33-67	-	-
WIPP-26	8/80	UNC	15100	0.33	3.2	-	-	1.4	0.24	17	33	-	-
WIPP-26	8/80	avg			3.2	-	-	1.4	0.24	17	-	-	-
WIPP-26	8/80	rng			(1)	-	-	(1)	(1)	(1)	(1)	-	-
WIPP-26	11/85	UNC	17600	0.37	3.9	1.7	0.070	1.6	0.23	20	35	0.026	<0.01
WIPP-26	11/85	avg			3.9	1.5	0.070	1.6	0.23	18	-	-	-
WIPP-26	11/85	rng			(1)	1.3-1.7	(1)	(1)	(1)	17-20	35-65	-	-
WIPP-27	9/80	UNC	134700	2.57	28	-	-	2.3	0.33	51	23	-	-
WIPP-27	(2)	avg			28	-	-	2.1	0.33	51	-	-	-
WIPP-27	(2)	rng			(1)	-	-	1.9-2.3	(1)	(1)	13-23	-	-
WIPP-28	9/80	UNC	46600	0.90	7.2	-	-	5.8	0.30	16	36	-	-
WIPP-28	9/80	avg			7.2	-	-	5.8	0.30	16	-	-	-
WIPP-28		rng			(1)	-	-	(1)	(1)	(1)	(1)	-	-
WIPP-29	8/80	UNC	245400	4.91	45	-	-	4.4	0.78	29	22	-	-
WIPP-29	8/80	avg			45	-	-	4.4	0.78	29	-	-	-
WIPP-29	8/80	rng			(1)			(1)	(1)	(1)	(1)	-	-
WIPP-29	12/85	UNC	324100	6.57	61	4.6	0.38	5.2	0.70	13	15	1.1	1.7
WIPP-29	12/85	avg			61	-	0.38	5.5	0.70	11	-	-	-
WIPP-29	12/85	rng			(1)	0.9-4.6	(1)	5.2-5.8	(1)	9-13	15-110	-	-
WIPP-30	9/80	UNC	29100	0.58	10	-	-	6.1	0.27	18	6.5	-	-
WIPP-30	9/80	avg			10	-	-	6.1	0.27	18	-	-	-
WIPP-30	9/80	rng			(1)			(1)	(1)	(1)	(1)	-	-

Table 4.13a: Major solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Concluded)

Well(s)	Collection Date(1)	Lab(2)	Total Dissolved Solids (mg/L)(7)	Ionic Strength (molal)(8)	Bromide (mg/L as Br)	Fluoride (mg/L as F)	Iodide (mg/L as I)	Boron (mg/L as B)	Lithium (mg/L as Li)	Strontium (mg/L as Sr)	Silica (mg/L as SiO_2)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)
Engle	3/85	UNC	3270	0.09	0.27	2.8	0.12	0.97	0.17	8.4	29	0.59	0.060
Engle	3/85	avg			0.27	2.8	0.12	0.87	0.17	7.7	-	-	-
Engle	3/85	rng			(1)	2.8-2.9	(1)	0.77-0.97	(1)	7.0-8.4	29-54	-	-
Magenta													
H-3B1	7/85	UNC	8560	-	5.8	2.4	1.2	2.0	0.32	17	10	0.11	0.028
H-3B1	(3)	rng			5.8-6.0	1.8-2.6	1.2-2.0	2.0-4.5	0.32	13-18	10-26	-	-
H-4C	11/86	UNC	23900	-	5.9	2.4	0.31	12	0.46	12	9.1	0.71	0.29
H-4C	(2)	rng			5.9-7.5	2.2-2.6	(1)	11-12	0.41-0.46	12-14	9-26	-	-
H-5C	10/86	UNC	6980	-	0.93	2.5	0.31	11	0.20	10	11	1.5	0.020
H-5C	10/86	rng			(1)	2.5	(1)	10-11	0.20	8-10	11-26	-	-
H-6C	10/86	UNC	4540	-	2.3	1.5	0.086	2.2	0.21	9.8	11	0.26	0.010
H-6C	10/86	rng			1.0-2.3	1.5-1.7	(1)	2.2-2.4	0.19-0.21	7.1-9.8	11-28	-	-
Dewey Lake Red Beds													
Ranch	6/86	UNC	2520	-	2.3	0.82	0.13	0.10	0.12	5.9	52	0.024	<0.01
Ranch	6/86	rng			2.3	0.8-1.0	(1)	0.10-0.19	(1)	3.2-5.9	52-86	-	-
Twin-Pasture	1/86	UNC	401	-	0.17	0.58	<0.01	0.13	<0.05	1.1	47	<0.01	<0.01
Twin-Pasture	1/86	rng			(1)	0.5-1.4	(1)	0.13-0.16	(1)	0.6-1.1	47-90	-	-
Bell Canyon Frm.													
DOE-2	7/85	UNC	149500		250	1.1	6.4	54	5.8	150	2.5	11	28
DOE-2	7/85	rng			(1)	0.4-1.4	6.4-7.9	54-61	2.8-5.8	150-300	2-30	-	-

Table 4.13b: Minor and trace solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b).

Well(s)	Collection Date(1)	Lab(2)	Zone(3)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Chloride (mg/L as Cl)	Sulfate (mg/L as So_4)	Bicarbonate (mg/L as HCO^3)(4)	pCO_2(5)	pH(4)
Culebra												
DOE-1	4/85	UNC	A	45800	1100	1730	1610	73600	7350	45	-2.60	7.1
DOE-1	(2)	avg	A	46000	1100	1700	1600	75000	7400	-		-
DOE-1	(2)	rng	A	45000-46000	(1)	(1)	(1)	73000-77000	(1)	45-46		7.1
DOE-2	3/85	UNC	C	18400	410	1960	1060	34600	3950	67	-2.33	7.0
DOE-2	(2)	avg	C	18000	420	1900	1000	33000	3700	-		-
DOE-2	(2)	rng	C	17000-19000	410-420	1900-2000	900-1100	32000-35000	3400-4000	(1)		(1)
H-2A	4/86	UNC	C	3570	93.5	743	167	5310	2980	57	-3.38	8.0
H-3B3	6/84	UNC	C	17400	495	1550	829	29500	5130	-	-2.83	7.4
H-3B3	2/85	UNC	C	18000	425	1470	783	30300	4820	52	-2.86	7.4
H-3B2, H-3B3	(4)	avg	C	18000	440	1400	760	29000	4800	-		-
H-3B2, H-3B3	(4)	rng	C	17000-19000	360-500	1200-1600	690-830	27000-31000	4600-5200	50-52		7.4
H-4B	5/81	UNC	C	6080	215	700	455	7980	6230	71	-3.35	8.0
H-4C	8/84	UNC	C	6150	222	698	505	7950	5700	75	-3.11	7.8
H-4B	7/85	UNC	C	5850	210	691	427	7480	5520	69	-3.04	7.7
H-4B, H-4C	(4)	avg	C	6000	220	690	450	7700	5700	-		-
H-4B, H-4C	(4)	rng	C	5800-6200	180-260	690-700	400-510	7400-8000	5500-6300	68-75		7.6-8.0
H-5B	6/81	UNC	A	52400	1290	1710	2140	89500	7360	80	-3.21	7.9
H-5C	10/81	UNC	A	52300	1300	1720	2150	89500	7570	86	-3.17	7.9
H-5B	8/85	UNC	A	54100	1350	1700	2170	85400	7840	50	-2.86	7.4
H-5B, H-5C	(4)	avg	A	53000	1300	1700	2200	87000	7600	-		-
H-5B, H-5C	(4)	rng	A	52000-55000	1200-1400	1700-1800	2100-2200	84000-90000	7300-7900	-		-
H-6B	5/81	UNC	C	18600	450	2150	1080	33000	3980	96	-2.16	7.0
H-6B	9/85	UNC	C	18000	375	2040	1040	32300	3570	94	-2.07	6.9
H-6B	(3)	avg	C	18000	420	2000	1100	33000	3600	-		-
H-6B	(3)	rng	C	17000-19000	370-450	1900-2200	1000-1200	32000-34000	3300-4000	90-96		6.9-7.2

Table 4.13b: Minor and trace solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Continued)

Well(s)	Collection Date(1)	Lab(2)	Zone(3)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Bicarbonate (mg/L as HCO^3)(4)	pCO_2(5)	pH(4)
H-7B1	3/86	UNC	B	207	7.0	587	130	320	1850	120	-2.20	7.
H-7B1	(3)	avg	B	210	7.0	570	130	320	1800	-		-
H-7B1	(3)	rng	B	200-210	7.0	540-590	130	300-350	1700-1900	120		7.3-7.4
H-8B	1/86	UNC	B	55.1	3.83	548	157	30.5	1950	96	-2.70	7.3
H-8B	(2)	avg	B	54	3.9	540	170	32	1800	-		-
H-8B	(2)	rng	B	51-56	3.7-4.1	520-550	150-180	30-33	1600-2000	93-96		7.2-7.3
H-9B	11/85	UNC	B	146	6.85	590	137	194	1900	110	-2.43	7.4
H-9B	(2)	avg	B	150	7.2	580	150	190	1800	-		-
H-9B	(2)	rng	B	140-150	6.8-7.6	560-620	130-170	170-200	1700-1900	110		7.3-7.4
H-10B	3/80	GS	C	21000	520	1600	1000	36000	5600	45	-	8.3
H-11B3	6/85	UNC	A	40400	943	1700	1320	65900	7180	54	-2.63	7.2
H-11B3	(2)	avg	A	39000	940	1600	1300	66000	7200	-		-
H-11B3	(2)	rng	A	37000-41000	(1)	1500-1700	1300-1400	65000-67000	(1)	54-55		7.2-7.3
H-12	8/85	UNC	A	49200	1270	1760	1980	79000	7210	53	-2.61	7.2
H-12	(2)	avg	A	50000	1300	1800	2000	80000	7200	-		-
H-12	(2)	rng	A	49000-51000	(1)	1700-1900	1900-2000	78000-80000	(1)	53-62		7.2
P-14	2/86	UNC	C	4360	37.9	3520	840	14500	1590	110	-1.81	6.8
P-14	(2)	avg	C	4100	41	3700	800	14000	1600	-		-
P-14	(2)	rng	C	3700-4400	37-45	3500-3900	760-840	13000-15000	1500-1700	100-110		6.8-6.9
P-17	3/86	UNC	C	28300	782	1620	1460	48200	6020	64	-2.90	7.5
P-17	(2)	avg	C	28000	820	1600	1500	49000	6000	-		-
P-17	(2)	rng	C	28000-29000	780-880	1500-1700	1400-1600	48000-51000	5900-6100	61-64		7.5
P-18	10/77	GS	A	9200	6200	5600	16000	80000	980	310	-	7.2

Table 4.13b: Minor and trace solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Continued)

Well(s)	Collection Date(1)	Lab(2)	Zone(3)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Bicarbonate (mg/L as HCO^3)(4)	pCO_2(5)	pH(4)
WIPP-13	2/87	avg	C	19000	340	-	-	36000	4500	~120	-	~6.6
WIPP-25	8/80	UNC	C	3160	73.5	905	260	5250	2500	210	-1.69	6.9
WIPP-25	8/80	avg	C	3200	74	900	260	5200	2500	-		-
WIPP-25	8/80	rng	C	(1)	(1)	(1)	(1)	5200-5300	(1)	(1)		(1)
WIPP-25	2/86	UNC	C	3180	102	1140	315	6320	2380	130	-	7.2
WIPP-25	2/86	avg	C	3300	100	1100	330	6200	2400	-		-
WIPP-25	2/86	rng	C	3100-3400	100-110	1100-1200	310-340	6200-6400	2300-2400	(1)		(1)
WIPP-26	8/80	UNC	C	3620	170	1240	355	7200	2480	140	-1.86	6.9
WIPP-26	8/80	avg	C	3600	170	1200	360	7000	2500	-		-
WIPP-26	8/80	rng	C	(1)	(1)	(1)	(1)	6900-	(1)	(1)		6.9
WIPP-26	11/85	UNC	C	4220	343	1340	380	8770	2420	120	-2.14	7.1
WIPP-26	11/85	avg	C	4100	350	1300	390	8600	2400	-		-
WIPP-26	11/85	rng	C	3800-4300	340-360	1200-1400	370-430	8400-8800	2300-2500	(1)		(1)
WIPP-27	9/80	UNC	D	39200	8060	3210	1900	78500	3830	120	-1.33	6.4
WIPP-27	(2)	avg	D	39000	8100	3200	2000	78000	3900	-		-
WIPP-27	(2)	rng	D	39000-40000	(1)	3100-3300	1900-2000	77000-79000	3800-3900	(1)		6.4
WIPP-28	9/80	UNC	C	15200	485	1180	555	24800	4380	-	-0.76	6.5
WIPP-28	9/80	avg	C	15000	480	1200	560	24000	4400	-		-
WIPP-28	9/80	rng	C	(1)	(1)	(1)	(1)	24000-25000	(1)	-		-
WIPP-29	8/80	UNC	D	71400	15600	950	5480	138000	14000	210	-0.87	6.1
WIPP-29	8/80	avg	D	71000	16000	880	5600	140000	14000	-		-
WIPP-29	8/80	rng	D	(1)	(1)	810-950	5400-5700	130000-140000	13000-14000	(1)		6.1
WIPP-29	12/85	UNC	D	94900	23300	413	6500	179000	20000	160	-0.75	5.9
WIPP-29	12/85	avg	D	92000	22000	410	6400	180000	18000	-		-
WIPP-29	12/85	rng	D	90000-95000	20000-24000	(1)	6300-6500	179000-180000	17000-20000	(1)		(1)

Table 4.13b: Minor and trace solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Concluded)

Well(s)	Collection Date(1)	Lab(2)	Zone(3)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Bicarbonate (mg/L as HCO_3)(4)	pCO_2(5)	pH(4)
WIPP-30	9/80	UNC	C	8570	255	1140	460	14600	4120	40 HCO_3	-4.41	8.8
WIPP-30	9/80	avg	C	8600	260	1100	460	15000	4100	17 CO_3		-
WIPP-30	9/80	rng	C	(1)	(1)	(1)	(1)	14000-15000	(1)	(1)		(1)
Engle	3/85	UNC	B	200	5.60	588	152	231	1990	110	-2.44	7.4
Engle	3/85	avg	B	190	5.5	580	140	230	1900	-		-
Engle	3/85	rng	B	180-200	5.4-5.6	570-590	130-160	220-240	1800-2000	(1)		(1)
Magenta												
H-3B1	7/85	UNC	Mag	1520	34.5	1000	292	3360	2310	47	-	8.0
H-3B1	(3)	rng	Mag	1500-1600	34-36	1000	270-300	3300-3400	2200-2400	45-47		7.7-8.0
H-4C	11/86	UNC	Mag	7110	85.1	651	411	8460	7100	70	-	8.4
H-4C	(2)	rng	Mag	7100-7300	85-99	610-660	390-420	8400-8500	(1)	70-85		8.1-8.4
H-5C	10/86	UNC	Mag	1480	33.6	550	173	1070	3620	56	-	8.0
H-5C	10/86	rng	Mag	1400-1500	(1)	(1)	170-190	1000-1100	(1)	(1)		(1)
H-6C	10/86	UNC	Mag	642	16.6	546	160	428	2700	51	-	7.7
H-6C	10/86	rng	Mag	(1)	(1)	(1)	160-170	420-430	2400-2700	(1)		(1)
Ranch	6/86	UNC	DL	200	4.0	420	202	418	1100	220	-	7.0
Ranch	6/86	rng	DL	180-200	3.6-4.0	(1)	190-210	390-420	920-1100	(1)		(1)
Dewey Lake Red Beds												
Twin-Pasture	1/86	UNC	DL	25.4	3.85	80.4	22.5	44.1	75.1	230	-	7.8
Twin-Pasture	1/86	rng	DL	24-26	3.7-4.3	80-81	22-25	44-47	70-76	(1)		(1)
Bell Canyon												
DOE-2	7/85	UNC	BC	49600	885	5910	1330	89700	2020	48	-	6.8
DOE-2	7/85	rng	BC	(1)	(1)	(1)	(1)	89000-90000	(1)	(lab)		(1)

Footnotes for Tables 4.13a and 4.13b

*Solute values from various labs have been rounded as follows:

-Na, K, Ca, Mg, CL, SO_4 from UNC	: 3 significant figures
-all others from UNC	: 2 sig. figs
-all solutes from GS	: 2 sig. figs
-all "avg" values	: 2 sig. figs
-all minimum 'rng' values	: down to 2 sig. figs
-all maximum 'rng' values	: up to 2 sig. figs
-all total dissolved solids (TDS)	: to nearest 100 mg/L or to 3 sig. figs (for TDS<10000)
-all bicarbonate values	: to 2 sig. figs
-all pH values	: to 0.1 pH unit
-all pCO_2 values	: to 0.01 unit
-all ionic strength values	: to 0.01 molal

(1) Collection date: a number in parentheses indicates that values in that row are averages or ranges of data for up to that number of samples

(2) avg - average of one or more values from one or more laboratories; used to calculate element ratios and generate contour plots (Siegel and others, 1988)
rng - range of values from one or more laboratories; gives a crude estimate of the uncertainties associated with the data. A single value in the range row means that all values were indentical. A "(1)" in the range row means that only one reliable value was available
GS - USGS Central labs
UNC - UNC Geotech (before Oct. 1, 1986, Bendix Field Engineering Corp.), Grand Junction, Co.

(3) zone - hydrochemical facies zone described by Siegel and others (1988). Applies only to Culebra.

(4) Bicarbonate and pH values were measured in the field when the samples were collected. (Exception: HCO_3 in the DOE-2 Bell Canyon sample was measured in the lab)

(5) pCO_2 - calculated using PHRQPITZ (Siegel and others, 1988)

(6) Stratigraphic horizon: BC - Bell Canyon Formation
DL - Dewey Lake Red Beds
Mag - Magenta Dolomite

(7) Total dissolved solids - calculated by summing the major solutes

(8) Ionic strength - calculated using PHRQPITZ (Siegel and others, 1988)

evaluated in compiling the table and methods for evaluating the data are discussed in Robinson (1988), Lambert and Harvey (1987), and Siegel et al. (1988b). The data in Tables 4.13a and 4.13b were used by Siegel et al. (1988a) in facies assignments of Culebra fluids, saturation-index calculations, and factor analyses, as well as in plotting of element-ratio contours.

On the basis of the available major-solute analyses (Table 4.13a), Culebra waters can be combined into four hydrochemical facies (Figure 4.3.1). These include:

1. Zone A (H-5, H-11, H-12; DOE-1, P-17, P-18(?)), containing saline NaCl brines (about 2 to 3 molal) with a Ca/Mg weight ratio near unity. These waters are found in the eastern third of the WIPP site and further east, in a region roughly coincident with the region of lowest Culebra transmissivity. In the western part of Zone A, halite is present only in the unnamed lower member (Figure 1.5); in the eastern part of the zone, halite is present throughout the Rustler.

2. Zone B (H-7, H-8, H-9, Engle), containing relatively fresh waters (<0.1 molal) in which Ca^{++} and $SO_4^{=}$ are the dominant solutes. These waters are found only south of the WIPP site. No Rustler halite is present in this zone. Data from the South and Indian wells (Bodine and Jones, 1988) suggest that these wells should also be classified as part of Zone B.

3. Zone C, containing waters of variable compositions, low to moderate ionic strength (about 0.3 to 1.1 molal), and Ca/Mg weight ratios greater than 1.5:1. These waters extend from the central part of the WIPP site to the eastern part of Nash Draw, in regions of low to high Culebra transmissivity. In the eastern part of the zone, halite is present in the unnamed lower member; on the western side of the zone, Rustler halite is absent. In general, the most saline brines in Zone C are found in the eastern part of the zone.

4. Zone D, containing waters of anomalously high salinities (about 3 to 7 molal) and K/Na mole ratios (about 0.2) relative to other sampled fluids (3 molal or less; K/Na mole ratios of 0.01 to 0.09) This zone is apparently confined to western Nash Draw, and contains only holes WIPP-27 and WIPP-29. Fluid compositions at WIPP-29 have have changed over the course of seven years of monitoring, probably in response to nearby potash refining operations.

The chemical characteristics of the defined Culebra fluid facies can be summarized graphically in a Piper (trilinear) diagram (Figure 4.3.2). This plot generalizes the relationships between several major solutes, i.e., those in the Na-K-Mg-Ca-Cl-SO_4-CO_3 system. Relative proportions of cations and anions are shown in the triangular plots in the bottom half of the figure, relative ratios of divalent to monovalent cations and chloride to (sulfate plus carbonate) in the parallelogram portion of the figure.

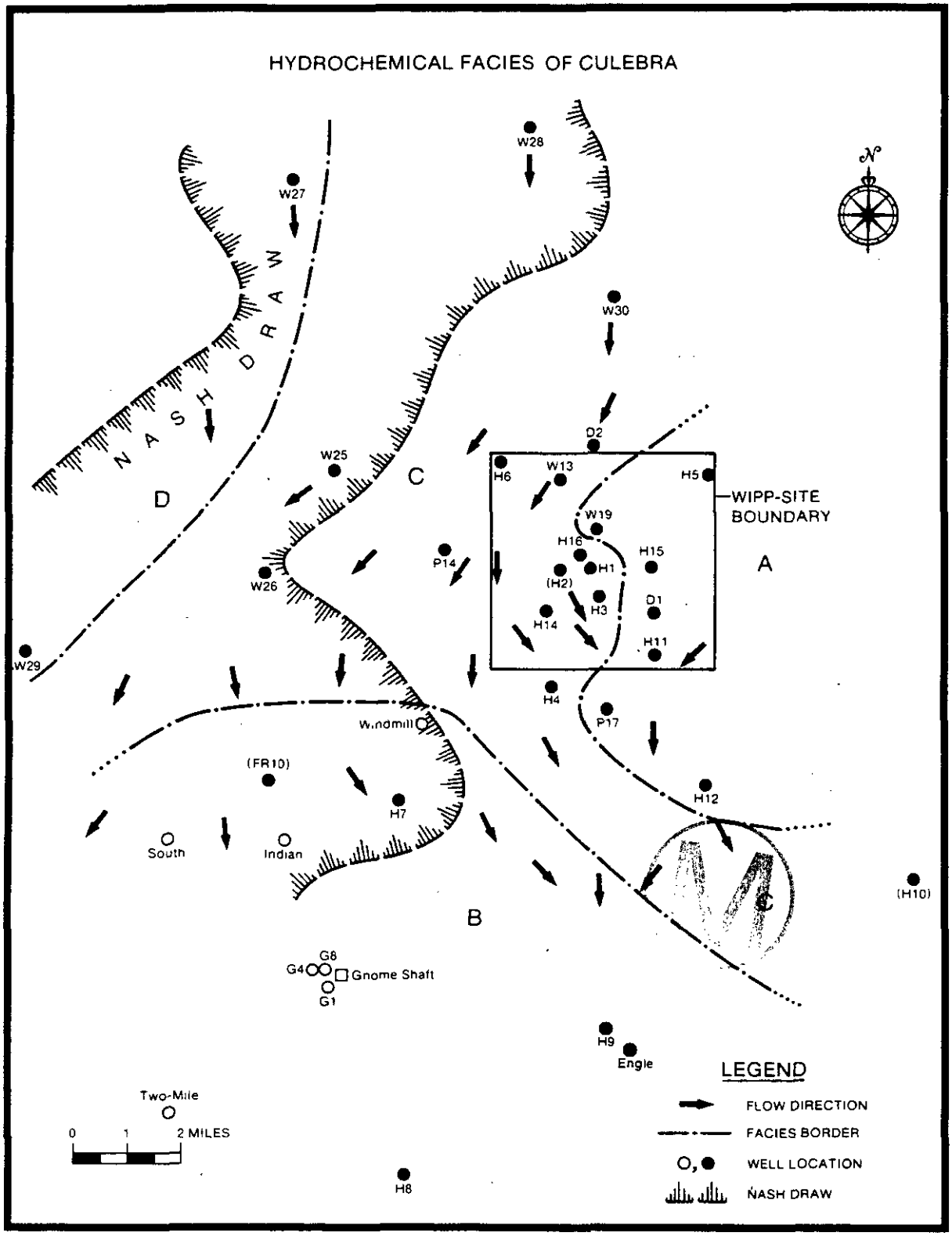

Figure 4.3.1: Summary of hydrochemical facies and local flow directions in the Culebra dolomite. Facies boundaries from Siegel et al. (1988a); modern flow directions from Figure 4.5B of LaVenue et al. (1988).

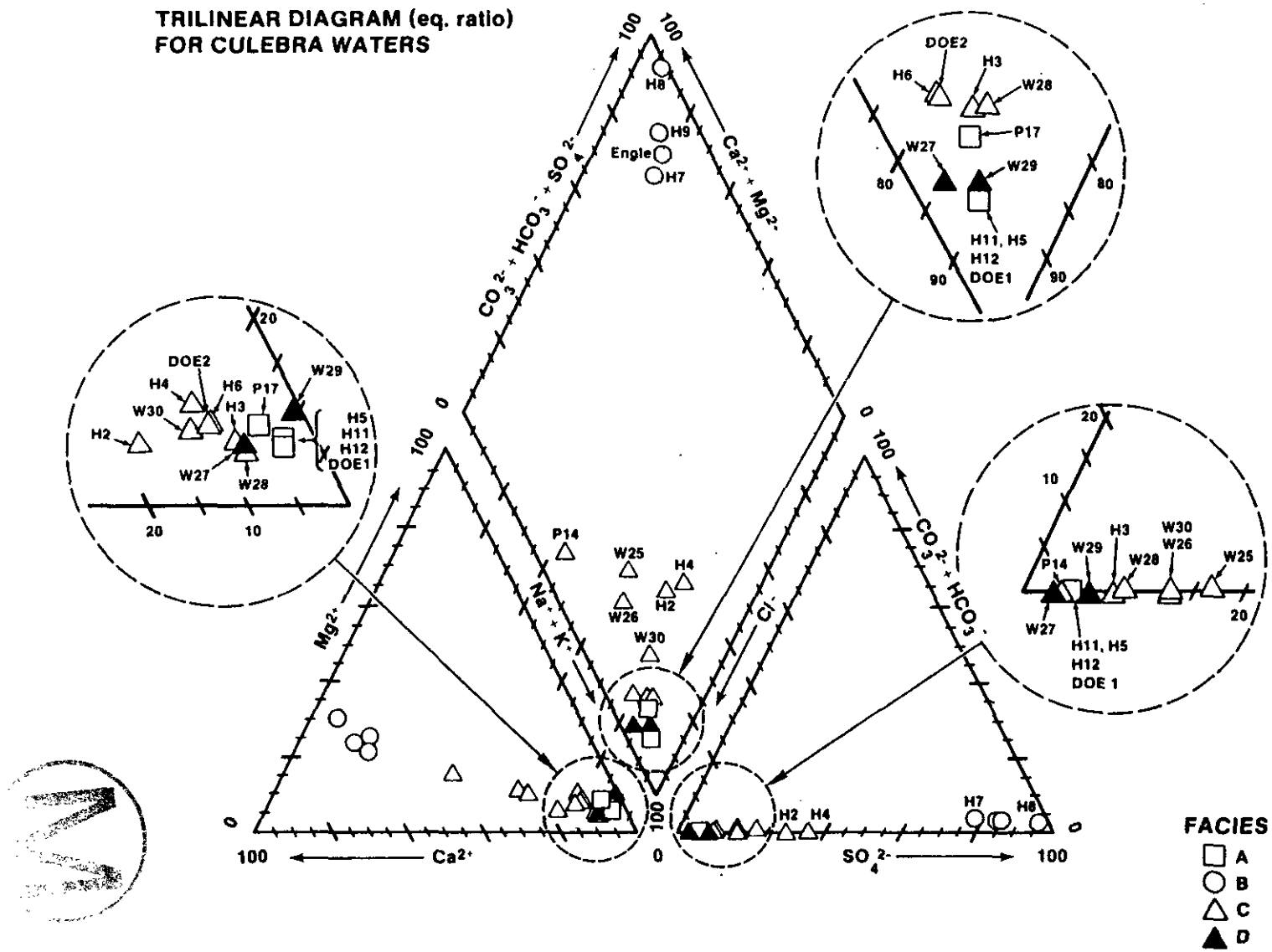

Figure 4.3.2: Piper (trilinear) diagram for analyzed Culebra fluids. Analyses are represented in terms of equivalents per liter. From Siegel et al. (1988b).

The analyses from Zone A have nearly identical ionic proportions (Figure 4.3.2), and plot very near the Na-Cl corner in both parts of the figure. In contrast, the analyses of the dilute fluids from Zone B all plot near the Ca-Mg-SO_4 corner in the upper part of the figure. Analyses from Zone C are variable, and those groundwaters closer to the Na-Cl corner of the plot are similar to waters from Zone A. Zones A and C are distinguished primarily on the basis of Ca/Mg ratio and ionic strength. Waters from Zone D have similar ionic ratios as fluids from Zone A except for K/Na; Zone D is distinguished primarily on the basis of its high K/Na ratios.

The overall interpretation of the facies distribution (Siegel et al., 1988a), assuming that the Culebra is relatively confined, is that flow directions within the Culebra must be transient. The inconsistency of Culebra fluid densities and steady-state confined flow was noted in Section 4.1, based on numerical modeling studies of Haug et al. (1987) and LaVenue et al. (1988). Ramey (1985) noted that modern flow directions within the Culebra do not appear consistent with the modern salinity distribution. This inconsistency is also evident in Figure 4.3.1, which is based on a larger and more reliable data base than considered by Ramey (1985). The most striking evidence is that fluids in Zone B, a facies with low salinity, lie down-gradient from more saline waters in Zone C. It is difficult to explain the origin of fluids presently in Zone B by steady-state confined flow through Zone C (Figure 4.3.1). One alternative to steady-state flow, based on isotopic studies (Sections 4.3.2, 4.3.3, and 4.3.4), is that there has been a significant change in flow directions within the Culebra dolomite in the last (approximately) 12,000 years. This is consistent with geologic evidence indicating the transient geologic and hydrologic setting of the WIPP site (Section 4.4).

4.3.1.2 Normative Salt Assemblages of Rustler Waters--The chemical variability of Culebra fluids has also been evaluated on the basis of normative salt assemblages, as summarized by Bodine et al. (1988). The normative salt assemblage (salt norm) of a given water is the equilibrium assemblage of salts that would precipitate from the water if it were evaporated to dryness under standard conditions (25 degrees C, 1 atmosphere pressure). In this interpretation, the SNORM code (Bodine and Jones, 1986) was applied by Bodine et al. (1988) to a different data base than that shown in Table 4.13.

The interpretations of the derivation of Culebra fluids based on hydrochemical facies, isotopic data, and physical hydrology are not in all cases consistent with those based on interpretation of salt norms. Siegel and Lambert (1988) conclude that the overall hydrologic setting of the Culebra is transient. Bodine et al. (1988) conclude that the present distribution of salt norms within the Rustler Formation is, when considered alone, generally consistent with the modern Culebra flow field. These authors relax the vertical confinement of the Rustler. On the basis of solutes alone, their interpretation cannot exclude dilution of primitive-diagenetic brines at P-14 and in the low-permeability, halite-rich zones of the Culebra east of WIPP Zone 3 (for example at P-18) by water that has infiltrated from the surface and dissolved both halite and anhydrite or gypsum. With increasing distances from P-18 and P-14, increasing amounts

of solutes from recharge are interpreted to have mixed with primitive-connate Culebra solutes.

Based on salt-norm calculations, Bodine et al. (1988) suggest four end-member fluid compositions from evaporitic rocks at the WIPP site. These are:

1. Brines containing alkaline earth (Ca, Mg, Ba, Sr, etc) chloride salts in their normative assemblages, combined with relatively low Cl/Br weight ratios (<300). These brines could arise as primitive-diagenetic fluids, for example when connate waters are involved in dolomitization. The data base supporting this end member is limited.

2. Dilute alkali-bearing carbonate waters, produced during recharge by carbonic-acid dissolution of detrital silicates in the zone of infiltration.

3. Dilute sulfate-rich waters, produced when meteoric waters dissolve anhydrite and/or gypsum, but little else.

4. Variably saline halite-rich fluids or brines, produced when meteoric waters dissolve both anhydrite/gypsum and halite in the Rustler and upper Salado Formations.

Bodine et al. (1988) conclude that the solutes in most waters in the Rustler Formation can be produced by mixing of these four end members. Water produced by dewatering of gypsum is not precluded by the solute assemblages. However, the stable-isotope compositions of confined Culebra and Magenta waters (Section 4.3.2) are characteristically meteoric, indicating that gypsum dewatering has not played an identifiable role in their derivation. Bodine et al. (1988) conclude that, if analyzed solutes from the Culebra at P-18 are representative, the Culebra water from P-18 has the highest proportion of apparent primitive-diagenetic brine. They also suggest that some components of the water from P-14 may be primitive, if it is assumed that there has been no mixing or contamination. Waters from the Rustler-Salado contact zone at H-5 and H-6 contain the highest proportion of the primitive-connate solutes. According to Bodine et al (1988), the relative proportion of recharge-type solutes to primitive-diagenetic solutes within the Culebra increases from the WIPP site towards the north, west, and south.

The interpretative model of Bodine et al. (1988) relies heavily on the compositions of Culebra fluids at P-18 and P-14. As noted by Siegel et al. (1988b), the representative character of samples of Culebra fluids from P-18 is suspect, i.e., the analyses appear reliable, but may not represent actual Culebra fluids at this location. Hydrologic considerations also weigh against the reliability of these data. The Culebra transmissivity at P-18 (7.5×10^{-11} to 4.3×10^{-9} m^2/s, Table 4.2) is the lowest yet measured at or near the WIPP site. Therefore, while the Culebra at P-18 intuitively seems likely to contain connate brine, consistent with the norm-based interpretation of Bodine et al. (1988), the very fact that the Culebra is

so low in transmissivity at P-18 permeability makes it extremely difficult if not impossible to collect a meaningful fluid sample from the hole. In P-14, the situation is reversed. The Culebra in P-14 is extremely transmissive (2.3 x 10^{-4} m^2/s, Table 4.1). The preservation of original connate or diagenetic fluids in such a permeable region does not seem possible or consistent with expected rates of fluid flow in the vicinity (Figure 4.1.28). In addition (Section 4.3.2), the stable-isotope composition of Culebra waters from P-14 is meteoric, suggesting that P-14 fluids have not been involved in extensive diagenetic reactions. However, the analyses of Culebra waters from P-14 do appear reliable. The cause of the apparent primitive-diagenetic component in these fluids is not known.

The salt-norm interpretation also relies heavily on vertical recharge from the surface to provide fluids for dilution of the interpreted primitive-diagenetic signature of Culebra fluids, especially south of the WIPP site. However, the isotopic evidence, discussed in later parts of Section 4.3 and in Section 4.4, as well as the measured head and transmissivity distributions within the Rustler, discussed in Section 4.1, suggest that vertical recharge to the Culebra from the surface is not currently active at and near the WIPP site. The Culebra dolomite is confined at and south of the site, while the Dewey Lake Red Beds, where tested, are effectively impermeable. Finally, as discussed in Section 4.4, the preservation of large amounts of anhydrite in the Tamarisk Member overlying the Culebra, suggests that vertical infiltration of dilute solutions through the Tamarisk has been minimal. These relationships do not indicate that there has been no vertical fluid movement within the Rustler Formation or between the Dewey Lake and the Rustler, but that such movement is limited, and does not currently extend from the surface down to the Culebra.

4.3.1.3 Saturation Indices and Factor Analysis of Culebra Waters--Saturation indices of several evaporite minerals in analyzed Culebra waters have been calculated using the code PHRQPITZ (Plummer et al., 1988), and are summarized in Siegel et al. (1988a). The variation in halite saturation index as a function of ionic strength is shown in Figure 4.3.3. All fluids are undersaturated with respect to halite and Na and Cl concentrations vary widely. *There is a consistent increase in halite saturation index with* increasing ionic strength.

The variations in calculated gypsum and anhydrite saturation indices with ionic strength are shown in Figure 4.3.4. The data are internally consistent and indicate both a general saturation with respect to gypsum and an increase in anhydrite saturation with increasing ionic strength. However, with the exception of WIPP-29 (Zone D) all samples are undersaturated with respect to anhydrite. As a result, almost all Culebra waters are capable of converting into gypsum any anhydrite with which they might come into contact.

Most calculated dolomite saturation indices for Culebra fluids indicate saturation or apparent supersaturation (Figure 4.3.5). The relationships between saturation indices, pH, and calculated pCO_2 suggest, as discussed in Siegel et al. (1988b), that loss of CO_2 during sample collection may be

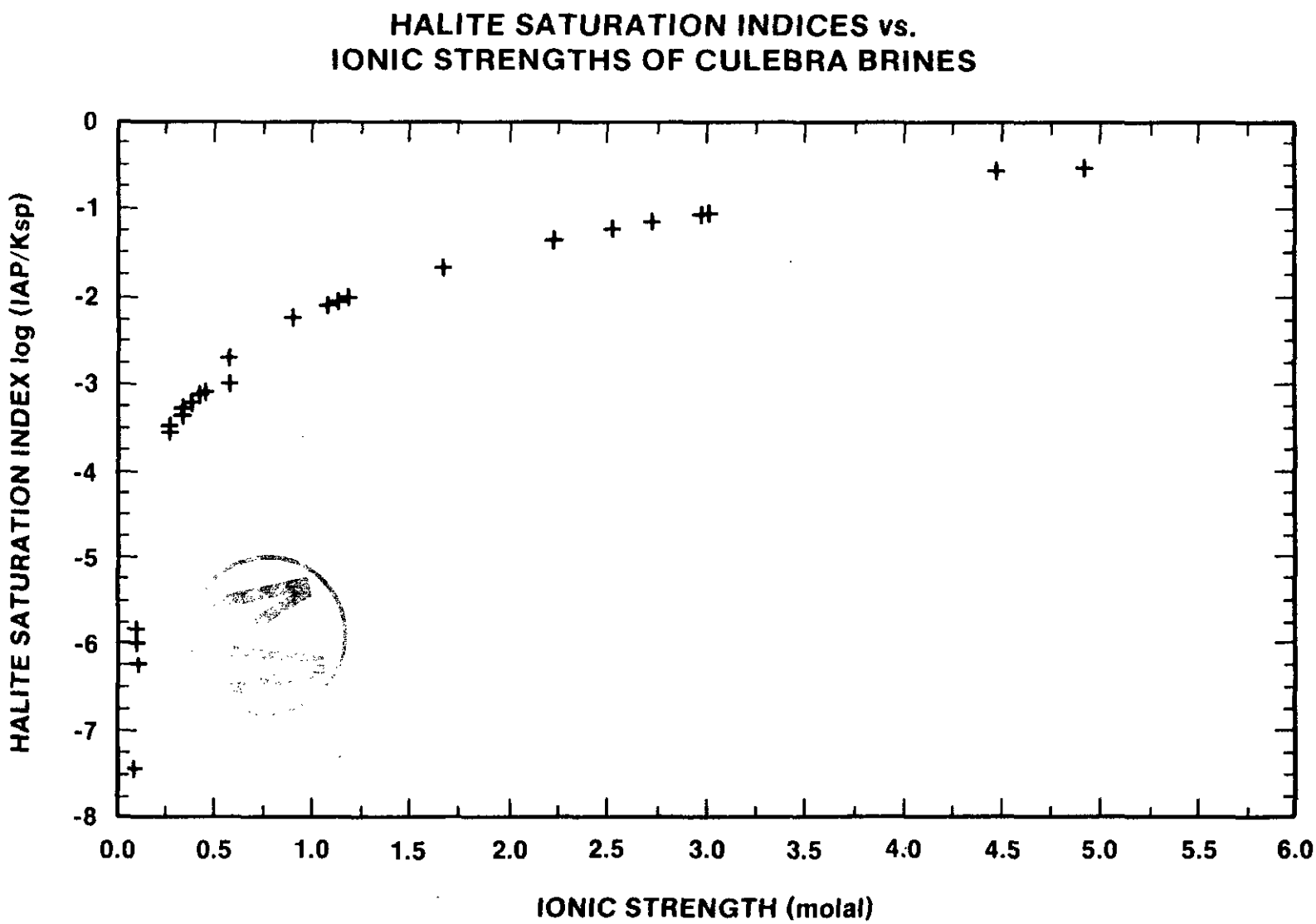

Figure 4.3.3: Variation in calculated halite saturation indices of Culebra waters as a function of ionic strength. From Siegel et al. (1988b).

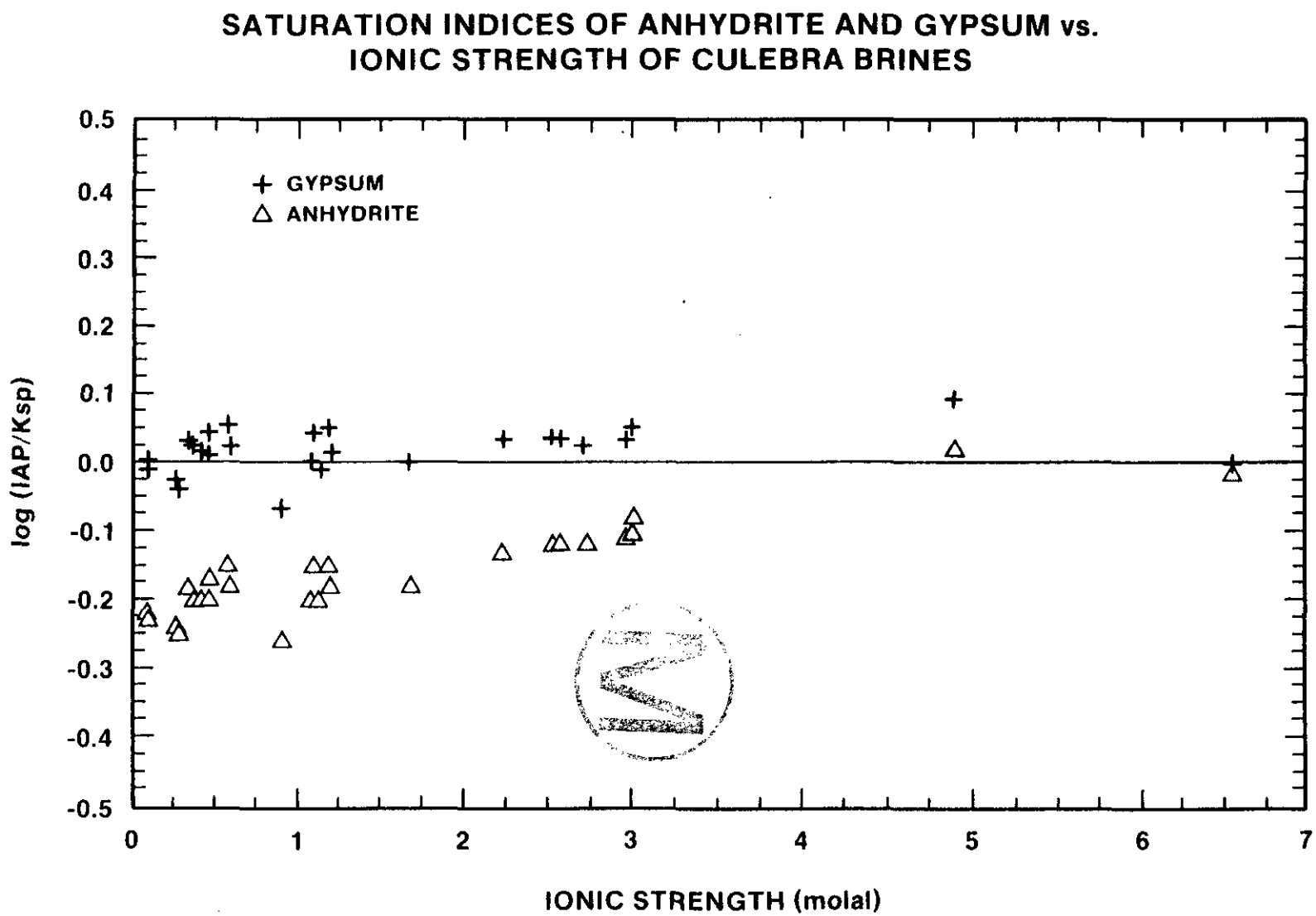

Figure 4.3.4: Variation in calculated gypsum and anhydrite saturation indices of Culebra waters as a function of ionic strength. From Siegel et al. (1988b).

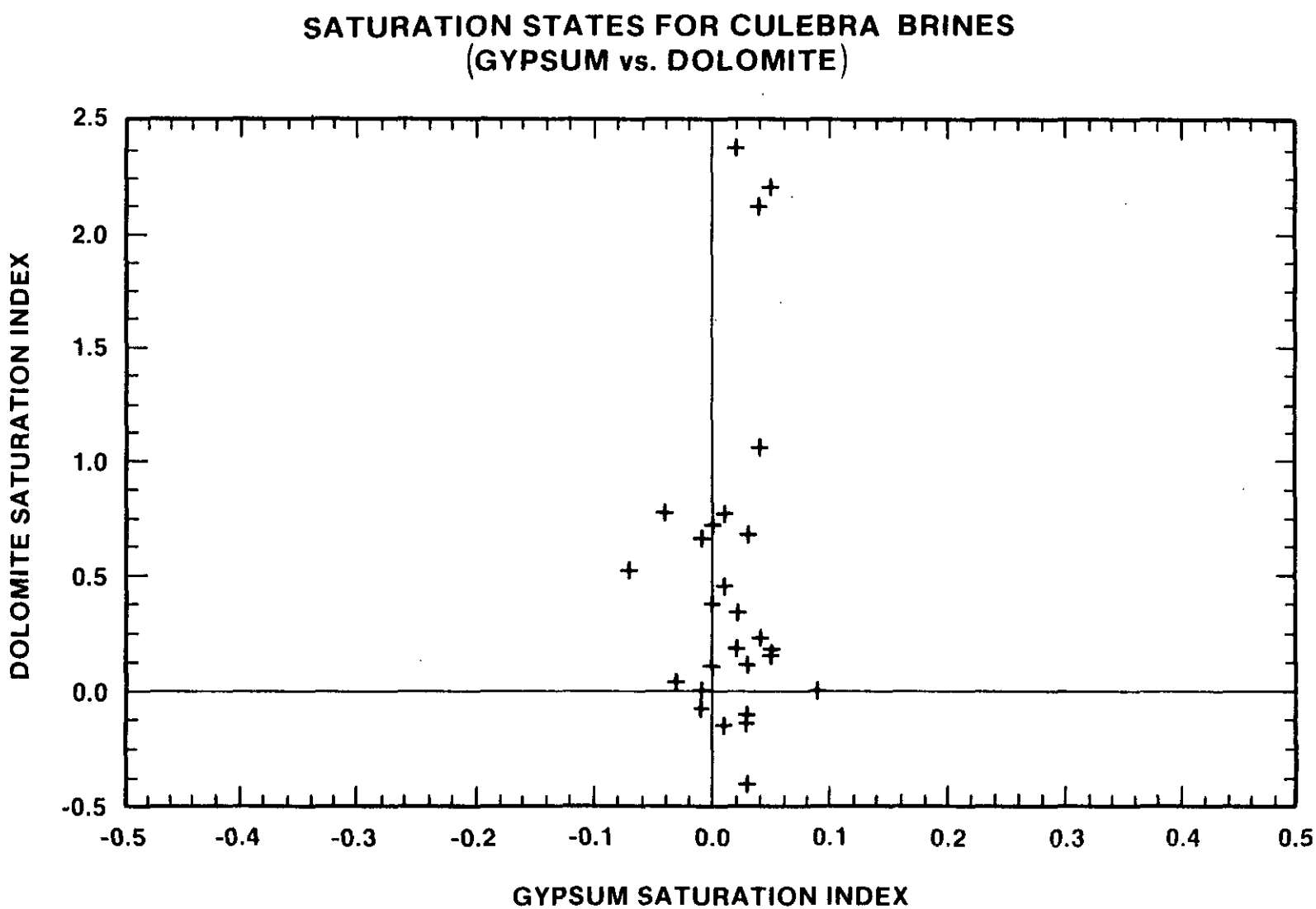

Figure 4.3.5: Variations in calculated dolomite saturation indices of Culebra waters as a function of calculated gypsum indices (Figure 4.3.4). From Siegel et al. (1988b).

responsible for the apparent supersaturation; other potential sources of error include use of an inappropriate free energy for dolomite and analytical error. The wide scatter in dolomite saturation indices gives some indication of the apparent effect of degassing on calculations involving dolomite. The origins of the high original pCO_2 in Culebra waters is not known, but may include carbonate dissolution and/or microbial action (see Section 4.3.3).

In addition to the major solutes used in defining hydrochemical facies and in calculating saturation indices considered thus far, there are consistent trends in both major-element (Ca, Mg, Na, K, Cl, and SO_4) and minor-element (Br, I, Sr) ratios in Culebra fluids. These trends, which are discussed in more detail in Siegel et al. (1988b) include the following:

1. The Na/Cl ratios of fluids south of the WIPP site are higher than would be produced by simple dissolution of halite, suggesting the importance of dissolution of Na-silicates at some time in the derivation of fluids in this area. This is consistent with the norm-based end member of dilute meteoric alkali-bearing carbonate waters discussed in Section 4.3.1.1.

2. At WIPP-27 and WIPP-29, the K/Na ratios and Na, K, Mg, Cl, and SO_4 concentrations are significantly higher than at other wells in Nash Draw or west of the site, suggesting that potash refining operations have significantly contaminated these locations. This is consistent with the definition of hydrochemical facies "D" in Section 4.3.1.1.

3. Both ratios and concentrations of several elements are anomalous in samples collected from P-14, compared to surrounding wells. For example, concentrations of Ca, Sr, and I are anomalously high at P-14, and K and SO_4, low. The Na/Cl, K/Na. and Mg/Ca ratios are somewhat low, and the Cl/Br ratio distinctly low at this well. The "primitive-diagenetic" salt norm at P-14 is anomalous (Section 4.3.1.1).

4. Regionally, the Cl/Br weight ratios are highest in Nash Draw, intermediate through the center of the WIPP site and to the south, and lowest at P-14 and H-4.

Examination of the relations between element ratios discussed above indicate that correlations between elements are not simply linear. For this reason, the data in Table 4.13 were also examined using Principal Component Analysis (PCA). The technique is described in detail in Siegel et al. (1988b). The purposes of PCA are to determine if the fluids come from a single or continuously variable population, and to delineate the different independent ways (factors) by which major and minor elements are correlated.

The preliminary results of factor analysis of Culebra fluids indicate that, on a regional scale, the samples are all drawn from a single chemical population; i.e., their chemistry is controlled by a consistent set of components. The most important component shown by R-mode PCA is dominated

by Na, K, Mg, Br, and Cl. All solutes except SiO_2, alkalinity, and pH exhibit positive correlation with this factor. The second major factor also includes Na and Cl, but is dominated by Ca, HCO_3, and Sr. Overall, the data are interpreted to suggest that the two fluid-compositional factors describing the variability of Culebra waters represent addition of solutes by dissolution of halite, gypsum/anhydrite, and carbonates (Siegel et al., 1988b).

However, because the amount of solute added by halite dissolution is so large relative to that added by other reactions, i.e., because halite solubility is much greater than that of other minerals considered, other chemical correlations may be masked. For this reason, a second set of PCA was carried out by Siegel et al. (1988b), using a method designed to be independent of total dissolved solids and hence halite dissolution. The primary component determined in this analysis contains two groups of elements that are inversely correlated. One group contains Mg, bicarbonate alkalinity, and SiO_2; the other group contains Na, pH, B, and Li. This pattern of element association is tentatively interpreted by Siegel et al. (1988b) to reflect clay diagenesis or silicate hydrolysis. The apparent uniformity of the compositional factors describing the variability of Culebra waters does not identify a discrete mechanistic or mineralogical delineation between the hydrochemical facies defined in Section 4.3.1.1.

4.3.1.4 Estimated Oxidation-Reduction Potentials of Culebra Waters--Many of the transuranic elements to be emplaced in the WIPP facility have multiple valence states. Therefore, given the possible role of the Culebra dolomite in transport to the accessible environment, it is important to estimate oxidation potentials (redox potentials, Eh) within the unit. Available measurements of redox potentials in Culebra waters are described in detail by Myers et al. (1988), and are summarized in Figure 4.3.6. Myers et al. (1988) conclude that the calculated potentials summarized in Figure 4.3.6, based on the data from Pt electrodes and redox pairs involving N, I, As, and Se, are fairly insensitive to assumptions concerning activity-concentration relationships, reasonable uncertainties in analytical data, and errors introduced by uncertainty in field pH. Absolute potential measurements made with Pt electrodes are not generally considered highly reliable; they are included here only for purposes of inter-well comparison. Nonetheless, many of the data are internally inconsistent.

The internally consistent values, indicated in Figure 4.3.6 by the vertical shaded bars, are interpreted by Myers et al. (1988) to bracket the redox potentials for the wells in Zone B (H-7, H-8, H-9, and Engle) between +330 and +630 mv (or higher). A similar range is indicated for WIPP-26 (Zone C) in the eastern part of Nash Draw. Data for the nitrogen couple in hydrochemical facies A and C (Figure 4.3.1), except for WIPP-26, indicate less oxidizing conditions, with an estimated Eh of less than approximately +330 mv.

Quantitative data are not available from within most of Nash Draw. The internally consistent data from WIPP-26 indicate a similar range of redox potential to that at H-7, H-8, and H-9. The platinum-electrode

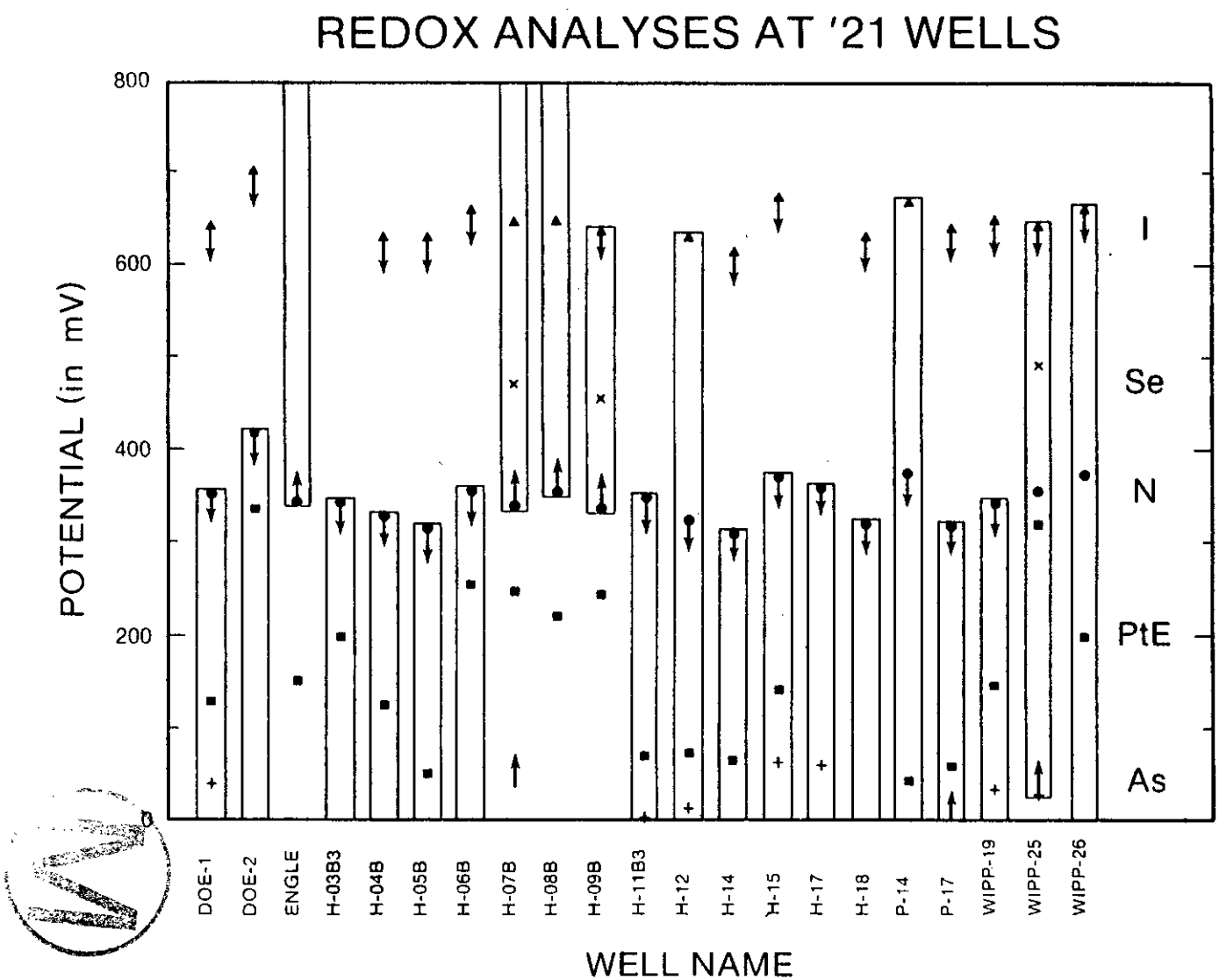

Figure 4.3.6: Variability in approximate redox potential of waters from several Culebra wells. Symbols: + = AsIII/AsV; □ = platinum electrode; o = NH_3/NO_3^-; x = SeIV/SeVI; ▲ = I^-/IO_3^-. Arrows indicate upper or lower limits resulting from one member of pair being present at levels below the detection limit. From Siegel et al. (1988b).

measurements in H-7, H-8, H-9 and WIPP-26 (Figure 4.3.6) are higher than those at most other locations. The apparent range of consistent potentials in WIPP-25 is large. Lambert and Robinson (1984) note, however, that WIPP-25 evolved H_2S during fluid sampling, suggesting that these results are suspect. Relative measurements with Pt electrodes (Lambert and Robinson, 1984), also indicate that redox potentials in the Culebra in Nash Draw are higher than those in the underlying Rustler/Salado contact zone.

Thus, there appear to be consistent variations in redox potential within the Culebra dolomite, with more reducing conditions to the northeast and more oxidizing conditions toward the southwest. This regional variation in the modern oxidation potential plays a significant role in interpretation of uranium-disequilibrium studies discussed in Section 4.3.4.

4.3.1.5 Mineralogy of the Culebra Dolomite--It has already been noted that both the composition and density of Culebra fluids vary considerably at and near the WIPP site. One objective of studies summarized in Siegel et al. (1988a) was to determine whether or not variations in Culebra mineralogy correlate with variations in Culebra fluid compositions. Accordingly, detailed mineralogical studies of Culebra samples from ten different locations along three east-west traverses have been conducted, and are described by Sewards et al. (1988).

Figure 4.3.7 shows a mineralogical cross section of the Culebra dolomite from Nash Draw towards the east, south of the WIPP site proper, as interpreted from sampled core (Sewards et al., 1988). As in any core study, especially in a locally fractured unit such as the Culebra, it cannot be demonstrated that the sampled core has been in contact with flowing groundwater. Mineralogical contents estimated by Lambert (1988) during preparation of rubbled material selected for isotopic analysis of Culebra matrix and veins (Section 4.4.2) differ somewhat from analyses summarized in Figure 4.3.7. The mineralogy at H-7 and H-10 (Figure 4.3.7) is probably representative of intact core samples at the WIPP. The dominant mineral in the selected cores is fairly pure dolomite, comprising about 85% of the bulk rock (by weight). Minor amounts of gypsum, calcite, and clay are observed throughout the sampled cores, but their distribution is heterogeneous both vertically and laterally. Fractures, which are present in most cores, are most commonly lined with clay and gypsum. Gypsum ($CaSO_4 \cdot 2H_2O$) occurs as both fracture and vug fillings. Available analyses indicate that it is nearly pure. Both the composition and textural features suggest that it is secondary in origin. Calcite from the upper portion of the Culebra in WIPP-29 is also interpreted to be secondary. Minor amounts of pyrite, magnesite, quartz, and authigenic feldspar have been observed in some cores. Finally, a dark optically-amorphous and X-ray-amorphous material is present in some abundance in Culebra samples examined, and has been tentatively identified as organic matter. It is generally associated with clays, and often occurs in algal structures or haloes surrounding vugs, the origin of which is attributed to biological activity.

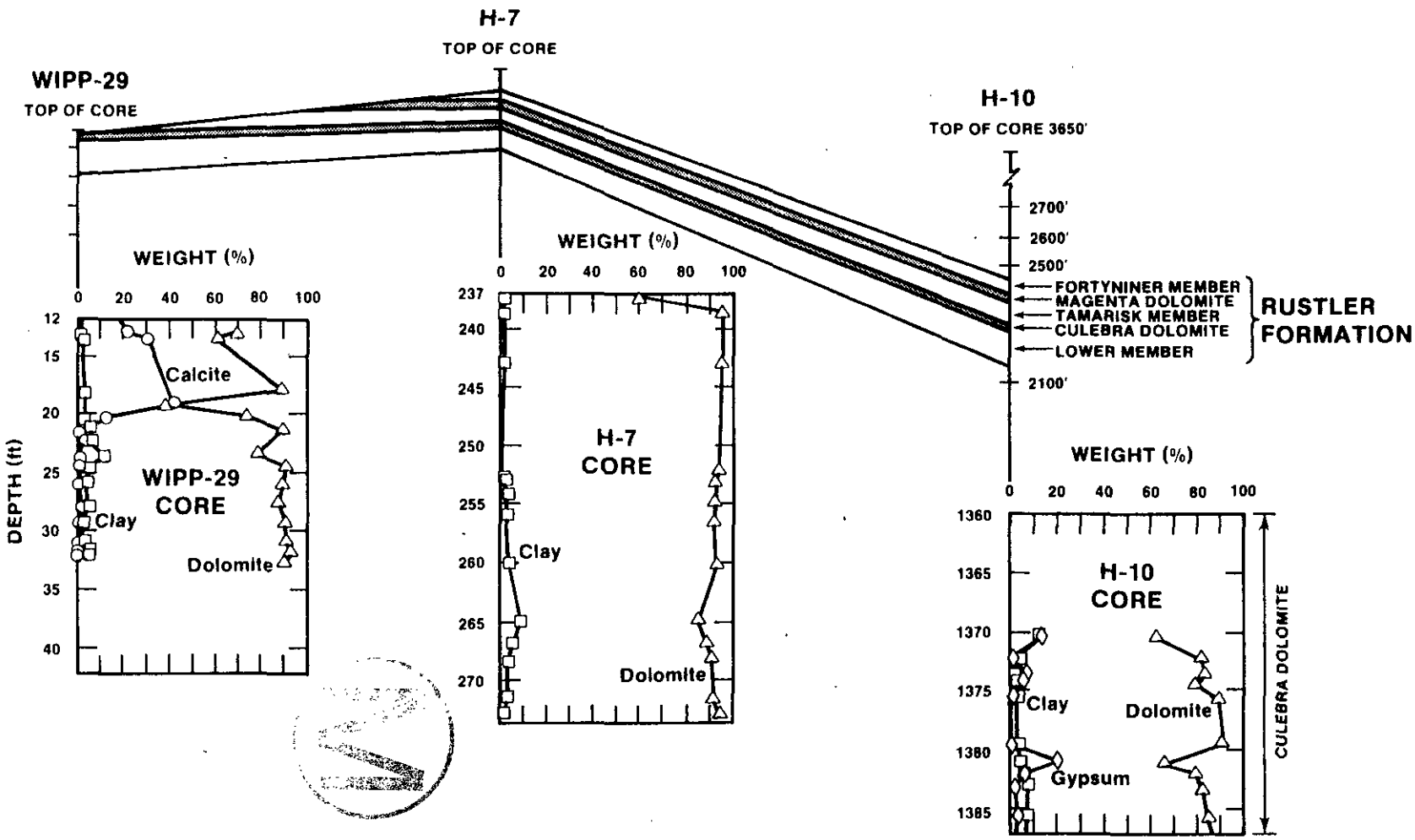

Figure 4.3.7: Fence diagram of variations in bulk mineralogy of core samples of the Culebra dolomite along the east-west section including holes WIPP-29, H-7, and H-10. From Siegel et al. (1988a).

In the intact cores examined by Sewards et al. (1988), corrensite, an ordered mixed-layer illite-smectite clay, is the second most abundant mineral within the Culebra after dolomite. In addition to occurring along fractures, clays are also present in the matrix of all Culebra samples, and commonly make up 3 to 5 weight percent of the bulk sample. The dominant clay minerals are corrensite, illite, chlorite, and a serpentine-like mineral, tentatively identified as amesite.

The recent mineralogical studies in the Culebra indicate that the unit is vertically and laterally heterogeneous. The dominant variation in Culebra fluids, variation in Na and Cl (Section 4.3.1.1), is not reflected in the presence or absence of halite in Culebra core. Dolomite, clays, and gypsum are ubiquitous, and calcite local in occurrence. Table 4.14 summarizes potential rock/water reactions that may influence the chemistry of Culebra waters. With the exception of halite, all of the minerals involved in reactions listed in Table 4.14 occur in the Culebra throughout the area at and near the WIPP site. Halite that has definitely not been introduced during drilling has not been reliably identified in any Culebra core. With the exception of halite dissolution, any of the reactions indicated in Table 4.14 can occur in any of the Culebra hydrochemical facies zones defined. Examination of potential rock/water reactions affecting fluids within the Culebra has not yet identified unique or discontinuous relationships between matrix mineralogy and fluid composition that can be used to place additional constraints on either present or past directions of fluid flow.

In summary, the highly variable fluids within the Culebra dolomite can be divided into four facies. The distribution of these facies is not consistent with modern regional flow directions estimated from hydrologic measurements, if steady-state confined flow is assumed. Zone B, containing lower-salinity fluids lies down-gradient from Zone C, which contains more saline waters. An internally consistent interpretation of the variability of Rustler fluids is possible on the basis of salt norms if large-scale vertical recharge is assumed in some areas. However, some of the analyses used in this interpretation do not appear to be representative, and both isotopic and hydrologic evidence suggest that such vertical fluid movement is not now operative at and near the WIPP site. The mineralogy of core samples from the Culebra dolomite is consistent only in its variability. It cannot be demonstrated that sampled fluids at a given well have been in contact with a given piece of core; therefore it cannot be directly demonstrated that rock/water interactions identified on the basis of a given core sample control or affect the local fluid composition. The available data cannot identify any unique relations between Culebra matrix mineralogy and major-solute or minor-solute compositions of Culebra waters that can themselves be used to place constraints on either past or present flow directions within either the Culebra or the Rustler Formation as a whole. As discussed in Section 4.4.2, however, the isotopic compositions of some minerals within the Rustler, especially gypsums, can be used to place constraints on vertical fluid flow.

Table 4.14: Summary of possible rock-water reactions affecting compositions of Culebra fluids. From Siegel et al. (1988a).

Chemical Process	Potential Effect on Culebra Water
Halite Dissolution	increase Na, Cl, Br, Li; decrease Cl/Br; increase solubility of carbonates and sulfates up to 3 molal NaCl and then decrease solubility causing changes in Ca, Mg, SO_4, CO_3
Precipitation/dissolution of gypsum	decrease/increase Ca, SO_4
Precipitation/dissolution of calcite and dolomite	decrease/increase Ca, Mg, CO_3
Dolomitization: calcite + Mg -> dolomite + Ca	decrease Mg/Ca
Dedolomitization: dissolution of gypsum and dolomite with concurrent precipitation of calcite.	decrease pH, alkalinity/SO_4; maintain Mg/Ca molar ration < 1
Ion exchange involving Mg, K-rich clays in NaCl brines	loss of Na, gain of Mg, K by solution
Mixing of connate hypersaline formation water with recharge water that has dissolved gypsum,	increase Mg, Ca, K, Na, Cl; decrease SO_4, Cl/Br
Incongruent dissolution of polyhalite	increase Mg, K, SO_4; decrease Ca, Cl/Br

4.3.2 Recent Stable-Isotope Studies of Groundwaters from the Rustler Formation and Younger Units

4.3.2.1 The Character of Modern Recharge in the Northern Delaware Basin--As mentioned above, stable-isotope studies do not provide direct information concerning the age of groundwater. Rather, they may indicate whether or not two or more bodies of water were recharged under similar climatic conditions and whether or not one of the bodies of water is modern. At the WIPP site, the approach requires both determination of the isotopic character of modern recharge in the region and determination of

whether or not the isotopic character of groundwaters in the Rustler Formation and younger units is consistent with that of modern precipitation. Recent stable-isotope studies of groundwaters in the northern Delaware Basin conducted as part of WIPP site-characterization activities are summarized by Lambert and Harvey (1987).

The present stable-isotope data base for waters from Carlsbad Caverns (Lambert and Harvey, 1987), is summarized in Figure 4.3.8. Samples were collected from active drips or pools in portions of the cavern system well above the modern water table. Depending on assumptions concerning seasonal averaging of fluid compositions during infiltration and possible evaporation within the caverns, these waters may or may not be representative of modern meteoric recharge in the northern Delaware Basin at elevations similar to that of the surface of the WIPP site.

Lambert and Harvey (1987) conclude that, with one possible exception (sample "GS"), evaporation and rock-water interaction do not play a significant role in derivation of the waters shown in Figure 4.3.8. This is because the waters fall in or near the "meteoric field," defined by the compositional space between the statistical world-wide precipitation trends calculated by Craig (1961) and by Epstein et al. (1965, 1970). Therefore, the isotopic character of the waters (Figure 4.3.8) is interpreted as consistent with that of modern meteoric recharge in the northern Delaware Basin.

The character of modern precipitation in the northern Delaware Basin also rests on other analyses. In 1983, waters from Carlsbad Caverns were essentially the only waters interpreted to represent this recharge. As shown in Figure 4.3.9, most of the more recent measurements on surficial waters and some on shallow groundwaters in the vicinity of the WIPP site and at similar elevations are consistent with measurements on unconfined waters from the Capitan limestone. Samples from a local storm (August 26, 1980) fall within the Carlsbad Caverns field, as do samples from the Dewey Lake Red Beds at the James Ranch and Quaternary alluvium at WIPP-15. The character of the water from the Dewey Lake Red Beds in the James Ranch well is consistent with the interpretation that the Dewey Lake is experiencing modern recharge at this location. The well at the James Ranch (identified as "ranch well" in Figure 1.2) is close to a locally active dune field south of the WIPP site; WIPP-15 was drilled specifically to investigate San Simon Sink (Figure 1.1), an active collapse feature over the Capitan limestone. The measured deuterium/hydrogen ratios of nine water-table samples from the Ogallala Formation in southeastern New Mexico are consistent with the lighter end of the Carlsbad Caverns field in Figure 4.3.9. Heavier Ogallala samples also high in tritium, discussed by Lambert (1988), are consistent with this field. Thus, Lambert and Harvey (1987) base the isotopic composition range of their field of "demonstrably modern precipitation" used in discussions below and in later figures in this section on measurements at several localities, and in several different geologic units. Additional information, especially concerning both the deuterium and tritium characteristics of groundwaters in the High Plains of Texas and the northern Delaware Basin of New Mexico is contained in Lambert (1988).

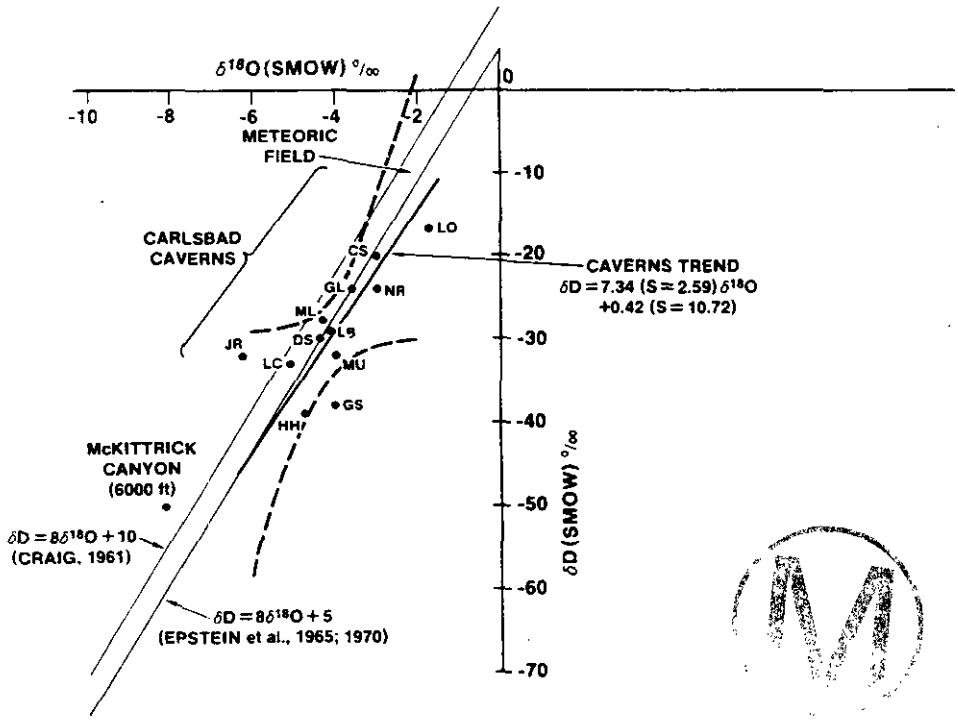

Figure 4.3.8: Available stable-isotope analyses of waters from the unconfined portion of the Capitan limestone in Carlsbad Caverns, New Mexico. The two-letter identification of individual samples is fully explained in Table 3 of Lambert and Harvey (1987). The meteoric field is defined as the area between the statistical correlation lines of Craig (1961) and Epstein et al. (1965, 1970). Slightly modified from Figure 6 of Lambert and Harvey (1987).

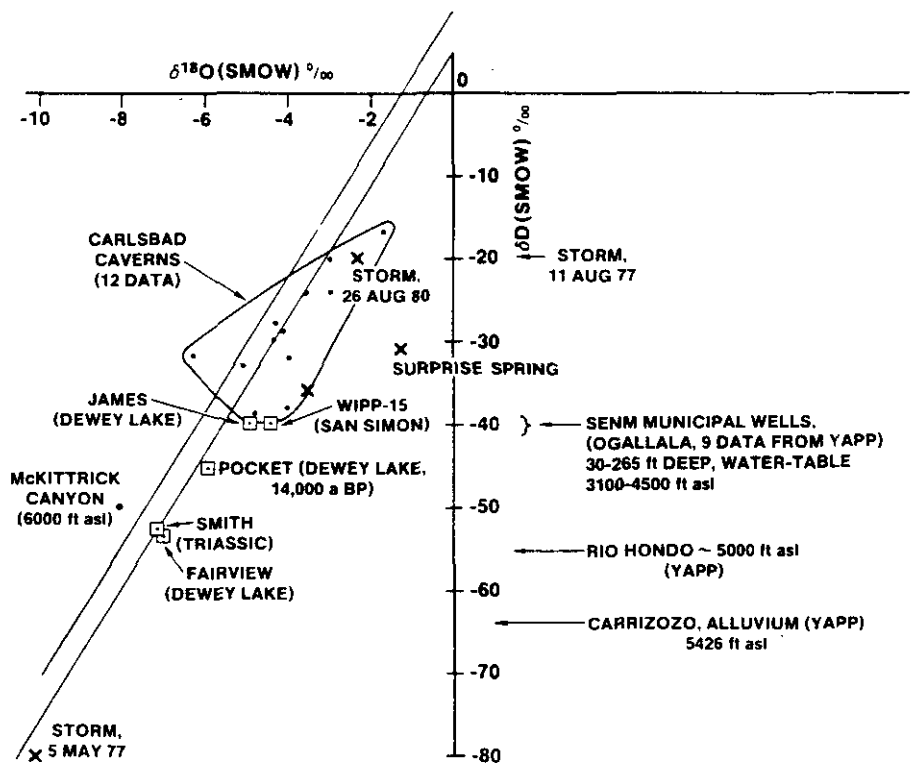

Figure 4.3.9: Recent stable-isotope analyses of surficial and near-surface waters in the northern Delaware Basin. Slightly modified from Figure 9 of Lambert and Harvey (1987).

Stable-isotope data from both the travertine deposit in McKittrick Canyon and a local storm (May 5, 1977) are much lighter than the Carlsbad Caverns field shown in Figure 4.3.9. The isotopic character of these samples is interpreted by Lambert and Harvey (1987) to be due to local elevation effects and point-data variability of individual storms. A similar elevation-dependent argument is made concerning the deuterium data available for Rio Hondo and at Carrizozo (see Lambert and Harvey, 1987 for discussion and detailed sample locations).

Not all data from stratigraphic units above the Rustler fall in the Carlsbad Caverns field in Figure 4.3.9. Water from the Dewey Lake Red Beds at the Pocket well is relatively light. This water has a calculated minimum radiocarbon age of 14,000 years (Section 4.3.3). The ages or isolation times of the relatively light waters from the Smith and Fairview wells are not known. The available stable-isotope results indicate complexity within the Dewey Lake Red Beds. The James Ranch well appears to contain "modern" water, and is located near an active dune field. The Pocket and Fairview wells, which both contain water isotopically distinct from the Carlsbad Caverns field in Figure 4.3.9, are both located near the southwestern lobe of Nash Draw.

4.3.2.2 <u>The Hydrology of the WIPP Site and Vicinity Relative to Modern Recharge</u>--Figure 4.3.10 summarizes the available stable-isotope data for groundwaters from the Magenta and Culebra dolomites at and near the WIPP site. In this figure, the isotopic character of these waters is contrasted with the Lambert and Harvey (1987) estimate of "demonstrably modern Delaware Basin recharge at 3,000 - 4,500 feet elevation," discussed above. The compositionally distinct waters from WIPP-29 and Surprise Spring, both of which are distinct from the meteoric field (Figure 4.3.8) are discussed separately below.

There is no overlap between the Culebra/Magenta data near the meteoric field and the interpreted compositional field representing modern recharge (Figure 4.3.10). On the basis of the consistent compositional distinctions shown in Figure 4.3.10, Lambert and Harvey (1987) conclude that: 1) the stable-isotope compositions of Culebra and Magenta groundwaters do not reflect modern meteoric recharge of the Rustler Formation; 2) there is no significant modern recharge to the Magenta and Culebra dolomites at and near the WIPP site; and 3) the waters presently contained within the Magenta and Culebra at and near the WIPP site were recharged under different climatic conditions than those at present. Therefore, at least some aspects of the hydrology of the Rustler Formation must be transient on some time scale.

The Rustler Formation is not the only unit in the northern Delaware Basin that contains older water. There is also significant variability in the isotopic character of fluids within the Capitan limestone (Figure 4.3.11). The heavier samples defining the "Carlsbad Caverns" compositional field in this figure, which is almost identical to the modern recharge field in Figure 4.3.10, are from the unconfined and partially saturated hydrologic system within Carlsbad Caverns. The lighter samples are from wells drilled

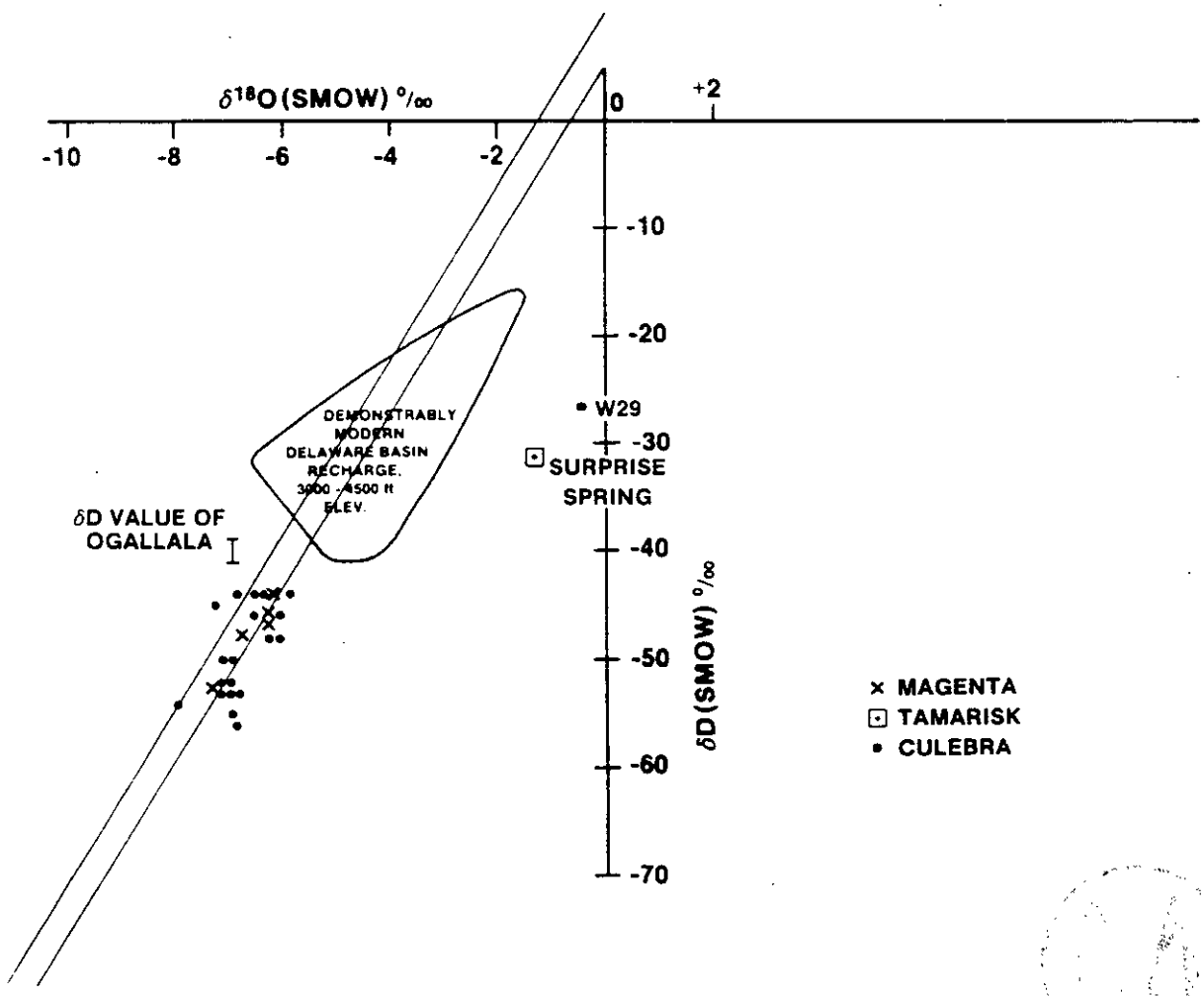

Figure 4.3.10: Stable-isotope compositions of waters from the Culebra and Magenta dolomites at and near the WIPP site. The "modern recharge" field is defined by the Carlsbad Caverns field and other consistent data contained in Figures 4.3.8 and 4.3.9. Note the anomalous character of samples from WIPP-29 and Surprise Spring. Slightly modified from Figure 14 of Lambert and Harvey (1987).

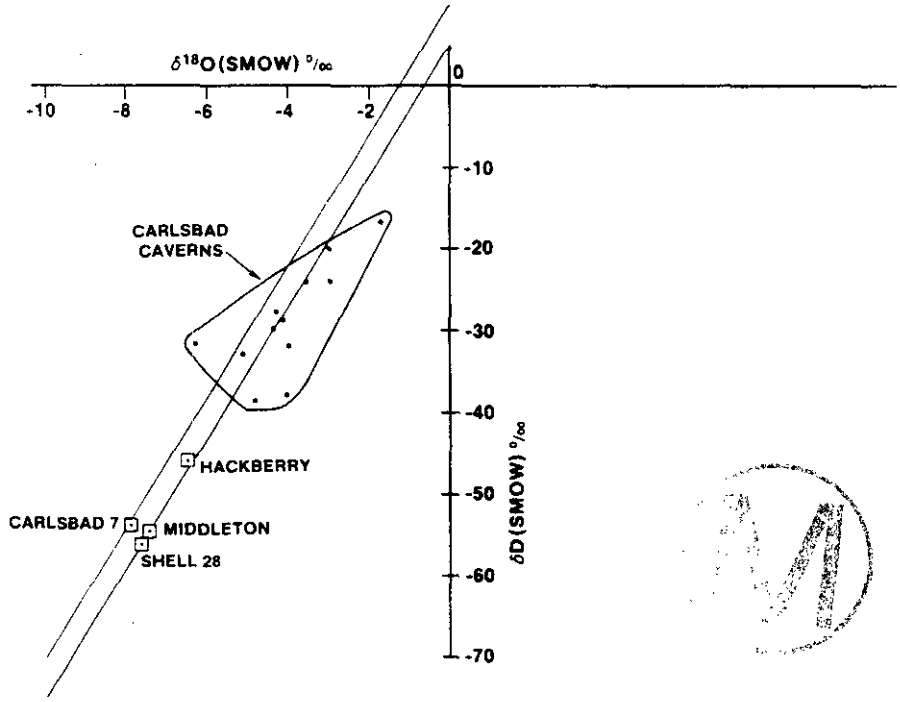

Figure 4.3.11: Comparison of stable-isotope character of waters from unconfined and confined portions of the Capitan limestone. Slightly modified from Figure 10 of Lambert and Harvey (1987).

into confined regions of the Capitan. The signatures of samples from confined portions of the Capitan limestone fall within the same compositional field as most Rustler fluids. Based on uranium-disequilibrium studies, Barr et al. (1983) estimate the isolation times for the Capitan waters from the Middleton and Hackberry wells (Figure 1.1) as 5.8×10^5 and 1.05×10^6 years, respectively.

Thus, stable-isotope measurements in the Rustler Formation, Dewey Lake Red Beds, and Capitan limestone are consistent with the conclusion that the hydrology of the northern Delaware Basin is transient. The fundamental conclusions of Lambert and Harvey (1987) and Lambert (1988) concerning the hydrologic setting of the northern Delaware Basin are:

1. The isotopic compositions of waters from unconfined portions of the Capitan limestone, the Ogallala Formation, and several other unconfined sampling locations at elevations similar to that of the WIPP site are representative of modern meteoric recharge within the northern Delaware Basin.

2. The general isotopic composition of samples from the Culebra and Magenta dolomites of the Rustler Formation at and near the WIPP site, as well as of samples from confined portions of the Capitan limestone, is distinct from that of modern meteoric precipitation within the northern Delaware Basin.

3. The Culebra and Magenta dolomites at and near the WIPP site, in addition to part of the Dewey Lake Red Beds and confined portions of the Capitan limestone, were recharged under climatic conditions different from those effective at the present time.

4. Therefore, the hydrology of the northern Delaware Basin is transient on some time scale. The stable-isotope technique itself provides no information concerning the possible times or time gaps between two interpreted recharge intervals or events, nor does it necessarily provide information concerning where recharge might have taken or be taking place. In the specific case of the Rustler Formation, however, the stable-isotope technique does indicate that significant modern meteoric recharge to the Culebra or Magenta is not taking place at any of the sampled localities.

One site-specific focus of Lambert and Harvey (1987) is the determination of whether or not southeastern Nash Draw, specifically the area including hole WIPP-29 and Surprise Spring (Figure 1.1), is a major point of discharge for Rustler fluids flowing across the WIPP site. Lambert and Harvey (1987) evaluate the question by comparison of the solute and isotopic characteristics of fluids from hole WIPP-29 and Surprise Spring with those of other Rustler fluids. As shown in Figure 4.3.10, the isotopic signatures of fluids from both WIPP-29 and Surprise Spring are quite distinct from the meteoric field. Lambert and Harvey (1987) conclude that the solute characters of WIPP-29 and Surprise Spring waters are also distinct.

In general, the modern flow directions within the Culebra in Nash Draw are roughly parallel to the axis of Nash Draw (Section 4.1). This suggests that, if Surprise Spring is to be a major point of Culebra discharge, fluids must first flow through the region of hole WIPP-29. Rustler groundwaters have been sampled at both Surprise Spring and WIPP-29. It is essentially impossible to derive Surprise Spring waters from evaporation of WIPP-29 Culebra waters, since the lower chloride content at Surprise Spring (Figure 4.3.1) indicates major dilution relative to WIPP-29. The same argument applies to derivation of Surprise Spring waters from Culebra waters at both H-5 and H-6 at the WIPP site, and at many holes within Nash Draw itself. Further, as noted by Lambert and Harvey (1987), Surprise Spring appears to discharge from the Tamarisk Member of the Rustler, rather than from either the Culebra or Magenta.

In addition, the Cl/K (weight) ratios for fluids from holes WIPP-27 and WIPP-29 are distinctly lower than those of other Rustler fluids both in and outside Nash Draw, including Surprise Spring (Section 4.3.1.1). Culebra groundwaters from WIPP-27 and WIPP-29 have Cl/K ratios of ten and nine, respectively, compared to ratios generally from 38 to 73 in holes outside Nash Draw, and a value of 52 at Surprise Spring. Hole WIPP-27 is downslope from the tailings ponds of Mississippi Chemical Corporation's potash refinery in Nash Draw, while WIPP-29 is downslope from the tailings ponds of the International Minerals and Chemicals refinery (Lambert and Harvey, 1987).

Lambert and Harvey (1987) interpret these relationships and the fact that the isotopic compositions of waters from WIPP-29 and Surprise Spring are both distinct from the meteoric field to indicate that:

1. The hydrology of Surprise Spring is essentially isolated and independent from that of the Culebra at WIPP-29, and is not dominated by confined Rustler groundwaters from elsewhere. Surprise Spring discharges from the Tamarisk Member of the Rustler. Nearby exposures of the Tamarisk serve as a likely recharge area for Tamarisk discharge at Surprise Spring, and may or may not be contaminated by local potash-refining operations. The isotopic compositions of groundwaters at both WIPP-29 and Surprise Spring appear to have been derived from surface-type water by partial evaporation.

2. Surprise Spring is not at present a significant point of discharge for Culebra and/or Magenta fluids flowing across the WIPP site.

3. As indicated by the relatively low Cl/K weight ratios in fluids from WIPP-27 and WIPP-29, local potash refining has a major impact on Rustler geochemistry and hydrology within Nash Draw (Section 4.3.1.1).

Lambert and Harvey (1987) conclude that the isotopic character of fluids collected from the Rustler/Salado contact zone (Figure 4.3.13) is strongly affected by rock-water interaction (isotope shift). The extent of this effect generally increases with increasing distance from Nash Draw, paralleling a general decrease in permeability (Section 4.1) and increase in rock-water ratios.

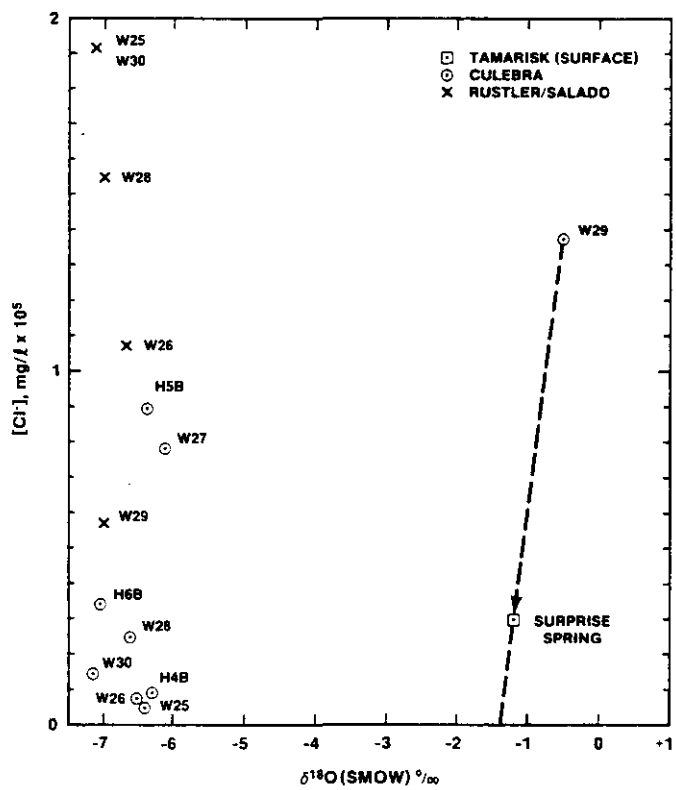

Figure 4.3.12: Relationship between oxygen fractionation and chloride content for analyzed fluids from the Culebra, Magenta, and Rustler/Salado contact. Figure 21 of Lambert and Harvey (1987).

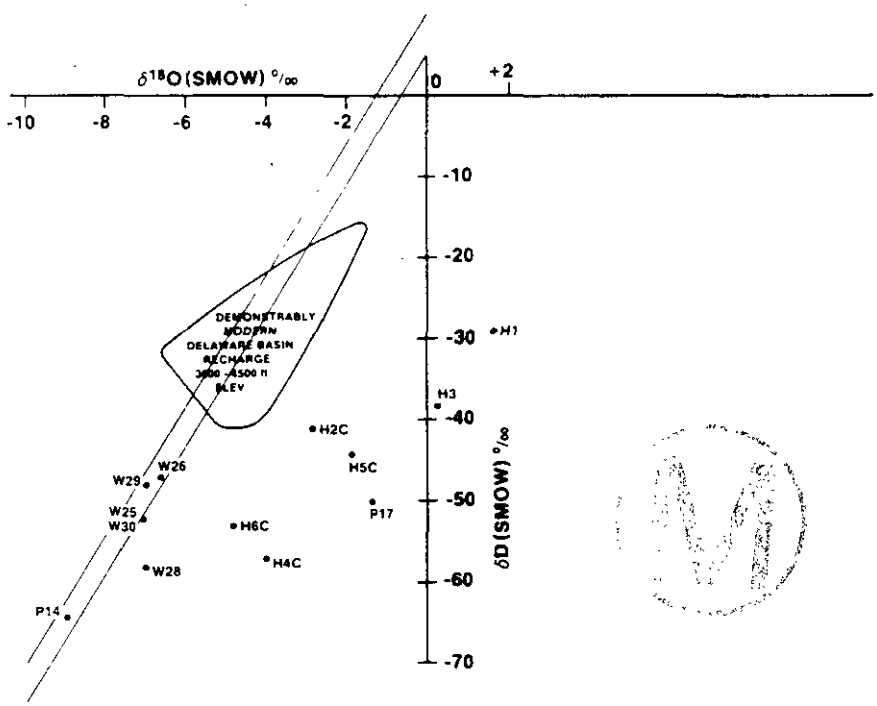

Figure 4.3.13: Stable-isotope character of waters from the Rustler/Salado contact, compared with modern precipitation in the northern Delaware Basin. The "modern recharge" field is defined as in Figure 4.3.10. Figure 15 of Lambert and Harvey (1987).

The interpretations of Lambert and Harvey (1987) and Lambert (1987b) are not consistent with some conclusions contained in Chapman (1986), which is based on review of much of the data contained in the two later reports. The fundamental disagreement lies in interpretation of the distinctions between waters from unconfined portions of the Capitan limestone, modern precipitation, and Rustler waters from at and near the WIPP site. The logic behind a portion of the disagreement is shown in Figure 4.3.14. Chapman (1986) concludes that the isotopic character of modern meteoric recharge in both the northern Delaware Basin and the Roswell Basin is represented by the weighted mean precipitation for the town of Roswell, calculated by Hoy and Gross (1982) (Figure 4.3.14), and that meteoric variability in both areas is closely represented by the trend line of Craig (1961). If these assumptions are valid, then it is possible to derive most of the isotopic compositions of unconfined waters collected within Carlsbad Caverns by "high-humidity" evaporation (line B in Figure 4.3.14) of water representing the calculated Roswell-weighted mean precipitation. Under this interpretation, the unconfined waters from Carlsbad Caverns would be secondary, and would not represent modern meteoric precipitation. As shown, the weighted mean precipitation used by Chapman to derive unconfined Capitan waters is also distinct from the compositional field defined by most Rustler, Dewey Lake, and confined Capitan waters. Chapman (1986) attributes this difference to a "seasonal or amount effect."

Chapman (1986) also notes that, if only stable-isotope relationships are considered, the isotopic character of waters from Surprise Spring can be derived by partial near-surface evaporation of Rustler groundwaters (Line A in Figure 4.3.14); i.e., that Surprise Spring could be a major point of discharge for Rustler waters at and near the WIPP site. While this appears to be theoretically possible on the basis of stable-isotope relationships alone, the solute-composition relationships described in Lambert and Harvey (1987) and summarized above preclude this possibility.

The disagreement between the interpretations contained in Lambert and Harvey (1987) and Chapman (1986) concerning the overall nature of the hydrology in southeastern New Mexico is fundamental, and cannot be resolved by stable-isotope studies alone. However, these studies do clarify the differences in opinion. Chapman (1986), in effect assumes that the hydrology of southeastern New Mexico is at steady state (or, alternatively, that its response to changing climatic conditions is effectively instantaneous). She assumes that the weighted mean precipitation for Roswell and the statistical correlation of Craig (1961) are significant by themselves, and demonstrates that it is possible, based on these assumptions, to generate unconfined waters from Carlsbad Caverns by evaporation. By Chapman's interpretation, the unconfined Capitan waters do not represent modern recharge. However, the field of demonstrably modern Delaware Basin recharge defined by Lambert and Harvey (1987) includes or is consistent with analyses from several other locations in addition to Carlsbad Caverns. The weighted mean precipitation used by Chapman to derive unconfined Capitan waters by evaporation is also distinct from the compositional field defined by most Rustler, Dewey Lake, and confined Capitan waters. Chapman (1986) attributes this difference to a "seasonal or amount effect." The

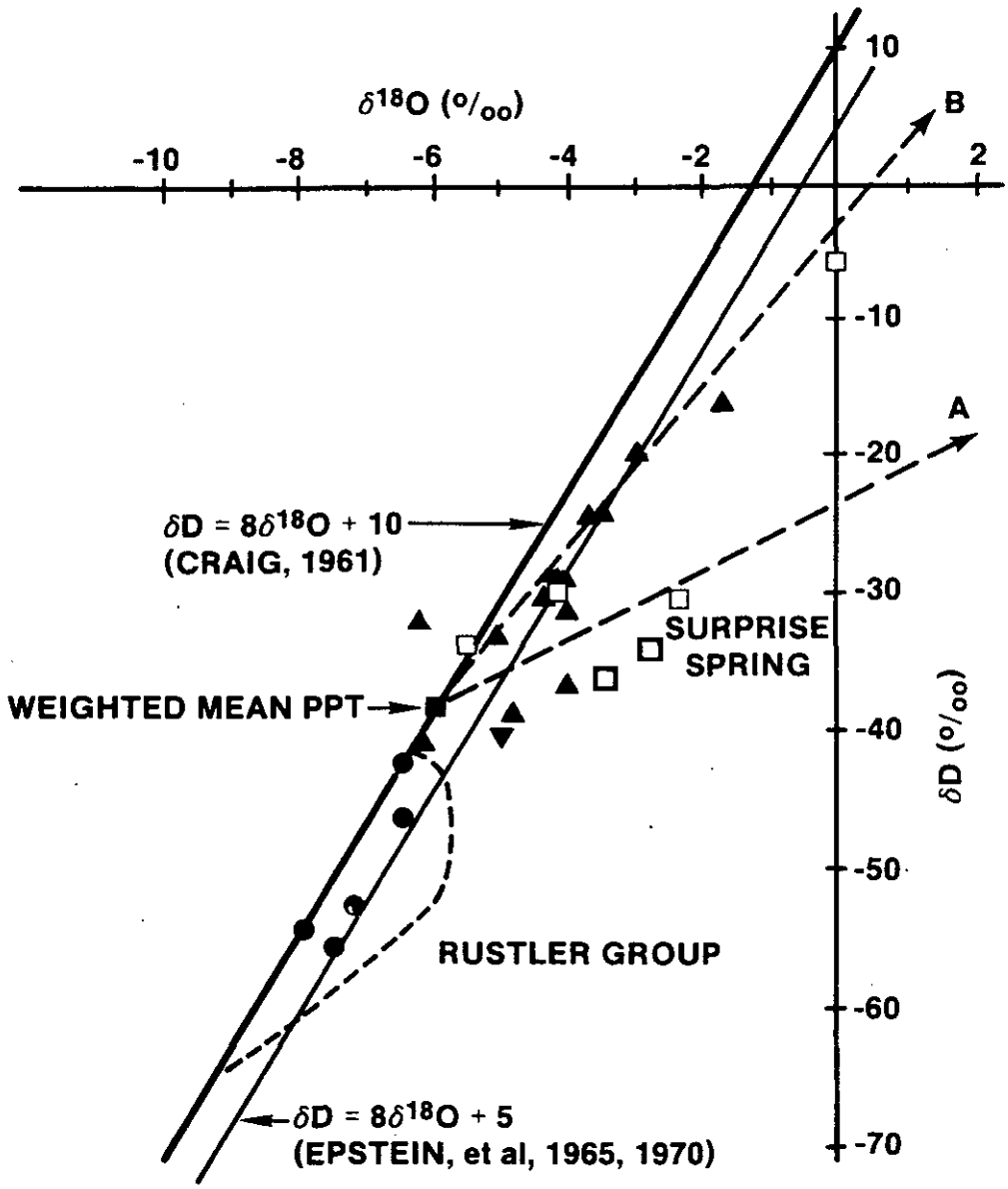

A: TREND FOR "LOW-HUMIDITY" EVAPORATION
B: TREND FOR "HIGH-HUMIDITY" EVAPORATION

- ● CAPITAN AQUIFER
- ▼ SHALLOW AQUIFERS: SANTA ROSA, DEWEY LAKE
- □ SURFACE WATER
- ▲ CARLSBAD CAVERNS
- ■ WEIGHTED MEAN PPT

Figure 4.3.14: Possible derivation of Carlsbad Caverns waters from modern precipitation. Modified from Figures 13 and 14 of Chapman (1986), by addition of the statistical correlation line for meteoric precipitation of Epstein et al. (1965, 1970) and deletion of waters from the Roswell Basin.

operation of this effect on Rustler, Dewey Lake, and confined Capitan waters, as well as Ogallala water from the High Plains is not explained.

Lambert and Harvey (1987) do not assume that the hydrology of southeastern New Mexico is at steady state. They do assume that significant departure in isotopic signature from the meteoric field defined by the compositional space between the statistical correlations of Craig (1961) and Epstein et al. (1965, 1970) is required before any recourse to evaporation is justified. Unconfined Capitan waters (and others, such as Ogallala fluids and samples from alluvium at WIPP-15) are interpreted by Lambert and Harvey (1987) to represent modern meteoric recharge in the northern Delaware Basin. The demonstrably different isotopic character of most Rustler, Dewey Lake, and confined Capitan waters from the field they interpret to represent modern recharge in the northern Delaware Basin is taken to reflect recharge under conditions distinctly different from those controlling modern recharge. Since steady state is not assumed, no single weighted mean precipitation is either defined or deemed relevant. The conclusions of isotopic studies discussed in Sections 4.3.3, 4.3.4, and 4.4.2 are consistent with the interpretation of a transient hydrologic setting of the Rustler Formation and shallower units at and near the WIPP site.

4.3.3 Recent Isotopic Studies with Emphasis on Radiocarbon

Studies investigating the applicability of several environmental isotopes (isotopes generated primarily within the atmosphere), especially radiocarbon, to the shallow stratigraphic units at the WIPP are summarized by Lambert (1987a, 1988). Although the emphasis in these studies was on radiocarbon, tritium, and chlorine-36 were briefly evaluated. No ^{36}Cl above background could be identified, nor could tritium values significantly above background be identified except in hole WIPP-27. The high chlorine background is to be expected in fluids in a halite-bearing evaporite section. The tritium at WIPP-27, consistent with the major-solute composition of Culebra groundwaters from WIPP-27 (Section 4.3.1.1), is interpreted to be due to contamination by potash-refining operations. Radiocarbon studies indicate that many of the sampled wells have been contaminated by organic materials during drilling, casing, and/or hydrologic testing. The successful radiocarbon measurements indicate isolation times of at least 12,000 to 16,000 years for three Culebra waters and one Dewey Lake water. Two of the four measurement points lie on nearly opposite sides of the WIPP site.

The relationship between calculated "percent modern carbon" (PMC) and the bicarbonate content of most of the fluids analyzed to date, including three samples from the Rustler/Salado contact zone, is summarized in Figure 4.3.15. PMC is carbon counts relative to 1950 wood. As shown in Figure 4.3.15, there is a strongly linear relationship between PMC and bicarbonate. The apparent end members are: a) a 0-PMC fluid with a bicarbonate content of approximately 60 mg/l, i.e., groundwater in equilibrium with carbonate, assuming bicarbonate is equal to total carbonate; and b) a 100-PMC fluid with a bicarbonate content of approximately 300 mg/l.

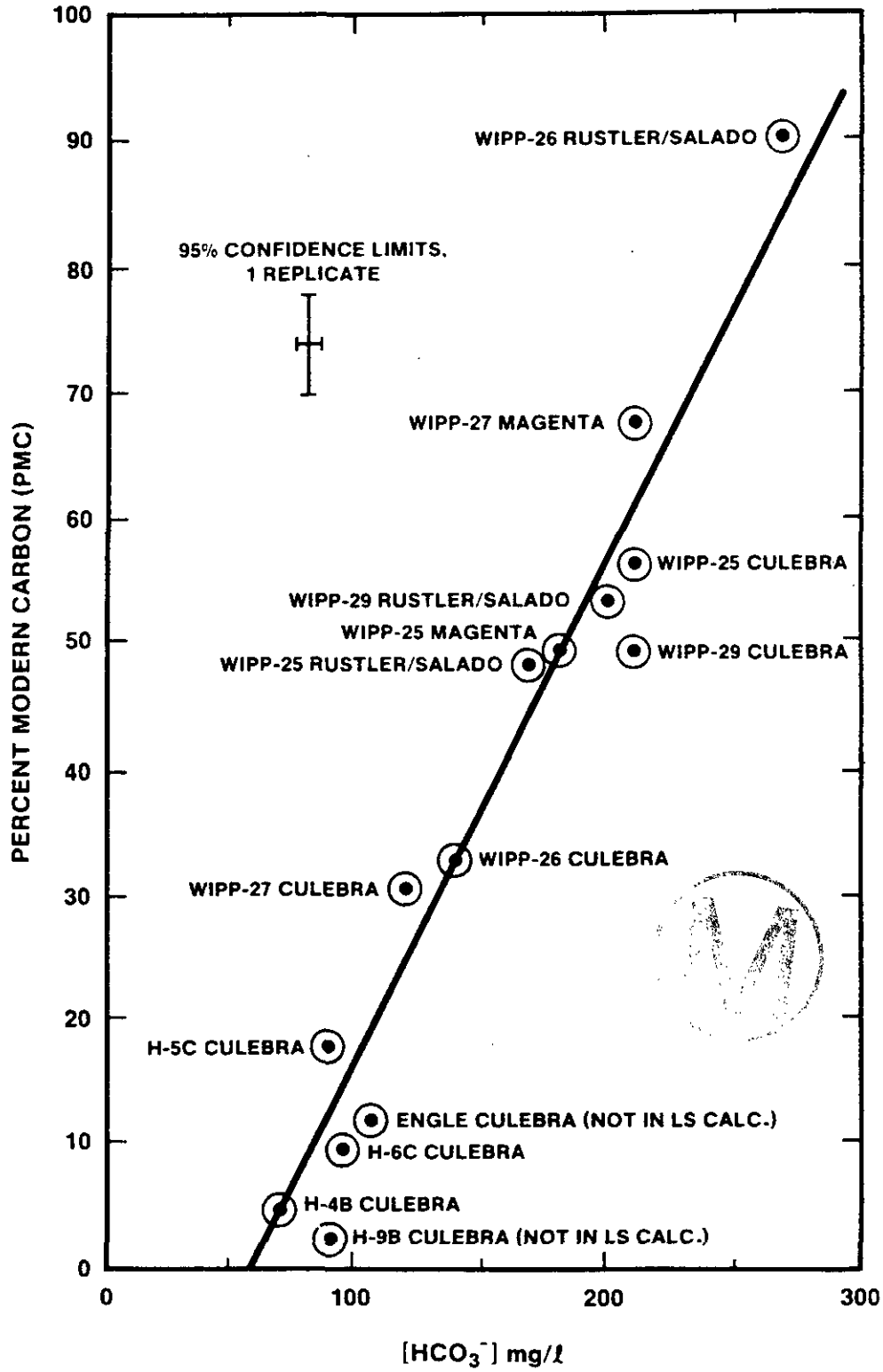

Figure 4.3.15: Relationship between calculated percent modern carbon (PMC) and bicarbonate in analyzed fluids. Figure 3 of Lambert (1987a).

If, as is commonly the case in radiocarbon studies, it is assumed that recharge groundwaters initially containing small amounts of atmospherically derived CO_2 (PMC near 100) equilibrate fairly quickly with carbonate minerals underground, it is difficult to explain waters in Figure 4.3.15 having greater than approximately 60 mg/l bicarbonate. In other words, one would expect the slope in Figure 4.3.15 to be negative rather than positive if this slope reflected increasing equilibration with underground carbonates with increasing time (decreasing PMC) (Lambert, 1987a). By this logic, the high-PMC samples in Figure 4.3.15 do not represent modern infiltration.

Regardless of the origin of high-PMC contents, a linear relationship should result from evaluation of any two compositional variables for the same fluids, if the data distribution in Figure 4.3.15 is a result of linear mixing of two fluid components. This is not the case for the analyzed fluids since the relationship between ^{13}C fractionation and bicarbonate (Figure 4.3.16) is statistically random. This result suggests that at least three fluid components may be involved in mixing to develop the indicated ^{13}C distribution. In such mixing, unique delineation of the mixing relationships and the ages or isolation times of the specific groundwater components involved is most likely impossible (Lambert, 1987a).

The relation between percent modern carbon (PMC) and ^{13}C fractionation for the samples on which adequate data are presently available is shown in Figure 4.3.17. The sampled fluids fall into two relatively distinct groups: a) a small group containing samples with less than approximately 10 PMC; and b) a larger group with from 10 to greater than 90 PMC. Data from H-5c and Engle could be included with the low-PMC group shown in Figure 4.53, though, as noted by Lambert (1987a), the statistical correlations within both data groupings are stronger if the four low-PMC samples (H-4b, H-6c, H-9b, and Pocket) are considered as a separate group. Of the four low-PMC samples, all but that from the Pocket well are for fluids from the Culebra dolomite; the Pocket sample is from the Dewey Lake Red Beds.

The definition of two distinct data groupings (Figure 4.3.17) leads to identification of three carbon-isotopic compositional components apparently involved in mixing within Rustler, Dewey Lake, and Rustler/Salado fluids. These are:

1. Dissolved carbon from Permian marine carbonates. Because the Permian carbonates are more than 200 million years old, this carbon is no longer measureably radioactive.

2. CO_2 derived from modern organic materials injected in variable amounts into the sampled holes during drilling and/or casing activities. Lambert (1987a) found it pointless to attempt dating of almost all of these contaminated samples, as discussed below.

3. CO_2 derived from Pleistocene and older organics during recharge. The location of this recharge cannot be specified on the basis of these studies. Because of the possible contamination of all these samples by small amounts of CO_2 from the modern reservoir, calculated PMC values

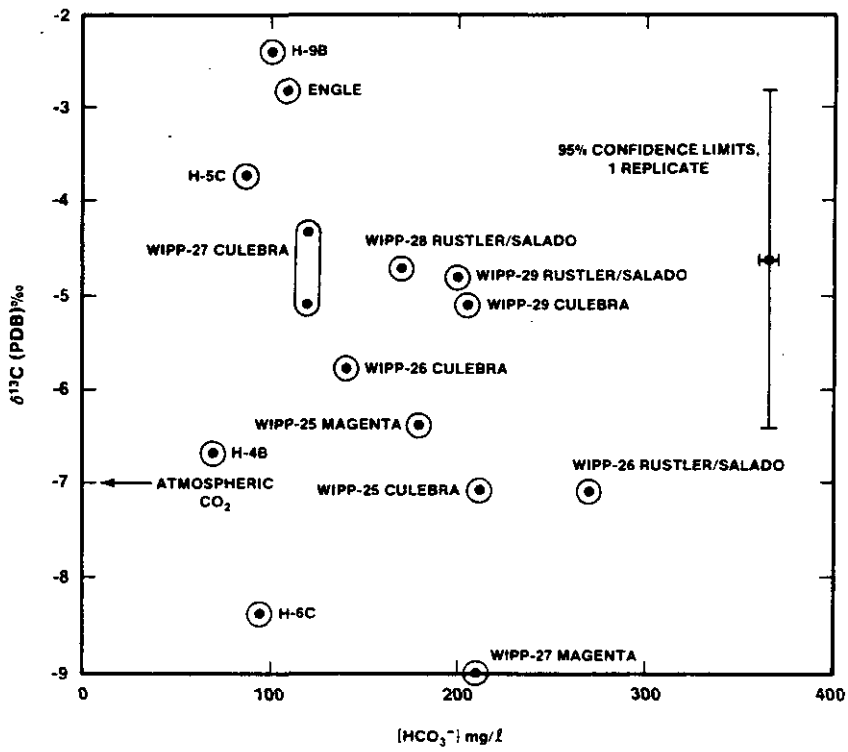

Figure 4.3.16: Relationship between ^{13}C fractionation and bicarbonate for analyzed fluids. Figure 4 of Lambert (1987a).

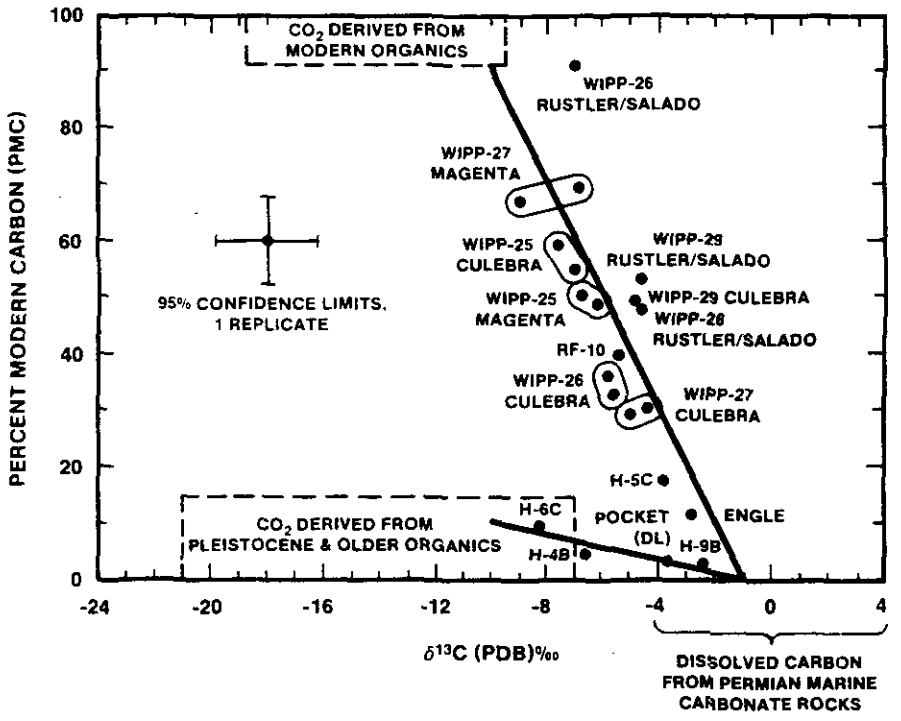

Figure 4.3.17: Relationship between percent modern carbon and ^{13}C fractionation for analyzed fluids. Three-component mixing is a plausible explanation for carbon-isotope characteristics of sampled Rustler and Dewey Lake fluids. In addition to "dead" carbon resulting from interaction with Permian carbonates, all samples may contain both CO_2 derived from Pleistocene and older organics and an unresolved component of CO_2 derived from modern organics. Figure 9 of Lambert (1987a).

in the four low-PMC samples shown in Figure 4.3.17 must be upper limits. Conversely, calculated ages or residence times for the fluids must be lower limits.

Lambert (1987a) applied several different numerical models to the analyzed groundwaters. The results, summarized in Table 4.15, indicate calculated isolation times of the sampled waters from any significant component of atmospherically derived carbon. The ages do not indicate that the fluids have been in their present location for the indicated time, simply that they have been isolated from a near-surface environment for approximately the time indicated. For the samples on which application of the models of Tamers (1975), Pearson and Swarzenki (1974), Mook (1976), and Evans et al. (1979) were generally successful, i.e., the four low-PMC samples (H-4 Culebra, H-6 Culebra, H-9 Culebra, and Pocket Dewey Lake), the results indicate isolation times of between 10,600 and 25,700 years, depending on both sample and model used. The different models used vary in the correction mechanisms assumed to effect fluid interaction with the rock. Lambert (1988) notes that it is not possible to reliably separate the effects of natural isotope evolution from effects of contamination for any data lying off the two-component mixing lines in Figure 4.3.17, i.e., within the three-component mixing triangle.

Because of the method it uses in correcting for equilibration between groundwater and carbonates, and because it involves only a limited number of empirically-derived inputs, Lambert (1987a) concludes that the model of Evans et al. (1979) is the available model most applicable in the WIPP environment. One conclusion arising from the presence of Permian marine carbonates in the Rustler and use of the model of Evans et al. (1979) is that any groundwater sample with greater then 50 PMC must either be contaminated, or must be assumed to have had very limited exposure to the carbonates present. Application of the model of Evans et al. (1979) to the entire data set results in: a) calculated isolation times of 12,100 to 16,100 years for the four low-PMC samples identified in Figure 4.3.17; and b) physically impossible negative model ages for all samples on and near the trend including modern organics in Figure 4.3.17, with the exception of samples from H-5c (Culebra) and Engle (Culebra). These two samples yield model ages of 714 and 2,410 years, respectively, but lie within the three-component mixing triangle shown in Figure 4.3.17.

Based on radiocarbon studies, Lambert (1987a) concludes that:

1. The four interpretable radiocarbon ages on Rustler and Dewey Lake fluids, i.e., those calculated on minimally contaminated samples using the model of Evans et al. (1979), indicate that some Culebra and Dewey Lake fluids present in the vicinity of the WIPP site were isolated from atmospheric radiocarbon at least 12,000 to 16,000 years ago. The relatively tight cluster of ages may suggest some type of recharge episode, rather than a gradient resulting from continuous recharge.

2. Because of there being no consistent directional age gradient in calculated ages in such old groundwaters, the radiocarbon technique provides no information concerning directions or rates of fluid flow within either the Rustler Formation or the Dewey Lake Red Beds in applications to date on WIPP groundwaters.

Table 4.15: Results of application of different interpretative models to available radiocarbon analyses, including corrections involving dolomite. Part of Table 4 of Lambert (1987a).

Locality	PMC	$\delta^{13}C$	Tamers (1975)	Pearson and Swarzenki (1974)	Mook (1976)	Evans et al. (1979)
H-4	4.82	-6.7	19300	17300	12000	16100
H-6	9.7	-8.4	13600	12600	10600	12100
H-9	2.22	-2.4	25700	20200	indet.	14900
Pocket	3.67	-3.8	21600	17400	indet.	14000

3. To date, most radiocarbon measurements on Rustler fluids collected in hydrologic drillholes are invalidated by unknown amounts and types of organic contamination occurring during and after drilling. Most fluids have a carbon-isotopic signature apparently reflecting nonresolvable three-component mixing among inorganic carbon, organic carbon from a past period of surficial recharge, and modern organic contamination introduced during drilling. All samples collected may be contaminated at some level; therefore, most calculated groundwater ages are lower limits.

4. Application of several models to calculate radiocarbon ages indicates that the best useable model is that of Evans et al. (1979), which accounts for both congruent dissolution of carbonates and possible continuing exhange of radiocarbon between the diluted groundwater solution and the surrounding country rock.

While the radiocarbon studies described by Lambert (1987a; 1988) were partially successful and indicate lower-limit isolation times for sampled fluids at four specific locations, extrapolation of the results must be done carefully. The results do not: a) mean that the sampled fluids have been in residence at the sampling sites for the indicated lengths of time; b) provide any information about where major recharge occurred when it did take place; or c) rule out small but indeterminate amounts of modern vertical recharge to the Rustler and Dewey Lake at the WIPP site. The available radiocarbon data can be interpreted consistently to mean that "steady-state" recharge of the Rustler and Dewey Lake is an actively ongoing process only at locations removed from the WIPP site, and that flow times from the point(s) of recharge to the sample localities are at least 12,000 to 16,000 years. However, the results mean that surficial recharge at the WIPP site, if significant at some time in the past, effectively stopped at the sampled localities at least 12,000 to 16,000 years ago. Two of the sampling localities, H-4 and H-6 lie close to and on nearly opposite sides of WIPP Zone 3.

Lambert (1987a) also concludes that measured ^{36}Cl and tritium contents on minimally contaminated Rustler fluids at and near the WIPP site cannot be discriminated from background values. Because of the high chlorine background in fluids that have been in contact with halite present in the Rustler and/or in surficial deposits in southeast New Mexico, no measurable ^{36}Cl was detected. No tritium content greater than 0.2 tritium units (TU) was found in any fluid that was demonstrably minimally contaminated, in contrast to a reasonable "background" level of 3 - 7 TU. The highest measured tritium content in Culebra water is 6.9 TU from WIPP-27 (Lambert, 1987a). However (Section 4.3.1.1) the Culebra at WIPP-27 is interpreted to be contaminated by potash-refining operations, on the ground of major-solute chemistry. Therefore, Lambert (1987a) concludes that there is no advantage in pursuing either technique further in the Rustler Formation at the WIPP site.

4.3.4 Uranium-Disequilibrium Studies in the Culebra Dolomite

The radiocarbon studies summarized in Section 4.3.3 indicate that the recharge age of groundwaters presently in the Culebra dolomite and part of the Dewey Lake Red Beds at and near the WIPP site is at least 12,000 to 16,000 years. While these results indicate that, independent of flow path, travel times from recharge to their present location are long, they indicate nothing about the flow directions or distances involved. The uranium-disequilibrium technique discussed in this section addresses some questions which cannot be addressed by radiocarbon or stable-isotope techniques, such as apparent directions of fluid flow. The basic principles of the uranium-disequilibrium method are discussed in both Lambert and Carter (1984) and Lambert and Carter (1987).

Interpretations of uranium-disequilibrium data can only be as reliable as the number and quality of the samples from which the data are derived, and are also limited by the applicability of the principles involved in the interpretations. There are two specific constraints to interpretation of uranium-disequilibrium data at and near the WIPP site. First, data east of Nash Draw are extremely limited in number, since values are known at only four locations, H-4, H-5, H-6, and WIPP-30. As a result, there is considerable uncertainty in both contouring of results and inferred flow directions east of Nash Draw. Second, as noted by Lambert and Carter (1987), there is no known trace component of Rustler fluids which reliably indicates whether or not any sampled groundwater is representative with respect to either total uranium content or uranium-disequilibrium "activity ratio" (A.R.). The activity ratio considered here is in terms of relative decay rates of the ^{234}U and ^{238}U isotopes, not the ratio of chemical activities. Two measurement trends have been noted which help evaluate the extent of approach to steady-state fluid composition during serial sampling and/or indicate the direction from which the sampled fluid may approach or bound a representative state for groundwater at the sampling locality. Uranium is a trace contaminant, at concentrations greater than normal for evaporitic rocks, in drilling and sampling apparatus, especially casing. Therefore, total uranium in the sampled fluid generally decreases with increasing pumping rate and/or total pumping time (Lambert and Carter, 1984), as the amount of contamination is reduced. Measured total uranium

contents in Culebra waters should represent upper bounds. The measured $^{234}U/^{238}U$ activity ratio in sampled fluids generally increases with total pumping volume and rate; i.e., with decreasing contamination from the casing and/or sampling apparatus (Lambert and Carter, 1984). This is presumably because the contamination present in sampling apparatus and casing has an Activity Ratio (A.R.) very near 1.0. Any measured A.R. in a sampled fluid should thus represent lower bounds.

As noted in Lambert and Carter (1987), interpretation of uranium-disequilibrium studies involves additional assumptions. During recharge, an initial A.R. equal to or not much greater than 1.0 (generally 1 - 3) is assumed to be fixed at the edge of the oxidation zone. There are several generalized sequences of behavior that can follow infiltration. The conceptual and numerical model used is essentially that of Osmond and Cowart (1976). The variability can be simplified by considering the relationship between A.R. and total uranium in the analyzed fluid. Under reducing conditions, the total uranium content of the fluids remains low, and the A.R. normally increases along the direction of fluid flow. This increase is a result of the preferential leachability of the ^{234}Th resulting from the alpha decay of ^{238}U within the country rock, relative to the leachability of ^{238}U (Lambert and Carter, 1984; 1987). Thus, the combination of low total uranium content and elevated A.R. is interpreted to reflect flow along a flow path under relatively reducing conditions or locally "stagnant" flow conditions, both occurring on a time scale for which the technique is applicable, approximately 2,000,000 years (Lambert and Carter, 1984). In contrast, a measured groundwater A.R. near 1.0 is taken to indicate one of three things: 1) approach to secular equilibrium after a lengthy period of radioactive decay; 2) sampling of fluids soon after recharge; and/or 3) possible "swamping" of a higher A.R. by dissolution of rock uranium having an A.R. very near 1.0. A strong correlation of increasing total uranium content of sampled fluids with decreasing fluid A.R. along an inferred flow path favors the third interpretation. This can only occur under relatively oxidizing conditions under which the congruent solubility of uranium is enhanced.

The available data for the $^{234}U/^{238}U$ A.R.s in Culebra fluids at and near the WIPP site are summarized in Figure 4.3.18. The figure shows a general eastward or southeastward increase in A.R.s east of Nash Draw. Contour lines shown in Figure 4.3.18 are based on the assumption that variations in A.R. are approximately linear between data points. From the resulting contours, it was inferred by Lambert and Carter (1987) that the most likely region of recharge for Culebra groundwaters is in or near the upturned edge of the Rustler units within Nash Draw. This interpretation reflects a major easterly or southeasterly component of flow from a recharge region within Nash Draw, assuming that high A.R.s such as measured in the WIPP site area at H-4, WIPP-30, and H-5 are generated by downgradient flow under relatively reducing conditions.

The flow directions implied by the contouring in Figure 4.3.18 are not unique, because of both the limited data east of Nash Draw and uncertain relationships between flow directions and directions in which A.R.s increase. All that is certain is that, unless no reaction is taking place, fluid flow must be at some angle to the lines of constant A.R., but need

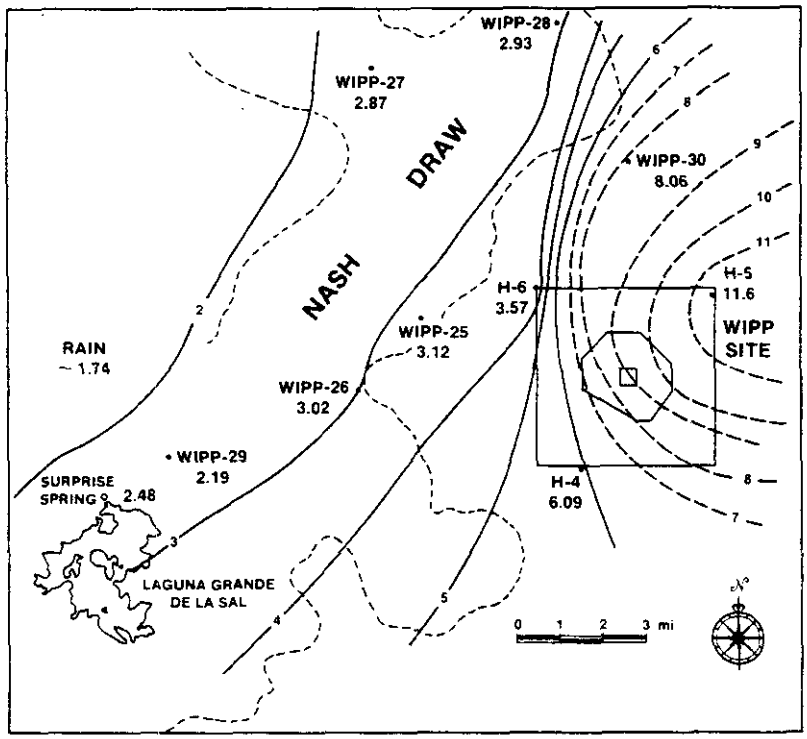

Figure 4.3.18: $^{234}U/^{238}U$ activity ratios in analyzed Culebra fluids. Figure 3 of Lambert and Carter (1987).

not be perpendicular to these lines. By analogy, groundwater flow in a fractured or anisotropic medium need not be perpendicular to potentiometric contours. If fluid flow is assumed to be perpendicular to the A.R. contours in Figure 4.3.18, flow is required to have taken place from regions of (present) high permeability in Nash Draw towards regions of (present) low permeability east of Nash Draw, such as the vicinity of H-5.

In addition, there is considerable freedom in the contouring of A.R. values themselves. An indication of this is shown in Figure 4.3.19. In the interpretation shown in Figure 4.3.19, the assumption of roughly linear variation in A.R. between data points is relaxed, and contours are rotated into a more north-south position. Under this interpretation, since the flow direction must be inclined to A.R. contours, the present A.R. distribution would be consistent with flow towards the south or southeast following recharge, i.e., at a lower angle to both the axis of Nash Draw and the very loose regional zonation of permeability within the Culebra (Section 4.1) than implied in Figure 4.3.18. However, flow towards the axis of Nash Draw is not consistent with the data.

While the uranium-disequilibrium method is not always capable of identifying the recharge area, it is capable, unlike radiocarbon applied to Rustler groundwaters, of estimating flow directions following recharge. The higher-permeability areas within the Rustler Formation in Nash Draw seem a more likely paleorecharge area than either the surface of the WIPP site area or the low-permeability areas east of WIPP-30. Therefore, flow within the Culebra following recharge probably had at least some easterly component.

Regardless of the estimated fluid-flow directions following recharge, the flow times estimated for the buildup to measured A.R.s east of Nash Draw depend on both the measured or assumed original uranium content of the host rock and the measured or assumed total uranium content of the groundwater fluid immediately after recharge. This buildup is a result of a combination of differential leachability of ^{234}Th and ^{238}U under reducing conditions and radioactive decay. In general, estimated flow times towards a measured high A.R. are inversely proportional to the initial uranium content of the groundwater and proportional to the estimated uranium content of the country rock. For example, Lambert and Carter (1987) found it impossible to generate calculated A.R.s greater than 3.4 using the mean present-day U concentration in Culebra core (0.9×10^{-6} g/g) and the lowest measured U concentration in Culebra fluid (0.134×10^{-9} g/g) as input. They interpret this inability to indicate that: (a) the present uranium concentration of the available Culebra core samples is probably not representative of the rock controlling A.R. buildup; and (b) the lowest measured uranium concentration in the fluid phase has been increased by at least some congruent dissolution.

Lambert and Carter (1987) estimated flow times to H-5, assuming that the original U content of Culebra fluids was the same as the lower value measured in fluid from the Rustler/Salado contact in hole WIPP-30 (0.024×10^{-9} g/g). Calculated travel times are approximately 550,000 and 30,000 years, for an assumed low-uranium and high-uranium Culebra matrix, respectively. The low-uranium matrix was taken as the average value

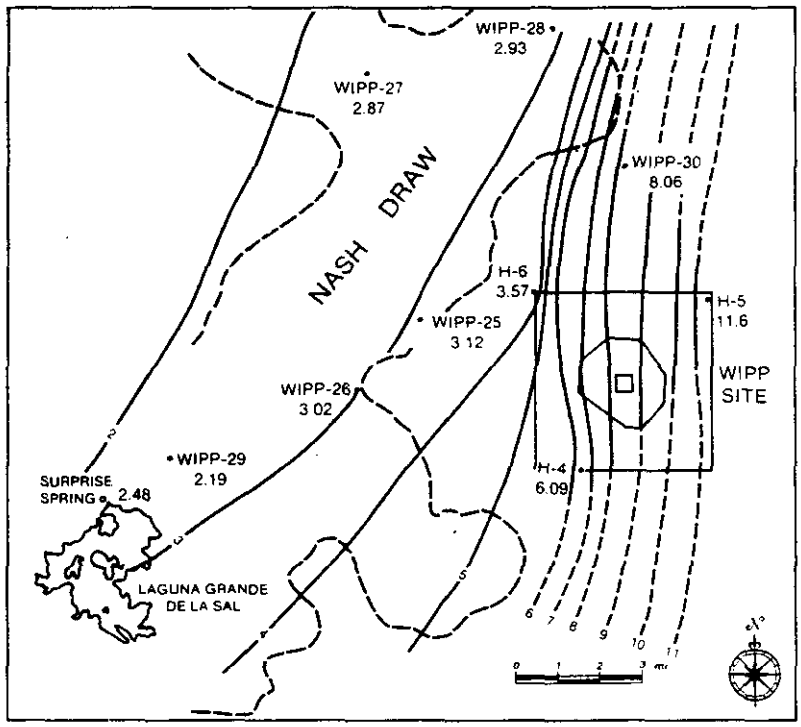

Figure 4.3.19: Contours of $^{234}U/^{238}U$ activity ratios in analyzed fluids, relaxing constraint of linear variation between data points. Modified from Figure 3 of Lambert and Carter (1987).

measured on core (0.9×10^{-6} g/g), and the high-uranium matrix (9.0×10^{-6} g/g) was assumed. The assumed value is similar to that measured in a silty zone found within a Permian limestone in Carlsbad Caverns. In the WIPP site area, local high U contents within Culebra are supported by a known (but uncored) occurrence of a silty zone in hole P-15, indicated by geophysical logging to be rich in (uranium + thorium + potassium). A final A.R.-evolution path, assuming the initial uranium content in the fluid was the same as that measured in Carlsbad rain, 0.01×10^{-9} g/g, yields estimated flow times to H-5 of 140,000 and 12,000 years, respectively for the low-uranium and high-uranium Culebra matrices.

Thus, the minimum estimated times required for ingrowth of ^{234}U to give the measured high A.R.s at H-5, assuming a uranium-rich Culebra matrix, are qualitatively consistent with the estimated minimum recharge ages based on radiocarbon studies reported in Lambert (1987a). Analyzed Culebra core has a lower uranium content than assumed in these calculations. Therefore, flow times from the position of recharge to H-5 were almost certainly much greater. The measured A.R. of greater than 11.0 at H-5 is inconsistent with any significant modern recharge in this area. A minimum flow time of at least several thousand years is required under reducing conditions to generate such an A.R., regardless of assumptions concerning initial fluid and rock-matrix properties, location of recharge, and directions of fluid flow.

The ingrowth of A.R.s cannot be considered independently of the total dissolved uranium in the fluid phase. Figure 4.3.20 indicates a westerly or northwesterly increase in the amount of uranium in Culebra waters, from the WIPP site towards Nash Draw. Although there is uncertainty in the contouring of total uranium contents, the general direction of increase correlates with a general decrease in A.R. in a similar direction (Figure 4.3.18 or 4.3.19).

It is difficult to explain how any easterly flow of oxidized fluids involved in significant evaporite dissolution could maintain both high A.R.s and low total uranium contents measured east of Nash Draw, as would be required by any interpretation involving steady-state flow directions consistent with A.R. contouring in either Figure 4.3.18 or 4.3.19. During such flow, uranium would have to be precipitated within the Culebra dolomite. No evidence for elevated uranium concentrations has been found within the Culebra, except in hole P-15; the P-15 occurrence may in fact be a detrital accumulation. Measured uranium contents of bulk Culebra core are too low to account for the measured A.R.s.

A logical explanation of the combination of measured A.R.s and total uranium contents of Culebra groundwaters at and near the WIPP site involves a change of flow directions, after development or ingrowth of the elevated A.R.s measured east of Nash Draw (Lambert and Carter, 1987). In this interpretation, an early flow system with at least some component of easterly flow under reducing conditions, would later be changed, resulting in some component of westerly flow. The magnitude of the required change in flow directions within the Culebra is not well defined at present. Combination of the contours in Figure 4.3.19 and 4.3.20 requires something like a 60-degree change, assuming recharge occurred in the northern part of

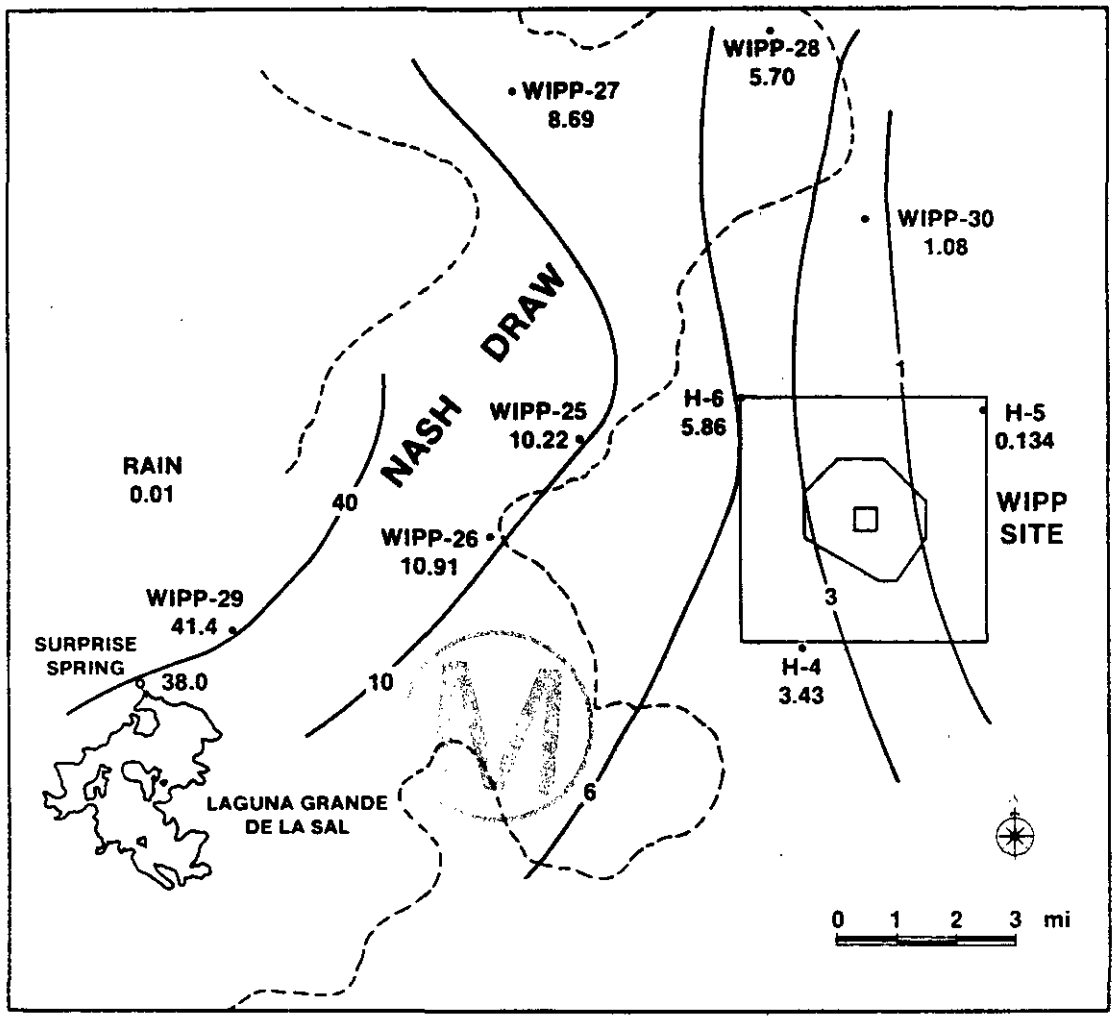

Figure 4.3.20: Total dissolved uranium content of analyzed fluids. Figure 2 of Lambert and Carter (1987).

Nash Draw. Combination of the contours in Figure 4.3.18 and Figure 4.3.20, assuming recharge within the main part of Nash Draw, implies a more marked "reversal" of flow directions.

Because of the general westward increase in total uranium in the Culebra groundwaters, the process resulting in a change in flow directions within the Culebra must include a general westward increase in oxidation potential, with resulting increase in uranium solubility. The mechanism for such an increase in oxidation potential, while not well defined at present, would presumably be related to the continuing exhumation of the Rustler Formation within Nash Draw (Lambert and Carter, 1987). Consistent with this interpretation, the redox measurements discussed in Section 4.3.1.4 generally indicate more oxidizing conditions within the Culebra south of the WIPP site and within at least part of Nash Draw than at the WIPP site.

Regardless of the detailed interpretation of transient flow directions within the Culebra, the uranium-disequilibrium studies of Lambert and Carter (1987) place strong constraints on some aspects of Culebra hydrology at and near the WIPP. These include the three constraints that:

1. *Culebra fluid residence times at or flow times to sampling* localities east of Nash Draw (H-4, H-5, H-6, and WIPP-30) are at least several thousand years. The shortest calculated residence or flow times are consistent with minimum groundwater isolation times estimated in radiocarbon studies (Section 4.3.3).

2. Regardless of the high Culebra head potentials in the area (Figure 4.1.23), no significant recharge is occurring in the vicinity of H-5. This conclusion is indicated by the high A.R. and low total fluid uranium in this area.

3. *A significant amount of evaporite dissolution, under relatively* oxidizing conditions appears to have taken place in and near Nash Draw, as indicated by the relatively high dissolved uranium contents in this area.

4.4 Recent Studies Addressing Near-Surface Geology and Hydrology at and near the WIPP Site

Considerable emphasis since 1983 has been given to evaluation of near-surface processes at the WIPP site. The primary objective of this effort has been evaluation of the potential for evaporite dissolution within the Rustler Formation. Regardless of conclusions concerning evaporite dissolution within the Rustler, studies of near-surface processes and stratigraphy at the WIPP demonstrate the transient nature of the climate and near-surface hydrologic setting in southeastern New Mexico. Section 4.4.1 summarizes recent studies of the near-surface stratigraphy and general geologic and hydrologic setting of southeastern New Mexico. Section 4.4.2 briefly summarizes recent studies concerning the extent of rock/water interactions and evaporite dissolution within the Rustler Formation.

4.4.1 Recent Studies of Near-Surface Stratigraphy at and near the WIPP Site

Recent studies of the near-surface stratigraphy at and near the WIPP site summarized in Bachman (1985) were conducted as part of the evaluation of possible near-surface evaporite dissolution. The present distribution of the Gatuna Formation at and near the WIPP site is shown in Figure 4.4.1. An ash bed relatively high in the Gatuna is between 500,000 and 600,000 years in age (Bachman, 1980). Since the Gatuna is overlain by the Mescalero caliche, which began to form approximately 500,000 years ago (Bachman, 1980), Bachman (1985) concludes that the Gatuna is ". . . at least as old as Middle Pleistocene and may contain some much older deposits." While preparing the isopachs shown in Figure 4.4.1, Bachman determined that the Gatuna along Livingston Ridge, on the east side of Nash Draw (Figure 1.1), contains cross-bedded channel deposits and conglomerates deposited by westward-flowing streams. The Bachman (1985) interpretation of the probable courses of streams at and near the WIPP site during Gatuna time is shown in Figure 4.4.2. Areas near the WIPP site presently overlain by Gatuna gravels were occupied approximately 600,000 years ago by moderate-energy stream channels. Based on comparison of the isopach maps for the Gatuna (Figure 4.4.1), Triassic rocks (Figure 4.4.3), and the Dewey Lake Red Beds (Figure 4.4.4), Bachman (1985) concludes that the Gatuna streams flowed across and eroded both Triassic and Dewey Lake Red Beds strata. In contrast, the present climate and surface-hydrologic setting at the WIPP site does not support any moderate-energy streams.

The Mescalero caliche, which overlies the Gatuna, is interpreted by Bachman (1985) as reflecting a slow process of soil formation on a stable geomorphic surface. The caliche is well-developed, and, in locations where the ". . . laminar horizon and the dense plugged horizons within the caliche are at the surface," contributes to ". . . rapid runoff and even to flooding during periods of heavy rainfall" (Bachman, 1985). Radiometric measurements indicate that the basal and upper portions of the Mescalero caliche began to form approximately 510,000 and 410,000 years ago, respectively (Bachman, 1980). The Mescalero surface on which the Mescalero caliche formed, encompasses the Livingston Ridge surface at and near the WIPP site (Figure 1.1). The widespread occurrence of the Mescalero caliche indicates relative structural stability of the Livingston Ridge surface over at least the last 400,000 years.

The Berino soil, a locally distributed paleosol up to approximately 1 m thick, is interpreted by Bachman (1985) as a remnant soil sequence that originally included the older Mescalero caliche. Local survival of the Berino, which began to form approximately 350,000 years ago, is interpreted to require ". . . a long period of tectonic and geomorphic stability within a limited climatic regime" (Bachman, 1985).

There is widespread evidence that the hydrologic setting of the vicinity of the WIPP site has changed at least once over the last 600,000 years. The Gatuna Formation, including moderate-energy stream gravels and conglomerates, was deposited at least 600,000 years ago in a setting which included actively eroding streams. Since approximately 350,000 years ago, the Livingston Ridge surface developed on the Mescalero caliche has remained

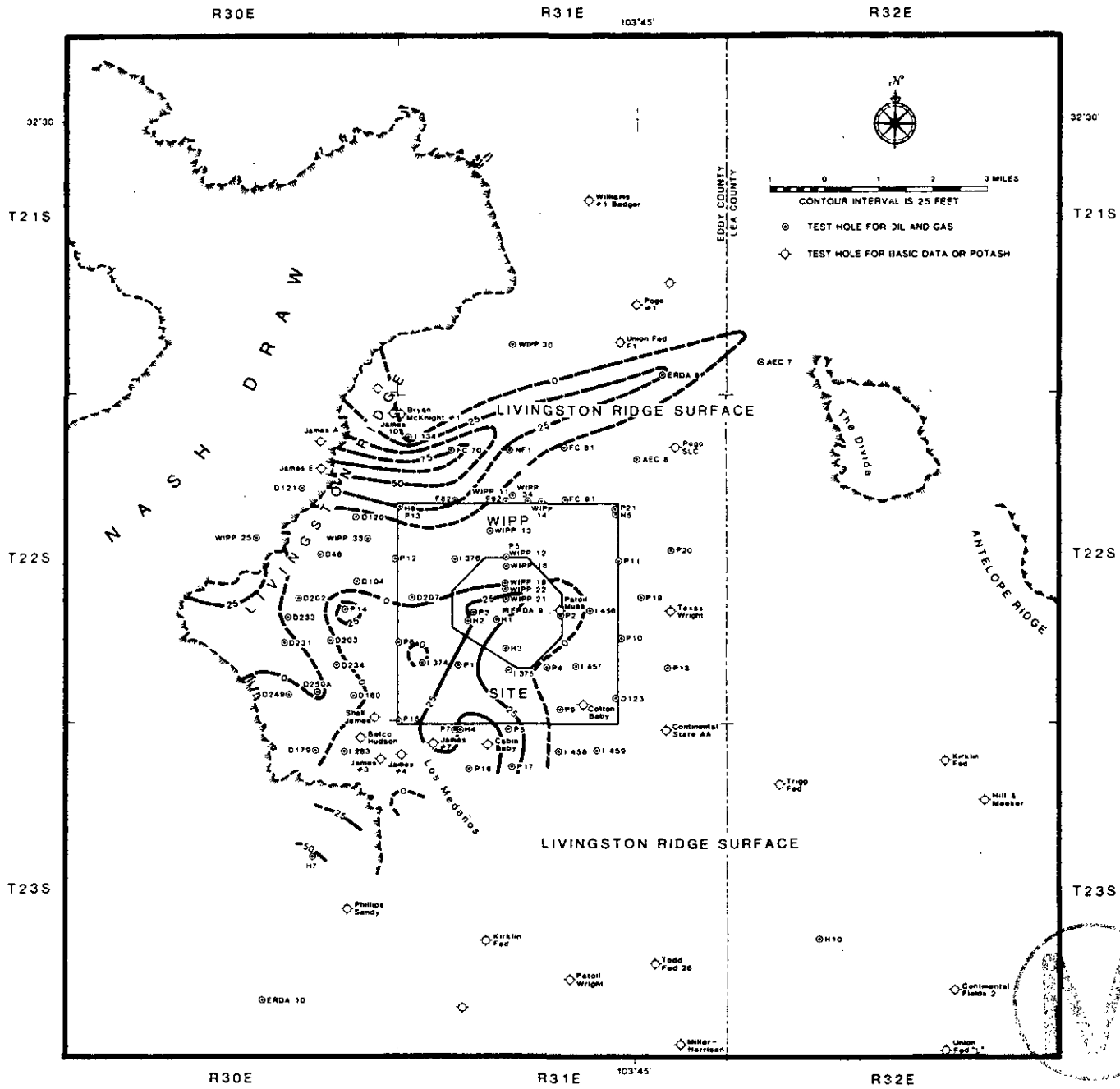

Figure 4.4.1: Distribution and thickness of the Gatuna Formation at and near the WIPP site. Figure 4 of Bachman (1985).

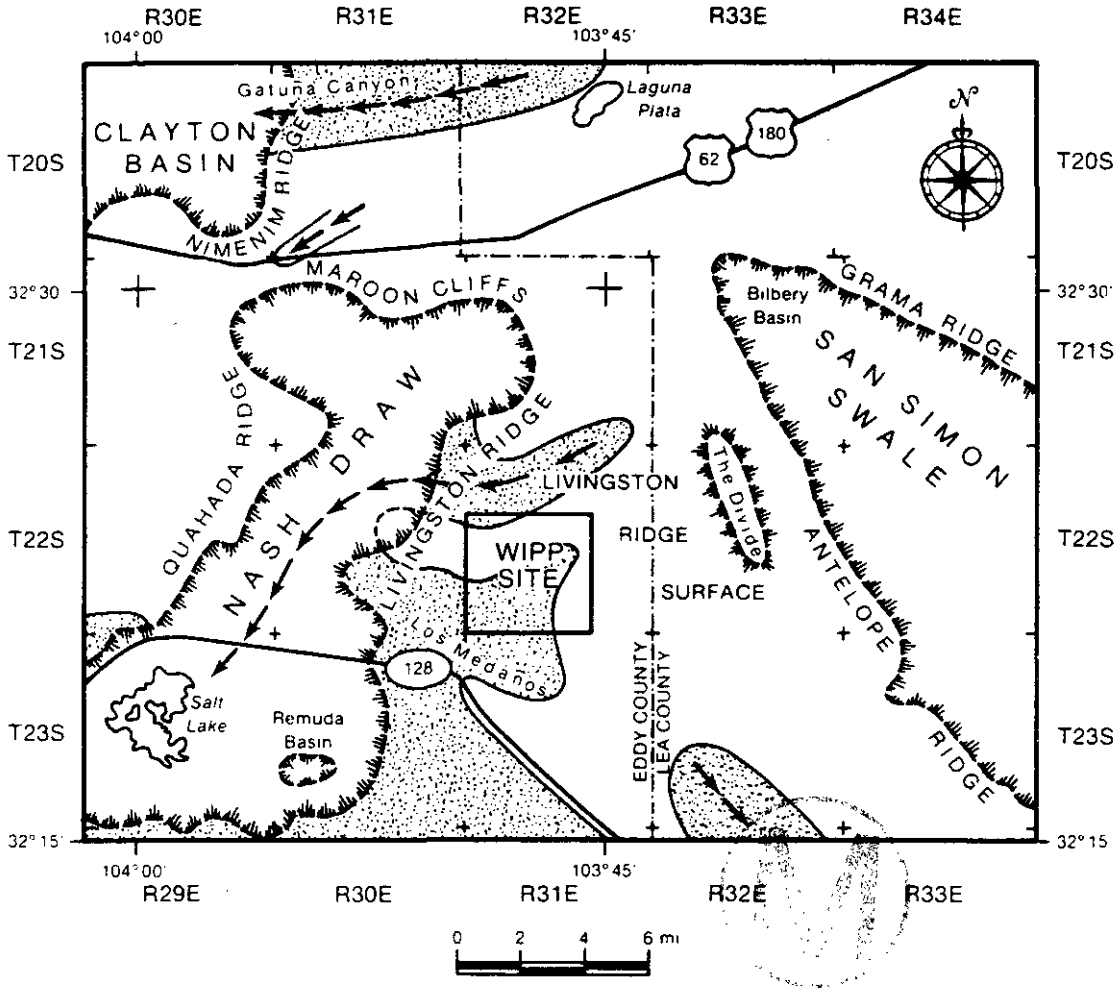

Figure 4.4.2: Probable distribution of stream channels and flow directions at and near the WIPP site during Gatuna time. Figure 11 of Bachman (1985). The present distribution of the Gatuna Formation is indicated by the stippled pattern.

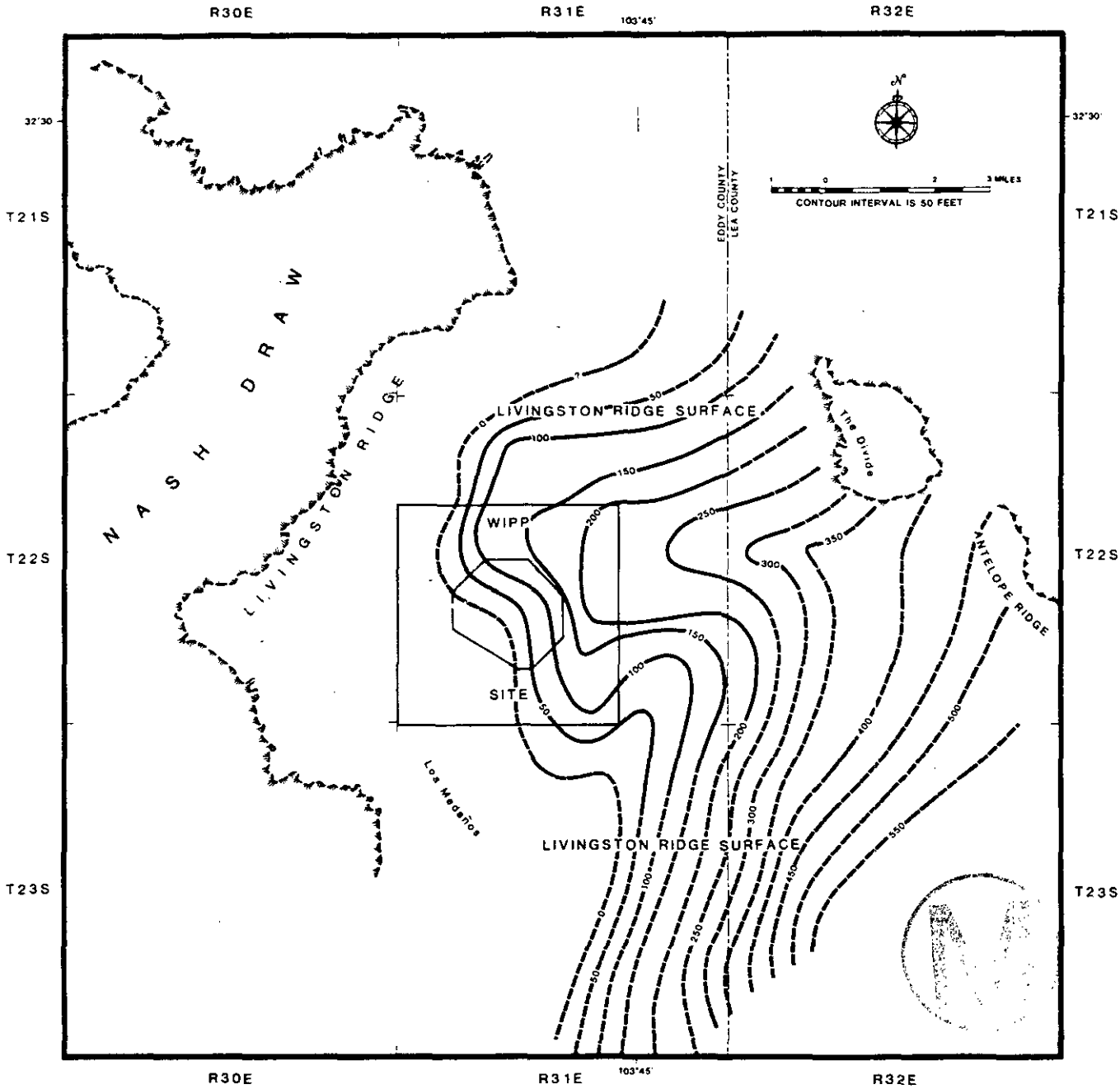

Figure 4.4.3: Distribution and thickness of Triassic rocks at and near the WIPP site. Figure 5 of Bachman (1985).

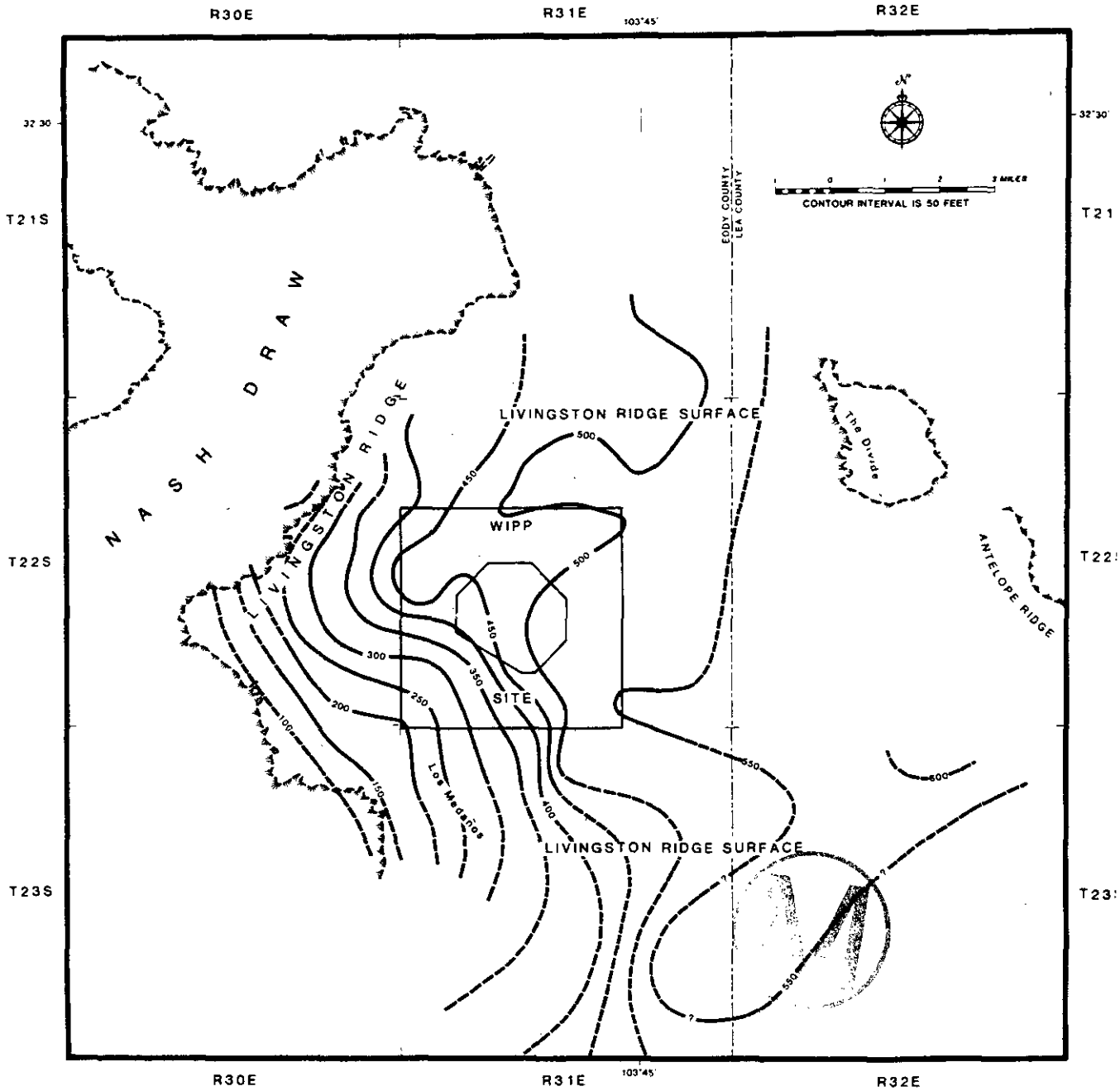

Figure 4.4.4: Distribution and thickness of the Dewey Lake Red Beds at and near the WIPP site. Figure 6 of Bachman (1985).

relatively stable; i.e., stable enough for local survival of the thin, 350,000-year-old Berino soil. The time scale of the climatic change between the Gatuna and Mescalero, however, is more than an order of magnitude greater than most groundwater residence, flow, and/or recharge times discussed in Section 4.3.

There is, however, evidence of local surface-water activity near the WIPP site, ending some 25,000 years ago (Bachman, 1980; 1985). This evidence consists of gypsite (calcium sulfate) spring deposits along the east side of Nash Draw. The fact that these springs are no longer active is interpreted by Bachman (1985) to indicate that ". . . the groundwater regime originally responsible for dissolving underground beds of gypsum and depositing spring deposits is no longer active." Bachman (1985) interprets the spring activity as ". . . part of a paleokarst system resulting from a much different [wetter] climatic regime" than the present regime in southeastern New Mexico.

There is limited evidence of regional climatic variability in southeastern New Mexico on approximately the same time scale as the gypsite springs in Nash Draw. As noted by Lambert (1987a), ". . . additional evidence for [a] wetter local climate is given by VanDevender (1980). From studying packrat middens in Rocky Arroyo, northwest of Carlsbad, New Mexico (about 35 miles northwest of the [present] study area . . . he determined that a juniper-oak community was present in the early Holocene (10,500 to 10,000 radiocarbon years ago), where now desert scrub communities exist." The presence of these middens is taken by Lambert and Harvey (1987) to indicate that ". . . in the immediate vicinity of the Delaware Basin, a wetter climate prevailed more than 10,000 years ago; the present desert scrub-plant communities have been stable in the last 4,000 years." Unfortunately, the data presented by VanDevender (1980) provide no information concerning variations in the climate in the area between approximately 10,000 and 4,000 years ago.

There is strong evidence for both climatic and hydrologic changes having occurred since at least 600,000 years ago in the vicinity of the WIPP site, and limited evidence for a "wetter" climate than present approximately 10,000 years ago. Unfortunately, there are broad time gaps in the regional information that is available. For example, no deposits are known at or near the WIPP site that are intermediate in age between the Berino soil and the gypsite springs in Nash Draw (Lambert, 1988).

The stratigraphic and paleoclimatic studies discussed in this section are not alone in indicating a transient hydrologic setting for the WIPP site and vicinity. Fluid-density and flow-time relations discussed in Sections 4.1.3.1 and 4.1.3.2, as well as hydrochemical facies discussed in Section 4.3.1 are all inconsistent with steady-state confined flow. The isotopic studies discussed in Sections 4.3.2, 4.3.3, and 4.3.4 indicate a transient hydrologic setting for the Rustler. The time scale of transience is generally consistent to within less than an order of magnitude with the time scale of the climatic change indicated by the gypsite springs in Nash Draw (Bachman, 1980; 1985) and the packrat-midden studies of Van Devender (1980).

4.4.2 Recent Studies of Evaporite Dissolution and/or Vertical Fluid Movement within the Rustler and Younger Formations

4.4.2.1 General Geologic Studies--As mentioned above, the Mescalero caliche is relatively continuous at and near the WIPP site. Where continuous, it plays a major role in limiting modern infiltration of precipitation. As noted by Bachman (1973), however, the unit is not completely continuous, since it is locally pierced by conical structures, roughly 1 m or less in diameter, resulting from localized caliche dissolution by humic acid released by plant roots. The structures generally do not completely penetrate the caliche (Bachman, 1973). Where these structures do completely penetrate, local infiltration through the Mescalero caliche may occur, at least to the depth of plant roots. The widespread presence of the Mescalero caliche on the Livingston Ridge surface must be taken to indicate structural stability of the surface, not to indicate the impossibility of localized infiltration. The widespread preservation of the caliche does indicate that not enough infiltration on a regional scale has taken place since its formation to result in its wholesale dissolution.

As discussed in Section 4.1.1 and 4.1.3, the measured head relations and relative transmissivities of members of the Rustler indicate only limited vertical fluid flow within the Rustler Formation. While there is limited vertical movement, stratabound or confined flow within the Culebra dolomite dominates the hydrology of the Rustler Formation at and near the WIPP site. If, however, vertical flow were to extend from the surface to the Rustler, through both the Mescalero caliche and the Dewey Lake Red Beds, the hydrologic setting of the Rustler Formation at and near the WIPP site might be "karstic." In such a system, vertical fluid movement both from the surface to the Rustler and within the Rustler might result in formation of solution channels or cavities. If karstic hydrology dominated within the Rustler at and near the WIPP site, transport rates to the accessible environment would be significantly increased (e.g., Chaturvedi and Channell, 1985). The presence of karstic cavities within the Rustler at the WIPP site has been proposed by Barrows et al. (1983) to explain apparent gravity patterns in the vicinity of holes WIPP-14 and WIPP-34 (Figure 4.4.1). Two additional structures have been interpreted by some to indicate the extension of the evaporite-karst behavior within Nash Draw over the WIPP site itself (see Neill et al., 1983). The first, a depression and related breach of the Mescalero caliche at hole WIPP-33, is interpreted (e.g., Bachman, 1985) as having originated by downward infiltration from the surface to sulfatic portions of the Forty-niner and Tamarisk Members of the Rustler immediately above and below the Magenta dolomite. The second is a relatively large but shallow depression in the SW1/4, SW1/4, Sec.29, T22S, R31E (see Figure 3.2 for general location), examined directly by Bachman. Bachman (1985) concludes that this structure is a result of wind erosion.

One approach used in arguing in favor of karstic hydrology in the Rustler at and near the WIPP (e.g., Barrows, 1982) is based on the assumption of an idealized water budget or water balance, independent of the presence or absence of specific structures indicating infiltration of surface recharge to the required depths. In such an approach, values of variables such as

infiltration, precipitation, and evapotranspiration are assumed to be known with high precision and accuracy. Any excess of estimated precipitation over estimated evapotranspiration is then attributed to vertical recharge from the surface to the Rustler, i.e., to karstic hydrology. As shown by Hunter (1985), however, the uncertainties in precipitation, infiltration, evapotranspiration and Rustler-discharge data at and near the WIPP site are so large that water-budget techniques cannot be used either to determine the amount of recharge or to determine that recharge is occurring. The detailed water budget described by Hunter (1985) is, in fact, not inconsistent with the conclusion (Sections 4.3.2, 4.3.3, 4.3.4) that no recharge is now occurring at and near the WIPP site. The evaluation of the potential for karst hydrology within the Rustler at and near the WIPP site must be by means of hydrologic and geochemical studies (see Sections 4.1, 4.3, and 4.4.2), rather than by an idealized water budget. The recent hydrologic and isotopic studies discussed in Sections 4.1, 4.3, and 4.4.2 place serious constraints on the plausibility of karstic recharge presently being active at the WIPP site.

If surface waters are to infiltrate to the level of the Rustler Formation, they must penetrate the Dewey Lake, after having penetrated both surficial sands and the Mescalero caliche. The presence of local structures penetrating the Mescalero indicates that localized infiltration is possible, although these structures generally do not completely penetrate the caliche and contain secondary laminar deposits resulting from infilling. Extensive studies of local surface depressions at and near the WIPP site led Bachman (1985) to conclude that:

1. Breaches of the Mescalero significantly larger than those represented by the structures resulting from dissolution by humic acid are required for more than extremely localized infiltration, i.e., for development of karstic structures or hydrology in underlying units. The Mescalero caliche continues underneath the depression in the SW1/4, SW1/4, Sec.29, T22S, R31E examined at the specific request of the New Mexico Environmental Evaluation Group (Neill et al., 1983). Therefore, Bachman (1985) concludes that the depression is a surface structure resulting from wind erosion.

2. The relatively large breach of the Mescalero beneath the surficial depression examined by drilling of hole WIPP-33 (Figure 4.4.1) in 1979 (Snyder and McIntyre, 1981) is a result of infiltration, but is unique at and near the WIPP site. The vicinity of WIPP-33 is the only region near the WIPP site in which vertical infiltration from the surface to the Rustler and resulting development of karstic hydrology and structures in the Rustler is reasonable.

Bachman (1985) does suggest that the gypsite springs along the east side of Nash Draw are the result of removal of anhydrite/gypsum from within the Rustler and development of a local flow system connecting WIPP-33 with the eastern side of Nash Draw. Either cavernous porosity or very soft clay-rich debris was encountered in Forty-niner and Tamarisk anhydrites directly above and below the Magenta dolomite in WIPP-33, but not in either the Magenta or Culebra dolomites. The depth of burial of the Forty-niner anhydrite in WIPP-33 is approximately 120 m.

The apparent WIPP-33 structure within the Rustler is consistent with interpretations that:

1. Rustler dolomites are nearly the last rock type to be significantly affected by evaporite dissolution (Snyder, 1985).

2. Because of the relative mechanical weakness of gypsum, the maintenance of open karstic structures within gypsum is possible only at relatively shallow depths. Bachman (1987) examines the regional distribution and impact of the dissolution of anhydrite and gypsum at relatively shallow depths. Certainly, sulfate dissolution has taken and is taking place within the Rustler Formation in Nash Draw, as evidenced by the continuing formation of small caves and sinkholes in the gypsums/anhydrites of the Tamarisk and Forty-niner Members.

3. The only Rustler carbonate from a water-bearing zone in the region to have recrystallized in response to input of meteoric water is at WIPP-33 (Lambert, 1988).

There is no consensus concerning the amount of evaporite dissolution within the Rustler east of Nash Draw. Two schools of thought exist. One approach, most recently summarized by Snyder (1985) and Lowenstein (1987), basically assumes an original laterally homogeneous halite distribution within the Rustler. By this assumption, lateral variability within the Rustler, especially the presence or absence of halite within the claystone portions of the unnamed lower member, Tamarisk, and Forty-niner Members, is due to halite dissolution. A simplified representation of halite distribution within the Rustler is shown in Figure 1.5. A representative cross section showing the variations in thicknesses and lithologies of individual members of the Rustler is shown in Figure 4.4.5.

As shown in Figure 4.4.5, the progressive east-to-west decrease in halite in successively lower members of the Rustler is reflected largely in decreasing thickness of the affected member. The thickness of the Culebra and Magenta dolomites varies only slightly across the area of the WIPP site. In fact, as shown by changes in Rustler thickness between holes WIPP-25 and BLM-1 (Figure 4.4.6), advanced stages of evaporite dissolution within the Rustler involve alteration/dissolution of anhydrite and gypsum rather than dolomites. The interpretations contained in Snyder (1985) and Lowenstein (1987) maximize both the total amount of halite originally present within the Rustler Formation and the amount of later dissolution. The conclusion in the WIPP FEIS (1980) that evaporite dissolution within the Rustler Formation was not of concern to the WIPP Project was based largely on extrapolation of vertical dissolution rates required to generate the depth of Nash Draw in the approximately 600,000 years since deposition of the Gatuna Formation (Bachman, 1974).

In contrast, Holt and Powers (1984; 1987) conclude on the basis of sedimentological arguments and structures that many structures within the Rustler Formation interpreted by authors such as Snyder (1985) and Lowenstein (1987) as resulting from halite dissolution are a result of primary depositional variability. By this interpretation, the amount of

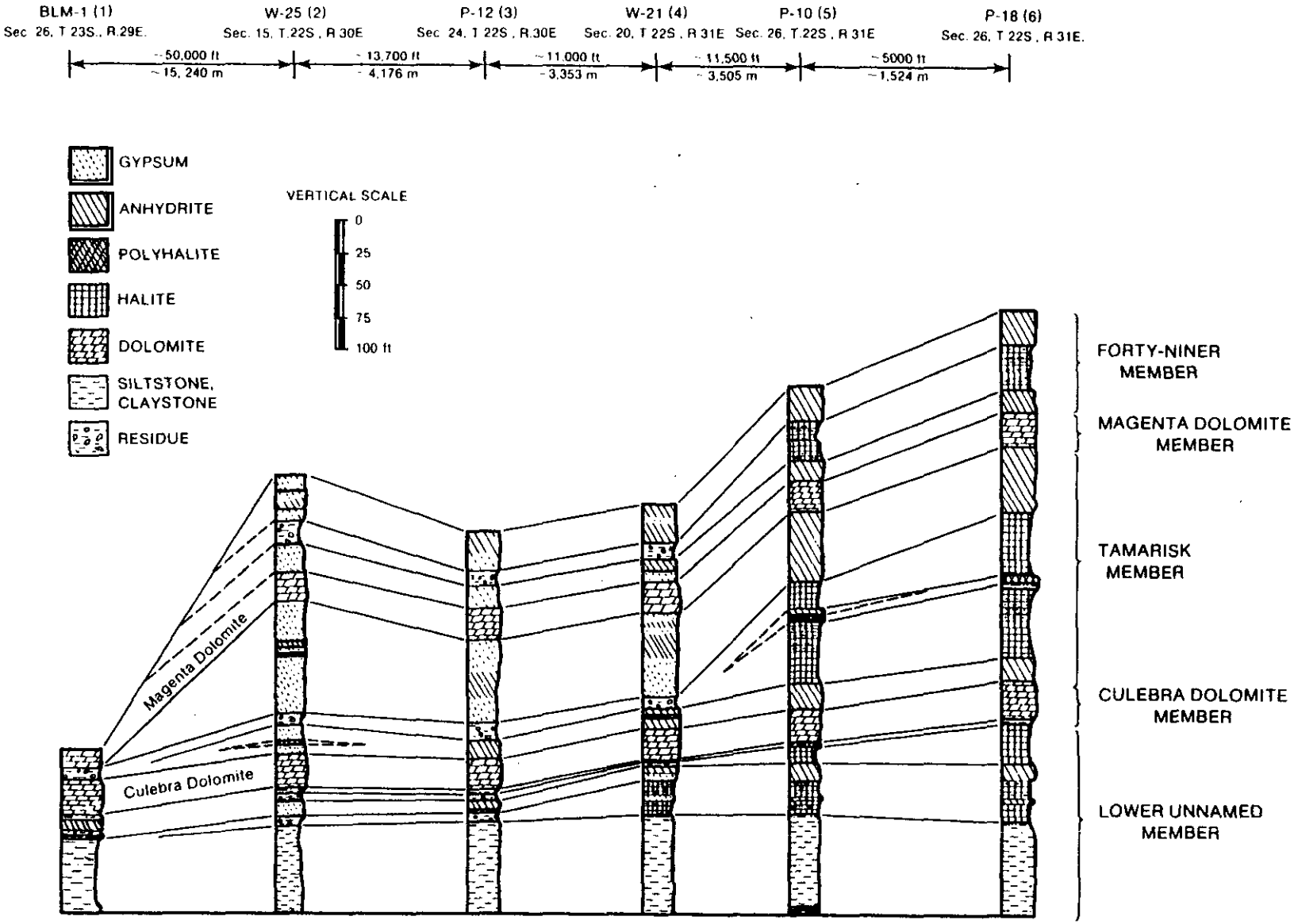

Figure 4.4.5: Columnar cross section across the WIPP site, showing lithologic correlations and variability of units in the Rustler Formation. Figure 2 of Snyder (1985).

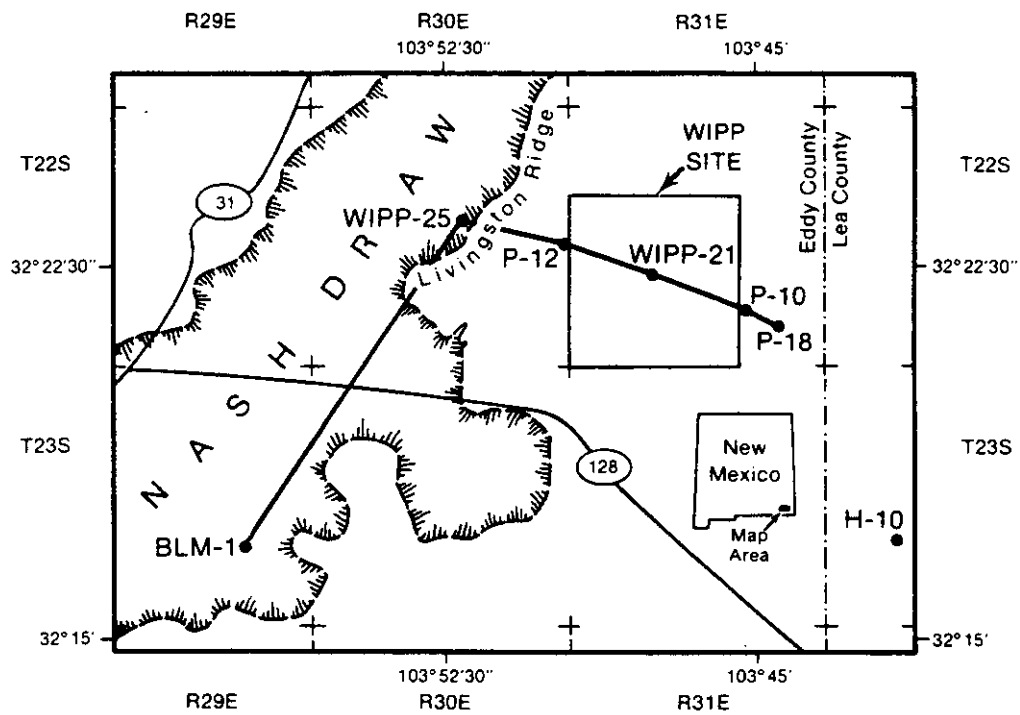

Figure 4.4.6: Hole locations used in Figure 4.4.5. Figure 1 of Snyder (1985).

halite later removed from the Rustler by evaporite dissolution is reduced. Since extrapolation of the estimated rates of dissolution within Nash Draw (Bachman, 1974) indicate that there is no need for concern at the WIPP site over the next 10,000 years, the differing interpretations do not directly affect the expected reliability of the WIPP facility. However, as discussed in Beauheim (1987b), primary depositional variability within the Rustler weakens the present understanding of the correlation between halite distribution within the Rustler, fracturing, and the transmissivity of the Culebra dolomite.

The conclusion that some of the gypsum observed within the Rustler is primary, rather than being due to alteration of preexisting anhydrite, is part of the interpretation by Holt and Powers (1984; 1987). Thus, little movement of water outside the Culebra or Magenta members might be required to account for gypsum observed in the Forty-niner or Tamarisk Members. At the other extreme, the assumption that infiltration from the surface to the Rustler is presently operative at the WIPP site, i.e., that karstic hydrology is important in the Rustler Formation east of Nash Draw or WIPP-33, requires that alteration within the Rustler and overlying formations involves surficial waters. At least localized flow through the anhydritic portions of the Forty-niner and Tamarisk Members is required by this assumption. Recent isotopic studies summarized by Lambert (1988) place constraints on the extent to which waters and hydrated minerals within the Rustler and Dewey Lake Red Beds reflect connate fluids, fluids resulting from stratabound movement, and fluids involved in vertical infiltration.

4.4.2.2 Isotopic Studies--Figure 4.4.7 summarizes $^{87}Sr/^{86}Sr$ measurements (Brookins and Lambert, 1988) on sulfates (anhydrites and gypsum) and carbonates from several evaporitic zones at the WIPP, as well as the Dewey Lake Red Beds. The isotopic signatures of samples from both the Nash Draw gypsite springs and the Mescalero caliche (see Section 4.4.1) are interpreted to represent surficial components; i.e., high $^{87}Sr/^{86}Sr$ ratios resulting from surficial weathering. At the other extreme, the markedly different and internally homogeneous isotopic signature of the anhydrites from throughout the Castile and Salado Formations is interpreted to imply that there has been no distinguishable input of surficial components to these rocks. Anhydrites and gypsums from the unnamed lower member, Tamarisk, and Forty-niner indicate only a very limited input of surficial material, presumably by solute transport by either vertical or stratabound flow.

The Magenta dolomite, which is significantly less permeable than the Culebra in most areas (see Section 4.1.1) is also more similar in $^{87}Sr/^{86}Sr$ character to the surrounding anhydrites and gypsums than is the Culebra. This implies, consistent with conclusions reached in Sections 4.1 and 4.3, dominantly stratabound fluid flow within the Rustler, with the Culebra dolomite being predominant. If the apparent surficial component of the Culebra were a result of vertical infiltration, rather than stratabound flow of originally surficial waters, the infiltration would be expected to alter the overlying portions of the Rustler. Instead, there is much less overlap between $^{87}Sr/^{87}Sr$ ratios measured in the Magenta, Tamarisk, and

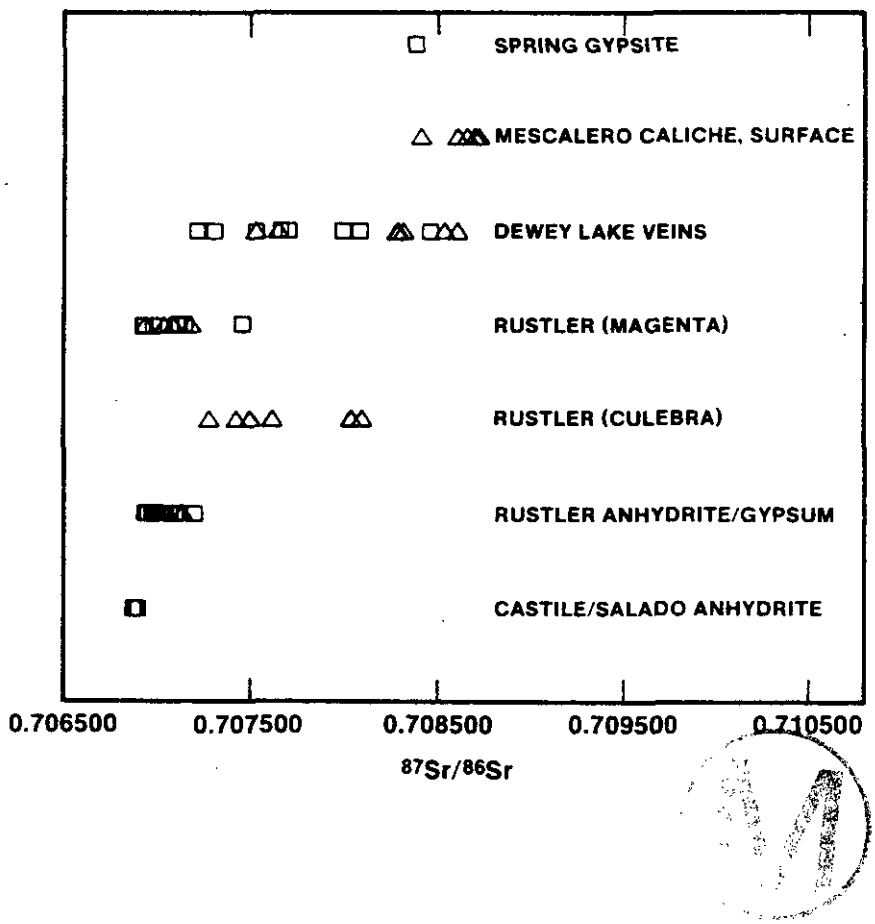

Figure 4.4.7: $^{87}Sr/^{86}Sr$ in Ochoan and related rocks at and near the WIPP site. Squares are anhydrites or gypsums; triangles are carbonates. All samples from the Dewey Lake are from veins. Samples from other units include both matrix and veins. Figure 17 of Lambert (1988).

Forty-niner Members with those measured in the Dewey Lake Red Beds than between the ratios measured in the Culebra and in the Dewey Lake.

Results contained in Figure 4.4.8 indicate further that the hydrologic system in the Dewey Lake Red Beds is significantly distinct from that of underlying units. With the exception of the Dewey Lake Red Beds, this figure summarizes the $^{87}Sr/^{86}Sr$ relationships between coexisting mineral pairs in evaporitic host rocks and in gypsum and/or calcite veins in the same unit. The question is whether these veins are locally derived or result from fluid movement over relatively long-distances. The matrix of the Dewey Lake Red Beds, however, is made up of silicic siltstones and sandstones. Therefore, carbonates and sulfates are rare in the matrix and analyses of Dewey Lake matrix materials are not included in Figure 4.4.8. The gypsum veins within the Dewey Lake probably cannot be locally derived. The strontium-isotopic character of the Dewey Lake gypsum veins (Figure 4.4.8) spans the range from surficial values represented by caliche and spring deposits in Figure 4.4.7 to isotopic values from underlying units. Since effectively none of the Dewey Lake veins can be locally derived, the range in their isotopic character indicates varying degrees of mixing of surficial waters and waters driven upward from the underlying evaporitic zones, consistent with modern head relationships discussed in Section 4.1.1.

Without exception, the strontium-isotope characters of coexisting mineral pairs from veins and host rock in units beneath the Dewey Lake are statistically identical to each other (Figure 4.4.8), indicating that the isotopic character of the vein material is controlled by that of the accompanying host rock, and not by a pervasive hydrologic system interconnected with veins in the Dewey Lake. This is even true for the one sample pair from the Culebra. These results indicate that there is little or no input of surficial material transported by groundwater below the Dewey Lake Red Beds, even into veins. All units below the Dewey Lake Red Beds considered here are evaporitic, i.e., they contain significant carbonates and/or sulfates in their matrix. Therefore, the local derivation of vein carbonates or sulfates is internally consistent.

Figures 4.4.9 and 4.4.10 indicate some constraints in rock-water ratios during gypsum crystallization or recrystallization in the Rustler and Dewey Lake. The dashed lines in Figures 4.4.9 and 4.4.10 represent the ranges in deuterium/hydrogen characteristics of Rustler water and modern surface-meteoric waters identified by Lambert and Harvey (1987) and Lambert (1988). At a sufficiently high rock/water ratio, i.e., when all of the available water is consumed in gypsum formation, for example during alteration of preexisting anhydrite, the deuterium characteristics of the resulting gypsum water of crystallization are constrained to be the same as that of the water added to the system. Therefore, the dashed fields in Figures 4.4.9 and 4.4.10 also represent the expected isotopic character of secondary gypsums formed under conditions involving very high rock/water ratios (Lambert, 1988). At equilibrium with a large excess of water, the deuterium/hydrogen ratio in gypsum is approximately 20 parts per thousand less than that of the coexisting water (Lambert, 1988). Therefore, the fields outlined by solid lines in Figures 4.4.9 and 4.4.10 are decreased from the fields outlined by dashed lines by 20 per mil and represent the

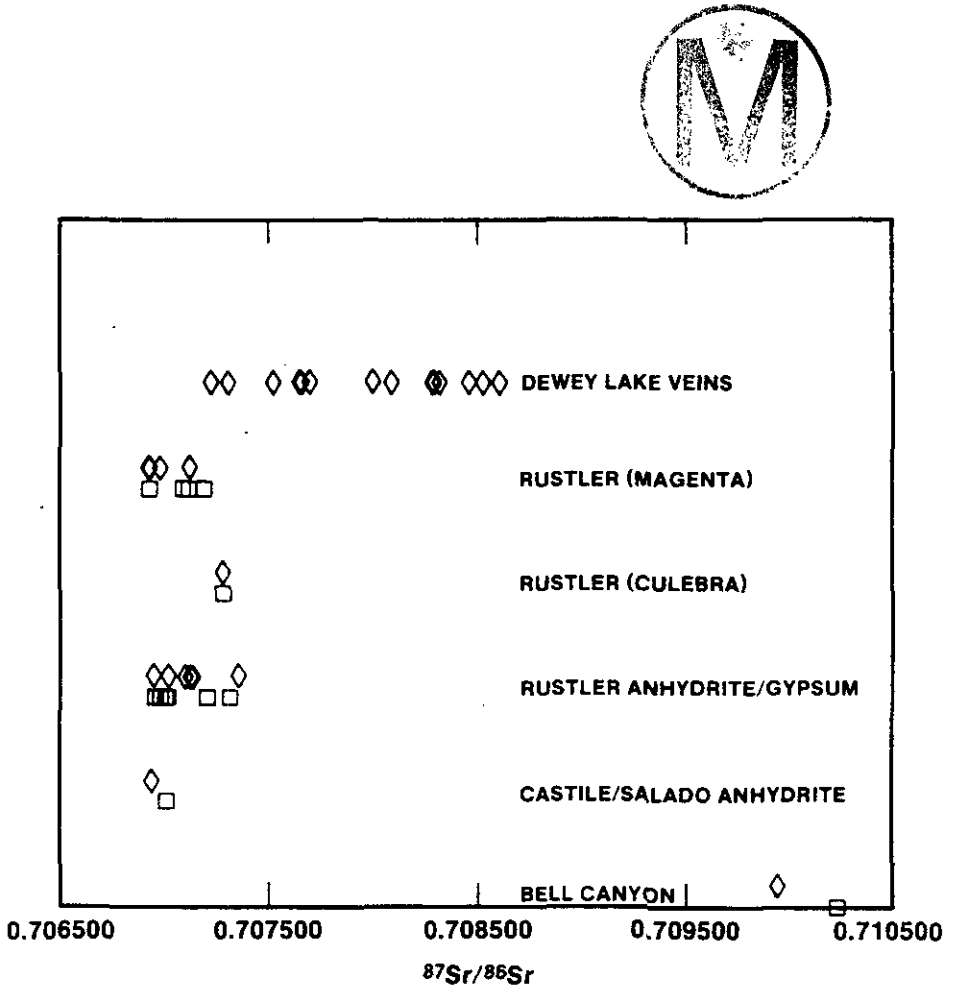

Figure 4.4.8: $^{87}Sr/^{86}Sr$ in coexisting mineral pairs from veins and Ochoan host rocks at and near the WIPP site. Squares are host rocks; diamonds are veins. Figure 18 of Lambert (1988).

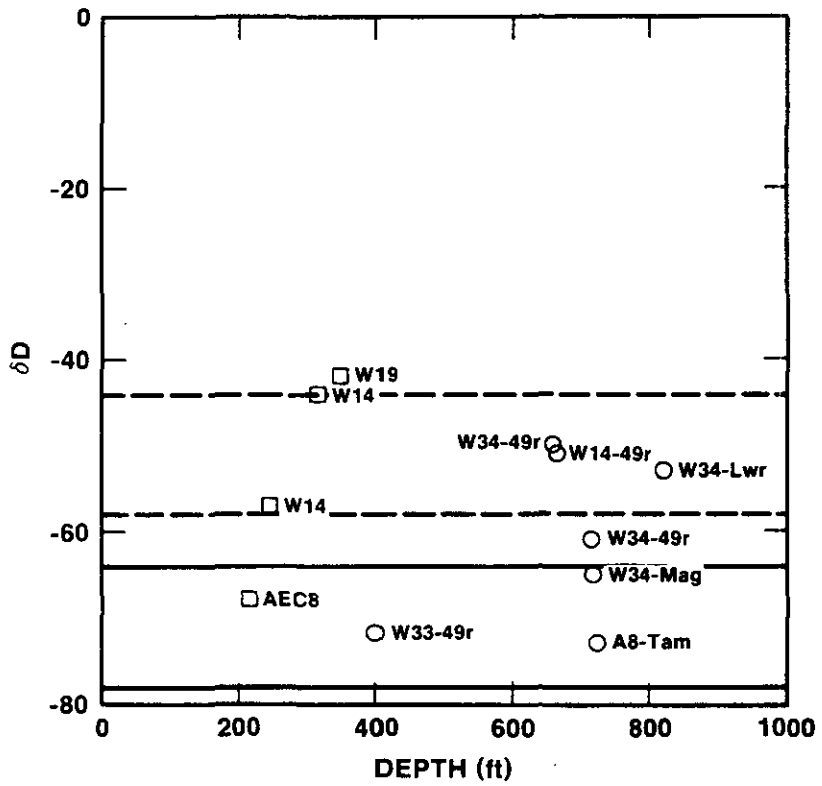

Figure 4.4.9: Deuterium distribution of the waters of crystallization of gypsums from the Dewey Lake Red Beds (squares) and Rustler Formation (circles) at and near the WIPP site, as a function of variations in rock/water ratio involving only Rustler-type water, the range in deuterium content of which is taken from Figure 4.3.10. Solid lines are for crystallization in the presence of a large amount of water, dashed lines for crystallization under conditions involving a very high rock/water ratio, in which all of the water is consumed in gypsum formation. Figure 19A of Lambert (1988).

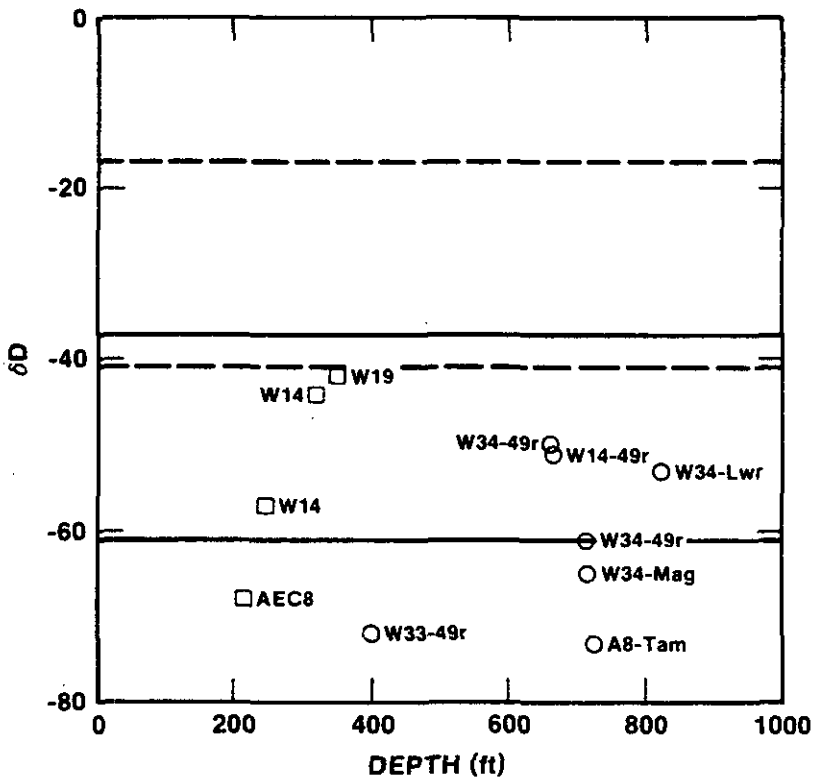

Figure 4.4.10: Deuterium distribution of the waters of crystallization of gypsums from the Dewey Lake Red Beds (squares) and Rustler Formation (circles) at and near the WIPP site, as a function of variations in rock/water ratio involving only surface-type water, the range in deuterium content of which is taken from consistent data in Figures 4.3.8 and 4.3.9. Solid lines are for crystallization in the presence of a large amount of water, dashed lines for crystallization under conditions involving a very high rock/water ratio, in which all of the water is consumed in gypsum formation. Figure 19B of Lambert (1988).

expected hydrogen-isotopic character of gypsums crystallized in the presence of excess amounts of Rustler-type and modern surface-meteoric waters, respectively.

The relationships shown in Figure 4.4.9 are consistent with crystallization of all of the analyzed gypsums with varying amounts of Rustler-type water, with the possible exception of vein material from the Dewey Lake in WIPP-19. Formation of the Dewey Lake gypsum veins in WIPP-19 apparently required infiltration of waters with the same isotopic character as those interpreted by Lambert and Harvey (1987) to represent modern meteoric precipitation. The character of the gypsum from WIPP-33 indicates crystallization in the presence of a large excess of Rustler-type water, but is not consistent with crystallization in the presence of any amount of modern-type water (Figure 4.4.10). [If it is assumed that the Magenta dolomite is more porous (permeable) than surrounding zones within the Rustler at this location, the isotopic variations in the vein gypsums from hole WIPP-34 are consistent with gypsum crystallization under varying ratios of rock to Rustler-type water.] The isotopic relationships (Figure 4.4.9) are consistent with crystallization of gypsums within the unnamed lower and Forty-niner members in response to vertical fluid flow upwards and downwards from the Magenta, assuming increasing effective rock/water ratio with increasing distance from the Magenta. This interpretation is also consistent with modern Rustler head relationships shown in Figure 4.1.3.

While results shown in Figure 4.4.9 are generally consistent with gypsum crystallization in equilibrium with varying amounts of Rustler-type waters, the results in Figure 4.4.10 indicate that this need not be the case for all samples. In Figure 4.4.10, the dashed field represents expected gypsum compositions for crystallization using modern surface-meteoric water, at a very high rock/water ratio, the solid field crystallization in the presence of greatly excess water. The hydrogen-isotopic relations indicate that it is impossible to form the gypsum from the Forty-niner Member at WIPP-33 with modern surface-meteoric water. This conclusion is consistent with the interpretations of Bachman (1980) that the gypsite springs in Nash Draw, which he believes to be the discharge for the WIPP-33 structure, are not presently active. The relations shown in Figure 4.4.10 also indicate that it is not possible to form the gypsum from the Magenta dolomite in WIPP-34 with surface-meteoric waters. The internally consistent interpretation of vertical variations in rock/water ratios within the Rustler Formation in WIPP-34, evident in Figure 4.4.9, breaks down if surface-meteoric waters are assumed to be involved.

The isotopic results summarized by Lambert (1988) indicate that there has been significant involvement of surficial waters in formation of gypsum veins within the Dewey Lake Red Beds. These same results indicate that the hydrologic behavior of the Dewey Lake is largely distinct from that of the underlying units and that there has been some upward movement of fluids into the Dewey Lake from the underlying Rustler Formation, consistent with the modern head relationships discussed in Section 4.1. Isotopic relations within secondary gypsums in the Rustler and Dewey Lake are somewhat ambiguous. In many cases, a given gypsum may have crystallized in equilibrium with either Rustler-type or modern surficial-meteoric waters,

depending on the rock/water ratio that is assumed to have been effective at the time of crystallization. The isotopic variability of gypsums from hole WIPP-34 is, however, best explained by local vertical movement of Rustler-type waters out of the Magenta dolomite, without the vertical karst channel system proposed for this locality by Barrows et al. (1983). It appears impossible to have crystallized secondary gypsum veins from the Dewey Lake at hole WIPP-19 without input of modern surface-meteoric waters. At WIPP-33, where the best physical evidence exists for vertical fluid movement from the surface downwards to the Rustler at depth, the isotopic character of analyzed vein gypsum from the Forty-niner indicates that this movement and related gypsum crystallization does not involve modern surface-meteoric water, i.e., that the WIPP-33 structure is essentially no longer active.

5.0 SUMMARY OF WIPP SITE-CHARACTERIZATION ACTIVITIES, 1983 THROUGH 1987

This section summarizes the present understanding of major aspects of WIPP site characterization, including some effort to place the WIPP facility in a regional hydrologic, structural, and geochemical prespective. A general conceptual model for the geologic behavior of the WIPP site and facility vicinity is presented in Section 5.1. Later sections describe more specific inclusions and briefly discuss remaining uncertainties or limitations. It must not be assumed either that any uncertainty discussed is significant to performance of the WIPP facility, or that any given uncertainty could be significantly reduced by further work. It is ultimately the role of the WIPP performance-assessment activity to determine which uncertainties are expected to be significant in evaluation of the short-term and long-term performance of the WIPP facility. The effort here is to provide as complete a conceptual model as possible for these decisions.

5.1 General Conceptual Model for the Geologic Behavior of the WIPP Site and Facility

The overall geologic and hydrologic setting of the WIPP site area has been transient (not steady-state) since before the beginning of deposition of the Bell Canyon Formation, approximately 250 million years ago, and will continue to be transient long after effective closure of the WIPP facility. Some events, such as crystallization of secondary minerals within the Salado Formation approximately 200 million years ago and formation of the Mescalero caliche 400,000 to 500,000 years ago, have taken place on a very long time scale relative to WIPP performance assessment, which must consider only a 10,000-year time frame. Two types of transient response have occurred or are occurring at and near the WIPP site within the 10,000-year time frame of regulatory interest. These are: a) the continuing natural response of the geologic and hydrologic systems to the end of the last pluvial period (period of decreased temperatures and increased precipitation) in southeast New Mexico; and b) the continuing responses to hydrologic, geochemical, and structural transients resulting from WIPP site characterization and facility construction. The transient responses induced by the presence of the WIPP underground workings will continue until reequilibration following effective structural and hydrologic closure of the facility.

The Bell Canyon Formation, consisting largely of shales, siltstones, and sandstones, contains the first relatively continuous water-bearing zone beneath the WIPP facility. In some parts of the northern Delaware Basin, the unit contains permeable channel sandstones that are targets for hydrocarbon exploration. Recent studies suggest that the upper Bell Canyon at the WIPP site does not contain any major channel sandstone. This decreases the probability of the Bell Canyon serving as a source of fluids for dissolution of overlying evaporites at the WIPP. These same studies indicate that the final direction of fluid flow following interconnection of the Bell Canyon, Salado, and Rustler Formations within a drillhole would be downward into the Bell Canyon, after accounting for density increases in the fluids due to dissolution of halite within the Salado. It is assumed

here that the measured hydrologic characteristics of the Bell Canyon Formation are more significant to WIPP performance assessment than those of underlying units. The head distribution within the upper Bell Canyon near the WIPP site indicates flow towards the northeast.

Both regional studies and studies within the WIPP facility indicate that the Castile and Salado Formations, both of which are made up predominantly of layered anhydrites and halites, should be considered as low-permeability units that deform regionally in response to gravity. In general, permeabilities and fluid-flow rates in both units are very low and insensitive to stratigraphy. Formation permeabilities in the Castile and Salado Formations remote from the WIPP excavations are generally 0.1 microdarcy or less, and the regional water content of Salado halites is up to 2 weight percent. Exceptions include local brine occurrences in Castile anhydrites and gas occurrences in the Salado Formation, both of which are fracture-controlled, can be large in volume, and can be under pressures high enough to cause fluid flow to the surface. No major gas occurrence within the Salado Formation has been encountered at the WIPP site. In fact, where it has been possible to measure far-field brine pressures within the Salado, the pressures, permeabilities, and available brine volumes combine to indicate the potential for only very limited fluid flow upwards into the overlying Rustler Formation. It is not certain that the Castile and Salado Formations are hydrologically saturated regionally.

Pressurized Castile brines have been encountered in Castile anhydrite in hole WIPP-12, approximately 1.5 km north of the center of the WIPP site. Geophysical studies indicate that Castile brines probably are present beneath a portion of the WIPP waste-emplacement panels, consistent with earlier assumptions. These brines are stratigraphically 200 m or more below the WIPP facility horizon and are not of concern except in the case of human-intrusion breach of the facility.

In the western part of the Delaware Basin, extensive halite dissolution has apparently taken place in both the Castile and Salado Formations. However, much of the variability in structure and internal stratigraphic thicknesses within the Castile and Salado Formations results from deformation and original depositional variability, rather than from evaporite dissolution. Regional or far-field deformation of the Castile and Salado Formations involves pressure solution as a major mechanism, due to the presence of intergranular fluids, but occurs too slowly to be of future concern to the WIPP Project. Structures within hole DOE-2 result from deformation rather than dissolution.

The hydrologic and structural characteristics of the Salado Formation in the disturbed zone generated by the presence of the WIPP facility are different than those in the far field. Formation permeability within a couple of meters of the underground workings at the facility horizon increases significantly. Near-field deformation of the Salado Formation involves both the opening of preexisting fractures in anhydrite beneath the facility horizon (Marker Bed 139) and generation of new fractures in halite. Fluid contents in the disturbed zone at the facility horizon decrease in response to facility ventilation and/or deformation. Within a few meters of the underground workings, both hydrologic and structural

behavior of the Salado Formation become essentially those of the far field. Brine seepage into the WIPP facility includes a significant transient phase, which will probably last until effective facility closure. The results of preliminary hydrologic testing in the Salado Formation adjacent to the WIPP air-intake shaft indicate extremely low permeabilities, with no apparent stratigraphic variability. The results also indicate that development of a disturbed zone around the WIPP shafts is less extensive than at the facility horizon. The extent, characteristics, and importance of the disturbed-rock zones around the WIPP shafts and at the facility horizon remain to be determined in detail.

Where not extensively altered, the Rustler Formation should be considered as a layered unit of anhydrites, siltstones, and halites, containing an important and variably fractured carbonate unit, the Culebra dolomite. The Culebra dolomite is the first continuous water-bearing unit above the WIPP facility and, at the WIPP site, is at least an order of magnitude more permeable than other members of the Rustler Formation, including the Magenta dolomite. The transmissivities of Rustler anhydrites at the WIPP site are too low to measure. As a result, the Culebra dominates fluid flow within the Rustler Formation at the WIPP site and is the most significant pathway to the accessible environment from the WIPP facility, except for direct breach to the surface by human intrusion. The transmissivity of the Culebra varies by approximately six orders of magnitude in the region containing the WIPP site. The Culebra transmissivity in the central portion of the site, including the locations of all four WIPP shafts, is low. Higher Culebra transmissivities are found in areas southeast and northwest of the central part of the site. Fluid flow rates within the Culebra are very low at the site center and in regions to the east, but relatively high within Nash Draw. Modern flow in the Culebra is confined and largely north-south in the area of the WIPP site.

Fluid flow and geochemistry within the Culebra dolomite and shallower units are in continuing transient response to the marked decrease or cessation of local recharge at approximately the end of the last pluvial period. Both bulk chemistry and isotopic relations within Culebra fluids are inconsistent with modern flow directions if steady-state confined flow is assumed. Because of the relative head potentials within the Rustler Formation at and near the WIPP site, there must be a small amount of vertical fluid flow between its members, even though the permeabilities of Rustler members other than the Culebra dolomite are quite low. Where measured successfully, the modern head potentials within the Rustler prevent fluid flow from the surface downward into the Rustler carbonates. These results do not prohibit either the modern movement of fluids from the underlying Salado Formation upwards into the Rustler Formation or the downward movement of Dewey Lake waters into the Rustler Formation during or even after the cessation of local recharge at the end of the last pluvial period. They do, however, suggest that recharge from the surface to the Rustler Formation is not now occurring at the WIPP site. The results of stable-isotope, radiocarbon, and uranium-disequilibrium studies are also consistent with the interpretation that there is no measurable modern recharge to the Culebra dolomite from the surface at and near the WIPP site. The transient hydrologic response of the Rustler Formation to the end of the last pluvial period has involved at least some change in flow

directions in the Culebra dolomite. Although the modern flow is largely north-south, the results of uranium-disequilibrium studies suggest that flow was more easterly during previous recharge.

Within and near Nash Draw, evaporite karst is operative within the Rustler, as evidenced by the continuing development of small caves and sinkholes in near-surface anhydrites and gypsums of the Forty-niner and Tamarisk Members. There is no evidence of karstic hydrology in the Rustler at and near the WIPP site. However fracturing of some portions of the Culebra dolomite is sufficient at the site to strongly affect both hydraulic and transport behavior on the hydropad scale, i.e., over distances of approximately 30 m. Interpretation of multipad interference tests conducted both north and south of the center of the WIPP site indicates that this fracturing need not be incorporated into numerical modeling of the regional-scale hydraulic behavior of the Culebra east of Nash Draw. Similarly, detailed transport calculations indicate that effects due to fracturing are not significant in regional-scale transport within the Culebra dolomite at and near the WIPP site, at least as long as the modern head distribution is not significantly disturbed and the calculated flow directions and transport properties are representative.

The Dewey Lake Red Beds overlying the Rustler Formation consist largely of siltstones and claystones, with subordinate sandstones. In tested locations, the Dewey Lake may be hydrologically unsaturated, but is too low in permeability for successful hydrologic testing. South of the WIPP site, near an area where the unit may be receiving modern recharge, sandstones within the Dewey Lake locally produce potable water. In general, water levels within the Dewey Lake Red Beds, like those in the underlying Rustler Formation, must be in transient response to the end of the last pluvial period. Isotopic relations suggest that surficial waters have been involved in the formation of secondary gypsum veins within the Dewey Lake, but that the Dewey Lake and Rustler hydrologic systems are largely separate.

The major near-surface units at the WIPP site are the Gatuna Formation and Mescalero caliche. The sandstones and stream-channel conglomerates within the Gatuna indicate that major changes in local climate have occurred over (at least) the last 600,000 years. The widespread preservation of the Mescalero caliche indicates not only the relative structural stability of the Livingston Ridge surface (on which the WIPP surface facilities are sited) over the last 400,000 years, but also that infiltration over this same time period has not been sufficient to dissolve a layer of carbonate 1 to 2 m thick.

5.2 Individual Conclusions and Discussions

This Section contains descriptions and discussions of more specific conclusions concerning geologic chracterization of the WIPP site and vicinity. In each case, the description of the conclusion is followed by a brief discussion.

5.2.1 Conclusions Concerning the Overall Geologic and Hydrologic Setting of the WIPP Site and Vicinity

1. Conclusion: The overall geologic behavior at the WIPP site has been transient since before the beginning of deposition of the Bell Canyon Formation approximately 250 million years ago. Radiometric age dating indicates that secondary polyhalites in the Salado Formation near the WIPP facility horizon crystallized approximately 200 million years ago, some 40 million years after deposition of the Salado. Fractures within MB139, which are now partially healed, probably formed in response to rapid unloading at the end of the Cretaceous or in the Tertiary, i.e., more than approximately 2 million years ago. The hydrologic setting of the WIPP site appears to be in transient response to the end of the last pluvial period.

Discussion: Not all of the secondary minerals in the Salado have been dated. The age of magnesite, which appears to play a large role in controlling the composition of fluid inclusions, has not been determined. The age of fracturing in MB139 has not been determined directly. However, given that estimated ages of secondary mineralization and fracturing within MB139 appear large relative to the regulatory time frame of 10,000 years, the present estimates are adequate. Understanding of the hydrology of the WIPP site, especially the Rustler Formation, has been a major focus of site-characterization activities (see below).

2. Conclusion: There is abundant evidence for climatic and hydrologic transients at the WIPP site over the time interval of approximately 600,000 to 300,000 years before the present, as well as for long-term structural stability of the Livingston Ridge surface, on which the WIPP surface facilities are sited. The Gatuna Formation indicates a much wetter climate approximately 600,000 years ago, resulting in the presence of relatively high-energy streams on what is now the Livingston Ridge surface. The formation of the Mescalero caliche and Berino soil indicate a relatively drier climate approximately 500,000 and 300,000 years ago. The widespread preservation of the Mescalero indicates structural stability of the Livingston Ridge surface for approximately 300,000 years. In addition to structural stability, the preservation of the Mescalero caliche indicates that the regional infiltration over approximately the last 500,000 years has been insufficient to dissolve the existing caliche.

Discussion: The available geologic data do not provide a continuous time-stratigraphic record over the last 600,000 years. For example, only the upper portion of the Gatuna Formation has been dated; the age of lower portions of the unit is unknown. No dated deposits younger than the Berino soil are present at the WIPP site. Regional preservation of the Mescalero caliche does not mean that there is no local infiltration of surficial waters, since local dissolution of caliche due to the action of plant roots is known; in some places, the resulting structures completely pierce the Mescalero.

3. Conclusion: There is localized evidence for climatic and hydrologic changes near the WIPP site on the time scale of 25,000 to 10,500 years ago. Gypsite springs along the east side of Nash Draw appear to have been inactive for approximately 25,000 years. Packrat middens northwest of Carlsbad indicate a climate approximately 10,000 years ago significantly cooler and wetter than that approximately 4,000 years ago.

Discussion: Neither gypsite springs nor packrat middens have been found at the WIPP site proper. The radiometric age-dating of the gypsite spring deposits is not internally consistent, although the faunal assemblage in the deposits is definitely Late Pleistocene in age. The gypsite springs and packrat middens provide only a qualitative indication of change in climate and precipitation. Therefore, they cannot be used as direct input for transient boundary conditions in numerical modeling of hydrology at the WIPP site. Little information is available concerning the climate and hydrology of the northern Delaware Basin between approximately 10,000 and 4,000 years ago.

4. Conclusion: There is abundant evidence that the natural fluid flow and geochemistry of the Rustler are dominated by confined flow within the Culebra dolomite at and near the WIPP site, and that flow within the Culebra is transient on a time scale of approximately 10,000 years or longer.

The hydrology and geochemistry of the Rustler, and therefore those of all other units as well, are recovering from the most recent pluvial interval in southeastern New Mexico. Factors indicating the overall transient setting of Rustler hydrology at and near the WIPP site include: a) the inconsistency between modern flow directions and present brine-density distribution within the Culebra dolomite if steady-state confined flow is assumed; b) the inconsistency between present hydrochemical facies within Culebra fluids and modern flow directions if steady-state confined flow is assumed; c) the inconsistency between the isotopic characteristics of Rustler fluids and both modern flow directions and surficial recharge to the Rustler at and near the WIPP site; and d) geologic, isotopic, and hydrologic studies indicating that vertical fluid movement into and out of the Rustler Formation is limited.

Because the transmissivities of non-carbonate units within the Rustler are not zero and different hydraulic heads are known in different Rustler members, there must be limited vertical fluid flow within the Rustler Formation. However, the transmissivities of Rustler anhydrites and the Tamarisk claystone at and near the WIPP site are too low to measure; therefore vertical fluid flow must be extremely limited.

Discussion: The present isotopic data bases are limited in size. Therefore, the presence of small structures inconsistent with regional interpretations is possible. In addition, because of the limited data base, directions of flow interpreted from uranium-disequilibrium studies include considerable uncertainty. The available results indicate that,

although stratabound flow within the Culebra dolomite dominates at and near the WIPP site, this is not necessarily true within Nash Draw. Because of the existence of small caves and sinkholes within Tamarisk and Forty-niner anhydrites in Nash Draw, there must be a qualitative increase in the transmissivity of these members somewhere between the WIPP site and Nash Draw. Avaliable evidence suggests that this change does not take place east of WIPP-33.

5. Conclusion: At least three types of man-induced transients at the WIPP site are known or can be expected. The transients include hydrologic, geochemical, and structural effects, independent of the emplacement of waste.

   The hydrology of the Rustler Formation at and near the WIPP has been and will continue to be affected by both hydrologic testing in the area and the construction and sealing of the WIPP shafts. The hydrologic behavior of the Salado Formation, both in the WIPP facility itself and adjacent to the access shafts, has been altered by construction of the WIPP facility and shafts. This alteration includes development of a local altered or disturbed rock zone, within which permeability is significantly increased and a zone of partial saturation has probably developed. The altered zone, however, is probably less extensive around lined shafts than at the facility horizon.

   In the Rustler Formation, the use of lost-circulation materials during the drilling of hydrocarbon-exploration holes and hydrologic test holes not drilled with air has resulted in development of at least local geochemical transients of unknown magnitude, lateral extent, and duration. Any far-field radionuclide migration outside the WIPP facility in the Rustler may be superimposed on these transients. Possible geochemical alteration within the Salado Formation due to the presence of the WIPP facility remains to be examined in detail, with the exception of effects due to emplacement of TRU wastes. For example, the long-term geochemical stability of grouting materials used in both the Rustler and Salado is not yet known.

   The construction of the WIPP facility imposes a transient near-field structural effect on at least nearby portions of the Salado Formation. At the facility horizon, this effect includes both local opening of preexisting fractures in MB139 and formation of fractures in halite. Transient structural behavior around the WIPP shafts will include the Rustler Formation and extend to the land surface. However, the limited information available to date suggests that structural effects around the WIPP shafts will be less than those at the facility horizon.

Discussion: The effective time scales of the man-induced transients in and near the WIPP facility are not well known. Transients directly resulting from the construction of the WIPP facility will last until reequilibration following the effective hydrologic and structural closure of the facility. The time scale of hydrologic transients within the Rustler induced by hydrologic testing is short, maybe decades. The time scale of induced geochemical transients within the Rustler is not known. Only those

transients which might affect the performance of the WIPP facility need be determined in any more detail than indicated here. Determination of which transients need be considered is part of the WIPP Performance Assessment activity.

5.2.2 Conclusions Concerning the Bell Canyon Formation

1. Conclusion: Calculations completed as part of the WIPP SPDV effort indicate that the Bell Canyon does not have sufficient brine-carrying capacity to dissolve halite rapidly enough for halite dissolution within the Castile and/or Salado Formations as a result of brine-density flow. Therefore, in regions of the Castile and Salado reasonably removed from concern regarding stratabound dissolution, such as the WIPP site, only halite dissolution as a result of diffusional processes need be considered. Such diffusion proceeds at a rate too slow to be of concern to the WIPP Project.

Discussion: The conclusions are dependent upon the assumed gradients within the Bell Canyon and range of Bell Canyon hydraulic properties, both of which are somewhat uncertain. The SPDV calculations did not result in total agreement that point-source dissolution was not a feasible mechanism at the WIPP site. However, the structure specifically proposed as a result of point-source dissolution was directly examined by drilling and testing of hole DOE-2, and was found to result from deformation within the Castile and Salado Formations, rather than from halite dissolution.

2. Conclusion: Investigations in holes Cabin Baby-1 and DOE-2 suggest indicate that the upper Bell Canyon Formation beneath the WIPP site is not significantly permeable. Therefore, regardless of the relative heads, the volumes of fluid flow between the Culebra dolomite and the upper Bell Canyon would be minor if the two units were interconnected as a result of drilling. These same studies indicate that the final direction of fluid flow would be downward into the Bell Canyon.

Discussion: Although Cabin Baby-1 and DOE-2 lie directly south and north of the WIPP site center, they provide only two data points. Given the regional trends of the Ramsey channel sands in the upper Bell Canyon, it is possible that a narrow sand crosses the center of the site from northeast to southwest, without having been intersected by either drill hole. The conclusion concerning directions of fluid flow pertains only to the final direction of flow, assuming halite saturation of both Bell Canyon and Culebra fluids as a result of dissolution of Salado halite. The conclusion does not describe either directions or rates of fluid flow prior to such saturation. In addition, the conclusion assumes that the fluid-carrying capacity of the Bell Canyon is sufficient to completely overwhelm any potential heads within the Salado Formation. This assumption appears reasonable, given the extremely small volumes of Salado flow intersected in hydrologic test holes at the WIPP site.

5.2.3 Conclusions Concerning the Castile and Salado Formations

1. Conclusion: Regional-scale deformation of the Castile and Salado Formations may well be ongoing at and near the WIPP site in response to gravity. However, estimation of the time required for formation of the WIPP-12 anticline indicates that such deformation probably occurs at a rate too slow to be of concern to the behavior of the WIPP facility. Fluids play a major role in regional-scale deformation of the Castile and Salado Formations, especially in deformation of halites and anhydrite stringers or laminae. Both estimated deformation rates and mechanistic considerations are consistent with pressure solution being a major deformation mechanism on the regional scale. This conclusion is consistent with greater deformation rates at lower differential stresses than would be the case for strictly anhydrous deformation. Inclusion of pressure solution as a deformation mechanism results in predicted strain rates at the WIPP site which are consistent with estimated rates elsewhere.

Discussion: Regional-scale deformation in response to gravity is not constrained to occur at a constant rate. Therefore, deformation rates averaged over long periods of time may be exceeded during shorter intervals. For pressure solution to be active, there must be a relatively continuous fluid film along grain boundaries. While textural evidence of pressure solution has been noted in core from the WIPP site, the presence of the required grain-boundary film has not been demonstrated directly. Although the role of pressure solution in regional-scale deformation is probable, it is not clear if or when the same mechanism will become dominant in near-field deformation around the WIPP facility. If it did become active, it would help accelerate mechanical closure of the facility by increasing deformation at relatively low differential stresses.

2. Conclusion: Much of the variability in both total and interval stratigraphic thicknesses of the Castile and Salado Formations at and near the WIPP site is due to syndepositional and postdepositional deformation, rather than to evaporite dissolution. Therefore, any interpretation of the thicknesses of these units must be done on a vertical scale involving as much of the Salado and Castile as possible, rather than on the scale of a single stratigraphic interval. Similarly, the interpretation must be done on as large a geographic scale as possible, since horizontal movement, especially of halites, is involved. Apparent one-hole anomalies are especially suspect.

Discussion: On the regional scale, especially in the western portion of the Delaware Basin, regional dissolution has apparently removed the halite from both the Castile and Salado Formations, and the original thickness of halite is unknown. At the local scale, as demonstrated in hole DOE-2, dissolution cannot be ruled out without interpretation on a broad stratigraphic and geographic scale.

3. Conclusion: The basinal structure in hole DOE-2, near the northern boundary of WIPP Zone 3, extends downwards from MB124 in the Salado to the top of Castile Anhydrite I. However, the DOE-2 structure resulted

from syndepositional and postdepositional deformation, rather than from halite dissolution. Deformation involved in formation of the DOE-2 structure resulted in displacement of all but 2 m of halite from the Castile Formation. However, both the Castile anhydrites and the entire Salado Formation (especially halites) are unusually thick in this hole. No evidence of dissolution was identified in DOE-2 core.

Discussion: The present understanding of the hydrology and structural behavior of the Castile and Salado Formations indicates that point-source dissolution of evaporites requires connection with a major source of unsaturated water, such as the Capitan limestone. This is not known to have occurrd within the body of the Delaware Basin, with the possible exception of the emplacement of Castile brines. While the present hydrologic and structural understanding does not allow prediction of where either point-source dissolution or a gravitational structure such as that at DOE-2 might form in the future, the drilling, coring, and hydrologic testing of DOE-2 demonstrates that no such structure presently exists within WIPP Zone 3. Calculations indicate that rates of gravitationally driven deformation are too slow to be of concern to the WIPP facility on the regulatory time scale.

4. Conclusion: The average far-field permeability of the Salado Formation, based on testing both from the surface and near the WIPP facility horizon, is 0.1 microdarcy or less, except where fractures locally contain small or large volumes of gas at elevated pressures. The stratigraphic variability of far-field permeability within the Salado is presently unknown, but appears negligible.

Discussion: It is not known for sure that the Salado is hydraulically saturated in the far-field. Known gas occurrences in drilling from the surface and within the WIPP facility indicate that partial saturation may be present in both the near-field and far-field, at relatively high confining pressures. The distribution of fracture systems, range of possible initial gas pressures, and effective fracture permeabilities in the far-field Salado remain unknown.

5. Conclusion: Where it has been possible to measure Salado fluid pressures, calculated heads indicate the potential for limited fluid flow upwards into the overlying Rustler Formation. Measurements to date indicate, however, that the amount of fluid available from the Salado is extremely limited. At least in the case of WIPP-12, the Salado fluid pressures and calculated heads exceed those in the underlying Castile brine reservoir. It has not been possible to determine any discrete source of fluid flow within the Salado Formation in testing from the surface.

Discussion: The measured Salado fluid pressures indicate only the possible directions of modern fluid flow. The measured pressures may be relict, developed under different geologic conditions than those at present, e.g., they may have been developed during the last pluvial period. The time scale on which such pressures or heads might change as part of the transient overall response of the WIPP hydrologic setting to the end of the

last pluvial period is not known, but must be long, given the low regional permeability of the Salado.

6. Conclusion: Water contents of Salado halites in the far-field appear to be as much as 2 weight percent, based on geophysical logging, greater than previously estimated. This does not have any direct impact on expected fluid flow into the WIPP facility, other than indicating that fluid volumes available to support long-term fluid flow may be greater than previously expected.

Discussion: To date, the interpretation of far-field water contents is based only on geophysical studies. Measurements on core are ongoing.

7. Conclusion: Consistent with assumptions maintained since brine was encountered in Castile Anhydrite III in WIPP-12, recent geophysical studies indicate that Castile brine may be present beneath a portion of the WIPP waste-emplacement panels. Brine is most likely present beneath the northern and northeastern portion of the waste-emplacement panels, and probably comes close to the southwestern and southeastern corners of the panels. However, the brines, if present, are 200 m or more below the WIPP facility horizon, and are not of concern except in the event of drilling-induced breach connecting a brine occurrence with the WIPP facility.

Discussion: Because of the dominant effect of the underlying Bell Canyon Formation, it is possible that the interpreted brine occurrences within the Castile are not real. Three-dimensional modeling of the results does not appear promising in defining the lateral distribution of Castile brines more accurately. Because of the vertical uncertainty inherent in the measurements, it is not possible to distinguish between brine occurrence within Anhydrite III and within Anhydrite II. However, where Castile brines have been encountered, it has always been present in the uppermost anhydrite.

8. Conclusion: Both uranium-disequilibrium studies and structural calculations appear consistent with emplacement of brines into fractured Castile anhydrites as a result of an episodic process. The process may involve either local brine movement during deformation and fracturing of anhydrite in low-pressure locations such as anticlinal crests, or long-distance fluid movement into preexisting fractures as a result of episodic hydrologic connection of the Capitan limestone and Castile Formation.

Discussion: It is not agreed that deformation or hydrologic connection of the Capitan limestone and Castile is the relevant episodic process involved in generation and/or emplacement of Castile brines. Structural studies indicate that deformation of the Castile Formation is episodic, with resultant episodic generation and emplacement of brines. Under these assumptions, generation of fractures and migration of brines into anhydrites may occur during the next 10,000 years, but probably at too low

a rate to be of concern to the WIPP Project. Isotopic studies are interpreted to indicate a residence time for Castile brines sampled at ERDA-6 and WIPP-12 of more than 100,000 years. While this interpretation indicates prior hydraulic connection of the Castile anhydrites and the Capitan limestone, it also indicates that this connection has not been operative for more than 100,000 years.

9. Conclusion: Both fluid-inclusion and grain-boundary fluids are present within the Salado Formation, in addition to loosely-held waters of hydration in hydrated minerals. The composition of Salado fluid inclusions is apparently controlled by the crystallization of polyhalite and magnesite. Radiometric age dating of polyhalites indicates that they are approximately 200 million years old. Therefore, the Salado fluid inclusions appear to be approximately 200 million years old. Fluids encountered within macroscopic flows into the WIPP facility appear to be dominantly grain-boundary fluids rather than fluids from fluid inclusions. The composition of grain boundary fluids within the Salado is apparently controlled by diagenetic reactions involving crystallization of Mg-rich layer silicates. Because the kinetics of these reactions are slow, it is concluded that the residence time of grain-boundary fluids within the Salado is at least several million years. The marked vertical variability of fluids near the WIPP facility horizon indicates very limited vertical fluid flow within the Salado.

Discussion: Crystallization of magnesite appears to have a major affect on fluid-inclusion compositions. However, magnesite from samples at the WIPP has not been dated. It has not been possible to estimate the residence time of Salado grain-boundary fluids directly. Radiometric measurements indicating ages for clay minerals greater than the Permian indicate that diagenetic or secondary reactions involving Mg have not involved complete recrystallization.

10. Conclusion: In the Salado Formation near the WIPP facility, there is strong coupling of deformation and hydraulic behavior. Within approximately 2 m of the underground rooms and entryways, fracturing and probable matrix dilation have led to a marked increase in permeability, and quite possibly to development of a zone of partial saturation. The increase in permeability appears to be both time-dependent and geometry-dependent. Within a few meters of the underground workings, however, the hydrologic properties of the Salado essentially become the same as regional properties.

The time scale on which the WIPP facility will affect the local hydrology of the Salado Formation, while undetermined at present, is likely to be extensive, continuing until reequilibration after effective mechanical closure of the facility. Within the facility, there is a three-stage generalized flow behavior. Holes are normally dry when first drilled. Fluid flow then normally rises rapidly to a maximum flow rate, after which it more slowly decreases to something approximating steady-state flow, though probably still decreasing. Porous-medium calculations based on the estimated far-field permeability indicate that steady-state fluid flow might not be

reached for more than 5000 years, because of the extremely low permeabilities; these calculations do not yet include consideration of facility closure. The observed "steady-state" flow is qualitatively consistent with measured far-field permeabilities. Both measurement and calculations to date indicate that effective pore pressures within the Salado have been affected by the presence of the WIPP facility only within a few meters of the facility.

Discussion: Within the altered zone around the WIPP facility, the porous-medium approximation may not be adequate for either flow or transport modeling. The distances from the underground workings at which this simplifying assumption becomes valid remain to be determined. At present, there is not an adequate characterization of the fracturing adjacent to the WIPP facility to allow realistic modeling of flow and transport behavior within the altered zone, nor do adequate models exist. The long-term extent of the altered (fractured) zone around both underground workings and shafts remains unknown. However, the zone should be larger around underground workings than around lined shafts. Both the total long-term brine seepage to be expected from the Salado and the total volume of the Salado affected by fluid flow depend on the available porosity as a function of time within the WIPP facility and any altered zone that may be present. The effects of stress relief around the WIPP facility on both near-field and far-field hydrology will be examined in detail during the WIPP operational-demonstration period.

11. Conclusion: Preliminary hydrologic testing adjacent to the WIPP waste-handling shaft indicates that all of the tested intervals, which include claystone and siltstone in the unnamed lower member of the Rustler and both halites and anhydrites within the Salado, are extremely low in permeability. While there was evidence of a hydraulic cone of depression around the shaft, there was no evidence of fracturing or alteration, except at the 850-ft level. At this level, pressurized fluids were encountered at the liner/rock interface and flowed into the test hole. Testing extended from approximately 2 m outside the shaft liner to a depth of some 10 m. The results are consistent with the interpretation that damage effects due to either blasting of the shaft or deformation around the shaft do not presently extend more than two meters into the surrounding rock mass.

Discussion: Due to scheduling constraints, only one or two holes was/were tested at each level. Therefore, these results do not indicate a complete absence of fracturing, merely that fractures were not intersected by the one or two holes at each level, except the 850-foot level. To better determine the presence or absence of fracturing by direct measurement, arrays of three or more holes would be needed at each level. The results do not indicate a potential altered zone within 2 m of the liner. Finally, the waste-handling shaft has been at its present diameter for approximately four years. The operational phase of the WIPP is expected to extend approximately 25 years, after which shaft seals must be emplaced successfully. The extrapolation of the present results to 25 years may not be reliable.

12. Conclusion: Anhydrite Marker Bed 139, approximately 1 to 2 m beneath the WIPP facility horizon, contains partially healed and filled fractures which predate construction of the WIPP facility and play a significant role in both mechanical deformation near the WIPP facility and the near-field enhancement in permeability. The estimated age of the fractures is at least two million years. However, the far-field permeability of MB139 is not significantly greater than that of the surrounding halites.

Discussion: Development of any altered zone around the WIPP facility will be time dependent. Therefore, the boundary between the hydrologic near-field and far-field regimes will also be time dependent. The rate and extent to which the fracture porosity and permeability of MB139 in the altered zone near the WIPP facility horizon will be reduced during closure of the WIPP facility has not yet been demonstrated.

5.2.4 Conclusions Concerning the Rustler Formation and Younger Units

1. Conclusion: The available transmissivity data base at and near the WIPP site suggests that: a) the Culebra dolomite is at least one order of magnitude more transmissive than other members of the Rustler at most locations; and b) except where it is fractured in or near Nash Draw, the transmissivity of the Magenta dolomite is the same order of magnitude as that of other members of the Rustler. Consequently, confined flow within the Culebra dominates the hydrology of the Rustler at and near the WIPP site, and Rustler karst is not present.

Discussion: The Magenta data base is significantly smaller than that of the Culebra. Transmissivities of Rustler claystone/siltstones are very low but measurable at the Site, except for the Tamarisk claystone, which has not been successfully tested due to its low transmissivity. The transmissivity of Rustler anhydrites at the Site are too low to measure successfully. Somewhere between the WIPP site and Nash Draw (including WIPP-33), there must be a marked increase in the local permeability of Rustler anhydrites/gypsums. Where they are exposed or relatively near the surface, i.e., in Nash Draw and at WIPP-33, Rustler anhydrites are capable of supporting open cavernous porosity. The character and location of this transition in behavior of the Rustler anhydrites are not known in detail, but apparently involve decreasing overburden pressure (allowing the gypsums to maintain open porosity) and specific structures at the locations of both recharge and discharge.

The WIPP-33 structure is unique at and near the WIPP site, since it includes the three components necessary but not sufficient for karstic geology within the Rustler: 1) a sufficiently large breach in the Mescalero caliche and relatively thin Dewey Lake Red Beds; 2) shallow enough depth to gypsums within the Forty-niner and Tamarisk Members to allow maintenance of open porosity in gypsums above and below the Magenta; and 3) a probable local base level at the time the structure was mainly active, namely the gypsite springs on the east side of Nash Draw. Both the deuterium/hydrogen ratios of secondary gypsum from WIPP-33 and approximate dating of the gypsite springs within Nash Draw suggest that the WIPP-33 structure is largely inactive at present.

2. Conclusion: Measurements of relative heads within the Rustler Formation at the WIPP site are not consistent with modern infiltration from the surface to the Magenta, let alone from the surface to the Culebra. Therefore, at least at the measured locations, there is no modern infiltration of surficial waters to Rustler carbonates.

Discussion: The holes on which this conclusion is based provide only limited geographic coverage, and do not include any locations at which the Dewey Lake Red Beds are known to be hydraulically saturated. Where tested, the Dewey Lake was too tight for hydraulic testing, and may be either completely or partially saturated. No head or transmissivity information is available from the Tamarisk Member of the Rustler, due to its exceedingly low transmissivity. These results do not rule out vertical movement of water from either the surface or the Dewey Lake into the Rustler in areas in which the Dewey Lake is saturated directly above the Rustler, or in any area in the past if heads in the Dewey Lake were higher at that time.

3. Conclusion: Culebra transmissivity varies by approximately six orders of magnitude in the region of the WIPP site and Nash Draw. Transmissivities generally decrease from west to east across the site area. For purposes of generalization, the distribution can be divided into broad areas of relatively low Culebra transmissivity ($\leq 10^{-6}$ m^2/s), in which the porous-medium assumption appears adequate to describe local hydraulic and transport behavior, and areas of relatively high transmissivity ($\geq 10^{-5}$ m^2/s), in which a dual-porosity formalism appears adequate to describe local hydraulic and transport behavior. Both of these zones are represented by several wells. Two wells (H-3 and H-18) penetrate an apparently thin transition zone, in which transmissivity varies between 10^{-6} and 10^{-5} m^2/s.

The central portion of the WIPP site, including all four WIPP shafts, lies within an apparently continuous area of low transmissivity. This area extends well east of the site, and includes the holes H-1, 2, 4, 5, 10, 12, 14, 15, 16, and 17; WIPP-12, 18, 19, 21, and 22; ERDA-9; Cabin Baby-1; P-15, 17, and 18, in addition to the WIPP shafts. North of the WIPP site, measurements at WIPP-30 indicate the presence of a northern zone of low transmissivity, which may or may not be continuous with the zone near the site center.

There is a zone of relatively high Culebra transmissivity southeast of the center of the Site, which is indicated both by point measurements at H-11 and DOE-1 and by the presence of very low hydraulic gradients south of WIPP Zone 3. Northwest of the site center, there is a relatively uniform high-transmissivity zone containing holes WIPP-13, DOE-2, and H-6. This zone is bounded by low-transmissivity domains to the north, east, and southeast, and by an even higher-transmissivity domain to the southwest and west. Within both Nash Draw and the valley south of the WIPP site containing H-7 and H-9, Culebra transmissivity is both high and variable.

Discussion: There are some exceptions to the generalizations listed above. WIPP-21, which has a low transmissivity, responds quite rapidly to activities in the WIPP shafts, indicating that the region containing WIPP-21 is connected to the shafts by a low-storativity structure, which may involve fractures. Tests at individual low-transmissivity wells examine only a very small area. Neither analytical nor numerical modeling is capable of identifying a small, discrete high-transmissivity structure embedded in a low-transmissivity domain, unless it is close to measured data points. No evidence for such a discrete structure is known at the WIPP site. On the other hand, the hydraulic behavior of the Engle well, which has a high transmissivity, shows no dual-porosity effects. Test results from the Culebra in Nash Draw have not been examined for dual-porosity behavior; fracturing may be extensive enough in Nash Draw to make a dual-porosity formalism unnecessary.

The boundaries of the low-transmissivity zone including WIPP-30 remain unknown. The interpretation based on the rapid and large response of this hole to the WIPP-13 pumping test suggests that the high-transmissivity domain including WIPP-13, DOE-2 and H-6 extends close to WIPP-30.

The boundaries of the high-transmissivity zone south of H-11 and DOE-1 and the connection of this zone with the larger high-transmissivity region containing H-7, H-8, and H-9 have not been determined directly, nor has the maximum transmissivity within the zone. The presence of the zone south of H-11 and DOE-1 is indicated by both analytical and numerical modeling of the H-3 multipad interference test, as well as by more recent calibration of Culebra transmissivities against calculated pre-shaft heads. This zone will be investigated during 1988 by a multipad interference test to be conducted at the H-11 pad. The reason for the relatively high transmissivities at H-11 and DOE-1 remains unknown.

4. Conclusion: The estimation error for Culebra transmissivities over most of the WIPP site (in terms of m^2/s) is less than one log unit at two standard deviations, including estimated uncertainties in field measurements. The estimation error is generally larger outside Zone 3.

Discussion: The statistical treatment of Culebra transmissivities should not be overinterpreted, since it does not include specific consideration of geologic processes. In addition, this treatment assumes vertical homogeneity within the Culebra. Testing at H-14 indicates that transmissivity may vary by a factor of about 2 across the Culebra at a given locality.

5. Conclusion: Groundwater flow rates within the Culebra vary greatly. Flow within Nash Draw is relatively rapid; flow in the central portion of the WIPP site and in regions further east is extremely slow. The estimated flow time from a position above the center of the WIPP waste-emplacement panels to the southern boundary of Zone 3, assuming steady-state distribution of the present heads and transmissivities within the Culebra, is approximately 13,000 years.

Discussion: Calculated particle-flow rates and integrated travel times are approximate. The head distribution and flow directions within the Culebra are not at steady state. The similar Culebra and Magenta heads within Nash Draw suggest that assumption of confined flow within the Culebra may not be realistic in this region. In addition, the calculations assume a uniform effective porosity of 16%. The effective Culebra porosity probably varies laterally, suggesting that both flow rates times and flow paths are more variable than calculated.

6. Conclusion: Single-pad interference testing at the H-3 and H-11 hydropads indicates a complex role of fracturing within the Culebra. At H-3, the system transmissivity is approximately 2 x 10^{-6} m^2/s, and no significant directional dependence of hydraulic response has been measured. However, the data from observation holes on the H-3 pad had to be interpreted as if the radius of the pumped well extended beyond the observation holes; i.e., the response of the observation holes to the beginning and end of pumping was practically instantaneous. At the H-11 pad, the transmissivity is 1.2 to 3.0 x 10^{-5} m^2/s. However, the observation holes on the H-11 pad responded more slowly during testing than those on the H-3 pad. The extent or effectiveness of fracturing is not a simple function of transmissivity.

Discussion: The available data are only sufficient for detailed interpretation of interference testing using a dual-porosity formalism, i.e., assuming uniform fracture spacing. This limitation is irreduceable, however, given the limited core recovery within the Culebra. Detailed interpretation of interference testing has been completed only for testing at the H-3 and H-11 hydropads. Interpretation of interference testing at the H-2, H-4, H-5, H-6, H-7, and H-9 hydropads will be completed in the next year.

7. Conclusion: Regional-scale simulations indicate that it is not necessary to incorporate a dual-porosity formalism into regional-scale modeling of Culebra head distributions. This is because the time scale for pressure equilibration between fracture and matrix for matrix-block sizes up to the thickness of the Culebra is very short relative to the time scale required for regional groundwater flow.

Discussion: The pressure effects of a discrete or narrow high-transmissivity structure embedded within a low-transmissivity domain remain to be determined in detail. It cannot be claimed that any reasonable amount of drilling or hydrologic testing will completely eliminate the possibility of a small high-transmissivity structure being present within the Culebra dolomite. However, no such structure is known to exist at or near the WIPP site.

8. Conclusion: Both fractures and matrix play a major role in pad-scale transport of contaminants within fractured portions of the Culebra dolomite. At the H-3 pad, the first detected arrival of conservative (non-reacting) tracers in a convergent-flow test was strongly

controlled by fracturing, while tracer behavior both at and after the time of peak concentration showed evidence of strong interaction between fractures and matrix. Storage within the matrix served to decrease peak concentrations, but also resulted in greater concentrations at longer times than expected for fracture transport alone. The results indicate that matrix storage should play a major role in regional-scale transport of even conservative contaminants, so long as these contaminants have a reasonable diffusion coefficient into the matrix.

In addition, the results of the conservative-tracer test at the H-3 pad indicate that the relationship between hydraulic properties and transport properties can be complex. At H-3, no directional dependence of hydraulic behavior has been measured. In contrast, the time interval before first detected arrivals of tracers along the two flow paths investigated differed by a factor of about four.

Discussion: Detailed interpretation of dual-porosity effects in contaminant transport within the Culebra is presently completed only for testing at the H-3 pad. An additional conservative-tracer test will be conducted during 1988 at the H-11 hydropad, along the apparent regional flow path from the center of the WIPP site to the southern boundary of Zone 3. Any significant role of the matrix in contaminant transport within fractured portions of the Culebra requires that conservative contaminants be able to diffuse into matrix blocks. Interpretation to date of the H-3 test involves superposition of two radial-flow solutions; calculations are ongoing to investigate the possible effects of matrix anisotropy on transport behavior.

9. Conclusion: Calculations indicate that regional-scale contaminant transport within the Culebra Dolomite can be modeled realistically using the porous-medium assumption, so long as the Culebra transport properties and flowpaths used in these calculations are representative, and at least so long as the existing distribution of head potentials within the Culebra is not significantly disturbed. Calculated times required for contaminants to break through to the southern boundary of WIPP Zone 3 following release at any point directly above the WIPP waste-emplacement panels are only approximately 10% lower if a dual-porosity formalism is used than if the same release is modeled using the porous-medium assumption. The completed regional-scale calculations assume a transmissivity distribution which probably assigns too high a transmissivity to the region including holes H-11 and DOE-1.

Discussion: Calculations are presently ongoing to investigate the utility validity of the porous-medium approximation in modeling transport within the Culebra in the event of a breach involving a Castile brine occurrence. The assumption that there is effective diffusion from fractures into the adjacent Culebra matrix is explicit in conclusions based on calculations completed to date. Results of interference testing support the conclusion that fluid flow is unrestricted between matrix blocks and fractures, i.e., that there are no significant or continuous low-permeability skins on

matrix blocks. This has been demonstrated in the conservative-tracer experiment at the H-3 pad. Effective matrix retardation within the Culebra has not yet been demonstrated for some radionuclides making up the WIPP inventory, but will be demonstrated experimentally in the laboratory during the WIPP operational-demonstration phase.

10. Conclusion: The variability in compositions of Culebra groundwaters allows their subdivision into four hydrochemical facies. Zone A, east of the WIPP site, contains saline Na-Cl brines. Zone B, south of the site, contains relatively fresh waters in which Ca and SO_4 are the main solutes. Zone C, which includes the WIPP site and the eastern part of Nash Draw, contains quite variable fluids. Zone D, within Nash Draw, shows evidence of contamination from potash refining operations. The modern distribution of hydrochemical facies within the Culebra is not consistent with steady-state confined flow within the Culebra. Therefore, the solute geochemistry of Culebra fluids is not at steady-state, nor is the overall hydrology of the Culebra.

Discussion: This conclusion assumes the dominance of confined flow within the Rustler in the vicinity of the WIPP site, consistent with both isotopic studies and measurements of the modern relative head potentials and transmissivities of the several members of the Rustler.

Interpretation of normative salts within Rustler fluids is partially consistent with steady-state flow, if extensive vertical mixing is allowed. The measured head relationships within the Rustler are inconsistent with infiltration from the surface. The composition of Culebra waters at P-18 and P-14 play a major role in normative interpretation Culebra waters. The representative character of groundwater samples from the Culebra from P-14 and P-18 is suspect.

11. Conclusion: Analyzed Culebra fluids are all undersaturated with respect to halite, but approximately saturated with respect to gypsum and carbonate (dolomite). All fluids except that from hole WIPP-29 are undersaturated with respect to anhydrite. Therefore, almost all Culebra waters are capable of converting into gypsum any anhydrite they may contact. Carbonates, sulfates, and clay minerals are ubiquitous in Culebra core. Halite not introduced during coring has not been identified reliably. With the exception of halite, all analyzed Culebra fluids appear to be in approximate equilibrium with the host rock. Studies to date have not identified any discrete variations in Culebra mineralogy that can be used to bound hydrochemical facies.

Discussion: The dominant reactions controlling the variability of Culebra fluids appear to be the dissolution of halite and reactions between fluids and a ubiquitous but variable clay-mineral phase. Both the compositions of clays and the detailed reactions between clays and Culebra remain to be determined in detail. It cannot be demonstrated that the mineralogy of intact core specimens is representative of portions of the Culebra that have been in significant contact with groundwater.

12. Conclusion: There appear to be significant lateral variations in the oxidation state of Culebra waters. Fluids from hydrochemical facies Zone B, south of the site, appear to be more oxidized than those within Zones A and C, which include the WIPP site. The available information from within Nash Draw indicates that the redox potential at WIPP-26 is similar to that within Zone B. Results at WIPP-25 appear to be problematical, due to evolution of H_2S during sampling. The results indicate generally more oxidizing conditions south and southwest of the WIPP site than at the site itself.

Discussion: Oxidation states of Culebra fluids are not known in detail, and are generally bracketed by the occurrence of one member of a redox couple at too low a concentration for analysis. The possible effects of contamination have been evaluated only in hole WIPP-25.

13. Conclusion: Recent stable-isotope studies indicate that the bulk of the Rustler Formation and part of the Dewey Lake Red Beds at and near the WIPP site were last recharged under climatic conditions significantly different than those of today. This is consistent with the interpretations that the overall hydrology of the Rustler Formation is in transient response to the end of the last pluvial period in southeastern New Mexico, and that there is no modern meteoric recharge to the Rustler Formation at and near the WIPP.

Discussion: The data base on which the interpreted isotopic range of modern meteoric recharge is based includes measurements from several different rock types and locations, including the Capitan limestone in Carlsbad Caverns, alluvium at WIPP-15, the Ogallala Formation in both southeastern New Mexico and on the High Plains of Texas, and the Dewey Lake Red Beds near an active dune field. The Dewey Lake, however, appears to include both modern and older waters. The stable-isotopic signature of all analyzed waters from confined portions of the Culebra and Magenta dolomites are distinct from the defined meteoric field.

The stable-isotope results do not provide any direct information about the timing of recharge, only about different conditions of recharge. In addition, the results do not rule out modern recharge to the Rustler at some location removed from the WIPP site itself. However, the results do indicate that measurable amounts of recharge are not now occurring at the WIPP site.

14. Conclusion: Both stable-isotope and compositional characteristics of Rustler waters at Surprise Spring, in the southwestern portion of Nash Draw, are dominated by near-surface recharge and discharge, including partial evaporation. Major dilution would be required to derive the solute chemistry at Surprise Spring from Culebra waters at WIPP-29, which is nearby. In addition, Surprise Spring apparently discharges from the Tamarisk Member of the Rustler, rather than the Culebra. Therefore, Surprise Spring, does not appear to be a discharge point for Culebra or Magenta waters crossing the WIPP site.

Discussion: It is possible that some Rustler waters from the area of the WIPP site discharge in southern Nash Draw, including Surprise Spring. The results summarized here, however, suggest that the hydrology and solute chemistry at Surprise Spring are dominated by local processes and groundwaters, and that any input of waters from the area of the WIPP site would not be identifiable, even if present.

15. Conclusion: Use of lost-circulation materials in hydrocarbon-exploration hole and hydrologic test holes (except those drilled with air) and metabolism of these materials by introduced and/or natural organisms within the Rustler makes meaningful radiocarbon measurements on Rustler fluids difficult. All Rustler and Dewey Lake holes may be contaminated to some degree. Therefore, estimated periods for which Rustler or Dewey Lake waters have been isolated from atmospheric carbon should represent lower bounds.

16. Conclusion: Available radiocarbon measurements indicate isolation times of three Culebra and one Dewey Lake water from input of atmospherically generated nuclides for at least 12,000 years. This is consistent with paleoclimatic studies indicating a wetter climate in the northern Delaware basin approximately 10,000 years ago. The results are taken to imply that there has not been significant (i.e., detectable) vertical recharge to the Culebra and at least part of the Dewey Lake near the WIPP site in at least 12,000 years. The results also indicate, because of the relatively tight clustering of ages, that recharge may have been a pulse event rather than continuous. At any rate, the available radiocarbon results do not indicate any consistent age gradient for waters within the Culebra, and cannot be used to indicate paleoflow directions.

Discussion: The data base of successful radiocarbon measurements is extremely limited in size. Extrapolation of these results to the confined Culebra over the entire Site area may be tenuous, but is consistent with both the fact that the Culebra is regionally confined and the results of both stable-isotope uranium-disequilibrium studies. Additional radiocarbon measurements will be made over the next (approximately) two years.

17. Conclusion: Available uranium-disequilibrium results for Culebra rocks and groundwaters indicate that there must have been a significant distinct change in flow directions within the Culebra on the time scale of approximately 10,000 years. The paleoflow direction involved at least some component of easterly flow, in contrast to the modern flow directions within the Culebra, which are essentially north-south in the Site area. The change in flow directions has apparently occurred as a result of the end of Culebra recharge at or near the end of the last pluvial period. The estimated flow time to the vicinity of H-5 is at least several thousand years, and flow has occurred under reducing conditions, regardless of where recharge is interpreted to have taken place. Therefore, modern recharge is not occurring at H-5, regardless of the relatively high Culebra heads in the region. The

current distribution of total dissolved uranium in analyzed Culebra groundwaters is qualitatively consistent with regional variations in the oxidation potential within the unit, with more reducing conditions in the area at the WIPP site than south of the site and in at least part of Nash Draw. The interpretation based on uranium-disequilibrium studies is consistent with the distribution of Culebra hydrochemical facies, stable-isotope studies, and radiocarbon studies in indicating that the overall hydrologic and geochemical setting of the Rustler is transient on a time scale of approximately 10,000 years, and is recovering from the last pluvial period in southeastern New Mexico.

Discussion: The present uranium-disequilibrium data base is extremely limited in size, especially south of the WIPP site. Therefore, significant uncertainty remains concerning the constraints imposed by these studies on both paleo and modern flow directions. However, some change in flow directions within the Culebra is required by the data.

18. Conclusion: $^{87}Sr/^{86}Sr$ studies on both matrix minerals and coexisting mineral pairs from matrix and veins in the evaporitic units below the Dewey Lake Red Beds, and on veins and/or matrix materials from the Dewey Lake, Mescalero caliche, and gypsite springs in Nash Draw indicate distinct variations in the amounts of high-$^{87}Sr/^{86}Sr$ material derived from surficial weathering that are involved in the different units. The measured strontium-isotopic character of the gypsite springs and the Mescalero caliche indicate derivation from surficial components. The character of both matrix minerals and coexisting mineral pairs from matrix and veins in the Castile and Salado Formations, as well as in Rustler anhydrites and the Magenta dolomite indicate little or no input of surficial components. The isotopic compositions of coexisting mineral pairs from veins and matrices are statistically identical, indicating that the components of the veins were locally derived in all units but the Dewey Lake.

There is a broad range of strontium-isotopic character of vein minerals from the Dewey Lake, from surficial values to values similar to those from underlying anhydrites and the Magenta dolomite. Since sulfates and carbonates are very rare in the matrix of the Dewey Lake, the broad range in strontium-isotopic character of Dewey Lake vein gypsums is taken to indicate a mix of surface-type components and components from the underlying Rustler. Upward flow from the Rustler Formation is consistent with measured head relationship. The strontium-isotopic character of analyzed carbonate minerals from the Culebra shows more overlap with that of vein material from the Dewey Lake than does the character of either the intervening Rustler anhydrites or the Magenta dolomite. This is taken to imply that surficial components in the Culebra probably result from confined flow following recharge at some location removed from the WIPP site. If the Culebra near the WIPP site were presently receiving surficial components by vertical recharge, this recharge would be expected to have altered the isotopic character of Rustler zones above the Culebra.

Discussion: The isotopic data base for veins and host-rock minerals in the Rustler and Dewey Lake is limited in size. It has not yet been possible to date any of the secondary minerals directly. Therefore the strontium-isotopic results, while indicating the types of waters involved, do not provide any direct information concerning the ages of these waters.

19. Conclusion: The study of deuterium/hydrogen ratios in vein gypsums in the Dewey Lake and Rustler indicate that all of the gypsums, with the possible exception of vein gypsum from the Dewey Lake in WIPP-19, may have crystallized in the presence of varying amounts of Rustler-type water, rather than in the presence of water representing modern meteoric recharge in the region. The hydrogen-isotope character of secondary Rustler gypsums in hole WIPP-34 is consistently explained by Rustler-type fluids moving both upwards and downwards from the Magenta dolomite into surrounding members, with increasing rock/water ratios corresponding to increasing distance from the Magenta. This internal consistency is lost if crystallization of gypsums from WIPP-34 is assumed to have taken place in the presence of modern meteoric waters.

    In fact, it does not appear possible to have crystallized vein gypsums from either the Magenta and Tamarisk in WIPP-34 or from the Forty-niner in WIPP-33 in the presence of any amount of water representing modern meteoric recharge. Both WIPP-33 and WIPP-34 were drilled to investigate either geophysical anomalies or structures that might be the result of Rustler karst. There is no indication of anomalous structure at WIPP-34. The WIPP-33 structure is interpreted to be the result of karst hydrology, but is apparently unique at and near the WIPP site. The isotopic results suggest, consistent with geologic interpretations, that the WIPP-33 structure is no longer significantly active.

6.0 REFERENCES

Anderson, R.Y., 1978: Deep Dissolution of Salt, Northern Delaware Basin, New Mexico; unpubl. report to Sandia National Laboratories, January, 1978.

Anderson, R.Y., 1981: Deep-Seated Salt Dissolution in the Delaware Basin, Texas and New Mexico, NM Geol. Soc., Special Publ. No. 10, pp. 133-145.

Anderson, R.Y., Dean, W.E. Jr., Kirkland, D.W., and Snider, H.I., 1972: Permian Castile Varved Evaporite Sequence, West Texas and New Mexico; Geol. Soc. Am., Bull., v. 83, pp 59-86.

Bachman, G.O., 1973: Surficial Features and Late Cenozoic History in southeastern New Mexico; Open-File Report USGS-4339-8, U.S. Geol. Surv., Albuquerque, New Mexico.

Bachman, G.O., 1974: Geologic Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico; Open-File Report 74-194, U.S. Geol.Surv., Denver, Colorado.

Bachman, G.O., 1980: Regional Geology and Cenozoic History of the Pecos Region, Southeastern New Mexico; Open-File Report D-77-946, U.S. Geol. Surv., Albuquerque, New Mexico.

Bachman, G.O., 1985: Assessment of Near-Surface Dissolution At and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; SAND84-7178, Sandia National Laboratories, Albuquerque, New Mexico.

Bachman, G.O., 1987: Karst in Evaporites in Southeastern New Mexico; SAND86-7078, Sandia National Laboratories, Albuquerque, New Mexico.

Bard, S.T., 1982: Estimated Radiation Doses Resulting if an Exploratory Borehole Penetrates a Pressurized Brine Reservoir Assumed to Exist Below the WIPP Repository Horizon - A Single Borehole Scenario; Report EEG-15, New Mexico Environmental Evaluation Group, Santa Fe, New Mexico.

Barr, G.E., Lambert, S.J., and Carter, J.A., 1979: Uranium-Isotope Disequilibrium in Groundwaters of Southeastern New Mexico and Implications Regarding Age-Dating of Waters; in STI/PUB/403, Proceedings of the International Symposium on Isotope Hydrology, 1978; International Atomic Energy Agency, Vienna, Austria.

Barr, G.E., Miller, W.B., and Gonzalez, D.D., 1983: Interim Report on the Modeling of the Regional Hydraulics of the Rustler Formation; SAND83-0391, Sandia National Laboratories, Albuquerque, New Mexico.

Barrows, L.J., 1982: WIPP Geohydrology - The Implications of Karst; unpublished manuscript, discussed in Neill et al., 1983: Evaluation of the Suitability of the WIPP Site; EEG-23, New Mexico Environmental Evaluation Group, Santa Fe, New Mexico.

Barrows, L.J., Shaffer, S-E., Miller, W.B., and Fett, J.D., 1983: Waste Isolation Pilot Plant (WIPP) Site, Gravity Survey and Interpretation; SAND82-2922, Sandia National Laboratories, Albuquerque, New Mexico.

Beauheim, R.L., Black, S.R., Christensen, C.L., Hunter, T.O., Jarolimek, L., Kuhn, A.K., Lambert, S.J., McKinney, R.F., Meyer, D., Murray, J.B., Newton, R.S., Powers, D.W., Stein, C.L., Stephenson, D.E., Sullivan, B.R., Timmer, M.J., and Weart, W.D., 1983a: Results of Site Validation Experiments, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico; TME3177, U.S. Dept. of Energy, Albuquerque, New Mexico (2 vols.).

Beauheim, R.L., Hassinger, B.W., and Klaiber, J.A., 1983b: Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico; WTSD-TME-020, U.S. Dept. of Energy, Albuquerque, New Mexico.

Beauheim, R.L., 1986: Hydraulic-Test Results for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site; SAND86-1364, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Beauheim, R.L., 1987a: Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site; SAND86-2311, Sandia National Laboratories, Albuquerque, New Mexico.

Beauheim, R.L., 1987b: Interpretations of Single-Well Hydraulic Tests Conducted at and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987: SAND87-0039, Sandia National Laboratories, Albuquerque, New Mexico.

Beauheim, 1987c: Interpretation of the WIPP-13 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site; SAND87-2456, Sandia National Laboratories, Albuquerque, New Mexico.

Bodine, M.W.Jr., 1978: Clay-Mineral Assemblages from Drill Core of Ochoan Evaporites, Eddy County; in Geology and Mineral Deposits of Ochoan Rocks in the Delaware Basin and Adjacent Areas, Circ. 159, New Mexico Bur. Mines and Resources, Socorro, New Mexico.

Bodine, M.W.Jr., and Jones, B.F., 1986: The Salt Norm: A Quantitative Chemical-Mineralogical Characterization of Natural Waters; Water-Resources Investigation Report 86-4086, U.S. Geol. Surv.

Bodine, M.W.Jr., and Jones, B.F., 1988: Normative Analyses of Groundwaters from the Rustler Formation, Associated with the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico, U.S. Geol. Surv., unpublished data.

Bodine, M.W.Jr., Jones, B.F., and Lambert, S.J., 1988: Normative Analysis of Groundwaters from the Rustler Formation; in Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds., Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico; SAND88-0196, Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D.J., 1983: Petrographic Study of Evaporite Deformation Near the Waste Isolation Pilot Plant (WIPP); SAND83-0166, Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D.J., Barrows, L.J., Powers, D.W., and Snyder, R.P., 1983: Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site; SAND82-1069, Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D.J., 1985: Marker Bed 139: A Study of Drillcore from a Systematic Array; SAND85-0023, Sandia National Laboratories, Albuquerque, New Mexico.

Borns, D.J., and Shaffer, S-E., 1985: Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin; SAND83-1798, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Borns, D.J., 1987a: The Geologic Structures Observed in Drillhole DOE-2 and Their Possible Origins: Waste Isolation Pilot Plant; SAND86-1495, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Borns, D.J., 1987b: Rates of Evaporite Deformation: the Role of Pressure Solution; SAND85-1599, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Borns, D.J., and Stormont, J.C., 1987: Delineation of the Disturbed Rock Zone Around Excavations in Salt, Waste Isolation Pilot Plant (WIPP), SE New Mexico; Geol. Soc. Amer. Abstracts with Programs; v. 19, #6.

Brookins, D.G., and Lambert, S.J., 1987: Radiometric Dating of Ochoan (Permian) Evaporites, WIPP Site, Delaware Basin, New Mexico, USA; pp. 771-780 in Mat. Res. Soc. Symp. Proc., v. 84.

Brookins, D.G., and Lambert, S.J., 1988: WIPP Site Studies: Secondary Selenite Veins in the Rustler Formation and Dewey Lake Red Beds; in Mat. Res. Soc. Symp. Proc. for 1987 (in press).

Carter, N.L., and Heard, H.C., 1970: Temperature and Rate-Dependent Deformation of Halite; Amer. Jour. of Sci., v.269, pp. 193-249.

Carter, N.L., and Hansen, F.D., 1983: Creep of Rock-Salt; Tectono-Physics, v. 92, pp. 275-360.

Case, J.B., Dass, S.M., Franzone, J.G., and Kuhn, A.K., 1982: Analysis of Potential Impacts of Brine Flow Through Boreholes Penetrating the WIPP Storage Facility; TME 3155, U.S. Department of Energy, Albuquerque, New Mexico.

Channell, J.K., 1982: Calculated Radiation Doses from Radionuclides Brought to the Surface if Future Drilling Intercepts the WIPP Repository and Pressurized Brine; EEG-11, New Mexico Environmental Evaluation Group, Santa Fe, New Mexico.

Chapman, J.B., 1986: Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area; EEG-35, New Mexico Environmental Evaluation Group, Santa Fe, New Mexico.

Chaturvedi, L., and Channell J.K., 1985: The Rustler Formation as a Transport Medium for Contaminated Groundwater; EEG-32, State of New Mexico, Environmental Evaluation Group, Santa Fe, New Mexico.

Craig, H., 1961: Isotopic Variations in Meteoric Waters; Science, v. 133, pp. 1702-1703.

Crawley, M.E., 1987: Second Data Release Report for the Pressure-Density Survey Program; IT Corporation/Westinghouse WID, Carlsbad, New Mexico.

Davies, P.B., 1983: Assessing the Potential for Deep-Seated Salt Dissolution and Subsidence at the Waste Isolation Pilot Plant (WIPP); unpbl. ms, presented at the State of New Mexico Environmental Evaluation Group Conference: "WIPP Site Suitability for Radioactive Waste Disposal," Carlsbad, New Mexico, May 12,13, 1983.

Deal, D.E., and Case, J.B., 1987: Brine Sampling and Evaluation Program, Phase I Report; DOE-WIPP-87-008, U.S. Dept. of Energy, Carlsbad, New Mexico.

Earth Technology Corp., 1987: Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP; SAND87-7144, Sandia National Laboratories, Albuquerque, New Mexico.

Epstein, S., Sharp, R.P., and Gow, A.J., 1965: Six-year Record of Oxygen and Hydrogen Isotope Variations in South Pole Firn; Jour. Geoph. Res., v. 70, pp. 1809-1814.

Epstein, S., Sharp, R.P., and Gow, A.J., 1970: Antarctic Ice Sheet: Stable-Isotope Analyses of Byrd Station Cores and Interhemispheric Climatic Implications: Science, v. 168, pp. 1570-1572.

Evans, G.V., Otlet, R.L., Downing, R.A., Monkhouse, R.A., and Rae, G., 1979: Some Problems in the Interpretation of Isotope Measurements in United Kingdom Aquifers; in Proceedings of the International Symposium on Isotope Hydrology, STI/PUB/493, Vol.2, International Atomic Energy Agency, Vienna, Austria.

Gonzalez, D.D., 1983a: Hydrogeochemical Parameters of Fluid-Bearing Zones in the Rustler and Bell Canyon Formations: Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico (SENM); SAND 83-0210, Sandia National Laboratories, Albuquerque, New Mexico.

Gonzalez, D.D., 1983b: Groundwater Flow in the Rustler Formation, Waste Isolation Pilot Plant (WIPP), Southeast New Mexico (SENM): Interim Report; SAND82-1012, Sandia National Laboratories, Albuquerque, New Mexico.

Haug, A., Kelly, V.A., LaVenue, A.M., and Pickens, J.F., 1987: Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report; SAND86-7167, Sandia National Laboratories, Albuquerque, New Mexico.

Heard, H.C., 1972: Steady-State Flow in Polycrystalline Halite at Pressure of 2 Kilobars, in H.C. Heard, I.V. Borg, N.L. Carter,and C.B. Raleigh, eds.; Flow and Fracture of Rocks, (Geophys. Monogr. Series), Amer. Geophys. Union, v. 16, pp. 191-210.

Holt, R.M., and Powers, D.W., 1984: Geotechnical Activities in the Waste-Handling Shaft; WTSD-TME-038, U.S. Dept. of Energy, Carlsbad, New Mexico.

Holt, R.M., and Powers, D.W., 1987: Rustler Formation in the Waste-Handling and Exhaust Shafts, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, pp.26-35 in The Rustler Formation at the WIPP Site, Rept. EEG-34, State of New Mexico Environmental Evaluation Group, Santa Fe, New Mexico.

Hoy, R.N., and Gross, G.W., 1982: A Baseline Study of Oxygen 18 and Deuterium in the Roswell, New Mexico, Groundwater Basin; Report No. 144, New Mexico Water Resources Research Institute.

Hudson, T., 1987: Preliminary personal communication to J.S. Stormont (Sandia) on USGS moisture and density measurements in bedded rock salt at the WIPP site.

Hunter, R.L., 1985: A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area; SAND84-2233, Sandia National Laboratories, Albuquerque, New Mexico.

Hydro Geo Chem, Inc., 1985: WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #1; SAND85-7206, Sandia National Laboratories, Albuquerque, New Mexico.

INTERA Technologies, Inc., 1986: WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #3, SAND86-7109, Sandia National Laboratories, Albuquerque, New Mexico.

INTERA Technologies, Inc., and Hydro Geo Chem, Inc., 1985: WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #2; SAND85-7263, Sandia National Laboratories, Albuquerque, New Mexico.

Jarolimek, L., Timmer, M.J., and Powers, D.W., 1983: Correlation of Drillhole and Shaft Logs, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico; Report TME 3179, U.S. DOE, Albuquerque, New Mexico.

Kelley, V.A., and Pickens, J.F., 1986: Interpretation of the Convergent-Flow Tracer Tests Conducted in the Culebra Dolomite at the H-3 and H-4 Hydropads at the Waste Isolation Pilot Plant (WIPP) Site; SAND86-7161, Sandia National Laboratories, Albuquerque, New Mexico.

Knauth, L.P., and Beeunas, M.A., 1986: Isotope Geochemistry of Fluid Inclusions in Permian Halite, with Implications for the Isotopic History of Ocean Water and the Origin of Saline Formation Waters; Geochim. et Cosmochim. Acta, v. 50, pp. 419-434.

LaVenue, A.M., Haug, A., and Kelley, V.A., 1988: Numerical Simulation of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site; Second Interim Report; SAND88-7002, Sandia National Laboratories, Albuquerque, New Mexico.

Lambert, S.J., 1983: Dissolution of Evaporities in and Around the Delaware Basin, Southeastern New Mexico and West Texas; SAND82-0461, Sandia National Laboratories, Albuquerque, New Mexico.

Lambert, S.J., and Carter, J.A., 1984: Uranium-Isotope Disequilibrium in Brine Reservoirs of the Castile Formation,Northern Delaware Basin, Southeastern New Mexico, I: Principles and Methods; SAND83-0144, Sandia National Laboratories, Albuquerque, New Mexico.

Lambert, S.J., and Robinson, K.L., 1984: Field Geochemical Studies of Groundwaters in Nash Draw, southeastern New Mexico; SAND83-1122, Sandia National Laboratories, Albuquerque, New Mexico.

Lambert, S.J., 1987a: Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and other Nuclides to the Groundwater Hydrology of the Rustler Formation; SAND86-1054, Sandia National Laboratories, Albuquerque, New Mexico.

Lambert, S.J., 1987b: Stable-Isotope Studies of Groundwaters in Southeastern New Mexico; SAND85-1978c, Sandia National Laboratories, Albuquerque, New Mexico, in Chaturvedi, L., ed.: The Rustler Formation at the WIPP Site; EEG-34, New Mexico Envir. Eval. Group, Santa Fe, New Mexico.

Lambert, S.J., and Carter, J.A., 1987: Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico; SAND87-0388, Sandia National Laboratories, Albuquerque, New Mexico.

Lambert, S.J., and Harvey, D.M., 1987: Stable-Isotope Geochemistry of Groundwaters in the Delaware Basin of Southeastern New Mexico; SAND87-0138, Sandia National Laboratories, Albuquerque, New Mexico.

Lambert, S.J., 1988: Isotopic Constraints on the Rustler and Dewey Lake Groundwater Systems; in Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds., Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico; SAND88-0196, Sandia National Laboratories, Albuquerque, New Mexico.

Lowenstein, T.K., 1987: Post-Burial Alteration of the Permian Rustler-Formation Evaporites, WIPP Site, New Mexico; EEG-36, State of New Mexico, Environmental Evaluation Group, Santa Fe, New Mexico.

Mercer, J.W., 1983: Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Los Medanos area, Southeastern New Mexico; U.S. Geological Survey, Water-Resources Investigations Report 83-4016, U.S. Geological Survey, Albuquerque, New Mexico.

Mercer, J.W., 1987: Compilation of Hydrologic Data from Drilling the Salado and Castile Fomations near the WIPP Site, Southeastern New Mexico; SAND86-0954, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Mercer, J.W., and Orr, B.R., 1979: Interim Data Report on the Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico; U.S. Geol. Surv., Water-Resources Investigations Rept. 79-98, U.S. Geol. Surv., Albuquerque, New Mexico.

Mercer, J.W., Beauheim, R.L., Snyder, R.P., and Fairer, G.M., 1987: Basic Data Report for Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site; SAND86-0611, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Mook, W.G., 1976: The Dissolution-exchange Model for Dating Groundwater with ^{14}C; in Interpretation of Environmental Isotope and Hydrochemical Data in Groundwater Hydrology, International Atomic Energy Agency, Vienna, Austria.

Munson, D.E., 1979: Preliminary Deformation-Mechanism Map for Salt (with Application to WIPP); SAND79-0076, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Myers, J., James, P., and Drez, P., 1988: The Redox State of the Culebra Member of the Rustler Formation; in Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds., Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico; SAND88-0196, Sandia National Laboratories, Albuquerque, New Mexico.

Neill, R.H., Channell, J.K., Chaturvedi, L., Little, M.S., Rehfeldt, K., and Spiegler, P., 1983: Evaluation of the Suitability of the WIPP Site; EEG-23, New Mexico Environmental Evaluation Group, Santa Fe, New Mexico.

Nowak, E.J., 1986: Preliminary Results of Brine Migration Studies in the Waste Isolation Pilot Plant (WIPP); SAND86-0720, Sandia National Laboratories, Albuquerque, New Mexico.

Nowak, E.J., and McTigue, D.F., 1987: Interim Results of Brine Transport Studies in the Waste Isolation Pilot Plant (WIPP); SAND87-0880, Sandia National Laboratories, Albuquerque, New Mexico 87185.

O'Neil, J.R., Johnson, C.M., White, L.D., and Roedder, E., 1986: The Origin of Fluids in the Salt Beds of the Delaware Basin, New Mexico and Texas; Jour. App. Geoch., v.1.

Osmond, J.K., and Cowart, J.B., 1976: The Theory and Uses of Natural Uranium Isotopic Variations in Hydrology; Atomic Energy Review, v.14.

Pearson, F.J.Jr., and Swarzenki, W.W., 1974: ^{14}C Evidence for the Origin of Arid-Region Groundwater, Northeastern Province, Kenya; pp. 95-108 in Isotope Techniques in Groundwater Hydrology 1974, International Atomic Energy Agency, Vienna, Austria.

Peterson, E.W., Lagus, P.L., and Lie, K., 1987: WIPP Horizon Free Field Fluid Transport Characteristics; SAND87-7164, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Pfeifer, M.C., 1987: Multicomponent Underground DC Resistivity Study at the Waste Isolation Pilot Plant, Southeast New Mexico; M.S. Thesis T-3372, Colorado School of Mines, Golden, Colorado.

Plummer, N.L., Parkhurst, D.L., Fleming, G.W., and Dunkle, S.A., 1988: PHRQPITZ - A Computer Program for Geochemical Calculations in Brines; U.S. Geol. Surv., unpublished data.

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L., 1983: Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant, Southeastern New Mexico; TME 3153, U.S. Dept. of Energy, Albuquerque, New Mexico.

Powers, D.W., Lambert, S.J., Shaffer, S-E., Hill, L.R., and Weart, W.D., eds., 1978: Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico; SAND78-1596, Sandia National Laboratories, Albuquerque, New Mexico.

Ramey, D.S., 1985: Chemistry of Rustler Fluids; EEG-31, New Mexico Environ. Eval. Group, Santa Fe, New Mexico.

Reeves, M., Ward, D.S., Johns, N.D., and Cranwell, R.M., 1986a: Theory and Implementation for SWIFT II, the Sandia Waste-Isolation Flow and Transport Model, Release 4.84; SAND83-1159, Sandia National Laboratories, Albuquerque, New Mexico (also NUREG/CR-3328).

Reeves, M., Ward, D.S., Johns, N.D., and Cranwell, R.M., 1986b: Data Input Guide for SWIFT II, the Sandia Waste-Isolation Flow and Transport Model for Fractured Media, Release 4.84; SAND84-1586, Sandia National Laboratories, Albuquerque, New Mexico (also NUREG/CR-3925).

Reeves, M., Kelley, V.A., and Pickens, J.F., 1987: Regional Double-Porosity Solute Transport in the Culebra Dolomite: An Analysis of Parameter Sensitivity and Importance at the Waste Isolation Pilot Plant (WIPP) Site; SAND87-7105, Sandia National Laboratories, Albuquerque, New Mexico.

Robinson, K.L., 1988: Analysis of Solutes in Groundwaters from the Rustler Formation at and Near the WIPP Site; SAND86-0917, Sandia National Laboratories, Albuquerque, New Mexico.

Sandia National Laboratories and United States Geological Survey, 1983: Basic Data Report for Drillhole ERDA-9 (Waste Isolation Pilot Plant - WIPP); SAND79-0270, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Saulnier, G.J.Jr., Freeze, G.A., and Stensrud, W.A., 1987: WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #4, SAND86-7166, Sandia National Laboratories, Albuquerque, New Mexico.

Saulnier, G.J.Jr., 1987: Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-11 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site; SAND87-7124, Sandia National Laboratories, Albuquerque, New Mexico.

Saulnier, G.J.Jr., and Avis, J.D., 1988: Interpretation of Hydraulic Tests Conducted in the Waste-Handling Shaft at the Waste Isolation Pilot Plant (WIPP) Site; SAND87-7001, Sandia National Laboratories, Albuquerque, New Mexico.

Sewards, T., Williams, M.L., Stein, C.L., and Keil, K., 1988: Mineralogy of the Culebra Dolomite; in Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds., Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico; SAND88-0196, Sandia National Laboratories, Albuquerque, New Mexico.

Siegel, M.D., and Lambert, S.J., 1988: Summary of Hydrogeochemical Constraints on Groundwater Flow in the Rustler Formation; in Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds., Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico; SAND88-0196, Sandia National Laboratories, Albuquerque, New Mexico.

Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds., 1988a: Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico; SAND88-0196, Sandia National Laboratories, Albuquerque, New Mexico.

Siegel, M.D., Robinson, K.L., and Myers, J., 1988b: Solute Relationships in Groundwaters from the Culebra Member of the Rustler Formation near the WIPP site, southeastern New Mexico; in Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds., Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the WIPP Area, Southeastern New Mexico; SAND88-0196, Sandia National Laboratories, Albuquerque, New Mexico.

Snyder, R.P., 1985: Dissolution of Halite and Gypsum, and Hydration of Anhydrite to Gypsum, Rustler Formation, in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico; Open-File Report 85-229, U.S. Geol. Survey, Denver, Colorado.

Snyder, R.P., and McIntyre, A.F., 1981: Basic Data Report for Drillhole WIPP-33; SAND80-2011, Sandia National Laboratories, Albuquerque, New Mexico.

Snyder, R.P., and Gard, L.M.Jr., 1982: Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site; Open-File Report 82-968, U.S. Geol. Surv., Denver, Colorado.

Stein, C.L., and Krumhansl, J.L., 1986: Chemistry of Brines in Salt from the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico: A Preliminary Investigation; SAND85-0897, Sandia National Laboratories, Albuquerque, New Mexico.

Stein, C.L., 1985: Mineralogy in the Waste Isolation Pilot Plant (WIPP) Facility Stratigraphic Horizon; SAND85-0321, Sandia National Laboratories, Albuquerque, New Mexico.

Stensrud, W.A., Bame, M.A., Lantz, K.D., LaVenue, A.M., Palmer, J.B., and Saulnier, G.J.Jr., 1987: WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #5, SAND87-7125, Sandia National Laboratories, Albuquerque, New Mexico.

Stensrud, W.A., Bame, M.A., Lantz, K.D., Cauffman, T.L., Palmer, J.B., and Saulnier, G.J.Jr., 1988: WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #6: SAND87-7166, Sandia National Laboratories, Albuquerque, New Mexico.

Stormont, J.C., Peterson, E.W., and Lagus, P.L., 1987: Summary of and Observations About WIPP Facility Horizon Flow Measurements Through 1986; SAND87-0176, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Tamers, M.A., 1975: Validity of Radiocarbon Dates on Groundwater; Geophys. Surv., v.2., pp. 217-239.

Tomasko, D., and Jensen, A.L., 1987: A Linear-Flow Interpretation of the H-3 Multiwell Pumping Test Conducted at the Waste Isolation Pilot Plant (WIPP) Site; SAND87-0630, Sandia National Laboratories, Albuquerque, New Mexico.

U.S. Department of Energy, 1980: Final Environmental Impact Statement, Waste Isolation Pilot Plant; DOE/EIS-0026, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy and State of New Mexico, 1981: Agreement for Consultation and Cooperation Between [the U.S.] Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant, as amended 1985.

U.S. Environmental Protection Agency, 1985: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste; Final Rule; 40CFR191, pp. 38066-38089, Federal Register, Vol. 50, No. 182 (Sept. 19, 1985).

Uhland, D.W., Randall, W.S., and Carrascco, R.C., 1987: 1987 Annual Water-Quality Data Report for the Waste Isolation Pilot Plant; DOE WIPP 87-006, U.S. Dept. of Energy, Carlsbad, New Mexico.

Van Devender, T.R., 1980: Holocene Plant Remains from Rocky Arroyo and Last Chance Canyon, Eddy County, New Mexico; The Southwestern Naturalist, v. 25.

Weart, W.D., 1983: Summary of Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability; SAND83-0450, Sandia National Laboratories, Albuquerque, New Mexico 87185.

Williamson, C.R., 1979: Deep-sea Sedimentation and Stratigraphic Traps, Bell Canyon Formation (Permian), Delaware Basin; pp. 39-74 in Sullivan, N.M., ed., Guadalupian Delaware Mountain Group of West Texas and southeast New Mexico; Society of Economic Paleontologists and Mineralogists (Permian Basin Section), Publication 79-18.

Wood, B.J., Snow, R.E., Cosler, D.J., and Haji-Djafari, S., 1982: Delaware Mountain Group (DMG) Hydrology - Salt Removal Potential; TME 3166, U.S. Dept. of Energy, Albuquerque, New Mexico.

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Appendix VCMP

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Volatile Organic Compound Monitoring Plan

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1.0 INTRODUCTION

This document describes the confirmatory monitoring plan for volatile organic compounds (VOC) which may be entrained in the exhaust air from the Waste Isolation Pilot Plant (WIPP), Carlsbad, New Mexico, during the disposal phase at the facility. This Monitoring Plan is designed to confirm the demonstration contained in the No-Migration Variance Petition (NMVP) that there will be no migration of VOCs from WIPP exceeding concentrations that pose unacceptable risks to human health and the environment. This Monitoring Plan includes the monitoring design, a description of sampling and analysis procedures, and quality assurance (QA) objectives and reporting activities.

1.1 BACKGROUND

The WIPP project was authorized by the U.S. Congress to provide a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from national defense activities and programs. The WIPP facility is constructed in a massive underground salt bed formation, with its design characterized as a "room and pillar" arrangement, allowing containerized solids or solidified waste to be placed in the excavations. Waste, equipment, and personnel enter the underground facility through designated shafts.

The hazardous waste management units, defined as waste panels, are located 2150 feet (ft)(655 meters(m)) below ground surface, in the WIPP underground. The waste panels consist of seven rooms and two access drifts each. Each room is approximately 300 ft (91 m) long, 33 ft (10 m) wide, and 13 f (4 m) high. Access drifts connect the

rooms and have the same cross section. The U.S. Department of Energy (DOE) intends to operate the facility in a manner that minimizes the number of panels that are open at any one time.

The panels provide room for 6.2 million cubic feet (ft^3)(175,600 cubic meters (m^3)) of transuranic (TRU) waste, of which 250,000 ft^3(7080 m^3) may be remote handled (RH) TRU waste. The remainder will be contact handled (CH) TRU waste. The CH TRU waste package assemblies will be stacked up to three containers high across the width of the room in an interlocking triangular pitch. The RH TRU waste canisters will be inserted into predrilled horizontal holes bored into the room wall of the disposal area. The facility performance objectives are derived from 40 Code of Federal Regulations (CFR) Part 268 and are directed at permanently isolating the waste from the biosphere.

The NMVP (DOE, 1996) demonstrates theoretical compliance with the requirements of 40 CFR Part 268.6, which allows the disposal of wastes prohibited from land disposal only if it can be demonstrated that, to a reasonable degree of certainty, there will be no migration of hazardous constituents from the disposal unit for as long as the wastes remain hazardous. This Confirmatory Monitoring Plan describes a sampling and analysis program to confirm the theoretical no-migration calculations contained in the NMVP. The monitoring program will be capable of quantifying VOC concentrations in ambient mine air at WIPP. As demonstrated in the NMVP, other media are not considered viable contaminant transport pathways during the WIPP operational time frame and are therefore not addressed in this program. By the nature of WIPP operations, there is no credible mechanism for direct release of hazardous constituents to water or soil during the operational time frame.

For the disposal phase, the mine ventilation system is the only possible migration pathway.

Accordingly, this Confirmatory Monitoring Plan is designed to confirm that there will be no migration of VOCs from disposed wastes in the WIPP repository via the air pathway during the Disposal Phase. This plan addresses the following information requirements:

1. Rationale for the design of the monitoring program, based on:

   - Possible migration pathways from WIPP during the active life of the facility

   - Operations at WIPP

   - Strength of engineered and natural material components at WIPP

   - Optimum location of the hazardous constituent monitoring stations to confirm the migration calculations contained in the NMVP

2. Descriptions of the specific elements of the monitoring program, including:

   - The type of monitoring conducted

   - The location of the monitoring stations

   - The monitoring interval

- The specific hazardous constituents monitored
- The implementation schedule for the monitoring program
- The equipment used at the monitoring stations
- Sampling and analytical techniques used
- Data recording/reporting procedures

The results of baseline VOC monitoring at WIPP were used, in part, to refine the monitoring program that will be established for the Disposal Phase, during which full-scale waste emplacement activities will occur. The baseline VOC monitoring results are presented in Appendix BAD of the NMVP, and the environmental monitoring currently anticipated during both the operational and post-closure phases are presented in Chapter 6 of the NMVP.

1.2 WASTE DISPOSAL

The DOE will operate and maintain WIPP so that it is free of both chemical and radiological contamination. Therefore, as allowed by New Mexico Administrative Code 4.1, Subpart V §264.13, and consistent with joint U.S. Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission guidance, all waste sampling and analyses are conducted by DOE generator sites in accordance with established procedures. The generator conducts the required waste characterization activities for each container of waste to be sent to WIPP under a QA program. The reports resulting from waste characterization activities are then reviewed for completeness and acceptability at WIPP prior to transport of the wastes.

Waste will be disposed of in the seven rooms of a panel. Each panel will be closed when it is full using a panel closure system installed in each of the two panel access drifts as described in Appendix CLP of the NMVP. The closure system conceptual design consists of concrete block bulkheads and a poured concrete bulkhead. The concrete block bulkheads provide a ventilation barrier while the concrete bulkhead is being installed. The concrete component provides strength and stability for maintenance-free service during the operational period. The DOE's analysis of the bulkhead shows that the structure has sufficient rigidity and compressive strength to remain stable for creep and short-term dynamic loadings. Once a panel has been filled and closed, it will be managed per the requirements of the WIPP RCRA Part B Permit and a No-Migration Determination.

1.3 OBJECTIVES OF THE VOLATILE ORGANIC COMPOUND CONFIRMATORY MONITORING PLAN

As described in the NMVP, minute quantities of VOCs could be released from open and closed panels located at WIPP during the disposal phase of the project. Chapter 5 of the NMVP contains a demonstration that any VOCs released from panels would be below any concentrations of concern (COC). This plan describes how VOCs released from waste panels will be monitored to confirm the VOC concentration estimates contained in the NMVP. This plan is responsive to requirements of 40 CFR Part 268.6 and addresses confirmatory monitoring of waste management activities during the WIPP disposal phase.

2.0 TARGET VOLATILE ORGANIC COMPOUNDS

The wastes proposed for disposal at WIPP are described in Chapter 4 of the NMVP. Approximately 60 percent of the waste proposed to be emplaced at WIPP during the entire lifetime of the facility is classified as TRU mixed waste, which consists of waste that contains both radioactive and Resource Conservation and Recovery Act (RCRA)-regulated hazardous chemical components.

Generator knowledge of the wastes and the processes by which they are generated, as well as available analytical data, indicate that the VOCs most commonly present in the wastes and responsible for approximately 99 percent of the calculated RCRA-constituent posed human health risk (Appendix WAP of the NMVP) are as follows:

- 1,1-Dichloroethylene
- Carbon tetrachloride
- Methylene chloride
- Chloroform
- 1,1,2,2-Tetrachloroethane
- 1,1,1-Trichloroethane
- Chlorobenzene
- 1,2-Dichloroethane

- Toluene

Physical and chemical data for these target VOCs are presented in Table 2.1.

2.1 SOURCES OF VOLATILE ORGANIC COMPOUND EMISSIONS

Figure 2.1 depicts the initial WIPP underground facility configuration. Potential waste-related sources of VOCs include: 1) open panels containing vented waste drums, and 2) closed panels of disposed waste. Any VOC emissions from emplaced waste will pass by a monitoring system as it is directed to the exhaust shaft. Other activities not related to normal waste management activities may also lead to VOC emissions.

Nonwaste-related sources of VOCs at WIPP include background sources and emissions from operational activities in ambient mine air. Background sources of VOCs include any sources that emit VOCs to the ambient air that are drawn into the air intake shaft of the underground WIPP facility. Examples of background sources are oil and gas exploration and petroleum production activities in the WIPP vicinity, potash production, and motor vehicle emissions in the WIPP parking lot and on nearby roads. Sources of VOC emissions also exist below ground surface that are related to WIPP mine operational activities. Fuel combustion, painting activities, cleaning solvents, equipment exhaust, and air conditioners are potential sources of VOCs.

Chapter 5 of the NMVP establishes COCs for the VOCs from waste in open and closed panels. Therefore, the VOC Confirmatory Monitoring

Plan is designed to differentiate VOC concentrations attributed to open and closed panels from other potential sources. Accordingly, VOC monitoring performed to confirm the calculations in the NMVP will begin when waste emplacement commences in the first panel. Potential VOC sources other than open and closed panels will not be directly monitored at WIPP.

2.2 MIGRATION PATHWAY

The only pathway for migration of VOCs to the unit boundary during the operational phase is via airborne transport. Any VOCs released in the underground facility would become entrained in the underground ventilation air and released to the atmosphere through the exhaust shaft (Figure 2.1).

Chapter 5 of the NMVP identifies COCs in the Drift E-300 air pathway for the target VOCs. COCs at the panels have been extrapolated from the levels of concern at the unit boundary using a mathematical dispersion model and facility ventilation design data.

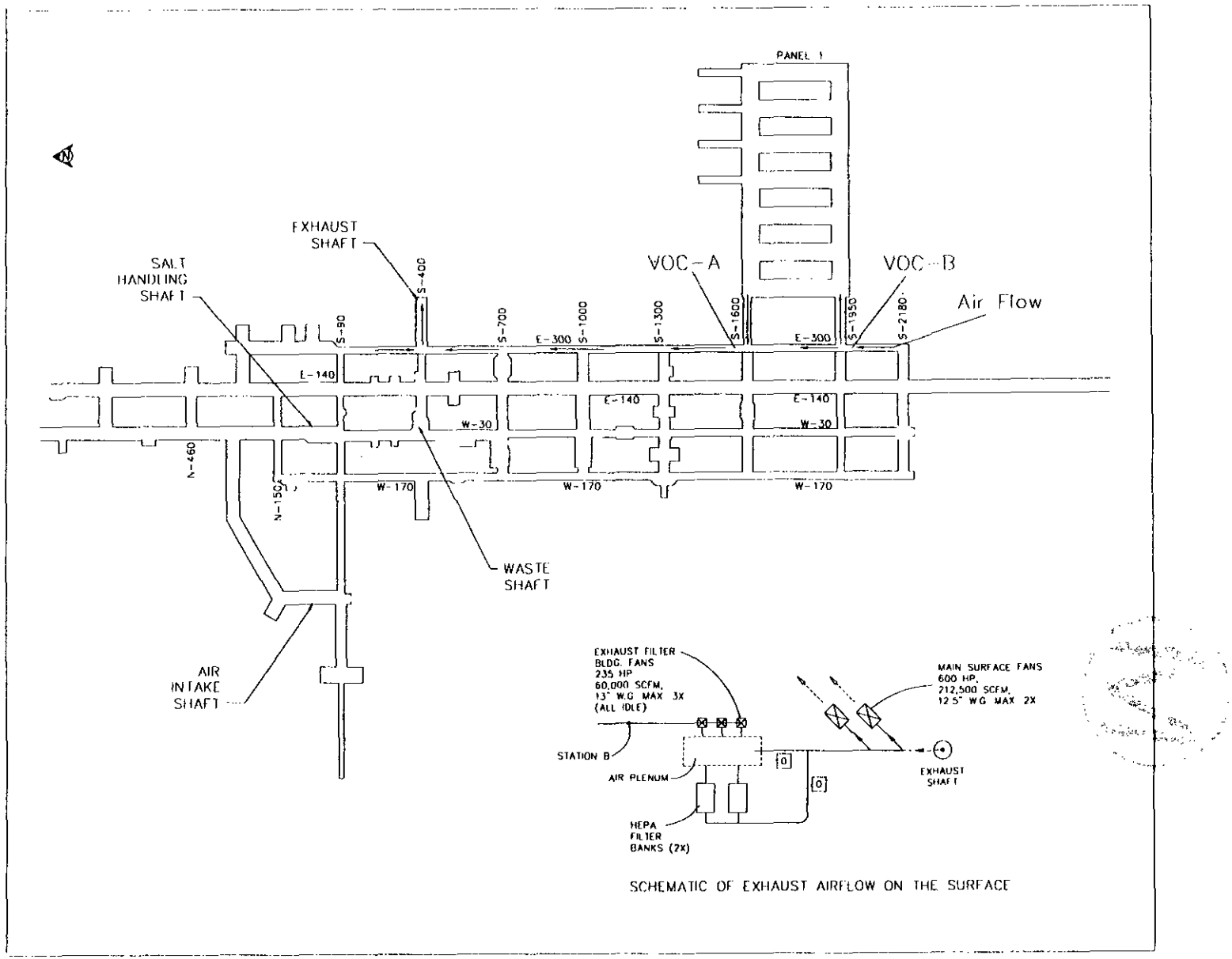

Figure 2.1 Panel Area Air Flow

3.0 MONITORING DESIGN

Detailed design features of the VOC Confirmatory Monitoring Plan are presented in this section. The purpose of this program is to confirm that there is no migration of specific target VOCs exceeding any COC. This monitoring plan uses available sampling and analysis techniques to measure VOC concentrations. Available sampling equipment includes the standard WIPP VOC canister samplers with minor modifications.

3.1 SAMPLING LOCATIONS

Air samples will be collected at two locations in the facility to quantify airborne VOC concentrations. VOCs emanating from Panel 1 will be measured by placing one VOC monitoring station just downstream from Panel 1 at VOC-A and another station upstream from Panel 1 at VOC-B (Figure 2.1). In this configuration VOC-B will measure VOC releases from the upstream sources (i.e., Panel 2) and other background sources of VOCs, and VOC-A will measure upstream VOC releases plus any additional releases from Panel 1. A sample will be collected from each station on designated sample days. For each quantified target VOC, the concentration measured at VOC-B will be subtracted from the concentration measured at VOC-A to assess any release from Panel 1. Measurements from the first panel will confirm estimates of releases from all panels since the releases will be cyclic from panel-to-panel.

The sampling locations were selected based on operational considerations and the calculations presented in Chapter 5 of the NMVP. As discussed in Section 2.0, there are several different potential

sources of release for VOCs. These sources include incoming air from above ground, facility support operations, open waste panels, and closed waste panels. In addition, because of the ventilation requirements of the underground facility and atmospheric dispersion characteristics, any VOCs that are released from Panel 1 may be difficult to detect and differentiate from other sources of VOCs at any underground or above ground location further downstream of Panel 1. By measuring VOC concentrations close to the potential source of release (i.e., Panel 1), it will be possible to differentiate potential releases from background levels and confirm the theoretical calculations included in the NMVP.

3.1.1 E-300 Panel 1 Air Outlet (Station VOC-A)

Panel 1 will be the first open panel, and it will become the first closed waste panel once it is filled and the panel closure systems are installed and certified. Waste disposal activities will continue in Panel 2 during closure of Panel 1. Because Panel 1 is a potential source of VOC releases to the ventilation air traveling to the exhaust shaft, sampling station VOC-A has been established in the Drift E-300 downstream of the Panel 1 air outlet (Drift S-1600). The purpose of this station is to evaluate whether the concentrations of VOCs measured at this point are sufficiently higher than upstream concentrations to indicate potential migration from Panel 1. Therefore, concentrations of VOCs measured upstream of Panel 1 will be subtracted from those measured at station VOC-A and the resulting differences will be compared to the calculated COCs for Drift E-300.

The COCs for releases from waste panels have been calculated for each of the target VOCs in the Drift E-300 under normal operational conditions (see Chapter 5 of the NMVP). The calculated COC

difference between VOC-A and VOC-B, is presented in Table 3.1 for each of the nine target compounds, in terms of micrograms per cubic meter ($\mu g/m^3$) and parts per billion by volume (ppbv). As presented in Appendix BAD of the NMVP, baseline VOC monitoring has been performed at WIPP for three of the target VOCs (i.e., carbon tetrachloride, methylene chloride, and 1,1,1-trichloroethane). The average measured concentrations of these compounds entrained in the facility exhaust air are less than 2 percent of the COC presented in Table 3.1. These data demonstrate that it will be possible to differentiate between the VOC concentrations measured at VOC-A and VOC-B for comparison to the COCs presented in Table 3.1.

3.1.2 E-300 Panel 2 Air Outlet (Station VOC-B)

To quantify VOC concentrations upstream of Panel 1, another sampling station will be established in Drift E-300 downstream of the Panel 2 air outlet. Results from this monitoring station will allow target VOC concentrations in the ventilation air upstream of Panel 1 to be distinguished from any target VOCs that may be released from Panel 1. VOC concentrations measured at this location will consist of background concentrations entering the facility through the Air Intake Shaft, concentrations attributed to upstream facility operations, and concentrations from waste disposal activities in open Panel 2 after Panel 1 is closed. For each sampling event, target compound concentrations detected at VOC-B will be subtracted from those measured at VOC-A to assess VOC releases from Panel 1.

Table 3.1: Volatile Organic Compound Concentrations of Concern*

Compound	Molecular Weight (g/mol)	Drift E-300 µg/m³	Drift E-300 ppbv
1,1-Dichloroethylene	96.95	106	27
Carbon tetrachloride	153.8	35	6
Methylene chloride	84.94	1,130	326
Chloroform	119.4	23	5
1,1,2,2-Tetrachloroethane	167.9	92	13
1,1,1-Trichloroethane	133.42	3,300	600
Chlorobenzene	112.6	10,000	2,300
1,2,-Dichloroethane	98.96	20	10
Toluene	92.13	212,000	57,000

g/mol Grams per mole
µg/m³ Micrograms per cubic meter
ppbv Parts per billion by volume

* Calculated at 25 degrees Celsius (°C) and 760 millimeters of mercury (mmHg).

3.2 ANALYTES TO BE MONITORED

Based on acceptable knowledge, previous analytical data, and recent risk calculations (Appendix WAP and Chapter 5 of the NVMP), nine VOCs have been initially identified for monitoring. These compounds are listed in Table 2.1. The analysis will focus on routine detection and quantification of these compounds in collected samples. Other compounds may also be present in the samples. As part of the analytical evaluations, the presence of other compounds will be investigated. The analytical method will allow semi-quantitative evaluation of these compounds as tentatively identified compounds (TIC).

3.3 SAMPLING AND ANALYSIS METHODS

A technically sound, reliable, and versatile sampling method is required for the VOC monitoring program. The selected method must be able to definitively identify and quantify the initial nine target compounds. Another consideration is the desire to use EPA approved or recommended methods that provide data of known and documented quality. In addition, the present WIPP program includes a comprehensive VOC monitoring program established at the facility; equipment, training, and documentation for VOC measurements are already in place.

The method selected for VOC sampling is EPA Compendium Method TO-14 (EPA, 1988b; Winberry and others, 1990). The TO-14 sampling technique uses 6-liter SUMMA® passivated stainless-steel canisters to collect integrated air samples at each sample location. This method will be used for guidance in collecting the samples at WIPP. The samples will be analyzed using gas chromatography/mass spectrometry (GC/MS) under an established Quality Assurance/Quality

Control (QA/QC) program (WP 12-7) following guidance from the Draft EPA CLP-SOW for Volatile Organics Analysis of Ambient Air in Canisters (EPA, 1991). The Quality Assurance Project Plan (QAPP), WP 12-7, was prepared for the baseline monitoring program at the WIPP. It will be updated once the confirmatory monitoring plan is finalized.

The TO-14 method is an EPA-recognized sampling procedure for VOC sampling and speciation. It can be used to provide integrated samples, or grab samples, and compound quantitation for a broad range of concentrations. The sampling system can be operated unattended but requires detailed operator training.

As presently designed, the field sampling systems will be operated in the pressurized mode. In this mode, air is drawn through the inlet and sampling system with a pump. The air is pumped into an initially evacuated SUMMA® passivated canister by the sampler, which regulates the rate and duration of sampling. The passivation process forms a pure chrome-nickel oxide on the interior surfaces of the canisters. This type of container has been used routinely at WIPP in the past and has demonstrated sample storage stability for a wide variety of VOCs. At the end of each sampling period, the canisters will be pressurized to about two atmospheres absolute. In the event of shortened sampling periods or other sampling conditions, the final pressure in the canister may be less than two atmospheres absolute. Sampling duration will be approximately six hours, so that a complete sample can be collected during a single work shift.

The canister sampling system and GC/MS analytical method are particularly appropriate for the VOC Confirmatory Monitoring Program because a relatively large sample volume is collected, and

multiple dilutions and reanalyses can occur to ensure identification and quantification of target VOCs within the working range of the method. The contract required quantitation limits (CRQL) proposed by EPA are 5 ppbv or less for the nine target compounds (EPA, 1991), so that low concentrations can be measured. CRQLs are the EPA-specified levels of quantitation for EPA contract laboratories that analyze canister samples by GC/MS. The CLP-SOW expressly states how instrument detection limits are demonstrated. For the purpose of this monitoring plan, the CRQLs are defined as the method reporting limits (MRL). The MRL is a function of instrument performance, sample preparation, sample dilution, and all steps involved in the sample analysis process.

Detailed analytical standard operating procedures (SOP) and a QAPP have been prepared for EPA Method TO-14 canister analysis as part of the baseline VOC monitoring at WIPP. Revisions to these documents will be made as necessary to meet the QA/QC objectives described in Section 5.0. In addition, canister and sampling system cleaning and certification SOPs and QAPPs have been prepared. These procedures and plan will be consistent with the QA/QC objectives defined for the program.

Alternative sampling methods will be considered for deployment. One option will be to use subatmospheric samplers rather than pressurized sampling systems for stations VOC-A and VOC-B. In addition, remote sensing by proposed draft EPA Method TO-16, open-path fourier transform infrared spectroscopy (OP-FTIR) and extractive FTIR, may constitute supplemental or alternative methods for detecting VOCs released from waste panels at WIPP. WIPP personnel will continue to follow the development of emerging FTIR technology, and other potentially applicable technologies for assessing VOCs in the WIPP environment. Real-time monitoring with

a FTIR system may be a feasible future option for the VOC Confirmatory Monitoring Program.

3.4 Sampling Schedule

Many tasks will be completed prior to the initiation of VOC monitoring according to the monitoring plan. For example, power will be run to the monitoring station locations, engineering drawings will be created/revised for the monitoring stations, and program QAPP and SOP documentation will be finalized. Some sampling will be conducted prior to waste emplacement to troubleshoot the monitoring system. The purpose of collecting data during this phase will be to evaluate whether the monitoring systems and analytical methods are properly functioning. The troubleshooting period will be determined by VOC monitoring group personnel.

Confirmatory VOC sampling at Stations VOC-A and VOC-B will begin with initial waste emplacement in Panel 1. Sampling will continue during Panel 1 operations and will end no earlier than 6 months after the certified closure of Panel 1.

The environment within Panel 1 is not expected to vary substantially from day to day. If releases from Panel 1 do occur, concentrations in Drift E-300 may increase gradually over time as the panel is filled. Once the panel is filled and closed, the panel closure systems are designed to minimize air leakage from the relatively static panel environment. For these reasons, routine sampling will be conducted twice a week during the time Panel 1 is filled and for the first 6 months after the closure of Panel 1 has been certified.

VOC concentrations will be evaluated quarterly to assess whether the sampling results represent adequate confirmation of the emission calculations. If the average measured concentrations for the Panel 1 monitoring period confirm the calculations, no additional sampling will be performed. Confirmation will be achieved if the annual average concentration is below the predicted value. Monitoring will be extended for at least 12 months if no emissions are detected. However, the sampling frequency will be decreased to one per week. In addition, if a 12-month average target compound concentration exceeds the concentration of concern, additional sampling will be considered.

4.0 SAMPLING AND ANALYSIS PROCEDURES

This section describes the equipment and procedures that will be implemented during sample collection and analysis activities for VOCs at WIPP.

4.1 SAMPLING EQUIPMENT

The sampling equipment that will be used during the study includes the following: 6-liter (L) stainless-steel SUMMA® canisters, and VOC canister samplers. A discussion of each of these items is presented below.

4.1.1 SUMMA® Canisters

Six-liter, stainless-steel canisters with SUMMA® passivated interior surfaces will be used to collect and store all ambient air and gas samples for VOC analyses collected as part of the monitoring processes. These canisters must be cleaned and certified prior to their use, as described by Compendium Method TO-14 and the draft EPA CLP-SOW for Analysis of Ambient Air in Canisters. A SOP describing this process in detail has been prepared by the analytical laboratory. Compendium Method TO-14 and the CLP-SOW (EPA, 1991) were used as guidance documents in the preparation of this SOP.

4.1.2 Volatile Organic Compound Canister Samplers

A conceptual diagram of a VOC sample collection unit is provided in Figure 4.1. Unless an alternate sampling method is selected, two

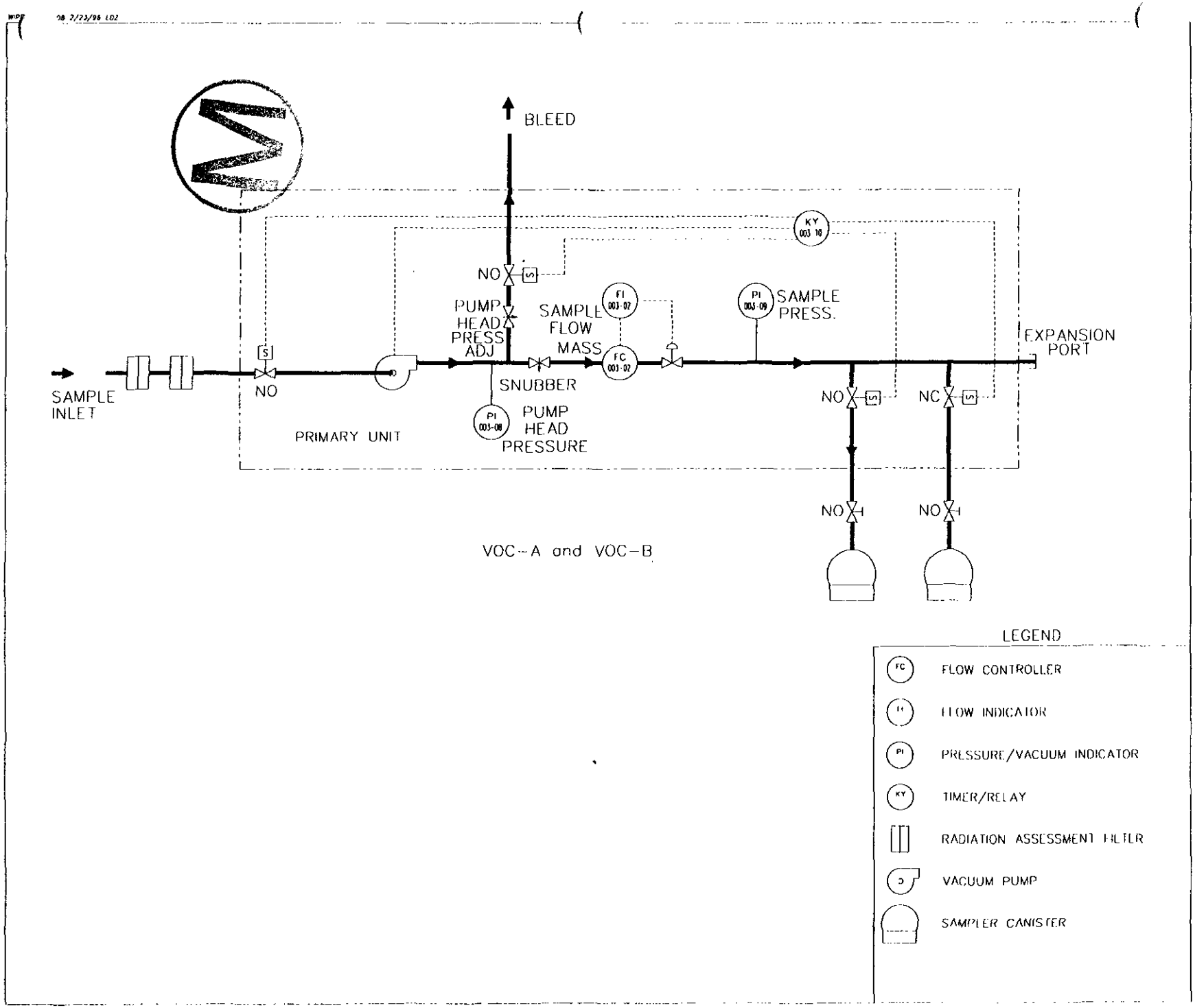

Figure 4.1 – VOC Monitoring System Design

such systems, VOC-A and VOC-B, will be operational at the time waste disposal operations begin in Panel 1. The sampling system consists of a sample pump, flow controller, sample inlet, two inlet filters in series to remove particulate matter, vacuum/pressure gauge, electronic timer, inlet purge vent, two sampling ports, and sufficient collection canisters so that any delays attributed to laboratory turnaround time and canister cleaning and certification will not result in canister shortages. Knowledge of sampler flow rates and duration of sampling will allow calculation of sample volume. The set point flow rate will be verified during sample collection by monitoring the mass flow indication. Prior to use, the sample collection units, including inlet line, will be tested and certified to demonstrate that they are free of contamination above the reporting limits of the VOC analytical method (see Section 5.0). Ultra high purity humidified zero air will be pumped through the sampling unit and collected in previously certified canisters as sampler blanks for analysis, as described in WP 12-7. A SOP describing in detail the cleaning and certification procedure for samplers (including pressure testing and target compound recovery evaluation) has been prepared.

4.2 SAMPLE COLLECTION

Samples collected from the underground facility should be representative of routine operations; therefore, six-hour integrated samples will be collected on each sample day. Alternative sampling durations may be defined for experimental purposes. The VOC canister sampler at each location will sample ambient air on the same programmed schedule. The sample pump will be programmed to sample continuously over a six-hour period during the work day. The units will sample at a nominal flow rate of 33.3 actual milliliters per minute over a six-hour sample period.

This schedule will yield a final sample volume of approximately 12 L. Flow rates and sampling duration may be modified as necessary for experimental purposes and to meet the data quality objectives.

Sample flow will be checked each sample day using the in-line mass flow controller. These flow controllers are initially factory-calibrated and specify a typical accuracy of better than 10 percent full scale. Additionally, each air flow controller is calibrated at a manufacturer-specified frequency using a National Institute of Standards and Testing (NIST) primary flow standard. Existing SOPs have been revised to address the specific calibration requirements of the VOC monitoring equipment.

Upon initiation of waste disposal activities in Panel 1, samples will be collected twice each week (at Stations VOC-A and VOC-B). Samples collected at the panel locations should represent the same matrix type (i.e., elevated levels of salt aerosols). To verify the matrix similarity, duplicate samples will be collected from each sampling station (stations VOC-A and VOC-B) during the first sampling event and at an overall frequency of five percent thereafter (see Section 5.1).

4.3 SAMPLE MANAGEMENT

Field sampling data sheets will be used to document the conditions under which each sample is collected. These data sheets have been developed specifically for VOC monitoring at the WIPP facility. The individuals assigned to collect the specific samples will be required to fill in all of the appropriate sample data and to maintain this record in sample logbooks. The program team leader will review these forms for each sampling event.

All samples will be maintained, and shipped if necessary, at ambient temperatures. Collected samples will be transported in appropriate containers. Prior to leaving the underground for analysis, all sample containers must undergo radiological screening. No potentially contaminated samples or equipment will be transported to surface.

Additional QA requirements for sample management contained in the sitewide Quality Assurance Program Description, WP 13-1, will be followed as appropriate. Chain-of-custody procedures will be followed closely, and additional requirements imposed by the laboratory for sample analysis will be included as necessary.

Individuals collecting samples will be responsible for the initiation of custody procedures. The chain of custody will include documentation as to the canister certification, location of sampling event, time, date, and individual handling the samples. Samples will be collected and handled in accordance with WP 12-7 and approved SOPs. Deviations from procedure will be considered a variance. Variances must be preapproved by the program manager and recorded in the project files. Unintentional deviations, sampler malfunctions, and other problems are nonconformances. Nonconformances must be documented and recorded in the project files. All field logs/data sheets must be incorporated into WIPP's records management program.

More detailed documentation of sample management is presented in WP 12-7, the QAPP for the VOC Monitoring Program (to be updated as described in Section 3.3).

4.4 SAMPLER MAINTENANCE

Routine sampler maintenance will be the responsibility of the sampling personnel. This maintenance will include, but not be limited to, replacement of damaged or malfunctioning parts without compromising the integrity of the sampler, filter changes, leak testing, and minor cleaning. Major cleaning and sampler cleanliness certification will be the responsibility of the sampling and analytical laboratory personnel. Additionally, complete spare units will be maintained onsite to minimize downtime because of sampler malfunction. A sampler preventative maintenance schedule has been developed and is included in WP 12-7. At a minimum, samplers will be certified for cleanliness initially, after any parts that are included in the sample flow path are replaced, or any time analytical results indicate potential contamination. All sample canisters will be certified prior to each usage.

4.5 ANALYTICAL PROCEDURES

Analytical procedures used in the analysis of VOC samples from canisters are based on EPA guidance in Compendium Method TO-14 (EPA, 1988b) and in the Draft CLP-SOW for Analysis of Ambient Air (EPA, 1991). Specific analytical SOPs and method validation data are in place at the program analytical laboratory for the performance of canister sample analyses. The technical approach for canister sample analysis is summarized below.

4.5.1 Sample Preparation

Because canisters will be pressurized during the sampling procedure, laboratory pressurization will not be necessary for analyses. Canister pressures will be verified by the laboratory when they are

received to confirm that significant losses did not take place during shipping and storage.

4.5.2 Analytical System Requirements

The GC/MS analytical system will consist of three major components: the sample introduction system, analyte separation system (GC), and the analyte detector system (MS).

- Sample Introduction System for Canisters: This system will include a drying tube to remove moisture from the gas stream. One or more cryogenic traps may be used to focus and desorb trapped material. Transfer lines within the introduction unit will be heated as necessary so that volatile compounds are not actively absorbed. Valves and solenoids will be heated and be of a low dead volume type. The introduction system will have an in-line mass flow controller. The introduction unit will be capable of introducing internal standards directly into the sample flow path.

- Analyte Separation: Analyte separation will be achieved by GC. The GC will be capable of subambient temperature programming.

- Detection System: Analyte detection will be accomplished by MS. The MS must be capable of scanning from 35 to 300 mass to charge ratio in one second or less, be fitted with a gas jet separator, a data system capable of storing all raw data, and a computer algorithm for analyte quantitation and forward library searching. All raw and processed GC/MS data must be stored on magnetic tape or disk and kept for the duration of this project.

4.5.3 Standard Preparation

Primary analytical standards will be prepared by the laboratory from commercially available, certified calibration gases. Alternatively, primary standards may be generated internally by the laboratory. Primary standards of analytes that are gases at standard temperature and pressure (STP) may be internally prepared in a static gas dilution bottle. For analytes that are liquid or solid at STP, a mixture may be made and loaded directly into a standard preparation cylinder. These internally generated standards will be checked against EPA audit cylinders or other reference materials to verify the accuracy of their concentrations.

Primary standards will be prepared for the nine target compounds as well as the internal standards. Secondary standards used for instrument calibration will be prepared from dilution of the primary standards.

4.5.4 Calibration Procedures

Prior to the analysis of a standard curve, the GC/MS system must undergo a mass calibration check. This check is performed by injecting 50 nanograms (ng) of 4-bromofluorobenzene (BFB) directly onto the capillary column. The requirements (criteria) for relative ion abundances for BFB, listed in Table 4.1, must be met before analyses may proceed. BFB requirements must be met for each 12 hours of operation.

Quantitative standards for the nine target analytes will be analyzed at five concentrations. These concentrations should

define the linear range of the instrument for these nine compounds; however, if some nonlinearity exists, concentrations may be determined by curve fitting or physically plotting the data. One standard concentration shall be at or near a concentration corresponding to the required MRL for each target compound. Relative response factors will be generated for each target compound. These response factors must meet the requirements listed in Section 5.1.3. As discussed above, if low concentration standards do not meet the linearity requirement, then a curve-fitting routine may be used. The method used to quantify the data must be reported with the analytical results.

Table 4.1 goes here

4.5.5 Library Searches

In every sample analyzed, a forward search of the NIST library of mass spectra must be performed for all chromatographic peaks greater than 10 percent of the nearest internal standard.

4.5.6 Data Reporting

Sample target analyte concentrations will be quantified using the mid-range calibration standards and will be reported in ppbv. Non-target sample contaminants identified by NIST library searches will be reported as TICs, and concentration calculations will be based on the response of the nearest internal standard. The relative response factor used for quantitation, as well as copies of spectra with the library search results (purity and fit), will be submitted with the results. A table listing the run sequence with the corresponding internal standard area counts must be reported with the analytical results. A narrative describing any problems with sample analysis must be included. Any nonconformances must be included with the reporting of the data. Data reporting and documentation requirements are discussed in greater detail in WP 12-7.

4.6 LABORATORY SELECTION

Sample analyses will occur at the WIPP onsite analytical laboratory and/or at a suitable contract analytical laboratory. Upon selection of an offsite contract laboratory, measures shall be taken, in accordance with the current Westinghouse Waste Isolation Division procurement policies and procedures, to ensure that procured services conform to specified requirements. These measures

will generally include one or more of the following: 1) evaluation of the supplier's capability to provide services in accordance with requirements, including a history of providing similar services; 2) evaluation of objective evidence of conformance, such as laboratory document submittals; and 3) examination of delivered services.

4.7 LABORATORY PROCEDURES

Analytical laboratories that perform analyses for the VOC Confirmatory Monitoring Plan are required to develop and maintain, at a minimum, the following SOPs:

- Canister cleaning and certification
- Sampler cleaning and certification
- Analysis of VOCs in SUMMA® canisters
- Data QA and reporting

Laboratories are also required to maintain an internal program QA Manual, and to develop and prepare a QAPP covering cleaning and certification of canisters and laboratory analysis of canister samples. In addition, laboratories will be required to review and comply with WP 12-7.

5.0 QUALITY ASSURANCE

Many quality assurance objectives for the VOC Confirmatory Monitoring Plan have been addressed in Sections 3.0 and 4.0. For example, sample collection procedures are discussed, including justification of sampling location selection. Additional topics include discussions of sampling program operations, preparation of sampling equipment and sample containers, redundancy in sampling equipment and sample containers (including canister certification), a general sample management/control scheme, and the selection of analytical procedures. More detailed descriptions of these functions, as well as additional quality-related objectives, are addressed in WP 12-7. WP 12-7 has been prepared in accordance with the document entitled "EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations" (EPA, 1994) and the "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans" (EPA, 1983), and QA criteria listed in Table 5.1. This section addresses the methods to be used to evaluate the components of the measurement system and how this evaluation will be used to assess data quality. In addition, project activities will be performed in conformance with QA requirements described in WP 12-7.

5.1 QUALITY ASSURANCE OBJECTIVES FOR THE MEASUREMENT OF PRECISION, ACCURACY, SENSITIVITY, AND COMPLETENESS

Quality assurance objectives for the VOC Confirmatory Monitoring Plan will be defined in terms of the following data quality parameters:

Table 5.1 goes here.

- **Precision.** For the duration of this project, precision will be defined and evaluated by the relative percent difference (RPD) values calculated between field duplicate samples and between laboratory duplicate samples.

$$RPD = \frac{(A - B)}{[(A + B)/2]} \times 100 \quad (3)$$

where:

A = Original sample result

B = Duplicate sample result

- **Accuracy.** Analytical accuracy will be defined and evaluated through the use of analytical standards. Because recovery standards cannot reliably be added to the sampling stream, overall system accuracy must be based on analytical instrument performance evaluation criteria. These criteria will include performance verification for instrument calibrations, laboratory control samples, and sample internal standard areas. These criteria will constitute the verification of accuracy for target analyte quantitation (i.e., quantitative accuracy). Evaluation of standard ion abundance criteria for BFB will be used to evaluate the accuracy of the analytical system in the identification of targeted analytes, as well as the evaluation of unknown contaminants (i.e., qualitative accuracy).

- **Sensitivity.** Sensitivity will be defined by the required MRLs for the program. Attainment of required MRLs will be verified by the performance of statistical method detection limit (MDL) studies in accordance with 40 CFR Part 136. The MDL represents the minimum concentration that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. An MDL study will be performed by the program analytical laboratory prior to sampling and analysis.

- **Completeness.** Completeness will be defined as the percentage of the ratio of the number of valid sample results received versus the total number of samples collected. Completeness may be affected, for example, by sample loss or destruction during shipping, by laboratory sample handling errors, or by rejection of analytical data during data validation.

5.1.1 Evaluation of Laboratory Precision

Laboratory sample duplicates and blank spike/blank spike duplicates (BS/BSD) will be used to evaluate laboratory precision. Quality assuarance objectives for laboratory precision are listed in Table 5.1, and are based on precision criteria proposed by EPA for canister sampling programs (EPA, 1991). These values will be appropriate for the evaluation of samples with little or no matrix effects. Because of the potentially high level of salt-type aerosols in the WIPP underground environment, the analytical precision achieved for WIPP samples may vary with respect to the

EPA criteria. RPDs for BS/BSD analyses will be tracked through the use of control charts. RPDs obtained for laboratory sample duplicates will be compared to those obtained for BS/BSDs to ascertain any sample matrix effects on analytical precision. BS/BSDs and laboratory sample duplicates will be analyzed at a frequency of 10 percent or one per analytical lot, whichever is more frequent. Precision windows and outlier criteria are addressed in WP 12-7.

5.1.2 Evaluation of Field Precision

Field duplicate samples will be collected at a frequency of five percent for both monitoring locations. Like the laboratory duplicate data, field duplicate data will be compared to the EPA precision criteria presented in Table 5.1, and matrix and sampling effects on precision will be assessed through comparison with internal laboratory precision data.

5.1.3 Evaluation of Laboratory Accuracy

Quantitative Accuracy

Quantitative analytical accuracy will be evaluated through performance criteria on the basis of: 1) relative response factors generated during instrument calibration, 2) analysis of laboratory control samples (LCS), and 3) recovery of internal standard compounds. The criteria for the initial calibration (5-point calibration) is that any single relative response factor for a particular target compound can differ by no more than 30 percent from the average of the five. After the successful completion of the 5-point calibration, it is sufficient to analyze only a midpoint standard for every 12 hours of operation. The midpoint

standard must pass the 30 percent difference acceptance criteria before sample analysis may begin.

A blank spike or LCS is an internal QC sample generated by the analytical laboratory by spiking a standard air matrix (humid zero air) with a known amount of a certified reference gas. The reference gas will contain the target VOCs at known concentrations. Percent recoveries for the target VOCs will be calculated for each LCS relative to the reference concentrations. Objectives for percent recovery are listed in Table 5.1, and are based on accuracy criteria proposed by EPA for canister sampling programs (EPA, 1991). LCSs will be analyzed at a frequency of 10 percent or one per analytical lot, whichever is more frequent. Recovery windows and outlier criteria are addressed in WP 12-7.

Internal standards will be introduced into each sample analyzed, and will be monitored as a verification of stable instrument performance. In the absence of any unusual interferences, areas should not change by more than 40 percent over a 12-hour period. Deviations larger than 40 percent are an indication of a potential instrument malfunction. If an internal standard area in a given sample changes by more than 40 percent, the sample must be reanalyzed. If the 40 percent criterion is not achieved during the reanalysis, the instrument must undergo a performance check and the midpoint standard must be reanalyzed to verify proper operation. Response and recovery of internal standards will also be compared between samples, LCSs, and calibration standards to identify any matrix effects on analytical accuracy.

Qualitative Accuracy

Qualitative accuracy in the identification of target VOCs will be evaluated by the relative ion abundance criteria established for the internal standard compound BFB. For each 12 hours of sample analysis, a 50-nanogram (ng) injection of BFB must be made, and the requirements listed in Table 4.1 must be met before the instrument may be used to analyze samples.

5.1.4 Evaluation of Sensitivity

The presence of aerosol salts in underground locations may affect the MDL of the samples collected in those areas. The intake manifold of the sampling systems will be sufficiently protected from the underground environment to minimize salt aerosol interference.

The MDL for each of the nine target compounds will be evaluated by the analytical laboratories before sampling begins. The initial MDL evaluation will be performed in accordance with 40 CFR Part 136 and with EPA/530-SW-90-021, as revised and retitled, "Quality Assurance and Quality Control" (Chapter 1 of SW-846) (1986).

5.1.5 Completeness

The expected completeness for this project is greater than or equal to 90 percent. Data completeness will be tracked monthly.

5.2 SAMPLE HANDLING AND CUSTODY PROCEDURES

Sample packaging, shipping, and custody procedures are addressed in WP 12-7 (see Sections 7.4 and 8.0).

5.3 CALIBRATION PROCEDURES AND FREQUENCY

Calibration procedures and frequencies for analytical instrumentation are listed in Section 4.5.4.

5.4 ANALYTICAL PROCEDURES

The analytical procedures for the VOC Confirmatory Monitoring Program, which are based on the draft CLP SOW for Analysis of Ambient Air in Canisters (EPA, 1991) and EPA guidance Method TO-14 (EPA, 1988b), are outlined in Section 4.5.

5.5 DATA REDUCTION, VALIDATION, AND REPORTING

Data reduction and validation are addressed in the WP 12-7. A brief description of data reporting is given in Section 4.5; more detail on data reporting is provided in WP 12-7.

A dedicated logbook will be maintained by the operators. This log will contain documentation of all pertinent data for the sampling. Sample collection conditions, maintenance, and calibration activities will be included in this log. Additional data collected by other groups at WIPP, such as ventilation airflow, temperature, pressure, etc., will also be obtained to document the sampling conditions, as necessary.

Data validation procedures will be specified in the monitoring program QA protocols. At a minimum, all field data forms and

sampling logbooks will be checked for completeness and correctness. Sample custody and analysis records will be routinely reviewed by the QA officer and the laboratory supervisor.

Data will be summarized quarterly. Data summaries will include target VOC results for each sample collected as well as overall statistical summaries. Graphical summaries may also be included.

5.6 PERFORMANCE AND SYSTEM AUDITS

System audits will initially address startup functions for each phase of the project. These audits will consist of onsite evaluation of materials and equipment, review of canister and sampler certification, review of laboratory qualification and operation, and may, at the request of the QA officer, include an onsite audit of the laboratory facilities. The function of the system audit is to verify that the requirements in this plan and the QAPP, have been met prior to initiating the program. System audits will be performed prior to the initiation of the monitoring program.

Performance audits will be accomplished as necessary through the evaluation of analytical quality control data, by performing periodic site audits throughout the duration of the project, and through the introduction of third-party audit cylinders (laboratory blinds) into the analytical sampling stream. Performance audits will also include a surveillance/review of all data associated with canister and sampler certification, a project-specific technical audit of field operations, and a laboratory performance audit. Field logs, logbooks, and data sheets will be reviewed weekly. Blind-audit canisters will be introduced once

during the sampling period. Details concerning scheduling, personnel, and data quality evaluation are addressed in WP 12-7.

5.7 PREVENTATIVE MAINTENANCE

A brief description of sampler maintenance is described in Section 4.4. Maintenance of analytical equipment will be addressed in the analytical SOP.

5.8 CORRECTIVE ACTIONS

Nonconformances and corrective actions of noncomformances will be processed as outlined in the Quality Assurance Program Description (DOE 1994).

5.9 QUALITY ASSURANCE REPORTS TO MANAGEMENT

The results of audits will be reported in accordance with sitewide Quality Assurance Plan (QAP) and WP 13-005. Audit reports will include identification of findings and/or observations, as well as an assessment of the effectiveness of the QAP elements review.

6.0 ACRONYMS

BFB	4-Bromofluorobenzene
BS/BSD	Blank spike/blank spike duplicate
CFR	Code of Federal Regulations
CH	Contact handled
CLP	Contract Laboratory Program
COC	Concentration of concern
CRQL	Contract required quantitation limit
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
g/mol	Grams per mole
GC/MS	Gas chromatography/mass spectroscopy
LCS	Laboratory control samples
MDL	Method detection limit
mmHg	Millimeters of mercury

MDL	Method detection limit
MRL	Method reporting limit
m/z	Mass to charge ratio
ng	Nanogram
NIST	National Institute of Standards and Testing
NMAC	New Mexico Administrative Code
NMVP	No-migration variance petition
OP-FTIR	Open-path fourier transform infrared spectroscopy
ppbv	Parts per billion by volume
QA/QC	Quality assurance/quality control
QA	Quality assurance
QAPD	Quality Assurance Program Description
QAPP	Quality Assurance Project Plan
QC	Quality control
RCRA	Resource Conservation and Recovery Act
RH	Remote handled

RPD	Relative percent difference
SOP	Standard operating procedure
SOW	Statement of work
STP	Standard temperature and pressure
TIC	Tentatively identified compound
TRU	Transuranic
UHP	Ultra high purity
VOCs	Volatile organic compounds
WAC	Waste acceptance criteria
WAP	Waste analysis plan
WID	Waste Isolation Division
WIPP	Waste Isolation Pilot Plant
$\mu g/m^3$	Micrograms per cubic meter
°C	Degrees Celsius

7.0 BIBLIOGRAPHY

Grant, W.B., R.H. Kagann, and W.A. McClenny. 1992. *Optical remote measurement of toxic gases.* Journal of the Air and Waste Management Association. 42(1): 18-30.

Haust, P.L. 1994. *Photolysis assisted pollution analysis.* Measurement of Toxic and Related Air Pollutants. U.S. EPA and Air and Waste management Association Report Number EPA/600/R-94/136, May.

Measurement of Toxic and Related Air Pollutants. 1994. U.S. EPA and Air and Waste Management Association Report Number EPA/600/R-94/136, May.

Russwurm. G.M., R.H. Kagann, O.A. Simpson, and W.F. Heget. 1991. *Long-path FTIR measurements of volatile organic compounds in an industrial setting.* Journal of the Air and Waste Management Association 41(8): 1062-1066.

DOE (U.S. Department of Energy). 1994. *U.S. Department of Energy Carlsbad Area Office Quality Assurance Program Description.* CAO-94-1012, Rev. 0, June 1994. U.S. Department of Energy, Carlsbad, NM.

U.S. Department of Energy. 1995a. DOE/WIPP 95-2057, Conceptual Design for Operational Phase Panel Closure Systems

U.S. Department of Energy. 1995b. DOE/CAO-Draft-2043,Draft No-Migration Variance Petition.

U.S. Environmental Protection Agency. 1983. *Interim guidelines and specifications for preparing quality assurance project plans.* QAMS-005/80, EPA-600/4-83-004.

U.S. Environmental Protection Agency. 1986. SW-846, *Test methods for evaluating solid waste, physical/chemical methods.* Third Edition. Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. Environmental Protection Agency. 1988a. 40 Code of Federal Regulations Part 268, Land Disposal Restrictions.

U.S. Environmental Protection Agency. 1988b. *Compendium method TO-14: the determination of volatile organic compounds (VOCs) in ambient air using SUMMA passivated canister sampling and gas chromatographic analysis.* Quality Assurance Division, Environmental Monitoring Systems Laboratory, Research Triangle Park, N. C.

U.S. Environmental Protection Agency. 1991. *Draft contract laboratory program statement of work, volatile organics analysis of ambient air in canisters*, Washington, D.C., December.

U.S. Environmental Protection Agency. 1994. EPA QA/R-5, Draft Interim Final, EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations, Washington, D.C.

Winberry, William T., N.J. Murphy, and R.M. Riggin. 1990. *Methods for determination of toxic organic compounds in air.* Noyes Data Corporation, Park Ridge, New Jersey.

WIPP/CAO 95-1014, Waste Isolation Pilot Plant Project Technical Baseline for Regulatory Compliance.

WP 13-005, Internal and Suppliers QA Audits.

WP 02-9, WIPP Final Safety Analysis Report.

WP 12-7, VOC Monitoring Quality Assurance Project Plan.

WP 13-QA3003, Corrective Action Program.

WP 13-1, WIPP Sitewide Quality Assurance Program.

Table 2.1: Target Analytes for VOC Monitoring During the WIPP Disposal Phase

Target Analyte	Common Synonyms and Acronyms	Chemical Formula	Molecular Weight (g/mol)	Boiling Point (°C)*
1,1-Dichloroethylene	1,1-Dichloroethene, Vinylidene chloride, 1,1-DCE	$C_2H_2Cl_2$	96.95	31
Carbon tetrachloride	Tetrachloromethane	CCl_4	153.8	77
Methylene chloride	Dichloromethane	CH_2Cl_2	84.94	40
Chloroform	Trichloromethane	$CHCl_3$	119.4	61
1,1,2,2-Tetrachloroethane	sym-Tetrachloroethane, Tetrachloroethane	$C_2H_2Cl_4$	167.9	147
1,1,1-Trichloroethane	1,1,1-TCA, TCA, Methyl chloroform	$C_2H_3CCl_3$	133.42	74
Chlorobenzene	Monochlorobenzene, Benzene chloride	C_6H_5Cl	112.6	132
1,2-Dichloroethane	1,2-DCA, DCA, Ethylene dichloride, EDC, sym-Dichloroethane	$C_2H_4Cl_2$	98.96	83
Toluene	Methyl benzene	C_7H_8	92.13	111

°C Degrees Celsius
VOC Volatile organic compound
WIPP Waste Isolation Pilot Plant

* Handbook of Chemistry and Physics, 62nd Edition, CRC Press, 1982.

Table 3.1: Volatile Organic Compound Concentrations of Concern*

Compound	Molecular Weight (g/mol)	Drift E-300 µg/m³	Drift E-300 ppbv
1,1-Dichloroethylene	96.95	106	27
Carbon tetrachloride	153.8	35	6
Methylene chloride	84.94	1,130	326
Chloroform	119.4	23	5
1,1,2,2-Tetrachloroethane	167.9	92	13
1,1,1-Trichloroethane	133.42	3,300	600
Chlorobenzene	112.6	10,000	2,300
1,2,-Dichloroethane	98.96	20	10
Toluene	92.13	212,000	57,000

g/mol Grams per mole
µg/m³ Micrograms per cubic meter
ppbv Parts per billion by volume

* Calculated at 25 degrees Celsius (°C) and 760 millimeters of mercury (mmHg).

Table 4.1: 4-Bromofluorobenzene Key Ions and Ion Abundance Criteria

Mass	Ion Abundance Criteria
50	8 to 40 percent of mass 95
75	30 to 60 percent of mass 95
95	Base Peak, 100 percent Relative Abundance
96	5 to 9 percent of mass 95
173	<2 percent of mass 174
174	>50 percent of mass 95
175	4 to 9 percent of mass 174
176	>93 percent but <101 percent of mass 174
177	5 to 9 percent of mass 176

Table 5.1: Quality Assurance Objectives for Accuracy, Precision, Sensitivity, and Completeness

Compound	Accuracy (Percent Recovery)	Precision (RPD)	Required MRL (ppbv)	Completeness (Percent)
1,1-Dichloroethylene	60 to 140	25	5	≥90
Carbon tetrachloride	60 to 140	25	2	≥90
Methylene chloride	60 to 140	25	5	≥90
Chloroform	60 to 140	25	2	≥90
1,1,2,2-Tetrachloroethane	60 to 140	25	2	≥90
1,1,1-Trichloroethane	60 to 140	25	5	≥90
Chlorobenzene	60 to 140	25	2	≥90
1,2-Dichloroethane	60 to 140	25	2	≥90
Toluene	60 to 140	25	5	≥90

These data quality objectives are based on control criteria proposed by EPA as presented in the Contract Laboratory Program Statement of Work for the Analysis of Ambient Air in Canisters (EPA, 1991).

EPA U.S. Environmental Protection Agency
MRL Method reporting limit
ppbv Parts per billion by volume
RPD Relative percent difference

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix WAP

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Waste Analysis Plan

M

CHAPTER C

WASTE ANALYSIS PLAN

CHAPTER C
WASTE ANALYSIS PLAN
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CHAPTER C
WASTE ANALYSIS PLAN

Introduction

This waste analysis plan (WAP) has been prepared for disposal activities to be conducted at the Waste Isolation Pilot Plant (WIPP) facility to meet requirements set forth in Title 20 of the New Mexico Administrative Code, Chapter 4, Part I (20 NMAC 4.1), Subpart V, §264.13. Guidance in the most recent U.S. Environmental Protection Agency (EPA) manual on waste analysis has been incorporated into the preparation of this WAP (EPA, 1994). Accordingly, this chapter includes a facility description; information on the waste to be managed; a discussion of parameters, rationale, and test methods; details of planned waste sampling and analysis; a description of the waste shipment screening and verification process; and a description of the quality assurance (QA)/quality control (QC) program.

When using this WAP, the term "WIPP," when used in the context of requiring a duty or responsibility, means the U.S. Department of Energy (DOE) as the facility owner and operator and the Westinghouse Waste Isolation Division (WID) as the co-operator, as set forth in the WIPP Resource Conservation and Recovery Act (RCRA) Permit Application certification (Chapter M of this permit application). This WAP establishes waste characterization requirements for DOE waste generators at other sites. Waste characterization requirements are implemented in lower-tier documents, including the Transuranic Waste Characterization Quality Assurance Program Plan (QAPP)[1] and quality assurance project plans (QAPjP) for individual generator sites and analytical laboratories.

The mission of the WIPP Project, as established by the U.S. Congress in 1979 (Public Law 96-164), is to provide a research and development facility to demonstrate the safe disposal of transuranic (TRU) mixed waste generated as a result of United States defense activities. This permit application and this WAP are for the management of TRU mixed waste to be disposed of at the WIPP facility.

TRU mixed waste contains both TRU radioactive and hazardous components, as defined in 20 NMAC 4.1, Subpart VIII, §268.35(d), and in the Federal Facility Compliance Act, Public Law 102- 386, Title 1, §3021(d). It is designated and separately packaged as either contact-handled (CH) or remote-handled (RH), based on the radiological dose rate at the surface of the waste

[1]The Transuranic Waste Characterization Quality Assurance Program Plan, DOE/CAO 94-1010 (April, 1995), utilizes a performance-based approach to allow individual sites to have the flexibility to employ analytical and examination methods that meet the quality assurance objectives specified in this WAP. The DOE will conduct waste characterization activities at each generator site planning to ship waste to the WIPP facility to obtain the requisite data. TRU mixed waste characterization described in the QAPP includes: 1) radiography, 2) headspace gas sampling and analysis, 3) solidified waste sampling and analysis, and 4) visual examination.

container. Both CH TRU and RH TRU mixed wastes will be received and disposed of at the WIPP facility.

The hazardous components of the TRU mixed waste to be managed at the WIPP facility are designated in the WIPP facility's RCRA Part A permit application. This WAP describes the measures that will be taken to assure that the wastes received at the WIPP facility are within the scope of the RCRA Part A permit application as established by 20 NMAC 4.1, Subpart V, §264.13, and that they comply with unit-specific requirements of 20 NMAC 4.1, Subpart V, Miscellaneous Units.

Both CH TRU and RH TRU mixed waste at the WIPP facility will be managed using containers that meet or exceed the requirements of the U.S. Department of Transportation (DOT) for Type A containers. The use of the term "container" when referring to waste characterization activities refers to a drum, canister, or Standard Waste Box (SWB) unit. Section D-1a(1) provides details regarding the design and use of these waste containers.

The WIPP facility requires TRU waste characterization programs to adhere to the requirements specified in this WAP, and enumerated in the WIPP Waste Acceptance Criteria (WAC), and the Transuranic Waste Characterization QAPP (DOE, 1995a). All waste characterization activities discussed in Section C-4 will be carried out at generator sites in accordance with this WAP. WIPP management will audit site waste characterization programs and activities as described in Section C-5. This WAP describes the relationship of the waste characterization data and information to the regulatory requirements of 20 NMAC 4.1. The waste characterization program for wastes to be received at the WIPP facility for disposal has been designed to utilize sampling and analysis. In addition, acceptable knowledge of waste generation processes may be used for those wastes for which no practical characterization techniques exist (such as debris waste).

Some TRU mixed waste is retrievably stored at the DOE generator sites. Additional waste will be generated and packaged into containers at these sites in the future. TRU mixed waste will be retrieved from storage areas at a DOE site. Retrievably stored waste is defined as waste generated after 1970 and before implementation of the QAPP characterization requirements. Newly generated waste is defined as waste generated after implementation of QAPP characterization requirements. Stored TRU waste will be characterized on an ongoing basis, as the waste is retrieved. Newly generated TRU waste will be characterized as it is generated. Waste characterization requirements for stored and newly generated wastes differ due to the QAPP requirements, as discussed in Sections C-3a and C-3b.

Characterization requirements for individual containers of waste are specified on a waste stream basis. A waste stream is defined as waste material generated from a single process or from an activity that is similar in material, physical form, isotopic make-up, and hazardous constituents. Waste streams are grouped by Waste Matrix Code Groups related to the physical and chemical properties of the waste. Generator/storage sites must use the characterization techniques described in this WAP to assign appropriate Waste Matrix Code Groups for WIPP disposal. The

Waste Matrix Code Groups are solidified inorganics, solidified organics, salt waste, soils, lead/cadmium metal, inorganic nonmetal waste, combustible waste, graphite, filters, heterogeneous debris waste, and uncategorized metal.

Wastes are initially categorized into three broad Summary Category Groups that are related to the final physical form of the wastes. Waste characterization requirements for these groups are specified separately in Section C-2 of this WAP. These groups include Homogeneous Solids (Summary Category S3000), Soil/Gravel (Summary Category S4000), and Debris Wastes (Summary Category S5000).

The WIPP waste characterization program carried out by generators will be controlled under this WAP and implemented by the requirements of the QAPP and the WAC Certification Program (DOE, 1991). Waste characterization activities at the generator sites include the following, although not all these techniques will be used on each container, as discussed in Section C-2:

- Radiography, which is an x-ray technique to determine physical contents of containers
- Visual examination of opened containers as an alternative way to determine their physical contents or to verify Radiography results
- Headspace-gas sampling to determine volatile organic compound (VOC) content of gases in the void volume of the containers
- Sampling and analysis of waste forms that are homogeneous and can be representatively sampled to determine concentrations of hazardous waste constituents and toxicity characteristic contaminants of waste in containers
- Compilation of documented acceptable knowledge into an auditable record

The DOE's objective is to operate and maintain the WIPP facility free of both chemical and radiological contamination. Therefore, as allowed by 20 NMAC 4.1, Subpart V, §264.13, and consistent with joint EPA and U.S. Nuclear Regulatory Commission (NRC) guidance, all waste sampling and analyses will be conducted by the DOE generator sites in accordance with the requirements of this WAP. The WAP specifies required characterization activities that the generator must complete in order to be able to provide the information needed to send TRU waste to the WIPP facility for disposal. In accordance with this WAP, the generator sites will conduct the required waste characterization activities. Once the sufficient waste characterization is complete, the generator will complete a Waste Stream Profile Form documenting the results of their characterization activities (see Section C-1b). Generators will perform specific waste analyses according to the Transuranic Waste Characterization Sampling and Analysis Methods Manual (hereinafter referred to as the Methods Manual), which prescribes appropriate EPA-specified analytical methods modified as needed due to the presence of TRU waste

contaminants (DOE, 1995b). Since the DOE has determined that the waste analysis parameters (Section C-2a) are the same for CH and RH TRU mixed waste, RH TRU waste will be characterized using the same techniques as are used for CH TRU waste, with the exception of visual examination. Most RH TRU waste will be inspected using radiographic examination, but the DOE decided that visual examination will not be used to verify radiographic examination for RH TRU waste due to the added radiological exposure, cost, and waste generation associated with visual examination. The sampling and analytical methods that are used for CH waste characterization will not change except for that they will be performed remotely in shielded facilities for most RH waste characterization. The remote manipulations used for waste characterization (i.e., shaking and pouring) are common and will not require additional operator training. If at some point in time more effective waste characterization methods are developed for CH TRU or RH TRU waste, they will be submitted for inclusion in the Methods Manual per the DOE/Carlsbad Area Office (CAO) procedure discussed in Appendix C7. The data reports and the Waste Stream Profile Forms (see Section C-1b) resulting from waste characterization activities will be transmitted to the WIPP, reviewed for completeness, and screened for acceptance prior to loading any waste into the Transuranic Package Transporter (TRUPACT-II) or RH TRU mixed waste shielded road cask at the generator facility, as described in Section C-5. Only waste that has been characterized in accordance with this WAP and that meets the WAC, will be accepted for disposal at the WIPP facility.

C-1 Facility Description

C-1a Description of Processes and Activities at the WIPP

General descriptions of the WIPP facility waste handling processes are provided below. Detailed process descriptions are provided in Chapter D, Section D-10a(3), of this permit application.

CH TRU Mixed Waste Handling Process Overview

Waste from DOE TRU mixed waste generator/storage sites identified by the DOE as meeting the WAC will be disposed of at the WIPP facility. The ten major generator/storage sites anticipated to send the majority of waste for disposal at the WIPP are:

- Argonne National Laboratories (East)
- Idaho National Engineering Laboratory
- Los Alamos National Laboratory
- Lawrence Livermore National Laboratory
- Mound Facility
- Nevada Test Site
- Oak Ridge National Laboratory
- Richland (Hanford) Site
- Rocky Flats Environmental Technology Site
- Savannah River Site

Figure C-3 shows the geographic location of these sites. There are several small generator/storage sites that will either ship their waste to the WIPP facility for disposal or to one of the major generator/storage sites for waste characterization and certification to the WIPP requirements. Those sites will be identified to the New Mexico Environment Department (NMED) as they are certified and prior to initiating any shipments from these sites to the WIPP facility.

CH TRU mixed waste will arrive at the WIPP facility in a DOT Type B transportation package (i.e., a TRUPACT-II or other approved package). Each TRUPACT-II is capable of carrying up to two DOT Type A SWBs, two seven-packs of DOT Type 7A 55-gallon (gal) drums, or one DOT Type 7A Ten-drum Overpack (TDOP).

When the TRUPACT-IIs arrive at the WIPP facility, radiological surveys, security checks, and shipping documentation reviews will be performed. Upon completion of these checks, the hazardous waste manifest will be signed to release the driver. Should radiological surveys (i.e., surface dose rate, contamination) exceed acceptable levels, the TRUPACT-IIs and transport trailer will be placed outside the Waste Handling Building (WHB) in the parking area container storage unit or in the WHB itself. Factors such as weather conditions, time of receipt, and space availability will determine the actual location for placement of the TRUPACT-IIs and transport trailer. Once the location is established, the appropriate radiological boundaries (i.e., ropes, placards, etc.) will be erected around the affected TRUPACT-IIs and transport trailer. In the event that fixed and/or removable contamination is detected on the external surface of TRUPACT-IIs in excess of WIPP free release limits, Waste Operations, in conjunction with Operational Health Physics, would assess the situation and formulate a plan of recovery to decontaminate the shipping container(s).

The TRUPACT-IIs will be removed from the transport trailer and taken inside the WHB. Inside the WHB, the TRUPACT-IIs will be opened and the waste containers removed. As the containers are being removed, radiological surveys will be conducted. If contamination is detected on the waste containers, a determination will be made as to whether small area "spot" decontamination activities will be performed or to replace the waste containers, reseal the TRUPACT-II, and prepare a new hazardous waste manifest to ship the payload back to the generator/storage facility. Should small area decontamination be conducted, the resulting waste will be managed as "derived" waste. Derived waste management is discussed in detail in Section D-10a(3)(a).

When the containers are removed from the TRUPACT-II, additional checks will be conducted to verify that the waste containers are the same as those described on the hazardous waste manifest and the WIPP Waste Information System (WWIS) database (described in Section C-5a). When all identification checks have been completed, the generator's copy of the manifest will be returned to them (within 30 days of waste receipt). If there are any discrepancies, the generator will be contacted for resolution. Discrepancies that are not resolved within 15 days of waste receipt will be reported to the NMED as required by 20 NMAC 4.1, Subpart V, §264.72. If a resolution is not reached within 30 days of waste receipt, the waste will be returned to the site

which shipped the containers. A more detailed discussion on discrepancy resolution is provided in Section C-5b of this chapter.

The waste containers will be loaded onto a facility pallet, which will be transferred to a conveyance loading car. The conveyance loading car will move the loaded facility pallet into the waste hoist cage, which will be lowered to the underground waste receiving station through the Waste Shaft. At the underground waste receiving station, the pallet will be transferred to an underground waste transporter, which will move the loaded facility pallet to an underground hazardous waste management unit (HWMU). At the HWMU, the waste containers will be removed from the facility pallet and will be emplaced in a waste emplacement room. Bags of backfill material will be placed around and on top of the stacked waste containers. Section D-10a(3)(b) of this permit application provides a more complete description of the facility and the CH waste management activities.

RH TRU Mixed Waste Handling Process Overview

RH TRU mixed waste will arrive at the WIPP facility in a shielded road cask. Upon arrival, radiological surveys, security checks, and shipping documentation reviews will be performed. Upon completion of these checks, the hazardous waste manifest will be signed to release the driver. Should radiological surveys (i.e., surface dose rate, contamination) exceed acceptable levels, the road cask and transport trailer will be placed outside the WHB in the controlled area or in the WHB itself. Factors such as weather conditions, time of receipt, and space availability will determine the actual location for placement of the road cask and transport trailer. Once the location is established, the appropriate radiological boundaries (i.e., ropes, placards, etc.) will be erected around the road cask and transport trailer. In the event that fixed and/or removable contamination is detected on the external surface of the road cask in excess of WIPP free release limits, Waste Operations, in conjunction with Operational Health Physics, would assess the situation and formulate a plan of recovery to decontaminate the road cask.

The RH TRU mixed waste canister will be removed from the shielded road cask in the WHB hot-cell complex, where it will be checked against the identity on the hazardous waste manifest and the WWIS to verify that the canister is suitable for emplacement. The generator's copy of the manifest is then returned to the generator. If there are any discrepancies, the generator will be contacted for resolution. Discrepancies that are not resolved within 15 days of waste receipt will be reported to the NMED, as required by 20 NMAC 4.1, Subpart V, §264.72. If a resolution is not reached within 30 days of receipt of the waste, the canister will be returned to the site that shipped the canister.

The RH canister will be checked for external surface contamination in the hot-cell complex. If an unacceptable condition is identified, the canister will be overpacked. The overpacked canister will then reenter the normal waste management process line. The canister will then be placed into a facility cask for transport to an HWMU. The facility cask will be placed onto the facility

cask transfer car and will be loaded onto the waste hoist and lowered to the underground waste receiving station.

At the underground waste receiving station, the facility cask transfer car will move the facility cask, loaded with the RH TRU mixed waste canister, from the waste hoist cage, and a forklift will transport it to an HWMU. The emplacement machine will be positioned in front of a predrilled horizontal hole bored into the room wall, and the facility cask will be placed on the machine assembly. The emplacement machine will then insert the waste canister into the hole. A shield plug will be inserted into the hole to provide radiation protection.

The amount of RH TRU mixed waste disposed in each panel is limited, based on thermal and geomechanical considerations. A nominal spacing of 8 feet (ft) (2.4 meters [m]) between centers for RH TRU mixed waste canisters is planned. Section D-10a(3)(c) of this permit application provides a more complete description of the facility and the RH waste management activities.

C-1b Identification of TRU Mixed Waste Managed at the WIPP Facility

Waste Stream Identification

Waste destined for disposal at WIPP is characterized on a waste stream basis. A waste stream is defined as waste material generated from a single process or activity that is similar in material, physical form, isotopic make-up, and hazardous constituents. Waste may be generated as either process or process batch waste streams. A process is defined as a system or series of continuous or regularly occurring actions taking place in a predetermined manner over extended periods of time, resulting in waste that is substantially uniform. A process batch is defined as an amount of material subject to a particular unit chemical process, unit physical mixing process, or another short-term operation, resulting in waste that is substantially uniform. Sites delineate waste streams using acceptable knowledge. Acceptable knowledge is fully described in Section C-4b and Appendix C9.

There are various identifiers used for waste streams, all developed for specific purposes. Table C-1 is a cross correlation table that shows the interrelation between all of these identifiers.

The Summary Category Group (Matrix Parameter Summary Category) description is the broadest grouping. The Summary Category Groups are assigned to each waste stream identified by generators to facilitate RCRA waste characterization and reflect the physical form of the waste.

The Waste Matrix Codes (or Matrix Parameter Categories) were developed by the DOE, in response to the Federal Facilities Compliance Act, as a methodology to aid in classifying mixed waste streams within the DOE system. These codes represent different physical and chemical matrices. The Waste Matrix Code Group (or Final Waste Form) is a grouping of the Waste Matrix Codes that have similar physical and chemical properties.

A Waste Stream WIPP Identifier (ID) is assigned to each specific waste stream at a specific generator site. Similarities in the IDs do not necessarily correlate to similarities between waste streams. The Waste Stream Name is linked to the ID.

Waste stream descriptions may also be associated with TRUPACT-II content (TRUCON) codes. TRUCON content codes were originally developed as a type of shorthand representation of the chemical content and physical waste form of generator waste streams for use in the TRUPACT-II transportation safety analysis. Each waste stream was reviewed and a TRUCON code was assigned. Newly identified waste streams eligible for WIPP disposal will be assigned TRUCON codes, which will be approved by the NRC prior to shipment of the waste streams.

The Item Description Code is a site-specific numerical code applied to individual waste streams to identify their source. These codes represent the local identifiers, used by the generator sites to specify the waste stream type and/or generation area of TRU and TRU mixed waste, and are used at most DOE facilities that generate TRU and TRU mixed waste.

The Waste Type is a numerical designator ranging from one to four that indicates if the waste is a solidified inorganic, solid inorganic, solid organic, or solidified organic. This description is used in the shipment of the waste.

Waste Categories are included in Table C-1 for the purposes of linking this information to the compatibility study presented in Appendix C1.

Waste stream information has been provided by the generator/storage sites and is documented in the WIPP Transuranic Waste Baseline Inventory Report (WTWBIR) (see Table C-2). The information provided by the generator/storage sites in the WTWBIR is not the result of waste characterization. It is an estimate of waste stream constituents. Therefore, one WTWBIR waste stream may relate to numerous waste streams for the purpose of waste characterization. The WTWBIR information was compiled in order to estimate waste volumes and properties for long-term performance assessment. All waste characterization activities must still be conducted and each waste stream submitted to the WIPP facility on a Waste Stream Profile Form for approval. Waste stream descriptions will be finalized over the course of waste characterization at the sites. Changes that have been made to the WTWBIR in recent revisions to this document do not affect this permit application.

Currently, the majority of existing retrievably stored waste to be disposed at WIPP is in earthen-covered storage or other storage which is not readily accessible. Because of this, all of the waste within a waste stream may not be available for sampling and analysis at one time. In these instances, sites will divide waste streams into waste stream lots based on staging, transportation, or handling issues. Characterization activities are then undertaken on a waste stream lot basis. Sites initially delineate and describe waste streams using acceptable knowledge. As waste characterization activities proceed, waste stream descriptions may change based on the results of sampling and analysis. Results from waste characterization are used to confirm acceptable knowledge, including the assignment of EPA hazardous waste codes to waste streams, as appropriate.

The quantity of waste reported in the WIPP RCRA Part A application was determined using reported generator information on waste generating processes, and waste constituents and characteristics. If it was suspected, based on knowledge of a waste generating process, that a RCRA-regulated hazardous constituent may be contained in the waste, the waste was assumed to contain that constituent. The waste volume associated with each reported EPA code was assumed to equal the volume of the waste stream. Therefore, it appears that receipt of the total annual waste volumes reported in the Part A application over WIPP's projected 25 year waste-emplacement period would exceed the 6.2 million cubic feet (ft^3) (175,600 cubic meters (m^3)) allowable waste capacity specified in the Land Withdrawal Act of 1992. This is because many waste streams with multiple EPA codes were counted as multiple volumes. A biennial report, in accordance with 20 NMAC 4.1, Subpart V, §264.75, will provide information on actual volume and waste descriptions received for disposal during the time period covered by the report.

Waste Summary Categories Accepted at the WIPP Facility

Once a waste stream has been delineated, sites assign a Waste Matrix Code to the waste stream based on the physical form of the waste. Waste streams are assigned to one of three broad Summary Category Groups; S3000-homogeneous solids, S4000-soils/gravel, and S5000-debris wastes. These Summary Category Groups are used to determine further characterization requirements.

S3000—Homogeneous Solids

Solid process residues are defined as solid materials, excluding soil, that do not meet the NMED criteria for classification as debris (20 NMAC 4.1, Subpart VIII, §268.2[g] and [h]). Included in the series of solid process residues are inorganic process residues, inorganic sludges, salt waste, and pyrochemical salt waste. Other waste streams are included in this Summary Category Group based on the specific waste stream types and final waste form. Each waste stream designated as a 3000 solid process residue is identified in Table C-2 with the EPA hazardous waste codes that are associated with that waste stream. This Summary Category Group is expected to contain toxic metals and spent solvents. This category includes wastes that are at least 50 percent by volume solid process residues.

S4000—Soils/Gravel

This Summary Category Group includes waste streams that are at least 50 percent by volume soil as identified in Table C-2 with the EPA hazardous waste codes that are associated with that waste stream. This Summary Category Group is expected to contain toxic metals. Soils are further categorized by the amount of debris included in the matrix.

S5000—Debris Wastes

This Summary Category Group includes waste that is at least 50 percent by volume materials that meet the NMAC criteria for classification as debris (20 NMAC 4.1, Subpart VIII, §268.2) as follows:

> Debris means solid material exceeding a 2.36 inch (in.) (60 millimeter) particle size that is intended for disposal and that is:
>
> 1. a manufactured object, or
> 2. plant or animal matter, or
> 3. natural geologic material.
>
> However, the following materials are not debris:
>
> 1. any material for which a specific treatment standard is provided in 20 NMAC 4.1, Subpart VIII, 268 Subpart D;
>
> 2. process residuals such as smelter slag and residues from the treatment of waste, wastewater, sludges, or air emission residues; and
>
> 3. intact containers of hazardous waste that are not ruptured and that retain a least 75 percent of their original volume.

However, for the purposes of this WAP, all heterogeneous materials, or waste materials whose physical form does not lend itself to sampling and analysis, are considered to be in the Summary Category Group regardless of the size of the waste materials. That is, this Summary Category Group includes heterogeneous waste materials that are less than 2.36 in.

A mixture of debris (that has not been treated to the standards provided by 20 NMAC 4.1, Subpart VIII, §268.45), and other material is subject to regulation as debris if the mixture is comprised primarily of debris, by volume, based on visual inspection (20 NMAC 4.1, Subpart VIII, §268.2[g]). Due to the presence of radioactive contaminants in the waste and the safety hazards involved in opening waste containers, the DOE has opted to use radiography as a form of nondestructive examination of the waste form in place of visual examination of the waste form. For these reasons, radiography will be used on 100 percent of stored waste containers and most RH TRU waste containers to determine the physical composition of debris mixtures. The percentage of debris materials in mixtures in newly generated CH TRU waste will be determined by visual examination during packaging.

"Hazardous debris" means debris that contains a hazardous waste listed in 20 NMAC 4.1, Subpart II, 261 Appendix VIII, or that exhibits a characteristic of hazardous waste identified in 20 NMAC 4.1, Subpart II, §261, Subpart C.

Included in the S5000 series are metal debris, lead containing metal debris, inorganic nonmetal debris, asbestos debris, combustible debris, graphite debris, heterogeneous debris, and composite filters, as well as other minor waste streams, as identified in Table C-2. This Summary Category Group is expected to contain toxic metals and spent solvents. The EPA hazardous waste codes associated with the debris waste streams are included in Table C-2.

Examples of waste that might be included in the S5000 series are asbestos-containing gloves, fire hoses, aprons, flooring tiles, pipe insulation, boiler jackets, and laboratory tabletops. Also included are combustible debris constructed of plastic, rubber, wood, paper, cloth, and graphite and biological materials. Examples of graphite waste that would be included in this series are crucibles, graphite components, and pure graphite.

Chemical Properties of the Waste

This section of the WAP provides an overview of the chemical properties of the waste and the waste source. Hazardous constituents and target analytes for waste to be disposed of at the WIPP facility are shown in Table C-3.

The most common hazardous constituents in the TRU mixed waste to be managed in the WIPP facility consist of the following:

Metals

Some of the TRU mixed waste to be emplaced in the WIPP facility contains metals for which 20 NMAC 4.1, Subpart II, §261.24, toxicity characteristics were established (EPA hazardous waste codes D004 through D011). These materials are known to be present based on acceptable knowledge of waste-generating processes and various analytical results used to verify acceptable knowledge. Cadmium, chromium, lead, mercury, selenium, and silver are present in discarded tools and equipment, solidified sludges, cemented laboratory liquids, and waste from decontamination and decommissioning activities. A large percentage of the waste consists of lead-lined gloveboxes, leaded rubber gloves and aprons, lead bricks and piping, lead tape, and other lead items. Lead, because of its radiation-shielding applications, is the most prevalent toxicity-characteristic metal present.

Halogenated Volatile Organic Compounds

Some of the mixed waste to be emplaced in the WIPP facility contains spent halogenated organic solvents identified in 20 NMAC 4.1, Subpart II, §261.31 (EPA hazardous waste numbers F001 through F005). The presence of these compounds is confirmed by analytical results from headspace gas sampling of TRU mixed waste. Tetrachloroethylene; trichloroethylene; methylene chloride; carbon tetrachloride; 1,1,1-trichloroethane; and 1,1,2-trichloro-1,2,2-trifluoroethane (EPA hazardous waste codes F001 and F002) are the most prevalent halogenated organic compounds identified in TRU mixed waste that may be managed at the WIPP facility during the Disposal Phase. These compounds are commonly used to clean metal surfaces prior to plating, polishing, or fabrication; to dissolve other compounds; or as coolants. Because they are highly volatile, only very small amounts typically remain on equipment after cleaning or, in the case of treated wastewaters, in the sludges after clarification and flocculation.

Nonhalogenated Volatile Organic Compounds

Xylene, methanol, and n-butanol are the most prevalent nonhalogenated VOCs in TRU mixed waste that may be managed at the WIPP facility during the Disposal Phase. These compounds occur in TRU mixed waste materials in much smaller quantities than halogenated VOCs. Like the halogenated VOCs, they are used as degreasers and solvents and are similarly volatile. The same analytical methods that are used for halogenated VOCs are used to detect the presence of nonhalogenated VOCs.

Waste Not Accepted at the WIPP Facility

The DOE has established WIPP WAC to specify the chemical and physical forms of TRU mixed waste that will be accepted at the WIPP facility. These criteria include those required to ensure occupational safety and protection of human health and the environment.

The following waste is unacceptable for management at the WIPP facility:

- Ignitable, reactive, and corrosive waste, as defined under 20 NMAC 4.1, Subpart II, Characteristics of Hazardous Waste
- Liquid wastes, (all waste must meet the WAC criteria regarding liquid content)
- Compressed gases

- Incompatible waste, as defined under 20 NMAC 4.1, Subpart V, Appendix V (waste must be compatible with backfill, seal and panel closure materials, container, cask, and TRUPACT-II materials as well as with other waste)

- Headspace-gas VOC concentrations resulting in average annual emissions not protective of human health and the environment (Table C-5 lists target maximum average headspace concentrations)

- Wastes with EPA codes not listed on RCRA Part A permit application

- Waste with equal to or more than 50 parts per million (ppm) (50 milligrams per liter [L]) polychlorinated biphenyls (PCB)

The WIPP facility will not accept waste that exhibits the characteristics of ignitability, reactivity, or corrosivity. The DOE ensures through administrative and operational procedures at the generator sites that TRU mixed waste received at the WIPP facility does not exhibit these characteristics. These characteristics are generally associated with liquid wastes or specific waste forms that may react violently. This WAP and the WAC, therefore, prohibit liquid waste, explosives, compressed gases, oxidizers, and pyrophorics. The absence of these wastes is confirmed by radiography, visual examination, and headspace analysis.

The TRU mixed waste received at the WIPP facility will not be aqueous or liquid, will not contain WAC-prohibited materials, and will be capable of being handled at standard temperatures and pressures without reaction to oxygen or water (see Table C-4). The WAC specifies that liquid waste is not acceptable at the WIPP. The WIPP facility will not accept containers holding waste that would be considered a liquid waste as defined in 20 NMAC 4.1, Subpart I, §260.10. Every container holding waste with less than 2 L of liquid for a 55-gal drum or 8 L in a SWB must contain as little residual liquid as is reasonably achievable, and all internal containers (e.g., bottles and cans) must contain less than one in. (2.5 centimeters) of liquid at the bottom of the container.

Additionally, TRU mixed waste cannot contain explosives, compressed gases, oxidizers, or nonradionuclide pyrophoric materials. (Waste generators have submitted information on waste streams based on known waste generation processes that indicate certain waste streams may have the potential for reactivity, ignitability, or corrosivity.) These characteristics must be eliminated prior to waste acceptance for disposal at the WIPP.

Before accepting a container holding TRU mixed waste, WIPP personnel will examine the radiography data records to verify that the container holds no unvented compressed gas containers and no greater than one percent by volume of residual liquid. If discrepancies or inconsistencies are detected during the radiography data record review, WIPP personnel may review the radiography video tape to verify that the observed physical form of the waste is consistent with the waste stream description provided by the generator and to ensure that no

WAC-prohibited materials are present in the waste. Section C-5 includes a description of the waste verification process that the DOE intends to conduct prior to receiving a shipment at the WIPP.

The WIPP will manage TRU mixed waste in a manner that mitigates the buildup of explosive or flammable gases within the waste. Containers are vented through individual carbon composite particulate filters, allowing any gases that are generated by radiolytic and microbial processes within a waste container to escape; to prevent over pressurization. Gas generation is discussed in detail in Chapter I, Section I-1e(4).

The WIPP facility is designed to manage only compatible waste. Therefore, a compatibility analysis was performed to identify potential incompatibilities for all defense generated TRU mixed waste reported in the WTWBIR. Wastes were screened for incompatibilities based on their chemical content and physical waste form by comparing information presented in 20 NMAC 4.1, Subpart V, Appendix V, and the EPA document "*A Method for Determining the Compatibility of Hazardous Wastes*," (Hatayama et al., 1980). The compatibility analysis also took into account waste compatibility with various aspects of the repository such as shaft, seal, and panel closure materials, backfill, and fire suppressant materials. Appendix C1 provides additional details and results of this analysis.

To ensure the integrity of the WIPP facility, waste streams identified to contain incompatible materials or materials incompatible with waste containers cannot be shipped to WIPP unless they are treated to remove the incompatibility. Only those waste streams that are compatible or have been treated to remove incompatibilities will be shipped to WIPP.

As described in Chapter D, Section D-9b(4), the potential risks to human health and the environment are due to emissions of VOCs from the waste containers into the air pathway. The most stringent environmental performance standard of 20 NMAC 4.1, Subpart V, §264.601(c) is the acceptable excess risk levels for residential (chronic) exposure to carcinogens (10^{-6} for Class A and B carcinogens and 10^{-5} for Class C carcinogens). In addition, the risk assessment in Chapter D examined occupational exposures and compared them to Occupational Safety and Health Administration risk standards. WAC have been developed to limit the VOC concentrations in the headspace of waste containers to those which when averaged will ensure compliance with the performance standards. These limits are presented in Table C-5 as VOC headspace concentration limits. In reality, these are maximum <u>average</u> headspace concentrations. This means that some containers can exceed these values as long as averages in a disposal room do not. For a generator to ship waste that exceeds any of these values, a WAC exception must be requested at which time WIPP personnel will evaluate the impact on the average concentrations in the disposal room.

The DOE will only allow generators to ship those waste streams with EPA Hazardous Waste Codes listed on Part A of this application. Characterization of all waste streams will be performed as required by this WAP. If during the characterization process, new hazardous

waste codes are identified, those wastes cannot be accepted for disposal at the WIPP facility until a permit modification has been submitted and approved. Similar waste streams at other generator sites will be examined more closely to ensure that the newly identified code does not apply. If other waste streams also require a new hazardous waste code, shipment of these waste streams will also cease until a permit modification has been submitted and approved. Approval will be based on the physical and chemical properties of the waste.

Transformer oils containing PCBs have been identified in a limited number of waste streams included in the Waste Matrix Code corresponding to organic sludges. Because the WIPP facility is not seeking permission to manage PCB waste, these waste streams are required to be screened to assure PCB levels are below 50 ppm.

Control of Waste Acceptance

The waste acceptance program is defined in the WAC (DOE, 1991 or current revision). This document provides a list of criteria that must be met for waste to be shipped to the WIPP facility for management. The WAC requires the generator to prepare a waste certification program that lists the methods and techniques used to determine compliance with the WAC and the QA/QC criteria that are applied to the generator's waste certification program. One of the criteria that the generator is required to meet is compliance with the applicable portions of this WAP. The WAC certification programs result in controlled and consistent waste properties and final packaging.

A Waste Stream Profile Form will describe a CH TRU or RH TRU mixed-waste stream destined for shipment to and disposal at the WIPP facility. The Waste Stream Profile Form summarizes important information about a particular waste stream. Examples of information contained in a Waste Stream Profile Form are:

- The generator's site name
- Original generator of waste stream
- A description of the waste stream
- The date of WAC certification by the DOE/CAO and the certification document title and date
- The Waste Stream WIPP Identification Number
- The designated Summary Category Group
- A listing of acceptable knowledge documentation used to identify the waste stream

- The waste-characterization procedures used and the reference and date of the procedure
- The data packages supporting the characterization
- The EPA hazardous waste codes
- Waste Stream Profile Form Certification statement signed by the manager of the generator site

These data will be provided for each waste stream prior to its acceptance for disposal at the WIPP. The Waste Stream Profile Form data will be transmitted once for each waste stream from a facility.

For waste streams that are continually generated, a Waste Stream Profile Form may be submitted once the waste stream has been characterized per the QAPP based on the variability of the waste stream (as shown in Appendix C6). Characterization activities will continue in order to verify consistency with the initial characterization and Waste Stream Profile Form (Section C-3a). If there are discrepancies, the waste will be redefined to a separate waste stream, and a new Waste Stream Profile Form will be submitted.

The WIPP Waste Operations Manager will be responsible for the review of Waste Stream Profile Forms (see Section C-1c and Figure C-4) and data records to verify compliance with the restrictions on TRU mixed wastes for WIPP disposal. The Waste Stream Profile Form includes a section requiring the waste generator to provide the data and documentation of WAC certification for the TRU mixed waste stream described on the form. The WIPP Waste Operations Manager will also be responsible for the review of shipping records (see Section C-5b) to verify that each container has been prepared under a WAC-certified program and in accordance with this WAP. Waste characterization data must indicate the absence of unacceptable materials.

Generator site waste stream characterization will be subject to the Generator/Storage Site Waste Screening and Certification Audit Program (Appendix C11) for compliance with this WAP. Section C-5 further discusses WIPP facility waste screening activities.

C-1c Waste-Generating Processes

Waste-Generating Processes At DOE Generator Facilities

TRU mixed waste generated at DOE sites results from specific processes and activities that are well-defined and well-controlled, enabling the DOE to characterize waste streams on the basis of knowledge of the process and the raw materials used. Examples of the major types of operations that generate TRU mixed waste include:

- Production of Nuclear Products—Production of nuclear products includes reactor operation, radionuclide separation/finishing, and weapons fabrication and manufacturing. The majority of the TRU mixed waste was generated by weapons fabrication and radionuclide separation/finishing processes. More specifically, wastes consist of residues from chemical processes, air and liquid filtration, casting, machining, cleaning, product quality sampling, analytical activities, and maintenance and refurbishment of equipment and facilities.

- Plutonium Recovery—Plutonium recovery wastes are residues from the recovery of valuable plutonium-contaminated molds, metals, glass, plastics, rags, salts used in electrorefining, precipitates, firebrick, soot, and filters.

- Research and Development (R&D)—R&D projects include a variety of hot cell or glovebox activities that often simulate full-scale operations described above, producing similar TRU mixed wastes. Other types of R&D projects include metallurgical research, actinide separations, process demonstrations, and chemical and physical properties determinations.

- Decontamination and Decommissioning—Facilities and equipment that are no longer needed or usable are decontaminated and decommissioned, resulting in TRU mixed wastes consisting of scrap materials, cleaning agents, tools, piping, filters, Plexiglas™, gloveboxes, concrete rubble, asphalt, cinder blocks, and other building materials. This is expected to be the largest category by volume of TRU mixed waste to be generated in the future.

Waste-Generating Processes at the WIPP Facility

Nonradioactive hazardous waste generated at the WIPP facility is characterized, placed in containers, and temporarily stored, in accordance with 40 CFR §262.34, until it is transported off site for treatment and/or disposal at a permitted facility. This waste generation and accumulation activity, which is performed in compliance with 20 NMAC 4.1, Subpart III, is not subject to RCRA permitting requirements and, as such, is not addressed in this permit application.

Administrative practices that direct normal operations at the WIPP facility will be implemented to minimize the possibility of generating new TRU mixed waste. For this reason, any TRU mixed waste generated through normal waste handling operations will be derived from the waste received from the off-site generator. Throughout this application, site-generated waste that is derived from waste generated at an off-site facility is referred to as *derived waste*. Because derived wastes can contain only those RCRA-regulated materials present in the waste from which they were derived, no additional characterization of the derived waste is proposed for disposal purposes. In other words, the generator's characterization data and knowledge of the

processes at the WIPP facility will be used to identify and characterize containers of derived waste. The management of derived waste is addressed in Section D-10a(3)(a).

Hazardous constituents within the waste containers are known and have been determined to be acceptable for disposal at the WIPP facility. Therefore if a spill, breach, or other type of release of TRU mixed waste from a container occurs, the waste generated during cleanup would be managed as derived waste. Anticipated sources of derived waste during the Disposal Phase include:

- Swipes used to detect external radioactive contamination during receipt inspection and other radiological checks

- Any TRU mixed waste generated through nonroutine events, such as the cleanup of spills

C-1d Description of HWMUs

The underground HWMUs (defined as waste panels) are 2,150 ft (655 m) beneath the surface, in the WIPP underground and are designated as Panels 1 through 10. Each waste panel, designated as Panels 1 through 8, consists of seven parallel rooms and two access drifts. Each room is approximately 300 ft (91 m) long, 33 ft (10 m) wide, and 13 ft (4 m) high. Access drifts connect the rooms and have the same cross section. Panels 9 and 10 are the disposal area access drifts which may be used by the DOE for waste disposal in the future. The DOE intends to operate the WIPP facility in a manner that minimizes the number of underground HWMUs that are open at any one time, as discussed in Section B-1b.

The underground HWMUs provide room for 6.2 million ft^3 (175,600 m^3) of TRU mixed waste, of which no more than 250,000 ft^3 (7,080 m^3) may be for RH TRU mixed waste. The remainder will be for CH TRU mixed waste. RH TRU mixed waste canisters will be inserted into horizontal holes bored into the walls of the HWMUs. The CH TRU mixed waste packages will fill the remaining HWMU space exclusive of the panel closures.

The surface HWMUs are inside the WHB and the parking area south of the WHB. The WHB is the surface facility where waste handling activities will take place (Figure D-1). The WHB has a total area of approximately 84,000 square ft (ft^2) (7,803 square m (m^2) of which 33,175 ft^2 (3,083 m^2) are designated for the waste handling and storage of CH TRU mixed waste and 21,318 ft^2 (1,981 m^2) are designated for the waste handling and storage of RH TRU mixed waste, as shown in Figure D-1. These combined areas are being permitted as a container storage unit. The CH side of the WHB will store up to 2718.2 ft^3 (77.02 m^3) and the RH side up to 377 ft^3 (10.7 m^3), under normal conditions of operations. The concrete floors are sealed with an impermeable coating that has excellent resistance to the chemicals in TRU mixed waste and, consequently, provide secondary containment for TRU mixed waste.

The parking area HWMU (Figure D-2) south of the WHB will be used for storage of waste in sealed shipping containers awaiting unloading, having a surface area of 272,500 ft^2 (25,315 m^2). This area is also being permitted as a container storage unit for 1536 ft^3 (43.5 m^3) of CH and 126 ft^3 (3.6 m^3) of RH waste. The sealed shipping containers provide secondary containment in this HWMU. System descriptions for the WHB HWMU and TRU mixed waste handling systems and a description of the impermeable coating are provided in Sections D-10a(2)(b), D-10a(2)(c), and D-10a(3).

C-2 Waste Parameters

This section discusses the parameters of interest for waste characterization purposes, and the rationale for their selection.

C-2a Selecting Waste Analysis Parameters

The following analytes were selected as parameters of interest:

- Toxicity characteristic contaminants listed in 20 NMAC 4.1, Subpart II, §261.24, Table 1 (excluding pesticides)
- F-listed solvents (F001, F002, F003, F004, F005) found in 20 NMAC 4.1, Subpart I, §261.31, and known to be used at DOE sites
- Hazardous constituents included in 20 NMAC 4.1, Subpart II, §261 Appendix VIII, and reported to be present in waste generated by DOE TRU waste generator/storage sites

Table C-3 summarizes the parameters of interest and the rationale for including each parameter in this WAP. The next sections provide a description of the acceptable methods to evaluate these parameters for each waste Summary Category Group.

C-2b Criteria and Rationale for Parameter Selection

Parameters were selected for characterization based on data needed to address regulatory requirements for accepting TRU mixed waste at the WIPP miscellaneous-unit disposal facility.

Radiography will be used to examine containerized waste to ascertain its physical form. This technique can detect liquid wastes and containerized gases, which are prohibited for WIPP disposal. Prohibiting liquids and containerized gases prevents the shipment of corrosives, ignitable waste, or reactive waste. Radiography will also be able to confirm that the physical form of the waste matches its waste stream description (i.e. Homogeneous Solids, Soil/Gravel, or Debris Waste [including uncategorized metals]). If the physical form does not match the waste stream description, the waste will be designated as another waste stream and assigned

the preliminary hazardous waste codes that are inherent to the new waste stream assignment. If radiography indicates that the waste does not match the waste stream description, a non-conformance report will be completed and the inconsistency will be resolved per Section C8-13 of Appendix C8. The proper waste stream assignment will be determined, the correct hazardous waste codes will be assigned, and the resolution will be documented.

Headspace-gas samples are used to determine the types and concentrations of VOCs in the void volume of waste containers. Averages of measured headspace VOC concentrations in waste containers received at the WIPP site will be compared routinely with those used in this permit application's environmental pathway analysis demonstration to ensure that on an annual basis there are no associated adverse worker or public-health impacts. Average concentrations of VOCs in headspace gas have been used in this permit application's environmental pathway analysis to demonstrate that average annual concentrations of VOCs emitted from containers emplaced at the WIPP will be well below health-based limits (headspace gas analytical data used to determine average concentrations is provided in Appendix C-2).

For wastes that can be representatively sampled (Homogeneous Solids and Soil/Gravel Wastes), the total concentrations of PCBs, VOCs, semivolatile organic compounds (SVOC), and metals will be determined analytically. A representative sample is defined in 20 NMAC 4.1, §260.10 as "a sample of a universe or whole (e.g., waste pile, lagoon, groundwater) which can be expected to exhibit the average properties of the universe or whole."

Data on total concentration will be used to quantify the types and quantities of RCRA-regulated listed hazardous constituents, and to determine whether the waste exhibits a toxicity characteristic under 20 NMAC 4.1, Subpart II. Toxicity characteristic will be determined using total extraction analysis rather than the toxicity characteristic leaching procedure (TCLP), because total concentrations are more useful for repository compliance demonstrations[2] and result in more conservative estimates of toxicity characteristics. (Appendix C3 discusses comparability of the results of these two methods.)

Documented acceptable knowledge will be used to determine the types and quantities of listed and toxicity characteristic waste that cannot be directly sampled for total metals or total organics. Debris waste is heterogeneous, having waste forms that cannot be representatively sampled (e.g. personal protective equipment, leaded rubber gloves, manufactured goods, and natural geologic material). In these types of wastes, acceptable knowledge is used to make a hazardous waste determination. Radiography, visual examination, and headspace gas sampling will be

[2]According to 20 NMAC 4.1, Subpart IX, §270.14(b)(2), the information needed regarding the chemical and physical properties is "...all the information which must be known to treat, store, or dispose of the wastes properly in accordance with Part 264 [Subpart V]." For a mined geological repository such as the WIPP, totals analyses provides such information needed to model the solubility and transport of waste and waste constituents over the long-term For this reason the DOE has opted to require totals analyses of representative samples of homogeneous waste.

used to verify the acceptable knowledge used. (Appendix C9 details the use of acceptable knowledge).

Table C-6 summarizes the parameters, methods, and rationales for stored and newly generated CH TRU wastes according to their waste forms, and Table C-7 is a parallel table for RH TRU wastes.

C-3 Characterization Techniques and Frequency

Generator/storage sites will characterize waste on a waste stream basis using a variety of techniques. Characterization techniques include: acceptable knowledge, radiography, headspace-gas sampling and analysis, and homogeneous solids and soils/gravel sampling and analysis.

Acceptable knowledge refers to applying knowledge of the hazardous nature of the waste based on the materials or processes used to generate the waste. This may include accompanying records; administrative, procurement and quality controls associated with the processes generating the waste; past sampling and analytical data; material inputs to the waste-generating process; and the time during which the waste was generated (certain waste-generating processes are associated with specific historical time periods). Information required for characterizing waste using acceptable knowledge includes the physical form of the waste and documented changes to the process or material inputs. Appendix C9 outlines the minimum set of requirements which must be met by the generator sites in order to use acceptable knowledge. In addition, verification of acceptable knowledge through sampling and analysis and the generator-site audit program is described in the appendix.

Acceptable knowledge is used in three ways: 1) to delineate waste streams, 2) to make hazardous waste determinations for debris waste, and 3) to determine if homogeneous solids and soil/gravel are RCRA-listed wastes. Used for these purposes, acceptable knowledge balances the requirements for providing definitive chemical and physical characterization of waste streams when it is difficult to obtain a representative sample because of the physical waste form and/or composition of the waste (e.g., metal, glass, and combustibles). This use of acceptable knowledge is outlined in *Waste Analysis: EPA Guidance Manual for Facilities That Generate, Treat, Store and Dispose of Hazardous Waste,* (EPA, 1994), where EPA has specifically referred to the characterization of mixed waste as a situation where the use of acceptable knowledge is appropriate.

Generator sites will use acceptable knowledge to sort waste containers into waste streams for the purposes of grouping waste for further characterization. Since the waste is characterized on a waste stream basis, minimal variability of hazardous constituents between waste containers in a waste stream will provide a more representative characterization of the waste stream. The analyses performed will not differ based on the waste stream, only on the physical form of the waste (i.e., debris waste cannot be sampled for totals analyses). Both stored and newly

generated wastes will be separated in this fashion, though the types of acceptable knowledge used may differ. Section C-4b discusses the use of acceptable knowledge, sampling, and analysis in more detail. Acceptable knowledge is discussed more completely in Appendix C9.

Radiography is used to verify the physical form of retrievably stored CH TRU waste and most RH TRU waste. Based on this physical form (ie, Homogeneous Solids/Soils/Gravel or Debris) it is determined whether a representative sample can be collected and totals analyses performed on the waste. For newly generated waste, physical form will be verified during packaging. Radiography is also used in conjunction with acceptable knowledge to characterize debris wastes. Radiography and the associated information compiled from acceptable knowledge (e.g., age of the waste, generating process) will be used to determine the RCRA-regulated constituents present in the waste.

All waste containers are sampled and analyzed for VOCs in the headspace gas. A statistically selected portion of homogeneous solids and soil/gravel is sampled and analyzed for RCRA-regulated total VOCs, SVOCs, and metals. Sampling and analytical methods used for waste characterization are discussed in Section C-4a.

In the process of performing organic analyses, nontarget compounds may be identified. These compounds will be reported as tentatively identified compounds (TIC). The specific procedures for positive TIC identification are implemented by the QAPP. Positively identified TICs listed in 20 NMAC 4.1, Subpart V, 264, Appendix IX,[3] will be added to the target analyte list if they are detected in 25 percent of all samples from a given waste stream as implemented in the QAPP. The DOE will add these compounds to the list of hazardous constituents for the waste stream (and additional EPA hazardous waste codes, if appropriate), and a permit modification will be submitted adding these constituents, if necessary.

Waste characterization sampling and analysis activities will differ for retrievably stored waste and newly generated waste. The waste characterization data collection design for each type of waste is described in the following sections. Figures C-1 and C-2 summarize the waste characterization data collection design for newly generated and retrievably stored waste, respectively. Table C-8 provides a summary of hazardous waste characterization requirements for all TRU mixed waste by waste characterization parameters.

C-3a Newly Generated Waste

The RCRA-regulated constituents in newly generated wastes will be documented and verified at the time of generation to provide acceptable knowledge for the waste stream. Newly generated mixed waste characterization will begin with verification that processes generating the waste have operated within established written procedures. Waste containers will be classified

[3]Appendix IX of 264 was chosen because analytical methods have been established for all analytes listed.

into waste streams using acceptable knowledge. Verification that the physical form of the waste (Summary Category Group) corresponds to the physical form of the assigned waste stream is accomplished during packaging. This process consists of the operator confirming that the waste is assigned to a waste stream that has the correct Summary Category Group for the waste being packaged. If a confirmation cannot be made, corrective actions will be taken per Section C8-13 of Appendix C8. A second operator, who is equally trained to the requirements of the WAC and QAPP (See Appendix C4, Section C4-3b for training requirements), will provide additional verification by reviewing the contents of the waste container to ensure correct reporting. If the second operator cannot provide concurrence, corrective actions will be taken per Section C8-13 of Appendix C8. The subsequent waste characterization activities depend on the assigned Summary Category Group since waste within the homogeneous solids and soils/gravel summary category groups will be characterized using different techniques than the waste in the debris waste summary category group.

All newly generated waste containers will undergo headspace-gas analysis for VOC concentrations. If the DOE believes the frequency can be reduced in the future based on trends in analytical results, it may provide technical arguments for such a reduction and request a permit modification. The headspace-gas sampling method is provided in Appendix C4, Section C4-1.

Newly generated waste streams of homogeneous solids and soils/gravel wastes will be randomly sampled a minimum of once per year for total VOCs, SVOCs and metals. Sampling frequency of once per year is only allowed if a process has operated within established bounds without any significant process changes or fluctuations. Otherwise, the waste must be considered as process batches. Significant process changes and process fluctuations can be determined using statistical process control charting techniques; these techniques require historical data for determining limits for indicator species and subsequent periodic sampling to assess process behavior relative to historical limits. If the limits are exceeded, the waste stream must be recharacterized, and the characterization must be performed according to procedures required in the QAPP for retrievably stored waste. The process behind this control charting technique is described in Appendix C6, Section C6-5.

Also, as another control of waste generated from a particular process, the bounds for a waste generating process will be established by the specific written procedures for that process. Examples of parameter bounds that could affect a waste generated by a process are volumes of input material, change in the input material, and any other changes that would change the output of that process.

To ensure that the generator site procedures for waste generating processes contain the proper controls of the waste stream, generator site waste generating process procedures must contain sections containing the following information:

- Scope

- Purpose
- Responsible organizations for implementing the requirements of the procedure
- Administrative process controls
- Material inputs
- Waste Streams Generated
- Process controls and range of operation that affect final hazardous waste determinations
- Rate and quantity of hazardous waste generated
- List of applicable operating procedures relevant to the hazardous waste determination
- Nonconformance reporting
- Process knowledge verification sampling
- Reporting and records management

Events where procedurally established bounds are exceeded or any condition of normal operation not being met are events that could trigger an increased sampling frequency of a waste stream. As long as a process does not change within a year, the waste generated by that process will have the same characteristics, and therefore, one sample could verify the lack of variability of that waste stream. Compliance with process procedures and the maintenance of the parameters specified by those procedures will be verified by WIPP during the Generator/Storage Site Waste Screening and Acceptance Audit Program (Appendix C11).

The records generated by the process procedures will be examined for indications of process changes or limits being exceeded that would change the output of that process. If these changes are apparent, WIPP will verify that a follow-up sample of process waste was collected and analyzed. Records of that analysis will be available for examination by the auditors. If records of the analysis are not available, the waste stream will not be acceptable at the WIPP facility for disposal and the site may lose certification authority. If a generator site changes a process but determines that increased sampling is not required because the change will not affect waste generated by that process, the DOE/CAO must be notified in the form of a memorandum to the CAO Waste Characterization Manager. The DOE/CAO must concur with

the decision to not increase the sampling frequency before any additional waste from that process is shipped.

The toxicity characteristics of homogeneous solids and soils/gravel waste streams will be determined using total analysis of toxicity characteristic contaminants, rather than the TCLP. The sampling methods for homogeneous solids and soil/gravel wastes is provided in Appendix C4, Section C4-2.

Acceptable knowledge, examination during packaging, and headspace-gas sampling and analysis are used to characterize debris waste. When waste is being generated by processes that are driven by written procedures, the waste generated by that process can be characterized by acceptable knowledge. Other documentation besides written procedures provide useful information that can be used for acceptable knowledge. Examples of documentation used for waste characterization by acceptable knowledge practices are described in Appendix C9. RCRA-regulated metals present in debris wastes are associated with specific waste materials (i.e., lead in leaded rubber gloves, leaded glass, or lead shielding). Knowledge of the materials and operations that generated these waste streams is used to determine if they contain RCRA-regulated metals. Acceptable knowledge is further explained in Section C-4b and Appendix C9.

C-3b Retrievably Stored Waste

All retrievably stored waste containers will be examined using radiography to confirm the physical waste form (Summary Category Group), to verify the absence of prohibited items, and to determine the waste characterization techniques to be used based on the Summary Category Groups (i.e., S3000, S4000, S5000). Repackaged retrievably stored waste may be handled as newly generated waste to confirm the Summary Category Group. The applicability of Real-Time Radiography (RTR) as an example for this purpose is detailed in Appendix C5.

To confirm the results of radiography, a statistically selected number of the CH waste container population will be visually examined by opening containers to inspect waste contents to verify radiography results. Appendix C6, Section C6-1 contains the approach used to statistically select the number of drums to be visually examined.

All retrievably stored containers will undergo headspace gas analysis for VOC concentrations. The headspace gas sampling method is provided in Appendix C4, Section C4-1.

A statistically selected portion of homogeneous solids and soil/gravel wastes will be sampled and analyzed for total VOCs, SVOCs, and metals. The approach used to statistically select drums for homogeneous solids and soil/gravel wastes is different than the method used to select waste containers for visual examination. This method is also included in Appendix C6, Section C6-2. The sampling methods for these wastes are provided in Appendix C4, Section C4-2.

The toxicity characteristic of homogeneous solids and soil/gravel wastes will be determined using total analysis of toxicity characteristic parameters, rather than the TCLP. Appendix C3 discusses comparability of these analytical results to those of the TCLP method.

Representativeness of containers selected for visual examination and waste subjected to homogeneous solids and soil/gravel sampling and analysis will be validated via examination of documentation that shows that true random samples were collected. (Because representativeness is a quality characteristic that expresses the degree to which a sample or group of samples represent the population being studied, the random sampling of waste streams ensures representativeness.)

Acceptable knowledge, along with radiography and headspace-gas sampling and analysis, is used to characterize debris waste. RCRA-regulated metals present in debris wastes are associated with specific waste materials (i.e., lead in leaded rubber gloves, leaded glass, or lead shielding). Knowledge of the materials and operations that generated these waste streams is used to determine if they contain RCRA-regulated metals. Acceptable knowledge is further explained in Section C-4b and Appendix C9.

Specific waste analysis methods are documented in the Methods Manual. Alternative methods will also be approved by the DOE/CAO Manager and accepted by the NMED. The procedure for this method of submittal and approval is provided in Appendix C7. Appendix C8 discusses required analytical method quality assurance objectives (QAO) and analytical procedures. Site-specific sampling and analysis activities will be documented in the QAPjP prepared by the generator sites, and approved by the WIPP facility personnel.

C-4 Characterization Methods

The characterization techniques used by sites include acceptable knowledge, headspace-gas sampling and analysis, radiography, and solidified waste sampling and analysis. All characterization activities are performed in accordance with the QAPP and the Methods Manual. Table C-8 provides a summary of the characterization requirements for TRU mixed waste.

As part of characterization efforts, waste containers will be tested in testing batches. A testing batch is a suite of waste containers undergoing radiography using the same testing equipment. A testing batch can be up to 20 waste containers without regard to waste matrix. Samples will be collected in sampling batches. A sampling batch is a suite of samples of similar matrix (i.e., gas or solid) collected consecutively, using the same sampling equipment within a specific time period. A sampling batch can be up to 20 samples (excluding field QC samples), all of which must be collected within 14 days of the first sample in the batch. Samples will be analyzed in analytical batches. An analytical batch is a suite of samples of similar matrix (i.e., gas or solid) processed as a unit, using the same analytical method within a specific time period. An analytical batch can be up to 20 samples (excluding laboratory QC samples), all of which must be received by the laboratory within 14 days of the validated time of sample receipt of the first sample in the batch. For on-line integrated headspace-gas sampling/analytical systems, samples

will be collected and analyzed in on-line batches. An on-line batch is the number of headspace gas samples that are collected and analyzed within a 12-hour period using the same on-line integrated sampling/analysis system.

C-4a Sampling and Analytical Methods

Headspace Gas Sampling and Analysis

All TRU waste will be sampled and analyzed to determine the concentrations of VOCs (presented in Table C-9) in headspace gases. Sampling protocols, equipment, and QA/QC methods for headspace-gas sampling are provided in Appendix C4, Section C4-1. In accordance with EPA convention, identification of compounds detected by gas chromatography/mass spectrometry methods that are not on the list of target analytes must be reported. These compounds are reported as tentatively identified compounds in the waste data package and must be added to the target analyte list if detected in 25 percent of all samples from a given waste stream and if they appear in the 20 NMAC 4.1, Subpart II, 264, Appendix IX list as implemented in the QAPP. The headspace gas analysis method QAOs are specified in Appendix C8.

Homogeneous and Soil/Gravel Sampling and Analysis

The goal of sampling of homogeneous and soil/gravel wastes is to collect a sample that is representative of the waste stream. This is accomplished through core sampling, which is described in Appendix C4, Section C4-2. The waste containers for sampling and analysis are selected randomly from the population of containers for the waste stream. The random selection methodology is specified in Appendix C6.

Totals analyses for VOCs, SVOCs, and RCRA-regulated metals are used instead of the TCLP to determine waste parameters that may be important to the performance within the disposal system (Tables C-10 and C-11). If sample preparation and/or cleanup methods are required, the analyst must use the procedures specified in the Methods Manual. Alternate sample preparation or cleanup methods must be submitted for review and approval in accordance with the DOE/CAO procedure contained in Appendix C7. The generator may use the results from these analyses to determine if a waste exhibits a toxicity characteristic. The mean concentration of toxicity characteristic contaminants are calculated for each waste stream such that it can be reported with an upper 90 percent confidence limit (UCL_{90}). The UCL_{90} values for the mean measured contaminant concentrations in a waste stream will be compared to the specified regulatory levels in 20 NMAC 4.1, Subpart II, expressed as total values. to determine if the waste stream exhibits a toxicity characteristic. A comparison of total analyses and TCLP analyses is presented in Appendix C3, and a discussion of the UCL_{90} is included in Appendix C6, Section C6-3.

Laboratory Selection

The DOE will conduct analyses using laboratories that are qualified through participation in the Performance Demonstration Program (DOE, 1995c, d) and in accordance with the QAPP. These laboratories will use methods presented in SW-846, *"Test Methods for Evaluating Solid Waste, Physical/Chemical Methods"*, (EPA, 1986). In the event that the SW-846 method cannot meet program specific QAO due to the properties of TRU waste, an alternate method may be submitted to CAO for approval. Since the original method is not acceptable for use due to inability to meet QAOs, the alternative method would have to be more sensitive and stable. The methods submitted as alternatives would be more restrictive, as far as data acceptability, than SW-846 methods. Appendix C7 contains the DOE/CAO procedure for submittal and approval of alternative analytical methods. The DOE specified analytical protocols and procedures for waste characterization are published in the Methods Manual.[4] The Methods Manual acts as a unified source of information on the sampling and analytical techniques used to comply with the requirements of the QAPP. Many of the procedures found in the Methods Manual are based on analytical methods found in SW-846. In these instances, the analyst is referred directly to the SW-846 method for the requirements of the procedure. Only information unique to the waste characterization program (e.g., target analytes, QAOs, QC requirements) is included in the Methods Manual. The differences between SW-846 methods and the methods contained in the Methods Manual are presented in Appendix C12.

A performance-based approach to analytical method selection also allows individual sites the flexibility to adapt methods to meet the specified analytical method QAOs in Appendix C8. In addition, methods and supporting performance data demonstrating QAO compliance must be submitted to the CAO for review and approval in accordance with Appendix C7. Once approved, the methods will be incorporated into the Methods Manual.

Analytical methods used by the laboratories must: 1) satisfy all of the appropriate QAOs as implemented in the QAPP, and 2) be implemented through laboratory-documented standard operating procedures. These methods fulfill all of the WAP requirements. Alternative methods must demonstrate equivalency, showing that the performance characteristics of the method (e.g., detection limit, accuracy, and precision and completeness for the waste matrix in question) meet or exceed the WAP requirements and objectives. These analytical QAOs are discussed in detail in Appendix C8.

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[4]*Analytical procedures that have been evaluated by the DOE and shown to produce acceptable results in* terms of data quality are implemented by the generator sites.

C-4b Acceptable Knowledge

RCRA regulations codified in 40 CFR Parts 260 through 265, 268, and 270, and New Mexico Hazardous Waste Management Regulations in 20 NMAC 4.1, Subparts I through Subpart VI, Subpart VIII, and Subpart IX, authorize the use of acceptable knowledge as a method which can be used in appropriate circumstances by waste generators, or treatment, storage, or disposal facilities to make hazardous waste determinations. Acceptable knowledge is defined in *Waste Analysis: EPA Guidance Manual for Facilities That Generate, Treat, Store and Dispose of Hazardous Waste* (EPA 1994) to include process knowledge, waste analysis data, and facility records of analysis performed before the effective date of RCRA regulations. Acceptable knowledge, as an alternative to sampling and analysis, can be used to meet all or part of the waste characterization requirements under RCRA (EPA 1994).

Acceptable knowledge is one of a number of techniques used to characterize TRU waste. It is used in conjunction with radiography, headspace gas sampling and analysis, and solidified waste sampling and analysis to meet the requirements of the WAP. Acceptable knowledge is used in TRU waste characterization activities in three ways:

- To delineate TRU waste streams
- To determine if TRU debris wastes exhibit a toxicity characteristic (40 CFR §261.24)
- To determine if TRU wastes are listed (40 CFR §261.31)

Acceptable knowledge is discussed in detail in Appendix C9, which outlines the minimum set of requirements which must be met by the generator sites in order to use acceptable knowledge. In addition, this appendix describes the verification of acceptable knowledge through sampling and analysis and the Generator/Storage Site Waste Screening and Acceptance Audit Program.

C-4c Radiography

Radiography is a nondestructive qualitative and quantitative technique that involves X-ray scanning of waste containers to identify and verify waste container contents. Since the system required for conducting radiography examination is fairly expensive, smaller generator sites reserve the right to conduct visual examination of waste containers in lieu of radiography. For sites that choose to use visual examination in lieu of radiography, the detection of liquid waste in non-transparent inner containers, detected from shaking the container, will be handled by assuming that any liquid that is detected is over WAC limits and the item will be rejected and/or repackaged to exclude the unacceptable characteristic. When radiography is used, or visual examination of transparent containers is performed, the same assumption will be used if the volume of liquid in inner containers is questionable. Radiography, or the equivalent, will be used on the existing/stored waste containers to verify the physical characteristics of the TRU mixed

waste correspond with its waste-stream identification/waste-stream Waste Matrix Code. This is used to determine that the sampling parameter and analysis requirements for that waste form are met. The results of radiography are verified through visual examination of a statistically selected subpopulation of CH TRU waste containers in each CH TRU waste stream. Radiographic examination protocols and QA/QC methods are provided in Appendix C4, Section C4-3.

The applicability of RTR is presented as an example of radiography in Appendix C5. However, the DOE is exploring other methods for the radiographic examination of TRU waste like digital radiography and computer tomography, which have the potential to increase the resolution of radiometric images and increase the discrimination of various waste items. These methods are being developed by DOE and private industry. Several prototype systems exist that are in the process of being validated as qualified radiographic examination methods. When these systems are completely operational and approved, per the procedure outlined in Appendix C7, they will be included in future revisions of the Methods Manual. The quality assurance, quality control and training requirements established for radiography will also apply to newly developed radiographic methods.

C-4d Quality Assurance Sampling and Analysis Requirements

The WIPP facility will assure adequate waste characterization by generator sites sending TRU mixed waste to the WIPP for disposal through appropriate data validation and usability and reporting controls. These steps will be taken at three program levels: 1) the data generation level, 2) the site project level, and 3) the WIPP facility level. These levels are shown in Figure C-5 and the validation process at each level is described in Appendix C8, Sections C8-10 and C8-11. These controls are implemented by the QAPP, by the site-prepared QAPjPs, and by site-specific SOPs. The sampling and analysis program data validation and compliance to data quality objectives (DQO) and QAOs make up the first level of control. The following general requirements must be met by the generator characterization programs:

- Raw data must be reported accurately in a pre-approved format, must be maintained in permanent files, and must be traceable.

- All data must receive a technical review by another qualified analyst, the technical supervisor, and the laboratory QA officer.

- All raw data must have the signatures of a technical supervisor and a QA officer before release.

Generator sites will be responsible for data validation and verification of waste characterization for each container and the data must be documented by release signatures from the Site Project Manager, Site Data Validation Officer, and the Site Data QA Officer. This is the second level of verification.

The DOE operates a QA/QC program to ensure and maintain the integrity of data, documents, and information associated with the management of TRU mixed waste. The following waste characterization activities are described within this subsection: QA/QC control procedures, DQOs, QAOs, data generation, data transmittal, data verification, and records management.

The WIPP will also institute QA/QC control over the waste characterization program through the Generator/Storage Site Waste Screening and Acceptance Audit Program. This audit program is discussed in Section C-5 of this chapter and Appendix C11.

QA/QC Control Practices

Waste characterization QA/QC ensures that the characterization data obtained at generator sites are suitable for regulatory compliance purposes. The WIPP facility implements stringent QA/QC over the generation, transmittal, and verification of data from waste characterization determinations. In addition, the WIPP facility extends QA/QC practices to the management of all records associated with waste shipment screening determinations.

Data Quality Objectives

As previously described, the waste characterization data obtained through this WAP implementation will be used to ensure that the WIPP facility meets regulatory requirements with regard to both regulatory compliance and to ensure that all wastes are properly managed during the Disposal Phase. The DQOs established for this plan are implemented by the QAPP. They are designed to address the specific waste characterization parameters that will be evaluated. To satisfy the RCRA regulatory compliance requirements, the following DQOs are established by this WAP and have been incorporated into the QAPP (DOE, 1995a):

- Headspace-Gas Sampling and Analysis
  - To quantify the concentrations of VOC constituents in the total waste inventory to ensure compliance with the environmental performance standards of 20 NMAC 4.1, Subpart V, §264.601(b).
- Total Analysis of Homogeneous solids and soil/gravel
  - To compare UCL_{90} values for the mean measured contaminant concentrations in a waste stream with specified toxicity characteristic levels in 20 NMAC 4.1.
  - To report the average concentration of hazardous constituents in a waste stream, as specified in 20 NMAC 2.1, Subpart II, 261, Appendix VIII, with a 90 percent confidence interval.

- Radiography

  - To verify the TRU waste streams by Waste Matrix Code for purposes of physical waste form identification and determination of sampling and analytical requirements.

- Visual Examination

  - To verify the TRU waste streams by Waste Matrix Code for purposes of physical waste form identification and determination of sampling and analytical requirements.

  - To provide a process check on a sample basis by verifying the information determined by radiography.

Reconciliation of these DQOs by the Generator/Storage Site Project Manager is addressed in Appendix C8, Section C8-11.

Quality Assurance Objectives

Each characterization method described in the QAPP has a corresponding set of QAOs that are intended to provide assurance that the data generated by that method is of known quality. The generator sites must demonstrate compliance with each QAO associated with the various characterization methods as described in the QAPP. Site Project Managers are further required to perform a reconciliation at the project level of the data sets submitted by the various organizations at the site with the DQOs established in this WAP and implemented in the QAPP. The Site Project Manager must determine that all of the DQOs have been met for the characterization of the waste stream prior to submitting a Waste Stream Profile Form to WIPP for approval (Appendix C8, Section C8-11). The following QAO elements must be considered for each technique as a minimum:

- Precision

  - Precision is a measure of the mutual agreement among multiple measurements.

- Accuracy

  - Accuracy is the degree of agreement between a measurement result and the true or known value.

- Completeness

  - Completeness is a measure of the amount of valid data obtained from a method compared to the total amount of data obtained that is expressed as a percentage.

- Comparability

  - Comparability is the degree to which one data set can be compared to another.

A more detailed discussion of the QAOs, including a mathematical representation, where appropriate, can be found in Appendix C8, which describes the QAOs associated with each method of analysis.

Sample Control

The sites will implement a sample handling and control program that will include the maintenance of field documentation records, proper labeling, and a chain of custody (COC) record. The site QAPjP will document this program and include COC forms to control the sample from the point of origin to the final analysis result reporting. WIPP will review and approve the QAPjP, including the determination that the sample control program is adequate. Details of this sample control program are provided in Appendix C4 and are summarized below to include:

- Field Documentation of samples including: point of origin, date of sample, container ID, sample type, analysis requested, and COC number.

- Proper Labeling and/or tagging including: proper sample numbering, sample ID, sample date, sampling conditions, and analysis requested.

- Chain-of-Custody control including: name of sample relinquisher, sample receiver, and the date and time of the sample transfer.

- Proper sample handling and preservation.

Data Generation

The DOE's waste characterization program implements the programmatic QA requirements in Chapter 1.0 of SW-846 (EPA, 1986), and the DOE/CAO verifies these requirements through QAPjP review and approval. The generator site QAPjPs are controlled by the QAPP. The QAPP identifies the specific requirements for all QAPjPs including: DQOs; QAOs; sampling procedures; sample custody procedures; calibration procedures and frequencies; analytical procedures; data reduction, validation, and reporting requirements; internal QC checks and frequencies;

performance and system audits and frequencies; preventive maintenance; procedures for assessing data quality; and procedures for corrective actions.

A pre-approved format will be used by each generator site for reporting waste characterization data. This form will be defined by the generator site QAPjP. The data reporting format will include all of the elements required by this WAP and implemented through the QAPP for data reports (Appendix C8, Section C8-12). The generator site must prepare data packages to meet the requirements of QAPjPs. All generator site QAPjPs are reviewed and approved by the DOE/CAO (See Appendix C10).

The DOE/CAO will perform audits of the generator site waste characterization programs to verify that site sampling, data collection, data validation, and reporting practices, as implemented by the site QAPjPs, will meet DQOs in this WAP (Generator/Storage Site Waste Screening and Acceptance Audit Program). The primary functions of these audits are to review data packages prepared by the generator sites that demonstrate adherence to the requirements of this WAP and assure adherence to the written, approved characterization program (as required by their QAPjPs). These audits ensure that implementation of the QAPjPs are consistent with the intent of the requirements of this WAP as implemented by the QAPP. Section C-5 and Appendix C11 provide additional information on the audits of the generator sites performed by the DOE/CAO.

The DOE/CAO further requires all analytical laboratories analyzing WIPP waste characterization samples for the generator sites to have established, documented QA/QC programs. The DOE/CAO annually evaluates these laboratories and their QA/QC programs as part of their participation in the laboratory performance program. The audits cover the requirements of the lab's QA/QC program as well as compliance with the method parameters specified in the Methods Manual, this WAP, and the QAPP. Continued compliance with these parameters will be verified by ongoing CAO audits. The laboratory's QA/QC program must include the following:

- Facility organization
- A list of equipment/instrumentation
- Operating Procedures
- Laboratory QA/QC Procedures
- Quality Assurance Review
- Laboratory Records Management

Data Transmittal

The DOE/CAO, through the QAPP and generator site QAPjPs, controls aspects of the waste-characterization data transmittal process. Data reports document the analytical results from the required characterization analyses and contain the characterization data plus documentation of required QA/QC activities associated with the sampling and analyses. The QAPP implements the WAP requirements for maintaining the integrity of the data in data reports by requiring data validation at both the data-generation level and the generator-site project level before the data are transmitted to the WIPP facility. Section C8-10 of Appendix C8 discusses the data validation process in more detail.

Data will be transmitted by hard copy from the data generation level to the generator site TRU mixed waste characterization project level. Transmitted data will include testing, sampling, and analytical data reports and data review checklists on forms approved under the generator sites QAPjP. Testing, sampling, and analytical data will be reported for each waste container. These data will also be input electronically into the WWIS. Data will be entered into the WWIS in the exact format required by the database (see Section C-5a for WWIS data requirements and Appendix C13 for the WWIS data dictionary). Summarized characterization information will be reported on a waste stream basis and transmitted by hard copy to the WIPP Waste Operations when requested. Hard copy data packages will include site name, program identification, waste container numbers, release signatures from the generator Site Project Manager and Site Project QA Officer, and a concise narrative summarizing the results of the site project-level review. Section C8-12 of Appendix C8 provides the format requirements for generator/storage site data reports; both hard copy and electronic. The report will briefly describe any problems or noteworthy observations (e.g., nonconformance reports, operational variances).

Once a waste stream is fully characterized, the site project manager will also submit to the WIPP facility a summary of the waste stream information and reconciliation with DQOs (Section C8-11 of Appendix C8). Based on this summary, the generator site project manager will complete a Waste Stream Profile Form (Figure C-4). This will be used as the basis for acceptance of waste characterization information on wastes to be disposed of at the WIPP.

Data Verification

The first level of data verification by the generator site will confirm that the waste characterization data are properly reported for the characterized waste containers that will be shipped to the WIPP. Data review, validation, and verification procedures used by the generator sites are required by the QAPP to assure that 100 percent of the data reported has received an independent technical review to assure that data generation and reduction were conducted in a technically correct manner, calculations have been verified correct, and all variances from accepted analytical methods (appropriate to the waste type being analyzed) have been documented and approved. Data packages will be reviewed for completeness to verify that they include field sampling records, raw analytical data, calculation records, COC documentation,

calibration records, QA sample results, and that sample holding times and preservation methods were met or exceptions documented. Completed data must be signed by the technical supervisor. At the second level of verification, the Site Project Manager, the Site Data Validation Officer, and the Site Data QA Officer will also ensure that a repeat of this review is performed for at least one randomly chosen container quarterly. Finally, a check for the data package elements required by the QAPP will be performed by the WIPP Waste Operations section as the third level of verification for data packages to assure that data packages are complete. Figure C-5 shows the components of each level of data verification. Data verification is discussed in more detail in Appendix C8, Section C8-10.

Records Management

Records related to waste characterization sampling and analysis activities at the generator sites will be maintained in the testing, sampling, or analytical facility files or site project files for those facilities located on sites. Contract waste analytical facilities will forward testing, sampling, and analytical QA documentation along with testing, sampling, and analytical batch data reports to the site project office for inclusion in site central files.

An appropriate records inventory and disposition schedule (RIDS) shall be prepared and approved by appropriate site personnel. All records relevant to an enforcement action, regardless of disposition, shall be maintained at the generator site until they are no longer needed for enforcement action, and then dispositioned per the approved RIDS. All waste characterization data and related QA/QC records in the site project files for waste to be shipped to the WIPP facility are designated according to NQA-1, Supplement 17S-1, as either Lifetime Records or Non-Permanent Records. Records that are designated as Lifetime Records shall be maintained for the life of the waste characterization program at a participating site plus six years, then offered to the DOE/CAO or transferred to the appropriate Federal Records Center (FRC). Waste characterization records designated as Non-Permanent Records shall be maintained for ten years from the date of (record) generation and then dispositioned according to their approved RIDS. If a site ceases to operate, all records shall be transferred before closeout. Table C-13 provides a listing of records designated as Lifetime Records and Non-Permanent Records.

All waste characterization data shall be maintained by DOE/CAO or WID for the active life of the WIPP facility plus two years. The active life of the WIPP facility is defined as the Disposal Phase and the Decommissioning Phase. After their active life, the records shall be retired to the FRC and maintained for 30 years. These records will then be offered to the National Archives. However, this disposition requirement does not preclude the inclusion of these records in the permanent marker system or other requirements for institutional control.

Raw data obtained by testing, sampling, and analyzing TRU waste in support of this WAP will be identifiable, legible, and provide documentary evidence of quality. The reporting requirements

are different for each technique used, but the forms for data reporting will be pre-approved forms, provided in site-specific documentation

C-5 Verification for TRU Mixed Waste

The third level of data verification, which is performed at the WIPP facility, involves screening and verification of waste stream data and waste shipments. Documentation on waste streams will be screened and verified to ensure that the waste is acceptable for disposal at the WIPP facility according to applicable RCRA requirements. Quality controls related to waste labeling, identification, transport, and screening will ensure that the waste packages arriving at the WIPP facility are the same as those transported from the generator sites and are correctly identified on the EPA Hazardous Waste Manifest.

WIPP waste screening is a two-phased process. Phase I will occur prior to transporting the waste to the WIPP facility. Phase II will occur after the waste shipment arrives but before it is emplaced. Figure C-6 presents the waste shipment screening process.

C-5a Phase I Waste Stream Screening and Verification

The first phase of the waste screening and verification process will occur before waste is shipped to the WIPP site. Before WIPP will begin the process of accepting waste from a generator site, an initial audit of that site will be conducted as part of the Generator/Storage Site Waste Screening and Acceptance Audit Program (Appendix C11). The RCRA portion of the generator site audit program will provide on-site verification of characterization procedures, data package preparation, and recordkeeping. The secondary verification step is the waste-characterization data package completeness/accuracy review and acceptance by the WIPP as part of the Waste Stream Profile Form approval process. At the WIPP facility, screening includes verification that all of the required elements of a data package are present (Appendix C8, Section C8-12) and that the waste characterization data meet acceptance criteria required for compliance with the WAP.

Once a generator site has prepared a QAPjP in accordance with the QAPP, it is submitted to the DOE/CAO for review and approval (See Appendix C10). The generator site will implement the specific parameters of the QAPjP once it is approved. The initial site RCRA audit will be performed at some point after this implementation has taken place and before a Waste Stream Profile Form has been submitted to the WIPP for approval. The checklists used in this audit will be based on each site's QAPjP. Additional audits, focusing on results of waste characterization, will be performed at least annually. The WIPP has the right to conduct unannounced audits and to examine any records that are related to the scope of the audit. More detail about this audit program is provided later in this section and in Appendix C11.

When the required waste stream characterization data have been collected by a generator and the initial site audit has been successfully completed, the generator Site Project Manager can

verify that waste stream characterization meets the WAP requirements as a part of the Level 2 data verification required by the QAPP (Appendix C8, Section C8-11). If the waste characterization does not meet the requirements of the WAP, the waste stream cannot be sent to the WIPP until those requirements are met. The generator will complete a Waste Stream Profile Form and submit it to Waste Operations, along with the accompanying waste characterization documentation for that waste stream. This provides notification that the generator considers that the waste stream (identified by the waste stream identification number) has been adequately characterized for disposal according to the WIPP facility approved QAPjP and QAPP DQOs.

The Waste Stream Profile Form is provided as Figure C-4. It includes information on the generator site name and EPA identification number, the technical contact for information on that waste stream, the WIPP ID, Summary Category Group, listing of acceptable knowledge documentation used, and waste characterization data package identification numbers associated with that waste stream. The form also requires the date of the WAC certification for that waste stream, procedures used for characterization, and EPA Hazardous Waste Code designations. Upon WIPP facility approval of the waste stream for disposal through the use of the Waste Stream Profile Form, the generator may begin shipping waste containers from that waste stream.

As part of the waste characterization data submittal, the generator site will also transmit the data on a container basis via the WWIS database. This data submittal can occur at any time as the data are being collected. The system will conduct internal limit checks as the data are entered, and the data will be available to WIPP personnel for review as supporting information for Waste Stream Profile Form review.

If discrepancies arise as a result of this review, the generator sites will be contacted by WIPP Waste Operations and required to provide the necessary additional information to resolve the discrepancy before that waste stream is approved for disposal at the WIPP facility. If the discrepancy is not resolved, the waste stream will not be approved.

WIPP WWIS Description

The WWIS is an electronic database that contains information and data related to the characterization, certification, and the shipment of waste destined for WIPP. The database design contains different modules for waste characterization data (as required by the QAPP and RCRA), waste certification data (as required by the WAC), and transportation data (as required by the TRUPACT-II Authorized Methods for Payload Control (TRAMPAC). The database contains edit, limit, and other data check functions to ensure that data supplied meet the requirements and the limits of the QAPP, RCRA, the WAC, and the TRAMPAC. All TRU waste sites planning to ship waste to WIPP will supply the required data to the WWIS. The WWIS will verify that all of the supplied data meet the edit and limit checks prior to the shipment of any waste to WIPP. The WWIS database will notify the generator site if any of the supplied data fails to meet the requirements of the edit and limit checks via an appropriate error message. The generator site

will be required to correct the discrepancy with the waste or the waste data and re-transmit the corrected data prior to acceptance of the data by the WWIS. WIPP facility personnel will review data reported for each container of each shipment prior to providing notification to the shipping site that the shipment is acceptable. Table C-12 gives a partial listing of the data fields contained in the WWIS.

The WWIS will generate the following:

- Container Emplacement Report

  This report will be added to the operating record as an indication of the quantities of waste, date of emplacement, and location in the repository. This report will be generated on a shipment basis. Reports that are included as part of the operating record will be retained at the site, for the life of the facility.

- Shipment Summary Report

  This report will contain the container IDs of every container in the shipment, listed by TRUPACT-II number and by assembly number (for seven packs), for every assembly in the TRUPACT-II. This report is used by Waste Operations to verify containers in a shipment and will be generated on a shipment basis.

- Characterization Data Report

  This report will be generated on a waste stream basis and will be used by the WIPP in the Waste Stream Profile Form review and approval process. This report will contain the data listed in the Waste Characterization Data Module on Table C-12. This report will be generated and attached to the Waste Stream Profile Form for inclusion in the facility operating record and will be kept for the life of the facility.

- Reports of Change Log

  This will consist of a short report that lists the user ID and the fields changed. The report will also include a reason for the change. A longer report will list the information provided on the short report and include a before and after image of the record for each change, a before-record for each deletion, and the new information for added records. These reports provide an auditable trail for the data in the database.

Access to the WWIS will be controlled by a Data Administrator (DA) of the Waste Operations section who will control the WWIS users based on approval from management personnel. Integrity of the WWIS data will be maintained by strict access control to the database. The WWIS system is located in a limited access area within the WIPP site. Access to the computer room area where the WWIS system will reside is controlled through a cipher lock door system whose combination is only granted to authorized personnel. This computer room also houses the systems that provide the WIPP local and wide area networks, and is staffed by experienced computer operators on a 24 hour basis.

The WWIS will be included in the contingency planning performed by the Information Technology Resources (ITR) Section at the WIPP site. This section operates the computer room. This planning includes dual storage (other than the computer room) of software backup tapes that will permit rapid restart of the system.

The computer room is provided with power by a uninterruptible power supply system that can provide clean, harmonic filtered power for 30 minutes after the loss of the primary power supply. This will provide for an orderly shutdown of the database.

Nightly backups of the WWIS system will occur as part of the overall backup program for all of the systems. The database can be restarted, if for whatever reason, a catastrophic failure occurs using the previous day's backup copy. In addition to the nightly backup procedure, the database will be archived quarterly and annually. The archived copies will be included in the operating record and retained for the life of the facility.

The WWIS system hardware and application software is constructed using client-server architecture. The client software will provide the user interface and communication to the server. This limits user access only to those database functions approved by the WIPP, such as allowing the small quantity generator sites to populate a defined data structure established on the system for them by the WIPP. Onsite terminals are located within controlled access areas designated for use by authorized WWIS users. Offsite access will be by direct log in through multi-layer password/user ID methodology. The first layer of control will provide authorized access to the WIPP network, the second layer will provide authorized users access to the WWIS system, and the third layer defines the specific functions of the WWIS that each user has been assigned. Access to the various WWIS functions is controlled by the WWIS DA. All access attempts will be logged by the system. Waste Operations and ITR personnel will routinely review the logs for the purpose of identifying and investigating unauthorized access attempts.

The TRU waste generator sites will only have access to data that they have supplied, and only until the data have been formally accepted by the WIPP. After the data have been accepted, the data will be protected from indiscriminate change and can only be changed by a qualified DA.

The database has a Data Change Log that will require a reason for the change from the DA prior to accepting the change. The data change information, the user ID of the qualified DA making the change, and the date of the change will be recorded in the data change log automatically. The data change log cannot be revised by any user, including the DA. The data change log will be subject to internal and external audits and will provide an auditable trail for all changes made to previously approved data.

Examination of the Waste Stream Profile Form

Members of the Waste Operations section will be responsible for the verification of completeness and accuracy of the Waste Stream Profile Form. This verification will consist of a review of the Waste Stream Profile Form by the Environmental Compliance and Support section and the Quality Assurance department. These groups will review the Waste Stream Profile Form based on their area of responsibility. Of particular importance are the assignment of the waste-stream description, Waste Matrix Code Group, and Summary Category Groups, the results of waste analyses, the acceptable knowledge documentation, the methods used for characterization, the WAC certification, and appropriate designation of EPA hazardous waste code(s). If the waste stream profile form is considered to be inaccurate, efforts will be made to resolve discrepancies by contacting the generator site. If discrepancies in the waste stream are detected at the generator site, the QAPP requires the site to implement a non-conformance program to identify, document, and report discrepancies (Appendix C8, Section C8-13). The QAPP requires that site management at all levels shall foster a "no fault" attitude to encourage the earliest identification of discrepancies and/or deviations from protocols. The Waste Stream Profile Form must pass all verification checks at the WIPP facility in order for the waste stream to be approved for shipment to the WIPP facility.

The identified EPA hazardous waste codes for the wastes that appear on the Waste Stream Profile Form will be compared to those in the WIPP RCRA Part A to ensure that only wastes that contain constituents contained in the Part A are approved for shipment to the WIPP. The analytical data package summaries will be reviewed to verify that the waste has been classified correctly. The analytical method used will be compared to those listed in Tables C-9, C-10, and C-11 to assure that only approved analytical methods were used for analysis of the waste. Waste Operations will verify that WAC certification has been granted to the generator.

Environmental Compliance and Support will verify three different types of data related to WAC on every container holding TRU mixed waste before a shipment leaves the generator site for the WIPP facility. The three verifications will be performed on data from the following determinations: 1) an assignment of the waste stream's waste description (by waste matrix codes) and Waste Matrix Code Group; 2) a determination of ignitability, reactivity, and corrosivity; and 3) a determination of compatibility. The verification of waste stream description will be performed by reviewing the waste characterization data package for consistency in the waste stream description. The data package will also indicate if the waste has been checked for the characteristics of ignitability, corrosivity, and reactivity. The final verification of waste

compatibility will be performed using Appendix C1, the compatibility study. Since the Part A does not include hazardous waste codes that are not consistent with the WAC, a consistency check between the hazardous waste codes listed in the data package for the waste stream and the hazardous waste codes listed on the Part A will verify that the waste stream is not ignitable, corrosive, or reactive, and that it is compatible with the other waste to be disposed of at the WIPP facility.

Generator/Storage Site Waste Screening and Acceptance Audit Program

An important part of the WIPP's verification process is the Generator/Storage Site Waste Screening and Acceptance Audit Program implemented by representatives of the DOE/CAO and WID. The focus of this audit program is compliance with the QAPP, site QAPjPs, this WAP, and the RCRA. The RCRA compliance portion of the audits will be performed by the Environmental Compliance and Support section. This audit program addresses all waste sampling and analysis activities, from waste-stream classification assignment through final loading of the TRUPACT-II or shielded road cask, and ensures that SOPs are being followed and the QAPjPs are fully implemented. Audits will assure that containers and their associated documentation are adequately tracked throughout the waste handling process. Operator qualifications will be verified, and QA/QC procedures will be surveyed. Results of all generator site audits will be kept in the WIPP facility operating record until closure of the facility.

An initial audit will be performed at each generator site performing waste characterization activities prior to the formal acceptance of the Waste Stream Profile Forms and/or any waste characterization data supplied by the sites. Audits will be performed at least annually thereafter, including the possibility of unannounced audits (this means not a regularly scheduled audit). These audits will verify that the generator site has implemented a QA program for the characterization of waste. The accuracy of physical waste description and waste stream assignment provided by the generator site will be verified by review of the radiography results, and visual examination of data records and radiography videotapes (as necessary) during audits. More detail on this audit process is provided in Appendix C11.

C-5b Phase II Waste Shipment Screening and Verification

Phase II of the waste shipment screening and verification process includes examination of a waste shipment after the waste shipment has arrived. The second-phase determinations are: 1) a determination of the completeness and accuracy of the EPA Hazardous Waste Manifest; 2) a determination of waste shipment completeness; 3) a determination of land disposal restriction notice completeness; and 4) an identification and resolution of waste shipment irregularities. Only those waste containers that pass all Phase II waste-screening determinations will be emplaced at the WIPP. For each container shipped, the generator site must provide the following information:

Typical Hazardous Waste Manifest Information:

- Generator site name and EPA ID
- Generator site contact name and phone number
- Quantity of waste
- List of the hazardous waste codes in the shipment
- Listing of all container IDs
- Signature of authorized generator representative

Typical Land Disposal Restriction Notice Information:

- EPA Hazardous Waste Number(s)
- Applicable treatment standards for F001-F005 wastes (D001-D003 wastes prohibited by the WAC)
- Supporting analyses and/or references to previously supplied analytical data (Such as Characterization Reports and data submitted to the WWIS)

Specific Container information:

- Waste Stream Identification Number
- List of Hazardous Codes per Container
- Certification Data (Nuclide info, etc.)
- Shipping Data (Assembly numbers, ship date, shipping category, etc.)

This information must also be supplied electronically to the WWIS and may be provided to the WWIS as part of the Phase I Screening or may be supplied at the time of shipment.

Waste Operations personnel will verify that all this information is provided for each container received. The ID will be compared with a list of those approved for disposal at the WIPP.

Examination of the EPA Uniform Hazardous Waste Manifest and Associated Waste Tracking Information

Upon receipt of a waste shipment, Waste Operations will make a determination of EPA Uniform Hazardous Waste Manifest completeness and sign the manifest to allow the driver to depart. Waste Operations will make a determination of waste shipment completeness by checking the unique, bar-coded identification number found on each container holding TRU mixed waste after opening the TRUPACT-II or shielded road cask. The bar-coded identification number(s) will be noted and checked against the WWIS database. The RH waste canister has a unique identification number stamped into it which will be verified in the Hot Cell during transfer to the facility cask. The WWIS computer database will maintain waste container receipt and emplacement information provided by the WIPP site. It will include, among other items, the following information associated with each container of TRU mixed waste:

- Package (container) receipt date
- Overpack identification number (if appropriate)
- Package (container) emplacement date
- Package (container) emplacement location (panel/room)

The WWIS links the bar-coded identification numbers of all containers in a specific waste shipment to the waste assembly (for 7-packs) and to the shipment identification number, which is also written on the EPA Hazardous Waste Manifest. Generators electronically transmit the waste shipment information to the WWIS before the waste shipment is transported. Once a waste shipment arrives, WIPP facility personnel can verify the identity of each container using the data already in the WWIS.

If there are discrepancies on the manifest, the generator will be contacted for resolution. A manifest discrepancy is a difference between the quantity or type of hazardous waste designated on the manifest and the quantity or type of hazardous waste a facility actually receives. Manifest discrepancy resolution is accomplished by contacting the generator site technical contact (as listed on the manifest). If the discrepancy is identified prior to the containers being removed from the TRUPACT-II, the waste will be retained in the parking area. If the discrepancy is identified after the waste containers are removed from the TRUPACT-II, the waste will be retained in the WHB. Errors on the manifest can be corrected by the accepting facility with a verbal concurrence by the generator. Discrepancies not resolved within 15 days of receiving the waste will be reported to the NMED. Notifications to the NMED will consist of a letter describing the discrepancies, attempts to reconcile the discrepancies, and a copy of the manifest. If the waste containers reside in the TRUPACT-II and the manifest discrepancies have not been resolved within 30 days of waste receipt, the shipment will be returned to the generator/storage facility. If it becomes necessary to return waste containers to the generator site, a new EPA Uniform Hazardous Waste Manifest will be prepared.

Documentation of the returned containers will be covered by Waste Operations protocols and the WWIS. Changes will be made to the WWIS data to indicate the current status of the container(s), and a reason will be required to change the data. This reason, plus the record of the WWIS data change will be maintained in the change log of the WWIS and will provide an auditable record of the returned shipment.

The Waste Operations section will be responsible for resolution of discrepancies, notification of the NMED, as well as returning the original copy of the manifest to the generator. The manifest will be returned within 30 days of delivery of the waste.

Examination of the Land Disposal Restriction (LDR) Notice

Unless TRU mixed waste is otherwise exempted from the LDRs, the DOE intends to petition the EPA for a variance from the prohibition on land disposal of untreated TRU mixed waste at the WIPP facility. If successful, the WIPP facility may dispose of the restricted waste. With each waste shipment of LDR waste, the generator must provide the WIPP facility with a LDR determination and a notice that the waste is not prohibited from land disposal because the waste is covered by a no-migration determination (NMD). (This assumes that a Disposal-Phase NMD will be made by the EPA. Wastes will be in conformance with conditions of the NMD.) WIPP facility personnel will review this notice for accuracy and completeness. The generator will prepare this notice in accordance with the requirements of 20 NMAC 4.1, §268.7(a)(3).

Verification

Waste Operations will make a determination of waste shipment irregularities. The following items will be noted for each waste shipment arriving at the WIPP facility:

- The number and type of containers holding TRU mixed waste match the information in the WWIS
- Container defects

Waste Operations will verify that the containers (as identified by their container ID numbers) are the containers for which accepted data already exists in the WWIS. A check will be performed by Waste Operations comparing the data on the WWIS Shipment Summary Report for the shipment to the actual shipping papers (including the EPA Hazardous Waste Manifest). This check also verifies that the containers included in the shipment are those for which approved shipping data already exist in the WWIS Transportation Data Module (Table C-12). For SWBs and TDOPs, this check will include comparing the barcode on the container with the shipping papers and the data on the WWIS Shipment Summary Report. For 7-pack assemblies, one of the seven container barcodes will be read by the barcode reader and compared to the assembly information for this container on the WWIS Shipment Summary Report. This will automatically identify the remaining six containers in the assembly. This process enables Waste Operations

to identify all of the containers in the assembly with minimum exposure. If all of the container IDs and the information on the shipping papers agree with the WWIS Shipment Summary Report, the operator is assured that the containers have been approved for disposal at the WIPP facility.

Waste Shipment Screening QA/QC

Waste shipment screening QA/QC ensures that waste received is that which has been approved for shipment during the Phase I screening. This is accomplished by maintaining stringent QA/QC control of the waste shipment screening process. The screening process will be controlled by administrative processes which will generate records documenting waste receipt that will become part of the waste receipt record. The waste receipt record documents that container identifications correspond to shipping information and approved waste streams. The WIPP extends QA/QC practices to the management of all records associated with waste shipment screening determinations.

Records Management

As part of the WIPP facility's operating record, data and documents associated with waste characterization data are managed in accordance with standard records management practices. The storage of WIPP's copy of the manifest, LDR information, waste characterization data, waste stream profile forms, and other related records will be identified on the appropriate records inventory and disposition schedule for Waste Operations.

Waste characterization data and documents related to waste characterization that are part of the WIPP facility operating record are managed in accordance with the following guidelines:

General Requirements

- Records must be legible
- Corrections must be made with a single line through the incorrect information, and a date and initial of the person making the correction
- Records must be paginated indicating the total number of pages that make up the record
- Black ink is encouraged, unless a copy test has been conducted to ensure the other color ink will copy
- Use of highlighters on records is discouraged
- Records must be reviewed for completeness
- Records must be validated by the cognizant manager

Records Storage

- Active records must be stored when not in use

- Quality records must be kept in a one-hour (certified) fire-rated container or a copy of a record must be stored separately (sufficiently remote from the original) in order to prevent destruction of both copies as a result of a single event such as fire or natural disaster
- Unauthorized access to the records is controlled by locking the storage container or controlling personnel access to the storage area

The following records will be maintained for waste characterization purposes as part of the WIPP facility operating record:

- Completed WIPP Waste Stream Profile Forms and accompanying documentation
- Completed Waste Receipt Checklists
- WIPP WWIS Container Emplacement Report
- Audit reports and corrective action reports from Generator/Storage Site Waste Screening and Acceptance Audit Program audits

These records will be maintained for each TRU mixed waste container managed at the WIPP facility.

Records at the WIPP facility will be managed in accordance with the CAO Quality Assurance Program Description (QAPD) record management requirements. The QAPD provides for generation of QA records; QA guidelines; indexing of QA records; classification of QA records; receipt of QA records; storage, preservation, and disposition of QA records; and retrieval of QA records.

Waste Shipment Tracking QA/QC

The Transportation Tracking and Communications System is a unique waste shipment monitoring system that will provide 24-hour-per-day feedback to the WIPP facility via satellite on the location and status of each waste shipment during transport.

C-6 List of References

U.S. Department of Energy (DOE), 1995a, "Transuranic Waste Characterization Quality Assurance Program Plan," DOE/CAO 94-1010, Revision 0, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy (DOE), 1995b, "Transuranic Waste Characterization Sampling and Analysis Methods Manual," DOE/WIPP 91-043, Current Revision, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

U.S. Department of Energy (DOE), 1995c, "Performance Demonstration Program Plan for the Analysis of Simulated Headspace Gases for the TRU Waste Characterization Program," CAO-95-1076, Current Revision, Carlsbad, New Mexico, Carlsbad Area Office, U.S. Department of Energy.

U.S. Department of Energy (DOE), 1995d, "Performance Demonstration Program Plans for Analysis of Solid Waste Forms," CAO-95-1077, Current Revision, Carlsbad, New Mexico, Carlsbad Area Office, U.S. Department of Energy.

U.S. Department of Energy (DOE), 1995e, "Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report," CAO 0-94-1005, Revision 1, Carlsbad, New Mexico.

U.S. Department of Energy, (DOE), 1994, "Quality Assurance Program Description," CAO-94-1012, Revision 0, Carlsbad, New Mexico.

U.S. Department of Energy, (DOE), 1991, "Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria," DOE/WIPP-069, Revision 4, Carlsbad, New Mexico,

U.S. Environmental Protection Agency (EPA), April 1994, "Waste Analysis at Facilities that Generate, Treat, Store, and Dispose of Hazardous Waste, a Guidance Manual," PB94-963603, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. Environmental Protection Agency (EPA), April 1980. "A Method for Determining the Compatibility of Hazardous Wastes," EPA-600/2-80-076, California Department of Health Services and the U.S. Environmental Protection Agency, Office of Research and Development.

U.S. Environmental Protection Agency (EPA), 1986 as amended by FR 46040, August 31, 1993. "Test Methods for Evaluating Solid Waste," Laboratory Manual Physical/Chemical Methods, SW-846, 3rd ed., U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

TABLES

TABLE C-1
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Homogeneous Solids—S3000	Solidified Inorganics	1000	AL-W005	Solidified Aqueous Liquids/Slurries				
	Solidified Inorganics	3150	IN-W157	Solidified Process Residues	ID 213	004	4	Solidified Liquid
	Solidified Inorganics	3150	IN-W166	Solidified Process Residues	ID 114	114	1	Inorganic Process Solids and Soils
	Solidified Inorganics	3150	IN-W177	Solidified Process Residues		835		
	Solidified Inorganics	3150	IN-W179	Solidified Process Residues	MD 111A	836	1	
	Solidified Inorganics	3150	IN-W181	Solidified Process Residues	ID 211A	978	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	3150	IN-W188	Solidified Process Residues	ID 211A	976	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	3150	IN-W216	Solidified Process Residues	ID 211A	001	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	3150	IN-W220	Solidified Process Residues	ID 111	111	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	3113	IN-W221	Absorbed Aqueous Liquids	ID 113	113	4	Solidified Liquid
	Solidified Inorganics	3150	IN-W222	Solidified Process Residues	ID NYD	292		
	Solidified Inorganics	3121	IN-W228	Solidified Wastewater Treatment Sludges	ID 211A	002	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	3150	IN-W332	Solidified Process Residues		204		
	Solidified Inorganics	3113	IN-W347	Absorbed Aqueous Liquids		102		

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Homogeneous Solids—S3000	Solidified Inorganics	---	LA-W002	Solidified Aqueous Waste	LA 111A; 211A	002	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	---	LA-W003	Dewatered Sludge	LA 111B; 211B	003	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	---	LA-W006	Cemented Process Residues	LA 114A	006	1	Inorganic Process Solids and Soil
	Solidified Inorganics	---	LL-W019	Solidified Waste	LL 111	002	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	3150	MD-W002	Absorbed Aqueous Liquids				
	Solidified Inorganics	3120	OR-W042	Inactive Storage Tank Contents—MTRU Sludge				
	Solidified Inorganics	1220	PA-W014	Solidified TRU Waste Liquids				
	Solidified Inorganics	3129	PA-W015	TRU Solid				
	Solidified Inorganics	1190	PA-W015A	TRU and Technetium Waste				
	Solidified Inorganics	3150	RF-M001	Solidified Process/TRM	RF 114	806	1	Inorganic Process Solids and Soils
	Solidified Inorganics	3150	RF-W010	Solidified Aqueous Sludge/ TRM	RF 111	800 803 807	1	Inorganic Waste Water Treatment Sludge
	Solidified Inorganics	3121	RF-W038	Solidified Laboratory Waste/TRM	RF 113	802	4	Solidified Liquid

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Homogeneous Solids—S3000	Solidified Inorganics	3111	RF-W040	Incinerator Ash/TRM		419 420 421 425 428		
	Solidified Inorganics	3119	RF-W059	Sand, Slag, and Crucible/ TRM		387 392 390 393 395 394 396 399 391		
	Solidified Inorganics	1190	RF-W063	Miscellaneous TRM		070 503 400 508 401 527 500 541		
	Solidified Inorganics	6290	RF-W065	Calcium Metal/TRM		333		
	Solidified Inorganics	3129	RF-W068	Particulate Sludge/TRM		292 299 372 823		
	Solidified Inorganics	3119	RF-W076	Process Residues/TRM		289 372 292 422 299 423 340		
	Solidified Inorganics	---	RL-M005	TRU Mixed Homogeneous Solids with Mercury				
	Solidified Inorganics	---	RL-M032	TRU Mixed Inorganic Homogeneous Solids				

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Homogeneous Solids—S3000	Solidified Inorganics	3111	SR-W053	Ash				
	Solidified Inorganics	3129	IN-W146	Uncategorized Inorganic Sludges				
	Solidified Inorganics	3000	OR-W046	Solidified Liquid Low Level Waste Tanks - Sludge				
	Solidified Organics	3150	IN-W167	Solidified Process Residues	ID 112	112	4	Organic Liquid and Sludge
	Solidified Organics	3113	IN-W174	Absorbed Aqueous Liquids		834		
	Solidified Organics	3114	IN-W309	Organic Setups	ID 212	003	4	Organic Liquid and Sludge
	Solidified Organics	3222	RF-W013	Solidified Organics/TRM	RF 112	801	4	Organic Liquid and Sludge
	Solidified Organics	3212	RF-W069	Organic Resins/TRM	RF 126	430 431 809	3	Cation and Anion Exchange Resins
	Solidified Organics	---	RL-M017	TRU Mixed Organic Labpacks				
	Solidified Organics	---	RL-M018	TRU Mixed Organic Labpacks (State only)				
	Solidified Organics	---	RL-M024	TRU Mixed Organic Labpacks with polychlorinated biphenyls (PCB)				
	Solidified Organics	2000	SR-W006	Organic TRU				
	Salt Waste	3140	IN-W311	Salt Waste		409		
	Salt Waste	3140	IN-W312	Salt Waste	ID 124	124	2	Pyrochemical Salt
	Salt Waste	3140	IN-W314	Salt Waste		409		

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Homogeneous Solids—S3000	Salt Waste	3141	RF-W058	Miscellaneous Pu Recovery By-products/TRM	RF 124	365 414 404 415 405 418 406 427 407 429 408 433 409 434 410 435 411 473 412 654 413	2	Pyrochemical Salt
	Salt Waste	---	IN-M001	Electrorefiner Stripped Salts—Barium (Ba) & Cadmium (Cd)				
Soils/Gravel—S4000	Soils	4200	IN-W263	Contaminated Soils/Debris	MD 111B	842	1	
	Soils	---	RL-M007	TRU Mixed Soils without Mercury				
Debris Waste—S5000	Combustible	5310	IN-W198	Plastic/Rubber Debris	ID 216C	337	3	Combustibles
	Combustible	5320	IN-W202	Wood Debris	ID 216A	970	3	Combustibles
	Combustible	5300	IN-W205	Combustible Debris	ID 216B	900	3	Combustibles
	Combustible	5311	IN-W250	Leaded Gloves/Aprons Debris	ID 123	123	3	Leaded Rubber
	Combustible	5311	IN-W252	Leaded Gloves/Aprons Debris	ID 123; 223A	339	3	Leaded Rubber
	Combustible	5311	IN-W254	Leaded Gloves/Aprons Debris	ID 223A	463	3	Leaded Rubber
	Combustible	5311	IN-W256	Leaded Gloves/Aprons Debris		802		

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Combustible	5300	IN-W325	Unknown Solids		815		
	Combustible	5300	IN-W327	Combustible Debris		847		
	Combustible	5310	IN-W330	Plastic/Rubber Debris		801		
	Combustible	5300	IN-W336	Combustible Debris		202		
	Combustible	---	LA-W004	Combustible Waste	LA 116A	004	3	
	Combustible	---	LL-M001	Research and Development Glovebox Waste	LL 116	001	3	
	Combustible	---	RL-M009	TRU Mixed Organic Debris with Corrosives				
	Combustible	---	RL-M010	TRU Mixed Organic Debris with Mercury				
	Combustible	---	RL-M011	TRU Mixed Organic Debris without Mercury				
	Combustible	---	RL-M012	TRU Mixed Organic Debris/ Contaminated without Organics				
	Combustible	---	RL-M013	TRU Mixed Organic Debris/ Contaminated with Organics				
	Combustible	---	RL-M014	TRU Mixed Leaded Gloves/ Aprons with Mercury				
	Combustible	---	RL-M015	TRU Mixed Leaded Gloves/ Aprons Metals without Mercury				

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Combustible	---	RL-M016	TRU Mixed Leaded Gloves/ Aprons Metals/Organics without Mercury				
	Combustible	---	RL-M022	TRU Mixed Leaded Gloves/ Aprons PCBs with Mercury				
	Combustible	---	RL-M023	TRU Mixed Resource Conservation and Recovery Act (RCRA) Organic Debris with PCBs				
	Filter	5410	IN-W214	Composite Filters		813		
	Filter	5410	RF-W066	Filters & Media/TRM	RF 119	328 376 331 490 335 491 342	3	Filters
	Filter	5410	RF-W067	Cemented Filters/TRM	RF 119	376 338	3	Filters
	Filter	5410	AW-M003	TRU Waste Used Pre-filters				
	Graphite	5000	IN-W272	Debris Waste	ID 115	312	2	Graphite
	Graphite	5000	IN-W275	Debris Waste		301		
	Graphite	5000	IN-W276	Debris Waste	ID 215A	300	2	Graphite
	Graphite	3119	RF-W060	Coarse Graphite/TRM	RF 115	303 312	2	Graphite
	Heterogeneous	5440	IN-W169	Predominantly Combustible Debris	ID 216C	330	3	Combustibles

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Heterogeneous	5440	IN-W170	Predominantly Combustible Debris	AE 116A AE 116B	120		Combustibles
	Heterogeneous	5440	IN-W171	Predominantly Combustible Debris	AE 116A AE 116B	110		Combustibles
	Heterogeneous	5440	IN-W172	Predominantly Combustible Debris		010		
	Heterogeneous	5440	IN-W186	Predominantly Combustible Debris	ID 116	116	3	Combustibles
	Heterogeneous	5440	IN-W189	Predominantly Combustible Debris	ID 221A	464	3	Benelex® and Plexiglas®
	Heterogeneous	5440	IN-W197	Predominantly Combustible Debris	ID 216A	336	3	Combustibles
	Heterogeneous	5440	IN-W203	Predominantly Combustible Debris		826		
	Heterogeneous	5440	IN-W204	Predominately Combustible Debris	MD 116A	827	3	
	Heterogeneous	5440	IN-W225	Predominantly Combustible Debris	ID 221A	302	3	Benelex® and Plexiglas®
	Heterogeneous	5400	IN-W259	Heterogeneous Debris		104		
	Heterogeneous	5430	IN-W265	Predominately Inorganic Nonmetal Debris	ID 121	374	3	Benelex® and Plexiglas®
	Heterogeneous	5000	IN-W269A	Debris Waste		150		
	Heterogeneous	3190	IN-W271	Uncategorized Inorganic Process Residues		814		

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Heterogeneous	5400	IN-W281	Heterogeneous Debris	MD 117A	824		
	Heterogeneous	5400	IN-W283	Heterogeneous Debris	ID 225A	241	3	Combustibles and Noncombustibles
	Heterogeneous	5400	IN-W285	Heterogeneous Debris		201		
	Heterogeneous	8200	IN-W289	Unknown Solids	AE 116A	121		
	Heterogeneous	5000	IN-W291	Debris Waste		100		
	Heterogeneous	8200	IN-W302	Unknown Solids		020		
	Heterogeneous	5400	IN-W329	Heterogeneous Debris		848		
	Heterogeneous	5000	IN-W334	Debris Waste		203		
	Heterogeneous	5000	IN-W345	Debris Waste		155		
	Heterogeneous	5000	IN-W351	Debris Waste		105		
	Heterogeneous	5490	NT-W001	Heterogeneous Debris, Uncategorized	NT 111; 116; 211; 225		1 & 3	
	Heterogeneous	5400	OR-W044	CH TRU Heterogeneous Debris	OR 125A; 125B		3	
	Heterogeneous	8000	OR-W045	CH TRU Uncategorized				
	Heterogeneous	5400	OR-W047	CH TRU Heterogeneous Debris				
	Heterogeneous	5330	RF-M002	Supercompacted Combustibles/TRM	RF 116C	2116	3	Combustibles

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Heterogeneous	5900	RF-W008	Soil & Cleanup Debris/TRM	RF 121	374	3	Benelex® and Plexiglas®
	Heterogeneous	5330	RF-W012	Combustibles/TRM	RF 116	330 831 336 832 337 833	3	Combustibles
	Heterogeneous	3119	RF-W036	Firebrick, Pulverized or Fines/ TRM	RF 122	377 378	2	Firebrick and Ceramic Crucibles
	Heterogeneous	---	RL-M004	TRU Mixed Heterogeneous Debris (State only)				
	Heterogeneous	---	RL-M006	TRU Mixed Inorganic Homogeneous Solids without Mercury				
	Heterogeneous	---	RL-M031	TRU Mixed Heterogeneous Debris (State only)				
	Heterogeneous	8900	SA-W134	TRU Waste at Hot Cell Facility				
	Heterogeneous	5400	SR-W026	Heterogeneous Debris				
	Heterogeneous	5400	SR-W027	Heterogeneous Debris				
	Heterogeneous	5400	AW-W020	TRU-Cd-Hot Cell Waste				
	Heterogeneous	---	IN-M002	TRU-Cd-Hot Cell Waste				
	Heterogeneous	---	IN-W139	TRU Contaminated Lead Debris				
	Heterogeneous	---	IN-W269B	Debris Waste		150		
	Heterogeneous	5440	IN-W323	Predominantly Combustible Debris		153		

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Heterogeneous	5000	KA-W016	TRU Debris				
	Heterogeneous	5400	OR-W040	RH TRU Heterogeneous Debris				
	Heterogeneous	5400	RL-M201	Projected RH-MTRU Waste				
	Inorganic Nonmetal	5230	IN-W161	Ceramic/Brick Debris	ID 122; 222B	371	2	Firebrick and Ceramic Crucibles
	Inorganic Nonmetal	5200	IN-W230	Inorganic Nonmetal Debris	ID 122	122	2	Firebrick and Ceramic Crucibles
	Inorganic Nonmetal	5220	IN-W240	Glass Debris	ID 118	118	2	Glass
	Inorganic Nonmetal	5220	IN-W243	Glass Debris	ID 218B	440	2	Glass
	Inorganic Nonmetal	8900	IN-W245	Uncategorized Unknown	ID 225B	441	3	Combustibles and Noncombustibles
	Inorganic Nonmetal	8900	IN-W247	Uncategorized Unknown	ID 218A	442	2	Glass
	Inorganic Nonmetal	8900	IN-W249	Uncategorized Unknown		810		
	Inorganic Nonmetal	5250	MD-M001	Asbestos Debris				
	Inorganic Nonmetal	3114	RF-W026	Used Absorbents/TRM	RF 122	375	2	Firebrick and Ceramic Crucibles
	Inorganic Nonmetal	3119	RF-W032	Ground Glass/TRM	RF 118	444	2	Glass
	Inorganic Nonmetal	5122	RF-W052	Glass/TRM	RF 118	440 442 441 856	2	Glass

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Inorganic Nonmetal	5123	RF-W056	Magnesium (Mg) Oxide Crucibles/TRM	RF 118	370 368 655	2	Glass
	Inorganic Nonmetal	5129	RF-W057	Insulation/TRM	RF 122	438	2	Firebrick and Ceramic Crucibles
	Lead/Cadmium Metal Waste	5400	AW-M001	ALHC Upgrade Decon Debris				
	Lead/Cadmium Metal Waste	5311	AW-M002	Lead/Cadmium Metal Waste				
	Lead/Cadmium Metal Waste	---	ET-M001	Hot Laboratory & Pu Facility D&D				
	Lead/Cadmium Metal Waste	5311	RF-W029	Leaded Gloves/TRM	RF 123	339	3	Leaded Rubber
	Lead/Cadmium Metal Waste	5311	RF-W041	Leaded Gloves-Acid Contaminated/TRM		341		
	Lead/Cadmium Metal Waste	---	RL-M019	TRU Mixed Elemental Hazardous Metals with Mercury				
	Lead/Cadmium Metal Waste	---	RL-M020	TRU Mixed Elemental Hazardous Metals without Mercury				
	Lead/Cadmium Metal Waste	3190	AW-W016	Electrorefiner Stripped Cadmium				
	Lead/Cadmium Metal Waste	3150	AW-W022	Electrorefiner Insolubles with Cadmium				

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Lead/Cadmium Metal Waste	---	IN-M004	Electrorefiner Stripped Cadmium				
	Lead/Cadmium Metal Waste	---	IN-M005	Electrorefiner Insolubles with Cadmium				
	Uncategorized Metal	3100	IN-W260A	Inorganic Process Residues		040		
	Uncategorized Metal	5100	IN-W280	Metal Debris		803	1	
	Uncategorized Metal	5100	IN-W287	Metal Debris		101		
	Uncategorized Metal	5100	IN-W294	Metal Debris	ID 217C	481	2	Metal
	Uncategorized Metal	5100	IN-W296	Metal Debris	ID 217C	480	2	Metal
	Uncategorized Metal	5100	IN-W298	Metal Debris	ID 117	320	2	Metal
	Uncategorized Metal	5100	IN-W300	Metal Debris	ID 117	117	2	Metal
	Uncategorized Metal	---	LA-W001	Mixed Metal Scrap and Incidental Combustibles	LA 125A	001	3	
	Uncategorized Metal	---	LA-W005	Noncombustible Scrap	LA 117A; 118A	005 006	2	
	Uncategorized Metal	---	LA-W009	Metal Waste from Gloveboxes and Equipment				
	Uncategorized Metal	---	LL-W018	Combined Metal Scrap and Incidental Combustibles	LL 125	003	3	
	Uncategorized Metal	5112	RF-W011	Metal/TRM	RF 117	480 481	2	Metal
	Uncategorized Metal	5190	RF-W037	Heavy Metal (non-SS)/TRU	RF 117	320	2	Metal

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

Summary Category Group	Waste Matrix Code Group	Waste Matrix Code	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	IDC	Type	Waste Category
Debris Waste—S5000	Uncategorized Metal	---	RL-M001	TRU Mixed Inorganic Debris with Mercury				
	Uncategorized Metal	---	RL-M002	TRU Mixed Inorganic Debris Metals without Mercury				
	Uncategorized Metal	---	RL-M003	TRU Mixed Inorganic Debris Metal with Corrosives				
	Uncategorized Metal	---	RL-M008	TRU Mixed Inorganic Debris Metals without Mercury				
	Uncategorized Metal	---	RL-M021	TRU Mixed Inorganic Debris PCBs with Mercury				
	Uncategorized Metal	6200	AW-W018	Sodium-TRU				
	Uncategorized Metal	6200	AW-W019	Sodium Potassium-(NaK)-TRU				
	Uncategorized Metal	5100	AW-W021	Metal Debris				
	Uncategorized Metal	---	IN-M003	Element Hardware FCF Waste				
	Uncategorized Metal	3100	IN-W260B	Inorganic Process Residues		040		
	Uncategorized Metal	5190	IN-W322	Sample Fuel		154		
	Uncategorized Metal	---	LA-WR01	Mixed Metal Scrap and Incidental Combustibles				
	Uncategorized Metal	---	LA-WR05	Noncombustible Scrap				

TABLE C-1 *(Continued)*
WASTE IDENTIFIERS CROSS-CORRELATION

[a] Waste stream unique identifications (ID) are taken from the U.S. Department of Energy (DOE), 1995, "Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report," CAO-94-1005, Rev. 1, U.S. Department of Energy, Albuquerque, New Mexico.

[b] TRUCON = TRUPACT-II Content

TABLE C-2
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	AL-W005	Solidified Aqueous Liquids/Slurries[c]		This waste stream will be generated during the remediation of a glovebox that has been used for plutonium (Pu) and other transuranic research. The glovebox continues to be used for transuranic research. Some of the contents of the glovebox will become mixed transuranic (MTRU) waste. It has not yet been determined what volume will be MTRU and what will be TRU. Isotopes that are known to be in the glovebox are: Pu-239, Pu-240, Pu-242, Np-237, Pa-233, U-235, U-236, and U-238. Concentrations of the TRU components range from 1 part per million (ppm) to 2,300 ppm in various concentrations of nitric acid. Uranium concentrations range from 0.1 ppb to 407,770 ppm. Note: This stream may contain Toxic Substance Control Act (TSCA) waste at unknown levels.	d D004 D005 D006 D007 D008 D010 D011
	Solidified Inorganics	IN-W157	Solidified Process Residues	ID 213	This waste comes from the Rocky Flats Plant (RFP). It contains alcohols and organic acids such as ethylene diamine tetra acetic acid (Versenes) set in portland and magnesia cements.	d D006 D008 F001 F002 F003
	Solidified Inorganics	IN-W166	Solidified Process Residues	ID 114	Solid inorganic process solution waste consists of cemented inorganic particulates of sludge-like (not chemically precipitated) wastes from Pu recovery operations.	D008 F001 F002 F003
	Solidified Inorganics	IN-W177	Solidified Process Residues		This waste comes from Mound Laboratory. It consists of caustic waste and neutralized waste liquids, adsorbed onto a clay called Florco®.	d

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	IN-W179	Solidified Process Residues		This waste comes from Mound Laboratory. The waste consists of shower water, decontamination water, cooling water, and some acids and caustics that have been solidified in portland cement.	d D006 D007 D008 D009 D010 D011 F001 F003 P015
	Solidified Inorganics	IN-W181	Solidified Process Residues	ID 211A	This waste is from RFP. The waste consists of sludge from laundry operations that have been cemented in portland. The cement is described as a poor grade.	d D006 D007 D008 D009 F001 F002 F003 P015
	Solidified Inorganics	IN-W188	Solidified Process Residues	ID 211A	This waste is from RFP. The waste consists of sludge from floor drains in a Pu process facility that have been cemented in portland cement, described as poor grade.	d D006 D007 D008 D009 D022 D028 F001 F002 F003 P015

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	IN-W216	Solidified Process Residues	ID 211A	The waste stream generated at RFP, consists of first- and second-stage sludges. Sludges were combined starting in 1979 to reduce the radiation levels of first stage sludge. Portland cement was added to absorb free liquids.	d D005 D006 D007 D008 D009 D011 D022 D028 F001 F002 F003 P015
	Solidified Inorganics	IN-W220	Solidified Process Residues	ID 111	This waste includes waste generated at Argonne National Laboratory-East (ANL-E) and solid wet sludge from RFP. The ANL-E waste is derived from research activities performed in a laboratory environment. The waste includes concrete and laboratory apparatus. The RFP solid wet sludge is cemented or dewatered sludge precipitated from aqueous waste treatment processes. Soils that are not contaminated with or by chemicals are also included.	d D004 D005 D006 D007 D008 D009 F001 F002 F003 P015
	Solidified Inorganics	IN-W221	Absorbed Aqueous Liquids	ID 113	Solid laboratory waste consists of cemented or absorbed neutralized aqueous laboratory waste.	d F003

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	IN-W222	Solidified Process Residues	ID NYD	This waste stream, generated at RFP, consists of sludge from the incinerator off-gas system, recovery building filter plenums, pumps, etc. Portland cement is added to absorb free liquids. The sludge may contain a limited number of surgical gloves.	d D006 D008 F001 F002 F003
	Solidified Inorganics	IN-W228	Solidified Wastewater Treatment Sludges	ID 211A	This waste stream, generated at RFP, consists of wet sludge from treatment of all other plant radioactive and/or chemical contaminated wastes and further treatment of the first stage effluent. Some pre-1973 wastes may include nonsludge wastes such as electric motors, mercury and lithium batteries, bottles of liquid chemicals, and small amounts of mercury in pint bottles. Portland cement was added to absorb the residual liquids.	d D005 D006 D007 D008 D009 D011 D022 D028 F001 F002 F003 P015
	Solidified Inorganics	IN-W332	Solidified Process Residues		This waste comes from the Battelle Columbus Laboratories. It is a turco soap decontamination solution (used to decontaminate glove boxes from a Pu laboratory) that is solidified in a plaster-of-paris.	e

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	IN-W347	Absorbed Aqueous Liquids		This waste comes from ANL-E. It consists of liquids adjusted to pH 10 using NaOH, which are then absorbed in vermiculite.	e
	Solidified Inorganics	LA-W002	Solidified Aqueous Waste,	LA 111A; 211A	Solidified aqueous waste, cemented sludge.	d
	Solidified Inorganics	LA-W003	Dewatered Sludge.	LA 111B; 211B	Dewatered sludge from Pu recovery operations.	D004
	Solidified Inorganics	LA-W006	Cemented Process Residues	LA 114A	Cemented process residues derived from decontamination activities.	D007
	Solidified Inorganics	LL-W019	Solidified Waste	LL 111	50 to 90% of this waste matrix consists of liquids solidified in 1- to 5-gallon (gal) plastic containers using portland cement or Aquaset® for the water-based liquids and Envirostone® or Petroset® for the oil-based liquids. The remainder consists of glovebox waste.	D040 F002
	Solidified Inorganics	MD-W002	Absorbed Aqueous Liquids[c]		TRU waste from PP-113, R-140, R-149. Note: This stream may contain TSCA waste at unknown levels.	e
	Solidified Inorganics	OR-W042	Inactive Storage Tank Contents—MTRU Sludge[c]		The waste stream is comprised of MTRU sludge that has settled and separated from wastewater that has been stored in large underground storage tanks. The waste is a product of past operations at Oak Ridge National Laboratories (ORNL) involving various nuclear research and radioisotope fabrication processes. Note: This stream may contain TSCA waste at unknown levels.	D006 D007 D008 D009
	Solidified Inorganics	PA-W014	Solidified TRU Waste Liquids		Aqueous Slurries—Basic. This stream is generated from the shutdown of the neptunium/technetium recovery system.	d

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	PA-W015	TRU Solid		Other inorganic sludges generated from the shutdown of the neptunium/technetium recovery system	D007
	Solidified Inorganics	PA-W015A	TRU and Technetium Waste		Other wastewaters. This stream is generated from the shutdown of the neptunium/technetium recovery system.	e
	Solidified Inorganics	RF-M001	Solidified Process/TRM	RF 114	This waste stream represents the solidified final form of all particulate and sludge-type materials. Particulates and sludge-type materials are immobilized with portland cement. The cemented wastes are cast into 1-gal molds and allowed to cure prior to packaging. This is the final waste form for Firebrick, Pulverized or Fines/TRM, Incinerator Ash/TRM, Particulate Sludge/TRM, and Sand, Slag, and Crucible/TRM.	d D004 D005 D006 D007 D008 D009 D010 D011 D018 D019 D035 D040 F001 F002 F003 F005

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	RF-W010	Solidified Aqueous Sludge/ TRM	RF 111	This waste stream consists of aqueous sludge from wastewater treatment mixed with 30% portland cement. The waste is generated as a result of process wastewater treatment in Building 374 and 774. Aqueous sludge is produced by vacuum filtration of precipitated solids from pretreated aqueous waste slurry. Untrapped solids are skimmed off the surface of the filter medium of the rotating drum as wet sludge. The precipitated solids are chiefly hydroxides with pH of 10 to 12. The final waste form is obtained by mixing the wet sludge with approximately 30% portland cement. RFP has several drums of aqueous sludge that were returned by Idaho National Engineering Laboratory (INEL). These old drums were packaged by alternating the layers of cement and wet sludge or by adding cement to the top and bottom of a drum containing wet sludge.	D006 D008 F001 F002 F005
	Solidified Inorganics	RF-W038	Solidified Laboratory Waste/TRM	RF 113	This waste stream is liquid waste solidified with portland cement. This waste consists of waste liquids from the analytical laboratories, research and development laboratories, and maintenance shops that are packaged and sent to Building 774 for immobilization with portland cement and absorbent cement. These are wastes which are incompatible with the process collection system and the liquid waste treatment plant. Acidic wastes are neutralized before immobilization. Immobilization is done in 55-gal drums. Approximately 21 gal of waste are added to each drum prior to storage.	D007

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	RF-W040	Incinerator Ash/TRM		This waste stream was previously named "fluidized bed incinerator ash (TRU)-mixed." Ash is generated from operation of a fluidized bed incinerator in Building 776 or an incinerator in RFP Building 771. The incinerator was used to burn office trash, combustible waste generated in process areas, combustible oils from refrigeration units, diesel fuel, and crank case oils. The oil had been accumulated as a low-level mixed waste. Fluid bed incinerator ash was packaged in 55-gal drums lined with a rigid polyethylene liner and one bag liner. It is a portion of the waste stream entitled "fluidized bed incinerator ash/LLW mixed" in the inventory report. The ash normally assays as low-level waste (LLW) but this portion was found to be TRU.	D004 D005 D006 D007 D008 D009 D010 D011 F001 F002 F005
	Solidified Inorganics	RF-W059	Sand, Slag, and Crucible/ TRM		This waste includes unpulverized slag, unpulverized sand and crucible, unpulverized sand, slag and crucible, sand slag and crucible heel, sand from button breakout, pulverized sand slag and crucible, and pulverized slag and crucible. This waste is generated during the reduction of Pu tetrafluoride to Pu metal. Its composition includes magnesium oxide sand, crucible, calcium metal, and stainless steel (SS).	d D007
	Solidified Inorganics	RF-W063	Miscellaneous TRM		As result of the shutdown of Pu operations at RFP in November 1989, several hundred plastic bottles and several tanks of process liquids remained in storage in Buildings 371, 559, 771, and 779.	d D007
	Solidified Inorganics	RF-W065	Calcium Metal/TRM		This material is elemental calcium used in Pu reduction operations. Calcium metal pellets are mixed with Pu tetrafluoride during the reduction process as a pyrotechnic initiator.	d

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	RF-W068	Particulate Sludge/TRM		This waste stream was previously named "Particulate-Sludge/TRU Mixed (2)." This waste was generated from Pu recovery operations in RFP Building 771. The waste consists of incineration sludge, miscellaneous sludge, sludge from size reduction area, grit, and cemented miscellaneous sludge. Spent ion exchange resin waste is not included in this data. The waste is packaged in 55-gal drums with multiple bag liners. This waste consists of a variety of organically contaminated sludges with particulate fines of heavy metals that are TRU contaminated.	d D006 D007 D008 F001 F002 F005
	Solidified Inorganics	RF-W076	Process Residues/TRM		This waste stream was previously named "Particulate-Sludge/TRU Mixed (2)." This waste was generated from Pu recovery operations in RFP Building 771. The waste consists of low-purity oxide heel, incineration sludge, miscellaneous sludge, sludge from size reduction area, grit, soot, and soot heel. The waste is packaged in 55-gal drums with multiple bag liners.	d D006 D007 D008 F001 F002 F005
	Solidified Inorganics	RL-M005	TRU Mixed Homogeneous Solids with Mercury[c]		This waste stream consists primarily of homogeneous solids. Some of the containers contain organic debris (plastic, cellulosics). Note: This stream may contain TSCA waste at unknown levels.	d D009
	Solidified Inorganics	RL-M032	TRU Mixed Inorganic Homogeneous Solids		This waste stream consists primarily of inorganic homogeneous solids (absorbents).	d D007 F003
	Solidified Inorganics	SR-W053	Ash		Ash from the RFP incinerator was sent to the Savannah River Site (SRS) for Pu recovery research purposes. It is stored in a satellite area in 235-F. The sample material was sent to SRS to investigate possible flow sheets for the recovery of Pu. The ash was classified as waste by the Colorado Court System, and the flow-sheet experiments were cancelled.	D004 D005 D006 D007 D008 D009 D010 D011 F001 F002 F005

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Organics	IN-W167	Solidified Process Residues	ID 112	TRU solid organic waste consisting of cemented or absorbed organic liquids from production or laboratory processes.	D022 F001 F003
	Solidified Organics	IN-W174	Absorbed Aqueous Liquids		This waste comes from Mound Laboratory. It consists of acid liquids, mainly nitric, absorbed onto a clay called Florco®.	d
	Solidified Organics	IN-W309	Organic Setups[c]	ID 212	This waste stream contains liquid organic wastes generated at RFP. About 47% of the organic waste stream is lathe coolant, which is 60% Texaco Regal oil and 40% carbon tetrachloride. About 10% of the organic waste stream is trichloroethane. The remainder is other organic wastes. These liquid wastes were mixed with calcium silicate to form a grease or paste-like material. Note: This stream may contain TSCA waste at unknown levels.	D005 D011 F001 F002 F004 P015
	Solidified Organics	RF-W013	Solidified Organics/TRM	RF 112	This waste stream includes waste TRU organic fluids that are transferred to RFP Building 774 for cementation from Buildings 707, 776, and 777. The liquids are mixed with gypsum cement within 55-gal drums. The drum is lined with one or two bag liners with a rigid polyethylene liner. This waste stream includes cemented solids and organic sludges/particulates.	F001 F002
	Solidified Organics	RF-W069	Organic Resins/TRM	RF 126	This waste stream was previously named "Particulate-Sludge/TRU Mixed (2)." This waste was generated from Pu recovery operations in Building 771. It consists of unleached resin and leached resin. The waste is packaged in 5-gal drums with multiple bag liners. Final waste form for this waste stream is cemented resin.	d D006 D007 D008 F001 F002 F005
	Solidified Organics	RL-M017	TRU Mixed Organic Labpacks		This waste stream consists primarily of organic labpacks. Some of the containers contain inorganic debris (metals), organic debris (plastic, cellulosics).	d F003
	Solidified Organics	RL-M018	TRU Mixed Organic Labpacks (State only)		This waste stream consists primarily of organic labpacks. Some of the containers contain organic debris (plastic, cellulosics).	e

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[c]	EPA Code
Homogeneous Solids—S3000	Solidified Organics	RL-M024	TRU Mixed Organic Labpacks with polychlorinated biphenyls (PCB)[e]		This waste stream consists primarily of organic labpacks. Some of the containers contain organic debris (plastic, rubber, cellulosics), and PCBs.	d
	Solidified Organics	SR-W006	Organic TRU		Laboratory waste from Pu extractions generated in the Savannah River Technology Center (SRTC) 773-A Facility. Homogeneous, liquid, flammable, xylene-based chelating agent. TTA - Thenoyl trifluoroacetone.	d
	Salt Waste	IN-W311	Salt Waste		This waste was generated at the RFP.	D028 F001
	Salt Waste	IN-W312	Salt Waste	ID 124	Pyrochemical salt consists of used chloride salts from pyrochemical processes such as electrorefining, molten salt extraction or direct oxide reduction.	d
	Salt Waste	IN-W314	Salt Waste		This waste, generated at the RFP, consists of chunks of salt and ceramic.	F001
	Salt Waste	RF-W058	Miscellaneous Pu Recovery By-products/TRM	RF 124	This waste is generated during Pu recovery operations such as direct oxide reduction molten salt extraction, electrorefining, and salt scrub. Its composition includes mixed salts, a probable presence of magnesium, sodium and potassium metals and chromium. This waste consists of reactive molten and electrorefining (ER) salt residues from Pu purification and direct oxide reduction.	d D007

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Soils/Gravel—S4000	Soils	IN-W263	Contaminated Soils/Debris		This waste, generated at Mound Laboratory, consists of soils, including small rocks and pebbles, generated from cleanup of a leak. All soil waste was dry when packaged. A few waste boxes also include picks, shovels, metal cans, rubber gloves, booties, respirators, plastic, and possibly an air hammer and chisel.	d D006 D007 D008 D009 D010 D011
	Soils	RL-M007	TRU Mixed Soils without Mercury		This waste stream consist primarily of soils. Some of the containers contain organic debris (rubber, cellulosics, plastic) and inorganic debris (metal).	D007 D010
Debris Waste - S5000	Combustible	IN-W198	Plastic/Rubber Debris	ID 216C	The waste stream is from the RFP and consists of various types of plastics such as polyethylene (PE), polyvinyl chloride (PVC), teflon (TFE), and nonleaded rubber items. The waste may be bags, vials, bottles, sheeting, and surgical gloves. Some other combustible wastes such as respirator facemasks and paper may be included. Some small amounts of noncombustible wastes may also be present.	D008 D022 D029 F001 F002 F003 F005
	Combustible	IN-W202	Wood Debris	ID 216A	This waste stream is from the RFP and primarily consists of wood in the form of lumber, plywood, filter frames, and possibly ladders. Some of the items such as plastic sheeting, Kimwipes®, and other combustibles are also present. Plastic sheeting may have some paint coatings. Limited noncombustibles such as nails and sheetrock may also be included.	D008 F001 F002 F003
	Combustible	IN-W205	Combustible Debris	ID 216B	This waste stream from the RFP primarily consists of line- and nonline-generated combustible materials such as plastics, paper, empty PE bottles, booties, paper, plastic sheeting, and surgical gloves. The waste may be dry or damp. Limited amounts of noncombustibles may also be present.	D008 F001 F002 F003
	Combustible	IN-W250	Leaded Gloves/Aprons Debris	ID 123	Discarded leaded glovebox gloves and leaded aprons.	D008

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Combustible	IN-W252	Leaded Gloves/Aprons Debris	ID 123; 223A	This waste comes from RFP. It consists of leaded rubber gloves and aprons. A limited amount of unleaded gloves, lead bricks, and lead sheeting may also be present.	D008 D022 D028 D029 F001 F002 F003 F005
	Combustible	IN-W254	Leaded Gloves/Aprons Debris	ID 223A	This waste comes from RFP. It consists of leaded rubber gloves and aprons. A limited amount of unleaded gloves, lead bricks, and lead sheeting may also be present.	D008 F001 F002
	Combustible	IN-W256	Leaded Gloves/Aprons Debris		This waste stream is generated at the Mound Laboratory. The waste consists of neoprene dry box (glovebox) gloves, neoprene, O-rings, and lead-lined gloves.	D008
	Combustible	IN-W325	Unknown Solids[e]		This waste stream was generated at Mound Laboratory and consists of classified parts.	e
	Combustible	IN-W327	Combustible Debris		This waste stream is from Mound Laboratory and consists of nonline generated combustible wastes such as plastic sheeting, paper, reagents, gloves (rubber and cloth), plastic bottles, wood, paper suits, and shoe covers. About 75% of the waste is compacted. The waste may be either dry or damp.	e
	Combustible	IN-W330	Plastic/Rubber Debris		This waste stream, generated at Mound Laboratory, consists of various types of plastics (PVC, PE, Tygon®, etc.) in the form of tubing, piping, sample vials, gaskets, manipulator boots, etc. Limited amounts of other combustible wastes may also be included. One drum contains liquid mercury. The wastes are primarily from decommissioning and decontamination (D&D) activities at the Pu processing and research buildings. Limited amounts of waste may be damp.	e

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Combustible	IN-W336	Combustible Debris		This waste stream, generated at Battelle Columbus Laboratories, contains such combustible items as wood, plastic suits, nylon reinforced plastic tent structures, shoe covers, rubber gloves, and air hose. The waste is from decontamination and deactivation of the Pu laboratory.	e
	Combustible	LA-W004	Combustible Waste	LA 116A	Combustible waste - paper, rags, plastic, rubber, etc.	D005
	Combustible	LL-M001	Research and Development Glovebox Waste	LL 116	The waste consists mostly of untreated dry solids such as tissues, paper, assorted plastics, glassware, ceramics, and metals. Portland cement or Aquaset® is used to solidify small amounts of water-based liquids; Envirostone® or Petroset® is used to solidify small amounts of solvents and oil-based liquids. The composition varies considerably, but it is predominantly organics (> 90% by weight).	d D006 D008 D009 D040
	Combustible	RL-M009	TRU Mixed Organic Debris with Corrosives		This waste stream consists primarily of organic debris. Some of the containers contain inorganic debris (metals) and soils.	d
	Combustible	RL-M010	TRU Mixed Organic Debris with Mercury		This waste stream consists primarily of organic debris. Some of the containers contain inorganic debris (metals, including mercury) and soils.	d D006 D009
	Combustible	RL-M011	TRU Mixed Organic Debris without Mercury		This waste stream consists primarily of organic debris. Some of the containers contain inorganic debris (metals) and soils.	d D007 D008
	Combustible	RL-M012	TRU Mixed Organic Debris/ Contaminated without Organics		This waste stream consists primarily of organic debris. Some of the containers contain inorganic debris (metals) and soils.	D019

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
	Combustible	RL-M013	TRU Mixed Organic Debris/ Contaminated with Organics		This waste stream consists primarily of organic debris. Some of the containers with organics contain inorganic debris (metals) and soils.	D019 F001 F002 F003 F004 F005
Debris Waste - S5000	Combustible	RL-M014	TRU Mixed Leaded Gloves/ Aprons with Mercury		This waste stream consists primarily of leaded gloves/aprons. Some of the containers contain inorganic debris (metals, including mercury), organic debris (plastic, rubber, cellulosics), and soils.	d D005 D006 D007 D008 D009
	Combustible	RL-M015	TRU Mixed Leaded Gloves/ Aprons Metals without Mercury		This waste stream consists primarily of leaded gloves/aprons. Some of containers contain inorganic debris metals, without mercury), organic debris plastic, rubber, cellulosics), and soils.	d D005 D006 D007 D008
	Combustible	RL-M016	TRU Mixed Leaded Gloves/ Aprons Metals/Organics without Mercury		This waste stream consists primarily of leaded gloves/aprons. Some of the containers contain inorganic debris metals), organic debris (plastic, rubber, cellulosics), and soils.	D007 D008 D019
	Combustible	RL-M022	TRU Mixed Leaded Gloves/ Aprons PCBs with Mercury[c]		This waste stream consists primarily of leaded gloves/aprons. Some of the containers contain inorganic debris (metal), organic debris (plastic) and hazardous constituents including PCBs and mercury. Note: This waste stream may contain TSCA waste at unknown levels.	D006 D008 D009
	Combustible	RL-M023	TRU Mixed Resource Conservation and Recovery Act (RCRA) Organic Debris with PCBs[c]		This waste stream consists primarily of organic debris contaminated with PCBs. Note: This waste may contain TSCA waste at unknown levels.	d

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
	Filter	IN-W214	Composite Filters		This waste stream, generated at the Mound Laboratory, consists primarily of spun glass filters and fiberglass glovebox prefilters. The waste may include limited amounts of other noncombustibles.	d D009
Debris Waste - S5000	Filter	RF-W066	Filters & Media/TRM	RF 119	This waste stream was previously named "Filter Waste/TRU." Filter waste is generated from process operations throughout the RFP site. This waste consists of Ful-flo filters from the Building 771 incinerator, Ful-flo filters from nonincineration operations, absolute glovebox filters from nonacid contaminated operations, acid contaminated absolute glovebox filters, acid contaminated high-efficiency particulate air (HEPA) filters, nonacid contaminated HEPA filters, plenum prefilters, filter media, and processed filter media. Processed filter media is material which has been treated using portland cement to absorb moisture and neutralize acid contamination. Filter waste is packaged in 55-gal drums and metal standard waste boxes.	d D004 D006 D007 D008 D009 D010 D011 F001 F002 F005
	Filter	RF-W067	Cemented Filters/TRM	RF 119	This waste stream was previously named "Filter Waste/TRU." Filter waste is generated from process operations throughout the RFP site. Processed filter media is material that has been treated using portland cement to absorb moisture and neutralize acid contamination. Filter waste is packaged in 55-gal drums and metal standard waste boxes. Hazardous constituents originate in liquid and gaseous effluents from processing operations.	d D005 D006 D007 D008 D009 F001 F002 F003
	Graphite	IN-W272	Debris Waste	ID 115	Coarse graphite chunks.	F001 F002
	Graphite	IN-W275	Debris Waste		This waste stream, generated at the RFP, is similar to graphite molds. A graphite core is part of the shaped graphite mold to cast Pu metal. The graphite has broken into pieces, and some of the graphite has been scarfed or wire brushed to remove any above-discard deposits of Pu.	F001

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Graphite	IN-W276	Debris Waste	ID 215A	This waste stream, generated at the RFP, consists of graphite molds used in casting Pu metal. The waste may also include small amounts of surgical gloves. The graphite is in the form of broken mold pieces. Some of the graphite has been scarfed or wire-brushed to remove above-discard deposits of Pu.	D022 D028 F001 F002 F003 F005
	Graphite	RF-W060	Coarse Graphite/TRM	RF 115	This waste form includes scarfed graphite chunks and coarse graphite. This waste is a result of broken graphite molds from the classified weapons shape casting process.	D006
	Heterogeneous	IN-W169	Predominantly Combustible Debris	ID 216C	The waste stream is from RFP and primarily consists of line- and nonline-generated dry combustible materials such as paper, rags, plastics, surgical gloves, cloth overalls and booties, cardboard, wood, wood filters frames, and laundry lint. Some combustibles may be damp or moist. Limited amounts of noncombustibles such as glass, concrete, cement, lead glovebox gloves, batteries, and metal scrap may also be present.	D008 D022 D029 F001 F002 F003 F005
	Heterogeneous	IN-W170	Predominantly Combustible Debris		This waste is generated at ANL-E. The waste is derived from decontamination and disposal of facilities and ancillary systems (e.g., gloveboxes).	D004 D006 D008 F003
	Heterogeneous	IN-W171	Predominantly Combustible Debris		This waste is generated at ANL-E. The waste is derived from research activities performed in a research environment. The waste includes soft plastics, cardboard, rags, paper, and cloth from various processes. The waste is packaged in 55-gal drums or in standard waste boxes.	D004 D006 D008 F003

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	IN-W172	Predominantly Combustible Debris		This waste stream, generated at Bettis Atomic Power Laboratory, consists primarily of rags, gloves, plastic, paper, carbo-wax, filters, oil-contaminated absorbent (diatomaceous earth), and rubber. The waste stream may also contain noncombustible items.	F001 F002
	Heterogeneous	IN-W186	Predominantly Combustible Debris	ID 116	Combustible waste consists of cellulosic, plastic or cloth waste from various processes.	D008 F001 F002
	Heterogeneous	IN-W189	Predominantly Combustible Debris	ID 221A	This waste, generated at RFP, contains mainly Benelex® which is a dense, laminated, lignocellulose hardboard made from wood chips and particles. Benelex® is generally 2 inches (in.) thick. Some of the Benelex® has lead shielding attached to it. Metal hinges and angle iron strongbacks are also present. Plexiglas™ is the other major constituent in the waste. The Plexiglas™ thickness ranges from 2 to 4 in. Both the Benelex® and the Plexiglas™ are combustible.	D008 F001
	Heterogeneous	IN-W197	Predominantly Combustible Debris	ID 216A	The waste stream is from the RFP and primarily consists of damp or wet line- and nonline-generated dry combustible materials such as paper, rags, plastics, surgical gloves, canvas, cardboard, wood, and rubber. Some combustibles may be damp or moist. Moisture content may range from damp to wet, and may include water, soaps, nitric acid, or caustic solutions. Limited amounts of noncombustibles such as glass, concrete, cement, leaded glovebox gloves, and metal scrap may also be present. These wastes are mostly from decontamination and cleanup work, and may be from any Pu area.	d D008 D022 F001 F002 F003 F005

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	IN-W203	Predominantly Combustible Debris		This waste stream, generated at Mound Laboratory, includes two different types waste depending on when the waste was generated. Prior to 1980 waste consisted of glovebox floor sweepings and rust. After 1980, waste may consist of large combustible waste such as plastic tanks, Plexiglas™ shielding and windows, wood, and fiberglass conveyor glovebox sections. Limited amounts of small combustibles such as shoe covers and surgical gloves are also included.	D009
	Heterogeneous	IN-W204	Predominately Combustible Debris		This waste stream is smaller combustible items from Mound Laboratory that fit into drums.	D008 D009
	Heterogeneous	IN-W225	Predominantly Combustible Debris	ID 221A	The waste, generated at RFP, contains mainly Benelex® which is a dense, laminated, lignocellulose hardboard made from wood chips and particles. Benelex® is generally 2 in. thick. Some of the Benelex® has lead shielding attached to it. Metal hinges, and angle iron strongbacks are also present. Plexiglas™ is the other major constituent in the waste. The Plexiglas™ thickness ranges from 2 to 4 in. Both the Benelex® and the Plexiglas™ are combustible.	D008 F001
	Heterogeneous	IN-W259	Heterogeneous Debris		This waste stream, generated at ANL-E, contains alpha hot cell waste. Noncombustible and combustible waste are segregated. Combustible wastes include: paper, plastic and PVC containers, rubber O-rings and gloves, rags, and Q-tips. Noncombustible wastes include: laboratory equipment, tools, fixtures, glassware, pipe, tubing, fitting, fasteners, firebrick, ferrous and nonferrous metal scraps and parts, and small electric motors. Sodium in the waste is reacted with ethyl alcohol, mixed with pelletized clay, and dried. Nitrates and oxidizing agents are neutralized or reduced, mixed with pelletized clay.	D008

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	IN-W265	Predominately Inorganic Nonmetal Debris	ID 121	This waste contains blacktop, concrete, reinforced concrete, cinder blocks, bricks, dirt and sand. Limited amounts of waste may be damp. A limited amount may contain combustibles such as coveralls and gloves. The waste is generated from cleanup of spills and leaks, process changes, maintenance, and D&D operations. Portland cement is added to containers that contain wet or damp waste.	F001 F002 F003 F004
	Heterogeneous	IN-W269A	Debris Waste		This waste stream, generated at INEL, contains laboratory waste from ANL-W including fluxwire, fission counters, analytical samples dissolved and absorbed on Oil-Dri, glassware, vials, miscellaneous waste from gloveboxes, dissolved pellets absorbed on Oil-Dri, enriched and normal U308 pellets, aluminum foil and capsules, TREAT® waste capsules, chlorinated ion exchange resins, Pu sources. Laboratory waste includes Kimwipes®, trash, glassware, dissolved samples absorbed in Oil-Dri, analytical samples, gloves, etc.	e
	Heterogeneous	IN-W271	Uncategorized Inorganic Process Residues[e]		This waste stream was generated at Mound Laboratory. The records at Mound Laboratory and at INEL do not agree on the content. The waste most likely is graphite crucibles and electrodes, with some containers of mercury.	D009
	Heterogeneous	IN-W281	Heterogeneous Debris		This waste stream, generated at the Mound Laboratory, consists of large, noncombustible wastes such as tanks (SS and tantalum), piping, ducts, conduit, electric motors, pumps, metallurgical presses, lathes, dissolvers, evaporators, furnaces, ladders, vacuum sweepers, 24- x 24- x 12-in. HEPA filters, fume hoods, gloveboxes, Plexiglas™ glovebox windows, and floor tile. Limited amounts of combustible wastes (plastic tanks, fiberglass gloveboxes, plastic contamination control tents, etc.) are also included.	D005 D006 D007 D008 D009 D010 D011

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	IN-W283	Heterogeneous Debris	ID 225A	This waste stream, generated at the RFP, consists of piping, flanges, valves, tools, equipment, PVC piping, glassware (flasks, broken ion exchange columns, etc.), glass filters, leaded glovebox gloves, paper, and plastics. Wastes from renovations of the americium recovery line were shipped only in 1972 and 1973. Some of the containers are lead-lined.	d D008 F002 F003
	Heterogeneous	IN-W285	Heterogeneous Debris		This waste stream, generated at Battelle Columbus Laboratories, contains noncombustible items such as tools, crucibles, piping, valves, pieces of equipment, lead bricks, Plexiglas™, and filters.	D008
	Heterogeneous	IN-W289	Unknown Solids[e]		This waste is generated at ANL-E and RFP. The waste is derived from decontamination and disposal of facilities and ancillary systems.	D004 D005 D006 D007 D008 D009 F001 F002 P015
	Heterogeneous	IN-W291	Debris Waste		This waste stream, generated at ANL-E, contains combustible and noncombustible items such as paper, rags, rubber gloves, plastic bottles, glassware, small tools, balances, and empty metal cans. The waste is usually separated into combustible and noncombustible streams.	d F003

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	IN-W302	Unknown Solids[a]		This waste stream, generated at Bettis Atomic Power Laboratory, contains noncompressible and noncombustible items such as absolute filters, solidified chemical waste, contaminated metal equipment, furnace brick, and highly contaminated glovebox equipment. Metal scrap could include bars, sheet, fixtures, small equipment tools, etc. made of carbon steel, SS, Inconnel, aluminum, copper, brass and zirconium. Chemical wastes include spent chemical solutions and associated solids from the isotope and isotopic dilution analysis of nuclear fuel specimens. The residues were neutralized before being either mixed with absorbent material solidified.	d F001 F002
	Heterogeneous	IN-W329	Heterogeneous Debris		This waste stream, generated at Mound Laboratory, consists of nonline generated noncombustible wastes such as tools, pipe, equipment, metal, glass, concrete, plaster, bricks, and dirt. Limited amounts of combustible wastes such as paper, rags, etc. are also included.	e
	Heterogeneous	IN-W334	Debris Waste		This waste stream, generated at Battelle Columbus Laboratories, contains a mixture of combustible and noncombustible items in roughly equal proportions. Combustible items include paper and paper products. Noncombustibles are primarily metal and some glass.	e
	Heterogeneous	IN-W345	Debris Waste		This waste stream, generated at INEL, consists of a plastic glovebox, a hydraulic pump containing oil, vacuum pump, centrifuges, tools, and experimental fuel capsules. The presence of hazardous materials is not known, but some absorbed oil is likely.	e

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	IN-W351	Debris Waste		This waste stream, generated at ANL-E, consists of glass bottles used to transport liquid wastes.	e
	Heterogeneous	NT-W001	Heterogeneous Debris, Uncategorized	NT 111; 116; 211;225	This waste stream consists of glovebox parts, laboratory trash, contaminated equipment, and solidified sludges. Real-time radiography has been performed on the waste to verify there are no free liquids present, with the exception of liquid in aerosol cans. Most of the waste is contact handled (CH) TRU waste; one and 3 drums are remote-handled (RH). The waste stream was generated at Lawrence Livermore National Laboratory, Livermore, CA (LLNL) and shipped to the Nevada Test Site (NTS) from 1974 until 1990. The waste was declared as potentially mixed TRU waste by the generator in April 1991.	d D006 D007 D008 D011 F001 F002 F003 P015
	Heterogeneous	OR-W044	CH TRU Heterogeneous Debris[c]	OR 125A; 125B	This waste stream consists of CH TRU waste which is classified as contaminated equipment, decontamination debris or dry solids. The physical form is solid. These wastes do not contain free or containerized liquids. Note: This stream may contain TSCA waste at unknown levels.	D006 D008 D009 D011
	Heterogeneous	OR-W045	CH TRU Uncategorized[c,d]		This waste stream consists of CH TRU waste which is not classified. The physical form is either solid, liquid, mixed (both solid and liquid), or unknown. Note: This stream may contain TSCA waste at unknown levels.	D006 D008 D009 D011
	Heterogeneous	OR-W047	CH TRU Heterogeneous Debris[c]		This waste stream consists of CH TRU waste which is classified as contamination equipment, decontaminated debris, or dry solids. The physical form is solid. Note: This stream may contain TSCA waste at unknown levels.	D006 D008 D009 D011
	Heterogeneous	RF-M002	Supercompacted Combustibles/TRM	RF-116C	This waste consists of cloth and paper products from cleanup of gloveboxes and spills, which has been supercompacted for volume reduction.	F001 F002 F005

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	RF-W008	Soil & Cleanup Debris/TRM	RF 121	This waste stream is construction rubble generated during D&D activities. The waste consists of blacktop/concrete/dirt/sand. The waste is generated from construction/demolition within the Pu process buildings. The waste is usually packed in 55-gal drums with multiple bag liners, a fiberboard liner, and a rigid polyethylene liner. Also, the waste can be packaged in DOT 7A, Type A metal boxes which are lined with a fiberboard and PVC liner. Metals are considered to be potentially present in the rubble from demolition and cleanup activities. Solvents are potentially present from the materials used during decontamination.	D006 D007 D008 F001 F002 F005
	Heterogeneous	RF-W012	Combustibles/TRM	RF 116	The waste consists mainly of cloth and paper products from cleanup of gloveboxes and spills, involving hazardous solvents. The bulk of these wastes are packaged in 55-gal drums with one rigid polyethylene liner and several bag liners. In addition the waste may be repackaged into DOT 7A, Type A metal boxes which are lined with a fiberboard and PVC liner.	F001 F002 F005
	Heterogeneous	RF-W036	Firebrick, Pulverized or Fines/TRM	RF 122	This waste stream was previously named "Firebrick - Pulverized or Fines." This waste is generated from replacement of fire brick in the Pu recovery incinerator in RFP Building 771. The fire brick must be replaced periodically because of the Pu buildup. The fire brick is pulverized to facilitate Pu recovery. Material which assays below the economic discard limit is discarded as pulverized fire brick waste. The waste is packaged in 55-gal drums lined with a rigid polyethylene liner.	D004 D006 D007 D008 F001 F002 F005
	Heterogeneous	RL-M004	TRU Mixed Heterogeneous Debris (State only)		This waste stream consists primarily of heterogeneous debris (filters). Some of the containers contain organic debris (plastic).	e
	Heterogeneous	RL-M006	TRU Mixed Inorganic Homogeneous Solids without Mercury		This waste stream consists primarily of inorganic homogeneous solids. Some of the containers contain organic debris (rubber, cellulosics).	d D019 F003

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	RL-M031	TRU Mixed Heterogeneous Debris (State only)		This waste stream consists primarily of heterogeneous debris. The waste is hazardous by state regulation.	e
	Heterogeneous	SA-W134	TRU Waste at Hot Cell Facility		Predominantly metal laboratory trash including saw blades, copper and brass fittings. Balance of waste is combustible laboratory trash including rubber gloves and Tygon® tubing. There are no liquids.	e
	Heterogeneous	SR-W026	Heterogeneous Debris		200 Areas (F and H Separations Facilities). This waste is primarily solids consisting of mainly bootles, laboratory coats, floor sweepings, rags, labware, and other job control wastes. This waste is generated primarily through separation activities in the course of Pu production, includes small amounts of TRU waste from on-site laboratories.	d D004 D006 D007 D008 D009 D011 D018 D019 D022 D023 D024 D025 D026 P015

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	SR-W027	Heterogeneous Debris		200 Areas (F and H Separations Facilities). This waste is generated primarily through separation activities in the course of Pu production and includes small amounts of TRU waste from on-site laboratories. This waste stream is primarily solids consisting of booties, laboratory coats, floor sweepings, labware, rags, and other job control waste.	d D004 D006 D007 D008 D009 D011 D018 D019 D022 D023 D024 D025 D026 F001 F002 F003 F005 P015
	Inorganic Nonmetal	IN-W161	Ceramic/Brick Debris	ID 122; 222B	This waste contains whole and broken pieces of construction bricks, cinderblocks, and firebrick. Waste generated in the 1971 to 1973 period includes firebrick from the Pu recovery incinerator and related refractory development and from four boilers; cinderblocks and other brick from routine maintenance and from following the RFP fire. Waste generated since 1973 is mostly firebrick from Pu recovery operations. The firebrick generated since 1973 is a high-alumina, high-strength brick manufactured by Plibrico (Plicast 40®). Some of the incinerator firebrick is scarfed to remove surface contamination and then leached with nitric acid to recover Pu.	F001 F002

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Inorganic Nonmetal	IN-W230	Inorganic Nonmetal Debris	ID 122	Insulation, firebrick, and concrete.	F001 F002
	Inorganic Nonmetal	IN-W240	Glass Debris	ID 118	Glass waste consists of discarded labware, windows, containers or raschig rings from various processes.	D008 D009 F001
	Inorganic Nonmetal	IN-W243	Glass Debris	ID 218B	This waste stream, generated at the RFP, consists of glass sample vials, bottles, lead-taped sample vials, ion exchange columns, dissolver pyrex laboratory glassware such as Pyrex™ flasks and beakers, glovebox windows (glass, Plexiglas™, leaded glass), and crushed and ground glass. The waste includes limited amounts of other noncombustibles such as metals, and limited amounts of combustible wastes. No sludges should be present although some glass vials may contain limited amounts of residual liquids.	D008 D029 F001 F002 F003 F005
	Inorganic Nonmetal	IN-W245	Uncategorized Unknown[e]	ID 225B	This waste stream, generated at the RFP, consists of boronated glass rings used to minimize neutron multiplication in liquid storage tanks. Unleached rashig rings was used from 1971–79 as a separate stream and then combined with leached rashig rings. The rings are about 1.75 in. high and 1.5 in. in diameter, with a 0.25 in. wall thickness. The rings are heat and chemical resistant borosilicate glass. Some of the rings, which had above-discard amounts of Pu, were leached with nitric acid to recover the Pu and then rinsed with water, and dried. Some of the rings may be contaminated with small amounts of oil.	d D008 F001

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[c]	EPA Code
Debris Waste - S5000	Inorganic Nonmetal	IN-W247	Uncategorized Unknown[e]	ID 218A	This waste stream, generated at the RFP, consists of boronated glass rings used to minimize neutron multiplication in liquid storage tanks. Unleached rashig rings was used from 1971–79 as a separate stream and then combined leached rashig rings. The rings are about 1.75 in. high and 1.5 in. in diameter, with a 0.25 in. wall thickness. The rings are heat and chemical resistant borosilicate glass. Some of the rings, which had above-discard amounts of Pu, were leached with nitric acid to recover the Pu and then rinsed with water, and dried. Some of the rings may be contaminated with small amounts of oil.	d D008 D028 D029 F001 F002 F003 F005
	Inorganic Nonmetal	IN-W249	Uncategorized Unknown[e]		This waste stream, generated at Mound Laboratory, consists mostly of whole and broken glassware and glass sample vials. The majority of the glass is Pyrex™. Limited amounts of other noncombustibles may be present.	D009
	Inorganic Nonmetal	MD-M001	Asbestos Debris[e]		(24) Asbestos filters, (1) glass filter. Note: This waste may contain TSCA waste at unknown levels.	e
	Inorganic Nonmetal	RF-W026	Used Absorbents/TRM	RF 122	This waste stream was previously named "Spent Absorbent/TRU (Oil Dry)". This waste stream was not specifically identified in the Storage and Inventory Report prepared by RFP in fulfillment of Federal Facility Compliance Act requirements. This waste is the TRU fraction of the waste titled "Oil Dry/LLW Mixed" in the Inventory Report. Normally it is low-level waste (LLW) but occasionally some assays as TRU. Absorbents, usually vermiculite materials, which are used in the absorption, or absorption of any liquids as needed. One of the most commonly used absorbents is Oil Dri®. Spent absorbents are assumed to be radiologically contaminated. The waste is packaged in 55-gal drums lined with two polyethylene bags.	F001

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Inorganic Nonmetal	RF-W032	Ground Glass/TRM	RF 118	This waste stream is crushed fluorescent lights with some leached glass. Glass waste consists of crushed fluorescent lamps that come from the fluorescent lights used throughout the Pu and uranium processing areas, as well as ground leaded glass. Small amounts of leached glass may be mixed with the crushed fluorescent lamp waste. This glass waste is packaged in 55-gal drums that are lined with one fiberboard liner and two polyethylene bags.	D008
	Inorganic Nonmetal	RF-W052	Glass/TRM	RF 118	This waste stream is glass from D&D, labs, etc. This waste stream is made up of glass from analytical laboratories, recovery processes, ceramics, and glovebox windows. This waste stream was previously named "glass." This waste form has been characterized by toxicity characteristic leaching procedure (TCLP) analytical data and process knowledge. Ground glass is characterized by process knowledged and limited analytical data.	D005 D008 F001 F002
	Inorganic Nonmetal	RF-W056	Magnesium (Mg) Oxide Crucibles/TRM	RF 118	This waste stream includes any type or size of ceramic crucibles or liners including LECO crucibles. This waste consists of magnesium oxide crucible, magnesium oxide crucible fragments with reactive salts of calcium, magnesium, sodium, and/or potassium adhering to the surface and containing Pu residue. This waste stream was generated during Pu recovery using pyrochemical and electro-chemical processing. Waste is placed in 4-liter poly bottles and double plastic bagged or placed in 1 gal or 1 quart paint cans, then placed into 55-gal drums.	d D006
	Inorganic Nonmetal	RF-W057	Insulation/TRM	RF 122	This waste stream is contaminated insulation. The insulation is generated from construction and demolition on site. This waste was characterized using process knowledge for manifesting purposes in 1987 and 1989 to determine if any reportable quantities per 49 CFR 172 were present. These are spent solvents from degreasing of Pu or other metals.	F001 F002

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Lead/Cadmium Metal Waste	AW-M001	ALHC Upgrade Decon Debris		Waste packaged for WIPP containing: radioactive cadmium debris from CH-ANL-242T, solidified to meet WIPP-WAC requirement for particulate immobilization, and bags of lead-lined gloves were placed in the solidified drums to fill the void space.	D006 D007 D008
	Lead/Cadmium Metal Waste	AW-M002	Lead/Cadmium Metal Waste		This waste is typically lead lined gloves replaced at the Experimental Fuel Laboratory glovebox.	D008
	Lead/Cadmium Metal Waste	ET-M001	Hot Laboratory & Pu Facility D&D		1 lead shielding brick plus additional hot material.	D008
	Lead/Cadmium Metal Waste	RF-W029	Leaded Gloves/TRM	RF 123	This waste stream consists of leaded rubber gloves that are used on gloveboxes to reduce radiation exposure to personnel. Gloves that are damaged or that do not meet safety inspection requirements are replaced with new gloves and discarded as waste. The gloves are packaged in 55-gal drums lined with a rigid polyethylene liner and one bag liner.	D008
	Lead/Cadmium Metal Waste	RF-W041	Leaded Gloves-Acid Contaminated/TRM		This waste stream consists of leaded rubber gloves used in the glovebox system for Pu recovery operations in RFP Buildings 771 and 371. These gloves are contaminated with nitric acid and other acids when replaced and discarded as waste. The gloves are packaged in 55-gal drums lined with a rigid polyethylene liner and a bag liner. Leaded gloves as waste are currently characterized by process knowledge and sample analysis using the Extraction Procedure (EP) Toxicity Test.	D008

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[c]	EPA Code
Debris Waste - S5000	Lead/Cadmium Metal Waste	RL-M019	TRU Mixed Elemental Hazardous Metals with Mercury		This waste stream consists primarily of elemental hazardous metals. Some of the containers contain inorganic debris (metals, including mercury), organic debris (plastic, rubber, cellulosics), and soils.	d D005 D006 D007 D008 D009
	Lead/Cadmium Metal Waste	RL-M020	TRU Mixed Elemental Hazardous Metals without Mercury		This waste stream consists primarily of elemental hazardous metals. Some of the containers contain inorganic debris (metals without mercury), organic debris (plastic, rubber, cellulosics), and soils.	D007 D008
	Uncategorized Metal	IN-W260A	Inorganic Process Residues		This waste stream, generated at Bettis Atomic Power Laboratory, contains solid binary scrap as powder, pellets, or rods. The material is made of ceramic based UO_2 and ThO_2. Some kilorods or fuel rods constructed of fuel pellets within hollow zirconium tubes are also included.	e
	Uncategorized Metal	IN-W280	Metal Debris		This waste comes from Mound Laboratory. It consists of SS, carbon steel, and small amounts of aluminum-metal wastes in the form of valves, piping, wrenches, nuts, bolts, SS tubing, spatulas, pans, hotplates, ringstands, etc. Limited amounts of combustible and noncombustible waste also present from. Most of the waste is metal waste that is primarily from D&D operations. Some of the metals were leached with nitric acid, ultrasonically cleaned and dried to remove above-discard amounts of Pu.	D009
	Uncategorized Metal	IN-W287	Metal Debris		This waste stream, generated at ANL-E, contains glovebox sections and associated equipment from decontamination and decommissioning operations. The waste is predominantly noncombustible.	D008

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Uncategorized Metal	IN-W294	Metal Debris	ID 217C	This waste comes from RFP. It consists of the smaller pieces of the waste that have been washed with water to recover Pu.	D008 D022 F001 F002 F005
	Uncategorized Metal	IN-W296	Metal Debris	ID 217C	The waste comes from RFP. It consists of nonline- and line-generated wastes. The waste may be in the form of gloveboxes, glovebox windows, furnaces, lathes, drill presses, ducting, piping, angle iron, tanks, downdraft tables, part carriers, respirator filters, ultrasonic cleaners, control panels, electronic instrumentation, vacuum sweepers, pumps, motors, railing stairs, metal racks and trays, hotplates, empty metal produce and paint cans, carts, power tools (saws, drills, etc.), hand tools (wrenches, hammers, saws, chisels, gauges, etc.), chairs, desks, tables, typewriters, filing cabinets, crushed 55-gal drums, etc. The waste may also include limited amounts of combustible waste.	D008 D028 D029 F001 F002 F003 F005
	Uncategorized Metal	IN-W298	Metal Debris	ID 117	This waste comes from the RFP. It consists of used tantalum crucibles, funnels, funnel inserts, and pour rods.	D008 F001 F002
	Uncategorized Metal	IN-W300	Metal Debris	ID 117	Discarded metal.	D008 F001 F002 P015
	Uncategorized Metal	LA-W001	Mixed Metal Scrap and Incidental Combustibles	LA 125A	Mixed metal scrap and incidental combustibles.	d

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[c]	EPA Code
Debris Waste - S5000	Uncategorized Metal	LA-W005	Noncombustible Scrap	LA 117A; 118A	Noncombustible scrap—small tools, cans, small equipment items, broken glass, etc.	D006
	Uncategorized Metal	LA-W009	Metal Waste from Gloveboxes and Equipment		Metal waste from gloveboxes and equipment	F001 F002 F005
	Uncategorized Metal	LL-W018	Combined Metal Scrap & Incidental Combustibles	LL 125	The waste consists mostly of metal scrap such as decommissioned gloveboxes, hoods, and other large equipment as well as laboratory trash. Typically, it will contain metal components, glassware, ceramics, plastics, paper, and wood. It will be mostly inorganic material but can vary widely.	D008
	Uncategorized Metal	RF-W011	Metal/TRM	RF 117	This waste includes items such as gloveboxes and machinery and empty containers. Items that are difficult to reduce to a size that would fit in a 55-gal drum are placed in DOT 7A, Type A metal boxes. These drums are lined with a rigid polyethylene liner, fiberboard liner and several bag liners. The boxes are lined with a fiberboard and PVC liner.	D008 F001 F002
	Uncategorized Metal	RF-W037	Heavy Metal (non-SS)/TRU	RF 117	Heavy (non-SS) metal waste is generated at various locations throughout the RFP. Heavy scrap metal is defined at RFP as metal elements above copper (Cu) on the periodic chart. Typically, these scrap metals consist of crucibles, funnels, rods and fixturing from several processes and production operations. Tantalum, tungsten, and platinum are examples of scrap metals at the RFP.	D008
	Uncategorized Metal	RL-M001	TRU Mixed Inorganic Debris with Mercury		This waste stream consists primarily of with mercury inorganic debris. Some of the containers contain organic debris (plastic and cellulosics).	D006 D009
	Uncategorized Metal	RL-M002	TRU Mixed Inorganic Debris Metals without Mercury		This waste stream consists primarily of inorganic metal debris. Some of the containers contain organic debris (plastic, rubber, cellulosics).	D008

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
CONTACT-HANDLED TRANSURANIC WASTE

CH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste—S5000	Uncategorized Metal	RL-M003	TRU Mixed Inorganic Debris Metal with Corrosives		This waste stream consists primarily of inorganic debris. Some of the containers contain organic debris (plastic, cellulosics, rubber).	d
	Uncategorized Metal	RL-M008	TRU Mixed Inorganic Debris Metals without Mercury		This waste stream consist primarily of inorganic debris metals. Some of the containers contain organic debris (plastic, rubber, cellulosics), and soils.	d D006 D007 D008
	Uncategorized Metal	RL-M021	TRU Mixed Inorganic Debris PCBs with Mercury[c]		This waste stream consists primarily of inorganic debris. Some of the containers contain organic debris (plastic, cellulosics). The hazardous constituents include PCBs and mercury. Note: This waste may contain TSCA waste at unknown levels.	D006 D008 D009

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
REMOTE-HANDLED TRANSURANIC WASTE

RH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Homogeneous Solids—S3000	Solidified Inorganics	IN-W146	Uncategorized Inorganic Sludges		Ten drums of TRU mixed waste sludge was generated from cleaning of four catch tanks. Concentrations of radionuclides and hazardous waste vary from drum to drum.	D006 D007 D008 D009 D011
	Solidified Inorganics	OR-W046	Solidified Liquid Low Level Waste Tanks - Sludge[c]		This waste stream is comprised of liquid low-level waste (LLLW) that has been concentrated by evaporation and subsequently stored in large underground storage tanks. The waste is generated as relative dilute low level waste in various nuclear research and radioisotope fabrication processes. These streams are collected centrally and the volumes reduced in an evaporation facility. After the waste has been stored, it separates into phases. The resulting solids (sludge phase) is fairly homogeneous chemically and radiochemically. Because the sludge is a product of solids concentration, it has been classified as a TRU waste. Note: This stream may contain TSCA waste at unknown levels.	D006 D007 D008 D009
	Salt Waste	IN-M001	Electrorefiner Stripped Salts—Barium (Ba) & Cadmium (Cd)		Chloride salts containing residual amounts of Cd and Ba.	e

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
REMOTE-HANDLED TRANSURANIC WASTE

RH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Filter	AW-M003	TRU Waste Used Pre-filters		The waste consists of metal or wood framed pre-filters. Prefilters are 2 x 2 x 0.5 feet (ft). HEPA filters are 2 x 2 x 1 ft. Both types of filters have screen mesh covering high-efficiency filtering media. The concentrations of radioisotopes and RCRA toxic metals vary in each filter. These filters were generated from the decontamination of the analytical hot cell in 1993.	e
	Heterogeneous	AW-W020	TRU-Cd-Hot Cell Waste		This waste stream consists of metallic cadmium, soils, and associated cleanup materials (paper towels and cloth rags). The waste is contaminated with activation and fission products as well as with Pu. This waste stream is generated for Fuel Cycle Facility demonstration support experiments.	D006
	Heterogeneous	IN-M002	TRU-Cd-Hot Cell Waste		Metallic cadmium, salts, and cleanup material such as paper towels and rags.	e
	Heterogeneous	IN-W139	TRU Contaminated Lead Debris		This waste is lead contaminated lead debris from various sources. This debris includes lead pieces, galvanized sheet metal, copper/bronzeware, silicon, impregnated fiberglass, paper, HEPA filters, duct, etc.	D008
	Heterogeneous	IN-W269B	Debris Waste		This waste stream, generated at Idaho National Engineering Laboratory, contains laboratory waste from ANL-W including fluxwire, fission counters, HEDL samples, analytical samples dissolved and absorbed on Oil-Dri, glassware, vials, miscellaneous waste from gloveboxes, dissolved pellets absorbed on Oil-Dri, enriched and normal U-308 pellets, aluminum foil and capsules, TREAT® waste capsules, chlorinated ion exchange resins, Pu sources. Laboratory waste includes Kimwipes®, trash, glassware, dissolved samples absorbed in Oil-Dri, analytical samples, gloves, etc.	e

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
REMOTE-HANDLED TRANSURANIC WASTE

RH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Heterogeneous	IN-W323	Predominantly Combustible Debris		This waste stream was generated at ANL-W and at INEL. Most of the waste is organic and combustible materials including paper, wood, PVC and plastic containers and items, rubber gaskets and gloves, leather, rags, towels, Q-tips, tubing, filter media, abrasive media and metal pieces. Small residuals of moderators and fuel are trapped on the filters. Drums of CH waste are stored at the TRU Storage Area (TSA). Drums of RH waste are stored at the Intermediate Level TRU Storage Facility (ILTSF).	D008
	Heterogeneous	OR-W040	RH TRU Heterogeneous Debris[c]		This waste stream consists of RH TRU waste which is classified as contaminated equipment, decontamination debris or dry solids. The physical form is solid. Note: This stream may contain TSCA waste at unknown levels.	D006 D008 D009 D011
Debris Waste - S5000	Heterogeneous	RL-M201	Projected RH-MTRU Waste		The waste includes failed and obsolete equipment or material, including tanks, pumps, agitators, ovens, heaters, hoods, jumpers, and accessories. Some waste will contain wood, plastics, paper, rubber, and soils.	e
	Lead/Cadmium Metal Waste	AW-W016	Electrorefiner Stripped Cadmium		This waste stream consists of cadmium dispersed in a copper alloy matrix. This waste stream will be generated from the electrorefiner station in the ANL-Fuel Cycle Facility.	D006
	Lead/Cadmium Metal Waste	AW-W022	Electro Refiner Insolubles with Cadmium		This waste stream consists of cadmium metal with other heavy metals and "mable" metals (that is, they are not reactive in the FCF electrorefining process). This waste stream will be generated from the electrorefiner station in the ANL-W Fuel Cycle Facility Integral Fast Reactor demonstration. This waste stream includes inorganic sludges/particulates.	D006
	Lead/Cadmium Metal Waste	IN-M004	Electrorefiner Stripped Cadmium		Encapsulated waste cadmium metal.	e

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
REMOTE-HANDLED TRANSURANIC WASTE

RH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Lead/Cadmium Metal Waste	IN-M005	Electrorefiner Insolubles with Cadmium		Cadmium and other heavy metals.	e
	Uncategorized Metal	AW-W018	Sodium - TRU		Sodium is used as a primary and secondary coolant for the EBR-II Reactor. Waste sodium metal is a hazardous constituent of the TRU waste stored at the ANL-W Radioactive Scrap and Waste Facility (RSWF). Waste at RSWF is RH. This waste is generated during maintenance and operational activities. The sodium typically coats waste metal equipment, experiments and components removed during reactor operations and maintenance activities.	d
	Uncategorized Metal	AW-W019	Sodium Potassium-(NaK) - TRU		Sodium potassium alloy is used as a coolant for some components of the EBR-II reactor. Waste NaK metal is stored at the ANL-W RSWF. The RH NaK waste at the RSWF is contained in SS capsules or tubing and placed inside carbon steel waste cans which are then placed in SS outer cans. The entire package is then stored in RSWF storage liners (carbon steel soil storage vaults). The NaK is generated during maintenance and operational activities. NaK waste is in canisters with TRU waste metal pieces and rods from reactor experiments.	d
	Uncategorized Metal	AW-W021	Metal Debris		This waste stream consists of metal, and of EER N fuel elements. This waste stream will be generated from the "Element Chopper" station in the ANL-W Fuel Cycle Facility demonstration.	D005 D006
Debris Waste - S5000	Uncategorized Metal	IN-M003	Element Hardware FCF Waste		Small pieces of SS from nuclear fuel.	e
	Uncategorized Metal	IN-W260B	Inorganic Process Residues		This waste stream, generated at Bettis Atomic Power Laboratory, contains solid binary scrap as powder, pellets, or rods. The material is made of ceramic based UO_2 and ThO_2. Some kilorods or fuel rods constructed of fuel pellets within hollow zirconium tubes are also included.	e

TABLE C-2 (CONTINUED)
TRU MIXED WASTE CHARACTERIZATION INFORMATION
REMOTE-HANDLED TRANSURANIC WASTE

RH TRU Waste Summary Category Group Description	Waste Matrix Code Group	Waste Stream Unique ID[a]	Waste Stream Name	TRUCON[b] Code	Waste Description (WTWBIR)[a]	EPA Code
Debris Waste - S5000	Uncategorized Metal	IN-W322	Sample Fuel		Waste consists of actinide neutron sources, a tadrum needle, small vials of fuel, and metal containers of experimental fuel capsules.	e
	Uncategorized Metal	LA-WR01	Mixed Metal Scrap and Incidental Combustibles		Mixed metal scrap and incidental combustibles.	e
	Uncategorized Metal	LA-WR05	Noncombustible Scrap		Noncombustible scrap—small tools, cans, equipment items, broken glass, etc.	e

[a]Waste stream unique identifications (ID) and waste descriptions are taken from the U.S. Department of Energy (DOE), 1995, "Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report," CAO-94-1005, Rev. 1, U.S. Department of Energy, Albuquerque, New Mexico. The WTWBIR contains the most complete description information available at this time. Hazardous contents listed for individual waste streams are subject to verification through the WIPP Generator/Storage Site Waste Screening and Acceptance Audit Program (Appendix C8).
[b]TRUCON = TRUPACT-II Content
[c]Waste streams with unknown levels of TSCA waste, PCBs, or asbestos will have to meet WAP acceptability criteria.
[d]Although waste generators have previously indicated that some waste streams may have had the potential for reactivity, ignitability, or corrosivity (based on known waste generating processes), the final waste form accepted for disposal at the WIPP facility would not be permitted with these characteristics.
[e]EPA hazardous waste codes have not been reported by the generators at this time. These wastes will be subjected to the characterization requirements of this WAP prior to acceptance. These may or may not actually be TRU mixed wastes but are retained in the table for completeness.
[f]Classification of waste matrix code group is based on the waste stream being at least 50 percent of the indicated waste form (e.g., solidified inorganics). Therefore, a cement matrix containing trace quantities of F-listed solvents is classified as solidified inorganics.

NOTE: The use of trade names or brand names in this table does not constitute endorsement by the DOE or its contractors.

TABLE C-3
RATIONALE FOR SELECTION OF PARAMETERS OF INTEREST

Compound[a]	Synonyms	CAS[b] Number	Toxicity Characteristic Contaminant	Other Listed Constituent	Appendix VIII Constituent
Acetone	2-Propanone, dimethyl ketone	67-64-1		F003	
Antimony		7440-36-0			+
Arsenic		7440-38-2	D004		+
Barium		7440-39-3	D005		+
Benzene	Benzol	71-43-2	D018	F005	+
Beryllium		7440-41-7		P015	+
Bromoform	Tribromomethane, methyl tribromide	75-25-2			+
n-Butyl alcohol	Butanol, 1-butanol, n-butanol	71-36-3		F003	
Cadmium		7440-43-9	D006		+
Carbon disulfide	Carbon bisulfide	75-15-0		F005	+
Carbon tetrachloride	Tetrachloromethane	56-23-5	D019	F001	+
Chlorobenzene		108-90-7	D021	F002	+
Chloroform	Trichloromethane	67-66-3	D022		+
Chromium	Chrome	7440-47-3	D007		+
Cresols	Cresylic acid	1319-77-3	D026	F004	+
1,4-Dichlorobenzene	p-Dichlorobenzene	106-46-7	D027		+
1,2-Dichlorobenzene	o-Dichlorobenzene	95-50-1		F002	+
1,1-Dichloroethane	Ethylidene dichloride	75-34-3			+
1,2-Dichloroethane	Ethylene dichloride	107-06-2	D028		+
cis-1,2-Dichloroethylene	cis-1,2-Dichloroethene, sym-Dichloroethylene	156-60-5			+
1,1-Dichloroethylene	1,1-Dichloroethene, vinylidene chloride	75-35-4	D029		+
2,4 Dinitrophenol		51-28-5			+
2,4-Dinitrotoluene	1-methyl-2, 4-dinitrobenzene	121-14-2	D030		+
Ethyl benzene		100-41-4		F003	
Ethyl ether	Diethyl ether, ether	60-29-7		F003	
Formaldehyde[c]		50-00-0			+
Hexachlorobenzene		118-74-1	D032		+
Hexachloroethane		67-72-1	D034		+
Hydrazine[c]		302-01-2			+
Isobutanol	Isobutyl alcohol, 2-methyl-1-propanol	78-83-1		F005	+
Lead		7439-92-1	D008		+
Mercury		7439-97-6	D009		+
Methanol	Methyl alcohol	67-56-1		F003	
Methyl ethyl ketone	2-Butanone	78-93-3	D035	F005	+
Methyl isobutyl ketone	4-Methyl-2-pentanone, hexone	108-10-1		F003	
Methylene chloride	Dichloromethane	75-09-2		F001,F002	+
Nickel		7440-02-0			+
Nitrobenzene	Nitrobenzol	98-95-3	D036	F004	+
Pentachlorophenol	PCP	87-86-5	D037		+
Polychlorinated biphenyls (PCBs)		1336-36-3			+
Pyridine		110-86-1	D038	F005	+
Selenium		7782-49-2	D010		+
Silver		7440-22-4	D011		+

TABLE C-3 (CONTINUED)
RATIONALE FOR SELECTION OF PARAMETERS OF INTEREST

Compound[a]	Synonyms	CAS[b] Number	Toxicity Characteristic Contaminant	Other Listed Constituent	Appendix VIII Constituent
1,1,2,2-Tetrachloroethane		79-34-5			+
Tetrachloroethylene	Tetrachloroethene, perchloroethylene	127-18-4	D039	F001,F002	+
Thallium		7440-28-0			+
Toluene	Methyl benzene	108-88-3		F005	+
1,1,1-Trichloroethane	Methyl chloroform	71-55-6		F001,F002	+
1,1,2-Trichloroethane	Ethane trichloride	79-00-5		F002	+
Trichloroethylene	Trichloroethene	79-01-6	D040	F001,F002	+
Trichlorofluoromethane	Freon-11	75-69-4		F001,F002	+
1,1,2-Trichloro-1,2,2-trifluoroethane	Freon-113	76-13-1		F001,F002	
Vanadium		7440-62-2			
Vinyl chloride	Chloroethene	75-01-4	D043		+
m-Xylene	1,3-Dimethylbenzene	108-38-3		F003	
o-Xylene	1,2-Dimethylbenzene	95-47-6		F003	
p-Xylene	1,4-Dimethylbenzene	106-42-3		F003	
Zinc[e]		7440-66-6			

[a] U.S. Department of Energy (DOE), 1995a, "Transuranic Waste Characterization Quality Assurance Program Plan" (QAPP), CAO-94-1010, Rev. 0, Carlsbad Area Office, Carlsbad, New Mexico.

[b] CAS=Chemical Abstracts Number

[c] Reported only by Los Alamos National Laboratory.

[d] Reported only by Oak Ridge National Laboratory and Savannah River Site.

[e] Zinc was added during development of the QAPP.

TABLE C-4
RATIONALE FOR COMPLIANCE WITH PROHIBITED CHARACTERISTIC WASTES

Prohibited Characteristics	Rationale for Transuranic Mixed Waste Compliance
Ignitability	Ignitability
• Liquid waste.	• Waste is not a liquid. Verified by radiography.
• Contains pyrophorics or materials capable of spontaneous chemical changes.	• Final waste form precludes pyrophorics or spontaneous reactions.* Pyrophorics prohibited by waste acceptance criteria (WAC).
• Contains ignitable compressed gases as defined in 49 Code of Federal Regulations (CFR) §173.300.	• Containers capable of containing any compressed gases are prohibited by the WAC . Verified by radiography.
• Contains oxidizers as defined in Title 49 CFR §173.151.	• Acceptable knowledge and final waste form precludes oxidizers.
Corrosivity	Corrosivity
• Contains aqueous or nonaqueous liquid waste.	• Liquid waste (greater than one percent by volume) is prohibited by WAC.
Reactivity	Reactivity
• Unstable and will readily undergo violent change without detonating.	• Final waste form precludes reactivity*.
• When mixed with water, will react violently, form a potentially explosive mixture, or generate harmful toxic gases, vapors, or fumes.	• Acceptable knowledge and final waste form*.
• If subjected to a strong initiating force or if heated under confinement, will detonate or explode.	• Acceptable knowledge and final waste form*.
• Cyanide- or sulfide-bearing waste.	• Acceptable knowledge and final waste form*.
• Capable of detonation or explosive decomposition at standard temperature and pressure.	• Final waste form precludes detonation or explosive decomposition*.
• A forbidden explosive as defined in 49 CFR §173.51, a Class A explosive as defined in 49 CFR §173.53 or a Class B explosive as defined in 49 CFR §173.88.	• Explosives prohibited by WAC.

*Waste compatibility analysis in Appendix C1 shows that these reactions will not occur based on waste constituents and final waste form.

TABLE C-5
VOC HEADSPACE CONCENTRATION LIMITS

COMPOUND	VOC HEADSPACE CONCENTRATION LIMITS[a] (PPM)
Carbon Tetrachloride	7,510
Chlorobenzene	17,660
Chloroform	6,325
1,1-Dichloroethene	28,750
1,2-Dichloroethane	9,100
Methylene Chloride	100,000
1,1,2,2-Tetrachloroethane	7,924
Toluene	41,135
1,1,1-Trichloroethane	100,000

[a] There are no maximum headspace limits for other VOCs. These concentrations are based on calculations provided in Appendix D9.

TABLE C-6
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR CH TRANSURANIC MIXED WASTE (STORED WASTE)

Waste Matrix Code Summary Categories	Waste Matrix Code Groups	Characterization Parameter	Method	Rationale
S3000-Homogeneous Solids S4000-Soil/Gravel	• Solidified inorganics • Salt waste • Solidified organics • Contaminated soil/debris	Physical waste form	100% radiography or visual examination	• Verify waste matrix • Demonstrate compliance with waste acceptance criteria (e.g., no free liquids, no incompatible wastes, no compressed gases)
		Headspace gases • Gas volatile organic compounds (VOC)	100% gas sampling and analysis (see Table C-9)	• Quantify concentration of flammable VOCs • Determine potential flammability of transuranic (TRU) waste headspace gases • Quantify concentrations of VOC constituents in headspace of containers • Support demonstration of no migration by headspace VOCs
		Hazardous constituents • Total metals • Total VOCs • Total semi-VOCs	Statistical sampling[a] (see Tables C-10 and C-11)	• Determine characteristic metals and organics • Determine total quantity of metals, VOCs, and semi-VOCs

TABLE C-6 (CONTINUED)
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR CH TRANSURANIC MIXED WASTE (STORED WASTE)

Waste Matrix Code Summary Categories	Waste Matrix Code Groups	Characterization Parameter	Method	Rationale
S5000-Debris Waste	• Uncategorized metal (metal waste other than lead/cadmium) • Lead/cadmium waste • Inorganic nonmetal waste • Combustible waste • Graphite waste • Heterogeneous waste • Composite filter waste	Physical waste form	100% Radiography Visual examination (statistical sample)[a]	• Verify waste matrix • Demonstrate compliance with waste acceptance (e.g., no free liquids, no incompatible wastes, no compressed gases)
		Headspace gases • Gas VOCs	100% gas sampling and analysis (see Table C-9)	• Quantify concentration of flammable VOCs • Determine potential flammability of TRU waste headspace gases • Quantify concentrations of VOC constituents in headspace of containers • Support demonstration of no migration by headspace VOCs • Verify acceptable knowledge
		Hazardous constituents • Total metals • Total VOCs • Total semi-VOCs	Acceptable knowledge	• Determine characteristic metals and organics • Determine total quantity of metals, VOCs, and semi-VOCs

TABLE C-6 (CONTINUED)
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR CH TRANSURANIC MIXED WASTE (NEWLY GENERATED WASTE)

Waste Matrix Code Summary Categories	Waste Matrix Code Groups	Characterization Parameter	Method	Rationale
S3000-Homogeneous Solids S4000-Soil/Gravel	• Solidified inorganics • Salt waste • Solidified organics • Contaminated soil/debris	Physical waste form	Documentation and verification[b]	• Verify waste matrix • Demonstrate compliance with waste acceptance criteria (e.g., no free liquids, no incompatible wastes, no compressed gases)
		Headspace gases • Gas VOCs (VOCs)	100% gas sampling and analysis (see Table C-9)	• Quantify concentration of flammable VOCs • Determine potential flammability of TRU waste headspace gases • Quantify concentrations of VOC constituents in headspace of containers • Support demonstration of no migration by headspace VOCs
		Hazardous constituents • Total metals • Total VOCs • Total semi-VOCs	Statistical sampling[a] (see Tables C-10 and C-11)	• Determine characteristic metals and organics • Determine total quantity of metals, VOCs, and semi-VOCs

TABLE C-6 (CONTINUED)
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR CH TRANSURANIC MIXED WASTE (NEWLY GENERATED WASTE)

Waste Matrix Code Summary Categories	Waste Matrix Code Groups	Characterization Parameter	Method	Rationale
S5000–Debris Waste	• Uncategorized metal (metal waste other than lead/cadmium) • Lead/cadmium waste • Inorganic nonmetal waste • Combustible waste • Graphite waste • Heterogeneous waste • Composite filter waste	Physical waste form	Documentation and verification[b]	• Verify waste matrix • Demonstrate compliance with waste acceptance (e.g., no free liquids, no incompatible wastes, no compressed gases)
		Headspace gases • Gas VOCs	100% gas sampling and analysis (see Table C-9)	• Quantify concentration of flammable VOCs • Determine potential flammability of TRU waste headspace gases • Quantify concentrations of VOC constituents in headspace of containers • Support demonstration of no migration by headspace VOCs • Verify acceptable knowledge
		Hazardous constituents • Total metals • Total VOCs • Total semi-VOCs	Acceptable knowledge	• Determine characteristic metals and organics • Determine total quantity of metals, VOCs, and semi-VOCs

TABLE C-6 (CONTINUED)
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR CH TRANSURANIC MIXED WASTE (STORED WASTE)

[a] Number determined per Quality Assurance Program Plan (QAPP), Section 5.0.
[b] See discussion in Section 5.3.3 of the QAPP.

U.S. Department of Energy (DOE), 1995, "TRU Waste Characterization Quality Assurance Program Plan," CAO-94-1010, Rev 0, Carlsbad Area Office, Carlsbad, New Mexico.

TABLE C-7
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR RH TRANSURANIC MIXED WASTE (STORED WASTE)

Waste Matrix Code Summary Categories	Waste Matrix Code Groups	Characterization Parameter	Method	Rationale
S3000-Homogeneous Solids S4000-Soil/Gravel	• Solidified inorganics • Salt waste • Solidified organics • Contaminated soil/debris	Physical waste form	Radiography for wastes <1 rem/hour Acceptable knowledge	• Verify waste matrix • Demonstrate compliance with waste acceptance criteria (e.g., no free liquids, no incompatible wastes, no compressed gases)
		Headspace gases • Gas VOCs	100% gas sampling and analysis (see Table C-9)	• Quantify concentration of flammable volatile organic compounds (VOCs) • Determine potential flammability of transuranic (TRU) waste headspace gases • Quantify concentrations of VOC constituents in headspace of containers • Support demonstration of no migration by headspace VOCs
		Hazardous constituents • Total metals • Total VOCs • Total semi-VOCs	Statistical sampling (see Tables C-10 and C-11)	• Determine characteristic metals and organics • Determine total quantity of metals, VOCs, and semi-VOCs

TABLE C-7 (CONTINUED)
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR RH TRANSURANIC MIXED WASTE (STORED WASTE)

Waste Matrix Code Summary Categories	Waste Matrix Code Groups	Characterization Parameter	Method	Rationale
S5000–Debris Waste	• Uncategorized metal (metal waste other than lead/cadmium) • Lead/cadmium waste • Inorganic nonmetal waste • Combustible waste • Graphite waste • Heterogeneous waste • Composite filter waste	Physical waste form	100% Radiography	• Verify waste matrix • Demonstrate compliance with waste acceptance (e.g., no free liquids, no incompatible wastes, no compressed gases)
		Headspace gases • Gas VOCs	100% gas sampling and analysis (see Table C-9)	• Quantify concentration of flammable VOCs • Determine potential flammability of TRU waste headspace gases • Quantify concentrations of VOC constituents in headspace of containers • Support demonstration of no migration by headspace VOCs • Verify acceptable knowledge
		Hazardous constituents • Total metals • Total VOCs • Total semi-VOCs	Acceptable knowledge	• Determine characteristic metals and organics • Determine total quantity of metals, VOCs, and semi-VOCs

TABLE C-7 (CONTINUED)
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR RH TRANSURANIC MIXED WASTE (NEWLY GENERATED WASTE)

Waste Matrix Code Summary Categories	Waste Matrix Code Groups	Characterization Parameter	Method	Rationale
S3000-Homogeneous Solids S4000-Soil/Gravel	• Solidified inorganics • Salt waste • Solidified organics • Contaminated soil/debris	Physical waste form	Documentation and verification	• Verify waste matrix • Demonstrate compliance with waste acceptance criteria (e.g., no free liquids, no incompatible wastes, no compressed gases)
		Headspace gases • Gas volatile organic compounds (VOCs)	100% gas sampling and analysis (see Table C-9)	• Quantify concentration of flammable VOCs • Determine potential flammability of TRU waste headspace gases • Quantify concentrations of VOC constituents in headspace of containers • Support demonstration of no migration by headspace VOCs
		Hazardous constituents • Total metals • Total VOCs • Total semi-VOCs	Statistical sampling (see Tables C-10 and C-11)	• Determine characteristic metals and organics • Determine total quantity of metals, VOCs, and semi-VOCs

TABLE C-7 (CONTINUED)
SUMMARY OF PARAMETERS, CHARACTERIZATION METHODS, AND RATIONALE FOR RH TRANSURANIC MIXED WASTE (NEWLY GENERATED WASTE)

Waste Matrix Code Summary Categories	Waste Matrix Code Groups	Characterization Parameter	Method	Rationale
S5000–Debris Waste	• Uncategorized metal (metal waste other than lead/cadmium) • Lead/cadmium waste • Inorganic nonmetal waste • Combustible waste • Graphite waste • Heterogeneous waste • Composite filter waste	Physical waste form	Documentation and verification	• Verify waste matrix • Demonstrate compliance with waste acceptance (e.g., no free liquids, no incompatible wastes, no compressed gases)
		Headspace gases • Gas VOCs	100% gas sampling and analysis (see Table C-9)	• Quantify concentration of flammable VOCs • Determine potential flammability of TRU waste headspace gases • Quantify concentrations of VOC constituents in headspace of containers • Support demonstration of no migration by headspace VOCs • Verify acceptable knowledge
		Hazardous constituents • Total metals • Total VOCs • Total semi-VOCs	Acceptable knowledge	• Determine characteristic metals and organics • Determine total quantity of metals, VOCs, and semi-VOCs

TABLE C-8

SUMMARY OF HAZARDOUS WASTE CHARACTERIZATION REQUIREMENTS FOR TRANSURANIC MIXED WASTE[a]

Parameter	Techniques and Methods Manual Procedure
Physical Waste Form Matrix Parameter Categories Summary Category Names S3000 Homogeneous Solid S4000 Soil/Gravel S5000 Debris Wastes	**Waste Inspection Procedures** Radiography, Procedure 310.1 Visual Examination, Procedure 310.2 (QAPP Section 10.0)
Headspace Gases **Volatile Organic Compounds** Benzene Bromoform Carbon tetrachloride Chlorobenzene Chloroform 1,1-Dichloroethane 1,2-Dichloroethane 1,1-Dichloroethylene (cis)-1,2-Dichloroethylene Ethyl benzene Ethyl ether Formaldehyde[b] Hydrazine[c] Methylene chloride 1,1,2,2-Tetrachloroethane Tetrachloroethylene Toluene 1,1,1-Trichloroethane Trichloroethylene 1,1,2-Trichloro-1,2,2-trifluoroethane Xylenes Alcohols and Ketones Acetone Butanol Methanol Methyl ethyl ketone Methyl isobutyl ketone	**Gas Analysis** Gas Chromatography (GC)/Mass Spectroscopy (MS), Procedure 430.1 or 430.2 (QAPP Section 12.0) GC/MS GC/Flame Ionization Detector (FID), Procedure 440.1 (QAPP Section 12.0) Fourier Transform Infrared Spectroscopy (FTIRS), Procedure 430.7

TABLE C-8 (CONTINUED)
SUMMARY OF HAZARDOUS WASTE CHARACTERIZATION REQUIREMENTS FOR TRANSURANIC MIXED WASTE[a]

Parameter		Techniques and Methods Manual Procedure
Total Volatile Organic Compounds		**Total Volatile Organic Compound Analysis**
Acetone	Isobutanol	GC/MS, Procedure 430.3 or 430.4
Benzene	Methanol	GC/FID, Procedure 440.2
Bromoform	Methyl ethyl ketone	(QAPP Section 13.0)
Butanol	Methylene chloride	
Carbon disulfide	Pyridine[d]	Acceptable Knowledge for Matrix Parameter Summary
Carbon tetrachloride	1,1,2,2-Tetrachloroethane	Category S5000 (Debris Wastes)
Chlorobenzene	Tetrachloroethylene	
Chloroform	Toluene	
1,4-Dichlorobenzene[d]	1,1,2-Trichloro-1,2,2-trifluoroethane	
1,2-Dichlorobenzene[d]	Trichlorofluoromethane	
1,2-Dichloroethane	1,1,1-Trichloroethane	
1,1-Dichloroethylene	1,1,2-Trichloroethane	
Ethyl benzene	Trichloroethylene	
Ethyl ether	Vinyl chloride	
Formaldehyde[b]	Xylenes	
Hydrazine[c]		
Total Semivolatile Organic Compounds		**Total Semivolatile Organic Compound Analysis**
Cresols		GC/MS, Procedure 430.5 or 430.6
1,4-Dichlorobenzene[e]		GC/ECD for PCBs , Procedure 440.3
1,2-Dichlorobenzene[e]		(QAPP Section 14.0)
2,4-Dinitrophenol		
2,4-Dinitrotoluene		Acceptable Knowledge for Matrix Parameter Summary
Hexachlorobenzene		Category S5000 (Debris Wastes)
Hexachloroethane		
Nitrobenzene		
Polychlorinated biphenyls		
Pentachlorophenol		
Pyridine[e]		
Total Metals		**Total Metals Analysis**
Antimony	Mercury	Atomic MS, Procedure 630.1
Arsenic	Nickel	Atomic Emission Spectroscopy, Procedure 640.1
Barium	Selenium	Atomic Absorption Spectroscopy , Procedures 650.1
Beryllium	Silver	through 650.7
Cadmium	Thallium	(QAPP Section 15.0)
Chromium	Vanadium	
Lead	Zinc	Acceptable Knowledge for Matrix Parameter Summary
		Category S5000 (Debris Wastes)

[a] U.S. Department of Energy (DOE), 1995a, "TRU Waste Characterization Quality Assurance Program Plan" (QAPP), CAO-94-1010, Rev. 0, Carlsbad Area Office, Carlsbad, New Mexico.
[b] Required only for homogeneous solids and soil/gravel from Los Alamos National Laboratory.
[c] Required only for homogeneous solids and soil/gravel from Oak Ridge National Laboratory and Savannah River Site.
[d] Can also be analyzed as a semi-volatile organic compound.
[e] Can also be analyzed as a volatile organic compound.

TABLE C-9
HEADSPACE TARGET ANALYTE LIST AND METHODS

Parameter	Methods Manual Procedure	EPA Specified Analytical Method
Benzene Bromoform Carbon tetrachloride Chlorobenzene Chloroform 1,1-Dichloroethane 1,2-Dichloroethane 1,1-Dichloroethylene (cis)-1,2-Dichloroethylene Ethyl benzene Ethyl ether Formaldehyde[b] Hydrazine[c] Methylene chloride 1,1,2,2-Tetrachloroethane Tetrachloroethylene Toluene 1,1,1-Trichloroethane Trichloroethylene 1,1,2-Trichloro-1,2,2-trifluoroethane Xylenes	430.1 430.2 430.7	EPA: Modified TO-14[a]; Modified 8240/8260 EPA - Approved Fourier Transform Infrared Spectroscopy
Acetone Butanol Methanol Methy ethyl ketone Methyl isobutyl ketone	430.1 430.2 430.7 440.1	EPA: Modified TO-14[a]; Modified 8240/8260 EPA - Approved Fourier Transform Infrared Spectroscopy No Equivalent EPA Method for Methods Manual Procedure 440.1

[a] U.S. Environmental Protection Agency (EPA), 1988, "Compendium Method TO-14, the Determination of Volatile Organic Compounds (VOC) in Ambient Air Using SUMMA® Passivated Canister Sampling and Gas Chromatographic Analysis," in Compendium of Methods for the Determination of Toxic Organic Compounds on Ambient Air. Research Triangle Park, North Carolina, Quality Assurance Division, Monitoring System Laboratory, U.S. EPA. The most current revision of the specified methods will be used.

[b] Required only for containers of homogeneous solids and soil/gravel waste from Los Alamos National Laboratory.

[c] Required only for containers of homogeneous solids and soil/gravel waste from Oak Ridge National Laboratory and the Savannah River Site.

TABLE C-10
REQUIRED TOTAL ORGANIC ANALYSES AND TEST METHODS ORGANIZED BY ORGANIC ANALYTICAL GROUPS

Organic Analytical Group	Required Organic Analyses	Methods Manual Procedure	EPA Specified Analytical Method[a]
Nonhalogenated Volatile Organic Compounds (VOCs)	Acetone Benzene n-Butanol Carbon disulfide Ethyl benzene Ethyl ether Formaldehyde Hydrazine[b] Isobutanol Methanol Methyl ethyl ketone Toluene Xylenes	430.3 430.4 440.2	8240B 8260A
Halogenated VOCs	Bromoform Carbon tetrachloride Chlorobenzene Chloroform 1,2-Dichloroethane 1,1-Dichloroethylene Methylene chloride 1,1,2,2-Tetrachloroethane Tetrachloroethylene 1,1,2-Trichloroethane 1,1,1-Trichloroethane Trichloroethylene Trichlorofluoromethane 1,1,2-Trichloro-1,2,2-trifluoroethane Vinyl Chloride	430.3 430.4	8240B 8260A
Semivolatile Organic Compounds (SVOCs)	Cresols (o, m, p) 1,2-Dichlorobenzene[c] 1,4-Dichlorobenzene[c] 2,4-Dinitrophenol 2,4-Dinitrotoluene Hexachlorobenzene Hexachloroethane Nitrobenzene Polychlorinated biphenyls (PCB)[d] Pentachlorophenol Pyridine[c]	430.5 430.6 440.3 (for PCBs only)	8250A 8270B 3620 8081 (for PCBs only) 3550

TABLE C-10 (CONTINUED)
REQUIRED ORGANIC ANALYSES AND TEST METHODS ORGANIZED BY ORGANIC ANALYTICAL GROUPS

[a] U.S. Environmental Protection Agency (EPA), 1993, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," SW-846, Third Edition Final Update I and Final Update II. Equivalent methods are demonstrated by meeting the quality assurance/quality control requirements specified in the QAPP and SW-846 protocols.

[b] Sites will have to develop an analytical method for hydrazine. This method will be submitted to the DOE CAO for approval.

[c] These compounds may also be analyzed as VOCs by SW-846 Methods 8240B and 8260A.

[d] Transformer oils containing PCBs have been identified in a limited number of waste streams included in the organic sludges waste matrix code. Therefore, only waste streams included in the solidified organics final waste form must be analyzed for PCBs.

TABLE C-11
SUMMARY OF SAMPLE PREPARATION AND ANALYTICAL METHODS FOR TOTAL METALS

Parameters	Methods Manual Procedure	EPA-Specified Analytical Methods[a]
Sample Preparation	610.1	3051, or equivalent, as appropriate for analytical method
Total Antimony	630.1, 640.1, 650.1, 650.2, 650.5	6010A, 6020, 7040, 7041, 7062
Total Arsenic	630.1, 640.1, 650.4, 650.5	6010A, 6020, 7060A, 7061A, 7062
Total Barium	630.1, 640.1, 650.1, 650.2	6010A, 6020, 7080A, 7081
Total Beryllium	630.1, 640.1, 650.1, 650.2	6010A, 6020, 7090, 7091
Total Cadmium	630.1, 640.1, 650.1, 650.2	6010A, 6020, 7130, 7131A
Total Chromium	630.1, 640.1, 650.1, 650.2	6010A, 6020, 7190, 7191
Total Lead	630.1, 640.1, 650.1, 650.2	6010A, 6020, 7420, 7421
Total Mercury	650.3	7471A
Total Nickel	630.1, 640.1, 650.1	6010A, 6020, 7520
Total Selenium	630.1, 650.2, 650.6, 650.7	6010A, 7740, 7741A, 7742
Total Silver	630.1, 640.1, 650.1, 650.2	6010A, 6020, 7760A, 7761
Total Thallium	630.1, 640.1, 650.1, 650.2	6010A, 6020, 7840, 7841
Total Vanadium	630.1, 650.1, 650.2	6010A, 7910, 7911
Total Zinc	630.1, 640.1, 650.1, 650.2	6010A, 6020, 7950, 7951

[a] U.S. Environmental Protection Agency (EPA), 1986 as amended by FR 46040, August 31, 1993. "Test Methods for Evaluating Solid Waste," Laboratory Manual Physical/Chemical Methods, SW-846, 3rd ed., U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C. Equivalent methods are demonstrated by meeting the quality assurance/quality control requirements specified in the Quality Assurance Program Plan (QAPP) and SW-846 protocols.

TABLE C-12
WIPP WASTE INFORMATION SYSTEM DATA FIELDS[a]

Characterization Module Data Fields [b]	
Container ID [c]	Total VOC Sample Date
Generator EPA ID	Total VOC Analysis Date
Generator Address	Total VOC Analyte Name [d]
Generator Name	Total VOC Analyte Concentration [d]
Generator Contact	Total Metal Sample Date
Hazardous Code	Total Metal Analysis Date
Headspace Gas Sample Date	Total Metal Analyte Name [d]
Headspace Gas Analysis Date	Total Metal Analyte Concentration [d]
Headspace Gas Analyte [d]	Semi-VOC Sample Date
Headspace Gas Concentration [d]	Semi-VOC Analysis Date
Headspace Gas Char. Method [d]	Semi-VOC Analyte Name [d]
Total VOC Char. Method [d]	Semi-VOC Concentration [d]
Total Metals Char. Method [d]	Transporter EPA ID
Total Semi-VOC-Char. Method [d]	Transporter Name
Item Description Code	Visual Exam Container [e]
Haz. Manifest Number	Waste Material Parameter [d]
NDE Complete [e]	Waste Material Weight [d]
PCB Concentration [f]	Waste Matrix Code
	Waste Matrix Code Group
	Waste Stream Profile Number

Certification Module Data Fields	
Container ID [c]	Fissile Gram Equiv.
Container type	Radioassay (RA) Date
Container Weight	RA Method
Contact Dose Rate	Radionuclide [d]
Container Certification date	Radionuclide Quan.[d]
Container Closure Date	Handling Code
Container Liner Type	Waste Weight
Decay Heat	Waste Fill %
Overpack Number (if any)	Surface Contamination
PE Curie Equiv.	Alpha Activity

Transportation Data Module	
Shipment Number	Layers of Packaging
TRUPACT Number	Ship Category
Assembly Number[g]	Ship Certification Date
Container IDs [c,d]	Ship Date
Filter Model	Receive Date
Filter Date	Vehicle Type
ICV Closure Date	

TABLE C-12 (CONTINUED)
WIPP WASTE INFORMATION SYSTEM DATA FIELDS

Disposal Module Data
Container ID [c] Disposal Date Disposal Location

[a] This is not a complete list of the WWIS data fields, but is a subset that contains the fields that are pertinent to RCRA.

[b] Some of the fields required for characterization are also required for certification and/or transportation.

[c] Container ID is the main relational field in the WWIS Database.

[d] This is a multiple occurring field for each analyte, nuclide, etc.

[e] These are logical fields requiring only a yes/no.

[f] Limits are applied to many fields. The limit for PCBs is 50 ppm.

[g] Required for 7-Packs of 55 gal drums to tie all of the drums in that assembly together. This facilitates the identification of waste containers in a shipment without need to breakup the assembly.

TABLE C-13
REQUIRED PROGRAM RECORDS MAINTAINED IN SITE PROJECT FILES

Lifetime Records • Field sampling data forms • Field and laboratory chain-of-custody forms • Laboratory analytical data reports • Analytical results of all QA/QC samples • Reports and data transmittals sent to DOE/CAO • Nonconformance and corrective action documentation • Sampling Plans • Audit plans, reports, responses, and final closure of corrective actions • Quality assurance reports to management • Data reduction, validation, and reporting records • Gas canister tags • Audio/video tapes
Non-Permanent Records • Performance Demonstration Program analytical results • Sampler certifications • All pertinent incoming and outgoing correspondence, memoranda, and telephone records related to QA/QC • Documentation of calculations and computer programs with associated verification • Reference material relevant to the waste characterization program • Training/qualification records • Documentation of revisions or changes to the QAPP or QAPjPs • Calibration records • Electronic instrument data (e.g., GC/MS files) • Procurement records • QC standard certification statements

1

FIGURES

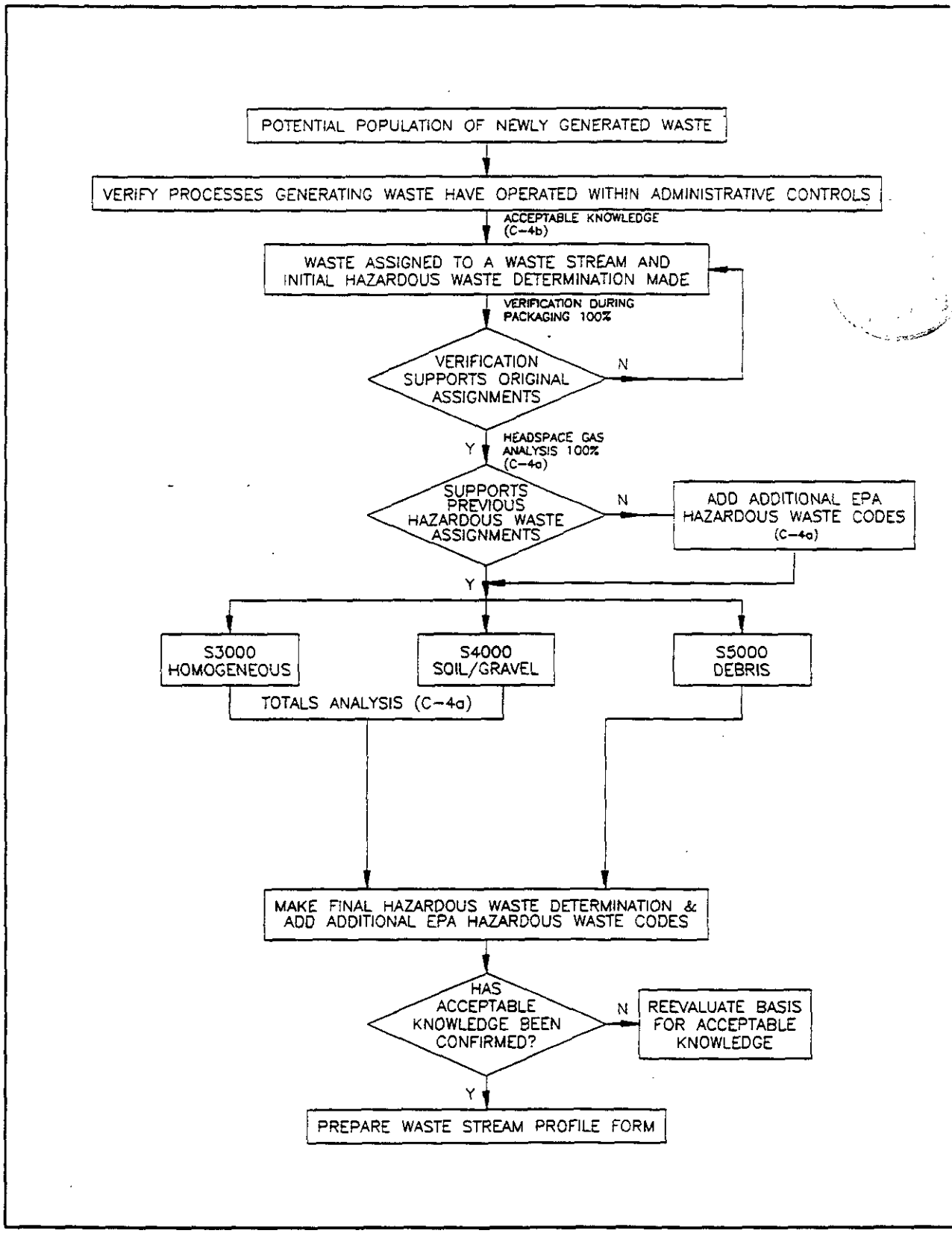

Figure C-1

Data Collection Design for Characterization of Newly Generated Waste

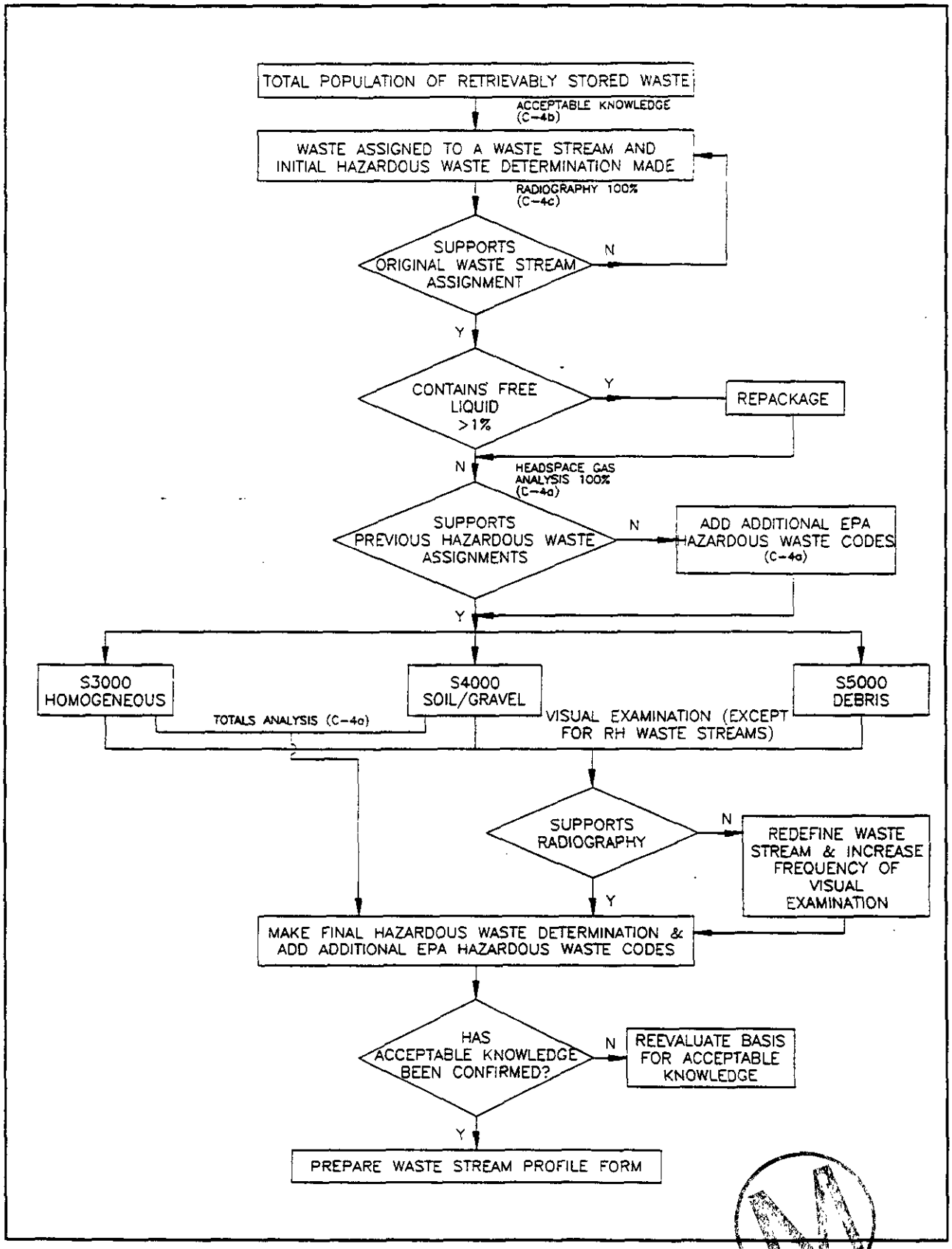

Figure C-2

Data Collection Design for Characterization of Retrievably Stored Waste

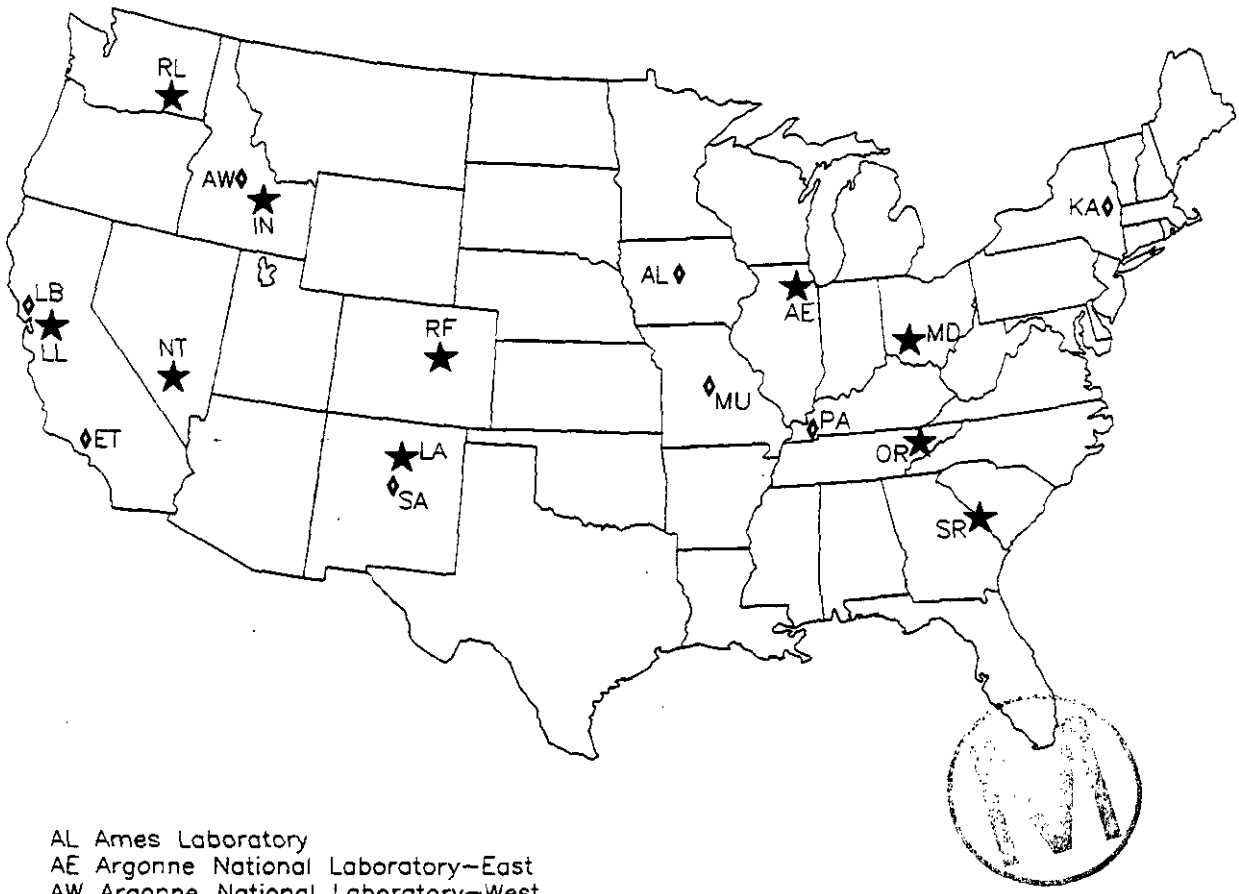

AL Ames Laboratory
AE Argonne National Laboratory–East
AW Argonne National Laboratory–West
ET Energy Technology Engineering Center
IN Idaho National Engineering Laboratory
KA Knolls Atomic Power Laboratory–Knolls Site
LA Los Alamos National Laboratory
LB Lawrence Berkeley Laboratory
LL Lawrence Livermore National Laboratory
MD Mound Plant
MU University of Missouri
NT Nevada Test Site
OR Oak Ridge National Laboratory
PA Paducah Gaseous Diffusion Plant
RF Rocky Flats Environmental Technology Site
RL Richland (Hanford) Site
SA Sandia National Laboratories/New Mexico
SR Savannah River Site

★ Indicates Major Site

◊ Indicates Minor Site

Figure C-3

U.S. Department of Energy Transuranic Mixed Waste Generator/Storage Sites

Form Number _____
Page ___ of ___

WIPP WASTE STREAM PROFILE FORM

Shipper/Generator Information:

Site Name _____ / EPA ID _____

Tech. Contact _____ / Phone _____

Orig. Generator _____ / EPA ID _____

Waste Stream Information:

Check one: ☐ CH ☐ RH

Waste Stream WIPP ID _____

Summary Category Group _____ /Waste Matrix Code Group _____

Waste Stream Name _____

Description _____

_____

_____

Date of WAC Certification _____

Title, version number, and date of documents used for WAC certification:

_____

Number of SWBs _____ Number of Drums _____ Number of Canisters _____

List all applicable EPA Hazardous Waste Codes _____

Acceptable Knowledge Information:

Required Program Information	Supporting Documentation Used (References and dates)
☐ Map of Site	_____
☐ Facility Mission Description	_____
☐ Description of Operations that Generate Waste	_____
☐ Waste Identification/Categorization Schemes	_____
☐ Types and quantities of waste generated	_____
☐ Correlation of waste streams generated from the same building and process, as appropriate	_____
☐ Waste certification procedures	_____

Required Waste Stream Information

☐ Area(s) and building(s) from which the waste stream was generated	_____
☐ Waste stream volume and time period of generation	_____
☐ Process flow diagrams	_____

Figure C-4
WIPP Waste Stream Profile Form

Form Number_____
Page ____ of ____

- ☐ Waste Generating Process Description _____
- ☐ Material inputs of other information identifying chemical/radionuclide content and physical waste form _____

Supplemental Documentation

- ☐ Process design documents _____
- ☐ Standard operating procedures _____
- ☐ Safety Analysis Reports _____
- ☐ Waste Packaging Logs _____
- ☐ Test Plans/Research Project Reports _____
- ☐ Site Databases _____
- ☐ Information from Site Personnel _____
- ☐ Standard Industry Documents _____
- ☐ Previous Analytical Data _____
- ☐ Material Safety Data Sheets _____
- ☐ Sampling and Analysis Data from Comparable/Surrogate Waste _____
- ☐ Laboratory Notebooks _____

Sampling and Analysis Information*: **Sampling and Analysis Procedures (reference and date)**

- ☐ Radiography _____
- ☐ Visual Examination _____
- ☐ Headspace Gas Analysis
  - VOCs _____
  - Other Gases (Specify) _____
- ☐ Homogeneous Solids/Soil/Gravel Sample Analysis
  - VOCs _____
  - Semi-VOCs _____
  - PCBs _____
  - Total Metals _____
  - Other (specify) _____
- ☐ Ignitable ☐ Corrosive ☐ Reactive ☐ Compatible

Waste Characterization Data Package Numbers: _____

_____

* Attach signed waste characterization summary data package to support hazardous waste code assignment to form

Certification:
I hereby certify that I have reviewed the information in this Waste Stream Profile Form, and it is complete and accurate to the best of my knowledge. I understand that this information will be made available to regulatory agencies and that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

_____	_____	_____
Signature of Site Project Manager	Printed Name and Title	Date

Figure C-4
WIPP Waste Stream Profile Form (Continued)

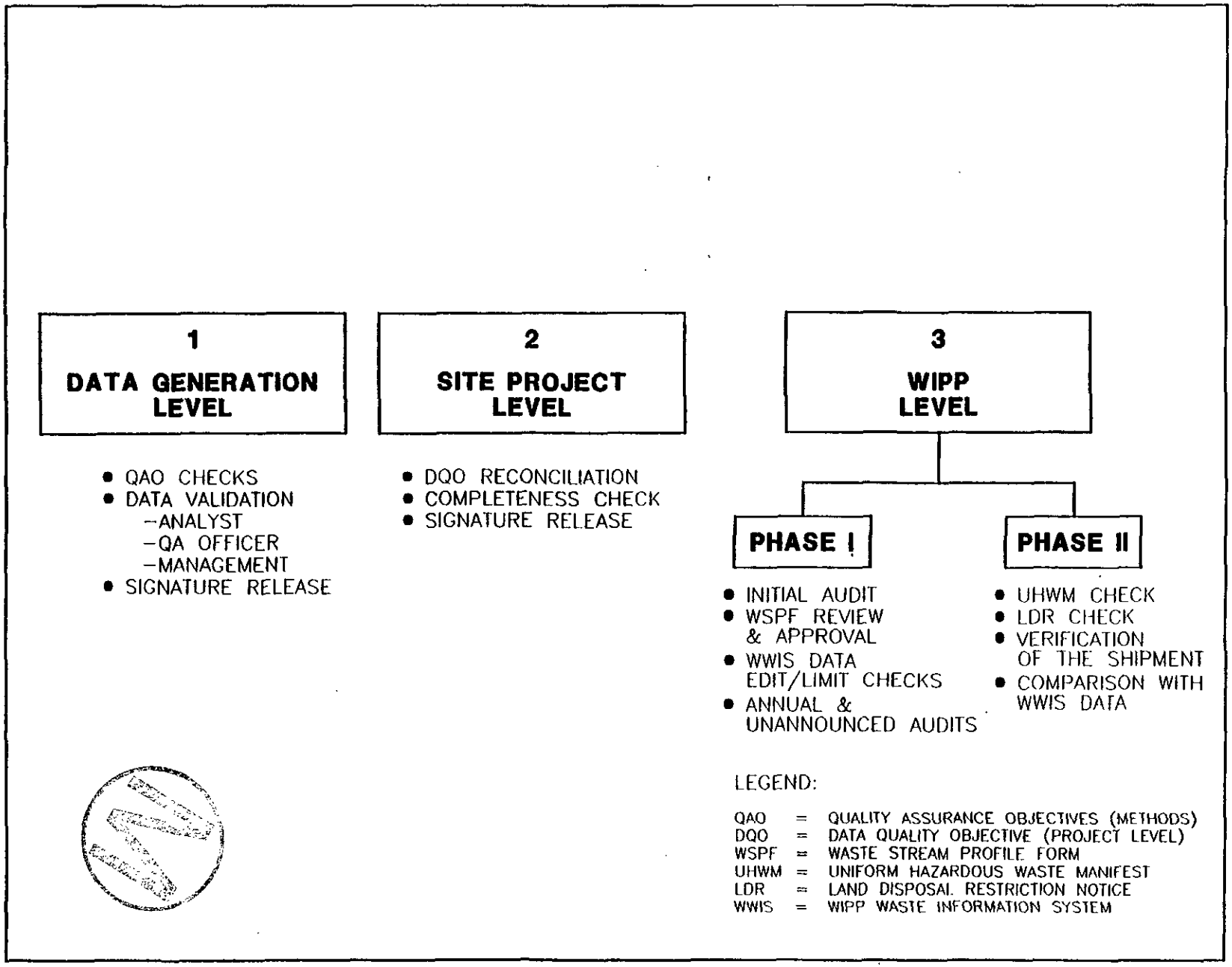

Figure C-5
Levels of Data Verification

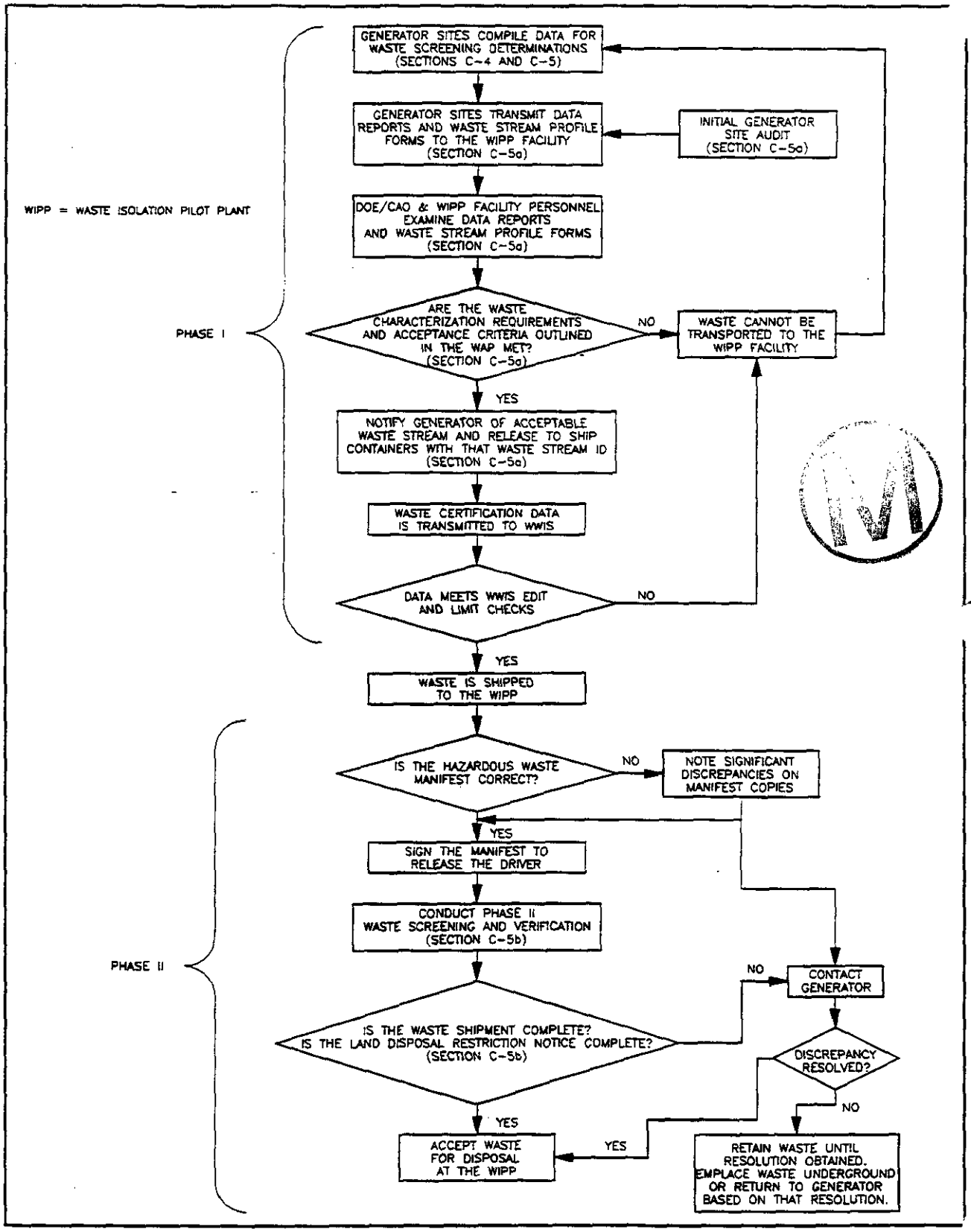

Figure C-6

TRU Waste Screening Flow Diagram

APPENDIX C1
CHEMICAL COMPATIBILITY ANALYSIS OF WASTE FORMS AND CONTAINER MATERIALS

APPENDIX C1
CHEMICAL COMPATIBILITY ANALYSIS OF WASTE FORMS AND CONTAINER MATERIALS

The chemical compatibility analysis was carried out with all defense generated, contact-handled (CH) and remote-handled (RH) transuranic (TRU)-mixed waste streams reported in the Waste Isolation Pilot Plant (WIPP) Transuranic Waste Baseline Inventory Report (WTWBIR) (DOE, 1995). A summary of these waste streams is given in Table C-1 (Chapter C). The reported content of CH and RH streams will be verified through the WIPP Generator/Storage Site Waste Screening and Acceptance Audit Program (Appendix C11).

All information for the chemical lists and compatibility study is maintained in databases on a personal computer. The chemicals reported by the generator sites are classified into reaction groups as defined by the U.S. Environmental Protection Agency (EPA) document, A Method for Determining the Compatibility of Hazardous Wastes (Hatayama et al., 1980). The chemical lists are derived from the TRUPACT-II database, EPA hazardous waste codes listed in the WTWBIR, and waste descriptions.

A database program was developed to evaluate the chemical compatibility of the WTWBIR waste streams. Potential incompatibilities are defined on Figure 6 of the EPA document (Hatayama et al., 1980), which identifies combinations of chemical groups that are incompatible and the consequences (e.g., heat generation) of mixing incompatible chemical groups. All incompatible mixtures have been entered into a reference data base to be used in assessing the chemical compatibility of a given list of chemicals. The logic of the program used in evaluating the chemical compatibility by content code is described in detail below.

As an initial step, the program indexes the entire database according to the WTWBIR waste stream codes. The program then locates the first reaction group within the first waste stream code and picks the highest concentration of any chemical in that group. The selected reaction group is then paired with every other reaction group in the waste stream to check for incompatibility. If a potential incompatibility is found, it is printed out along with the corresponding waste stream codes. After finding all potential incompatibilities for a given waste stream code, the program moves on to the next waste stream code until all waste stream codes have been processed.

To ensure accuracy, the reference database was printed and checked against the EPA document for chemical compatibility, and the WTWBIR waste stream database was printed and checked against the original WTWBIR forms from the generator sites. The list of potential chemical incompatibilities reported by the program was hand checked using the EPA document as a reference to assure proper functioning of the program. All potential chemical incompatibilities were then evaluated on a case-by-case basis to identify which, if any, of the reactions could occur, given the nature of the waste, and the its chemical constituents, and final waste form.

Waste streams are classified as "incompatible" if the potential exists for any of the following reactions:

- corrosion
- explosion
- heat generation
- gas generation (flammable gases)
- pressure build-up (nonflammable gases)
- toxic by-product generation

Each generator and storage site has produced a comprehensive list of all possible chemicals present in its waste. The chemical components found in each waste generation process are determined by examination of the process technology, by chemical analysis, or by process flow analysis. Under this system, all chemical inputs into the system are accounted for, even though all of these components may not be a part of the waste. For example, generator sites might include both acids and bases in their lists, even though the two groups have been neutralized prior to placement in a waste container.

In addition to the chemicals listed in Appendix 2 of the EPA document (Hatayama et al., 1980), the following components that exhibit toxicity characteristics defined under 40 CFR §261.24 were added to the chemical list in trace (<1 weight percent) quantities:

Group 3 Acids, Organic
- 2,4-D
- 2,4,5-TP (Silvex)

Group 17 Halogenated Organics
- Methoxychlor
- Toxaphene
- 2,4-D
- Hexachlorobutadiene
- Hexachloroethane
- Tetrachloroethylene
- 2,4,5-Trichlorophenol
- 2,4,6-Trichlorophenol

All hazardous constituents listed in the Part A Permit are present in the chemical lists and accounted for in the compatibility analysis.

The compounds listed on the Material Safety Data Sheet for Radiac™ wash were added to the chemical compatibility assessment. The reactive compounds associated with Radiac™ wash are:

GROUP	COMPOUND	CONCENTRATION
3	citric acid	M
106	water	D

The compounds found in the fire suppressants in use at the WIPP facility were added to evaluate chemical compatibility of these materials with the test wastes. The following reactive compounds were added:

GROUP	COMPOUND	CONCENTRATION
14	diethylene glycol monobutyl ether	D
15	fluorosurfactants	D
106	water	D

Ansulite 6 percent AFFF (AFC-3) contains diethylene glycol monobutyl ether, fluorosurfactants, and water. The FORAY Dry Chemical Extinguishing Agent contains potassium aluminum silicate, magnesium aluminum silicate, monoammonium phosphate, ammonium sulfate, and methyl hydrogen polysiloxane, which are not hazardous reactive constituents.

To account for packaging, container, and backfill materials, the following components were added to the database for each content code in dominant (>10 weight %) quantities:

Group 10 Caustics
Magnesium Oxide

Group 23 Metals, other elemental and alloys as sheets, rods, moldings, drops, etc.
Low Carbon Steel D

Group 101 Combustible Materials
Polyethylene D

The chemical concentration levels are reported as either Trace (T) (<1% by weight), Minor (M) (1-10%), or Dominant (D) (>10%). The chemical list is divided into groups based on chemical properties and structure (e.g., acids, caustics, metals, etc.). If incompatible groups are combined, the possibility exists for the reactions listed above. For example, a reaction between Group 1 (Acids, Mineral, Non-oxidizing) and Group 10 (Caustics) could result in heat generation.

Possible chemical incompatibilities between compounds present in trace quantities (<1 percent by weight) and compounds present in concentrations $\geq$ 1 percent by weight (i.e., D x T, D x T1, D x T2, D x T3, M x T, M x T1, M x T2, or M x T3) are included in this report. However, interactions between compounds present in trace quantities (<1 percent by weight) and compounds present in concentrations $\leq$ 1 percent by weight do not pose an incompatibility problem for the following reasons:

- The trace chemicals reported by the sites are in concentrations well below the trace limit of 1 weight percent. Sampling programs show that the concentration levels of these compounds are significantly lower than the upper limit of 1 percent.

- The trace chemicals are usually dispersed in the waste, which further dilutes concentrations of these materials.

- Trace chemicals that might be incompatible with major and dominant materials/chemicals would have reacted during the waste treatment process prior to placement in waste containers.

- Because of restrictions imposed by the EPA on reporting of hazardous wastes, some chemicals are listed in trace quantities even if they have already reacted. Hazardous waste regulations as promulgated by the EPA (EPA, 1988) (known as the mixture rule) require that a mixture of any solid waste and a hazardous waste listed in 40 CFR Part 261, Subpart D, be considered a hazardous waste subject to Resource Conservation and Recovery Act regulations. However, Subpart D does not list minimum concentrations for these listed wastes, with the result that any such mixtures must be considered hazardous waste even if the Subpart D constituent is at or below detection limits.

- The waste is either solidified and immobilized (solidified materials) or present in bulk form as a solid (solid materials). In almost all cases, any possible reactions take place before the waste is generated in its final form.

- Total trace chemicals within a payload container are limited to less than 5 weight percent.

All potential incompatibilities between trace, minor, and dominant compounds have been analyzed on a case-by-case basis for each waste stream reported in Table C-2 (Chapter C). Some chemicals listed as being present in the waste have reacted prior to placement in a waste container. For example, a site listing a caustic (Group 10) and an acid (Group 1) in its waste has only the neutralized product present in an immobilized form. Further reactions of this type do not occur once the waste is neutralized in its final form. An additional constraint on the chemicals and materials that can be present within each waste stream code is their gas generation potential due to radiolysis.

Unresolved incompatibilities between trace and minor, trace and dominant, minor and dominant, minor and minor, or dominant and dominant waste constituents were identified and segregated. These wastes cannot be transported until the incompatibilities are resolved (NuPac, 1989). Table C1-1 presents the chemical compatibility analysis for the modified chemical lists for the

waste streams presented in Table C-2 (Chapter C). A list of explanations describing any noted incompatibilities precedes Table C1-1.

Summary of Potential Incompatibilities for Waste Forms and Container Material

The following is a listing and explanation of compatibility code numbers used to identify potential incompatibilities in Table C1-1. Where incompatibilities are noted, it is important to remember that these potential incompatibilities will be removed prior to shipment of the waste to WIPP. That is, unacceptable waste properties listed in Chapter C, Section C1-b will be removed prior to shipping. Verification of the compatibility of final waste forms will be carried out by the WIPP Generator/Storage Site Waste Screening and Acceptance Audit Program (Appendix C8).

Explanation Code Number Descriptions

00 (1 x 10, 2 x 10, 3 x 10, 5 x 10, 10 x 13, 10 x 17, 10 x 18, 10 x 19, 10 x 21, 10 x 22, 10 x 23, 10 x 24, 10 x 25, 10 x 27, 10 x 32, 10 x 102, 10 x 107) These potential incompatibilities result from the addition of magnesium oxide backfill material. However, the hydration of magnesium oxide results in the formation of brucite ($Mg[OH]_2$), which buffers the pH of the solution at approximately 8.5. Therefore, caustic conditions are not produced by the use of magnesium oxide backfill.

0a. (1 x 4) The potential chemical incompatibility is the possible dehydration or displacement reactions between non-oxidizing mineral acids (Group 1) and alcohols and glycols in waste forms (Group 4) resulting in heat generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of non-oxidizing acid in generator waste streams. However, the non-oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

0aa. (1 x 10) The potential chemical incompatibility is the possible acid-base reaction between strong mineral acids (Group 1) and strong caustics (Group 10) resulting in heat generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of non-oxidizing acid in generator waste streams. However, the non-oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

0aaa. (1 x 14) The potential chemical incompatibility is the possible hydrolysis reaction between strong mineral acids (Group 1) and ethers (Group 14), resulting in heat generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of non-oxidizing acid in generator waste streams. However, the non-oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

0aaaa. (1 x 15) The potential chemical incompatibility is the possible formation of hydrogen fluoride when strong mineral acids (Group 1) mix with inorganic fluorides (Group 15), resulting in toxic gas generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of non-oxidizing acid in generator waste streams. However, the non-oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

0b. (1 x 17) The potential chemical incompatibility is the possible reaction between strong mineral acids (Group 1) and halogenated organics (Group 17), resulting in generation of heat and toxic hydrogen halide fumes. The potential chemical incompatibility results from reporting trace quantities (<1%) of non-oxidizing acid in generator waste streams. However, the non-oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

0bb. (1 x 19) The potential chemical incompatibility is the possible condensation reaction between strong mineral acids (Group 1) and ketones (Group 19), resulting in generation of heat. The potential chemical incompatibility results from reporting trace quantities (<1%) of non-oxidizing acid in generator waste streams. However, the non-oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

1. (1 x 23) The potential chemical incompatibility is the possible reaction between non-oxidizing mineral acids (Group 1) and metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23). The non-oxidizing mineral acids are present only in trace quantities (<1%) and are neutralized and bound in the cemented waste form. Due to the immobilization and prior reaction of the acids, the materials in this waste stream are considered chemically compatible.

2. (1 x 24) The potential chemical incompatibility is the tendency of non-oxidizing mineral acids (Group 1) to solubilize toxic metals and metal compounds (Group 24). The mineral acids are present only in trace quantities (<1%) and are neutralized and bound in the cemented waste form. Due to the immobilization and prior reaction of the non-oxidizing acids, the materials in this waste stream are considered chemically compatible.

3. (1 x 101) The potential chemical incompatibility is the possible reaction between non-oxidizing mineral acids (Group 1) and combustible materials (Group 101). The mineral acids are present only in trace quantities (<1%) and are neutralized and bound in the cemented waste form. An absorbent has been added to immobilize free liquids. Due to the immobilization and prior reaction of the non-oxidizing acids, the materials in this waste stream are considered chemically compatible.

3a. (1 x 102) The potential chemical incompatibility is the possible violent reaction between non-oxidizing mineral acids (Group 1) and explosives (Group 102). However, explosives are not allowed to be shipped to WIPP unless treatment renders them inert. Additionally, mineral acids are present only in trace quantities (<1%) and are neutralized prior to loading in waste containers. Therefore, the materials in this waste stream are considered chemically compatible.

3aa. (1 x 104) The potential chemical incompatibility is the possible reaction between non-oxidizing mineral acids (Group 1) and strong oxidizing agents (Group 104), resulting in heat and generation of toxic and corrosive gases. However, the mineral acids and oxidizing agents are present in trace quantities (<1%) and neutralized prior to loading in waste containers. Therefore, the materials in this waste stream are considered chemically compatible.

3b. (1 x 106) The potential chemical incompatibility is the possible reaction between mineral acids (Group 1) and water (Group 106), resulting in the generation of heat. This potential incompatibility results from the presence of water in Ansulite™ fire extinguishing agents and/or Radiac™ wash solutions and/or absorbed water. However, the mineral acids are present only in trace quantities (<1%) and are neutralized prior to loading in waste containers. In addition, the presence of any absorbed liquids are immobilized in an absorbent and would not be available for reaction.

3c. (2 x 3) The potential chemical incompatibility is the reaction of oxidizing mineral acids (Group 2) with organic acids (Group 3) resulting in heat and gas generation. The potential chemical incompatibility results from the use of citric acid in Radiac™ wash solutions. The solid citric acid is diluted during preparation of the Radiac™ wash and is often further diluted prior to use for decontamination. As a result, the potential for reactions of solid citric acid with oxidizing mineral acids in waste forms is removed.

3d. (2 x 4) The potential chemical incompatibility is the possible dehydration or displacement reactions between oxidizing mineral acids (Group 2) and alcohols and glycols (Group 4), resulting in heat generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

3e. (2 x 10) The potential chemical incompatibility is the possible acid-base reaction between oxidizing mineral acids (Group 2) and strong caustics (Group 10), resulting in heat generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

3ee. (2 x 13) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and esters (Group 13), resulting in heat generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

3f. (2 x 14) The potential chemical incompatibility is the possible hydrolysis reaction between oxidizing mineral acids (Group 2) and ethers (Group 14), resulting in heat generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

3g. (2 x 15) The potential chemical incompatibility is the possible formation of hydrogen fluoride when oxidizing mineral acids (Group 2) mix with inorganic fluorides (Group 15), resulting in toxic gas generation. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

3gg. (2 x 16) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and aromatic hydrocarbons (Group 16). Oxidation of the hydrocarbon may produce enough heat to ignite the mixture. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

3h. (2 x 17) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and halogenated organics (Group 17), resulting in generation of heat and toxic hydrogen halide fumes. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

3i. (2 x 19) The potential chemical incompatibility is the possible condensation reaction between oxidizing mineral acids (Group 2) and ketones (Group 19), resulting in generation of heat. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

3j. (2 x 20) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and mercaptans (Group 20), resulting in generation of heat and toxic hydrogen sulfide fumes. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

4. (2 x 23) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23). The oxidizing mineral acids are present only in trace quantities (<1%) and are reacted prior to loading in waste containers. In addition, the oxidizing mineral acids are fixed in the solidified product and would not be available to react with the metal.

5. (2 x 23) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23). The oxidizing mineral acids are present only in trace quantities (<1%) as residues on glass or rubber gloves, and not as free liquids that could react with metals.

6. (2 x 24) The potential chemical incompatibility is the solubilization of toxic metals and metal compounds (Group 24) in oxidizing mineral acids (Group 2). The oxidizing mineral acids are present only in trace quantities (<1%) and are reacted prior to loading in waste containers. In addition, the oxidizing mineral acids are fixed in the solidified product and would not be available to react with the metal.

7. (2 x 24) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and toxic metals and compounds (Group 24). The oxidizing mineral acids are present only in trace quantities (<1%) as residues on glass or rubber gloves, and not as free liquids that could react with metals.

7a. (2 x 27) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and nitro compounds (Group 27), resulting in generation of heat and toxic nitrogen oxide fumes. The potential chemical incompatibility results from reporting trace quantities (<1%) of oxidizing acid in generator waste streams. However, the oxidizing mineral acids are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

8. (2 x 101) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and combustible materials (Group 101). The oxidizing mineral acids are present only in trace quantities (<1%) as residues on glass or rubber gloves, and not as free liquids that could react with metals.

9. (2 x 101) The potential chemical incompatibility is the possible decomposition of combustible materials (Group 101) by the oxidizing mineral acids (Group 2). The oxidizing mineral acids are present only in trace quantities (<1%) and are reacted prior to loading in waste containers. In addition, the oxidizing mineral acids are fixed in the solidified product and would not be available to react with the combustible materials.

9a. (2 x 102) The potential chemical incompatibility is the possible violent reaction between oxidizing mineral acids (Group 2) and explosives (Group 102). However, explosives are not allowed to be shipped to WIPP unless treatment renders them inert. Additionally, mineral acids are present only in trace quantities (<1%) and are neutralized prior to loading in waste containers. Therefore, the materials in this waste stream are considered chemically compatible.

10. (2 x 106) The potential chemical incompatibility is the possible dissolution of oxidizing mineral acids (Group 2) by water (Group 106). The oxidizing mineral acids are present only in trace quantities (<1%) and reacted prior to loading in waste containers. Both the water and the oxidizing mineral acids are fixed in the solidified product and would not be available for reaction.

10a. (2 x 106) *The potential chemical incompatibility is the possible reaction between* oxidizing mineral acids (Group 2) and water (Group 106), resulting in the generation of heat. This potential incompatibility results from the presence of water in Ansulite™ fire extinguishing agents and/or Radiac™ wash solutions and/or absorbed water. However, the mineral acids are present only in trace quantities (<1%) and are neutralized prior to loading in waste containers. In addition, the presence of any absorbed liquids are immobilized in an absorbent and would not be available for reaction.

11. (3 x 4) The potential chemical incompatibility is the possible reaction between organic acids (Group 3) and alcohols and glycols (Group 4). The organic acids are immobilized in a cement matrix and not available to react with the alcohols and glycols. The alcohols and glycols are also immobilized in the solidified product.

11aa. (3 x 4) The potential chemical incompatibility is the heat generated by polymerization *of alcohols and glycols (Group 4) by organic acids (Group 3). Carboxylic acids with* α-halogen substituents, or α- or β-hydroxyl substituents (e.g., citric acid) are the main concern among the organic acids (Group 3). The potential chemical incompatibility results from the use of citric acid in Radiac™ wash solutions. The solid citric acid is diluted during preparation of the Radiac™ wash and is often further diluted prior to use for decontamination. As a result, the potential for reactions of solid citric acid with alcohols and glycols (Group 4) that are dispersed and fixed in waste forms is removed.

11b. (3 x 10) The potential chemical incompatibility is the possibility of acid-base reactions. The organic acids (Group 3) are neutralized in a cement matrix and are not available to react with the Caustics (Group 10). Thus, this potential chemical incompatibility would not occur.

11c. (3 x 10) The potential chemical incompatibility is the heat generated by reactions of organic acids (Group 3) with caustics (Group 10). The potential chemical incompatibility results from the use of citric acid in Radiac™ wash solutions. The solid citric acid is diluted during preparation of the Radiac™ wash and is often further diluted prior to use for decontamination. As a result, the potential for reactions of solid citric acid with caustics in test waste forms is removed. The caustic in the waste forms is calcium oxide. Thus, the more significant incompatibility is potential hydrolysis reaction between water and calcium oxide to release heat. Because the calcium oxide is dispersed in the wastes, reaction is considered unlikely.

11d. (3 x 15) The potential chemical incompatibility is toxic and corrosive fumes generated by reactions of organic acids (Group 3) with metal fluoride salts (Group 15). The potential chemical incompatibility results from the use of citric acid in Radiac™ wash solutions. The solid citric acid is diluted during preparation of the Radiac™ wash and is often further diluted prior to use for decontamination. As a result, the potential for reactions of solid citric acid with fluoride salts in waste forms is removed.

12. (3 x 24) The potential chemical incompatibility is the possible reaction between organic acids (Group 3) and toxic metals and compounds (Group 24). The organic acids are basified prior to cementation and do not exist as free acids in the resulting product. Based on the immobilization of the acids, reactions are considered highly unlikely. In this case, solubilization is not possible.

12aa. (3 x 24) The potential chemical incompatibility is solubilization of toxic metals (Group 24) by complexation with organic acids (Group 3). The potential chemical incompatibility results from the use of citric acid in Radiac™ wash solutions. The solid citric acid is diluted during preparation of the Radiac™ wash and is often further diluted prior to use for decontamination. As a result, the potential for reactions of solid citric acid with toxic metals in waste forms is removed.

12bbb. (3 x 104) The potential chemical incompatibility is decomposition of the hydrocarbon moiety of organic acids (Group 3) by oxidizing agents (Group 104) resulting in heat and gas formation. The potential chemical incompatibility results from the use of citric acid in Radiac™ wash solutions. The solid citric acid is diluted during preparation of the Radiac™ wash and is often further diluted prior to use for decontamination. As a result, the potential for reactions of solid citric acid with oxidizing agents that are dispersed and fixed in waste forms is removed.

12bb. (4 x 104) The potential chemical incompatibility is formation of unstable compounds by reaction of alcohols and glycols (Group 4) with oxidizing agents (Group 104). However the alcohols and glycols are present as trace quantities (<1%) in the waste stream, and they are further isolated by dissemination within the waste stream. Additionally, oxidizing agents must be neutralized prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

12b. (7 x 17) The potential chemical incompatibility between amines (Group 7) and halogenated organics (Group 17) would not occur because the halogenated organics are solidified and are not available for reaction.

12c. (7 x 24) The potential chemical incompatibility is the possible increase in the solubility of toxic metal compounds in water due to amines acting as potential surfactants. The amines are present only in trace (<1%) and are immobilized through absorption on sorbent materials. Also, these solid waste forms usually contain very little water and excess sorbents are added to waste containers to sorb any fluids.

12d. (7 x 104) The potential chemical incompatibility is formation of toxic nitrogen oxide fumes by reaction of amines (Group 7) with oxidizing agents (Group 104). However, the alcohols and glycols are present as trace quantities (<1%) in the waste stream, they are further isolated by dissemination within the waste stream. Additionally, oxidizing agents must be neutralized prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

12e. (8 x 23) The potential chemical incompatibility is combustion of some azo compounds (Group 8) on contact with surfaces of metal sheets, rods, drops, etc (Group 23). However the azo compounds are present as trace quantities (<1%) in the waste stream and are further isolated by dissemination within the waste stream. Therefore, spontaneous combustion by reaction with metal surfaces is unlikely.

12f. (8 x 106) The potential chemical incompatibility is the generation of nitrogen gas by reaction of some azo compounds (Group 8) with water (Group 106). This potential incompatibility results from the presence of water in Ansulite™ fire extinguishing agents and/or Radiac™ wash solutions and/or absorbed water. However, the azo compounds are present only in trace quantities (T<1%) and are disseminated in the waste containers, which minimizes their potential to form nitrogen gas. In addition, the presence of any absorbed liquids are immobilized in an absorbent and would not be available for reaction.

13. (10 x 17) The potential chemical incompatibility is the possible reaction between caustics (Group 10) and halogenated organics (Group 17). The caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. The halogenated

organics are present in only trace quantities (T<1%) and are absorbed, immobilized, or solidified. Due to the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

13a. (10 x 19) The potential chemical incompatibility is the possible self-condensation of ketones (Group 19) catalyzed by caustics (Group 10). The caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. Due to the immobilization of the calcium oxide in salt, reactions are considered highly unlikely.

14. (10 x 23) The potential incompatibility is the possible reaction between caustics (Group 10) metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23). The caustic in this waste stream code is calcium oxide, a solid, which is dispersed in the chloride salts. Due to the immobilization of the calcium oxide in salt, dissolution of metals in caustics is not possible.

15. (10 x 23) The potential incompatibility is the possible dissolution of metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23) in caustics (Group 10). The caustics are present only in trace quantities (<1%) and are reacted prior to loading in waste containers. In addition, the caustics are fixed in the cemented sludge and would not be available to react with the metals.

16. (10 x 24) The potential chemical incompatibility is the possible solubilization of toxic metals (Group 24) in caustics (Group 10). The caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. In this case, solubilization is not possible.

16a. (10 x 24) The potential incompatibility is the possible solubility of toxic metals (Group 24) in caustics (Group 10). The caustics are present only in trace (<1% quantities and are reacted prior to loading in waste containers. In addition, the caustics are fixed in the cemented sludge and would not be available to react with the metals.

16b. (10 x 27) The potential chemical incompatibility is the formation of salts from nitro alkanes (Group 27) and caustics (Group 10) in the presence of water. The only caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. In addition, liquids are immobilized through absorption on sorbent materials. Due to the immobilization of the caustic in the fused salt, this reaction would not occur.

16c. (10 x 102) The potential chemical incompatibility is the possible violent reaction between caustics (Group 10) and explosives (Group 102) due to the generation of heat. However, explosives are not allowed to be shipped to WIPP unless treatment renders them inert. Additionally, caustics are present only in minor quantities (<10%) and are

neutralized prior to loading in waste containers. Therefore, the materials in this waste stream are considered chemically compatible.

17. (10 x 107) This potential incompatibility is an artifact of the EPA method. Calcium oxide appears in Groups 10 and 107, and is compatible within itself.

17a. (14 x 104) This potential incompatibility is the reaction of ethers (Group 14) with strong oxidizers (Group 104) to produce heat, and possibly ignition or explosions. This incompatibility arises from the presence of diethylene glycol monobutyl ether in Ansulite™ fire extinguishing agents. However, the strong oxidizers are present in trace quantities (<1%) and disseminated in the waste, making ignition or explosions unlikely in the event the fire extinguishers are used.

17b. (14 x 107) This potential chemical incompatibility is the reaction of ethers (Group 14) with water reactives (Group 107). This incompatibility arises from the presence of diethylene glycol monobutyl ether in Ansulite™ fire extinguishing agents. However, the water reactive substances are present in trace quantities (<1%) and disseminated in the waste, making reactions unlikely in the event the fire extinguishers are used.

18. (15 x 107) This potential chemical incompatibility is the reaction of fluorides (Group 15) and water reactive substances (Group 107). The solid fluorides are present in only trace quantities (T<1%) and form part of the pyrochemical salt matrix. Calcium oxide, the only water reactive substance present, is a solid dispersed in the pyrochemical salt matrix. These salts always occur with each other and are compatible.

18a. (17 x 20) The potential chemical incompatibility is the possible reaction between halogenated organics (Group 17) and mercaptans (Group 20), resulting in generation of heat. The potential chemical incompatibility results from reporting trace quantities (<1%) of halogenated organics and mercaptans in generator waste streams. However, the chemicals are neutralized prior to packaging, and the materials in this waste stream are considered chemically compatible.

19. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23). The halogenated organics are present in only trace quantities (T1<1%) and are fixed in cemented sludge and would not be available to react with the metals.

20. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys, as sheets, rods, moldings, drops, etc. (Group 23). The halogenated organics are present in only trace quantities (T<1%) and are absorbed on combustibles. The halogenated organics are not present as free liquids to react with the metals.

21. (17 x 23) The potential chemical incompatibility is the potential reaction between halogenated organics (Group 17) and metals and other elemental alloys as sheets, rods, drops, moldings, etc. (Group 23). Aluminum and magnesium in bulk forms are especially reactive with halogenated hydrocarbons, releasing much heat. Although this is a potential incompatibility, the potential effects are considered minimal for the following reasons. First, the halogenated hydrocarbons are only present in trace quantities (<1 percent by weight) and are immobilized through absorption on sorbent materials or solidification with calcium silicates or gypsum-base processes. Second, although the metals of concern may occur in dominant quantities in the content code, the metals only occur as large pieces and not in powder form. Due to the trace quantities of immobilized halogenated organics and the non-powder size of the metal pieces, any reaction that may occur will produce minimal heat.

22. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys, as sheets, rods, moldings, drops, etc. (Group 23). The halogenated organics are present in only very small trace quantities (<1 part per million) as residual films on the glass and not as free liquids that could react with metals.

23. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23). The halogenated organics are present in only trace quantities (<1%) as coatings on solid organic materials and are not present as free liquids that could react with metals.

24. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23). The halogenated organics are present in only trace quantities (<1%) as coating on the inorganic solid materials and are not present as free liquids that could react with metals.

25. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23). The halogenated organics are fixed in the cemented product and would not be available for reaction.

26. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys, as sheets, rods, moldings, drops, etc. (Group 23). The halogenated organics are fixed in the solidified product and are not available for reaction with the metals.

27. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys, as sheets, rods, moldings, drops, etc. (Group 23). An absorbent has been added to immobilize any free liquids that may exist. Due to the trace quantities and immobilization of the halogenated organics, reactions are highly unlikely.

28. (17 x 104) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with oxidizing agents (Group 107), resulting in the liberation of heat and formation of toxic gases. The halogenated organics are present in only trace quantities (<1%) and are not in the form of free liquids. Additionally, the oxidizing agents are neutralized prior to loading waste containers. Therefore, based on the neutralization of the oxidizing agents, reactions are considered highly unlikely.

28a. (18 x 106) The potential incompatibility is the possible reaction between isocyanates (Group 18) with water (Group 106). The isocyanates are present only in trace quantities (<1%). The water is usually fixed in the solidified product and would not be available for reaction.

28aa. (18 x 106) The potential chemical incompatibility is between isocyanates (Group 18) and water (Group 106) to generate carbon dioxide gas and heat. The potential chemical incompatibility results from the use of water in Ansulite™ fire extinguishing agents and Radiac™ wash solutions. However, isocyanates in the waste forms are present in trace quantities (<1%), are neutralized and fixed prior to loading the waste containers, and are not available for reaction. Therefore, the final waste form contains compatible materials.

28aaa. (19 x 20) The potential chemical incompatibility is the reaction between ketones (Group 19) and mercaptans (Group 20), resulting in heat generation. These chemicals are present only in trace quantities (<1%) as coatings on laboratory glassware. Therefore, contact between the chemicals, if it occurs, will be limited.

28b. (21 x 101) The potential chemical incompatibility is the reaction of alkali and alkaline earth metals (Group 21) with residual water present in the combustible materials (101), resulting in heat generation and ignition of the combustible materials. However, the combustible materials are polyethylene and polyvinyl chloride packaging materials which contain no residual water. Additionally, alkali and alkaline earth metals must be neutralized prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

28c. (21 x 104) The potential chemical incompatibility is the violent reaction between alkali and alkaline earth metals (Group 21) and oxidizing agents (Group 104). Oxidizing agents are present in trace quantities (<1%) and are neutralized prior to packaging

Additionally, alkali and alkaline earth metals must be neutralized prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

28d. (21 x 106) The potential chemical incompatibility is the violent reaction between alkali and alkaline earth metals (Group 21) and water (Group 106), resulting in the evolution of hydrogen gas and formation of strong caustics. However, alkali and alkaline earth metals must be neutralized prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

28e. (22 x 106) The potential chemical incompatibility is the reaction of metal powders (Group 22) with water (Group 106), resulting in the evolution of hydrogen gas and production of heat. Metal powders or shavings are present as trace quantities (<1%) on paper, rags, and rubber. This potential incompatibility results from the presence of water in Ansulite™ fire extinguishing agents and/or Radiac™ wash solutions and/or absorbed water. However, metal powders or shavings are present as trace quantities (<1%) on paper, rags, and rubber, which minimizes their potential to form hydrogen gas. In addition, the presence of any absorbed liquids are immobilized in an absorbent and would not be available for reaction.

29. (23 x 104) The potential incompatibility is the possible reaction between metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23) and oxidizing agents (Group 104). The oxidizing agents are present only in trace quantities (<1%) and reacted prior to loading in waste containers. The waste is mixed with cement to absorb any residual liquid. Due to the immobilization and prior reaction of the oxidizing agents, reactions are highly unlikely.

30. (23 x 104) The potential incompatibility is the possible reaction between metals, other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23) and oxidizing agents (Group 104). The oxidizing agents are present only in trace quantities (<1%) and dissolved in aqueous solutions that were cemented into a solid monolith-type structure. Due to the immobilization and prior reaction of the oxidizing agents, reactions will not occur.

31. (23 x 107) The potential incompatibility is the possible reaction between metals and other elemental alloys, as sheets, rods, moldings, drops, etc. (Group 23) and water reactive substances (Group 107). The outer low carbon steel drum is the only Group 23 metal found in this content code. Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

32. (23 x 107) The potential incompatibility is the possible reaction between metals and other elemental alloys as sheets, rods, moldings, drops, etc. (Group 23) and water reactive substances (Group 107). Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

33. (24 x 106) The potential chemical incompatibility is the possible solubilization of toxic metals (Group 24), which is not a concern since the water (Group 106) from the sludge is fixed in the cemented product and would not be available for reaction.

33a. (24 x 106) The potential chemical incompatibility is the possible solubilization of toxic metals (Group 24) by water (Group 106). This potential chemical incompatibility results from the use of water in Ansulite™ fire extinguishing agents or Radiac™ wash solutions. Metals in the test waste forms are present in trace quantities (T<1%) as large pieces and not in powdered form. As a result, only minimal heat is expected to be formed.

34. (24 x 106) The potential incompatibility is the possible solubilization of toxic metals (Group 24). The water (Group 106) is fixed the in the cemented product and would not be available for reaction.

35. (24 x 107) The potential incompatibility is the possible reaction between toxic metals and metal compounds (Group 24) and water reactive substances (Group 107). The metals are present only in trace quantities (<1% by weight). Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

36. (24 x 107) The potential incompatibility is the possible reaction between toxic metals and metal compounds (Group 24) and water reactive substances (Group 107). Calcium oxide, the only water reactive substance present, is dispersed in chloride salts. Based on the immobilization of the calcium oxide in the salts, reactions are considered highly unlikely.

36a. (25 x 101) The potential chemical incompatibility is the reaction of nitrides (Group 25) with residual water present in the combustible materials (Group 101), resulting in formation of ammonia gas, heat generation, and possible ignition of the combustible materials. However, the combustible materials are polyethylene and polyvinyl chloride packaging materials which contain no residual water. Additionally, any reactive nitrides must be neutralized prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

36aa. (25 x 106) The potential chemical incompatibility is the reaction of nitrides (Group 25) with water present in the combustible materials (101), resulting in formation of ammonia gas, heat generation, and possible ignition of the combustible materials. However, any reactive nitrides must be neutralized prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

36b. (27 x 104) The potential incompatibility is the possible reaction between nitro compounds (Group 27) and oxidizing agents (Group 107). Calcium oxide, the only water reactive substance present, is dispersed in chloride salts. Reactive oxidizing agents must be neutralized prior to shipment to WIPP. Based on the immobilization of the calcium oxide in the salts and neutralization of oxidizing agents, reactions are considered highly unlikely.

36c. (29 x 104) The potential incompatibility is the possible reaction between saturated aliphatics (Group 29) and oxidizing agents (Group 104). However, reactive oxidizing agents must be neutralized prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

36d. (101 x 102) The potential incompatibility is the possible oxidation reaction between combustibles (Group 101) and explosives (102). However, explosives must be reacted prior to shipment to WIPP. Therefore, the final waste form will contain compatible materials.

37. (101 x 104) The potential incompatibility is the possible reaction between combustible materials (Group 101) and oxidizing agents (Group 104). The oxidizing agents are present only in trace quantities (<1%) and are reacted prior to loading in waste containers. In addition, cement is added to absorb any residual liquid. Due to the immobilization and prior reaction of the oxidizing agents, this content code is considered to be chemically compatible.

38. (101 x 104) The potential incompatibility is the possible reaction between combustible materials (Group 101) and oxidizing agents (Group 104). The oxidizing agents are present only in trace quantities (<1%) and are fixed in the solidified product. Due to the immobilization and prior reaction of the oxidizing agents, this content code is considered to be chemically compatible.

39. (101 x 107) The potential incompatibility is the possible reaction between combustible and flammable materials (Group 101) and water reactive substances (Group 107). The dominant combustible material in Group 101 is the polyethylene rigid drum liner. Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

40. (102 x 104) The potential incompatibility is the possible violent reaction between explosives (Group 102) and oxidizing agents (Group 104). However, both of these groups must be neutralized before shipment to WIPP. Therefore, the final waste form will contain compatible materials.

41. (104 x 107) The potential incompatibility is the possible violent reaction between oxidizing agents (Group 104) and water reactives (Group 107). However, both of these groups must be neutralized before shipment to WIPP. Therefore, the final waste form will contain compatible materials.

List of References for Appendix C1

Hatayama, H. K., J. J. Chen, E. R. de Vera, R. D. Stephens, and D. L. Storm, 1980, "A Method for Determining the Compatibility of Hazardous Wastes," EPA-600/2-80-076, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Nuclear Packaging, Inc. (NuPac), 1989, "Safety Analysis Report for the TRUPACT-II Shipping Package," Revision 4, Appendix 2.10.12, Nuclear Packaging, Inc., Federal Way, Washington.

U.S. Department of Energy (DOE), 1989, "TRUPACT-II Content Codes" (TRUCON), Revision 3, DOE/WIPP 89-004, U.S. Department of Energy, Carlsbad, New Mexico.

U.S. Environmental Protection Agency (EPA), 1988, Code of Federal Regulations, Part 190 to 399, U.S. Government Printing Office, Washington, D.C.

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TABLES

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
COMBUSTIBLE	IN W198	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
COMBUSTIBLE	IN W198	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x T	GF H	00
COMBUSTIBLE	IN W198	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	IN W198	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	IN W202	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
COMBUSTIBLE	IN W202	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x T	GF H	00
COMBUSTIBLE	IN W202	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	IN W202	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	IN W205	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
COMBUSTIBLE	IN W205	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x T	GF H	00
COMBUSTIBLE	IN W205	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	IN W205	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	IN W250	AMINES, ALIPHATIC & AROMATIC x METALS & METAL COMPOUNDS, TOXIC (7 x 24)	T x D	S	12c
COMBUSTIBLE	IN W250	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	0
COMBUSTIBLE	IN W250	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
COMBUSTIBLE	IN W250	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
COMBUSTIBLE	IN W252	AMINES, ALIPHATIC & AROMATIC x METALS & METAL COMPOUNDS, TOXIC (7 x 24)	T x D	S	12c
COMBUSTIBLE	IN W252	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
COMBUSTIBLE	IN W252	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
COMBUSTIBLE	IN W252	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
COMBUSTIBLE	IN W254	AMINES, ALIPHATIC & AROMATIC x METALS & METAL COMPOUNDS, TOXIC (7 x 24)	T x D	S	12c
COMBUSTIBLE	IN W254	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	IN W254	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
COMBUSTIBLE	IN W254	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
COMBUSTIBLE	IN W256	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	IN W256	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x M	S	00
COMBUSTIBLE	IN W256	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	M x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
COMBUSTIBLE	IN W325	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	IN W327	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	IN W330	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	IN W330	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	IN W330	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33
COMBUSTIBLE	IN W336	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	LA W004	ACIDS, MINERAL, NON-OXIDIZING x CAUSTICS (1 x 10)	T1 x D	H	00
COMBUSTIBLE	LA W004	ACIDS, MINERAL, NON-OXIDIZING x ETHERS (1 x 14)	T1 x D	H	0aaa
COMBUSTIBLE	LA W004	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	T1 x D	GT	0aaaa

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANA CODE NUMBER
COMBUSTIBLE	LA W004	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	T1 x D	GF H F	1
COMBUSTIBLE	LA W004	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	T1 x D	H G	3
COMBUSTIBLE	LA W004	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER (1 x 106)	T1 x D	H	3b
COMBUSTIBLE	LA W004	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T1 x D	H	00
COMBUSTIBLE	LA W004	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T1 x D	H F	3f
COMBUSTIBLE	LA W004	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T1 x D	GT	3g
COMBUSTIBLE	LA W004	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T1 x D	GF H F	4
COMBUSTIBLE	LA W004	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T1 x D	H F GT	9
COMBUSTIBLE	LA W004	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T1 x D	H	10a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c)
COMBUSTIBLE	LA W004	ACIDS, ORGANIC x CAUSTICS	T x D	H	00
		(3 x 10)			
COMBUSTIBLE	LA W004	ACIDS, ORGANIC x FLUORIDES, INORANIC	T x D	GT	11d
		(3 x 15)			
COMBUSTIBLE	LA W004	CAUSTICS x HALOGENATED ORGANICS	D x T1	H	00
		(10 x 17)			
COMBUSTIBLE	LA W004	CAUSTICS x KETONES	D x T	H	00
		(10 x 19)			
COMBUSTIBLE	LA W004	CAUSTICS x METALS OTHER ELEMENTAL & ALLOYS IN THE FORM OF POWDERS, VAPORS OR SPONGES	D x T2	GF H	0
		(10 x 22)			
COMBUSTIBLE	LA W004	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	15 00
		(10 x 23)			
COMBUSTIBLE	LA W004	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T1	S	00
		(10 x 24)			
COMBUSTIBLE	LA W004	CAUSTICS x NITRIDES	D x T1	U	00
		(10 x 25)			
COMBUSTIBLE	LA W004	CAUSTICS x NITRO COMPOUNDS	D x T1	H E	00
		(10 x 27)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
COMBUSTIBLE	LA W004	CAUSTICS x ORHANOPHOSPHATES, PHOSPHOTHIOATES & PHOSPHODITHIOATES (10 x 32)	D x T1	H E	00
COMBUSTIBLE	LA W004	CAUSTICS x EXPLOSIVES (10 x 102)	D x T2	H E	00
COMBUSTIBLE	LA W004	CAUSTICS x WATER REACTIVE SUBSTANCES (10 x 107)	D x T	EXTREMELY	00
COMBUSTIBLE	LA W004	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T1	H F	17a
COMBUSTIBLE	LA W004	ETHERS x WATER REACTIVE SUBSTANCES (14 x 107)	D x T	EXTREMELY	17b
COMBUSTIBLE	LA W004	FLUORIDES, INORANIC x WATER REACTIVE SUBSTANCES (15 x 107)	D x T	EXTREMELY	18
COMBUSTIBLE	LA W004	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T1 x D	H F	20
COMBUSTIBLE	LA W004	METALS OTHER ELEMENTAL & ALLOYS IN THE FORM OF POWDERS, VAPORS OR SPONGES x WATER & MIXTURES CONTAINING WATER (22 x 106)	T2 x D	GF H	28e
COMBUSTIBLE	LA W004	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG (23 x 104)	D x T1	H F	29

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c)
COMBUSTIBLE	LA W004	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x WATER REACTIVE SUBSTANCES	D x T	EXTREMELY	31
		(23 x 107)			
COMBUSTIBLE	LA W004	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T1 x D	S	33a
		(24 x 106)			
COMBUSTIBLE	LA W004	NITRIDES x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC	T1 x D	H GF F	36a
		(25 x 101)			
COMBUSTIBLE	LA W004	NITRIDES x WATER & MIXTURES CONTAINING WATER	T1 x D	GF H	36aa
		(25 x 106)			
COMBUSTIBLE	LA W004	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x EXPLOSIVES	D x T2	H E	36
		(101 x 102)			
COMBUSTIBLE	LA W004	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG	D x T1	H F G	38
		(101 x 104)			
COMBUSTIBLE	LA W004	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x WATER REACTIVE SUBSTANCES	D x T	EXTREMELY	39
		(101 x 107)			
COMBUSTIBLE	LL M001	ACIDS, MINERAL, NON-OXIDIZING x CAUSTICS	T x D	H	00
		(1 x 10)			
COMBUSTIBLE	LL M001	ACIDS, MINERAL, NON-OXIDIZING x ETHERS	T x D	H	0aaa
		(1 x 14)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
COMBUSTIBLE	LL M001	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	T x D	GT	0aaaa
COMBUSTIBLE	LL M001	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	T x D	GF H F	1
COMBUSTIBLE	LL M001	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	T x D	H G	3
COMBUSTIBLE	LL M001	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER (1 x 106)	T x D	H	3b
COMBUSTIBLE	LL M001	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
COMBUSTIBLE	LL M001	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
COMBUSTIBLE	LL M001	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
COMBUSTIBLE	LL M001	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	4
COMBUSTIBLE	LL M001	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	9

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
COMBUSTIBLE	LL M001	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER	T x D	H	10
		(2 x 106)			
COMBUSTIBLE	LL M001	ACIDS, ORGANIC x CAUSTICS	T x D	H	00
		(3 x 10)			
COMBUSTIBLE	LL M001	ACIDS, ORGANIC x FLUORIDES, INORANIC	T x D	GT	11d
		(3 x 15)			
COMBUSTIBLE	LL M001	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
COMBUSTIBLE	LL M001	CAUSTICS x KETONES	D x T	H	0
		(10 x 19)			
COMBUSTIBLE	LL M001	CAUSTICS x METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS	D x T	GF H	00
		(10 x 21)			
COMBUSTIBLE	LL M001	CAUSTICS x METALS OTHER ELEMENTAL & ALLOYS IN THE FORM OF POWDERS, VAPORS OR SPONGES	D x T	GF H	00
		(10 x 22)			
COMBUSTIBLE	LL M001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	15 00
		(10 x 23)			
COMBUSTIBLE	LL M001	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
COMBUSTIBLE	LL M001	CAUSTICS x EXPLOSIVES (10 x 102)	D x T	H E	00
COMBUSTIBLE	LL M001	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T	H F	17a
COMBUSTIBLE	LL M001	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	26
COMBUSTIBLE	LL M001	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (21 x 101)	T x D	H G F	28b
COMBUSTIBLE	LL M001	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x WATER & MIXTURES CONTAINING WATER (21 x 106)	T x D	GF H	28d
COMBUSTIBLE	LL M001	METALS OTHER ELEMENTAL & ALLOYS IN THE FORM OF POWDERS, VAPORS OR SPONGES x WATER & MIXTURES CONTAINING WATER (22 x 106)	T x D	GF H	28e
COMBUSTIBLE	LL M001	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG (23 x 104)	D x T	H F	30
COMBUSTIBLE	LL M001	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34
COMBUSTIBLE	LL M001	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x EXPLOSIVES (101 x 102)	D x T	H E	36d

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
COMBUSTIBLE	LL M001	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG (101 x 104)	D x T	H F G	38
COMBUSTIBLE	RL M009	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	RL M010	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	RL M010	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 23)	D x T	S	00
COMBUSTIBLE	RL M010	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	RL M011	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	RL M011	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	RL M011	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	RL M012	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
COMBUSTIBLE	RL M012	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	RL M012	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
COMBUSTIBLE	RL M013	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
COMBUSTIBLE	RL M013	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
COMBUSTIBLE	RL M013	CAUSTICS x KETONES (10 x 19)	D x T	H	00
COMBUSTIBLE	RL M013	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	RL M013	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00
COMBUSTIBLE	RL M013	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
COMBUSTIBLE	RL M014	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
COMBUSTIBLE	RL M014	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	RL M014	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	RL M015	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	RL M015	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	RL M015	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	RL M016	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
COMBUSTIBLE	RL M016	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	RL M016	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	RL M016	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
COMBUSTIBLE	RL M016	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	RL M022	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
COMBUSTIBLE	RL M022	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
COMBUSTIBLE	RL M022	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
COMBUSTIBLE	RL M023	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
FILTER	AW M003	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
FILTER	AW M003	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
FILTER	AW M003	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
FILTER	IN W214	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
FILTER	IN W214	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
FILTER	IN W214	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
FILTER	RF W066	CAUSTICS x HALOGENATED ORGANICS	D x T1	H	00
		(10 x 17)			
FILTER	RF W066	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
FILTER	RF W066	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T1 x D	H F	21
		(17 x 23)			
FILTER	RF W067	CAUSTICS x HALOGENATED ORGANICS	D x T1	H	00
		(10 x 17)			
FILTER	RF W067	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
FILTER	RF W067	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T1 x D	H F	23
		(17 x 23)			
GRAPHITE	IN W272	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
GRAPHITE	IN W272	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
GRAPHITE	IN W272	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	24
GRAPHITE	IN W275	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
GRAPHITE	IN W275	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
GRAPHITE	IN W275	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	24
GRAPHITE	IN W276	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
GRAPHITE	IN W276	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
GRAPHITE	IN W276	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
GRAPHITE	RF W060	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
GRAPHITE	RF W060	CAUSTICS x METALS & METAL COMPOUNDS,TOXIC (10 x 24)	D x M	S	00
GRAPHITE	RF W060	METALS & METAL COMPOUNDS,TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	M x D	S	33a
HETEROGENEOUS	AW W020	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	AW W020	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
HETEROGENEOUS	AW W020	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	3
HETEROGENEOUS	IN M002	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN M002	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
HETEROGENEOUS	IN M002	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
HETEROGENEOUS	IN W139	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	IN W139	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
HETEROGENEOUS	IN W139	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
HETEROGENEOUS	IN W169	AMINES, ALIPHATIC & AROMATIC x HALOGENATED ORGANICS (7 x 17)	D x T	H G	12b
HETEROGENEOUS	IN W169	AMINES, ALIPHATIC & AROMATIC x METALS & METAL COMPOUNDS, TOXIC (7 x 24)	D x T	S	12c
HETEROGENEOUS	IN W169	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	IN W169	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W169	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
HETEROGENEOUS	IN W169	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
HETEROGENEOUS	IN W169	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
HETEROGENEOUS	IN W170	CAUSTICS x ESTERS	D x T	H	00
		(10 x 13)			
HETEROGENEOUS	IN W170	CAUSTICS x KETONES	D x T	H	00
		(10 x 19)			
HETEROGENEOUS	IN W170	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	IN W170	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
HETEROGENEOUS	IN W170	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33
		(24 x 106)			
HETEROGENEOUS	IN W171	CAUSTICS x ESTERS	D x T	H	00
		(10 x 13)			
HETEROGENEOUS	IN W171	CAUSTICS x KETONES	D x T	H	00
		(10 x 19)			
HETEROGENEOUS	IN W171	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	IN W171	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER
HETEROGENEOUS	IN W171	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
HETEROGENEOUS	IN W172	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	IN W172	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W172	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	33a
HETEROGENEOUS	IN W186	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	IN W186	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W186	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
HETEROGENEOUS	IN W186	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
HETEROGENEOUS	IN W186	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

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HETEROGENEOUS	IN W189	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W189	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
HETEROGENEOUS	IN W189	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
HETEROGENEOUS	IN W197	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	IN W197	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x T	GF H	[illegible]
HETEROGENEOUS	IN W197	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
HETEROGENEOUS	IN W197	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
HETEROGENEOUS	IN W203	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W203	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
HETEROGENEOUS	IN W203	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
HETEROGENEOUS	IN W204	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	IN W204	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
HETEROGENEOUS	IN W204	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
HETEROGENEOUS	IN W225	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	IN W225	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x D	S	00
		(10 x 24)			
HETEROGENEOUS	IN W225	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	D x D	S	33a
		(24 x 106)			
HETEROGENEOUS	IN W259	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	IN W259	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	IN W259	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
HETEROGENEOUS	IN W265	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	IN W265	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W265	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
HETEROGENEOUS	IN W265	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	2
HETEROGENEOUS	IN W265	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
HETEROGENEOUS	IN W269	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W271	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W271	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	IN W271	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
HETEROGENEOUS	IN W281	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W281	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
HETEROGENEOUS	IN W281	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
HETEROGENEOUS	IN W283	ACIDS, MINERAL, NON-OXIDIZING x CAUSTICS (1 x 10)	T x D	H	00
HETEROGENEOUS	IN W283	ACIDS, MINERAL, NON-OXIDIZING x ETHERS (1 x 14)	T x D	H	0aaa
HETEROGENEOUS	IN W283	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	T x D	GT	0aaaa
HETEROGENEOUS	IN W283	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	T x D	GF H F	1
HETEROGENEOUS	IN W283	ACIDS, MINERAL, NON-OXIDIZING x METALS & METAL COMPOUNDS, TOXIC (1 x 24)	T x M	S	2

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	IN W283	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	T x D	H G	3
HETEROGENEOUS	IN W283	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER (1 x 106)	T x D	H	3b
HETEROGENEOUS	IN W283	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
HETEROGENEOUS	IN W283	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
HETEROGENEOUS	IN W283	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3
HETEROGENEOUS	IN W283	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	5
HETEROGENEOUS	IN W283	ACIDS, MINERAL, OXIDIZING x METALS & METAL COMPOUNDS, TOXIC (2 x 24)	T x M	S	7
HETEROGENEOUS	IN W283	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	8
HETEROGENEOUS	IN W283	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER
HETEROGENEOUS	IN W283	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	IN W283	CAUSTICS x ISOCYANATES (10 x 18)	D x T	H P G	00
HETEROGENEOUS	IN W283	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W283	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x M	S	00
HETEROGENEOUS	IN W283	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T	H F	17a
HETEROGENEOUS	IN W283	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	24
HETEROGENEOUS	IN W283	ISOCYANATES x WATER & MIXTURES CONTAINING WATER (18 x 106)	T x D	H G	28aa
HETEROGENEOUS	IN W283	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG (23 x 104)	D x T	H F	30
HETEROGENEOUS	IN W283	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	M x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI(CODE NUMBER(c
HETEROGENEOUS	IN W283	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG (101 x 104)	D x T	H F G	37
HETEROGENEOUS	IN W285	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W285	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
HETEROGENEOUS	IN W285	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
HETEROGENEOUS	IN W289	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	0
HETEROGENEOUS	IN W289	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W289	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
HETEROGENEOUS	IN W289	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
HETEROGENEOUS	IN W289	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
HETEROGENEOUS	IN W291	CAUSTICS x ESTERS	D x T	H	00
		(10 x 13)			
HETEROGENEOUS	IN W291	CAUSTICS x KETONES	D x T	H	00
		(10 x 19)			
HETEROGENEOUS	IN W291	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	IN W302	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
HETEROGENEOUS	IN W302	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	IN W302	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	20
		(17 x 23)			
HETEROGENEOUS	IN W323	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	IN W323	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
HETEROGENEOUS	IN W323	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
HETEROGENEOUS	IN W329	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W334	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W345	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	IN W351	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	INW2698	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	[illegible]
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x ALCOHOLS & GLYCOLS (1 x 4)	M x T	H	0a
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x CAUSTICS (1 x 10)	M x D	H	0aa 00
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x ETHERS (1 x 14)	M x D	H	0aaa
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	M x D	GT	0aaaa

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x HALOGENATED ORGANICS (1 x 17)	M x T	H GT	0b
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x KETONES (1 x 19)	M x T	H	0bb
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x METALS & METAL COMPOUNDS, TOXIC (1 x 24)	M x T	S	2
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	M x T	H G	3
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x EXPLOSIVES (1 x 102)	M x T	H E	3a
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x OXIDIZING AGENTS, STRONG (1 x 104)	M x T	H GT	3aa
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER (1 x 106)	M x D	H	3b
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x ACIDS, ORGANIC (2 x 3)	M x T	G H	3c
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x ALCOHOLS & GLYCOLS (2 x 4)	M x T	H F	3d

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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(c) See text

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HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	M x D	H	3e 00
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	M x D	H F	3f
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	M x D	GT	3g
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x HALOGENATED ORGANICS (2 x 17)	M x T	H F GT	3h
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x KETONES (2 x 19)	M x T	H F	3i
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x METALS & METAL COMPOUNDS, TOXIC (2 x 24)	M x T	S	6 7
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	M x T	H F GT	8 9
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x EXPLOSIVES (2 x 102)	M x T	H E	9a
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	M x D	H	10a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
HETEROGENEOUS	NT W001	ACIDS, ORGANIC x CAUSTICS (3 x 10)	T x D	H	11b 00
HETEROGENEOUS	NT W001	ACIDS, ORGANIC x FLUORIDES, INORANIC (3 x 15)	T x D	GT	11d
HETEROGENEOUS	NT W001	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	13 00
HETEROGENEOUS	NT W001	CAUSTICS x KETONES (10 x 19)	D x T	H	13a 00
HETEROGENEOUS	NT W001	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	16a 00
HETEROGENEOUS	NT W001	CAUSTICS x EXPLOSIVES (10 x 102)	D x T	H E	16c 00
HETEROGENEOUS	NT W001	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T	H F	17a
HETEROGENEOUS	NT W001	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33 33a
HETEROGENEOUS	NT W001	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	T x M	GF H F	1

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	NT W001	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x M	GF H F	4 5
		(2 x 23)			
HETEROGENEOUS	NT W001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x M	GF H	15 00
		(10 x 23)			
HETEROGENEOUS	NT W001	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x M	H F	20 24
		(17 x 23)			
HETEROGENEOUS	NT W001	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC	T x D	H G F	28b
		(21 x 101)			
HETEROGENEOUS	NT W001	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG	M x T	H F	3[illegible]
		(23 x 104)			
HETEROGENEOUS	NT W001	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x EXPLOSIVES	D x T	H E	36d
		(101 x 102)			
HETEROGENEOUS	NT W001	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG	D x T	H F G	38
		(101 x 104)			
HETEROGENEOUS	OR W040	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	OR W040	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	OR W040	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
HETEROGENEOUS	OR W044	ACIDS, MINERAL, NON-OXIDIZING x CAUSTICS	T x D	H	00
		(1 x 10)			
HETEROGENEOUS	OR W044	ACIDS, MINERAL, NON-OXIDIZING x ETHERS	T x D	H	0aaa
		(1 x 14)			
HETEROGENEOUS	OR W044	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC	T x D	GT	0aaaa
		(1 x 15)			
HETEROGENEOUS	OR W044	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	GF H F	1
		(1 x 23)			
HETEROGENEOUS	OR W044	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC	T x D	H G	3
		(1 x 101)			
HETEROGENEOUS	OR W044	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER	T x D	H	3b
		(1 x 106)			
HETEROGENEOUS	OR W044	ACIDS, MINERAL, OXIDIZING x CAUSTICS	T x D	H	00
		(2 x 10)			
HETEROGENEOUS	OR W044	ACIDS, MINERAL, OXIDIZING x ETHERS	T x D	H F	3f
		(2 x 14)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	OR W044	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
HETEROGENEOUS	OR W044	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	5
HETEROGENEOUS	OR W044	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	8
HETEROGENEOUS	OR W044	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10a
HETEROGENEOUS	OR W044	ACIDS, ORGANIC x CAUSTICS (3 x 10)	T2 x D	H	00
HETEROGENEOUS	OR W044	ACIDS, ORGANIC x FLUORIDES, INORANIC (3 x 15)	T2 x D	GT	11d
HETEROGENEOUS	OR W044	AZO COMPOUNDS, DIAZO COMPOUNDS, & HYDRAZINES x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (8 x 23)	T2 x D	H F G	12e
HETEROGENEOUS	OR W044	AZO COMPOUNDS, DIAZO COMPOUNDS, & HYDRAZINES x WATER & MIXTURES CONTAINING WATER (8 x 106)	T2 x D	G	12f
HETEROGENEOUS	OR W044	CAUSTICS x ESTERS (10 x 13)	D x T2	H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
HETEROGENEOUS	OR W044	CAUSTICS x HALOGENATED ORGANICS	D x T2	H	00
		(10 x 17)			
HETEROGENEOUS	OR W044	CAUSTICS x KETONES	D x T2	H	00
		(10 x 19)			
HETEROGENEOUS	OR W044	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	15 00
		(10 x 23)			
HETEROGENEOUS	OR W044	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
HETEROGENEOUS	OR W044	CAUSTICS x ORHANOPHOSPHATES, PHOSPHOTHIOATES & PHOSPHODITHIOATES	D x T1	H E	00
		(10 x 32)			
HETEROGENEOUS	OR W044	ETHERS x OXIDIZING AGENTS, STRONG	D x T1	H F	17a
		(14 x 104)			
HETEROGENEOUS	OR W044	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T2 x D	H F	20 22
		(17 x 23)			
HETEROGENEOUS	OR W044	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG	D x T1	H F	29
		(23 x 104)			
HETEROGENEOUS	OR W044	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	OR W044	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG	D x T1	H F G	38
		(101 x 104)			
HETEROGENEOUS	OR W045	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	OR W045	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
HETEROGENEOUS	OR W045	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
HETEROGENEOUS	OR W047	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	OR W047	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
HETEROGENEOUS	OR W047	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
HETEROGENEOUS	RF M002	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
HETEROGENEOUS	RF M002	CAUSTICS x KETONES	D x T	H	00
		(10 x 19)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
HETEROGENEOUS	RF M002	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	RF M002	CAUSTICS x NITRO COMPOUNDS	D x T	H E	00
		(10 x 27)			
HETEROGENEOUS	RF M002	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	20
		(17 x 23)			
HETEROGENEOUS	RF W008	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
HETEROGENEOUS	RF W008	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	RF W008	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	23
		(17 x 23)			
HETEROGENEOUS	RF W012	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
HETEROGENEOUS	RF W012	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	RF W012	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	20
		(17 x 23)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
HETEROGENEOUS	RF W036	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	RF W036	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	RF W036	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
HETEROGENEOUS	RF W036	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	24
HETEROGENEOUS	RF W036	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	?
HETEROGENEOUS	RL M004	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
HETEROGENEOUS	RL M006	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
HETEROGENEOUS	RL M006	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	RL M006	CAUSTICS x KETONES (10 x 19)	D x T	H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANA CODE NUMBER
HETEROGENEOUS	RL M006	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	RL M006	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	20
		(17 x 23)			
HETEROGENEOUS	RL M031	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	RL M201	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	SA W134	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	SR W026	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
HETEROGENEOUS	SR W026	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
HETEROGENEOUS	SR W026	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
HETEROGENEOUS	SR W026	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	20
		(17 x 23)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
HETEROGENEOUS	SR W026	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
HETEROGENEOUS	SR W027	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
HETEROGENEOUS	SR W027	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
HETEROGENEOUS	SR W027	CAUSTICS x KETONES (10 x 19)	D x T	H	00
HETEROGENEOUS	SR W027	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	r
HETEROGENEOUS	SR W027	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
HETEROGENEOUS	SR W027	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00
HETEROGENEOUS	SR W027	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
HETEROGENEOUS	SR W027	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
INORGANIC NON-METAL	IN W161	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
INORGANIC NON-METAL	IN W161	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
INORGANIC NON-METAL	IN W161	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
INORGANIC NON-METAL	IN W230	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
INORGANIC NON-METAL	IN W230	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
INORGANIC NON-METAL	IN W230	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	24
INORGANIC NON-METAL	IN W240	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T3	H	00
INORGANIC NON-METAL	IN W240	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
INORGANIC NON-METAL	IN W240	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT =toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
INORGANIC NON-METAL	IN W240	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T3 x D	H F	24
INORGANIC NON-METAL	IN W240	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
INORGANIC NON-METAL	IN W243	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
INORGANIC NON-METAL	IN W243	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	5
INORGANIC NON-METAL	IN W243	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISCELLANEOUS (2 x 101)	T x D	H F GT	8
INORGANIC NON-METAL	IN W243	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10a
INORGANIC NON-METAL	IN W243	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
INORGANIC NON-METAL	IN W243	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
INORGANIC NON-METAL	IN W243	CAUSTICS x KETONES (10 x 19)	D x T	H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER
INORGANIC NON-METAL	IN W243	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
INORGANIC NON-METAL	IN W243	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
INORGANIC NON-METAL	IN W243	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00
INORGANIC NON-METAL	IN W243	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	24
INORGANIC NON-METAL	IN W243	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
INORGANIC NON-METAL	IN W245	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
INORGANIC NON-METAL	IN W245	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
INORGANIC NON-METAL	IN W245	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
INORGANIC NON-METAL	IN W245	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	5

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
INORGANIC NON-METAL	IN W245	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC	T x D	H F GT	8
		(2 x 101)			
INORGANIC NON-METAL	IN W245	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER	T x D	H	10a
		(2 x 106)			
INORGANIC NON-METAL	IN W245	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
INORGANIC NON-METAL	IN W245	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
INORGANIC NON-METAL	IN W245	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
INORGANIC NON-METAL	IN W245	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	24
		(17 x 23)			
INORGANIC NON-METAL	IN W245	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
INORGANIC NON-METAL	IN W247	ACIDS, MINERAL, OXIDIZING x CAUSTICS	T x D	H	00
		(2 x 10)			
INORGANIC NON-METAL	IN W247	ACIDS, MINERAL, OXIDIZING x ETHERS	T x D	H F	3f
		(2 x 14)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
INORGANIC NON-METAL	IN W247	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC	T x D	GT	3g
		(2 x 15)			
INORGANIC NON-METAL	IN W247	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC	T x D	H F GT	8
		(2 x 101)			
INORGANIC NON-METAL	IN W247	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER	T x D	H	10a
		(2 x 106)			
INORGANIC NON-METAL	IN W247	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
INORGANIC NON-METAL	IN W247	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x T	GF H	00
		(10 x 23)			
INORGANIC NON-METAL	IN W247	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
INORGANIC NON-METAL	IN W247	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
INORGANIC NON-METAL	IN W249	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
INORGANIC NON-METAL	IN W249	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
INORGANIC NON-METAL	IN W249	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
INORGANIC NON-METAL	MD M001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
INORGANIC NON-METAL	RF W026	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
INORGANIC NON-METAL	RF W026	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
INORGANIC NON-METAL	RF W026	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	
		(17 x 23)			
INORGANIC NON-METAL	RF W032	CAUSTICS x HALOGENATED ORGANICS	D x T3	H	00
		(10 x 17)			
INORGANIC NON-METAL	RF W032	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
INORGANIC NON-METAL	RF W032	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x D	S	00
		(10 x 24)			
INORGANIC NON-METAL	RF W032	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T3 x D	H F	22
		(17 x 23)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
INORGANIC NON-METAL	RF W032	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
INORGANIC NON-METAL	RF W052	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T3	H	00
INORGANIC NON-METAL	RF W052	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
INORGANIC NON-METAL	RF W052	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
INORGANIC NON-METAL	RF W052	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T3 x D	H F	22
INORGANIC NON-METAL	RF W052	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
INORGANIC NON-METAL	RF W056	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T3	H	00
INORGANIC NON-METAL	RF W056	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
INORGANIC NON-METAL	RF W056	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIO CODE NUMBER(c)
INORGANIC NON-METAL	RF W056	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T3 x D	H F	22
INORGANIC NON-METAL	RF W056	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
INORGANIC NON-METAL	RF W057	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
INORGANIC NON-METAL	RF W057	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
INORGANIC NON-METAL	RF W057	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	22
LEAD/CADMIUM METAL WASTE	AW M001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
LEAD/CADMIUM METAL WASTE	AW M001	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
LEAD/CADMIUM METAL WASTE	AW M001	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a 34
LEAD/CADMIUM METAL WASTE	AW M002	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
LEAD/CADMIUM METAL WASTE	AW M002	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
LEAD/CADMIUM METAL WASTE	AW M002	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
LEAD/CADMIUM METAL WASTE	AW W016	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
LEAD/CADMIUM METAL WASTE	AW W016	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x M	S	00
LEAD/CADMIUM METAL WASTE	AW W016	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	M x D	S	33a
LEAD/CADMIUM METAL WASTE	AW W022	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
LEAD/CADMIUM METAL WASTE	AW W022	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x M	S	00
LEAD/CADMIUM METAL WASTE	AW W022	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	M x D	S	33a 34
LEAD/CADMIUM METAL WASTE	ET M001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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LEAD/CADMIUM METAL WASTE	ET M001	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x D	S	00
		(10 x 24)			
LEAD/CADMIUM METAL WASTE	ET M001	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	D x D	S	33a
		(24 x 106)			
LEAD/CADMIUM METAL WASTE	IN M004	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
LEAD/CADMIUM METAL WASTE	IN M004	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x M	S	00
		(10 x 24)			
LEAD/CADMIUM METAL WASTE	IN M004	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	M x D	S	3
		(24 x 106)			
LEAD/CADMIUM METAL WASTE	IN M005	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
LEAD/CADMIUM METAL WASTE	IN M005	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x M	S	00
		(10 x 24)			
LEAD/CADMIUM METAL WASTE	IN M005	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	M x D	S	33a
		(24 x 106)			
LEAD/CADMIUM METAL WASTE	RF W029	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
LEAD/CADMIUM METAL WASTE	RF W029	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
LEAD/CADMIUM METAL WASTE	RF W029	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
LEAD/CADMIUM METAL WASTE	RF W041	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
LEAD/CADMIUM METAL WASTE	RF W041	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
LEAD/CADMIUM METAL WASTE	RF W041	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
LEAD/CADMIUM METAL WASTE	RF W041	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	5
LEAD/CADMIUM METAL WASTE	RF W041	ACIDS, MINERAL, OXIDIZING x METALS & METAL COMPOUNDS, TOXIC (2 x 24)	T x D	S	7
LEAD/CADMIUM METAL WASTE	RF W041	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	8
LEAD/CADMIUM METAL WASTE	RF W041	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
LEAD/CADMIUM METAL WASTE	RF W041	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
LEAD/CADMIUM METAL WASTE	RF W041	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
LEAD/CADMIUM METAL WASTE	RF W041	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
LEAD/CADMIUM METAL WASTE	RL M019	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
LEAD/CADMIUM METAL WASTE	RL M019	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
LEAD/CADMIUM METAL WASTE	RL M019	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
LEAD/CADMIUM METAL WASTE	RL M020	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
LEAD/CADMIUM METAL WASTE	RL M020	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
LEAD/CADMIUM METAL WASTE	RL M020	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
SALT WASTE	IN M001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SALT WASTE	IN M001	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SALT WASTE	IN M001	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SALT WASTE	IN W311	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SALT WASTE	IN W311	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SALT WASTE	IN W311	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
SALT WASTE	IN W312	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	14 00
SALT WASTE	IN W312	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T1	S	16 00
SALT WASTE	IN W312	CAUSTICS x WATER REACTIVE SUBSTANCES (10 x 107)	D x M	EXTREMELY	17 00

M

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
SALT WASTE	IN W312	ETHERS x WATER REACTIVE SUBSTANCES (14 x 107)	D x M	EXTREMELY	17b
SALT WASTE	IN W312	FLUORIDES, INORANIC x WATER REACTIVE SUBSTANCES (15 x 107)	D x M	EXTREMELY	18
SALT WASTE	IN W312	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x WATER REACTIVE SUBSTANCES (23 x 107)	D x M	EXTREMELY	31
SALT WASTE	IN W312	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T1 x D	S	33a
SALT WASTE	IN W312	METALS & METAL COMPOUNDS, TOXIC x WATER REACTIVE SUBSTANCES (24 x 107)	T1 x M	EXTREMELY	3[illegible]
SALT WASTE	IN W312	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x WATER REACTIVE SUBSTANCES (101 x 107)	D x M	EXTREMELY	39
SALT WASTE	IN W314	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SALT WASTE	IN W314	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SALT WASTE	IN W314	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
SALT WASTE	RF W058	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15 00
SALT WASTE	RF W058	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T1	S	16 00
SALT WASTE	RF W058	CAUSTICS x WATER REACTIVE SUBSTANCES (10 x 107)	D x M	EXTREMELY	17 00
SALT WASTE	RF W058	ETHERS x WATER REACTIVE SUBSTANCES (14 x 107)	D x M	EXTREMELY	17b
SALT WASTE	RF W058	FLUORIDES, INORANIC x WATER REACTIVE SUBSTANCES (15 x 107)	D x M	EXTREMELY	18
SALT WASTE	RF W058	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x WATER REACTIVE SUBSTANCES (23 x 107)	D x M	EXTREMELY	31
SALT WASTE	RF W058	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T1 x D	S	33a
SALT WASTE	RF W058	METALS & METAL COMPOUNDS, TOXIC x WATER REACTIVE SUBSTANCES (24 x 107)	T1 x M	EXTREMELY	35
SALT WASTE	RF W058	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x WATER REACTIVE SUBSTANCES (101 x 107)	D x M	EXTREMELY	39

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
SOILS	IN W263	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOILS	IN W263	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOILS	IN W263	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SOILS	RL M007	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOILS	RL M007	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOILS	RL M007	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SOLIDIFIED INORGANICS	AL W005	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
SOLIDIFIED INORGANICS	AL W005	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
SOLIDIFIED INORGANICS	AL W005	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
SOLIDIFIED INORGANICS	AL W005	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	4
SOLIDIFIED INORGANICS	AL W005	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	9
SOLIDIFIED INORGANICS	AL W005	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10 10a
SOLIDIFIED INORGANICS	AL W005	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	AL W005	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	AL W005	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34
SOLIDIFIED INORGANICS	IN W146	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	IN W146	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	IN W146	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c)
SOLIDIFIED INORGANICS	IN W157	ACIDS, ORGANIC x ALCOHOLS & GLYCOLS (3 x 4)	M x T	H P	11 11a
SOLIDIFIED INORGANICS	IN W157	ACIDS, ORGANIC x CAUSTICS (3 x 10)	M x D	H	00
SOLIDIFIED INORGANICS	IN W157	ACIDS, ORGANIC x FLUORIDES, INORANIC (3 x 15)	M x D	GT	11d
SOLIDIFIED INORGANICS	IN W157	ACIDS, ORGANIC x METALS & METAL COMPOUNDS, TOXIC (3 x 24)	M x T	S	12 12aa
SOLIDIFIED INORGANICS	IN W157	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	IN W157	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	IN W157	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	IN W157	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	25
SOLIDIFIED INORGANICS	IN W157	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
SOLIDIFIED INORGANICS	IN W166	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T1	H	00
SOLIDIFIED INORGANICS	IN W166	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	IN W166	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T1	S	00
SOLIDIFIED INORGANICS	IN W166	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T1 x D	H F	25
SOLIDIFIED INORGANICS	IN W166	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T1 x D	S	33a 34
SOLIDIFIED INORGANICS	IN W177	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15 00
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, NON-OXIDIZING x CAUSTICS (1 x 10)	T x D	H	00
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, NON-OXIDIZING x ETHERS (1 x 14)	T x D	H	0aaa
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	T x D	GT	0aaaa

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	T x D	GF H F	1
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	T x D	H G	3
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER (1 x 106)	T x D	H	3b
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	4
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	9
SOLIDIFIED INORGANICS	IN W179	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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SOLIDIFIED INORGANICS	IN W179	ACIDS, ORGANIC x CAUSTICS (3 x 10)	T x D	H	00
SOLIDIFIED INORGANICS	IN W179	ACIDS, ORGANIC x FLUORIDES, INORANIC (3 x 15)	T x D	GT	11d
SOLIDIFIED INORGANICS	IN W179	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
SOLIDIFIED INORGANICS	IN W179	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	IN W179	CAUSTICS x KETONES (10 x 19)	D x T	H	00
SOLIDIFIED INORGANICS	IN W179	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15 00
SOLIDIFIED INORGANICS	IN W179	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	IN W179	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	19
SOLIDIFIED INORGANICS	IN W179	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
SOLIDIFIED INORGANICS	IN W181	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
SOLIDIFIED INORGANICS	IN W181	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
SOLIDIFIED INORGANICS	IN W181	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
SOLIDIFIED INORGANICS	IN W181	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	4
SOLIDIFIED INORGANICS	IN W181	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	9
SOLIDIFIED INORGANICS	IN W181	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10 10a
SOLIDIFIED INORGANICS	IN W181	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	IN W181	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15 00
SOLIDIFIED INORGANICS	IN W181	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER
SOLIDIFIED INORGANICS	IN W181	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	25
SOLIDIFIED INORGANICS	IN W181	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34
SOLIDIFIED INORGANICS	IN W188	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
SOLIDIFIED INORGANICS	IN W188	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
SOLIDIFIED INORGANICS	IN W188	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
SOLIDIFIED INORGANICS	IN W188	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	4
SOLIDIFIED INORGANICS	IN W188	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	9
SOLIDIFIED INORGANICS	IN W188	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10
SOLIDIFIED INORGANICS	IN W188	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
SOLIDIFIED INORGANICS	IN W188	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	15 00
		(10 x 23)			
SOLIDIFIED INORGANICS	IN W188	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
SOLIDIFIED INORGANICS	IN W188	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	2b
		(17 x 23)			
SOLIDIFIED INORGANICS	IN W188	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a 34
		(24 x 106)			
SOLIDIFIED INORGANICS	IN W216	ACIDS, MINERAL, OXIDIZING x CAUSTICS	T x D	H	00
		(2 x 10)			
SOLIDIFIED INORGANICS	IN W216	ACIDS, MINERAL, OXIDIZING x ETHERS	T x D	H F	3f
		(2 x 14)			
SOLIDIFIED INORGANICS	IN W216	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC	T x D	GT	3g
		(2 x 15)			
SOLIDIFIED INORGANICS	IN W216	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	GF H F	4
		(2 x 23)			
SOLIDIFIED INORGANICS	IN W216	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC	T x D	H F GT	9
		(2 x 101)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT =toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
SOLIDIFIED INORGANICS	IN W216	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10
SOLIDIFIED INORGANICS	IN W216	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	IN W216	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15 00
SOLIDIFIED INORGANICS	IN W216	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	IN W216	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	25
SOLIDIFIED INORGANICS	IN W216	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34
SOLIDIFIED INORGANICS	IN W220	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
SOLIDIFIED INORGANICS	IN W220	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
SOLIDIFIED INORGANICS	IN W220	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
SOLIDIFIED INORGANICS	IN W220	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	4
SOLIDIFIED INORGANICS	IN W220	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	9
SOLIDIFIED INORGANICS	IN W220	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10
SOLIDIFIED INORGANICS	IN W220	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	IN W220	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15
SOLIDIFIED INORGANICS	IN W220	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	IN W220	CAUSTICS x ORHANOPHOSPHATES, PHOSPHOTHIOATES & PHOSPHODITHIOATES (10 x 32)	D x T3	H E	00
SOLIDIFIED INORGANICS	IN W220	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	25
SOLIDIFIED INORGANICS	IN W220	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33 33a 34

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
SOLIDIFIED INORGANICS	IN W221	ACIDS, ORGANIC x ALCOHOLS & GLYCOLS	M x T1	H P	11
		(3 x 4)			
SOLIDIFIED INORGANICS	IN W221	ACIDS, ORGANIC x CAUSTICS	M x D	H	00
		(3 x 10)			
SOLIDIFIED INORGANICS	IN W221	ACIDS, ORGANIC x FLUORIDES, INORANIC	M x D	GT	11d
		(3 x 15)			
SOLIDIFIED INORGANICS	IN W221	ACIDS, ORGANIC x METALS & METAL COMPOUNDS, TOXIC	M x T	S	12
		(3 x 24)			
SOLIDIFIED INORGANICS	IN W221	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
SOLIDIFIED INORGANICS	IN W221	CAUSTICS x KETONES	D x T	H	00
		(10 x 19)			
SOLIDIFIED INORGANICS	IN W221	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
SOLIDIFIED INORGANICS	IN W221	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
SOLIDIFIED INORGANICS	IN W221	CAUSTICS x ORHANOPHOSPHATES, PHOSPHOTHIOATES & PHOSPHODITHIOATES	D x T	H E	00
		(10 x 32)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c)
SOLIDIFIED INORGANICS	IN W221	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	25
SOLIDIFIED INORGANICS	IN W221	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34
SOLIDIFIED INORGANICS	IN W222	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
SOLIDIFIED INORGANICS	IN W222	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	IN W222	CAUSTICS x KETONES (10 x 19)	D x T	H	00
SOLIDIFIED INORGANICS	IN W222	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	IN W222	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	IN W222	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	25
SOLIDIFIED INORGANICS	IN W222	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33 33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
SOLIDIFIED INORGANICS	IN W228	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
SOLIDIFIED INORGANICS	IN W228	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
SOLIDIFIED INORGANICS	IN W228	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
SOLIDIFIED INORGANICS	IN W228	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	4
SOLIDIFIED INORGANICS	IN W228	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	9
SOLIDIFIED INORGANICS	IN W228	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10
SOLIDIFIED INORGANICS	IN W228	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	IN W228	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15 00
SOLIDIFIED INORGANICS	IN W228	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
SOLIDIFIED INORGANICS	IN W228	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	25
SOLIDIFIED INORGANICS	IN W228	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33 33a
SOLIDIFIED INORGANICS	IN W332	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	IN W347	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15 00
SOLIDIFIED INORGANICS	LA W002	CAUSTICS x KETONES (10 x 19)	D x T3	H	[illegible]
SOLIDIFIED INORGANICS	LA W002	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T2	S	00
SOLIDIFIED INORGANICS	LA W002	CAUSTICS x EXPLOSIVES (10 x 102)	D x T2	H E	00
SOLIDIFIED INORGANICS	LA W002	CAUSTICS x WATER REACTIVE SUBSTANCES (10 x 107)	D x T2	EXTREMELY	00
SOLIDIFIED INORGANICS	LA W002	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T2	H F	17a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
SOLIDIFIED INORGANICS	LA W002	ETHERS x WATER REACTIVE SUBSTANCES (14 x 107)	D x T2	EXTREMELY	17b
SOLIDIFIED INORGANICS	LA W002	FLUORIDES, INORANIC x WATER REACTIVE SUBSTANCES (15 x 107)	D x T2	EXTREMELY	18
SOLIDIFIED INORGANICS	LA W002	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T2 x D	S	33a 34
SOLIDIFIED INORGANICS	LA W003	CAUSTICS x KETONES (10 x 19)	D x T3	H	00
SOLIDIFIED INORGANICS	LA W003	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T3	S	00
SOLIDIFIED INORGANICS	LA W003	CAUSTICS x EXPLOSIVES (10 x 102)	D x T2	H E	00
SOLIDIFIED INORGANICS	LA W003	CAUSTICS x WATER REACTIVE SUBSTANCES (10 x 107)	D x T2	EXTREMELY	00
SOLIDIFIED INORGANICS	LA W003	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T2	H F	17a
SOLIDIFIED INORGANICS	LA W003	ETHERS x WATER REACTIVE SUBSTANCES (14 x 107)	D x T2	EXTREMELY	17b

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
SOLIDIFIED INORGANICS	LA W003	FLUORIDES, INORANIC x WATER REACTIVE SUBSTANCES (15 x 107)	D x T2	EXTREMELY	18
SOLIDIFIED INORGANICS	LA W003	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T3 x D	S	33 33a
SOLIDIFIED INORGANICS	LA W003	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x EXPLOSIVES (101 x 102)	D x T2	H E	36d
SOLIDIFIED INORGANICS	LA W003	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG (101 x 104)	D x T2	H F G	37
SOLIDIFIED INORGANICS	LA W003	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x WATER REACTIVE SUBSTANCES (101 x 107)	D x T2	EXTREMELY	39
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, NON-OXIDIZING x ETHERS (1 x 14)	T2 x D	H	0aaa
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	T2 x D	GT	0aaaa
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	T2 x D	GF H F	1
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	T2 x D	H G	3

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, NON-OXIDIZING x OXIDIZING AGENTS, STRONG	T2 x D	H GT	3aa
		(1 x 104)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER	T2 x D	H	3b
		(1 x 106)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, OXIDIZING x CAUSTICS	T2 x D	H	
		(2 x 10)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, OXIDIZING x ETHERS	T2 x D	H F	3f
		(2 x 14)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC	T2 x D	GT	3g
		(2 x 15)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T2 x D	GF H F	4
		(2 x 23)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC	T2 x D	H F GT	9
		(2 x 101)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER	T2 x D	H	10
		(2 x 106)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, ORGANIC x CAUSTICS	T2 x D	H	00
		(3 x 10)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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SOLIDIFIED INORGANICS	LA W006	ACIDS, ORGANIC x FLUORIDES, INORANIC	T2 x D	GT	11d
		(3 x 15)			
SOLIDIFIED INORGANICS	LA W006	ACIDS, ORGANIC x OXIDIZING AGENTS, STRONG	T2 x D	H GT	12bbb
		(3 x 104)			
SOLIDIFIED INORGANICS	LA W006	ALCOHOLS & GLYCOLS x OXIDIZING AGENTS, STRONG	T2 x D	H F	12bb
		(4 x 104)			
SOLIDIFIED INORGANICS	LA W006	AMINES, ALIPHATIC & AROMATIC x OXIDIZING AGENTS, STRONG	T2 x D	H F GT	12d
		(7 x 104)			
SOLIDIFIED INORGANICS	LA W006	CAUSTICS x HALOGENATED ORGANICS	D x T2	H	00
		(10 x 17)			
SOLIDIFIED INORGANICS	LA W006	CAUSTICS x METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS	D x T	GF H	00
		(10 x 21)			
SOLIDIFIED INORGANICS	LA W006	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	15 00
		(10 x 23)			
SOLIDIFIED INORGANICS	LA W006	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T1	S	00
		(10 x 24)			
SOLIDIFIED INORGANICS	LA W006	CAUSTICS x NITRO COMPOUNDS	D x T2	H E	00
		(10 x 27)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
SOLIDIFIED INORGANICS	LA W006	CAUSTICS x EXPLOSIVES (10 x 102)	D x T	H E	00
SOLIDIFIED INORGANICS	LA W006	CAUSTICS x WATER REACTIVE SUBSTANCES (10 x 107)	D x T1	EXTREMELY	00
SOLIDIFIED INORGANICS	LA W006	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x D	H F	17a
SOLIDIFIED INORGANICS	LA W006	ETHERS x WATER REACTIVE SUBSTANCES (14 x 107)	D x T1	EXTREMELY	17b
SOLIDIFIED INORGANICS	LA W006	FLUORIDES, INORANIC x WATER REACTIVE SUBSTANCES (15 x 107)	D x T1	EXTREMELY	18
SOLIDIFIED INORGANICS	LA W006	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T2 x D	H F	25
SOLIDIFIED INORGANICS	LA W006	HALOGENATED ORGANICS x OXIDIZING AGENTS, STRONG (17 x 104)	T2 x D	H GT	28
SOLIDIFIED INORGANICS	LA W006	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (21 x 101)	T x D	H G F	28b
SOLIDIFIED INORGANICS	LA W006	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x OXIDIZING AGENTS, STRONG (21 x 104)	T x D	H F E	28c

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
SOLIDIFIED INORGANICS	LA W006	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x WATER & MIXTURES CONTAINING WATER (21 x 106)	T x D	GF H	28d
SOLIDIFIED INORGANICS	LA W006	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG (23 x 104)	D x D	H F	29
SOLIDIFIED INORGANICS	LA W006	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x WATER REACTIVE SUBSTANCES (23 x 107)	D x T1	EXTREMELY	31
SOLIDIFIED INORGANICS	LA W006	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T1 x D	S	33a 34
SOLIDIFIED INORGANICS	LA W006	NITRO COMPOUNDS x OXIDIZING AGENTS, STRONG (27 x 104)	T2 x D	H E	36b
SOLIDIFIED INORGANICS	LA W006	HYDROCARBON, ALIPHATIC, SATURATED x OXIDIZING AGENTS, STRONG (29 x 104)	T2 x D	H F	36c
SOLIDIFIED INORGANICS	LA W006	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x EXPLOSIVES (101 x 102)	D x T	H E	36d
SOLIDIFIED INORGANICS	LA W006	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG (101 x 104)	D x D	H F G	37
SOLIDIFIED INORGANICS	LA W006	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x WATER REACTIVE SUBSTANCES (101 x 107)	D x T1	EXTREMELY	39

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SOLIDIFIED INORGANICS	LA W006	EXPLOSIVES x OXIDIZING AGENTS, STRONG (102 x 104)	T x D	H E	40
SOLIDIFIED INORGANICS	LA W006	OXIDIZING AGENTS, STRONG x WATER REACTIVE SUBSTANCES (104 x 107)	D x T1	EXTREMELY	41
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x ALCOHOLS & GLYCOLS (1 x 4)	M x T	H	0a
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x CAUSTICS (1 x 10)	M x D	H	0aa 00
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x ETHERS (1 x 14)	M x D	H	0aaa
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	M x D	GT	0aaaa
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x HALOGENATED ORGANICS (1 x 17)	M x T	H GT	0b
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x KETONES (1 x 19)	M x T	H	0bb
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	M x D	GF H F	1

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x METALS & METAL COMPOUNDS, TOXIC (1 x 24)	M x T	S	2
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	M x D	H G	3
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x EXPLOSIVES (1 x 102)	M x T	H E	3a
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x OXIDIZING AGENTS, STRONG (1 x 104)	M x T	H GT	3aa
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER (1 x 106)	M x D	H	3
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x ACIDS, ORGANIC (2 x 3)	M x T	G H	3c
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x ALCOHOLS & GLYCOLS (2 x 4)	M x T	H F	3d
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	M x D	H	3e 00
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	M x D	H F	3f

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	M x D	GT	3g
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x HALOGENATED ORGANICS (2 x 17)	M x T	H F GT	3h
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x KETONES (2 x 19)	M x T	H F	3i
SOLIDIFIED INORGANICS	-LL W019 -	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	M x D	GF H F	4
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x METALS & METAL COMPOUNDS, TOXIC (2 x 24)	M x T	S	6
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	M x D	H F GT	9
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x EXPLOSIVES (2 x 102)	M x T	H E	9a
SOLIDIFIED INORGANICS	LL W019	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	M x D	H	10 10a
SOLIDIFIED INORGANICS	LL W019	ACIDS, ORGANIC x CAUSTICS (3 x 10)	T x D	H	11b 00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SOLIDIFIED INORGANICS	LL W019	ACIDS, ORGANIC x FLUORIDES, INORANIC (3 x 15)	T x D	GT	11d
SOLIDIFIED INORGANICS	LL W019	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	13 00
SOLIDIFIED INORGANICS	LL W019	CAUSTICS x KETONES (10 x 19)	D x T	H	13a 00
SOLIDIFIED INORGANICS	LL W019	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	16a 00
SOLIDIFIED INORGANICS	LL W019	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	16a 00
SOLIDIFIED INORGANICS	LL W019	CAUSTICS x EXPLOSIVES (10 x 102)	D x T	H E	16c 00
SOLIDIFIED INORGANICS	LL W019	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T	H F	17a
SOLIDIFIED INORGANICS	LL W019	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	25
SOLIDIFIED INORGANICS	LL W019	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG (23 x 104)	D x T	H F	29

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SOLIDIFIED INORGANICS	LL W019	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34
SOLIDIFIED INORGANICS	LL W019	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x EXPLOSIVES (101 x 102)	D x T	H E	36d
SOLIDIFIED INORGANICS	LL W019	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG (101 x 104)	D x T	H F G	37
SOLIDIFIED INORGANICS	MD W002	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	OR W042	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	OR W042	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	OR W042	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33 33a
SOLIDIFIED INORGANICS	OR W046	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	OR W046	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SOLIDIFIED INORGANICS	OR W046	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SOLIDIFIED INORGANICS	PA W014	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	PA W015	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	PA W015	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	PA W015	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34
SOLIDIFIED INORGANICS	PAW015A	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RF M001	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T1	H	00
SOLIDIFIED INORGANICS	RF M001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RF M001	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T1	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SOLIDIFIED INORGANICS	RF M001	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T1 x D	H F	19
SOLIDIFIED INORGANICS	RF M001	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T1 x D	S	33a
SOLIDIFIED INORGANICS	RF W010	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T1	H	00
SOLIDIFIED INORGANICS	RF W010	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RF W010	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	RF W010	CAUSTICS x ORHANOPHOSPHATES, PHOSPHOTHIOATES & PHOSPHODITHIOATES (10 x 32)	D x T3	H E	00
SOLIDIFIED INORGANICS	RF W010	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T1 x D	H F	19
SOLIDIFIED INORGANICS	RF W010	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SOLIDIFIED INORGANICS	RF W038	ACIDS, ORGANIC x CAUSTICS (3 x 10)	T x D	H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SOLIDIFIED INORGANICS	RF W038	ACIDS, ORGANIC x FLUORIDES, INORANIC (3 x 15)	T x D	GT	11d
SOLIDIFIED INORGANICS	RF W038	CAUSTICS x KETONES (10 x 19)	D x T	H	00
SOLIDIFIED INORGANICS	RF W038	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RF W038	CAUSTICS x ORHANOPHOSPHATES, PHOSPHOTHIOATES & PHOSPHODITHIOATES (10 x 32)	D x T	H E	00
SOLIDIFIED INORGANICS	RF W040	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	RF W040	CAUSTICS x KETONES (10 x 19)	D x T	H	00
SOLIDIFIED INORGANICS	RF W040	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RF W040	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	RF W040	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SOLIDIFIED INORGANICS	RF W040	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	26
SOLIDIFIED INORGANICS	RF W040	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SOLIDIFIED INORGANICS	RF W059	CAUSTICS x METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS (10 x 21)	D x D	GF H	00
SOLIDIFIED INORGANICS	RF W059	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RF W059	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	RF W059	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (21 x 101)	D x D	H G F	28b
SOLIDIFIED INORGANICS	RF W059	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x WATER & MIXTURES CONTAINING WATER (21 x 106)	D x D	GF H	28d
SOLIDIFIED INORGANICS	RF W059	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SOLIDIFIED INORGANICS	RF W063	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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SOLIDIFIED INORGANICS	RF W063	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
SOLIDIFIED INORGANICS	RF W063	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33 33a 34
		(24 x 106)			
SOLIDIFIED INORGANICS	RF W065	CAUSTICS x METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS	D x D	GF H	00
		(10 x 21)			
SOLIDIFIED INORGANICS	RF W065	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
SOLIDIFIED INORGANICS	RF W065	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC	D x D	H G F	28b
		(21 x 101)			
SOLIDIFIED INORGANICS	RF W065	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x WATER & MIXTURES CONTAINING WATER	D x D	GF H	28d
		(21 x 106)			
SOLIDIFIED INORGANICS	RF W068	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
SOLIDIFIED INORGANICS	RF W068	CAUSTICS x KETONES	D x T	H	00
		(10 x 19)			
SOLIDIFIED INORGANICS	RF W068	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
SOLIDIFIED INORGANICS	RF W068	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	RF W068	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00
SOLIDIFIED INORGANICS	RF W068	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	19
SOLIDIFIED INORGANICS	RF W068	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a 34
SOLIDIFIED INORGANICS	RF W076	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED INORGANICS	RF W076	CAUSTICS x KETONES (10 x 19)	D x T	H	00
SOLIDIFIED INORGANICS	RF W076	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RF W076	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED INORGANICS	RF W076	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
SOLIDIFIED INORGANICS	RF W076	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	19
SOLIDIFIED INORGANICS	RF W076	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33 33a
SOLIDIFIED INORGANICS	RL M005	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RL M005	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x M	S	00
SOLIDIFIED INORGANICS	RL M005	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	M x D	S	33a
SOLIDIFIED INORGANICS	RL M032	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
SOLIDIFIED INORGANICS	RL M032	CAUSTICS x KETONES (10 x 19)	D x T	H	00
SOLIDIFIED INORGANICS	RL M032	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED INORGANICS	RL M032	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
SOLIDIFIED INORGANICS	RL M032	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
SOLIDIFIED INORGANICS	SR W053	CAUSTICS x HALOGENATED ORGANICS	D x T	H	00
		(10 x 17)			
SOLIDIFIED INORGANICS	SR W053	CAUSTICS x KETONES	D x T	H	00
		(10 x 19)			
SOLIDIFIED INORGANICS	SR W053	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
SOLIDIFIED INORGANICS	SR W053	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x T	S	00
		(10 x 24)			
SOLIDIFIED INORGANICS	SR W053	CAUSTICS x NITRO COMPOUNDS	D x T	H E	00
		(10 x 27)			
SOLIDIFIED INORGANICS	SR W053	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T x D	H F	19
		(17 x 23)			
SOLIDIFIED INORGANICS	SR W053	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	T x D	S	33a
		(24 x 106)			
SOLIDIFIED ORGANICS	IN W167	CAUSTICS x HALOGENATED ORGANICS	D x D	H	00
		(10 x 17)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIO CODE NUMBER(c)
SOLIDIFIED ORGANICS	IN W167	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED ORGANICS	IN W167	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED ORGANICS	IN W167	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	D x D	H F	23
SOLIDIFIED ORGANICS	IN W167	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SOLIDIFIED ORGANICS	IN W174	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	D x D	H	00
SOLIDIFIED ORGANICS	IN W174	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	D x D	H F	3f
SOLIDIFIED ORGANICS	IN W174	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	D x D	GT	3g
SOLIDIFIED ORGANICS	IN W174	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	D x D	GF H F	4
SOLIDIFIED ORGANICS	IN W174	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	D x D	H F GT	9

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
SOLIDIFIED ORGANICS	IN W174	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	D x D	H	10a
SOLIDIFIED ORGANICS	IN W174	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED ORGANICS	IN W309	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x D	H	00
SOLIDIFIED ORGANICS	IN W309	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED ORGANICS	IN W309	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
SOLIDIFIED ORGANICS	IN W309	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	D x D	H F	23
SOLIDIFIED ORGANICS	IN W309	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
SOLIDIFIED ORGANICS	RF W013	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x D	H	00
SOLIDIFIED ORGANICS	RF W013	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
SOLIDIFIED ORGANICS	RF W013	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	D x D	H F	25
SOLIDIFIED ORGANICS	RF W069	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
SOLIDIFIED ORGANICS	RF W069	CAUSTICS x KETONES (10 x 19)	D x T	H	00
SOLIDIFIED ORGANICS	RF W069	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED ORGANICS	RF W069	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00
SOLIDIFIED ORGANICS	RF W069	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	23 26
SOLIDIFIED ORGANICS	RL M017	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
SOLIDIFIED ORGANICS	RL M017	CAUSTICS x KETONES (10 x 19)	D x T	H	00
SOLIDIFIED ORGANICS	RL M017	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
SOLIDIFIED ORGANICS	RL M018	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED ORGANICS	RL M024	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
SOLIDIFIED ORGANICS	SR W006	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	AW W018	CAUSTICS x METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS (10 x 21)	D x D	GF H	00
UNCATEGORIZED METAL	AW W018	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	AW W018	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (21 x 101)	D x D	H G F	28b
UNCATEGORIZED METAL	AW W018	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x WATER & MIXTURES CONTAINING WATER (21 x 106)	D x D	GF H	28d
UNCATEGORIZED METAL	AW W019	CAUSTICS x METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS (10 x 21)	D x D	GF H	00
UNCATEGORIZED METAL	AW W019	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
UNCATEGORIZED METAL	AW W019	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (21 x 101)	D x D	H G F	28b
UNCATEGORIZED METAL	AW W019	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x WATER & MIXTURES CONTAINING WATER (21 x 106)	D x D	GF H	28d
UNCATEGORIZED METAL	AW W021	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	AW W021	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
UNCATEGORIZED METAL	AW W021	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33
UNCATEGORIZED METAL	IN M003	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	IN W280	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	IN W280	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
UNCATEGORIZED METAL	IN W280	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
UNCATEGORIZED METAL	IN W287	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	IN W287	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x M	S	00
UNCATEGORIZED METAL	IN W287	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	M x D	S	33a
UNCATEGORIZED METAL	IN W294	AMINES, ALIPHATIC & AROMATIC x HALOGENATED ORGANICS (7 x 17)	D x D	H G	12b
UNCATEGORIZED METAL	IN W294	AMINES, ALIPHATIC & AROMATIC x METALS & METAL COMPOUNDS, TOXIC (7 x 24)	D x D	S	12c
UNCATEGORIZED METAL	IN W294	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x D	H	00
UNCATEGORIZED METAL	IN W294	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	IN W294	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
UNCATEGORIZED METAL	IN W294	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x D	H E	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c)
UNCATEGORIZED METAL	IN W294	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	D x D	H F	24
UNCATEGORIZED METAL	IN W294	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
UNCATEGORIZED METAL	IN W296	AMINES, ALIPHATIC & AROMATIC x METALS & METAL COMPOUNDS, TOXIC (7 x 24)	T x D	S	12c
UNCATEGORIZED METAL	IN W296	CAUSTICS x ESTERS (10 x 13)	D x T	H	00
UNCATEGORIZED METAL	IN W296	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
UNCATEGORIZED METAL	IN W296	CAUSTICS x KETONES (10 x 19)	D x T	H	00
UNCATEGORIZED METAL	IN W296	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	IN W296	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
UNCATEGORIZED METAL	IN W296	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
UNCATEGORIZED METAL	IN W296	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	24
UNCATEGORIZED METAL	IN W296	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
UNCATEGORIZED METAL	IN W298	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
UNCATEGORIZED METAL	IN W298	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	IN W298	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
UNCATEGORIZED METAL	IN W298	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	24
UNCATEGORIZED METAL	IN W298	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
UNCATEGORIZED METAL	IN W300	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T1	H	00
UNCATEGORIZED METAL	IN W300	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
UNCATEGORIZED METAL	IN W300	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x D	S	00
		(10 x 24)			
UNCATEGORIZED METAL	IN W300	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	T1 x D	H F	24
		(17 x 23)			
UNCATEGORIZED METAL	IN W300	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	D x D	S	33a
		(24 x 106)			
UNCATEGORIZED METAL	IN W322	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
UNCATEGORIZED METAL	INW260A	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
UNCATEGORIZED METAL	LA W001	ALDEHYDES x CAUSTICS	T2 x D	H	00
		(5 x 10)			
UNCATEGORIZED METAL	LA W001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC	D x D	GF H	00
		(10 x 23)			
UNCATEGORIZED METAL	LA W001	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC	D x D	S	00
		(10 x 24)			
UNCATEGORIZED METAL	LA W001	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER	D x D	S	33a
		(24 x 106)			

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, NON-OXIDIZING x ETHERS (1 x 14)	T2 x D	H	0aaa
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	T2 x D	GT	0aaaa
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	T2 x D	GF H F	1
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	T2 x D	H G	3
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER (1 x 106)	T2 x D	H	3b
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T2 x D	H F	3f
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T2 x D	GT	3g
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T2 x D	GF H F	5
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T2 x D	H F GT	8

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

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(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIO CODE NUMBER(c)
UNCATEGORIZED METAL	LA W005	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T2 x D	H	10a
UNCATEGORIZED METAL	LA W005	ACIDS, ORGANIC x CAUSTICS (3 x 10)	T2 x D	H	00
UNCATEGORIZED METAL	LA W005	ACIDS, ORGANIC x FLUORIDES, INORANIC (3 x 15)	T2 x D	GT	11d
UNCATEGORIZED METAL	LA-W005	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T2	H	00
UNCATEGORIZED METAL	LA W005	CAUSTICS x KETONES (10 x 19)	D x T2	H	00
UNCATEGORIZED METAL	LA W005	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15
UNCATEGORIZED METAL	LA W005	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
UNCATEGORIZED METAL	LA W005	CAUSTICS x ORHANOPHOSPHATES, PHOSPHOTHIOATES & PHOSPHODITHIOATES (10 x 32)	D x T2	H E	00
UNCATEGORIZED METAL	LA W005	CAUSTICS x WATER REACTIVE SUBSTANCES (10 x 107)	D x T2	EXTREMELY	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIC CODE NUMBER(c
UNCATEGORIZED METAL	LA W005	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T2	H F	17a
UNCATEGORIZED METAL	LA W005	ETHERS x WATER REACTIVE SUBSTANCES (14 x 107)	D x T2	EXTREMELY	17b
UNCATEGORIZED METAL	LA W005	FLUORIDES, INORANIC x WATER REACTIVE SUBSTANCES (15 x 107)	D x T2	EXTREMELY	18
UNCATEGORIZED METAL	LA W005	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T2 x D	H F	24
UNCATEGORIZED METAL	LA W005	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG (23 x 104)	D x T2	H F	30
UNCATEGORIZED METAL	LA W005	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x WATER REACTIVE SUBSTANCES (23 x 107)	D x T2	EXTREMELY	32
UNCATEGORIZED METAL	LA W005	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
UNCATEGORIZED METAL	LA W005	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG (101 x 104)	D x T2	H F G	38
UNCATEGORIZED METAL	LA W005	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x WATER REACTIVE SUBSTANCES (101 x 107)	D x T2	EXTREMELY	39

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(
UNCATEGORIZED METAL	LA W009	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
UNCATEGORIZED METAL	LA W009	CAUSTICS x KETONES (10 x 19)	D x T	H	00
UNCATEGORIZED METAL	LA W009	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	LA W009	CAUSTICS x NITRO COMPOUNDS (10 x 27)	D x T	H E	00
UNCATEGORIZED METAL	LA W009	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	20
UNCATEGORIZED METAL	LA WR01	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	LA WR05	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, NON-OXIDIZING x CAUSTICS (1 x 10)	T x D	H	00
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, NON-OXIDIZING x ETHERS (1 x 14)	T x D	H	0aaaa

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, NON-OXIDIZING x FLUORIDES, INORANIC (1 x 15)	T x D	GT	0aaa
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, NON-OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (1 x 23)	T x D	GF H F	1
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, NON-OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (1 x 101)	T x D	H G	3
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, NON-OXIDIZING x WATER & MIXTURES CONTAINING WATER (1 x 106)	T x D	H	3b
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, OXIDIZING x CAUSTICS (2 x 10)	T x D	H	00
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, OXIDIZING x ETHERS (2 x 14)	T x D	H F	3f
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, OXIDIZING x FLUORIDES, INORANIC (2 x 15)	T x D	GT	3g
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, OXIDIZING x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (2 x 23)	T x D	GF H F	5
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, OXIDIZING x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (2 x 101)	T x D	H F GT	8

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATI CODE NUMBER(c
UNCATEGORIZED METAL	LL W018	ACIDS, MINERAL, OXIDIZING x WATER & MIXTURES CONTAINING WATER (2 x 106)	T x D	H	10a
UNCATEGORIZED METAL	LL W018	ACIDS, ORGANIC x CAUSTICS (3 x 10)	T x D	H	00
UNCATEGORIZED METAL	LL W018	ACIDS, ORGANIC x FLUORIDES, INORANIC (3 x 15)	T x D	GT	11d
UNCATEGORIZED METAL	LL W018	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T	H	00
UNCATEGORIZED METAL	LL W018	CAUSTICS x KETONES (10 x 19)	D x T	H	
UNCATEGORIZED METAL	LL W018	CAUSTICS x METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS (10 x 21)	D x T	GF H	00
UNCATEGORIZED METAL	LL W018	CAUSTICS x METALS OTHER ELEMENTAL & ALLOYS IN THE FORM OF POWDERS, VAPORS OR SPONGES (10 x 22)	D x T	GF H	00
UNCATEGORIZED METAL	LL W018	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	15 00
UNCATEGORIZED METAL	LL W018	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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TABLE C1-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER

WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANAT CODE NUMBER(
UNCATEGORIZED METAL	LL W018	CAUSTICS x EXPLOSIVES (10 x 102)	D x T	H E	00
UNCATEGORIZED METAL	LL W018	ETHERS x OXIDIZING AGENTS, STRONG (14 x 104)	D x T	H F	17a
UNCATEGORIZED METAL	LL W018	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T x D	H F	22
UNCATEGORIZED METAL	LL W018	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x COMBUSTIBLE & FLAMMABLE MATERIALS, MISC (21 x 101)	T x D	H G F	28b
UNCATEGORIZED METAL	LL W018	METALS, ALKALI & ALKALINE EARTH, ELEMENTAL & ALLOYS x WATER & MIXTURES CONTAINING WATER (21 x 106)	T x D	GF H	28d
UNCATEGORIZED METAL	LL W018	METALS OTHER ELEMENTAL & ALLOYS IN THE FORM OF POWDERS, VAPORS OR SPONGES x WATER & MIXTURES CONTAINING WATER (22 x 106)	T x D	GF H	28e
UNCATEGORIZED METAL	LL W018	METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC x OXIDIZING AGENTS, STRONG (23 x 104)	D x T	H F	30
UNCATEGORIZED METAL	LL W018	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
UNCATEGORIZED METAL	LL W018	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x EXPLOSIVES (101 x 102)	D x T	H E	36d

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIO CODE NUMBER(c)
UNCATEGORIZED METAL	LL W018	COMBUSTIBLE & FLAMMABLE MATERIALS, MISC x OXIDIZING AGENTS, STRONG (101 x 104)	D x T	H F G	38
UNCATEGORIZED METAL	RF W011	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T1	H	00
UNCATEGORIZED METAL	RF W011	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	RF W011	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00
UNCATEGORIZED METAL	RF W011	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T1 x D	H F	21
UNCATEGORIZED METAL	RF W011	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
UNCATEGORIZED METAL	RF W037	CAUSTICS x HALOGENATED ORGANICS (10 x 17)	D x T1	H	00
UNCATEGORIZED METAL	RF W037	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	RF W037	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x D	S	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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UNCATEGORIZED METAL	RF W037	HALOGENATED ORGANICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (17 x 23)	T1 x D	H F	24
UNCATEGORIZED METAL	RF W037	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	D x D	S	33a
UNCATEGORIZED METAL	RL M001	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	RL M001	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
UNCATEGORIZED METAL	RL M001	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
UNCATEGORIZED METAL	RL M002	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	RL M002	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
UNCATEGORIZED METAL	RL M002	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
UNCATEGORIZED METAL	RL M003	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

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WASTE MATRIX CODE GROUP	WASTE STREAM UNIQUE ID	POTENTIAL CHEMICAL COMPATIBILITY REACTION	CONCENTRATION OF REACTANTS(a)	REACTION CODE(b)	EXPLANATIO CODE NUMBER(c)
UNCATEGORIZED METAL	RL M008	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	RL M008	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
UNCATEGORIZED METAL	RL M008	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a
UNCATEGORIZED METAL	RL M021	CAUSTICS x METALS, OTHER ELEMENTAL, & ALLOY, AS SHEETS, RODS, MOLDINGS, DROPS, ETC (10 x 23)	D x D	GF H	00
UNCATEGORIZED METAL	RL M021	CAUSTICS x METALS & METAL COMPOUNDS, TOXIC (10 x 24)	D x T	S	00
UNCATEGORIZED METAL	RL M021	METALS & METAL COMPOUNDS, TOXIC x WATER & MIXTURES CONTAINING WATER (24 x 106)	T x D	S	33a

x=Combined with

(a) Concentration of reactants: T=Trace (<1% by wt.); T1=Trace (<0.1% by wt.); T2=Trace (low ppm range); T3=Trace (<1 ppm range); M=Minor (1-10% by wt.); D=Dominant (>10% by wt.)

(b)Reaction code: H=heat generation; S= solubilization of toxic substances; F=fire; GF= flammable gas generation; G= nonflammable gas generation GT=toxic gas generation; P=violent polymerization; E=explosive

(c) See text

APPENDIX C2
DATA ACCUMULATED FROM HEADSPACE-GAS ANALYSES

APPENDIX C2
DATA ACCUMULATED FROM HEADSPACE GAS ANALYSES

This appendix presents all available headspace waste characterization data. The data include drum headspace analytical results for approximately 900 drums of transuranic mixed waste from Idaho National Engineering Laboratory (INEL) and Rocky Flats Environmental Technology Site (RFETS). The waste characterization data cut-off date was September 29, 1995. Item Description Code, and Transuranic Package Transporter Content (TRUCON) Code column entries correspond to Waste Matrix Code groups as described in Chapter C, Table C-1.

To reflect expected proportions of different waste types, the data were weighted according to Waste Matrix Code Group volumes reported in the *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report* (BIR). Table C2-1 presents the weighted average headspace concentrations. The Waste Matrix Code Group (WMCG) volumes and the weighting factors used to calculate the average concentrations are presented in Table C2-2.

Before the data could be manipulated, the RFETS database structure was converted into a modified INEL database structure, and the data from the two sites were combined into a single database. The weighted averages were calculated using computer codes developed for this effort that were validated and verified through independent review of the codes and associated documentation.

The database was modified as follows before the weighted averages were calculated:

- TRUCON codes assigned to each waste drum were converted to a Waste Stream ID using the cross-correlation table in the BIR (DOE 1995a, app. F).

- The Waste Profile Forms from the BIR (DOE 1995a, vol. II) were used to determine the WMCG for each waste stream.

- If the data qualifier was "U," then one-half of the associated value, the sample quantitation limit (SQL) was used for the concentration in calculating the weighted average.

- If the qualifier was "E" or "JE" and a dilution analysis was available for that sample number, the dilution analysis was used for all analytes. Analytes in the diluted sample, qualified as "U," were treated as above.

- All "J"-qualified (estimated) data were used.

- All "B"-qualified (constituent found in blanks) data were used. This was a conservative treatment of the data in the absence of information on the level of contamination observed in the blank.

All WMCGs, with the exception of soils and unknown waste, were represented by the data from the INEL and RFETS. Since the soils and unknown waste groups comprise a small percentage of the entire inventory (0.74 and 0.97 percent, respectively), their contribution to the calculated average concentrations was assumed to be insignificant. The weighted averages were calculated by:

$$\bar{x} = \sum_{i=1}^{t} w_i \bar{x}_i \qquad \text{(C2-1)}$$

where,

$\bar{x}$ = weighted average
$\bar{x}_i$ = average for WMCG i
w_i = weighting factor for WMCG i
t = number of WMCGs,

and $\bar{x}_i$ was calculated by:

$$\bar{x}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} x_{ij} \qquad \text{(C2-2)}$$

where,

n_i = number of samples in WMCG i
x_{ij} = analysis j for WMCG i.

For several volatile organic compounds (VOC) (carbon disulfide, isobutanol, 1,1,2-trichloroethane, trichlorofluoromethane, and vinyl chloride), headspace sampling data were not available. The headspace concentrations of these VOCs for screening purposes and for calculation of migration concentrations were assumed to be equal to one-half of the SQL. The SQLs for these VOCs were calculated from information on the required method detection limits (8 nanograms per 10-milliliter sample) contained in the *Transuranic Waste Characterization Quality Assurance Program Plan Transuranic Waste Characterization Program Sampling and Analysis Methods Manual:*

The SQL is the Method Detection Limit (MDL) expressed in part(s) per million per volume (ppmv).

$$SQL = \frac{R \times T}{P \times MW} \times MDL \times (10^6\ ppmv/mole\text{-}fraction) \qquad \text{(C2-3)}$$

where,

SQL = sample quantitation limit for the VOC, ppmv
R = Ideal Gas Constant, 0.082 L•atm/mol•K
T = temperature, 298 K
P = pressure, 1 atm
MW = molecular weight of VOC, g/mole
MDL = method detection limit of VOC, g/L

The minimum, maximum, and median concentrations for each compound are shown in Table C2-3, separated by the waste matrix code. These values show that the distribution of data is not normal and, therefore, using the weighted average headspace concentrations in calculations is a conservative approach.

Table C2-4 contains the headspace gas data by drum number.

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REFERENCE

DOE (U.S. Department of Energy). 1995a. *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report*. DOE/CAO-94-1005, Rev. 1. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

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BIBLIOGRAPHY

DOE (U.S. Department of Energy). 1995a. *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report*. DOE/CAO-94-1005, Rev. 1. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995b. *Transuranic Waste Characterization Quality Assurance Program Plan*. Rev. 0. U.S. Department of Energy, Carlsbad Area Office, Waste Isolation Pilot Plant, Carlsbad, NM.

DOE (U.S. Department of Energy). 1995c. *Transuranic Waste Characterization Sampling and Analysis Methods Manual*. Rev. 0. U.S. Department of Energy, Carlsbad Area Office, Waste Isolation Pilot Plant, Carlsbad, NM.

TABLE C2-1
WEIGHTED AVERAGE CONCENTRATIONS OF HEADSPACE GASES

Constituent	Weighted Average (ppmv)
1,1,1-Trichloroethane	3.17E+02
1,1,2,2-Tetrachloroethane	9.35E+00
1,1,2-Trichloro-1,2,2-trifluoroethane	3.30E+01
1,1-Dichloroethane	1.02E+01
1,1-Dichloroethylene	1.15E+01
1,2,4-Trimethylbenzene	1.22E+01
1,2-Dichloroethane	9.07E+00
1,3,5-Trimethylbenzene	8.62E+00
Butanol	7.81E+01
Methyl ethyl ketone	6.37E+01
Methyl isobutyl ketone	7.90E+01
Acetone	7.98E+01
Benzene	9.25E+00
Bromoform	9.38E+00
Carbon tetrachloride	3.76E+02
Chlorobenzene	1.25E+01
Chloroform	2.53E+01
(cis)-1,2-Dichloroethylene	8.97E+00
Cyclohexane	2.75E+01
Ethyl benzene	1.16E+01
Ethyl ether	1.33E+01
Methanol	2.13E+02
Methylene chloride	3.68E+02
o-Xylene	1.60E+01
p/m-Xylene	1.93E+01
Tetrachloroethylene	9.40E+00
Toluene	1.94E+01
Trichloroethylene	2.51E+01

Table C2-2
TRU Waste Disposal Inventory and Weighting Factors for Weighted Average Calculation

Waste Matrix Code Groups	Stored Volumes (cubic meters)	Projected Volumes (cubic meters)	Scaled Volumes (cubic meters)	Weighting Factor
Contact-Handled Waste				
Combustible	7.10E+03	2.70E+04	6.20E+04	3.53E-01
Filter	4.30E+02	1.10E+03	2.60E+03	1.48E-02
Graphite	6.70E+02	4.30E+01	7.60E+02	4.30E-03
Heterogeneous	3.00E+04	4.60E+03	3.90E+04	2.22E-01
Inorganic non-metal	1.20E+03	3.20E+02	1.80E+03	1.02E-02
Lead/cadmium metal	5.60E+01	1.30E+02	3.10E+02	1.80E-03
Salt waste	3.30E+01	6.00E+01	1.50E+02	8.52E-04
Soils	3.70E+02	4.50E+02	1.30E+03	7.39E-03
Solidified inorganics	1.70E+04	8.00E+03	3.40E+04	1.94E-01
Solidified organics	1.50E+03	3.00E+02	2.10E+03	1.20E-02
Uncategorized metal	1.20E+04	8.60E+03	3.00E+04	1.71E-01
Unknown	1.70E+03	0.00E+00	1.70E+03	9.66E-03
TOTAL	7.21E+04	5.06E+04	1.76E+05	1.00
Remote-Handled Waste				
Combustible	1.50E+01	3.20E+00	2.00E+01	2.80E-03
Filter	8.90E-01	2.10E+00	4.30E+01	6.02E-03
Heterogeneous	4.40E+02	3.30E+03	5.90E+03	8.26E-01
Inorganic non-metal				
Lead/cadmium metal	0.00E+00	6.00E+00	9.80E+00	1.37E-03
Salt waste	0.00E+00	2.80E+00	4.60E+00	6.44E-04
Solidified inorganic	6.10E+02	1.70E+02	9.00E+02	1.26E-01
Uncategorized metal	8.80E+01	8.60E+01	2.30E+02	3.22E-02
Unknown	1.10E+01	2.40E+01	3.50E+01	4.90E-03
TOTAL	1.16E+03	3.59E+03	7.14E+03	1.00

Table C2-3
Minimum, Maximum, and Median Values of Waste Matrix Code Groups

Waste Matrix Code Group	Value	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoroethane	1,1-Dichloroethene	Acetone	Methylene Chloride	1,1-Dichloroethane	(cis)-1,2-Dichloroethene
Combustible	Minimum	5.00	0.02	0.03	0.02	3.60	0.15	0.02	0.01
	Maximum	360.00	110.00	180.00	120.00	59.00	270.00	130.00	93.00
	Median	17.00	0.44	0.50	0.52	17.00	2.70	0.37	0.30
Filter	Minimum	1.30	0.02	0.03	0.02	0.56	0.02	0.04	0.02
	Maximum	245.44	1.60	3.08	5.20	844.03	2.22	2.00	0.76
	Median	17.00	0.20	0.22	0.26	17.00	0.40	0.21	0.16
Graphite	Minimum	5.00	0.01	0.03	0.02	5.00	0.02	0.01	0.01
	Maximum	610.00	2.60	1.60	2.40	51.00	23.00	35.00	1.20
	Median	17.00	0.02	0.04	0.02	17.00	0.07	0.03	0.02
Heterogeneous	Minimum	1.30	0.03	0.06	0.10	0.50	0.10	0.02	0.02
	Maximum	4750.00	384.00	798.33	880.24	3000.00	29668.00	250.00	250.00
	Median	16.26	0.40	0.40	0.40	9.60	0.54	0.40	0.30
Inorganic non-metal	Minimum	1.96	0.01	0.04	0.02	2.40	0.03	0.02	0.01
	Maximum	147.84	3.80	2.40	44.00	62.00	56.00	52.00	2.10
	Median	17.00	0.18	0.14	0.17	17.00	0.56	0.26	0.09
Lead/cadmium metal waste	Minimum	1.30	0.20	0.10	0.10	3.15	0.10	0.10	0.06
	Maximum	1710.00	90.00	90.00	113.67	1080.00	90.00	90.00	90.00
	Median	8.47	0.47	0.28	0.24	23.83	5.80	0.75	0.24

Table C2-3
Minimum, Maximum, and Median Values of Waste Matrix Code Groups (Continued)

Waste Matrix Code Group	Value	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoroethane	1,1-Dichloroethene	Acetone	Methylene Chloride	1,1-Dichloroethane	(cis)-1,2-Dichloroethene
Salt waste	Minimum	5.00	0.02	0.04	0.02	5.00	0.05	0.01	0.01
	Maximum	17.00	1.00	6.70	1.00	37.00	3.30	2.20	0.47
	Median	5.00	0.06	0.06	0.07	5.00	0.25	0.05	0.03
Soils	Minimum	-	-	-	-	-	-	-	-
	Maximum	-	-	-	-	-	-	-	-
	Median	-	-	-	-	-	-	-	-
Solidified Inorganics	Minimum	1.30	0.01	0.01	0.02	0.00	0.02	0.01	0.01
	Maximum	4900.00	500.00	12000.00	460.00	130.00	440.00	380.00	230.00
	Median	6.06	0.20	0.46	0.26	5.00	0.36	0.21	0.13
Solidified Organics	Minimum	1.90	0.06	0.05	0.05	1.20	0.08	0.02	0.03
	Maximum	82991.00	4367.90	20000.00	4367.9	52415.00	8080.9	4367.90	4367.90
	Median	17.00	2.08	1.85	5.00	17.00	3.38	1.00	1.00
Uncategorized metal	Minimum	2.70	0.01	0.02	0.02	0.50	0.02	0.01	0.01
	Maximum	30221.00	2400.00	1200.00	1200.00	6000.00	179752.0	1200.00	1200.00
	Median	17.00	0.39	0.30	0.32	17.00	0.78	0.24	0.24
Unknown	Minimum	-	-	-	-	-	-	-	-
	Maximum	-	-	-	-	-	-	-	-
	Median	-	-	-	-	-	-	-	-

Table C2-3
Minimum, Maximum, and Median Values of Waste Matrix Code Groups
(Continued)

Waste Matrix Code Group	Value	2-Butanone	Chloroform	1,1,1-Trichloroethane	Cyclohexane	Carbon Tetrachloride	Benzene	1,2-Dichloroethane	1-Butanol
Combustible	Minimum	1.00	0.06	0.05	0.02	0.02	0.04	0.02	1.20
	Maximum	18.00	1100.00	920.00	740.00	25000.00	78.00	110.00	18.00
	Median	17.00	2.80	48.00	0.45	0.83	0.42	0.42	17.00
Filter	Minimum	0.50	0.01	0.03	0.02	0.02	0.01	0.02	0.50
	Maximum	17.00	0.82	120.00	2.69	36.00	6.90	1.50	17.00
	Median	5.58	0.26	0.50	0.27	0.22	0.26	0.21	6.00
Graphite	Minimum	5.00	0.01	0.02	0.01	0.02	0.01	0.01	5.00
	Maximum	17.00	1.60	250.00	0.19	1.20	1.50	1.20	17.00
	Median	17.00	0.02	0.10	0.02	0.06	0.02	0.02	17.00
Heterogeneous	Minimum	0.50	0.04	0.10	0.03	0.09	0.06	0.03	0.50
	Maximum	2250.00	2074.30	14569.00	1922.1	6912.50	250.00	250.00	2304.0
	Median	4.50	0.40	0.67	1.18	0.55	0.50	0.37	3.85
Inorganic non-metal	Minimum	0.60	0.01	0.09	0.02	0.07	0.01	0.01	0.87
	Maximum	17.00	22.00	320.00	110.00	83.00	2.20	1.70	17.00
	Median	17.00	0.30	9.80	0.14	0.33	0.19	0.10	17.00
Lead/cadmium metal waste	Minimum	0.50	0.10	0.10	0.10	0.10	0.10	0.10	1.10
	Maximum	810.00	90.00	5612.30	90.00	2006.3	90.00	90.00	450.00
	Median	4.67	1.70	0.32	0.29	2.62	2.35	0.86	4.30

Table C2-3
Minimum, Maximum, and Median Values of Waste Matrix Code Groups
(Continued)

Waste Matrix Code Group	Value	2-Butanone	Chloroform	1,1,1-Trichlroroethane	Cyclohexane	Carbon Tetrachloride	Benzene	1,2-Dichloroethane	1-Butanol
Salt Waste	Minimum	5.00	0.01	0.10	0.01	0.07	0.01	0.01	5.00
	Maximum	17.00	2.30	23.00	0.72	50.00	0.58	0.46	17.00
	Median	5.00	0.06	0.39	0.10	0.16	0.09	0.03	5.00
Soils	Minimum	-	-	-	-	-	-	-	-
	Maximum	-	-	-	-	-	-	-	-
	Median	-	-	-	-	-	-	-	-
Solidified inorganic	Minimum	0.50	0.01	0.04	0.01	0.01	0.01	0.01	0.50
	Maximum	130.00	250.00	21000.00	1700.00	43000.00	290.00	230.00	132.00
	Median	5.00	0.13	4.70	0.29	0.28	0.24	0.13	5.00
Solidified organic	Minimum	0.50	0.04	0.12	0.04	0.07	0.10	0.03	0.50
	Maximum	39311.00	6023.40	85795.00	4367.9	88979.00	4367.90	4367.9	32467.00
	Median	17.00	1.35	81.50	1.75	1.60	3.00	0.99	17.00
Uncategorized metal	Minimum	0.50	0.01	0.05	0.01	0.02	0.01	0.01	0.50
	Maximum	6000.00	1200.0	5400.00	1200.00	1200.00	1200.00	1200.00	14400.00
	Median	17.00	0.32	12.50	0.31	0.39	0.37	0.24	17.00
Unknown	Minimum	-	-	-	-	-	-	-	-
	Maximum	-	-	-	-	-	-	-	-
	Median	-	-	-	-	-	-	-	-

Table C2-3
Minimum, Maximum, and Median Values of Waste Matrix Code Groups
(Continued)

Waste Matrix Code Group	Value	Trichlororo ethylene	Methyl isobutyl ketone	Toluene	Tetrachloro ethene	Chlorobenzene	Ethyl benzene	m,p-Xylene	o-Xylene
Combustible	Minimum	0.02	1.10	0.18	0.01	0.02	0.02	0.05	0.02
	Maximum	340.00	18.00	130.00	110.00	120.00	130.00	150.00	130.0
	Median	0.61	17.00	4.00	0.33	0.34	0.38	0.55	0.46
Filter	Minimum	0.02	0.10	0.03	0.02	0.02	0.02	0.02	0.02
	Maximum	260.00	17.00	53.00	2.80	1.20	1.00	1.40	1.00
	Median	0.40	4.59	2.77	0.30	0.20	0.20	0.24	0.21
Graphite	Minimum	0.01	5.00	0.02	0.01	0.01	0.01	0.01	0.01
	Maximum	3.00	51.00	9.40	1.10	1.40	2.30	7.60	2.50
	Median	0 02	17.00	0.07	0.02	0.02	0.02	0.02	0.02
Heterogeneous	Minimum	0.03	0.60	0.13	0.03	0.03	0.03	0.05	0.03
	Maximum	1600.00	2750.00	574.53	250.00	384.00	1996.80	8500.1	2764.00
	Median	0.40	4.40	13.98	0.30	0.40	0.40	0.46	0.60
Inorganic non-metal	Minimum	0.01	1.10	0.06	0.01	0.01	0.01	0.01	0.01
	Maximum	390.00	18.00	45.00	14.00	2.00	2.10	5.10	2.30
	Median	0.24	17.00	2.10	0.09	0.10	0.12	0.13	0.13
Lead/cadmium metal waste	Minimum	0.05	0.60	0.22	0.05	0.06	0.06	0.10	0.10
	Maximum	90.00	990.00	90.00	90.00	90.00	90.00	90.00	180.00
	Median	0.24	2.79	5.62	0.24	0.47	0.29	0.54	0.91

Table C2-3
Minimum, Maximum, and Median Values of Waste Matrix Code Groups (Continued)

Waste Matrix Code Group	Value	Trichlororo ethylene	Methyl isobutyl ketone	Toluene	Tetrachloro ethene	Chlorobenzene	Ethyl benzene	m,p-Xylene	o-Xylene
Salt waste	Minimum	0.01	5.00	0.43	0.01	0.01	0.01	0.01	0.01
	Maximum	12.00	17.00	12.00	0.46	0.54	0.57	0.57	0.57
	Median	0.11	5.00	5.00	0.03	0.03	0.04	0.05	0.04
Soils	Minimum	-	-	-	-	-	-	-	-
	Maximum	-	-	-	-	-	-	-	-
	Median	-	-	-	-	-	-	-	-
Solidified inorganics	Minimum	0.01	0.60	0.01	0.01	0.01	0.01	0.01	0.01
	Maximum	230.00	130.00	320.00	220.00	260.00	280.00	386.14	0.280
	Median	0.16	5.00	2.20	0.12	0.18	0.15	0.26	0.20
Solidified Organics	Minimum	0.03	0.60	0.43	0.03	0.03	0.03	0.03	0.03
	Maximum	4367.90	48047.50	6991.60	4367.90	4367.9	4367.90	8626.8	8735.9
	Median	20.50	17.00	18.00	1.40	1.20	1.25	1.30	1.45
Uncategorized metals	Minimum	0.01	0.70	0.02	0.01	0.01	0.01	0.01	0.01
	Maximum	1821.1	8400.00	1494.70	1200.00	2400.00	1200.0	1200.0	1200.00
	Median	0.40	17.00	5.10	0.24	0.28	0.29	0.32	0.30
Unknown	Minimum	-	-	-	-	-	-	-	-
	Maximum	-	-	-	-	-	-	-	-
	Median	-	-	-	-	-	-	-	-

Table C2-3
Minimum, Maximum, and Median Values of Waste Matrix Code Groups (Continued)

Waste Matrix Code Group	Value	Bromoform	1,1,2,2-Tetra chlororethane	1,3,5-Trimethyl benzene	1,2,4-Trimethyl benzene
Combustible	Minimum	0.02	0.02	0.01	0.01
	Maximum	160.00	140.00	77.00	93.00
	Median	0.40	0.38	0.24	0.26
Filter	Minimum	0.03	0.02	0.01	0.02
	Maximum	1.30	1.10	0.61	1.20
	Median	0.20	0.20	0.13	0.20
Graphite	Minimum	0.01	0.01	0.01	0.01
	Maximum	1.20	1.40	0.95	2.00
	Median	0.02	0.02	0.01	0.02
Heterogeneous	Minimum	0.03	0.03	0.02	0.02
	Maximum	250.00	250.00	250.00	384.00
	Median	0.30	0.30	0.30	0.40
Inorganic non-metal	Minimum	0.01	0.01	0.01	0.01
	Maximum	5.00	2.00	1.40	1.60
	Median	0.09	0.10	0.07	0.08
Lead/cadmium metal waste	Minimum	0.05	0.06	0.04	0.06
	Maximum	90.00	90.00	90.00	90.00
	Median	0.24	0.24	0.24	0.47
Salt waste	Minimum	0.01	0.01	0.01	0.01
	Maximum	0.48	0.54	0.38	0.38
	Median	0.03	0.03	0.03	0.04

Table C2-3
Minimum, Maximum, and Median Values of Waste Matrix Code Groups
(Continued)

Waste Matrix Code Group	Value	Bromoform	1,1,2,2-Tetra chlororethane	1,3,5-Trimethyl benzene	1,2,4-Trimethyl benzene
Soils	Minimum	-	-	-	-
	Maximum	-	-	-	-
	Median	-	-	-	-
Solidified inorganics	Minimum	0.01	0.01	0.01	0.01
	Maximum	240.00	270.00	190.00	250.00
	Median	0.13	0.13	0.10	0.18
Solidified organics	Minimum	0.03	0.03	0.02	0.02
	Maximum	4367.90	4367.96	4367.90	4367.90
	Median	1.05	1.20	0.83	0.99
Uncategorized metals	Minimum	0.01	0.01	0.01	0.01
	Maximum	1200.00	1200.00	1200.00	2400.00
	Median	0.23	0.26	0.20	0.23
Unknown	Minimum	-	-	-	-
	Maximum	-	-	-	-
	Median	-	-	-	-

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
000365	RFETS	Uncategorized Metal	217	480	17.00 U	24.00 U	15.00 U	22.00 U	32.00 J	280.00	18.00 U	11.00 U
000371	INEL	Graphite	215	300	17.00 U	0.02 U	0.60 J	0.03 U	17.00 U	0.76 J	0.03 U	0.03 U
000373	INEL	Graphite	215	300	17.00 U	0.02 U	0.04 J	0.02 U	17.00 U	0.07 J	0.02 U	0.02 U
000384	RFETS	Uncategorized Metal	217	320	5.00 U	0.02 U	0.02 J	0.02 U	5.00 U	0.05 J	0.01 U	0.01 U
000393	INEL	Uncategorized Metal	217	480	17.00 U	0.06 U	0.08 J	0.05 U	17.00 U	0.17 J	0.04 U	0.03 U
000401	RFETS	Inorganic Non-metal	222	371	5.00 U	0.03 U	0.04 J	0.03 U	8.70 J	0.51 U	0.02 U	0.01 U
000403	INEL	Inorganic Non-metal	218	440	17.00 U	0.06 U	0.13 J	0.05 U	17.00 U	0.33 J	0.04 U	0.03 U
000405	RFETS	Uncategorized Metal	217	480	8.00 J	1.80 U	1.10 U	1.60 U	55.00 J	250.00	1.30 U	0.81 U
000436	INEL	Solidified Organics	212	3	17.00 U	35.00 U	740.00	44.00 U	17.00 U	56.00 U	42.00 U	40.00 U
000442	INEL	Solidified Inorganics	213	4	3300.0	0.04 U	0.08 U	0.06 U	51.00 U	1.90	0.05 U	0.05 U
000446	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 U	0.04 J	0.02 U	5.00 U	0.08 J	0.01 U	0.01 U
000478	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 U	0.05 J	0.02 U	5.00 U	0.13	0.01 U	0.01 U
000501	INEL	Graphite	215	300	17.00 U	0.02 U	0.03 J	0.02 U	17.00 U	0.05 J	0.02 U	0.02 U
000558	INEL	Heterogeneous	221	464	17.00 U	0.19 U	0.12 U	0.17 U	17.00 U	0.35 J	0.14 U	0.09 U
000567	RFETS	Inorganic Non-metal	222	371	17.00 J	3.20 U	2.00 J	3.00 U	5.00 U	56.00	2.40 U	1.50 U
000568	RFETS	Solidified Organics	226	432	17.00 U	2.00 U	1.20 U	1.80 U	17.00 U	1.40 U	1.50 U	0.90 U
000593	INEL	Solidified Inorganics	211	7	17.00 U	0.01 U	0.30 J	0.02 U	17.00 U	0.13 J	0.02 U	0.02 U
000613	INEL	Graphite	215	300	17.00 U	0.06 U	0.04 J	0.05 U	17.00 U	0.04 U	0.04 U	0.03 U
000630	INEL	Solidified Inorganics	213	4	4300.0	0.05 U	0.10 U	0.07 U	51.00 U	0.23 J	0.07 U	0.06 U
000648	RFETS	Solidified Inorganics	213	4	1700.0 D	0.06 U	0.04 U	0.05 U	70.00 U	0.47 D	0.04 U	0.03 U
000675	RFETS	Inorganic Non-metal	218	440	6.20 J	0.30 U	0.19 J	0.27 U	14.00 J	0.62 J	0.22 U	0.14 U
000823	RFETS	Solidified Inorganics	213	4	3700.0 D	0.04 U	0.19 JB	0.04 U	120.00 U	1.50	0.03 U	0.02 U
000828	INEL	Graphite	215	300	17.00 U	0.02 U	0.04 J	0.02 U	17.00 U	0.05 J	0.02 U	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
001016	INEL	Graphite	215	300	17.00 U	0.02 U	0.03 J	0.02 U	17.00 U	0.05 J	0.02 U	0.02 U
001024	INEL	Graphite	215	300	24.00 J	0.02 U	0.03 J	0.02 U	17.00 U	0.07 J	0.02 U	0.02 U
001084	INEL	Solidified Inorganics	213	4	17.00 U	0.02 U	0.13 JB	0.02 U	17.00 U	0.19 J	0.02 U	0.02 U
001139	INEL	Solidified Inorganics	211	7	17.00 U	0.13 U	0.31 J	0.76 J	17.00 U	0.21 U	0.19 J	0.15 U
001157	INEL	Combustible	223	339	17.00 U	0.06 U	0.04 J	0.05 U	17.00 U	1.60	0.07 J	0.03 U
001161	INEL	Graphite	215	300	17.00 U	0.02 U	0.03 U	0.03 U	17.00 U	0.05 J	0.03 U	0.02 U
001258	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 U	0.16	0.02 U	5.00 U	0.09 J	0.01 U	0.01 U
001370	INEL	Combustible	223	339	17.00 U	0.11 U	0.77 J	0.12 U	17.00 U	2.00	0.13 U	0.09 U
001377	INEL	Combustible	223	339	17.00 U	0.06 U	0.08 J	0.05 U	17.00 U	4.10	0.02 U	0.04 J
001410	INEL	Solidified Inorganics	214	292	17.00 U	0.24 U	0.15 U	0.22 U	17.00 U	0.19 J	0.18 U	0.11 U
001437	RFETS	Solidified Inorganics	211	7	5.00 U	0.02 U	0.03 J	0.04 J	7.20 J	0.45	0.02 J	0.01 U
001475	RFETS	Solidified Inorganics	211	1	5.00 U	0.39 U	23.00 D	0.36 U	5.00 U	0.21 U	0.29 U	0.18 U
001493	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 U	0.15	0.02 U	5.00 U	0.08 J	0.01 U	0.01 U
001619	INEL	Graphite	215	300	17.00 U	0.06 U	0.06 J	0.05 U	17.00 U	0.05 J	0.04 U	0.03 U
001625	INEL	Graphite	215	300	17.00 U	0.01 U	0.04 J	0.02 U	17.00 U	0.08 J	0.02 U	0.02 U
001633	INEL	Solidified Organics	226	432	17.00 U	1.40 U	0.89 U	1.30 U	17.00 U	0.98 U	1.00 U	0.89 J
001655	INEL	Combustible	223	339	17.00 U	3.80 U	2.40 U	3.40 U	17.00 U	3.00 J	0.02 U	1.70 U
001662	INEL	Graphite	215	300	17.00 U	0.01 U	0.06 J	0.02 U	17.00 U	0.04 J	0.02 U	0.02 U
001663	RFETS	Solidified Organics	226	432	17.00 U	0.84 U	0.53 U	0.77 U	17.00 U	140.00	0.63 U	0.39 U
001667	INEL	Graphite	215	300	17.00 U	0.01 U	0.06 J	0.02 U	17.00 U	0.08 J	0.02 U	0.02 U
001670	RFETS	Salt Waste	224	411	5.00 U	0.07 U	0.06 J	0.07 U	5.00 U	0.85	0.06 U	0.03 U
001677	INEL	Heterogeneous	221	302	17.00 U	0.38 U	0.70 U	0.50 J	17.00 U	0.74 J	0.46 U	0.58 J
001678	RFETS	Combustible	223	339	5.00 U	0.20 U	0.28 J	0.18 U	18.00 J	7.40	1.20	0.09 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
001689	INEL	Heterogeneous	221	302	17.00 U	0.07 U	0.06 J	0.07 U	17.00 U	0.68	0.06 U	0.03 U
001692	RFETS	Solidified Organics	226	432	17.00 U	0.51 U	0.32 U	0.46 U	17.00 U	0.35 U	0.38 U	0.23 U
001695	INEL	Combustible	223	339	17.00 U	3.20 U	2.00 U	3.00 U	2.40 U	4.80 J	0.03 U	1.50 U
001697	INEL	Graphite	215	300	17.00 U	0.01 U	0.05 J	0.02 U	17.00 U	0.07 J	0.02 U	0.02 U
001751	RFETS	Uncategorized Metal	217	320	5.00 U	0.02 U	0.03 J	0.02 U	5.00 U	0.09 J	0.01 U	0.01 U
001752	INEL	Graphite	215	300	17.00 U	0.01 U	0.04 J	0.02 U	17.00 U	0.08 J	0.02 U	0.02 U
001754	INEL	Uncategorized Metal	217	320	11.00 U	0.37 U	0.15 J	0.20 U	17.00 U	1.70 B	5.60 U	0.04 U
001757	INEL	Inorganic Non-metal	222	371	17.00 U	0.06 U	0.07 JB	0.05 U	17.00 U	0.19 J	0.04 U	0.03 U
001773	INEL	Graphite	215	300	17.00 U	0.01 U	0.04 J	0.02 U	17.00 U	0.10 J	35.00 U	0.02 U
001779	INEL	Graphite	215	300	17.00 U	0.01 U	0.04 J	0.02 U	17.00 U	0.04 J	0.04 U	0.02 U
001784	INEL	Combustible	223	339	17.00 U	0.06 U	0.07 J	0.05 U	17.00 U	1.10	0.02 U	0.03 U
001813	INEL	Solidified Inorganics	213	4	17.00 U	4.60 U	8.60 JB	5.90 U	17.00 U	7.40 U	0.30 J	5.40 U
001873	INEL	Solidified Inorganics	214	292	17.00 U	0.07 U	0.05 J	0.06 U	17.00 U	0.05 U	0.05 U	0.03 U
001899	RFETS	Solidified Inorganics	211	3	92.00 J	260.00 U	3300.0 B	240.00 U	5.70 J	230.00 U	200.00 U	120.00
001900	INEL	Solidified Inorganics	214	292	17.00 U	0.07 U	0.07 J	0.08 J	17.00 U	0.05 J	0.05 U	0.03 U
001919	RFETS	Uncategorized Metal	217	320	5.00 U	0.02 U	0.03 J	0.02 U	5.00 U	0.20	0.01 U	0.01 U
001937	RFETS	Solidified Organics	212	3	74.00 J	31.00 U	31.00 JB	29.00 U	6.90 J	27.00 U	24.00 U	14.00 U
002013	RFETS	Solidified Organics	212	3	68.00 J	22.00 U	17.00 JB	20.00 U	5.00 U	20.00 U	17.00 U	10.00 U
002046	INEL	Solidified Organics	212	3	17.00 U	29.00 U	140.00	37.00 U	17.00 U	46.00 U	1.30	34.00 U
002065	INEL	Solidified Inorganics	214	292	5.00 U	0.21 U	0.13 U	0.19 U	5.00 U	0.18 U	0.16 U	0.10 U
002084	INEL	Solidified Inorganics	213	4	1900.0	0.03 U	0.11 J	0.04 U	0.00	0.47 J	7.60 U	0.03 U
002220	RFETS	Uncategorized Metal	217	481	5.00 U	0.06 U	0.04 U	0.05 U	5.00 U	0.98	1.10	0.03 U
002222	INEL	Graphite	215	300	79.00 J	0.02 U	0.06 J	0.02 U	17.00 U	0.07 J	0.07 U	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
002338	RFETS	Inorganic Non-metal	222	371	17.00 U	1.60 U	1.00 U	1.40 U	17.00 U	1.10 U	1.20 U	0.72 U
002354	INEL	Combustible	223	339	17.00 U	0.06 U	0.09 U	0.07 U	17.00 U	4.20	0.04 U	0.05 U
002363	INEL	Inorganic Non-metal	222	371	17.00 U	0.06 U	0.09 JB	0.05 U	17.00 U	0.32 J	0.04 U	0.03 U
002365	INEL	Uncategorized Metal	217	480	17.00 U	0.14 U	0.09 U	0.13 U	17.00 U	6.20	0.04 U	0.06 U
002542	INEL	Solidified Organics	212	3	17.00 U	6.30 U	47.00	7.90 U	17.00 U	10.00 U	77.00 U	7.30 U
002678	RFETS	Solidified Organics	226	432	17.00 U	1.80 U	1.10 U	1.60 U	17.00 U	1.30 U	1.40 U	0.82 U
002791	INEL	Inorganic Non-metal	222	371	17.00 U	0.09 U	0.11 J	0.09 U	17.00 U	0.64	36.00 U	0.04 U
002797	RFETS	Solidified Organics	226	432	17.00 U	0.90 U	0.57 U	0.82 U	17.00 U	0.63 U	0.67 U	0.41 U
002814	RFETS	Solidified Inorganics	211	7	5.00 U	0.41 U	31.00	0.52 J	5.00 U	0.36 U	0.31 U	0.19 U
003017	INEL	Solidified Inorganics	211	1	5.00 U	0.10 U	0.06 U	0.09 U	5.00 U	1.00	0.08 U	0.05 U
003088	INEL	Inorganic Non-metal	222	371	17.00 U	0.06 U	0.08 J	0.05 U	17.00 U	0.56	0.04 J	0.03 U
003091	RFETS	Inorganic Non-metal	222	371	64.00 J	0.06 U	0.07 J	0.05 U	17.00 U	0.14 J	0.04 U	0.03 U
003111	INEL	Inorganic Non-metal	222	371	17.00 U	0.06 U	0.10 J	0.05 U	15.00 U	0.46	0.25 J	0.03 U
003121	RFETS	Solidified Inorganics	211	7	5.00 U	0.28 U	17.00 D	0.25 U	5.00 U	0.24 U	0.21 U	0.13 U
003129	RFETS	Solidified Inorganics	211	7	5.00 U	0.04 U	2.40	0.06 J	5.00 U	0.10 J	0.03 U	0.02 U
003130	RFETS	Solidified Inorganics	211	7	5.00 U	0.08 U	5.00 D	0.09 JD	5.00 U	0.13 JD	0.06 U	0.04 U
003173	RFETS	Solidified Inorganics	211	7	5.00 U	0.03 U	1.00	0.03 J	5.00 U	0.12 J	0.03 U	0.02 U
003181	RFETS	Solidified Inorganics	211	7	5.00 U	0.03 U	0.23	0.03 U	5.00 U	0.05 J	0.02 U	0.01 U
003189	INEL	Solidified Organics	212	3	17.00 U	64.00 U	1800.0	81.00 U	17.00 U	100.00 U	0.02 U	74.00 U
003192	RFETS	Solidified Inorganics	211	7	5.00 U	0.46 U	20.00	0.77 J	7.10 J	7.20	0.35 U	0.21 U
003215	RFETS	Solidified Inorganics	211	7	5.00 U	0.03 U	1.60	0.08 J	5.00 U	0.12 J	0.02 U	0.01 U
003277	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 U	0.04 J	0.02 U	5.00 U	0.08 J	0.01 U	0.01 U
003394	RFETS	Solidified Inorganics	211	7	5.00 U	0.06 U	0.09 J	0.07 J	5.00 U	0.26 J	0.04 U	0.03 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
003406	RFETS	Solidified Inorganics	211	7	5.00 U	0.02 U	1.00	0.02 J	5.00 U	0.06 J	0.01 U	0.01 U
003455	RFETS	Solidified Inorganics	211	3	190.00	500.00 U	12000 B	460.00 U	10.00 J	440.00 U	380.00 U	230.00 U
003547	RFETS	Solidified Inorganics	211	7	5.00 U	0.18 U	0.51 J	0.17 U	5.00 U	0.16 U	0.14 U	0.08 U
003577	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 U	0.04 J	0.02 U	5.00 U	0.07 J	0.02 U	0.01 U
003854	INEL	Solidified Organics	212	3	17.00 U	29.00 U	400.00	37.00 U	17.00 U	47.00 U	0.04 J	34.00 U
003890	INEL	Solidified Inorganics	111	7	5.00 U	0.06 U	0.13 J	0.05 U	5.00 U	0.11 J	0.04 U	0.03 U
003921	INEL	Solidified Inorganics	111	7	5.00 U	0.07 U	0.17 J	0.06 U	5.00 U	0.14 J	0.05 U	0.03 U
003991	INEL	Combustible	223	339	17.00 U	0.02 U	0.03 U	0.02 U	17.00 U	1.30	0.02 U	0.02 U
003997	INEL	Combustible	223	339	15.00 U	0.04 U	0.06 U	0.04 U	17.00 U	5.00	130.00 U	0.03 U
004099	INEL	Solidified Inorganics	211	1	5.00 U	0.03 U	0.04 J	0.03 U	5.00 U	0.06 J	0.02 U	0.01 U
004111	RFETS	Salt Waste	224	411	5.00 U	0.06 U	0.04 U	0.05 U	5.00 U	0.25 J	0.04 U	0.03 U
004112	INEL	Graphite	215	300	17.00 U	0.02 U	0.04 J	0.02 U	17.00 U	0.09 J	0.04 J	0.02 U
004123	INEL	Combustible	223	339	17.00 U	0.02 U	0.03 U	0.02 U	17.00 U	3.00	0.02 U	0.02 U
004125	INEL	Uncategorized Metal	217	480	17.00 U	0.06 U	0.04 U	0.05 U	17.00 U	0.37 J	0.04 U	0.03 U
004150	INEL	Graphite	215	300	17.00 U	0.01 U	0.05 J	0.02 U	15.00 U	0.06 J	0.10 J	0.02 U
004160	INEL	Combustible	223	339	110.00	110.00 U	180.00	120.00 U	17.00 U	100.00 U	0.02 U	93.00 U
004166	INEL	Inorganic Non-metal	222	371	40.00 J	0.06 U	0.09 J	0.05 U	17.00 U	0.23 J	0.04 U	0.03 U
004186	INEL	Combustible	223	339	17.00 U	0.02 U	0.16 J	0.02 U	17.00 U	1.20	0.02 U	0.02 U
004195	RFETS	Salt Waste	224	411	5.00 U	0.02 U	0.03 J	0.02 U	5.00 U	0.11	0.01 U	0.01 U
004196	INEL	Graphite	215	300	17.00 U	0.02 U	0.04 J	0.02 U	17.00 U	0.29 J	0.02 U	0.02 U
004206	INEL	Combustible	223	339	15.00 U	0.02 U	0.03 J	0.02 U	17.00 U	2.70	0.02 U	0.01 U
004208	INEL	Graphite	215	300	17.00 U	0.02 U	0.03 U	0.02 U	51.00 U	0.05 J	0.03 U	0.02 U
004283	INEL	Solidified Inorganics	211	1	17.00 U	0.01 U	4.40	0.02 U	22.00 J	2.70	0.50 J	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
004326	INEL	Solidified Inorganics	213	4	1100.0	0.01 U	0.11 J	0.02 U	17.00 U	0.32 J	0.02 U	0.02 U
004393	INEL	Solidified Inorganics	211	1	5.00 U	0.03 U	0.06 J	0.03 U	5.00 U	0.62	0.03 U	0.02 U
004410	INEL	Solidified Inorganics	211	1	5.00 U	0.06 U	0.10 J	0.05 U	5.00 U	0.12 J	0.04 U	0.03 U
004495	INEL	Solidified Inorganics	213	4	17.00 U	0.01 U	0.08 J	0.02 U	17.00 U	0.13 J	220.00 U	0.02 U
004516	INEL	Solidified Inorganics	211	1	5.00 U	0.06 U	0.05 J	0.05 U	5.00 U	0.12 J	0.04 U	0.03 U
004884	INEL	Solidified Inorganics	213	4	4000.0	0.02 U	0.04 U	0.03 U	17.00 U	1.30	0.02 U	0.03 U
004963	INEL	Combustible	223	339	31.00 J	0.06 U	0.15 J	0.07 U	17.00 U	4.10	0.02 U	0.05 U
004968	RFETS	Uncategorized Metal	217	320	5.00 U	1.10 U	1.00 J	1.00 U	12.00 J	0.96 U	0.82 U	0.51 U
004981	RFETS	Uncategorized Metal	217	320	5.00 U	0.02 U	0.19	0.02 U	5.00 U	0.07 J	0.01 U	0.01 U
004988	RFETS	Salt Waste	224	411	5.00 U	0.06 U	0.04 U	0.05 U	5.00 U	0.36	0.04 U	0.03 U
005006	RFETS	Salt Waste	224	411	5.00 U	0.06 U	0.04 J	0.05 U	5.00 U	0.41	0.04 U	0.03 U
005012	INEL	Combustible	223	339	17.00 U	0.01 U	0.11 J	0.02 U	17.00 U	0.61 J	0.04 U	0.02 U
005015	INEL	Solidified Organics	226	432	17.00 U	2.80 U	1.80 U	2.60 U	17.00 U	38.00	2.10 U	1.30 U
005235	INEL	Solidified Organics	226	432	17.00 U	0.06 U	0.09 JB	0.05 U	17.00 U	0.08 U	0.04 U	0.03 U
005262	INEL	Solidified Organics	212	3	80.00 J	180.00 U	6400.0 B	230.00 U	17.00 U	290.00 U	0.10 J	210.00 U
005358	INEL	Solidified Inorganics	211	1	17.00 U	0.01 U	0.20 J	0.02 U	17.00 U	0.14 J	0.05 J	0.02 U
005398	INEL	Solidified Inorganics	211	1	5.00 U	0.06 U	18.00 E	0.10 J	5.00 U	0.05 U	0.04 U	0.03 U
005415	INEL	Solidified Inorganics	211	1	5.00 U	0.06 U	0.04 J	0.05 U	5.00 U	0.06 J	0.04 U	0.03 U
005530	INEL	Graphite	215	303	17.00 U	0.02 U	0.06 J	0.02 U	33.00 J	0.20 J	3.00 U	0.02 U
005535	INEL	Solidified Organics	226	432	17.00 U	0.11 U	0.07 J	0.10 U	17.00 U	0.08 JD	0.08 U	0.05 U
005735	INEL	Solidified Inorganics	211	7	5.00 U	0.06 U	2.20	0.05 U	5.00 U	0.06 J	0.04 U	0.03 U
005738	INEL	Solidified Inorganics	211	7	5.00 U	0.04 U	0.40	0.04 U	5.00 U	0.05 J	0.03 U	0.02 U
006242	INEL	ganic Non-metal	222	371	17.00 U	0.06 U	0.08 J	0.05 U	17.00 U	0.37	2.40 U	0.03 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
006252	RFETS	Lead/Cadmium Metal Waste	123	339	5.00 U	7.40 U	4.70 U	6.80 U	16.00 J	6.50 U	5.60 U	3.40 U
006325	RFETS	Solidified Inorganics	213	4	2700.0 D	0.02 U	0.04 JB	0.02 U	100.00 U	0.22	0.02 U	0.01 U
006669	INEL	Solidified Inorganics	214	292	5.00 U	0.28 U	0.18 U	0.26 U	5.00 U	0.24 U	0.21 U	0.13 U
006773	RFETS	Solidified Inorganics	213	4	2800.0 D	0.21 U	0.44 JB	13.00	120.00 U	1.80	14.00	0.10 U
006857	INEL	Combustible	223	339	17.00 U	0.02 U	0.04 J	0.02 U	18.00 U	1.10	12.00	0.02 J
006865	RFETS	Solidified Organics	226	432	5.00 U	0.15 U	0.36 J	0.14 U	5.00 U	0.13 U	0.11 U	0.07 U
006876	INEL	Filter	219	335	17.00 U	0.02 U	0.03 U	0.02 U	17.00 U	0.78 J	0.17 U	0.02 U
006879	INEL	Solidified Organics	226	432	17.00 U	0.19 U	0.12 U	0.17 U	17.00 U	0.13 U	0.14 U	0.09 U
006886	INEL	Solidified Organics	226	432	17.00 U	0.62 U	0.39 U	0.57 U	17.00 U	0.43 U	0.46 U	0.97 J
007034	INEL	Combustible	216	337	15.00 U	4.00 U	2.50 U	3.60 U	17.00 U	2.80 U	0.20 U	2.60
007146	INEL	Inorganic Non-metal	222	371	17.00 U	3.20 U	2.00 U	3.10	17.00 U	2.20 U	0.02 U	1.90
007170	INEL	Combustible	216	337	18.00 U	0.31 U	0.49 U	0.35 U	39.00 J	0.32 J	4.60	0.26 U
007231	INEL	Filter	219	338	17.00 U	0.14 U	0.22 U	0.16 U	17.00 U	0.22 J	0.07 J	0.12 U
007511	INEL	Inorganic Non-metal	122	374	17.00 U	0.07 U	0.10 J	0.06 U	17.00 U	0.21 J	0.05 U	0.03 U
007518	INEL	Inorganic Non-metal	122	374	17.00 U	0.11 U	0.07 J	0.10 U	27.00 J	0.93	0.08 U	0.05 U
007667	INEL	Salt Waste	124	411	5.00 U	0.02 U	0.04 J	0.02 U	5.00 U	0.05 J	0.01 U	0.01 U
007920	INEL	Filter	121	302	17.00 U	0.45 U	0.28 U	0.41 U	17.00 U	0.39 U	0.34 U	0.21 U
008203	INEL	Inorganic Non-metal	118	440	17.00 U	0.11 U	0.08 J	0.10 U	17.00 U	0.16 J	0.08 U	0.05 U
008207	INEL	Heterogeneous	116	336	17.00 U	0.14 U	0.09 U	0.13 U	36.00 J	7.40 J	1.00 U	0.08 J
008218	INEL	Heterogeneous	116	330	17.00 U	0.14 U	0.10 J	0.13 U	36.00 J	6.40	0.77 J	0.06 U
008269	INEL	Uncategorized Metal	117	320	17.00 U	0.36 U	0.23 U	0.34 U	17.00 U	0.32 U	0.27 U	0.17 U
008287	INEL	Inorganic Non-metal	122	374	17.00 U	0.06 U	0.06 J	0.05 U	17.00 U	0.13 J	0.04 U	0.03 U
008359	INEL	Heterogeneous	116	330	33.00 J	0.36 U	0.23 U	0.34 U	33.00 J	6.80	0.82 J	0.17 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
008383	INEL	Lead/Cadmium Metal Waste	123	339	13.00 J	9.90 U	6.30 J	13.00 J	5.00 U	8.60 U	7.40 U	4.60 U
008848	INEL	Inorganic Non-metal	218	440	120.00	0.16 U	0.30 U	0.28 J	17.00 U	2.60	16.00	0.19 U
008859	INEL	Inorganic Non-metal	218	440	17.00 U	0.84 U	0.53 U	0.77 U	17.00 U	0.59 U	0.55 U	0.39 U
008860	INEL	Uncategorized Metal	217	480	17.00 U	2.10 U	1.40 U	2.00 U	17.00 U	15.00	1.60 U	0.98 U
008864	INEL	Uncategorized Metal	217	480	17.00 U	0.19 U	0.12 U	0.17 U	17.00 U	0.21 J	0.14 U	0.09 U
008872	INEL	Solidified Inorganics	214	292	5.00 U	0.07 U	0.05 U	0.07 U	5.00 U	0.07 U	0.06 U	0.03 U
008874	RFETS	Uncategorized Metal	217	480	5.00 U	66.00 U	42.00 U	61.00 U	14.00 J	58.00 U	50.00 U	30.00 U
008878	INEL	Uncategorized Metal	217	480	17.00 U	9.00 U	5.70 U	8.30 U	17.00 U	6.30 U	6.70 U	4.10 U
008880	RFETS	Graphite	115	312	5.00 U	2.60 U	1.60 J	2.40 U	8.40 J	23.00	1.90 U	1.20 U
009006	INEL	Solidified Inorganics	211	7	17.00 U	0.02 U	18.00 E	0.05 J	18.00 U	0.02 U	0.09 U	0.02 U
009011	RFETS	Solidified Inorganics	211	7	5.00 U	0.02 U	0.58	0.04 J	5.00 U	0.33	0.02 U	0.01
009061	RFETS	Inorganic Non-metal	218	440	5.00 U	0.18 U	0.13 J	0.17 U	5.00 U	1.10	0.14 U	0.08 U
009180	INEL	Combustible	223	339	17.00 U	0.71 U	10.00	1.00	17.00 U	14.00	0.70 U	0.59 U
009225	INEL	Uncategorized Metal	217	481	17.00 U	0.06 U	0.13 J	0.05 U	18.00 U	0.07 U	0.22 U	0.03 U
009252	INEL	Combustible	223	339	17.00 U	40.00 U	25.00 U	36.00 U	17.00 U	270.00	11.00	18.00 U
009296	INEL	Combustible	223	339	17.00 U	5.60 U	3.60 U	5.20 U	17.00 U	3.90 U	0.02 U	2.60 U
009299	INEL	Combustible	223	339	17.00 U	0.02 U	0.03 U	0.02 U	22.00 J	1.90	6.10	0.02 U
009399	INEL	Inorganic Non-metal	218	440	17.00 U	0.73 U	0.46 U	0.67 U	17.00 U	0.61 J	0.55 U	0.34 U
009422	RFETS	Combustible	216	337	5.00 U	10.00 U	6.60 U	9.60 U	5.00 U	150.00 D	7.80 U	4.80 U
009423	INEL	Combustible	216	337	17.00 U	1.40 U	2.70 U	7.30	17.00 U	11.00	1.10 U	1.70 U
009435	INEL	Combustible	216	337	39.00 J	0.73 U	0.46 U	0.67 U	17.00 U	0.51 U	0.32 U	0.34 U
009449	INEL	Inorganic Non-metal	218	440	17.00 U	0.08 U	0.15 J	0.07 U	17.00 U	0.31 J	0.85 J	0.04 U
009471	INEL	nbustible	216	337	18.00 U	0.07 U	0.11 U	0.08 U	18.00 U	0.23 J	0.16 U	0.06 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
009475	INEL	Inorganic Non-metal	218	442	17.00 U	0.58 U	1.10 U	0.73 U	17.00 U	4.90	0.12 J	0.67 U
009489	INEL	Combustible	216	337	18.00 U	0.18 U	0.29 U	0.21 U	3.60 J	3.30	0.52 J	0.15 U
009587	INEL	Uncategorized Metal	117	320	5.00 U	0.02 U	0.04 J	0.02 U	5.00 U	0.08 J	0.01 U	0.01 U
009591	INEL	Inorganic Non-metal	118	440	17.00 U	0.07 U	0.06 J	0.06 U	17.00 U	0.13 J	0.05 U	0.03 U
009592	INEL	Inorganic Non-metal	118	440	17.00 U	0.14 U	0.09 U	0.13 U	17.00 U	0.16 J	0.10 U	0.06 U
009596	INEL	Uncategorized Metal	117	320	17.00 U	0.26 U	0.16 U	0.23 U	17.00 U	0.22 U	0.19 U	0.12 U
009599	INEL	Inorganic Non-metal	118	440	17.00 U	0.06 U	0.08 J	0.05 U	17.00 U	0.21 J	0.04 U	0.03 U
009602	INEL	Inorganic Non-metal	218	442	17.00 U	3.80 U	2.40 U	3.50 U	17.00 U	54.00	2.80 U	1.70 U
009694	INEL	Graphite	215	300	17.00 U	0.01 U	0.04 J	0.02 U	17.00 U	0.09 J	0.04 U	0.02 U
009735	INEL	Graphite	215	300	17.00 U	0.01 U	0.05 J	0.02 U	17.00 U	0.05 J	0.02 U	0.02 U
009773	INEL	Combustible	223	339	17.00 U	4.40 U	8.10 U	5.50 U	17.00 U	29.00	0.14 J	5.10 U
009787	RFETS	Solidified Organics	212	3	8.90 J	350.00 U	20000	320.00 U	5.00 U	300.00 U	260.00 U	160.00 U
009873	RFETS	Solidified Inorganics	211	1	5.00 U	0.09 U	0.10 J	0.14 J	5.00 U	0.43 J	0.07 U	0.04 U
010216	INEL	Filter	219	338	17.00 U	0.89 U	1.40 U	5.20	17.00 U	0.83 U	0.82 U	0.74 U
010224	INEL	Filter	219	338	17.00 U	0.27 U	0.42 U	0.30 U	17.00 U	0.44 J	0.16 J	0.22 U
010230	INEL	Heterogeneous	216	330	17.00 U	0.14 U	0.22 U	3.60	18.00 U	0.75 J	0.55 U	2.30
010273	INEL	Combustible	216	337	18.00 U	0.13 U	0.20 U	0.18 J	18.00 U	1.30	0.44 U	0.11 U
010295	INEL	Inorganic Non-metal	218	442	17.00 U	0.11 U	0.14 J	0.10 U	17.00 U	3.00	0.15 U	0.05 U
010305	RFETS	Inorganic Non-metal	218	442	91.00 J	1.30 U	0.84 U	1.20 U	5.00 U	1.20 U	0.99 U	0.61 U
010364	RFETS	Combustible	216	337	5.00 U	1.70 U	1.10 U	1.50 U	5.00 U	2.80 J	1.30 U	0.77 U
010371	INEL	Combustible	216	337	6.60 U	0.27 U	63.00 E	1.70	17.00 U	8.50	0.37 U	0.39 U
010407	RFETS	Uncategorized Metal	217	480	5.00 U	0.23 U	1.30 J	0.21 U	13.00 J	0.56 J	0.17 U	0.11 U
010411	INEL	Combustible	216	337	160.00	3.80 U	2.40 U	3.40 U	15.00 U	2.60 U	0.42 U	1.70 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
010415	INEL	Inorganic Non-metal	218	442	17.00 U	0.06 U	0.06 J	0.05 U	17.00 U	0.04 U	0.14 U	0.03 U
010426	INEL	Inorganic Non-metal	218	442	17.00 U	0.01 U	0.11 J	0.05 J	17.00 U	3.30	2.50	0.02 U
010463	INEL	Solidified Inorganics	213	4	860.00 U	0.56 U	0.36 U	1.50 J	34.00 U	0.39 U	1.40 J	0.26 U
010487	INEL	Salt Waste	224	414	17.00 U	1.00 U	6.70	0.94 U	37.00 J	3.30 J	2.20 J	0.47 U
010492	INEL	Uncategorized Metal	217	480	17.00 U	1.10 U	0.70 U	1.00 U	94.00 U	0.77	2.00	0.50 U
010498	INEL	Uncategorized Metal	217	480	17.00 U	0.04 U	0.11 J	0.06 J	17.00 U	2.30	1.20	0.04 U
010510	RFETS	Heterogeneous	216	336	5.00 U	3.20 U	2.00 U	3.00 U	9.60 J	2.80 U	2.40 U	1.50 U
010546	RFETS	Heterogeneous	216	330	10.00 U	88.00 U	300.00 J	81.00 U	270.00	3000.0	66.00 U	40.00 U
010578	INEL	Solidified Organics	226	432	17.00 U	1.90 U	5.00 J	1.80 U	17.00 U	1.30 U	1.40 U	0.88 U
010588	RFETS	Solidified Inorganics	211	2	5.00 U	1.60 U	1.00 U	1.50 U	5.00 U	1.40 U	1.20 U	0.76 U
010663	INEL	Combustible	216	337	18.00 U	0.46 U	0.72 U	0.52 U	18.00 U	0.43 U	0.55 U	0.38 U
010676	INEL	Heterogeneous	216	330	18.00 U	0.37 U	0.57 U	1.40	17.00 U	0.34 U	1.60	0.31 U
010800	INEL	Filter	219	338	17.00 U	0.12 U	0.19 U	0.20 J	17.00 U	0.12 U	0.07 J	0.15 J
010807	INEL	Combustible	216	337	17.00 U	2.50 U	1.60 U	2.30 U	17.00 U	1.70 U	1.30 U	1.20 U
010808	INEL	Combustible	216	337	17.00 U	0.30 U	0.56 U	0.38 U	18.00 U	0.49 U	1.80 U	0.56 J
010814	RFETS	Solidified Inorganics	211	1	5.00 U	0.67 U	0.42 U	0.61 U	5.00 U	0.58 U	0.50 U	0.31 U
010837	INEL	Solidified Organics	226	432	17.00 U	0.84 U	0.53 U	0.77 U	17.00 U	0.59 U	0.63 U	0.39 U
010848	INEL	Filter	219	338	15.00 U	0.35 U	0.54 U	0.39 U	17.00 U	0.53 J	0.59 U	0.29 U
010883	INEL	Solidified Organics	226	432	17.00 U	2.20 U	1.40 U	2.00 U	17.00 U	1.50 U	1.60 U	1.00 U
010921	INEL	Inorganic Non-metal	222	371	17.00 U	0.19 U	0.12 U	17.00	18.00 U	0.13 U	0.66 U	0.09 U
011004	INEL	Uncategorized Metal	217	480	17.00 U	0.06 U	0.06 J	0.05 U	17.00 U	0.09 J	0.04 U	0.03 U
011021	INEL	Solidified Organics	226	432	17.00 U	0.34 U	0.21 U	0.78 J	17.00 U	0.24 U	2.20	0.16 U
011042	INEL	ganic Non-metal	218	442	17.00 U	1.20 U	0.75 U	1.40	17.00 U	16.00	2.80 U	0.54 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
011044	INEL	Inorganic Non-metal	218	440	17.00 U	0.67 U	0.43 U	0.62 U	17.00 U	0.47 U	0.21 U	0.31 U
011067	RFETS	Solidified Inorganics	213	4	610.00	2.20 U	1.40 U	5.50 J	25.00 U	1.90 U	1.90 J	1.00 U
011102	RFETS	Solidified Inorganics	211	1	5.00 U	0.53 U	0.34 U	1.20 J	5.00 U	4.60	0.40 U	0.24 U
011109	INEL	Solidified Inorganics	211	1	17.00 U	0.17 U	1.20	3.40	17.00 U	4.10	0.02 U	0.20 U
011147	INEL	Solidified Inorganics	213	4	4900.0	0.20 U	0.37 U	1.00	17.00 U	1.60	1.70 U	0.23 U
011173	INEL	Uncategorized Metal	217	480	17.00 U	0.05 U	0.16 J	0.06 U	17.00 U	1.50	0.04 U	0.06 U
011194	INEL	Inorganic Non-metal	218	442	83.00 J	0.14 U	0.09 U	0.13 U	17.00 U	0.10 U	0.02 U	0.06 U
011393	INEL	Uncategorized Metal	217	480	59.00 J	0.28 U	0.18 U	0.26 U	17.00 U	0.52 J	0.21 U	0.13 U
011416	INEL	Combustible	216	337	17.00 U	1.20 U	0.78 U	1.10 U	17.00 U	0.86 U	0.93 U	0.57 U
011433	INEL	Heterogeneous	216	330	18.00 U	0.46 U	0.72 U	2.70	17.00 U	0.47 J	4.20 U	0.38 U
011498	RFETS	Solidified Organics	226	432	17.00 U	3.20 U	2.00 U	3.00 U	17.00 U	2.20 U	2.40 U	1.50 U
011529	INEL	Uncategorized Metal	217	480	17.00 U	0.06 U	0.04 U	0.05 U	17.00 U	0.07 J	0.04 U	0.03 U
011601	INEL	Heterogeneous	216	336	17.00 U	1.10 U	1.70 U	1.20 U	17.00 U	1.00 U	1.30 U	1.80
011607	INEL	Heterogeneous	216	330	17.00 U	0.03 U	0.30 J	0.05 J	37.00 J	0.16 J	0.67 U	0.02 U
011637	RFETS	Filter	219	338	8.40 J	1.60 U	1.00 U	1.50 U	6.20 J	1.40 U	1.20 U	0.76 U
011735	INEL	Heterogeneous	216	330	17.00 U	1.70 U	1.10 U	1.60 U	17.00 U	1.20 U	0.48 U	0.77 U
011749	INEL	Inorganic Non-metal	225	441	100.00	0.48 U	0.30 U	0.44 U	62.00 J	0.33 U	0.56 J	0.22 U
011785	RFETS	Solidified Inorganics	211	1	5.00 U	0.06 U	0.06 J	0.05 U	5.00 U	0.08 J	0.04 U	0.03 U
012021	INEL	Solidified Inorganics	211	1	17.00 U	0.73 U	0.46 U	0.81 J	17.00 U	0.51 U	0.65 J	0.34 U
012108	INEL	Solidified Inorganics	214	292	17.00 U	0.73 U	0.46 U	0.67 U	17.00 U	0.51 U	0.55 U	0.34 U
012111	INEL	Combustible	216	337	18.00 U	1.50 U	2.30 U	1.80	17.00 U	13.00	0.02 U	1.20 U
012215	INEL	Uncategorized Metal	217	480	17.00 U	0.79 U	0.50 U	0.72 U	17.00 U	0.55 U	0.58 U	0.36 U
012313	INEL	Heterogeneous	216	336	18.00 U	0.55 U	0.86 U	0.62 U	17.00 U	0.59 J	0.02 U	0.62 J

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
012320	INEL	Heterogeneous	216	336	17.00 U	3.70 U	2.40 U	3.40 U	17.00 U	2.60 U	0.04 U	2.50
012356	INEL	Filter	219	338	110.00	0.20 U	0.38 U	0.26 U	18.00 J	0.33 U	2.00	0.24 U
012357	RFETS	Uncategorized Metal	217	480	8.00 J	6.00 U	3.80 U	5.50 U	22.00 J	5.20 U	4.50 U	2.70 U
012433	INEL	Filter	219	338	17.00 U	0.18 U	0.28 U	0.95 J	17.00 U	0.60 J	0.59 J	0.15 U
012469	RFETS	Solidified Inorganics	211	1	5.00 U	0.68 U	0.75 JB	0.62 U	5.00 U	0.59 U	0.51 U	0.31 U
012471	RFETS	Filter	219	338	5.00 U	0.35 U	0.22 U	0.32 U	10.00 J	1.30 J	0.26 U	0.16 U
012487	INEL	Inorganic Non-metal	218	440	17.00 U	0.02 U	0.05 JB	0.02 U	17.00 U	0.03 U	0.06 U	0.02 U
012494	INEL	Heterogeneous	216	330	17.00 U	2.20 U	1.40 U	2.10 U	17.00 U	1.60 U	2.80 U	1.00 U
012541	INEL	Inorganic Non-metal	218	442	17.00 U	0.06 U	0.06 J	0.05 U	17.00 U	0.14 J	0.05 U	0.03 U
012553	INEL	Solidified Inorganics	211	1	17.00 U	0.06 U	0.04 J	0.05 U	17.00 U	0.28 J	0.04 U	0.03 U
012571	INEL	Uncategorized Metal	217	320	17.00 U	0.01 U	0.05 J	0.02 U	38.00 J	0.28 J	11.00 U	0.02 U
012611	INEL	Solidified Inorganics	211	1	17.00 U	1.20 U	0.75 U	1.10 U	17.00 U	7.00 J	0.88 U	0.54 U
012634	INEL	Solidified Inorganics	211	1	17.00 U	3.20 U	2.00 U	3.00 U	17.00 U	12.00 J	2.40 U	1.50 U
012749	INEL	Solidified Inorganics	211	1	17.00 U	0.62 U	0.39 U	0.60 J	17.00 U	0.43 U	0.46 U	0.28 U
012766	INEL	Heterogeneous	216	336	17.00 U	5.60 U	3.60 U	7.30	17.00 U	3.90 U	0.02 U	2.60 U
012802	INEL	Combustible	216	337	17.00 U	1.00 U	1.90 U	2.60	17.00 U	1.70 U	0.38 J	1.20 U
012875	RFETS	Solidified Organics	226	432	17.00 U	7.60 U	4.80 U	7.00 U	17.00 U	5.30 U	8.30	3.50 U
012878	INEL	Uncategorized Metal	217	480	17.00 U	0.55 U	1.00 U	0.70 U	17.00 U	0.88 U	0.03 U	0.64 U
012891	INEL	Heterogeneous	216	330	17.00 U	0.65 U	0.41 U	0.59 U	17.00 U	2.60	0.07 U	0.51 J
012902	INEL	Filter	219	338	17.00 U	0.02 U	0.03 U	0.02 U	17.00 U	0.02 U	0.04 J	0.02 U
012920	INEL	Inorganic Non-metal	222	371	17.00 U	2.20 U	1.40 U	44.00	17.00 U	1.60 U	1.70 U	1.00 U
012985	INEL	Inorganic Non-metal	222	371	17.00 U	3.80 U	2.40 U	3.40 U	17.00 U	2.60 U	0.32 J	2.10 J
012986	INEL	Heterogeneous	221	302	43.00 J	0.48 U	0.89 U	0.68 J	2.40 U	0.77 U	0.05 U	0.56 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
012998	INEL	Combustible	216	337	17.00 U	1.30 U	0.82 U	1.20 U	17.00 U	1.60	0.97 U	0.87 J
013106	INEL	Solidified Inorganics	111	7	5.00 U	0.03 U	1.70	0.03 U	5.00 U	0.08 J	0.04 J	0.01 U
013229	RFETS	Solidified Organics	226	432	17.00 U	0.28 U	0.18 U	0.26 U	17.00 U	0.20 U	0.21 U	0.13 U
013231	INEL	Graphite	215	300	17.00 U	0.02 U	0.03 U	0.02 U	17.00 U	0.09 J	0.07 U	0.02 U
013252	INEL	Inorganic Non-metal	222	371	19.00 J	0.06 U	0.07 JB	0.05 U	17.00 U	0.19 J	52.00 U	0.03 U
013266	INEL	Combustible	223	339	17.00 U	0.79 U	0.50 U	0.72 U	17.00 U	3.90	0.02 U	0.36 U
013269	INEL	Inorganic Non-metal	218	440	17.00 U	0.05 U	0.09 U	0.06 U	17.00 U	2.80	0.02 U	0.06 U
013313	INEL	Inorganic Non-metal	218	440	17.00 U	0.06 U	0.09 U	0.05 U	17.00 U	0.04 U	0.02 U	0.03 U
013331	INEL	Salt Waste	124	411	17.00 U	0.14 U	0.09 U	0.13 U	17.00 U	0.25 J	0.10 U	0.06 U
013342	INEL	Inorganic Non-metal	218	440	17.00 U	0.01 U	0.06 J	0.02 U	17.00 U	0.72 J	0.04 J	0.02 U
013346	RFETS	Inorganic Non-metal	222	371	12.00 J	0.04 U	0.04 J	0.04 U	5.00 U	0.11 J	0.03 U	0.02
013618	INEL	Heterogeneous	216	330	17.00 U	3.80 U	2.40 U	3.40 U	17.00 U	2.60	0.04 U	1.70 U
013677	INEL	Filter	219	338	17.00 U	0.05 U	0.07 U	0.05 U	17.00 U	0.04 U	0.04 J	0.04 U
013751	INEL	Uncategorized Metal	217	480	17.00 U	1.70 U	1.10 U	1.60 U	17.00 U	1.20 U	1.30 U	0.77 U
013763	INEL	Combustible	223	339	6.60 U	11.00 U	50.00	11.00 U	17.00 U	12.00	0.32 J	16.00 U
013773	RFETS	Solidified Inorganics	111	7	5.00 U	0.15 U	0.84 J	0.26 J	5.00 U	0.13 U	0.11 U	0.07 U
013818	RFETS	Solidified Inorganics	211	1	94.00 J	0.04 U	0.04 J	0.04 U	5.00 U	0.10 J	0.03 U	0.02 U
013820	RFETS	Solidified Inorganics	211	1	11.00 U	0.05 U	0.05 J	0.04 U	11.00 U	0.28 J	0.04 U	0.02 U
013847	INEL	Graphite	215	300	17.00 U	0.01 U	0.04 J	0.02 U	17.00 U	0.05 J	0.02 U	0.02 U
013860	INEL	Combustible	223	339	17.00 U	0.06 U	0.24 J	0.07 U	17.00 U	2.70	0.18 U	0.05 U
013876	RFETS	Solidified Inorganics	211	7	5.00 U	0.18 U	3.60	0.17 U	5.00 U	0.16 U	0.14 U	0.08 U
014007	INEL	Solidified Inorganics	211	1	17.00 U	0.02 U	0.07 J	0.02 U	17.00 U	0.20 J	0.25 U	0.02 U
014009	INEL	Solidified Inorganics	211	7	17.00 U	0.06 U	3.40	0.37 J	17.00 U	0.09 U	3.50 U	0.07 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

;um #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
)14010	INEL	Solidified Inorganics	211	7	17.00 U	0.01 U	3.30	0.10 J	17.00 U	0.13 J	0.29 J	0.02 U
)14127	RFETS	Solidified Inorganics	211	7	5.00 U	0.03 U	2.10	0.03 U	5.00 U	0.24	0.03 U	0.02 U
)14170	INEL	Solidified Inorganics	211	7	5.00 U	0.03 U	0.21	0.03 U	5.00 U	0.08 J	0.03 U	0.02 U
)14330	INEL	Graphite	215	303	21.00 J	0.04 U	0.06 U	0.04 U	17.00 U	6.20	0.30 J	0.03 U
)14334	INEL	Filter	219	335	11.00 U	0.05 U	0.10 J	0.05 U	17.00 U	0.22 J	0.04 U	0.07 U
)14339	INEL	Solidified Organics	226	432	17.00 U	0.11 U	0.07 U	0.10 U	17.00 U	0.08 U	0.08 U	0.05 U
)14342	INEL	Graphite	215	303	17.00 U	0.06 U	0.09 U	0.07 U	17.00 U	0.43 J	0.04 U	0.05 U
014345	INEL	Solidified Organics	226	432	17.00 U	0.09 U	0.10 JB	0.09 U	17.00 U	0.09 J	0.07 U	0.04 U
014346	INEL	Combustible	223	339	17.00 U	0.02 U	2.30	0.04 J	17.00 U	3.30	0.04 J	0.02 J
014348	INEL	Graphite	215	300	17.00 U	0.01 U	0.05 J	0.02 U	17.00 U	0.04 J	0.02 U	0.02 U
014354	RFETS	Uncategorized Metal	217	481	5.00 U	0.02 U	0.22	0.02 U	5.00 U	0.33	0.02 U	0.01 U
014357	INEL	Combustible	223	339	11.00 U	11.00 U	14.00 U	11.00 U	17.00 U	11.00 U	1.20 U	16.00 U
014387	INEL	Solidified Inorganics	211	7	17.00 U	0.01 U	23.00 E	0.19 J	17.00 U	0.10 J	0.63 J	0.02 U
014466	INEL	Heterogeneous	221	302	17.00 U	0.62 U	0.39 U	0.57 U	17.00 U	0.43 U	0.46 U	0.28 U
014484	INEL	Graphite	215	300	17.00 U	0.01 U	0.03 J	0.02 U	17.00 U	0.12 J	0.02 U	0.02 U
014502	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 U	0.12	0.02 U	5.00 U	0.10 J	0.01 U	0.01 U
014504	RFETS	Solidified Inorganics	211	1	5.00 U	0.06 U	0.53 J	0.05 U	5.00 U	0.11 J	0.04 U	0.03 U
014773	INEL	Solidified Inorganics	214	292	5.00 U	0.10 U	0.06 U	0.09 U	5.00 U	0.09 U	0.07 U	0.05 U
015228	RFETS	Solidified Organics	226	432	17.00 U	0.34 U	0.21 U	1.90	17.00 U	0.24 U	0.72 J	0.16 U
015231	INEL	Inorganic Non-metal	218	440	17.00 U	0.06 U	0.09 J	0.05 U	17.00 U	0.99 J	0.88 U	0.03 U
015241	INEL	Inorganic Non-metal	218	442	17.00 U	0.10 U	0.11 J	0.09 U	17.00 U	0.45 J	0.46 U	0.04 U
015249	INEL	Graphite	215	300	17.00 U	0.02 U	0.04 J	0.02 U	17.00 U	0.13 J	0.04 U	0.02 U
015262	RFETS	;idified Organics	226	432	17.00 U	3.20 U	2.00 U	36.00	17.00 U	2.20 U	10.00	1.50 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
015267	INEL	Uncategorized Metal	217	480	17.00 U	2.80 U	1.80 U	2.60 U	17.00 U	2.00 U	2.10 U	1.30 U
015338	INEL	Solidified Inorganics	211	7	29.00 J	0.02 U	22.00 E	0.09 J	17.00 U	0.02 U	0.20 U	0.02 U
015434	RFETS	Solidified Organics	226	432	17.00 U	0.08 U	0.05 J	6.80	17.00 U	0.78 J	0.09 J	0.04 U
015440	RFETS	Solidified Organics	226	432	17.00 U	0.73 U	0.46 U	5.40	17.00 U	1.20	22.00	0.34 U
015515	RFETS	Solidified Organics	212	3	5.00 U	53.00 U	37.00 J	49.00 U	5.00 U	47.00 U	40.00 U	24.00 U
015532	RFETS	Solidified Organics	212	3	5.00 U	160.00 U	100.00 U	150.00 U	6.00 J	140.00 U	120.00 U	75.00 U
015543	INEL	Solidified Organics	212	3	17.00 U	70.00 U	44.00 U	64.00 U	17.00 U	49.00 U	0.39 J	32.00 U
015627	INEL	Graphite	215	300	17.00 U	0.02 U	0.03 U	0.02 U	32.00 J	0.02 U	0.14 U	0.02 U
015655	INEL	Solidified Inorganics	211	7	17.00 U	0.01 U	0.50 J	0.02 U	17.00 U	0.07 J	0.21 J	0.02 U
015674	INEL	Graphite	215	300	17.00 U	0.01 U	0.08 J	0.02 U	17.00 U	0.16 J	0.03 J	0.02 U
015675	INEL	Uncategorized Metal	217	480	17.00 U	0.14 U	0.09 U	0.13 U	17.00 U	5.50	0.75 J	0.06 U
015777	RFETS	Solidified Organics	226	432	17.00 U	0.14 U	0.09 U	1.60	17.00 U	0.20 J	3.40	0.06 U
015785	RFETS	Solidified Inorganics	211	1	15.00 U	0.65 U	0.41 U	0.85 J	15.00 U	6.40	0.48 U	0.30 U
015786	INEL	Solidified Inorganics	211	1	17.00 U	0.02 U	0.05 U	0.17 J	17.00 U	0.25 J	0.76 U	0.03 U
016242	INEL	Graphite	215	300	17.00 U	0.01 U	0.04 J	0.02 U	17.00 U	0.09 J	0.02 U	0.02 U
016612	INEL	Inorganic Non-metal	218	442	17.00 U	0.06 U	0.08 J	0.05 U	17.00 U	0.17 J	0.22 J	0.03 U
016613	INEL	Solidified Organics	226	432	17.00 U	0.39 U	0.33 J	1.90 J	17.00 U	0.28 U	0.30 U	0.18 U
016707	INEL	Graphite	215	300	17.00 U	0.01 U	0.03 U	0.02 U	17.00 U	0.02 U	0.02 U	0.02 U
016738	RFETS	Solidified Inorganics	211	7	5.00 U	2.50 U	1.60 U	3.40 J	5.00 U	39.00	1.90 U	1.10 U
016790	INEL	Graphite	215	300	610.00	0.02 U	0.04 J	0.14 J	17.00 U	0.18 J	0.21 U	0.02 U
016807	INEL	Solidified Inorganics	211	1	17.00 U	0.13 U	0.24 U	0.42 J	17.00 U	2.80	1.80 U	0.15 U
016842	INEL	Graphite	215	300	17.00 U	0.01 U	0.05 J	0.02 U	27.00 J	0.07 J	0.85 J	0.02 U
016855	RFETS	Solidified Organics	212	3	8.70 J	250.00 U	790.00 JD	230.00 U	8.30 J	220.00 U	190.00 U	120.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

·um #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
)16869	INEL	Solidified Inorganics	211	7	17.00 U	0.14 U	18.00	0.66 J	17.00 U	12.00	1.50	0.17 U
)16964	RFETS	Solidified Inorganics	211	7	5.00 U	2.20 U	2.00 J	2.50 J	5.00 U	33.00	1.60 U	1.00 U
)16986	INEL	Inorganic Non-metal	218	442	17.00 U	0.34 U	0.21 U	0.31 U	17.00 U	0.24 U	0.02 U	0.16 U
)17148	INEL	Solidified Organics	226	432	17.00 U	1.20 U	0.76 U	87.00	17.00 U	3.60	0.90 U	0.55 U
)17190	INEL	Solidified Inorganics	211	7	17.00 U	2.90 U	19.00	13.00	17.00 U	260.00	3.30	3.40 U
)17444	INEL	Graphite	215	300	17.00 U	0.06 U	0.06 J	0.05 U	17.00 U	0.18 J	0.04 U	0.03 U
)17453	INEL	Solidified Organics	212	3	5.00 U	73.00 U	46.00 U	67.00 U	7.00 J	64.00 U	54.00 U	33.00 U
)17486	INEL	Solidified Inorganics	211	1	17.00 U	0.13 U	0.24 U	0.16 U	17.00 U	0.21 U	2.10 U	0.15 U
)17491	INEL	Graphite	215	300	17.00 U	0.14 U	0.27 U	0.18 U	17.00 U	6.20	0.50 J	0.17 U
)17495	INEL	Inorganic Non-metal	218	442	17.00 U	0.06 U	0.08 J	0.05 U	17.00 U	0.16 J	0.62 U	0.03 U
)17496	INEL	Inorganic Non-metal	218	442	17.00 U	0.06 U	0.07 J	0.05 U	17.00 U	0.15 J	0.36 J	0.03 U
)17698	RFETS	Solidified Inorganics	211	292	5.00 U	4.60 U	2.90 U	4.30 U	5.00 U	4.00 U	3.50 U	2.10 U
)17709	INEL	Solidified Inorganics	211	1	17.00 U	0.01 U	0.10 J	0.03 J	17.00 U	0.40 J	0.93 J	0.02 U
)17728	RFETS	Solidified Inorganics	211	1	5.00 U	1.30 U	0.84 U	1.20 U	5.00 U	14.00	0.99 U	0.61 U
)17742	INEL	Inorganic Non-metal	218	440	17.00 U	1.10 U	0.71 U	1.00 U	17.00 U	2.50	1.40	0.52 U
)17756	RFETS	Solidified Organics	226	432	17.00 U	3.20 U	2.00 U	130.00	17.00 U	13.00 U	2.40 U	1.50 U
)17759	INEL	Solidified Organics	226	432	17.00 U	2.20 U	1.40 J	110.00	17.00 U	21.00	1.70 U	1.00 U
)17788	INEL	Solidified Inorganics	211	7	17.00 U	0.97 U	15.00	3.00	17.00 U	78.00	0.88 U	1.10 U
)17863	INEL	Filter	119	376	17.00 U	0.19 U	0.12 U	0.17 U	17.00 U	0.67 J	0.14 U	0.09 U
)18111	RFETS	Solidified Inorganics	211	1	5.00 U	0.03 U	0.09 J	0.03 U	5.00 U	0.14 J	0.02 U	0.01 U
)18219	RFETS	Solidified Inorganics	211	7	5.00 U	2.20 U	1.40 U	2.00 U	5.00 U	48.00	2.30 J	1.00 U
)18299	INEL	Filter	119	376	17.00 U	0.28 U	0.22 J	0.26 U	17.00 U	1.20 J	0.21 U	0.13 U
)18413	INEL	)hite	115	300	5.00 U	0.02 U	0.03 J	0.02 U	5.00 U	0.04 J	0.01 U	0.01 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
018441	INEL	Graphite	115	300	17.00 U	0.06 U	0.04 J	0.05 U	17.00 U	0.16 J	0.04 U	0.03 U
018464	INEL	Graphite	115	300	5.00 U	0.02 U	0.03 J	0.02 U	5.00 U	0.07 J	0.02 U	0.01 U
018476	INEL	Solidified Inorganics	111	292	5.00 U	0.18 U	0.12 U	0.17 U	5.00 U	0.16 U	0.14 U	0.08 U
018491	INEL	Graphite	115	300	17.00 U	0.06 U	0.05 J	0.05 U	17.00 U	0.08 J	0.04 U	0.03 U
019410	INEL	Lead/Cadmium Metal Waste	123	339	5.00 U	1.20 U	9.20 D	1.10 U	6.00 J	1.10 U	0.92 U	0.56 U
019413	INEL	Lead/Cadmium Metal Waste	123	339	5.00 U	5.40 U	6.20 J	4.90 U	7.90 J	4.70 U	4.00 U	2.50 U
019572	INEL	Lead/Cadmium Metal Waste	123	339	17.00 U	0.11 U	0.28 J	0.10 U	43.00 J	7.20	0.53 J	0.06 J
021031	RFETS	Solidified Inorganics	214	292	5.00 U	0.08 U	0.10 J	0.08 U	5.00 U	0.07 U	0.06 U	0.04 U
021172	RFETS	Inorganic Non-metal	218	442	5.00 U	0.02 U	0.04 J	0.02 U	5.00 U	0.08 J	0.02 U	0.01 U
021306	INEL	Solidified Inorganics	213	4	580.00	0.06 U	0.04 U	0.05 U	17.00 U	0.04 U	0.04 U	0.03 U
021392	RFETS	Solidified Inorganics	214	292	5.00 U	0.31 U	0.56 J	0.31 J	5.00 U	4.90	0.25 J	0.14 U
021442	INEL	Solidified Inorganics	211	1	17.00 U	0.41 U	0.75 U	0.69 J	17.00 U	5.30	0.45 J	0.47 U
021488	RFETS	Inorganic Non-metal	218	442	5.00 U	0.07 U	0.22 J	0.07 U	5.00 U	0.20 J	0.06 U	0.03 U
021503	RFETS	Inorganic Non-metal	218	440	5.00 U	0.31 U	0.20 U	0.29 U	5.00 U	0.27 U	0.24 U	0.14 U
021511	RFETS	Solidified Inorganics	213	4	54.00 J	0.08 U	0.05 U	0.08 U	5.00 U	0.10 J	0.06 U	0.04 U
021512	INEL	Solidified Inorganics	211	7	17.00 U	1.80 U	1.10 U	1.60 U	17.00 U	3.90 J	1.40 U	0.82 U
021523	INEL	Solidified Organics	226	432	17.00 U	1.10 U	0.99 J	9.80	17.00 U	2.60	2.40	0.52 U
021565	INEL	Solidified Inorganics	211	7	17.00 U	0.73 U	1.30 U	2.20	17.00 U	31.00	2.60 U	0.84 U
021572	INEL	Solidified Inorganics	211	7	17.00 U	0.38 U	0.70 U	1.30	17.00 U	16.00	1.40 U	0.44 U
021600	RFETS	Solidified Inorganics	211	1	5.00 U	0.53 U	0.48 J	0.48 U	5.00 U	0.51 J	0.40 U	0.24
021631	INEL	Inorganic Non-metal	218	442	21.00 J	0.06 U	0.07 J	0.05 U	17.00 U	0.04 U	1.20	0.03 U
021698	INEL	Inorganic Non-metal	218	440	17.00 U	2.10 U	1.30 U	1.90 U	17.00 U	1.50 U	1.60 U	0.97 U
021699	INEL	Solidified Inorganics	213	4	2600.0	0.62 U	0.39 U	0.57 U	68.00 U	0.43 U	0.46 U	0.28 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

um #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
21700	RFETS	Solidified Inorganics	213	4	5.00 U	0.02 U	0.01 J	0.02 U	5.00 U	0.02 J	0.01 U	0.01 U
21806	INEL	Inorganic Non-metal	218	440	17.00 U	0.17 U	0.31 U	0.21 U	17.00 U	0.27 U	0.30 U	0.20 U
21816	INEL	Solidified Inorganics	211	1	42.00 J	0.09 U	0.16 U	1.20	17.00 U	3.70	0.27 J	0.10 U
21865	INEL	Solidified Inorganics	211	1	17.00 U	1.80 U	1.10 U	1.60 U	17.00 U	4.80 J	1.40 U	0.82 U
21993	INEL	Solidified Inorganics	211	2	17.00 U	0.84 U	0.53 U	0.77 U	17.00 U	4.10 J	0.64 J	0.39 U
22000	INEL	Inorganic Non-metal	218	440	17.00 U	0.19 U	0.12 U	0.17 U	17.00 U	0.13 U	0.55 U	0.09 U
22036	INEL	Uncategorized Metal	217	480	17.00 U	0.06 U	0.14 J	0.08 U	17.00 U	0.10 U	0.14 U	0.07 U
22038	RFETS	Uncategorized Metal	217	481	11.00 J	0.35 U	4.00	0.66 J	28.00 J	0.30 U	1.30 J	0.52 J
22052	INEL	Uncategorized Metal	217	481	17.00 U	0.02 U	0.03 U	0.02 U	17.00 U	0.02 J	0.54 J	0.02 U
22102	INEL	Solidified Organics	226	432	17.00 U	0.19 U	0.12 U	2.00	17.00 U	0.13 U	3.90	0.09 U
22105	INEL	Solidified Inorganics	211	1	17.00 U	0.79 U	0.50 U	0.72 U	17.00 U	0.55 U	0.59 U	0.36 U
22119	INEL	Inorganic Non-metal	222	371	17.00 U	1.00 U	0.64 U	0.93 U	17.00 U	7.70	0.88 U	0.46 U
22121	INEL	Solidified Inorganics	211	7	17.00 U	0.13 U	19.00	0.33 J	15.00 U	9.00	0.66 J	0.15 U
22135	INEL	Solidified Inorganics	211	7	17.00 U	1.30 U	46.00	1.20 U	17.00 U	24.00	0.97 U	0.59 U
22136	RFETS	Solidified Inorganics	211	7	5.00 U	1.60 U	4.10 J	1.50 J	5.00 U	11.00	1.20 U	0.76 U
22149	RFETS	Solidified Inorganics	211	7	5.00 U	0.41 U	1.10 J	0.38 U	5.00 U	1.90 J	6.70	0.19 U
22224	INEL	Solidified Inorganics	211	1	17.00 U	0.79 U	0.50 U	2.50 J	17.00 U	4.80	1.30 J	1.90 J
22226	RFETS	Inorganic Non-metal	222	371	14.00 J	2.20 U	1.40 U	2.00 U	11.00 J	2.30 JD	1.60 U	1.00 U
22228	INEL	Inorganic Non-metal	222	371	17.00 U	0.28 U	0.18 U	0.26 U	18.00 U	3.20	0.10 U	0.13 U
22230	INEL	Inorganic Non-metal	222	371	17.00 U	0.22 U	0.14 U	0.21 U	17.00 U	4.80	0.17 U	0.10 U
22249	INEL	Uncategorized Metal	217	480	17.00 U	1.50 U	2.70 U	1.80 U	17.00 U	2.30 U	3.30 U	1.70 U
22275	INEL	Uncategorized Metal	217	480	64.00 J	0.33 U	0.61 U	0.58 J	17.00 U	12.00	0.88 U	0.38 U
22286	RFETS	[illegible]tegorized Metal	217	480	65.00 J	0.94 U	0.60 U	0.87 U	8.90 J	8.60	0.71 U	0.43 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
022296	INEL	Solidified Inorganics	211	1	17.00 U	0.72 U	1.30 U	2.00	17.00 U	8.20	0.14 U	0.84 U
022306	INEL	Inorganic Non-metal	218	440	17.00 U	1.70 U	1.10 U	1.60 U	15.00 U	1.20	0.56 U	0.77 U
022338	INEL	Solidified Organics	212	3	17.00 U	220.00 U	5500.0	210.00 U	27.00 J	160 00 U	170.00 U	100.00 U
022347	INEL	Inorganic Non-metal	218	440	17.00 U	0.22 U	0.42 U	0.34 J	17.00 U	1.70	0.27 U	0.26 U
022358	INEL	Uncategorized Metal	217	480	17.00 U	0.02 U	0.07 J	0.24 J	17.00 U	0.02 U	0.08 J	0.02 U
022416	RFETS	Uncategorized Metal	217	320	12.00 J	0.10 U	0.10 JB	0.09 U	8.20 J	0.78	0.07 U	0.05 U
022434	INEL	Solidified Organics	226	432	17.00 U	0.73 U	0.46 U	3.70	17.00 U	0.51 U	7.60	0.34 U
022442	INEL	Solidified Organics	226	432	17.00 U	2.15 U	1.36 U	19.00	17.00 U	2.00 U	9.00 J	0.99 U
022450	RFETS	Uncategorized Metal	217	320	5.00 U	0.17 U	0.10 U	0.15 U	5.00 U	1.60	0.12 U	0.08 U
022453	RFETS	Solidified Inorganics	211	2	5.00 U	0.15 U	0.17 J	0.91	5.00 U	0.13 U	0.11 U	0.07 U
022486	RFETS	Inorganic Non-metal	218	440	5.00 U	3.30 U	2.10 U	3.10 U	11.00 J	2.90 U	2.50 U	1.50 U
022511	INEL	Uncategorized Metal	217	480	17.00 U	1.70 U	1.10 U	1.60 U	18.00 U	2.20	0.35 U	0.80 U
022513	INEL	Solidified Organics	212	1	17.00 U	0.51 U	0.32 U	0.49 J	17.00 U	1.10 J	0.38 U	0.23 U
022517	INEL	Solidified Organics	226	432	17.00 U	0.22 U	0.14 U	2.60	17.00 U	0.15 U	2.30 J	0.10 U
022539	INEL	Solidified Organics	226	432	17.00 U	0.22 U	0.14 U	1.60	17.00 U	0.15 U	1.60	0.10 U
022549	INEL	Uncategorized Metal	217	480	17.00 U	2.80 U	1.80 U	2.60 U	18.00 U	2.00 U	0.34 U	1.30 U
022552	INEL	Inorganic Non-metal	218	442	17.00 U	0.65 U	0.41 U	0.59 U	17.00 U	6.40	1.90 U	0.30 U
022557	INEL	Uncategorized Metal	217	480	17.00 U	0.51 U	0.95 U	0.65 U	17.00 U	3.70	0.02 U	0.60 U
022595	INEL	Solidified Inorganics	211	1	17.00 U	0.25 U	0.46 U	0.31 U	15.00 U	7.00	0.48 U	0.29 U
022600	RFETS	Solidified Inorganics	213	4	3800.0 D	0.52 U	0.33 U	2.10 J	130.00 U	0.45 U	0.69 J	0.24 U
022780	INEL	Solidified Inorganics	211	7	17.00 U	0.36 U	12.00	0.96 J	18.00 U	30.00	0.53 U	0.42 U
022789	INEL	Solidified Inorganics	211	7	17.00 U	1.20 U	6.00	1.10 U	17.00 U	19 00	0 93 U	0.57 U
022790	INEL	Solidified Inorganics	214	292	17.00 U	0.17 U	0.32 U	0 22 U	18.00 U	1.90	0.22 U	0.20 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
022803	INEL	Inorganic Non-metal	222	371	17.00 U	1.20 U	0.75 U	1.10 U	15.00 U	3.80 J	1.00 U	0.54 U
022807	INEL	Salt Waste	224	414	17.00 U	0.23 U	0.15 U	0.27 J	17.00 U	0.81 J	0.18 U	0.11 U
022811	INEL	Solidified Inorganics	211	7	17.00 U	0.30 U	19.00	0.65 J	17.00 U	20.00	0.32 U	0.35 U
022833	INEL	Solidified Inorganics	211	7	17.00 U	2.20 U	38.00	3.70	15.00 U	120.00	0.74 U	2.50 U
022841	INEL	Solidified Inorganics	211	7	17.00 U	1.20 U	5.20	2.80	17.00 U	84.00	0.04 U	1.40 U
022850	INEL	Solidified Inorganics	211	7	17.00 U	0.72 U	47.00	1.80	17.00 U	41.00	0.14 U	0.84 U
022874	INEL	Inorganic Non-metal	222	371	17.00 U	0.40 U	0.25 U	0.36 U	17.00 U	5.00	0.38 U	0.18 U
022894	INEL	Solidified Inorganics	211	1	17.00 U	0.10 U	0.29 J	0.34 J	15.00 U	3.50	0.19 U	0.12 U
022923	INEL	Inorganic Non-metal	218	440	17.00 U	0.73 U	0.46 U	0.67 U	17.00 U	0.61 J	0.05 U	0.34 U
023005	INEL	Solidified Inorganics	211	7	17.00 U	0.34 U	9.30	0.31 U	17.00 U	4.00	0.25 U	0.16 U
023027	RFETS	Uncategorized Metal	217	480	5.00 U	0.33 U	0.21 U	0.30 U	5.00 U	0.29 U	0.25 U	0.15 U
023041	RFETS	Inorganic Non-metal	222	371	13.00 J	0.54 U	0.34 U	0.49 U	10.00 J	1.10 J	0.40 U	0.25 U
023046	RFETS	Solidified Inorganics	211	7	5.00 U	0.95 U	6.50	0.87 U	5.90 J	10.00	0.71 U	0.43 U
023048	RFETS	Solidified Organics	226	432	17.00 U	0.79 U	0.50 U	12.00	17.00 U	0.55 U	1.90	0.36 U
023062	INEL	Solidified Inorganics	211	7	17.00 U	0.34 U	2.50	0.31 U	17.00 U	4.90	0.25 U	0.16 U
023211	INEL	Filter	119	376	17.00 U	0.11 U	0.09 J	0.10 U	17.00 U	0.34 J	0.08 U	0.05 U
023212	RFETS	Uncategorized Metal	217	480	5.00 U	1.10 U	0.70 U	3.20 J	9.20 J	5.20 J	1.30 J	0.51 U
023227	INEL	Uncategorized Metal	217	480	17.00 U	0.19 U	0.12 U	0.17 U	17.00 U	0.25 J	0.50 U	0.09 U
023229	INEL	Combustible	216	337	17.00 U	1.10 U	0.71 U	1.00 U	17.00 U	0.78 U	0.84 U	0.52 U
023235	RFETS	Heterogeneous	216	336	95.00 J	0.30 U	0.19 U	0.27 U	23.00 J	4.30	0.66 J	0.14 U
023238	INEL	Solidified Inorganics	211	1	17.00 U	0.16 U	0.62 J	0.75 J	17.00 U	4.50	4.10	0.18 U
023277	INEL	Inorganic Non-metal	222	371	17.00 U	2.00 U	1.20 U	1.80 U	17.00 U	9.20 J	1.50 U	0.90 U
023285	INEL	idified Inorganics	211	7	17.00 U	3.80 U	3.40 J	4.10 J	17.00 U	27.00	5.00 J	1.70 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
023312	INEL	Uncategorized Metal	217	480	17.00 U	0.73 U	1.40 U	1.80	17.00 U	5.80	0.35 J	0.84 U
023341	RFETS	Solidified Inorganics	211	7	5.00 U	0.02 U	1.40 E	0.05 J	5.00 U	0.94	0.02 J	0.01 U
023357	INEL	Solidified Inorganics	211	1	17.00 U	0.28 U	0.18 U	0.89 J	17.00 U	0.72 J	1.30 J	0.13 U
023383	RFETS	Uncategorized Metal	217	481	5.00 U	0.02 U	0.06 J	0.02 U	5.00 U	0.07 J	0.02 J	0.01 U
023384	INEL	Combustible	223	339	15.00 U	0.09 U	0.15 U	0.11 U	15.00 U	14.00	2.20 U	0.08 U
023388	INEL	Heterogeneous	216	330	18.00 U	0.08 U	0.12 U	0.12 J	15.00 U	1.30	1.30 U	0.07 U
023392	INEL	Solidified Inorganics	213	4	1000.0	1.30 U	0.80 U	2.60 J	43.00 U	0.88 U	3.00 J	0.58 U
023407	INEL	Solidified Organics	212	3	17.00 U	44.00 U	28.00 U	40.00 U	17.00 U	31.00 U	33.00 U	20.00 U
023460	INEL	Inorganic Non-metal	218	442	17.00 U	0.06 U	0.06 J	0.05 U	23.00 J	0.88 J	0.66 J	0.03 U
023469	INEL	Solidified Organics	212	3	17.00 U	0.67 U	45.00	4.60	17.00 U	22.00	2.10 J	0.31 U
023492	INEL	Solidified Inorganics	211	7	17.00 U	1.40 U	1.20 J	1.30 U	17.00 U	7.10 J	1.00 U	0.64 U
023519	INEL	Solidified Organics	212	3	17.00 U	2.80 U	49.00	3.50 U	17.00 U	44.00	0.44 J	3.20 U
023535	INEL	Solidified Inorganics	211	7	17.00 U	0.72 U	1.60	1.70	15.00 U	30.00	3.90	0.84 U
023552	INEL	Solidified Inorganics	211	1	17.00 U	1.60 U	1.00 U	1.40 U	17.00 U	9.40 J	1.20 U	0.72 U
023662	INEL	Inorganic Non-metal	218	442	17.00 U	0.19 U	0.12 U	0.17 U	2.40 U	1.30	0.55 J	0.09 U
023681	INEL	Solidified Inorganics	211	1	36.00 J	0.67 U	0.43 U	0.63 J	17.00 U	0.47 U	0.93 J	0.31 U
023695	RFETS	Solidified Inorganics	211	2	5.00 U	0.35 U	0.39 J	0.32 U	5.00 U	2.50	0.29 J	0.16 U
023771	RFETS	Heterogeneous	216	330	12.00 J	0.36 U	0.23 U	0.33 U	35.00 J	8.00	4.70	0.17 U
023776	INEL	Heterogeneous	216	330	15.00 U	0.74 U	0.47 U	0.68 U	51.00 J	2.50	0.77 J	0.34 U
023805	INEL	Uncategorized Metal	217	480	17.00 U	0.01 U	0.07 J	0.02 U	17.00 U	1.10	0.17 U	0.02 U
023827	RFETS	Uncategorized Metal	217	320	5.00 U	0.02 U	0.03 J	0.02 U	5.00 U	0.61	0.03 J	0.01 U
023840	INEL	Combustible	216	337	150.00	0.29 U	0.46 U	0.42 J	17.00 U	5.20	0.81 J	0.24 U
023901	INEL	Heterogeneous	216	330	18.00 U	0.28 U	0.44 U	2.70	27.00 J	0.26 U	0.16 U	0.23 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
023929	RFETS	Inorganic Non-metal	218	440	5.00 U	1.10 U	0.71 U	1.00 U	5.00 U	0.98 U	0.84 U	0.51 U
023959	INEL	Uncategorized Metal	217	480	17.00 U	2.50 U	1.60 U	2.30 U	17.00 U	14.00	0.05 J	1.20 U
024028	RFETS	Inorganic Non-metal	218	440	5.00 U	0.23 U	0.15 U	0.22 U	5.00 U	1.00 J	0.18 U	0.11 U
024029	INEL	Uncategorized Metal	217	480	17.00 U	0.02 U	0.03 U	0.02 U	18.00 J	0.02 U	0.37 J	0.02 U
024058	INEL	Solidified Inorganics	211	1	17.00 U	0.84 U	0.53 U	0.77 U	17.00 U	0.59 U	0.63 U	0.39 U
024059	INEL	Solidified Inorganics	214	292	17.00 U	0.34 U	0.21 U	0.31 U	17.00 U	0.25 J	0.25 U	0.16 U
024088	INEL	Combustible	216	337	15.00 U	0.64 U	0.41 U	0.59 U	15.00 J	1.30	11.00 U	0.30 U
024090	INEL	Combustible	216	337	55.00 J	0.44 U	0.69 U	0.50 U	17.00 U	2.10	0.02 U	0.37 U
024092	INEL	Combustible	216	337	17.00 U	2.80 U	1.90	2.60 U	17.00 U	4.10	0.05 J	1.30 U
024095	INEL	Combustible	216	337	18.00 U	0.18 U	0.29 U	0.21 U	17.00 U	0.17 U	0.02 U	0.15 U
024102	INEL	Combustible	216	337	120.00	0.96 U	0.61 U	0.88 U	17.00 U	0.67 U	0.10 J	0.44 U
024106	INEL	Combustible	216	337	360.00	1.40 U	1.50	1.30 U	17.00 U	0.98 U	0.04 U	0.64 U
024113	INEL	Combustible	216	337	140.00	0.42 U	0.27 U	0.39 U	17.00 U	0.29 U	0.02 U	0.19 U
024147	INEL	Solidified Inorganics	211	1	17.00 U	1.30 U	0.82 U	1.20 U	17.00 U	2.40 J	0.97 U	0.59 U
024165	INEL	Combustible	216	337	230.00	0.99 U	0.63 U	0.91 U	17.00 U	2.30	2.10 U	0.46 U
024168	INEL	Heterogeneous	216	330	17.00 U	0.06 U	0.04 U	0.05 U	17.00 U	0.04 U	0.10 J	0.03 U
024185	INEL	Salt Waste	224	409	17.00 U	0.06 U	0.09 J	0.10 J	17.00 U	0.21 J	0.05 U	0.03 U
024254	INEL	Salt Waste	224	414	17.00 U	0.09 U	0.06 U	0.09 U	17.00 U	0.07 U	0.07 U	0.04 U
024271	INEL	Inorganic Non-metal	218	442	17.00 U	0.19 U	0.12 U	0.17 U	17.00 U	0.55 J	2.80 U	0.09 U
024273	INEL	Inorganic Non-metal	218	442	17.00 U	0.36 U	0.23 U	0.34 U	17.00 U	0.26	0.27 U	0.17 U
024289	RFETS	Inorganic Non-metal	218	440	5.20 J	0.66 U	0.69 J	0.61 U	5.30 J	0.67 J	0.50 U	0.30 U
024295	INEL	Salt Waste	224	414	17.00 U	0.19 U	0.12 U	1.00 J	17.00 U	0.13 U	0.14 U	0.09 U
024308	INEL	lidified Inorganics	211	2	17.00 U	0.28 U	0.18 U	0.26 U	17.00 U	0.20 U	0.21 U	0.13 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
024309	INEL	Solidified Inorganics	211	2	17.00 U	0.23 U	0.14 U	0.41 J	17.00 U	0.16 U	0.17 U	0.10 U
024311	INEL	Solidified Inorganics	211	2	41.00 U	0.46 U	0.29 U	0.42 U	41.00 U	0.32 U	0.34 U	0.21 U
024318	INEL	Solidified Inorganics	211	2	17.00 U	0.45 U	0.28 U	0.41 U	17.00 U	0.31 U	0.34 U	0.21 U
024506	INEL	Inorganic Non-metal	122	374	17.00 U	0.11 U	0.07 U	0.10 U	17.00 U	0.10 U	0.08 U	0.05 U
024507	INEL	Uncategorized Metal	117	480	17.00 U	0.19 J	0.09 U	0.13 U	17.00 U	0.20 J	0.10 U	0.06 U
024600	INEL	Uncategorized Metal	217	480	17.00 U	0.51 U	0.32 U	0.46 U	18.00 J	0.35 U	2.40 U	0.23 U
024638	INEL	Heterogeneous	216	330	15.00 U	0.25 U	0.16 U	0.23 U	17.00 U	0.17 U	0.04 U	0.11 U
024670	INEL	Solidified Inorganics	211	1	17.00 U	1.00 U	0.64 U	0.93 U	17.00 U	3.10 J	0.76 U	0.46 U
024765	INEL	Uncategorized Metal	217	480	17.00 U	0.05 U	0.07 U	0.11 J	17.00 U	1.30	0.63 U	0.04 U
024786	INEL	Uncategorized Metal	217	480	17.00 U	0.68 U	0.43 U	0.62 U	17.00 U	5.60	0.13 J	0.31 U
024850	INEL	Solidified Organics	226	432	17.00 U	0.19 U	0.12 BJ	0.98 J	17.00 U	0.13 U	7.10	0.09 U
024884	INEL	Uncategorized Metal	217	480	17.00 U	0.45 U	0.28 U	0.41 U	17.00 U	0.31 U	0.34 U	0.21 U
024897	INEL	Solidified Inorganics	211	1	17.00 U	0.45 U	0.28 U	0.41 U	17.00 U	0.31 U	0.34 U	0.21 U
024920	INEL	Solidified Inorganics	211	1	17.00 U	1.30 U	0.82 U	1.20 U	17.00 U	0.90 U	0.97 U	0.59 U
024991	INEL	Solidified Inorganics	211	1	17.00 U	0.62 U	0.39 U	0.57 U	17.00 U	0.43 U	0.46 U	0.28 U
025001	INEL	Solidified Organics	212	3	17.00 U	2.20 U	1.40 U	2.10 U	17.00 U	1.60 U	1.70 J	1.00 U
032284	INEL	Combustible	223	339	17.00 U	0.30 U	0.46 U	0.53 J	17.00 U	46.00	4.20 U	0.25 U
032287	RFETS	Solidified Inorganics	211	7	5.00 U	2.20 U	8.20 JB	2.00 U	6.00 J	29.00	1.60 U	1.00 U
032467	INEL	Combustible	216	337	17.00 U	0.45 U	0.28 U	0.41 U	59.00 J	0.31 U	58.00 J	0.21 U
032469	RFETS	Combustible	216	337	5.00 U	0.73 U	2.10 JB	0.67 U	5.00 U	0.64 U	0.55 U	0.34 U
032473	INEL	Combustible	216	337	15.00 U	3.00 U	1.90 U	2.80 U	17.00 U	19.00	0.06 U	1.40 U
032485	INEL	Combustible	216	337	72.00 J	1.80 U	2.20	1.60 U	17.00 U	1.40	1.90 U	0.80 U
032517	RFETS	Combustible	223	339	5.00 U	0.16 U	0.10 U	0.15 U	18.00 J	8.40	0.53 J	0.08 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
032521	INEL	Combustible	223	339	17.00 U	0.07 U	0.10 U	0.07 U	17.00 U	17.00	0.88 U	0.05 U
032525	INEL	Combustible	223	339	17.00 U	0.04 U	0.24 J	0.05 J	17.00 U	12.00	0.50 U	0.03 U
032526	INEL	Combustible	223	339	15.00 U	0.55 U	1.20	0.62 U	17.00 U	24.00	0.10 U	0.46 U
032529	INEL	Heterogeneous	216	336	11.00 U	1.80 U	0.32 U	1.00 U	17.00 U	55.00 B	0.07 U	0.18 U
032540	INEL	Uncategorized Metal	217	480	18.00 J	0.73 U	0.46 U	1.10	17.00 U	19.00	0.84 U	0.34 U
032632	INEL	Uncategorized Metal	217	480	17.00 U	0.14 U	0.22 U	0.39 J	17.00 U	3.40	1.30 U	0.12 U
032659	RFETS	Uncategorized Metal	217	480	5.00 U	0.58 U	0.37 U	0.53 U	9.50 J	6.40	0.43 U	0.26 U
032669	RFETS	Uncategorized Metal	217	480	7.60 J	0.63 U	0.40 U	0.58 U	18.00 J	2.30 J	0.47 U	0.29 U
032712	INEL	Uncategorized Metal	217	480	17.00 U	0.54 U	0.34 U	0.49 U	17.00 U	0.55 J	0.06 J	0.25 U
032715	RFETS	Combustible	216	337	5.00 U	0.17 U	0.28 JB	0.15 U	5.00 U	0.15 J	0.13 U	0.08 U
032748	INEL	Combustible	223	339	11.00 U	1.80 U	0.32 U	1.00 U	17.00 U	36.00 B	0.72 U	0.18 U
032753	INEL	Uncategorized Metal	217	481	17.00 U	0.06 U	0.04 J	0.05 U	17.00 U	0.04 U	0.04 U	0.03 U
033091	INEL	Combustible	223	339	17.00 U	0.02 U	0.03 U	0.02 U	17.00 U	1.60	26.00	0.02 U
D01332	RFETS	Heterogeneous	116	832	31.27 J	1.00 U	0.50 U	0.50 U	16.95 J	0.50 U	0.50 U	0.50 U
D06288	RFETS	Filter	119	338	1.30 U	0.20 U	0.10 U	0.10 U	0.56 J	0.10 U	0.10 U	0.10 U
D06339	RFETS	Heterogeneous	0	337	32.49 J	0.40 U	0.20 U	0.20 U	144.65 J	3.84	0.27 J	0.20 U
D11129	RFETS	Filter	119	338	5.87 J	0.20 U	0.10 U	0.10 U	2.76 J	0.29 J	0.10 U	0.10 U
D13364	RFETS	Uncategorized Metal	117	480	37.92 J	0.10 U	0.10 U	0.10 U	46.78 J	3.15	0.33 J	0.10 U
D15680	RFETS	Heterogeneous	116	831	866.66 U	133.33 U	66.67 U	66.67 U	333.33 U	66.67 U	66.67 U	66.67 U
D17184	RFETS	Solidified Inorganics	111	800	1.90 U	0.10 U	0.45 J	0.12 J	1.20 U	0.26 J	0.10 U	0.10 U
D32439	RFETS	Filter	119	338	5.96 J	0.20 U	0.10 U	0.10 U	4.57 J	1.19	0.10 U	0.10 U
D32978	RFETS	Solidified Inorganics	111	803	73.67 U	11.33 U	73.26	19.57 J	28.34 U	161.84	7.44 J	5.67 U
D35301	RFETS	idified Inorganics	111	800	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D35306	RFETS	Lead/Cadmium Metal Waste	123	339	22.26 J	0.40 U	0.20 U	0.20 U	92.37 J	22.22	1.17 J	0.20 U
D36606	RFETS	Uncategorized Metal	117	480	9.44 J	0.80 U	0.40 U	0.40 U	2.00 U	0.40 U	0.40 U	0.40 U
D38859	RFETS	Solidified Inorganics	111	803	2.74 J	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D38989	RFETS	Heterogeneous	0	336	1.69 J	0.20 U	0.10 U	0.10 U	17.99 J	1.18	0.19 J	0.10 U
D41681	RFETS	Filter	119	338	52.16 J	0.20 U	0.10 U	0.10 U	35.93 J	2.22	0.13 J	0.10 U
D42280	RFETS	Solidified Organics	112	801	5416.6 U	833.33 U	1682.9 J	416.67 U	2083.3 U	416.67 U	416.67 U	416.67 U
D47501	RFETS	Lead/Cadmium Metal Waste	0	341	11.85 J	0.20 U	0.10 U	0.10 U	31.67 J	0.52 J	0.10 U	0.10 U
D48182	RFETS	Filter	119	376	50.37 J	0.40 U	0.40 U	0.40 U	4.80 U	0.40 U	0.40 U	0.40 U
D48200	RFETS	Heterogeneous	116	831	152.00 U	8.00 U	8.00 U	8.00 U	96.00 U	8.00 U	8.00 U	8.00 U
D48377	RFETS	Inorganic Non-metal	118	368	1.90 U	0.10 U	0.10 U	0.10 U	4.95 J	0.12 J	0.10 U	0.10 U
D49662	RFETS	Solidified Inorganics	0	292	1.38 J	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D49880	RFETS	Heterogeneous	0	336	3.47 U	0.53 U	0.27 U	0.27 U	22.48 J	3.36	0.66 J	0.27 U
D52318	RFETS	Lead/Cadmium Metal Waste	117	321	5.08 J	0.20 U	0.10 U	0.10 U	3.15 J	0.10 U	0.10 U	0.10 U
D52362	RFETS	Heterogeneous	116	821	7.99 J	0.20 U	0.20 U	0.20 U	2.40 U	0.23 J	0.20 U	0.20 U
D52726	RFETS	Heterogeneous	116	833	10.40 U	1.60 U	0.80 U	0.80 U	4.00 U	0.80 U	0.80 U	0.80 U
D53672	RFETS	Inorganic Non-metal	118	440	147.84 J	0.20 U	0.21 J	0.20 U	7.22 J	0.20 U	0.20 U	0.20 U
D55656	RFETS	Heterogeneous	116	831	5.70 U	0.30 U	0.34 J	0.30 U	6.81 J	0.30 U	0.30 U	0.30 U
D55680	RFETS	Heterogeneous	116	821	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D55938	RFETS	Heterogeneous	116	831	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D56095	RFETS	Heterogeneous	0	337	10.20 J	0.20 U	0.10 U	0.10 U	0.59 J	0.10 U	0.10 U	0.10 U
D56595	RFETS	Heterogeneous	116	831	173.33 U	26.67 U	798.33	13.33 U	66.67 U	13.33 U	13.33 U	13.33 U
D56755	RFETS	Heterogeneous	116	821	1.90 U	0.10 U	0.16 J	0.10 U	1.20 U	0.32 J	0.10 U	0.10 U
D56823	RFETS	Heterogeneous	116	831	29.77 J	0.40 U	0.40 J	0.40 U	4.80 U	0.40 U	0.40 U	0.40 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D57179	RFETS	Heterogeneous	0	330	27.22 J	4.00 U	35.83	4.85 J	10.00 U	2.00 U	2.00 U	2.00 U
D57522	RFETS	Heterogeneous	0	336	292.23 J	0.80 U	0.40 U	0.40 U	61.39 J	0.40 U	0.40 U	0.40 U
D57847	RFETS	Uncategorized Metal	117	480	18.12 J	0.80 U	0.65 J	0.40 U	7.25 J	0.40 U	0.40 U	0.40 U
D58143	RFETS	Solidified Inorganics	111	807	1.90 U	0.10 U	0.65 J	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D58154	RFETS	Heterogeneous	116	831	33.35 J	0.80 U	0.40 U	0.40 U	19.22 J	1.10 J	0.40 U	0.40 U
D58627	RFETS	Heterogeneous	116	831	9.82 J	0.40 U	0.20 U	0.20 U	1.00 U	0.47 J	0.20 U	0.20 U
D58889	RFETS	Heterogeneous	116	831	2.60 U	0.40 U	0.20 U	0.20 U	1.00 U	0.20 U	0.20 U	0.20 U
D58970	RFETS	Solidified Inorganics	111	807	1.90 U	0.10 U	0.79 J	0.10 U	1.20 U	0.16 J	0.10 U	0.10 U
D59053	RFETS	Lead/Cadmium Metal Waste	0	341	4.44 J	0.20 U	0.10 U	0.10 U	32.29 J	5.31	0.45 J	0.10 U
D59703	RFETS	Heterogeneous	116	831	13.44 J	1.00 U	0.50 U	0.50 U	15.55 J	1.67 J	0.50 U	0.50 U
D59899	RFETS	Filter	0	331	18.73 Ja	1.00 U	0.50 U	0.50 U	844.03 J	0.50 U	0.50 U	0.50 U
D60056	RFETS	Lead/Cadmium Metal Waste	0	341	23.41 J	0.53 U	0.27 U	0.27 U	118.24 J	13.76	0.96 J	0.27 U
D60218	RFETS	Heterogeneous	116	821	26.43 J	0.20 U	0.20 U	0.20 U	35.91 J	0.20 U	0.20 U	0.20 U
D60298	RFETS	Solidified Organics	112	801	10893 U	573.33 U	605.44 J	573.33 U	6880.0 U	573.33 U	573.33 U	573.33 U
D60320	RFETS	Heterogeneous	0	330	364.00 U	56.00 U	28.70 J	28.00 U	144.48 J	28.00 U	28.00 U	28.00 U
D60463	RFETS	Inorganic Non-metal	118	440	9.15 J	0.10 U	0.29 J	0.10 U	2.58 J	0.18 J	0.10 U	0.10 U
D60511	RFETS	Filter	119	491	194.76 J	0.20 U	0.20 U	0.20 U	11.29 J	0.20 U	0.20 U	0.20 U
D60635	RFETS	Filter	119	491	12.71 J	0.10 U	0.10 U	0.10 U	1.28 J	0.18 J	0.10 U	0.10 U
D61245	RFETS	Heterogeneous	0	336	93.88 J	0.93 U	1.08 J	0.47 U	143.48 J	1.12 J	0.47 U	0.47 U
D61278	RFETS	Heterogeneous	0	336	110.62 J	0.53 U	0.27 U	0.27 U	45.34 J	22.83	1.16 J	0.27 U
D61473	RFETS	Heterogeneous	0	377	79.38 J	0.30 U	0.30 U	0.30 U	2.60 U	0.33 J	0.30 U	0.30 U
D61504	RFETS	Lead/Cadmium Metal Waste	0	341	27.30 J	0.20 U	0.10 U	0.10 U	87.45 J	9.88	0.57 J	0.10 U
D61747	RFETS	erogeneous	0	330	21.66 J	0.53 U	0.27 U	0.27 U	30.03 J	1.43 J	0.27 U	0.27 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D62340	RFETS	Heterogeneous	116	821	7.60 U	0.40 U	0.40 U	0.40 U	6.66 J	0.43 J	0.40 U	0.40 U
D62478	RFETS	Filter	119	376	77.31 J	0.40 U	0.40 U	0.40 U	4.80 U	0.40 U	0.40 U	0.40 U
D62714	RFETS	Heterogeneous	116	831	13.00 U	2.00 U	1.00 U	1.00 U	5.00 U	1.00 U	1.00 U	1.00 U
D62851	RFETS	Heterogeneous	116	825	10.44 J	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D62855	RFETS	Heterogeneous	116	821	114.00 U	6.00 U	6.00 U	6.00 U	72.00 U	6.00 U	6.00 U	6.00 U
D63098	RFETS	Filter	0	331	16.50 Ja	1.00 U	3.08 J	0.50 U	715.70 J	0.50 U	0.50 U	0.50 U
D63229	RFETS	Heterogeneous	116	831	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D63281	RFETS	Solidified Inorganics	111	807	1.90 U	0.10 U	0.15 J	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D63460	RFETS	Heterogeneous	116	831	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	2.64	0.10 J	0.10 U
D63654	RFETS	Solidified Inorganics	111	807	2.95 J	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D63808	RFETS	Heterogeneous	116	831	43.27 J	0.80 U	0.80 U	0.80 U	9.60 U	0.80 U	0.80 U	0.80 U
D63817	RFETS	Heterogeneous	116	821	30.40 U	1.60 U	1.60 U	1.60 U	19.20 U	202.29	1.60 U	1.60 U
D63819	RFETS	Solidified Inorganics	111	807	3.80 U	0.20 U	0.58 J	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D63999	RFETS	Filter	119	491	245.84 J	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D64004	RFETS	Filter	0	331	185.61 Ja	0.80 U	0.40 U	0.40 U	409.36 J	0.40 U	0.40 U	0.40 U
D64137	RFETS	Filter	119	335	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D64448	RFETS	Heterogeneous	116	821	2090.0 U	110.00 U	110.00 U	110.00 U	1320.0 U	110.00 U	110.00 U	110.00 U
D64555	RFETS	Solidified Organics	112	801	10893 U	573.33 U	573.33 U	573.33 U	6880.0 U	573.33 U	573.33 U	573.33 U
D64632	RFETS	Solidified Inorganics	111	800	2.58 J	0.10 U	0.23 J	0.12 J	1.20 U	0.32 J	0.10 U	0.10 U
D64752	RFETS	Uncategorized Metal	117	480	26.00 U	4.00 U	2.00 U	2.68 J	10.00 U	2.00 U	2.00 U	2.00 U
D64758	RFETS	Heterogeneous	116	831	20.93 J	1.00 U	0.71 J	0.50 U	13.05 J	0.59 J	0.50 U	0.50 U
D64860	RFETS	Heterogeneous	116	831	156.00 U	24.00 U	12.00 U	12.00 U	60.00 U	12.00 U	12.00 U	12.00 U
D65212	RFETS	Heterogeneous	116	831	117.00 U	18.00 U	88.80 J	330.62	45.00 U	9.00 U	9.00 U	9.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D65213	RFETS	Heterogeneous	116	831	104.00 U	16.00 U	8.00 U	8.00 U	40.00 U	70.37 J	8.00 U	8.00 U
D65214	RFETS	Heterogeneous	116	831	1399.6 U	73.67 U	73.67 U	73.67 U	884.00 U	73.67 U	73.67 U	73.67 U
D65530	RFETS	Solidified Inorganics	111	807	1.90 U	0.10 U	0.89 J	0.13 J	1.20 U	0.10 J	0.10 U	0.10 U
D65535	RFETS	Solidified Inorganics	111	807	1.90 U	0.10 U	0.33 J	0.41 J	1.20 U	0.10 U	0.10 U	0.10 U
D65546	RFETS	Solidified Inorganics	111	807	1.90 U	0.10 U	0.33 J	0.37 J	1.20 U	0.10 U	0.10 U	0.10 U
D65600	RFETS	Solidified Inorganics	111	807	1.90 U	0.10 U	1.25	1.02	1.20 U	0.10 J	0.12 J	0.10 U
D65731	RFETS	Inorganic Non-metal	122	375	12.20 J	0.40 U	1.81 J	0.40 U	5.01 J	0.62 J	0.40 U	0.40 U
D65734	RFETS	Uncategorized Metal	117	480	33.76 J	0.70 U	0.70 U	0.70 U	30.96 J	89.04	0.70 U	0.70 U
D65754	RFETS	Heterogeneous	116	831	10.46 J	1.33 U	3.60 J	0.67 U	106.20 J	0.67 U	0.67 U	0.67 U
D65757	RFETS	Heterogeneous	116	831	39.00 U	6.00 U	3.00 U	3.00 U	15.00 U	3.00 U	3.00 U	3.00 U
D65972	RFETS	Filter	119	376	18.35 J	0.30 U	0.30 J	0.30 U	3.60 U	0.50 J	0.30 U	0.30 U
D66128	RFETS	Heterogeneous	116	831	24.20 J	1.00 U	3.03 J	0.50 U	2.87 J	0.50 U	0.50 U	0.50 U
D66157	RFETS	Uncategorized Metal	117	480	29.29 J	4.00 U	2.00 U	2.00 U	56.91 J	2.00 U	2.00 U	2.00 U
D66162	RFETS	Lead/Cadmium Metal Waste	123	339	1710.0 U	90.00 U	90.00 U	113.67 J	1080.0 U	90.00 U	90.00 U	90.00 U
D66211	RFETS	Heterogeneous	116	833	19.95 J	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D66213	RFETS	Heterogeneous	116	831	7.49 J	0.60 U	2.63 J	8.85	5.57 J	0.30 U	0.30 U	0.30 U
D66356	RFETS	Heterogeneous	116	831	2166.6 U	333.33 U	166.67 U	166.67 U	833.33 U	166.67 U	166.67 U	166.67 U
D66378	RFETS	Heterogeneous	116	831	2496.0 U	384.00 U	192.00 U	192.00 U	960.00 U	192.00 U	192.00 U	192.00 U
D66438	RFETS	Uncategorized Metal	117	480	30.40 U	1.60 U	107.82	1.60 U	19.20 U	12.16 J	1.60 U	1.60 U
D66523	RFETS	Solidified Organics	112	801	10893 U	573.33 U	649.01 J	573.33 U	6880.0 U	573.33 U	573.33 U	573.33 U
D66525	RFETS	Solidified Inorganics	111	800	3.47 U	0.53 U	0.27 U	0.27 U	1.53 J	0.27 U	0.27 U	0.27 U
D66631	RFETS	Heterogeneous	116	831	9.82 J	0.50 U	0.50 U	0.50 U	9.29 J	0.50 U	0.50 U	0.50 U
D66637	RFETS	erogeneous	116	831	104.00 U	16.00 U	8.00 U	8.00 U	40.00 U	8.00 U	8.00 U	8.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D66641	RFETS	Heterogeneous	116	831	1140.0 U	60.00 U	60.00 U	60.00 U	720.00 U	60.00 U	60.00 U	60.00 U
D66649	RFETS	Lead/Cadmium Metal Waste	123	339	1064.0 U	56.00 U	56.00 U	60.65 J	672.00 U	56.00 U	56.00 U	56.00 U
D66773	RFETS	Uncategorized Metal	117	480	16.38 J	0.30 U	0.30 U	0.30 U	11.15 J	0.44 J	0.30 U	0.30 U
D66783	RFETS	Heterogeneous	116	831	4750.0 U	250.00 U	250.00 U	250.00 U	3000.0 U	250.00 U	250.00 U	250.00 U
D66792	RFETS	Heterogeneous	116	831	1900.0 U	100.00 U	100.00 U	100.00 U	1200.0 U	100.00 U	100.00 U	100.00 U
D66860	RFETS	Heterogeneous	116	833	12.16 J	0.20 U	13.02	0.20 U	20.46 J	2.49	0.20 U	0.20 U
D66875	RFETS	Heterogeneous	116	832	1.90 U	0.10 U	0.10 U	0.23 J	1.20 U	0.10 U	0.10 U	0.10 U
D66948	RFETS	Heterogeneous	116	831	114.00 U	6.00 U	6.00 U	6.00 U	72.00 U	6.00 U	6.00 U	6.00 U
D66949	RFETS	Heterogeneous	116	831	11.40 U	0.60 U	0.60 U	0.60 U	7.20 U	0.60 U	0.60 U	0.60 U
D66953	RFETS	Uncategorized Metal	117	480	20.80 U	3.20 U	1.60 U	1.60 U	8.00 U	1.60 U	1.60 U	1.60 U
D66958	RFETS	Heterogeneous	116	831	12.97 J	0.30 U	0.33 J	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D67009	RFETS	Solidified Organics	112	801	6460.0 U	340.00 U	624.24 J	340.00 U	4080.0 U	340.00 U	340.00 U	340.00 U
D67012	RFETS	Solidified Organics	112	801	17100 U	900.00 U	3386.7 J	900.00 U	10800 U	900.00 U	900.00 U	900.00 U
D67047	RFETS	Solidified Inorganics	111	807	5.58 J	0.20 U	1.59 J	0.20 U	3.21 J	0.20 U	0.20 U	0.20 U
D67251	RFETS	Uncategorized Metal	117	480	30221 J	2400.0 U	1200.0 U	1200.0 U	6000.0 U	179752	1200.0 U	1200.0 U
D67263	RFETS	Heterogeneous	116	831	171.00 U	9.00 U	9.00 U	11.37 J	108.00 U	9.00 U	10.00 J	9.00 U
D67277	RFETS	Heterogeneous	116	831	266.00 U	14.00 U	14.00 U	14.00 U	168.00 U	14.00 U	14.00 U	14.00 U
D67278	RFETS	Heterogeneous	116	831	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	0.53 J	0.10 U	0.10 U
D67312	RFETS	Heterogeneous	116	825	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D67317	RFETS	Uncategorized Metal	117	480	24.15 J	0.53 U	0.27 U	0.27 U	11.63 J	0.77 J	0.27 U	0.27 U
D67390	RFETS	Solidified Organics	112	801	2470.0 U	130.00 U	330.07 J	130.00 U	1560.0 U	130.00 U	130.00 U	130.00 U
D67391	RFETS	Heterogeneous	116	833	10.08 J	0.53 U	0.27 U	0.27 U	1.33 U	0.53 J	0.27 U	0.27 U
D67413	RFETS	Solidified Organics	112	801	14250 U	750.00 U	1446.0 J	750.00 U	9000.0 U	750.00 U	750.00 U	750.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D67434	RFETS	Solidified Inorganics	111	800	6.06 J	0.80 U	0.49 J	0.40 U	2.00 U	0.70 J	0.40 U	0.40 U
D67436	RFETS	Solidified Inorganics	111	800	5.75 J	0.27 U	0.58 J	0.13 U	0.73 J	0.49 J	0.13 U	0.13 U
D67441	RFETS	Solidified Inorganics	111	800	5.72 J	0.80 U	0.72 J	0.40 U	2.00 U	0.40 U	0.40 U	0.40 U
D67448	RFETS	Heterogeneous	116	852	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	2.50	0.10 U	0.10 U
D67455	RFETS	Filter	119	490	18.05 J	0.40 U	0.40 J	0.40 U	67.52 J	2.09 J	0.40 U	0.40 U
D67464	RFETS	Heterogeneous	116	831	4560.0 U	240.00 U	240.00 U	240.00 U	2880.0 U	240.00 U	240.00 U	240.00 U
D67524	RFETS	Heterogeneous	116	832	368.35 J	18.59 U	18.59 U	18.59 U	223.12 U	18.59 U	18.59 U	18.59 U
D67532	RFETS	Lead/Cadmium Metal Waste	123	339	119.70 U	6.30 U	6.30 U	6.30 U	75.60 U	6.30 U	6.30 U	6.30 U
D67535	RFETS	Heterogeneous	116	831	4.31 J	0.40 U	0.23 J	0.20 U	1.00 U	0.20 U	0.20 U	0.20 U
D67539	RFETS	Solidified Organics	112	801	6080.0 U	320.00 U	1238.4 J	320.00 U	3840.0 U	320.00 U	320.00 U	320.00 U
D67541	RFETS	Heterogeneous	116	825	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D67545	RFETS	Solidified Organics	112	801	1710.0 U	90.00 U	227.16 J	90.00 U	1080.0 U	90.00 U	90.00 U	90.00 U
D67567	RFETS	Heterogeneous	116	831	19.53 J	0.30 U	0.30 U	0.30 U	10.53 J	0.72 J	0.30 U	0.30 U
D67582	RFETS	Heterogeneous	116	831	87.17 J	0.40 U	0.73 J	0.40 U	10.79 J	0.40 U	0.40 U	0.40 U
D67603	RFETS	Uncategorized Metal	117	480	293.37 J	13.00 U	13.00 U	13.00 J	156.00 U	13.00 U	13.00 U	13.00 U
D67654	RFETS	Solidified Inorganics	111	800	3.47 U	0.53 U	0.33 J	0.27 U	1.57 J	0.47 J	0.27 U	0.27 U
D67657	RFETS	Solidified Inorganics	111	800	8.88 J	0.53 U	0.66 J	0.27 U	1.33 U	0.27 U	0.27 U	0.27 U
D67678	RFETS	Heterogeneous	116	825	20.37 J	0.43 U	0.43 U	0.43 U	11.98 J	0.43 U	0.43 U	0.43 U
D67698	RFETS	Heterogeneous	116	831	20.80 U	3.20 U	1.60 U	1.60 U	146.01 J	239.94	1.60 U	1.60 U
D67707	RFETS	Heterogeneous	116	831	6.50 U	1.00 U	0.50 U	0.50 U	2.50 U	0.50 U	0.50 U	0.50 U
D67734	RFETS	Heterogeneous	116	831	2090.0 U	110.00 U	110.00 U	252.34 J	1320.0 U	110.00 U	110.00 U	110.00 U
D67735	RFETS	Uncategorized Metal	117	480	34.20 U	1.80 U	1.80 U	2.04 J	21.60 U	1.80 U	1.80 U	1.80 U
D67759	RFETS	Heterogeneous	116	831	53.20 U	2.80 U	2.80 U	2.80 U	33.60 U	220.86	2.80 U	2.80 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D67764	RFETS	Heterogeneous	116	831	26.00 U	4.00 U	2.00 U	2.00 U	10.00 U	298.84	2.00 U	2.00 U
D67766	RFETS	Heterogeneous	116	831	19.50 U	3.00 U	1.50 U	1.50 U	7.50 U	233.17	1.50 U	1.50 U
D67781	RFETS	Heterogeneous	116	831	7.13 J	0.30 U	0.30 U	0.30 U	11.63 J	0.49 J	0.30 U	0.30 U
D67908	RFETS	Heterogeneous	116	832	2.52 J	0.10 U	0.10 U	0.10 U	1.20 U	0.75 J	0.10 U	0.10 U
D67929	RFETS	Heterogeneous	116	832	1.30 U	0.20 U	0.10 U	0.10 J	0.50 U	0.10 U	0.10 U	0.10 U
D67989	RFETS	Heterogeneous	116	831	9.50 U	0.50 U	0.50 U	0.50 U	6.00 U	0.50 U	0.50 U	0.50 U
D67994	RFETS	Heterogeneous	116	831	39.51 J	5.33 U	2.67 J	2.67 U	13.34 U	2.67 U	2.67 U	2.67 U
D68044	RFETS	Heterogeneous	116	825	9.50 U	0.50 U	0.50 U	0.50 U	6.00 U	0.50 U	0.50 U	0.50 U
D68096	RFETS	Heterogeneous	116	821	5.34 J	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D68247	RFETS	Solidified Inorganics	111	800	1.73 U	0.27 U	0.15 J	0.13 U	0.67 U	0.13 U	0.13 U	0.13 U
D68248	RFETS	Solidified Organics	112	801	2850.0 U	150.00 U	566.85 J	150.00 U	1800.0 U	150.00 U	150.00 U	150.00 U
D68250	RFETS	Solidified Organics	112	801	3230.0 U	170.00 U	577.32 J	170.00 U	2040.0 U	170.00 U	170.00 U	170.00 U
D68254	RFETS	Solidified Inorganics	111	800	3.47 U	0.53 U	0.27 U	0.27 U	2.83 J	0.27 U	0.27 U	0.27 U
D68256	RFETS	Solidified Inorganics	111	800	5.20 U	0.80 U	0.50 J	0.40 U	2.00 U	0.49 J	0.40 U	0.40 U
D68276	RFETS	Heterogeneous	116	852	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	1.38	0.16 J	0.10 U
D68277	RFETS	Uncategorized Metal	117	480	10.42 J	0.50 U	0.50 U	0.50 U	8.70 J	0.50 U	0.50 U	0.50 U
D68377	RFETS	Uncategorized Metal	117	480	4.24 J	0.40 U	0.20 U	0.20 U	1.36 J	0.20 U	0.20 U	0.20 U
D68460	RFETS	Heterogeneous	116	832	1.30 U	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D68480	RFETS	Solidified Inorganics	111	800	9.99 J	0.20 U	0.10 U	0.10 U	0.71 J	4.09	0.10 U	0.10 U
D68486	RFETS	Solidified Organics	112	801	2660.0 U	140.00 U	196.98 J	140.00 U	1680.0 U	140.00 U	140.00 U	140.00 U
D68514	RFETS	Uncategorized Metal	117	480	20.24 J	0.10 U	0.10 U	0.10 U	7.15 J	0.10 U	0.10 U	0.10 U
D68538	RFETS	Lead/Cadmium Metal Waste	123	339	1.30 U	0.20 U	0.10 U	0.10 U	7.50 J	0.47 J	0.10 U	0.10 U
D68600	RFETS	Heterogeneous	116	825	342.00 U	18.00 U	85.91 J	18.00 U	216.00 U	18.00 U	18.00 U	18.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D68601	RFETS	Heterogeneous	116	825	133.00 U	7.00 U	40.26 J	7.00 U	84.00 U	7.00 U	7.00 U	7.00 U
D68702	RFETS	Heterogeneous	116	833	1.90 U	0.10 U	0.11 J	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D68724	RFETS	Heterogeneous	116	831	3420.0 U	180.00 U	180.00 U	180.00 U	2160.0 U	180.00 U	180.00 U	180.00 U
D68756	RFETS	Heterogeneous	116	831	2.60 U	0.40 U	0.20 U	0.20 U	1.00 U	0.20 U	0.20 U	0.20 U
D68885	RFETS	Heterogeneous	116	831	760.00 U	40.00 U	40.00 U	40.00 U	480.00 U	40.00 U	40.00 U	40.00 U
D68896	RFETS	Heterogeneous	116	831	4047.0 U	213.00 U	213.00 U	335.05 J	2556.0 U	213.00 U	213.00 U	213.00 U
D68975	RFETS	Solidified Organics	112	801	10260 U	540.00 U	553.50 J	540.00 U	6480.0 U	540.00 U	540.00 U	540.00 U
D68999	RFETS	Heterogeneous	116	821	7.60 U	0.40 U	0.40 U	0.40 U	14.03 J	0.74 J	0.40 U	0.40 U
D69091	RFETS	Heterogeneous	116	825	9.50 U	0.50 U	0.50 U	0.50 U	6.00 U	0.50 U	0.50 U	0.50 U
D69095	RFETS	Heterogeneous	116	833	10.26 U	0.54 U	0.54 U	0.54 U	6.48 U	0.54 U	0.54 U	0.54 U
D69113	RFETS	Heterogeneous	116	831	912.00 U	48.00 U	49.20 J	48.00 J	576.00 U	48.00 U	48.00 U	48.00 U
D69250	RFETS	Heterogeneous	116	833	4.29 J	0.10 U	0.11 J	0.10 U	2.15 J	0.10 U	0.10 U	0.10 U
D69287	RFETS	Heterogeneous	116	821	2622.0 U	138.00 U	138.00 U	138.00 U	1656.0 U	138.00 U	138.00 U	138.00 U
D69306	RFETS	Solidified Organics	112	801	4750.0 U	250.00 U	250.00 U	250.00 U	3000.0 U	250.00 U	250.00 U	250.00 U
D69312	RFETS	Solidified Inorganics	111	800	8.61 J	0.80 U	0.47 J	0.40 U	2.00 U	0.40 U	0.40 U	0.40 U
D69364	RFETS	Heterogeneous	116	833	18.66 J	0.30 U	0.30 U	0.30 U	15.17 J	0.30 U	0.30 U	0.30 U
D69400	RFETS	Heterogeneous	116	831	703.00 U	37.00 U	37.00 U	37.00 U	444.00 U	37.00 U	37.00 U	37.00 U
D69406	RFETS	Heterogeneous	116	831	950.00 U	50.00 U	50.00 U	50.00 U	600.00 U	50.00 U	50.00 U	50.00 U
D69413	RFETS	Heterogeneous	116	831	11.40 U	0.60 U	0.60 U	0.60 U	7.20 U	0.60 U	0.60 U	0.60 U
D69418	RFETS	Heterogeneous	116	831	1884.0 J	73.40 U	73.40 U	73.40 U	880.80 U	73.40 U	73.40 U	73.40 U
D69431	RFETS	Heterogeneous	116	831	693.33 U	106.67 U	53.33 U	53.33 U	266.67 U	53.33 U	53.33 U	53.33 U
D69518	RFETS	Heterogeneous	116	833	10.34 J	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D69602	RFETS	Heterogeneous	116	821	19.00 U	1.00 U	1.00 U	1.00 U	12.00 U	1.00 U	1.00 U	1.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D69759	RFETS	Heterogeneous	116	833	5.84 J	0.30 U	0.30 U	0.46 J	3.60 U	0.30 U	0.30 U	0.30 U
D69855	RFETS	Heterogeneous	116	833	25.25 J	0.20 U	0.20 U	0.20 U	6.60 J	0.20 U	0.20 U	0.20 U
D69877	RFETS	Heterogeneous	116	825	13.44 J	0.50 U	0.50 U	0.50 U	12.09 J	0.50 U	0.50 U	0.50 U
D69883	RFETS	Heterogeneous	116	825	5.70 U	0.30 U	0.30 U	0.30 U	5.97 J	0.30 U	0.30 U	0.30 U
D69975	RFETS	Heterogeneous	116	821	13.30 U	0.70 U	0.70 U	0.70 U	8.40 U	0.70 U	0.70 U	0.70 U
D70063	RFETS	Heterogeneous	116	821	9.69 U	0.51 U	0.85 J	0.51 U	6.12 U	0.51 U	0.51 U	0.51 U
D70077	RFETS	Heterogeneous	116	831	1140.0 U	60.00 U	60.00 U	60.00 U	720.00 U	60.00 U	60.00 U	60.00 U
D70229	RFETS	Heterogeneous	116	831	5.41 J	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D70353	RFETS	Heterogeneous	116	833	6.79 J	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D70370	RFETS	Heterogeneous	116	821	14.73 J	0.30 U	0.30 U	0.30 U	7.78 J	3.02	0.30 U	0.30 U
D70379	RFETS	Heterogeneous	116	833	6.20 J	0.10 U	0.10 J	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D70383	RFETS	Heterogeneous	116	833	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D70446	RFETS	Uncategorized Metal	117	480	19.29 J	2.00 U	16.42	1.00 U	17.99 J	1.14 J	1.00 U	1.00 U
D70448	RFETS	Heterogeneous	116	831	2850.0 U	150.00 U	150.00 U	150.00 U	1800.0 U	150.00 U	150.00 U	150.00 U
D70455	RFETS	Heterogeneous	116	831	13.30 U	0.70 U	1.07 J	0.70 U	8.40 U	0.80 J	0.70 U	0.70 U
D70543	RFETS	Solidified Organics	112	801	15732 U	828.00 U	7954.6 J	828.00 U	9936.0 U	828.00 U	828.00 U	828.00 U
D70661	RFETS	Filter	0	331	8.58 J	1.20 U	0.60 U	0.60 U	227.94 J	0.60 U	0.60 U	0.60 U
D70669	RFETS	Uncategorized Metal	117	480	41.70 J	0.10 U	0.10 U	0.16 J	1.20 U	0.10 U	0.10 U	0.10 U
D70675	RFETS	Solidified Organics	112	801	10.25 J	0.10 U	0.10 U	0.42 J	17.69 J	0.10 U	0.17 J	0.42 J
D70682	RFETS	Heterogeneous	116	831	855.00 U	45.00 U	45.00 U	45.00 U	540.00 U	45.00 U	45.00 U	45.00 U
D70696	RFETS	Heterogeneous	116	821	57.57 J	0.60 U	0.60 U	0.60 U	7.20 U	0.60 U	0.60 U	0.60 U
D70734	RFETS	Heterogeneous	116	833	2.14 J	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D70780	RFETS	Heterogeneous	116	832	1.30 U	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D70856	RFETS	Heterogeneous	116	833	1.90 U	0.10 U	0.10 U	0.10 U	1.65 J	0.10 U	0.10 U	0.10 U
D70882	RFETS	Heterogeneous	116	831	266.00 U	14.00 U	14.00 U	22.74 J	168.00 U	14.00 U	14.00 U	14.00 U
D70937	RFETS	Filter	0	331	6.50 U	1.00 U	0.50 U	0.50 U	374.16 J	0.50 U	0.50 U	0.50 U
D71019	RFETS	Solidified Organics	112	801	24.70 U	1.30 U	1.30 U	2.48 J	15.60 U	1.30 U	1.30 U	1.30 U
D71020	RFETS	Solidified Organics	112	801	17318 U	911.50 U	4880.1 J	911.50 U	10938 U	911.50 U	911.50 U	911.50 U
D71022	RFETS	Solidified Organics	112	801	15600 U	2400.0 U	3597.6 J	1200.0 U	6000.0 U	1200.0 U	1200.0 U	1200.0 U
D71241	RFETS	Heterogeneous	116	833	2.33 J	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D71351	RFETS	Uncategorized Metal	117	480	3.81 J	0.20 U	0.10 U	0.10 U	5.90 J	0.25 J	0.10 U	0.10 U
D71354	RFETS	Uncategorized Metal	117	480	2.70 J	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D71385	RFETS	Heterogeneous	116	833	10.75 J	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D71494	RFETS	Solidified Organics	112	801	7.11 J	0.10 U	0.10 U	0.15 J	7.80 J	0.10 U	0.10 U	0.23 J
D71504	RFETS	Solidified Organics	112	801	3.80 U	0.20 U	0.20 U	0.20 U	7.96 J	0.20 U	0.20 U	0.20 U
D71514	RFETS	Heterogeneous	116	833	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D71521	RFETS	Heterogeneous	116	825	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D71638	RFETS	Uncategorized Metal	117	480	13.00 U	2.00 U	1.00 U	1.00 U	5.00 U	1.00 U	1.00 U	1.00 U
D71804	RFETS	Heterogeneous	116	832	1.89 J	0.20 U	0.10 U	0.10 U	4.23 J	1.17	0.26 J	0.10 U
D71829	RFETS	Heterogeneous	116	852	4180.0 U	220.00 U	220.00 U	220.00 U	2640.0 U	29668	220.00 U	220.00 U
D71838	RFETS	Heterogeneous	116	831	144.40 U	7.60 U	442.97	7.60 U	91.20 U	7.60 U	7.60 U	7.60 U
D71921	RFETS	Heterogeneous	116	833	24.57 J	0.20 U	0.10 U	0.10 U	1.67 J	0.10 U	0.10 U	0.10 U
D71932	RFETS	Solidified Organics	112	801	82991 U	4367.9 U	7014.9 J	4367.9 U	52415 U	4367.9 U	4367.9 U	4367.9 U
D71933	RFETS	Solidified Organics	112	801	10.20 J	0.20 U	0.10 U	0.10 U	4.94 J	0.10 U	0.10 U	0.10 U
D71934	RFETS	Solidified Organics	112	801	13.70 J	0.20 U	0.10 U	0.10 U	9.11 J	0.10 U	0.10 U	0.10 U
D71936	RFETS	Heterogeneous	116	833	411.67 U	21.67 U	85.52 J	59.76 J	260.00 U	21.67 U	21.67 U	21.67 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D71937	RFETS	Heterogeneous	116	833	433.33 U	66.67 U	74.43 J	33.33 U	166.67 U	33.33 U	33.33 U	33.33 U
D71938	RFETS	Heterogeneous	116	833	34.20 U	1.80 U	1.80 U	1.80 U	21.60 U	1.80 U	1.80 U	1.80 U
D71940	RFETS	Solidified Organics	112	801	19000 U	1000.0 U	3580.0 J	1000.0 U	12000 U	1000.0 U	1000.0 U	1000.0 U
D71941	RFETS	Solidified Organics	112	801	19000 U	1000.0 U	8276.0 J	1000.0 U	12000 U	1000.0 U	1000.0 U	1000.0 U
D72010	RFETS	Heterogeneous	116	832	38.55 J	0.60 U	0.30 U	0.30 U	17.91 J	0.30 U	0.30 U	0.30 U
D72079	RFETS	Uncategorized Metal	117	480	123.50 U	6.50 U	6.50 U	6.50 U	78.00 U	6.50 U	6.50 U	6.50 U
D72127	RFETS	Solidified Organics	112	801	7.60 U	0.40 U	0.40 U	0.42 J	4.80 U	0.40 U	0.40 U	0.40 U
D72128	RFETS	Solidified Organics	112	801	6359.9 J	130.00 U	130.00 U	130.00 U	4542.0 J	2721.4	130.00 U	130.00 U
D72131	RFETS	Heterogeneous	116	833	3.47 U	0.53 U	0.27 U	0.27 U	2.44 J	0.27 U	0.27 U	0.27 U
D72132	RFETS	Solidified Organics	112	801	1612.4 J	96.00 U	48.00 U	48.00 U	283.06 J	8080.9	48.00 U	48.00 U
D72133	RFETS	Solidified Organics	112	801	4.48 J	0.20 U	0.20 J	0.20 U	3.54 J	0.20 U	0.20 U	0.20 U
D72136	RFETS	Solidified Organics	112	801	399.00 U	21.00 U	21.00 U	21.00 U	252.00 U	665.70	21.00 U	21.00 U
D72139	RFETS	Solidified Organics	112	801	36.10 U	1.90 U	1.90 U	1.90 U	24.65 J	22.74	1.90 U	1.90 U
D72178	RFETS	Heterogeneous	116	821	5.70 U	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D72186	RFETS	Heterogeneous	116	821	16.26 J	0.20 U	0.20 U	0.20 U	2.40 U	0.21 J	0.20 U	0.20 U
D72195	RFETS	Heterogeneous	116	833	15.12 J	0.10 U	0.30 J	0.10 U	6.84 J	0.25 J	0.10 U	0.11 J
D72255	RFETS	Heterogeneous	116	833	25.68 J	0.30 U	0.30 U	0.30 U	9.46 J	0.30 U	0.30 U	0.30 U
D72267	RFETS	Solidified Inorganics	111	800	1.30 U	0.20 U	0.15 J	0.10 U	0.50 U	0.10 U	0.11 J	0.10 U
D72293	RFETS	Heterogeneous	116	833	6.63 J	0.10 U	0.14 J	0.10 U	16.50 J	0.77 J	0.17 J	0.10 U
D72333	RFETS	Heterogeneous	116	831	5.70 U	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D72339	RFETS	Heterogeneous	116	821	9.50 U	0.50 U	0.50 U	0.50 U	6.00 U	0.50 U	0.50 U	0.50 U
D72347	RFETS	Heterogeneous	116	833	8.58 J	0.10 U	0.10 U	0.10 U	3.45 J	0.89 J	0.10 U	0.10 U
D72375	RFETS	Heterogeneous	116	831	1520.0 U	80.00 U	80.00 U	80.00 U	960.00 U	80.00 U	80.00 U	80.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D72434	RFETS	Heterogeneous	116	831	3990.0 U	210.00 U	210.00 U	210.00 U	2520.0 U	210.00 U	210.00 U	210.00 U
D72436	RFETS	Uncategorized Metal	117	480	66.00 J	0.60 U	0.30 U	0.30 U	2.60 J	0.30 U	0.30 U	0.30 U
D72542	RFETS	Heterogeneous	116	832	130.00 U	20.00 U	10.00 U	10.00 U	50.00 U	10.00 U	10.00 U	10.00 U
D72545	RFETS	Solidified Inorganics	111	800	2.46 J	0.20 U	0.10 U	0.10 U	0.52 J	0.10 U	0.10 U	0.10 U
D72546	RFETS	Heterogeneous	116	832	195.00 U	30.00 U	15.00 U	15.00 U	75.00 U	15.00 U	15.00 U	15.00 U
D72566	RFETS	Solidified Organics	112	801	15.20 U	0.80 U	0.80 U	0.80 U	21.82 J	0.80 U	0.80 U	0.80 U
D72598	RFETS	Heterogeneous	116	821	11.40 U	0.60 U	4.11 J	0.60 U	7.20 U	0.60 U	0.60 U	0.60 U
D72618	RFETS	Heterogeneous	116	833	2.83 J	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D72619	RFETS	Solidified Organics	112	801	1.90 U	0.10 U	0.10 U	0.10 U	314.00 J	0.10 U	0.10 U	0.10 U
D72623	RFETS	Solidified Organics	112	801	6.50 U	1.00 U	0.50 U	0.50 U	6.19 J	0.50 U	0.50 U	0.50 U
D72631	RFETS	Solidified Organics	112	801	1.90 U	0.10 U	0.10 U	0.34 J	6.46 J	0.10 U	0.10 U	0.10 U
D72632	RFETS	Solidified Organics	112	801	2.64 J	0.10 U	0.10 U	0.29 J	8.42 J	0.10 U	0.10 U	0.10 U
D72673	RFETS	Heterogeneous	116	833	17.92 J	0.20 U	1.29 J	0.42 J	18.02 J	0.20 U	0.20 U	0.26 J
D72819	RFETS	Heterogeneous	116	833	29.08 J	0.40 U	0.40 U	0.40 U	7.14 J	0.40 U	0.40 U	0.40 U
D72822	RFETS	Heterogeneous	116	831	3.47 U	0.53 U	0.81 J	0.27 U	1.34 U	0.27 U	0.27 U	0.27 U
D72831	RFETS	Uncategorized Metal	117	480	52.00 U	8.00 U	4.00 U	4.00 U	20.00 U	4.00 U	4.00 U	4.00 U
D72887	RFETS	Heterogeneous	116	833	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D72923	RFETS	Heterogeneous	116	833	54.23 J	0.40 U	0.40 U	0.40 U	17.22 J	0.40 U	0.40 U	0.40 U
D72932	RFETS	Heterogeneous	116	825	8.68 J	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D73054	RFETS	Heterogeneous	0	336	1473.3 U	226.67 U	113.33 U	113.33 U	566.67 U	508.19 U	113.33 U	113.33 U
D73074	RFETS	Heterogeneous	116	833	75.28 J	0.20 U	0.20 U	0.20 J	9.61 J	1.00 J	0.20 U	0.20 U
D73117	RFETS	Uncategorized Metal	117	480	5.20 U	0.80 U	0.40 U	0.40 U	2.00 U	0.40 U	0.40 U	0.40 U
D73123	RFETS	[illegible]erogeneous	116	831	2394.0 U	126.00 U	[illegible]26.00 U	880.24 J	1512.0 U	126.00 U	126.00 U	126.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D73134	RFETS	Heterogeneous	116	831	936.00 U	144.00 U	72.00 U	72.00 U	360.00 U	72.00 U	72.00 U	72.00 U
D73136	RFETS	Solidified Inorganics	111	807	2.19 J	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D73274	RFETS	Heterogeneous	116	831	950.00 U	50.00 U	50.00 U	50.00 U	600.00 U	50.00 U	50.00 U	50.00 U
D73285	RFETS	Solidified Organics	112	801	7.06 J	0.10 U	0.10 J	0.14 J	5.84 J	0.10 U	0.10 U	0.10 U
D73293	RFETS	Solidified Organics	112	801	3.27 J	0.10 U	0.22 J	0.33 J	1.20 U	0.10 U	0.10 U	0.10 U
D73295	RFETS	Solidified Organics	112	801	6.58 J	0.10 U	0.10 U	0.21 J	3.42 J	0.10 U	0.10 U	0.10 U
D73296	RFETS	Solidified Organics	112	801	1.90 U	0.10 U	0.96 J	0.14 J	1.20 U	0.25 J	0.12 J	0.10 U
D73301	RFETS	Solidified Organics	112	801	10.40 J	0.20 U	0.20 U	1.24 J	8.20 J	0.20 U	0.20 U	0.20 U
D73605	RFETS	Lead/Cadmium Metal Waste	123	339	1.30 U	0.20 U	0.15 J	0.10 U	5.07 J	0.15 J	0.10 U	0.10 U
D73632	RFETS	Heterogeneous	116	825	13.30 U	0.70 U	0.70 U	0.70 U	8.40 U	0.70 U	0.70 U	0.70 U
D73667	RFETS	Solidified Organics	112	801	2.64 J	0.10 U	0.10 U	0.10 U	5.79 J	0.10 U	0.10 U	0.10 U
D73672	RFETS	Solidified Organics	112	801	4.94 J	0.10 U	0.10 U	0.22 J	1.20 U	0.10 U	0.10 U	0.10 U
D73745	RFETS	Heterogeneous	116	832	1.89 J	0.20 U	0.10 J	0.10 U	11.29 J	0.10 U	0.10 U	0.10 U
D73828	RFETS	Heterogeneous	116	833	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D73848	RFETS	Heterogeneous	116	821	2.80 J	0.13 U	0.13 U	0.13 U	1.60 U	0.13 U	0.13 U	0.13 U
D73987	RFETS	Lead/Cadmium Metal Waste	123	339	3.90 U	0.60 U	20.72	0.30 U	4.47 J	0.30 U	0.30 U	0.30 U
D74007	RFETS	Uncategorized Metal	117	480	11.47 J	0.60 U	0.30 U	0.30 U	6.01 J	0.30 U	0.30 U	0.30 U
D74110	RFETS	Heterogeneous	116	833	1.90 U	0.10 U	0.14 J	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D74147	RFETS	Solidified Organics	112	801	15.20 U	0.80 U	6.00 J	1.82 J	9.60 U	3.15 J	2.12 J	0.80 U
D74156	RFETS	Solidified Organics	112	801	11.40 U	0.60 U	4.17 J	1.92 J	7.20 U	3.65 J	2.15 J	0.60 U
D74374	RFETS	Heterogeneous	116	833	4.98 J	0.20 U	0.16 J	0.10 U	0.94 J	0.10 U	0.10 U	0.10 U
D74683	RFETS	Heterogeneous	116	821	28.50 U	1.50 U	1.50 U	0.15 U	18.00 U	1.50 U	1.50 U	1.50 U
D74904	RFETS	Heterogeneous	116	832	2.60 J	0.20 U	0.10 U	0.10 U	0.83 J	0.10 U	0.10 U	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D74913	RFETS	Heterogeneous	116	832	5.70 U	0.30 U	0.30 U	0.30 U	43.43 J	0.33 J	0.30 U	0.30 U
D75039	RFETS	Heterogeneous	116	832	158.92 J	0.30 U	0.30 U	0.30 U	35.16 J	0.30 U	0.30 U	0.39 J
D75265	RFETS	Heterogeneous	116	833	63.88 J	1.20 U	0.12 U	0.12 U	19.11 J	1.20 U	1.20 U	1.20 U
D75267	RFETS	Heterogeneous	116	832	3.80 U	0.20 U	0.20 U	0.20 U	2.92 J	0.20 U	0.20 U	0.20 U
D75278	RFETS	Heterogeneous	116	832	17.98 J	0.30 U	0.30 U	0.30 U	10.17 J	1.50 J	0.30 U	0.30 U
D75399	RFETS	Heterogeneous	116	833	7.60 U	0.40 U	0.40 U	0.40 U	4.80 U	0.40 U	0.40 U	0.40 U
D75564	RFETS	Heterogeneous	116	825	4.47 J	0.13 U	0.13 U	0.13 U	1.60 U	0.13 U	0.13 U	0.13 U
D75868	RFETS	Heterogeneous	116	825	11.40 U	0.60 U	0.60 U	0.60 U	7.20 U	0.60 U	0.60 U	0.60 U
D75888	RFETS	Heterogeneous	116	833	7.77 J	0.10 U	0.12 J	0.10 U	4.92 J	0.10 U	0.10 U	0.10 U
D75926	RFETS	Heterogeneous	116	832	7.60 U	0.40 U	0.40 U	0.40 U	4.80 U	0.40 U	0.40 U	0.40 U
D75930	RFETS	Heterogeneous	116	832	1300.0 U	200.00 U	100.00 U	100.00 U	500.00 J	100.00 U	100.00 U	100.00 U
D75947	RFETS	Heterogeneous	116	832	5.27 J	0.10 U	0.10 U	0.10 U	2.82 J	0.10 U	0.10 U	0.10 U
D75976	RFETS	Heterogeneous	116	833	5.57 J	0.27 U	0.13 U	0.13 U	0.67 U	0.13 U	0.13 U	0.13 U
D76044	RFETS	Heterogeneous	116	831	18.17 J	0.27 U	0.27 U	0.27 U	4.29 J	0.27 U	0.27 U	0.27 U
D76050	RFETS	Heterogeneous	116	832	1.90 U	0.10 U	0.10 U	0.10 J	1.20 U	0.10 U	0.10 U	0.10 U
D76054	RFETS	Heterogeneous	116	831	5.70 U	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D76098	RFETS	Heterogeneous	116	832	2.60 U	0.40 U	0.20 U	0.20 U	4.22 J	0.20 U	0.20 U	0.20 U
D76135	RFETS	Solidified Organics	112	801	346.67 U	53.33 U	26.67 U	26.67 U	133.34 U	26.67 U	26.67 U	26.67 U
D76136	RFETS	Solidified Inorganics	111	803	5.20 U	0.80 U	1.30 J	1.42 J	2.00 U	5.00	0.40 U	0.40 U
D76138	RFETS	Solidified Inorganics	111	800	1.30 U	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D76142	RFETS	Solidified Inorganics	111	800	3.12 U	0.48 U	0.66 J	0.24 U	5.55 J	0.24 U	0.24 U	0.24 U
D76143	RFETS	Solidified Inorganics	111	803	3.90 U	0.60 U	0.90 J	0.96 J	1.50 U	3.26	0.30 U	0.30 U
D76144	RFETS	.dified Inorganics	111	800	8.67 U	1.33 U	0.67 U	0.98 J	3.34 U	1.50 J	0.67 U	0.67 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D76146	RFETS	Solidified Inorganics	0	292	1.30 U	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D76147	RFETS	Solidified Inorganics	111	803	1.90 U	0.10 U	1.66	0.25 J	4.53 J	0.10 U	0.20 J	0.10 U
D76182	RFETS	Solidified Inorganics	111	800	13.30 U	0.70 U	4.07 J	0.70 U	8.40 U	0.70 U	0.70 U	0.70 U
D76183	RFETS	Solidified Inorganics	111	800	1.73 U	0.27 U	0.47 J	0.18 J	0.92 J	0.37 J	0.13 U	0.13 U
D76185	RFETS	Solidified Inorganics	111	800	1.30 U	0.20 U	0.12 J	0.10 U	0.50 J	0.10 U	0.10 U	0.10 U
D76187	RFETS	Solidified Inorganics	111	803	6.50 U	1.00 U	1.56 J	1.44 J	2.50 U	6.37	0.50 U	0.50 U
D76189	RFETS	Solidified Inorganics	111	803	26.00 U	4.00 U	2.00 U	4.64 J	10.00 U	12.57 J	2.00 U	2.00 U
D76192	RFETS	Solidified Inorganics	111	803	1.30 U	0.20 U	0.32 J	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D76194	RFETS	Solidified Inorganics	111	800	1.30 U	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D76195	RFETS	Solidified Organics	112	801	9120.0 U	480.00 U	480.00 U	480.00 U	5760.0 U	480.00 U	480.00 U	480.00 U
D76196	RFETS	Solidified Organics	112	801	3732.5 J	333.33 U	2042.3	166.67 U	833.34 U	166.67 U	166.67 U	166.67 U
D76199	RFETS	Solidified Inorganics	111	800	1.30 U	0.20 U	0.19 J	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D76200	RFETS	Solidified Organics	112	801	8233.3 U	1266.6 U	2371.8 J	633.33 U	3166.6 U	633.33 U	633.33 U	633.33 U
D76203	RFETS	Solidified Organics	112	801	2903.3 U	446.67 U	283.41 J	223.33 U	1116.6 U	223.33 U	223.33 U	223.33 U
D76205	RFETS	Solidified Inorganics	111	800	1.30 U	0.20 U	0.10 U	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D76206	RFETS	Solidified Inorganics	111	803	5.20 U	0.80 U	0.51 J	0.74 J	2.00 U	4.19	0.40 U	0.40 U
D76217	RFETS	Heterogeneous	116	833	20.84 J	2.00 U	60.66	1.00 U	7.67 J	1.00 U	1.00 U	1.00 U
D76282	RFETS	Solidified Inorganics	111	800	147.33 U	22.67 U	39.18 J	11.33 U	56.67 U	11.33 U	11.33 U	11.33 U
D76283	RFETS	Solidified Organics	112	801	1170.0 U	180.00 U	90.00 J	90.00 U	450.00 U	90.00 U	90.00 U	90.00 U
D76287	RFETS	Solidified Inorganics	111	800	69.33 U	10.67 U	14.69 J	5.33 U	26.67 U	5.33 U	5.33 U	5.33 U
D76293	RFETS	Heterogeneous	116	833	7.60 U	0.40 U	0.40 U	0.40 U	4.80 U	0.40 U	0.40 U	0.40 U
D76302	RFETS	Solidified Inorganics	111	800	39.00 U	6.00 U	3.00 U	3.00 U	15.00 U	3.00 U	3.00 U	3.00 U
D76303	RFETS	Solidified Inorganics	111	803	3.47 U	0.53 U	1.03 J	1.64 J	5.51 J	1.98 J	0.27 U	0.27 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D76305	RFETS	Solidified Inorganics	111	800	156.00 U	24.00 U	22.21 J	12.00 U	60.00 U	12.00 U	12.00 U	12.00 U
D76306	RFETS	Heterogeneous	116	833	18.88 J	0.80 U	1.15 J	0.80 U	9.60 U	0.80 U	0.80 U	0.80 U
D76362	RFETS	Heterogeneous	116	833	97.62 J	13.33 U	13.46 J	6.67 U	33.34 U	6.67 U	6.67 U	6.67 U
D76406	RFETS	Heterogeneous	116	831	1.90 U	0.10 U	0.16 J	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D76437	RFETS	Heterogeneous	116	833	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 J	0.20 U	0.20 U
D76443	RFETS	Heterogeneous	116	825	16.85 J	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D76452	RFETS	Heterogeneous	116	825	14.20 J	0.20 U	0.20 U	0.20 U	2.00 U	0.20 U	0.20 U	0.20 U
D76454	RFETS	Heterogeneous	116	825	1.90 U	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D76456	RFETS	Heterogeneous	116	825	11.80 J	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D76461	RFETS	Heterogeneous	116	825	5.70 U	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D76463	RFETS	Heterogeneous	116	825	5.70 U	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U	0.30 U	0.30 U
D76470	RFETS	Solidified Inorganics	111	803	1.30 U	0.20 U	0.42 J	0.10 U	0.50 U	0.10 U	0.10 U	0.10 U
D76587	RFETS	Heterogeneous	116	825	1.90 U	0.10 U	0.14 J	0.12 J	1.20 U	0.17 J	0.10 U	0.10 U
D76596	RFETS	Heterogeneous	116	825	25.44 J	0.10 U	0.11 J	0.18 J	2.27 J	0.25 J	0.10 U	0.10 U
D76627	RFETS	Heterogeneous	116	825	1.90 U	0.10 U	0.10 J	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D76630	RFETS	Heterogeneous	116	825	14.78 J	0.10 U	0.10 U	0.11 J	3.66 J	0.17 J	0.10 U	0.10 U
D76635	RFETS	Heterogeneous	116	825	3.80 U	0.20 U	0.20 U	0.20 U	2.40 U	0.21 J	0.20 U	0.20 U
D76652	RFETS	Heterogeneous	116	833	6.87 J	0.20 U	0.10 U	0.10 U	0.57 J	0.10 U	0.10 U	0.10 U
D76677	RFETS	Solidified Inorganics	111	800	45.60 U	2.40 U	2.53 J	7.61 J	28.80 U	6.65 J	2.40 U	2.40 U
D76710	RFETS	Heterogeneous	116	833	38.00 U	2.00 U	2.51 J	2.00 U	24.00 U	2.00 U	2.00 U	2.00 U
D76712	RFETS	Heterogeneous	116	833	11.83 J	0.30 U	0.30 U	0.30 U	106.59 J	1.80 J	0.30 U	0.30 U
D76715	RFETS	Heterogeneous	116	832	4.34 J	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D76811	RFETS	Heterogeneous	116	832	3.80 U	0.20 U	0.20 U	0.20 U	3.95 J	0.20 U	0.20 U	0.20 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methanol	Ethyl Ether	1,1,2-Trichloro-1,2,2-Trifluoro ethane	1,1-Di-chloro-ethene	Acetone	Methylene Chloride	1,1-Di-chloro-ethane	cis-1,2-Dichloro-ethene
D76908	RFETS	Heterogeneous	116	833	53.56 J	0.10 U	6.99	0.10 U	1.20 U	0.10 U	0.10 U	0.10 U
D76911	RFETS	Heterogeneous	116	832	2.60 U	0.40 U	0.20 U	0.20 U	1.00 U	0.20 U	0.20 U	0.20 U
D77088	RFETS	Heterogeneous	116	833	11.76 J	0.40 U	0.20 U	0.20 U	1.00 J	0.20 U	0.20 U	0.20 U
D77227	RFETS	Heterogeneous	116	833	5.20 U	0.80 U	0.40 U	0.40 U	2.00 U	0.40 U	0.40 U	0.40 U
D77285	RFETS	Heterogeneous	116	833	3.80 U	0.20 U	0.20 U	0.20 U	4.60 J	0.20 U	0.20 U	0.20 U
D77621	RFETS	Heterogeneous	0	336	3.47 U	0.53 U	6.22	0.27 U	1.34 U	0.27 U	0.27 U	0.27 U
D80765	RFETS	Heterogeneous	116	833	3.80 U	0.20 U	0.30 J	0.20 U	2.40 U	0.20 U	0.20 U	0.20 U
D80772	RFETS	Heterogeneous	116	833	19.00 U	1.00 U	1.00 U	1.00 U	12.00 U	1.00 U	1.00 U	1.00 U
D80774	RFETS	Heterogeneous	116	833	58.90 U	3.10 U	4.13 J	3.10 U	37.20 U	3.10 U	3.10 U	3.10 U
D80776	RFETS	Heterogeneous	116	832	24.39 J	0.10 U	0.10 U	0.13 J	39.82 J	1.68	0.51 J	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
00365	RFETS	Uncategorized Metal	217	480	17.00 U	12.00 U	1600.0 J	17.00 U	11.00 U	13.00	11.00 U	17.00 U	28.00 J
00371	INEL	Graphite	215	300	17.00 U	0.03 U	9.20	0.03 U	0.10 J	0.03 U	0.03 U	17.00 U	0.26 J
00373	INEL	Graphite	215	300	17.00 U	0.01 U	0.66 J	0.02 U	0.03 J	0.01 U	0.02 U	17.00 U	0.02 U
00384	RFETS	Uncategorized Metal	217	320	5.00 U	0.01 J	0.09 U	0.01 U	0.10	0.14	0.01 U	5.00 U	0.01 U
00393	INEL	Uncategorized Metal	217	480	17.00 U	0.03 U	0.14 J	0.04 U	0.05 J	0.18 J	0.03 J	17.00 U	0.03 U
00401	RFETS	Inorganic Non-metal	222	371	5.00 U	1.80	0.15 J	0.02 U	0.07 JB	0.06	0.03 J	5.00 U	0.01 J
00403	INEL	Inorganic Non-metal	218	440	17.00 U	8.20 E	0.27 J	0.04 U	1.80	0.21 J	0.05 J	17.00 U	0.03 J
00405	RFETS	Uncategorized Metal	217	480	7.30 J	0.88 U	53.00 J	1.20 U	0.85 U	1.00	0.80 U	5.00 U	1.50 J
00436	INEL	Solidified Organics	212	3	17.00 U	44.00 U	1500.0	42.00 U	8200.0	46.00 U	42.00 U	17.00 U	42.00 U
00442	INEL	Solidified Inorganics	213	4	51.00 U	0.06 U	0.32 J	0.55 J	0.36 J	0.18 J	0.05 U	51.00 U	0.05 U
00446	RFETS	Solidified Inorganics	211	1	5.00 U	0.01 U	0.49 J	0.01 U	0.10 JB	0.11	0.01 U	5.00 U	0.02 J
00478	RFETS	Solidified Inorganics	211	1	5.00 U	0.01 U	0.20 J	0.01 U	0.18	0.05	0.01 U	5.00 U	0.05 J
00501	INEL	Graphite	215	300	17.00 U	0.01 U	0.12 J	0.02 U	0.02 J	0.01 U	0.02 U	17.00 U	0.02 U
00558	INEL	Heterogeneous	221	464	17.00 U	0.15 J	0.17 J	0.36 J	0.27 J	0.18 J	0.08 U	17.00 U	0.08 U
00567	RFETS	Inorganic Non-metal	222	371	5.00 U	3.50 J	320.00 U	2.30 U	2.50 J	1.80	1.50 U	5.00 U	1.50 U
00568	RFETS	Solidified Organics	226	432	17.00 U	0.98 U	0.87 U	2.90 J	0.95 U	1.10	0.88 U	17.00 U	0.89 U
00593	INEL	Solidified Inorganics	211	7	17.00 U	0.02 U	0.33 J	0.02 U	0.13 J	0.06 J	0.02 U	17.00 U	0.02 U
00613	INEL	Graphite	215	300	17.00 U	0.03 U	0.08 J	0.04 U	0.06 J	0.03 U	0.03 U	17.00 U	0.03 U
00630	INEL	Solidified Inorganics	213	4	51.00 U	0.07 U	0.46 J	12.00	0.34 J	0.46 J	0.07 U	51.00 U	0.07 U
00648	RFETS	Solidified Inorganics	213	4	70.00 U	0.03 U	0.09 U	5.40 D	0.25 JD	0.25	0.03 U	70.00 U	0.03 U
00675	RFETS	Inorganic Non-metal	218	440	12.00 J	0.39 J	0.23 U	0.64 J	0.90 J	0.50	0.13 U	5.00 U	0.13 U
00823	RFETS	Solidified Inorganics	213	4	120.00 U	0.02 U	0.28 J	1.50	0.85	0.20	0.02 U	120.00 U	0.03 J
00828	INEL	Graphite	215	300	17.00 U	0.01 U	0.08 J	0.09 J	0.05 J	0.01 U	0.02 U	17.00 U	0.02 U
01016	INEL	[illegible]aphite	215	300	17.00 U	0.01 U	[illegible]09 J	0.19 J	0.03 J	0.01 U	0.02 U	17.00 U	0.02 U
01024	INEL	[illegible]raphite	215	300	17.00 U	0.01 U	[illegible].07 J	0.09 J	0.04 J	0.01 U	0.02 U	17.00 U	0.02 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
001084	INEL	Solidified Inorganics	213	4	17.00 U	0.04 J	0.25 J	0.66 J	0.34 J	0.02 U	0.02 U	17.00 U	0.02 U
001139	INEL	Solidified Inorganics	211	7	17.00 U	0.17 U	34.00	0.16 U	0.23 J	0.17 U	0.16 U	17.00 U	0.16 U
001157	INEL	Combustible	223	339	17.00 U	0.47 J	0.12 J	0.04 U	0.35 J	0.09 U	0.23 J	17.00 U	0.03 U
001161	INEL	Graphite	215	300	17.00 U	0.02 U	0.06 J	0.03 U	0.04 J	0.02 U	0.02 U	17.00 U	0.03 U
001258	RFETS	Solidified Inorganics	211	1	5.00 U	0.01 U	0.15 J	0.01 U	0.14	0.29	0.01 U	5.00 U	0.02 J
001370	INEL	Combustible	223	339	17.00 U	2.70	0.78 J	0.12 U	28.00	0.13 J	0.24 J	17.00 U	0.22 J
001377	INEL	Combustible	223	339	17.00 U	0.36	0.18 J	0.04 U	0.20 J	0.21 J	0.64	17.00 U	0.03 J
001410	INEL	Solidified Inorganics	214	292	17.00 U	0.12 U	0.22 J	0.61 J	0.12 U	0.14 U	0.11 U	17.00 U	0.11 U
001437	RFETS	Solidified Inorganics	211	7	5.00 U	0.02 J	1.40 J	0.01 U	0.08 J	0.16	0.01 U	5.00 U	0.07 J
001475	RFETS	Solidified Inorganics	211	1	5.00 U	0.20 U	0.04 U	0.28 U	0.42 JB	3.40	0.18 U	5.00 U	0.18 U
001493	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 J	0.15 J	0.06 J	0.18	0.18	0.01 U	5.00 U	0.06 J
001619	INEL	Graphite	215	300	17.00 U	0.03 U	0.08 J	0.04 U	0.07 J	0.03 U	0.03 U	17.00 U	0.03 U
001625	INEL	Graphite	215	300	17.00 U	0.02 U	0.13 J	0.02 U	0.05 J	0.02 U	0.02 U	17.00 U	0.02 U
001633	INEL	Solidified Organics	226	432	17.00 U	0.70 U	36.00 B	2.60 J	0.68 U	0.80 U	0.63 U	17.00 U	150.00
001655	INEL	Combustible	223	339	17.00 U	21.00 J	12.00 J	2.60 U	290.00	2.10 U	1.70 U	17.00 U	16.00 J
001662	INEL	Graphite	215	300	17.00 U	0.02 U	0.08 J	0.02 U	0.07 J	0.02 U	0.02 U	17.00 U	0.02 U
001663	RFETS	Solidified Organics	226	432	17.00 U	5.50	0.38 U	0.59 U	0.57 J	4.40	0.38 U	17.00 U	0.38 U
001667	INEL	Graphite	215	300	17.00 U	0.02 U	0.17 J	0.05 J	0.05 J	0.02 U	0.02 U	17.00 U	0.02 U
001670	RFETS	Salt Waste	224	411	5.00 U	0.09 J	1.10 B	0.14 J	0.16 JB	0.10	0.03 U	5.00 U	1.80 B
001677	INEL	Heterogeneous	221	302	17.00 U	2.00	45.00	0.45 U	0.50 U	1.00	0.46 U	17.00 U	130.00
001678	RFETS	Combustible	223	339	5.00 U	23.00	0.39 J	0.14 U	64.00 E	0.99	0.45 J	5.00 U	0.14 J
001689	INEL	Heterogeneous	221	302	17.00 U	0.04 J	0.20 J	0.13 J	0.22 J	0.09 J	0.03 U	17.00 U	0.03 U
001692	RFETS	Solidified Organics	226	432	17.00 U	0.25 U	0.22 U	0.40 J	0.24 U	1.30	0.23 U	17.00 U	0.23 U
001695	INEL	Combustible	223	339	17.00 U	13.00 J	4.80 BJ	2.30 U	290.00	1.80 U	1.40 U	17.00 U	1.50 J
001697	INEL	Graphite	215	300	17.00 U	0.02 U	0.09 J	0.02 U	0.04 J	0.02 U	0.02 U	17.00 U	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
001751	RFETS	Uncategorized Metal	217	320	5.00 U	0.01 U	0.12 J	0.01 U	0.08 J	0.02	0.01 U	5.00 U	0.02 J
001752	INEL	Graphite	215	300	17.00 U	0.02 U	0.10 J	0.02 U	0.04 J	0.02 U	0.02 U	17.00 U	0.02 U
001754	INEL	Uncategorized Metal	217	320	1.30 U	0.04 U	0.43 J	0.28 J	0.11 J	0.04 U	0.06 U	1.30 U	0.06 U
001757	INEL	Inorganic Non-metal	222	371	17.00 U	2.40	0.62	0.04 U	0.96	0.03 U	0.03 U	17.00 U	0.03 J
001773	INEL	Graphite	215	300	17.00 U	0.02 U	0.10 J	0.02 U	0.04 J	0.02 U	0.02 U	17.00 U	0.02 U
001779	INEL	Graphite	215	300	17.00 U	0.02 U	0.06 J	0.02 U	0.03 J	0.02 U	0.02 U	17.00 U	0.02 U
001784	INEL	Combustible	223	339	17.00 U	0.73 J	0.17 J	0.04 U	0.13 J	0.26 J	0.12 J	17.00 U	0.03 U
001813	INEL	Solidified Inorganics	213	4	17.00 U	6.00 U	6.00 U	1700.0	6.10 U	6.20 U	5.70 U	17.00 U	5.70 U
001873	INEL	Solidified Inorganics	214	292	17.00 U	0.04 U	0.11 J	0.07 J	0.17 J	0.04 U	0.03 U	17.00 U	0.03 U
001899	RFETS	Solidified Inorganics	211	3	5.00 U	130.00 U	15000 U	180.00 U	23000	150.00	120.00 U	5.00 U	120.00 U
001900	INEL	Solidified Inorganics	214	292	17.00 U	0.04 U	0.15 J	0.19 J	0.20 J	0.12 J	0.03 U	17.00 U	0.03 U
001919	RFETS	Uncategorized Metal	217	320	5.00 U	0.02 J	0.53 J	0.01 U	0.09 J	0.01	0.01 U	5.00 U	0.01 J
001937	RFETS	Solidified Organics	212	3	5.00 U	16.00 U	180.00 U	22.00 U	2100.0	18.00	14.00 U	5.00 U	14.00 U
002013	RFETS	Solidified Organics	212	3	5.00 U	11.00 U	120.00 U	16.00 U	1600.0	13.00	10.00 U	5.00 U	10.00 U
002046	INEL	Solidified Organics	212	3	17.00 U	37.00 U	530.00	35.00 U	5600.0	39.00 U	35.00 U	17.00 U	35.00 U
002065	INEL	Solidified Inorganics	214	292	5.00 J	0.10 J	0.16 U	0.26 U	0.16 U	0.12 U	0.09 U	5.00 U	0.09 U
002084	INEL	Solidified Inorganics	213	4	34.00 U	0.04 U	0.19 J	0.04 U	0.18 J	0.10 J	0.04 U	34.00 U	0.04 U
002220	RFETS	Uncategorized Metal	217	481	5.00 U	0.03 U	4.00 JB	0.04 U	0.03 U	0.03	0.03 U	5.00 U	0.17 JB
002222	INEL	Graphite	215	300	17.00 U	0.02 U	0.12 J	0.02 U	0.12 J	0.02 U	0.02 U	17.00 U	0.02 U
002338	RFETS	Inorganic Non-metal	222	371	17.00 U	0.78 U	32.00	1.10 U	0.76 U	0.90	0.71 U	17.00 U	140.00
002354	INEL	Combustible	223	339	17.00 U	2.80	8.20	0.07 U	15.00	0.87 J	0.42 J	17.00 U	0.09 J
002363	INEL	Inorganic Non-metal	222	371	17.00 U	0.20 J	0.25 J	0.04 U	0.14 J	0.40	0.06 J	17.00 U	0.04 J
002365	INEL	Uncategorized Metal	217	480	17.00 U	0.07 U	13.00	0.10 U	0.09 J	0.43 J	0.13 J	17.00 U	0.06 U
002542	INEL	[illegible]lidified Organics	212	3	17.00 U	11.00	[illegible]00	7.60 U	2100.0	8.40 U	7.70 U	17.00 U	7.70 U
002678	RFETS	[illegible]olidified Organics	226	432	17.00 U	0.89 U	130.00	1.30 U	0.87 U	1.00	0.81 U	17.00 U	170.00

Table . .-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
002791	INEL	Inorganic Non-metal	222	371	17.00 U	10.00	0.72	0.07 U	0.35 J	0.05 U	0.08 J	17.00 U	0.06 J
002797	RFETS	Solidified Organics	226	432	17.00 U	2.60 J	0.40 U	1.20 J	0.43 U	2.40	0.40 U	17.00 U	0.41 U
002814	RFETS	Solidified Inorganics	211	7	5.00 U	0.20 U	40.00 J	0.29 U	0.58 J	0.24	0.19 U	5.00 U	1.60 J
003017	INEL	Solidified Inorganics	211	1	5.00 U	0.05 U	5.80 U	0.07 U	0.13 J	0.15 J	0.05 U	5.00 U	0.05 U
003088	INEL	Inorganic Non-metal	222	371	17.00 U	0.31 J	0.27 J	0.04 U	0.28 J	0.13 J	0.05 J	17.00 U	0.03 J
003091	RFETS	Inorganic Non-metal	222	371	17.00 U	0.04 U	0.62 J	0.04 U	0.20 J	0.08	0.03 U	17.00 U	0.03 J
003111	INEL	Inorganic Non-metal	222	371	17.00 U	7.30 E	0.29 J	0.04 U	0.25 J	0.03 U	0.04 J	17.00 U	0.04 J
003121	RFETS	Solidified Inorganics	211	7	5.00 U	0.14 U	2.50 U	0.50 JD	0.13 U	0.16	0.12 U	5.00 U	0.12 U
003129	RFETS	Solidified Inorganics	211	7	5.00 U	0.02 U	1.50 J	0.03 U	0.08 J	0.07	0.02 U	5.00 U	0.04 J
003130	RFETS	Solidified Inorganics	211	7	5.00 U	0.04 U	1.90 JD	0.06 U	0.08 JD	0.10	0.04 U	5.00 U	0.10 JD
003173	RFETS	Solidified Inorganics	211	7	5.00 U	0.02 U	1.80	0.02 U	0.14 J	0.07	0.02 U	5.00 U	0.32
003181	RFETS	Solidified Inorganics	211	7	5.00 U	0.01 U	0.18 J	0.02 U	0.07 J	0.02	0.01 U	5.00 U	0.01 J
003189	INEL	Solidified Organics	212	3	17.00 U	82.00 U	4100.0	77.00 U	15000	85.00 U	78.00 U	17.00 U	78.00 U
003192	RFETS	Solidified Inorganics	211	7	5.00 U	0.23 U	46.00 U	0.33 U	0.62 J	0.26	0.21 U	5.00 U	0.21 U
003215	RFETS	Solidified Inorganics	211	7	5.00 U	0.01 U	1.00 J	0.02 U	0.07 J	0.02	0.06 J	5.00 U	0.03 J
003277	RFETS	Solidified Inorganics	211	1	5.00 U	0.01 J	0.14 J	0.01 U	0.17	0.10	0.01 U	5.00 U	0.04 J
003394	RFETS	Solidified Inorganics	211	7	5.00 U	0.03 U	4.70 J	0.04 U	0.12 J	0.03	0.03 U	5.00 U	0.10 J
003406	RFETS	Solidified Inorganics	211	7	5.00 U	0.01 U	0.80 J	0.01 U	0.13	0.03	0.01 J	5.00 U	0.02 J
003455	RFETS	Solidified Inorganics	211	3	5.70 J	250.00 U	21000 U	350.00 U	43000	290.00	230.00 U	5.00 U	230.00 U
003547	RFETS	Solidified Inorganics	211	7	5.00 U	0.09 U	15.00 J	0.13 U	0.12 J	0.10	0.08 U	5.00 U	0.15 J
003577	RFETS	Solidified Inorganics	211	1	5.00 U	0.01 U	0.10 J	0.36	0.11 J	0.06	0.10 J	5.00 U	0.03 J
003854	INEL	Solidified Organics	212	3	17.00 U	50.00	1800.0	35.00 U	6700.0	39.00 U	36.00 U	17.00 U	36.00 U
003890	INEL	Solidified Inorganics	111	7	5.00 U	0.03 U	0.92	0.08 J	0.19 J	0.06 J	0.03 U	5.00 U	0.03 U
003921	INEL	Solidified Inorganics	111	7	5.00 U	0.03 U	2.90	0.05 U	0.32 J	0.04 U	0.03 U	5.00 U	0.03 U
003991	INEL	Combustible	223	339	17.00 U	0.13 J	0.05 J	0.02 U	0.03 J	0.06 J	0.02 J	17.00 U	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
003997	INEL	Combustible	223	339	15.00 U	0.23 J	0.13 J	0.04 U	0.04 U	0.29 J	0.39 J	15.00 U	0.05 U
004099	INEL	Solidified Inorganics	211	1	5.00 U	0.10 J	0.25	0.02 U	0.01 J	0.12 J	0.01 U	5.00 U	0.02 J
004111	RFETS	Salt Waste	224	411	5.00 U	0.06 J	0.12 U	0.13 J	0.10 JB	0.06	0.03 U	5.00 U	0.03 U
004112	INEL	Graphite	215	300	17.00 U	0.01 U	0.09 J	0.02 U	0.03 J	0.01 U	0.02 U	17.00 U	0.02 U
004123	INEL	Combustible	223	339	17.00 U	0.10 J	0.09 J	0.02 U	0.06 J	0.08 J	0.17 J	17.00 U	0.02 U
004125	INEL	Uncategorized Metal	217	480	17.00 U	0.03 U	0.05 J	0.04 U	0.05 J	0.07 J	0.03 U	17.00 U	0.03 U
004150	INEL	Graphite	215	300	17.00 U	0.02 U	0.11 J	0.02 U	0.08 J	0.02 U	0.02 U	17.00 U	0.02 U
004160	INEL	Combustible	223	339	17.00 U	580.00	290.00	120.00 U	25000	78.00 U	110.00 U	17.00 U	130.00 U
004166	INEL	Inorganic Non-metal	222	371	17.00 U	0.03 U	0.28 J	0.04 U	0.26 J	0.05 J	0.03 U	17.00 U	0.03 U
004186	INEL	Combustible	223	339	17.00 U	0.29 J	0.06 J	0.11 J	1.20	0.07 J	0.11 J	17.00 U	0.02 U
004195	RFETS	Salt Waste	224	411	5.00 U	0.01 U	0.11 J	0.14	0.16 B	0.01	0.01 U	5.00 U	0.02 J
004196	INEL	Graphite	215	300	17.00 U	0.03 J	0.13 J	0.02 U	0.07 J	0.08 J	0.03 J	17.00 U	0.02 U
004206	INEL	Combustible	223	339	15.00 U	0.36 J	0.13 J	0.18 J	0.05 J	0.19 J	0.26 J	15.00 U	0.02 U
004208	INEL	Graphite	215	300	17.00 U	0.01 U	0.05 J	0.02 U	0.03 J	0.01 U	0.02 U	17.00 U	0.02 U
004283	INEL	Solidified Inorganics	211	1	17.00 U	0.02 U	0.17 J	0.29 J	0.12 J	0.14 J	0.02 U	17.00 U	0.02 U
004326	INEL	Solidified Inorganics	213	4	17.00 U	0.02 J	0.23 J	0.02 U	0.39 J	0.09 J	0.02 U	17.00 U	0.02 J
004393	INEL	Solidified Inorganics	211	1	5.00 U	0.02 U	0.43	0.02 U	0.08 J	0.08 J	0.02 U	5.00 U	0.02 U
004410	INEL	Solidified Inorganics	211	1	5.00 U	0.03 U	0.28 J	0.04 U	0.20 J	0.11 J	0.03 U	5.00 U	0.03 U
004495	INEL	Solidified Inorganics	213	4	17.00 U	0.02 U	0.15 J	0.23 J	0.19 J	0.02 U	0.02 U	17.00 U	0.02 J
004516	INEL	Solidified Inorganics	211	1	5.00 U	0.03 U	0.21 J	0.09 J	0.12 J	0.60	0.03 U	5.00 U	0.03 U
004884	INEL	Solidified Inorganics	213	4	51.00 U	0.03 U	0.59 J	6.10	0.60 J	0.54 J	0.03 U	51.00 U	0.03 U
004963	INEL	Combustible	223	339	17.00 U	7.10	0.19 J	0.07 U	13.00	0.91 J	0.40 J	17.00 U	0.07 U
004968	RFETS	Uncategorized Metal	217	320	22.00 J	0.55 U	1.70 U	0.78 U	2.90 J	0.63	0.50 U	5.00 U	0.50 U
004981	RFETS	Uncategorized Metal	217	320	5.00 U	0.01 J	0.39 J	0.01 U	0.49	0.01	0.01 U	5.00 U	0.01 J
004988	RFETS	Salt Waste	224	411	5.00 U	0.06 J	0.30 J	0.04 U	0.10 JB	0.09	0.03 U	5.00 U	0.32 J

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Trichloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
005006	RFETS	Salt Waste	224	411	5.00 U	0.04 J	0.39	0.04 U	0.07 JB	0.10	0.03 U	5.00 U	0.42
005012	INEL	Combustible	223	339	17.00 U	0.06 J	0.18 J	0.02 U	0.18 J	0.04 J	0.04 J	17.00 U	0.02 J
005015	INEL	Solidified Organics	226	432	17.00 U	1.40 U	82.00	2.00 U	1.40 U	1.60 U	1.30 U	17.00 U	230.00
005235	INEL	Solidified Organics	226	432	17.00 U	0.28 J	0.61 JB	0.04 U	0.38 J	1.30	0.03 U	17.00 U	0.03 U
005262	INEL	Solidified Organics	212	3	17.00 U	230.00 U	33000	220.00 U	52000	240.00 U	220.00 U	17.00 U	220.00 U
005358	INEL	Solidified Inorganics	211	1	17.00 U	0.03 J	0.30 J	0.80 J	0.23 J	1.00	0.02 U	17.00 U	0.02 U
005398	INEL	Solidified Inorganics	211	1	5.00 U	0.03 U	4.90	0.04 U	0.07 J	0.04 J	0.03 U	5.00 U	0.03 U
005415	INEL	Solidified Inorganics	211	1	5.00 U	0.03 U	0.16 J	0.10 J	0.09 J	0.31 J	0.03 U	5.00 U	0.03 U
005530	INEL	Graphite	215	303	17.00 U	0.07 J	0.11 J	0.02 U	0.06 J	0.05 J	0.02 J	17.00 U	0.02 U
005535	INEL	Solidified Organics	226	432	17.00 U	0.06 U	0.17 JD	0.16 JD	0.17 JD	2.80 D	0.05 U	17.00 U	0.05 U
005735	INEL	Solidified Inorganics	211	7	5.00 U	0.03 U	0.56	0.16 J	0.08 J	0.04 J	0.03 U	5.00 U	0.03 U
005738	INEL	Solidified Inorganics	211	7	5.00 U	0.02 U	0.29	0.03 U	0.08 J	0.02 U	0.02 U	5.00 U	0.02 U
006242	INEL	Inorganic Non-metal	222	371	17.00 U	3.70	0.26 J	0.04 U	0.28 J	0.03 U	0.04 J	17.00 U	0.03 J
006252	RFETS	Lead/Cadmium Metal	123	339	5.00 U	9.20 JD	5.80 U	5.20 U	460.00 D	4.20	3.30 U	5.00 U	3.40 U
006325	RFETS	Solidified Inorganics	213	4	100.00 U	0.01 U	0.12 J	0.70	0.11 J	0.33	0.01 U	100.00 U	0.08 J
006669	INEL	Solidified Inorganics	214	292	5.00 U	0.14 U	0.33 J	1.20 J	0.37 J	0.16 U	0.13 U	5.00 U	0.22 J
006773	RFETS	Solidified Inorganics	213	4	120.00 U	0.10 U	18.00 J	20.00	0.17 J	0.40	0.09 U	120.00 U	0.18 J
006857	INEL	Combustible	223	339	17.00 U	0.34 J	0.11 J	0.02 U	0.70 J	0.15 J	0.26 J	17.00 U	0.04 J
006865	RFETS	Solidified Organics	226	432	5.00 U	0.07 U	0.66 J	0.63 J	0.88 J	1.40	0.07 U	5.00 U	0.08 J
006876	INEL	Filter	219	335	17.00 U	0.04 J	0.03 J	0.06 J	0.02 J	0.34 J	0.12 J	17.00 U	0.02 U
006879	INEL	Solidified Organics	226	432	17.00 U	0.09 U	0.17 J	0.18 J	0.16 J	0.99 J	0.08 U	17.00 U	0.09 U
006886	INEL	Solidified Organics	226	432	17.00 U	0.31 U	12.00 B	2.60	0.30 U	0.54 J	0.28 U	17.00 U	57.00
007034	INEL	Combustible	216	337	15.00 U	210.00	290.00	2.80 U	1.90 U	2.30 U	1.80 U	15.00 U	310.00
007146	INEL	Inorganic Non-metal	222	371	17.00 U	1.60 U	150.00	2.30 U	1.60 U	1.80 U	1.40 U	17.00 U	280.00
007170	INEL	Combustible	216	337	18.00 U	0.25 U	71.00	0.35 U	0.34 U	0.22 U	0.31 U	18.00 U	92.00

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
07231	INEL	Filter	219	338	17.00 U	0.11 U	21.00	0.16 U	0.15 U	0.10 U	0.90 J	17.00 U	6.20
07511	INEL	Inorganic Non-metal	122	374	17.00 U	0.04 U	0.48	0.06 J	0.35 J	0.04 U	0.03 U	17.00 U	0.03 U
07518	INEL	Inorganic Non-metal	122	374	17.00 U	0.12 J	0.44 J	0.08 U	0.16 J	1.30	0.10 J	17.00 U	0.05 U
07667	INEL	Salt Waste	124	411	5.00 U	0.01 J	0.10 J	0.01 U	0.12	0.02 J	0.01 U	5.00 U	0.01 U
07920	INEL	Filter	121	302	17.00 U	0.22 U	1.80 J	0.72 J	0.22 U	0.26 U	0.20 U	17.00 U	0.29 J
08203	INEL	Inorganic Non-metal	118	440	17.00 U	0.06 U	0.10 J	0.20 J	0.13 J	0.39 J	0.05 U	17.00 U	0.05 U
08207	INEL	Heterogeneous	116	336	20.00 J	0.87 U	0.27 J	0.10 U	0.12 J	2.00 J	1.30 U	17.00 U	0.06 U
08218	INEL	Heterogeneous	116	330	17.00 U	1.70	0.20 J	0.10 U	0.16 J	1.30	0.84 J	17.00 U	0.06 U
08269	INEL	Uncategorized Metal	117	320	17.00 U	0.18 U	0.28 U	0.64 JD	0.32 JD	0.21 U	0.16 U	17.00 U	0.16 U
08287	INEL	Inorganic Non-metal	122	374	17.00 U	0.03 U	0.20 J	0.09 J	0.16 J	0.03 U	0.03 U	17.00 U	0.03 U
08359	INEL	Heterogeneous	116	330	17.00 U	1.50 J	0.28 U	0.73 J	0.18 U	2.70	2.00 J	17.00 U	0.16 U
08383	INEL	Lead/Cadmium Metal	123	339	6.10 J	13.00 J	1000.0	7.00 U	930.00	5.60 U	4.50 U	5.00 U	4.50 U
08848	INEL	Inorganic Non-metal	218	440	17.00 U	22.00	36.00	0.20 U	0.47 J	0.22 U	0.20 U	17.00 U	1.30
08859	INEL	Inorganic Non-metal	218	440	17.00 U	1.10	11.00	0.59 U	66.00	0.48 U	0.38 U	17.00 U	0.80 J
08860	INEL	Uncategorized Metal	217	480	17.00 U	1.10 U	160.00	1.50 U	1.00 U	1.20 U	0.96 U	17.00 U	4.30
08864	INEL	Uncategorized Metal	217	480	17.00 U	0.09 U	20.00	0.13 U	0.14 J	0.11 U	0.08 U	17.00 U	0.98 J
08872	INEL	Solidified Inorganics	214	292	5.00 U	0.04 U	0.23 J	0.31 J	0.12 J	0.09 J	0.03 U	5.00 U	0.06 J
08874	RFETS	Uncategorized Metal	217	480	12.00 J	33.00 U	5400.0 U	46.00 U	32.00 U	38.00	30.00 U	5.00 U	30.00 U
08878	INEL	Uncategorized Metal	217	480	17.00 U	4.50 U	580.00	6.30 U	4.30 U	5.10 U	4.00 U	17.00 U	4.10
08880	RFETS	Graphite	115	312	5.00 U	1.60 J	250.00 J	1.80 U	1.20 J	1.50	1.20 U	5.00 U	3.00 J
09006	INEL	Solidified Inorganics	211	7	17.00 U	0.04 J	0.63 J	0.02 U	0.18 J	0.08 J	0.02 U	17.00 U	0.02 U
09011	RFETS	Solidified Inorganics	211	7	5.00 U	0.01 U	2.30 JB	0.02 U	0.17 B	0.04	0.01 U	5.00 U	0.09 JB
09061	RFETS	Inorganic Non-metal	218	440	5.00 U	0.43 J	6.00	0.13 U	0.49 J	0.10	0.08 U	5.00 U	18.00
09180	INEL	[illegible]mbustible	223	339	17.00 U	22.00	[illegible]00	0.79 U	150.00	0.68 J	0.70 U	17.00 U	0.81 U
09225	INEL	Uncategorized Metal	217	481	17.00 U	0.03 U	2.20	0.04 U	0.03 J	0.03 U	0.03 U	17.00 U	0.03 U

Table [illegible]-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
009252	INEL	Combustible	223	339	17.00 U	1100.0	390.00	28.00 U	3700.0	22.00 U	18.00 U	17.00 U	18.00 J
009296	INEL	Combustible	223	339	17.00 U	2.80 U	2.50 U	740.00	2.70 U	3.20 U	4.10	17.00 U	2.50 U
009299	INEL	Combustible	223	339	17.00 U	0.10 J	1.10	0.03 J	0.02 U	0.04 J	0.11 J	17.00 U	0.02 U
009399	INEL	Inorganic Non-metal	218	440	17.00 U	1.30	37.00	0.52 U	83.00 E	0.42 U	0.33 U	17.00 U	2.10
009422	RFETS	Combustible	216	337	5.00 U	5.70 JD	920.00 JD	7.40 U	26.00 JD	6.00	4.70 U	5.00 U	5.20 JD
009423	INEL	Combustible	216	337	17.00 U	1.90 U	300.00	160.00	1.90 U	1.90 U	1.80 U	17.00 U	1.80 U
009435	INEL	Combustible	216	337	17.00 U	15.00	55.00	0.52 U	0.43 J	0.42 U	0.33 U	17.00 U	0.33 U
009449	INEL	Inorganic Non-metal	218	440	17.00 U	3.10	0.23 J	0.06 U	0.66 J	0.36 J	0.06 J	17.00 U	0.04 U
009471	INEL	Combustible	216	337	18.00 U	4.50	24.00	0.08 U	0.08 U	0.50 U	0.07 U	18.00 U	0.08 U
009475	INEL	Inorganic Non-metal	218	442	17.00 U	0.74 U	140.00	0.70 U	0.77 U	1.10	0.71 U	17.00 U	0.71 U
009489	INEL	Combustible	216	337	18.00 U	4.60	59.00	0.20 U	0.20 U	0.13 U	0.18 U	18.00 U	0.21 U
009587	INEL	Uncategorized Metal	117	320	5.00 U	0.01 J	0.24	0.15	0.24	0.01 U	0.01 U	5.00 U	0.01 J
009591	INEL	Inorganic Non-metal	118	440	17.00 U	0.04 U	0.09 J	0.05 U	0.10 J	0.05 J	0.03 U	17.00 U	0.03 U
009592	INEL	Inorganic Non-metal	118	440	17.00 U	0.07 U	0.11 J	0.14 J	0.13 J	0.26 J	0.06 U	17.00 U	0.06 U
009596	INEL	Uncategorized Metal	117	320	17.00 U	0.13 U	17.00	0.18 U	0.25 J	0.15 U	0.12 U	17.00 U	0.54 J
009599	INEL	Inorganic Non-metal	118	440	17.00 U	0.11 J	0.33 J	0.04 U	0.18 J	0.37	0.04 J	17.00 U	0.03 U
009602	INEL	Inorganic Non-metal	218	442	17.00 U	1.90 U	250.00	2.70 U	1.80 U	2.20 U	1.70 U	17.00 U	1.70 U
009694	INEL	Graphite	215	300	17.00 U	0.02 U	0.18 J	0.02 U	0.15 J	0.02 U	0.02 U	17.00 U	0.02 U
009735	INEL	Graphite	215	300	17.00 U	0.02 U	0.12 J	0.02 U	0.06 J	0.02 U	0.02 U	17.00 U	0.22 J
009773	INEL	Combustible	223	339	17.00 U	74.00	450.00	5.20 U	1300.0	5.80 U	5.30 U	17.00 U	5.30 U
009787	RFETS	Solidified Organics	212	3	5.00 U	180.00 J	10000 U	240.00 U	32000 B	200.00	160.00 U	5.00 U	160.00 U
009873	RFETS	Solidified Inorganics	211	1	5.00 U	0.05 U	8.10 U	0.06 U	0.20 J	0.16	0.04 U	5.00 U	0.04 U
010216	INEL	Filter	219	338	17.00 U	0.70 U	88.00	0.99 U	5.60	0.62 U	0.89 U	17.00 U	260.00
010224	INEL	Filter	219	338	17.00 U	0.21 U	42.00	0.30 U	0.29 U	0.19 U	0.78 J	17.00 U	20.00
010230	INEL	Heterogeneous	216	330	17.00 U	0.11 U	200.00 E	0.16 U	0.76 J	2.20	0.34 J	17.00 U	290.00 E

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
010273	INEL	Combustible	216	337	18.00 U	4.40	37.00	0.14 U	0.14 U	0.09 U	0.13 U	18.00 U	0.15 U
010295	INEL	Inorganic Non-metal	218	442	17.00 U	0.40 J	7.00	0.08 U	0.26 J	0.10 J	0.24 J	17.00 U	0.05 U
010305	RFETS	Inorganic Non-metal	218	442	5.00 U	0.66 U	110.00 U	0.93 U	0.66 J	0.75	0.59 U	5.00 U	0.60 U
010364	RFETS	Combustible	216	337	5.00 U	5.20 J	120.00 U	1.20 U	0.81 U	0.95	0.75 U	5.00 U	0.76 U
010371	INEL	Combustible	216	337	1.00 U	46.00	140.00 E	350.00 E	0.75 J	0.42 J	0.34 U	1.20 U	0.75 J
010407	RFETS	Uncategorized Metal	217	480	16.00 J	0.73 J	13.00 J	0.16 U	6.30	0.16	0.10 U	5.00 U	0.12 J
010411	INEL	Combustible	216	337	17.00 U	78.00	140.00	120.00	1.80 U	2.10 U	1.70 U	17.00 U	1.70 U
010415	INEL	Inorganic Non-metal	218	442	17.00 U	0.03 U	4.00	0.04 U	0.18 J	0.03 U	0.03 U	17.00 U	0.03 U
010426	INEL	Inorganic Non-metal	218	442	17.00 U	0.41 J	12.00 E	0.02 U	0.26 J	0.08 J	0.30 J	17.00 U	0.02 J
010463	INEL	Solidified Inorganics	213	4	34.00 U	0.28 U	40.00 J	0.40 U	0.35 J	0.32 U	0.25 U	34.00 U	0.25 U
010487	INEL	Salt Waste	224	414	17.00 U	2.30 J	23.00	0.72 U	50.00	0.58 U	0.46 U	17.00 U	0.46 U
010492	INEL	Uncategorized Metal	217	480	17.00 U	0.55 U	74.00	0.77 U	0.53 U	0.63 U	0.49 U	17.00 U	0.50 U
010498	INEL	Uncategorized Metal	217	480	17.00 U	0.37 J	12.00	0.04 U	0.09 J	0.49 J	0.13 J	17.00 U	0.04 U
010510	RFETS	Heterogeneous	216	336	5.00 U	9.40 J	240.00 B	18.00 J	3.80 JB	1.80	1.40 U	5.00 U	340.00 B
010546	RFETS	Heterogeneous	216	330	16.00 J	44.00 U	6600.0 B	62.00 U	42.00 U	50.00	40.00 U	10.00 U	1600.0 B
010578	INEL	Solidified Organics	226	432	17.00 U	0.95 U	65.00	1.40 U	0.92 U	1.10 U	0.86 U	17.00 U	200.00
010588	RFETS	Solidified Inorganics	211	2	5.00 U	0.82 U	76.00	1.20 U	0.84 J	0.94	0.74 U	5.00 U	160.00
010663	INEL	Combustible	216	337	18.00 U	0.36 U	110.00	0.51 U	0.49 U	0.32 U	0.46 U	18.00 U	140.00
010676	INEL	Heterogeneous	216	330	18.00 U	0.29 U	92.00	0.41 U	0.49 J	0.95 J	0.37 U	18.00 U	110.00
010800	INEL	Filter	219	338	17.00 U	0.10 U	23.00	0.14 U	0.13 U	0.14 J	0.12 U	17.00 U	42.00
010807	INEL	Combustible	216	337	17.00 U	1.20 U	120.00	1.80 U	1.20 U	1.40 U	1.10 U	17.00 U	240.00
010808	INEL	Combustible	216	337	17.00 U	3.60	53.00	21.00	0.40 U	0.41 U	0.37 U	17.00 U	120.00
010814	RFETS	Solidified Inorganics	211	1	5.00 U	0.33 U	53.00 E	0.47 U	0.80 JB	0.38	0.30 U	5.00 U	96.00 E
010837	INEL	lidified Organics	226	432	17.00 U	0.42 U	00	0.59 U	1.30 J	0.48 U	0.38 U	17.00	78.00
010848	INEL	Filter	219	338	15.00 U	0.28 U	100.00	0.39 U	0.37 U	0.24 U	0.92 J	15.00 U	95.00

Table .-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Trl chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Dl-chloro-ethane	1-Butanol	Trichloro-ethene
010883	INEL	Solidified Organics	226	432	17.00 U	1.10 U	81.00	1.50 U	1.00 U	1.20 U	0.98 U	17.00 U	190.00
010921	INEL	Inorganic Non-metal	222	371	17.00 U	0.09 U	3.60	0.13 U	0.22 J	0.11 U	0.08 U	17.00 U	20.00
011004	INEL	Uncategorized Metal	217	480	17.00 U	0.03 U	10.00 E	0.04 U	0.13 J	0.03 U	0.03 U	17.00 U	0.03 U
011021	INEL	Solidified Organics	226	432	17.00 U	0.17 U	7.20	0.24 U	0.19 J	7.50	0.15 U	17.00 U	0.29 J
011042	INEL	Inorganic Non-metal	218	442	17.00 U	0.59 U	83.00	0.83 U	0.57 U	0.67 U	0.53 U	17.00 U	0.53 U
011044	INEL	Inorganic Non-metal	218	440	17.00 U	0.98 J	22.00	0.48 U	63.00	0.38 U	0.30 U	17.00 U	0.30 U
011067	RFETS	Solidified Inorganics	213	4	5.00 U	1.10 U	190.00 U	1.60 U	1.70 J	1.30	1.00 U	5.00 U	1.00 U
011102	RFETS	Solidified Inorganics	211	1	5.00 U	0.26 U	54.00 U	0.37 U	2.70 J	0.30	0.24 U	5.00 U	0.24 U
011109	INEL	Solidified Inorganics	211	1	17.00 U	0.22 U	44.00	0.21 U	0.23 U	0.23 U	0.21 U	17.00 U	0.78 J
011147	INEL	Solidified Inorganics	213	4	94.00 U	0.26 U	56.00	0.24 U	0.27 J	0.26 U	0.24 U	94.00 U	0.24 U
011173	INEL	Uncategorized Metal	217	480	17.00 U	19.00	11.00	0.06 U	5.50	0.37 J	0.07 J	17.00 U	0.48 J
011194	INEL	Inorganic Non-metal	218	442	17.00 U	0.07 U	14.00	0.10 U	0.39 J	0.08 U	0.06 U	17.00 U	2.40
011393	INEL	Uncategorized Metal	217	480	17.00 U	0.14 U	22.00	0.20 U	0.17 J	0.16 U	0.13 U	17.00 U	1.00
011416	INEL	Combustible	216	337	17.00 U	0.61 U	82.00	0.87 U	0.83 J	0.70 U	0.56 U	17.00 U	90.00
011433	INEL	Heterogeneous	216	330	18.00 U	0.36 U	75.00	0.51 U	0.49 U	0.48 J	0.46 U	18.00 U	150.00
011498	RFETS	Solidified Organics	226	432	17.00 U	1.60 U	140.00	2.30 U	1.60 U	1.80	1.40 U	17.00 U	270.00
011529	INEL	Uncategorized Metal	217	480	17.00 U	0.03 U	0.66 J	0.04 U	0.06 J	0.03 U	0.03 U	17.00 U	0.03 U
011601	INEL	Heterogeneous	216	336	17.00 U	0.85 U	160.00	1.20 U	1.20 U	0.75 U	1.10 U	17.00 U	260.00
011607	INEL	Heterogeneous	216	330	17.00 U	3.50	5.80	0.03 U	0.13 J	0.06 J	0.03 U	17.00 U	0.14 J
011637	RFETS	Filter	219	338	5.00 U	0.82 U	120.00 D	1.20 U	0.80 U	0.94	0.74 U	5.00 U	150.00 D
011735	INEL	Heterogeneous	216	330	17.00 U	0.84 U	85.00	1.20 U	2.90	0.96 U	0.76 U	17.00 U	130.00
011749	INEL	Inorganic Non-metal	225	441	17.00 U	0.24 U	39.00	0.34 U	0.65 J	0.27 U	0.22 U	17.00 U	5.50
011785	RFETS	Solidified Inorganics	211	1	5.00 U	0.03 U	0.15 U	0.04 J	0.50	0.13	0.03 U	5.00 U	0.03 U
012021	INEL	Solidified Inorganics	211	1	17.00 U	0.36 U	45.00	0.52 U	0.35 U	0.42 U	0.33 U	17.00 U	18.00
012108	INEL	Solidified Inorganics	214	292	17.00 U	0.36 U	40.00	0.52 U	0.35 U	0.42 U	0.33 U	17.00 U	2.00 J

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
012111	INEL	Combustible	216	337	18.00 U	1.20 U	160.00	590.00	1.60 U	1.00 U	1.50 U	18.00 U	1.70 U
012215	INEL	Uncategorized Metal	217	480	17.00 U	0.39 U	56.00	0.55 U	0.38 U	0.45 U	0.35 U	17.00 U	9.80
012313	INEL	Heterogeneous	216	336	18.00 U	7.80	92.00	30.00	0.59 U	0.38 U	0.55 U	18.00 U	110.00
012320	INEL	Heterogeneous	216	336	17.00 U	12.00	200.00	2.60 U	1.80 U	2.10 U	1.70 U	17.00 U	300.00
012356	INEL	Filter	219	338	17.00 U	0.26 U	41.00	0.24 U	0.27 U	0.27 U	1.50	17.00 U	29.00
012357	RFETS	Uncategorized Metal	217	480	5.00 U	3.00 U	190.00	4.20 U	2.90 U	3.40	2.70 U	5.00 U	610.00
012433	INEL	Filter	219	338	17.00 U	0.72 J	44.00	0.20 U	36.00	0.12 U	0.21 J	17.00 U	61.00
012469	RFETS	Solidified Inorganics	211	1	5.00 U	0.34 U	23.00	0.48 U	0.57 J	0.38	0.30 U	5.00 U	60.00
012471	RFETS	Filter	219	338	5.00 U	0.56 J	35.00	0.25 U	0.17 U	0.91	0.16 U	5.00 U	10.00
012487	INEL	Inorganic Non-metal	218	440	17.00 U	0.15 J	2.90	2.40	0.19 J	0.06 J	0.02 U	17.00 U	19.00 E
012494	INEL	Heterogeneous	216	330	17.00 U	1.10	85.00	1.60 U	14.00	2.30	1.00 U	17.00 U	160.00
012541	INEL	Inorganic Non-metal	218	442	17.00 U	0.03 U	8.40 E	0.04 U	0.19 J	0.03 U	0.03 U	17.00 U	2.90
012553	INEL	Solidified Inorganics	211	1	17.00 U	0.03 U	6.70 E	0.04 U	0.17 J	0.03 U	0.03 U	17.00 U	0.06 J
012571	INEL	Uncategorized Metal	217	320	17.00 U	0.08 J	0.33 J	0.02 U	0.12 J	0.02 U	0.02 U	17.00 U	0.03 J
012611	INEL	Solidified Inorganics	211	1	17.00 U	0.59 U	66.00	0.83 U	0.57 U	0.67 U	0.53 U	17.00 U	0.53 U
012634	INEL	Solidified Inorganics	211	1	17.00 U	1.60 U	220.00	2.30 U	1.60 U	1.80 U	1.40 U	17.00 U	1.40 U
012749	INEL	Solidified Inorganics	211	1	17.00 U	0.31 U	40.00	0.44 U	0.30 U	0.35 U	0.28 U	17.00 U	6.80
012766	INEL	Heterogeneous	216	336	17.00 U	2.80 U	310.00	4.00 U	4.00	3.20 U	2.50 U	17.00 U	400.00
012802	INEL	Combustible	216	337	17.00 U	1.40 U	250.00	1.30 U	42.00	1.40 U	1.30 U	17.00 U	340.00
012875	RFETS	Solidified Organics	226	432	17.00 U	3.80 U	310.00	5.30 U	3.70 U	4.30	3.40 U	17.00 U	630.00
012878	INEL	Uncategorized Metal	217	480	17.00 U	0.71 U	48.00	0.66 U	0.73 U	0.73 U	0.67 U	17.00 U	210.00
012891	INEL	Heterogeneous	216	330	17.00 U	0.32 U	44.00	0.46 U	0.44 J	0.37 U	0.29 U	17.00 U	51.00
012902	INEL	Filter	219	338	17.00 U	0.01 U	0.49 J	0.02 U	0.02 U	0.01 U	0.02 U	17.00 U	0.70 J
012920	INEL	[illegible]organic Non-metal	222	371	17.00 U	1.10 U	[illegible].00	1.60 U	1.10 U	1.30 U	1.00 U	17.00 [illegible]	180.00
012985	INEL	[illegible]norganic Non-metal	222	371	17.00 U	1.90 U	[illegible].00	2.60 U	1.80 U	2.10 U	1.70 U	17.00 U	390.00

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
012986	INEL	Heterogeneous	221	302	17.00 U	0.62 U	120.00	0.58 U	0.63 U	0.64 U	0.58 U	17.00 U	170.00
012998	INEL	Combustible	216	337	17.00 U	0.64 U	50.00	0.91 U	0.98 J	0.74 U	0.58 U	17.00 U	97.00
013106	INEL	Solidified Inorganics	111	7	5.00 U	0.01 U	0.85	0.02 U	0.23	0.02 U	0.01 U	5.00 U	0.05 J
013229	RFETS	Solidified Organics	226	432	17.00 U	0.14 U	0.12 U	0.32 J	0.14 U	0.27	0.13 U	17.00 U	0.13 U
013231	INEL	Graphite	215	300	17.00 U	0.01 U	0.05 J	0.02 U	0.02 J	0.01 U	0.02 U	17.00 U	0.02 U
013252	INEL	Inorganic Non-metal	222	371	17.00 U	0.16 J	0.25 J	0.04 U	0.22 J	0.03 U	0.03 U	17.00 U	0.03 U
013266	INEL	Combustible	223	339	17.00 U	16.00	0.45 J	0.55 U	65.00	0.45 U	0.35 U	17.00 U	0.36 U
013269	INEL	Inorganic Non-metal	218	440	17.00 U	0.06 U	12.00	0.06 U	0.09 J	0.06 U	0.06 U	17.00 U	0.10 J
013313	INEL	Inorganic Non-metal	218	440	17.00 U	0.08 J	0.25 J	0.04 U	0.24 J	0.03 U	0.03 U	17.00 U	0.03 U
013331	INEL	Salt Waste	124	411	17.00 U	0.07 U	0.12 J	0.10 U	0.10 J	0.26 J	0.06 U	17.00 U	0.06 U
013342	INEL	Inorganic Non-metal	218	440	17.00 U	0.02 U	0.10 J	0.15 J	1.20	0.15 J	0.02 U	17.00 U	0.02 U
013346	RFETS	Inorganic Non-metal	222	371	5.00 U	0.10 J	0.10 U	0.03 U	0.08 JB	0.02	0.02 U	5.00 U	0.02 U
013618	INEL	Heterogeneous	216	330	17.00 U	1.90 U	70.00	2.60 U	1.80 U	2.10 U	1.70 U	17.00 U	290.00
013677	INEL	Filter	219	338	17.00 U	0.04 U	13.00	0.05 U	0.05 J	0.13 J	0.11 J	17.00 U	3.70
013751	INEL	Uncategorized Metal	217	480	17.00 U	0.84 U	58.00	1.20 U	0.81 U	0.96 U	0.76 U	17.00 U	170.00
013763	INEL	Combustible	223	339	2.60 J	78.00	84.00	13.00 U	3800.0 E	13.00 U	14.00 U	1.20 U	15.00 U
013773	RFETS	Solidified Inorganics	111	7	5.00 U	0.07 U	11.00 U	0.10 U	0.09 JB	0.09	0.07 U	5.00 U	0.07 U
013818	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 U	0.25 U	0.03 U	0.10 JB	0.30	0.02 U	5.00 U	0.02 U
013820	RFETS	Solidified Inorganics	211	1	11.00 U	0.22 J	0.18 J	0.04 J	0.12 JB	0.16	0.02 U	11.00 U	0.04 J
013847	INEL	Graphite	215	300	17.00 U	0.02 U	0.08 J	0.02 U	0.03 J	0.02 U	0.02 U	17.00 U	0.02 U
013860	INEL	Combustible	223	339	17.00 U	0.68 J	19.00	0.07 U	1.00	0.62 J	0.36 J	17.00 U	0.07 U
013876	RFETS	Solidified Inorganics	211	7	5.00 U	0.09 U	6.90 U	0.13 U	13.00	0.10	0.08 U	5.00 U	0.08 U
014007	INEL	Solidified Inorganics	211	1	17.00 U	0.02 U	0.16 J	0.02 U	0.10 J	0.06 J	0.02 U	17.00 U	0.03 J
014009	INEL	Solidified Inorganics	211	7	17.00 U	0.08 U	22.00	0.07 U	0.41 J	0.10 J	0.07 U	17.00 U	0.07 U
014010	INEL	Solidified Inorganics	211	7	17.00 U	0.02 U	6.00	0.02 U	0.07 J	0.06 J	0.02 U	17.00 U	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
014127	RFETS	Solidified Inorganics	211	7	5.00 U	0.02 U	0.83 J	0.02 U	0.09 J	0.05	0.02 U	5.00 U	0.03 J
014170	INEL	Solidified Inorganics	211	7	5.00 U	0.02 J	0.24	0.02 U	0.14 J	0.14 J	0.02 U	5.00 U	0.02 U
014330	INEL	Graphite	215	303	17.00 U	0.35 J	11.00	0.04 U	0.06 J	0.08 J	0.16 J	17.00 U	0.04 U
014334	INEL	Filter	219	335	1.30 U	0.06 U	0.34 J	0.09 J	0.13 J	0.05 U	0.06 U	1.30 U	0.06 U
014339	INEL	Solidified Organics	226	432	17.00 U	0.06 U	0.15 JD	0.31 JD	0.13 JD	0.65 JD	0.05 U	17.00 U	0.05 U
014342	INEL	Graphite	215	303	17.00 U	0.05 U	16.00	0.07 U	0.06 U	0.04 U	0.06 U	17.00 U	0.07 U
014345	INEL	Solidified Organics	226	432	17.00 U	0.05 U	0.23 JB	0.12 J	0.07 J	0.97 J	0.04 U	17.00 U	0.04 U
014346	INEL	Combustible	223	339	17.00 U	5.50	0.55 J	0.02 U	20.00 E	0.54 J	0.20 J	17.00 U	0.03 J
014348	INEL	Graphite	215	300	17.00 U	0.02 U	0.07 J	0.02 U	0.04 J	0.02 U	0.02 U	17.00 U	0.02 U
014354	RFETS	Uncategorized Metal	217	481	5.00 U	0.02 J	0.87 J	0.02 U	0.02 JB	0.01	0.01 U	5.00 U	0.04 J
014357	INEL	Combustible	223	339	2.10 J	48.00	820.00	85.00	3400.0 E	13.00 U	14.00 U	1.30 U	15.00 U
014387	INEL	Solidified Inorganics	211	7	17.00 U	0.02 U	4.30	0.02 U	0.07 J	0.22 J	0.02 U	17.00 U	0.38 J
014466	INEL	Heterogeneous	221	302	17.00 U	0.31 U	50.00	0.44 U	0.30 U	0.35 U	0.28 U	17.00 U	67.00
014484	INEL	Graphite	215	300	17.00 U	0.02 U	0.07 J	0.02 U	0.10 J	0.05 J	0.02 U	17.00 U	0.02 U
014502	RFETS	Solidified Inorganics	211	1	5.00 U	0.02 J	0.29 J	0.01 U	0.10	0.10	0.01 U	5.00 U	0.04 J
014504	RFETS	Solidified Inorganics	211	1	5.00 U	0.03 U	0.30 J	0.04 J	0.16 J	0.46	0.03 U	5.00 U	0.04 J
014773	INEL	Solidified Inorganics	214	292	5.00 U	0.05 U	0.18 J	0.16 J	0.26 J	0.06 U	0.05 U	5.00 U	0.08 J
015228	RFETS	Solidified Organics	226	432	17.00 U	0.17 U	30.00	0.24 U	0.25 J	1.30	0.15 U	17.00 U	1.50
015231	INEL	Inorganic Non-metal	218	440	17.00 U	0.45 J	1.30	0.04 U	0.25 J	0.08 J	0.07 J	17.00 U	0.03
015241	INEL	Inorganic Non-metal	218	442	17.00 U	0.05 U	13.00 E	0.07 U	0.32 J	0.06 U	0.04 U	17.00 U	0.14 J
015249	INEL	Graphite	215	300	17.00 U	0.06 J	2.10	0.02 U	0.07 J	0.01 U	0.02 U	17.00 U	0.02 U
015262	RFETS	Solidified Organics	226	432	17.00 U	1.60 U	230.00 U	2.30 U	1.60 U	3.60	1.40 U	17.00 U	1.40 U
015267	INEL	Uncategorized Metal	217	480	17.00 U	1.40 U	180.00	2.00 U	1.40 U	1.60 U	1.30 U	17.00 U	1.30 U
015338	INEL	olidified Inorganics	211	7	17.00 U	0.01 U	.20	0.02 U	0.02 U	0.07 J	0.02 U	17.00	0.02 U
015434	RFETS	Solidified Organics	226	432	17.00 U	0.04 U	5.40 J	0.06 U	0.14 J	0.89	0.04 U	17.00 U	0.09 J

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
015440	RFETS	Solidified Organics	226	432	17.00 U	0.36 U	53.00 J	0.52 U	0.35 U	5.40	0.33 U	17.00 U	0.78 J
015515	RFETS	Solidified Organics	212	3	5.00 U	26.00 U	210.00 U	38.00 U	4400.0	30.00	24.00 U	5.00 U	24.00 U
015532	RFETS	Solidified Organics	212	3	5.00 U	81.00 U	6600.0 U	120.00 U	15000	93.00	73.00 U	5.00 U	74.00 U
015543	INEL	Solidified Organics	212	3	17.00 U	35.00 U	620.00	49.00 U	6000.0	40.00 U	32.00 U	17.00 U	32.00 U
015627	INEL	Graphite	215	300	17.00 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	17.00 U	0.10 J
015655	INEL	Solidified Inorganics	211	7	17.00 U	0.02 U	0.87 J	0.02 U	0.03 J	0.02 U	0.02 U	17.00 U	0.04 J
015674	INEL	Graphite	215	300	17.00 U	0.07 J	3.20	0.02 U	0.19 J	0.02 U	0.02 U	17.00 U	0.02 U
015675	INEL	Uncategorized Metal	217	480	17.00 U	0.07 U	15.00	0.10 U	0.07	0.15 J	0.07 J	17.00 U	0.25 J
015777	RFETS	Solidified Organics	226	432	17.00 U	0.07 U	12.00 J	0.10 U	0.18 J	4.50	0.06 U	17.00 U	0.08 J
015785	RFETS	Solidified Inorganics	211	1	15.00 U	0.32 U	50.00 J	0.46 U	2.10 JB	0.37	0.29 U	15.00 U	0.37 J
015786	INEL	Solidified Inorganics	211	1	17.00 U	0.03 U	6.40	0.03 U	0.07 J	0.30 J	0.03 U	17.00 U	0.09 J
016242	INEL	Graphite	215	300	17.00 U	0.02 U	0.09 J	0.02 U	0.10 J	0.02 U	0.02 U	17.00 U	0.02 U
016612	INEL	Inorganic Non-metal	218	442	17.00 U	0.10 J	3.60	0.04 U	0.22 J	0.03 U	0.03 U	17.00 U	0.03 J
016613	INEL	Solidified Organics	226	432	17.00 U	0.20 U	7.40	0.28 U	2.00 J	0.22 U	0.18 U	17.00 U	0.18 U
016707	INEL	Graphite	215	300	17.00 U	0.02 U	0.04 J	0.02 U	0.02 U	0.02 U	0.02 U	17.00 U	0.02 U
016738	RFETS	Solidified Inorganics	211	7	5.00 U	1.20 U	250.00 JB	1.80 U	1.20 U	1.40	1.10 U	5.00 U	8.00 JB
016790	INEL	Graphite	215	300	17.00 U	0.02 U	12.00 E	0.12 J	0.03 J	0.05 J	0.02 J	17.00 U	1.50
016807	INEL	Solidified Inorganics	211	1	17.00 U	0.17 U	38.00	0.16 U	0.36 J	0.17 U	0.16 U	17.00 U	3.20
016842	INEL	Graphite	215	300	17.00 U	0.02 U	0.35 J	0.02 U	0.04 J	0.02 U	0.02 U	17.00 U	0.02 U
016855	RFETS	Solidified Organics	212	3	5.00 U	130.00 U	2200.0 U	180.00 U	16000 D	140.00	110.00 U	5.00 U	110.00 U
016869	INEL	Solidified Inorganics	211	7	17.00 U	0.19 U	40.00	0.17 U	0.19 U	0.19 U	0.18 U	17.00 U	0.45 J
016964	RFETS	Solidified Inorganics	211	7	5.00 U	1.10 U	170.00 J	1.60 U	1.10 U	1.30	0.99 U	5.00 U	5.90 J
016986	INEL	Inorganic Non-metal	218	442	17.00 U	0.17 U	26.00	0.24 U	0.28 J	0.19 U	0.15 U	17.00 U	2.90
017148	INEL	Solidified Organics	226	432	17.00 U	0.60 U	120.00	0.85 U	0.58 U	0.68 U	0.54 U	17.00 U	0.54 U
017190	INEL	Solidified Inorganics	211	7	17.00 U	3.70 U	680.00	3.50 U	3.80 U	3.90 U	3.50 U	17.00 U	3.50 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
017444	INEL	Graphite	215	300	17.00 U	0.03 U	3.60	0.04 U	0.09 J	0.03 U	0.03 U	17.00 U	0.09 J
017453	INEL	Solidified Organics	212	3	5.00 U	36.00 U	690.00 J	51.00 U	6300.0 J	41.00 U	33.00 U	5.00 U	33.00 U
017486	INEL	Solidified Inorganics	211	1	17.00 U	0.17 U	13.00	0.16 U	1.40	0.43 J	0.16 U	17.00 U	0.75 J
017491	INEL	Graphite	215	300	17.00 U	0.19 U	43.00	0.17 U	0.19 U	0.19 U	0.18 U	17.00 U	0.74 J
017495	INEL	Inorganic Non-metal	218	442	17.00 U	0.07 J	2.60	0.04 U	0.35 J	0.03 U	0.03 U	17.00 U	0.04 J
017496	INEL	Inorganic Non-metal	218	442	17.00 U	0.03 U	1.00	0.04 U	0.23 J	0.03 U	0.03 U	17.00 U	0.03
017698	RFETS	Solidified Inorganics	211	292	5.00 U	2.30 U	510.00 J	3.30 U	3.50 J	2.60	2.10 U	5.00 U	2.50 J
017709	INEL	Solidified Inorganics	211	1	17.00 U	0.02 U	4.70	0.02 U	0.25 J	0.04 J	0.02 U	17.00 U	0.14 J
017728	RFETS	Solidified Inorganics	211	1	5.00 U	0.66 U	61.00 U	0.93 U	3.00 JB	0.75	0.59 U	5.00 U	0.60 U
017742	INEL	Inorganic Non-metal	218	440	17.00 U	0.56 U	33.00	110.00	0.54 U	0.64 U	0.60 J	17.00 U	2.00
017756	RFETS	Solidified Organics	226	432	17.00 U	1.60 U	230.00 U	2.30 U	1.60 U	1.80	1.40 U	17.00 U	2.20 U
017759	INEL	Solidified Organics	226	432	17.00 U	1.10 U	240.00	1.60 U	1.10 U	1.30 U	1.00 U	17.00 U	1.00 U
017788	INEL	Solidified Inorganics	211	7	17.00 U	1.20 U	210.00	1.20 U	1.30 U	1.30 U	1.20 U	17.00 U	1.20 U
017863	INEL	Filter	119	376	17.00 U	0.09 U	0.35 J	0.23 J	0.16 J	0.11 U	0.13 J	17.00 U	0.08 U
018111	RFETS	Solidified Inorganics	211	1	5.00 U	0.01 U	2.20 J	0.02 U	0.47	0.02	0.01 U	5.00 U	0.02 J
018219	RFETS	Solidified Inorganics	211	7	5.00 U	1.10 U	160.00 J	1.60 U	1.10 U	1.20	0.99 U	5.00 U	4.10 J
018299	INEL	Filter	119	376	17.00 U	0.24 J	0.29 J	0.27 J	0.14 U	0.26 J	0.13 U	17.00 U	0.13 U
018413	INEL	Graphite	115	300	5.00 U	0.01 U	0.12	0.01 U	0.09 J	0.01 U	0.01 U	5.00 U	0.01 U
018441	INEL	Graphite	115	300	17.00 U	0.03 U	0.07 J	0.0411	0.06 J	1.10	0.03 U	17.00 U	0.03 U
018464	INEL	Graphite	115	300	5.00 U	0.02 J	0.49	0.02 U	0.41	0.01 U	0.01 U	5.00 U	0.01 U
018476	INEL	Solidified Inorganics	111	292	5.00 U	0.09 U	0.23 J	0.22 J	0.12 J	0.10 U	0.08 U	5.00 U	0.08 U
018491	INEL	Graphite	115	300	17.00 U	0.03 U	0.07 J	0.04 U	0.09 J	0.03 U	0.03 U	17.00 U	0.03 U
019410	INEL	Lead/Cadmium Metal	123	339	5.00 U	0.61 U	0.95 U	0.86 U	83.00 D	0.70 U	0.55 U	5.00 U	0.55 U
019413	INEL	Lead/Cadmium Metal	123	339	5.00 U	5.50 J	7.70 J	3.80 U	430.00	3.10 U	2.40 U	5.00 U	2.40 U
019572	INEL	Lead/Cadmium Metal	123	339	17.00 U	3.70	0.34 J	0.30 J	7.90	0.52 J	0.81	17.00 U	0.05 U

Table -4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
021031	RFETS	Solidified Inorganics	214	292	5.00 U	0.04 U	0.18 J	0.06 U	0.24 J	0.08	0.04 U	5.00 U	0.05 J
021172	RFETS	Inorganic Non-metal	218	442	5.00 U	0.01 J	0.84 J	0.02 U	0.14 B	0.01	0.01 U	5.00 U	0.02 J
021306	INEL	Solidified Inorganics	213	4	17.00 U	0.03 U	1.80	0.04 U	0.14 J	0.03 U	0.03 U	17.00 U	0.03 J
021392	RFETS	Solidified Inorganics	214	292	5.00 U	0.15 U	32.00 U	0.22 U	19.00	0.18	0.14 U	5.00 U	0.14 U
021442	INEL	Solidified Inorganics	211	1	17.00 U	0.52 U	98.00	0.49 U	0.54 U	0.54 U	0.50 U	17.00 U	7.20
021488	RFETS	Inorganic Non-metal	218	442	5.00 U	0.21 J	3.20 J	0.05 U	7.50 E	0.04	0.03 U	5.00 U	0.33 J
021503	RFETS	Inorganic Non-metal	218	440	5.00 U	0.16 U	18.00 U	0.22 U	0.29 J	0.18	0.14 U	5.00 U	0.14 U
021511	RFETS	Solidified Inorganics	213	4	5.00 U	0.04 U	6.80 U	0.06 U	0.16 J	0.05	0.04 U	5.00 U	0.04 U
021512	INEL	Solidified Inorganics	211	7	17.00 U	0.89 U	110.00	1.30 U	0.87 U	1.00 U	0.81 U	17.00 U	5.00 J
021523	INEL	Solidified Organics	226	432	17.00 U	0.57 U	66.00	0.80 U	0.55 U	2.30	0.51 U	17.00 U	0.52 U
021565	INEL	Solidified Inorganics	211	7	17.00 U	0.93 U	190.00	0.87 U	0.97 J	0.97 U	0.89 U	17.00 U	1.00
021572	INEL	Solidified Inorganics	211	7	17.00 U	0.48 U	92.00	0.45 U	0.50 U	0.50 U	0.46 U	17.00 U	0.78 J
021600	RFETS	Solidified Inorganics	211	1	5.00 U	0.26 U	55.00	0.37 U	0.40 J	0.30	0.24 U	5.00 U	3.40
021631	INEL	Inorganic Non-metal	218	442	17.00 U	0.03 U	8.60 E	0.04 U	0.32 J	0.04 J	0.09 J	17.00 U	2.20
021698	INEL	Inorganic Non-metal	218	440	17.00 U	1.00 U	37.00	86.00	2.30	1.20 U	0.95 U	17.00 U	16.00
021699	INEL	Solidified Inorganics	213	4	68.00 U	0.31 U	47.00	0.44 U	0.68 J	0.35 U	0.28 U	68.00 U	26.00
021700	RFETS	Solidified Inorganics	213	4	5.00 U	0.04 J	0.26	0.01 U	0.48	0.01	0.01 U	5.00 U	0.13
021806	INEL	Inorganic Non-metal	218	440	17.00 U	0.22 U	16.00	84.00	0.44 J	0.22 U	0.33 J	17.00 U	6.60
021816	INEL	Solidified Inorganics	211	1	17.00 U	0.11 U	29.00	0.10 U	0.31 J	0.31 J	0.11 U	17.00 U	0.11 U
021865	INEL	Solidified Inorganics	211	1	17.00 U	0.89 U	120.00	1.30 U	0.87 U	1.00 U	0.81 U	17.00 U	0.81 U
021993	INEL	Solidified Inorganics	211	2	17.00 U	0.42 U	51.00	0.59 U	0.41 U	0.48 U	0.38 U	17.00 U	3.00 J
022000	INEL	Inorganic Non-metal	218	440	17.00 U	1.10	18.00	0.13 U	0.32 J	0.21 J	0.08 U	17.00 U	6.20
022036	INEL	Uncategorized Metal	217	480	17.00 U	0.32 J	19.00	0.07 U	0.10 J	0.33 J	0.07 J	17.00 U	3.00
022038	RFETS	Uncategorized Metal	217	481	18.00 J	0.38 J	29.00	0.24 U	1.50 JB	0.51	0.16 U	5.00 U	7.50
022052	INEL	Uncategorized Metal	217	481	17.00 U	0.02 J	0.84 J	0.02 U	0.02 U	0.01 U	0.02 U	17.00 U	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
022102	INEL	Solidified Organics	226	432	17.00 U	0.09 U	17.00	0.13 U	0.20 J	2.00	0.08 U	17.00 U	0.68 J
022105	INEL	Solidified Inorganics	211	1	17.00 U	0.39 U	50.00	0.55 U	0.50 J	0.45 U	0.35 U	17.00 U	20.00
022119	INEL	Inorganic Non-metal	222	371	17.00 U	0.50 U	66.00	0.71 U	0.49 U	0.58 U	0.46 U	17.00 U	0.46 U
022121	INEL	Solidified Inorganics	211	7	17.00 U	0.17 U	38.00	0.16 U	0.23 J	0.17 U	0.16 U	17.00 U	0.16 U
022135	INEL	Solidified Inorganics	211	7	17.00 U	0.64 U	92.00	0.91 U	0.62 U	0.74 U	0.58 U	17.00 U	0.58 U
022136	RFETS	Solidified Inorganics	211	7	5.00 U	0.82 U	160.00 U	1.20 U	0.80 U	0.94	0.74 U	11.00 J	0.75 U
022149	RFETS	Solidified Inorganics	211	7	5.00 U	0.20 U	38.00 U	0.29 U	0.20 U	0.24	0.19 U	5.00 U	0.19 U
022224	INEL	Solidified Inorganics	211	1	17.00 U	0.39 U	39.00	0.55 U	0.38 U	0.45 U	0.35 U	17.00 U	60.00
022226	RFETS	Inorganic Non-metal	222	371	5.00 U	1.10 U	200.00 U	1.60 U	1.00 U	1.20	0.99 U	5.00 U	0.99 U
022228	INEL	Inorganic Non-metal	222	371	17.00 U	0.14 U	24.00	0.20 U	0.21 J	0.16 U	0.13 U	17.00 U	0.13 U
022230	INEL	Inorganic Non-metal	222	371	17.00 U	0.11 U	29.00 E	0.16 U	0.19 J	0.13 U	0.10 U	17.00 U	0.10 U
022249	INEL	Uncategorized Metal	217	480	17.00 U	1.90 U	480.00	1.80 U	1.90 U	1.90 U	1.80 U	17.00 U	1.80 U
022275	INEL	Uncategorized Metal	217	480	17.00 U	0.42 U	94.00	0.39 U	0.43 U	0.72 J	0.40 U	17.00 U	0.40 U
022286	RFETS	Uncategorized Metal	217	480	6.10 J	0.47 U	96.00 J	0.67 U	0.46 U	0.54	0.42 U	5.00 U	0.59 J
022296	INEL	Solidified Inorganics	211	1	17.00 U	0.93 U	150.00	0.87 U	0.96 U	0.96 U	0.88 U	17.00 U	7.00
022306	INEL	Inorganic Non-metal	218	440	17.00 U	0.84 U	75.00	34.00	0.81 U	0.96 U	0.76 U	17.00 U	1.10
022338	INEL	Solidified Organics	212	3	17.00 U	820.00 J	18000	160.00 U	10000	130.00 U	100.00 U	17.00 U	100.00 U
022347	INEL	Inorganic Non-metal	218	440	17.00 U	2.10	58.00	0.27 U	0.30 U	0.43 J	0.28 U	17.00 U	0.28 U
022358	INEL	Uncategorized Metal	217	480	17.00 U	0.02 U	8.10 E	0.02 U	0.16 J	1.50	0.02 U	17.00 U	0.04 J
022416	RFETS	Uncategorized Metal	217	320	5.00 U	1.10	7.60 J	0.07 U	0.12 J	0.06	0.16 J	5.00 U	0.40 J
022434	INEL	Solidified Organics	226	432	17.00 U	0.36 U	55.00	0.52 U	0.35 U	7.50	0.33 U	17.00 U	3.00
022442	INEL	Solidified Organics	226	432	17.00 U	1.07 U	138.50	1.50 U	1.05 U	2.05 J	0.98 U	17.00 U	0.98 U
022450	RFETS	Uncategorized Metal	217	320	5.00 U	0.12 J	11.00 U	0.12 U	0.13 JB	0.09	0.07 U	5.00 U	0.07 U
022453	RFETS	idified Inorganics	211	2	5.00 U	0.07 U	30	0.10 U	0.45 J	0.13	0.07 U	5.00	5.10
022486	RFETS	Inorganic Non-metal	218	440	5.00 U	1.70 U	120.00	110.00	1.80 JB	1.90	1.50 U	5.00 U	42.00

Table ..-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
22511	INEL	Uncategorized Metal	217	480	17.00 U	0.86 U	130.00	1.20 U	0.84 U	0.99 U	0.78 U	17.00 U	0.79 U
22513	INEL	Solidified Organics	212	1	17.00 U	0.25 U	30.00	0.36 U	0.24 U	0.29 U	0.23 U	17.00 U	1.50 J
22517	INEL	Solidified Organics	226	432	17.00 U	0.11 U	23.00 B	0.15 U	0.27 J	2.50 J	0.10 U	17.00 U	0.94 J
22539	INEL	Solidified Organics	226	432	17.00 U	0.11 U	7.20	0.15 U	0.26 J	3.20	0.10 U	17.00 U	0.31 J
22549	INEL	Uncategorized Metal	217	480	17.00 U	1.40 U	230.00	2.00 U	1.40 U	1.60 U	1.30 U	17.00 U	1.30 U
22552	INEL	Inorganic Non-metal	218	442	17.00 U	0.32 U	44.00	0.46 U	0.31 U	0.37 U	0.29 U	17.00 U	0.54 J
22557	INEL	Uncategorized Metal	217	480	17.00 U	0.66 U	130.00	0.62 U	0.79 J	0.68 U	0.62 U	17.00 U	0.63 U
22595	INEL	Solidified Inorganics	211	1	17.00 U	0.32 U	63.00	0.30 U	0.33 U	0.33 U	0.30 U	17.00 U	0.30 U
22600	RFETS	Solidified Inorganics	213	4	130.00 U	0.26 U	46.00	0.36 U	0.25 U	0.34	0.23 U	130.00 U	9.00
22780	INEL	Solidified Inorganics	211	7	17.00 U	0.47 U	130.00	0.44 U	0.78 J	0.48 U	0.44 U	17.00 U	0.44 U
22789	INEL	Solidified Inorganics	211	7	17.00 U	0.62 U	82.00	0.88 U	0.60 U	0.71 U	0.56 U	17.00 U	0.56 U
22790	INEL	Solidified Inorganics	214	292	17.00 U	1.50	51.00	0.21 U	1.40	0.23 U	0.21 U	17.00 U	0.21 U
22803	INEL	Inorganic Non-metal	222	371	17.00 U	0.59 U	80.00	0.83 U	0.57 U	0.67 U	0.53 U	17.00 U	0.53 U
22807	INEL	Salt Waste	224	414	17.00 U	0.12 U	15.00	0.16 U	0.25 J	0.13 U	0.10 U	17.00 U	0.11 U
22811	INEL	Solidified Inorganics	211	7	17.00 U	0.39 U	75.00	0.37 U	0.54 J	0.40 U	0.37 U	17.00 U	0.37 U
22833	INEL	Solidified Inorganics	211	7	17.00 U	2.80 U	490.00	2.60 U	2.90 U	2.90 U	2.60 U	17.00 U	2.60 U
22841	INEL	Solidified Inorganics	211	7	17.00 U	1.50 U	290.00	1.40 U	1.50 U	1.50 U	1.40 U	17.00 U	1.40 U
22850	INEL	Solidified Inorganics	211	7	17.00 U	0.93 U	170.00	0.87 U	0.96 U	0.97 U	0.88 U	17.00 U	0.88 U
22874	INEL	Inorganic Non-metal	222	371	17.00 U	0.20 U	34.00	0.28 U	0.36 J	0.22 U	0.18 U	17.00 U	0.18 U
22894	INEL	Solidified Inorganics	211	1	17.00 U	0.13 U	38.00	0.12 U	0.93 J	0.14 U	0.13 U	17.00 U	0.13 U
22923	INEL	Inorganic Non-metal	218	440	17.00 U	0.36 U	50.00	0.52 U	0.35 U	0.42 U	0.33 U	17.00 U	0.33 U
23005	INEL	Solidified Inorganics	211	7	17.00 U	0.17 U	14.00	0.24 U	0.30 J	0.19 U	0.15 U	17.00 U	0.15 U
23027	RFETS	Uncategorized Metal	217	480	5.00 U	0.16 U	34.00 B	0.23 U	0.70 JB	0.19	0.15 U	5.00 U	4.50 B
23041	RFETS	Inorganic Non-metal	222	371	5.00 U	0.29 J	39.00 J	0.38 U	1.70 JB	0.31	0.24 U	5.00 U	0.28 J
23046	RFETS	Solidified Inorganics	211	7	5.00 U	0.47 U	97.00 U	0.67 U	0.70 J	0.54	0.42 U	5.00 U	0.43 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
023048	RFETS	Solidified Organics	226	432	17.00 U	0.39 U	60.00 U	0.55 U	0.38 U	0.86	0.35 U	17.00 U	0.36 U
023062	INEL	Solidified Inorganics	211	7	17.00 U	0.17 U	18.00	0.24 U	0.18 J	0.19 U	0.15 U	17.00 U	0.15 U
023211	INEL	Filter	119	376	17.00 U	0.06 U	0.10 J	0.08 U	0.47 J	0.41 J	0.05 U	17.00 U	0.05 U
023212	RFETS	Uncategorized Metal	217	480	5.80 J	0.63 J	94.00 U	0.78 U	1.10 J	0.63	0.50 U	7.50 J	0.50 U
023227	INEL	Uncategorized Metal	217	480	17.00 U	0.09 U	12.00	0.13 U	0.12 J	0.11 U	0.08 U	17.00 U	0.08 U
023229	INEL	Combustible	216	337	17.00 U	0.56 U	74.00	0.79 U	0.55 J	0.64 U	0.50 U	17.00 U	0.51 U
023235	RFETS	Heterogeneous	216	336	7.10 J	0.15 U	29.00 U	0.21 U	5.70	1.00	0.13 U	5.00 U	0.13 U
023238	INEL	Solidified Inorganics	211	1	17.00 U	0.20 U	43.00	0.19 U	1.80	0.21 U	0.20 U	17.00 U	0.20 U
023277	INEL	Inorganic Non-metal	222	371	17.00 U	0.98 U	130.00	1.40 U	0.95 U	1.10 U	0.88 U	17.00 U	0.89 U
023285	INEL	Solidified Inorganics	211	7	17.00 U	1.90 U	260.00	2.60 U	1.80 U	2.10 U	1.70 U	17.00 U	1.70 U
023312	INEL	Uncategorized Metal	217	480	17.00 U	0.93 U	180.00	0.87 U	0.96 U	0.97 U	0.89 U	17.00 U	0.89 U
023341	RFETS	Solidified Inorganics	211	7	5.00 U	0.01 U	4.60 J	0.01 U	0.18	0.05	0.04 J	5.00 U	0.06 J
023357	INEL	Solidified Inorganics	211	1	17.00 U	0.14 U	19.00	0.20 U	0.26 J	0.16 J	0.13 U	17.00 U	0.16 J
023383	RFETS	Uncategorized Metal	217	481	5.00 U	0.02 J	0.88 U	0.01 U	0.03 JB	0.03	0.01 U	5.00 U	0.01 U
023384	INEL	Combustible	223	339	15.00 U	0.44 J	32.00	0.10 U	0.10 U	0.11 J	0.21 J	15.00 U	0.11 U
023388	INEL	Heterogeneous	216	330	18.00 U	0.06 U	23.00	0.09 U	0.09 U	0.06 U	0.08 U	18.00 U	0.09 U
023392	INEL	Solidified Inorganics	213	4	43.00 U	0.63 U	80.00	0.89 U	0.61 U	0.72 U	0.57 U	43.00 U	0.57 U
023407	INEL	Solidified Organics	212	3	17.00 U	22.00 U	360.00	31.00 U	3200.0	25.00 U	20.00 U	17.00 U	20.00 U
023460	INEL	Inorganic Non-metal	218	442	17.00 U	0.31 J	5.40	0.04 U	0.19 J	0.12 J	0.24 J	17.00 U	0.45 J
023469	INEL	Solidified Organics	212	3	17.00 U	86.00 E	280.00 E	0.48 U	300.00 E	0.38 U	0.30 U	17.00 U	3.10 J
023492	INEL	Solidified Inorganics	211	7	17.00 U	0.70 U	78.00	0.99 U	0.68 U	0.80 U	0.63 U	17.00 U	0.63 U
023519	INEL	Solidified Organics	212	3	17.00 U	8.80	140.00	3.30 U	640.00	3.70 U	3.40 U	17.00 U	3.40 U
023535	INEL	Solidified Inorganics	211	7	17.00 U	0.93 U	180.00	0.87 U	0.96 U	0.96 U	0.88 U	17.00 U	0.88 U
023552	INEL	[illegible]lidified Inorganics	211	1	17.00 U	0.78 U	[illegible]00	1.10 U	0.76 U	0.90 U	0.71 U	17.00 [illegible]	0.71 U
023662	INEL	Inorganic Non-metal	218	442	17.00 U	0.73 J	16.00	0.13 U	0.38 J	0.11 J	0.15 J	17.00 U	1.80

Table ..2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Trl chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Dl-chloro-ethane	1-Butanol	Trichloro-ethene
023681	INEL	Solidified Inorganics	211	1	17.00 U	0.34 U	69.00	0.48 U	0.40 J	0.38 U	0.30 U	17.00 U	33.00
023695	RFETS	Solidified Inorganics	211	2	5.00 U	0.17 U	33.00 J	0.24 U	0.19 J	0.20	0.16 U	5.00 U	1.60 J
023771	RFETS	Heterogeneous	216	330	12.00 J	0.18 U	7.70 J	0.72 J	1.10 JB	4.90	0.16 U	5.00 U	0.23 J
023776	INEL	Heterogeneous	216	330	15.00 U	0.37 U	56.00	0.52 U	0.36 U	0.42 U	0.33 U	15.00 U	10.00
023805	INEL	Uncategorized Metal	217	480	17.00 U	0.23 J	1.20	0.02 U	0.10 J	0.12 J	0.11 J	17.00 U	0.23 J
023827	RFETS	Uncategorized Metal	217	320	5.00 U	0.11	1.40 J	0.01 U	0.10 B	0.03	0.05 J	5.00 U	0.01 J
023840	INEL	Combustible	216	337	18.00 U	58.00	76.00	0.33 U	0.32 U	0.21 U	0.29 U	18.00 U	0.34 U
023901	INEL	Heterogeneous	216	330	18.00 U	0.22 U	91.00	0.31 U	0.36 J	0.20 U	0.28 U	18.00 U	19.00
023929	RFETS	Inorganic Non-metal	218	440	0.60 U	0.56 U	42.00 U	32.00	1.80 JB	0.64	0.50 U	5.00 U	0.50 U
023959	INEL	Uncategorized Metal	217	480	17.00 U	1.20 U	170.00	1.80 U	1.20 U	1.40 U	1.10 U	17.00 U	1.10 U
024028	RFETS	Inorganic Non-metal	218	440	5.00 U	0.19 J	21.00 U	0.16 U	1.00 J	0.13	0.10 U	5.00 U	0.11 U
024029	INEL	Uncategorized Metal	217	480	17.00 U	0.01 U	1.20	0.02 U	0.02 U	0.08 J	0.02 U	17.00 U	0.02 U
024058	INEL	Solidified Inorganics	211	1	17.00 U	0.42 U	51.00	0.59 U	0.41 U	0.48 U	0.38 U	17.00 U	22.00
024059	INEL	Solidified Inorganics	214	292	17.00 U	0.17 U	30.00	0.24 U	0.26 J	0.19 U	0.15 U	17.00 U	1.40 J
024088	INEL	Combustible	216	337	15.00 U	0.32 U	48.00 B	0.45 U	0.31 U	0.37 U	0.29 U	15.00 U	2.10 B
024090	INEL	Combustible	216	337	18.00 U	26.00	48.00	30.00	0.47 U	0.31 U	0.44 U	18.00 U	0.61 J
024092	INEL	Combustible	216	337	17.00 U	11.00	180.00	2.00 U	140.00	1.60 U	1.30 U	17.00 U	2.40
024095	INEL	Combustible	216	337	18.00 U	53.00	12.00	0.20 U	0.20 U	0.13 U	0.18 U	18.00 U	1.80
024102	INEL	Combustible	216	337	17.00 U	47.00	65.00	0.68 U	0.46 U	0.54 U	0.43 U	17.00 U	12.00
024106	INEL	Combustible	216	337	15.00 U	53.00	88.00	0.99 U	3.80	0.80 U	0.63 U	15.00 U	20.00
024113	INEL	Combustible	216	337	17.00 U	35.00	29.00	0.30 U	22.00	0.24 U	0.19 U	17.00 U	3.40
024147	INEL	Solidified Inorganics	211	1	17.00 U	0.64 U	86.00	0.91 U	0.62 U	0.74 U	0.58 U	17.00 U	0.58 U
024165	INEL	Combustible	216	337	15.00 U	68.00	48.00	0.70 U	0.48 U	0.56 U	0.45 U	15.00 U	1.60
024168	INEL	Heterogeneous	216	330	17.00 U	0.08 J	3.00	0.04 U	0.09 J	0.56 J	0.05 J	17.00 U	0.32 J
024185	INEL	Salt Waste	224	409	17.00 U	0.03 U	5.60	0.04 U	0.33 J	0.04 U	0.03 U	17.00 U	0.04 J

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
024254	INEL	Salt Waste	224	414	17.00 U	0.05 U	5.00	0.07 U	0.20 J	0.05 U	0.04 U	17.00 U	1.70
024271	INEL	Inorganic Non-metal	218	442	17.00 U	0.09 U	21.00 E	0.13 U	0.31 J	0.12 J	0.08 U	17.00 U	3.10
024273	INEL	Inorganic Non-metal	218	442	17.00 U	0.18 U	33.00	0.26 U	0.44 J	0.21 U	0.16 U	17.00 U	4.50
024289	RFETS	Inorganic Non-metal	218	440	5.00 U	0.33 U	61.00	76.00	0.58 J	0.38	0.41 J	5.00 U	18.00
024295	INEL	Salt Waste	224	414	17.00 U	0.09 U	7.50	0.13 U	0.28 J	0.11 U	0.08 U	17.00 U	12.00
024308	INEL	Solidified Inorganics	211	2	17.00 U	0.14 U	16.00	0.20 U	0.47 J	0.16 U	0.13 U	17.00 U	8.40
024309	INEL	Solidified Inorganics	211	2	17.00 U	0.11 U	14.00	0.16 U	0.28 J	0.13 U	0.10 U	17.00 U	6.10
024311	INEL	Solidified Inorganics	211	2	41.00 U	0.23 U	18.00	0.32 U	0.30 J	0.26 U	0.20 U	41.00 U	6.60
024318	INEL	Solidified Inorganics	211	2	17.00 U	0.23 U	27.00	0.32 U	0.48 J	0.26 U	0.20 U	17.00 U	16.00
024506	INEL	Inorganic Non-metal	122	374	17.00 U	0.06 U	0.12 J	0.08 U	0.12 J	0.06 U	0.05 U	17.00 U	0.05 U
024507	INEL	Uncategorized Metal	117	480	17.00 U	0.07 U	0.68 J	0.47 J	0.16 J	0.08 U	0.06 U	17.00 U	0.06 U
024600	INEL	Uncategorized Metal	217	480	17.00 U	0.25 U	42.00	0.36 U	0.56 J	0.29 U	0.23 U	17.00 U	14.00
024638	INEL	Heterogeneous	216	330	15.00 U	0.12 U	24.00	0.18 U	0.12 U	0.14 U	0.11 U	15.00 U	10.00
024670	INEL	Solidified Inorganics	211	1	17.00 U	0.50 U	63.00	0.71 U	0.54 J	0.58 U	0.46 U	17.00 U	0.46 U
024765	INEL	Uncategorized Metal	217	480	17.00 U	0.04 U	14.00	0.05 U	0.05 U	0.03 U	0.04 U	17.00 U	0.05 U
024786	INEL	Uncategorized Metal	217	480	17.00 U	0.34 U	56.00	0.48 U	0.32 U	0.38 U	0.30 U	17.00 U	0.30 U
024850	INEL	Solidified Organics	226	432	17.00 U	0.09 U	17.00	0.13 U	0.21 J	5.10	0.08 U	17.00 U	0.51 J
024884	INEL	Uncategorized Metal	217	480	17.00 U	0.49 J	30.00	0.32 U	29.00	0.26 U	0.20 U	17.00 U	7.40
024897	INEL	Solidified Inorganics	211	1	17.00 U	0.22 U	23.00	0.32 U	0.27 J	0.26 U	0.20 U	17.00 U	7.60
024920	INEL	Solidified Inorganics	211	1	17.00 U	0.64 U	81.00	0.91 U	0.62 U	0.74 U	0.58 U	17.00 U	36.00
024991	INEL	Solidified Inorganics	211	1	17.00 U	0.31 U	35.00	0.44 U	0.68 J	0.35 U	0.28 U	17.00 U	16.00
025001	INEL	Solidified Organics	212	3	17.00 U	1.10 U	140.00	1.60 U	1.10 U	1.30 U	1.00 U	17.00 U	47.00
032284	INEL	Combustible	223	339	17.00 U	1.10	97.00	0.33 U	0.32 U	0.33 J	0.62 J	17.00 U	0.34 U
032287	RFETS	[illegible]lidified Inorganics	211	7	5.00 U	1.10 U	[illegible].00 U	1.60 U	1.10 U	1.30	0.99 U	5.00 [illegible]	1.00 U
032467	INEL	Combustible	216	337	17.00 U	0.22 U	38.00	0.32 U	1.00	0.26 U	0.20 U	17.00 U	0.20 U

Table [illegible]-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
032469	RFETS	Combustible	216	337	5.00 U	0.36 U	51.00 U	48.00	0.35 U	0.42	0.33 U	5.00 U	0.33 U
032473	INEL	Combustible	216	337	15.00 U	26.00	200.00 B	2.10 U	1.40 U	1.70 U	1.40 U	15.00 U	1.40 U
032485	INEL	Combustible	216	337	15.00 U	19.00	53.00	68.00	0.84 U	1.00 U	0.78 U	15.00 U	0.79 U
032517	RFETS	Combustible	223	339	5.00 U	0.48 J	14.00 J	0.12 U	0.26 JB	0.18	0.29 J	5.00 U	0.10 J
032521	INEL	Combustible	223	339	17.00 U	1.10	14.00	0.07 U	0.10 J	0.31 J	0.51 J	17.00 U	0.10 J
032525	INEL	Combustible	223	339	17.00 U	0.70 J	12.00	0.04 U	0.07 J	0.27 J	0.83 J	17.00 U	0.04 U
032526	INEL	Combustible	223	339	15.00 U	24.00	70.00	0.61 U	130.00	0.38 U	0.55 U	15.00 U	0.63 U
032529	INEL	Heterogeneous	216	336	1.30 U	0.19 U	250.00 E	0.27 U	1.10	0.21 U	0.30 U	1.30 U	0.31 U
032540	INEL	Uncategorized Metal	217	480	17.00 U	0.36 U	60.00	0.52 U	0.35 U	2.70	0.33 U	17.00 U	0.33 U
032632	INEL	Uncategorized Metal	217	480	17.00 U	0.11 U	44.00	0.16 U	0.21 J	0.10 U	0.14 U	17.00 U	0.16 U
032659	RFETS	Uncategorized Metal	217	480	5.00 U	0.29 U	57.00 U	0.41 U	0.16 U	0.33	0.26 U	5.00 U	0.26 U
032669	RFETS	Uncategorized Metal	217	480	5.00 U	0.31 U	61.00 U	0.44 U	0.30 U	0.36	0.28 U	5.00 U	0.28 U
032712	INEL	Uncategorized Metal	217	480	17.00 U	0.27 U	40.00	0.38 U	0.51 J	0.30 U	0.24 U	17.00 U	0.24 U
032715	RFETS	Combustible	216	337	5.00 U	2.20	13.00 J	0.12 U	4.90	0.10	0.08 U	5.00 U	1.00 J
032748	INEL	Combustible	223	339	2.30 J	0.19 U	84.00	0.27 U	1.10	0.21 U	0.30 U	1.30 U	0.31 U
032753	INEL	Uncategorized Metal	217	481	17.00 U	0.03 U	2.80	0.04 U	0.07 J	0.03 U	0.03 U	17.00 U	0.03 U
033091	INEL	Combustible	223	339	17.00 U	0.11 J	2.60	0.02 U	0.03 J	0.60 J	0.05 J	17.00 U	0.02 U
001332	RFETS	Heterogeneous	116	832	7.06 J	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	9.11 J	0.50 U
006288	RFETS	Filter	119	338	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
006339	RFETS	Heterogeneous	0	337	12.73 J	0.28 J	0.20 U	0.20 U	0.20 U	3.45	0.44 J	4.78 J	0.20 U
011129	RFETS	Filter	119	338	0.50 U	0.18 J	0.10 U	0.10 U	0.10 U	0.10 U	0.36 J	1.13 J	0.10 U
013364	RFETS	Uncategorized Metal	117	480	10.47 J	0.78 J	0.27 J	0.18 J	2.45	0.55 J	0.33 J	0.50 U	0.10 U
015680	RFETS	Heterogeneous	116	831	333.33 U	66.67 U	4587.4	66.67 U	66.67 U	66.67 U	66.67 U	733.33 U	66.67 U
017184	RFETS	Solidified Inorganics	111	800	0.90 U	0.10 U	0.32 J	0.39 J	0.23 J	0.83 J	0.10 U	0.50 U	0.10 U
032439	RFETS	Filter	119	338	0.67 J	0.62 J	0.10 U	0.10 U	0.10 U	0.10 U	0.13 J	1.10 U	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
032978	RFETS	Solidified Inorganics	111	803	28.34 U	5.67 U	429.17	5.67 U	5.67 U	5.67 U	5.67 U	62.34 U	5.67 U
035301	RFETS	Solidified Inorganics	111	800	0.90 U	0.10 U	0.10 U	0.10 U	0.10 J	0.10 U	0.10 U	0.50 U	0.10 U
035306	RFETS	Lead/Cadmium Metal	123	339	3.12 J	3.87	0.20 U	0.20 U	0.20 U	14.44	2.43	2.20 U	0.20 U
036606	RFETS	Uncategorized Metal	117	480	2.00 U	0.40 U	1.08 J	0.40 U	0.45 J	0.40 U	0.40 U	4.80 U	0.40 U
038859	RFETS	Solidified Inorganics	111	803	0.90 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.20 J	0.10 U
038989	RFETS	Heterogeneous	0	336	5.78 J	0.10 U	0.10 U	0.10 U	0.14 J	8.13	0.10 U	1.10 U	0.10 U
041681	RFETS	Filter	119	338	3.58 J	0.47 J	0.10 U	0.10 U	0.10 U	0.52 J	0.12 J	1.10 U	0.10 U
042280	RFETS	Solidified Organics	112	801	2083.3 U	1017.9 J	24947	416.67 U	30767	416.67 U	416.67 U	4583.3 U	416.67 U
047501	RFETS	Lead/Cadmium Metal	0	341	4.50 J	0.10 U	0.10 U	0.10 U	0.10 U	0.48 J	0.10 U	1.10 U	0.10 U
048182	RFETS	Filter	119	376	3.60 U	0.40 U	0.40 U	1.83 J	0.40 U	0.40 U	0.40 U	2.00 U	0.40 U
048200	RFETS	Heterogeneous	116	831	72.00 U	8.00 U	349.15	8.00 U	8.00 U	8.00 U	8.00 U	98.30 J	8.00 U
048377	RFETS	Inorganic Non-metal	118	368	0.90 U	0.10 U	0.10 U	0.10 U	0.10 U	0.15 J	0.10 U	0.87 J	0.10 U
049662	RFETS	Solidified Inorganics	0	292	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
049880	RFETS	Heterogeneous	0	336	9.09 J	0.28 J	0.27 U	0.27 U	0.27 U	39.84	0.27 U	2.94 U	0.27 U
052318	RFETS	Lead/Cadmium Metal	117	321	0.61 J	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
052362	RFETS	Heterogeneous	116	821	1.80 U	0.20 U	2.01	1.05 J	0.31 J	0.20 U	0.20 U	1.00 U	0.20 U
052726	RFETS	Heterogeneous	116	833	4.00 U	0.80 U	62.32	2.02 J	0.80 J	0.80 U	0.80 U	8.80 U	21.12
053672	RFETS	Inorganic Non-metal	118	440	2.93 J	0.20 U	0.36 J	0.53 J	0.25 J	0.20 U	0.20 U	1.00 U	0.20 U
055656	RFETS	Heterogeneous	116	831	3.25 J	0.30 U	0.31 J	0.30 U	0.33 J	0.30 U	0.30 U	1.50 U	0.30 U
055680	RFETS	Heterogeneous	116	821	1.80 U	0.20 U	0.32 J	0.20 J	0.55 J	0.20 U	0.20 U	1.00 U	0.20 U
055938	RFETS	Heterogeneous	116	831	1.80 U	0.20 U	0.68 J	0.40 U	0.24 J	0.20 U	0.20 U	1.00 U	0.20 U
056095	RFETS	Heterogeneous	0	337	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
056595	RFETS	Heterogeneous	116	831	66.67 U	13.33 U	13.33 U	13.33 U	13.33 U	13.33 U	13.33 U	146.66 U	13.33 U
056755	RFETS	[illegible]erogeneous	116	821	0.90 U	0.10 U	[illegible]32 J	0.11 J	0.52 J	0.10 U	0.10 U	0.50 U	0.10 U
056823	RFETS	Heterogeneous	116	831	3.60 U	0.40 U	3.96 J	0.99 J	1.50 J	0.40 U	0.40 U	2.00 U	0.40 U

Table ..-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D57179	RFETS	Heterogeneous	0	330	10.00 U	2.00 U	108.25	2.00 U	2.00 U	2.00 U	2.00 U	30.93 J	2.00 U
D57522	RFETS	Heterogeneous	0	336	2.00 U	0.40 U	0.40 U	0.40 U	0.40 U	1.06 J	0.40 U	4.40 U	0.40 U
D57847	RFETS	Uncategorized Metal	117	480	2.00 U	0.40 U	0.40 U	0.86 J	0.40 U	0.74 J	0.40 U	4.80 U	0.40 U
D58143	RFETS	Solidified Inorganics	111	807	0.90 U	0.10 U	0.10 U	0.88 J	0.21 J	0.10 U	0.10 U	0.50 U	0.10 U
D58154	RFETS	Heterogeneous	116	831	5.55 J	0.73 J	0.76 J	4.52	0.61 J	3.10 J	0.40 U	4.40 U	0.40 U
D58627	RFETS	Heterogeneous	116	831	1.00 U	0.20 U	0.51 J	0.20 U	0.20 U	0.20 U	0.20 U	2.20 U	0.20 U
D58889	RFETS	Heterogeneous	116	831	1.00 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U
D58970	RFETS	Solidified Inorganics	111	807	0.90 U	0.10 U	0.43 J	0.57 J	0.69 J	0.10 U	0.10 U	0.51 J	0.10 U
D59053	RFETS	Lead/Cadmium Metal	0	341	2.26 J	1.17	0.10 U	0.10 U	0.10 U	1.59	0.92 J	1.10 U	0.10 U
D59703	RFETS	Heterogeneous	116	831	12.74 J	0.50 U	0.52 J	1.91 J	0.50 U	0.77 J	0.50 U	6.00 U	0.50 U
D59899	RFETS	Filter	0	331	6.81 Ja	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	6.00 U	0.50 U
D60056	RFETS	Lead/Cadmium Metal	0	341	2.57 J	1.94 J	0.27 U	0.27 U	0.27 U	3.53	2.10 J	2.94 U	0.27 U
D60218	RFETS	Heterogeneous	116	821	1.80 U	0.20 U	0.23 J	0.29 J	0.35 J	0.20 U	0.20 U	2.21 J	0.20 U
D60298	RFETS	Solidified Organics	112	801	5160.0 U	573.33 U	12909	573.33 U	16369	573.33 U	573.33 U	4036.8 J	573.33 U
D60320	RFETS	Heterogeneous	0	330	166.35 J	68.40 J	28.00 U	28.00 U	1265.6	28.00 U	28.00 U	475.47 J	28.00 U
D60463	RFETS	Inorganic Non-metal	118	440	0.90 U	0.14 J	0.10 U	0.26 J	0.10 J	0.12 J	0.10 U	2.21 J	0.10 U
D60511	RFETS	Filter	119	491	2.09 J	0.20 U	9.99	0.47 J	0.20 U	0.20 U	0.20 U	1.13 J	0.20 U
D60635	RFETS	Filter	119	491	0.90 U	0.10 U	1.37	0.28 J	0.10 U	0.10 U	0.10 U	0.50 U	0.10 U
D61245	RFETS	Heterogeneous	0	336	16.09 J	0.47 U	0.47 U	0.47 U	0.47 U	5.02	0.47 U	18.25 J	0.47 U
D61278	RFETS	Heterogeneous	0	336	2.96 J	4.74	0.27 U	0.27 U	0.48 J	22.81	1.12 J	2.94 U	0.27 U
D61473	RFETS	Heterogeneous	0	377	2.70 U	0.30 U	0.30 U	0.66 J	0.30 U	0.34 J	0.30 U	1.50 U	0.30 U
D61504	RFETS	Lead/Cadmium Metal	0	341	4.83 J	1.47	0.10 U	0.10 U	0.10 U	5.11	0.77 J	9.60 J	0.10 U
D61747	RFETS	Heterogeneous	0	330	7.76 J	0.27 U	0.27 U	0.27 U	0.27 U	12.64	0.40 J	7.81 J	0.27 U
D62340	RFETS	Heterogeneous	116	821	3.60 U	0.40 U	0.49 J	0.40 U	0.40 U	0.40 J	0.40 U	2.00 U	0.40 U
D62478	RFETS	Filter	119	376	3.60 U	0.40 U	0.40 U	2.69 J	0.40 U	0.40 U	0.40 U	2.00 U	0.40 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D62714	RFETS	Heterogeneous	116	831	5.00 U	1.00 U	30.09	1.00 U	15.72	1.00 U	1.00 U	12.00 U	1.00 U
D62851	RFETS	Heterogeneous	116	825	2.70 U	0.30 U	3.32	1.34 J	0.48 J	0.30 U	0.30 U	1.50 U	0.30 U
D62855	RFETS	Heterogeneous	116	821	54.00 U	6.00 U	6.00 U	6.00 U	214.07	6.00 U	6.00 U	30.00 U	6.00 U
D63098	RFETS	Filter	0	331	8.26 Ja	0.50 U	0.50 U	0.50 U	0.50 U	0.62 J	0.50 U	6.00 U	0.50 U
D63229	RFETS	Heterogeneous	116	831	1.80 U	0.20 U	0.20 J	1.43 J	0.26 J	0.20 U	0.20 U	1.00 U	0.20 U
D63281	RFETS	Solidified Inorganics	111	807	0.90 U	0.10 U	0.10 U	0.65 J	0.10 U	0.10 U	0.10 U	0.50 U	0.10 U
D63460	RFETS	Heterogeneous	116	831	0.90 U	0.10 U	2.43	1.09	1.36	0.10 J	0.10 U	0.50 U	0.10 U
D63654	RFETS	Solidified Inorganics	111	807	0.90 U	0.10 U	0.10 J	0.17 J	0.30 J	0.10 U	0.10 U	0.50 U	0.10 U
D63808	RFETS	Heterogeneous	116	831	7.20 U	0.80 U	45.12	2.42 J	1.77 J	0.80 U	0.80 U	4.00 U	0.80 U
D63817	RFETS	Heterogeneous	116	821	14.40 U	1.60 U	1.60 U	1.60 U	1.60 U	1.60 U	1.60 U	8.00 U	1.60 U
D63819	RFETS	Solidified Inorganics	111	807	1.80 U	0.20 U	1.40 J	0.44 J	2.30	0.20 U	0.20 U	1.00 U	0.20 U
D63999	RFETS	Filter	119	491	2.70 U	0.30 U	0.31 J	0.31 J	0.56 J	0.30 U	0.30 U	1.50 U	0.30 U
D64004	RFETS	Filter	0	331	5.58 Ja	0.40 U	0.40 U	0.40 U	0.40 U	0.86 Ja	0.40 U	4.80 U	0.40 U
D64137	RFETS	Filter	119	335	0.90 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.50 U	0.10 U
D64448	RFETS	Heterogeneous	116	821	990.00 U	110.00 U	110.00 U	110.00 U	110.00 U	110.00 U	110.00 U	2110.9 J	110.00 U
D64555	RFETS	Solidified Organics	112	801	5160.0 U	573.33 U	904.15 J	573.33 U	18198	573.33 U	573.33 U	2866.6 U	573.33 U
D64632	RFETS	Solidified Inorganics	111	800	0.90 U	0.10 U	0.90 J	0.76 J	1.09	0.70 J	0.10 U	0.54 J	0.10 U
D64752	RFETS	Uncategorized Metal	117	480	10.00 U	2.00 U	175.17	2.00 U	2.00 U	2.00 U	2.00 U	24.00 U	2.00 U
D64758	RFETS	Heterogeneous	116	831	2.50 U	0.59 J	1.52 J	3.67 J	0.78 J	0.86 J	0.50 U	5.50 U	0.50 U
D64860	RFETS	Heterogeneous	116	831	60.00 U	12.00 U	681.08	12.00 U	12.00 U	12.00 U	12.00 U	144.00 U	12.00 U
D65212	RFETS	Heterogeneous	116	831	45.00 U	9.00 U	664.72	9.00 U	9.00 U	9.00 U	9.00 U	108.00 U	9.00 U
D65213	RFETS	Heterogeneous	116	831	40.00 U	8.00 U	394.11	8.00 U	8.00 U	8.00 U	8.00 U	96.00 U	8.00 U
D65214	RFETS	Heterogeneous	116	831	663.00 U	73.67 U	4170.2	73.67 U	73.67 U	73.67 U	73.67 U	823.82 J	73.67 U
D65530	RFETS	lidified Inorganics	111	807	0.90 U	0.10 U	12 J	0.33 J	0.10 U	0.14 J	0.10 U	0.50	0.10 U
D65535	RFETS	Solidified Inorganics	111	807	0.90 U	0.10 U	0.30 J	0.22 J	0.65 J	0.10 U	0.10 U	0.50 U	0.10 U

Table . .-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D65546	RFETS	Solidified Inorganics	111	807	0.90 U	0.10 U	0.98 J	0.42 J	0.22 J	0.10 J	0.10 U	0.50 U	0.10 U
D65600	RFETS	Solidified Inorganics	111	807	0.90 U	0.10 U	0.14 J	0.76 J	0.10 U	0.10 U	0.10 U	0.50 U	0.10 U
D65731	RFETS	Inorganic Non-metal	122	375	3.60 U	4.11	0.40 U	0.40 J	20.60	0.40 U	0.40 U	6.13 J	0.40 U
D65734	RFETS	Uncategorized Metal	117	480	6.30 U	0.70 U	2.27 J	0.70 U	0.70 U	0.95 J	0.70 U	3.50 U	0.70 U
D65754	RFETS	Heterogeneous	116	831	3.34 U	0.67 U	0.67 U	0.67 U	0.67 U	0.67 U	0.67 U	7.34 U	0.67 U
D65757	RFETS	Heterogeneous	116	831	15.00 U	3.00 U	34.29	3.00 U	133.99	3.00 U	3.00 U	33.55 J	3.00 U
D65972	RFETS	Filter	119	376	2.70 U	0.30 U	1.99 J	2.26 J	2.30 J	0.30 U	0.30 U	6.67 J	0.30 U
D66128	RFETS	Heterogeneous	116	831	2.50 U	0.52 J	1.13 J	1.50 J	21.90	0.50 U	0.50 U	7.66 J	0.50 U
D66157	RFETS	Uncategorized Metal	117	480	18.75 J	2.00 U	2.00 U	6.63 J	2.00 U	2.00 U	2.00 U	189.97 J	2.00 U
D66162	RFETS	Lead/Cadmium Metal	123	339	810.00 U	90.00 U	5612.3	90.00 U	413.64 J	90.00 U	90.00 U	450.00 U	90.00 U
D66211	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.19 J	0.10 U	0.38 J	0.10 U	0.10 U	0.50 U	0.10 U
D66213	RFETS	Heterogeneous	116	831	1.50 U	0.30 U	23.08	5.20	10.07	0.30 U	0.30 U	3.30 U	0.70 J
D66356	RFETS	Heterogeneous	116	831	833.33 U	166.67 U	10386	166.67 U	166.67 U	166.67 U	166.67 U	1833.3 U	166.67 U
D66378	RFETS	Heterogeneous	116	831	960.00 U	192.00 U	9184.5	192.00 U	192.00 U	192.00 U	192.00 U	2304.0 U	192.00 U
D66438	RFETS	Uncategorized Metal	117	480	14.40 U	54.53	1.60 U	1.60 U	25.18	1.60 U	1.60 U	8.00 U	1.60 U
D66523	RFETS	Solidified Organics	112	801	5160.0 U	573.33 U	12516	573.33 U	19219	573.33 U	573.33 U	2866.6 U	573.33 U
D66525	RFETS	Solidified Inorganics	111	800	1.33 U	0.27 U	1.26 J	1.22 J	0.27 U	0.45 J	0.27 U	3.20 U	0.43 J
D66631	RFETS	Heterogeneous	116	831	4.50 U	0.50 U	4.86 J	0.50 U	4.48 J	0.50 U	0.50 U	5.87 J	0.50 U
D66637	RFETS	Heterogeneous	116	831	40.00 U	8.00 U	403.75	8.00 U	8.00 U	8.00 U	8.00 U	96.00 U	8.00 U
D66641	RFETS	Heterogeneous	116	831	540.00 U	60.00 U	4144.3	60.00 U	60.00 U	60.00 U	60.00 U	300.00 U	60.00 U
D66649	RFETS	Lead/Cadmium Metal	123	339	504.00 U	56.00 U	1594.3	56.00 U	2006.3	56.00 U	56.00 U	280.00 U	56.00 U
D66773	RFETS	Uncategorized Metal	117	480	2.70 U	0.30 U	0.30 U	0.30 U	0.30 U	1.63 J	0.30 U	1.50 U	0.30 U
D66783	RFETS	Heterogeneous	116	831	2250.0 U	250.00 U	14569	250.00 U	250.00 U	250.00 U	250.00 U	1250.0 U	250.00 U
D66792	RFETS	Heterogeneous	116	831	900.00 U	100.00 U	6432.5	100.00 U	100.00 U	100.00 U	100.00 U	500.00 U	100.00 U
D66860	RFETS	Heterogeneous	116	833	1.80 U	0.22 J	0.20 U	0.86 J	0.25 J	0.71 J	0.20 U	2.35 J	0.20 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Trichloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D66875	RFETS	Heterogeneous	116	832	0.90 U	0.10 U	0.10 U	1.38	0.33 J	0.10 U	0.10 U	1.64 J	0.10 U
D66948	RFETS	Heterogeneous	116	831	54.00 U	6.00 U	348.67	6.00 U	6.00 U	6.00 U	6.00 U	38.93 J	6.00 U
D66949	RFETS	Heterogeneous	116	831	5.40 U	0.60 U	36.09	0.60 U	3.54 J	0.60 U	0.60 U	7.95 J	0.60 U
D66953	RFETS	Uncategorized Metal	117	480	8.00 U	1.60 U	117.31	1.60 U	1.60 U	1.60 U	1.60 U	19.20 U	1.60 U
D66958	RFETS	Heterogeneous	116	831	2.70 U	0.30 U	1.23 J	0.30 U	4.06	0.30 U	0.30 U	4.27 J	0.30 U
D67009	RFETS	Solidified Organics	112	801	3060.0 U	340.00 U	3392.8	340.00 U	12288	340.00 U	340.00 U	1700.0 U	340.00 U
D67012	RFETS	Solidified Organics	112	801	8100.0 U	900.00 U	8430.3 J	900.00 U	34118	900.00 U	900.00 U	4500.0 U	900.00 U
D67047	RFETS	Solidified Inorganics	111	807	1.80 U	0.20 U	0.20 U	0.70 J	0.20 U	0.20 U	0.20 U	6.60 J	0.20 U
D67251	RFETS	Uncategorized Metal	117	480	6000.0 U	1200.0 U	1686.5 J	1200.0 U	1200.0 U	1200.0 U	1200.0 U	14400 U	1821.1 J
D67263	RFETS	Heterogeneous	116	831	81.00 U	9.00 U	481.60	9.00 U	9.00 U	9.00 U	9.00 U	45.00 U	9.00 U
D67277	RFETS	Heterogeneous	116	831	126.00 U	14.00 U	45.18 J	14.00 U	1170.2	14.00 U	14.00 U	70.00 U	14.00 U
D67278	RFETS	Heterogeneous	116	831	0.90 U	0.10 U	0.10 U	0.10 U	0.26 J	0.10 U	0.10 U	0.50 U	0.10 U
D67312	RFETS	Heterogeneous	116	825	1.80 U	0.20 U	0.20 U	0.20 U	0.27 J	0.20 U	0.20 U	1.00 U	0.20 U
D67317	RFETS	Uncategorized Metal	117	480	1.44 J	0.27 U	0.27 U	0.27 U	1.00 J	2.03 J	0.27 U	3.20 U	0.27 U
D67390	RFETS	Solidified Organics	112	801	1170.0 U	194.61 J	916.24 J	130.00 U	4459.1	130.00 U	130.00 U	650.00 U	130.00 U
D67391	RFETS	Heterogeneous	116	833	3.30 J	0.27 U	0.27 U	0.27 U	0.27 U	0.27 U	0.27 U	2.93 U	0.27 U
D67413	RFETS	Solidified Organics	112	801	6750.0 U	750.00 U	18543	750.00 U	27354	750.00 U	750.00 U	6834.0 J	750.00 U
D67434	RFETS	Solidified Inorganics	111	800	2.00 U	0.40 U	0.40 U	0.86 J	0.40 U	0.64 J	0.40 U	4.80 U	0.40 U
D67436	RFETS	Solidified Inorganics	111	800	0.67 U	0.13 U	0.28 J	0.76 J	0.13 U	0.42 J	0.13 U	2.25 J	0.13 U
D67441	RFETS	Solidified Inorganics	111	800	2.00 U	0.40 U	1.80 J	0.40 U	0.40 U	0.40 U	0.40 U	4.80 U	0.73 J
D67448	RFETS	Heterogeneous	116	852	0.90 U	0.10 U	0.56 J	0.10 U	0.10 U	0.10 U	0.10 U	0.88 J	0.10 U
D67455	RFETS	Filter	119	490	7.08 J	0.40 U	0.40 U	0.40 U	0.40 U	6.90	0.40 U	2.00 U	0.40 U
D67464	RFETS	Heterogeneous	116	831	2160.0 U	240.00 U	14009	240.00 U	240.00 U	240.00 U	240.00 U	1200.0 U	240.00 U
D67524	RFETS	Heterogeneous	116	832	167.34 U	33.34 J	18.59 U	18.59 U	887.74	18.59 U	18.59 U	266.96 J	18.59 U
D67532	RFETS	Lead/Cadmium Metal	123	339	56.70 U	6.30 U	[illegible].31	6.30 U	6.30 U	6.30 U	6.30 U	62.62	6.30 U

Table . -4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Trl chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D67535	RFETS	Heterogeneous	116	831	1.00 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U
D67539	RFETS	Solidified Organics	112	801	2880.0 U	320.00 U	4071.6	320.00 U	12796	320.00 U	320.00 U	1600.0 U	320.00 U
D67541	RFETS	Heterogeneous	116	825	0.90 U	0.10 U	0.10 U	0.33 J	0.26 J	0.10 U	0.10 U	0.54 J	0.10 U
D67545	RFETS	Solidified Organics	112	801	810.00 U	147.15 J	731.16 J	90.00 U	2836.4	90.00 U	90.00 U	450.00 U	90.00 U
D67567	RFETS	Heterogeneous	116	831	5.62 J	0.30 U	0.31 J	1.91 J	0.30 U	1.75 J	0.30 U	1.50 U	0.30 U
D67582	RFETS	Heterogeneous	116	831	9.56 J	0.40 U	3.04 J	2.22 J	8.78	0.40 U	0.40 U	54.34 J	0.40 U
D67603	RFETS	Uncategorized Metal	117	480	117.00 U	13.00 U	912.67	13.00 U	13.00 U	13.00 U	13.00 U	251.28 J	13.00 U
D67654	RFETS	Solidified Inorganics	111	800	1.33 U	0.27 U	0.56 J	1.15 J	0.27 U	0.38 J	0.27 U	3.20 U	0.27 U
D67657	RFETS	Solidified Inorganics	111	800	1.33 U	0.27 U	0.46 J	1.43 J	0.27 U	0.40 J	0.27 U	3.20 U	0.27 U
D67678	RFETS	Heterogeneous	116	825	3.87 U	0.43 U	2.30 J	19.19	0.55 J	1.61 J	0.43 U	2.15 U	0.43 U
D67698	RFETS	Heterogeneous	116	831	8.00 U	1.60 U	1.60 U	1.60 U	1.60 U	1.60 U	1.60 U	17.60 U	1.60 U
D67707	RFETS	Heterogeneous	116	831	2.50 U	0.94 J	0.50 U	0.50 U	36.34	0.50 U	0.50 U	5.50 U	0.50 U
D67734	RFETS	Heterogeneous	116	831	990.00 U	110.00 U	7283.8	110.00 U	110.00 U	110.00 U	110.00 U	550.00 U	110.00 U
D67735	RFETS	Uncategorized Metal	117	480	16.20 U	1.80 U	130.61	1.80 U	1.80 U	1.80 U	1.80 U	9.00 U	1.80 U
D67759	RFETS	Heterogeneous	116	831	25.20 U	2.80 U	2.80 U	2.80 U	2.80 U	2.80 U	2.80 U	14.00 U	2.80 U
D67764	RFETS	Heterogeneous	116	831	10.00 U	2.00 U	2.00 U	2.00 U	2.00 U	2.00 U	2.00 U	22.00 U	2.00 U
D67766	RFETS	Heterogeneous	116	831	7.50 U	1.50 U	1.50 U	1.50 U	1.50 U	3.46 J	1.50 U	16.50 U	1.50 U
D67781	RFETS	Heterogeneous	116	831	2.70 U	0.30 U	0.52 J	1.94 J	0.30 U	0.55 J	0.30 U	2.15 J	0.30 U
D67908	RFETS	Heterogeneous	116	832	0.90 U	0.10 U	2.49	0.10 U	0.22 J	0.10 U	0.10 U	2.28 J	0.10 U
D67929	RFETS	Heterogeneous	116	832	0.50 U	0.10 U	0.20 J	0.81 J	0.13 J	0.10 U	0.10 U	1.10 U	0.10 U
D67989	RFETS	Heterogeneous	116	831	4.50 U	0.76 J	11.24	0.50 U	43.36	0.50 U	0.50 U	2.50 U	0.50 U
D67994	RFETS	Heterogeneous	116	831	13.34 U	2.67 U	29.48	2.67 U	164.99	2.67 U	2.67 U	29.34 U	2.67 U
D68044	RFETS	Heterogeneous	116	825	4.50 U	0.50 U	0.50 U	12.13	0.50 U	0.52 J	0.50 U	2.50 U	0.50 U
D68096	RFETS	Heterogeneous	116	821	2.46 J	0.20 U	0.37 J	0.60 J	0.61 J	0.28 J	0.20 U	1.00 U	0.20 U
D68247	RFETS	Solidified Inorganics	111	800	0.67 U	0.13 U	0.32 J	0.13 U	0.13 U	0.25 J	0.13 U	1.60 U	0.13 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

m #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
68248	RFETS	Solidified Organics	112	801	1350.0 U	150.00 U	2762.7	150.00 U	6364.6	150.00 U	150.00 U	750.00 U	150.00 U
68250	RFETS	Solidified Organics	112	801	1530.0 U	170.00 U	2796.8	170.00 U	6225.7	170.00 U	170.00 U	850.00 U	170.00 U
68254	RFETS	Solidified Inorganics	111	800	1.33 U	0.27 U	0.68 J	0.66 J	0.27 U	0.35 J	0.27 U	3.20 U	0.41 J
68256	RFETS	Solidified Inorganics	111	800	2.00 U	0.40 U	1.83 J	1.32 J	0.40 U	0.55 J	0.40 U	4.80 U	0.68 J
68276	RFETS	Heterogeneous	116	852	0.90 U	0.10 U	0.50 J	0.37 J	0.10 U	0.10 U	0.10 U	0.50 U	0.10 U
68277	RFETS	Uncategorized Metal	117	480	4.50 U	0.50 U	1.97 J	0.98 J	37.08	0.50 U	0.50 U	3.38 J	0.50 U
68377	RFETS	Uncategorized Metal	117	480	1.00 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U
68460	RFETS	Heterogeneous	116	832	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
68480	RFETS	Solidified Inorganics	111	800	0.50 J	0.10 U	0.13 J	0.17 J	0.10 U	0.26 J	0.10 U	2.36 J	0.10 U
68486	RFETS	Solidified Organics	112	801	1260.0 U	206.92 J	8439.3	140.00 U	4240.3	140.00 U	140.00 U	831.18 J	140.00 U
68514	RFETS	Uncategorized Metal	117	480	1.11 J	0.10 U	0.10 U	0.70 J	0.10 U	0.10 U	0.10 U	0.50 U	0.10 U
68538	RFETS	Lead/Cadmium Metal	123	339	0.50 U	0.10 U	0.16 J	0.12 J	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U
68600	RFETS	Heterogeneous	116	825	162.00 U	18.00 U	18.00 U	1922.1	18.00 U	18.00 U	18.00 U	90.00 U	18.00 U
68601	RFETS	Heterogeneous	116	825	63.00 U	7.00 U	7.00 U	745.07	7.00 U	7.00 U	7.00 U	35.00 U	7.00 U
68702	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.10 U	0.17 J	0.13 J	0.10 U	0.10 U	0.50 U	0.10 U
68724	RFETS	Heterogeneous	116	831	1620.0 U	180.00 U	10740	180.00 U	180.00 U	180.00 U	180.00 U	900.00 U	180.00 U
68756	RFETS	Heterogeneous	116	831	1.37 J	0.20 U	0.20 U	1.06 J	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U
68885	RFETS	Heterogeneous	116	831	360.00 U	40.00 U	2205.7	40.00 U	334.76 J	40.00 U	40.00 U	200.00 U	40.00 U
68896	RFETS	Heterogeneous	116	831	1917.0 U	213.00 U	4021.8	213.00 U	213.00 U	213.00 U	213.00 U	1065.0 U	213.00 U
68975	RFETS	Solidified Organics	112	801	4860.0 U	540.00 U	13431	540.00 U	15676	540.00 U	540.00 U	2700.0 U	540.00 U
68999	RFETS	Heterogeneous	116	821	3.60 U	0.40 U	0.67 J	2.00 J	0.60 J	0.50 J	0.40 U	2.00 U	0.40 U
69091	RFETS	Heterogeneous	116	825	4.50 U	0.50 U	0.50 U	3.56 J	0.50 U	0.50 U	0.50 U	2.50 U	0.50 U
69095	RFETS	Heterogeneous	116	833	4.86 U	0.54 U	0.54 U	32.79	0.54 U	0.54 U	0.54 U	2.70 U	0.54 U
69113	RFETS	[illegible]erogeneous	116	831	432.00 U	48.00 U	0	48.00 U	48.00 U	48.00 U	48.00 U	240.00 U	48.00 U
69250	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.47 J	0.67 J	0.24 J	0.10 U	0.10 U	0.50 U	0.10 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D69287	RFETS	Heterogeneous	116	821	1242.0 U	138.00 U	8372.6	138.00 U	138.00 U	138.00 U	138.00 U	690.00 U	138.00 U
D69306	RFETS	Solidified Organics	112	801	2250.0 U	250.00 U	13804	250.00 U	6213.5	250.00 U	250.00 U	1250.0 U	250.00 U
D69312	RFETS	Solidified Inorganics	111	800	2.00 U	0.40 U	1.11 J	1.39 J	0.40 U	0.57 J	0.40 U	4.80 U	0.69 J
D69364	RFETS	Heterogeneous	116	833	2.70 U	0.30 U	0.30 U	3.20	0.30 U	0.42 J	0.30 U	1.95 J	0.30 U
D69400	RFETS	Heterogeneous	116	831	333.00 U	37.00 U	2679.9	37.00 U	37.00 U	37.00 U	37.00 U	185.00 U	37.00 U
D69406	RFETS	Heterogeneous	116	831	450.00 U	50.00 U	3750.4	50.00 U	50.00 U	50.00 U	50.00 U	250.00 U	50.00 U
D69413	RFETS	Heterogeneous	116	831	5.40 U	0.60 U	15.20	0.60 U	0.60 U	0.60 U	0.60 U	3.00 U	0.60 U
D69418	RFETS	Heterogeneous	116	831	660.60 U	73.40 U	4816.7	73.40 U	73.40 U	73.40 U	73.40 U	699.21 J	73.40 U
D69431	RFETS	Heterogeneous	116	831	266.67 U	53.33 U	4070.6	53.33 U	53.33 U	53.33 U	53.33 U	586.66 U	53.33 U
D69518	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	0.36 J	2.40	0.28 J	0.20 U	0.20 U	1.00 U	0.20 U
D69602	RFETS	Heterogeneous	116	821	9.00 U	1.00 U	1.00 U	3.40 J	1.00 U	1.00 U	1.00 U	5.00 U	1.00 U
D69759	RFETS	Heterogeneous	116	833	2.70 U	0.30 U	20.43	2.40 J	0.34 J	0.30 U	0.30 U	1.53 J	7.59
D69855	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	1.01 J	8.75	0.74 J	0.28 J	0.20 U	1.00 U	0.20 U
D69877	RFETS	Heterogeneous	116	825	4.50 U	0.50 U	0.53 J	1.79 J	0.50 U	0.50 U	0.50 U	2.50 U	0.50 U
D69883	RFETS	Heterogeneous	116	825	2.70 U	0.30 U	0.95 J	0.30 U	0.51 J	1.72 J	0.30 U	1.50 U	0.30 U
D69975	RFETS	Heterogeneous	116	821	6.30 U	0.70 U	4.64 J	4.42 J	0.81 J	0.70 U	0.70 U	3.50 U	0.70 U
D70063	RFETS	Heterogeneous	116	821	4.59 U	0.57 J	0.51 U	2.00 J	7.12	0.51 U	0.51 U	2.55 U	0.51 U
D70077	RFETS	Heterogeneous	116	831	540.00 U	60.00 U	3533.4	60.00 U	60.00 U	60.00 U	60.00 U	300.00 U	60.00 U
D70229	RFETS	Heterogeneous	116	831	1.80 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	1.00 U	0.20 U
D70353	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	0.20 J	1.94 J	0.65 J	0.20 U	0.20 U	5.36 J	0.20 U
D70370	RFETS	Heterogeneous	116	821	2.70 U	0.30 U	0.52 J	0.92 J	0.58 J	0.30 U	0.30 U	1.50 U	0.30 U
D70379	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.48 J	0.10 U	0.33 J	0.10 U	0.10 U	0.50 U	0.10 U
D70383	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	0.20 U	1.78 J	0.20 U	0.20 U	0.20 U	1.00 U	0.20 U
D70446	RFETS	Uncategorized Metal	117	480	5.00 U	5.85 J	1.00 U	1.00 U	58 86	1.00 U	1.00 U	12.00 U	1.00 U
D70448	RFETS	Heterogeneous	116	831	1350.0 U	150.00 U	8313.3	150.00 U	150.00 U	150.00 U	150.00 U	750.00 U	150.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D70455	RFETS	Heterogeneous	116	831	6.30 U	5.12 J	0.70 U	4.62 J	11.69	0.70 U	0.70 U	3.50 U	0.70 U
D70543	RFETS	Solidified Organics	112	801	7452.0 U	828.00 U	55410	828.00 U	62380	828.00 U	828.00 U	4140.0 U	828.00 U
D70661	RFETS	Filter	0	331	3.17 J	0.60 U	0.76 J	0.60 U	0.60 U	0.60 U	0.60 U	6.60 U	0.60 U
D70669	RFETS	Uncategorized Metal	117	480	0.90 U	0.10 U	0.10 U	0.10 U	0.13 J	0.10 U	0.10 U	0.54 J	0.10 U
D70675	RFETS	Solidified Organics	112	801	0.99 J	0.10 U	6.31	0.69 J	1.29	0.45 J	0.10 U	1.85 J	8.47
D70682	RFETS	Heterogeneous	116	831	405.00 U	45.00 U	2682.6	45.00 U	45.00 U	45.00 U	45.00 U	225.00 U	45.00 U
D70696	RFETS	Heterogeneous	116	821	5.40 U	0.60 U	0.60 U	3.33 J	0.60 U	0.60 U	0.60 U	3.00 U	0.60 U
D70734	RFETS	Heterogeneous	116	833	0.57 J	0.10 U	0.14 J	0.10 U	0.14 J	0.10 U	0.10 U	1.10 U	0.10 U
D70780	RFETS	Heterogeneous	116	832	0.50 U	0.10 U	0.10 U	0.10 U	0.13 J	0.10 U	0.10 U	1.10 U	0.10 U
D70856	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.21 J	0.52 J	0.23 J	1.21	0.10 U	0.94 J	0.10 U
D70882	RFETS	Heterogeneous	116	831	126.00 U	14.00 U	1277.8	14.00 U	14.00 U	14.00 U	14.00 U	70.00 U	14.00 U
D70937	RFETS	Filter	0	331	5.08 J	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	0.50 U	5.50 U	0.50 U
D71019	RFETS	Solidified Organics	112	801	11.70 U	1.30 U	21.30	1.30 U	1.32 J	1.30 U	1.30 U	6.50 U	97.64
D71020	RFETS	Solidified Organics	112	801	9988.2 J	911.50 U	44413	911.50 U	61914	911.50 U	911.50 U	32467 J	911.50 U
D71022	RFETS	Solidified Organics	112	801	6000.0 U	1200.0 U	32496	1200.0 U	66727	1200.0 U	1200.0 U	13200 U	1200.0 U
D71241	RFETS	Heterogeneous	116	833	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
D71351	RFETS	Uncategorized Metal	117	480	0.67 J	0.18 J	0.10 U	0.10 U	0.20 J	0.10 U	0.10 U	1.20 U	0.10 U
D71354	RFETS	Uncategorized Metal	117	480	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U
D71385	RFETS	Heterogeneous	116	833	2.70 U	0.30 U	0.30 U	4.10	0.30 U	0.30 U	0.30 U	1.50 U	0.30 U
D71494	RFETS	Solidified Organics	112	801	1.07 J	0.10 U	1.69	0.42 J	0.25 J	0.23 J	0.10 U	3.13 J	10.16
D71504	RFETS	Solidified Organics	112	801	1.80 U	0.20 U	1.91 J	0.20 U	0.20 U	0.20 U	0.20 U	1.00 U	11.44
D71514	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	0.20 U	1.13 J	0.33 J	0.20 U	0.20 U	1.00 U	0.20 U
D71521	RFETS	Heterogeneous	116	825	1.80 U	0.20 U	0.20 U	1.00 J	0.33 J	0.20 U	0.20 U	1.00 U	0.20 U
D71638	RFETS	Uncategorized Metal	117	480	5.00 U	1.02 J	00 U	1.00 U	62.96	1.00 U	1.00 U	12.00	1.00 U
D71804	RFETS	Heterogeneous	116	832	0.81 J	0.60 J	0.23 J	0.10 U	0.10 U	2.07	0.70 J	1.20 U	0.10 U

Table [illegible]-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Trichloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D71829	RFETS	Heterogeneous	116	852	1980.0 U	220.00 U	220.00 U	220.00 U	220.00 U	220.00 U	220.00 U	1100.0 U	220.00 U
D71838	RFETS	Heterogeneous	116	831	68.40 U	7.60 U	364.82	7.60 U	7.60 U	7.60 U	7.60 U	50.37 J	7.60 U
D71921	RFETS	Heterogeneous	116	833	0.50 U	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U	52.84 J	0.10 U
D71932	RFETS	Solidified Organics	112	801	39311 U	6023.4 J	85795	4367.9 U	88612	4367.9 U	4367.9 U	21839 U	4367.9 U
D71933	RFETS	Solidified Organics	112	801	0.50 U	0.10 U	2.59	0.10 U	0.89 J	0.10 U	0.10 U	1.10 U	10.21
D71934	RFETS	Solidified Organics	112	801	0.88 J	0.10 U	3.66	0.10 U	2.43	0.10 U	0.10 U	2.53 J	4.17
D71936	RFETS	Heterogeneous	116	833	195.00 U	21.67 U	1264.7	21.67 U	1946.0	21.67 U	21.67 U	108.34 U	21.67 U
D71937	RFETS	Heterogeneous	116	833	166.67 U	33.33 U	1343.4	33.33 U	2458.8	33.33 U	33.33 U	366.66 U	33.33 U
D71938	RFETS	Heterogeneous	116	833	16.20 U	1.80 U	97.42	1.80 U	69.15	1.80 U	1.80 U	9.00 U	1.80 U
D71940	RFETS	Solidified Organics	112	801	9000.0 U	1000.0 U	24298	1000.0 U	67524	1000.0 U	1000.0 U	5000.0 U	1000.0 U
D71941	RFETS	Solidified Organics	112	801	9000.0 U	1000.0 U	36373	1000.0 U	88979	1000.0 U	1000.0 U	6075.0 J	1000.0 U
D72010	RFETS	Heterogeneous	116	832	1.50 U	0.30 U	0.30 U	0.30 U	0.30 U	0.30 U	0.30 U	3.60 U	0.30 U
D72079	RFETS	Uncategorized Metal	117	480	58.50 U	6.50 U	544.22	6.50 U	6.50 U	6.50 U	6.50 U	32.50 U	6.50 U
D72127	RFETS	Solidified Organics	112	801	3.60 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	2.00 U	24.63
D72128	RFETS	Solidified Organics	112	801	3570.0 J	130.00 U	130.00 U	130.00 U	130.00 U	130.00 U	130.00 U	5061.2 J	130.00 U
D72131	RFETS	Heterogeneous	116	833	1.34 U	0.27 U	12.25	0.27 U	0.27 U	0.27 U	0.27 U	2.94 U	19.86
D72132	RFETS	Solidified Organics	112	801	316.85 J	48.00 U	48.00 U	48.00 U	48.00 U	48.00 U	48.00 U	1245.8 J	48.00 U
D72133	RFETS	Solidified Organics	112	801	1.80 U	0.20 U	0.93 J	0.20 U	1.52 J	0.20 U	0.20 U	3.84 J	1.32 J
D72136	RFETS	Solidified Organics	112	801	189.00 U	21.00 U	21.00 U	21.00 U	21.00 U	21.00 U	21.00 U	105.00 U	21.00 J
D72139	RFETS	Solidified Organics	112	801	17.10 U	1.90 U	8.18 J	1.90 U	12.29 J	1.90 U	1.90 U	9.50 U	3.72 J
D72178	RFETS	Heterogeneous	116	821	2.70 U	0.30 U	0.30 U	0.35 J	0.35 J	0.30 U	0.30 U	1.50 U	0.30 U
D72186	RFETS	Heterogeneous	116	821	1.80 U	0.20 U	0.46 J	0.56 J	0.45 J	0.20 U	0.20 U	1.00 U	0.20 U
D72195	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	3.12	1.68	0.22 J	0.10 U	0.10 U	0.50 U	0.10 U
D72255	RFETS	Heterogeneous	116	833	2.70 U	22.90	0.30 U	0.93 J	0.30 U	0.37 J	0.30 U	1.50 U	0.30 U
D72267	RFETS	Solidified Inorganics	111	800	0.50 U	0.10 U	0.36 J	0.10 U	0.10 U	0.24 J	0.10 U	1.20 U	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D72293	RFETS	Heterogeneous	116	833	3.22 J	0.11 J	0.51 J	0.10 U	0.21 J	3.14	0.11 J	0.55 J	0.10 U
D72333	RFETS	Heterogeneous	116	831	2.70 U	0.30 U	0.30 J	1.13 J	0.31 J	0.30 U	0.30 U	1.50 U	0.30 U
D72339	RFETS	Heterogeneous	116	821	4.50 U	0.50 U	0.50 U	0.50 U	0.56 J	0.50 U	0.50 U	2.50 U	0.50 U
D72347	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.13 J	15.33	0.23 J	0.10 U	0.10 U	0.50 U	0.10 U
D72375	RFETS	Heterogeneous	116	831	720.00 U	80.00 U	4620.7	80.00 U	80.00 U	80.00 U	80.00 U	400.00 U	80.00 U
D72434	RFETS	Heterogeneous	116	831	1890.0 U	210.00 U	10516	210.00 U	210.00 U	210.00 U	210.00 U	2174.5 J	210.00 U
D72436	RFETS	Uncategorized Metal	117	480	2.00 J	0.30 U	20.40	0.30 U	0.30 U	0.30 U	0.30 U	11.10 J	0.60 J
D72542	RFETS	Heterogeneous	116	832	50.00 U	10.00 U	10.00 U	1394.3	10.00 U	10.00 U	10.00 U	110.00 U	10.00 U
D72545	RFETS	Solidified Inorganics	111	800	0.50 U	0.10 U	0.12 J	0.21 J	0.10 U	0.15 J	0.10 U	1.20 U	0.10 U
D72546	RFETS	Heterogeneous	116	832	75.00 U	15.00 U	15.00 U	1801.2	15.00 U	15.00 U	15.00 U	165.00 U	15.00 U
D72566	RFETS	Solidified Organics	112	801	7.20 U	0.80 U	16.52	0.80 U	0.80 U	0.80 U	0.80 U	4.09 J	57.15
D72598	RFETS	Heterogeneous	116	821	5.40 U	0.60 U	0.60 U	2.29 J	1.16 J	1.70 J	0.60 U	4.14 J	0.60 U
D72618	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.17 J	0.22 J	0.30 J	0.10 U	0.10 U	0.50 U	0.10 U
D72619	RFETS	Solidified Organics	112	801	0.90 U	0.10 U	0.99 J	0.10 U	0.23 J	0.10 U	0.10 U	0.83 J	1.75
D72623	RFETS	Solidified Organics	112	801	2.50 U	0.50 U	6.29	0.50 U	0.50 U	0.50 U	0.50 U	5.50 U	26.30
D72631	RFETS	Solidified Organics	112	801	0.90 U	0.10 U	1.79	0.10 U	0.21 J	0.10 U	0.10 U	0.90 J	10.15
D72632	RFETS	Solidified Organics	112	801	0.90 U	0.10 U	1.52	0.10 U	0.24 J	0.10 U	0.10 U	2.95 J	6.93
D72673	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	3.61	1.49 J	5.78	0.23 J	0.20 U	1.00 U	0.20 U
D72819	RFETS	Heterogeneous	116	833	3.60 U	3.26 J	0.82 J	1.89 J	0.49 J	0.47 J	0.40 U	2.00 U	0.40 U
D72822	RFETS	Heterogeneous	116	831	1.34 U	0.27 U	0.27 U	0.27 U	15.11	0.27 J	0.27 U	2.94 U	0.27 U
D72831	RFETS	Uncategorized Metal	117	480	20.00 U	4.00 U	305.00	4.00 U	4.00 U	4.00 U	4.00 U	48.00 U	4.00 U
D72887	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.15 J	0.87 J	0.30 J	0.10 U	0.10 U	0.50 U	0.10 U
D72923	RFETS	Heterogeneous	116	833	9.66 J	6.55	0.49 J	0.95 J	0.40 U	0.68 J	0.40 U	42.52 J	0.40 U
D72932	RFETS	Heterogeneous	116	825	2.70 U	0.30 U	[illegible]73 J	5.12	0.46 J	0.30 U	0.30 U	1.50 U	0.30 U
D73054	RFETS	Heterogeneous	0	336	566.67 U	2074.3	[illegible]3.33 U	113.33 U	5153.2	113.33 U	113.33 U	1580.3 J	113.33 U

Table . .-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D73074	RFETS	Heterogeneous	116	833	1.80 J	0.81 J	0.20 U	0.20 U	0.64 J	0.20 U	0.20 U	4.17 J	0.20 U
D73117	RFETS	Uncategorized Metal	117	480	2.00 U	0.40 U	30.42	0.40 U	0.40 U	0.40 U	0.40 U	4.80 U	0.40 U
D73123	RFETS	Heterogeneous	116	831	1134.0 U	126.00 U	7343.0	126.00 U	126.00 U	126.00 U	126.00 U	630.00 U	126.00 U
D73134	RFETS	Heterogeneous	116	831	360.00 U	72.00 U	3648.5	72.00 U	72.00 U	72.00 U	72.00 U	792.00 U	72.00 U
D73136	RFETS	Solidified Inorganics	111	807	0.50 U	0.10 U	0.10 U	0.18 J	0.10 U	0.10 U	0.10 U	1.20 U	0.10 U
D73274	RFETS	Heterogeneous	116	831	450.00 U	50.00 U	2711.7	50.00 U	50.00 U	50.00 U	50.00 U	250.00 U	50.00 U
D73285	RFETS	Solidified Organics	112	801	0.90 U	0.10 U	1.53	0.39 J	0.10 J	0.10 U	0.10 U	2.15 J	10.59
D73293	RFETS	Solidified Organics	112	801	0.90 U	0.10 U	3.18	0.10 U	2.42	0.10 U	0.10 U	1.17 J	3.25
D73295	RFETS	Solidified Organics	112	801	0.90 U	0.10 U	1.55	0.10 U	0.86 J	0.10 U	0.10 U	0.50 U	2.35
D73296	RFETS	Solidified Organics	112	801	0.90 U	0.10 U	2.51	0.10 J	0.14 J	0.10 U	0.10 U	0.61 J	0.95 J
D73301	RFETS	Solidified Organics	112	801	1.80 U	0.20 U	1.42 J	0.43 J	2.30	0.20 U	0.20 U	1.44 J	12.42
D73605	RFETS	Lead/Cadmium Metal	123	339	0.50 U	0.10 U	2.96	0.10 U	3.87	0.12 J	0.10 U	1.20 U	0.10 U
D73632	RFETS	Heterogeneous	116	825	6.30 U	0.70 U	33.16	0.70 U	0.70 U	0.70 U	0.70 U	3.50 U	35.70
D73667	RFETS	Solidified Organics	112	801	0.90 U	0.10 U	1.03	0.17 J	0.10 U	0.10 U	0.10 U	1.16 J	2.36
D73672	RFETS	Solidified Organics	112	801	0.90 U	0.24 J	1.75	0.29 J	0.19 J	0.10 U	0.10 U	0.50 U	2.27
D73745	RFETS	Heterogeneous	116	832	0.50 U	0.18 J	1.89	10.64	1.75	0.10 U	0.10 U	1.20 U	0.10 U
D73828	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.17 J	0.65 J	0.31 J	0.10 U	0.10 U	0.50 U	0.10 U
D73848	RFETS	Heterogeneous	116	821	1.20 U	0.13 U	0.21 J	1.46	0.25 J	0.13 U	0.13 U	0.67 U	0.13 U
D73987	RFETS	Lead/Cadmium Metal	123	339	1.50 U	0.30 U	0.30 U	0.30 U	1.36 J	0.30 U	0.30 U	3.60 U	0.30 U
D74007	RFETS	Uncategorized Metal	117	480	1.74 J	0.30 U	0.56 J	0.30 U	0.74 J	0.30 U	0.30 U	3.60 U	0.30 U
D74110	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.28 J	6.63	0.60 J	0.10 U	0.10 U	0.50 U	0.10 U
D74147	RFETS	Solidified Organics	112	801	7.20 U	0.80 U	36.24	0.80 U	0.80 U	0.80 U	0.80 U	4.00 U	2.73 J
D74156	RFETS	Solidified Organics	112	801	5.40 U	0.60 U	36.75	0.60 U	4.68 J	0.60 U	0.60 U	3.00 U	3.09 J
D74374	RFETS	Heterogeneous	116	833	0.55 J	0.13 J	0.45 J	0.88 J	1.87	0.10 U	0.10 U	1.10 U	1.83
D74683	RFETS	Heterogeneous	116	821	29.51 J	1.50 U	1.50 U	5.85 J	1.50 U	1.50 U	1.50 U	7.50 U	1.50 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

rum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
)74904	RFETS	Heterogeneous	116	832	0.50 U	0.10 U	0.10 U	0.39 J	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
)74913	RFETS	Heterogeneous	116	832	2.70 U	0.30 U	0.30 U	1.50 J	0.30 U	0.30 U	0.30 U	1.50 U	0.30 U
)75039	RFETS	Heterogeneous	116	832	2.70 U	0.30 U	0.35 J	0.30 U	0.30 U	0.30 U	0.30 U	1.99 J	0.30 U
)75265	RFETS	Heterogeneous	116	833	14.89 J	1.20 U	1.20 U	3.95 J	63.67	1.20 U	1.20 U	6.00 U	1.20 U
)75267	RFETS	Heterogeneous	116	832	1.80 U	0.20 U	0.20 U	2.39	0.20 U	0.20 U	0.20 U	1.27 J	0.20 U
)75278	RFETS	Heterogeneous	116	832	2.70 U	0.30 U	0.30 U	3.74	0.30 U	0.30 U	0.30 U	3.85 J	0.30 U
)75399	RFETS	Heterogeneous	116	833	3.60 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	7.01 J	0.40 U
)75564	RFETS	Heterogeneous	116	825	1.20 U	0.13 U	0.13 U	0.85 J	0.24 J	0.13 U	0.13 U	0.92 J	0.13 U
)75868	RFETS	Heterogeneous	116	825	5.40 U	0.60 U	0.60 U	2.53 J	0.60 U	0.60 U	0.60 U	3.56 J	0.60 U
)75888	RFETS	Heterogeneous	116	833	1.18 J	0.10 U	0.20 J	0.10 U	0.31 J	0.13 J	0.10 U	0.50 U	0.10 U
)75926	RFETS	Heterogeneous	116	832	10.19 J	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	2.00 U	0.40 U
)75930	RFETS	Heterogeneous	116	832	500.00 U	100.00 U	100.00 U	100.00 U	6912.5	100.00 U	100.00 U	1100.0 U	100.00 U
)75947	RFETS	Heterogeneous	116	832	0.90 U	0.29 J	0.10 U	0.87 J	0.40 J	0.10 U	0.10 U	0.99 J	0.10 U
)75976	RFETS	Heterogeneous	116	833	3.37 J	0.13 U	0.13 U	1.50	0.13 U	0.13 U	0.13 U	1.46 U	0.13 U
)76044	RFETS	Heterogeneous	116	831	3.63 J	0.27 U	0.27 U	2.39 J	0.27 U	0.27 U	0.27 U	7.19 J	0.27 U
)76050	RFETS	Heterogeneous	116	832	1.02 J	0.10 U	0.10 U	0.99 J	0.10 U	0.10 U	0.10 U	0.73 J	0.10 U
)76054	RFETS	Heterogeneous	116	831	2.70 U	0.30 U	0.30 U	5.36	0.30 U	0.30 U	0.30 U	1.50 U	0.30 U
)76098	RFETS	Heterogeneous	116	832	1.00 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	2.40 U	0.20 U
)76135	RFETS	Solidified Organics	112	801	133.34 U	26.67 U	257.42 J	26.67 U	1583.9	26.67 U	26.67 U	293.34 U	26.67 U
)76136	RFETS	Solidified Inorganics	111	803	2.00 U	0.40 U	41.04	0.40 U	10.00	0.40 U	0.40 U	4.40 U	1.10 J
)76138	RFETS	Solidified Inorganics	111	800	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
)76142	RFETS	Solidified Inorganics	111	800	1.36 J	0.24 U	7.62	0.24 U	0.84 J	1.82 J	0.24 U	2.64 U	0.24 U
)76143	RFETS	Solidified Inorganics	111	803	1.50 U	0.30 U	31.39	0.30 U	4.26	0.30 U	0.30 U	3.30 U	0.87 J
)76144	RFETS	[illegible]idified Inorganics	111	800	3.34 U	0.67 U	10	0.67 U	0.67 U	0.68 J	0.67 U	7.34 [illegible]	2.78 J
)76146	RFETS	Solidified Inorganics	[illegible]	202	0.50 U	0.10 U	0.18 J	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U

Table _-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D76147	RFETS	Solidified Inorganics	111	803	1.39 J	0.10 U	2.44	0.13 J	0.15 J	0.15 J	0.10 U	1.84 J	0.13 J
D76182	RFETS	Solidified Inorganics	111	800	6.30 U	0.70 U	0.70 U	0.70 U	1.04 J	4.03 J	0.70 U	3.50 U	0.70 U
D76183	RFETS	Solidified Inorganics	111	800	0.67 U	0.13 U	4.25	0.13 U	0.13 U	0.93 J	0.13 U	1.46 U	0.13 U
D76185	RFETS	Solidified Inorganics	111	800	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.55 J	0.10 U
D76187	RFETS	Solidified Inorganics	111	803	2.50 U	0.50 U	49.01	0.50 U	11.65	0.50 U	0.50 U	5.50 U	1.46 J
D76189	RFETS	Solidified Inorganics	111	803	10.00 U	2.00 U	165.71	2.00 U	2.00 U	2.00 U	2.00 U	22.00 U	7.50 J
D76192	RFETS	Solidified Inorganics	111	803	0.50 U	0.10 U	0.93 J	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.57 J
D76194	RFETS	Solidified Inorganics	111	800	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.10 U
D76195	RFETS	Solidified Organics	112	801	4320.0 U	480.00 U	13758	480.00 U	6208.6	480.00 U	480.00 U	3249.5 J	480.00 U
D76196	RFETS	Solidified Organics	112	801	833.34 U	166.67 U	1020.1 J	166.67 U	12990	166.67 U	166.67 U	1833.3 U	166.67 U
D76199	RFETS	Solidified Inorganics	111	800	0.50 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	0.10 U	1.13 J	0.10 U
D76200	RFETS	Solidified Organics	112	801	3166.6 U	633.33 U	4123.0 J	633.33 U	43418	633.33 U	633.33 U	6966.6 U	633.33 U
D76203	RFETS	Solidified Organics	112	801	1116.6 J	223.33 U	3535.3	223.33 U	13365	223.33 U	223.33 U	2456.6 U	223.33 U
D76205	RFETS	Solidified Inorganics	111	800	0.50 U	0.10 U	0.62 J	0.18 J	0.86 J	0.46 J	0.10 U	1.10 U	0.10 U
D76206	RFETS	Solidified Inorganics	111	803	2.00 U	0.40 U	28.65	0.40 U	0.40 U	0.40 U	0.40 U	4.40 U	0.87 J
D76217	RFETS	Heterogeneous	116	833	5.00 U	1.00 U	1.00 U	1.00 U	1.00 U	1.00 U	1.00 U	12.29 J	1.00 U
D76282	RFETS	Solidified Inorganics	111	800	56.67 U	11.33 U	118.35	11.33 U	675.83	11.33 U	11.33 U	124.66 U	11.33 U
D76283	RFETS	Solidified Organics	112	801	450.00 U	90.00 U	1068.5	90.00 U	5328.1	90.00 U	90.00 U	990.00 U	90.00 U
D76287	RFETS	Solidified Inorganics	111	800	26.67 U	5.33 U	72.31	5.33 U	402.58	5.33 U	5.33 U	58.66 U	5.33 U
D76293	RFETS	Heterogeneous	116	833	3.60 U	0.40 U	5.02	0.40 U	22.39	0.40 U	0.40 U	3.53 J	0.40 U
D76302	RFETS	Solidified Inorganics	111	800	15.00 U	3.00 U	3.00 U	3.00 U	3.00 U	3.00 U	3.00 U	33.00 U	3.00 U
D76303	RFETS	Solidified Inorganics	111	803	1.34 U	0.27 U	21.61	0.27 U	0.27 U	0.27 U	0.27 U	2.94 U	0.70 J
D76305	RFETS	Solidified Inorganics	111	800	60.00 U	12.00 U	91.70 J	12.00 U	494.26	12.00 U	12.00 U	132.00 U	12.00 U
D76306	RFETS	Heterogeneous	116	833	7.20 U	0.80 U	17.00	0.80 U	37.08	0.80 U	0.80 U	5.52 J	0.80 U
D76362	RFETS	Heterogeneous	116	833	33.34 U	554.17	6.67 U	6.67 U	6.67 U	6.67 U	6.67 U	183.17 J	6.67 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D76406	RFETS	Heterogeneous	116	831	0.90 U	0.10 U	0.45 J	0.10 U	0.37 J	0.10 U	0.10 U	0.50 U	0.10 U
D76437	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	0.20 U	2.24	0.20 U	0.20 U	0.20 U	1.44 J	0.20 U
D76443	RFETS	Heterogeneous	116	825	2.70 U	0.30 U	0.30 U	0.63 J	0.33 J	0.30 U	0.30 U	1.50 U	0.30 U
D76452	RFETS	Heterogeneous	116	825	1.70 J	0.20 U	0.20 J	0.20 U	0.40 J	0.20 U	0.20 U	1.10 J	0.20 U
D76454	RFETS	Heterogeneous	116	825	0.90 U	0.10 U	0.12 J	0.66 J	0.21 J	0.10 U	0.10 U	0.50 U	0.10 U
D76456	RFETS	Heterogeneous	116	825	0.90 U	0.10 U	0.13 J	0.72 J	0.23 J	0.10 U	0.10 U	1.95 J	0.10 U
D76461	RFETS	Heterogeneous	116	825	2.70 U	0.30 U	0.30 U	1.89 J	0.30 U	0.30 U	0.30 U	1.50 U	0.39 J
D76463	RFETS	Heterogeneous	116	825	2.70 U	0.30 U	0.33 J	1.09 J	0.31 J	0.30 U	0.30 U	1.50 U	0.30 U
D76470	RFETS	Solidified Inorganics	111	803	0.50 U	0.10 U	0.83 J	0.10 U	0.10 U	0.10 U	0.10 U	1.10 U	0.28 J
D76587	RFETS	Heterogeneous	116	825	0.90 U	0.10 U	0.20 J	1.07	0.69 J	0.10 U	0.10 U	0.90 U	0.10 U
D76596	RFETS	Heterogeneous	116	825	3.13 J	0.10 U	0.20 J	1.67	0.97 J	0.10 U	0.10 U	5.14 J	0.10 U
D76627	RFETS	Heterogeneous	116	825	0.90 U	0.10 U	0.10 J	0.91 J	0.21 J	0.10 U	0.10 U	0.79 J	0.10 U
D76630	RFETS	Heterogeneous	116	825	2.01 J	0.10 U	0.20 J	0.89 J	0.65 J	0.10 U	0.10 U	1.30 J	0.10 U
D76635	RFETS	Heterogeneous	116	825	1.80 U	0.20 U	0.25 J	0.61 J	0.81 J	0.20 U	0.20 U	1.71 J	0.20 U
D76652	RFETS	Heterogeneous	116	833	0.66 J	0.10 U	0.11 J	0.47 J	0.10 U	0.10 U	0.10 U	2.98 J	0.10 U
D76677	RFETS	Solidified Inorganics	111	800	21.60 U	2.40 U	199.52	2.40 U	2.40 U	2.40 U	2.40 U	12.00 U	14.06 J
D76710	RFETS	Heterogeneous	116	833	18.00 U	136.89	2.00 U	2.00 U	2.00 U	2.00 U	2.00 U	10.00 U	2.00 U
D76712	RFETS	Heterogeneous	116	833	2.70 U	0.95 J	0.30 U	0.30 U	0.30 U	0.30 U	0.30 U	1.50 U	0.30 U
D76715	RFETS	Heterogeneous	116	832	1.80 U	0.20 U	0.20 U	1.88 J	0.20 U	0.20 U	0.20 U	2.35 J	0.20 U
D76811	RFETS	Heterogeneous	116	832	2.46 J	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	8.62 J	0.20 U
D76908	RFETS	Heterogeneous	116	833	0.90 U	0.10 U	0.14 J	0.66 J	0.79 J	0.10 U	0.10 U	0.50 U	0.32 J
D76911	RFETS	Heterogeneous	116	832	1.00 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	2.20 U	0.20 U
D77088	RFETS	Heterogeneous	116	833	2.93 J	0.20 U	0.20 U	0.20 U	0.30 J	0.20 U	0.20 U	2.20 J	0.20 U
D77227	RFETS	Heterogeneous	116	833	2.00 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	4.40 U	0.40 U
D77285	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	0.27 J	1.18 J	0.20 U	0.20 U	0.20 U	1.00 U	0.20 U

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Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl ethyl Ketone	Chloroform	1,1,1-Tri chloro-ethane	Cyclo-hexane	Carbon Tetra-chloride	Benzene	1,2-Di-chloro-ethane	1-Butanol	Trichloro-ethene
D77621	RFETS	Heterogeneous	0	336	1.34 U	0.27 U	0.27 U	0.27 U	19.30	0.27 U	0.27 U	3.20 U	0.27 U
D80765	RFETS	Heterogeneous	116	833	1.80 U	0.20 U	0.20 U	2.61	0.20 U	0.20 U	0.20 U	2.79 J	0.20 U
D80772	RFETS	Heterogeneous	116	833	9.00 U	1.00 U	47.56	5.62 J	1.00 U	1.00 U	1.00 U	5.00 U	13.18
D80774	RFETS	Heterogeneous	116	833	27.90 U	3.10 U	53.30	3.10 U	127.73	3.10 U	3.10 U	15.50 U	3.10 U
D80776	RFETS	Heterogeneous	116	832	7.59 J	2.48	0.10 U	0.10 U	0.20 J	1.23	0.18 J	5.18 J	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
000365	RFETS	Uncategorized Metal	217	480	17.00 U	15.00	11.00 U	12.00 U	13.00 U	13.00 U	13.00 U	11.00 U
000371	INEL	Graphite	215	300	17.00 U	3.30	0.02 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
000373	INEL	Graphite	215	300	17.00 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.04 U
000384	RFETS	Uncategorized Metal	217	320	5.00 U	0.29	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
000393	INEL	Uncategorized Metal	217	480	17.00 U	4.80	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
000401	RFETS	Inorganic Non-metal	222	371	5.00 U	2.60	0.01 U	0.01 U	0.02 U	0.02 J	0.02 U	0.01 U
000403	INEL	Inorganic Non-metal	218	440	17.00 U	1.50	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
000405	RFETS	Uncategorized Metal	217	480	5.00 U	27.00	0.79 U	0.93 U	0.99 U	0.99 U	0.99 U	0.83 U
000436	INEL	Solidified Organics	212	3	17.00 U	39.00 U	30.00 U	38.00 U	36.00 U	44.00 U	42.00 U	45.00 U
000442	INEL	Solidified Inorganics	213	4	51.00 U	6.50	0.04 U	0.05 U	0.05 U	0.10 J	0.05 U	0.06 U
000446	RFETS	Solidified Inorganics	211	1	5.00 U	0.56	0.01 U	0.01 U	0.01 U	0.02 J	0.01 U	0.01 U
000478	RFETS	Solidified Inorganics	211	1	5.00 U	0.48	0.01 U	0.01 U	0.02 J	0.04 J	0.01 J	0.01 U
000501	INEL	Graphite	215	300	17.00 U	0.03 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.03 U
000558	INEL	Heterogeneous	221	464	17.00 U	16.00	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
000567	RFETS	Inorganic Non-metal	222	371	5.00 U	3.70	1.40 U	1.70 U	1.80 U	1.80 U	1.80 U	1.50 U
000568	RFETS	Solidified Organics	226	432	17.00 U	67.00	0.88 U	1.00 U	1.10 U	1.10 U	1.10 U	0.92 U
000593	INEL	Solidified Inorganics	211	7	17.00 U	2.40	0.01 U	0.02 U	0.02 U	0.05 J	0.02 J	0.02 U
000613	INEL	Graphite	215	300	17.00 U	0.04 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
000630	INEL	Solidified Inorganics	213	4	51.00 U	7.40 B	0.05 U	0.06 U	0.06 U	0.09 J	0.07 U	0.07 U
000648	RFETS	Solidified Inorganics	213	4	70.00 U	1.10	0.03 U	0.03 U	0.03 U	0.08 JD	0.03 U	0.03 U
000675	RFETS	Inorganic Non-metal	218	440	5.00 U	45.00	0.13 U	0.16 U	0.17 U	0.17 U	0.17 U	0.14 U
000823	RFETS	Solidified Inorganics	213	4	120.00 U	4.60	0.02 U	0.02 U	0.02 U	0.05 J	0.02 U	0.02 U
000828	INEL	Graphite	215	300	17.00 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.04 U
001016	INEL	Graphite	215	300	17.00 U	0.08 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.03 U
001024	IN[illegible]	Graphite	215	300	17.00 U	0.07	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	[illegible] U

Table _ _-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
001084	INEL	Solidified Inorganics	213	4	17.00 U	10.00 B	0.02 U	0.02 U	0.03 J	0.07 JB	0.02 U	0.02 U
001139	INEL	Solidified Inorganics	211	7	17.00 U	3.60	0.11 U	0.14 U	0.14 U	0.17 U	0.16 U	0.17 U
001157	INEL	Combustible	223	339	17.00 U	1.80	0.03 U	0.03 U	0.08 U	0.19 J	0.20 J	0.03 U
001161	INEL	Graphite	215	300	17.00 U	0.03 U	0.02 U	0.02 U	0.03 U	0.03 U	0.03 U	0.05 U
001258	RFETS	Solidified Inorganics	211	1	5.00 U	1.60	0.01 U	0.01 U	0.06 J	0.14	0.02 J	0.01 U
001370	INEL	Combustible	223	339	17.00 U	1.10	0.11 U	0.12 U	0.13 U	0.27 J	0.25 J	0.16 U
001377	INEL	Combustible	223	339	17.00 U	7.90	0.03 U	0.03 U	0.37	0.96	0.81	0.03 U
001410	INEL	Solidified Inorganics	214	292	17.00 U	29.00	0.11 U	0.13 U	0.13 U	0.13 U	0.13 U	0.11 U
001437	RFETS	Solidified Inorganics	211	7	5.00 U	2.40	0.01 U	0.01 U	0.01 U	0.03 J	0.01 U	0.01 U
001475	RFETS	Solidified Inorganics	211	1	15.00 J	13.00	0.18 U	0.21 U	0.85 JD	2.80 D	0.22 U	0.18 U
001493	RFETS	Solidified Inorganics	211	1	5.00 U	1.10	0.01 U	0.01 U	0.01 U	0.02 J	0.01 U	0.01 U
001619	INEL	Graphite	215	300	17.00 U	0.04 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
001625	INEL	Graphite	215	300	17.00 U	0.08 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
001633	INEL	Solidified Organics	226	432	17.00 U	4.20 J	0.63 U	0.74 U	0.78 U	0.78 U	0.78 U	0.66 U
001655	INEL	Combustible	223	339	17.00 U	2.40 U	1.70 U	2.00 U	2.10 U	2.10 U	2.10 U	1.80 U
001662	INEL	Graphite	215	300	17.00 U	0.06 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
001663	RFETS	Solidified Organics	226	432	17.00 U	19.00	0.38 U	0.44 U	0.47 U	0.47 U	0.47 U	0.40 U
001667	INEL	Graphite	215	300	17.00 U	0.34 J	0.01 U	0.02 U	0.12 J	0.02 U	0.02 U	0.02 U
001670	RFETS	Salt Waste	224	411	5.00 U	10.00	0.03 U	0.39 U	0.04 U	0.05 J	0.04 U	0.04 U
001677	INEL	Heterogeneous	221	302	17.00 U	9.70	0.73 J	0.42 U	0.39 U	0.48 U	0.46 U	0.49 U
001678	RFETS	Combustible	223	339	5.00 U	18.00	0.11 J	0.10 U	0.11 U	0.20 J	0.11 U	0.09 U
001689	INEL	Heterogeneous	221	302	17.00 U	21.00 E	0.03 U	0.04 U	0.19 J	0.39 J	0.09 J	0.03 U
001692	RFETS	Solidified Organics	226	432	17.00 U	22.00	0.23 U	0.27 U	0.28 U	0.28 U	0.28 U	0.24 U
001695	INEL	Combustible	223	339	1.10 U	23.00	1.40 U	1.70 U	1.80 U	1.80 U	1.80 U	1.50 U
001697	INEL	Graphite	215	300	17.00 U	0.13 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
001751	RFETS	Uncategorized Metal	217	320	5.00 U	2.60	0.01 U	0.01 U	0.04 J	0.13	0.14	0.01 U
001752	INEL	Graphite	215	300	17.00 U	0.06 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
001754	INEL	Uncategorized Metal	217	320	17.00 U	13.00	0.05 U	0.07 U	0.21 J	0.70 J	0.19 J	0.03 U
001757	INEL	Inorganic Non-metal	222	371	17.00 U	0.36	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
001773	INEL	Graphite	215	300	17.00 U	0.05 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
001779	INEL	Graphite	215	300	34.00 U	0.11 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
001784	INEL	Combustible	223	339	17.00 U	1.90	0.03 U	0.03 U	0.05 J	0.09 J	0.09 J	0.03 U
001813	INEL	Solidified Inorganics	213	4	17.00 U	6.60 B	4.00 U	5.10 U	4.80 U	6.00 U	5.60 U	6.00 U
001873	INEL	Solidified Inorganics	214	292	17.00 U	5.70	0.03 U	0.04 U	0.04 U	0.04 U	0.04 U	0.03 U
001899	RFETS	Solidified Inorganics	211	3	5.00 U	170.00	120.00 U	140.00 U	150.00 U	150.00 U	150.00 U	120.00 U
001900	INEL	Solidified Inorganics	214	292	17.00 U	8.00	0.06 J	0.04 U	0.04 U	0.04 U	0.04 U	0.03 U
001919	RFETS	Uncategorized Metal	217	320	5.00 U	0.30	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
001937	RFETS	Solidified Organics	212	3	5.00 U	20.00	14.00 U	16.00 U	18.00 U	18.00 U	18.00 U	15.00 U
002013	RFETS	Solidified Organics	212	3	5.00 U	14.00	10.00 U	12.00 U	12.00 U	12.00 U	12.00 U	10.00 U
002046	INEL	Solidified Organics	212	3	17.00 U	33.00 U	25.00 U	32.00 U	30.00 U	37.00 U	35.00 U	38.00 U
002065	INEL	Solidified Inorganics	214	292	5.00 U	27.00 U	0.09	0.11 U	0.12 U	0.12 U	0.12 U	0.10 U
002084	INEL	Solidified Inorganics	213	4	17.00 U	0.54 JB	0.03 U	0.03 U	0.03 U	0.06 JB	0.04 U	0.04 U
002220	RFETS	Uncategorized Metal	217	481	5.00 U	0.06	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
002222	INEL	Graphite	215	300	17.00 U	0.09 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
002338	RFETS	Inorganic Non-metal	222	371	17.00 U	5.10	0.71 U	0.83 U	0.88 U	0.88 U	0.88 U	0.74 U
002354	INEL	Combustible	223	339	17.00 U	1.30	0.06 U	0.06 U	0.07 U	0.08 U	0.09 J	0.09 U
002363	INEL	Inorganic Non-metal	222	371	17.00 U	0.28 J	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
002365	INEL	Uncategorized Metal	217	480	17.00 U	1.80	0.06 U	0.07 U	0.08 U	0.08 U	0.08 U	0.07 U
002542	IN[illegible]	Solidified Organics	212	3	17.00 U	7.10	5.50 U	6.90 U	6.50 U	8.10 U	7.60 U	8[illegible]
002678	RFETS	Solidified Organics	226	432	17.00 U	6.20	14.00 U	0.95 U	1.00 U	1.00 U	1.00 U	0.84 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
002791	INEL	Inorganic Non-metal	222	371	17.00 U	4.30	0.04 U	0.05 U	0.05 U	0.05 U	0.05 U	0.04 U
002797	RFETS	Solidified Organics	226	432	17.00 U	57.00	0.40 U	0.47 U	0.50 U	0.50 U	0.50 U	0.42 U
002814	RFETS	Solidified Inorganics	211	7	5.00 U	2.60	0.18 U	0.22 U	0.23 U	0.23 U	0.23 U	0.19 U
003017	INEL	Solidified Inorganics	211	1	5.00 U	5.00	0.05 U	0.05 U	0.06 U	0.06 U	0.06 U	0.05 U
003088	INEL	Inorganic Non-metal	222	371	17.00 U	4.20	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
003091	RFETS	Inorganic Non-metal	222	371	17.00 U	0.59	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
003111	INEL	Inorganic Non-metal	222	371	15.00 U	2.00	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
003121	RFETS	Solidified Inorganics	211	7	5.00 U	1.60	0.12 U	0.14 U	0.15 U	0.15 U	0.15 U	0.13 U
003129	RFETS	Solidified Inorganics	211	7	5.00 U	1.80	0.02 U	0.02 U	0.14 J	0.46	0.05 J	0.02 U
003130	RFETS	Solidified Inorganics	211	7	5.00 U	2.20	0.04 U	0.04 U	0.06 JD	0.22 JD	0.05 U	0.04 U
003173	RFETS	Solidified Inorganics	211	7	5.00 U	2.50	0.02 U	0.02 U	0.02 U	0.06 J	0.02 U	0.02 U
003181	RFETS	Solidified Inorganics	211	7	5.00 U	2.00	0.01 U	0.01 U	0.02 U	0.02 U	0.02 U	0.01 U
003189	INEL	Solidified Organics	212	3	17.00 U	72.00 U	56.00 U	71.00 U	66.00 U	82.00 U	78.00 U	83.00 U
003192	RFETS	Solidified Inorganics	211	7	5.00 U	1.70	0.21 U	0.24 U	0.26 U	0.26 U	0.26 U	0.22 U
003215	RFETS	Solidified Inorganics	211	7	5.00 U	2.10	0.01 U	0.01 U	0.02 J	0.08 J	0.02 U	0.01 U
003277	RFETS	Solidified Inorganics	211	1	5.00 U	0.23	0.01 U	0.01 U	0.01 U	0.02 J	0.01 U	0.01 U
003394	RFETS	Solidified Inorganics	211	7	5.00 U	1.80	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
003406	RFETS	Solidified Inorganics	211	7	5.00 U	0.86	0.01 J	0.01 U	0.01 U	0.03 J	0.01 J	0.01 U
003455	RFETS	Solidified Inorganics	211	3	5.00 U	320.00	220.00 U	260.00 U	280.00 U	280.00 U	280.00 U	240.00 U
003547	RFETS	Solidified Inorganics	211	7	5.00 U	0.91	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
003577	RFETS	Solidified Inorganics	211	1	5.00 U	1.70	0.01 U	0.01 U	0.01 U	0.02 J	0.01 U	0.01 U
003854	INEL	Solidified Organics	212	3	17.00 U	33.00 U	26.00 U	32.00 U	30.00 U	38.00 U	36.00 U	38.00 U
003890	INEL	Solidified Inorganics	111	7	5.00 U	1.80	0.03 U	0.03 U	0.03 U	0.03 J	0.03 U	0.03 U
003921	INEL	Solidified Inorganics	111	7	5.00 U	2.00	0.03 U	0.04 U	0.04 U	0.07 J	0.04 U	0.03 U
003991	INEL	Combustible	223	339	17.00 U	0.71 J	0.02 U	0.02 U	0.05 J	0.08 J	0.11 J	0.03 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
003997	INEL	Combustible	223	339	17.00 U	5.10	0.04 U	0.04 U	0.14 J	0.33 J	0.33 J	0.06 U
004099	INEL	Solidified Inorganics	211	1	5.00 U	1.90	0.02 J	0.01 U	0.02 U	0.02 U	0.02 U	0.01 U
004111	RFETS	Salt Waste	224	411	5.00 U	5.00	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
004112	INEL	Graphite	215	300	17.00 U	0.07 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.03 U
004123	INEL	Combustible	223	339	17.00 U	1.50	0.02 U	0.02 U	0.10 J	0.24 J	0.27 J	0.03 U
004125	INEL	Uncategorized Metal	217	480	17.00 U	1.80	0.03 U	0.03 U	0.03 U	0.03 J	0.03 U	0.03 U
004150	INEL	Graphite	215	300	15.00 U	0.02 U	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
004160	INEL	Combustible	223	339	17.00 U	130.00 U	110.00 U	120.00 U	130.00 U	150.00 U	130.00 U	160.00 U
004166	INEL	Inorganic Non-metal	222	371	17.00 U	0.31 J	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
004186	INEL	Combustible	223	339	17.00 U	2.00	0.02 U	0.02 U	0.06 J	0.17 J	0.13 J	0.03 U
004195	RFETS	Salt Waste	224	411	5.00 U	1.20	0.01 U	0.01 U	0.01 U	0.01 J	0.01 U	0.01 U
004196	INEL	Graphite	215	300	17.00 U	0.26 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.04 U
004206	INEL	Combustible	223	339	17.00 U	1.40	0.02 U	0.02 U	0.06 J	0.09 J	0.12 J	0.02 U
004208	INEL	Graphite	215	300	51.00 U	0.18 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.03 U
004283	INEL	Solidified Inorganics	211	1	17.00 U	1.10	0.01 U	0.02 U	0.14 J	0.40 J	0.07 J	0.02 U
004326	INEL	Solidified Inorganics	213	4	17.00 U	2.70 B	0.01 U	0.02 U	0.09 J	0.35 JB	0.13 J	0.02 U
004393	INEL	Solidified Inorganics	211	1	5.00 U	2.10	0.02 U	0.02 U	0.02 U	0.03 J	0.02 U	0.02 U
004410	INEL	Solidified Inorganics	211	1	5.00 U	4.10	0.03 U	0.03 U	0.03 U	0.04 J	0.03 U	0.03 U
004495	INEL	Solidified Inorganics	213	4	17.00 U	2.50	0.01 U	0.02 U	0.02 U	0.02 J	0.02 U	0.02 U
004516	INEL	Solidified Inorganics	211	1	5.00 U	5.40	0.03 U	0.03 U	0.03 U	0.10 J	0.03 U	0.03 U
004884	INEL	Solidified Inorganics	213	4	17.00 U	5.10	0.02 U	0.02 U	0.04 J	0.13 J	0.03 J	0.03 U
004963	INEL	Combustible	223	339	17.00 U	10.00	0.06 U	0.06 U	0.21 J	0.57 J	0.23 J	0.09 U
004968	RFETS	Uncategorized Metal	217	320	5.00 U	170.00	0.49 U	0.58 U	0.62 U	0.62 U	0.62 U	0.52 U
004981	RF[illegible]	Uncategorized Metal	217	320	5.00 U	0.22	0.01 U	0.01 U	0.01 U	0.01 J	0.01 U	0.[illegible] J
004988	RFETS	Salt Waste	224	411	5.00 U	6.50	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U

Table _-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
005006	RFETS	Salt Waste	224	411	5.00 U	5.00	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
005012	INEL	Combustible	223	339	17.00 U	0.31 J	0.01 U	0.02 U	0.04 J	0.05 J	0.02 J	0.02 U
005015	INEL	Solidified Organics	226	432	17.00 U	4.30 J	1.30 U	1.50 U	1.60 U	1.60 U	1.60 U	1.30 U
005235	INEL	Solidified Organics	226	432	17.00 U	5.70	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
005262	INEL	Solidified Organics	212	3	17.00 U	200.00 U	160.00 U	200.00 U	190.00 U	230.00 U	220.00 U	240.00 U
005358	INEL	Solidified Inorganics	211	1	17.00 U	6.90	0.01 U	0.02 U	0.45 J	1.70	0.30 J	0.02 U
005398	INEL	Solidified Inorganics	211	1	5.00 U	3.60	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
005415	INEL	Solidified Inorganics	211	1	5.00 U	5.90	0.03 U	0.03 U	0.03 U	0.07 J	0.03 U	0.03 U
005530	INEL	Graphite	215	303	15.00 U	0.98 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.04 U
005535	INEL	Solidified Organics	226	432	17.00 U	15.00 D	0.05 U	0.06 U	0.06 U	0.06 U	0.06 U	0.05 U
005735	INEL	Solidified Inorganics	211	7	5.00 U	3.80	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
005738	INEL	Solidified Inorganics	211	7	5.00 U	3.40	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
006242	INEL	Inorganic Non-metal	222	371	17.00 U	1.70	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
006252	RFETS	Lead/Cadmium Metal	123	339	5.00 U	5.80	3.30 U	3.90 U	4.20 U	4.20 U	4.20 U	3.50 U
006325	RFETS	Solidified Inorganics	213	4	100.00 U	3.30	0.01 U	0.01 U	0.02 J	0.05 J	0.02 J	0.01 U
006669	INEL	Solidified Inorganics	214	292	5.00 U	38.00	0.13 U	0.15 U	0.16 U	0.16 U	0.16 U	0.13 U
006773	RFETS	Solidified Inorganics	213	4	120.00 U	3.40	0.09 U	0.11 U	0.12 U	0.14 J	0.12 U	0.10 U
006857	INEL	Combustible	223	339	18.00 U	7.20	0.02 U	0.02 U	0.02 J	0.06 J	0.05 J	0.03 U
006865	RFETS	Solidified Organics	226	432	5.00 U	18.00	0.07 U	0.08 U	0.08 U	0.08 U	0.08 U	0.07 U
006876	INEL	Filter	219	335	17.00 U	0.75 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.03 U
006879	INEL	Solidified Organics	226	432	17.00 U	19.00	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
006886	INEL	Solidified Organics	226	432	17.00 U	6.20	0.82 J	0.33 U	0.34 U	0.38 J	0.34 U	0.29 U
007034	INEL	Combustible	216	337	17.00 U	3.30	1.80 U	2.10 U	2.20 U	2.20 U	2.20 U	1.90 U
007146	INEL	Inorganic Non-metal	222	371	17.00 U	2.10 U	3.30	1.70 U	1.80 U	1.80 U	1.80 U	1.50 U
007170	INEL	Combustible	216	337	17.00 U	0.94 J	0.37 J	0.34 U	0.36 U	0.41 U	0.37 U	0.68 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
007231	INEL	Filter	219	338	17.00 U	0.29 J	0.67 J	0.15 U	0.16 U	0.19 U	0.17 U	0.20 U
007511	INEL	Inorganic Non-metal	122	374	17.00 U	2.90	0.03 U	0.04 U	0.16 J	0.58	0.29 J	0.03 U
007518	INEL	Inorganic Non-metal	122	374	17.00 U	6.60	0.05 U	0.06 U	0.06 U	0.13 J	0.08 J	0.05 U
007667	INEL	Salt Waste	124	411	5.00 U	0.43	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
007920	INEL	Filter	121	302	17.00 U	53.00	0.20 U	0.24 U	0.25 U	0.25 U	0.25 U	0.21 U
008203	INEL	Inorganic Non-metal	118	440	17.00 U	13.00	0.05 U	0.06 U	0.06 U	0.06 U	0.06 U	0.05 U
008207	INEL	Heterogeneous	116	336	17.00 U	2.30	0.06 U	0.07 U	0.08 U	0.08 U	0.08 U	0.07 U
008218	INEL	Heterogeneous	116	330	17.00 U	2.90	0.06 U	0.07 U	0.08 U	0.08 U	0.08 U	0.07 U
008269	INEL	Uncategorized Metal	117	320	17.00 U	34.00 D	0.16 U	0.19 U	0.28 JD	0.85 JD	0.22 JD	0.17 U
008287	INEL	Inorganic Non-metal	122	374	17.00 U	1.00	0.03 U	0.03 U	1.50	5.10	2.30	0.03 U
008359	INEL	Heterogeneous	116	330	17.00 U	40.00	0.16 U	0.19 U	0.20 U	0.20 U	0.20 U	0.17 U
008383	INEL	Lead/Cadmium Metal	123	339	5.00 U	12.00 J	4.40 U	5.20 U	5.50 U	5.50 U	5.50 U	4.60 U
008848	INEL	Inorganic Non-metal	218	440	17.00 U	5.70	0.14 U	0.18 U	0.17 U	0.21 U	0.20 U	0.22 J
008859	INEL	Inorganic Non-metal	218	440	17.00 U	7.40	0.38 U	0.44 U	0.47 U	0.76 J	0.47 U	0.40 U
008860	INEL	Uncategorized Metal	217	480	17.00 U	8.40	0.96 U	1.10 U	1.20 U	1.20 U	1.20 U	1.00 U
008864	INEL	Uncategorized Metal	217	480	17.00 U	2.40	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
008872	INEL	Solidified Inorganics	214	292	5.00 U	6.60	0.03 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U
008874	RFETS	Uncategorized Metal	217	480	5.00 U	42.00	30.00 U	35.00 U	37.00 U	37.00 U	37.00 U	31.00 U
008878	INEL	Uncategorized Metal	217	480	17.00 U	5.80 U	4.00 U	4.70 U	5.00 U	5.00 U	5.00 U	4.20 U
008880	RFETS	Graphite	115	312	5.00 U	9.40	1.10 U	1.40 U	1.40 U	1.40 U	1.40 U	1.20 U
009006	INEL	Solidified Inorganics	211	7	18.00 U	1.30	0.04 J	0.02 U	0.05 J	0.15 J	0.04 J	0.02 U
009011	RFETS	Solidified Inorganics	211	7	5.00 U	1.90	0.02 J	0.01 U	0.05 J	0.19	0.02 J	0.01 U
009061	RFETS	Inorganic Non-metal	218	440	5.00 U	0.41	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
009180	IN[illegible]	Combustible	223	339	17.00 U	5.30 [illegible]	0.69 U	0.76 U	0.81 U	1.00	0.83 U	[illegible] U
009225	INEL	Uncategorized Metal	217	481	18.00 U	0.04 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
009252	INEL	Combustible	223	339	17.00 U	27.00 J	18.00 U	21.00 U	22.00 U	22.00 U	22.00 U	18.00 U
009296	INEL	Combustible	223	339	17.00 U	16.00	2.50 U	3.00 U	3.10 U	3.10 U	3.10 U	2.60 U
009299	INEL	Combustible	223	339	17.00 U	0.32 J	0.02 U	0.02 U	0.04 J	0.07 J	0.08 J	0.03 U
009399	INEL	Inorganic Non-metal	218	440	17.00 U	2.10	0.33 U	0.38 U	0.41 U	0.41 U	0.41 U	0.34 U
009422	RFETS	Combustible	216	337	5.00 U	8.50	4.70 U	5.50 U	5.90 U	5.90 U	5.90 U	4.90 U
009423	INEL	Combustible	216	337	17.00 U	3.60	1.30 U	1.60 U	1.50 U	1.90 U	1.80 U	1.90 U
009435	INEL	Combustible	216	337	17.00 U	6.40	0.33 U	0.38 U	0.41 U	0.41 U	0.41 U	0.34 U
009449	INEL	Inorganic Non-metal	218	440	17.00 U	15.00 E	0.04 U	0.04 U	0.05 U	0.10 J	0.05 U	0.04 U
009471	INEL	Combustible	216	337	18.00 U	0.85 J	0.07 U	0.08 U	0.08 U	0.09 U	0.08 U	0.15 U
009475	INEL	Inorganic Non-metal	218	442	17.00 U	0.65 U	0.51 U	0.64 U	0.60 U	0.74 U	0.70 U	0.75 U
009489	INEL	Combustible	216	337	1.10 U	0.94 J	0.18 U	0.20 U	0.21 U	0.24 U	0.22 U	0.40 U
009587	INEL	Uncategorized Metal	117	320	5.00 U	1.20	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
009591	INEL	Inorganic Non-metal	118	440	17.00 U	2.00	0.03 U	0.04 U	0.04 U	0.04 U	0.04 U	0.03 U
009592	INEL	Inorganic Non-metal	118	440	17.00 U	11.00	0.06 U	0.07 U	0.08 U	0.08 U	0.08 U	0.07 U
009596	INEL	Uncategorized Metal	117	320	17.00 U	8.80	0.11 U	0.14 U	0.14 U	0.14 U	0.14 U	0.12 U
009599	INEL	Inorganic Non-metal	118	440	17.00 U	1.30	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
009602	INEL	Inorganic Non-metal	218	442	17.00 U	2.40	1.70 U	2.00 U	2.10 U	2.10 U	2.10 U	1.80 U
009694	INEL	Graphite	215	300	17.00 U	0.04 J	0.01 U	0.02 U	0.02 U	0.03 J	0.02 J	0.02 U
009735	INEL	Graphite	215	300	17.00 U	0.04 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
009773	INEL	Combustible	223	339	17.00 U	7.00	3.80 U	4.80 U	4.50 U	5.60 U	5.30 U	5.60 U
009787	RFETS	Solidified Organics	212	3	5.00 U	220.00	160.00 U	180.00 U	190.00 U	190.00 U	190.00 U	160.00 U
009873	RFETS	Solidified Inorganics	211	1	5.00 U	3.00	0.04 U	0.05 U	0.05 U	0.05 U	0.05 U	0.04 U
010216	INEL	Filter	219	338	17.00 U	1.00 U	2.80	0.96 U	1.00 U	1.20 U	1.00 U	1.30 U
010224	INEL	Filter	219	338	17.00 U	1.20	1.20	0.29 U	0.31 U	0.35 U	0.32 U	0.38 U
010230	INEL	Heterogeneous	216	330	18.00 U	11.00	1.50	0.15 U	0.16 U	0.19 U	0.17 U	0.20 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
010273	INEL	Combustible	216	337	18.00 U	2.00	0.13 U	0.14 U	0.15 U	0.17 U	0.15 U	0.28 U
010295	INEL	Inorganic Non-metal	218	442	17.00 U	0.60 J	0.05 U	0.06 U	0.06 U	0.06 U	0.06 U	0.05 U
010305	RFETS	Inorganic Non-metal	218	442	5.00 U	8.40	0.59 U	0.70 U	0.74 U	0.74 U	0.74 U	0.62 U
010364	RFETS	Combustible	216	337	5.00 U	4.20	0.75 U	0.88 U	0.94 U	0.94 U	0.94 U	0.79 U
010371	INEL	Combustible	216	337	17.00 U	22.00	0.35 U	0.33 U	0.35 U	0.44 U	0.37 U	0.29 U
010407	RFETS	Uncategorized Metal	217	480	5.00 U	25.00	0.10 U	0.12 U	0.39 J	0.89 J	0.43 J	0.11 U
010411	INEL	Combustible	216	337	15.00 U	18.00	1.70 U	2.00 U	2.10 U	2.10 U	2.10 U	1.80 U
010415	INEL	Inorganic Non-metal	218	442	17.00 U	0.20 J	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
010426	INEL	Inorganic Non-metal	218	442	17.00 U	0.11 JB	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
010463	INEL	Solidified Inorganics	213	4	34.00 U	2.20 J	0.25 U	0.30 U	0.31 U	0.31 U	0.31 U	0.26 U
010487	INEL	Salt Waste	224	414	17.00 U	5.70 J	0.46 U	0.54 U	0.57 U	0.57 U	0.57 U	0.48 U
010492	INEL	Uncategorized Metal	217	480	17.00 U	7.10	0.49 U	0.58 U	0.61 U	0.61 U	0.61 U	0.52 U
010498	INEL	Uncategorized Metal	217	480	17.00 U	4.60	0.03 U	0.04 U	0.04 U	0.05 U	0.04 U	0.05 U
010510	RFETS	Heterogeneous	216	336	5.00 U	12.00	1.60 J	1.70 U	1.80 U	1.80 U	1.80 U	1.50 U
010546	RFETS	Heterogeneous	216	330	10.00 U	57.00	39.00 U	46.00 U	49.00 U	49.00 U	49.00 U	41.00 U
010578	INEL	Solidified Organics	226	432	17.00 U	9.90 J	1.50 J	1.00 U	1.10 U	1.10 U	1.10 U	0.90 U
010588	RFETS	Solidified Inorganics	211	2	5.00 U	1.10	11.00	0.87 U	0.92 U	0.92 U	0.92 U	0.78 U
010663	INEL	Combustible	216	337	18.00 U	2.60	2.60	0.49 U	0.53 U	0.61 U	0.54 U	1.00 U
010676	INEL	Heterogeneous	216	330	17.00 U	7.20	1.90	0.40 U	0.42 U	0.48 U	0.43 U	0.80 U
010800	INEL	Filter	219	338	17.00 U	1.50	0.37 J	0.13 U	0.14 U	0.16 U	0.15 U	0.18 U
010807	INEL	Combustible	216	337	17.00 U	4.90	1.10 U	1.30 U	1.40 U	1.40 U	1.40 U	1.20 U
010808	INEL	Combustible	216	337	18.00 U	4.10	0.56 J	0.34 U	0.32 U	0.58 J	0.37 U	0.40 U
010814	RFETS	Solidified Inorganics	211	1	5.00 U	0.83	41.00	0.35 U	0.37 U	0.37 U	0.37 U	0.31 U
010837	II	Solidified Organics	226	432	17.00 U	1.70	0.80 J	0.44 U	0.47 U	0.47 U	0.47 U	U
010848	INEL	Filter	219	338	17.00 U	3.20	2.20	0.37 U	0.40 U	0.46 U	0.41 U	0.50 U

Table .-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
010883	INEL	Solidified Organics	226	432	17.00 U	7.20	8.60	1.20 U	1.20 U	1.20 U	1.20 U	1.00 U
010921	INEL	Inorganic Non-metal	222	371	18.00 U	0.12 U	0.13 J	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
011004	INEL	Uncategorized Metal	217	480	17.00 U	1.00	0.03 U	0.03 U	0.05 J	0.09 J	0.04 J	0.03 U
011021	INEL	Solidified Organics	226	432	17.00 U	23.00	0.15 U	0.18 U	0.19 U	0.19 U	0.19 U	0.16 U
011042	INEL	Inorganic Non-metal	218	442	17.00 U	2.90	0.53 U	0.62 U	0.66 U	0.66 U	0.66 U	0.55 U
011044	INEL	Inorganic Non-metal	218	440	17.00 U	3.50	0.30 U	0.36 U	0.38 U	0.38 U	0.38 U	0.32 U
011067	RFETS	Solidified Inorganics	213	4	5.00 U	2.20	0.99 U	1.20 U	1.20 U	1.20 U	1.20 U	1.00 U
011102	RFETS	Solidified Inorganics	211	1	5.00 U	1.10	0.24 U	0.28 U	0.30 U	0.30 U	0.30 U	0.25 U
011109	INEL	Solidified Inorganics	211	1	17.00 U	0.94 J	2.00	0.19 U	0.18 U	0.22 U	0.21 U	0.22 U
011147	INEL	Solidified Inorganics	213	4	17.00 U	3.20 B	0.17 U	0.22 U	0.21 U	0.26 U	0.24 U	0.26 U
011173	INEL	Uncategorized Metal	217	480	17.00 U	2.90	0.21 J	0.05 U	0.05 U	0.06 U	0.06 U	0.06 U
011194	INEL	Inorganic Non-metal	218	442	17.00 U	2.00	0.06 U	0.07 U	0.08 U	0.08 U	0.08 U	0.07 U
011393	INEL	Uncategorized Metal	217	480	17.00 U	4.90	0.13 U	0.15 U	0.16 U	0.18 J	0.16 U	0.13 U
011416	INEL	Combustible	216	337	17.00 U	0.80 U	0.55 U	0.65 U	0.69 U	0.69 U	0.69 U	0.58 U
011433	INEL	Heterogeneous	216	330	17.00 U	3.10	0.88 J	0.49 U	0.53 U	0.61 U	0.54 U	1.00 U
011498	RFETS	Solidified Organics	226	432	17.00 U	3.90	22.00	1.70 U	1.80 U	1.80 U	1.80 U	1.50 U
011529	INEL	Uncategorized Metal	217	480	17.00 U	0.04 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
011601	INEL	Heterogeneous	216	336	17.00 U	6.20	1.00 U	1.20 U	1.20 U	1.40 U	1.30 U	1.50 U
011607	INEL	Heterogeneous	216	330	17.00 U	0.65 J	0.06 J	0.03 U	3.40	8.00	1.60	0.04 U
011637	RFETS	Filter	219	338	5.00 U	2.70	1.90 JD	0.87 U	0.92 U	0.92 U	0.92 U	0.78 U
011735	INEL	Heterogeneous	216	330	17.00 U	4.60	1.00	0.89 U	0.94 U	0.94 U	0.94 U	0.79 U
011749	INEL	Inorganic Non-metal	225	441	17.00 U	0.31 U	12.00	0.25 U	0.27 U	0.27 U	0.27 U	0.22 U
011785	RFETS	Solidified Inorganics	211	1	5.00 U	4.40	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
012021	INEL	Solidified Inorganics	211	1	17.00 U	1.40 J	0.33 U	0.38 U	0.41 U	0.41 U	0.41 U	0.34 U
012108	INEL	Solidified Inorganics	214	292	17.00 U	4.10 J	0.33 U	0.38 U	0.41 U	0.41 U	0.41 U	0.34 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
012111	INEL	Combustible	216	337	17.00 U	2.50	1.40 U	1.60 U	2.10	5.10	1.70 U	3.20 U
012215	INEL	Uncategorized Metal	217	480	17.00 U	7.00	0.35 U	0.41 U	0.44 U	0.44 U	0.44 U	0.37 U
012313	INEL	Heterogeneous	216	336	17.00 U	2.10	0.68 J	0.59 U	0.63 U	0.73 U	0.65 U	1.20 U
012320	INEL	Heterogeneous	216	336	17.00 U	13.00	5.20	2.00 U	2.10 U	2.10 U	2.10 U	1.80 U
012356	INEL	Filter	219	338	17.00 U	2.40	1.30	0.22 U	0.21 U	0.26 U	0.25 U	0.26 U
012357	RFETS	Uncategorized Metal	217	480	7.10 J	4.00	34.00 J	3.10 U	3.30 U	3.30 U	3.30 U	2.80 U
012433	INEL	Filter	219	338	17.00 U	1.30	2.00	0.19 U	0.20 U	0.24 U	0.21 U	0.25 U
012469	RFETS	Solidified Inorganics	211	1	5.00 U	0.75	1.30 J	0.36 U	0.38 U	0.38 U	0.38 U	0.32 U
012471	RFETS	Filter	219	338	5.00 U	2.50	0.29 J	0.18 U	0.20 U	0.20 U	0.20 U	0.16 U
012487	INEL	Inorganic Non-metal	218	440	17.00 U	0.58 JB	1.70	0.02 U	0.03 J	0.10 JB	0.05 U	0.02 U
012494	INEL	Heterogeneous	216	330	17.00 U	6.50	2.30	1.20 U	2.20	5.50	1.30 U	1.10 U
012541	INEL	Inorganic Non-metal	218	442	17.00 U	2.70	0.03 U	0.03 U	0.03 U	0.06 J	0.04 J	0.03 U
012553	INEL	Solidified Inorganics	211	1	17.00 U	0.15 J	0.03 U	0.03 U	0.03 U	0.03 U	0.05 J	0.03 U
012571	INEL	Uncategorized Metal	217	320	1.10 U	0.03 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
012611	INEL	Solidified Inorganics	211	1	17.00 U	2.40 J	0.53 U	0.62 U	0.66 U	0.66 U	0.66 U	0.55 U
012634	INEL	Solidified Inorganics	211	1	17.00 U	2.60 J	1.40 U	1.70 U	1.80 U	1.80 U	1.80 U	1.50 U
012749	INEL	Solidified Inorganics	211	1	17.00 U	0.58 J	0.28 U	0.33 U	0.34 U	0.34 U	0.34 U	0.29 U
012766	INEL	Heterogeneous	216	336	17.00 U	4.80	2.50 U	3.00 U	3.10 U	3.10 U	3.10 U	2.60 U
012802	INEL	Combustible	216	337	17.00 U	15.00	3.40	1.20 U	1.10 U	1.40 U	1.30 U	1.40 U
012875	RFETS	Solidified Organics	226	432	17.00 U	6.90	3.40 U	4.00 U	4.20 U	4.20 U	4.20 U	3.60 U
012878	INEL	Uncategorized Metal	217	480	17.00 U	2.20	1.20	0.61 U	0.57 U	0.71 U	0.67 U	0.71 U
012891	INEL	Heterogeneous	216	330	17.00 U	4.70	0.29 U	0.34 U	0.36 U	1.40	0.46 J	0.30 U
012902	INEL	Filter	219	338	17.00 U	0.03 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.03 U
012920	II	Inorganic Non-metal	222	371	17.00 U	1.40	1.00 U	1.20 U	1.30 U	1.30 U	1.30 U	U
012985	INEL	Inorganic Non-metal	222	371	17.00 U	5.80 J	14.00 J	2.00 U	2.10 U	2.10 U	2.10 U	1.80 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
012986	INEL	Heterogeneous	221	302	1.10 U	22.00	2.60	0.53 U	0.50 U	0.61 U	0.58 U	0.62 U
012998	INEL	Combustible	216	337	17.00 U	3.90	10.00	0.68 U	0.72 U	0.72 U	0.72 U	0.61 U
013106	INEL	Solidified Inorganics	111	7	5.00 U	0.84	0.01 U	0.01 U	0.02 U	0.04 J	0.02 U	0.01 U
013229	RFETS	Solidified Organics	226	432	17.00 U	21.00	0.13 U	0.15 U	0.16 U	0.16 U	0.16 U	0.13 U
013231	INEL	Graphite	215	300	17.00 U	0.03 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.03 U
013252	INEL	Inorganic Non-metal	222	371	17.00 U	3.00	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
013266	INEL	Combustible	223	339	17.00 U	14.00	0.35 U	0.41 U	0.44 U	0.44 U	0.44 U	0.37 U
013269	INEL	Inorganic Non-metal	218	440	17.00 U	12.00	0.04 U	0.05 U	0.05 U	0.06 U	0.06 U	0.06 U
013313	INEL	Inorganic Non-metal	218	440	17.00 U	3.30	0.03 U	0.03 U	0.20 J	0.54 J	0.15 J	0.03 U
013331	INEL	Salt Waste	124	411	17.00 U	12.00	0.06 U	0.07 U	0.08 U	0.08 U	0.08 U	0.07 U
013342	INEL	Inorganic Non-metal	218	440	17.00 U	23.00 E	0.01 U	0.02 U	0.02 J	0.04 J	0.02 U	0.02 U
013346	RFETS	Inorganic Non-metal	222	371	5.00 U	3.70	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
013618	INEL	Heterogeneous	216	330	17.00 U	11.00	1.70 U	2.00 U	2.10 U	2.10 U	2.10 U	1.80 U
013677	INEL	Filter	219	338	17.00 U	0.41 J	0.17 J	0.05 U	0.05 U	0.06 U	0.05 U	0.06 U
013751	INEL	Uncategorized Metal	217	480	17.00 U	1.60	4.30	0.89 U	0.94 U	0.94 U	0.94 U	0.79 U
013763	INEL	Combustible	223	339	17.00 U	13.00 U	14.00 U	13.00 U	14.00 U	18.00 U	15.00 U	12.00 U
013773	RFETS	Solidified Inorganics	111	7	5.00 U	2.50	0.07 U	0.08 U	0.34 J	1.30	0.30 J	0.07 U
013818	RFETS	Solidified Inorganics	211	1	7.10 J	2.50	0.02 U	0.02 U	0.09 J	0.35	0.07 J	0.02 U
013820	RFETS	Solidified Inorganics	211	1	11.00 U	3.40	0.02 U	0.03 U	0.03 U	0.05 JB	0.03 U	0.02 U
013847	INEL	Graphite	215	300	17.00 U	0.06 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
013860	INEL	Combustible	223	339	17.00 U	1.50	0.06 U	0.06 U	0.07 U	0.08 U	0.07 U	0.09 U
013876	RFETS	Solidified Inorganics	211	7	5.00 U	0.84	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
014007	INEL	Solidified Inorganics	211	1	17.00 U	4.10	0.02 U	0.02 U	0.03 U	0.03 U	0.03 U	0.03 U
014009	INEL	Solidified Inorganics	211	7	17.00 U	2.20	0.05 U	0.06 U	0.06 U	0.13 J	0.07 U	0.08 U
014010	INEL	Solidified Inorganics	211	7	17.00 U	0.64 J	0.01 U	0.02 U	0.03 J	0.09 J	0.02 J	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
014127	RFETS	Solidified Inorganics	211	7	5.00 U	1.50	0.02 U	0.02 U	0.04 J	0.14 J	0.02 J	0.02 U
014170	INEL	Solidified Inorganics	211	7	5.00 U	2.40	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
014330	INEL	Graphite	215	303	17.00 U	0.47 J	0.04 U	0.04 U	0.04 U	0.05 U	0.04 U	0.08 U
014334	INEL	Filter	219	335	17.00 U	0.10 J	0.06 U	0.05 U	0.06 U	0.07 U	0.06 U	0.05 U
014339	INEL	Solidified Organics	226	432	17.00 U	15.00 D	0.05 U	0.06 U	0.06 U	0.06 U	0.06 U	0.05 U
014342	INEL	Graphite	215	303	17.00 U	0.12 J	0.06 U	0.06 U	0.07 U	0.08 U	0.07 U	0.13 U
014345	INEL	Solidified Organics	226	432	17.00 U	14.00	0.04 U	0.05 U	0.05 U	0.05 U	0.05 U	0.04 U
014346	INEL	Combustible	223	339	17.00 U	4.00	0.07 J	0.02 U	0.04 J	0.09 J	0.07 J	0.03 U
014348	INEL	Graphite	215	300	17.00 U	0.24 J	0.01 U	0.02 U	0.02 U	0.02 J	0.02 U	0.02 U
014354	RFETS	Uncategorized Metal	217	481	5.00 U	0.14	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
014357	INEL	Combustible	223	339	17.00 U	16.00	14.00 U	13.00 U	14.00 U	18.00 U	15.00 U	12.00 U
014387	INEL	Solidified Inorganics	211	7	17.00 U	4.60	0.01 U	0.02 U	0.11 J	0.33 J	0.06 J	0.02 U
014466	INEL	Heterogeneous	221	302	17.00 U	4.80	2.00 J	0.33 U	0.35 U	0.35 U	0.35 U	0.29 U
014484	INEL	Graphite	215	300	17.00 U	0.26 J	0.01 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
014502	RFETS	Solidified Inorganics	211	1	5.00 U	2.00	0.01 U	0.01 U	0.01 U	0.03 J	0.01 J	0.01 U
014504	RFETS	Solidified Inorganics	211	1	5.00 U	5.40	0.03 U	0.03 U	0.03 U	0.04 J	0.03 U	0.46 U
014773	INEL	Solidified Inorganics	214	292	5.00 U	11.00	0.04 U	0.05 U	0.06 U	0.06 U	0.06 U	0.05 U
015228	RFETS	Solidified Organics	226	432	17.00 U	4.20	0.15 U	0.18 U	0.19 U	0.26 J	0.19 U	0.16 U
015231	INEL	Inorganic Non-metal	218	440	17.00 U	2.10	0.03 U	0.03 U	0.03 J	0.05 J	0.03 U	0.03 U
015241	INEL	Inorganic Non-metal	218	442	17.00 U	0.33 J	0.04 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
015249	INEL	Graphite	215	300	17.00 U	0.04 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.04 U
015262	RFETS	Solidified Organics	226	432	17.00 U	12.00	1.40 U	1.70 U	1.80 U	1.80 U	1.80 U	1.50 U
015267	INEL	Uncategorized Metal	217	480	17.00 U	11.00	1.30 U	1.50 U	1.60 U	1.60 U	1.60 U	1.30 U
015338	INEL	Solidified Inorganics	211	7	17.00 U	3.50	0.09 J	0.02 U	0.08 J	0.29 J	0.03 J	[illegible] U
015434	RFETS	Solidified Organics	226	432	17.00 U	13.00	0.04 U	0.04 U	0.05 U	0.08 J	0.05 U	0.04 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
022511	INEL	Uncategorized Metal	217	480	18.00 U	2.70	0.78 U	0.92 U	0.97 U	0.97 U	0.97 U	0.82 U
022513	INEL	Solidified Organics	212	1	17.00 U	0.81 J	0.23 U	0.27 U	0.28 U	0.28 U	0.28 U	0.24 U
022517	INEL	Solidified Organics	226	432	17.00 U	16.00	0.10 U	0.11 U	0.12 U	0.12 U	0.12 U	0.10 U
022539	INEL	Solidified Organics	226	432	17.00 U	15.00	0.10 U	0.11 U	0.12 U	0.12 U	0.12 U	0.10 U
022549	INEL	Uncategorized Metal	217	480	18.00 U	3.30	1.30 U	1.50 U	1.60 U	1.60 U	1.60 U	1.30 U
022552	INEL	Inorganic Non-metal	218	442	17.00 U	0.61 J	0.29 U	0.34 U	0.36 U	0.36 U	0.36 U	0.30 U
022557	INEL	Uncategorized Metal	217	480	17.00 U	17.00	0.45 U	0.56 U	0.53 U	0.66 U	0.62 U	0.66 U
022595	INEL	Solidified Inorganics	211	1	15.00 U	1.10	0.22 U	0.27 U	0.26 U	0.32 U	0.30 U	0.32 U
022600	RFETS	Solidified Inorganics	213	4	130.00 U	2.10	0.23 U	0.27 U	0.29 U	0.29 U	0.29 U	0.24 U
022780	INEL	Solidified Inorganics	211	7	18.00 U	2.80	1.10	0.40 U	0.38 U	0.46 U	0.44 U	0.47 U
022789	INEL	Solidified Inorganics	211	7	17.00 U	0.80 U	0.70 J	0.66 U	0.70 U	0.70 U	0.70 U	0.58 U
022790	INEL	Solidified Inorganics	214	292	18.00 U	5.00 B	0.15 U	0.19 U	0.18 U	0.27 JB	0.21 U	0.23 U
022803	INEL	Inorganic Non-metal	222	371	15.00 U	0.76 U	0.53 U	0.62 U	0.66 U	0.66 U	0.66 U	0.55 U
022807	INEL	Salt Waste	224	414	17.00 U	4.00	0.10 U	0.12 U	0.15 J	0.30 J	0.13 U	0.11 U
022811	INEL	Solidified Inorganics	211	7	17.00 U	1.80	1.30	0.34 U	0.32 U	0.39 U	0.37 U	0.39 U
022833	INEL	Solidified Inorganics	211	7	15.00 U	3.90	1.90 U	2.40 U	2.30 U	2.80 U	2.60 U	2.80 U
022841	INEL	Solidified Inorganics	211	7	17.00 U	3.10	1.00 U	1.30 U	1.20 U	1.50 U	1.40 U	1.50 U
022850	INEL	Solidified Inorganics	211	7	17.00 U	2.70	1.70	0.80 U	0.75 U	0.93 U	0.88 U	0.94 U
022874	INEL	Inorganic Non-metal	222	371	17.00 U	0.88 J	0.18 U	0.21 U	0.22 U	0.22 U	0.22 U	0.19 U
022894	INEL	Solidified Inorganics	211	1	15.00 U	1.20	0.16 J	0.11 U	0.89 J	1.80	0.78 J	0.13 U
022923	INEL	Inorganic Non-metal	218	440	17.00 U	6.90	0.33 U	0.38 U	0.41 U	0.41 U	0.41 U	0.34 U
023005	INEL	Solidified Inorganics	211	7	17.00 U	1.70 J	1.30 J	0.18 U	0.30 J	0.55 J	0.19 U	0.16 U
023027	RFETS	Uncategorized Metal	217	480	5.00 U	0.46	0.43 J	0.18 U	0.18 U	0.47 J	0.36 J	0.16 U
023041	RFETS	Inorganic Non-metal	222	371	5.00 U	0.42	0.24 U	0.28 U	0.30 U	0.30 U	0.30 U	0.25 U
023046	RFETS	Solidified Inorganics	211	7	5.00 U	2.50	0.66 J	0.50 U	0.53 U	0.53 U	0.53 U	0.44 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
023048	RFETS	Solidified Organics	226	432	17.00 U	22.00	0.35 U	0.41 U	0.44 U	0.44 U	0.44 U	0.37 U
023062	INEL	Solidified Inorganics	211	7	17.00 U	1.20 J	0.58 J	0.18 U	0.19 U	0.19 U	0.19 U	0.16 U
023211	INEL	Filter	119	376	17.00 U	9.30	0.05 U	0.06 U	0.06 U	0.17 J	0.08 J	0.05 U
023212	RFETS	Uncategorized Metal	217	480	5.00 U	7.40	0.49 U	0.58 U	0.62 U	0.62 U	0.62 U	0.52 U
023227	INEL	Uncategorized Metal	217	480	17.00 U	2.50	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
023229	INEL	Combustible	216	337	17.00 U	4.00 J	0.50 U	0.59 U	0.63 U	0.63 U	0.63 U	0.53 U
023235	RFETS	Heterogeneous	216	336	5.00 U	16.00	0.13 U	0.16 U	0.32 J	0.65 J	0.17 U	0.14 U
023238	INEL	Solidified Inorganics	211	1	17.00 U	1.70	0.17 J	0.18 U	0.17 U	0.20 U	0.19 U	0.21 U
023277	INEL	Inorganic Non-metal	222	371	17.00 U	1.30 U	0.88 U	1.00 U	1.10 U	1.10 U	1.10 U	0.92 U
023285	INEL	Solidified Inorganics	211	7	17.00 U	3.30 J	1.70 U	2.00 U	2.10 U	2.10 U	2.10 U	1.80 U
023312	INEL	Uncategorized Metal	217	480	17.00 U	4.10	0.63 U	0.80 U	0.76 U	0.93 U	0.88 U	0.94 U
023341	RFETS	Solidified Inorganics	211	7	5.00 U	0.83	0.49	0.01 U	0.14	0.26	0.10	0.01 U
023357	INEL	Solidified Inorganics	211	1	17.00 U	1.70 J	0.13 U	0.15 U	0.16 U	0.16 U	0.16 U	0.13 U
023383	RFETS	Uncategorized Metal	217	481	5.00 U	0.16	0.01 U	0.01 U	0.01 U	0.03 J	0.01 U	0.01 U
023384	INEL	Combustible	223	339	15.00 U	0.18 J	0.09 U	0.10 U	0.11 U	0.17 J	0.22 J	0.13 U
023388	INEL	Heterogeneous	216	330	15.00 U	0.49 J	0.08 U	0.09 U	0.09 U	0.11 U	0.10 U	0.17 U
023392	INEL	Solidified Inorganics	213	4	43.00 U	0.95 J	0.56 U	0.67 U	0.71 U	0.71 U	0.71 U	0.59 U
023407	INEL	Solidified Organics	212	3	17.00 U	28.00 U	20.00 U	23.00 U	24.00 U	24.00 U	24.00 U	21.00 U
023460	INEL	Inorganic Non-metal	218	442	17.00 U	1.20	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
023469	INEL	Solidified Organics	212	3	17.00 U	0.43 U	0.30 U	0.36 U	0.38 U	0.88 J	0.58 J	0.32 U
023492	INEL	Solidified Inorganics	211	7	17.00 U	0.90 U	0.63 U	0.74 U	0.78 U	0.78 U	0.78 U	0.66 U
023519	INEL	Solidified Organics	212	3	17.00 U	3.10 U	2.40 U	3.00 U	2.90 U	3.50 U	3.30 U	3.60 U
023535	INEL	Solidified Inorganics	211	7	15.00 U	0.82 U	0.63 U	0.80 U	0.75 U	0.93 U	0.88 U	0.94 U
023552	IN[illegible]	Solidified Inorganics	211	1	17.00 U	1.90 [illegible]	0.70 U	0.83 U	0.88 U	0.88 U	0.88 U	[illegible] U
023662	INEL	Inorganic Non-metal	218	442	1.10 U	1.40	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
023681	INEL	Solidified Inorganics	211	1	17.00 U	0.70 J	0.30 U	0.36 U	0.38 U	0.38 U	0.38 U	0.32 U
023695	RFETS	Solidified Inorganics	211	2	5.00 U	0.62	0.22 J	0.18 U	0.19 U	0.23 J	0.19 U	0.16 U
023771	RFETS	Heterogeneous	216	330	5.00 U	23.00	0.16 U	0.19 U	0.20 U	0.20 U	0.20 U	0.17 U
023776	INEL	Heterogeneous	216	330	17.00 U	6.50	0.33 U	0.39 U	0.42 U	0.42 U	0.42 U	0.35 U
023805	INEL	Uncategorized Metal	217	480	17.00 U	5.20	0.01 U	0.02 U	0.07 J	0.10 J	0.07 J	0.02 U
023827	RFETS	Uncategorized Metal	217	320	5.00 U	0.16	0.01 U	0.01 U	0.01 J	0.02 J	0.01 U	0.01 U
023840	INEL	Combustible	216	337	17.00 U	3.00	0.29 U	0.32 U	0.34 U	0.39 U	0.35 U	0.64 U
023901	INEL	Heterogeneous	216	330	1.10 U	1.20	0.27 U	0.30 U	0.32 U	0.37 U	0.33 U	0.61 U
023929	RFETS	Inorganic Non-metal	218	440	5.00 U	2.30	0.50 U	0.59 U	0.63 U	0.63 U	0.63 U	5.00 U
023959	INEL	Uncategorized Metal	217	480	17.00 U	22.00	1.10 U	1.30 U	1.40 U	1.40 U	1.40 U	1.20 U
024028	RFETS	Inorganic Non-metal	218	440	5.00 U	0.50	0.10 U	0.12 U	0.13 U	0.13 U	0.13 U	0.11 U
024029	INEL	Uncategorized Metal	217	480	17.00 U	0.13 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.03 U
024058	INEL	Solidified Inorganics	211	1	17.00 U	2.20 J	0.38 U	0.44 U	0.47 U	0.47 U	0.47 U	0.40 U
024059	INEL	Solidified Inorganics	214	292	17.00 U	10.00	0.15 U	0.18 U	0.29 J	0.47 J	0.28 J	0.16 U
024088	INEL	Combustible	216	337	1.10 U	11.00	0.29 U	0.34 U	7.40	20.00	3.60	0.30 U
024090	INEL	Combustible	216	337	17.00 U	8.00	0.43 U	0.47 U	0.51 U	0.58 U	0.52 U	0.96 U
024092	INEL	Combustible	216	337	17.00 U	15.00	1.30 U	1.50 U	1.60 U	1.60 U	1.60 U	1.30 U
024095	INEL	Combustible	216	337	17.00 U	2.30	0.18 U	0.20 U	0.21 U	0.24 U	0.22 U	0.40 U
024102	INEL	Combustible	216	337	17.00 U	14.00	0.43 U	0.50 U	0.54 U	0.54 U	0.54 U	0.45 U
024106	INEL	Combustible	216	337	17.00 U	22.00	0.63 U	0.74 U	0.78 U	0.78 U	0.78 U	0.66 U
024113	INEL	Combustible	216	337	17.00 U	12.00	0.19 U	0.22 U	0.24 U	0.24 U	0.24 U	0.20 U
024147	INEL	Solidified Inorganics	211	1	17.00 U	3.60 J	0.58 U	0.68 U	0.72 U	0.72 U	0.72 U	0.61 U
024165	INEL	Combustible	216	337	17.00 U	12.00	0.44 U	0.52 U	9.80	28.00	3.40	0.46 U
024168	INEL	Heterogeneous	216	330	17.00 U	0.56 J	0.03 U	0.03 U	0.03 U	0.05 J	0.03 U	0.26 U
024185	INEL	Salt Waste	224	409	17.00 U	1.90	0.03 U	0.03 U	0.14 J	0.23 J	0.14 J	0.03 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
024254	INEL	Salt Waste	224	414	17.00 U	6.30	0.04 U	0.05 U	0.09 J	0.33 J	0.23 J	0.04 U
024271	INEL	Inorganic Non-metal	218	442	17.00 U	3.90	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
024273	INEL	Inorganic Non-metal	218	442	17.00 U	4.90	0.16 U	0.19 U	0.20 U	0.20 U	0.20 U	0.17 U
024289	RFETS	Inorganic Non-metal	218	440	5.00 U	13.00	0.30 U	0.35 U	0.37 U	0.37 U	0.37 U	0.31 U
024295	INEL	Salt Waste	224	414	17.00 U	2.40	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
024308	INEL	Solidified Inorganics	211	2	17.00 U	1.40 J	0.13 U	0.15 U	0.20 J	0.64 J	0.39 J	0.13 U
024309	INEL	Solidified Inorganics	211	2	17.00 U	1.20 J	0.10 U	0.12 U	0.19 J	0.66 J	0.37 J	0.11 U
024311	INEL	Solidified Inorganics	211	2	41.00 U	0.89 J	0.20 U	0.24 U	0.26 U	0.50 J	0.30 J	0.21 U
024318	INEL	Solidified Inorganics	211	2	17.00 U	0.39 J	0.20 U	0.24 U	0.25 U	0.46 J	0.25 U	0.21 U
024506	INEL	Inorganic Non-metal	122	374	17.00 U	6.80	0.05 U	0.06 U	0.06 U	0.06 U	0.06 U	0.05 U
024507	INEL	Uncategorized Metal	117	480	17.00 U	14.00	0.06 U	0.07 U	0.08 U	0.19 J	0.09 J	0.07 U
024600	INEL	Uncategorized Metal	217	480	17.00 U	9.30	0.23 U	0.27 U	0.43 J	0.80 J	0.42 J	0.24 U
024638	INEL	Heterogeneous	216	330	17.00 U	1.40	0.11 U	0.13 U	0.14 U	0.14 U	0.14 U	0.12 U
024670	INEL	Solidified Inorganics	211	1	17.00 U	3.80 J	0.45 U	0.53 U	0.56 U	0.56 U	0.56 U	0.48 U
024765	INEL	Uncategorized Metal	217	480	17.00 U	1.90	0.04 U	0.05 U	0.05 J	0.06 U	0.05 U	0.06 U
024786	INEL	Uncategorized Metal	217	480	17.00 U	5.00	0.30 U	0.36 U	0.38 U	0.38 U	0.38 U	0.32 U
024850	INEL	Solidified Organics	226	432	17.00 U	18.00	0.08 U	0.10 U	0.10 U	0.10 U	0.10 U	0.09 U
024884	INEL	Uncategorized Metal	217	480	17.00 U	22.00	0.20 U	0.24 U	0.25 U	0.25 U	0.25 U	0.21 U
024897	INEL	Solidified Inorganics	211	1	17.00 U	1.00 J	0.20 U	0.24 U	0.25 U	0.25 U	0.25 U	0.21 U
024920	INEL	Solidified Inorganics	211	1	17.00 U	5.30 J	0.58 U	0.68 U	0.72 U	0.72 U	0.72 U	0.61 U
024991	INEL	Solidified Inorganics	211	1	17.00 U	3.90	0.28 U	0.33 U	0.35 U	0.35 U	0.35 U	0.29 U
025001	INEL	Solidified Organics	212	3	17.00 U	2.40 J	1.00 U	1.20 U	1.30 U	1.30 U	1.30 U	1.10 U
032284	INEL	Combustible	223	339	17.00 U	3.70	0.29 U	0.32 U	0.37 J	0.98 J	0.86 J	0.42 U
032287	RF[illegible]S	Solidified Inorganics	211	7	5.00 U	1.40 [illegible]	0.99 U	1.20 U	1.20 U	1.20 U	1.20 U	1.[illegible] U
032467	INE[illegible]	Combustible	216	337	17.00 U	0.29 [illegible]	0.20 U	0.24 U	0.25 U	0.25 U	0.25 U	0.2[illegible] U

Table .-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
032469	RFETS	Combustible	216	337	5.00 U	6.80	0.33 U	0.39 U	0.41 U	0.41 U	0.41 U	0.34 U
032473	INEL	Combustible	216	337	17.00 U	9.80	1.30 U	1.60 U	1.70 U	1.70 U	1.70 U	1.40 U
032485	INEL	Combustible	216	337	17.00 U	8.60	0.78 U	0.92 U	0.98 U	0.98 U	0.98 U	0.82 U
032517	RFETS	Combustible	223	339	5.00 U	2.60	0.07 U	0.09 U	0.20 J	0.41 JB	0.46 J	0.08 U
032521	INEL	Combustible	223	339	17.00 U	3.10	0.06 U	0.07 U	0.31 J	0.55 J	0.76 J	0.09 U
032525	INEL	Combustible	223	339	17.00 U	2.00	0.04 U	0.04 U	0.11 J	0.16 J	0.23 J	0.05 U
032526	INEL	Combustible	223	339	17.00 U	2.40	0.54 U	0.59 U	0.63 U	1.30	0.83 J	0.78 U
032529	INEL	Heterogeneous	216	336	17.00 U	26.00	0.23 U	0.33 U	0.38 U	0.32 U	0.25 U	0.15 U
032540	INEL	Uncategorized Metal	217	480	17.00 U	0.94 J	0.33 U	0.39 U	0.41 U	0.41 U	0.41 U	0.34 U
032632	INEL	Uncategorized Metal	217	480	17.00 U	1.70	0.14 U	0.15 U	0.16 U	0.19 U	0.17 U	0.20 U
032659	RFETS	Uncategorized Metal	217	480	5.00 U	4.30	0.26 U	0.30 U	0.32 U	0.34 J	0.32 U	0.27 U
032669	RFETS	Uncategorized Metal	217	480	5.00 U	3.40	0.28 U	0.33 U	0.35 U	0.35 U	0.35 U	0.30 U
032712	INEL	Uncategorized Metal	217	480	17.00 U	0.82 J	0.24 U	0.28 U	0.30 U	0.30 U	0.30 U	0.25 U
032715	RFETS	Combustible	216	337	5.00 U	0.86	0.07 U	0.09 U	0.09 U	0.09 U	0.09 U	0.08 U
032748	INEL	Combustible	223	339	17.00 U	4.40	0.23 U	0.33 U	0.38 U	0.32 U	0.25 U	0.15 U
032753	INEL	Uncategorized Metal	217	481	17.00 U	0.04 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
033091	INEL	Combustible	223	339	17.00 U	2.70	0.02 U	0.02 U	0.38 J	1.10	0.86 J	0.03 U
D01332	RFETS	Heterogeneous	116	832	3.00 U	19.36	0.50 U	1.00 U	42.90	133.38	62.59	0.50 U
D06288	RFETS	Filter	119	338	0.60 U	0.10 U	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D06339	RFETS	Heterogeneous	0	337	4.72 J	1.27 J	0.20 U	0.40 U	0.20 U	0.20 U	0.20 U	0.20 U
D11129	RFETS	Filter	119	338	0.79 J	0.10 U	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D13364	RFETS	Uncategorized Metal	117	480	1.10 U	2.48	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D15680	RFETS	Heterogeneous	116	831	400.00 U	66.67 U	66.67 U	133.33 U	66.67 U	66.67 U	66.67 U	66.67 U
D17184	RFETS	Solidified Inorganics	111	800	1.10 U	1.61	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D32439	RFETS	Filter	119	338	0.60 U	0.10 U	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D32978	RFETS	Solidified Inorganics	111	803	34.00 U	5.67 U	5.67 U	11.33 U	5.67 U	5.67 U	5.67 U	5.67 U
D35301	RFETS	Solidified Inorganics	111	800	1.10 U	0.20 J	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D35306	RFETS	Lead/Cadmium Metal	123	339	1.20 U	7.86	0.20 U	0.40 U	0.20 U	0.45 J	1.03 J	0.20 U
D36606	RFETS	Uncategorized Metal	117	480	2.80 U	40.46	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D38859	RFETS	Solidified Inorganics	111	803	1.10 U	0.45 J	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D38989	RFETS	Heterogeneous	0	336	0.60 U	9.27	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D41681	RFETS	Filter	119	338	0.10 U	3.39	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D42280	RFETS	Solidified Organics	112	801	2500.00 U	416.67 U	416.67 U	833.33 U	416.67 U	416.67 U	416.67 U	416.67 U
D47501	RFETS	Lead/Cadmium Metal	0	341	0.68 J	5.91	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D48182	RFETS	Filter	119	376	4.40 U	27.92	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D48200	RFETS	Heterogeneous	116	831	88.00 U	16.39 J	8.00 U	8.00 U	8.00 U	8.00 U	16.00 U	8.00 U
D48377	RFETS	Inorganic Non-metal	118	368	1.10 U	2.61	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D49662	RFETS	Solidified Inorganics	0	292	0.60 U	6.19	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D49880	RFETS	Heterogeneous	0	336	1.60 U	16.66	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D52318	RFETS	Lead/Cadmium Metal	117	321	0.60 U	0.22 J	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D52362	RFETS	Heterogeneous	116	821	2.20 U	9.50	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D52726	RFETS	Heterogeneous	116	833	4.80 U	11.72	0.80 U	1.60 U	0.80 U	0.80 U	0.80 U	0.80 U
D53672	RFETS	Inorganic Non-metal	118	440	2.20 U	8.14	0.20 U	0.20 U	0.20 U	0.29 J	0.40 U	0.20 U
D55656	RFETS	Heterogeneous	116	831	3.30 U	33.36	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D55680	RFETS	Heterogeneous	116	821	2.20 U	8.57	0.20 U	0.20 U	0.20 U	0.23 J	0.40 U	0.20 U
D55938	RFETS	Heterogeneous	116	831	2.20 U	12.11	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D56095	RFETS	Heterogeneous	0	337	0.60 U	3.59	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D56595	RFETS	Heterogeneous	116	831	80.00 U	13.33 U	13.33 U	26.67 U	13.33 U	13.33 U	13.33 U	13.33 U
D56755	RF[illegible]	Heterogeneous	116	821	1.10 U	0.20 [illegible]	0.10 U	0.10 U	0.10 U	0.18 J	0.20 U	0.[illegible] J
D56823	RF[illegible]S	Heterogeneous	116	831	4.40 U	23.57 [illegible]	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U

Table -4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D57179	RFETS	Heterogeneous	0	330	12.00 U	6.90 J	2.00 U	4.00 U	2.00 U	2.00 U	2.00 U	2.00 U
D57522	RFETS	Heterogeneous	0	336	2.40 U	7.15	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D57847	RFETS	Uncategorized Metal	117	480	2.80 U	41.16	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D58143	RFETS	Solidified Inorganics	111	807	1.10 U	8.03	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D58154	RFETS	Heterogeneous	116	831	2.40 U	40.69	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D58627	RFETS	Heterogeneous	116	831	1.20 U	11.64	0.20 U	0.40 U	10.02	36.00	10.31	0.20 U
D58889	RFETS	Heterogeneous	116	831	1.40 U	12.97	0.20 U	0.40 U	0.20 U	0.20 U	0.20 U	0.20 U
D58970	RFETS	Solidified Inorganics	111	807	1.10 U	3.12	0.10 U	0.10 U	0.10 U	0.17 J	0.20 U	0.10 U
D59053	RFETS	Lead/Cadmium Metal	0	341	0.60 U	3.49	0.10 U	0.20 U	0.15 J	0.32 J	0.78 J	0.10 U
D59703	RFETS	Heterogeneous	116	831	3.50 U	62.59	0.50 U	1.00 U	0.50 U	0.50 U	0.50 U	0.50 U
D59899	RFETS	Filter	0	331	3.50 U	50.44 a	0.50 U	1.00 U	0.50 U	0.50 U	0.50 U	0.50 U
D60056	RFETS	Lead/Cadmium Metal	0	341	1.60 U	5.44	0.27 U	0.53 U	0.27 U	0.63 J	1.53 J	0.27 U
D60218	RFETS	Heterogeneous	116	821	2.20 U	5.17	0.20 U	0.20 U	1.75 J	11.25	8.61	0.20 U
D60298	RFETS	Solidified Organics	112	801	6306.66 U	573.33 U	573.33 U	573.33 U	573.33 U	573.33 U	1146.6 U	573.33 U
D60320	RFETS	Heterogeneous	0	330	256.93 J	28.00 U	28.00 U	56.00 U	28.00 U	28.00 U	28.00 U	28.00 U
D60463	RFETS	Inorganic Non-metal	118	440	1.10 U	1.92	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D60511	RFETS	Filter	119	491	2.20 U	8.05	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D60635	RFETS	Filter	119	491	1.10 U	4.79	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D61245	RFETS	Heterogeneous	0	336	5.48 J	12.27	0.47 U	0.93 U	0.47 U	0.47 U	0.47 U	0.47 U
D61278	RFETS	Heterogeneous	0	336	1.60 U	18.50	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D61473	RFETS	Heterogeneous	0	377	3.30 U	26.06	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D61504	RFETS	Lead/Cadmium Metal	0	341	3.47 J	6.80	0.10 U	0.34 J	0.31 J	0.82 J	1.58	0.10 U
D61747	RFETS	Heterogeneous	0	330	3.33 J	23.52	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D62340	RFETS	Heterogeneous	116	821	4.40 U	29.08	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D62478	RFETS	Filter	119	376	4.40 U	28.29	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D62714	RFETS	Heterogeneous	116	831	7.00 U	29.92	1.00 U	2.00 U	1.00 U	1.00 U	1.00 U	1.00 U
D62851	RFETS	Heterogeneous	116	825	3.30 U	6.69	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D62855	RFETS	Heterogeneous	116	821	66.00 U	26.39 J	6.00 U	6.00 U	6.00 U	6.00 U	12.00 U	6.00 U
D63098	RFETS	Filter	0	331	4.59 J	48.86 a	0.50 U	1.00 U	0.50 U	0.50 U	0.50 U	0.50 U
D63229	RFETS	Heterogeneous	116	831	2.20 U	22.72	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D63281	RFETS	Solidified Inorganics	111	807	1.10 U	5.39	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D63460	RFETS	Heterogeneous	116	831	1.10 U	14.84	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D63654	RFETS	Solidified Inorganics	111	807	1.10 U	5.82	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D63808	RFETS	Heterogeneous	116	831	8.80 U	44.69	0.80 U	0.80 U	0.80 U	0.80 U	1.60 U	0.80 U
D63817	RFETS	Heterogeneous	116	821	17.60 U	8.12 J	1.60 U	1.60 U	1.60 U	1.60 U	3.20 U	1.60 U
D63819	RFETS	Solidified Inorganics	111	807	2.20 U	2.57	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D63999	RFETS	Filter	119	491	3.30 U	11.61	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D64004	RFETS	Filter	0	331	2.80 U	36.31 a	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D64137	RFETS	Filter	119	335	1.10 U	0.14 J	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D64448	RFETS	Heterogeneous	116	821	1210.00 U	574.53 J	110.00 U	110.00 U	1996.8	8500.1	2764.0	110.00 U
D64555	RFETS	Solidified Organics	112	801	6306.66 U	573.33 U	573.33 U	573.33 U	573.33 U	573.33 U	1146.6 U	573.33 U
D64632	RFETS	Solidified Inorganics	111	800	1.10 U	2.64	0.10 U	0.10 U	0.10 U	0.25 J	0.20 U	0.10 U
D64752	RFETS	Uncategorized Metal	117	480	14.00 U	28.39	2.00 U	4.00 U	2.00 U	2.00 U	2.00 U	2.00 U
D64758	RFETS	Heterogeneous	116	831	3.00 U	46.17	0.50 U	1.00 U	0.50 U	0.50 U	0.50 U	0.50 U
D64860	RFETS	Heterogeneous	116	831	84.00 U	24.89 J	12.00 U	24.00 U	12.00 U	12.00 U	12.00 U	12.00 U
D65212	RFETS	Heterogeneous	116	831	63.00 U	19.34 J	9.00 U	18.00 U	9.00 U	9.00 U	9.00 U	9.00 U
D65213	RFETS	Heterogeneous	116	831	56.00 U	27.39 J	8.00 U	16.00 U	8.00 U	8.00 U	8.00 U	8.00 U
D65214	RFETS	Heterogeneous	116	831	810.34 U	73.67 U	73.67 U	73.67 U	73.67 U	73.67 U	147.33 U	73.67 U
D65530	RFETS	Solidified Inorganics	111	807	1.10 U	5.64	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D65535	RF	Solidified Inorganics	111	807	1.10 U	1.84	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.[illegible] J

Table _ _-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D65546	RFETS	Solidified Inorganics	111	807	1.10 U	5.54	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D65600	RFETS	Solidified Inorganics	111	807	1.10 U	4.21	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D65731	RFETS	Inorganic Non-metal	122	375	4.40 U	7.18	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D65734	RFETS	Uncategorized Metal	117	480	7.70 U	56.70	0.70 U	0.70 U	0.70 U	0.84 J	1.40 U	0.70 U
D65754	RFETS	Heterogeneous	116	831	4.00 U	68.61	0.67 U	1.33 U	0.67 U	0.67 U	0.67 U	0.67 U
D65757	RFETS	Heterogeneous	116	831	18.00 U	11.25 J	3.00 U	6.00 U	3.00 U	3.00 U	3.00 U	3.00 U
D65972	RFETS	Filter	119	376	3.30 U	19.73	0.30 U	0.30 U	0.30 U	0.39 J	0.60 U	0.30 U
D66128	RFETS	Heterogeneous	116	831	3.00 U	39.06	0.50 U	1.00 U	0.50 U	0.50 U	0.50 U	0.50 U
D66157	RFETS	Uncategorized Metal	117	480	725.65 J	106.82	2.00 U	4.00 U	132.20	407.06	59.58	2.00 U
D66162	RFETS	Lead/Cadmium Metal	123	339	990.00 U	90.00 U	90.00 U	90.00 U	90.00 U	90.00 U	180.00 U	90.00 U
D66211	RFETS	Heterogeneous	116	833	1.10 U	8.42	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D66213	RFETS	Heterogeneous	116	831	1.80 U	13.19	0.30 U	0.60 U	0.30 U	0.30 U	0.30 U	0.30 U
D66356	RFETS	Heterogeneous	116	831	1000.00 U	166.67 U	166.67 U	333.33 U	166.67 U	166.67 U	166.67 U	166.67 U
D66378	RFETS	Heterogeneous	116	831	1344.00 U	192.00 U	192.00 U	384.00 U	192.00 U	192.00 U	192.00 U	192.00 U
D66438	RFETS	Uncategorized Metal	117	480	17.60 U	5.56 J	1.60 U	1.60 U	1.60 U	1.60 U	3.20 U	1.60 U
D66523	RFETS	Solidified Organics	112	801	6306.66 U	573.33 U	573.33 U	573.33 U	573.33 U	573.33 U	573.33 U	1146.6 U
D66525	RFETS	Solidified Inorganics	111	800	1.87 U	15.55	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D66631	RFETS	Heterogeneous	116	831	5.50 U	48.16	0.50 U	0.50 U	0.50 U	0.50 U	1.00 U	0.50 U
D66637	RFETS	Heterogeneous	116	831	56.00 U	25.59 J	8.00 U	16.00 U	8.00 U	8.00 U	8.00 U	8.00 U
D66641	RFETS	Heterogeneous	116	831	660.00 U	60.00 U	60.00 U	60.00 U	60.00 U	60.00 U	120.00 U	60.00 U
D66649	RFETS	Lead/Cadmium Metal	123	339	616.00 U	56.00 U	56.00 U	56.00 U	56.00 U	56.00 U	112.00 U	56.00 U
D66773	RFETS	Uncategorized Metal	117	480	3.30 U	12.48	0.30 U	0.30 U	0.90 J	1.43 J	0.60 U	0.30 U
D66783	RFETS	Heterogeneous	116	831	2750.00 U	250.00 U	250.00 U	250.00 U	250.00 U	250.00 U	500.00 U	250.00 U
D66792	RFETS	Heterogeneous	116	831	1100.00 U	100.00 U	100.00 U	100.00 U	100.00 U	100.00 U	200.00 U	100.00 U
D66860	RFETS	Heterogeneous	116	833	2.20 U	13.86	0.20 U	0.20 U	0.35 J	1.21 J	0.41 J	0.20 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D66875	RFETS	Heterogeneous	116	832	1.10 U	5.76	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D66948	RFETS	Heterogeneous	116	831	66.00 U	13.34 J	6.00 U	6.00 U	6.00 U	6.00 U	12.00 U	6.00 U
D66949	RFETS	Heterogeneous	116	831	6.60 U	13.62	0.60 U	0.60 U	0.60 U	0.60 U	1.20 U	0.60 U
D66953	RFETS	Uncategorized Metal	117	480	11.20 U	2.96 J	1.60 U	3.20 U	1.60 U	1.60 U	1.60 U	1.60 U
D66958	RFETS	Heterogeneous	116	831	3.30 U	22.22	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D67009	RFETS	Solidified Organics	112	801	3740.00 U	739.16 J	340.00 U	340.00 U	340.00 U	340.00 U	680.00 U	340.00 U
D67012	RFETS	Solidified Organics	112	801	9900.00 U	1799.1 J	900.00 U	900.00 U	900.00 U	900.00 U	1800.0 U	900.00 U
D67047	RFETS	Solidified Inorganics	111	807	2.20 U	5.32	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D67251	RFETS	Uncategorized Metal	117	480	8400.00 U	1494.7 J	1200.0 U	2400.0 U	1200.0 U	1200.0 U	1200.0 U	1200.0 U
D67263	RFETS	Heterogeneous	116	831	99.00 U	9.45 J	9.00 U	9.00 U	9.00 U	9.00 U	18.00 U	9.00 U
D67277	RFETS	Heterogeneous	116	831	154.00 U	14.00 U	14.00 U	14.00 U	14.00 U	14.00 U	28.00 U	14.00 U
D67278	RFETS	Heterogeneous	116	831	1.10 U	1.31	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D67312	RFETS	Heterogeneous	116	825	2.20 U	11.14	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D67317	RFETS	Uncategorized Metal	117	480	1.87 U	20.00	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D67390	RFETS	Solidified Organics	112	801	1430.00 U	130.00 U	130.00 U	130.00 U	130.00 U	130.00 U	260.00 U	130.00 U
D67391	RFETS	Heterogeneous	116	833	1.60 U	26.96	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D67413	RFETS	Solidified Organics	112	801	8250.00 U	1799.2 J	750.00 U	750.00 U	750.00 U	750.00 U	1500.0 U	750.00 U
D67434	RFETS	Solidified Inorganics	111	800	2.80 U	14.94	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D67436	RFETS	Solidified Inorganics	111	800	0.93 U	10.37	0.13 U	0.27 U	0.13 U	0.28 J	0.13 U	0.13 U
D67441	RFETS	Solidified Inorganics	111	800	2.80 U	7.70	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D67448	RFETS	Heterogeneous	116	852	1.10 U	4.38	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D67455	RFETS	Filter	119	490	4.40 U	2.77 J	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D67464	RFETS	Heterogeneous	116	831	2640.00 U	240.00 U	240.00 U	240.00 U	240.00 U	240.00 U	480.00 U	240.00 U
D67524	RF[illegible]	Heterogeneous	116	832	204.52 U	18.59 [illegible]	18.59 U	18.59 U	18.59 U	18.59 U	37.19 U	18[illegible]
D67532	RF[illegible]	Lead/Cadmium Metal	123	339	69.30 U	6.30 [illegible]	6.30 U	6.30 U	6.30 U	6.30 U	12.60 U	6.30 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D67535	RFETS	Heterogeneous	116	831	1.40 U	19.28	0.20 U	0.40 U	0.20 U	0.20 U	0.20 U	0.20 U
D67539	RFETS	Solidified Organics	112	801	3520.00 U	629.76 J	320.00 U	320.00 U	320.00 U	320.00 U	640.00 U	320.00 U
D67541	RFETS	Heterogeneous	116	825	1.10 U	7.66	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D67545	RFETS	Solidified Organics	112	801	990.00 U	90.00 U	90.00 U	90.00 U	90.00 U	90.00 U	180.00 U	90.00 U
D67567	RFETS	Heterogeneous	116	831	3.30 U	32.27	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D67582	RFETS	Heterogeneous	116	831	12.39 J	28.03	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D67603	RFETS	Uncategorized Metal	117	480	143.00 U	29.89 J	13.00 U	13.00 U	13.00 U	13.00 U	26.00 U	13.00 U
D67654	RFETS	Solidified Inorganics	111	800	1.87 U	14.87	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D67657	RFETS	Solidified Inorganics	111	800	1.87 U	20.04	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D67678	RFETS	Heterogeneous	116	825	4.73 U	33.45	0.43 U	0.43 U	0.43 U	0.43 U	0.86 U	0.43 U
D67698	RFETS	Heterogeneous	116	831	9.60 U	138.80	1.60 U	3.20 U	1.60 U	4.53 J	1.60 U	1.60 U
D67707	RFETS	Heterogeneous	116	831	3.00 U	7.89	0.50 U	1.00 U	0.50 U	0.50 U	0.50 U	0.50 U
D67734	RFETS	Heterogeneous	116	831	1210.00 U	110.00 U	110.00 U	110.00 U	110.00 U	110.00 U	220.00 U	110.00 U
D67735	RFETS	Uncategorized Metal	117	480	19.80 U	18.17	1.80 U	1.80 U	1.80 U	1.80 U	3.60 U	1.80 U
D67759	RFETS	Heterogeneous	116	831	30.80 U	86.98	2.80 U	2.80 U	2.80 U	2.86 J	5.60 U	2.80 U
D67764	RFETS	Heterogeneous	116	831	12.00 U	142.10	2.00 U	4.00 U	2.00 U	3.15 J	2.00 U	2.00 U
D67766	RFETS	Heterogeneous	116	831	9.00 U	60.77	1.50 U	3.00 U	1.50 U	1.50 U	1.50 U	1.50 U
D67781	RFETS	Heterogeneous	116	831	3.30 U	24.04	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D67908	RFETS	Heterogeneous	116	832	1.10 U	7.25	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D67929	RFETS	Heterogeneous	116	832	0.60 U	0.88 J	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D67989	RFETS	Heterogeneous	116	831	5.50 U	4.42 J	0.50 U	0.50 U	0.50 U	0.50 U	1.00 U	0.50 U
D67994	RFETS	Heterogeneous	116	831	16.00 U	2.67 U	2.67 U	5.33 U	2.67 U	2.67 U	2.67 U	2.67 U
D68044	RFETS	Heterogeneous	116	825	5.50 U	25.12	0.50 U	0.50 U	0.50 U	0.50 U	1.00 U	0.50 U
D68096	RFETS	Heterogeneous	116	821	2.20 U	9.29	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D68247	RFETS	Solidified Inorganics	111	800	0.93 U	7.90	0.13 U	0.27 U	0.13 U	0.13 U	0.13 U	0.13 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D68248	RFETS	Solidified Organics	112	801	1650.00 U	150.00 U	150.00 U	150.00 U	150.00 U	150.00 U	300.00 U	150.00 U
D68250	RFETS	Solidified Organics	112	801	1870.00 U	170.00 U	170.00 U	170.00 U	170.00 U	170.00 U	340.00 U	170.00 U
D68254	RFETS	Solidified Inorganics	111	800	1.87 U	8.28	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D68256	RFETS	Solidified Inorganics	111	800	2.80 U	11.30	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D68276	RFETS	Heterogeneous	116	852	1.10 U	1.80	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D68277	RFETS	Uncategorized Metal	117	480	5.50 U	27.39	0.50 U	0.50 U	0.50 U	0.50 U	1.00 U	0.50 U
D68377	RFETS	Uncategorized Metal	117	480	1.40 U	2.52	0.20 U	0.40 U	0.20 U	0.20 U	0.20 U	0.20 U
D68460	RFETS	Heterogeneous	116	832	0.60 U	0.13 J	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D68480	RFETS	Solidified Inorganics	111	800	0.89 J	3.64	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D68486	RFETS	Solidified Organics	112	801	1540.00 U	140.00 U	140.00 U	140.00 U	140.00 U	140.00 U	280.00 U	140.00 U
D68514	RFETS	Uncategorized Metal	117	480	1.10 U	7.36	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D68538	RFETS	Lead/Cadmium Metal	123	339	0.70 U	2.10	0.10 U	0.20 U	0.10 U	0.25 J	0.24 J	0.10 U
D68600	RFETS	Heterogeneous	116	825	198.00 U	18.00 U	18.00 U	18.00 U	18.00 U	18.00 U	36.00 U	18.00 U
D68601	RFETS	Heterogeneous	116	825	77.00 U	13.12 J	7.00 U	7.00 U	7.00 U	7.00 U	14.00 U	7.00 U
D68702	RFETS	Heterogeneous	116	833	1.10 U	4.93	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D68724	RFETS	Heterogeneous	116	831	1980.00 U	180.00 U	180.00 U	180.00 U	180.00 U	180.00 U	360.00 U	180.00 U
D68756	RFETS	Heterogeneous	116	831	1.40 U	17.92	0.20 U	0.40 U	0.20 U	0.20 U	0.20 U	0.20 U
D68885	RFETS	Heterogeneous	116	831	440.00 U	40.00 U	40.00 U	40.00 U	40.00 U	40.00 U	80.00 U	40.00 U
D68896	RFETS	Heterogeneous	116	831	2343.00 U	213.00 U	213.00 U	213.00 U	213.00 U	213.00 U	426.00 U	213.00 U
D68975	RFETS	Solidified Organics	112	801	5940.00 U	540.00 U	540.00 U	540.00 U	540.00 U	540.00 U	1080.0 U	540.00 U
D68999	RFETS	Heterogeneous	116	821	4.40 U	26.90	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D69091	RFETS	Heterogeneous	116	825	5.50 U	30.60	0.50 U	0.50 U	0.50 U	0.50 U	1.00 U	0.50 U
D69095	RFETS	Heterogeneous	116	833	5.94 U	38.57	0.54 U	0.54 U	0.54 U	0.54 U	1.08 U	0.54 U
D69113	RF[illegible]	Heterogeneous	116	831	528.00 U	48.00 [illegible]	48.00 U	48.00 U	48.00 U	48.00 U	96.00 U	48[illegible] U
D69250	RFETS	Heterogeneous	116	833	1.10 U	7.05 [illegible]	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D69287	RFETS	Heterogeneous	116	821	1518.00 U	138.00 U	138.00 U	138.00 U	138.00 U	138.00 U	276.00 U	138.00 U
D69306	RFETS	Solidified Organics	112	801	2750.00 U	250.00 U	250.00 U	250.00 U	250.00 U	250.00 U	500.00 U	250.00 U
D69312	RFETS	Solidified Inorganics	111	800	2.80 U	14.58	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D69364	RFETS	Heterogeneous	116	833	3.30 U	11.79	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D69400	RFETS	Heterogeneous	116	831	407.00 U	37.00 U	37.00 U	37.00 U	37.00 U	37.00 U	74.00 U	37.00 U
D69406	RFETS	Heterogeneous	116	831	550.00 U	50.00 U	50.00 U	50.00 U	50.00 U	50.00 U	100.00 U	50.00 U
D69413	RFETS	Heterogeneous	116	831	6.60 U	6.00	0.60 U	0.60 U	0.60 U	0.60 U	1.20 U	0.60 U
D69418	RFETS	Heterogeneous	116	831	807.40 U	73.40 U	73.40 U	73.40 U	73.40 U	73.40 U	146.80 U	73.40 U
D69431	RFETS	Heterogeneous	116	831	320.00 U	53.33 U	53.33 U	106.67 U	53.33 U	53.33 U	53.33 U	53.33 U
D69518	RFETS	Heterogeneous	116	833	2.20 U	11.12	0.20 U	0.20 U	0.20 U	0.74 J	0.47 J	0.20 U
D69602	RFETS	Heterogeneous	116	821	11.00 U	68.03	1.00 U	1.00 U	1.00 U	1.00 U	2.00 U	1.00 U
D69759	RFETS	Heterogeneous	116	833	3.30 U	16.46	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D69855	RFETS	Heterogeneous	116	833	2.20 U	8.80	0.20 U	0.20 U	0.32 J	1.19 J	0.40 U	0.20 U
D69877	RFETS	Heterogeneous	116	825	5.50 U	17.53	0.50 U	0.50 U	0.71 J	2.53 J	1.00 U	0.50 U
D69883	RFETS	Heterogeneous	116	825	3.30 U	10.62	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D69975	RFETS	Heterogeneous	116	821	7.70 U	44.47	0.70 U	0.70 U	0.70 U	0.70 U	1.40 U	0.70 U
D70063	RFETS	Heterogeneous	116	821	5.61 U	34.81	0.51 U	0.51 U	0.56 J	1.92 J	1.02 U	0.51 U
D70077	RFETS	Heterogeneous	116	831	660.00 U	60.00 U	60.00 U	60.00 U	60.00 U	60.00 U	120.00 U	60.00 U
D70229	RFETS	Heterogeneous	116	831	2.20 U	19.11	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D70353	RFETS	Heterogeneous	116	833	2.20 U	19.69	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D70370	RFETS	Heterogeneous	116	821	3.30 U	13.37	0.30 U	0.30 U	0.30 U	0.72 J	0.60 U	0.30 U
D70379	RFETS	Heterogeneous	116	833	1.10 U	10.35	0.10 U	0.10 U	0.10 U	0.10 J	0.20 U	0.10 U
D70383	RFETS	Heterogeneous	116	833	2.20 U	11.65	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D70446	RFETS	Uncategorized Metal	117	480	7.00 U	37.41	1.00 U	2.00 U	1.00 U	7.19 J	1.61 J	1.00 U
D70448	RFETS	Heterogeneous	116	831	1650.00 U	150.00 U	150.00 U	150.00 U	150.00 U	150.00 U	300.00 U	150.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D70455	RFETS	Heterogeneous	116	831	7.70 U	50.51	0.70 U	0.70 U	0.70 U	0.70 U	1.40 U	0.70 U
D70543	RFETS	Solidified Organics	112	801	9108.00 U	828.00 U	828.00 U	828.00 U	828.00 U	828.00 U	1656.0 U	828.00 U
D70661	RFETS	Filter	0	331	3.60 U	13.50	0.60 U	1.20 U	0.60 U	0.60 U	0.60 U	0.60 U
D70669	RFETS	Uncategorized Metal	117	480	1.10 U	11.84	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D70675	RFETS	Solidified Organics	112	801	2.15 J	1.88	0.60 J	0.10 U	0.11 J	0.29 J	0.20 U	0.10 U
D70682	RFETS	Heterogeneous	116	831	495.00 U	45.00 U	45.00 U	45.00 U	45.00 U	45.00 U	90.00 U	45.00 U
D70696	RFETS	Heterogeneous	116	821	6.60 U	35.16	0.60 U	0.60 U	0.60 U	0.60 U	1.20 U	0.60 U
D70734	RFETS	Heterogeneous	116	833	0.60 U	7.19	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D70780	RFETS	Heterogeneous	116	832	0.60 U	6.00	0.10 U	0.20 U	0.10 U	0.14 J	0.10 U	0.10 U
D70856	RFETS	Heterogeneous	116	833	1.10 U	5.02	0.10 U	0.10 U	0.13 J	0.42 J	0.20 U	0.10 U
D70882	RFETS	Heterogeneous	116	831	154.00 U	24.14 J	14.00 U	14.00 U	14.00 U	14.00 U	28.00 U	14.00 U
D70937	RFETS	Filter	0	331	3.00 U	15.32	0.50 U	1.00 U	0.50 U	1.11 J	0.92 J	0.50 U
D71019	RFETS	Solidified Organics	112	801	14.30 U	4.06 J	2.38 J	1.30 U	1.30 U	1.30 U	2.60 U	1.30 U
D71020	RFETS	Solidified Organics	112	801	13822.9 J	911.50 U	911.50 U	911.50 U	911.50 U	911.50 U	1823.0 U	911.50 U
D71022	RFETS	Solidified Organics	112	801	7200.00 U	1200.0 U	1200.0 U	2400.0 U	2551.2 J	8626.8 J	2212.8 J	1200.0 U
D71241	RFETS	Heterogeneous	116	833	0.60 U	5.29	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D71351	RFETS	Uncategorized Metal	117	480	0.70 U	1.19	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D71354	RFETS	Uncategorized Metal	117	480	0.70 U	1.63	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D71385	RFETS	Heterogeneous	116	833	3.30 U	23.02	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D71494	RFETS	Solidified Organics	112	801	2.31 J	2.17 J	0.10 U	0.10 U	0.10 U	0.26 J	0.20 U	0.10 U
D71504	RFETS	Solidified Organics	112	801	2.20 U	2.55	0.54 J	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D71514	RFETS	Heterogeneous	116	833	2.20 U	14.12	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D71521	RFETS	Heterogeneous	116	825	2.20 U	9.03	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D71638	RFETS	Uncategorized Metal	117	480	7.00 U	10.80	1.00 U	2.00 U	1.00 U	1.00 U	1.00 U	[illegible] U
D71804	RFETS	Heterogeneous	116	832	0.70 U	1.48	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	[illegible] U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D71829	RFETS	Heterogeneous	116	852	2420.00 U	220.00 U	220.00 U	220.00 U	220.00 U	220.00 U	440.00 U	220.00 U
D71838	RFETS	Heterogeneous	116	831	83.60 U	11.96 J	7.60 U	7.60 U	7.60 U	7.60 U	15.20 U	7.60 U
D71921	RFETS	Heterogeneous	116	833	0.70 U	7.15	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D71932	RFETS	Solidified Organics	112	801	48047.5 U	4367.9 U	4367.9 U	4367.9 U	4367.9 U	4367.9 U	8735.9 U	4367.9 U
D71933	RFETS	Solidified Organics	112	801	0.60 U	2.01	0.10 U	0.20 U	0.10 U	0.16 J	0.11 J	0.10 U
D71934	RFETS	Solidified Organics	112	801	1.48 J	2.88	0.10 U	0.20 U	0.10 U	0.17 J	0.10 U	0.10 U
D71936	RFETS	Heterogeneous	116	833	238.34 U	21.67 U	21.67 U	21.67 U	21.67 U	21.67 U	43.33 U	21.67 U
D71937	RFETS	Heterogeneous	116	833	200.00 U	33.33 U	33.33 U	66.67 U	33.33 U	33.33 U	33.33 U	33.33 U
D71938	RFETS	Heterogeneous	116	833	19.80 U	1.80 U	1.80 U	1.80 U	1.80 U	1.92 J	3.60 U	1.80 U
D71940	RFETS	Solidified Organics	112	801	11000.0 U	1000.0 U	1000.0 U	1000.0 U	1000.0 U	1000.0 U	2000.0 U	1000.0 U
D71941	RFETS	Solidified Organics	112	801	11000.0 U	1000.0 U	1000.0 U	1000.0 U	1000.0 U	1000.0 U	2000.0 U	1000.0 U
D72010	RFETS	Heterogeneous	116	832	2.10 U	34.34	0.30 U	0.60 U	0.30 U	0.30 U	0.30 U	0.30 U
D72079	RFETS	Uncategorized Metal	117	480	71.50 U	43.37 J	6.50 U	6.50 U	6.50 U	6.50 U	13.00 U	6.50 U
D72127	RFETS	Solidified Organics	112	801	4.40 U	0.66 J	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D72128	RFETS	Solidified Organics	112	801	3446.04 J	6991.6	130.00 U	130.00 U	130.00 U	130.00 U	260.00 U	130.00 U
D72131	RFETS	Heterogeneous	116	833	1.60 U	0.75 J	0.48 J	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D72132	RFETS	Solidified Organics	112	801	538.32 J	370.66 J	48.00 U	96.00 U	48.00 U	48.00 U	48.00 U	48.00 U
D72133	RFETS	Solidified Organics	112	801	2.20 U	1.34 J	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D72136	RFETS	Solidified Organics	112	801	231.00 U	1395.5	21.00 U	21.00 U	21.00 U	21.00 U	42.00 U	21.00 U
D72139	RFETS	Solidified Organics	112	801	20.90 U	207.08	1.90 U	1.90 U	1.90 U	1.90 U	3.80 U	1.90 U
D72178	RFETS	Heterogeneous	116	821	3.30 U	8.16	0.30 U	0.30 U	0.37 J	1.67 J	0.60 U	0.30 U
D72186	RFETS	Heterogeneous	116	821	2.20 U	9.78	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D72195	RFETS	Heterogeneous	116	833	1.10 U	12.27	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D72255	RFETS	Heterogeneous	116	833	3.30 U	19.33	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D72267	RFETS	Solidified Inorganics	111	800	0.70 U	3.23	0.12 J	0.20 U	0.94 J	3.28	0.61 J	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D72293	RFETS	Heterogeneous	116	833	1.10 U	10.66	0.10 U	0.10 U	0.12 J	0.39 J	0.20 U	0.10 U
D72333	RFETS	Heterogeneous	116	831	3.30 U	18.22	0.30 U	0.30 U	0.30 U	0.46 J	0.60 U	0.30 U
D72339	RFETS	Heterogeneous	116	821	5.50 U	37.30	0.50 U	0.50 U	0.50 U	0.50 U	1.00 U	0.50 U
D72347	RFETS	Heterogeneous	116	833	1.10 U	9.87	0.10 U	0.10 U	0.10 U	0.11 J	0.20 U	0.10 U
D72375	RFETS	Heterogeneous	116	831	880.00 U	80.00 U	80.00 U	80.00 U	80.00 U	80.00 U	160.00 U	80.00 U
D72434	RFETS	Heterogeneous	116	831	2310.00 U	210.00 U	210.00 U	210.00 U	210.00 U	210.00 U	420.00 U	210.00 U
D72436	RFETS	Uncategorized Metal	117	480	3.50 J	17.20	0.30 U	0.60 U	0.30 U	0.30 U	0.30 U	0.30 U
D72542	RFETS	Heterogeneous	116	832	60.00 U	13.25 J	10.00 U	20.00 U	10.00 U	10.00 U	10.00 U	10.00 U
D72545	RFETS	Solidified Inorganics	111	800	0.70 U	5.28	0.10 U	0.20 U	0.10 U	0.64 J	0.13 J	0.10 U
D72546	RFETS	Heterogeneous	116	832	90.00 U	23.24 J	15.00 U	30.00 U	15.00 U	15.00 U	15.00 U	15.00 U
D72566	RFETS	Solidified Organics	112	801	8.80 U	5.58 J	7.46 J	0.80 U	0.80 U	0.80 U	1.60 U	0.80 U
D72598	RFETS	Heterogeneous	116	821	6.60 U	27.50	0.60 U	0.60 U	0.60 U	0.60 U	1.20 U	0.60 U
D72618	RFETS	Heterogeneous	116	833	1.10 U	2.48	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D72619	RFETS	Solidified Organics	112	801	1.10 U	3.60	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D72623	RFETS	Solidified Organics	112	801	3.00 U	5.45	0.50 U	1.00 U	0.50 U	0.50 U	0.50 U	0.50 U
D72631	RFETS	Solidified Organics	112	801	1.10 U	1.92	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D72632	RFETS	Solidified Organics	112	801	1.10 U	4.04	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D72673	RFETS	Heterogeneous	116	833	2.20 U	10.67	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D72819	RFETS	Heterogeneous	116	833	4.40 U	35.51	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D72822	RFETS	Heterogeneous	116	831	1.60 U	19.90	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D72831	RFETS	Uncategorized Metal	117	480	28.00 U	22.59 J	4.00 U	8.00 U	4.00 U	4.00 U	4.00 U	4.00 U
D72887	RFETS	Heterogeneous	116	833	7.35 J	9.47	0.10 U	0.10 U	0.41 J	1.53	0.40 J	0.10 U
D72923	RFETS	Heterogeneous	116	833	8.67 J	33.51	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D72932	RFETS	Heterogeneous	116	825	3.30 U	20.99	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D73054	RFETS	Heterogeneous	0	336	680.00 U	113.33	113.33 U	226.67 U	113.33 U	113.33 U	113.33 U	113.33 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D73074	RFETS	Heterogeneous	116	833	2.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D73117	RFETS	Uncategorized Metal	117	480	2.80 U	15.05	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D73123	RFETS	Heterogeneous	116	831	1386.00 U	126.00 U	126.00 U	126.00 U	126.00 U	126.00 U	252.00 U	126.00 U
D73134	RFETS	Heterogeneous	116	831	432.00 U	72.00 U	72.00 U	144.00 U	72.00 U	72.00 U	72.00 U	72.00 U
D73136	RFETS	Solidified Inorganics	111	807	0.70 U	3.39	0.10 U	0.20 U	0.10 U	0.49 J	0.12 J	0.10 U
D73274	RFETS	Heterogeneous	116	831	550.00 U	50.00 U	50.00 U	50.00 U	50.00 U	50.00 U	100.00 U	50.00 U
D73285	RFETS	Solidified Organics	112	801	1.10 U	4.71	0.34 J	0.10 U	0.10 U	0.12 J	0.20 U	0.10 U
D73293	RFETS	Solidified Organics	112	801	1.10 U	3.03	0.38 J	0.10 U	0.10 U	0.14 J	0.20 U	0.10 U
D73295	RFETS	Solidified Organics	112	801	1.10 U	2.65	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D73296	RFETS	Solidified Organics	112	801	1.10 U	2.37	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D73301	RFETS	Solidified Organics	112	801	2.20 U	9.08	0.50 J	0.20 U	0.20 U	0.30 J	0.40 U	0.20 U
D73605	RFETS	Lead/Cadmium Metal	123	339	0.70 U	3.87	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D73632	RFETS	Heterogeneous	116	825	7.70 U	5.16 J	0.70 U	0.70 U	0.70 U	1.49 J	1.40 U	0.70 U
D73667	RFETS	Solidified Organics	112	801	1.10 U	2.22	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D73672	RFETS	Solidified Organics	112	801	1.10 U	3.07	0.31 J	0.10 U	0.10 U	0.16 J	0.20 U	0.10 U
D73745	RFETS	Heterogeneous	116	832	0.70 U	9.49	0.10 U	0.20 U	0.40 J	1.13	0.36 J	0.10 U
D73828	RFETS	Heterogeneous	116	833	1.10 U	9.45	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D73848	RFETS	Heterogeneous	116	821	1.46 U	6.01	0.13 U	0.13 U	0.13 U	0.13 U	0.27 U	0.13 U
D73987	RFETS	Lead/Cadmium Metal	123	339	2.10 U	3.09	0.30 U	0.60 U	0.30 U	0.30 U	0.30 U	0.30 U
D74007	RFETS	Uncategorized Metal	117	480	2.10 U	19.46	0.30 U	0.60 U	0.30 U	0.30 U	0.30 U	0.30 U
D74110	RFETS	Heterogeneous	116	833	1.10 U	3.36	0.10 U	0.10 U	0.24 J	0.18 J	0.20 U	0.10 U
D74147	RFETS	Solidified Organics	112	801	8.80 U	3.80 J	0.80 U	0.80 U	0.80 U	0.80 U	1.60 U	0.80 U
D74156	RFETS	Solidified Organics	112	801	6.60 U	4.30 J	0.60 U	0.60 U	0.60 U	0.60 U	1.20 U	0.60 U
D74374	RFETS	Heterogeneous	116	833	0.60 U	14.03	0.10 U	0.20 U	0.10 U	0.77 J	0.21 J	0.10 U
D74683	RFETS	Heterogeneous	116	821	16.50 U	106.54	1.50 U	1.50 U	1.50 U	1.50 U	3.00 U	1.50 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D74904	RFETS	Heterogeneous	116	832	0.60 U	4.59	0.10 U	0.20 U	0.10 U	0.19 J	0.20 J	0.10 U
D74913	RFETS	Heterogeneous	116	832	3.30 U	11.94	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D75039	RFETS	Heterogeneous	116	832	3.30 U	1.74 J	0.30 U	0.30 U	2.22 J	19.98	12.03	0.30 U
D75265	RFETS	Heterogeneous	116	833	13.20 U	24.74	1.20 U	1.20 U	1.20 U	1.20 U	2.40 U	1.20 U
D75267	RFETS	Heterogeneous	116	832	2.20 U	18.50	0.20 U	0.20 U	0.23 J	0.47 J	0.40 U	0.20 U
D75278	RFETS	Heterogeneous	116	832	3.30 U	36.13	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D75399	RFETS	Heterogeneous	116	833	4.40 U	16.33	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D75564	RFETS	Heterogeneous	116	825	1.46 U	7.19	0.13 U	0.13 U	0.13 U	0.13 U	0.27 U	0.13 U
D75868	RFETS	Heterogeneous	116	825	6.60 U	23.45	0.60 U	0.60 U	0.60 U	0.60 U	1.20 U	0.60 U
D75888	RFETS	Heterogeneous	116	833	1.10 U	8.30	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D75926	RFETS	Heterogeneous	116	832	4.40 U	27.16	0.40 U	0.40 U	0.40 U	0.40 U	0.80 U	0.40 U
D75930	RFETS	Heterogeneous	116	832	600.00 U	100.00 U	100.00 U	200.00 U	100.00 U	100.00 U	100.00 U	100.00 U
D75947	RFETS	Heterogeneous	116	832	1.10 U	8.86	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D75976	RFETS	Heterogeneous	116	833	0.80 U	14.43	0.13 U	0.27 U	0.13 U	0.13 U	0.13 U	0.13 U
D76044	RFETS	Heterogeneous	116	831	4.05 J	25.07	0.27 U	0.27 U	0.27 U	0.27 U	0.53 U	0.27 U
D76050	RFETS	Heterogeneous	116	832	1.10 U	4.80	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D76054	RFETS	Heterogeneous	116	831	3.30 U	20.75	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D76098	RFETS	Heterogeneous	116	832	1.40 U	18.43	0.20 U	0.40 U	0.20 U	0.20 U	0.20 U	0.20 U
D76135	RFETS	Solidified Organics	112	801	160.00 U	26.67 U	26.67 U	53.33 U	26.67 U	26.67 U	26.67 U	26.67 U
D76136	RFETS	Solidified Inorganics	111	803	2.40 U	1.89 J	0.41 J	0.80 U	0.40 U	3.02 J	0.82 J	0.40 U
D76138	RFETS	Solidified Inorganics	111	800	0.60 U	1.21	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D76142	RFETS	Solidified Inorganics	111	800	1.44 U	2.56	0.24 U	0.48 U	4.41	18.08	3.45	0.24 U
D76143	RFETS	Solidified Inorganics	111	803	1.80 U	2.12 J	0.37 J	0.60 U	0.30 J	2.25 J	0.63 J	0.30 U
D76144	RF[illegible]	Solidified Inorganics	111	800	4.00 U	0.67 [illegible]	0.67 U	1.33 U	0.67 U	0.67 U	0.67 U	[illegible] U
D76146	RFETS	Solidified Inorganics	0	292	0.60 U	3.33	0.10 U	0.20 U	0.10 U	0.22 J	0.10 U	0.10 U

Table [illegible]-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D76147	RFETS	Solidified Inorganics	111	803	1.10 U	1.69	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D76182	RFETS	Solidified Inorganics	111	800	7.70 U	71.38	0.70 U	0.70 U	9.54	38.35	7.49	0.70 U
D76183	RFETS	Solidified Inorganics	111	800	0.80 U	3.96	0.13 U	0.27 U	0.18 J	0.66 J	0.17 J	0.13 U
D76185	RFETS	Solidified Inorganics	111	800	0.60 U	0.33 J	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D76187	RFETS	Solidified Inorganics	111	803	3.00 U	1.45 J	0.50 U	1.00 U	1.11 J	3.57 J	0.91 J	0.50 U
D76189	RFETS	Solidified Inorganics	111	803	12.00 U	2.00 U	2.00 U	4.00 U	2.00 U	2.00 U	2.00 U	2.00 U
D76192	RFETS	Solidified Inorganics	111	803	0.60 U	1.11	0.10 U	0.20 U	0.10 U	0.21 J	0.10 U	0.10 U
D76194	RFETS	Solidified Inorganics	111	800	0.60 U	0.10 U	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D76195	RFETS	Solidified Organics	112	801	5280.00 U	480.00 U	480.00 U	480.00 U	480.00 U	480.00 U	960.00 U	480.00 U
D76196	RFETS	Solidified Organics	112	801	1000.00 U	166.67 U	166.67 U	333.33 U	166.67 U	166.67 U	166.67 U	166.67 U
D76199	RFETS	Solidified Inorganics	111	800	0.60 U	1.31	0.10 U	0.20 U	0.10 U	0.17 U	0.10 U	0.10 U
D76200	RFETS	Solidified Organics	112	801	3800.00 U	633.33 U	633.33 U	1266.6 U	633.33 U	633.33 U	633.33 U	633.33 U
D76203	RFETS	Solidified Organics	112	801	1340.00 J	223.33 U	223.33 U	446.67 U	223.33 U	223.33 U	223.33 U	223.33 U
D76205	RFETS	Solidified Inorganics	111	800	0.60 U	2.66	0.10 U	0.20 U	0.10 U	0.43 J	0.10 U	0.10 U
D76206	RFETS	Solidified Inorganics	111	803	2.40 U	1.09 J	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	0.40 U
D76217	RFETS	Heterogeneous	116	833	6.75 J	7.45 J	1.00 U	2.00 U	1.00 U	1.00 U	1.00 U	1.00 U
D76282	RFETS	Solidified Inorganics	111	800	68.00 U	11.33 U	11.33 U	22.67 U	11.33 U	11.33 U	11.33 U	11.33 U
D76283	RFETS	Solidified Organics	112	801	540.00 U	90.00 U	90.00 U	180.00 U	90.00 U	90.00 U	90.00 U	90.00 U
D76287	RFETS	Solidified Inorganics	111	800	32.00 U	5.33 U	5.33 U	10.67 U	5.33 U	5.33 U	5.33 U	5.33 U
D76293	RFETS	Heterogeneous	116	833	4.40 U	0.59 J	0.40 U	0.40 U	0.96 J	2.65 J	0.80 U	0.40 U
D76302	RFETS	Solidified Inorganics	111	800	18.00 U	34.11	3.00 U	6.00 U	101.74	386.14	30.35	3.00 U
D76303	RFETS	Solidified Inorganics	111	803	1.60 U	1.56 J	0.30 J	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D76305	RFETS	Solidified Inorganics	111	800	72.00 U	12.00 U	12.00 U	24.00 U	12.00 U	12.00 U	12.00 U	12.00 U
D76306	RFETS	Heterogeneous	116	833	8.80 U	1.84 J	0.80 U	0.80 U	2.86 J	8.72	1.60 U	0.80 U
D76362	RFETS	Heterogeneous	116	833	40.00 U	6.67 U	6.67 U	13.33 U	6.67 U	6.67 U	6.67 U	6.67 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D76406	RFETS	Heterogeneous	116	831	1.10 U	4.58	0.10 U	0.10 U	0.10 U	0.15 J	0.20 U	0.10 U
D76437	RFETS	Heterogeneous	116	833	2.20 U	24.00	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D76443	RFETS	Heterogeneous	116	825	3.30 U	5.66	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D76452	RFETS	Heterogeneous	116	825	1.90 U	9.30	0.20 U	0.20 U	0.20 U	0.20 U	0.30 U	0.20 U
D76454	RFETS	Heterogeneous	116	825	1.10 U	5.19	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D76456	RFETS	Heterogeneous	116	825	1.10 U	6.59	0.10 U	0.10 U	0.10 U	0.10 J	0.20 U	0.10 U
D76461	RFETS	Heterogeneous	116	825	3.30 U	12.50	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D76463	RFETS	Heterogeneous	116	825	3.30 U	21.50	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D76470	RFETS	Solidified Inorganics	111	803	0.60 U	3.29	0.10 U	0.20 U	0.10 U	0.23 J	0.10 U	0.10 U
D76587	RFETS	Heterogeneous	116	825	1.10 U	7.16	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D76596	RFETS	Heterogeneous	116	825	1.10 U	14 57	0.10 U	0.10 U	0.10 U	0.10 J	0.20 U	0.10 U
D76627	RFETS	Heterogeneous	116	825	1.10 U	7.34	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D76630	RFETS	Heterogeneous	116	825	1.10 U	8.52	0.10 U	0.10 U	0.19 J	0.71 J	0.20 U	0.10 U
D76635	RFETS	Heterogeneous	116	825	2.20 U	5.12	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D76652	RFETS	Heterogeneous	116	833	0.60 U	8.81	0.10 U	0.20 U	0.10 U	0.10 U	0.10 U	0.10 U
D76677	RFETS	Solidified Inorganics	111	800	26.40 U	2.40 U	2.40 U	2.40 U	2.40 U	2.40 U	4.80 U	2.40 U
D76710	RFETS	Heterogeneous	116	833	22.00 U	9.15 J	2.00 U	2.00 U	2.00 U	2.00 U	4.00 U	2.00 U
D76712	RFETS	Heterogeneous	116	833	3.30 U	13.98	0.30 U	0.30 U	0.30 U	0.30 U	0.60 U	0.30 U
D76715	RFETS	Heterogeneous	116	832	2.20 U	10.09	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D76811	RFETS	Heterogeneous	116	832	2.40 J	20.45	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U
D76908	RFETS	Heterogeneous	116	833	1.10 U	3.36	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U
D76911	RFETS	Heterogeneous	116	832	1.20 U	19.65	0.20 U	0.40 U	0.56 J	1.42 J	0.20 U	0.20 U
D77088	RFETS	Heterogeneous	116	833	1.20 U	14.47	0.20 U	0.40 U	0.20 U	0.20 U	0.20 U	0.20 U
D77227	RF[illegible]	Heterogeneous	116	833	2.40 U	32.95 [illegible]	0.40 U	0.80 U	0.40 U	0.40 U	0.40 U	[illegible] U
D77285	RFETS	Heterogeneous	116	833	2.20 U	8.62	0.20 U	0.20 U	0.20 U	0.20 U	0.40 U	0.20 U

Table ,-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	Methyl isobutyl ketone	Toluene	Tetra chloro ethene	Chloro benzene	Ethyl benzene	m,p-Xylene	o-Xylene	Bromoform
D77621	RFETS	Heterogeneous	0	336	1.87 U	9.47	0.27 U	0.53 U	0.27 U	0.27 U	0.27 U	0.27 U
D80765	RFETS	Heterogeneous	116	833	2.20 U	10.02	0.20 U	0.20 U	0.20 U	0.51 J	0.40 U	0.20 U
D80772	RFETS	Heterogeneous	116	833	11.00 U	24.39	1.00 U	1.00 U	1.00 U	1.00 U	2.00 U	1.00 U
D80774	RFETS	Heterogeneous	116	833	34.10 U	3.10 U	3.10 U	3.10 U	3.10 U	3.10 U	6.20 U	3.10 U
D80776	RFETS	Heterogeneous	116	832	1.34 J	11.32	0.10 U	0.10 U	0.10 U	0.10 U	0.20 U	0.10 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
000365	RFETS	Uncategorized Metal	217	480	12.00 U	8.70 U	8.70 U
000371	INEL	Graphite	215	300	0.03 U	0.01 U	0.02 U
000373	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
000384	RFETS	Uncategorized Metal	217	320	0.01 U	0.01 U	0.01 U
000393	INEL	Uncategorized Metal	217	480	0.03 U	0.02 U	0.02 U
000401	RFETS	Inorganic Non-metal	222	371	0.02 U	0.01 U	0.01 U
000403	INEL	Inorganic Non-metal	218	440	0.03 U	0.02 U	0.02 U
000405	RFETS	Uncategorized Metal	217	480	0.94 U	0.66 U	0.87 U
000436	INEL	Solidified Organics	212	3	43.00 U	19.00 U	27.00 U
000442	INEL	Solidified Inorganics	213	4	0.05 U	0.02 U	0.03 U
000446	RFETS	Solidified Inorganics	211	1	0.01 U	0.01 U	0.01 J
000478	RFETS	Solidified Inorganics	211	1	0.01 U	0.01 U	0.01 J
000501	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
000558	INEL	Heterogeneous	221	464	0.10 U	0.07 U	0.07 U
000567	RFETS	Inorganic Non-metal	222	371	1.70 U	1.20 U	1.60 U
000568	RFETS	Solidified Organics	226	432	1.00 U	0.73 U	0.73 U
000593	INEL	Solidified Inorganics	211	7	0.02 U	0.01 J	0.02 J
000613	INEL	Graphite	215	300	0.03 U	0.02 U	0.02 U
000630	INEL	Solidified Inorganics	213	4	0.07 U	0.03 U	0.04 U
000648	RFETS	Solidified Inorganics	213	4	0.03 U	0.02 U	0.03 U
000675	RFETS	Inorganic Non-metal	218	440	0.16 U	0.11 U	0.15 U
000823	RFETS	Solidified Inorganics	213	4	0.02 U	0.02 U	0.02 U
000828	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
001016	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
001024	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
001084	INEL	Solidified Inorganics	213	[illegible]	0.02 U	0.01 U	0.01 U
001139	INEL	Solidified Inorganics	211	[illegible]	0.16 U	0.07 U	0.10 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
001157	INEL	Combustible	223	339	0.03 U	0.02 U	0.02 U
001161	INEL	Graphite	215	300	0.03 U	0.02 U	0.02 U
001258	RFETS	Solidified Inorganics	211	1	0.01 U	0.01 U	0.01 U
001370	INEL	Combustible	223	339	0.14 U	0.08 U	0.09 U
001377	INEL	Combustible	223	339	0.03 U	0.02 U	0.02 U
001410	INEL	Solidified Inorganics	214	292	0.13 U	0.09 U	0.09 U
001437	RFETS	Solidified Inorganics	211	7	0.01 U	0.06 U	0.01 J
001475	RFETS	Solidified Inorganics	211	1	0.21 U	0.14 U	0.19 U
001493	RFETS	Solidified Inorganics	211	1	0.01 U	0.01 U	0.01 U
001619	INEL	Graphite	215	300	0.03 U	0.02 U	0.02 U
001625	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
001633	INEL	Solidified Organics	226	432	0.74 U	0.52 U	0.52 U
001655	INEL	Combustible	223	339	2.00 U	1.40 U	1.40 U
001662	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 JB
001663	RFETS	Solidified Organics	226	432	0.45 U	0.31 U	0.31 U
001667	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
001670	RFETS	Salt Waste	224	411	0.04 U	0.03 U	0.04 U
001677	INEL	Heterogeneous	221	302	0.46 U	0.20 U	0.29 U
001678	RFETS	Combustible	223	339	0.10 U	0.07 U	0.10 U
001689	INEL	Heterogeneous	221	302	0.04 U	0.03 U	0.03 U
001692	RFETS	Solidified Organics	226	432	0.27 U	0.19 U	0.19 U
001695	INEL	Combustible	223	339	1.70 U	1.20 U	1.20 U
001697	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
001751	RFETS	Uncategorized Metal	217	320	0.01 U	0.01 U	0.02 JB
001752	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
001754	INEL	Uncategorized Metal	217	320	0.04 U	0.03 J	0.04 J
001757	INEL	Inorganic Non-metal	222	371	0.03 U	0.02 U	0.02 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
001773	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
001779	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
001784	INEL	Combustible	223	339	0.03 U	0.02 U	0.02 U
001813	INEL	Solidified Inorganics	213	4	5.70 U	2.50 U	3.60 U
001873	INEL	Solidified Inorganics	214	292	0.04 U	0.03 U	0.03 U
001899	RFETS	Solidified Inorganics	211	3	140.00 U	97.00 U	130.00 U
001900	INEL	Solidified Inorganics	214	292	0.04 U	0.03 U	0.03 U
001919	RFETS	Uncategorized Metal	217	320	0.01 U	0.01 U	0.01 U
001937	RFETS	Solidified Organics	212	3	17.00 U	12.00 U	16.00 U
002013	RFETS	Solidified Organics	212	3	12.00 U	8.20 U	11.00 U
002046	INEL	Solidified Organics	212	3	36.00 U	16.00 U	23.00 U
002065	INEL	Solidified Inorganics	214	292	0.11 U	0.08 U	0.10 U
002084	INEL	Solidified Inorganics	213	4	0.04 U	0.02 U	0.02 U
002220	RFETS	Uncategorized Metal	217	481	0.03 U	0.02 U	0.03 U
002222	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
002338	RFETS	Inorganic Non-metal	222	371	0.84 U	0.58 U	0.58 U
002354	INEL	Combustible	223	339	0.08 U	0.04 U	0.05 U
002363	INEL	Inorganic Non-metal	222	371	0.03 U	0.02 U	0.02 U
002365	INEL	Uncategorized Metal	217	480	0.07 U	0.05 U	0.05 U
002542	INEL	Solidified Organics	212	3	7.70 U	3.40 U	4.90 U
002678	RFETS	Solidified Organics	226	432	0.95 U	0.66 U	0.66 U
002791	INEL	Inorganic Non-metal	222	371	0.05 U	0.04 U	0.04 U
002797	RFETS	Solidified Organics	226	432	0.48 U	0.33 U	0.33 U
002814	RFETS	Solidified Inorganics	211	7	0.22 U	0.15 U	0.20 U
003017	INEL	Solidified Inorganics	211	1	0.05 U	0.04 U	0.05 U
003088	INEL	Inorganic Non-metal	222	371	0.03 U	0.02 U	0.02 U
003091	RFETS	Inorganic Non-metal	222	3[illegible]	0.03 U	0.02 U	0.02 U

Table 2-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
003111	INEL	Inorganic Non-metal	222	371	0.03 U	0.02 U	0.02 U
003121	RFETS	Solidified Inorganics	211	7	0.15 U	0.10 U	0.14 U
003129	RFETS	Solidified Inorganics	211	7	0.02 U	0.02 U	0.02 J
003130	RFETS	Solidified Inorganics	211	7	0.04 U	0.03 U	0.04 J
003173	RFETS	Solidified Inorganics	211	7	0.02 U	0.01 U	0.02 J
003181	RFETS	Solidified Inorganics	211	7	0.02 U	0.01 U	0.01 U
003189	INEL	Solidified Organics	212	3	79.00 U	35.00 U	50.00 U
003192	RFETS	Solidified Inorganics	211	7	0.25 U	0.17 U	0.23 U
003215	RFETS	Solidified Inorganics	211	7	0.02 U	0.01 U	0.03 J
003277	RFETS	Solidified Inorganics	211	1	0.01 U	0.01 U	0.01 J
003394	RFETS	Solidified Inorganics	211	7	0.03 U	0.02 U	0.03 U
003406	RFETS	Solidified Inorganics	211	7	0.01 U	0.02 J	0.04 J
003455	RFETS	Solidified Inorganics	211	3	270.00 U	190.00 U	250.00 U
003547	RFETS	Solidified Inorganics	211	7	0.10 U	0.07 U	0.09 U
003577	RFETS	Solidified Inorganics	211	1	0.01 U	0.01 U	0.01 U
003854	INEL	Solidified Organics	212	3	36.00 U	16.00 U	23.00 U
003890	INEL	Solidified Inorganics	111	7	0.03 U	0.02 U	0.03 U
003921	INEL	Solidified Inorganics	111	7	0.04 U	0.02 U	0.03 U
003991	INEL	Combustible	223	339	0.02 U	0.01 U	0.02 U
003997	INEL	Combustible	223	339	0.05 U	0.03 U	0.03 U
004099	INEL	Solidified Inorganics	211	1	0.02 U	0.01 U	0.01 U
004111	RFETS	Salt Waste	224	411	0.03 U	0.02 U	0.03 U
004112	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
004123	INEL	Combustible	223	339	0.02 U	0.01 U	0.02 U
004125	INEL	Uncategorized Metal	217	480	0.03 U	0.02 U	0.02 U
004150	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
004160	INEL	Combustible	223	339	140.00 U	77.00 U	93.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
004166	INEL	Inorganic Non-metal	222	371	0.03 U	0.02 U	0.02 U
004186	INEL	Combustible	223	339	0.02 U	0.01 U	0.02 U
004195	RFETS	Salt Waste	224	411	0.01 U	0.01 U	0.01 U
004196	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
004206	INEL	Combustible	223	339	0.02 U	0.01 U	0.01 U
004208	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
004283	INEL	Solidified Inorganics	211	1	0.02 U	0.01 U	0.01 U
004326	INEL	Solidified Inorganics	213	4	0.02 U	0.01 U	0.01 U
004393	INEL	Solidified Inorganics	211	1	0.02 U	0.01 U	0.02 U
004410	INEL	Solidified Inorganics	211	1	0.03 U	0.02 U	0.03 U
004495	INEL	Solidified Inorganics	213	4	0.02 U	0.01 U	0.01 U
004516	INEL	Solidified Inorganics	211	1	0.03 U	0.02 U	0.03 U
004884	INEL	Solidified Inorganics	213	4	0.03 U	0.01 U	0.02 U
004963	INEL	Combustible	223	339	0.08 U	0.04 U	0.05 U
004968	RFETS	Uncategorized Metal	217	320	0.58 U	0.41 U	0.54 U
004981	RFETS	Uncategorized Metal	217	320	0.01 U	0.01 U	0.01 U
004988	RFETS	Salt Waste	224	411	0.03 U	0.02 U	0.03 U
005006	RFETS	Salt Waste	224	411	0.03 U	0.02 U	0.03 U
005012	INEL	Combustible	223	339	0.02 U	0.01 U	0.01 U
005015	INEL	Solidified Organics	226	432	1.50 U	1.00 U	1.00 U
005235	INEL	Solidified Organics	226	432	0.03 U	0.02 U	0.02 U
005262	INEL	Solidified Organics	212	3	220.00 U	98.00 U	140.00 U
005358	INEL	Solidified Inorganics	211	1	0.02 U	0.01 U	0.01 U
005398	INEL	Solidified Inorganics	211	1	0.03 U	0.02 U	0.03 U
005415	INEL	Solidified Inorganics	211	1	0.03 U	0.02 U	0.03 U
005530	INEL	Graphite	215	3[illegible]	0.02 U	0.01 U	0.02 U
005535	INEL	Solidified Organics	226	4[illegible]	0.06 U	0.04 U	0.04 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
005735	INEL	Solidified Inorganics	211	7	0.03 U	0.02 U	0.03 U
005738	INEL	Solidified Inorganics	211	7	0.02 U	0.02 U	0.02 U
006242	INEL	Inorganic Non-metal	222	371	0.03 U	0.02 U	0.02 U
006252	RFETS	Lead/Cadmium Metal Waste	123	339	3.90 U	2.80 U	3.70 U
006325	RFETS	Solidified Inorganics	213	4	0.01 U	0.01 J	0.04 J
006669	INEL	Solidified Inorganics	214	292	0.15 U	0.10 U	0.14 U
006773	RFETS	Solidified Inorganics	213	4	0.11 U	0.08 U	0.10 U
006857	INEL	Combustible	223	339	0.02 U	0.01 U	0.02 U
006865	RFETS	Solidified Organics	226	432	0.08 U	0.06 U	0.07 U
006876	INEL	Filter	219	335	0.02 U	0.01 U	0.02 U
006879	INEL	Solidified Organics	226	432	0.10 U	0.07 U	0.07 U
006886	INEL	Solidified Organics	226	432	0.33 U	0.23 U	0.23 U
007034	INEL	Combustible	216	337	2.10 U	1.50 U	1.50 U
007146	INEL	Inorganic Non-metal	222	371	1.70 U	1.20 U	1.20 U
007170	INEL	Combustible	216	337	0.40 U	0.22 U	0.26 U
007231	INEL	Filter	219	338	0.18 U	0.10 U	0.12 U
007511	INEL	Inorganic Non-metal	122	374	0.04 U	0.03 U	0.04 U
007518	INEL	Inorganic Non-metal	122	374	0.06 U	0.04 U	0.06 U
007667	INEL	Salt Waste	124	411	0.01 U	0.01 U	0.01 U
007920	INEL	Filter	121	302	0.24 U	0.17 U	0.22 U
008203	INEL	Inorganic Non-metal	118	440	0.06 U	0.04 U	0.06 U
008207	INEL	Heterogeneous	116	336	0.07 U	0.05 U	0.07 U
008218	INEL	Heterogeneous	116	330	0.07 U	0.05 U	0.07 U
008269	INEL	Uncategorized Metal	117	320	0.19 U	0.14 U	0.18 U
008287	INEL	Inorganic Non-metal	122	374	0.03 U	0.02 U	0.03 U
008359	INEL	Heterogeneous	116	330	0.19 U	0.14 U	0.18 U
008383	INEL	Lead/Cadmium Metal Waste	123	339	5.20 U	3.70 U	4.90 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
008848	INEL	Inorganic Non-metal	218	440	0.60 JB	0.28 JB	0.42 JB
008859	INEL	Inorganic Non-metal	218	440	0.45 U	0.31 U	0.31 U
008860	INEL	Uncategorized Metal	217	480	1.10 U	0.79 U	0.79 U
008864	INEL	Uncategorized Metal	217	480	0.10 U	0.07 U	0.07 U
008872	INEL	Solidified Inorganics	214	292	0.04 U	0.03 U	0.04 U
008874	RFETS	Uncategorized Metal	217	480	35.00 U	24.00 U	33.00 U
008878	INEL	Uncategorized Metal	217	480	4.80 U	3.30 U	3.30 U
008880	RFETS	Graphite	115	312	1.40 U	0.95 U	1.30 U
009006	INEL	Solidified Inorganics	211	7	0.05 JB	0.04 JB	0.06 JB
009011	RFETS	Solidified Inorganics	211	7	0.01 U	0.01 J	0.02 JB
009061	RFETS	Inorganic Non-metal	218	440	0.10 U	0.07 U	0.09 U
009180	INEL	Combustible	223	339	0.90 U	0.49 U	0.59 U
009225	INEL	Uncategorized Metal	217	481	0.03 U	0.02 U	0.02 U
009252	INEL	Combustible	223	339	21.00 U	15.00 U	15.00 U
009296	INEL	Combustible	223	339	3.00 U	2.10 U	2.10 U
009299	INEL	Combustible	223	339	0.02 U	0.01 U	0.02 U
009399	INEL	Inorganic Non-metal	218	440	0.39 U	0.27 U	0.27 U
009422	RFETS	Combustible	216	337	5.60 U	3.90 U	5.20 U
009423	INEL	Combustible	216	337	1.80 U	0.78 U	1.10 U
009435	INEL	Combustible	216	337	0.39 U	0.27 U	0.27 U
009449	INEL	Inorganic Non-metal	218	440	0.04 U	0.03 U	0.03 U
009471	INEL	Combustible	216	337	0.09 U	0.05 U	0.06 U
009475	INEL	Inorganic Non-metal	218	442	0.72 U	0.31 U	0.45 U
009489	INEL	Combustible	216	337	0.23 U	0.13 U	0.15 U
009587	INEL	Uncategorized Metal	117	320	0.01 U	0.01 U	0.01 U
009591	INEL	Inorganic Non-metal	118	[illegible]	0.04 U	0.03 U	0.04 U
009592	INEL	Inorganic Non-metal	118	440	0.07 U	0.05 U	0.08 J

Table 2-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
009596	INEL	Uncategorized Metal	117	320	0.14 U	0.09 U	0.13 U
009599	INEL	Inorganic Non-metal	118	440	0.03 U	0.02 U	0.03 U
009602	INEL	Inorganic Non-metal	218	442	2.00 U	1.40 U	1.40 U
009694	INEL	Graphite	215	300	0.02 U	0.02 J	0.03 J
009735	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
009773	INEL	Combustible	223	339	5.40 U	2.40 U	3.40 U
009787	RFETS	Solidified Organics	212	3	180.00 U	130.00 U	170.00 U
009873	RFETS	Solidified Inorganics	211	1	0.05 U	0.03 U	0.05 U
010216	INEL	Filter	219	338	1.10 U	0.61 U	0.74 U
010224	INEL	Filter	219	338	0.34 U	0.18 U	0.22 U
010230	INEL	Heterogeneous	216	330	0.18 U	0.10 U	0.15 J
010273	INEL	Combustible	216	337	0.16 U	0.09 U	0.11 U
010295	INEL	Inorganic Non-metal	218	442	0.06 U	0.04 U	0.04 U
010305	RFETS	Inorganic Non-metal	218	442	0.70 U	0.49 U	0.65 U
010364	RFETS	Combustible	216	337	0.89 U	0.62 U	0.83 U
010371	INEL	Combustible	216	337	0.40 U	0.25 U	0.28 U
010407	RFETS	Uncategorized Metal	217	480	0.12 U	0.10 J	0.19 J
010411	INEL	Combustible	216	337	2.00 U	1.40 U	1.40 U
010415	INEL	Inorganic Non-metal	218	442	0.03 U	0.02 U	0.02 U
010426	INEL	Inorganic Non-metal	218	442	0.02 U	0.01 U	0.01 U
010463	INEL	Solidified Inorganics	213	4	0.30 U	0.21 U	0.21 U
010487	INEL	Salt Waste	224	414	0.54 U	0.38 U	0.38 U
010492	INEL	Uncategorized Metal	217	480	0.58 U	0.41 U	0.41 U
010498	INEL	Uncategorized Metal	217	480	0.05 U	0.02 U	0.03 U
010510	RFETS	Heterogeneous	216	336	1.70 U	1.20 U	1.60 U
010546	RFETS	Heterogeneous	216	330	47.00 U	32.00 U	43.00 U
010578	INEL	Solidified Organics	226	432	1.00 U	0.71 U	0.71 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
010588	RFETS	Solidified Inorganics	211	2	0.88 U	0.61 U	0.82 U
010663	INEL	Combustible	216	337	0.58 U	0.32 U	0.38 U
010676	INEL	Heterogeneous	216	330	0.46 U	0.25 U	0.31 U
010800	INEL	Filter	219	338	0.16 U	0.09 U	0.10 U
010807	INEL	Combustible	216	337	1.30 U	0.92 U	0.92 U
010808	INEL	Combustible	216	337	0.38 U	0.16 U	0.25 JB
010814	RFETS	Solidified Inorganics	211	1	0.36 U	0.25 U	0.33 U
010837	INEL	Solidified Organics	226	432	0.45 U	0.31 U	0.31 U
010848	INEL	Filter	219	338	0.44 U	0.24 U	0.29 U
010883	INEL	Solidified Organics	226	432	1.20 U	0.81 U	0.81 U
010921	INEL	Inorganic Non-metal	222	371	0.10 U	0.07 U	0.07 U
011004	INEL	Uncategorized Metal	217	480	0.03 U	0.02 U	0.02 U
011021	INEL	Solidified Organics	226	432	0.18 U	0.12 U	0.12 U
011042	INEL	Inorganic Non-metal	218	442	0.62 U	0.44 U	0.44 U
011044	INEL	Inorganic Non-metal	218	440	0.36 U	0.25 U	0.25 U
011067	RFETS	Solidified Inorganics	213	4	1.20 U	0.82 U	1.10 U
011102	RFETS	Solidified Inorganics	211	1	0.28 U	0.20 U	0.26 U
011109	INEL	Solidified Inorganics	211	1	0.21 U	0.09 U	0.14 U
011147	INEL	Solidified Inorganics	213	4	0.25 U	0.11 U	0.16 U
011173	INEL	Uncategorized Metal	217	480	0.06 U	0.03 U	0.04 U
011194	INEL	Inorganic Non-metal	218	442	0.07 U	0.05 U	0.05 U
011393	INEL	Uncategorized Metal	217	480	0.15 U	0.10 U	0.10 U
011416	INEL	Combustible	216	337	0.66 U	0.46 U	0.46 U
011433	INEL	Heterogeneous	216	330	0.58 U	0.32 U	0.38 U
011498	RFETS	Solidified Organics	226	432	1.70 U	1.20 U	1.20 U
011529	INEL	Uncategorized Metal	217	480	0.03 U	0.02 U	0.02 U
011601	INEL	Heterogeneous	216		1.40 U	0.74 U	0.90 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
011607	INEL	Heterogeneous	216	330	0.03 U	0.02 U	0.02 U
011637	RFETS	Filter	219	338	0.88 U	0.61 U	0.82 U
011735	INEL	Heterogeneous	216	330	0.89 U	0.62 U	0.62 U
011749	INEL	Inorganic Non-metal	225	441	0.25 U	0.18 U	0.18 U
011785	RFETS	Solidified Inorganics	211	1	0.03 U	0.02 U	0.03 U
012021	INEL	Solidified Inorganics	211	1	0.39 U	0.27 U	0.27 U
012108	INEL	Solidified Inorganics	214	292	0.39 U	0.27 U	0.27 U
012111	INEL	Combustible	216	337	1.90 U	1.00 U	1.20 U
012215	INEL	Uncategorized Metal	217	480	0.42 U	0.29 U	0.29 U
012313	INEL	Heterogeneous	216	336	0.70 U	0.38 U	0.46 U
012320	INEL	Heterogeneous	216	336	2.00 U	1.40 U	1.40 U
012356	INEL	Filter	219	338	0.25 U	0.31 J	0.24 J
012357	RFETS	Uncategorized Metal	217	480	3.20 U	2.20 U	2.90 U
012433	INEL	Filter	219	338	0.22 U	0.12 U	0.15 U
012469	RFETS	Solidified Inorganics	211	1	0.36 U	0.25 U	0.33 U
012471	RFETS	Filter	219	338	0.19 U	0.13 U	0.27 JB
012487	INEL	Inorganic Non-metal	218	440	0.02 U	0.01 U	0.02 JB
012494	INEL	Heterogeneous	216	330	1.20 U	0.83 U	0.83 U
012541	INEL	Inorganic Non-metal	218	442	0.03 U	0.02 U	0.03 J
012553	INEL	Solidified Inorganics	211	1	0.03 U	0.09 J	0.09 J
012571	INEL	Uncategorized Metal	217	320	0.02 U	0.01 U	0.01 U
012611	INEL	Solidified Inorganics	211	1	0.62 U	0.44 U	0.44 U
012634	INEL	Solidified Inorganics	211	1	1.70 U	1.20 U	1.20 U
012749	INEL	Solidified Inorganics	211	1	0.33 U	0.23 U	0.23 U
012766	INEL	Heterogeneous	216	336	3.00 U	2.10 U	2.10 U
012802	INEL	Combustible	216	337	1.30 U	0.57 U	0.82 U
012875	RFETS	Solidified Organics	226	432	4.00 U	2.80 U	2.80 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
012878	INEL	Uncategorized Metal	217	480	0.68 U	0.30 U	0.43 U
012891	INEL	Heterogeneous	216	330	0.34 U	0.24 U	0.24 U
012902	INEL	Filter	219	338	0.02 U	0.01 U	0.02 U
012920	INEL	Inorganic Non-metal	222	371	1.20 U	0.83 U	0.83 U
012985	INEL	Inorganic Non-metal	222	371	2.00 U	1.40 U	1.40 U
012986	INEL	Heterogeneous	221	302	1.60 B	0.96 JB	2.30 B
012998	INEL	Combustible	216	337	0.68 U	0.48 U	0.48 U
013106	INEL	Solidified Inorganics	111	7	0.02 U	0.01 JB	0.02 J
013229	RFETS	Solidified Organics	226	432	0.15 U	0.10 U	0.10 U
013231	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
013252	INEL	Inorganic Non-metal	222	371	0.03 U	0.02 U	0.02 U
013266	INEL	Combustible	223	339	0.42 U	0.29 U	0.29 U
013269	INEL	Inorganic Non-metal	218	440	0.06 U	0.03 U	0.04 U
013313	INEL	Inorganic Non-metal	218	440	0.03 U	0.02 U	0.02 U
013331	INEL	Salt Waste	124	411	0.07 U	0.05 U	0.07 U
013342	INEL	Inorganic Non-metal	218	440	0.02 U	0.01 U	0.02 J
013346	RFETS	Inorganic Non-metal	222	371	0.02 U	0.02 U	0.02 U
013618	INEL	Heterogeneous	216	330	2.00 U	1.40 U	1.40 U
013677	INEL	Filter	219	338	0.06 U	0.03 U	0.04 U
013751	INEL	Uncategorized Metal	217	480	0.89 U	0.62 U	0.62 U
013763	INEL	Combustible	223	339	16.00 U	10.00 U	11.00 U
013773	RFETS	Solidified Inorganics	111	7	0.08 U	0.07 J	0.14 JB
013818	RFETS	Solidified Inorganics	211	1	0.02 U	0.02 J	0.03 J
013820	RFETS	Solidified Inorganics	211	1	0.03 U	0.02 U	0.02 U
013847	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
013860	INEL	Combustible	223	[illegible]	0.08 U	0.04 U	0.05 U
013876	RFETS	Solidified Inorganics	211	[illegible]	0.10 U	0.07 U	0.09 U

Table 2-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
014007	INEL	Solidified Inorganics	211	1	0.03 U	0.02 U	0.02 U
014009	INEL	Solidified Inorganics	211	7	0.19 JB	0.10 JB	0.17 JB
014010	INEL	Solidified Inorganics	211	7	0.02 U	0.01 J	0.03 J
014127	RFETS	Solidified Inorganics	211	7	0.02 U	0.02 J	0.05 J
014170	INEL	Solidified Inorganics	211	7	0.02 U	0.01 U	0.02 U
014330	INEL	Graphite	215	303	0.05 U	0.02 U	0.03 U
014334	INEL	Filter	219	335	0.07 U	0.04 U	0.05 U
014339	INEL	Solidified Organics	226	432	0.06 U	0.04 U	0.04 U
014342	INEL	Graphite	215	303	0.08 U	0.04 U	0.05 U
014345	INEL	Solidified Organics	226	432	0.05 U	0.03 U	0.04 J
014346	INEL	Combustible	223	339	0.02 U	0.01 U	0.02 U
014348	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
014354	RFETS	Uncategorized Metal	217	481	0.01 U	0.01 U	0.01 U
014357	INEL	Combustible	223	339	16.00 U	10.00 U	11.00 U
014387	INEL	Solidified Inorganics	211	7	0.04 JB	0.04 JB	0.06 JB
014466	INEL	Heterogeneous	221	302	0.33 U	0.23 U	0.23 U
014484	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
014502	RFETS	Solidified Inorganics	211	1	0.01 U	0.02 J	0.03 J
014504	RFETS	Solidified Inorganics	211	1	0.03 U	0.02 U	0.03 U
014773	INEL	Solidified Inorganics	214	292	0.05 U	0.04 U	0.05 U
015228	RFETS	Solidified Organics	226	432	0.18 U	0.12 U	0.12 U
015231	INEL	Inorganic Non-metal	218	440	0.03 U	0.02 U	0.02 U
015241	INEL	Inorganic Non-metal	218	442	0.05 U	0.04 U	0.04 U
015249	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 U
015262	RFETS	Solidified Organics	226	432	1.70 U	1.20 U	1.20 U
015267	INEL	Uncategorized Metal	217	480	1.50 U	1.00 U	1.00 U
015338	INEL	Solidified Inorganics	211	7	0.02 U	0.01 J	0.02 J

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
015434	RFETS	Solidified Organics	226	432	0.04 U	0.03 U	0.03 U
015440	RFETS	Solidified Organics	226	432	0.39 U	0.27 U	0.27 U
015515	RFETS	Solidified Organics	212	3	28.00 U	20.00 U	26.00 U
015532	RFETS	Solidified Organics	212	3	87.00 U	60.00 U	81.00 U
015543	INEL	Solidified Organics	212	3	37.00 U	26.00 U	26.00 U
015627	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
015655	INEL	Solidified Inorganics	211	7	0.02 U	0.01 U	0.01 U
015674	INEL	Graphite	215	300	0.02 U	0.01 U	0.02 J
015675	INEL	Uncategorized Metal	217	480	0.07 U	0.05 U	0.05 U
015777	RFETS	Solidified Organics	226	432	0.07 U	0.05 U	0.05 U
015785	RFETS	Solidified Inorganics	211	1	0.34 U	0.24 U	0.32 U
015786	INEL	Solidified Inorganics	211	1	0.03 U	0.01 U	0.02 U
016242	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 JB
016612	INEL	Inorganic Non-metal	218	442	0.03 U	0.02 U	0.02 U
016613	INEL	Solidified Organics	226	432	0.21 U	0.15 U	0.15 U
016707	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
016738	RFETS	Solidified Inorganics	211	7	1.30 U	0.92 U	1.20 U
016790	INEL	Graphite	215	300	0.02 U	0.91 J	2.00
016807	INEL	Solidified Inorganics	211	1	0.43 JB	0.23 JB	0.34 JB
016842	INEL	Graphite	215	300	0.02 U	0.01 U	0.01 U
016855	RFETS	Solidified Organics	212	3	130.00 U	94.00 U	120.00 U
016869	INEL	Solidified Inorganics	211	7	0.18 U	0.08 U	0.11 U
016964	RFETS	Solidified Inorganics	211	7	1.20 U	0.82 U	1.10 U
016986	INEL	Inorganic Non-metal	218	442	0.18 U	0.12 U	0.12 U
017148	INEL	Solidified Organics	226	432	0.64 U	0.44 U	0.44 U
017190	INEL	Solidified Inorganics	211	[illegible]	9.90 B	4.60 B	6.80 B
017444	INEL	Graphite	215	30[illegible]	0.03 U	0.02 U	0.02 U

Tab. .2-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
017453	INEL	Solidified Organics	212	3	39.00 U	27.00 U	36.00 U
017486	INEL	Solidified Inorganics	211	1	0.16 U	0.07 U	0.10 U
017491	INEL	Graphite	215	300	0.18 U	0.08 U	0.11 U
017495	INEL	Inorganic Non-metal	218	442	0.03 U	0.02 U	0.02 U
017496	INEL	Inorganic Non-metal	218	442	0.03 U	0.02 U	0.02 U
017698	RFETS	Solidified Inorganics	211	292	2.50 U	1.70 U	2.30 U
017709	INEL	Solidified Inorganics	211	1	0.02 U	0.01 U	0.01 U
017728	RFETS	Solidified Inorganics	211	1	0.70 U	0.49 U	0.65 U
017742	INEL	Inorganic Non-metal	218	440	0.60 U	0.42 U	0.42 U
017756	RFETS	Solidified Organics	226	432	1.70 U	1.20 U	1.20 U
017759	INEL	Solidified Organics	226	432	1.20 U	0.83 U	0.83 U
017788	INEL	Solidified Inorganics	211	7	1.20 U	0.52 U	0.75 U
017863	INEL	Filter	119	376	0.10 U	0.07 U	0.09 U
018111	RFETS	Solidified Inorganics	211	1	0.02 U	0.01 U	0.01 U
018219	RFETS	Solidified Inorganics	211	7	1.20 U	0.82 U	1.10 U
018299	INEL	Filter	119	376	0.15 U	0.10 U	0.14 U
018413	INEL	Graphite	115	300	0.01 U	0.01 U	0.01 U
018441	INEL	Graphite	115	300	0.03 U	0.02 U	0.03 U
018464	INEL	Graphite	115	300	0.01 U	0.01 U	0.01 U
018476	INEL	Solidified Inorganics	111	292	0.10 U	0.07 U	0.09 U
018491	INEL	Graphite	115	300	0.03 U	0.02 U	0.03 U
019410	INEL	Lead/Cadmium Metal Waste	123	339	0.65 U	0.45 U	0.60 U
019413	INEL	Lead/Cadmium Metal Waste	123	339	2.80 U	2.00 U	2.60 U
019572	INEL	Lead/Cadmium Metal Waste	123	339	0.06 U	0.04 U	0.06 U
021031	RFETS	Solidified Inorganics	214	292	0.04 U	0.03 U	0.04 U
021172	RFETS	Inorganic Non-metal	218	442	0.01 U	0.01 U	0.01 U
021306	INEL	Solidified Inorganics	213	4	0.03 U	0.02 U	0.03 J

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
021392	RFETS	Solidified Inorganics	214	292	0.16 U	0.11 U	0.15 U
021442	INEL	Solidified Inorganics	211	1	0.50 U	0.22 U	0.32 U
021488	RFETS	Inorganic Non-metal	218	442	0.04 U	0.03 U	0.04 U
021503	RFETS	Inorganic Non-metal	218	440	0.17 U	0.12 U	0.16 U
021511	RFETS	Solidified Inorganics	213	4	0.04 U	0.03 U	0.04 U
021512	INEL	Solidified Inorganics	211	7	0.95 U	0.66 U	0.66 U
021523	INEL	Solidified Organics	226	432	0.60 U	0.43 J	0.98 J
021565	INEL	Solidified Inorganics	211	7	0.90 U	0.39 U	0.57 U
021572	INEL	Solidified Inorganics	211	7	1.30	0.64 J	0.98 J
021600	RFETS	Solidified Inorganics	211	1	0.28 U	0.20 U	0.26 U
021631	INEL	Inorganic Non-metal	218	442	0.03 U	0.02 U	0.02 U
021698	INEL	Inorganic Non-metal	218	440	1.10 U	0.78 U	0.78 U
021699	INEL	Solidified Inorganics	213	4	0.33 U	0.23 U	0.23 U
021700	RFETS	Solidified Inorganics	213	4	0.01 U	0.01 U	0.01 U
021806	INEL	Inorganic Non-metal	218	440	0.21 U	0.09 U	0.13 U
021816	INEL	Solidified Inorganics	211	1	0.11 U	0.05 U	0.07 U
021865	INEL	Solidified Inorganics	211	1	0.95 U	0.66 U	0.66 U
021993	INEL	Solidified Inorganics	211	2	0.45 U	0.31 U	0.31 U
022000	INEL	Inorganic Non-metal	218	440	0.10 U	0.07 U	0.07 U
022036	INEL	Uncategorized Metal	217	480	0.07 U	0.03 U	0.05 U
022038	RFETS	Uncategorized Metal	217	481	0.18 U	0.13 U	0.17 U
022052	INEL	Uncategorized Metal	217	481	0.02 U	0.01 U	0.02 U
022102	INEL	Solidified Organics	226	432	0.10 U	0.12 J	0.07 J
022105	INEL	Solidified Inorganics	211	1	0.42 U	0.29 U	0.29 U
022119	INEL	Inorganic Non-metal	222	371	0.54 U	0.37 U	0.37 U
022121	INEL	Solidified Inorganics	211	[illegible]	0.16 U	0.07 U	0.10 U
022135	INEL	Solidified Inorganics	211	[illegible]	0.68 U	0.48 U	0.48 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
022136	RFETS	Solidified Inorganics	211	7	0.88 U	0.61 U	0.82 U
022149	RFETS	Solidified Inorganics	211	7	0.22 U	0.15 U	0.20 U
022224	INEL	Solidified Inorganics	211	1	0.42 U	0.29 U	0.29 U
022226	RFETS	Inorganic Non-metal	222	371	1.20 U	0.82 U	1.10 U
022228	INEL	Inorganic Non-metal	222	371	0.15 U	0.26 J	0.21 J
022230	INEL	Inorganic Non-metal	222	371	0.12 U	0.11 J	0.08 U
022249	INEL	Uncategorized Metal	217	480	1.80 U	0.79 U	1.10 U
022275	INEL	Uncategorized Metal	217	480	0.40 U	0.18 U	0.26 U
022286	RFETS	Uncategorized Metal	217	480	0.50 U	0.35 U	0.47 U
022296	INEL	Solidified Inorganics	211	1	0.89 U	0.39 U	0.56 U
022306	INEL	Inorganic Non-metal	218	440	0.89 U	0.62 U	0.62 U
022338	INEL	Solidified Organics	212	3	120.00 U	83.00 U	83.00 U
022347	INEL	Inorganic Non-metal	218	440	0.28 U	0.12 U	0.18 U
022358	INEL	Uncategorized Metal	217	480	0.02 U	0.01 U	0.01 JB
022416	RFETS	Uncategorized Metal	217	320	0.05 U	0.04 U	0.05 U
022434	INEL	Solidified Organics	226	432	0.39 U	0.27 U	0.27 U
022442	INEL	Solidified Organics	226	432	1.14 U	0.77 U	0.77 U
022450	RFETS	Uncategorized Metal	217	320	0.09 U	0.06 U	0.08 U
022453	RFETS	Solidified Inorganics	211	2	0.08 U	0.14 J	0.19 J
022486	RFETS	Inorganic Non-metal	218	440	1.80 U	1.20 U	1.60 U
022511	INEL	Uncategorized Metal	217	480	0.92 U	0.64 U	0.64 U
022513	INEL	Solidified Organics	212	1	0.27 U	0.19 U	0.19 U
022517	INEL	Solidified Organics	226	432	0.11 U	0.08 U	0.09 J
022539	INEL	Solidified Organics	226	432	0.11 U	0.08 U	0.08 U
022549	INEL	Uncategorized Metal	217	480	1.50 U	1.00 U	1.00 U
022552	INEL	Inorganic Non-metal	218	442	0.34 U	0.24 U	0.24 U
022557	INEL	Uncategorized Metal	217	480	0.63 U	0.28 U	0.40 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
022595	INEL	Solidified Inorganics	211	1	0.30 U	0.13 U	0.19 U
022600	RFETS	Solidified Inorganics	213	4	0.27 U	0.27 J	0.26 U
022780	INEL	Solidified Inorganics	211	7	0.45 U	0.23 J	0.31 J
022789	INEL	Solidified Inorganics	211	7	0.66 U	0.46 U	0.46 U
022790	INEL	Solidified Inorganics	214	292	0.22 U	0.13 JB	0.29 JB
022803	INEL	Inorganic Non-metal	222	371	0.62 U	0.44 U	0.44 U
022807	INEL	Salt Waste	224	414	0.12 U	0.09 U	0.09 U
022811	INEL	Solidified Inorganics	211	7	0.38 U	0.16 U	0.24 U
022833	INEL	Solidified Inorganics	211	7	2.70 U	1.20 U	1.70 U
022841	INEL	Solidified Inorganics	211	7	1.40 U	0.63 U	0.90 U
022850	INEL	Solidified Inorganics	211	7	0.89 U	0.39 U	0.56 U
022874	INEL	Inorganic Non-metal	222	371	0.21 U	0.15 U	0.15 U
022894	INEL	Solidified Inorganics	211	1	0.13 U	0.31 J	0.62 J
022923	INEL	Inorganic Non-metal	218	440	0.39 U	0.27 U	0.27 U
023005	INEL	Solidified Inorganics	211	7	0.18 U	0.12 U	0.12 U
023027	RFETS	Uncategorized Metal	217	480	0.18 U	0.48 JB	0.99 JB
023041	RFETS	Inorganic Non-metal	222	371	0.28 U	0.20 U	0.26 U
023046	RFETS	Solidified Inorganics	211	7	0.50 U	0.35 U	0.47 U
023048	RFETS	Solidified Organics	226	432	0.42 U	0.29 U	0.29 U
023062	INEL	Solidified Inorganics	211	7	0.18 U	0.12 U	0.12 U
023211	INEL	Filter	119	376	0.06 U	0.04 U	0.06 U
023212	RFETS	Uncategorized Metal	217	480	0.58 U	0.41 U	0.54 U
023227	INEL	Uncategorized Metal	217	480	0.10 U	0.07 U	0.07 U
023229	INEL	Combustible	216	337	0.60 U	0.42 U	0.42 U
023235	RFETS	Heterogeneous	216	336	0.16 U	0.11 U	0.26 J
023238	INEL	Solidified Inorganics	211	1	0.20 U	0.09 U	0.12 U
023277	INEL	Inorganic Non-metal	222	[illegible]	1.00 U	0.73 U	0.73 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
023285	INEL	Solidified Inorganics	211	7	2.00 U	1.40 U	1.40 U
023312	INEL	Uncategorized Metal	217	480	0.90 U	0.39 U	0.57 U
023341	RFETS	Solidified Inorganics	211	7	0.01 U	0.05 J	0.08 J
023357	INEL	Solidified Inorganics	211	1	0.15 U	0.10 U	0.10 U
023383	RFETS	Uncategorized Metal	217	481	0.01 U	0.01 U	0.01 U
023384	INEL	Combustible	223	339	0.12 U	0.07 U	0.08 U
023388	INEL	Heterogeneous	216	330	0.10 U	0.06 U	0.07 U
023392	INEL	Solidified Inorganics	213	4	0.67 U	0.47 U	0.47 U
023407	INEL	Solidified Organics	212	3	23.00 U	16.00 U	16.00 U
023460	INEL	Inorganic Non-metal	218	442	0.03 U	0.02 U	0.02 U
023469	INEL	Solidified Organics	212	3	0.36 U	1.10 J	3.00 J
023492	INEL	Solidified Inorganics	211	7	0.74 U	0.52 U	0.52 U
023519	INEL	Solidified Organics	212	3	3.40 U	1.50 U	2.20 U
023535	INEL	Solidified Inorganics	211	7	0.89 U	0.39 U	0.56 U
023552	INEL	Solidified Inorganics	211	1	0.83 U	0.58 U	0.58 U
023662	INEL	Inorganic Non-metal	218	442	0.10 U	0.07 U	0.07 U
023681	INEL	Solidified Inorganics	211	1	0.36 U	0.25 U	0.25 U
023695	RFETS	Solidified Inorganics	211	2	0.18 U	0.13 U	0.17 U
023771	RFETS	Heterogeneous	216	330	0.19 U	0.13 U	0.18 U
023776	INEL	Heterogeneous	216	330	0.39 U	0.28 U	0.28 U
023805	INEL	Uncategorized Metal	217	480	0.02 U	0.06 J	0.04 JB
023827	RFETS	Uncategorized Metal	217	320	0.01 U	0.03 J	0.02 J
023840	INEL	Combustible	216	337	0.37 U	0.20 U	0.24 U
023901	INEL	Heterogeneous	216	330	0.36 U	0.19 U	0.24 U
023929	RFETS	Inorganic Non-metal	218	440	0.59 U	0.41 U	0.55 U
023959	INEL	Uncategorized Metal	217	480	1.30 U	0.93 U	0.93 U
024028	RFETS	Inorganic Non-metal	218	440	0.12 U	0.09 U	0.12 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
024029	INEL	Uncategorized Metal	217	480	0.02 U	0.01 U	0.02 U
024058	INEL	Solidified Inorganics	211	1	0.45 U	0.31 U	0.31 U
024059	INEL	Solidified Inorganics	214	292	0.18 U	0.32 J	0.18 J
024088	INEL	Combustible	216	337	0.34 U	0.24 U	0.24 U
024090	INEL	Combustible	216	337	0.56 U	0.30 U	0.37 U
024092	INEL	Combustible	216	337	1.50 U	1.00 U	1.00 U
024095	INEL	Combustible	216	337	0.23 U	0.13 U	0.15 U
024102	INEL	Combustible	216	337	0.51 U	0.35 U	0.35 U
024106	INEL	Combustible	216	337	0.74 U	0.52 U	0.52 U
024113	INEL	Combustible	216	337	0.22 U	0.16 U	0.16 U
024147	INEL	Solidified Inorganics	211	1	0.68 U	0.48 U	0.48 U
024165	INEL	Combustible	216	337	0.53 U	0.37 U	0.37 U
024168	INEL	Heterogeneous	216	330	0.03 U	0.02 U	0.02 U
024185	INEL	Salt Waste	224	409	0.03 U	0.12 J	0.07 J
024254	INEL	Salt Waste	224	414	0.05 U	0.25 J	0.34 J
024271	INEL	Inorganic Non-metal	218	442	0.10 U	0.07 U	0.07 U
024273	INEL	Inorganic Non-metal	218	442	0.19 U	0.14 U	0.14 U
024289	RFETS	Inorganic Non-metal	218	440	0.35 U	0.24 U	0.33 U
024295	INEL	Salt Waste	224	414	0.10 U	0.07 U	0.07 U
024308	INEL	Solidified Inorganics	211	2	0.15 U	0.42 J	0.51 J
024309	INEL	Solidified Inorganics	211	2	0.12 U	0.43 J	0.49 J
024311	INEL	Solidified Inorganics	211	2	0.24 U	0.33 J	0.45 J
024318	INEL	Solidified Inorganics	211	2	0.24 U	0.17 U	0.17 U
024506	INEL	Inorganic Non-metal	122	374	0.06 U	0.04 U	0.06 U
024507	INEL	Uncategorized Metal	117	480	0.07 U	0.05 U	0.07 U
024600	INEL	Uncategorized Metal	217	480	0.27 U	0.19 U	0.19 U
024638	INEL	Heterogeneous	216	[illegible]	0.13 U	0.09 U	0.09 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
024670	INEL	Solidified Inorganics	211	1	0.54 U	0.37 U	0.37 U
024765	INEL	Uncategorized Metal	217	480	0.06 U	0.03 U	0.04 U
024786	INEL	Uncategorized Metal	217	480	0.36 U	0.25 U	0.25 U
024850	INEL	Solidified Organics	226	432	0.10 U	0.07 U	0.07 U
024884	INEL	Uncategorized Metal	217	480	0.24 U	0.17 U	0.17 U
024897	INEL	Solidified Inorganics	211	1	0.24 U	0.17 U	0.17 U
024920	INEL	Solidified Inorganics	211	1	0.68 U	0.48 U	0.48 U
024991	INEL	Solidified Inorganics	211	1	0.33 U	0.23 U	0.23 U
025001	INEL	Solidified Organics	212	3	1.20 U	0.83 U	0.83 U
032284	INEL	Combustible	223	339	0.37 U	0.20 U	0.25 U
032287	RFETS	Solidified Inorganics	211	7	1.20 U	0.82 U	1.10 U
032467	INEL	Combustible	216	337	0.24 U	0.17 U	0.17 U
032469	RFETS	Combustible	216	337	0.39 U	0.27 U	0.36 U
032473	INEL	Combustible	216	337	1.60 U	1.10 U	1.10 U
032485	INEL	Combustible	216	337	0.93 U	0.65 U	0.65 U
032517	RFETS	Combustible	223	339	0.09 U	0.06 U	0.08 U
032521	INEL	Combustible	223	339	0.08 U	0.05 U	0.06 U
032525	INEL	Combustible	223	339	0.05 U	0.02 U	0.03 U
032526	INEL	Combustible	223	339	0.70 U	0.38 U	0.46 U
032529	INEL	Heterogeneous	216	336	0.22 U	0.10 U	0.11 J
032540	INEL	Uncategorized Metal	217	480	0.39 U	0.27 U	0.27 U
032632	INEL	Uncategorized Metal	217	480	0.18 U	0.10 U	0.12 U
032659	RFETS	Uncategorized Metal	217	480	0.31 U	0.21 U	0.28 U
032669	RFETS	Uncategorized Metal	217	480	0.33 U	0.23 U	0.31 U
032712	INEL	Uncategorized Metal	217	480	0.28 U	0.20 U	0.20 U
032715	RFETS	Combustible	216	337	0.09 U	0.06 U	0.08 U
032748	INEL	Combustible	223	339	0.22 U	0.10 U	0.11 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
032753	INEL	Uncategorized Metal	217	481	0.03 U	0.02 U	0.02 U
033091	INEL	Combustible	223	339	0.02 U	0.46 J	1.10
D01332	RFETS	Heterogeneous	116	832	0.50 U	0.50 U	1.00 U
D06288	RFETS	Filter	119	338	0.10 U	0.10 U	0.20 U
D06339	RFETS	Heterogeneous	0	337	0.20 U	0.20 U	0.40 U
D11129	RFETS	Filter	119	338	0.10 U	0.10 U	0.20 U
D13364	RFETS	Uncategorized Metal	117	480	0.10 U	0.10 U	0.10 U
D15680	RFETS	Heterogeneous	116	831	66.67 U	66.67 U	133.33 U
D17184	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.10 U
D32439	RFETS	Filter	119	338	0.10 U	0.10 U	0.20 U
D32978	RFETS	Solidified Inorganics	111	803	5.67 U	5.67 U	11.33 U
D35301	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.10 U
D35306	RFETS	Lead/Cadmium Metal Waste	123	339	0.20 U	0.20 U	0.40 U
D36606	RFETS	Uncategorized Metal	117	480	0.40 U	0.40 U	0.80 U
D38859	RFETS	Solidified Inorganics	111	803	0.10 U	0.10 U	0.10 U
D38989	RFETS	Heterogeneous	0	336	0.10 U	0.10 U	0.20 U
D41681	RFETS	Filter	119	338	0.10 U	0.10 U	0.20 U
D42280	RFETS	Solidified Organics	112	801	416.67 U	416.67 U	833.33 U
D47501	RFETS	Lead/Cadmium Metal Waste	0	341	0.10 U	0.10 U	0.20 U
D48182	RFETS	Filter	119	376	0.40 U	0.40 U	0.40 U
D48200	RFETS	Heterogeneous	116	831	8.00 U	8.00 U	8.00 U
D48377	RFETS	Inorganic Non-metal	118	368	0.10 U	0.10 U	0.10 U
D49662	RFETS	Solidified Inorganics	0	292	0.10 U	0.10 U	0.20 U
D49880	RFETS	Heterogeneous	0	336	0.27 U	0.27 U	0.53 U
D52318	RFETS	Lead/Cadmium Metal Waste	117	321	0.10 U	0.10 U	0.20 U
D52362	RFETS	Heterogeneous	116	[illegible]	0.20 U	0.20 U	0.20 U
D52726	RFETS	Heterogeneous	116	[illegible]	0.80 U	0.80 U	1.60 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D53672	RFETS	Inorganic Non-metal	118	440	0.20 U	0.20 U	0.20 U
D55656	RFETS	Heterogeneous	116	831	0.30 U	0.30 U	0.30 U
D55680	RFETS	Heterogeneous	116	821	0.20 U	0.20 U	0.20 U
D55938	RFETS	Heterogeneous	116	831	0.20 U	0.20 U	0.20 U
D56095	RFETS	Heterogeneous	0	337	0.10 U	0.10 U	0.20 U
D56595	RFETS	Heterogeneous	116	831	13.33 U	13.33 U	26.67 U
D56755	RFETS	Heterogeneous	116	821	0.10 U	0.10 U	0.10 U
D56823	RFETS	Heterogeneous	116	831	0.40 U	0.40 U	0.40 U
D57179	RFETS	Heterogeneous	0	330	2.00 U	2.00 U	4.00 U
D57522	RFETS	Heterogeneous	0	336	0.40 U	0.40 U	0.80 U
D57847	RFETS	Uncategorized Metal	117	480	0.40 U	0.40 U	0.80 U
D58143	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.10 U
D58154	RFETS	Heterogeneous	116	831	0.40 U	0.40 U	0.80 U
D58627	RFETS	Heterogeneous	116	831	0.20 U	0.20 U	0.40 U
D58889	RFETS	Heterogeneous	116	831	0.20 U	0.20 U	0.40 U
D58970	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.10 U
D59053	RFETS	Lead/Cadmium Metal Waste	0	341	0.10 U	0.10 U	0.20 U
D59703	RFETS	Heterogeneous	116	831	0.50 U	0.50 U	1.00 U
D59899	RFETS	Filter	0	331	0.50 U	0.50 U	1.00 U
D60056	RFETS	Lead/Cadmium Metal Waste	0	341	0.27 U	0.27 U	0.53 U
D60218	RFETS	Heterogeneous	116	821	2.20	4.61	8.44
D60298	RFETS	Solidified Organics	112	801	573.33 U	573.33 U	573.33 U
D60320	RFETS	Heterogeneous	0	330	28.00 U	28.00 U	56.00 U
D60463	RFETS	Inorganic Non-metal	118	440	0.10 U	0.10 U	0.10 U
D60511	RFETS	Filter	119	491	0.20 U	0.20 U	0.20 U
D60635	RFETS	Filter	119	491	0.10 U	0.10 U	0.10 U
D61245	RFETS	Heterogeneous	0	336	0.47 U	0.47 U	0.93 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D61278	RFETS	Heterogeneous	0	336	0.27 U	0.27 U	0.53 U
D61473	RFETS	Heterogeneous	0	377	0.30 U	0.30 U	0.30 U
D61504	RFETS	Lead/Cadmium Metal Waste	0	341	0.10 U	0.10 U	0.20 U
D61747	RFETS	Heterogeneous	0	330	0.27 U	0.27 U	0.53 U
D62340	RFETS	Heterogeneous	116	821	0.40 U	0.40 U	0.40 U
D62478	RFETS	Filter	119	376	0.40 U	0.40 U	0.40 U
D62714	RFETS	Heterogeneous	116	831	1.00 U	1.00 U	2.00 U
D62851	RFETS	Heterogeneous	116	825	0.30 U	0.30 U	0.30 U
D62855	RFETS	Heterogeneous	116	821	6.00 U	6.00 U	6.00 U
D63098	RFETS	Filter	0	331	0.50 U	0.50 U	1.00 U
D63229	RFETS	Heterogeneous	116	831	0.20 U	0.20 U	0.20 U
D63281	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.10 U
D63460	RFETS	Heterogeneous	116	831	0.10 U	0.10 U	0.10 U
D63654	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.10 U
D63808	RFETS	Heterogeneous	116	831	0.80 U	0.80 U	0.80 U
D63817	RFETS	Heterogeneous	116	821	1.60 U	1.60 U	1.60 U
D63819	RFETS	Solidified Inorganics	111	807	0.20 U	0.20 U	0.20 U
D63999	RFETS	Filter	119	491	0.30 U	0.30 U	0.30 U
D64004	RFETS	Filter	0	331	0.40 U	0.40 U	0.80 U
D64137	RFETS	Filter	119	335	0.10 U	0.10 U	0.10 U
D64448	RFETS	Heterogeneous	116	821	110.00 U	110.00 U	110.00 U
D64555	RFETS	Solidified Organics	112	801	573.33 U	573.33 U	573.33 U
D64632	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.10 U
D64752	RFETS	Uncategorized Metal	117	480	2.00 U	2.00 U	4.00 U
D64758	RFETS	Heterogeneous	116	831	0.50 U	0.50 U	1.00 U
D64860	RFETS	Heterogeneous	116	8[illegible]	12.00 U	12.00 U	24.00 U
D65212	RFETS	Heterogeneous	116	[illegible]	9.00 U	9.00 U	18.00 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D65213	RFETS	Heterogeneous	116	831	8.00 U	8.00 U	16.00 U
D65214	RFETS	Heterogeneous	116	831	73.67 U	73.67 U	73.67 U
D65530	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.10 U
D65535	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.10 U
D65546	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.10 U
D65600	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.10 U
D65731	RFETS	Inorganic Non-metal	122	375	0.40 U	0.40 U	0.40 U
D65734	RFETS	Uncategorized Metal	117	480	0.70 U	0.70 U	0.70 U
D65754	RFETS	Heterogeneous	116	831	0.67 U	0.67 U	1.33 U
D65757	RFETS	Heterogeneous	116	831	3.00 U	3.00 U	6.00 U
D65972	RFETS	Filter	119	376	0.30 U	0.30 U	0.30 U
D66128	RFETS	Heterogeneous	116	831	0.50 U	0.50 U	1.00 U
D66157	RFETS	Uncategorized Metal	117	480	2.00 U	2.00 U	4.54 J
D66162	RFETS	Lead/Cadmium Metal Waste	123	339	90.00 U	90.00 U	90.00 U
D66211	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D66213	RFETS	Heterogeneous	116	831	0.30 U	0.30 U	0.60 U
D66356	RFETS	Heterogeneous	116	831	166.67 U	166.67 U	333.33 U
D66378	RFETS	Heterogeneous	116	831	192.00 U	192.00 U	384.00 U
D66438	RFETS	Uncategorized Metal	117	480	1.60 U	1.60 U	1.60 U
D66523	RFETS	Solidified Organics	112	801	573.33 U	573.33 U	573.33 U
D66525	RFETS	Solidified Inorganics	111	800	0.27 U	0.27 U	0.53 U
D66631	RFETS	Heterogeneous	116	831	0.50 U	0.50 U	0.50 U
D66637	RFETS	Heterogeneous	116	831	8.00 U	8.00 U	16.00 U
D66641	RFETS	Heterogeneous	116	831	60.00 U	60.00 U	60.00 U
D66649	RFETS	Lead/Cadmium Metal Waste	123	339	56.00 U	56.00 U	56.00 U
D66773	RFETS	Uncategorized Metal	117	480	0.30 U	0.30 U	0.30 U
D66783	RFETS	Heterogeneous	116	831	250.00 U	250.00 U	250.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D66792	RFETS	Heterogeneous	116	831	100.00 U	100.00 U	100.00 U
D66860	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D66875	RFETS	Heterogeneous	116	832	0.10 U	0.15 J	0.38 J
D66948	RFETS	Heterogeneous	116	831	6.00 U	6.00 U	6.00 U
D66949	RFETS	Heterogeneous	116	831	0.60 U	0.60 U	0.60 U
D66953	RFETS	Uncategorized Metal	117	480	1.60 U	1.60 U	3.20 U
D66958	RFETS	Heterogeneous	116	831	0.30 U	0.30 U	0.30 U
D67009	RFETS	Solidified Organics	112	801	340.00 U	340.00 U	340.00 U
D67012	RFETS	Solidified Organics	112	801	900.00 U	900.00 U	900.00 U
D67047	RFETS	Solidified Inorganics	111	807	0.20 U	0.20 U	0.20 U
D67251	RFETS	Uncategorized Metal	117	480	1200.00 U	1200.0 U	2400.0 U
D67263	RFETS	Heterogeneous	116	831	9.00 U	9.00 U	9.00 U
D67277	RFETS	Heterogeneous	116	831	14.00 U	14.00 U	14.00 U
D67278	RFETS	Heterogeneous	116	831	0.10 U	0.10 U	0.10 U
D67312	RFETS	Heterogeneous	116	825	0.20 U	0.20 U	0.20 U
D67317	RFETS	Uncategorized Metal	117	480	0.27 U	0.27 U	0.27 U
D67390	RFETS	Solidified Organics	112	801	130.00 U	130.00 U	130.00 U
D67391	RFETS	Heterogeneous	116	833	0.27 U	0.27 U	0.53 U
D67413	RFETS	Solidified Organics	112	801	750.00 U	750.00 U	750.00 U
D67434	RFETS	Solidified Inorganics	111	800	0.40 U	0.40 U	0.80 U
D67436	RFETS	Solidified Inorganics	111	800	0.13 U	0.13 U	0.27 U
D67441	RFETS	Solidified Inorganics	111	800	0.40 U	0.40 U	0.80 U
D67448	RFETS	Heterogeneous	116	852	0.10 U	0.10 U	0.10 U
D67455	RFETS	Filter	119	490	0.40 U	0.40 U	0.40 U
D67464	RFETS	Heterogeneous	116	831	240.00 U	240.00 U	240.00 U
D67524	RFETS	Heterogeneous	116	8[illegible]	18.59 U	18.59 U	18.59 U
D67532	RFETS	Lead/Cadmium Metal Waste	123	3[illegible]	6.30 U	6.30 U	6.30 U

Table c.2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D67535	RFETS	Heterogeneous	116	831	0.20 U	0.20 U	0.40 U
D67539	RFETS	Solidified Organics	112	801	320.00 U	320.00 U	320.00 U
D67541	RFETS	Heterogeneous	116	825	0.10 U	0.10 U	0.10 U
D67545	RFETS	Solidified Organics	112	801	90.00 U	90.00 U	90.00 U
D67567	RFETS	Heterogeneous	116	831	0.30 U	0.30 U	0.30 U
D67582	RFETS	Heterogeneous	116	831	0.40 U	0.40 U	0.40 U
D67603	RFETS	Uncategorized Metal	117	480	13.00 U	13.00 U	13.00 U
D67654	RFETS	Solidified Inorganics	111	800	0.27 U	0.27 U	0.53 U
D67657	RFETS	Solidified Inorganics	111	800	0.27 U	0.27 U	0.53 U
D67678	RFETS	Heterogeneous	116	825	0.43 U	0.43 U	0.43 U
D67698	RFETS	Heterogeneous	116	831	1.60 U	1.60 U	3.20 U
D67707	RFETS	Heterogeneous	116	831	0.50 U	0.50 U	1.00 U
D67734	RFETS	Heterogeneous	116	831	110.00 U	110.00 U	110.00 U
D67735	RFETS	Uncategorized Metal	117	480	1.80 U	1.80 U	1.80 U
D67759	RFETS	Heterogeneous	116	831	2.80 U	2.80 U	2.80 U
D67764	RFETS	Heterogeneous	116	831	2.00 U	2.00 U	4.00 U
D67766	RFETS	Heterogeneous	116	831	1.50 U	1.50 U	3.00 U
D67781	RFETS	Heterogeneous	116	831	0.30 U	0.30 U	0.30 U
D67908	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.10 U
D67929	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.20 U
D67989	RFETS	Heterogeneous	116	831	0.50 U	0.50 U	0.50 U
D67994	RFETS	Heterogeneous	116	831	2.67 U	2.67 U	5.33 U
D68044	RFETS	Heterogeneous	116	825	0.50 U	0.50 U	0.50 U
D68096	RFETS	Heterogeneous	116	821	0.20 U	0.20 U	0.20 U
D68247	RFETS	Solidified Inorganics	111	800	0.13 U	0.13 U	0.27 U
D68248	RFETS	Solidified Organics	112	801	150.00 U	150.00 U	150.00 U
D68250	RFETS	Solidified Organics	112	801	170.00 U	170.00 U	170.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D68254	RFETS	Solidified Inorganics	111	800	0.27 U	0.27 U	0.53 U
D68256	RFETS	Solidified Inorganics	111	800	0.40 U	0.40 U	0.80 U
D68276	RFETS	Heterogeneous	116	852	0.10 U	0.10 U	0.10 U
D68277	RFETS	Uncategorized Metal	117	480	0.50 U	0.50 U	0.50 U
D68377	RFETS	Uncategorized Metal	117	480	0.20 U	0.20 U	0.40 U
D68460	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.20 U
D68480	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.20 U
D68486	RFETS	Solidified Organics	112	801	140.00 U	140.00 U	140.00 U
D68514	RFETS	Uncategorized Metal	117	480	0.10 U	0.10 U	0.10 U
D68538	RFETS	Lead/Cadmium Metal Waste	123	339	0.10 U	0.10 U	0.20 U
D68600	RFETS	Heterogeneous	116	825	18.00 U	18.00 U	18.00 U
D68601	RFETS	Heterogeneous	116	825	7.00 U	7.00 U	7.00 U
D68702	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D68724	RFETS	Heterogeneous	116	831	180.00 U	180.00 U	180.00 U
D68756	RFETS	Heterogeneous	116	831	0.20 U	0.20 U	0.40 U
D68885	RFETS	Heterogeneous	116	831	40.00 U	40.00 U	40.00 U
D68896	RFETS	Heterogeneous	116	831	213.00 U	213.00 U	213.00 U
D68975	RFETS	Solidified Organics	112	801	540.00 U	540.00 U	540.00 U
D68999	RFETS	Heterogeneous	116	821	0.40 U	0.40 U	0.40 U
D69091	RFETS	Heterogeneous	116	825	0.50 U	0.50 U	0.50 U
D69095	RFETS	Heterogeneous	116	833	0.54 U	0.54 U	0.54 U
D69113	RFETS	Heterogeneous	116	831	48.00 U	48.00 U	48.00 U
D69250	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D69287	RFETS	Heterogeneous	116	821	138.00 U	138.00 U	138.00 U
D69306	RFETS	Solidified Organics	112	801	250.00 U	250.00 U	250.00 U
D69312	RFETS	Solidified Inorganics	111	8[illegible]	0.40 U	0.40 U	0.80 U
D69364	RFETS	Heterogeneous	116	8[illegible]	0.30 U	0.30 U	0.30 U

Table 2-4

WIPP WASTE CHARACTERIZATION DATA

Gas Chromotography/Mass Spectrometry Results

(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D69400	RFETS	Heterogeneous	116	831	37.00 U	37.00 U	37.00 U
D69406	RFETS	Heterogeneous	116	831	50.00 U	50.00 U	50.00 U
D69413	RFETS	Heterogeneous	116	831	0.60 U	0.60 U	0.60 U
D69418	RFETS	Heterogeneous	116	831	73.40 U	73.40 U	73.40 U
D69431	RFETS	Heterogeneous	116	831	53.33 U	53.33 U	106.67 U
D69518	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D69602	RFETS	Heterogeneous	116	821	1.00 U	1.00 U	1.00 U
D69759	RFETS	Heterogeneous	116	833	0.30 U	0.30 U	0.30 U
D69855	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D69877	RFETS	Heterogeneous	116	825	0.50 U	0.50 U	0.50 U
D69883	RFETS	Heterogeneous	116	825	0.30 U	0.30 U	0.30 U
D69975	RFETS	Heterogeneous	116	821	0.70 U	0.70 U	0.70 U
D70063	RFETS	Heterogeneous	116	821	0.51 U	0.51 U	0.51 U
D70077	RFETS	Heterogeneous	116	831	60.00 U	60.00 U	60.00 U
D70229	RFETS	Heterogeneous	116	831	0.20 U	0.20 U	0.20 U
D70353	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D70370	RFETS	Heterogeneous	116	821	0.30 U	0.30 U	0.30 U
D70379	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D70383	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D70446	RFETS	Uncategorized Metal	117	480	1.00 U	1.00 U	2.00 U
D70448	RFETS	Heterogeneous	116	831	150.00 U	150.00 U	150.00 U
D70455	RFETS	Heterogeneous	116	831	0.70 U	0.70 U	0.70 U
D70543	RFETS	Solidified Organics	112	801	828.00 U	828.00 U	828.00 U
D70661	RFETS	Filter	0	331	0.60 U	0.60 U	1.20 U
D70669	RFETS	Uncategorized Metal	117	480	0.10 U	0.10 U	0.10 U
D70675	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D70682	RFETS	Heterogeneous	116	831	45.00 U	45.00 U	45.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D70696	RFETS	Heterogeneous	116	821	0.60 U	0.60 U	0.60 U
D70734	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.20 U
D70780	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.20 U
D70856	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D70882	RFETS	Heterogeneous	116	831	14.00 U	14.00 U	14.00 U
D70937	RFETS	Filter	0	331	0.50 U	0.50 U	1.00 U
D71019	RFETS	Solidified Organics	112	801	1.30 U	1.30 U	1.30 U
D71020	RFETS	Solidified Organics	112	801	911.50 U	911.50 U	911.50 U
D71022	RFETS	Solidified Organics	112	801	1200.00 U	1200.0 U	2400.0 U
D71241	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.20 U
D71351	RFETS	Uncategorized Metal	117	480	0.10 U	0.10 U	0.20 U
D71354	RFETS	Uncategorized Metal	117	480	0.10 U	0.10 U	0.20 U
D71385	RFETS	Heterogeneous	116	833	0.30 U	0.30 U	0.30 U
D71494	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D71504	RFETS	Solidified Organics	112	801	0.20 U	0.20 U	0.20 U
D71514	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D71521	RFETS	Heterogeneous	116	825	0.20 U	0.20 U	0.20 U
D71638	RFETS	Uncategorized Metal	117	480	1.00 U	1.00 U	2.00 U
D71804	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.20 U
D71829	RFETS	Heterogeneous	116	852	220.00 U	220.00 U	220.00 U
D71838	RFETS	Heterogeneous	116	831	7.60 U	7.60 U	7.60 U
D71921	RFETS	Heterogeneous	116	833	0.10 U	0.14 J	0.20 U
D71932	RFETS	Solidified Organics	112	801	4367.96 U	4367.9 U	4367.9 U
D71933	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.20 U
D71934	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.20 U
D71936	RFETS	Heterogeneous	116	833	21.67 U	21.67 U	21.67 U
D71937	RFETS	Heterogeneous	116		33.33 U	33.33 U	66.67 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D71938	RFETS	Heterogeneous	116	833	1.80 U	1.80 U	1.80 U
D71940	RFETS	Solidified Organics	112	801	1000.00 U	1000.0 U	1000.0 U
D71941	RFETS	Solidified Organics	112	801	1000.00 U	1000.0 U	1000.0 U
D72010	RFETS	Heterogeneous	116	832	0.30 U	0.30 U	0.60 U
D72079	RFETS	Uncategorized Metal	117	480	6.50 U	6.50 U	6.50 U
D72127	RFETS	Solidified Organics	112	801	0.40 U	0.40 U	0.40 U
D72128	RFETS	Solidified Organics	112	801	130.00 U	130.00 U	130.00 U
D72131	RFETS	Heterogeneous	116	833	0.27 U	0.27 U	0.53 U
D72132	RFETS	Solidified Organics	112	801	48.00 U	48.00 U	96.00 U
D72133	RFETS	Solidified Organics	112	801	0.20 U	0.20 U	0.20 U
D72136	RFETS	Solidified Organics	112	801	21.00 U	21.00 U	21.00 U
D72139	RFETS	Solidified Organics	112	801	1.90 U	1.90 U	1.90 U
D72178	RFETS	Heterogeneous	116	821	0.30 U	0.30 U	0.30 U
D72186	RFETS	Heterogeneous	116	821	0.20 U	0.20 U	0.20 U
D72195	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D72255	RFETS	Heterogeneous	116	833	0.30 U	0.30 U	0.30 U
D72267	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.10 U
D72293	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D72333	RFETS	Heterogeneous	116	831	0.30 U	0.37 J	0.30 U
D72339	RFETS	Heterogeneous	116	821	0.50 U	0.50 U	0.50 U
D72347	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D72375	RFETS	Heterogeneous	116	831	80.00 U	80.00 U	80.00 U
D72434	RFETS	Heterogeneous	116	831	210.00 U	210.00 U	210.00 U
D72436	RFETS	Uncategorized Metal	117	480	0.30 U	0.30 U	0.60 U
D72542	RFETS	Heterogeneous	116	832	10.00 U	10.00 U	20.00 U
D72545	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.20 U
D72546	RFETS	Heterogeneous	116	832	15.00 U	15.00 U	30.00 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D72566	RFETS	Solidified Organics	112	801	0.80 U	0.80 U	0.80 U
D72598	RFETS	Heterogeneous	116	821	0.60 U	0.60 U	0.60 U
D72618	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D72619	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D72623	RFETS	Solidified Organics	112	801	0.50 U	0.50 U	1.00 U
D72631	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D72632	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D72673	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D72819	RFETS	Heterogeneous	116	833	0.40 U	0.40 U	0.40 U
D72822	RFETS	Heterogeneous	116	831	0.27 U	0.27 U	0.53 U
D72831	RFETS	Uncategorized Metal	117	480	4.00 U	4.00 U	8.00 U
D72887	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D72923	RFETS	Heterogeneous	116	833	0.40 U	0.40 U	0.40 U
D72932	RFETS	Heterogeneous	116	825	0.30 U	0.30 U	0.30 U
D73054	RFETS	Heterogeneous	0	336	113.33 U	113.33 U	226.67 U
D73074	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D73117	RFETS	Uncategorized Metal	117	480	0.40 U	0.40 U	0.80 U
D73123	RFETS	Heterogeneous	116	831	126.00 U	126.00 U	126.00 U
D73134	RFETS	Heterogeneous	116	831	72.00 U	72.00 U	144.00 U
D73136	RFETS	Solidified Inorganics	111	807	0.10 U	0.10 U	0.20 U
D73274	RFETS	Heterogeneous	116	831	50.00 U	50.00 U	50.00 U
D73285	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D73293	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D73295	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D73296	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D73301	RFETS	Solidified Organics	112	[illegible]	0.20 U	0.20 U	0.20 U
D73605	RFETS	Lead/Cadmium Metal Waste	123	[illegible]	0.10 U	0.10 U	0.20 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D73632	RFETS	Heterogeneous	116	825	0.70 U	0.70 U	0.70 U
D73667	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D73672	RFETS	Solidified Organics	112	801	0.10 U	0.10 U	0.10 U
D73745	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.20 U
D73828	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D73848	RFETS	Heterogeneous	116	821	0.13 U	0.13 U	0.13 U
D73987	RFETS	Lead/Cadmium Metal Waste	123	339	0.30 U	0.30 U	0.60 U
D74007	RFETS	Uncategorized Metal	117	480	0.30 U	0.30 U	0.60 U
D74110	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D74147	RFETS	Solidified Organics	112	801	0.80 U	0.80 U	0.80 U
D74156	RFETS	Solidified Organics	112	801	0.60 U	0.60 U	0.60 U
D74374	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.20 U
D74683	RFETS	Heterogeneous	116	821	1.50 U	1.50 U	1.50 U
D74904	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.20 U
D74913	RFETS	Heterogeneous	116	832	0.30 U	0.30 U	0.30 U
D75039	RFETS	Heterogeneous	116	832	3.47	10.55	16.31
D75265	RFETS	Heterogeneous	116	833	1.20 U	1.20 U	1.20 U
D75267	RFETS	Heterogeneous	116	832	0.20 U	0.20 U	0.20 U
D75278	RFETS	Heterogeneous	116	832	0.30 U	0.30 U	0.30 U
D75399	RFETS	Heterogeneous	116	833	0.40 U	0.40 U	0.40 U
D75564	RFETS	Heterogeneous	116	825	0.13 U	0.13 U	0.21 J
D75868	RFETS	Heterogeneous	116	825	0.60 U	0.60 U	0.60 U
D75888	RFETS	Heterogeneous	116	833	0.10 U	0.15 J	0.49 J
D75926	RFETS	Heterogeneous	116	832	0.40 U	0.40 U	0.40 U
D75930	RFETS	Heterogeneous	116	832	100.00 U	100.00 U	200.00 U
D75947	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.10 U
D75976	RFETS	Heterogeneous	116	833	0.13 U	0.13 U	0.27 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D76044	RFETS	Heterogeneous	116	831	0.27 U	0.27 U	0.27 U
D76050	RFETS	Heterogeneous	116	832	0.10 U	0.30 J	0.80 J
D76054	RFETS	Heterogeneous	116	831	0.30 U	0.30 U	0.30 U
D76098	RFETS	Heterogeneous	116	832	0.20 U	0.20 U	0.40 U
D76135	RFETS	Solidified Organics	112	801	26.67 U	26.67 U	53.33 U
D76136	RFETS	Solidified Inorganics	111	803	0.40 U	0.40 U	0.80 U
D76138	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.20 U
D76142	RFETS	Solidified Inorganics	111	800	0.24 U	0.24 J	0.48 U
D76143	RFETS	Solidified Inorganics	111	803	0.30 U	0.30 U	0.60 U
D76144	RFETS	Solidified Inorganics	111	800	0.67 U	0.67 U	1.33 U
D76146	RFETS	Solidified Inorganics	0	292	0.10 U	0.10 U	0.20 U
D76147	RFETS	Solidified Inorganics	111	803	0.10 U	0.10 U	0.10 U
D76182	RFETS	Solidified Inorganics	111	800	1.02 J	0.70 U	0.70 U
D76183	RFETS	Solidified Inorganics	111	800	0.13 U	0.23 J	0.44 J
D76185	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.20 U
D76187	RFETS	Solidified Inorganics	111	803	0.50 U	0.50 U	1.00 U
D76189	RFETS	Solidified Inorganics	111	803	2.00 U	2.00 U	4.00 U
D76192	RFETS	Solidified Inorganics	111	803	0.10 U	0.10 U	0.20 U
D76194	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.20 U
D76195	RFETS	Solidified Organics	112	801	480.00 U	480.00 U	480.00 U
D76196	RFETS	Solidified Organics	112	801	166.67 U	166.67 U	333.33 U
D76199	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.20 U
D76200	RFETS	Solidified Organics	112	801	633.33 U	633.33 U	1266.6 U
D76203	RFETS	Solidified Organics	112	801	223.33 U	223.33 U	446.67 U
D76205	RFETS	Solidified Inorganics	111	800	0.10 U	0.10 U	0.20 U
D76206	RFETS	Solidified Inorganics	111	803	0.40 U	0.40 U	0.80 U
D76217	RFETS	Heterogeneous	116	8	1.00 U	1.00 U	2.00 U

Table 2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromatography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D76282	RFETS	Solidified Inorganics	111	800	11.33 U	11.33 U	22.67 U
D76283	RFETS	Solidified Organics	112	801	90.00 U	90.00 U	180.00 U
D76287	RFETS	Solidified Inorganics	111	800	5.33 U	5.33 U	10.67 U
D76293	RFETS	Heterogeneous	116	833	0.40 U	0.40 U	0.40 U
D76302	RFETS	Solidified Inorganics	111	800	3.00 U	3.00 U	6.00 U
D76303	RFETS	Solidified Inorganics	111	803	0.27 U	0.27 U	0.53 U
D76305	RFETS	Solidified Inorganics	111	800	12.00 U	12.00 U	24.00 U
D76306	RFETS	Heterogeneous	116	833	0.80 U	0.80 U	0.80 U
D76362	RFETS	Heterogeneous	116	833	6.67 U	6.67 U	13.33 U
D76406	RFETS	Heterogeneous	116	831	0.10 U	0.10 U	0.10 U
D76437	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D76443	RFETS	Heterogeneous	116	825	0.30 U	0.30 U	0.33 J
D76452	RFETS	Heterogeneous	116	825	0.20 U	0.20 U	0.20 U
D76454	RFETS	Heterogeneous	116	825	0.10 U	0.10 U	0.29 J
D76456	RFETS	Heterogeneous	116	825	0.10 U	0.10 U	0.24 J
D76461	RFETS	Heterogeneous	116	825	0.30 U	0.30 U	0.30 U
D76463	RFETS	Heterogeneous	116	825	0.30 U	0.30 U	0.30 U
D76470	RFETS	Solidified Inorganics	111	803	0.10 U	0.10 U	0.20 U
D76587	RFETS	Heterogeneous	116	825	0.10 U	0.10 U	0.10 U
D76596	RFETS	Heterogeneous	116	825	0.10 U	0.10 U	0.10 U
D76627	RFETS	Heterogeneous	116	825	0.10 U	0.10 U	0.10 U
D76630	RFETS	Heterogeneous	116	825	0.10 U	0.10 U	0.18 J
D76635	RFETS	Heterogeneous	116	825	0.20 U	0.20 U	0.59 J
D76652	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.20 U
D76677	RFETS	Solidified Inorganics	111	800	2.40 U	2.40 U	2.40 U
D76710	RFETS	Heterogeneous	116	833	2.00 U	2.00 U	2.00 U
D76712	RFETS	Heterogeneous	116	833	0.30 U	0.30 U	0.30 U

Table C2-4
WIPP WASTE CHARACTERIZATION DATA
Gas Chromotography/Mass Spectrometry Results
(all data in ppmv)

Drum #	Site	Waste Matrix Code Group	TruCon Code	IDC Code	1,1,2,2-Tetra chloro ethane	1,3,5-Tri methyl benzene	1,2,4-Tri methyl benzene
D76715	RFETS	Heterogeneous	116	832	0.20 U	0.20 U	0.20 U
D76811	RFETS	Heterogeneous	116	832	0.20 U	0.20 U	0.20 U
D76908	RFETS	Heterogeneous	116	833	0.10 U	0.10 U	0.10 U
D76911	RFETS	Heterogeneous	116	832	0.20 U	0.20 U	0.40 U
D77088	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.40 U
D77227	RFETS	Heterogeneous	116	833	0.40 U	0.40 U	0.80 U
D77285	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D77621	RFETS	Heterogeneous	0	336	0.27 U	0.27 U	0.53 U
D80765	RFETS	Heterogeneous	116	833	0.20 U	0.20 U	0.20 U
D80772	RFETS	Heterogeneous	116	833	1.00 U	1.00 U	1.00 U
D80774	RFETS	Heterogeneous	116	833	3.10 U	3.10 U	3.10 U
D80776	RFETS	Heterogeneous	116	832	0.10 U	0.10 U	0.10 U

APPENDIX C3

TOTALS ANALYSIS VERSUS TOXICITY CHARACTERISTIC LEACHING PROCEDURE

APPENDIX C3

TOTALS ANALYSIS VERSUS TOXICITY CHARACTERISTIC LEACHING PROCEDURE

Data from totals analyses (total organic compound analysis and total metals analysis) are compared to the Regulatory Toxicity Levels (RTL) expressed as total values. RTL values are obtained by calculating the weight/weight concentration (in the solid) of a Toxicity Characteristic (TC) analyte that would give the regulatory weight/volume concentration (in the extract), assuming 100 percent analyte dissolution. Table C3-1 lists the TC levels expressed as RTL values for toxicity characteristic leaching procedure (TCLP) and totals analysis.

To demonstrate the appropriateness and conservatism of using totals analysis rather than the TCLP, consider the following example. Assume that a solid sample contains 100 milligrams per kilogram (mg/kg) of lead (Pb). The current TCLP regulatory level for Pb is 5 milligrams per liter (mg/L). This is comparable to a concentration of 5 mg/kg as demonstrated by the following calculation:

$$\frac{5 \text{ mg Pb}}{1 \text{ L solution}} \times \frac{1 \text{ L solution}}{1000 \text{ milliliters (ml) solution}} \times \frac{1 \text{ ml solution}}{1 \text{ gram (g) solution}} \times \frac{1000 \text{ g solution}}{1 \text{ kg solution}} = 5 \text{ mg Pb/kg}$$

When one compares the predicted results of totals analysis and TCLP analysis on the same sample, the following is observed:

Totals Analysis

Analyzing a sample by totals analysis yields a result equal to the actual contaminant concentration in the sample (assuming that the instrument and the methodology are 100 percent accurate).

Predicted result = 100 mg Pb/kg sample

TCLP Analysis

Assuming that 5 grams [g] (0.2 ounces (oz)) of sample is extracted and analyzed, 100 g of extraction fluid must be used (TCLP requires that the weight of extraction fluid must be 20 times the weight of the solid sample). Assuming that 100 percent of the lead in the sample is leachable, and as a result, is extracted into the solution where it will be detected in the analysis, the predicted concentration of the TCLP solution will be 5 mg/kg, as demonstrated in the following calculation:

$$\frac{5 \text{ g sample} \times \frac{100 \text{ mg Pb}}{1 \text{ kg sample}} \times \frac{1 \text{ kg sample}}{1000 \text{ g sample}}}{100 \text{ g solution} \times \frac{1 \text{ kg solution}}{1000 \text{ g solution}}} = 5 \text{ mg Pb/kg solution}$$

These calculations demonstrate that, by conservatively assuming a 100 percent leaching efficiency, a concentration of 100 mg/kg obtained by totals analysis is comparable to a concentration of 5 mg/kg (or 5 mg/L) using TCLP (See Figure C3-1). As such, by using a regulatory level of 100 mg/kg for totals analysis for lead (i.e., 20 times the TCLP level), the U.S. Department of Energy (DOE) is taking a conservative approach to the regulation, because a leaching efficiency of 100 percent is improbable. A comparison of the regulatory levels used for TCLP versus totals analysis for all TC analytes is presented in Table C3-1.

This approach was also addressed by the U.S. Environmental Protection Agency (EPA) in the preamble to a proposed rule issued in the Federal Register (FR) on October 24, 1991. In this preamble, the EPA stated the following:

> One could compare the numerical value of a potential TCLP standard to a theoretical maximum leaching level derived from a total constituent standard. One would have to assume that the entire amount of the toxicity characteristic constituent (as represented by the total constituent concentration at the level of the standard) would be extracted into an aqueous leaching medium. One would then have to account for the 20-fold dilution inherent in the TCLP analytical procedure. A theoretical maximum leaching value could, thus be calculated by dividing the numerical value of the total constituent treatment standard by a factor of 20 (56 FR 55167).

TABLE C3-1
RTLS FOR TCLP ANALYSIS VS. RTLS FOR TOTALS ANALYSIS

Analyte	TCLP RTL Value (mg/kg)	Totals RTL Value (mg/kg)[a]
Metals and Semi-VOCs[b]		
Arsenic	5.0	100
Barium	100.0	2000
Cadmium	1.0	20
Chromium	5.0	100
Cresols	200.0	4000
1,4-Dichlorobenzene	7.5	150
2,4-Dinitrotoluene	0.13	2.6
Hexachlorobenzene	0.13	2.6
Hexachloroethane	3.0	60
Lead	5.0	100
Mercury	0.2	4
Nitrobenzene	2.0	40
Pentachlorophenol	100.0	2000
Pyridine	5.0	100
Selenium	1.0	20
Silver	5.0	100
VOCs[c]		
Benzene	0.5	10
Carbon tetrachloride	0.5	10
Chlorobenzene	100.0	2000
Chloroform	6.0	120
1,2-Dichloroethane	0.5	10
1,1-Dichloroethylene	0.7	14
Methyl ethyl ketone	200.0	4000
Pyridine	5.0	100
Tetrachloroethylene	0.7	14
Trichloroethylene	0.5	10
Vinyl chloride	0.2	4

[a]The calculations assume 1) the maximum amount of material suggested by the TCLP is used, 2) wastes are 100 percent solid (no liquid fraction), 3) the maximum amount of extraction fluid is used, and 4) all analytes are 100 percent soluble in the extraction fluid.
[b]For metals and semi-VOCs, RTL value (mg/kg) = (TC level, mg/L) (volume of extraction fluid, 2L)/(weight of sample, 0.100 kg)
[c]For VOCs, RTL value (mg/kg) = (TC level, mg/L) (volume of extraction fluid, 0.5 L)/(weight of sample, 0.025 kg)

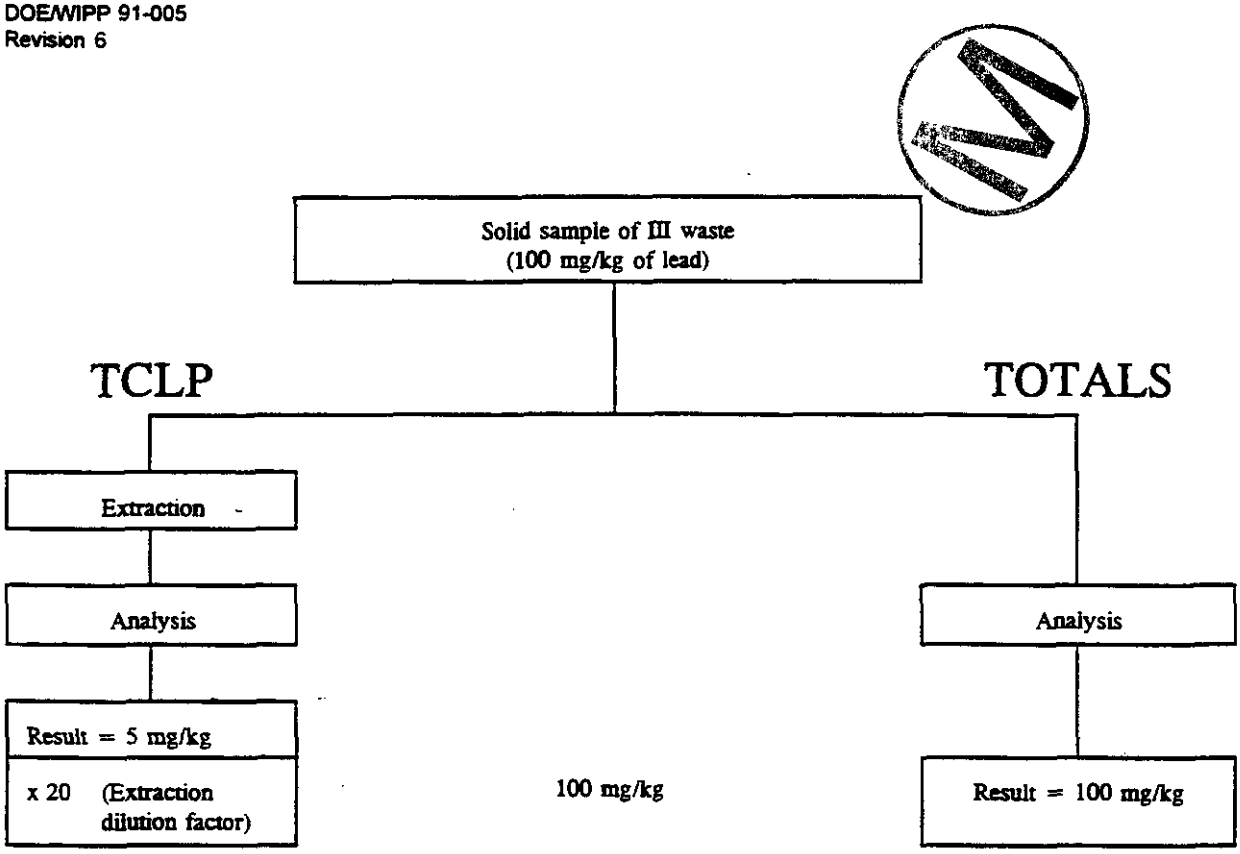

FIGURE C3-1
Comparison of TCLP and Totals Analyses for 100 mg/kg Lead Sample

APPENDIX C4
WASTE CHARACTERIZATION SAMPLING METHODS

APPENDIX C4
WASTE CHARACTERIZATION SAMPLING METHODS

C4-1 Headspace-Gas Sampling

C4-1a Method Requirements

All sampling must be accomplished within a radiation containment area (e.g., glovebox or hot/warm cell). The configuration of the containment area and remote-handling equipment at each sampling facility are expected to differ. A description of the containment area and remote-handling equipment must be provided in the site quality assurance project plan (QAPjP). Headspace-gas samples will be analyzed for the analytes listed in Table C8-2 of Appendix C8.

Sites may collect samples in SUMMA® canisters using the headspace gas sampling methods described in the Methods Manual. As an alternative, sites may use on-line integrated sampling/analysis systems. In this case, samples are immediately directed to an analytical instrument instead of being collected in SUMMA® canisters. The same sampling manifold and sampling heads are used with on-line integrated sampling/analysis systems and all of the requirements associated with sampling manifolds and sampling heads must be met. However, when using an on-line integrated sampling/analysis system, the sampling batch and analytical batch quality control (QC) samples are combined as on-line batch QC samples as outlined in Section C4-1b.

Manifold

This headspace gas sampling protocol employs a multiport manifold capable of collecting multiple simultaneous headspace samples for analysis and QC purposes. The manifold can be used to collect samples in SUMMA® canisters or as part of an on-line integrated sampling/analysis system. The sampling equipment must be leak checked and cleaned prior to first use and as needed thereafter. The manifold and sample canisters must be evacuated to 0.0039 inches (in.) (0.10 millimeters [mm]) mercury (Hg) prior to sample collection. Cleaned and evacuated sample canisters must be attached to the evacuated manifold before the manifold inlet valve is opened. The manifold inlet valve must be attached to a changeable filter connected to different sampling head(s), capable of punching through the metal lid of the drum or penetrating a carbon-composite filter.

The manifold must also be equipped with a purge assembly that allows applicable QC samples to be collected through the entire manifold, from the needle tip through all of the same manifold components that the drum headspace gas passes through. Field blanks shall be samples of room air collected in the sampling area in the immediate vicinity of the waste container to be sampled. If using SUMMA® canisters, field blanks are collected directly into the canister, without the use of the manifold.

The manifold, the associated sampling heads, and the headspace-gas sample volume requirements must be designed to ensure that a representative sample is collected. The

manifold internal volume must be calculated and documented in the field logbook. The total volume of headspace gases collected during each sampling operation can be determined by adding the combined volume of the canisters attached to the manifold to the internal volume of the manifold. When an estimate of the available headspace gas volume can be made, less than 10 percent of that volume should be withdrawn.

As illustrated in Figure C4-1, the sampling manifold must consist of a sample side and a standard side. The dotted line indicates how the sample side shall be connected to the standard side for cleaning and collecting equipment blanks and field reference standards. The sample side must consist of the following major components:

- An applicable sampling head that forms a leak-tight connection with the headspace sampling manifold.

- A flexible hose that allows movement of the sampling head from the purge assembly (standard side) to the waste container.

- A pressure sensor(s) that must be pneumatically connected to the manifold. This manifold pressure sensor(s) must be able to measure absolute pressure in the range from 0.002 in. (0.05 mm) Hg to 39.3 in. (1,000 mm) Hg. Resolution must be ±0.0002 in. (0.005 mm) Hg at 0.0020 in. (0.05 mm) of Hg. The manifold pressure sensor(s) must have an operating range from approximately 59°F (15°C) to 104°F (40°C).

- Ports for attaching sample canisters. If using canister-based sampling methods, a sufficient number of ports must be available to allow simultaneous collection of headspace-gas samples and duplicates for volatile organic compounds (VOC) analyses. If using an on-line integrated sampling/analysis system, only one port is necessary for the collection of comparison samples. Ports not occupied with sample canisters during cleaning or headspace-gas sampling activities require a plug to prevent ambient air from entering the system. In place of using plugs, sites may choose to install valves that can be closed to prevent intrusion of ambient air into the manifold. Ports must have VCR® fittings for connection to the sample canister(s) to prevent degradation of the fittings on the canisters and manifold.

- Sample canisters, as illustrated in Figure C4-2, that are leak-free, welded stainless steel pressure vessels, with a chromium-nickel oxide (Cr-NiO) SUMMA®-passivated interior surface, bellows valve, and a pressure/vacuum gauge. All sample canisters must have VCR® fittings for connection to sampling and analytical equipment. The pressure/vacuum gauge must be mounted on each canister. It must be helium-leak tested to 1.5×10^{-7} standard cubic centimeters per second (cc/s), have all stainless steel construction, and be capable of tolerating temperatures to 125°C. The gauge range must be capable of indicating leaks and sample collection.

- A dry vacuum pump with the ability to reduce the pressure in the manifold to 0.05 mm Hg. A vacuum pump that requires oil may be used, but precautions must be taken to prevent diffusion of oil vapors back to the manifold. Precautions may include the use of a molecular sieve and a cryogenic trap in series between the headspace sampling ports and the pump.

- A minimum distance between the tip of the needle and the valve that isolates the pump from the manifold in order to minimize the dead volume in the manifold. The outer diameter of the system's tubing must be 1/8 in. (3.1750 mm).

- If real-time blanks are not available, the manifold must be equipped with an organic vapor analyzer (OVA) that is capable of detecting all analytes listed in Table C8-2 of Appendix C8. The OVA must be capable of measuring total VOC concentrations as low as 0.1 parts per million (ppm). Detection of 1,1,2-trichloro-1,2,2-trifluoroethane may not be possible if a photoionization detector is used. The OVA measurement must be confirmed by the collection of equipment blanks at the frequency specified in Section C4-1 to check for manifold cleanliness.

The standard side must consist of the following major elements:

- A cylinder of compressed zero air, helium, nitrogen or hydrocarbon and carbon dioxide (CO_2)-free air to clean the manifold between samples and to provide gas for the collection of equipment blanks or on-line blanks. These high-purity gases must be certified by the manufacturer to contain less than one ppm total VOCs. The gases must be metered into the standard side of the manifold by two-stage stainless steel regulators. Alternatively, a zero air generator may be used, provided a sample of the zero air is collected and demonstrated to contain less than one ppm total VOCs. Zero air from a generator must be humidified.

- Cylinders of field-reference standard gases or on-line control sample gases. These cylinders provide gases for evaluating the accuracy of the headspace-gas sampling process. Each cylinder of field-reference gas or on-line control sample gas must have a flow-regulating device. The field-reference standard gases or on-line control sample gas must be certified by the manufacturer to contain known analytes at known concentrations.

- If using an analytical method other than Fourier Transform Infrared System (FTIRS) a humidifier filled with American Society for Testing and Materials (ASTM) Type II water, connected, and opened to the standard side of the manifold between the compressed gas cylinders and the purge assembly. Dry gases flowing to the purge assembly will pick up moisture from the humidifier. Moisture is added to the dry gases to condition the equipment blanks and field-reference standards and to assist with system cleaning between headspace-gas sample collection. If using FTIRS for analysis, the sample and sampling system must be kept dry.

NOTE: Caution should be exercised to isolate the humidifier during the evacuation of the system to prevent flooding the manifold. In lieu of the humidifier, the compressed gas cylinders (e.g., zero air and field-reference standard gas) may contain water vapor in the concentration range of 1,000 to 10,000 parts per million by volume (ppmv).

- A purge assembly that allows the sampling head (sample side) to be connected to the standard side of the manifold. The ability to make this connection is required to transfer gases from the compressed gas cylinders to the canisters or on-line analytical instrument. This connection is also required for system cleaning.

- A flow-indicating device that is connected downstream of the purge assembly to monitor the flow rate of gases through the purge assembly. The flow rate through the purge assembly must be monitored to assure that excess flow exists during cleaning activities and during QC sample collection. Maintaining excess flow will prevent ambient air from contaminating the QC samples and allow samples of gas from the compressed gas cylinders to be collected near ambient pressure.

In addition to a manifold consisting of a sample side and a standard side, the area in which the manifold is operated must contain sensors for measuring ambient pressure and ambient temperature, as follows:

- The ambient-pressure sensor must have a sufficient measurement range for the ambient barometric pressures expected at the sampling location. It must be kept in the sampling area during sampling operations. Its resolution must be 1.0 mm Hg or less, and calibration must be based on National Institute of Standards and Technology (NIST), or equivalent, standards.

- The temperature sensor must have a sufficient measurement range for the ambient temperatures expected at the sampling location. The temperature sensor calibration must be traceable to NIST, or equivalent, standards.

Direct Canister

This headspace gas sampling protocol employs a canister-sampling system to collect headspace-gas samples for analysis and QC purposes without the use of the manifold described above. Rather than attaching sampling heads to a manifold, in this method the sampling heads are attached directly to an evacuated sample canister as shown in Figure C4-3.

Canisters must be evacuated to 0.0039 in. (0.10 mm) Hg prior to use and attached to a changeable filter connected to the appropriate sampling head. The sampling head(s) must be capable of punching through the metal lid of the drums and the rigid 90-mil poly liner or penetrating a carbon-composite filter to obtain the drum headspace samples. Field duplicates must be collected at the same time, in the same manner, and using the same type of sampling apparatus as used for headspace-gas sample collection. Field blanks must be samples of room air collected in the immediate vicinity of the waste-drum sampling area prior to removal of the

drum lid. Equipment blanks and field-reference standards must be collected using a purge assembly equivalent to the standard side of the manifold described above. These samples must be collected from the needle tip through the same components (e.g., needle and filter) that the headspace-gas samples pass through.

The sample canisters, associated sampling heads, and the headspace-sample volume requirements ensure that a representative sample is collected. When an estimate of the available headspace-gas volume can be made, less than 10 percent of that volume should be withdrawn. A determination of the sampling head internal volume must be made and documented. The total volume of headspace gases collected during each headspace gas sampling operation can be determined by adding the volume of the sample canister(s) attached to the sampling head to the internal volume of the sampling head. Every effort must be made to minimize the internal volume of sampling heads.

Each sample canister used with the direct canister method must have a pressure/vacuum gauge capable of indicating leaks and sample collection. Canister gauges are intended to be gross leak-detection devices not vacuum-certification devices. If a canister pressure/vacuum gauge indicates an unexpected pressure change, determine if the change is a result of ambient temperature and pressure differences or a canister leak. Prior to sampling, canisters must be evacuated to 0.0039 in. (0.10 mm) Hg. This gauge must be helium-leak tested to 1.5×10^{-7} standard cc/s, have all stainless steel construction, and be capable of tolerating temperatures to 125°C.

The SUMMA® sample canisters must be used when sampling each drum. Three different sampling heads for attachment to the sample canister are described below. These heads must form a leak-tight connection with the canister and allow sampling through the drum-lid carbon-composite filter, or through the drum lid itself. Figure C4-3 illustrates the direct canister-sampling equipment.

Sampling Heads

A sample of the headspace gas directly under the drum lid must be collected from within the drum. Two methods, sampling through the carbon filter and sampling through the drum lid, have been developed for collecting a representative sample.

Sampling Through the Carbon Filter

To sample the drum-headspace gas through the drum's carbon-composite filter, a side-port needle (i.e., a hollow needle sealed at the tip with a small opening on its side close to the tip) must be pressed through the filter and into the headspace beneath the drum lid. This permits the gas to be drawn into the manifold or directly into the canister(s). This procedure is described in detail in the Methods Manual and is specific to a type of carbon-composite filter that permits insertion of the needle. To assure that the sample collected is representative, all of the general method requirements, sampling apparatus requirements, and QC requirements described in this section must be met in addition to the following requirements that are pertinent to drum headspace-gas sampling through the carbon filter:

- The lid of the drum's 90-mil poly liner must contain a hole for venting to the drum. If headspace-gas samples are collected prior to venting the 90-mil poly liner, a nonconformance report must be prepared, submitted, and resolved. Nonconformance procedures are outlined in Appendix C8 (Section C8-13).

- For sample collection, the drum's carbon-composite filter must be sealed as specified in the Methods Manual, or equivalent, to prevent outside air from entering the drum and diluting and/or contaminating the sample.

The sampling head for collecting drum headspace by penetrating the carbon-composite filter must consist of a side-port needle, a filter to prevent particles from contaminating the gas sample, and an adapter to connect the two. To prevent cross contamination, the sampling head must be cleaned or replaced after sample collection, after field-reference standard collection, and after field-blank collection. The following requirements must also be met:

- The housing of the carbon-composite filter must allow insertion of the sampling needle through the filter element into the drum headspace.

- The side-port needle must be used to reduce the potential for plugging.

- The purge assembly must be modified for compatibility with the side-port needle.

Sampling Through the Drum Lid

Sampling through the drum lid must be performed when the drum's carbon-composite filter does not permit insertion of the side-port needle. To sample the drum headspace-gas through the drum lid, the lid must be breached using a sparkless punch. The punch must form an airtight seal between the drum lid and the manifold or direct canister. To assure that the sample collected is representative, all of the general method requirements, sampling apparatus requirements, and QC requirements specified in Methods Manual Procedures 110.1 through 110.4, as appropriate, must be met in addition to the following requirements:

- The seal between the drum lid and sampling head must be designed to minimize intrusion of ambient air [See Methods Manual Procedure 110.4, Section 8.0].

- All components of the drum-punch sampling system that come into contact with sample gases must be purged with humidified zero air, nitrogen, or helium prior to sample collection [See Methods Manual Procedure 110.4, Section 8.0].

- Equipment blanks and field reference standards must be collected through all the components of the punch that contact the headspace-gas sample.

- Pressure must be applied to the sparkless punch until the drum lid has been breached. Then the punch must be backed out to expose the headspace gas.

- Provisions must be made to relieve potential drum pressure increases during drum-punch operations; pressure increases may occur during sealing of the drum punch to the drum lid.

- The lid of the drum's 90-mil poly liner must contain a hole for venting to the drum. If headspace-gas samples are collected prior to venting the 90-mil poly liner, a nonconformance report must be prepared, submitted, and resolved.

- During sampling, the drum's carbon-composite filter, if present, must be sealed to prevent outside air from entering the drum.

Sampling through the drum lid must be accomplished using the drum punch described in the Methods Manual (Procedure 110.4), or an equivalent. The same type of sampling head as used for the 55-gallon (208-liter) poly bag sampling must be pneumatically connected to the drum punch to provide a seal between the drum lid and the manifold or direct canister. The following requirements must also be met:

- A flow-indicating device to verify excess flow of QC gases (for system purge) must be pneumatically connected downstream of the drum punch and operated in the same manner as the flow-indicating device described in the "Manifold" section. A flowrate of approximately one liter per minute for approximately three minutes is required.

- Equipment must be used adequately to secure the drum-punch sampling system to the drum lid.

- Provisions must be made to prevent the punch from rotating as it is pressed through the drum lid.

C4-1b Quality Control

For manifold and direct canister sampling systems, field QC samples must be collected on a per sampling batch basis. A sampling batch is a suite of samples collected consecutively using the same sampling equipment within a specific time period. A sampling batch can be up to 20 samples (excluding QC samples), all of which must be collected within 14 days of the first sample in the batch. For on-line integrated sampling/analysis systems, QC samples must be collected and analyzed on a per on-line batch basis. An on-line batch is the number of headspace gas samples collected and analyzed within a 12-hour period using the same on-line integrated analysis system. Table C4-2 provides a summary of field QC sample collection requirements. Table C4-3 provides a summary of QC sample acceptance criteria.

For on-line integrated sampling analysis systems, the on-line batch QC samples serve as combined sampling batch/analytical batch QC samples as follows:

- The on-line blank replaces the equipment blank and laboratory blank

- The on-line control sample replaces the field reference standard and laboratory control sample

- The on-line duplicate replaces the field duplicate and laboratory duplicate

The acceptance criteria for on-line batch QC samples are the same as for the sampling batch and analytical batch QC samples they replace. Acceptance criteria are shown in Table C4-3. A separate field blank must still be collected and analyzed for each on-line batch. However, if the results of a field blank collected through the sampling manifold meets the acceptance criterion, a separate on-line blank need not be collected and analyzed.

The site project Quality Assurance (QA) officer shall have the responsibility to monitor and document field QC sample results and fill out a nonconformance report if acceptance criteria are not met. The site project manager shall have the responsibility to ensure appropriate corrective action is taken if acceptance criteria are not met.

Field Blanks

Field blanks must be collected to evaluate background levels of program-required analytes. Field blanks must be collected prior to sample collection, and at a frequency of one per sampling batch. The site project manager shall use the field blank data to assess impacts of ambient contamination, if any, on the sample results. A nonconformance report (Section C8-13) must be initiated and resolved if the final reported QC sample results do not meet the acceptance criteria.

Equipment Blanks

Equipment blanks must be collected to assess cleanliness prior to first use of all sampling equipment. After the initial cleanliness check, equipment blanks collected through the manifold must be collected at a frequency of one per sampling batch for VOC analysis. If the direct canister method is used, field blanks may be used in lieu of equipment blanks. The site project manager shall use the equipment blank data to assess impacts of potentially contaminated sampling equipment on the sample results. Equipment blank results determined by gas chromatography/mass spectrometry and gas chromatography/flame ionization detection shall be acceptable if the concentration of each VOC analyte is less than three times the method detection limit (MDL) listed in Table C8-2 in Appendix C8. Equipment blank results determined by FTIRS shall be acceptable if the concentration of each VOC analyte is less than the program required quantitation limit and listed in Table C8-2.

Field Reference Standards

Field reference standards shall be used to assess the accuracy with which the sampling equipment collects VOC samples into SUMMA® canisters prior to first use of the sampling equipment. Field reference standards must contain a minimum of six of the analytes listed in Table C8-2 in Appendix C8 at concentrations within a range of 0 to 100 ppmv. Field reference standards must have a known valid relationship to a nationally recognized standard (e.g., NIST). If commercial gases are used, a Certificate of Analysis from the manufacturer documenting

traceability is required. Commercial stock gases must not be used beyond their manufacturer-specified shelf life. After the initial accuracy check, field reference standards collected through the manifold must be collected at a frequency of one per sampling batch and submitted blind to the analytical laboratory. For the direct canister method, field reference standard collection may be discontinued if the field reference standard results demonstrate the quality assurance objectives (QAO) for accuracy specified in Appendix C8. Field reference standard results shall be acceptable if the accuracy is 70 to 130 percent recovery.

Field Duplicates

Field duplicate samples must be collected simultaneously and in accordance with Table C4-1 to assess the precision with which the sampling procedure can collect samples into SUMMA® canisters. Field duplicate results shall be acceptable if the relative percent difference is less than or equal to 25.

C4-1c Equipment Testing, Inspection and Maintenance

All sampling equipment components that come into contact with headspace sample gases must be constructed of relatively inert materials such as stainless steel or Teflon®. A passivated interior surface on the stainless steel components is recommended.

To minimize the potential for cross contamination of samples, the headspace sampling manifold and sample canisters must be properly cleaned and leak-checked prior to headspace gas sampling. Procedures for cleaning and preparing the manifold and sample canisters are provided in the Methods Manual (Procedures 110.1 and 110.2). Cleaning requirements are presented below.

Headspace Gas Sample Canister Cleaning

SUMMA® canisters used in these methods must be subjected to a rigorous cleaning and certification procedure prior to use in the collection of any samples. Guidance for the development of this procedure has been derived from Method TO-14 (EPA 1988a) and can be found in the Methods Manual (Procedure 210.1). Specific details must be provided in laboratory standard operating procedures (SOPs) for the cleaning and certification of canisters.

Canisters must be cleaned and certified on an equipment cleaning batch basis. An equipment cleaning batch is any number of canisters cleaned together at one time using the same cleaning method. A cleaning system, capable of processing multiple canisters at a time, composed of an oven (optional) and a cryogenic trap vacuum manifold must be used to clean SUMMA® canisters. Prior to cleaning, a 24-hour leak test must be performed on all canisters. For a positive pressure check, a canister passes if the pressure does not change by more than ±2 psig in 24 hours. Any canister that fails must be checked for leaks, repaired, and reprocessed. One canister per equipment cleaning batch must be filled with humid zero air or humid high purity nitrogen and analyzed for VOCs. The equipment cleaning batch of canisters shall be considered clean if there are no VOCs above three times the MDLs listed in Table C8-2 of Appendix C8. After the canisters have been certified for leak-tightness and free of background contamination, they must be evacuated to 0.0039 in. (0.10 mm) Hg or less for storage prior to shipment. The

laboratory responsible for canister cleaning and certification shall maintain canister certification documentation and initiate the canister tags as described in Section 6.0 of the Transuranic Waste Characterization Quality Assurance Program Plan (QAPP).

Sampling Equipment Initial Cleaning and Leak Check

The surfaces of all headspace gas sampling equipment components that will come into contact with headspace gas must be thoroughly inspected and cleaned prior to assembly, in accordance with Methods Manual Procedures 110.1 and 110.2, or equivalent. The manifold and associated sampling heads must be purged with humidified zero air, nitrogen, or helium, and leak checked after assembly. This cleaning must be repeated if the manifold and/or associated sampling heads are contaminated to the extent that the routine system cleaning is inadequate.

Sampling Equipment Routine Cleaning and Leak Check

The manifold and associated sampling heads which are reused must be cleaned and checked for leaks in accordance with the cleaning and leak check procedures described in Procedures 110.1 and 110.2 of the Methods Manual, or equivalent. The procedures must be conducted after headspace gas and field duplicate collection; after field blank collection, if the field blank is collected through the manifold; and after the additional cleaning required for field reference standard collection has been completed. The protocol for routine manifold cleaning and leak check requires that sample canisters be attached to the canister ports, or that the ports be capped or closed by valves, and requires that the sampling head be attached to the purge assembly. Humidified zero air, nitrogen, or helium, regulated through the purge assembly, must then be swept through the sample side of the sampling system.

VOCs must be removed from the internal surfaces of the headspace sampling manifold to levels that are less than three times the MDLs of the analytes listed in Table C8-2 of Appendix C8, as determined by analysis of an equipment blank or the OVA. This is achieved by sweeping the sample side of the sampling system. It is recommended that the headspace sampling manifold be heated and periodically evacuated and flushed with humidified zero air, nitrogen, or helium. When not in use, the manifold must be demonstrated clean before storage with a positive pressure of high purity gas (i.e., zero air, nitrogen, or helium) in both the standard and sample sides.

Sampling must be suspended and corrective actions must be taken when the analysis of an equipment blank indicates these limits have been exceeded. The site project manager must ensure that corrective action has been taken prior to resumption of sampling.

Manifold Cleaning After Field Reference Standard Collection

The sampling system must be specially cleaned after a field reference standard has been collected, because the field reference standard gases contaminate the standard side of the headspace sampling manifold when they are regulated through the purge assembly. This cleaning requires the installation of a gas-tight connector in place of the sampling head, between the flexible hose and the purge assembly. This configuration allows both the sample and standard sides of the sampling system to be flushed (evacuated and pressurized) with humidified

zero air, nitrogen, or helium which, combined with heating the pneumatic lines, should sweep and adequately clean the system's internal surfaces. After this protocol has been completed and prior to collecting another sample, the routine system cleaning and leak check (see previous section) must also be performed.

Sampling Head Cleaning

To prevent cross contamination, the needle, adapters, and filter of the sampling heads must be cleaned in accordance with the cleaning procedures described in Procedures 110.1 and 110.2 of the Methods Manual, or equivalent. After sample collection, a sampling head must be disposed of or cleaned in accordance with the Methods Manual procedures, or equivalent, prior to reuse. As a further QC measure, the needle and filter, after cleaning, should be purged with zero air, nitrogen, or helium and capped for storage to prevent sample contamination by VOCs potentially present in ambient air.

C4-1d Equipment Calibration and Frequency

The manifold pressure sensor must be certified prior to initial use, then annually, using NIST traceable, or equivalent, standards. If necessary, the pressure indicated by the pressure sensor(s) must be temperature compensated. The ambient air temperature sensor, if present, must be certified prior to initial use, then annually, to NIST traceable, or equivalent, temperature standards.

The OVA must be calibrated once per day, prior to first use, or as necessary according to the manufacturer's specifications. Calibration gases must be certified to contain known analytes at known concentrations. The balance of the OVA calibration gas must be consistent with the manifold purge gas when the OVA is used (i.e., zero air, nitrogen, or helium).

C4-2 Sampling of Homogenous Solids and Soil/Gravel

C4-2a Method Requirements

The methods used to collect samples of transuranic (TRU) waste, classified as homogenous solids and soil/gravel from waste containers, must be such that the samples are representative of the waste from which they were taken. To minimize the quantity of investigation-derived waste, laboratories conducting the analytical work may require no more sample than is required for the analysis, based on the analytical methods. Therefore, sampling must be conducted to collect samples in accordance with the QAO specifications as described below.

Core Collection

Coring tools must be used to collect cores of homogenous solids and soil/gravel from waste containers, when possible, in a manner that minimizes disturbance to the core. A rotational coring tool (i.e., a tool that is rotated longitudinally), similar to a drill bit, to cut, lift the waste cuttings, and collect a core from the bore hole, must be used to collect sample cores from containers of the waste. For homogenous solids and soil/gravel that are relatively soft, nonrotational coring tools may be used in lieu of a rotational coring tool.

To provide a basis for describing the requirements for core collection, diagrams of a rotational coring tool (i.e., a light weight auger) and a nonrotational coring tool (i.e., a thin-walled sampler) are provided in Figures C4-4 and C4-5, respectively. Each has been tested for its ability to collect a vertical core of simulated solidified waste contained in 55-gal (208-L) drums and 1-gal (3.8-L) poly bottles (EG&G 1994). The nonrotational coring tool has demonstrated core recoveries greater than 88 percent for soft simulated wastes. The rotational coring tool has demonstrated core recoveries greater than 75 percent for soft simulated wastes and greater than 94 percent for hard simulated wastes.

The following requirements apply to the use of coring tools:

- Each coring tool must contain a removable tube (liner) that is constructed of fairly rigid material unlikely to affect the composition and/or concentrations of target analytes in the sample core. Materials that are acceptable for use for coring device sleeves are polycarbonate, teflon, or glass for most samples, and stainless steel or brass if samples are not to be analyzed for metals (Methods Manual Procedure 120.1). Site QAPjPs must document that analytes of concern are not likely to be present in liner material. Sites must document that the materials are unlikely to affect sample results through the collection and analysis of equipment prior to first use as specified in the 'Equipment Blanks' section of this appendix. Liner outer diameter is recommended to be no more than 2 in. and no less than one in. Liner wall thickness is recommended to be no greater than 1/16 in. Before use, the liner must be cleaned in accordance the requirements in Section C4-2b. The liner must fit flush with the inner wall of the coring tool and must be of sufficient length to hold a core that is representative of the waste along the entire depth of the waste. The liner material must have sufficient transparency to allow visual examination of the core after sampling. If sub-sampling is not conducted immediately after core collection and liner extrusion, then end caps constructed of material unlikely to affect the composition and/or concentrations of target analytes in the core (e.g., Teflon®) must be placed over the ends of the liner. End caps must fit tightly to the ends of the liner.

- A spring retainer, similar to that illustrated in Figures C4-4 and C4-5, must be used with each coring tool when the physical properties of the waste are such that the waste may fall out of the coring tool's liner during sampling activities. The spring retainer must be constructed of relatively inert material (e.g., stainless steel or Teflon®) and its inner diameter must not be less than the inner diameter of the liner. Before use, spring retainers must be cleaned in accordance with the requirements in Section C4-2b.

- Coring tools must have an air-lock mechanism that opens to allow air inside the liners to escape as the tool is pressed into the waste (e.g., ball check valve). This air-lock mechanism must also close when the core is removed from the waste container.

- After disassembling the coring tool, a device (extruder) to forcefully extrude the liner from the coring tool must be used if the liner does not slide freely. All

surfaces of the extruder that may come into contact with the core must be cleaned in accordance with the requirements in Section C4-2(b) prior to use.

- Coring tools must be of sufficient length to hold the liner and must be constructed to allow placement of the liner leading edge as close as possible to the coring tools leading edge.

- All surfaces of the coring tool that have the potential to contact the sample core must be cleaned in accordance with the requirements in Section C4-2(b) prior to use.

- The leading edge of the coring tools must be sharpened and tapered to a diameter equivalent to, or slightly smaller than, the inner diameter of the liner. Based on tests conducted with the coring tools described in the Methods Manual, a diameter slightly smaller (e.g., 1/10 in.) has demonstrated a reduction in the drag of the homogenous solids and soil/gravel against the internal surfaces of the liner, thereby enhancing sample recovery.

- Rotational coring tools must have a mechanism to prevent the liner inside the coring tool from rotating with the coring tool during coring activities, thereby minimizing physical disturbance to the core.

- Rotational coring must be conducted in a manner that minimizes transfer of frictional heat to the core, thereby minimizing potential loss of VOCs.

- Nonrotational coring tools must be designed such that the tool's kerf width is minimized. Kerf width is defined as one-half of the difference between the outer diameter of the tool and the inner diameter of the tool's inlet.

Sample Collection

Sampling must be conducted in accordance with the following requirements:

- Sampling must be conducted as soon as possible after core collection. If a substantial delay (i.e., more than 60 minutes) is expected between core collection and sampling, the core must remain in the liner and the liner must be capped at each end. If the liner containing the core is not extruded from the coring tool and capped, then two alternatives are permissible: 1) the liner must be left in the coring tool and the coring tool must be capped at each end, or 2) the coring tool must remain in the waste container with the air-lock mechanism attached.

- Samples of homogenous solids and soil/gravel for VOC analyses must be collected prior to extruding the core from the liner. The sampling location must be randomly selected along the long axis of the liner and access to the waste must be gained by making a perpendicular cut through the liner and the core. Sites must develop procedures to select, and document the selection, of random sampling locations. True random sampling involves the proper use of random

numbers for identifying sampling locations. A sampling device such as the metal coring cylinder described in ASTM Designation: 4547-91 (ASTM 1991a), or modified disposable syringe described in Procedure 120.1 of the Methods Manual, or equivalent, must be immediately used to collect a 15-gram sample once the core has been exposed to air. Immediately after sample collection, the sample must be extruded into a 40-mL Volatile Organics Analysis (VOA) vial, the top rim of the vial visually inspected and wiped clean of any waste residue, and the vial cap secured. Sample handling requirements are outlined in Table C4-4. Additional guidance for this type of sampling can be found in *Soil Sampling and Analysis for Volatile Organic Compounds* (EPA, 1991).

- Samples of the homogenous solids and soil/gravel for semi-volatile organic compound, polychlorinated biphenyls, and metals analyses must be collected. These samples may be collected from the same location and in the same manner as the sample(s) collected for VOC analysis, or they may be collected by splitting or compositing a representative subsection of the core. The representative subsection is chosen by randomly selecting a location along the core. Sites must develop procedures to select, and document the selection, of random sampling locations. True random sampling involves the proper use of random numbers for identifying sampling locations. Guidance for splitting and compositing solid materials can be found in "Standard Practice for Reducing Field Samples of Aggregate to Testing Size" (ASTM, 1987). All surfaces of the sampling tools that have the potential to come into contact with the sample must be constructed of materials unlikely to affect the composition or concentrations of target analytes in the waste (e.g., Teflon®). Sample sizes and handling requirements are outlined in Table C4-4.

C4-2b Quality Control

QC requirements for sampling of homogenous solids and soil/gravel include collection of collocated cores to determine precision; equipment blanks to verify cleanliness of the coring tools and sampling equipment; and analysis of reagent blanks to ensure reagents, such as deionized or high pressure liquid chromatography (HPLC) water, are of sufficient quality. Coring and sampling of homogenous solids and soil/gravel must comply, at minimum, with the following QC requirements.

Co-located Cores

In accordance with the requirement to collect field duplicates required by Environmental Protection Agency (EPA) methods found in SW-846, co-located cores must be collected to determine the combined precision of the coring and sampling procedures. The co-located core methodology is a duplicate sample collection methodology intended to collect samples from approximately the same location within the drum. Cores must be collected side by side as close as feasible to one another, handled in the same manner, visually inspected through the transparent liner, and sampled in the same manner at the same randomly selected sample location. If the visual examination detects inconsistencies such as color, texture, or waste type in the waste at the sample location, another sampling location may be randomly selected, or the

cores may be invalidated and co-located cores may again be collected. Co-located cores must be collected at a frequency of one per sampling batch. A sampling batch is a suite of homogenous solids and soil/gravel samples collected consecutively using the same sampling equipment within a specific time period. A sampling batch can be up to 20 samples (excluding field QC samples), all of which must be collected within 14 days of the first sample in the batch. Because of the normally slow rate of core collection (1-2 cores per day), daily collection of field QC samples would result in numerous QC samples being collected for each field sample. This is inappropriate for sampling operations and is unnecessary for QC purposes. The collection of field QC samples on a "per sampling batch" basis provides adequate control for sampling operations.

Equipment Blanks

In accordance with SW-846, equipment blanks must be collected from fully assembled coring tools prior to first use at a frequency of one per equipment cleaning batch. An equipment cleaning batch is the number of sampling equipment items cleaned together at one time using the same cleaning method. The equipment blank must be collected from the fully assembled coring tool, in the area where the coring tools are cleaned, prior to covering with protective wrapping and storage. The equipment blank must be collected by pouring clean water (e.g., deionized water, HPLC water) down the inside of the liners of the assembled coring tool. The water must be collected in a clean sample container placed at the leading edge of the coring tool and analyzed for the analytes listed in Tables C8-4, C8-6, and C8-9 of Appendix C8. The results of the equipment blank will be considered acceptable if the analysis indicates no analyte at a concentration greater than three times the MDLs listed in Tables C8-4 and C8-6 or in the Program Required Detection Limits (PRDL) in Table C8-9 of Appendix C8. If analytes are detected at concentrations greater than three times the MDLs, then the associated equipment cleaning batch of coring tools must be cleaned again and another equipment blank collected.

Equipment blanks must be collected from liners that are cleaned separately from the coring tools. These equipment blanks must be collected at a frequency of one per equipment cleaning batch. The equipment blanks must be collected by randomly selecting a liner from the equipment cleaning batch, pouring clean water (e.g., deionized water or HPLC water) across its internal surface, collecting the water in a clean sample container, and analyzing the water for the analytes listed in Tables C8-4, C8-6, and the PRDLs in C8-9 of Appendix C8. The results of the equipment blank analysis will be considered acceptable if the results indicate no analyte at a concentration greater than three times the MDLs listed in Tables C8-4, C8-6, or C8-9 of Appendix C8. If analytes are detected at concentrations greater than three times the MDLs (or PRDLs for metals), then the associated equipment cleaning batch of liners must be cleaned again and another equipment blank collected.

Sampling equipment (e.g., bowls, spoons, chisel, VOC sub-sampler) must also be cleaned. Equipment blanks must be collected for the sampling equipment at a frequency of one per equipment cleaning batch. After the sampling equipment has been cleaned, one item from the equipment cleaning batch is randomly selected, water (e.g., deionized water, HPLC water) is passed over its surface, collected in a clean container, and analyzed for the analytes listed in Tables C8-4, C8-6, and C8-9 of Appendix C8. The results of the equipment blank will be considered acceptable if the results indicate no analyte present at a concentration greater than

three times the MDLs listed in Tables C8-4 and C8-6 and in the PRDLs in C8-9 of Appendix C8. If analytes are detected at concentrations greater than three times the MDLs (or PRDLs for metals), then the associated equipment cleaning batch of sampling equipment must be cleaned again and another equipment blank collected.

The results of equipment blanks must be traceable to the items in the equipment cleaning batch that the equipment blank represents. It is recommended that the equipment blank results for the coring tools, liners, and sampling equipment be reviewed prior to use. A sufficient quantity of these items should be maintained in storage to prevent disruption of sampling operations.

A site may choose to discard liners and sampling tools after one use. In this instance, cleaning and equipment blank collection is not required.

Coring Tool and Sampling Equipment Cleaning

Coring tools and sampling equipment must be cleaned in accordance with the following requirements:

- All surfaces of coring tools and sampling equipment that will come into contact with the core and the samples must be clean prior to use. All items of sampling equipment must be cleaned in the same manner. Immediately following cleaning, coring tools and sampling equipment must be assembled and sealed inside clean protective wrapping.

- Each coring tool must have a unique identification number. Each number must be referenced to the waste container on which it was used. This information must be recorded in the field records. One coring tool from the equipment cleaning batch must be tested for cleanliness in accordance with the requirements specified above. The identification number of the coring tool from which the equipment blank was collected must be recorded in the field records. The results of the equipment blank analysis for the equipment cleaning batch in which each coring tool was cleaned must be submitted to the sampling facility with the identification numbers of all coring tools in the equipment cleaning batch.

- Sample containers must be cleaned in accordance with the *Specifications and Guidance for Obtaining Contaminant-Free Sample Containers* (EPA, 1992).

C4-2c Equipment Testing, Inspection and Maintenance

Prior to initiation of coring activities, coring tools must be tested in accordance with manufacturer specifications to ensure operation within the manufacturer's tolerance limits. Other specifications specific to the sampling operations (e.g., operation of containment structure and safety systems) should also be tested and verified as operating properly prior to initiating coring activities. Coring tools must be assembled, including liners, and tested. Air-lock mechanisms and rotation mechanisms must be inspected for free movement of critical parts. Coring tools found to be malfunctioning must be repaired or replaced prior to use.

Coring tools and sample collection equipment must be maintained in accordance with manufacturer's specifications. Clean coring tools and sampling equipment must be sealed inside clean protective wrapping and maintained in a clean storage area prior to use. Sampling equipment must be properly maintained to avoid contamination. A sufficient supply of spare parts should be maintained to prevent delays in sampling activities due to equipment down time. Records of equipment maintenance and repair must be maintained in the field records in accordance with site SOPs.

Inspection of sampling equipment and work areas shall include the following:

- Sample collection equipment in the immediate area of sample collection must be inspected daily for cleanliness. Visible contamination on any equipment (e.g., waste on floor of sampling area, hydraulic fluid from hoses) that has the potential to contaminate a waste core or waste sample must be thoroughly cleaned upon its discovery.

- The waste coring and sampling work areas must be maintained in clean condition to minimize the potential for cross contamination between cores and samples.

- Expendable equipment (e.g., plastic sheeting, plastic gloves) must be visually inspected for cleanliness prior to use and properly discarded after each sample.

- Prior to removal of the protective wrapping from a coring tool designated for use, the condition of the protective wrapping must be visually assessed. Coring tools with torn protective wrapping should be returned for cleaning. Coring tools visibly contaminated after the protective wrapping has been removed must not be used and must be returned for cleaning or properly discarded.

- Sampling equipment must be visually inspected prior to use. All sampling equipment that comes into contact with waste samples must be stored in protective wrapping until use. Prior to removal of the protective wrapping from sampling equipment, the condition of the protective wrapping must be visually assessed. Sampling equipment with torn protective wrapping should be discarded or returned for cleaning. Sampling equipment visibly contaminated after the protective wrapping has been removed must not be used and must be returned for cleaning or properly discarded.

C4-2d Equipment Calibration and Frequency

The scale used for weighing sub-samples must be calibrated as necessary to maintain its operation within manufacturer's specification, and after repairs and routine maintenance. Weights used for calibration must be traceable to a nationally recognized standard. Calibration records must be maintained in the field records.

C4-3 Radiography

C4-3a Methods Requirements

Radiography has been developed by the Department of Energy (DOE) specifically to aid in the examination and identification of containerized waste. There is no equivalent or associated method found in EPA sampling and analysis guidance documents. All activities required to achieve the radiography objectives must be described in site QAPjPs and SOPs.

A radiography system normally consists of an X-ray-producing device, an imaging system, an enclosure for radiation protection, a waste container handling system, an audio/video recording system, and an operator control and data acquisition station. Although these six components are required, it is expected there will be some variation within a given component between sites. The X-ray-producing device must have controls which allow the operator to vary the voltage, thereby controlling image quality. It should be possible to vary the voltage, typically between 150 to 400 kilovolts (k), to provide an optimum degree of penetration through the waste. For example, high-density material should be examined with the X-ray device set on the maximum voltage. This ensures maximum penetration through the waste container. Low-density material should be examined at lower voltage settings to improve contrast and image definition. The imaging system typically utilizes a fluorescent screen and a low-light television camera.

To perform radiography, the waste container is scanned while the operator views the television screen. An audio/videotape is made of the waste container scan and is maintained as a permanent record. A radiography data form is also used to document the matrix parameter category and estimated waste material parameter weights of the waste. The estimated waste material parameter weights should be determined by compiling an inventory of waste items, residual materials, and packaging materials. The items on this inventory should be sorted by waste material parameter and combined with a standard weight look-up table to provide an estimate of waste material parameter weights.

C4-3b Quality Control

The radiography system involves qualitative and semiquantitative evaluations of visual displays. Operator training and experience are the most important considerations for assuring quality controls in regard to the operation of the radiography system and for interpretation and disposition of radiography results. Only trained personnel must be allowed to operate radiography equipment.

Standardized training requirements for radiography operators must be based upon existing industry standard training requirements and must comply with the training and qualification requirements of NQA-1, Element 2, except for Supplement 2S-2 (ASME, 1994). Supplement 2S-2 is associated with radiography used in verifying safety-related parameters, such as welding, where quantitative comparisons can be utilized. As such, it is not applicable to waste management operations and not considered necessary or appropriate for training radiography operators involved in TRU waste characterization activities.

Each site must develop a training program that provides radiography operators with both formal and on-the-job (OJT) training. Radiography operators must be instructed in the specific waste generating practices, typical packaging configurations, and associated waste material parameters expected to be found in each matrix parameter category at the site. The OJT and apprenticeship must be conducted by an experienced, qualified radiography operator prior to qualification of the training candidate. The training programs will be site-specific due to differences in equipment, waste configurations, and the level of waste characterization efforts. For example, certain sites use digital radiography equipment, which is more sensitive than real-time radiography equipment. In addition, the particular physical forms and packaging configurations at each site will vary; therefore, radiography operators must be trained on the types of waste that are generated, stored, and/or characterized at that particular site.

Although each site must develop its own training program, all of the radiography QC requirements specified in this Waste Analysis Plan (WAP) and the Methods Manual must be incorporated into the training programs and radiography operations. In this way data quality and comparability will not be affected.

Radiography training programs will be the subject of the Generator/Storage Site Waste Screening and Acceptance Audit Program (Appendix C11).

Although the site-specific training programs will vary to some degree, each program will contain the following required elements based on NQA-1 requirements:

Formal Training

- Project Requirements
- State and Federal Regulations
- Basic Principles of Radiography
- Radiographic Image Quality
- Radiographic Scanning Techniques
- Application Techniques
- Radiography of Waste Forms
- Standards, Codes, and Procedures for Radiography
- Site-Specific Instruction

On-the-Job Training

- System Operation
- Identification of Packaging Configurations
- Identification of Waste Material Parameters
- Weight and Volume Estimation
- Identification of Prohibited Items

A radiography test drum will include items common to the waste streams to be generated/stored at the generator/storage site. The test drums must be divided into layers with varying packing densities or different drums may be used to represent different situations that may occur during

radiography examination at the site. The following is a list of required elements of a radiography test drum:

- Aerosol can with puncture
- Horsetail bag
- Pair of coveralls
- Empty bottle
- Irregular shaped pieces of wood
- Empty one gallon paint can
- Full container
- Aerosol can with fluid
- One gallon bottle with three tablespoons of fluid
- One gallon bottle with one cup of fluid (upside down)
- Leaded glove or leaded apron
- Wrench

These items must be successfully identified by the operator as part of the qualification process. Qualification of radiography operators must, at a minimum, encompass the following requirements:

- Successfully pass a comprehensive exam based upon training enabling objectives. This exam will be reviewed as part of the Generator/Storage Site Waste Screening and Acceptance Audit Program (Appendix C11)

- Perform practical capability demonstration in the presence of appointed site radiography subject matter expert. This person is an experienced radiography operator who is qualified as an OJT trainer.

Requalification of operators must be based upon evidence of continued satisfactory performance (primarily audio/videotape reviews) and must be done at least every two years. Unsatisfactory performance will result in disqualification. Unsatisfactory performance is defined as the misidentification of a prohibited item in a training drum or a score of less than 80% on the comprehensive exam. Retraining and demonstration of satisfactory performance are required before an operator is again allowed to operate the radiography system.

A training drum with various container sizes must be periodically scanned by each operator. The videotape must then be reviewed by a supervisor to ensure that operators' interpretations remain consistent and accurate. Imaging system characteristics must be verified on a routine basis.

Independent replicate scans and replicate observations of the video output of the radiography process must be performed under uniform conditions and procedures. Independent replicate scans must be performed on one waste container per day or once per testing batch, whichever is less frequent. Independent observations of one scan (not the replicate scan) must also be made once per day or once per testing batch, whichever is less frequent, by a qualified radiography operator other than the individual who performed the first examination. A testing batch is a suite of waste containers undergoing radiography using the same testing equipment A testing batch can be up to 20 waste containers without regard to waste matrix.

Oversight functions include periodic audio/video tape reviews of accepted waste containers and must be performed by qualified radiography personnel other than the operator who dispositioned the waste container. The results of this verification must be available to the radiography operator. The site project QA officer shall be responsible for monitoring the quality of the radiography data and calling for corrective action, when necessary.

Visual Examination

As an additional QC check, the radiography results must be verified directly by visual examination of the waste container contents. Visual examination must be performed on a statistically determined portion of waste containers to verify the results of radiography. This verification must include the matrix parameter category and waste material parameter weights. The verification must be performed through a comparison of radiography and visual examination results. The results of the visual examination must be transmitted to the radiography facility.

The visual examination must consist of a semi-quantitative and/or qualitative evaluation of the waste container contents, and must be recorded on audio/videotape. The visual examination program has been developed by the DOE to provide an acceptable level of confidence in radiography. There is no equivalent method found in EPA sampling and analysis guidance documents. A detailed procedure that meets the requirements of this method can be found in the Methods Manual.

Standardized training for visual inspection must be developed to include both formal classroom and OJT. Visual inspectors must be instructed in the specific waste generating processes, typical packaging configurations, and expected waste material parameters expected to be found in each matrix parameter category at the site. The OJT and apprenticeship must be conducted by an operator experienced and qualified in visual examination prior to qualification of the candidate. The training must be site specific to include the various waste configurations generated/stored at the site. For example, the particular physical forms and packaging configurations at each site will vary so operators must be trained on types of waste that are generated, stored, and/or characterized at that particular site. Visual examination personnel must be requalified once every two years.

Although site-specific training programs will vary to some degree, each program will contain the following required elements based on NQA-1 requirements:

Formal Training

- Project Requirements
- State and Federal Regulations
- Application Techniques
- Site-Specific Instruction

On-the-Job Training

- Identification of Packaging Configurations
- Identification of Waste Material Parameters

- Weight and Volume Estimation
- Identification of Prohibited Items

Each visual examination facility must designate a visual examination expert. The visual examination expert must be familiar with the waste generating processes that have taken place at that site and also be familiar with all of the types of waste being characterized at that site. The visual examination expert shall be responsible for the overall direction and implementation of the visual examination at that facility. Site QAPjPs must specify the selection, qualification, and training requirements of the visual examination expert.

Figure C4-6 illustrates the overall programmatic approach to the visual examination of waste. If the waste is homogeneous, the expert may decide that a limited visual examination involving a confirmation of the radiography data is appropriate. If the waste is heterogeneous, the expert may decide a full visual examination by opening bags and segregating waste is warranted. Various degrees of segregation are possible based on the expert's judgment and availability of acceptable knowledge data. Site QAPjPs must specify decision-making criteria for the visual examination expert. In all cases, SOPs must be developed to support the visual examination process, and the basis for the expert's decisions must be documented.

A description of the waste container contents must be recorded on a data form as implemented in the site QAPjP. The description can be brief, but it must clearly identify the appropriate waste matrix parameters and provide enough information to estimate weights of waste material parameters. In cases where bags are not opened, a brief written description of the contents of the bags must contain an estimate of the amount of each waste type in the bags. The written records of visual examination must be supplemented with the audio/video recording.

C4-4 Sample Custody of Samples

Chain-of-Custody on field samples (including field QC samples) will be initiated immediately after sample collection or preparation. Sample custody will be maintained until the associated analyses are completed and the data have been validated at the project level. Sample custody will be maintained until the sample is expended or until the sample is removed from the sample analysis program. Site QAPjPs will include a copy of the sample chain-of-custody form; this form will include provisions for each of the following:

- Signature of individual initiating custody control, along with the date and time
- Documentation of sample numbers for each sample under custody
- Signatures of custodians relinquishing and receiving custody, along with date and time of the transfer
- Description of final waste container disposition, along with signature of individual removing waste container from custody
- Comment section

C4-5 Sample Packing and Shipping

In the event that the analytical facilities are not at the generator site, the samples must be packaged and shipped to an off-site laboratory. Sample containers must be packed to prevent any damage to the sampling container and maintain the preservation temperature, if necessary. Department of Transportation (DOT) regulations must be adhered to for shipment of the package.

When preparing SUMMA® canisters for shipment, special care must be taken with the pressure gauge and the associated connections. Metal boxes which have separate compartments, or cardboard boxes with foam inserts are standard shipping containers. The chosen shipping container may be required to meet selected DOT regulations. If temperatures must be maintained, cold packs can be added to the package.

Glass jars are wrapped in bubble wrap or another type of protection. The wrapped jar should be placed in a plastic bag inside of the shipping container, so that if the jar breaks, the inside of the shipping container and the other samples will not be contaminated. The plastic bag will enable the receiving analytical lab to prevent contamination of their shipping and receiving area. Plastic jars do not present a problem for shipping purposes. A DOT approved cooler, or similar package may be used as the shipping container. If temperatures must be maintained, cold packs can be added to the package. If a fill material is needed, compatibility between the samples and the fill should be considered.

Sample containers should be affixed with a tamper-proof seal so that it is apparent if the sample integrity has been compromised. A seal should also be placed on the outside of the shipping container for the same reason. Sample custody documentation must be placed inside of the shipping container, with the current custodian signing to release custody. The shipping documentation will serve as proof of custody during shipment, so the transporter does not need to sign the chain-of-custody documentation.

A Uniform Hazardous Waste Manifest is not required, since samples are exempted from the definition of hazardous waste. All other shipping documentation (i.e., bill of lading, site-specific shipping documentation) is required.

C4-6 List of References

American Society of Mechanical Engineers (ASME), 1994, Quality Assurance Requirements f Nuclear Facility Applications. ASME NQA-1-1994 Edition, New York, New York, America Society of Mechanical Engineers.

American Society for Testing and Materials (ASTM), 1987, "Standard Practice for Reducir Field Samples of Aggregate to Testing Size." ASTM C702-87, Annual Book of ASTM Standard Philadelphia, Pennsylvania; American Society for Testing and Materials.

American Society for Testing and Materials (ASTM), 1991a, "Standard Practice for Samplir Waste and Soils for Volatile Organic Compounds." ASTM D4547-91, Annual Book of AST Standards, Philadelphia, Pennsylvania, American Society for Testing and Materials.

American Society for Testing and Materials (ASTM), 1995b, Transuranic Waste Characterizatic Sampling and Analysis Methods Manual. DOE/WIPP-91-043, Current Revision, Carlsbad, Ne Mexico, Carlsbad Area Office, U.S. Department of Energy.

EG&G, 1994, Idaho National Engineering Laboratory Simulated Solidified Transuranic Was Sampling Program. EGG-WM-11222, Idaho Falls, Idaho, M. J. Connolly, EG&G - Idaho Inc Idaho National Engineering Laboratory.

U.S. Department of Energy (DOE), 1995, Transuranic Waste Characterization Sampli n Analysis Methods Manual. DOE/WIPP-91-043, Current Revision, Carlsbad, New Mexic Carlsbad Area Office, U.S. Department of Energy.

U.S. Environmental Protection Agency (EPA), 1991, Soil Sampling and Analysis for Volatil Organic Compounds. EPA/540/4-91/001, T. E. Lewis, A. B. Crockett, R. L. Siegrist, K. Zarrab Office of Research and Development, U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (EPA), 1992, Specification and Guidance for Obtainin Contaminant-Free Sample Containers. Directive No. 9240.0-05A, Office of Solid Waste an Emergency Response, U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (EPA), 1988, "Compendium Method TO-14, Th Determination of Volatile Organic Compounds (VOC) in Ambient Air Using SUMMA Passivate Canister Sampling and Gas Chromatographic Analyses." *Compendium of Methods fc Determination of Toxic Organic Compounds in Ambient Air.* Research Triangle Part, Nort Carolina, Quality Assurance Division, Environmental Monitoring Systems Laboratory, U.S Environmental Protection Agency.

1

TABLES

TABLE C4-1

GAS SAMPLE CONTAINERS AND HOLDING TIMES

Parameter	Container	Minimum Drum Headspace Sample Volume[a]	Holding Temperatures	Field Holding Time[b]	Shipping Allowance	Laboratory Holding Time[c]
VOCs	SUMMA® Canister	250 ml	0-40 °C	4 days	2 days	28 days

[a] Alternatively, if available headspace is limited, a single 100 ml sample may be collected for determination of VOCs.
[b] From the time of headspace sample collection to shipment.
[c] Programmatic-based maximum holding time. Holding time begins at VTSR.

TABLE C4-2
SUMMARY OF DRUM FIELD QC HEADSPACE SAMPLE FREQUENCIES

QC Samples	Manifold	Direct Canister	On-Line Systems
Field blanks[a]	1 per sampling batch[d]	1 per sampling batch[d]	1 per on-line batch[f]
Equipment blanks[b]	1 per sampling batch[d]	once[e]	1 per on-line batch[f]
Field reference standards[c]	1 per sampling batch[d]	once[e]	1 per on-line batch[f]
Field duplicates	1 per sampling batch[d]	1 per sampling batch[d]	1 per on-line batch[f]

[a]Analysis of field blanks for VOCs (Table C8-2 of Appendix C8), only, is required. For on-line integrated sampling/analysis systems, if field blank results meet the acceptance criterion, a separate on-line blank is not required.

[b]One equipment blank or on-line sample must be collected, analyzed for VOCs (Table C8-2), and demonstrated clean prior to first use of the headspace gas sampling equipment with each of the sampling heads, then at the specified frequency, for VOCs only thereafter. Daily, prior to work, the sampling manifold, if in use, must be verified clean using an OVA.

[c]One field reference standard or on-line control sample must be collected, analyzed, and demonstrated to meet the QAOs specified in Appendix C8 prior to first use, then at the specified frequency thereafter.

[d]A sampling batch is a suite of samples collected consecutively using the same sampling equipment within a specific time period. A sampling batch can be up to 20 samples (excluding field QC samples), all of which must be collected within 14 days of the first sample in the batch.

[e]One equipment blank and field reference standard must be collected after equipment purchase, cleaning, and assembly.

[f]An on-line batch is the number of samples collected and analyzed within a 12-hour period using the same on-line integrated sampling/analysis system.

TABLE C4-3
SUMMARY OF SAMPLING QUALITY CONTROL SAMPLE ACCEPTANCE CRITERIA

QC Sample	Acceptance Criteria	Corrective Action[a]
Field blanks	VOC amounts < 3 x MDLs in Table C8-2 of Appendix C8 for GC/MS and GC/FID; < PRQLs in Table C8-2 for FTIRS	Nonconformance if any VOC amount > 3 x MDLs in Table C8-2 of Appendix C8 for GC/MS and GC/FID; > PRQLs in Table C8-2 for FTIRS
Equipment blanks	VOC amounts < 3 x MDLs in Table C8-2 of Appendix C8 for GC/MS and GC/FID; < PRQLs in Table C8-2 for FTIRS	Nonconformance if any analyte amount > 3 x MDLs in Table C8-2 of Appendix C8 for GC/MS and GC/FID; > PRQLs in Table C8-2 for FTIRS
Field reference standards or on-line control sample	70 - 130 %R	Nonconformance if %R < 70 or > 130
Field duplicates or on-line duplicate	RPD ≤ 25	Nonconformance if RPD > 25

[a]Corrective action is only required if the final reported QC sample results do not meet the acceptance criteria.
MDL = Method detection limit
%R = Percent recovery
RPD = Relative percent difference

TABLE C4-4

SAMPLE HANDLING REQUIREMENTS FOR HOMOGENEOUS SOLIDS AND SOIL/GRAVEL

Parameter	Suggested Quantity[a]	Required Preservative	Suggested Container	Maximum Holding Time[b]
VOCs	15 grams	Cool to 4°C	Glass Vial[c]	14 Days Prep/ 40 Days Analyze[d]
SVOCs	50 grams	Cool to 4°C	Glass Jar[e]	14 Days Prep/ 40 Days Analyze[d]
Polychlorinated Biphenyls (PCBs)	50 grams	Cool to 4°C	Glass Jar[e]	14 Days Prep/ 40 Days Analyze[d]
Metals	10 grams	Cool to 4°C	Plastic Jar[g]	180 Days[h]

[a]Quantity may be increased or decreased according to the requirements of the analytical laboratory, as long as the QAOs are met.
[b]Holding time begins at sample collection (holding times are consistent with SW-846 requirements).
[c]VOA vial, must have septum cap.
[d]40-day holding time allowable only for methanol extract - 14-day holding time for non-extracted VOCs.
[e]Opaque glass container, must have Teflon® lined cap (example, amber jar).
[f]Analysis for PCBs is required only for waste streams in matrix parameter category S3220 (organics sludges).
[g]Polyethylene or polypropylene preferred, glass jar is allowable.
[h]Holding time for mercury analysis is 28 days.

FIGURES

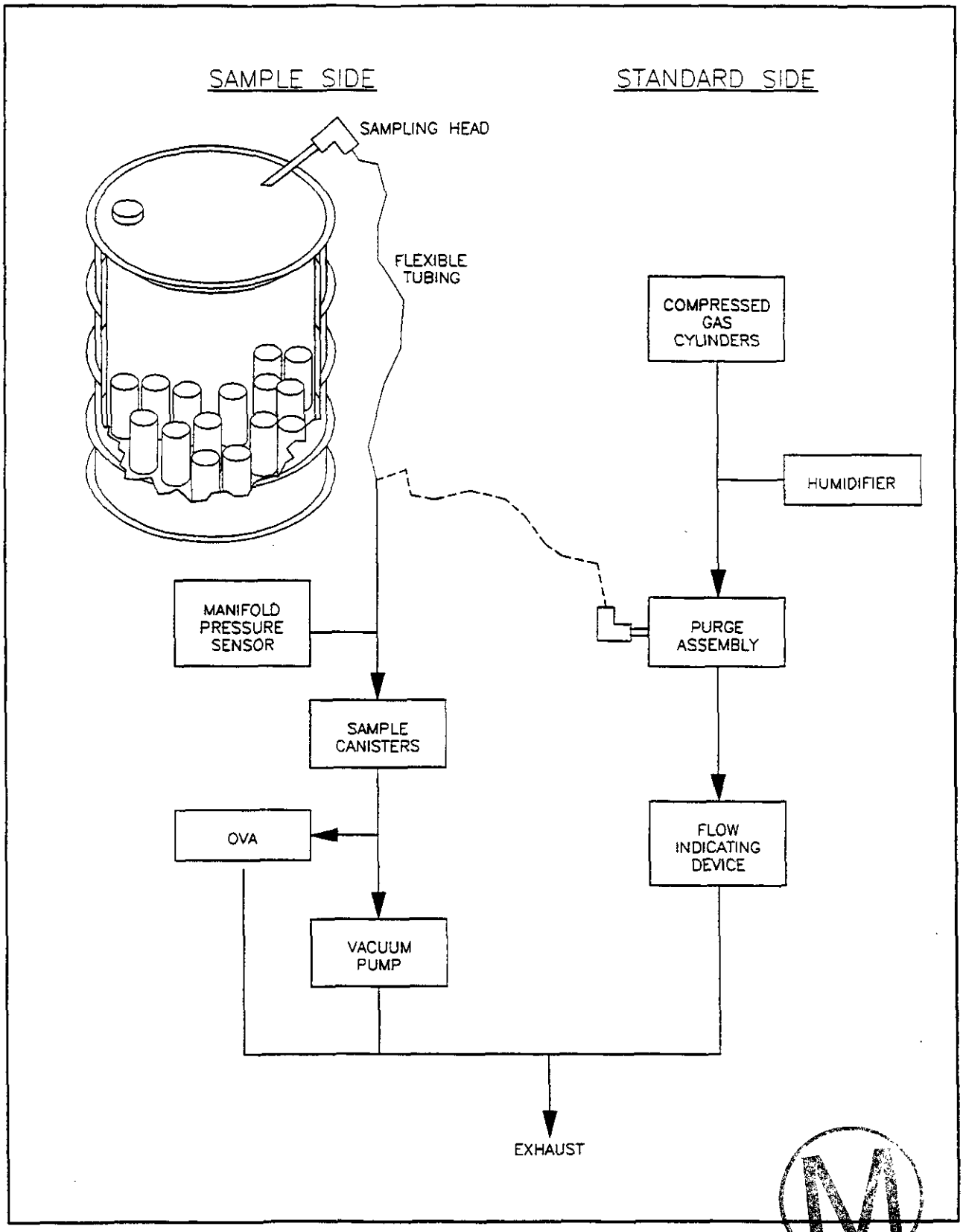

Figure C4-1
Headspace Sampling Manifold

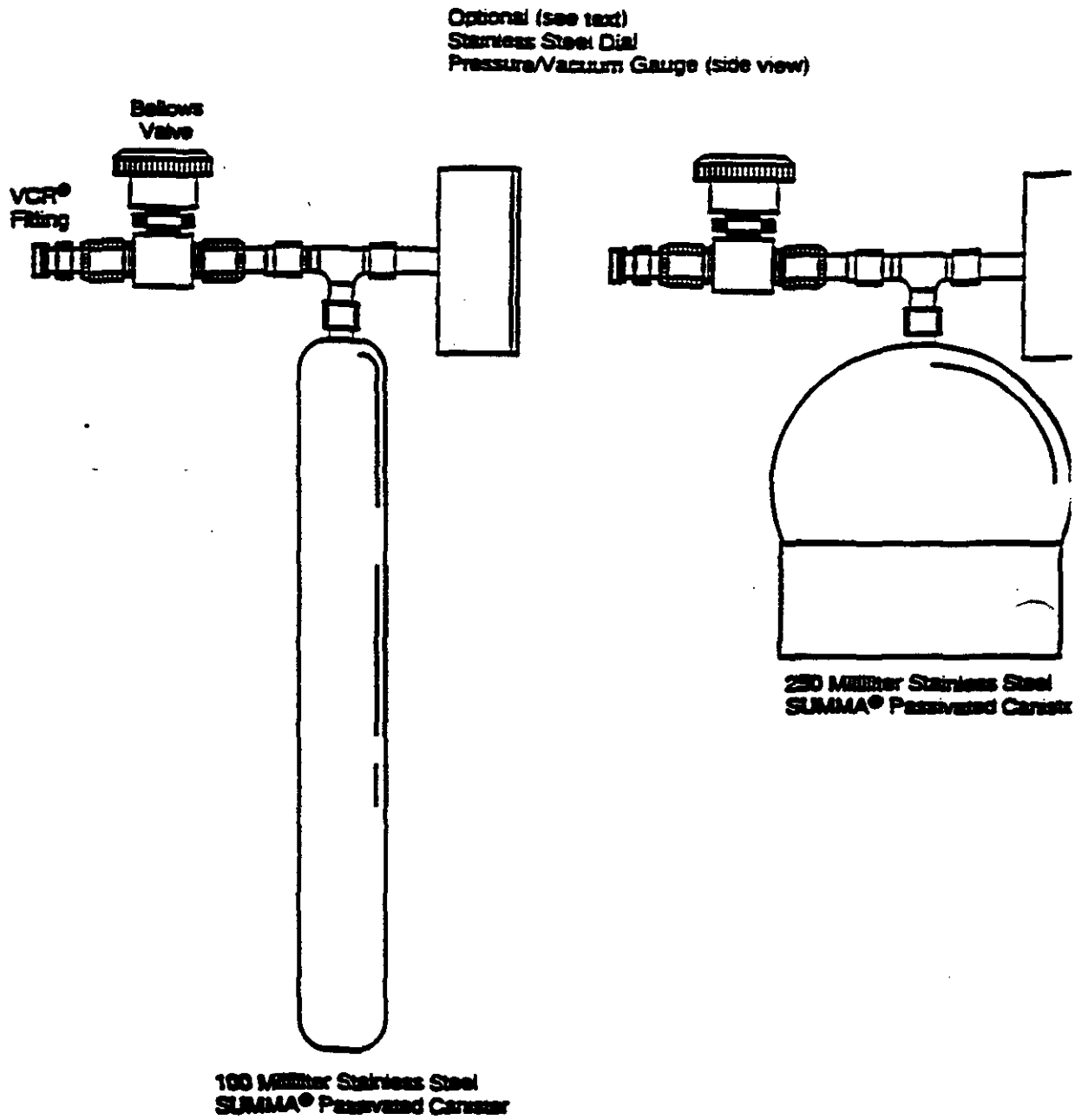

FIGURE C4-2
SUMMA® Canister Components Configuration
(Not to Scale)

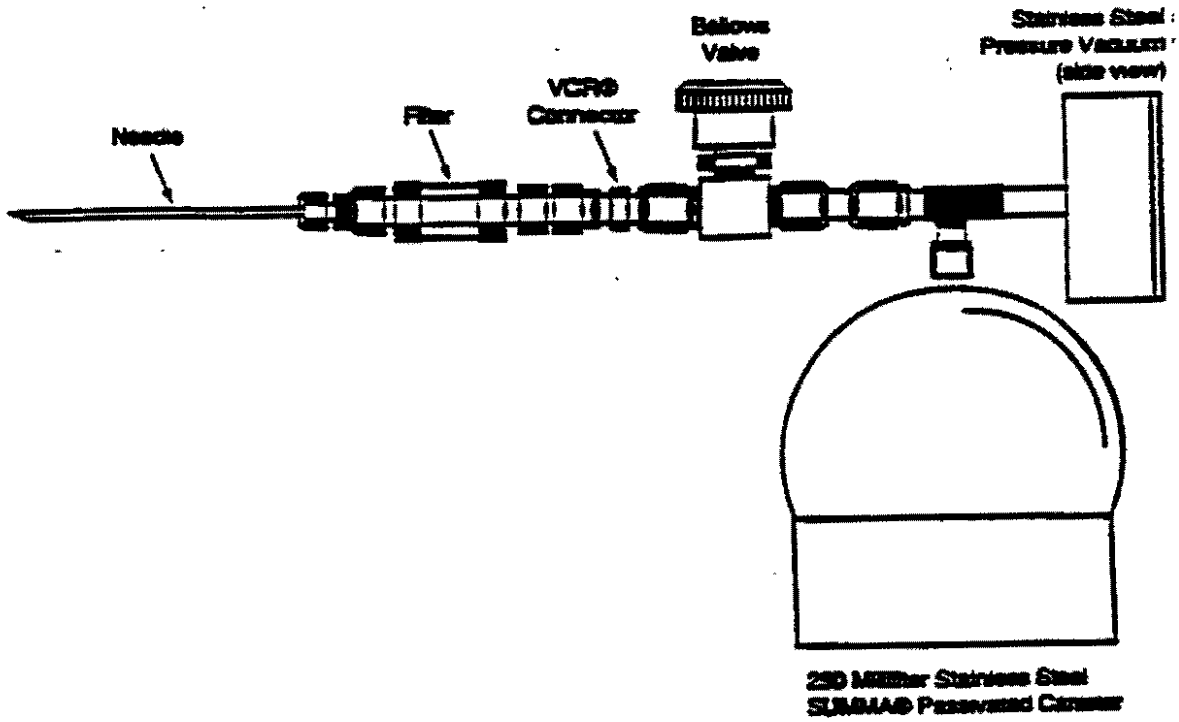

FIGURE C4-3

Schematic Diagram of Direct Canister with the Poly Bag Sampling Head

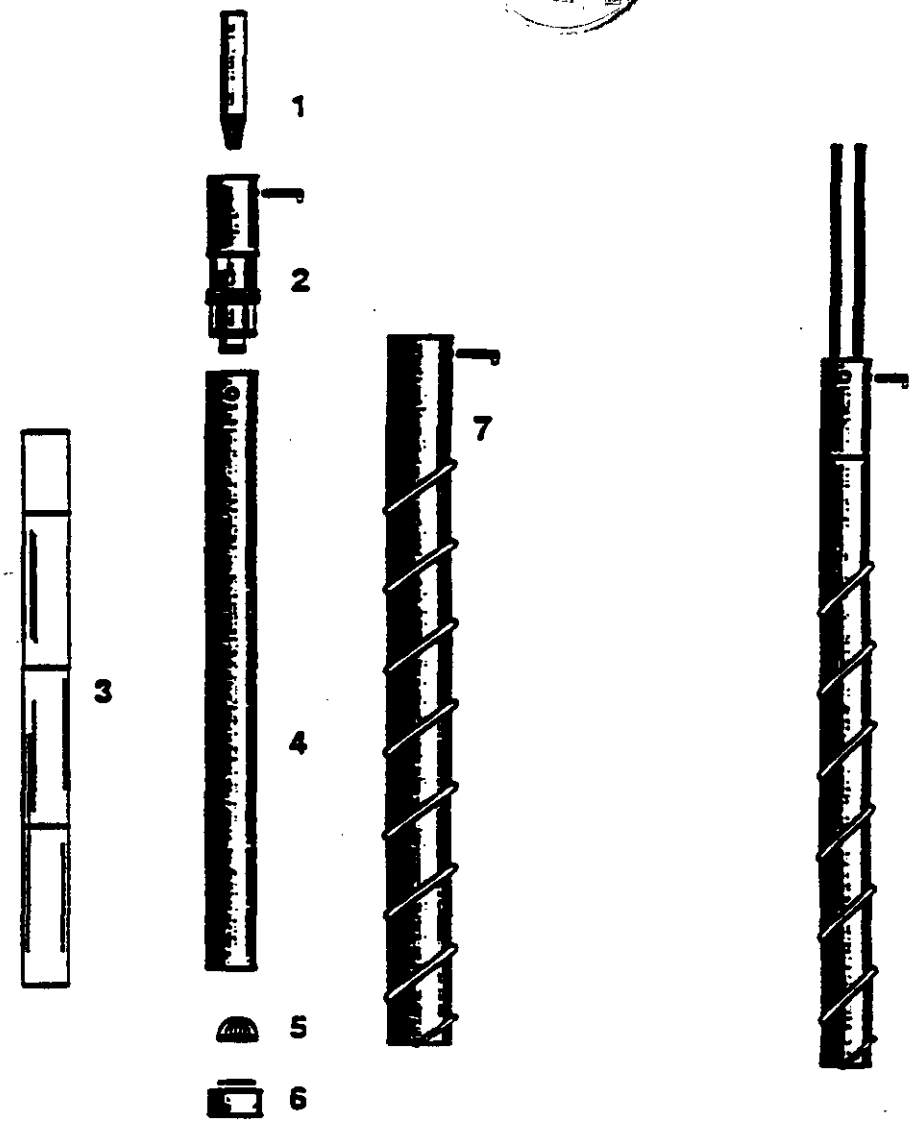

1 Drill Rod
2 Thrust Bearing Ball Check Valve
3 Clear Teflon® Liners
4 Core Barrel
5 Spring Retainer (optional)
6 Core Barrel Tip
7 Auger and Pin

FIGURE C4-4
Rotational Coring Tool
(Light Weight Auger)

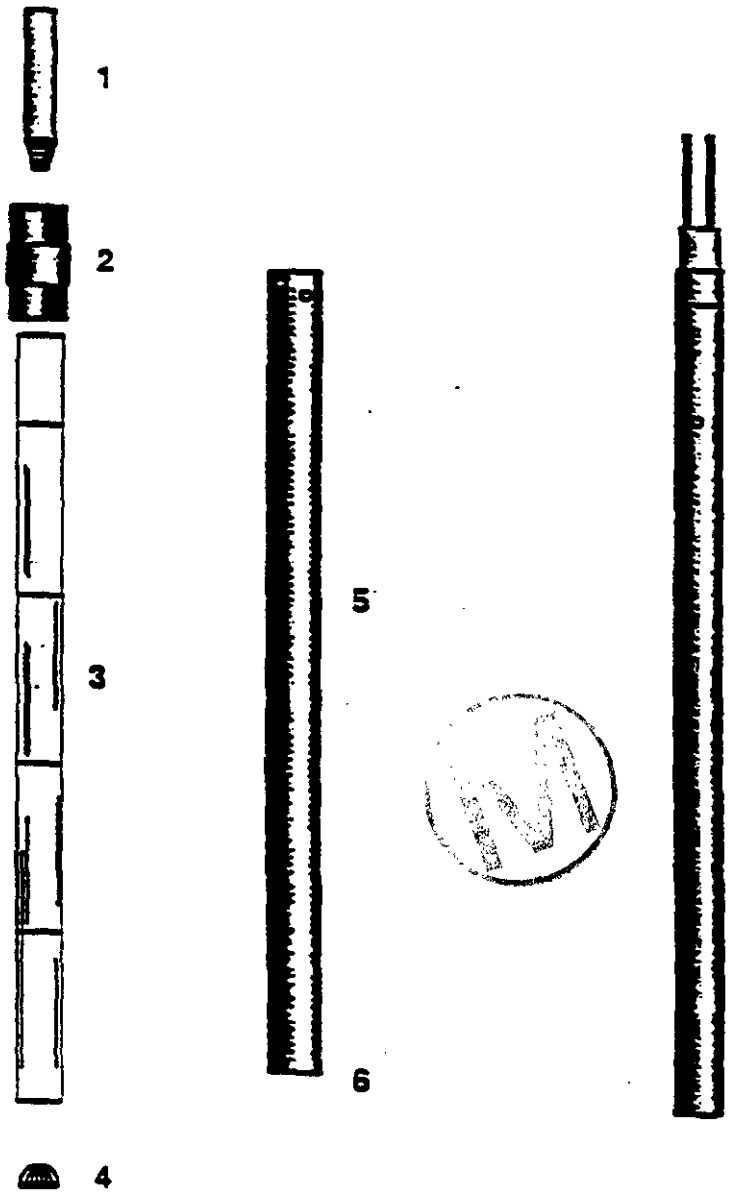

1 Drill Rod
2. Ball Check Valve
3. Clear Teflon® Liners
4. Spring Retainer (optional)
5. Tube
6. Tapered Tip

FIGURE C4-5
Non-Rotational Coring Tool
(Thin Walled Sampler)

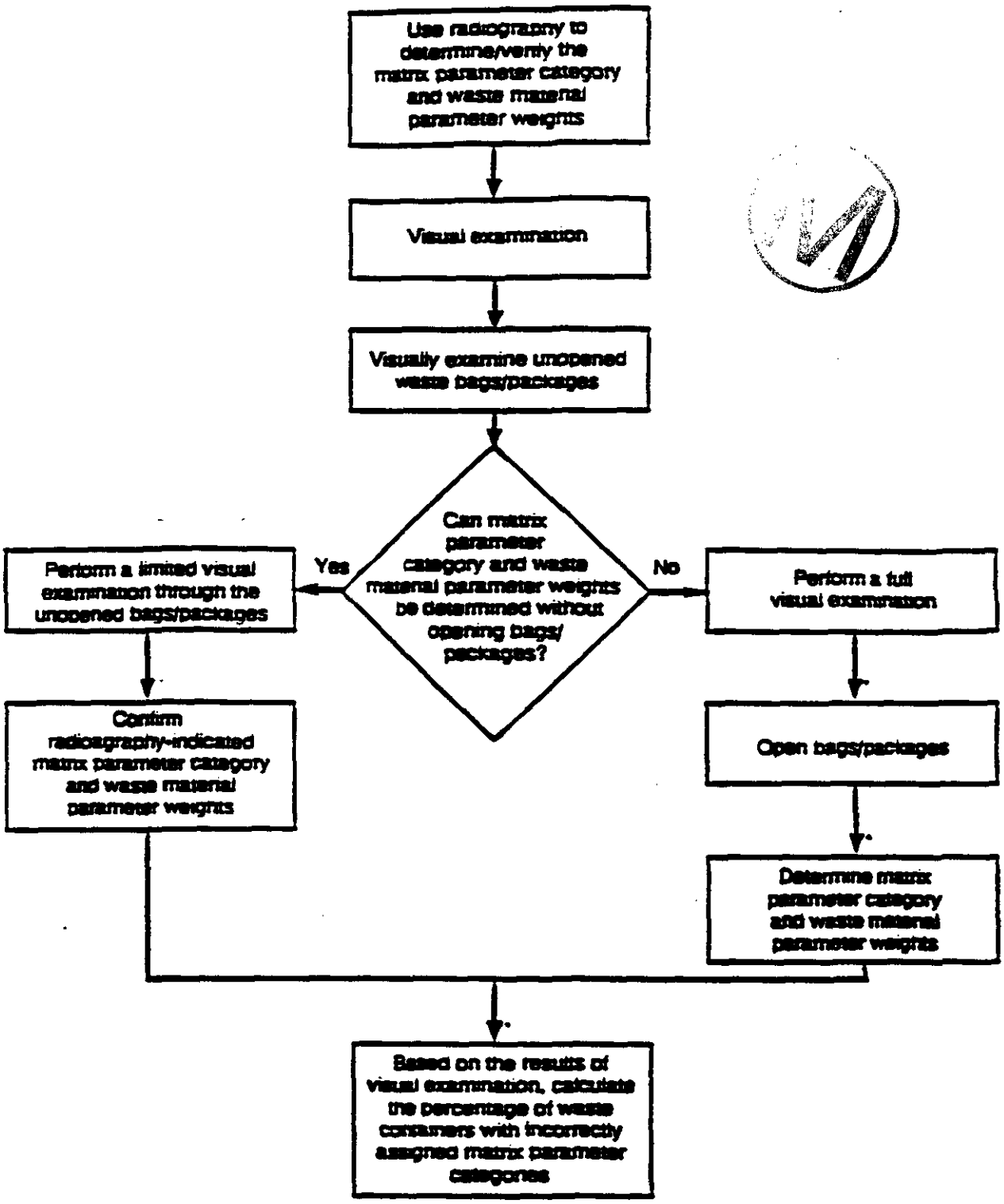

FIGURE C4-6
Overall Programmatic Approach to Visual Examination

APPENDIX C5
APPLICABILITY OF REAL-TIME RADIOGRAPHY

APPENDIX C5
APPLICABILITY OF REAL-TIME RADIOGRAPHY (RTR) [a]

Summary Category Group	Waste Category	Applicable RTR Codes[b]	Waste Description
Homogeneous Solids S3000	Cation and Anion Exchange Resin	A, B, E, G	• Anion and cation exchange resins washed with hot HNO_3 and water then mixed with water and portland cement to form solid mass. Resins are a polystyrene and divinylbenzene copolymer.
Homogeneous Solids S3000	Inorganic Waste Water Treatment Sludge	A, B, E, G, H	• Solidified aqueous waste generated by vacuum filtration of precipitated solids from pretreated aqueous slurry. Filter medium is diatomaceous earth. Wet sludge is solidified with portland cement. • Wet sludge from chemical treatment and mixed with absorbents (i.e., portland cement and Oil-Dri® to absorb free liquid). • Sludges removed from tanks that collected liquid effluent from floor drains; sludge consists of dirt, sand, gravel, floor sweepings, and similar materials; sludges mixed with portland cement. • Sludges removed from tanks that collected liquid effluent from the laundry; sludge consists of lint, spent detergent, and dirt mixed with portland cement. • Cemented inorganic process solids; waste is filter sludge, grit, and firebrick fines, solidified in portland cement. • Cemented or solidified process solids (i.e., grit, firebrick fines, filter sludges, and resins).
Homogeneous Solids S3000	Organic Liquid and Sludge	A, B, E, G	• Waste organic liquid (oil and/or solvents) mixed with gypsum cement (Envirostone®); oils are machining oil and lathe coolant. • Waste organic liquid (oil and/or solvents) mixed with gypsum cement (Envirostone®); oils are machining oil and lathe coolant.

Refer to footnotes at end of table.

APPENDIX C5 (CONTINUED)
APPLICABILITY OF RTR[a]

Summary Category Group	Waste Category	Applicable RTR Codes[b]	Waste Description
Homogeneous Solids S3000	Pyrochemical Salt	A, B, E, G	• Spent chloride salt (combinations of cesium, calcium, magnesium, potassium, and NaCl) from pyrochemical operations.
		A, B, E, F	• Fused halide salt mixtures of NaCl, KCl, and/or $CaCl_2$; some salts also contain $MgCl_2$, CaF_2, CaO.
Homogeneous Solids S3000	Solidified Liquid	A, B, E, G	• Aqueous laboratory wastes that are not compatible with primary aqueous treatment system; waste contains organic acids. Wastes are pH adjusted and solidified by mixing with portland and magnesia cement.
		A, B, E, G, H	• Waste consists of solidified organics that contain plutonium complexing chemicals (i.e., alcohols, organic acids, and chelating agents (EDTA). Liquids mixed with portland cement and magnesia cement.
Solids/Gravel S4000	Soils/Gravel	A, B, C, E, G	• Soil and gravel waste that comprises more than 50% of the waste volume.
Debris Waste S5000	Benelex® and Plexiglas™	A, B, E, G	• Organic solid waste that is noncombustible. Benelex®/Plexiglas™ neutron shielding, black top, concrete, dirt, and sand. • Benelex® and Plexiglas™ glovebox windows. Benelex® (dense laminated, lignocellulose hardboard made from wood chips and particles). Benelex® usually coated with fire retardant paint sometimes had lead sheeting attached to it. Also, leaded glass may be present.
Debris Waste S5000	Combustibles	A, B, C, D	• Solid combustible waste, including paper, rags, cloth, coveralls, plastic, rubber, wood, and other similar material.

Refer to footnotes at end of table.

APPENDIX C5 (CONTINUED)
APPLICABILITY OF RTR[a]

Summary Category Group	Waste Category	Applicable RTR Codes[b]	Waste Description
Debris Waste S5000	Combustibles	A, B, C, E, F	• Combustible solids (dry, damp, or moist), including paper, rags, plastic, surgeon's gloves, coveralls and booties, cardboard, wood, plywood sheeting, filter frames, ladders, bottles, laundry lint, Kimwipes®, canvas, sample vials, respirator face masks, etc.; some waste coated with paint and some contain trace levels of HNO_3.
Debris Waste S5000	Combustibles and Noncombustibles	A, B, C, E, F	• Combustible and noncombustible solids, i.e., dissolved lab samples, absorbed in Oil-Dri®, uranium pellets, plutonium sources, glassware, gloves, Kimwipes®, and used equipment. • Piping, flanges, valves, tools, glasswares, filters, polyethylene bottles, glovebox gloves, paper, and plastics.
Debris Waste S5000	Filters	A, B, C, D OR A, B, E,G	• Frames of filters made of wood or metal and medium is fiberglass or Nomex®-type material. Fulflo® filter cartridges consist of polypropylene plastic. Some filter wastes are processed by the addition of portland cement.
		A, B, C, D	• Absolute filters, high-efficiency particulate air (HEPA) filters, chemical warfare service (CWS) filters, fiberglass and asbestos filter media, asbestos pipe insulation, and asbestos gloves and fire blankets. Filter frames are wood, particle board, or aluminum; filter media either fiberglass or asbestos.
Debris Waste S5000	Firebrick and Ceramic Crucibles	A, B, E, G	• Firebrick, clay absorbent (Oil-Dri®), and insulation. • Leco crucible waste: silicate-based ceramic crucibles and caps. Some contain an accelerator (Fe, Sn, Cu, Tl, stainless steel). • Firebrick wastes consisting of whole or broken pieces of construction bricks, cinderblocks, and incinerator firebrick. Firebrick (high-aluminum/high-strength) composition: Al_2O_3, CaO, Fe_2O_3, MgO, SiO_3, TiO_2, and alkalies.

Refer to footnotes at end of table.

APPENDIX C5 (CONTINUED)
APPLICABILITY OF RTR[a]

Summary Category Group	Waste Category	Applicable RTR Codes[b]	Waste Description
Debris Waste S5000	Glass	A, B, C, E, F	• Glass and ceramic waste including leached Raschig rings, ceramic crucibles, glovebox windows, lab glassware, process equipment, and empty containers.
Debris Waste S5000	Glass (Oil Residue)	A, B, C, E, F	• Unleached glass neutron-absorbing Raschig rings.
Debris Waste S5000	Graphite	A, B, C, E, F	• Broken graphite molds and graphite furnace equipment or graphite chunks and pieces from mold cleaning and declassification. Also discarded lab equipment.
Debris Waste S5000	Leaded Rubber	A, B, C, E, F	• Leaded gloves and aprons comprised of layers of Hypalon® rubber and PbO-impregnated neoprene. Limited amounts of unleaded gloves, lead bricks, and lead sheeting may be included.
Debris Waste S5000	Metal	A, B, C, E, F	• Nonpyrophoric waste metals (iron, copper, aluminum, stainless steel, tungsten, lead, and tantalum). • Beryllium chips. • Billets of Zn-Mg alloy. • Noncompressible and noncombustible items (i.e., filters, metal equipment, furnace brick, metal crucibles, and funnels). Metals are tantalum, tungsten, platinum, and lead. • Metals from small hand tools, valves, trays, clamps, pipes, gloveboxes, furnaces, tanks, respirator filters, control panels, etc.

[a]Remote-handled (RH) transuranic (TRU) waste characterization data requirements will provide the same types of information to the extent that this is consistent with RH TRU waste forms.
[b]Real-Time Radiography (RTR) codes:

A Verification of compliance with packaging requirements.

B Verification of physical waste form identification.

C Verification of Waste Matrix Code.

Refer to footnotes at end of table.

APPENDIX C5 (CONTINUED)
APPLICABILITY OF RTR

D Verification of absence of noncompliant items, including free liquids and compressed gases throughout the volume of the container.

E Verification of absence of free liquids around the perimeter of the container (between drum/liner, liner/poly bag, and poly bag/waste).

F Verification of absence of noncompliant items, including free liquids and compressed gases throughout the volume of the container, conditional on the physical geometry of the waste and the resulting package density (variable void volume).

G Density of the waste may negate RTR examination of the entire container.

H Process knowledge is well defined and precludes introduction of extraneous materials, such as pressure vessels.

NOTE: The use of trade names or brand names in this table does not constitute endorsement by the DOE or its contractors.

APPENDIX C6
STATISTICAL METHODS USED IN SAMPLING AND ANALYSIS

APPENDIX C6
STATISTICAL METHODS USED IN SAMPLING AND ANALYSIS

C6-1 Approach for Statistically Selecting Waste Containers for Visual Inspection

As a Quality Control check on radiography, a statistically selected portion of the certified waste containers must be opened and visually examined. The data from visual examination must be used to verify the matrix parameter category and waste material parameter weights as determined by radiography.

The data obtained from the visual examination must also be used to determine, with acceptable confidence, the percentage of miscertified waste containers. Miscertified containers are those that radiography indicates meet the Waste Isolation Pilot Plant Waste Acceptance Criteria and Transuranic Package Transporter-II Authorized Methods for Payload Control but visual examination indicates do not meet these criteria.

Experience at the Idaho National Engineering Laboratory indicates that two-percent of the radiography-certified waste containers have been miscertified when compared to the results of visual examination (EG&G 1994). Participating sites must use this historical miscertification rate to calculate the number of waste containers that must be visually examined. The miscertification rate must be determined each year based on results of certification activities over a minimum of 12 months. Table C6-1 provides the number of waste containers that must be visually examined for several miscertification rates and waste container population sizes.

Table C6-1 has been developed with the use of an EG&G Idaho, Inc. engineering design file (EG&G 1994). The number of waste containers requiring visual examination will ensure the program is 80-percent confident that if the true miscertification rate is the same as the percent column heading of Table C6-1, and if the indicated number of waste containers is examined, the Upper Confidence Level of 90 percent (UCL_{90}) of the miscertification percentage will be less than 14 percent (i.e., there is only a 10-percent chance that the miscertification rate is greater than 14 percent). If the number of containers listed in Table C6-1 are visually examined, it is simply guaranteed that the UCL_{90} of the miscertification percentage will be less than 14 percent; 14 percent is a worst case. In actuality, when UCL_{90}s have been calculated from sample data, most of them will be much smaller than 14 percent.

For the hypergeometric approach to determining the number of containers to be visually examined, the acceptable level of uncertainty is the estimate of the proportion miscertified (along with the information on the previous percentage miscertified) determines the number of containers that must be examined. The rationale and details of this methodology are discussed below.

In a population of size N, there are M miscertified containers, so the true proportion of the miscertified containers in the population is $M/N = p_{true}$. Since p_{true} (or M) is not known, we wish to estimate it by randomly sampling some of the containers. If in a sample of n containers, x are found to be miscertified, the sample estimate ($\hat{p}$) of the true population proportion p_{true} is:

$$\hat{p} = \frac{x}{n} \tag{C6-1}$$

This value is only an estimate, and as such has some uncertainty associated with it. This uncertainty is quantified by calculating the upper one-sided ($1-\alpha$) percent confidence limit for p, defined as p_{UCL}. This confidence limit gives the largest value the true proportion could take on and still have a "reasonable" chance (e.g., an $\alpha = 0.10$ probability) of producing x miscertified containers in a sample of n out of N. This upper confidence limit is calculated as:

$$p_{UCL} = \frac{M_{UCL}}{N} \tag{C6-2}$$

where M_{UCL} is the largest value of M such that the probability of observing x or fewer miscertified containers in a sample of size n is less than or equal to α. That is, it is the largest value of M such that the following inequality is true:

$$\sum_{k=0}^{x} \frac{\binom{M}{k}\binom{N-M}{n-k}}{\binom{N}{n}} \le \alpha \tag{C6-3}$$

where each term in parentheses has the usual combinatorial interpretation. For example:

$$\binom{M}{k} = \frac{M!}{k!\,(M-k)!} \tag{C6-4}$$

Each term in the sum in Equation C6-3 is the hypogeometric probability of observing k miscertified containers in a sample size n from a population of size N in which there are M miscertified containers (and hence the population proportion of miscertified containers is p =M/N). The value M_{UCL} is obtained by substituting different values for M into Equation C6-3 until the largest value satisfying the inequality is found.

Note that in Equation C6-3, the upper confidence limit is dependent on x, the number of miscertifications observed in the sample, as well as on n, the sample size. So, to obtain the required sample size, the values of x that are likely to be seen also need to be considered. Sample size is thus determined by setting a desired upper confidence limit value and then manipulating x and n in Equation C6-3.

C6-2 Approach for Statistically Selecting Waste Containers for Totals Analysis

The statistical approach for characterizing retrievably stored homogeneous solids and soil/gravel waste using sampling and analysis relies on acceptable knowledge to segregate waste containers into relatively homogeneous waste streams. In this way it is reasonable to classify as hazardous or nonhazardous the entire waste stream rather than individual waste containers. Individual waste containers serve as convenient units for characterizing the combined mass of waste from the waste stream of interest. Once segregated by waste stream, random selection and sampling of the waste containers followed by analysis of the waste samples must be performed to ensure that the resulting mean contaminant concentration provides an unbiased representation of the true mean contaminant concentration for each waste stream. The site project manager shall verify that the samples collected from within a waste stream were selected randomly.

The end use of analytical results for retrievably stored homogeneous solids and soil/gravel is for determining the Environmental Protection Agency hazardous waste D-codes that apply to each waste stream. The D-codes are indicators that the waste exhibits the toxicity characteristic for specific contaminants under the Resource Conservation and Recovery Act (RCRA). The RCRA-toxicity determination is made on the basis of sampling and analysis of waste streams and on whether or not the waste stream carries F-codes. If a waste stream carries one or more RCRA F-codes, toxicity characteristic contaminants associated with the F-codes are not included in the RCRA-toxicity characteristic determination. That is, the F-codes take precedence over RCRA-toxicity D-code. Therefore, toxicity characteristics contaminants associated with F-codes(s) for a waste stream must be omitted from all calculations for determining the number of containers to sample. In addition, each toxicity characteristic contaminant associated with the F-code(s) must be excluded from evaluation of analytical results to determine D-codes. Contaminants of interest for the sampling, analysis, and RCRA-toxicity determination of a waste stream, then, excludes contaminants associated with F-codes that have been assigned to the waste stream.

The sampling and analysis strategy is illustrated in Figure C6-1. Preliminary estimates of the mean concentration and variance of each RCRA regulated contaminant in the waste will be used to determine the number of waste containers to select for sampling and analysis. The preliminary estimates will be made by obtaining a preliminary sample from the waste stream or from previous sampling from the waste stream. The applicability of the preliminary estimates to the waste stream to be sampled must be justified and documented. The estimates will be determined in accordance with the following equations:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \tag{C6-5}$$

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \tag{C6-6}$$

where $\bar{x}$ is the calculated mean and s^2 is the calculated concentration variance, n is the number of samples analyzed, x_i is the concentration determined in the *ith* sample, and *I* is an index from 1 to n.

The ratio of the standard deviation, s, to the mean is called the coefficient of variation (CV); preliminary estimates for CV must be calculated for all contaminants of interest which are described above. The highest CV will be used in determining the number of samples to collect and analyze. Analysis results will then be summarized on a contaminant-specific basis. The calculations for the number of samples to collect and calculations for analysis summaries are described in subsequent paragraphs.

The preliminary estimated concentration mean and associated variance for the contamination with the highest CV among all contaminants of interest must then be used to calculate the number of samples required, n, in accordance with the procedure described in Cochran (1977). As a first approximation, take

$$n_0 = \frac{s^2}{\bar{x}^2 c} \tag{C6-7}$$

where s^2 and $\bar{x}$ are the preliminary estimates for the variance and the mean, and

$$c = \frac{r^2}{t^2_{\alpha, n_0-1}} \tag{C6-8}$$

where t_{α,n_0-1} is the 90th percentile for a t distribution with n_0-1 degrees of freedom. The parameter r is taken as 1.0, which represents a relative error of 100 percent. This choice of r is made in order to obtain the Type I and Type II error rates. This reduces Equation C6-7 to

$$n_0 = \frac{t^2_{\alpha, n_0-1} s^2}{\bar{x}^2} \tag{C6-9}$$

Because t_{α,n_0-1} is dependent on n_0, the calculation procedure is iterative. If the ratio of n_0 to the number of containers in the waste stream, N, is appreciable, the number of samples required may be reduced to

$$n = \frac{n_0}{1 + \frac{n_0}{N}} \qquad \text{(C6-10)}$$

The effect of the ratio n_0/N on n in Equation C6-10 depends on n_0. Equation C6-10 should be used for cases where it results in a different number of samples from n_0. All calculations should be rounded up to the nearest integer. A minimum of five containers must be sampled and analyzed in each waste stream. If there are fewer than the minimum or required number of containers in a waste stream, one or more containers must be sampled more than once to obtain the samples of the waste. Otherwise any one container may be selected for sampling only once.

The calculated number of required waste containers will then be randomly sampled and analyzed. If waste container samples for the preliminary mean and variance estimates were randomly collected from the same waste stream lot being examined and were collected and analyzed in the manner required for characterization samples, then these samples may be counted toward meeting the required number. The number of waste containers that must be sampled is dependent on defined levels of acceptable error for the hazardous versus nonhazardous determination, as described below.

C6-3 Upper Confidence Limit

Upon completion of the required sampling, final mean and variance estimates and the UCL_{90} for the mean concentration for each contaminant must be determined. The UCL_{90} for the mean concentration of each contaminant will be calculated in accordance with the following equation:

$$UCL_{90} = \bar{x} + \frac{t_{\alpha,n-1}s}{\sqrt{n}} \qquad \text{(C6-11)}$$

The observed sample CV must be checked against the preliminary estimate for CV used in determining the number of samples to be collected before proceeding. If the observed sample CV is greater than the preliminary estimate for CV, the required number of samples must be recomputed using the observed CV. If the observed sample CV estimate results in greater than 20 percent more required samples, then additional sampling and analysis must occur. Once sufficient sampling and analysis has occurred, the determination of whether the waste stream is RCRA-hazardous or nonhazardous will proceed. The determination will be made with 90 percent confidence. If the UCL_{90} for the mean concentration is less than the regulatory threshold limit, the waste stream will be classified as nonhazardous for this contaminant. If the UCL_{90} is

greater than or equal to the regulatory threshold limit, the waste stream will be classified as hazardous for this contaminant.

C6-4 Justification for Use of the 90 Percent Confidence Limit for RCRA Characterization of Transuranic Waste

A 90 percent confidence limit was determined to be adequate and appropriate for the following reasons:

- The hazardous waste determination is made based on "Total Analysis" of waste as opposed to the Toxicity Characteristic Leaching Procedure. This approach uses the regulatory limits that incorporate assumptions that samples are 100 percent solid (i.e., no moisture content) and contaminants are 100 percent soluble in the extraction fluid. "Total Analysis" also uses a more aggressive extraction procedure (i.e., stronger acids) which more completely solubilize contaminants. This is an inherently conservative approach and waste analyzed by "Total Analysis" methods.

- Regardless of the hazardous or non-hazardous determination associated with any particular waste stream or individual waste container, all contact-handled waste will be handled in the same manner during transportation to and emplacement at the WIPP. All waste will be handled, stored, and disposed in a way that meets the requirements for hazardous waste.

- Waste will not be segregated on the basis of a RCRA hazardous determination for the purpose of handling or disposal, so safety related issues are not a concern for "mis-designated" waste. Emergency response personnel will be adequately equipped to mitigate health and safety concerns associated with hazardous waste.

Simulated hazardous waste determinations using both the 90 percent and 95 percent confidence limits indicate an approximate 60 percent increase in sampling and analysis costs to achieve a 95-percent confidence limit. The Department of Energy considered the consequence of increasing the confidence level from 90 to 95 percent for determining whether or not waste streams exhibit the toxicity characteristic. Calculations show that the number of containers to sample increases from 57 to 70 percent with the increase in confidence.

Calculations used Equation C6-9, which pertains to sampling of retrievably stored homogeneous solids and soil/gravel waste. The factor that changes with confidence level is $t^2_{\alpha, n-1}$, which also changes with the calculated number of containers to sample (n). Therefore, this factor is used to calculate the percent increase in n, for different possible values of n. The finite population factor (Equation C6-10) is not used in these calculations; however, it is not expected to significantly affect the results.

The results are given in Table C6-2. For the values of n between 5 and 500 at 90 percent confidence, increases the range from 57 to 70 percent. The values of n for both 90 and 95 percent confidence are given in the table so the number of containers required to be sampled can be directly compared. Because of the formulation for calculating the required number of containers to sample, the tabled values do not depend on the number of containers in the waste stream. The number of containers to sample reflects variabilities of constituent concentrations observed in the waste stream; in particular, it reflects the maximum ratio of standard deviation to mean concentration, which is the maximum coefficient of variation. For example, for a waste stream of any size that has a coefficient of variation of 0.918, the required number of containers to sample increases 60 percent from 5 for 90 percent confidence to 8 for 95 percent confidence.

C6-5 Control Charting for Newly Generated Waste Stream Sampling

Significant process changes and process fluctuations can be determined using statistical process control (SPC) charting techniques; these techniques require historical data for determining limits for indicator species, and subsequent periodic sampling to assess process behavior relative to historical limits. SPC may be performed on waste prior to solidification or packaging for ease of sampling. If the limits are exceeded, the waste stream must be recharacterized, and the characterization must be performed according to procedures required in the Transuranic Waste Characterization Quality Assurance Program Plan for retrievably stored waste.

A Shewhart control chart (Gilbert, 1987) is a control chart for means that can be used for checking whether current data are consistent with past data and whether shifts or trends in means have occurred. The control chart for means is constructed of a center line and upper and lower control limits that are based on the mean and standard deviation of historical data for the process. If a current sample mean from the process lies within the limits, the process is said to be "in control", or consistent with historical data. If the current mean exceeds the limits, the process has likely changed from historical periods.

Logical sets of historical data to be used for the construction of limits in this application are the data from the initial characterization of the waste stream, if available, from characterization of a different lot of the waste stream, or from a retrievably stored waste stream of the same type from the same process. The data used for construction of the limits must be justified. The underlying assumptions for control charts are that the data are independent and normally distributed with constant mean μ and constant variance σ^2. The statistical tests for normality must be conducted and data transformation to normality performed, if necessary. Transformations must take place prior to any calculations that use the data.

Each limit will be constructed such that there is a 90 percent confidence that the true mean does not exceed a limit. One-sided control limits are used because once a waste stream has been determined to be RCRA-hazardous, the limit exceedence of interest is on the lower side; that is when the process may become nonhazardous. Likewise, once a waste stream has been determined to be RCRA-hazardous, the limit exceedence of interest is on the upper side; that

is when the process may become RCRA-hazardous. Whether or not exceeding the limit would result in a change in the RCRA-hazardous nature of the waste stream depends on how close the limits are to RCRA limits.

Current process data will be collected and averaged for comparison to the control limit for the mean. The collection period and number of samples to be included in the average are dependent on the waste stream characteristics. A small number of samples will reflect more of the process variability and there will potentially be more limit exceedence. If two or three samples are collected for the mean in the required annual (or batch) sampling of a relatively homogeneous waste stream, limit exceedences may not occur. If the waste stream is more variable, it will be necessary to collect more samples to meet the required confidence limit.

Periodically it will be necessary to update the control limit for a process. An update is performed that includes all historical data if there is no evidence of a trend in the process or a shift in the mean for the process. If there has been a shift in the mean, only more recent data that reflects the shift is used. In general, control limits should be based on at least ten data points that are representative of the process and do not exhibit outliers or a trend with time.

REFERENCES

Cochran, William G. 1977. *Sampling Techniques.* New York, New York, John Wiley & Sons: pp.77-78.

EG&G. 1994. *Description of the SWEPP Certified Waste Sampling Program for FY-94.* Engineering Design File, RWMC-363, Revision 6, Idaho Falls, Idaho, EG&G - Idaho Inc., Idaho National Engineering Laboratory.

Gilbert, Richard O. 1987. *Statistical Methods for Environmental Pollution Monitoring.* New York, Van Nostrand Reinhold.

TABLES

TABLE C6-1
NUMBER OF WASTE CONTAINERS REQUIRING VISUAL EXAMINATION

Annual Number of Waste Containers Undergoing Characterization	Number of Waste Containers Requiring Visual Examination Based on Percent of Waste Containers Miscertified to WIPP-WAC by Radiography in Previous Year(s)					
	1%	2%	3%	4%	5%	6%
50	22[a]	22	22[a]	22	29[a]	29
100	15	24	24	33	33	41
200	15	26	26	35	44	52
300	15	26	26	35	44	53
400	15	26	26	36	45	62
500	16	26	26	36	45	63

[a]Number of containers for the higher even-number percent of miscertified containers is used because an odd percent implies a noninteger number of containers are likely to be miscertified.

TABLE C6-2

PERCENT INCREASE IN NUMBER OF CONTAINERS (*n*) TO SAMPLE WITH INCREASE IN CONFIDENCE FROM 90 PERCENT TO 95 PERCENT

n for 90 Percent Confidence	n for 95 Percent Confidence	Approximate Percent Increase
5	8	60.00
6	10	66.67
7	11	57.14
8	13	62.50
9	15	66.67
10	17	70.00
25	41	64.00
100	165	65.00
500	824	64.80

Note: Finite population factor not accounted for.

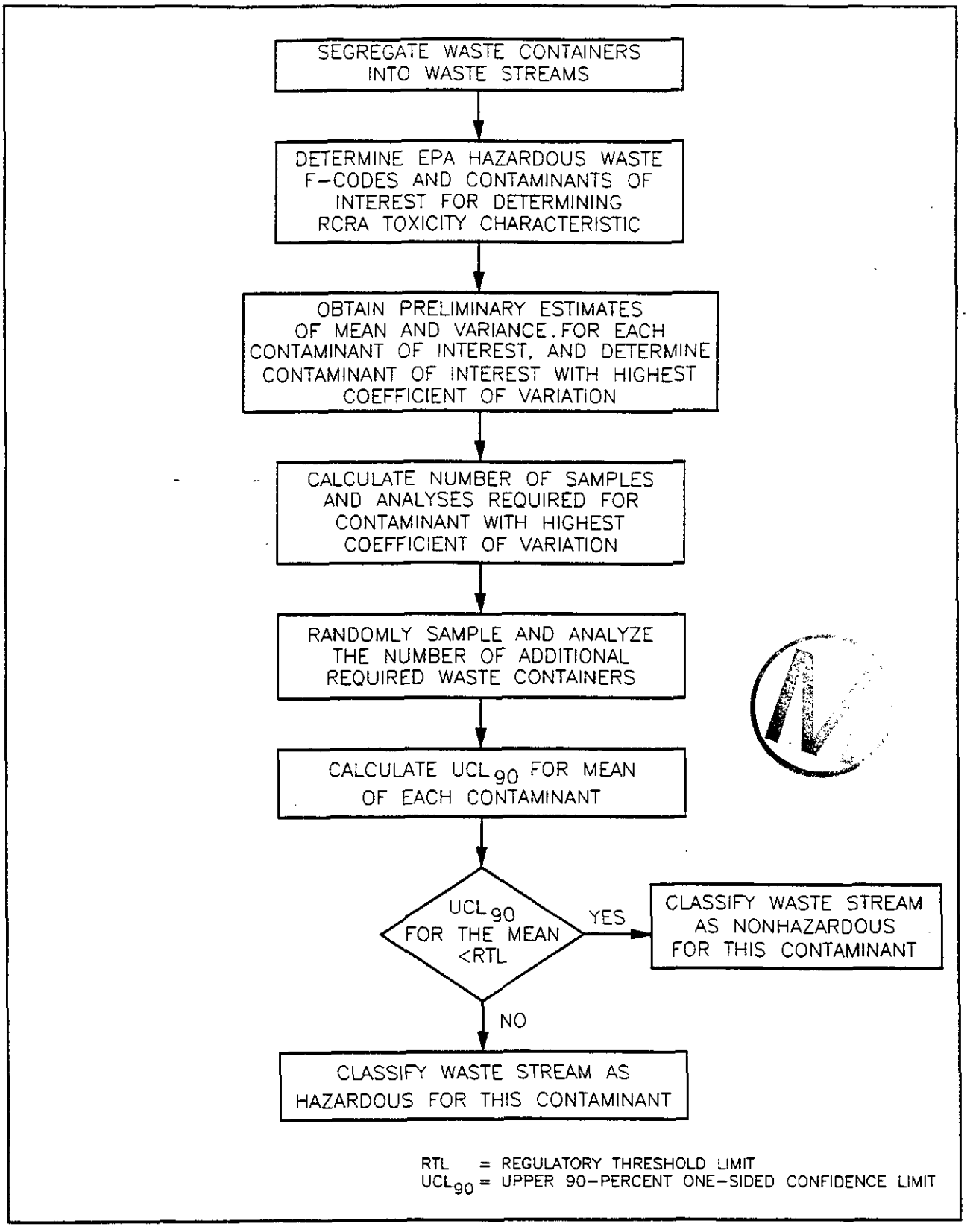

Figure C6-1

Statistical Approach to Sampling and Analysis of Waste Streams of Retrievably Stored Homogenous Solids and Soil/Gravel

APPENDIX C7
SUBMITTAL AND APPROVAL OF ALTERNATIVE TRU WASTE CHARACTERIZATION ANALYTICAL METHODS

APPENDIX C7

SUBMITTAL AND APPROVAL OF ALTERNATIVE TRU WASTE CHARACTERIZATION ANALYTICAL METHODS

C7-1 Purpose and Scope

The National Transuranic Program (NTP) Organization provides the *Transuranic Waste Characterization Sampling and Analysis Methods Manual* (Methods Manual) (DOE 1995a) for use when characterizing transuranic (TRU) waste. However, the NTP recognizes that new or modified techniques may be needed to meet performance objectives for specific wastes and to minimize waste generation associated with sampling and analysis. The NTP has developed a written procedure for guidance to the analytical laboratories at the generator site who want to submit an alternative analytical method for approval by the NTP.

The procedure provides an initial approval process, a list of minimum performance data required for approval of the alternative method verification, and the process of method acceptance. It includes method format specifications, documentation, and supporting data required as part of requests for alternative method approval.

The *Transuranic Waste Characterization Quality Assurance Program Plan* (QAPP) (DOE 1995b) establishes a performance based program where quality assurance objectives (QAO) are defined for all analytes. The Methods Manual contains approved methods with demonstrated performance data that meet the QAOs and should be used if possible. The TRU Waste Characterization Interface Working Group (WCIWG) is responsible for the review and recommendation of alternative methods to the NTP (DOE 1995c). Final approval of alternative methods will not be granted unless the QAOs described in the QAPP have been met.

C7-2 Preliminary Approval

The preliminary approval process is used to screen the number of alternative methods requiring review and approval. The approval must be obtained in the planning and initial testing stages of the method development process to avoid duplication of efforts and conserve time and resources. To obtain the preliminary approval, the author must submit a written description of the method, with justification and supporting documentation, to the NTP Waste Characterization Manager at the Department of Energy Carlsbad Area Office (DOE/CAO).

The method description must be complete enough so that the technical applicability can be assessed. Any limitations of the method must be clearly stated. Criteria for appropriate justifications are: 1) previous analytical data supporting the fact that existing or approved methods cannot be used (e.g., a radioisotope creates an interference), 2) data supporting the fact that an approved method cannot meet the QAOs for a specific matrix, or 3) information demonstrating that an alternative analytical method offers a distinct advantage over the approved methods, such as waste minimization, reduction of analytical time, or reducing worker radiation exposure.

When submitting justification statements in cases of waste matrix interferences that prohibit compliance with required QAOs, the author must demonstrate with supporting data that: 1) the laboratory personnel can satisfactorily analyze other less complex matrices (e.g., water) using an existing approved method, 2) the analyte or matrix interferences from the specific waste is the cause for nonconformance with the QAOs, and 3) there is sufficient evidence from literature or other studies that support the potential use of this alternative method for this waste.

A description of the method will be posted on the WCIWG bulletin board in the Analytical and Test Methods Development Forum to enable the review committee to seek input from other sites. In addition, other sites may comment with supporting data or additional information that will aid the review committee.

C7-3 Required Elements of Alternative Methods

When a method is submitted for approval, all twelve sections of the method, as presented in the Methods Manual, must be included. Tables, figures, flowcharts, equations, units, nomenclature, and references must be clearly labeled and follow the Methods Manual format. The performance criteria must apply to at least one matrix, and the actual method must have been successfully tested on simulated or actual waste samples.

Minimum performance data, demonstrating compliance with the requirements of the QAPP, must be provided for each waste matrix for which the method is to be used that consists of:

- A detection limit study including the statistical method for calculation (seven spiked replicates)
- A precision and bias study using spike and replicate samples of the matrix of interest or similar matrix
- A method blank study using reagents and equipment to ensure contamination will not be a problem
- Data demonstrating the QAPP QAOs are met for accuracy and precision (spike, duplicate, and replicate measurements)
- An interference study using waste matrix spikes

C7-4 Final Approval

A review committee for review and approval of proposed methods will be assembled by the WCIWG chairperson. The review committee will be composed of individuals with expertise in the field of the proposed method. The review process includes determining the applicability of the method; reviewing the performance data, quality control sample requirements, and acceptance criteria, bias and interferences; and checking the equations and calculations. The data that demonstrate results, sensitivity, and repeatability also will be reviewed and checked for accuracy and completeness.

A formal comment and response process will be documented to provide for the clarification of issues relating to the methods and performance data. This also ensures that methods undergo a comparable review process and obtain equal consideration. In some cases, additional performance information, Quality Control data, or more investigation will be required before approval. In other cases, the method may not be approved because the QAOs were not met. In either situation, the method author is allowed one written challenge to the WCIWG review committee's decision.

After the method has undergone WCIWG committee review, all reviewer's comments have been satisfactorily resolved, and the final changes have been made to the method, the method is submitted to the DOE/CAO Quality Assurance Manager for concurrence. After concurrence, the method will be submitted to the DOE/CAO Regulatory Compliance Manager for review and approval. The DOE/CAO Regulatory Compliance Manager will submit the proposed method to the New Mexico Environment Department (NMED) for concurrent review. Upon completion of its review of the proposed method, the NMED must provide a written statement that the method is acceptable, or written comments to the DOE/CAO Regulatory Compliance Manager. The DOE/CAO Regulatory Compliance Manager will notify in writing the WCIWG chairperson regarding whether the method can or cannot be used for TRU waste characterization. Methods approved by both the DOE/CAO Regulatory Compliance Manager and the NMED will be incorporated into the Methods Manual. Methods not approved by the DOE/CAO Regulatory Compliance Manager or found unacceptable by the NMED will not be incorporated into the Methods Manual until all comments have been resolved. Also, the availability of approved, alternative methods will be posted on the WCIWG electronic bulletin board in the TRU Waste Characterization Methods Manual Protocols Forum (DOE 1995d). As additional performance data are generated, these data are also made available through the bulletin board to ensure the most current information is available to the generator sites. Records associated with this review and approval process will be kept on file by the DOE/CAO and will be available for review.

C7-5 References

DOE. 1995a. *Transuranic Waste Characterization Sampling and Analysis Methods Manual.* DOE/WIPP-91-043, Current Revision, Carlsbad, New Mexico, Carlsbad Area Office, U.S. Department of Energy.

DOE. 1995b. *Transuranic Waste Characterization Quality Assurance Program Plan.* CAO-94-1010, Revision 0, Carlsbad, New Mexico, Carlsbad Area Office, U.S. Department of Energy.

DOE. 1995c. *Waste Characterization Interface Working Group Charter.* Carlsbad, New Mexico, Carlsbad Area Office National Transuranic Program, U.S. Department of Energy.

DOE. 1995d. *TRU Waste Characterization Interface Working Group Communications Plan.* May, 1995, Carlsbad, New Mexico, Carlsbad Area Office, U.S. Department of Energy.

APPENDIX C8
QUALITY ASSURANCE OBJECTIVES AND DATA VALIDATION TECHNIQUES FOR WASTE CHARACTERIZATION SAMPLING AND ANALYTICAL METHODS

APPENDIX C8
QUALITY ASSURANCE OBJECTIVES FOR WASTE CHARACTERIZATION SAMPLING AND ANALYTICAL METHODS

C8-1 Validation Methods

Validation of all data (qualitative as well as quantitative) shall be performed so that data used for Waste Isolation Pilot Plant (WIPP) compliance programs will be of known and acceptable quality. Validation includes a quantitative determination of precision, accuracy, completeness, comparability, and method detection limit (as appropriate) for analytical data (headspace Volatile Organics Compounds (VOC) and total VOCs, Semivolatile Organic Compounds (SVOC), and metals data). Quantitative data validations shall be performed by the data generation level Quality Assurance (QA) officer according to the conventional methods outlined below (equations C8-1 through C8-8). These quantitative determinations will be compared to the Quality Assurance Objectives (QAOs) specified in Sections C8-2 through C8-9. A qualitative determination of representativeness will also be performed.

The qualitative data or descriptive information generated by radiography is not amenable to statistical analysis. However, radiography and visual examination are complementary techniques yielding similar data for determining the waste matrix code and waste material parameter weights of waste present in a waste container. Therefore, visual examination results shall be used to verify the waste matrix code and waste material parameter weights determined by radiography.

Representativeness of waste containers from waste streams subjected to visual examination and homogeneous solids and soil/gravel sampling and analysis will be validated, through documentation, that a true random sample was collected. Since representativeness is a quality characteristic that expresses the degree to which a sample or group of samples represents the population being studied, the random selection of waste containers ensures representativeness on a Program level. The Site Project Manager shall document that the selected waste containers from within a waste stream were randomly selected. Sampling personnel shall verify that proper procedures are followed to ensure that samples are representative of the waste contained in a particular waste container or a waste stream.

Precision

Precision is a measure of the mutual agreement among multiple measurements of a single analyte, either by the same method or by different methods. Precision is either expressed as the relative percent difference (RPD) for duplicate measurements or as the percent relative standard deviation (%RSD) for three or more replicate measurements. For duplicate measurements, the precision expressed as the RPD is calculated as follows:

$$RPD = \frac{C_1 - C_2}{\frac{(C_1 + C_2)}{2}} \times 100 \qquad \text{(C8-1)}$$

where C_1 and C_2 are the two values obtained by analyzing the duplicate samples. C_1 is the larger of the two observed values.

For three or more replicate measurements, the precision expressed as the %RSD is calculated as follows:

$$\%RSD = \frac{s}{\bar{y}} \times 100 \qquad \text{(C8-2)}$$

where s is the standard deviation and $\bar{y}$ is the mean of the replicate sample analyses.

The standard deviation, s, is calculated as follows:

$$s = \sqrt{\sum_{i=1}^{n} \frac{(y_i - \bar{y})^2}{n - 1}} \qquad \text{(C8-3)}$$

where y_i is the measured value of the ith replicate sample analysis measurement, and n equals the number of replicate analyses.

Another aspect of precision is associated with analytical equipment calibration. In these instances, the percent difference (%D) between multiple measurements of an equipment calibration standard shall be calculated as follows:

$$\%D = \left|\frac{C_1 - C_2}{C_1}\right| \times 100 \qquad \text{(C8-4)}$$

where C_1 is the initial measurement and C_2 is the second or other additional measurement.

Accuracy

Accuracy is the degree of agreement between a measured analyte concentration (or the average of replicate measurements of a single analyte concentration) and the true or known concentration. Accuracy is determined as the percent recovery (%R).

For situations where a standard reference material is used, the %R is calculated as follows:

$$\%R = \frac{C_m}{C_{srm}} \times 100 \qquad \text{(C8-5)}$$

where C_m is the measured concentration value obtained by analyzing the sample and C_{srm} is the "true" or certified concentration of the analyte in the sample.

For measurements where matrix spikes are used, the %R is calculated as follows:

$$\%R = \frac{S - U}{C_{sc}} \times 100 \qquad \text{(C8-6)}$$

where S is the measured concentration in the spiked aliquot, U is the measured concentration in the unspiked aliquot, and C_{sc} is the actual concentration of the spike added.

Method Detection Limit

The method detection limit (MDL) is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. The MDL for all quantitative measurements (except for those using Fourier Transform Infared Spectroscopy [FTIRS]) is defined as follows:

$$MDL = t_{(n-1,1-\alpha=.99)} \times s \qquad \text{(C8-7)}$$

where $T_{(n-1,1-\alpha=.99)}$ is the t-distribution value appropriate to a 99 percent confidence level and a standard deviation estimate with n-1 degrees of freedom, n is the number of observations, and s is the standard deviation of replicate measurements.

For headspace-gas analysis using FTIRS, MDL is defined as follows:

$$\mathbf{MDL = 3s} \qquad \text{(C8-8)}$$

where s is the standard deviation. Initially, a minimum of seven samples of ambient air or seven blanks must be used to establish the MDLs. MDLs should be constantly updated using the results of the laboratory control sample or on-line control sample.

Completeness

Completeness is a measure of the amount of valid data (i.e., data that meets all Quality Assurance/Quality Control (QA/QC) requirements) obtained from the overall measurement system compared to the amount of data collected and submitted for analysis. Completeness must be expressed as the number of samples analyzed with valid results as a percent of the

total number of samples submitted for analysis. Completeness, expressed as the percent complete (%C), is calculated as follows:

$$\%C = \frac{V}{n} \times 100 \qquad \text{(C8-9)}$$

where V is the number of valid analytical results obtained and n is the number of samples submitted for analysis.

Comparability

Comparability is the degree to which one data set can be compared to another. Comparability of data generated at different sites will be assured through the use of standardized, approved testing, sampling, and analytical techniques and by meeting the QAOs specified in Sections C8-2 through C8-9. The techniques presented in Sections C8-2 through C8-9 are provided in detail in the Quality Assurance Program Plan (QAPP) and in the Transuranic Waste Characterization Sampling and Analysis Methods Manual (Methods Manual) (DOE,1995).

Representativeness

Representativeness is the degree to which sample data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, or an environmental condition. Representativeness is a qualitative parameter that concerns the proper design of the sampling program.

C8-2 Headspace-Gas Sampling

Quality Assurance Objectives

Headspace-gas sampling may occur from three areas within drums of transuranic (TRU) waste (see Figure C6-1): 1) the drum headspace (i.e., the headspace directly under the drum lid), 2) the 55-gallon (gal) (208-liter [L]) polyethylene (poly) bag headspace, and 3) the headspace of the innermost layers of confinement. The precision and accuracy of the drum headspace-gas sampling operations must be assessed by analyzing field QC headspace-gas samples. These samples must include equipment blanks, field reference standards, field blanks, and field duplicates. If the QAOs described below are not met, a nonconformance report must be prepared, submitted, and resolved.

Precision

The precision of the headspace-gas sampling and analysis operation must be assessed by simultaneous collection of field duplicates for VOCs determination. Corrective actions must be taken if the RPD exceeds 25 percent.

Accuracy

A field reference standard must be collected using headspace-gas sampling equipment to assess the accuracy of the headspace-gas sampling operation. Corrective action must be taken if the %R of the field-reference standard is less than 70 or greater than 130.

Completeness

Sampling completeness shall be expressed as the number of valid samples collected as a percent of the total number of samples collected. Participating sampling facilities must achieve a minimum 90 percent completeness. The amount and type of data that may be lost during the headspace-gas sampling operation cannot be predicted in advance. The importance of any lost or contaminated headspace-gas samples must be evaluated by the Site Project QA Officer, and corrective action must be taken as appropriate.

Comparability

Consistent use and application of uniform procedures and equipment, as specified in the Methods Manual, should ensure that headspace gas sampling operations are comparable when sampling different layers of confinement and at the different sampling facilities.

Representativeness

Specific headspace-gas sampling steps to ensure samples are representative include:

- A sample canister cleaning and leak check
- Sampling equipment cleaning or disposal after use
- Sampling equipment leak check
- Use of sample canisters with passivated internal surfaces
- Use of low-internal-volume sampling equipment
- Collection of small-sample volume: low-sample volume to available headspace volume ratio
- Careful pressure regulation
- Performance audits
- Collection of equipment blanks, field reference standard, field blanks, and field duplicates

C8-3 Sampling of Homogenous Solids and Soils/Gravel

Quality Assurance Objectives

To ensure that sampling is conducted in a representative manner on a waste-stream basis for waste containers containing homogenous solids and soil/gravel, samples must be collected randomly in both the horizontal and vertical planes of each container's waste. For waste containers that contain homogenous solids and soil/gravel in smaller containers (e.g., 1 gal [4.0 L] poly bottles) within the waste container, one randomly chosen smaller container must be sampled.

Precision

Sampling precision must be determined by collecting and sampling field duplicates (e.g., co-located cores as described in Appendix C4-2.2) once per sampling batch or once per week during sampling operations, whichever is more frequent. A sampling batch is a suite of homogenous solids and soil/gravel samples collected consecutively using the same sampling equipment within a specific time period. A sampling batch can be up to 20 samples (excluding field QC samples), all of which must be collected within 14 days of the first sample in the batch. The RPD between co-located samples must be calculated and reported by the Site Project QA Officer.

The recommended method for establishing acceptance criteria for co-located cores is development of control charts for the RPD in the cores. Control charts will be developed for each constituent and for each waste matrix or waste type (e.g., pyrochemical salts or organic sludges), as needed, using historical analysis results. The historical analysis results currently do not exist, but would be collected over the course of future waste characterization activities. RPDs for at least 25 to 30 pairs of co-located cores would be used in the construction of the control charts. The limits for the control chart will be three standard deviations above or below the average RPD. Once constructed, RPDs for additional co-located pairs will be compared with the control chart to determine whether or not the co-located cores are acceptable. Periodically, the control charts will be updated using all available data.

In order to establish acceptance criteria to be used at the beginning of waste characterization activities, the variance between co-located cores will be compared to the variance measured within the waste stream (exclusive of containers with co-located core measurement) using a statistical test. The test will be performed for each constituent in each waste stream. The test is not considered sensitive and is presented as an interim method until the preferred method of control charting is established. Because of the expected difference between the co-located core variance and the waste stream variance, the test will rarely reject the hypothesis that the co-located core variance is less than the waste stream variance. However, without sufficient data to develop control charts and without established acceptance criteria for field duplicates (i.e., as specified by SW-846), the interim method is a reasonable approach for evaluating co-located cores.

The statistical test will involve calculating the variance for co-located cores by pooling the variances computed for each pair of co-located cores. The variance for the waste stream will be computed excluding any data from drums with co-located cores, because the test requires

the variance estimates to be independent. All data must be transformed to normality prior to computing variances and performing the test. The test hypothesis is evaluated using the F distribution and the method for testing the difference in variances. The method will be replaced with the control charting method once sufficient data are available.

Accuracy

Sampling accuracy shall not be measured. Because waste containers containing homogenous solids and soil/gravel with known quantities of analytes are not available, sampling accuracy cannot be determined. However, sampling methods and requirements described are designed to minimize sample degradation and hence maximize sampling accuracy.

Completeness

Sampling completeness shall be expressed as the number of valid samples collected as a percent of the total number of samples collected. Participating sampling facilities must achieve a minimum 90 percent completeness.

Comparability

Consistent use and application of uniform procedures, sampling equipment, and measurement units must ensure that sampling operations are comparable. The analysis results of field duplicates (samples taken of the same medium, under the same conditions, using the same procedures) are examined to determine the comparability. In addition, laboratories analyzing samples must participate in the Performance Demonstration Program (PDP).

Representativeness

Specific steps to ensure the representativeness of samples include the following for both waste containers and smaller containers:

- Coring tools and sampling equipment must be clean prior to sampling.
- The entire depth of the waste must be cored, and the core collected must have a length greater than or equal to 50 percent of the depth of the waste. This is called the core recovery and is calculated as follows:

$$\textit{Core recovery (percent)} = \frac{y}{x} \bullet 100 \qquad \text{(C8-10)}$$

where

x = the depth of the waste in the container
y = the length of the core collected from the waste.

- Coring operations and tool selection should be designed to minimize alteration of the in-place waste characteristics. Minimal waste disturbance must be verified by visually examining the core and describing the observation (e.g., undisturbed, cracked, or pulverized) in the field logbook.

If core recovery is less than 50 percent of the depth of the waste, a second coring location shall be randomly selected. The core from the second location shall be used for sample collection regardless of the core recovery.

$$MDC = K_1 K_2 (2.71 + 4.65 * s_b) \qquad \text{C8-11}$$

C8-4 Radiography

Quality Assurance Objectives

The QAOs for radiography are detailed in this section. If the QAOs described below are not met, then corrective action, such as additional operator training must be taken. It should be noted that radiography does not have a specific MDL because it is primarily a qualitative determination. The objective of radiography for the program is to verify the waste matrix parameters for each waste container and to estimate each waste material parameter weight (Table C8-1). All activities required to achieve these objectives must be described in the site quality assurance project plan (QAPjP) and standard operating procedures (SOP).

Data to meet these objectives must be obtained from an audio/videotaped scan provided by trained radiography operators at the sites. Results must also be recorded on a radiography data form. The precision, accuracy, completeness, and comparability objectives for radiography data are presented below.

Precision

The qualitative determinations, such as verifying the waste matrix code, made during radiography do not lend themselves to statistical evaluation of precision. However, comparison of data derived from radiography and visual examination on the same waste containers at the Rocky Flats Environmental Technology Site and the Idaho National Engineering Laboratory indicates that radiography operators can provide estimated inventories and weights of waste items in a waste container. As a measure of precision, the Site Project QA Officer shall calculate and report the RPD between the estimated waste material parameter weights as determined by radiography and these same parameters as determined by visual examination.

Accuracy

The accuracy with which the waste matrix code and waste material parameter weights can be determined must be documented through visual examination of a randomly selected statistical portion of waste containers. The percentage of waste containers that require assignment to a

different waste matrix code after visual examination must be calculated and reported by the Site Project QA Officer as a measure of radiography accuracy.

Completeness

An audio/videotape of the radiography examination and a validated radiography data form will be obtained for 100 percent of the retrievably stored waste containers in the program.

Comparability

The comparability of radiography data from different sites shall be enhanced by using standardized radiography procedures and operator qualifications.

C8-5 Gas Volatile Organic Compound Analysis

Quality Assurance Objectives

The development of data quality objectives (DQO) specifically for this program has resulted in the QAOs listed in Table C8-2. The specified QAOs represent the required quality of data necessary to draw valid conclusions regarding program objectives. Program-required limits, such as the program required quantitation limits (PRQL) associated with VOC analysis, are specified to ensure that the analytical data collected satisfy the requirements of all data users. A summary of the Quality Control Samples and the associated acceptance criteria is included in Table C8-3. Key data-quality indicators for laboratory measurements are defined below.

Precision

Precision shall be assessed by analyzing laboratory duplicates and replicate analyses of laboratory-control samples and PDP blind-audit samples. Results from measurements on these samples must be compared to the criteria listed in Table C8-2. These QC measurements will be used to demonstrate acceptable method performance and to trigger corrective action when control limits are exceeded.

Accuracy

Accuracy as %R shall be assessed for the laboratory operations by analyzing PDP blind audit samples and laboratory-control samples. Results from these measurements must be compared to the criteria listed in Table C8-2. These QC measurements will be used to demonstrate acceptable method performance and to trigger corrective action when control limits are exceeded.

Method Detection Limit

MDLs shall be expressed in nanograms for VOCs and must be less than or equal to those listed in Table C8-2. MDLs shall be determined based on the method described in the QAPP. The detailed procedures for MDL determination shall be included in site SOPs.

Program Required Quantitation Limit

Laboratories must demonstrate the capability to quantitate analytes at or below the PRQLs given in Table C8-2. Laboratories shall set the concentration of at least one calibration standard below the PRQL. The detailed procedures for PRQL demonstration shall be included in laboratory SOPs.

Completeness

Laboratory completeness shall be expressed as the number of samples analyzed with valid results as a percent of the total number of samples submitted for analysis. Participating laboratories must meet the completeness specified in Table C8-2.

Comparability

For VOC analysis, data generated through analysis of samples from different sites shall be comparable. Comparability will be achieved by using standardized methods and traceable standards and by requiring all sites to participate in the PDP.

Representativeness

Representativeness for VOC analysis shall be achieved by collecting sufficient numbers of samples using clean sampling equipment that does not introduce sample bias. Samples must be collected as described in Appendix C4.

C8-6 Total Volatile Organic Compound Analysis

Quality Assurance Objectives

The development of DQOs specifically for this program has resulted in the QAOs listed in Table C8-4. The specified QAOs represent the required quality of data necessary to draw valid conclusions regarding program objectives. Program-required limits, such as the PRQL associated with VOC analysis, are specified to ensure that the analytical data collected satisfy the requirements of all data users. Key data-quality indicators for laboratory measurements are defined below.

Precision

Precision shall be assessed by analyzing laboratory duplicates, replicate analyses of laboratory-control samples, matrix-spike duplicates, and PDP blind-audit samples. Results from measurements on these samples must be compared to the criteria listed in Table C8-4. These QC measurements will be used to demonstrate acceptable method performance and to trigger corrective action when control limits are exceeded.

Accuracy

Accuracy as %R shall be assessed for the laboratory operations by analyzing laboratory control samples, matrix spikes, surrogate compounds, and PDP blind-audit samples. Results from these

measurements must be compared to the criteria listed in Table C8-5. These QC measurements will be used to demonstrate acceptable method performance and to trigger corrective action when control limits are exceeded.

Method Detection Limit

MDLs shall be expressed in milligrams per kilogram (mg/kg) for VOCs and must be less than or equal to those listed in Table C8-4. The detailed procedures for MDL determination shall be included in site SOPs.

Program Required Quantitation Limit

Laboratories must demonstrate the capability to quantitate analytes in samples at or below the PRQLs given in Table C8-4. Laboratories shall set the concentration of at least one calibration standard below the PRQL. The detailed procedures for PRQL demonstration shall be included in laboratory SOPs.

Completeness

Laboratory completeness shall be expressed as the number of samples analyzed with valid results as a percent of the total number of samples submitted for analysis. Participating laboratories must meet the completeness specified in Table C8-4.

Comparability

For VOC analysis, data generated through analysis of samples from different sites shall be comparable. Comparability will be achieved by using standardized methods and traceable standards and by requiring all sites to participate in the PDP.

Representativeness

Representativeness for VOC analysis shall be achieved by collecting unbiased samples. Samples must be collected as described in Appendix C4.

C8-7 Total Semivolatile Organic Compound Analysis

Quality Assurance Objectives

The development of DQOs specifically for this program has resulted in the QAOs listed in Table C8-6. The specified QAOs represent the required quality of data necessary to draw valid conclusions regarding program objectives. Program-required limits, such as the PRQLs, are specified to ensure that the analytical data collected satisfy the requirements of all data users. A summary of Quality Control Samples and associated acceptance criteria for this analysis is included in Table C8-7. Key data-quality indicators for laboratory measurements are defined below.

Precision

Precision shall be assessed by analyzing laboratory duplicates, replicate analyses of laboratory control samples, matrix spike duplicates, and PDP blind-audit samples. Results from measurements on these samples must be compared to the criteria listed in Table C8-7. These QC measurements will be used to demonstrate acceptable method performance and to trigger corrective action when control limits are exceeded.

Accuracy

Accuracy, as %R, shall be assessed for the laboratory operations by analyzing laboratory-control samples, matrix spikes, surrogate compounds, and PDP blind-audit samples. Results from these measurements must be compared to the criteria listed in Table C8-7. These QC measurements will be used to demonstrate acceptable method performance and to trigger corrective action when control limits are exceeded.

Method Detection Limit

MDLs shall be expressed in mg/kg for SVOCs and must be less than or equal to those listed in Table C8-6. The detailed procedures for MDL determination shall be included in site SOPs.

Program Required Quantitation Limit

Laboratories must demonstrate the capability to quantitate analytes in samples at or below the PRQLs given in Table C8-6. Laboratories shall set the concentration of at least one calibration standard below the PRQL. The detailed procedures for PRQL demonstration shall be included in laboratory SOPs.

Completeness

Laboratory completeness shall be expressed as the number of samples analyzed with valid results as a percent of the total number of samples submitted for analysis. Participating laboratories must meet the level of completeness specified in Table C8-6.

Comparability

For SVOC analysis, data generated through analysis of samples from different sites shall be comparable. Comparability will be achieved by using standardized methods and traceable standards and by requiring all sites to participate in the PDP.

Representativeness

Representativeness for SVOC analysis shall be achieved by collecting unbiased samples. Samples must be collected as described in Appendix C4.

C8-8 Total Metal Analysis

Quality Assurance Objectives

The development of DQOs for the program has resulted in the QAOs listed in Table C8-8. The specified QAOs represent the required quality of data necessary to draw valid conclusions regarding program objectives. Program-required limits, such as the PRQLs associated with metal analysis, are specified to ensure that the analytical data collected satisfy the requirements of all data users. A summary of Quality Control Samples and the associated acceptance criteria for this analysis is provided in Table C8-9. Key data-quality indicators for laboratory measurements are defined below.

Precision

Precision shall be assessed by analyzing laboratory matrix spike duplicates, replicate analyses of laboratory-control samples, and PDP blind-audit samples. Results from measurements on these samples must be compared to the criteria listed in Table C8-8. These QC measurements will be used to demonstrate acceptable method performance and to trigger corrective action when control limits are exceeded.

Accuracy

Accuracy shall be assessed through the analysis of laboratory matrix spikes, PDP blind-audit samples, and laboratory-control samples. Results from these measurements must be compared to the criterion listed in Table C8-8. These QC measurements will be used to demonstrate acceptable method performance and to trigger corrective action when control limits are exceeded.

Program Required Detection Limits

PRDLs, expressed in units of micrograms per L (μg/L), are the maximum values for instrument detection limits (IDL) permissible for program support under the QAPP. IDLs must be less than or equal to the PRDL for the method used to quantitate a specific analyte. Any method listed in Table C-11 of the application may be used if the IDL meets this criteria. For high concentration samples, an exception to the above requirements may be made in cases where the sample concentration exceeds five times the IDL of the instrument being used. In this case, the analyte concentration may be reported even though the IDL may exceed the PRDL. IDLs shall be determined semiannually (i.e., every six months). Detailed procedures for IDL determination shall be included in laboratory SOPs.

Program Required Quantitation Limit

Laboratories must demonstrate the capability of analyte quantitation at or below the PRQLs in units of mg/kg dry weight (given in Table C8-8). The PRDLs are set an order of magnitude less than the PRQLs (assuming 100 percent solid sample diluted by a factor of 100 during preparation). Laboratories shall set the concentration of at least one QC or calibration standard

at or below the solution concentration equivalent of the PRQL. Detailed calibration procedures shall be included in site SOPs.

Completeness

Laboratory completeness shall be expressed as the number of samples analyzed with valid results as a percent of the total number of samples submitted for analysis. Participating laboratories must meet the completeness specified in Table C8-8.

Comparability

Data generated through analysis of samples from different sites shall be comparable. Comparability will be achieved by using standardized methods and traceable standards and by requiring all sites to participate in the PDP.

Representativeness

Representativeness for metals analysis shall be achieved by the collection of unbiased samples. Samples must be collected as described in Appendix C4.

C8-9 Acceptable Knowledge

Acceptable knowledge documentation provides primarily qualitative information that cannot be assessed according to specific data quality goals that are used for analytical techniques. QAOs for analytical results are described in terms of precision, accuracy, completeness, comparability, and representativeness. Analytical results will be used to confirm the characterization of wastes based on acceptable knowledge (Section C9-4). To ensure that the acceptable knowledge process is consistently applied, sites must comply with the following data quality requirements for acceptable knowledge documentation:

- Precision - Precision is the agreement among a set of replicate measurements without assumption of the knowledge of a true value. The qualitative determinations, such as compiling and assessing acceptable knowledge documentation, do not lend themselves to statistical evaluations of precision. However, the acceptable knowledge information will be addressed by the independent review of acceptable knowledge information during internal and external audits.

- Accuracy - Accuracy is the degree of agreement between an observed sample result and the true value. The percentage of waste containers which require reassignment to a new waste matrix code and/or designation of different hazardous waste codes based an the reevaluation of acceptable knowledge and sampling and analysis data will be reported as a measure of acceptable knowledge accuracy.

- Completeness - Completeness is an assessment of the number of waste streams or number of samples collected to the number of samples determined to be useable through the data validation process. The acceptable knowledge record

must contain 100 percent of the required information (Section C9-3). The useability of the acceptable knowledge information will be assessed for completeness during audits.

- Comparability - Data are considered comparable when one set of data can be compared to another set of data. Comparability is ensured through sites meeting the training requirements and complying with the minimum standards outlined for procedures that are used to implement the acceptable knowledge process. All sites must assign hazardous waste codes in accordance with Section C9-4 and provide this information regarding its waste to other sites who store or generate a similar waste stream.

- Representativeness - Representativeness expresses the degree to which sample data accurately and precisely represent characteristics of a population. Representativeness is a qualitative parameter that will be satisfied by ensuring that the process of obtaining, evaluating, and documenting acceptable knowledge information is performed in accordance with the minimum standards established in Section C9-4. Sites also must assess and document the limitations of the acceptable knowledge information used to assign hazardous waste codes (e.g., purpose and scope of information, date of publication, type and extent to which waste parameters are addressed).

Each site must address quality control by tracking its performance with regard to the use of acceptable knowledge by: 1) assessing the frequency of inconsistencies among information, and 2) documenting the results of acceptable knowledge confirmation through radiography, headspace-gas analyses, and solidified waste analyses. In addition, the acceptable knowledge process and waste stream documentation must be evaluated through internal assessments by quality assurance organizations and assessments by auditors external to the organization (i.e., DOE/CAO).

C8-10 Data Review, Validation, and Verification Requirements

Data review, validation, and verification requirements include procedures for the review, validation, and verification of data at the data generation level; the validation and verification of data at the project level; and the verification of data at the CAO level. Data review determines if raw data have been properly collected and ensures raw data are properly reduced. Requirements for data reduction are provided in Sections 9.0 through 15.0 of the QAPP, as appropriate, and in the Methods Manual. Data validation confirms that the data reported satisfy the requirements defined by the user and is accompanied by signature release. Data verification authenticates that data are in fact that which is claimed. The procedures presented in this section ensure that Program records furnish documentary evidence of quality.

Data Generation Level

The following are minimum requirements for raw data collection and management:

- All raw data shall be signed and dated in black ink by the person generating it.

- *All data must be recorded clearly, legibly, and accurately in field and laboratory* records (bench sheets, logbooks), and include applicable sample identification numbers.

- All changes to original data must be lined out, initialed, and dated by the individual making the change. A justification for changing the original data may also be included. Original data must not be obliterated or otherwise disfigured so as not to be readable.

- All data must be transferred and reduced from field and laboratory records completely and accurately.

- All field and laboratory records must be maintained in permanent files according to NEIC guidelines.

- Data must be organized into a standard format for reporting purposes (testing, sampling, analytical or on-line batch data report), as outlined in specific sampling and analytical techniques.

- All electronic and video data must be stored appropriately to ensure that waste container, sample, and associated QC data are readily retrievable.

Data review, validation, and verification at this level involves scrutiny and signature release from *qualified independent technical reviewer(s), technical supervisors(s), and a QA officer,* as specified below. Any nonconformance identified during this process shall be documented on a nonconformance report (Section C8-13). Facilities may combine the positions of independent technical reviewer and QA officer. Individuals conducting this data review, validation, and verification must use checklists that address all of the items included in this section. Checklists must contain tables showing the results of sampling, analytical or on-line batch QC samples, if applicable. Completed checklists must be forwarded with testing, sampling, analytical and on-line batch data reports to the project level.

- One hundred percent of the batch data reports must receive an independent technical review. This review shall be performed by an individual other than the data generator who is qualified to have performed the initial work. The reviewer(s) must release the data as evidenced by signature, and as a consequence ensure the following:

  - Data generation and reduction were conducted in a technically correct manner in accordance with the methods used. Data were reported in the proper units and correct number of significant figures.

  - Calculations have been verified by a valid calculation program, a spot check of verified calculation programs, and/or 100 percent check of all hand calculations.

  - *All variances from an accepted method and the rationale for the variations* have been documented and approved (Section C8-13).

- The data have been reviewed for transcription errors.

- The testing, sampling, or analytical data QA documentation (testing batch, sampling batch, analytical or on-line batch) is complete and includes raw data, calculation records, chain-of-custody (COC) forms, calibration records, QC sample results, and gas canister sample tags (if applicable).

- QC sample results are within established control limits, and if not, the data have been appropriately qualified.

- Reporting flags were assigned correctly.

- Sample holding time and preservation requirements were met, or exceptions documented.

- Radiography tapes have been reviewed, at a minimum for every tenth waste container, against the data reported on the radiography form to ensure that the data are correct and complete.

- Field sampling records are complete.

• One hundred percent of the batch data reports must receive technical supervisory signature release for each testing batch, sampling batch, analytical batch and on-line batch. This release must ensure the following:

  - The data are technically reasonable based on the technique used.

  - All data have received independent technical review with the exception of radiography tapes, which shall receive periodic technical review as specified above.

  - The testing, sampling, or analytical data QA documentation (testing batch, sampling batch, analytical batch or on-line batch) is complete and includes raw data, calculation records, COC forms, calibration records, QC sample results, and gas sample canister tags (if applicable).

  - Sample holding time requirements were met, or exceptions documented.

  - Field sampling records are complete.

• One hundred percent of the batch data reports must receive QA officer signature release. This release must ensure the following:

  - *Independent technical and technical supervisory reviews* have been performed as evidenced by the appropriate signature releases.

- The testing, sampling, or analytical data QA documentation (testing batch, sampling batch, analytical batch or on-line batch) is complete as appropriate for the point of data generation (i.e., radiography, RA, sampling, and analysis).

- Sampling and analytical QC checks have been properly performed. QC criteria that were not met are documented.

- QAOs have been met according to the methods outlined in Section C8-11.

Project Level

Data validation and verification at this level involves scrutiny and signature release from the Site Project Manager (or designee) and the Site Project QA Officer (or designee). This must be accomplished by meeting the following minimum requirements for each waste container. Any nonconformance identified during this process shall be documented on a nonconformance report (Section C8-13).

- One hundred percent of the testing, sampling, and analytical batch data reports must have Site Project Manager signature release. This signature release must ensure the following:

  - Data generation level independent technical, technical supervisory, and QA officer review, validation, and verification have been performed as evidenced by the appropriate signature releases.

  - Testing, sampling, analytical and on-line batch data review checklists are complete.

  - Testing, sampling, analytical and on-line batch data reports are complete and data are properly reported (e.g., data are reported in the correct units, with the correct number of significant figures, and with qualifying flags).

  - Reconciliation with the DQOs was performed (Section C8-12).

- One hundred percent of the testing, sampling, and analytical batch data reports must receive Site Project QA Officer signature release. This signature release must ensure the following:

  - Sampling batch QC checks (e.g., equipment blanks, field duplicates, field reference standards) were properly performed, and meet the established QAOs.

  - Testing batch QC checks (e.g., replicate scans, measurement system checks, replicate counts) were properly performed.

- Analytical batch QC checks (e.g., laboratory duplicates, laboratory blanks, matrix spikes, matrix spike duplicates, laboratory control samples) were properly performed and meet the established QAOs.

- On-line batch QC checks (e.g., field blanks, on-line blanks, on-line duplicates, on-line control samples) were properly performed and meet the established QAOs.

- Proper procedures were followed to ensure representative samples of headspace gas and homogenous solids and soil/gravel were taken.

- Radiography data are complete and acceptable based on the videotape review of one waste container per testing batch, at a minimum.

- RA data are complete and acceptable.

- The Site Project Manager and Site Project QA Officer shall ensure that a repeat of the data generation level review, validation, and verification is performed on the data for a minimum of one randomly chosen waste container quarterly (every three months). This exercise will document that the data generation level review, validation, and verification is being performed according to implementing procedures.

In association with the project-level validation and verification described above, the Site Project QA Officer (or designee) must prepare a Site Project QA Officer Summary and the Site Project Manager (or designee) must prepare a Data Validation Summary. The Site Project QA Officer Summary includes, on a per waste container basis, a validation checklist for each testing, sampling, analytical and on-line batch. Checklists for the Site Project QA Officer Summary must be sufficiently detailed to validate all aspects of a testing, sampling, analytical or on-line batch that affect data quality. The Data Validation Summary provides confirmation that, on a per waste container basis, all data have been validated in accordance with the site QAPjP. The Data Validation Summary must list each testing, sampling, analytical or on-line batch, describe how the validation was performed and whether or not problems were detected, and include a statement indicating that all data are acceptable.

Once the data have received project-level validation and verification, the Site Project Manager must ensure that the laboratory is notified. Samples must be retained by the laboratory until this notification is received. Gas sample canisters may then be released from storage for cleaning, recertification, and subsequent reuse. Sample tags must be removed and forwarded to the Site Project QA Officer before recycling the canisters. If the site project manager requests that samples or canisters be retained for future use (e.g., an experimental holding time study), the same sample identification and COC forms shall be used and cross-referenced to a document which specifies the purpose for sample or canister retention.

CAO Level

The third and final level of data verification occurs at CAO and must, at a minimum, consist of an inventory check of the data packages to verify completeness. The CAO Office of Regulatory Compliance manager is responsible for the verification that data packages include the following:

- Project-level signature releases
- Listing of all waste containers being reported in the package
- Listing of all testing, sampling, and analytical batch numbers associated with each waste container being reported in the package
- Data package case narrative
- Site Project QA Officer Summary
- Data Validation Summary
- Complete summarized qualitative and quantitative data for all waste containers

The CAO Office of Regulatory Compliance manager must verify that each data package is complete and notify the originating site in writing of the acceptance status of the data within two weeks of data package receipt. CAO will maintain the data as appropriate for use in the regulatory compliance programs.

C8-11 Reconciliation with Data Quality Objectives

Reconciling the results of waste testing and analysis with the DQOs provides a way to ensure that data will be of adequate quality to support the regulatory compliance programs. Reconciliation with the DQOs will take place at both the project level and the CAO level. At the project level, reconciliation will be performed by the Site Project Manager; at CAO, reconciliation will be performed by the CAO Office of Regulatory Compliance manager.

Reconciliation at the Project Level

The Site Project Manager will ensure that all data generated and used in decision making meet the DQOs provided in Section C-4d of the text of Chapter C. To do so, the Site Project Manager must assess whether data of sufficient type, quality, and quantity have been collected. The Site Project Manager must determine if the variability of the data set is small enough to provide the required confidence in the results. The Site Project Manager must also determine if, based on the desired error rates and confidence levels, a sufficient number of valid data points have been determined. In addition, the Site Project Manager must document that random sampling of containers was performed for the purposes of waste stream characterization.

For each waste stream characterized, the Site Project Manager must determine if sufficient data have been collected to determine the following Program-required waste parameters:

- Waste matrix code
- Waste material parameter weights
- Average mass and activity of each radionuclide of concern
- If each waste container of waste is TRU radioactive waste
- Average concentration of hydrogen, methane, and each VOC in the headspace gas of waste containers in the waste stream
- Total masses of VOCs, hydrogen, and methane in the headspace gas of the waste stream
- The potential flammability of TRU waste headspace gases
- Mean concentrations, UCL_{90} for the mean concentrations, standard deviations, and number of samples collected for VOCs, SVOCs, and metals in the waste stream
- Total masses of VOCs, SVOCs, and metals in the waste stream
- Whether the waste stream exhibits a toxicity characteristic (TC) under 40 CFR Part 261, Subpart C
- Whether the waste stream can be classified as hazardous or nonhazardous at the 90-percent confidence level
- Whether a sufficient number of waste containers have been visually examined to determine with a reasonable level of certainty that the UCL_{90} for the miscertification rate is less than 14 percent

If the Site Project Manager determines that insufficient data have been collected to make the determinations listed above, additional data collection efforts must be undertaken.

The statistical procedure presented in Appendix C6 shall be used by participating Site Project Managers to evaluate and report waste characterization data from the analysis of homogenous solids and soil/gravel. The procedure, which calculates UCL_{90} values, shall be used to assess compliance with the DQOs in Section 1.5 as well as with RCRA regulations. The procedure must be applied to all laboratory analytical data for total VOCs, total SVOCs, and total metals. For RCRA regulatory compliance (40 CFR § 261.24), data from the analysis of the appropriate metals and organic compounds shall be compared to the TC levels expressed as total values. These total values will be considered the regulatory threshold limit (RTL) values for the Program. RTL values are obtained by calculating the weight/weight concentration (in the solid) of a TC analyte that would give the regulatory weight/volume concentration (in the toxicity characteristic leaching procedure (TCLP) extract), assuming 100-percent analyte dissolution.

Reconciliation at the CAO Level

CAO must also ensure that data of sufficient type, quality, and quantity have been collected to meet Program DQOs. The CAO Office of Regulatory Compliance manager is responsible for determining if sufficient data have been collected to determine the following:

- The concentration of headspace gas VOCs in the total waste inventory to support a demonstration that VOCs will not migrate through the air beyond the WIPP unit boundary in concentrations greater than Environmental Protection Agency (EPA)-determined health-based limits during WIPP operations;

- The concentration of VOCs, SVOCs, and metals in the total waste inventory to support a demonstration that hazardous constituents will not migrate beyond the WIPP unit boundary in concentrations greater than EPA-determined health-based limits;

- The total curie, hydrogen, and methane concentrations in TRU waste to support revision of the thermal power restrictions for shipment of waste in the Transuranic Package Transporter (TRUPACT-II);

- An inventory of radioactive materials and physical waste forms to support an assessment of repository performance;

- Whether waste streams proposed for disposal in WIPP have been adequately characterized; and

- Whether data supports the preparation of the WIPP facility no-migration variance petition, the WIPP RCRA permit application, the WIPP facility 40 CFR Part 191 Certification Application, and a revised safety analysis report for the TRUPACT-II.

C8-12 Data Reporting Requirements

Data reporting requirements define the type of information and the method of transmittal for data transfer from the data generation level to the project level and from the project level to CAO.

Data Generation Level

Data shall be transmitted by hard copy from the data generation level to the project level. Transmitted data shall include all testing, sampling, and analytical batch data reports, and data review checklists. The report forms and checklists used must contain all of the information required by the testing, sampling, and analytical techniques described in Sections 7.0 through 15.0 of the QAPP, as well as the signature releases to document the review, validation, and verification as described in Section C8-10. All testing, sampling, and analytical batch data reports and checklists shall be on approved forms, as provided in site-specific documentation.

Testing, sampling, and analytical batch data reports shall be forwarded to the site project office. Site QAPjPs shall specify the individual at the site project office who will receive these reports. Testing batch data reports shall be forwarded to the site project office within 28 days of the

testing of the last waste container in a testing batch. Sampling batch data reports shall be forwarded to the site project office within 28 days of sample collection of the last sample in a sampling batch. Analytical batch data reports shall be forwarded to the site project office within 28 days of the VTSR of the last sample in an analytical batch. After review by the Site Project QA Officer, all batch data reports will be forwarded to the Site Project Manager. All testing, sampling, and analytical batch data reports shall be assigned serial numbers, and each page shall be numbered at the bottom. The serial number used for data reports can be the same as the testing, sampling, or analytical batch number.

QA documentation shall be maintained in either testing, sampling, and analytical facility files, or site project files for those facilities located on sites. Contract waste operation facilities shall forward testing, sampling, and analytical QA documentation along with testing, sampling, and analytical batch data reports to the site project office for inclusion in site central files.

Project Level

There are two aspects to project level reporting. First, summarized testing, sampling, and analytical data must be reported on a per-waste container basis. Second, summarized characterization information must be reported on a waste stream basis.

Summarized testing, sampling, and analytical data shall be transmitted by hard copy from the Site Project Manager to CAO when requested. Participating sites shall combine data from individual waste containers into data packages for reporting. Hard copy data packages shall consist of the following:

- Cover page with the site name, program identification, waste container numbers for containers included in the data package, and release signatures of the Site Project Manager and Site Project QA Officer
- Table of contents; and
- A concise narrative that summarizes the results of the project-level review and briefly describes any problems or other noteworthy items of interest associated with the data (i.e., nonconformance reports, operational variances). The narrative shall include separate sections which address results of duplicates/replicates and nonconformance reports associated with the waste containers being reported in the package.

For each waste container being reported in the data package, the following information shall be included:

- Cover page with the site name, program identification, waste container number, and approval/release signatures of the Site Project Manager and Site Project QA Officer
- A table that relates sample numbers (testing, sampling, and analytical) to waste container number

- Table of contents
- Site Project QA Officer Summary
- Data Validation Summary
- Radiography results
- Radioassay (RA) results
- Waste container headspace gas hydrogen, methane, and VOC analytical results
- Innermost layer of confinement headspace gas hydrogen, methane, and VOC analytical results for waste containers with inner layers of confinement (if applicable)
- Total VOC, SVOC, and metal analytical results for homogenous solids and soil/gravel (if applicable)

WIPP Waste Information System (WWIS) Data Reporting

The WWIS Data Dictionary (Appendix C13) contains all of the data fields, the field format and the limits associated with the data as established by various waste acceptance criteria. This data will be subjected to edit and limit checks that are performed automatically by the database.

WIPP will coordinate the data transmission with each generator site using the Internet and the TCP/IP transmission protocol. Actual data transmission will use DES encryption technology to ensure the integrity of the data transmissions. The sites with large waste inventories and large databases will populate a data structure provided by WIPP that contains the required data dictionary fields that are appropriate for the waste stream (or waste streams) at that site. For example, totals analysis data will not be requested from sites that do not have homogeneous solids or soil/gravel waste. WIPP will access this data via the Internet to ensure an efficient transfer of this data. Small quantity sites will be given a similar data structure that is tailored to their types of waste. Sites with very small quantities of waste will be provided with the ability to assemble the data interactively to this data structure on the WWIS.

C8-13 Nonconformances and Operational Variances

The status of work and the Program activities at participating sites shall be monitored and controlled by the Site Project Manager and Site Project QA Officer. This monitoring and control shall include: 1) nonconformance identification, documentation, and reporting; and 2) operational variance identification, documentation, and reporting.

Nonconformances

Nonconformances are uncontrolled and unapproved deviations from an approved plan, procedure, or expected result. Nonconforming items and activities are those that do not meet the Program requirements, procurement document criteria, or approved work procedures.

Nonconforming items shall be identified by marking, tagging, or segregating, and the affected organization(s) notified. Participating sites shall disposition nonconforming items as appropriate in accordance with the Quality Assurance Program Description (QAPD). Disposition of nonconforming items shall be identified and documented. The QAPjPs shall identify the person(s) responsible for evaluating and dispositioning nonconforming items and shall include referenced procedures for handling them.

Management at all levels shall foster a "no-fault" attitude to encourage the identification of nonconforming items and processes. Nonconformances may be detected and identified by anyone performing Program activities, including

- Project staff - during field operations, supervision of subcontractors, data validation and verification, and self-assessment
- Laboratory staff - during the preparation for and performance of laboratory testing; calibration of equipment; QC activities; laboratory data review, validation, and verification; and self-assessment
- QA personnel - during oversight activities or audits

A nonconformance report shall be prepared for each nonconformance identified. Each nonconformance report shall be initiated by the individual(s) identifying the nonconformance. The nonconformance report shall then be processed by knowledgeable and appropriate personnel. For this purpose, a nonconformance report including, or referencing as appropriate, results of laboratory analysis, QC tests, audit reports, internal memoranda, or letters shall be prepared. The nonconformance report must provide the following information:

- Identification of the individual(s) identifying or originating the nonconformance
- Description of the nonconformance
- Method(s) or suggestions for correcting the nonconformance (corrective action) or description of the variance granted
- Schedule for completing the corrective action
- An indication of the potential ramifications and overall useability the data, if applicable
- Any approval signatures specified in the QAPjPs

The Site Project QA Officer shall oversee the nonconformance report process and be responsible for developing a plan to identify and track all nonconformances and report this information to the DOE field office. Documentation of nonconformances shall be made available to the Site Project Manager, who in turn is responsible for notifying project personnel of the nonconformance. Completion of the corrective action for nonconformances must be verified by the Site Project QA Officer.

Operational Variances

Variances are approved and controlled changes to Program-related plans or procedures. The need for a variance is caused by the identification of improvement opportunities or unusual or nonroutine occurrences that affect operations but not the ability to achieve the performance standards or quality requirements specified in this QAPP or site QAPjPs. Each person performing Program activities is responsible for the quality of their work and adherence to the applicable requirements contained in this QAPP and site QAPjPs. When a need to deviate from established procedures is identified, it is the responsibility of the person performing the work to initiate a variance.

When a variance is required, the person identifying the need for the variation shall complete a Record of Variance and have a direct supervisor approve it. A Record of Variance must be completed and approved before initiation of the activity to document the variation from normal, approved procedures. The Site Project QA Officer shall assess the significance of the variance and determine if changes to the plans or procedures and further notifications are required.

A Record of Variance must contain at least the following information:

- Title or heading, "Record of Variance"
- Waste container or sample identification number
- Reason for the deviation from the requirements contained in the QAPjP or SOP
- A description of the variation from the accepted sampling, testing, or analytical procedure
- A description of special equipment or personnel required
- Initiator's signature and date
- Supervisor's signature and date
- Site Project Manager's signature and date
- Site Project QA Officer's signature and date

DOE/CAO Corrective Action Process

DOE/CAO initiates a corrective action process when internal nonconformances and nonconformances at the generator/storage sites are identified. Activities and processes that do not meet requirements are documented as deficiencies. All deficiencies regardless of type and origin are processed through the CAO corrective action process.

When a deficiency is identified by the CAO, the following process action steps are initiated:

- The condition is documented on a Corrective Action Report (CAR) by the individual identifying the problem.

- The CAO QA Manager and the National TRU Programs (NTP) Team Leader review the CAR, determine validity of the finding (determine that a requirement has been violated), classify the significance of the condition, assign a response due date, and issue the CAR to the responsible party.

- The responsible organization reviews the CAR, evaluates the extent and cause of the deficiency and provides a response to the CAO, indicating remedial actions and actions to preclude recurrence that will be taken.

- The CAO reviews the response from the responsible organization and, if acceptable, communicates the acceptance to the responsible organization.

- The responsible organization completes remedial actions and actions to preclude recurrence of the condition.

- After all corrective actions have been completed, the CAO schedules and performs a verification to assure that corrective actions have been completed and are effective. When all actions have been completed and verified as being effective, the CAR is closed by the CAO QA Manager and the NTP Team Leader.

- As part of the planning process for subsequent audits and surveillances, past deficiencies are reviewed and the previous deficient activity or process is subject to reassessment.

C8-14 Special Training Requirements and Certifications

Before performing activities that affect Program quality, all personnel are required to receive indoctrination into the scope, purpose, and objectives of the Program and the specific QAOs of the assigned task. Personnel assigned to perform activities for the Program shall have the education, experience, and training applicable to the functions associated with the work. Evidence of personnel proficiency and demonstration of competence in the task(s) assigned must be demonstrated and documented. All personnel designated to work on specific aspects of the Program shall maintain qualification (i.e., training and certification) throughout the duration of the work as specified in this QAPP and applicable QAPjPs. Job performance shall be evaluated and documented at periodic intervals, as specified in the QAPjPs.

Personnel involved in Program activities shall receive continuing training to ensure that job proficiency is maintained. Training includes both education in principles and enhancement of skills. Each participating site shall include in its QAPjP a description of the procedures for implementing personnel qualification and training in accordance with the QAPD and 10 CFR § 830.120. All training records that specify the scope of the training, the date of completion, and documentation of job proficiency shall be maintained in the site project file.

Analytical laboratory line management must ensure that analytical personnel are qualified to perform the analytical method(s) for which they are responsible. The minimum qualifications for certain specified positions for the Program are summarized in Table C8-10. QAPjPs, or their implementing SOPs, shall specify the site-specific titles and minimum training and qualification requirements for personnel performing Program activities. QAPjPs shall also contain the requirements for maintaining records of the qualification, training, and demonstrations of proficiency by these personnel.

An evaluation of personnel qualifications shall include comparing and evaluating the requirements specified in the job/position description and the skills, training, and experience included in the current resume of the person. This evaluation also must be performed for personnel who change positions because of a transfer or promotion as well as personnel assigned to short-term or temporary work assignments that may affect the quality of the Program. QAPjPs shall identify the responsible person(s) for ensuring that all personnel maintain proficiency in the work performed and identify any additional training that may be required.

C8-11 List of References

Currie, Lloyd A. 1968. "Limits for Qualitative Detection and Quantitative Determination." *Analytical Chemistry*, No. 40: pp. 586-93.

DOE. 1995a. Performance Demonstration Program Plan for the Analysis of Simulated Headspace Gases for the TRU Waste Characterization Program. CAO-95-1076, Current Revision, Carlsbad, new Mexico, Carlsbad Area Office, U.S. Department of energy.

DOE. 1995b. Performance Demonstration Program Plan for the Analysis of Solid Wastes for the TRU Waste Characterization Program. CAO-95-1077, Current Revision, Carlsbad, New Mexico, Carlsbad Area Office, U.S. Department of Energy.

EG&G. 1993a. *Preliminary Assessment of Real-Time Radiography and Visual Characterization for Selected Waste Containers.* RFP-4604, Golden, Colorado, D. L. Zeigler and R. V. Harder, EG&G Rocky Flats, Rocky Flats Plant.

EPA. 1995. *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods.* SW-846, Third Edition, Final Update I and Final Update II, Washington, D.C., Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency.

Fisenne, I. M., et al. 1973. "Least Squares Analysis and Minimum Detection Levels Applied to Multi-Component Alpha Emitting Samples." *Radiochem. Radioanal. Letters,* 16, No. 1: pp. 5-16.

Pasternack B. S. and N. H. Harley. 1971. "Detection Limits for Radionuclides in the Analysis of Multi-Component Gamma-Spectrometric Data." *Nucl. Instr. and Meth,* No. 91: pp. 533-40.

U.S. Department of Energy (DOE), 1995a, "Transuranic Waste Characterization Sampling and Analysis Methods Manual," DOE/WIPP 91-043, Current Revision, Waste Isolation Pilot Plant, Carlsbad, New Mexico.

TABLES

TABLE C8-1
WASTE MATERIAL PARAMETERS AND DESCRIPTIONS

Waste Material Parameter	Description
Iron-based Metals/Alloys	Iron and steel alloys in the waste; does not include the waste container materials
Aluminum-based Metals/Alloys	Aluminum or aluminum-based alloys in the waste materials
Other Metals	All other metals found in the waste materials
Other Inorganic Materials	Nonmetallic inorganic waste including concrete, glass, firebrick, ceramics, sand, and inorganic sorbents
Cellulosics	Materials generally derived from high-polymer plant carbohydrates; (e.g., paper, cardboard, wood, and cloth)
Rubber	Natural or man-made elastic latex materials; (e.g., surgeons' gloves, and leaded rubber gloves)
Plastics (waste materials)	Generally man-made materials, often derived from petroleum feedstock; (e.g., polyethylene and polyvinylchloride)
Organic Matrix	Cemented organic resins, solidified organic liquids and sludges
Inorganic Matrix	Any homogeneous materials consisting of sludge or aqueous-based liquids that are solidified with cement, calcium silicate, or other solidification agents; (e.g., wastewater treatment sludge, cemented aqueous liquids, and inorganic particulates)
Soils/gravel	Generally consists of naturally occurring soils that have been contaminated with inorganic waste materials
Steel (packaging materials)	55-gal (208-L) drums
Plastics (packaging materials)	90-mil polyethylene drum liner and plastic bags

TABLE C8-2
GAS VOLATILE ORGANIC COMPOUNDS TARGET ANALYTE LIST AND QUALITY ASSURANCE OBJECTIVES

Compound	CAS Number	Precision[a] (%RSD or RPD)	Accuracy[a] (%R)	MDL[b] (ng)	FTIRS MDL[b] (ppmv)	PRQL (ppmv)	Completeness (%)
Benzene	71-43-2	≤25	70-130	10	5	10	90
Bromoform	75-25-2	≤25	70-130	10	5	10	90
Carbon tetrachloride	56-23-5	≤25	70-130	10	5	10	90
Chlorobenzene	108-90-7	≤25	70-130	10	5	10	90
Chloroform	67-66-3	≤25	70-130	10	5	10	90
1,1-Dichloroethane	75-34-3	≤25	70-130	10	5	10	90
1,2-Dichloroethane	107-06-2	≤25	70-130	10	5	10	90
1,1-Dichloroethylene	75-35-4	≤25	70-130	10	5	10	90
cis-1,2-Dichloroethylene	156-59-2	≤25	70-130	10	5	10	90
Ethyl benzene	100-41-4	≤25	70-130	10	10	10	90
Ethyl ether	60-29-7	≤25	70-130	10	5	10	90
Formaldehyde[c]	50-00-0	≤25	70-130	10		10	90
Hydrazine[d]	302-01-2	≤25	70-130	10		10	90
Methylene chloride	75-09-2	≤25	70-130	10	5	10	90
1,1,2,2-Tetrachloroethane	79-34-5	≤25	70-130	10	5	10	90
Tetrachloroethylene	127-18-4	≤25	70-130	10	5	10	90
Toluene	108-88-3	≤25	70-130	10	5	10	90
1,1,1-Trichloroethane	71-55-6	≤25	70-130	10	5	10	90
Trichloroethylene	79-01-6	≤25	70-130	10	5	10	90
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	≤25	70-130	10	5	10	90
m-Xylene[e]	108-38-3	≤25	70-130	10	5	10	90
o-Xylene	95-47-6	≤25	70-130	10	5	10	90
p-Xylene[e]	106-42-3	≤25	70-130	10	5	10	90
Acetone	67-64-1	≤25	70-130	150	50	100	90
Butanol	71-36-3	≤25	70-130	150	50	100	90
Methanol	67-56-1	≤25	70-130	150	50	100	90
Methyl ethyl ketone	78-93-3	≤25	70-130	150	50	100	90
Methyl isobutyl ketone	108-10-1	≤25	70-130	150	50	100	90

[a]Criteria apply to PRQL concentrations.
[b]Values based on delivering 10 mL to the analytical system.
[c]Required only for homogenous solids and soil/gravel from Los Alamos National Laboratory.
[d]Required only for homogenous solids and soil/gravel from Oak Ridge National Laboratory and the Savannah River Site.
[e]These xylene isomers cannot be resolved by GC/MS.

CAS = Chemical Abstract Service
%RSD = Percent relative standard deviation
RPD = Relative percent difference
%R = Percent recovery
MDL = Method detection limit (maximum permissible value), for GC/MS and GC/FID; total number of nanograms delivered to the analytical system per sample (nanograms); for FTIRS based on 1m sample cell
PRQL = Program required quantitation limit (parts per million/volume basis)

TABLE C8-3
SUMMARY OF LABORATORY QUALITY CONTROL SAMPLES AND FREQUENCIES FOR GAS VOLATILE ORGANIC COMPOUND ANALYSIS

QC Sample	Minimum Frequency	Acceptance Criteria	Corrective Action[a]
Method performance samples	Seven (7) samples initially and four (4) semiannually	Meet method QAOs	Repeat until acceptable
Laboratory duplicates or on-line duplicates	One (1) per analytical batch for GC/MS and GC/FID. One (1) per analytical batch or on-line batch for FTIRS	RPD ≤ 25[b]	Nonconformance if RPD >25
Laboratory blanks or on-line blanks	Daily prior to sample analysis for GC/MS and GC/FID. Daily prior to sample analysis and one (1) per analytical batch or on-line batch for FTIRS.	Analyte amounts <3 x MDLs for GC/MS and GC/FID; <PRQL for FTIRS	Nonconformance if analyte amounts > 3 x MDLs for GC/MS and GC/FID; >PRQL for FTIRS
Laboratory control samples or on-line control samples	One (1) per analytical batch for GC/MS and GC/FID. One (1) per analytical batch or on-line batch for FTIRS	70-130 %R	Nonconformance is %R <70 or >130
GC/MS comparison sample (for FTIRS only)	One (1) per analytical or on-line batch	RPD ≤ 25	Nonconformance if RPD >25
Blind audit samples	Samples and frequency controlled by the Gas PDP Plan	Specified in the Gas PDP Plan	Specified in the Gas PDP Plan

[a]Corrective action per section C8-13 when final reported QC samples do not meet the acceptance criteria.
[b]Applies only to concentrations greater than the PRQLs listed in Table C8-2.

MDL = Method Detection Limit
QAO = Quality Assurance Objective
PDP = Performance Demonstration Program
PRQL = Program Required Quantitation Limit
%R = Percent Recovery
RPD = Relative Percent Difference

TABLE C8-4
TOTAL VOLATILE ORGANIC COMPOUNDS TARGET ANALYTE LIST AND QUALITY ASSURANCE OBJECTIVES

Compound	CAS Number	Precision[a] (%RSD or RPD)	Accuracy[a] (%R)	MDL (mg/kg)	PRQL (mg/kg)	Completeness (%)
Benzene	71-43-2	≤45	37-151	1	10	90
Bromoform	75-25-2	≤47	45-169	1	10	90
Carbon disulfide	75-15-0	≤50	60-150	1	10	90
Carbon tetrachloride	56-23-5	≤30	70-140	1	10	90
Chlorobenzene	108-90-7	≤38	37-160	1	10	90
Chloroform	67-66-3	≤44	51-138	1	10	90
1,4-Dichlorobenzene[b]	106-46-7	≤60	18-190	1	10	90
ortho-Dichlorobenzene[b]	95-50-1	≤60	18-190	1	10	90
1,2-Dichloroethane	107-06-2	≤42	49-155	1	10	90
1,1-Dichloroethylene	75-35-4	≤250	D-234[c]	1	10	90
Ethyl benzene	100-41-4	≤43	37-162	1	10	90
Methylene chloride	75-09-2	≤50	D-221[c]	1	10	90
1,1,2,2-Tetrachloroethane	79-34-5	≤55	46-157	1	10	90
Tetrachloroethylene	127-18-4	≤29	64-148	1	10	90
Toluene	108-88-3	≤29	47-150	1	10	90
1,1,1-Trichloroethane	71-55-6	≤33	52-162	1	10	90
1,1,2-Trichloroethane	79-00-5	≤38	52-150	1	10	90
Trichloroethylene	79-01-6	≤36	71-157	1	10	90
Trichlorofluoromethane	75-69-4	≤110	17-181	1	10	90
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	≤50	60-150	1	10	90
Vinyl chloride	75-01-4	≤200	D-251[c]	1	4	90
m-xylene	108-38-3	≤50	60-150	1	10	90
o-xylene	95-47-6	≤50	60-150	1	10	90
p-xylene	106-42-3	≤50	60-150	1	10	90
Acetone	67-64-1	≤50	60-150	10[d]	100	90
Butanol	71-36-3	≤50	60-150	10[d]	100	90
Ethyl ether	60-29-7	≤50	60-150	10[d]	100	90
Formaldehyde[e]	50-00-0	≤50	60-150	10[d]	100	90
Hydrazine[f]	302-01-2	≤50	60-150	10[d]	100	90
Isobutanol	78-83-1	≤50	60-150	10[d]	100	90
Methanol	67-56-1	≤50	60-150	10[d]	100	90
Methyl ethyl ketone	78-93-3	≤50	60-150	10[d]	100	90
Pyridine[b]	110-86-1	≤50	60-150	10[d]	100	90

[a]Criteria apply to PRQL concentrations.
[b]Can also be analyzed as a semi-volatile organic compound.
[c]Detected; result must be greater than zero.
[d]Estimate, to be determined.
[e]Required only for homogenous solids and soil/gravel from Los Alamos National Laboratory.
[f]Required only for homogenous solids and soil/gravel from Oak Ridge National Laboratory and Savannah River Site.

CAS = Chemical Abstract Service
%RSD = Percent relative standard deviation
RPD = Relative percent difference
%R = Percent recovery
MDL = Method detection limit (maximum permissible value) (milligrams per kilogram)
PRQL = Program required quantitation limit; calculated from the toxicity characteristic level for benzene assuming a 0.9 oz (25-gram (g)) sample, 0.1 gal (0.5 liter (L)) of extraction fluid, and 100 percent analyte extraction (milligrams per kilogram)

TABLE C8-5
SUMMARY OF LABORATORY QUALITY CONTROL SAMPLES AND FREQUENCIES FOR TOTAL VOLATILE ORGANIC COMPOUND ANALYSIS

QC Sample	Minimum Frequency	Acceptance Criteria	Corrective Action[a]
Method performance samples	Seven (7) samples initially and four (4) semiannually	Meet total VOC analysis QAOs	Repeat until acceptable
Laboratory duplicates[b]	One (1) per analytical batch	Meet total VOC analysis RPDs	Nonconformance if RPDs > values in Table C8-4
Laboratory blanks	One (1) per analytical batch	Analyte concentrations < 3 x MDLs	Nonconformance if analyte concentrations > 3 x MDLs
Matrix spikes	One (1) per analytical batch	Meet total VOC analysis %Rs in QAP	Nonconformance if %Rs are outside the range specified in QAPP
Matrix spike duplicates	One (1) per analytical batch	Meet total VOC analysis RPDs and %Rs	Nonconformance if RPDs and %Rs > values in Table C8-4
Laboratory control samples	One (1) per analytical batch	80 - 120 %R	Nonconformance if %R < 80 or > 120
Surrogate compounds	Each analytical sample	Average %R from minimum of 30 samples for a given matrix ±3 standard deviations	Nonconformance if %R < (average %R - 3 standard deviation) or > (average %R + 3 standard deviation)
Blind audit samples	Samples and frequency controlled by the Solid PDP Plan	Specified in the Solid PDP Plan	Specified in the Solid PDP Plan

[a]Corrective Action per section C8-13 when final reported QC samples do not meet the acceptance criteria.
[b]May be satisfied using matrix spike duplicate; acceptance criteria applies only to concentrations greater than the PRQLs listed in Table C8-4.

MDL = Method detection limit
QAO = Quality assurance objective
PDP = Performance Demonstration Program
%R = Percent recovery
RPD = Relative percent difference

TABLE C8-6
SEMI-VOLATILE ORGANIC COMPOUND TARGET ANALYTE LIST AND QUALITY ASSURANCE OBJECTIVES

Compound	CAS Number	Precision[a] (%RSD or RPD)	Accuracy [a] (%R)	MDL (mg/kg)	PRQL (mg/kg)	Completeness (%)
Cresols	1319-77-3	≤50	60-150	5	40	90
1,4-Dichlorobenzene[b]	106-46-7	≤86	20-124	5	40	90
ortho-Dichlorobenzene[b]	95-50-1	≤64	32-129	5	40	90
2,4-Dinitrophenol	51-28-5	≤119	D-172[d]	5	40	90
2,4-Dinitrotoluene	121-14-2	≤46	39-139	0.3	2.6	90
Hexachlorobenzene	118-74-1	≤319	D-152[d]	0.3	2.6	90
Hexachloroethane	67-72-1	≤44	40-113	5	40	90
Nitrobenzene	98-95-3	≤72	35-180	5	40	90
Polychlorinated Biphenyls				5	40	90
Aroclor 1016[c]	12674-11-2	≤33	50-114	5	40	90
Aroclor 1221[c]	11104-28-2	≤110	15-178	5	40	90
Aroclor 1232[c]	11141-16-5	≤128	10-215	5	40	90
Aroclor 1242[c]	53469-21-9	≤49	39-150	5	40	90
Aroclor 1248[c]	12672-29-6	≤55	38-158	5	40	90
Aroclor 1254[c]	11097-69-1	≤62	29-131	5	40	90
Aroclor 1260[c]	11096-82-5	≤56	8-127	5	40	90
Pentachlorophenol	87-86-5	≤128	14-176	5	40	90
Pyridine[b]	110-86-1	≤50	60-150	5	40	90

CAS = Chemical Abstract Service
%RSD = Percent relative standard deviation
RPD = Relative percent difference
%R = Percent recovery
MDL = Method detection limit (maximum permissible value) (milligrams per kilogram)
PRQL = Program required quantitation limit; calculated from the toxicity characteristic level for nitrobenzene assuming a 100-gram (g) sample, 0.5 gal (2 liter [L]) of extraction fluid, and 100 percent analyte extraction (milligrams per kilograms)

[a]Criteria apply to PRQL concentrations
[b]Can also be analyzed as a volatile organic compound
[c]Required only for waste matrix code S3220 (organic sludges)
[d]*Detected; result must be greater than zero*

TABLE C8-7
SUMMARY OF LABORATORY QUALITY CONTROL SAMPLES AND FREQUENCIES FOR TOTAL SEMI-VOLATILE ORGANIC COMPOUNDS ANALYSIS

QC Sample	Minimum Frequency	Acceptance Criteria	Corrective Action[a]
Method performance samples	Seven (7) samples initially and four (4) semiannually	Meet Table C8-7 QAOs	Repeat until acceptable
Laboratory duplicates[b]	One (1) per analytical batch	Meet Table C8-7 RPDs	Nonconformance if RPDs > Table C8-7
Laboratory blanks	One (1) per analytical batch	Analyte concentrations <3 x MDLs	Nonconformance if analyte concentrations > 3 x MDLs
Matrix spikes	One (1) per analytical batch	Meet Table C8-7 %Rs	Nonconformance if %Rs are outside the range specified in Table C8-7
Matrix spike duplicates	One (1) per analytical batch	Meet Table C8-7 RPDs and %Rs	Nonconformance if RPDs and %Rs > Table C8-7 values
Laboratory control samples	One (1) per analytical batch	80 - 120 %Rs	Nonconformance if %R < 80 or > 120
Surrogate compounds	Each analytical sample	Average %R from minimum of 30 samples from a given matrix ±3 standard deviations	Nonconformance if %R < (average %R - 3 standard deviations) or > (average %R + 3 standard deviations)
Blind audit samples	Samples and frequency controlled by the Solid PDP Plan	Specified in the Solid PDP Plan	Specified in the Solid PDP Plan

[a]Corrective action per section C8-13 when final reported QC samples do not meet the acceptance criteria

[b]May be satisfied by using matrix spike duplicate; acceptance criteria applies only to concentrations greater than the PQRLs listed in Table C8-6.

MDL = Method Detection Limit
QAO = Quality Assurance Objective
PDP = Performance Demonstration Program
%R = Percent Recovery
RPD = Relative Percent Difference

TABLE C8-8
TOTAL METALS TARGET ANALYTE LIST AND QUALITY ASSURANCE OBJECTIVES

Analyte	CAS Number	Precision (%RSD or RPD)[a]	Accuracy (%R)[b]	PRDL[c] (µg/L)	PRQL (mg/kg)	Completeness (%)
Antimony	7440-36-0	≤30	80-120	100	100	90
Arsenic	7440-38-2	≤30	80-120	100	100	90
Barium	7440-39-3	≤30	80-120	2000	2000	90
Beryllium	7440-41-7	≤30	80-120	100	100	90
Cadmium	7440-43-9	≤30	80-120	20	20	90
Chromium	7440-47-3	≤30	80-120	100	100	90
Lead	7439-92-1	≤30	80-120	100	100	90
Mercury	7439-97-6	≤30	80-120	4.0	4.0	90
Nickel	7440-02-0	≤30	80-120	100	100	90
Selenium	-7782-49-2	≤30	80-120	20	20	90
Silver	7440-22-4	≤30	80-120	100	100	90
Thallium	7440-28-0	≤30	80-120	100	100	90
Vanadium	7440-62-2	≤30	80-120	100	100	90
Zinc	7440-66-6	≤30	80-120	100	100	90

[a]≤ 30 percent control limits apply when sample and duplicate concentrations are ≥ 10 x IDL for ICP-AES and AA techniques, and ≥ 100 x IDL for Inductively Coupled Plasma—Mass Spectrometry (ICP-MS) techniques. If less than these limits, the absolute difference between the two values shall be less than or equal to the PRDL.
[b]Applies to laboratory control samples, laboratory matrix spikes, and PDP blind audit samples. If a solid laboratory control sample material which has established statistical control limits is used, then the established control limits for that material should be used for accuracy requirements.
[c]PRDL set such that it is a factor of 10 below the PRQL for 100 percent solid samples, assuming a 100 x dilution during digestion.

CAS = Chemical Abstract Service
%RSD = Percent relative standard deviation
RPD = Relative percent difference
%R = Percent recovery
PRDL = Program required detection limit (i.e., maximum permissible value for IDL) (milligrams per liter)
PRQL = Program required quantitation limit (milligrams pre kilogram)

TABLE C8-9
SUMMARY OF LABORATORY QUALITY CONTROL SAMPLES AND FREQUENCIES FOR TOTAL METALS ANALYSIS

QC Sample	Minimum Frequency	Acceptance Criteria	Corrective Action[a]
Method performance samples	Seven (7) samples initially and four (4) semiannually	Meet Table C8-9 QAOs	Repeat until acceptable
Laboratory blanks	One (1) per analytical batch	≤ 3 x IDL (≤ 5 x IDL for ICP-MS)[b]	Redigest and reanalyze any samples with analyte concentrations which are ≤10 x blank value and ≥ 0.5 x PQRL
Matrix spikes	One (1) per analytical batch	80 - 120 %Rs	Nonconformance if %Rs are <80 or >120
Matrix spike duplicates	One (1) per analytical batch	RPD ≤ 30 80-120 %R	Nonconformance if RPD > 30 or if %R < 80 or > 120
Laboratory control samples	One (1) per analytical batch	80 - 120 %Rs	Redigest and reanalyze for affected analytes
Blind audit samples	Samples and frequency controlled by the Solid PDP Plan	Specified in the Solid PDP Plan	Specified in the Solid PDP Plan

[a]Corrective action per section C8-13 when final reported QC samples do not meet the acceptance criteria

[b] Applies only to concentrations greater than the PQRLs listed in Table C8-8.

IDL = Instrument Detection Limit
PDP = Performance Demonstration Program
PQRL = Program Required Detection Limit
%R = Percent Recovery
RPD = Relative Percent Difference

TABLE C8-10
MINIMUM TRAINING AND QUALIFICATIONS REQUIREMENTS[a]

Personnel	Requirements[a]
Radiography Operators[c]	Site-specific training based on waste matrix codes and waste material parameters; requalification every 2 years
Gas Chromatography Technical Supervisors[b] Gas Chromatography Operators[c]	B.S. or equivalent experience and 6 months previous applicable experience
Gas Chromatography/Mass Spectrometry Operators[c] Mass Spectrometry Operators[c]	B.S. or equivalent experience and 1 year independent spectral interpretation or demonstrated expertise
Gas Chromatography/Mass Spectrometry Technical Supervisors[b] Mass Spectrometry Technical Supervisors[b] Atomic Absorption Spectroscopy Technical Supervisors[b] Atomic Absorption Spectroscopy Operators[c] Atomic Mass Spectrometry Operators[c] Atomic Emission Spectroscopy Operators[c]	B.S. or equivalent experience and 1 year applicable experience
Atomic Mass Spectrometry Technical Supervisors[b]	B.S. and specialized training in Atomic Mass Spectrometry and 2 years applicable experience
Atomic Emission Spectroscopy Technical Supervisors[b]	B.S. and specialized training in Atomic Emission Spectroscopy and 2 years applicable experience.

[a]Based on requirements contained in *USEPA Contract Laboratory Program Statement of Work for Organics Analysis* (Document Number OLM 01.0) and *Statement of Work for Inorganics Analysis* (Document Number ILM 03.0).
[b]Technical Supervisors are those persons responsible for the overall technical operation and development of a specific laboratory technique. QAPjPs shall include the site-specific title for this position.
[c]Operators are those persons responsible for the actual operation of analytical equipment. QAPjPs shall include the site-specific title for this position.

1

FIGURES

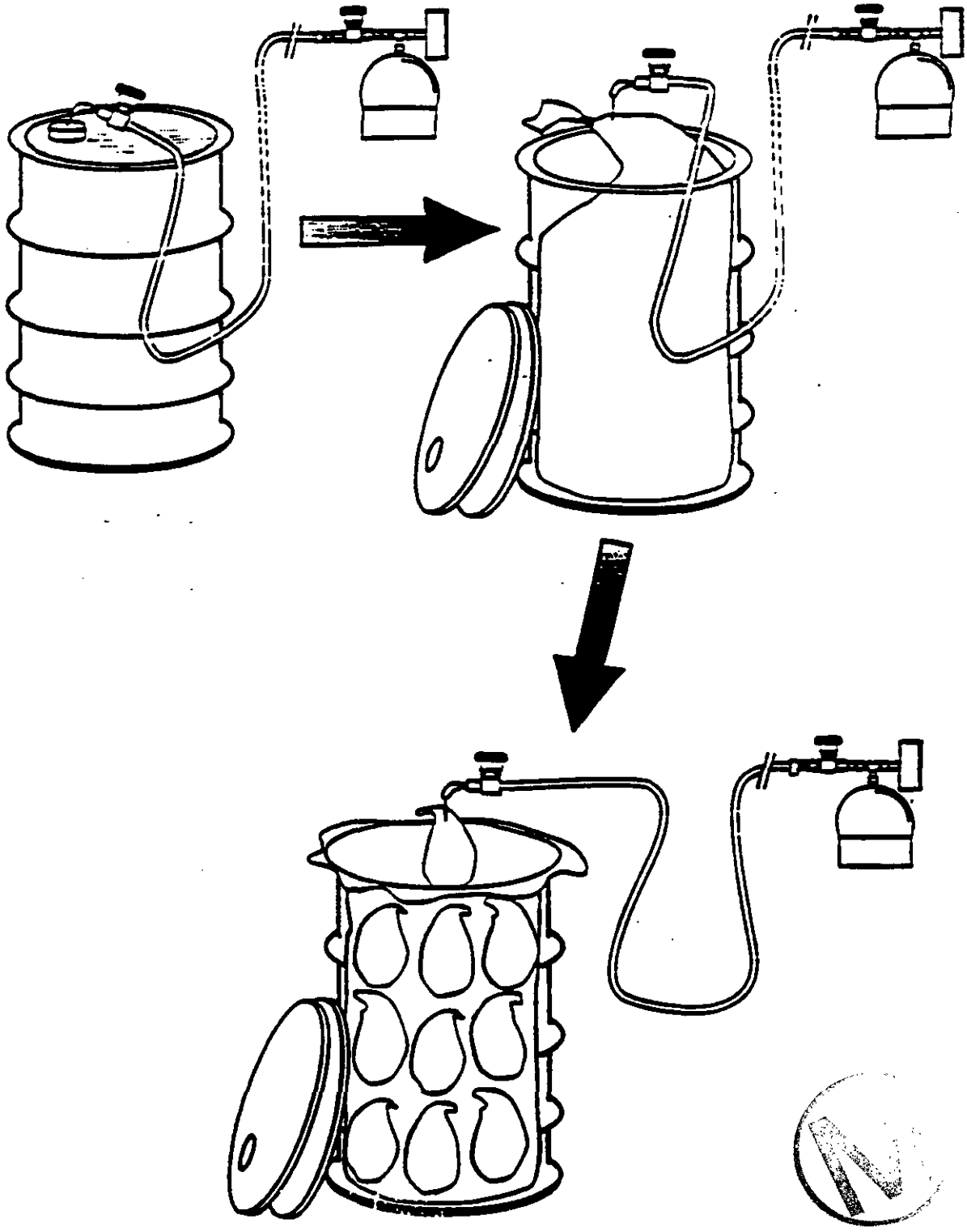

FIGURE C8-1
OVERALL HEADSPACE-GAS SAMPLING SCHEME ILLUSTRATING MANIFOLD SAMPLING

APPENDIX C9
TRU WASTE CHARACTERIZATION USING ACCEPTABLE KNOWLEDGE

APPENDIX C9
TRU WASTE CHARACTERIZATION USING ACCEPTABLE KNOWLEDGE

C9-1 Introduction

The Resource Conservation and Recovery Act (RCRA) regulations codified in 40 CFR Parts 260 through 265, 268, and 270, and the New Mexico Hazardous Waste Management Regulations in Title 20 New Mexico Administrative Code, Chapter 4, Part 1, (20 NMAC 4.1) Subparts I through VI, Subpart VIII, and Subpart IX, authorize the use of acceptable knowledge as a method which can be used in appropriate circumstances by waste generators, or treatment, storage, or disposal facilities to make hazardous waste determinations. Acceptable knowledge is defined in *Waste Analysis: EPA Guidance Manual for Facilities That Generate, Treat, Store and Dispose of Hazardous Waste* (EPA 1994) to include process knowledge, waste analysis data, and facility records of analysis performed before the effective date of RCRA regulations. Acceptable knowledge, as an alternative to sampling and analysis, can be used to meet all or part of the waste characterization requirements under the RCRA (EPA 1994).

Acceptable knowledge is one of a number of techniques used to characterize transuranic (TRU) waste. It is used in conjunction with radiography, headspace gas sampling and analysis, and solidified waste sampling and analysis to meet the requirements of the Waste Analysis Plan (WAP). Acceptable knowledge is used in TRU waste characterization activities in three ways:

- To delineate TRU waste streams
- To determine if TRU debris wastes exhibit a toxicity characteristic (40 CFR §261.24)
- To determine if TRU wastes are listed (40 CFR §261.31)

Acceptable knowledge is confirmed using nondestructive techniques and sampling and analysis.

C9-2 Reasons for Using of Acceptable Knowledge

The Environmental Protection Agency (EPA) (1994) describes four situations in which the use of acceptable knowledge is appropriate. Three of these situations are applicable to TRU waste characterization and are discussed below.

Waste Generating Processes are Well Documented

Waste generating processes from nonspecific sources are included in RCRA regulations at 40 CFR §261.31. The waste generated from these processes are known to contain certain hazardous constituents. Generators of these wastes are not required to perform sampling and analysis of their wastes; knowledge of the process used to generate the waste is required to make an accurate hazardous waste determination.

TRU wastes from nonspecific sources are spent solvent-contaminated wastes (i.e., EPA hazardous waste codes F001 through F005). Acceptable knowledge must be used to determine if these wastes meet the requirements for listing as a spent solvent. To be listed, it must be known if the solvent compound was used for its solvent properties, that is, to solubilize or mobilize other constituents. Examples of solvent use are degreasing, cleaning, use as diluents, extractants, and reaction and synthesis media. In addition, the solvent mixture must have originally contained more than 10 percent by volume of the solvents included under the F001 through F005 listings.

Because listed wastes (i.e., wastes from nonspecific sources under 40 CFR §261.31) are well defined and are based on knowledge of the materials and processes that generate the waste, sampling, and analysis is not required to make a hazardous waste determination. Generators of TRU waste that meets the criteria included in 40 CFR §261.31 (F-listed wastes) must use acceptable knowledge to characterize their TRU waste.

Health and Safety Risks

TRU waste presents serious health and safety risks to waste characterization personnel. Extensive measures are taken by the Department of Energy (DOE) to package this waste so that the potential for human exposure to ionizing radiation is limited. Packaging measures include multiple layers of plastic and shielding to reduce the potential exposure of alpha and gamma radiation, respectively. The breaching of confinement layers or increasing the potential for respirable particulates by size reduction (e.g., shredding or grinding) of TRU debris waste increases the health and safety risks associated with TRU waste management. The design of a data collection program that includes the use of acceptable knowledge allows characterization of TRU waste, while limiting radiation exposure to personnel and the environment.

Physical Nature of the Waste

The TRU waste characterization requirements have been established using the EPA's Data Quality Objectives (DQO) process. The DOE employed this process to establish a defensible, cost-effective program to generate data for regulatory decision making. To make defensible decisions based on sampling and analytical data, a representative sample must be collected. The physical nature of TRU debris wastes (e.g., glass, metal, or combustible waste forms) does not lend itself to the collection and analysis of a representative sample.

To collect a representative sample of TRU debris waste, size reduction and compositing, along with extensive handling of the waste, would be required. During the process of size reduction, target volatile organic compounds (VOC) would be lost so that the final sample would not be representative of the initial waste. Size reduction of alpha-contaminated materials is in direct conflict with DOE's health and safety protocols for the management of TRU waste. Because the greatest risk of exposure to alpha-radiation is by inhalation, TRU waste packaging and handling operations are designed to minimize the potential for airborne particulates. Size reduction of TRU waste would increase the quantities of respirable particulates and increase the potential for release of radionuclides and human exposure. Because of the limited use of data obtained from sampling TRU debris waste, the increase in potential human exposure and the costs associated with facilities to sample and contain TRU waste is not justified.

The EPA (1994) suggests that swiping the surface of waste materials (e.g., metals or glass) may be an alternative to sampling debris wastes. The DQO process requires that the end use of the data be considered in developing sampling and analytical protocols. Swiping the surfaces of TRU waste materials would not provide a representative sample that the DOE could use to make hazardous waste determinations. For example, if VOCs are not detected on the surface of materials, the DOE could not classify the waste as nonhazardous. Many TRU debris wastes contain spent solvents, which are listed according to how the wastes were generated and not whether they contain a listed constituent. In addition, the DOE cannot determine if a waste exhibits a toxicity characteristic based on the concentration of a particular constituent present on surfaces of materials. Therefore, collecting surface swipes is not justified in light of the potential increased exposure to radiation. Collection and preparation of surface swipe samples would not be representative of the waste for the purpose of waste characterization, would be very costly, and would increase the potential exposure of personnel to radiation.

C9-3 Acceptable Knowledge Documentation

It is the responsibility of each DOE TRU waste generator/storage site to develop a logical sequence of acceptable knowledge information that progresses from general facility information (TRU Waste Management Program Information) to more detailed waste-specific information (TRU Waste Stream Information). The consistent presentation of acceptable knowledge documentation among DOE sites in auditable records will allow Waste Isolation Pilot Plant (WIPP) personnel to verify the completeness and adequacy of acceptable knowledge for TRU waste characterization during the audit process.

The following sections include the minimum information that each site must have to characterize TRU waste using acceptable knowledge. Because waste generating processes are site-specific, DOE sites may supplement the minimum required acceptable knowledge records with additional information (Supplemental Acceptable Knowledge Documentation). If the mandatory information is not available for a particular waste, then this waste will not be accepted for disposal at the WIPP facility based on acceptable knowledge alone. Sites may submit additional sampling and analytical data that may provide the required waste characterization information.

TRU Waste Management Program Information

An overview of the TRU waste program provides an understanding of TRU waste management operations at each site. This overview, which will establish the basis for more detailed TRU waste stream information, must reveal an overall perspective of TRU waste management operations and serve as a guide to the waste stream-specific information.

TRU waste management program information must clearly define waste categorization schemes and terminology, provide a breakdown of the types and quantities of TRU waste that are generated and stored at the site, and describe how waste is tracked and managed at the site, including historical and current operations. Information related to TRU waste certification procedures and the types of documentation (e.g., waste profile forms) used to summarize acceptable knowledge must also be provided. The following information must be included as part of the acceptable knowledge record:

- Map of the site with the areas and facilities involved in TRU waste generation, treatment, and storage identified
- Facility mission description as related to TRU waste generation and management (e.g., nuclear weapons research may involve metallurgy, radiochemistry, and nuclear physics operations that result in specific waste streams)
- Description of the operations that generate TRU waste at the site (e.g., plutonium recovery, weapons design, or weapons fabrication)
- Waste identification or categorization schemes used at the facility (e.g., item description codes, content codes)
- Types and quantities of TRU waste generated, including historical generation through future projections
- Correlation of waste streams generated from the same building and process, as appropriate (e.g., sludge, combustibles, metals, and glass)
- Waste certification procedures for retrievably stored and newly generated wastes to be sent to the WIPP facility

TRU Waste Stream Information

For each TRU waste stream, sites must compile all process information and data that support the acceptable knowledge used to characterize that waste stream. The type and quantity of supporting documentation will vary by waste stream, depending on the process generating the waste and site-specific requirements imposed by DOE or state agencies. At a minimum, the waste process information must include:

- Area(s) and building(s) from which the waste stream was or is generated
- Waste stream volume and time period of generation (e.g., 100 standard waste boxes of retrievable stored waste generated from June 1977 through December 1977)
- Waste generating process described for each building (e.g., batch waste stream generated during decommissioning operations of glove boxes)
- Process flow diagrams (e.g., a diagram illustrating glove boxes from a specific building to a size reduction facility to a container storage area)
- Material inputs or other information that identifies the chemical and radionuclide content of the waste stream and the physical waste form (e.g., glove box materials, chemicals and radionuclides handled during glove box operations, if applicable)

A summary must identify all sources of information. The basis and rationale for defining each waste stream based on the parameters of interest must be clearly summarized and traceable to referenced documents. Assumptions made in defining each waste stream also must be identified and justified.

Supplemental Acceptable Knowledge Documentation

Examples of additional documentation that may be used for acceptable knowledge include, but are not limited to, the following:

- Process design documents (e.g., Title II Design)
- Standard operating procedures that may include a list of raw materials or reagents, a description of the process or experiment generating the waste, and a description of wastes generated and how the wastes are managed at the point of generation
- Preliminary and final safety analysis reports and technical safety requirements
- Waste packaging logs
- Test plans or research project reports that describe reagents and other raw materials used in experiments
- Site databases (e.g., chemical inventory database for Superfund Amendments and Reauthorization Act Title III requirements)
- Information from site personnel (e.g., documented interviews)
- Standard industry documents (e.g., vendor information)
- Previous analytical data relevant to the waste stream, including results from fingerprint analyses, spot checks, or routine verification sampling
- Material Safety Data Sheets, product labels, or other product package information
- Sampling and analysis data from comparable or surrogate waste streams (e.g., equivalent nonradioactive materials)
- Laboratory notebooks that detail the research processes and raw materials used in an experiment

The specific, relevant information must be identified and justification provided for its use (e.g., identification of a toxicity characteristic). Supplemental documentation is not required but may be used, if available, to further document the rationale for the hazardous waste designations. Similar to required information, if discrepancies exist between supplemental information and the required documentation, then sites must include all potential hazardous waste codes to the subject waste stream. For example, if personnel interviews indicate that lead was part of the

input materials, then D008 must be designated in spite of the fact that no records of the use of lead exist in the required documentation. Sites must prioritize the sources of information used to assign hazardous waste codes in terms of accuracy of the information. Published documents and controlled databases are considered the most reliable information. Second priority will be given to unpublished data, internal procedures, and notes. Correspondence, such as memoranda, letters, telephone logs, and interviews are considered the least defensible. The pages from large documents, such as safety analysis reports, must be flagged with the relevant information noted.

C9-4 Acceptable Knowledge Process

Consistency among DOE sites in using acceptable knowledge information to characterize TRU waste involves a three phase process: 1) compiling the minimum acceptable knowledge documentation in an auditable record, 2) confirming acceptable knowledge information using radiography and headspace-gas sampling and analysis and solidified waste sampling, and 3) auditing acceptable knowledge records. This section describes each phase of the process and specifies the procedures that sites must develop to implement the requirements for using acceptable knowledge.

Site personnel responsible for compiling, assessing, and resolving discrepancies associated with acceptable knowledge must have the following minimum qualifications and training:

- WIPP WAP, Waste Acceptance Criteria, and Quality Assurance Program Plan (QAPP) Requirements
- State and Federal RCRA regulations associated with solid and hazardous waste determinations
- Nonconformance process, including discrepancy resolution and reporting
- Site-specific procedures associated with waste characterization using acceptable knowledge

Assembling an Acceptable Knowledge Record

Figure C9-1 provides an overview of the process for assembling acceptable knowledge documentation into an auditable record. The first step is to assemble all of the mandatory acceptable knowledge information and any supplemental information regarding the materials and processes that generate a specific waste stream. DOE sites must ensure the following criteria are met in establishing acceptable knowledge records:

- Acceptable knowledge information must be compiled in an auditable record, including a road map for all applicable information.
- The overview of the facility and TRU waste management operations in the context of the facility's mission must be correlated to specific waste stream information.

- Correlations between waste streams, with regard to time of generation, waste generating processes, and site-specific facilities must be clearly described.

- A reference list must be provided that identifies documents, databases, Quality Assurance protocols, and other sources of information that support the acceptable knowledge information.

Container inventories for TRU waste currently in retrievable storage are then defined as waste streams by correlating the container identification to the mandatory acceptable knowledge information. For newly generated wastes, the rate and quantity of waste to be generated must be defined and procedures implemented to make hazardous waste determinations using acceptable knowledge prior to packaging the waste.

For all TRU wastes, sites must develop written procedures that describe how RCRA hazardous waste codes are assigned using acceptable knowledge information and how unacceptable wastes (e.g., reactive, ignitable, and corrosive RCRA-regulated hazardous wastes) are identified and segregated from certifiable TRU waste populations. Site-specific procedures must address the following elements:

- Sites must prepare a written procedure outlining the specific methodology used to assemble acceptable knowledge records, including the origin of the documentation, how it will be used, and any limitations associated with the information (e.g., identify the purpose and scope of a study that included limited sampling and analysis data).

- To compile the required acceptable knowledge record, sites must assemble and evaluate available documentation in the following priority: a) relevant information from published documents and controlled databases, b) unpublished data, c) internal procedures and notes, such as log books, and d) correspondence, such as memoranda, letters, telephone logs, and interviews.

- Sites must comply with Section C9-4 to identify hazardous wastes and assign the appropriate hazardous waste codes to each waste stream.

- Sites must describe the waste certification program and procedures that are used to ensure unacceptable wastes are identified and segregated.

- Sites must develop and implement a procedure(s) for the confirmation of acceptable knowledge in accordance with Section C9-4.

- Sites must provide a cross reference to the applicable waste summary category group (i.e., S3000, S4000, and S5000) to verify all of the required confirmation data has been evaluated and the proper hazardous waste codes have been assigned.

The waste certification procedure(s) must describe the administrative controls used by the site to ensure that nonconforming items are documented and managed in accordance with site-

specific certification plans. The following minimum elements must be addressed in site-specific documentation associated with administrative controls:

- Identify the organization(s) responsible for compliance with administrative controls.
- Identify the oversight procedures and frequency of actions to verify compliance with administrative controls.
- Develop on-the-job training specific to administrative control procedures.
- Ensure that personnel may stop work if noncompliance with administrative controls is identified.
- Develop a nonconformance process that complies with the requirements in Section C8-13 of the WAP to document and establish corrective actions.
- As part of the corrective action process, assess the potential time frame of the noncompliance, the potentially affected waste population(s), and the reassessment and recertification of those wastes.

Sites must develop procedures that describe how acceptable knowledge information is evaluated and any discrepancies in documentation resolved. If different sources of information indicate different hazardous wastes are present, then sites must include all sources of information in its records and conservatively assign all potential hazardous waste codes. Discrepancies in acceptable knowledge documentation must be resolved by including all available information in the auditable records and assigning all hazardous waste codes indicated by all of these records to the subject waste. For example, if one record indicates that solvents were not part of a process, while another record indicates that 1,1,1-trichloroethane was used for cleaning parts, then the F001 hazardous waste code must be applied to the waste. No judgements may be made regarding the quality of the required documentation,and the assignment of hazardous waste codes must be tracked to all required documentation.

Sites must compile adequate documentation to demonstrate consistency in assigning hazardous waste codes and to defend and justify the use of acceptable knowledge in making hazardous waste determinations to independent auditors. The following are minimum baseline requirements/standards that site-specific procedures must include to ensure comparable and consistent identification of hazardous waste:

- Compile all of the required information in an auditable record.
- Review the required information to determine if the waste is listed under 40 CFR Part 261, Subpart D. Assign all listed hazardous waste codes.
- Review the required information to determine if the waste may contain hazardous constituents included in the toxicity characteristics specified in 40 CFR Part 261, Subpart C. If a toxicity characteristic contaminant is identified and is not included as a listed waste, assign the toxicity characteristic code. Unless data is available from the sampling and analysis of a representative sample of the waste stream

that demonstrates that the concentration of the constituent in the waste is less than the toxicity characteristic regulatory level, no judgement may be made regarding the concentration of the constituent. When analytical data is not available, the toxicity characteristic hazardous waste code for the identified hazardous constituent must be applied to the waste stream.

In the case of discrepancies in information, no judgement may be made regarding the quality of the information. Sites must ensure that all potential hazardous waste codes are assigned to the waste stream.

Confirmation of Acceptable Knowledge Information

Acceptable knowledge includes information regarding the physical form of the waste, the base materials composing the waste, and the process that generates the waste. Waste characterization (i.e., radiography, headspace-gas sampling and analysis, and solidified waste sampling and analysis) will be used to confirm acceptable knowledge information. Figure C-2 illustrates the process sites will use to confirm acceptable knowledge.

All retrievably stored waste must be characterized using radiography to confirm the waste matrix code and certify compliance with the RCRA Waste Analysis Plan. If a site must repackage its retrievably stored waste, then visual examination of the waste during repackaging is used to confirm acceptable knowledge information rather than radiography.

For newly generated wastes, sites must have written procedures to document the confirmation of acceptable knowledge information with visual examination prior to or during waste packaging. The following minimum requirements must be addressed in site-specific procedures: 1) scope (i.e., waste streams) and purpose, 2) responsible organization(s), 3) administrative process controls, 4) material inputs to process, 5) process controls and range of operation that affect final hazardous waste determinations, 6) rate and quantity of the hazardous waste generated, 7) list of applicable operating procedures relevant to the hazardous waste determination, 8) nonconformance reporting, 9) process knowledge verification sampling (i.e., headspace-gas sampling and/or solidified waste annual sample), and 10) reporting and records management.

Sites must establish procedures for reevaluating acceptable knowledge if radiography or visual examination results in the assignment of a different waste matrix code [e.g., Plastic/Rubber (S5310) versus Paper/Cloth (S5330)]. Site procedures must describe how the waste is reassigned, acceptable knowledge reevaluated, and appropriate hazardous waste codes assigned.

The base materials that compose TRU debris waste (e.g., lead, stainless steel, glass) are well established, and potential toxicity characteristics can be determined without destructive sampling and analysis. The waste matrix code is related to the base materials and waste generating process. In lieu of sampling and analytical data to the contrary, sites must assign the toxicity characteristic hazardous waste codes based on the presence of the constituent, regardless of the quantity or concentration. Radiography or visual examination must be used to confirm the waste matrix code identified using acceptable knowledge. Procedures must describe how discrepancies in the waste matrix code are recorded and changes to hazardous waste codes based on material composition are documented, as necessary. If a waste must be assigned to

a different waste matrix code based on radiography or visual examination, the following minimum steps must be taken to reevaluate acceptable knowledge:

- Review existing information based on the container identification number and document all differences in hazardous waste code assignments
- If differences exist in the hazardous waste codes that were assigned, reassess and document all required acceptable knowledge information (Section C9-3) associated with the new designation
- Reassess and document all sampling and analytical data associated with the waste
- Verify and document that the reassigned waste matrix code was generated within the specified time period, area and buildings, waste generating process, and that the process material inputs are consistent with the waste material parameters identified during radiography or visual examination
- Record all changes to acceptable knowledge records
- If discrepancies exist in the acceptable knowledge information for the reassigned waste matrix code, complete a nonconformance report (Appendix C8-13), document the segregation of this container, and define the corrective actions necessary to fully characterize the waste

Finally, radiography and visual examination procedures must include a list of nonconforming items that the operator must verify are not present in each container of waste (i.e., corrosives, ignitables, reactives, incompatible waste). Sites must establish and document administrative controls to ensure that nonconforming items or waste are segregated from certifiable populations.

Headspace-gas sampling and analysis must be conducted on all TRU waste to be sent to the WIPP facility. Headspace-gas data will be used to confirm the presence or absence of VOCs identified using acceptable knowledge.

Sites must use acceptable knowledge to identify spent solvents associated with each TRU waste stream or waste stream lot. Headspace-gas data will be used to confirm acceptable knowledge concerning the presence or absence of F-listed solvents. Headspace-gas data may be used to assist in confirming the characterization of waste contaminated with F-listed solvents by the "mixture rule" (e.g., solvent-contaminated rags mixed with other wastes materials). Sites must provide documentation to support any determination that organic constituents are associated with packaging materials or other uses not consistent with solvent use. If the source of the detected solvents can not be identified, the appropriate spent solvent hazardous waste code will be conservatively applied to the waste stream.

Hazardous wastes associated with S3000 and S4000 waste streams will be verified based on the results of the total analysis of a representative solidified waste sample. If discrepancies between the results obtained from solidified waste sampling and analysis and headspace-gas sampling and analysis exist (i.e., a VOC is detected in the solidified waste but not in the

headspace), the solidified waste data will be used to verify acceptable knowledge and assign hazardous waste codes.

Sites must confirm the assignment of spent solvent hazardous waste codes (40 CFR §261.31) by evaluating the average concentrations of each VOC detected in container headspace gas and/or solidified waste matrix using the upper 90 percent confidence limit (UCL_{90}). The UCL_{90} for the mean concentration must be compared to the program required quantitation limit (PRQL) for the constituent. If the UCL_{90} for the mean concentration exceeds the PRQL, sites must reevaluate their acceptable knowledge information and determine the potential source of the constituent.

If the source of the constituent is identified as a spent solvent used in the process or is determined to be the result of mixing a listed waste with a solid waste during waste packaging, then the site will either: 1) assign the applicable listed hazardous waste code to the entire waste stream, or 2) segregate the drums containing detectable concentrations of the solvent into a separate waste stream and assign applicable hazardous waste codes. Each site must document, justify, and consistently define waste streams and assign hazardous waste codes based on site-specific permit requirements and other state-enforced agreements.

To determine the mean concentration of solvent VOCs, all headspace-gas data and solidified waste data for a waste stream or waste stream lot (i.e., the portion of the waste stream that is characterized as a unit) will be used, including data qualified with a 'J' flag (i.e., less than the PRQL but greater than the method detection limit [MDL]) or qualified with a 'U' flag (i.e., undetected). For data qualified with a 'U' flag, sites must use one-half the MDL in calculating the mean concentration. Because listed wastes are not defined based on concentration, sites may not remove hazardous waste codes assigned using acceptable knowledge if hazardous constituents are not detected in the headspace.

In many cases, TRU headspace gases and solidified waste matrices contain one or two constituents (e.g., carbon tetrachloride and 1,1,1-trichloroethane) at concentrations that are orders of magnitude higher than the other target analytes. In these cases, samples must be diluted to remain within the instrument calibration range. Sample dilution results in elevated MDLs. Only the concentrations of detected constituents will be used to calculate the mean for the purpose of assigning F-listed hazardous waste codes. Because the presence or absence of F-listed solvents can not be confirmed based on the artificially high MDLs that are caused by sample dilution, data flagged as 'U' and showing an elevated MDL will not be used in calculating the mean concentration.

Acceptable knowledge documentation provides primarily qualitative information that cannot be assessed according to specific data quality goals that are used for analytical techniques. Quality assurance objectives for analytical results are described in terms of precision, accuracy, completeness, comparability, and representativeness. Analytical results will be used to confirm the characterization of wastes based on acceptable knowledge (Section C9-4).

The data quality objectives for sampling and analysis techniques are provided in Appendix C8. To ensure that the acceptable knowledge process is consistently applied, sites must comply with the following data quality requirements for acceptable knowledge documentation:

- Precision - Precision is the agreement among a set of replicate measurements without assumption of the knowledge of a true value. The qualitative determinations, such as compiling and assessing acceptable knowledge documentation, do not lend themselves to statistical evaluations of precision.

- Accuracy - Accuracy is the degree of agreement between an observed sample result and the true value. The percentage of waste containers which require reassignment to a new waste matrix code and/or designation of different hazardous waste codes based an the reevaluation of acceptable knowledge and sampling and analysis data will be reported as a measure of acceptable knowledge accuracy.

- Completeness - Completeness is an assessment of the number of waste streams or number of samples collected to the number of samples determined to be useable through the data validation process. The acceptable knowledge record must contain 100 percent of the required information (Section C9-3). The useability of the acceptable knowledge information will be assessed for completeness during audits.

- Comparability - Data are considered comparable when one set of data can be compared to another set of data. Comparability is ensured through sites meeting the training requirements and complying with the minimum standards outlined for procedures that are used to implement the acceptable knowledge process. All sites must assign hazardous waste codes in accordance with Section C9-4 and provide this information regarding its waste to other sites who store or generate a similar waste stream.

- Representativeness - Representativeness expresses the degree to which sample data accurately and precisely represent characteristics of a population. Representativeness is a qualitative parameter that will be satisfied by ensuring that the process of obtaining, evaluating, and documenting acceptable knowledge information is performed in accordance with the minimum standards established in Section C9-4. Sites also must assess and document the limitations of the acceptable knowledge information used to assign hazardous waste codes (e.g., *purpose and scope of information, date of publication, type and extent to which* waste parameters are addressed and limitations of information in identifying hazardous wastes).

Each site must address quality control by tracking its performance with regard to the use of acceptable knowledge by: 1) assessing the frequency of inconsistencies among information, and 2) documenting the results of acceptable knowledge confirmation through radiography, headspace-gas analyses, and solidified waste analyses. In addition, the acceptable knowledge process and waste stream documentation must be evaluated through internal assessments by quality assurance organizations and assessments by auditors external to the organization (i.e., DOE/Carlsbad Area Office (CAO).

DOE Site Audits of Acceptable Knowledge

The DOE/CAO will conduct an initial audit of each generator/storage site prior to certifying the site for shipment of TRU waste to the WIPP facility. This initial audit will establish an approved baseline that will be reassessed annually. The QAPP/RCRA portion of these audits will verify compliance with the requirements specified in the WAP and QAPP. The QAPP/RCRA audits will be used to ensure the consistent compilation, application, and interpretation of acceptable knowledge information throughout the DOE complex and to evaluate the completeness and defensibility of site-specific acceptable knowledge documentation related to hazardous waste determinations. Appendix C11 gives a description of the overall audit program and a sample checklist. Figure C9-3 includes the primary steps associated with the audit process of acceptable knowledge.

Audit plans will identify the scope of the audit, requirements to be assessed, participating personnel, activities to be audited, organizations to be notified, applicable documents, and schedule. Audits will be performed in accordance with written procedures and checklists. The audit checklists will include specific items associated with the compilation and evaluation of the required acceptable knowledge information.

Audit checklists must include all of the following elements for review during the audit:

- Documentation of the process used to compile, evaluate, and record acceptable knowledge is available and implemented;
- Personnel qualifications and training are documented;
- All of the required acceptable knowledge documentation specified in Section C9-3 has been compiled in an auditable record;
- A procedure exists for assigning hazardous waste codes to waste streams in accordance with Section C9-4;
- A procedure exists for resolving inconsistencies in acceptable knowledge documentation in accordance with Section C9-4;
- A procedure exists for confirming acceptable knowledge information through: a) radiography or visual examination, b)headspace gas sampling and analysis, and c) solidified waste sampling in accordance with Section C9-4; and
- Results of other audits of the TRU waste characterization programs at the site are available in site records.

Members of the audit team will be knowledgeable regarding the required acceptable knowledge information, RCRA regulations and EPA guidance regarding the use of acceptable knowledge for waste characterization, RCRA hazardous waste determinations, and the WAP and QAPP requirements. Audit team members will be independent of all TRU waste management operations at the site being audited.

Auditors will evaluate all documents associated with the evaluation of the acceptable knowledge documentation for at least one debris waste stream and one solidified waste stream during the audit. For these waste streams, auditors will review all procedures and associated processes developed by the site for documenting the process of compiling acceptable knowledge documentation; correlating information to specific waste inventories; assigning hazardous waste codes; and identifying, resolving, and documenting discrepancies in acceptable knowledge records. The adequacy of acceptable knowledge procedures and processes will be assessed and any deficiencies in procedures documented in the audit report.

Auditors will review the acceptable knowledge documentation for selected waste streams for logic, completeness, and defensibility. The criteria that will be used by auditors to evaluate the logic and defensibility of the acceptable knowledge documentation include completeness and traceability of the information, consistency of application of information, clarity of presentation, degree of compliance with Appendix C9 of the WAP with regard to acceptable knowledge confirmation data, nonconformance procedures, and oversight procedures. Auditors will evaluate compliance with written site procedures for developing the acceptable knowledge record. A completeness review will evaluate the availability of the minimum required TRU waste management and TRU waste stream information (Section C9-3). Records will be reviewed for correlation to specific waste streams and the basis for making hazardous waste determinations. Auditors will verify that sites include all required information and conservatively include all potential hazardous waste codes indicated by the acceptable knowledge records. All deficiencies in the acceptable knowledge documentation will be included in the audit report.

Auditors will verify and document that sites use administrative controls and follow written procedures to make hazardous waste determinations for newly-generated and retrievably stored wastes. Auditors will review procedures used by the sites to confirm acceptable knowledge information using radiography or visual examination and headspace gas sampling and analysis and solidified waste sampling and analysis. Procedures to document changes in acceptable knowledge documentation and hazardous waste code assignments to specific waste streams also will be evaluated for compliance with the WAP.

After the audit is complete, the DOE/CAO will provide the site with preliminary results at a close-out meeting. The DOE/CAO will prepare a final audit report that includes all observations and findings identified during the audit. Sites must respond to all audit findings and identify corrective actions. Audit results will be available at DOE/CAO for review by regulatory agencies, and copies will be provided upon request. If acceptable knowledge procedures do not exist, the minimum required information is not available, or findings of noncompliance are identified associated with hazardous waste determinations, the DOE/CAO will not grant the site waste characterization and certification authority for the subject waste. Waste stream characterization and certification authority may be revoked or suspended if findings during subsequent annual audits indicate a lack of compliance with approved acceptable knowledge procedures. Waste characterization and certification authority will not be reinstated until the site demonstrates all corrective actions have been implemented and the program is reassessed by the DOE/CAO.

The National TRU Program disseminates information regarding TRU waste characterization requirements and program status through the TRU Waste Characterization Interface Working Group. Sites use the CAO electronic bulletin board to disseminate information to other generator sites regarding TRU waste streams, RCRA compliance, and operational and programmatic

issues, methods development, and waste characterization information, including the application of acceptable knowledge. WIPP personnel are provided the required waste characterization information prior to waste acceptance at WIPP and also will conduct audits at least annually. WIPP will maintain an operating record for review during regulatory agency audits. Regulatory agencies may also review information during generator site audits. The NMED will be notified regarding any site's failure to implement corrective actions associated with hazardous waste determinations.

C9-5 Confirmation of Acceptable Knowledge

Prior to notifying a site that a waste stream can be shipped and accepted at the WIPP facility, the DOE/CAO will review the Waste Stream Profile Forms and associated data packages to ensure that radiography, and headspace-gas data confirm hazardous waste determinations made using acceptable knowledge. Sites must provide all of the required data associated with waste stream characterization, including radiography or visual examination results, headspace gas sampling and analysis, and solidified waste sampling and analysis. In addition, sites will designate the assigned hazardous waste codes for the waste stream on the waste profile form. The data packages will be evaluated as illustrated in Figure C9-2 and compared to the hazardous waste codes specified on the waste profile form. The DOE/CAO will review information provided by the sites to ensure that changes to hazardous waste codes are identified and justified based on data and that hazardous waste codes are included in the Part A of the WIPP permit application. As part of the reconciliation of DQOs (Appendix C8, Section C8-11), sites are required to track and report changes to hazardous waste determinations. If data consistently indicates discrepancies with acceptable knowledge information, the DOE/CAO will require sites to increase sampling, reassess the materials and processes that generate the waste, and resubmit waste stream profile information. Until discrepancies are resolved, shipment of the waste stream to the WIPP will be prohibited. Consistent nonconformances by a site in implementing and documenting WAP and QAPP requirements will result in the termination of a site's waste characterization and waste certification authority.

Any drum with unresolved discrepancies associated with hazardous waste determinations will not be shipped to the WIPP facility until the discrepancies are resolved. Sites must reassess the materials and processes that generate the waste, including headspace-gas sampling and analysis, radiography or visual examination, and solidified waste sampling and analysis. All shipments of the subject waste stream will cease until the corrective action(s), as necessary, have been implemented and the discrepancy resolved. The DOE/CAO will notify the New Mexico Environment Department (NMED) when the certification status of a waste stream at a site is revoked. If the site does not comply with the corrective actions associated with the hazardous waste determination, which are specified during the nonconformance process, the DOE/CAO will notify the NMED prior to accepting the subject waste at the WIPP facility.

C9-6 Summary

Acceptable knowledge is used in conjunction with other waste characterization techniques to delineate waste streams, identify listed wastes from nonspecific and specific sources in accordance with 40 CFR §261.31, and determine the toxicity characteristics associated with TRU debris wastes. Acceptable knowledge is a key component in properly making hazardous waste determinations under RCRA. The physical form and the associated increased health and safety

risks associated with obtaining a representative sample of TRU debris wastes, clearly justify the use of acceptable knowledge to make hazardous waste determinations. Acceptable knowledge information is confirmed using nondestructive techniques and sampling and analysis.

The proper assignment of listed hazardous waste codes relies on knowledge of the materials and processes that generated the waste and not on the concentration of constituents. Nuclear weapons production resulted in a variety of wastes contaminated with spent solvents used for cleaning and degreasing (i.e., hazardous waste codes F001-F005). Acceptable knowledge documentation must be used to identify these TRU wastes.

To ensure consistency in the use and interpretation of acceptable knowledge information, sites must compile the minimum required information (Section C9-3) in an auditable record. Sites must develop and implement written procedures that describe the compilation, use, and confirmation of acceptable knowledge. In addition, sites must demonstrate through compliance with written procedures that discrepancies in information will be documented and that hazardous waste codes will be conservatively applied.

The DOE/CAO will audit DOE sites to initially grant TRU waste certification authority to each site. The DOE/CAO will conduct audits at least annually thereafter to verify compliance with approved plans and procedures. Sites will implement corrective action plans that address all audit findings. Waste stream characterization and certification authority will be revoked if trends of consistent noncompliance with the WAP and QAPP are identified by the DOE/CAO at a site.

The DOE/CAO will review waste stream profile forms and associated data packages to ensure that radiography and headspace gas data confirm acceptable knowledge and that the correct hazardous waste codes have been assigned to each waste stream. If complete and adequate information is not provided by the generator regarding the hazardous waste determinations, then the waste will not be authorized for shipment to and disposal at the WIPP facility.

FIGURES

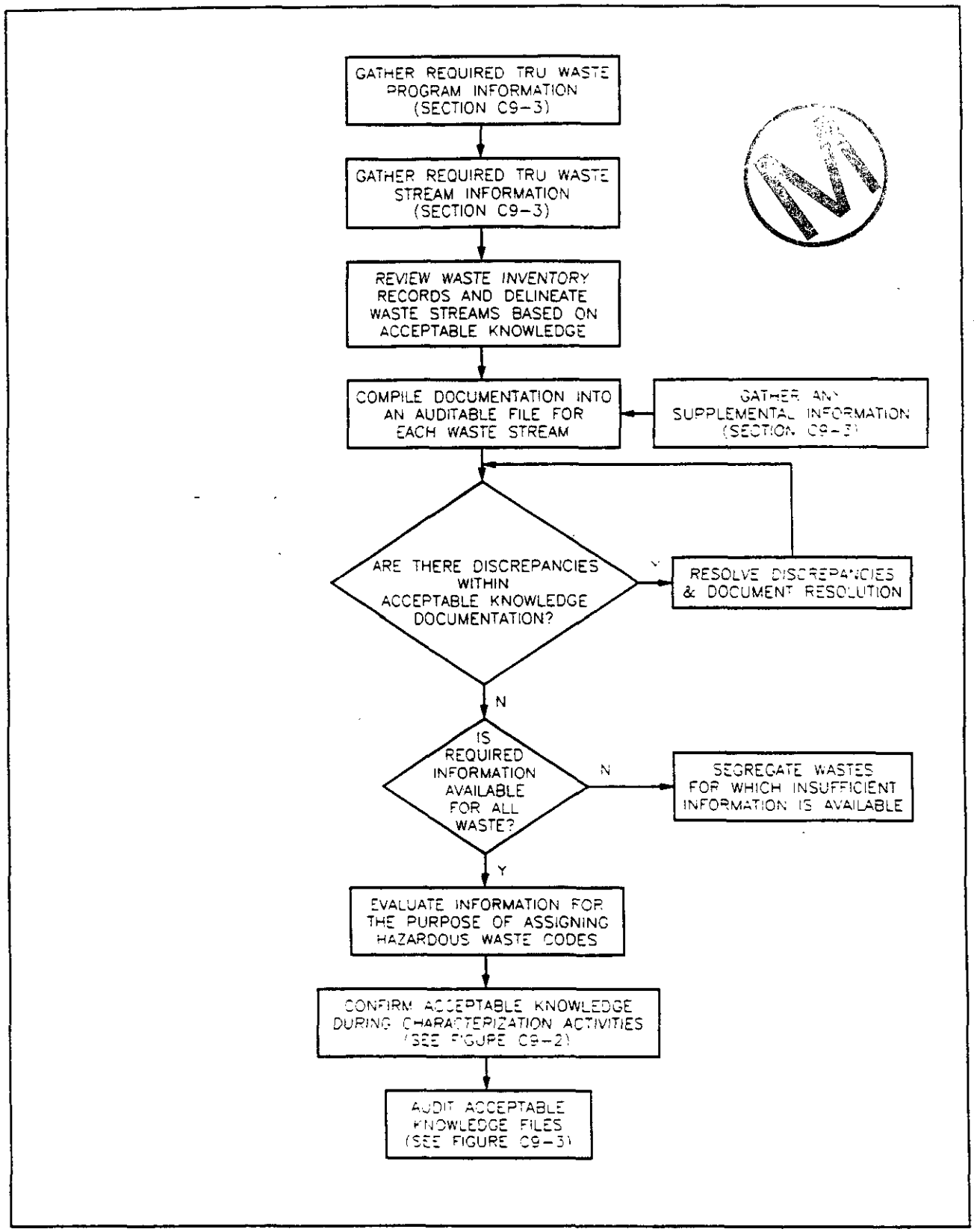

Figure C9-1
Compilation of Acceptable Knowledge Documentation

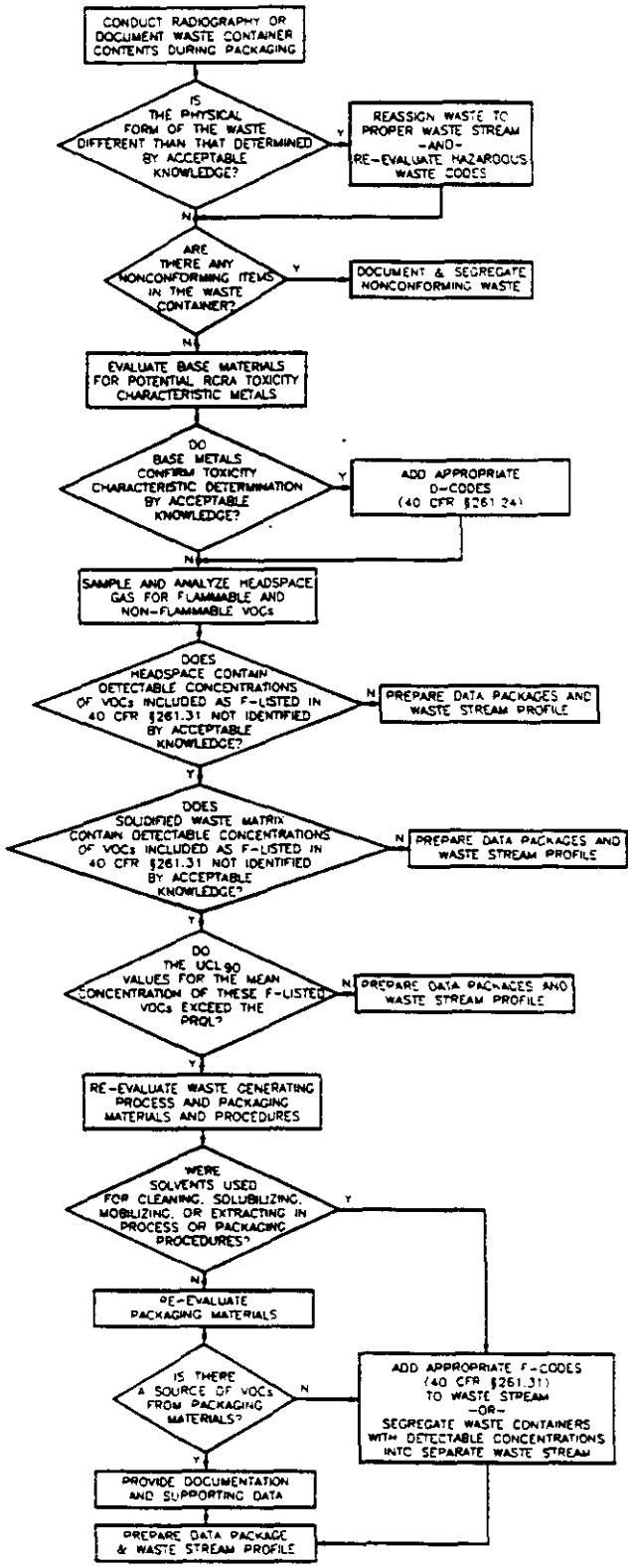

Figure C9-2
Confirmation of Acceptable Knowledge

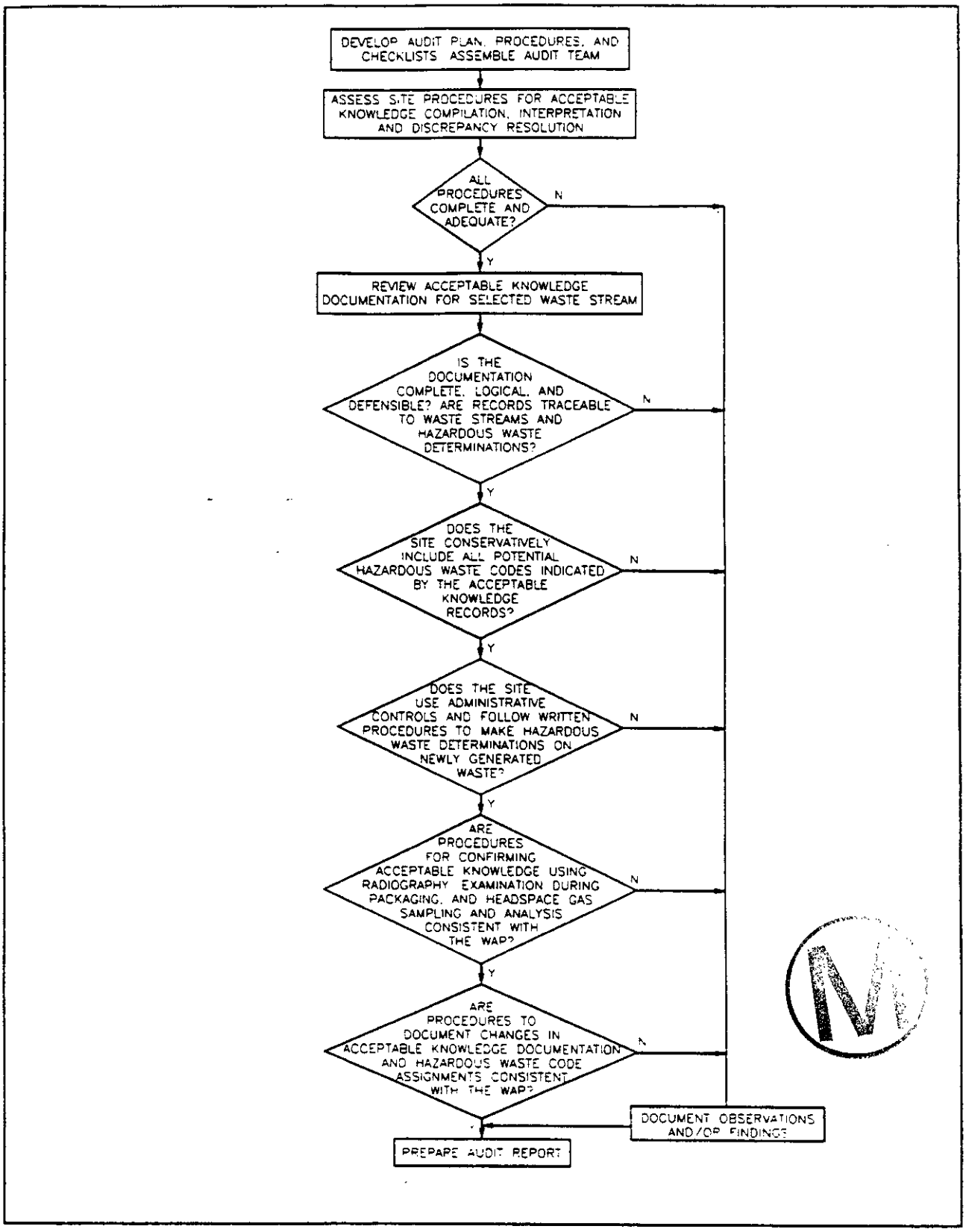

Figure C9-3
Acceptable Knowledge Auditing

APPENDIX C10
QUALITY ASSURANCE PROJECT PLAN REQUIREMENTS

APPENDIX C10
QUALITY ASSURANCE PROJECT PLAN REQUIREMENTS

C10-1 Quality Assurance Project Plans

Each participating site shall develop and implement a quality assurance project plan (QAPjP) that addresses all the requirements specified in Waste Isolation Pilot Plant waste analysis plan and implemented in the Transuranic Waste Characterization Quality Assurance Program Plan (QAPP)(CAO-94-1010, April 30, 1995). These QAPjPs shall include or reference the appropriate management and technical criteria of the quality assurance program, as well as qualitative or quantitative criteria for determining that waste characterization program activities are being satisfactorily performed. QAPjPs shall identify the organization(s) and position(s) responsible for their implementation. The QAPjPs shall also reference site-specific documentation that details how each of the required elements of the characterization program will be performed.

Prior to the implementation of characterization activities at participating sites, standard operating procedures (SOP) will be developed for all activities affecting waste characterization program quality that require written instructions or procedures. For the purposes of the quality assurance program, the term SOP refers to any site-specific implementing document. Compliance with SOPs will ensure that tasks are performed in a consistent manner that results in achieving the quality required for the quality assurance program. The organization, format, content, and designation of SOPs must be described in the QAPjPs. Site-specific SOPs will be reviewed for consistency with the QAPjP during the Generator/Storage Site Waste Screening and Acceptance Audit Program.

C10-2 Document Review, Approval, and Control

The preparation, issue, and change to documents that specify quality requirements or prescribe activities affecting quality for the transuranic waste characterization program shall be controlled to assure that correct and current documents are used and referenced. The QAPjPs shall include the document control format implemented by the QAPP consisting of a unique document identification number in the upper left-hand corner of each page, and the section number, current revision number, date, and page number placed in the upper right-hand corner of each page. All quality documents for the waste characterization program shall be reviewed prior to approval and issuance by qualified and independent individuals. This review shall consider, as appropriate, the technical adequacy, completeness, and correctness of the documents and the inclusion of appropriate quality requirements. Approval shall be indicated by a signature and date page included in the front of each document. Table C10-1 shows the parties responsible for document review, review/approval, implementation, change approval, and change control. Whenever the quality assurance (QA) documents are revised, review and approval of the revision shall be conducted by the same level of approval authority and in accordance with the requirements of review as the original documents.

At a minimum, revisions to QA documents shall be denoted by including the current revision number on the document title page, the revised signature page, and each page that has been revised. Only revised pages need to be reissued. A vertical bar, indicating the change to the

text, shall be included along the left-hand margin of the page. Revised document submittals shall also identify the changes, the reason for the changes, and the justification for concluding that the revised contents continue to satisfy the requirements of the quality assurance program.

The QAPP shall be controlled by the U.S. Department of Energy Carlsbad Area Office National Transuranic Program (NTP) team leader and distributed by this position to the applicable DOE field offices. A distribution list for the QAPP shall be used to control the issuance of revisions and shall be maintained by the NTP team leader.

The QAPP shall be initially reviewed, approved, and concurred with by those positions indicated in Table C10-1, and thereafter reviewed by the NTP team leader at least annually to ensure it addresses the current needs of the waste characterization quality assurance program. If changes to the QAPP are required, the NTP team leader shall be responsible for scheduling and coordinating the review and approval of the revised document. Changes shall be reported by the NTP team leader to the DOE field office managers for notification to the sites. Each site project manager shall be responsible for the revision of the QAPjP and SOPs in accordance with the approved changes to the QAPP.

Each site must have a document control system to control the review and approval of controlled documents. The NTP team leader, the applicable DOE field office, the site project manager, and the site project QA officer are responsible for the initial review and approval of the QAPjPs. Thereafter, the QAPjPs shall be reviewed at least annually by the site project manager. If changes to the QAPjP are required, the site project manager shall be responsible for scheduling and coordinating the review and approval of the revised document. The QAPjPs shall include a description of the organization(s) or person(s) responsible for distributing revisions to those plans.

The QAPjPs shall include a detailed description of the reporting and approval requirements for changes to approved QA documents and SOPs, including procedures for implementing changes to these documents. All members of the site project staff are responsible for reporting any obsolete or superseded information to the site project manager. All site-specific changes shall be evaluated and approved by the site project manager and the site project QA officer before implementation. The site project manager shall notify the appropriate personnel and the affected documents shall be revised as necessary. The site project manager shall also be responsible for notifying the DOE field office of the changes. No changes that affect performance criteria or data quality; such as sample handling and custody requirements, sampling, and analytical procedures, quality assurance objectives, calibration requirements, or QC sample acceptance criteria; shall be made without prior approval of the DOE field office and the NTP team leader. However, minor changes to QAPjPs and SOPs that do not affect the transuranic waste characterization quality assurance program performance criteria or data quality may be made without prior notification of the DOE field office and the NTP team leader.

TABLE C10-1
REQUIREMENTS FOR REVIEW, APPROVAL, IMPLEMENTATION, AND CONTROL OF THE QAPP AND QAPjPs

	Responsible Party							
	Deputy Assistant Secretary, EM-30	Manager, CAO	Manager, Office of Regulatory Compliance	Manager, CAO Quality Assurance	Team Leader, National TRU Program	DOE Field Office	Site Project Manager	Site Project QA Officer
QAPP								
Review	X							
Review/Concurrence			X	X	X			
Review/Approval		X						
Implementation					X			
Change Approval		X	X	X	X			
Change Control					X			
QAPjPs								
Review/Approval				X	X	X	X	X
Implementation							X	
Change Approval				X		X	X	X
Change Control							X	

APPENDIX C11

WASTE ISOLATION PILOT PLANT GENERATOR/STORAGE SITE WASTE SCREENING AND ACCEPTANCE AUDIT PROGRAM

APPENDIX C11
WASTE ISOLATION PILOT PLANT GENERATOR/STORAGE SITE WASTE SCREENING AND ACCEPTANCE AUDIT PROGRAM

The Waste Isolation Pilot Plant (WIPP) Generator Site Waste Screening and Acceptance Audit Program ensures that: 1) the operators of generator/storage sites that plan to transport transuranic (TRU) mixed waste to the WIPP facility conduct sampling and analysis of wastes in accordance with the current WIPP Waste Analysis Plan (WAP), and 2) the information supplied by each generator/storage site to satisfy the waste screening and acceptability requirements of Section C-5 of the WAP is being managed properly. WIPP (meaning both the U.S. Department of Energy Carlsbad Area Office [DOE/CAO] and Westinghouse Waste Isolation Division [WID] personnel) will conduct these audits at the generator sites in accordance with a standard operating procedure. This procedure will contain steps for selecting audit personnel, reviewing applicable background information, preparing an audit plan, preparing audit checklists, conducting the audit, developing an audit report, and following up audit deficiencies. The checklists used in the audit are tailored for each site to be audited, based on the approved site quality assurance project plan (QAPjP), which is the site-specific implementation of the Transuranic Waste Characterization Quality Assurance Program Plan (QAPP).

Audit procedures incorporate the applicable requirements (e.g., auditor and technical specialist qualifications, lead auditor certification) of 10 Code of Federal Regulations 830.120 (Quality Assurance), and the American Society of Mechanical Engineers NQA-1, part 2.7 of NQA-2, NQA-3, and incorporate requirements of DOE Order 5700.6C (Quality Assurance). It further establishes the responsibilities and methodology for planning, scheduling, performing, reporting, verifying, and closing announced and unannounced audits of TRU mixed waste generator and storage sites. Records of all audit activities are part of the WIPP Operating Record and will be maintained at the WIPP facility until closure.

Approved procedures are used to describe audit activities and requirements. Procedures define the responsibilities of specific positions necessary to manage this audit program. The manager who oversees this program must perform the following:

- Schedule audits, including initial audits prior to approval of waste stream profile forms
- Designate lead auditor(s)
- Appoint auditor and lead auditor trainees
- Maintain auditor training and qualification records
- Assure that all auditors have been given appropriate training, including training on the WAP
- Assign auditors and lead auditors to perform annual certification audits

- Review and approve final audit reports
- Track and close all deficiencies and any observations requiring action
- Assure records are entered into the WIPP Operating Record and are properly maintained until facility closure

The DOE will approve lead auditors, auditors, and technical specialists based upon the expertise required for the functions being examined according to the audit scope, including personnel available from WID. The WID will supply auditors/technical specialists with expertise in the Resource Conservation and Recovery Act (RCRA) requirements and knowledge of the analysis and documentation methods required to verify the hazardous determinations made by the generator sites.

Lead auditors must meet the established experience and education requirements and pass a qualification exam. The lead auditor who is assigned to be the audit team leader must perform the following tasks:

- Concur that assigned auditors and technical specialists have the collective experience and training commensurate with the scope, complexity, or special nature of the activities to be audited
- Develop an audit plan and coordinate the preparation of an overall checklist to cover the scope of the audit, with consideration given to previous audit results from that site
- Assign specific audit areas to individual auditors and technical specialists within their particular specialty and provide guidance on checklist development
- Review individual auditor checklists to assure complete coverage of assigned scope, and approve the checklists
- Conduct the audit at the generator site, with entrance meetings, daily team meetings, daily management update, and exit meetings, ensuring that the site is kept fully apprised of the audit progress and results
- Encourage observers to participate according to the protocol established by the DOE/CAO
- Communicate audit results at the conclusion of the audit, including any deficiencies and observations
- Prepare and sign the audit report
- Maintain complete records of each audit and transfer them to the manager when the audit report is issued

Auditors and technical specialists assigned to the specific audit will report to the audit team leader for supervision and perform the following tasks:

- Attend any required specific training and team orientation and planning meetings as directed by the audit team leader.
- Prepare specific audit checklists to verify that the QAPP Quality Assurance Objectives (QAO) are met for the areas being audited.
- Obtain audit team leader approval of checklist.
- Review acceptable knowledge documentation packages, test report data, and documentation of data verification activities.
- Obtain and evaluate objective evidence by means of observation, document reviews, or the conduct of interviews with operators, analysts, technicians, and others necessary to determine the adequacy and effective implementation of the QAPP programs and this WAP.
- Conduct inspection tours of waste generating stations, analytical laboratories, calibration facilities, administrative, and document control/record facility.
- Complete checklist during the audit indicating the objective evidence observed verifies that the generator site has met the QAOs for the program elements, methods, and the activities being audited. Add other items to the checklist as they are observed or as needed during the audit.
- Prepare narrative statements for all deficiencies, and observations that clearly and concisely identify the conditions involved.
- Prepare any portion of the final audit report assigned by the lead auditor.

Audits will be conducted at least annually for each generator site involved in the waste characterization program. Both announced and unannounced audits address the following:

- Results of previous audits
- Changes in programs or operations
- New programs or activities being implemented
- Changes in key personnel

The conduct of the audit commences with an entrance meeting, conducted by the audit team leader, with site or facility management. At this meeting, the audit objectives and scope, the specific areas to be audited, the processes or functions to be observed, and the site-participation required, including site interfaces, will be identified. The purpose of this meeting is to confirm

the audit scope, discuss the audit sequence, establish channels of communication, and confirm the daily and exit meeting. The audit is performed using the approved audit checklist. Audit checklists are tailored for each site to provide an assessment of the specific activities at that generator site. Consistency of evaluation is ensured before the audit through the generator site QAPjP approval. The QAPjPs for the generator sites must incorporate the same requirements from the QAPP. Objective evidence is examined (to the depth necessary) to determine if the identified activities, procedures, or QAOs are adequate and are being effectively implemented.

Audit conduct is accomplished through site personnel interviews, document and record reviews, observations of operations, and any other activities deemed necessary by the auditors to meet the objectives of the audit. Observations or deficiencies identified during the audit will be investigated or evaluated, as necessary, to determine if they are isolated conditions or represent a general breakdown of the waste characterization quality assurance program. During audit interviews or during the daily management meetings, site personnel will be advised of deficiencies identified within their areas of responsibility to establish a clear understanding of the identified condition.

The site personnel will be given the opportunity to correct any condition that can be corrected during the audit period. Deficiencies and observations will be documented and included as part of the final audit report. Those items that can be resolved during the audit (isolated conditions that do not require a root cause determination or actions to preclude recurrence), will be verified prior to the end of the audit, and so noted in the audit report. Those items that affect the quality of the program, and/or the data generated by that program, will be documented on a Corrective Action Report (CAR) and included as a part of the audit report. The CAR will be entered into the DOE/CAO CAR tracking system and tracked until closure. Also, WID will track RCRA-related items on the systematic tracking and action reporting system.

When a deficiency is identified by the audit team, the condition is documented on a CAR by the audit team leader. The DOE/CAO Quality Assurance (QA) Manager and the National Transuranic Program (NTP) Team Leader review the CAR, determine validity (assures that a requirement has really been violated), classify the significance of the condition, assign a response due date, and issue the CAR to the generator site. The generator site reviews the CAR, evaluates the extent and cause of the deficiency, and provides a response to the WIPP indicating the remedial actions and actions taken to preclude recurrence. The WIPP reviews the response from the generator site and, if acceptable, communicates the acceptance to the generator site. The generator site completes remedial actions and actions to preclude recurrence. After all corrective actions have been completed, the WIPP schedules and performs a verification visit to assure that corrective actions have been completed and are effective. When all actions have been completed and verified as being effective, the CAR is closed by the DOE/CAO QA Manager and the NTP Team Leader. As part of the planning process for subsequent audits and surveillances, past deficiencies are reviewed and the previous deficient activity or process is subject to reassessment.

The generator site management will be required to submit a corrective action plan to eliminate the adverse condition stated on the CAR including a resolution of the acceptability of any data generated prior to the resolution of the corrective action.

The corrective action response will include a discussion of the investigation performed to determine the extent and impact of the deficiency, a description of the remedial actions taken, determination of root cause, and actions to preclude recurrence.

An exit meeting will be conducted by the lead auditor prior to departure of the audit team from the site. This meeting will be with site management personnel, including DOE personnel. All draft audit results will be presented to the generator site management.

The formal audit report will be prepared, approved, and issued to the site within 30 days of the completion of the audit by the WIPP facility. The report will include, as a minimum, sections describing the scope, purpose, summary of deficiencies, and observations in narrative format, as well as an identification of the organization audited, the dates of the audit, and the requested response date. The audited site will respond to any deficiencies and observations within 30 days after receipt of any CARs and indicate the corrective action taken or to be taken. If the corrective action has not been completed, the response must indicate the expected date the action will be completed. Subsequent audits or specific verifications, announced or unannounced, will determine if the corrective action has been satisfactorily implemented. Deficiencies, observations, and CARs will be tracked to completion according to established procedure(s). In addition, all audit items will be trended to determine if similar situations exist system wide. Trend reports will be issued as necessary to provide a "lessons learned" announcement to other generator sites who might benefit from program improvements implemented as a result of resolutions to the specific situations discovered at the performance of these audits.

If a generator/storage site fails to implement a corrective action that directly affects the waste characterization activities at the site, the site will have their certification authority suspended and waste shipments to the WIPP will be suspended until the corrective action is completed.

The audit records will be maintained at WIPP as a part of the Operating Record. These records will be included on the Record Inventory and Disposition Schedule and maintained on-site until closure of the WIPP facility.

TABLE C11-1
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
Quality Assurance Objectives			
A. Radiography			
Does documentation exist to verify the performance of the radiography analyses?			
Does documentation exist to verify the use of specific training drums?			
Does documentation exist to verify independent replicate scans by another qualified operator for each batch of containers scanned?			
Does documentation exist to require the use of test screens for routine equipment checks?			
Are radiography operator qualifications current?			
Has radiography been conducted on all retrievably stored drums planned for disposal at the Waste Isolation Pilot Plant (WIPP) facility?			
Have periodic audio/video tape reviews been performed?			
Have corrective actions, if needed, been implemented per the QAPP?			

_____ _____ _____ _____
Auditor Date Lead Auditor Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
B. Drum-Headspace Sampling			
Does documentation exist to verify the precision and accuracy of drum-headspace sampling and analysis?			
Have field duplicates been collected for drum-headspace sampling?			
Does the precision of field duplicate analyses meet the quality assurance objective (QAO) specified in the Quality Assurance Program Plan (QAPP)?			
Have field reference standards been collected for drum-headspace sampling?			
Does the accuracy of field reference standards meet the QAO specified in the QAPP?			
Have measures listed in the QAPP been taken to ensure that drum-headspace samples are representative?			
Have corrective actions, if needed, been implemented per the QAPP?			

_____ _____ _____ _____
Auditor Date Lead Auditor Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
C. Homogeneous Solids and Soils/Gravel Sampling			
Does documentation exist to verify precision and accuracy of homogeneous solids and soils/gravel sampling?			
Have co-located cores been collected for each sampling batch?			
Does the precision of the co-located cores analyses meet the QAO?			
Have measures listed in the QAPP been taken to ensure that homogeneous solids and soils/gravel samples are representative?			
Have corrective actions, if needed, been implemented per the QAPP?			

_____ _____ _____ _____
Auditor Date Lead Auditor Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
D. Visual Examination			
Does documentation exist to verify the precision and accuracy of the visual examination analyses?			
Are visual examination operator qualifications current?			
Has visual examination been conducted on the required sample of drums planned for disposal at and currently awaiting shipment to the WIPP facility?			
Does documentation exist to confirm that visual examination has been performed on a statistical portion of waste containers?			
Does documentation exist to indicate that the QA Officer has determined the Relative Percent Difference of radiography visual examination?			
Have corrective actions, if needed, been implemented per the QAPP?			

_____ Auditor _____ Date

_____ Lead Auditor _____ Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
E. Gas and Volatile Organic Compound Analyses			
Does documentation exist to verify the precision and accuracy of headspace analyses?			
Have duplicate or replicate measurements been conducted for headspace analyses?			
Does the precision of duplicate or replicate analyses meet the quality assurance objective specified in the QAPP?			
Does the accuracy of U.S. Environmental Protection Agency blind samples and laboratory control standards meet the quality assurance objectives specified in the QAPP?			
Does the instrument meet the method detection limits specified in the QAPP?			
Have corrective actions, if needed, been implemented per the QAPP?			

_____ Auditor _____ Date

_____ Lead Auditor _____ Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
F. Totals Analyses			
Does documentation exist to verify the precision and accuracy of totals analyses?			
Have duplicate and replicate measurements been conducted for totals analyses?			
Does the precision and duplicate or replicate analyses meet the quality assurance objective specified in the QAPP?			
Does the accuracy of the U.S. Environmental Protection Agency blind samples and laboratory control standards meet the quality assurance objectives specified in the QAPP?			
Do the instruments meet the method detection limits specified in the QAPP?			
Have corrective actions, if needed, been implemented per the QAPP?			

_____ Auditor _____ Date _____ Lead Auditor _____ Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
Acceptable Knowledge			
A. Acceptable Knowledge Record Is the acceptance knowledge documentation assembled into an *auditable record?* Have resolutions between document discrepancies been documented? Are the required documents included in the acceptable knowledge *record?* Does the acceptable knowledge documentation support the waste stream hazardous waste code assignment? *Is the logic behind the assignment of the hazardous waste codes* documented and kept as part of the acceptable knowledge record? Are results of other audits of the TRU Waste Characterization Programs at the site available in site records?			
B. Verification Has the acceptable knowledge been verified? Have discrepancies and resolutions been documented?			

_____ Auditor _____ Date _____ Lead Auditor _____ Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
C. Acceptable Knowledge Procedures Does a procedure exist for assigning hazardous waste codes to waste streams in accordance with the WAP? Does a procedure exist for resolving inconsistencies in acceptable knowledge documentation in accordance with the WAP? Does a procedure exist for confirming acceptable knowledge information through a) radiography or visual examination, b) headspace gas sampling and analysis, and c) solidified waste sampling in accordance with the WAP?			
D. Acceptable Knowledge Training Are the people using acceptable knowledge to make hazardous waste determinations trained per the requirements in the WAP? Are personnel qualifications and training documented? Does the acceptable knowledge training program contain the elements outlined in the WAP?			

_____ Auditor _____ Date

_____ Lead Auditor _____ Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
Sample Custody			
A. Waste Containers (Drums) Have Chain of Custody (COC) Forms been completed and maintained (per the QAPP) for waste containers, from the time they are removed from inventory until their contents are placed in a shipping container?			
B. *Samples* Have COC Forms been completed and maintained (per the QAPP) for samples?			
Calibration			
A. Radiography Has radiography equipment been qualified to meet the performance criteria specified in the site Quality Assurance Project Plan (QAPJP) and Standard Operating Procedures?			
B. Headspace Sampling Have the headspace sampling equipment and instrumentation been calibrated per the requirements of the QAPP?			

_____ Auditor _____ Date

_____ Lead Auditor _____ Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
C. Visual Examination Has the weighing system used during the visual examination process been calibrated per the requirements of the QAPP?			
D. Determination of Headspace Gases Have the instruments used for the analysis of headspace gases been calibrated per the requirements of the QAPP?			
E. Determination of Headspace Organic Gases Have the instruments used for the analysis of headspace organic gases been calibrated per the requirements of the QAPP?			
F. Determination of Total Metals Have the instruments used for total metals analysis been calibrated per the requirements of the QAPP?			
G. Determination of Total VOCs Have the instruments used for total VOCs analysis been calibrated per the requirements of the QAPP?			

_____ _____ _____ _____
Auditor Date Lead Auditor Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
H. Determination of Total SVOCs *Have the instruments used for total SVOCs analysis been calibrated* per the requirements of the QAPP?			
Data Reduction, Validation, and Reporting			
A. Data Reduction Is data reduction being conducted at the data generation level per the requirements of the QAPP? Is data reduction being conducted at the project level per the requirements of the QAPP?			
B. Data Validation Is data validation being conducted at the data generation level per the requirements of the QAPP? Is data validation being conducted at the project level per the requirements of the QAPP?			

_____ Auditor _____ Date _____ Lead Auditor _____ Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
C. Data Reporting Is data reporting being conducted at the data generation level per the requirements of the QAPP? Is data reporting being conducted at the project level per the requirements of the QAPP?			
Other Quality Control Checks			
A. Radiography Are radiography QC checks (e.g., replicate radiography examinations by a different qualified operator) conducted per the requirements and at the frequency specified in the QAPP?			
B. Drum Headspace Sampling Are field blanks, sampling equipment blanks, field-reference standards, and field sample duplicates taken per the requirements and at the frequency specified in the QAPP?			
C. Visual Examination Are visual examination quality control (QC) checks conducted per the requirements and at the frequency specified in the QAPP?			

_____ Auditor _____ Date

_____ Lead Auditor _____ Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
D. Gas Analysis Are laboratory control standards, sampling manifold blanks, equipment blanks, laboratory blanks, and duplicates analyzed per the requirements and at the frequency specified in the QAPP?			
E. Organic Gas Analysis Are laboratory control standards, sampling manifold blanks, equipment blanks, laboratory blanks, laboratory duplicates, and internal standards analyzed per the requirements and at the frequency specified in the QAPP?			
F. Total Metals Analysis Are laboratory blanks, matrix spikes, matrix spike duplicates and laboratory control samples analyzed per the requirements and the frequency specified in the QAPP?			
G. Total VOCs Analysis Are laboratory duplicates, laboratory blanks, matrix spikes, matrix spike duplicates, laboratory control samples and surrogate compounds analyzed per the requirements and the frequency specified in the QAPP?			

_____ _____ _____ _____
Auditor Date Lead Auditor Date

TABLE C11-1 (CONTINUED)
EXAMPLE OF WIPP GENERATOR/STORAGE SITE AUDIT CHECKLIST

AUDIT NO. _____ FACILITY/SITE: _____ DATE: _____

Compliance Requirement	Compliance Document	Objective Evidence	Comments
H. Total SVOCs Analysis Are laboratory duplicates, laboratory blanks, matrix spikes, matrix spike duplicates, laboratory control samples, and surrogate compounds analyzed per the requirements and the frequency specified in the QAPP?			
Procedures			
A. Waste Generating Process Procedures Does each waste generating process procedure follow the format specified in the WAP? Does each waste generating process procedure have a section which lists the process controls and range of operation that affect final hazardous waste determinations? Does the procedure specify what actions are to be taken if the parameters do not remain within the specified range and how it is verified that the parameters stay within the given range?			

_____ Auditor _____ Date _____ Lead Auditor _____ Date

APPENDIX C12
COMPARISON OF TRANSURANIC WASTE CHARACTERIZATION PROCEDURES WITH EPA-APPROVED WASTE CHARACTERIZATION METHODS

APPENDIX C12
COMPARISON OF TRANSURANIC (TRU) WASTE CHARACTERIZATION PROCEDURES WITH EPA-APPROVED WASTE CHARACTERIZATION METHODS

The Department of Energy (DOE) sites characterize waste in accordance with this Waste Analysis Plan (WAP) and the Transuranic Waste Characterization Quality Assurance Program Plan (QAPP), which specify waste characterization procedures found in the *Transuranic Waste Characterization Sampling and Analysis Methods Manual* (Methods Manual). The Methods Manual provides a unified source of information on the testing, sampling, and analytical techniques that enable sites to comply with this WAP. The Methods Manual includes all of the testing, sampling, and analytical methodologies accepted by DOE for use in transuranic (TRU) waste characterization requirements.

Many of the analytical procedures found in the Methods Manual are based on methods found in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods,* SW-846, Third Edition, Final Update I, and Final Update II. Specifically, analytical procedures for solid phase waste in the Methods Manual are based on SW-846 methods. In these instances, the analyst is referred directly to the SW-846 method for the requirements of the procedure. Only information unique to the Program (e.g., target analytes, quality assurance objectives, quality control requirements) is included in the Methods Manual. The testing and sampling procedures included in the Methods Manual were developed specifically for characterizing TRU waste and equivalent methods are not found in SW-846.

The DOE has examined the consequence of modifying SW-846 methods for use in TRU waste characterization to ensure program specific changes do not compromise the integrity of the original SW-846 methods. This examination considered program-specific modifications (i.e., target analysis, quality assurance objectives, quality control requirements) to ensure: 1) these modifications could be met by the SW-846 method being referenced, and 2) these modifications do not compromise the integrity of the SW-846 method being referenced. DOE examined the following elements of each method:

- Scope and Application
- Summary of Procedure
- Interferences
- Safety
- Apparatus and Materials
- Reagents
- Sample Collection, Preservation, and Handling
- Procedure
- Calculations
- Quality Control
- Procedure Performance
- References

For each element, a comparison was made between the Methods Manual and the SW-846 method. Often, the Methods Manual procedure referred directly, and only, to the SW-846

method. In instances where this is not the case, the Methods Manual procedure requirements were evaluated for applicability and compliance with the requirements of the SW-846 method.

A comparison is made in Table C12-1 which indicates which Methods Manual procedures are based on SW-846 methods, and specifies the appropriate SW-846 method. Tables C12-2 through C12-16 are specific comparisons between SW-846 methods and Method Manual procedures. The "comments" column of Tables C12-2 through C12-16 includes reasoning as to why the differences in the SW-846 method and the Methods Manual procedure are non-impactive.

TABLES

TABLE C12-1
CORRELATION BETWEEN SW-846 METHODS AND METHODS MANUAL METHODS

Methods Manual Procedure	SW-846 Method
Procedure 110.1: Sampling Manifold Method to Collect Headspace Gas Samples From a TRU Waste Drum	Program specific procedure, no equivalent SW-846 method
Procedure 110.2: Direct Canister Method to Collect Headspace Gas Samples From a TRU Waste Drum	Program specific procedure, no equivalent SW-846 method
Procedure 110.3: Using a Side-Port Needle to Collect Headspace Gas Samples Through a TRU Waste Drum's Carbon Composite Filter	Program specific procedure, no equivalent SW-846 method
Procedure 110.4: Punching the Drum Lid to Collect Headspace Gas Samples from a TRU Waste Drum	Program specific procedure, no equivalent SW-846 method
Procedure 120.1: Collecting Samples from TRU Waste Drums Containing Homogenous Solids and Soil/Gravel (Sludge)	Program specific procedure, no equivalent SW-846 method
Procedure 210.1: SUMMA® Passivated Stainless Steel Canister Certification and Cleaning	Program specific procedure, no equivalent SW-846 method
Procedure 310.1: Physical Waste Form Characterization Using Radiography	Program specific procedure, no equivalent SW-846 method
Procedure 310.2: Physical Waste Form Characterization Using Visual Examination	Program specific procedure, no equivalent SW-846 method
Procedure 430.1: Modified Method TO-14 for the Gas Chromatography/Mass Spectrometry Determination of Volatile Organic Compounds in Waste Container Headspace	Program specific procedure, no equivalent SW-846 method
Procedure 430.2: Modified Method 8240/8260 for the Determination of Volatile Organic Compounds in Waste Container Headspace	Program specific procedure, no equivalent SW-846 method

TABLE C12-1 (CONTINUED)
CORRELATION BETWEEN SW-846 METHODS AND METHODS MANUAL METHODS

Methods Manual Procedure	SW-846 Method
Procedure 430.3: Method 8240B for the Determination of Total Volatile Organic Compounds in Homogenous Solids and Soil/Gravel	SW-846 Method 8240B: Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS) – See Table C12-2
Procedure 430.4: Method 8260A for the Determination of Total Volatile Organic Compounds in Homogenous Solids and Soil/Gravel	SW-846 Method 8260A: Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS): Capillary Column Technique – See Table C12-3
Procedure 430.5: Method 8250A for the Determination of Total Semi-Volatile Organic Compounds in Homogenous Solids and Soil/Gravel	SW-846 Method 8250A: Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS) – See Table C12-4
Procedure 430.6: Method 8270B for the Determination of Total Semi-Volatile Organic Compounds in Homogenous Solids and Soil/Gravel	SW-846 Method 8270B: Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS): Capillary Column Technique – See Table C12-5
Procedure 440.1: Gas Chromatography/Flame Ionization Detector Determination of Alcohols and Ketones in Waste Container Headspace	Program specific procedure, no equivalent SW-846 method
Procedure 440.2: Direct Injection Gas Chromatography/Flame Ionization Detector Determination of Nonhalogenated Volatile Organic Compounds in Homogenous Solids and Soil/Gravel	Program specific procedure, no equivalent SW-846 method
Procedure 440.3: Gas Chromatography/Electron Capture Detection Determination of PCBs in Organic Sludge	SW-846 Method 8081: Organochlorine Pesticides and PCBs as Aroclors by Gas Chromatography: Capillary Column Technique; SW-846 Method 3550: Ultrasonic Extraction; SW-846 Method 3620: Florisil Column Cleanup. These methods have been optimized for the determination of PCBs only in TRU waste – See Table C-12-6

TABLE C12-1 (CONTINUED)
CORRELATION BETWEEN SW-846 METHODS AND METHODS MANUAL METHODS

Methods Manual Procedure	SW-846 Method
Procedure 510.1: Mass Spectrometry Determination of Hydrogen and Methane in Waste Container Headspace	Program specific procedure, no equivalent SW-846 method
Procedure 520.1: Gas Chromatography Determination of Hydrogen and Methane in Waste Container Headspace	Program specific procedure, no equivalent SW-846 method
Procedure 610.1: Microwave Assisted Acid Digestion of Homogenous Solids and Soil/Gravel	SW-846 Method 3051: Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils – See Table C-12-7
Procedure 620.1: Extraction Chromatography Cleanup of Homogenous Solids and Soil/Gravel Samples Undergoing Total Metals Analysis	Program specific procedure, no equivalent SW-846 method
Procedure 630.1: Method 6020 for the Inductively Coupled Plasma-Mass Spectrometry Determination of Total Metals in Homogenous Solids and Soil/Gravel	SW-846 Method 6020: Inductively Coupled Plasma-Mass Spectrometry – See Table C-12-8
Procedure 640.1: Method 6010A for the Inductively Coupled Plasma-Atomic Emission Spectroscopy Determination of Total Metals in Homogenous Solids and Soil/Gravel	SW-846 Method 6010A: Inductively Coupled Plasma-Atomic Emission Spectroscopy – See Table C-12-9
Procedure 650.1: Flame Atomic Absorption Spectroscopy Determination of Total Metals in Homogenous Solids and Soil/Gravel	Various SW-846 Direct Aspiration Atomic Absorption Methods, including 7040 (antimony), 7080A (barium), 7090 (beryllium), 7130 (cadmium), 7190 (chromium), 7420 (lead), 7520 (nickel), 7760A (silver), 7840 (thallium), 7910 (vanadium), 7950 (zinc) – See Table C12-10

TABLE C12-1 (CONTINUED)
CORRELATION BETWEEN SW-846 METHODS AND METHODS MANUAL METHODS

Methods Manual Procedure	SW-846 Method
Procedure 650.2: Graphite Furnace Atomic Absorption Spectroscopy Determination of Total Metals in Homogenous Solids and Soil/Gravel	Various SW-846 Graphite Furnace Atomic Absorption Methods, including 7041 (antimony), 7081 (barium), 7091 (beryllium), 7131A (cadmium), 7191 (chromium), 7421 (lead), 7761 (silver), 7841 (thallium), 7911 (vanadium), 7951 (zinc) – See Table C12-11
Procedure 650.3: Cold Vapor Atomic Absorption Spectroscopy Determination of Total Mercury in Homogenous Solids and Soil/Gravel	SW-846 Method 7471A Mercury in Solid or Semisolid Waste (Manual Cold-Vapor Technique) – See Table C12-12
Procedure 650.4: Hydride Generation Atomic Absorption Spectroscopy Determination of Total Arsenic in Homogenous Solids and Soil/Gravel	SW-846 Method 7061A Arsenic (AA, Gaseous Hydride) – See Table C12-13
Procedure 650.5: Borohydride Generation Atomic Absorption Spectroscopy Determination of Total Antimony and Arsenic in Homogenous Solids and Soil/Gravel	SW-846 Method 7062 Antimony and Arsenic (AA, Borohydride Reduction) – See Table C12-14
Procedure 650.6: Hydride Generation Atomic Absorption Spectroscopy Determination of Total Selenium in Homogenous Solids and Soil/Gravel	SW-846 Method 7741A Selenium (AA, Gaseous Hydride) – See Table C12-15
Procedure 650.7: Borohydride Generation Atomic Absorption Spectroscopy Determination of Total Selenium in Homogenous Solids and Soil/Gravel	SW-846 Method 7742 Selenium (AA, Borohydride Reduction) – See Table C12-16

TABLE C12-2
COMPARISON OF SW-846 METHOD 8240B AND METHODS MANUAL PROCEDURE 430.3

Methods Manual Procedure 430.3 Section	Corresponding SW-846 Method 8240B Section	Comments
Section 1.0 Scope and Application • Program analyte list and quality assurance objectives (QAOs) included in Table 1 • Analyte list is a subset of SW-846 Method 8240B analyte list except for 1,4-dichlorobenzene, ortho-dichlorobenzene, and 1,1,2-trichloro-1,2,2-trifluoroethane • Refers directly and only to SW-846 Method 8240B • Method detection limit of 1 mg/kg • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Analyte list does not include 1,4-dichlorobenzene, ortho-dichlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113) and specifies total xylenes • Estimated quantitation limit for soil/sediment samples is 0.5 mg/kg • Batch not to exceed 20 samples as per SW-846 Chapter One	• SW-846 Method 8240B allows analysis of most volatile organic compounds with boiling points below 200 degrees C and are insoluble or slightly soluble in water. • Dichlorobenzenes can be analyzed as semivolatile organic compound as per Table 1 in the Methods Manual procedure. • Freon 113 is very similar to other freon compound included on the analyte list of SW-846 Method 8240B. • Program QAOs are derived based on SW-846 Method 8240B Table 6 calibration and quality control acceptance criteria (precision and accuracy) and regulatory requirements (MDL and PRQL) • SW-846 Method is capable of quantitating at Procedure 430.3 method detection limit.
Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Method 8240B	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 8240B	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training.	No equivalent section in SW-846 Method 8240B	

TABLE C12-2 (CONTINUED)
COMPARISON OF SW-846 METHOD 8240B AND METHODS MANUAL PROCEDURE 430.3

Methods Manual Procedure 430.3 Section	Corresponding SW-846 Method 8240B Section	Comments
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 8240B	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Method 8240B	Section 5.0 Reagents	
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to Chapter Four, Section 4.1 of SW-846	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for VOC samples included in SW-846, Chapter Four, Section 4.1.
Section 8.0 Procedure • Allows analyst to determine appropriate preparation techniques based on SW-846 or other nationally recognized standard methods • Refers directly and only to SW-846 Method 8240B for initial calibration • Refers directly and only to SW-846 Method 8240B continuing calibration • All calibration requirements are summarized in Table 2 • Refers directly and only to SW-846 Method 8240B for analytical steps	Section 7.0 Procedure • Subsection 7.2 addresses initial calibration • Subsection 7.3 addresses continuing calibration • Subsection 7.4.3 addresses the analysis of sediment/soil and waste samples	• Calibration requirements in Procedure 430.3 are the same as found in SW-846 Method 8240B except for the response factor for bromoform listed in Table 2 of Procedure 430.3. This error in Procedure 430.3 will be corrected.

TABLE C12-2 (CONTINUED)
COMPARISON OF SW-846 METHOD 8240B AND METHODS MANUAL PROCEDURE 430.3

Methods Manual Procedure 430.3 Section	*Corresponding SW-846 Method 8240B Section*	*Comments*
Section 9.0 Calculations • Refers directly and only to SW-846 Method 8240B • Specifies results reported in mg/kg wet-weight basis	Section 7.5 Data Interpretation • Specifies waste reported in ug/kg wet-weight basis	• Conversion from ug/kg to mg/kg is a simple multiplication step.

TABLE C12-2 (CONTINUED)
COMPARISON OF SW-846 METHOD 8240B AND METHODS MANUAL PROCEDURE 430.3

Methods Manual Procedure 430.3 Section	Corresponding SW-846 Method 8240B Section	Comments
Section 10.0 Quality Control • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, method detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs. • Laboratory duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision • Laboratory blanks must be run once per batch, acceptance criteria is <3 x MDLs in Table 1 • Matrix spikes must be run once per batch, acceptance criteria are the Table 1 QAOs for accuracy • Matrix spike duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision and accuracy • Laboratory control samples must be run once per batch, acceptance criteria are 80-120 %R • Surrogate compounds required in each sample, acceptance criteria are average %R from at least 30 samples ±3 standard deviations • Blind audit samples are distributed, analyzed and reported as part of the	Section 8.0 Quality Control • SW-846 Method 8000A requires each laboratory to operate a formal quality control program • Requires demonstration of acceptable accuracy and precision through the analysis of quality control reference sample • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • Laboratory duplicates required once per batch in SW-846 Method 8000A, acceptance criteria not addressed • Method blanks required initially and once per batch in SW-846 Method 8000A and Chapter One, various acceptance criteria are recommended • Matrix spikes required once per batch, no acceptance criteria specified for solid samples • Matrix spike duplicates not required in addition to laboratory duplicates • Laboratory control samples required once per batch in SW-846 Chapter One, minimum acceptance criteria 70-140 %R as indicated in Table 6 of SW-846 Method 8240B • Surrogate compounds required in each	• Procedure 430.3 quality control requirements meet or exceed SW-846 Method 8240B quality control requirements • Procedure 430.3 provides a better defined quality control program than SW-846 Method 8240B

TABLE C12-2 (CONTINUED)
COMPARISON OF SW-846 METHOD 8240B AND METHODS MANUAL PROCEDURE 430.3

Methods Manual Procedure 430.3 Section	Corresponding SW-846 Method 8240B Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 8240B	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 8240B	

TABLE C12-3
COMPARISON OF SW-846 METHOD 8260A AND METHODS MANUAL PROCEDURE 430.4

Methods Manual Procedure 430.4 Section	Corresponding SW-846 Method 8260A Section	Comments
Section 1.0 Scope and Application • Program analyte list and quality assurance objectives (QAOs) included in Table 1 • Analyte list is a subset of SW-846 Method 8260A analyte list except for 1,1,2-trichloro-1,2,2-trifluoroethane • Refers directly and only to SW-846 Method 8260A • Method detection limit of 1 mg/kg • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Analyte list does not include 1,1,2-trichloro-1,2,2-trifluoroethane, (Freon 113) • Estimated quantitation limit for soil/sediment samples is 0.5 mg/kg • Batch not to exceed 20 samples as per SW-846 Chapter One	• SW-846 Method 8260A allows analysis of most volatile organic compounds with boiling points below 200 degrees C and are insoluble or slightly soluble in water. • Freon 113 is very similar to other freon compounds included in the analyte list of SW-846 Method 8260A • Program QAOs are derived based on SW-846 Method 8240B Table 6 calibration and quality control acceptance criteria (precision and accuracy) and regulatory requirements (MDL and PRQL) • SW-846 Method 8260A is capable of quantitating at Procedure 430.4 method detection limit.
Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Method 8260A	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 8260A	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training.	No equivalent section in SW-846 Method 8260A	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 8260A	Section 4.0 Apparatus and Materials	

TABLE C12-3 (CONTINUED)
COMPARISON OF SW-846 METHOD 8260A AND METHODS MANUAL PROCEDURE 430.4

Methods Manual Procedure 430.4 Section	Corresponding SW-846 Method 8260A Section	Comments
Section 6.0 Reagents • Refers directly and only to SW-846 Method 8260A	Section 5.0 Reagents	
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to Chapter Four, Section 4.1 of SW-846	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for VOC samples included in SW-846, Chapter Four, Section 4.1.
Section 8.0 Procedure • Allows analyst to determine appropriate preparation techniques based on SW-846 or other nationally recognized standard methods • Refers directly and only to SW-846 Method 8260A for initial calibration • Refers directly and only to SW-846 Method 8260A continuing calibration • All calibration requirements are summarized in Table 2 • Refers directly and only to SW-846 Method 8260A for analytical steps	Section 7.0 Procedure • Subsection 7.3 addresses initial calibration • Subsection 7.4 addresses continuing calibration • Subsections 7.1, 7.2, and 7.5 address the analysis of sediment/soil and waste samples	• Calibration requirements in Procedure 430.4 are the same as found in SW-846 Method 8260A except for the response factor for bromoform listed in Table 2 of Procedure 430.4. This error in Procedure 430.4 will be corrected.

TABLE C12-3 (CONTINUED)
COMPARISON OF SW-846 METHOD 8260A AND METHODS MANUAL PROCEDURE 430.4

Methods Manual Procedure 430.4 Section	Corresponding SW-846 Method 8260A Section	Comments
Section 9.0 Calculations • Refers directly and only to SW-846 Method 8260A • Specifies results reported in mg/kg wet-weight basis	Section 7.5 Data Interpretation • Specifies waste reported in ug/kg wet-weight basis	• Conversion from ug/kg to mg/kg is a simple multiplication step.

TABLE C12-3 (CONTINUED)
COMPARISON OF SW-846 METHOD 8260A AND METHODS MANUAL PROCEDURE 430.4

Methods Manual Procedure 430.4 Section	Corresponding SW-846 Method 8260A Section	Comments
Section 10.0 Quality Control • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, method detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs. • Laboratory duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision • Laboratory blanks must be run once per batch, acceptance criteria is <3 x MDLs in Table 1 • Matrix spikes must be run once per batch, acceptance criteria are the Table 1 QAOs for accuracy • Matrix spike duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision and accuracy • Laboratory control samples must be run once per batch, acceptance criteria is 80-120 %R • Surrogate compounds required in each sample, acceptance criteria are average %R from at least 30 samples ±3 standard deviations • Blind audit samples are distributed, analyzed and reported as part of the	Section 8.0 Quality Control • SW-846 Method 8000A requires each laboratory to operate a formal quality control program • Requires demonstration of acceptable accuracy and precision through the analysis of quality control reference sample • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • Laboratory duplicates required once per batch in SW-846 Method 8000A, acceptance criteria not addressed • Method blanks required initially and once per batch in SW-846 Method 8000A and Chapter One, various acceptance criteria are recommended • Matrix spikes required once per batch in SW-846 Method 8000A, no acceptance criteria specified for solid samples • Matrix spike duplicates not required in addition to laboratory duplicates • Laboratory control samples required once per batch in SW-846 Chapter One, minimum acceptance criteria 70-140 %R as indicated in Table 6 of SW-846 Method 8240B	• Procedure 430.4 quality control requirements meet or exceed SW-846 Method 8260A quality control requirements • Procedure 430.4 provides a better defined quality control program than SW-846 Method 8260A

TABLE C12-3 (CONTINUED)
COMPARISON OF SW-846 METHOD 8260A AND METHODS MANUAL PROCEDURE 430.4

Methods Manual Procedure 430.4 Section	Corresponding SW-846 Method 8260A Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 8260A	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 8260A	

TABLE C12-4
COMPARISON OF SW-846 METHOD 8250A AND METHODS MANUAL PROCEDURE 430.5

Methods Manual Procedure 430.5 Section	Corresponding SW-846 Method 8250A Section	Comments

Section 1.0 Scope and Application
• Program analyte list and quality assurance objectives (QAOs) included as Table 1, which includes:
  • cresols (a mixture of all isomers of cresol (o, m, p))
  • ortho-dichlorobenzene
  • pyridine
• Analyte list is a subset of SW-846 Method 8250A analyte list, except pyridine
• Refers directly and only to SW-846 Method 8250A
• Requires samples to be analyzed in batches not to exceed 20 samples
	Section 1.0 Scope and Application
	• The table in Subsection 1.1 lists the applicable analytes, including:
	  • 2-methylphenol and 4-methylphenol
	  • 1,2-dichlorobenzene
	• Subsection 1.2 includes pyridines as compounds that can be quantitated
	• Batch not to exceed 20 samples as per SW-846 Chapter One
		• The Methods Manual list is a subset of that in SW-846. Cresols are the same as methylphenols and ortho-dichlorobenzene is the same as 1,2-dichlorobenzene. The Methods Manual includes m-cresol (3-methylphenol) in its list (under cresols), which is not included in SW-846. SW-846 does not include pyridine in the analyte list, but allows for it in Subsection 1.2.
		• Program QAOs are derived based on SW-846 Method 8250A Table 6 (accuracy and precision) and regulatory requirements (MDL and PRQL)

Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Method 8250A	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 8250A	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 8250A	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 8250A	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Method 8250A	Section 5.0 Reagents	

TABLE C12-4 (CONTINUED)
COMPARISON OF SW-846 METHOD 8250A AND METHODS MANUAL PROCEDURE 430.5

Methods Manual Procedure 430.5 Section	Corresponding SW-846 Method 8250A Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter 4; Section 4.1	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846, Chapter 4, Section 4.1.
Section 8.0 Procedure • Refers directly and only to SW-846 Method 8250A for sample preparation and cleanup. • Refers directly and only to SW-846 Method 8250A for GC/MS operating conditions • Refers directly and only to SW-846 Method 8250A for initial calibration • Refers directly and only to SW-846 Method 8250A for continuing calibration • All calibration requirements are summarized in Table 2 • Refers directly and only to SW-846 Method 8250A for analytical steps	Section 7.0 Procedure • Subsections 7.1 and 7.2 refer to other SW-846 methods for sample preparation and cleanup • Subsection 7.3 addresses recommended GC/MS operating conditions • Subsection 7.4 addresses initial calibration • Subsection 7.5 addresses continuing (daily) calibration • Subsection 7.6 addresses the analytical procedure	• Calibration requirements in Procedure 430.5 are the same as found in SW-846 Method 8250A, except for the %RSD for CCCs listed in Table 2 of Procedure 430.5. This error in Procedure 430.5 will be corrected. • Procedure 430.5 includes accuracy criteria for surrogate compounds in its continuing calibration criteria; SW-846 Method 8250A provides this criteria in Subsection 8.9 and Table 8.

TABLE C12-4 (CONTINUED)
COMPARISON OF SW-846 METHOD 8250A AND METHODS MANUAL PROCEDURE 430.5

Methods Manual Procedure 430.5 Section	Corresponding SW-846 Method 8250A Section	Comments
Section 9.0 Calculations • Refers directly and only to SW-846 *Method 8250A* • Specifies results reported in mg/kg wet-weight basis	Subsection 7.7 Data Interpretation • Specifies waste reported in µg/kg wet-*weight basis*	• Conversion from µg/kg to mg/kg is a simple multiplication step.

TABLE C12-4 (CONTINUED)
COMPARISON OF SW-846 METHOD 8250A AND METHODS MANUAL PROCEDURE 430.5

Methods Manual Procedure 430.5 Section	Corresponding SW-846 Method 8250A Section	Comments
Section 10.0 Quality Control • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, method detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision • Laboratory blanks must be run once per batch, acceptance criteria is <3 x MDLs in Table 1 • Matrix spikes must be run once per batch, acceptance criteria are the Table 1 QAOs for accuracy • Matrix spike duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision and accuracy • Laboratory control samples must be run once per batch, acceptance criterion is 80-120 %R • Surrogate compounds must be included in every sample, acceptance criteria are average %R from at least 30 samples ±3 standard deviations • Blind audit samples are distributed,	Section 8.0 Quality Control • Requires each laboratory to operate a formal quality control program • Requires demonstration of acceptable precision and accuracy through the analysis of quality control check standard • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • Laboratory duplicates not addressed • Method blanks required initially and once per batch in SW-846 Method 8000A and Chapter One, various acceptance criteria are recommended • Matrix spikes required once per batch, acceptance criteria are the accuracy ranges provided in Method 8250A Table 6 • Matrix spike duplicates required once per batch, acceptance criteria are not addressed • Laboratory control samples required once per batch in SW-846 Chapter One, acceptance criteria are not addressed • Surrogate compounds required in each sample, acceptance criteria are average	• Procedure 430.5 quality control requirements meet or exceed SW-846 Method 8250A quality control requirements • Procedure 430.5 provides a better defined quality control program than SW-846 Method 8250A

TABLE C12-4 (CONTINUED)
COMPARISON OF SW-846 METHOD 8250A AND METHODS MANUAL PROCEDURE 430.5

Methods Manual Procedure 430.5 Section	Corresponding SW-846 Method 8250A Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 8250A	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 8250A	

TABLE C12-5
COMPARISON OF SW-846 METHOD 8270B AND METHODS MANUAL PROCEDURE 430.6

Methods Manual Procedure 430.6 Section	Corresponding SW-846 Method 8270B Section	Comments

Section 1.0 Scope and Application
• Program analyte list and quality assurance objectives (QAOs) included as Table 1, which includes:
  • cresols (a mixture of all isomers of cresol (o, m, p))
  • ortho-dichlorobenzene
  • pyridine
• Analyte list is a subset of SW-846 Method 8270B analyte list, except pyridine
• Refers directly an only to SW-846 Method 8270B
• Requires samples to be analyzed in batches not to exceed 20 samples
	Section 1.0 Scope and Application
	• The table in Subsection 1.1 lists the applicable analytes, including:
	  • 2-methylphenol, 3-methylphenol, and 4-methylphenol
	  • 1,2-dichlorobenzene
	• Subsection 1.2 includes pyridines as compounds that can be quantitated
	• Batch not to exceed 20 samples as per SW-846 Chapter One
		• The Methods Manual list is a subset of that in SW-846. Cresols is the same as methylphenols and ortho-dichlorobenzene is the same as 1,2-dichlorobenzene. SW-846 does not include pyridine in the analyte list, but allows for it in Subsection 1.2.
		• Program QAOs are derived based on SW-846 Method 8270B Table 6 quality control criteria (accuracy and precision) and regulatory requirements (MDL and PRQL)

Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Method 8270B	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 8270B	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 8270B	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 8270B	Section 4.0 Apparatus and Materials	

TABLE C12-5 (CONTINUED)
COMPARISON OF SW-846 METHOD 8270B AND METHODS MANUAL PROCEDURE 430.6

Methods Manual Procedure 430.6 Section	Corresponding SW-846 Method 8270B Section	Comments
Section 6.0 Reagents • Refers directly and only to SW-846 Method 8270B	Section 5.0 Reagents	
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter 4, Section 4.1	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846, Chapter 4, Section 4.1.
Section 8.0 Procedure • Refers directly and only to SW-846 Method 8270B for sample preparation and cleanup • Refers directly and only to SW-846 Method 8270B for initial calibration • Refers directly and only to SW-846 Method 8270B for continuing calibration • All calibration requirements are summarized in Table 2 • Refers directly and only to SW-846 Method 8270B for analytical steps	Section 7.0 Procedure • Subsections 7.1 and 7.2 refer to other SW-846 methods for sample preparation and cleanup • Subsection 7.3 addresses initial calibration • Subsection 7.4 addresses continuing (daily) calibration • Subsection 7.5 addresses the analytical procedure	• Calibration requirements in Procedure 430.6 are the same as found in SW-846 Method 8270B, except for the %RSD for CCCs listed in Table 2 of Procedure 430.6. This error in Procedure 430.6 will be corrected. • Procedure 430.6 includes accuracy criteria for surrogate compounds in its continuing calibration criteria; SW-846 Method 8270B provides this criteria in Subsection 8.9 and Table 8.

TABLE C12-5 (CONTINUED)
COMPARISON OF SW-846 METHOD 8270B AND METHODS MANUAL PROCEDURE 430.6

Methods Manual Procedure 430.6 Section	Corresponding SW-846 Method 8270B Section	Comments
Section 9.0 Calculations • Refers directly and only to SW-846 Method 8270B • Specifies results reported in mg/kg wet-weight basis	Subsection 7.6 Data Interpretation • Specifies waste reported in µg/kg wet-weight basis	• Conversion from µg/kg to mg/kg is a simple multiplication step.

TABLE C12-5 (CONTINUED)
COMPARISON OF SW-846 METHOD 8270B AND METHODS MANUAL PROCEDURE 430.6

Methods Manual Procedure 430.6 Section	Corresponding SW-846 Method 8270B Section	Comments
Section 10.0 Quality Control • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, method detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision • Laboratory blanks must be run once per batch, acceptance criteria is <3 x MDLs in Table 1 • Matrix spikes must be run once per batch, acceptance criteria are the Table 1 QAOs for accuracy • Matrix spike duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision and accuracy • Laboratory control samples must be run once per batch, acceptance criterion is 80-120 %R • Surrogate compounds must be included in every sample, acceptance criteria are average %R from at least 30 samples ±3 standard deviations • Blind audit samples are distributed, analyzed and reported as part of the	Section 8.0 Quality Control • Requires each laboratory to operate a formal quality control program • Requires demonstration of acceptable precision and accuracy through the analysis of quality control reference standard • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • Laboratory duplicates required once per batch, acceptance criteria are not addressed • Method blanks required initially and once per batch in SW-846 Method 8000A and Chapter One, various acceptance criteria are recommended • Matrix spikes required once per batch, acceptance criteria are not addressed for solid samples • Matrix spike duplicates not required in addition to laboratory duplicates • Laboratory control samples required once per batch in SW-846 Chapter One, acceptance criteria are not addressed • Surrogate compounds required in each sample, acceptance criteria are average %R from at least 30 samples ± 3	• Procedure 430.6 quality control requirements meet or exceed SW-846 Method 8270B quality control requirements • Procedure 430.6 provides a better defined quality control program than SW-846 Method 8270B

TABLE C12-5 (CONTINUED)
COMPARISON OF SW-846 METHOD 8270B AND METHODS MANUAL PROCEDURE 430.6

Methods Manual Procedure 430.6 Section	Corresponding SW-846 Method 8270B Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 8270B	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 8270B	

TABLE C12-6
COMPARISON OF COMBINED SW-846 METHODS (8081, 3550, 3620) AND METHODS MANUAL PROCEDURE 440.3

Methods Manual Procedure 440.3 Section	Corresponding SW-846 Method(s) Section	Comments
Section 1.0 Scope and Application • Program analyte list (limited to 7 PCB Aroclors) and quality assurance objectives (QAOs) included as Table 1 • Analyte list is a subset of SW-846 Method 8081 analyte list • Refers directly SW-846 Methods 8000A, 8081, 3550, and 3620 • Requires samples to be analyzed in batches not to exceed 20 samples • Method detection limit set at 5 mg/kg	Section 1.0 Scope and Application • SW-846 Method 8081 analyte list includes numerous pesticides and PCB aroclors • Batch not to exceed 20 samples as per SW-846 Chapter One • Minimum reported method detection limits are 0.057-0.070 mg/kg for PCB aroclors	• Procedure 440.3 has been optimized for the determination of PCBs in TRU waste sludge • Procedure 440.3 analyte list is a subset of SW-846 Method 8081 analyte list • Program QAOs are derived based on SW-846 Method 8081 Tables 15 and 16 and procedure development work (precision and accuracy) and regulatory requirements (MDL and PRQL) • SW-846 Method 8081 capable of quantitating at Procedure 440.3 method detection limit
Section 2.0 Summary of Procedure • Sample preparation, hexane extraction with vortex mixing, Florisil cleanup, and quantitation by GC/ECD is summarized	Section 2.0 Summary of Method • SW-846 Method 8081 requires appropriate extraction method, hexane-acetone extraction according to SW-846 Method 3550 allowed • SW-846 Method 8081 allows for a variety of cleanup steps as discussed in Section 3.0 • SW-846 Method 8081 allows quantitation with GC/ECD	
Section 3.0 Interferences • General discussion of possible interferences • Requires Florisil cleanup for spindle oil • Refers directly to SW-846 Method 8081	Section 3.0 Interferences • SW-846 allows for a variety of cleanup methods, including Florisil cleanup according to SW-846 Method 3620	

TABLE C12-6 (CONTINUED)
COMPARISON OF COMBINED SW-846 METHODS (8081, 3550, 3620) AND METHODS MANUAL PROCEDURE 440.3

Methods Manual Procedure 440.3 Section	Corresponding SW-846 Method(s) Section	Comments
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Methods	
Section 5.0 Apparatus and Materials • Refers directly to SW-846 Method 8081 • Specifies extraction and cleanup equipment and materials	Section 4.0 Apparatus and Materials • Equivalent equipment specified in SW-846 Methods 3550 and 3620	
Section 6.0 Reagents • Refers directly to SW-846 Method 8081 • Requires certified standard solutions • Stock standards limited to 6 months shelf life, or as required for purity • Calibration standards must include all aroclors, individually and as mixes • 5 standards required that encompass 5-500 ppm range • Calibration standards limited to 2 months shelf life • Surrogate standards are DCBP as primary, TCMX as secondary • Surrogate final concentration in cleaned extract to be 0.05 ppm • Refers to SW-846 Method 8081, Section 8.3 for corrective action for out-of-control surrogate recovery	Section 5.0 Reagents • Stock standards limited to 1 year shelf life, or as required for purity • Calibration standards to encompass expected concentration range of samples • Calibration standards limited to 6 months shelf life, or as required for purity • Surrogate standards are DCBP as primary, TCMX as secondary	• Procedure 440.3 should refer to SW-846 Method 8081, Section 8.2.2 for corrective action of out-of-control surrogate standards. This error will be corrected.

TABLE C12-6 (CONTINUED)
COMPARISON OF COMBINED SW-846 METHODS (8081, 3550, 3620) AND METHODS MANUAL PROCEDURE 440.3

Methods Manual Procedure 440.3 Section	Corresponding SW-846 Method(s) Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Requires sample extracts to be stored under refrigeration and in dark and must be analyzed within 40 days of extraction • Refers to SW-846 Chapter Four	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846 Method 8081 and Chapter Four.
Section 8.0 Procedure • Requires hexane extraction and vortex mixing of 2.0 gram sample; surrogate must be added to each sample and blank • Requires Florisil cleanup of all samples • Refers directly to SW-846 Method 8000A for initial and continuing calibration • Requires a 3 point calibration curve • All calibration requirements are summarized in Table 2 • Refers directly to SW-846 Methods 8000A and 8081 for analytical steps	Section 7.0 Procedure • SW-846 Method 8000A, Subsection 7.4.2 addresses calibration requirements and requires a 5 point calibration curve • SW-846 Method 8000A, Subsection 7.6, and Method 8081, Subsection 7.5 addresses analysis	• Because Procedure 440.3 was developed to analyze PCBs in samples of radioactive organic sludge, extraction and cleanup steps are modified from SW-846 Methods 3550 and 3620. Extensive procedure performance documentation is included in Section 11.0 to support and justify modified techniques. • Procedure 440.3 requires a 3 point calibration curve. Extensive procedure performance documentation is included in Section 11.0 to support and justify this calibration.
Section 9.0 Calculations • Requires quantitation by summing 3-5 peaks associated with appropriate Aroclor(s)	Section 7.6.4 Quantitation of PCBs • Allows quantitation by summing areas of 3-5 peaks associated with appropriate Aroclor	

TABLE C12-6 (CONTINUED)
COMPARISON OF COMBINED SW-846 METHODS (8081, 3550, 3620) AND METHODS MANUAL PROCEDURE 440.3

Methods Manual Procedure 440.3 Section	Corresponding SW-846 Method(s) Section	Comments
Section 10.0 Quality Control • Refers directly to SW-846 Method 8081, Subsections 8.4 (GC/MS confirmation) and 8.5 (Florisil cleanup) • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, method detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision • Laboratory blanks must be run once per batch, acceptance criteria is <3 x MDLs in Table 1 • Matrix spikes must be run once per batch, acceptance criteria are the Table 1 QAOs for accuracy • Matrix spike duplicates must be run once per batch, acceptance criteria are the Table 1 QAOs for precision and accuracy • Laboratory control samples must be run once per batch, acceptance criteria are 80-120 %R • Surrogate compounds must be included in every sample, acceptance criteria are	Section 8.0 Quality Control • SW-846 Method 8000A requires each laboratory to operate a formal quality control program • Recommends demonstration of acceptable accuracy through the analysis of quality control reference standard once per batch, acceptance criteria is 80-120 %R • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • Laboratory duplicates required once per batch in SW-846 Method 8000A and Chapter One, acceptance criteria are not addressed • Method blanks required initially and once per batch in SW-846 Method 8000A and Chapter One, various acceptance criteria are recommended • Matrix spikes required once per batch in SW-846 Method 8000A, no acceptance criteria specified for solid samples • Matrix spike duplicates not required in addition to laboratory duplicates • Laboratory control samples not addressed	• The laboratory control sample required by Procedure 440.3 fulfills the quality control reference standard recommended by SW-846 Method 8081 • Procedure 440.3 quality control requirements meet or exceed SW-846 Method 8081 quality control requirements • Procedure 440.3 provides a better defined quality control program than SW-846 Method 8081

TABLE C12-6 (CONTINUED)
COMPARISON OF COMBINED SW-846 METHODS (8081, 3550, 3620) AND METHODS MANUAL PROCEDURE 440.3

Methods Manual Procedure 440.3 Section	Corresponding SW-846 Method(s) Section	Comments
Section 11.0 Procedure Performance • Extensive documentation of performance of the optimized extraction, cleanup, and analytical procedure developed by Argonne National Laboratory	Section 9.0 Method Performance • References extensive method performance work performed by Oak Ridge National Laboratory	• Because Procedure 440.3 was developed to analyze PCBs in samples of radioactive organic sludge, extraction and cleanup steps are modified from SW-846 Methods 3550 and 3620. Extensive procedure performance documentation is included in Section 11.0 of Procedure 440.3 to support and justify modified techniques.
Section 12.0 References • *Determination of PCBs in Rocky Flats Type IV Waste Sludge by Gas Chromatography/Electron Capture Detection* (ANL 1993) • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 8081	

TABLE C12-7
COMPARISON OF SW-846 METHOD 3051 AND METHODS MANUAL PROCEDURE 610.1

Methods Manual Procedure 610.1 Section	Corresponding SW-846 Method 3051 Section	Comments
Section 1.0 Scope and Application • Program analyte indicated (subset of analytes allowed by SW-846 Method 3051) • List of analytical methods applicable to this preparation procedure • Refers directly to SW-846 Method 3051 • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Section 1.1, analyte list • Section 1.2, addresses analytical methods applicable to this preparation procedure • Batch not to exceed 20 samples as per SW-846 Chapter One	• Procedure 610.1 analyte list is a subset of the analyte list in SW-846 Method 3051 • The acceptable analytical procedures to be used for the digestates generated by this procedure are identical
Section 2.0 Summary of Procedure • Refers directly and only to SW-846, Method 3051	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846, Method 3051	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 3051	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846, Method 3051	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846, Method 3051	Section 5.0 Reagents	

TABLE C12-7 (CONTINUED)
COMPARISON OF SW-846 METHOD 3051 AND METHODS MANUAL PROCEDURE 610.1

Methods Manual Procedure 610.1 Section	Corresponding SW-846 Method 3051 Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody procedures in Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation, and Handling • Samples collected following sampling plan in SW-846 Chapter Nine • Sample containers must be prewashed in SW-846 Chapter Three • Samples must be refrigerated and analyzed as soon as possible	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements in SW-846 Method 3051, Chapter Nine, and Chapter Three
Section 8.0 Procedure • Refers to SW-846 Method 3051 for procedural requirements. • Final acid concentration of digestate should be 4 M nitric acid if using Procedure 620.1 for transuranic element cleanup.	Section 7.0 Procedure	• Procedure 620.1 does not have an equivalent method in SW-846 because it is used to preferentially extract transuranic elements from the sample matrix to reduce interferences.
Section 9.0 Calculations • Does not apply to procedure	Section 7.0 Procedure • Section 7.0 of SW-846, Method 3051 includes all required calculations	• Procedure 610.1 will be revised to refer to Section 7.0 of SW-846, Method 3051

TABLE C12-7 (CONTINUED)
COMPARISON OF SW-846 METHOD 3051 AND METHODS MANUAL PROCEDURE 610.1

Methods Manual Procedure 610.1 Section	Corresponding SW-846 Method 3051 Section	Comments
Section 10.0 Quality Control • Laboratory blank must be included in analytical batch. • Matrix spike must be included in analytical batch. • Matrix spike duplicate must be included in analytical batch. • Laboratory control sample must be included in analytical batch. • Refers analyst to quality control section of the analytical procedure used for any additional requirements.	Section 8.0 Quality Control • Method blank required once per batch in SW-846 Chapter One, various acceptance criteria are recommended • Matrix spike required once per batch in SW-846 Method 3051, Section 8.3, acceptance criteria are not addressed • Matrix spike duplicate or duplicate recommended once per batch in SW-846 Method 3051, Section 8.2, acceptance criteria are not addressed • Laboratory control samples required once per batch in SW-846 Chapter One	• No acceptance criteria given in Procedure 610.1 for quality control samples. Acceptance criteria are found in the analytical methods • Procedure 610.1 quality control requirements (as included in analytical procedures) meet or exceed SW-846 quality control requirements • Methods Manual procedure provide a better defined quality control program than SW-846
Section 11.0 Procedure Performance • Refers directly and only to SW-846, Method 3051	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 3051	

TABLE C12-8
COMPARISON OF SW-846 METHOD 6020 AND METHODS MANUAL PROCEDURE 630.1

Methods Manual Procedure 630.1 Section	Corresponding SW-846 Method 6020 Section	Comments
Section 1.0 Scope and Application • Program analyte list and quality assurance objectives (QAOs) included in Table 1 • Analyte list is a subset of SW-846 Method 6020 analyte list • Refers directly to SW-846 Method 6020 • Requires samples to be analyzed in *batches not to exceed 20 samples*	Section 1.0 Scope and Application • Analyte list included as Table 1 • Batch not to exceed 20 samples per SW-846 Chapter One	• Program QAOs are derived from SW-846 Method 6020 (precision and accuracy) and regulatory requirements (MDL and PRQL)
Section 2.0 Summary of Procedure • *Refers directly and only to SW-846* Method 6020	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 6020	*Section 3.0 Interferences*	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 6020	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 6020	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Method 6020	Section 5.0 Reagents	

TABLE C12-8 (CONTINUED)
COMPARISON OF SW-846 METHOD 6020 AND METHODS MANUAL PROCEDURE 630.1

Methods Manual Procedure 630.1 Section	Corresponding SW-846 Method 6020 Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation, and Handling • Samples collected following SW-846 Chapter Nine • Reference to SW-846 Chapter Three, Section 3.1.3 for sample handling and preservation	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846 Chapter Three and Chapter Nine
Section 8.0 Procedure • Sample preparation procedures must follow Procedure 610.1 of Methods Manual • Sample cleanup Procedure 620.1 of the Methods Manual may be used • Refers directly and only to SW-846 Method 6020 for initial and continuing calibration • All calibration requirements are summarized in Table 2 • Refers directly and only to SW-846 Method 6020 for analytical steps	Section 7.0 Procedure • Subsection 7.1 references sample preparation methods, SW-846 Method 3051, microwave assisted digestion, allowed • Subsections 7.2 through 7.10 address calibration and analytical requirements	• Procedure 610.1 is based on SW-846 Method 3051 (see Table C-12-7)

TABLE C12-8 (CONTINUED)
COMPARISON OF SW-846 METHOD 6020 AND METHODS MANUAL PROCEDURE 630.1

Methods Manual Procedure 630.1 Section	*Corresponding SW-846 Method 6020 Section*	*Comments*
Section 9.0 Calculations • Refers to Section 7.12 of SW-846 Method 6020 for required calculations. • Sample dilution must be taken into account • Results reported in mg/kg (wet weight basis) • Percent solid content must be determined on a separate sample aliquot to convert analytical results into mg/kg dry weight	Section 7.0 Procedure • Section 7.11 of SW-846 Method 6020 addresses required calculations	• Procedure 630.1 will be revised to reference Section 7.11 of SW-846 Method 6020

TABLE C12-8 (CONTINUED)
COMPARISON OF SW-846 METHOD 6020 AND METHODS MANUAL PROCEDURE 630.1

Methods Manual Procedure 630.1 Section	Corresponding SW-846 Method 6020 Section	Comments
Section 10.0 Quality Control • Refers to Section 8.1 through 8.5 of SW-846 Method 6020 and states that all quality control requirements are mandatory • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, method detection limit, and percent recovery for quality control samples • IDL must be at or below PRDL • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory blanks must be run once per batch, acceptance criteria are ≤5 x IDL • Matrix spikes must be run once per batch, acceptance criteria are 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are 80-120 %R and ≤30 RPD • Laboratory control samples must be run once per batch, acceptance criteria are 80-120 %R • Blind audit samples are distributed, analyzed, and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • Subsection 8.1 requires the laboratory to establish a formal quality control program • SW-846 Chapter One includes equations for calculating precision, accuracy and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • SW-846 Chapter One and SW-846 6020, Subsection 5.5 lists three blanks that must be included (calibration blank, preparation blank, and rinse blank), acceptance criteria is programmatic • Matrix spike required once per batch, acceptance criteria are not addressed • One duplicate (may be matrix spike duplicate) is required per batch, recommended acceptance criteria are ≤20 RPD for concentrations >100 x IDL • Laboratory control sample recommended once per batch, acceptance criteria are not addressed • Blind audit samples not addressed, however participation in an external performance evaluation program is addressed in SW-846 Chapter One	• Procedure 630.1 quality control requirements meet or exceed SW-846 Method 6020 quality control requirements • Procedure 630.1 provides a better defined quality control program than SW-846 Method 6020

TABLE C12-8 (CONTINUED)
COMPARISON OF SW-846 METHOD 6020 AND METHODS MANUAL PROCEDURE 630.1

Methods Manual Procedure 630.1 Section	Corresponding SW-846 Method 6020 Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 6020	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 6020	

TABLE C12-9
COMPARISON OF SW-846 METHOD 6010A AND METHODS MANUAL PROCEDURE 640.1

Methods Manual Procedure 640.1 Section	Corresponding SW-846 Method 6010A Section	Comments
Section 1.0 Scope and Application • Program analyte list and quality assurance objectives (QAOs) included as Table 1 • Analyte list is a subset of SW-846 Method 6010A analyte list • Refers directly SW-846 Method 6010A • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Analyte list included as Table 1 • Batch not to exceed 20 samples as per SW-846 Chapter One	• Program QAOs are derived from SW-846 Method 6010A (precision and accuracy) and regulatory requirements (MDL and PRQL)
Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Method 6010A	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 6010A	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 6010A	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 6010A	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Method 6010A	Section 5.0 Reagents	

TABLE C12-9 (CONTINUED)
COMPARISON OF SW-846 METHOD 6010A AND METHODS MANUAL PROCEDURE 640.1

Methods Manual Procedure 640.1 Section	Corresponding SW-846 Method 6010A Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter Three, Section 3.1 through 3.3 for sample handling and preservation	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846, Chapters Three and Nine
Section 8.0 Procedure • Procedure 610.1 of the Methods Manual must be followed • Procedure 620.1 of the Methods Manual may be used if cleanup is required • Refers directly and only to SW-846 Method 6010A for initial calibration • Refers directly and only to SW-846 Method 6010A for continuing calibration • All calibration requirements are summarized in Table 2 • Refers directly and only to SW-846 Method 6010A for analytical steps	Section 7.0 Procedure • Subsection 7.1 references sample preparation methods, SW-846 Method 3051, microwave assisted digestion, allowed • Subsections 7.2 through 7.5 address initial calibration, continuing calibration, and analytical steps	• Procedure 610.1 is based on SW-846 Method 3051 (see Table C-12-7)
Section 9.0 Calculations • Specifies results reported in mg/kg wet-weight basis • Use the calibration curve to determine analyte concentration	• Section 7.0 addresses quantitation	

TABLE C12-9 (CONTINUED)
COMPARISON OF SW-846 METHOD 6010A AND METHODS MANUAL PROCEDURE 640.1

Methods Manual Procedure 640.1 Section	Corresponding SW-846 Method 6010A Section	Comments
Section 10.0 Quality Control • Refers to Section 8.1 through 8.5 of SW-846, Method 6010A and requires that all quality control requirements are mandatory • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, method detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory blanks must be run once per batch, acceptance criteria are ≤3 x IDL • Matrix spikes required once per batch, acceptance criteria are 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are 80-120 %R and ≤30 RPD • Laboratory control samples must be run once per batch, acceptance criteria are 80-120 %R • Blind audit samples are distributed, analyzed and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • SW-846 Chapter One requires each laboratory to operate a formal quality control program • SW-846 Chapter One requires demonstration of acceptable precision and accuracy through the analysis of quality control reference standard • SW-846 Chapter One includes equations used for calculating accuracy, precision, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • SW-846 Chapter One and SW-846 Method 6010A requires the method blank be run once per batch, acceptance criteria are ±3 standard deviations of mean blank value • Matrix spikes required once per batch, acceptance criteria 80-120 %R • Matrix spike duplicates required once per batch, acceptance criteria is ≤20 RPD and 80-120 %R • Laboratory control samples required once per batch in SW-846 Chapter One, acceptance criteria are not addressed • Blind audit samples not addressed, however participation in an external	• Procedure 640.1 quality control requirements meet or exceed SW-846 Method 6010A quality control requirements • Procedure 640.1 provides a better defined quality control program than SW-846 Method 6010A

TABLE C12-9 (CONTINUED)
COMPARISON OF SW-846 METHOD 6010A AND METHODS MANUAL PROCEDURE 640.1

Methods Manual Procedure 640.1 Section	Corresponding SW-846 Method 6010A Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 6010A	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 6010A	

TABLE C12-10
COMPARISON OF SW-846 METHODS 7000A, 7040, 7080A, 7090, 7130, 7190, 7420, 7520, 7760A, 7840, 7910, AND 7950 AND METHODS MANUAL PROCEDURE 650.1

Methods Manual Procedure 650.1 Section	Corresponding SW-846 Methods Section	Comments
Section 1.0 Scope and Application • Program analyte list and quality assurance objectives (QAOs) included as Table 2 • Analyte list is correlated directly to appropriate SW-846 Method • Refers directly to SW-846 Methods listed in Table 1 and 7000A • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Table 1 analyte list, no specified QAOs in SW-846 Method 7000A • Batch not to exceed 20 samples as per SW-846 Chapter One	• Each individual method refers to SW-846 Method 7000A for general requirements. However each method for a specific analyte may have additional requirements unique to the analyte • Program QAOs are derived based on SW-846 Methods (precision and accuracy) and regulatory requirements (PRDL and PRQL)
Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Methods listed in Table 1	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Methods listed in Table 1	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Methods	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Methods listed in Table 1	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Methods listed in Table 1	Section 5.0 Reagents	

TABLE C12-10 (CONTINUED)
COMPARISON OF SW-846 METHODS 7000A, 7040, 7080A, 7090, 7130, 7190, 7420, 7520, 7760A, 7840, 7910, AND 7950 AND METHODS MANUAL PROCEDURE 650.1

Methods Manual Procedure 650.1 Section	Corresponding SW-846 Methods Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter Nine for sampling plan considerations • Requires all sample containers prewashed with detergents, acids, and reagents • Allows for both glass and plastic containers • Requires nonaqueous samples to be refrigerated (when possible) and analyzed as soon as possible	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846 Chapter Nine
Section 8.0 Procedure • Procedure 610.1 of the Methods Manual must be followed • Procedure 620.1 of the Methods Manual may be used if cleanup is required • Refers directly to SW-846 Methods listed in Table 1 for analytical steps except for silver which refers to Section 7.4 through 7.6 of SW-846 Method 7760A • Use of proven matrix modifiers other than those specified in SW-846 is acceptable • All calibration requirements are summarized in Table 3	Section 7.0 Procedure • Subsection 7.1 addresses sample preparation, Section 5.0 addresses standard preparation Section 7.0 addresses analysis • Calibration criteria are provided in SW-846 Method 7000A Subsections • Serial dilution and post-digestion spike criteria are provided in SW-846 Method 7000A Subsection 8.6	• Calibration requirements in Procedure 650.1 are the same as found in SW-846 Method 7000A. • Procedure 650.1 requires 3 standards in the initial calibration; Method 7000A requires a minimum of three standards.

TABLE C12-10 (CONTINUED)
COMPARISON OF SW-846 METHODS 7000A, 7040, 7080A, 7090, 7130, 7190, 7420, 7520, 7760A, 7840, 7910, AND 7950 AND METHODS MANUAL PROCEDURE 650.1

Methods Manual Procedure 650.1 Section	Corresponding SW-846 Methods Section	Comments
Section 9.0 Calculations • Allows for reading analyte concentration from calibration curve or directly from instrument readout • Requires sample dilution taken into account • Specifies results reported in mg/kg wet weight basis • Provides for conversion to mg/kg dry weight	Subsection 7.4 • Subsection 7.4 in SW-846 Method 7000A addresses concentration determination calculations including sample dilution calculations	

TABLE C12-10 (CONTINUED)
COMPARISON OF SW-846 METHODS 7000A, 7040, 7080A, 7090, 7130, 7190, 7420, 7520, 7760A, 7840, 7910, AND 7950 AND METHODS MANUAL PROCEDURE 650.1

Methods Manual Procedure 650.1 Section	Corresponding SW-846 Methods Section	Comments
Section 10.0 Quality Control • Refers to Subsection 8.6 and 8.7 of SW-846 Method 7000A and requires that all quality control requirements are mandatory • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, instrument detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 2 QAOs • Laboratory blanks must be run once per batch, acceptance criteria is ≤3 x IDL • Matrix spikes must be run once per batch, acceptance criteria is 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are ≤30 RPD and 80-120 %R • Laboratory control samples must be run once per batch, acceptance criteria is 80-120 %R • Blind audit samples are distributed, analyzed and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • Refers to SW-846 Method 7000A Section 8.0 • SW-846 Method 7000A Section 8.0 recommends quality control data be maintained and available for easy reference or inspection • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • Method blanks required once per batch per SW-846 Chapter One, various acceptance criteria recommeded • Matrix spikes required once per batch in SW-846 Method 7000A Section 8.0, acceptance criteria not addressed • Matrix spike duplicates required once per batch in SW-846 Method 7000A Section 8.0, acceptance criteria not addressed • Laboratory control samples (reference standard) required once per batch in SW-846 Method 7000A Section 8.0, acceptance criteria not addressed • Blind audit samples not addressed, however participation in an external performance evaluation program is addressed in SW-846 Chapter One	• Procedure 650.1 quality control requirements meet or exceed SW-846 Methods quality control requirements • Procedure 650.1 provides a better defined quality control program than the SW-846 Methods

TABLE C12-10 (CONTINUED)
COMPARISON OF SW-846 METHODS 7000A, 7040, 7080A, 7090, 7130, 7190, 7420, 7520, 7760A, 7840, 7910, AND 7950 AND METHODS MANUAL PROCEDURE 650.1

Methods Manual Procedure 650.1 Section	Corresponding SW-846 Methods Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Methods listed in Table 1	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Methods 7000A, 7040, 7080, 7090,7130, 7190, 7420, 7520, 7760A, 7840, 7910, and 7950	

TABLE C12-11
COMPARISON OF SW-846 METHODS 7000A, 7041, 7081, 7091, 7131A, 7191, 7421, 7761, 7841, 7911, AND 7951 AND METHODS MANUAL PROCEDURE 650.2

Methods Manual Procedure 650.2 Section	Corresponding SW-846 Methods Section	Comments
Section 1.0 Scope and Application • Program analyte list and quality assurance objectives (QAOs) included as Table 2 (Nickel is listed as an analyte for analysis by GFAA) • Refers directly to SW-846 Methods listed in Table 1 and 7000A • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • SW-846 Method 7000A, Table 1 analyte list • SW-846 does not list a GFAA method for nickel • Batch not to exceed 20 samples as per SW-846 Chapter One	• Each individual method refers to SW-846 Method 7000A for general requirements. However each method for a specific analyte may have additional requirements unique to the analyte • Program QAOs are derived based on SW-846 Methods (precision and accuracy) and regulatory requirements (PRDL and PRQL) • Table 1 in Procedure 650.2 will be revised to reflect the correct SW-846 method numbers • Analyte list for Procedure 650.2 will be revised to exclude nickel
Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Methods listed in Table 1	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Methods listed in Table 1	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Methods	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Methods listed in Table 1	Section 4.0 Apparatus and Materials	

TABLE C12-11 (CONTINUED)
COMPARISON OF SW-846 METHODS 7000A, 7041, 7081, 7091, 7131A, 7191, 7421, 7761, 7841, 7911, AND 7951 AND METHODS MANUAL PROCEDURES 650.2

Methods Manual Procedure 650.2 Section	*Corresponding SW-846 Methods Section*	*Comments*
Section 6.0 Reagents • *Refers directly and only to SW-846 Methods listed in Table 1*	Section 5.0 Reagents	
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter Nine for sampling plan considerations • Requires all sample containers prewashed with detergents, acids, and reagents • Allows for both glass and plastic containers • Requires nonaqueous samples to be refrigerated (when possible) and *analyzed as soon as possible*	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846 Chapter Nine

TABLE C12-11 (CONTINUED)
COMPARISON OF SW-846 METHODS 7000A, 7041, 7081, 7091, 7131A, 7191, 7421, 7761, 7841, 7911, AND 7951 AND METHODS MANUAL PROCEDURES 650.2

Methods Manual Procedure 650.2 Section	Corresponding SW-846 Methods Section	Comments
Section 8.0 Procedure • Procedure 610.1 of the Methods Manual must be followed • Procedure 620.1 of the Methods Manual may be used if cleanup is required • Refers directly to SW-846 Methods listed in Table 1 for analytical steps except for arsenic, selenium, and silver which refer to Sections of SW-846 Methods 7061, 7741, and 7761 respectively • Use of proven matrix modifiers other than those specified in SW-846 is acceptable • All calibration requirements are summarized in Table 3	Section 7.0 Procedure • Subsection 7.1 addresses sample preparation, Section 5.0 addresses standard preparation Section 7.0 addresses analysis • Calibration criteria are provided in SW-846 Method 7000A Subsections • Serial dilution and post-digestion spike criteria are provided in SW-846 Method 7000A Subsection 8.6	• Calibration requirements in Procedure 650.1 are the same as found in SW-846 Method 7000A. • Procedure 650.1 requires 3 standards in the initial calibration; Method 7000A requires a minimum of three standards.
Section 9.0 Calculations • Allows for reading analyte concentration from calibration curve or directly from instrument readout • Requires sample dilution taken into account • Specifies results reported in mg/kg wet weight basis • Provides for conversion to mg/kg dry weight	Subsection 7.4 • Subsection 7.4 in SW-846 Method 7000A addresses concentration determination calculations including sample dilution calculations	

TABLE C12-11 (CONTINUED)
COMPARISON OF SW-846 METHODS 7000A, 7041, 7081, 7091, 7131A, 7191, 7421, 7761, 7841, 7911, AND 7951 AND METHODS MANUAL PROCEDURES 650.2

Methods Manual Procedure 650.2 Section	Corresponding SW-846 Methods Section	Comments
Section 10.0 Quality Control • Refers to Subsection 8.6 and 8.7 of SW-846 Method 7000A and requires that all quality control requirements are mandatory • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, instrument detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 2 QAOs • Laboratory blanks must be run once per batch, acceptance criteria are ≤3 x IDL • Matrix spikes must be run once per batch, acceptance criteria are 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are ≤30 RPD and 80-120 %R • Laboratory control samples must be run once per batch, acceptance criteria are 80-120 %R • Blind audit samples are distributed, analyzed and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • Refers to SW-846 Method 7000A Section 8.0 • SW-846 Method 7000A Section 8.0 recommends quality control data be maintained and available for easy reference or inspection • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field sample analysis • Method blanks required once per batch per SW-846 Chapter One, various acceptance criteria recommended • Matrix spikes required once per batch in SW-846 Method 7000A Section 8.0, acceptance criteria not addressed • Matrix spike duplicates required once per batch in SW-846 Method 7000A Section 8.0, acceptance criteria not addressed • Laboratory control samples (reference standard) required once per batch in SW-846 Method 7000A Section 8.0, acceptance criteria not addressed • Blind audit samples not addressed, however participation in an external performance evaluation program is	• Procedure 650.2 quality control requirements meet or exceed SW-846 Methods quality control requirements • Procedure 650.2 provides a better defined quality control program than SW-846 Methods

TABLE C12-11 (CONTINUED)
COMPARISON OF SW-846 METHODS 7000A, 7041, 7081, 7091, 7131A, 7191, 7421, 7761, 7841, 7911, AND 7951 AND METHODS MANUAL PROCEDURES 650.2

Methods Manual Procedure 650.2 Section	Corresponding SW-846 Methods Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Methods listed in Table 1	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Methods 7000A, 7041, 7081, 7091, 7131A, 7191, 7421, 7761, 7841, 7911, and 7951	

TABLE C12-12
COMPARISON OF SW-846 METHOD 7471A AND METHODS MANUAL PROCEDURE 650.3

Methods Manual Procedure 650.3 Section	Corresponding SW-846 Method 7471A Section	Comments
Section 1.0 Scope and Application • Program quality assurance objectives (QAOs) for mercury included as Table 1 • Refers directly to SW-846 Methods 7471A and 7000A • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Method 7471A is approved for measuring total mercury • Batch not to exceed 20 samples as per SW-846 Chapter One	• Program QAOs are derived based on SW-846 Method 7471A (precision and accuracy) and regulatory requirements (PRDL and PRQL)
Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Method 7471A	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 7471A	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 7471A	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 7471A	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • *Refers directly and only to SW-846* Method 7471A	Section 5.0 Reagents	

TABLE C12-12 (CONTINUED)
COMPARISON OF SW-846 METHOD 7471A AND METHODS MANUAL PROCEDURE 650.3

Methods Manual Procedure 650.3 Section	Corresponding SW-846 Method 7471A Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter Nine for sampling plan considerations • Requires all sample containers prewashed with detergents, acids, and reagents • Allows for both glass and plastic containers • *Requires nonaqueous samples to be* refrigerated (when possible) and analyzed as soon as possible	• *Procedure 120.1 is a program specific* procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and *preservation requirements for samples* included in SW-846 Chapter Nine
Section 8.0 Procedure • Refers directly and only to SW-846 Method 7471A for sample and standard preparation and analysis • Allows for use of fluorescence *detection instead of absorption as long* as all other method requirements are met • All calibration requirements are summarized in Table 2	Section 7.0 Procedure • Subsections 7.1 through 7.4 address sample and standard preparation and analysis • Calibration criteria are provided in SW-846 Method 7000A Subsections 8.2 and 8.3 • Serial dilution and post-digestion spike criteria are provided in SW-846 Method 7000A Subsection 8.6	• Calibration requirements in Procedure 650.3 are the same as found in SW-846 Method 7000A. • Procedure 650.3 requires 5 standards in the initial calibration; SW-846 Method 7000A *requires a minimum of* three standards.
Section 9.0 Calculations • Allows for reading mercury concentration from calibration curve or directly from instrument readout • Requires sample dilution taken into account • Specifies results reported in mg/kg wet weight basis • Provides for conversion to mg/kg dry weight	Subsections 7.5 and 7.6 • Subsections 7.5 and 7.6 address constructing a calibration curve and determining mercury concentration • Subsection 7.6 requires sample dilution taken into account and concentrations appropriately qualified (e.g., dry weight)	M

TABLE C12-12 (CONTINUED)
COMPARISON OF SW-846 METHOD 7471A AND METHODS MANUAL PROCEDURE 650.3

Methods Manual Procedure 650.3 Section	Corresponding SW-846 Method 7471A Section	Comments
Section 10.0 Quality Control • Refers to Subsections 8.5, 8.6, and 8.7 of SW-846 Method 7000A • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, instrument detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory blanks must be run once per batch, acceptance criterion is ≤3 x IDL • Matrix spikes must be run once per batch, acceptance criterion is 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are ≤30 RPD and 80-120 %R • Laboratory control samples must be run once per batch, acceptance criterion is 80-120 %R • Blind audit samples are distributed, analyzed and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • Refers to SW-846 Method 7000 Section 8.0 • SW-846 Method 7000 Section 8.0 recommends quality control data be maintained and available for easy reference or inspection • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field analysis • Method blanks required once per batch per SW-846 Chapter One, various acceptance criteria recommended • Matrix spikes required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Matrix spike duplicates required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Laboratory control samples required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Blind audit samples not addressed, however participation on an external performance demonstration program is addressed in SW-846 Chapter One	• Procedure 650.3 quality control requirement meet or exceed SW-846 7471A quality control requirements • Procedure 650.3 provides a better defined quality control program than SW-846 Method 7471A

TABLE C12-12 (CONTINUED)
COMPARISON OF SW-846 METHOD 7471A AND METHODS MANUAL PROCEDURE 650.3

Methods Manual Procedure 650.3 Section	Corresponding SW-846 Method 7471A Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 7471A	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 7471A	

TABLE C12-13
COMPARISON OF SW-846 METHOD 7061A AND METHODS MANUAL PROCEDURE 650.4

Methods Manual Procedure 650.4 Section	Corresponding SW-846 Method 7061A Section	Comments
Section 1.0 Scope and Application • Program quality assurance objectives (QAOs) for arsenic included as Table 1 • Refers directly to SW-846 Methods 7061A and 7000A • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Method 7061A is approved for determining the concentration of arsenic in waste • Batch not to exceed 20 samples as per SW-846 Chapter One	• Program QAOs are derived based on SW-846 Method 7061A (precision and accuracy) and regulatory requirements (PRDL and PRQL)
Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Method 7061A	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 7061A	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 7061A	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 7061A	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Method 7061A	Section 5.0 Reagents	

TABLE C12-13 (CONTINUED)
COMPARISON OF SW-846 METHOD 7061A AND METHODS MANUAL PROCEDURE 650.4

Methods Manual Procedure 650.4 Section	Corresponding SW-846 Method 7061A Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter Nine for sampling plan considerations • Requires all sample containers prewashed with detergents, acids, and reagents • Allows for both glass and plastic containers • Requires nonaqueous samples to be refrigerated (when possible) and analyzed as soon as possible	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846, Chapter Nine
Section 8.0 Procedure • Refers directly and only to SW-846 Method 7061A for procedural requirements • All calibration requirements are summarized in Table 2	Section 7.0 Procedure • Provides sample and standard preparation and analytical procedures • Calibration criteria are provided in SW-846 Method 7000A Subsections 8.2 and 8.3 • Serial dilution and post-digestion spike criteria are provided in SW-846 Method 7000A Subsection 8.6	• Calibration requirements in Procedure 650.4 are the same as found in SW-846 Method 7000A. • Procedure 650.4 requires 5 standards in the initial calibration; SW-846 Method 7000A requires a minimum of three standards.
Section 9.0 Calculations • Allows for reading arsenic concentration from calibration curve or directly from instrument readout • Requires sample dilution taken into account • Specifies results reported in mg/kg wet weight basis • Provides for conversion to mg/kg dry weight	• SW-846 Method 7061A does not address determining the concentration of arsenic • SW-846 Method 7000A Subsection 7.4 addresses determining metal concentration	

TABLE C12-13 (CONTINUED)
COMPARISON OF SW-846 METHOD 7061A AND METHODS MANUAL PROCEDURE 650.4

Methods Manual Procedure 650.4 Section	Corresponding SW-846 Method 7061A Section	Comments
Section 10.0 Quality Control • Refers to SW-846 Method 7000A Subsections 8.5, 8.6, and 8.7 • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, instrument detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory blanks must be run once per batch, acceptance criterion is ≤3 x IDL • Matrix spikes must be run once per batch, acceptance criterion is 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are ≤30 RPD and 80-120 %R • Laboratory control samples must be run once per batch, acceptance criterion is 80-120 %R • Blind audit samples are distributed, analyzed and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • Refers to SW-846 Method 7000 Section 8.0 • SW-846 Method 7000 Section 8.0 recommends quality control data be maintained and available for easy reference or inspection • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however, SW-846 Chapter One requires demonstration of method performance prior to field analysis • Method blanks required once per batch per SW-846 Chapter One, various acceptance criteria recommended • Matrix spikes required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Matrix spike duplicates required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Laboratory control samples required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Blind audit samples not addressed, however participation on an external performance demonstration program is addressed in SW-846 Chapter One	• *Procedure 650.4 quality control* requirements meet or exceed SW-846 Method 7061A quality control requirements • Procedure 650.4 provides a better defined quality control program than SW-846 Method 7061A

TABLE C12-13 (CONTINUED)
COMPARISON OF SW-846 METHOD 7061A AND METHODS MANUAL PROCEDURE 650.4

Methods Manual Procedure 650.4 Section	Corresponding SW-846 Method 7061A Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 7061A	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 7061A	

TABLE C12-14
COMPARISON OF SW-846 METHOD 7062 AND METHODS MANUAL PROCEDURE 650.5

Methods Manual Procedure 650.5 Section	Corresponding SW-846 Method 7062 Section	Comments
Section 1.0 Scope and Application • Program quality assurance objectives (QAOs) for antimony and arsenic included as Table 1 • Refers directly to SW-846 Methods 7062 and 7000A • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Method 7062 is approved for determining 1 µg/L to 400 µg/L of antimony and arsenic in waste • Batch not to exceed 20 samples as per SW-846 Chapter One	• Program QAOs are derived based on SW-846 Method 7062 (precision and accuracy) and regulatory requirements (PRDL and PRQL)
Section 2.0 Summary of Procedure • Refers directly to SW-846 Method 7062 • *Requires sample preparation according* to Methods Manual Procedure 610.1 before evaporating the samples to near dryness at the end of the digestion	Section 2.0 Summary of Method • Refers to SW-846 Method 3050 for digestion	• SW-846 Method 3051 is provided as an alternative to Method 3050 • Procedure 610.1 is based on SW-846 Method 3051 (see Table C-12-7)
Section 3.0 Interferences • Refers directly and only to SW-846 Method 7062	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 7062	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 *Method 7062*	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Method 7062	Section 5.0 Reagents	

TABLE C12-14 (CONTINUED)
COMPARISON OF SW-846 METHOD 7062 AND METHODS MANUAL PROCEDURE 650-5

Methods Manual Procedure 650.5 Section	Corresponding SW-846 Method 7062 Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter Nine for sampling plan considerations • Requires all sample containers prewashed with detergents, acids, and reagents • Allows for both glass and plastic containers • Requires nonaqueous samples to be refrigerated (when possible) and analyzed as soon as possible	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846, Chapter Nine
Section 8.0 Procedure • Refers directly and only to SW-846 Method 7062 for procedural requirements • All calibration requirements are summarized in Table 2	Section 7.0 Procedure • Provides analytical procedures • Calibration criteria are provided in SW-846 Method 7000A Subsections 8.2 and 8.3 • Serial dilution and post-digestion spike criteria are provided in SW-846 Method 7000A Subsection 8.6	• Calibration requirements in Procedure 650.5 are the same as found in SW-846 Method 7000A. • Procedure 650.5 requires 5 standards in the initial calibration; Method 7000A requires a minimum of three standards.
Section 9.0 Calculations • Allows for reading antimony and arsenic concentration from calibration curve or directly from instrument readout • Requires sample dilution taken into account • Specifies results reported in mg/kg wet weight basis • Provides for conversion to mg/kg dry weight	Subsections 7.6 and 7.7 • Addresses reading the concentration of antimony and arsenic from the calibration curve and using method of standard additions	

TABLE C12-14 (CONTINUED)
COMPARISON OF SW-846 METHOD 7062 AND METHODS MANUAL PROCEDURE 650-5

Methods Manual Procedure 650.5 Section	Corresponding SW-846 Method 7062 Section	Comments
Section 10.0 Quality Control • Refers to SW-846 Method 7000A Subsections 8.5, 8.6, and 8.7 • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, instrument detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory blanks must be run once per batch, acceptance criterion is ≤3 x IDL • Matrix spikes must be run once per batch, acceptance criterion is 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are ≤30 RPD and 80-120 %R • Laboratory control samples must be run once per batch, acceptance criterion is 80-120 %R • Blind audit samples are distributed, analyzed and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • Refers to SW-846 Method 7000 Section 8.0 • SW-846 Method 7000 Section 8.0 recommends quality control data be maintained and available for easy reference or inspection • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field analysis • Method blanks required once per batch per SW-846 Chapter One, various acceptance criteria recommended • Matrix spikes required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Matrix spike duplicates required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Laboratory control samples required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Blind audit samples not addressed, however participation on an external performance demonstration program is addressed in SW-846 Chapter One	• Procedure 650.5 quality control requirements meet or exceed SW-846 Method 7062 quality control requirements • Procedure 650.5 provides a better defined quality control program than SW-846 Method 7062

TABLE C12-14 (CONTINUED)
COMPARISON OF SW-846 METHOD 7062 AND METHODS MANUAL PROCEDURE 650-5

Methods Manual Procedure 650.5 Section	Corresponding SW-846 Method 7062 Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 7062	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 7062	

TABLE C12-15
COMPARISON OF SW-846 METHOD 7741A AND METHODS MANUAL PROCEDURE 650.6

Methods Manual Procedure 650.6 Section	Corresponding SW-846 Method 7741A Section	Comments
Section 1.0 Scope and Application • Program quality assurance objectives (QAOs) for selenium included as Table 1 • Refers directly to SW-846 Methods 7741A and 7000A • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Method 7741A is approved for determining the concentration of selenium in waste • Batch not to exceed 20 samples as per SW-846 Chapter One	• Program QAOs are derived based on SW-846 Method 7741A (precision and accuracy) and regulatory requirements (PRDL and PRQL)
Section 2.0 Summary of Procedure • Refers directly and only to SW-846 Method 7741A	Section 2.0 Summary of Method	
Section 3.0 Interferences • Refers directly and only to SW-846 Method 7741A	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 7741A	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 7741A	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Method 7741A	Section 5.0 Reagents	

TABLE C12-15 (CONTINUED)
COMPARISON OF SW-846 METHOD 7741A AND METHODS MANUAL PROCEDURE 650.6

Methods Manual Procedure 650.6 Section	Corresponding SW-846 Method 7741A Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • *Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP*	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter Nine for sampling plan considerations • *Requires all sample containers* prewashed with detergents, acids, and reagents • Allows for both glass and plastic containers • Requires nonaqueous samples to be refrigerated (when possible) and analyzed as soon as possible	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through *coring and subsampling. Procedure* 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846, Chapter Nine
Section 8.0 Procedure • Refers directly and only to SW-846 Method 7741A for procedural requirements • All calibration requirements are summarized in Table 2	Section 7.0 Procedure • Provides sample and standard preparation and analytical procedures • Calibration criteria are provided in SW-846 Method 7000A Subsections 8.2 and 8.3 • Serial dilution and post-digestion spike criteria are provided in SW-846 Method 7000A Subsection 8.6	• Calibration requirements in Procedure 650.6 are the same as found in SW-846 Method 7000A. • Procedure 650.6 requires 5 standards in the initial calibration; SW-846 Method 7000A requires a minimum of three standards.
Section 9.0 Calculations • Allows for reading selenium concentration from calibration curve or directly from instrument readout • Requires sample dilution taken into account • Specifies results reported in mg/kg wet weight basis • Provides for conversion to mg/kg dry weight	• SW-846 Method 7741A does not address determining the concentration of selenium • SW-846 Method 7000A Subsection 7.4 addresses determining metal concentration	

TABLE C12-15 (CONTINUED)
COMPARISON OF SW-846 METHOD 7741A AND METHODS MANUAL PROCEDURE 650.6

Methods Manual Procedure 650.6 Section	Corresponding SW-846 Method 7741A Section	Comments
Section 10.0 Quality Control • Refers to SW-846 Method 7000A Subsections 8.5, 8.6, and 8.7 • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, instrument detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory blanks must be run once per batch, acceptance criterion is ≤3 x IDL • Matrix spikes must be run once per batch, acceptance criterion is 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are ≤30 RPD and 80- 120 %R • Laboratory control samples must be run once per batch, acceptance criterion is 80-120 %R • Blind audit samples are distributed, analyzed and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • Refers to SW-846 Method 7000 Section 8.0 • SW-846 Method 7000 Section 8.0 recommends quality control data be maintained and available for easy reference or inspection • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field analysis • Method blanks required once per batch per SW-846 Chapter One, various acceptance criteria recommended • Matrix spikes required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Matrix spike duplicates required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Laboratory control samples required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Blind audit samples not addressed, however participation on an external performance demonstration program is addressed in SW-846 Chapter One	• Procedure 650.6 quality control requirements meet or exceed SW-846 Method 7741A quality control requirements • Procedure 650.6 provides a better defined quality control program than SW-846 Method 7741A

TABLE C12-15 (CONTINUED)
COMPARISON OF SW-846 METHOD 7741A AND METHODS MANUAL PROCEDURE 650.6

Methods Manual Procedure 650.6 Section	Corresponding SW-846 Method 7741A Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 7741A	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 7741A	

TABLE C12-16
COMPARISON OF SW-846 METHOD 7742 AND METHODS MANUAL PROCEDURE 650.7

Methods Manual Procedure 650.7 Section	Corresponding SW-846 Method 7742 Section	Comments
Section 1.0 Scope and Application • Program quality assurance objectives (QAOs) for selenium included as Table 1 • Refers directly to SW-846 Methods 7742 and 7000A • Requires samples to be analyzed in batches not to exceed 20 samples	Section 1.0 Scope and Application • Method 7742 is approved for determining 3 µg/L to 750 µg/L of selenium in waste • Batch not to exceed 20 samples as per SW-846 Chapter One	• Program QAOs are derived based on SW-846 Method 7742 (precision and accuracy) and regulatory requirements (PRDL and PRQL)
Section 2.0 Summary of Procedure • Refers directly to SW-846 Method 7742 • Requires sample preparation according to Methods Manual Procedure 610.1 before evaporating the samples to near dryness at the end of the digestion	Section 2.0 Summary of Method • Refers to SW-846 Method 3050 for digestion	• SW-846 Method 3051 is provided as an alternative to Method 3050 • Procedure 610.1 is based on SW-846 Method 3051 (see Table C-12-7)
Section 3.0 Interferences • Refers directly and only to SW-846 Method 7742	Section 3.0 Interferences	
Section 4.0 Safety • Responsibilities for safety and health and training	No equivalent section in SW-846 Method 7742	
Section 5.0 Apparatus and Materials • Refers directly and only to SW-846 Method 7742	Section 4.0 Apparatus and Materials	
Section 6.0 Reagents • Refers directly and only to SW-846 Method 7742	Section 5.0 Reagents	

TABLE C12-16 (CONTINUED)
COMPARISON OF SW-846 METHOD 7742 AND METHODS MANUAL PROCEDURE 650.7

Methods Manual Procedure 650.7 Section	Corresponding SW-846 Method 7742 Section	Comments
Section 7.0 Sample Collection, Preservation and Handling • Requires sample collection according to Methods Manual Procedure 120.1 • Requires sample handling and chain-of-custody according to Section 6.0 of the QAPP	Section 6.0 Sample Collection, Preservation and Handling • Refers to SW-846 Chapter Nine for sampling plan considerations • Requires all sample containers prewashed with detergents, acids, and reagents • Allows for both glass and plastic containers • Requires nonaqueous samples to be refrigerated (when possible) and analyzed as soon as possible	• Procedure 120.1 is a program specific procedure developed specifically for the collection of samples from containers of TRU waste through coring and subsampling. Procedure 120.1 refers to SW-846 for guidance and requirements for sampling. • Section 6.0 of the QAPP incorporates applicable sample handling and preservation requirements for samples included in SW-846, Chapter Nine
Section 8.0 Procedure • Refers directly and only to SW-846 Method 7742 for procedural requirements • All calibration requirements are summarized in Table 2	Section 7.0 Procedure • Provides analytical procedures • Calibration criteria are provided in SW-846 Method 7000A Subsections 8.2 and 8.3 • Serial dilution and post-digestion spike criteria are provided in SW-846 Method 7000A Subsection 8.6	• Calibration requirements in Procedure 650.7 are the same as found in SW-846 Method 7000A. • Procedure 650.7 requires 5 standards in the initial calibration; Method 7000A requires a minimum of three standards.
Section 9.0 Calculations • Allows for reading selenium concentration from calibration curve or directly from instrument readout • Requires sample dilution taken into account • Specifies results reported in mg/kg wet weight basis • Provides for conversion to mg/kg dry weight	Subsections 7.6 and 7.7 • Addresses reading the concentration of selenium from the calibration curve and using method of standard additions	

TABLE C12-16 (CONTINUED)
COMPARISON OF SW-846 METHOD 7742 AND METHODS MANUAL PROCEDURE 650.7

Methods Manual Procedure 650.7 Section	Corresponding SW-846 Method 7742 Section	Comments
Section 10.0 Quality Control • Refers to SW-846 Method 7000A Subsections 8.5, 8.6, and 8.7 • Requires formal quality control program • Requires demonstration of acceptable performance prior to analyzing program samples • Specifies equations for calculating analytical precision, accuracy, instrument detection limit, and percent recovery for quality control samples • Method performance samples must be run initially and semiannually, acceptance criteria are Table 1 QAOs • Laboratory blanks must be run once per batch, acceptance criterion is ≤3 x IDL • Matrix spikes must be run once per batch, acceptance criterion is 80-120 %R • Matrix spike duplicates must be run once per batch, acceptance criteria are ≤30 RPD and 80-120 %R • Laboratory control samples must be run once per batch, acceptance criterion is 80-120 %R • Blind audit samples are distributed, analyzed and reported as part of the DOE Performance Demonstration Program	Section 8.0 Quality Control • Refers to SW-846 Method 7000 Section 8.0 • SW-846 Method 7000 Section 8.0 recommends quality control data be maintained and available for easy reference or inspection • SW-846 Chapter One includes equations for calculating precision, accuracy, and method detection limit • Method performance samples not addressed, however SW-846 Chapter One requires demonstration of method performance prior to field analysis • Method blanks required once per batch per SW-846 Chapter One, various acceptance criteria recommended • Matrix spikes required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Matrix spike duplicates required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Laboratory control samples required once per batch in SW-846 Method 7000 Subsection 8.4, acceptance criteria not addressed • Blind audit samples not addressed, however participation on an external performance demonstration program is addressed in SW-846 Chapter One	• Procedure 650.7 quality control requirements meet or exceed SW-846 Method 7742 quality control requirements • Procedure 650.7 provides a better defined quality control program than SW-846 Method 7742

TABLE C12-16 (CONTINUED)
COMPARISON OF SW-846 METHOD 7742 AND METHODS MANUAL PROCEDURE 650.7

Methods Manual Procedure 650.7 Section	Corresponding SW-846 Method 7742 Section	Comments
Section 11.0 Procedure Performance • Refers directly and only to SW-846 Method 7742	Section 9.0 Method Performance	
Section 12.0 References • *Performance Demonstration Program Plan for the Analysis of Solidified Wastes for the Transuranic Waste Characterization Program* (DOE 1995a) • *Transuranic Waste Characterization Quality Assurance Program Plan* (DOE 1995b) • *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846* (EPA 1995)	Section 10.0 References • See SW-846 Method 7742	

APPENDIX C13

WIPP WASTE INFORMATION SYSTEM DATA DICTIONARY

WWIS DATA DICTIONARY (DRAFT Version 0.1)

NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
I.	Aspiration Method	None	Method used for aspirating the container prior to shipment per Appendix 1.3.7 of the TRUPACT-II Safety Analysis Report. Method is to be identified as either Option 1, 2, or 3.	A1	Edit check of either 1, 2, or 3. No Blanks	No
II.	Aspiration Period	Days	Time that the container must be aspirated based on the aspiration method selected per Appendix 3.6.11 of the TRUPACT-II Safety Analysis Report	999	Look-up table of container aspiration periods	No
III.	Assay Characterization Method	None	Identifies the site-specific approved characterization method(s) or system(s) that was used to identify and quantify the radionuclide masses	A4	Look-up table listing approved methods	No
IV.	Assay Date	None	The date when the assay was completed at the certification site	Date	None	No
V.	Assembly Identification Number	None	A unique number assigned by the shipper to an assembly. The number consists of the 2-letter site identification code followed by the last two digits of the year and the 4-digit package assembly number.	AAYY9999	Unique number Each container in an assembly (e.g. a seven pack) must be of the same *shipping category*	No
VI.	Bore Hole Number	None	Disposal location within the WIPP where a remote handled waste canister is disposed.	A6	None	No
VII.	Characterization Methods	None	Identifies the approved EPA characterization methods or systems that were used to obtain the waste characterization data.	A20	Look-up table of characterization techniques	No
VIII.	Column Height	None	The column height within a room/drift at the WIPP which designates the location within the height of the room/drift where the container is emplaced	9	None	No
IX.	Column Number	None	The column number within a room/drift at the WIPP which designates the location within the width of the room/drift where the container is emplaced	9	None	No
X.	Comments	None	Data field to be used to provide additional information	A200	None	No
XI.	Contact Dose Rate of Container (Beta/Gamma)	mrem/hr	Beta/gamma contact dose rate at the surface of the Type A container	9999999	≤ 200 mrem/hr for CH ≤ 1000 rem/hr for RH	No
XII.	Contact Dose Rate of Container (Neutron)	mrem/hr	Neutron contact dose rate at the surface of the Type A container	9999999	≤ 270 mrem/hr for RH	No
XIII.	Contact Dose Rate of Container (Total)	mrem/hr	Total contact dose rate at the surface of the Type A container	9999999	≤ 200 mrem/hr for CH ≤ 1000 rem/hr for RH	Yes

WWIS DATA DICTIONARY (DRAFT Version 0.1)

NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
XIV.	Contact Dose Rate of Package (Total at Surface)	mrem/hr	Total contact dose rate at the surface of the Type B packaging (TRUPACT-II and RH Cask)	9999999	≤ 200 mrem/hr	No
XV.	Contact Phone	None	Phone number of the shipper technical contact. Number to be listed is to include area code + prefix + number	A12	None	No
XVI.	Container Closure Date	None	Date the container was closed	Date	None	No
XVII.	Container Identification Number	None	A unique identification number assigned to each container	AA999999999 99	Unique number	No
XVIII.	Container Liner Punctured	None	Identifies whether the container liner was punctured (if applicable)	Logical (yes/no)	If field 16 had identified the use of a liner, reject if "no"	No
XIX.	Container Liner Type	None	Identifies the type of container liner (if applicable)	A3	Look-up table of standard liners. Look-up table is also to contain the option of "no liner".	No
XX.	Container Type Code	None	A 3-digit container type code	A3	Look-up table of approved container type codes 001 55-gallon drum 002 SWB 003 TDOP 004 Pipe component (6") 005 Pipe component (12") 101 RH-TRU 72-B canister 102 RH-TRU drum canister	No
XXI.	Decay Heat	Watts	The rate of deposition of thermal energy within the container associated with the decay of radionuclides. The terms "decay heat" and "thermal power" are synonymous.	9.99E+99	None	Yes
XXII.	Decay Heat of Package	Watts	Sum of decay heats of containers within the package	9.99E+99	≤ 40 watts per TRUPACT-II package	Yes
XXIII.	Decay Heat Uncertainty	Watts	Uncertainty in the decay heat	9.99E+99	None	Yes
XXIV.	Decay Heat Uncertainty of Package	Watts	Square root of the sum of the squares of the container decay heat uncertainties	9.99E+99	None	Yes
XXV.	Decay Heat (Maximum)	Watts	Sum of the decay heat and decay heat uncertainty for a container	9.99E+99	Look-up table containing decay heat limits for each shipping category	Yes
XXVI.	Disposal Date	None	The date when the container is emplaced in the underground of the WIPP	Date	Date equal to or later than the shipment receipt date	No

WWIS DATA DICTIONARY (DRAFT Version 0.1)

NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
XXVII.	Dose Rate of Package at 1 Meter	mrem/hr	Total dose rate at 1 meter from the surface of the Type B packaging (required to assign a transport index)	9999999	None	No
XXVIII.	Dose Rate of Package at 2 Meters	mrem/hr	Total dose rate at 2 meters from the surface of the Type B packaging (TRUPACT-II and RH Cask)	9999999	≤ 10 mrem/hr	No
XXIX.	DOT Description	None	U.S. Department of Transportation description for the Uniform Hazardous Waste Manifest	Memo	None	No
XXX.	Drift Number	None	The geotechnical location within the WIPP where a container is emplaced	A6	None	No
XXXI.	EPA ID	None	U.S. Environmental Protection Agency's number for the waste site having responsibility for shipment of the waste	A15	Look-up table containing the corresponding name and address of the generator	No
XXXII.	Filter Install Date	None	The date the filter was installed in the container	Date	None	No
XXXIII.	Filter Model	None	Vendor model number of the filter used to vent a container	A6	Look-up table listing approved filters	No
XXXIV.	Gas Generation Completion Date	None	The date of test completion for a container shipping category	Date	None	No
XXXV.	Gas Generation Rate - Measured H_2 + CH_4	moles/s	Measured hydrogen and methane gas generation rate for a container shipping category	9.9E+99	Look-up table containing hydrogen and methane gas generation rate limits as a function of packaging layers, content code, and radionuclide activity	No
XXXVI.	Gas Generation Rate - Measured Total	moles/s	Measured total gas generation rate for a container shipping category	9.9E+99	Look-up table containing total gas generation rate limits as a function of packaging layers, content code, and radionuclide activity	No
XXXVII.	Hazardous ID Code	None	Hazardous waste EPA codes listed for the container. This is a multiple occurring field.	A4	Look-up table listing the codes	No
XXXVIII.	Headspace Gas Innermost Layer: Analyte Name	None	The element, ion, or compound an analysis seeks to determine; the element of interest	A20	Look-up table containing the 29 targeted analytes (this is a multiple occurring data field)	No
XXXIX.	Headspace Gas Innermost Layer: Characterization Method	None	Identifies the characterization method or system that was used to obtain the innermost layer gas data.	A30	Look-up table listing approved methods	No

WWIS DATA DICTIONARY (DRAFT Version 0.1)

NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
XL.	Headspace Gas Innermost Layer: Date Analyzed	None	Date gas of innermost layer was analyzed	Date	≤ 34 days from date sampled	No
XLI.	Headspace Gas Innermost Layer: Date Sampled	None	Date gas of innermost layer was sampled	Date	None	No
XLII.	Headspace Gas Innermost Layer: Flammable Gas Concentrations	Volume Percent	Concentrations of flammable gases in the innermost layer including but not limited to H_2 and CH_4	999	≤ 5% (H_2 + CH_4)	No
XLIII.	Headspace Gas Innermost Layer: Identification	None	Innermost layers of confinement must be consecutively numbered and labeled starting with 1 as they are sampled and removed from the waste container during visual examination. The sample collected from each innermost layer of confinement must be referenced to that particular inner most layer of confinement and to the waste container.	99	None	No
XLIV.	Headspace Gas Innermost Layer: VOC Concentrations	ppmv	Concentrations of the 29 target VOCs in the innermost layer	999999	This is a multiple occurring data field	No
XLV.	Headspace Gas: Analyte Name	None	The element, ion, or compound an analysis seeks to determine; the element of interest. This is a multiple occurring field.	A20	Look-up table containing the 29 targeted VOC analytes	No
XLVI.	Headspace Gas: Characterization Method	None	Identifies the characterization method or system used to obtain the headspace gas data.	A30	Look-up table listing approved methods	No
XLVII.	Headspace Gas: Date Analyzed	None	Date headspace gas was analyzed	Date	≤ 34 days after sampling date	No
XLVIII.	Headspace Gas: Date Sampled	None	Date headspace gas was sampled	Date	None	No
XLIX.	Headspace Gas: Flammable Gas Concentrations	Volume Percent	Concentrations of H_2 plus CH_4 flammable gases in the headspace	A20	≤ 5% (H_2 + CH_4)	No
L.	Headspace Gas: Total Flammable VOC Concentration	ppmv	Total concentration of target flammable VOCs in the headspace.	999999	≤ 500 ppm total flammable VOCs	Yes

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NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
LI.	*Headspace Gas: VOC* Concentrations	*ppmv*	*Concentrations of the 29 target VOCs in the* headspace. This is a multiple occurring field.	*999999*	*No limits for the target VOCs* except for the following: carbon tetrachoride ≤ 7510 chloroform ≤ 6325 1,1-dichloroethene ≤ 28750 1,2-dichloroethane ≤ 9100 methylene chloride ≤ 368500	Yes
LII.	ICV Closure Date	None	The date when the inner containment vessel was closed	Date	None	No
LIII.	Item Description Code	None	A site specific numerical code applied to individual waste forms to identify their source	A4	Look-up table listing approved item description codes taken from the site's certification plan	No
LIV.	Layers of Packaging	None	Identifies the number of layers of plastic confinement within a container	9	None	No
LV.	Manifest Document Number	None	Identifies the manifest number assigned to the waste shipment	A5	None	No
LVI.	Nondestructive Examination	None	The radiometric examination of retrievably stored waste	Logical (yes/no)	100% sampling of retrievably stored waste	No
LVII.	Packaging Serial Number	None	The TRUPACT-II, cask, or other Type B shipping container number	A3	None	No
LVIII.	Panel Number	None	The panel number in which the container is disposed	A2	None	No
LIX.	PCB Concentration	ppm	The concentration of polychlorinated biphenyls (PCBs) in the container	9999	≤ 50 ppm No blanks	No
LX.	Plutonium-239 Equivalent Activity	PE-Ci	The plutonium-239 equivalent activity per container	9.9E+99	≤ 80 PE-Ci per drum ≤ 130 PE-Ci per SWB ≤ 1000 PE-Ci per canister	Yes
LXI.	Plutonium-239 FGE per *Type B RH-TRU 72-B* Waste Shipping Package (Total)	FGE	The Plutonium-239 FGE plus the Plutonium-239 FGE *uncertainty per RH-TRU 72-B waste shipping* package	9.9E+99	≤ 325 FGE	Yes
LXII.	Plutonium-239 Fissile Gram Equivalent	FGE	The Plutonium-239 fissile gram equivalent per container	9.9E+99	≤ 200 FGE per drum ≤ 325 FGE per SWB ≤ 325 FGE per canister ≤ 200 FGE per pipe overpack package	Yes

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NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
LXIII.	Plutonium-239 Fissile Gram Equivalent (Total)	FGE	The Plutonium-239 FGE plus twice the Plutonium-239 FGE uncertainty per container	9.9E+99	≤ 200 FGE per drum ≤ 325 FGE per SWB ≤ 325 FGE per canister ≤ 200 FGE per pipe overpack package	Yes
LXIV.	Plutonium-239 Fissile Gram Equivalent per Type B Package	FGE	Sum of the Plutonium-239 fissile gram equivalent per container per Type B package	9.9E+99	≤ 325 FGE ≤ 2800 FGE for pipe overpack packages	Yes
LXV.	Plutonium-239 Fissile Gram Equivalent per Type B Package for CH-TRU (Total)	FGE	The Plutonium-239 FGE plus twice the Plutonium-239 FGE uncertainty per Type B package for CH-TRU	9.9E+99	≤ 325 FGE ≤ 2800 FGE for pipe overpack packages	Yes
LXVI.	Plutonium-239 Fissile Gram Equivalent Uncertainty	FGE	The Plutonium-239 fissile gram equivalent uncertainty per container	9.9E+99	None	Yes
LXVII.	Plutonium-239 Fissile Gram Equivalent Uncertainty per Type B Package	FGE	Square root of the sum of the squares of the Plutonium-239 fissile gram equivalent uncertainties per container per Type B package	9.9E+99	None	Yes
LXVIII.	Radionuclide Activity	Curies	Activity of the individual radionuclides	9.9E+99	None	No
LXIX.	Radionuclide Activity Uncertainty	Curies	Uncertainty in the activity of the individual radionuclides	9.9E+99	None	No
LXX.	Radionuclide Activity Uncertainty (Total)	Curies	Uncertainty in the summation of activities of the individual radionuclides within a container	9.9E+99	None	Yes
LXXI.	Radionuclide Highway Route Controlled Quantity	None	A highway route controlled quantity is that quantity of normal form material in a type B package which exceeds 3000 times the A2 value of the radionuclides as specified in 49 CFR 173.443 or 30,000 curies, whichever is least	Logical (yes/no)	yes if > 1 no if ≤ 1	Yes
LXXII.	Radionuclide Mass	Grams	Mass of the individual radionuclides	9.9E+99	None	Yes
LXXIII.	Radionuclide Mass Uncertainty	Grams	Uncertainty in the mass of the individual radionuclides	9.9E+99	None	Yes
LXXIV.	Radionuclide Reportable Quantity	None	A reportable quantity is that quantity of material in a type B package which equals or exceeds the quantity listed in the Appendix to 49 CFR 172.101	Logical (yes/no)	None	Yes
LXXV.	Radionuclide Symbol	None	The radionuclide the analysis seeks to determine	A7	Look-up table containing the predominant radionuclides (this is a multiple occurring data field)	No

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NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
LXXVI.	Reporting Flag	None	Designator which is used by the analytical laboratory to identify detection levels of the various analytes within a sample	A2	Coded to indicate appropriate flag per QAPP requirements	No
LXXVII.	Room Number	None	The room number within a panel in which the container is emplaced	A1	None	No
LXXVIII.	Row Number	None	The row number within a room/drift at the WIPP which designates the location within the length of the room/drift where the container is emplaced	A4	None	No
LXXIX.	Shipment Certification Date	None	The date when the shipment was certified for transport to the WIPP	Date	Shipment certification date ≥ WAC certification date	No
LXXX.	Shipment Number	None	Number assigned to the shipment	A12	Unique	No
LXXXI.	Shipment Receipt Date	None	The date the waste shipment was received at the WIPP	Date	Shipment receipt date ≥ shipment send date	No
LXXXII.	Shipment Send Date	None	The date the waste shipment left the shipper site (to be entered at the time of receipt at the WIPP using date on manifest)	Date	Shipment send date ≥ shipment certification date	No
LXXXIII.	Shipping Category	None	A category under which a content code is shipped	A8	All containers within a package must be of the same shipping category	No
LXXXIV.	Site Address	None	Address of the waste site having responsibility for shipment of the waste	A50	None	No
LXXXV.	Site Name	None	Name of the site which shipped the waste	A30	None	No
LXXXVI.	Solid Waste Metals: Analyte Name	None	The element, ion, or compound an analysis seeks to determine; the element of interest	A50	Look-up table of target solid waste metal analytes (this is a multiple occurring field)	No
LXXXVII.	Solid Waste Metals: Concentration	mg/kg	The concentration of the solid waste metal analytes the analysis seeks to determine	9.99E+99	None	No
LXXXVIII.	Solid Waste Metals: Date Analyzed	None	The date solid waste metals were analyzed	Date	≤ 180 days after sampling date ≤ 28 days for mercury	No
LXXXIX.	Solid Waste Metals: Date Sampled	None	The date solid waste metals were sampled	Date	None	No
XC.	Solid Waste Semi-VOC: Analyte Name	None	The element, ion, or compound an analysis seeks to determine; the element of interest	A50	Look-up table of target solid waste semi-VOC analytes (this is a multiple occurring field)	No
XCI.	Solid Waste Semi-VOC: Concentration	mg/kg	The concentration of the solid waste semi-VOC analytes the analysis seeks to determine	9.99E+99	Look-up table of target solid waste semi-VOC analytes	No

NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
XCII.	Solid Waste Semi-VOC: Date Analyzed	None	The date solid waste semi-VOCs were analyzed	Date	≤ 180 days after sampling date	No
XCIII.	Solid Waste Semi-VOC: Date Sampled	None	The date solid waste semi-VOCs were sampled	Date	None	No
XCIV.	Solid Waste VOC: Analyte Name	None	The element, ion, or compound an analysis seeks to determine; the element of interest	A50	Look-up table of target solid waste VOC analytes (this is a multiple occurring field)	No
XCV.	Solid Waste VOC: Concentration	mg/kg	The concentration of the solid waste VOC analytes the analysis seeks to determine	9.99E+99	Look-up table of target solid waste VOC analytes	No
XCVI.	Solid Waste VOC: Date Analyzed	None	The date solid waste VOCs were analyzed	Date	≤ 54 days after sampling date	No
XCVII.	Solid Waste VOC: Date Sampled	None	The date solid waste VOCs were sampled	Date	None	No
XCVIII.	Surface Contamination of Container (Alpha)	dpm/cm²	The removable alpha emitting radionuclide surface contamination on waste containers	9.9E+99	≤ 20 dpm/100 cm² (alpha)	No
XCIX.	Surface Contamination of Container (Beta/Gamma)	dpm/cm²	The removable beta/gamma emitting radionuclide surface contamination on waste containers	9.99E+99	≤ 200 dpm/100 cm² (beta/gamma)	No
C.	Technical Contact	None	Name of the person at the shipper site who is the technical contact for the site. Information is to be recorded based on the last name, first name, and middle initial (if available)	A20	None	No
CI.	Tentatively Identified Compounds (TICs): Date Analyzed	None	The date the TICs were analyzed	Date	See limits in fields 36, 77, 80, and 83	No
CII.	Tentatively Identified Compounds (TICs): Date Sampled	None	The date the TICs were sampled	Date	None	No
CIII.	Tentatively Identified Compounds: Analyte Name	None	Compounds not intially anticipated to be in the waste stream but subsequently identified in either the headspace gas or solid waste analysis	A30	Look-up table of TICs identified in 40 CFR 264, Appendix IX	No
CIV.	Tentatively Identified Compounds: Concentration (mg/kg)	mg/kg	If applicable, the concentrations of compounds not initially anticipated to be in the waste stream but subsequently identified in either the headspace gas or solid waste analysis	9.99E+99	None	No
CV.	Tentatively Identified Compounds: Concentration (ppmv)	ppmv	If applicable, the concentrations of compounds not initially anticipated to be in the waste stream but subsequently identified in either the headspace gas or solid waste analysis	9.99E+99	None	No

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NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
CVI.	Thermal Power Density	Watts/ft³	The thermal power per unit volume of the container	9.9E+99	A flag is to be raised ≥ 0.1 watt/ft3 when averaged over the container	Yes
CVII.	Transporter EPA ID	None	U.S. Environmental Protection Agency *identification number for the transporter of the* waste shipment	A15	Look-up table containing the *corresponding name and* address of the transporter	No
CVIII.	Transporter Name	None	The name of the transporter of the waste shipment	A25	None	No
CIX.	TRU Alpha Activity	Curies	Summation of the alpha activities of the transuranic (TRU) isotopes within a container	9.9E+99	None	Yes
CX.	TRU Alpha Activity Concentration	Curies per gram	Summation of the alpha activities of the transuranic isotopes divided by the mass of the waste within a container (excluding the masses of the container, liner (if applicable), and shielding (if applicable))	9.9E+99	> 100 nCi/gram	Yes
CXI.	TRU Alpha Activity Concentration Uncertainty	Curies per gram	Uncertainty in the TRU waste alpha activity concentration	9.9E+99	None	
CXII.	TRU Alpha Activity Uncertainty	Curies	Uncertainty in the TRU waste alpha activity	9.9E+99	None	Yes
CXIII.	TRUCON Content Code	None	The TRUCON content code which describes the contents of the container based on the site Item Description Code.	A6	Look-up table of approved content codes	No
CXIV.	*TRUPACT-II OCA Lid* Number	None	*The TRUPACT-II OCA lid number*	A8	None	No
CXV.	Vehicle Type	None	The type of vehicle used to transport the waste.	A1	Look-up table containing either "R" for railcar or "T" for truck	No
CXVI.	Vent/Puncture Date	None	The date when the container was vented and, if applicable, the liner punctured	Date	None	No
CXVII.	Verification Date	None	The date when the radiography or visual inspection was completed at the certification site	Date	None	No
CXVIII.	Verification Method	None	Identifies if radiography or visual inspection was used to identify and quantify the radionuclide masses	A4	Radiography or Visual Inspedtion	No
CXIX.	Visual Examination of Container	None	A statistical sample of retrievably stored waste streams must be examined visually. This field *serves to identify whether visual examination was* performed.	Logical (yes/no)	None	No

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NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
CXX.	WAC Certification Date	None	The date when the certifying official signed the certification statement for the container	Date	None	No
CXXI.	WAC Certification Site	None	The site where the container was certified shall be identified by the 2-character site code as in Table B-3 of the WIPP WAC	A2	Look-up table of site identification codes	No
CXXII.	WAC Exception Number	None	A number granted to the shipper for an exception to the WAC. The number consists of a 2-character site code plus the last two numbers of the year the request was made plus a sequential number beginning with one each year.	AAYYXXX	Look-up table containing approved WAC exception numbers	No
CXXIII.	WAC Revision Number	None	Revision number of the WIPP-WAC to which the waste was certified	A2	≥ Revision 4	No
CXXIV.	Waste Container Fill Factor	Percentage	Estimated percentage of the waste container volume occupied by the waste (zero percent is interpreted as dunnage)	999	Lower bound = 0 Upper bound = 100	No
CXXV.	Waste Handling Code	None	The code is "CH" for contact-handled TRU waste or "RH" for remote-handled TRU waste	A2	None	No
CXXVI.	Waste Material Parameters	None	Waste materials having the potential of impacting performance assessment	A40	Look-up table of waste material parameters	No
CXXVII.	Waste Matrix Code	None	Numerical codes used to classify mixed waste at DOE facilities	A4	Look-up table of waste matrix codes	No
CXXVIII.	Waste Matrix Code Date	None	The date the site Project review of the waste matrix code has been completed	Date	None	No
CXXIX.	Waste Matrix Code Group	None	The group identification taken from the Baseline Inventory Report	A2	None	No
CXXX.	Waste Stream MWIR ID	None	The waste stream MWIR identification number	A6	None	No
CXXXI.	Waste Stream Profile Form Number	None	The waste stream profile form number	9999	Look-up table of approved waste stream profile form numbers	No
CXXXII.	Waste Stream WIPP ID	None	The waste stream WIPP identification number	A6	None	No
CXXXIII.	Waste Type Code	None	The code is "TRU" for non-mixed waste and "MTRU" for mixed waste	A4	None	No
CXXXIV.	Weight (empty container, liner, and shielding)	kg	The weight of the empty container including liner & shielding if applicable	999999.9	None	No
CXXXV.	Weight (Gross)	kg	The gross weight of a container	999999.9	≤ 1000 lbs per drum ≤ 4000 lbs per SWB ≤ 6450 lbs per TDOP ≤ 8000 lbs per canister	No

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NO	FIELD	UNITS	DEFINITION	FORMAT	LIMITS, EDITS, & RANGE CHECKS	CALCULATED
CXXXVI.	Weight of a TRUPACT-II Shipment	kg	The weight of the TRUPACT-II packages including their payloads per railcar or truck	999999.9	The sum of the weights of the TRUPACT-II packages (unique for each serial number) including their payloads per railcar or truck	Yes
CXXXVII.	Weight of Payload Assembly	kg	The weight of a seven pack payload assembly	999999.9	Equal to the sum of the gross weights of the seven drums contained in the payload assembly	Yes
CXXXVIII.	Weight of TRUPACT-II	kg	The weight of a TRUPACT-II package (unique per serial number) including its payload	999999.9	The sum of the weights of the TRUPACT-II (using a look-up table of TRUPACT-II weights per serial number) and the payload.	Yes
CXXXIX.	Weight of Waste	kg	The weight of the waste inside a container	999999.9	None	Yes
CXL.	Weight of Waste Material Parameters	kg	The estimated weight of the waste material parameters	999999.9	Sum of the estimated waste material parameter weights should equal the weight of the waste	Yes
CXLI.	Weight of Waste Uncertainty	kg	The uncertainty in the weight of the waste inside a container	999999.9	None	Yes
CXLII.	Weight Uncertainty (empty container, liner, and shielding)	kg	The uncertainty in the weight of the empty container including liner & shielding if applicable	999999.9	None	No
CXLIII.	Weight Uncertainty (Gross)	kg	The uncertainty in the gross weight of a container	999999.9	None	No

WWIS DATA DICTIONARY (DRAFT Version 0.1)

* NOTES - FIELD SPECIFIC

III. The method used for this designator is to be determined.

IV. Data field will include a list of acronyms for the characterization equipment used.

X. No more than 5% of the RH canisters received at the WIPP are allowed to have dose rates > 100 rem/hr. This requirement necessitates that a running calculation of the percentage be performed in the background. If the percentage exceeds 5%, a flag will be raised. Prior approval by the WIPP is required before RH canisters having dose rates > 100 rem/hr but ≤ 1000 rem/hr may be shipped to the WIPP.

XVI. The look-up table used for this field will also include the internal volume of each container listed. This volume is required for the calculation of thermal power density (see field #90).

XVIII. Reporting of thermal power per container will be made using the calculated value of the container's decay heat.

XXIX. A unique generator name and address corresponds to each generator EPA ID.

XXXVIa. The 11 flammable VOCs, a subset of the 29 target VOC analytes, need to be identified in order to calculate the total flammable VOC concentration required by field #39a.

XXXIX. A flag will be raised if any of the VOC headspace gas concentration limits are exceeded. Based on a running average of these concentrations, a determination will be made whether to accept the container with the outerlying VOC(s).

XXXIXa A flag will be raised if any of the flammable VOC headspace gas concentration limits are exceeded. Based on a running average of these concentrations, a determination will be made whether to accept the container with the outerlying VOC(s).

LXIV. A running total of RH activity needs to be performed. Total activity of RH waste cannot exceed 5,100,000 curies.

XCI. A unique transporter name and address corresponds to each transporter EPA ID.

CVII. A running total of TRU waste volume, in ft^3 and m^3, needs to be performed. Total volume of TRU waste (CH & RH) cannot exceed 6.2E + 6 cubic feet.

NOTES - GENERIC

- Since SI units will be used in all reports, conversion constants need to be identified for the purpose of implementing this requirement. This includes curies to becquerels, pounds to kilograms, grams to kilograms, feet to meters, centimeters to meters, etc.
- Approved project plans are required <u>before</u> waste characterization data will be accepted for waste certification. Interim QAPjPs will suffice.
- Data calculated by the sites will be verified in the background; i.e., the data (whether measured or calculated) is the property of the sites, any calculations performed by the WWIS are for purposes of verification only.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix WCA

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Waste Characterization Analysis

PREFACE

Appendix WCA of this application is a reproduction of a draft report that was reviewed by the Waste Characterization Analyses Peer Review panel. See Section 9.3.2 and Appendix PEER of this application for discussion of this peer review. Because of its draft status, the report reviewed by the peer review panel contained minor errors (for example, transuranic elements are incorrectly described in one location as those in atomic weights, rather than atomic numbers, greater than 92). These errors do not affect the technical content of the discussions, and have not been corrected in this reproduction although this appendix has undergone formatting to be consistent with other appendices in this application. Also, a preface has been added to Attachments WCA.8.1 and WCA.8.2 which describes the proper context of the attachment(s) with regard to the Compliance Certification Application. These prefaces are included here for completeness and clarification, but were not in the draft report reviewed by the peer review panel. Exact copies of all materials provided to the peer review panel are contained in the appropriate WIPP files.

In the case of the discussion of the temperature rise in the disposal region that may occur as a result of exothermic reactions, technical information presented to the peer panel has been superseded. The original discussion is reproduced here for historical accuracy. The updated discussion of temperature rise is provided in a memorandum by Bennett et al. (1996), contained in Appendix PEER of this application. Conclusions of Appendix WCA are not affected by the change, which results in a lowering of the maximum possible temperature rise from the 7°C reported here as 6°C, as reported by Bennett et al.

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LIST OF ACRONYMS

BID	Background Information Document (for an EPA regulation)
BIR	Baseline Inventory Report
BRAGFLO	BRine And Gas FLOw code
CCA	Compliance Certification Application
CCDF	complementary cumulative distribution function
CFR	Code of Federal Regulations
CH-TRU	contact-handled transuranic (waste)
CUTTINGS_S	code that models radionuclide release from drilling, caving, spalling
DOE, USDOE	United States Department of Energy
EDTA	ethylene diamine tetra-acetate
EPA, USEPA	United States Environmental Protection Agency
FEP	feature, event, or process
FFCA	Federal Facilities Compliance Act of 1992 (PL 102-386)
IDB	(USDOE) Integrated Data Base
INEL	Idaho National Engineering Laboratory
INGRES	name of performance assessment database
K_d	equilibrium constant for distribution of a solute between solution and adsorption
LANL	Los Alamos National Laboratory
NUTS	NUclide Transport System code
PA	performance assessment
PANEL	code that decays and dissolves radionuclides
PCB	polychlorinated biphenyl
PIC	passive institutional control
pH	the negative $\log_{10}$ of the hydrogen ion concentration
PL	Public Law
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RH-TRU	remote-handled transuranic (waste)
RTR	real-time radiography
SEIS	Supplementary Environmental Impact Statement (for the WIPP)
SNL	Sandia National Laboratories
SRS	Savannah River Site
TOC	total organic carbon
TRU	transuranic (waste)
TWBIR	TRU Baseline Inventory Report
TWBID	TRU Waste Baseline Inventory Data Base
WIPP	Waste Isolation Pilot Plant

WCA.1 INTRODUCTION

WCA.1.1 Scope

The objective of this appendix is to satisfy the requirements specified in 40 CFR 194.24(b):

> *40 CFR 194.24(b) The Department shall submit in the compliance certification application the results of an analysis which substantiates:*
> *(1) That all waste characteristics influencing containment of waste in the disposal system have been identified and assessed for their impact on disposal system performance. The characteristics to be analyzed shall include, but shall not be limited to: solubility; formation of colloidal suspensions containing radionuclides; production of gas from the waste; shear strength; compactability; and other waste-related inputs into the computer models that are used in the performance assessment.*
> *(2) That all waste components influencing the waste characteristics identified in paragraph (b)(1) of this section have been identified and assessed for their impact on disposal system performance. The components to be analyzed shall include, but shall not be limited to: metals; cellulosics; chelating agents; water and other liquids; and activity in curies of each isotope of the radionuclides present.*
> *(3) Any decision to exclude consideration of any waste characteristic or waste component because such characteristic or component is not expected to significantly influence the containment of the waste in the disposal system.*

This appendix identifies those waste components and waste characteristics that can influence the containment of waste and that are included as inputs to the computer models and codes used in performance assessment. Waste components are the elements that make up the waste (for example, radionuclides, paper and other cellulosic materials, steel drums that contain the waste, solidified organic and inorganic sludges, etc.). These components have characteristics with the potential to impact disposal system performance. For example, paper is a component of the waste and a nutrient for microbes in the repository. The property of the paper to act as a substrate for microbial gas production is a characteristic of the paper. Microbes metabolizing paper will produce CO_2, methane, and other gaseous metabolic products, which can increase the pressure in a waste panel and potentially impact the performance of the repository.

This appendix represents a step in the process of using sensitivity analysis to specify limiting values and associated uncertainties in the waste characteristics and components as required in 40 CFR Part 194.24 (c). Initial evaluations, based on previous sensitivity analyses, calculations related to features, events, and processes (FEPs) (Appendix SCR), and reasoned arguments, have identified those waste characteristics that are included or excluded from performance assessment. These preliminary evaluations will be refined once sensitivity studies with the final performance assessment (PA) model for the Compliance Certification Application (CCA) are completed.

The repository performance considered in this appendix is only with respect to the movement of radionuclides to the accessible environment. More specifically, disposal system performance means the ability of the Waste Isolation Pilot Plant (WIPP) to comply with 40 CFR Part 191 (b) and (c). This appendix does not discuss Resource Conservation and Recovery Act (RCRA) related matters; the Department of Energy (DOE) has submitted a No-Migration Variance Petition to the Environmental Protection Agency (EPA) and a RCRA Part B Permit Application to the State of New Mexico that cover issues related to hazardous waste.

WCA.1.2 History of Identification of Components and Characteristics Affecting Performance

The waste components and characteristics affecting repository performance have evolved as understanding about repository processes and disposal system performance has increased. Development of 40 CFR Parts 191 and 194 have also influenced this process. Three major changes that have occurred during the historical development of WIPP conceptual models are as follows:

(1) the change from assuming an essentially dry repository to consideration of brine inflow and outflow, and

(2) promulgation of 40 CFR Part 191 in 1985; Part 191 required consideration of human intrusion, set release limits at defined boundaries, and established a regulatory time period of 10,000 years, and

(3) promulgation of 40 CFR Part 194 in 1996. Part 194 requires that all well types be included in calculations of the future intrusion rate, that mining within the controlled area be considered in performance assessment, and that performance assessment calculations may take credit for passive institutional controls (PICs).

WCA.1.2.1 Initial Estimate of Significant Waste Characteristics

During the 1975-1976 site selection period, the Salado Formation (hereafter referred to as the Salado) was thought to be dry; gas generation by microbial action on the waste was recognized as a possible pressure-building mechanism, and radiolysis of host rock salts could occur. At that time, the emplacement of heat-emitting high-level radioactive waste in a separate repository in the same salt formation was also envisioned, and thermal effects were considered to be significant. Postulated breach of the repository was only by natural processes, which were deemed sufficiently unlikely that repository performance would not be affected.

Experimental activities at the WIPP site focused on characterizing the Salado host rock, microbial gas generation, and migration of intra-granular brine in a thermal gradient. Radionuclides from the repository could be transported in aquifers above the Salado if they reached those aquifers, but a fluid connection between the repository and these aquifers was not

established. Measured permeability of the Salado rock matrix proved to be such that microbially generated gas would dissipate in the rock, rather than building to high pressure. Consequently, the program to analyze gas generation was canceled in 1981.

A new gas generation program began in 1988 (Brush 1990) because Salado permeability had been overestimated. Observed brine seepage into the repository suggested the potential for gas generation by corrosion of iron compounds in the waste and waste containers. Thus, gas generation by both corrosion and microbial reaction remains a moderately significant influence on repository performance. In addition, microbially produced CO_2 has a significant effect on actinide solubility, although this effect will be mitigated by MgO backfill. The hydrogen gas produced by corrosion has no effect on repository chemistry.

WCA.1.2.2 Impact of 40 CFR Part 191 on Identification of Significant Characteristics

Promulgation of 40 CFR Part 191 in 1985 required the consideration of human intrusion into the repository, raising the possibility of multiple boreholes into and through the repository, thus allowing brine saturation. Several new release mechanisms were then possible: gas spallation, drill cuttings and cavings, and brine flow, both directly to the surface and to the overlying aquifers.

Mobilization of radionuclides by dissolution of waste added actinide solubility to microbial gas generation and corrosion as a characteristic to be considered, as well as the characteristics that affect solubility, like complexants and pH and redox determinants. Carbon dioxide generation was a characteristic of concern, in addition to total gas generation, because of its effect on pH and actinide solubility. With the increase in importance of dissolved actinide transport in overlying aquifers, identification of the Culebra member of the Rustler Formation (hereafter referred to as the Culebra) as the predominant groundwater route, possible retardation in the Culebra was considered, and waste characteristics that can influence such retardation were studied.

In the late 1980s, transport of actinides in colloidal forms was recognized as potentially significant, adding colloid formation as a waste characteristic to be studied. In 1989, a literature review and analysis resulted in a very large range of estimated actinide solubility (Trauth et al. 1992; Hobart et al. 1996), resulting in an experimental program to study these solubilities more intensively (Novak 1995a). This program also showed the importance of dissolved iron as a corrosion product for actinide solubility.

WCA.1.2.3 Interaction of Performance Assessment and Identification of Significant Waste Characteristics

Since 1989, performance has been (and continues to be) assessed by constructing cumulative distribution functions (CDFs) of releases under various probable scenarios and comparing the complement of this function (CCDFs) with the EPA criteria of 40 CFR 191.13. Before 1996,

there were three complete cycles of performance assessment calculations (Lappin et al. 1989; WIPP PA Division 1991; WIPP PA Dept. 1992, 1993). After each of these cycles, the results of a sensitivity analysis were used to refine both waste characterization procedures and experimental work related to the waste characteristics and their expected influence on repository performance. Some examples of this use of sensitivity analysis are:

(1) Estimates of brine inflow from the 1989 performance assessment prompted studies of brine inflow rates and volumes, leading ultimately to the laboratory studies of humid and inundated anoxic corrosion and microbial reaction (Brush 1990). These studies, in turn, highlighted the importance of cellulosics, plastic, and rubber in the emplaced waste as microbial substrates. The latter studies led to assessment of nitrates, sulfates, and phosphates in the waste because these compounds supply microbes with necessary nutrients.

(2) Systems analyses carried out by Lappin et al. (1989) demonstrated that gas would affect repository performance if present in significant quantities. Laboratory studies of gas generation were restarted in February of 1989, and focused on single-process experiments on anoxic corrosion, microbial activity, and radiolysis. Between 1989 and 1995, the DOE project developed gas generation models.

(3) Assessment of brine inflow and brine volumes in the waste prompted the combined modeling and experimental study of actinide solubilities, described in Appendix SOTERM. Modeling actinide solubility revealed the need to assess the impact of waste components on the redox environment of both the Castile and Salado brine.

(4) Calculation of actinide activity through the 10,000-year regulatory period identified those radionuclides that make up less than 1 percent of the EPA release limit (WIPP PA Dept. 1993, 7-12). This information was used in waste characterization and in the actinide source term program to identify the radionuclides that do not need complete characterization and transport and is illustrated by the graphs in Section WCA.8.3.

(5) Studies of the Culebra transmissivity suggested that both physical and chemical retardation could occur, and separate conceptual models were analyzed for cases with and without chemical retardation (WIPP PA Dept. 1993, Section 8.4.3). As a result, the dissolved actinide chemical retardation research program has studied the sorption of dissolved and colloidally sorbed actinides and the components of the waste, primarily organic ligands, that would affect retardation.

(6) Results from the solubility model (Novak 1995a, b) that actinide solubility was pH-dependent led to an evaluation of the influence of cementitious materials in the waste on pH.

WCA.1.3 Organization

This appendix is organized as follows:

Section WCA.1.0 Introduction

The introduction includes a discussion of the overall approach to compliance with 40 CFR 194.24 (b) and the organization of the appendix. This section also discusses the history of using performance assessment to identify the waste components and characteristics that affect performance.

Section WCA.2.0 Summary of Waste Components and Characteristics: Waste Characterization Analysis

This section includes lists of the components and characteristics that are important to performance, as well as those that are not.

Section WCA.3.0 Characteristics That Affect Performance: Curie Content

Section WCA.3.0 considers all of the radionuclides inventoried in the TRU Baseline Inventory Report (TWBIR) (USDOE 1996) and identifies those radionuclides that will affect performance. The only characteristic discussed in Section WCA.3.0 is radioactivity.

Section WCA.4.0 Characteristics of Radionuclides: Solubility and Colloid Formation

Section WCA.4.0 has two subsections devoted to characteristics that affect performance: subsection WCA.4.1 discusses solubility, while subsection WCA.4.2 discusses colloid formation.

Section WCA.5.0 Nonradioactive Waste Components and Characteristics

Section WCA.5.0 has four subsections: subsection WCA.5.1 discusses components and characteristics affecting gas generation; subsection WCA.5.2, those affecting mechanical properties of the repository; and subsection WCA.5.3, those affecting heat generation.

Section WCA.6.0 Summary

Section WCA.7.0 References

Section WCA.8.0 Supplemental Documents

WCA.1.4 Terminology

WCA.1.4.1 Terms Used to Refer to Radioactive Materials

The terms "actinide," "radionuclide" or "nuclide," and "isotope" have particular, but often overlapping, meanings. "Actinide" is used as a general term for an element in the actinium series of the periodic table: for example, thorium, uranium, neptunium, plutonium, americium, and curium are all actinides. This term is used in connection with the chemical properties of these elements and generally not in connection with radiological properties. "Radionuclide" (or "nuclide") is used when referring to one of the class of radioactive elements. "Isotopes" of an element have the same atomic number and chemical properties, but different atomic masses. The term is used most often in conjunction with radiological properties.

WCA.1.4.2 The Waste Unit Factor and EPA Units

The "waste unit factor" is the number of millions of curies of α-emitting transuranic (TRU) radionuclides with half-lives longer than 20 years (40 CFR Part 191, Appendix A). In the WIPP, 4.07 million curies of TRU waste will be in the repository at closure, so the waste unit factor is 4.07.

The number of EPA units of a radionuclide is the activity (in curies) of the radionuclide divided by the release limit for that radionuclide. EPA units are important because the containment requirement for the repository is expressed in EPA units.

As an example of EPA units, the Pu-239 inventory at closure is 7.95×10^5 curies (TWBIR; USDOE 1996), and the release limit for Pu-239 is 407 curies, so the number of EPA units is calculated as:

$$\frac{7.95\times10^5 \text{ curies}}{407 \text{ curies}} = 1{,}954 \text{ EPA units.}$$

The release limit for Pu-239 is given by the waste unit factor (4.07) multiplied by the release limit per million curies of TRU. The release limit per million curies is given in Table WCA-1, a copy of Table 1 in Appendix A, 40 CFR Part 191. The value for Pu-239 is 100 curies, giving a release limit of 407.

WCA.1.4.3 Normalized Release for All Radionuclides

With a mix of radionuclides, each radionuclide is normalized with respect to its release limit and the sum of all releases must have

Table WCA-1. Table 1 of Appendix A, 40 CFR Part 191

Radionuclide	Release Limit per Million Curies of TRU Radionuclides* (Curies)	Release Limit for the WIPP Normalized By Total from Table WCA-5 (Curies)
Americium: Am-241 or -243	100	407
Carbon: C-14	100	407
Cesium: Cs-135, or -137	1,000	4,070
Iodine: I-129	100	407
Neptunium: Np-237	100	407
Plutonium: Pu-238, -239, -240, or -242	100	407
Radium: Ra-226	100	407
Strontium: Sr-90	1,000	4,070
Technetium: Tc-99	10,000	40,700
Thorium: Th-230 or -232	10	40.7
Tin: Sn-126	1,000	4,070
Uranium: U-233, -234, -235, -236, or -238	100	407
Any other α-emitting radionuclide with a half-life greater than 20 years	100	407
Any other radionuclide with a half-life greater than 20 years that does not emit α particles	1,000	4,070

* In Appendix A of 40 CFR Part 191, this column is in terms of metric tons heavy metal (MTHM), and the equivalence to curies of TRU is presented in Footnote *e* to the table.

- less than one chance in 10 of exceeding the release limit, and
- less than one chance in 1,000 of exceeding ten times the release limit.

The sum of releases in EPA units is expressed by

$$R_j = \frac{1}{f_w}\left[\frac{Q_{1j}}{L_1} + \frac{Q_{2j}}{L_2} + \ldots\right] = \sum_{i=1}^{nR} \frac{Q_{ij}}{f_w L_i} \leq \begin{Bmatrix} 1 \text{ with a probability of } 0.1 \\ 10 \text{ with a probability of } 0.001 \end{Bmatrix}$$

in which R_j is the total release in EPA units under scenario *j*, f_w is the waste unit factor, Q_{ij} is the cumulative release for radionuclide *I* under scenario *j*, L_i is the EPA release limit for radionuclide *I*, and the EPA release limit nR is the number of radionuclides contributing to the release. The regulatory time period over which these releases are summed is 10,000 years. A brief explanation of these release limits is given in Section WCA.8.2, and a comprehensive discussion of the background for these limits is provided in EPA (1985).

WCA.1.4.4 Chelating Agents

Although 40 CFR 194.24 refers to "chelating agents," this appendix uses the term "organic ligands." In general, organic ligands increase the solubility of the complexed substance. Chelating agents are a particular category of organic ligand that increases solubility by forming a cage around certain ligated (or chelated) substances. Although this mechanism is peculiar to chelators, performance assessment looks only at the effect — increase in solubility. Performance assessment, therefore, does not distinguish between chelators and other organic ligands.

WCA.2 SUMMARY OF WASTE COMPONENTS AND CHARACTERISTICS: WASTE CHARACTERIZATION ANALYSIS

Tables WCA-2, WCA-3, and WCA-4 summarize, in tabular form, all the waste characteristics and waste components considered in this appendix. These tables provide:

- a list of the waste characteristics retained as a result of the analysis,
- a list of the waste components influencing these characteristics,
- identification of specific waste-related inputs to computer models,
- a list of all waste characteristics and components that were considered and excluded.

Table WCA-2 lists the waste characteristics and components that are included in performance assessment and were expected prior to the analysis to have a significant impact on repository performance. Table WCA-3 lists the waste characteristics and components that are included in performance assessment, but were expected prior to the analysis to have a negligible impact on performance. The impact of microbially generated CO_2 on performance is insignificant because the CO_2 will react with the MgO backfill, forming Mg carbonate minerals that greatly reduce the impact of CO_2 on pH. Actual sensitivities of the analysis to waste characteristics and components are described in Appendix SA. The relationships between components, characteristics, and performance assessment codes is illustrated in Figure WCA-1.

Table WCA-4 lists the waste characteristics and components that are excluded from performance assessment. Some of these excluded characteristics, however, can indirectly influence performance. For example, the ability of nonferrous metals to bind organic ligands prevents those ligands from increasing actinide solubility, which is considered in performance assessment analyses.

Each waste characteristic shown in Tables WCA-2 and WCA-3 is reflected in one or more parameters that are used in performance assessment. The performance assessment parameters are compiled in the INGRES database (presented in Appendix PAR), and the INGRES material and parameter names are the variable names used by the performance assessment models.

Table WCA-2. Table of Waste Characteristics and Components Used in Performance Assessment: Characteristics Expected to Have Significant Effect on Disposal System Performance

Characteristic	Component	Effect on Performance	INGRES* Material Name (App. PAR)	INGRES* Parameter Name (App. PAR)	Section of WCA
radioactivity in curies of each isotope	radioactivity in curies of each isotope	used in calculating normalized releases	AM241 CM245 NP237 CS137 TH229 RA226 U238 PU239 PU240, etc	EPAREL ATWEIGHT INVCHD	3.1, 3.2
TRU radioactivity at closure	α-emitting TRU radionuclides, $t_{1/2} > 20$ years	determines waste unit factor	AM241 CM245 NP237 PU238 PU239 PU240, etc	HALFLIFE ATWEIGHT INVCHD INVRHD	3.1
solubility	radionuclides	actinide mobility	SOLAM3 SOLPU3 SOLPU4 SOLU4 SOLTH4 SOLU6, etc* CS RA SR	OXSTAT SOLSIM SOLCIM LOGSOLM	4.1
colloid formation	radionuclides, cellulose, soils, plastics, rubber	actinide mobility	PHUMOX3, etc* AM NP PU U, etc	PHUMCIM CAPHUM CAPMIC CONCINT CONCMIN PROPMIC	4.2
redox state	radionuclides	actinide mobility	U+6, U+4 PU+3, PU+4 TH+4, AM+3	MKD_U MKD_PU MKD_TH MKD_AM	4.1

* The material and parameter names given here are examples only.

Table WCA-2. Table of Waste Characteristics and Components Used in Performance Assessment: Characteristics Expected to Have Significant Effect on Disposal System Performance (Continued)

Characteristic	Component	Effect on Performance	INGRES* Material Name (App. PAR)	INGRES* Parameter Name (App. PAR)	Section of WCA
redox potential	ferrous metals	actinide oxidation state; actinide mobility	STEEL REFCON	STOIFX ASDRUM DRROOM	4.1.1
gas (H_2) generation	ferrous metals	increase in H_2 pressure	STEEL REFCON	STOIFX CORRMCO2 HUMCOR ASDRUM DRROOM	4.1.2, 5.1
microbial substrate: CH_4 generation	cellulose	increase in gas pressure	WAS_AREA	GRATMICI GRATMICH	4.1.2, 5.1
microbial substrate: CH_4 generation	plastics, rubber	increase in gas pressure	WAS_AREA	PROBDEG	4.1.2, 5.1
particle diameter	solid waste components	spalling release	BLOWOUT	PARTDIA	5.2
microbial nutrients: CH_4 generation	sulfates	increase in gas pressure	SULFATE	QINIT	5.1
microbial nutrients: CH_4 generation	nitrates	increase in gas pressure	NITRATE	QINIT	5.1
compressibility and shear strength	solid waste components	effect on creep closure, cuttings, caving, spalling	WAS_AREA	COMP_RCK	5.2

*The material and parameter names given here are examples only

Table WCA-3. Table of Waste Characteristics and Components Used in Performance Assessment: Characteristics Expected to Have A Negligible Effect on Disposal System Performance

Characteristic	Component	Effect on Performance	INGRES* Material Name	INGRES* Parameter Name	Section of WCA
permeability	solid waste components	negligible effect on brine movement, gas storage; see 2.4.1, SCR 2.3.8.1***	WAS_AREA	PRMX_LOG PRMY_LOG PRMZ_LOG	5.2
porosity	solid waste components	negligible effect on brine movement, see SCR 2.3.8***	WAS_AREA	SAT_WICK POROSITY	5.2
microbial nutrients, CO_2 generation	sulfates	negligible: MgO reacts with CO_2	SULFATE	QINIT**	4.1.2
microbial nutrients, CO_2 generation	nitrates	negligible: MgO backfill reacts with CO_2,	NITRATE	QINIT**	4.1, 5.1
microbial substrate: CO_2 generation	cellulose	negligible: MgO backfill reacts with CO_2	WAS_AREA	GRATMICI GRATMICH	4.1.2, 5.1
microbial substrate: CO_2 generation	plastics, rubber	negligible: MgO backfill reacts with CO_2	WAS_AREA	PROBDEG	4.1.2, 5.1
gas generation	water in the waste	enhances initial gas generation	WAS_AREA	SAT_RBRN	5.3.2

* The material and parameter names given here are examples only
** These parameters are significant to gas generation and are therefore also listed in Table WCA-2.
*** Appendix SCR

Table WCA-4. Table of Waste Characteristics and Components Not Used in Performance Assessment

Characteristic	Component	Effect on Performance	Section of SCR***	Section of WCA
cellulose radiolysis	radionuclides	negligible effect on total CO_2	2.2.4	**
explosivity	other organic compounds	none	2.3.3	
brine radiolysis	radionuclides	negligible effect on actinide valence	2.5.1.3.1	**
galvanic action	nonferrous metals	negligible	2.5.1.2.1	**
complexation with actinides*	soil and humic material*	actinide mobility	**	4.1.3
buffering action*	cement*	negligible: reacts with CO_2 and $MgCl_2$	2.5.4.5	4.1.2
heat of solution	cement	negligible	2.5.7	**
Ca^{2+} binding to organic ligands	cement	negligible compared to other metals	2.5.4.5	4.1.3
binding to organic ligands*	ferrous metals*	can reduce actinide mobility	**	4.1.3
buffering action*	ferrous metals*	actinide mobility	**	4.1.2
galvanic action	ferrous metals	negligible	2.5.1.2.1, 2.7.4	**
binding to organic ligands*	ferrous alloy components*	can reduce actinide mobility	**	4.1.3
redox reactions	nonferrous metals	negligible compared to iron	**	4.1.1
binding to organic ligands*	nonferrous metals*	can reduce actinide mobility	**	4.1.3
complexation with actinides	organic ligands	negligible	**	4.1.3
gas generation	Al and other nonferrous metals	negligible relative to steels	**	5.1
microbial nutrients, CO_2 generation	phosphates	negligible because MgO backfill reacts with CO_2	**	4.1.2
microbial nutrients: CH_4 generation	phosphates*	negligible	**	5.1
heat generation	RH-TRU	negligible	SCR 2.2.2, 2.3.7, 2.3.8.1	5.3.2
electrochemical processes	sulfate, nitrate, phosphate	negligible	SCR 2.7.4	**

* Waste characteristics and components that influence performance indirectly—by influencing components and characteristics listed in Table WCA-2.

** The waste characteristics and components in the table are either discussed in a section of this appendix or are the subject of a FEP.

*** Appendix SCR

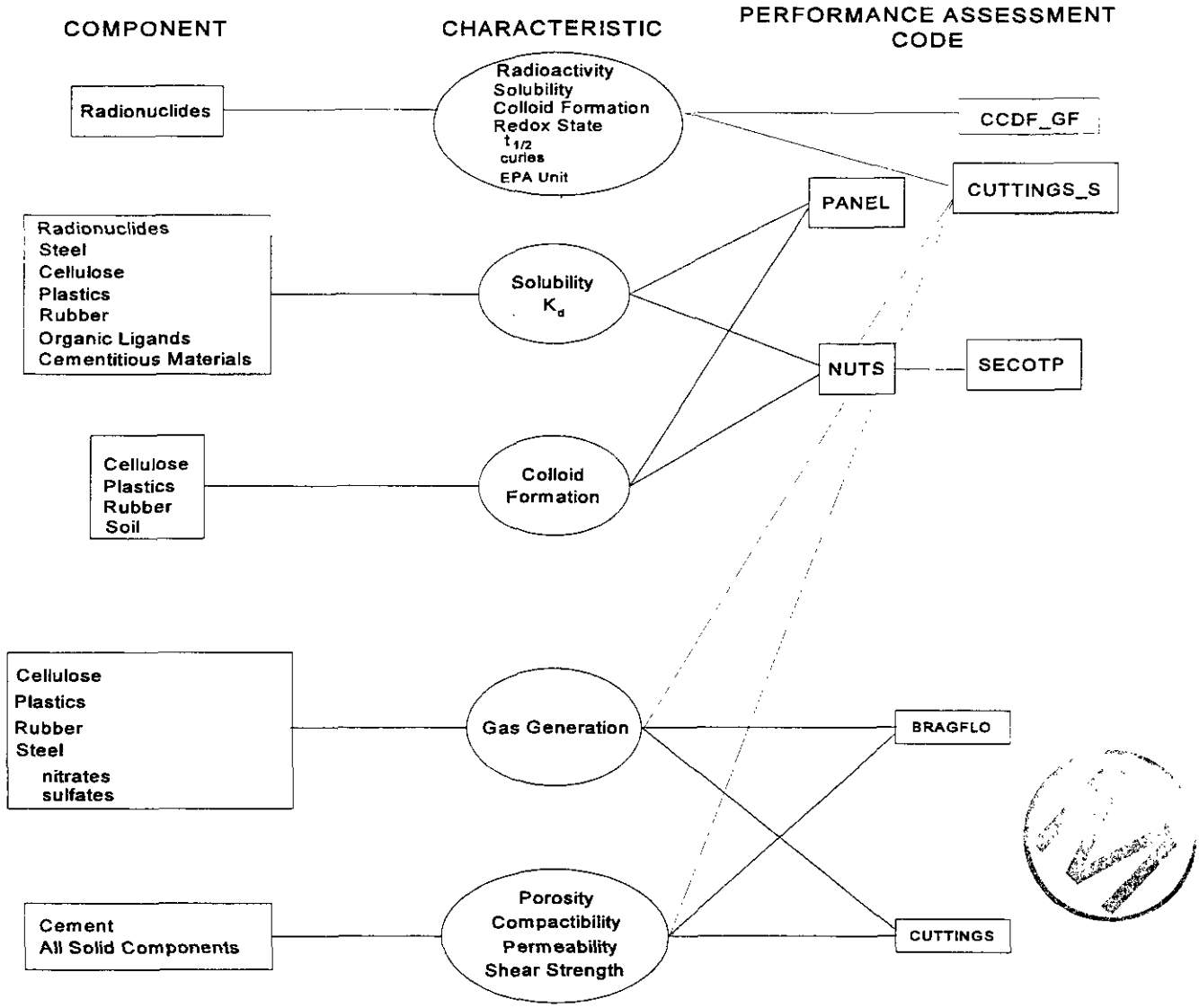

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Figure WCA-1. Waste components, the associated waste characteristics, and a performance assessment code related to each characteristic.

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WCA.2.1 Relationship Between Inventory Data and Performance Assessment

The TWBIR, Revision 3 (USDOE 1996) provides both site-level data and waste stream-level data on the radionuclide inventory for the WIPP. PA models generally use the site-level data, normalized to 1995 and scaled-up to the full WIPP capacity. The one exception to this approach is for the cuttings/caving model, which uses waste stream level data to capture potential inhomogeneities in the contact-handled (CH) TRU waste.

The relationship between TWBIR data and performance assessment is shown in Figure WCA-2. As Figure WCA-2 shows, the waste stream level data are used only in modeling direct release by cuttings and cavings (see Appendix CUTTINGS). This direct release scenario includes the probability of penetrating each of the 569 CH-TRU waste streams, and the single remote-handled (RH)-TRU waste stream, as discussed in Chapter 6, Section 6.4.12 of the CCA and in Sanchez et al. (1996).

This approach for cuttings and caving releases represents the potential inhomogeneities in the CH-TRU waste. This approach is necessary because the size scale for cuttings and cavings is on the order of the drill bit diameter, 0.3112 meters (12.25 inches), which is less than the diameter of a 55-gallon drum. A cuttings and cavings intrusion will, therefore, extract waste from three specific drums (remember that drums are stacked three high in the disposal rooms), rather than sampling from a larger volume of waste.

Scenarios in which radionuclides would be released in brine, either directly to the surface or through the Culebra reservoir, assume that the mobility of radionuclides in brine results in an essentially homogeneous mixture of radionuclides. Brine flow will contact a much larger portion of the waste than the direct release of cuttings and cavings. For brine-related release pathways, the total radionuclide inventory is more applicable than the inventory of a particular waste stream. Performance assessment, therefore, uses the total inventory from all generator sites, as shown in Figure WCA-2. In a similar fashion, spall releases use site-level data because this mechanism is assumed to release waste from a volume larger than several drums, averaging out any inhomogeneities in waste streams.

Radionuclide content will be evaluated in 2033, when the WIPP is decommissioned. Stored waste was decayed and grown in to a base year of 1995. Ingrowth occurs in a radioactive decay chain: as a nuclide decays, it produces a daughter, which is said to grow in. The memo of L. R. Sanchez, attached as Section WCA 8.1, includes decay calculations showing that application of the 1995 decayed values to 2033 does not make a significant difference in either the EPA unit or the waste unit factor. Discussions of the scaling of the stored waste inventory to WIPP capacity and of the renormalization of the waste stream data are in the TWBIR.

WCA.3 COMPONENTS THAT AFFECT PERFORMANCE: CURIE CONTENT

The radioactivity of a particular isotope, often called the activity, is significant to two different aspects of compliance: (1) inclusion in the waste unit factor, which is the normalization factor for the release limits given in Table WCA-1, and (2) inclusion in the source term for the compliance demonstration. The waste unit factor is based only on TRU wastes that are α-emitters with a half-life greater than 20 years, while the CCDF is based on the full inventory of all radioactive elements in the repository. This section, therefore, includes two subsections: WCA.3.1, components relevant to inclusion in the waste unit factor; and WCA.3.2, components relevant to inclusion in CCDFs for each applicable scenario.

WCA.3.1 Radioactivity Included in the Waste Unit Factor

The waste unit factor is the activity of TRU, α-emitting waste with a half-life greater than 20 years at the time of repository closure. The units for the waste unit factor are millions of curies.

Figure WCA-3 is a flow diagram for the selection of those radionuclides in the inventory that contribute to the waste unit factor. As noted above, not all radionuclides are included in this factor. For example, Sr-90 is excluded because it is not a transuranic and is a β-emitter. Even uranium is excluded because it is not a transuranic, which is defined as elements with atomic weight greater than 92.

The radionuclides that are included in the waste unit factor are listed in Table WCA-5. As noted in the table, the relevant inventory at closure is 4.07×10^6 curies, resulting in a waste unit factor of 4.07. Table WCA-5 is based on an analysis (see Section WCA.8.2) of the radionuclide inventory in Revision 3 of the TWBIR (USDOE 1996).

It is worthwhile to note that the inventory in Table WCA-5 is dominated by americium and plutonium. More specifically, the radionuclides Am-241, Pu-238, -239, -240, -242, and Cm-245 capture 99.9% of the waste unit factor. The combined activity at emplacement of Am-241, Pu-238, Pu-239, and Pu-240 is three orders of magnitude greater than the combined activity of the remaining 11 radionuclides.

WCA.3.2 Radioactivity Included in the Source Term for Performance Assessment

Unlike the waste unit factor, all radionuclides are potentially included in a demonstration of compliance and must therefore be considered for inclusion in the source term for performance assessment. An exhaustive list of radionuclides in the waste is presented in Table 3 of Section WCA.8.2. However, many of these radionuclides are present in such small quantities that their impact on long-term performance is negligible. That is, their total combined initial inventory in EPA units is much less than one percent so they will have negligable impact on compliance.

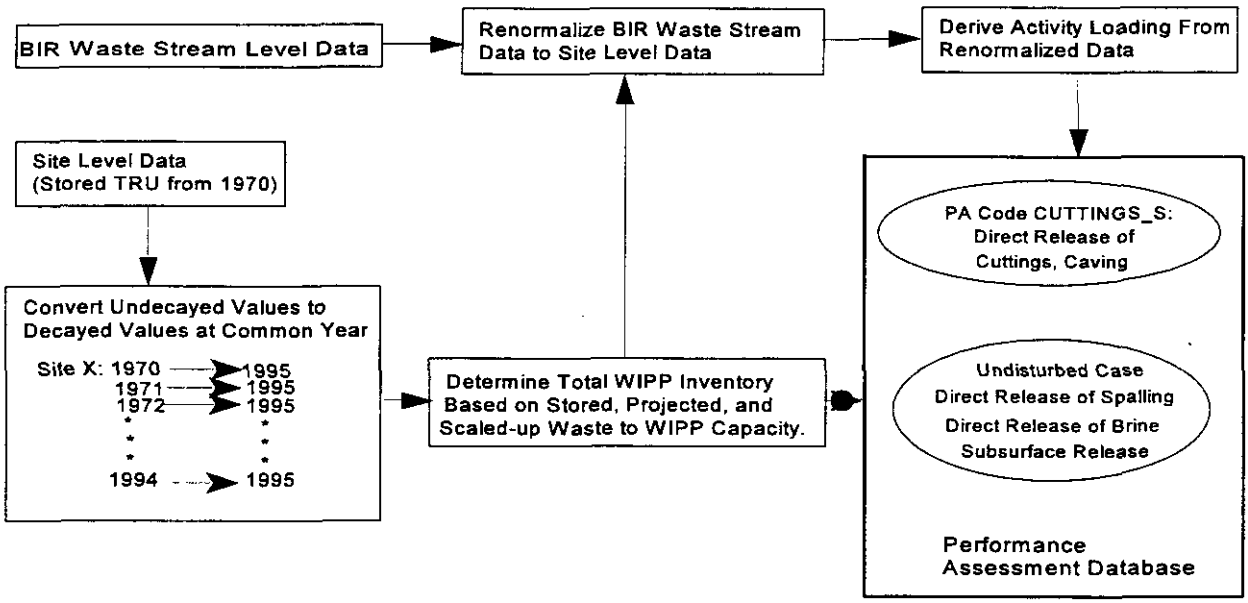

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Figure WCA-2. **Flow chart for inventory input into performance assessment database. Data reported by the generator sites are decayed and grown in to the year 1995. These data are then scaled up to the capacity of the WIPP and used in performance assessment. Data for individual waste streams are renormalized and rolled up to site level data. Waste stream level data are unnormalized from this roll-up and used in performance assessment to calculate direct release of cuttings and cavings.**

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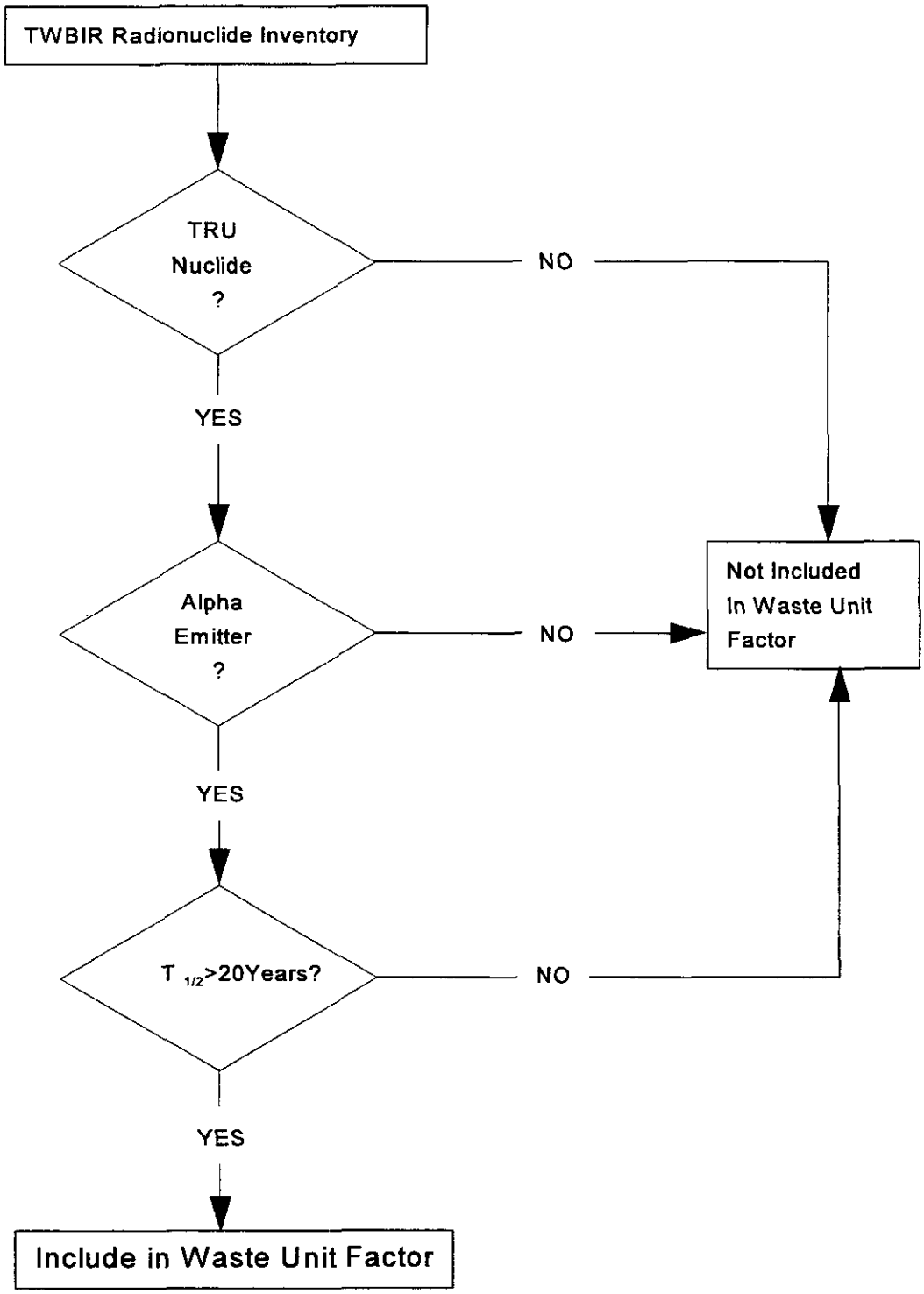

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Figure WCA-3. Flow diagram for including radionuclides in the waste unit factor.

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Table WCA-5. Radionuclides That Contribute to the Waste Unit Factor

Nuclide	Half-Life (years)	Inventory at Closure (curies)	% of Waste Unit
Am-241	432.7	4.48×10^{5}	11.0
Am-243	7370	32.6	8.01×10^{-4}
Cf-249	351	0.687	1.69×10^{-6}
Cf-251	900	3.78×10^{-3}	9.28×10^{-6}
Cm-243	29.1	101.7	2.50×10^{-3}
Cm-245	8500	115	2.82×10^{-3}
Cm-246	4760	0.102	2.51×10^{-6}
Cm-247	1.56×10^{7}	3.21×10^{-9}	7.88×10^{-14}
Cm-248*	3.48×10^{5}	0.0369	9.1×10^{-7}
Np-237	2.14×10^{6}	56.4	1.39×10^{-3}
Pu-238	87.7	2.61×10^{6}	64.1
Pu-239	2.41×10^{4}	7.95×10^{5}	19.5
Pu-240	6560	2.15×10^{5}	5.28
Pu-242	3.75×10^{5}	1170	2.87×10^{-2}
Pu-244	8.0×10^{7}	1.50×10^{-6}	3.68×10^{-11}
TOTAL		4.07×10^{6}	

*This number differs slightly from that in Section WCA.8.2 as a result of more recent information.

Two different release pathways are used in performance assessment: (1) direct releases comprised of (a) material brought to the surface by cuttings, caving, spalling, and (b) brine under pressure that flows to the surface during a drilling intrusion through the repository; and (2) releases to the accessible environment in brine that moves through the subsurface, primarily the Culebra aquifer. Note that the time scales for these two releases are quite different. The direct release during drilling events (Item 1) occurs within a few days. The flow and transport of radionuclides through the Culebra (Item 2) will require hundreds to thousands of years.

Different radionuclides are used for these pathways because of the time-scale differences and different release media (solid particles containing radionuclides or brine containing radionuclides) as well as the computational efficiency of each computer code used in the PA calculations. Figure WCA-4 is a flow diagram for selecting radionuclides for different release mechanisms according to the criteria of Table WCA-1. The result of applying these criteria to the

radionuclides in the TWBIR is shown in Table WCA-6, which also lists the radionuclides used for specific release mechanisms. The EPA unit at 10,000 years (the end of the regulatory period) is also shown in Table WCA-6 because some nuclides experience considerable ingrowth, but not enough to affect the domination by the most prevalent radionuclides Pu-239 and Pu-240. Am-241 is also important for the first 3,000 years after closure.

WCA.3.2.1 Radionuclides Included in Direct Releases by Cuttings, Caving, and Spalling

The 10 isotopes listed in the column headed "Cuttings/Cavings/Spallings" (see Table WCA-6) are used to model direct release by cuttings, caving, or spalling. Release is assumed to occur when containers of CH-TRU or RH-TRU waste are breached during a borehole intrusion. The amount of radionuclide in the source term is estimated from the inventory per drum of the waste stream penetrated, including decay and ingrowth. Details of the EPA unit distribution in the waste streams are provided in Sanchez et al. (1996). The direct release scenario is discussed in greater detail in Section 6.4.12.4 of the CCA.

Eight of the listed isotopes comprise more than 99.9 percent of the EPA units for the entire regulatory period. The other two are included because they are parent nuclides of significant daughters. Inclusion of 99 percent or more of the EPA unit provides an accurate representation of the source term, while maintaining efficiency in computation by limiting the total number of isotopes to 10. The addition of the many radionuclides that make up the final 1 percent would increase computational time and difficulty without any impact on compliance (see Section WCA.8.3). The lack of impact on compliance is clear because if 1 percent of the calculated release is significant, then the calculated release itself would be a much greater violation.

WCA.3.2.2 Radionuclides Included in Direct Releases of Brine to the Surface

Direct release of brine to the surface carries radionuclides that are dissolved in the brine or sorbed on colloidal particles.

The radionuclides released in direct release of brine to the surface include several isotopes that comprise negligible fractions of the total EPA unit, but must be included in the source term because of their influence on the total quantity of dissolved radionuclides. This influence occurs because the isotopes of a radionuclide will dissolve based on mass ratio, rather than the activity ratio, in which they are present in the waste. That is, if 90 percent of the mass of uranium in the waste is U-238 (for example), 90 percent of the dissolved uranium in moles/liter will be U-238, even though 90 percent of the radioactivity will not be U-238. This phenomenon is illustrated for the uranium isotopes in Table WCA-7.

The EPA units of Sr-90 and Cs-137 at closure are large enough that an explanation is needed for not including them in the source term for direct release of brine. Although the EPA units of Sr-90 and Cs-137 are initially large (about 55), rapid decay from a short half-life (about 30 years)

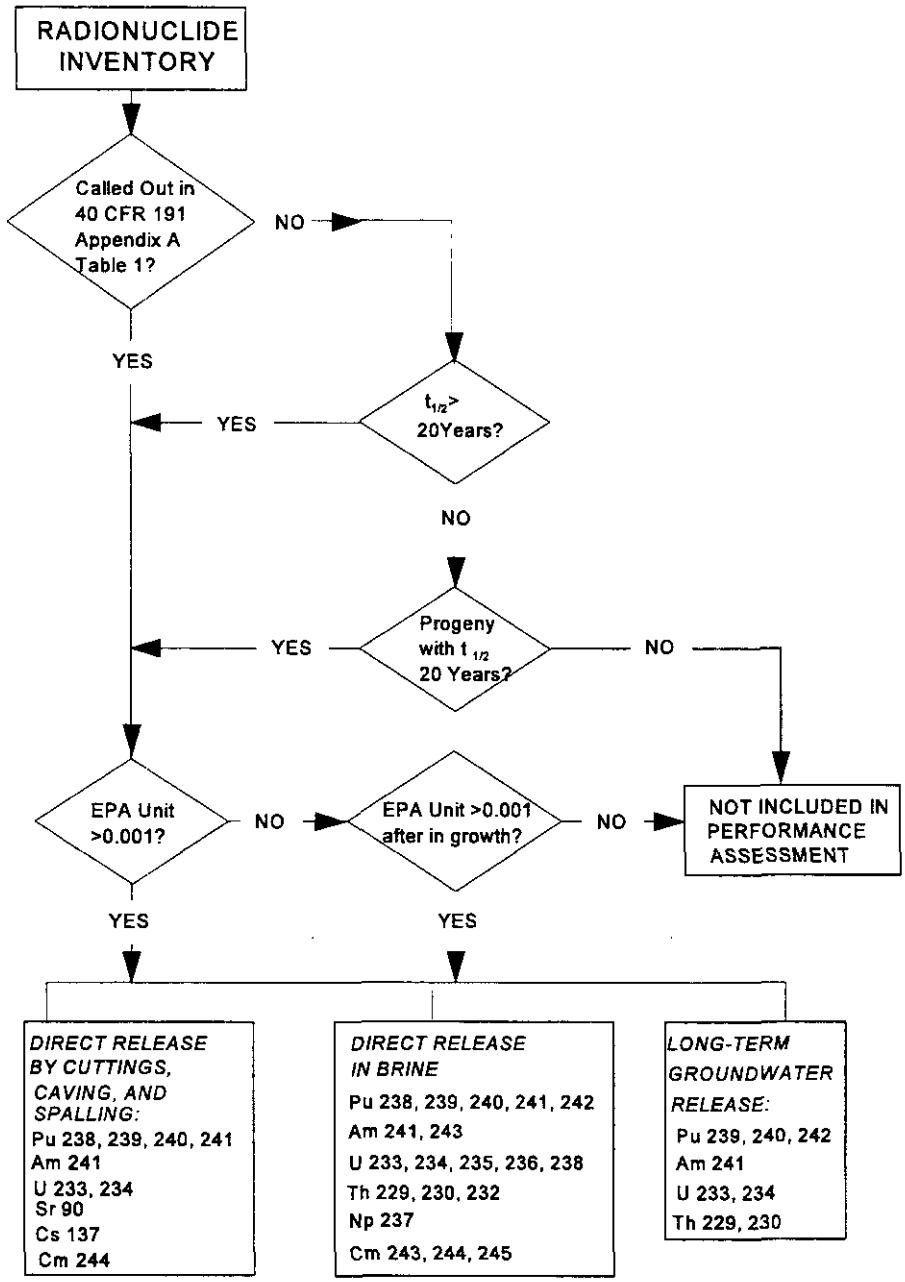

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Figure WCA-4. Flow diagram for selecting radionuclides for the release pathways conceptualized by performance assessment. The top part of the diagram describes the criteria for selecting radionuclides in Table WCA-6. The criteria for selecting specific radionuclides for each release mechanism are described in Sections WCA.3.2.1 through WCA.3.2.3.

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Table WCA-6. Radionuclides Included

Radionuclide	Inventory at Closure (curies)	EPA Unit at Closure***	EPA Unit at 10,000 Years	Releases		
				Cutting/ Cavings/ Spall Release	Direct Brine Release	Culebra Release
Pu-238	2.61×10^6	6416	0.00**	x	x	--
Pu-239	7.95×10^5	1954	1464	x	x	x
Am-241	4.48×10^5	1101	0.13	x	x	x
Pu-240	2.15×10^5	528	183	x	x	c
Cs-137	2.24×10^5	55.0	0.00	x	--	--
Sr-90	2.16×10^5	53.0	0.00	x	--	--
U-233	1.95×10^3	4.79	4.59	x	x	c
U-234	5.08×10^2	1.25	3.45	x	x	x
Th-230	0.0882	2.17×10^{-3}	2.99	--	x	x
Pu-242	1.17×10^3	2.88	2.82	--	x	c
Th-229	2.997	7.36×10^{-3}	2.86	--	x	c
Np-237	58.95	0.145	0.41	--	x	--
Cm-245	1.15×10^2	0.28	0.13	--	x	--
Ra-226	11.6	0.029	0.23	--	--	--
Cm-243	52.22	0.13	0.00	--	x	--
U-238	50.1	0.12	0.12	--	x	--
U-236	0.43	1.06×10^{-3}	0.10	--	x	--
Am-243	32.6	0.08	0.03	--	x	--
U-232	25.8	0.0634	0.00	--	--	--
U-235	17.4	0.0428	0.06	--	x	--
C-14	12.9	0.03	0.01	--	--	--
Th-232	1.006	0.0248	0.02	--	x	--
Pb-210	2.55	6.27×10^{-3}	0.023	--	--	--
Pa-231	0.453	1.1×10^{-3}	1.08×10^{-3}	--	--	--
Ac-227	0.61	1.5×10^{-3}	1.5×10^{-3}	--	x	--
Cm-248	0.090	2.2×10^{-4}	2.2×10^{-4}	--	x	--
Pu-241	2.45×10^6	*	*	x	x	--
Cm-244	3.18×10^4	*	*	x	x	--
% of EPA Units at closure represented by nuclides in source term				99.96%	98.93%	35.48%
% of EPA Units at 10,000 years represented by nuclides in source term				99.41%	99.98%	99.76%

* Pu-241 and Cm-244 are not regulated by 40 CFR Part 191, but are included because their daughters, Am-241 and Pu-242, respectively, are significant to PA.

** Pu-238 ($t_{1/2}$ = 87.8 years) dominates the initial EPA unit but will have decayed away, even with some ingrowth, by 10,000 years.

***The EPA units in this column are accurate. Calculating EPA units from the inventory may produce rounding errors

x indicates an isotope included in the source term

c indicates nuclides that are carried during transport with an isotope having similar characteristics

Table WCA-7. Activities and EPA Units of Uranium Isotopes

Radionuclide	Curies Emplaced	Half - Life (yr)	Moles	% of Total	% at 10,000 yr
U-232	25.8	70	5.05E-3	7.6E-7	1.43E-8
U-233	1948	1.59E5	867.4	0.13	0.122
U-234	507.5	2.46E5	349.3	0.05	6.45
U-235	17.43	7.04E8	3.43E4	5.18	4.84
U-236	0.4298	2.34E7	28.1	0.004	0.165
U-238	50.1	4.47E9	6.26E5	94.6	88.4

results in negligible impact on the performance assessment from those two isotopes. The lack of impact on compliance is explained below.

Sr-90 and Cs-137 decay by about 90 percent during the first 100 years after closure, when borehole intrusions are excluded by 40 CFR Part 191. During this time period, the EPA unit of either isotope decays from 55 down to 5.5 for the whole repository. At 200 years, the EPA unit for either isotope are down to 0.94, again for the whole repository.

In addition to the rapid decay, were an individual borehole intrusion to occur at 100 years, it would release 5.5 EPA units (Appendix SA) much less than the total inventory. Even at 350 years, when either isotope decays down to 0.03 percent of the initial inventory, the maximum volume of brine release is only 0.01 m^3. In summary, the rapid decay of Cs-137 and Sr-90 and the negligible volumes of brine release at early times provide the basis for excluding these isotopes from the inventory.

C-14 is not included in this (or any) source term. Any C-14 transported out of the repository will be diluted by the large excess of nonradioactive carbon. With the current inventory, there is 0.2 moles of C-14 (see Section WCA.8.9) out of 3×10^8 moles of carbon in the cellulosics (see TWBIR), or one part in 100 million.

WCA.3.2.3 Radionuclides Included in Releases to the Culebra Aquifer

Release of brine from the repository to the Culebra also carries dissolved and colloidal radionuclides. The eight radionuclides in the source term for Culebra release include those that dominate the EPA unit for all but the earliest part of the regulatory period. Other less prevalent radionuclides are excluded because they would comprise a negligible fraction of the EPA unit or because transport through the Rustler is sufficiently slow that shorter-lived radionuclides would decay to negligible amounts before reaching the accessible environment. The selection of the eight radionuclides is discussed in Section WCA.8.3.

Of the eight radionuclides, only Pu-239, Am-241, U-234, and Th-230 are transported separately in performance assessment. Isotopes of the same element will be transported together, unless

their half-lives differ greatly. The movement of most of the radionuclides can be calculated indirectly, as presented in detail in Section WCA.8.3:

- U-233 can be combined with U-234 for transport because their half-lives are similar.
- Similarly, Th-229 can be combined with Th-230, because they will be in a fixed ratio to each other. Th-232 can be dropped because it is a constant small fraction of the EPA unit throughout the regulatory period.
- Pu-240 and Pu-242 can be combined with Pu-239; their long half-lives also indicate a fixed ratio between them.
- Pu-238 will have decayed to about 0.5 percent of its initial inventory after 700 years, and its contribution to the EPA unit will be negligible because travel time in the Culebra is much greater than 700 years.

Pu-239 and Pu-240 dominate the EPA limit during the regulatory period, and Am-241 is also a factor for the first 3,000 years. Toward the end of the regulatory period, Th-230 has grown in by about 2.5 orders of magnitude, Th-229 by about 1.5 orders of magnitude, and U-234 by a factor of 3, but all are still small fractions of the EPA unit. Ra-226 grows in during the regulatory period, but even at 10,000 years would comprise a very small fraction of the EPA limit.

WCA.3.2.4 Radionuclides Excluded From Source Terms

A large number of radionuclides were not included in any source term because they did not survive the screening process outlined in Figure WCA-4. Table WCA-8 lists those excluded radionuclides that have not already been discussed, and indicates the reason for their exclusion.

Table WCA-8. Radionuclides Excluded From All Source Terms

Radionuclide	Reason for Exclusion		
	Short $t_{1/2}$ and Progeny With Short $t_{1/2}$*	Small EPA Unit	Negligible** Ingrowth
H-3	NA	x	NA
Cr-51	x	NA	NA
Mn-54	x	NA	NA
Fe-55	x	NA	NA
Co-58	x	NA	NA
Fe-59	x	NA	NA

Table WCA-8. Radionuclides Excluded From All Source Terms (Continued)

Radionuclide	Reason for Exclusion		
	Short $t_{1/2}$ and Progeny With Short $t_{1/2}$*	Small EPA Unit	Negligible** Ingrowth
Ni-59	NA***	x	NA
Co-60	NA	x	NA
Ni-63	NA	x	NA
Zn-65	x	NA	NA
Se-79	NA	x	NA
Kr-85	x	NA	NA
Sr-89	x	NA	NA
Y-90	x	NA	NA
Zr-93	NA	x	NA
Nb-95	x	NA	NA
Zr-95	x	NA	NA
Tc-99	NA	x	NA
Rh-106	x	NA	NA
Ru-106	x	NA	NA
Ag-109m	x	NA	NA
Cd-109	x	NA	NA
Ag-110	x	NA	NA
Pd-107	NA	x	NA
Cd-113m	x	NA	NA
Sn-119m	x	NA	NA
Sb-125	x	NA	NA
Te-125	x	NA	NA
Sn-126	NA	x	NA
Sb-126m	x	NA	NA
Te-127	x	NA	NA
Te-127m	x	NA	NA
I-129	NA	x	NA
Cs-134	x	NA	NA
Ba-137m	x	NA	NA
Ce-144	x	NA	NA

Table WCA-8. Radionuclides Excluded From All Source Terms (Continued)

Radionuclide	Reason for Exclusion		
	Short $t_{1/2}$ and Progeny With Short $t_{1/2}$*	Small EPA Unit	Negligible** Ingrowth
Pr-144	x	NA	NA
Sn-121m	NA	x	NA
Gd-150	NA	x	NA
Sm-151	x	NA	NA
Eu-152	x	NA	NA
Eu-154	x	NA	NA
Eu-155	x	NA	NA
Ta-182	x	x	NA
Tl-207	x	x	NA
Tl-208	x	x	NA
Tl-209	x	NA	NA
Pb-209	x	NA	NA
Pb-210	NA	x	NA
Pb-211	x	NA	NA
Pb-212	x	NA	NA
Ac-227	x	x	NA
Ra-225	x	NA	x
Ra-228	x	NA	NA
Pa-231	NA	x	NA
Pa-233	x	NA	x
Pa-234	x	NA	x
Pa-234m	x	NA	x
Th-231	x	NA	x
Np-238	x	x	x
Np-239	x	NA	x
Np-240m	x	NA	x
Pu-243	NA	x	NA
Cm-246	NA	x	NA
Cf-249	NA	x	NA

Table WCA-8. Radionuclides Excluded From All Source Terms (Continued)

Radionuclide	Reason for Exclusion		
	Short $t_{1/2}$ and Progeny With Short $t_{1/2}$*	Small EPA Unit	Negligible** Ingrowth
Cf-251	x	x	NA
Cf-252	x	NA	x

* "Short" half-life means $t_{1/2} < 20$ years. Radionuclides with $t_{1/2} < 20$ years are not regulated by 40 CFR Part 191(b) and (c).

** Negligible ingrowth includes ingrowth of the progeny that are radionuclides already predominant in the inventory.

***NA indicates that the column heading does not apply to the particular isotope.

WCA.4 CHARACTERISTICS OF RADIONUCLIDES: SOLUBILITY AND COLLOID FORMATION

The major characteristics of the radionuclides that are expected to affect disposal system performance are (1) solubility and (2) the tendency to form or sorb to colloidal particles. Except for direct release from drilling (cutting) and caving, in which particles containing radionuclides will be released with circulation of drilling mud, radionuclides are mobilized for transport from the repository either in brine or as colloidal particles transported by brine. Gas-phase transport is not expected to occur (see Appendix SCR, Section SCR 2.6.5).

All isotopes of a particular radioactive element exhibit essentially identical characteristics: solubility, colloid formation, and sorption.

Solubility and colloid formation are discussed for: thorium, uranium, neptunium, plutonium, and americium. The experimental determination and modeling of solubility and colloid formation, and the manner in which they are taken into account by performance assessment, are discussed in detail in Appendix SOTERM, Sections SOTERM.4 through SOTERM.6 when relevant to performance assessment. Cesium and strontium are assumed to be extremely soluble and their concentrations will be limited by their inventories (see Section WCA.3.2.2). Thus, the two elements are not considered in this section. Radium is excluded from the source term because of its short half life.

Actinide mobility depends on the particular chemical environment (brine pH, fugacity of CO_2, redox potential, organic ligand concentration, etc). That environment will be controlled by the MgO backfill reacting with brine, steels, cellulosics, plastics, and rubber. MgO backfill is added to mitigate the effect of CO_2 generated by microbial degradation of organic materials. The mechanism of the control is discussed in Sections WCA.8.9 and WCA.8.10, and in Section SOTERM.2 of Appendix SOTERM.

WCA.4.1 Components and Characteristics Influencing Solubility

In the absence of the MgO backfill, the factors that would most directly affect solubility in the repository are pH, CO_2 fugacity, redox conditions, the availability of complexing agents, and the source of brine (brine composition) (clearly not a waste characteristic). The important waste components that affect actinide solubility are steels, cellulosics, plastics, rubber, organic ligands, and cementitious materials. Actinide solubility also depends on temperature. However, the temperature in the repository will remain almost constant (about 300 K) and the thermal effect of exothermal chemical reactions among brine, waste component, and MgO will be negligible (see WCA.5.3.1 and WCA.8.15). Repository pressure does not influence solubility until it is at least an order of magnitude higher than lithostatic pressure and this will not occur (Butcher et al. 1991). The following subsections discuss the influence of waste characteristics and components on each of these factors, as well as those that have little or no influence on solubility.

WCA.4.1.1 Components Influencing Redox Environment

The components of the waste that greatly influence the redox environment in the inundated WIPP repository are steels and biodegradable organic materials (cellulosics, plastics, and rubber). The radionuclides contributing to the brine release source terms are all actinides. Because of their electronic structure, these elements can form a wide variety of inorganic compounds that dissolve in aqueous solutions like brine in several different valence or oxidation states. In the WIPP environment, the solubilities of these compounds can vary from about 10^{-9} M to about 10^{-5} M (see Appendix SOTERM). In general, for both plutonium and the other actinides, the higher oxidation states (V and VI) are more soluble than the lower oxidation states (III and IV). The redox environment determines which of these oxidation states are likely to be stable in solution under WIPP conditions—an important determinant of solubility because of the differences among oxidation states. Although a detailed discussion of the experimental determination of oxidation state distribution is found in Appendix SOTERM.4, a brief discussion is given here. The bibliography of Appendix SOTERM also includes documentation of the experimental program.

Anoxic conditions will be dominant during the whole time period of 10,000 years. A small amount of oxygen, trapped at emplacement, will be used quickly by oxic corrosion and microbial action. Anoxic steel corrosion will produce both hydrogen and $Fe(OH)_2$ (Section WCA.8.17). Experimental work described in Appendix SOTERM.4 has shown that both metallic iron and Fe^{2+} ($Fe(OH)_2$) in simulated WIPP brine, under anoxic conditions, will reduce Pu(+VI) stoichiometrically to the much less soluble Pu(+IV). Pu(+V) is seen in this chemical reaction as an unstable intermediate. It is expected, therefore, that Pu(+VI) and P(+V) will not be stable in solution in WIPP brines. The iron in the drums and waste boxes is enough to provide several thousand-fold excess over what is needed stoichiometrically, even if all the emplaced plutonium existed in the +VI oxidation state. The other metals in the waste may also be able to reduce the actinides, but their effect would be negligible compared to the effect of iron, because they are present in smaller quantities.

The oxidation state distribution used in performance assessment, based on experimental data as well as the published literature, is (Katz et al. 1986, 917, 970, 1135 and following; Hobart 1990; Clark et al. 1995; Felmy et al. 1996; Rai and Strickert 1980; Rai et al. 1982; Kim et al. 1985; Pryke and Rees 1987; Nitsche and Edelstein 1985):

- thorium: +IV
- uranium: +IV and +VI
- neptunium: +IV and +V
- plutonium: +III and +IV
- americium: +III

Curium exhibits essentially the same chemical behavior and oxidation state as americium. In performance assessment, half of the realizations will include the lower oxidation states of uranium, neptunium, and plutonium; the other half will include the higher oxidation states (Appendix SOTERM 4.7; Katz et al. 1986; Weiner 1996).

WCA.4.1.2 Components Influencing pH and CO_2 Fugacity

In the absence of the MgO backfill, actinide solubility would be highly dependent on pH and CO_2 fugacity of the brine. Lower pH and higher CO_2 fugacity result in higher actinide solubility (Appendix SOTERM). Original Salado and Castile brines exhibit pH values of about 6 and 7, respectively (Brush 1990, Tables 2-2 and 2-3). The production of carbon dioxide by microbial degradation in the repository would acidify the brine and lower the brine pmH to about 4.5, if no MgO backfill were added (Appendix SOTERM.2). Microbial CO_2 production can be described by the following sequential reactions (Section WCA.8.17):

$$C_6H_{10}O_5 + 4.8H^+ + 4.8NO_3^- \rightarrow 7.4H_2O + 6CO_2 + 2N_2$$

$$C_6H_{10}O_5 + 6H^+ + 4.8SO_4^{2-} \rightarrow 5H_2O + 6CO_2 + 3H_2S$$

$$C_6H_{10}O_5 + H_2O \rightarrow 3CO_2 + 3CH_4.$$

Nitrate and sulfate are used as electron acceptors in these reactions and determine CO_2 yield per mole of organic carbon. Based on the inventory estimates for nitrate and sulfate, over 90% of organic materials (cellulosics, plastics, rubbers) will be biodegraded via the third reaction, methanogenesis, in which one mole of organic carbon will produce half a mole each of CO_2 and CH_4.

Based on the inventory estimate for organic carbon and the estimated CO_2 yield per mole of organic carbon, to mitigate the negative effect of microbially produced CO_2, 2×10^9 moles of MgO will be added to the repository as a backfill (USDOE 1996; WCA.8.17). The waste components of organic carbon, nitrate, and sulfate here are used to determine the amount of MgO needed. The hydrated MgO backfill will react with CO_2:

$$Mg(OH)_2 + CO_2 = MgCO_3 + H_2O.$$

The above reaction will buffer the pmH at approximately 9.4 in Salado brine and 9.9 in Castile brine and CO_2 fugacity at 10^{-7} (atm) for both brines. Actinide solubility calculated for the brine in equilibrium with $Mg(OH)_2$ and $MgCO_3$ is minimal (Appendix SOTERM.3).

Cementitious waste (that contains calcium oxide) could also be expected to raise the pH, and the waste is currently estimated to contain about a total of 8.54×10^6 kg cementitious material (Section WCA.8.13). This amount of cementitious material contains about 8×10^6 moles of $Ca(OH)_2$. However, this amount of $Ca(OH)_2$ will be not enough to affect pH or brine composition significantly. It is shown that $Ca(OH)_2$ will be consumed easily by reaction with microbial generated CO_2 or with $MgCl_2$ in the Salado brine and thus the repository chemistry will be dominantly controlled by the $Mg(OH)_2$ / Mg CO_3 buffer, rather than the $Ca(OH)_2$ / $CaCO_3$ buffer (Sections WCA.8.9 and WCA.8.10). Because the excess of MgO will be added, other components of the waste are unlikely to affect the pH in important ways.

WCA.4.1.3 Waste Components That Directly Enhance Solubility

A number of organic compounds are capable of forming strong complexes with actinide ions, thereby stablizing the actinide in the solution. The TWBIR (USDOE 1996) initially identified about 60 organic compounds in the waste (Drez and James-Lipponer 1989; Brush 1990; Section WCA.8.11). Four of these (acetate, citrate, oxalate, and EDTA) have been identified to have an effect on actinide mobility, because they are water-soluble and present in significant quantities (WCA.8.11).

Ligand concentration in the repository was estimated using inventory amounts of ligands and a brine volume equal to 75 percent of the total repository volume of 29841 m^3—the minimum brine for significant brine release to occur (Section WCA.8.12). The ligand concentrations are estimated to be: acetate : 8×10^{-4} M; oxalate : 2×10^{-4} M; citrate: 4×10^{-3} M; and EDTA: 2×10^{-6} M (Section WCA.8.12; Appendix SOTERM.5).

The effect of these organic ligands on the solubility of actinides in both Salado and Castile brines has been studied, and is discussed in detail in Appendix SOTERM.6. Modeling predicts that for the amount of these complexants expected to be emplaced in the repository, the concentration of americium and plutonium in solution is increased by less than 18 percent in the simulated Salado brine; in this brine, about 88 percent of the EDTA, 98 percent of the oxalate, 74 percent of the acetate, and 65 percent of the citrate is bound with Mg. In simulated Castile brines, which have much lower Mg concentrations, modeling predicts increases of americium and plutonium concentrations less than a factor of 8. Even so, about 40 percent of EDTA is bound with Mg (Novak and Moore 1996; Appendix SOTERM.6).

To estimate the effectiveness of other metals in binding organic ligands and thereby reducing the free ligand concentrations, some simple competition calculations were performed using

parameters obtained in dilute solutions, because parameters for concentrated salt solutions like the WIPP brines are not available. These metal species include iron (Fe), nickel (Ni), chromium (Cr), vanadium (V), and manganese (Mn), because the steels used for the waste drums contain on average at least 0.001 weight percent of Ni, Cr, V, and Mn as minor constituents. Based on at least 1.9×10^9 moles of steels destined to be disposed of in the WIPP, there should be at least 1×10^4 moles of each of Ni, Cr, V, and Mn in the repository (Appendix SOTERM). There are also expected to be more than 6×10^7 moles of Pb. Additionally, several other metals that can sequester organic ligands will be present in some of the waste forms.

Table WCA-9 presents complexation constants for several metals with EDTA. These values were measured in dilute solution. For comparison, for EDTA in 5 molal NaCl, the magnesium association constant is log $K_{Mg} = 6.6$ (Martell and Smith 1982).

Table WCA-9. Complexation Constants for Selected Metals*

Species	log K
Fe^{2+}	14.3
Cr^{2+}	13.6
Ni^{2+}	18.4
Mn^{2+}	13.9
V^{2+}	12.7
Cu^{2+}	18.9
Pb^{2+}	18

* From Martell and Smith (1982).

To assess the ability of these metals to sequester the organic ligands, the calculations for competition between these metals and actinides for organic ligands were performed by the DOE. The calculation results show that under expected WIPP conditions, 99.8% of the EDTA was complexed by Ni, effectively rendering it unavailable for complexation with the actinides (Appendix SOTERM).

WCA.4.2 Components and Characteristics Influencing Colloidal Actinide Mobility

The waste components that directly contribute to actinide colloid formation include mineral fragments, and humic substances (soil). Cellulosic materials, plastic, and rubber can contribute to the quantity of humic colloids. Actinides can form intrinsic colloids or can be sorbed on to nonradioactive colloidal particles. A complete discussion of colloid formation in the WIPP can be found in Appendix SOTERM and Sections WCA.8.4 through WCA.8.8.

In principle, intrinsic colloids are formed by condensation (or polymerization) of hydrolyzed actinide ions. Examples of polymeric species of many of the actinides of importance to the WIPP have been found in the literature (see Papenguth and Behl 1996, for an extensive literature review). However, except for Pu, the intrinsic colloids of other actinides (Am, U, Th, and Np) do not develop to sizes large enough to affect transport behavior of these actinides relative to their dissolved form (Appendix SOTERM.6). Therefore, the intrinsic colloid concentrations for Am, U, Th, and Np will be modeled as zero in the disposal room and only intrinsic plutonium colloid will have any impact on performance. Pu(IV) readily forms an intrinsic colloid; evidence suggests that the initial polymerization, or condensation, of hydrolyzed Pu(IV) produces a macromolecule that becomes progressively more crystalline with time. As the Pu polyelectrolytes mature, they are expected to be kinetically destabilized and immobilized by the high ionic strength of the WIPP brines, then coagulate and settle out of solution (Appendix SOTERM).

Within the repository, mineral fragment colloids could form from corrosion of iron-bearing waste, soils, and portland cement-based matrices. Because a wide range of mineralogies with different sorptive behavior are present at the WIPP, a bounding approach was used to estimate the maximum concentration of actinides bound to mineral fragment colloids (Appendix SOTERM). Mineral fragments are expected to be kinetically destabilized in the high-ionic strength brines present in the disposal room. Experimental information, combined with a conservative estimate of adsorption site density, provided a most likely value of 2.6×10^{-9} mole of colloidal mineral-fragment-bound actinides per liter of dispersion; the experimental results were increased by a factor of two to account for the possibility that the indigenous mineral fragment colloids in the Culebra could sorb dissolved actinides. This value is presumed to be the same for all five key actinides. Although mineral fragments contribute to actinide mobility and are included in performance assessment, their contribution is negligible and they will not impact repository performance.

Humic colloids will be present in the repository, both (a) in soil and humic material that is part of the emplaced waste and (b) in colloids that will be formed if the cellulosic, plastic, and rubber in the waste is microbially degraded. The contribution of humic colloids to repository performance is therefore calculated by quantifying humic-actinide complexation coupled with solubilities of humic substances in WIPP brines and expressing the result as the ratio of moles of humic-bound actinide to moles of dissolved actinide. The detailed ratios for the WIPP brines are given in (Papenguth 1996; Section WCA.8.4; Appendix SOTERM). The range of ratios is from about 4.3 $\times 10^{-4}$ to about 6.3 in Castile brine and from about 5.3×10^{-5} to about 6.3 in Salado brine.

To compute the concentration of actinides bound to humic substances, several parameters, such as solubility of humic substances, site binding capacity, actinide complexation factors, and stability constants, were measured or obtained from published literature (Section WCA.8.7). The oxidation state analogy was also used to develop parameter values for actinides expected to have multiple oxidation states in the WIPP disposal room. In addition, the theoretical maximum

concentration of actinides that can be bound to humic substances was also computed and found to be 1.1×10^{-5} M (Appendix SOTERM).

The other major source of colloidal material in the repository is the microbes themselves, though they are not necessarily waste components. Microbes are known to actively bioaccumulate actinides intercellularly as well as act as substrates for passive extracellular sorption. Naturally occurring halophilic and halotolerant microbes have been observed in the Salado brines at the WIPP site (Brush 1990; Francis and Gillow 1994). The waste material in the disposal room will serve as a nutrient and substrate for microbes, and consequently increase the microbe population, making them potentially important to actinide mobility.

The uptake of actinides by microbes and humic substances is quantified through two parameters for each actinide and substrate (Table WCA-2): proportionality constants (with performance assessment parameter designations PROPMIC, PHUMSIM, and PHUMCIM) describing the amount of each actinide bound to mobile microbes and humic colloids, respectively, and the maximum concentrations (CAPMIC and CAPHUM) of each actinide associated with mobile microbes and humics, respectively. As discussed above, the concentrations of mineral-fragment-bound actinides and intrinsic actinides are very small, and are presented as concentrations (CONCMIN and CONCINT) only. A series of bioaccumulation and toxicity experiments (Sections WCA.8.4 to 8.8; Appendix SOTERM) were performed to obtain the following values of performance assessment parameters for each actinide shown in Table WCA-10.

As evident in Table WCA-10, microbial colloids can transport concentrations of actinides that are several multiples of the dissolved concentration, and thus increase the potential for actinide mobility considerably. Humic colloids are waste components, and microbial colloids increase in quantity as they metabolize waste components. Both types of colloids are incorporated in performance assessment (details are discussed in Appendix SOTERM.7) and are expected to affect disposal system performance.

WCA.5 NONRADIOACTIVE WASTE COMPONENTS AND CHARACTERISTICS

WCA.5.1 Gas Generation

The waste components that contribute to gas generation are: (a) ferrous and nonferrous metals, (b) cellulosics, plastics, rubber, and (c) nitrate and sulfate.

The mechanisms and reactions for gas generation are discussed in Section WCA.8.17.

Metals contribute to gas generation through corrosion. The anoxic corrosion reaction of iron in the WIPP is

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2(g)$$

Table WCA-10. Colloid Concentration Factors

	Concentration on Mineral Fragments*	Concentration as Intrinsic Colloid*	Proportion Sorbed on Microbes**	Maximum Sorbed on Microbes*	Proportion Sorbed on Humics**		Maximum Sorbed on Humics*
					Salado	*Castile*	
Th	2.6×10^{-8}	0.0	3.1	0.0019	6.3	6.3	1.1×10^{-5}
U(IV)	2.6×10^{-8}	0.0	0.0021	0.0023	6.3	6.3	1.1×10^{-5}
U(VI)	2.6×10^{-8}	0.0	0.0021	0.0023	0.12	0.51	1.1×10^{-5}
Np(IV)	2.6×10^{-8}	0.0	12.0	0.0027	6.3	6.3	1.1×10^{-5}
Np(V)	2.6×10^{-8}	0.0	12.0	0.0027	9.1×10^{-4}	7.1×10^{-3}	1.1×10^{-5}
Pu(III)	2.6×10^{-8}	0.0	0.3	6.8×10^{-5}	0.19	1.1	1.1×10^{-5}
Pu(IV)	2.6×10^{-8}	1.0×10^{-9}	0.3	6.8×10^{-5}	6.3	6.3	1.1×10^{-5}
Am	2.6×10^{-8}	0.0	3.6	NA	0.19	1.1	1.1×10^{-5}

* in units of moles total mobile actinide per liter
** in units of moles microbial actinide per moles dissolved actinide

The hydrogen gas produced by this reaction contributes to total gas pressure, but does not affect repository chemistry. In addition, steel corrosion will consume water in the repository; this effect is taken into account in computer code BRAGFLO. Nonferrous metals such as alumimum alloys also corrode, producing H_2, but their contribution to total gas pressure is negligible, because they are present in much smaller quantities than iron (TWBIR; USDOE 1996).

Cellulose materials, plastic, rubber, nitrate and sulfate control microbial gas generation. Cellulosics, plastics, and rubbers will be used as substrates by anaerobic microbes in the WIPP. Nitrate and sulfate will be used as electron acceptors by microbes to oxidize the organic materials. Organic materials will be biodegraded through reactions (Section WCA.8.17)

$$C_6H_{10}O_5 + 4_1\,8H^+ + 4.8\ NO_3^- \rightarrow +7.4H_2O + 6CO_2 + 24N_{2(g)}$$

$$C_6H_{10}O_5 + 6H^+ + 3SO_4^{2-} \rightarrow 5H_2O + 6CO_2 + 3H_2S(g)$$

$$C_6H_{10}O_5 + H_2O \rightarrow 3CH_{4(g)} + 3CO_{2(g)}$$

The above reactions will proceed sequentially according to the energy yield per mole of carbon in each reaction. Based on the inventory estimates for nitrate and sulfate, the third reaction is expected to be dominant. Because the CO_2 produced by these reactions will be removed by reaction with the MgO backfill, the methane is a major microbially generated gas that will contribute to the total gas in the repository.

Phosphate in the waste may enhance microbial activity in the repository. The rates of cellulosics biodegradation used in performance assessment are derived from the incubation experiments amended with nutrients including phosphate. Thus, the effect of phosphate on microbial reactions is captured indirectly in the parameters submitted to performance assessment (Francis and Gillow 1994).

Based on the inventories of steels and organic materials and the rates of gas generation estimated by Wang and Brush (Section WCA.8.17), microbially produced gases may dominate early in the repository's history. Gas pressure does affect repository performance. Pressure in the repository may approach lithostatic, initiating or propagating fractures within the interbeds, and clay seams in the Salado. Gas pressure will not exceed lithostatic (Butcher et al. 1991) because gas can leak out through the interbeds.

Gas pressure is incorporated into performance assessment through the specific variables identified in Table WCA-2 in BRAGFLO calculations.

WCA.5.1.1 Waste Fluid Content

The initial water content of the waste contributes to generation of gas because it defines how much brine is immediately available for the corrosion reaction. All of the liquid in the waste is assumed to be aqueous with no volume correction. A mean value of 0.06 percent, is assumed in performance assessment for the initial free unbound water saturation of the waste, based on waste characterization data and transportation restrictions on the amount of free liquid that the waste can contain (Appendix PAR, Table PAR-39; Butcher 1996).

Materials such as dry portland cement, vermiculite, and other sorbents have intentionally been added to the waste to absorb any excess water that may be present. Sorbed water is much less readily available than any brine available from the surrounding rock. Therefore, the effect of initial water content on gas generation is negligible.

WCA.5.2 Components and Characteristics Influencing Physical Properties

As noted in Tables WCA-2 and WCA-3, the following physical properties of the solid waste components are used in performance assessment:

- *Expected Significant Effect on Disposal System Performance*:

Compressibility: this affects the creep closure, and the porosity of the waste.

Shear Strength: the amount of material released directly on a drilling intrusion, calculated as cuttings, cavings and spalling, depends on the erosion and the spall strengths of the waste at the time of the intrusion, which in turn depend on the time-dependent extent of waste consolidation.

• *Expected Negligible Effect on Disposal System Performance*

Porosity: effects on brine movement in the waste. Also controls the maximum volume that can exist in the waste for potential saturation with radionuclides or gas storage

Permeability: effect on brine movement in the waste

WCA.5.2.1 Compressibility

An important characteristic of the WIPP repository is the closure of the disposal rooms over time due to the creep response of the surrounding salt in response to the presence of the mined openings. This ability of salt to deform with time, eliminate voids, and create an impermeable salt barrier around waste is one of the principal reasons for locating the WIPP repository in a bedded salt formation, as suggested by the National Academy of Sciences (NAS-NRC 1957). This closure process is rather complex, and the rate at which it occurs depends in large part on the balance of forces tending to close the repository (the far-field lithostatic stresses) and those resisting the closure. These resisting forces are the tendency of the waste to resist deformation, measured in terms of its compressibility, and the effect of any gas pressure within the rooms.

The condition of the waste at any time can be represented in terms of its porosity, which gives a measure of the pore volume available for storage of generated gas or brine. A subcategory of this issue is that release may depend on how much contaminated brine exists in the waste before the intrusion, which depends on the waste porosity.

The compressibility of the waste has been determined from a series of laboratory tests on simulated waste materials, which are described in detail in Butcher et al. 1991. These included small-scale compaction tests, as well as a number of tests on full-scale waste drums filled with simulated waste materials. In these tests the materials used were simulations of all of the main classes of waste anticipated at the WIPP, including metallics, combustibles, cellulosics, and sludges. Waste compressibility was determined by combining the individual compressibilities of the different waste types in the proportions expected at the WIPP.

The conceptual model for creep closure assumes that compaction takes place before complete degradation. This assumption is borne out by observation of microbial gas generation rates. Estimates of degraded waste response suggest that the porosity of the corroded and biodegraded waste would be comparable to that of the unreacted waste, even though the cellulosics have been totally consumed (Luker et al. 1991). A volumetric plasticity model of the waste is used (Weatherby et al. 1991). The model and the experimental data supporting it are described in Butcher et al. (1991) and Callahan (1993).

WCA.5.2.2 Strength

Strength of the waste is important in evaluating the potential for release due to caving or spalling following an inadvertent human intrusion. As described in Appendix CUTTINGS, solid waste can be released through a borehole by erosion of the borehole walls by circulating drilling mud (caving), and by suspension in gas released from the repository during a high pressure blowout (spalling). Cavings are controlled in large part by the erosional shear strength of the waste, which is based upon analogy to deep-sea sediment erosion, which provides a minimum, conservative estimate of this property. Spalling is controlled largely by the velocity of gas flow, and the particle diameter, but is limited by the tensile strength. As argued by Berglund et al. (1996), a tensile strength of the waste of 1 psi may be established from a study of analog materials, and a consideration of mechanisms in the repository, including salt precipitation.

WCA.5.2.3 Permeability

Fluid flow within a disposal room affects the fluid distribution in the waste and backfill, and the flow of brine and gas within the room and repository. Both waste permeability and liquid present in the waste can affect fluid flow.

The permeability of the waste at a given time can influence repository performance by controlling how rapidly gas or brine can flow through the waste. The WIPP waste region is confined between layers of very low permeability (intact halite permeability $<10^{-21}$ square meters). Therefore, the waste is much more permeable than the halite and may be expected to be the dominant path for fluids flowing into and through the repository. The flow path through the repository will be short in comparison to the external flow paths for brine migration (through seals and up shafts or boreholes, etc.). Thus, assuming a permeability of about 10^{-13} square meters is analogous to assuming that there is little restriction of flow of either gas or brine within the waste.

The mean permeability of waste on the scale of a drum is 1.7×10^{-13} square meters, based upon laboratory data reported in Luker et al. 1991. For the preliminary performance assessment (WIPP PA Dept. 1993) a median value of 1×10^{-13} square meters used, and was assumed to be independent of porosity (WIPP PA Dept. 1993, Table 3.4-1, 3-56, 3-57). Any time-dependent variation in permeability has been shown to have no significant effect on system performance.

WCA.5.3 Components and Characteristics Affecting Heat Generation

Heat generation is a characteristic of some components of the waste, or of their interactions. The WIPP includes two possibly significant sources of heat: the heat generated by RH-TRU waste (USDOE 1995) and the heat generated by MgO hydration and carbonization, steel corrosion, aluminum corrosion, and organic biodegradation.

WCA.5.3.1 Exothermal Reactions

MgO hydration and carbonization, steel corrosion, aluminum corrosion, and organic biodegradation are all exothermal reactions. Evaluation of the ability of each of these reactions to produce heat while conservatively accounting for the repository's ability to dissipate the resulting heat generated has provided the following maximum temperature increases (Wang 1996: WCA 8.15), as shown in Table WCA-11:

Table WCA-11. Maximum Temperature Increases

Reaction Number	Maximum Temperature Increase (K)
MgO hydration	5
$Mg(OH_2)$ carbonization	0.8
Steel corrosion	2
Microbial degradation	1
Aluminum corrosion	7

In the worst case, a temperature increase of 7 K could be experienced. However, these temperature extremes will not persist, if they are ever reached at all. Because all but one reaction consume brine, possible reactions will be competing with each other for what brine may enter the repository and will therefore temper the heat increase that could be predicted based on the most exothermic reaction alone. To evaluate the worst case possible, for the maximum temperature increase to be realized from the corrosion of aluminum, all of the aluminum would have to be corroded within 2.5 years, after which the heat would be dissipated very rapidly. Therefore, if such a condition were to be created, it would be transitory on the repository time scale and its influence inconsequential.

The effect of small temperature increases arising from exothermal reactions has previously been screened out of the performance assessment on the basis of low consequence to factors such as creep closure, seal performance, transport, etc. (see Appendix SCR.2.5.7). The effect of heat generated by radiolysis has been considered as part of the repository conditions (Brush 1990) and utilized in the specification of experimental parameters, thus yielding data consistent with the anticipated conditions. Additionally, the small temperature increases cited above for exothermic reactions are insignificant to the thermodynamic modeling of solubility. For example, a temperature increase of 7 K (the maximum temperature increase possible) would result in an approximately 3 percent change in the free energy of formation of any species contained within the model. This value is well within the model parameter bounds.

WCA.5.3.2 RH-TRU Thermal Heat Load

The "worst case" heat load from RH-TRU emplaced in the WIPP is estimated to be between 71 and 82 watts per cubic meter, which would result in a temperature rise near the "worst-case" RH-TRU canister between 2.85 K and 3.19 K. The expected WIPP average temperature increase from RH-TRU heat loading is between 0.38 K and 0.49 K. The RH-TRU thermal heat load is small enough that there is no anticipated impact on repository performance. A complete discussion and analysis is given in Section WCA.8.16.

WCA.6 SUMMARY

The waste characteristics and components expected to be most significant to performance are the predominant radionuclides and those characteristics and components affecting actinide mobility. The waste characteristics and components expected to be significant to performance are summarized in Table WCA-12:

Table WCA-12. Waste Characteristics and Components Expected to be Most Significant to Performance

Characteristic/Component	Reason for Significance
Pu-239, Pu-240, Am 241, U-233, and U-234	99 percent of EPA unit after 2,000 years
Pu-238	dominates EPA unit at early times
solubility of Pu and Am	large EPA unit; mobility depends on solubility
U-238	very low activity; dilutes higher-activity uranium isotopes for brine-based releases
iron	1. maintains reducing environment so that lower, less soluble oxidation states of actinides predominate 2. corrodes to produce hydrogen, increasing gas pressure;
cellulose, plastic, rubber, nitrate, sulfate	microbial nutrients that are metabolized to methane and several other gases, increasing gas pressure; formation of colloids
humic materials, cellulose breakdown products	form humic colloids that sorb and transport actinides
nonferrous metals	prevent increase in actinide solubility by binding with ligands
waste shear strength	important to spalling and cavings

It should be noted that these components and characteristics have both positive and negative effects on performance. Iron has a beneficial effect because it reduces actinides to lower, less soluble oxidation states. Nonferrous metals are beneficial because they bind organic ligands, thereby sequestering them. Mobility enhancers like colloidal substrates, on the other hand, have a detrimental effect. Gas buildup can both enhance and detract from repository performance. Although gas can open fractures, it can also keep brine from entering the repository, thereby reducing transport of soluble actinides (WIPP PA Dept. 1992).

Table WCA-13 summarizes those characteristics and components with an insignificant impact on performance.

Table WCA-13. Waste Characteristics and Components Expected to be Not Significant

Characteristics/Component	Reason for insignificant impact
Radionuclides other than those in Table WCA-12	EPA unit is negligible fraction of total, even with ingrowth
substances that may affect pH*	pH is buffered by MgO backfill
substances that produce CO_2*	CO_2 is removed by reaction with MgO backfill
intrinsic and mineral fragment colloids	fraction of actinides mobilized by these colloids is insignificant
organic ligands	removed by binding with Mg and nonferrous metal
heat generated by exothermic reactions	Heats of formation are small and thermal mass of repository is large so that temperature rise is negligible.
Fluid in the waste	negligible compared to brine volume

* These components are significant for gas generation, but not for actinide solubility.

WCA.7 REFERENCES

Berglund, J.W., J. Myers, L.R. Lenke. Memo to M.S.Y. Chu, "Estimate of the Tensile Strength of Degraded Waste," July 19, 1996. (Copy on file in the Sandia WIPP Central File.)

Brush, L.H. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266. Albuquerque, NM: Sandia National Laboratories.

Butcher, B.M. 1996. "QAP 9-2 Documentation of the Initial Waste Water Content for the CCA," Memo, June 29, 1996. (Copy on file in the Sandia WIPP Central File.)

Butcher, B.M., T.W. Thompson, R.G. VanBuskirk, and N.C. Patti. 1991. *Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste.* SAND90-1206. Albuquerque, NM: Sandia National Laboratories.

Callahan, G.D. 1993. "Appendix A: Further Discussion of the TRU Waste Model," *A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance to 40 CFR 191, Subpart B.* B.M. Butcher and F.T. Mendenhall. SAND92-0427. Albuquerque, NM: Sandia National Laboratories. A-27 through A-30.

Clark, D.L., Hobart, D.E., and Neu, M.P. 1995. "Actinide Carbonate Complexes and Their Importance in Actinide Environmental Chemistry" *Chem Revs.* v. 95, pp. 25-48.

Drez, P.E., and P. James-Lipponer. 1989. "Preliminary Nonradionuclide Inventory for CH-TRU Waste," unpublished report cited in Brush, L.H. 1990. *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266. Albuquerque, NM: Sandia National Laboratories.

Felmy, A.R., D. Rai, S.M. Sterner, M.J. Mason, N.J. Hess, and S.D. Conradson. 1996. "Thermodynamic Models for Highly Charged Aqueous Species: The Solubility of Th(IV) Hydrous Oxide in Concentrated $NaHCO_3$ and Na_2CO_3 Solutions." manuscript in preparation.

Francis, A.J., and J.B. Gillow. 1994. *Effects of Microbial Processes on Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions.* Progress Report through 1992. SAND93-7036. Albuquerque, NM: Sandia National Laboratories.

Hobart, D.E. 1990. "Actinides in the Environment," in *Proceedings of the Robert A. Welch Foundation Conference on Chemical Research, No. XXXIV: 50 Years With Transuranium Elements. October 22-23, 1990.*

Hobart, D.E., C.J. Bruton, F.J. Millero, I-Ming Chou, K.M. Trauth, D.R. Anderson. 1996. *Estimates of the Solubilities of Waste Element Radionuclides in WIPP Brines.* SAND96-0098.

Katz, J.J., G.T. Seaborg, and L.R. Morss. 1986. *The Chemistry of the Actinide Elements,* 2 volumes, New York: Chapman and Hall.

Kim, J.I., Ch. Apostolidis, G. Buckau, K. Bueppelmann, B. Kannellakopoulos, Ch. Lierse, S. Magirius, R. Stumpe, I. Hedler, Ch. Rahner, and W. Stoewer. 1985. "Chemisches Verhalten von Np, Pu und Am in verschiedenen konzentrierten Salzloesunger" RCM 01085. Munich, Germany: Institut fuer Radiochemie der Technische Universitaet Muenchen.

Lappin, A. R., Hunter, R. L., and Garber, D. P. eds. 1989. *Systems Analysis, Long-term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP) Southeastern New Mexico* SAND89-0462, Sandia National Laboratories, Albuquerque, NM.

Luker, R.S., T.W. Thompson, and B.M. Butcher. 1991. "Compaction and Permeability of Simulated Waste," *Rock Mechanics as a Multidisciplinary Science: Proceedings of the 32nd U.S. Symposium, The University of Oklahoma, Norman, OK, July 10-12, 1991.* Ed. J-C. Roegiers. SAND90-2368C. Brookfield, VT: A.A. Balkema. 693-702.

Martell, Arthur E. and Robert M. Smith. 1982. *Critical Stability Constants, Volume 5: Other Organic Ligands*, Plenum Press, New York.

NAS-NRC. 1957. *Disposal of Radioactive Waste on Land.* Report by the Committee on Waste Disposal, Division of Earth Sciences, National Academy of Sciences-National Research Council, Washington, DC.

Nitsche, H. and N.M. Edelstein *Radiochimica Acta* 1985, 39, 22.

Novak, C.F. and R.C. Moore. "Estimates of Dissolved Concentrations for +III, +IV, +V, and +VI Actinides in Salado and Castile Brine". SNL Tech Memo, March 28, 1996. (Copy on file in the Sandia WIPP Central Files.)

Novak, C. F. 1995a. *Actinide Chemistry Research Supporting the Waste Isolation Pilot Plant (WIPP): FY94 Results.* SAND 94-2274, Sandia National Laboratories, Albuquerque, NM.

Novak, C. F. 1995b. *The WIPP Actinide Source Term: Test Plan for the Conceptual Model, and the Dissolved Concentration Submodel.* Sandia National Laboratories, Albuquerque, NM.

Papenguth, H.W., and Y.K. Behl. 1996. Test plan for evaluation of colloid-facilitated actinide transport at the Waste Isolation Pilot Plant. SNL Test Plan TP 96-01.

Pryke, D.C. and J.H. Rees. 1987. "Understanding the Behavior of the Actinides Under Disposal Conditions: a Comparison between Calculated and Experimental Solubilities" *Radiochimica Acta,* v. 51 p. 27.

Rai, D. and Strickert, R.G. 1980. "Chemical Aspects of Medium and Long-term Radioactive Waste Disposal" *Trans. Am. Nuclear Soc. and Eur. Nuclear Soc.* v. 35, p. 185.

Rai, D., Strickert, R.G. and McVay, G.L. 1982. "Neptunium Concentration in Solutions Containing Actinide-Doped Glass" *Nuclear Technology* v. 58, p. 69.

Sanchez, L. C., J. Liscum-Powell, J. S. Rath,and H. R. Trellue. 1996. *WIPP PA Analysis Report for EPAUNI: Estimating Probability Distribution of EPA Unit Loading in the WIPP Repository for Performance Assessment Calculations.* Document Record Package for WBS 1.2.07.1.1 Sandia National Laboratories, Albuquerque, NM.

Trauth, K. M., Hora, S. C., Rechard, R. P., and Anderson, D. R. 1992. *The Use of Expert Judgment to Quantify Uncertainty in Solubility and Sorption Parameters for Waste Isolation Pilot Plant Performance Assessment.* SAND92-0479. Sandia National Laboratories, Albuquerque, NM.

U.S. Department of Energy. 1995. Remote-Handled Transuranic Waste Study. DOE/CAO95-1095. Carlsbad, NM.

U. S. Department of Energy. 1996. *Transuranic Waste Baseline Inventory Report (Revision 3).* DOE/CAO-95-1121, Carlsbad, NM.

U. S. Environmental Protection Agency. 1985. *High-Level and Transuranic Radioactive Wastes: Background Information for Final Rule.* EPA 520/1-85-023. Washington, DC.

Wang, Y. 1996. *Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment*, memorandum to Richard Vann Bynum and Laurence H. Brush, July 19, 1996.

Weatherby, J.R., W.T. Brown, and B.M. Butcher. 1991. "The Closure of WIPP Disposal Rooms Filled with Various Waste and Backfill Combinations," *Rock Mechanics as a Multidisciplinary Science, Proceedings of the 32nd U.S. Symposium, University of Oklahoma, Norman, OK, July 10-12, 1991.* Ed. J.C. Roegiers. SAND90-2399C. Brookfield, VT: A.A. Balkema. 919-928.

Weiner, R. 1996. Documentation package for: oxidation state distribution of actinides in the repository. SNL Technical memorandum dated 27 March 1996 to SWCF-A: Records Center, SWCF-A: WBS 1.1.10.1.1: PDD: QA: Dissolved Species: Oxidation State Distribution: Actinides: OX3: OX4: OX5: OX6 (WPO# 35194).

WIPP PA (Performance Assessment) Division. 1991. *Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volumes 1 and 3: Reference Data.* SAND91-0893/1 and SAND91-0893/3. Eds. R.P. Rechard, A.C. Peterson, J.D. Schreiber, H.J. Iuzzolino, M.S. Tierney, and J.S. Sandha. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 2: Technical Basis.* SAND92-0700/2. Albuquerque, NM: Sandia National Laboratories.

WIPP PA (Performance Assessment) Department. 1993. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. Volume 4: Uncertainty and Sensitivity Analyses for 40 CFR 191, Subpart B.* SAND92-0700/4. Albuquerque, NM: Sandia National Laboratories.

WCA.8 SUPPLEMENTARY DOCUMENTS

WCA.8.1 Memo from L. C. Sanchez to M. Martell, April 24, 1996, "Justification for Choice of CCA Radionuclide Values." WPO# 37428

WCA.8.2 Memo From L. C. Sanchez: "Identification of Important Radionuclides Used in 1996 CCA WIPP Performance Assessment", April 25, 1996 WPO# 37432

WCA.8.3 Memo From James Garner to Christine Stockman "Radioisotopes to Be Used in the 1996 CCA Calculations", March 15, 1996 WPO# 35202

WCA.8.4 H. W. Papenguth to Christine T. Stockman: "Colloidal Actinide Source Term Parameters" March 29, 1996 WPO# 36771

WCA.8.5 H. W. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7, 1996: Attachment A: Rationale for Definition of Parameter Values for Actinide Intrinsic Colloids." WPO# 35852.

WCA.8.6 H. W. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7, 1996: Attachment A: Rationale for Definition of Parameter Values for Microbes." WPO# 35856

WCA.8.7 H. W. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7, 1996: Attachment A: Rationale for Definition of Parameter Values for Humic Substances." WPO# 35855

WCA.8.8 H. W. Papenguth to Christine T. Stockman: "Parameter Record Package for Colloidal Actinide Source Term Parameters" May 7, 1996: Attachment A: Rationale for Definition of Parameter Values for Mineral Fragment Type Colloids." WPO# 35850

WCA.8.9 Yifeng Wang, "Estimate of repository pH and f(CO_2) Distribution of the Long-Term WIPP Performance Assessment," March 29, 1996 WPO# 37415

WCA.8.10 Yifeng Wang, "Define Chemical Conditions for FMT Actinide Solubility Calculations," March 22, 1996. PDD# 3O819

WCA.8.11 P. Drez to J. Harvill, "Final Estimate of Complexing Agents in TRU Solidified Waste Forms Scheduled for Disposal in WIPP" March 20, 1996 WPO# 35552

WCA.8.12 R. Weiner to C. F. Novak, March 27, 1996, "Dissolved Ligand Concentrations" WPO# 36163

WCA.8.13 D. Watkins to L. E. Shephard, April 4, 1996, "Estimate of Cement Content in TRU Solidifed Waste Forms Schedules for Disposal in WIPP" WPO# 37064

WCA.8.14 P. E. Drez, "Preliminary Estimate for SNL/NM Performance Assessment Calculations of Nitrate, Sulfate, and Phosphate Content in Transuranic Solidified Wastes Destined for Disposal in WIPP," January 26, 1996. WPO# 31379

WCA.8.15 Yifeng Wang, May 9, 1996. "Evaluation of the Thermal Effect of MgO Hydration for the Long-term WIPP Performance Assessment." WPO# 37743

WCA.8.16 L. C. Sanchez and H. R. Trellue, January 17, 1996. "Estimation of Maximum RH-TRU Thermal Heat Load for WIPP." WPO# 31165

WCA.8.17 Yifeng Wang and Larry Brush, January 26, 1996, "Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance Assessment. WPO# 31943

WCA.8.18 Kurt Larson to R. V. Bynum, March 13, 1996, "Brine-Waste Contact Volumes for Scoping Analysis of Organic Ligand Concentration" WPO# 36044

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

WCA Attachment WCA.8.1

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PREFACE TO ATTACHMENT WCA.8.1

Title 40 of the Code of Federal Regulations (CFR) § 194.31 states that

The release limits shall be calculated according to part 191, appendix A of this chapter, using the total activity, in curies, that will exist in the disposal system at the time of disposal.

Making an exact assessment of the total activity (the radionuclide inventory) at the time of disposal (2033) requires assessing the total activity, in 2033, of three categories of contact-handled transuranic (CH-TRU) waste.

Category 1: the stored, "legacy" waste; CH-TRU waste that currently exists, is packaged, and has been inventoried and decayed to the year 1995.

Category 2: future waste that has already been generated; CH-TRU waste that currently exists and has been identified, is not packaged, and has not been inventoried for shipment to the Waste Isolation Pilot Plant (WIPP).

Category 3: future to-be-generated waste; CH-TRU waste that has not been identified.

Categories 2 and 3, the projected waste, comprise 66% of the WIPP waste by volume (Transuranic Waste Baseline Inventory Report [TWBIR], DOE 1995, p. 3-1).

Category 1 waste has already been inventoried and the inventory data can be readily decayed to any common base year (that is, to 1995, as is done in the TWBIR). Category 2 waste is expected to be similar to Category 1 waste, and could thus also be assessed at any common base year (for example, 1995). The Category 1 and 2 inventories can also be decayed to any other common year such as the year of closure, 2033. However, Category 3 waste is not necessarily similar to the other two categories and therefore should be estimated separately on a year-by-year basis as it is generated. Then each yearly contribution should be decayed separately to the closure year (2033).

TWBIR data collection methods estimated Category 3 data in the same manner as Category 2 data, and prorated Category 3 data accordingly. Thus, Category 3 data are estimated at 1995 instead of the later years during which the waste would be generated. Additional decay calculations of Category 3 data would result in over-decay of the inventory. For example, waste assayed in 2030 should be decayed for only three years to 2033; decaying such waste for the 38 years from 1995 to 2033 would result in an underestimate, particularly since the fraction of projected waste that is Category 3 cannot be determined. 40 CFR § 194.31 requires assessing the radionuclide inventory at the time of closure, that is, the year 2033. This can be done readily for Category 1 and Category 2 data. Because the Category 3 data were not separated from the Category 2 data, decaying from 1995 to 2033 underestimates portions of the Category 3 inventory by between one and 37 years of decay.

Because Category 3 wastes cannot currently be assessed separately from Category 2 wastes, there are two alternatives for calculating the waste unit factor: (1) calculation on the basis of

the entire inventory decayed to 1995 or (2) calculation on the basis of the entire inventory decayed to 2033. The first yields a waste unit factor of 4.07×10^6, and the second, a waste unit factor of 3.44×10^6. The waste unit factor determines the normalization factor used in calculating the release limit, according to Table 1 of 40 CFR Part 191 Appendix A. The curies of radionuclides are divided by the release limit to determine the EPA units. All else being equal, a smaller release limit (and thus a smaller waste unit factor) is the more conservative of the two possibilities. Therefore, the entire inventory is decayed to 2033 for the performance assessment calculations as specified in 40 CFR § 194.31 above.

Attachment WCA.8.1 states that the inventory decayed to 1995 is used. However, as described above, in keeping with the specification of 40 CFR § 194.31 the inventory decayed to 2033 is used instead.

Reference:

DOE (U. S. Department of Energy). 1995. *Transuranic Waste Baseline Inventory Report, Rev. 2,* DOE/CAO 95-1121, Carlsbad, NM.

WPO 37428

Sandia National Laboratories

Managed and Operated by Sandia Corporation
a Lockheed Martin Corporation
Albuquerque, New Mexico 87185-1328

date : April 24, 1996

to : M. Martell, Org 6749, MS-1328

from : L. C. Sanchez, Org 6741, MS-1328, PH-(505)848-0685, Fax-848-0705

subject : **Justification For Choice of CCA Radionuclide Values**

This memo gives the justification for the choice of the radionuclide data and their corresponding "Unit of Waste" value to be used in the 1996 WIPP CCA PA calculations. These data are obtained directly from the Transuranic Waste Baseline Inventory Database (TWBID). These values supersede the published values in Rev. 2 of the Transuranic Waste Baseline Inventory Report (TWBIR, Ref. BIR-2) and are intended for use in WIPP PA calculations until Rev. 3 TWBIR data are available.

The concern that arose while generating the "Unit of Waste" value was: At what calendar year should the radionuclide decay values and the "Unit of Waste" correspond to? Obviously, the answer is that they should be evaluated at the year that WIPP is decommissioned, which is expected to be the year 2033. The problem at hand is that the TWBID data is all evaluated at the year 1995 and these data values are comprised of two key components: 1) stored (legacy) and 2) future (projected and scaled) waste. The stored radionuclide inventory data are comprised of data values from many individual years (representing annual assessment made from 1970 → 1995). The stored values are easy to deal with because they have already been "decayed" to a common base year of 1995 (i.e., 1970 values are decayed to 1995, and 1971 values independently decayed to 1995, and so on). These decay calculations (SNL-3) were performed prior to the projection and scaling operations for future generated waste (see discussions in Ref. BIR-2). Thus, they can easily be decayed to any future base year. The problem, therefore, resides only with the future waste. Unfortunately, the TWBID does not contain sufficient data from the waste generation sites to predict radionuclide inventories in the future. However, the waste generator sites can make some predictions of the volumes of waste that may be expected to be generated in the future based on process knowledge available at the sites. The methodology used within the TWBIR is to estimate the future radionuclide inventories by multiplying the future volumes by the curie density (Ci/vol) of the stored radionuclides. This approach makes it impossible to properly decay these data values to the base year of 2033. This is because TWBID future values are already decayed from as far back as 1970 to the base year of 1995. Added decay of this data to the year 2033 would result in a portion of the data being decayed in excess of 38 years. Thus, this approach would yield non-conservative estimates (under-estimated values) for key radionuclides. An additional complication is that the majority of the radionuclide inventory is dominated by future generated radionuclides and each radionuclide has different breakdown of stored versus future inventory values (see Tables 1 and 2). The preferred approach would be to identify future radionuclide inventories on a yearly basis using curie densities based only on the last year production (undecayed) rates. Thus 1996 values could be decayed to the base

year of 2033 independently of the 1997 values (plus later yearly values). Since this is not currently possible within the TWBID, it was decided to apply the 1995 (stored and future) data to the year 2033. Thus, radionuclide inventory data will be slightly conservative. This will only be of some importance in the early human intrusion scenarios. At later years the difference in radionuclide estimates due to the delta time of 38 years will be minuscule.

To identify if there are any significant impacts of applying 1995 data to the base year of 2033, a set of ORIGEN2 (Ref. OR-1) decay calculations were performed. These calculations decayed the 1995 TWBID values to the year 2033 and then values for the Unit of Waste and EPA Units calculated. Detailed calculations for the Unit of Waste and the EPA Units for 1995 data are showned in Tables 3 and 4. Results of ORIGEN2 decay calculations are showned in Table 5 (slight differences in 1995 curie values presented in Table 5 versus those presented in Tables 3 and 4 are due to conversion errors when translating input curie values into mass units for ORIGEN2 and also in the translating output mass values into curies). The most important finding from Table 5 is that the cumulative EPA Unit for 2033 base year is nearly the same as that for a base year of 1995. The reason for this is that over the first 38 years, the cumulative inventory of the key radionuclides that contribute to the EPA Unit decay at a rate comparable to that of the Unit of Waste. This is more easily observable at the bottom of Table 5 which shows the top four radionuclides of importance. As can be seen, while some radionuclides decay rapidly with time, some increase due to in growth. And the overall effect is that during this small time period the EPA Unit is essentially constant.

REFERENCES

[BIR-1]

DOE (U.S. Department of Energy); Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report; CAO-94-1005; Revision 1; February 1995, Volume 1, Table 4-2, pg. 4-6.

[BIR-2]

DOE (U.S. Department of Energy); Transuranic Waste Baseline Inventory Report; DOE/CAO-95-1121; Revision 2; printed December 1995.

[BIR-2d]

Ibid., Table 3-4, pp. 3-27 → 29 (Volume 1).

[CCA-1]

S. Chakraborti (SAIC/CTAC); Letter to: J. Harvill (ASI/CTAC), Subject: "Revised Radionuclide Data In Support Of The CCA", Dated: April 12, 1996.

[CCA-2] SAIC LOS 4-25-26

S. Chakraborti (SAIV/CTAC); Letter to: J. Harvill (ASI/CTAC), Subject: "Final Radionuclide Data In Support Of The CCA", Dated: April 19, 1996. [This letter gives radionuclide data that supersedes Rev. 2 of the TWBIR and should be used in the 1996 CCA calculations for the WIPP facility. This letter also supersedes Ref. CCA-1, which had preliminary values. The reason that that this reference was generated was that after publication of Ref. BIR-2 it was identified that inventory data for several key radionuclides needed to be modified in accordance to new information obtained from the waste generation sites (this information was deemed important enough that the updated information was needed for the 1996 CCA calculations).]

[DOE-1]

DOE (U.S. Department of Energy); Remote-Handled Transuranic Waste Study; DOE/CAO-1095, DOE Carlsbad Area Office; Carlsbad, NM, October 1995.

[DOE-2]
DOE (U.S. Department of Energy), Waste Isolation Pilot Plant (WIPP); Record of Decision, **Federal Register** , Vol. 46, No. 18, pg. 9163, January 28, 1981 (46 FR 9162), Office of Environmental Restoration and Waste Management, Washington, D.C.

[DOE-3]
DOE (U.S. Department of Energy), Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant; DOE/EIS-0026-FS, January 1990., Volume 2, pg. B-4, Office of Environmental Restoration and Waste Management, Washington, D.C.

[DOE-4]
DOE (U.S. Department of Energy) and State of New Mexico (1981 originally); Agreement for Consulation and Cooperation Between Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant, Updated April 18, 1988; Article VI (WIPP Mission), pg. 7.

[EPA-1]
EPA (Environmental Protection Agency). 1985a. :40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radionactive Waste: Final Rule," *Federal Register,* **Vol. 50,** No, 182, 38066-38089 (1985).

[EPA-1b]
Ibid., Appendix A to Part 191, Subpart B, Table 1, Note 1 (e).

[GE-1]General Electric Company (Nuclear Energy Operations), **Nuclides and Isotopes** , Fourteenth Edition, 1989.

[LWA-1]
Public Law 102-579, 102d Congress, October 30, 1992; *Waste Isolation Pilot Plant Land Withdrawal Act.;* 1992. Section 7, subparts (a)(1)(A) and (a)(3). [Note, the WIPP LWA in addition to limiting the RH-TRU canister surface dose equivalent rate to 1,000 rem/hr also limits the design capacity of (all) transuranics to 6.2 million cubic feet of volume of which no more than 5.1 million curies (Ci) may be RH-TRU. The volume limit for the RH-TRU is identified in the WIPP ROD (Record of Decision) to be 0.25 million cubic feet of volume [Ref. DOE-2]. Also, prior to the WIPP LWA 6.2 million cubic feet volume was assign to CH-TRU waste only (for instance, Ref. DOE-3 identifies that the total volume of WIPP was to be 6.45 million cubic feet -- 6.2 for CH-TRU and 0.25 for RH-TRU) and not CH-TRU plus RH-TRU. The WIPP LWA seems to be patterned after the WIPP C&C agreement [DOE-4]. It is in the WIPP C&C that a misquote was made to the WIPP ROD. The WIPP C&C quotes the WIPP ROD as applying the 6.2 million cubic meters to (all) transuranic waste. Even though the WIPP LWA is technically incorrect, the volumes identified there are to be used for WIPP calculations. More thorough discussion can be found in Ref. SA-1.]

[OR-1]Croff, A.G.; "ORIGEN2: A Users Manual for ORIGEN2 Computer Code," Oak Ridge National Laboratory, July 1980. (Further generalized discussion on ORIGEN2 can be found in Ref. OR-2.) (Detailed information on the validation (as applied to analysis of PWR spent fuel) and functional requirements (related to long-term storage of LWR spent fuel) of ORIGEN2 can be found in Refs. OR-3 and OR-4.)

[OR-2]Croff, A.G.; "ORIGEN2: A Versatile Computer Code for Calculating the Nuclide Compositions and Characteristics of Nuclear Materials," **Nuclear Technology,** Vol. 62, September 1983.

[OR-3]Hermann, O.W., S.M. Bowman, M.C. Brady and C.V. Parks; "Validation of the Scale System for PWR Spent Fuel Isotropic Composition Analyses," ORNL/TM-12667, Oak Ridge National Laboratory, March 1995.

[OR-4]Broadhead, B.L., M.D. DeHart, J.C. Ryman, J.S. Tang and C.V. Parks; "Investigation of Nuclide Importance to Functional Requirements Related to Transport and Long-Term Storage of LWR Spent Fuel," Oak Ridge National Laboratory, June 1995. ORNL/TM-12742,

[SA-1]L.C. Sanchez (SNL Org 6741) and S.G. Bertram (SNL Org 6747); Memo to: L.E. Shephard (SNL Org 6800), Subject: "WIPP Capacity", dated: October 6, 1995.

[SNL-1]
J.W. Garner (SNL Org 6749); Memo to: C.T. Stockman (SNL Org 6749), Subject: "Radioisotopes to be used in the 1996 CCA Calculations", dated: 3/15/96

[SNL-2]
L.C. Sanchez (SNL Org 6741); Memo to: M. Martell (SNL Org 6747), Subject: "Radionuclide Half-lives and Specific Activities Obtained From ORIGEN2 Data", dated: March 28, 1996.

[SNL-3]
J. Powell, R. Carter, and H. Trellue; "WIPP PA Analysis Report for ORIGEN2 Suite", Sandia National Laboratories, April 1996.

[YMP-1]
Sandia YMP Project. 1994. *Total-System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993), Volume 1.* (SAND93-2675), Albuquerque, NM; Sandia National Laboratories.

[YMP-1b]
Ibid., Table 5-1, pg. 5-1 (Volume 1).

[YMP-1c]
Ibid., Table 5-2, pp. 5-2 → 5-3 (Volume 1).

[YMP-1d]
Ibid., Table 5-7, pg. 5-6 (Volume 1).

LCS:6741:lcs/(96-2108)

Copy to:
MS-1328, Day File [Dept. 6741]
MS-1328, L.C. Sanchez [Dept. 6741]
File - SWCF-A WBS 1.1.6.2;PA;PBWAC - WIPP ACTIVITY

Table 1.
WIPP CH TOTAL (1995 DECAYED) CURIES (a)

Nuclide (b)	Stored	Projected	Total Ci	Stored (%)	Projected (%)
Ac225	1.94E+00	9.37E-01	2.88E+00	67 %	33 %
Ac227	2.80E-01	3.27E-01	6.07E-01	46 %	54 %
Ac228	3.76E-01	3.70E-01	7.46E-01	50 %	50 %
Ag109m	6.56E+00	9.12E+00	1.57E+01	42 %	58 %
Ag110	4.14E-09	2.92E-09	7.06E-09	59 %	41 %
Ag110m	3.11E-07	2.19E-07	5.31E-07	59 %	41 %
Am241	**2.39E+05**	**2.02E+05**	**4.42E+05**	**54 %**	**46 %**
Am242	2.34E-01	1.51E+00	1.74E+00	13 %	87 %
Am242m	2.35E-01	1.52E+00	1.75E+00	13 %	87 %
Am243	**1.79E+01**	**1.46E+01**	**3.25E+01**	**55 %**	**45 %**
Am245	1.27E-09	6.13E-11	1.33E-09	95 %	5 %
At217	1.94E+00	9.37E-01	2.88E+00	67 %	33 %
Ba137m	2.96E+03	4.66E+03	7.62E+03	39 %	61 %
Bi210	1.64E+00	9.12E-01	2.55E+00	64 %	36 %
Bi211	2.81E-01	3.27E-01	6.08E-01	46 %	54 %
Bi212	2.66E+01	4.59E-01	2.70E+01	98 %	2 %
Bi213	1.94E+00	9.37E-01	2.88E+00	67 %	33 %
Bi214	7.69E+00	3.93E+00	1.16E+01	66 %	34 %
Bk249	8.73E-05	4.23E-06	9.15E-05	95 %	5 %
Bk250	4.20E-11	1.64E-12	4.37E-11	96 %	4 %
C14	1.77E+00	9.06E+00	1.08E+01	16 %	84 %
Cd109	6.55E+00	9.12E+00	1.57E+01	42 %	58 %
Cd113m	7.81E-07	1.04E-06	1.82E-06	43 %	57 %
Ce144	3.70E-02	2.54E-02	6.25E-02	59 %	41 %
Cf249	5.08E-02	1.33E-02	6.41E-02	79 %	21 %
Cf250	3.20E-01	1.03E-02	3.30E-01	97 %	3 %
Cf251	1.58E-03	2.20E-03	3.77E-03	42 %	58 %
Cf252	**3.61E+01**	**2.03E+02**	**2.39E+02**	**15 %**	**85 %**
Cm242	1.54E-01	9.84E-01	1.14E+00	14 %	86 %
Cm243	**1.11E+00**	**1.61E+00**	**2.71E+00**	**41 %**	**59 %**
Cm244	**6.31E+03**	**2.51E+04**	**3.14E+04**	**20 %**	**80 %**
Cm245	**1.76E-03**	**9.70E-03**	**1.15E-02**	**15 %**	**85 %**
Cm246	4.28E-02	5.92E-02	1.02E-01	42 %	58 %
Cm247	1.34E-09	1.87E-09	3.21E-09	42 %	58 %
Cm248	**3.35E-02**	**5.59E-02**	**8.94E-02**	**37 %**	**63 %**
Co58	1.34E-13	1.70E-13	3.04E-13	44 %	56 %
Co60	6.27E+01	1.78E+00	6.45E+01	97 %	3 %
Cs134	6.09E-03	7.32E-03	1.34E-02	45 %	55 %
Cs135	2.15E-04	2.87E-04	5.01E-04	43 %	57 %
Cs137	**3.12E+03**	**4.93E+03**	**8.05E+03**	**39 %**	**61 %**
Es254	4.11E-11	1.25E-12	4.23E-11	97 %	3 %
Eu150	3.50E-05	0.00E+00	3.50E-05	100 %	0 %
Eu152	1.22E+00	3.30E-02	1.26E+00	97 %	3 %
Eu154	1.10E+00	4.89E-02	1.14E+00	96 %	4 %
Eu155	6.18E-01	3.27E-01	9.45E-01	65 %	35 %
Fe55	1.91E-05	0.00E+00	1.91E-05	100 %	0 %
Fe59	1.87E-07	7.68E-08	2.64E-07	71 %	29 %
Fr221	1.94E+00	9.37E-01	2.88E+00	67 %	33 %

Table 1 Continued.
WIPP CH TOTAL (1995 DECAYED) CURIES (a)

Nuclide (b)	Stored	Projected	Total Ci	Stored (%)	Projected (%)
Fr223	3.87E-03	4.51E-03	8.38E-03	46 %	54 %
H3	8.66E-01	1.96E-03	8.68E-01	100 %	0 %
I129	1.17E-07	5.87E-07	7.04E-07	17 %	83 %
Kr85	1.96E-01	5.96E-03	2.02E-01	97 %	3 %
Mn54	8.49E-04	7.67E-08	8.50E-04	100 %	0 %
Nb95	2.41E-09	1.26E-10	2.54E-09	95 %	5 %
Nb95m	8.06E-12	4.22E-13	8.49E-12	95 %	5 %
Ni59	1.25E-03	6.27E-03	7.52E-03	17 %	83 %
Ni63	1.53E-01	7.66E-01	9.18E-01	17 %	83 %
Np237	**1.08E+01**	**4.52E+01**	**5.60E+01**	**19 %**	**81 %**
Np238	1.18E-03	7.58E-03	8.76E-03	13 %	87 %
Np239	1.79E+01	1.46E+01	3.25E+01	55 %	45 %
Np240m	1.20E-06	3.04E-07	1.50E-06	80 %	20 %
Pa231	**3.16E-01**	**1.34E-01**	**4.50E-01**	**70 %**	**30 %**
Pa233	1.08E+01	4.52E+01	5.60E+01	19 %	81 %
Pa234	7.90E-03	4.35E-02	5.14E-02	15 %	85 %
Pa234m	6.08E+00	3.35E+01	3.95E+01	15 %	85 %
Pb209	1.94E+00	9.37E-01	2.88E+00	67 %	33 %
Pb210	**1.64E+00**	**9.12E-01**	**2.55E+00**	**64 %**	**36 %**
Pb211	2.81E-01	3.27E-01	6.08E-01	46 %	54 %
Pb212	2.66E+01	4.59E-01	2.70E+01	98 %	2 %
Pb214	7.69E+00	3.93E+00	1.16E+01	66 %	34 %
Pd107	3.17E-05	4.23E-05	7.41E-05	43 %	57 %
Pm147	**4.79E+00**	**3.06E+00**	**7.86E+00**	**61 %**	**39 %**
Po210	1.64E+00	9.12E-01	2.55E+00	64 %	36 %
Po211	7.86E-04	9.17E-04	1.70E-03	46 %	54 %
Po212	1.70E+01	2.94E-01	1.73E+01	98 %	2 %
Po213	1.90E+00	9.17E-01	2.81E+00	67 %	33 %
Po214	7.69E+00	3.93E+00	1.16E+01	66 %	34 %
Po215	2.81E-01	3.27E-01	6.08E-01	46 %	54 %
Po216	2.66E+01	4.59E-01	2.70E+01	98 %	2 %
Po218	7.69E+00	3.94E+00	1.16E+01	66 %	34 %
Pr144	3.66E-02	2.52E-02	6.18E-02	59 %	41 %
Pu236	1.04E-02	7.47E-17	1.04E-02	100 %	0 %
Pu238	**5.54E+05**	**2.06E+06**	**2.61E+06**	**21 %**	**79 %**
Pu239	**3.51E+05**	**4.33E+05**	**7.84E+05**	**45 %**	**55 %**
Pu240	**6.87E+04**	**1.41E+05**	**2.10E+05**	**33 %**	**67 %**
Pu241	**1.07E+06**	**1.23E+06**	**2.30E+06**	**47 %**	**53 %**
Pu242	**4.93E+02**	**6.79E+02**	**1.17E+03**	**42 %**	**58 %**
Pu243	1.34E-09	1.87E-09	3.21E-09	42 %	58 %
Pu244	**1.20E-06**	**3.04E-07**	**1.50E-06**	**80 %**	**20 %**
Ra223	2.81E-01	3.27E-01	6.08E-01	46 %	54 %
Ra224	2.66E+01	4.59E-01	2.70E+01	98 %	2 %
Ra225	1.94E+00	9.37E-01	2.88E+00	67 %	33 %
Ra226	**7.69E+00**	**3.94E+00**	**1.16E+01**	**66 %**	**34 %**
Ra228	**3.76E-01**	**3.70E-01**	**7.46E-01**	**50 %**	**50 %**
Rh106	1.52E-02	1.37E-02	2.89E-02	53 %	47 %
Rn219	2.81E-01	3.27E-01	6.08E-01	46 %	54 %

Table 1 Continued.
WIPP CH TOTAL (1995 DECAYED) CURIES (a)

Nuclide (b)	Stored	Projected	Total Ci	Stored (%)	Projected (%)
Rn220	2.66E+01	4.59E-01	2.70E+01	98 %	2 %
Rn222	7.69E+00	3.94E+00	1.16E+01	66 %	34 %
Ru106	1.52E-02	1.37E-02	2.89E-02	53 %	47 %
Sb125	5.22E-02	6.84E-02	1.21E-01	43 %	57 %
Sb126	5.78E-05	7.72E-05	1.35E-04	43 %	57 %
Sb126m	4.12E-04	5.51E-04	9.64E-04	43 %	57 %
Se 79	1.86E-04	2.49E-04	4.35E-04	43 %	57 %
Sm151	6.28E-01	8.40E-01	1.47E+00	43 %	57 %
Sn119m	2.44E-06	1.69E-06	4.14E-06	59 %	41 %
Sn121m	1.14E-02	1.52E-02	2.66E-02	43 %	57 %
Sn126	4.12E-04	5.51E-04	9.64E-04	43 %	57 %
Sr90	**2.22E+03**	**4.62E+03**	**6.84E+03**	**32 %**	**68 %**
Tc99	1.78E+01	7.33E+00	2.51E+01	71 %	29 %
Te125m	1.27E-02	1.67E-02	2.94E-02	43 %	57 %
Te127	1.07E-07	2.34E-08	1.30E-07	82 %	18 %
Te127m	1.09E-07	2.39E-08	1.33E-07	82 %	18 %
Th227	2.77E-01	3.23E-01	6.00E-01	46 %	54 %
Th228	2.66E+01	4.59E-01	2.70E+01	98 %	2 %
Th229	**1.94E+00**	**9.37E-01**	**2.88E+00**	**67 %**	**33 %**
Th230	**3.04E-02**	**5.01E-02**	**8.05E-02**	**38 %**	**62 %**
Th231	2.31E+00	1.05E+01	1.28E+01	18 %	82 %
Th232	**4.22E-01**	**4.90E-01**	**9.12E-01**	**46 %**	**54 %**
Th234	6.08E+00	3.35E+01	3.95E+01	15 %	85 %
Tl207	2.80E-01	3.27E-01	6.07E-01	46 %	54 %
Tl208	9.55E+00	1.65E-01	9.72E+00	98 %	2 %
Tl209	4.19E-02	2.02E-02	6.21E-02	67 %	33 %
U232	2.56E+01	1.20E-01	2.58E+01	100 %	0 %
U233	**1.20E+03**	**5.88E+02**	**1.79E+03**	**67 %**	**33 %**
U234	**9.23E+01**	**3.72E+02**	**4.64E+02**	**20 %**	**80 %**
U235	**2.31E+00**	**1.05E+01**	**1.28E+01**	**18 %**	**82 %**
U236	**6.74E-02**	**2.65E-01**	**3.33E-01**	**20 %**	**80 %**
U237	2.63E+01	3.02E+01	5.65E+01	47 %	53 %
U238	**6.08E+00**	**3.35E+01**	**3.95E+01**	**15 %**	**85 %**
U240	1.20E-06	3.04E-07	1.50E-06	80 %	20 %
Y90	2.22E+03	4.62E+03	6.85E+03	32 %	68 %
Zr93	2.41E-03	3.21E-03	5.62E-03	43 %	57 %
Zr95	1.09E-09	5.69E-11	1.14E-09	95 %	5 %
Total	2.31E+06	4.11E+06	6.41E+06	36 %	64 %

(a) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID)

(b) Radionuclides in bold are those 29 incorporated into the WIPP PA database, Ref. SNL-1.

Table 2.
WIPP RH TOTAL (1995 DECAYED) CURIES (a)

Nuclide (b)	Stored	Projected	Total Ci	Stored (%)	Projected (%)
Ac225	8.55E-02	3.18E-02	1.17E-01	73 %	27 %
Ac227	2.08E-04	5.49E-04	7.57E-04	27 %	73 %
Ac228	2.51E-02	5.26E-02	7.77E-02	32 %	68 %
Ag110	1.45E-09	2.92E-10	1.74E-09	83 %	17 %
Ag110m	1.09E-07	2.20E-08	1.31E-07	83 %	17 %
Am241	**1.36E+02**	**5.83E+03**	**5.96E+03**	**2 %**	**98 %**
Am243	**2.23E-04**	**5.10E-06**	**2.28E-04**	**98 %**	**2 %**
Am245	2.43E-16	4.40E-17	2.87E-16	85 %	15 %
At217	8.55E-02	3.18E-02	1.17E-01	73 %	27 %
Ba137m	5.02E+03	1.99E+05	2.04E+05	2 %	98 %
Bi210	1.33E-07	7.03E-06	7.16E-06	2 %	98 %
Bi211	2.08E-04	5.49E-04	7.58E-04	27 %	73 %
Bi212	2.45E-02	4.92E-02	7.36E-02	33 %	67 %
Bi213	8.55E-02	3.18E-02	1.17E-01	73 %	27 %
Bi214	7.97E-07	3.50E-05	3.58E-05	2 %	98 %
Bk249	1.68E-11	3.03E-12	1.98E-11	85 %	15 %
C14	1.74E+00	3.13E-01	2.05E+00	85 %	15 %
Cd113m	2.83E-07	2.63E-07	5.46E-07	52 %	48 %
Ce144	4.51E+00	6.17E-01	5.13E+00	88 %	12 %
Cf249	3.79E-03	6.85E-04	4.47E-03	85 %	15 %
Cf252	**1.09E+00**	**1.97E-01**	**1.29E+00**	**85 %**	**15 %**
Cm243	**4.19E+01**	**7.58E+00**	**4.95E+01**	**85 %**	**15 %**
Cm244	**2.67E+02**	**4.83E+01**	**3.15E+02**	**85 %**	**15 %**
Cm245	**1.24E-06**	**2.24E-07**	**1.46E-06**	**85 %**	**15 %**
Cm248	**1.73E-04**	**3.14E-05**	**2.05E-04**	**85 %**	**15 %**
Co58	1.24E-11	0.00E+00	1.24E-11	100 %	0 %
Co60	2.75E+02	1.02E+04	1.04E+04	3 %	97 %
Cr51	3.04E-06	0.00E+00	3.04E-06	100 %	0 %
Cs134	1.79E+01	4.96E-01	1.84E+01	97 %	3 %
Cs135	6.07E-05	5.66E-05	1.17E-04	52 %	48 %
Cs137	**5.31E+03**	**2.11E+05**	**2.16E+05**	**2 %**	**98 %**
Eu152	1.04E+03	1.87E+02	1.22E+03	85 %	15 %
Eu154	5.00E+02	9.05E+01	5.91E+02	85 %	15 %
Eu155	9.96E+01	1.84E+01	1.18E+02	84 %	16 %
Fe55	1.69E-01	0.00E+00	1.69E-01	100 %	0 %
Fr221	8.55E-02	3.18E-02	1.17E-01	73 %	27 %
Fr223	2.87E-06	7.58E-06	1.04E-05	27 %	73 %
H3	6.21E-02	3.94E-03	6.60E-02	94 %	6 %
Kr85	1.68E+00	0.00E+00	1.68E+00	100 %	0 %
Mn54	2.35E-02	0.00E+00	2.35E-02	100 %	0 %
Nb95	5.66E-01	1.02E-01	6.69E-01	85 %	15 %
Nb95m	1.90E-03	3.43E-04	2.24E-03	85 %	15 %
Ni63	9.88E-01	0.00E+00	9.88E-01	100 %	0 %
Np237	**2.37E+00**	**4.76E-01**	**2.85E+00**	**83 %**	**17 %**
Np239	2.23E-04	5.10E-06	2.28E-04	98 %	2 %
Np240m	1.87E-11	3.39E-12	2.21E-11	85 %	15 %
Pa231	**4.15E-05**	**1.87E-03**	**1.91E-03**	**2 %**	**98 %**
Pa233	2.37E+00	4.76E-01	2.85E+00	83 %	17 %

Table 2 Continued.
WIPP RH TOTAL (1995 DECAYED) CURIES (a)

Nuclide (b)	Stored	Projected	Total Ci	Stored (%)	Projected (%)
Pa234	1.12E-02	2.43E-03	1.36E-02	82 %	18 %
Pa234m	8.61E+00	1.87E+00	1.05E+01	82 %	18 %
Pb209	8.55E-02	3.18E-02	1.17E-01	73 %	27 %
Pb210	**1.33E-07**	**7.03E-06**	**7.16E-06**	**2 %**	**98 %**
Pb211	2.08E-04	5.49E-04	7.58E-04	27 %	73 %
Pb212	2.45E-02	4.92E-02	7.36E-02	33 %	67 %
Pb214	7.97E-07	3.50E-05	3.58E-05	2 %	98 %
Pd107	8.97E-06	8.37E-06	1.76E-05	52 %	48 %
Pm147	**7.40E+00**	**3.34E+00**	**1.07E+01**	**69 %**	**31 %**
Po210	1.33E-07	7.03E-06	7.16E-06	2 %	98 %
Po211	5.83E-07	1.54E-06	2.12E-06	27 %	73 %
Po212	1.57E-02	3.15E-02	4.72E-02	33 %	67 %
Po213	8.36E-02	3.11E-02	1.15E-01	73 %	27 %
Po214	7.97E-07	3.49E-05	3.57E-05	2 %	98 %
Po215	2.08E-04	5.49E-04	7.58E-04	27 %	73 %
Po216	2.45E-02	4.92E-02	7.36E-02	33 %	67 %
Po218	7.97E-07	3.50E-05	3.58E-05	2 %	98 %
Pr144	4.46E+00	6.09E-01	5.07E+00	88 %	12 %
Pu238	**3.95E+01**	**1.41E+03**	**1.45E+03**	**3 %**	**97 %**
Pu239	**1.57E+02**	**1.01E+04**	**1.03E+04**	**2 %**	**98 %**
Pu240	**5.06E+01**	**5.01E+03**	**5.07E+03**	**1 %**	**99 %**
Pu241	**1.33E+03**	**1.40E+05**	**1.42E+05**	**1 %**	**99 %**
Pu242	**1.67E-03**	**1.48E-01**	**1.50E-01**	**1 %**	**99 %**
Pu244	**1.87E-11**	**3.39E-12**	**2.21E-11**	**85 %**	**15 %**
Ra223	2.08E-04	5.49E-04	7.58E-04	27 %	73 %
Ra224	2.45E-02	4.92E-02	7.36E-02	33 %	67 %
Ra225	8.55E-02	3.18E-02	1.17E-01	73 %	27 %
Ra226	**7.97E-07**	**3.50E-05**	**3.58E-05**	**2 %**	**98 %**
Ra228	**2.51E-02**	**5.26E-02**	**7.77E-02**	**32 %**	**68 %**
Rh106	9.18E+00	1.74E+00	1.09E+01	84 %	16 %
Rn219	2.08E-04	5.49E-04	7.58E-04	27 %	73 %
Rn220	2.45E-02	4.92E-02	7.36E-02	33 %	67 %
Rn222	7.97E-07	3.50E-05	3.58E-05	2 %	98 %
Ru106	9.18E+00	1.74E+00	1.09E+01	84 %	16 %
Sb125	1.06E+00	8.25E-01	1.89E+00	56 %	44 %
Sb126	1.63E-05	1.52E-05	3.16E-05	52 %	48 %
Sb126m	1.17E-04	1.09E-04	2.25E-04	52 %	48 %
Se79	5.27E-05	4.91E-05	1.02E-04	52 %	48 %
Sm151	1.85E-01	1.72E-01	3.57E-01	52 %	48 %
Sn119m	8.05E-07	1.54E-07	9.59E-07	84 %	16 %
Sn121m	3.47E-03	3.23E-03	6.69E-03	52 %	48 %
Sn126	1.17E-04	1.09E-04	2.25E-04	52 %	48 %
Sr90	**1.23E+04**	**1.96E+05**	**2.09E+05**	**6 %**	**94 %**
Ta182	4.21E-08	0.00E+00	4.21E-08	100 %	0 %
Tc99	3.03E-03	2.82E-03	5.85E-03	52 %	48 %
Te125m	2.62E-01	2.03E-01	4.65E-01	56 %	44 %
Te127	1.67E-09	3.87E-11	1.71E-09	98 %	2 %
Te127m	1.71E-09	3.95E-11	1.75E-09	98 %	2 %

Table 2 Continued.
WIPP RH TOTAL (1995 DECAYED) CURIES (a)

Nuclide (b)	Stored	Projected	Total Ci	Stored (%)	Projected (%)
Th227	2.05E-04	5.42E-04	7.47E-04	27 %	73 %
Th228	2.45E-02	4.92E-02	7.36E-02	33 %	67 %
Th229	**8.55E-02**	**3.18E-02**	**1.17E-01**	**73 %**	**27 %**
Th230	**2.56E-04**	**7.30E-03**	**7.56E-03**	**3 %**	**97 %**
Th231	2.01E-01	4.43E+00	4.63E+00	4 %	96 %
Th232	**2.86E-02**	**6.39E-02**	**9.25E-02**	**31 %**	**69 %**
Th234	8.61E+00	1.87E+00	1.05E+01	82 %	18 %
Tl207	2.08E-04	5.48E-04	7.56E-04	27 %	73 %
Tl208	8.79E-03	1.77E-02	2.65E-02	33 %	67 %
Tl209	1.85E-03	6.88E-04	2.53E-03	73 %	27 %
U233	**1.23E+02**	**3.47E+01**	**1.58E+02**	**78 %**	**22 %**
U234	**3.30E+00**	**3.94E+01**	**4.27E+01**	**8 %**	**92 %**
U235	**2.01E-01**	**4.43E+00**	**4.63E+00**	**4 %**	**96 %**
U236	**7.97E-02**	**1.70E-02**	**9.68E-02**	**82 %**	**18 %**
U237	3.27E-02	3.45E+00	3.48E+00	1 %	99 %
U238	**8.61E+00**	**1.87E+00**	**1.05E+01**	**82 %**	**18 %**
U240	1.87E-11	3.39E-12	2.21E-11	85 %	15 %
Y90	1.23E+04	1.96E+05	2.09E+05	6 %	94 %
Zr93	6.81E-04	6.35E-04	1.32E-03	52 %	48 %
Zr95	2.56E-01	4.63E-02	3.02E-01	85 %	15 %
Total	3.91E+04	9.76E+05	1.02E+06	4 %	96 %

(a) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID)

(b) Radionuclides in bold are those 29 incorporated into the WIPP PA database, Ref. SNL-1.

Table 3.
40CFR191 Unit of Waste for (1995 Decayed) WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Transuranic Inventory [α-Curies] (e)		% of Unit of Waste
			CH	RH	CH	RH	(%)
Ac225	α,γ	10.0 d	2.88E+00	1.17E-01			
Ac227	α,β⁻,γ	21.77 a	6.08E-01	7.57E-04			
Ac228	α,β⁻,γ	6.15 h	7.46E-01	7.77E-02			
Ag109m	*IT*e⁻	39.8 s	1.57E+01	NR			
Ag110	β⁻,γ,ε	24.6 s	7.07E-09	1.74E-09			
Ag110m	β⁻,γ,*IT*e⁻	249.8 d	5.31E-07	1.31E-07			
Am241	α,γ,*SF*	432.7 a	4.42E+05	5.96E+03	**4.42E+05**	**5.96E+03**	**11.0**
Am242	β,γ,εe⁻	16.02 h	1.75E+00	NR			
Am242m	α,*IT*e⁻	141. h	1.75E+00	NR			
Am243	α,β⁻,γ	7.37E+03 a	3.26E+01	2.28E-04	**3.26E+01**	**2.28E-04**	**8.01E-04**
Am245	β⁻,γ	2.05 h	1.33E-09	2.87E-16			
At217	α,β⁻,γ	32 ms	2.88E+00	1.17E-01			
Ba137m	*IT*	2.552 m	7.63E+03	2.04E+05			
Bi210	α,β⁻,γ	5.01 d	2.55E+00	7.16E-06			
Bi211	α,β⁻,γ	2.14 m	6.09E-01	7.58E-04			
Bi212	α,β⁻,γ	1.009 h	2.71E+01	7.36E-02			
Bi213	α,β⁻,γ	45.6 m	2.88E+00	1.17E-01			
Bi214	α,β⁻,γ	19.9 m	1.16E+01	3.58E-05			
Bk249	α,β⁻,γ	3.2E+02 d	9.16E-05	1.98E-11			
Bk250	β⁻,γ	3.217 h	4.37E-11	NR			
C14	β⁻	5730 a	1.08E+01	2.05E+00			
Cd109	γ,ε	462.0 d	1.57E+01	NR			
Cd113m	β⁻,*IT*	14.1 a	1.82E-06	5.46E-07			
Ce144	β⁻,γ	284.6 d	6.26E-02	5.13E+00			
Cf249	α,γ,*SF*	351 a	6.42E-02	4.47E-03	6.42E-02	4.47E-03	1.69E-06
Cf250	α,γ,*SF*	13.1 a	3.30E-01	NR			
Cf251	α,γ	9.0E+02 a	3.78E-03	NR	3.78E-03	NR	9.28E-08
Cf252	α,γ,*SF*	2.638 a	2.39E+02	1.29E+00			
Cm242	α,γ,*SF*	162.8 d	1.14E+00	NR			
Cm243	α,γ,*SF*,ε	29.1 a	2.72E+00	4.95E+01	**2.72E+00**	**4.95E+01**	**1.28E-03**
Cm244	α,γ,*SF*	18.1 a	3.15E+04	3.15E+02			
Cm245	α,γ,*SF*	8.5E+03 a	1.15E+02	1.46E-06	**1.15E+02**	**1.46E-06**	**2.82E-03**
Cm246	α,γ,*SF*	4.76E+03 a	1.02E-01	NR	1.02E-01	NR	2.51E-06
Cm247	α,γ	1.56E+07 a	3.21E-09	NR	3.21E-09	NR	7.88E-14
Cm248	α,*SF*	3.48E+05 a	8.95E-02	2.05E-04	**8.95E-02**	**2.05E-04**	**2.20E-06**
Co58	β⁺,γ,ε	70.88 d	3.05E-13	1.24E-11			
Co60	β⁻,γ	5.271 a	6.46E+01	1.04E+04			
Cr51	εγ	27.70 d	NR	3.04E-06			
Cs134	β⁻,γ,ε	2.065 a	1.34E-02	1.84E+01			
Cs135	β⁻	2.3E+06 a	5.02E-04	1.17E-04			
Cs137	β⁻,γ	30.17 a	8.06E+03	**2.16E+05 (g)**			
Es254	α,γ	276 d	4.24E-11	NR			

Table 3 Continued.
40CFR191 Unit of Waste for (1995 Decayed) WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Transuranic Inventory [α-Curies] (e)		% of Unit of Waste
			CH	RH	CH	RH	(%)
Eu150	γ,ε	36 a	3.51E-05	NR			
Eu152	β⁻,γ,εβ⁺	13.48 a	1.26E+00	1.22E+03			
Eu154	β⁻,γ,εγ	8.59 a	1.15E+00	5.91E+02			
Eu155	β⁻,γ	4.71 a	9.46E-01	1.18E+02			
Fe55	ε	2.73 a	1.91E-05	1.69E-01			
Fe59	β⁻,γ	44.51 d	2.64E-07	NR			
Fr221	α,γ	4.8 m	2.88E+00	1.17E-01			
Fr223	α,β⁻,γ	21.8 m	8.39E-03	1.04E-05			
H3	β⁻	12.3 a	8.69E-01	6.60E-02			
I129	β⁻,γ	1.57E+07 a	7.05E-07	NR			
Kr85	β⁻,γ	10.73 a	2.02E-01	1.68E+00			
Mn54	εγ	312.2 d	8.51E-04	2.35E-02			
Nb95	β⁻,γ	34.97 d	2.54E-09	6.69E-01			
Nb95m	β⁻,γ,IT	3.61 d	8.50E-12	2.24E-03			
Ni59	ε	7.6E+04 a	7.52E-03	NR			
Ni63	β⁻	100. a	9.19E-01	9.88E-01			
Np237	α,γ	2.14E+06 a	5.61E+01	2.85E+00	**5.61E+01**	**2.85E+00**	**1.45E-03**
Np238	β,γ	2.117 d	8.77E-03	NR			
Np239	β⁻,γ	2.355 d	3.26E+01	2.28E-04			
Np240‡	β,γ	1.032 h	NR	NR			
Np240m	β⁻,γ,IT	7.22 m	1.50E-06	2.21E-11			
Pa231	α,γ	3.28E+04 a	4.51E-01	1.91E-03			
Pa233	β⁻,γ	27.0 d	5.61E+01	2.85E+00			
Pa234	β⁻,γ	6.69 h	5.14E-02	1.36E-02			
Pa234m	β⁻,γ,IT	1.17 m	3.96E+01	1.05E+01			
Pb209	β⁻	3.25 h	2.88E+00	1.17E-01			
Pb210	α,β⁻,γ	22.3 a	2.55E+00	7.16E-06			
Pb211	β⁻,γ	36.1 m	6.09E-01	7.58E-04			
Pb212	β⁻,γ	10.64 hr	2.71E+01	7.36E-02			
Pb214	β⁻,γ	27 m	1.16E+01	3.58E-05			
Pd107	β⁻,γ	6.5E+06 a	7.41E-05	1.73E-05			
Pm147	β⁻,γ	2.6234 a	7.87E+00	1.07E+01			
Po210	α,γ	138.38 d	2.55E+00	7.16E-06			
Po211	α,γ	0.516 s	1.71E-03	2.12E-06			
Po212	α	0.298 μs	1.73E+01	4.72E-02			
Po213	α	4 μs	2.82E+00	1.15E-01			
Po214	α,γ	163.7 μs	1.16E+01	3.57E-05			
Po215	α,β⁻,γ	1.780 ms	6.09E-01	7.58E-04			
Po216	α,γ	0.145 s	2.71E+01	7.36E-02			
Po218	α,β⁻,γ	3.10 m	1.16E+01	3.58E-05			
Pr144	β⁻,γ	17.28 m	6.18E-02	5.07E+00			
Pu236	α,γ,SF	2.87 a	1.04E-02	NR			

Table 3 Continued.
40CFR191 Unit of Waste for (1995 Decayed) WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Transuranic Inventory [α-Curies] (e)		% of Unit of Waste
			CH	RH	CH	RH	(%)
Pu238	α,γ,*SF*	87.7 a	**2.61E+06 (f)**	1.45E+03	**2.61E+06**	**1.45E+03**	**64.1**
Pu239	α,γ,*SF*	2.410E+04 a	7.85E+05	1.03E+04	**7.85E+05**	**1.03E+04**	**19.5**
Pu240	α,γ,*SF*	6.56E+03 a	2.10E+05	5.07E+03	**2.10E+05**	**5.07E+03**	**5.28**
Pu241	α,β⁻,γ	14.4 a	2.31E+06	1.42E+05			
Pu242	α,γ,*SF*	3.75E+05 a	1.17E+03	1.50E-01	**1.17E+03**	**1.50E-01**	**2.87E-02**
Pu243	β⁻,γ	4.956 h	3.21E-09	NR			
Pu244	α,*SF*	8.0E+07 a	1.50E-06	2.21E-11	**1.50E-06**	**2.21E-11**	**3.68E-11**
Ra223	α,γ	11.435 d	6.09E-01	7.58E-04			
Ra224	α,γ	3.66 d	2.71E+01	7.36E-02			
Ra225	β⁻,γ	14.9 d	2.88E+00	1.17E-01			
Ra226	α,γ	1.60E+03 a	1.16E+01	3.58E-05			
Ra228	β⁻,γ	5.76 a	7.47E-01	7.77E-02			
Rh106	β⁻,γ	29.9 s	2.90E-02	1.09E+01			
Rn219	α,γ	3.96 s	6.09E-01	7.58E-04			
Rn220	α,γ	55.6 s	2.71E+01	7.36E-02			
Rn222	α,γ	3.8235 d	1.16E+01	3.58E-05			
Ru106	β⁻	1.02 a	2.90E-02	1.09E+01			
Sb125	β⁻,γ	2.758 a	1.21E-01	1.89E+00			
Sb126	β⁻,γ	12.4 d	1.35E-04	3.16E-05			
Sb126m	γ,*εe*⁻	19.0 m	9.65E-04	2.25E-04			
Se79	β⁻	6.5E+04 a	4.35E-04	1.02E-04			
Sm151	β⁻,γ	90 a	1.47E+00	3.57E-01			
Sn119m	γ,*ITe*⁻	293 d	4.14E-06	9.59E-07			
Sn121m	β⁻,γ,*ITe*⁻	55 a	2.66E-02	6.69E-03			
Sn126	β⁻,γ	1.0E+05 a	9.65E-04	2.25E-04			
Sr89†	β⁻,γ	50.52 d	NR	NR			
Sr90	β⁻	29.1 a	6.85E+03	2.09E+05			
Ta182	β⁻,γ	114.43 d	NR	4.21E-08			
Tc99	β⁻,γ	2.13E+05 a	2.52E+01	5.85E-03			
Te125m	γ,*ITe*⁻	58 d	2.95E-02	4.65E-01			
Te127	β⁻,γ	9.4 h	1.30E-07	1.71E-09			
Te127m	β⁻,γ,*ITe*⁻	109 d	1.33E-07	1.75E-09			
Th227	α,γ	18.72 d	6.01E-01	7.47E-04			
Th228	α,γ	1.913 a	2.71E+01	7.36E-02			
Th229	α,γ	7.3E+03 a	2.88E+00	1.17E-01			
Th230	α,γ	7.54E+04 a	8.06E-02	7.56E-03			
Th231	β⁻,γ	1.063 d	1.28E+01	4.63E+00			
Th232	α,γ	1.4E+10 a	9.13E-01	9.25E-02			
Th234	β⁻,γ	24.10 m	3.96E+01	1.05E+01			
Tl207	β⁻,γ	4.77 m	6.07E-01	7.56E-04			
Tl208	β⁻,γ	3.053 m	9.73E+00	2.65E-02			

Table 3 Continued.
40CFR191 Unit of Waste for (1995 Decayed) WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Transuranic Inventory [α-Curies] (e)		% of Unit of Waste
			CH	RH	CH	RH	(%)
Tl209	β^-,γ	2.2 m	6.22E-02	2.53E-03			
Tl210‡	β,γ	1.30 m	NR	NR			
U232	α,γ,SF	70 a	2.58E+01	NR			
U233	α,γ,SF	1.592E+05 a	1.79E+03	1.58E+02			
U234	α,γ,SF	2.46E+05 a	4.65E+02	4.27E+01			
U235	α,γ,SF	7.04E+08 a	1.28E+01	4.63E+00			
U236	α,γ,SF	2.342E+07 a	3.33E-01	9.68E-02			
U237	β^-,γ	6.75 d	5.66E+01	3.48E+00			
U238	α,γ,SF	4.47E+09 a	3.96E+01	1.05E+01			
U240	β^-,γ	14.1 h	1.50E-06	2.21E-11			
Y90	β^-,γ	2.67 d	6.85E+03	2.09E+05			
Zn65†	$\beta^+,\gamma,\varepsilon$	243.8 d	NR	NR			
Zr93	β^-,γ	1.5E+06 a	5.63E-03	1.32E-03			
Zr95	β^-,γ	64.02 d	1.15E-09	3.02E-01			
		Sum =	6.42E+06 (h)	1.02E+06 (i)	(4.048E+06) **4.048E+06 (j)**	(2.283E+04) **2.283E+04 (k)**	100.00 %
		Sum =	7.44E+06 (l)		(4.07E+06) **4.07E+06** **(Unit of Waste = 4.07) (m)**		
Top 5 Radionuclides							
Pu238	α,γ,SF	87.7 a	**2.61E+06 (f)**	1.45E+03	**2.61E+06**	**1.45E+03**	**64.1**
Pu239	α,γ,SF	2.410E+04 a	7.85E+05	1.03E+04	**7.85E+05**	**1.03E+04**	**19.5**
Am241	α,γ,SF	432.7 a	4.42E+05	5.96E+03	**4.42E+05**	**5.96E+03**	**11.0**
Pu240	α,γ,SF	6.56E+03 a	2.10E+05	5.07E+03	**2.10E+05**	**5.07E+03**	**5.28**
Pu242	α,γ,SF	3.75E+05 a	1.17E+03	1.50E-01	**1.17E+03**	**1.50E-01**	**2.87E-02**

NR Not Reported by sites (see Ref. CCA-2).

‡ Data values for radionuclides were previously reported in Rev. 1 of WTWBIR (BIR-1).

† Data values for radionuclides were previously reported in Rev. 2 of WTWBIR (BIR-2).

(a) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID)

(b) Radionuclides in bold are those 29 incorporated into the WIPP PA database, Ref. SNL-1.

(c) Decay mode and half-life information taken from the Chart of the Nuclides, 14th Ed. Ref. GE-1. [It is better for technical calculations, to use halflives that are extracted from the databases of ORIGEN2 [Ref. OR-1] because the ORIGEN2 data are of a later version than that of Ref. GE-1 (see Ref. SNL-2 for ORIGEN2 values).]

(d) Total inventory (curie) data taken from Ref. CCA-2. Values correspond to a "WIPP-Scale" design basis.

(e) Transuranic inventory data corresponds to the activity (curie) data only for radionuclides that are "transuranic waste" per definitions in 40CFR191 Inventory data in bold corresponds to those data incorporated into the WIPP PA database (see Ref. SNL-1).

(f) Isotope with dominate curie load for CH-TRU wastes.

(g) Isotope with dominate curie load for RH-TRU wastes.

(h) Note, the total CH-TRU curie load is 6.42 MCi (also, 86.3 % of the total curie load in WIPP). The average CH-TRU volumetric total curie load is 6.42E+06/5.95E+06 = 1.08 (Ci/cu. ft.) = **38.1 (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes – CH→5.95E+06 cu. ft. Also note that the 5.95E+06 volume number is a volume limit, stored waste and projected waste volumes sum up to a volume less than this volume. The summed up volume is then "scaled" to yield a total volume of 5.95E+06, likewise the curie loads are also "scaled" by the same factor. Thus ratios of curie loads (or heat loads) to volume yield values are applicable to expected waste at WIPP (see Ref. BIR-2d).]

(i) Note, the total RH-TRU curie load is only 1.02 MCi (also, only 13.7 % of the total curie load in WIPP). This curie load is much less than the RH-TRU limit of 5.1 MCi [Ref. LWA-1]. The average RH-TRU volumetric total curie load is 1.02E+06/0.25E+06 = 4.08 (Ci/cu. ft.) = **144. (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- RH→0.25E+06 cu. ft.]

(j) Note, there are only 15 radionuclides that comprise the "transuranic waste" (see footnote e above). Eleven of these radionuclides are included in the WIPP PA data base and correspond to 99.99999% of the total CH "transuranic" inventory. The average CH-TRU volumetric "transuranic" curie load is 4.048E+06/5.95E+06 = **0.680 (TRU-Ci/cu. ft.) = 24.0 (TRU-Ci/cu. m.)**.

(k) Note, there are only 15 radionuclides that comprise the "transuranic waste" (see footnote e above). Eleven of these radionuclides are included in the WIPP PA data base and correspond to 99.99998% of the total RH "transuranic" inventory. The average RH-TRU volumetric "transuranic" curie load is 2.283E+04/0.25E+06 = **0.0913 (TRU-Ci/cu. ft.) = 3.22 (TRU-Ci/cu. m.)**. [The RH contribution to the WIPP-scale inventory of transuranic curie load is 2.283E+04*100%/(2.283E+04 + 4.048E+06)=**0.561% (very small)**.] Note, this value is an order of magnitude less than that presented for the CH-TRU wastes – since the majority of the curie content of the RH-TRU waste is due to shorter-lived non-transuranic radionuclides, this means that as the shorter-lived components decay away the remaining RH-TRU waste will have a lesser curie content than CH-TRU waste (i.e., as the RH-TRU waste decays, it becomes "wimpier" than CH-TRU waste). This is evident from the RH Study (Ref. DOE-1) which showed that after about 150 → 250 years that CH-TRU waste has a higher specific activity than that of RH-TRU waste.

(l) It is interesting to know that the Yucca Mountain Project (YMP) has approximately 12.4 billion curies of inventory (spent fuel -- 63,000 MTU [YMP-1b] × 1.57E+05 Ci/MTU [YMP-1c] + vitrified high-level waste -- 2.47E+09 Ci [YMP-1d]). Thus YMP is equivalent to 1660 WIPPs as far as curie load is concerned. Even though WIPP is less than one part in a thousand in comparison to YMP it still requires the same amount of work (with the exception of thermal effects) to demonstrate compliance for WIPP as it does for YMP because the EPA compliance requirements are based on a normalized basis (i.e., whether a repository has a radionuclide inventory on the order of millicuries, curies, millions of curies (like WIPP), or billions of curies (like YMP), the amount of work (with the exception of thermal effects) to show compliance is the same).

(m) Note, the unit of waste (UW, calculated to three significant figures) is the same whether the UW is calculated using all available information in the TWBID (Ref. CCA-2) or using the limited data within the WIPP PA database. [Also, only 4 radionuclides (Am241, Pu238, Pu239, and Pu240) make up 99.96% of the Unit of Waste value [see Ref. EPA-1b] -- using 5 radionuclides (adding Pu242) makes up 99.9936% of the Unit of Waste value].

Table 4.
40CFR191 Release Limits for (1995 Decayed) WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Release Limits Inventory [α-Curies] (e)		EPA Unit
			CH	RH	(Ci./UW)	(Ci)	
Ac225	α,γ	10.0 d	2.88E+00	1.17E-01			
Ac227	α,β⁻,γ	21.77 a	6.08E-01	7.57E-04	100.	407.	1.50E-03
Ac228	α,β⁻,γ	6.15 h	7.46E-01	7.77E-02			
Ag109m	*IT*e⁻	39.8 s	1.57E+01	NR			
Ag110	β⁺,γ,ε	24.6 s	7.07E-09	1.74E-09			
Ag110m	β⁻,γ,*IT*e⁻	249.8 d	5.31E-07	1.31E-07			
Am241	α,γ,*SF*	432.7 a	4.42E+05	5.96E+03	**100.**	**407.**	**1101.**
Am242	β,γ,εe⁻	16.02 h	1.75E+00	NR			
Am242m	α,*IT*e⁻	141. h	1.75E+00	NR			
Am243	α,β⁻,γ	7.37E+03 a	3.26E-01	2.28E-04	**100.**	**407.**	**8.01E-02**
Am245	β⁻,γ	2.05 h	1.33E-09	2.87E-16			
At217	α,β⁻,γ	32 ms	2.88E+00	1.17E-01			
Ba137m	*IT*	2.552 m	7.63E+03	2.04E+05			
Bi210	α,β⁻,γ	5.01 d	2.55E+00	7.16E-06			
Bi211	α,β⁻,γ	2.14 m	6.09E-01	7.58E-04			
Bi212	α,β⁻,γ	1.009 h	2.71E+01	7.36E-02			
Bi213	α,β⁻,γ	45.6 m	2.88E+00	1.17E-01			
Bi214	α,β⁻,γ	19.9 m	1.16E+01	3.58E-05			
Bk249	α,β⁻,γ	3.2E+02 d	9.16E-05	1.98E-11			
Bk250	β⁻,γ	3.217 h	4.37E-11	NR			
C14	β⁻	5730 a	1.08E+01	2.05E+00	100.	407.	3.16E-02
Cd109	γ,ε	462.0 d	1.57E+01	NR			
Cd113m	β⁻,*IT*	14.1 a	1.82E-06	5.46E-07			
Ce144	β⁻,γ	284.6 d	6.26E-02	5.13E+00			
Cf249	α,γ,*SF*	351 a	6.42E-02	4.47E-03	100.	407.	1.69E-04
Cf250	α,γ,*SF*	13.1 a	3.30E-01	NR			
Cf251	α,γ	9.0E+02 a	3.78E-03	NR	100.	407.	9.29E-06
Cf252	α,γ,*SF*	2.638 a	2.39E+02	1.29E+00			
Cm242	α,γ,*SF*	162.8 d	1.14E+00	NR			
Cm243	α,γ,*SF*,ε	29.1 a	2.72E+00	4.95E+01	**100.**	**407.**	**0.128**
Cm244	α,γ,*SF*	18.1 a	3.15E+04	3.15E+02			
Cm245	α,γ,*SF*	8.5E+03 a	1.15E+02	1.46E-06	**100.**	**407.**	**0.283**
Cm246	α,γ,*SF*	4.76E+03 a	1.02E-01	NR	100.	407.	2.51E-04
Cm247	α,γ	1.56E+07 a	3.21E-09	NR	100.	407.	7.89E-12
Cm248	α,*SF*	3.48E+05 a	8.95E-02	2.05E-04	**100.**	**407.**	**2.20E-04**
Co58	β⁺,γ,ε	70.88 d	3.05E-13	1.24E-11			
Co60	β⁻,γ	5.271 a	6.46E+01	1.04E+04			
Cr51	εγ	27.70 d	NR	3.04E-06			
Cs134	β⁻,γ,ε	2.065 a	1.34E-02	1.84E+01			
Cs135	β⁻	2.3E+06 a	5.02E-04	1.17E-04	1000.	4070.	1.52E-07
Cs137	β⁻,γ	30.17 a	8.06E+03	**2.16E+05 (g)**	**1000.**	**4070.**	**55.1**
Es254	α,γ	276 d	4.24E-11	NR			

Table 4 Continued.
40CFR191 Release Limits for (1995 Decayed) WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Release Limits Inventory [α-Curies] (e)		EPA Unit
			CH	RH	(Ci./UW)	(Ci)	
Eu150	γ,ε	36 a	3.51E-05	NR			
Eu152	β⁻,γ,εβ⁺	13.48 a	1.26E+00	1.22E+03			
Eu154	β⁻,γ,εγ	8.59 a	1.15E+00	5.91E+02			
Eu155	β⁻,γ	4.71 a	9.46E-01	1.18E+02			
Fe55	ε	2.73 a	1.91E-05	1.69E-01			
Fe59	β⁻,γ	44.51 d	2.64E-07	NR			
Fr221	α,γ	4.8 m	2.88E+00	1.17E-01			
Fr223	α,β⁻,γ	21.8 m	8.39E-03	1.04E-05			
H3	β⁻	12.3 a	8.69E-01	6.60E-02			
I129	β⁻,γ	1.57E+07 a	7.05E-07	NR	100.	407.	1.73E-09
Kr85	β⁻,γ	10.73 a	2.02E-01	1.68E+00			
Mn54	εγ	312.2 d	8.51E-04	2.35E-02			
Nb95	β⁻,γ	34.97 d	2.54E-09	6.69E-01			
Nb95m	β⁻,γ,IT	3.61 d	8.50E-12	2.24E-03			
Ni59	ε	7.6E+04 a	7.52E-03	NR	1000.	4070.	1.85E-06
Ni63	β⁻	100. a	9.19E-01	9.88E-01	1000.	4070.	4.69E-04
Np237	α,γ	2.14E+06 a	5.61E+01	2.85E+00	**100.**	**407.**	**1.45E-01**
Np238	β,γ	2.117 d	8.77E-03	NR			
Np239	β⁻,γ	2.355 d	3.26E+01	2.28E-04			
Np240‡	β,γ	1.032 h	NR	NR			
Np240m	β⁻,γ,IT	7.22 m	1.50E-06	2.21E-11			
Pa231	α,γ	3.28E+04 a	4.51E-01	1.91E-03	**100.**	**407.**	**1.11E-03**
Pa233	β⁻,γ	27.0 d	5.61E+01	2.85E+00			
Pa234	β⁻,γ	6.69 h	5.14E-02	1.36E-02			
Pa234m	β⁻,γ,IT	1.17 m	3.96E+01	1.05E+01			
Pb209	β⁻	3.25 h	2.88E+00	1.17E-01			
Pb210	α,β⁻,γ	22.3 a	2.55E+00	7.16E-06	**100.**	**407.**	**6.27E-03**
Pb211	β⁻,γ	36.1 m	6.09E-01	7.58E-04			
Pb212	β⁻,γ	10.64 hr	2.71E+01	7.36E-02			
Pb214	β⁻,γ	27 m	1.16E+01	3.58E-05			
Pd107	β⁻,γ	6.5E+06 a	7.41E-05	1.73E-05	1000.	4070.	2.25E-08
Pm147	β⁻,γ	2.6234 a	7.87E+00	1.07E+01			
Po210	α,γ	138.38 d	2.55E+00	7.16E-06			
Po211	α,γ	0.516 s	1.71E-03	2.12E-06			
Po212	α	0.298 μs	1.73E+01	4.72E-02			
Po213	α	4 μs	2.82E+00	1.15E-01			
Po214	α,γ	163.7 μs	1.16E+01	3.57E-05			
Po215	α,β⁻,γ	1.780 ms	6.09E-01	7.58E-04			
Po216	α,γ	0.145 s	2.71E+01	7.36E-02			
Po218	α,β⁻,γ	3.10 m	1.16E+01	3.58E-05			
Pr144	β⁻,γ	17.28 m	6.18E-02	5.07E+00			
Pu236	α,γ,SF	2.87 a	1.04E-02	NR			

Table 4 Continued.
40CFR191 Release Limits for (1995 Decayed) WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Release Limits Inventory [α-Curies] (e)		EPA Unit
			CH	RH	(Ci./UW)	(Ci)	
Pu238	α,γ,*SF*	87.7 a	**2.61E+06 (f)**	1.45E+03	**100.**	**407.**	**6416.**
Pu239	α,γ,*SF*	2.410E+04 a	7.85E+05	1.03E+04	**100.**	**407.**	**1954.**
Pu240	α,γ,*SF*	6.56E+03 a	2.10E+05	5.07E+03	**100.**	**407.**	**528.**
Pu241	α,β⁻,γ	14.4 a	2.31E+06	1.42E+05			
Pu242	α,γ,*SF*	3.75E+05 a	1.17E+03	1.50E-01	**100.**	**407.**	**2.88**
Pu243	β⁻,γ	4.956 h	3.21E-09	NR			
Pu244	α,*SF*	8.0E+07 a	1.50E-06	2.21E-11	**100.**	**407.**	**3.69E-09**
Ra223	α,γ	11.435 d	6.09E-01	7.58E-04			
Ra224	α,γ	3.66 d	2.71E+01	7.36E-02			
Ra225	β⁻,γ	14.9 d	2.88E+00	1.17E-01			
Ra226	α,γ	1.60E+03 a	1.16E+01	3.58E-05	**100.**	**407.**	**2.85E-02**
Ra228	β⁻,γ	5.76 a	7.47E-01	7.77E-02			
Rh106	β⁻,γ	29.9 s	2.90E-02	1.09E+01			
Rn219	α,γ	3.96 s	6.09E-01	7.58E-04			
Rn220	α,γ	55.6 s	2.71E+01	7.36E-02			
Rn222	α,γ	3.8235 d	1.16E+01	3.58E-05			
Ru106	β⁻	1.02 a	2.90E-02	1.09E+01			
Sb125	β⁻,γ	2.758 a	1.21E-01	1.89E+00			
Sb126	β⁻,γ	12.4 d	1.35E-04	3.16E-05			
Sb126m	γ,*ee*⁻	19.0 m	9.65E-04	2.25E-04			
Se79	β⁻	6.5E+04 a	4.35E-04	1.02E-04	1000.	4070.	1.32E-07
Sm151	β⁻,γ	90 a	1.47E+00	3.57E-01	1000.	4070.	4.49E-04
Sn119m	γ,*ITe*⁻	293 d	4.14E-06	9.59E-07			
Sn121m	β⁻,γ,*ITe*⁻	55 a	2.66E-02	6.69E-03	1000.	4070.	8.18E-06
Sn126	β⁻,γ	1.0E+05 a	9.65E-04	2.25E-04	1000.	4070.	2.92E-07
Sr89†	β⁻,γ	50.52 d	NR	NR			
Sr90	β⁻	29.1 a	6.85E+03	2.09E+05	**1000.**	**4070.**	**53.0**
Ta182	β⁻,γ	114.43 d	NR	4.21E-08			
Tc99	β⁻,γ	2.13E+05 a	2.52E+01	5.85E-03	10000.	40700.	6.19E-04
Te125m	γ,*ITe*⁻	58 d	2.95E-02	4.65E-01			
Te127	β⁻,γ	9.4 h	1.30E-07	1.71E-09			
Te127m	β⁻,γ,*ITe*⁻	109 d	1.33E-07	1.75E-09			
Th227	α,γ	18.72 d	6.01E-01	7.47E-04			
Th228	α,γ	1.913 a	2.71E+01	7.36E-02			
Th229	α,γ	7.3E+03 a	2.88E+00	1.17E-01	**100.**	**407.**	**7.36E-03**
Th230	α,γ	7.54E+04 a	8.06E-02	7.56E-03	**10.**	**40.7**	**2.17E-03**
Th231	β⁻,γ	1.063 d	1.28E+01	4.63E+00			
Th232	α,γ	1.4E+10 a	9.13E-01	9.25E-02	**10.**	**40.7**	**2.48E-02**
Th234	β⁻,γ	24.10 m	3.96E+01	1.05E+01			
Tl207	β⁻,γ	4.77 m	6.07E-01	7.56E-04			
Tl208	β⁻,γ	3.053 m	9.73E+00	2.65E-02			

Table 4 Continued.
40CFR191 Release Limits for (1995 Decayed) WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Release Limits Inventory [α-Curies] (e)		EPA Unit
			CH	RH	(Ci./UW)	(Ci)	
Tl209	β^-,γ	2.2 m	6.22E-02	2.53E-03			
Tl210‡	β,γ	1.30 m	NR	NR			
U232	α,γ,SF	70 a	2.58E+01	NR	100.	407.	6.34E-02
U233	α,γ,SF	1.592E+05 a	1.79E+03	1.58E+02	**100.**	**407.**	**4.79**
U234	α,γ,SF	2.46E+05 a	4.65E+02	4.27E+01	**100.**	**407.**	**1.25**
U235	α,γ,SF	7.04E+08 a	1.28E+01	4.63E+00	**100.**	**407.**	**4.28E-02**
U236	α,γ,SF	2.342E+07 a	3.33E-01	9.68E-02	100.	407.	1.06E-03
U237	β^-,γ	6.75 d	5.66E+01	3.48E+00			
U238	α,γ,SF	4.47E+09 a	3.96E+01	1.05E+01	**100.**	**407.**	**1.23E-01**
U240	β^-,γ	14.1 h	1.50E-06	2.21E-11			
Y90	β^-,γ	2.67 d	6.85E+03	2.09E+05			
Zn65†	$\beta^+,\gamma,\varepsilon$	243.8 d	NR	NR			
Zr93	β^-,γ	1.5E+06 a	5.63E-03	1.32E-03	1000.	4070.	1.71E-06
Zr95	β^-,γ	64.02 d	1.15E-09	3.02E-01			
		Sum =	6.42E+06 (h)	1.02E+06 (i)			(1.012E+04) **1.012E+04 (j)**
		Sum =	7.44E+06				

Top 10 Radionuclides (k)

ID (b)	Total Inventory			EPA Unit			
	CH	RH	Total	CH	RH	Total	CUMULATIVE (%)
Pu238	**2.61E+06 (f)**	1.45E+03	2.61E+06	6413.	3.56	6416.	0.63418
Pu239	7.85E+05	1.03E+04	7.95E+05	1929.	25.3	1954.	0.82732
Am241	4.42E+05	5.96E+03	4.48E+05	1086.	14.6	1101.	0.93611
Pu240	2.10E+05	5.07E+03	2.15E+05	516.	12.5	528.	0.98834
Cs137	8.06E+03	**2.16E+05 (g)**	2.24E+05	1.98	53.1	55.1	0.99378
Sr90	6.85E+03	2.09E+05	2.16E+05	1.68	51.4	53.0	0.99902
U233	1.79E+03	1.58E+02	1.95E+03	4.40	0.39	4.79	0.99950
Pu242	1.17E+03	1.50E-01	1.17E+03	2.87	3.69E-04	2.88	0.99978
U234	4.65E+02	4.27E+01	5.08E+02	1.14	0.10	1.25	0.99990
Cm245	1.15E+02	1.46E-06	1.15E+02	0.283	3.59E-09	0.283	0.99993

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NR Not Reported by sites (see Ref. CCA-2).

‡ Data values for radionuclides were previously reported in Rev. 1 of WTWBIR (BIR-1).

† Data values for radionuclides were previously reported in Rev. 2 of WTWBIR (BIR-2).

(a) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID)

(b) Radionuclides in bold are those 29 incorporated into the WIPP PA database, Ref. SNL-1.

(c) Decay mode and half-life information taken from the Chart of the Nuclides, 14th Ed. Ref. GE-1. [It is better for technical calculations, to use halflives that are extracted from the databases of ORIGEN2 [Ref. OR-1] because the ORIGEN2 data are of a later version than that of Ref. GE-1 (see Ref. SNL-2 for ORIGEN2 values).]

(d) Total inventory (curie) data taken from Ref. CCA-2. Values correspond to a "WIPP-Scale" design basis.

(e) Release limits are determined in accordance with 40CFR191 (Appendix A, Table 1) [Ref. EPA-1]. Left column corresponds to specific release limits (cumulative releases to the accessible environment for 10,000 years after disposal per "unit of waste" identified in Note 1(e) of Table 1, Appendix A, 40CFR191). Right column corresponds to release limit obtained for 4.07 Units of Waste (see Table 2 for calculation of the Unit of Waste) determined from data in the Transuranic Waste Baseline Inventory Report (BIR) [Ref. BIR-2].

(f) Isotope with dominate curie load for CH-TRU wastes.

(g) Isotope with dominate curie load for RH-TRU wastes.

(h) Note, the total CH-TRU curie load is 6.42 MCi (also, 86.3 % of the total curie load in WIPP). The average CH-TRU volumetric total curie load is 6.42E+06/5.95E+06 = 1.08 (Ci/cu. ft.) = **38.1 (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- CH→5.95E+06 cu. ft. Also note that the 5.95E+06 volume number is a volume limit, stored waste and projected waste volumes sum up to a volume less than this volume. The summed up volume is then "scaled" to yield a total volume of 5.95E+06, likewise the curie loads are also "scaled" by the same factor. Thus ratios of curie loads (or heat loads) to volume yield values are applicable to expected waste at WIPP (see Ref. BIR-2d).]

(i) Note, the total RH-TRU curie load is only 1.02 MCi (also, only 13.7 % of the total curie load in WIPP). This curie load is much less than the RH-TRU limit of 5.1 MCi [Ref. LWA-1]. The average RH-TRU volumetric total curie load is 1.02E+06/0.25E+06 = 4.08 (Ci/cu. ft.) = **144. (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- RH→0.25E+06 cu. ft.]

(j) Note, there are 42 radionuclides that comprise the "EPA Unit" (see footnote e above). 25 of these radionuclides are included in the WIPP PA data base and correspond to 99.99903% of the total CH- and RH-TRU "EPA Unit" inventory. The average CH-TRU volumetric "EPA Unit" load is 9.956E+03/5.95E+06 = **1.67E-03 (EPA Unit/cu. ft.)** = **5.91E-02 (EPA Unit/cu. m.)**. The average RH-TRU volumetric "EPA Unit" load is 1.611E+02/0.25E+06 = **6.44E-04 (EPA Unit/cu. ft.)** = **2.28E-02 (EPA Unit/cu. m.)**. [The RH contribution to the WIPP-scale inventory of transuranic curie load is 1.611E+02*100%/(1.611E+02 + 9.956E+03)=**1.592% (very small)**.] Note, this value is about two orders of magnitude less than that presented for the CH-TRU wastes -- since the majority of the curie content of the RH-TRU waste is due to shorter-lived non-transuranic radionuclides, this means that as the shorter-lived components decay away the remaining RH-TRU waste will have a lesser curie content than CH-TRU waste (i.e., as the RH-TRU waste decays, it becomes "wimpier" than CH-TRU waste). This is evident from the RH Study (Ref. DOE-1) which showed that after about 150 → 250 years that CH-TRU waste has a higher specific activity than that of RH-TRU waste.

(k) Note, the EPA Unit (calculated to four significant figures) is the same whether the EPA Unit is calculated using all available information in the TWBID (Ref. CCA-2) or using the limited data within the WIPP PA database. [Also, only 4 radionuclides (Pu238, Pu239, Am241, and Pu240) make up 98.83% of the EPA Unit (see Ref. EPA-1b) -- using 6 radionuclides (adding Cs137 & Sr90) makes up 99.9023% -- using the top 10 radionuclides makes up 99.9932% of the EPA Unit].

Table 5.
Unit of Waste and EPA Units for WIPP TRU Waste (a)

Nuclide ID (b)	WIPP TRU Waste					
	Total Ci Inventory [Curies] (c)		Total TRU Inventory [α-Curies] (d)		EPA Unit (e)	
	1995	2033	1995	2030	1995	2033
Ac225	3.00E+00	9.97E+00				
Ac227	6.09E-01	5.05E-01			1.50E-03	1.47E-03
Ac228	8.24E-01	1.00E+00				
Ag109m	1.57E+01	1.55E-08				
Ag110	8.81E-09	1.68E-25				
Ag110m	6.62E-07	1.26E-23				
Am241	**4.48E+05**	**4.88E+05**	**4.48E+05**	**4.88E+05**	**1101.**	**1419.**
Am242	1.75E+00	1.47E+00				
Am242m	1.75E+00	1.47E+00				
Am243	**3.26E+01**	**3.25E+01**	**3.26E+01**	**3.25E+01**	**8.01E-02**	**9.45E-02**
Am245	1.33E-09	1.17E-22				
At217	3.00E+00	9.97E+00				
Ba137m	2.12E+05	8.81E+04				
Bi210	2.55E+00	8.75E+00				
Bi211	6.10E-01	5.06E-01				
Bi212	2.72E+01	1.94E+01				
Bi213	3.00E+00	9.97E+00				
Bi214	1.16E+01	1.14E+01				
Bk249	9.17E-05	8.06E-18				
Bk250	4.37E-11	2.97E-26				
C14	1.29E+01	1.28E+01			3.17E-02	3.72E-02
Cd109	1.57E+01	1.55E-08				
Cd113m	2.39E-06	3.92E-07				
Ce144	5.19E+00	1.04E-14				
Cf249	6.87E-02	6.38E-02	6.87E-02	6.38E-02	1.69E-04	1.86E-04
Cf250	3.30E-01	4.41E-02				
Cf251	3.78E-03	3.67E-03	3.78E-03	3.67E-03	9.29E-06	1.07E-05
Cf252	**2.41E+02**	**1.11E-02**				
Cm242	1.14E+00	1.21E+00				
Cm243	**5.23E+01**	**2.07E+01**	**5.23E+01**	**2.07E+01**	**0.128**	**0.060**
Cm244	**3.18E+04**	**7.44E+03**				
Cm245	**1.15E+02**	**1.15E+02**	**1.15E+02**	**1.15E+02**	**0.283**	**0.334**
Cm246	1.02E-01	1.02E-01	1.02E-01	1.02E-01	2.51E-04	2.97E-04
Cm247	3.21E-09	9.51E-09	3.21E-09	9.51E-09	7.89E-12	2.77E-11
Cm248	**8.98E-02**	**9.16E-02**	**8.98E-02**	**9.16E-02**	**2.21E-04**	**2.66E-04**
Co58	1.27E-11	0.00E+00				
Co60	1.05E+04	7.06E+01				
Cr51	3.04E-06	0.00E+00				
Cs134	1.84E+01	5.22E-05				
Cs135	6.19E-04	6.19E-04			1.52E-07	1.80E-07

Table 5 Continued.
Unit of Waste and EPA Units for WIPP TRU Waste (a)

Nuclide	WIPP TRU Waste					
ID (b)	Total Ci Inventory [Curies] (c)		Total TRU Inventory [α-Curies] (d)		EPA Unit (e)	
	1995	2033	1995	2030	1995	2033
Cs137	**2.24E+05**	**9.31E+04**			**55.0**	**27.1**
Es254	4.24E-11	2.97E-26				
Eu150	3.51E-05	1.69E-05				
Eu152	1.22E+03	1.76E+02				
Eu154	5.92E+02	2.77E+01				
Eu155	1.19E+02	5.87E-01				
Fe55	1.69E-01	6.73E-06				
Fe59	2.64E-07	0.00E+00				
Fr221	3.00E+00	9.97E+00				
Fr223	8.41E-03	6.98E-03				
Gd152	0.00E+00	3.67E-11				
H3	9.40E-01	1.11E-01				
I129	7.05E-07	7.05E-07			1.73E-09	2.05E-09
Kr85	1.88E+00	1.61E-01				
Mn54	2.43E-02	1.04E-15				
Nb93m	0.00E+00	5.65E-03				
Nb95	6.69E-01	0.00E+00				
Nb95m	2.24E-03	0.00E+00				
Nd144	0.00E+00	1.90E-15				
Ni59	7.52E-03	7.51E-03			1.85E-06	2.18E-06
Ni63	1.91E+00	1.43E+00			4.69E-04	4.16E-04
Np237	**5.90E+01**	**6.49E+01**	**5.90E+01**	**6.49E+01**	**1.45E-01**	**1.89E-01**
Np238	8.78E-03	7.36E-03				
Np239	3.26E+01	3.25E+01				
Np240m	1.50E-06	1.53E-06				
Pa231	**4.53E-01**	**4.67E-01**			**1.11E-03**	**1.36E-03**
Pa233	5.90E+01	6.49E+01				
Pa234	6.50E-02	6.52E-02				
Pa234m	5.01E+01	5.01E+01				
Pb209	3.00E+00	9.97E+00				
Pb210	**2.55E+00**	**8.75E+00**			**6.26E-03**	**2.54E-02**
Pb211	0.00E+00	5.06E-01				
Pb212	2.72E+01	1.94E+01				
Pb214	1.16E+01	1.14E+01				
Pd107	9.14E-05	9.14E-05			2.25E-08	2.66E-08
Pm147	**1.86E+01**	**8.10E-04**				
Po210	2.55E+00	8.75E+00				
Po211	1.71E-03	1.42E-03				
Po212	1.74E+01	1.24E+01				
Po213	2.94E+00	9.76E+00				

Table 5 Continued.
Unit of Waste and EPA Units for WIPP TRU Waste (a)

Nuclide ID (b)	WIPP TRU Waste					
	Total Ci Inventory [Curies] (c)		Total TRU Inventory [α-Curies] (d)		EPA Unit (e)	
	1995	2033	1995	2030	1995	2033
Po214	1.16E+01	1.14E+01				
Po215	6.10E-01	5.06E-01				
Po216	2.72E+01	1.94E+01				
Po218	1.16E+01	1.14E+01				
Pr144	5.13E+00	1.03E-14				
Pu236	1.04E-02	1.01E-06				
Pu238	**2.61E+06**	**1.94E+06**	**2.61E+06**	**1.94E+06**	**6412.**	**5642.**
Pu239	**7.96E+05**	**7.95E+05**	**7.96E+05**	**7.95E+05**	**1956.**	**2312.**
Pu240	**2.15E+05**	**2.14E+05**	**2.15E+05**	**2.14E+05**	**528.**	**622.**
Pu241	**2.45E+06**	**3.94E+05**				
Pu242	**1.17E+03**	**1.17E+03**	**1.17E+03**	**1.17E+03**	**2.87**	**3.40**
Pu243	3.21E-09	9.51E-09				
Pu244	**1.50E-06**	**1.53E-06**	**1.50E-06**	**1.53E-06**	**3.69E-09**	**4.45E-09**
Ra223	6.10E-01	5.06E-01				
Ra224	2.72E+01	1.94E+01				
Ra225	3.00E+00	9.97E+00				
Ra226	**1.16E+01**	**1.14E+01**			**2.85E-02**	**3.32E-02**
Ra228	**8.25E-01**	**1.00E+00**				
Rh106	1.09E+01	4.90E-11				
Rn219	6.10E-01	5.06E-01				
Rn220	2.72E+01	1.94E+01				
Rn222	1.16E+01	1.14E+01				
Ru106	1.09E+01	4.90E-11				
Sb125	2.01E+00	1.49E-04				
Sb126	1.67E-04	1.67E-04				
Sb126m	1.19E-03	1.19E-03				
Se79	5.37E-04	5.37E-04			1.32E-07	1.56E-07
Sm147	0.00E+00	4.55E-10			0.00E+00	1.32E-12
Sm148	0.00E+00	7.87E-26			0.00E+00	2.29E-28
Sm151	1.83E+00	1.36E+00			4.50E-04	3.96E-04
Sn119m	5.10E-06	4.52E-23				
Sn121m	3.33E-02	1.96E-02			8.18E-06	5.70E-06
Sn126	1.19E-03	1.19E-03			2.92E-07	3.46E-07
Sr90	**2.16E+05**	**8.73E+04**			**53.1**	**25.4**
Ta182	4.21E-08	0.00E+00				
Tc99	2.52E+01	2.52E+01			6.19E-04	7.33E-04
Te125m	4.94E-01	3.64E-05				
Te127	1.32E-07	0.00E+00				
Te127m	1.35E-07	0.00E+00				
Th227	6.02E-01	4.99E-01				
Th228	2.72E+01	1.94E+01				

Table 5 Continued.
Unit of Waste and EPA Units for WIPP TRU Waste (a)

Nuclide	WIPP TRU Waste					
ID (b)	Total Ci Inventory [Curies] (c)		Total TRU Inventory [α-Curies] (d)		EPA Unit (e)	
	1995	2033	1995	2030	1995	2033
Th229	**3.00E+00**	**9.97E+00**			**7.37E-03**	**2.90E-02**
Th230	**8.82E-02**	**3.06E-01**			**2.17E-03**	**8.90E-03**
Th231	1.74E+01	1.75E+01				
Th232	**1.01E+00**	**1.01E+00**			**2.48E-02**	**2.94E-02**
Th234	5.01E+01	5.01E+01				
Tl207	6.08E-01	5.04E-01				
Tl208	9.76E+00	6.97E+00				
Tl209	6.48E-02	2.15E-01				
U232	2.58E+01	1.79E+01			6.34E-02	5.21E-02
U233	**1.95E+03**	**1.95E+03**			**4.79**	**5.67**
U234	**5.08E+02**	**7.51E+02**			**1.25**	**2.18**
U235	**1.74E+01**	**1.75E+01**			**4.27E-02**	**5.09E-02**
U236	**4.30E-01**	**6.72E-01**			**1.06E-03**	**1.95E-02**
U237	6.01E+01	9.67E+00				
U238	**5.01E+01**	**5.01E+01**			**1.23E-01**	**1.46E-01**
U240	1.50E-06	1.53E-06				
Y90	2.16E+05	8.73E+04				
Zr93	6.95E-03	6.95E-03			1.71E-06	2.02E-06
Zr95	3.02E-01	0.00E+00				
Sum	7.44E+06	4.20E+06	4.07E+06	3.44E+06	1.011E+04	1.006E+04
Top 4 Radionuclides						
Pu238	**2.61E+06**	**1.94E+06**	**2.61E+06**	**1.94E+06**	**6412.**	**5642.**
Pu239	**7.96E+05**	**7.95E+05**	**7.96E+05**	**7.95E+05**	**1956.**	**2312.**
Am241	**4.48E+05**	**4.88E+05**	**4.48E+05**	**4.88E+05**	**1101.**	**1419.**
Pu240	**2.15E+05**	**2.14E+05**	**2.15E+05**	**2.14E+05**	**528.**	**622.**

(a) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID)

(b) Radionuclides in bold are those 29 incorporated into the WIPP PA database, Ref. SNL-1.

(c) Total inventory (curie) data taken from Ref. CCA-2. Values correspond to a "WIPP-Scale" design basis.

(d) Transuranic inventory data corresponds to the activity (curie) data only for radionuclides that are "transuranic waste" per definitions in 40CFR191 Inventory data in bold corresponds to those data incorporated into the WIPP PA database (see Ref. SNL-1).

(e) EPA Units are determined using Unit of Waste values from columns 4 and 5.

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.2

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PREFACE TO ATTACHMENT WCA.8.2

Title 40 of the Code of Federal Regulations (CFR) § 194.31 states that

The release limits shall be calculated according to part 191, appendix A of this chapter, using the total activity, in curies, that will exist in the disposal system at the time of disposal.

Making an exact assessment of the total activity (the radionuclide inventory) at the time of disposal (2033) requires assessing the total activity, in 2033, of three categories of contact-handled transuranic (CH-TRU) waste.

Category 1: the stored, "legacy" waste; CH-TRU waste that currently exists, is packaged, and has been inventoried and decayed to the year 1995.

Category 2: future waste that has already been generated; CH-TRU waste that currently exists and has been identified, is not packaged, and has not been inventoried for shipment to the Waste Isolation Pilot Plant (WIPP).

Category 3: future to-be-generated waste; CH-TRU waste that has not been identified.

Categories 2 and 3, the projected waste, comprise 66% of the WIPP waste by volume (Transuranic Waste Baseline Inventory Report [TWBIR], DOE 1995, p. 3-1).

Category 1 waste has already been inventoried and the inventory data can be readily decayed to any common base year (that is, to 1995, as is done in the TWBIR). Category 2 waste is expected to be similar to Category 1 waste, and could thus also be assessed at any common base year (for example, 1995). The Category 1 and 2 inventories can also be decayed to any other common year such as the year of closure, 2033. However, Category 3 waste is not necessarily similar to the other two categories and therefore should be estimated separately on a year-by-year basis as it is generated. Then each yearly contribution should be decayed separately to the closure year (2033).

TWBIR data collection methods estimated Category 3 data in the same manner as Category 2 data, and prorated Category 3 data accordingly. Thus, Category 3 data are estimated at 1995 instead of the later years during which the waste would be generated. Additional decay calculations of Category 3 data would result in over-decay of the inventory. For example, waste assayed in 2030 should be decayed for only three years to 2033; decaying such waste for the 38 years from 1995 to 2033 would result in an underestimate, particularly since the fraction of projected waste that is Category 3 cannot be determined. 40 CFR § 194.31 requires assessing the radionuclide inventory at the time of closure, that is, the year 2033. This can be done readily for Category 1 and Category 2 data. Because the Category 3 data were not separated from the Category 2 data, decaying from 1995 to 2033 underestimates portions of the Category 3 inventory by between one and 37 years of decay.

Because Category 3 wastes cannot currently be assessed separately from Category 2 wastes, there are two alternatives for calculating the waste unit factor: (1) calculation on the basis of

the entire inventory decayed to 1995 or (2) calculation on the basis of the entire inventory decayed to 2033. The first yields a waste unit factor of 4.07×10^6, and the second, a waste unit factor of 3.44×10^6. The waste unit factor determines the normalization factor used in calculating the release limit, according to Table 1 of 40 CFR Part 191 Appendix A. The curies of radionuclides are divided by the release limit to determine the EPA units. All else being equal, a smaller release limit (and thus a smaller waste unit factor) is the more conservative of the two possibilities. Therefore, the entire inventory is decayed to 2033 for the performance assessment calculations as specified in 40 CFR § 194.31 above.

Attachment WCA.8.1 states that the inventory decayed to 1995 is used. However, as described above, in keeping with the specification of 40 CFR § 194.31 the inventory decayed to 2033 is used instead.

Reference:

DOE (U. S. Department of Energy). 1995. *Transuranic Waste Baseline Inventory Report, Rev. 2,* DOE/CAO 95-1121, Carlsbad, NM.

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from : L. C. Sanchez, Org 6741, MS 1328, PH-(505)848-0685, Fax-848-0705

subject : **Identification of Important Radionuclides Used in 1996 CCA WIPP Performance Assessment**

Recently the data in the Transuranic Waste Baseline Inventory Database (TWBID) has been updated to reflect reassessments of key radionuclides at some of the major transuranic (TRU) waste generation sites. These new TWBID values (Ref. CCA-2) are termed the "CCA data" and they supersede the data currently published in Revision 2 of the Transuranic Waste Baseline Inventory Report (TWBIR, Ref. BIR-2). This memo identifies which of these radionuclides are of most concern to the Performance Assessment (PA) of WIPP. Of the CCA radionuclides, those that are of the most concern to PA and will be studied in the 1996 CCA calculations are shown in Table 1. The basis for their importance is based upon several factors: 1) the subsurface transportability of the radionuclides (solubility in brine, chemical sorption, etc.,), 2) transuranic inventory, and 3) allowable release limits. There are other serious concerns such as the fissile material (e.g., fissile gram equivalent (FGE) of Pu239), Pu239 equivalent activities, etc. But, these would be more applicable to transportation and WIPP operations limits than to WIPP PA and are not addressed in this memo.

In order to understand why the radionuclides in Table 1 are considered the most important, with respect to WIPP PA, one must become familiar with Table 2, which identifies the the release limits per 40CFR191 (Ref. EPA-1). These release limits are normalized to a "Unit of Waste". For the TRU waste to be disposed of in the WIPP, the unit of waste is "An amount of transuranic (TRU) wastes containing one million curies of alpha-emitting transuranic radionuclides with half lives greater than 20 years" (Ref. EPA-1b). The unit of waste is determined in Table 3. From this table it can be seen that of the 135 radionuclides in the current TWBIR, there are reported data for 15 transuranic waste radionuclides that contribute to the unit of waste. In total there are only 17 possible radionuclides that fall into the "transuranic waste" category. The two that are not identified in the TWBIR are: 1) Am242m and 2) Bk247. Since these radionuclides are very proton rich, it is expected that they are very difficult to generate and should not exist in appreciable quantities. The overall quantity of transuranic waste radionuclides from Table 3 that apply to the unit of waste is 4.07E+06 curies, thus the value for the unit of waste is 4.07. From this table it easily identified that the plutonium and americium radionuclides dominate the unit of waste. For releases to the accessible environment that involve a mix of radionuclides, the limits in Table 2 are used to define normalized releases for comparison with the release limits. Now the unit of waste and the specific release limits are used to determine release

limits and cumulative normalized release limits. (To help describe the 40CFR191 containment requirements, the following two paragraphs were taken as is from Ref RE-1 -- This reference gives a very through introduction to the mechanics of the WIPP PA process and is considered a must for reading if a person wants to be able to understand the results presented in Ref. SNL-1 or any comparable PA reports.) Containments Requirements (40CFR191.13, Ref. EPA-1) specify general limits on the release of transuranic (TRU) waste, high-level waste, or spent nuclear fuel (SNF) from a geologic repository. Environmental Protection Agency (EPA) release limits are defined as the normalizing factors for various radionuclides listed in Table 1 of Appendix A of EPA regulation 40 CFR 191 (see Table 2). According to the Containment Requirements, there must be a reasonable expectation, based on a performance assessment that includes all significant process and events, that the cumulative release of any one radionuclide over 10,000 yr to the accessible environment shall have (these two points alone determine the EPA limits drawn on all WIPP CCDFs):

- less than 1 chance in 10 of exceeding the promulgated EPA radionuclide limits (L_i), and
- less than 1 chance in 1000 of exceeding 10 times those quantities.

For a mix of radionuclides, the sum of all releases, where each radionuclide is normalized with respect to its L_i, shall have:

- less than 1 chance in 10 of exceeding 1, and
- less than 1 chance in 1000 of exceeding 10.

Where the sum of all releases is expressed by:

$$R_j = \frac{1}{f_w}\left[\frac{Q_{1j}}{L_1} + \frac{Q_{2j}}{L_2} + \cdots + \frac{Q_{nRj}}{L_{nR}}\right] = \sum_{i=1}^{nR} \frac{Q_{ij}}{f_w L_i} \leq 1 \ (or\ 10) \qquad (1)$$

where

f_w = waste unit factor = $\frac{\sum W_i}{10^6\, Ci}$, see Table 2 for units

W_i = activity in curies (Ci) for α-emitting TRU repository wastes having half-lives (τ_u) ≥ 20 years

L_i = the EPA release limit for radionuclide i (see Table 2 for examples and units)

nR = number of radionuclides contributing to the release

R_j = total normalized release (EPA sum) for the jth scenario

Q_{ij} = cumulative release for radionuclide u beyond a specified boundary, $\int_o^{10,000yr} q_{ij}\, dt$

q_{ij} = release rate into accessible environment at time t for radionuclide i and scenario j calculated from consequence model(s) (see Chapter 5.0 Ref. RE-1)

The EPA release limits (L_i), for radionuclides i=1, ..., nR are based on generic analyses of hypothetical repositories containing SNF, not TRU waste. The models the contractors for the EPA used to establish the limits considered releases to a river, an ocean, and the land surface. The analysis assumed radionuclides released from the disposal-system boundary were instantaneously deposited into a river, an ocean, or into the land surface. The total cancers per curie were then calculated for each of the three pathways to humans. The most stringent of the three pathways, river water ingestion, was used in calculating the release limits. That is, the release limits are

addition to limiting the RH-TRU canister surface dose equivalent rate to 1,000 rem/hr also limits the design capacity of (all) transuranics to 6.2 million cubic feet of volume of which no more than 5.1 million curies (Ci) may be RH-TRU. The volume limit for the RH-TRU is identified in the WIPP ROD (Record of Decision) to be 0.25 million cubic feet of volume [Ref. DOE-2]. Also, prior to the WIPP LWA 6.2 million cubic feet volume was assign to CH-TRU waste only (for instance, Ref. DOE-3 identifies that the total volume of WIPP was to be 6.45 million cubic feet -- 6.2 for CH-TRU and 0.25 for RH-TRU) and not CH-TRU plus RH-TRU. The WIPP LWA seems to be patterned after the WIPP C&C agreement [DOE-4]. It is in the WIPP C&C that a misquote was made to the WIPP ROD. The WIPP C&C quotes the WIPP ROD as applying the 6.2 million cubic meters to (all) transuranic waste. Even though the WIPP LWA is technically incorrect, the volumes identified there are to be used for WIPP calculations. More thorough discussion can be found in Ref. SA-1.]

[OR-1]Croff, A.G.; "ORIGEN2: A Users Manual for ORIGEN2 Computer Code," Oak Ridge National Laboratory, July 1980. (Further generalized discussion on ORIGEN2 can be found in Ref. OR-2.) (Detailed information on the validation (as applied to analysis of PWR spent fuel) and functional requirements (related to long-term storage of LWR spent fuel) of ORIGEN2 can be found in Refs. OR-3 and OR-4.)

[OR-2]Croff, A.G.; "ORIGEN2: A Versatile Computer Code for Calculating the Nuclide Compositions and Characteristics of Nuclear Materials," **Nuclear Technology,** Vol. 62, September 1983.

[OR-3]Hermann, O.W., S.M. Bowman, M.C. Brady and C.V. Parks; "Validation of the Scale System for PWR Spent Fuel Isotropic Composition Analyses," ORNL/TM-12667, Oak Ridge National Laboratory, March 1995.

[OR-4]Broadhead, B.L., M.D. DeHart, J.C. Ryman, J.S. Tang and C.V. Parks; "Investigation of Nuclide Importance to Functional Requirements Related to Transport and Long-Term Storage of LWR Spent Fuel," Oak Ridge National Laboratory, June 1995. ORNL/TM-12742,

[RE-1]Rechard, R.P.; "An Introduction to the Mechanics of Performance Assessment Using Examples of Calculations Done for the Waste Isolation Pilot Plant Between 1990 and 1992", SAND93-1378, UC-721, Sandia National Laboratories, Albuquerque, New Mexico, Printed October 1995.

[SA-1]L.C. Sanchez (SNL Org 6741) and S.G. Bertram (SNL Org 6747); Memo to L.E. Shephard (SNL Org 6800), subject: "WIPP Capacity", dated October 6, 1995.

[SNL-1]
Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992.* (SAND92-0700), Albuquerque, NM; Sandia National Laboratories.

[SNL-2]
L.C. Sanchez (SNL Org 6741); Memo to M. Marietta (SNL Org 6821), dated February 26, 1995.

[SNL-3]
Helton,J.C., J.W. Garner, R.P. Rechard, D.K. Rudeen, and P.N. Swift. 1992; *Preliminary Comparison with 40CFR191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 4: Uncertainty and Sensitivity Analysis Results,* SAND91-0893/4. Albuquerque, NM; Sandia National Laboratories.

[SNL-4]
J.W. Garner (SNL Org 6749); Memo to: C.T. Stockman (SNL Org 6749), Subject: "Radioisotopes to be used in the 1996 CCA Calculations", dated: 3/15/96

determined such that releases from the disposal system, the land withdrawal boundary for the WIPP [less than the maximum 5 km (~ 3 mi) from the boundary of the disposal region] into a river providing a large population with drinking water, would result in fewer than 1000 cancer deaths over 10,000 yr, a health hazard from the amount of unmined uranium ore needed to produce 100,000 metric tons of reactor fuel (Ref. EPA-2).

Further information can be found in Table 4. This table identifies the 42 radionuclides within the TWBIR that contribute to the release limits. From this table it easily identified that the plutonium and americium radionuclides dominate the EPA units. Also, the total number of EPA units is 10,120 Ci for a unit of waste value of 4.07. This indicates that over the regulatory time frame, on an average, the allowable release of radionuclides is 1/10,120 or ~ 100 ppm (parts per million). In Table 5, there is a list of the radionuclides that are not reported in the TWBIR but are applicable to 40CFR191 (these radionuclides tend to be difficult to produce and are not expected in appreciable amounts). (Should significant quantities of any of these radionuclides be identified in the future, they will be factored into the normalized release calculations.) Also presented in this memo are Tables 6 and 7. These tables, only of minor concern with respect to EPA limits, are shown to give additional information.

From the tables presented in this memo, especially Tables 2, 3 and 4, it should be apparent that the most important radionuclide are the americiums, plutoniums, and uraniums. This was verified by Helton et al. (Ref. SNL-3), and the eight isotopes that dominate the radioactive material that could cross the WIPP regulatory boundary under breach scenarios are: Pu-239, Am-241, Pu-238, Pu-240, Np-237, U-234, U-233, and Th-230. U-234, U-233, and Th-230 are not strictly speaking "transuranic", but are included because they are long-lived daughters of the transuranic radionuclides, and are expected to be present in the TRU waste in non-negligible amounts (either as initial inventory or as ingrowth during the 10,000 year regulatory time frame). This is also demonstrated in Figure 1 which shows the temporal changes in radionuclide activity in a panel of the WIPP repository that occurs as a result of radioactivity decay for the eight most important radionuclides [the plots in Figure are taken from RE-1]. At 10,000 yr, the total normalization activity in a panel for all omitted radionuclides is less than 2 percent of the EPA limit (inclusion of radium-226 drops the total normalized activity to one percent).

REFERENCES

[BIR-1]

DOE (U.S. Department of Energy); Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report; CAO-94-1005; Revision 1; February 1995, Volume 1, Table 4-2, pg. 4-6.

[BIR-2]

DOE (U.S. Department of Energy); Transuranic Waste Baseline Inventory Report; DOE/CAO-95-1121; Revision 2; printed December 1995.

[BIR-2b]

Ibid., Table 3-4, pp. 3-30 → 3-36 (Volume 1).

[BIR-2c]

Ibid., Table 3-4, pg. 3-31 (Volume 1).

[BIR-2d]

Ibid., Table 3-4, pp. 3-27 → 29 (Volume 1).

[BIR-2e]
Ibid., pg. 1-20 (Volume 1).

[CCA-1]
S. Chakraborti (SAIC/CTAC); Letter to: J. Harvill (ASI/CTAC), Subject: "Revised Radionuclide Data In Support Of The CCA", Dated: April 12, 1996.

[CCA-2]
S. Chakraborti (SAIC/CTAC); Letter to: J. Harvill (ASI/CTAC), Subject: "Final Radionuclide Data In Support Of The CCA", Dated: April 19, 1996. [This letter gives radionuclide data that supersedes Rev. 2 of the TWBIR and should be used in the 1996 CCA calculations for the WIPP facility. This letter also supersedes Ref. CCA-1, which had preliminary values. The reason that that this reference was generated was that after publication of Ref. BIR-2 it was identified that inventory data for several key radionuclides needed to be modified in accordance to new information obtained from the waste generation sites (this information was deemed important enough that the updated information was needed for the 1996 CCA calculations).]

[DOE-1]
DOE (U.S. Department of Energy); Remote-Handled Transuranic Waste Study; DOE/CAO-1095, DOE Carlsbad Area Office; Carlsbad, NM, October 1995.

[DOE-2]
DOE (U.S. Department of Energy), Waste Isolation Pilot Plant (WIPP); Record of Decision, **Federal Register** , Vol. 46, No. 18, pg. 9163, January 28, 1981 (46 FR 9162), Office of Environmental Restoration and Waste Management, Washington, D.C.

[DOE-3]
DOE (U.S. Department of Energy), Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant; DOE/EIS-0026-FS, January 1990., Volume 2, pg. B-4, Office of Environmental Restoration and Waste Management, Washington, D.C.

[DOE-4]
DOE (U.S. Department of Energy) and State of New Mexico (1981 originally); Agreement for Consulation and Cooperation Between Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant, Updated April 18, 1988; Article VI (WIPP Mission), pg. 7.

[EPA-1]
EPA (Environmental Protection Agency). 1985a. :40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radionactive Waste: Final Rule," *Federal Register,* **Vol. 50,** No, 182, 38066-38089 (1985).

[EPA-1b]
Ibid., Appendix A to Part 191, Subpart B, Table 1, Note 1 (e).

[EPA-2]
EPA (Environmental Protection Agency). 1985b. *Background Information Document - Final Rule for High-Level and Transuranic Radioactive Wastes,* EPA 520/1-85-023. Washington, DC; U.S. Environmental Protection Agency, Office of Radiation Programs.

[GE-1]General Electric Company (Nuclear Energy Operations), **Nuclides and Isotopes** , Fourteenth Edition, 1989.

[GE-1b]
Ibid., pg. 46.

[LWA-1]
Public Law 102-579, 102d Congress, October 30, 1992; *Waste Isolation Pilot Plant Land Withdrawal Act.;* 1992. Section 7, subparts (a)(1)(A) and (a)(3). [Note, the WIPP LWA in

[SNL-5]
L.C. Sanchez (SNL Org 6741); Memo to: M. Martell (SNL Org 6747), Subject: "Radionuclide Half-lives and Specific Activities Obtained From ORIGEN2 Data", dated: March 28, 1996.

[YMP-1]
Sandia YMP Project. 1994. *Total-System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993), Volume 1.* (SAND93-2675), Albuquerque, NM; Sandia National Laboratories.

[YMP-1b]
Ibid., Table 5-1, pg. 5-1 (Volume 1).

[YMP-1c]
Ibid., Table 5-2, pp. 5-2 → 5-3 (Volume 1).

[YMP-1d]
Ibid., Table 5-7, pg. 5-6 (Volume 1).

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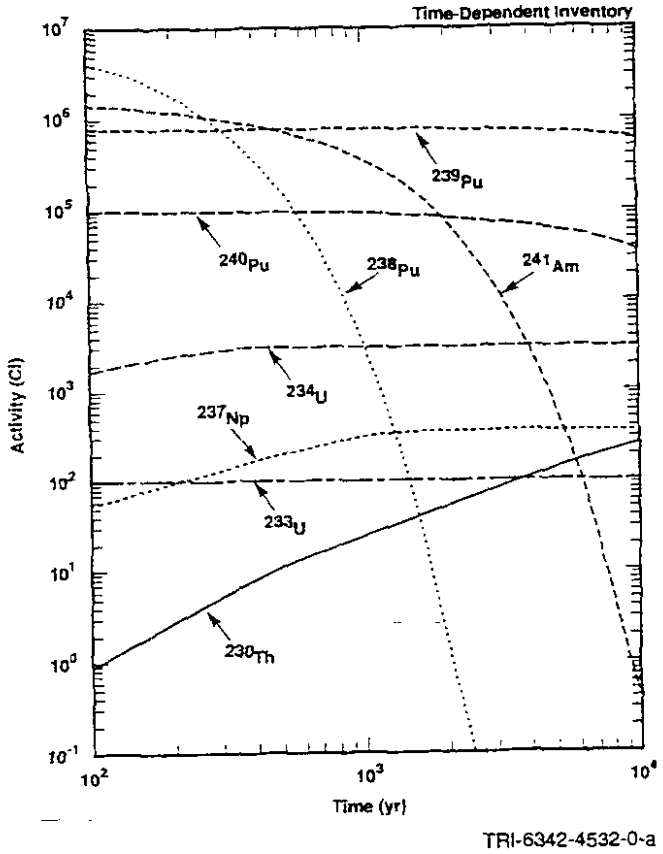

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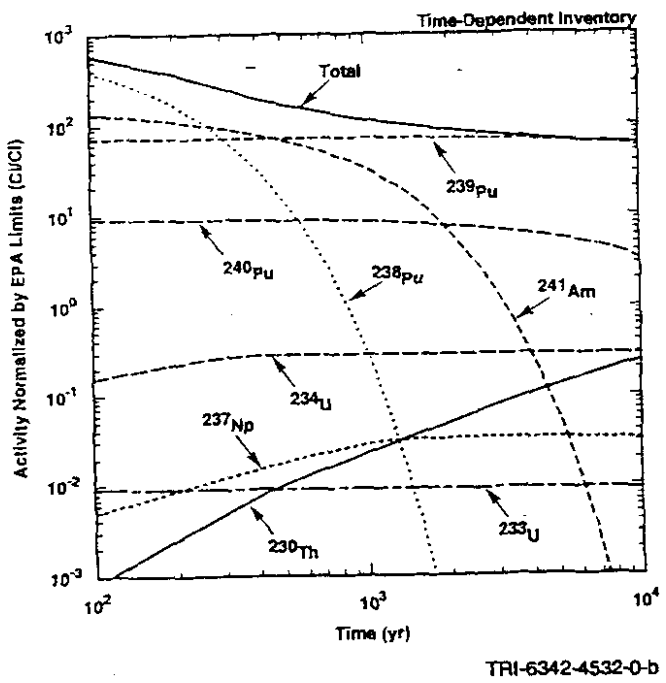

(b)

Figure 1. Changes in radionuclide activity of waste in (based on the inventory used in the 1991 performance assessment calculations) a) activity unnormalized, b) and the one WIPP panel normalized by number of panels in the WIPP (9.49), waste factor 4.225 (million curies in 1992), and the EPA release limits (usually 1000) [Taken from Ref. RE-1].

LCS 7-11-96

Table 1.
Key Radionuclides of Concern to 1996 WIPP PA (a)

Am-241	Cm-248	Pu-238	Ra-226	U-233
Am-243	Cs-137	Pu-239	Ra-228	U-234
Cf-252	Np-237	Pu-240	Sr-90	U-235
Cm-243	Pa-231	Pu-241	Th-229	U-236
Cm-244	Pb-210	Pu-242	Th-230	U-238
Cm-245	Pm-147	Pu-244	Th-232	

(a) Not shown are decay daughters that are be calculated within the PA codes for the 1996 CCA calculations. (See Ref. SNL-4)

Table 2.
Release Limits for the Containment Requirements (a)

Radionuclide	Release Limit per 1000 MTHM (b) or Other Unit of Waste (c) (Ci)
Americium (Am)-241 or -243	100
Carbon (C)-14	100
Cesium (Cs)-135 or -137	1,000
Iodine (I)-129	100
Neptunium (Np)-237	100
Plutonium (Pu)-238, -239, -240, or -242	100
Radium (Ra)-226	100
Strontium (Sr)-90	1,000
Technetium (Tc)-99	10,000
Thorium (Th)-230 or -232	10
Tin (Sn)-126	1,000
Uranium (U)-233, -234, -235, -236, or -238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

(a) Based on Table I of Appendix A of Ref. EPA-1
(b) Metric tons of heavy metal exposed to a burnup between 25,000 and 40,000 MWd/tonne heavy metal.
(c) For TRU waste the unit of waste is "An amount of Transuranic (TRU) wastes containing one million curies of alpha-emitting transuranic radionuclides with half lives greater than 20 years" (Ref. EPA-1b).

Table 3.
40CFR191 Unit of Waste for WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Transuranic Inventory [α-Curies] (e)		% of Unit of Waste
			CH	RH	CH	RH	(%)
Ac225	α,γ	10.0 d	2.88E+00	1.17E-01			
Ac227	α,β⁻,γ	21.77 a	6.08E-01	7.57E-04			
Ac228	α,β⁻,γ	6.15 h	7.46E-01	7.77E-02			
Ag109m	*ITe⁻*	39.8 s	1.57E+01	NR			
Ag110	β⁻,γ,ε	24.6 s	7.07E-09	1.74E-09			
Ag110m	β⁻,γ,*ITe⁻*	249.8 d	5.31E-07	1.31E-07			
Am241	α,γ,*SF*	432.7 a	4.42E+05	5.96E+03	**4.42E+05**	**5.96E+03**	**11.0**
Am242	β,γ,ε*e⁻*	16.02 h	1.75E+00	NR			
Am242m	α,*ITe⁻*	141. h	1.75E+00	NR			
Am243	α,β⁻,γ	7.37E+03 a	3.26E+01	2.28E-04	**3.26E+01**	**2.28E-04**	**8.01E-04**
Am245	β⁻,γ	2.05 h	1.33E-09	2.87E-16			
At217	α,β⁻,γ	32 ms	2.88E+00	1.17E-01			
Ba137m	*IT*	2.552 m	7.63E+03	2.04E+05			
Bi210	α,β⁻,γ	5.01 d	2.55E+00	7.16E-06			
Bi211	α,β⁻,γ	2.14 m	6.09E-01	7.58E-04			
Bi212	α,β⁻,γ	1.009 h	2.71E+01	7.36E-02			
Bi213	α,β⁻,γ	45.6 m	2.88E+00	1.17E-01			
Bi214	α,β⁻,γ	19.9 m	1.16E+01	3.58E-05			
Bk249	α,β⁻,γ	3.2E+02 d	9.16E-05	1.98E-11			
Bk250	β⁻,γ	3.217 h	4.37E-11	NR			
C14	β⁻	5730 a	1.08E+01	2.05E+00			
Cd109	γ,ε	462.0 d	1.57E+01	NR			
Cd113m	β⁻,*IT*	14.1 a	1.82E-06	5.46E-07			
Ce144	β⁻,γ	284.6 d	6.26E-02	5.13E+00			
Cf249	α,γ,*SF*	351 a	6.42E-02	4.47E-03	6.42E-02	4.47E-03	1.69E-06
Cf250	α,γ,*SF*	13.1 a	3.30E-01	NR			
Cf251	α,γ	9.0E+02 a	3.78E-03	NR	3.78E-03	NR	9.28E-08
Cf252	α,γ,*SF*	2.638 a	2.39E+02	1.29E+00			
Cm242	α,γ,*SF*	162.8 d	1.14E+00	NR			
Cm243	α,γ,*SF*,ε	29.1 a	2.72E+00	4.95E+01	**2.72E+00**	**4.95E+01**	**1.28E-03**
Cm244	α,γ,*SF*	18.1 a	3.15E+04	3.15E+02			
Cm245	α,γ,*SF*	8.5E+03 a	1.15E+02	1.46E-06	**1.15E+02**	**1.46E-06**	**2.82E-03**
Cm246	α,γ,*SF*	4.76E+03 a	1.02E-01	NR	1.02E-01	NR	2.51E-06
Cm247	α,γ	1.56E+07 a	3.21E-09	NR	3.21E-09	NR	7.88E-14
Cm248	α,*SF*	3.48E+05 a	8.95E-02	2.05E-04	**8.95E-02**	**2.05E-04**	**2.20E-06**
Co58	β⁻,γ,ε	70.88 d	3.05E-13	1.24E-11			
Co60	β⁻,γ	5.271 a	6.46E+01	1.04E+04			
Cr51	εγ	27.70 d	NR	3.04E-06			
Cs134	β⁻,γ,ε	2.065 a	1.34E-02	1.84E+01			
Cs135	β⁻	2.3E+06 a	5.02E-04	1.17E-04			
Cs137	β⁻,γ	30.17 a	8.06E+03	**2.16E+05 (g)**			
Es254	α,γ	276 d	4.24E-11	NR			

Table 3 Continued.
40CFR191 Unit of Waste for WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Transuranic Inventory [α-Curies] (e)		% of Unit of Waste
			CH	RH	CH	RH	(%)
Eu150	γ,ε	36 a	3.51E-05	NR			
Eu152	β^-,γ,εβ^+	13.48 a	1.26E+00	1.22E+03			
Eu154	β^-,γ,εγ	8.59 a	1.15E+00	5.91E+02			
Eu155	β^-,γ	4.71 a	9.46E-01	1.18E+02			
Fe55	ε	2.73 a	1.91E-05	1.69E-01			
Fe59	β^-,γ	44.51 d	2.64E-07	NR			
Fr221	α,γ	4.8 m	2.88E+00	1.17E-01			
Fr223	α,β^-,γ	21.8 m	8.39E-03	1.04E-05			
H3	β^-	12.3 a	8.69E-01	6.60E-02			
I129	β^-,γ	1.57E+07 a	7.05E-07	NR			
Kr85	β^-,γ	10.73 a	2.02E-01	1.68E+00			
Mn54	εγ	312.2 d	8.51E-04	2.35E-02			
Nb95	β^-,γ	34.97 d	2.54E-09	6.69E-01			
Nb95m	β^-,γ,*IT*	3.61 d	8.50E-12	2.24E-03			
Ni59	ε	7.6E+04 a	7.52E-03	NR			
Ni63	β^-	100. a	9.19E-01	9.88E-01			
Np237	α,γ	2.14E+06 a	5.61E+01	2.85E+00	**5.61E+01**	**2.85E+00**	**1.45E-03**
Np238	β,γ	2.117 d	8.77E-03	NR			
Np239	β^-,γ	2.355 d	3.26E+01	2.28E-04			
Np240‡	β,γ	1.032 h	NR	NR			
Np240m	β^-,γ,*IT*	7.22 m	1.50E-06	2.21E-11			
Pa231	α,γ	3.28E+04 a	4.51E-01	1.91E-03			
Pa233	β^-,γ	27.0 d	5.61E+01	2.85E+00			
Pa234	β^-,γ	6.69 h	5.14E-02	1.36E-02			
Pa234m	β^-,γ,*IT*	1.17 m	3.96E+01	1.05E+01			
Pb209	β^-	3.25 h	2.88E+00	1.17E-01			
Pb210	α,β^-,γ	22.3 a	2.55E+00	7.16E-06			
Pb211	β^-,γ	36.1 m	6.09E-01	7.58E-04			
Pb212	β^-,γ	10.64 hr	2.71E+01	7.36E-02			
Pb214	β^-,γ	27 m	1.16E+01	3.58E-05			
Pd107	β^-,γ	6.5E+06 a	7.41E-05	1.73E-05			
Pm147	β^-,γ	2.6234 a	7.87E+00	1.07E+01			
Po210	α,γ	138.38 d	2.55E+00	7.16E-06			
Po211	α,γ	0.516 s	1.71E-03	2.12E-06			
Po212	α	0.298 μs	1.73E+01	4.72E-02			
Po213	α	4 μs	2.82E+00	1.15E-01			
Po214	α,γ	163.7 μs	1.16E+01	3.57E-05			
Po215	α,β^-,γ	1.780 ms	6.09E-01	7.58E-04			
Po216	α,γ	0.145 s	2.71E+01	7.36E-02			
Po218	α,β^-,γ	3.10 m	1.16E+01	3.58E-05			
Pr144	β^-,γ	17.28 m	6.18E-02	5.07E+00			
Pu236	α,γ,*SF*	2.87 a	1.04E-02	NR			

Table 3 Continued.
40CFR191 Unit of Waste for WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Transuranic Inventory [α-Curies] (e)		% of Unit of Waste
			CH	RH	CH	RH	(%)
Pu238	α,γ,*SF*	87.7 a	**2.61E+06 (f)**	1.45E+03	**2.61E+06**	**1.45E+03**	**64.1**
Pu239	α,γ,*SF*	2.410E+04 a	7.85E+05	1.03E+04	**7.85E+05**	**1.03E+04**	**19.5**
Pu240	α,γ,*SF*	6.56E+03 a	2.10E+05	5.07E+03	**2.10E+05**	**5.07E+03**	**5.28**
Pu241	α,β^-,γ	14.4 a	2.31E+06	1.42E+05			
Pu242	α,γ,*SF*	3.75E+05 a	1.17E+03	1.50E-01	**1.17E+03**	**1.50E-01**	**2.87E-02**
Pu243	β^-,γ	4.956 h	3.21E-09	NR			
Pu244	α,*SF*	8.0E+07 a	1.50E-06	2.21E-11	**1.50E-06**	**2.21E-11**	**3.68E-11**
Ra223	α,γ	11.435 d	6.09E-01	7.58E-04			
Ra224	α,γ	3.66 d	2.71E+01	7.36E-02			
Ra225	β^-,γ	14.9 d	2.88E+00	1.17E-01			
Ra226	α,γ	1.60E+03 a	1.16E+01	3.58E-05			
Ra228	β^-,γ	5.76 a	7.47E-01	7.77E-02			
Rh106	β^-,γ	29.9 s	2.90E-02	1.09E+01			
Rn219	α,γ	3.96 s	6.09E-01	7.58E-04			
Rn220	α,γ	55.6 s	2.71E+01	7.36E-02			
Rn222	α,γ	3.8235 d	1.16E+01	3.58E-05			
Ru106	β^-	1.02 a	2.90E-02	1.09E+01			
Sb125	β^-,γ	2.758 a	1.21E-01	1.89E+00			
Sb126	β^-,γ	12.4 d	1.35E-04	3.16E-05			
Sb126m	γ,ee^-	19.0 m	9.65E-04	2.25E-04			
Se79	β^-	6.5E+04 a	4.35E-04	1.02E-04			
Sm151	β^-,γ	90 a	1.47E+00	3.57E-01			
Sn119m	γ,*ITe*$^-$	293 d	4.14E-06	9.59E-07			
Sn121m	β^-,γ,*ITe*$^-$	55 a	2.66E-02	6.69E-03			
Sn126	β^-,γ	1.0E+05 a	9.65E-04	2.25E-04			
Sr89†	β^-,γ	50.52 d	NR	NR			
Sr90	β^-	29.1 a	6.85E+03	2.09E+05			
Ta182	β^-,γ	114.43 d	NR	4.21E-08			
Tc99	β^-,γ	2.13E+05 a	2.52E+01	5.85E-03			
Te125m	γ,*ITe*$^-$	58 d	2.95E-02	4.65E-01			
Te127	β^-,γ	9.4 h	1.30E-07	1.71E-09			
Te127m	β^-,γ,*ITe*$^-$	109 d	1.33E-07	1.75E-09			
Th227	α,γ	18.72 d	6.01E-01	7.47E-04			
Th228	α,γ	1.913 a	2.71E+01	7.36E-02			
Th229	α,γ	7.3E+03 a	2.88E+00	1.17E-01			
Th230	α,γ	7.54E+04 a	8.06E-02	7.56E-03			
Th231	β^-,γ	1.063 d	1.28E+01	4.63E+00			
Th232	α,γ	1.4E+10 a	9.13E-01	9.25E-02			
Th234	β^-,γ	24.10 m	3.96E+01	1.05E+01			
Tl207	β^-,γ	4.77 m	6.07E-01	7.56E-04			
Tl208	β^-,γ	3.053 m	9.73E+00	2.65E-02			

Table 3 Continued.
40CFR191 Unit of Waste for WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Transuranic Inventory [α-Curies] (e)		% of Unit of Waste
			CH	RH	CH	RH	(%)
Tl209	β^-,γ	2.2 m	6.22E-02	2.53E-03			
Tl210‡	β,γ	1.30 m	NR	NR			
U232	α,γ,SF	70 a	2.58E+01	NR			
U233	α,γ,SF	1.592E+05 a	1.79E+03	1.58E+02			
U234	α,γ,SF	2.46E+05 a	4.65E+02	4.27E+01			
U235	α,γ,SF	7.04E+08 a	1.28E+01	4.63E+00			
U236	α,γ,SF	2.342E+07 a	3.33E-01	9.68E-02			
U237	β^-,γ	6.75 d	5.66E+01	3.48E+00			
U238	α,γ,SF	4.47E+09 a	3.96E+01	1.05E+01			
U240	β^-,γ	14.1 h	1.50E-06	2.21E-11			
Y90	β^-,γ	2.67 d	6.85E+03	2.09E+05			
Zn65†	$\beta^+,\gamma,\varepsilon$	243.8 d	NR	NR			
Zr93	β^-,γ	1.5E+06 a	5.63E-03	1.32E-03			
Zr95	β^-,γ	64.02 d	1.15E-09	3.02E-01			
		Sum =	6.42E+06 (h)	1.02E+06 (i)	(4.048E+06) **4.048E+06 (j)**	(2.283E+04) **2.283E+04 (k)**	100.00 %
		Sum =	7.44E+06 (l)		(4.07E+06) **4.07E+06** **(Unit of Waste = 4.07) (m)**		
Top 5 Radionuclides							
Pu238	α,γ,SF	87.7 a	**2.61E+06 (f)**	1.45E+03	**2.61E+06**	**1.45E+03**	**64.1**
Pu239	α,γ,SF	2.410E+04 a	7.85E+05	1.03E+04	**7.85E+05**	**1.03E+04**	**19.5**
Am241	α,γ,SF	432.7 a	4.42E+05	5.96E+03	**4.42E+05**	**5.96E+03**	**11.0**
Pu240	α,γ,SF	6.56E+03 a	2.10E+05	5.07E+03	**2.10E+05**	**5.07E+03**	**5.28**
Pu242	α,γ,SF	3.75E+05 a	1.17E+03	1.50E-01	**1.17E+03**	**1.50E-01**	**2.87E-02**

NR Not Reported by sites (see Ref. CCA-2).

‡ Data values for radionuclides were previously reported in Rev. 1 of WTWBIR (Ref. BIR-1).

† Data values for radionuclides were previously reported in Rev. 2 of TWBIR (Ref. BIR-2).

(a) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID)

(b) Radionuclides in bold are those 29 incorporated into the WIPP PA database, Ref. SNL-4.

(c) Decay mode and half-life information taken from the Chart of the Nuclides, 14th Ed. Ref. GE-1. [It is better for technical calculations, to use halflives that are extracted from the databases of ORIGEN2 [Ref. OR-1] because the ORIGEN2 data are of a later version than that of Ref. GE-1 (see Ref. SNL-5 for ORIGEN2 values).].

(d) Total inventory (curie) data taken from Ref. CCA-2. Values correspond to a "WIPP-Scale" design basis.

(e) Transuranic inventory data corresponds to the activity (curie) data only for radionuclides that are "transuranic waste" per definitions in 40CFR191 Inventory data in bold corresponds to those data incorporated into the WIPP PA database (see Ref. SNL-4).

(f) Isotope with dominate curie load for CH-TRU wastes.

(g) Isotope with dominate curie load for RH-TRU wastes.

(h) Note, the total CH-TRU curie load is 6.42 MCi (also, 86.3 % of the total curie load in WIPP). The average CH-TRU volumetric total curie load is 6.42E+06/5.95E+06 = 1.08 (Ci/cu. ft.) = **38.1 (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- CH→5.95E+06 cu. ft. Also note that the 5.95E+06 volume number is a volume limit, stored waste and projected waste volumes sum up to a volume less than this volume. The summed up volume is then "scaled" to yield a total volume of 5.95E+06, likewise the curie loads are also "scaled" by the same factor. Thus ratios of curie loads (or heat loads) to volume yield values are applicable to expected waste at WIPP (see Ref. BIR-2d).]

(i) Note, the total RH-TRU curie load is only 1.02 MCi (also, only 13.7 % of the total curie load in WIPP). This curie load is much less than the RH-TRU limit of 5.1 MCi [Ref. LWA-1]. The average RH-TRU volumetric total curie load is 1.02E+06/0.25E+06 = 4.08 (Ci/cu. ft.) = **144. (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- RH→0.25E+06 cu. ft.]

(j) Note, there are only 15 radionuclides that comprise the "transuranic waste" (see footnote e above). Eleven of these radionuclides are included in the WIPP PA data base and correspond to 99.99999% of the total CH "transuranic" inventory. The average CH-TRU volumetric "transuranic" curie load is 4.048E+06/5.95E+06 = **0.680 (TRU-Ci/cu. ft.) = 24.0 (TRU-Ci/cu. m.)**.

(k) Note, there are only 15 radionuclides that comprise the "transuranic waste" (see footnote e above). Eleven of these radionuclides are included in the WIPP PA data base and correspond to 99.99998% of the total RH "transuranic" inventory. The average RH-TRU volumetric "transuranic" curie load is 2.283E+04/0.25E+06 = **0.0913 (TRU-Ci/cu. ft.) = 3.22 (TRU-Ci/cu. m.)**. [The RH contribution to the WIPP-scale inventory of transuranic curie load is 2.283E+04*100%/(2.283E+04 + 4.048E+06)=**0.561% (very small)**.] Note, this value is an order of magnitude less than that presented for the CH-TRU wastes -- since the majority of the curie content of the RH-TRU waste is due to shorter-lived non-transuranic radionuclides, this means that as the shorter-lived components decay away the remaining RH-TRU waste will have a lesser curie content than CH-TRU waste (i.e., as the RH-TRU waste decays, it becomes "wimpier" than CH-TRU waste). This is evident from the RH Study (Ref. DOE-1) which showed that after about 150 → 250 years that CH-TRU waste has a higher specific activity than that of RH-TRU waste.

(l) It is interesting to know that the Yucca Mountain Project (YMP) has approximately 12.4 billion curies of inventory (spent fuel -- 63,000 MTU [YMP-1b] × 1.57E+05 Ci/MTU [YMP-1c] + vitrified high-level waste -- 2.47E+09 Ci [YMP-1d]). Thus YMP is equivalent to 1660 WIPPs as far as curie load is concerned. Even though WIPP is less than one part in a thousand in comparison to YMP it still requires the same amount of work (with the exception of thermal effects) to demonstrate compliance for WIPP as it does for YMP because the EPA compliance requirements are based on a normalized basis (i.e., whether a repository has a radionuclide inventory on the order of millicuries, curies, millions of curies (like WIPP), or billions of curies (like YMP), the amount of work (with the exception of thermal effects) to show compliance is the same).

(m) Note, the unit of waste (UW, calculated to three significant figures) is the same whether the UW is calculated using all available information in the TWBID (Ref. CCA-2) or using the limited data within the WIPP PA database. [Also, only 4 radionuclides (Am241, Pu238, Pu239, and Pu240) make up 99.96% of the Unit of Waste value [see Ref. EPA-1b] -- using 5 radionuclides (adding Pu242) makes up 99.9936% of the Unit of Waste value].

Table 4.
40CFR191 Release Limits for WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Release Limits Inventory [α-Curies] (e)		EPA Unit
			CH	RH	(Ci./UW)	(Ci)	
Ac225	α,γ	10.0 d	2.88E+00	1.17E-01			
Ac227	α,β⁻,γ	21.77 a	6.08E-01	7.57E-04	100.	407.	1.50E-03
Ac228	α,β⁻,γ	6.15 h	7.46E-01	7.77E-02			
Ag109m	*ITe⁻*	39.8 s	1.57E+01	NR			
Ag110	β⁻,γ,ε	24.6 s	7.07E-09	1.74E-09			
Ag110m	β⁻,γ,*ITe⁻*	249.8 d	5.31E-07	1.31E-07			
Am241	α,γ,*SF*	432.7 a	4.42E+05	5.96E+03	**100.**	**407.**	**1101.**
Am242	β,γ,ε*e⁻*	16.02 h	1.75E+00	NR			
Am242m	α,*ITe⁻*	141. h	1.75E+00	NR			
Am243	α,β⁻,γ	7.37E+03 a	3.26E+01	2.28E-04	**100.**	**407.**	**8.01E-02**
Am245	β⁻,γ	2.05 h	1.33E-09	2.87E-16			
At217	α,β⁻,γ	32 ms	2.88E+00	1.17E-01			
Ba137m	*IT*	2.552 m	7.63E+03	2.04E+05			
Bi210	α,β⁻,γ	5.01 d	2.55E+00	7.16E-06			
Bi211	α,β⁻,γ	2.14 m	6.09E-01	7.58E-04			
Bi212	α,β⁻,γ	1.009 h	2.71E+01	7.36E-02			
Bi213	α,β⁻,γ	45.6 m	2.88E+00	1.17E-01			
Bi214	α,β⁻,γ	19.9 m	1.16E+01	3.58E-05			
Bk249	α,β⁻,γ	3.2E+02 d	9.16E-05	1.98E-11			
Bk250	β⁻,γ	3.217 h	4.37E-11	NR			
C14	β⁻	5730 a	1.08E+01	2.05E+00	100.	407.	3.16E-02
Cd109	γ,ε	462.0 d	1.57E+01	NR			
Cd113m	β⁻,*IT*	14.1 a	1.82E-06	5.46E-07			
Ce144	β⁻,γ	284.6 d	6.26E-02	5.13E+00			
Cf249	α,γ,*SF*	351 a	6.42E-02	4.47E-03	100.	407.	1.69E-04
Cf250	α,γ,*SF*	13.1 a	3.30E-01	NR			
Cf251	α,γ	9.0E+02 a	3.78E-03	NR	100.	407.	9.29E-06
Cf252	α,γ,*SF*	2.638 a	2.39E+02	1.29E+00			
Cm242	α,γ,*SF*	162.8 d	1.14E+00	NR			
Cm243	α,γ,*SF*,ε	29.1 a	2.72E+00	4.95E+01	**100.**	**407.**	**0.128**
Cm244	α,γ,*SF*	18.1 a	3.15E+04	3.15E+02			
Cm245	α,γ,*SF*	8.5E+03 a	1.15E+02	1.46E-06	**100.**	**407.**	**0.283**
Cm246	α,γ,*SF*	4.76E+03 a	1.02E-01	NR	100.	407.	2.51E-04
Cm247	α,γ	1.56E+07 a	3.21E-09	NR	100.	407.	7.89E-12
Cm248	α,*SF*	3.48E+05 a	8.95E-02	2.05E-04	**100.**	**407.**	**2.20E-04**
Co58	β⁺,γ,ε	70.88 d	3.05E-13	1.24E-11			
Co60	β⁻,γ	5.271 a	6.46E+01	1.04E+04			
Cr51	εγ	27.70 d	NR	3.04E-06			
Cs134	β⁻,γ,ε	2.065 a	1.34E-02	1.84E+01			
Cs135	β⁻	2.3E+06 a	5.02E-04	1.17E-04	1000.	4070.	1.52E-07
Cs137	β⁻,γ	30.17 a	8.06E+03	**2.16E+05 (g)**	**1000.**	**4070.**	**55.1**
Es254	α,γ	276 d	4.24E-11	NR			

Table 4 Continued.
40CFR191 Release Limits for WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Release Limits Inventory [α-Curies] (e)		EPA Unit
			CH	RH	(Ci/UW)	(Ci)	
Eu150	γ,ε	36 a	3.51E-05	NR			
Eu152	β⁻,γ,εβ⁺	13.48 a	1.26E+00	1.22E+03			
Eu154	β⁻,γ,εγ	8.59 a	1.15E+00	5.91E+02			
Eu155	β⁻,γ	4.71 a	9.46E-01	1.18E+02			
Fe55	ε	2.73 a	1.91E-05	1.69E-01			
Fe59	β⁻,γ	44.51 d	2.64E-07	NR			
Fr221	α,γ	4.8 m	2.88E+00	1.17E-01			
Fr223	α,β⁻,γ	21.8 m	8.39E-03	1.04E-05			
H3	β⁻	12.3 a	8.69E-01	6.60E-02			
I129	β⁻,γ	1.57E+07 a	7.05E-07	NR	100.	407.	1.73E-09
Kr85	β⁻,γ	10.73 a	2.02E-01	1.68E+00			
Mn54	εγ	312.2 d	8.51E-04	2.35E-02			
Nb95	β⁻,γ	34.97 d	2.54E-09	6.69E-01			
Nb95m	β⁻,γ,*IT*	3.61 d	8.50E-12	2.24E-03			
Ni59	ε	7.6E+04 a	7.52E-03	NR	1000.	4070.	1.85E-06
Ni63	β⁻	100. a	9.19E-01	9.88E-01	1000.	4070.	4.69E-04
Np237	α,γ	2.14E+06 a	5.61E+01	2.85E+00	**100.**	**407.**	**1.45E-01**
Np238	β,γ	2.117 d	8.77E-03	NR			
Np239	β⁻,γ	2.355 d	3.26E+01	2.28E-04			
Np240‡	β,γ	1.032 h	NR	NR			
Np240m	β⁻,γ,*IT*	7.22 m	1.50E-06	2.21E-11			
Pa231	α,γ	3.28E+04 a	4.51E-01	1.91E-03	**100.**	**407.**	**1.11E-03**
Pa233	β⁻,γ	27.0 d	5.61E+01	2.85E+00			
Pa234	β⁻,γ	6.69 h	5.14E-02	1.36E-02			
Pa234m	β⁻,γ,*IT*	1.17 m	3.96E+01	1.05E+01			
Pb209	β⁻	3.25 h	2.88E+00	1.17E-01			
Pb210	α,β⁻,γ	22.3 a	2.55E+00	7.16E-06	**100.**	**407.**	**6.27E-03**
Pb211	β⁻,γ	36.1 m	6.09E-01	7.58E-04			
Pb212	β⁻,γ	10.64 hr	2.71E+01	7.36E-02			
Pb214	β⁻,γ	27 m	1.16E+01	3.58E-05			
Pd107	β⁻,γ	6.5E+06 a	7.41E-05	1.73E-05	1000.	4070.	2.25E-08
Pm147	β⁻,γ	2.6234 a	7.87E+00	1.07E+01			
Po210	α,γ	138.38 d	2.55E+00	7.16E-06			
Po211	α,γ	0.516 s	1.71E-03	2.12E-06			
Po212	α	0.298 μs	1.73E+01	4.72E-02			
Po213	α	4 μs	2.82E+00	1.15E-01			
Po214	α,γ	163.7 μs	1.16E+01	3.57E-05			
Po215	α,β⁻,γ	1.780 ms	6.09E-01	7.58E-04			
Po216	α,γ	0.145 s	2.71E+01	7.36E-02			
Po218	α,β⁻,γ	3.10 m	1.16E+01	3.58E-05			
Pr144	β⁻,γ	17.28 m	6.18E-02	5.07E+00			
Pu236	α,γ,*SF*	2.87 a	1.04E-02	NR			

Table 4 Continued.
40CFR191 Release Limits for WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Release Limits Inventory [α-Curies] (e)		EPA Unit
			CH	RH	(Ci./UW)	(Ci)	
Pu238	α,γ,*SF*	87.7 a	**2.61E+06 (f)**	1.45E+03	**100.**	**407.**	**6416.**
Pu239	α,γ,*SF*	2.410E+04 a	7.85E+05	1.03E+04	**100.**	**407.**	**1954.**
Pu240	α,γ,*SF*	6.56E+03 a	2.10E+05	5.07E+03	**100.**	**407.**	**528.**
Pu241	α,β^-,γ	14.4 a	2.31E+06	1.42E+05			
Pu242	α,γ,*SF*	3.75E+05 a	1.17E+03	1.50E-01	**100.**	**407.**	**2.88**
Pu243	β^-,γ	4.956 h	3.21E-09	NR			
Pu244	α,*SF*	8.0E+07 a	1.50E-06	2.21E-11	**100.**	**407.**	**3.69E-09**
Ra223	α,γ	11.435 d	6.09E-01	7.58E-04			
Ra224	α,γ	3.66 d	2.71E+01	7.36E-02			
Ra225	β^-,γ	14.9 d	2.88E+00	1.17E-01			
Ra226	α,γ	1.60E+03 a	1.16E+01	3.58E-05	**100.**	**407.**	**2.85E-02**
Ra228	β^-,γ	5.76 a	7.47E-01	7.77E-02			
Rh106	β^-,γ	29.9 s	2.90E-02	1.09E+01			
Rn219	α,γ	3.96 s	6.09E-01	7.58E-04			
Rn220	α,γ	55.6 s	2.71E+01	7.36E-02			
Rn222	α,γ	3.8235 d	1.16E+01	3.58E-05			
Ru106	β^-	1.02 a	2.90E-02	1.09E+01			
Sb125	β^-,γ	2.758 a	1.21E-01	1.89E+00			
Sb126	β^-,γ	12.4 d	1.35E-04	3.16E-05			
Sb126m	γ,εe^-	19.0 m	9.65E-04	2.25E-04			
Se79	β^-	6.5E+04 a	4.35E-04	1.02E-04	1000.	4070.	1.32E-07
Sm151	β^-,γ	90 a	1.47E+00	3.57E-01	1000.	4070.	4.49E-04
Sn119m	γ,*ITe*$^-$	293 d	4.14E-06	9.59E-07			
Sn121m	β^-,γ,*ITe*$^-$	55 a	2.66E-02	6.69E-03	1000.	4070.	8.18E-06
Sn126	β^-,γ	1.0E+05 a	9.65E-04	2.25E-04	1000.	4070.	2.92E-07
Sr89†	β^-,γ	50.52 d	NR	NR			
Sr90	β^-	29.1 a	6.85E+03	2.09E+05	**1000.**	**4070.**	**53.0**
Ta182	β^-,γ	114.43 d	NR	4.21E-08			
Tc99	β^-,γ	2.13E+05 a	2.52E+01	5.85E-03	10000.	40700.	6.19E-04
Te125m	γ,*ITe*$^-$	58 d	2.95E-02	4.65E-01			
Te127	β^-,γ	9.4 h	1.30E-07	1.71E-09			
Te127m	β^-,γ,*ITe*$^-$	109 d	1.33E-07	1.75E-09			
Th227	α,γ	18.72 d	6.01E-01	7.47E-04			
Th228	α,γ	1.913 a	2.71E+01	7.36E-02			
Th229	α,γ	7.3E+03 a	2.88E+00	1.17E-01	**100.**	**407.**	**7.36E-03**
Th230	α,γ	7.54E+04 a	8.06E-02	7.56E-03	**10.**	**40.7**	**2.17E-03**
Th231	β^-,γ	1.063 d	1.28E+01	4.63E+00			
Th232	α,γ	1.4E+10 a	9.13E-01	9.25E-02	**10.**	**40.7**	**2.48E-02**
Th234	β^-,γ	24.10 m	3.96E+01	1.05E+01			
Tl207	β^-,γ	4.77 m	6.07E-01	7.56E-04			
Tl208	β^-,γ	3.053 m	9.73E+00	2.65E-02			

Table 4 Continued.
40CFR191 Release Limits for WIPP TRU Waste (a)

Nuclide			WIPP TRU Waste				
ID (b)	Decay Mode (c)	Half-Life (c)	Total Inventory [Curies] (d)		Release Limits Inventory [α-Curies] (e)		EPA Unit
			CH	RH	(Ci./UW)	(Ci)	
Tl209	β^-,γ	2.2 m	6.22E-02	2.53E-03			
Tl210‡	β,γ	1.30 m	NR	NR			
U232	α,γ,SF	70 a	2.58E+01	NR	100.	407.	6.34E-02
U233	α,γ,SF	1.592E+05 a	1.79E+03	1.58E+02	**100.**	**407.**	**4.79**
U234	α,γ,SF	2.46E+05 a	4.65E+02	4.27E+01	**100.**	**407.**	**1.25**
U235	α,γ,SF	7.04E+08 a	1.28E+01	4.63E+00	**100.**	**407.**	**4.28E-02**
U236	α,γ,SF	2.342E+07 a	3.33E-01	9.68E-02	100.	407.	1.06E-03
U237	β^-,γ	6.75 d	5.66E+01	3.48E+00			
U238	α,γ,SF	4.47E+09 a	3.96E+01	1.05E+01	**100.**	**407.**	**1.23E-01**
U240	β^-,γ	14.1 h	1.50E-06	2.21E-11			
Y90	β^-,γ	2.67 d	6.85E+03	2.09E+05			
Zn65†	$\beta^+,\gamma,\varepsilon$	243.8 d	NR	NR			
Zr93	β^-,γ	1.5E+06 a	5.63E-03	1.32E-03	1000.	4070.	1.71E-06
Zr95	β^-,γ	64.02 d	1.15E-09	3.02E-01			
		Sum =	6.42E+06 (h)	1.02E+06 (i)			(1.012E+04) **1.012E+04 (j)**
		Sum =	7.44E+06				

Top 10 Radionuclides (k)

ID (b)	Total Inventory			EPA Unit			
	CH	RH	Total	CH	RH	Total	Cumulative
Pu238	**2.61E+06 (f)**	1.45E+03	2.61E+06	6413.	3.56	6416.	0.63418
Pu239	7.85E+05	1.03E+04	7.95E+05	1929.	25.3	1954.	0.82732
Am241	4.42E+05	5.96E+03	4.48E+05	1086.	14.6	1101.	0.93611
Pu240	2.10E+05	5.07E+03	2.15E+05	516.	12.5	528.	0.98834
Cs137	8.06E+03	**2.16E+05 (g)**	2.24E+05	1.98	53.1	55.1	0.99378
Sr90	6.85E+03	2.09E+05	2.16E+05	1.68	51.4	53.0	0.99902
U233	1.79E+03	1.58E+02	1.95E+03	4.40	0.39	4.79	0.99950
Pu242	1.17E+03	1.50E-01	1.17E+03	2.87	3.69E-04	2.88	0.99978
U234	4.65E+02	4.27E+01	5.08E+02	1.14	0.10	1.25	0.99990
Cm245	1.15E+02	1.46E-06	1.15E+02	0.283	3.59E-09	0.283	0.99993

NR Not Reported by sites (see Ref. CCA-2).

‡ Data values for radionuclides were previously reported in Rev. 1 of WTWBIR (Ref. BIR-1).

† Data values for radionuclides were previously reported in Rev. 2 of TWBIR (Ref. BIR-2).

(a) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID)

(b) Radionuclides in bold are those 29 incorporated into the WIPP PA database, Ref. SNL-4.

(c) Decay mode and half-life information taken from the Chart of the Nuclides, 14th Ed. Ref. GE-1. [It is better for technical calculations, to use halflives that are extracted from the databases of ORIGEN2 [Ref. OR-1] because the ORIGEN2 data are of a later version than that of Ref. GE-1 (see Ref. SNL-5 for ORIGEN2 values).]

(d) Total inventory (curie) data taken from Ref. CCA-2. Values correspond to a "WIPP-Scale" design basis.

(e) Release limits are determined in accordance with 40CFR191 (Appendix A, Table 1) [Ref. EPA-1]. Left column corresponds to specific release limits (cumulative releases to the accessible environment for 10,000 years after disposal per "unit of waste" identified in Note 1(e) of Table 1, Appendix A, 40CFR191). Right column corresponds to release limit obtained for 4.07 Units of Waste (see Table 2 for calculation of the Unit of Waste) determined from data in the Transuranic Waste Baseline Inventory Database (BID) [Ref. CCA-2].

(f) Isotope with dominate curie load for CH-TRU wastes.

(g) Isotope with dominate curie load for RH-TRU wastes.

(h) Note, the total CH-TRU curie load is 6.42 MCi (also, 86.3 % of the total curie load in WIPP). The average CH-TRU volumetric total curie load is 6.42E+06/5.95E+06 = 1.08 (Ci/cu. ft.) = **38.1 (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- CH→5.95E+06 cu. ft. Also note that the 5.95E+06 volume number is a volume limit, stored waste and projected waste volumes sum up to a volume less than this volume. The summed up volume is then "scaled" to yield a total volume of 5.95E+06, likewise the curie loads are also "scaled" by the same factor. Thus ratios of curie loads (or heat loads) to volume yield values are applicable to expected waste at WIPP (see Ref. BIR-2d).]

(i) Note, the total RH-TRU curie load is only 1.02 MCi (also, only 13.7 % of the total curie load in WIPP). This curie load is much less than the RH-TRU limit of 5.1 MCi [Ref. LWA-1]. The average RH-TRU volumetric total curie load is 1.02E+06/0.25E+06 = 4.08 (Ci/cu. ft.) = **144. (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- RH→0.25E+06 cu. ft.]

(j) Note, there are 42 radionuclides that comprise the "EPA Unit" (see footnote e above). 25 of these radionuclides are included in the WIPP PA data base and correspond to 99.99903% of the total CH- and RH-TRU "EPA Unit" inventory. The average CH-TRU volumetric "EPA Unit" load is 9.956E+03/5.95E+06 = **1.67E-03 (EPA Unit/cu. ft.)** = **5.91E-02 (EPA Unit/cu. m.)**. The average RH-TRU volumetric "EPA Unit" load is 1.611E+02/0.25E+06 = **6.44E-04 (EPA Unit/cu. ft.)** = **2.28E-02 (EPA Unit/cu. m.)**. [The RH contribution to the WIPP-scale inventory of transuranic curie load is 1.611E+02*100%/(1.611E+02 + 9.956E+03)=**1.592% (very small)**.] Note, this value is about two orders of magnitude less than that presented for the CH-TRU wastes -- since the majority of the curie content of the RH-TRU waste is due to shorter-lived non-transuranic radionuclides, this means that as the shorter-lived components decay away the remaining RH-TRU waste will have a lesser curie content than CH-TRU waste (i.e., as the RH-TRU waste decays, it becomes "wimpier" than CH-TRU waste). This is evident from the RH Study (Ref. DOE-1) which showed that after about 150 → 250 years that CH-TRU waste has a higher specific activity than that of RH-TRU waste.

(k) Note, the EPA Unit (calculated to four significant figures) is the same whether the EPA Unit is calculated using all available information in the TWBID (Ref. CCA-2) or using the limited data within the WIPP PA database. [Also, only 4 radionuclides (Pu238, Pu239, Am241, and Pu240) make up 98.83% of the EPA Unit (see Ref. EPA-1b) -- using 6 radionuclides (adding Cs137 & Sr90) makes up 99.9023% -- using the top 10 radionuclides makes up 99.9932% of the EPA Unit].

Table 5.
Radionuclides Applicable to 40CFR191
But Not Reported in TWBIR (a)

Any other alpha-emitting radionuclide with a half-life > 20 yr		
Ac-227	Gd-150	Po-209
Am-242m	Gd-152	Pt-190
Bi-210m	Hf-174	Sm-146
Bk-247	Nd-144	Sm-147
Dy-154	Np-235	Sm-148
Gd-148	Os-186	

Any other radionuclide with a half-life > 20 yr that does not emit alpha particles		
Ag-108m	Ho-166m	Pt-193
Al-26	In-115	Rb-87
Ar-39	Ir-192m	Re-186m
Ar-42	K-40	Re-187
Be-10	Kr-81	Se-82
Bi-207	La-137	Si-32
Bi-208	La-138	Ta-180m
Ca-41	Lu-176	Tb-157
Cd-113	Mn-53	Tb-158
Cl-36	Mo-93	Tc-97
Cm-250 (b)	Nb-91	Tc-98
Fe-60	Nb-92	Te-123
Hf-178m	Nb-94	Te-130
Hf-182	Np-236	Ti-44
Hg-194	Pb-202	V-50
Ho-163	Pb-205	

(a) See Refs. BIR-2b & EPA-1.
(b) It has not yet been proven that Cm-250 decays by anything other than spontaneous fission (since Cm-250 is very neutron rich, it is very difficult to generate it [GE-1b]).

Table 6. Disposal Radionuclide Inventory

Nuclide ID	WIPP TRU Waste							
	Total Inventory [Curies] (a)		Mass Load [Kg] (b)			Moles Load [Moles] (c)		
	CH	RH	CH	RH	Total	CH	RH	Total
Ac225	2.88E+00	1.17E-01	4.96E-08	2.02E-09	5.16E-08	2.21E-07	8.96E-09	2.30E-07
Ac227	6.08E-01	7.57E-04	8.41E-06	1.05E-08	8.42E-06	3.70E-05	4.61E-08	3.71E-05
Ac228	7.46E-01	7.77E-02	3.33E-10	3.47E-11	3.67E-10	1.46E-09	1.52E-10	1.61E-09
Ag109m	1.57E+01	NR	6.00E-12	--	6.00E-12	5.51E-11	--	5.51E-11
Ag110	7.07E-09	1.74E-09	1.69E-21	4.17E-22	2.11E-21	1.54E-20	3.79E-21	1.92E-20
Ag110m	5.31E-07	1.31E-07	1.12E-13	2.76E-14	1.39E-13	1.02E-12	2.51E-13	1.27E-12
Am241	4.42E+05	5.96E+03	1.29E+02	1.74E+00	1.31E+02	5.34E+02	7.21E+00	5.42E+02
Am242	1.75E+00	NR	2.17E-09	--	2.17E-09	8.95E-09	--	8.95E-09
Am242m	1.75E+00	NR	1.80E-04	--	1.80E-04	7.44E-04	--	7.44E-04
Am243	3.26E+01	2.28E-04	1.64E-01	1.14E-06	1.64E-01	6.73E-01	4.71E-06	6.73E-01
Am245	1.33E-09	2.87E-16	2.15E-19	4.65E-26	2.15E-19	8.79E-19	1.90E-25	8.79E-19
At217	2.88E+00	1.17E-01	1.79E-15	7.27E-17	1.86E-15	8.25E-15	3.35E-16	8.58E-15
Ba137m	7.63E+03	2.04E+05	1.42E-08	3.79E-07	3.93E-07	1.04E-07	2.77E-06	2.87E-06
Bi210	2.55E+00	7.16E-06	2.06E-08	5.77E-14	2.06E-08	9.79E-08	2.75E-13	9.79E-08
Bi211	6.09E-01	7.58E-04	1.46E-12	1.81E-15	1.46E-12	6.90E-12	8.59E-15	6.91E-12
Bi212	2.71E+01	7.36E-02	1.85E-09	5.02E-12	1.86E-09	8.73E-09	2.37E-11	8.75E-09
Bi213	2.88E+00	1.17E-01	1.49E-10	6.05E-12	1.55E-10	6.99E-10	2.84E-11	7.28E-10
Bi214	1.16E+01	3.58E-05	2.63E-10	8.11E-16	2.63E-10	1.23E-09	3.79E-15	1.23E-09
Bk249	9.16E-05	1.98E-11	5.59E-11	1.21E-17	5.59E-11	2.25E-10	4.85E-17	2.25E-10
BK250	4.37E-11	NR	1.12E-20	--	1.12E-20	4.49E-20	--	4.49E-20
C14		1.08E+01	2.05E+00	2.42E-03	4.60E-04	2.88E-03	1.73E-01	3.29E-02
Cd109	1.57E+01	NR	6.08E-06	--	6.08E-06	5.58E-05	--	5.58E-05
Cd113m	1.84E-06	5.46E-07	8.48E-12	2.52E-12	1.10E-11	7.51E-11	2.23E-11	9.74E-11
Ce144	6.26E-02	5.13E+00	1.96E-08	1.61E-06	1.63E-06	1.36E-07	1.12E-05	1.13E-05
Cf249	6.42E-02	4.47E-03	1.57E-05	1.09E-06	1.68E-05	6.29E-05	4.38E-06	6.73E-05
Cf250	3.30E-01	NR	3.02E-06	--	3.02E-06	1.21E-05	--	1.21E-05
Cf251	3.78E-03	NR	2.38E-06	--	2.38E-06	9.50E-06	--	9.50E-06
Cf252	2.39E+02	1.29E+00	4.45E-04	2.40E-06	4.47E-04	1.76E-03	9.52E-06	1.77E-03
Cm242	1.14E+00	NR	3.45E-07	--	3.45E-07	1.42E-06	--	1.42E-06
Cm243	2.72E+00	4.95E+01	5.27E-05	9.59E-04	1.01E-03	2.17E-04	3.95E-03	4.16E-03
Cm244	3.15E+04	3.15E+02	3.89E-01	3.89E-03	3.93E-01	1.60E+00	1.60E-02	1.61E+00
Cm245	1.15E+02	1.46E-06	6.70E-01	8.51E-09	6.70E-01	2.73E+00	3.47E-08	2.73E+00
Cm246	1.02E-01	NR	3.32E-04	--	3.32E-04	1.35E-03	--	1.35E-03
Cm247	3.21E-09	NR	3.46E-08	--	3.46E-08	1.40E-07	--	1.40E-07
Cm248	8.95E-02	2.05E-04	2.11E-02	4.82E-05	2.11E-02	8.49E-02	1.94E-04	8.51E-02
Co58	3.05E-13	1.24E-11	9.58E-21	3.89E-19	3.99E-19	1.65E-19	6.72E-18	6.89E-18
Co60	6.46E+01	1.04E+04	5.71E-05	9.19E-03	9.25E-03	9.52E-04	1.53E-01	1.54E-01
Cr51	NR	3.04E-06	--	3.29E-14	3.29E-14	--	6.45E-13	6.45E-13
Cs134	1.34E-02	1.84E+01	1.03E-08	1.42E-05	1.42E-05	7.73E-08	1.06E-04	1.06E-04
Cs135	5.02E-04	1.17E-04	4.36E-04	1.02E-04	5.37E-04	3.23E-03	7.53E-04	3.98E-03
Cs137	8.06E+03	**2.16E+05** (f)	9.26E-02	2.48E+00	2.57E+00	6.76E-01	1.81E+01	1.88E+01

2.06 E-01

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Table 6 Continued. Disposal Radionuclide Inventory

Nuclide	WIPP TRU Waste							
ID	Total Inventory [Curies] (a)		Mass Load [Kg] (b)			Moles Load [Moles] (c)		
	CH	RH	CH	RH	Total	CH	RH	Total
Es254	4.24E-11	NR	2.27E-17	--	2.27E-17	8.95E-17	--	8.95E-17
Eu150	3.51E-05	NR	5.30E-10	--	5.30E-10	3.53E-09	--	3.53E-09
Eu152	1.26E+00	1.22E+03	7.28E-06	7.05E-03	7.06E-03	4.79E-05	4.64E-02	4.65E-02
Eu154	1.15E+00	5.91E+02	4.26E-06	2.19E-03	2.19E-03	2.77E-05	1.42E-02	1.42E-02
Eu155	9.46E-01	1.18E+02	2.03E-06	2.54E-04	2.56E-04	1.31E-05	1.64E-03	1.65E-03
Fe55	1.91E-05	1.69E-01	7.63E-12	6.75E-08	6.75E-08	1.39E-10	1.23E-06	1.23E-06
Fe59	2.64E-07	NR	5.36E-15	--	5.36E-15	9.10E-14	--	9.10E-14
Fr221	2.88E+00	1.17E-01	1.62E-11	6.60E-13	1.69E-11	7.35E-11	2.99E-12	7.65E-11
Fr223	8.39E-03	1.04E-05	2.17E-13	2.69E-16	2.17E-13	9.73E-13	1.21E-15	9.74E-13
H3	8.69E-01	6.60E-02	9.05E-08	6.88E-09	9.74E-08	3.00E-05	2.28E-06	3.23E-05
I129	7.05E-07	NR	3.99E-06	--	3.99E-06	3.10E-05	--	3.10E-05
Kr85	2.02E-01	1.68E+00	5.14E-07	4.28E-06	4.79E-06	6.06E-06	5.04E-05	5.64E-05
Mn54	8.51E-04	2.35E-02	1.10E-10	3.03E-09	3.14E-09	2.04E-09	5.62E-08	5.83E-08
Nb95	2.54E-09	6.69E-01	6.49E-17	1.71E-08	1.71E-08	6.84E-16	1.80E-07	1.80E-07
Nb95m	8.50E-12	2.24E-03	2.23E-20	5.88E-12	5.88E-12	2.35E-19	6.19E-11	6.19E-11
Ni59	7.52E-03	NR	9.92E-05	--	9.92E-05	1.68E-03	--	1.68E-03
Ni63	9.19E-01	9.88E-01	1.49E-05	1.60E-05	3.09E-05	2.36E-04	2.54E-04	4.91E-04
Np237	5.61E+01	2.85E+00	7.96E+01	4.04E+00	8.36E+01	3.36E+02	1.71E+01	3.53E+02
Np238	8.77E-03	NR	3.38E-11	--	3.38E-11	1.42E-10	--	1.42E-10
Np239	3.26E+01	2.28E-04	1.41E-07	9.83E-13	1.41E-07	5.88E-07	4.11E-12	5.88E-07
Np240m	1.50E-06	2.21E-11	1.42E-17	2.09E-22	1.42E-17	5.90E-17	8.70E-22	5.90E-17
Pa231	4.51E-01	1.91E-03	9.55E-03	4.04E-05	9.59E-03	4.13E-02	1.75E-04	4.15E-02
Pa233	5.61E+01	2.85E+00	2.70E-06	1.37E-07	2.84E-06	1.16E-05	5.89E-07	1.22E-05
Pa234	5.14E-02	1.36E-02	2.57E-11	6.81E-12	3.25E-11	1.10E-10	2.91E-11	1.39E-10
Pa234m	3.96E+01	1.05E+01	5.77E-11	1.53E-11	7.30E-11	2.46E-10	6.53E-11	3.12E-10
Pb209	2.88E+00	1.17E-01	6.34E-10	2.57E-11	6.60E-10	3.03E-09	1.23E-10	3.16E-09
Pb210	2.55E+00	7.16E-06	3.34E-05	9.38E-11	3.34E-05	1.59E-04	4.47E-10	1.59E-04
Pb211	6.09E-01	7.58E-04	2.47E-11	3.07E-14	2.47E-11	1.17E-10	1.46E-13	1.17E-10
Pb212	2.71E+01	7.36E-02	1.95E-08	5.30E-11	1.96E-08	9.20E-08	2.50E-10	9.23E-08
Pb214	1.16E+01	3.58E-05	3.54E-10	1.09E-15	3.54E-10	1.65E-09	5.10E-15	1.65E-09
Pd107	7.41E-05	1.73E-05	1.44E-04	3.36E-05	1.78E-04	1.35E-03	3.14E-04	1.66E-03
Pm147	7.87E+00	1.07E+01	8.48E-06	1.15E-05	2.00E-05	5.78E-05	7.85E-05	1.36E-04
Po210	2.55E+00	7.16E-06	5.68E-07	1.59E-12	5.68E-07	2.70E-06	7.59E-12	2.70E-06
Po211	1.71E-03	2.12E-06	1.79E-17	2.22E-20	1.79E-17	8.49E-17	1.05E-19	8.50E-17
Po212	1.73E+01	4.72E-02	9.75E-20	2.66E-22	9.78E-20	4.60E-19	1.26E-21	4.61E-19
Po213	2.82E+00	1.15E-01	2.24E-19	9.12E-21	2.33E-19	1.05E-18	4.28E-20	1.09E-18
Po214	1.16E+01	3.57E-05	3.62E-17	1.11E-22	3.62E-17	1.69E-16	5.20E-22	1.69E-16
Po215	6.09E-01	7.58E-04	2.07E-17	2.57E-20	2.07E-17	9.61E-17	1.20E-19	9.62E-17
Po216	2.71E+01	7.36E-02	7.78E-14	2.11E-16	7.80E-14	3.60E-13	9.79E-16	3.61E-13
Po218	1.16E+01	3.58E-05	4.10E-11	1.27E-16	4.10E-11	1.88E-10	5.81E-16	1.88E-10
Pr144	6.18E-02	5.07E+00	8.18E-13	6.71E-11	6.79E-11	5.68E-12	4.66E-10	4.72E-10
Pu236	1.04E-02	NR	1.96E-08	--	1.96E-08	8.29E-08	--	8.29E-08

Table 6 Continued. Disposal Radionuclide Inventory

Nuclide	WIPP TRU Waste							
ID	Total Inventory [Curies] (a)		Mass Load [Kg] (b)			Moles Load [Moles] (c)		
	CH	RH	CH	RH	Total	CH	RH	Total
Pu238	**2.61E+06** (e)	1.45E+03	1.52E+02	8.47E-02	1.53E+02	6.41E+02	3.56E-01	6.41E+02
Pu239	7.85E+05	1.03E+04	1.26E+04	1.66E+02	1.28E+04	5.28E+04	6.93E+02	5.35E+04
Pu240	2.10E+05	5.07E+03	9.22E+02	2.23E+01	9.44E+02	3.84E+03	9.27E+01	3.93E+03
Pu241	2.31E+06	1.42E+05	2.24E+01	1.38E+00	2.38E+01	9.30E+01	5.72E+00	9.88E+01
Pu242	1.17E+03	1.50E-01	3.07E+02	3.93E-02	3.07E+02	1.27E+03	1.62E-01	1.27E+03
Pu243	3.21E-09	NR	1.23E-18	--	1.23E-18	5.08E-18	--	5.08E-18
Pu244	1.50E-06	2.21E-11	8.46E-05	1.25E-09	8.46E-05	3.47E-04	5.11E-09	3.47E-04
Ra223	6.09E-01	7.58E-04	1.19E-08	1.48E-11	1.19E-08	5.33E-08	6.64E-11	5.34E-08
Ra224	2.71E+01	7.36E-02	1.70E-07	4.62E-10	1.71E-07	7.60E-07	2.06E-09	7.62E-07
Ra225	2.88E+00	1.17E-01	7.35E-08	2.98E-09	7.65E-08	3.27E-07	1.33E-08	3.40E-07
Ra226	1.16E+01	3.58E-05	1.17E-02	3.62E-08	1.17E-02	5.19E-02	1.60E-07	5.19E-02
Ra228	7.47E-01	7.77E-02	3.19E-06	3.32E-07	3.52E-06	1.40E-05	1.46E-06	1.55E-05
Rh106	2.90E-02	1.09E+01	8.14E-15	3.06E-12	3.07E-12	7.69E-14	2.89E-11	2.90E-11
Rn219	6.09E-01	7.58E-04	4.68E-14	5.83E-17	4.69E-14	2.14E-13	2.66E-16	2.14E-13
Rn220	2.71E+01	7.36E-02	2.94E-11	7.98E-14	2.95E-11	1.34E-10	3.63E-13	1.34E-10
Rn222	1.16E+01	3.58E-05	7.54E-08	2.33E-13	7.54E-08	3.40E-07	1.05E-12	3.40E-07
Ru106	2.90E-02	1.09E+01	8.66E-09	3.25E-06	3.26E-06	8.18E-08	3.07E-05	3.08E-05
Sb125	1.21E-01	1.89E+00	1.17E-07	1.83E-06	1.95E-06	9.38E-07	1.46E-05	1.56E-05
Sb126	1.35E-04	3.16E-05	1.61E-12	3.78E-13	1.99E-12	1.28E-11	3.00E-12	1.58E-11
Sb126m	9.65E-04	2.25E-04	1.23E-14	2.86E-15	1.51E-14	9.75E-14	2.27E-14	1.20E-13
Se79	4.35E-04	1.02E-04	6.24E-06	1.46E-06	7.70E-06	7.90E-05	1.85E-05	9.76E-05
Sm151	1.47E+00	3.57E-01	5.58E-05	1.36E-05	6.94E-05	3.70E-04	8.99E-05	4.60E-04
Sn119m	4.14E-06	9.59E-07	9.24E-13	2.14E-13	1.14E-12	7.77E-12	1.80E-12	9.57E-12
Sn121m	2.66E-02	6.69E-03	4.50E-07	1.13E-07	5.63E-07	3.72E-06	9.35E-07	4.65E-06
Sn126	9.65E-04	2.25E-04	3.40E-05	7.93E-06	4.19E-05	2.70E-04	6.29E-05	3.33E-04
Sr89†	NR	NR	--	--	--	--	--	--
Sr90	6.85E+03	2.09E+05	5.02E-02	1.53E+00	1.58E+00	5.58E-01	1.70E+01	1.76E+01
Ta182	NR	4.21E-08	--	6.75E-15	6.75E-15	--	3.71E-14	3.71E-14
Tc99	2.52E+01	5.85E-03	1.49E+00	3.45E-04	1.49E+00	1.50E+01	3.49E-03	1.50E+01
Te125m	2.95E-02	4.65E-01	1.64E-09	2.58E-08	2.74E-08	1.31E-08	2.07E-07	2.20E-07
Te127	1.30E-07	1.71E-09	4.92E-17	6.47E-19	4.99E-17	3.88E-16	5.10E-18	3.93E-16
Te127m	1.33E-07	1.75E-09	1.41E-14	1.85E-16	1.43E-14	1.11E-13	1.46E-15	1.12E-13
Th227	6.01E-01	7.47E-04	1.96E-08	2.43E-11	1.96E-08	8.61E-08	1.07E-10	8.62E-08
Th228	2.71E+01	7.36E-02	3.31E-05	8.98E-08	3.32E-05	1.45E-04	3.94E-07	1.45E-04
Th229	2.88E+00	1.17E-01	1.35E-02	5.50E-04	1.41E-02	5.91E-02	2.40E-03	6.15E-02
Th230	8.06E-02	7.56E-03	3.99E-03	3.75E-04	4.37E-03	1.74E-02	1.63E-03	1.90E-02
Th231	1.28E+01	4.63E+00	2.41E-08	8.71E-09	3.28E-08	1.04E-07	3.77E-08	1.42E-07
Th232	9.13E-01	9.25E-02	8.33E+03	8.44E+02	9.17E+03	3.59E+04	3.64E+03	3.95E+04
Th234	3.96E+01	1.05E+01	1.71E-06	4.54E-07	2.16E-06	7.31E-06	1.94E-06	9.25E-06
Tl207	6.07E-01	7.56E-04	3.19E-12	3.97E-15	3.19E-12	1.54E-11	1.92E-14	1.54E-11
Tl208	9.73E+00	2.65E-02	3.30E-11	9.00E-14	3.31E-11	1.59E-10	4.33E-13	1.59E-10

Table 6 Continued. Disposal Radionuclide Inventory

Nuclide	WIPP TRU Waste							
ID	Total Inventory [Curies] (a)		Mass Load [Kg] (b)			Moles Load [Moles] (c)		
	CH	RH	CH	RH	Total	CH	RH	Total
Tl209	6.22E-02	2.53E-03	1.52E-13	6.19E-15	1.58E-13	7.28E-13	2.96E-14	7.57E-13
U232	2.58E+01	NR	1.21E-03	--	1.21E-03	5.20E-03	--	5.20E-03
U233	1.79E+03	1.58E+02	1.85E+02	1.63E+01	2.01E+02	7.94E+02	7.01E+01	8.64E+02
U234	4.65E+02	4.27E+01	7.44E+01	6.83E+00	8.13E+01	3.18E+02	2.92E+01	3.47E+02
U235	1.28E+01	4.63E+00	5.92E+03	2.14E+03	8.07E+03	2.52E+04	9.12E+03	3.43E+04
U236	3.33E-01	9.68E-02	5.15E+00	1.50E+00	6.64E+00	2.18E+01	6.34E+00	2.82E+01
U237	5.66E+01	3.48E+00	6.94E-07	4.26E-08	7.36E-07	2.93E-06	1.80E-07	3.11E-06
U238	3.96E+01	1.05E+01	**1.18E+05** (g)	**3.12E+04** (h)	**1.49E+05** (i)	**4.95E+05** (j)	**1.31E+05** (k)	**6.26E+05** (l)
U240	1.50E-06	2.21E-11	1.62E-15	2.39E-20	1.62E-15	6.75E-15	9.94E-20	6.75E-15
Y90	6.85E+03	2.09E+05	1.26E-05	3.84E-04	3.96E-04	1.40E-04	4.27E-03	4.41E-03
Zn65†	NR	NR	--	--	--	--	--	--
Zr93	5.63E-03	1.32E-03	2.24E-03	5.25E-04	2.76E-03	2.41E-02	5.65E-03	2.97E-02
Zr95	1.15E-09	3.02E-01	5.35E-17	1.40E-08	1.40E-08	5.64E-16	1.48E-07	1.48E-07
Total	6.42E+06	1.02E+06	1.47E+05	3.44E+04	1.81E+05	6.17E+05	1.45E+05	7.62E+05

-- Not calculated.

NR Not Reported by sites (see Ref. CCA-2).

† Data values for radionuclides were previously reported in Rev. 2 of TWBIR (Ref. BIR-2).

(a) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID) Values correspond to a "WIPP-Scale" design basis.

(b) Data calculated from the equation;

$$\text{Mass Load} = TOTAL\ ACTIVITY(Ci)\frac{3.7E+10(dis/sec)}{Ci}\ \frac{\tau_{1/2}}{ln(2)}\ \frac{AtWt}{Na}\ \frac{kg}{1000\,gm}$$

(c) Data calculated from the equation;

$$\text{Mole Load} = MassLoad\ \frac{1}{AtWt}\ \frac{1000\,gm}{kg}$$

(e) Isotope with dominate curie load for CH-TRU wastes.

(f) Isotope with dominate curie load for RH-TRU wastes.

(g) Isotope with dominate mass load for CH-TRU wastes.

(h) Isotope with dominate mass load for RH-TRU wastes.

(i) Isotope with dominate mass load for CH- & RH-TRU wastes.

(j) Isotope with dominate mole load for CH-TRU wastes.

(k) Isotope with dominate mole load for RH-TRU wastes.

(l) Isotope with dominate mole load for CH- & RH-TRU wastes.

Table 7. Disposal Radionuclide Inventory

Nuclide			WIPP TRU Waste					
ID	Energy		Total Inventory [Curies] (b)		Heat Load [Watts] (c)		% Heat Load [%]	
	$\frac{MeV}{dis}$ (a)	$\frac{W}{Ci}$	CH	RH	CH	RH	CH	RH
Ac225	5.893	3.49E-02	2.88E+00	1.17E-01	1.01E-01	4.09E-03	7.56E-05	1.22E-04
Ac227	0.082	4.84E-04	6.08E-01	7.57E-04	2.94E-04	3.67E-07	2.21E-07	1.09E-08
Ac228	1.458	8.64E-03	7.46E-01	7.77E-02	6.45E-03	6.72E-04	4.85E-06	2.00E-05
Ag109m	0.087	5.15E-04	1.57E+01	NR	8.09E-03	--	6.08E-06	--
Ag110	1.212	7.18E-03	7.07E-09	1.74E-09	5.08E-11	1.25E-11	3.82E-14	3.72E-13
Ag110m	2.817	1.67E-02	5.31E-07	1.31E-07	8.87E-09	2.19E-09	6.67E-12	6.51E-11
Am241	5.604	3.32E-02	4.42E+05	5.96E+03	1.47E+04	1.98E+02	1.10E+01	5.89E+00
Am242	0.192	1.14E-03	1.75E+00	NR	1.99E-03	--	1.49E-06	--
Am242m	0.067	3.95E-04	1.75E+00	NR	6.91E-04	--	5.20E-07	--
Am243	5.423	3.21E-02	3.26E+01	2.28E-04	1.05E+00	7.33E-06	7.88E-04	2.18E-07
Am245	0.313	1.86E-03	1.33E-09	2.87E-16	2.47E-12	5.32E-19	1.86E-15	1.58E-20
At217	7.199	4.27E-02	2.88E+00	1.17E-01	1.23E-01	4.99E-03	9.24E-05	1.49E-04
Ba137m	0.662	3.93E-03	7.63E+03	2.04E+05	3.00E+01	8.01E+02	2.25E-02	2.38E+01
Bi210	0.389	2.31E-03	2.55E+00	7.16E-06	5.88E-03	1.65E-08	4.42E-06	4.91E-10
Bi211	6.729	3.99E-02	6.09E-01	7.58E-04	2.43E-02	3.02E-05	1.83E-05	9.00E-07
Bi212	2.869	1.70E-02	2.71E+01	7.36E-02	4.61E-01	1.25E-03	3.47E-04	3.73E-05
Bi213	0.709	4.20E-03	2.88E+00	1.17E-01	1.21E-02	4.92E-04	9.10E-06	1.46E-05
Bi214	2.162	1.28E-02	1.16E+01	3.58E-05	1.49E-01	4.59E-07	1.12E-04	1.37E-08
Bk249	0.125	7.41E-04	9.16E-05	1.98E-11	6.79E-08	1.47E-14	5.10E-11	4.37E-16
Bk250	1.172	6.95E-03	4.37E-11	NR	3.04E-13	--	2.28E-16	--
C14	0.049	2.93E-04	1.08E+01	2.05E+00	3.17E-03	6.01E-04	2.38E-06	1.79E-05
Cd109	0.020	1.16E-04	1.57E+01	NR	1.82E-03	--	1.37E-06	--
Cd113m	0.284	1.68E-03	1.84E-06	5.46E-07	3.10E-09	9.19E-10	2.33E-12	2.74E-11
Ce144	0.112	6.63E-04	6.26E-02	5.13E+00	4.15E-05	3.40E-03	3.12E-08	1.01E-04
Cf249	7.806	4.63E-02	6.42E-02	4.47E-03	2.97E-03	2.07E-04	2.23E-06	6.16E-06
Cf250	6.267	3.71E-02	3.30E-01	NR	1.23E-02	--	9.22E-06	--
Cf251	6.027	3.57E-02	3.78E-03	NR	1.35E-04	--	1.02E-07	--
Cf252	12.04	7.14E-02	2.39E+02	1.29E+00	1.71E+01	9.21E-02	1.28E-02	2.74E-03
Cm242	6.216	3.68E-02	1.14E+00	NR	4.20E-02	--	3.16E-05	--
Cm243	6.189	3.67E-02	2.72E+00	4.95E+01	9.98E-02	1.82E+00	7.50E-05	5.40E-02
Cm244	5.901	3.50E-02	3.15E+04	3.15E+02	1.10E+03	1.10E+01	8.28E-01	3.28E-01
Cm245	5.598	3.32E-02	1.15E+02	1.46E-06	3.82E+00	4.84E-08	2.87E-03	1.44E-09
Cm246	5.523	3.27E-02	1.02E-01	NR	3.34E-03	--	2.51E-06	--
Cm247	5.390	3.20E-02	3.21E-09	NR	1.03E-10	--	7.71E-14	--
Cm248	21.00	1.24E-01	8.95E-02	2.05E-04	1.11E-02	2.55E-05	8.38E-06	7.59E-07
Co58	1.009	5.98E-03	3.05E-13	1.24E-11	1.82E-15	7.42E-14	1.37E-18	2.21E-15
Co60	2.601	1.54E-02	6.46E+01	1.04E+04	9.96E-01	1.60E+02	7.49E-04	4.77E+00
Cr51	0.036	2.15E-04	NR	3.04E-06	--	6.52E-10	--	1.94E-11
Cs134	1.717	1.02E-02	1.34E-02	1.84E+01	1.36E-04	1.87E-01	1.03E-07	5.57E-03
Cs135	0.056	3.34E-04	5.02E-04	1.17E-04	1.68E-07	3.90E-08	1.26E-10	1.16E-09
Cs137	0.187	1.11E-03	8.06E+03	**2.16E+05** (f)	8.92E+00	2.39E+02	6.70E-03	7.11E+00
Es254	6.623	3.93E-02	4.24E-11	NR	1.66E-12	--	1.25E-15	--

Table 7 Continue. Disposal Radionuclide Inventory

Nuclide			WIPP TRU Waste					
ID	Energy		Total Inventory [Curies] (b)		Heat Load [Watts] (c)		% Heat Load [%]	
	$\frac{MeV}{dis}$ (a)	$\frac{W}{Ci}$	CH	RH	CH	RH	CH	RH
Eu150	1.540	9.13E-03	3.51E-05	NR	3.20E-07	--	2.41E-10	--
Eu152	1.276	7.56E-03	1.26E+00	1.22E+03	9.53E-03	9.23E+00	7.17E-06	2.75E-01
Eu154	1.509	8.95E-03	1.15E+00	5.91E+02	1.03E-02	5.29E+00	7.73E-06	1.57E-01
Eu155	0.123	7.27E-04	9.46E-01	1.18E+02	6.88E-04	8.58E-02	5.17E-07	2.55E-03
Fe55	0.006	3.38E-05	1.91E-05	1.69E-01	6.45E-10	5.71E-06	4.85E-13	1.70E-07
Fe59	1.306	7.74E-03	2.64E-07	NR	2.04E-09	--	1.54E-12	--
Fr221	6.511	3.86E-02	2.88E+00	1.17E-01	1.11E-01	4.52E-03	8.36E-05	1.34E-04
Fr223	0.438	2.60E-03	8.39E-03	1.04E-05	2.18E-05	2.70E-08	1.64E-08	8.04E-10
H3	0.006	3.37E-05	8.69E-01	6.60E-02	2.93E-05	2.22E-06	2.20E-08	6.61E-08
I129	0.078	4.63E-04	7.05E-07	NR	3.26E-10	--	2.45E-13	--
Kr85	0.253	1.50E-03	2.02E-01	1.68E+00	3.03E-04	2.52E-03	2.28E-07	7.49E-05
Mn54	0.840	4.98E-03	8.51E-04	2.35E-02	4.24E-06	1.17E-04	3.19E-09	3.48E-06
Nb95	0.809	4.80E-03	2.54E-09	6.69E-01	1.22E-11	3.21E-03	9.16E-15	9.55E-05
Nb95m	0.234	1.39E-03	8.50E-12	2.24E-03	1.18E-14	3.11E-06	8.88E-18	9.26E-08
Ni59	0.007	3.97E-05	7.52E-03	NR	2.99E-07	--	2.25E-10	--
Ni63	0.017	1.01E-04	9.19E-01	9.88E-01	9.26E-05	9.96E-05	6.96E-08	2.96E-06
Np237	5.156	3.06E-02	5.61E+01	2.85E+00	1.71E+00	8.71E-02	1.29E-03	2.59E-03
Np238	0.408	4.79E-03	8.77E-03	NR	4.20E-05	--	3.16E-08	--
Np239	1.788	2.42E-03	3.26E+01	2.28E-04	7.88E-02	5.51E-07	5.93E-05	1.64E-08
Np240m	0.978	5.80E-03	1.50E-06	2.21E-11	8.69E-09	1.28E-13	6.54E-12	3.81E-15
Pa231	5.083	3.01E-02	4.51E-01	1.91E-03	1.36E-02	5.76E-05	1.02E-05	1.71E-06
Pa233	0.383	2.27E-03	5.61E+01	2.85E+00	1.27E-01	6.47E-03	9.57E-05	1.93E-04
Pa234	2.423	1.44E-02	5.14E-02	1.36E-02	7.38E-04	1.95E-04	5.55E-07	5.81E-06
Pa234m	0.834	4.94E-03	3.96E+01	1.05E+01	1.96E-01	5.19E-02	1.47E-04	1.54E-03
Pb209	0.194	1.15E-03	2.88E+00	1.17E-01	3.31E-03	1.35E-04	2.49E-06	4.00E-06
Pb210	0.039	2.32E-04	2.55E+00	7.16E-06	5.91E-04	1.66E-09	4.44E-07	4.94E-11
Pb211	0.505	3.00E-03	6.09E-01	7.58E-04	1.82E-03	2.27E-06	1.37E-06	6.76E-08
Pb212	0.321	1.90E-03	2.71E+01	7.36E-02	5.16E-02	1.40E-04	3.88E-05	4.17E-06
Pb214	0.538	3.19E-03	1.16E+01	3.58E-05	3.70E-02	1.14E-07	2.78E-05	3.40E-09
Pd107	0.010	5.93E-05	7.41E-05	1.73E-05	4.39E-09	1.03E-09	3.30E-12	3.05E-11
Pm147	0.061	3.59E-04	7.87E+00	1.07E+01	2.82E-03	3.84E-03	2.12E-06	1.14E-04
Po210	5.408	3.21E-02	2.55E+00	7.16E-06	8.17E-02	2.30E-07	6.15E-05	6.83E-09
Po211	7.592	4.50E-02	1.71E-03	2.12E-06	7.70E-05	9.54E-08	5.79E-08	2.84E-09
Po212	8.940	5.30E-02	1.73E+01	4.72E-02	9.17E-01	2.50E-03	6.89E-04	7.44E-05
Po213	8.537	5.06E-02	2.82E+00	1.15E-01	1.43E-01	5.82E-03	1.07E-04	1.73E-04
Po214	7.833	4.64E-02	1.16E+01	3.57E-05	5.39E-01	1.66E-06	4.05E-04	4.93E-08
Po215	7.531	4.46E-02	6.09E-01	7.58E-04	2.72E-02	3.38E-05	2.04E-05	1.01E-06
Po216	6.906	4.09E-02	2.71E+01	7.36E-02	1.11E+00	3.01E-03	8.34E-04	8.97E-05
Po218	6.113	3.62E-02	1.16E+01	3.58E-05	4.20E-01	1.30E-06	3.16E-04	3.86E-08
Pr144	1.240	7.35E-03	6.18E-02	5.07E+00	4.54E-04	3.73E-02	3.42E-07	1.11E-03
Pu236	5.871	3.48E-02	1.04E-02	NR	3.62E-04	--	2.72E-07	--

Table 7 Continue. Disposal Radionuclide Inventory

Nuclide			WIPP TRU Waste					
ID	Energy		Total Inventory [Curies] (b)		Heat Load [Watts] (c)		% Heat Load [%]	
	$\frac{MeV}{dis}$ (a)	$\frac{W}{Ci}$	CH	RH	CH	RH	CH	RH
Pu238	5.591	3.31E-02	**2.61E+06** (e)	1.45E+03	**8.65E+04** (g)	4.81E+01	**6.50E+01** (g)	1.43E+00
Pu239	5.199	3.08E-02	7.85E+05	1.03E+04	2.42E+04	3.17E+02	1.82E+01	9.45E+00
Pu240	5.253	3.11E-02	2.10E+05	5.07E+03	6.54E+03	1.58E+02	4.92E+00	4.70E+00
Pu241	0.005	3.10E-05	2.31E+06	1.42E+05	7.16E+01	4.40E+00	5.38E-02	1.31E-01
Pu242	4.982	2.95E-02	1.17E+03	1.50E-01	3.46E+01	4.43E-03	2.60E-02	1.32E-04
Pu243	0.195	1.15E-03	3.21E-09	NR	3.70E-12	--	2.79E-15	--
Pu244	4.892	2.90E-02	1.50E-06	2.21E-11	4.35E-08	6.41E-13	3.27E-11	1.91E-14
Ra223	6.007	3.56E-02	6.09E-01	7.58E-04	2.17E-02	2.70E-05	1.63E-05	8.03E-07
Ra224	5.790	3.43E-02	2.71E+01	7.36E-02	9.30E-01	2.53E-03	6.99E-04	7.52E-05
Ra225	0.118	7.01E-04	2.88E+00	1.17E-01	2.02E-03	8.20E-05	1.52E-06	2.44E-06
Ra226	4.871	2.89E-02	1.16E+01	3.58E-05	3.35E-01	1.03E-06	2.52E-04	3.08E-08
Ra228	0.013	7.71E-05	7.47E-01	7.77E-02	5.76E-05	5.99E-06	4.33E-08	1.78E-07
Rh106	1.618	9.59E-03	2.90E-02	1.09E+01	2.78E-04	1.05E-01	2.09E-07	3.11E-03
Rn219	7.000	4.15E-02	6.09E-01	7.58E-04	2.53E-02	3.15E-05	1.90E-05	9.36E-07
Rn220	6.405	3.80E-02	2.71E+01	7.36E-02	1.03E+00	2.79E-03	7.74E-04	8.32E-05
Rn222	5.590	3.31E-02	1.16E+01	3.58E-05	3.84E-01	1.19E-06	2.89E-04	3.53E-08
Ru106	0.010	5.95E-05	2.90E-02	1.09E+01	1.72E-06	6.48E-04	1.30E-09	1.93E-05
Sb125	0.527	3.13E-03	1.21E-01	1.89E+00	3.78E-04	5.91E-03	2.84E-07	1.76E-04
Sb126	3.117	1.85E-02	1.35E-04	3.16E-05	2.49E-06	5.84E-07	1.88E-09	1.74E-08
Sb126m	2.148	1.27E-02	9.65E-04	2.25E-04	1.23E-05	2.86E-06	9.24E-09	8.53E-08
Se79	0.042	2.49E-04	4.35E-04	1.02E-04	1.08E-07	2.54E-08	8.14E-11	7.56E-10
Sm151	0.020	1.17E-04	1.47E+00	3.57E-01	1.72E-04	4.19E-05	1.30E-07	1.25E-06
Sn119m	0.087	5.17E-04	4.14E-06	9.59E-07	2.14E-09	4.96E-10	1.61E-12	1.48E-11
Sn121m	0.338	2.00E-03	2.66E-02	6.69E-03	5.33E-05	1.34E-05	4.01E-08	3.99E-07
Sn126	0.210	1.25E-03	9.65E-04	2.25E-04	1.20E-06	2.81E-07	9.05E-10	8.35E-09
Sr89†	0.583	3.46E-03	NR	NR	--	--	--	--
Sr90	0.196	1.16E-03	6.85E+03	2.09E+05	7.95E+00	2.43E+02	5.98E-03	7.22E+00
Ta182	1.502	8.90E-03	NR	4.21E-08	--	3.75E-10	--	1.12E-11
Tc99	0.085	5.01E-04	2.52E+01	5.85E-03	1.26E-02	2.93E-06	9.50E-06	8.73E-08
Te125m	0.142	8.41E-04	2.95E-02	4.65E-01	2.48E-05	3.91E-04	1.86E-08	1.16E-05
Te127	0.228	1.35E-03	1.30E-07	1.71E-09	1.76E-10	2.31E-12	1.32E-13	6.87E-14
Te127m	0.091	5.38E-04	1.33E-07	1.75E-09	7.15E-11	9.41E-13	5.38E-14	2.80E-14
Th227	6.157	3.65E-02	6.01E-01	7.47E-04	2.19E-02	2.73E-05	1.65E-05	8.11E-07
Th228	5.517	3.27E-02	2.71E+01	7.36E-02	8.86E-01	2.41E-03	6.66E-04	7.16E-05
Th229	5.161	3.06E-02	2.88E+00	1.17E-01	8.81E-02	3.58E-03	6.62E-05	1.07E-04
Th230	4.774	2.83E-02	8.06E-02	7.56E-03	2.28E-03	2.14E-04	1.71E-06	6.37E-06
Th231	0.095	5.61E-04	1.28E+01	4.63E+00	7.18E-03	2.60E-03	5.40E-06	7.73E-05
Th232	4.084	2.42E-02	9.13E-01	9.25E-02	2.21E-02	2.24E-03	1.66E-05	6.66E-05
Th234	0.068	4.05E-04	3.96E+01	1.05E+01	1.61E-02	4.26E-03	1.21E-05	1.27E-04
Tl207	0.495	2.94E-03	6.07E-01	7.56E-04	1.78E-03	2.22E-06	1.34E-06	6.61E-08
Tl208	3.970	2.35E-02	9.73E+00	2.65E-02	2.29E-01	6.24E-04	1.72E-04	1.86E-05

Table 7 Continue. Disposal Radionuclide Inventory

Nuclide			WIPP TRU Waste					
ID	Energy		Total Inventory [Curies] (b)		Heat Load [Watts] (c)		% Heat Load [%]	
	$\frac{MeV}{dis}$ (a)	$\frac{W}{Ci}$	CH	RH	CH	RH	CH	RH
Tl209	2.803	1.66E-02	6.22E-02	2.53E-03	1.03E-03	4.20E-05	7.77E-07	1.25E-06
U232	5.416	3.21E-02	2.58E+01	NR	8.28E-01	--	6.23E-04	--
U233	4.904	2.91E-02	1.79E+03	1.58E+02	5.20E+01	4.59E+00	3.91E-02	1.37E-01
U234	4.859	2.88E-02	4.65E+02	4.27E+01	1.34E+01	1.23E+00	1.01E-02	3.66E-02
U235	4.418	2.62E-02	1.28E+01	4.63E+00	3.35E-01	1.21E-01	2.52E-04	3.61E-03
U236	4.570	2.71E-02	3.33E-01	9.68E-02	9.02E-03	2.62E-03	6.78E-06	7.80E-05
U237	0.319	1.89E-03	5.66E+01	3.48E+00	1.07E-01	6.58E-03	8.05E-05	1.96E-04
U238	4.279	2.54E-02	3.96E+01	1.05E+01	1.00E+00	2.66E-01	7.55E-04	7.93E-03
U240	0.138	8.20E-04	1.50E-06	2.21E-11	1.23E-09	1.81E-14	9.25E-13	5.40E-16
Y90	0.935	5.54E-03	6.85E+03	2.09E+05	3.80E+01	**1.16E+03** (h)	2.85E-02	**3.45E+01** (h)
Zn65†	0.590	3.50E-03	NR	NR	--	--	--	--
Zr93	0.020	1.16E-04	5.63E-03	1.32E-03	6.54E-07	1.53E-07	4.92E-10	4.56E-09
Zr95	0.855	5.07E-03	1.15E-09	3.02E-01	5.83E-12	1.53E-03	4.38E-15	4.55E-05
Sum=			**6.42E+06** (i)	**1.02E+06** (j)	**1.33E+05** (k)	**3.36E+03** (l)	1.00E+02	1.00E+02

-- Not calculated.

NR Not Reported by sites (see Ref. CCA-2).

† Data values for radionuclides were previously reported in Rev. 2 of TWBIR (Ref. BIR-2).

(a) Data from Ref OR-1.

(b) Radionuclide inventory information taken from Transuranic Waste Baseline Inventory Database (TWBID), Ref. CCA-2. (in total, 135 radionuclides are inventoried in the TWBID) Values correspond to a "WIPP-Scale" design basis.

(c) Data calculated from the equation;

$$\text{Heat Load} = TOTAL\ ACTIVITY(Ci)\frac{3.7E+10(dis/sec)}{Ci}\ ENERGY(MeV/dis)\ \frac{E+06\,eV}{MeV}\ \frac{1.60219E-19\,J}{eV}\ \frac{watt-sec}{J}$$

$$\text{Heat Load (watts)} = 0.005928103 \times TOTAL\ ACTIVITY(Ci) \times ENERGY(MeV/dis)$$

(e) Isotope with dominate curie load for CH-TRU wastes.

(f) Isotope with dominate curie load for RH-TRU wastes.

(g) Isotope with dominate heat load for CH-TRU wastes.

(h) Isotope with dominate heat load for RH-TRU wastes.

(i) Note, the total CH-TRU curie load is 6.42 MCi (also, 86.3 % of the total curie load in WIPP). The average CH-TRU volumetric total curie load is 6.42E+06/5.95E+06 = 1.079 (Ci/cu. ft.) = **38.10 (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- CH→5.95E+06 cu. ft. Also note that the 5.95E+06 volume number is a volume limit, stored waste and projected waste volumes sum up to a volume less than this volume. The summed up volume is then "scaled" to yield a total volume of 5.95E+06, likewise the curie loads are also "scaled" by the same factor. Thus ratios of curie loads (or heat loads) to volume yield values applicable to expected waste at WIPP (See Ref. BIR-2d).]

(j) Note, the total RH-TRU curie load is only 1.02 MCi (also, 13.7 % of the total curie load in WIPP). This curie load is much less than the RH-TRU limit of 5.1 MCi [Ref. LWA-1]. The average RH-TRU volumetric total curie load is 1.02E+06/0.25E+06 = 4.08 (Ci/cu. ft.) = **144.1 (Ci/cu. m.)**. [See discussion note on Ref. LWA-1 for volumes -- RH→0.25E+06 cu. ft.]

(k) Note, the total CH-TRU heat load is only **133. kW** (also, 97.5 % of the total heat load in WIPP). The ratio for CH-TRU of total heat load to total curie load is 133.E+03/6.42E+06 = **0.0207 W/Ci**. The average CH-TRU volumetric heat load is 133.E+03/5.95E+06 = 0.0224 (W/cu. ft.) = 0.7894 (W/cu. m.). The average CH-TRU drum heat load is 0.7894 (W/cu. m.)x 0.2082 (cu. m.) = **0.1644 W**. [The volume of a CH-TRU drum was set equal to the nominal volume of a 55-gal drum.]

(l) Note, the total RH-TRU heat load is only **3.36 kW** (also, 2.5 % of the total heat load in WIPP). The ratio for RH-TRU of total heat load to total curie load is 3.36E+03/1.02E+06 = **0.003294 W/Ci**. The average RH-TRU volumetric heat load is 3.36E+03/0.25E+06 = 0.0134 (W/cu. ft.) = 0.47 (W/cu. m.). The average RH-TRU canister heat load is 0.47 (W/cu. m.)x 0.6246 (cu. m.) = **0.2964 W** (this is about two times that of an average CH-TRU drum). [The volume of a RH-TRU canister was set equal to three times the nominal volume of a 55-gal drum. Even though the reported volume of a RH-TRU canister is 0.89 cu. m. (Ref. BIR-2e), these canisters are loaded with three 55-gal drums internally. Ref. DOE-1.]

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.3

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WPO 35202

INFORMATION ONLY

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: 3/15/96

to: Christine T. Stockman, MS-1328

from: James W. Garner, MS-1328

subject: Radioisotopes to be used in the 1996 CCA Calculations

The following 29 isotopes are the ones of interest from the BIR Report. They are as follows:

^{241}Am, ^{243}Am, ^{252}Cf, ^{243}Cm, ^{244}Cm, ^{245}Cm, ^{248}Cm, ^{137}Cs, ^{237}Np, ^{231}Pa, ^{210}Pb, ^{147}Pm, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{244}Pu, ^{226}Ra, ^{228}Ra, ^{90}Sr, ^{229}Th, ^{230}Th, ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U. ^{14}C is not included because of its small inventory and a large inventory of other forms of carbon.

There were chosen for their inventory content and CFR191 importance values.
All of these isotopes can be used in the codes that evaluate the direct releases from Cuttings, Spalling, and Blowout.

For the codes that compute the indirect releases (i.e., NUTS, CCDFGF and SECOTP), we need a shorter list in order to maintain a reasonable calculation burden.

^{241}Am, ^{243}Am, ^{245}Cm, ^{137}Cs, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{226}Ra, ^{90}Sr, ^{229}Th, ^{230}Th, ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U are selected because they all have an EPA normalized release greater than .01. This is still a large (19) number of isotopes to transport.

To further reduce the number of isotopes to transport, let us look at uranium. From a EPA normalized perspective, ^{233}U and ^{234}U are a factor of $10^{1.5}$ to 10^{2} higher than the other uranium isotopes. We could drop ^{235}U, ^{236}U, and ^{238}U without any impact on the final EPA normalized release. Since the inventory in moles of ^{233}U and ^{234}U is less than one percent of the uranium inventory, we can reduce the solubility of uranium by a factor of 100. Furthermore, we can combine ^{233}U and ^{234}U into ^{234}U, since their half-lives are similar. Likewise, with thorium we can combine ^{229}Th and ^{230}Th into ^{230}Th and reduce the solubility by a factor of 1000 and drop ^{232}Th. With plutonium, we can combine ^{239}Pu, ^{240}Pu, and ^{242}Pu into ^{239}Pu and we can also combine ^{90}Sr and ^{137}Cs into ^{90}Sr because of similar half-lives and transport properties.

This will leave us with the following ten isotopes:
^{241}Am, ^{243}Am, ^{245}Cm, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{226}Ra, ^{90}Sr, ^{230}Th, ^{234}U.
At late times, we can drop ^{90}Sr and ^{238}Pu because of their short half-lives.

To define late times for ^{90}Sr, we can look at the plots and determine when the EPA releases drop below .1. This is about 300 years. For ^{238}Pu, we can define late times as when the ratio of ^{238}Pu to ^{239}Pu is less than .01. This is about 800 years.

We can rank these isotopes in order of EPA normalized release.

all times:

1) ^{239}Pu releases from 2000 to 1000
2) ^{241}Am releases from 1000 to .1
3) ^{234}U releases from 7 to 8
4) ^{230}Th releases from .06 to 5.0
5) ^{237}Np releases from .1 to .3
6) ^{245}Cm releases from .2 to .1
7) ^{226}Ra releases from .02 to .2
8) ^{243}Am releases from .06 to .025

early times only:

1) ^{238}Pu from 3000 to 100@800yr
2) ^{90}Sr from 8 to .07@300 yr

It then appears that we only need to transport ^{239}Pu, ^{241}Am, ^{234}U, and ^{230}Th. Any realizations that are close to the regulatory limit can be re-computed with the ten isotopes listed above. This scheme can be verified by a duplicate run using the 19 isotopes listed above.

If a further reduction in the number of radioisotopes in needed to reduce calculation time, we could also eliminate ^{234}U and ^{230}Th. This elimination should only be done as a last resort.

cc:
MS-1320 Richard V. Bynum
MS-1320 E. James Novak
MS-1328 Mert E. Fewell
MS-1328 Jon C. Helton
MS-1328 James L. Ramsey
MS-1328 Ali A. Shinta
MS-1335 Margaret S. Y. Chu
MS-1341 Larry H. Brush
MS-1343 Ruth F. Weiner
MS-1395 Mel G. Marietta
...
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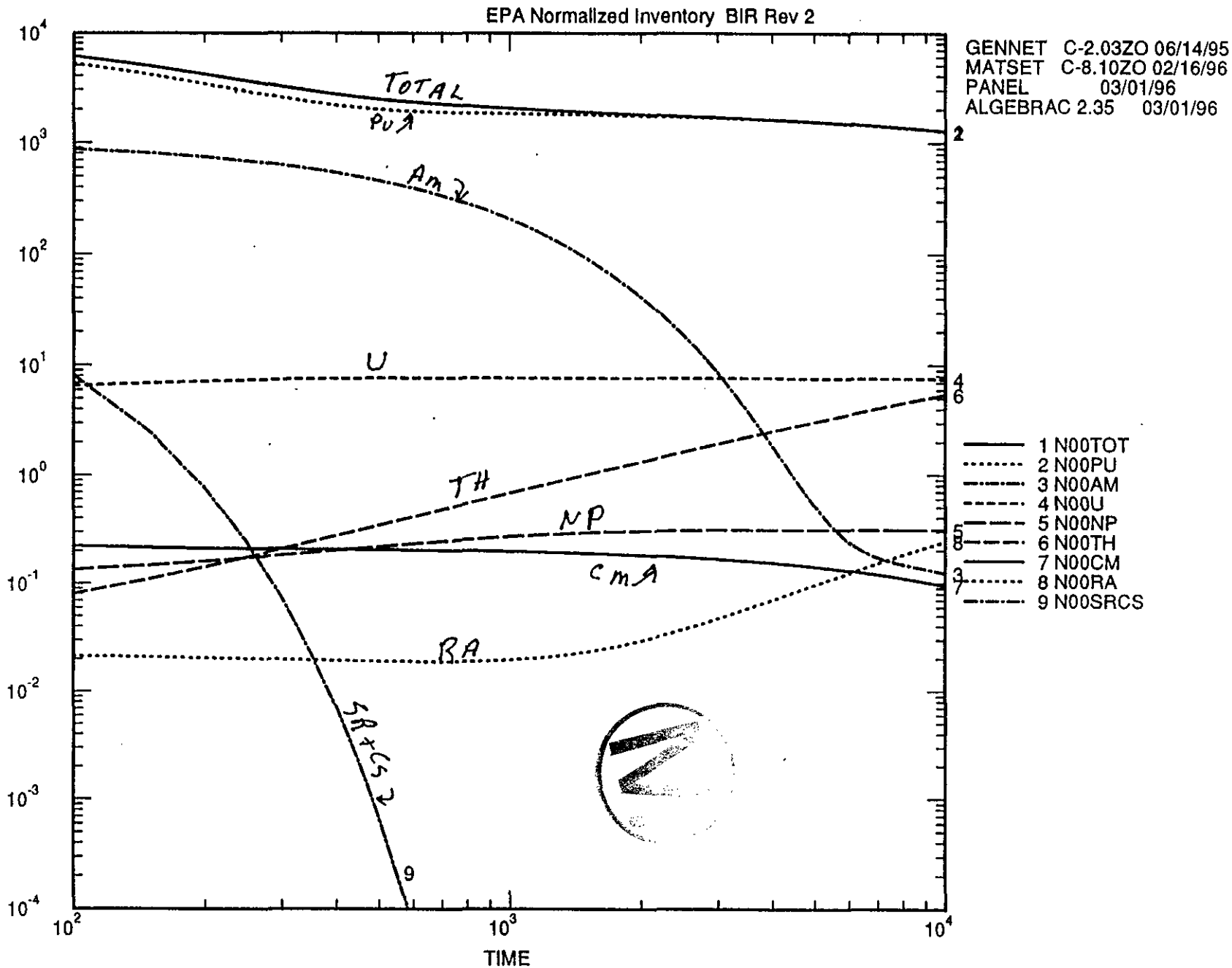

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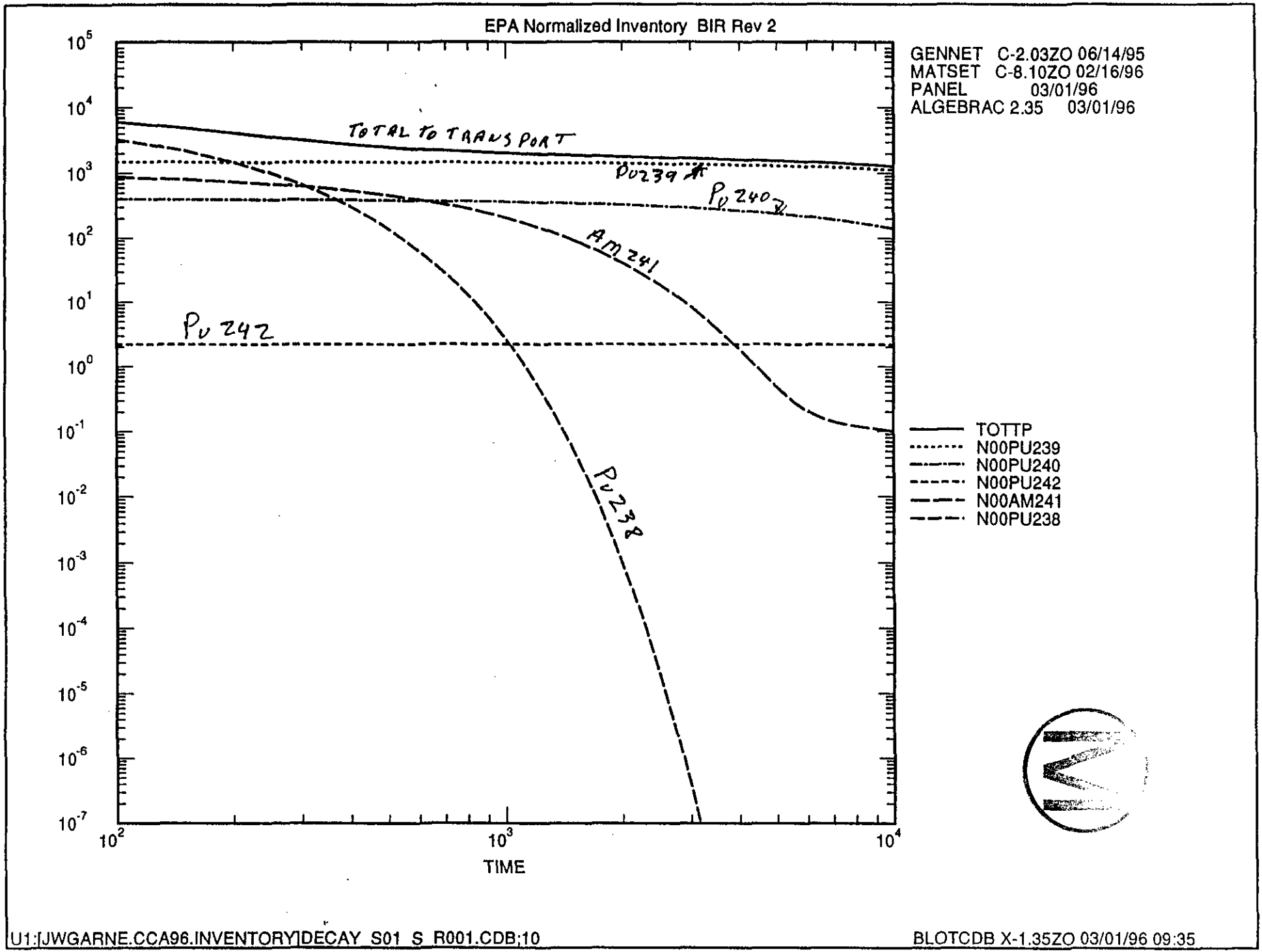
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MATSET C-8.10ZO 02/16/96
PANEL 03/01/96
ALGEBRAC 2.35 03/01/96
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PU242
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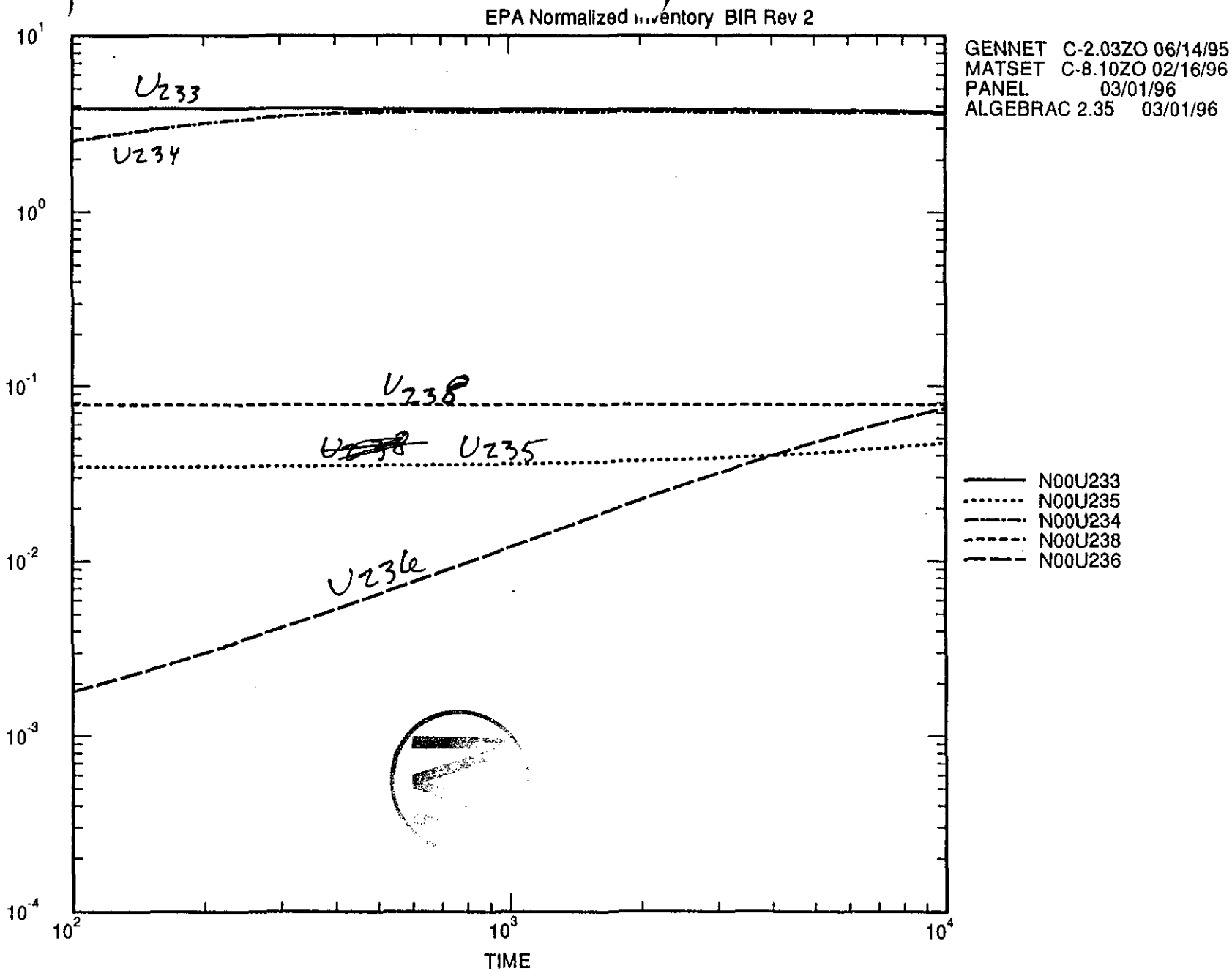

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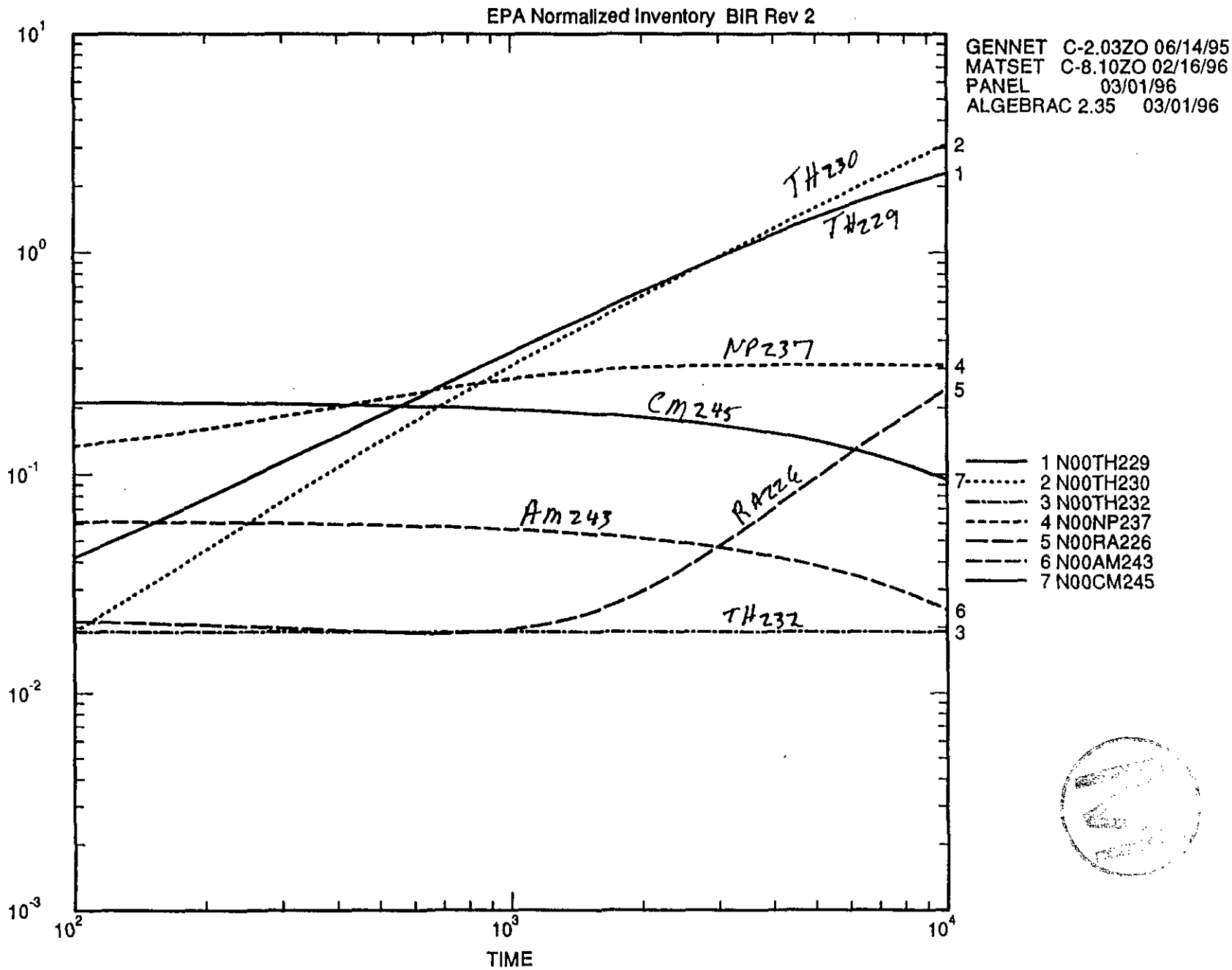

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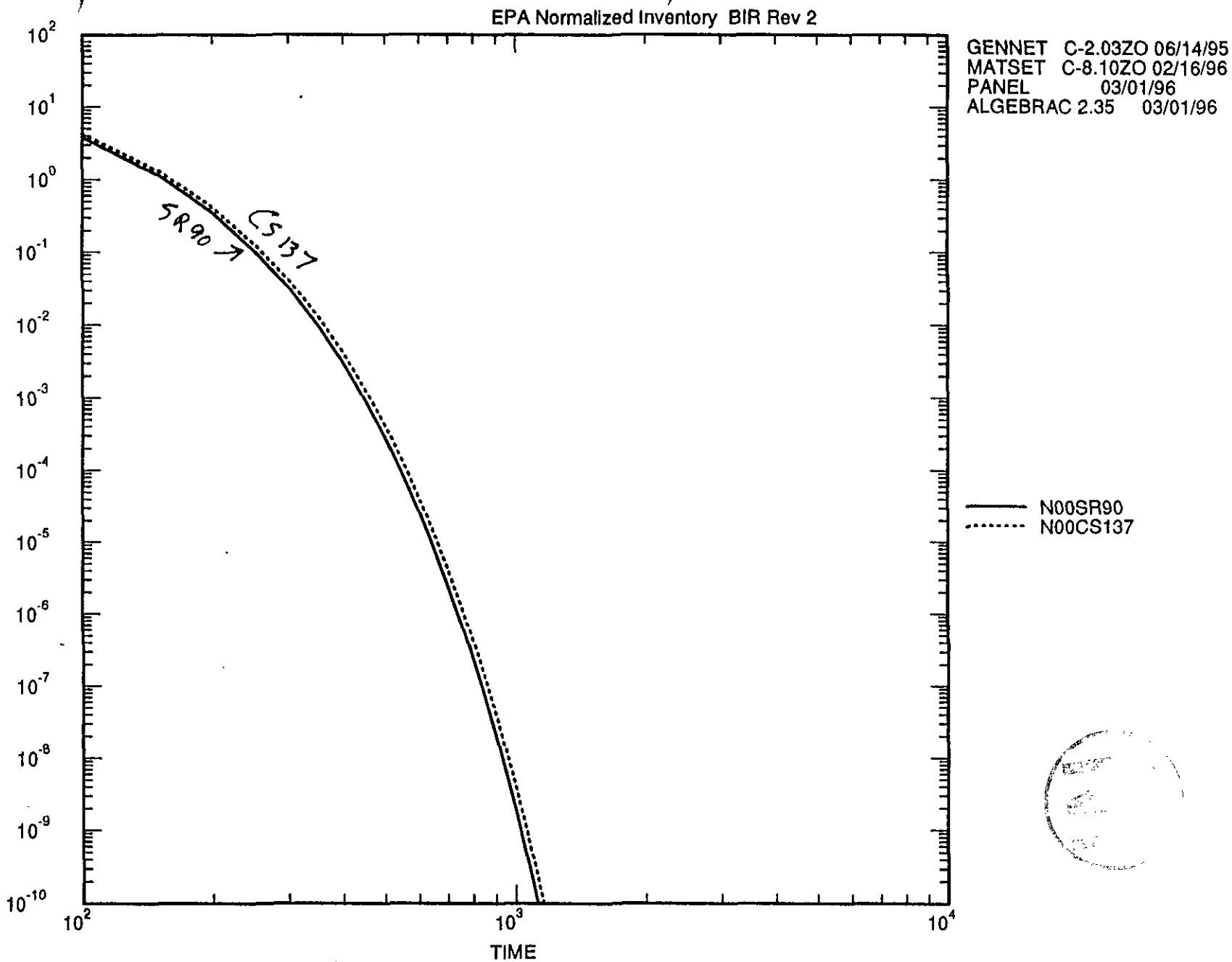

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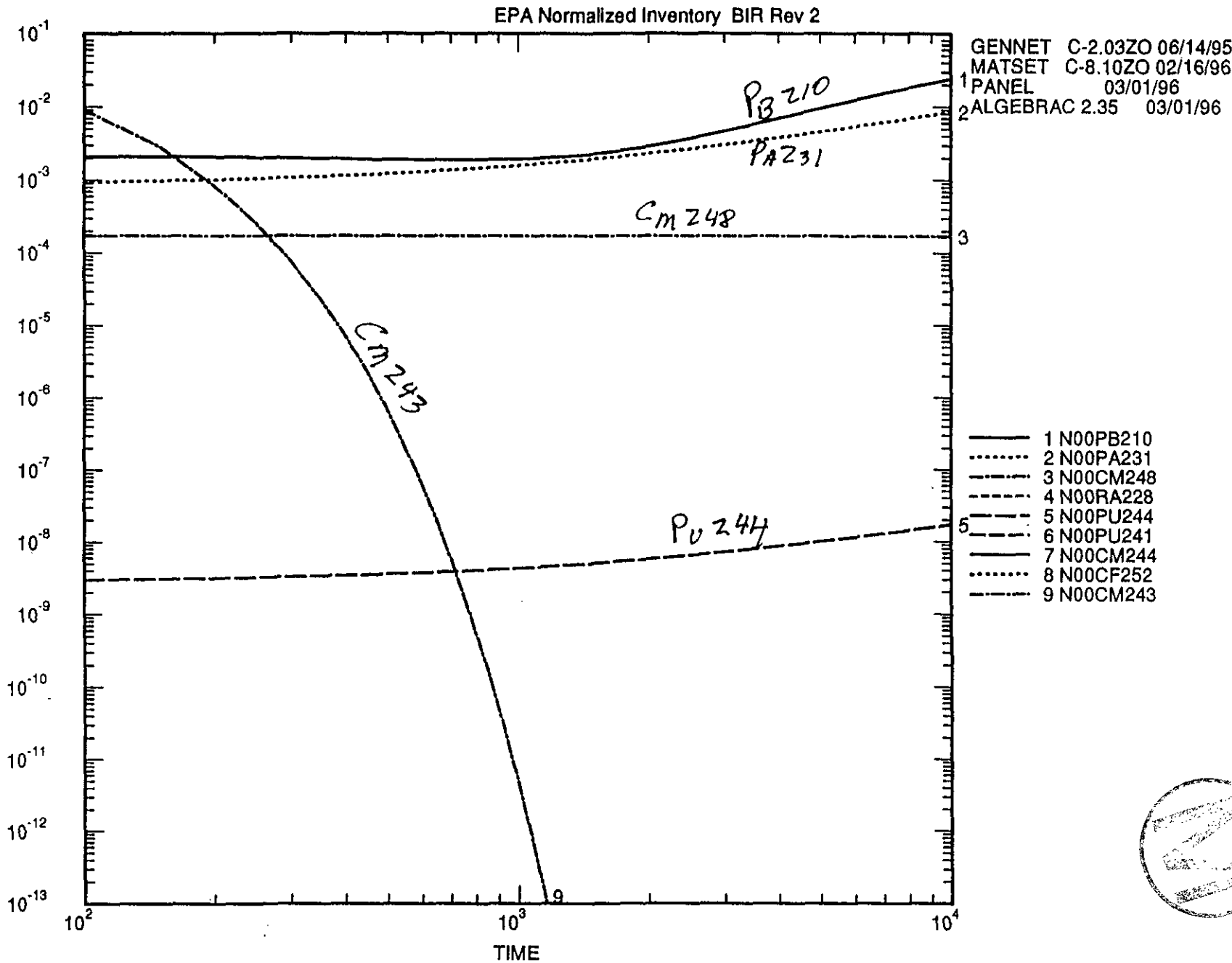

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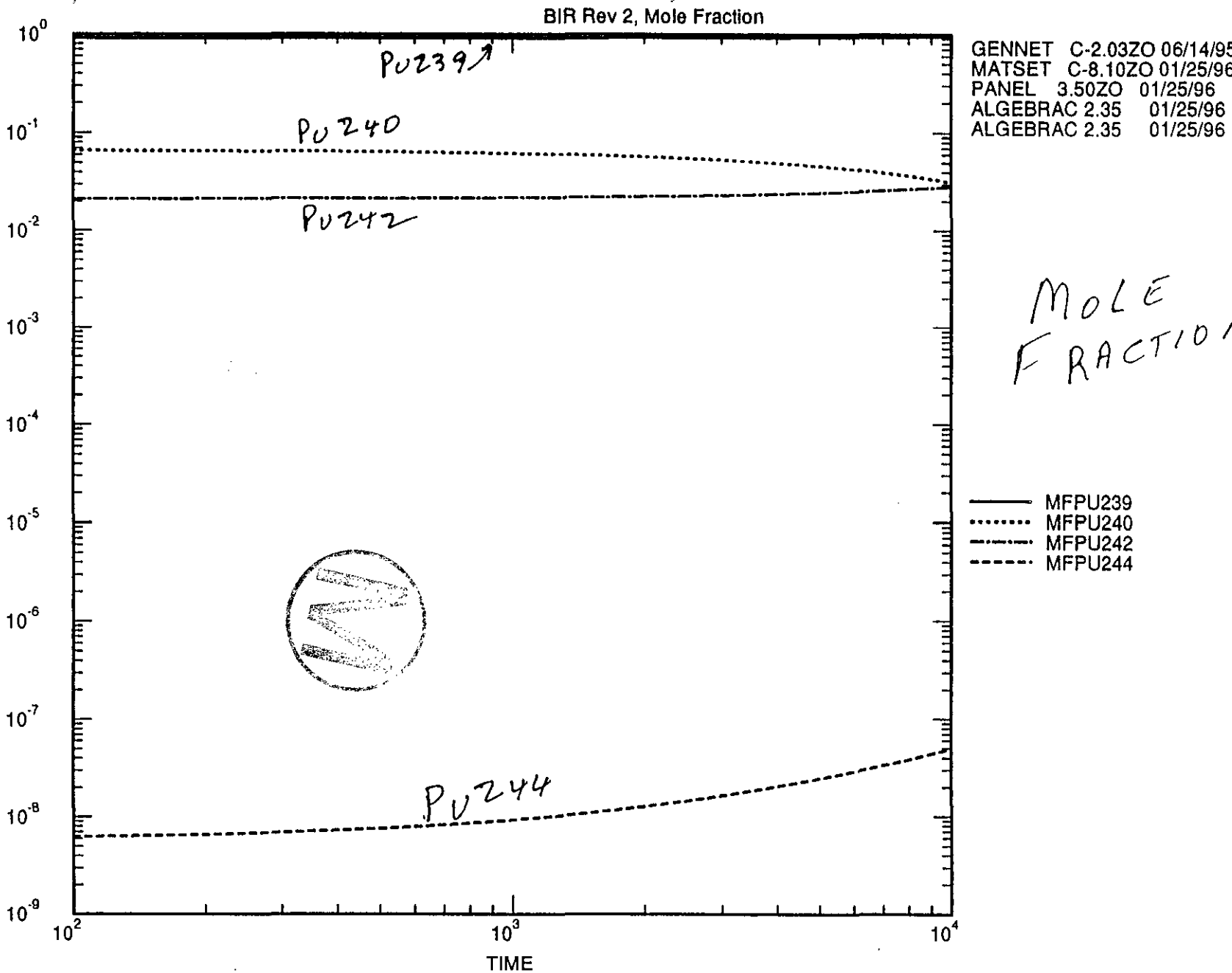

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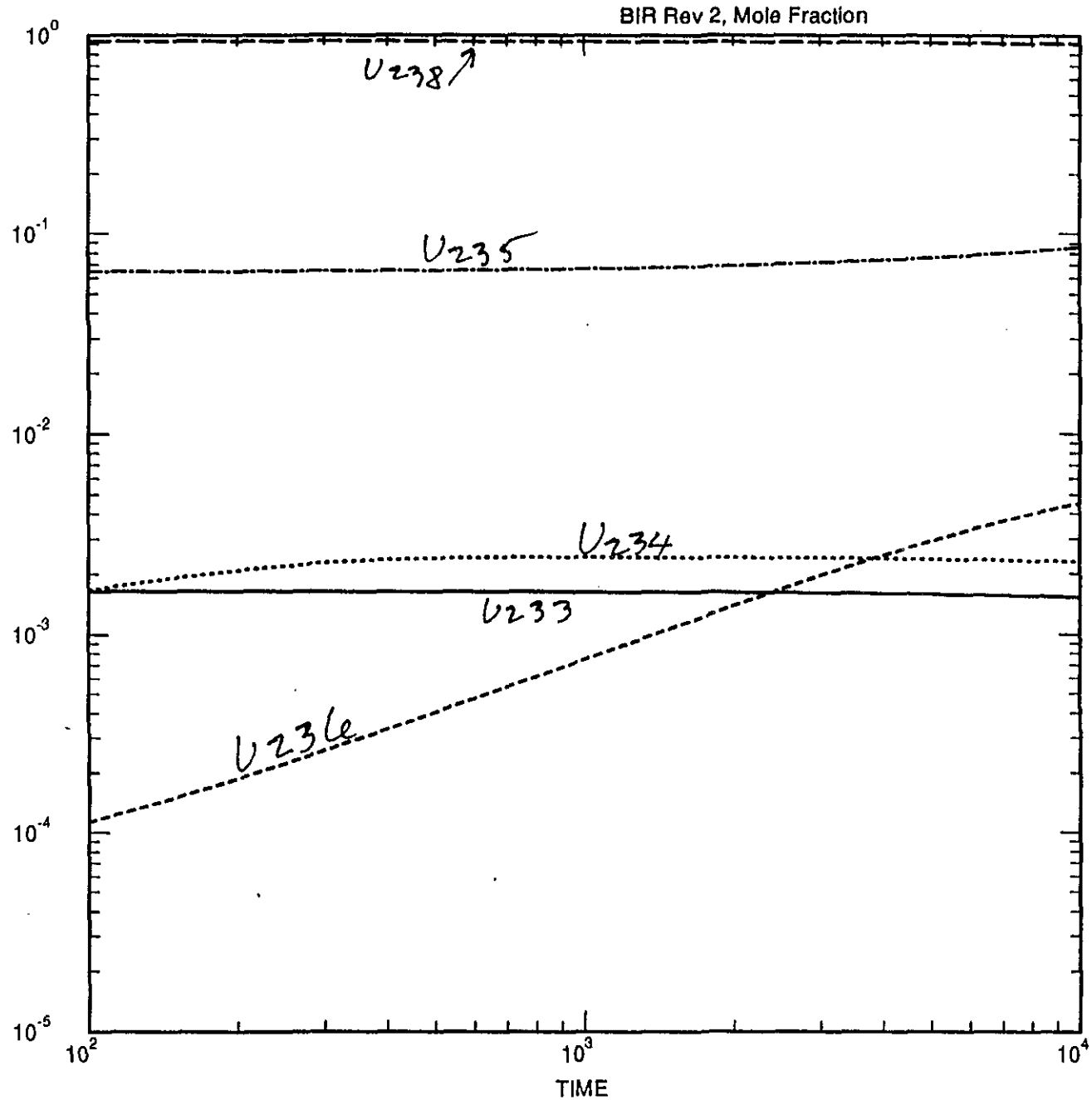

MOLE FRACTION

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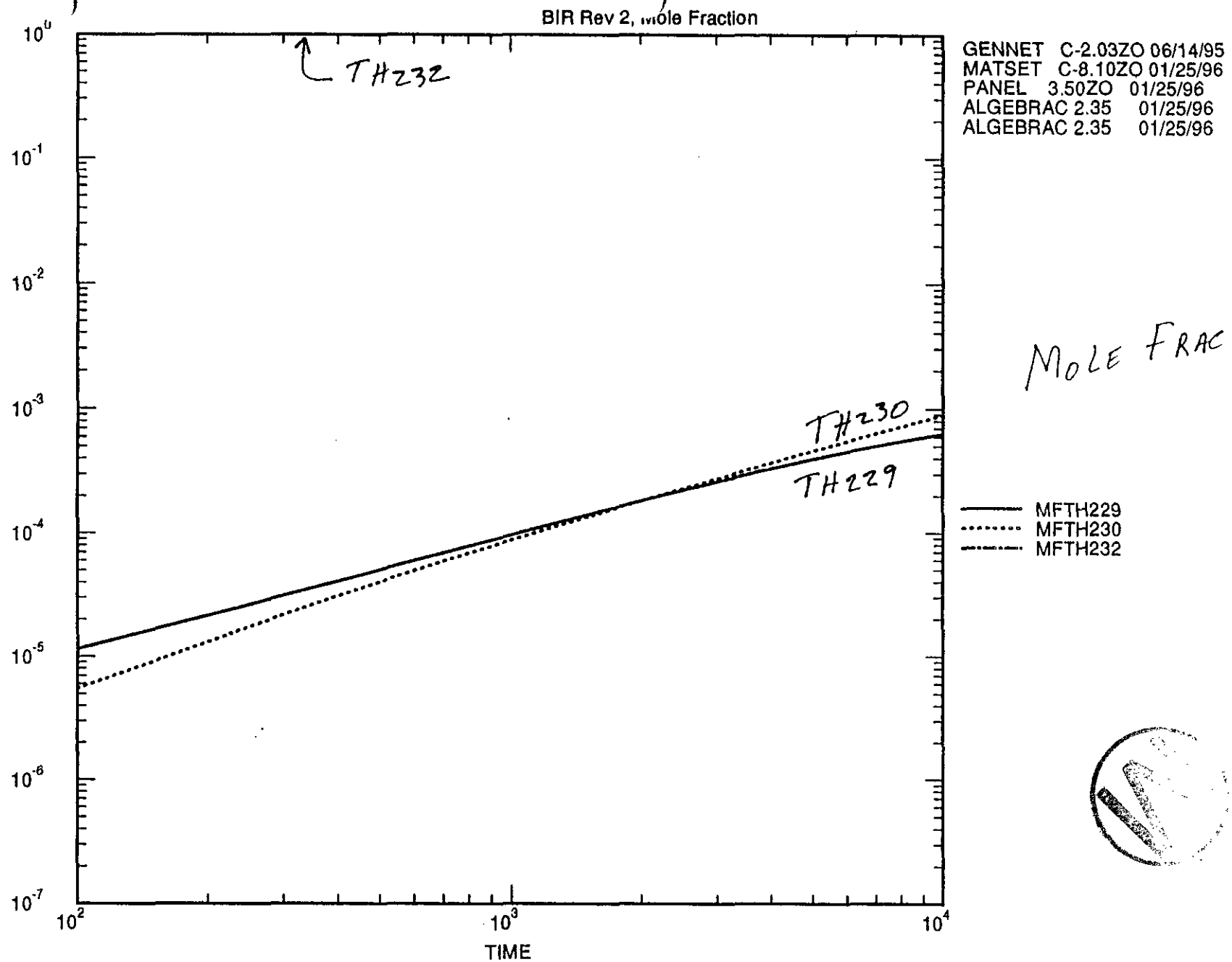

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Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.4

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Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 29 March 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters

This memorandum summarizes best estimates for the mobile colloidal actinide source term for input to the WIPP Compliance Certification Application. The use of material and parameter identification codes is consistent with your letter to me dated 29 March 1996 requesting parameter values. In the attached table, I have provided best estimates for the following material-parameter combinations:

IDMTRL: Th, U, Np, Pu, Am

IDPRAM:

CONCINT	concentration of actinide associated with mobile actinide intrinsic colloids
CONCMIN	concentration of actinide associated with mobile mineral fragment colloids
CAPHUM	maximum concentration of actinide associated with mobile humic colloids
CAPMIC	maximum concentration of actinide associated with mobile microbes
PROPHUM	proportionality constant for concentration of actinides associated with mobile humic colloids
PROPMIC	proportionality constant for concentration of actinides associated with mobile microbes

As a first approximation, the colloidal behavior of curium can be simulated be using parameter values for americium. The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CONCMIN	Th	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
CONCMIN	U	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
CONCMIN	Np	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
CONCMIN	Pu	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
CONCMIN	Am	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
PROPHUM	Th	6.4e+00	6.4e+00	6.4e+00	moles colloidal humic-bound Th per moles dissolved Th	constant	2,3
PROPHUM	U	1.4e+00	1.6e-01	2.0e+00	moles colloidal humic-bound U per moles dissolved U	triangular	2,3,4
PROPHUM	Np	4.0e+00	4.0e+00	4.0e+00	moles colloidal humic-bound Np per moles dissolved Np	constant	2,3
PROPHUM	Pu	5.9e+00	5.9e+00	5.9e+00	moles colloidal humic-bound Pu per moles dissolved Pu	constant	2,3
PROPHUM	Am	2.5e+00	1.9e-01	3.9e+00	moles colloidal humic-bound Am per moles dissolved Am	triangular	2,3,4

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

WCA Attachment WCA.8.5

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WPO # 35852

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 7 May 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Parameter Record Package for Colloidal Actinide Source Term Parameters

Attached is the Parameter Record Package for the WIPP PA parameters describing actinide concentrations associated with mobile **actinide intrinsic colloids**. This Package is one of four describing the concentration of actinides associated with the four colloidal particle types. The complete set of Packages consists of the following:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

copy with Attachments to:

MS 1320	Hans W. Papenguth, 6748
MS 1320	W. George Perkins, 6748
DOE/CAO	Robert A. Stroud

SWCF-A:WBS 1.1.10.2.1: Colloid Characterization and Transport.
SWCF-A:WPO# 35852: Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids

copy without Attachments to:

MS 1320	E. James Nowak, 6831
MS 1324	Susan A. Howarth, 6115
MS 1328	Hong-Nian Jow, 6741
MS 1328	Amy S. Johnson, 6741
MS 1328	Martin S. Tierney, 6741
MS 1328	Mary-Alena Martell, 6749
MS 1341	John T. Holmes, 6748

Parameter Record Package for Mobile-Colloidal Actinide Source Term.
Part 2. Actinide Intrinsic Colloids

The parameter values in this package are based on data which were collected under the guidance of the Principal Investigator for the Waste Isolation Pilot Plant (WIPP) Colloid Research Program, Hans W. Papenguth, for input to the WIPP Data Entry Form and for use in WIPP Performance Assessment (PA) calculations.

I. *Parameter No. (id):* Not applicable.

II. *Data/Parameter:* Not applicable.

III. *Parameter id (idpram):* CONCINT.

IV. *Material:* Intrinsic colloids of actinides Th, U, Np, Pu, and Am.

V. *Material Identification (idmtrl):* Th, U, Np, Pu, and Am.

VI. *Units:* Concentrations of actinide intrinsic colloids (CONCINT) are in units of "moles colloidal actinide per liter of dispersion."

VII. *Distribution Information.*

A. *Category:* The development of parameter values and their distributions is described in Attachment A. Summaries of the parameter values are presented in Attachments C, E, and F. Constant CONCINT values are supplied for all five actinide elements listed above.

B. *Mean:* See Attachments A, C, E, and F.

C. *Median:* Not applicable.

D. *Standard Deviation:* Not applicable.

E. *Maximum:* See Attachments A, C, E, and F.

F. *Minimum:* See Attachments A, C, E, and F.

G. *Number of data points:* Not applicable.

VIII. *Data Collection and Interpretation Information.*

A. *Data Source Information:* WIPP observational data and literature.

B. *Data Collection (for WIPP observational data).*

1. *Data Collection or Test Method:* Experiments were conducted at Lawrence Livermore National Laboratory (LLNL; contract number AG-4965; Cynthia E. A. Palmer, LLNL PI). Descriptions of experiments conducted at LLNL are included in Attachment A.

2. *Assumptions Made During Testing:* See Attachment A.

3. *Standard Error of Measurement of Tests Performed:* See Attachment A.

4. *Form of Raw Data:* Data on actinide concentration associated with actinide intrinsic colloids is reported in molarity.

5. *References Related to Data Collection:* See Attachment A.

6. *QA Status of Data:*

   a. *Are all of the data qualified?* Yes.

   b. *Were data qualified by QAP 20-3?* No. Data packages will be submitted for work conducted at LLNL (see VIII,B,1 above for contract numbers), under File code WBS 1.1.10.2.1.

   c. *Were the data the subject of audit/surveillance by SNL or DOE?* Yes. LLNL (contract number AG-4965) was audited twice by SNL (94-04; EA95-13). DOE/CAO conducted a surveillance (S-96-08). LLNL is scheduled to be audited by SNL (EA96-22) in May 1996.

   d. *Were the data collected under an SNL approved QA program?* Yes. Data were collected under SNL WIPP QAPD, Rev. P, effective October 1, 1992, and SNL WIPP QAPD, Rev. R, effective July 31, 1995. LLNL conducted work under an approved QAPP prepared especially for their program (WIPP Actinide Source Term Test Program Quality Assurance Program Plan (LLNL WIPP-LLNL-NCD-ETG-CS-QAPP, Rev. 0-CN1). Data were collected under a test plan for the WIPP Colloid Research Program (Papenguth and Behl, 1996). Detailed descriptions of the experiments and interpretation listed herein will be published in a SAND report. Documents related to data collection at LLNL will be archived in the Sandia WIPP Central Files (SWCF; File code WBS 1.1.10.2.1).

C. *Interpretation of Data.*

1. *Was the interpretation made by reference to previous work.* No.

2. *Was the interpretation made by using newly performed calculations?* Yes.

3. *Form of Interpreted Data.* List of interpreted values.

4. *Assumptions Made During Interpretation.* See Attachment A.

5. *Name of Code(s)/Software used to Interpret Data:* Not applicable.

6. *QA Status of Code(s) used to Interpret Data:* Not applicable.

   a. *Was the code qualified under QAP 19-1?* Not applicable.

   b. *Was the code qualified under QAP 9-1?* Not applicable.

7. *References Related to Data Interpretation:* See XI below and Attachment A.

8. *For interpretations made by using a newly performed calculations provide documentation that you followed the requirements of QAP 9-1 Appendix B.* The data analysis is controlled by Analysis Plan for the Colloid Research Program, AP-004 (Behl and Papenguth, 1996).

9. *For routine calculations (not using code) did you follow requirements of QAP 9-5?* Yes.

IX. *Correlation with other Parameters:* None.

X. *Limitations or qualifications for usage of data by Performance Assessment (PA):* None.

XI. *References cited above:*

Behl, Y.K., and Papenguth, H.W., 1996, Analysis Plan for the WIPP Colloid Research Program WBS #1.1.10.2.1, SNL Analysis Plan AP-004.

Papenguth, H.W., and Behl, Y.K., 1996, Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant, SNL Test Plan TP 96-01.

XII. *Attachments:*

Attachment A: Papenguth, Hans W., 1996, Rationale for Definition of Parameter Values for Actinide Intrinsic Colloids.

Attachment B: Stockman, Christine T., 1996, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 29 March 1996 to Hans W. Papenguth.

Attachment C: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters. SNL Technical Memorandum dated 29 March 1996 to Christine T. Stockman.

Attachment D: Stockman, Christine T., 1996, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 2 April 1996 to Hans W. Papenguth.

Attachment E: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL Technical Memorandum dated 18 April 1996 to Christine T. Stockman.

Attachment F: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 2. SNL Technical Memorandum dated 22 April 1996 to Christine T. Stockman.

XIII. *Distribution*

SWCF-A:WPO# 35852: Mobile-Colloidal Actinide Source Term. 2. Actinide Intrinsic Colloids.

SWCF-A:WBS 1.1.10.2.1: Colloid Characterization and Transport.

Attachment A:

Papenguth, Hans W., 1996, Rationale for Definition of Parameter Values for Actinide Intrinsic Colloids.

Attachment A.
Rationale for Definition of Parameter Values for Actinide Intrinsic Colloids

Hans W. Papenguth

Introduction

The actinide source term at the WIPP is defined as the sum of contributions from dissolved actinide species and mobile colloidal actinide species. The dissolved actinide source term has been defined elsewhere (Novak, 1996; Novak and Moore, 1996; Siegel, 1996). It is important to note that colloidal actinides which are not suspended in the aqueous phase (i.e., not mobile) are not included in the colloidal actinide source term. Colloidal actinides may become immobilized by several mechanisms, including precipitation followed by coagulation and gravitational settling (humic substances and actinide intrinsic colloids), adhesion to fixed substrates (microbes), and flocculation or coagulation of colloidal particles followed by gravitational settling (mineral fragments). Sorption of colloidal actinides onto fixed substrates will also reduce the mobile colloidal actinide source term, but no credit is currently being taken for reduction by that means.

To facilitate quantification of the colloidal actinide source term, as well as an efficient experimental approach, the source term has been divided into four components according to colloid types. On the basis of (1) the behavior of colloidal particles in high ionic strength electrolytes, (2) the way in which colloidal particles interact with actinide ions, and (3) the transport behaviors of colloidal particles, four colloidal particle types are recognized (Papenguth and Behl, 1996): mineral fragments, actinide intrinsic colloids, humic substances, and microbes.

In this document, we focus on the quantification of the actinide concentration mobilized by actinide intrinsic colloidal particles. In terms of the WIPP performance assessment (PA) calculations, we discuss the rationale for selecting the values corresponding to the following parameter designators:

idpram:	CONCINT	concentration of actinide associated with mobile actinide intrinsic colloids.
idmtrl:	Th	thorium [i.e., Th(IV)];
	U	uranium [i.e., U(IV) and U(VI)];
	Np	neptunium [i.e., Np(IV) and Np(V)];
	Pu	plutonium [i.e., Pu(III) and Pu(IV)]; and
	Am	americium [i.e., Am(III)].

Actinide intrinsic colloids (also known as true colloids, real colloids, type I colloids, and Eigenkolloide) form by condensation reactions of hydrolyzed actinide ions and consist solely of actinide cations linked by anions. There are several stages in the development of actinide intrinsic colloids at which they have significantly different behaviors. When immature, actinide intrinsic colloids display physicochemical properties that are similar to ionized humic substances. With age, they become more similar to mineral-fragment type colloidal particles.

The experimental approach used was strongly influenced by reviews of published literature on actinide intrinsic colloids. Pertinent literature is discussed below (see also Papenguth and Behl, 1996).

Intrinsic Colloids of Plutonium

The most well-known and well-studied actinide intrinsic colloid is the Pu(IV) intrinsic colloid, which has been used as a basis of comparison for investigating intrinsic colloids of other actinides. Most of the knowledge about the Pu(IV) intrinsic colloid comes from research at high Pu concentrations in highly acidic solutions, which was conducted to help improve the efficiency of processing techniques. The Pu(IV) intrinsic colloid is notorious in its propensity to polymerize to form a gel-like material, which can even plug process lines.

A conclusive demonstration of the mechanisms of formation of the Pu(IV) intrinsic colloid has not yet been made, but there is a preponderance of evidence that suggests that polymerization is strongly linked to hydrolysis, and that the initial polymerization, or condensation, produces a macromolecule that becomes progressively more crystalline with time. The final mature colloid has a composition between $Pu(OH)_{4\ (amorphous)}$ and $PuO_{2\ (crystalline)}$, although the latter compound may be only partly crystalline and both may include interstitial water molecules.

The most convincing and consistent explanation for the chemistry of the Pu(IV) intrinsic colloid is presented by Johnson and Toth (1978) of Oak Ridge National Laboratory. Those authors developed a conceptual model to explain the solution chemistry of a variety of metal cations and a variety of oxidation states. The conceptual model involves processes referred to as "olation" and "oxolation" in which metal cations become bridged with hydroxyl groups, which in turn undergo irreversible elimination of water and concurrent formation of oxygen bridges. Johnson and Toth demonstrate that the model is consistent with the observed behavior of the Pu(IV) intrinsic colloid.

Hydrolysis reactions for metal cations such as plutonium may be written as follows:

first: $Pu^{4+}_{(aq)} + H_2O \leftrightarrow PuOH^{3+}_{(aq)} + H^+$ (1)

second: $PuOH^{3+}_{(aq)} + H_2O \leftrightarrow Pu(OH)^{2+}_{2\,(aq)} + H^+$ (2)

third: $Pu(OH)^{2+}_{2\,(aq)} + H_2O \leftrightarrow Pu(OH)^{+}_{3\,(aq)} + H^+$ (3)

fourth: $Pu(OH)^{+}_{3\,(aq)} + H_2O \leftrightarrow Pu(OH)^{0}_{4\,(aq)} + H^+$ (4)

Johnson and Toth point out, however, that in interpreting the formation of the Pu(IV) intrinsic colloid, it makes better sense to include the implied waters of hydration that surround metal cations in solution. Hydrolysis equations (1) through (4) can be rewritten as follows, where n equals 4:

first: $[Pu(H_2O)_m]^{n+} \leftrightarrow [Pu(OH)(H_2O)_{m-1}]^{n-1} + H^+$ (5)

second: $[Pu(H_2O)_{m-1}]^{n-1} \leftrightarrow [Pu(OH)(H_2O)_{m-2}]^{n-2} + H^+$ (6)

third: $[Pu(H_2O)_{m-2}]^{n-2} \leftrightarrow [Pu(OH)(H_2O)_{m-3}]^{n-3} + H^+$ (7)

fourth: $[Pu(H_2O)_{m-3}]^{n-3} \leftrightarrow [Pu(OH)(H_2O)_{m-4}]^{n-4} + H^+$ (8)

From the literature, it is clear that polymerization occurs nearly immediately after the first hydrolysis occurs (5). Johnson and Toth suggest the following reaction involving polymerization of two hydrolyzed species by loss of water (oxolation):

$$2\{[(H_2O)_{d-2}Pu(OH)(H_2O)]^{+(y-1)}\} \leftrightarrow [(H_2O)_{d-2}Pu(OH)(OH)Pu(H_2O)_{d-2}]^{+2(y-1)} + 2H_2O \quad (9)$$

Aging or maturation of polymer then occurs by loss of water (olation) as follows:

$$Pu(OH)(OH)Pu(OH)(OH)Pu(OH)(OH)\cdots] \rightarrow [Pu(O)Pu(O)Pu(O)\cdots]_n + 3nH_2O \quad (10)$$

Maiti et al. (1989) and Laul et al. (1985) describe similar reactions, but it appears as though they believe that the third hydrolysis reaction occurs, because they use the $Pu(OH)^{+}_{3\,(aq)}$ ion in their proposed polymerization reaction. Use of that ion does not appear to be consistent with observations by many workers that polymerization occurs immediately after the first hydrolysis reaction.

As the actinide polyelectrolytes mature through the olation process to become closer in composition to an actinide-oxide mineral, they will be kinetically destabilized by the high ionic strengths of the WIPP brines, and will not be mobile. Further, the solubilities of the mature solid phase cannot be exceeded. In fairly long-term experiments, Nitsche et al. (1992, 1994) showed

that the concentration of Pu(IV) intrinsic colloid stabilized at about 10^{-8} M. It is not known whether the form was Pu(IV) polyelectrolyte or Pu(IV) mineral fragment type colloid.

Intrinsic Colloids of other Actinides

Reference is made to a variety of intrinsic colloids of other actinides, but no systematic investigations of their formation and behaviors appear to have been made. Plutonium is apparently unique in its propensity to form an intrinsic colloid. No mention is made in the literature of maturation of polyelectrolytes of other actinides to form mineral fragment type colloidal particles as plutonium does.

In general, the tendency of actinides to hydrolyze and to polymerize to form intrinsic colloids follows the order:

$$An^{4+} >> An(VI)O_2^{2+} > An^{3+} > An(V)O_2^{+} \qquad (11)$$

where An represents an actinide element (Cleveland, 1979a,b; Choppin, 1983; Kim, 1992; Lieser et al., 1991, p. 119). The order of oxidation states in the equation above results from the ionic charge to ionic radius ratios. The tendency for hydrolysis of $An(VI)O_2^{2+}$ is greater than for An^{3+} because the effective charge on the central cation on the linear $[O\text{-}An\text{-}O]^{2+}$ ion is 3.3±0.1, slightly greater than 3. This trend generally holds true for the actinide elements in general, because of the very small changes in ionic radii among the actinide elements (this is the oxidation state analogy; refer to Novak, 1996). There are differences in the behaviors of the actinides from element to element that stem from very subtle changes in the charge to radius ratio and the nature of the configuration of the f molecular orbital.

Considering Pu as an example, hydrolysis becomes significant for Pu^{4+}, $Pu(VI)O_2^{2+}$, Pu^{3+}, and $Pu(V)O_2^{+}$ at pH values of <1, 4-5, 6-8, and 9-10, respectively (Choppin, 1983). On the basis of the hydrolysis trend, it is not likely that An(III) and An(V) actinides will form actinide intrinsic colloids. That group includes Pu^{3+}, Am^{3+}, $Pu(V)O_2^{+}$, and $Np(V)O_2^{+}$. There are suggestions in the literature, however, that Am^{3+} may form an intrinsic colloid, which is surprising because it does not undergo hydrolysis until relatively high pH values. Thorium does not follow the trend described by equation (11) because its large size makes it resistant to hydrolysis (Cotton and Wilkinson, 1988). Nevertheless, thermodynamic data suggest that in almost all environments (near neutral or higher pH) thorium exists as $Th(OH)_{4(aq)}^{0}$. Moreover, thorium has been reported to form a polymer (Kraus, 1956; Johnson and Toth, 1978), although as discussed below, should be referred to as an oligomer.

Examples can be found in the literature of polymeric species of many of the actinides of importance to WIPP (see e.g., Baes and Mesmer, 1976; Kim, 1992). It is important, however, to note the sizes of polymers described in the literature. It is well known that as polyvalent metals, the actinides can form polynuclear species, but they are largely lower polymers (i.e., oligomers) such as dimers, trimers, tetramers, and hexamers (see, e.g., Choppin, 1983, p. 46). However, in terms of physical transport behavior, lower polymers will behave no differently than dissolved monomeric species. In contrast, the higher polymers, such as the Pu(IV)-polymer, may reach colloidal sizes (1 nm to 1 μm) and will have different hydrodynamic properties than the sub-colloidal-sized dissolved species. Johnson and Toth (1978) reported a molecular weight of 4000 for a Th polymer. Assuming that it consisted of $Th(OH)_4$, that polymer would consist of about 13 thorium metal ions (i.e., the degree of polymerization number, N). That observation is consistent with Kraus (1956), in which he quotes an N value of about 9 for Th polyelectrolyte.

Empirical evidence published in the literature does not always support the suggestion that Am, as a trivalent cation, will form an intrinsic colloidal particle. Avogadro and de Marsily (1984) suggested that, like Pu, Am is a likely candidate to form an insoluble hydroxide. Buckau et al. (1986) reported the formation of Am(III) intrinsic colloids at near neutral pH conditions, with a particle size greater than 1 nm. In their study of the hydrolysis of Am(III) over a pH range from 3 to 13.5, however, Kim et al. (1984a) found only monomers of Am. Regardless of whether Am(III) intrinsic colloids will form under highly idealized laboratory environments, it would be highly unlikely that they would form in a geologic system, because of the tremendously strong sorption properties of the Am(III) ion.

Experimental

Because of the absence of conclusive evidence in the literature that intrinsic colloids of Th, U, Np, and Am develop to sizes large enough to affect transport behavior, the focus of the experimental program was on Pu. A variety of screening experiments were conducted at Lawrence Livermore National Laboratory (LLNL; contract number AG-4965, Cynthia E. A. Palmer, LLNL PI) to test phenomena described in the published literature, under WIPP-relevant conditions:

- Critical coagulation concentration for mature Pu(IV) mineral fragment type colloid (refer to description of experiment AIC-1 in Papenguth and Behl, 1996);
- formation of Pu(IV) colloid, from oversaturation and undersaturation in the absence of carbon dioxide (AIC-8 and AIC-9, respectively);
- inhibition of Pu(IV) polymerization due to organic complexants (AIC-2);
- depolymerization of Pu-colloid due to organic complexants (AIC-2b);

- polyelectrolyte chain termination by non-actinide metal cations (AIC-4); and
- sorption effects of WIPP repository substrates on Pu(IV) colloid (AIC-5).

The last four experiments listed above provide evidence that, under some conditions at the WIPP, the Pu(IV)-colloid is less likely to form or is sorbed. To parameterize the WIPP PA calculations, however, the first two experiments listed above were used. Both sets of experiments (AIC-1, AIC-8/9) can essentially be viewed as solubility experiments. The critical coagulation experiments are solubility experiments conducted from undersaturation conditions, in which the in-growth of free Pu(IV) is observed (and are therefore equivalent to AIC-9). In both sets of experiments (AIC-1, AIC-8/9), the Pu solution concentration is measured as a function of time for as long as 5 weeks, as steady-state concentration is being reached. The two sets of experiments were anticipated to provide information to resolve the question of kinetic versus thermodynamic stability control on the formation and development of the Pu(IV) colloid. That question was not resolved, but the data still provide the necessary information for parameterizing the WIPP PA calculations. The values for the parameters submitted to PA were derived from the following experiments:

number	experiment	starting material	approx. pcH	[NaCl]	duration
AIC-1	c.c.c. (equivalent to undersaturation experiment AIC-9)	Pu(IV)-colloid; aged 1-month: ~2×10^{-4} M	4 7 10	0.001 m 0.01 m 0.1 m 0.8 m 3.0 m 5.0 m	3 to 5 weeks
AIC-8	oversaturation	Pu(IV) aquo ion: ~1×10^{-4} M	3 7 11	0.05 m 0.5 m 1.0 m 5.0 m	4 weeks

The data from those experiments are plotted in Figure 1 along with regression lines for data collected by Rai et al. (1980) for $Pu(OH)_{4\,(amorphous)}$ and PuO_2 and Rai and Swanson (1981) for Pu(IV)-polymer under acidic pH conditions. The current WIPP Project position is that MgO backfill will be added to control pCO_2. With MgO backfill, the pcH of the repository brine is expected to be about 9.3 (refer to Wang, 1996; also see Novak and Moore, 1996; Siegel, 1996). As shown in Figure 1, the regression line calculated from the LLNL data suggests that at a pcH of 9.3 the solubility of Pu(IV)-polymer is approximately 5×10^{-10} M. Because the extrapolated concentration is less than the minimum analytical detection limit (ADL) of 1×10^{-9} M, the ADL value was selected for use in WIPP PA calculations. The LLNL results are consistent with the extrapolated relationships based on published results of Rai et al. (1980) and Rai and Swanson (1981).

Interpreted Results

Parameter values (CONCINT) describing the amount of actinide element bound by actinide intrinsic colloidal particles were determined from the information described above. For the Pu(IV)-polymer, the minimum ADL was selected. In the absence of conclusive evidence that intrinsic colloids of other actinides form, or form polymers rather than oligomers, the concentration of Th-, U-, Np-, and Am-intrinsic colloids was set to zero.

Geochemical conditions in the Culebra are not conducive to the formation of a new supplementary population of actinide intrinsic colloids. In particular, the concentration of actinide ions is reduced. Therefore, the source term for actinide intrinsic colloids only reflects what would form in the WIPP repository.

Summary

Interpreted values for CONCINT are summarized in Attachments C, E, and F.

References

Avogadro, A., and G. de Marsily. 1984. "The Role of Colloids in Nuclear Waste Disposal," *Scientific Basis for Nuclear Waste Management VII, Materials Research Society Symposia Proceedings, Boston, MA, November 14-17, 1983*. Ed. G.L. McVay. New York, NY: North-Holland. Vol. 26, 495-505.

Baes, C.F., Jr., and R.E. Mesmer. 1976. *The Hydrolysis of Cations*. New York, NY: Wiley Interscience.

Buckau, G., R. Stumpe, and J.I. Kim. 1986. "Americium Colloid Generation in Groundwaters and Its Speciation by Laser-Induced Photoacoustic Spectroscopy," *Journal of the Less-Common Metals*. Vol. 122, 555-562.

Choppin, G.R. 1983. "Solution Chemistry of the Actinides," *Radiochimica Acta*. Vol. 32, no. 1-3, 43-53.

Cleveland, J.M. 1979a. *The Chemistry of Plutonium*. La Grange Park, IL: American Nuclear Society.

Cleveland, J.M. 1979b. "Critical Review of Plutonium Equilibria of Environmental Concern," *Chemical Modeling in Aqueous Systems: Speciation, Sorption, Solubility, and Kinetics, 176th Meeting of the American Chemical Society, Miami Beach, FL, September 11-13, 1978*. Ed. E.A. Jenne. Washington, DC: American Chemical Society. 321-338.

Cotton, F.A., and G. Wilkinson. 1988. *Advanced Inorganic Chemistry*. 5th ed. New York, NY: John Wiley & Sons.

Johnson, G.L., and L.M. Toth. 1978. *Plutonium(IV) and Thorium(IV) Hydrous Polymer Chemistry*. ORNL/TM-6365. Oak Ridge, TN: Oak Ridge National Laboratory, Chemistry Division.

Katz, J.J., L.R. Morss, and G.T. Seaborg. 1986. "Summary and Comparative Aspects of the Actinide Elements," *The Chemistry of the Actinide Elements*. 2nd ed. Eds. J.J. Katz, G.T. Seaborg, and L.R. Morss. New York, NY: Chapman and Hall. Vol. 2, 1121-1195.

Kim, J.I. 1992. "Actinide Colloid Generation in Groundwater," *Radiochimica Acta*. Vol. 52/53, pt. 1, 71-81.

Kim, J.I., M. Bernkopf, Ch. Lierse, and F. Koppold. 1984a. "Hydrolysis Reactions of Am(III) and Pu(VI) Ions in Near-Neutral Solutions," *Geochemical Behavior of Disposed Radioactive Waste*. Eds. G.S. Barney, J.D. Navratil, and W.W. Schulz. ACS Symposium Series 246. Washington, DC: American Chemical Society. 115-134.

Kraus, K.A. 1956. "Hydrolytic Behavior of the Heavy Elements," *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, August 8-20, 1955*. New York, NY: United Nations. Vol. 7, 245-257.

Laul, J.C., M.R. Smith, and N. Hubbard. 1985. "Behavior of Natural Uranium, Thorium and Radium Isotopes in the Wolfcamp Brine Aquifers, Palo Duro Basin, Texas," *Scientific Basis for Nuclear Waste Management, Materials Research Society Symposia Proceedings, Boston, MA, November 26-29, 1984*. Eds. C.M. Jantzen, J.A. Stone, and R.C. Ewing. Pittsburgh, PA: Materials Research Society. Vol. 44, 475-482.

Lieser, K.H., R. Hill, U. Mühlenweg, R.N. Singh, T. Shu-De, and Th. Steinkopff. 1991. "Actinides in the Environment," *Journal of Radioanalytical and Nuclear Chemistry, Articles*. Vol. 147, no. 1, 117-131.

Maiti, T.C., M.R. Smith, and J.C. Laul. 1989. "Colloid Formation Study of U, Th, Ra, Pb, Po, Sr, Rb, and Cs in Briny (High Ionic Strength) Groundwaters: Analog Study for Waste Disposal," *Nuclear Technology*. Vol. 84, no. 1, 82-87.

Nitsche, H., K. Roberts, R. Xi, T. Prussin, K. Becraft, I. Al Mahamid, H.B. Silber, S.A. Carpenter, R.C. Gatti, and C.F. Novak. 1994. "Long Term Plutonium Solubility and Speciation Studies in a Synthetic Brine," *Radiochimica Acta, Special Issue: Chemistry and Migration Behaviour of Actinides and Fission Products in the Geosphere, Proceedings of the Fourth International Conference, Charleston, SC, December 12-17, 1993*. Munich: R. Oldenbourg Verlag. Vol. 66/67, 3-8.

Nitsche, H., K. Roberts, R.C. Gatti, T. Prussin, K. Becraft, S.C. Leung, S.A. Carpenter, and C.F. Novak. 1992. *Plutonium Solubility and Speciation Studies in a Simulant of Air Intake Shaft Water from the Culebra Dolomite at the Waste Isolation Pilot Plant*. SAND92-0659. Albuquerque, NM: Sandia National Laboratories.

Novak, C. F., 1996, The Waste Isolation Pilot Plant (WIPP) Actinide Source Term Program: Test Plan for the Conceptual Model and the Dissolved Concentration Submodel, Albuquerque, New Mexico, Sandia National Laboratories, SAND95-1895 (submitted).

Novak, C. F., and Moore, R. C., 1996, Estimates of dissolved Concentration for +III, +IV, +V, and +VI Actinides in a Salado and a Castile Brine under Anticipated Repository Condtions. SNL Technical memorandum dated 28 March 1996 to Malcolm D. Siegel.

Papenguth, H. W., and Behl, Y. K., 1996, Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant, SNL Test Plan TP 96-01.

Rai, D., and J.L. Swanson. 1981. "Properties of Plutonium(IV) Polymer of Environmental Importance," *Nuclear Technology*. Vol. 54, no. 1, 107-111.

Rai, D., R.J. Serne, and Moore. 1980. "Solubility of Plutonium Compounds and their Behavior in Soils," *Soil Science Society of America Journal*. Vol. 44, 490-.

Siegel, M. D., 1996, Solubility parameters for use in the CCA NUTS and GRIDFLOW calculations. SNL Technical memorandum dated 29 March 1996 to Martin S. Tierney.

Wang, Y., 1996, Estimate of Repository pH and f_{CO2} Distribution for the Long-Term WIPP Performance Assessment (PA). SNL Technical memorandum dated 29 March 1996 to Martin S. Tierney and Christine T. Stockman.

Figure 1.

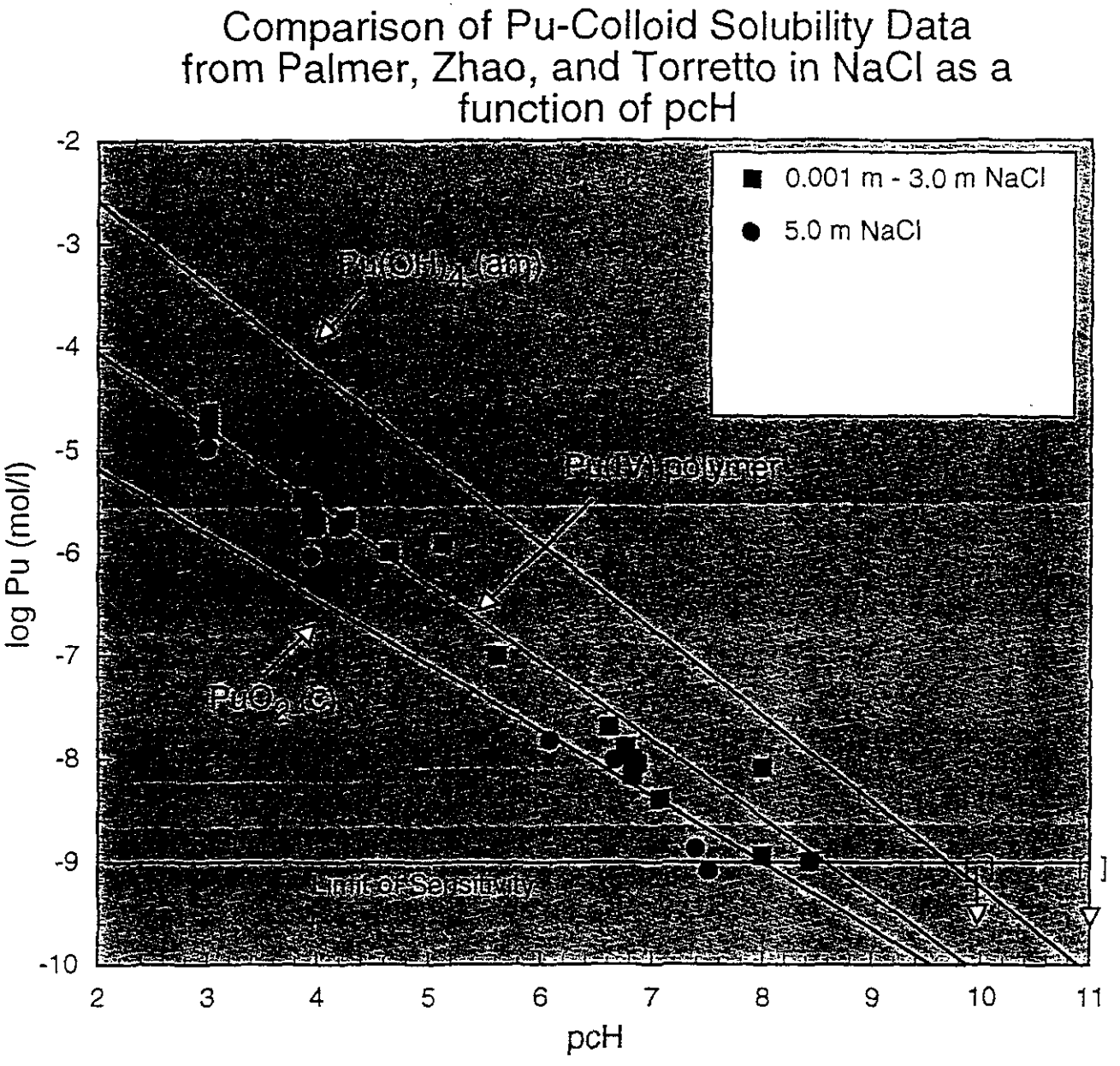

Figure 1: Solubility of Pu(IV)-polymer as a function of pcH+. Open brackets with arrows pointing down indicate that Pu concentration is below the Limit of Sensitivity. Note: Solubility lines for $Pu(OH)_4$ and PuO_2 are extrapolated from Rai, Serne, and Moore, *Soil Sci. Soc. Am. J.*, **44**, 490, (1980). Solubility line for Pu(IV) polymer is extrapolated from Rai and Swanson, *Nuc. Tech.*, **54**, 107, (1981)

Attachment B:

Stockman, Christine T., 1996, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 29 March 1996 to Hans W. Papenguth.

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: 3/29/96

to: Hans W. Papenguth

Christine T. Stockman

from: Christine T. Stockman

subject: Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations

In order to properly model the transport of radionuclides within the Salado formation, we will need information about the possible transport of these radionuclide on colloids. In this memo we request the maximum mobilized radionuclide concentration and/or the proportionality constant defining the moles mobilized on colloid per moles in solution, for each transported element and colloid type. We are planning to transport Am, Pu, U, and Th, and may also transport Cm, Np, Ra, and Sr. If we transport Ra and Sr, we are planning to model them as very soluble, and not sorbed, so I believe modeling of colloids for them will not be necessary. For Cm solubility, we will be using the Am(III) model. If you believe that Cm colloids also behave similarly to Am colloids, we could extend the chemical analogy to the colloid behavior. If you agree with these simplifications then we will need the parameters for Am, Pu, U, Th and Np only.

Suggested names for database entry:
IDMTRL: Am, Pu, U, Th, Np

IDPRAM:

CONCINT	for concentration of actinide on mobilized intrinsic colloid
CONCMIN	for concentration of actinide on mobilized mineral fragments
CAPHUM	for maximum concentration of actinide on humic colloids
CAPMIC	for maximum concentration of actinide on microbe colloids
PROPHUM	for moles actinide mobilized on humic colloids per moles dissolved
PROPMIC	for moles actinide mobilized on microbe colloids per moles dissolved

You will need to provide a distribution for each material-parameter pair, but that distribution may be "CONSTANT" for most of the numbers. Eight sampling slots have been reserved for the most important of these parameters that have non-constant distributions.

cc:

Mary-Alena Martell	Amy S. Johnson	J. T. Schneider
Hong-Nian Jow	Martin S. Tierney	Richard V. Bynum
E. James Nowak	W. George Perkins	Ali A. Shinta
James L. Ramsey		

SWCF-A:WBS1.2.07.1.1:PDD:QA:GENERAL

Attachment C:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters. SNL Technical Memorandum dated 29 March 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 29 March 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters

This memorandum summarizes best estimates for the mobile colloidal actinide source term for input to the WIPP Compliance Certification Application. The use of material and parameter identification codes is consistent with your letter to me dated 29 March 1996 requesting parameter values. In the attached table, I have provided best estimates for the following material-parameter combinations:

IDMTRL: Th, U, Np, Pu, Am

IDPRAM:

CONCINT	concentration of actinide associated with mobile actinide intrinsic colloids
CONCMIN	concentration of actinide associated with mobile mineral fragment colloids
CAPHUM	maximum concentration of actinide associated with mobile humic colloids
CAPMIC	maximum concentration of actinide associated with mobile microbes
PROPHUM	proportionality constant for concentration of actinides associated with mobile humic colloids
PROPMIC	proportionality constant for concentration of actinides associated with mobile microbes

As a first approximation, the colloidal behavior of curium can be simulated be using parameter values for americium. The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

copy to:

MS 1328	Hong-Nian Jow, 6741
MS 1328	Amy S. Johnson, 6741
MS 1328	Martin S. Tierney, 6741
MS 1320	E. James Nowak, 6831 EJN
MS 1320	R. Vann Bynum, 6831
MS 1341	John T. Holmes, 6748
MS 1341	Laurence H. Brush, 6748
MS 1341	Robert C. Moore, 6748
MS 1341	W. Graham Yelton, 6748
MS 1320	W. George Perkins, 6748 wgp
MS 1320	John W. Kelly, 6748
MS 1320	Daniel A. Lucero, 6748
MS 1320	Craig F. Novak, 6748
MS 1320	Hans W. Papenguth, 6748
MS 1320	Malcolm D. Siegel, 6748
MS 1324	Susan A. Howarth, 6115
MS 1341	Kurt O. Larson, 6747
MS 1341	Ruth F. Weiner, 6747
MS 1324	Richard Aguilar, 6851

SWCF-A:WBS1.1.10.2.1

Mobile-Colloidal-Actinide Source Term—Concentration/Proportionality Constants

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CONCMIN	Th	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
CONCMIN	U	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
CONCMIN	Np	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
CONCMIN	Pu	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
CONCMIN	Am	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
PROPHUM	Th	6.4e+00	6.4e+00	6.4e+00	moles colloidal humic-bound Th per moles dissolved Th	constant	2,3
PROPHUM	U	1.4e+00	1.6e-01	2.0e+00	moles colloidal humic-bound U per moles dissolved U	triangular	2,3,4
PROPHUM	Np	4.0e+00	4.0e+00	4.0e+00	moles colloidal humic-bound Np per moles dissolved Np	constant	2,3
PROPHUM	Pu	5.9e+00	5.9e+00	5.9e+00	moles colloidal humic-bound Pu per moles dissolved Pu	constant	2,3
PROPHUM	Am	2.5e+00	1.9e-01	3.9e+00	moles colloidal humic-bound Am per moles dissolved Am	triangular	2,3,4

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CAPHUM	Th	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
CAPHUM	U	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
CAPHUM	Np	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
CAPHUM	Pu	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
CAPHUM	Am	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
Notes:							
general	The colloidal actinide source term is added to the dissolved actinide source term.						
general	None of the parameters are correlated.						
1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
3	Proportionality constants are to be used with the sum of actinide oxidation species for each actinide element (uncomplexed only, i.e., without organic ligand contribution).						
4	If a distribution is not used for humic-bound U or Am, use the maximum concentration as a constant value.						
5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e. the sum of dissolved plus colloidal actinide).						

Attachment D:

Stockman, Christine T., 1996, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 2 April 1996 to Hans W. Papenguth.

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: 4/2/96

to: Hans W. Papenguth

Christine T. Stockman

from: Christine T. Stockman

subject: Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations

YiFeng Wang has revised his recommendation to use 2 invariant points in the PA calculation. He now recommends that we use the $Mg(OH)_2 + MgCO_3$ invariant point for all calculations. If this invalidates the assumptions that you used to prepare colloid concentration or proportion parameters please indicate as soon as possible which parameters are affected, and as soon as possible after that provide a memo documenting the new values.

cc:
Mary-Alena Martell
Amy S. Johnson
Hong-Nian Jow
Martin S. Tierney
J. T. Schneider
Richard V. Bynum
E. James Nowak
W. George Perkins
SWCF-A:WBS1.2.07.1.1:PDD:QA:GENERAL

Attachment E:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL Technical Memorandum dated 18 April 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 18 April 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters, Revision 1

This memorandum summarizes the revised best estimates for the mobile colloidal-actinide source term for input to the WIPP Compliance Certification Application. Values presented herein supersede the values provided to you on 29 March 1996 (Papenguth, 1996) in response to your memorandum of 29 March 1996 (Stockman, 1996a). The present memorandum addresses your request for modifications stated in your memorandum dated 2 April 1996 (Stockman, 1996b).

In the attached table, I have summarized the complete set of parameters and values for the mobile colloidal-actinide source term. Revised values for maximum actinide concentration values for humic substances and constants describing actinide concentrations associated with mineral-fragment-type colloidal particles are included. New values (i.e., corresponding to new idpram's and idmtrl's) for proportionality constants describing actinide concentrations associated with humic substances are also included.

The revisions described herein for humic substances reflect a shift in approach from proportionality constants describing actinide-humic concentration by element, to proportionality constants describing actinide-humic concentration by actinide oxidation state. That change affects treatment of actinide elements that will have multiple oxidation states in the WIPP repository [e.g., U(IV) and U(VI); Np(IV) and Np(V); Pu(III) and Pu(IV)]. A second modification in approach, is that I now provide values for two cases: (1) a Castile brine in equilibrium with brucite and magnesite; and (2) a Salado brine in equilibrium with brucite and magnesite. For humic substances, the following material-parameter combinations apply:

IDMTRL: PHUMOX3 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 3;

PHUMOX4 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 4;

PHUMOX5 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 5; and

PHUMOX6 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 6.

IDPRAM: PHUMCIM proportionality constant for concentration of actinides associated with mobile humic colloids, in Castile brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite);

PHUMSIM proportionality constant for concentration of actinides associated with mobile humic colloids, in Salado brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite).

The revisions made for actinide concentration associated with mineral-fragment-type colloidal particles were made to include the potential contribution of actinide-mineral colloids formed in the Culebra. To accomplish that, the original repository source term values (Papenguth, 1996) have been doubled. That approach is not necessary for humic substances or actinide intrinsic colloids [i.e., Pu(IV)-polymer], because their concentrations are limited by solubilities. Concentrations of actinides associated with microbes are limited by the steady-state population of microbes in the repository, which will not increase when introduced to the Culebra.

The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

References

Papenguth, H.W., 1996, Colloidal Actinide Source Term Parameters, SNL technical memorandum dated 29 March 1996 to Christine T. Stockman.

Stockman, C.T., 1996a, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations, SNL technical memorandum dated 29 March 1996 to Hans W. Papenguth.

Stockman, C.T., 1996b, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations, SNL technical memorandum dated 2 April 1996 to Hans W. Papenguth.

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MS 1324	Richard Aguilar, 6851
DOE/CAO	Robert A. Stroud

SWCF-A:WBS1.1.10.2.1

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CONCMIN	Th	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
revised	CONCMIN	U	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
revised	CONCMIN	Np	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
revised	CONCMIN	Pu	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
revised	CONCMIN	Am	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
	CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
	CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
	CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
	CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
	CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
revised (new)	PHUMSIM	PHUMOX3	1.3e-01	8.0e-03	1.9e-01	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
revised (new)	PHUMSIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
revised (new)	PHUMSIM	PHUMOX5	4.8e-04	5.3e-05	9.1e-04	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
revised (new)	PHUMSIM	PHUMOX6	5.6e-02	8.0e-03	1.2e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX3	1.1e+00	6.5e-02	1.6e+00	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
revised (new)	PHUMCIM	PHUMOX5	3.9e-03	4.3e-04	7.4e-03	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX6	2.8e-01	6.2e-02	5.1e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CAPHUM	Th	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
revised	CAPHUM	U	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
revised	CAPHUM	Np	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
revised	CAPHUM	Pu	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
revised	CAPHUM	Am	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
	PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
	PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
	PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
	PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
	PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
	CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
	CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
	CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
	CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
	CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
	Notes:							
		general	The colloidal actinide source term is added to the dissolved actinide source term.					
		general	None of the parameters are correlated.					
		1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.					
		2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.					
		3	Proportionality constants are to be used with the inorganic actinide solubility value (uncomplexed only, i.e., without organic ligand contribution).					
		4	If a distribution is not used, use the maximum concentration as a constant value.					
		5	The maximum ("cap") values are in units comparable to molarity rather than molality.					
		6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.					
		7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e., the sum of dissolved plus colloidal actinide).					

Attachment F:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 2. SNL Technical Memorandum dated 22 April 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 22 April 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters, Revision 2

In my rush to complete and distribute Revision 1 (Papenguth, 1996), I made mistakes on the minimum and maximum values for actinide concentrations associated with mineral-fragment-type colloidal particles. The attached Table contains the correct values.

References

Papenguth, H.W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL technical memorandum dated 18 April 1996 to Christine T. Stockman.

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DOE/CAO	Robert A. Stroud

SWCF-A:WBS1.1.10.2.1

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CONCMIN	Th	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
revised	CONCMIN	U	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
revised	CONCMIN	Np	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
revised	CONCMIN	Pu	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
revised	CONCMIN	Am	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
	CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
	CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
	CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
	CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
	CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
	PHUMSIM	PHUMOX3	1.3e-01	8.0e-03	1.9e-01	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
	PHUMSIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
	PHUMSIM	PHUMOX5	4.8e-04	5.3e-05	9.1e-04	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
	PHUMSIM	PHUMOX6	5.6e-02	8.0e-03	1.2e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4
	PHUMCIM	PHUMOX3	1.1e+00	6.5e-02	1.6e+00	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
	PHUMCIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
	PHUMCIM	PHUMOX5	3.9e-03	4.3e-04	7.4e-03	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
	PHUMCIM	PHUMOX6	2.8e-01	6.2e-02	5.1e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
	CAPHUM	Th	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
	CAPHUM	U	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
	CAPHUM	Np	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
	CAPHUM	Pu	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
	CAPHUM	Am	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
	PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
	PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
	PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
	PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
	PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
	CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
	CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
	CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
	CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
	CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
	Notes:							
		general	The colloidal actinide source term is added to the dissolved actinide source term.					
		general	None of the parameters are correlated.					
		1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.					
		2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.					
		3	Proportionality constants are to be used with the inorganic actinide solubility value (uncomplexed only, i.e., without organic ligand contribution).					
		4	If a distribution is not used, use the maximum concentration as a constant value.					
		5	The maximum ("cap") values are in units comparable to molarity rather than molality.					
		6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.					
		7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e., the sum of dissolved plus colloidal actinide).					

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.6

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WPO #35856

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 7 May 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Parameter Record Package for Colloidal Actinide Source Term Parameters

Attached is the Parameter Record Package for the WIPP PA parameters describing actinide concentrations associated with mobile **microbes**. This Package is one of four describing the concentration of actinides associated with the four colloidal particle types. The complete set of Packages consists of the following:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

copy with Attachments to:

MS 1320 Hans W. Papenguth, 6748
MS 1320 W. George Perkins, 6748

DOE/CAO Robert A. Stroud

~~SWCF-A:WBS:1.1.10.2.1: Colloid Characterization and Transport~~
~~SWCF-A:WPO#:35856: Mobile-Colloidal-Actinide Source Term: 4. Microbes~~

copy without Attachments to:

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MS 1328 Hong-Nian Jow, 6741
MS 1328 Amy S. Johnson, 6741
MS 1328 Martin S. Tierney, 6741
MS 1328 Mary-Alena Martell, 6749
MS 1341 John T. Holmes, 6748

Parameter Record Package for Mobile-Colloidal Actinide Source Term.
Part 4. Microbes

The parameter values in this package are based on data which were collected under the guidance of the Principal Investigator for the Waste Isolation Pilot Plant (WIPP) Colloid Research Program, Hans W. Papenguth, for input to the WIPP Data Entry Form and for use in WIPP Performance Assessment (PA) calculations.

I. *Parameter No. (id):* Not applicable.

II. *Data/Parameter:* Not applicable.

III. *Parameter id (idpram):* PROPMIC and CAPMIC.

IV. *Material:* Microbes and the actinides Th, U, Np, Pu, and Am.

V. *Material Identification (idmtrl):* Th, U, Np, Pu, and Am.

VI. *Units:* For proportionality constants (PROPMIC), the units are "moles microbe-bound actinide per moles of dissolved actinide." For the maximum concentration of each actinide associated with mobile microbes (CAPMIC), the units are "moles microbe-bound actinide per liter of dispersion."

VII. *Distribution Information.*

A. *Category:* The development of parameter values and their distributions is described in Attachment A. Summaries of the parameter values are presented in Attachments C, E, and F. Constant CAPMIC values are supplied for Th, U, Np, and Pu. CAPMIC values for Am are not available (refer to Attachment A, page 6). Constant PROPMIC values are supplied for all five actinide elements listed above.

B. *Mean:* See Attachments A, C, E, and F.

C. *Median:* Not applicable.

D. *Standard Deviation:* Not applicable.

E. *Maximum:* See Attachments A, C, E, and F.

F. *Minimum:* See Attachments A, C, E, and F.

G. *Number of data points:* Not applicable.

VIII. *Data Collection and Interpretation Information.*

A. *Data Source Information:* WIPP observational data and literature.

B. *Data Collection (for WIPP observational data).*

1. *Data Collection or Test Method:* Experiments were conducted at Brookhaven National Laboratory (BNL; contract number AP-2273; A. J. Francis, BNL PI) and at Los Alamos National Laboratory (LANL; contract number AP-2272; Inés

R. Triay, LANL PI). Work conducted at LANL was done as a collaborative effort under the guidance of the BNL PI. Descriptions of experiments conducted at those institutions are described in Attachment A.

2. *Assumptions Made During Testing:* See Attachment A.

3. *Standard Error of Measurement of Tests Performed:* See Attachment A.

4. *Form of Raw Data:* Data on actinide bioaccumulation by microbes is reported in actinide concentration or counts per unit volume. Data on actinide toxicity effects is reported in actinide concentration or counts per unit volume and cell population in cells per unit volume or in optical density.

5. *References Related to Data Collection:* See Attachment A.

6. *QA Status of Data:*

   a. *Are all of the data qualified?* Yes.

   b. *Were data qualified by QAP 20-3?* No. Data packages will be submitted for work conducted at BNL and LANL (see VIII,B,1 above for contract numbers), under File code WBS 1.1.10.2.1.

   c. *Were the data the subject of audit/surveillance by SNL or DOE?* Yes. LANL (contract number AP-2272) was audited by SNL (EA96-11) and by DOE/CAO (S-96-08). BNL (contract number AP-2273) is scheduled to be audited by SNL (EA96-19) in May 1996. DOE/CAO conducted a surveillance of BNL (S-96-08).

   d. *Were the data collected under an SNL approved QA program?* Yes. Data were collected under SNL WIPP QAPD, Rev. P, effective October 1, 1992, and SNL WIPP QAPD, Rev. R, effective July 31, 1995. LANL conducted work under an approved QAPP prepared especially for their program (WIPP Colloid and Bacterial Transport Project, CST-CBT-QAP1-001/0). BNL conducted work under an approved QAPP prepared especially for their program (Examination of the Role of Microorganisms in Colloidal Transport of Actinides under WIPP Repository Relevant Test Conditions). Data were collected under a test plan for the WIPP Colloid Research Program (Papenguth and Behl, 1996). Detailed descriptions of the experiments and interpretation listed herein will be published in a SAND report. Documents related to data collection at BNL and LANL will be archived in the Sandia WIPP Central Files (SWCF; File code WBS 1.1.10.2.1).

C. *Interpretation of Data.*

1. *Was the interpretation made by reference to previous work.* No.

2. *Was the interpretation made by using newly performed calculations?* Yes.

3. *Form of Interpreted Data.* List of interpreted values.

4. *Assumptions Made During Interpretation.* See Attachment A.

5. *Name of Code(s)/Software used to Interpret Data:* Not applicable.

6. *QA Status of Code(s) used to Interpret Data:* Not applicable.

   a. *Was the code qualified under QAP 19-1?* Not applicable.

   b. *Was the code qualified under QAP 9-1?* Not applicable.

7. *References Related to Data Interpretation:* See XI below and Attachment A.

8. *For interpretations made by using a newly performed calculations provide documentation that you followed the requirements of QAP 9-1 Appendix B.* The data analysis is controlled by Analysis Plan for the Colloid Research Program, AP-004 (Behl and Papenguth, 1996).

9. *For routine calculations (not using code) did you follow requirements of QAP 9-5?* Yes.

IX. *Correlation with other Parameters:* Parameter values describing the concentration of actinides associated with mobile humic substances are linked to solubility of the dissolved actinides, with a maximum value which cannot be exceeded.

X. *Limitations or qualifications for usage of data by Performance Assessment (PA):* None.

XI. *References cited above:*

Behl, Y.K., and Papenguth, H.W., 1996, Analysis Plan for the WIPP Colloid Research Program WBS #1.1.10.2.1, SNL Analysis Plan AP-004.

Papenguth, H.W., and Behl, Y.K., 1996, Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant, SNL Test Plan TP 96-01.

XII. *Attachments:*

Attachment A: Papenguth, Hans W., 1996, Rationale for Definition of Parameter Values for Microbes.

Attachment B: Stockman, Christine T., 1996, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 29 March 1996 to Hans W. Papenguth.

Attachment C: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters. SNL Technical Memorandum dated 29 March 1996 to Christine T. Stockman.

Attachment D: Stockman, Christine T., 1996, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 2 April 1996 to Hans W. Papenguth.

Attachment E: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL Technical Memorandum dated 18 April 1996 to Christine T. Stockman.

Attachment F: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 2. SNL Technical Memorandum dated 22 April 1996 to Christine T. Stockman.

XIII. *Distribution*

SWCF-A:WPO# 35856: Mobile-Colloidal Actinide Source Term. 4. Microbes.
SWCF-A:WBS 1.1.10.2.1: Colloid Characterization and Transport.

Attachment A:

Papenguth, Hans W., 1996, Rationale for Definition of Parameter Values for Microbes.

Attachment A.
Rationale for Definition of Parameter Values for Microbes

Hans W. Papenguth

Introduction

The actinide source term at the WIPP is defined as the sum of contributions from dissolved actinide species and mobile colloidal actinide species. The dissolved actinide source term has been defined elsewhere (Novak, 1996; Novak and Moore, 1996; Siegel, 1996). It is important to note that colloidal actinides which are not suspended in the aqueous phase (i.e., not mobile) are not included in the colloidal actinide source term. Colloidal actinides may become immobilized by several mechanisms, including precipitation followed by coagulation and gravitational settling (humic substances and actinide intrinsic colloids), adhesion to fixed substrates (microbes), and flocculation or coagulation of colloidal particles followed by gravitational settling (mineral fragments). Sorption of colloidal actinides onto fixed substrates will also reduce the mobile colloidal actinide source term, but no credit is currently being taken for reduction by that means.

To facilitate quantification of the colloidal actinide source term, as well as an efficient experimental approach, the source term has been divided into four components according to colloid types. On the basis of (1) the behavior of colloidal particles in high ionic strength electrolytes, (2) the way in which colloidal particles interact with actinide ions, and (3) the transport behaviors of colloidal particles, four colloidal particle types are recognized (Papenguth and Behl, 1996): mineral fragments, actinide intrinsic colloids, humic substances, and microbes.

The focus of this document is on the quantification of the actinide concentration mobilized by microbes. In terms of the WIPP performance assessment (PA) calculations, the rationale for selecting the values corresponding to the following parameter designators is discussed:

idpram:	PROPMIC	proportionality constant for concentration of actinides associated with mobile microbes; and
	CAPMIC	maximum (cap) concentration of actinide associated with mobile microbes
idmtrl:	Th	thorium;
	U	uranium;
	Np	neptunium;
	Pu	plutonium; and
	Am	americium.

Potentially important colloidal sized microorganisms include bacteria, fungi, yeast, and protozoa. Fungi and yeast are not important for the WIPP Site because of the anticipated anoxic environment of the repository. For the WIPP Site, the focus is on the halophilic and halotolerant microbes that have been identified at the Site (Brush, 1990; Francis and Gillow, 1994). Microbes are important to consider in performance assessments of the WIPP because they may significantly affect the characteristics of the waste stored at the WIPP, and also participate in transport of actinides in the event of human intrusion. Microbes are known to actively bioaccumulate actinides intracellularly as well as act as substrates for passive extracellular sorption.

At the WIPP Site, concentrations of naturally occurring microbes are on the order of 10^4 to 10^7 cells per milliliter (Francis and Gillow, 1994, Table 1). In the presence of nutrients provided by WIPP waste constituents, including nitrates, sulfates, and cellulosic materials such as protective clothing and wood, the population of microbes is likely to increase. Lysis, a natural phenomenon whereby cells die and release their cell constituents to the solution, also provides a source of nutrients to microbes.

When introduced to nutrient, microbes typically follow a predictable growth curve (defined by the number population of microbes plotted as a function of time), consisting of an initial period of inactivity ("very early log phase") ranging up to several days, followed by a sharp increase in growth ("early log phase"). That level of growth is sustained for one or more days ("log phase") during which time microbial metabolites, including carboxylic acids, enzymes, and exocellular polymers, are generated. The growth rate eventually begins to decline ("late log phase") due to the effects of those metabolites, limitations in nutrients or substrates, or population dynamics, and reaches a steady-state population ("stationary phase"). Viable microbes may aggregate to form clusters.

Experimental

Several types of experiments were conducted to evaluate the impact of microbes in support of the WIPP Colloid Research Program (refer to descriptions in Papenguth and Behl, 1996): (1) evaluation of indigenous concentrations of microbes; (2) quantification of mobile concentrations under nutrient- and substrate-rich conditions; (3) quantification and characterization of actinide bioaccumulation by microbes; and (4) evaluation of toxicity effects of actinide elements on microbe growth.

Experiments were conducted at Brookhaven National Laboratory (BNL; contract number AP-2273; A. J. Francis, BNL PI) and as a collaborative effort between BNL and Los Alamos National Laboratory (LANL; contract number AP-2272; Inés R. Triay, LANL PI). Evaluation of indigenous concentrations was a collaborative effort between BNL and LANL. Quantification of mobile concentrations was conducted at BNL. The bioaccumulation and toxicity work was conducted at BNL or LANL depending on actinide element. Thorium and uranium were investigated at BNL. The other actinide elements of interest, neptunium, plutonium, and americium, were investigated at LANL under the guidance of BNL personnel.

Experiments to determine the mobile concentrations of microbes remaining suspended in the fluid column were conducted similarly to experiments previously conducted in support of the WIPP Gas Generation Program (Brush, 1990; Francis and Gillow, 1994). Bacterial cultures were introduced to a solution containing nutrient and substrate, and sealed. Bacteria population was monitored over periods of several weeks or more using measurements of optical density or by direct counting of aliquots of fixed cells. An important change in protocol from previous experiments, however, is that instead of filtering the entire contents of the vessels, only the mobile cells remaining suspended in the fluid column were counted. Results of the experiments showed that the mobile concentration of microbes was a couple orders-of-magnitude less than the total concentration of microbes. The existence of indigenous microbes in Salado groundwaters has been demonstrated in previous work (Francis and Gillow, 1994). As part of the WIPP Colloid Research Program, samples of Culebra groundwater were carefully collected from the H-19 hydropad, processed, and characterized for indigenous microbes. Concentrations of naturally occurring microbes were on the order of 10^5 cells per milliliter, determined using direct counting methods.

The evaluation of indigenous concentrations of microbes and quantification of mobile concentrations provided important supporting evidence for quantifying the microbial actinide source term and for evaluating microbe-facilitated transport of actinides in the Culebra. However, the basis for developing the actual parameter values to be used in PA calculations was established with bioaccumulation and toxicity experiments, referred to herein as filtration experiments. Those experiments were conducted by combining microbe cultures with various concentrations and complexes of ^{232}Th, ^{238}U, ^{237}Np, ^{239}Pu, or ^{243}Am. The actinide reagents used were thorium nitrate, thorium EDTA, uranyl(VI) nitrate, uranyl(VI) citrate, neptunyl(V) EDTA, plutonyl(V) perchlorate, plutonyl(V) EDTA, and americium EDTA. For those experiments, a pure bacterial culture (WIPP-1A) and a mixed bacterial culture (BAB) were used. Most of the experiments were conducted with the WIPP-1A culture, because of the fast growth of that pure culture. The WIPP-1A mixed culture typically reaches steady-state concentration within several days, whereas the BAB pure culture requires several weeks. Because of the rapid response of the WIPP-1A culture, most of the experiments in support of the WIPP Colloid Research Program were conducted with that culture to expedite the research program. A

complementary set of experiments were repeated with the BAB mixed culture, to evaluate the representativeness of the pure culture. Experiments were conducted over periods of 11 to 15 days for the WIPP-1A microbe culture, and up to 21 days for the BAB culture. Each experiment consisted of a subset of two or three replicate test vessels, which were sampled during the overall test interval, to provide time sequence data. In addition, replicate test vessels which were not inoculated with microbes were included in each experiment to provide a control. Sequential filtration with 0.03 μm, 0.4 μm, and 10 μm filter pore sizes was conducted on each vessel. The following size fractions were obtained:

fluid column sample	**particle size**	**actinide association with:**
not filtered	all	all forms listed below
0.22 μm syringe filter, filtrate	< 0.22 μm	dissolved; lysed microbes
10 μm filter, filter rententate	> 10 μm	clumped microbes
10 μm filter, filtrate	< 10 μm	dissolved; dispersed microbes; lysed microbes
0.4 μm filter, filter rententate	= 0.4 to 10 μm	dispersed microbes
0.4 μm filter, filtrate	< 0.4 μm	dissolved; lysed microbes
0.03 μm filter, filter rententate	= 0.03 to 0.4 μm	lysed microbes
0.03 μm filter, filtrate	< 0.03 μm	dissolved; lysed microbes

In addition to the potential actinide associations listed above, there was some evidence of the formation of inorganic precipitates in some of the experiments. The nutrient used in many experiments was phosphate (1 g PO_4^{3-}/L), which is known to coprecipitate actinide cations. The inoculated control samples provided the means to evaluate the extent of that experimental artifact. The control samples also provided the means to assess the extent of sorption of actinides onto test vessels, sampling, and filtration equipment. All sequential filters were composed of the same material, which simplifies assessment of sorption on the filtration equipment.

The toxicity experiments were conducted as a component of the filtration experiments described above, by varying the actinide concentration, and comparing growth curves measured by optical density and/or by direct cell counting. To increase the total concentration of actinides in solution, EDTA was added in some experiments in a one-to-one molar ratio with the actinide element. That approach was taken for some Pu experiments, and all of the Th, Np, and Am experiments.

Interpretation of Experimental Results

Proportionality constants (PROPMIC) describing the amount of actinide element bound to mobile microbes were determined from the data listed above. In addition, maximum concentrations of actinides that could be associated with microbes (CAPMIC) were determined from the experimental data. Those two parameters are suitable for use in PA calculations, when coupled with dissolved actinide solubility values.

The 0.4 μm filter rententate and 0.03 μm filtrate (acquired from the inoculated vessels, not the uninoculated control vessels) were selected to represent the microbial actinide and dissolved actinide concentrations, respectively. The ratio between the microbial actinide and dissolved actinide, both expressed in molarity, represents the proportionality constant value used for the PROPMIC parameter. The 0.4 μm filter rententate was selected to represent the microbial fraction because nearly all of the bacteria biomass was associated with that filter. A small concentration of actinides was associated with suspected biomass trapped on the 10 μm filter, as clumped microbes, and on the 0.03 μm filter, as lysed microbes. The contribution of actinides associated biomass consisting of clumped and lysed microbes was typically at least one order-of-magnitude less than the actinide concentration associated with the dispersed microbes collected on the 0.4 μm filter. The concentration of dissolved actinides measured from the 0.03 filter filtrate was used in the ratio because it provides the best indication of final dissolved actinide concentration. The individual proportionality constants for the filtration experiments are summarized in Table 1. Representative values for PROPMIC were developed from the individual proportionality constants on an element-by-element basis. Results of experiments using the BAB culture were disregarded, because of their lower uptake of actinides (especially plutonium), and because of the limited number of experiments conducted with that culture. For the WIPP-1A culture, the first sampling period (2 to 4 days, but generally 3 days) was disregarded in determining proportionality constants because steady state population had not yet been reached. The remaining values were averaged arithmetically (refer to comment column in Table 1).

The filtration experiments discussed above (see Table 1) also provided the basis for determining CAPMIC values. Final cell population numbers in the test vessels were estimated using measurements of optical density at a wavelength of 600 nm or by direct counting with epifluorescent microscopy. The magnitude of the toxicity effects were estimated by comparing final cell numbers obtained from a series of test vessels with varying actinide concentration. The direct counting technique provided the most dependable measure of cell number and was used where available. The CAPMIC value is defined as the actinide concentration in molarity at which no growth was observed. For cases where growth clearly diminished as actinide concentration increased, but the actinide concentration was not great enough to stop growth, CAPMIC values were determined by linear extrapolation of population numbers, and then

adding an order-of-magnitude to account for uncertainty. It appears that the toxicity effects are due to chemical toxicity rather than radiotoxicity. Because of the high radiation levels of americium and safety considerations in the laboratory facility used, the molar concentration could not be increased to the point at which toxicity effects could be observed. Consequently no CAPMIC value is currently available for americium. The experimental basis for determination of CAPMIC values and comments on the determination of parameter values are summarized in Table 2.

The experiments conducted do not provide sufficient information to enable us to formulate a distribution of values for PROPMIC and CAPMIC. Therefore, single values for PROPMIC and CAPMIC are provided to the PA Department. Uncertainties due to analytical precision are small compared to uncertainties in knowledge of the microbe culture which might predominate in the WIPP repository or in the Culebra in an intrusion scenario. The proportionality factor approach coupled with the plus or minus one order-of-magnitude uncertainty in actinide solubilities results in a plus or minus one order-of-magnitude uncertainty in the concentration of actinides bound by mobile microbes.

Summary

Interpreted values for PROPMIC and CAPMIC are summarized in Attachments C, E, and F.

References

Brush, L. H., 1990. Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant. SAND90-0266. Albuquerque, NM: Sandia National Laboratories.

Francis, A. J., and J. B. Gillow, 1994. Effects of Microbial Processes on Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions. Progress Report Through 1992. SAND93-7036. Albuquerque, NM: Sandia National Laboratories.

Novak, C. F., 1996, The Waste Isolation Pilot Plant (WIPP) Actinide Source Term Program: Test Plan for the Conceptual Model and the Dissolved Concentration Submodel, Albuquerque, New Mexico, Sandia National Laboratories, SAND95-1895 (submitted).

Novak, C. F., and Moore, R. C., 1996, Estimates of dissolved Concentration for +III, +IV, +V, and +VI Actinides in a Salado and a Castile Brine under Anticipated Repository Condtions. SNL Technical memorandum dated 28 March 1996 to Malcolm D. Siegel.

Papenguth, H. W., and Behl, Y. K., 1996, Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant, SNL Test Plan TP 96-01.

Siegel, M. D., 1996, Solubility parameters for use in the CCA NUTS and GRIDFLOW calculations. SNL Technical memorandum dated 29 March 1996 to Martin S. Tierney.

Table 1.—Microbe filtration results.

date of experiment	actinide	form	initial target actinide concentration (M)	microbe culture	sampling time (days)	0.4 µm filter, filter retentate, inoculated vessel	uncertainty	0.03 µm filter, filtrate, inoculated vessel	uncertainty	proportionality constant (microbial An/dissolved An in M/M)	comments related to selection of PROPMIC values
PLUTONIUM											
28-Nov-95	Pu-239	Pu(V) EDTA	1.00E-05	WIPP-1A	3	3.59E-07	not available	1.30E-06	not available	0.2762	disregard
28-Nov-95	Pu-239	Pu(V) EDTA	1.00E-05	WIPP-1A	8	3.67E-08	not available	5.80E-07	not available	0.0633	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) EDTA	1.00E-05	WIPP-1A	15	7.85E-09	not available	1.66E-07	not available	0.0473	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) EDTA	1.00E-06	WIPP-1A	3	1.81E-07	not available	6.85E-08	not available	2.6423	disregard
28-Nov-95	Pu-239	Pu(V) EDTA	1.00E-06	WIPP-1A	8	7.55E-09	not available	3.05E-08	not available	0.2475	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) EDTA	1.00E-06	WIPP-1A	15	2.69E-09	not available	1.07E-08	not available	0.2514	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) EDTA	1.00E-07	WIPP-1A	3	7.28E-09	not available	1.94E-08	not available	0.3753	disregard
28-Nov-95	Pu-239	Pu(V) EDTA	1.00E-07	WIPP-1A	15	1.11E-10	not available	5.82E-08	not available	0.0019	include in mean for Pu
12-Feb-96	Pu-239	Pu(V) EDTA	1.00E-06	WIPP-1A	2	3.16E-08	4.59E-10	1.38E-08	1.34E-09	2.2899	disregard
12-Feb-96	Pu-239	Pu(V) EDTA	1.00E-06	WIPP-1A	8	1.44E-09	9.50E-11	6.02E-09	1.11E-10	0.2392	include in mean for Pu
12-Feb-96	Pu-239	Pu(V) EDTA	1.00E-06	WIPP-1A	11	9.24E-10	1.70E-10	6.33E-09	3.22E-10	0.1460	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-05	WIPP-1A	3	2.54E-07	not available	1.63E-06	not available	0.1558	disregard
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-05	WIPP-1A	8	5.18E-07	not available	1.16E-06	not available	0.4466	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-05	WIPP-1A	15	2.87E-08	not available	1.83E-06	not available	0.0157	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-06	WIPP-1A	3	2.43E-07	not available	9.94E-08	not available	2.4447	disregard
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-06	WIPP-1A	8	1.17E-08	not available	4.08E-08	not available	0.2868	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-06	WIPP-1A	15	1.00E-09	not available	2.01E-08	not available	0.0498	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-07	WIPP-1A	3	1.15E-08	not available	2.29E-08	not available	0.5022	disregard
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-07	WIPP-1A	8	2.93E-09	not available	1.43E-09	not available	2.0490	include in mean for Pu
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00E-07	WIPP-1A	15	7.65E-11	not available	1.07E-07	not available	0.0007	include in mean for Pu
12-Feb-96	Pu-239	Pu(V) EDTA	1.00E-06	BAB	3	2.52E-10	4.28E-11	5.68E-08	3.19E-10	0.0044	disregard
12-Feb-96	Pu-239	Pu(V) EDTA	1.00E-06	BAB	9	1.45E-09	1.14E-10	3.89E-08	5.96E-10	0.0373	disregard
12-Feb-96	Pu-239	Pu(V) EDTA	1.00E-06	BAB	21	1.22E-09	2.00E-10	5.46E-08	5.45E-10	0.0223	disregard
PROPMIC(Pu):	mean										3.0e-01
	standard deviation										5.44e-01
	number of samples										1.3e+01

Table 1.—Microbe filtration results.

date of experiment	actinide	form	initial target actinide concentration (M)	microbe culture	sampling time (days)	0.4 µm filter, filter retentate, inoculated vessel	uncertainty	0.03 µm filter, filtrate, inoculated vessel	uncertainty	proportionality constant (microbial An/dissolved An in M/M)	comments related to selection of PROPMIC values
AMERICIUM											
11-Mar-96	Am-243	Am EDTA	5.00E-07	WIPP-1A	3	1.82E-08	1.15E-10	1.84E-09	2.12E-10	9.8913	disregard
11-Mar-96	Am-243	Am EDTA	5.00E-07	WIPP-1A	7	6.32E-09	2.52E-10	3.35E-09	6.65E-10	1.8866	include in mean for Am
11-Mar-96	Am-243	Am EDTA	5.00E-07	WIPP-1A	11	1.22E-08	5.33E-10	2.28E-09	1.05E-10	5.3509	include in mean for Am
PROPMIC(Am):	mean										3.6e+00
	standard deviation										2.45e+00
	number of samples										2.0e+00
NEPTUNIUM											
29-Mar-96	Np-237	Np(V) EDTA	5.00E-05	WIPP-1A	3	6.24E-06	1.58E-07	8.04E-06	4.11E-06	0.7761	disregard
29-Mar-96	Np-237	Np(V) EDTA	5.00E-05	WIPP-1A	7	2.33E-06	1.24E-06	1.98E-07	8.89E-09	11.7677	include in mean for Np
29-Mar-96	Np-237	Np(V) EDTA	5.00E-05	WIPP-1A	11	not available	not available	not available	not available	not available	disregard
PROPMIC(Np):	mean										1.2e+01
	standard deviation										not applicable
	number of samples										1.0e+00
THORIUM											
11-Mar-96	Th-232	Th EDTA	1.00E-03	WIPP-1A	7	4.90E-04	1.41E-04	2.72E-04	9.14E-05	1.8015	include in mean for Th
11-Mar-96	Th-232	Th EDTA	1.00E-03	WIPP-1A	13	6.95E-04	7.55E-05	1.55E-04	6.10E-06	4.4839	include in mean for Th
PROPMIC(Th):	mean										3.1e+00
	standard deviation										1.90e+00
	number of samples										2.0e+00
URANIUM											
9-Feb-96	U-238	U(VI) nitrate	1.00E-03	WIPP-1A	4	5.30E-07	3.18E-08	2.93E-04	1.06E-06	0.0018	disregard
9-Feb-96	U-238	U(VI) nitrate	1.00E-03	WIPP-1A	13	2.11E-06	2.61E-07	9.83E-04	1.68E-05	0.0021	include in mean for U
22-Feb-96	U-238	U(VI) nitrate	1.00E-03	BAB	5	2.17E-06	1.64E-07	1.24E-03	4.20E-06	0.0018	disregard
22-Feb-96	U-238	U(VI) nitrate	1.00E-03	BAB	13	2.22E-06	1.89E-07	1.16E-03	4.20E-06	0.0019	disregard
PROPMIC(U):	mean										2.1e-03
	standard deviation										not applicale
	number of samples										1

Table 2.—Microbe toxicity results.

date of experiment	actinide	form	initial target actinide concentration (M)	0.2 µm filter, filtrate (actinide solubility; M)	final cell number (cells/mL)	final optical density at 600 nm (units)	final pH	magnitude of toxicity (relative to no actinide control)	toxic concentration - observed (M)	toxic concentration - extrapolated (M)	comments related to selection of CAPMIC values
THORIUM											
13-Mar-96	control (none)	not applicable	not applicable	not applicable	not analyzed	0.567	8.08	not applicable			
13-Mar-96	Th-232	Th(IV) nitrate	4.30e-04	0 (ppt.)	not analyzed	0.645	8.22	none			
13-Mar-96	Th-232	Th(IV) nitrate	1.10e-03	0 (ppt.)	not analyzed	0.58	8.28	none			
13-Mar-96	Th-232	Th(IV) nitrate	2.20e-03	0 (ppt.)	not analyzed	0.352 (ppt.)	6.05	extreme	1.90e-03		use for Th
13-Mar-96	Th-232	Th(IV) nitrate	4.30e-03	0 (ppt.)	not analyzed	0.427 (ppt.)	5.76	extreme	3.46e-03		disregard, toxicity observed at lower value
13-Mar-96	Th-232	Th(IV) EDTA	4.30e-04	3.41e-04	not analyzed	0.063	6.45	inconclusive			
13-Mar-96	Th-232	Th(IV) EDTA	1.10e-03	1.01e-03	4.24e+06	0.071	6.13	moderate			
13-Mar-96	Th-232	Th(IV) EDTA	2.20e-03	1.90e-03	not analyzed	0.004	6.08	extreme	2.20e-03		disregard, toxicity observed at lower value
13-Mar-96	Th-232	Th(IV) EDTA	4.30e-03	3.46e-03	not analyzed	0	6.32	extreme	4.30e-03		disregard, toxicity observed at lower value
URANIUM											
17-Oct-95	control (none)	not applicable	not applicable	not applicable	2.62e+08	0.541	8.1	not applicable	not applicable	not applicable	
17-Oct-95	U-238	U(VI) nitrate	4.20e-04	4.20e-04	2.57e+08	0.543	8.04	none			
17-Oct-95	U-238	U(VI) nitrate	1.10e-03	1.00e-03	3.08e+08	0.539	7.94	none			
17-Oct-95	U-238	U(VI) nitrate	2.10e-03	0 (ppt.)	2.24e+05	0.272	6.26	extreme	2.10e-03		use for U
17-Oct-95	U-238	U(VI) nitrate	4.20e-03	0 (ppt.)	2.02e+05	0.533	5.9	extreme	4.20e-03		disregard, toxicity observed at lower value
17-Oct-95	U-238	U(VI) citrate	4.20e-04	4.20e-04	2.77e+08	0.514	8.01	none			
17-Oct-95	U-238	U(VI) citrate	1.10e-03	1.10e-03	2.39e+08	0.508	7.96	none			
17-Oct-95	U-238	U(VI) citrate	2.10e-03	0 (ppt.)	2.58e+05	0.318	6.11	extreme	2.10e-03		use for U
17-Oct-95	U-238	U(VI) citrate	4.20e-03	0 (ppt.)	1.93e+05	0.344	5.91	extreme	4.20e-03		disregard, toxicity observed at lower value
NEPTUNIUM											
19-Mar-96	control (none)	not applicable	not applicable	not applicable	not analyzed	0.8	8.04	none			
19-Mar-96	Np-237	Np(V) EDTA	5.00e-06	2.70e-06	not analyzed	0.788	8.02	none			
19-Mar-96	Np-237	Np(V) EDTA	5.00e-05	2.53e-05	not analyzed	0.802	7.95	none			
19-Mar-96	Np-237	Np(V) EDTA	5.00e-04	2.65e-04	not analyzed	0.141	6.57	but some growth	2.65e-04		use for Np, but increase by one order of magnitude because of some growth
PLUTONIUM											
28-Nov-95	control (none)	not applicable	not applicable	not applicable	3.40e+08	0.672	8.157	not applicable	not applicable	not applicable	
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00e-07	5.01e-08	3.20e+08	0.683	8.197	none			
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00e-06	6.90e-07	1.40e+08	0.453	8.327	moderate			
28-Nov-95	Pu-239	Pu(V) perchlorate	1.00e-05	8.80e-06	5.50e+07	0.237	7.94	extreme		7.71e-06	disregard, toxicity observed at lower value
28-Nov-95	Pu-239	Pu(V) EDTA	1.00e-07	5.50e-08	2.80e+08	0.691	8.223	none			
28-Nov-95	Pu-239	Pu(V) EDTA	1.00e-06	6.20e-07	1.20e+08	0.499	8.387	moderate			
28-Nov-95	Pu-239	Pu(V) EDTA	1.00e-05	8.00e-06	9.80e+07	0.532	8.363	extreme		6.83e-06	use for Pu, but increase by one order of magnitude
AMERICIUM											
5-Mar-96	control (none)	not applicable	not applicable	not applicable	not analyzed	0.89	7.93	not applicable			
5-Mar-96	Am-243	Am(III) EDTA	5.00e-08	2.62e-08	not analyzed	0.864	7.98	none			
5-Mar-96	Am-243	Am(III) EDTA	5.00e-07	3.36e-07	not analyzed	0.821	8.04	none			
5-Mar-96	Am-243	Am(III) EDTA	5.00e-06	2.65e-06	not analyzed	0.79	8.04	slight	>2.65E-06		inconclusive; Am concentrations not sufficiently high

Attachment B:

Stockman, Christine T., 1996, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 29 March 1996 to Hans W. Papenguth.

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: 3/29/96

to: Hans W. Papenguth

Christine T. Stockman

from: Christine T. Stockman

subject: Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations

In order to properly model the transport of radionuclides within the Salado formation, we will need information about the possible transport of these radionuclide on colloids. In this memo we request the maximum mobilized radionuclide concentration and/or the proportionality constant defining the moles mobilized on colloid per moles in solution, for each transported element and colloid type. We are planning to transport Am, Pu, U, and Th, and may also transport Cm, Np, Ra, and Sr. If we transport Ra and Sr, we are planning to model them as very soluble, and not sorbed, so I believe modeling of colloids for them will not be necessary. For Cm solubility, we will be using the Am(III) model. If you believe that Cm colloids also behave similarly to Am colloids, we could extend the chemical analogy to the colloid behavior. If you agree with these simplifications then we will need the parameters for Am, Pu, U, Th and Np only.

Suggested names for database entry:
IDMTRL: Am, Pu, U, Th, Np

IDPRAM:

CONCINT	for concentration of actinide on mobilized intrinsic colloid
CONCMIN	for concentration of actinide on mobilized mineral fragments
CAPHUM	for maximum concentration of actinide on humic colloids
CAPMIC	for maximum concentration of actinide on microbe colloids
PROPHUM	for moles actinide mobilized on humic colloids per moles dissolved
PROPMIC	for moles actinide mobilized on microbe colloids per moles dissolved

You will need to provide a distribution for each material-parameter pair, but that distribution may be "CONSTANT" for most of the numbers. Eight sampling slots have been reserved for the most important of these parameters that have non-constant distributions.

cc:

Mary-Alena Martell	Amy S. Johnson	J. T. Schneider
Hong-Nian Jow	Martin S. Tierney	Richard V. Bynum
E. James Nowak	W. George Perkins	Ali A. Shinta
James L. Ramsey		

SWCF-A:WBS1.2.07.1.1:PDD:QA:GENERAL

Attachment C:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters. SNL Technical Memorandum dated 29 March 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 29 March 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters

This memorandum summarizes best estimates for the mobile colloidal actinide source term for input to the WIPP Compliance Certification Application. The use of material and parameter identification codes is consistent with your letter to me dated 29 March 1996 requesting parameter values. In the attached table, I have provided best estimates for the following material-parameter combinations:

IDMTRL: Th, U, Np, Pu, Am

IDPRAM:

CONCINT	concentration of actinide associated with mobile actinide intrinsic colloids
CONCMIN	concentration of actinide associated with mobile mineral fragment colloids
CAPHUM	maximum concentration of actinide associated with mobile humic colloids
CAPMIC	maximum concentration of actinide associated with mobile microbes
PROPHUM	proportionality constant for concentration of actinides associated with mobile humic colloids
PROPMIC	proportionality constant for concentration of actinides associated with mobile microbes

As a first approximation, the colloidal behavior of curium can be simulated be using parameter values for americium. The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

copy to:

MS 1328	Hong-Nian Jow, 6741
MS 1328	Amy S. Johnson, 6741
MS 1328	Martin S. Tierney, 6741
MS 1320	E. James Nowak, 6831 EJN
MS 1320	R. Vann Bynum, 6831
MS 1341	John T. Holmes, 6748
MS 1341	Laurence H. Brush, 6748
MS 1341	Robert C. Moore, 6748
MS 1341	W. Graham Yelton, 6748
MS 1320	W. George Perkins, 6748 wgp
MS 1320	John W. Kelly, 6748
MS 1320	Daniel A. Lucero, 6748
MS 1320	Craig F. Novak, 6748
MS 1320	Hans W. Papenguth, 6748
MS 1320	Malcolm D. Siegel, 6748
MS 1324	Susan A. Howarth, 6115
MS 1341	Kurt O. Larson, 6747
MS 1341	Ruth F. Weiner, 6747
MS 1324	Richard Aguilar, 6851

SWCF-A:WBS1.1.10.2.1

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CONCMIN	Th	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
CONCMIN	U	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
CONCMIN	Np	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
CONCMIN	Pu	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
CONCMIN	Am	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
PROPHUM	Th	6.4e+00	6.4e+00	6.4e+00	moles colloidal humic-bound Th per moles dissolved Th	constant	2,3
PROPHUM	U	1.4e+00	1.6e-01	2.0e+00	moles colloidal humic-bound U per moles dissolved U	triangular	2,3,4
PROPHUM	Np	4.0e+00	4.0e+00	4.0e+00	moles colloidal humic-bound Np per moles dissolved Np	constant	2,3
PROPHUM	Pu	5.9e+00	5.9e+00	5.9e+00	moles colloidal humic-bound Pu per moles dissolved Pu	constant	2,3
PROPHUM	Am	2.5e+00	1.9e-01	3.9e+00	moles colloidal humic-bound Am per moles dissolved Am	triangular	2,3,4

Mobile-Colloidal-Actinide Source Term—Concentration/Proportionality Constants

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CAPHUM	Th	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
CAPHUM	U	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
CAPHUM	Np	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
CAPHUM	Pu	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
CAPHUM	Am	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
Notes:							
general	The colloidal actinide source term is added to the dissolved actinide source term.						
general	None of the parameters are correlated.						
1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
3	Proportionality constants are to be used with the sum of actinide oxidation species for each actinide element (uncomplexed only, i.e., without organic ligand contribution).						
4	If a distribution is not used for humic-bound U or Am, use the maximum concentration as a constant value.						
5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e. the sum of dissolved plus colloidal actinide).						

Attachment D:

Stockman, Christine T., 1996, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 2 April 1996 to Hans W. Papenguth.

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: 4/2/96

to: Hans W. Papenguth

Christine T. Stockman

from: Christine T. Stockman

subject: Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations

YiFeng Wang has revised his recommendation to use 2 invariant points in the PA calculation. He now recommends that we use the $Mg(OH)_2 + MgCO_3$ invariant point for all calculations. If this invalidates the assumptions that you used to prepare colloid concentration or proportion parameters please indicate as soon as possible which parameters are affected, and as soon as possible after that provide a memo documenting the new values.

cc:
Mary-Alena Martell
Amy S. Johnson
Hong-Nian Jow
Martin S. Tierney
J. T. Schneider
Richard V. Bynum
E. James Nowak
W. George Perkins
SWCF-A:WBS1.2.07.1.1:PDD:QA:GENERAL

Attachment E:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL Technical Memorandum dated 18 April 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 18 April 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters, Revision 1

This memorandum summarizes the revised best estimates for the mobile colloidal-actinide source term for input to the WIPP Compliance Certification Application. Values presented herein supersede the values provided to you on 29 March 1996 (Papenguth, 1996) in response to your memorandum of 29 March 1996 (Stockman, 1996a). The present memorandum addresses your request for modifications stated in your memorandum dated 2 April 1996 (Stockman, 1996b).

In the attached table, I have summarized the complete set of parameters and values for the mobile colloidal-actinide source term. Revised values for maximum actinide concentration values for humic substances and constants describing actinide concentrations associated with mineral-fragment-type colloidal particles are included. New values (i.e., corresponding to new idpram's and idmtrl's) for proportionality constants describing actinide concentrations associated with humic substances are also included.

The revisions described herein for humic substances reflect a shift in approach from proportionality constants describing actinide-humic concentration by element, to proportionality constants describing actinide-humic concentration by actinide oxidation state. That change affects treatment of actinide elements that will have multiple oxidation states in the WIPP repository [e.g., U(IV) and U(VI); Np(IV) and Np(V); Pu(III) and Pu(IV)]. A second modification in approach, is that I now provide values for two cases: (1) a Castile brine in equilibrium with brucite and magnesite; and (2) a Salado brine in equilibrium with brucite and magnesite. For humic substances, the following material-parameter combinations apply:

IDMTRL: PHUMOX3 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 3;

PHUMOX4 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 4;

PHUMOX5 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 5; and

PHUMOX6 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 6.

IDPRAM: PHUMCIM proportionality constant for concentration of actinides associated with mobile humic colloids, in Castile brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite);

PHUMSIM proportionality constant for concentration of actinides associated with mobile humic colloids, in Salado brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite).

The revisions made for actinide concentration associated with mineral-fragment-type colloidal particles were made to include the potential contribution of actinide-mineral colloids formed in the Culebra. To accomplish that, the original repository source term values (Papenguth, 1996) have been doubled. That approach is not necessary for humic substances or actinide intrinsic colloids [i.e., Pu(IV)-polymer], because their concentrations are limited by solubilities. Concentrations of actinides associated with microbes are limited by the steady-state population of microbes in the repository, which will not increase when introduced to the Culebra.

The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

References

Papenguth, H.W., 1996, Colloidal Actinide Source Term Parameters, SNL technical memorandum dated 29 March 1996 to Christine T. Stockman.

Stockman, C.T., 1996a, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations, SNL technical memorandum dated 29 March 1996 to Hans W. Papenguth.

Stockman, C.T., 1996b, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations, SNL technical memorandum dated 2 April 1996 to Hans W. Papenguth.

copy to:

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MS 1341	Kurt W. Larson, 6747
MS 1341	Ruth F. Weiner, 6747
MS 1324	Richard Aguilar, 6851
DOE/CAO	Robert A. Stroud

SWCF-A:WBS1.1.10.2.1

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CONCMIN	Th	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
revised	CONCMIN	U	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
revised	CONCMIN	Np	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
revised	CONCMIN	Pu	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
revised	CONCMIN	Am	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
	CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
	CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
	CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
	CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
	CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
revised (new)	PHUMSIM	PHUMOX3	1.3e-01	8.0e-03	1.9e-01	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
revised (new)	PHUMSIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
revised (new)	PHUMSIM	PHUMOX5	4.8e-04	5.3e-05	9.1e-04	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
revised (new)	PHUMSIM	PHUMOX6	5.6e-02	8.0e-03	1.2e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX3	1.1e+00	6.5e-02	1.6e+00	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
revised (new)	PHUMCIM	PHUMOX5	3.9e-03	4.3e-04	7.4e-03	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX6	2.8e-01	6.2e-02	5.1e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CAPHUM	Th	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
revised	CAPHUM	U	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
revised	CAPHUM	Np	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
revised	CAPHUM	Pu	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
revised	CAPHUM	Am	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
	PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
	PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
	PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
	PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
	PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
	CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
	CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
	CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
	CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
	CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
	Notes:							
	general	The colloidal actinide source term is added to the dissolved actinide source term.						
	general	None of the parameters are correlated.						
	1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
	2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
	3	Proportionality constants are to be used with the inorganic actinide solubility value (uncomplexed only, i.e., without organic ligand contribution).						
	4	If a distribution is not used, use the maximum concentration as a constant value.						
	5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
	6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
	7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e., the sum of dissolved plus colloidal actinide).						

Attachment F:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 2. SNL Technical Memorandum dated 22 April 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 22 April 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters, Revision 2

In my rush to complete and distribute Revision 1 (Papenguth, 1996), I made mistakes on the minimum and maximum values for actinide concentrations associated with mineral-fragment-type colloidal particles. The attached Table contains the correct values.

References

Papenguth, H.W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL technical memorandum dated 18 April 1996 to Christine T. Stockman.

copy to:

MS 1328	Hong-Nian Jow, 6741
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MS 1341	Ruth F. Weiner, 6747
MS 1324	Richard Aguilar, 6851
DOE/CAO	Robert A. Stroud

SWCF-A:WBS1.1.10.2.1

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CONCMIN	Th	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
revised	CONCMIN	U	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
revised	CONCMIN	Np	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
revised	CONCMIN	Pu	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
revised	CONCMIN	Am	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
	CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
	CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
	CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
	CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
	CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
	PHUMSIM	PHUMOX3	1.3e-01	8.0e-03	1.9e-01	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
	PHUMSIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
	PHUMSIM	PHUMOX5	4.8e-04	5.3e-05	9.1e-04	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
	PHUMSIM	PHUMOX6	5.6e-02	8.0e-03	1.2e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4
	PHUMCIM	PHUMOX3	1.1e+00	6.5e-02	1.6e+00	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
	PHUMCIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
	PHUMCIM	PHUMOX5	3.9e-03	4.3e-04	7.4e-03	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
	PHUMCIM	PHUMOX6	2.8e-01	6.2e-02	5.1e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
	CAPHUM	Th	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
	CAPHUM	U	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
	CAPHUM	Np	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
	CAPHUM	Pu	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
	CAPHUM	Am	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
	PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
	PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
	PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
	PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
	PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
	CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
	CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
	CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
	CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
	CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
	Notes:							
	general	The colloidal actinide source term is added to the dissolved actinide source term.						
	general	None of the parameters are correlated.						
	1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
	2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
	3	Proportionality constants are to be used with the inorganic actinide solubility value (uncomplexed only, i.e., without organic ligand contribution).						
	4	If a distribution is not used, use the maximum concentration as a constant value.						
	5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
	6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
	7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e., the sum of dissolved plus colloidal actinide).						

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.7

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WPO # 35855

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 7 May 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Parameter Record Package for Colloidal Actinide Source Term Parameters

Attached is the Parameter Record Package for the WIPP PA parameters describing actinide concentrations associated with mobile **humic substances**. This Package is one of four describing the concentration of actinides associated with the four colloidal particle types. The complete set of Packages consists of the following:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

copy with Attachments to:

MS 1320	Hans W. Papenguth, 6748
MS 1320	W. George Perkins, 6748
MS 1341	Robert C. Moore, 6748
DOE/CAO	Robert A. Stroud

~~SWCF-A:WBS.1.1.10.2.1: Colloid Characterization and Transport~~
~~SWCF-A:WPO#:35855: Mobile-Colloidal-Actinide Source Term. 3. Humic Substances.~~

copy without Attachments to:

MS 1320	E. James Nowak, 6831
MS 1324	Susan A. Howarth, 6115
MS 1328	Hong-Nian Jow, 6741
MS 1328	Amy S. Johnson, 6741
MS 1328	Martin S. Tierney, 6741
MS 1328	Mary-Alena Martell, 6749
MS 1341	John T. Holmes, 6748

Parameter Record Package for Mobile-Colloidal Actinide Source Term.
Part 3. Humic Substances

The parameter values in this package are based on data which were collected under the guidance of the Principal Investigator for the Waste Isolation Pilot Plant (WIPP) Colloid Research Program, Hans W. Papenguth, for input to the WIPP Data Entry Form and for use in WIPP Performance Assessment (PA) calculations.

I. *Parameter No. (id):* Not applicable.

II. *Data/Parameter:* Not applicable.

III. *Parameter id (idpram):* PROPHUM, PHUMCIM, PHUMSIM, and CAPHUM.

IV. *Material:* Humic substances, which include fulvic acid, aliphatic humic acid, and aromatic humic acid, and the actinides Th, U, Np, Pu, and Am.

V. *Material Identification (idmtrl):* Th, U, Np, Pu, and Am (for PROPHUM and CAPHUM); PHUMOX3, PHUMOX4, PHUMOX5, and PHUMOX6 (for PHUMCIM and PHUMSIM).

VI. *Units:* For proportionality constants (PROPHUM, PHUMCIM and PHUMSIM), the units are "moles colloidal humic-bound actinide per moles of dissolved actinide." For the maximum concentration of each actinide associated with mobile humic colloids (CAPHUM), the units are "moles colloidal humic-bound actinide per liter of dispersion."

VII. *Distribution Information.*

A. *Category:* The development of parameter values and their distributions is described in Attachment A. Summaries of the parameter values are presented in Attachments C, E, and F. Constant CAPHUM values are supplied for all five of the actinide elements listed. Constant PROPHUM values are supplied for Th, Np, and Pu. Constant PHUMCIM and PHUMSIM values are supplied for PHUMOX4. Triangular distributions are supplied for PROPHUM values for U and Am. Triangular distributions are supplied for PHUMCIM and PHUMSIM values for PHUMOX3, PHUMOX5, and PHUMOX6. In the event that those triangular distributions of parameter values cannot be sampled in the PA calculations, the maximum value should be selected. The decision of whether to use the distribution or the constant value is to be made by the PA Department.

B. *Mean:* See Attachments A, C, E, and F. (Note that for triangular distributions, the apices of the triangle are defined by the minimum value, the most likely value, and the maximum value; refer to Attachments).

C. *Median:* Not applicable.

D. *Standard Deviation:* Not applicable.

E. *Maximum:* See Attachments A, C, E, and F.

F. *Minimum:* See Attachments A, C, E, and F.

G. *Number of data points:* Not applicable.

VIII. *Data Collection and Interpretation Information.*

A. *Data Source Information:* WIPP observational data and literature.

B. *Data Collection (for WIPP observational data).*

1. *Data Collection or Test Method:* Experiments were conducted at Florida State University (FSU; contract number AH-5590; Greg R. Choppin, FSU PI), at Colorado School of Mines (CSM; contract number AR-9240; Bruce D. Honeyman, CSM PI), and at SNL (Hans W. Papenguth and co-workers). Descriptions of experiments conducted at those institutions are included in Attachment A.

2. *Assumptions Made During Testing:* See Attachment A.

3. *Standard Error of Measurement of Tests Performed:* See Attachment A.

4. *Form of Raw Data:* Solubilities of humic substances were reported in units of mg/L. Complexation of actinides by humic substances were described in terms of stability constants. Humic substance site binding density was reported in units of milliequivalents of OH^- per gram of humic substance.

5. *References Related to Data Collection:* See Attachment A.

6. *QA Status of Data:*

a. *Are all of the data qualified?* Yes.

b. *Were data qualified by QAP 20-3?* No. Data packages will be submitted for work conducted at FSU, CSM, and at SNL (see VIII,B,1 above for contract numbers), under File code WBS 1.1.10.2.1.

c. *Were the data the subject of audit/surveillance by SNL or DOE?* Yes. Florida State University (contract number AH-5590) was audited by SNL (94-03 and EA95-02) and is scheduled to be audited again in May 1996 (EA96-15). Colorado School of Mines (contract number AR-9240) is working under the SNL WIPP QA Program.

d. *Were the data collected under an SNL approved QA program?* Yes. Data were collected under SNL WIPP QAPD, Rev. P, effective October 1, 1992, and SNL WIPP QAPD, Rev. R, effective July 31, 1995. Data were collected under a test plan for the WIPP Colloid Research Program (Papenguth and Behl, 1996). Detailed descriptions of the experiments and interpretation listed herein will be published in a SAND report. Documents related to data collection at SNL, Florida State University, and the Colorado School of Mines will be archived in the Sandia WIPP Central Files (SWCF; File code WBS 1.1.10.2.1).

C. *Interpretation of Data.*

1. *Was the interpretation made by reference to previous work.* No.

2. *Was the interpretation made by using newly performed calculations?* Yes.

3. *Form of Interpreted Data.* List of interpreted values.

4. *Assumptions Made During Interpretation.* See Attachment A.

5. *Name of Code(s)/Software used to Interpret Data:* Not applicable.

6. *QA Status of Code(s) used to Interpret Data:* Not applicable.

   a. *Was the code qualified under QAP 19-1?* Not applicable.

   b. *Was the code qualified under QAP 9-1?* Not applicable.

7. *References Related to Data Interpretation:* See XI below and Attachment A.

8. *For interpretations made by using a newly performed calculations provide documentation that you followed the requirements of QAP 9-1 Appendix B.* The data analysis is controlled by Analysis Plan for the Colloid Research Program, AP-004 (Behl and Papenguth, 1996).

9. *For routine calculations (not using code) did you follow requirements of QAP 9-5?* Yes.

IX. *Correlation with other Parameters:* Parameter values describing the concentration of actinides associated with mobile humic substances are linked to solubility of the dissolved actinides, with a maximum value which cannot be exceeded.

X. *Limitations or qualifications for usage of data by Performance Assessment (PA):* None.

XI. *References cited above:*

Behl, Y.K., and Papenguth, H.W., 1996, Analysis Plan for the WIPP Colloid Research Program WBS #1.1.10.2.1, SNL Analysis Plan AP-004.

Papenguth, H.W., and Behl, Y.K., 1996, Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant, SNL Test Plan TP 96-01.

XII. *Attachments:*

Attachment A: Papenguth, Hans W., and Moore, Robert C., 1996, Rationale for Definition of Parameter Values for Humic Substances.

Attachment B: Stockman, Christine T., 1996, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 29 March 1996 to Hans W. Papenguth.

Attachment C: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters. SNL Technical Memorandum dated 29 March 1996 to Christine T. Stockman.

Attachment D: Stockman, Christine T., 1996, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 2 April 1996 to Hans W. Papenguth.

Attachment E: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL Technical Memorandum dated 18 April 1996 to Christine T. Stockman.

Attachment F: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 2. SNL Technical Memorandum dated 22 April 1996 to Christine T. Stockman.

XIII. *Distribution*

SWCF-A:WPO# 35855: Mobile-Colloidal Actinide Source Term. 3. Humic Substances.

SWCF-A:WBS 1.1.10.2.1: Colloid Characterization and Transport.

Attachment A:

Papenguth, Hans W., and Moore, Robert C., 1996, Rationale for Definition of Parameter Values for Humic Substances.

Attachment A.
Rationale for Definition of Parameter Values for Humic Substances

Hans W. Papenguth and Robert C. Moore

Introduction

The actinide source term at the WIPP is defined as the sum of contributions from dissolved actinide species and mobile colloidal actinide species. The dissolved actinide source term has been defined elsewhere (Novak, 1996; Novak and Moore, 1996; Siegel, 1996). It is important to note that colloidal actinides which are not suspended in the aqueous phase (i.e., not mobile) are not included in the colloidal actinide source term. Colloidal actinides may become immobilized by several mechanisms, including precipitation followed by coagulation and gravitational settling (humic substances and actinide intrinsic colloids), adhesion to fixed substrates (microbes), and flocculation or coagulation of colloidal particles followed by gravitational settling (mineral fragments). Sorption of colloidal actinides onto fixed substrates will also reduce the mobile colloidal actinide source term, but no credit is currently being taken for reduction by that means.

To facilitate quantification of the colloidal actinide source term, as well as an efficient experimental approach, the source term has been divided into four components according to colloid types. On the basis of (1) the behavior of colloidal particles in high ionic strength electrolytes, (2) the way in which colloidal particles interact with actinide ions, and (3) the transport behaviors of colloidal particles, four colloidal particle types are recognized (Papenguth and Behl, 1996): mineral fragments, actinide intrinsic colloids, humic substances, and microbes.

In this document, we focus on the quantification of the actinide concentration mobilized by humic substances. In terms of the WIPP performance assessment (PA) calculations, we discuss the rationale for selecting the values corresponding to the following parameter designators:

idpram:	PROPHUM	proportionality constant for concentration of actinides associated with mobile humic colloids;
	PHUMCIM	proportionality constant for concentration of actinides associated with mobile humic colloids, in Castile brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite);
	PHUMSIM	proportionality constant for concentration of actinides associated with mobile humic colloids, in Salado brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite); and

	CAPHUM	maximum (cap) concentration of actinide associated with mobile humic colloids.
idmtrl:	Th	thorium [i.e., Th(IV)];
	U	uranium [i.e., U(IV) and U(VI)];
	Np	neptunium [i.e., Np(IV) and Np(V)];
	Pu	plutonium [i.e., Pu(III) and Pu(IV)];
	Am	americium [i.e., Am(III)];
	PHUMOX3	proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 3 [i.e., Pu(III) and Am(III)];
	PHUMOX4	proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 4 [i.e., Th(IV), U(IV), Np(IV), and Pu(IV)];
	PHUMOX5	proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 5 [i.e., Np(V)]; and
	PHUMOX6	proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 6 [i.e., U(VI)].

Humic substances are defined as high-molecular-weight organic compounds generally present as anions in natural waters. Humic substances may consist of humic acids, which may be aliphatic or aromatic, or fulvic acids. The difference between humic acids and fulvic acids is largely an operational distinction; humic acids can be precipitated at pH values below about 2, whereas fulvic acids are soluble over the entire pH range. Fulvic acids generally have lower molecular weights than humic acids. The dominant functional group which may react with dissolved actinides are carboxyl groups, but phenolic hydroxyl and alcoholic hydroxyl groups also contribute to complexation. At the WIPP, humic substances may be introduced to the repository as a constituent of soil-bearing waste or may be a constituent of the organic carbon component of Castile, Salado, or Culebra groundwaters. Probably more importantly, humic substances may form from condensation reactions between microbial metabolites (e.g., carboxylic acids), cellulosic degradation products, and the extracellular polymers associated with microbes. Because of the general lack of knowledge in the scientific community regarding the formation and humic substances form, we have not attempted to directly quantify the amounts of humic substances likely to be introduced to the WIPP or that would form in situ. Instead, we have elected to bound the contribution of humic-bound actinides through quantification of humic-actinide complexation behavior coupled with quantification of solubilities of humic substances in WIPP-relevant brines. Regardless of the source of humic substances, the total concentration is

limited by the solubility of humic substances in WIPP brines. The chemical nature of humic substances generated in situ cannot be predicted either, but can be bounded by the three types of humic substances.

To determine the concentration of actinides associated with humic substances, four pieces of information are required: (1) the concentration of reactive humic substance in the aqueous phase (i.e., humic solubility); (2) the binding capacity of the humic substance; (3) actinide uptake (i.e., actinide complexation constants); and (4) concentrations of actinide ions in the aqueous phase (i.e., actinide solubility). The quantification of actinide solubilities (4) is described in Novak (1996) and results are summarized in Siegel (1996). In the remainder of this document, we focus on the determination of items (1) through (3), the interpretation of that information, and the development of parameter values suitable for PA calculations.

Experimental

In general, humic substances encompass a broad variety of high-molecular-weight organic compounds. The range of their chemical behaviors, however, is covered by consideration of three types: aliphatic humic acid (generally terrestrial); aromatic humic acid (generally marine); and fulvic acid. In our work, the following humic substances were used:

- FA-Suw: fulvic acid isolated from the Suwannee River purchased from the International Humic Substances Society, Golden, Colorado;
- HA_{al}-LBr: aliphatic humic acid isolated from sediments collected from Lake Bradford, Florida, prepared by Florida State University;
- HA_{al}-Ald: aliphatic humic acid purchased from Aldrich Chemical Co., purified by Florida State University;
- HA_{ar}-Gor: aromatic humic acid isolated from groundwaters near Gorleben, Germany, obtained from Professor J.-I. Kim, Institut für Radiochemie, München; and
- HA_{ar}-Suw: aromatic humic acid isolated from the Suwannee River purchased from the International Humic Substances Society, Golden, Colorado.

Solubilities of humic substances were measured at SNL (Hans W. Papenguth and coworkers) and at the Colorado School of Mines (CSM; contract number AR-9240; Bruce D. Honeyman, CSM PI). At SNL, solubilities were measured in experiments which were conducted over periods of several weeks. The concentrations of humic substances remaining in the fluid column was determined using a scanning fluorometer, carbon coulometer, and UV/Visible light spectrophotometer, in WIPP-relevant brine simulants with FA-Suw, HA_{al}-LBr, HA_{al}-Ald, and HA_{ar}-Suw. In addition to spectroscopic data, visible inspection proved valuable. In over saturation experiments, humic substances were dissolved in deionized water under basic pH

conditions to enhance dissolution and then added as a spike to a brine solution. In undersaturation experiments, humic substances were added directly to brine solutions and allowed to dissolve until an equilibrium was reached. In either case, an equilibrium was reached between dissolved (i.e., ionic) and precipitated humic substances. The precipitated humic substances coagulated and settled by gravity. The kinetics of precipitation were sufficiently slow that several weeks were required for equilibrium to be reached. Brine solutions consisted of a NaCl matrix with various concentrations of Ca^{2+} and Mg^{2+}. The concentration of Na^{+} in the brine had little effect on solubility except at very high concentrations, but the concentration of the divalent cations had a significant impact on humic substance solubilities. Consequently, experiments were conducted with a NaCl background electrolyte concentration with concentrations of Ca and Mg ranging from 10 mM each (representative of natural WIPP brines) to 500 mM each (representative of CaO or MgO backfill scenarios). At SNL, solubilities between approximately 1.5 mg/L and 2.0 mg/L were observed in systems containing 10 mM or greater Ca^{2+} and Mg^{2+}. For the calculations described below, the higher solubility value of 2.0 mg/L was used.

At the CSM, three humic substances (FA-Suw, HA_{al}-LBr, and HA_{ar}-Suw) were labeled with ^{14}C so that concentrations in WIPP-relevant brines could be tracked with liquid scintillation counting. That technique was anticipated to provide better analytical results because it is free from spectral interference problems of spectroscopic techniques. Because of slow precipitation kinetics, the duration of the experiment of only one week was not sufficient for equilibrium to be reached. Consequently, we elected to use the SNL results, which were conducted over a period of several weeks.

Site-binding capacity values were determined by titration at Florida State University for two humic substances (HA_{al}-LBr and HA_{al}-Ald). Those values were supplemented with values for a variety of humic substances compiled from published literature. In general, site-binding capacities for humic substances are between 3 and 6 meq OH^{-}/g, but in isolated cases are as low as about 1.5 and as high as about 9.5 meq OH^{-}/g. For the calculations described below, we used values of 4.65, 5.38, and 5.56 meq OH-/g for aliphatic humic acid, aromatic humic acid, and fulvic acid, respectively. The aliphatic humic acid value was determined from HA_{al}-LBr at FSU. The aromatic humic acid value was from Gorleben (Gohy-573). The fulvic acid value represents the mean of 11 published values for fulvic acids collected in Europe (Ephraim et al., 1995).

Actinide complexation factors for Am(III) and U(VI) binding on three humic substances (FA-Suw, HA_{al}-LBr, and HA_{ar}-Gor) were measured at Florida State University (FSU; contract number AH-5590; Greg R. Choppin, FSU PI). Complexation measurements were made at measured pH_{obs} values of approximately 4.8 and 6, conditions at which the humic substances are highly deprotonated, and actinides U and Am have not undergone hydrolysis reactions. Those conditions were chosen to maximize complexation between the humic substances and those

actinide elements. Measurements were made in NaCl media with ionic strengths of approximately 3 and 6 molal. Those experiments were completed prior to the WIPP Project establishing the position that MgO backfill would be emplaced to scrub CO_2 and fix pcH at about 9.3. The experiments conducted at FSU represent worst-case scenarios designed to provide high-end estimates of actinide uptake by humic substances. Actinide complexation by humic substances generally decreases at basic pH values because of the reduction in actinide-complex charges due to hydrolysis reactions. In addition, the high concentrations of Mg^{2+} in solution due to the presence of MgO backfill will compete with actinides for binding sites on humic substances and reduce the actinide uptake. FSU reported the first and second stability constants defined as follows (square brackets represent concentration):

$$An + HS \leftrightarrow AnHS; \qquad b_{1;An} = \frac{[AnHS]}{[An]\,[HS]} \tag{1}$$

$$An + 2(HS) \leftrightarrow An(HS)_2; \qquad b_{2;An} = \frac{[An(HS)_2]}{[An]\,[HS]^2} \tag{2}$$

where:

HS	=	humic substance (eq OH^-/L, i.e., site-binding capacity incorporated)
An	=	actinide element
$b_{1;An}$	=	first stability constant, for 1:1 An:humic binding
$b_{2;An}$	=	second stability constant, for 1:2 An:humic binding

For the calculations described below, complexation constants were selected from the most relevant experimental conditions, which were pH_{obs} 6 and 6 molal NaCl. The following stability constants reported by FSU were used (reported as log values):

humic substance	Am^{3+}; b_1	Am^{3+}; b_2	$U(VI)O_2^{2+}$; b_1	$U(VI)O_2^{2+}$; b_2
HA_{al}-LBr	6.09±0.05	10.46±0.12	5.91±0.16	10.43±0.19
HA_{ar}-Gor	6.02±0.04	10.41±0.10	5.35±0.15	8.98±0.26
FA-Suw	4.6±0.3	8.95±0.45	not measured	not measured

The FSU results show that there is little difference in Am(III) and $U(VI)O_2^{2+}$ uptake by aliphatic and aromatic humic acids, but that uptake by fulvic acid is significantly less. The FSU results also show that an increase of NaCl ionic strength from 3 to 6 has little effect on actinide uptake. Those observations aid in justifying the use of published stability constants for other actinide elements experimentally determined at lower ionic strengths and for other humic substances. On

the basis of the similarities in stability constants for Am(III) and $U(VI)O_2^{2+}$ for the humic acids, we have used the Am(III) stability constant for FA-Suw for $U(VI)O_2^{2+}$ on FA-Suw.

Stability constants for Th(IV) with several humic and fulvic acids were reported by Nash and Choppin (1979). In NaCl media at pH values between 3.95 and 5.03, those authors reported log stability constants between 9.7 and 13.2. Under basic conditions expected in the WIPP repository, it is likely that complexation of Th(IV) will be markedly less, because the dominant Th(IV)-bearing aqueous species will be $Th(OH)_4^0$ (Novak and Moore, 1996). As far as we know, no investigations of Th-complex binding on humic substances have been made. For the calculations described herein, we have elected to use published results from Baskaran et al. (1992) describing the distribution of Th(IV) in sea water. From that work, a ratio of dissolved versus colloidal Th(IV) of 6.349 was calculated, assuming that the solubility of colloidal organic material in sea water is equivalent to our measured value of humic substances in WIPP-relevant brines (i.e., 2.0 mg/L). The nature of the humic substances is likely to be dominated by aromatic humic acid, but may also contain fulvic acid.

For the calculations described herein, we use a log stability constant for $Np(V)O_2^+$ of 3.67 measured at pH 9 for a Gorleben humic acid (Gohy-573; Kim and Sekine, 1991). Results presented in Rao and Choppin (1995) for Lake Bradford humic acid and a Gorleben humic acid (Gohy-573) show little effect of pH on Np(V) stability constants, presumably because of the lack of hydrolysis of reactions for Np(V) over the pH range those authors studied. The Gorleben humic acid is aromatic in nature.

No published stability constants were found for plutonium. For the calculations described herein, we use an oxidation state analogy for the plutonium oxidation species, which we believe is conservative. Allard et al. (1980) have shown that at pH 9, Pu(IV) undergoes hydrolysis reactions to a greater extent than Th(IV), which should result in reduced complexation of Pu(IV).

We also used an oxidation state analogy to develop parameter values for elements expected to have multiple oxidation states in the WIPP repository. Oxidation speciation of the actinide elements was evaluated as part of the dissolved actinide source term program. Weiner (1996) has concluded that in the WIPP repository, the following species will be present: Th(IV); U(IV) and U(VI); Np(IV) and Np(V); Pu(III) and Pu(IV); and Am(III). The relative concentrations of oxidation species of a particular element are designated by their respective solubility values. The substitutions made following the oxidation state analogy are summarized in the following table:

required binding constant	substitute	source of data
Th(IV)	Th(IV)	Baskaran et al. (1992)
U(IV)	Th(IV)	Baskaran et al. (1992)
U(VI)	U(VI)	WIPP-specific data, FSU
Np(IV)	Th(IV)	Baskaran et al. (1992)
Np(V)	Np(V)	Kim and Sekine (1991)
Pu(III)	Am(III)	WIPP-specific data, FSU
Pu(IV)	Th(IV)	Baskaran et al. (1992)
Am(III)	Am(III)	WIPP-specific data, FSU

To compensate for the effects of competition for actinide complexation by the high concentrations of calcium and magnesium in repository brines in the presence of MgO backfill, stability constants for Ca^{2+} and Mg^{2+} were used in simultaneously solved equations (described below). Stability constants for Ca^{2+} and Mg^{2+} at basic pH values are not available, but several published reports provide values in the acidic range. Choppin and Shanbhag reported log stability constants of 2.25 to 3.32 for Ca^{2+} in 0.1m $NaClO_4$ at pH 3.9 and 5.0 for an aliphatic humic acid (Aldrich humic acid). Schnitzer and Skinner (1966) reported log binding constants ranging from 2.2 to 3.72 for Ca^{2+} in low ionic strength solutions over a pH range of 3.5 to 5.0 for fulvic acid. For Mg^{2+}, Schnitzer and Skinner (1966) reported log stability constants ranging from 1.23 to approximately 2.0 under the same experimental conditions. For our calculations, we used a log stability constant of 2.0 for the sum of Ca^{2+} and Mg^{2+} concentrations, which we believe is a conservative value.

Binding of Ca^{2+} and Mg^{2+} to humic substances is described in the same way as equation (1) above:

$$(Ca+Mg) + HS \leftrightarrow (CaMg)HS; \qquad b_{1;Ca,Mg} = \frac{[(Ca+Mg)HS]}{[Ca+Mg]\,[HS]} \tag{3}$$

where:

$b_{1;CaMg}$ = first stability constant, for 1:1 (Ca+Mg):humic binding (note that no second stability constants exists for divalent cation binding)

Interpretation of Experimental and Literature Results

Proportionality constants (PROPHUM, PHUMCIM, and PHUMSIM) describing the amount of actinide element bound to humic substances were determined from the data listed above, coupled with dissolved actinide concentrations. In addition, maximum theoretical concentrations of actinides that could be associated with humic substances (CAPHUM) were calculated from the data above.

The concentration of an actinide element of a given oxidation state was calculated by simultaneous solution of equations (1) and (3), combined with a mass-balance expression:

$$[HS_{tot}] = [AnHS] + [(CaMg)HS] + [HS] \tag{4}$$

where:

$[HS_{tot}]$	=	total concentration of humic substance
$[HS]$	=	concentration of uncomplexed humic substance
$[AnHS]$	=	concentration of humic complexed with an actinide element
$[(CaMg)HS]$	=	concentration of humic complexed with divalent cations

Equation (2) describing the effect of two humic substances binding with one actinide ion was disregarded for these calculations, because its contribution to the total humic-bound actinide concentrations was negligible.

Rearranging equations (1) and (3) provides:

$$[AnHS] = b_{1;An}\,[An]\,[HS] \tag{5}$$

$$[(CaMg)HS] = b_{1;CaMg}\,[Ca+Mg]\,[HS] \tag{6}$$

Substituting equations (5) and (6) into equation (4) results in:

$$[HS_{tot}] = b_{1;An}\,[An]\,[HS] + b_{1;Ca,Mg}\,[Ca+Mg]\,[HS] + [HS] \tag{7}$$

Rearranging equation (7) provides:

$$[HS] = \frac{[HS_{tot}]}{b_{1;An}\,[An] + b_{1;CaMg}\,[Ca+Mg] + 1} \tag{8}$$

Equations (5), (6), and (8) were used to calculate humic-bound actinide concentrations ([AnHS]). The resulting AnHS concentration values were then summed for actinide elements with multiple oxidation states, and then divided by the dissolved concentration of the respective actinide element. The final forms of the parameter values PROPHUM, PHUMCIM, and PHUMSIM are proportionality constants in units of "moles humic-bound colloidal actinide per mole of dissolved actinide." In WIPP PA calculations, the proportionality values may be multiplied by the dissolved actinide concentration expressed in molarity or molality, depending on what the desired final unit should be. Note, however, that dissolved actinide element concentration to be used in that calculation must not include complexes containing commercial organic complexants (e.g., EDTA).

Depending on the intrusion scenario, the WIPP repository may be dominated by Castile brine or by intergranular Salado brine, resulting in different actinide solubilities. In addition to brine type, commercial organic complexants such as EDTA affect actinide solubilities. Finally, actinide solubilities are dependent on the mineral assemblage (either brucite plus magnesite, or portlandite plus calcite) buffering the system. On the basis of those scenarios, Siegel (1996) provided solubility parameters for the following eight brine compositions:

idpram	brine	invariant point	organic complexants
SOLSIM	Salado	$Mg(OH)_2$-$MgCO_3$-CO_2	absent
SOLSIC	Salado	$Ca(OH)_2$-$CaCO_3$-CO_2	absent
SOLCIM	Castile	$Mg(OH)_2$-$MgCO_3$-CO_2	absent
SOLCIC	Castile	$Ca(OH)_2$-$CaCO_3$-CO_2	absent
SOLSOM	Salado	$Mg(OH)_2$-$MgCO_3$-CO_2	present
SOLSOC	Salado	$Ca(OH)_2$-$CaCO_3$-CO_2	present
SOLCOM	Castile	$Mg(OH)_2$-$MgCO_3$-CO_2	present
SOLCOC	Castile	$Ca(OH)_2$-$CaCO_3$-CO_2	present

In determining the concentration of humic-bound actinides, we assume that dissolved actinides complexed with commercial organic complexants are not available for interaction with humic substances. Therefore the brines listed above with organic complexants present can be disregarded herein. Wang (1996) conducted calculations which demonstrate that the brines buffered by portlandite plus calcite will not be present in the WIPP repository. Therefore, those brines can be disregarded. For determination of humic-bound actinide concentrations, therefore, we are left with two brine types, designated by SOLSIM and SOLCIM above. The solubilities of actinides of oxidation states III, IV, V, and VI in those brines were provided by Siegel (1996) (solubility values are listed in molality):

IDPRAM:	IDMTRL: SOLMOD3	IDMTRL: SOLMOD4	IDMTRL: SOLMOD5	IDMTRL: SOLMOD6
SOLSIM	4.4e-6	5.0e-6	2.6e-6	1.0e-5
SOLCIM	4.1e-7	6.8e-9	2.5e-6	1.0e-5

In our calculations described herein, those values were used. Concentrations of Ca^{2+} and Mg^{2+} in those two brines were obtained from Novak and Moore (1996).

Calculations are summarized in three tables. Tables 1a and 1b are calculations using equations (5), (6), and (8) to determine humic-bound actinide concentrations ([AnHS]) for one or more humic substance type for Am(III), Th(IV), Np(V), and U(VI). In Tables 2a through 2f, results of Tables 1a and 1b are transferred to facilitate summing humic-bound actinide concentrations for actinide elements with multiple oxidation species. The oxidation state analogy is most heavily drawn on for plutonium, because stability constants for Pu(III) or Pu(IV) are not available.

In Table 3, results of Tables 2a through 2f are summarized according to brine type and humic substance type. Table 3 was used to formulate the final PROPHUM, PHUMCIM, and PHUMSIM parameter values provided to PA. For americium and uranium (i.e., III and VI oxidation states, respectively), for which the greatest amount of information is available, we have calculated a "most-likely value" for humic-bound actinide concentration by taking the largest values for fulvic acid, aromatic humic acid, and aliphatic humic, and calculated the arithmetic mean. We recommend that a triangular distribution be established about that "most-likely value." The "minimum value" and "maximum value" correspond to the largest humic-bound actinide concentrations associated with fulvic acid and aliphatic humic acid, respectively. For thorium, plutonium, and neptunium (i.e., IV, V, and V oxidation states, respectively), for which less information is available, we have used the largest humic-bound actinide value for each as the "most-likely value." No distribution is recommended for those three actinide elements. For uranium and americium, in the event that the distributions of parameter values cannot be sampled in the PA calculations, we recommend that the maximum value be used as a constant value. The decision of whether to use the distribution or the constant value is to be made by the PA Department.

The PROPHUM idpram, used in conjunction with idmtrls Th, U, Np, Pu, or U, is designed to be used to calculate actinide-humic concentration by element. The PHUMCIM and PHUMSIM idpram's, used in conjunction with idmtrls PHUMOX3, PHUMOX4, PHUMOX5, or PHUMOX6, provides the means to calculate actinide-humic concentrations by actinide oxidation state and for different brine intrusion scenarios. The latter approach may be more analogous to the approach used to determine concentrations of dissolved actinide elements in the repository. For example, in an E1 scenario under "reducing conditions" in the WIPP repository, PHUMCIM

would be used with the following idmtrls to determine actinide-humic concentrations: thorium = PHUMOX4; uranium = PHUMOX4; neptunium = PHUMOX4; plutonium = PHUMOX3; and americium = PHUMOX3. For an E2 scenario under "oxidizing conditions" in the WIPP repository, PHUMSIM would be used with the following idmtrls to determine actinide-humic concentrations: thorium = PHUMOX4; uranium = PHUMOX6; neptunium = PHUMOX5; plutonium = PHUMOX4; and americium = PHUMOX3.

Uncertainties due to analytical precision are small compared to uncertainties in knowledge of the dominant humic substance type, site binding densities, and actinide solubilities. The proportionality factor approach coupled with the plus or minus one order-of-magnitude uncertainty in actinide solubilities results in a plus or minus one order-of-magnitude uncertainty in the concentration of actinides bound by mobile humic substances.

The CAPHUM parameter simply represents the theoretical maximum concentration of actinides that can be bound by a humic substance. Based on a solubility limit concentration of humic substances of 2.0 mg/L, and the highest site-binding capacity (for fulvic acids) of 5.56 meq OH^-/g, the theoretical maximum is 1.1×10^{-5} eq/L (refer to Tables 1a and b, column 4). Assuming the conservative case in which actinide species are monovalent, the maximum theoretical concentration of actinides that can be bound by humic substances is 1.1×10^{-5} molar. Note that that number is conservative, because it assumes a pool of humic substances is available for each actinide element, when in reality, actinide elements will compete for the same pool of humic substances. CAPHUM is intended to be used in an expression such as the following:

$$[\text{AnHS}] = \text{MIN}(\text{AnHS value calculated using PROPHUM, 1.1e-5}) \quad (9)$$

Summary

Interpreted values for PROPHUM, PHUMCIM, PHUMSIM, and CAPHUM are summarized in Attachments C, E, and F.

References

Allard, B., H. Kipatsi, and J. O. Liljenzin, 1980, Expected Species of Uranium, Neptunium, and Plutonium in Neutral Aqueous Solutions, Journal of Inorganic Nuclear Chemistry, v. 42, p. 1015-1027.

Baskaran, M., P. H. Santschi, G. Benoit, and B. D. Honeyman, 1992, Scavenging of Thorium Isotopes by Colloids in Seawater of the Gulf of Mexico, Geochimica et Cosmochimica Acta, v. 56, p. 3375-3388.

Choppin, G. R., and P. M. Shanbhag, 1981, Binding of Calcium by Humic Acid, Journal of Inorganic Nuclear Chemistry, v. 43, p. 921-922.

Ephraim, J. H., C. Petersson, M. Norden, and B. Allard, 1995, Poteniometric titrations of humic substances: Do ionic strength effects depend on the molecular weight? Environmental Science and Technology, v. 29, p. 622-628.

Fuger, J., I. L. Khodakovsky, E. I. Sergeyeva, V. A. Medvedev, and J. D. Navratil, 1992, The Chemical Thermodynamics of Actinide Elements and Compounds, IAEA Report part 12.

Hering, J. G., and F. M. M. Morel, 1988, Humic Acid Complexation of Calcium and Copper, Environmental Science and Technology, v. 22, no. 10, p. 1234-1237.

Kim, J.-I. , G. Buckau, G. H. Li, H. Duschner, and N. Psarros, 1990, Characterization of Humic and Fulvic Acids from Gorleben Groundwater, Journal of Analytical Chemistry, v. 338, p. 245-252.

Kim, J.-I., and T. Sekine, 1991, Complexation of Neptunium(V) with Humic Acid, Radiochimica Acta, v. 55, p. 187-192.

Novak, C. F., 1996, The Waste Isolation Pilot Plant (WIPP) Actinide Source Term Program: Test Plan for the Conceptual Model and the Dissolved Concentration Submodel, Albuquerque, New Mexico, Sandia National Laboratories, SAND95-1895 (submitted).

Novak, C. F., and Moore, R. C., 1996, Estimates of dissolved Concentration for +III, +IV, +V, and +VI Actinides in a Salado and a Castile Brine under Anticipated Repository Condtions. SNL Technical memorandum dated 28 March 1996 to Malcolm D. Siegel.

Papenguth, H. W., and Behl, Y. K., 1996, Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant, SNL Test Plan TP 96-01.

Rao, L., and G. R. Choppin, 1995, Thermodynamic Study of the Complexation of Neptunium(V) with Humic Acids, Radiochimica Acta, v. 68, p. 87-95.

Schnitzer, M., and S. I. M. Skinner, 1967, Organo-Metallic Interactions in Soils: 7 Stability Constants of Pb^{++}, Ni^{++}, Mn^{++}, Co^{++}, Ca^{++}, and Mg^{++} - Fulvic Acid Complexes, Soil Science, v. 103, no. 4, p. 247-252.

Siegel, M. D., 1996, Solubility parameters for use in the CCA NUTS and GRIDFLOW calculations. SNL Technical memorandum dated 29 March 1996 to Martin S. Tierney.

Torres, R. A., and G. R. Choppin, 1984, Europium(III) and Americium(III) Stability Constants with Humic Acid, Radiochimica Acta, v. 35, p. 143-148.

Wang, Y., 1996, Estimate of Repository pH and f_{CO2} Distribution for the Long-Term WIPP Performance Assessment (PA). SNL Technical memorandum dated 29 March 1996 to Martin S. Tierney and Christine T. Stockman.

Weiner, R., 1996, Documentation package for: oxidation state distribution of actinides in the repository. SNL Technical memorandum dated 27 March 1996 to SWCF-A: Records Center, SWCF-A: WBS 1.1.10.1.1: PDD: QA: Dissolved Species: Oxidation State Distribution: Actinides: OX3: OX4: OX5: OX6 (WPO# 35194).

Table 1a. Complexation of actinides with humic substances in Castile brine in the presence of magnesium oxide backfill.

	pH	Am(III)	Th(IV)	Np(V)	U(VI)	Mg+Ca
Dissolved Actinide Concentration (molality)	9.24	4.12E-07	6.78E-09	2.53E-06	1.00E-05	5.76E-02

Actinide	Type of humic Substance	humic substance total amount mg/L	humic substance meq OH⁻/g	humic substance total capacity eq/L	$\beta_{1;An}$	$\beta_{1;(MgCa)}$	$[HS]_{free}$ molality	[An-HS] molality	[(MgCa)-HS] molality	Check sum: humic substance total cap. eq/L
Am(III)	Suwannee River Fulvic Acid	2	5.56	1.11E-05	3.98E+04	1.00E+02	1.64E-06	2.69E-08	9.45E-06	1.11E-05
	Lake Bradford Humic Acid	2	4.65	9.30E-06	1.23E+06	1.00E+02	1.28E-06	6.49E-07	7.37E-06	9.30E-06
	Gorleben Humic Acid	2	5.38	1.08E-05	1.05E+06	1.00E+02	1.50E-06	6.45E-07	8.62E-06	1.08E-05
Th(IV)	Constant ratio of humic bound actinide conc. to dissolved actinide conc. of 6.34 used in all calculations.									
Np(V)	Lake Bradford Humic Acid	2	4.65	9.30E-06	3.16E+02	1.00E+02	1.38E-06	1.10E-09	7.92E-06	9.30E-06
	Gorleben Humic Acid	2	5.38	1.08E-05	4.68E+03	1.00E+02	1.59E-06	1.88E-08	9.17E-06	1.08E-05
U(VI)	Suwannee River Fulvic Acid	2	5.56	1.11E-05	3.98E+04	1.00E+02	1.55E-06	6.18E-07	8.95E-06	1.11E-05
	Lake Bradford Humic Acid	2	4.65	9.30E-06	8.13E+05	1.00E+02	6.25E-07	5.08E-06	3.60E-06	9.30E-06
	Gorleben Humic Acid	2	5.38	1.08E-05	2.24E+05	1.00E+02	1.20E-06	2.68E-06	6.89E-06	1.08E-05

Table 1b. Complexation of actinides with humic substances in Salado brine in the presence of magnesium oxide backfill.

	pH	Am(III)	Th(IV)	Np(V)	U(VI)	Mg+Ca
Dissolved Actinide Concentration (molality)	8.69	4.39E-06	4.98E-06	2.64E-06	1.00E-05	5.42E-01

Actinide	Type of humic Substance	humic substance total amount mg/L	humic substance meq OH^-/g	humic substance total capacity eq/L	$\beta_{1;An}$	$\beta_{1;(MgCa)}$	$[HS]_{free}$ molality	[An-HS] molality	[(MgCa)-HS] molality	Check sum: humic substance total cap. eq/L
Am(III)	Suwannee River Fulvic Acid	2	5.56	1.11E-05	3.98E+04	1.00E+02	2.01E-07	3.51E-08	1.09E-05	1.11E-05
	Lake Bradford Humic Acid	2	4.65	9.30E-06	1.23E+06	1.00E+02	1.53E-07	8.29E-07	8.32E-06	9.30E-06
	Gorleben Humic Acid	2	5.38	1.08E-05	1.05E+06	1.00E+02	1.80E-07	8.27E-07	9.75E-06	1.08E-05
Th(IV)	Constant ratio of humic bound actinide conc. to dissolved actinide conc. of 6.34 used in all calculations.									
Np(V)	Lake Bradford Humic Acid	2	4.65	9.30E-06	3.16E+02	1.00E+02	1.68E-07	1.41E-10	9.13E-06	9.30E-06
	Gorleben Humic Acid	2	5.38	1.08E-05	4.68E+03	1.00E+02	1.95E-07	2.41E-09	1.06E-05	1.08E-05
U(VI)	Suwannee River Fulvic Acid	2	5.56	1.11E-05	3.98E+04	1.00E+02	2.00E-07	7.96E-08	1.08E-05	1.11E-05
	Lake Bradford Humic Acid	2	4.65	9.30E-06	8.13E+05	1.00E+02	1.47E-07	1.19E-06	7.96E-06	9.30E-06
	Gorleben Humic Acid	2	5.38	1.08E-05	2.24E+05	1.00E+02	1.87E-07	4.19E-07	1.02E-05	1.08E-05

Table 2a. Concentration of dissolved and fulvic acid complexed actinide for each oxidation state in Castile brine in the presence of magnesium oxide backfill.

Actinide	Oxidation State				moles fulvic acid bound actinide/ moles dissolved actinide concentration
	(III)	(IV)	(V)	(VI)	
U					
dissolved concentration		6.78E-09		1.00E-05	6.2E-02.
Fulvic-U concentration		*		6.18E-07	
Np					
dissolved concentration		6.78E-09	2.53E-06		*
Fulvic-Np concentration		*	*		
Pu					
dissolved concentration	4.12E-07	6.78E-09			*
Fulvic-Pu concentration	*	*			
Am					
dissolved concentration	4.12E-07				6.5E-02
Fulvic-Am concentration	2.69E-08				
Th					
dissolved concentration		6.78E-09			*
Fulvic-Th concentration		*			

* no available information

Table 2b. Concentration of dissolved and fulvic acid complexed actinide for each oxidation state *in Salado brine in the presence of magnesium oxide backfill.*

Actinide	Oxidation State				mole fulvic acid bound actinide/ mole dissolved actinide concentration
	(III)	(IV)	(V)	(VI)	
U					
dissolved concentration		4.98E-06		1.00E-05	8.0E-03
Fulvic-U concentration		*		7.96E-08	
Np					
dissolved concentration		4.98E-06	2.64E-06		*
Fulvic-Np concentration		*	*		
Pu					
dissolved concentration	4.39E-06	4.98E-06			*
Fulvic-Pu concentration	*	*			
Am					
dissolved concentration	4.39E-06				8.0E-03
Fulvic-Am concentration	3.51E-08				
Th					
dissolved concentration		4.98E-06			*
Fulvic-Th concentration		*			

* no available information

Table 2c. Concentration of dissolved and Gorleben humic acid (aromatic) complexed actinide for each oxidation state in Castile brine in the presence of magnesium oxide backfill.

Actinide	Oxidation State				mole humic acid bound actinide/ mole dissolved actinide concentration
	(III)	(IV)	(V)	(VI)	
U					
dissolved concentration		6.78E-09		1.00E-05	2.7E-01
Humic-U concentration		4.30E-08		2.68E-06	
Np					
dissolved concentration		6.78E-09	2.53E-06		2.4E-02
Humic-Np concentration		4.30E-08	1.88E-08		
Pu					
dissolved concentration	4.12E-07	6.78E-09			1.6E+00
Humic-Pu concentration	6.45E-07	4.30E-08			
Am					
dissolved concentration	4.12E-07				1.6E+00
Humic-Am concentration	6.45E-07				
Th					
dissolved concentration		6.78E-09			6.3E+00
Humic-Th concentration		4.30E-08			

Table 2d. Concentration of dissolved and Gorleben humic acid (aromatic) complexed actinide for each oxidation state in Salado brine in the presence of magnesium oxide backfill.

Actinide	Oxidation State				mole humic acid bound actinide/ mole dissolved actinide concentration
	(III)	(IV)	(V)	(VI)	
U					
dissolved concentration		4.98E-06		1.00E-05	2.1E+00
Humic-U concentration		3.16E-05		4.19E-07	
Np					
dissolved concentration		4.98E-06	2.64E-06		4.1E+00
Humic-Np concentration		3.16E-05	2.41E-09		
Pu					
dissolved concentration	4.39E-06	4.98E-06			3.5E+00
Humic-Pu concentration	8.27E-07	3.16E-05			
Am					
dissolved concentration	4.39E-06				1.9E-01
Humic-Am concentration	8.27E-07				
Th					
dissolved concentration		4.98E-06			6.3E+00
Humic-Th concentration		3.16E-05			

Table 2e. Concentration of dissolved and Lake Bradford humic acid (aliphatic) complexed actinide for each oxidation state in Castile brine in the presence of magnesium oxide backfill.

Actinide	Oxidation State				mole humic acid bound actinide/ mole dissolved actinide concentration
	(III)	(IV)	(V)	(VI)	
U					
dissolved concentration		6.78E-09		1.00E-05	5.1E-01
Humic-U concentration		4.30E-08		5.08E-06	
Np					
dissolved concentration		6.78E-09	2.53E-06		1.7E-02
Humic-Np concentration		4.30E-08	1.10E-09		
Pu					
dissolved concentration	4.12E-07	6.78E-09			1.7E+00
Humic-Pu concentration	6.49E-07	4.30E-08			
Am					
dissolved concentration	4.12E-07				1.6E+00
Humic-Am concentration	6.49E-07				
Th					
dissolved concentration		6.78E-09			6.3E+00
Humic-Th concentration		4.30E-08			

Table 2f. Concentration of dissolved and Lake Bradford humic acid (aliphatic) complexed actinide for each oxidation state in Salado brine in the presence of magnesium oxide backfill.

Actinide	Oxidation State				mole humic acid bound actinide/ mole dissolved actinide concentration
	(III)	(IV)	(V)	(VI)	
U					
dissolved concentration		4.98E-06		1.00E-05	2.2E+00
Humic-U concentration		3.16E-05		1.19E-06	
Np					
dissolved concentration		4.98E-06	2.64E-06		4.1E+00
Humic-Np concentration		3.16E-05	1.41E-10		
Pu					
dissolved concentration	4.39E-06	4.98E-06			3.5E+00
Humic-Pu concentration	8.29E-07	3.16E-05			
Am					
dissolved concentration	4.39E-06				1.9E-01
Humic-Am concentration	8.29E-07				
Th					
dissolved concentration		4.98E-06			6.3E+00
Humic-Th concentration		3.16E-05			

Table 3. Summary of humic substance actinide complexation in Castile and Salado brines in the presence of magnesium oxide backfill.

Actinide	Brine/ Backfill	Ratio of humic bound actinide to dissolved actinide concentration		
		Suwannee River Fulvic Acid	Gorleben Humic Acid	Lake Bradford Humic Acid
U	Castile/Mg	6.2E-02	2.7E-01	5.1E-01
	Salado/Mg	8.0E-03	2.1E+00	2.2E+00
Pu	Castile/Mg	*	1.6E+00	1.7E+00
	Salado/Mg	*	3.5E+00	3.5E+00
Am	Castile/Mg	6.5E-02	1.6E+00	1.6E+00
	Salado/Mg	8.0E-03	1.9E-01	1.9E-01
Th	Castile/Mg	*	6.3E+00	6.3E+00
	Salado/Mg	*	6.3E+00	6.3E+00
Np	Castile/Mg	*	2.4E-02	1.7E-02
	Salado/Mg	*	4.1E+00	4.1E+00

* no available information

Attachment B:

Stockman, Christine T., 1996, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 29 March 1996 to Hans W. Papenguth.

Sandia National Laboratories
Operated for the U.S. Department of Energy by
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Albuquerque, New Mexico 87185-

date: 3/29/96

to: Hans W. Papenguth

Christine T. Stockman

from: Christine T. Stockman

subject: Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations

In order to properly model the transport of radionuclides within the Salado formation, we will need information about the possible transport of these radionuclide on colloids. In this memo we request the maximum mobilized radionuclide concentration and/or the proportionality constant defining the moles mobilized on colloid per moles in solution, for each transported element and colloid type. We are planning to transport Am, Pu, U, and Th, and may also transport Cm, Np, Ra, and Sr. If we transport Ra and Sr, we are planning to model them as very soluble, and not sorbed, so I believe modeling of colloids for them will not be necessary. For Cm solubility, we will be using the Am(III) model. If you believe that Cm colloids also behave similarly to Am colloids, we could extend the chemical analogy to the colloid behavior. If you agree with these simplifications then we will need the parameters for Am, Pu, U, Th and Np only.

Suggested names for database entry:
IDMTRL: Am, Pu, U, Th, Np

IDPRAM:

CONCINT	for concentration of actinide on mobilized intrinsic colloid
CONCMIN	for concentration of actinide on mobilized mineral fragments
CAPHUM	for maximum concentration of actinide on humic colloids
CAPMIC	for maximum concentration of actinide on microbe colloids
PROPHUM	for moles actinide mobilized on humic colloids per moles dissolved
PROPMIC	for moles actinide mobilized on microbe colloids per moles dissolved

You will need to provide a distribution for each material-parameter pair, but that distribution may be "CONSTANT" for most of the numbers. Eight sampling slots have been reserved for the most important of these parameters that have non-constant distributions.

cc:

Mary-Alena Martell	Amy S. Johnson	J. T. Schneider
Hong-Nian Jow	Martin S. Tierney	Richard V. Bynum
E. James Nowak	W. George Perkins	Ali A. Shinta
James L. Ramsey		

SWCF-A:WBS1.2.07.1.1:PDD:QA:GENERAL

Attachment C:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters. SNL Technical Memorandum dated 29 March 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 29 March 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters

This memorandum summarizes best estimates for the mobile colloidal actinide source term for input to the WIPP Compliance Certification Application. The use of material and parameter identification codes is consistent with your letter to me dated 29 March 1996 requesting parameter values. In the attached table, I have provided best estimates for the following material-parameter combinations:

IDMTRL: Th, U, Np, Pu, Am

IDPRAM:

- CONCINT — concentration of actinide associated with mobile actinide intrinsic colloids
- CONCMIN — concentration of actinide associated with mobile mineral fragment colloids
- CAPHUM — maximum concentration of actinide associated with mobile humic colloids
- CAPMIC — maximum concentration of actinide associated with mobile microbes
- PROPHUM — proportionality constant for concentration of actinides associated with mobile humic colloids
- PROPMIC — proportionality constant for concentration of actinides associated with mobile microbes

As a first approximation, the colloidal behavior of curium can be simulated be using parameter values for americium. The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

copy to:

MS 1328	Hong-Nian Jow, 6741
MS 1328	Amy S. Johnson, 6741
MS 1328	Martin S. Tierney, 6741
MS 1320	E. James Nowak, 6831 EJN
MS 1320	R. Vann Bynum, 6831
MS 1341	John T. Holmes, 6748
MS 1341	Laurence H. Brush, 6748
MS 1341	Robert C. Moore, 6748
MS 1341	W. Graham Yelton, 6748
MS 1320	W. George Perkins, 6748 wgp
MS 1320	John W. Kelly, 6748
MS 1320	Daniel A. Lucero, 6748
MS 1320	Craig F. Novak, 6748
MS 1320	Hans W. Papenguth, 6748
MS 1320	Malcolm D. Siegel, 6748
MS 1324	Susan A. Howarth, 6115
MS 1341	Kurt O. Larson, 6747
MS 1341	Ruth F. Weiner, 6747
MS 1324	Richard Aguilar, 6851

SWCF-A:WBS1.1.10.2.1

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CONCMIN	Th	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
CONCMIN	U	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
CONCMIN	Np	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
CONCMIN	Pu	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
CONCMIN	Am	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
PROPHUM	Th	6.4e+00	6.4e+00	6.4e+00	moles colloidal humic-bound Th per moles dissolved Th	constant	2,3
PROPHUM	U	1.4e+00	1.6e-01	2.0e+00	moles colloidal humic-bound U per moles dissolved U	triangular	2,3,4
PROPHUM	Np	4.0e+00	4.0e+00	4.0e+00	moles colloidal humic-bound Np per moles dissolved Np	constant	2,3
PROPHUM	Pu	5.9e+00	5.9e+00	5.9e+00	moles colloidal humic-bound Pu per moles dissolved Pu	constant	2,3
PROPHUM	Am	2.5e+00	1.9e-01	3.9e+00	moles colloidal humic-bound Am per moles dissolved Am	triangular	2,3,4

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CAPHUM	Th	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
CAPHUM	U	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
CAPHUM	Np	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
CAPHUM	Pu	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
CAPHUM	Am	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
Notes:							
general	The colloidal actinide source term is added to the dissolved actinide source term.						
general	None of the parameters are correlated.						
1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
3	Proportionality constants are to be used with the sum of actinide oxidation species for each actinide element (uncomplexed only, i.e., without organic ligand contribution).						
4	If a distribution is not used for humic-bound U or Am, use the maximum concentration as a constant value.						
5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e. the sum of dissolved plus colloidal actinide).						

Attachment D:

Stockman, Christine T., 1996, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 2 April 1996 to Hans W. Papenguth.

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: 4/2/96

to: Hans W. Papenguth

Christine T. Stockman

from: Christine T. Stockman

subject: Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations

YiFeng Wang has revised his recommendation to use 2 invariant points in the PA calculation. He now recommends that we use the $Mg(OH)_2 + MgCO_3$ invariant point for all calculations. If this invalidates the assumptions that you used to prepare colloid concentration or proportion parameters please indicate as soon as possible which parameters are affected, and as soon as possible after that provide a memo documenting the new values.

cc:
Mary-Alena Martell
Amy S. Johnson
Hong-Nian Jow
Martin S. Tierney
J. T. Schneider
Richard V. Bynum
E. James Nowak
W. George Perkins
SWCF-A:WBS1.2.07.1.1:PDD:QA:GENERAL

Attachment E:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL Technical Memorandum dated 18 April 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 18 April 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters, Revision 1

This memorandum summarizes the revised best estimates for the mobile colloidal-actinide source term for input to the WIPP Compliance Certification Application. Values presented herein supersede the values provided to you on 29 March 1996 (Papenguth, 1996) in response to your memorandum of 29 March 1996 (Stockman, 1996a). The present memorandum addresses your request for modifications stated in your memorandum dated 2 April 1996 (Stockman, 1996b).

In the attached table, I have summarized the complete set of parameters and values for the mobile colloidal-actinide source term. Revised values for maximum actinide concentration values for humic substances and constants describing actinide concentrations associated with mineral-fragment-type colloidal particles are included. New values (i.e., corresponding to new idpram's and idmtrl's) for proportionality constants describing actinide concentrations associated with humic substances are also included.

The revisions described herein for humic substances reflect a shift in approach from proportionality constants describing actinide-humic concentration by element, to proportionality constants describing actinide-humic concentration by actinide oxidation state. That change affects treatment of actinide elements that will have multiple oxidation states in the WIPP repository [e.g., U(IV) and U(VI); Np(IV) and Np(V); Pu(III) and Pu(IV)]. A second modification in approach, is that I now provide values for two cases: (1) a Castile brine in equilibrium with brucite and magnesite; and (2) a Salado brine in equilibrium with brucite and magnesite. For humic substances, the following material-parameter combinations apply:

IDMTRL: PHUMOX3 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 3;

PHUMOX4 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 4;

PHUMOX5 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 5; and

PHUMOX6 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 6.

IDPRAM: PHUMCIM proportionality constant for concentration of actinides associated with mobile humic colloids, in Castile brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite);

PHUMSIM proportionality constant for concentration of actinides associated with mobile humic colloids, in Salado brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite).

The revisions made for actinide concentration associated with mineral-fragment-type colloidal particles were made to include the potential contribution of actinide-mineral colloids formed in the Culebra. To accomplish that, the original repository source term values (Papenguth, 1996) have been doubled. That approach is not necessary for humic substances or actinide intrinsic colloids [i.e., Pu(IV)-polymer], because their concentrations are limited by solubilities. Concentrations of actinides associated with microbes are limited by the steady-state population of microbes in the repository, which will not increase when introduced to the Culebra.

The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

References

Papenguth, H.W., 1996, Colloidal Actinide Source Term Parameters, SNL technical memorandum dated 29 March 1996 to Christine T. Stockman.

Stockman, C.T., 1996a, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations, SNL technical memorandum dated 29 March 1996 to Hans W. Papenguth.

Stockman, C.T., 1996b, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations, SNL technical memorandum dated 2 April 1996 to Hans W. Papenguth.

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MS 1341	Ruth F. Weiner, 6747
MS 1324	Richard Aguilar, 6851
DOE/CAO	Robert A. Stroud

SWCF-A:WBS1.1.10.2.1

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CONCMIN	Th	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
revised	CONCMIN	U	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
revised	CONCMIN	Np	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
revised	CONCMIN	Pu	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
revised	CONCMIN	Am	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
	CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
	CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
	CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
	CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
	CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
revised (new)	PHUMSIM	PHUMOX3	1.3e-01	8.0e-03	1.9e-01	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
revised (new)	PHUMSIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
revised (new)	PHUMSIM	PHUMOX5	4.8e-04	5.3e-05	9.1e-04	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
revised (new)	PHUMSIM	PHUMOX6	5.6e-02	8.0e-03	1.2e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX3	1.1e+00	6.5e-02	1.6e+00	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
revised (new)	PHUMCIM	PHUMOX5	3.9e-03	4.3e-04	7.4e-03	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX6	2.8e-01	6.2e-02	5.1e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CAPHUM	Th	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
revised	CAPHUM	U	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
revised	CAPHUM	Np	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
revised	CAPHUM	Pu	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
revised	CAPHUM	Am	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
	PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
	PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
	PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
	PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
	PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
	CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
	CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
	CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
	CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
	CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
	Notes:							
	general	The colloidal actinide source term is added to the dissolved actinide source term.						
	general	None of the parameters are correlated.						
	1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
	2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
	3	Proportionality constants are to be used with the inorganic actinide solubility value (uncomplexed only, i.e., without organic ligand contribution).						
	4	If a distribution is not used, use the maximum concentration as a constant value.						
	5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
	6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
	7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e., the sum of dissolved plus colloidal actinide).						

Attachment F:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 2. SNL Technical Memorandum dated 22 April 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 22 April 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters, Revision 2

In my rush to complete and distribute Revision 1 (Papenguth, 1996), I made mistakes on the minimum and maximum values for actinide concentrations associated with mineral-fragment-type colloidal particles. The attached Table contains the correct values.

References

Papenguth, H.W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL technical memorandum dated 18 April 1996 to Christine T. Stockman.

copy to:

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MS 1324	Richard Aguilar, 6851
DOE/CAO	Robert A. Stroud

SWCF-A:WBS1.1.10.2.1

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CONCMIN	Th	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
revised	CONCMIN	U	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
revised	CONCMIN	Np	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
revised	CONCMIN	Pu	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
revised	CONCMIN	Am	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
	CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
	CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
	CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
	CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
	CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
	PHUMSIM	PHUMOX3	1.3e-01	8.0e-03	1.9e-01	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
	PHUMSIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
	PHUMSIM	PHUMOX5	4.8e-04	5.3e-05	9.1e-04	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
	PHUMSIM	PHUMOX6	5.6e-02	8.0e-03	1.2e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4
	PHUMCIM	PHUMOX3	1.1e+00	6.5e-02	1.6e+00	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
	PHUMCIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
	PHUMCIM	PHUMOX5	3.9e-03	4.3e-04	7.4e-03	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
	PHUMCIM	PHUMOX6	2.8e-01	6.2e-02	5.1e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
	CAPHUM	Th	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
	CAPHUM	U	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
	CAPHUM	Np	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
	CAPHUM	Pu	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
	CAPHUM	Am	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
	PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
	PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
	PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
	PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
	PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
	CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
	CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
	CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
	CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
	CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
	Notes:							
	general	The colloidal actinide source term is added to the dissolved actinide source term.						
	general	None of the parameters are correlated.						
	1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
	2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
	3	Proportionality constants are to be used with the inorganic actinide solubility value (uncomplexed only, i.e., without organic ligand contribution).						
	4	If a distribution is not used, use the maximum concentration as a constant value.						
	5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
	6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
	7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e., the sum of dissolved plus colloidal actinide).						

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.8

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WPO # 35850

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 7 May 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Parameter Record Package for Colloidal Actinide Source Term Parameters

Attached is the Parameter Record Package for the WIPP PA parameters describing actinide concentrations associated with mobile **mineral fragment type colloids**. This Package is one of four describing the concentration of actinides associated with the four colloidal particle types. The complete set of Packages consists of the following:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

copy with Attachments to:

MS 1320 Hans W. Papenguth, 6748
MS 1320 W. George Perkins, 6748
MS 1324 Richard Aguilar, 6851

DOE/CAO Robert A. Stroud

[redacted]

copy without Attachments to:

MS 1320 E. James Nowak, 6831
MS 1324 Susan A. Howarth, 6115
MS 1328 Hong-Nian Jow, 6741
MS 1328 Amy S. Johnson, 6741
MS 1328 Martin S. Tierney, 6741
MS 1328 Mary-Alena Martell, 6749
MS 1341 John T. Holmes, 6748

Parameter Record Package for Mobile-Colloidal Actinide Source Term.
Part 1. Mineral Fragment Type Colloids

The parameter values in this package are based on data which were collected under the guidance of the Principal Investigator for the Waste Isolation Pilot Plant (WIPP) Colloid Research Program, Hans W. Papenguth, for input to the WIPP Data Entry Form and for use in WIPP Performance Assessment (PA) calculations.

I. *Parameter No. (id):* Not applicable.

II. *Data/Parameter:* Not applicable.

III. *Parameter id (idpram):* CONCMIN.

IV. *Material:* Mineral fragment type colloidal particles and the actinides Th, U, Np, Pu, and Am.

V. *Material Identification (idmtrl):* Th, U, Np, Pu, and Am.

VI. *Units:* For CONCMIN, the units are "moles colloidal mineral-fragment-bound actinide per liter of dispersion."

VII. *Distribution Information.*

A. *Category:* The development of parameter values and their distributions is described in Attachment A. Summaries of the parameter values are presented in Attachments C, E, and F. Triangular distributions are supplied for CONCMIN values for each of the five actinide elements (idmtrl). In the event that those triangular distributions of parameter values cannot be sampled in the PA calculations, the maximum value should be selected. The decision of whether to use the distribution or the constant value is to be made by the PA Department.

B. *Mean:* See Attachments A, C, E, and F. (Note that for triangular distributions, the apices of the triangle are defined by the minimum value, the most likely value, and the maximum value; refer to Attachments).

C. *Median:* Not applicable.

D. *Standard Deviation:* Not applicable.

E. *Maximum:* See Attachments A, C, E, and F.

F. *Minimum:* See Attachments A, C, E, and F.

G. *Number of data points:* Not applicable.

VIII. *Data Collection and Interpretation Information.*

A. *Data Source Information:* WIPP observational data and literature.

B. *Data Collection (for WIPP observational data).*

1. *Data Collection or Test Method:* Experiments were conducted at SNL (Hans W. Papenguth and co-workers). Descriptions of experiments conducted at those institutions are described in Attachment A.

2. *Assumptions Made During Testing:* See Attachment A.

3. *Standard Error of Measurement of Tests Performed:* See Attachment A.

4. *Form of Raw Data:* Measurements of residual concentrations of colloidal particles are reported in number population.

5. *References Related to Data Collection:* See Attachment A.

6. *QA Status of Data:*

   a. *Are all of the data qualified?* Yes.

   b. *Were data qualified by QAP 20-3?* No. Data packages will be submitted for work conducted, under File code WBS 1.1.10.2.1.

   c. *Were the data the subject of audit/surveillance by SNL or DOE?* Yes.

   d. *Were the data collected under an SNL approved QA program?* Yes. Data were collected under SNL WIPP QAPD, Rev. P, effective October 1, 1992, and SNL WIPP QAPD, Rev. R, effective July 31, 1995. Data were collected under a test plan for the WIPP Colloid Research Program (Papenguth and Behl, 1996. Detailed descriptions of the experiments and interpretation listed herein will be published in a SAND report. Documents related to data collection at SNL will be archived in the Sandia WIPP Central Files (SWCF; File code WBS 1.1.10.2.1).

C. *Interpretation of Data.*

1. *Was the interpretation made by reference to previous work.* No.

2. *Was the interpretation made by using newly performed calculations?* Yes.

3. *Form of Interpreted Data.* List of interpreted values.

4. *Assumptions Made During Interpretation.* See Attachment A.

5. *Name of Code(s)/Software used to Interpret Data:* Not applicable.

6. *QA Status of Code(s) used to Interpret Data:* Not applicable.

   a. *Was the code qualified under QAP 19-1?* Not applicable.

   b. *Was the code qualified under QAP 9-1?* Not applicable.

7. *References Related to Data Interpretation:* See XI below and Attachment A.

8. *For interpretations made by using a newly performed calculations provide documentation that you followed the requirements of QAP 9-1 Appendix B.* The

data analysis is controlled by Analysis Plan for the Colloid Research Program, AP-004 (Behl and Papenguth, 1996).

9. *For routine calculations (not using code) did you follow requirements of QAP 9-5?* Yes.

IX. *Correlation with other Parameters:* Parameter values describing the concentration of actinides associated with mobile humic substances are linked to solubility of the dissolved actinides, with a maximum value which cannot be exceeded.

X. *Limitations or qualifications for usage of data by Performance Assessment (PA):* None.

XI. *References cited above:*

Behl, Y.K., and Papenguth, H.W., 1996, Analysis Plan for the WIPP Colloid Research Program WBS #1.1.10.2.1, SNL Analysis Plan AP-004.

Papenguth, H.W., and Behl, Y.K., 1996, Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant, SNL Test Plan TP 96-01.

XII. *Attachments:*

Attachment A: Papenguth, Hans W., and Aguilar, Richard, 1996, Rationale for Definition of Parameter Values for Mineral Fragment Type Colloidal Particles.

Attachment B: Stockman, Christine T., 1996, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 29 March 1996 to Hans W. Papenguth.

Attachment C: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters. SNL Technical Memorandum dated 29 March 1996 to Christine T. Stockman.

Attachment D: Stockman, Christine T., 1996, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 2 April 1996 to Hans W. Papenguth.

Attachment E: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL Technical Memorandum dated 18 April 1996 to Christine T. Stockman.

Attachment F: Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 2. SNL Technical Memorandum dated 22 April 1996 to Christine T. Stockman.

XIII. *Distribution*

SWCF-A:WPO# 35850: Mobile-Colloidal Actinide Source Term. 1. Mineral Fragment Colloids.

SWCF-A:WBS 1.1.10.2.1: Colloid Characterization and Transport.

Attachment A:

Papenguth, Hans W., and Aguilar, Richard, 1996, Rationale for Definition of Parameter Values for Mineral Fragment Type Colloids.

Attachment A.
Rationale for Definition of Parameter Values for Mineral Fragment Type Colloids

Hans W. Papenguth and Richard Aguilar

Introduction

The actinide source term at the WIPP is defined as the sum of contributions from dissolved actinide species and mobile colloidal actinide species. The dissolved actinide source term has been defined elsewhere (Novak, 1996; Novak and Moore, 1996; Siegel, 1996). It is important to note that colloidal actinides which are not suspended in the aqueous phase (i.e., not mobile) are not included in the colloidal actinide source term. Colloidal actinides may become immobilized by several mechanisms, including precipitation followed by coagulation and gravitational settling (humic substances and actinide intrinsic colloids), adhesion to fixed substrates (microbes), and flocculation or coagulation of colloidal particles followed by gravitational settling (mineral fragments). Sorption of colloidal actinides onto fixed substrates will also reduce the mobile colloidal actinide source term, but no credit is currently being taken for reduction by that means.

To facilitate quantification of the colloidal actinide source term, as well as an efficient experimental approach, the source term has been divided into four components according to colloid types. On the basis of (1) the behavior of colloidal particles in high ionic strength electrolytes, (2) the way in which colloidal particles interact with actinide ions, and (3) the transport behaviors of colloidal particles, four colloidal particle types are recognized (Papenguth and Behl, 1996): mineral fragments, actinide intrinsic colloids, humic substances, and microbes.

In this document, we focus on the quantification of the actinide concentration mobilized by mineral fragment type colloidal particles. In terms of the WIPP performance assessment (PA) calculations, we discuss the rationale for selecting the values corresponding to the following parameter designators:

idpram:	CONCMIN	concentration of actinide associated with mobile mineral fragment colloids.
idmtrl:	Th	thorium;
	U	uranium;
	Np	neptunium;
	Pu	plutonium; and
	Am	americium.

Mineral fragment type colloidal particles may be present in naturally occurring groundwaters, and they may be released from the host rock due to disruption of fragile aggregates by changes in ionic strength or hydrodynamic forces, dissolution of a more soluble surrounding matrix, mechanical grinding of mineral surfaces, or mechanical disruption of secondary minerals present at mineral surfaces. Under certain conditions, such as extreme changes in ionic strength of the groundwater or by physical disruption due to natural or human-induced events, mineral fragment type colloidal particles could also be produced within the Culebra. In an intrusion scenario at the WIPP, mixing of repository brines with Culebra brines is likely to result in mineral precipitation which may include coprecipitation of actinide-bearing mineral fragment type colloidal particles. Within the repository, mineral fragment type colloidal particles may form from corrosion of iron-bearing waste and the steel packaging materials. In addition, Portland cement based matrixes will be attacked and will produce mineral fragment type colloidal particles. Bentonite, which may be a constituent of drilling mud is itself a potential source of mineral fragment type colloidal material that should be considered for actinide transport.

In terms of colloidal actinide transport, mineral fragment type colloids act as carriers, in that actinide ions sorb onto the surfaces of the colloids. Because each mineral substrate has a different affinity for actinides, quantification of actinide concentrations associated with the wide range of mineralogies likely to be present at the WIPP is insurmountable. Instead, we elected to use a bounding approach based on residual concentrations of colloidal particles in WIPP-relevant brines coupled with estimates of reasonable maximum concentrations of actinides which could be sorbed onto the colloid surfaces. That approach requires three pieces of information: (1) the number population of mineral fragment type colloidal particles in the aqueous phase; (2) the geometric surface area of individual colloidal particles; and (3) the site-binding capacity of the mineral surface. In the remainder of this document, we focus on the determination of items (1) through (3), the interpretation of that information, and the development of parameter values suitable for PA calculations.

Experimental

Hydrophobic colloidal particles, such as mineral fragments, are kinetically stabilized and destabilized by electrostatic forces (refer to detailed discussion in Papenguth and Behl, 1996, Sections 2.5.1 and 2.6). In an aqueous dispersant, hydrophobic colloidal particles are attracted to one another by van der Waals forces. That electrostatic attraction is countered by repulsive forces generated by a cloud of counterions surrounding each particle. In a kinetically stable colloidal dispersion colloidal particles are usually repelled from one another before they get close enough to become agglomerated. However, as the ionic strength of the dispersion is increased, the thickness of the cloud of counterions is compressed, allowing closer particle-particle

interaction. The net effect is that as colloidal particles come into proximity with one another in the dispersion, a greater chance for sticking exists, and so the rate of agglomeration increases. That phenomenon is very effective at removing colloidal particles from suspension even at fairly low ionic strengths over periods of hours to days.

The kinetic stability of the mineral-fragment-type colloids in WIPP-relevant brines was evaluated in coagulation series experiments. Colloidal dispersions of mineral fragments were prepared by mechanical disaggregation of representative mineral, rock samples, and other materials or by chemical precipitation from laboratory reagents. Brine simulants were prepared which covered the ranges of ionic strengths observed in WIPP brines. The brines were sequentially diluted with deionized water by factors of 10 and adjusted to acidic, neutral, and basic pH conditions to evaluate the effects of ionic strength and pH on kinetic stability. At the ionic strength referred to as the critical coagulation concentration (c.c.c.), colloidal particles will rapidly coagulate, forming agglomerates large enough to settle by gravitational forces. The number population of colloidal particles remaining in suspension in the various dispersions was measured over time to assess their stability as a function of solution ionic strength and time.

Colloidal dispersions were prepared for the following minerals or materials: bentonite, kaolinite, montmorillonite, vermiculite, illite, anhydrite, calcium carbonate, magnesite, hematite (mechanically disaggregated), hematite (chemical precipitate), limonite, goethite, magnetite, quartz, siderite, brucite, strontianite, diatomaceous earth, pyrite, and cellulosic materials (Masslinn paper towels and Scott paper towels). The brine solutions used included a Salado-like brine simulant (SPC brine) and a Culebra brine simulant (H-17). For c.c.c. experiments, sequential dilutions of those brines were made which spanned approximately five orders-of-magnitude. Brine simulants consisting of 0.5M NaCl or $CaCl_2$ were also used. For the residual concentration measurements which were used as the basis for the PA deliverables described herein, the one order-of-magnitude dilution (i.e., 10 percent of original strength) of the Salado-like brine and the Culebra brine simulants were used. That reduction in ionic strength provides a degree of conservatism in the results.

C.c.c. experiments for the various concentrations of WIPP brine simulants were conducted under acidic (observed pH generally ranging from 3 to 4), neutral (pH 6 to 8), and basic (pH 9 to 12) conditions. Following the introduction of an aliquot of dispersed colloidal particles to a series of test tubes containing the sequentially diluted brine, colloidal particle concentrations remaining near the top of the fluid columns (residual concentration) were measured as a function of time. The degree of coagulation and settling was quantified using an inductively coupled argon-plasma atomic emission spectrophotometer (ICP-AES), nephelometry, and direct particle counting.

Most of the experiments conducted relating to the kinetic stability of mineral fragment colloidal particles were qualitative to semi-quantitative, and were focused on evaluating whether a c.c.c.

existed. For the final experiments, however, we used a state-of-the-art particle spectrometer designed for semiconductor fabrication plants, which require extremely pure processing water, and use a similar instrument to ascertain purity. Our final experiments were conducted over an extended period of time using that more sensitive analytical technique to determine the number and size of colloids in the brine suspensions. Those experiments were conducted in a similar fashion to previous experiments for bentonite (Aldrich Chemical Co.), goethite, and hematite (mechanically disaggregated), but in a relatively dilute (and therefore conservative) brine simulant consisting of 0.1 M NaCl. Residual particle concentrations made with the particle spectrometer compared favorably with measurements made with spectroscopic techniques made at similar experiment times. Generally after the first day of the c.c.c. experiments, the majority (greater than 99 percent) of the colloidal particles had already settled out of suspension. With the more sensitive particle spectrometer, however, residual concentrations of colloidal particles were observed to continue to decrease. For experiments analyzed by spectroscopic or light-scattering techniques, final residual colloid number populations remaining suspended in the test vessels were determined by multiplying the initial colloid number populations determined at the start of our experiments by the fraction of suspended colloids remaining at the final reading. Using the particle spectrometer, final number populations were measured directly.

Discussion

Parameter values (CONCMIN) describing the amount of actinide element bound by mineral fragment type colloidal particles were determined from the information described above, combined with estimates of adsorption site densities.

Actinides sorbed to the surfaces of colloidal particles can be estimated using ranges of values for adsorption site densities taken from published surface complexation modeling research. The actinide concentration contained by a single mineral fragment type colloidal particle is calculated by considering the geometrical surface area of a spherical particle:

$$[An]_p = \frac{\pi D^2 N_s}{N_A} \qquad (1)$$

where:

$[An]_p$	=	concentration of an adsorbed actinide element (moles/particle)
D	=	spherical colloidal particle diameter (nm)
N_s	=	adsorption site density (sites/nm^2)
N_A	=	Avogadro constant

An adsorption site density of 1 site/nm^2 was used for N_s in the above equation, a value which we believe is conservative. With that site density, 10 nm and 1 μm diameter particles could have a

maximum of about 10^{-22} and 10^{-18} moles actinide per particle, respectively. To obtain an estimate of the maximum actinide concentrations that could be associated with the colloids, the estimates of residual colloid number populations (particles per liter of dispersion) were multiplied by the estimated maximum actinide transport capacity described by equation (1). Our use of a uniform adsorption site density is a conservative approach, because the actual sorption on mineral surfaces should be described by some kind of isotherm which will result in less than 100 percent coverage.

Interpreted Results

Final residual colloid number populations quantified by spectrophotometry or nephelometry showed that mineral fragment type colloidal particles are kinetically destabilized by brines similar in composition to those present at the WIPP Site. Colloid number population values were, with a few exceptions, reduced to less than 5 percent of the initial values within 1 day. Conservative estimates of maximum actinide concentrations associated with those residual colloid populations are on the order of 10^{-7} to 10^{-9} moles actinide per liter of dispersion.

The final experiments, which utilized the particle spectrometer to measure the quantity of colloids remaining in suspension offered the most sensitive estimates. Moreover, those experiments were conducted for substantially longer periods of time than the semi-quantitative c.c.c. experiments. Those experimental results are the following:

Mineral	Time of final reading (days)	Estimated actinide concentration (moles/L dispersion)
hematite	12.8	1.6×10^{-8}
goethite	12.9	9.5×10^{-10}
bentonite	12.8	1.6×10^{-10}
geometric mean		1.3×10^{-9}

We believe that the experimental results using the particle spectrometer, although only reflecting three distinct colloids (hematite, goethite, and bentonite), are representative of other mineral fragment type colloidal particles in terms of their behavior in brine solutions. The geometric mean was assumed to be a more representative average of the final colloid concentrations than the arithmetic mean because of the very small final colloid concentrations (which, for this particular case, is also conservative).

Mineral fragment type colloidal particles are unique among the four colloidal particle types addressed for WIPP, because their concentrations are not generally linked to solubility, as are actinide intrinsic colloids and humic substances, or to a maximum supportable population in the case of microbes. Consequently, in an intrusion scenario at the WIPP, as dissolved actinide elements are introduced to the Culebra, it is possible that those dissolved actinides could sorb onto a separate population of indigenous mineral fragments, producing a supplemental source term. To account for that possibility, we recommend multiplying the geometric mean value listed above by a factor of two, producing a final "most-likely value" of 2.6×10^{-9} moles actinide per liter of dispersion.

To capture uncertainty, mainly stemming from knowledge of the adsorption site density value, we recommend a triangular distribution with "minimum values" and "maximum values" spanning one order of magnitude about the geometric mean.

Summary

Interpreted values for CONCMIN are summarized in Attachments C, E, and F. In those values, we have incorporated conservatism in two ways. First, we have increased the experimental results by a factor of two to account for the possibility that the indigenous mineral fragment colloidal particles in the Culebra could sorb dissolved actinides (see Attachment F). Second, we have essentially multiplied the total concentration of actinides carried by mineral fragment colloidal particles by a factor of five, because we have assumed a separate population of colloidal particles for each actinide element. No consideration of competition for sorption sites is incorporated into our calculation approach. We believe that the value used for adsorption site density is conservative, but reasonable. The triangular distribution of one-order-of-magnitude about the "most-likely value" essentially captures our uncertainty in site density values. If the WIPP PA Department elects to not use the triangular distribution in their calculations, we recommend that the "maximum values" be used as constant values.

References

Novak, C. F., 1996, The Waste Isolation Pilot Plant (WIPP) Actinide Source Term Program: Test Plan for the Conceptual Model and the Dissolved Concentration Submodel, Albuquerque, New Mexico, Sandia National Laboratories, SAND95-1895 (submitted).

Novak, C. F., and Moore, R. C., 1996, Estimates of dissolved Concentration for +III, +IV, +V, and +VI Actinides in a Salado and a Castile Brine under Anticipated Repository Condtions. SNL Technical memorandum dated 28 March 1996 to Malcolm D. Siegel.

Papenguth, H. W., and Behl, Y. K., 1996, Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant, SNL Test Plan TP 96-01.

Siegel, M. D., 1996, Solubility parameters for use in the CCA NUTS and GRIDFLOW calculations. SNL Technical memorandum dated 29 March 1996 to Martin S. Tierney.

Attachment B:

Stockman, Christine T., 1996, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 29 March 1996 to Hans W. Papenguth.

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: 3/29/96

to: Hans W. Papenguth

Christine T. Stockman

from: Christine T. Stockman

subject: Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations

In order to properly model the transport of radionuclides within the Salado formation, we will need information about the possible transport of these radionuclide on colloids. In this memo we request the maximum mobilized radionuclide concentration and/or the proportionality constant defining the moles mobilized on colloid per moles in solution, for each transported element and colloid type. We are planning to transport Am, Pu, U, and Th, and may also transport Cm, Np, Ra, and Sr. If we transport Ra and Sr, we are planning to model them as very soluble, and not sorbed, so I believe modeling of colloids for them will not be necessary. For Cm solubility, we will be using the Am(III) model. If you believe that Cm colloids also behave similarly to Am colloids, we could extend the chemical analogy to the colloid behavior. If you agree with these simplifications then we will need the parameters for Am, Pu, U, Th and Np only.

Suggested names for database entry:
IDMTRL: Am, Pu, U, Th, Np

IDPRAM:

CONCINT	for concentration of actinide on mobilized intrinsic colloid
CONCMIN	for concentration of actinide on mobilized mineral fragments
CAPHUM	for maximum concentration of actinide on humic colloids
CAPMIC	for maximum concentration of actinide on microbe colloids
PROPHUM	for moles actinide mobilized on humic colloids per moles dissolved
PROPMIC	for moles actinide mobilized on microbe colloids per moles dissolved

You will need to provide a distribution for each material-parameter pair, but that distribution may be "CONSTANT" for most of the numbers. Eight sampling slots have been reserved for the most important of these parameters that have non-constant distributions.

cc:

Mary-Alena Martell	Amy S. Johnson	J. T. Schneider
Hong-Nian Jow	Martin S. Tierney	Richard V. Bynum
E. James Nowak	W. George Perkins	Ali A. Shinta
James L. Ramsey		

SWCF-A:WBS1.2.07.1.1:PDD:QA:GENERAL

Attachment C:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters. SNL Technical Memorandum dated 29 March 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 29 March 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters

This memorandum summarizes best estimates for the mobile colloidal actinide source term for input to the WIPP Compliance Certification Application. The use of material and parameter identification codes is consistent with your letter to me dated 29 March 1996 requesting parameter values. In the attached table, I have provided best estimates for the following material-parameter combinations:

IDMTRL: Th, U, Np, Pu, Am

IDPRAM:

CONCINT	concentration of actinide associated with mobile actinide intrinsic colloids
CONCMIN	concentration of actinide associated with mobile mineral fragment colloids
CAPHUM	maximum concentration of actinide associated with mobile humic colloids
CAPMIC	maximum concentration of actinide associated with mobile microbes
PROPHUM	proportionality constant for concentration of actinides associated with mobile humic colloids
PROPMIC	proportionality constant for concentration of actinides associated with mobile microbes

As a first approximation, the colloidal behavior of curium can be simulated be using parameter values for americium. The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

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MS 1328	Amy S. Johnson, 6741
MS 1328	Martin S. Tierney, 6741
MS 1320	E. James Nowak, 6831 EJN
MS 1320	R. Vann Bynum, 6831
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MS 1324	Richard Aguilar, 6851

SWCF-A:WBS1.1.10.2.1

Mobile-Colloidal-Actinide Source Term—Concentration/Proportionality Constants

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CONCMIN	Th	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
CONCMIN	U	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
CONCMIN	Np	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
CONCMIN	Pu	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
CONCMIN	Am	1.3e-09	1.3e-10	1.3e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
PROPHUM	Th	6.4e+00	6.4e+00	6.4e+00	moles colloidal humic-bound Th per moles dissolved Th	constant	2,3
PROPHUM	U	1.4e+00	1.6e-01	2.0e+00	moles colloidal humic-bound U per moles dissolved U	triangular	2,3,4
PROPHUM	Np	4.0e+00	4.0e+00	4.0e+00	moles colloidal humic-bound Np per moles dissolved Np	constant	2,3
PROPHUM	Pu	5.9e+00	5.9e+00	5.9e+00	moles colloidal humic-bound Pu per moles dissolved Pu	constant	2,3
PROPHUM	Am	2.5e+00	1.9e-01	3.9e+00	moles colloidal humic-bound Am per moles dissolved Am	triangular	2,3,4

Mobile-Colloidal-Actinide Source Term—Concentration/Proportionality Constants

Parameter	Material	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
CAPHUM	Th	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
CAPHUM	U	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
CAPHUM	Np	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
CAPHUM	Pu	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
CAPHUM	Am	1.5e-05	1.5e-05	1.5e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
Notes:							
general	The colloidal actinide source term is added to the dissolved actinide source term.						
general	None of the parameters are correlated.						
1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
3	Proportionality constants are to be used with the sum of actinide oxidation species for each actinide element (uncomplexed only, i.e., without organic ligand contribution).						
4	If a distribution is not used for humic-bound U or Am, use the maximum concentration as a constant value.						
5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e. the sum of dissolved plus colloidal actinide).						

Attachment D:

Stockman, Christine T., 1996, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations. SNL Technical Memorandum dated 2 April 1996 to Hans W. Papenguth.

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation

Albuquerque, New Mexico 87185-

date: 4/2/96

to: Hans W. Papenguth

Christine T. Stockman

from: Christine T. Stockman

subject: Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations

YiFeng Wang has revised his recommendation to use 2 invariant points in the PA calculation. He now recommends that we use the $Mg(OH)_2 + MgCO_3$ invariant point for all calculations. If this invalidates the assumptions that you used to prepare colloid concentration or proportion parameters please indicate as soon as possible which parameters are affected, and as soon as possible after that provide a memo documenting the new values.

cc:
Mary-Alena Martell
Amy S. Johnson
Hong-Nian Jow
Martin S. Tierney
J. T. Schneider
Richard V. Bynum
E. James Nowak
W. George Perkins
SWCF-A:WBS1.2.07.1.1:PDD:QA:GENERAL

Attachment E:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL Technical Memorandum dated 18 April 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 18 April 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters, Revision 1

This memorandum summarizes the revised best estimates for the mobile colloidal-actinide source term for input to the WIPP Compliance Certification Application. Values presented herein supersede the values provided to you on 29 March 1996 (Papenguth, 1996) in response to your memorandum of 29 March 1996 (Stockman, 1996a). The present memorandum addresses your request for modifications stated in your memorandum dated 2 April 1996 (Stockman, 1996b).

In the attached table, I have summarized the complete set of parameters and values for the mobile colloidal-actinide source term. Revised values for maximum actinide concentration values for humic substances and constants describing actinide concentrations associated with mineral-fragment-type colloidal particles are included. New values (i.e., corresponding to new idpram's and idmtrl's) for proportionality constants describing actinide concentrations associated with humic substances are also included.

The revisions described herein for humic substances reflect a shift in approach from proportionality constants describing actinide-humic concentration by element, to proportionality constants describing actinide-humic concentration by actinide oxidation state. That change affects treatment of actinide elements that will have multiple oxidation states in the WIPP repository [e.g., U(IV) and U(VI); Np(IV) and Np(V); Pu(III) and Pu(IV)]. A second modification in approach, is that I now provide values for two cases: (1) a Castile brine in equilibrium with brucite and magnesite; and (2) a Salado brine in equilibrium with brucite and magnesite. For humic substances, the following material-parameter combinations apply:

IDMTRL: PHUMOX3 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 3;

PHUMOX4 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 4;

PHUMOX5 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 5; and

PHUMOX6 proportionality constant for concentration of actinides associated with mobile humic substances, for actinide elements with oxidation state 6.

IDPRAM: PHUMCIM proportionality constant for concentration of actinides associated with mobile humic colloids, in Castile brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite);

PHUMSIM proportionality constant for concentration of actinides associated with mobile humic colloids, in Salado brine, actinide solubilities are inorganic only (no man-made ligands), brine is in equilibrium with Mg-bearing minerals (brucite and magnesite).

The revisions made for actinide concentration associated with mineral-fragment-type colloidal particles were made to include the potential contribution of actinide-mineral colloids formed in the Culebra. To accomplish that, the original repository source term values (Papenguth, 1996) have been doubled. That approach is not necessary for humic substances or actinide intrinsic colloids [i.e., Pu(IV)-polymer], because their concentrations are limited by solubilities. Concentrations of actinides associated with microbes are limited by the steady-state population of microbes in the repository, which will not increase when introduced to the Culebra.

The basis for the values summarized in the attached table is described in the following record packages for WBS 1.1.10.2.1:

WPO#	Parameter Record Package Name
35850	Mobile-Colloidal-Actinide Source Term. 1. Mineral Fragment Colloids
35852	Mobile-Colloidal-Actinide Source Term. 2. Actinide Intrinsic Colloids
35855	Mobile-Colloidal-Actinide Source Term. 3. Humic Substances
35856	Mobile-Colloidal-Actinide Source Term. 4. Microbes

References

Papenguth, H.W., 1996, Colloidal Actinide Source Term Parameters, SNL technical memorandum dated 29 March 1996 to Christine T. Stockman.

Stockman, C.T., 1996a, Request for colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations, SNL technical memorandum dated 29 March 1996 to Hans W. Papenguth.

Stockman, C.T., 1996b, Request for any modifications to the colloid parameters for use in NUTS, GRIDFLOW and direct brine release calculations, SNL technical memorandum dated 2 April 1996 to Hans W. Papenguth.

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MS 1341	Ruth F. Weiner, 6747
MS 1324	Richard Aguilar, 6851
DOE/CAO	Robert A. Stroud

SWCF-A:WBS1.1.10.2.1

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CONCMIN	Th	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
revised	CONCMIN	U	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
revised	CONCMIN	Np	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
revised	CONCMIN	Pu	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
revised	CONCMIN	Am	2.6e-09	2.6e-09	2.6e-09	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
	CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
	CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
	CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
	CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
	CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
revised (new)	PHUMSIM	PHUMOX3	1.3e-01	8.0e-03	1.9e-01	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
revised (new)	PHUMSIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
revised (new)	PHUMSIM	PHUMOX5	4.8e-04	5.3e-05	9.1e-04	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
revised (new)	PHUMSIM	PHUMOX6	5.6e-02	8.0e-03	1.2e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX3	1.1e+00	6.5e-02	1.6e+00	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
revised (new)	PHUMCIM	PHUMOX5	3.9e-03	4.3e-04	7.4e-03	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
revised (new)	PHUMCIM	PHUMOX6	2.8e-01	6.2e-02	5.1e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CAPHUM	Th	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
revised	CAPHUM	U	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
revised	CAPHUM	Np	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
revised	CAPHUM	Pu	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
revised	CAPHUM	Am	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
	PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
	PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
	PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
	PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
	PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
	CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
	CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
	CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
	CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
	CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7
	Notes:							
	general	The colloidal actinide source term is added to the dissolved actinide source term.						
	general	None of the parameters are correlated.						
	1	If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.						
	2	Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.						
	3	Proportionality constants are to be used with the inorganic actinide solubility value (uncomplexed only, i.e., without organic ligand contribution).						
	4	If a distribution is not used, use the maximum concentration as a constant value.						
	5	The maximum ("cap") values are in units comparable to molarity rather than molality.						
	6	CAPHUM is compared to the concentration of the respective humic-bound actinide element.						
	7	CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e., the sum of dissolved plus colloidal actinide).						

Attachment F:

Papenguth, Hans W., 1996, Colloidal Actinide Source Term Parameters, Revision 2. SNL Technical Memorandum dated 22 April 1996 to Christine T. Stockman.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 22 April 1996

to: Christine T. Stockman, MS-1328 (Org. 6749)

Hans W. Papenguth

from: Hans W. Papenguth, MS-1320 (Org. 6748)

subject: Colloidal Actinide Source Term Parameters, Revision 2

In my rush to complete and distribute Revision 1 (Papenguth, 1996), I made mistakes on the minimum and maximum values for actinide concentrations associated with mineral-fragment-type colloidal particles. The attached Table contains the correct values.

References

Papenguth, H.W., 1996, Colloidal Actinide Source Term Parameters, Revision 1. SNL technical memorandum dated 18 April 1996 to Christine T. Stockman.

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MS 1324	Richard Aguilar, 6851
DOE/CAO	Robert A. Stroud

SWCF-A:WBS1.1.10.2.1

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
revised	CONCMIN	Th	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Th per liter of dispersion	triangular	1
revised	CONCMIN	U	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound U per liter of dispersion	triangular	1
revised	CONCMIN	Np	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Np per liter of dispersion	triangular	1
revised	CONCMIN	Pu	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Pu per liter of dispersion	triangular	1
revised	CONCMIN	Am	2.6e-09	2.6e-10	2.6e-08	moles colloidal mineral-fragment-bound Am per liter of dispersion	triangular	1
	CONCINT	Th	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Th per liter of dispersion	constant	
	CONCINT	U	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal U per liter of dispersion	constant	
	CONCINT	Np	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Np per liter of dispersion	constant	
	CONCINT	Pu	1.0e-09	1.0e-09	1.0e-09	moles actinide-intrinsic colloidal Pu per liter of dispersion	constant	
	CONCINT	Am	0.0e+00	0.0e+00	0.0e+00	moles actinide-intrinsic colloidal Am per liter of dispersion	constant	
	PHUMSIM	PHUMOX3	1.3e-01	8.0e-03	1.9e-01	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
	PHUMSIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
	PHUMSIM	PHUMOX5	4.8e-04	5.3e-05	9.1e-04	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
	PHUMSIM	PHUMOX6	5.6e-02	8.0e-03	1.2e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4
	PHUMCIM	PHUMOX3	1.1e+00	6.5e-02	1.6e+00	moles colloidal humic-bound actinide (III) per moles dissolved actinide (III)	triangular	2,3,4
	PHUMCIM	PHUMOX4	6.3e+00	6.3e+00	6.3e+00	moles colloidal humic-bound actinide (IV) per moles dissolved actinide (IV)	constant	2,3
	PHUMCIM	PHUMOX5	3.9e-03	4.3e-04	7.4e-03	moles colloidal humic-bound actinide (V) per moles dissolved actinide (V)	triangular	2,3,4
	PHUMCIM	PHUMOX6	2.8e-01	6.2e-02	5.1e-01	moles colloidal humic-bound actinide (VI) per moles dissolved actinide (VI)	triangular	2,3,4

Status	Parameter (IDPRAM)	Material (IDMTRL)	Most Likely Value	Minimum Value	Maximum Value	Units	Distribution Type	Notes
	CAPHUM	Th	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Th per liter of dispersion	constant	5,6
	CAPHUM	U	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound U per liter of dispersion	constant	5,6
	CAPHUM	Np	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Np per liter of dispersion	constant	5,6
	CAPHUM	Pu	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Pu per liter of dispersion	constant	5,6
	CAPHUM	Am	1.1e-05	1.1e-05	1.1e-05	moles colloidal humic-bound Am per liter of dispersion	constant	5,6
	PROPMIC	Th	3.1e+00	3.1e+00	3.1e+00	moles microbial Th per moles dissolved Th	constant	2,3
	PROPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles microbial U per moles dissolved U	constant	2,3
	PROPMIC	Np	1.2e+01	1.2e+01	1.2e+01	moles microbial Np per moles dissolved Np	constant	2,3
	PROPMIC	Pu	3.0e-01	3.0e-01	3.0e-01	moles microbial Pu per moles dissolved Pu	constant	2,3
	PROPMIC	Am	3.6e+00	3.6e+00	3.6e+00	moles microbial Am per moles dissolved Am	constant	2,3
	CAPMIC	Th	1.9e-03	1.9e-03	1.9e-03	moles total mobile Th per liter	constant	5,7
	CAPMIC	U	2.1e-03	2.1e-03	2.1e-03	moles total mobile U per liter	constant	5,7
	CAPMIC	Np	2.7e-03	2.7e-03	2.7e-03	moles total mobile Np per liter	constant	5,7
	CAPMIC	Pu	6.8e-05	6.8e-05	6.8e-05	moles total mobile Pu per liter	constant	5,7
	CAPMIC	Am	not currently available	not currently available	not currently available	moles total mobile Am per liter	constant	5,7

Notes:

general The colloidal actinide source term is added to the dissolved actinide source term.

general None of the parameters are correlated.

1 If a distribution is not used for mineral-fragment-bound actinides, use the maximum concentration as a constant value.

2 Proportionality constants may be used with actinide solubility expressed in molarity or molality, depending on the desired final units.

3 Proportionality constants are to be used with the inorganic actinide solubility value (uncomplexed only, i.e., without organic ligand contribution).

4 If a distribution is not used, use the maximum concentration as a constant value.

5 The maximum ("cap") values are in units comparable to molarity rather than molality.

6 CAPHUM is compared to the concentration of the respective humic-bound actinide element.

7 CAPMIC is compared to the total concentration of the respective actinide element in the mobile system (i.e., the sum of dissolved plus colloidal actinide).

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37415

INFORMATION ONLY

Estimate of Repository pH and f_{CO2} Distribution for the Long-Term WIPP Performance Assessment

WBS 1.1.09.1.1 (BC)
March 29, 1996

Performed by: Y. Wang — Date: 3/29/96
WIPP Chemical and Disposal Room Processes Department

Organizational Approval: J. T. Holmes — Date: 4/1/96
Manager
WIPP Chemical and Disposal Room Processes Department

Technical Reviewer: C. C. Crafts — Date: 4/1/96
WIPP Chemical and Disposal Room Processes Department

WPO 37415

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

date: March 29, 1996

to: Martin S. Tierney (Org. 6741)

Christine T. Stockman (Org. 6749)

from: Yifeng Wang (Org. 6748)

subject: Estimate of Repository pH and f_{CO2} Distribution for the Long-Term WIPP Performance Assessment (PA)

In my memo to M. D. Siegel (Wang, 1996), I justified that, due to the addition of MgO backfill, WIPP brine pH and f_{CO2} will be determined mainly by two chemical invariant points: $Mg(OH)_2 + MgCO_3$ or $Ca(OH)_2 + CaCO_3$. I thus suggested that actinide solubility be calculated only for these two invariant points. In this memo, I want to define the likelihood for the occurrence of each invariant point in WIPP repository over 10000 years.

I assume that $2x10^9$ moles of MgO will be added to the repository for controlling brine chemistry (Bynum, per comm., 3/26/1996) and $8x10^6$ moles of $Ca(OH)_2$ will be present as a cementious material in the waste (Drez, 1996; Storz, 1996). Since the quantities of MgO and $Ca(OH)_2$ are fixed, the pH and f_{CO2} will be a function only of the amount of CO_2 produced by microbial reaction , the volume of brine in the repository, and the type of brine. With computer code EQ3/6 (Wolery, 1992; Wolery & Daveler, 1992), I conducted titration calculations for each WIPP brine (ERDA-6 and Brine-A) with various amounts of $Mg(OH)_2$ and CO_2. In the calculations, $Ca(OH)_2$ was added in proportion to MgO. Furthermore, in order to avoid the numerical problem caused by water consumption, $Mg(OH)_2$, instead of MgO, was used in the calculations. The brine compositions were from Brush (1990). Based on the calculations, the distribution of the chemical invariant points was constructed as a function of moles of CO_2 /kg H_2O and moles of $Mg(OH)_2$/kg H_2O for each brine (Figures 1 and 2). For Castile brine ERDA-6, the transition from one invariant point to another is very sharp (Figure 1), while, for Salado brine Brine-A, a transition region (III) exists due to the formation of Mg-oxychlorite (Figure 2). The transition region and region I have very similar pH values. Note that pH in this memo always refers to pmH = -log $[H^+]$.

From Figures 1 and 2, the following conclusions can be drawn:

(1) The biodegradation of a small percentage of total cellulosics will produce sufficient CO_2 to react all $Ca(OH)_2$ in the waste (see dash lines region I in both Figure1 and 2). Therefore, for the cases with microbial gas generation, the brine chemistry will be controlled mainly by $Mg(OH)_2 + MgCO_3$ invariant point

(2) Without CO_2 production, in order for Salado brine to reach region II, the ratio of $Mg(OH)_2$/kg H_2O needs to be larger than 400, corresponding to the brine volume of 5000 m^3 (Figure 2). This brine volume is small and may only account for a few percents of total pore volume in the repository. Therefore, the brine chemistry in E2 scenario is unlikely to be controlled by the $Ca(OH)_2 + CaCO_3$ chemical invariant point, although this control may be in effect for some undisturbed cases.

(3) Figure 1 indicates that the brine chemistry will be controlled by $Ca(OH)_2$ + $CaCO_3$ in an E1 scenario with no CO_2 production. But, this may not be true, if there is enough Salado brine (> 5000 m^3) in the repository to react with all $Ca(OH)_2$ before human intrusion; for these cases, the brine chemistry will not be controlled by $Ca(OH)_2$ + $CaCO_3$.

Because the volumes of the brine in the repository and the brine released can not be predetermined, it is difficult to give a good estimate of the relative probability of being in region I versus region II. However, based on the above discussion, I expect that, given the current inventory estimate of $Ca(OH)_2$, the overall chance for a WIPP brine to be in region II is low. Considering that actinide solubility is higher at $Mg(OH)_2$ + $MgCO_3$ (Novak & Moore, 1996, *I recommend using the actinide solubility calculated for $Mg(OH)_2$ + $MgCO_3$ invariant point for all PA calculations.* This recommendation is conservative.

Figure 1. Chemical-Invariant-Point Distribution for Castile Brine (ERDA-6) as a Function of CO_2 Produced and $Mg(OH)_2$ Added per Kilograms of Water. Since MgO and $Ca(OH)_2$ are fixed, the ratio of $Mg(OH)_2/H_2O = 2x10^9$ moles/kg of total water in the repository. The ratio of $Ca(OH)_2$/kg H_2O = 0.004*$Mg(OH)_2$/kg H_2O. The dash line is the CO_2/H_2O ratio corresponding to 8% of cellulosics biodegraded.

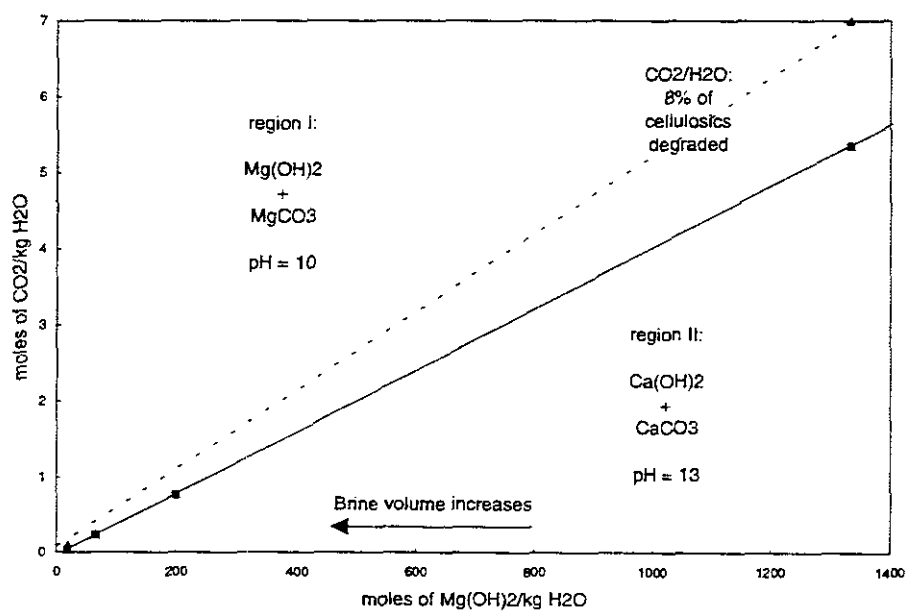

Figure 2. Chemical-Invariant-Point Distribution for Salado brine (Brine-A) as a Function of CO_2 Produced and $Mg(OH)_2$ Added per Kilograms of Water. Since MgO and $Ca(OH)_2$ are fixed, the ratio of $Mg(OH)_2/H2O = 2x10^9$ moles/kg of total water in the repository. The ratio of $Ca(OH)_2$/kg H_2O = 0.004*$Mg(OH)_2$/kg H_2O. The dash line is the CO_2/H_2O ratio corresponding to 8% of cellulosics biodegraded. Region III can be combined into region I, because they have similar pH values.

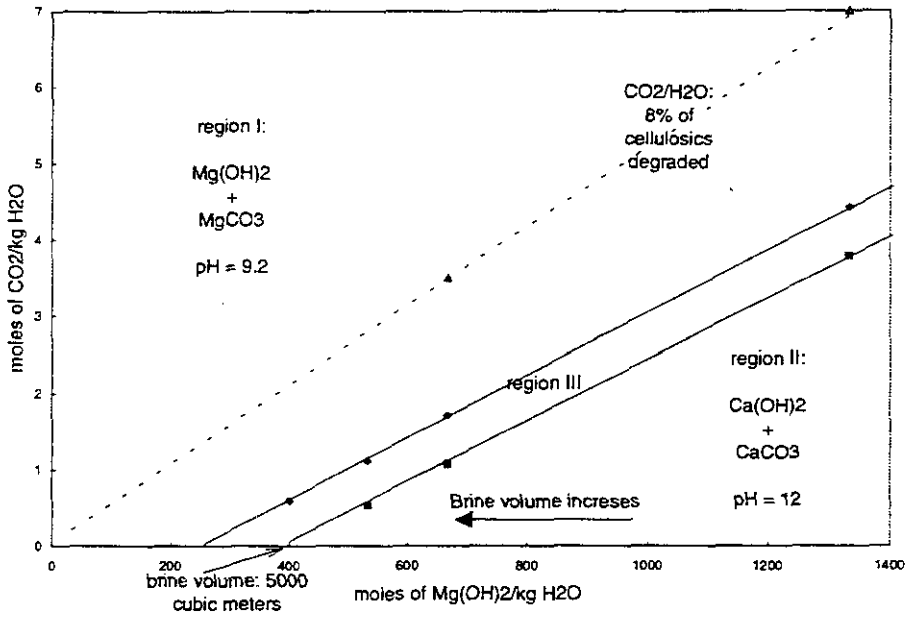

References:

Brush L. H. (1990) *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266, Sandia National Lab., Albuquerque, NM.

Drez P. (1996) Estimate of portland cement in TRU waste for disposal in theWIPP. CTAC. 3/28/1996.

Novak C. F. & R. C. Moore (1996) Estimates of dissolved concentrations for +III, +IV, +V, and +VI actinides in a Salado and a Castile brine under anticipated repository conditions. Memo to M. D. Siegel, 3/28/96.

Storz L. (1996) Estimate of the amount of Ca(OH)2 contained in the portland cement fraction of the waste for disposal in the WIPP. Memo to Y. Wang, 4/2/1996.

Wang Y. (1996) Define chemical conditions for FMT actinide solubility calculations. WBS 1.1.09.1.1 (BC).

Wolery T. J. (1992) *EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0).* Lawrence Livermore Lab., Livemore, CA.

Wolery T. J. & Daveler S. A. (1992) *EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0).* Lawrence Livermore Lab., Livemore, CA.

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From Estimates of Gas Generation 30819

Sandia National Laboratories
Albuquerque, New Mexico 87185-1341

date: March 18, 1996

to: Malcolm D. Siegel (Org. 6748)

INFORMATION ONLY

from: Yifeng Wang (Org. 6748)

subject: Define Chemical Conditions for FMT Actinide Solubility Calculations

Reflecting the recent decision of adding MgO as a backfill to control WIPP repository chemistry, this memorandum is to define the chemical conditions for FMT actinide solubility calculations for WIPP performance assessment (PA). The decision of adding backfill will significantly simplify the FMT calculations. In the original plan, the actinide solubility was supposed to be calculated for the whole ranges of brine chemical conditions (pH, CO_2 fugacity) and the results would be submitted to PA as lookup tables. However, due to the addition of MgO, we now only need to calculate the actinide solubility for two chemical invariant points, and the full-range lookup tables are no longer needed.

To define WIPP brine pH and CO_2 fugacity (f_{CO2}), I have conducted the titration calculations for both Salado brine (Brine-A) and Castile brine (ERDA-6) with computer code EQ3/6 (Wolery, 1992; Wolery & Daveler, 1992). In the calculations, I have assumed (1) that the repository chemistry will be mainly controlled by microbial CO_2 production and the dissolution of MgO backfill and $Ca(OH)_2$ originally present in the waste as a cementious material and (2) that the amount of MgO added will be sufficient to remove all CO_2 from gaseous and liquid phases. The brine chemical composition used in the calculations are from Brush (1990, tables 2-2 and 2-3). The calculation results are shown in Figures 1 and 2. Note that pH in this memo always refers to pmH = $-\log[H^+]$.

The calculation results show (1) that adding sufficient MgO to the repository will buffer brine pH at 10 for Castile brine (ERDA-6) and 9.2 for Salado brine (Brine-A), after all CO_2 in the gaseous and liquid phases are consumed, and (2) that the presence of $Ca(OH)_2$ in the waste may bring pH to 13 for Castile brine and 12 for Salado brine (Figures 1 and 2). Thermodynamic calculation shows that the reaction:

$$MgCO_3 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCO_3 \qquad \Delta G = -9.4 \text{ kcal/mole (Drever, 1982)}$$

will proceed until all $MgCO_3$ is consumed. Thus, the effect of $Ca(OH)_2$ on pH will depend will only on the ratio of $Ca(OH)_2$ to water, regardless of how much MgO will be added. Figure 1 and 2 indicates that the brine pH and f_{CO2} will be essentially determined by either of two chemical invariant points:

(1) $MgCO_3 + Mg(OH)_2$ — pH = 10 for Castile brine and 9.2 for Salado brine
(2) $CaCO_3 + Ca(OH)_3$ — pH = 13 for Castile brine and 12 for Salado brine.

The transition between the two invariant is sudden.

From the calculation results, I suggest using FMT to calculate the actinide solubility only for the two chemical invariant points for each brine. The solubility in the transition zone between the two invariant points will be determined, if needed, by a linear interpolation method. In FMT calculations, the chemical invariant points can be obtained by adding sufficient amounts of $Mg(OH)_2$ and $Ca(OH)_2$ to the brines and they are characterized by the presence of a typical mineral set: either $MgCO_3 + Mg(OH)_2$ or $CaCO_3 + Ca(OH)_2$.

In a separate memo to PA, I will provide the relationship between the brine chemistry and its controlling factors such as the quantity of CO_2 produced, the amount $Ca(OH)_2$ present, and the brine volume. This relationship will allow us to determine the probability of the chemical system falling at each chemical invariant point or the transition zone between the two invariant points.

Figure 1. (A) Castile brine (ERDA-6) titrated with $Mg(OH)_2$. (B) and (C) The resulting system in (A) is further titrated with $Ca(OH)_2$. Note a sudden transition from $MgCO_3 + Mg(OH)_2$ to $CaCO_3 + Ca(OH)_2$ regions.

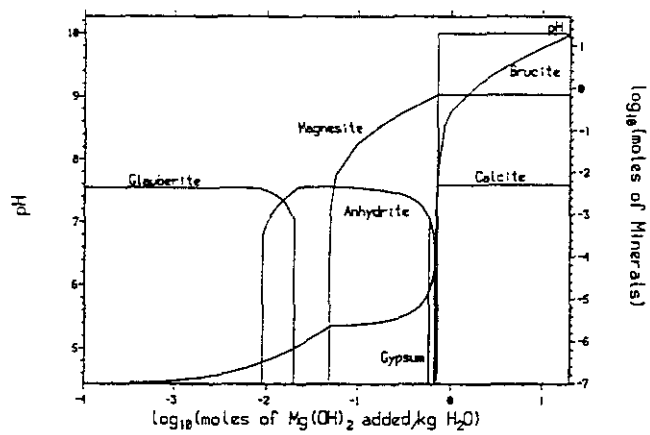

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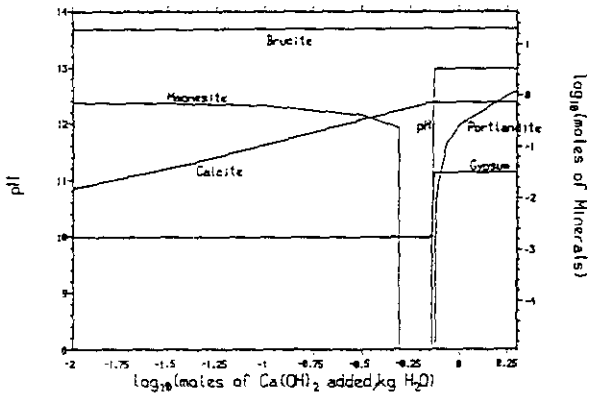
Brucite
Magnesite
Calcite
pH
Portlandite
Gypsum
pH
log10(moles of Minerals)
log10(moles of Ca(OH)2 added/kg H2O)

B

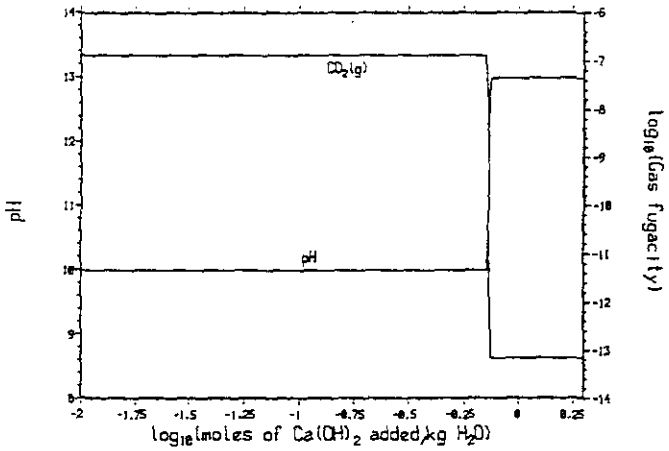
CO2(g)
pH
pH
log10(Gas fugacity)
log10(moles of Ca(OH)2 added/kg H2O)

C

Figure 2. (A) Salado brine (Brine-A) titrated with $Mg(OH)_2$. (B) and (C) The resulting system in (A) is further titrated with $Ca(OH)_2$. Note a sudden transition from $MgCO_3$ + $Mg(OH)_2$ to $CaCO_3$ + $Ca(OH)_2$ regions

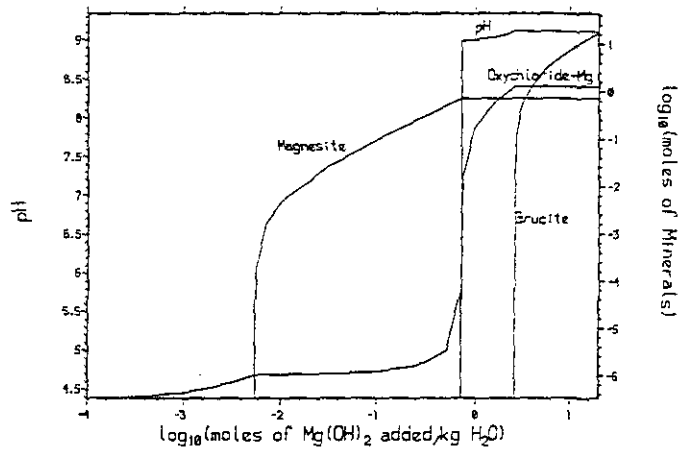

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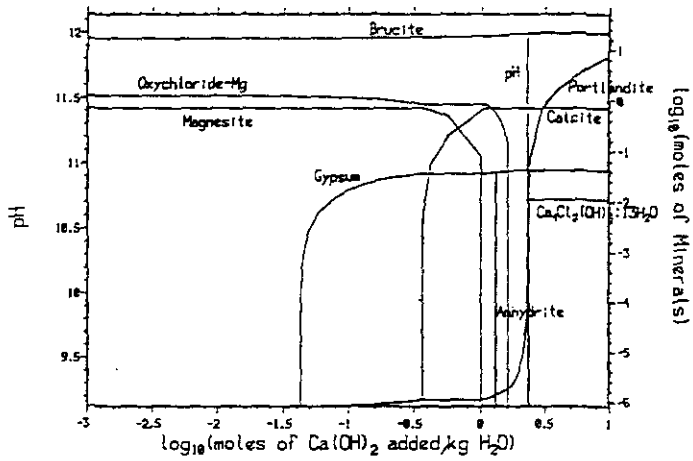

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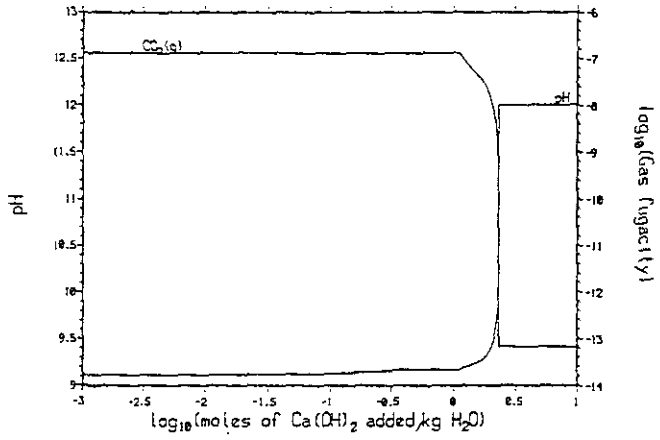

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References:

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Drever J. I. (1982) *The geochemistry of Natural Waters.* Prentice Hall.

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WP035552

INFORMATION ONLY

REVISED INFORMAL MEMO

To: Joe Harvill, CTAC March 20, 1996

From: Paul Drez, PD CTAC

Subject: FINAL PRELIMINARY ESTIMATE OF COMPLEXING AGENTS IN TRU SOLIDIFIED WASTE FORMS SCHEDULED FOR DISPOSAL IN WIPP

SUMMARY

This memo provides the best estimate of complexing agents, based on transuranic (TRU) waste generator/storage site input, in TRU waste expected to be shipped to the Waste Isolation Pilot Plant (WIPP) for disposal. The complexing agent inventories quoted in this memo are in response to a Sandia National Laboratory/New Mexico (SNL/NM) request for information to the U. S. Department of Energy (DOE) Carlsbad Area Office (CAO). The memo requesting the complexing agent information is contained in Appendix B of Revision 2 of the Transuranic Waste Baseline Inventory Report (TWBIR) (DOE, 1995). All waste inventory volumes quoted are derived from Rev. 2 of the TWBIR.

SNL/NM should use Table 3 as a summary of specific complexing agents that may be present in the TRU waste. Tables 1 and 2 provides a summary of Total Organic Carbon in the remote-handled (RH)-TRU sludges from Oak Ridge National Laboratory (ORNL) and a list of possible complexing agents that may contribute to the TOC in the sludges.

Estimates are provided in Table 4 of the volume of stored and projected TRU waste that contribute to the estimate of complexing agents in the waste. For contact handled (CH)-TRU waste, greater than 94% of TRU stored and projected final waste forms contribute to the complexing agent estimate and greater than 98% of the Solidified Organic final waste forms and greater than 92% of the Solidified Inorganic final waste forms. For RH-TRU waste, greater than 86% of TRU stored and projected final waste forms contribute to the complexing agent estimate and 100% of the Solidified Organic final waste forms and 100% of the Solidified Inorganic final waste forms.

BACKGROUND

Information has been received from all sites that were requested to provide data on potential complexing agents in their solidified waste forms: Rocky Flats Environmental Technology Site (RFETS), Los Alamos National Laboratory (LANL) and ORNL. In addition, several TRU waste sites which do not generate solidified waste forms (or small quantities) have also responded. A copy of the CAO memo requesting the complexing agent information is included as Attachment 1.

SWCF-A: 1.2.07.2.1; PA; PBWAC

The term "complexing agent" is being used in lieu of "chelating agents" in this memo, since chelating agents usually have a certain structure (chelating comes from the Greek work "chele" for claw, as in a crab), and are considered a subset of complexing agents. That is, acetate ion will "complex" with some metals and increase their solubility but does not have the structure that would label it as a chelating agent. A "commonly" known chelating agent is EDTA (ethylenediaminetetraacetic acid), which contains functional (acetate) anion groups arrange in parallel which resemble a "claw" like structure for complexing the cations. EDTA has two "claw" structures at either end of the molecule.

The original scope of this task was to ask the TRU waste generator/storage sites about "aqueous-soluble" complexing agents in their solidified waste forms. As this task was researched, the authors realized that the term "aqueous-soluble" is only a relative term, since everything is "aqueous-soluble" at some concentration level. Therefore, every potential chemical compound that has been reported from the TRU waste sites is included and the task of selecting aqueous soluble compounds is left to the SNL personnel in charge of performance assessment calculations.

TRU WASTE SITE RESPONSES

ORNL

ORNL has provided a list of organic compounds which contain some aqueous-soluble compounds that are apparent complexing agents. A copy of the list of all compounds reported by ORNL to the BIR team is attached for completeness (Table 1). The list in Table 1 is from an ORNL report on low-level waste (Kaiser, 1988), but the same compounds are anticipated to occur in the TRU waste based on process history (but not necessarily at the same concentrations). ORNL cannot quantify these compounds in their RH-TRU solidified wastes, but have provided an estimate of Total Organic Carbon (TOC) for each RH-TRU waste tank (Table 2). The sum of the TOC from all the RH-TRU tanks is approximately 3691 kg. It is anticipated that most of the TOC in the tanks is not associated with complexing agents, but that has not been verified at this time. As a conservatism, SNL/NM can assume that any complexing agents listed in Table 1 could form the bulk of the TOC in the ORNL RH-TRU tanks.

LANL

Los Alamos National Laboratory has provided estimates of four complexing agents that are anticipated to occur in their TRU solidified waste streams and as materials used in decontamination and spill clean-up operations (that would occur with the debris wastes) (Attachment 2). The quantities of these compounds are summarized in Table 3.

RFETS/INEL

The information provided by RFETS has been used to estimate the amount of complexing agents in the RFETS retrievable waste (post 1970) at Idaho National Engineering Laboratory (INEL). Attached is a listing of chemicals from RFETS that was provided to the BIR team as a basis for potential complexing agents in TRU waste scheduled for shipment to and disposal in WIPP (Table 3). This same list was originally put together as part of the documentation requested by the State of Nevada to document that less than 1% "complexing" agents occur in RFETS solidified low-level "saltcrete" waste that would be shipped to NTS for disposal (Attachment 5).

The list was provided as a yearly estimate of complexing agents used on site at RFETS. It is conservative to assume that all of these complexing agents would reside in the TRU waste. The inventory of complexing agents is the best estimate for all TRU waste generated across the entire RFETS site, which includes debris wastes. The mass of complexing agents reported in Table 3 for RFETS results from multiply the yearly estimates (in kilograms) by 20 years of production at RFETS (1970-1989), which includes RFETS waste in storage at INEL. The yearly estimates can be found in Attachment 3.

SRS

The Savannah River Site (SRS) has provided a letter in response to the DOE CAO request (Attachment 1) which is included as Attachment 4. SRS has provided information on three complexing agents used on site in connection with their operations, tributyl phosphate (TBP), tri-octyl phosphine oxide (TOPO) and tri-iso octylamine (TIOA). As discussed in the SRS letter, none of these compounds are expected to be found in SRS TRU waste.

Hanford

Hanford Operations has provided a listing from their database of potential chemicals in their TRU waste. The only chemical that appears on the list that might act as a chelating agent in aqueous solutions and has a reportable quantity associated with the waste is tributly phosphate (TBP). TBP is reported under three different spellings with a total of 92.5 kg. This value is summarized in Table 3. The entire list of chemicals reported by Hanford and quantities (in kg) are included in Attachment 5.

LLNL

Lawrence Livermore National Laboratory submitted the letter included as Attachment 6 documenting that no chelating agents occur in the LLNL TRU waste streams.

ESTIMATED VOLUME OF TRU WASTE INCLUDED IN COMPLEXING AGENT MEMO

Table 4 contains a listing of the total TRU waste destined for disposal in WIPP (stored plus projected to 2022), listed in Column 2. Column 3 estimates what volume of waste from each major site that has contributed to the estimate of complexing agents in TRU waste. Column 4 and 5 provide the same data for Solidified Organics and Solidified Inorganics final waste forms. The two rows labelled "PERCENTAGE" provide an estimate of the percentage of waste that TRU waste generator/storage sites have provided data for estimating complexing agents in the waste.

REFERENCES

Kaiser, L. L., 1988, "ORNL Inactive Waste Tanks Sampling and Analysis Plan," ORNL/RAP/LTR-88/24, April 29, 1988, Oak Ridge National Laboratory, Oak Ridge, Tennessee

U. S. Department of Energy, 1995, "Transuranic Waste Baseline Inventory Report (Revision 2)," DOE/CAO-95-1121, December 1995, Carlsbad, New Mexico

cc: R. Bisping, DOE/CAO
M. Chu, SNL/NM
L. Storz, SNL/NM
L. Sanchez, SNL/NM

PRELIMINARY

Table 1 Organic chemicals used regularly in the TPP (7920) and TURF (7930) and subsequently discharged to the ORNL LLLW system

Chemical	Approximate annual usage
Acetic acid	m[a]
Acetone	100 L
Adogen-364-HP (tri-n-triluarylamine)	100 L
Carbon tetrachloride	m
Deodorized mineral spirits (Amsco)	1000 L
2,5-di-tert-butylhydroquinone (DBHQ)	m
Deithylbenzene (DEB)	800 L
Diethylenetriaminepentaacetic acid (DPTA)	m
Di(2-ethylhexyl) phosphoric acid (HDEHP)	200 L
Di-isopropylbenzene (DIPB)	100 L
Ethanol	100 L
Ether	m
Ethylenediaminetetraacetic acid (EDTA)	m
2-ethyl-1-hexanol	m
α-hydroxyisobutyric acid (AHIB)	m
Isopropanol	m
Methanol	m
n-dodecane	m
n-paraffin (NPH)	m
Oxalic acid	m
Thenoyltrifluoroacetone (TTA)	m
Tributylphosphate (TBP)	m
Trichloroethylene (TCE)	m
Xylene	m

[a]m = minimal usage: ≤10 kg/year or ≤L/year.

FINAL PRELIMINARY

TABLE 2. ORNL TOTAL ORGANIC CARBON ESTIMATES

TRU TANKS	TANK NO.	VOLUME (m3)	MASS (kg)	TOC (mg/kg)	TOC (kg)
INACTIVE TANKS					
North Tank Farm	W-03	5.3	5670	5300	30.05
	W-04	18.2	24527	200	4.91
South Tank Farm	W-07	37.5	45715	1300	59.43
	W-08	11.4	14080	8400	118.27
	W-09	0.8	833	2900	2.42
	W-10	28	31650	4900	155.09
Old Hydrofracture Facility	T-01	3	4845	18600	90.12
	T-02	4.6	7328	28000	205.18
	T-03	7.7	14829	9140	135.54
	T-04	5	6242	4620	28.84
	T-09	1.9	2967	7620	22.61
ACTIVE TANKS					
Evaporator Facility	C[illegible]	45.6	63353	3281	209.50
	W-21	27.5	38524	6480	249.64
	W-22	43.5	60939	22.1	1.35
	W-23	64.2	89818	4120	370.05
MVST	W-24	52	72861	2940	214.21
	W-25	90.7	126911	2330	295.70
	W-26	59.2	82930	6220	515.82
	W-27	69.1	96707	3135	303.18
	W-28	16.5	23051	250[illegible]	57.63
	W-29	46.[illegible]	64913	353[illegible]	229.21
	W-30	46	64383	353[illegible]	227.34
	W-31	26.3	36828	4470	164.62
				Total TOC	3690.69

PRELIMINARY

TABLE 3. RF/INEL AND LANL COMPLEXING CHEMICALS ESTIMATE

POTENTIAL COMPLEXING AGENTS IN ROCKY FLATS (INCLUDING STORED AT INEL), LANL, HANFORD TRU WASTE				
COMPOUND	RF MASS (kg)(1)	LANL MASS (kg)(2)	HANFORD MASS (kg)(3)	TOTAL MASS (kg)
Ascorbic Acid	90	7		97
Acetic Acid	132	10		142
Sodium Acetate	1110			1110
Citric Acid	90	1100.5		1190.5
Sodium Citrate	400			400
Oxalic Acid	90	13706		13796
EDTA	23			23
8-Hydroxyquinoline	46			46
Tributly Phosphate	74		92.5	166.5
1,10 Phenanthroline	0.24			0.24
Dihexyl-n,n-diethylcarbamoyl-methylphosphonate	72			72
(1) Letter from W.F. Weston to E.S. Goldberg, No. 89-RF-3055, dated September 1, 1989 (Attachment 3)				
(2) Memorandum from C.L. Foxx to P. Drez dated March 12, 1996 (Attachment 2)				
(3) Memorandum from F.M. Coony and M.R. Kerns to L.C. Sanchez thru S. Sellott, dated January 25, 1996 (Attachment 5)				

PRELIMINARY

TABLE 4. CALCULATION OF AMOUNT OF WASTE COVERED IN COMPLEXING AGENT MEMO

Major Sites	Total TRU (m3)	Accounted For In Complexing Agent Estimate (m3)	Solidif. Org (m3)	Solidif. Inorg. (m3)		
CH-TRU(1)						
RL (9)	45515.43	45515.43	0	23.39		
INEL(2)	28606.74	28657.4	789.67	3349.6		
LLNL(3)	941.13	941.13	0	20.18		
LANL (4)	18405.15	18405.15	30.58	6922.02		
NTS (5)	627.91	627.91	0	5.67		
ORNL (6)	1560.42	0	0	0		
RFETS (7)	5107.92	5107.92	140.93	1423.01		
SRS (8)	9648.15	9648.15	0	1369.8		
Total Major Sites	110[illegible]12.85	105903.09	961.[illegible]	13113.67		
Total CH-TRU	111721.43	111721.43	9[illegible]0	14108.51		
PERCENTAGE (10)		94.79%	98.08%	92.95%		
RH-TRU(1)						
RL (9)	21729.35	21729.35	0	0		
INEL (2)	220.72	196.98	3.56	[illegible].27		
LANL (4)	193.13	1.93E+02	0	0		
ORNL (6)	2915.64	1243.33	0	1243.33		
Total Major Sites	25058.84	23[illegible]2.7[illegible]	3.56	1308.6		
Total RH-TRU	26930.88	26[illegible].88	3.56	1308.6		
PERCENTAGE (10)		86.75%	100.00%	100.00%		
(1) Table 4-3 to 4-23, Rev 2 TWBIR						
(2) Non RFETS Waste Subtracted						
(3) Letter from K. Hainebach to J. Teak dated March 7, 1996 (Attachment 6)						
(4) Memorandum from C.L. Foxx to P. Drez dated March 12, 1996 (Attachment 2)						
(5) NTS waste is derived from LANL only, see (4)						
(6) ORNL was only asked to estimate complexing agents in solidified						
RH-TRU waste per DOE memorandum dated January 5, 1996 (Attachment 1)						
(7) Letter from W.F. Weston to E.S. Goldberg, Letter No. 89-RF-3055,						
dated September 1, 1989 (Attachment 3)						
(8) Letter from J. D'Amelio to J. Teak SWE-SWE-96-0106, dated February 2[illegible], 1996 (Attachment 4)						
(9) Memorandum from F.M. Coony and M.R. Kems to L.C. Sanchez thru S. [illegible],						
dated January 25, 1996 (Attachment 5)						
(10) VOLUME PERCENTAGE OF TOTAL TRU WASTE, SOLIDIFIED ORGANICS AND						
SOLIDIFIED INORGANICS ACCOUNTED FOR IN COMPLEXING AGENT MEMO						

PRELIMINARY

ATTACHMENT 1

United States Government Department of Energy

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: JAN 5 1996

REPLY TO ATTN OF: CAO:NTP:RLB 96-0605

SUBJECT: Additional Transuranic (TRU) Waste Data Request for Sandia National Laboratories' Waste Isolation Pilot Plan (WIPP) Performance Assessment

TO: Distribution

We have been informed by representatives from Sandia National Laboratories (SNL) working on WIPP Performance Assessment (PA) that they require more information on certain TRU waste-related parameters in order to assess their influence on WIPP PA (see attached copy of relevant pages form SNL memo).

Data for most of these parameters have already been received from the sites either through responses to the Baseline Inventory Report (BIR), Revision 2, questionnaire or by discussions with site representatives. However, since the request from SNL for data on water soluble organic ligands (i.e., chelating agents) was not received in time for inclusion in the BIR Rev. 2 data call, WIPP PA still needs data for this parameter. As per the SNL memo, the data are needed by the end of February 1996, and therefore it is being addressed through this request separately from the upcoming BIR Rev. 3 data call.

As documented in the SNL memo, WIPP PA would like to have "best estimates" that are realistic and not overly conservative. Consequently, all sites that have existing data on chelating agents present in their waste are requested to submit the best available information to the BIR technical staff by February 26, 1996. The details on the nature of the information being requested by WIPP PA are being provided in Table 3 of the attachment.

A representative from SNL WIPP PA will be available at the upcoming BIR, Revision 3, Data Call Meeting to be held in Concord, California, on January 10, 1996. We anticipate that a brief presentation will be made at this meeting by WIPP PA staff explaining the importance of the data followed by any questions from site representatives. If you have any questions/clarifications regarding this matter, please be ready to discuss these at the upcoming meeting in Concord with the SNL WIPP PA representative.

Thank you for your continued cooperation.

Russ Bisping
Russ Bisping
Waste Certification Manager

Attachment

printed on recycled paper

APPENDIX B

B) Special Request Non-PA Items

Also wanted at this time is additional information for several waste material characteristics. Although these characteristics have not been identified as waste material parameters to be used for WIPP PA, they are needed for non-PA scoping calculations to assess their influence on PA. Since these items are not currently PA parameters, inventory estimates of these characteristics as "additional information" in the TWBIR or supplied outside of the TWBIR via written correspondence. Below you will find an itemized list of these special request items.

1) **Non-radioactive Materials**
Additional information is needed on the five waste material characteristics (see Table 2): 1) vitrified wastes, 2) nitrates (NO_3^-), 3) sulfates (SO_4^{2-}), 4) phosphorus, and 5) cement. Of these waste parameters, the last four are needed for the gas generation modeling. The nitrates and the sulfates are involved in the denitrification and sulfate reduction processes which breakup the cellulosics, while the phosphorus is a nutrient for biodecay of cellulosics. The estimate of the mass quantities of cement in the waste inventory should include both the cement that is contained in the waste as cement itself (due to D&D activities, etc.) and the cement found in various sludges. Cement consumes CO_2 due to its content of $Ca(OH)_2$. The estimates for this non-radioactive waste constituent need only be "best estimates" at this present time so that non-PA scoping calculations can be made to determine their importance on overall repository performance. (Do not generate upper-bound estimates that are overly conservative.)

2) **Residues**
"Best estimates" are needed for residues, in addition to those already identified at the Rocky Flats Plant (RFP), that have the possibility of being changed from a resource category to a TRU waste category.

3) **Organic Ligands (Chelating Agents)**
"Best estimates", from currently available information, are needed for major water-soluble organic ligands which are under consideration for the actinide source term (see Table 3). If it is not possible to obtain data from major waste generating sites then supply guidance on how a first-order estimate may be made (from existing information such as process knowledge etc.,) so that non-PA scoping calculations can be performed to identify if the presence of these ligands would have any significant impacts. (Do not generate estimates that are overly conservative.) Requested data is for final form "process-level" quantities used in production only for the key sites. If information on the "process-level" values does not exist at the key sites, then "laboratory-scale" values should be used in the requested assessment of the inventory. Should it be determined that more detailed information on organic ligands will be needed, you will be given a specific written request at a future time. This effort should be performed in parallel with the TWBIR. Technical data should be supplied in memorandum form by the end of February 1996 with supporting documentation by the end of March 1996.

Table 3. Justification of Special Request For Info On Organic Complexing Agents. (a)

Ligand (b)	Discussion (c)
1) Total Complexants	The most valuable information at this time is a "best estimate" of the total amount of water soluble complexing agents (ligands) in the TRU waste matrix.
2) Citrate	Preliminary information indicates that citrate (citric acid) may be the largest used ligand at TRU waste generating sites. Hence, inventory quantities are very important.
3) Lactate	This is an important ligand that is produced by bacteria as part of its own metabolism. What is requested here is a "best estimate" of the quantity of lactate that actually exists in the TRU waste matrix (not just an initial amount supplied as part of a waste stream). However, if this information cannot be developed, then supply information on the initial amount.
4) Oxalate	This is an important ligand that is produced by bacteria as part of its own metabolism. What is requested here is a "best estimate" of the quantity of oxalate that actually exists in the TRU waste matrix (not just an initial amount supplied as part of a waste stream). However, if this information cannot be developed, then supply information on the initial amount.
5) EDTA	This ligand (ethylenediaminetetraacetic acid) is also of major importance due to its common use as a cleaning solvent.

(a) Information on these additional waste materials are needed for non-PA scoping calculations for assessment of their importance. The presence of these complexing agents are important for the actinide source term, with respect to increasing the solubility of radionuclides.
(b) These items are ranked in the order of their importance in the actinide source term.
(c) Also supply any available information that TRU waste generation sites may have on the degradation or decay rates of ligands in current (and expected) waste matrixes if possible. In cases where no information is available, supply guidance on estimating first-order quantities.

LCS:6741:lcz/(95-2082)

Copy to:
P.E. Drez [Drez Environmental Associates]
D. Bretzke [Science Applications International Corporation]
S. Chakraborti [Science Applications International Corporation]
MS-1320, C.F. Novak [Dept. 6119]
MS-1323, H. Jow [Dept. 6741]

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JAN 5 1998

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Jerry Wells, ID

ATTACHMENT 2

Los Alamos
NATIONAL LABORATORY
memorandum

Waste Management and Environmental Compliance
NMT-7, MS E501

To/MS: Paul Drez, Drez Environ. Assoc.
Thru: James I. Balkey, NMT-7, MS E501 998

From/MS: C. L. Foxx, NMT-7, MS E501 CLF
Phone/FAX: 7-2328/ 7-9201
Symbol: NMT-7-WM/EC-96-035
Date: March 12, 1996

SUBJECT: CHELATING AGENTS IN LANL WASTE

I am certain that I have not captured all chelating agents, but I believe that I have identified and quantified roughly the important materials. The chelators are found in three waste streams:

1) Cemented evaporator bottoms from TA-55
2) Cemented sludge from the TA-50 Pretreatment Plant and dewatered sludge from the TA-50 Liquid Waste Treatment Plant
3) Combustible waste from TA-55

The three streams are summarized below.

It should be noted that waste generation data and analyses exist over the time frame of 1980 through 1995 or shorter intervals to support the estimated values. In some cases, quantitative data is almost nonexistent and the results are qualitative at best. Like Rocky Flats, plutonium processing at LANL attempts to avoid chelating agents which can interfere with recovery operations. From your list of compounds of interest, I am unaware of any significant usage of lactate or EDTA, so they have been eliminated from detailed consideration. I have added ascorbate which has been used as a reducing agent in HCl solutions, but not in nitric acid which attacks and decomposes ascorbate. One of the above streams is not an immobilized stream, but I believe that it is an important contributor of a soluble chelating agent in the form of citrate. If this information is extraneous to your purposes, just ignore it.

Cemented evaporator bottoms from TA-55. The evaporator bottoms are derived from nitric acid solutions some of which (27%) contain oxalate resulting from the precipitation of plutonium oxalate. Because of the pervasive usage of oxalate, it is contained at lower concentrations even in those solutions that do not arise from filtering an oxalate precipitate. Those numbers are based on analytical results. In addition the drums contain on the average, 3.2 liters of analytical solution residues. Those solutions contribute a negligible additional quantity of oxalate and small quantities of ascorbate, citrate and acetate. We have semi-quantitative values from the analytical organization for those chelators, based on the quantities used in the analytical processes that give rise to the residues. We know that 28 liters of solution went into a drum of cemented waste on the average from 1980 through June of 1988. Since that time, the average has been 43 liters of solution. In addition we have information regarding the number of drums generated from May, 1987 through April, 1995. The drum numbers and alternate cemented forms

for the remaining years are estimated. The totals based on those data and estimates are shown here.

oxalate	1600 kg	90.04 / 88.04	= 1632	
ascorbate	7 kg	176.14 / 175.14	= 7.04	≈ 7
citrate	0.5 kg	192.14 / 191.14	= 0.5	≈ 0.5
acetate	10 kg	60.05 / 59.05		≈ 10

Cemented sludge from the TA-50 Pretreatment Plant and dewatered sludge from the TA-50 Liquid Waste Treatment Plant. Based on experience at the liquid waste treatment plant with upsets in the treatment process due to the presence of chelators in the waste stream, it has been assumed that TA-55 is the only significant source of chelating agents in the sludge generated at that facility. Three waste lines carry liquids from TA-55 to TA-50. The industrial waste line is thought to be reasonably free of chelating agents. The evaporator distillate in the process acid waste line is unlikely to contain significant quantities of chelators because the distillation process creates a sharp reduction in the content of nonvolatile solution species.

The process caustic waste line solution is dominated by oxalate filtrates in hydrochloric acid that have been subjected to caustic treatment and filtration. Under the conditions of that treatment the oxalate and ascorbate (used historically) are soluble and follow the solution to TA-50 for a ferrofloculation treatment. The solution is used to neutralize the nitric acid distillate. Because there is an excess of nitric acid, the neutralization is completed with the addition of stock sodium hydroxide. I have assumed that the short term excess of nitric acid decomposes the ascorbate leaving only the oxalate. I have estimated the oxalate concentration in the hydroxide filtrate at 0.075 moles/liter. If this number drives the calculation then we should sample the solution in the caustic holding tank at TA-50 and get a representative value.

Volumes of caustic solution generated by TA-55 were available for the years 1983 and 1986 through 1992. Volumes for all other years were estimated. I am assuming that the oxalate will appear in the sludges due to the low solubility of calcium oxalate and because the flocculations have relatively high concentrations of calcium. In addition magnesium and aluminum oxalates are insoluble in a caustic environment. The oxalate precipitates will be found in the cemented sludge, whenever generated, and in the dewatered sludge from the early and middle 80's. These oxalates will also be found in the cement-filled corrugated metal pipe (CMP) waste stream generated at DP site when plutonium operations were located there. The total of oxalate in those waste streams is 11,800 kg. = 12070

Combustible waste from TA-55. The combustible waste stream contains rags that were used in decontamination and spill clean-up operations. In spill clean-up the rags from the first pass are nearly always TRU waste as measured on our MEGAS assay instrument. The rags are dampened with a solution labeled "versene". Versene is a name for EDTA. In the very early days of the laboratory versene solution may have contained EDTA, but it had been changed to sodium citrate solution by the time I arrived in 1969. Drums of combustible waste do not usually contain only decontamination rags and often contain no

such rags. However our waste management personnel apparently used a unique identifier over about a four year period (1987 to 1991) for the decontamination rags. Each item also had a net disposal weight associated with it. Thus I was able to get a handle on the weight of decon rags generated in that time frame. The rags were discarded not dripping but distinctly damp. I dampened some cheesecloth, weighing before and after, to estimate the weight of solution contained in the rags. Knowing the weight of solution and the concentration of the citrate, I was able to calculate a weight of citrate in the discarded rags. In May, 1991 the usage of citrate for decontamination was restricted to certain matrices. I was able to locate records for versene solution preparation from 1989 into early 1991 and then again for the past year so I could understand usage before and after 1991. From that I have estimated the usage for the remaining years. With that information, I have estimated that the citrate contained in the combustible waste stream from 1971 to 2033 will be 1100 kg.

Cy: Andy Montoya, NMT-7, MS E501
NMT-7 File

ATTACHMENT 3

CORRES. CONTROL
OUTGOING LTR. NO.

89RF3055

DIST.	LTR	ENCL
SANCHINI, O.J.		
BADER, C.P.		
BERRUROT, R.J.		
HEINTZ, E.R.		
HOOD, R.C.		
DEKER, E.H.		
INGER, J.E.		
IRBY, W.A.		
MNETT, J.F.		
MEYERS, G.W.		
NOECKER, J.H.		
SHANNON, W.M.		
WESTON, W.F.	X	
WOZNIAK, B.D.		
YOUNG, E.R.		
BETCHER, D.K.		
CARNIVAL, G.J.		
FERRERA, D.W.		
HARMAN, L.K.		
HEBERT, J.L.		
HOEY, J.B.		
HOFFMAN, R.B.		
KLAMANN, R.L.		
KRIEG, D.M.	X	X
LOX TURG, G.E.		
MOR, T.K.B.	X	
MUNION, E.R.	X	X
NEWBY, R.L.		
TURNER, H.L.		
VELASQUEZ, R.N.		
CORRES. CONTROL	X	X
CONTRACT ADMIN.		
Arnold, PM	X	X
D'Amico, EL	X	X
Joskat, GF	X	X
Hinkle, EL	X	X
CLASSIFICATION		
UNCLASSIFIED	X	X
CONFIDENTIAL		
SECRET		

AUTH. CLASSIFIER SIG.
Tim P. Fuller
9/1/89
DATE

IN REPLY TO LTR. NO.
245RF89

SEC #

TRA VALS
TRANS

SIG. & TYPIST INITIALS
ELD

46453 (Rev. 4/89)

Rocky Flats Plant
Aerospace Operations
Rockwell International Corporation
P.O. Box 464
Golden, Colorado 80402-0464
(303) 966-7000
Contractor to U.S. Department of Energy

SEP 01 1989

89-RF-3055

Edward S. Goldberg
Acting Area Manager, RFO

Attn: Mark Van Der Puy

APPLICATION TO SHIP SALTCRETE

Attached is a copy of the re-formatted Application to Ship Waste for saltcrete. This application addresses all the comments from the Nevada Operations Office document attached to your letter 1245-RF-89.

Please refer any questions regarding the attached application to E.L. D'Amico at (303) 966-5362 or P.M. Arnold at FTS 320-2056.

W.F. Weston, Director
Plutonium Operations

Orig. and 3 cc - E.S. Goldberg
Enc.

Table 8 (continued)
Reference Documents/Results Outlining Compliance
to the General Waste Form Criteria

		Boxes," specifies Waste Operations personnel to visually inspect for and remove any excessive particulate from each stored saltcrete box.
Gases	Not Applicable	Saltcrete is not a gaseous waste and does not contain radioactive gases.
Stabilization	WO-5004	As described in WO-5004, "Waste Treatment Spray Dryer and Saltcrete Process," cement is added to the salt waste stream to immobilize the particulate, solidify the liquids and moderate oxidizing characteristics.
Etiologic Agents	Not Applicable	Saltcrete does not contain pathogens, infectious wastes or other etiologic agents.
Chelating Agents	Quantity and type of complexing agents used per year at Rocky Flats: Ascorbic Acid: 4.5 kg Acetic Acid: 6.6 kg Sodium Acetate: 55.5 kg Citric Acid: 4.5 kg Sodium Citrate: 20.0 kg Oxalic Acid: 4.5 kg EDTA: 1.15 kg	Between 5/15/87 and 5/7/88, 917 triwall boxes of saltcrete were produced. The estimated saltcrete generation for any given year is between 1200 to 1600 triwalls. The average net weight of one triwall box of saltcrete is approximately 1600 pounds. Total weight of saltcrete produced between 5/15/87 and 5/7/88 is 917 boxes * 1600 pounds * 1 kg/2.2 pounds = $6.67*10^5$ kg. As a worst case, if it is assumed that all 106.36 kg of complexing agents are

Table 8 (continued)
Reference Documents/Results Outlining Compliance
to the General Waste Form Criteria

	8-Hydroxyquinoline: 2.3 kg Tributyl Phosphate: 3.7 kg 1,10 Phenanthroline: 0.012 kg dihexyl-n,n-diethylcarbamoyl methylphosphonate: 3.6 kg Total: 106.36 kg	disposed of with the saltcrete, then, $106.36/6.67*10^5=1.59*10^{-4}$ is the weight fraction of the complexing agents with respect to the saltcrete. Therefore, Rocky Flats' total yearly usage of complexing agents amounts to only 0.0159 weight percent of the total saltcrete production between 5/15/87 and 5/7/88. This extremely conservative estimate is well under the NTS limit of 1 weight percent.
GCD Waste	Not Applicable	Saltcrete does not meet any of the guidelines to be identified as a GCD waste.
Bulk LLW	Not Applicable	Saltcrete is not a bulk LLW.

4. Additional Mixed Waste Form Criteria

Table 9 references the documents (procedures, specifications, etc.) or test/analysis results that specify compliance to the Additional Mixed Waste Form Criteria outlined in Section 2.2.2 of NVO-325.

Table 9
Reference Documents/Results Outlining Compliance
to the Additional Mixed Waste Form Criteria

Criterion	Compliance Documents or Results	Comments
Treated Waste	Not Applicable	Saltcrete is a treated waste that meets the land disposal restrictions and

ATTACHMENT 4

Westinghouse
Savannah River Company

P.O. Box 616
Aiken, SC 29802

February 28, 1996

SWE-SWE-96-0106
F/WSWE/XXX/ARNR
Response Required: N/A
Key Words: TRU Waste
Record Retention: Permanent

Jim Teak
Advanced Sciences, Incorporated
6739 Academy Road, N. E.
Albuquerque, New Mexico 87106-3345

Dear Mr. Teak:

FY96 TRANSURANIC WASTE BASELINE INVENTORY REPORT (TWBIR): RESPONSE TO THE TWBIR MEETING MINUTES REGARDING CHELATING AGENTS AND CONCRETE STABILIZATION (U)

The Savannah River Site (SRS) has reviewed its waste practices to determine whether chelating agents are present in retrievably stored TRU waste. SRS also has reviewed these practices to determine whether concrete has been used to solidify/stabilize TRU waste. These reviews revealed that SRS TRU waste steams do not currently contain chelating agents/complexants nor has SRS used concrete to solidify/stabilize TRU waste.

The Separations processes and the analytical/research laboratories at SRS have used chelating agents in the separation of plutonium from irradiated uranium and other materials. For example, tri-butyl phosphate (TBP) is the complexing agent used in SRS's PUREX process and many other laboratory processes. Also, agents such as tri-octyl phosphine oxide (TOPO) and tri-iso octylamine (TiOA) have been used or investigated through the years. However, none of these chelating agents/complexants has entered SRS TRU waste. The complexants are dissolved in organic solvents for use as liquid/liquid extractants in the separation process. These solvents are recycled until depleted and then discarded to SRS's solvent waste tanks in the Waste Disposal Facility. This means that SRS organic liquid streams have not entered the production lines (e.g., HB and FB-Lines) where most of SRS TRU waste is generated. Further, a small amount of liquid TBP containing TRU nuclides is generated by SRS laboratories. This laboratory waste is discarded to liquid waste streams, which are eventually disposed in SRS's High Level Waste Tanks. So, none of these liquid streams that contain complexants have entered SRS solid TRU waste streams.

SRS has not used concrete to solidify/stabilize TRU waste. The processes that generate slurries, which require stabilization, do not contain TRU radionuclides (e.g., plating of depleted uranium). For other processes that generate slurries, the waste is disposed in SRS's High Level Waste Tanks. Even the Low Level Waste (LLW) sludge generated by SRS's Effluent Treatment Facility (ETF) is disposed in the High Level Waste Tanks and is eventually

fed to SRS's Saltstone Facility or the Defense Waste Processing Facility (DWPF). Finally, SRS does not expect to generate TRU waste containing chelating agents nor anticipate using concrete to solidify/stabilize TRU waste in the near-future.

Please direct your questions to L. Williams (803) 557-6759.

Sincerely,

Joseph A. D'Amelio
TRU Engineering Manager

JAD:lw

cc: A. Gibbs, 724-21E
W. T. Goldston, 705-3C
F. H. Gunnels, 705-3C
S. J. Macknull, 703-A
S. J. Mentrup, 724-21E
D. Ormond, 703-A
L. Williams, 705-3C
Records Management, 705-3C
SWE Files, 705-3C

ATTACHMENT 5

To: L. C. Sanchez, SNL January 25, 1996

Thru: Sheila Lott, CTAC

From: F. M. Coony and M. R. Kerns, Hanford Site

RE: Additional TRU Waste Data Request for Sandia National Laboratories' Waste Isolation Pilot Plan Performance Assessment

References: 1) Memorandum, Russ Bisping, DOE/CAO to Distribution, same subject, dated January 5, 1996.

2) Trip Report, F. M. Coony to K. L. Hladek, January 15, 1996

The Reference 1 memo requests additional data on waste soluble organic ligands (i.e. chelating agents) from the generating sites by February 26, 1996.

Hanford's approach for responding to the additional data request is presented in the Reference 2 trip report. The first item of this approach is to provide SNL, through CTAC, a list of all hazardous constituents, and their quantities, that have been reported in solid TRU waste at Hanford since 1987, the date of the By-Product Rule.

The list of hazardous constituents and their quantities, from Hanford's record container tracking system, are presented in Table 2. The chemical names have been truncated to 30 characters. Hanford can provide complete names if needed. In some cases, the constituent is listed more than once because the constituent is spelled differently in the container tracking system. A quantity of 0.00 kg means typically that the constituent has been identified solely because it is a listed hazardous waste under RCRA. In these cases, the quantity is either absent or minimal.

Please evaluate the list of constituents, and indicate, in the space provided for each constituent, if the constituent is a soluble organic ligand. The suggested nomenclature is the following:

- N/A (meaning not soluble organic legand)
- C (meaning citrate
- L (meaning lactate)
- OX (meaning oxalate)
- EDTA (meaning ethylenediaminetetraacadid acids

Please indicate any other relevant information by footnotes.

To meet the requested due date, please provide a response to me (by fax) no later than February 5, 1996. Please copy CTAC on the response.

If you have any questions, please contact Mike Coony at 509-376-9774 or Mark Kerns at 509-372-2383.

MASS
(KG)

Table 2. Quantities of Hanford Constituents

[illegible]	[illegible]
1,1,1-TRICHLOROETHANE	0.00
2-BUTOXYETHANOL	0.02
ACETONE	0.00
ACID	0.14
ALUMINUM NITRATE	0.10
ALUMINUM NITRATE MONOHYDRATE	3.90
AMERCOAT 234	0.05
AMMONIUM CHLORIDE	0.01
ARSENIC	0.02
ASBESTOS	27.00
BARIUM	1.86
BERYLLIUM	0.17
BIS(2-ETHYLHEXYL)PHTHALATE	0.82
BISPHENOL A RESIN	0.54
BUTYL ALCOHOL	0.41
BUTYL GLYCIDYL ETHER	0.11
CADMIUM	99.17
CADMIUM HYDROXIDE	0.10
CALCIUM CHLOROFLUOROPHOSPHATE	0.83
CALCIUM HYDROXIDE	0.06
CARBON TETRACHLORIDE	87.88
CARBONTETRACHLORIDE	95.90
CHLOROFORM	0.00
CHROMIUM	14.52
COPPER	0.00
COPPER SULFATE	0.38
CRESYLIC ACID	0.00
CUPROUS CYANIDE	0.21
CYANIDE SOLUTIONS	0.21
CYCLOHEXANE	0.00
DI(2-ETHYLHEXYL)PHTHALATE	0.06
DI-OCTYL PHTHALATE	0.40
DIOCTYL PHTHALATE	0.20
DIOCTYL PHTHALATE (DOP)	8.47
ETHANOL	0.20
FERRIC NITRATE	4.38
FORMIC ACID	0.21
HEXONE	0.10
HYDRAULIC FLUID	328.20
HYDROCHLORIC ACID	0.07

HAZARDOUS CONSTITUENT	MASS (KG)	[illegible]
KEROSINE	0.00	
LEAD	8,915.59	
LEAD ACID	0.27	
LEAD CHROMATE	28.97	
LEAD CHROMATE OXIDE	1.54	
LEAD CHROMATE,CHLORIN.PARAFFIN	1.33	
LEAD CHROMATES	0.05	
LEAD SHIELDING	5,587.50	
LIGHT AROMATIC NAPHTHA	0.30	
MERCURY	1.51	
MERCURY METAL	0.00	
METHYL ETHYL KETONE	0.00	
METHYL ISOBUTYL KETONE	0.00	
METHYLENE CHLORIDE	8.03	
NICKEL HYDROXIDE	0.10	
NITRIC ACID	1.21	
OIL	0.00	
PCB	130.13	
PHOSPHORIC ACID	0.33	
PHTHALIC ACID BENZYL BUTYL EST	0.00	
PHTHALIC ACID BIS(2-ETHYLHEXYL	0.00	
PHTHALIC ACID, BIS(2-ETHYLHEXY	0.05	
POTASSIUM CYANIDE	0.21	
POTASSIUM FLUORIDE	0.00	
POTASSIUM HYDROXIDE	5.80	
RESIDUAL TANK FARM CORE SAMPLE	0.80	
SELENIUM	1.10	
SILVER	0.00	
SODIUM	0.13	
SODIUM CYANIDE	0.21	
SODIUM FLUORIDE	1.08	
SODIUM HYDROXIDE	24.37	
SODIUM NITRATE	173.00	
SODIUM SULFATE	3.92	
STRIPCOAT	34.08	
SULFAMIC ACID	0.04	
SULFURIC ACID	1.53	
THENOYL TRIFLUOROACETONE	0.00	
TRI BUTYL PHOSPHATE	49.30	
TRIBUTYL PHOSPHATE	43.13	
TRIBUTYLPHOSPHATE	0.07	

HAZARDOUS CONSTITUENTS	MASS (KG)	
TRICHLOROETHENE	3.28	
TRIISOOCTYLAMINE	0.00	
TRIMETHYLBENZENE	1.01	
TRIOCTYLPHOSPHINE OXIDE	0.00	
VANADIUM PENTOXIDE AQUEOUS SOL	0.21	
XYLENE	4.23	

ATTACHMENT 6

Lawrence Livermore National Laboratory

WASTE CERTIFICATION PROGRAM
WCP96-055

March 7, 1996

Jim Teak
Advanced Sciences Incorporated
6739 Academy Road NE
Albuquerque, NM 87109

Dear Jim,

This is in response to the CAO request concerning the presence of organic ligands (chelating agents) in TRU waste. I have consulted with Joe Magana, a chemist working in LLNL's Plutonium Facility. He tells me that there are no chelating agents in LLNL's TRU waste.

Sincerely yours,

Kem Hainebach

Kem Hainebach, Ph. D.
Waste Certification Engineer
Environmental Protection Department

KH:lh
c: Robert Fischer

DEA Drez Environmental Associates

FAX COVER SHEET

DATE: March 20, 1996

TO:	COMPANY	FAX NO.	CONFIRMATION NO.
RUSS BISPING	CAO	505-887-0707	505-234-7446
MARGARET CHU	SNL/NM	505-848-0518	505-848-0778
JOE HARVILL	ASI/CTAC	505-887-5494	505-885-4218
LARRY SANCHEZ (GIVE TO JIM NOWAK)	SNL/NM	505-848-0705	505-848-0685
LENNY STORZ	SNL/NM	505-848-0881	505-848-0877
SAYAN CHAKRABORTI	SAIC	505-842-7798	505-842-7816
SHEILA LOTT	ASI/CTAC	505-823-6830	505-823-6873

FROM: PAUL DREZ PAGES TO FOLLOW: 25

SUBJECT/PROJECT: FINAL PRELIMINARY COMPLEXING AGENT MEMO

COMMENTS:

THESE ARE THE FINAL NUMBERS FOR THE COMPLEXING AGENTS. SNL/NM SHOULD USE THESE NUMBERS IN THEIR CALCULATIONS. THE ONLY NUMBER THAT HAS CHANGED SINCE THE MARCH 13, 1996 REVISED MEMO IS THE TRIBUTYL PHOSPHATE (INCLUDES ESTIMATE FROM HANFORD). I AM SENDING THIS MEMO TO ALL TRU WASTE SITES THAT CONTRIBUTED DATA FOR THEIR REVIEW (A SEPARATE FAX SHEET). COMMENTS ARE DUE BACK COB THIS FRIDAY FROM EVERYONE TO ME. THIS REVIEW BY THE TRU WASTE SITES WAS PART OF THE AGREEMENT OF PROVIDING DATA TO THE BIR TEAM. ONLY DOE CAN ISSUE A "FINAL" MEMO AFTER RESOLUTION OF COMMENTS WITH THE TRU WASTE SITES.

PAUL

P.S. ATTACHMENT 3 HAS BEEN INCLUDED WITH ONLY A FEW PERTINENT PAGES TO CUT DOWN ON THE FAXING OF PAPER!!!!!!

If you do not receive all pages, please call:

Paul Drez
Drez Environmental Associates
8816 Cherry Hills Rd., NE
Albuquerque, NM 87111
Phone: (505) 828-9857 FAX: (505) 828-1342

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.12

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NPO 361163

INFORMATION ON

Sandia National Laboratories

Albuquerque, New Mexico 87185-

date: March 27, 1996

to: Craig F. Novak

from: Ruth Weiner

Subject: Dissolved ligand concentrations

Ligand concentrations (acetate, citrate, oxalate, and EDTA) in the inundated repository were calculated from the "final preliminary" memo of Paul Drez to Joe Harvill of March 20, 1996 (scaled by a scaling factor of 2.05 as per BIR Rev. 2 Page 3-1) and the brine volume equal to 75% of the total repository area -- 29,841 m^3 -- as per the memo from Kurt Larsen to Vann Bynum of March 13, 1996. The table below summarizes the calculation:

	Inventory grams	Repositor g/L	Molarity	Inventory x 2.05
acetate	1252000	0.041956	0.000518	0.001062
citrate	1590500	0.053299	0.000227	0.000465
oxalate	13796000	0.462317	0.003612	0.007404
EDTA	23000	0.000771	2.03E-06	4.16E-06

The numbers in the second column -- "Repository g/L" -- were obtained by dividing the numbers in the first column by 29.841 x 10^6 liters. The molarities were obtained by dividing the numbers in the second column by the appropriate molecular weight.

cc:

E. J. Nowak

R. V. Bynum

C. C. Crafts

J. T. Holmes

M. S. Y. Chu

M. Siegel

SWCF-A: WBS 1.1.10.1.1:AST:NonQA: Actinide source term:chelators:ligands

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Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.13

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DOE F 1325.8

WPO 370664

United States Government

Department of Energy

memorandum

Carlsbad Area Office
Carlsbad, New Mexico 88221

DATE: April 4, 1996

REPLY TO ATTN OF: CAO:NTP:DW:96-1126

SUBJECT: Estimate of Cement Content in TRU Solidified Waste Forms Scheduled for Disposal in WIPP

TO: Les Shephard, Director, SNL

Attached is a summary of the best estimate of portland cement in stored and projected volumes of solidified waste streams listed in Revision 2 of the Transuranic (TRU) Waste Baseline Inventory Report (TWBIR). This information was requested from the TWBIR team in support of the Performance Assessment team.

These values have been scaled (similar to the methodology used for waste material parameters in the TWBIR) to the full volume of the Waste Isolation Pilot Plant (WIPP) repository. The total estimated weight of portland cement in these scaled solidified waste forms is 8.54E+06 kg. Dividing this value by 6.2E+06 ft^3 (~175,600 m^3), the maximum capacity of WIPP, yields a portland cement density in the overall combined contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste of 48.6 kg/m^3. The portland cement reported is both reacted and unreacted cement in the waste. There are no data available to estimate the percentage of reacted versus unreacted cement.

The basic methodology was to perform a sort of the Revision 2 database that supports the TWBIR for all Solidified Inorganic and Solidified Organic waste streams. This sort resulted in 221 waste streams. Some waste streams were eliminated from further consideration for the following reasons:

- Data about most Rocky Flats waste streams (both residue and nonresidue waste streams) are for waste in current form only and not in final form. The item description code (IDC) for many particulate waste streams will change to final form because the waste is in a cemented final form. A total of 91 current-form RF TRU waste streams were eliminated because of this constraint, (the final form of these waste streams, however, is included in the portland cement estimate.)

- The Solidified Inorganic waste streams listed from Savannah River Site are all vitrified and therefore do not contain any portland cement. A total of 20 waste streams were eliminated because of this constraint.

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If you have any questions concerning the attached information, please contact Mr. Russ Bisping of my staff at (505) 234-7446.

Don Watkins
Manager
National TRU Program

Attachment

cc w/attachment:
M. McFadden, CAO
K. Hunter, CAO
R. Bisping, CAO
P. Drez, CTAC
J. Harvill, CTAC
L. Sanchez, SNL
M. Chu, SNL
M. Marietta, SNL

Calculation Summary

At the bottom of Table 1 the total kilograms of portland cement is summarized for CH-TRU and RH-TRU waste for both stored plus projected waste (in "Total kg" column) and projected only waste (in "Projected kg" column). The TOTAL SCALED portland cement is calculated as follows:

CH-TRU "Total kg" + 2.05 * CH-TRU "Projected kg" + RH-TRU "Total Kg" = TOTAL SCALED kg of portland cement, or

5.28E+06 + 2.05(1.34E+06) + 5.05E+05 = 8.54E+06 kg portland cement

The total density of portland cement is calculated as follows:

8.54E+06 kg/175,600 m^3 = 48.6 kg/ m^3 portland cement

Table 1. Estimate of Portland Cement in TRU Waste for Disposal in the WIPP

WIPP ID	Waste Type	Handling	Final Waste Form	Solidification	Cement (kg/m³)	Stored (m³)	Projected (m³)	Total kg	Projected kg
W-W012.10	MTRU	RH	Solidified Inorganics	salt(1)	n/a				
W-W016.20	MTRU	RH	Solidified Inorganics	encapsulated metal(2)	n/a				
W-W020.13	MTRU	RH	Solidified Inorganics	evaporitic salt/sludge(3)	73.1	1.8	1.8	263.16	131.58
W-W022.22	MTRU	RH	Solidified Inorganics	sludge/particulates(3)	73.1	0	0.9	65.79	65.79
I-W216.877	MTRU	RH	Solidified Inorganics	BIR	215.3	43.9	0	9451.67	0
I-W228.886	MTRU	RH	Solidified Inorganics	BIR	92.6	21.4	0	1981.64	0
R-W042	MTRU	RH	Solidified Inorganics	BIR	396.6	175.3	0	69523.98	0
R-W046	MTRU	RH	Solidified Inorganics	BIR	396.6	861.5	206.5	423568.8	81897.9
I-W317.1029	MTRU	RH	Solidified Organics	resins(3)	73.1	3.6	0	263.16	0
E-W038	MTRU	CH	Solidified Inorganics	acid lab packs(3)	73.1	4.8	0	350.88	0
E-W040	MTRU	CH	Solidified Inorganics	evaporitic salt/sludge(3)	73.1			0	0
L-W005	MTRU	CH	Solidified Inorganics	nitric acid liquids(3)	73.1	0	0.4	29.24	29.24
I-W146.699	MTRU	CH	Solidified Inorganics	Assumed IN-W216.98	273.8	2.3	0	629.74	0
I-W159.1072	MTRU	CH	Solidified Inorganics	evaporitic salt/sludge	n/a				
I-W163.1007	MTRU	CH	Solidified Inorganics	Ash(3)	73.1	0.7	0	51.17	0
I-W166.151	MTRU	CH	Solidified Inorganics	BIR	73.8	16	0	1180.8	0
I-W166.928	MTRU	CH	Solidified Inorganics	BIR	83.6	56.8	0	4748.48	0
I-W174.1082	MTRU	CH	Solidified Inorganics	Florco(4)	n/a				
I-W174.154	MTRU	CH	Solidified Inorganics	Florco(4)	n/a				
I-W177.1083	MTRU	CH	Solidified Inorganics	Florco(4)	n/a				
I-W177.156	MTRU	CH	Solidified Inorganics	Florco(4)	n/a				
I-W179.1084	MTRU	CH	Solidified Inorganics	BIR(5)	394.2	4.6	0	1813.32	0
I-W179.158	MTRU	CH	Solidified Inorganics	BIR(5)	325	1.5	0	487.5	0
I-W181.162	MTRU	CH	Solidified Inorganics	BIR	308.8	9.6	0	2964.48	0
I-W187.1094	MTRU	CH	Solidified Inorganics	Assumed IN-W222.116	102	0.7	0	71.4	0
I-W188.1093	MTRU	CH	Solidified Inorganics	BIR	308.8	1	0	308.8	0
I-W188.160	MTRU	CH	Solidified Inorganics	BIR	188.3	0	0.7	131.81	131.81
I-W216.875	MTRU	CH	Solidified Inorganics	BIR	308.8	1478.9	0	456684.32	0
I-W216.98	MTRU	CH	Solidified Inorganics	BIR	273.8	555.6	0	152123.28	0
I-W218.909	MTRU	CH	Solidified Inorganics	Assumed RF-MT0007	130.6	101.9	0	13308.14	0
I-W219.914	MTRU	CH	Solidified Inorganics	Grinding Sludge(3)	73.1	2.3	0	168.13	0
I-W220.114	MTRU	CH	Solidified Inorganics	BIR	27.6	122.8	0	3389.28	0
I-W220.925	MTRU	CH	Solidified Inorganics	BIR	308.8	443	0	136798.4	0
I-W221.113	MTRU	CH	Solidified Inorganics	BIR(6)	127.673	11.6	0	1481.0068	0
I-W221.927	MTRU	CH	Solidified Inorganics	BIR(6)	109.129	3.6	0	392.8644	0
I-W222.116	MTRU	CH	Solidified Inorganics	BIR	102	24.7	0	2519.4	0
I-W222.965	MTRU	CH	Solidified Inorganics	BIR	115.6	10.6	0	1225.36	0
I-W228.101	MTRU	CH	Solidified Inorganics	BIR	117.7	287.3	0	33815.21	0
I-W228.883	MTRU	CH	Solidified Inorganics	BIR	132.8	608.8	0	80848.64	0
I-W247.523	MTRU	CH	Solidified Inorganics	no solidification used	n/a				
I-W257.947	MTRU	CH	Solidified Inorganics	Diatomaceous earth(7)	n/a				
I-W263.520	MTRU	CH	Solidified Inorganics	no solidification used	n/a				
I-W315.601	MTRU	CH	Solidified Inorganics	Wet Salt-Assumed INW216.875	308.8	0.4	0	123.52	0
I-W332.661	TRU	CH	Solidified Inorganics	Plaster(8)	n/a				
I-W332.962	TRU	CH	Solidified Inorganics	Plaster(8)	n/a				
I-W347.646	TRU	CH	Solidified Inorganics	Vermiculite(9)	n/a				
I-W347.818	TRU	CH	Solidified Inorganics	Vermiculite(9)	n/a				
I-W348.1012	TRU	CH	Solidified Inorganics	Particulates(3)	73.1	2.3	0	168.13	0
I-W353.859	TRU	CH	Solidified Inorganics	Liquid(3)	73.1	0.7	0	51.17	0
I-W353.917	TRU	CH	Solidified Inorganics	Liquid(3)	73.1	0.2	0	14.62	0
I-W375.1096	TRU	CH	Solidified Inorganics	Sludge- Assumed IN-W216.875	308.8	4.5	0	1389.6	0
A-M002	MTRU	CH	Solidified Inorganics	(10)	693	3053.5	553.3	2499512.4	383436.9
A-W003	MTRU	CH	Solidified Inorganics	(10)	645.9	1079.4875	559.1	1058363.666	361122.69
A-W006	MTRU	CH	Solidified Inorganics	(10)	508.1	301.7773	839.9	580086.2361	426753.19
A-T006	TRU	CH	Solidified Inorganics	(10)	514.4	4.225	81.5	44096.94	41923.6
-T001	TRU	CH	Solidified Inorganics	(10)	100	14.4	5.8	2020	580

Table 1. Estimate of Portland Cement in TRU Waste for Disposal in the WIPP

WIPP_ID	Waste_Type	Handling	Final Waste Form	Solidification	Cement (kg/m³)	Stored (m³)	Projected (m³)	Total kg	Projected kg	
D-T001	TRU	CH	Solidified Inorganics	Sludge - Assumed IN-W179.1084	394.2	4.2	0	1655.64	0	
D-W002	MTRU	CH	Solidified Inorganics	Florco(4)	n/a					
T-W021	TRU	CH	Solidified Inorganics	Mainly debris	n/a					
F-MT0001	MTRU	CH	Solidified Inorganics	BIR	187.6	3.7	0	694.12	0	
F-MT0007	MTRU	CH	Solidified Inorganics	BIR	130.6	0.8	0	104.48	0	
F-MT0800	MTRU	CH	Solidified Inorganics	BIR	193.8	65.5	38.9	20232.72	7538.82	
F-MT0803	MTRU	CH	Solidified Inorganics	BIR	55.6	2.9	2.1	278	116.76	
F-MT0807	MTRU	CH	Solidified Inorganics	BIR	71.7	73.4	41.6	8245.5	2982.72	
F-MT0377	MTRU	CH	Solidified Inorganics	Particulate(3)	73.1	3.5	0	255.85	0	
F-MT0806	MTRU	CH	Solidified Inorganics	BIR	73.1	0	1110.7	81192.17	81192.17	
F-TT0823	TRU	CH	Solidified Inorganics	BIR	17.5	7.1	23.1	528.5	404.25	
F-TT0806	TRU	CH	Solidified Inorganics	BIR	73.1	0	202.2	14780.82	14780.82	
F-T010	TRU	CH	Solidified Inorganics	BIR	140.2	0.6	0	84.12	0	
F-TT0802	TRU	CH	Solidified Inorganics	BIR(6)	68.32	7.5	26	2288.72	1776.32	
L-W281	MTRU	CH	Solidified Inorganics	Vermiculite(9)	n/a					
L-W383	TRU	CH	Solidified Inorganics	Vermiculite(9)	n/a					
L-W394	TRU	CH	Solidified Inorganics	Vermiculite(9)	n/a					
E-W039	MTRU	CH	Solidified Organics	resins(3)	73.1	0.2	0	14.62	0	
I-W157.144	MTRU	CH	Solidified Organics	BIR(6)	187.88	49.9	0	9375.212	0	
I-W157.906	MTRU	CH	Solidified Organics	BIR(6)	212.768	163.7	0	34830.1216	0	
I-W164.1060	MTRU	CH	Solidified Organics	Envirostone(11)	n/a					
I-W164.153	MTRU	CH	Solidified Organics	Envirostone(11)	n/a					
I-W167.149	MTRU	CH	Solidified Organics	calc-silicate(12)	n/a					
I-W167.926	MTRU	CH	Solidified Organics	calc-silicate(12)	n/a					
I-W309.610	MTRU	CH	Solidified Organics	calc-silicate(12)	n/a					
I-W317.757	MTRU	CH	Solidified Organics	resins(3)	73.1	39.1	0	2858.21	0	
I-W317.758	MTRU	CH	Solidified Organics	resins(3)	73.1	11.5	0	840.65	0	
I-W319.584	MTRU	CH	Solidified Organics	resins(3)	73.1	0.7	0	51.17	0	
I-W321.1023	MTRU	CH	Solidified Organics	resins(3)	73.1	1.3	0	95.03	0	
A-T002	TRU	CH	Solidified Organics	(10)	693	1.5	29.1	21205.8	20166.3	
-W019	MTRU	CH	Solidified Organics	Envirostone(11)	n/a					
F-MT0003	MTRU	CH	Solidified Organics	calc-silicate(12)	n/a					
F-MT0801	MTRU	CH	Solidified Organics	Envirostone(11)	n/a					
F-MT0375	MTRU	CH	Solidified Organics	Oil Dri(13)	n/a					
F-TT0809	TRU	CH	Solidified Organics	BIR	32	0	35.2	1126.4	1126.4	
L-W280	MTRU	CH	Solidified Organics	paint(14)	n/a					
L-W282	MTRU	CH	Solidified Organics	Mainly debris	n/a					
L-W285	MTRU	CH	Solidified Organics	Conweb pads(15)	n/a					
L-W286	MTRU	CH	Solidified Organics	Oil Dri(13)	n/a					
L-W326	MTRU	CH	Solidified Organics	Conweb pads(15)	n/a					
L-W329	MTRU	CH	Solidified Organics	PCB waste(16)	n/a					
L-W333	MTRU	CH	Solidified Organics	PCB waste(16)	n/a					
L-W338	MTRU	CH	Solidified Organics	Conweb pads(15)	n/a					
L-W344	MTRU	CH	Solidified Organics	Diatomaceous earth(7)	n/a					
L-W345	MTRU	CH	Solidified Organics	Conweb pads(15)	n/a					
L-W348	MTRU	CH	Solidified Organics	animal waste	n/a					
L-W361	TRU	CH	Solidified Organics	Vermiculite(9)	n/a					
L-W380	TRU	CH	Solidified Organics	Diatomaceous earth(7)	n/a					
						RH-TRU Total		505118.2	82095.27	kg
						CH-TRU Total		5282085.787	1344061.99	kg
otal Cement equals Stored + Projected plus 2.05 times Projected for CH TRU						TOTAL SCALED			8542531.067	kg
plus Stored + Projected for RH-TRU										

Table 1. Estimate of Portland Cement in TRU Waste for Disposal in the WIPP

WIPP_ID	Waste_Type	Handling	Final_Waste_Form	Solidification	Cement (kg/m^3)	Stored (m^3)	Projected (m^3)	Total kg	Projected kg	
1) Salt waste, does not contain any portland cement										
2) Encapsulated metal waste, does not contain any portland cement										
3) Assume RF-MT0806 for final form cement density										
4) Florco (clay) is used as sorbent not portland cement										
5) The portland cement for this waste stream in the BIR occurs in the "Other Inorganic Material"										
6) Only 61% of the solidification agent reported as cement in the TWBIR is portland cement										
7) Diatomaceous earth is used as the sorbent in this waste stream										
8) Plaster of Paris used as solidification agent										
9) Vermiculite used as sorbent in this waste stream										
10) Basis for portland cement are values reported in TWBIR supplemented with information provided by LANL										
for previous WIPP memo on nitrate, sulfate, and phosphate										
11) Solidification agent is Envirostone (a gypsum-based process) that does not contain portland cement										
12) Solidification agent is a calcium-silicate process that does not use portland cement										
13) Oil Dri is used as sorbent										
14) Solidified organics is paint, contains no portland cement										
15) Solidification agent/sorbent is conwed pads (plastic fiber absorbent) +/- vermiculite										
16) PCB containing waste, excluded from current WIPP inventory										

Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.14

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WPO 31379

INFORMATION ONLY

CTAC MEMORANDUM

To: File

From: Paul E. Drez, CTAC PED

Subject: Preliminary Estimate for SNL/NM Performance Assessment Calculations of Nitrate, Sulfate, and Phosphate Content in Transuranic Solidified Wastes Destine for Disposal in WIPP

Date: January 26, 1996

SUMMARY

The density and mass of nitrate and sulfate in transuranic (TRU) waste destine for transport to and disposal in the Waste Isolation Pilot Plant (WIPP) has been estimated based on data from the TRU waste generator/storage sites. The average density scaled over the entire WIPP disposal inventory is 9.24 kg/m^3 for nitrate and 3.60 kg/m^3 for sulfate, and the total mass scaled over the entire WIPP disposal inventory is 1.62E+06 kg for nitrate and 6.33E+05 kg for sulfate. These densities and masses are for combined CH and RH TRU waste inventories. No value for phosphate has been proposed due to the lack of sufficient information. Trace quantities of inorganic phosphate might be expected in some of the sludges and solidification agents, but no supporting analytical data is available.

INTRODUCTION

Sandia National Laboratories/New Mexico (SNL/NM) has requested an estimate of the amount of nitrate, sulfate, and phosphate expected to be in the transuranic (TRU) inventory destined for transport to and disposal in the Waste Isolation Pilot Plant (WIPP)(Appendix B; DOE, 1995). The remainder of this memo describes the methodology and data used in order to calculate these preliminary estimates.

ASSUMPTIONS

This PRELIMINARY ESTIMATE is made based on the following assumptions:

- Values presented are those expected for final waste forms to be disposed of in the WIPP.

- Information has been requested from sites based on solidified inorganic and solidified organic waste forms only, and is the best available data from the TRU waste generator/storage sites:

  - The main source of nitrate is anticipated to be from the solidified inorganic

waste forms, which in most cases, are sludges produced from the neutralization/ solidification of nitric acid-based solutions used at the TRU waste generator/storage sites. Nitrates are very soluble in aqueous solutions and generally do not produce precipitates in the sludges. The nitrates are generally thought to be present as ions sorbed on precipitates or as interstitial solution trapped in the precipitated sludges prior to solidification.

Minor amounts of nitrate, as evaporites, are anticipated in the debris waste forms that will be acceptable for WIPP disposal, but insufficient data is available to make any such estimates in the TRU waste at this time.

The main sources of sulfates are anticipated to be: 1) chemicals (e.g. iron sulfates) added to the inorganic solutions at the time of flocculation and precipitation of sludges and 2) the use of Envirostone [a gypsum ($CaSO_4$) based solidification material] for solidification of inorganic and/or organic solutions/ sludges at some TRU waste generator/storage sites.

No quantifiable sources of phosphate have been identified in the inorganic solidified final waste forms at present. Trace quantities might be expected in some of the sludges and solidification agents, but no supporting analytical data is available. The quantities of inorganic phosphate are anticipated to be low in inorganic sludges based on process histories at TRU waste sites.

Analytical data in Attachment 2 provides only "less than 0.0025" weight percent values for phosphate, which are similar to the 0.001 weight percent estimate provided by LANL in Attachment 1. These values are too low to make any reliable estimate of phosphate in TRU waste, but indicate that the quantities will be very small, compared with the nitrate and sulfate values reported. The "40%" value reported on page A2-7 is an analytical error based on process knowledge and the lack of cations to support such a large value of phosphate in that particular analysis.

GENERAL VOLUME CALCULATIONS

Nitrate

The amount of nitrate is estimated on the basis of the volumes of Solidified Inorganics, which are calculated as explained below:

- Table 1 lists (in Column 2) the final waste form volumes of Solidified Inorganics for Contact-Handled (CH) TRU and Remote Handled (RH) TRU from Figures 3-9 and 3-16 of Revision 2 of the TWBIR (DOE, 1995) for the anticipated WIPP inventory (stored plus projected volumes until 2022).

- Footnotes in Columns 3 and 4 indicate why certain volumes of waste have been eliminated from further consideration in the calculations:

  - Footnote 1 eliminates those volumes of chemically precipitated solidified inorganics for which no nitrate estimates in the waste are available. An estimate of the nitrate contribution from these solidified inorganics will be accounted for in the scaling process.

  - Footnote 2 eliminates the volume of Solidified Inorganics from SRS from further consideration because it is a "vitrified" waste form which should not contain any significant amount of nitrates due to the thermal treatment proposed for that waste form.

  - Footnote 3 eliminates from further consideration those volumes of Solidified Inorganics which represent non-precipitated particulates (e.g., incinerator ash, graphite fines, etc.) which have been cemented to meet the WIPP WAC; nitrates are not expected to be present in these particulates.

- Rocky Flats Environmental Technology Site (RFETS) and Los Alamos National Laboratory (LANL) have provided analytical data/estimates for nitrate in Solidified Inorganics. The RFETS data has been used also for the RFETS waste stored at INEL.

Sulfate

- To determine the amount of solidified wastes that need to be considered for calculating the sulfate content of the WIPP inventory (Table 2), the volume of Solidified Organics must be added to the volume of Solidified Inorganics from Table 1:

  - The Solidified Organics from Figures 3-10 and 3-17 of Revision 2 of the TWBIR (DOE, 1995) have been added to Table 1 (above) to produce Table 2

  - LANL has used an Envirostone (gypsum-based) process for solidification of inorganic sludges in the past (approximately 9% of 4888 m^3 in storage at LANL) but plan to eliminate the process in the future and only use portland-based cement for solidification (as was used in the past prior to usage of the Envirostone)

  - Since the mid 1980's, RFETS has used an Envirostone solidification process for their organic sludges. Therefore, some of their waste in storage and projected contain large amounts of sulfate, as well as some Solidified Organics in storage at INEL.

  - LLNL is the only other TRU waste site known to be using Envirostone for the solidification of organic liquids/sludges (approximately 7 m^3 stored/projected).

NITRATE MASS CALCULATIONS

Table 3 contains in Column 1 a list of those waste streams that contain the volume of waste from each TRU waste generator/storage site listed in Column 4 of Table 1. The additional data provided are:

- Column 2 lists the Item Description Codes (IDCs) for waste streams produced at RFETS and/or stored at INEL. The RF111 designation is for Content Code 111 from RFETS, where the IDC is not specified.

- Column 3 lists the stored + projected volume for each waste stream.

- Column 4 lists the sum of the waste material parameters (WMP) for each waste stream from the individual Waste Stream Profiles in Revision 2 of the TWBIR. Exceptions to this rule are listed in footnotes in Table 3.

- Column 5 lists the mass of the waste for each waste stream which is the product of multiplying Columns 3 and 4.

- Column 6 lists the values of nitrate used for each waste stream. The sources of the these values are:

  - For RFETS, the nitrate values are from Appendix I of Revision 2 of the TWBIR. The 8% values for IDC 001 has also been applied to IDCs 002 and 007 at both RFETS and INEL. All these IDCs represent "older" methods of solidification where the sludges contain portland cement mainly as a sorbent interlayered with sludge which did not contain diatomaceous earth (see Clements, 1982 for drawings).

    The 4% value listed in Appendix I of the TWBIR for IDC 807 represents a "newer" method of solidification where diatomaceous earth is used as a vacuum filtration agent and portland cement is mixed with the resulting sludge to form a "monolithic" solidified final waste form. The dilution with diatomaceous earth and additional portland cement lowers the overall nitrate value of the final waste form.

  - For waste stream IN-W315.601, Clements (1982) indicates that the waste stream is made up of approximately 60% $NaNO_3$ and 30% KNO_3 (assumed weight percents). This calculates as 62% nitrate.

  - Attachment 1 represents a memo from LANL that provides estimates for nitrates in the waste streams. Note that the Envirostone process only accounts for a small percentage of stored volume for 3 of the waste streams. The values quoted in Column 6 are based on the small percentage of Envirostone

solidification agent in the overall waste streams.

- Column 7 represents the mass of nitrates in kg which is the product of multiplying Columns 5 and 6.

SULFATE MASS CALCULATIONS

The sulfate calculations presents in Table 4 follow the same format as the nitrate calculations in Table 3. The origin of the values used for sulfate in the RFETS, INEL, LLNL, and LANL waste streams are summarized below:

- RFETS/INEL

  - The 0.11% sulfate value is an average of the three analyses marked "7412 Sludge" in Attachment 2 which are applied to IDCs 001 and 002, and at half that value for IDCs 800 and 803 (as explained in the nitrate section).

  - The sulfate value of 0.02% is derived from the Attachment 2 analysis marked "374 Waste Sludge - Dried Sludge". This value is used for IDC 007 and at half value for IDC 807.

  - The sulfate value (25.1%) for the Envirostone solidification of organic sludges (IDC 801) is derived from an average value in Attachment 3, which represents guidelines for mixing constituents together for IDC 801 and IDC 700 (at INEL only in storage).

- LANL

  - The values for sulfate quoted in Column 7 are derived from data provided in Attachment 1. As with the nitrate calculations, the percentage of waste in each waste stream solidified by Envirostone versus portland cement is used to calculated the overall sulfate value for each waste stream.

- LLNL

  - No value for sulfate was requested from LLNL for their one Solidified Organic waste stream. The same value for Envirostone-solidified waste at RFETS (25.1%) was assumed for the LLNL waste stream.

SUMMARY CALCULATIONS

Table 5 presents the summary calculations for determining the density (kg/m^3) of nitrate and sulfate in the overall WIPP inventory and scaling of the density to take into account those chemically precipitated waste streams for which data was not available. SNL/NM should use the scaled densities for their calculations. The last column in Table 5 provides the estimated mass of nitrate and sulfate if the design capacity of WIPP for CH-TRU and RH-TRU are fully utilized based on the scaled densities for nitrate and sulfate.

REFERENCES

Clements, 1982, "Content Code Assessments for INEL Contact-Handled Stored Transuranic Wastes," WM-F1-82-021, Idaho Falls, Idaho.

U. S. Department of Energy, 1995, "Transuranic Waste Baseline Inventory Report (Revision 2)," DOE/CAO-95-1121, Carlsbad, New Mexico.

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+ File - SWCF-A WBS 1.1.6.2 ; PA ; PBVAC - WIPP ACTIVITY

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TABLE 1. TRU VOLUMES FOR NITRATE CALCULATIONS (SOLIDIFIED INORGANICS ONLY)

TRU WASTE SITE	TOTAL VOLUME (STORED + PROJECTED) (m^3)	VOLUMES WITH NITRATE DATA OR WITH PARTICULATES (m^3)	VOLUMES OF SLUDGES WITH NITRATE DATA (m^3)
Hanford (CH)	23.39	(TO BE SCALED)[1]	(TO BE SCALED)[1]
ANL-E (CH)	5.20	(TO BE SCALED)[1]	(TO BE SCALED)[1]
NTS (CH)	5.67	(TO BE SCALED)[1]	(TO BE SCALED)[1]
SRS (CH)	1369.8	1369.8	[2]
RFETS (CH)	1423.01	1389.52	229.63[3]
INEL (CH)	4344.44	3900.39	3598.84[3]
Mound (CH)	6.03	(TO BE SCALED)[1]	(TO BE SCALED)[1]
LANL(CH)	6922.02	6922.02	6922.02
AL (CH)	0.42	(TO BE SCALED)[1]	(TO BE SCALED)[1]
LLNL (CH)	20.18	(TO BE SCALED)[1]	(TO BE SCALED)[1]
CH TOTAL	14120.15	13581.73	10750.49
ORNL (RH)	1243.33	(TO BE SCALED)[1]	(TO BE SCALED)[1]
INEL (RH)	65.27	65.27	65.27
ANL-E (RH)	30.26	(TO BE SCALED)[1]	(TO BE SCALED)[1]
RH TOTAL	1338.86	65.27	65.27
TRU TOTAL	15459.01	13647.0	10815.76

1 Eliminates those volumes of chemically precipitated solidified inorganics for which no nitrate estimates in the waste are available. An estimate of the nitrate contribution from these solidified inorganics will be accounted for in the scaling process.

2 Eliminates the volume of Solidified Inorganics from SRS from further consideration because it is a "vitrified" waste form which should not contain any significant amount of nitrates due to the thermal treatment proposed for that waste form.

3 Eliminates from further consideration those volumes of Solidified Inorganics which represent non-precipitated particulates (e.g., incinerator ash, graphite fines, etc.) which have been cemented to meet the WIPP WAC and nitrates are not expected to be present in the particulates.

TABLE 2. TRU VOLUMES FOR SULFATE CALCULATIONS

TRU WASTE SITE	FINAL WASTE FORM	TOTAL VOLUME (m^3)	VOLUME WITH SULFATE DATA (m^3)
Hanford (CH)	Solidif. Inorg.	23.39	(TO BE SCALED)[1]
ANL-E (CH)	Solidif. Inorg.	5.20	(TO BE SCALED)[1]
NTS (CH)	Solidif. Inorg.	5.67	(TO BE SCALED)[1]
SRS (CH)	Solidif. Inorg.	1369.8	(TO BE SCALED)[1]
RFETS (CH)	Solidif. Inorg.	1423.01	229.63
INEL (CH)	Solidif. Inorg.	4344.44	3598.42
Mound (CH)	Solidif. Inorg.	6.03	(T BE SCALED)[1]
LANL (CH)	Solidif. Inorg.	6922.02	6922.02
AL (CH)	Solidif. Inorg.	0.42	(TO BE SCALED)[1]
LLNL (CH)	Solidif. Inorg.	20.18	(TO BE SCALED)[1]
RFETS (CH)	Solidif. Org.	140.93	108.99
Hanford (CH)	Solidif. Org.	76.13	(TO BE SCALED)[1]
LANL (CH)	Solidif. Org.	30.58	(TO BE SCALED)[1]
INEL (CH)	Solidif. Org.	789.67	2.55
ANL-E (CH)	Solidif. Org.	0.21	(TO BE SCALED)[1]
LLNL (CH)	Solidif. Org.	6.86	6.86
CH TOTAL		15164.53	10868.93
ORNL (RH)	Solidif. Inorg.	1243.33	(TO BE SCALED)[1]
INEL (RH)	Solidif. Inorg.	65.27	65.27
ANL-E (RH)	Solidif. Inorg.	30.26	(TO BE SCALED)[1]
INEL (RH)	Solidif. Org.	3.56	(TO BE SCALED)[1]
RH TOTAL		1342.42	65.27
TRU TOTAL		16506.95	10933.74

[1] No sulfate data available from these sites for any waste streams.

TABLE 3. NITRATE CALCULATION

Waste Stream	IDCs	Volume (m3)	Sum WMP (kg/m3)	Mass Waste (kg)	% Nitrate (weight%)	Nitrate (kg)
RF-MT0001	001	3.74	781.9	2924.31	8	233.94
RF-MT007	007	0.832	544.3	452.86	8	36.23
RF-MT0800	800	104.42	775.2	80946.38	4	3237.86
RF-MT0803	803	4.99	635.2	3169.65	4	126.79
RF-MT0807	807	115.02	819.6	94270.39	4	3770.82
RF-T010	800/803/807	0.62	796.1	493.58	4	19.74
TOTAL RFETS		229.622		182257.17		7425.37
IN-W216.875	001/002	1478.88	819.6	1212090.05	8	96967.20
IN-W216.877	001/002	43.91	571.4	25090.17	8	2007.21
IN-W216.98	001/002	555.65	726.6	403735.29	8	32298.82
IN-W218.909*	007	101.91	544.3	55469.61	8	4437.57
IN-W220.114	RF111	122.8	725.6	89103.68	4	3564.15
IN-W220.925	RF111	443.04	819.6	363115.58	4	14524.62
IN-W228.101	002	287.33	317.3	91169.81	8	7293.58
IN-W228.883	002	608.82	358	217957.56	8	17436.60
IN-W228.886	002	21.36	249.6	5331.46	8	426.52
IN-W315.601**	005	0.42	664	278.88	62	172.91
TOTAL INEL		3664.12		2463342.09		179129.19
LA-M002		3606.81	1296	4674425.76	8.8	411349.47
LA-T006		86.53	1004.8	86945.34	8.8	7651.19
LA-W003		1836.58	1339.3	2459731.59	8.7	213996.65
LA-W006		1392.1	1004.8	1398782.08	8.7	121694.04
TOTAL LANL		6922.02		8619884.78		754691.35
TOTAL TRU		10815.76		11265484		941245.91

* INEL did not report waste material parameters for this waste stream. The value for this IDC at RFETS was assumed.

** This waste stream was reported in Clements (1983) to be 60% $NaNO_3$ and 30% KNO_3. The weight of the waste for this IDC was used from Clements (1983), since no value was quoted in Revision 2 of the TWBIR.

TABLE 4. SULFATE CALCULATION

Waste Stream	IDCs	Waste Form	Volume (m3)	Sum WMP (kg/m3)	Mass Waste (kg)	% Sulfate (weight%)	Sulfate (kg)
RF-MT0001	001	Solidified Inorg	3.74	781.9	2924.31	0.11	3.22
RF-MT007	007	Solidified Inorg	0.832	544.3	452.86	0.02	0.09
RF-MT0800	800	Solidified Inorg	104.42	775.2	80946.38	0.055	44.52
RF-MT0801	801	Solidified Org.	108.99	877.1	95595.13	25.1	23994.38
RF-MT0803	803	Solidified Inorg	4.99	635.2	3169.65	0.055	1.74
RF-MT0807	807	Solidified Inorg	115.02	819.6	94270.39	0.01	9.43
RF-T010	800/803/807	Solidified Inorg	0.62	796.1	493.58	0.055	0.27
TOTAL RFETS			338.612		277852.30		24053.65
IN-W164.1060**	700	Solidified Org	1.66	877.1	1455.99	25.1	365.45
IN-W164.153**	700	Solidified Org	0.89	877.1	780.62	25.1	195.94
IN-W216.875	001/002	Solidified Inorg	1478.88	819.6	1212090.05	0.11	1333.30
IN-W216.877	001/002	Solidified Inorg	43.91	571.4	25090.17	0.11	27.60
IN-W216.98	001/002	Solidified Inorg	555.65	726.6	403735.29	0.11	444.11
IN-W218.909*	007	Solidified Inorg	101.91	544.3	55469.61	0.02	11.09
IN-W220.114	RF111	Solidified Inorg	122.8	725.6	89103.68	0.055	49.01
IN-W220.925	RF111	Solidified Inorg	443.04	819.6	363115.58	0.055	199.71
IN-W228.101	002	Solidified Inorg	287.33	317.3	91169.81	0.11	100.29
IN-W228.883	002	Solidified Inorg	608.82	358	217957.56	0.11	239.75
IN-W228.886	002	Solidified Inorg	21.36	249.6	5331.46	0.11	5.86
TOTAL INEL			3666.25		2465299.82		2972.11
LA-M002		Solidified Inorg	3606.81	1296	4674425.76	1.4	65441.96
LA-T006		Solidified Inorg	86.53	1004.8	86945.34	1.7	1478.07
LA-W003		Solidified Inorg	1836.58	1339.3	2459731.59	5.5	135285.24
LA-W006		Solidified Inorg	1392.1	1004.8	1398782.08	8.1	113301.35
TOTAL LANL			6922.02		8619884.78		315506.62
LL-W019***		Solidified Org	6.86	268	1838.48	25.1	461.46
TOTAL LLNL			6.86		1838.48		461.46
TOTAL TRU			10933.74		11364875.4		342993.8

* INEL did not report waste material parameters for this waste stream. The value for this IDC at RFETS was asumed

** INEL did not report waste material parameters for this waste stream. The value for this IDC at RFETS was asumed

*** Sulfate value for LLNL Solidified Organic waste orm assumed to be same as for RFETS Solidified Organics (IDC 801)

TABLE 5. NITRATE/SULF DENSITY CALCULATIONS

Constituent	Volume Solidified Waste	Mass Solidified Waste	Mass Constituent	Anticipated Waste Volume	WIPP Average Density of Constituent	% Sludge Used In Calculations	WIPP Average Scaled Density of Constituent	Total Mass of Consituent for WIPP Design Capacity
	m3	kg	kg	m3	kg/m3	%	kg/m3	kg
Footnotes	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Nitrate	10815.76	11265484	941245.9	1.19E+05	7.91	85.6	9.24	1.62E+06
Sulfate	10933.74	11364875	342993.8	1.19E+05	2.88	80	3.60	6.33E+05

(1) "Total TRU" Volumes for Tables 3 and 4.
(2) "Total TRU" Mass from Tables 3 and 4.
(3) "Total TRU" Nitrate/Sulfate from Tables 3 and 4.
(4) Anticipated Volume of CH- and RH-TRU Waste (stored + projected to 2022) from Table 3-1 in Rev. 2 of TWBIR.
RH-TRU anticipated volume is limited to 7080 m3; design capcaity of WIPP.
(5) "Mass of Constituent" Column divided by "Anticipated Waste Volume" Column.
(6) Calculated from Table 1 "Total TRU" data. Nitrate = subtract 10815.76 from 13647 to get amount of particulate waste (2831.24).
Subtract 2831.24 from 15459.01 to get total chemically precipitated waste (12627.77).
Divide 10815.76 by 12627.77 and multiply by 100%. Sulfate is calculated in similar manner.
(7) Divide "Density of Constituent" by "% Sludge Used in Calculations".
(8) Multiply "Scaled Density of Consituent" by 175,600 m3 (design capacity of WIPP).

ATTACHMENT 1

TELEPHONE CONFERENCE SUMMARY

Parties: Paul Drez, DEA/CTAC
Davis Christenson, LANL

For Solidified Inorganics waste stream LA-T006; LA-W003; LA-W006; and LA-M002 assume the following composition for final waste form:

Envirostone-based solidified waste forms:

Nitrate 8.2%
Sulfate 38.5%
Phosphate 0.001%

Portland Cement-based solidified waste forms:

Nitrate 8.8%
Sulfate 1.4%
Phosphate 0.001%

LA-M002 has only used portland cement; the other three have use portland cement until 1985 and then Envirostone:

	Stored Wasted		Projected Waste	
WS#	Portland	Envirostone	Portland	Envirostone
LA-T006	84.5%	15.5%	100%	0%
LA-W006	54.65%	45.35%	100%	0%
LA-W003	84.5%	15.5%	100%	0%
LA-M002	100%	0%	100%	0%

ATTACHMENT 2

D61472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80

7412 Sludge PAGE 1

SAMPLE-ID	00-008395	DJO NUMBER	97038000
ENTRY DATE	11-01-79	ACCOUNT CHARGED	8037
COMPLETION DATE	04-10-80	BUILDING	559
		CLASS	SSPI
CUSTOMER	P. T. GODESAIBOIS		

** ATOMIC ABSORPTION SPECTROMETRY RESULTS

CA		86512.	PPM(W)	FE		61597.	PPM(W)
GA	<	50.	PPM(W)	K		6162.	PPM(W)
NA		65501.	PPM(W)	SI		3659.	PPM(W)

** PLUTONIUM CHEMISTRY LABORATORY RESULTS

CL(-)		0.16	%(W)	CO3=		0.36	%(W)
F(-)		57.	PPM(W)	H2O		61.0	%(W)
NO3		4.2	%(W)	PO4	<	0.0025	%(W)
SO4		0.085	%(W)				

** SEMI-QUANTATIVE EMISSION SPEC RESULTS

AG		50.	PPM(W)	AL		20000.	PPM(W)
AS	<	50.	PPM(W)	B		100.	PPM(W)
BA		100.	PPM(W)	BE		50.	PPM(W)
BI	<	50.	PPM(W)	CA	>	200000.	PPM(W)
CD	<	1000.	PPM(W)	CE	<	500.	PPM(W)
CO	<	50.	PPM(W)	CR		500.	PPM(W)
CS	<	1000.	PPM(W)	CU		4000.	PPM(W)
FE		50000.	PPM(W)	GE	<	10.	PPM(W)
HG	<	10.	PPM(W)	K		40000.	PPM(W)
LI	<	1000.	PPM(W)	MG		10000.	PPM(W)
MN		500.	PPM(W)	MO		500.	PPM(W)
NA		50000.	PPM(W)	NB	<	50.	PPM(W)
NI		2000.	PPM(W)	P	<	1000.	PPM(W)
PB	<	50.	PPM(W)	RB	<	500.	PPM(W)
SB	<	50.	PPM(W)	SI		100000.	PPM(W)
SN	<	10.	PPM(W)	SR		10000.	PPM(W)
TA	<	50.	PPM(W)	TE	<	100.	PPM(W)
TH	<	500.	PPM(W)	TI		500.	PPM(W)
TL	<	500.	PPM(W)	U	<	500.	PPM(W)
V	<	5.	PPM(W)	W	<	1000.	PPM(W)
ZN	<	500.	PPM(W)	ZR	<	50.	PPM(W)

** RADIOCHEMISTRY LABORATORY RESULTS

AM	0.0000317	G/G

ATTACHMENT 2

D61472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80

PAGE 2

SAMPLE-ID 00-008395

** RADIOCHEMISTRY LABORATORY RESULTS (CONTINUED)

PU	0.0000223	G/G	U	0.0017	G/G

AUTHORIZED SIGNATURE

Howell

ATTACHMENT 2

061472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80

7412 Sludge PAGE 1

SAMPLE-ID	00-008396	DJO NUMBER	97038000
ENTRY DATE	11-01-79	ACCOUNT CHARGED	8037
COMPLETION DATE	04-10-80	BUILDING	559
		CLASS	SSP1
CUSTOMER	P. T. GODESAIBOIS		

** ATOMIC ABSORPTION SPECTROMETRY RESULTS

CA	194587.	PPM(W)	FE	47915.	PPM(W)
GA	< 50.	PPM(W)	MG	9581.	PPM(W)
NA	105060.	PPM(W)	SI	158.	PPM(W)

** PLUTONIUM CHEMISTRY LABORATORY RESULTS

CL(-)	0.15	%(W)	CO3=	0.74	%(W)
F(-)	101.	PPM(W)	H2O	55.0	%(W)
NO3	8.0	%(W)	PO4	< 0.0025	%(W)
SO4	0.096	%(W)			

** SEMI-QUANTATIVE EMISSION SPEC RESULTS

AG	10.	PPM(W)	AL	10000.	PPM(W)
AS	< 50.	PPM(W)	B	100.	PPM(W)
BA	500.	PPM(W)	BE	1000.	PPM(W)
BI	< 50.	PPM(W)	CA	> 200000.	PPM(W)
CD	< 1000.	PPM(W)	CE	< 500.	PPM(W)
CO	< 50.	PPM(W)	CR	500.	PPM(W)
CS	< 1000.	PPM(W)	CU	500.	PPM(W)
FE	50000.	PPM(W)	GE	< 10.	PPM(W)
HG	< 10.	PPM(W)	K	40000.	PPM(W)
LI	< 1000.	PPM(W)	MG	50000.	PPM(W)
MN	500.	PPM(W)	MO	200.	PPM(W)
NA	50000.	PPM(W)	NB	< 50.	PPM(W)
NI	1000.	PPM(W)	P	< 1000.	PPM(W)
PB	50.	PPM(W)	PU	< 100.	PPM(W)
RB	< 500.	PPM(W)	SB	< 50.	PPM(W)
SI	100000.	PPM(W)	SN	< 10.	PPM(W)
SR	10000.	PPM(W)	TA	< 50.	PPM(W)
TE	< 100.	PPM(W)	TH	< 500.	PPM(W)
TI	500.	PPM(W)	TL	< 500.	PPM(W)
U	< 500.	PPM(W)	V	< 5.	PPM(W)
W	< 1000.	PPM(W)	ZN	< 500.	PPM(W)
ZR	< 50.	PPM(W)			

ATTACHMENT 2

D61472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80

PAGE 2

SAMPLE-ID 00-008396

** RADIOCHEMISTRY LABORATORY RESULTS

AM	0.00000546 G/G			
PU	0.0000389 G/G	U	0.000198	G/G

AUTHORIZED SIGNATURE

ATTACHMENT 2

D61472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80

7412 Sludge PAGE 1

SAMPLE-ID	00-008397	DJO NUMBER	97038000
ENTRY DATE	11-01-79	ACCOUNT CHARGED	8037
COMPLETION DATE	04-10-80	BUILDING	559
		CLASS	SSPL
CUSTOMER	P. T. GODESAIBOIS		

** ATOMIC ABSORPTION SPECTROMETRY RESULTS

CA		121661.	PPM(W)	FE		49286.	PPM(W)
GA	<	50.	PPM(W)	MG		18377.	PPM(W)
NA		100179.	PPM(W)	SI		217.	PPM(W)

** PLUTONIUM CHEMISTRY LABORATORY RESULTS

CL(-)		1.5	%(W)	CO3=		0.59	%(W)
F(-)		143.	PPM(W)	H2O		60.2	%(W)
NO3		9.1	%(W)	PO4	<	0.0025	%(W)
SO4		0.14	%(W)				

** SEMI-QUANTATIVE EMISSION SPEC RESULTS

AG		40000.	PPM(W)	AL		10000.	PPM(W)
AS	<	50.	PPM(W)	B		100.	PPM(W)
BA		50.	PPM(W)	BE		1000.	PPM(W)
BI	<	50.	PPM(W)	CA		200000.	PPM(W)
CD	<	1000.	PPM(W)	CE	<	500.	PPM(W)
CO	<	50.	PPM(W)	CR		500.	PPM(W)
CS	<	1000.	PPM(W)	CU		1000.	PPM(W)
FE		50000.	PPM(W)	GE	<	10.	PPM(W)
HG	<	10.	PPM(W)	K		40000.	PPM(W)
LI	<	1000.	PPM(W)	MG		100000.	PPM(W)
MN		100.	PPM(W)	MO		200.	PPM(W)
NA		60000.	PPM(W)	NB	<	50.	PPM(W)
NI		500.	PPM(W)	P	<	1000.	PPM(W)
PB		50.	PPM(W)	PU	<	100.	PPM(W)
RB	<	500.	PPM(W)	SB	<	50.	PPM(W)
SI		100000.	PPM(W)	SN	<	10.	PPM(W)
SR		10000.	PPM(W)	TA	<	50.	PPM(W)
TE	<	100.	PPM(W)	TH	<	500.	PPM(W)
TI		300.	PPM(W)	TL	<	500.	PPM(W)
U	<	500.	PPM(W)	V	<	5.	PPM(W)
W	<	1000.	PPM(W)	ZN	<	500.	PPM(W)
ZR	<	50.	PPM(W)				

ATTACHMENT 2

D61472-01 LABORATORY SAMPLE RESULTS DATE 04/10/80

PAGE 2

SAMPLE-ID 00-008397

** RADIOCHEMISTRY LABORATORY RESULTS

AM	0.000628	MG/G			
PU	0.00000481	G/G	U	0.000561	G/G

AUTHORIZED SIGNATURE

Hughes

ATTACHMENT 2

Rockwell International

Energy Systems Group
Rocky Flats Plant
P.O. Box 464
Golden, Colorado 80401

ANALYTICAL REPORT

To C.T. Hewitt 374 / File

Account No. 371

Date 7-24-81

Lab. No. M81-1109

Reported by

Approved A.M. Miller

Sample Description

374 Waste Sludge — Dried sludge

Analysis Results

A characterization of the 374 waste sludge was requested. The analysis of a composited sample is given. All results are in %.

Ca	11
Mg	3.8
Si	5.8
Al	0.4
Cr	0.12
Fe	0.9
K	0.25
Na	0.8
C	13
S	0.36
SO_4	0.02
Cl	1.3
F	0.5
PO_4	40
NO_3	6.6
CO_3	0.04
HCO_3	0.33

The cations greater than 1% were determined by A^2 and those less than 1% by emission spectroscopy. The anions, except for HCO_3, CO_3, and NO_3 were determined on a nitric acid leach of the sludge. Eighteen percent of the sludge was soluble in water, and 36% soluble in nitric acid.

CORRES CONTROL
OUTGOING LTR NO
88-RF-1089

DIST.	LTR	ENCL
SANCHINI, D. J.		
BADER, C. P.		
CAMPBELL, G.W.		
HOOD, R. C.		
KINZER, J. E.		
KIRBY, W. A.		
McNETT, J.F.		
MEYERS, G.W.		
SHANNON, W.M.		
SMITH, R.E.		
WEIDNER, C.W.		
WESTON, W.F.	X	
WILSON, G.L.		
WOZNIAK, B.D.		
YOUNG, E.R.		
BETCHER, D.H.		
CARNIVAL, G.J.		
HARMAN, L.K.		
HEBERT, J.L.		
HOEY, J.B.		
HOFFMAN, R.B.		
KRIEG, D.M.	X	X
LIM, B.W.		
LOUDENBURG, G.E.		
NAIMON, E.R.	X	
NEWBY, R.L.		
ROECKER, J.H.		
VELASQUEZ, R.N.		
CORRES. CONTROL		
BRETLKE, C.D.	X	
REINHART, W.D.	X	
PAYNTER, J.F.	X	X
HICKLE, G.L.	X	

CLASSIFICATION
UNCLASSIFIED X X
CONFIDENTIAL
SECRET

AUTH. CLASSIFIER SIG.
4/6/88
DATE

IN REPLY TO LTR NO
C521-RF-87

DEC. WCPOU #32
LTR APPROVALS

JKP/jb

Rocky Flats Plant
North American Space Operations
Rockwell International Corporation
P.O. Box 464
Golden, Colorado 80402-0464
(303) 966-7000
Contractor to U.S. Department of Energy

Rockwell International

April 4, 1988 88-RF-1089

Albert E. Whiteman
Area Manager
DOE, RFAO

ENGINEERING PARAMETERS FOR ROCKY FLATS WASTE FORMS

This information is for the attention of W. C. Rask.

Attached are the engineering parameters for Rocky Flats waste forms that were requested in the letter from J. B. Tollison to distribution, dated March 1, 1988. Information is included for all thirteen Rocky Flats waste forms, which will be transported in the TRUPACT-II container.

If you have questions regarding the enclosed information, contact Jim Alexander at (303) 966-7585 or Jeff Paynter at (303) 966-5252. With your approval please forward to DOE/AL, Waste Transportation.

E. R. Naimon, Manager
Waste Operations
Rocky Flats Plant
Aerospace Operations

Orig. and 3 cc - A. E. Whiteman
Enc.

ENGINEERING PARAMETERS FOR TRUPACT-II

Waste Stream - - TRU SOLIDIFIED ORGANIC WASTE (WF-112)

For data in Section 1, Secondary Container, and Section 2, Arrangement of Secondary Containers, see the General Engineering Parameters for TRUPACT II.

3 WASTE MATERIAL INFORMATION:

3.1 Structural:

3.1.1 Maximum and Minimum Weight - -

Drums: 750 lb max. / 530 lb avg. / 200 lb. min. (including the weight of the drum)

3.1.2 Acceptable Projectile Envelope - - NA, solid monolith cast in the liner inside the drum.

3.2 Thermal:

3.2.1 Quantity of Radionuclides - - Isotopic Composition (Mix Group 9, TRUPACT-II Spec.):

Isotope	Fraction
Pu-238	TRACE
Pu-239	0.930
Pu-240	0.058
Pu-241	0.004
Pu-242	TRACE
Am-241	TRACE
OTHER	0.007

Max. radionuclides (Weapons Grade Pu): 200 grams/drum

Maximum decay heat (Pu): 0.4 watts/drum
(Am): 0.3 watts/drum
Total: 0.7 watts/drum

3.2.2 Chemical Form - -

	min.	max.	ave.
oils	10 %	30 %	
trichloroethane and trichlorotrifluoroethane	5 %	10 %	
carbon tetrachloride	2 %	5 %	
emulsifier (a polyethyl glycol ester)	5 %	10 %	
water	5 %	15 %	
gypsum cement	40 %	50 %	200 lb
total liquid (32 gallons)			250 lb

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

WCA Attachment WCA.8.15

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WPO 37743

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

INFORMATION ONLY

date: May 9, 1996

to: Distribution

from: Yifeng Wang (Org. 6748)

subject: Evaluation of the Thermal Effect of MgO Hydration for the Long-Term WIPP Performance Assessment

The hydration reaction of backfill MgO with inflow brines can potentially change repository temperatures, due to the exothermic nature of the reaction. This memorandum is to evaluate the thermal effect of MgO hydration on the long-term WIPP performance assessment.

To simplify the problem, we assume that MgO hydration can be described by the overall reaction:

$$MgO + H_2O \rightarrow Mg(OH)_2 \quad . \tag{1}$$

and that the reaction rate is much higher than the brine inflow rate and, therefore, the reaction will be limited by brine inflow. Considering the dimensions of the repository, we also assume that the heat released from the reaction will be dissipated away mainly from the ceiling and ground of the repository and the heat loss from the side walls is negligible. In addition, we assume that the hydration reaction will take place uniformly in a reaction region, which can be a panel or the whole repository.

Based on these assumptions, the thermal effect of MgO hydration can be modeled by a simplified system shown in Figure 1. The temperature distribution (T) can be described by the following equations:

$$C_p \rho \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial X^2} \tag{2}$$

$$T(X,0) = T_0 \tag{3}$$

$$\rho_W V \Delta H = -2Sk \left. \frac{\partial T}{\partial X} \right|_{X=0} \tag{4}$$

$$T(\infty,t) = T_0 \tag{5}$$

where C_p is the heat capacity of surrounding rocks; ρ is the molar density of surrounding rocks; t is time; X is the spatial coordinate; k is the thermal conductivity of surrounding rocks; T_0 is the background temperature; ρ_W is the molar density of water; V is the brine inflow rate; ΔH is the enthalpy change in Reaction (1); S is the horizontal area of the reaction region.

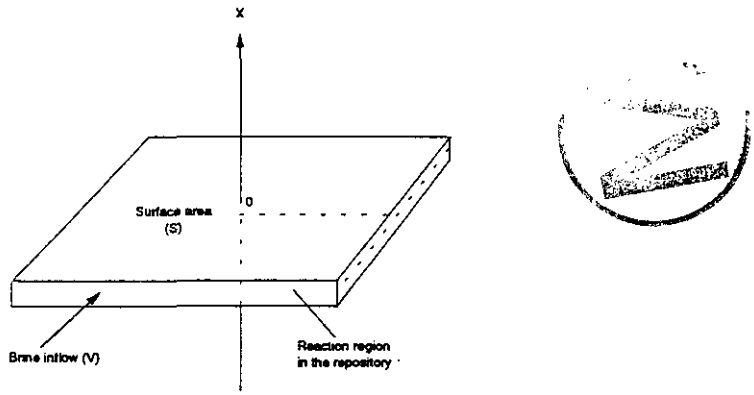

Figure 1. A modeling system for hydration heat production and heat conduction.

The above equations can be solved for T with a Laplace-transformation method:

$$T - T_0 = \frac{\rho_w V \Delta H}{2S\sqrt{C_p \rho k}}\left[2\sqrt{\frac{t}{\pi}}e^{-\frac{C_p \rho X^2}{4Kt}} - \sqrt{\frac{C_p \rho}{k}} X\, erfc\left(\frac{X}{2}\sqrt{\frac{Cp\rho}{kt}}\right)\right]. \tag{6}$$

The temperature increase in the repository (ΔT) is obtained by setting X = 0 in equation (6):

$$\Delta T = T(0,t) - T_0 = \frac{\rho_w V \Delta H}{S}\sqrt{\frac{t}{\pi C_p \rho k}}. \tag{7}$$

Equation (7) shows that the repository temperature will increase with t until all MgO becomes hydrated. Therefore, the maximum temperature increase (ΔT_{max}) in the repository can be calculated by

$$\Delta T_{max} = T(0,t) - T_0 = \frac{\Delta H}{S}\sqrt{\frac{\rho_w V M_{MgO}}{\pi C_p \rho k}} \tag{8}$$

Where M_{MgO} is the inventory of MgO in the reaction region.

To be consistent with actinide solubility calculations, we assume that the reaction will occur uniformly in the whole repository, i.e., the reaction region shown in Figure 1 will extend to the whole repository. Then, $S = 1.1 \times 10^5$ m^2 and $M_{MgO} = 2 \times 10^9$ moles. The other parameters are estimated as follows:

$\rho_W = 5.56 \times 10^4$ moles/m^3;

maximum V = 1000 m^3/year (Joel Miller, personal communication);

$\Delta H = 3.89 \times 10^4$ J/mole (Drever, 1982);

$\rho = 3.7 \times 10^4$ moles/m^3 (Lide, 1994), assuming that the surrounding rocks can be represented by halite;

$C_p = 50$ J/mole/K (Lide, 1994), assuming that the surrounding rocks can be represented by halite;

$k = 6.3$ W/m/K $= 1.99 \times 10^8$ J/year/m/K (Lide, 1994), assuming the surrounding rocks can be represented by halite.

From these data, we estimate the maximum temperature increase in the repository due to MgO hydration to be 3.4 K. Therefore, the thermal effect of MgO hydration can be negligible.

References:

Drever J. I. (1982) The Geochemistry of Natural Water. Prentice-Hall.
Lide D. R. (1994) Handbook of Chemistry and Physics. CRC Press.

Distribution:

MS 1320 J. Nowak (Org. 6831)
MS 1320 R. V. Bynum (Org. 6831)
MS 1328 C. T. Stockman (Org. 6749)
MS 1335 M. S. Y. Chu (Org. 6801)
MS 1341 C. C. Crafts (Org. 6748)
MS 1341 J. T. Holmes (Org. 6748)
MS 1341 B. M. Butcher (Org. 6748)
MS 1341 L. H. Brush (Org. 6748)
MS 1341 Y. Wang (Org. 6748)
MS 1341 R. F. Weiner (Org. 6751)
MS 1343 A. S. Reiser (Org. 6751)
MS 1330 SWCF-A (Org. 6352), WBS 1.1.09.1.1(RC)

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Title 40 CFR Part 191
Compliance Certification
Application
for the
Waste Isolation Pilot Plant

WCA Attachment WCA.8.16

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WPO 31165

INFORMATION ONLY

Sandia National Laboratories

Managed and Operated by Sandia Corporation
a Lockheed Martin Company
Albuquerque, New Mexico 87185-1328

date : January 17, 1996

to : T. Hicks, (Galson Science Ltd.)

from : L. C. Sanchez, Org 6741, MS-1328 (505)848-0685
H. R. Trellue, Org 6741, MS-1328 (505)848-0820

subject : **Estimation of Maximum RH-TRU Thermal Heat Load for WIPP**

[1] **Requested Information**

In previous communications [Ref. Hi-1], a request was made for an estimate of the upper bound for the expected thermal payload (internal heat generation) of a RH-TRU canister. This information can then be used to estimate the maximum temperature rise in the immediate vicinity of a RH-TRU canister with the largest expected thermal payload. Calculations presented in this memo correspond to two major analysis steps: 1) inverse internal shielding calculations, to identify the corresponding thermal payload for maximum allowable surface dose; and 2) heat conduction calculations for thermal payloads based on limited empirical data. The analysis steps are discussed below.

[2] **Inverse Internal Shielding Calculations**

These calculations yield first order "hand calculations" that are used to identify the radiation source term corresponding to the maximum allowable surface dose rate (1,000 *rem/hr*) for RH-TRU canisters [Ref. LWA-1]. The shielding calculations were performed only for gamma radiation because betas and alphas would not penetrate the waste matrix and/or the RH canister in any appreciable quantities (note: the internal heat generation of betas and alphas are incorporated when converting gamma activities to total (alpha, beta, and gamma) internal activities). Neutrons are not included because the dose equivalent rate from neutrons is about three orders of magnitude less than that for the maximum total allowable surface dose rate (i.e., the allowed neutron dose rate is 270 *mrem/hr* max [Ref. DOE-5]) and the corresponding neutron heating rate is insignificant. The computational steps used for gamma shielding are shown in Table 1.

Table 1. Calculation Steps For Inverse Shielding Calculations

Step	Calculation
1	For the identified dose equivalent rate (sometimes termed "biological dose" rate, formerly called "RBE dose" rate, or relative biological effectiveness, determine the corresponding absorbed dose rate for gamma-ray radiation.
2	For the identified absorbed dose rate determine the corresponding exposure rate for gamma-ray radiation.
3	Use the dose exposure rate equation for biological shielding to determine the gamma flux corresponding to the maximum allowed surface dose rate. Note: here we want a method for determining the activity load internal to the RH-TRU canister, not a kerma calculation for determining the gamma heating rate, because that heating rate value could not be used to identify the energy deposited internally in the canister.
4	Use the proper shielding equation with the point source isotropic exposure buildup factor for a self-shielding distributed source to identify the corresponding internally distributed gamma source strength (gamma activity).
5	Determine the total internal source strength (activity) from the gamma source strength.
6	Determine the total heat payload corresponding to the total internal source strength.

Step 1 requires use of Equation 1 [Ref. La-1], which incorporates the "quality factor" (see Table 2) which is a factor that takes into account the fact that equal absorbed doses of radiation of different qualities have, in general, different biological effects.

$$\dot{H} = Q\,\dot{D} \quad , \quad \textit{rewritten as}: \ \dot{D} = \dot{H}/Q \qquad [1]$$

Likewise, Equation 2 [La-1b] relates the absorbed dose rate to the exposure rate through the parameter f (see Figure 1) and Equation 3 [La-1c], which describes the biological shielding (shielding to reduce radiation exposure to persons in the vicinity of radiation sources), relates the exposure rate to the gamma-ray flux density.

$$\dot{D} = f\,\dot{X} \quad , \quad \textit{rewritten as}: \ \dot{X} = \dot{D}/f \qquad [2]$$

$$\dot{X} = C_d\,\phi \quad , \quad \textit{rewritten as}: \ \phi = \dot{X}/C_d \qquad [3]$$

where:

$\dot{H}$ = *dose equivalent rate* [*rem/hr*]

$\dot{D}$ = *absorbed dose rate* [*rad/hr*]

Q = *quality factor* [*rem/rad*]

$\dot{X}$ = *exposure rate* [*R/hr*]

f = *exposure to absorbed dose conversion ratio* [*rad/R*]

$$= 0.874 \frac{(\mu_a/\rho)^{tissue}}{(\mu_a/\rho)^{air}} \qquad \text{[Ref. La–1b]} \qquad [3b]$$

ϕ = *gamma–ray flux density* [γ/cm^2–s]

C_d = *flux–to–dose conversion factor* [(cm^2–sec/γ)×(R/hr)]

$$= 0.0659E{-}03\ E_\gamma(\mu_a/\rho)^{air} \qquad \text{[Ref. La–1c]} \qquad [3c]$$

E_γ = *gamma-ray energy* [*MeV*]

$(\mu_a/\rho)^{air}$ = *mass energy-absorption coefficient for air* [cm^2/g]

Table 2. Quality Factors for Various Types of Radiation *

Type of Radiation	Q
x–rays and γ–rays	1
β-rays, $E_{max} > 0.03\,MeV$	1 †
β-rays, $E_{max} < 0.03\,MeV$	1.7 †
Naturally occurring α-particles	10
Heavy recoil nuclei	20
Neutrons;	
Thermal to 1*keV*	2
10*keV*	2.5
100*keV*	7.5
500*keV*	11
1*MeV*	11
2.5*MeV*	9
5*MeV*	8
7*MeV*	7
10*MeV*	6.5
14*MeV*	7.5
20*MeV*	8
Energy not specified	10

* Taken from Lamarsh [Ref. La-1d], based on NCRP report 39 [Ref. Nc-1].
† Recommended in ICRP publication 9 [Ref. Ic-1].

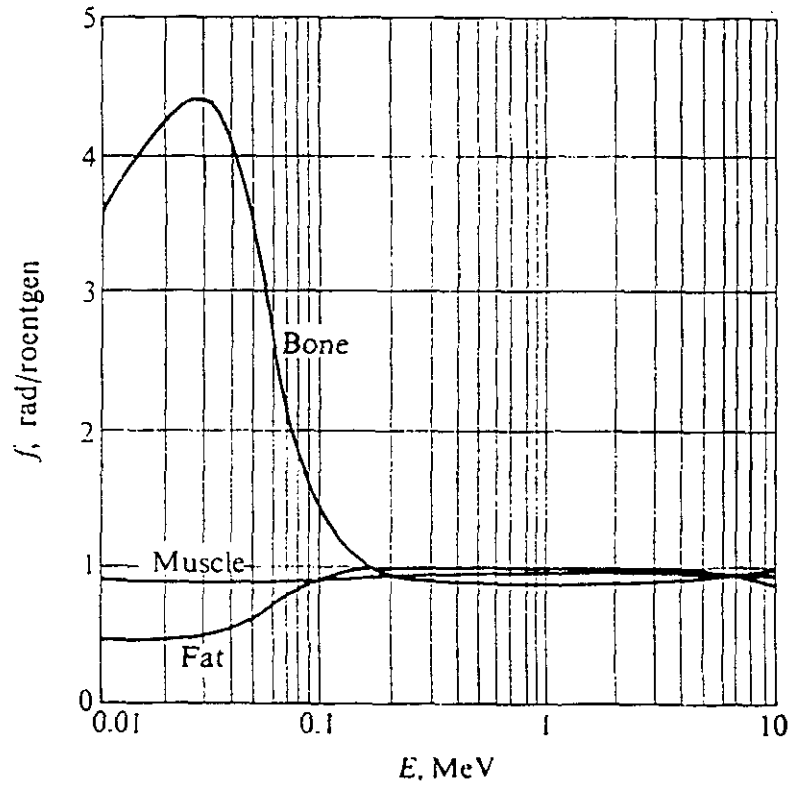

Figure 1 Parameter f as function of γ-ray energy.
(Taken from Ref. La-1b, originally from Mo-1.)

The mass energy-absorption coefficients (μ_a/ρ) for air and tissue for various gamma-ray energies are shown in Table 3. Performing Steps 1, 2 and 3 of Table 1 with the use of Equations 1, 2 and 3 yields Equation 4, which identifies the maximum allowable RH-TRU canister surface gamma flux density for a given maximum allowable surface dose (equivalent) rate.

$$\phi_s(max) = \frac{\dot{X}_S(max)}{C_d} = \frac{\dot{D}_s(max)}{C_d f} = \frac{\dot{H}_s(max)}{C_d f Q} \qquad [4a]$$

$$= \frac{\dot{H}_s(max)}{0.0659E{-}03\, E_\gamma(\mu_a/\rho)^{air} f Q} = \frac{\dot{H}_s(max)}{5.75966E{-}05\, E_\gamma(\mu_a/\rho)^{tissue} Q} \qquad [4b]$$

Table 3. Mass Energy-Absorption Coefficients for Air *

Gamma-ray Energy [MeV]	Mass Energy-Absorption Coefficient $(\mu_a/\rho)^x$ $[cm^2/g]$ Air	Tissue
0.1	0.0233	0.0271
0.15	0.0251	0.0282
0.2	0.0268	0.0293
0.3	0.0288	0.0312
0.4	0.0296	0.0317
0.5	0.0297	0.0320
0.6	0.0296	0.0319
0.8	0.0289	0.0311
1.0	**0.0280**	**0.0300**
1.25	0.0268	0.0288
1.50	0.0256	0.0276
2.0	0.0238	0.0256
3.0	0.0211	0.0220
4.0	0.0194	0.0206
5.0	0.0181	0.0192
6.0	0.0172	0.0182
8.0	0.0160	0.0168
10.0	0.0153	0.0160

* Data from Ref La-1f.
NOTE
are to be used for dose calculations. They are not attenuation coefficients which are used for shielding calculations.

If there is more than one radionuclide emitting gammas to be included in the gamma source term, then the total dose (equivalent) rate is composed of several components (see Equation 5) and, likewise, the gamma flux density will be composed of several components (not necessarily of the same gamma energy distribution).

$$\dot{H}_{total} = \sum_i \dot{H}_i \qquad [5]$$

Now the gamma flux density due to gamma-ray attenuation is needed. The equations for a point source are Equations 6 and 7.

$$\phi_o = \frac{S}{4\pi R^2} \qquad [\gamma/cm^2\text{–}sec] \qquad [6]$$

$$\phi_u = \phi_o e^{-\mu t} = \frac{Se^{-\mu t}}{4\pi R^2} \qquad [7]$$

where:

ϕ_o = *gamma-ray flux of an unshielded uncollided isotropic point source*

ϕ_u = *gamma-ray flux of a shielded uncollided isotropic point source*

S = *source strength* [γ/sec]

R = *distance from the point source* [*cm*]

t = *shielding thickness* [*cm*]

μ = *linear attenuation coefficient for shield* [*1/cm*]

= *mass attenuation coefficient* × *mass density* = $(\mu_s/\rho) \times \rho$ [7b]

Equation 6 corresponds to a bare isotropic point (gamma emitting) source and describes the direct-beam (uncollided) component of the unshielded source. Equation 7 includes the attenuation (the $e^{-\mu t}$ term) of an intervening absorbing material (ϕ_u corresponds only to the uncollided component of the gamma flux). ϕ_u does not include, however, important effects due to: 1) the Compton effect (scattering with loss of energy: this is very important since non-direct beams can be scattered to detector locations), 2) the photoelectric effect (producing x-rays), and 3) pair production (the incident photon in the vicinity of a nucleus produces a electron-positron pair and the annihilation of the positron with an electron generates gamma-ray radiation). The importance of these effects can be identified from Figures 2 and 3, which show qualitative effects on gamma energy spectra due to shielding material.

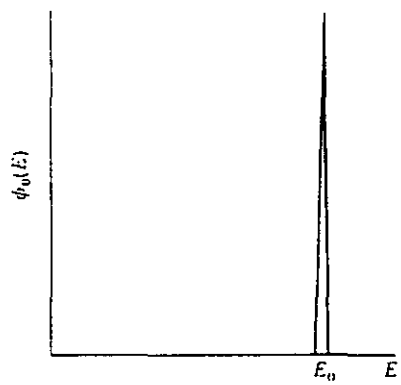

Figure 2 Energy spectrum of incident gamma-ray beam. (Taken from Ref. La-1g.)

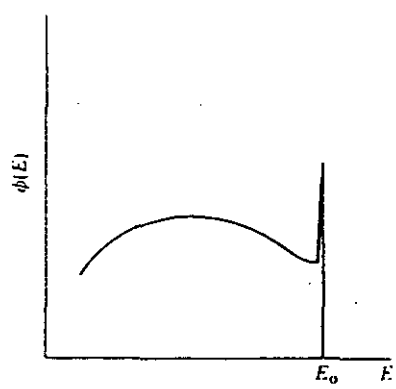

Figure 3 Energy spectrum of gamma-rays emerging from shield. (Taken from Ref. La-1g.)

The necessary correction factor for these effects is the gamma buildup factor ($B_p(\mu t)$ tabulated in many references and for many cases yielding acceptable estimates for calculated gamma fluxes) for the gamma-ray transport. The addition of this term yields Equation 8.

$$\phi_b = B_p(\mu t)\phi_u = B_p(\mu t)\phi_o e^{-\mu t} = S\, B_p(\mu t)\,\frac{e^{-\mu t}}{4\pi R^2} \qquad [8]$$

If more accurate gamma-ray transport calculations are needed, they should be performed with the Boltzmann transport equation which incorporates the complete treatment of the scattering component (this was not deemed necessary for this simple study). The time-independent transport theory (Boltzmann Equation) for photons is given by [Ref. Sc-1b]:

$$\nabla\cdot\Omega\phi(\mathbf{r},\Omega,E) + \Sigma_t(\mathbf{r},E)\phi(\mathbf{r},\Omega,E) = \qquad [9]$$
$$\iint_{E'\Omega'} \Sigma_s(\mathbf{r},E')p(E'\rightarrow E,\Omega'\rightarrow\Omega)\phi(\mathbf{r},\Omega',E')d\Omega' dE' + S(\mathbf{r},\Omega,E)$$

where:

$\mathbf{r}$ = *gamma-ray position vector*

E = *gamma-ray energy*

Ω = *solid angle*

ϕ = *gamma-ray flux*

p = *probability that a particle of energy E' and direction Ω' scatters into dE about E and $d\Omega$ about Ω*

S = *source term*

Σ_i = *macroscopic cross section (i=t → total, i=s → scattering)*

= *atom density × microscopic cross-section*

Equation 9 is a complex integral differential equation which has the extra dimensions of particle energy (E) and angular distribution (Ω), thus a one dimensional steady-state problem is actually a three dimensional problem. There are a significant number of available discrete ordinates and Monte Carlo codes for solving the Boltzmann equation, but this extra level of effort is not necessary for the problem at hand.

Proceeding with the simple shielding expressions, Equation 8 represents the total (direct and scattered) component with an intervening absorbing and scattering shield for a point source. The buildup factor is a function of the shielding thickness and the gamma-ray linear attenuation coefficient, which is dependent on gamma energy. Note; the buildup factors are problem specific; there is separate buildup factor for each source type – mono-directional beam, isotropic, etc. There are various buildup factors for different specific geometries, such as a point source, line source, etc., see Refs. Sc-1 & Ja-1. Since real geometries correspond to distributed sources, it is necessary to integrate the collective fluxes from multipoint sources that are used to represent a distributed gamma source. Thus Equation 8 (which is for a point source) is integrated over all point source strengths convoluted with the attenuation kernel to yield Equation 10:

$$\phi(\mathbf{r}) = \int_{\text{all space}} S_V(\mathbf{r}')K(|\mathbf{r}'-\mathbf{r}|)d\mathbf{r}' \qquad [10]$$

$\mathbf{r}$ = *vector to the measuring point*

$\mathbf{r}'$ = *vector to any source-bearing point in space*

$S_V(\mathbf{r}')$ = *source strength per unit volume at* $\mathbf{r}'$

This equation for the "extended source term" (integrated volumetric source term) has the exponential point attenuation kernel given by:

$$K(R) = B(\mu t)\frac{e^{-\mu t}}{4\pi R^2} \qquad [11]$$

The solution to Equation 10, for simple cases of uniformly distributed source geometries, is an exponential integral function [Gl-1], whose general form is given by Equation [12].

$$E_n(x) = x^{n-1}\int_x^{\infty}\frac{e^{-p}}{p^n}dp \qquad [12]$$

Further description of the exponential point attenuation kernel can be found in Ref. Gl-1b.

For the problem at hand, the uncollided gamma flux at the source-shield interface (i.e., the interface between the RH-TRU waste matrix and the steel drum itself), from a right cylinder geometry, with a uniform source that is self-shielding, is given by Equation 13 [Ref. Ja-1].

$$\phi_u(upper\ limit) = \frac{S_V}{4\mu_s}\left[G(\mu_s h_1, b_5) + G(\mu_s h_2, b_5) + G(\mu_s h_1, b_6) + G(\mu_s h_2, b_6)\right] \qquad [13a]$$

$$\phi_u(lower\ limit) = \frac{S_V}{4\mu_s}\left[G(\mu_s h_1, b_6) + G(\mu_s h_2, b_6) + G(\mu_s h_1, b_4) + G(\mu_s h_2, b_4)\right] \qquad [13b]$$

where: ϕ_u = *uncollided gamma flux density within the RH-TRU waste matrix* [γ/cm^2–s]

S_V = *volumetric source term* [γ/cm^3–s]

G = *special exponential integral function*

μ_s = *linear attenuation coefficient of RH-TRU waste matrix* [$1/cm$]

$h_{1/2}$ = *half-height of the RH-TRU waste matrix* = $\frac{1}{2}H$ [cm]

h_1 = *height within RH-TRU waste matrix* [cm]

$h_2 = 2h_{1/2} - h_1$ [cm]

a = *radius of position under investigation* [cm]

R = *radius of the RH-TRU waste matrix* [cm]

$b_4 = \mu_s(R - a)$

$b_5 = \mu_s(R + a)$

$b_6 = \mu_s\sqrt{R^2 - a^2}$

Evaluating Equation 13 at the waste matrix-drum interface (i.e., $a = R$, $b_4 = b_6 = 0$) at center-plane (i.e., mid-height where $h_1 = h_2 = h_{1/2}$) yields Equation 14:

$$\phi_u(center\ plane) = \phi_u(cp) = \frac{S_V}{2\mu_s}\left[G(\mu_s h_{1/2}, 2\mu_s R)\right] \qquad [14]$$

The values for G (for right cylinders) can be estimated from the graphical representation shown in Figures 4a and 4b [Ja-1]. From these figures, it should be noted that for significant values for $\mu_s h_{1/2}$ and $2\mu_s R$ that $G(\mu_s h_{1/2}, 2\mu_s R) \rightarrow 1.0$. This results because $\mu_s h_{1/2}$ and $2\mu_s R$ are the mean free path (mfp) lengths (also called the relaxation lengths) in the azimuthal and radial directions; for cylindrical sources with significant thickness and radii, the source looks like an infinite source (semi-infinite space volume source). For large waste matrix dimensions ($\mu_s h_{1/2} \geq 3$, $2\mu_s R \geq 3$), the surface flux can be approximated by:

$$\phi_u(cp) \approx \frac{S_V}{2\mu_s} \qquad [15]$$

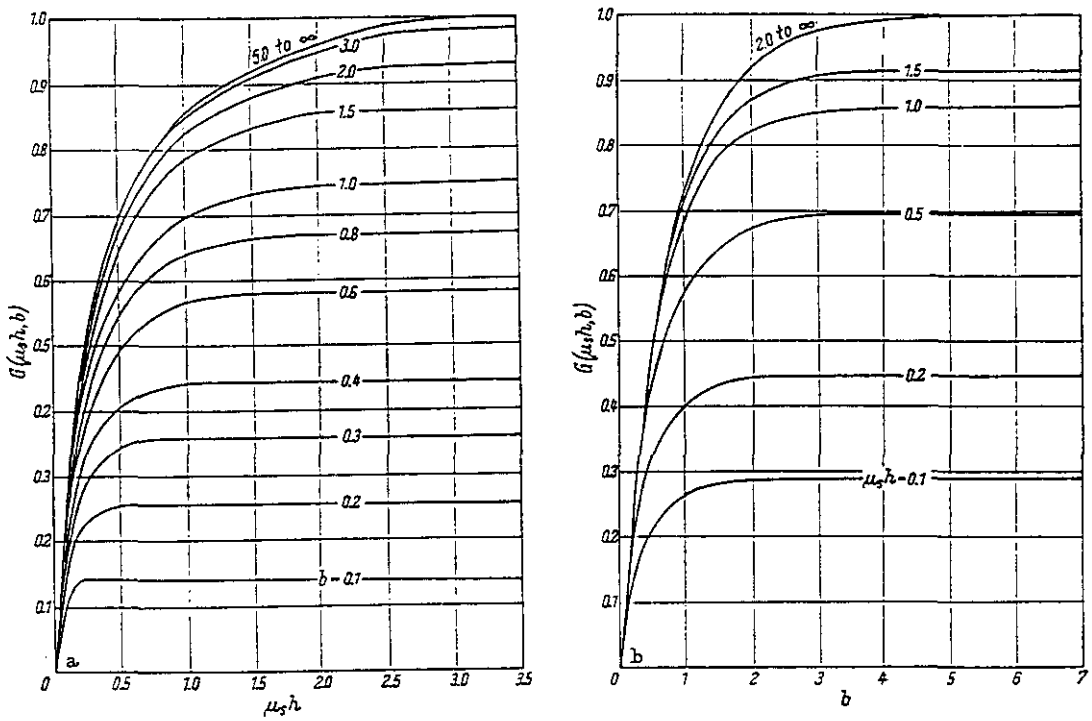

Figure 4 The function $G(\mu_s h, b)$ for G=0 to 1; (taken from Ja-1, originally from Ro-1). a) G vs. $\mu_s h$ for $\mu_s h$ = 0 to 3.5, b= 0.1 to ∞; b) G vs. b for $\mu_s h$ = 0.1 to ∞, b = 0, to 7.

To calculate the azimuthal and radial mean free path lengths requires the dimensions of the waste matrix within the RH-TRU canister. From Figure 5 [Ref. DOE-1] it can be identified that the inside dimensions of the RH-TRU canister is 25.5 in. for the diameter (not shown in Figure 5 is the thickness of the RH-TRU canister, which 0.25 in.), and a corresponding height slightly less that 120.5 in. In Ref. BIR-1f, the usable internal volume has been identified to be 0.89 cu.m.; thus, the active internal height can be calculated to be 270.12 cm. The 0.89 cu.m. volume, however, is inconsistent with the Ref. DOE-1b, which indicates that the RH-TRU canisters are to internally incorporate three standard (DOT-7C) CH-TRU waste drums (55-gal nominal volume), resulting in a waste matrix payload of 0.625 cu.m. for the RH-TRU canister. This inconsistency arises because there are actually two options for loading RH-TRU canisters: OPTION A -- place RH-TRU waste directly in the canisters (corresponding to a waste loading volume of 0.89 cu.m.) and OPTION B -- place RH-TRU waste directly into three 55-gallon DOT-7C drums, which would then in turn be placed into the RH-TRU canister (corresponding to a waste loading of 3x0.2082=0.6246 cu.m.) (see Ref. Sa-4 for more discussion). For OPTION B calculations, the drum dimension of a DOT-6M (the 6M uses a DOT 6C or 17C 55-gal metal outer drum, see Figures 6 and 7) were used because they were readily available in a previous report [Sa-1], and should be similar to DOT 7C specs. The internal waste matrix radius is 28.58 cm. and the internal individual drum height is 84.46 cm. Since the RH-TRU canister container contains three CH-TRU drums, the total internal waste matrix height is 253.38 cm, with a corresponding half-height (which is the parameter used in Equation 14) of 126.69 cm. Using 1) the waste matrix dimensions, 2) Equation 7b, and 3) a mass

attenuation coefficient of 0.0595 cm^2/g (from Table 4 it can be seen that for gammas with energy of 1.0 MeV or less, that the mass attenuation coefficients are 0.0595 or greater, the 0.0595 number is used because it gives a conservative result for the final solution for the internal source term), a rough approximation for $G(\mu_s h_{1/2}, 2\mu_s R)$ can be approximated by Equation 16 (obtained by using singular value decomposition (SVD) [Ref. Sa-2], based on graphical data displayed in Figures 4a and 4b; note that there are noticeable errors in Figures 4a and 4b):

$$G(\mu_s h_{1/2}, 2\mu_s R) = \begin{cases} 1.0 & \text{if } sp.gr. > 2 \quad (\textit{good} \text{ for } 0.1\% \textit{ accuracy}) \\ 1 - e^{-(c_1 sp.gr. + c_2 sp.gr.^2)} & \text{if } 2 \geq sp.gr. \geq 0 \quad (\textit{good} \text{ for } 4\% \textit{ accuracy/OPTION A}) \\ 1 - e^{-(c_3 sp.gr. + c_4 sp.gr.^2)} & \text{if } 2 \geq sp.gr. \geq 0 \quad (\textit{good} \text{ for } 4\% \textit{ accuracy/OPTION B}) \end{cases} \quad [16]$$

where

$c_1 = 5.4079558E{+}00 \quad c_2 = -9.7716046E{-}01$ *(for RH-TRU loading Option A)*

$c_3 = 4.8045511E{+}00 \quad c_4 = -6.7351092E{-}01$ *(for RH-TRU loading Option B)*

sp.gr. = the specific gravity of the RH-TRU waste matrix

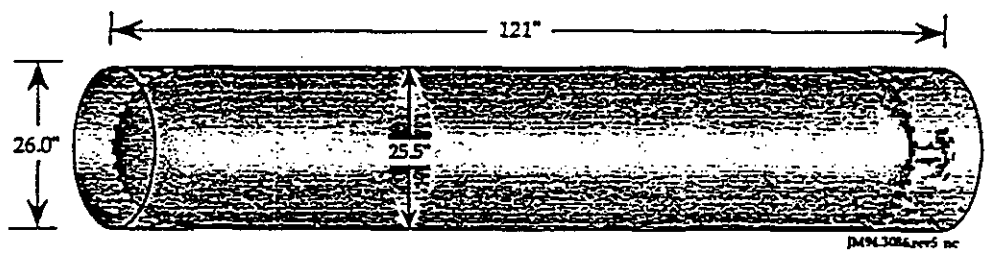

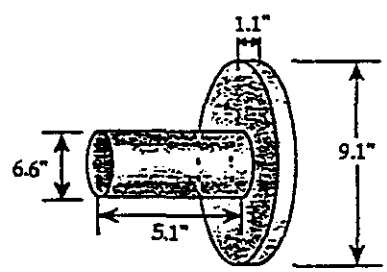

Note:
Drawing Not to Scale
* These are nominal estimates which support the inventory assessment for corrodible metals.

Figure 5 General dimensions of the RH-TRU canister (Taken from Ref. DOE-1.)

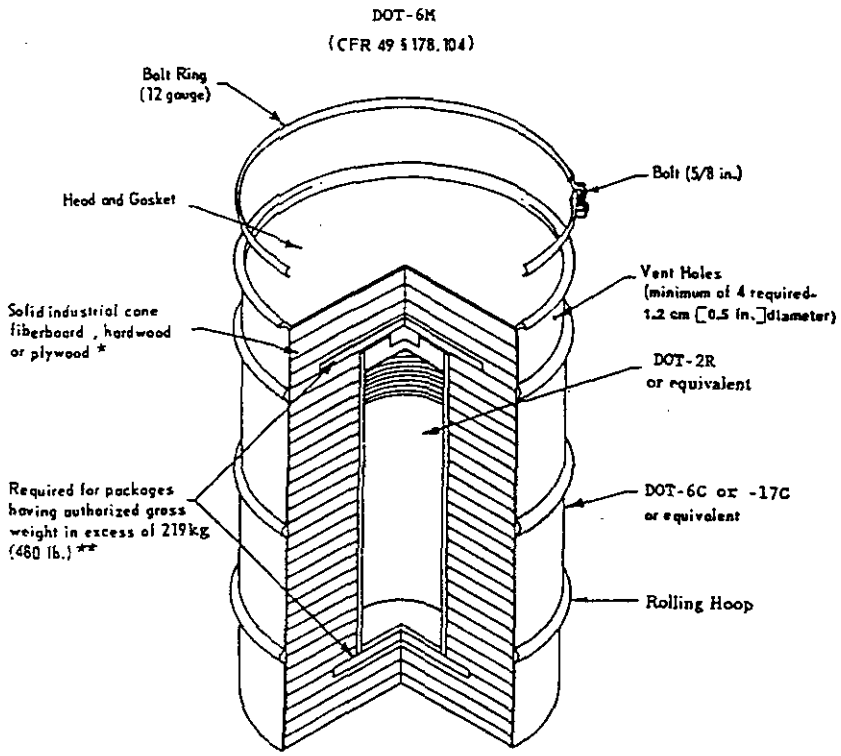

Figure 6 Geometry of 6M Containers (Taken from Sa-1, original Ref. Ed-1).

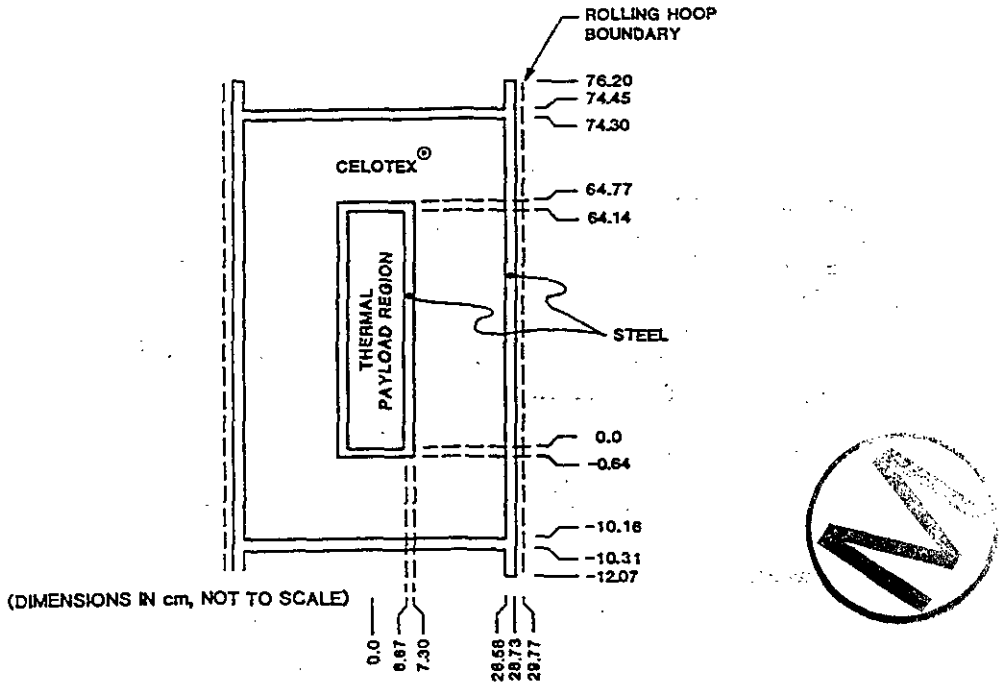

Figure 7 Schematic of the 55-Gallon 6M Container (taken from Sa-1).

Table 4. Mass Attenuation Coefficients *

Gamma Energy [MeV]	Mass Attenuation Coefficients, $(\mu_s/\rho)^x$ $[cm^2/g]$						
	Air	Concrete	Iron	Calcium	Silicon	Aluminum	Oxygen
0.1	0.151	0.169	0.344	0.238	0.172	0.161	0.151
0.3	0.106	0.107	0.106	0.109	0.107	0.103	0.107
0.5	0.0868	0.0870	0.0828	0.0876	0.0869	0.0840	0.0870
0.6	0.0804	0.0804	0.0762	0.0809	0.0802	0.0777	0.0806
0.8	0.0706	0.0706	0.0664	0.0708	0.0706	0.0683	0.0708
1.0	**0.0635**	**0.0635**	**0.0595**	**0.0634**	**0.0635**	**0.0614**	**0.0636**
1.5	0.0517	0.0517	0.0485	0.0518	0.0517	0.0500	0.0518
2.0	0.0445	0.0445	0.0424	0.0451	0.0447	0.0423	0.0445

* Data from Ref. Ra-1 (see Equation 7b for usage).

Equation 14 should now be modified to include the gamma flux buildup. The desired result is:

$$\phi_b(cp) = B_p^{waste} \frac{S_V}{2\mu_s} \left[G(\mu_s h_{1/2}, 2\mu_s R) \right] \qquad [17]$$

where

B_p^{waste} = *the buildup factor for the extended source*

We were not able to find a buildup factor for the extended source term. What is desired here is a buildup factor which has been properly integrated over the volumetric geometry of interest. As a first order approximation, a value of 1.31 was selected. From Table 5 it can be seen that this point source value was the minimum, hence conservative, of the values shown for gammas of energy of about 1.0 MeV. Equation 17 is only for the gamma flux at the waste matrix-drum interface. The buildup flux (uncollided plus collided) at the outer surface of the drum and RH-TRU canister can be estimated by using the expression for added linear shielding to a semi-infinite volume source term (see Ref. Ja-1b). Note; that this model does not include an inner liner for the RH-TRU canister, most likely made of polyethylene, which would have a linear attenuation coefficient (see Equation 7) that is an order of magnitude smaller than that of the RH-TRU canister itself. Using Equation 8, this yields Equation 18.

$$\phi_b(surface\ @\ cp) = \phi_s \approx \phi_u B_p^{waste} B_p^{canister} E_2(\mu_{canister} t_{canister}) \qquad [18]$$

$$= \frac{0.655\, S_V B_p^{canister}}{\mu_s} G(\mu_s h_{1/2}, 2\mu_s R)\, E_2(\mu_{canister} t_{canister})$$

where:

$\mu_{canister}$ = *linear attenuation coefficient of RH canister and inner drum* $[1/cm]$

$t_{canister}$ = *combined thickness of RH canister and inner drum* $[cm]$

E_2 = *exponential integral function*

Table 5. Dose Buildup Factors for a Point Isotropic Source (a)

Material	Gamma Energy [MeV]	Relaxation Lengths, μx (b)				
		1	2	4	7	10
Water	0.5	2.52	5.14	14.3	38.8	77.6
	1.0	2.13	3.71	7.68	16.2	27.1
	2.0	1.83	2.77	4.88	8.46	12.4
Aluminum	0.5	2.37	4.24	9.47	21.5	38.9
	1.0	2.02	3.31	6.57	13.1	21.2
	2.0	1.75	2.61	4.62	8.05	11.9
Iron	0.5	1.98	3.09	5.98	11.7	19.2
	1.0	1.87	2.89	5.39	10.2	16.2
	2.0	1.76	2.43	4.13	7.25	10.9
Tin	0.5	1.56	2.08	3.09	4.57	6.04
	1.0	1.64	2.30	3.74	6.17	8.85
	2.0	1.57	2.17	3.53	5.87	8.53
Tungsten	0.5	1.28	1.50	1.84	2.24	2.61
	1.0	1.44	1.83	2.57	3.62	4.64
	2.0	1.42	1.85	2.72	4.09	5.27
Lead	0.5	1.24	1.42	1.69	2.00	2.27
	1.0	1.37	1.69	2.26	3.02	3.74
	2.0	1.39	1.76	2.51	3.66	4.84
Uranium	0.5	1.17	1.30	1.48	1.67	1.85
	1.0	1.31	1.56	1.98	2.50	2.97
	2.0	1.33	1.64	2.23	3.09	3.95

(a) Data from Ref. Ra-1b.

(b) μx = mass attenuation coefficient $[cm^2/g]$ × shield thickness $[cm]$ × shield density $[g/cm^3]$.

Since the combined thickness of the metal drum (if OPTION B loading is used) and the RH-TRU canister is small, the gammas will be transported through less than one mean free path length; hence a conservative step is to set B_p^{waste} to unity. The solution for $E_2(b)$ is shown in Figure 8. A rough approximation for $E_2(b)$ can be given by Equation 19 (the fit for b values greater than 14 was based on data in Ref. Ab-1 and the fit for b values less than 14 (obtained by using singular value decomposition (SVD, Ref Sa-2)) was based on data in Ref. Ja-1b):

$$E_2(b) \approx \begin{cases} e^{-b}/(b+2) & \text{if } b > 14 \quad (\textit{good for 1\% accuracy}) \\ e^{-(c_5+c_6 b+c_7 b^2+c_8 b^3)} & \text{if } 14 \geq b \geq 1 \quad (\textit{good for 7\% accuracy}) \\ e^{-(c_9+c_{10} b+c_{11} b^2+c_{12} b^3)} & \text{if } 1 \geq b \geq 0 \quad (\textit{good for 3\% accuracy}) \end{cases} \qquad [19]$$

where

$c_5 = 5.5565607E{-01}$ $\quad c_9 = 1.7837543E{-02}$

$c_6 = 1.4190903E{+00}$ $\quad c_{10} = 3.0105850E{+00}$

$c_7 = -3.3941944E{-02}$ $\quad c_{11} = -2.0438538E{+00}$

$c_8 = 1.1209473E{-03}$ $\quad c_{12} = 9.3175783E{-01}$

Reformalizing Equation 18 to solve for S_V yields:

$$S_V = \frac{\phi_s \mu_s}{0.655\, G(\mu_s h_{1/2}, 2\mu_s R)\, E_2(\mu_{canister}\, t_{canister})} \qquad [20]$$

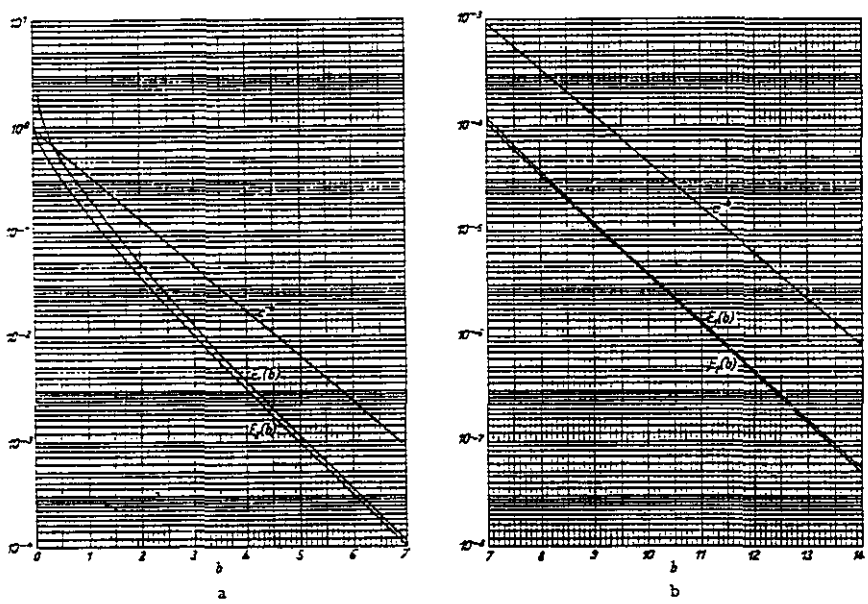

Figure 8 Solution for E_2. (Taken from Ja-1b.)

Assigning the maximum surface gamma flux density (from Equation 4) to ϕ_b nows gives us our final solution:

$$S_V(max) = \frac{\phi_s(max)\mu_s(max)}{0.655\, G(\mu_s h_{1/2}, 2\mu_s R)\, E_2(\mu_{canister}\, t_{canister})} \qquad [21a]$$

$$= \frac{\phi_s(max)(\mu_a/\rho)^{waste}\, \rho^{waste}(max)}{0.655\, G(\mu_s h_{1/2}, 2\mu_s R)\, E_2(\mu_{canister}\, t_{canister})} \qquad [21b]$$

$$= \frac{\dot{H}_s(max)\mu_s(max)}{C_d\, f\, Q\, 0.655\, G(\mu_s h_{1/2}, 2\mu_s R)\, E_2(\mu_{canister}\, t_{canister})} \qquad [21c]$$

$$= \frac{\dot{H}_s(max)(\mu_a/\rho)^{waste}\, \rho^{waste}(max)}{3.77258E{-05}\, E_\gamma(\mu_a/\rho)^{tissue}\, Q\, G(\mu_s h_{1/2}, 2\mu_s R)\, E_2(\mu_{canister}\, t_{canister})} \qquad [21d]$$

The key information that is needed to use Equation 21 is the linear attenuation coefficient for the RH-TRU waste matrix and the geometric dimensions for the RH-TRU canister. Several mass attenuation coefficients are presented in Table 4. As can be seen from this table, the mass attenuation coefficient is fairly similar for a wide variety of materials. Since the linear attenuation coefficient is comprised of the product of the mass attenuation

coefficient (not the mass energy-absorption coefficient) and the total mass density (see Equation 7b), Table 4 indicates that the driving component of the linear attenuation coefficient is the total mass density. For this study it was assumed that the gamma energy of interest is about 1.0 MeV. For this energy, the mass attenuation coefficient for most waste matrix materials would be expected to be on the order of 0.0595 $[cm^2/g]$ (see Table 4 for coefficients and note that the 0.0595 number corresponds to the minimum value of the various materials at 1.0 MeV). Also, as can be noted from Figures 5 and 7, the combined thickness of carbon steel (due to the drum wall and the RH-TRU canister wall) is *0.15 + 0.6350 = 0.7850 cm (this is for OPTION B loading of RH-TRU waste, for* OPTION A loading the combined thickness is 0.6350 cm.). With a specific gravity of 7.86 for carbon steel [Ref. CRC-1d] for which $\mu_{canister} t_{canister} = 0.3671$ mean free path lengths (this value is for OPTION B assuming $(\mu/\rho)^{steel} = 0.0595\ cm^2/g$ -- the value for OPTION A loading is 0.2970) we get a value of 0.4091296 for $E_2(\mu_{canister} t_{canister})$ (this value is for OPTION B -- the value for OPTION A loading is 0.46951977). Using the above information and the value of $\phi_s(max)$, Equation 21b can be simplified to the form in Equation 22 which only depends upon the total specific gravity (or density) of the RH-TRU waste matrix and correctly indicates that the internal gamma source term increases with increasing waste matrix density.

$$S_V(max)\ [dis/(s-cm^3] = \frac{(5.787E{+}08)(0.0595)\,sp.gr.^{waste}(max)}{(0.655)\,E_2(\mu_{canister} t_{canister})\,G(\mu_s h_{1/2}, 2\mu_s R)} \qquad [22a]$$

$$\approx \begin{cases} 1.1196E{+}08 \dfrac{sp.gr.^{waste}(max)}{G(\mu_s h_{1/2}, 2\mu_s R)} & (\textit{for RH-TRU loading Option A}) \\ 1.2849E{+}08 \dfrac{sp.gr.^{waste}(max)}{G(\mu_s h_{1/2}, 2\mu_s R)} & (\textit{for RH-TRU loading Option B}) \end{cases}$$

$$\approx \begin{cases} 1.1196E{+}08\, sp.gr.(max) & (\textit{if } sp.gr.^{waste} \geq 2) \\ \left[\dfrac{1.1196E{+}08\, sp.gr.(max)}{1-e^{-(c_1 sp.gr.(max)+c_2 sp.gr.^2(max))}}\right] & (\textit{if } 2 \geq sp.gr.^{waste} \geq 0) \end{cases} \quad \textit{Option A} \quad [22b]$$

$$\approx \begin{cases} 1.2849E{+}08\, sp.gr.(max) & (\textit{if } sp.gr.^{waste} \geq 2) \\ \left[\dfrac{1.2849E{+}08\, sp.gr.(max)}{1-e^{-(c_3 sp.gr.(max)+c_4 sp.gr.^2(max))}}\right] & (\textit{if } 2 \geq sp.gr.^{waste} \geq 0) \end{cases} \quad \textit{Option B}$$

The above equations yields the total gamma source term in units of (*disintegration/sec*); to convert this to curies, one must remember that 3.7E+10 (*dis/s*) is equal to 1 curie of activity. Rewriting Equation 22b in units of curies yields:

$$S_V(max)\,[\gamma curies/cm^3] = S_V(max)/3.7E{+}10 \qquad [22c]$$

$$\approx \begin{cases} 3.0260E{-}03\, sp.gr.(max) & (\textit{if } sp.gr.^{waste} \geq 2) \\ \left[\dfrac{3.0260E{-}03\, sp.gr.(max)}{1-e^{-(c_1 sp.gr.(max)+c_2 sp.gr.^2(max))}}\right] & (\textit{if } 2 \geq sp.gr.^{waste} \geq 0) \end{cases} \quad \textit{Option A}$$

$$\approx \begin{cases} 3.4727E{-}03\, sp.gr.(max) & (\textit{if } sp.gr.^{waste} \geq 2) \\ \left[\dfrac{3.4727E{-}03\, sp.gr.(max)}{1-e^{-(c_3 sp.gr.(max)+c_4 sp.gr.^2(max))}}\right] & (\textit{if } 2 \geq sp.gr.^{waste} \geq 0) \end{cases} \quad \textit{Option B}$$

$$S_V(max)\,[\gamma curies/canister] = S_V(max) \times Volume/3.7E{+}10 \qquad [22d]$$

$$= \begin{cases} 2.6932E{+}03\, sp.gr.(max) & (if\ \ sp.gr.^{waste} \geq 2) \qquad Option\ A \\ \left[\dfrac{2.6932E{+}03\, sp.gr.(max)}{1-e^{-(c_1 sp.gr.(max)+c_2 sp.gr.^2(max))}}\right] & (if\ \ 2 \geq sp.gr.^{waste} \geq 0) \end{cases}$$

$$= \begin{cases} 2.1704E{+}03\, sp.gr.(max) & (if\ \ sp.gr.^{waste} \geq 2) \qquad Option\ B \\ \left[\dfrac{2.1704E{+}03\, sp.gr.(max)}{1-e^{-(c_3 sp.gr.(max)+c_4 sp.gr.^2(max))}}\right] & (if\ \ 2 \geq sp.gr.^{waste} \geq 0) \end{cases}$$

The identification of the appropriate total mass density for the RH-TRU waste matrix requires an interrogation of the data in the WIPP Transuranic Waste Baseline Inventory Report (WTWBIR) Rev. 1 [Ref. BIR-1]. As can be seen in Table 6, the majority (79%) of the RH-TRU waste volume is in the "heterogeneous" waste form, of which 80% will come from the Hanford site. In Table 7 the heterogeneous waste form, along with the other waste forms, is further broken down according to its material composition. Unfortunately, the data reported in the WTWBIR is presented for partial densities (not total density as is needed). To further complicate the matter, there was not enough data presented to identify the statistical nature of the reported data (i.e., statistical variances are not presented). Only presented was the minimum, average (assumed to be the arithmetic *sampled* mean), and the maximum of the partial density of each material component. At this point, an "engineering" judgement is required. One's first inclination to determining a maximum total density would be to sum all the maximum partial densities of the RH-TRU waste matrix materials (i.e., sum-up the maximum values identified in column two of Table 7). However, it is not possible to have all maximum partial densities occur in the same waste matrix [Ref. Br-1]. Thus the plan-of-attack is to determine a statistically-based maximum total density. Not enough data is presented to allow one to identify the probability distribution function (pdf) (i.e., identify if the pdf is a "normal", "log-normal", or some other type of distribution) or calculate the statistical variance. Enough data is present, however, to identify an upper bound on the cumulative distribution function (cdf). This is done by applying the "maximum entropy formalism" which yields a distribution that maximizes the uncertainty [Refs. Ti-1 and Ti-2]. The maximizing distribution identified for this problem is the truncated exponential distribution function with a pdf given by Equation 23.

$$f(x) = \frac{\lambda e^{-\lambda x}}{e^{-\lambda a} - e^{-\lambda b}} \qquad [23]$$

where:

$\int f(x)\,dx$ = *probability that uncertain parameter X lies in interval [x,x+dx]*

λ = *a yet to be determined constant*

a = *minimum value of uncertain parameter X*

b = *maximum value of uncertain parameter X*

The corresponding cdf is given by:

$$F(x) = Pr\{X \leq x\} = \int_a^x f(s)\,ds \qquad [24]$$

= *probability that uncertain parameter* $X \leq x$

$$= \int_a^x \frac{\lambda e^{-\lambda x}}{e^{-\lambda a} - e^{-\lambda b}}\,dx = \frac{\lambda}{e^{-\lambda a} - e^{-\lambda b}} \int_a^x e^{-\lambda x}\,dx$$

Using Ref. CRC-1 yields:

$$F(x) = \frac{e^{-\lambda a} - e^{-\lambda x}}{e^{-\lambda a} - e^{-\lambda b}} = P = \textit{Percentile with range } (0 \le P \le 1) \qquad [25]$$

It's Equation 25 that we need to use to identify the percentiles of $F(x)$ (i.e., we can use Equation 25 to identify x_P for a given percentile, see Equation 26).

$$x_P = F^{-1}(P) = -\frac{1}{\lambda} \ln \left[e^{-\lambda a} - P\,(e^{-\lambda a} - e^{-\lambda b}) \right] \qquad [26]$$

Unfortunately, Equation 25 has the unknown constant λ. The trick to solving for this constant [Ref. Ti-1] is to determine the expression for the "population" mean value (also called the "expectation" value or more simply, *mean,* denoted by $[x]$) of the distribution in Equation 23 and equate it to the *sample mean* (denoted by $\hat{x}$) that is identified in the WTWBIR. The population mean, $[x]$, is defined by Equation 27.

$$[x] = \hat{x} = \int_a^b x\, f(x)\, dx \quad \textit{for a continuous distribution} \qquad [27]$$

$$= \int_a^b \frac{\lambda x e^{-\lambda x}}{e^{-\lambda a} - e^{-\lambda b}}\, dx = \frac{\lambda}{e^{-\lambda a} - e^{-\lambda b}} \int_a^b x\, e^{-\lambda x}\, dx$$

Using Ref. CRC-1b, Equation 27 can be integrated to yield:

$$[x] = \frac{1}{\lambda} + \frac{a\, e^{-\lambda a} - b\, e^{-\lambda b}}{e^{-\lambda a} - e^{-\lambda b}} \qquad [28]$$

The value of λ can now be solved for by finding the roots of the function $h(\lambda)$ given by:

$$h(\lambda) = \hat{x} - \frac{1}{\lambda} - \frac{a\, e^{-\lambda a} - b\, e^{-\lambda b}}{e^{-\lambda a} - e^{-\lambda b}} \qquad [29]$$

Using standard iteration techniques, the values of λ for most of the RH-TRU waste matrix materials (those identified with $a \neq \hat{x}$) were determined to five significant digits and are displayed in column three of Table 7. Also identified in columns 4 thru 6 in Table 7 are the values of the 68.26%, 95.44% and 99.74% percentiles [Ref. CRC-1c] (i.e., the x values corresponding to $F(x) \approx .6826$, .9544 and .9974), which correspond to the normal benchmarks of 1σ, 2σ, and 3σ. All of the statistical results calculated up to now correspond only to partial densities and not the maximum total density that is needed for determining the linear attenuation coefficient (remember Equation 21?). The engineering judgement made at this time is to sum-up partial densities in the following manner: 1) the maximum partial material density is identified for each waste matrix material, 2) percentile values for the non-maximum values are identified (for cases where minimum and average partial densities are equal it is not possible to calculate λ, in which case the maximum partial density is used for the percentile values), and 3) the total density is comprised of the sum of the non-maximum percentile values with the maximum value (see Equation 30).

$$\textit{total density (for F(68.26\%))} = \rho_{maximum} + \sum_{i \neq \max} \rho_i \qquad [30]$$

In Table 7 we have thus determined the following five total densities for each RH-TRU waste matrix: 1) the "average" total density, 2) the "F(68%.26)" total density (this corresponds to a 1σ value for the partial densities, with the exception of the maximum value which is added at full value), 3) the "F(95.44%)" total density (corresponding to a 2σ value), 4) the "F(99.74%)" total density (corresponding to a 3σ value), and 5) the "worst-case" total density (even though we previously identified that this case is not possible, it is included to provide an absolute upper-bound case). The maximum of each of the above described cases is displayed in Table 7 in bold, which shows that "heterogeneous" waste has the largest statistical values and the largest "worst-case" value and "solidified

inorganics" waste has the largest "average" value.

Now there is enough data to identify the internal source term of the RH-TRU waste matrix. Table 8 displays the dose rate and gamma density flux at the surface of the RH-TRU canister. In order to use Table 8 data to calculate the internal heat load, additional data is needed (i.e., the RH-TRU total heat-to-total curie load ratio and the RH-TRU total curie-to-total gamma curie ratio). The total heat-to-total curie load ratio is 0.003668 watts/curie and was obtained by calculating the heat load for each radionuclide, summing up these values, and then comparing to the sum of the total curie load from data reported in the WTWBIR [BIR-1d] (see footnote 1 of Table 9). The total curie-to-total gamma curie ratio is 1.01 and was obtained by comparing the total curie load to the sum of the calculated total gamma curie inventory load for each of the radionuclides (see footnote 1 of Table 10). There was a lot of work involved in generating Tables 9 and 10, and the major findings (such as average waste container heat loads, etc.,) can be found in the many footnotes at the end of the tables. With the conversion ratios calculated in Tables 9 and 10, the internal volumetric heat generation rates (source terms) can be calculated and are presented in Table 11. In this table, many various source terms (i.e., RH-TRU waste average value, 300 watt LWA limit, etc.,) were calculated and will be used as input for heat transfer calculations. As will be identified in the next section (heat transfer section), these case studies do not present a problem.

Table 6. Site RH-TRU Waste Anticipated Volumes *

Final Waste From	Site RH-TRU Anticipated Waste Volumes [m^3]					
	Site Name					
	ANL-W	BCLDP	BT	HAN	INEL	KAPL
Combustible						
Filter	2.98					
Graphite						
Heterogeneous	0.67	71.	1.557	**3,006.873**	16.434	36.46
Inorganic Non-metal						
Salt Waste					2.8	
Solidified Inorganics					2.1	
Solidified Organics						
Uncategorized Metals	8.532				9.71	
Unknown	23.736				11.13	
Lead/Cadmium Metal Waste	0.36				5.6	
Site Total	36.278	71.00	1.557	3006.873	47.774	36.46

	Site Name					
	LANL	ORNL	SRS		WIPP Total	WIPP %
Combustible	18.				18.	0.38
Filter					2.98	0.06
Graphite						
Heterogeneous		565.51	63.92		3,762.424	78.57
Inorganic Non-metal						
Salt Waste					2.8	0.06
Solidified Inorganics		785.00			787.1	16.44
Solidified Organics						
Uncategorized Metals	155.96				174.202	3.64
Unknown					34.866	0.73
Lead/Cadmium Metal Waste					5.96	0.12
Site Total	173.96	**1,350.51**	63.92		4,788.332	100.00 %

* Data from Ref. BIR-1b.

Table 7. Statistics for RH-TRU Waste Densities (a)

Materials		Waste Density [Kg/m^3]				
		Heterogeneous (78.6 vol%) a / $\hat{x}$ / b [min/ave/max]	Truncated Exponential Distribution (b)			
			λ [m^3/Kg]	Statistical Results F(68.26%)	F(95.44%)	F(99.74%)
Inorganic	Iron Based	0.0/108.5/1716.4	9.21657-1	1.2451+2	3.3503+2	6.4581+2
	Aluminum Based	0.0/23.0/263.0	4.34728-2	2.6397+1	7.1024+1	1.3682+2
	Other Metals	0.0/0.2/500.0	4.99999+0	2.2952-1	6.1757-1	1.1905+0
	Other Inorganics	0.0/38.6/**2000.0**	NC (c)	**2000.0**(d)	**2000.0**(d)	**2000.0**(d)
Organics	Cellulose	0.0/34.3/961.5	2.91545-2	3.9362+1	1.0591+2	2.0416+2
	Rubber	0.0/5.9/163.5	1.69491-1	6.7708+0	1.8218+1	3.5118+1
	Plastics	0.0/30.7/550.0	3.25732-2	3.5231+1	9.4797+1	1.8273+2
Solidified	Inorganic	0.0/0.1/15.0	9.99999+0	1.1476-1	3.0879-1	5.9522-1
Materials	Organic	0.0/0.0/3.0	NP	3.0(d)	3.0(d)	3.0(d)
Soils		0.0/2.3/193.0	4.34783-1	2.6395+0	7.1021+0	1.3690+1
	Total(ave)	243.6				
	Total(max)	**6,365.4**		**2,238.3**	**2,636.0**	**3,223.1**

		Solidified Inorganics (16.4 vol%) a / $\hat{x}$ / b [min/ave/max]	Truncated Exponential Distribution (b)			
			λ [m^3/Kg]	Statistical Results F(68.26%)	F(95.44%)	F(99.74%)
Inorganic	Iron Based	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Aluminum Based	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Other Metals	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Other Inorganics	0.0/1.1/528.8	9.09090-1	1.2624+0	3.3966+0	6.5475+0
Organics	Cellulose	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Rubber	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Plastics	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Solidified	Inorganic	173.1/792.2/1057.7	NC (c)	1057.7(d)	1057.7(d)	1057.7(d)
Materials	Organic	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Soils		0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Total(ave)	793.3				
	Total(max)	1,586.5		1,059.0	1,061.1	1,064.2

(a) Data from Ref. BIR-1c (ranked by volume percentages to be sent to WIPP).
(b) Statistical analysis perform with use of Equations 22 → 27.
(c) Maximum material partial density for final waste form.
(d) Value assign is material maximum, not calculated value.
NC Not computed because parameter is maximum partial density of material.
NP Not possible to compute because $a=\hat{x}$ (i.e., data does not correspond to a truncated exponential function).

Table 7 Continued. Statistics for RH-TRU Waste Densities (a)

Materials		Waste Density [Kg/m^3]				
		Uncategorized Metal (3.6 vol%) a / $\hat{x}$ / b [min/ave/max]	Truncated Exponential Distribution (b)			
			λ [m^3/Kg]	Statistical Results F(68.26%)	F(95.44%)	F(99.74%)
Inorganic	Iron Based	0.0/226.8/380.3	2.9133-19	3.8030+2	3.803+2	3.803+2
	Aluminum Based	0.0/2.2/141.4	4.54545-1	2.5247+0	6.7933+0	1.3095+1
	Other Metals	0.0/279.0/913.5	NC (c)	913.5(d)	913.5(d)	913.5(d)
	Other Inorganics	0.0/7.7/34.6	1.21617-1	9.1771+0	2.3161+1	3.3294+1
Organics	Cellulose	0.0/1.8/68.7	5.55555-1	2.0657+0	5.5581+0	1.0714+1
	Rubber	0.0/0.1/18.0	9.99999+0	1.1476-1	3.0878-1	5.9522-1
	Plastics	0.0/1.6/82.1	6.24999-1	1.8362+0	4.9406+0	9.5236+0
Solidified	Inorganic	0.0/0.0/3.7	NP	3.7(d)	3.7(d)	3.7(d)
Materials	Organic	0.0/0.0/3.7	NP	3.7(d)	3.7(d)	3.7(d)
Soils		0.0/0.0/2.9	NP	2.9(d)	2.9(d)	2.9(d)
	Total(ave)	519.2				
	Total(max)	1,648.9		1,318.8	1,344.9	1,371.3
		Unknown (0.73 vol%) a / $\hat{x}$ / b [min/ave/max]	Truncated Exponential Distribution (b)			
			λ [m^3/Kg]	Statistical Results F(68.26%)	F(95.44%)	F(99.74%)
Inorganic	Iron Based	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Aluminum Based	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Other Metals	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Other Inorganics	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Organics	Cellulose	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Rubber	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Plastics	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Solidified	Inorganic	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Materials	Organic	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Soils		0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Total(ave)	0.0				
	Total(max)	0.0		0.0	0.0	0.0

(a) Data from Ref. BIR-1c (ranked by volume percentages to be sent to WIPP).
(b) Statistical analyses performed with use of Equations 22 → 27.
(c) Maximum material partial density for final waste form.
(d) Value assign is material maximum, not calculated value.
NC Not computed because parameter is maximum partial density of material.
NP Not possible to compute because $a = \hat{x}$ (i.e., data does not correspond to a truncated exponential function).

Table 7 Continued. Statistics for RH-TRU Waste Densities (a)

Materials		Waste Density [Kg/m^3]				
		Combustible (0.38 vol%) a / $\hat{x}$ / b [min/ave/max]	Truncated Exponential Distribution (b)			
			λ [m^3/Kg]	Statistical Results F(68.26%)	F(95.44%)	F(99.74%)
Inorganic	Iron Based	254.0/257.7/265.2	NC (c)	265.2	265.2	265.2
	Aluminum Based	0.4/0.4/0.4	NP	0.4(d)	0.4(d)	0.4(d)
	Other Metals	18.8/18.8/89.7	NP	89.7(d)	89.7(d)	89.7(d)
	Other Inorganics	6.8/6.8/6.8	NP	6.8(d)	6.8(d)	6.8(d)
Organics	Cellulose	59.2/64.0/68.7	1.40200-9	6.5685+1	6.8267+1	6.8675+1
	Rubber	1.0/1.1/1.2	1.01000-7	1.1365+0	1.1909+0	1.1995+0
	Plastics	4.9/5.3/5.7	1.02010-8	5.4461+0	5.6635+0	5.6979+0
Solidified	Inorganic	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Materials	Organic	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Soils		0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Total(ave) Total(max)	354.1 437.7		434.4	437.2	437.7
		Lead/Cadmium Metal Waste (0.12 vol%) a / $\hat{x}$ / b [min/ave/max]	Truncated Exponential Distribution (b)			
			λ [m^3/Kg]	Statistical Results F(68.26%)	F(95.44%)	F(99.74%)
Inorganic	Iron Based	0.0/12.0/256.1	8.33333-2	1.3771+1	3.7054+1	7.1427+1
	Aluminum Based	0.0/1.3/27.8	7.69230-1	1.4919+0	4.0142+0	7.7379+0
	Other Metals	0.0/43.6/109.6	1.14806-2	5.8419+1	1.0013+2	1.0903+2
	Other Inorganics	1.2/165.7/754.8	NC (c)	754.8(d)	754.8(d)	754.8(d)
Organics	Cellulose	0.0/7.7/45.3	1.27539-1	8.9459+0	2.3719+1	4.0531+1
	Rubber	0.0/92.3/190.4	9.60477-4	1.2611+2	1.8092+2	1.8986+2
	Plastics	0.0/15.1/67.6	6.19505-2	1.8006+1	4.5391+1	6.5084+1
Solidified	Inorganic	0.0/5.9/619.2	1.69491-1	6.7708+0	1.8218+1	3.5118+1
Materials	Organic	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Soils		0.0/0.4/1.2	1.79093+0	5.1586-1	1.0343+0	1.1891+0
	Total(ave) Total(max)	344.0 2,072.0		988.8	1,165.3	1,274.8

(a) Data from Ref. BIR-1c (ranked by volume percentages to be sent to WIPP).
(b) Statistical analysis perform with use of Equations 22 → 27.
(c) Maximum material partial density for final waste form.
(d) Value assign is material maximum, not calculated value.
NC Not computed because parameter is maximum partial density of material.
NP Not possible to compute because $a=\hat{x}$ (i.e., data does not correspond to a truncated exponential function).

Table 7 Continued. Statistics for RH-TRU Waste Densities (a)

Materials		Waste Density $[Kg/m^3]$				
		Filter (0.06 vol%) a / $\hat{x}$ / b [min/ave/max]	Truncated Exponential Distribution (b)			
			λ $[m^3/Kg]$	Statistical Results F(68.26%)	F(95.44%)	F(99.74%)
Inorganic	Iron Based	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Aluminum Based	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Other Metals	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Other Inorganics	214.9/232.5/241.2	NC (c)	241.2(d)	241.2(d)	241.2(d)
Organics	Cellulose	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Rubber	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Plastics	8.8/8.8/8.8	NP	8.8(d)	8.8(d)	8.8(d)
Solidified	Inorganic	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Materials	Organic	0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
Soils		0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Total(ave) Total(max)	241.3 250.0		250.0	250.0	250.0
		Salt Waste (0.06 vol%) a / $\hat{x}$ / b [min/ave/max]	Truncated Exponential Distribution (b)			
			λ $[m^3/Kg]$	Statistical Results F(68.26%)	F(95.44%)	F(99.74%)
Inorganic	Iron Based	3.7/20.1/28.6	1.30100-12	2.0697+1	2.7465+1	2.8535+1
	Aluminum Based	0.0/0.2/3.1	4.99998+0	2.2952-1	6.1757-1	1.1904+0
	Other Metals	1.6/8.4/16.9	4.38995-2	1.0855+1	1.5927+1	1.6843+1
	Other Inorganics	106.3/239.2/591.1	NC (c)	591.1(d)	591.1(d)	591.1(d)
Organics	Cellulose	0.0/1.0/3.8	8.7642-1	1.2248+0	2.8855+0	3.7227+0
	Rubber	0.0/0.0/0.8	NP	0.8(d)	0.8(d)	0.8(d)
	Plastics	1.1/1.9/5.2	1.20560+0	2.0393+0	3.5458+0	4.9438+0
Solidified	Inorganic	0.0/0.0/0.4	NP	0.4(d)	0.4(d)	0.4(d)
Materials	Organic	0.0/0.0/0.4	NP	0.4(d)	0.4(d)	0.4(d)
Soils		0.0/0.0/0.0	NP	0.0(d)	0.0(d)	0.0(d)
	Total(ave) Total(max)	270.8 650.3		627.7	643.1	647.9

(a) Data from Ref. BIR-1c (ranked by volume percentages to be sent to WIPP).
(b) Statistical analysis perform with use of Equations 22 → 27.
(c) Maximum material partial density for final waste form.
(d) Value assign is material maximum, not calculated value.
NC Not computed because parameter is maximum partial density of material.
NP Not possible to compute because $a=\hat{x}$ (i.e., data does not correspond to a truncated exponential function).

Table 8. RH-TRU Surface Dose and Gamma Flux Rates

Variable	Corresponding Result (a)	
	Conventional Units	SI Units
$\dot{H}$ (b)	1000.0 [*rem/hr*]	10. [*Sv/hr*]
Q (c)	1.0	1.0
$\dot{D}$ (d)	1000.0 [*rad/hr*]	10. [*Gy/hr*]
f (e)	0.93643	0.93643
$\dot{X}$ (f)	~ 1067.9 [*R/hr*]	~ 0.276 [*coul/kg–hr*] (i)
C_p (g)	1.8452*E*–6	1.8452*E*–6
ϕ_s (h)	~ 5.787*E*+08 [γ/cm^2–*sec*] (j)	~ 5.787*E*+08 [γ/cm^2–*sec*]

(a) Results in this table correspond to steps 1 → 4 of Table 1.
(b) Maximum RH-TRU canister surface dose rate allowed by Ref. LWA-1.
(c) Value from Table 2.
(d) Calculated via Equation 1.
(e) Calculated via Equation 3b using Table 3, assuming $E_\gamma = 1.0\,MeV$.
(f) Calculated via Equation 2.
(g) Calculated via Equation 3c using Table 3, assuming $E_\gamma = 1.0\,MeV$.
(h) Calculated via Equation 4.
(i) There isn't a SI conversion for Roentgen, mks equivalent is given.
(j) Note, this is a very large gamma flux, very dangerous radiation field.

Table 9. Disposal Radionuclide Inventory

Nuclide		WIPP TRU Waste					
ID	Energy [*MeV/dis*] (a)	Total Inventory [Curies] (b)		Heat Load [Watts] (c)		% Heat Load [%]	
		CH	RH	CH	RH	CH	RH
Ac225	5.893E+00	2.030E+00	3.280E-01	7.09E-02	1.15E-02	8.39E-05	1.48E-04
Ac227	8.169E-02	6.550E-01	1.520E-02	3.17E-04	7.36E-06	3.75E-07	9.51E-08
Ac228	1.458E+00	5.270E-01	4.080E-03	4.55E-03	3.53E-05	5.39E-06	4.56E-07
Ag109m	8.696E-02	4.850E+01	NR	2.50E-02	--	2.96E-05	--
Ag110	1.212E+00	5.610E-06	1.070E-05	4.03E-08	7.69E-08	4.77E-11	9.93E-10
Ag110m	2.817E+00	4.210E-04	8.060E-04	7.03E-06	1.35E-05	8.32E-09	1.74E-07
Am241	5.604E+00	2.230E+05	5.300E+02	7.41E+03	1.76E+01	8.76E+00	2.28E-01
Am242	1.915E-01	4.930E-02	NR	5.60E-05	--	6.62E-08	--
Am242m	6.664E-02	4.960E-02	NR	1.96E-05	--	2.32E-08	--
Am243	5.423E+00	2.940E+01	1.220E-02	9.45E-01	3.92E-04	1.12E-03	5.07E-06
Am245	3.130E-01	9.070E-09	2.520E-14	1.68E-11	4.68E-17	1.99E-14	6.04E-19
At217	7.199E+00	2.030E+00	3.280E-01	8.66E-02	1.40E-02	1.02E-04	1.81E-04
Ba137m	6.624E-01	5.030E+03	3.100E+05	1.98E+01	1.22E+03	2.34E-02	1.57E+01
Bi210	3.890E-01	1.010E+00	4.090E-11	2.33E-03	9.43E-14	2.75E-06	1.22E-15
Bi211	6.729E+00	6.570E-01	1.460E-02	2.62E-02	5.82E-04	3.10E-05	7.53E-06
Bi212	2.869E+00	2.770E+01	9.030E+00	4.71E-01	1.54E-01	5.57E-04	1.98E-03
Bi213	7.092E-01	2.030E+00	3.280E-01	8.53E-03	1.38E-03	1.01E-05	1.78E-05
Bi214	2.162E+00	5.840E+00	7.230E-10	7.48E-02	9.27E-12	8.85E-05	1.20E-13
Bk249	1.250E-01	6.250E-04	1.740E-09	4.63E-07	1.29E-12	5.48E-10	1.67E-14
Bk250	1.172E+00	2.350E-06	NR	1.63E-08	--	1.93E-11	--
C14	4.947E-02	1.830E+01	1.510E+02	5.37E-03	4.43E-02	6.35E-06	5.72E-04
Cd109	1.960E-02	4.850E+01	NR	5.64E-03	--	6.66E-06	--
Cd113m	2.840E-01	4.650E-05	2.360E-05	7.83E-08	3.97E-08	9.26E-11	5.13E-10
Ce144	1.119E-01	8.220E+01	5.580E+02	5.45E-02	3.70E-01	6.45E-05	4.78E-03
Cf249	7.806E+00	1.560E+00	8.110E-02	7.22E-02	3.75E-03	8.54E-05	4.85E-05
Cf250	6.267E+00	3.540E-01	NR	1.32E-02	--	1.56E-05	--
Cf251	6.027E+00	3.930E-03	NR	1.40E-04	--	1.66E-07	--
Cf252	1.204E+01	1.850E+02	5.110E+01	1.32E+01	3.65E+00	1.56E-02	4.71E-02
Cm242	6.216E+00	1.480E-02	NR	5.45E-04	--	6.45E-07	--
Cm243	6.189E+00	1.330E+00	2.010E+03	4.88E-02	7.37E+01	5.77E-05	9.53E-01
Cm244	5.901E+00	5.400E+03	1.070E+04	1.89E+02	3.74E+02	2.23E-01	4.84E+00
Cm245	5.598E+00	5.160E+01	1.320E-05	1.71E+00	4.38E-07	2.03E-03	5.66E-09
Cm246	5.523E+00	1.100E-01	NR	3.60E-03	--	4.26E-06	--
Cm247	2.390E+00	2.980E-09	NR	4.22E-11	--	4.99E-14	--
Cm248	2.100E+01	5.060E-02	2.340E-03	6.30E-03	2.91E-04	7.45E-06	3.76E-06
Co58	1.009E+00	5.500E-05	7.920E-07	3.29E-07	4.74E-09	3.89E-10	6.12E-11
Co60	2.601E+00	1.530E+02	1.080E+04	2.36E+00	1.67E+02	2.79E-03	2.15E+00
Cr51	3.620E-02	NR	2.540E-31	--	5.45E-35	--	7.04E-37
Cs134	1.717E+00	5.880E+00	2.150E+03	5.98E-02	2.19E+01	7.08E-05	2.83E-01
Cs135	5.630E-02	7.900E-03	4.580E-03	2.64E-06	1.53E-06	3.12E-09	1.98E-08

Table 9 Continued. Disposal Radionuclide Inventory

Nuclide		WIPP TRU Waste					
ID	Energy [*MeV/dis*] (a)	Total Inventory [Curies] (b)		Heat Load [Watts] (c)		% Heat Load [%]	
		CH	RH	CH	RH	CH	RH
Cs137	1.866E-01	5.320E+03	3.280E+05	5.88E+00	3.63E+02	6.96E-03	4.69E+00
Es254	6.623E+00	2.350E-06	NR	9.23E-08	--	1.09E-10	--
Eu150	1.540E+00	3.650E-05	NR	3.33E-07	--	3.94E-10	--
Eu152	1.276E+00	7.410E+00	5.280E+04	5.61E-02	3.99E+02	6.63E-05	5.16E+00
Eu154	1.509E+00	3.050E+01	2.760E+04	2.73E-01	2.47E+02	3.23E-04	3.19E+00
Eu155	1.227E-01	4.140E+01	6.780E+03	3.01E-02	4.93E+00	3.56E-05	6.37E-02
Fe55	5.700E-03	3.296E-05	1.440E+01	1.11E-09	4.87E-04	1.32E-12	6.29E-06
Fe59	1.306E+00	1.960E-02	4.040E-19	1.52E-04	3.13E-21	1.79E-07	4.04E-23
Fr221	6.511E+00	2.030E+00	3.280E-01	7.84E-02	1.27E-02	9.27E-05	1.64E-04
Fr223	4.381E-01	9.040E-03	2.100E-04	2.35E-05	5.45E-07	2.78E-08	7.05E-09
H3	5.608E-03	9.640E-01	8.230E+01	3.20E-05	2.74E-03	3.79E-08	3.54E-05
I129	7.804E-02	1.280E-09	NR	5.92E-13	--	7.00E-16	--
Kr85	2.527E-01	2.240E-01	9.580E+01	3.36E-04	1.44E-01	3.97E-07	1.85E-03
Mn54	8.398E-01	1.120E-02	2.760E+00	5.58E-05	1.37E-02	6.59E-08	1.78E-04
Nb95	8.092E-01	4.960E-01	9.900E+00	2.38E-03	4.75E-02	2.81E-06	6.14E-04
Nb95m	2.344E-01	1.660E-03	3.410E-02	2.31E-06	4.74E-05	2.73E-09	6.12E-07
Ni59	6.700E-03	3.380E-03	NR	1.34E-07	--	1.59E-10	--
Ni63	1.700E-02	4.190E-01	5.030E+01	4.22E-05	5.07E-03	4.99E-08	6.55E-05
Np237	5.156E+00	8.820E+01	1.180E-02	2.70E+00	3.61E-04	3.19E-03	4.66E-06
Np238	8.080E-01	2.480E-04	NR	1.19E-06	--	1.40E-09	--
Np239	4.078E-01	2.940E+01	1.220E-02	7.11E-02	2.95E-05	8.41E-05	3.81E-07
Np240	1.788E+00	1.100E-09	1.780E-13	1.17E-11	1.89E-15	1.38E-14	2.44E-17
Np240m	9.776E-01	1.000E-06	1.620E-10	5.80E-09	9.39E-13	6.85E-12	1.21E-14
Pa231	5.083E+00	4.080E-03	1.780E-01	1.23E-04	5.36E-03	1.45E-07	6.93E-05
Pa233	3.829E-01	3.320E+01	1.180E-02	7.54E-02	2.68E-05	8.91E-05	3.46E-07
Pa234	2.423E+00	2.440E-02	1.700E-02	3.50E-04	2.44E-04	4.15E-07	3.16E-06
Pa234m	8.337E-01	1.880E+01	1.310E+01	9.29E-02	6.47E-02	1.10E-04	8.37E-04
Pb209	1.940E-01	2.030E+00	3.280E-01	2.33E-03	3.77E-04	2.76E-06	4.87E-06
Pb210	3.908E-02	1.010E+00	4.090E-11	2.34E-04	9.48E-15	2.77E-07	1.22E-16
Pb211	5.055E-01	6.570E-01	1.460E-02	1.97E-03	4.38E-05	2.33E-06	5.65E-07
Pb212	3.212E-01	2.770E+01	9.030E+00	5.27E-02	1.72E-02	6.24E-05	2.22E-04
Pb214	5.380E-01	5.840E+00	7.230E-10	1.86E-02	2.31E-12	2.20E-05	2.98E-14
Pd107	1.000E-02	1.170E-03	6.770E-04	6.94E-08	4.01E-08	8.20E-11	5.19E-10
Pm147	6.051E-02	1.260E+03	4.100E+03	4.52E-01	1.47E+00	5.35E-04	1.90E-02
Po210	5.408E+00	8.920E-01	3.050E-11	2.86E-02	9.78E-13	3.38E-05	1.26E-14
Po211	7.592E+00	1.790E-03	3.980E-05	8.06E-05	1.79E-06	9.53E-08	2.31E-08
Po212	8.940E+00	1.780E+01	5.780E+00	9.43E-01	3.06E-01	1.12E-03	3.96E-03
Po213	8.537E+00	1.990E+00	3.210E-01	1.01E-01	1.62E-02	1.19E-04	2.10E-04

Table 9 Continued. Disposal Radionuclide Inventory

Nuclide		WIPP TRU Waste					
ID	Energy [*MeV/dis*] (a)	Total Inventory [Curies] (b)		Heat Load [Watts] (c)		% Heat Load [%]	
		CH	RH	CH	RH	CH	RH
Po214	7.833E+00	5.840E+00	7.230E-10	2.71E-01	3.36E-11	3.21E-04	4.34E-13
Po215	7.531E+00	6.570E-01	1.460E-02	2.93E-02	6.52E-04	3.47E-05	8.42E-06
Po216	6.906E+00	2.770E+01	9.030E+00	1.13E+00	3.70E-01	1.34E-03	4.78E-03
Po218	6.113E+00	5.840E+00	7.230E-10	2.12E-01	2.62E-11	2.50E-04	3.39E-13
Pr144	1.240E+00	8.220E+01	5.580E+02	6.04E-01	4.10E+00	7.15E-04	5.30E-02
Pu236	5.871E+00	1.690E-02	NR	5.88E-04	–	6.96E-07	–
Pu238	5.591E+00	**1.890E+06** (e)	3.530E+03	6.26E+04	1.17E+02	**7.41E+01** (g)	1.51E+00
Pu239	5.199E+00	3.850E+05	6.410E+03	1.19E+04	1.98E+02	1.40E+01	2.55E+00
Pu240	5.253E+00	7.220E+04	1.740E+02	2.25E+03	5.42E+00	2.66E+00	7.00E-02
Pu241	5.230E-03	1.010E+06	9.060E+02	3.13E+01	2.81E-02	3.70E-02	3.63E-04
Pu242	4.982E+00	1.270E+03	1.480E-02	3.75E+01	4.37E-04	4.44E-02	5.65E-06
Pu243	1.947E-01	2.980E-09	NR	3.44E-12	–	4.07E-15	–
Pu244	4.892E+00	1.000E-06	1.620E-10	2.90E-08	4.70E-12	3.43E-11	6.07E-14
Ra223	6.007E+00	6.570E-01	1.460E-02	2.34E-02	5.20E-04	2.77E-05	6.72E-06
Ra224	5.790E+00	2.770E+01	9.030E+00	9.51E-01	3.10E-01	1.12E-03	4.00E-03
Ra225	1.183E-01	2.040E+00	3.310E-01	1.43E-03	2.32E-04	1.69E-06	3.00E-06
Ra226	4.871E+00	5.840E+00	7.230E-10	1.69E-01	2.09E-11	1.99E-04	2.70E-13
Ra228	1.300E-02	5.270E-01	4.080E-03	4.06E-05	3.14E-07	4.80E-08	4.06E-09
Rh106	1.618E+00	4.020E+01	8.420E+02	3.86E-01	8.08E+00	4.56E-04	1.04E-01
Rn219	7.000E+00	6.570E-01	1.460E-02	2.73E-02	6.06E-04	3.22E-05	7.83E-06
Rn220	6.405E+00	2.770E+01	9.030E+00	1.05E+00	3.43E-01	1.24E-03	4.43E-03
Rn222	5.590E+00	5.840E+00	7.230E-10	1.94E-01	2.40E-11	2.29E-04	3.10E-13
Ru106	1.003E-02	4.020E+01	8.420E+02	2.39E-03	5.01E-02	2.83E-06	6.47E-04
Sb125	5.274E-01	1.580E+01	2.460E+03	4.94E-02	7.69E+00	5.84E-05	9.94E-02
Sb126	3.117E+00	2.130E-03	1.230E-03	3.94E-05	2.27E-05	4.65E-08	2.94E-07
Sb126m	2.148E+00	1.520E-02	8.850E-03	1.94E-04	1.13E-04	2.29E-07	1.46E-06
Se79	4.200E-02	6.860E-03	3.970E-03	1.71E-06	9.88E-07	2.02E-09	1.28E-08
Sm151	1.978E-02	2.500E+01	1.420E+01	2.93E-03	1.67E-03	3.47E-06	2.15E-05
Sn119m	8.720E-02	6.800E-03	1.370E-02	3.52E-06	7.08E-06	4.16E-09	9.15E-08
Sn121m	3.380E-01	4.820E-01	2.690E-01	9.66E-04	5.39E-04	1.14E-06	6.96E-06
Sn126	2.104E-01	1.520E-02	8.800E-03	1.90E-05	1.10E-05	2.24E-08	1.42E-07
Sr90	1.958E-01	4.070E+03	**6.680E+05** (f)	4.72E+00	7.75E+02	5.59E-03	1.00E+01
Ta182	5.000E-01	NR	1.720E-04	–	5.10E-07	–	6.59E-09
Tc99	8.460E-02	2.460E+01	2.280E-01	1.23E-02	1.14E-04	1.46E-05	1.48E-06
Te125m	1.418E-01	6.550E-04	1.010E+03	5.51E-07	8.49E-01	6.51E-10	1.10E-02
Te127	2.278E-01	3.070E-02	1.130E-01	4.15E-05	1.53E-04	4.90E-08	1.97E-06
Te127m	9.074E-02	3.150E-02	1.150E-01	1.69E-05	6.19E-05	2.00E-08	7.99E-07

Table 9 Continued. Disposal Radionuclide Inventory

Nuclide		WIPP TRU Waste					
ID	Energy [*MeV/dis*] (a)	Total Inventory [Curies] (b)		Heat Load [Watts] (c)		% Heat Load [%]	
		CH	RH	CH	RH	CH	RH
Th227	6.157E+00	6.560E-01	1.480E-02	2.39E-02	5.40E-04	2.83E-05	6.98E-06
Th228	5.517E+00	2.770E+01	9.040E+00	9.06E-01	2.96E-01	1.07E-03	3.82E-03
Th229	5.161E+00	2.050E+00	3.360E-01	6.27E-02	1.03E-02	7.42E-05	1.33E-04
Th230	4.774E+00	4.900E-02	8.790E-07	1.39E-03	2.49E-08	1.64E-06	3.21E-10
Th231	9.466E-02	2.880E+00	2.210E+03	1.62E-03	1.24E+00	1.91E-06	1.60E-02
Th232	4.084E+00	6.070E-01	7.090E-03	1.47E-02	1.72E-04	1.74E-05	2.22E-06
Th234	6.840E-02	1.880E+01	1.310E+01	7.62E-03	5.31E-03	9.02E-06	6.86E-05
Tl207	4.954E-01	6.560E-01	1.450E-02	1.93E-03	4.26E-05	2.28E-06	5.50E-07
Tl208	3.970E+00	9.960E+00	3.240E+00	2.34E-01	7.63E-02	2.77E-04	9.85E-04
Tl209	2.803E+00	4.390E-02	7.080E-03	7.29E-04	1.18E-04	8.63E-07	1.52E-06
Tl210	--(d)	1.230E-03	1.520E-13	--	--	--	--
U232	5.416E+00	2.630E+01	1.160E+01	8.44E-01	3.72E-01	9.99E-04	4.81E-03
U233	4.904E+00	1.380E+03	8.570E+02	4.01E+01	2.49E+01	4.74E-02	3.22E-01
U234	4.859E+00	2.500E+02	4.180E-02	7.20E+00	1.20E-03	8.52E-03	1.56E-05
U235	4.418E+00	2.880E+00	5.660E+00	7.54E-02	1.48E-01	8.92E-05	1.92E-03
U236	4.570E+00	1.340E-01	4.110E-05	3.63E-03	1.11E-06	4.29E-06	1.44E-08
U237	3.192E-01	2.470E+01	2.220E-02	4.67E-02	4.20E-05	5.53E-05	5.43E-07
U238	4.279E+00	1.880E+01	1.310E+01	4.77E-01	3.32E-01	5.64E-04	4.29E-03
U240	1.384E-01	1.000E-06	1.620E-10	8.20E-10	1.33E-13	9.70E-13	1.72E-15
Y90	9.350E-01	4.070E+03	**6.680E+05** (f)	2.26E+01	3.70E+03	2.67E-02	**4.78E+01** (h)
Zn65	5.904E-01	1.210E-08	NR	4.23E-11	--	5.01E-14	--
Zr93	1.960E-02	8.870E-02	5.140E-02	1.03E-05	5.97E-06	1.22E-08	7.72E-08
Zr95	8.545E-01	2.240E-01	4.600E+00	1.13E-03	2.33E-02	1.34E-06	3.01E-04
Sum =		**3.61E+06** (i)	**2.11E+06** (j)	**8.46E+04** (k)	**7.74E+03** (l)	1.00E+02	1.00E+02

-- Not calculated.
NR Not Reported by sites (see Ref. BIR-1d).
(a) Data from Ref Or-1.
(b) Data from Ref BIR-1d.
(c) Data calculated from the equation;

$$\text{Heat Load} = TOTAL\ ACTIVITY(Ci)\frac{3.7E+10(dis/sec)}{Ci}\ ENERGY(MeV/dis)\ \frac{E+06\,eV}{MeV}\ \frac{1.60219E-19\,J}{eV}\ \frac{watt-sec}{J}$$

$$\text{Heat Load (watts)} = 0.005928103 \times TOTAL\ ACTIVITY(Ci) \times ENERGY(MeV/dis)$$

(d) Disintegration energy not available in Ref. Or-1.
(e) Max total curie load for CH-TRU wastes.
(f) Max total curie load for RH-TRU wastes.
(g) Max heat load for CH-TRU wastes.
(h) Max heat load for RH-TRU wastes.
(i) Note, the total CH-TRU curie load is only 3.61 MCi (also, 63.1 % of the total curie load in WIPP).
The average CH-TRU volumetric total curie load is 3.61E+06/5.95E+06 = 0.607 (Ci/cu. ft.) = **21.43** (Ci/cu. m.).
[See discussion note on Ref. LWA-1 for volumes -- CH→5.95E+06 cu. ft. Also note that the 5.95E+06 volume number is a volume limit, stored waste and projected waste volumes sum up to a volume less than this volume.

The summed up volume is then "scaled" to yield a total volume of 5.95E+06. likewise the curie loads are also "scaled" by the same factor. Thus ratios of curie loads (or heat loads) to volume yield values applicable to expected waste at WIPP (See Ref. BIR-1e).]

(j) Note, the total RH-TRU curie load is only 2.11 MCi (also, 36.9 % of the total curie load in WIPP).
This curie load is much less than the RH-TRU limit of 5.1 MCi [Ref. LWA-1].
The average RH-TRU volumetric total curie load is 2.11E+06/0.25E+06 = 8.440 (Ci/cu. ft.) = **298.1 (Ci/cu. m.)**.
[See discussion note on Ref. LWA-1 for volumes -- RH→0.25E+06 cu. ft.]

(k) Note, the total CH-TRU heat load is only **84.6 kW** (also, 91.6 % of the total heat load in WIPP).
The ratio for CH-TRU of total heat load to total curie load is 84.6E+03/3.61E+06 = **0.02343**.
The average CH-TRU volumetric heat load is 84.6E+03/5.95E+06 = 0.0142 (W/cu. ft.) = 0.502 (W/cu. m.).
The average CH-TRU drum heat load is 0.502 (W/cu. m.)x 0.2082 (cu. m.) = **0.1045 W**.
[The volume of a CH-TRU drum was set equal to the nominal volume of a 55-gal drum.]

(l) Note, the total RH-TRU heat load is only 7.74 kW (also, 8.4 % of the total heat load in WIPP).
The ratio for RH-TRU of total heat load to total curie load is 7.74E+03/2.11E+06 = **0.003668**.
The average RH-TRU volumetric heat load is 7.74E+03/0.25E+06 = 0.0310 (W/cu. ft.) = 1.09 (W/cu. m.).
The average RH-TRU canister heat load is 1.09 (W/cu. m.)x 0.6246 (cu. m.) = **0.6808 W** (this is about ten times that of an average CH-TRU drum). [The volume of a RH-TRU canister was set equal to three times the nominal volume of a 55-gal drum. Even though the reported volume of a RH-TRU canister is 0.89 cu. m. [Ref. BIR-1f], these canisters are loaded with three 55-gal drums internally. Ref. Lo-1.]

Table 10. RH-TRU Waste Radionuclide Gamma Activity Ratios

Nuclide		WIPP TRU Waste					
ID	Gamma Activity Fraction (a)	Total Inventory [Curies] (b)		Gamma Inventory [Curies] (c)		% Gamma Inventory [%]	
		CH	RH	CH	RH	CH	RH
Ac225	0.000E+00	2.030E+00	3.280E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ac227	9.862E-01	6.550E-01	1.520E-02	6.46E-01	1.50E-02	6.27E-05	7.18E-07
Ac228	1.000E+00	5.270E-01	4.080E-03	5.27E-01	4.08E-03	5.11E-05	1.95E-07
Ag109m	1.000E+00	4.850E+01	NR	4.85E+01	--	4.70E-03	--
Ag110	1.000E+00	5.610E-06	1.070E-05	5.61E-06	1.07E-05	5.44E-10	5.13E-10
Ag110m	1.000E+00	4.210E-04	8.060E-04	4.21E-04	8.06E-04	4.08E-08	3.86E-08
Am241	0.000E+00	2.230E+05	5.300E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am242	1.000E+00	4.930E-02	NR	4.93E-02	--	4.78E-06	--
Am242m	9.950E-01	4.960E-02	NR	4.94E-02	--	4.79E-06	--
Am243	0.000E+00	2.940E+01	1.220E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Am245	1.000E+00	9.070E-09	2.520E-14	9.07E-09	2.52E-14	8.80E-13	1.21E-18
At217	0.000E+00	2.030E+00	3.280E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba137m	1.000E+00	5.030E+03	3.100E+05	5.03E+03	3.10E+05	4.88E-01	1.49E+01
Bi210	1.000E+00	1.010E+00	4.090E-11	1.01E+00	4.09E-11	9.80E-05	1.96E-15
Bi211	2.800E-03	6.570E-01	1.460E-02	1.84E-03	4.09E-05	1.79E-07	1.96E-09
Bi212	6.407E-01	2.770E+01	9.030E+00	1.78E+01	5.79E+00	1.72E-03	2.77E-04
Bi213	9.784E-01	2.030E+00	3.280E-01	1.99E+00	3.21E-01	1.93E-04	1.54E-05
Bi214	9.998E-01	5.840E+00	7.230E-10	5.84E+00	7.23E-10	5.66E-04	3.46E-14
Bk249	1.000E+00	6.250E-04	1.740E-09	6.25E-04	1.74E-09	6.06E-08	8.33E-14
Bk250	1.000E+00	2.350E-06	NR	2.35E-06	--	2.28E-10	--
C14	1.000E+00	1.830E+01	1.510E+02	1.83E+01	1.51E+02	1.78E-03	7.23E-03
Cd109	1.000E+00	4.850E+01	NR	4.85E+01	--	4.70E-03	--
Cd113m	1.000E+00	4.650E-05	2.360E-05	4.65E-05	2.36E-05	4.51E-09	1.13E-09
Ce144	1.000E+00	8.220E+01	5.580E+02	8.22E+01	5.58E+02	7.97E-03	2.67E-02
Cf249	0.000E+00	1.560E+00	8.110E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cf250	8.000E-04	3.540E-01	NR	2.83E-04	--	2.75E-08	--
Cf251	0.000E+00	3.930E-03	NR	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cf252	3.090E-02	1.850E+02	5.110E+01	5.72E+00	1.58E+00	5.55E-04	7.56E-05
Cm242	0.000E+00	1.480E-02	NR	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm243	2.400E-03	1.330E+00	2.010E+03	3.19E-03	4.82E+00	3.10E-07	2.31E-04
Cm244	0.000E+00	5.400E+03	1.070E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm245	0.000E+00	5.160E+01	1.320E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm246	3.000E-04	1.100E-01	NR	3.30E-05	--	3.20E-09	--
Cm247	0.000E+00	2.980E-09	NR	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm248	8.260E-02	5.060E-02	2.340E-03	4.18E-03	1.93E-04	4.05E-07	9.26E-09
Co58	1.000E+00	5.500E-05	7.920E-07	5.50E-05	7.92E-07	5.34E-09	3.79E-11
Co60	1.000E+00	1.530E+02	1.080E+04	1.53E+02	1.08E+04	1.48E-02	5.17E-01
Cr51	1.000E+00	NR	2.540E-31	--	2.54E-31	--	1.22E-35
Cs134	1.000E+00	5.880E+00	2.150E+03	5.88E+00	2.15E+03	5.70E-04	1.03E-01
Cs135	1.000E+00	7.900E-03	4.580E-03	7.90E-03	4.58E-03	7.66E-07	2.19E-07

Table 10 Continued. RH-TRU Waste Radionuclide Gamma Activity Ratios

Nuclide		WIPP TRU Waste					
ID	Gamma Activity Fraction (a)	Total Inventory [Curies] (b)		Gamma Inventory [Curies] (c)		% Gamma Inventory [%]	
		CH	RH	CH	RH	CH	RH
Cs137	1.000E+00	5.320E+03	3.280E+05	5.32E+03	3.28E+05	5.16E-01	1.57E+01
Es254	0.000E+00	2.350E-06	NR	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eu150	1.000E+00	3.650E-05	NR	3.65E-05	--	3.54E-09	--
Eu152	1.000E+00	7.410E+00	5.280E+04	7.41E+00	5.28E+04	7.19E-04	2.53E+00
Eu154	1.000E+00	3.050E+01	2.760E+04	3.05E+01	2.76E+04	2.96E-03	1.32E+00
Eu155	1.000E+00	4.140E+01	6.780E+03	4.14E+01	6.78E+03	4.02E-03	3.25E-01
Fe55	1.000E+00	3.296E-05	1.440E+01	3.30E-05	1.44E+01	3.20E-09	6.90E-04
Fe59	1.000E+00	1.960E-02	4.040E-19	1.96E-02	4.04E-19	1.90E-06	1.94E-23
Fr221	0.000E+00	2.030E+00	3.280E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fr223	9.999E-01	9.040E-03	2.100E-04	9.04E-03	2.10E-04	8.77E-07	1.01E-08
H3	1.000E+00	9.640E-01	8.230E+01	9.64E-01	8.23E+01	9.35E-05	3.94E-03
I129	1.000E+00	1.280E-09	NR	1.28E-09	--	1.24E-13	--
Kr85	1.000E+00	2.240E-01	9.580E+01	2.24E-01	9.58E+01	2.17E-05	4.59E-03
Mn54	1.000E+00	1.120E-02	2.760E+00	1.12E-02	2.76E+00	1.09E-06	1.32E-04
Nb95	1.000E+00	4.960E-01	9.900E+00	4.96E-01	9.90E+00	4.81E-05	4.74E-04
Nb95m	1.000E+00	1.660E-03	3.410E-02	1.66E-03	3.41E-02	1.61E-07	1.63E-06
Ni59	1.000E+00	3.380E-03	NR	3.38E-03	--	3.28E-07	--
Ni63	1.000E+00	4.190E-01	5.030E+01	4.19E-01	5.03E+01	4.06E-05	2.41E-03
Np237	0.000E+00	8.820E+01	1.180E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np238	1.000E+00	2.480E-04	NR	2.48E-04	--	2.41E-08	--
Np239	1.000E+00	2.940E+01	1.220E-02	2.94E+01	1.22E-02	2.85E-03	5.84E-07
Np240	1.000E+00	1.100E-09	1.780E-13	1.10E-09	1.78E-13	1.07E-13	8.53E-18
Np240m	1.000E+00	1.000E-06	1.620E-10	1.00E-06	1.62E-10	9.70E-11	7.76E-15
Pa231	0.000E+00	4.080E-03	1.780E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pa233	1.000E+00	3.320E+01	1.180E-02	3.32E+01	1.18E-02	3.22E-03	5.65E-07
Pa234	1.000E+00	2.440E-02	1.700E-02	2.44E-02	1.70E-02	2.37E-06	8.14E-07
Pa234m	1.000E+00	1.880E+01	1.310E+01	1.88E+01	1.31E+01	1.82E-03	6.27E-04
Pb209	1.000E+00	2.030E+00	3.280E-01	2.03E+00	3.28E-01	1.97E-04	1.57E-05
Pb210	1.000E+00	1.010E+00	4.090E-11	1.01E+00	4.09E-11	9.80E-05	1.96E-15
Pb211	1.000E+00	6.570E-01	1.460E-02	6.57E-01	1.46E-02	6.37E-05	6.99E-07
Pb212	1.000E+00	2.770E+01	9.030E+00	2.77E+01	9.03E+00	2.69E-03	4.33E-04
Pb214	1.000E+00	5.840E+00	7.230E-10	5.84E+00	7.23E-10	5.66E-04	3.46E-14
Pd107	1.000E+00	1.170E-03	6.770E-04	1.17E-03	6.77E-04	1.14E-07	3.24E-08
Pm147	1.000E+00	1.260E+03	4.100E+03	1.26E+03	4.10E+03	1.22E-01	1.96E-01
Po210	0.000E+00	8.920E-01	3.050E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po211	0.000E+00	1.790E-03	3.980E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po212	0.000E+00	1.780E+01	5.780E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po213	0.000E+00	1.990E+00	3.210E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 10 Continued. RH-TRU Waste Radionuclide Gamma Activity Ratios

Nuclide		WIPP TRU Waste					
ID	Gamma Activity Fraction (a)	Total Inventory [Curies] (b)		Gamma Inventory [Curies] (c)		% Gamma Inventory [%]	
		CH	RH	CH	RH	CH	RH
Po214	0.000E+00	5.840E+00	7.230E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po215	0.000E+00	6.570E-01	1.460E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po216	0.000E+00	2.770E+01	9.030E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po218	2.000E-04	5.840E+00	7.230E-10	1.17E-03	1.45E-13	1.13E-07	6.93E-18
Pr144	1.000E+00	8.220E+01	5.580E+02	8.22E+01	5.58E+02	7.97E-03	2.67E-02
Pu236	0.000E+00	1.690E-02	NR	0.00E+00	–	0.00E+00	–
Pu238	0.000E+00	**1.890E+06** (e)	3.530E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu239	0.000E+00	3.850E+05	6.410E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu240	0.000E+00	7.220E+04	1.740E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu241	1.000E+00	1.010E+06	9.060E+02	1.01E+06	9.06E+02	**9.80E+01** (g)	4.34E-02
Pu242	0.000E+00	1.270E+03	1.480E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu243	1.000E+00	2.980E-09	NR	2.98E-09	–	2.89E-13	–
Pu244	1.300E-03	1.000E-06	1.620E-10	1.30E-09	2.11E-13	1.26E-13	1.01E-17
Ra223	0.000E+00	6.570E-01	1.460E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra224	0.000E+00	2.770E+01	9.030E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra225	1.000E+00	2.040E+00	3.310E-01	2.04E+00	3.31E-01	1.98E-04	1.59E-05
Ra226	0.000E+00	5.840E+00	7.230E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ra228	1.000E+00	5.270E-01	4.080E-03	5.27E-01	4.08E-03	5.11E-05	1.95E-07
Rh106	1.000E+00	4.020E+01	8.420E+02	4.02E+01	8.42E+02	3.90E-03	4.03E-02
Rn219	0.000E+00	6.570E-01	1.460E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn220	0.000E+00	2.770E+01	9.030E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rn222	0.000E+00	5.840E+00	7.230E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ru106	1.000E+00	4.020E+01	8.420E+02	4.02E+01	8.42E+02	3.90E-03	4.03E-02
Sb125	1.000E+00	1.580E+01	2.460E+03	1.58E+01	2.46E+03	1.53E-03	1.18E-01
Sb126	1.000E+00	2.130E-03	1.230E-03	2.13E-03	1.23E-03	2.07E-07	5.89E-08
Sb126m	1.000E+00	1.520E-02	8.850E-03	1.52E-02	8.85E-03	1.47E-06	4.24E-07
Se79	1.000E+00	6.860E-03	3.970E-03	6.86E-03	3.97E-03	6.65E-07	1.90E-07
Sm151	1.000E+00	2.500E+01	1.420E+01	2.50E+01	1.42E+01	2.43E-03	6.80E-04
Sn119m	1.000E+00	6.800E-03	1.370E-02	6.80E-03	1.37E-02	6.60E-07	6.56E-07
Sn121m	1.000E+00	4.820E-01	2.690E-01	4.82E-01	2.69E-01	4.68E-05	1.29E-05
Sn126	1.000E+00	1.520E-02	8.800E-03	1.52E-02	8.80E-03	1.47E-06	4.22E-07
Sr90	1.000E+00	4.070E+03	6.680E+05	4.07E+03	6.68E+05	3.95E-01	**3.20E+01** (h)
Ta182	1.000E+00	NR	1.720E-04	--	1.72E-04	–	8.24E-09
Tc99	1.000E+00	2.460E+01	2.280E-01	2.46E+01	2.28E-01	2.39E-03	1.09E-05
Te125m	1.000E+00	6.550E-04	1.010E+03	6.55E-04	1.01E+03	6.35E-08	4.84E-02
Te127	1.000E+00	3.070E-02	1.130E-01	3.07E-02	1.13E-01	2.98E-06	5.41E-06
Te127m	1.000E+00	3.150E-02	1.150E-01	3.15E-02	1.15E-01	3.06E-06	5.51E-06

Table 10 Continued. RH-TRU Waste Radionuclide Gamma Activity Ratios

Nuclide		WIPP TRU Waste					
ID	Gamma Activity Fraction (a)	Total Inventory [Curies] (b)		Gamma Inventory [Curies] (c)		% Gamma Inventory [%]	
		CH	RH	CH	RH	CH	RH
Th227	0.000E+00	6.560E-01	1.480E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th228	0.000E+00	2.770E+01	9.040E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th229	0.000E+00	2.050E+00	3.360E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th230	0.000E+00	4.900E-02	8.790E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th231	1.000E+00	2.880E+00	2.210E+03	2.88E+00	2.21E+03	2.79E-04	1.06E-01
Th232	0.000E+00	6.070E-01	7.090E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th234	1.000E+00	1.880E+01	1.310E+01	1.88E+01	1.31E+01	1.82E-03	6.27E-04
Tl207	1.000E+00	6.560E-01	1.450E-02	6.56E-01	1.45E-02	6.36E-05	6.94E-07
Tl208	1.000E+00	9.960E+00	3.240E+00	9.96E+00	3.24E+00	9.66E-04	1.55E-04
Tl209	1.000E+00	4.390E-02	7.080E-03	4.39E-02	7.08E-03	4.25E-06	3.39E-07
Tl210	--(d)	1.230E-03	1.520E-13	--	--	--	--
U232	0.000E+00	2.630E+01	1.160E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U233	0.000E+00	1.380E+03	8.570E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U234	0.000E+00	2.500E+02	4.180E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U235	0.000E+00	2.880E+00	5.660E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U236	0.000E+00	1.340E-01	4.110E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U237	1.000E+00	2.470E+01	2.220E-02	2.47E+01	2.22E-02	2.40E-03	1.06E-06
U238	0.000E+00	1.880E+01	1.310E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U240	1.000E+00	1.000E-06	1.620E-10	1.00E-06	1.62E-10	9.70E-11	7.76E-15
Y90	1.000E+00	4.070E+03	**6.680E+05** (f)	4.07E+03	6.68E+05	3.95E-01	**3.20E+01** (h)
Zn65	1.000E+00	1.210E-08	NR	1.21E-08	--	1.17E-12	--
Zr93	1.000E+00	8.870E-02	5.140E-02	8.87E-02	5.14E-02	8.60E-06	2.46E-06
Zr95	1.000E+00	2.240E-01	4.600E+00	2.24E-01	4.60E+00	2.17E-05	2.20E-04
Sum =		**3.610E+06** (i)	**2.112E+06** (j)	**1.03E+06** (k)	**2.09E+06** (l)	1.00E+02	1.00E+02
% =				**28.551 %** (m)	**98.848 %** (n)		

-- Not calculated.
NR Not Reported by sites (see Ref. BIR-1d).
(a) Fraction of radionuclide disintegrations due to gammas only.
(γ fraction = 1 - (α, β, & n fractions).
α, β, and n fraction values from Ref Or-1.
(b) Data from Ref BIR-1d.
(c) Data calculated from the equation;
Gamma inventory(Ci) = $ACTIVITY(Ci) \times GAMMA\ FRACTION$
(d) Fraction values not available in Ref. Or-1.
(e) Max total curie load for CH-TRU wastes.
(f) Max total curie load for RH-TRU wastes.
(g) Max total gamma load for CH-TRU wastes.

(h) Max total gamma load for RH-TRU wastes.
(i) Note, the total CH-TRU curie load is only 3.61 MCi (also, 63.1 % of the total curie load in WIPP).
The average CH-TRU volumetric curie load is 3.61E+06/5.95E+06 = 0.607 (Ci/cu. ft.) = **21.43 (Ci/cu. m.)**.
[See discussion note on Ref. LWA-1 for volumes -- CH→5.95E+06 cu. ft.]
(j) Note, the total RH-TRU curie load is only 2.11 MCi (also, 36.9 % of the total curie load in WIPP).
This curie load is much less than the RH-TRU limit of 5.1 MCi [Ref. LWA-1].
The average RH-TRU volumetric curie load is 2.11E+06/0.25E+06 = 8.440 (Ci/cu. ft.) = **298.1 (Ci/cu. m.)**.
[See discussion note on Ref. LWA-1 for volumes -- RH→0.25E+06 cu. ft. Also note that the 5.95E+06 volume number is a volume limit, stored waste and projected waste volumes sum up to a volume less than this volume. The summed up volume is then "scaled" to yield a total volume of 5.95E+06, likewise the curie loads are also "scaled" by the same factor. Thus ratios of curie loads (or heat loads) to volume yield values applicable to expected waste at WIPP (see Ref. BIR-1e).]
(k) Note, the total CH-TRU gamma curie load is 1.031MCi (28.550912 % of the total curie load).
The ratio for CH-TRU of total curie load to gamma curie load is 3.61/1.031 = **3.50**.
The majority of the curie load of the CH-TRU is due to alpha and beta emitters.
The average CH-TRU volumetric gamma curie load is 1.03E+06/5.95E+06 = 0.173 (Ci/cu. ft.) = **6.113 (Ci/cu. m.)**.
[See discussion note on Ref. LWA-1 for volumes -- CH→5.95E+06 cu. ft.]
The average CH-TRU drum gamma curie load is 6.113 (Ci/cu. m.)x 0.2082 (cu. m.) = **1.273 Ci**.
[The volume of a CH-TRU drum was set equal to the nominal volume of a 55-gal drum.]
(l) Note, the total RH-TRU gamma curie load is 2.088MCi (98.848088 % of the total curie load).
The ratio for RH-TRU of total curie load to gamma curie load is 2.11/2.088 = **1.01**.
The vast majority of the curie load of the RH-TRU is due to gamma emitters.
Since gamma emitters tend to be short lived this means that the RH-TRU waste curie load should rapidly (within several hundred years) decay to low levels.
The average RH-TRU volumetric gamma curie load is 2.09E+06/0.25E+06 = 8.360 (Ci/cu. ft.) = **295.2 (Ci/cu. m.)**.
The average RH-TRU drum canister curie load is 295.2 (Ci/cu. m.)x 0.6246 (cu. m.) = **184.4 Ci**.
[The volume of a RH-TRU canister was set equal to three times the nominal volume of a 55-gal drum. Even though the reported volume of a RH-TRU canister is 0.89 cu. m. [Ref. BIR-1f], these canisters are loaded with three 55-gal drums internally. Ref. Lo-1.]
(m) Percent of total CH-TRU waste curie load due to gammas.
(n) Percent of total RH-TRU waste curie load due to gammas.

Table 11. Results of Shielding Calculations (RH-TRU Waste Matrix Only)

Case (a) Study	Total (b) Density [kg/m^3]	$S_v(\gamma)$ (c) [Ci(γ)/cm^3]		$S_v(total)$ (d) [Ci(total)/cm^3]	
		Option A	Option B	Option A	Option B
1) Maximum Ave (e)	793.3	2.463E-03	2.851E-03	2.489E-03	2.881E-03
2) F(68.26%) (e)	2,238.3	6.773E-03	7.773E-03	6.844E-03	7.855E-03
3) F(95.44%) (e)	2,636.0	7.977E-03	9.154E-03	8.061E-03	9.250E-03
4) F(99.74%) (e)	3,223.1	9.783E-03	1.123E-02	9.886E-03	1.135E-02
5) Worst Case (e)	6,365.4	1.926E-02	2.211E-02	1.946E-02	2.234E-02
6) 300 Watt Limit (f)	--	--	--	--	--
7) WIPP Ave	--	--	--	2.981E-04(g)	2.981E-04(g)
7b) WIPP Ave +/- 10%	--	--	--	3.279E-04(g)	3.279E-04(g)
7c) WIPP Ave +/- 100%	--	--	--	5.962E-04(g)	5.962E-04(g)
7d) WIPP Ave +/- 200%	--	--	--	8.943E-04(g)	8.943E-04(g)

(a) Results in this table correspond to steps 1 → 5 of Table 1.
(b) Values obtained from Table 7.
(c) Calculated using Equation 22c.
(d) $S_v(total) = 1.01\ S_v(\gamma)$
The total curie-to-total gamma curies ratio of 1.01 was calculated in footnote l of Table 10.
(e) See Table 7.
(f) 300 Watt limit from Ref. LWA-1.
(g) Calculated using footnote j in Table 10.

[3] **Heat Conduction Calculations**

The purpose of the heat transfer calculations is to identify if there is any significant temperature rise near the "worst-case" RH-TRU canister. Should there be a meaningful temperature increase rise, this could significantly affect thermally dependent properties. For instance, the solubility of actinides in WIPP brine could increase by about an order of magnitude for a temperature rise of ten degrees centigrade (assuming that solubility acts like many thermal-chemical properties that can be described by classical collision theory, where the collision frequency increases exponentially with increasing temperature and generally increases by an order of magnitude for each ten degree increase in temperature). The heat transfer problem was addressed by solving a simple steady-state solution. This approach would be realistic if the heat source term was constant for all time. However, the true heat source decreases with time (in fact the heat and curie loads of RH-TRU waste eventually decay to values less than that of CH-TRU waste -- see Ref. DOE-1) and performing steady-state calculations yield very conservative results. Since the volumetric heat loads identified in Table 11 were very low, using very conservative steady-state heat transfer calculations will still show low (insignificant) thermal results. The problem was solved for a two region geometry (see Figure 9).

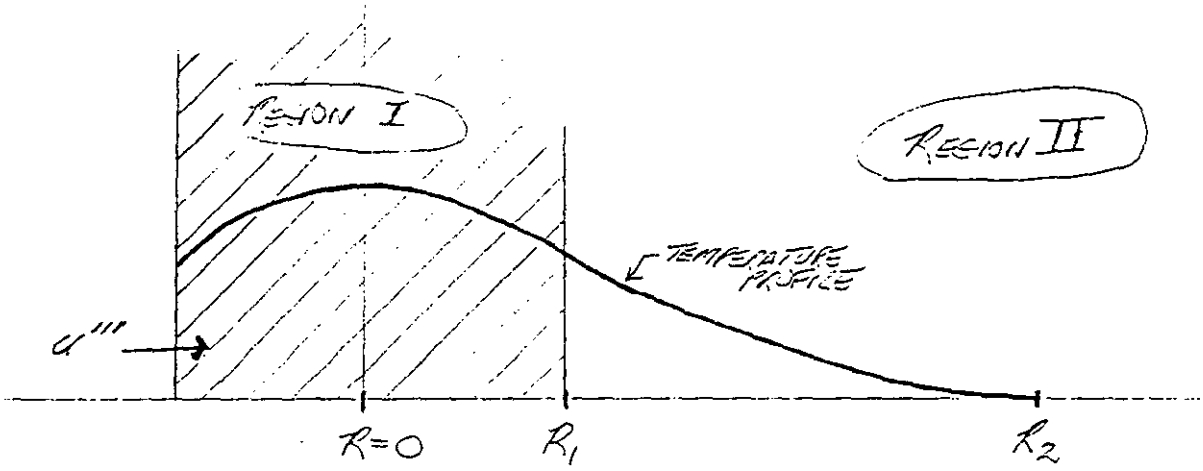

Figure 9 Geometry for two region heat conduction analyses.

The first region corresponds to a pure conduction region with a uniform heat generation source term. The second region corresponds to a pure conduction region without a heat generation source term. In both regions, the thermal conductivity is assumed to be a

constant. The differential equations were derived from Equation 31 (a general form of the heat conduction equation). For the assumptions made above, this equation then becomes Equations 32 and 33.

$$\rho c_p \frac{dT}{d\tau} = \nabla \cdot \left[k \nabla T \right] + u''' \qquad [31]$$

where

$u''' = heat\ source\ load \quad [W/m^3]$

$k = thermal\ conductivity \quad [W/m-K]$

$\rho = material\ density \quad [kg/m^3]$

$c_p = material\ specific\ heat \quad [J/kg-K]$

$T = temperature \quad [K]$

$\tau = time \quad [\text{sec}]$

$$\frac{d}{dr}\left[r \frac{dT^I}{dr} \right] + r \frac{u'''}{k_I} = 0 \qquad [for\ Region\ I,\ \ steady-state] \qquad [32]$$

$$\frac{d}{dr}\left[r \frac{dT^{II}}{dr} \right] = 0 \qquad [for\ Region\ II,\ \ steady-state] \qquad [33]$$

Performing a change of variable, changing to a ΔT via Equation 34, yields Equations 35 and 36.

$$\Theta = \Delta T = T - T_\infty \qquad (d\Theta = dT) \qquad [34]$$

$$\frac{d}{dr}\left[r \frac{d\Theta^I}{dr} \right] + r \frac{u'''}{k_I} = 0 \qquad [for\ Region\ I] \qquad [35]$$

$$\frac{d}{dr}\left[r \frac{d\Theta^{II}}{dr} \right] = 0 \qquad [for\ Region\ II] \qquad [36]$$

The general solutions to these equations are given by Equations 37 and 38.

$$\Theta^I = -\frac{r^2}{4}\frac{u'''}{k_I} + C_1 ln(r) + C_2 \qquad [37]$$

$$\Theta^{II} = C_3 ln(r) + C_4 \qquad [38]$$

The necessary boundary conditions are given by Equations 39 → 42 (note, boundary condition # 4 corresponds to the sphere of influence for this boundary value problem).

$$B.C.\#1 \qquad \frac{d\Theta^I}{dr}\Big|_{r=0} = 0 \qquad [39]$$

$$B.C.\#2 \qquad k_I \frac{d\Theta^I}{dr}\Big|_{r=R_1} = k_{II}\frac{d\Theta^{II}}{dr}\Big|_{r=R_1} \qquad [40]$$

$$B.C.\#3 \qquad \Theta^I\Big|_{r=R_1} = \Theta^{II}\Big|_{r=R_1} \qquad [41]$$

$$B.C.\#4 \qquad \Theta^I\Big|_{r=R_2} = 0 \qquad [42]$$

Applying boundary conditions is shown in Equations 43 → 46 which yield the particular solutions shown in Equations 47 and 48.

$$Applying\ \ B.C.\ \#1 \qquad \frac{d\Theta^I}{dr}\Big|_{r=0} = 0 = \frac{C_1}{r}\Big|_{r\to 0} \quad \Rightarrow \quad C_1 = 0 \qquad [43]$$

$$\textit{Applying B.C. \#4} \quad \Theta^{II}\,|_{r=R_2} = 0 = C_3\,ln(R_2) + C_4 \quad \Rightarrow \quad C_4 = -C_3 ln(R_2) \qquad [44]$$

$$\textit{Applying B.C. \#2} \quad k_I \frac{d\Theta^I}{dr}\,|_{r=R_1} = k_{II}\frac{d\Theta^{II}}{dr}\,|_{r=R_1} = \frac{-R_1 u'''}{2} \qquad [45]$$

$$= \frac{C_3 k_{II}}{R_1} \quad \Rightarrow \quad C_3 = -\frac{R_1^2 u'''}{2k_{II}}$$

$$\textit{Applying B.C. \#3} \quad \Theta^I\,|_{r=R_1} = \Theta^{II}\,|_{r=R_1} = C_2 - \frac{R_1^2 u'''}{4k_I} = C_3 \ln\left[\frac{R_1}{R_2}\right] \qquad [46]$$

$$= -\frac{R_1^2 u'''}{2k_{II}} \ln\left[\frac{R_1}{R_2}\right]$$

$$\Rightarrow \quad C_2 = \frac{R_1^2 u'''}{4}\left[\frac{1}{k_I} - \frac{2}{k_{II}}\ln\left[\frac{R_1}{R_2}\right]\right]$$

$$\Theta^I = \frac{R_1^2 u'''}{4}\left[\frac{1}{k_I} - \frac{2}{k_{II}}\ln\left[\frac{R_1}{R_2}\right]\right] - \frac{r^2}{4}\frac{u'''}{k_I} \qquad [47]$$

$$\Theta^{II} = \frac{R_1^2 u'''}{2k_{II}} \ln\left[\frac{R_2}{r}\right] \qquad [48]$$

Since the Δ temperature of interest is that which occurs at $r = R_1$, evaluating either Equation 47 or 48 will yield the desired result (given by Equation 49).

$$\Theta(R_1) = \Theta^I(R_1) = \Theta^{II}(R_1) = \frac{R_1^2 u'''}{2k_{II}} \ln\left[\frac{R_2}{R_1}\right] \qquad [49]$$

Using the assumptions in Equation 50 yields the final result shown in Equation 51.

$$\textit{assume} \quad R_2 = 100\,R_1 \qquad [50]$$

$$k_{II} = k_{salt} = k_{salt\ @\ 300K}$$

$$= \lambda_{300} \quad (1992\ WIPP\ PA\ Vol\ 3,\ pg.\ A-117 \quad [Ref.WPA-1]$$

$$= 5.40\ \frac{W}{mK}$$

$$R_1 = \begin{cases} 0.32385\,m. & Option\ A \\ 0.28580\,m & Option\ B \end{cases}$$

$$\Theta(R_1)\ \ [K(=^{\circ}C)] = \Delta T(due\ to\ max\ RH\text{-}TRU\ canister) \qquad [51]$$

$$= \begin{cases} 0.044720817 \times u''' & Option\ A \\ 0.034829431 \times u''' & Option\ B \end{cases}$$

where

$$u'''\ is\ in\ units\ of\ [W/m^3]$$

Computational results using Equation 51 are shown in Table 12.

Table 12. Results of Heat Transfer Calculations

Case (a) Study	u''' (b) [$Watt/m^3$]		ΔT (c) [K]	
	Option A	Option B	Option A	Option B
1) Maximum Ave (d)	9.121E+00	1.056E+01	4.079E-01	3.678E-01
2) F(68.26%) (d)	2.508E+01	2.879E+01	1.122E+00	1.003E+00
3) F(95.44%) (d)	2.954E+01	3.390E+01	1.321E+00	1.181E+00
4) F(99.74%) (d)	3.623E+01	4.158E+01	1.620E+00	1.448E+00
5) Worst Case (d)	7.133E+01	8.186E+01	3.190E+00	2.851E+00
6) 300 Watt limit (e)	3.371E+02	4.800E+02	1.507E+01	1.672E+01
7) WIPP Ave	1.093E+00	1.093E+00	4.885E-02	3.805E-02
7b) WIPP Ave +/- 10%	1.202E+00	1.202E+00	5.374E-02	4.185E-02
7c) WIPP Ave +/- 100%	2.185E+00	2.185E+00	9.771E-02	7.610E-02
7d) WIPP Ave +/- 200%	3.277E+00	3.277E+00	1.466E-01	1.142E-01

(a) Results in this table correspond to step 6 of Table 1.
(b) Values calculated from values in Table 11, using footnote l of Table 9.
(d) $u''' = 0.003668E+06\ S_v(total)$
The total heat load-to-total curies ratio of 0.003668E+06 was calculated in footnote l of Table 10.
(c) Calculated using Equation 51.
(d) See Table 7.
(e) 300 Watt limit from Ref. LWA-1.

[4] Overall Results

The results obtained in this study (see Table 12) indicate that a negligible thermal increase is expected in the immediate vicinity of an RH-TRU canister such as those expected at the WIPP (based on Rev.1 data from the WTWBIR). The only calculated temperature difference of any significance found in this study was that associated with the 300 Watt limit. That value was computed using a simple thermal analysis that yields a conservative value (i.e., an overestimated value for the temperature difference). The other computed values have additional conservatism because the "maximum" values (see Table 7) from Rev.1 of the WTWBIR are the maximum of values of both "Stored" (legacy) and "Projected" (future) wastes, and for most cases, the maximum values estimated for projected wastes are overpredicted. In this study, the worst-case RH waste form was "Heterogeneous" waste as identified in Table 7. Unfortunately, the maximum estimated material density was extreme, namely, fifty times the average value. The extreme value for the "maximum" waste density was identified as coming from a "Projected" RH-TRU heterogeneous waste from the Battelle Columbus Laboratory (BCLDP). This waste stream may never be generated, because the funding for the project that would generate this waste stream is questionable. Moreover, the total volume from this projected waste stream is small (Table 6 indicates that the total amount of waste overall originating at BCLDP is only 71. cu.m.) and the BCLDP may have grossly overestimated the expected density of the waste stream (BCLDP does not currently have RH-TRU waste on site and they may not have a lot of experience with RH-TRU waste).

REFERENCES

[Ab-1]Abramowitz, M and I.A. Stegun (Editors); **Handbook of Mathematical Functions With Formulas, Graphs, and Mathematical Tables;** National Bureau of Standards, Applied Mathematics Series, 55, 2nd printing November 1964, pg. 248.

[BIR-1]
DOE (U.S. Department of Energy); Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report; CAO-94-1005; Revision 1; February 1995.

[BIR-1b]
Ibid; Volume 1; pp. 6-6 → 6-24.

[BIR-1c]
Ibid; pp. 3-31, 3-34, and 3-35.

[BIR-1d]
Ibid; pp. 4-6 → 4-11.

[BIR-1e]
Ibid; pp. 4-2, and 4-3.

[BIR-1f]
Ibid; pp. 1-14.

[Br-1]Personal communications with D. Bretzke (Science Application Incorporated Company), October 5, 1995.

[CRC-1]
Weast, R.C. (Editor); **CRC Handbook of Chemistry and Physics;** 66th Edition, CRC Press, INc., Boca Raton, Florida, 1985, pg. A-52 (exponential form #519).

[CRC-1b]
Ibid; pg. A-52 (exponential form #520).

[CRC-1c]
Ibid; pg. A-104.

[CRC-1d]
Ibid; pg. D-184 (data for plain carbon steel, AISI-SAE 1020).

[ED-1]Edling, D.A. and J.F. Griffin, "Certification of ERDA Contractors' Packaging With Respect to Compliance With DOT Specification 7A Performance Requirements, Phase II Summary Report," MLM-2228, Mound Laboratory, Miamisburg, Ohio, June 12, 1975.

[Ic-1] *Radiation Quantities and Units,* International Commission on Radiation Units and Measurements report 19, 1971. (Although Table 2 indicates report 9 as the citation, only report 19 was identified in the reference list of Ref. La-1e.)

[DOE-1]
DOE (U.S. Department of Energy); Remote-Handled Transuranic Waste Study; DOE/CAO-1095, DOE Carlsbad Area Office; Carlsbad, NM, October 1995, pg. A-3.

[DOE-1b]
Ibid; pg. A-2.

[DOE-2]
DOE (U.S. Department of Energy), Waste Isolation Pilot Plant (WIPP); Record of Decision, **Federal Register** , Vol. 46, No. 18, pg. 9163, January 28, 1981 (46 FR 9162), Office of Environmental Restoration and Waste Management, Washington, D.C.

[DOE-3]
DOE (U.S. Department of Energy), Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant; DOE/EIS-0026-FS, January 1990., Volume 2, pg. B-4, Office of Environmental Restoration and Waste Management, Washington, D.C.

[DOE-4]
DOE (U.S. Department of Energy) and State of New Mexico (1981 originally); Agreement for Consulation and Cooperation Between Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant, Updated April 18, 1988; Article VI (WIPP Mission), pg. 7; [Could not find a more recent upgrade version than this 1988 copy.].

[DOE-5]
DOE (U.S. Department of Energy), Final Safety Analysis Report, Waste Isolation Pilot Plant; WP 02-9, Rev. 0, Westinghouse, Volume III, pg. 6.1-3, May 1990.

[Gl-1]Glasstone, S and A. Sesonske; **Nuclear Reactor Engineering;** Van Nostrand Reinhold Company; New York; 1967; pp. 580.

[Gl-1b]
Ibid; pp. 568-585.

[Hi-1]Personal communications with T. Hicks (Galson Science Ltd.), September 1995.

[Ja-1]Jaeger, R.G. (Editor), et al.; **Engineering Compendium on Radiation Shielding, Volume I - Shielding Fundamentals and Methods;** Springer-Verlag; Berlin; 1968; pg. 383. (For additional discussion on the use of this equation for RH-TRU calculations, see Memo from David Louie (LATA) to Dan Osetek (LATA) dated: August 22, 1995; subject: "Calculation of Decay Times of Three RH-TRU Waste Streams Assuming a 55-Gal Drum Waste Package".)

[Ja-1b]
Ibid; pg. 412.

[La-1]Lamarsh, J.R.; **Introduction To Nuclear Engineering, 2nd Edition;** Addison-Wesley; Reading, Massachusetts; 1983; pg. 405, (Equation 9.10).

[La-1b]
Ibid; pg. 441, (Equations 9.28 and 9.29, Figure 9.10).

[La-1c]
Ibid; pg. 473, (Equations 10.1, 10.2, and 10.3).

[La-1d]
Ibid; pg. 404, (Table 9.2).

[La-1e]
Ibid; pg. 467, (Reference list).

[La-1f]Ibid; Appendix II, Table II.5, pg. 649, [Originally from L.T. Templin, Editor, **Reactor Physics Constants,** ANL-5800, 2nd ed., 1963; based on G.W. Grodstein, National Bureau of Standards circular 583, 1957.]

[La-1g]
Ibid; pg. 474, (Figures 10.2 and 10.3).

[Lo-1]Personal communications with Sheila Lott (Advanced Sciences Inc.), October 19, 1995. [Sheila Lott has expertise with the RH-TRU canister design.]

[LWA-1]
Public Law 102-579, 102d Congress, October 30, 1992; *Waste Isolation Pilot Plant Land Withdrawal Act.;* 1992. Section 7, subparts (a)(1)(A) and (a)(3). [Note, the WIPP LWA in addition to limiting the RH-TRU canister surface dose equivalent rate to 1,000 rem/hr also limits the design capacity of (all) transuranics to 6.2 million cubic feet of volume of which no more than 5.1 million curies (Ci) may be RH-TRU. The volume limit for the RH-TRU is identified in the WIPP ROD (Record of Decision) to be 0.25 million cubic feet of volume [Ref. DOE-2]. Also, prior to the WIPP LWA 6.2 million cubic feet volume was assign to CH-TRU waste only (for instance, Ref. DOE-3 identifies that the total volume of WIPP was to be 6.45 million cubic feet -- 6.2 for CH-TRU and 0.25 for RH-TRU) and not

CH-TRU plus RH-TRU. The WIPP LWA seems to be patterned after the WIPP C&C agreement [DOE-4]. It is in the WIPP C&C that a misquote was made to the WIPP ROD. The WIPP C&C quotes the WIPP ROD as applying the 6.2 million cubic meters to (all) transuranic waste. Even though the WIPP LWA is technically incorrect, the volumes identified there are to be used for WIPP calculations. More thorough discussion can be found in Ref. Sa-3.]

[Mo-1]Morgan, K.Z. and J.E. Turner, *Principles of Radiation Protection*, Wiley, New York, 1967.

[Nc-1]*Basic Radiation Protection Criteria*, National Council on Radiation Protection and Measurements report 39, 1971.

[Or-1]Croff, A.G.; "ORIGEN2: A Users Manual for ORIGEN2 Computer Code," Oak Ridge National Laboratory, July 1980. (Also see Croff, A.G.; "ORIGEN2: A Versatile Computer Code for Calculating the Nuclide Compositions and Characteristics of Nuclear Materials," **Nuclear Technology,** Vol. 62, September 1983.)

[Pe-1]Personal communications with A. Peterson (Org. 6748, Sandia National Laboratories), October 3, 1995.

[Ra-1]Shleien, B. and M.S. Terpilak; **The Health Physics and Radiological Health Handbook;** Nucleon Lectern Associates, 1984, pp. 125.

[Ra-1b]
Ibid; pg. 136.

[Ro-1]Foderaro, A.H. and F. Obenshain; Effect of Geometry of Radiation Source, Chapter 9 in "Reactor Shielding Design Manual", ed. by. Th. Rockwell III, TID 7004 (March 1956); pp. 366/7.

[Sa-1]Sanchez. L.C. et.al; "Thermal Analysis of the 10-Gallon and the 55-Gallon DOT-6M Containers With Thermal Boundary Conditions Corresponding to 10CFR71 Normal Transport and Accident Conditions", SAND87-1896, TTC-0748, UC-71, Sandia National Laboratories, Albuquerque, New Mexico, March 1988, pp. 2 and 5 (see SA-1 reference #9 for source of dimensions used on page 5).

[Sa-2]Sanchez, L.C. and M.L. Hudson; "Determination of Effective Thermal Conductivities for a Full-Scale Mock-Up of a 217-Element Breeder Reactor Fuel Assembly Subjected to Normal Conditions"; SAND85-2827, TTC 0635, Sandia National Laboratories, Albuquerque, New Mexico, December 1986, Appendix C, pp. 80 → 99.

[Sa-3]L.C. Sanchez (SNL Org 6741) and S.G. Bertram (SNL Org 6747); Memo to L.E. Shephard (SNL Org 6800), subject: "WIPP Capacity", dated October 6, 1995.

[Sa-4]L.C. Sanchez (SNL Org 6741); Memo to M.G. Marietta (SNL Org 6821), subject: "RH-TRU Volumes", dated October 21, 1995.

[Sc-1]Schaeffer, N.M. (Editor); **Reactor Shielding for Nuclear Engineers;** U.S. Atomic Energy Commission (UC-80), 1973, TID-25951, ISBN 0-87079-004-8, LCCCN 73-600001.

[Sc-1b]
Ibid; pp.127 (Equation 4.2-8).

[Ti-1]Personal communications with M. Tierney (Org. 6749, Sandia National Laboratories), October 13, 1995.

[Ti-1]Tierney, M.S.; "Constructing Probability Distributions of Uncertain variables in Models of the Performance of the Waste Isolation Pilot Plant: The 1990 Performance Simulations", SAND90-2510, UC-721, Sandia National Laboratories, Albuquerque, New Mexico, December 1990.

[WPA-1]
WIPP Performance Assessment Department; "Preliminary Performance Assessment for the

Waste Isolation Pilot Plant, December 1992; Volume 1: Third Comparison with 40 CFR Part 191, Subpart B", SAND92-0700/1 UC-721, Sandia National Laboratories, Albuquerque, New Mexico, December 1992, pg. 2-16.

LCS:6741:lcs/(96-2083)

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INFORMATION ONLY

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to: Martin S. Tierney (6741)

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from: Yifeng Wang & Larry Brush (Org. 6748)

subject: Estimates of Gas-Generation Parameters for The Long-Term WIPP Performance Assessment

Introduction

Steel corrosion and organic-material biodegradation have been identified as major gas-generation processes in the WIPP repository (Brush, 1995). Gas production will affect room closure and chemistry (Butcher, 1990; Brush, 1990). This memorandum provides the current estimates of gas-generation parameters for the long-term WIPP performance assessment. The parameters provided here include the rates of gas generation under inundated and humid conditions, the stoichiometric factors of gas generation reactions, and the probability of the occurrence of organic material biodegradation (Table 1). To satisfy the quality assurance (QA) requirement (QAP 9-5), we summarize all hand calculations for estimating these parameters in Appendices I and II.

Biodegradation of Organic Materials

Cellulosics, plastics, and rubbers have been identified as the major organic materials to be emplaced in the WIPP repository (DOE/CAO, 1996) and could be degraded by microbes in 10,000 years. Cellulosics has been demonstrated experimentally to be the most biodegradable among these materials (Francis et al., 1995). The occurrence of significant microbial gas generation in the repository will depend on: (1) whether microbes capable of consuming the emplaced organic materials will be present and active; (2) whether sufficient electron acceptors will be present and available; (3) whether enough nutrients will be present and available. Considering uncertainties in evaluation of these factors and also in order to bracket all possible effect of gas generation on the WIPP performance assessment, we assign a 50% probability to the occurrence of significant microbial gas generation.

- *Microbial Reactions*

Microorganism will consume cellulosics mainly via the following reaction pathways in the repository (Brush, 1995):

$$C_6H_{10}O_5 + 4.8\ H^+ + 4.8\ NO_3^- \rightarrow 7.4\ H_2O + 6\ CO_2 + 2.4\ N_2 \quad (1)$$

$$C_6H_{10}O_5 + 6\ H^+ + 3\ SO_4^{2-} \rightarrow 5\ H_2O + 6\ CO_2 + 3\ H_2S \quad (2)$$

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$$C_6H_{10}O_5 \rightarrow 3\ CH_4 + 3\ CO_2. \quad (3)$$

We assume that Reactions 1 to 3 will proceed sequentially according to the energy yield of each reaction. Here we ignore the reaction pathways of aerobic respiration, Mn(IV) and Fe(III) dissimilatory reduction, since the quantities of O_2, Mn(IV) and Fe(III) initially present in the repository will be negligible relative to the other electron acceptors. In Reactions 1 to 3, biomass accumulation is also not taken into account. This is because significant biomass accumulation seems unlikely in the WIPP repository and the accumulated biomass, if any, will be recycled by microbes after all biodegradable cellulosics is consumed.

In addition to Reaction (3), methanogenesis may proceed via:

$$4\ H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O. \quad (4)$$

However, this reaction will be ignored in our calculations, because (1) no experimental data are available to evaluate the rate of this reaction and (2) the net effect of this reaction is to reduce the total gas generation and the amount of CO_2 in the repository and, therefore, it is conservative to ignore this reaction in respect of repository pressurization and actinide solubility.

- *Rates of Cellulosics Biodegradation*

The rate of cellulosics biodegradtion was measured by incubating representative cellulose materials (filter paper, paper towels, and tissue) in WIPP brine with microbes enriched from various WIPP environments (Francis & Gillow, 1994; Francis et al., 1995). The incubation experiments were conducted under various conditions: aerobic or anaerobic, inundated or humid, with or without bentonite, amended or unamended with nutrients or NO_3^-. Because the repository is expected to become anoxic shortly after waste emplacement and also because bentonite will not be added as a backfill according to the current waste emplacement plan, we think that the experimental data from anaerobic incubation without bentonite present are most relevant to expected WIPP conditions. Considering that the current experimental data are mostly for denitrification (Reaction 1), but not sulfate reduction (Reaction 2) and methanogenesis (Reaction 3) (Francis & Gillow, 1994; Francis et al., 1995), we assume that the ranges of the rates of cellulosics biodegradation via sulfate reduction and methanogenesis are equal to those observed for denitrification.

We use CO_2 production data to estimate the rates of cellulosics biodegradation. There are two advantages of using CO_2 production data: (1) there are experimental data available on the CO_2 dissolution in WIPP brine (Telander & Westerman, 1995) and, therefore, it is easy to correct the CO_2 production data for gas dissolution (Appendix I); (2) since cellulosics biodegradation did not reach the stage of methanogenesis in the experiments, according to

Reactions 1 and 2, the consumption of one mole carbon of cellulosics will produce one mole of CO_2. This 1:1 relationship is independent of oxidation state of carbon in cellulosics. Therefore, it is rather straightforward to determine the amount of cellulosics biodegraded from the amount of CO_2 produced.

Experimental data show a strong dependence of CO_2 generation on the concentrations of nutrients and nitrate (Francis & Gillow, 1994; Francis et al., 1995). The maximum CO_2 generation was observed in nitrate-and-nutrient-amended samples. In those experiments, after a short lag phase, CO_2 first linearly increased with time and then approached some limiting value as its production rate diminished. If we assume that biodegradation is nitrate- or nutrient-limited, the experimental data can be explained by Michaelis-Menton kinetics (Chapelle, 1993). Michaelis-Menton kinetics, which describes the dependence of microbial reaction rate on substrate concentration, can be expressed by:

$$V = \frac{V_{max} S}{K_s + S} \tag{5}$$

where V is the microbial reaction rate; V_{max} is the maximum value of the rate; S is the concentration of the limiting substrate; K_s is a constant. Equation (5) states that the microbial reaction rate becomes independent of the substrate concentration, if the latter is high enough, i.e. $S >> K_s$ and $V = V_{max}$. In this circumstance, the reaction product will accumulate linearly with time before the substrate is sufficiently depleted. In other words, in our cases, the linear part of CO_2 vs. time curve will give the estimate of the maximum rate of cellulosics biodegradation.

From the experimental data of Francis & Gillow (1994) and Francis et al. (1995), we estimate the maximum and minimum rates of cellulosics biodegradation under inundated conditions to be 0.3 and 0.01 mole C/kg/year, respectively (Appendix I). The maximum rate is estimated from the data obtained from both NO_3^-- and nutrients-amended experiments, whereas the minimum rate is derived from the data obtained from the inoculated-only experiments without any nutrient and NO_3^- amendment. Under humid conditions, experimental data show no clear correlation between CO_2 production and nutrient concentration. The best estimate of the maximum rate of cellulosics biodegradation under humid condition is 0.04 mole C/kg/year (Appendix I). The minimum of the humid biodegradation rate is set to 0, corresponding to the cases where microbes become inactive due to nutrient and water stress.

- *Biodegradation of Plastics and Rubbers*

The rates of plastics and rubber biodegradation under expected WIPP conditions were

measured by Francis et al.(1995). The experimental data show that plastics and rubbers are much less biodegradable than cellulosics, although the data themselves are not sufficient for us to constrain the long-term biodegradation rate for plastics and rubbers. There are two factor that may potentially increase the biodegradibility of those materials: long time scale and cometabolism. Over a time scale of 10,000 years, plastics and rubbers may change their chemical properties and therefore their biodegradibility. Cometabolism means that microbes degrade an organic compound but do not use it as a source of energy or of their constituent elements, all of which are derived from other substrates (Alexander, 1994). In the WIPP repository, plastics and rubbers, which are resistant to biodegradation, may still be cometabolized with cellulosics and other more biodegradable organic compounds. Because of these uncertainties, we recommend a 50% chance for the biodegradation of plastics and rubbers in the event of significant microbial gas generation. We further suggest lumping plastics and rubbers into cellulosics and applying the ranges of cellulosics biodegradation rate to plastics and rubbers. This treatment is conservative in respect of repository pressurization and actinide solubility. We propose to use the following equation to convert plastics and rubbers to the carbon-equivalent quantity of cellulosics (Appendix I):

$$\text{total cellulosics (kg)} = \text{actual cellulosics (kg)} + 1.7 \text{ plastics (kg)} + \text{rubbers (kg)}. \qquad (6)$$

Anoxic Steel Corrosion

According to current waste inventory estimates, a large amount of steels will be emplaced in the WIPP repository (DOE/CAO, 1996). Those steels will be capable of reacting with the repository brine to form H_2 gas. Both thermodynamic calculations and experimental observations indicate that the H_2 gas can be generated to pressures exceeding the lithostatic pressure at the WIPP horizon, if enough brine enters the repository (Brush, 1990; Telander & Westerman, 1993, 1995). Since the repository will become anoxic shortly after waste emplacement and sealing, we here focus only on anoxic steel corrosion.

- *Steel Corrosion in the Absence of CO_2 and H_2S*

In this case, steel corrosion will follow the reaction (Telander & Westerman, 1993, 1995):

$$Fe + 2\,H_2O \rightarrow Fe(OH)_2 + H_2. \qquad (7)$$

In the Mg-rich WIPP brines (exemplified by Brine A), a significant fraction of Fe in the corrosion product is substituted by Mg. This substitution can substantially increase the stability of the corrosion product. Experimental observations indicate that steel corrosion can still proceed even at an 127 atm H_2 pressure (Telander & Westerman, 1995). Aside from this thermodynamic stability argument, the experimental observations indicate no

essential effect of Mg in the brine on the corrosion rate. As a matter of fact, the corrosion rates measured in Mg-rich Brine A are not significantly different from those measured in Mg-depleted Brine ERDA-6 (Telander & Westerman, 1995).

It was observed in the experiments that the steel corrosion rate decreased with time until some limiting rate was achieved (Telander & Westerman, 1995). Our long-term corrosion rate is estimated from the longest-term data available in a WIPP-relevant Brine A environment. The estimated inundated rate is 0.5 μm/year or 0.07 mole Fe /m^2/year (Appendix II). In addition, the corrosion rate is also found to increase with decreasing brine pH (Telander & Westerman, 1993, 1995). Without addition of CO_2 from microbial reactions, the pH in the repository is unlikely to go below its experimental value, which is about 10 (Telander & Westerman, 1993, 1995). Therefore, we recommend using 0.5 μm/year as the upper limit of inundated corrosion rate for the cases without microbial gas generation. On the other hand, the pH in the repository can be ~2 units higher than its experimental value due to the presence of $Ca(OH)_2$ as a cementious material in the waste, and thus, based on the scaling factor (= 0.01) given by Telander & Westerman (1995), the steel corrosion rate could be as low as 0.005 μm/year. In addition, the experimental work for Source Term Test Program (STTP) at Los Alamose National Laboratory indicates that salt crystallization on steel surface may possibly prevent the steel from corrosion. To include this possibility, we set the minimum inundated steel corrosion rate to 0.

The corrosion rate observed on specimens exposed to humid conditions is negligible, based on essentially non-existent presence of corrosion product and lack of apparent H_2 generation (Telander & Westerman, 1995). Therefore, we set the humid steel corrosion rate to 0.

- *Steel Corrosion in the Presence of CO_2 and H_2S*

In the event of significant microbial gas generation, steel corrosion can proceed via the following reactions in addition to Reaction (7) (Telander & Westerman, 1993, 1995):

$$Fe + CO_2 + H_2O \rightarrow FeCO_3 + H_2 \quad (8)$$
$$Fe + H_2S \rightarrow FeS + H_2. \quad (9)$$

One possible effect of CO_2 and H_2S on steel corrosion is that they may cause passivation of the steel. Steel passivation was observed in the experiments in which large quantities of CO_2 and H_2S were added to the reaction vessels. It usually took place after tens of days and was caused by the formation of a protective layer of $FeCO_3$ or FeS on steel surfaces (Telander & Westerman, 1995). However, we think that this passivation is unlikely to occur under the repository conditions. This is because the microbial production rate of CO_2 and H_2S is too slow and it will take an exceedingly long time period (relative to the experimental time scale) for these gases in the repository to reach their concentration levels required for

passivation under the experimental conditions. The conclusion of no steel passivation under the WIPP repository conditions is consistent with other studies (e.g., Ikeda et al., 1983; Schmitt, 1983). In fact, aside from the previously cited work of Telander & Westerman (1993), total passivation of steel by CO_2 and H_2S in low-temperature solutions has not been reported, though varying degrees of corrosion inhibition have been observed.

In the absence of passivation, the microbial generation of CO_2 and H_2S will increase steel corrosion rates in the repository either by lowering the repository pH or by initiating additional reaction pathways (Reactions 8 and 9) (Telander & Westerman, 1995). We take this effect into account by modifying the sampling range of steel corrosion rate. Obviously, Reactions 8 and 9 will be limited by microbial CO_2 and H_2S production, and therefore the upper limit of the reaction rate can be estimated from the maximum cellulosics biodegradation rate, which is 0.3 mole/kg cellulosics/year, equivalent to 6 μm/year of steel corrosion rate (Appendix II). Thus, in the event of significant microbial gas generation, the upper limit of steel corrosion rate is 6.5 μm/year, the sum of the maximum rates of Reactions 7 through 9. The corresponding lower limit will be kept the same as that estimated for the cases without CO_2 production, i.e. 0.0 μm/year. Under humid conditions, experimental results show a negligible effect of CO_2 and H_2S on steel corrosion (Telander & Westerman, 1995). We thus set the humid corrosion rate to 0.

Stoichiometric Factors in the Average-Stoichiometry Model

In the Average-Stoichiometry Model, which is currently implemented in BRAGFLO, microbial gas generation is represented by the overall reaction:

$$\frac{1}{6}C_6H_{10}O_5 \;+\; unknown \;\rightarrow\; y\;\; gas \;+\; unknown \tag{10}$$

and H_2 production due to steel corrosion is described by:

$$\mathrm{Fe} + \frac{4+2x}{3}\,\mathrm{H_2O} \rightarrow \frac{4-x}{3}\,\mathrm{H_2} + \mathrm{x\,Fe(OH)_2} + \frac{1-x}{3}\,\mathrm{Fe_3O_4}. \tag{11}$$

The stoichiometric factors x and y in Reaction 10 and 11 are estimated as follows.

- *Average-Stoichiometric FactorY in Microbial Reaction*

The stoichiometric factor y depends on the extent of the progress of each individual reaction pathway (Reactions 1 through 3). It can be estimated based on the inventory estimates of the transuranic waste to be emplaced in the Waste Isolation Pilot Plant (DOE/CAO, 1996; Drez, 1996).

First, we estimate the maximum quantities (in moles) of cellulosics and steels that will be potentially consumed in 10,000 years:

$$M'_{cel} = \min \left\{ \frac{6000 M_{cel}}{162},\ 10000 R'_C M_{cel} \right\} \tag{12}$$

$$M'_{Fe} = \min \left\{ \frac{1000 M_{Fe}}{56},\ 1410 R_{c,i} A \right\} \tag{13}$$

with

$$R'_c = \max \left\{ R_{m,i},\ R_{m,h} \right\} \tag{14}$$

where M_{cel} and M_{Fe} are the quantities (in kg) of cellulosics and steels initially present in the repository; $R_{c,i}$ is the inundated steel-corrosion rate (μm/year); $R_{m,i}$ and $R_{m,h}$ are the sampled rates of cellulosics biodegradation under inundated and humid conditions respectively (mole/kg/year). In Equation (13), we use the factor of 0.141 mole/μm/m^2 to convert steel-corrosion-rate unit from μm/year to mole/m^2/year (Telander and Westerman, 1995). Here, we assume that cellulosics biodegradation and steel corrosion both follow zero order reaction kinetics. Next, we calculate the average stoichiometric factor y by distributing M'_{cel} into individual biodegradation pathways. Consider two extreme cases, corresponding to the maximum and minimum values of y: (1) no reaction of microbially produced CO_2 and H_2S with steel and steel-corrosion products; (2) complete reaction of microbially produced CO_2 and H_2S with steel and steel-corrosion products.

If no CO_2 or H_2S is consumed by reactions with steel and steel-corrosion products, we would expect the maximum quantity of microbial gas production in the repository and therefore the maximum value for y. We assume that Reactions 1 to 3 will proceed sequentially. The maximum value of y can be estimated by averaging the gas-yields for all reaction pathways:

$$y_{\max} = \frac{\frac{8.4 M_{NO3}}{4.8} + \frac{9 M_{SO4}}{3} + \left(M'_{cel} - \frac{6 M_{NO3}}{4.8} - \frac{6 M_{SO4}}{3} \right)}{M'_{cel}} \tag{15}$$

where M_{NO3} and M_{SO4} are the quantities of NO_3^- and SO_4^{2-} (in moles) initially present in the repository.

If CO_2 or H_2S reacts with steel and steel-corrosion products, we expect that a significant quantity or, perhaps, all of these microbially produced gases would be consumed, thus forming $FeCO_3$ and FeS. This would result in the minimum value of y. The total gas consumed by those reactions (G) is:

$$G = \min\left\{\frac{6M_{NO3}}{4.8} + \frac{9M_{SO4}}{3} + \frac{3}{6}\left(M'_{cel} - \frac{6M_{NO3}}{4.8} - \frac{6M_{SO4}}{3}\right),\ M'_{Fe}\right\} \tag{16}$$

The minimum value of y can then be estimated by:

$$y_{\min} = \frac{\frac{8.4M_{NO3}}{4.8} + \frac{9M_{SO4}}{3} + \left(M'_{cel} - \frac{6M_{NO3}}{4.8} - \frac{6M_{SO4}}{3}\right) - G}{M'_{cel}} = y_{\max} - \frac{G}{M'_{cel}} \tag{17}$$

For each BRAGFLO simulation, y will be uniformly sampled over $[y_{min}, y_{max}]$:

$$y = y_{\min} + \beta(y_{\max} - y_{\min}) \tag{18}$$

with $0 \le \beta \le 1.0$. The calculational scheme proposed here automatically correlates y with waste inventory estimates as well as with reaction rates.

The above calculational scheme does not take into account the SO_4^{2-} that will be brought into repository by brine inflow. Based the previous BRAGFLO simulations for undisturbed cases, the total volume of the brine entering the repository in 10000 years is unlikely to be larger than 2.2×10^7 liters, the value corresponding to the case with unrealistically low gas generation and therefore the worst repository flooding. With a typical SO_4^{2-} concentration of 200 mM in WIPP brines (Brush, 1990), we estimate that the amount of SO_4^{2-} brought into the repository by brine inflow would be less than 0.4×10^7 moles. This amount of SO_4^{2-} will increase the fraction of sulfate reduction pathway in total cellulosics biodegradation only by less than 1%. Therefore, neglecting the sulfate brought by brine inflow would introduce an error of no more than a few percents in y values.

• *Average-Stoichiometric FactorX in Steel Corrosion Reaction*

While magnetite (Fe_3O_4) has been observed to form on steel as a corrosion product in low-Mg anoxic brines at elevated temperatures (Telander & Westerman, 1995) and in oxic brine (Haberman & Frydrych, 1988), there is no evidence that it will form at WIPP repository temperatures. If Fe_3O_4 were to form, it would be expected that H_2 would be produced (on a molar basis) in excess of Fe consumed. But, the anoxic corrosion experiments did not show the production of H_2 in excess of Fe reacted. Therefore, we set the stoichiometric factor x to 1.0 in Reaction 11.

Table 1. Gas-Generation Parameters for the Long-Term WIPP Performance Assessment

Parameter	Estimated Value
Probability of occurrence of significant microbial gas generation	50%
Probability of occurrence of plastics and rubber biodegradation in the event of significant gas generation	50%
Rate of inundated cellulosics biodegradation	0.01 - 0.3 mole C/kg/year
Rate of humid cellulosics biodegradation	0.0 - 0.04 mole C/kg/year
Rate of inundated steel corrosion for the cases without microbial gas generation	0.0 - 0.5 μm/year[1]
Rate of humid steel corrosion for the cases without microbial gas generation	0.0 μm/year
Rate of inundated steel corrosion for the cases with microbial gas generation	0.0 - 6.5 μm/year
Rate of humid steel corrosion for the cases with microbial gas generation	0.0 μm/year
Stoichiometric factor x in Reaction 11	1.0
Stoichiometric factor y in Reaction 10	calculated from Eqn. (18)
Factor β in Equation 18	0 - 1.0
NO_3^- initially present in the waste[2]	2.6×10^7 moles
SO_4^{2-} initial present in the waste[2]	6.6×10^6 moles

1. Multiplying 0.141 mole/μm/m^2 will convert the unit of steel corrosion rate from μm/year to mole/m^2/year (Telander & Westerman, 1993). 2. See Appendix I.6.

References

Alexander M. (1994) *Biodegradation and Bioremediation.* Academic Press, NY.

Brush L. H. (1990) *Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant.* SAND90-0266, Sandia national Laboratories, Albuquerque, NM.

Brush L. H. (1995) *Systems Priority Method - Iteration 2 Baseline Position Paper: Gas Generation in the Waste Isolation Pilot Plant.* Sandia National Laboratories, Albuquerque, NM.

Butcher B. M. (1990) *Preliminary Evaluation of Potential Engineered Modifications for the Waste Isolation Pilot Plant (WIPP).* SAND89-3095, Sandia National Laboratories, Albuquerque, NM.

Chapelle F. H. (1993) *Ground-Water Microbiology and Geochemistry.* John Wiley & Sons, NY.

DOE/CAO (1996) *Transuranic Waste Baseline Inventory Report.* (Rev. 2)

Drez P. (1996) Preliminary estimate for SNL/NM performance assessment calculations of nitrate, sulfate, and phosphate content in transuranic solidified wastes destine for disposal in WIPP. CTAC. (memo, 1/26/1996)

Francis A. J & Gillow J. B. (1994) *Effects of Microbial Processes on Gas Generation under Expected WIPP Repository Conditions: Progress Report through 1992.* SAND93-7036, Sandia National Laboratories, Albuquerque, NM.

Francis A. J., Gillow J. B. & Giles M. R. (1995) *Effects of Microbial Processes on Gas Generation under Expected WIPP Repository Conditions: Data Report for the Period 1993 - 1995.* (draft)

Haberman J. H. & Frydrych D. J. (1988) Corrosion studies of A216 Grade WCA steel in hydrothermal magnesium-containing brines. *Scientific Basis for Nuclear Waste Management XI, Materials Research Society Symposium Proceedings, Boston, MA, November 30 - December 3, 1987.* Eds. M. J. Apted and R. E. Westerman. Materials Research Society, Pittsburgh, PA. 112, 761-772.

Ikeda A., Ueda M. & Mukai S. (1983) CO_2 corrosion behavior and mechanism of carbon steel and alloy steel. *Corrosion '83, Anaheim, CA, April 18 - 22, 1983.* Paper no. 45. National Association of Corrosion Engineers, Huston, TX.

Molecke M. A. (1979) *Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation.* SAND79-1245, Sandia National Laboratories, Albuquerque, NM.

Schmitt G. (1983) CO_2 corrosion of steels - An attempt to range parameters and their effects. *Advances in CO_2 Corrosion in the Oil and Gas Industry, Proceedings of the*

Corrosion/83 Symposium, Anaheim, CA, April 18 - 19. Ed. R. H. Hausler. National Association of Corrosion Engineers, Huston, TX. 1, 1-2.

Telander M. R. & Westerman (1993) *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Progress Report for the Period November 1989 through December 1992.* SAND92-7347, Sandia National Laboratories, Albuquerque, NM.

Telander M. R. & Westerman (1995) *Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Final Report.* (draft)

Appendix I. Hand Calculations for Estimating Microbial Gas generation Parameters

Name of person performing the calculations: Yifeng Wang, Jan. 26, 1996 Yifeng Wang
Name of person reviewing the calculations: Larry Brush, Jan. 26, 1996 Larry Brush

I.1 Correction for CO_2 Dissolution in the Brine

Data and definition of variables:

- TCO_2: Total CO_2 produced in an incubating experiment (moles)
- n: Measured CO_2 in headspace (moles)
- C_l: Dissolved CO_2 (moles/l)
- V_l: Brine volume = 0.104 (l) (Gillow, per. comm.)
- V_g: Headspace volume 0.046 (l) (Francis & Gillow, 1994)
- P: Partial pressure of CO_2 (atm)
- K: Partition coefficient of CO_2 between brine and gas phase = 0.01 (mole/l/atm) (Telander & Westerman, 1995)
- R: Gas constant = 0.082 (l•atm/mole/K)
- T: Temperature = 303.15 (K)

Assumption: Gaseous CO_2 approximately follows the idea gas law during these experiments.

Calculations:

$$TCO_2 = V_l*C_l + n = K*P*V_l + n = K*V_l*n*R*T/V_g + n = (K*V_l*R*T/V_g + 1)*n = (0.01*0.104*0.082*303.15/0.046 + 1)*n = 1.56*n \text{ (moles).}$$

I.2 Estimate of the Maximum Inundated Cellulosics Biodegradation Rate

Data:

Source: Francis et al. 1995, p. 41, 148-149.
Experimental conditions: anaerobic inoculated, nutrients and nitrate amended

We only take the linear part of CO_2 vs. time curve:

time	CO_2
69 days	6.1 µmol/g of cel.
411 days	163 µmol/g of cel.

Calculations:

(1) Rate = (163 - 6.1)/(411 - 69) = 0.459 micro-moles/g/day = 0.168 mole/kg/year.
(2) Correcting it for dissolved CO_2 (see I.1), we finally have:
maximum rate = 0.168*1.56 = 0.3 mole/kg/year.

I.3 Estimate of the Minimum Inundated Cellulosics Biodegradation Rate

Data:
Source: Francis et al. 1995, p. 148-149.
Experimental conditions: anaerobic, inoculated only,

time	CO_2
0 days	2.1 µmol/g of cel.
1034 days	14.0 µmol/g of cel.

Calculations:
(1) Rate = (14.0 - 2.1)/(1034 - 0) = 0.0115 µmol/g/day = 0.004 mole/kg/year.
(2) Correcting it for dissolved CO_2 (Appendix I.1), we finally have:
minimum rate = 0.004*1.56 = 0.01 mole/kg/year.

I.4 Estimate of the Maximum Humid Cellulosics Biodegradation Rate

Data:
Source: Francis et al. 1995, p. 80.
Experimental conditions: anaerobic, inoculated only;
anaerobic, inoculated and amended

time	CO_2
6 days	(7.7 + 13.3)/2 = 10.5 µmol/g of cel.
415 days	(83.1 + 28.8)/2 = 56 µmol/g of cel.

Calculations:
Maximum rate = (56 - 10.5)/(415 - 6) = 0.11µmol/g/day = 0.04 mole/kg/year.

I.5 Convert Plastics and Rubbers to the Equivalent Quantity of Cellulosics

Data:

Source: Molecke (1979)

Celllulosics: $C_6H_{10}O_5$	M. W. = 162 g/mole
Polyethylene: $(-C_2H_4-)n$	M. W. = 28 g/mole
Polyvinychloride: $(-C_2H_3Cl-)n$	M. W. = 62 g/mole
Neoprene: $(-C_4H_5Cl-)n$	M. W. = 88 g/mole
Hypalon: $.(-(C_7H_{13}Cl)_{12}-(CHSO_2Cl)_{17}-]n$	M. W. = 3488 g/mole

Assumption:

Plastics: 80% polyethylene, 20% polyvinychloride
Rubbers: 50% neoprene, 50% hypalon
Based on Molecke (1979).

Calculations:

The P kilograms of plastics and R kilograms of rubbers are equivalent to the Q kilograms of cellulosics, based on carbon equivalence:

$$Q = (0.8*2*162/28/6 + 0.2*2*162/62/6)*P + (0.5*4*162/88/6 + 0.5*101*162/3488/6)*R = 1.7\ P + R \text{ (kilograms)}$$

I.6 Moles of NO_3^- and SO_4^{2-} Initially Present in the Waste

NO_3^- : $1.62x10^6$ kg (Drez, 1996) = $1000/62*1.62x10^6 = 2.6x10^7$ moles
SO_4^{2-} : $6.33x10^5$ kg (Drez, 1996) = $1000/96*6.33x10^5 = 6.6x10^6$ moles

Appendix II. Hand Calculations for Estimating Steel Corrosion Parameters

Name of person performing the calculations: Yifeng Wang, Jan. 26, 1996 Yifeng Wang
Name of person reviewing the calculations: Larry Brush, Jan. 26, 1996 Larry Brush

II.1 Estimate of the Maximum Inundated Steel Corrosion Rate for the Cases without Microbial Gas Generation

Data:

(1) Anoxic corrosion rate obtained from the 12th to 24th month experimental data = 0.71 μm/year (Telander & Westerman, 1993, p. 6-14).

(2) Scaling factor for the long-term rate = 70% (Telander & Westerman, 1995, p. 6 - 19).

Calculation:

The maximum long-term steel corrosion rate = 0.71*70% = 0.5 μm/year.

II.2 Estimate the Maximum Inundated Steel Corrosion Rate for the Cases with Microbial Gas Generation

Data:

Total transuranic waste volume: 1.5×10^5 m^3 (DOE/CAO, 1996)
Drum volume: 0.208 m^3 (DOE/CAO, 1996)
Surface area of steel: 6 m^2/drum (Brush, 1995)
Maximum cellulosics biodegradation rate: 0.3 mole/kg/year (Appendix I.2)
Maximum inundated steel corrosion rate for the cases without microbial gas generation: 0.5 μm/year.
Total cellulosics (including plastics and rubbers): 2.1×10^7 kg (DOE/CAO, 1996; Appendix I.5)
NO_3^- initially present in the waste: 2.6×10^7 moles (Appendix I.6)
SO_4^{2-} initial present in the waste: 6.6×10^6 moles (Appendix I.6)

Assumption:

Reactions 8 and 9 will be limited by microbial CO_2 and H_2S production rate.

Calculations:

(1) Number of drums = $1.5 \times 10^5 / 0.208 = 7.2 \times 10^5$ drums.

(2) Total moles of C in cellulosics = $6 * 2.1 \times 10^7 * 1000/162 = 7.74 \times 10^8$ moles of C.

Molar fraction of cellulosics biodegraded via denitrification =
$2.6 \times 10^7 / 7.74 \times 10^8 = 3\%$.

Molar fraction of cellulosics biodegraded via sulfate reduction =
$6.6 \times 10^6 / 7.74 \times 10^8 = 1\%$.

(3) Maximum CO_2 and H_2S production rate for the whole repository = $(0.03 + 1.5*0.01 + 0.5*0.96)*0.3*2.1 \times 10^7 = 3.3 \times 10^6$ moles CO2/year.

(4) Total steel surface area = $6*7.2 \times 10^5 = 4.32 \times 10^6$ m^2.

(5) The maximum rate of steel corrosion via Reactions 8 and 9 = $3.3 \times 10^6 / 4.32 \times 10^6$ = 0.8 mole Fe/m^2/year = 6 μm/year.

(6) The upper limit of inundated steel corrosion rate for the cases with microbial gas generation = 0.5 + 6 = 6.5 μm/year.

Distribution:

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Title 40 CFR Part 191
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WCA Attachment WCA.8.18

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WP036044

Sandia National Laboratories

Albuquerque, New Mexico 87185-1341

INFORMATION ONLY

date: March 13, 1996

to: R. Vann Bynum 6831 MS 1395

from: Kurt Larson 6751 MS 1341

subject: Brine-Waste contact volumes for scoping analysis of organic ligand concentration

You requested information on the volume of brine required in the repository prior to possible release, for the purpose of estimating bounds to the possible concentration of organic ligands.

I have discussed your question with Palmer Vaughn and Peter Swift, and suggest the following.

In general, assume that a 75% brine saturation is required in any unit volume of waste prior to releases being possible up an intrusion borehole. It is considered that this is a lower but still reasonable value, in that such a high gas saturation (25%) would likely segregate brine near the base of any region intersected by a borehole and effectively prevent upward flow. In other words, higher saturations would likely be required to initiate and sustain flow upward through a borehole, but can't be proven at this time given your need for immediate information on this subject.

There are two time scales that you should be aware of with respect to brine contacting waste. In the long-term and for undisturbed conditions, it is reasonable and the project position that no barriers constructed within the repository will be effective in isolating regions from fluid flow.

In the short time frame, perhaps up to two hundred years, panel closures, or closures on other scales such as the room scale (if constructed), will be relatively effective in isolating the intersected, closed off volume from the rest of the repository volume. This is especially true if boreholes are assigned high permeabilities in PA. High permeability boreholes could allow saturation with Castile brine of intruded waste regions because flow into them could occur more rapidly than flow through closures would drain the intruded area. Because a project position on borehole properties has not been established, I cannot speculate further.

In the following table, I present excavation volumes, and consolidated void volumes for several divisions of the repository. These volumes are taken from or

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calculated based on [1] Sandia WIPP Project, (1992, V. 3, 3-4) and [2] Freeze et al., (1995, 2-7 to 2-8).

Scale	Excavated Volume m^3	Room Equivalents	Consolidated Porosity[1]	Consolidated Void Volume m^3	Brine Volume (saturation) m^3
room	3644. [1]	1	0.22 [2]	343. [2]	257. (75%)
exterior panel	46100. [1]	12.65	0.22 [2]	4339.	3254. (75%)
waste region	420881.[2] [1]	116	0.22 [2]	39788.	29841. (75%)

[1] assumes no gas generation, a bounding case
[2] excluding panel closure volume

References:

Freeze, G.A., Larson, K.W., and Davies, P.B., 1995. A Summary of Methods for Approximating Salt Creep and Disposal Room Closure in Numerical Models of Multiphase Flow. CENT.-0251. Albuquerque, NM: Sandia National Laboratories.

Sandia WIPP Project, 1992. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. CENT.-0700/3. Albuquerque, NM: Sandia National Laboratories.

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Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix WCL

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Waste Component Limits

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WCL-1. Emplacement Limits for Waste Components WCL-2

ACRONYMS

CFR	Code of Federal Regulations
CH	contact handled
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
LWA	Land Withdrawal Act
TRU	transuranic
TWBIR	Transuranic Waste Baseline Inventory Report
WAC	Waste Acceptance Criteria
WIPP	Waste Isolation Pilot Plant

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APPENDIX WCL

40 CFR § 194.24(c) states that the U.S. Department of Energy (DOE) shall specify the limiting values for waste components to be emplaced in the repository:

> "For each waste component identified and assessed pursuant to paragraph (b) of this section, the Department shall specify the limiting value (expressed as an upper or lower limit of mass, volume, curies, concentration, etc.), and the associated uncertainty (i.e., margin of error) for each limiting value, of the total inventory of such waste proposed for disposal in the disposal system . . . . "

Appendix WCA identifies the specific waste components that are associated with the waste proposed for disposal at the Waste Isolation Pilot Plant (WIPP) that address paragraph (b) of 40 CFR § 194.24. Tables WCA-2 and WCA-12 present waste characteristics and the associated components expected prior to the analysis to have significant effect on the performance of the disposal system. Tables WCA-3 and WCA-13 present waste characteristics and associated components expected prior to the analysis to have negligible or insignificant effect on the performance of the disposal system. Table WCA-4 presents waste characteristics and components that were considered but not included in the performance assessment.

This appendix presents the rationale for establishing limits (or for not establishing limits, as the case may be) for those waste components identified as potentially significant in Table WCA-2. As well, it presents the rationale for not establishing limits for one component, organic ligands, that was not anticipated to have significant impact on the results of the assessment. Because the sensitivity analysis (Appendix SA) shows that disposal system performance is not sensitive to most properties of the emplaced waste, limits need not be established for other components listed in Table WCA-3.

Table WCL-1 shows the components listed as potentially significant in Tables WCA-2 and WCA-13, the organic ligands component from Table WCA-3, and the waste characteristics these components influence, the constituents of the component for which assaying during emplacement is required, and the limits for emplacement of each component. Following this table are discussions of the rationale for the proposed assaying and emplacement limits for each component. All of the components listed in Tables WCA-3, WCA-4, and WCA-13 were found to be insignificant to disposal system performance. Therefore, it is not necessary to establish emplacement limits for them other than the relatively coarse limits based on the Transuranic Waste Baseline Inventory Report (TWBIR) (DOE 1996) or imposed through the specific criteria imposed on waste through limitations in the Waste Acceptance Criteria (WAC).

Table WCL-1. Emplacement Limits for Waste Components

Components	Associated Characteristics	Constituent Components Requiring Assaying	Emplacement Limits
radionuclides	*radioactivity at closure* radioactivity after closure solubility colloid formation redox state	^{241}Am ^{238}Pu ^{239}Pu ^{240}Pu ^{242}Pu ^{233}U ^{234}U ^{238}U ^{90}Sr ^{137}Cs	*none*[a]
ferrous metals (iron)	redox potential H_2 gas generation complexing with organic ligands	none	minimum = 2×10^7 kg (amount from containers)[b]
cellulose,	gas generation humic colloids (see below)	sum	maximum = 2×10^7 kg[c]
plastics, rubber	gas generation		
sulfates	gas generation	none	none[d]
nitrates	gas generation	none	none[d]
solid components	particle size effective shear resistance to erosion tensile strength	none	none
free water emplaced *with waste*	gas generation	none	maximum = 1685 m^3 *(limit of 1% total* waste volume as set by the WAC)[e]
humic substances	radionuclide-bearing humic colloids	none	none
nonferrous metals (metals other than iron)	bind with organic ligands and prevent increased solubility	none	minimum = 2×10^3 kg[f]
organic ligands	*solubility*	*none*	*none*[d]

[a] Inventory curie content will be tracked.
[b] Minimum sets to ensure sufficient reactants for reducing radionuclides to lower and less soluble oxidation states. Average density for contact-handled transuranic (CH-TRU) container steel of 139 kilograms per cubic meter multiplied by the design basis value of 168,500 cubic meters.
[c] Maximum set to ensure sufficient MgO backfill is available to react with CO_2 produced. See SWCF-A:WBS.1.1.09.1.1(BC):QA, also in WPO#36453.
[d] For the current waste generation processes that are documented in the TWBIR
[e] *1 percent of the design basis values for CH-TRU of 168,500 cubic meters*
[f] Minimum quantity for complexing with organic ligands (see Appendix SOTERM, Section SOTERM.5).

WCL.1 Radionuclide Components

As discussed in Appendix WCA, nine component radionuclides have activities greater than one EPA unit at closure: ^{241}Am, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu, ^{233}U, ^{234}U, ^{90}Sr, and ^{137}Cs. The total activity of the waste at emplacement and during the entire 10,000-year performance period is dominated by the activities of four emplaced radionuclides: ^{241}Am, ^{238}Pu, ^{239}Pu, and ^{240}Pu. The radionuclides, ^{242}Pu, ^{233}U and ^{234}U, have significantly less total activity than the other Am and Pu components, but since their activities exceed one EPA unit they are not excluded from assaying. The ^{238}U component is to be assayed as well, because its large mass fraction and low activity dilutes the overall activity of transported uranium species. ^{90}Sr and ^{137}Cs can contribute to direct releases at the surface resulting from inadvertent intrusion in the first several hundred years or so after closure. Because of radioactive decay and ingrowth, the major contributors to the overall activity of the repository among these radionuclides change during 10,000 years. For the first several hundred years, ^{241}Am, ^{238}Pu, ^{239}Pu, and ^{240}Pu are important contributors to the total activity of the waste. At the present and projected inventory level, ^{90}Sr and ^{137}Cs may be important for about 200 years. ^{241}Am is important for about 3,000 years. At 10,000 years, ^{239}Pu and ^{240}Pu remain as the only significant contributers to the total activity of the waste. Because the activities of these ten radionuclides in existing and projected waste overwhelmingly exceed the activities of all other radionuclides combined, they are the only radionuclides that need to be limited (see Appendix WCA).

The total activity of the waste is not important for 40 CFR § 194.24(c), because the containment requirements are normalized to the initial inventory. However, the performance assessment is sensitive to relative changes in inventory curie content as a function of radionuclide decay and ingrowth over time. The magnitude of change in the total curie content depends on the initial ratios of the total activities of the assayed radionuclides at the time of repository closure. Accordingly, the results of the performance assessment analysis are conditional on the ratios assumed, which can be derived from data presented in Appendix WCA. 40 CFR § 194.15(a)(5) states that

> "In submitting documentation of continued compliance pursuant to section 8(f) of the WIPP LWA, . . . Updated documentation shall include: . . . A description of all waste emplaced in the disposal system since the most recent compliance certification or re-certification application."

As appropriate, the performance assessment to be conducted for compliance recertification purposes will use adjusted inventory curie content reflecting any significant changes relative to projected values for the four important radioisotopes. The effect of replacing the original estimated ratios with estimates obtained in the future will be captured in recertification performance assessment results. Therefore, the inventory curie content for only the nine important radioisotopes plus ^{238}U need to be tracked. At repository closure, the ratios of the activities of the ten listed radionuclides may or may not be similar to those ratios used in this assessment, but compliance with the containment requirements of 40 CFR § 191.13 will be maintained for the full capacity of emplaced waste at the WIPP.

WCL.2 Ferrous and Ferrous-Alloy Components

Ferrous and ferrous-alloy metal components in the waste have two significant effects on the repository. Ferrous and ferrous-alloy metals may corrode, thus creating gas (see Section 6.4.3.3), and they provide reducing conditions in the repository (see Sections 6.4.3.4, 6.4.3.5, and Appendices WCA, Section WCA.4, and SOTERM, Section SOTERM.4). These effects are captured in performance assessment as described in Chapter 6.0 (Section 6.4.3.3).

The results of this performance assessment show that release of radionuclides is sensitive to the quantity of gas generated. There are two release mechanisms, direct brine release and spallings, that occur only if the pressure in the repository exceeds 8 megapascals (for example, Appendix MASS, Stoelzel and O'Brien, Attachment 16-2, and Appendix SA, Figures SA-8 and SA-17). Eight megapascals corresponds to the hydrostatic pressure at the repository depth in a column of drilling mud. If repository pressure is sufficient for these two direct release mechanisms to occur, the quantity of radionuclides released is controlled by factors other than the total pressure in the repository.

The waste inventory contains sufficient ferrous and ferrous-alloy components that gas could be generated significantly in excess of that required to reach 8 megapascals in the repository. The predicted long-term performance of the repository is improved if insufficient gas is generated to produce pressures of 8 megapascals, because direct brine release and spallings mechanisms do not occur at lower pressures. The actual quantity of gas generated is not solely a function of the emplaced waste, but depends as well on the quantity of brine that flows into the repository and is available to corrode the metal. Since low gas generation (resulting in pressures less than 8 megapascals) is controlled by processes not related to waste components (for example, brine inflow), and because performance assessment results are not sensitive to gas generation in excess of that required to produce a repository pressure of 8 megapascals, it is unnecessary to place restrictions on the quantity of ferrous and ferrous-alloy metals emplaced for the purpose of controlling the quantity of gas generated.

Ferrous and ferrous-alloy metals (and their corroded products) provide the reactants that reduce radionuclides to lower and less-soluble oxidation states. As discussed in Appendix WCA, the anticipated quantity of these metals to be emplaced in the WIPP is two to three orders of magnitude in excess of the quantity required to assure reducing conditions. The waste containers supply more than enough iron to provide adequate reductant. Therefore, no upper or lower limit need be established for the quantity of ferrous and ferrous-alloy metals that may be emplaced, beyond the present projection of containers.

WCL.3 Cellulose, Plastic, Rubber, Nitrate, and Sulfate Components

The cellulose, plastic, rubber, nitrate, and sulfate components of the waste influence the production of CH_4 gas in the repository by microbial action. Performance assessment assumes that the process of microbial degradation is viable only 50 percent of the time. Therefore, a lower limit for these materials is effectively zero. As discussed in the preceding section, releases are not sensitive to the quantity of gas generated, and the inventory of ferrous and

ferrous-alloy metals is already in excess of that required to produce a significant amount of gas, which is that amount required to produce pressures of 8 megapascals, or greater. Therefore, the additional influence of components influencing microbial degradation are negligible, and it is unnecessary with respect to gas generation to assign an upper limit on the amount of cellulosics that may be emplaced in the repository, with one caveat. One of the barriers incorporated into the design of the WIPP facility as an assurance requirement is MgO backfill (Chapter 7.0, Section 7.4.3). The amount of MgO backfill currently projected for the WIPP is in excess of the amount needed to react with the CO_2 produced (Appendix SOTERM, Section SOTERM.2.2). A coarse upper limit is set on the sum of cellulosics, plastics, and rubbers to ensure that the amount of MgO emplaced is adequate.

WCL.4 Solid Components

Solid components in the waste affect the waste characteristics of effective shear resistance to erosion, particle size, and tensile strength. These properties affect the cavings and spallings releases. The basic assumption for the assignment of these properties is that fully degraded waste will have the least favorable properties, and will eventually be similar to granular materials whose properties can be measured today. The actual properties of the waste over the 10,000-year regulatory period are unknown, since the physical nature of the degraded waste is unknown. The parameter values assigned are chosen to conservatively reflect measured properties of natural and constructed materials. These properties are reasonable analogs for degraded waste. The effective shear resistance to erosion (see Appendix PAR) used to calculate cavings is based on the erodibility of unconsolidated marine clays and other easily eroded materials, and is considered to be near a physical limit for the minimum value of this property. The minimum particle size (see Appendix PAR) used in the range for the spallings model is based on assuming an average pore diameter consistent with an average waste permeability; this value is considered conservative because in reality the waste will not have a uniform distribution of permeability (see Appendix SA, Section SA.3). The larger particles will define the more permeable pathways, along which most gas will flow during a spalling event, and larger particles are less likely to spall than small particles. Last, the strength of the waste assigned for the spalling process is fixed at 1 pound per square inch, which is considerably less than the measured strength of granular materials that were assumed to have properties analogous to those of degraded waste (Berglund et al. 1996).

The properties assumed for solid components in performance assessment bound the least favorable behavior of these components. Therefore, the performance assessment analysis is not conditional on the quantities and kinds of solid components that will be emplaced.

WCL.5 Water Component

The water component in the waste is the subject of other regulations. The amount of water emplaced with the waste can affect the rate at which gas is generated for a short period soon after closure, but the small quantity of water acceptable in the waste is not of concern for long-term performance. Consequently, there is no need to monitor water in the waste for

compliance with 40 CFR § 194.24(c). In fact, the quantity of water in the waste used for performance assessment calculations is greater than the Waste Acceptance Criteria allow, so the only limit on free water content of the waste is set by the Waste Acceptance Criteria.

WCL.6 Humic Substances Component

Humic substances are likely to be introduced into the repository as a component of wastes containing soils or may form in situ from reactions involving microbial metabolites produced during degradation of cellulosics. Humic substances will dissolve until a solubility limit is reached. Dissolved humic substances are colloidal in nature and may complex radionuclides. The radionuclide-bearing humic colloids may be transported in moving liquid and contribute to a radionuclide release.

In performance assessment, a steady-state concentration of humic colloids is assumed to exist in the repository during the performance period. This concentration is not inventory limited; in other words, it is assumed in performance assessment that sufficient source materials exist that a constant concentration of humic colloids will be present at all times. Because it is assumed that there is sufficient solid material present for a steady-state concentration to exist at all times in the repository, performance assessment results are not conditional on the quantity of total humic substances present, and there is effectively no limit to the quantity of humic substances that may be emplaced in the repository. If few humic substances are present, then the concentration of humic colloids will be less than that assumed in performance assessment, with negligible or beneficial consequences to the overall analysis. Therefore, no minimum limit is necessary for the quantity of humic substances to be emplaced in the WIPP.

WCL.7 Nonferrous Metals Component

The nonferrous metals present in the waste stream impact performance assessment because they will dissolve and bind to organic ligands, thereby reducing the impact of organic ligands on the solubility of radionuclides. According to the existing and projected inventory and composition of waste canister steels, these components will be emplaced in considerable excess of that required to sequester organic ligands. Assay is therefore not required for these metals (see Appendix SOTERM, Section SOTERM.5). Calculations for low-ionic strength NaCl solution showed that the available Ni alone can complex 99.8 percent of available EDTA, rendering it unavailable for complexation with actinides.

WCL.8 Organic Ligands Component

The effects of organic ligands were eliminated from this performance assessment because the presence of large quantities of magnesium from the MgO backfill (see Appendix SOTERM, Section SOTERM.6) effectively sequesters organic ligands in the repository and thereby prevents them from influencing the concentration of dissolved actinides. The actual inventory of organic ligands is difficult to quantify, and if considerably more organic ligands are

contained in emplaced waste than presently estimated (refer to TWBIR, Appendices B3 and B4), actinide solubilities could be affected. Increased amounts of organic ligands in the waste stream would have an insignificant effect on performance of the WIPP disposal system because of the more likely preferential binding of organic ligands with magnesium and other nonferrous metals, which will render them ineffective in increasing radionuclide solubilities. The quantity of organic ligands in existing and future waste is extremely small, so the use of organic ligands in processes that generate waste will be monitored. If the rate of use of organic ligands in waste-generating processes increases significantly over current usage, the DOE will take action to control the quantity of organic ligands emplaced in the repository.

WCL.9 Summary of Activities to Satisfy Criteria in 40 CFR § 194.24(c)

As shown in the preceding discussion, the only activity that is necessary to satisfy the requirements of 40 CFR § 194.24(c)(4) and (5) is tracking changes in future projections of total inventory curie content. The purpose of tracking is to assure that the ratio of emplaced activities of the ten waste component radionuclides recommended for assay is either similar to that assumed in this performance assessment or reflected in performance assessments used for re-certification. Coarse lower limits are set on ferrous and non-ferrous metals. These limits are based on current estimates (see TWBIR, Tables 3-2 and 3-4, and Appendix SOTERM, for quantity of nonferrous metals used). A coarse upper limit is set on the sum of cellulose, plastics, and rubbers to ensure that the amount of MgO emplaced is adequate. The only other limits that need to be imposed are those set by the Waste Acceptance Criteria. This conclusion was reached after (1) consideration of the components in the waste, which are discussed in Appendix WCA, (2) analysis of the results of the performance assessment, which are discussed in Section 6.5 and Appendix SA, and (3) consideration of the assumptions made regarding waste component availability and their physical properties for the performance assessment, which are discussed in Section 6.4 and supporting appendices.

REFERENCES

Berglund, J.W., J. Myers, and L.R. Lenke. 1996. Memo to M.S.Y. Chu, "Estimate of the Tensile Strength of Degraded Waste for Use in Solids Blowout," July 19, 1996. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM, as WPO 39423.)

EPA (U.S. Environmental Protection Agency). 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. *Federal Register,* Vol. 61, pp. 5224-5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C.

U.S. Department of Energy. 1996. *Transuranic Waste Baseline Inventory Report (Revision 3).* DOE/CAO-95-1121. Carlsbad, NM: U.S. Department of Energy.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix WRAC

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Waste Removal After Closure

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ACRONYMS

CAG	Compliance Application Guidance
CFR	Code of Federal Regulations
CH	contact-handled
DOE	Department of Energy
DRZ	disturbed rock zone
EPA	U.S. Environmental Protection Agency
GSSI	Geophysical Survey Systems, Inc.
HEPA	high efficiency particulate air
HSLA	high-strength low alloy
LWA	Land Withdrawal Act
MB	marker bed
MgO	magnesium oxide
RH	remote-handled
SWB	standard waste box
TRU	transuranic
WHS	waste handling shaft
WIPP	Waste Isolation Pilot Plant

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APPENDIX WRAC

This analysis discusses the techniques that could be applied in removing transuranic (TRU) waste from the Waste Isolation Pilot Plant (WIPP) repository after disposal. Title 40 Code of Federal Regulations (CFR) § 191.02(l) defines disposal of waste in a mined geologic repository as occurring ". . .when all of the shafts to the repository are backfilled and sealed." This report will serve to document compliance with the requirement in 40 CFR § 191.14(f) that the disposal system not preclude ". . .removal of most of the waste . . .for a reasonable period of time after disposal." The removal discussion is based on currently available technologies. The reasoning for waste removal is not considered relevant except that it is assumed the destination and transportation mechanism for the removed waste will be known. Transportation methods, end use, and destinations of the removed waste are not considered in this analysis.

WRAC.1 WIPP Mission Description

The WIPP is a research and development facility of the U.S. Department of Energy (DOE) designed to demonstrate the safe transportation, handling, and disposal of defense-generated TRU radioactive waste. The facility is located 26 miles (42 kilometers) east of Carlsbad, New Mexico. The repository is located in a salt deposit, 2,150 feet (655 meters) below ground. The waste will be shipped to the facility from numerous generator sites around the United States and placed in the underground repository for disposal. Figure WRAC-1 details the WIPP location and Figure WRAC-2 contains a diagram of the WIPP surface and underground facilities. The facility is scheduled to begin disposal operations in 1998. A comprehensive description of the WIPP disposal system is presented in Chapter 2.0. A description of the planned operation and closure of the facility is in Chapter 3.0. The waste is described in Chapter 4.0.

WRAC.2 Analytical Scope

This analysis examines the feasibility of removing emplaced waste from the WIPP repository after closure. The regulatory and technical bases for removal are discussed. The emplacement and closure scenarios are defined to describe the condition of the repository and waste after closure. The sequence of steps for removal are described including a detailed discussion of their implementation. Since today's equipment is used to mine materials deposited millions or billions of years ago, it is technically feasible to remove the waste anytime during the regulatory time frame. The feasibility of waste removal is demonstrated by describing a method for waste removal.

For the purposes of this feasibility analysis, it is important to distinguish the difference between waste removal and waste retrieval. Waste removal differs from waste retrieval in that removal refers to actions taken after the repository is closed and sealed. Retrieval, which is essentially the reverse of emplacement, refers to recovering the waste prior to waste panel closure. This analysis specifically deals with waste removal.

WRAC.3 Regulations Applicable to This Feasibility Analysis

As an assurance requirement in 40 CFR Part 191, waste removal is one of several cautious steps that are to be taken to reduce the problems caused by the uncertainties inherent in the long-term predictions of disposal system performance. The EPA believes that recovery of the waste, though not necessarily easy or inexpensive, would be prudent in the event some future discovery or insight made it clear that the wastes needed to be relocated. The EPA provides specific insights regarding the implementation of this requirement as well as criteria in 40 CFR Part 194 for judging the adequacy of the DOE's demonstration of compliance to this requirement. Each is discussed below.

WRAC.3.1 40 CFR Part 191 Requirements

40 CFR § 191.14(f) states, "Disposal systems shall be selected so that removal of most of the waste is not precluded for a reasonable period of time after disposal". With respect to the recovery of waste after disposal, the preamble to 40 CFR Part 191 (50 *Federal Register* (FR) 38082) states that

> ...any current concept for mined geologic repository meets this requirement without any additional procedures or design features. For example, there is no intent to require that the repository shafts be kept open to allow future recovery. To meet this assurance requirement, it only need be technically feasible (assuming current technology levels) to be able to mine the sealed repository and recover the waste - albeit at substantial cost and occupational risk." (EPA 1985).

WRAC.3.2 40 CFR Part 194 Certification Criteria

40 CFR § 194.36 states that

> Any compliance application shall include documentation which demonstrates that removal of waste is feasible for a reasonable period of time after disposal. Such documentation shall include an analysis of the technological feasibility of mining the sealed disposal system, given technology levels at the time a compliance application is prepared.

By way of guidance for the requisite analysis referenced in the criterion, the EPA has provided a specific list of expectations in its Compliance Application Guidance (CAG) (EPA 1996). In the CAG, the EPA states:

> EPA expects the required analysis to include:
>
> - a sequence of procedures or steps which would need to be accomplished in order for waste to be removed from the disposal system after closure;
>
> - a discussion of how the sequence described above could be implemented, including descriptions of how currently available equipment and technologies could be utilized; and

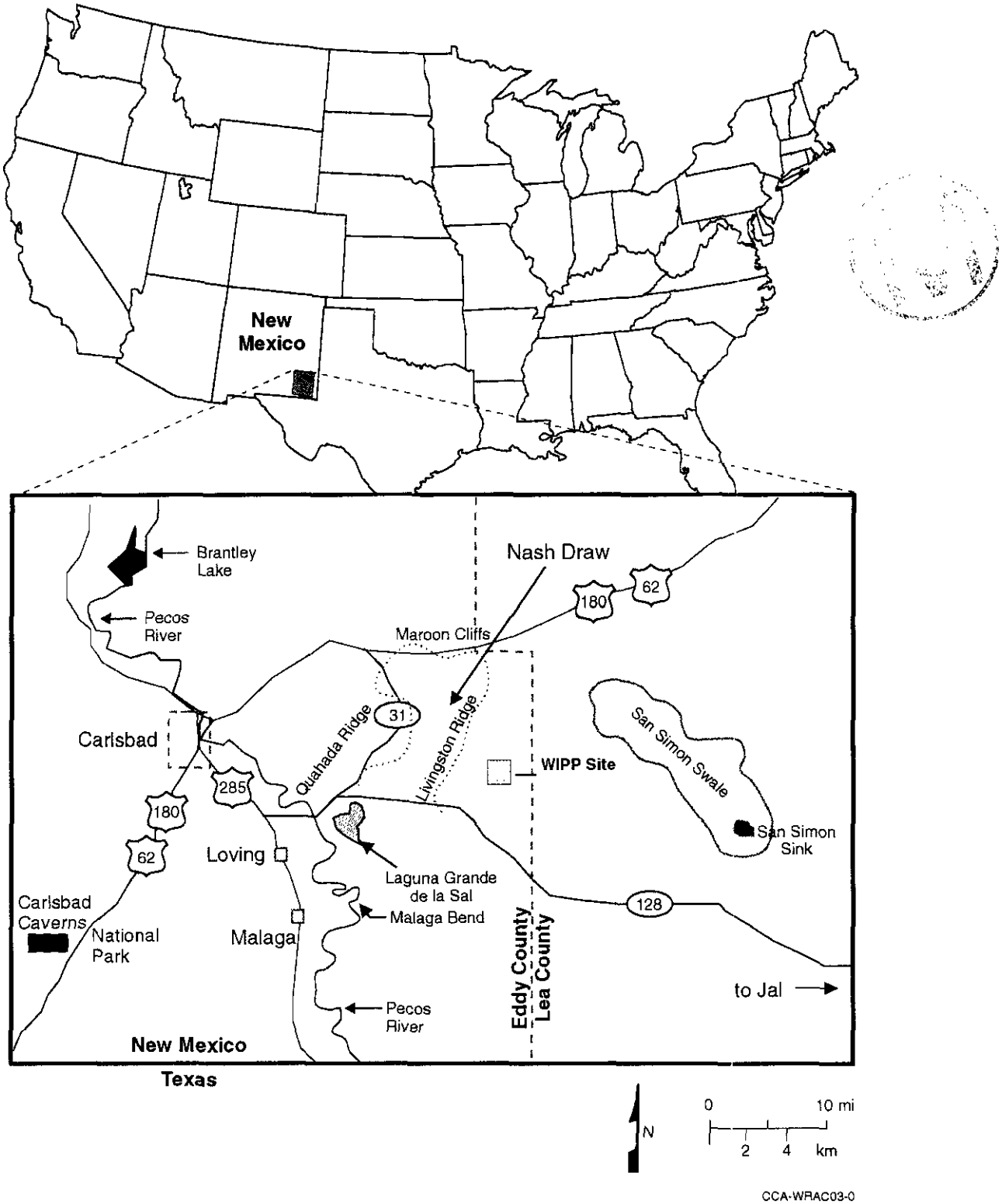

Figure WRAC-1. General Location of the WIPP Facility

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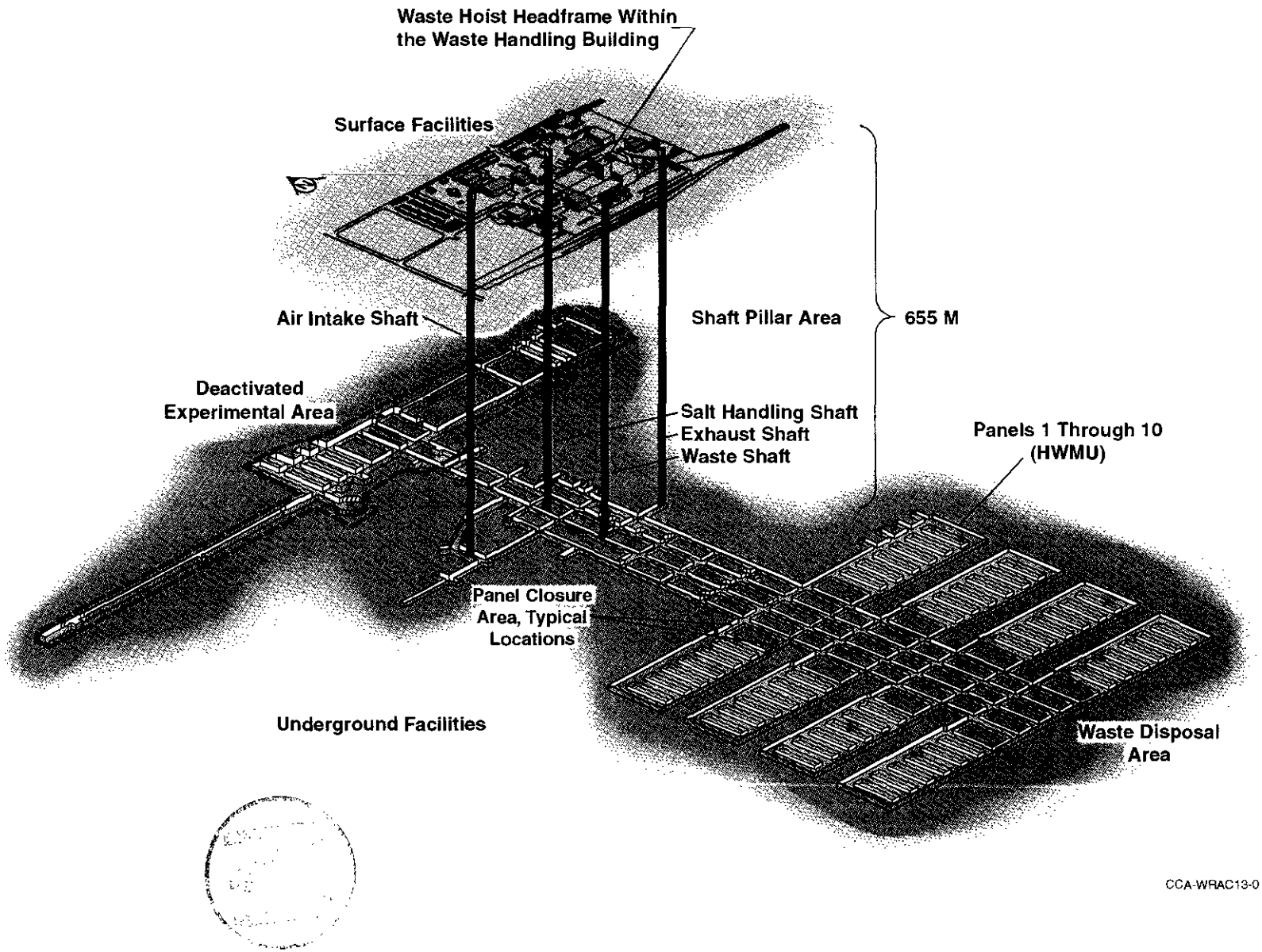

Figure WRAC-2. WIPP Surface and Underground Facilities

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- an estimate of how long after disposal it would be technologically feasible to remove the waste, based on the disposal system design and closure, and using the system and equipment described in the application. (EPA 1996, 66)

The following feasibility analysis examines and addresses this criterion and the implementation guidance. Background information is provided as part of the feasibility analysis. This background information includes a description of the disposal system and the waste at the time of disposal and the assumed condition at the time of removal (to the practicable extent to which this condition can be anticipated).

WRAC.4 WIPP Repository Description

The WIPP will dispose of TRU waste in rooms 2,150 feet (655 meters) below the surface. These rooms are mined in a bedded halite (salt) layer known as the Salado Formation (hereafter referred to as the Salado). The Salado is approximately 2,000 feet (610 meters) thick at the repository location. Figure WRAC-3 shows the general geologic cross section of the WIPP site. The underground repository is mined on one contiguous working level. With the exception of the shafts and sumps, no excavations are located above or below this level. The waste will be emplaced in eight panels, each panel composed of seven rooms, and the inter-connecting access entries (drifts) identified as Panels 9 and 10. The rooms are mined to the initial dimensions of 300 feet long by 33 feet wide by 13 feet high (91 meters by 10 meters by 4 meters). The repository layout is shown in Figure WRAC-4. The waste will be emplaced in the shaded areas of Figure WRAC-4.

The waste will be composed of radioactive and hazardous waste materials generated by the DOE's nuclear weapons programs. The materials are primarily laboratory and production equipment such as glassware, solidified spent solvents, cleaning rags, laboratory clothing, solidified sludges, metal tools, pipes, plastics, and paper. TRU waste is defined as waste contaminated with alpha emitting radionuclides having atomic numbers greater than 92, half-lives greater than 20 years, and a specific activity greater than 100 nanocuries per gram. Some of the waste to be disposed of at WIPP will contain hazardous constituents as defined by the Resource Conservation and Recovery Act (RCRA). This waste is referred to as TRU mixed waste. The waste is currently generated or stored at numerous sites in the United States.

There are two classifications for the TRU waste, contact-handled (CH) TRU and remote-handled (RH) TRU. The CH-TRU waste is defined as TRU waste packaged in containers whose maximum surface dose rate does not exceed 200 millirem per hour. Surface dose rates greater than 200 millirem per hour are classified as RH-TRU waste. For emplacement into the WIPP the RH-TRU surface dose rates cannot exceed 1,000 rems per hour with a maximum total of five percent of the canisters exceeding 100 rems per hour. The total maximum activity for RH-TRU waste at WIPP cannot exceed 5.1 million curies. These limits including a maximum TRU waste volume of 6,200,000 cubic feet (175,588 cubic meters) are established by the Land Withdrawal Act (LWA).

The high radiation associated with RH-TRU waste is due to the presence of isotopes of cesium, strontium, barium, plutonium, and yttrium. The longest half-life among these isotopes is 30.0 years. Therefore, after about 300 years, the isotopes will have gone through a minimum of 10 half-lives and their radioactivity, relative to the longer lived isotopes associated with the CH-TRU waste, will be significantly diminished. For this reason, in discussion of the removal of waste after 300 years, the DOE does not distinguish between the RH-TRU and CH-TRU types.

It is anticipated that a majority of CH-TRU waste will be shipped to the WIPP in either 55-gallon (208 liter) drums or standard waste boxes (SWBs). The 55-gallon drums will be strapped together in an arrangement of seven drums called seven-packs. A seven-pack and an SWB are shown in Figure WRAC-5. Rows of containers will be placed in the rooms three high. The waste will also be emplaced in the panel access entries. After a panel is filled, a closure system will be constructed to isolate the waste from further operations. The closure system conceptual design uses concrete.

A backfill consisting of magnesium oxide (MgO) will be placed over, within, and around the containers of CH-TRU waste. Backfill will be emplaced in super sacks over the top of the waste stack and mini sacks within and around the waste. Backfill sacks are intended to burst as the room creeps closed, allowing the granular materials to be exposed to the room environment. Alkaline earth oxides (such as MgO) are known to readily react with water to form hydroxides. These hydroxides are free to react with carbonic acid that may form in the disposal room. The reaction buffers the brine to a pH which serves to reduce the amount of actinides in solution.

The RH-TRU waste canisters are constructed of painted carbon steel, 26 inches (66 centimeters) in diameter with a maximum length of 121 inches (307.3 centimeters). The maximum weight of a filled canister is 8,000 pounds (3628.7 kilograms) (DOE 1991). In order for personnel to handle the RH-TRU waste, the RH waste canisters must be shielded to reduce radiation levels to allowable limits. The shielded facility cask is used to transport RH-TRU waste to the underground. The RH-TRU waste canister will be emplaced in a disposal room wall prior to CH-TRU waste emplacement in that room. The waste canister is pushed out of the facility cask and into a horizontal borehole in a disposal room wall. The borehole is then closed with a shield plug. The shield plug is a cylinder 29 inches (73.7 centimeters) in diameter and 70 inches (177.8 centimeters) long with a wall thickness of 1.5 inches (3.8 centimeters). The bottom of the plug is constructed from a 5-inch (12.7-centimeter) thick plate. The 3-inch (7.6-centimeter) thick top plate also has a standard waste handling pintle. The total weight of the plug is approximately 4,200 pounds (1,905 kilograms). All emplaced RH-TRU waste locations will be recorded.

WRAC.4.1 Repository Configuration at the Time of Closure

The anticipated final configuration of the repository at the time of closure is shown in Figure WRAC-6. This is the configuration that is used as input to the conceptual model developed to

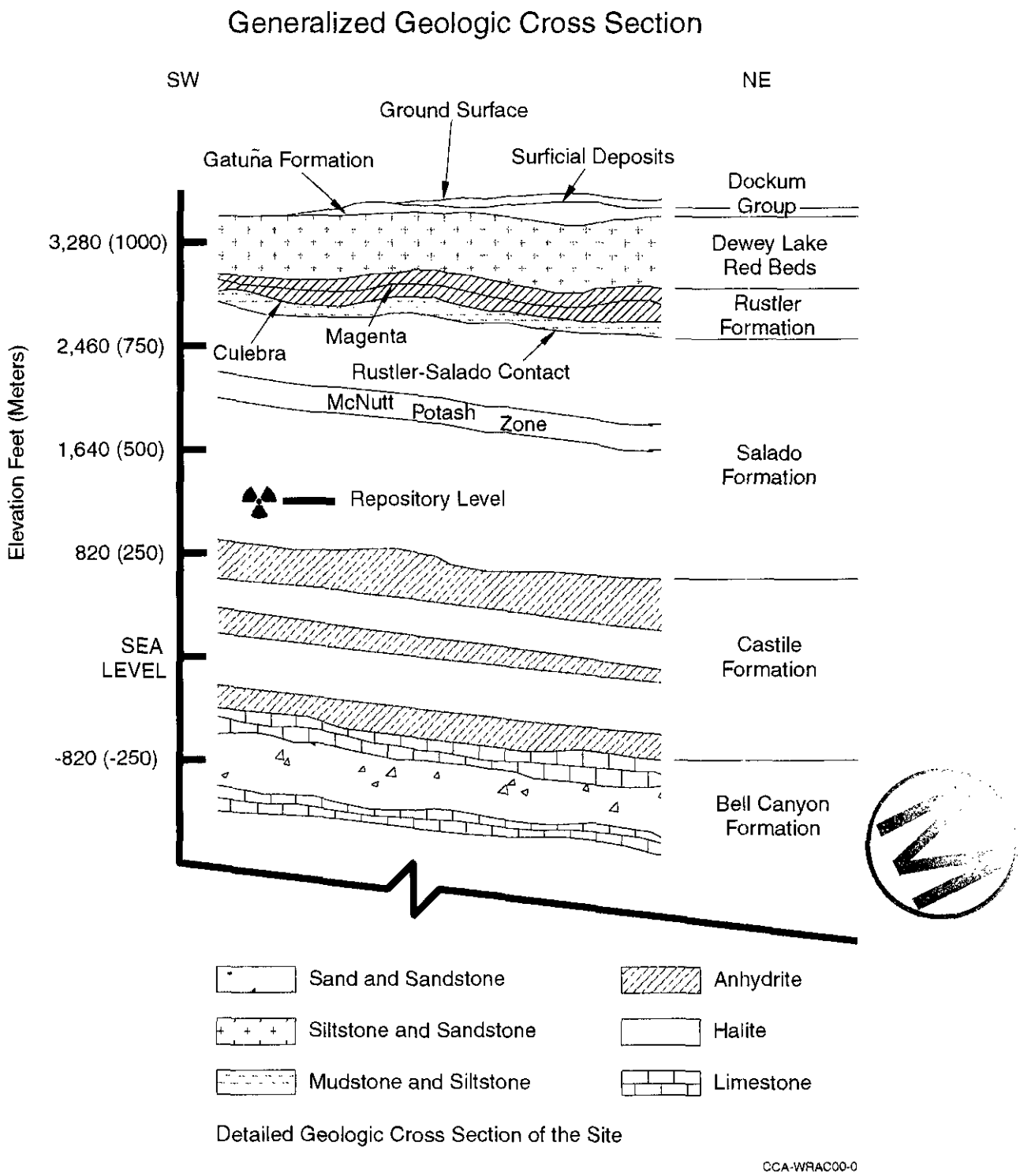

Figure WRAC-3. Generalized Geologic Cross Section

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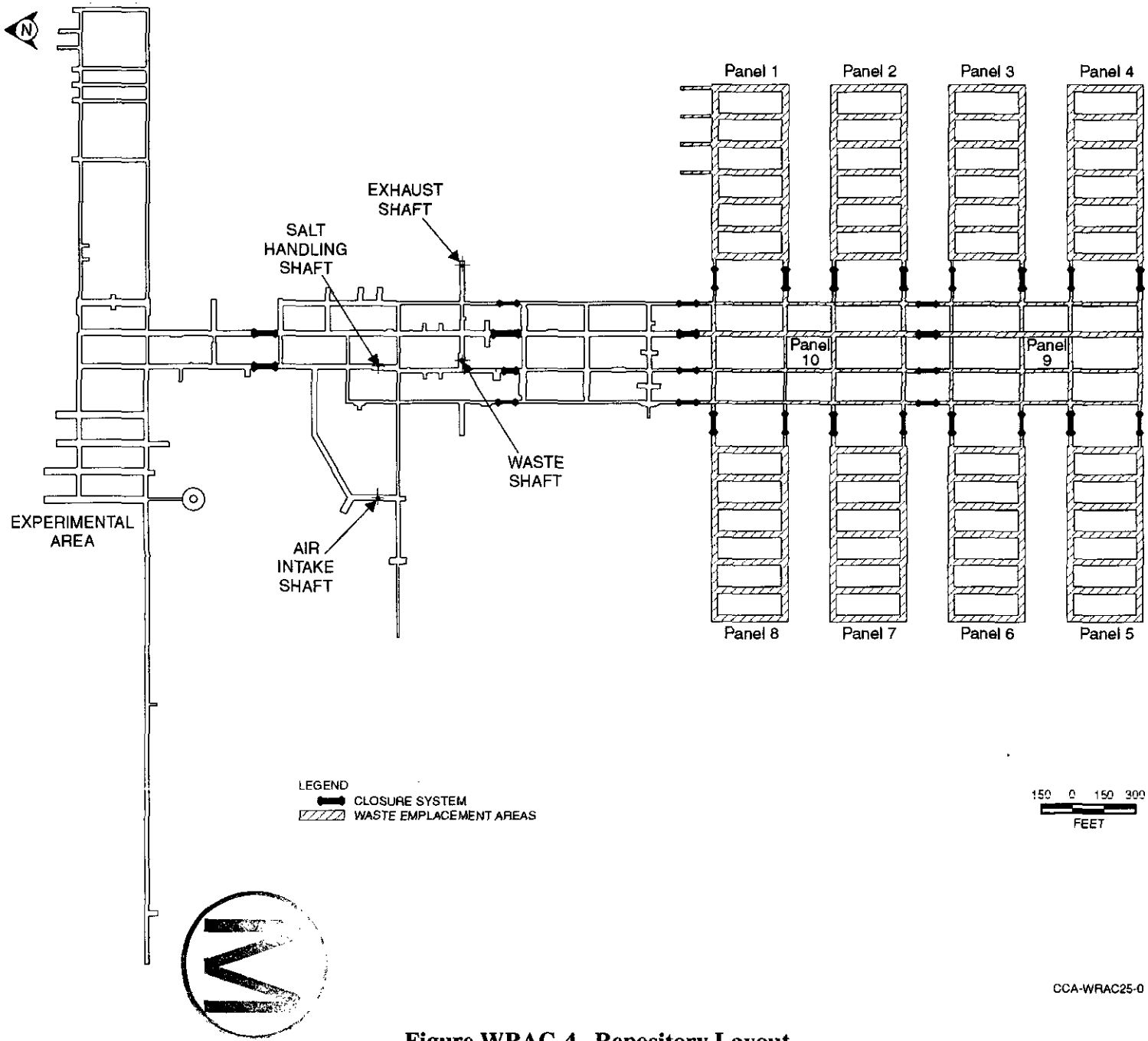

Figure WRAC-4. Repository Layout

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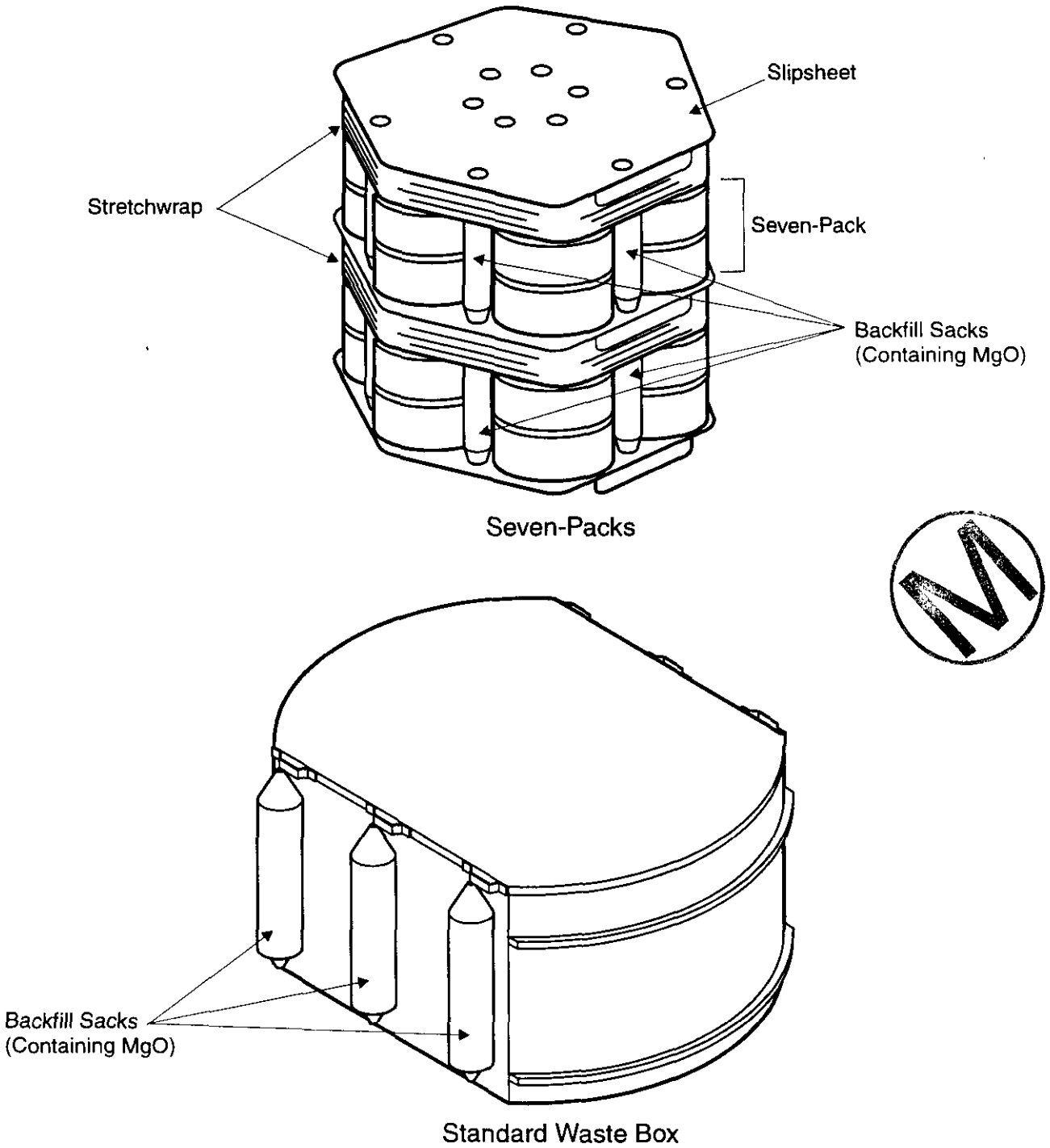

Figure WRAC-5. SWB and Seven-Pack Configuration

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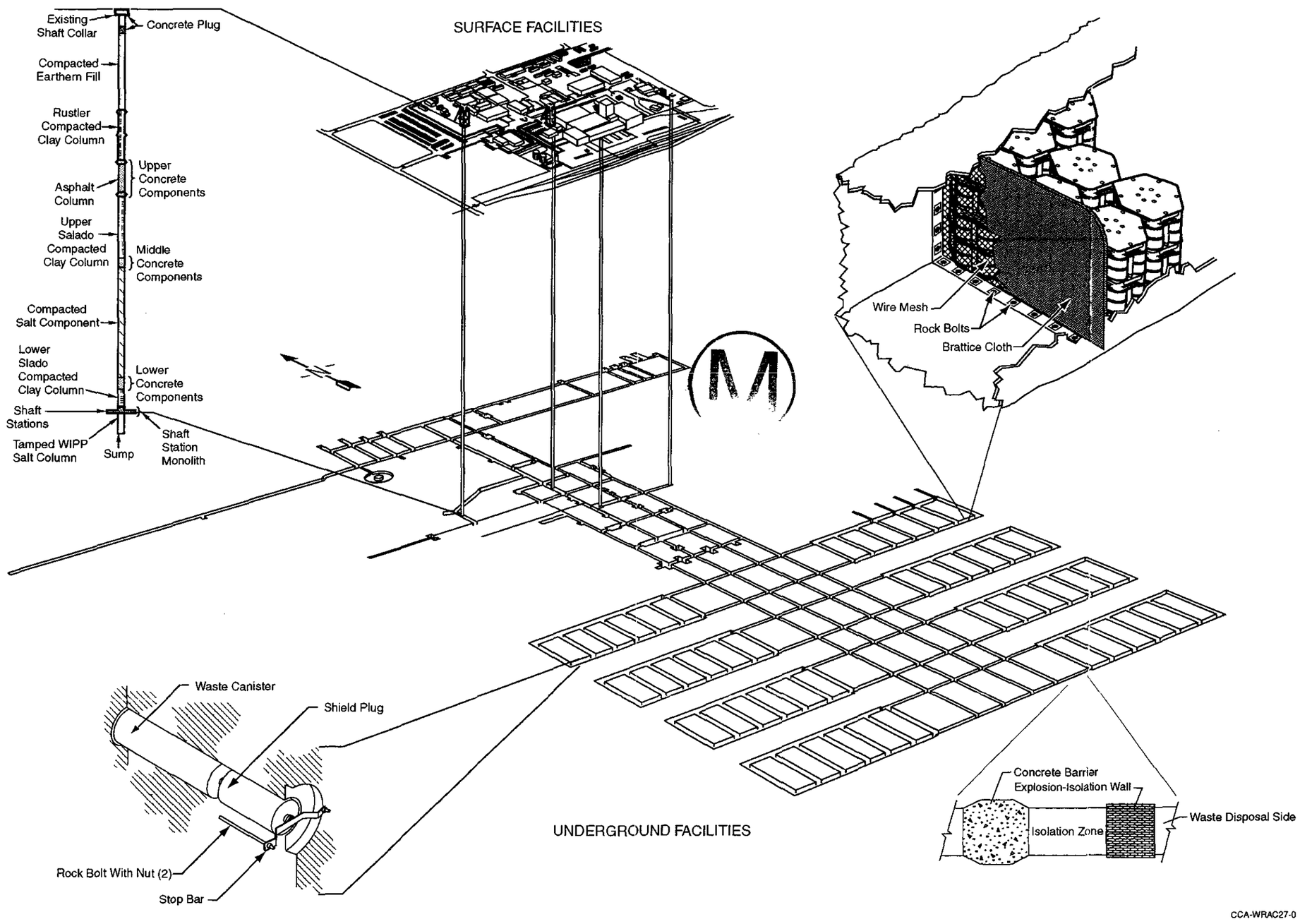

Figure WRAC-6. WIPP Repository at Time of Closure

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predict repository performance. The model geometry is discussed in Chapter 6.0, Section 6.4.2.1 and includes 30 separate elements. Those of interest to this analysis are Regions 23 to 27 in Figures 6-13 and 6-14 in Chapter 6.0. These regions include the waste disposal panel (Region 23), panel closures (Region 25), the panels and access drifts in the rest of the waste disposal area (Region 24), the operations region (Region 26), and the experimental region at the north end of the excavation (Region 27). In addition, the conceptual model described in Section 6.4 of Chapter 6.0 incorporates the stratigraphic units surrounding the repository into the model as discrete regions. These include the Salado Formation outside the disposal region (Region 19), MB138 (Region 20), Anhydrite Layers A and B (Region 21), the disturbed rock zone (Region 22) and MB139 (Region 28) (as shown in Figure 6-13 in Chapter 6.0). Parameter values have been assigned to important properties (such as porosity and permeability) of these various regions. Initial values and value ranges are summarized in Table 6-8 in Chapter 6.0 and are detailed in Appendix PAR.

The LWA limits the total disposed TRU waste to 6,200,000 cubic feet (175,600 cubic meters). After waste emplacement is complete, the surface structures will be decontaminated and decommissioned. This will include decontaminating the surface facilities and dismantling the aboveground structures. TRU waste generated by these activities will be emplaced in the repository, the last waste panel will be closed, and the remaining access entries will be backfilled. The four shafts will be sealed using crushed Salado salt in combination with other materials such as concrete, cementitious grout, clay, and asphalt. Appendix SEAL details the shaft seal design.

WRAC.4.2 Repository Condition at Time of Removal

The requirement to remove the waste does not specify when or if removal would occur, only that removal not be precluded. The condition of the repository is time dependent with respect to salt reconsolidation and waste compaction. For the purposes of this analysis, the DOE assumes that the reason for removal is the result of a discovery or insight gained by a future generation and not the result of an event that necessitates removal. This is reasonable because any such event that would make it necessary to remove waste would have to be cataclysmic in nature (such as meteor strike or volcanic activity). Such events, if they were sufficiently likely to be of concern, would be included in the assessment of the disposal system performance. All such events have been screened out as unlikely as discussed in Section SCR.1 of Appendix SCR. As the result of this assumption, there are no time or cost limits imposed on the removal process in this analysis. Radioactive contamination within the disposal region can be removed at whatever rate is necessary to safely manage occupational and public exposure.

Additional assumptions include the following.

- The reason for waste removal is known and what will be done with the waste is unimportant. This analysis need only demonstrate removal feasibility.

- The length of time the repository has been closed at the time of removal is known to those planning the removal and the anticipated conditions of the waste panels and panel closure can be determined for use in designing removal systems (see Chapter 6.0 and Appendix SCR for a discussion of rock creep and porosity and permeability values assumed for performance assessment).

- The CH-TRU containers have been breached.

- Removal of most of the waste means that all waste within the disposal region will be removed, however contamination that has migrated into marker beds and moved out of the disposal region will not be removed.

Numerical calculations have been performed for the repository which are focused on predictions of performance over 10,000 years. In the shorter term, the configuration of the excavation and waste within the repository is changing as it reaches a steady state configuration. As steady state is reached, the brine inflow rate is affected by the increasing pressure in the repository caused by gas generation and creep closure. These three phenomena are related in the numerical modeling that is detailed in Chapter 6.0. All of these phenomena and the various associated states of the excavation need to be considered in evaluating the feasibility of removal. In no case, however, are conditions expected to render removal impossible.

Gas generation affects pressure within the excavation, which in turn is an important parameter in creep closure. The computer simulation of this process uses an average-stoichiometry model to estimate the potential for gas generation in the waste disposal region. Parameter values for the average-stoichiometry gas generation model are in Section 6.4.3.3 of Chapter 6.0. Modeling shows that gas pressure in the disposal room can range from slightly above atmospheric to near lithostatic. The model assumes that interbed fracturing occurs at high pressures thereby limiting pressure buildup. If the agency removing the waste in the future anticipates that high pressures are present, techniques are available to detect and safely relieve such pressures. Such techniques are currently in use in the WIPP to prevent dangerous pressure blowouts from localized pressurized zones ahead of mining. The technique involves drilling small diameter probe holes into the rock ahead of the mining machine.

For the computer simulation used in this analysis, the DOE conceptualized the Salado as a porous medium composed of several rock types arranged in layers, through which fluid flow occurs according to Darcy's Law. This model was chosen because it can be simulated using standard numerical techniques and because it is the most conservative of the three mechanisms in that it predicts the maximum rate and cumulative volume of brine inflow. Two rock types, impure halite and anhydrite, are used to represent the intact Salado. Near the repository, the disturbed rock zone (DRZ) has increased permeability compared to intact rock and offers little resistance to flow between anhydrite interbeds and the repository. Except for the DRZ and anhydrite interbeds, under certain circumstances, this simulation assumes spatially constant properties for Salado rock repository. The inference is that there is little

variation in large-scale averages of rock or flow properties across the disposal system. Assumptions about Salado flow in general are presented in Section 6.4.3.2 of Chapter 6.0. This model serves to maximize the potential brine inflow to the repository.

In the computer simulation, brine flows from the Salado and into the repository in response to fluid potential gradients that form over time. Because of the low permeability of the impure halite and relatively small surface area of the excavation, direct brine flow between the impure halite and the repository is limited. The interbeds, however, can serve as conduits for brine flow between the impure halite and the repository. Conceptually, brine flows laterally along higher-permeability interbeds towards or away from the repository and vertically between the interbeds and the lower-permeability halite. Because the interbeds have a very large contact area with adjacent halite-rich rock, even very small flux from the halite into the interbeds (for brine inflow) or to the halite from the interbeds (for brine outflow) can accumulate into a significant quantity of brine.

Alternatively, in the modeling for the disturbed case, brine could flow into the repository as the result of a drill hole that connects a disposal panel with the Castile Formation. In such a case, a portion or all of the excavation could be saturated with brine. Removal feasibility must consider a range of brine saturation ranging from dry to saturated.

Creep closure of the excavation is the focus of a computer model that implements the repository processes associated with rock properties in the repository rooms and the shafts. The amount of waste consolidation resulting from creep closure, and the time it takes to consolidate the waste, are governed by properties of the waste (waste strength), properties of the surrounding rock, the dimensions and location of the room, and the quantities and pressure of fluids present in the room. Creep closure of waste disposal areas will cause their volume to decrease as the Salado deforms to consolidate and encapsulate the waste, changing waste porosity and permeability. Waste strength and fluid pressure may act to resist creep closure. The conceptual model implementing creep closure is discussed in Section 6.4.3.1 of Chapter 6.0.

Fluids that could affect closure are (1) brine that may enter the repository from the Salado and is present in the repository when it is sealed, and (2) gas produced by reactions occurring during waste degradation. Closure and consolidation slowed by fluid pressure in the repository can be quantified according to the principle of effective stress:

$$\sigma_T = \sigma_e + p \qquad (1)$$

where σ_T is the stress caused by the weight of the overlying rock and brine (an essentially constant value), p is the pressure of the repository pore fluid, and σ_e is the stress that is applied to the waste skeleton or matrix. In this formulation, the waste is considered a skeleton structure immersed in pore fluids. As the pore pressure increases, an increasing amount of overburden stress is supported by pore fluid pressure, and less overburden stress is supported by the strength of the waste matrix. Because of the strength, waste consolidation can cease

even if pore fluid pressures do not reach lithostatic. If gas and brine quantities in the repository stabilize, creep closure will act to establish a constant pressure and void volume.

Creep closure becomes an important consideration for the removal process since it determines, to a major extent, the dimensions of the excavation that is needed to remove the waste and the condition of the rock that must be mined. Conditions where the creep has been minimal also indicate the situations where brine content or gas pressure are highest and represent the most hazardous conditions.

WRAC.4.3 Summary of Conditions to Be Anticipated for Removal Feasibility

Based on the descriptions in the preceding sections, there are five potentially hazardous conditions that must be anticipated in preparing for the removal of disposed waste. These are radioactivity, hazardous constituents, gas, brine, and rock integrity.

The amount of radioactivity depends on the time at which removal is initiated. Within the first 300 years of disposal, it may be necessary to consider treating (removing) RH-TRU and CH-TRU waste differently, because of higher radioactivity. Beyond 300 years, all the waste can be managed as CH-TRU waste. Regardless of when removal is initiated, the inventory of the waste documentation that will be accumulated by the DOE during operations and archived after closure will contain sufficient information to determine rather precisely the radioactivity levels to be anticipated and the locations of any containers of waste that may pose higher radioactivity hazards.

With regards to the hazardous constituents in the waste, the volatile organics do not occur in sufficient quantities to pose a hazard as long as adequate ventilation is provided. Non-volatile hazardous constituents only pose threats if they are released during the removal process. Here, as with both the volatile components and the radioactive contaminants, proper ventilation will be needed to provide adequate protection to workers, the public, and the environment. If environmental protection laws are the same at the time of removal as they are today, the planning for removal will require that the agency implementing removal provide detailed plans for controlling hazardous constituent contamination.

Gas pressures can range from one atmosphere (14.7 pounds per square inch or 0.101 megapascals) to pressures near 2,000 pounds per square inch (13 megapascals). Experience with mining in halite indicates that in virgin rock, high pressure zones are maintained because of the low permeability of the rock. Therefore, mining activities are conducted in anticipation of pressure in areas where such pressures are known to exist. Due to the nature of the disposal operations and the panel closure practices, pressures could vary from panel to panel.

Brine quantities can vary from little to no brine, caused by brine consuming processes such as corrosion and microbial degradation, to panels full of brine as the result of a borehole that connects the repository with a brine pocket in the Castile Formation. As with gas, the quantity

of brine can be different from one panel to the next because of the anticipated efficiency of the panel closures.

The amount of pore space in a disposal panel can be used to represent the degree of consolidation that has occurred due to creep closure. While brine and gas can act to maintain rather large pore volumes in a sealed panel, this condition is considered unlikely since creep closure acts fairly rapidly and it is unlikely that sufficient brine and subsequent gas will be available to support large pore volumes without an external source such as a Castile brine pocket. Because active and passive controls are expected to deter human intrusion for up to 700 years after closure, an encounter with such a brine source is not expected during this time period. Consequently, the repository is expected to reach its maximum closure before large quantities of brine are available. In this case, the resulting pore volume is likely to be about 30 percent and the excavation will have closed to less than half of its original height.

Each of the factors above represent variable conditions that the removal planning activity must evaluate prior to actually removing the waste from the repository. None of these are expected to create conditions that will render the waste impossible to remove. However, the safety hazards imposed by the ranges of possible conditions dictate careful evaluation and appropriate planning prior to removal.

WRAC.5 Sequence of Steps to Remove Waste

The DOE has identified a sequence of five phases for implementing removal:

Phase 1 — planning and permitting.

Phase 2 — initial aboveground setup and shaft sinking.

Phase 3 — underground excavation and facility setup of underground ventilation, radiation control, packaging areas, decontamination areas, maintenance, remote control center, and personnel support rooms.

Phase 4 — waste location and removal operations, including mining waste removal, packaging, package surveying and decontamination, transportation to surface, staging for off-site transportation, and off-site transportation.

Phase 5 — closure and D&D of the facility.

Each of the five phases is summarized below and described in detail in Section WRAC.6.

WRAC.5.1 Planning and Permitting

A decision to remove waste will initiate the planning and permitting phase. Permitting requirements will be based on governing regulations at the time removal is authorized. The

planning and permitting program will identify all permits and research the available technologies at that time to determine available removal techniques and the condition of the repository. After initial research is completed, a plan will be drafted to itemize and schedule all removal activities. It is at this stage that initial estimates of the condition of the waste will be made. These will be based on the performance assessment results, the record of reassessments that may have been done as the facility was filled, the records of the waste that was actually placed in the facility, and any other information that may be useful in determining the status with regard to pressure, water content, and disposal room configuration. Strategies for evaluating the conditions in the repository will be developed. These may include surface drilling or drilling from within an initial excavation adjacent to the waste areas. Appropriate geophysical techniques and other remote sensing measures will be identified for determining the condition of the waste areas in a manner that minimizes the chance for radiation exposure.

WRAC.5.2 Initial Aboveground Setup and Shaft Sinking

Aboveground support buildings will house the exhaust fans and any radiation control equipment such as HEPA filters, administration facilities, operations and maintenance facilities, control center, waste staging and decontamination areas, the warehouse (containers), laboratories, and others as deemed necessary. Initial estimates of the amount of mining necessary will be made based on the results of the planing phase. The amount of mining will dictate the size and capacity of the surface support facilities.

WRAC.5.3 Underground Excavation and Facility Setup

After the shafts are completed, drifts will be run and ventilation paths will be established using conventional mine ventilation techniques. During shaft sinking, provision will be made to test the muck prior to its release to the surface to detect radioactive or hazardous constituent contamination. If such contamination is found, shaft muck will be isolated for future disposition. If contamination is minor, this material will likely be isolated from the environment by placing it back into the facility at the time of closure. Underground support and service areas will be excavated. The location of the shafts and initial excavations will be determined based on the anticipated brine and gas conditions. These areas will have sufficient intact salt between them and the waste areas that seepage or blowout of contaminated brine or gas into the shafts and service areas will be precluded. There are not expected to be any limitations on the amount of distance that can be specified between the wastes and the service areas. Support rooms will be excavated for maintenance, control, and packaging. Air locks will be constructed to provide the necessary level of ventilation control and separation between contaminated and non-contaminated areas. All equipment required for removal, packaging, and related support equipment will be installed.

Excavation will be in two stages. Initial excavation will not contact waste and will provide for mine support rooms, haulage drifts, ventilation, and access to the waste. The second stage will remove the waste.

WRAC.5.4 Waste Location and Removal Operations

The waste removal will be performed in discrete operations depending on the anticipated level of radioactivity. The waste will be removed by mining the area where the waste was emplaced. The mined waste will be transported to the packaging areas. The waste can be removed many ways using standard equipment. Section WRAC.6.2 contains a brief description and describes the feasibility of using various mining techniques for waste removal. An appropriate level of radiological controls will be used depending upon the radioactivity of the mined waste.

WRAC.5.5 Closure and D&D of the Facility

After waste is removed from the repository, the facility will be decommissioned according to the current regulations at that time.

WRAC.6 Removal Implementation

To support the requirement that waste removal is not precluded, a system for waste removal is described using available mining technologies. This description includes standard shaft sinking practices and drift excavations. Standard mining techniques may be used until contamination or radiation exceeding personnel safety limits then in force are encountered. In these contaminated areas, currently available remote controlled mining equipment or equipment modified with off-the-shelf systems may be used. Where practical or necessary, removal operations will be performed remotely. All support, radiation and air quality monitoring, and geotechnical surveying will be performed remotely in the contaminated areas. The clean and contaminated areas will be segregated from each other and maintained using separate air intake paths and ventilation control structures.

The excavated waste and materials will be placed in appropriately designed waste containers. The container surfaces will be decontaminated if necessary prior to being transported aboveground. Aboveground facilities will include a control center where any necessary remote waste handling and packaging operations are coordinated, and a decontamination area where waste containers will undergo any necessary additional decontamination. The waste containers will be staged aboveground for transportation. A control center in the underground will provide the interface between the aboveground control center and the underground operational activities.

The mining and waste removal operations will be designed to reduce the amount of contamination and exposure to allow limited human access for assessments, equipment retrieval, and equipment repairs. Operations will be designed to reduce human involvement to the extent practicable. Radiological work will be performed using standard industry practices and approved procedures.

The mining operations will use standard equipment to sink the shafts and excavate the drifts and support rooms. After the underground support areas are completed, the waste will be removed. Smaller scale mining equipment will be used to perform the removal. Modifications to the equipment will enable the vehicles and support equipment to be remotely controlled and handle the waste materials. The length of time since disposal will determine whether or not the RH-TRU and CH-TRU wastes will be retrieved in separate operations. It is currently anticipated that the radioactivity level of RH will decay to CH levels within 300 years after disposal (DOE 1995). Thus if removal is conducted subsequent to 300 years after disposal, a single mining operation may remove CH and RH simultaneously. However, removal prior to that time may require separate operations. Because RH wastes may pose a greater radiation hazard, RH-TRU removal activities may be more rigorous in order to limit the exposure to personnel. RH-TRU waste should be removed as intact as possible.

The preamble to 40 CFR Part 191 states that waste removal must be feasible but would likely incur great cost and overall occupational hazard. No time limit is specified. The removal approach will include measures that reduce the overall hazards but will require a long time period to complete. No time limits or cost estimates are included in this study.

The removal requirement states that removal of most of the waste will not be precluded but does not quantify the term most. This study assumes that the quantity removed shall be the amount that can be removed practically. No quantitative figure is specified because removal is speculative. The amount that practically can be removed using the technologies available at the time of removal shall be achieved. Since today's equipment is very effectively used to mine materials deposited millions or billions of years ago, this same equipment technology would provide for the feasibility to remove the waste anytime during the regulatory time frame.

WRAC.6.1 Planning and Permitting (P&P)

The need to remove the waste would initiate the planning and permitting phase. By definition (40 CFR § 191.02[l]), waste removal does not occur until after disposal. The permitting requirements will be based on governing regulations at the time removal is authorized. The planning and permitting program will identify all required permits. This program will also research the available technologies to determine the appropriate removal techniques, the waste conditions, and the repository conditions (see Chapter 6.0 for performance assessment assumed conditions after repository closure). After the initial research is completed, a plan will be drafted to itemize and schedule all removal activities.

The following considerations would be included in the planning and permitting process for the WIPP. These are necessarily general since the actual activities are solely dependent on the conditions at the time removal is deemed necessary. It should be noted that technologically, removal could be accomplished without any of the steps in this section. Such brute force approaches would meet the requirement of describing feasible techniques for removal; they are not, however, considered to be prudent.

Availability of Records. Available records will be collected to determine the location of waste containers, the nature of the waste placed in the facility, the underground excavation conditions during operations and at the time of closure, the location of seals and panel closures, and the amount and nature of backfill materials. Since the DOE plans to place records in numerous locations, records should be readily available for needed evaluations. Additionally, WIPP will also have complete inventories of the contents of both the buried CH and RH containers.

Location of the Site. Records and markers will be used to identify site locations such as the previous shaft locations, the area of the disposal region footprint, previously drilled boreholes, location of monitoring activities, and other features that will aid in delineating the areas for new excavation and new surface structures.

Background Environmental Conditions. A baseline of environmental conditions will be established prior to any surface disturbing activity in order to get an accurate assessment of pre-operational conditions. Background measurements will be compared with environmental data stored in the site archives to determine any changes in conditions since the closure of the facility.

Time Since Disposal. This will be used to determine the expected condition of the disposal rooms, the amount of radioactivity and hazardous constituents that need to be dealt with, the amount of migration outside the disposal zone that may have occurred, and the presence of potential hazardous conditions such as pressurized gas and brine.

Facility Design. Initial facility designs will be prepared so that appropriate technologies can be identified and so that environmental impacts can be assessed. Release and exposure pathways will be identified and risk analyses performed to ensure appropriate environmental protection measures are taken. Design will be in accordance with applicable commercial and regulatory standards in effect at the time. Regulations such as those promulgated by the Occupational Safety and Health Administration and the Mine Safety and Health Administration will be given due consideration in designing systems that are protective of human health and the environment. Final facility design will be appropriately reviewed and approved by the implementing agency and appropriate regulatory organizations.

Permitting. Environmental regulations governing releases to environmental media and protection of the public from exposure to noise, gases, dust, hazardous waste, radioactivity, and other potentially harmful substance will be identified and appropriate permits obtained in the time frames dictated by the regulations.

Radiological Controls. The removal process will require a comprehensive assessment of the facilities and the precautions necessary to ensure the safety of workers and the public during the entire removal operation from initial coring until final closure and decommissioning of the facility. The facilities will include appropriate areas for washing

and decontamination of containers and equipment and separate areas for the decontamination of personnel should such requirements arise. Decontamination areas and washing areas will be designed and constructed both in the underground and on the surface. Special areas will also be constructed on the surface and in the underground for storage of material and/or containers having high radiation levels. Such areas will be shielded to permit operational activities nearby without undue risk to personnel. Rigorous radiation and hazardous material monitoring of all activities from initial borehole drilling and coring to actual removal will be required until such time as removal activity experience provides sufficient information to understand the actual conditions existing in the repository and permit formulation of appropriate monitoring policy.

WRAC.6.2 Aboveground Setup and Shaft Sinking

Existing geological characterization data will be supplemented with new borings at the site. During all boring, shaft sinking, and mining activities in the vicinity of the waste panels careful monitoring will be conducted to ensure early determination of the presence of any hazardous or radioactive material. An initial shaft location sufficiently distant from the waste will be identified and drilled. Coring in the vicinity of the repository horizon will be preformed in order to capture any horizons that contain radioactive contamination caused by brine migration through marker beds. The level of contamination will be assessed and appropriate precautions taken to protect personnel, the public, and the environment from contamination. Such precautions are used today in cleanup activities in which contamination is kept within well defined barriers and entrance and egress is carefully controlled and monitored. Emphasis will be placed on avoiding the areas that were originally mined for the repository. The DOE currently believes that for the WIPP, the best approach to the waste is from the south because this area avoids the existing shafts and mined areas.

Use of the intact portion of the formation instead of using previous shafts and tunnels minimizes the ground control problems. Additional geological studies would be conducted to determine the adequacy of the rock south of the repository.

Aboveground support buildings will be constructed to house the exhaust fans and ventilation (HEPA) filters, administration offices, engineering offices, training facilities, safety facilities, maintenance support facilities, control center, waste staging and decontamination areas, and warehouse. Portable and/or temporary structures such as trailers could be used for miscellaneous activities. Power and water distribution network shelters will be required.

Where practicable, aboveground support facilities should be designed for later disassembly and removal to facilitate decommissioning. Removal facilities would closely resemble those currently in use at the WIPP and described in Chapter 3.0 with some additional radiological control facilities and decontamination facilities.

A shielded area for the protection of personnel from higher levels of radiation, similar in construction to the shielded storage room currently located in the Waste Handling Building

(see Appendix D&D), may be required to handle and store the RH-TRU canisters and their containers prior to off-site shipment. This area will contain all the equipment necessary to transfer the RH-TRU waste into suitable waste containers and load shielded shipping casks. If necessary, remote operations can be used for any removed waste that exceeds CH-TRU safe handling levels.

Security fencing will be required around the facilities. The extent of the security devices required will be governed by the regulatory requirements at that time.

A control center will be located aboveground that houses the personnel and equipment that controls the remote mining equipment and all other remote operations.

At least three shafts will be constructed. The number and size of the shafts will be based on removal throughput requirements, airflow requirements, and mining regulations at that time. The underground ventilation requirement should be lower than the original ventilation system assuming a reduction in both manpower and diesel equipment usage. To reduce the discharge of hazardous and radioactive particulate contamination, the removal working area and packaging areas will be provided with separate HEPA filtration systems. This precaution will reduce migration of particulate material from the mining areas.

The three shaft concept would include two intake shafts and an exhaust shaft. The current WIPP shaft designs would be adequate, although technology improvements may make operations more efficient and reliable.

Each shaft will include a hoisting system. The waste handling shaft (WHS) and hoist will be fully enclosed and will allow air intake without backflow. The WHS will be an air intake shaft that ventilates the maintenance, packaging, and contaminated work areas of the mine.

The ventilation exhaust system for the removal of the waste will be significantly more complex than the system supporting waste emplacement. Because of the likelihood of the production of hazardous and radioactive particulate material during the remote removal of waste material, the ventilation system will require local systems within the underground that include the appropriate exhaust fans, monitoring, and HEPA filtration systems used to filter the exhaust air during removal operations. The levels of dust in a potentially highly contaminated environment will present a significant maintenance challenge. Maintenance of these systems will require high degrees of redundancy of system components, system configurations, or flow paths. Flexibility of operation will be a major operational requirement of the ventilation system design in order to ensure that removal operations remain within the regulatory and safety limitations imposed for workers and the general public. The system design must permit remaining within the allowable limits at all times. Since the potential for hazardous or radioactive material contamination will exist, once waste removal begins, filtration of all exhaust air will be required. Self-cleaning or roughing pre-filters may be used to increase HEPA filter life and reduce down time for filter change-out.

After the first shaft (no particular order) is completed, the others may be excavated from the bottom up using a drill and ream system similar to the system used at WIPP to excavate the existing air intake shaft. This will require access entries (drifts) to be excavated to the base of each shaft and drilling to this area. An ore transfer station will also be installed to facilitate removal of excavated salt (uncontaminated) from drift and support area mining.

WRAC.6.3 Underground Excavation and Facility Setup

After the shafts are completed, drifts will be excavated using commercially available equipment such as continuous miners, roadheaders, scalers, and ventilation paths will be established using air control regulators. Support rooms for use as maintenance areas, control rooms, and packaging areas will be excavated. Air locks will be constructed to isolate the clean areas from the contaminated areas by use of differential pressure. All equipment required for removal, packaging, and related support activities will be installed.

Excavation will be in two phases. The initial excavation will not contact waste but will mine support rooms and haulage drifts that provide ventilation and access to the waste panels. A barrier pillar will be maintained. The size of the barrier piller depends on the anticipated conditions in the waste panels. The barrier pillar will provide protection from blowout or flooding due to pressurized gas or brine. The second phase will remove the waste. Conceptual layout of removal operations is shown in Figure WRAC-7.

Air locks will be used to allow travel between air circuits while maintaining the isolation of contaminated areas from the clean areas. Lined sumps may be used to manage liquids if conditions involving flowing brine are encountered.

The following support areas may be required:

Control Centers. Rooms that contain the remote control support interface between the surface control center and the equipment supporting the underground ventilation, mining, packaging, and transportation operations.

Maintenance Rooms. Shop areas where all maintenance and repairs are performed, including wash bay and parts warehouse for support equipment.

Personnel Support. Lunch room, lockers, washrooms, and facilities.

Container Warehouse. Storage for clean, empty waste containers, and decontamination supplies.

Packaging Area. Waste emplacement into containers, container filling, and container sealing area.

Decontamination Area. Container radiation survey and decontamination area.

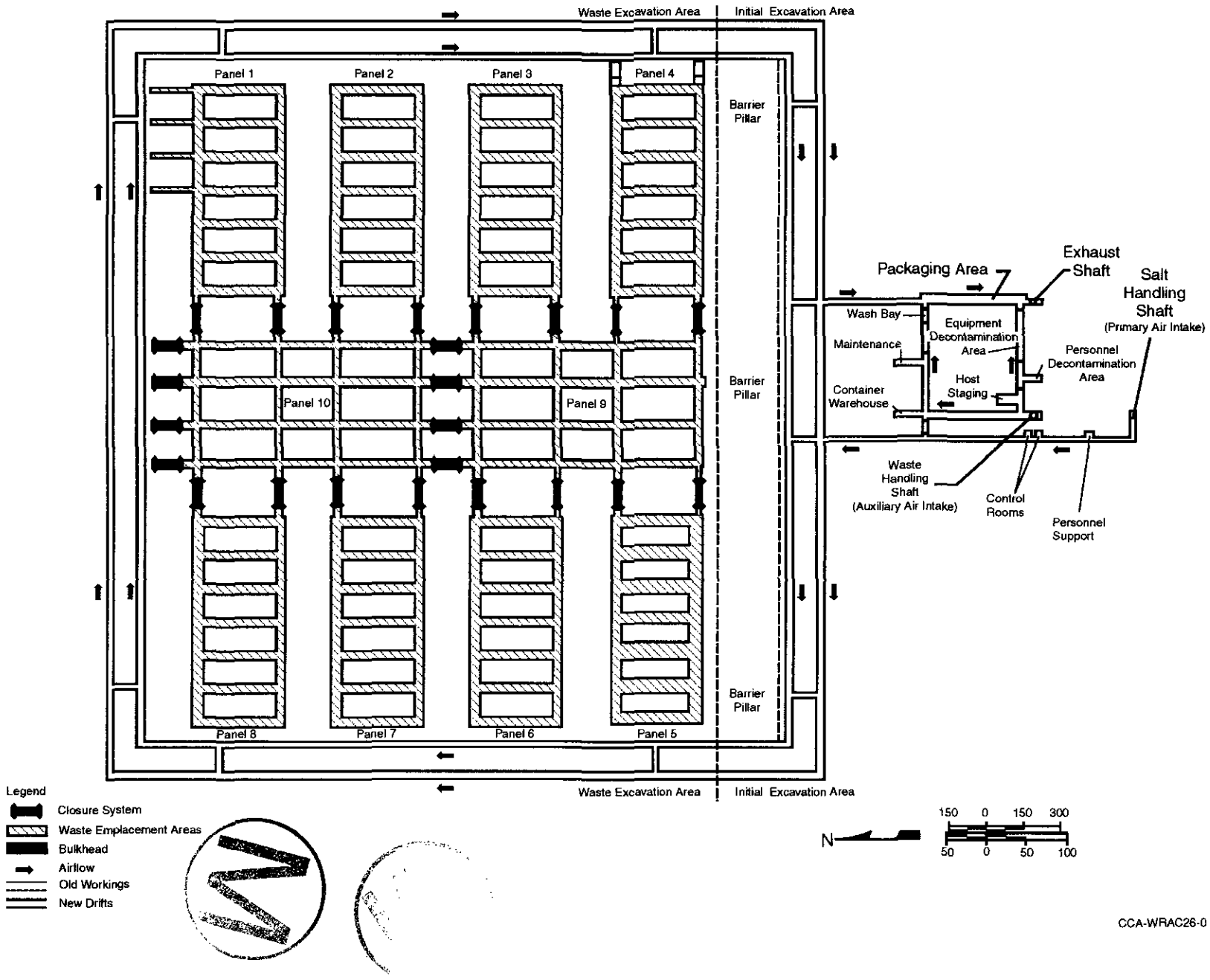

Figure WRAC-7. Repository Removal Operations Layout

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Ore Transfer Station. Virgin salt transfer and removal station at base of shaft.

Container Staging Area. Lower hoist loading area with staging area (clean area) located in clean intake air feeding contamination area; final radiation survey area.

WRAC.6.4 Waste Location and Removal Operations

A single drift should be excavated around the waste panels. This drift will provide ventilation that will be used during removal operations. After the support, ventilation, and access drifts are completed, the first panel can be entered to remove the waste. Panel 9, the panel closest to the exhaust shaft should be excavated first to reduce initial contamination. An entrance and exit will be excavated, dust and moisture control systems installed, and isolation bulkheads erected. The location of the panel closures should be available from the detailed information at record centers and archives. With the exception of mining Panel 9 (the southern most portion of the access drifts) the panel closures can be used as markers for locating panels and drifts. To determine the relative position of the waste, ground penetrating impulse radar technology could be used. Impulse radar technology, specifically a Geophysical Survey Systems, Inc. (GSSI) SIR-7 impulse radar, has been successfully tested in salt mines and has demonstrated the capability of locating metallic targets up to ten meters away (Cook 1982). The access entries could be completed and the entrances to each panel could be located by the panel closure systems and radar. Radar and gamma detectors could be used to help locate the RH-TRU waste. The gamma detectors should be effective during the first few hundred years after disposal prior to extensive decay of the RH radioactivity.

Initially, each waste panel will be evaluated using a small diameter probe hole drilled from the access drifts. The hole will be used to investigate the conditions within the panel. Of particular interest will be the porosity (degree of consolidation), pressure, and moisture content. In addition, gasses will be tested for explosive or flammable constituents.

For conditions requiring that the CH-TRU and RH-TRU waste removal operations be performed in separate operations, the CH-TRU waste will be removed by mining the area where this waste was emplaced. The CH-TRU waste and surrounding rock will be removed and transported to the packaging areas without disturbing the RH-TRU waste. The RH-TRU waste will be removed by excavating the rock salt around the waste and removing it in as intact a condition as possible. This waste may be placed in a waste container at the work face and then transported to the packaging area. The waste container may be the shipping container if sealing and decontamination are possible underground or it may be over-packed at the packaging area prior to decontamination.

The CH-TRU waste can be removed many ways using standard equipment. The waste could be mined out using a large-scale continuous miner. Continuous miners such as the EIMCO Coal Machinery Division's 3612 Marietta Drum Miner (see Figure WRAC-8) have been used very successfully at WIPP and are readily available. However, this method does have the potential to spread excessive amounts of particulate contamination and could be difficult to

control particularly with respect to the RH-TRU wastes. A more practical approach would be to use small-scale mining equipment such as road headers, scalers, hydraulic breakers, small loaders, and excavators. A small head continuous miner or a roadheader (telescopic boom miner) similar to a Hawker Siddley DOSCO M.D. 1100 (see Figure WRAC-9) could be used to excavate a large portion of the waste. The other extraction equipment would be used to remove the most difficult waste such as large metallic items.

A practical approach to CH-TRU removal is to excavate an area approximately three feet high directly below the waste and then, using a hydraulic breaker/scaler system similar to the Fletcher Model SV-4D diesel powered scaler capable of being equipped with either an Alpine No Gap cutting head, a percussion scaling hammer, or a scaling claw attachment devices (see Figure WRAC-10) to dislodge the waste above. Similar scaling devices have been successfully utilized at WIPP and other mines in the Delaware Basin.

The CH-TRU waste will be excavated behind bulkheads separating the mining area from normal ventilation. After removing a predetermined amount of excavated materials, loaders will transport the waste materials to the packaging area.

The CH-TRU waste will be transferred to the waste handling and packaging system which packages the waste into containers. Bulk material handling equipment may be used to transfer the waste from the loaders to the waste containers. The container will move into the decontamination area where it is automatically surveyed and decontaminated. The container is then moved into the hoist underground staging area where it is surveyed again and transported to the surface. The container will be warehoused until transported off site.

The CH-TRU waste containers will be selected using the regulatory requirements at that time. Currently available containers will be researched to determine their suitability, and if none are found, new containers will be built and certified.

An aboveground decontamination area will be used if any contamination is found during the off-site container loading and transportation operations.

RH-TRU waste will be removed after the CH-TRU waste is excavated past the shield plugs to allow equipment access. The equipment will be set up to remove and excavate the materials around the waste. The waste will be loaded into a container and moved to the packaging area.

There, the container may be decontaminated, if possible, or overpacked prior to shipment aboveground. After completion of any necessary decontamination, the RH-TRU waste will be transported to the surface and then warehoused in a shielded area prior to off-site shipping. Radiation surveying and decontamination procedures will be similar to the CH-TRU operations.

The waste will be removed from the panel and its original access entries. After initial panel waste removal is completed, all other panels will be excavated.

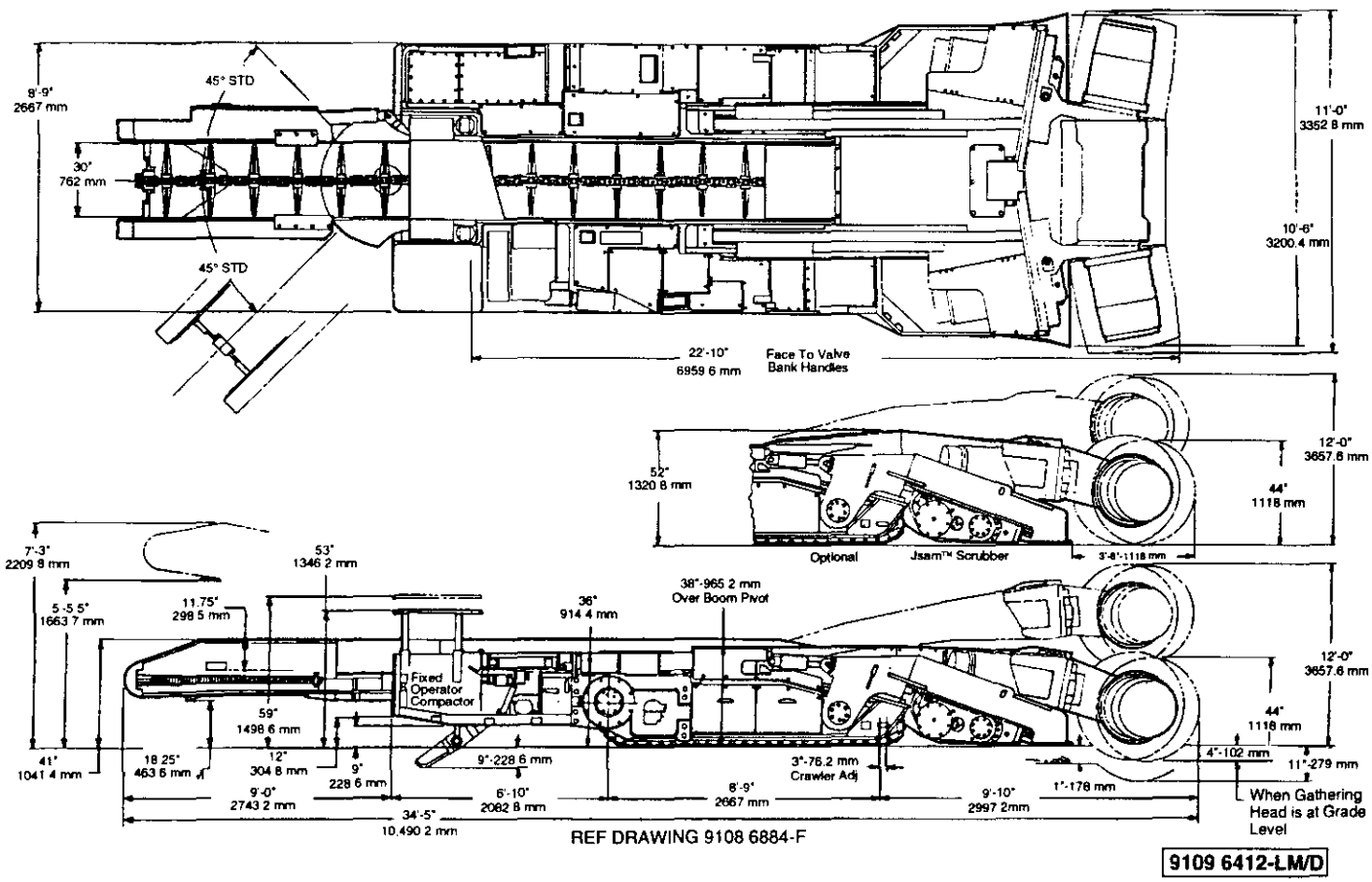

Figure WRAC-8. EIMCO Coal Machinery Division 3612 Marietta Drum Miner

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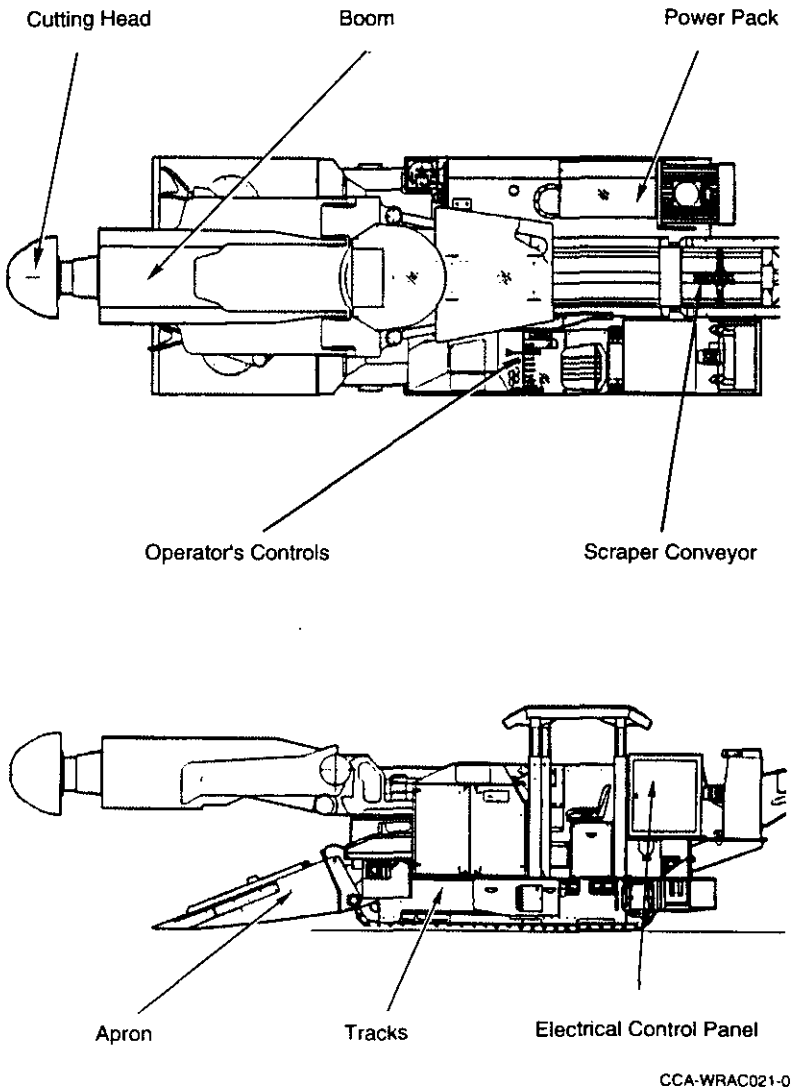

Figure WRAC-9. Hawker Siddley DOSCO MATERIAL DESCRIPTION.1100 Roadheader with Telescopic Boom

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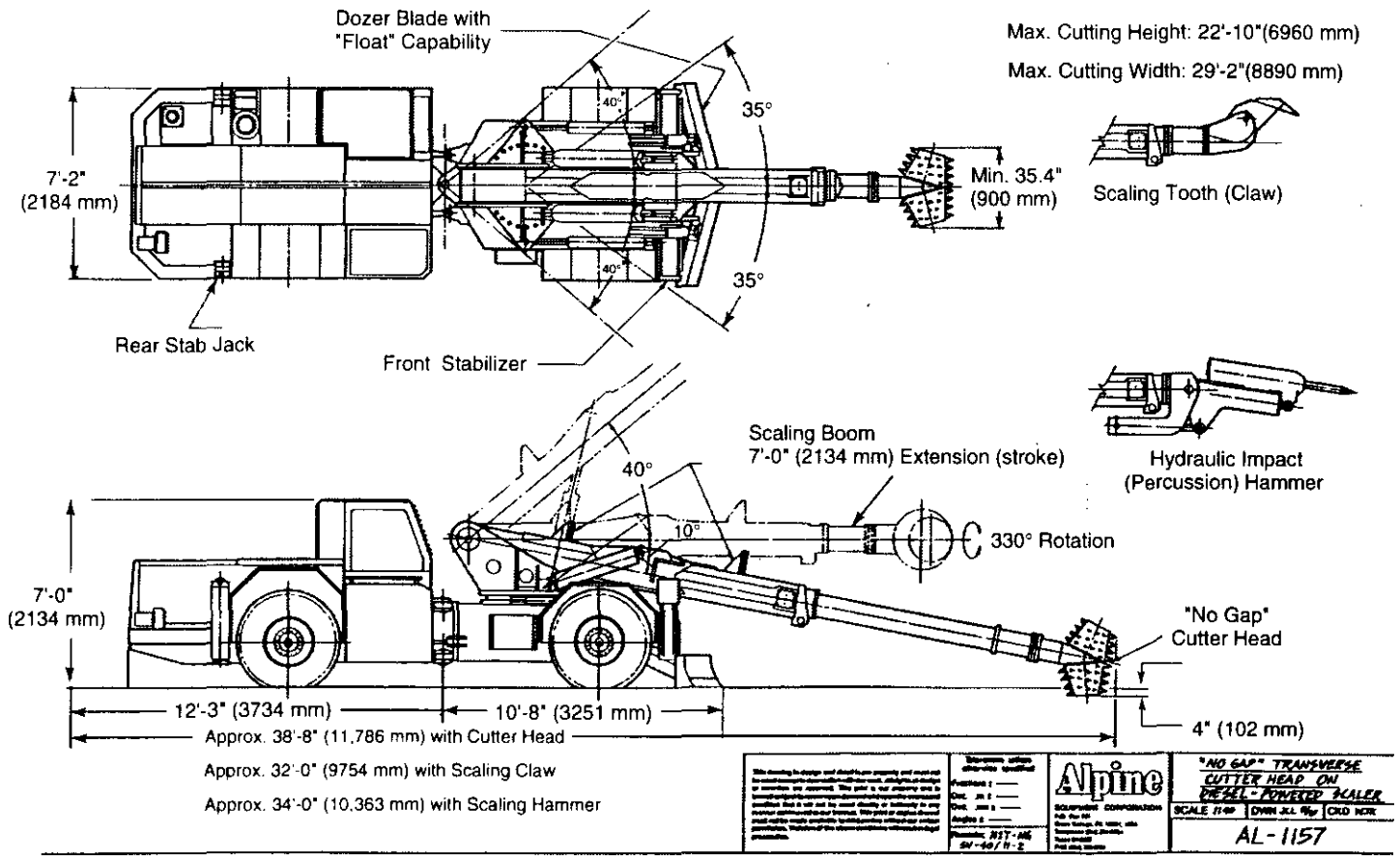

Figure WRAC-10. Fletcher Model SV-4D Diesel Powered Scaler with Alpine Attachments

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If the removal of waste is not initiated until hundreds of years after disposal and the RH radioactivity has decayed to near the activity levels of the CH waste, the decision may be made to remove the RH waste in conjunction with CH waste removal. Under these conditions, evaluation of the probable condition of the RH containers should be made. The heavier wall thickness of the RH containers may provide an opportunity to remove the RH waste intact provided that corrosion has not yet destroyed the containers' integrity. Under these conditions, RH removal should be conducted in a manner similar to that described above. That is, CH removal within a given panel should proceed until sufficient clearance is obtained to permit installation of equipment to excavate the rock salt around the RH container and then remove the container in as intact a condition as possible. Under conditions which the RH container has lost its integrity, removal of RH waste would be accomplished using the procedures applicable to CH waste removal.

WRAC.6.5 Closure

After the waste is removed from the repository, the facility will be decommissioned in accordance with the regulatory requirements applicable at that time. Closure may include partial backfilling of the mine and support areas. The mine may be used for disposal of both contaminated and uncontaminated muck. The shafts will be sealed (see Appendix SEAL for the details of what a seal may look like) and the surface facilities will be decontaminated and decommissioned (see Appendix D&D for an outline of a decontamination and decommissioning program). All decontamination wastes could be packaged and shipped in the same fashion as the removed waste.

WRAC.7 Currently Available Removal Technologies

As part of the feasibility demonstration, the DOE has identified technologies that are available today that could be used to facilitate removal. These are divided into mining technologies (Section WRAC.7.1) and remote removal technologies (Section WRAC.7.2).

WRAC.7.1 Mining Techniques for Waste Removal

Waste removal can be accomplished in many ways using available technologies. Mining techniques are the most plausible since they must be used initially to provide access to and locate the waste. Methods used to extract salt and potash were briefly evaluated to determine the best removal technique. Since the waste is hazardous and radioactive, the technique used must limit the spread of contamination to the environment and exposure to facility personnel. The condition of the waste at the time of removal will be unknown and is related to the amount of time the waste was exposed to repository conditions.

Removal processes should be performed with as little direct human interaction as possible. Limited contamination is acceptable provided that the exhaust from these areas is controlled and filtered. Roughing filters and HEPA filters can be used to control contamination. Limiting the air throughput in the work areas will minimize the spread of contamination.

Mining techniques that were evaluated include the following:

- continuous mining,
- drill and blast,
- solution mining and mechanical extraction, and
- mechanical excavation techniques.

WRAC.7.1.1 Continuous Mining

Continuous mining was used to excavate most of the WIPP facility. A continuous miner (see Figure WRAC-8) is used to mechanically excavate materials by ripping, milling, or boring the rock from the work face. Rotary drums and heads with cutting bits attached to the surface cut the rock. The miner mechanically removes the loose material and transports it away from the face onto a conveyor where it can be transferred to haulage equipment or transported by belting to other areas. Continuous mining equipment can precisely remove rock and hold tolerances in the order of a few inches. The equipment is available in a wide variety of styles and sizes. Remote controlled continuous miners are commercially available.

The waste contains some metallic items (for example, cadmium, lead, silver) and the containers are steel. Continuous mining heads can be made with bits utilizing various steel alloys. Examples of these alloys include high-strength low alloy (HSLA) ordnance-grade steels such as AISI 4140 chromium molydbenum steel and AISI 8650 nickel chromium molybdenum steels; molybdenum or tungsten-based high speed tool steels such as M2 or T6; and the powder-metallurgy-produced sintered tungsten carbide steel groups such as the six percent cobalt group 2 alloy. All of these alloys are frequently used for various mining, petroleum production drilling, ordnance, and tooling applications such as drilling, mining, and cutting through metals, ores, and hardened rock. The equipment may be further modified by changing the cutting head configuration and sizing to efficiently handle the metallic substances by altering the cutting surface, speed, and bit angles. The need to address cutting through metals, particularly the metal containers, will be dependent upon the time after disposal that removal is initiated (see Chapter 6.0 for performance assessment assumptions regarding metal persistence).

Large-scale continuous mining of the waste is possible but is impractical because of the potential for spreading contaminated material. Excessive amounts of dust are generated during continuous mining. Water is generally used for dust control which may increase the spread of contamination. Water will transport the contamination into the fractures of the surrounding rock.

Small-scale continuous mining of the waste is practical if electric equipment is used and the area is isolated during mining operations. To control contamination, bulkheads can be placed close to the mining face that isolates the mining activities from normal mine ventilation. Ventilation in the mining area can be reduced or eliminated since remote controlled electrical equipment would be used and no diesel equipment or personnel are required. Suspended

particles can be effectively removed from the air during mining and loading operations using local HEPA filtered systems with prefiltering capability to reduce the maintenance of HEPA filters.

WRAC.7.1.2 Drill and Blast

This method excavates by drilling holes in a rock face and filling the holes with explosives. The explosion fractures and loosens the rock material. Other equipment is then used to remove the debris and the cycle starts again.

This method could also be used to remove the waste. However, this method generally requires personnel to drill and load and would be difficult to perform remotely. The dust and fumes caused after the explosives are detonated must be ventilated and would cause a contamination problem. Isolating the working areas with bulkheads would be difficult because of the large pressures produced by the blast. Thus, while this method could possibly be used to remove the waste, the associated problems of personnel in the vicinity, ventilation, contamination, and blast side-effects make this method impractical.

WRAC.7.1.3 Solution Mining

Solution mining uses a solvent to extract the material of interest. In salt solution mining, water is injected into the formation and saturated brine is pumped out.

A modified version of this technique could possibly be used to remove the salt from around the waste at the repository level. After the salt is removed, remote controlled mechanical equipment would remove the exposed waste. Hence, both standard mechanical mining methods and solution mining would be required. However, this method would require large amounts of water and would require a system to be designed to recycle the water. Water treatment would also be required to extract salt and any contaminated material. These processes involved add significant complexity to the system and the salt, and probably the water, would still be contaminated and would have to be packaged along with the waste. Additionally, this method would produce a large volume of contaminated material and would spread contaminants into the fractures of the surrounding rock. Therefore, based on the problems of the systems' complexity and of the likely ineffectiveness of those systems, in general, this method is impracticable.

WRAC.7.1.4 Small-Scale Mechanical Excavation Techniques

Smaller-scale mechanical excavation techniques can be used and are the most favorable. One method uses roadheaders, hydraulic breakers, and scalers (see Figures WRAC-9 and WRAC-10) to dislodge material from the face by scaling or cleaving the material. This method is extremely slow and precise. It produces the least amount of dust and can be performed remotely.

Additionally, other forms of mechanical excavation equipment such as Melroe bobcats with various small backhoes, manipulators, and earth moving and cutting attachments (see Figures WRAC-11, WRAC-12, and WRAC-13) exist and would also be used to dislodge, move, cut, and crush the waste. These types of equipment will be required to support any method used.

WRAC.7.1.5 Remote Mining

Two examples of remote mining operations include work in Australia and France. Australia removed 198,334 tons of coal from a McQueen Company mine using a remote controlled flexible conveyor train, a continuous miner, and roof-bolting machines between 1985 and 1987 (McQueen 1988). The French have been actively pursuing remote coal mining since 1972. In 1983, 93 percent of French coal shearers were remotely controlled and monitored. (Boutonnat 1986)

In 1986, the U.S. Bureau of Mines initiated research to develop technology to enable the relocation of workers from hazardous areas (Schnakenberg 1993). Such work includes developing computer assisted operation of continuous miners, roof bolters, and haulage systems (Schnakenberg 1993). Remote mining technology is continuing to progress making the likelihood of its success in any future removal operations highly probable.

WRAC.7.2 Remote Removal

On April 27, 1992, a retrieval demonstration took place that successfully retrieved SWBs from a WIPP storage room. This demonstration simulated a cave-in or roof fall condition with salt and metal roof support materials piled on top of the SWBs. All retrieval operations were performed using remote controlled equipment.

The equipment used for this demonstration consisted of two remote controlled Melroe bobcats (see Figures WRAC-11 thru WRAC-16), a remote controlled freestanding portable television camera, a WILD TM 3000 automatic laser survey station, a portable beta-gamma radiation detector, and an ANDROS Mark VA hazardous duty robot (see Figure WRAC-17). One remote-controlled bobcat used a backhoe attachment and the other used either a manipulator, front loader bucket, hydraulic breaker, or grapple bucket attachment. The attachments were changed out when required. The equipment used both radio and tethered cable remote control methods.

The demonstration used the robot to survey the areas using television cameras and laser ranging equipment. The condition and location of the SWBs were determined using the robot's data. The robot also set up equipment and surveyed the areas for radioactive contamination.

In order to remove the SWBs, the salt and metal materials were removed and boxed in containers using the remote controlled equipment. The SWBs were successfully removed from the room.

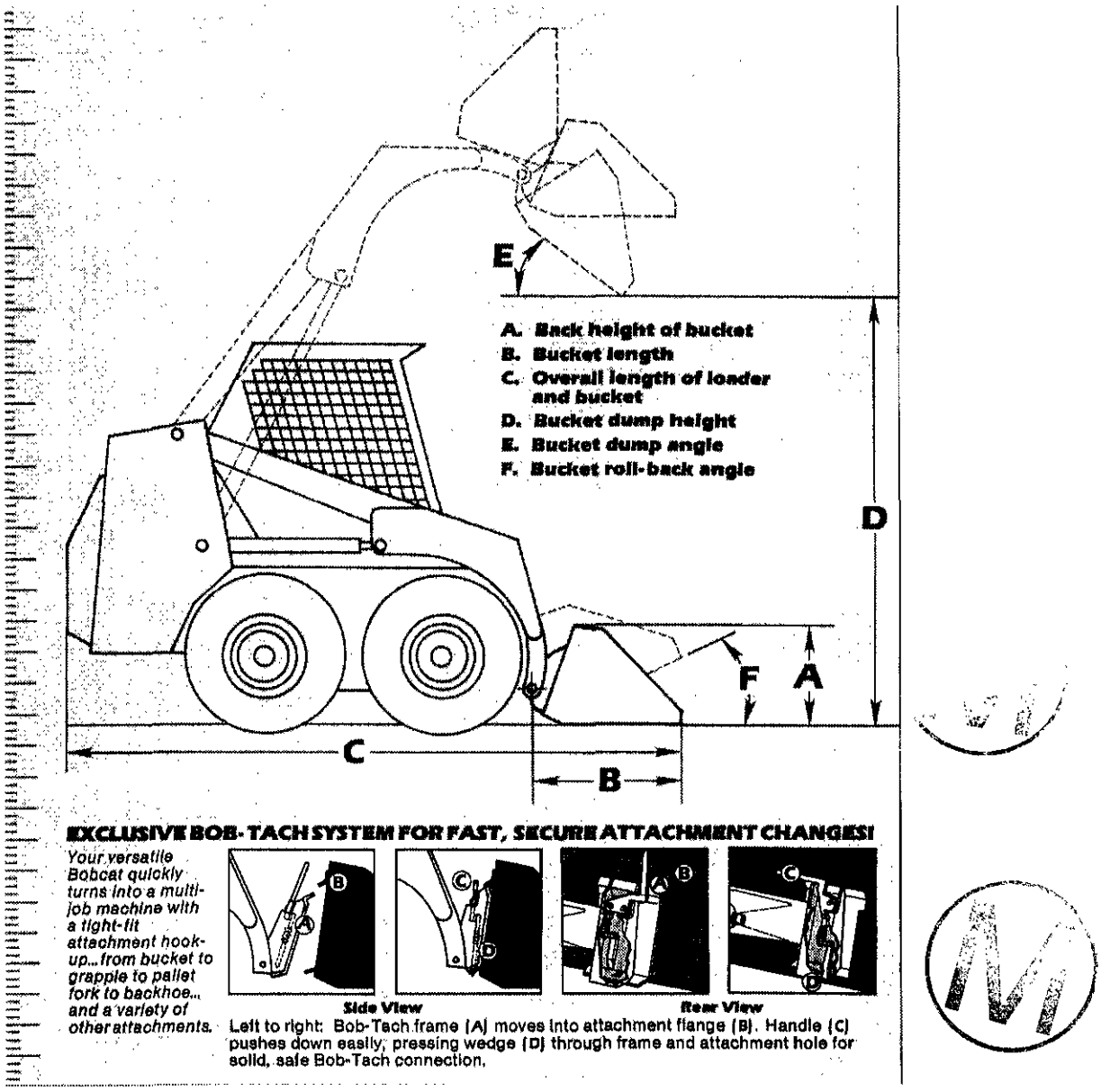

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Figure WRAC-11. Melroe Schematic Drawing

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FOR 700, 800 AND 900 SERIES AND ARTICULATED 1600, 2400 MTC LOADERS

INDUSTRIAL FORK GRAPPLE

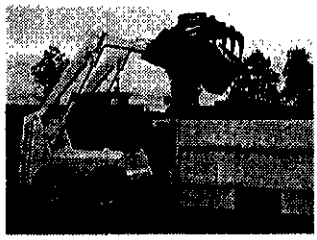

Handle scrap and assorted metal. Bobcat fork grapples join the other Bob-Tach attachments that allow change ability from the operators cab. *The Fork grapple is perfect for* handling sharp, irregular-shaped metal, other assorted scrap and heavy duty agricultural applications.

FOR BOBCAT 443, 500, 600, 700, 800, 900 SERIES, AND ARTICULATED 2400 MTC LOADERS

HYDRAULIC BREAKER

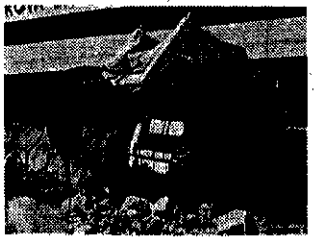

Break up concrete quick and easy.*

- Up To 750 Ft.-Lb. Impact energy class.
- Backhoe or Loader Mounting.
- *2-position Loader Mounting Frame for Vertical and Horizontal Breaking.*
- Quick-Change Tool System – Variety of Tools Available.
- Low Recoil Operating Cycle.

*SPECIAL APPLICATIONS IN WHICH INCLUDES A 16-INCH LEAN FRONT DOOR WITH 14 INCH TOP AND REAR WINDOWS SHOULD BE USED WHEN OPERATING THE BOB-TACH MOUNTED HYDRAULIC BREAKERS

FOR BOBCAT 600, 700, 800 AND ARTICULATED 1600, 2400 MTC LOADERS

LANDSCAPE RAKE

Grade, level and scarify in close quarters. Break up lumpy soil, pick up rocks as small as 3/4", grade, level and scarify in close quarters *with the Bobcat Landscape Rake. Use it for* ground preparation, for seeding, sodding and lawn leveling. Pick up rocks or hard-packed clumps of soil and dump them where you need them with the Bobcat Landscape Rake.

AN ALLIED ATTACHMENT FOR BOBCAT 740s, 843, 900 AND ARTICULATED 1600, 2400 MTC LOADERS

LONGWOOD GRAPPLE

Turn your Bobcat into a high performance log handler. The Multitek Longwood Grapples* are made of high quality steel providing strength and durability for rough working conditions.

*SPECIAL APPLICATIONS IN WHICH INCLUDES A 16 INCH LEAN FRONT DOOR WITH 14 INCH TOP AND REAR WINDOWS SHOULD BE USED WHEN OPERATING THE BOB-TACH MOUNTED LONGWOOD GRAPPLE

FOR BOBCAT 500, 600, 700, 800 AND 900 SERIES AND ARTICULATED 1600, 2400 MTC LOADERS

PALLET FORK

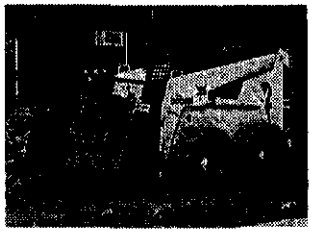

Move bulky or bagged materials in one load. Hook on a Bobcat pallet fork and move your bagged or bulk material fast. Ideal for all kinds of farm chores and fertilizer handling. In industrial plants and landscaping, handle baled or pallet materials

FOR BOBCAT 843 SERIES LOADERS

PLANER

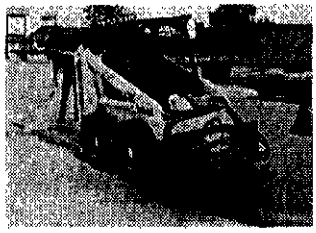

Cut and remove deteriorated asphalt. The Bobcat 843 becomes an effective, cost-efficient planing machine* with the Melroe Planer attachment. Quickly removes deteriorated asphalt surfaces. An ideal tool for busy municipal and construction contractors.

*The 843 loader must be equipped with the High Horsepower Auxiliary Hydraulics option which provides 22.3 GPM and 3000 PSI for attachment operation

CCA-WRAC008-0

Figure WRAC-12. Melroe Bobcat Optional Attachments

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AN ALLIED ATTACHMENT FOR BOBCAT 500, 600, 700, 800 SERIES & ARTICULATED 1600, 2400 MTC LOADERS

GANNON LANDSCAPER

Grade, Scarify, backfill or level. With this tool, a Bobcat operator can grade, scarify, backfill or level in close quarters. Use it on road construction, lawn leveling, ripping hard packed soil or gravel, piling and leveling dirt, manure or other materials. Drag a load or doze it right where you need it.

FOR BOBCAT 740, 843, 843 SERIES AND ARTICULATED 1600, 2400 MTC LOADERS

COMBINATION BUCKET

Perform a wide variety of job functions. The versatile Melroe Bobcat combination bucket is ideal for dozing, grappling, leveling, digging, loading and dumping. And built durable with heavy-duty cutting edges and cylinders for long life on those construction, demolition, landscaping or municipal jobs.

FOR BOBCAT ARTICULATED 2400 MTC LOADERS

COUNTERWEIGHT

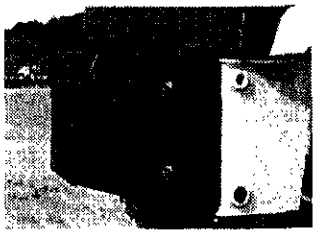

Now you can even lift more. With the addition of the optional counterweight attachment, you can increase the rated operating capacity of your MTC from 2400 pounds to 3000 pounds.

FOR BOBCAT 500, 600, 700, 800 SERIES AND ARTICULATED 1600, 2400 MTC LOADERS

EARTH AUGER

Dig 6"-24" holes with speed and plumb-line accuracy. Utilizing Bobcat loader hydraulics, the heavy-duty hydraulic auger bites in with low speed, high torque power. Because of a unique knuckle-joint design, the auger will dig vertical holes even though the Bobcat is working on uneven terrain.

FOR BOBCAT 740s, 843 AND ARTICULATED 1600s LOADERS

GRADER

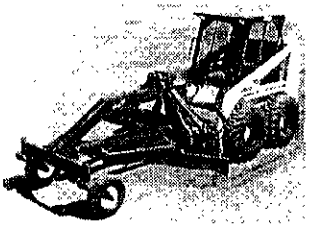

Turn your Bobcat into a high performance grading machine. Designed for use by landscaping, asphalt, curb and gutter and concrete flatwork contractors. Featuring a seven foot, six-way hydraulically controlled moldboard, operated with switches mounted on the loader's steering levers for precise control.

FOR BOBCAT 700, 800, 900 SERIES AND ARTICULATED 1600, 2400 MTC LOADERS

GRAPPLE BUCKET

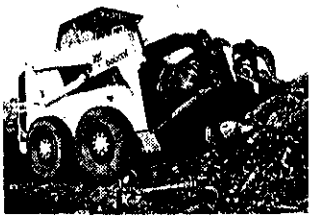

Clamp onto heavy and odd-shaped objects, and move them with ease. The Bobcat Industrial Grapple is the ideal attachment for handling scrap, waste or pipe. It's built strong for tough working conditions.

CCA-WRAC007-0

Figure WRAC-13. Melroe Bobcat Optional Attachments

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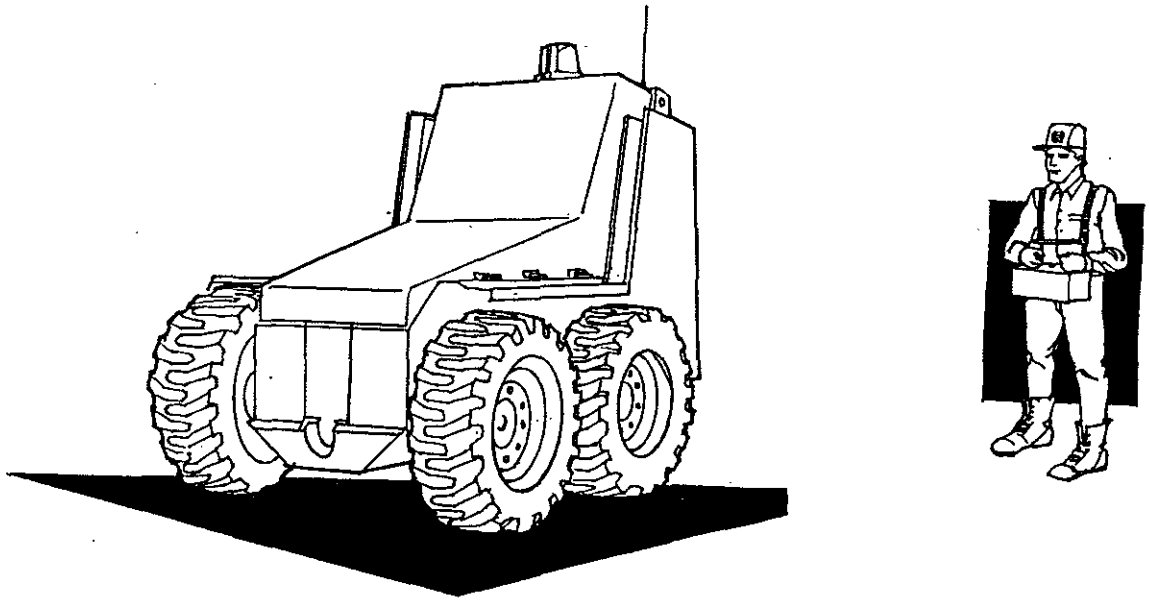

Figure WRAC-14. Modified Remote-Controlled Melroe Bobcat Without Attachments

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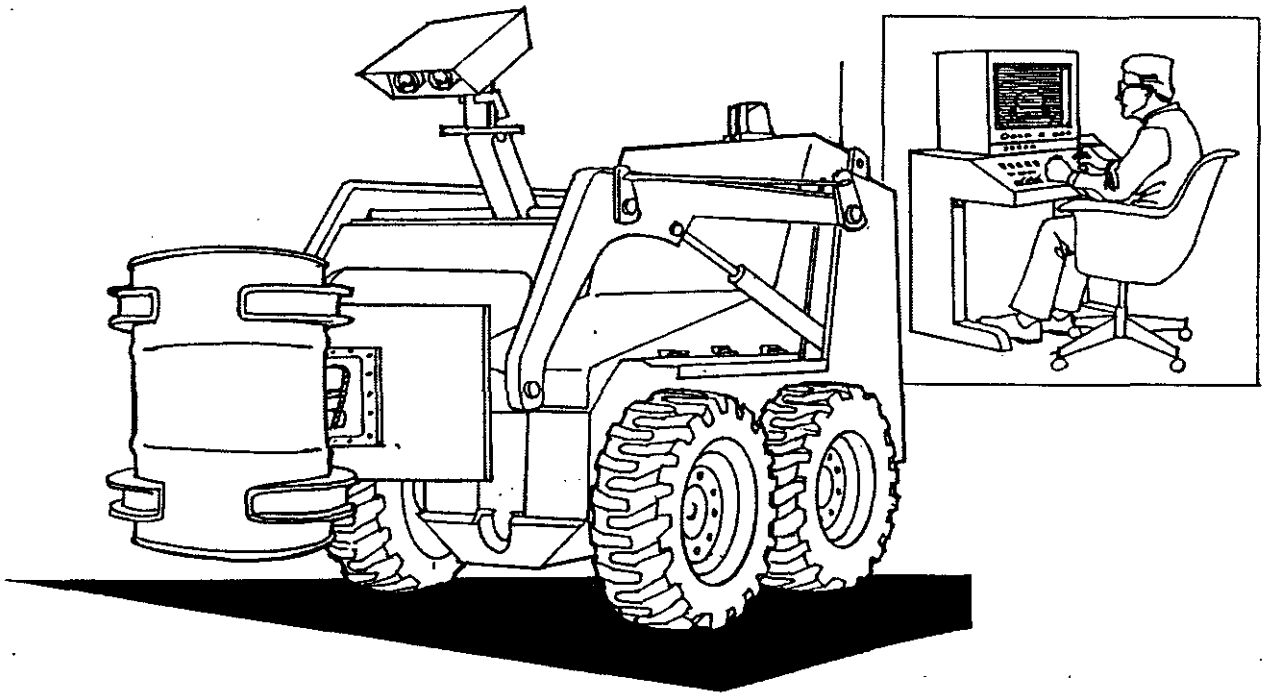

CCA-WRAC014-0

Figure WRAC-15. Modified Remote-Controlled Melroe Bobcat With Manipulator Attachments

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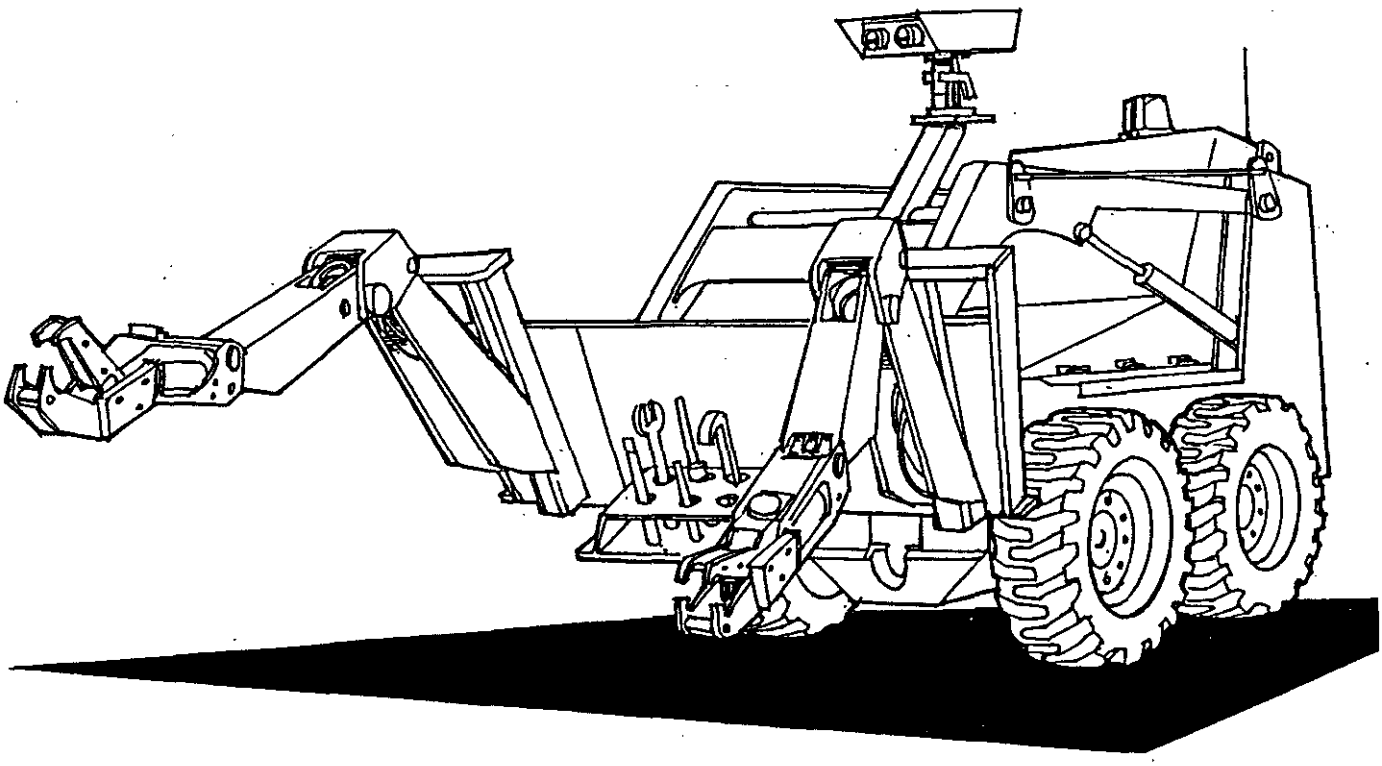

CCA-WRAC015-0

Figure WRAC-16. Modified Remote-Controlled Melroe Bobcat With Manipulator Attachments

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Figure WRAC-17. REMOTEC ANDROS Robotic Probe

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Although the retrieval demonstration was performed on a small scale, it proved that remote controlled equipment could be used to remove salt and metal materials from around a waste container, package the excess material, and remove the waste container. The removal of waste from a consolidated salt condition will involve a more complex set of circumstances. However, current technological capabilities permit remote operation of current equipment and will permit these complexities to be solved operationally. Thus, no new technology will be required.

Current technology exists and is in operation in mines throughout the world to excavate materials using remote controlled machinery. Remote coal mining has been performed for many years by countries including Australia, France, Austria, Canada, Russia, and the United States. Remote controlled continuous miners, rock bolters, drills, haulage, road headers, loaders, and locomotives are examples of the equipment used at these mines (Naunkovic 1986).

WRAC.8 Conclusion

The requirement for waste removal after closure originates in 40 CFR § 191.14(f). Specifically, 40 CFR § 191.14(f) states that WIPP disposal systems will be selected so that removal of the waste is not precluded for a reasonable period of time after disposal (EPA 1993). Removal of the waste after the repository is sealed is possible. Because access to the repository was accomplished using standard mining practices, access to the waste after closure can be accomplished using the same mining technologies supplemented by a more extensive use of remote controlled and robotic equipment. The degree of robotic and remote controlled technology required to successfully remove the waste is not only available and but also has been used in mining and industrial packaging activities around the world. The accessibility for waste removal has no operational time limit assuming use of today's technology. 40 CFR § 194.46 states that the analysis of the technological feasibility of removing the waste use ". . .technology levels at the time a compliance application is prepared." Locating and removing the waste is feasible using currently available equipment modified to operate remotely. Packaging the removed waste and decontaminating the containers can be safely accomplished by using established techniques. The concept of sealing and decommissioning the facility will have been demonstrated prior to waste removal.

As stated in the preamble to 40 CFR Part 191, with respect to the waste removal requirement:

> Any current concept for mined geologic repository meets this requirement without any additional procedures or design features. For example, there is no intent to require that the repository shafts be kept open to allow future recovery. To meet this assurance requirement, it only need be technically feasible (assuming current technology levels) to be able to mine the sealed repository and recover the waste - albeit at substantial cost and occupational risk.

The WIPP is a mined geologic repository and, as such, meets the removal requirement without any additional design requirements since current technology can be used to remove the waste if the need arises. Examples of the necessary mining equipment are in existence today, are

readily available, and have been effectively used for mining applications. Thus, it is logical to conclude that since the necessary equipment not only exists in off the shelf forms but also has been effectively used in a variety of mining applications, then waste removal utilizing this equipment is feasible. Partial proof of this concept has already been demonstrated by retrieving waste containers from under salt and metal roof support materials using remote controlled equipment.

REFERENCES

Cook C. W. 1982. *Underground Scanning With an Impulse Radar*, Sandia National Laboratories, SAND82-0470, 1982.

DOE (U. S. Department of Energy). 1991. *System Design Description (SDD), WH-OO Waste Handling*, Revision 0, October 1991.

DOE (U.S. Department of Energy). 1995. *Remote-Handled Transuranic Waste Study*, DOE/CAO 95-1095, October 1995.

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191: *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes*, 1993.

EPA (U.S. Environmental Protection Agency). 1996. *Compliance Application Guidance for 40 CFR Part 194*, EPA 402-R-95-014, March 29, 1996. Office of Radiation and Indoor Air, Washington, D.C.

Naunkovic, S. 1986. *Remote Control of Mining Machinery By Means of Radio Waves*, JUREMA, Yugoslavia, 1986. (Abstract Only)

BIBLIOGRAPHY

Boutonnat, M., Leclercq, A. 1986. *Computer-Assisted Monitoring and Remote Control Systems for Longwall Shearer*, JUREMA, Yugoslavia, 1986. (Abstract Only)

DOE (U. S. Department of Energy). 1990. *Final Safety Analysis Report, Waste Isolation Pilot Plant*, WP 02-9, Revision 0, May 1990. Westinghouse Electric Corporation, Carlbad, NM.

EPA (U. S. Environmental Protection Agency). 1985. 40 CFR Part 191, *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, 50 FR 38066, September 19, 1985. Office of Radiation and Air, Washington, D.C.

McQueen. 1988. *Deep Seam-Face Automation Stage 3-Continuous Haulage and Miner Remote Control*, McQueen and Co. Pty. Ltd., 1988 ISBN: 0-642-12713-1. (Abstract Only)

Schnakenberg, G. H. Jr. 1993. *Technology Development for Remote, Computer-Assisted Operation of a Continuous Mining Machine*, U.S. Bureau of Mines, Pittsburgh, PA., 1993. (Abstract Only)

SNL (Sandia National Laboratories). 1992. WIPP Performance Assessment Department, *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Vol 1: Third Comparison with 40 CFR 191, Subpart B*, SAND92-0700/1, 1992.

Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

Appendix XRE

United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

Reference Expansion

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DOE (U.S. Department of Energy), 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026, Volumes 1 and 2, Office of Environmental Restoration and Waste Management, Washington, D.C. WPO 38835, WPO 38838, and WPO 38839.

p 1-2, Section 1.2.1 1980 WIPP FEIS

" The 1980 WIPP Final Environmental Impact statement (FEIS) and the associated public review and comment period provided environmental input for the DOE's initial decision to proceed with the WIPP (DOE, 1980). The significance of impacts associated with the various alternatives was assessed. For the selected alternative, a two-phased approach to development was proposed: 1) a site and preliminary design validation (SPDV) program, as discussed in Subsection 8.2.1 of the FEIS, and 2) full construction, as discussed in FEIS Subsection 8.2.2. The durations of key WIPP activities are shown in Figure 1.1.

The 1980 FEIS presented an analysis of the environmental impacts of a number of alternatives for demonstrating the safe disposal of TRU waste. The alternatives considered include:

- Alternative 1. No action. A research and development facility to demonstrate safe disposal of TRU waste would not be developed and post-1970 TRU waste would continue to be retrievably stored.
- Alternative 2. Developing the WIPP at the Los Medanos site in southeastern New Mexico.
- Alternative 3. Disposing of stored TRU waste in the first available repository for high-level radioactive waste.
- Alternative 4. Delaying a decision on the site for a WIPP until at least 1984 to allow for investigation of alternative sites.

Alternative methods and geologic media for TRU waste disposal were also considered but rejected in the FEIS. The alternative methods included burial in deep ocean sediments, emplacement in deep drillholes, transmutation, and ejection into space. The alternative geologic media included igneous, volcanic, and argillaceous rocks.

The DOE's Record of Decision, published January 28, 1981 (46 FR 9162), announced the DOE's selection of Alternative 2: to proceed with the phased development of the WIPP at the Los Medanos site in southeastern New Mexico. . . ."

DOE (U.S. Department of Energy), 1981. Waste Isolation Pilot Plant: Record of Decision. Federal Register, Vol. 46, No. 18, p. 9162, January 28, 1981. Office of Environmental Restoration and Waste Management, Washington, D.C.

p. 9162, col. 3;

" This Record of Decision has been prepared on the Waste Isolation Pilot Plant (WIPP) Project pursuant to Regulations of the Council on Environmental Quality, 40 CFR 1505.

DECISION

The U.S. Department of Energy (DOE) has decided to proceed with the WIPP project at the Los Medanos Site in the Delaware Basin of southeast New Mexico as directed by the U.S. Congress in Public Law 96-164 'Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980'. The WIPP project, which is described as alternative 2 in the Final Environmental Impact Statement (FEIS), DOE/EIS-0026, October, 1980, will be developed 'as a defense activity of the DOE for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from defense activities and programs of the United States' Public Law 96-164. Construction of permanent surface and underground facilities will proceed on a phased basis consistent with the evaluation of data obtained during the Site and Preliminary Design Validation (SPDV) program as defined in the FEIS. If significant new environmental data results from the SPDV program or other WIPP project activities, the FEIS will be supplemented as appropriate to reflect such data, and this decision to proceed with phased construction and operation of th (sic) WIPP facility will be reexamined in the light of the supplemental National Environmental Policy Act (NEPA) review."

EPA (U.S. Environmental Protection Agency), 1985. "40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes: Final Rule." Federal Register, Vol. 50, No. 182, pp. 38066-38089, September 19, 1985, Office of Radiation Programs, Washington, D.C. WPO 39132.

SUMMARY, p. 38066, col. 1;

" The Environmental Protection Agency (EPA) is promulgating generally applicable environmental standards for the management and disposal of spent nuclear fuel and high-level and transuranic wastes. The standards apply to management and disposal of such materials generated by activities regulated by the Nuclear Regulatory Commission (NRC) and to disposal of similar materials generated by atomic energy defense activities under the jurisdiction of the Department of Energy (DOE). These standards have been developed pursuant to the Agency's authorities and responsibilities under the Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act of 1982.

Subpart A of these standards limits the radiation exposure of members of the public from the management and storage of spent fuel or high-level or transuranic wastes prior to disposal at waste management and disposal facilities regulated by the NRC. Subpart A also limits the radiation exposures to members of the public from waste emplacement and storage operations at DOE disposal facilities that are not regulated by the NRC.

Subpart B establishes several different types of requirements for disposal of these materials. The primary standards for disposal are long-term containment requirements that limit projected releases of radioactivity to the accessible environment for 10,000 years after disposal. These release limits should insure that risks to future generations from disposal of these wastes will be no greater than the risks that would have existed if the uranium ore used to create the wastes had not been mined to begin with. A set of six qualitative assurance requirements is an equally important element of Subpart B designed to provide adequate confidence that all containment requirements will be met. The third set of requirements are limitations on exposures to individual members of the public for 1,000 years after disposal. Finally, a set of ground water protection requirements limits radionuclide concentrations for 1,000 years after disposal in water withdrawn from most Class I ground waters to the concentrations allowed by the Agency's interim drinking water standards (unless concentrations in the Class I ground waters already exceed limits in 40 CFR Part 141, in which case this set of requirements would limit the increases in the radionuclide concentrations to those specified in 40 CFR Part 141). Subpart B also contains informational guidance for implementation of the disposal standards to clarify the Agency's intended application of these standards, which address a time frame without precedent in environmental regulations. Although disposal of these materials in mined geologic repositories has received the most attention, the disposal standards apply to disposal by any method, except disposal directly into the oceans or ocean sediments.

This notice describes the final rule that the Agency developed after considering the public comments received on the proposed rule published on December 29, 1982, and the recommendations of a technical review conducted by the Agency's Science Advisory Board (SAB). The major comments received on the proposed standards are summarized together with

the Agency's responses to them. Detailed responses to all the comments received are discussed in the Response to Comments Document prepared for this final rule.
DATE: These standards shall be promulgated for purposes of judicial review at 1:00 p.m. eastern time on October 3, 1985. These standards shall become effective on November 18, 1985."

EPA (U.S. Environmental Protection Agency), 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. Federal Register, Vol. 58, no. 242, pp. 66398-66416, December 20, 1993, Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

Federal register, Vol. 58 No. 242, p 66398, dated December 20,1993
"191.15 Individual protection requirements.

(a) Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts).

(b) Annual committed effective doses shall be calculated in accordance with appendix B of this part.

(c) Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved.

(d) Compliance with the provisions in this section does not negate the necessity to comply with any other applicable Federal regulations or requirements.

(e) The standards in this section shall be effective on January 19, 1994."

"Subpart C-Environmental Standards for Ground-Water Protection
. . .191.23 General provisions.

(a) Determination of compliance with this subpart shall be based upon underground sources of drinking water which have been identified on the date the implementing agency determines compliance with subpart C of this part.

191.24 Disposal standards.

(a) Disposal systems.

(1) General. Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that 10,000 years of undisturbed performance after disposal shall not cause the levels of radioactivity in any underground source of drinking water, in the accessible environment, to exceed the limits specified in 40 CFR part 141 as they exist on January 19, 1994.

(2) Disposal systems above or within a formation which within one-quarter (1/4) mile contains an underground source of drinking water. [Reserved]

(b) Compliance assessments need not provide complete assurance that the requirements

of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved. . . ."

EPA (U.S. Environmental Protection Agency), 1996a. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. Federal Register, Vol. 61, No. 28, pp. 5224-5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C. In NWM Library as KF70.A35.C751 1966 (Reference).

SUMMARY, p. 5224, col. 1;

" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992.

EPA (U.S. Environmental Protection Agency) 1996b. Compliance Application Guidance for 40 CFR Part 194. EPA 402-R-95-014, March 29, 1996. Office of Radiation and Indoor Air, Washington, D.C. WPO 39159.

INTRODUCTION, p. 1;

" The Compliance Application Guidance (CAG) is a companion to the final rule published at 61 FR 5224, February 9, 1996, 'Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's (WIPP) Compliance With the 40 CFR Part 191 Disposal Regulations' (to be codified at 40 CFR Part 194).

The CAG summarizes and explains the February 9, 1996 final rule. The United States Environmental Protection Agency (EPA) developed this guidance to assist the United States Department of Energy (DOE) with the preparation of any Compliance Certification Application (CCA) for the WIPP and, in turn, to assist in EPA's review of the CCA for completeness and generally to enhance the readability and accessibility of the CCA for EPA and public scrutiny. It is EPA's intent that this guidance will facilitate the understanding that DOE and the public have of the specific information that is expected to be included in a *complete* application for certification of compliance. Examples used for clarification purposes in this guidance should not be considered exhaustive or definitive, since they are provided merely to facilitate DOE's understanding of the types of information EPA is expecting. . . ."

p. 2, para. 2;

" The CAG summarizes and explains EPA's expectations of the format and content of the CCA, based on the February 9, 1996 final rule (hereafter referred to as '40 CFR Part 194'). The technical and legal requirements pertaining to the CCA are addressed by 40 CFR Parts 191 and 194. The CAG's format follows that of 40 CFR Part 194, restating the rule language in *italics*, followed by the specific guidance for that section in standard type. Only those portions of 40 CFR Part 194 (and, by reference, applicable portions of 40 CFR Part 191) for which DOE is required to submit specific information to EPA, are addressed. Portions of 40 CFR Part 194 which are applicable only to EPA, such as Subpart D, were excluded from this guidance.

The information DOE presents in any compliance application must conform to the requirements of 40 CFR Part 194."

ORNL (Oak Ridge National Laboratory). 1973. Site Selection Factors for the Bedded Salt Pilot Plant. ORNL-TM-4219. Oak Ridge National Laboratory, Oak Ridge, TN.

ABSTRACT, p 1;

" Because of the nature of radioactive waste disposal in geologic formations, the selection of suitable sites is a unique exercise totally different from that for any other type of facility. This compilation of the various factors which must be taken into consideration was assembled as an aid in the selection and confirmation of a site for the Bedded Salt Pilot Plant. As might be expected, most of these factors are related to geologic characteristics, which are discussed under the headings of: (1) stratigraphy, (2) structure, (3) hydrology, and (4) mineral resources. Other factors concerned with geography and facility design and operation are also included."

BIBLIOGRAPHY DOCUMENTS

NAS-NRC (National Academy of Sciences-National Research Council), 1957. Disposal of Radioactive Wastes on Land. Publication 519. National Academy of Sciences, Washington, D.C.

ABSTRACT p 1, para. 2;
" Disposal in cavities mined in salt beds and salt domes is suggested as the possibility promising the most practical immediate solution of the problem."

U.S. Congress, 1992. Waste Isolation Pilot Plant Land Withdrawal Act, Public Law 102-579, 106 Stat. 4777, October 1992. 102nd Congress, Washington, D.C. WPO 39015.

An Act
To withdraw land for the Waste Isolation Pilot Plant, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SEC. 8. ENVIRONMENTAL PROTECTION AGENCY DISPOSAL REGULATIONS.

(a) REINSTATEMENT.--

(1) IN GENERAL.--Except as provided in paragraph (2), the disposal regulations issued by the Administrator on September 19, 1985, and contained in subpart B of part 191 of title 40, Code of federal regulations, shall be in effect.

. . .

(d) DISPOSAL REGULATIONS.--

(A) IN GENERAL.--The Secretary shall comply at WIPP with the final disposal regulations. Within 7 years of the date of first receipt of transuranic waste at WIPP, the Secretary shall submit to the Administrator an application for certification of compliance with such regulations.

(B) CERTIFICATION BY ADMINISTRATOR.--Within 1 year of receipt of the application under subparagraph (A), the Administrator shall certify, by rule pursuant to section 553 of title 5, United States Code, whether the WIPP facility will comply with the final disposal regulations, and sections 556 and 557 of such title shall not apply.

(C) JUDICIAL REVIEW.--Judicial review of the certification of the Administrator under subparagraph (B) shall not be restricted by the provisions of section 221 c. of the Atomic Energy Act of 1954 (42 U.S.C. 2271(c)).

(D) LIMITATION.--Any certification of the Administrator under subparagraph (B) may only be made after the application is submitted to the Administrator under subparagraph (A)."

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Adams, J.E. 1944. "Upper Permian Ochoa Series of the Delaware Basin, West Texas and Southeastern New Mexico." American Association of Petroleum Geologists Bulletin, Vol. 28, No. 11, 1596-1625. WPO 37940.

p 1612, para 4, line 4;

" It seems probable, however, that the uppermost Castile salts were dissolved to form a shallow solution valley along the original margin of these salts. This and the tilting of the Delaware basin northward probably mark a time break between the two formations. The unconformity between the Salado and the overlying Rustler formation is marked by extensive erosion and solution.

It is probable that the Salado should be correlated with the Tessey formation of the Glass Mountains. The Tessey is made up of practically pure, almost non-fossiliferous dolomites and probably reprssents the back-reef facies of a post-Capitan reef, into which the limed-up section of the southern Salado appears to grade.[18]

RUSTLER FORMATION

Deposition of the Rustler, the third formation of the Ochoa series, was preceded by a period of uplift and erosion in the area along the west edge of the Delaware basin. This erosion stripped off all the western Salado and may have truncated the entire Castile formation as well. The lowest Rustler outcrops observed are about 100 feet above the top of the Delaware Mountain group. As a result of uplifts beyond the limits of the Delaware basin, the oldest deposit of the Rustler formation, in its western outcrops, is a clastic member. Included are coarse, siliceous conglomerates with well rounded pebbles up to 2 or 3 inches in diameter, coarse gray sandstones, traces of red and yellow shale, coarse dolomite conglomerates, and bedded gray and buff dolomite. Many of the siliceous pebbles are etched in a peculiar manner with all the broken crystals of the original surface spalled out, leaving well rounded pebbles covered with unmarred crystal faces. The bedding in all these deposits seems to be distorted. Toward the east the conglomerates grade into sandstones."

p 1614, para 3;

" The first five members in the foregoing section belong to the upper Rustler, the others to the lower part of the formation. The 30-foot gypsiferous dolomite, No. 2 in the sequence, is a persistent marker in the north half of the Delaware basin. For this stringer Lang favors the name Magenta member of the Rustler formation, after Magenta Point north of the Laguna Grande salt lake, and this name is used on the stratigraphic sections. For the 35-foot dolomite, No. 6 in the section, he favors the name Culebra member of the Rustler formation, from Culebra Bluff on the east side of the Pecos River where the member is well exposed. Because this member is a good marker in the subsurface, the name Culebra is also used in the cross sections."

p. 1614, para 5;

" Local features include a zone of euhedral quartz crystals in the anhydrite between the

magenta and Culebra dolomites, and oölites in one or the other of the two main dolomite members. The oölites are most common in that part of the Rustler overlying the Capitan reef and the back-reef areas."

Algermissen, S.T., and Perkins, D.M. 1976. A Probabilistic Estimate of Maximum Ground Acceleration in the Contiguous United States. Open-file Report 76-416, pp. 1-45. U.S. Geological Survey.

INTRODUCTION, p 1;

" This paper presents a probabilistic estimate of the maximum ground acceleration to be expected from earthquakes occurring in the contiguous United States. It is based primarily upon the historic seismic record which ranges from very incomplete before 1930 to moderately complete after 1960. Geologic data, primarily distribution of faults, have been employed only to a minor extent, because such data have not been interpreted yet with earthquake hazard evaluation in mind.

The map provides a preliminary estimate of the relative hazard in various parts of the country. The report provides a method for evaluating the relative importance of the many parameters and assumptions in hazard analysis. The map and methods of evaluation described reflect the current state of understanding and are intended to be useful for engineering purposes in reducing the effects of earthquakes on buildings and other structures.

Studies are underway on improved methods for evaluating the relative earthquakes hazard of different regions. Comments on this paper are invited to help guide future research and revisions of the accompanying map.

The earthquake hazard in the United States has been estimated in a variety of ways since the initial effort by Ulrich (see Roberts and Ulrich, 1950). In general, the earlier maps provided an estimate of the severity of ground shaking or damage but the frequency of occurrence of the shaking or damage was not given. Ulrich's map showed the distribution of expected damage in terms of no damage (zone 0), minor damage (zone 1), moderate damage (zone 2), and major damage (zone 3). The zones were not defined further and the frequency of occurrence of damage was not suggested. Richter (1959) and Algermissen (1969) estimated the ground motion in terms of maximum Modified Mercalli intensity. Richter used the terms 'occasional' and 'frequent' to characterize intensity IX shaking and Algermissen included recurrence curves for various parts of the country in the paper accompanying his map.

The first probabilistic hazard maps covering portions of the United States were by Milne and Davenport (1969a). Recently, Wiggins, Hirshberg and Bronowicki (1974) prepared a probabilistic map of maximum particle velocity and Modified Mercalli intensity for the entire United States. The maps are based on an analysis of the historical seismicity. In general, geological data were not incorporated into the development of the maps."

Anderson, R.Y., 1978. Deep Dissolution of Salt, Northern Delaware Basin, New Mexico. Report to Sandia National Laboratories, Albuquerque, NM. WPO 29527 - WPO 29530.

Abstract, p v:

" Deep-seated dissolution in the Delaware basin has developed in association with the Capitan (reef) and the underlying Bell Canyon (Delaware) aquifers and at a more permeable horizon between the Castile and Salado formations. The uplift, erosion, and exposure of the reef in the Guadalupe and Glass mountains has channeled meteoric waters through the reef aquifer. These waters gained access to the salt through fractures around the reef margin, and dissolved overlying and superjacent salt by means of brine density flow. This type of deep dissolution moved into the salt beds laterally at a horizon of increased permeability between the Castile and Salado formations and dissolved a wedge that undercut the overlying evaporites. The deep-seated dissolution also produced a number of large-scale collapse structures along the basin margin and along the western edge of salt. This wedge-like effect, combined with surface dissolution, has removed 50 percent of the original salt from the basin and removed 70 percent of the original salt at the lower Salado horizon.

The water in the aquifers, by gaining access to overlying chambers though fractures, have also dissolved smaller scale localized chambers in overlying salt beds that subsequently collapse to form breccia pipes, deep-seated sinks, and other collapse structures. These features have been exhumed to different stratigraphic levels in the tilted and eroded basin, resulting in surface expression as limestone buttes (Castiles), collapsed outliers, domal structures with collapsed centers (breccia pipes), and deep-seated sinks. Many of the deep-seated sinks are associated with salt anticlines which probably formed as a result of differential stress from unloading related to dissolution. Localized collapse, as well as regional dissolution, is an ongoing process.

The W.I.P.P. site lies in a corner of the Delaware basin that has been relatively protected from regional but not localized effects of deep dissolution. Deep seated, wedge-like dissolution, however, has progressed from north to south in the basin and salt in the northern part of the Delaware basin will eventually be dissolved at the lower Salado horizons before overlying salt has been removed from the basin by processes of near-surface dissolution (suberosion)."

Introduction, p 1, para 1;

" Two types of salt dissolution, deep and shallow, can be recognized in the Delaware Basin. The more familiar shallow type is the result of the subsurface movement of undersaturated ground water across the upper surface of salt. Near-surface dissolution has left a residue at the top of the salt body of the Salado Formation referred to by Vine (1963) as the leached zone. Estimates of the rate of dissolution and surface lowering (suberosion) for this process can be obtained from ground water flow data or, indirectly, from the rate of retreat of the dissolving edge of the salt (Bachman and Johnson, 1973, p. 41; Jones, 1973, p 4; Bachman, 1974, p. 68; Piper, 1973).

A second type of salt dissolution can be recognized as having dissolved salt from

somewhere within the body of evaporites, generally resulting in the collapse and lowering of the overlying stratigraphic units. This type of salt dissolution was recognized by Anderson and others (1972) as a blanket dissolution breccia which occurs to the west of the present salt edge in the basin. In addition, abundant evidence exists that deep-seated dissolution within the evaporites has resulted in more localized collapse features around the margin of the basin and within the basin. The origin of these deep dissolution features and breccias is more problematical than the origin of surface dissolution and the rates of dissolution more difficult to assess. This report summarizes investigations to recognize and delineate the effects of deep dissolution in the northern Delaware basin. It relates observed patterns of deep dissolution to probable hydrologic and tectonic factors and offers some explanations concerning the origin of the dissolution features. Finally, the report briefly summarizes the implications of the findings for the stability of the W.I.P.P. site."

POTENTIAL GEOLOGIC HAZARDS FROM DEEP-SEATED DISSOLUTION
(Implications for the W.I.P.P. Site), p. 76;

" Long-term Hazards:

The northern part of the Delaware basin has been relatively protected from the effects of advancing deep dissolution from the west and from the development of large dissolution depressions and a wedge along the reef margin. The area selected for the site is about equidistant from large-scale dissolution features to the southwest, southeast, and northwest. Of the possible locations in the basin, the present site is probably the best available from the standpoint of large-scale features of deep dissolution.

The Delaware basin itself, however, has been extensively affected by deep dissolution and the disposal horizons selected are the ones most susceptible to the process. I hesitate to make estimates of long-term site stability on the basis of what little information is available concerning the timing of the uplift and the age of the dissolution-related deposits. A general idea can be obtained by a slightly different approach than using the rate of advance of a dissolution edge as was done by Bachman and Johnson (1973). About 50 percent of the original volume of salt from the salt beds of the Castile and Salado formations has been dissolved from the basin. The removal of salt from the beds below the middle Salado probably did not begin until the western edge of the basin was well exposed and until a considerable volume of salt had already been removed from the upper Salado units. If we assume as Bachman and Johnson (1973, p. 39) did, that the stripping of the protective Ogallala Formation began about 4 m.y. ago, we can use this figure as a starting point for the beginning of deep dissolution. If we also assume a linear relationship (probably not a valid assumption) and that 73 percent of the lower Salado salt has been dissolved since that time, then the salt from that unit will be gone from the basin in about another million years.

For the site area, this would probably be a minimum estimate of the time until total dissolution of the lower Salado unit because of the protection afforded by the northeast corner of the basin, unless, of course, the 4 m.y. assumption is incorrect or if the dissolution rate should be nonlinear and faster during later stages."

Anderson, R.Y., and Kirkland, D.W. 1980. Dissolution of Salt Deposits by Brine Density Flow. Geology, Vol. 8, No. 2, pp. 66–69.

ABSTRACT, P 66;

" The origin of collapse structures and breccias that vertically penetrate or occur within impermeable evaporites has never really been understood. The density of the brine that develops as salt deposits are dissolved can generate continuous gravitational brine movement. If the source of the dissolving water is artesian, or continuous, a flow cycle is developed in which the salt itself supplies the density gradient that becomes the vehicle of its own dissolution. The Delaware Basin in western Texas and southeastern New Mexico provides a particularly good example of how brine density flow can produce dissolution chambers that collapse to form breccias. The potential for dissolution by brine flow is an inherent property of partly exhumed evaporites and may constitute a risk factor in the storage of radioactive waste in evaporite deposits."

Anderson, R.Y., 1981. "Deep-Seated Salt Dissolution in the Delaware Basin, Texas and New Mexico." In Environmental Geology and Hydrology in New Mexico, S.G. Wells and W. Lambert, eds., Special Publication No. 10., pp. 133-145. New Mexico Geological Society.

ABSTRACT, p 133, col 1;
" Patterns of salt dissolution in the Delaware Basin are related to the bedrock geometry and hydrology that developed following uplift, tilting, and erosion in the late Cenozoic, and the greatest volume of salt has been removed since that time. During the Permian, some salt was dissolved from the top of the Castile Formation before deposition of the Salado Formation and from the top of the Salado before deposition of the Rustler Formation. In addition, some salt dissolution occurred after the Permian and before the Cretaceous. Post-uplift surface dissolution has progressed across the Delaware Basin from south to north and from west to east and generally down the regional dip. Deep-seated dissolution has occurred around the margin of the basin where the Capitan Limestone aquifer is in contact with the Permian evaporites and within the basin where selective dissolution in the lower Salado has undercut the overlying salt beds of the middle and upper Salado. Dissolution has not advanced down regional dip uniformly but has left outliers of salt and has progressed selectively into structurally predisposed areas. This selective advance has significance for the stability of the U. S. Department of Energy's Waste Isolation Pilot Plant (WIPP) site."

Reef and Reef-Margin Dissolution, p 137, col 2;
" The inner margin of the reef, where buried around the northern and eastern sides of the basin, is the locus of a number of deep-seated dissolution features. Some of the small isolated domes in the northern part of the basin described by Vine (1960) (fig. 2) have recently been cored as part of the WIPP exploration, and Dome A exhibits collapse and brecciation to a depth equivalent to the top of the reef (D. Powers, personal commun.). The eastern chain of large dissolution depressions of Maley and Huffington (1953) occupy an equivalent position with respect to the reef margin. The absence of Salado salt in the deeper part of these depressions indicates that they 'root' in or above the Capitan reef aquifer. A depression occupying the same position with respect to the reef appears to have controlled the western edge of Salado salt where it crosses the reef in the northern part of the basin (fig. 2 and illustrated by Brokaw and others, 1972). Both San Simon Sink and its surrounding depression, San Simon Swale (fig. 2), have developed relatively recently along the inner reef margin in the northeastern corner of the basin. A new sink developed in June, 1980 between Kermit and Wink, Texas (fig. 2)(Baumgardner and others, 1980) on the edge of one of the depressions defined by Maley and Huffington (1953)."

STAGE AND RATE OF DISSOLUTION, p. 144, col. 1, para. 4;
" Compared to some other evaporite basins on the continental platform containing even older salt beds, such as the Michigan Basin or the evaporites in Saskatchewan, the Delaware Basin with 50 percent of the salt removed has reached a rather mature stage of dissolution.

This is reflected in the size, abundance, and distribution of dissolution features.

. . .

This schedule of uplift and exhumation agrees quite well with the age of the stratigraphic and geomorphic units associated with dissolution in the basin for which some age information is available. Substantial dissolution is associated with Gatuna Formation which is probably early Pleistocene and pre-Kansan in age (Bachman, 1974, P. 28). The Mescalero surface, which is developed on top of Gatuna sediments and which developed after the formation of the major features in the central part of the basin (i.e., Big Sinks depression) has been dated indirectly with an ash bed at about 600,000 years (Bachman, 1980). Deposits associated with the recent development of Nash Draw was placed in the Wisconsin. San Simon Swale and Sink sediments are no older than about 50,000 years."

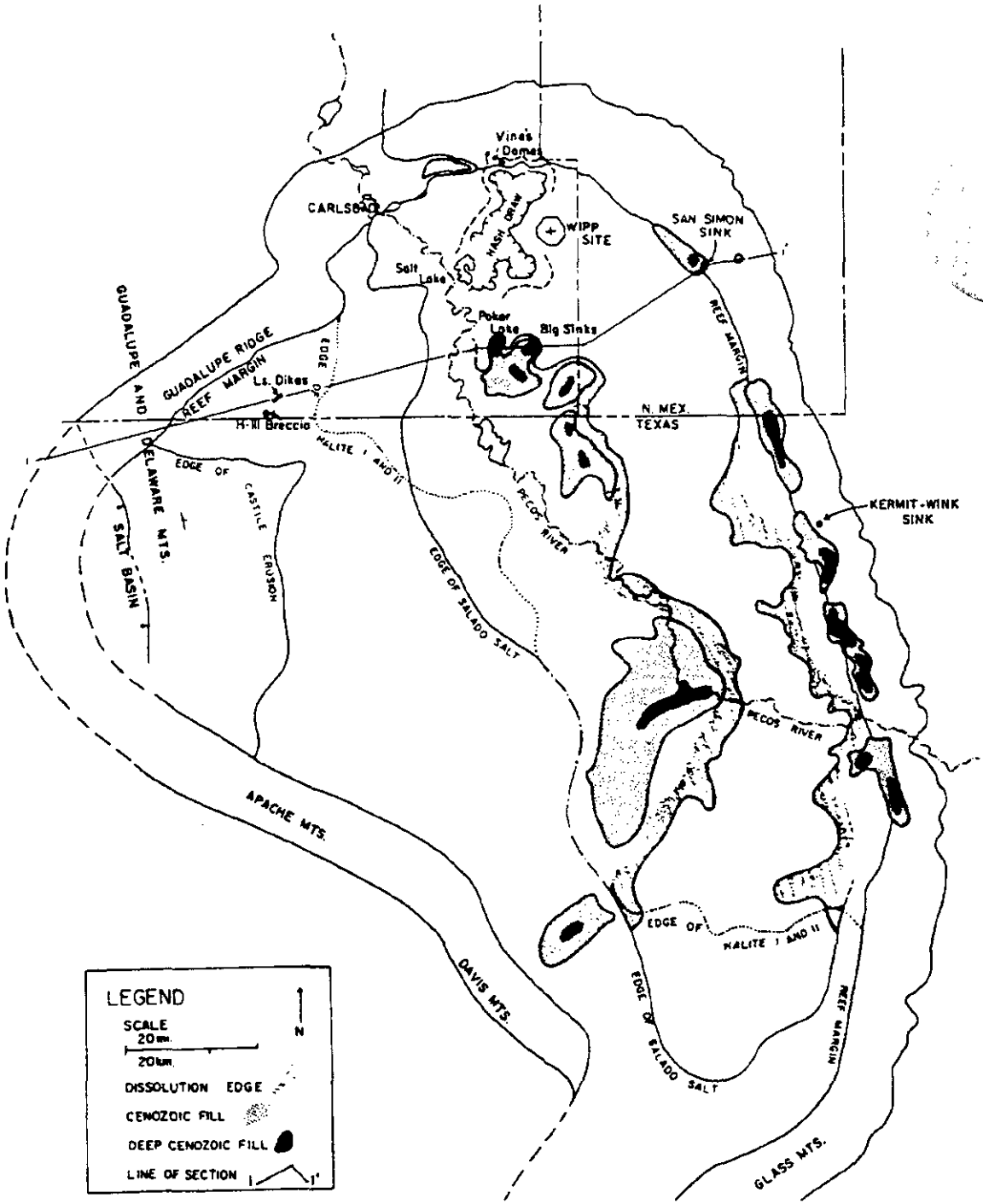

Figure 2. Map of Delaware Basin showing location of Capitan reef, major dissolution depressions, and western dissolution edge of evaporites and of major salt units.

Anderson, R.Y. 1993. "The Castile as a 'Nonmarine' Evaporite." In Carlsbad Region, New Mexico and Texas, New Mexico Geological Society, Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993, D.W. Love et al., eds., pp. 12-13. New Mexico Geological Society, Socorro, NM.

p 12, col 2;

" After King (1947) showed that the low proportion of halite to anhydrite in the Castile evaporite could be explained by the reflux of brine from the Delaware Basin, the Castile became the classical example of a marine, 'deep water' evaporite. Anderson and Dean (in press) have reexamined the distribution of evaporites units, as well as geochemical evidence and they suggest that reflux is not the only way to explain the compositional and stratigraphic relationships of the Castile. According to the alternate explanation, the brine was not a residual of sea water flowing directly into the basin. Rather, it is suggested that chloride recharge was from ground water seeping into the basin from the south, especially during lowstands (Fig. 1.12a), with the brine derived from a partly marine source or from previously deposited evaporites. In this model, the Delaware Basin was a hydrologically closed basin with water level subject to extreme highstands (Fig. 1.12b) and lowstands, a type of response similar to that observed in existing closed basins in western North America.

Support for a closed-basin model can be found in the record of climatic variability that is preserved in the Castile. For example, millennial oscillations in climate and lake level are strongly expressed in the closed hydrologic basins in western North America during the late Pleistocene. Millennial cycles also are dominant in the Castile and determine the incidence and duration of halite accumulation (lowstands). Cycles of precession and eccentricity also are well defined in the Castile and in the record of the ocean and cryosphere over the past million years. The occurrence of climate cycles recognized in the Pleistocene and Holocene does not address the question of marine recharge for the Castile. However, strong expression of the same climatic periodicities within the Castile is consistent with a closed-basin hydrologic setting and meteoric recharge.

More direct evidence for meteoric recharge can be seen in the depletion of ^{18}O in limestone beds along the western margin of the basin (Magaritz et al., 1983) and in rapid, synchronous changes in the seasonal rate of accumulation of calcium sulfate (freshening events) that resulted in beds of laminated limestone. Such events can be traced from the western margin to the center of the basin, suggesting that a significant volume of meteoric recharge entered the basin from the west during those times when water level was at or near a highstand (Fig. 1.12b). Other evidence for meteoric contributions can be found in the low bromine concentrations in halite, which give the Castile an affinity with other nonmarine evaporites. Ground-water recharge of ions derived from preexisting evaporites provides an alternate mechanism to account for the low ratio of halite to sulfate.

The geometrical relationships of stratigraphic units provides indirect evidence for ground-water recharge and for large changes in water level within the Delaware Basin. For example, as the basin filled with sediment there was a southward shift in the locus of thick accumulation of halite (Fig 1.12c) that can best be explained if water level was initially

drawn down to a minimum pool several hundred meters below the basin rim (Fig 1.12a). Reflux during such lowstands seems unlikely. Also, beds of laminated halite are thicker to the north, implying that seasonal accumulation of halite was less continuous in the south, even during lowstands, as would be expected if chloride entered the basin in ground water.

Although no single line of evidence eliminated direct marine inflow as a source for the brine, the strong response to climate forcing, combined with evidence for drawdown and meteoric contributions, leaves the clear possibility that the Delaware Basin was isolated from the sea."

Figures are not included. Unable to scan into document without breaking backing of original document. This document is otherwise totally included.

Anderson, R.Y., Dean, W.E., Jr., Kirkland, D.W., and Snider, H. I. 1972. "Permian Castile Varved Evaporite Sequence, West Texas and New Mexico." Geological Society of America Bulletin, Vol. 83, No. 1, pp. 59-85.

ABSTRACT; p 59, col 1;

" Laminations in the Upper Permian evaporite sequence in the Delaware Basin appear in the preevaporite phase of the uppermost Bell Canyon Formation as alternation of siltstone and organic layers. The laminations then change character and composition upward to organically laminated claystone, organically laminated calcite, the calcite-laminated anhydrite typical of the Castile Formation, and finally to the anhydrite-laminated halite of the Castile and Salado.

Laminae are correlative for distances up to 111 km (70.2 mi) and probably throughout most of the basin. Each laminae is synchronous, and each couplet of two laminated components is interpreted as representing an annual layer of sedimentation--a varve.

The thickness of each couplet in the 260,000-varve sequence (a total thickness of 447.2 m, (1465 ft) has been measured individually and recorded and provides the basis for subdividing and correlating major stratigraphic units within the basin. The uppermost 9.2 m (30.3 ft) of the Bell Canyon Formation contains about 50,850 varve couplets; the Basal Limestone Member of the Castile about 600; the lowermost anhydrite member of the Castile (Anhydrite I) contains 38,397; Halite I, 1,063;Anhydrite II, ??,414; Halite II, 1,758; Anhydrite III, 46,592; Halite III, 17,879; and Anhydrite IV, 54,187. The part of the Salado collected (126.6 m) contains 35,422 varve couplets. The Bell Canyon-Castile sequence in the cores studies is apparently continuous, with no recognizable unconformities.

The dominant petrologic oscillation in the Castile and Salado, other than the laminations, is a change from thinner undisturbed anhydrite laminae to thicker anhydrite laminae that generally show a secondary or penecontemporaneous nodular character, with about 1,000 to 3,000 units between major oscillations or nodular beds. These nodular zones are correlative throughout the area of study and underly halite when it is present. The halite layers alternate with anhydrite laminae, are generally recrystallized, and have an average thickness of about 3 cm. The halite beds were once west of their present occurrence in the basin but were dissolved, leaving beds of anhydrite breccia. The onset and cessation of halite deposition in the basin was nearly synchronous.

The Anhydrite I and II Members thicken gradually across the basin from west to east, whereas the Halite I, II, and III Members are thickest in the eastern and northeastern part of the basin and thicken from southeast to northwest. This distribution and the synchroneity indicate a departure from the classical model of evaporite zonation."

SUBDIVISION AND DISTRIBUTION OF THE CASTILE AND UPPERMOST BELL CANYON FORMATION, p. 73, col. 1, para. 3;

" The Castile Formation has been subdivided here into eight members which permit examination of the present areal distribution patterns of halite and anhydrite."

TABLE 2. SUBDIVISIONS OF THE UPPER BELL CANYON-CASTILE SEQUENCE, DELAWARE BASIN, TEXAS AND NEW MEXICO.

UNM-Phillips #1			
Formation	Number of varve couplets	Thickness	Average thickness of calcite-anhydrite varve couplets
Salado Formation (partial section, undifferentiated)	35,422	12,660 cm	0.36 cm
Members			
Castile Formation			
Anhydrite IV	54,187	9,842 cm	0.18 cm
Halite III (including anhydrite beds)	*17,879	2,748 cm	0.16 cm
Anhydrite III	46,592	9,554 cm	0.21 cm
Halite II (including anhydrite beds)	+ 1,758	801 cm	0.45 cm
Anhydrite II	14,414	2,738 cm	0.19 cm
Halite I	+ 1,063	330 cm	0.31 cm
Anhydrite I	38,397	5,092 cm	0.13 cm
Basal Limestone	600	28 cm	0.04 cm
Estimated totals (Castile Formation)	174,890	31,133 cm	
Units			Average thickness of clastic-organic varve couplets
Bell Canyon Formation			
Claystone III	5,800	78 cm	0.01 cm
Siltstone III	24,814	551 cm	0.02 cm
Claystone II	15,650	166 cm	0.01 cm
Siltstone II	1,086	44 cm	0.04 cm
Claystone I	++ca 2,000	24 cm	ca. 0.01 cm
Siltstone I	++ca 1,500	61 cm	ca. 0.04 cm
Estimated totals (Bell Canyon Formation)	50,850	924 cm	
Combined totals	261,162	44,717 cm	

* Number of layers i halite fraction determined by extrapolation.
\+ Number of layers determined in Union-University "37" #4 core; thickness of calcite-anhydrite fractions only.
++ Number of layers in UNM-Cowden #4 core.

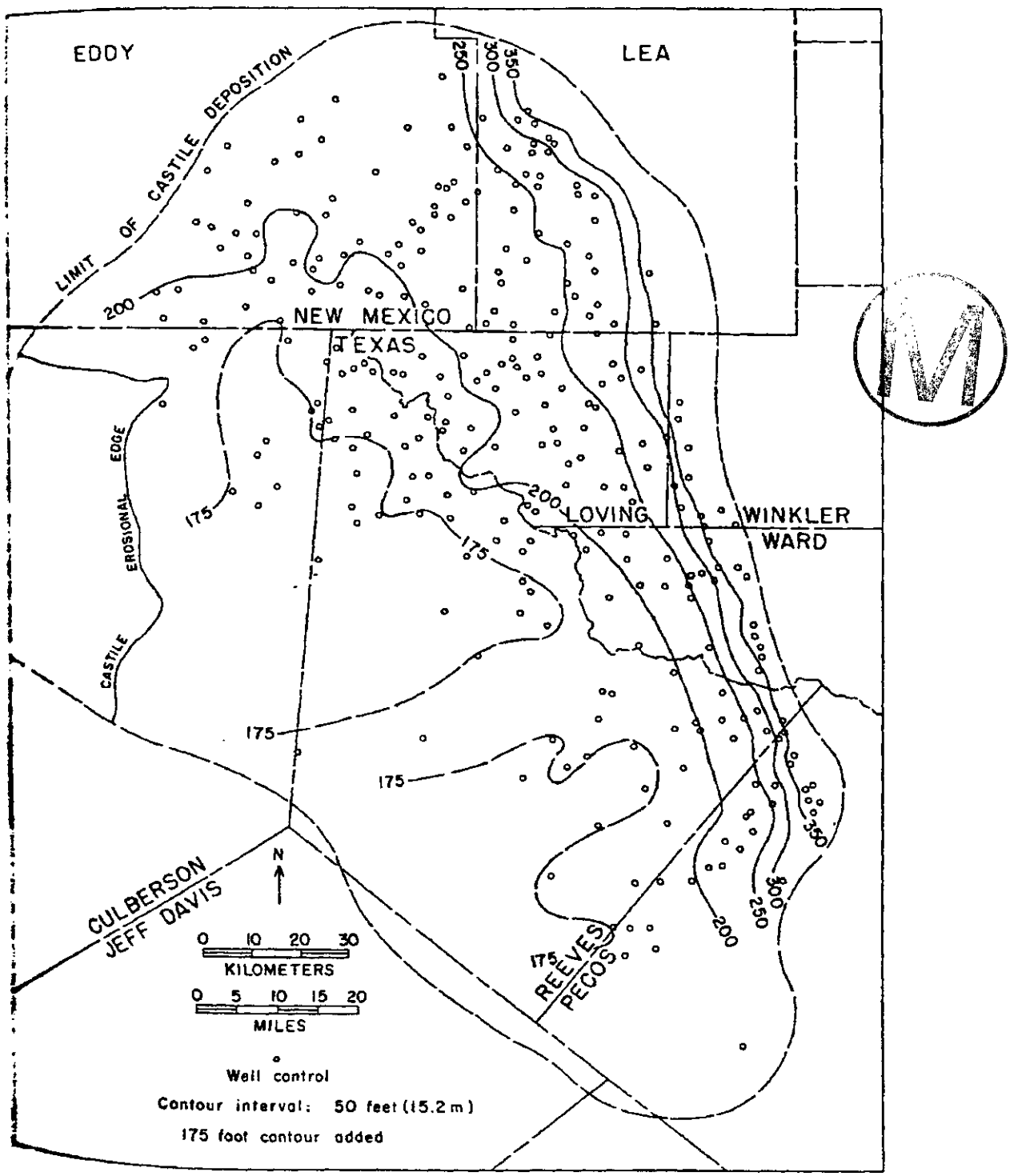

Figure 10. Thickness distribution of Anhydrite I Member, Castile Formation.

EFFECTS OF SOLUTION, p 81, col 1;

" The interpretation that breccia beds in the University of New Mexico-Phillips no. 1 core represented halite beds in the eastern part of the basin had been made on the basis of sonic log correlations prior to the availability of the Union-University '37' halite core. The Winkler County core, however, revealed that thin anhydrite beds of only a few decimeters thick within more massive halite units maintained their position and character after halite solution. This fact, and the observation that single anhydrite laminae, once separated by several centimeters of halite, were sometimes little disturbed upon solution, showed that the withdrawal of halite was a very gentle process.

With the exception of one halite bed in Anhydrite IV, every halite bed observed in the Winkler County core from the eastern part of the basin has an equivalent breccia bed in the University of New Mexico-Phillips no. 1 core. Inasmuch as this core locality is only about 32 km (20 mi) from the western edge of the basin, there is every reason to suppose that halite deposition once extended to, or nearly to, the western margin. The present western solution margin of halite units within the Castile shifts progressively eastward, with Halite II more areally restricted than Halite I. The halite in the Salado, however, extends farther westward than the present western solution limit of Castile halite (fig. 8). This suggests that an episode of solution might have taken place prior to Salado deposition. The isopach map of the halite beds within Anhydrite IV (Fig. 17) shows a very irregular distribution of halite in the east-central and northeastern part of the basin that is not present in any of the lower Castile halites and could also represent solution prior to Salado deposition.

It seems more likely, however, that all of the solution took place after Salado time and that the irregular distribution pattern in Anhydrite IV developed later. A comparison of the Anhydrite IV isopach for halite and the published map of Tertiary basin fill of Maley and Huffington (1953) shows a very close agreement between the locus of Cenozoic basin fill in the Delaware Basin and the areas of thin or missing halite in Anhydrite IV. Similarly, there is also a correlation between the Cenozoic basins and thin areas in the Salado."

Anderson, R.Y., and Powers, D.W. 1978. "Salt Anticlines in the Castile-Salado Evaporite Sequence, Northern Delaware Basin, New Mexico." In Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas, G.S. Austin, ed., Circular 159. pp. 79-83. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p 79, col 1, para 1;
" A number of structures have been encountered within the body of the Castile-Salado evaporites that can reasonably be interpreted as salt anticlines. One such structure, associated with brine, H_2S, and dissolution effects, was found during exploratory coring for the proposed nuclear waste disposal site near Carlsbad, New Mexico. Correlation of stratigraphic units in the recovered core with cores and logs from nearby boreholes shows that the middle anhydrite unit (A-II) of the Castile Formation, which attains dips of as much as 70°, has been displaced vertically by as much as 950 ft (290 m). Extension fractures in the A-II unit suggest that it has been stretched over a pod of exceptionally thick salt of the lower halite unit (H-I) of the Castile Formation that moved into the axis of the anticlinal structure. Exceptionally thick and thin units of lower salt (H-I) occur in other nearby boreholes in a zone of deformation marginal to the reef. Suspected salt anticlines also occur at scattered localities in the northern part of the Delaware Basin. The association of extension fracturing to microfolding in the middle anhydrite unit (A-II) suggests that salt deformation accompanied or followed Cenozoic uplift and tilting of the basin."

p 83, col 1, para 1, line 7;
" . . . It is even conceivable that original dissolution, particularly around the margin of the basin, may have developed the differential loading required to initiate salt movement."

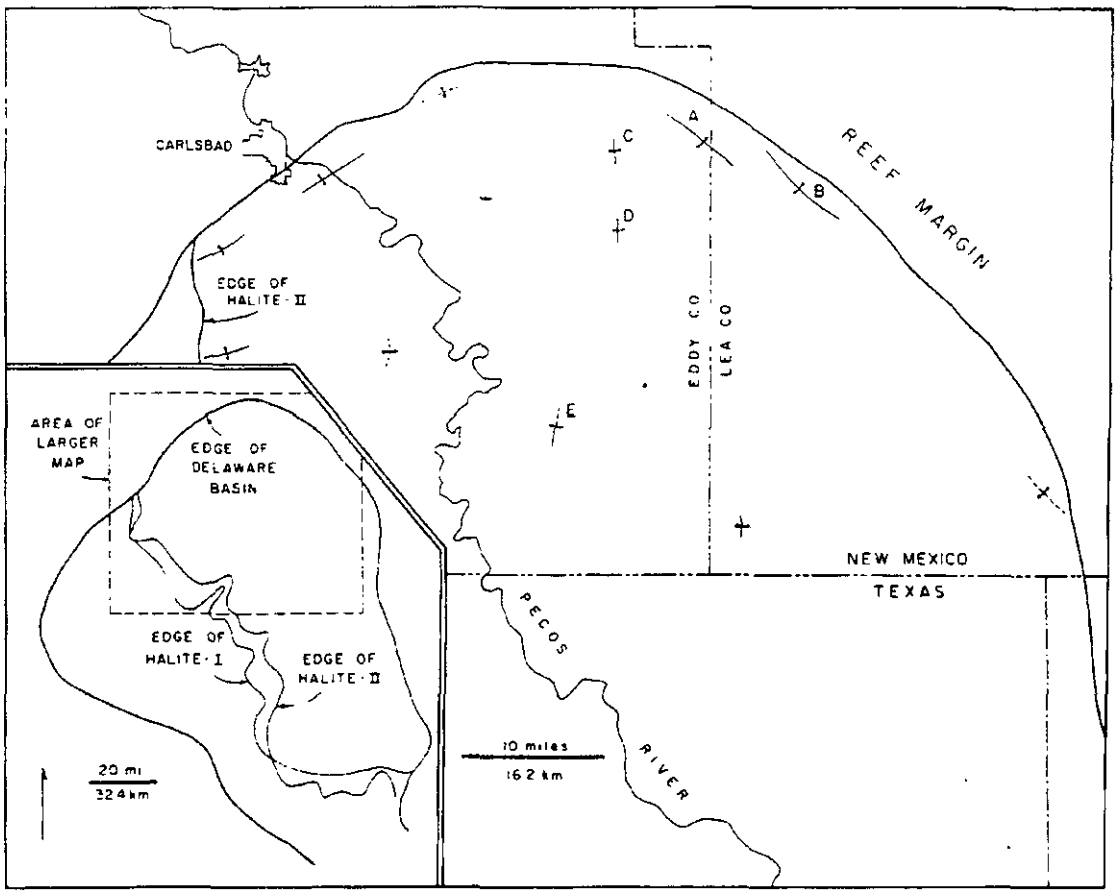

FIGURE 1—INDEX MAP SHOWING THE DISTRIBUTION OF THE LOWER TWO HALITE BEDS (I AND II) OF THE CASTILE FORMATION AND THE LOCATION OF ANTICLINAL STRUCTURES DEVELOPED WITHIN THOSE SALTS. Structures with dashed pattern were located with only one data point. ERDA No. 6, AEC No. 7, and AEC No. 8 are wells drilled on top and on the flanks of structure A.

FIGURE 3—SLABBED AND POLISHED SECTION FROM THE UPPER ANHYDRITE SHOWN IN FIG. 2. a indicates calcium sulfate filling "pull-apart" structures; b indicates zone of cross-hatched fracture pattern.

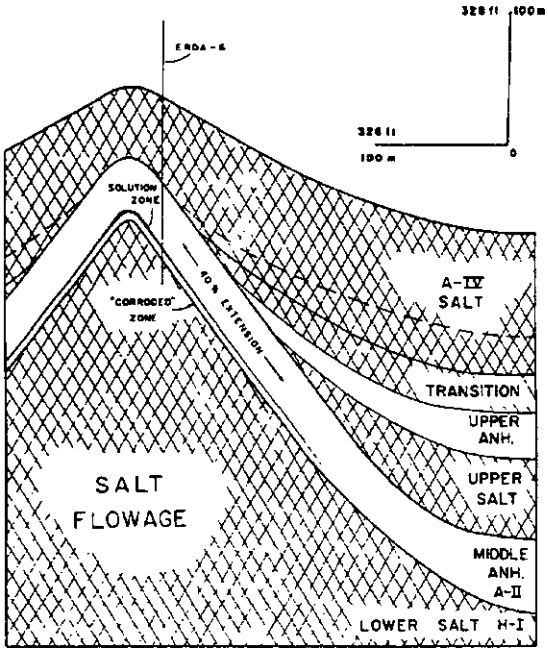

FIGURE 4—DIAGRAMMATIC CROSS SECTION OF STRUCTURE AT ERDA No. 6, ILLUSTRATING LOSS OF STRATIGRAPHIC SECTION AND FLOWAGE IN HALITE I OF CASTILE FORMATION. The middle anhydrite was encountered at a depth of 2,550 ft.

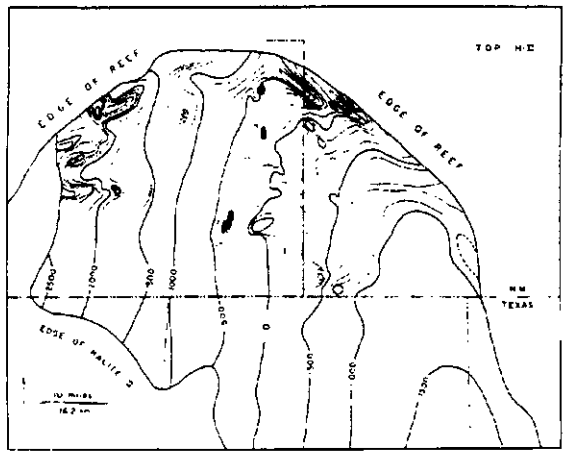

FIGURE 5—STRUCTURE CONTOUR MAP ON THE TOP OF SECOND HALITE OF CASTILE FORMATION (HALITE II). General N-S strike of the bed and gentle (1°) eastward dip is also reflected very well by the Bell Canyon Formation underlying the Castile Formation, but the Bell Canyon Formation does not have the smaller anticline and syncline pattern. Structures with dashed pattern were located with only one data point.

Anderson, R.Y., Kietzke, K.K., and Rhodes, D.J. 1978. "Development of Dissolution Breccias, Northern Delaware Basin, New Mexico and Texas." In Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas, G.S. Austin, ed., Circular 159. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p. 47;

" Beds of dissolution breccia are persistent in Castile-Salado evaporites in the western part of the Delaware Basin. Dissolution breccia consists of subangular to somewhat rounded and elongate fragments of individual laminae of calcite-laminated anhydrite set in an anhydrite matrix. Collapse breccias consisting of angular fragments of laminated anhydrite with little or no matrix often overlie dissolution breccias or may occur separately within the anhydrite some distance above dissolution horizons. Correlation of individual calcite-laminated anhydrite laminae associated with dissolution breccias with the same laminae associated with halite beds shows that dissolution breccias are equivalent to halite beds. Even the thinnest halite beds in the eastern part of the basin once extended west of their present distribution, probably to near the western margin of the basin. The tracing of identified dissolution horizons to large areas of deep dissolution west of existing halite beds shows that it is removal of salt from the lower part of the Salado and upper part of the Castile Formation that has caused collapse of the depressions."

Bachman, G.O. 1973. Surficial Features and Late Cenozoic History in Southeastern New Mexico. Open-File Report 4339-8. U.S. Geological Survey, Reston, VA..

ABSTRACT, p. 1;
" Since deposition of the Ogallala Formation during Pliocene time, southeastern New Mexico has been subjected to erosion, solution, subsidence, and widespread eolian activity. These processes have combined to influence the formation and morphology of major drainage systems. Aligned drainage patterns resulted from solution of caliche localized by longitudinal sand dunes. San Simon Swale appears to have formed by processes of erosion and solution-subsidence of Permian evaporites, and was formerly an important tributary to the Pecos River. The combination of processes that formed San Simon Swale was similar to the combination of erosion and coalescing sinks that formed the lower Pecos Valley in southern New Mexico.

Caliche on the Mescalero Plain, p 17;
" A prominent caliche formed on deposits overlying the Mescalero Plain is the most extensive physiographic surface in southeastern New Mexico. The surface is an uneven one that has been disrupted by solution-subsidence. It is about 150-250 feet above the floodplain of the Pecos on the west and rises gradually toward the High Plains on the east. To the northeast, near Mescalero Ridge, the surface rises to 3,800-4,100 feet in altitude; south of Big Sinks, it descends to about 3,100 feet.

Caliche on the Mescalero Plain is 3-5 feet thick, light gray to white, and sandy. The beds are nodular, with some concretionary growth on the nodules; but the concretionary growth is not as pronounced as on the pisolitic limestone of the Ogallala. Most of the nodules are randomly oriented, but the long axes of some are horizontal. Vertical caliche veinlets indicate several generations of solution and recementation. Occasional pipes 1 foot in diameter or more penetrate 2 or 3 feet into the caliche from the top and are filled with light-reddish-brown sandy soil. Some of these pipes pass entirely through the caliche bed. They presumable represent the former position of roots. Dissolution of this caliche is greater at the depressions. At numerous places on the Mescalero Plain the caliche thins towards depressions, and in some of these depressions the caliche is entirely absent.

The caliche on the Mescalero Plain is the remnant of an extensive soil profile. At places a younger sandy soil is preserved above the caliche but the surface is covered over broad areas by Pleistocene or Holocene windblown sand. This surface is correlative with Surface II of Leonard and Frye (1962, p. 11-12) in the Pecos region of Texas. The Mescalero Plain is analogous to the Jornada-La Mesa surface in the Rio Grande trough in southern New Mexico. Faunal remains indicate that rounded gravels on the Jornada-La Mesa surface are Kansan or younger (Ruhe, 1962, p. 163). Owing to lack of more positive evidence, it is here suggested that the Mescalero Plain formed in early to middle Pleistocene time."

Bachman, G.O., 1974. Geologic Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico, Open-File Report 74-194, U.S. Geological Survey. Denver, CO.

ABSTRACT, P 1;

" Salt of Permian age in the subsurface of an area near The Divide, east of Carlsbad, N. Mex., is being considered for a nuclear waste repository. The geologic history of the region indicates that dissolution of salt has occurred in the past during at least three distinct epochs: (1) after Triassic but before middle Pleistocene time; (2) during middle Pleistocene; and (3) during late Pleistocene. Thus, destructive geologic processes have been intermittent through more than 100 million years.

Nash Draw, near The Divide, formed during late Pleistocene time by the coalescing of collapse sinks. The rate of its subsidence is estimated to have been about 10 cm (0.33 ft) per thousand years. The immediate area of the Divide adjacent to Nash Draw has not undergone stress by geologic processes during Pleistocene time and there are no present indications that this geologic environment will change drastically within the period of concern for the repository."

SUMMARY OF EROSION AND SALT DISSOLUTION, p 6, para 3;

" 1. The western part of the Delaware basin (fig. 2) was exposed to erosion, and presumably salt dissolution, possibly as early as Triassic time and certainly as early as Jurassic time. This period of exposure may have been as long as 50 m.y. However, surface relief was probably low and erosion was not deep. Rocks of Triassic age covered much of the Delaware basin and helped to protect some of the underlying Permian beds. In the western part of the basin, however, Triassic rocks were stripped away, if they were ever deposited, and some erosion and dissolution of Permian rocks probably occurred.

2. During Cretaceous tine the Delaware basin was submerged beneath the sea, but at the close of cretaceous time regional uplift and major erosion occurred. This period of erosion lasted from the close of Cretaceous until late in Tertiary (Miocene) time, possibly a period of as much as 50 m.y. At the beginning of Tertiary time Cretaceous rocks blanketed the basin and protected the underlying rocks, but before the Ogallala Formation was deposited most of these Cretaceous rocks had been eroded away from the western half of the basin. Erosion again exposed the Permian rocks to dissolution. Some dissolution of Permian salt occurred at this time in the vicinity of San Simon Swale.

3. While the Ogallala Formation was being deposited there was very little, if any, erosion in the Delaware basin. During the past 3-4 m.y. since Ogallala time, wide fluctuations in climate have occurred and erosion and dissolution have been intermittent. The most humid climate and the greatest erosion were during middle Pleistocene time when the Gatuna Formation was being deposited. Then streams were capable of severely eroding the western escarpment of the High Plains as well as eroding and carrying pebble debris from as far to the west as the Sierra Blanca and Capitan uplifts (fig. 9). Rainfall probably exceeded 600 mm (25 in.) per year and it is assumed that major dissolution of salt in the Delaware

basin occurred at this time--more than 600,000 years ago.

4. After Gatuna time, but still during the middle Pleistocene, the region became more stable and semiarid. The Mescalero caliche accumulated in this climate. During late Pleistocene time, however, there were again periods of humidity accompanied by erosion and dissolution of salt. As a result of these processes the Mescalero caliche has subsided locally and collapsed into sinks.

5. Although erosion and dissolution are still, active processes, the climate during Holocene time has been somewhat more arid than during the late Pleistocene. Present climate is neither as humid nor as arid as extremes of the past and it may represent an average of the past 1 m.y.

6. I have estimated that at one place in Nash Draw, dissolution of salt and accompanying subsidence of the surface has been about 58.5 m (180 ft) during the past 600,000 years."

Gatuna Formation, p. 22, Para. 2;

" The Gatuna Formation of Pleistocene age was named for exposures of light-reddish-brown sandstone and conglomerate more than 25 m (80 ft) thick in Gatuna Canyon, eastern Eddy County (Robinson and Lang, 1938, p. 84-85). A type section has not been described. The physical stratigraphy and field relationships of this formation indicate that it was deposited during the most moist conditions that prevailed in southeastern New Mexico during Pleistocene time. Because of the indications of climatic conditions inherent in the Gatuna Formation it was examined carefully at many exposures during the present study.

The Gatuna Formation is well represented along the east side of Clayton Basin where it rests on rocks of Permian age and is overlain by the Mescalero caliche that formed during Pleistocene time. The Gatuna is also present around Nash Draw where it was mapped by Vine (1963, p. 31) who stated that Gatuna deposition 'followed immediately after, or in part accompanied, a period of active solution in the Rustler and Salado Formations.' In the vicinity of Crow Flats, Chaves County, the Gatuna Formation is also associated with extensive solution of gypsum and salt and subsequent collapse of the surface. The Gatuna is well exposed in Long Arroyo, Chaves County, and is present at many outlying localities along the Pecos River drainage.

The Gatuna Formation was examined in the type area during the present study. A stratigraphic section was measured on the north side of Gatuna Canyon (SW 1/4 SW 1/4 sec. 36, T. 19 S., R. 30 E.). Although the Gatuna is estimated to be thicker at other localities, this locality is the least disturbed by slumping and is one of the better exposed in Gatuna Canyon. For these reasons it is here proposed that this locality be regarded as a reference section for the Gatuna Formation in the type area."

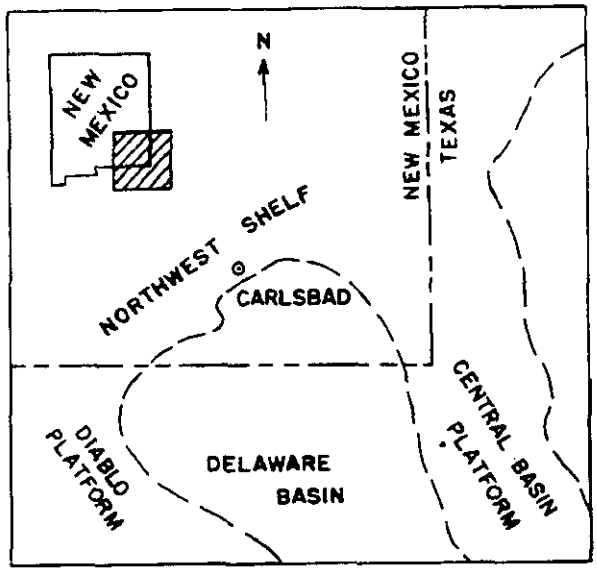

Figure 2.--Index map showing subsurface features in southeastern New Mexico.

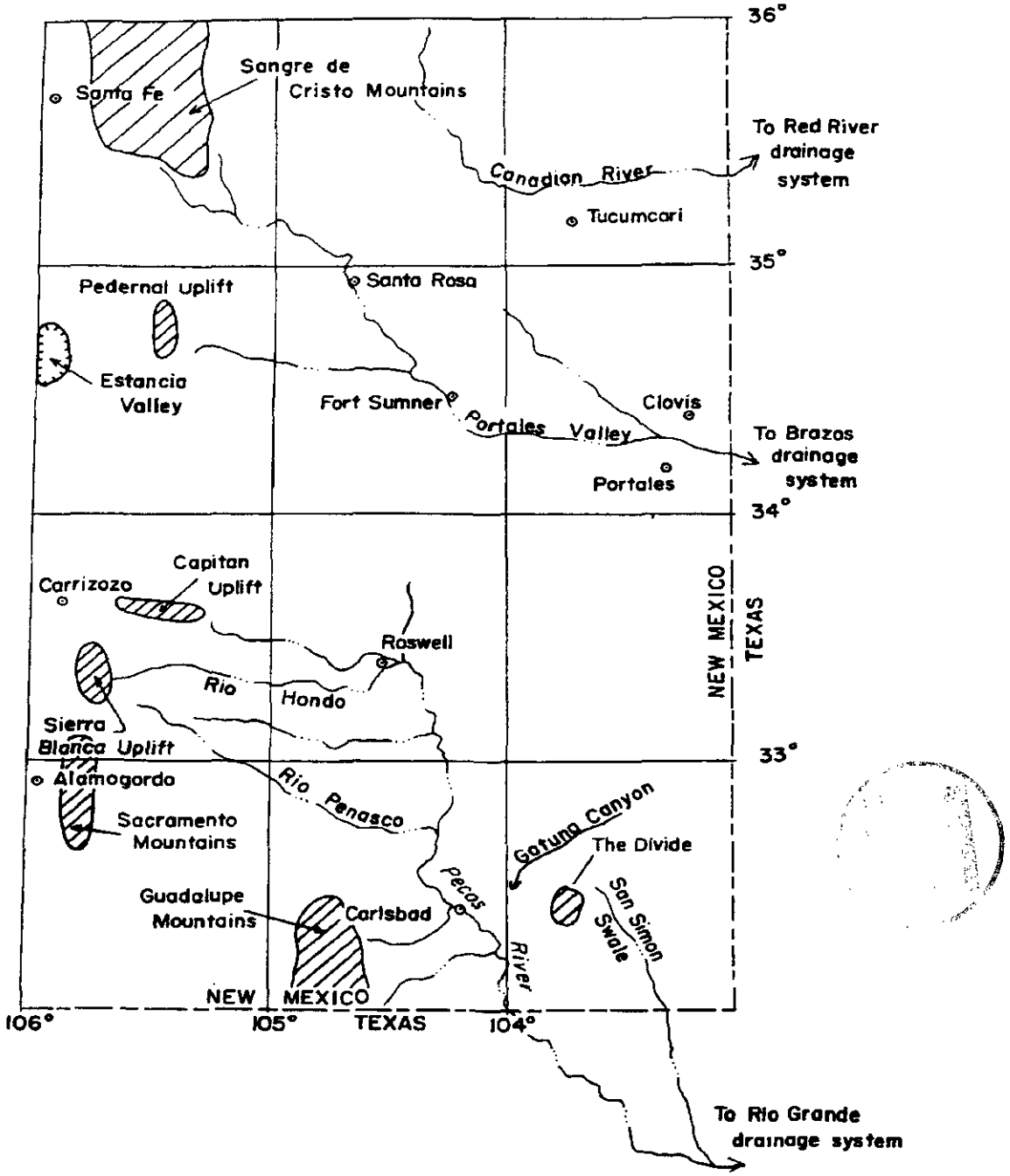

Figure 9.--Map showing middle Pleistocene drainage systems in southeastern New Mexico.

Bachman, G.O., 1976. "Cenozoic Deposits of Southeastern New Mexico and an Outline of the History of Evaporite Dissolution." Journal of Research, Vol. 4, No. 2, pp. 135-149. U.S. Geological Survey.

ABSTRACT, p 135;

" Sedimentary records of Cenozoic history in Southeastern New Mexico begin with the Ogallala Formation , Miocene and Pliocene age. Later records include the Gatuna Formation of early or middle Pleistocene age, Mescalero caliche, an informal term, of middle Pleistocene age, and fluvial deposits of late Pleistocene age but there are many gaps in some record. The modern landscape is the result of erosion and deposition in climates that have ranged from semihumid to semiarid as well as dissolution of soluble rocks in Permian Formations in the subsurface. This dissolution may have been as early as Jurassic time and has continued intermittently to the present.

TABLE 1.--Summary of late Tertiary and Quaternary events in southeastern New Mexico

Age		Stratigraphic unit	Deposits	Events	Probable climate	Tentative correlations
Holocene		Young sand dunes	Sand	Working wind from southwest	More dry than present.	
		Old soil	. . . . .	. . . . .	More moist than present.	
		Old sand dunes	. . . . .	. . . . .	More dry than present.	
Pleistocene	Late	Lakewood terrace deposits.	River conglomerate, pond, marsh, and lake silts.	Pecos River developed as axial stream from Fort Sumner to Roswell.	More moist than present. Probably cooler.	Wisconsin.
		Orchard Park alluvial deposits.	Limestone-porphyry conglomerate. Caliche caprock.	Reworking of Blackdom deposits.	More moist than present. Probably cooler.	Probably early Wisconsin.
		Blackdom alluvial deposits.	Limestone-porphyry conglomerate. Caliche caprock.	Major erosion of back slope of Sierra Blanca and Sacramento and Capitan Mountains.	More moist than present. Probably cooler.	Do.
		Hiatus	. . . . .	. . . . .		
	Middle	Mescalero caliche, an informal name.	Caliche	Land surface stable. Soil evolopment over much of southeast New Mexico.	More dry than present. Probably warmer.	Yarmouth(?). Unnamed gravel surface West of Pecos.
	Middle or early	Gatuna Formation	Gravel. Stream gravels, pond sediments, solution basin fill. Conglomerate, sand, silt, some gypsum.	Pediments formed in area between Carlsbad and San Simon Swale. Streams cut High Plains escarpment eastward. Extensive solution of salt and gypsum in subsurface. Collapse of Nash Draw and Clayton Basin. San Simon Swale may have been of major stream.	Much more moist than present. Probably cooler.	Analogous to Kansan deposits in Trans-Pecos Texas.
	Early (?)	Hiatus	. . . . .	. . . . .	. . . . .	
Pliocene		Ogallala "climax-soil."	Caliche	Land surface stable. Soil development.	Similar to, or more dry than, present.	

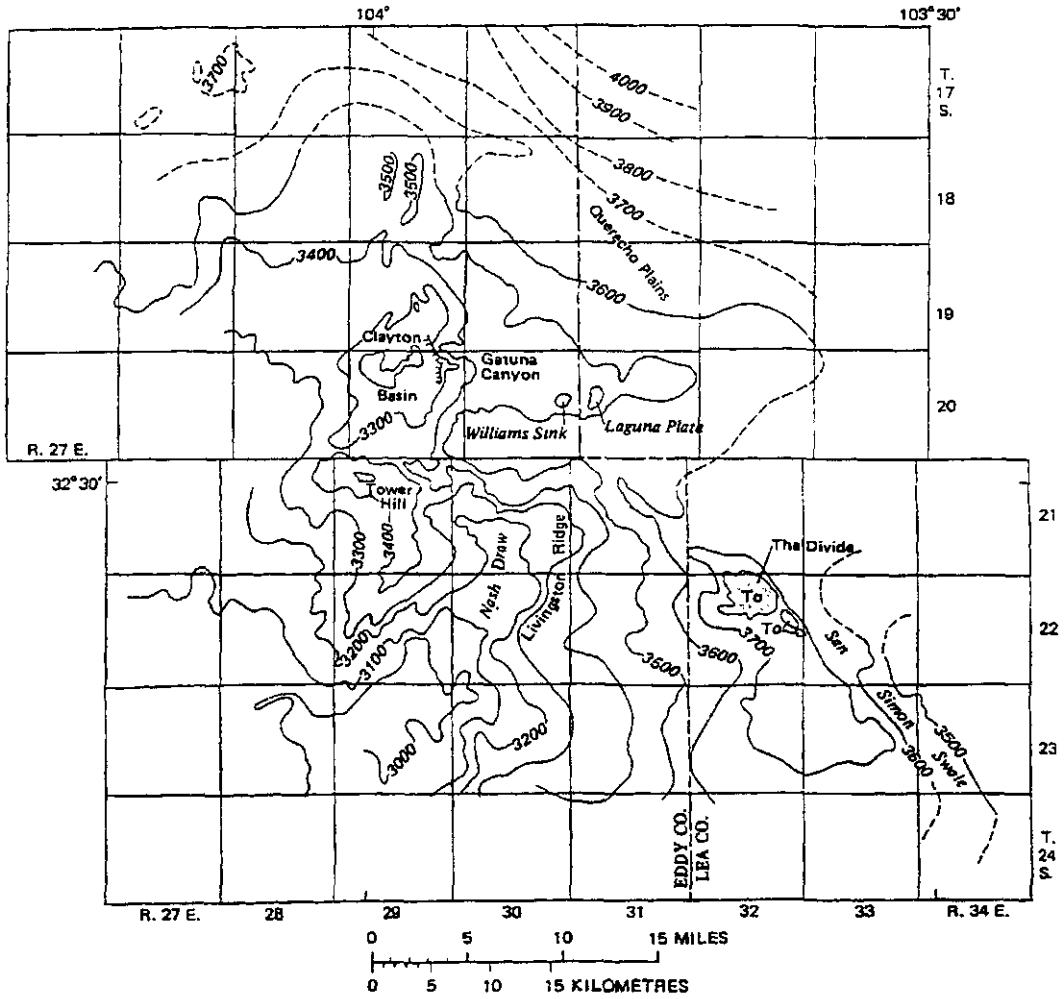

EXPLANATION

Slump in Mescalero caliche

To — *Ogallala Formation at The Divide*

3300 — Structure contours on Mescalero caliche — Dashed where control is sparse. Interval is 100 feet (30.5 m)

3200

FIGURE 8.—Structure contour map of Mescalero caliche.

Bachman, G.O., 1980. Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico. Open-File Report 80-1099, U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;

" This report summarizes the Cenozoic history of the Pecos drainage in the Delaware basin, southeastern New Mexico, and incorporates an outline of the dissolution and karst development in Permian evaporites in the region.

Evaporites include anhydrite, gypsum, halite and related minerals. They are included in the Castile, Salado and Rustler Formations of Late Permian (ochoan) age. These formations have been transgressed by strata of the Dockum Group of Late Triassic age and unnamed formations of early Cretaceous age.

Complex karst features include collapse sinks, karst mounds (new term), karst domes (new term) and caves. Karst mounds are erosional remnants of regional breccia. Karst domes are structural features which have formed on a very irregular dissolution surface. They are analogous to towers, kegelkarst or mogotes in tropical regions except that karst domes are almost buried by their own dissolution residue.

Breccia chimneys are collapse sinks which have formed over the Capitan aquifer system. They appear to be the result of unsaturated water rising under a strong hydraulic head through fractures and dissolving upward into the evaporite sequence.

Breccia chimneys, karst mounds and karst domes studied during this work were formed during middle Pleistocene time.

Dissolution has been an active process in the Delaware basin at least since Triassic time and it is impractical to attempt to calculate a rate of dissolution for the basin. Earlier estimates of the rate of dissolution are considered to be conservative. Subsurface evidence does not suggest that deep dissolution is presently an active process in the Castile Formation beneath the thick beds of Salado salt.

Pleistocene glaciation in the northern and central United States was probably accompanied by 'pluvial' periods in southeastern New Mexico. Pluvials are characterized by less extreme temperatures, less evaporation and more effective moisture than at present."

Rocks of Cretaceous Age, p. 28, para 4;

" Rocks of Early cretaceous age are preserved at a few localities in the Pecos drainage system as collapse debris in areas of dissolution. Lang (1947) reported an occurrence of fossiliferous Lower Cretaceous sandy limestone in Black River Valley about 9.6 km (6 mi) southwest of Whites City (NW 1/4 sec. 31. T. 25 S., R. 25 E., Eddy County, N.M.) (fig. 9).

These rocks containing Cretaceous marine fossils are scattered as collapse debris on the surface of the Castile Formation. This locality was examined during the present study and the Cretaceous debris appears to rest in a collapse sink about 60 m (200 ft) in diameter in the Castile Formation. Another occurrence of Cretaceous rocks and associated fossils resting on the Castile Formation is about 11.5 km (7.8 mi) southwest of Whites City (NE 1/4 sec. 1, T. 26 S., R. 24 E.), Lower Cretaceous rocks are mingled with debris of Culebra

Dolomite Member of the Rustler Formation and Triassic conglomerate.

All these Lower Cretaceous rocks in southeastern New Mexico are of equivalent age. The locality northeast of Carlsbad contains the following marine fauna:

Echinoid (probably Holectypus)
Texigryphea washitaensis (Hill)
Ostrea quadriplicata Shumard"

Ogallala Formation, p 35, para 2;

" In southeastern New Mexico the Ogallala Formation consists largely of well-sorted windblown sand. There are minor poorly sorted stream deposits and local carbonate pans. Generally the sediments suggest that the climate during Ogallala time was not much different from that in the region today. The pedogenic caliche caprock indicates a long period of quiescence during which constructive and destructive processes approached a steady state."

Mescalero caliche, p 42, para 3;

" many workers have attempted to develop techniques for measuring the rate of carbonate accumulation in pedogenic caliche (Arkley, 1963; Gardner, 1972; Goudie, 1973; Szabo, 1969; Bachman and Machette, 1977). Of the various methods studied the most promising is a technique which measures uranium series disequilibrium. This technique has been applied to the Mescalero caliche with notable results (table 3). Using this technique it has been determined that the Mescalero began to accumulate about 510,000 years ago (J.N. Rosholt, written commun., 1979). The upper crust of this caliche formed about 410,000 years ago."

Berino soil, p 44;

" The Berino soil is an informal stratigraphic unit, but the term 'Berino series' is used by the U. S. Department of Agriculture for mapping soils in Eddy County (Chugg and others, 1971). As used in this report the Berino is a dark red, sandy argillic paleosol which overlies the Mescalero caliche at some places in the vicinity of the WIPP site. It is usually overlain by windblown sand, but it is exposed along pipeline roads and at other construction sites. It varies in thickness but is rarely more than 1 m thick.

It is probable that the Berino soil represents a remnant B horizon of the underlying Mescalero caliche. The Berino is noncalcareous which suggests that the carbonates have been leached. The uranium-series disequilibrium technique indicates that the Berino began to form about 350,000 ($\pm$60,000) years ago (J. N. Rosholt, written commun., 1979)(table 3).

Hill A, p 62, para 3;

" Hill A of this report was designated 'Dome A' by Vine (1960, p. 1905). It is in Eddy County about 38 km (18.5 mi) east of Carlsbad on U. S. Highway 62-180 (SW1/4 sec. 35, T. 20 S., R. 30 E.). It is about 0.4 km (0.25 mi) north of the highway and is transected by a spur of the Atchinson, Topeka and Santa Fe Railroad. It is expressed as a low, circular breached hill with relief of about 12-15 m (40-50 ft) and about 370 m (1,200 ft) in diameter. During the present study, Hill A was mapped at a scale of 30 m to 25 mm (110 ft equals 1 inch) and the map was reduced for presentation in this report (fig. 12, in pocket).

The central part of Hill A has been eroded to form a shallow basin with an outlet to the west. The rim of the hill is capped by Mescalero caliche which engulfs slopes dipping rather uniformly about 15° away from the rim.

Dewey Lake Red Beds are exposed in the east, north, and west sides of the shallow basin. These beds are lithologically typical of the formation and dip away from the center of the hill. These dips average about 15° but locally steepen to 20°-22°. Rocks of the Triassic Dockum Group are well exposed along the east and south side of the basin with dips approximately parallel to the underlying Dewey Lake Red Beds.

Superficially Hill A has some of the characteristics of a collapse sink. Within the basin, brecciated debris composed of angular blocks of Triassic claystone, sandstone, and conglomerate are confined within a circular area about 245 m (800 ft) in diameter. The circular contact surrounding the central brecciated core is a fracture and was termed a 'peripheral fault or ring-fault' by Vine (1960, p. 1905). He stated that the brecciated core is composed of blocks similar to the Triassic beds exposed around the flanks of the hill but with greater range in lithologic character. He indicated that some breccia was derived from rocks stratigraphically higher than any now exposed around the flanks. . . ."

Dissolution During Geologic History, p. 81, Para. 1;

" Major dissolution occurs while land masses are above sea level. Regional uplifts have occurred in southeastern New Mexico following both Permian and Cretaceous times. Consequently, there is a long history of dissolution in the Delaware Basin. Although Castile and Salado rocks are transitional in the central part of the basin, some dissolution occurred locally after Castile and before Salado time (Adams, 1944, p. 1622-1624). Dissolution occurred again along the western edge of the basin after Salado and before Rustler time during Triassic time (Adams, 1944, p. 1622-1624). In addition to being above sea level throughout Triassic time the region was above sea level through Jurassic and again from the beginning of Tertiary time to the present. In summary, the region has been above sea level for a minimum of 154 million years and below sea level less than 71 million years since the end of Permian time (see table 1)."

p. 85, Para. 2;

" The estimates for the age of Nash Draw proposed by Bachman (1974, p. 68-71) are also too young. More recent work indicates that much of Nash Draw formed by solution-and-fill before Mescalero, and even Gatuna, time. Although there are places in Nash Draw

where the Mescalero caliche has slumped since its deposition, there are many localities along the east side of Nash Draw where the caliche was deposited on the slopes and in the bottom of an ancient topographic basin. This caliche has been weathered and eroded but remnants of depositional morphology are present."

SUMMARY AND CONCLUSIONS, p 97;

" The purpose of this study has been to determine if there are continuing geologic processes in the Delaware Basin which may pose a threat to the proposed WIPP site. The preserved geologic record of erosion and dissolution have been examined to learn the pattern of these processes in geologic history.

The salt beds at the proposed site have been preserved for about 225 million years. Some dissolution, in places of major proportions, has occurred in the Delaware Basin intermittently during this long period of time. The Salado Formation itself has been dissolved and preserved only as a mass of chaotic breccia along its western line of outcrop. The nearest exposures of this breccia to the WIPP site are in karst domes in the vicinity of Malaga Bend 19 km (12 mi) southwest of the proposed WIPP site. The main belt of outcrop of Salado breccia is 24 km (15 mi) to the west of Malaga Bend.

Evidence is presented here that dissolution of the Salado Formation along its western belt of outcrop began at least as early as Triassic time more than 190 million years ago. Dissolution in the subsurface near this belt of outcrop is presumed to be continuing today. This dissolution has been intermittent throughout its history, and it is unrealistic to attempt to calculate an average rate of dissolution for the region. However, if dissolution continues to be no more severe than during the time since the formation of the Mescalero caliche about 500,000 years ago there is no reason to believe that the repository horizon will be threatened by dissolution for another 500,000 years.

Deep-seated breccia chimneys collapsed over the Capitan aquifer system about 600,000 years ago. Dissolution is presently an active process over the Capitan aquifer system along San Simon Swale about 32 km (20 mi) east of the WIPP site. However, this aquifer system does not underlie the site and there is no presently known aquifer system or process of dissolution in this area which is undermining the site. Near-surface dissolution has been and is presently active along Nash Draw about 10 km (6 mi) west of the site but this dissolution has not penetrated the major salt bodies in the Salado Formation.

Fluctuations in climate have not greatly accelerated the process of dissolution in terms of geologic time and the longer history of the salt bodies. Dissolution during past glacio-pluvial intervals was probably at a more rapid rate than today but the present state of the evaporite deposits is a summation of the processes operating on them throughout 225 million years. It is improbable that a continuation of these fluctuations on their past scale will pose a threat to the deposits during the life of the WIPP repository."

Bachman, G.O. 1981. Geology of Nash Draw, Eddy County, New Mexico. Open-File Report 81-31. U.S. Geological Survey, Denver, CO.

ABSTRACT, p. 1;

" Nash Draw is a partially closed depression about 29 km (17 mi) east of Carlsbad, Eddy County, New Mexico. It has been mapped geologically in conjunction with detailed studies to evaluate the proposed nuclear Waste Isolation Pilot Plant (WIPP). Maps at scales of 1:24,000 accompany this report.

The stratigraphic section exposed in Nash Draw includes the Rustler Formation and Dewey Lake Red Beds of Late Permian (Ochoan) age, the Dockum Group of Late Triassic age, and the Pleistocene Gatuna Formation. Other deposits of Middle to late Quaternary age include the Mescalero caliche, spring deposits, and windblown sand.

Dissolution of evaporites has been a major process in the formation of Nash Draw. Nash Draw formed before, and during, Gatuna time about 600,000 years ago. Near-surface dissolution of gypsum in the Rustler Formation is presently active and is responsible for numerous collapse sinks and related karst features."

Bachman, G.O., 1984. Regional Geology of Ochoan Evaporites, Northern Part of Delaware Basin. Circular 184, pp. 1-22. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p 5;

" The Ochoan Series (Permian) in the northern part of the Delaware Basin, southeastern New Mexico, includes in ascending order the Castile, Salado, and Rustler Formations, and the Dewey Lake Red Beds. The Castile and Salado Formations comprise a sequence of evaporites which include anhydrite, gypsum, halite, and associated potash salts. The Rustler Formation contains some halite and minor amounts of potash minerals. These evaporites were deposited within the basin formed by the Capitan barrier reef, as well as across the reef. The evaporites, as well as the Capitan reef, are all subject to dissolution with resulting karst features analogous to those formed in limestone regions.

An Ancestral Pecos River was the major drainage system in the western part of the Delaware Basin, New Mexico, during the Cenozoic time. That ancient river system was responsible for the formation of an extensive karst terrain along the east side of the present Pecos River in New Mexico and southward into Texas. During late Cenozoic time extensive dissolution occurred in the Salado Formation within the karst area as a result of the ground-water regime. The dissolution front was perched on the upper anhydrite member of the Castile Formation.

On the eastern side of the Delaware Basin in New Mexico, a large collapse sink--San Simon sink--overlies the Capitan reef which is a prominent aquifer system in that area. So-called 'breccia pipes' are ancient sinks which collapsed into the caverns in the reef on the northern margin of the basin. These have since been partially exhumed. The San Simon sink is presumed to be a modern analog of these breccia pipes."

Rustler Formation, p 11, col 2, para 6;

" The Rustler ranges in thickness from a thin dissolution breccia at places on the surface to more than 550 ft in the subsurface in southwestern Lea County. Over much of the study area it averages 300-350 ft in thickness. Much of the variation in thickness is the result of the dissolution of salts. . . . At places where the salts have been dissolved, a 'collapse breccia' occupies their stratigraphic position. At these places the anhydrite is usually altered to gypsum."

Bachman, G.O., 1985. Assessment of Near-Surface Dissolution at and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico. SAND84-7178, Sandia National Laboratories, Albuquerque, NM. WPO 24609.

ABSTRACT, p. 3;
" The area at and near the WIPP site was examined for evidence of karst development on the geomorphic surface encompassing the site. Certain surficial depressions of initial concern were identified as blowouts in sand dune fields (shallow features unrelated to karstification). An ancient stream system active more than 500,000 years ago contained more water than any system since. During that time (Gatuña, Middle Pleistocene), many karst features such as Clayton Basin and Nash Draw began to form in the region. Halite was probably dissolved from parts of the Rustler Formation at that time. Dissolution of halite and gypsum from intervals encountered in Borehole WIPP-33 west of the WIPP site occurred during later Pleistocene time (i.e., <450,000 yr ago). However, there is no evidence of active near-surface dissolution within a belt to the east of WIPP-33 in the vicinity of the WIPP shaft."

p 19, column 1, para 2;
" Soil formation is a relatively slow process requiring a stable surface for development. Soils do not mature on constantly eroding surfaces or surfaces disrupted by subsidence, collapse, or persistent tectonic adjustment. Extensive soil development should not be expected at places where specific karst processes are extremely active. Soil classes depend on the nature of parent material, the amount of rainfall, the temperature, and the absence or presence of organic material. Soils may change character or may even be destroyed by radical changes in climate. For these reasons soils are a valuable tool for estimating the duration of stability of a geomorphic surface and the persistence of a climatic regime."

p 20, column 1, para 1;
" The basal part of the Mescalero caliche began to form ~510,000 yr ago, as determined by measuring the disequilibrium of the uranium series. The upper crust of the caliche began to form ~410,000 yr ago (Rosholt, written communication, 1979). The technique used in these determinations has been described by Szabo (1969) and Rosholt (1980)."

p 23, column 2, para 3;
Karst terminology should be defined with precision. Careless treatment of concepts of karst phenomena, and even carelessly using karst terminology, can contribute to misunderstanding and false impressions. The interpretation of karst activity in the vicinity of the WIPP site depends in part on understanding the distribution and physical nature of the stratigraphic units in the area. Although deep-seated dissolution has been active at localities around the periphery of the Delaware Basin in units associated with the Capitan Limestone and in the Pecos River drainage system overlying the Castile Formation (Lambert, 1983; Bachman,

1980 and 1984), deep-seated dissolution within the Delaware Basin is less probable because of physical limitations on the circulation of fresh water at depth. In contrast, dissolution of near-surface evaporites is responsible for the visible karst features in Nash Draw and at other places at and near the WIPP site. The caves, collapse sinks, and spring deposits in Nash Draw indicate a relatively long geologic history of dissolution of gypsum and associated evaporites.

Stream gravels in the Gatuña Formation on both the east and west sides of Nash Draw indicate flowing streams across the area now encompassed by Nash Draw before it became a topographic depression (Figure 11). The Gatuña stream system eroded into the evaporites of the Rustler Formation, and collapse sinks began to form near the end of Gatuña time before the formation of Mescalero caliche was well underway (Bachman, 1980). As a result of following the strike of the Rustler Formation for a time, Gatuña drainage contributed to coalescing these sinks. Thus, part of Nash Draw is a paleokarst feature. Paleokarst is prominent in Pierce Canyon ~20 mi (33 km) south of the WIPP site."

Discussion and Conclusions, p 26, col 2, para 3, line 18;
"Despite the statement of Barrows and others (1983) that 'all [gravity anomalies] are assumed to have a common origin' (p 63), karstic features are by definition associated with surface collapse; not all the gravity anomalies show surface collapse or even topographic depressions. In fact, the center of one -- 0.8 mgal gravity anomaly is 1/4 mi (400 m) east of the WIPP-14 topographic depression, which is here interpreted as a blowout. WIPP-14 contained no subsurface cavities. Thus, the 'modeled gravity...from the infinitely long polygonal bodies [the assumed 'karst conduits']' (p 63) does not provide a unique or inescapable interpretation of the gravity data, but was evidently the interpretation preferred by Barrows and others.

The absence of true surface karst features at and near the WIPP site may be explained by the depth of burial of the Rustler Formation in that area and by the protective cover of the rocks overlaying the Rustler. The Rustler is at least 500 ft (152 m) beneath the surface at the site. The overlying Dewey Lake has 'minimal permeability and does not contain significant quantities of ground water...The Dewey Lake is a protective cover that retards dissolution of evaporites in the Rustler Formation' (Mercer, 1983, p 70).

Dissolution will become a major process east of WIPP-33 *only* if large quantities of unsaturated water gain access to the Rustler Formation. Except for minor intermittent drainage from Livingston Ridge into Nash Draw, erosion does not appear capable of breaching the Mescalero caliche. At present, the Mescalero is an additional obstruction to infiltrating and recharging underlying beds."

Barrows, L.J., Shaffer, S.E., Miller, W.B., and Fett, J.D. 1983. Waste Isolation Pilot Plant (WIPP) Site Gravity Survey and Interpretation. SAND82-2922, Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. 3;

" A portion of the WIPP site has been extensively surveyed with high-precision gravity. The main survey (in T22S, R31E) covered a rectangular area 2 by 4-1/3 mi. encompassing all of WIPP site Zone II and part of the disturbed zone to the north of the site. Stations were at 293-ft intervals along 13 north-south lines 880 ft apart. The data are considered accurate to within a few hundredths of a milligal.

Long-wavelength gravity anomalies correlate well with seismic time structures on horizons below the Castile Formation. Both the gravity anomalies and the seismic time structures are interpreted as resulting from related density and velocity variations within the Ochoan series. Shorter wavelength negative gravity anomalies are interpreted as resulting from bulk density alteration in the vicinity of karst conduits.

The WIPP gravity survey was unable to resolve low-amplitude, long-wavelength anomalies that should result from the geologic structures within the disturbed zone. It did indicate the degree and character of karst development within the surveyed area."

Section 1.2.3 Karst; p 19, col 2;

" Evaporite and carbonate rocks dissolve, or corrode, when they contact chemically undersaturated water. Karst refers to a distinctive surface morphology and groundwater hydrology resulting from such dissolution. Karst surface morphology is characterized by collapse sinks, alluvial dolines, caves, grikes, and various domes and mounds. The hydrology is characterized by sinking streams, swallow holes, the absence of surface runoff, and integrated arterial system of sub-surface conduits, and a few large irregular springs. The general principles of karst morphology are discussed by M. Sweeting (1973), and karst hydrology is discussed by A. Bogli (1980).

A large area of southeastern New Mexico and west Texas, including the Delaware Basin, is underlain by soluble carbonates and evaporites. Much of this material has been removed by dissolution, and the area is recognized as one of the karstlands of the United States (Davies and LeGrand, 1972; LeGrand et. al., 1976). Regional karst is described by G. O. Bachman (1980) in his report on the geology and Cenozoic history of the Pecos region, and by Powers et. al. (1978)."

3.2.1 The WIPP 14 Anomaly, p. 57, col. 1, para. 1;

" The negative gravity anomalies are the most distinctive and unanticipated feature of the gravity field. These anomalies were first detected on the detailed grid surveyed over the closed topographic depression midway along the line between Sections 9 and 16 (later drilled as WIPP 14). They were later found to extend in an east-west direction across the northern part of the survey area. Reconsideration of data from a coarsely spaced, poorly documented survey at the 'old site' (Gera, 1974) showed their presence east of our survey area; the

reconnaissance profiles around WIPP 33 show their presence to the west.

The interpretation of the negative anomalies involves consideration of shallow geologic structure, densilogs, velocity surveys, seismic profiles, surface topography, and regional and local geology. Different portions of the anomalies are interpreted with various logs from various holes. This was done because not all holes were logged with the same tools and not all logs were usable. The interpretation may seem piecemeal, but it is mutually consistent. The negative anomalies are here interpreted as caused by rock density decrease, solution/removal, and gypsum hydration in the vicinity of karst conduits. Interpretation begins with comparisons of WIPP 14/WIPP 34 density logs. These densilogs indicate sufficient mass deficiency in the Dewey Lake and Rustler Formations to account for the negative gravity at WIPP 14. Next, the negative anomaly is modeled at its intersection with seismic line 77X2. The seismic line indicates a seismic time syncline coincident with the negative gravity anomaly. Both the seismic time syncline and the negative anomaly are explained by lateral velocity and inferred density variations comparable to those observed in uphole velocity surveys. Finally, the negative gravity anomaly and alluvial doline at WIPP 33 are related to the solution cavities encountered in that hole."

p. 58, col. 2, para 1;

" Depositional facies variations and buried stream channels were considered as possible causes of the WIPP 14 gravity anomaly. Both of these interpretations are inconsistent with the observations and are considered highly unlikely.

'Facies' refers to those aspects of the lithology that are attributable to lateral variations in the depositional environment. The Dewey Lake and Rustler Formations were deposited over tens of thousands of square miles in a broad basin that extended over the Capitan Reef and Central Basin Platform (Snider, 1966, Figure 34). C. L. Jones (1954, p. 110) notes that some of the halite of the Rustler Formation thins reefward and pinches out in the shelf area. He also notes that the two dolomite members and several siltstone and sandstone layers form remarkably persistent stratigraphic markers. The implication of the areal extent and the lateral persistence is that, while some gradational north-south variations may be attributable to depositional facies, the east-west thinning (Figures 1.2.1-4 and 1.2.3-1) cannot. In particular, there is nothing in the depositional environment that suggests abrupt lateral variations over distances of several hundred feet.

When the WIPP 14 gravity anomaly was first detected, a buried stream channel was one of the hypotheses considered to explain it. A model of such a channel had a density contrast of 0.3 g/c^3 and a maximum thickness of 150 ft. A shallower channel would require a greater density contrast; a lesser density contrast would require a deeper channel. Both the 0.3 g/c^3 density contrast and the 150-ft thickness are larger than reasonably anticipated at this location. The lithologic character of such a feature should have been clearly discernible in the core.

When WIPP 14 was drilled, neither stratigraphic facies variations nor buried stream channels were identified in the core. Rather, the gravity anomaly was found to be reasonably attributed to diffuse density reductions in the Dewey Lake and Rustler

Formations. The relation between these density reductions and the closed topographic depression will become clearer after considering the other elements in the interpretation."

3.2.3 The WIPP 33 Anomaly, p. 63, col. 1, para. 2;
" The relation between negative gravity anomalies and karst conduits is clarified at borehole WIPP 33 (SNLA and USGS, February 1981). This hole was drilled in Section 13, R31E, T22S to determine the nature of a closed topographic depression."

Section 4. Summary, p 65;
" The WIPP gravity survey demonstrates both the utility and limitations of microgravity in a karst terrain. We were unable to resolve the low-amplitude long-wavelength anomolies that should originate in the Castile Formation geologic structures. We did map short-wave length anomolies that may reveal the style and extent of karst development in the Dewey Lake and Rustler Formations. The implications of this karst to the WIPP geohydrology are being carefully assessed (Barrows, 1982)."

Beauheim, R.L., Hassinger, B.W., and Klaiber, J.A. 1983. Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. WTSD-TME-020, U.S. Department of Energy, Albuquerque, NM.

Section 1.0 ABSTRACT, p 1-1;

" Borehole Cabin Baby-1 was originally drilled to a depth of 4159.0 feet below kelly bushing (8.0 feet above ground surface) in 1974 and 1975 as a 'wildcat' hydrocarbon exploratory well. Control of the borehole was given to the U. S. Department of Energy (DOE) after it was found to be a 'dry hole'. Cabin Baby-1 was reentered, deepened, and hydrologically tested in August and September, 1983. The well is located in Section 5, T23S, R31E, just outside the limit of WIPP Zone III, approximately 2.5 miles south of the WIPP exploratory shaft.

The deepening and testing of Cabin Baby-1 was undertaken for several reasons:

- To provide data on the hydrologic properties, including hydrostatic head potential of selected permeable zones in the Bell Canyon Formation.
- To provide representative fluid samples from selected permeable zones in the Bell Canyon Formation for determination of fluid composition and density.
- To define further the stratigraphy of the upper Bell Canyon Formation at the Cabin Baby-1 location.

The borehole was deepened from the previous total depth to a new depth of 4298.6 feet below kelly bushing by continuous coring. Field operations related to deepening and logging of the borehole began August 12, 1983 and were completed August 30, 1983. Hydrologic testing activities began August 30, 1983 and were completed September 29, 1983. Drill-stem tests were conducted in four zones in the Bell Canyon Formation, and one test of the Salado Formation was performed. Fluid samples were collected from the Hays and Olds sandstones of the Bell Canyon Formation."

4.6 TEST RESULTS, p. 4-9;

" Testing began on September 4, 1983 and ended on September 23, 1983. A summary of the tests performed is provided in Table 5. The results of the tests are summarized in Table 6, and discussed below. The FFL analyses are not presented because first flows are typically dominated by drilling fluid unloading, and serve primarily to help clean the hole for the more important SFL. Flow tests and slug tests are similar, repetitive tests. The quality of the data should increase with each successive test, as the effects of loading the formation with drilling fluid are progressively lessened. For this reason, and because slug tests are performed until a greater degree of recovery is achieved than during flow tests, the slug tests provide the results most representative of actual reservoir properties of all the flow tests. Of the buildup period analyses, the SBU results are regarded as the more reliable because the SFL's better meet the theoretical assumptions of the analysis technique than the FFL's, and because the SBU's were continued until a greater degree of recovery was obtained than during the FBU's.

4.6.1 DST-4178: Hays Sandstone

The Hays sandstone was tested between the depths 4178.0 and 4298.6 feet below KB. Two flow tests (DST-4178/FFL and SFL), two buildup tests (FBU and SBU), and one slug test (SLUG) were performed (Figure 8). As shown in Table 6 and Figures 9 and 10, the analyses of the first and second buildups provided permeability estimates of 0.57 md and 0.71 md, respectively. These correspond to hydraulic conductivity values of 1.3 x 10^{-3} ft/day and 1.7 x 10^{-3} ft/day, respectively. The flow-period permeability estimates are slightly higher, with the second-flow data yielding a value of 1.7 md (Figure 11) and the slug-test data yielding a value of 0.94 md (Figure 12). These values correspond to hydraulic conductivity estimates of 3.9 x 10^{-3} ft/day and 2.2 x 10^{-3} ft/day.

The Horner plot of DST-4178/FBU (Figure 9) shows an early-time deviation below the Horner straight line, representing a slight positive skin, perhaps a mudcake, on the borehole wall. A similar effect was apparent in early-time data from DST-4178/SBU not shown in Figure 10. When the FBU data are extrapolated to infinite recovery time, they yield a static formation pressure (p_{ext}) of 1883 psig (Figure 9). The very late-time SBU data show a slight deviation above the Horner straight line, probably reflecting the fact that the SFL was initiated before complete recovery from the FFL was achieved. This upward-deviation phenomenon reflects a superposition of buildups from separate flow events, and is typically distinguishable only when the buildup from the most recent flow becomes of very small magnitude. When the latest SBU data are extrapolated to infinite time, they provide a static formation pressure estimate of 1880 psig (Figure 10). With the transducer at a depth of 4165.4 feet below KB, and a fluid pressure gradient of 0.485 psi/ft (SG = 1.12; Table 7), these static formation pressure estimates correspond to a static fluid level (in an open borehole) 283 to 289 feet below KB, which is about the level of the Dewey Lake Redbeds.

4.6.2 DST-4138: Olds Sandstone

The Olds sandstone was tested between the depths 4138.5 and 4170.9 feet below KB. Two flow tests (DST-4138/FFL and SFL), two buildup tests (FBU and SBU), and one slug test (SLUG) were performed (Figure 13). The permeability values derived from the first and second buildups are 2.2 x 10^{-2} md (Figure 14) and 3.5 x 10^{-2} md (Figure 15), respectively. These correspond to hydraulic conductivity estimates of 4.5 x 10^{-5} ft/day and 7.2 x 10^{-5} ft/day, respectively. The flow-period permeability estimates are slightly higher, being 6.7 x 10^{-2} md for the second flow (Figure 16) and 8.2 x 10^{-2} md for the slug test (Figure 17). These values correspond to hydraulic conductivity estimates of 1.4 x 10^{-4} ft/day and 1.7 x 10^{-4} ft/day, respectively.

The Horner plots of DST-4138/FBU (Figure 14) and SBU (Figure 15) both show the very late time data deviating below the Horner straight line. Such deviations are typically the result of some type of negative reservoir boundary, such as a decrease in permeability at some distance from the well. The deviations could also represent depletion of a finite reservoir. Extrapolating the FBU and SBU very late time data to infinite time provides static formation pressure estimates of 1934 psig (Figure 14) and 19101 psig (Figure 15), respectively. With the transducer at a depth of 4125.9 feet below KB, and a fluid pressure gradient of 0.503 psi/ft (SG = 1.16; Table 7), these pressures correspond to static fluid

levels (in an open borehole) 281 feet and 329 feet below KB, respectively, which are in the middle of the Dewey Lake Redbeds.

4.6.3 DST-4100: Ramsey Sandstone

The Ramsey sandstone was tested between the depths 4100.5 and 4132.9 feet below KB. Two flow tests (DST-4100/FFL and SFL), two buildup tests ((FBU and SBU) and one slug test (SLUG) were performed (Figure 18). The first and second buildups provided permeability estimates of 2.3 x 10^{-2}md (Figure 19) and 2.9 x 10^{-2}md (Figure 20), respectively. These values correspond to hydraulic conductivity estimates of 4.7 x 10^{-5} ft/day and 6.0 x 10^{-5} ft/day, respectively. Again, the flow-period permeability estimates are slightly higher, being 8.2 x 10^{-2} md for the second flow (Figure 21), and 8.7 x 10^{-2} md for the slug test (Figure 22). These values correspond to hydraulic conductivity estimates of 1.7 x 10^{-4} ft/day and 1.8 x 10^{-4} ft/day, respectively.

The Horner plots of DST-4100/FBU (Figure 19) and SBU (Figure 20) both show a very late time deviation of the data below the Horner straight line similar to that observed in DST-4138/FBU and SBU (Figures 14 and 15). Again, the deviations probably represent some type of negative reservoir boundary. Extrapolating the FBU and SBU very late time date to infinite time provides static formation pressure estimates of 1916 psig (Figure 19) and 1892 psig (Figure 20), respectively. With the transducer at a depth of 4087.9 feet below KB, and assuming a fluid pressure gradient similar to that of the Olds sandstone fluid (0.503 psi/ft), these pressures correspond to static fluid levels (in an open borehole) 279 feet and 326 feet below KB, respectively. These levels are virtually identical to those calculated for the Olds sandstone fluid.

4.6.4 DST-4044: Lamar Limestone

The Lamar limestone was tested between the depths of 4044.2 and 4097.4 feet below KB. Because of the extremely low magnitude response of the unit, only a single flow (FFL) and buildup (FBU) cycle was performed (Figure 23). As shown on Figure 24, the buildup response in the Lamar was slow and prolonged. The permeability estimated from the buildup data is 6 x 10^{-4} md(0.6 μd) (Figure 25). This corresponds to a hydraulic conductivity of 1 x 10^{-6} ft/day. Permeabilities of this order cannot be determined precisely with DST techniques, and thus, these values should be regarded as order-of-magnitude estimates.

The expanded-scale Horner plot of DST-4044/FBU (Figure 25) shows the data deviating below the Horner straight line at extremely late time, probably in response to some type of negative reservoir boundary. The extrapolation of these data to infinite time provides a static formation pressure estimate for the Lamar of 1886 psig. With the transducer at a depth of 4031.6 feet below KB, and assuming a fluid pressure gradient similar to that of the Olds sandstone fluid (0.503 psi/ft), this pressure corresponds to a static fluid level (in an open borehole) 282 feet below KB, virtually identical to that of the underlying sandstones."

The 15 tables and figures refereed to in this text are not included to save space. Refer to the specific reference to see these figures.

Beauheim, R.L., 1986. Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-1364. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3;
" Eleven different zones were tested in Well DOE-2 in five phases of testing between 1984 and 1986. Testing techniques included a constant-head, borehole-infiltration test, drill-stem tests, slug tests, pressure-pulse tests, and multiwell pumping tests. Four of the zones tested--the lower Dewey Lake Red Beds, the Tamarisk Member of the Rustler Formation, the lower unnamed member of the Rustler Formation and the Rustler/Salado contact, and the entire Salado Formation--had permeabilities too low to measure with the equipment and test techniques used. The other zones had permeabilities ranging over six orders of magnitude. No saturated strata were encountered above the Rustler Formation, although parts of the middle Dewey Lake Red Beds appear to have appreciable permeability.

In the Rustler Formation, the Culebra Dolomite Member is the most permeable unit, having a transmissivity of ~90 ft^2/day. The Culebra behaves hydraulically as a double-porosity system, with the major permeability provided by fractures and the major storage provided by matrix porosity. The Culebra at DOE-2 is well connected hydraulically to the Culebra at Wells H-6b and WIPP-13 to the west, probably by interconnected fractures. Response times between these wells are very short (<1 day/10,000 ft). The Culebra does not appear to be as fractured to the south at Wells WIPP-12 and 18, or to the east at Well H-5b, as indicated by delayed, low-magnitude (or nonexistent) responses to DOE-2 pumping, and by low permeabilities interpreted from other tests conducted at those wells. The other Rustler members at DOE-2, which are not known to be fractured and do not display hydraulic responses typical . . ."

Section 7.4.1 Ramsey Sandstone (DST 4138-4180), p 61, col 2, para 2, line 11;
"The corresponding groundwater units are transmissivities of 5.4 x 10^{-3} and 5.7 x $10^{-3}ft^2$/day and hydraulic conductivities of 1.9 x 10^{-4} and 2.0 x 10^{-4}ft/day for the FBU and SBU, respectively. . . ."

Section 7.4.1 Ramsey Sandstone (DST 4138-4180), p 63, col 1, para 1;
" The late-time SBU data are shown in a Horner plot in Figure 7-34. Extrapolating the data trend to infinite time provides a static formation pressure estimate of ~1816 psia (1805 psig). With the transducer at a depth of 4120.6 ft and a fluid pressure gradient in the borehole from drilling fluid of 0.542 psi/ft (assumed SG = 1.25), 1805 psig corresponds to a formation pressure of 1833 psig at the base of the Ramsey, 4127 ft deep. ..."

Section 7.4.2 Olds Sandstone (DST 4177-4218), p 63, col 2, para 2, line 10;
"The corresponding groundwater units are transmissivities of 7.0 x 10^{-3} and 6.6 x $10^{-3}ft^2$/day and hydraulic conductivities of 2.3 x 10^{-4} and 2.2 x 10^{-4}ft/day for the FBU and SBU, respectively. . . ."

Section 7.4.2 Olds Sandstone (DST 4177-4218), p 66, col 1, para 2, line 4;
" ... The final pressure, 1843.0 psia (1832.5 psig), is the maximum possible static formation pressure for the Olds sandstone. With the transducer at a depth of 4159.2 ft and a fluid pressure gradient in the borehole from drilling fluid of 0.537 psi/ft (measured SG = 1.24), this pressure corresponds to a formation pressure of 1863.6 psig at the base of the Olds, 4217 ft deep. ..."

Section 7.4.3 Hays Sandstone (DST 4220-4325), p 68, col 1, para 2, line 10;
"The corresponding groundwater units are transmissivities of 0.56 and 0.53 ft^2/day and hydraulic conductivities of 5.6×10^{-3} and 5.3×10^{-3}ft/day for the FBU and SBU, respectively. . . ."

Section 7.4.3 Hays Sandstone (DST 4220-4325), p 68, col 2, para 3, line 11;
" ... The very latest time SBU data extrapolate to a pressure of ~1845.5 psia (1835 psig) at infinite time. This value can be taken as the maximum possible Hays pressure."

Section 7.4.4 Bell Canyon Fluid-Level Measurements, p 72, col 1, para 3, line 1;
" The observed Bell Canyon fluid level at a depth of 384 ft is ~20 ft lower than the observed Culebra fluid level at DOE-2. Because of the higher specific gravity of the Bell Canyon fluid, however, the Bell Canyon *head* at the elevation of the base of the Culebra is slightly higher than that of the Culebra. This indicates that, in the event of an interconnection between the Bell Canyon and the Culebra, the undisturbed head gradient would drive fluid upward from the Bell Canyon into the Culebra.

If the interconnection were through an uncased borehole, however, salt dissolution in the Salado section would increase the specific gravity of the Bell Canyon fluid so that, *at the elevation of the Culebra*, the Culebra head would be higher than that of the Bell Canyon. In this event, the flow direction would be downward. The long-term flow rate would be governed by a combination of factors, including the transmissivity and storativity of both the Culebra and Bell Canyon and the rate of halite dissolution."

Section 8. Summary and Conclusions, p 73, col 1, para 2;
" In the Bell Canyon Formation, the Hays sandstone was the most permeable unit tested, with an average permeability of ~2.4 md (0.55 ft/day). The Olds and Ramsey sandstones, overlying the Hays, have permeabilities almost two orders of magnitude lower. Hydraulic heads in the Bell Canyon sandstones could not be quantified precisely enough to define vertical gradients within the Bell Canyon.

In freshwater terms, the observed Bell Canyon head is higher than the hydraulic head of the Culebra dolomite. If the Bell Canyon and Culebra were connected by an open borehole, however, salt dissolution in the Salado section would increase the specific gravity of the Bell Canyon fluid so that, *at the elevation of the Culebra*, the Culebra head would be higher than that of the Bell Canyon. In this event, the flow direction would be downward from the Culebra into the Bell Canyon."

Beauheim, R.L., 1987a. Interpretations of Single-Well Hydraulic Tests Conducted at and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987. SAND87-0039. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3, para 1;

" Both single-well and multiple-well hydraulic tests have been performed in wells at and near the WIPP site as part of the site hydrogeologic-characterization program. The single-well tests conducted from 1983 to 1987 in 23 wells are the subject of this report. The stratigraphic horizons tested include the upper Castile Formation; the Salado Formation; the unnamed, Culebra, Tamarisk, Magenta, and Forty-niner Members of the Rustler Formation; The Dewey Lake Red Beds; and Cenozoic alluvium. Tests were also performed to assess the integrity of a borehole plug isolating a pressurized brine reservoir in the Anhydrite III unit of the Castile Formation. The types of tests performed included drillstem tests (DST's), rising-head slug tests, falling-head slug tests, pulse tests, and pumping tests."

The Castile and Solado testing was performed at well WIPP-12 to try to define the source of high pressures measured at the WIPP-12 wellhead between 1980 and 1985. The test of the plug above the Castile brine reservoir indicated that the plug may transmit pressure, but if so, the apparent surface pressure from the underlying brine reservoir is significantly lower than the pressure measured at the wellhead. The remainder of the upper Castile did not show a pressure response differentiable from that of the plug. All attempts at testing the Salado in WIPP-12 using a straddle-packer DST tool failed because of an inability to locate good packer seats. Four attempts to test large sections of the Salado using a single-packer DST tool and a bridge plug were successful. All zones tested showed pressure buildups, but none showed a clear trend to positive surface pressures. The result of the WIPP-12 testing indicate that the source of the observed high pressures is within the Salado Formation rather than within the upper Castile Formation and that this source must have a very low flow capacity and can only create high pressures in a well shut in over a period of days to weeks.

DST's performed on the lower siltstone portion of the unnamed lower member of the Rustler Formation at H-16 indicated a transmissivity for the siltstone of about 2.4×10^{-4} ft^2/day. The formation pressure of the siltstone is higher than that of the overlying Culebra at H-16 (compensated for the elevation difference), indicating the potential for vertical leakage upward into the Culebra. However, the top of the tested interval is separated from the Culebra by over 50 ft of claystone, halite, and gypsum.

The Culebra Dolomite Member of the Rustler Formation was tested in 22 wells. In 12 of these wells (H-4c, H-12, WIPP-12, WIPP-18, WIPP-19, WIPP-21, WIPP-22, WIPP-30 P-15, P-17, ERDA-9, and Cabin Baby-1), falling-head slug tests were performed in H-1, and only a rising-head slug test was performed in P-18. DSTs were performed in conjunction with rising-head slug tests in wells H-14, H-15, H-16, H-17, and H-18. At all of these wells except H-18, the indicated transmissivities were 1 ft^2/day or less and single-porosity models fit the data well. At H-18, the Culebra has a transmissivity of about 2 ft^2/day. The apparent single-porosity behavior of the Culebra at H-18 may be due to the small spatial scale of the

tests rather than to the intrinsic nature of the Culebra at that location. Pumping tests were performed in the other 3 Culebra wells. The Culebra appears to behave hydraulically like a double-porosity medium at wells H-8b and DOE-1, where transmissivities are 8.2 and 11 ft^2/day, respectively. The Culebra transmissivity is highest, 43 ft^2/day, at the Engle well. No double-porosity behavior was apparent in the Engle drawdown data, but the observed single-porosity behavior may be related more to wellbore and near-wellbore conditions than to the true nature of the Culebra at that location.

The claystone portion of the Tamarisk Member of the Rustler Formation was tested in wells H-14 and H-16. At H-14, the pressure in the claystone failed to stabilize in three days of shut-in testing, leading to the conclusion that the transmissivity of the claystone is too low to measure in test performed on the time scale of days. Similar behavior at H-16 led to the abandonment of testing at that location as well.

The Magenta Dolomite Member of the Rustler Formation was tested in wells H-14 and H-16. At H-14, examination of the pressure response during DSTs revealed that the Magenta had taken on a significant overpressure skin during drilling and Tamarisk-testing activities. Overpressure-skin effects were less pronounced during the drillstem and rising-head slug tests performed on the Magenta at H-16. The transmissivity of the Magenta at H-14 is about 5.5. x 10^{-3} ft^2/day, while at H-16 it is about 2.7 x 10^{-2} ft^2/day. The static formation pressures calculated for the Magenta at H-14 and H-16 are higher than those of the other Rustler members.

The Forty-niner Member of the Rustler Formation was tested in wells H-14 and H-16. Two portions of the Forty-niner were tested at H-14: the medial claystone and the upper anhydrite. DST's and a rising-head slug test were performed on the claystone, indicating a transmissivity of about 7 x 10^{-2} ft^2/day. A buildup test of the forty-niner anhydrite revealed a transmissivity too low to measure on a time scale of days. a pulse test, DST's, and a rising-head slug test of the Forty-niner clay at H-16 indicated a transmissivity of about 5.3 x 10^{-3} ft^2/day. Formation pressures estimated for the Forty-niner at H-14 and H-16 are lower than those calculated for the Magenta (compensated for the elevation differences), indicating that water cannot be moving downwards from the Forty-niner to the Magenta at these locations. . . ."

Section 5.2.1 Unnamed Lower Member., p 50, col 1, para 4;

" The unnamed lower member of the Rustler was tested only at H-16. This testing had two objectives: 1)to determine the transmissivity of the unit; and 2) to determine the hydraulic head of the unit. The transmissivity is a parameter needed to calculate potential leakage rates from the unnamed lower member into the WIPP shafts. The hydraulic head is also needed for leakage calculations, as well as to evaluate directions of potential vertical movement of groundwaters within the Rustler Formation. . . ."

p 50, col 2, para 4;

" The simulation in Figure 5-12 is of a single-porosity medium with a transmissivity of 2.7 x 10^{-4} ft^2/day (Table 5-2). Assuming a porosity of 30%, a total-system compressibility of

1.0×10^{-5} psi^{-1}, and a fluid viscosity of 1.0 cp, the skin factor for the well in this simulation is -0.4, indicating a very slightly stimulated well. The dimensionless Horner plot of the FBU (Figure 5-13) shows an excellent fit of the simulation to the data, and indicates that the static formation pressure is about 213 psia.

The SLF lasted about 29 minutes, and was followed by a 50-hr SBU. The log-log plot of the SBU data (Figure 5-14) shows behavior similar to that seen in the FBU plot (Figure 5-12). The single-porosity simulation shown, however, uses a transmissivity of 2.2×10^{-4}ft^2/day, and a skin factor of 0.2 (Table 5-2). These values imply a slightly less permeable formation and a slightly more damaged well than were indicated by the FBU analysis."

$$\frac{2.7 \times 10^{-4}\text{ft}^2}{\text{day}} \times \frac{12^2\text{in}^2}{\text{ft}^2} \times \frac{\text{m}^2}{39.3^2\text{in}^2} \times \frac{\text{day}}{24\text{ hour}} \times \frac{\text{hour}}{3600\text{ sec.}} = \frac{2.9 \times 10^{-10}\text{m}^2}{\text{second}}$$

$$\frac{2.2 \times 10^{-4}\text{ft}^2}{\text{day}} \times \frac{12^2\text{in}^2}{\text{ft}^2} \times \frac{\text{m}^2}{39.3^2\text{in}^2} \times \frac{\text{day}}{24\text{ hour}} \times \frac{\text{hour}}{3600\text{ sec.}} = \frac{2.4 \times 10^{-10}\text{m}^2}{\text{second}}$$

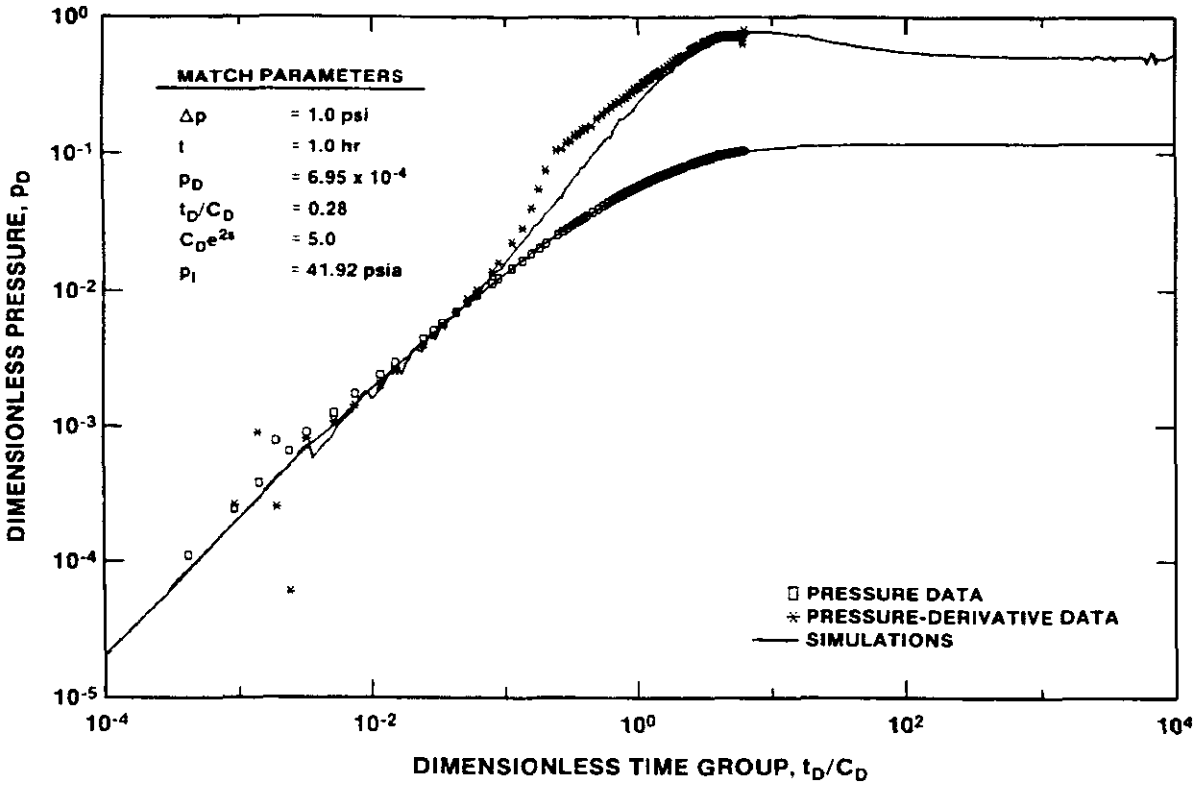

Figure 5-12. H-16/Unnamed Lower Member Siltstone First Buildup Log-Log Plot with INTERPRET Simulation

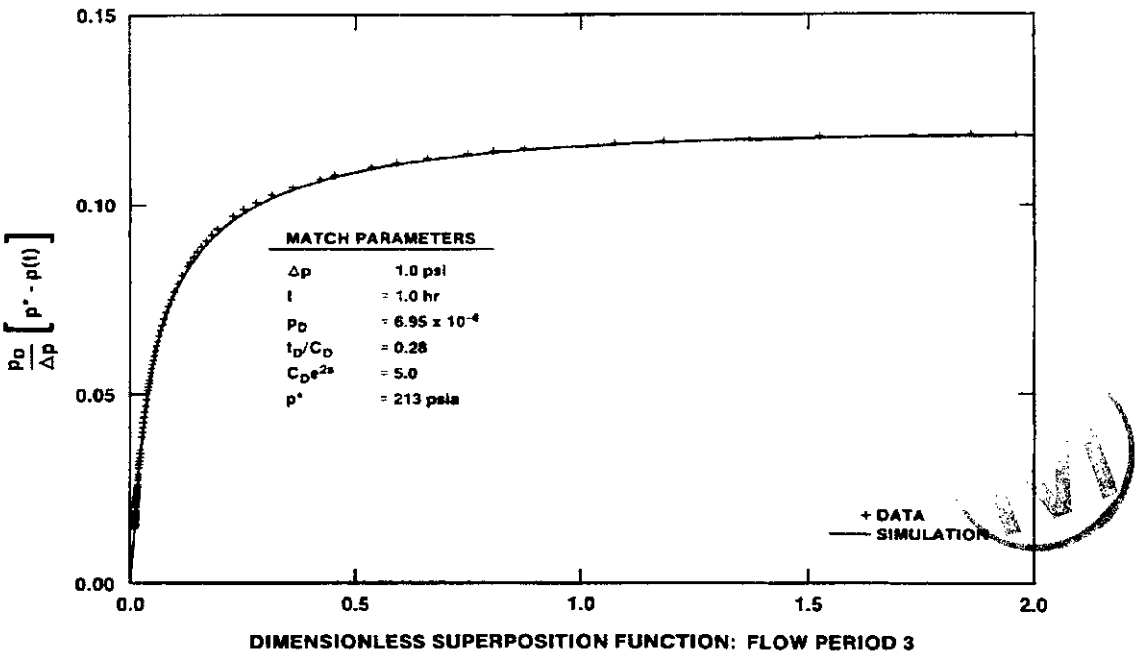

Figure 5-13. H-16/Unnamed Lower Member Siltstone First Buildup Dimensionless Horner Plot with INTERPRET Simulation

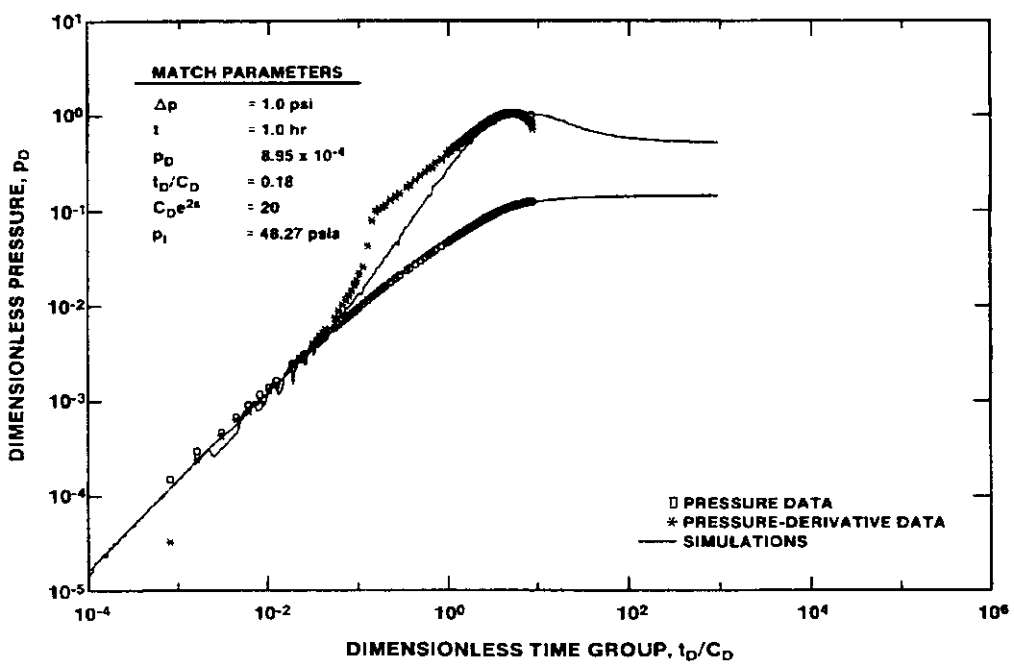

Figure 5-14. H-16/Unnamed Lower Member Siltstone Second Buildup Log-Log Plot with INTERPRET Simulation

TABLE 5-2
SUMMARY OF NON-CULEBRA SINGLE-WELL TEST RESULTS

WELL	ZONE NAME	ZONE DEPTH INTERVAL (ft)	DEPTH INTERVAL TESTED (ft)*	TEST TYPE	TRANSMISSIVITY (ft^2/day)	SKIN FACTOR
H-16	Unnamed lower member siltstone	778-842	739-851	DST/FBU	2.7×10^{-4}	-0.4
				DST/SBU	2.2×10^{-4}	0.2
H-14	Magenta	424-448	420-448	DST/FBU	5.6×10^{-3}	0.5
				DST/SBU	5.6×10^{-3}	0.4
				DST/TBU	5.3×10^{-3}	0.3
H-16	Magenta	590-616	589-621	DST/FBU	2.8×10^{-2}	-0.4
				DST/SBU	2.8×10^{-2}	-0.8
				slug	2.4×10^{-2}	–
H-14	Forty-niner claystone	390-405	381-409	DST/FBU	7.1×10^{-2}	3.2
				DST/SBU	6.9×10^{-2}	3.3
				slug	3.0×10^{-2}	–
H-16	Forty-niner clay	563-574	560-581	pulse	2.2×10^{-4}	–
				DST/FBU	5.3×10^{-3}	0.7
				DST/SBU	5.6×10^{-3}	0.6
				slug	5.0×10^{-3}	–
Carper	Cenozoic alluvium	263-386	263-386	pumping	55	–

*Actual intervals open to the wells.

Section 5.2.3 Tamarisk Member, p. 108, col. 1, para 2;

" The Tamarisk Member of the Rustler Formation was tested in wells H-14 and H-16. The purposes of the Tamarisk testing were to: 1) define the hydraulic head of the unit; and 2) measure the transmissivity of the unit. Information on the hydraulic head of the Tamarisk is needed to evaluate potential direction of vertical movement of groundwater between the Rustler members. The transmissivity of the Tamarisk is a parameter needed for vertical cross-sectional or three-dimensional modeling of groundwater flow in the Rustler. The claystone/mudstone/siltstone portion of the Tamarisk (referred to hereafter simply as the claystone) is believed to be more permeable than the anhydrite/gypsum sections, and therefore easier to test. Consequently, tests were attempted only on the claystone portion of the Tamarisk at H-14 and H-16.

5.2.3.1 H-14.

At H-14, the Tamarisk claystone extends from about 517 to 525 ft deep (Figure 3-6). The initial test was performed over an interval from the base of a packer at a depth of 494.5 ft to the then-bottom of the hole 533 ft deep. Thus, the test interval included the 8-ft thickness of claystone, and 30.5 ft of overlying and underlying anhydrite and gypsum. Descriptions of the test instrumentation and the test data are contained in Stensrud et al. (1987).

Testing began on October 7, 1986, by setting the packer, swabbing the tubing to decrease the pressure in the test interval, and closing the shut-in tool to isolate the test interval and allow the test-interval pressure to recover and equilibrate at the existing static formation pressure. The pressure response observed during the testing is shown in Figure 5-82. After being shut in for nearly 37 hr, the fluid pressure in the Tamarisk claystone test interval had still not stabilized, but was rising at an ever-decreasing rate. The pressure in the wellbore above the packer, in contrast, was dropping as fluid was apparently entering the exposed Magenta and Forty-niner Members. Because the Tamarisk pressure had not stabilized, and did not appear likely to stabilize for several days or weeks, no drillstem tests were performed.

To verify that the observed response during the shut-in period was representative of the Tamarisk claystone and not caused by a tool malfunction, the packer was deflated and the DST tool was reset 8 ft deeper in the hole on October 9, 1986. After swabbing and shutting in the new test interval, a pressure buildup similar to that observed at the previous depth was measured for 4.5 hr (Figure 5-82). At this point, we concluded that the permeability of the Tamarisk at H-14 is too low to allow testing on the time scale of a few days, and abandoned the effort.

No conclusions about the static formation pressure of the Tamarisk can be drawn from the observed pressure buildups, because we have no way of evaluating the role played by the overpressure skin that was probably created during drilling. Subsequent testing of the Magenta and Forty-niner Members, discussed below, revealed fluid-pressure buildups to be significantly affected by overpressure skins.

5.2.3.2 H-16

At H-16, the Tamarisk claystone extends from 677.5 to 690.1 ft deep (Figure 3-8).

The interval tested extended from 674.5 to 697.9 ft, the bottom of the hole at that time, thus including 10.8 ft of overlying and underlying gypsum. Descriptions of the test instrumentation and the test data are presented in Stensrud et al. (1988).

Testing was performed on August 5, 1987. After the packer was set, the tubing was swabbed and the shut-in tool was opened to relieve the pressure that had been exerted on the formation by the column of drilling fluid in the well. The test interval was then shut in to allow the wellbore and formation pressures to equilibrate. Figure 5-83 shows the slow pressure rise that resulted over the next 10 hr. This pressure recovery was very similar to that observed for the Tamarisk claystone at H-14 (Figure 5-82). Based on the similarity to the H-14 response and the conclusion that the Tamarisk could not be tested on the time scale of a few days at H-14, the testing effort at H-16 was abandoned.

This decision was borne out by subsequent pressure measurements made by the transducer installed at the Tamarisk horizon as part of the 5-packer installation in H-16 (Figure 3-8). From August 31, 1987, 4 days after the 5-packer installation was completed, until December 15, 1987, the pressure in the Tamarisk interval declined from 204 psig to 169 psig (Stensrud et al., 1988 and in preparation), with complete stabilization apparently several months in the future. The Tamarisk transducer in the 5-packer system is mounted at a depth of 647.1 ft. IN a borehole containing brine with a specific gravity of 1.2, the pressure at the midpoint of the Tamarisk claystone 684 ft deep is about 19 psi higher than that measured by the transducer. Hence, the most that can be said at present is that the static formation pressure of the Tamarisk is less than 188 psig. The very slow pressure stabilization of the Tamarisk claystone likely indicates that its transmissivity is one or more orders of magnitude lower than that of the least-transmissive unit successfully tested in H-16, the unnamed lower member siltstone ($2 \times 10^{-4} ft^2/day$; Table 5-2)."

Section 5.2.4.1 H-14, p 111, col 1, para 2, line 3;

" The simulation is representative of a single-porosity medium with a transmissivity of 5.6×10^{-3} ft^2/day (Table 5-2). Assuming a porosity of 20%, a total-system compressibility of $1.0 \times 10^{-5} psi^{-1}$, and a fluid viscosity of 1.0 cp, the skin factor of this simulation is about 0.5 indicating a well with very little wellbore damage. The simulation does not fit the observed early-time data very well, but it does fit the middle- and late-time pressure data adequately."

Section 5.2.4.2 H-16, page 115, col 2, para 2, line 3;

" The simulation is representative of a single-porosity medium with a transmissivity of $2.8 \times 10^{-2} ft^2/day$ (Table 5-2). Assuming a porosity of 20%, a total system compressibility of $1.0 \times 10^{-5} psi^{-1}$, and a fluid viscosity of 1.0 cp, the skin factor for this simulation is -0.4, indicating a very slightly stimulated well. The pressure derivative shows oscillations similar, although with much lower amplitudes, to those observed in the H-14 Magenta SBU and TBU data (Figures 5-87 and 89)."

Section 5.2.5 Forty-niner Member, p. 119;

" The Forty-niner Member of the Rustler Formation was tested in wells H-14 and H-16.

The objectives of the testing were to obtain hydraulic-head and transmissivity estimates. The hydraulic-head measurements are particularly important in helping to determine whether or not water from the Dewey Lake Red Beds, and by extension from the surface, can be recharging the Magenta and Culebra dolomites at the WIPP site. The transmissivity estimates allow an evaluation of the ability of the Forty-niner to provide water to the WIPP shafts, as well as providing data for cross-sectional or three-dimensional modeling of groundwater flow in the Rustler.

5.2.5.1 H-14.

Two sets of Forty-niner tests were performed at H-14, tests of the medial claystone/mudstone/siltstone unit (hereafter referred to simply as claystone) and tests of the upper anhydrite unit. The claystone tests were to provide data on the hydraulic head and transmissivity of the most permeable section of the Forty-niner. The anhydrite tests were intended to verify the assumptions that the Rustler anhydrites are much less permeable than the claystones, and that they cannot be tested on the time scale of days.

Forty-niner Claystone:

At H-14, the claystone portion of the Forty-niner lies between 390 and 405 ft deep (Figure 3-6). The claystone was tested in a DST straddle interval extending from 381.0 to 409.5 ft deep. Thus, about 13.5 ft of Forty-niner anhydrite and gypsum were included in the test interval. Descriptions of the test instrumentation and the test data are contained in Stensrud et al. (1987).

The Forty-niner claystone was tested on October 13 and 14, 1986. Testing consisted of two flow periods, two buildup periods, and a rising-head slug test (Figure 5-95). The FFL lasted about 18 minutes, and was followed by a 92-minute FBU. The SFL lasted about 32 minutes, and was followed by a SBU almost 16 hr long. To obtain equivalent constant-rate flow periods, each of the flow periods was divided into two shorter periods. The FFL was divided into two periods with flow rates of 0.028 and 0.021 gpm, and the SFL was divided into periods with flow rates of 0.022 and 0.017 gpm (Table 5-1). The slug test lasted slightly over 6 hr, by which time about 57% of the induced pressure differential had dissipated.

Overpressure skin effects were apparent during the Forty-niner claystone testing, just as they were during all other testing at H-14. The fluid pressure reached a maximum of 67.9 psia during the initial equilibration period, was essentially constant at 66.8 psia at the end of the FBU, and peaked at 66.2 psia during the SBU (Figure 5-95). The superposition of pressure-skin effects manifested in the Magenta test data (see Section 5.2.4.1) was not apparent, however, in the Forty-niner claystone test data.

Figure 5-96 shows a log-log plot of the Forty-niner claystone FBU data with an INTERPRET-generated simulation. The late-time pressure derivative shows the decline indicative of overpressure skin. The simulation is representative of a single-porosity medium with a transmissivity of 7.1×10^{-2} ft^2/day (Table 5-2). Assuming a porosity of 30%, a total-system compressibility of 1.0×10^{-5} psi^{-1}, and a fluid viscosity of 1.0 cp, the skin factor for this simulation is about 3.2, indicating a damaged well.

The dimensionless Horner plot of the FBU data is shown in Figure 5-97. The

simulation matches the observed data very well until late time, when the data deviate towards a static pressure lower than the 67.8 psia specified for the simulation. This discrepancy between the observed data and the simulation is entirely consistent with the effects of an overpressure skin.

The log-log plot of the SBU data is shown in Figure 5-98. Overpressure-skin effects are once again evident in the late-time pressure derivative. The simulation shown was generated by INTERPRET using a single-porosity model and a transmissivity of 6.9 x 10^{-2}ft^2/day (Table 5-2). With the assumed parameter values listed above, the skin factor for this simulation is about 3.3, comparable to the value obtained from the FBU analysis.

A log-log early-time plot of the rising-head slug-test data is shown in Figure 5-99, along with the best-fit type curve. The fit is quite good until near the end, when the observed data oscillate for an unknown reason. The type-curve fit shown provides a transmissivity estimate of 3.0 x 10^{-2}ft^2/day (Table 5-2), which is slightly less than half of the values provided by the FBU and SBU analyses. A slightly different type-curve fit might have been indicated had the late-time data been better behaved.

The static formation pressure for the Forty-niner claystone is difficult to estimate because of the overpressure-skin effects present during the buildup tests, and because of the nonideal behavior during the latter portion of the slug test. The static formation pressure must be less than the final pressure measured at the end of the SBU, 65.5 psia. The slug-test analysis relied on a static formation pressure estimate of 62 psia, although a reasonably good fit was also obtained using an estimate of 65 psia. Considering that the transducer during these tests was set 362.9 ft deep, that the transducer measured an atmospheric pressure of 12 psia before testing began, and that the borehole contained brine with a specific gravity of 1.2, 65 psia corresponds to a static formation pressure of 71 psig at the midpoint of the claystone 398 ft deep. This value is reliably a maximum.

Forty-niner Anhydrite.

The upper anhydrite and gypsum unit of the Forty-niner Member lies 359.5 to 390 ft deep at H-14 (Figure 3-6). The unit is roughly 75% anhydrite and 25% gypsum, based on interpretation of a neutron log. The unit was tested in a DST straddle interval extending from 356.0 to 384.5 ft deep. Thus, the bottom 3.5 ft of the Dewey Lake Red Beds and the Dewey Lake/Rustler contact were included in the test interval. Descriptions of the test instrumentation and the test data are contained in Stensrud et al. (1987).

The Forty-niner anhydrite was tested from October 14 to 15, 1986. Because the anhydrite was expected to have too low a permeability to allow quantitative testing the few days available for testing, no pressure-equilibration period preceded the testing. Instead, as soon as the packers were set, the tubing was swabbed with the shut-in tool open, and the test interval was left open to the tubing for about 16 minutes for a flow period (Figure 5-100). Very little fluid entered the tubing at this time. The test interval was then shut in for about 16.5 hr. The pressure increased by about 1 psi over the first 1.5 hr of the buildup, and by another psi over the last 1.5 hr. At that time, the testing was terminated. The Forty-niner anhydrite was judged to have a permeability much lower than that of the claystone, and quantitative testing of the anhydrite appeared to require weeks to months of effort."

Pg. 124, col. 2;

" Figure 5-102 is a semilog plot of the Forty-niner pulse-test data, showing the best type-curve match achieved. That data and type curve match reasonably well, with the greatest discrepancy occurring at early time. The transmissivity calculated from this match is 2.2 X 10^{-4} ft^2/day (Table 5-2).

Figure 5-103 is a log-log plot of the DST FBU data, along with a simulation generated by INTERPRET. The simulation fit the data very well, and is representative of a single-porosity medium with a transmissivity of 5.3 X 10^{-3} ft^2/day (Table 5-2). Assuming a porosity of 30%, a total-system compressibility of 1.0 X 10^{-5} psi^{-1}, and a fluid viscosity of 1.0 cp, the skin factor for this simulation is 0.7, indicating a wellbore with little damage. The decline in the pressure derivative at late time reflects minor overpressure-skin effects. The dimensionless Horner plot of the FBU data (Figure 5-104) shows an excellent fit between the data and the simulation using a static formation pressure estimate of 117.2 psia."

Pg. 126, col. 1, para. 1;

" The log-log plot of the SBU data (Figure 5-105) is very similar to that of the FBU data (Figure 5-103). The INTERPRET simulation is also similar, using a transmissivity of 5.6 X 10^{-3} ft^2/day and a skin factor of 0.6 (Table 5-2). Again, overpressure-skin effects are evident in the late-time behavior of the pressure derivative.

Figure 5-106 is an early-time log-log plot of the Forty-niner slug-test data. Because of the low degree of pressure recovery during the slug test, the data are inadequate to provide definitive results on their own, but they do serve to confirm the DST results. The type-curve match shown provides a transmissivity estimate of 5.0 X 10^{-3} ft^2/day (Table 5-2), and uses a static formation pressure estimate of 116.1 psia. Both of these values are in reasonable agreement with the DST interpretations.

In contrast, the transmissivity value provided by the pulse-test interpretation is over an order of magnitude lower than the transmissivity values estimated from the DST and slug-test analyses. This low apparent value of transmissivity may have been caused by two, perhaps interrelated, factors. First, pulse tests inherently, factors. First, pulse tests inherently test very small volumes of rock around the borehole, much smaller than do DST's and slug tests. The average transmissivity of the rock tested could easily change between the two scales of tests. Second, the pulse test was the first test performed and was an injection test, whereas the DST's and slug test were withdrawal tests. Any skin that may have been present on the borehole wall after drilling, such as a mud cake, could be loosened by a withdrawal test, but would be intensified by an injection test. Consequently, the pulse-injection test may have measured an average transmissivity of both the nearby rock <u>and</u> the wellbore skin. The subsequent DST's and slug test, which caused water to flow <u>into</u> the well, should have served to decrease any skin present, and this may be evidenced by the slight drop in skin values between the FBU and the SBU (Table 5-2). For these reasons, and because of the consistency of the DST and slug-test results, the most reliable value for the transmissivity of the Forty-niner clay at H-16 is probably about 5.3 X 10^{-3} ft^2/day."

Section 6. DISCUSSION OF RUSTLER FLOW SYSTEM, p. 131;
" The single-well testing discussed in this report has provided significant information on the transmissivities and hydraulic-head relations of the five Rustler members. IN particular, our knowledge of the distribution of transmissivity within the Culebra dolomite has increased considerably. Section 6.1 attempts to explain the distribution of Culebra transmissivity in the context of geologic models of halite deposition and dissolution within the Rustler. Section 6.2 discusses the hydraulic-head relations among the Rustler members, and their implications regarding recharge to the Rustler Formation."

Section 6.1 Culebra Transmissivity, p. 131;
" Mercer (1983) reported values for Culebra transmissivity at 20 locations. The testing described in this report has provided values for Culebra transmissivity at 15 new locations, and new estimates at 7 locations for which values had previously been reported. Combined with other recent work performed at DOE-2 (Beauheim, 1986), H-3 (Beauheim, 1987a), H-11 (Saulnier, 1987), and WIPP-13 (Beauheim, 1987b), the WIPP project has tested 38 locations and the transmissivity values at each provided by this report or those referenced above.

Figure 6-2 shows the areas around the WIPP site where halite is present in the non-dolomite Rustler members, as indicated by Snyder (1985 and personal communication) and Powers (personal communication). According to Snyder, halite was originally deposited in the unnamed lower, Tamarisk, and Forty-niner Members of the Rustler over the entire area covered by Figure 6-2. The present-day absence of halite from these members reflects the eastward progression of a dissolution front. This dissolution front apparently affects the uppermost Rustler halite, that in the Forty-niner, first, and works progressively downsection to the upper Salado Formation. Thus, the eastward extent of the Forty-niner dissolution front is greater than that of the Tamarisk dissolution front, which is in turn greater than the eastward extent of the dissolution front in the unnamed lower member (Figure 6-2). Dissolution of the upper Salado follows dissolution of halite from the unnamed lower member of the Rustler. Lagging behind the dissolution front in each member is a second front where anhydrite is being hydrated to gypsum. In Snyder's view, as halite is removed beneath the Rustler dolomites, the dolomites subside and fracture. Similar subsidence and fracturing may affect the anhydrites, allowing more groundwater flow through them which may effect their hydration to gypsum. Note that the areas shown on Figure 6-2 indicate that only some halite is present in the appropriate members, not that the full thicknesses originally deposited are present. For example, Snyder (1985) states that only about half of the halite originally present in the unnamed lower member at WIPP-21 is there today.

Alternatively, Holt and Powers (1988) believe that the different amounts of halite seen in the Rustler members at the WIPP site more likely represent original depositional differences and/or syndepositional dissolution that later progressive dissolution. They relate fracturing to stress relief caused by unloading of the Rustler, citing a preponderance of horizontal (as opposed to vertical) fractures within the Rustler as evidence. According to their hypothesis, fracturing would be expected to become less pronounced eastward as the

depth of burial of the Rustler increases. Holt and Powers (1988) also do not believe that all of the gypsum present in the Rustler is related to the hydration of anhydrite, but that it is instead primary, pointing to the preservation of primary sedimentary structures as evidence. Hold and Powers do find evidence for late-stage dissolution of halite from the upper Salado in Nash Draw, however, and relate disruption of the overlying Rustler to this dissolution.

As can be seen on Figure 6-2, the highest values of Culebra transmissivity are found in areas in or close to Nash Draw where no halite is present in the Rustler. At DOE-2 and WIPP-13, which are very close to the boundary west of which no halite is present in the unnamed lower member, the transmissivity of the Culebra is also relatively high. Relatively high transmissivities are also found, however, ate DOE-1 and H-11, where little or no halite is missing beneath the Culebra. WIPP-30, on the other hand, lies in an area of no Rustler halite, and yet the transmissivity of the Culebra is low at that location. Neither Snyder's (1985) nor Holt and Powers' (1988) model of halite deposition and dissolution can adequately explain the entire transmissivity distribution observed around the WIPP site.

If the absence of halite in the unnamed lower member is caused by dissolution and if this dissolution causes fracturing of the Culebra as Snyder (1985) suggests, then the high transmissivities shown in the area of no halite on Figure 6-2 would be expected. Further, the high transmissivities at DOE-2 and WIPP-13 could be explained as the result of partial dissolution of halite from the unnamed lower member. The lower transmissivity at WIPP-30, however, cannot be explained by this hypothesis, nor can the low transmissivities at H-14 and P-15, which are closer to the no-halite boundary than is H-18. The relatively high transmissivities at DOE-1 and H-11 also cannot be related to dissolution of underlying halite.

Holt and Powers' (1988) model could predict the high transmissivities in Nash Draw by relating them to dissolution of the upper Salado. Their model further states that no Rustler halite was deposited and no dissolution of the Salado has occurred at WIPP-30, thus explaining the low Culebra transmissivity at that location. If their argument that fracturing is related to unloading is correct, then a correlation between the present-day depth of burial of the Culebra and the transmissivity of the Culebra might be expected to exist. Preliminary evaluation by Holt (personal communication) indicates that some correlation between depth of burial and Culebra transmissivity is evident, but that the correlation is not perfect. For example, despite the fact that the Culebra is approximately 200 ft shallower at WIPP-30 than at DOE-2, the Culebra transmissivity is over two orders of magnitude lower at WIPP-30 than at DOE-2. Other, as yet undefined, factors may be as important as depth of burial in controlling the transmissivity of the Culebra. The Holt and Powers (1988) model also fails to explain the relatively high transmissivities at DOE-1 and H-11.

Clearly, neither of the geologic models cited above provides a complete understanding of the distribution of transmissivity within the Culebra. The two models need not be considered completely mutually exclusive, however, and as discussed above, elements of both models provide reasonable explanations of <u>some</u> features observed in the Culebra. Nondeposition (or syndepositional dissolution) of halite may have been more widespread than believed by Snyder (1985), and late-stage dissolution may have occurred more than is believed by Holt and Powers (1988). The most significant problem area is in the vicinity of

DOE-1 and H-11, where relatively high transmissivities would not be expected based on either model.

One additional observation that can be made from consideration of Figure 6-2 is that all measurements of Culebra transmissivity greater than 1 ft^2/day coincide with areas having no halite in the Tamarisk. The simple dissolution of Tamarisk halite would not seem likely to affect the transmissivity of the Culebra. The lack of high Culebra transmissivity everywhere that halite has been removed from the Tamarisk further argues against a direct relationship between Culebra transmissivity and Tamarisk halite. Nevertheless, absence of Tamarisk halite appears to be a necessary, but not sufficient, condition for high Culebra transmissivity. Perhaps the removal of Tamarisk halite makes possible a second process that directly affects the transmissivity of the Culebra."

p. 137, col. 2, line 7;
" ... Attempts to collect representative data on the formation pressure of the Tamarisk have failed to date, but recent data from DOE-2, H-14, and H-16 support Mercer's observation of downward hydraulic gradients from the Magenta to the Culebra at the WIPP site. Together these observations imply that the Culebra, the most transmissive member of the Rustler, acts as a drain on the overlying and underlying Rustler"

p 138, col 2, para 1;
" The unnamed lower member of the Rustler Formation was tested only in well H-16, where DST's were performed on the lower siltstone portion of the unit. The transmissivity of the siltstone is about 2.4 x $10^{-4}ft^2$/day (Table 5-2). . . ."

p 138, col 2, para 3;
" The claystone portion of the Tamarisk member of the Rustler Formation was tested in wells H-14 and H-16. At H-14, the pressure in the claystone failed to stabilize in three days of shut-in testing, leading to the conclusion that the transmissivity of the claystone is too low to measure in tests performed on the time scale of days. Similar behavior at H-16 led to the abandonment of testing at that location as well."

Section 7. SUMMARY AND CONCLUSIONS, p 139, col 1, para 3;
" The Forty-niner Member of the Rustler Formation was also tested in wells H-14 and H-16. Two portions of the Forty-niner were tested in H-14: the medial claystone and the upper anhydrite. DST's and a rising-head slug test were performed on the claystone. The transmissivity of the claystone is about 7 x $10^{-2}ft^2$/day (table 5-2). A prolonged buildup test performed on the Forty-niner anhydrite revealed a transmissivity too low to measure on a time scale of days. A pulse test, DST's, and a rising-head plug test were performed on the Forty-niner clay at H-16, indicating the clay has a transmissivity of about 5 x $10^{-3}ft^2$/day (Table 5-2). Formation pressures estimated for the Forty-niner at H-14 and H-16 are lower than those calculated for the Magenta (compensated for the elevation differences), indicating that water cannot be moving downwards from the Forty-niner to the Magenta at these

locations."

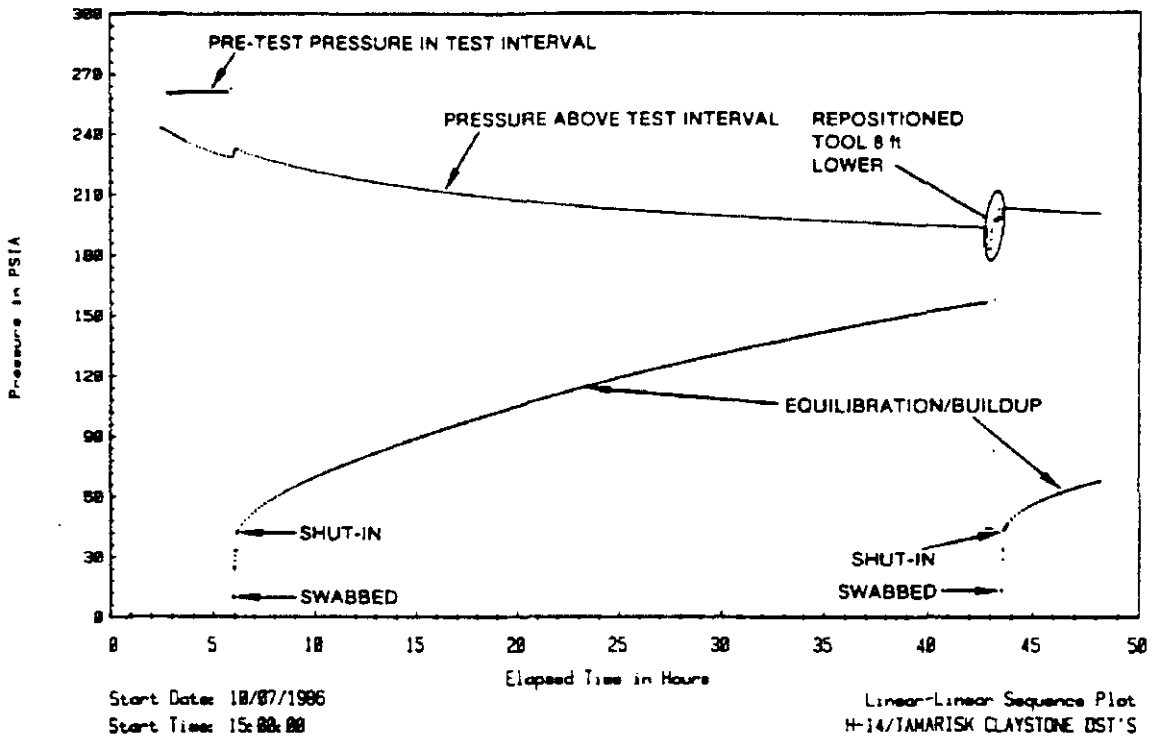

Figure 5-82. H-14/Tamarisk Claystone Shut-In Test Linear-Linear Sequence Plot

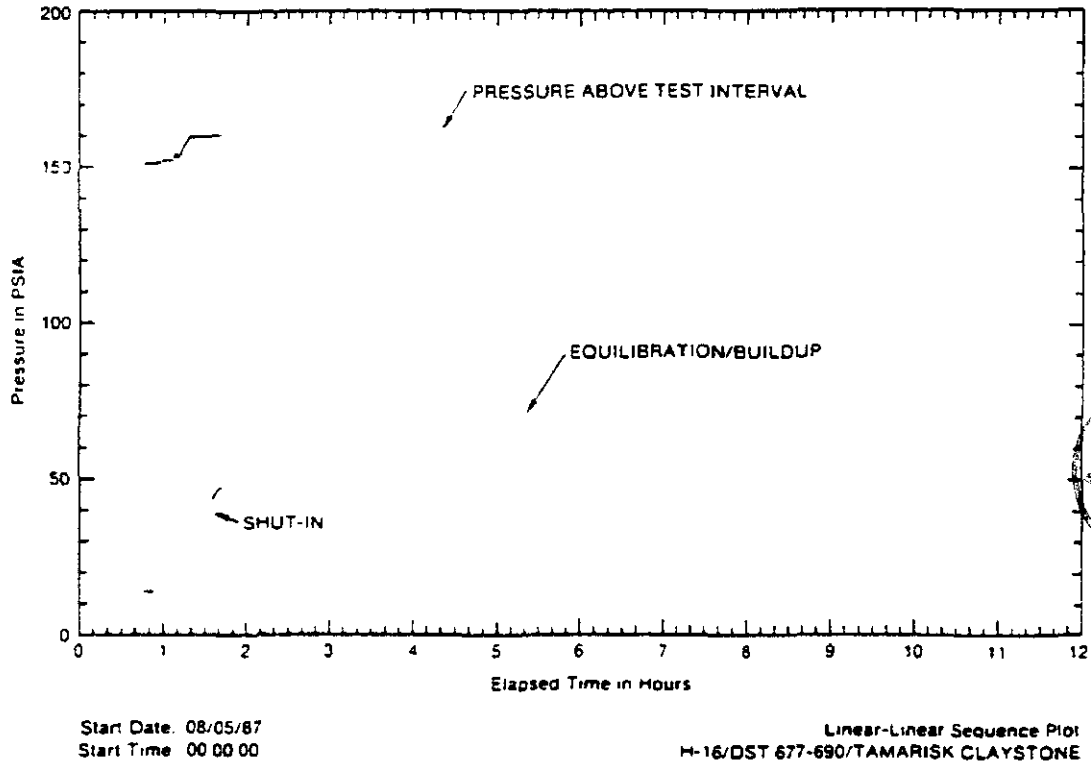

Figure 5-83. H-16/Tamarisk Claystone Shut-In Test Linear-Linear Sequence Plot

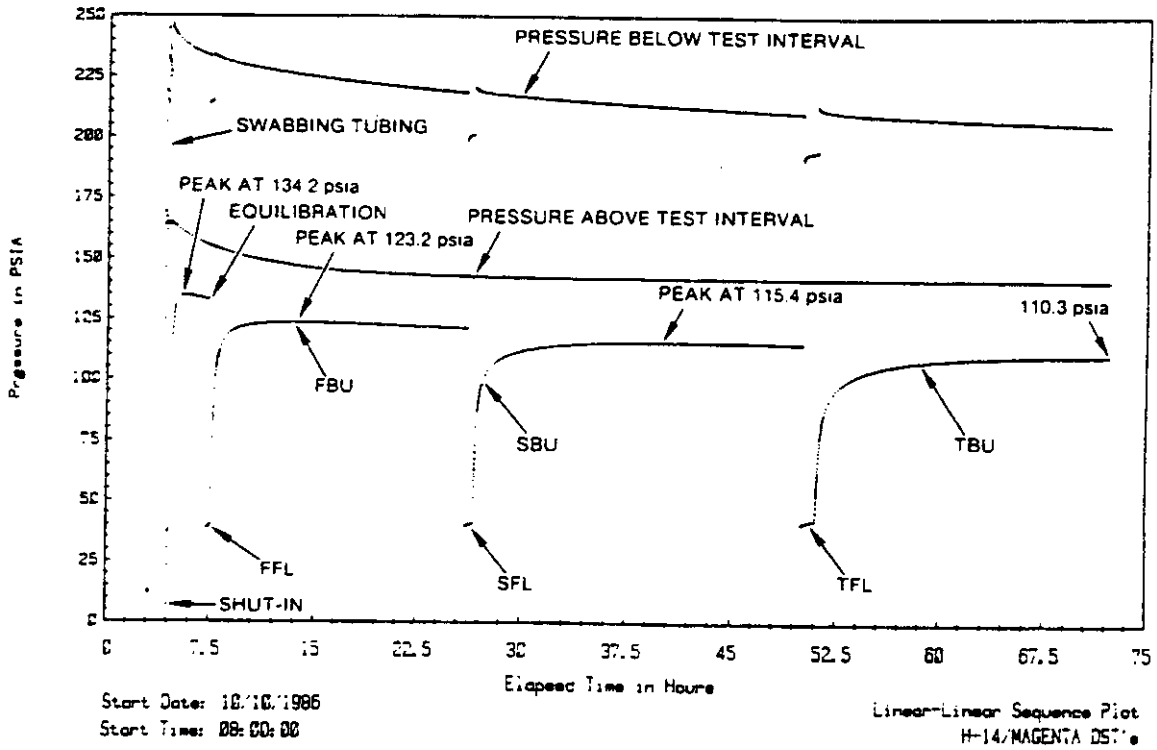

Figure 5-84. H-14/Tamarisk Claystone Shut-In Linear-Linear Sequence Plot

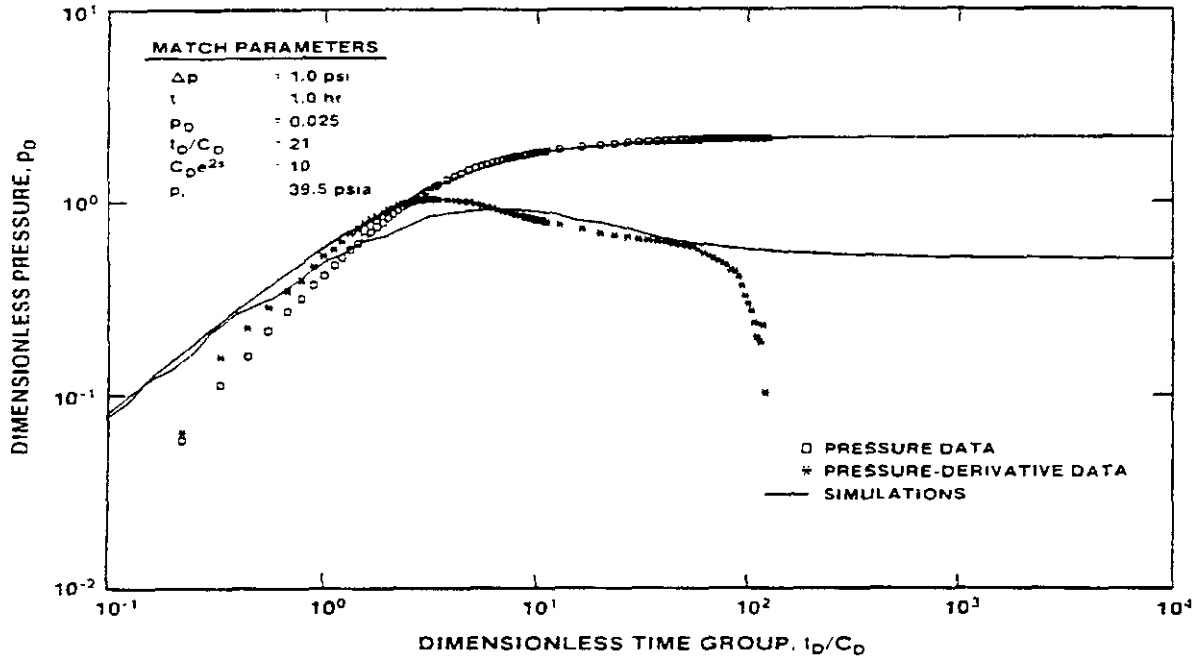

Figure 5-85. H-14/Magenta First Buildup Log-Log Plot with INTERPRET Simulation

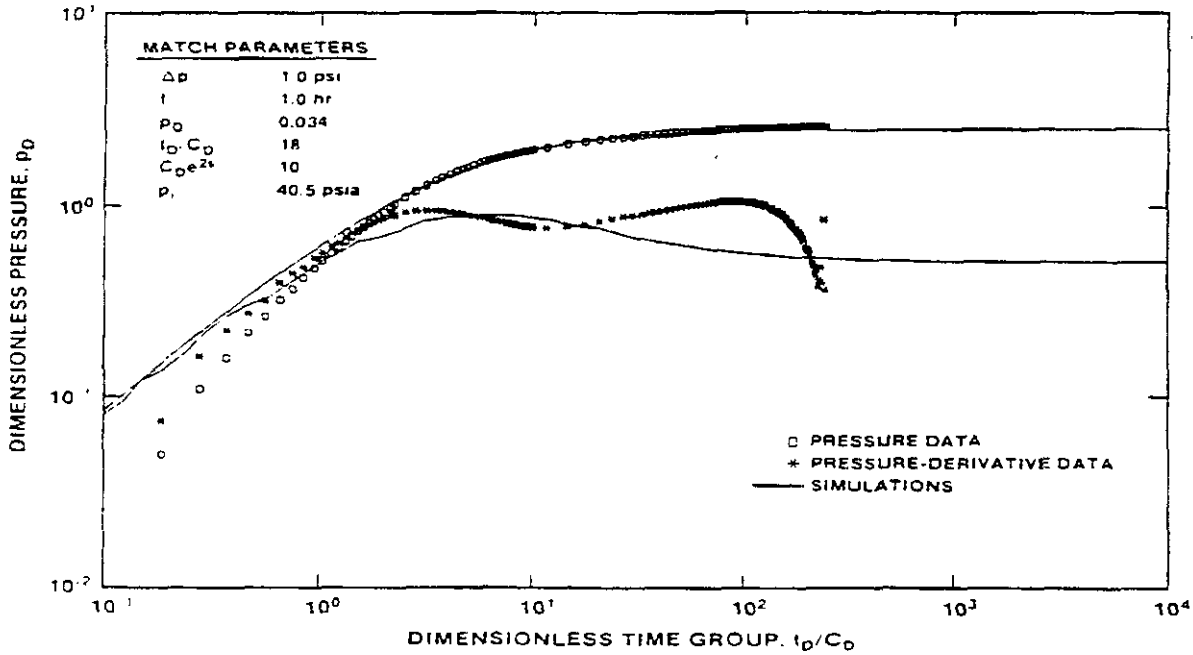

Figure 5-86. H-14/Magenta Second Buildup Log-Log Plot with INTERPRET Simulation

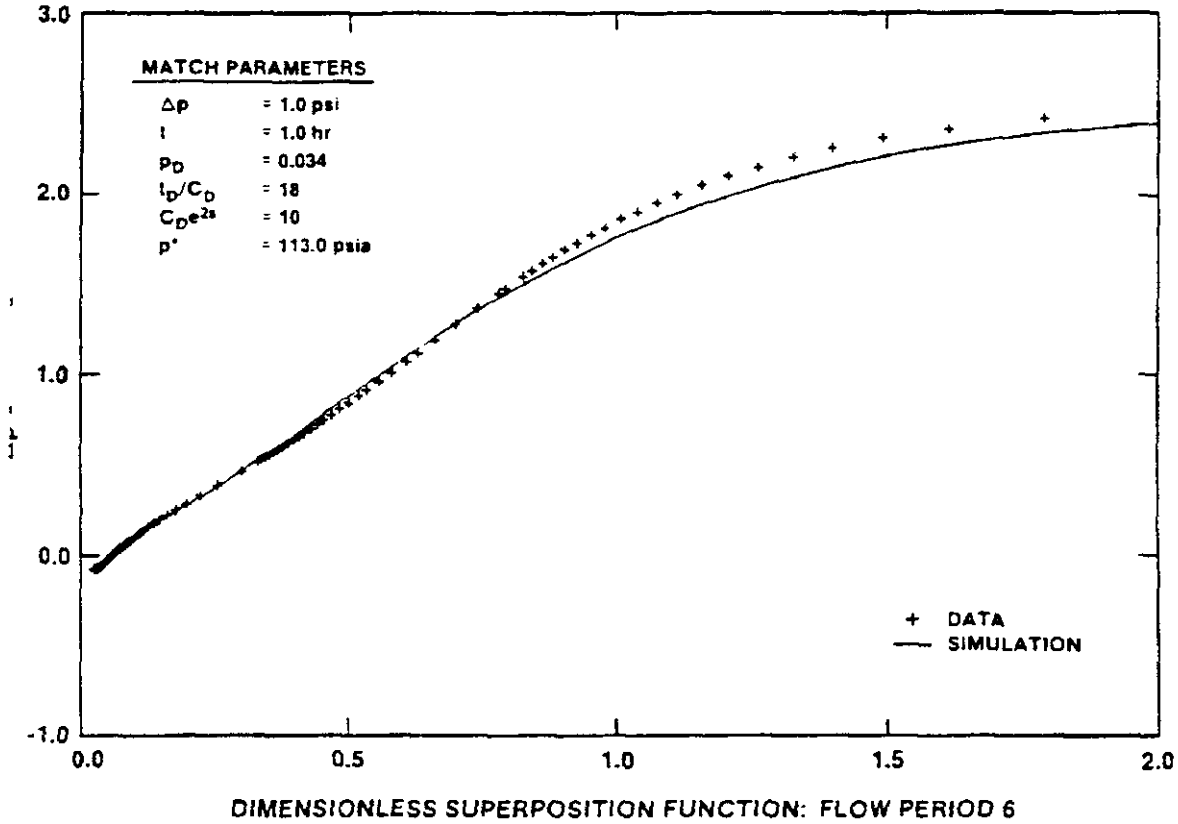

ıre 5-87. H-14/Magenta Second Buildup Dimensionless Horner Plot with INTERPRET Simulation

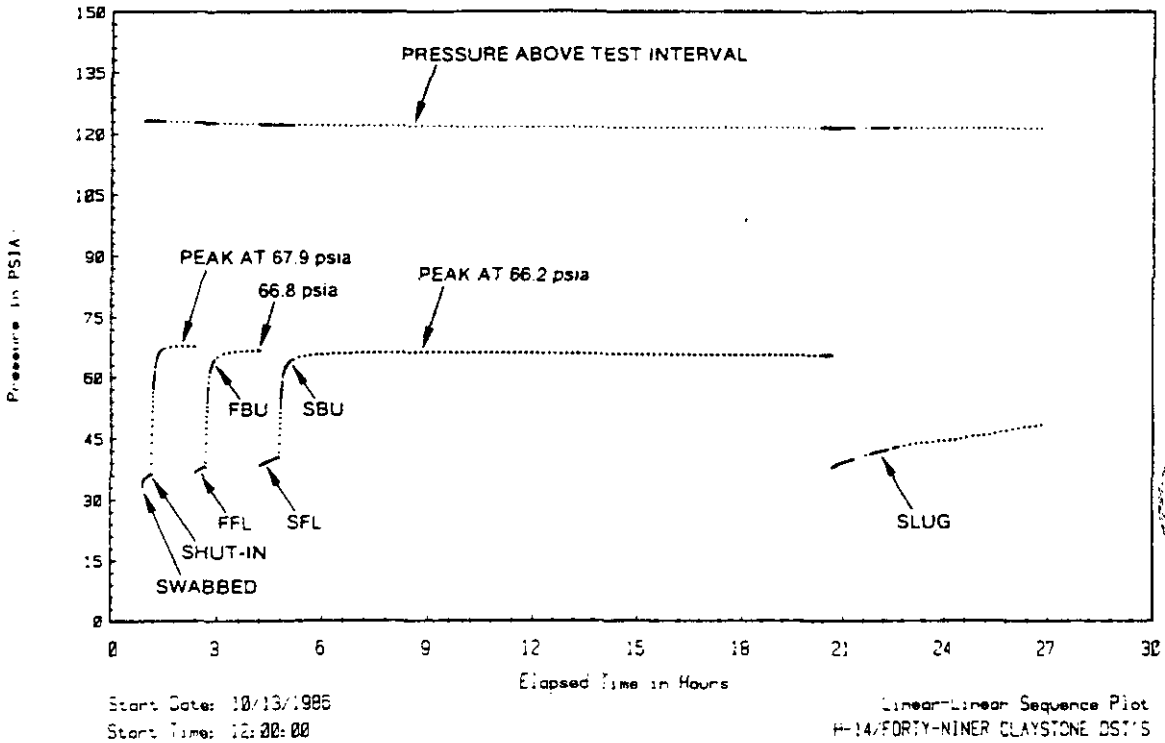

Figure 5-95. H-14/Forty-Niner Claystone Drillstem and Slug Testing Linear-Linear Sequence Plot

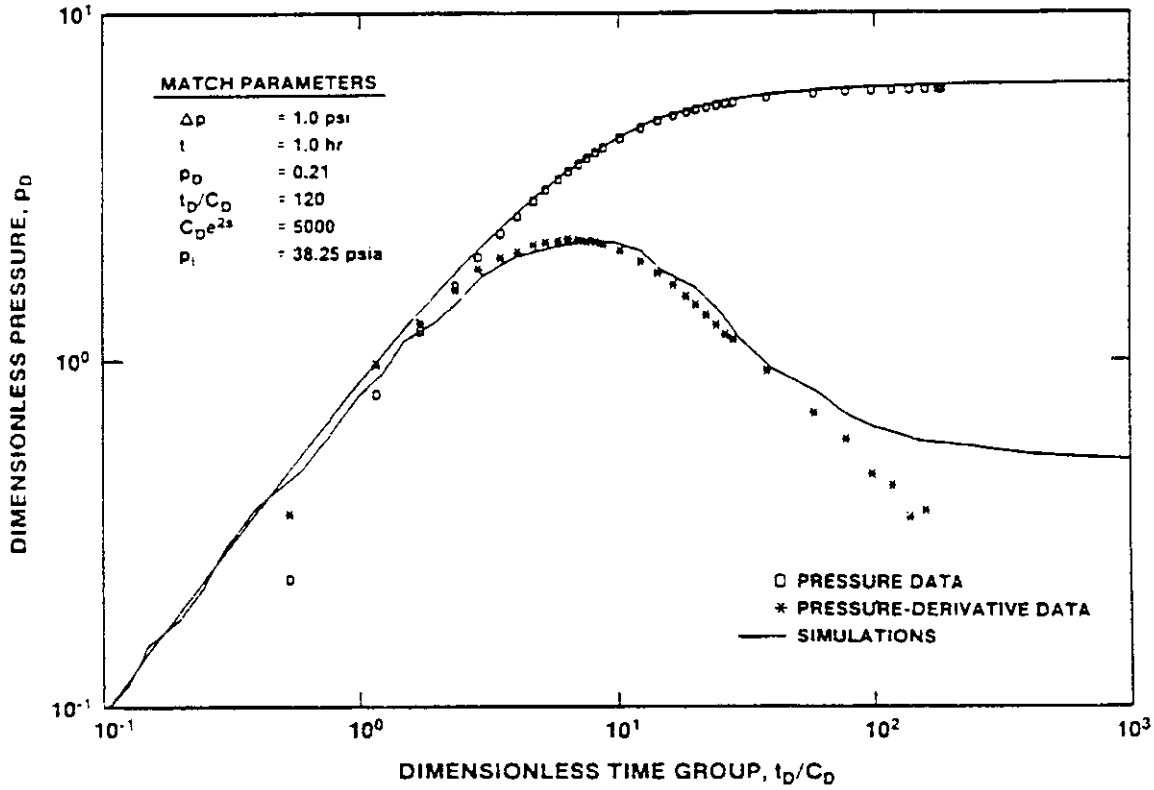

Figure 5-96. H-14/Forty-Niner Claystone First Buildup Log-Log Plot with INTERPRET Simulation

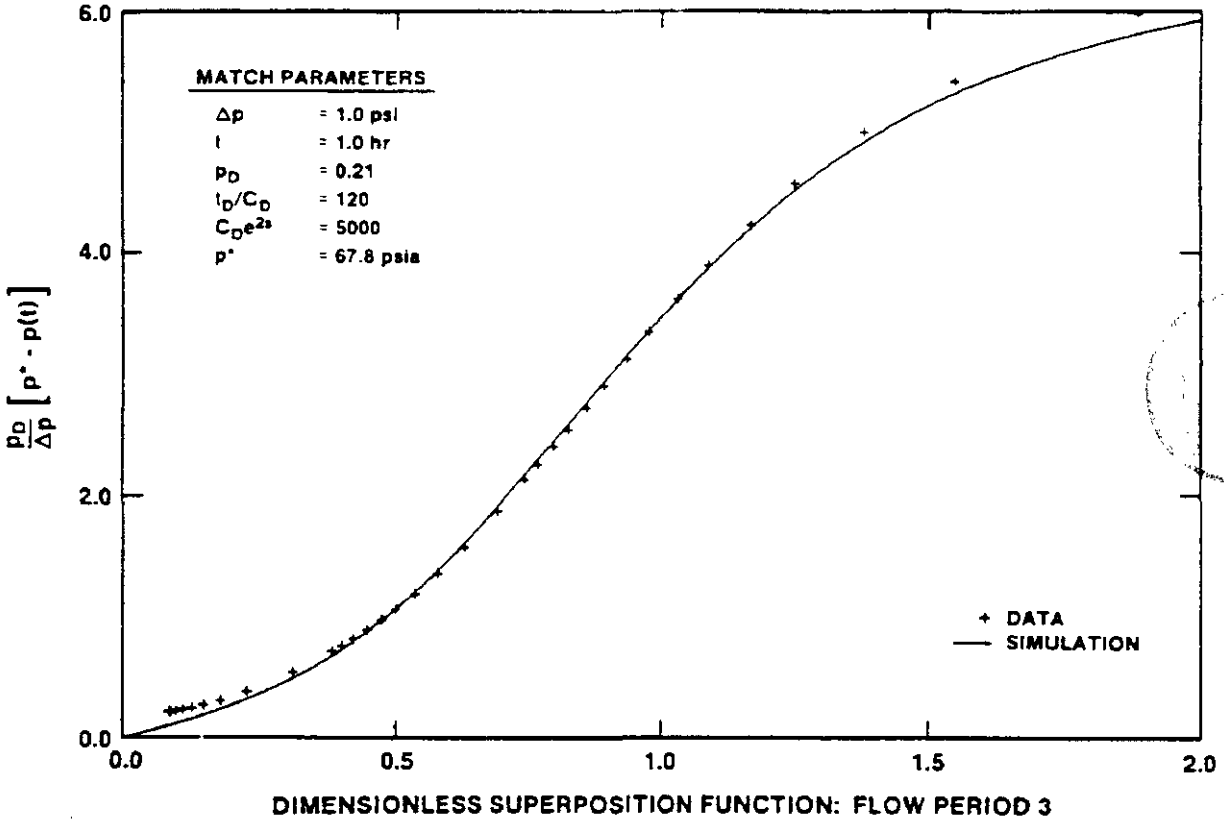
MATCH PARAMETERS
Δp = 1.0 psi
t = 1.0 hr
pD = 0.21
tD/CD = 120
CDe2s = 5000
p* = 67.8 psia
+ DATA
SIMULATION
6.0
4.0
2.0
0.0
0.0
0.5
1.0
1.5
2.0
pD/Δp [p* - p(t)]
DIMENSIONLESS SUPERPOSITION FUNCTION: FLOW PERIOD 3

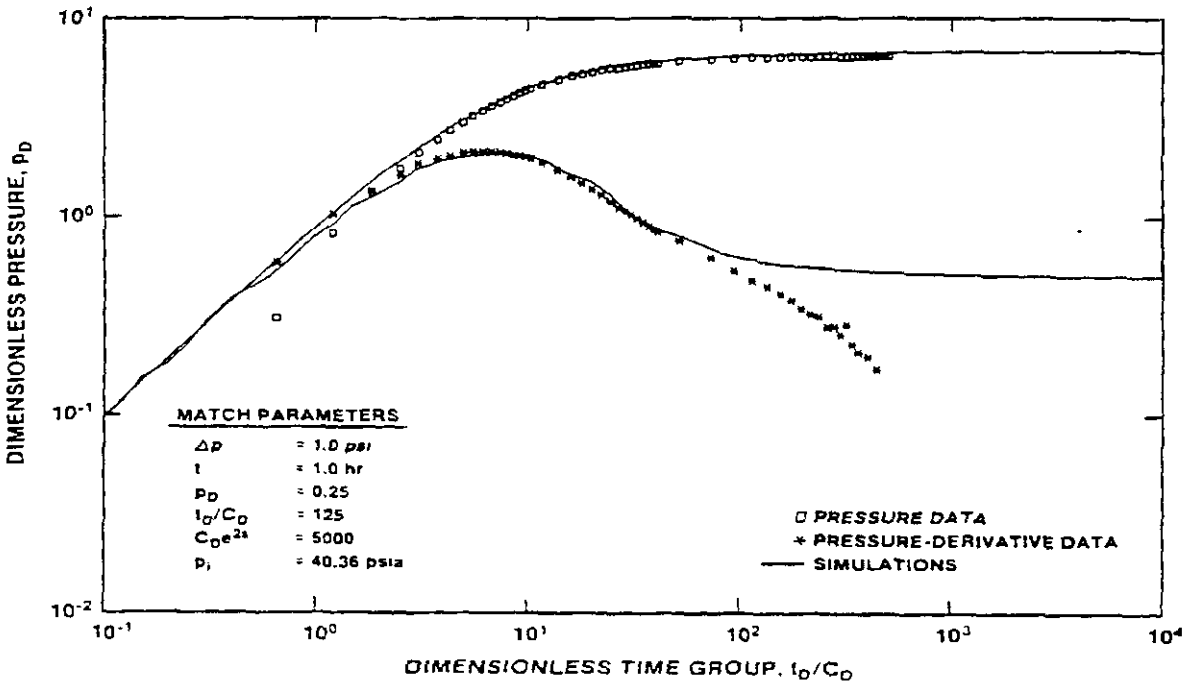

Figure 5-98. H-14/Forty-Niner Claystone Second Buildup Log-Log Plot with INTERPRET Simulation

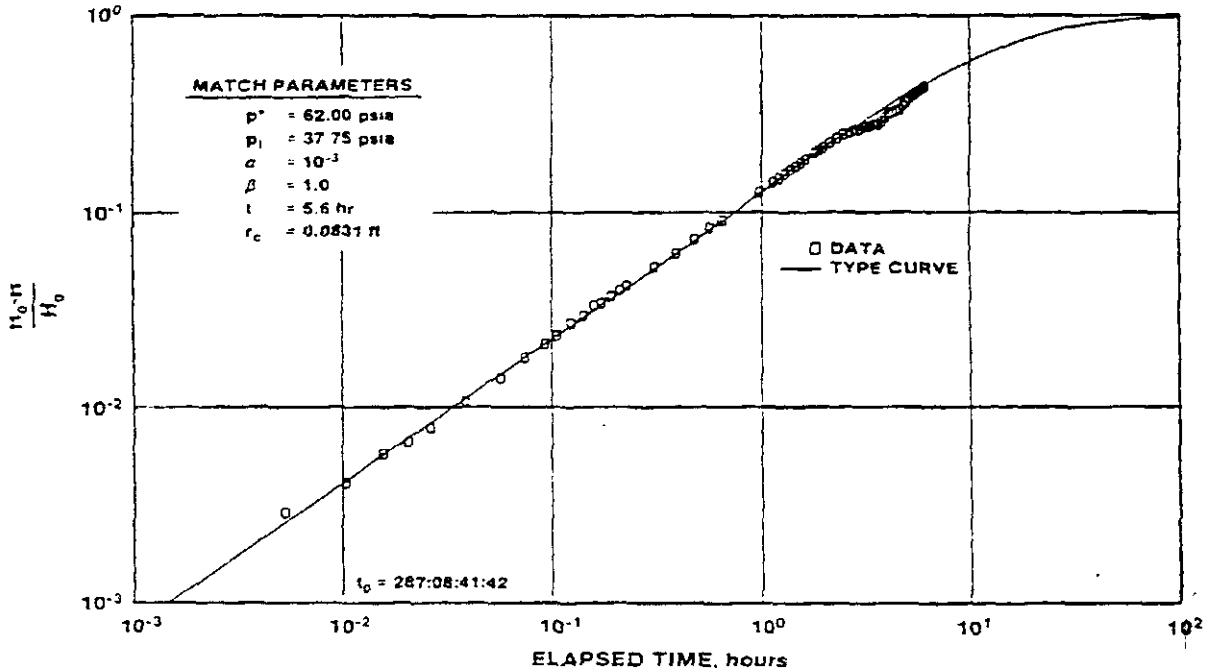

Figure 5-99. H-14/Forty-Niner Claystone Early-Time Slug-Test Plot

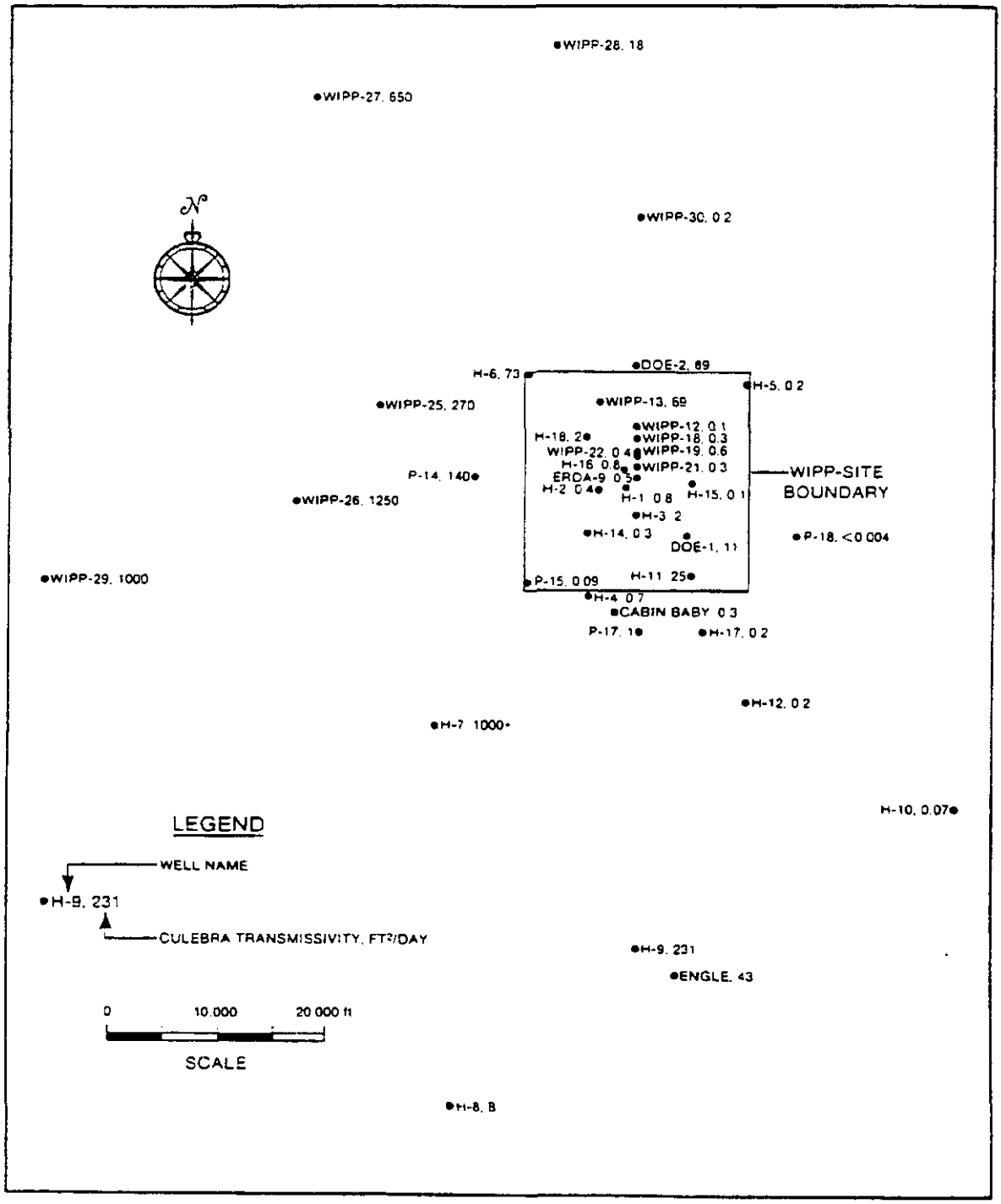

Figure 6-1. Culebra Wells Tested by the WIPP Project

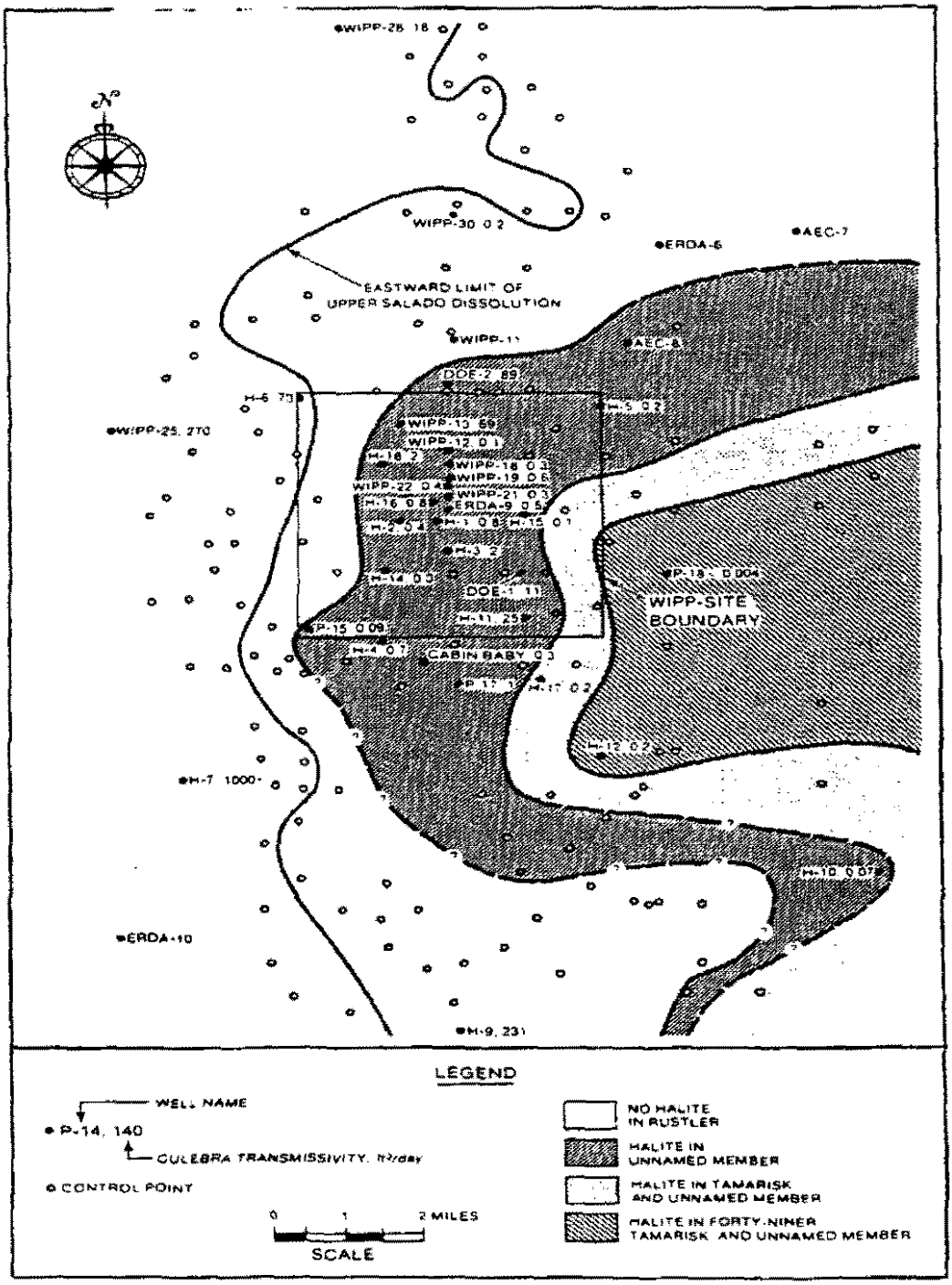

Figure 6-2. Distribution of Rustler Halite and Culebra Transmissivity Around the WIPP Site.

Beauheim, R.L. 1987b. Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-2311. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" Two pumping tests were conducted in the Culebra Dolomite Member of the Rustler Formation at the H-3 hydropad at the Waste Isolation Pilot Plant (WIPP) site. The first test was in 1984, with well H-3b3 pumped for 14 days at an average rate of 4 gpm. The second test, the H-3 multipad test, was in late 1985 and early 1986, with well H-3b2 pumped for 62 days at an average rate of 4.8 gpm. Both tests provided information on the hydraulic properties of the Culebra at the H-3 hydropad. The second test provided information on average Culebra hydraulic properties on a much larger scale; responses were observed up to 8000 ft from the pumping well.

The interpretation of these tests had three principle objectives. The first was to determine the most appropriate conceptualization of the nature of the Culebra flow system around the H-3 hydropad. The pumping well responses during the H-3 tests appear to be those of wells completed in a double-porosity medium with unrestricted interporosity flow. In such a system, fractures provide the bulk of the permeability, while matrix pores provide the majority of the storage capacity. The importance of fracture flow is indicated by the speed with which the observation wells on the H-3 hydropad respond to pumping and the nearly identical behaviors of these wells and the pumping well. The similarity between pumping- and observation-well behavior on the H-3 hydropad is so pronounced that the responses of all three wells on the hydropad can be interpreted only by using pumping-well analytical techniques, not observation-well analytical techniques. H-3b1 and H-3b3, in particular, appear to be very well connected by fractures.

The second objective was to quantify the hydraulic properties of the Culebra in the vicinity of the H-3 hydropad. The total-system (fractures plus matrix) transmissivity of the Culebra derived from the first test is 2.9 ft^2/day; that from the second test is 1.7 ft^2/day. The lower value derived from the second test probably represents lower transmissivity (lower fracture connectivity) at H-3b2 than at H-3b3, and/or lower average transmissivity of the volume of Culebra stressed in the multipad test as opposed to the smaller volume stressed in the first test. The fracture-to-total-system storativity ratios derived from the various analyses range from 0.03 to 0.25, indicating a relatively high degree of storage within the fractures. The highest storativity ratios were consistently found at H-3b1. Wellbore skin values are highly negative, indicating direct wellbore connection with fractures.

The third objective was to quantify the average hydraulic properties of the Culebra between the H-3 hydropad and more-distant observations wells. Meeting this objective . . ."

Pg. 100 Table A-3

Table A-3. Water Levels and Pressures in Observation Well DOE-1 During the 1984 H-3 Pumping Test

Day	Hr	Min	Elapsed Time (hr)	Depth to Water (ft)	Pressure* (psi)	Comments
101	16	32	-305.970	499.18	47.69	
108	14	10	-140.330	499.21	47.67	
110	8	55	-97.583	499.31	47.63	
110	14	5	-92.417	499.08	47.74	
110	15	44	-90.767	499.21	47.67	
111	12	45	-69.750	499.18	47.69	
114	8	45	-1.750	499.74	47.42	
114	12	7	1.617	499.61	47.48	PUMP ON AT H-3B3
115	9	42	23.200	499.61	47.48	114:10:30
117	13	46	75.267	499.41	47.58	
118	13	40	99.167	500.00	47.30	
121	13	17	170.783	500.75	46.95	
122	13	20	194.833	500.85	46.90	
123	11	52	217.367	501.05	46.80	
124	9	24	238.900	501.35	46.66	
125	10	6	263.600	501.51	46.59	
128	13	48	339.300	502.46	46.14	

*Pressure = (600 ft - Depth to Water) x 0.473 psi/ft

Beauheim, R.L., 1987c. Interpretation of the WIPP-13 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site. SAND87-2456. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3;

" A large-scale pumping test of the Culebra Dolomite Member of the Rustler Formation was performed in early 1987 at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. This test (the WIPP-13 or northern) multipad test, complemented the H-3 (or southern) multipad test (conducted in late 1985 and early 1986) by creating a hydraulic stress that could be measured over the northern portion of the WIPP site. The test consisted of pumping well WIPP-13 at a rate of 30 gpm for 36 days and monitoring drawdown and recovery responses in 17 observation wells and one WIPP shaft. Responses were observed in 14 of these wells, including one well 20 550 ft from WIPP-13 and in the WIPP exhaust shaft. Several of these wells had also responded during the H-3 multipad test.

Individual well tests at locations around the WIPP site have demonstrated that the Culebra is a heterogeneous, water-bearing unit. The responses measured at observation wells to pumping tests in heterogeneous systems cannot be rigorously interpreted using standard analytical (as opposed to numerical) techniques developed for tests in homogeneous, porous media. Application of analytical techniques to data from heterogeneous media results in evaluations of average hydraulic properties between pumping and observation wells that are nonunique in the sense that they are representative only of the responses observed when a hydraulic stress is imposed at a certain location. These 'apparent' hydraulic properties do, however, provide a qualitative understanding of the nature and distribution of both hydraulic properties and heterogeneities or boundaries within the tested area.

The interpretations of the responses at the pumping and observation wells are consistent with the following conceptualization: The Culebra is a fractured, double-porosity system around WIPP-12, H-6, and DOE-2, with relatively high transmissivity (~ 70 ft^2/day) and relatively low storativity (5×10^{-6} to 8×10^{-6}). This system appears to extend further to the north toward WIPP-30, although WIPP-30 itself lies in a lower transmissivity zone. The apparent transmissivity between WIPP-13 and observation wells toward the center of the WIPP site to the south and east, where fracturing in the Culebra decreases, decreases to 16 to 28 ft^2/day, and apparent storativity increases to 3.6×10^{-5} to 5.5×10^{-5}. To the west toward Nash Draw, the apparent transmissivity increases to 265 to 650 ft^2/day, reflecting increased fracturing in that direction, while the apparent storativity increases to 5.2×10^{-5} to 6.4×10^{-5}.

The analyses of the responses measured at observation wells to the WIPP-13 multipad pumping test provide a qualitative conceptualization of three distinct domains within a heterogeneous portion of the Culebra north of the center of the WIPP site. This conceptualization is being refined by using numerical-modeling techniques to simulate the WIPP-13 multipad test and other tests at the WIPP site in an attempt to define the distribution of hydraulic properties that will reproduce the responses observed."

Beauheim, R.L. 1989. Interpretation of H-14b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site, SAND89-0536. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. 3;

" Drillstem tests, slug tests, a small-scale pumping test, and a large-scale pumping test of the Culebra Dolomite Member of the Rustler Formation were performed in 1988 at the H-11 hydropad at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The drillstem, slug, and small-scale pumping tests were conducted in well H-11b4 to evaluate well and aquifer properties in preparation for a tracer test. The large-scale pumping test, known as the H-11 multipad test, was performed by pumping well H-11b1 in the southern part of the WIPP site at a rate of six gpm for 63 days and monitoring drawdown and recovery responses in three other wells on the H-11 hydropad and at 11 observation wells within a three-mile radius. Responses were observed in 10 of these distant wells. The H-11 multipad pumping test complemented the H-3 and WIPP-13 multipad pumping tests conducted in the central and northern portions of the WIPP site in late 1985 and early 1987, respectively.

Individual well tests at various locations around the WIPP site have demonstrated that the Culebra is a laterally heterogeneous water-bearing unit. The responses measured at observation wells to pumping tests in heterogeneous systems cannot be rigorously interpreted using standard analytical (as opposed to numerical) techniques developed for tests in homogeneous results in evaluations of average hydraulic properties between pumping and observation wells that are nonunique in the sense that they are representative only of the responses observed when a hydraulic stress is imposed at a certain location. These 'apparent' hydraulic properties do, however, provide a qualitative understanding of the nature and distribution of both hydraulic properties and heterogeneities or hydraulic boundaries with the tested area.

The interpretations of the responses at the test and observation wells provided the following information: The Culebra is a fractured, double-porosity system at H-11 with a transmissivity between 27 and 43 ft^2/day and a storativity between 3.4×10^{-5} and 1.5×10^{-4}. Drawdown during the multipad test appeared to be largely concentrated to the north and south of H-11; wells to the east and west showed relatively low-magnitude responses. The rapid and high-magnitude responses observed at DOE-1, H-3b2, and H-15 during the multipad test are believed to reflect the presence of a fracture network extending to the north from H-11. Numerical simulations indicate that the fracture network extends south of H-11. but no wells are currently situated within it.

Double-porosity hydraulic behavior was observed at DOE-1 during the multipad test, and at both DOE-1 and H-3b2 during other pumping tests performed at those locations. The fractures appear to continue past DOE-1 to the north toward H-15, although H-15 itself lies in a lower transmissivity, apparently single-porosity zone. Apparent transmissivities in the region north of H-11 range from 7.1 to 9.0 ft^2/day and apparent storativities range from 2.4×10^{-6} to 8.4×10^{-6}. Apparent transmissivities between H-11 and observation wells to the

west, southwest, and southeast, where fracturing in the Culebra decreases and single-porosity hydraulic behavior is observed, range from 6.0 to 21.0 ft^2/day and apparent storativities range from 1.8×10^{-5} to 6.5×10^{-5}. Interpretation of the responses to the multipad test observed at the western and southern wells was complicated by an anomalous and widespread rise in water levels of unknown origin.

Thus, the analyses of the responses measured at observation wells to the H-11 multipad pumping test are consistent with a conceptualization of two distinct domains within a heterogeneous portion of the Culebra south of the center of the WIPP site: a fractured region having low storativity extending to the north and south from H-11, and a relatively unfractured region west, southwest, and southeast of H-11 having higher storativity. This conceptualization is being refined using numerical-modeling techniques to simulate the H-11 multipad test and other tests at the WIPP site, in an attempt to define a distribution of hydraulic properties that will reproduce the response observed."

Beauheim, R.L., and Holt, R.M. 1990. "Hydrogeology of the WIPP Site." In Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, Geological Society of America 1990 Annual Meeting Field Trip #14 Guidebook, pp. 131-179. Dallas Geological Society, Dallas, TX. WPO 29378.

Introduction, p 2, col. 1;
" The field trip provides an on site introduction to the geology and hydrology of the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The mission of the WIPP is to dispose of transuranic (TRU) waste generated since 1970 by the U. S. defense programs. After 18 years of study and the publication of hundreds of documents, these studies remain unknown to many geologists. Although many of the studies are unique, they lack recognition. This field trip and guidebook begin to redress this imbalance."

Unnamed Lower Member Hydrology, p 144, col 2;
" The unnamed lower member of the Rustler consists of interbedded siltstone, sandstone, halite, and anhydrite (Figure 12) (Holt and Powers, 1988). Holt and others (in prep.) recognize two confining beds and two water-producing units within the unnamed lower member.

Holt and others (in prep.) consider the sulfate unit at the base of the Rustler to be the lowermost confining bed within the Rustler, although this hydrologic role is mostly due to low permeability halite in the Salado. Where dissolution has affected the upper Salado, this stratigraphic unit is hydrologically compromised, and the lower confining bed for water-bearing unit 1 is the top of intact Salado halite.

Water-producing unit 1 (WPU-1) of Holt and others (in prep.) consists of the bioturbated clastic interval and transitional sandstone, and it includes the M-1/H-1 interval when halite is not present. WPU-1 is confined by anhydrite. The bioturbated clastic interval is the principle water-bearing zone within WPU-1. The siltstone and sandstone within this zone are argillaceous and cemented with halite (Holt and Powers, 1988; Holt and others, in prep.). The transitional sandstone is also cemented with halite and locally with sulfate (Holt and Powers, 1988). The M-1/H-1 interval contains bedded and argillaceous halite with some halitic clastic rocks. Halite cements are dissolved in the units to create secondary intergranular porosity and permeability. Dissolution of halite from the upper part of the Salado causes structural collapse of, and upward sloping through, overlying units. Fracture porosity develops around displaced blocks of collapsed material, and the thickness of the water-bearing zone increases to include the interval hydraulically connected by fractures. After collapse, the evaporite cements within the collapsed blocks are more readily dissolved. Hydrologic testing of WPU-1 is difficult as the borehole may only effectively intersect a few fractures and the permeability between collapse blocks may be limited by clay skins developed on the margins of the blocks during the collapse process.

Transmissivity values for WPU-1 (Mercer, 1983; Beauheim, 1987) generally show a transmissivity increase in the direction of Nash Draw (Figure 13). Holt and others (in prep.) suggest that the transmissivity values from areas where Salado dissolution and collapse of

overlying strata have occurred may not be representative of the entire WPU-1 interval thickness at the tested locations.

Few measurements have been made of the stabilized water level or fluid pressure of WPU-1 (Figure 14). Although freshwater head calculations are somewhat limited due to the quality of specific gravity measurements, estimated freshwater head values are probably accurate to within 10 ft (Holt and others, in prep.). The freshwater heads in those wells completed within the collapse material associated with Salado dissolution do not appear to differ significantly from the hydraulic heads in wells completed in intact Rustler siltstone, indicating good lateral hydraulic connection. The heads are consistent with Mercer's (1983) interpretation that flow through the low transmissivity sections of WPU-1 is generally westerly or southwesterly across the WIPP site towards Nash Draw, while flow within Nash Draw is generally southwesterly towards Malaga Bend on the Pecos River."

Culebra Hydrology, p 150, col 1, para 4;
" The transmissivity of the Culebra across the WIPP region varies by six orders of magnitude (Figure 17) due to varying degrees of fracturing within the Culebra. In the vicinity of the WIPP, the Culebra has been tested in 41 locations, including the combined testing of the WIPP project and Project Gnome (Beauheim, 1988). . . ."

Culebra Hydrogeology, p 157, col 1, para 2;
" Gypsum and anhydrite commonly fill pores within the Culebra near the WIPP site. Sulfate (usually gypsum) occurs as cements, passive void-fillings, nodules, and incremental fracture-fillings. A clear pattern of alternation occurs within the Culebra from east to west. Anhydrite vugs and crystals are replaced by gypsum, and gypsum occurs as incremental fracture fillings within the Culebra dolomite. Further west, all sulfate consists of gypsum, and gypsum fracture-fillings, cements, and vug-fillings are partly to completely dissolved. Continuing west, gypsum is almost totally removed, and many of the vugs and vug complexes are collapsed, thereby increasing local fracture porosity. In the westernmost part of the region, no gypsum occurs. The areal distribution of this relationship is best shown by the percentage of natural fractures filled with gypsum (Figure 21). This map shows a general inverse relationship between the presence of gypsum pore-fillings and transmissivity (Figure 17). Presence or absence of gypsum pore-fillings may, therefore, be one of the factors controlling the distribution of transmissivity within the Culebra."

Culebra Hydrogeology, p 157, col 1, para 3;
" The effective porosity within the Culebra is related to fractures, and the transmissivity values at various locations indicate degree of fracturing. This allows the degree of fracturing to be compared with other geologic information on a regional scale. The Culebra fractured significantly in response to differential unloading, dissolution of evaporites from above and below the Culebra, and dissolution of large vug-fillings or fillings within zones of vugs in the Culebra. . . ."

Culebra Hydrogeology, p 159, col 1, para 3;
" Much of the fracturing within the Culebra in the vicinity of the WIPP site can be attributed to unloading (Holt and others, 1988). An isopach map of the Culebra overburden shows a general decrease of overburden from east to west, with the overburden north and south of the WIPP site slightly less than that across the WIPP site (Figure 22). Culebra transmissivity (Figure 17) is generally higher where there is less overburden. As the transmissivity contours do not correlate precisely with the amount of overburden present, other mechanisms must contribute to the variations of transmissivity and the degree of fracturing in the Culebra across the WIPP area."

Culebra Hydrogeology, p 159, col 1, para 4;
" Aside from unloading, the most significant control on fracturing within the Culebra is the dissolution of evaporites from strata above and below the Culebra. The overlying strata collapse, and stress in the underlying strata is relieved. Both collapse and stress relief can cause or enhance the fracturing within a brittle unit such as the Culebra. Holt and others (in prep.) evaluate the extent of dissolution from the Salado and Rustler on the basis of core, shaft, and geophysical log data (Figure 23). Salado dissolution affects the area south and west of the WIPP site, while Rustler dissolution is concentrated along the depositional margins of halite within the Rustler."

The uppermost halite within the Salado is dissolved in the area in and around Nash Draw and in a region south of the WIPP site. Salado dissolution parallels the course of the ancestral Pecos River and its major tributaries, such as Nash Draw. Salado dissolution was hydrologically driven by the groundwater system associated with the ancestral Pecos River and its major tributaries. This system was most active during the Cenozoic, although dissolution of Salado continues to occur within Nash Draw.
Culebra core from areas of Salado dissolution shows evidence of fracturing and high transmissivity values due to collapse.

Salado dissolution close to a halite depositional margin within the Rustler increases the potential for dissolution of halite within the Rustler. Collapse associated with Salado dissolution tends to increase the vertical hydraulic connection between Rustler water-bearing zones and Rustler intervals containing halite. One such zone penetrates the southern part of the WIPP site. Features attributable to dissolution of halite and attendant collapse are found within the interval M-3/H-3 (Holt and Powers, 1988). This zone, although not well defined, corresponds with the highly transmissive zone within the Culebra in the southern part of the WIPP site. As dissolution has not occurred below the Culebra at this location, fracturing responded to stress-relief following dissolution."

Culebra Hydrogeology, p 159, col 2, para 1, line 9;
" Culebra core from areas of Salado dissolution shows evidence of fracturing and high transmissivity values due to collapse."

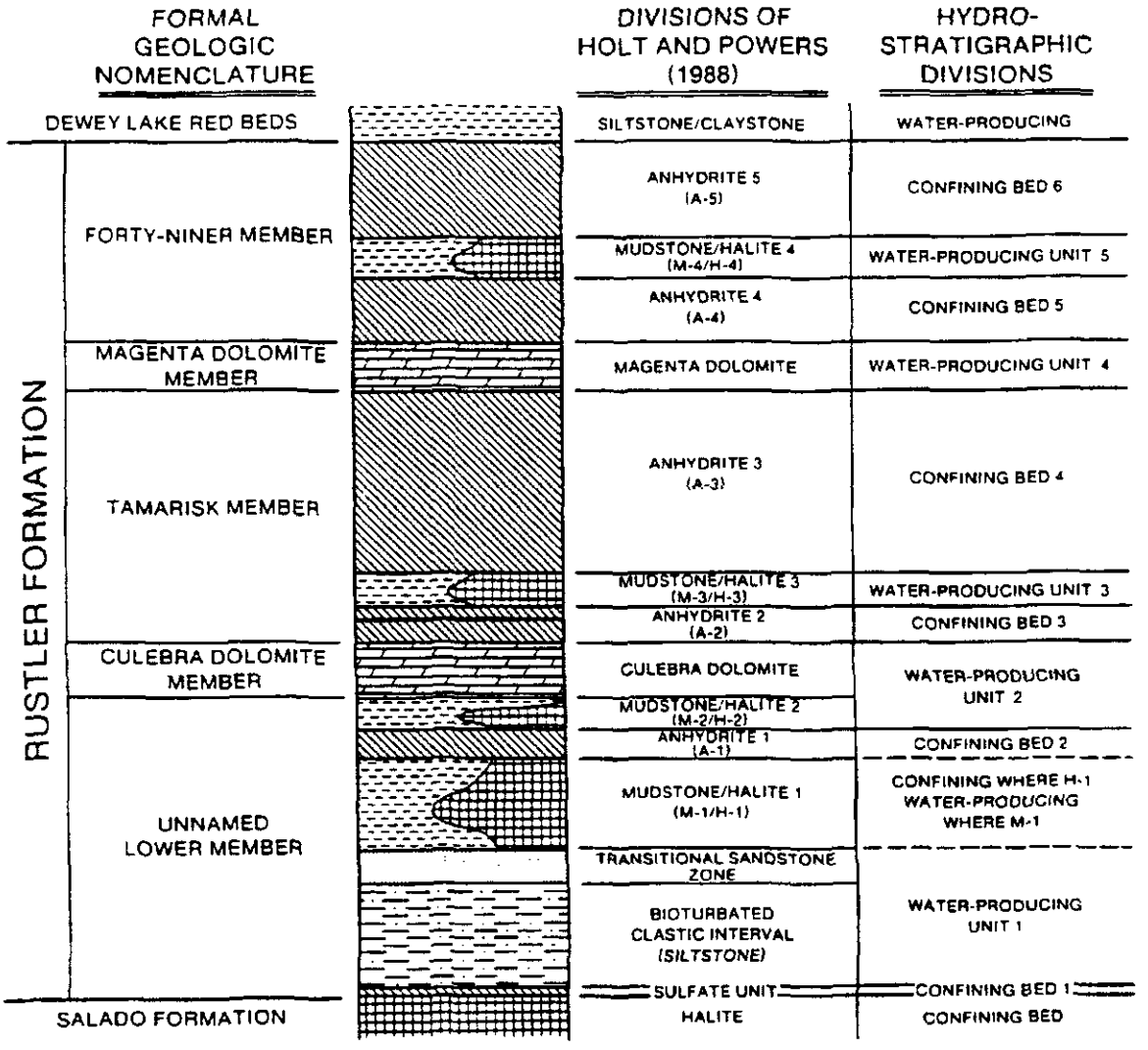

Figure 12. Relationship of lithostratigraphic and hydrostratigraphic units for the Rustler Formation (from Holt and others, in prep.).

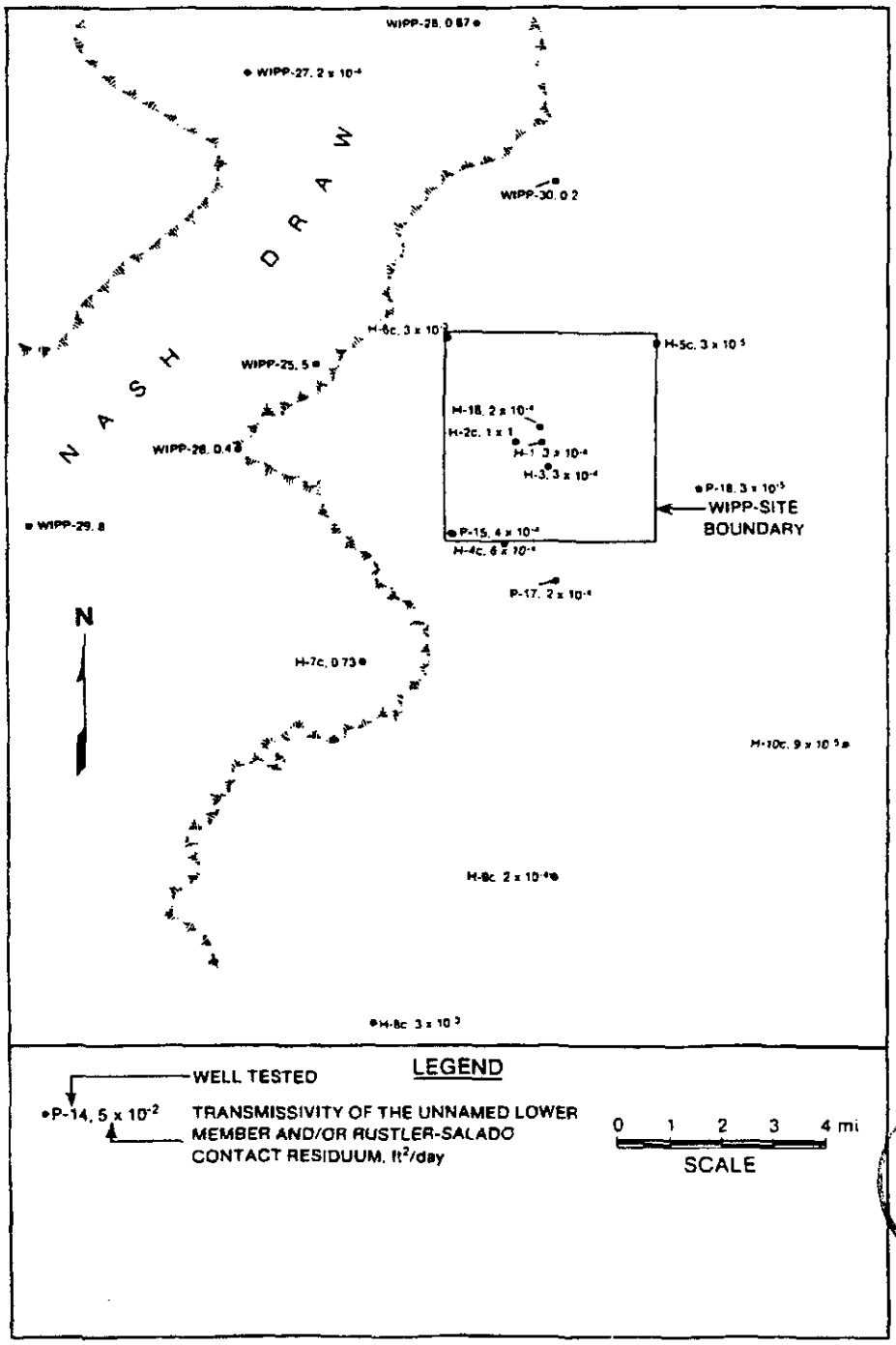

Figure 13. Transmissivity of the unnamed lower member of the Rustler and/or residuum along the Rustler/Salado contact (from Holt and others, in prep.).

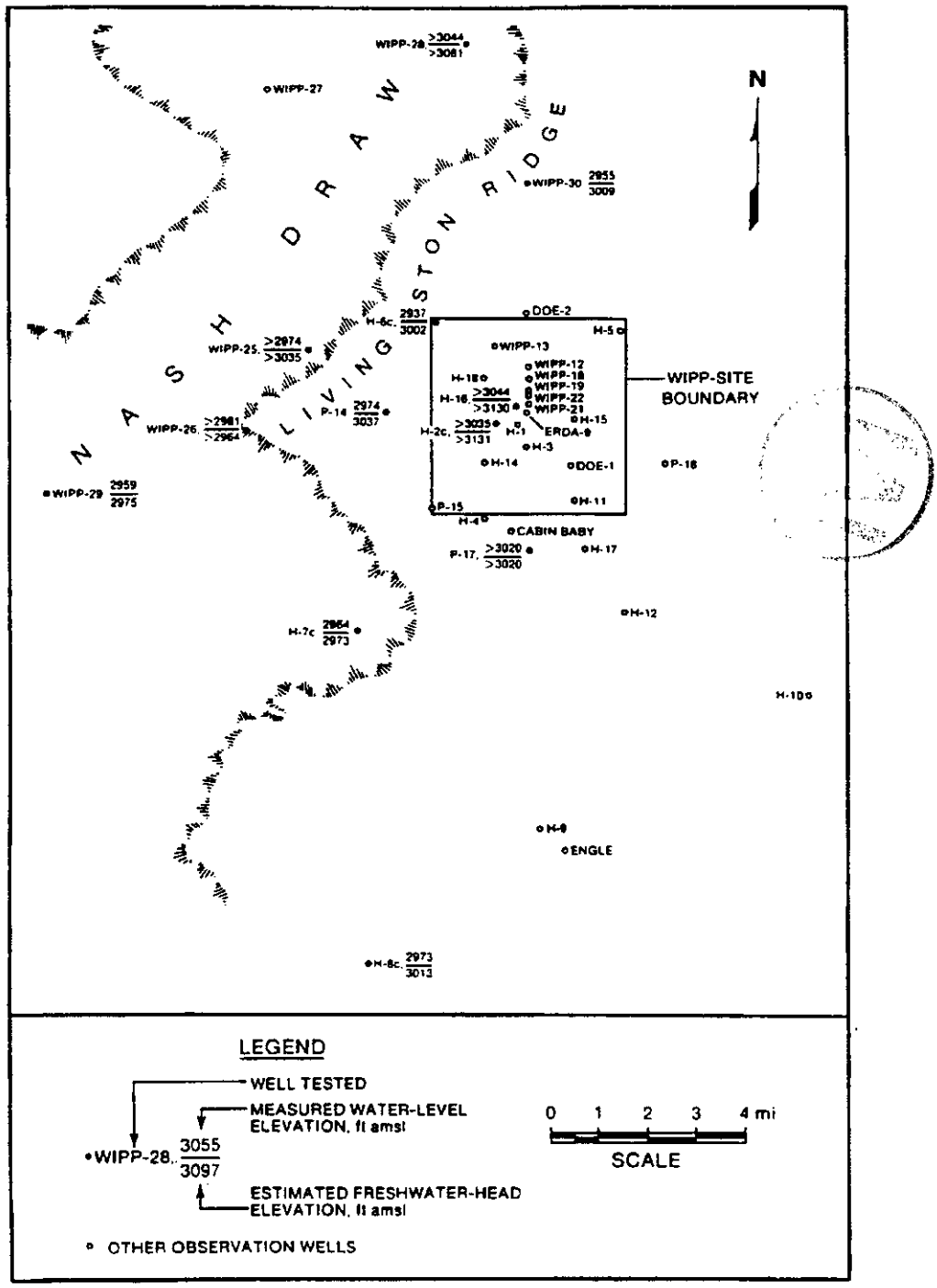

Figure 14. Measured water level and estimated freshwater head elevation of the unnamed lower member of the Rustler and/or residuum along the Rustler/Salado contact (from Holt and others, in prep.).

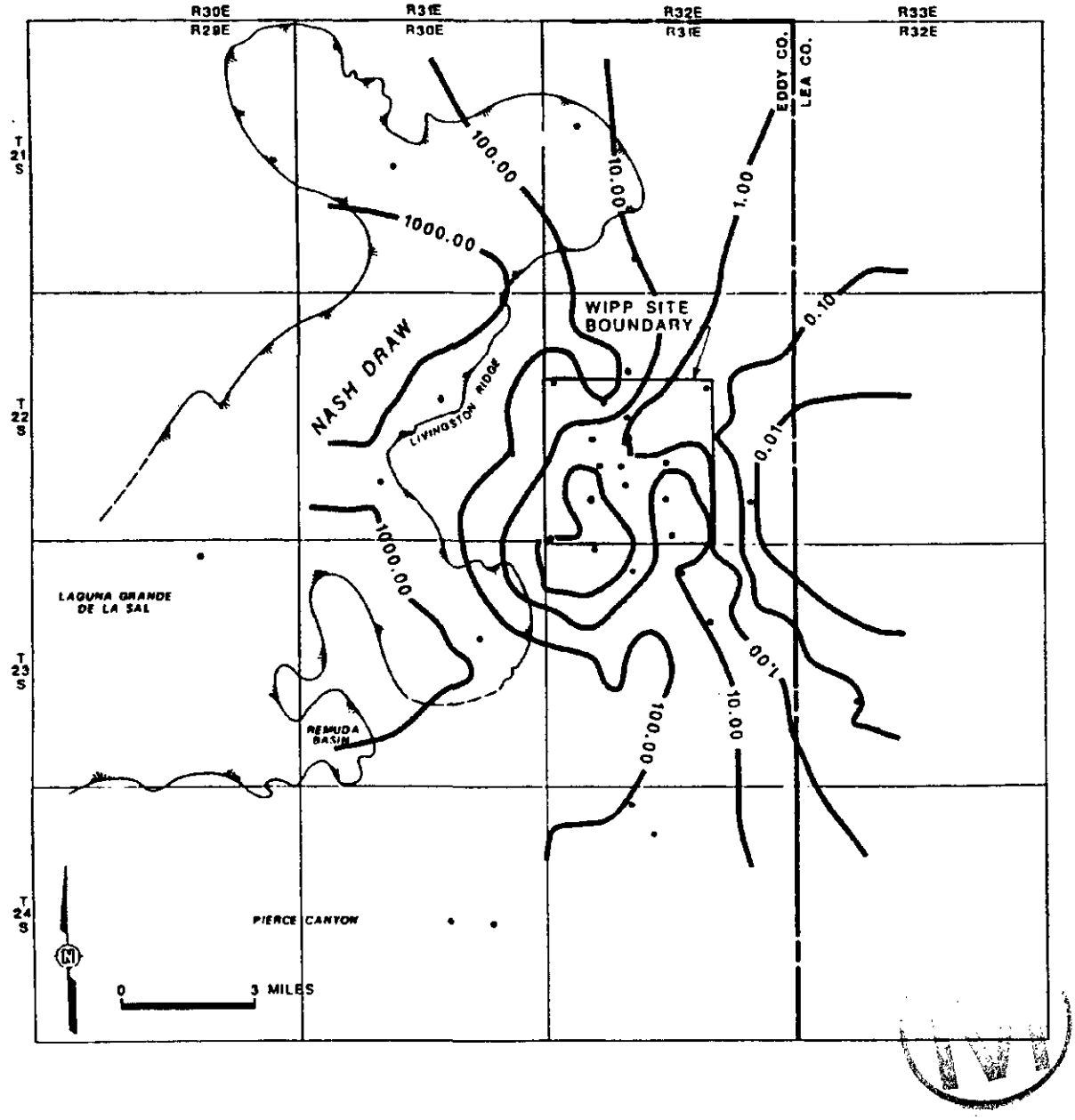

Figure 17. Calculated transmissivities for the Culebra Dolomite Member (ft^2/day) (from LaVenue and others, 1988).

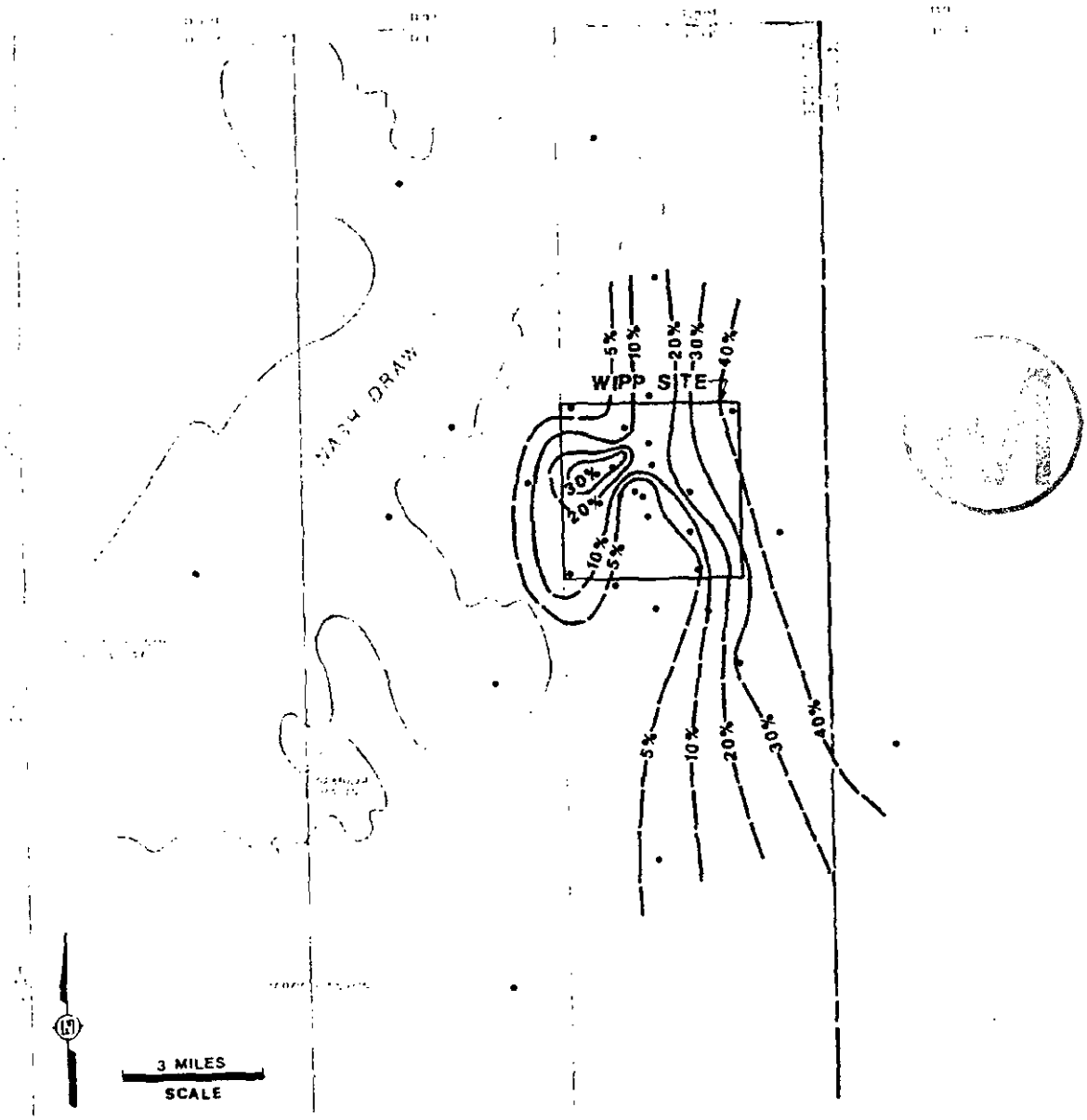

EXPLANATION

• WELLS EXAMINED CONTOUR INTERVAL 10% 5% LINE SHOWN FOR CLARITY

Figure 21. Percentage of natural fractures in the Culebra Dolomite Member filled with gypsum (from Holt and others, in prep.).

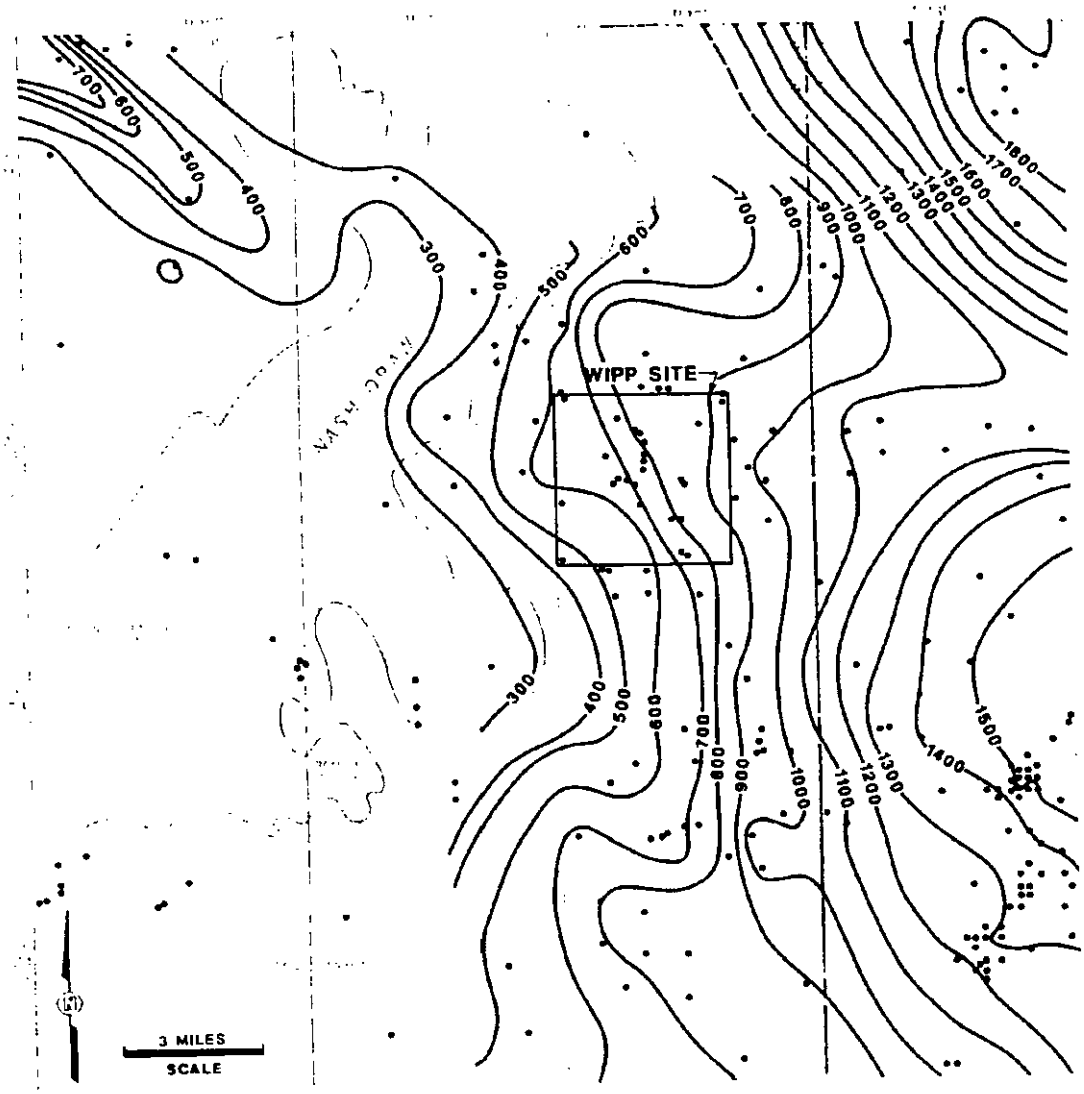

Figure 22. Isopach of overburden for the Culebra Dolomite Member (from Holt and others, in prep.).

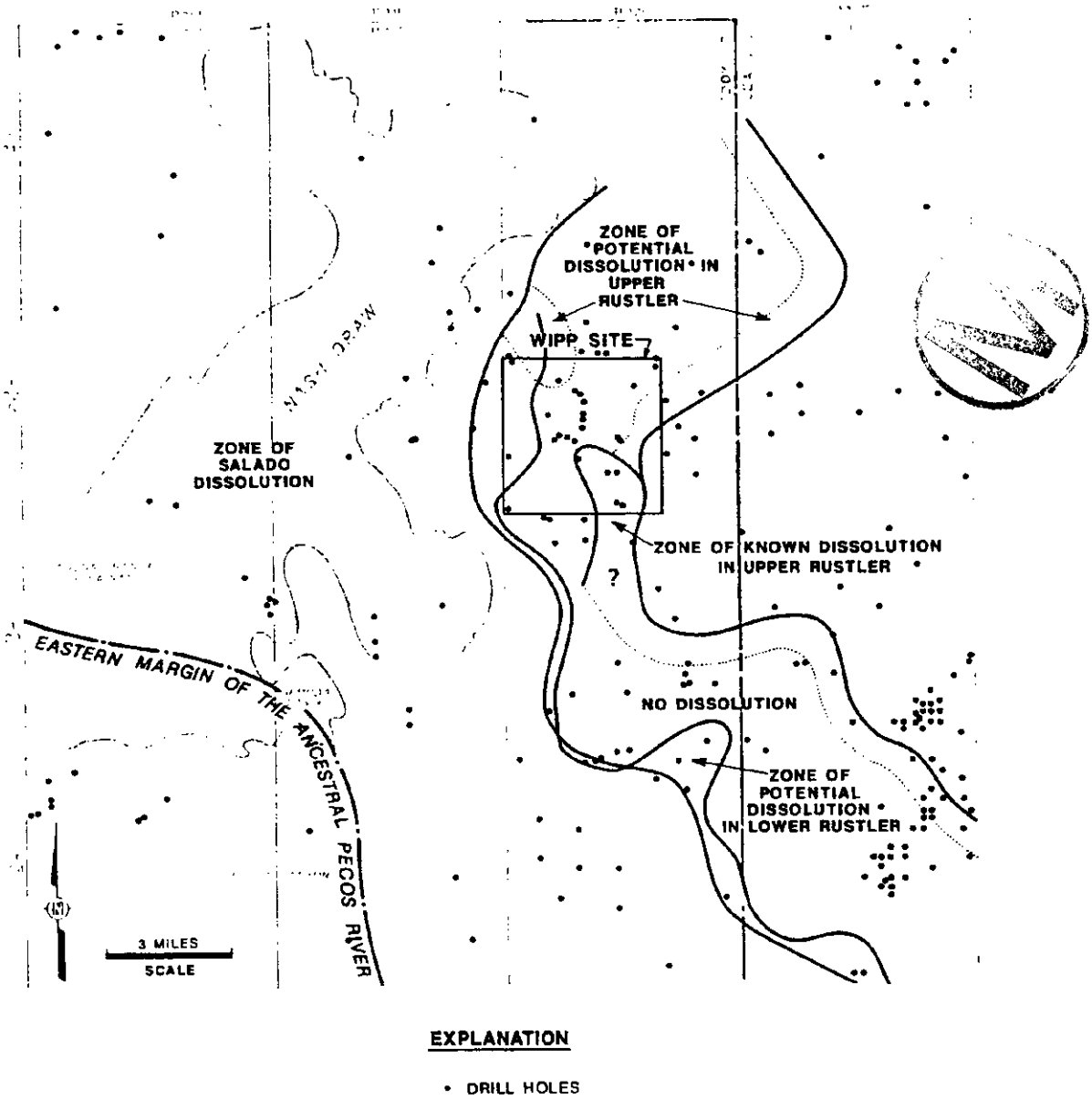

Figure 23. Distribution of Rustler and Salado dissolution near the WIPP site (from Holt and others, in prep.).

Beauheim, R.L., Roberts, R.M., Dale, T.F., Fort, M.D., and Stensrud, W.A. 1993. Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report. SAND92-0533. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" Pressure-pulse, constant-pressure flow, and pressure-buildup tests have been performed in bedded evaporites of the Salado Formation at the Waste Isolation Pilot Plant (WIPP) site to evaluate the hydraulic properties controlling brine flow through the Salado. Transmissivities ranging from about 7 x 10^{-15} to 5 x 10^{-13} m^2/s have been interpreted from six sequences of tests conducted on five stratigraphic intervals within 15 m of the WIPP underground excavations. The corresponding vertically averaged hydraulic conductivities of the intervals range from about 1.1 x 10^{-14} to 2 x 10^{-12} m/s (permeabilities of 2 x 10^{-21} to 3 x 10^{-19} m^2). Storativities of the tested intervals range from about 1 x 10^{-8} to 2 x 10^{-6}, and values of specific storage range from 9 x 10^{-8} to 1 x 10^{-5} m^{-1}. Pore pressures in eight stratigraphic intervals range from about 2.5 to 12.5 MPa, and appear to be affected by stress relief around the excavations. Anhydrite interbeds appear to be one or more orders of magnitude more permeable than the surrounding halite, primarily because of subhorizontal bedding-plane fractures present in the anhydrites. Interpretations of the tests revealed no apparent hydrologic boundaries within the radii of influence of the tests, which were calculated to range from about 2 to 20 m from the test holes. An assumption of Darcy flow through the evaporites is thought to be a reasonable interpretive approach because Darcy-flow models are able to replicate the flow and pressure behavior observed during entire testing sequences involving different types of tests performed with different hydraulic gradients."

Section 8.1, p 139, col 1, para 2;

" The primary objectives of the hydraulic tests were to estimate the transmissivities, storativities, and formation pore pressures of different stratigraphic intervals in the Salado formation around the WIPP facility. Pressure-pulse, constant-pressure withdrawal, and/or pressure-buildup tests of five stratigraphic units were successfully conducted in six intervals. Interpreted transmissivities range from 3.8 x 10^{-14} to 5.3 x 10^{-13} m^2/s for anhydrite intervals, with vertically averaged hydraulic conductivities ranging from 3.8 x 10^{-13} to 2.2 x 10^{-12} m/s(permeabilities of 5.1 x 10^{-20} to 2.9 x 10^{-19} m^2). The transmissivity of a halite interval tested was about 7.4 x 10^{-15} m^2/s, with an average hydraulic conductivity of either 1.4 x 10^{-14} or 7.2 x 10^{-15} m/s(permeability of 1.8 x 10^{-21} or 9.6 x 10^{-22} m^2), depending on whether flow was horizontal or radial toward the slanted test interval. The transmissivity of another halite interval in the SCP01-A guard zone was apparently too low to measure over a six-month period. . . ."

Section 8.1 Results of Testing, p 139, col 2, para 3;

" The formation pore pressures of the anhydrite intervals tested range from zero (or atmospheric) in anhydrites 'a' and 'b' directly above Room 7 of Waste Panel 1 to 12.55 MPa

in Marker Bed 139 beyond the westernmost extreme of the Core-storage library. Pore pressures in halite intervals range from about 2.55 MPa to greater than 4.2 MPa. Pore pressures in halite may be decreased more by stress relief around the excavations than those in anhydrite because of the different mechanical and rheological responses of the two rock types."

Section 8.3 Conclusions, p 142, col 1, para 3;
" Pressure-pulse, constant-pressure flow, and pressure-buildup tests have been performed in bedded evaporites of the Salado Formation at the WIPP site to evaluate the hydraulic properties controlling brine flow through the Salado. Transmissivities ranging from about 7 x 10^{-15} to 5 x 10^{-13} m^2/s have been interpreted from six sequences of tests conducted on five stratigraphic intervals within 15 m of the WIPP underground excavations. The corresponding vertically averaged hydraulic conductivities of the intervals range from about 1 x 10^{-14} to 2 x 10^{-12} m/s (permeabilities of 2 x 10^{-21} to 3 x 10^{-19} m^2). Storativities of the tested intervals range from about 1 x 10^{-18} to 2 x 10^{-6}, and values of specific storage range from 9 x 10^{-8} to 1 x 10^{-5} m^{-1}. Pore pressures in eight stratigraphic intervals range from about 2.5 to 12.5 MPa, and appear to be affected by stress relief around the excavations. Anhydrite interbeds appear to be one or more orders of magnitude more permeable than the surrounding halite, primarily because of subhorizontal bedding-plane fractures present in the anhydrites. Interpretations of the tests revealed no apparent boundaries within the radii of influence of the tests, which were calculated to range from about 2 to 20 m from the test holes. An assumption of darcy flow through the evaporites is thought to be a reasonable interpretive approach because Darcy-flow models are able to replicate the flow and pressure behavior observed during entire testing sequences involving different types of tests performed with different hydraulic gradients."

Beauheim, R.L., Saulnier, Jr., G.J., and Avis, J.D. 1991. Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report. SAND90-0083. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" Pressure-pulse tests have been performed in bedded evaporites of the Salado Formation at the Waste Isolation Pilot Plant (WIPP) site to evaluate the hydraulic properties controlling brine flow through the Salado. Hydraulic conductivities ranging from about 10^{-14} to 10^{-11} m/s (permeabilities of about 10^{-21} to 10^{-18} m^2) have been interpreted from nine tests conducted on five stratigraphic intervals within eleven meters of the WIPP underground excavations. Tests of a pure halite layer showed no measurable permeability. Pore pressures in the stratigraphic intervals range from about 0.5 to 9.3 MPa. An anhydrite interbed (Marker Bed 139) appears to be one or more orders of magnitude more permeable than the surrounding halite. Hydraulic conductivities appear to increase, and pore pressures decrease, with increasing proximity to the excavations. These effects are particularly evident within two or three meters of the excavations. Two tests indicated the presence of apparent zero-flow boundaries about two to three meters from the boreholes. The other tests revealed no apparent boundaries within the radii of influence of the tests, which were calculated to range from about four to thirty-five meters from the test holes. The data are sufficient to determine if brine flow through evaporites results from Darcy-like flow driven by pressure gradients within naturally interconnected porosity or from shear deformation around excavations connecting previously isolated pores, thereby providing pathways for fluids at or near lithostatic pressure to be driven towards the low-pressure excavations. Future testing will be performed at greater distances from the excavations to evaluate hydraulic properties and processes beyond the range of excavation effects.

Section 7.1.5.1 Test Zone, p 70, col 2;

" As shown on Figure 7-26, the fluid pressure in the C2H03 test zone did not increase during the 30-day shut-in period, but instead decreased by about 0.01 MPa. Testing of multipacker test tool #5 before and after C2H03 testing revealed no problems that could have caused the tool to fail to hold pressure during the testing. Therefore, the observed behavior is thought to be representative of the formation response to the testing conditions.

For the shut-in pressure to decrease, a combination of events would have to occur. First, the test-zone volume would have to increase slightly. This could occur in response to packer readjustment or hole elongation. Second, little or no inflow from the formation would also be required, implying very low formation permeability. Two possible conditions could explain a lack of inflow to the borehole. First, the relatively pure halite of map unit 9 may not have continuous interconnected porosity that would lead to permeability. Second, map unit 9 may have continuous interconnected permeability, but the permeability may be so low that no observable pressure response could occur on the time scale of the monitoring period. The first possibility cannot be evaluated with the available data; a much longer monitoring period and perhaps a different type of testing would be required to establish the

complete absence of permeability. The second possibility can be evaluated, at least qualitatively, by considering the pressure responses that would be expected to occur given a range of permeability (hydraulic conductivity) values. . . ."

p 73, col 2, line 2;

" Presumably, if the permeability of map unit 9 is so low as to preclude any observable pressure response during the C2H03 testing, then that same low permeability should have prevented significant depressurization at the test-zone depth from the excavation of Room C2. Specific storage for the simulations was assumed to be 9.5 x $10^{-8}m^{-1}$. The simulations assume radial flow to the borehole, which in the case of the horizontal borehole C2H03, may be a questionable assumption. Given the lack of an observed pressure-buildup response, however, use of a more complex model designed specifically for tests in horizontal holes appears unwarranted at this time.

Figure 7-27 shows the results of these simulations. At a hydraulic conductivity $\leq 10^{-14}$m/s, less than 0.01 MPa pressure buildup would have occurred during the monitoring period. At a hydraulic conductivity of 10^{-13} m/s, a few hundredths of an MPa pressure increase would have been observed, while at a hydraulic conductivity of 10^{-12}m/s, the pressure would have increased by a few tenths of an MPa. If the test-zone compressibility was less than the value assumed for these simulations, then the simulations shown in Figure 7-27 would be representative of proportionally lower hydraulic conductivities. Considering that no pressure buildup at all was observed, we might conclude that the hydraulic conductivity of the relatively pure halite around C2H03 is less than 10^{-14}m/s. This may be a conservatively high upper bound on the hydraulic conductivity around C2H03, considering the responses observed during testing of the C2H01-B guard zone, which had an interpreted hydraulic conductivity of 1.4 x 10^{-14}m/s (Figure 7-14).

Finley (personal communication) has attempted to measure brine inflow to 10-cm-diameter holes drilled horizontally into map unit 9 from Room D (see Figure 5-1). Over a monitoring period of more than three years, no observable brine inflow to the holes has been detected, providing further indication of small or non-existent permeability in the pure halite of map unit 9.

The simulations discussed above are highly speculative and are only presented in an attempt to give an upper bound on the hydraulic conductivity of relatively pure halite, based on an underlying assumption that map unit 9 has some permeability and pore pressure. When similar hydraulic behavior is encountered in future test holes, additional testing will be performed to try to address questions about the presence or absence of pore pressure and permeability more directly."

All of the testing discussed in this report was performed in intervals where stress redistribution must have occurred as a result of excavation of the WIPP facility. Furthermore, all test intervals except for those of C2H01-C, C2H02, and C2H03 extended no farther than 5.6 m from a room or drift, and were within about two room radii of the openings. Thus, the interpreted hydraulic properties presented in this report may not be representative of undisturbed rock, but may reflect permeability and porosity enhancement

and depressurization within the DRZ around the WIPP facility. Possible effects of the DRZ on the observed test responses are discussed below."

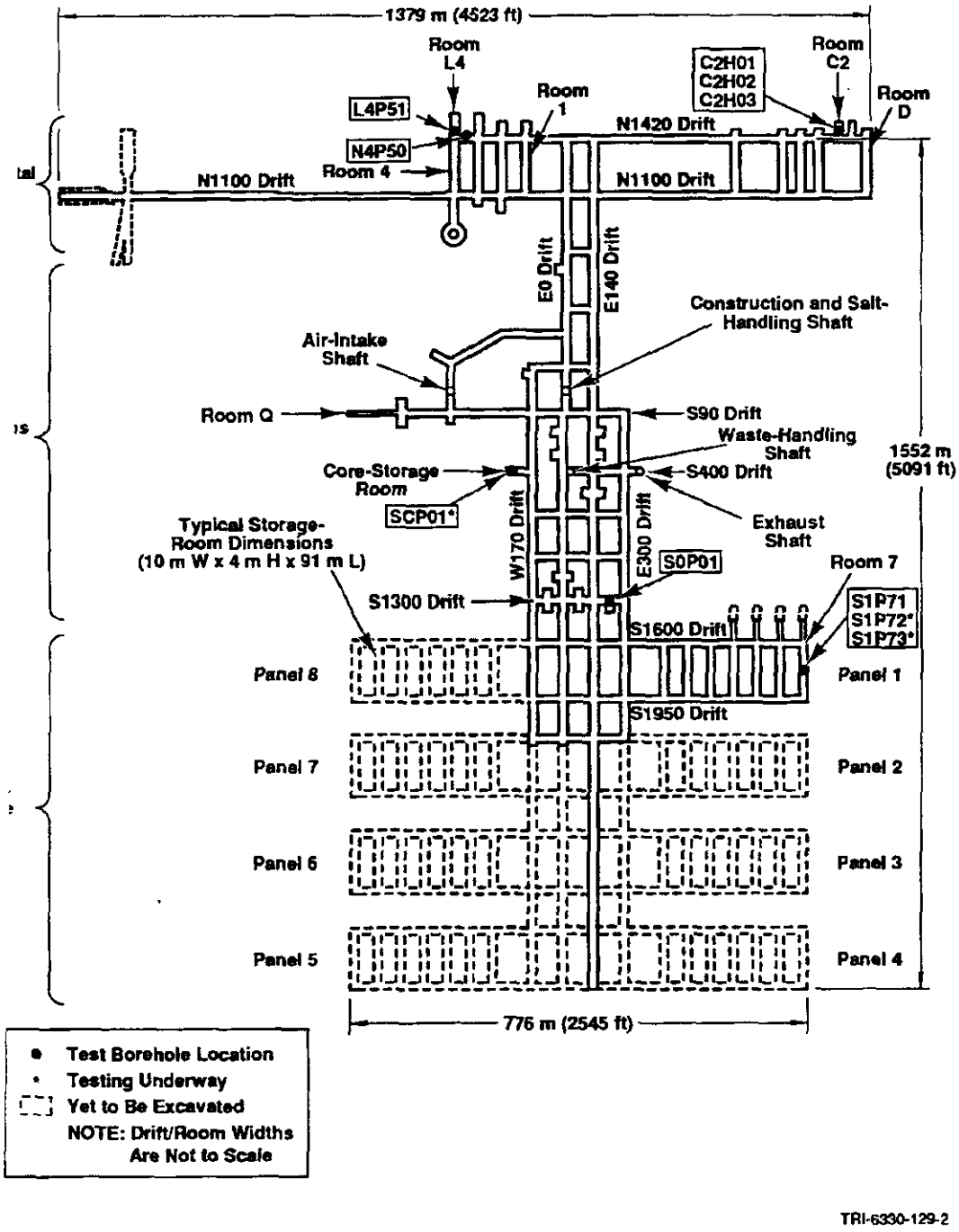

Figure 5-1. Map of the WIPP Underground Facility Showing Test Locations.

Section 8.3 Conclusions, p 131, col 2, para 1;

" The tests discussed in this report have demonstrated that the hydraulic properties of bedded evaporites can be determined from *in situ* hydrogeologic testing. Hydraulic conductivities of evaporites are low (10^{-14} to 10^{-11} m/s) when compared to those of most other water-bearing rock types, but they can be estimated using techniques and equipment specifically designed for low-permeability media. Questions remain, however, as to the nature and degree of interconnected porosity and permeability naturally present in halite. Hydraulic conductivities were found to increase, and formation pore pressures decrease, with increasing proximity to the underground excavations. Whether or not any of the tests can be considered to be unaffected by rock response to the excavations (deviatoric stress) is as yet unknown. This question can probably only be resolved by testing at greater distances from the excavations to establish the distance beyond which hydraulic properties remain relatively constant. A comparison of the hydraulic behaviors observed within and beyond the region influenced by deviatoric stress should provide insight into the mechanisms affecting brine flow through evaporites."

Beauheim, R.L., Meigs, L.C., Saulnier, G.J., and Stensrud, W.A. 1995. Culebra Transport Program Test Plan: Tracer Testing of the Culebra Dolomite Member of the Rustler Formation at the H-19 and H-11 Hydropads on the WIPP Site. On file in the Sandia WIPP Central Files.

1. SUMMARY, p. 1;

" The Culebra Dolomite Member of the Rustler Formation is considered to be the most likely pathway for radionuclide transport to the accessible environment in the event of a breach of the Waste Isolation Pilot Plant (WIPP) repository by inadvertent human intrusion. Evaluation of WIPP's compliance with 40 CFR 191 Subpart B by the WIPP Performance Assessment Computational Support Department of Sandia National Laboratories (SNL) relies in part on a model of radionuclide transport through the Culebra. Modeling of transport through the Culebra requires, first, a conceptual model of the mechanisms and processes governing that transport and, second, quantitative estimates of the parameters required for numerical simulation of those processes. The Culebra Transport Program represents the combined efforts of the SNL Geohydrology (6115) and WIPP Chemical and Disposal Room Processes (6748) Departments to provide the conceptual understanding and data necessary to construct a model for Culebra transport.

Field tracer tests are a major component of the Culebra Transport Program. Tracer tests provide data with which to evaluate different processes affecting transport and to estimate transport parameters. Interpretations of previous tracer tests conducted at the WIPP site (Jones et al, 1992) suggest that the Culebra behaves locally as a double-porosity medium in which advective flow occurs through fractures wile diffusion of solutes from the fractures to the surrounding rock matrix acts to retard solute transport. Using a double-porosity transport model based on these tracer-test interpretations, the WIPP PA Department (1993b) showed that physical retardation arising from matrix diffusion makes the Culebra an effective barrier to release of radionuclides to the accessible environment.

Independent reviewers of the interpretations of the previous tracer tests have questioned the assumption that matrix diffusion was the only mechanism causing physical retardation during those tracer tests, and suggested other processes, such as channelling caused by variations in fracture apertures (causing heterogeneity in permeability) and delayed tracer release from the injection wells, that might have contributed to the observed physical retardation. These other processes might be less effective at retarding transport on the regional scale than matrix diffusion. The data from the previous tests are inadequate to determine the relative contributions of different potential retardation mechanisms, primarily because too few flow paths were tested, only one tracer-injection technique was employed, tracers having different free-water diffusion coefficients were not used, and tests were not repeated at different pumping rates. The previous tests also did not: 1)examine the importance of vertical heterogeneity in the Culebra; 2) address scaling issues (changing transport parameters as a function of transport distance); and 3) provide sufficient data to determine whether variations in transport behavior along different flow paths were due solely to anisotropic permeability in the Culebra or were caused by heterogeneity.

The tracer tests of the Culebra described in the Test Plan are being designed to provide data with which to: 1) demonstrate the importance of matrix diffusion as a physical-retardation mechanism; 2) evaluate the relative importances of different processes causing physical retardation during transport; 3) investigate transport processes at different scales; 4) evaluate the effects of heterogeneity, anisotropy, and layering on transport; 5) quantify important transport parameters; and 6) as an end result, develop a model of transport in the Culebra that can be used by PA and defended with a high level of confidence. An added benefit of the tracer testing is that the long-term pumping associated with the tests will produce transient pressure responses that can be interpreted to define the distribution of transmissivity in the Culebra in the area within which transport is expected to occur in the event of a breach of the WIPP repository by inadvertent human intrusion.

New tracer tests are being planned at two locations, the H-19 and H-11 hydropads. The testing planned at the H-19 hydropad is much more extensive than that to be performed at the H-11 hydropad. The H-19 testing will include a single-well injection-withdrawal (SWIW) test over the lower portion of the Culebra and a convergent-flow multiwell tracer test involving multiple tracer injections, tracer injections over different intervals of the Culebra, tracer injections using different injection techniques, tracers with different tracer-breakthrough and recovery curves that can be used to quantify the amount of matrix diffusion occurring, determine how the different layers within the Culebra interact, and evaluate the effects of anisotropy and heterogeneity on transport on the hydropad scale.

Tracer testing at the H-11 hydropad is focused on a few key issues. This testing will consist of a single-well tracer test in H-11b1 and a two-well convergent-flow tracer test between H-11b3 and H-11b1. Both H-11 tests will be performed over the entire thickness of Culebra. The single-well test should provide additional evidence for the occurrence of matrix diffusion and, in combination with the H-19 single-well test, provide information on the heterogeneity of the Culebra. The two-well test at H-11 will serve to corroborate and quantify the effects of matrix diffusion interpreted from the 1988 tracer test at that location by providing a repeated test at a different pumping rate. Tracers with different free-water diffusion coefficients, if available, will also be used in this test to provide additional evidence for matrix diffusion. An improved tracer-injection tool, which will prevent tracer-laden water from sinking to the bottom of the hole and providing a potential long-term diffusional source of tracer in the wellbore, will help to resolve source-term questions associated with the earlier test.

This Test Plan describes the overall goals and objectives of the tracer test program and the methods that will be employed to achieve them. The plan describes the types of test to be performed, equipment configurations, testing requirements and procedures, data-acquisition systems, data-quality objectives, quality assurance requirements, regulatory requirements, and health and safety concerns."

Blackwell, D.D., Steele, J.L., and Carter, L.S. 1991. "Heat-Flow Patterns of the North American Continent; A Discussion of the Geothermal Map of North America." In Neotectonics of North America, D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 423-436. Geological Society of America, Boulder, CO.

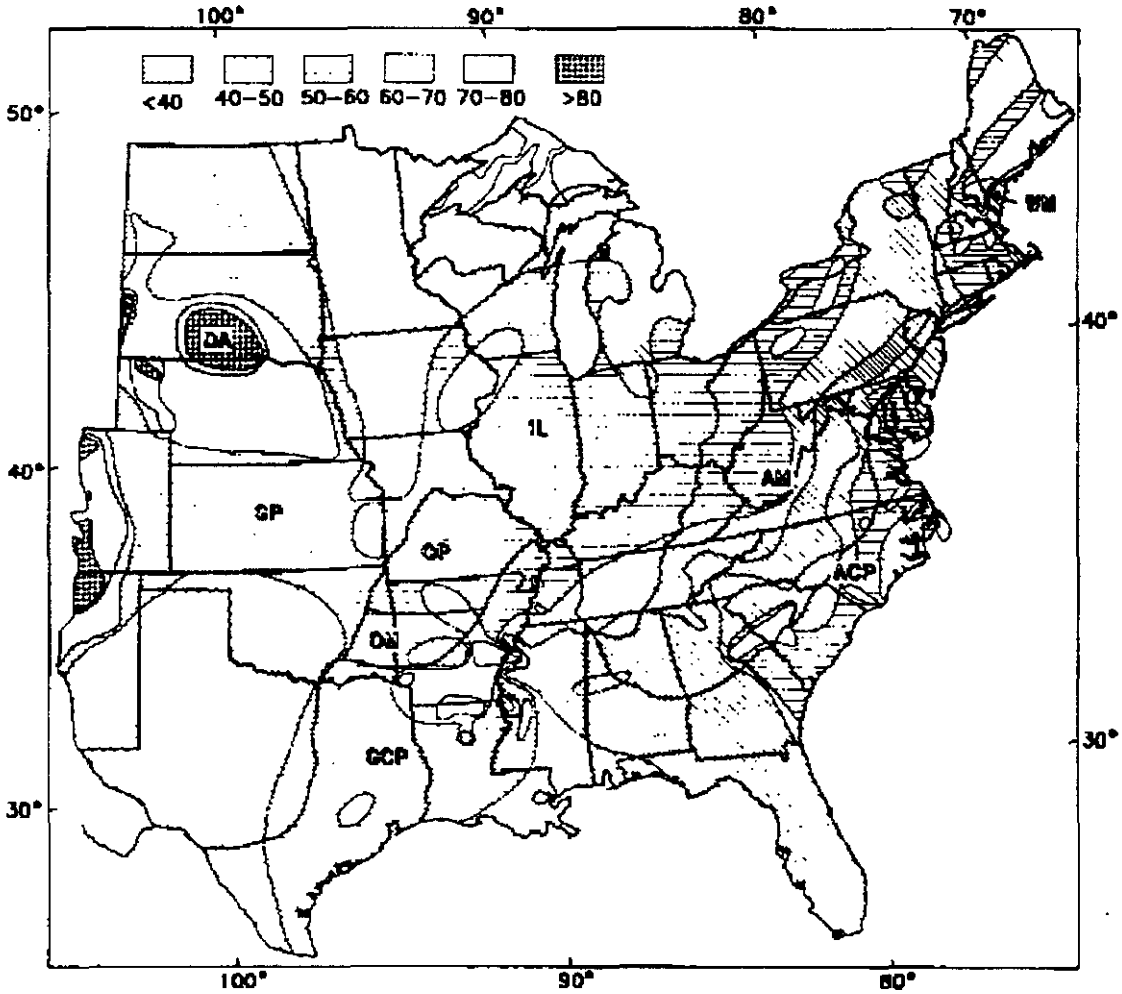

Figure 2. Heat-flow map for the eastern United States. The contours are from the DNAG *Geothermal Map of North America* and are shown at 10-mWm^{-2} intervals. Each band of heat flow is shown by a different pattern. Abbreviations are explained in the text.

Bodine, Jr., M.W. 1978. "Clay-Mineral Assemblages from Drill Core of Ochoan Evaporites, Eddy County, New Mexico." In Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas. G.S. Austin, ed., Circular 159, pp. 21-31. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p. 21;

" The ERDA-9 drill hole, Eddy County, New Mexico, was cored for 1,987 ft, from 230 ft below the top of the Salado Formation through the upper 41 ft of the Castile Formation. Clay minerals in 47 insoluble residues include corrensite, random to partially ordered clinochlore-saponite mixed-layer clays, illite, clinochlore, saponite, a tentatively identified talc-saponite mixed-layer clay, serpentine, and talc. Serpentine is restricted to the Castile and lowermost Salado Formations; (?)talc-saponite is confined to some polyhalite beds in and overlying the McNutt potash zone. The salztons (thin argillaceous seams) consist of corrensite, illite, and clinochlore, while the adjacent evaporite strata often contain abundant to random mixed-layer clinochlore-saponite, mixed-layer (?)talc-saponite, or saponite. Chemical compositions of the residues have high Mg-Al atom ratios reflecting abundance of the trioctahedral clays. Mineralogy and chemistry of the assemblages strongly indicate that severe alteration and Mg-enrichment of normal clay detritus occurred in the evaporite environment through brine-sediment interaction. It is further suggested that the relatively immature clays--saponite, mixed-layer (?)talc-saponite, and randomly interstratified clinochlore-saponite--formed later through recrystallization of preexisting trioctahedral clays in response to transient pore fluids; the salztons, impermeable to such fluids, developed a more mature clay assemblage in a static pore fluid environment. The serpentine-saponite residues with their high Mg-Al and Si-Al atom ratios in Castile and lowermost Salado evaporites are indicative of a silica-rich detrital source; the more aluminous clay assemblages with decreased Mg-Al and Si-Al atom ratios in the overlying evaporite strata suggest a substantially more argillaceous detrital source."

INTRODUCTION, p 1, col 1;

" Clay assemblages in core samples from the Salado Formation and the uppermost anhydrites of the Castile Formation from the ERDA-9 drill hole in Eddy County, New Mexico, are highly distinctive. They have unusually extreme Al-Ca-poor and Mg-rich compositions and consist of a variety of abundant trioctahedral clays with subordinate amounts of illite. Although far different from most sedimentary clay assemblages, they do show a marked similarity to clays in marine evaporite rocks from other localities. Their pronounced dissimilarity with clays in normal fluvial or marine sediments strongly suggests that detrital accumulations in the marine hypersaline environment must have been subjected to severe alteration and magnesium enrichment as a result of brine-sediment interaction. It is equally likely that alteration, through reaction with subsequent transient pore fluids, continued long after deposition and burial.

This project is one part of a recently initiated geochemical and mineralogical investigation of silicate assemblages in the Ochoan evaporites of southeastern New Mexico.

The project is not completed, and the conclusions presented in this report are tentative and susceptible to later modifications as additional data become available."

CHEMICO-MINEROLOGIC DISCONTINUITY IN LOWER SALADO FORMATION, p 28, col 2, para 4;

" An abrupt change in the minerology and chemical composition of the EDTA-leach residues occurs about 15 ft above the base of the Salado Formation at a drilling depth of 2,820 ft in the ERDA-9 hole. The contrasting minerologic and chemical features above and below this discontinuity are presented in table 4.

Above the discontinuity through the Cowden Anhydrite, the prevailing minerology in the residues of intercalated rock salts and anhydrites consists of either a dominant mixed-layer clinochlore-saponite variety or saponite alone, with lesser quantities of quartz, feldspar, illite, and clinochlore. Below the discontinuity through 15 ft of the lowermost Salado Formation and the uppermost 30 ft of the Castile Formation, the dominant minerology in the residues from anhydrites and rock salts is a saponite-serpentine association, with other silicates rarely present and never abundant.

The chemical data for the contrasting residues are compatible with their respective minerologies; the residues below the discontinuity show far greater aluminum and silica deficiency than those above (table 4)."

TABLE 4--Mineral Distribution and atom ratios in EDTA-leach residues from ERDA-9:A) the lower Salado Formation from 2,512.5-2,819.3 ft (Cowden Anhydrite to 16 ft above the base of the Salado Formation); B) the lowermost lower Salado and uppermost upper Castile Formation, from 2,820.2-2,876.5 ft (15 ft above the base of the Salado Formation to 25 ft below the top of the Castile Formation). "Random" cl-sap refers to randomly interstratified or slightly ordered clinochlore-saponite mixed-layer clay.

Mineral distribution			Atom ratios		
	A	B		A	B
Samples	11	7	Samples	6	4
Quartz	10	3			
Feldspar	8	1	Mg/Al	2.1	12.
Illite	10	1	Si/Al	4.3	9.9
Clinochlore	10	2	Si/Mg	2.1	0.8
Corrensite	5	--	(Na+K)/Al	0.5	1.3
"Random" cl-sap	3	1	K/NA	0.6	0.5
Saponite	3	4			
Talc	--	1			
Serpentine	--	5			

Borns, D.J. 1987. The Geologic Structures Observed in Drillhole DOE-2 and Their Possible Origins: Waste Isolation Pilot Plant. SAND86-1495. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. i;

" The Department of Energy is developing the Waste Isolation Pilot Plant (WIPP) for underground storage of transuranic waste produced by defense-related programs. The WIPP underground storage facility will be located approximately 650 m below the surface within a sequence of evaporites over 1000 m thick. This evaporite sequence is divided into three major units (in descending order): the 100-m-thick Rustler Formation; the 600-m-thick Salado Formation in which the underground facility is placed;the 300-m-thick Castile Formation. After 10 years of geological site-characterization, the major effort of this task is drawing to a close. Still, such questions remain as the origins of evaporite deformation within the Salado and Castile formations. Two miles north of the WIPP site, a stacked sequence of depressions,defined by marker beds in the Salado, was indicated by shallow boreholes. Such structures raise questions regarding the role of dissolution and gravity tectonics at the WIPP site. To investigate these structures, DOE decided to drill hole DOE-2 north of the WIPP site.

At DOE-2, the downward displacement of stratigraphic markers in the Salado confirmed the presence of stacked depressions, which were the primary target of the drilling program. The halitic units between the marker beds were thickened compared to the average section determined from basin-wide drilling. Halitic units in the lower Salado show evidence of recrystallization during deformation and parasitic fold structures. Such deformation structures and thickened halitic units are inconsistent with dissolution within the Salado as a cause of deformation in the basal units of the Salado. The remaining question is whether dissolution occurred in the underlying Castile and resulted in the deformation of the Salado. At drill hole DOE-2 and in nearby deep boreholes, complex structures in the Castile Formation are found. One hundred m or more of halite is expected in an average section of the Castile Formation; however, the only Castile halite section penetrated by DOE-2 is less than 3 m thick. In contrast, markers in the anhydrite units indicate recumbent structures and thickening of the anhydrite units by folding. As a consequence, the Castile Formation is nearly its average thickness, with the folded thickness of anhydrite compensating for the missing halite. The nearby thickening of halite within the Castile, the absence of relic anhydrite laminae in the attenuated halite units, and the high strain fabric of the remaining halite suggest that dissolution was not the dominant process in the Castile. The favored hypothesis for the Castile structures is salt flow in response to gravity inversion of the anhydrite and halite units of the Castile."

Borns, D.J., Barrows, L.J., Powers, D.W., and Snyder, R.P. 1983. Deformation of Evaporites Near the Waste Isolation Pilot Plant (WIPP) Site. SAND82-1069. Sandia National Laboratories, Albuquerque, NM. WPO 27532.

ABSTRACT, p3;

" The Delaware Basin is a broad asymmetric sedimentary trough in southeastern New Mexico and west Texas. Basin subsidence occurred from the Pennsylvanian into the Triassic. The basin also underwent tilting since the early Cenozoic.

Layered evaporite units of Ochoan age in the basin are 1000 m thick. These evaporites are divided into three stratigraphic units (listed in order of increasing age): the Rustler Formation, the Salado Formation, the Castile Formation. These units, especially the Castile, are deformed along portions of the margin of the Delaware Basin and in some areas internal to the basin. In the northern Delaware Basin adjacent to the WIPP site, the term 'Disturbed Zone' (DZ) has been applied to an area in which deformation structures are found in boreholes and from which chaotic seismic reflection data were obtained. The origin and timing of this deformation is considered important for the determination of failure scenarios for the WIPP site. However, the deformation does not present a major hazard to the construction and operational stages of the facility.

Geophysical studies (borehole logging, seismic reflection, and detailed gravity) have covered the DZ areas. Logs show vertical relief in the order of tens to hundreds of meters. Seismic profiles suggest a blocky structure with abrupt offsets and changes in dip between units. This chaotic structure occurs within the Castile Formation, but with little or no deformation exhibited by the overlaying and underlying strata. Changes in seismic character, such as wiggle shapes, imply that unit thicknesses and/or acoustic properties vary. On the periphery of the DZ, seismic profiles indicate salt flowage flexures. Outside the DZ, the seismic time structures appear to be generated by lateral velocity variations. The gravity field is dominated by anomalies originating in lateral density variations within relatively flat-lying strata. Low amplitude, long-wavelength effects of DZ structures cannot be resolved.

Through detailed core description, both meso- and microscopic, fold-styles in the DZ units are separable into distinct stages and sequences of generation. An older sedimentary stage of folding is distinguished from later tectonic folding by microfabric development and opposite senses of asymmetry. The tectonic folding and deformation displays a progressive development of fabrics ending in late-stage fracturing of competent anhydrite units. Petrofabrics reveal synkinematic growth of rotated anhydrite porphyroblasts and stress shadow growth. Microboudinage is also common. Of the possible deformation mechanism for anhydrite and halite, pressure solution appears the most applicable to the DZ. Therefore, an intergranular fluid plays an important role in facilitating deformation under the pressure, temperature, and stress histories of the region.

The following hypotheses of origin of deformation have been considered:

Gravity Foundering

Gravity Sliding

Gypsum Dehydration

Dissolution

Depositional Variations (e.g., thickness)

Of these, gravity foundering and sliding are considered the most probable causes of deformation. However, no hypothesis adequately answers why the deformation has a limited areal distribution. A possible explanation would be areal variations in rock strength caused by variations of intergranular water content. Age and timing of deformation are also crucial. Standard stratigraphic arguments based on superposition may not apply to such a highly incompetent material as halite. Gravity foundering could have happened at any time since deposition including the present; gravity sliding would probably have occurred since basin tilting began in the Cenozoic.

Deformation could be ongoing. However, the strain rates are such ($\approx 10^{-16} s^{-1}$) that deformation would progress slowly relative to the facility's time frame of 2.5×10^5 yr. Deformation of Salado units would be minimal (<10m) or nonexistent, but within this time frame, upper anhydrite units of the Castile could fracture and provide the volume for a brine reservoir. Such volumes would be small ($<1\%$) and would require $\approx 10^4$ to 10^6 yr to develop. At these strain rates, fractures that connect the fractured anhydrites of the Castile with the middle Salado could not develop. Deformation should not directly jeopardize the facility over the next 2.5×10^5 yr."

p. 79, Col. 2, Para. 2;

" The lateral extent of the DZ is best established from figures 3-6, 3-7, 3-10, and 3-11. These maps show an "area of complex structure" within which the Castile Formation's geologic structures are too complex to map with the seismic technique. This area includes boreholes WIPP 13, WIPP 11, ERDA 6, AEC 7, and is open to the northeast. Bordering this is an area where the Castile Formation horizons show salt flow structures and some faulting. Boreholes AEC 8. WIPP 12, and SCL Fed. No. 1 are in this peripheral region. The outer edge of the mapped flow structures is here taken as the limit of the DZ. This definition is necessarily ambiguous. It includes the anticline at WIPP 12, and may or may not include the anticline in Sec. 19.

The seismically indicated DZ affects primarily the Castile Formation horizons. The underlying Cherry Canyon and Bone Spring horizons have reduced data quality, but are continuous enough to map. As noted below, the irregular seismic time structure on these horizons may be caused by velocity variations within the evaporites. Borehole control supports the interpretation that the DZ structures either do not extend into the Delaware Mountain Group or are very much reduced in amplitude."

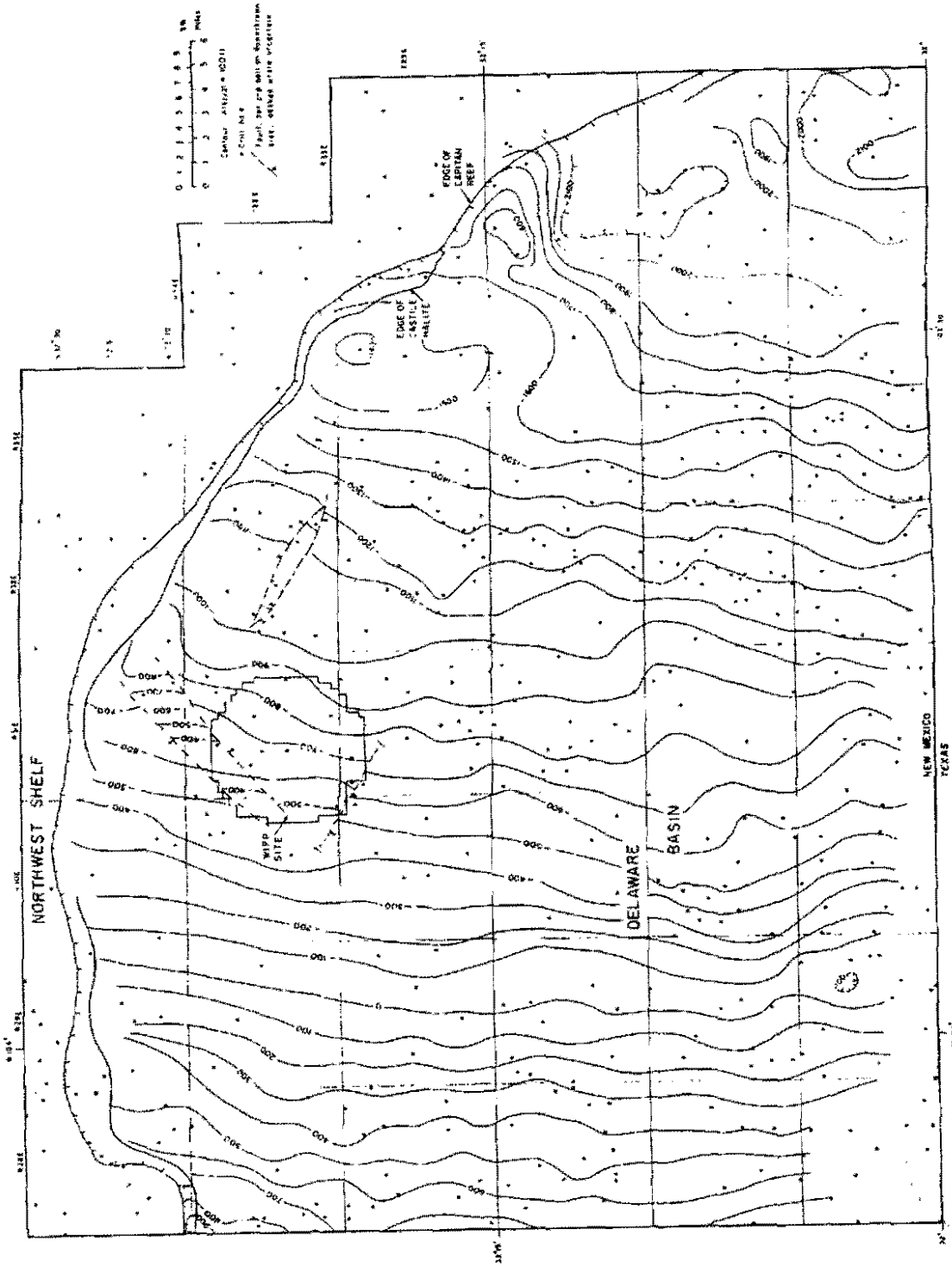

Figure 2-3. Structure Contour Map, Top of Bell Canyon Formation, Northern Part of Delaware Basin

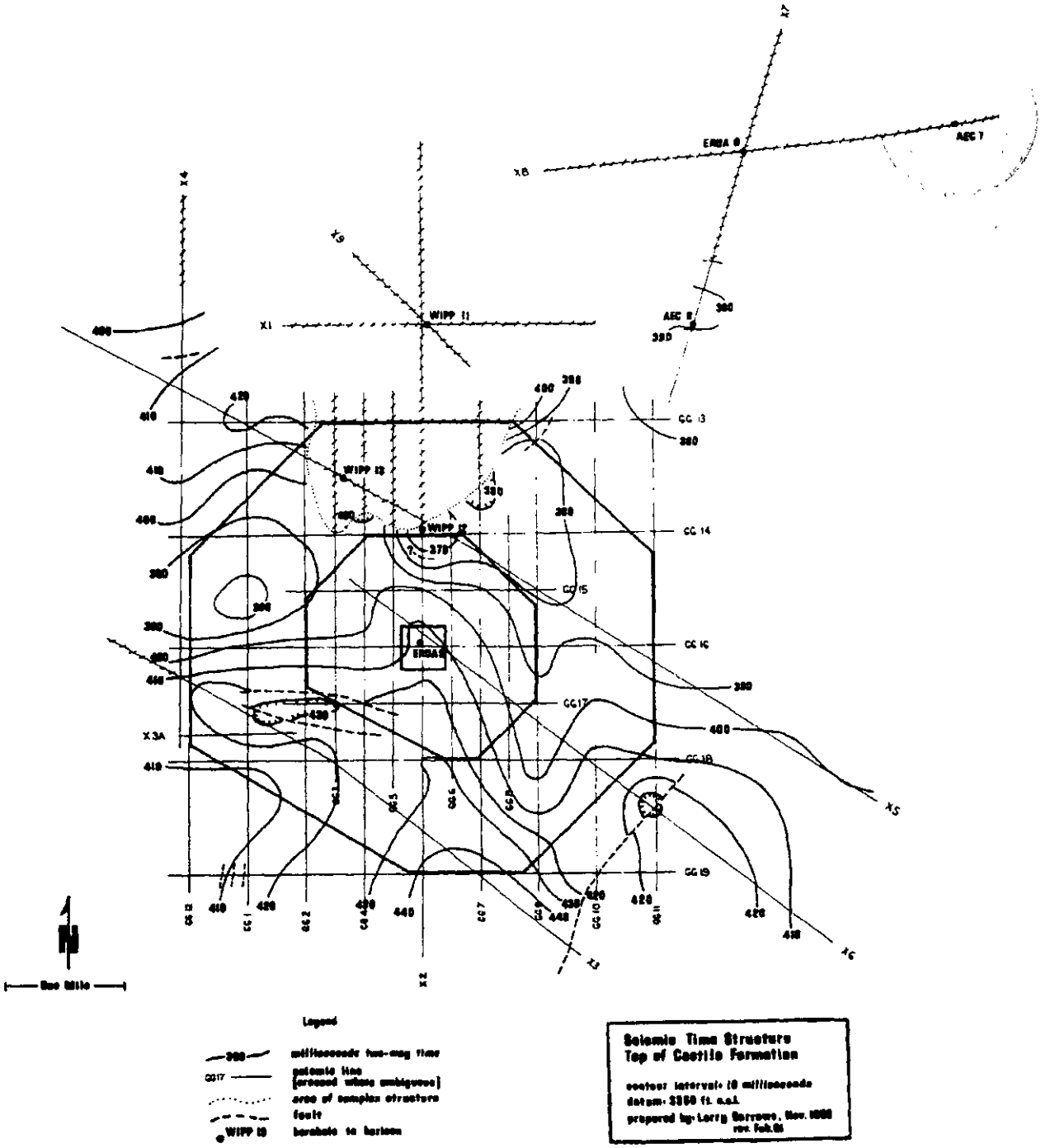

Figure 3-6. Seismic Time Structure – Top of Castile Formation

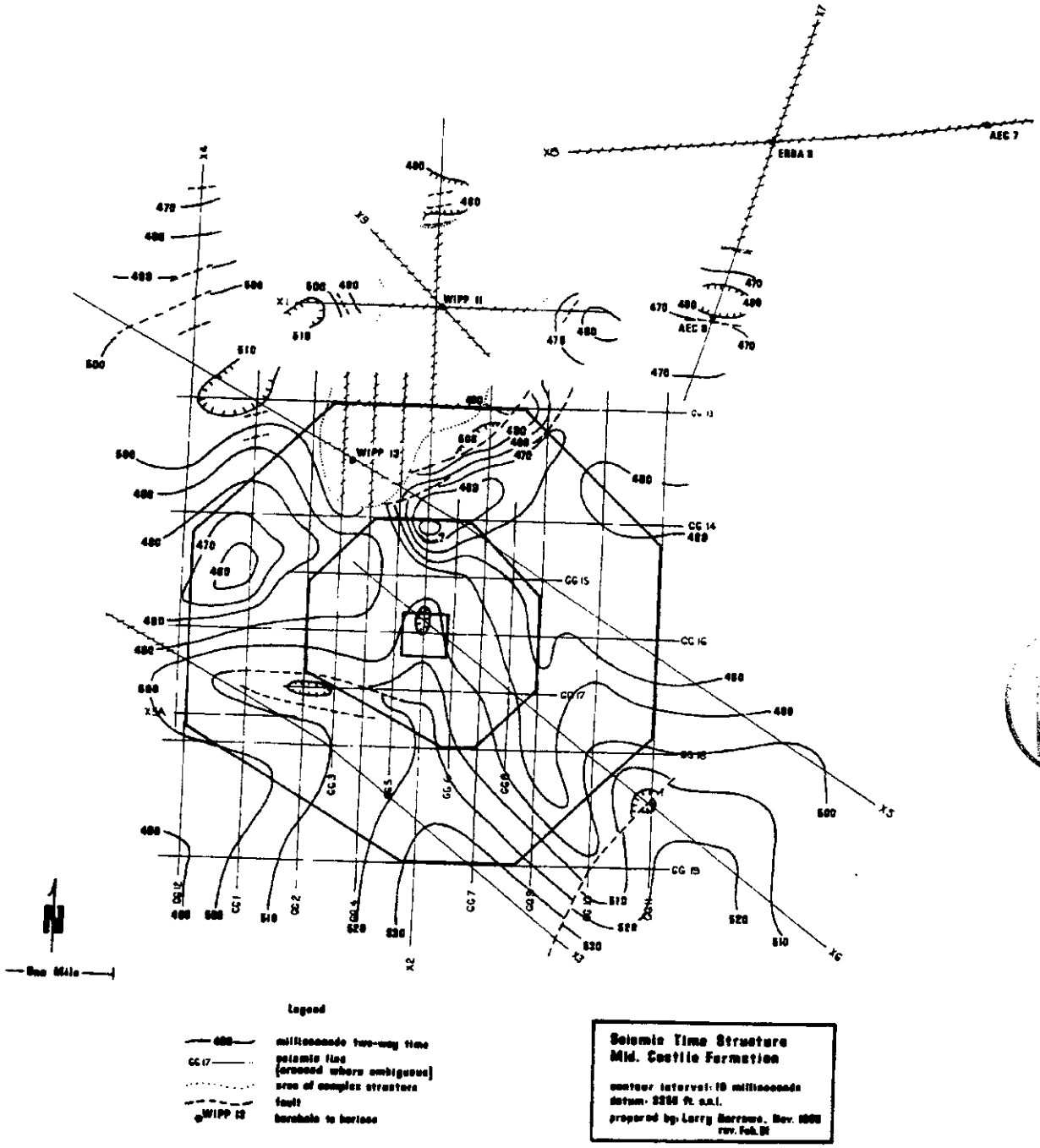

Figure 3-7. Seismic Time Structure – Mid-Castile Formation

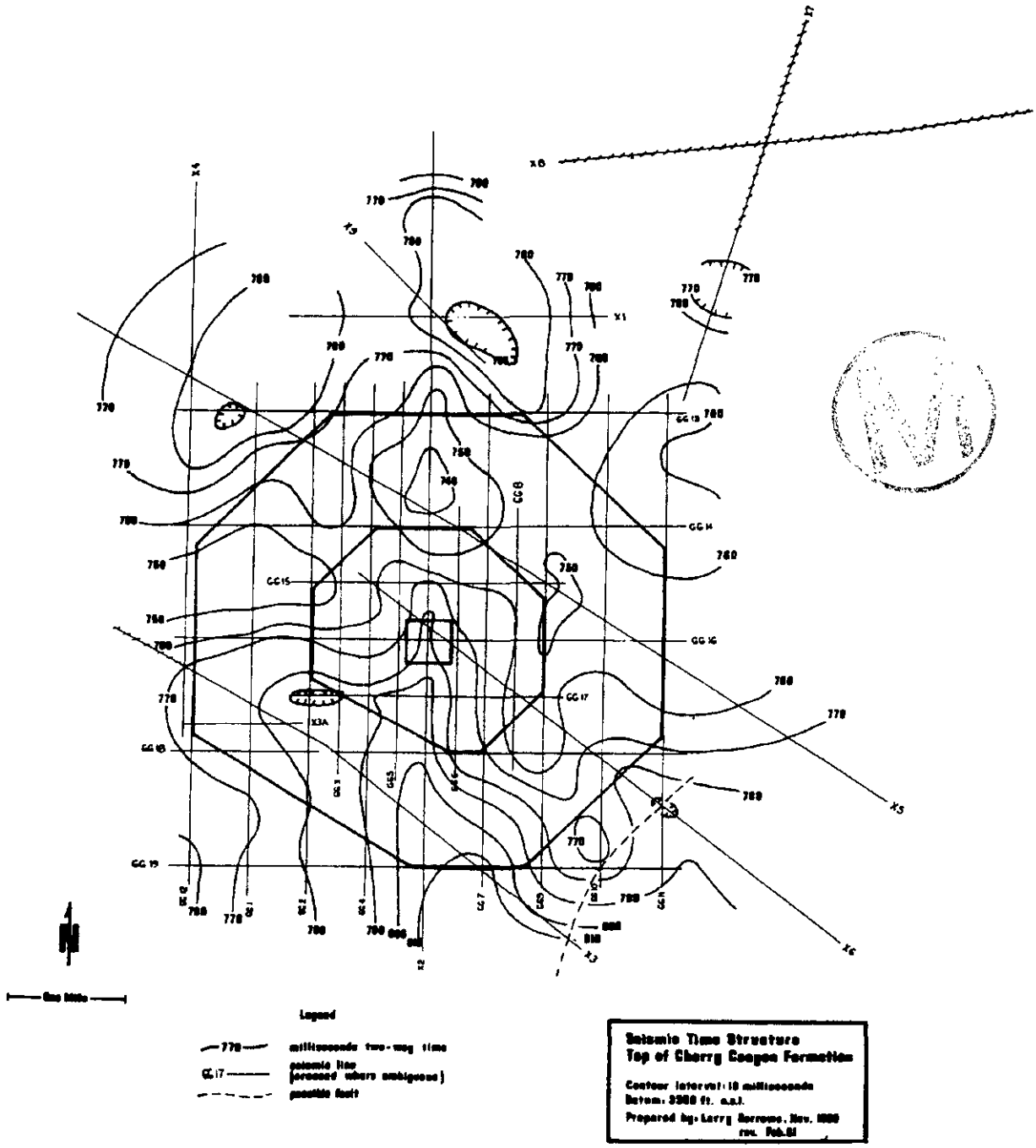

Figure 3-8. Seismic Time Structure – Top of Cherry Canyon Formation

Borns, D.J., 1985. Marker Bed 139: A study of Drillcore from a Systematic Array. SAND85-0023. Sandia National Laboratories, Albuquerque, NM. WPO 24529.

ABSTRACT, p 3;

" In southeastern New Mexico, Marker Bed 139 (referred to in this report as MB139) is one of 45 numbered siliceous or sulfatic units within the Salado Formation of the northern Delaware Basin. MB139 is divided into five zones. Zones I and V are the upper and lower contact zones, respectively. Zone II is a syndepositionally deformed subunit of polyhalitic anhydrite. Zone III is mixed anhydrite and polyhalitic anhydrite, a distinctive pale-green and pink, with subhorizontal fractures. Zone IV consists of interlayered halite and anhydrite without the overprint of polyhalite.

This sequence was transitional between submarine and subaerial. The anhydritic units of MB139 formed in salt-pan or mudflat environments or both. Undulations observed along the upper contact of MB139 are interpreted to result from traction deposits or from reworking of the upper portion of the marker bed during the transition from anhydrite to halite deposition. Zones II and III exhibit soft-sediment deformation and later traces of dewatering; e.g., formation of stylolites. Such deformation is not observed in the halite above MB139 or in Zone V and the halite units below MB139.

A distinctive set of subhorizontal fractures occurs in MB139 in mid-Zone III and, to some extent, in Zone IV. These fractures are partially infilled with halite and polyhalite. Brine occurrences at the mined facility horizon at the Waste Isolation Pilot Plant may be related to these fractures. The fractures formed either in response to stress cycles that were functions of sedimentation and erosion, or in response to deformation in the underlying Castile Formation. The subhorizontal orientation, dominant in the sampling to date, is more consistent with the interplay between stress and sedimentation cycles."

Statement of the Problem, p. 7, col. 2;

" During early development of the underground Waste Isolation Pilot Plant (WIPP) facility, Jarolimek et al (1983) reported that MB139 exhibited and undulatory upper surface in several shafts and vertical boreholes. These undulations were reported to have vertical amplitudes of ~20 in. and wavelengths of 2 to 6 ft.*

The Environmental Evaluation Group (EEG) of the State of New Mexico expressed concern that, since MB139 was a short distance below the facility level (<3 m), these undulations may be evidence of some deformational event that affected the repository level at a stage later than deposition or diagenesis. Jarolimek et al (1983), however, argued that the undulations of the upper surface of MB139 were formed during deposition."

p. 7, col. 2, para. 6;

" As an expression of the work described above, the objective of this report was to assess our understanding of MB139 and to record a systematic drilling program to study MB139."

p. 14, col. 1;
" The **Upper Contact Zone I** displays complex structure and mineralogy. The zone includes a distinctive claystone up to several centimeters thick in which are observed the major undulation structures of interest within MB139. The claystone occurs primarily along the undulatory upper contact of Zone I, with the polyhalitic halite above. The undulations along the upper surface of MB139 are 10 to 50 cm in amplitude and 30 to 100 cm in wavelength. The lower portion of this zone is not as regular in form and content as in the upper portion."

p 18, col 1, para 4, line 15;
" The apparent contradiction between theory and field observation is partly a result of not considering the effects of intergranular fluids and of different mineral mixtures for the evaporite units. The significant observation about the fractures in Zone III is that they are predominantly subhorizontal (>90%) and are partially infilled. The partially infilled nature indicates that these fractures were not formed after excavation of the facility, although their current configuration may be modified by the excavation. The orientation suggests a consistent orientation of the stress field at the time of fracture formation. The textures suggest that fracturing occurred between deposition and excavation. Only a few processes could have produced these fractures:

- Stresses that developed in the Salado and were generated by deformation in the underlying Castile Formation, such as gentle buckling of the Salado over a Castile anticline

- Changes in the overburden pressure coupled to sedimentation and erosion cycles affecting the rock sequence above the marker bed

- Buildup of gas pressures within the unit as a result of decomposition of organic material, whether algal or bacterial"

Borns, D.J. and Shaffer, S.E. 1985. Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin. SAND83-1798. Sandia National Laboratories,Albuquerque, NM.

ABSTRACT, p 3;

" Although well logs provide the most complete record of stratigraphy and structure in the northern Delaware Basin, regional interpretations of these logs generate problems of ambiguous lithologic signatures and one-hole anomalies. Interpretation must therefore be based on log-to-log correlation rather than on inferrences from single logs. In this report, logs from 276 wells were used to make stratigraphic picks of Ochoan horizons (the Rustler, Salado, and Castile Formations) in the New Mexico portion of the Delaware Basin. Current log correlation suggests that: (1) the Castile is characterized by lateral thickening and thinning; (2) some Castile thinnings are of Permian age; (3) irregular topography in the Guadalupian Bell Canyon Formation may produce apparent structures in the overlying Ochoan units; and (4) extensive dissolution of the Salado is not apparent in the area of the Waste Isolation Pilot Plant (WIPP) site."

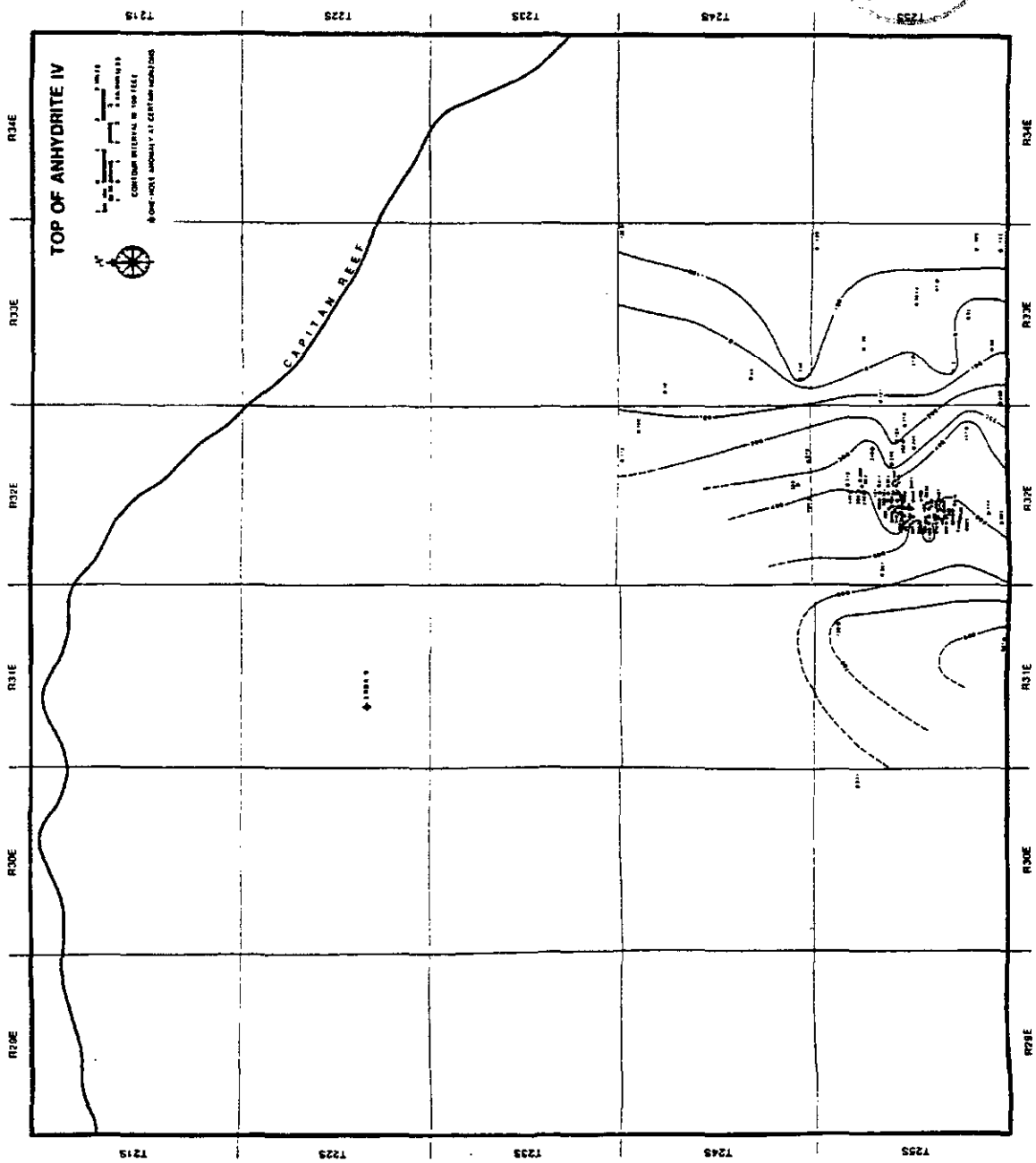

Figure 9. Top of Anhydrite IV Elevation Above MSL in feet

16

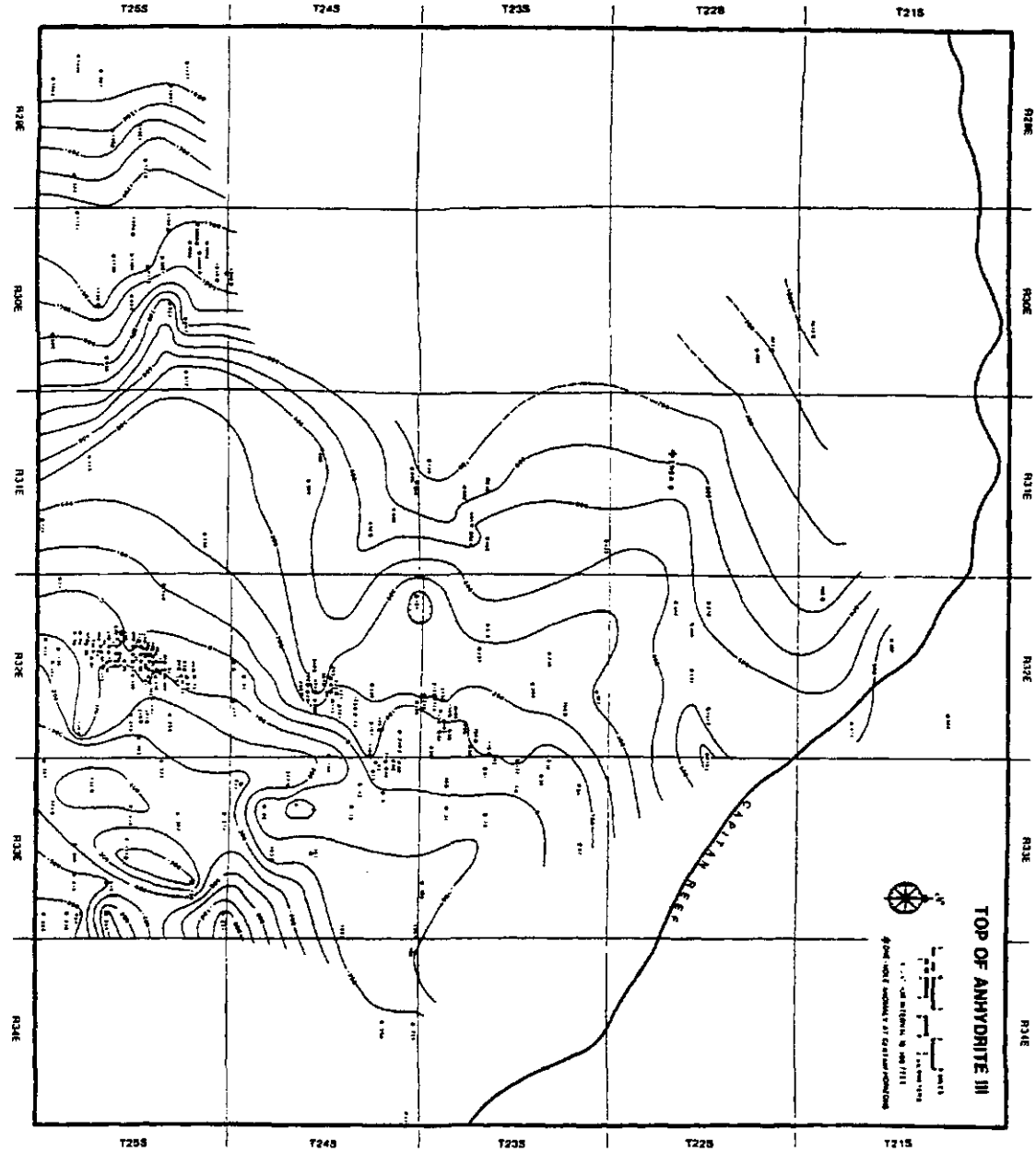

Figure 11 Top of Anhydrite III (ft absolute above MSL) in feet

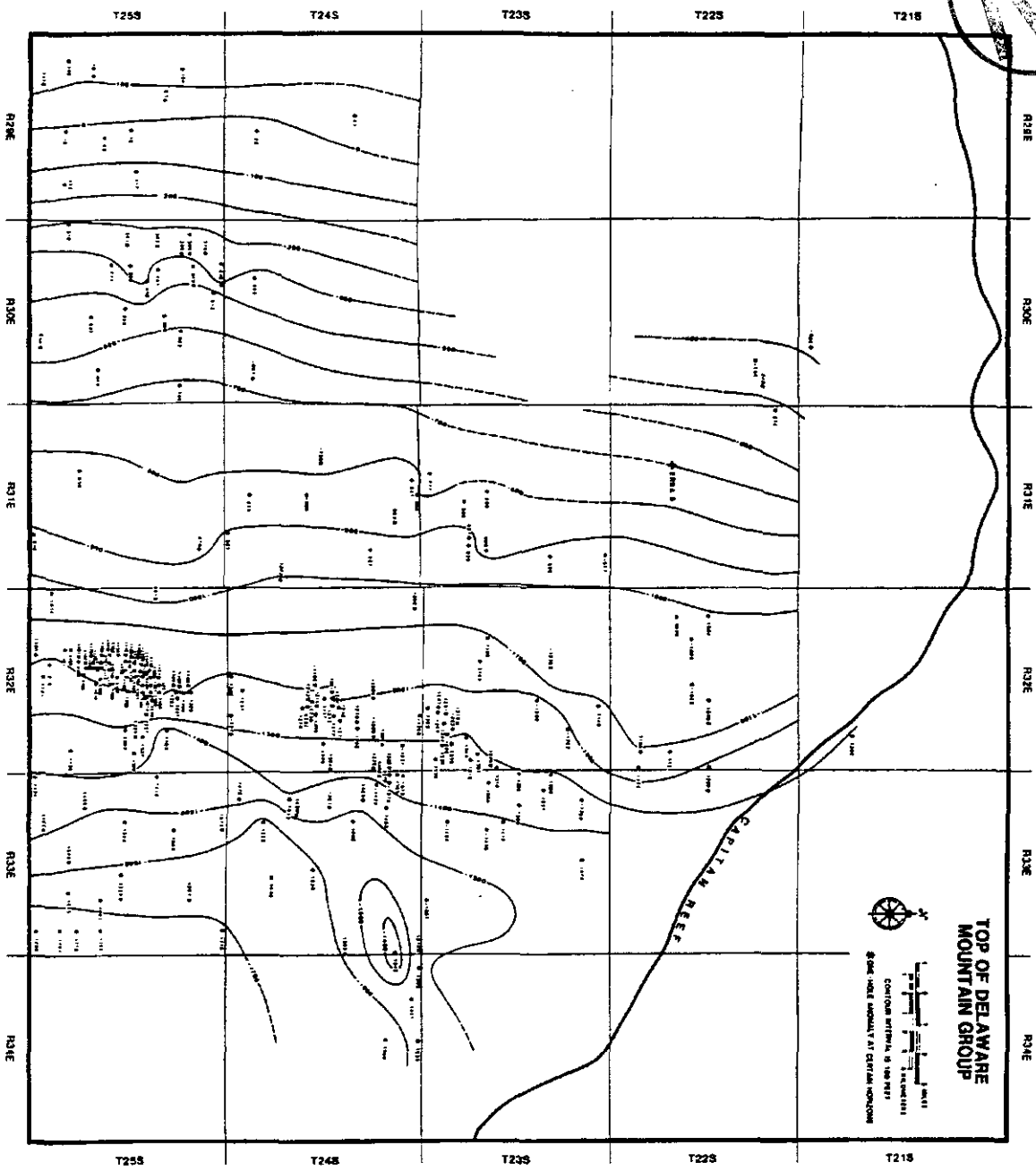

Figure 16. Map of the Lower Mountain Group (Elevation above MSL, in feet)

Poker Lake Anticline, p 44, col 1, para 2;

" Another observation from the dense pack of holes in the Poker Lake area is that the upper surface of the DMG exhibits an uneven topography. Such irregularities can produce apparent flow or dissolution structures in the lower and mid-Castile. However, the depression on the sedimentary surface existed before and during deposition.

Examples have been provided above for (1) the misleading contour extrapolation for one-hole anomalies and (2) the ambiguous nature of certain stratigraphic picks. However, resultant maps (Anderson, 1978; Davies, 1983) have been used as compelling evidence for dissolution and other processes in the Delaware Basin. In the case of the Poker Lake structures, the actual sizes of the anticline and syncline are significantly smaller (6x) in map view, than the structures extrapolated by Anderson (1978) and Anderson and Powers (1978). The remaining smaller structures (one-hole anomalies) can still be attributed to salt flowage and/or dissolution since the Permian."

Conclusions, p 45, col 2, para 4;

". . . Current log correlations suggest the following:

- The Castile is characterized by thickening and thinning. Hence, mass redistribution rather than mass removal is the dominant process.
- Thinning in some lower Castile structures was compensated for by thickened upper Castile and lower Salado sedimentation. This relationship suggests that the synform existed during Permian (Ochoan) sedimentation.
- Irregular topography in the top of the Bell Canyon can produce apparent structures in the overlying Ochoan units.

Anderson (1978, 1981, 1983) has proposed deep dissolutions as a major mechanism of salt removal in the northern Delaware Basin. He suggested that dissolution was marked in two zones, which are linear series of sinks. One zone trends SSE from the Poker Lake structures with a linear extent >30 km; the other zone, which includes San Simon Sink, is a line of troughs overlying the Capitan Reef on the eastern side of the basin. The northern end of Anderson's dissolution structure appears in the southwestern corner of the area covered in Figures 3 through 26. This zone is 20+ km SSW of the WIPP site. It is conceivable that this set of troughs was caused by dissolution, although the mechanism may not be deep dissolution but dissolution related to the ancestral Pecos River (Bachman, 1983). At the scale of resolution for the spacing wells, no continuation is observed of this structure NNE towards the WIPP site.

Locally, Davies (1983) has proposed that finger sands within the Bell Canyon control dissolution; such finger sands have higher transmissivities than do adjacent rock types. These finger sands trend NE. Structure contours do not reflect these sands; nor, in fact, do Anderson's line troughs. Davies has also proposed that a structural depression in the mid-Salado is evidence of deep dissolution two miles north of the WIPP site center as marked by the contour maps of Snyder in Borns et al (1983). The size of this structure is such that it does not appear on maps based on hydrocarbon industry holes. However, DOE has proposed to drill this structure to investigate its origins."

Brausch, L.M., Kuhn, A.K., and Register, J.K. 1982. Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern, New Mexico. TME 3156. Albuquerque, NM: U.S. Department of Energy, Waste Isolation Pilot Plant. WPO 39094.

Section 1.1.2.1 Potash, p 11, para 2;

" The two separate studies of the economic potential of the potash resources at the WIPP site (U. S. Department of the Interior, 1977; Agricultural and Industrial Minerals, Inc., 1979) used varying approaches and report different results describing the economic attractiveness of the potash resources. Each of these evaluations involved segmenting the ore deposits into distinct blocks of ore and identifying which areas could be economically developed by mining operations. Both studies agree, however, that no economically attractive deposits (i.e., reserves) of sylvite exist within the inner three control zones at the WIPP site and that the majority of the langbeinite reserves are located outside the inner zones (Table 2). The most attractive langbeinite deposits, and the only 'reserves' under current market conditions (USBM Mining Unit B-1), are located north-northeast of the site center in Control Zones III and IV (Figure 5)."

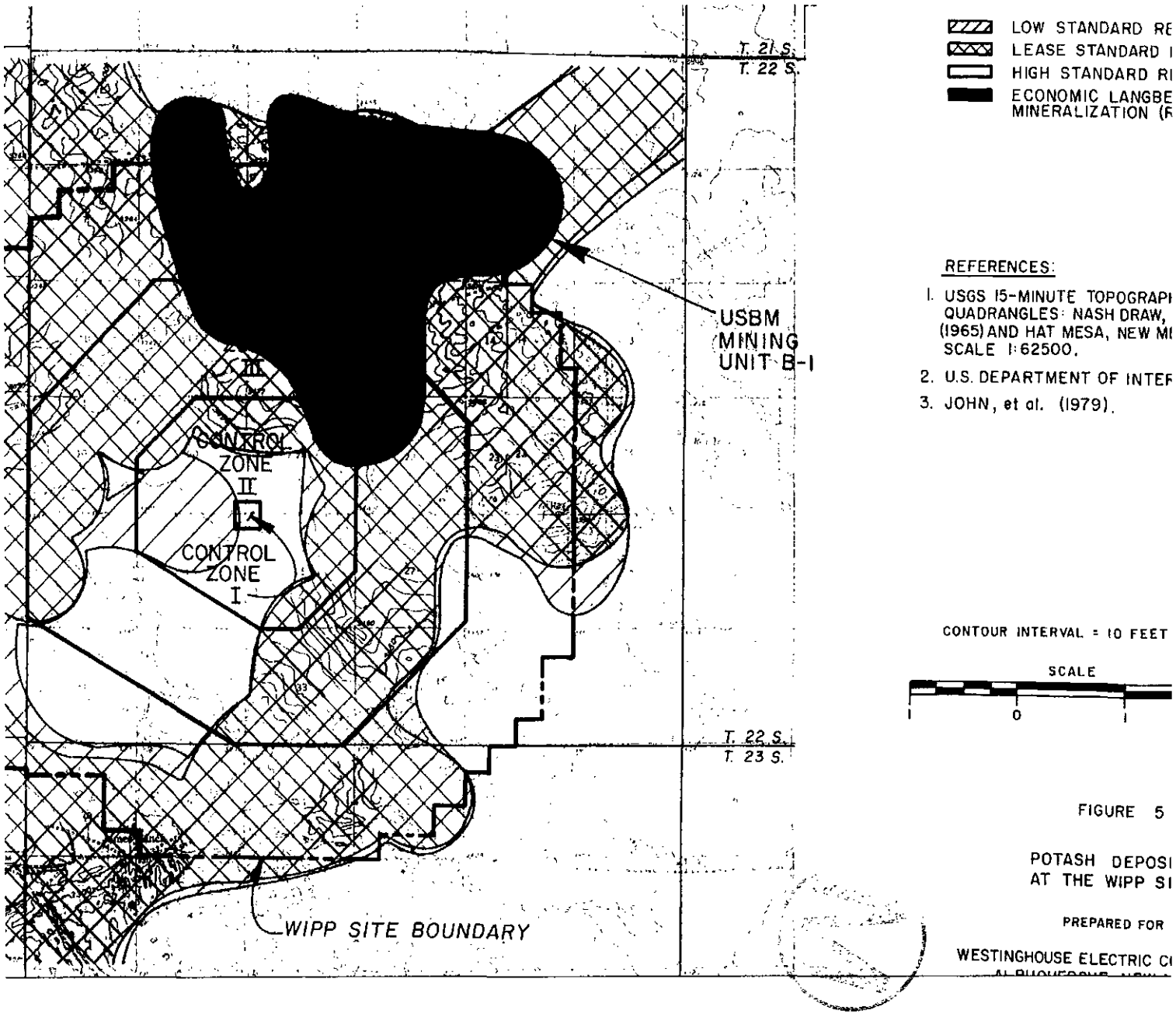
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WIPP SITE BOUNDARY
REFERENCES:
1. USGS 15-MINUTE TOPOGRAPI
QUADRANGLES: NASH DRAW,
(1965) AND HAT MESA, NEW MI
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2. U.S. DEPARTMENT OF INTEF
3. JOHN, et al. (1979).
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FIGURE 5
POTASH DEPOSI
AT THE WIPP SI
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Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hays, W.H. 1972. Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico. Open File Report 4339-1. U.S. Geological Survey, Denver, CO.

ABSTRACT;

" The potash mines of southeastern New Mexico are in a sparsely populated area 15-30 miles east of Carlsbad. Topographic relief is low, surface drainage poor, and collapse features common. The climate is semiarid.

Sedimentary rocks attain thicknesses of more than 20,000 feet and range in age from Ordovician to Quaternary. The area includes the northern end of the Delaware basin and the largely buried Capitan Reef. The basin contains as much as 13,000 feet of Permian strata. The oldest exposed rocks are of Late Permian age, but drilling has provided much data on the buried older rocks. The principle structures are broad gentle features related to late Paleozoic sedimentation: the northern Delaware basin, a shelf north and west of the basin, and a central basin platform to the east. These structures were tilted eastward before Pliocene time, have been inactive since, and now show a general eastward dip of less than 2°.

The salt deposits are in the Late Permian Ochoan Series composed of a thick salt-bearing evaporite lower part (Castile, Salado, and Rustler Formations) and a thin non-salt-bearing upper part (Dewey Redbeds).

The Castile Formation consists largely of interlaminated gray anhydrite and brownish-gray limestone, but includes much rock salt. It is about 1,500-1,600 feet thick along the southern edge of the potash area; it thins northward to about 1,000 feet near the margin of the Delaware basin and tongues out in the southernmost parts of the northwest shelf. All the salt is concentrated in a thick middle member which lies 200-300 ft above the base of the formation.

The Salado Formation, the main salt-bearing unit of the potash area, ranges in thickness from about 1,900 feet in the south to about 1,000 feet in the north. The formation is characterized by thick persistent units of rock salt alternating with thinner units of anhydrite and polyhalite. Thin seams of claystone underlie the anhydrite and polyhalite unit, and there are a few beds of sandstone and siltstone at large intervals. The Salado Formation is divided into three informal units: a lower and an upper salt member, generally free of sylvite and other potassium and magnesium evaporite minerals, and the McNutt potash zone, generally rich in these minerals.

The Rustler Formation mostly anhydrite and rock salt, thins from 300 to 400 feet in the southern part of the area to about 200-250 feet in the northern part. Some dolomite is present in the upper and lower parts of the formation, and thin to thick units of sandstone and shale are interbedded at long to short intervals.

The Dewey Lake Redbeds at the top of the Ochoan Series consist of reddish-brown siltstone and fine-grained sandstone. The formation is 250-550 feet thick in the potash area.

Three main hydrologic units control the ground-water hydrology of the Carlsbad potash mining area: the Pecos River, the water-bearing strata overlying the Salado

Formation, and the Capitan Limestone and other water-bearing strata underlying the Salado. The distribution and development of large dissolution features, particularly in the Nash Draw and Clayton Basin areas, exert a major effect on the occurrence and movement of the ground water. The Pecos River receives nearly all of the ground-water outflow from the area. Most of that outflow reaches the Pecos near Malaga Bend.

The main water-yielding units overlying the Salado Formation are the basal solution breccia zone and the Culebra Dolomite Member of the Rustler Formation, the Santa Rosa Sandstone, and the alluvium. The basal solution breccia zone is the hydrologic unit most significant in the solution of halite from the upper part of the Salado Formation. The easternmost extent of evaporite solution in the potash mining area is roughly at the common boundary between Ranges 30 and 31 E. The formations above the Salado Formation seem to be connected hydrologically and can be considered a single multiple aquifer system. Solution activity and associated collapse, subsidence, and fracturing have increased the overall permeability of the rocks and the interformational movement of water in the aquifer system.

Ground water in the formations above the Salado moves generally southward and southwestward across the potash mining area toward the Pecos River. Although the total amount of ground water discharging to the Pecos River is not known, it has been estimated that 200 gals per minute enter the river from the basal solution breccia zone.

The potentiometric and water-table contours outline a series of ground-water ridges and troughs imposed on the regional southward to southwestward pattern of ground-water movement. A large southwestward-plunging ground-water trough extends from Malaga Bend northeastward roughly through Nash Draw to beyond the mining area in the vicinity of Laguna Plata. Another much smaller trough is east and southeast of the Project Gnome site.

The Salado Formation has an intergranular porosity and permeability that ranges from low to virtually none. Locally, fractures and solution openings impart a spotty formational permeability. In the potash mining area, the Salado Formation is dry except for water in the leached zone at the top of the formation and small pockets of water or water and gas encountered ocassionally during mining.

The Cambrian to Permian sedimentary rocks underlying the Salado Formation contain water of brine composition and are under high artesian pressure. These rocks are not exposed in the potash mining area but lie deeply buried throughout much of southeastern New Mexico and western Texas. In the potash mining area the elevations of the potentiometric surfaces of different zones of these rocks range from a few feet to a few hundred feet above or below the land surface."

p 30;

" The Delaware basin was first defined in Early Pennsylvanian time, when an earlier very broad basin was divided by initial uplift of a large median ridge that became the central basin platform of Permian time. The basin subsided relative to the bounding platform and shelf until Late Permian time, when its history as an active structural feature ended.

The form of the northern part of the basin, as defined by contours on the surface of the Precambrian floor (Foster and Stipp, 1961), is a broad asymmetrical trough, trending

north and plunging south. The axis is in central Lea County, roughly parallel to the central basin platform. The eastern slope of the trough rises rapidly to the platform, whereas the western slope is much gentler.

As in any gradually subsiding basin, the older sediments are downwarped in a form like that of the basement floor, and the warping dies out upward in the basin section (fig. 4A). The Late Permian Ochoan rocks and the Triassic rocks exposed in the basin today do not reflect basinwide warping, and their major structural feature is the regional eastward slope mentioned above. This slope is 75-100 feet per mile in proximity to the Gnome site and the southern potash mines.

Disruption of the regional slope of the Ochoan and younger rocks is minor. The vicinity of the Gnome site and the southern mines is apparently representative in its scattering of open folds, domes, and small faults, which may be, in part, of tectonic origin. Deep-seated faults with more than 20 feet of vertical displacement are rare if not absent there (Jones, 1960, p. 16). Near the western edge of the basin and the present upper course of the Black River, Cenozoic tectonism may be involved in a northwest-trending monoclinal flexure. Kelley (1971, pl. 5) showed 600 feet of relief across this monocline on the upper surface of the Bell Canyon Formation. Several minor high-angle faults cutting the Castile Formation in the same part of the basin and two inferred faults at the northwestern edge of the basin (Kelley, 1971, p. 48-51) are most probably products of solution subsidence. Subsurface solution has produced many other minor faults and numerous local flexures in the near-surface rocks, as well as the many sinks and larger depressions. In addition, small surficial domes that are attributed to differential solution of salt or to expansion of anhydrite during hydration are numerous (Vine, 1960)"

Brookins, D.G. 1980. "Polyhalite K-Ar Radiometric Ages from Southeastern New Mexico." In Isochron/West No. 29, pp. 29-31.

p. 29, col. 1;
" This paper lists four new radiometric K-Ar age determinations for polyhalites from southeastern New Mexico. These data are compared with seven published ages by Brookins and others (1980). The new (nos. 1-4) samples were chosen because they were mixed with halite and sylvite, although the exact halide content could not be determined from x-ray diffratometry. Nor can it be stated with certainty that other halides and-or other evaporite minerals are present or not. The detailed geology, mineralogy, chemistry and precise sample locations are given in SAND (1978). Earlier studies of langbeinite and langbeinite-sylvite mixtures have been reported in this journal by Schilling (1973), and will not be repeated here except to note that a distinct lowering of K-Ar ages with increasing sylvite content was noted. The purpose of this note is to see if similar effects are noted for polyhalites. The K-Ar analyses and age calculations were carried out by Geochron Laboratories, Inc., Cambridge, Mass."

p. 30, col. 1;
" 11. MB76-22 K-Ar

Polyhalite mixed with halite and sylvite, from contact zone of evaporites intruded by lamprophyre dike (Kerr-McGee Potash Mine, Lea County, NM). *Analytical data*: K = 12.14%, $^{*40}Ar$ = 0.01807 ppm $^{*40}Ar/\Sigma^{40}Ar$ = 31.7%. *Collected by*: Marc Bodine, Jr. *Analyzed by*: Geochron Laboratories, Inc.

(impure polyhalite) 21.4 ± 0.8 m.y."

Brookins, D.G. 1981. "Geochronologic Studies Near the WIPP Site, Nouthestern New Mexico." In Environmental Geology and Hydrology in New Mexico. S.G. Wells, and W. Lambert, ed., Special Publication 10, pp. 147-152. New Mexico Geological Society.

ABSTRACT, p. 147;

" The U. S. Department of Energy's Waste Isolation Pilot Plant (WIPP) site is currently being investigated for pilot storage of defense-generated radioactive waste. A critical facet of the overall study is the question whether the rocks have remained closed systems with respect to their bulk chemistry and isotopic composition since formation in the Late Permian as opposed to episodic or more-or-less continuous recrystallization during the post-Late Permian. Early attempts at K-Ar dating of sylvites mixed with other salts yielded inconclusive results, primarily because sylvite is not well suited for K-Ar study because of loss of radiogenic ^{40}Ar. Rb-Sr study of sylvites (Register and Brookins, 1980) yields a 214 $\pm$ 15 m.y.B.P (million years before present) isochron indicating closed system conditions to Rb and Sr since latest Permian or earliest Triassic. Pre-200 m.y.B.P. K-Ar dates have also been determined for pure langbeinites and polyhalites (Brookins and others, 1980a). When mixed with sylvite, age lowering results. The Rb-Sr systematics of eolian clay minerals known to have interacted with the evaporite brine yield a poorly defined isochron of 390 $\pm$ 77 m.y.B.P., but the apparent date does not indicate that the clay mineral-brine interactions were not so severe as to completely rehomogenize Sr isotopes despite the clay mineral alteration. A 34 $\pm$ 1.5 m.y.b.P. lamphrophyre dike intrudes the evaporite sequence some 70 km north of the WIPP Site. Contact effects, including recrystallization of polyhalite, are restricted to within 10 m of the dike. Finally, polyhalite inclusions in one rubble chimney yield a pre-200 m.y.B.P. age indicating no major recrystallization effects due to this disturbance of the evaporite sequence. Collectively, the geochronologic studies argue for pre-200 m.y.B.P. formation of the evaporite minerals and stability of the rocks since that time."

Brookins, D.G. and Lambert, S.J. 1987. "Radiometric Dating of Ochoan (Permian) Evaporites, WIPP Site, Delaware Basin, New Mexico, USA." Scientific Basis for Nuclear Waste Management X, Materials Research Society Symposia Proceedings, Boston, MA, December 1-4, 1986, J.K. Bates and W.B. Seefeldt, eds., Vol. 84, pp. 771-780, Materials Research Society, Pittsburgh, PA.

ABSTRACT, p. 771;

" We have attempted radiometric dating of halide-sulfate salts and clay minerals from the Delaware Basin, New Mexico, USA, as part of geochemical study of the stability of the evaporite sequence at the WIPP (Waste Isolation Pilot Plant--a US DOE facility) site. We undertook this dating to determine: (1) primary age of evaporite genesis or time(s) of recrystallization, (2) if previously undated evaporite minerals (leonite, polyhalite, kieserite) give useful data, and (3) if the detrital clay minerals have been radiometrically reset at any time following their incorporation into the evaporite medium. We have shown earlier that polyhalites can indeed be successfully dated by the K-Ar method, and once corrections are applied for admixed halide minerals, dates of 210-230 Ma for the Delaware Basin are obtained. Rb-Sr isochrons from early stage sylvites-polyhalites-anhydrites yield 220 $\pm$ 10 Ma, even when some sylvites yield lower K-Ar dates due to loss of $^{40}Ar^*$. K-Ar dates on leonites and kieserites are also low due to $^{40}Ar^*$ loss, but their Rb-Sr dates are higher. Detrital clay minerals from the Delaware Basin collectively yield a highly scattered isochron (390 $\pm$ 77 Ma), but samples from a local area, such as the WIPP Site, give a much better age of 428 $\pm$ 7 Ma. These dates show that the interaction between the clay minerals and the evaporitic brines was insufficient to reset the clay minerals Rb-Sr systematics. In a related study, we note that a dike emplaced in the evaporite at 34 Ma had only very limited effect on the intruded rocks; contact phenomena were all within 2 m of the dike. All of our geochemical (radio-metric and trace element) studies of the WIPP site argue for preservation of the isotopic and chemical integrity of the major minerals for the past 200 Ma."

Brookins, D.G., Register, J.K, Jr., and Krueger, H.W. 1980. "Potassium-Argon Dating of Polyhalite in New Mexico." *Geochimica et Cosmoshimica Acta* Vol. 44, No. 5, pp. 635-637.

ABSTRACT, p 635;
" Polyhalite $K_2Ca_2Mg(SO_4)_4 \bullet 2H_2O$, is an important mineral in many evaporites. Although its use for K-Ar dating has never been investigated, our results indicate that it is a very useful mineral for dating events ranging from the time of potash mineralization to any younger events which may have affected the evaporite. Five K-Ar dates on pure polyhalite, including two from included material and from beds distorted by the formation of a rubble chimney, yield dates between 198 and 216 Myp, in good agreement with Rb-Sr dates and the diagenetic age of the potash deposits from the same rocks. Two polyhalites mixed with sylvite gave lower dates (154 and 174 Myr) which is to be expected because of radiogenic ^{40}K loss from the sylvite phase. One polyhalite, formed after the intrusion of a 31 Myr lamphrophyre dike, yielded 21 Myr. Collectively our results indicate that pure polyhalite is satisfactory for K-Ar dating and may provide critical age information in studies of the geologic history of the evaporite sequences."

p 637, col 1, para 3;
" In the Kerr-McGee Potash Mine a lamprophyre dike yields a K-Ar apparent emplacement date of 31 Myr (See SAND. 1978). The evaporite minerals immediately adjacent to this dike have been recrystallized and second generation sylvite, polyhalite, halite and other minerals sometimes fill fractures in the lamprophyre. Because the exposures in the Kerr-McGee Mine have been mined out and are no longer accessible, a sample of very pure polyhalite from this area (See Table 2) was obtained from the New Mexico Institute of Technology (courtesy of Dr. M. Bodine). This sample (No. 8) was free of sylvite and yielded a date of 21.4 $\pm$ 0.8 Myr. in rough agreement with the age of the lamprophyre. If a predike age had been obtained, questions about the use of polyhalite for dating could be raised. The result corresponds well with the established age of the dike. The ages of about 210 Myr for samples one through five provide indirect evidence that the emplacement of the dike was a local event and apparently affected only the contact zones."

Calzia, J.P., and Hiss, W.L. 1978. "Igneous Rocks in Northern Delaware Basin, New Mexico and Texas," In Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas, G.S. Austin, ed., Circular 159, pp. 39 - 45. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

p 44, col 1, para 2;
" Since the rate of argon diffusion varies during alteration, it is not likely that analysis of two altered samples would produce: 1) closely similar percentages of radiogenic argon, and 2) calculated age dates that agree within the range of standard deviation. These data suggest that radiogenic argon was not lost during alteration and that igneous dikes east of the Pecos River are early Oligocene (32.2 to 33.9 m.y.) in age."

Cartwright, Jr., L.D. 1930. Transverse Section of Permian Basin, West Texas and Southeastern New Mexico. American Association of Petroleum Geologists Bulletin, Vol. 14,

ABSTRACT, p 969;

" The Permian basin is divided into structural units each of which is characterized by a distinctive stratigraphic section. The Main Permian basin, Central basin platform, and Delaware Mountain basin are included in the transverse section presented in this paper. The strata of the Main Permian basin are divided into the Wichita, Albany, Clear Fork, and Double Mountain groups, the Double Mountain group being divided into the San Angelo, Blaine, Whitehorse-Cloudchief, and Quartermaster formations. The formations of the Main Permian basin are relatively uniform along the strike, but thicken and become more marine basinward.

The Central basin platform is a regional limestone 'high' on which there are pronounced changes in the limestone section penetrated east and west across it. Two explanations of these changes are generally accepted. The first recognizes an extension of the Capitan reef system bordering the Delaware Mountain basin. Back of the reef is a lagoonal facies comprising dolomitic limestone, sandstone, and anhydrite. The second recognizes an older dolomitic limestone known as the 'White lime' on the eroded surface of which there is a heterogeneous deposit of dolomitic limestone, sandstone, and anhydrite known as the 'Brown lime.'

The strata of the Delaware Mountain basin comprise the Bone Springs limestone, the Delaware Mountain sandstone, the Capitan formation, the Lower Castile, the Upper Castile, and Rustler formations. Of special interest are the Capitan, which is a reef phase of the upper Delaware Mountain, and the Lower Castile, which is a peculiar evaporite formation."

Casas, E., and Lowenstein, T.K. 1989. Diagenesis of Saline Pan Halite: ^Comparison of Petrographic Features of Modern, Quaternary and Permian Halites. Journal of Sedimentary Petrology, Vol. 59.

ABSTRACT, p 724;

" Petrographic studies of modern saline pan halites (Saline Valley, CA; Salina Omotepec, Baja California, Mexico) and Quaternary shallow-buried (0-200 m) halites (Saline Valley, CA; Bristol Dry Lake, CA; Searles Lake, CA; Qarhan saline pan, Qaidam Basin, China; Lake Uyuni, Bolivia) show that the diagenetic modification of halite begins contemporaneously with deposition, is most intense within the upper few meters of burial, and is essentially complete within the first 45 m of burial. Halite crusts from modern saline pans that have undergone repeated episodes of flooding, evaporative concentration, and desiccation contain abundant syndepositional diagenetic features. These 'mature' modern halites are dominated by dissolution textures and fabrics (formed during flood stages) and cementation textures (formed during desiccation stages). Interlayered mud beds contain varying amounts of displacive halite crystals.

At shallow burial depths, halites retain many textural features of 'mature' modern saline pan halite. Halites below the first few meters are no longer susceptible to dissolution from floodwaters but continue to be cemented by clear halite. Within the first 10 m of burial, cementation reduces the porosity of halite crusts to less than 10%. The remaining pore spaces are completely filled by burial depths of approximately 45 m. Displacive growth of halite in muds continues at shallow-burial depths and is probably limited to the first few tens of meters of burial depth. The mechanisms for cementation and displacive growth of halite at shallow-burial depths probably include (1) evaporative concentration of groundwater brines and (2) cooling of surface brines when they sink below the sediment surface.

Undeformed halites from the Permian Salado and Rustler Formations of New Mexico contain delicate syndepositional textures and abundant clear halite cements that are comparable to those observed in modern saline pan halites and shallow-buried halites. The Permian halites are interpreted to have undergone a depositional and early diagenetic history similar to the modern and Quaternary analogs.

Complete cementation of saline pan halites at shallow burial depths has important implications for the origin of saline formation waters in sedimentary basins. Parent evaporite brines may not be stored in the pores of halite rocks and later expelled during burial compaction if the rocks are cemented early, and tightly crystallized halite rocks may also impede the downward migration of dense syndepositional brines."

Chugg, J.C., Anderson, G.W., Kink, D.L., and Jones, L.H. 1971. Soil Survey of Eddy Area, New Mexico. Prepared by the U.S. Soil Conservation Service in cooperation with New Mexico Agricultural Experiment Station. For sale by the Superintendent of Documents, U.S. Government Priniting Office, Washington, D.C.

How This Soil Survey Was Made, p 1, col 1, para 5;
" Soil scientists made this survey to learn what kinds of soils are in the Eddy Area, where they are located, and how they can be used. They went into the county knowing they would likely find many soils they had already seen, and perhaps some they had not. As they traveled over the county, they observed steepness, length, and shape of slopes; size and speed of streams; kinds of native plants or crops; kinds of rock; and many facts about the soils. They dug many holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material that has not been changed much by leaching or by roots of plants.
The soil scientists made comparisons among the profiles they studied, and they compared these profiles with those in counties nearby and in places more distant. They classified and named the soils according to nationwide uniform procedures. . . ."

NOTE: Figure 113 is too large and detailed to scan into this document.

Claiborne, H.C. and Gera, F. 1974. Potential Containment Failure Mechanisms and Their Consequences at a Radioactive Waste Repository in Bedded Salt in New Mexico. ORNL-TM 4639. Oak Ridge National Laboratories, Oak Ridge, TN.

ABSTRACT, p 1;

" This report examines potential containment failure mechanisms and estimates their probabilities and consequences, when possible, for a hypothetical waste repository located in bedded salt in southeastern New Mexico.

The preliminary conclusion of this study is that a serious breach of containment for such a repository, either by human action or natural events, is only a very remote possibility and falls into the category of least likely occurrences that affect society.

A sealed repository 600 m underground would be virtually sabotage proof; even the surface burst of a 50-megaton nuclear weapon could not breach the containment. Accidental drilling of bore holes through the disposal horizon could cause relatively minor local contamination.

The mechanism of containment failure with the most serious potential consequences seems to be the impact of a meteorite that produces a crater extending to the disposal horizon. The probability of such a catastrophic meteorite impact was estimated at 1.6×10^{-13} per year. The calculated exposure from the global fallout resulting from such an event would be of the same order of magnitude as that from nuclear bomb tests, provided the impact did not take place during the first few hundred years after closure of the mine. The ejecta falling back into the nearby area would cause a serious and protracted contamination problem. A pathway analysis showed that individuals living exclusively on foodstuffs produced in the contaminated area would be exposed to high radiation doses.

Based on the tectonic activity of the Delaware Basin over the past 200 million years, the probability of faulting through the repository has been estimated at 4×10^{-11} per year; however, the probability that faulting would cause failure of waste containment is only a small but unknown fraction of this value.

Exposure of the waste horizon to the action of ground water by a large fault with a vertical displacement of at least 350 m cannot be proved impossible. However, at least a few hundred thousand years would be required for an offset of 350 m to take place. A more sudden breach of containment could be effected by a large fault that cuts through the disposal zone and hydraulically connects the over- and underlying aquifers. In this case, any water flowing along the fracture zone would be downward into the deep aquifers. Fortunately, the geologic evidence indicates that such a fracture could eventually be healed by plastic flow of the salt beds. Even in the event that the deep aquifers became contaminated, it is extremely unlikely that activity could be brought to the surface because the normal flow velocities in these aquifers are on an order of only a few kilometers per million years.

In view of the hydraulic heads of the various aquifers, it is difficult to visualize circumstances that could result in an upward flow and contamination of the fresh water in the Culebra Dolomite aquifer. The only possibility for the release of radioactive material to the Culebra Dolomite aquifer would appear to be on the basis of a model that permits faulting

and progressive displacement of the disposal horizon until waste contacts the circulating ground water. The contamination of surface aquifers by this mechanism of release could be relatively serious, despite the very long time necessary to produce such a displacement."

3.2.4 Erosion, p. 43, Para. 2;

" Average rates of erosion in the United States, based on recent stream load records, are on the order of a few centimeters per thousand years.[13] Occasionally erosion rates can be higher; for example, small drainage basins or river valleys are known where materials are removed at rates ranging from tens of centimeters up to meters per thousand years.[13]

The selected site for this report is located in the Mescalero plain, a geomorphic surface in southeastern New Mexico situated between the Pecos River on the west and the High Plains on the east. The Mescalero plain has limited relief and is covered by windblown sand over large areas; the surface is usually underlain by a layer of caliche of Pleistocene age.

No significant lowering of the land surface by erosion occurred during Quaternary time as indicated by the existence of the caliche layer. Large depressions are due more to subrosion and subsidence than surface erosion. Small depressions can be formed either by subrosion or wind deflation. Bachman[63] has reviewed removal processes in the Mescalero plain, concluding that the site area underwent very limited erosion and salt dissolution in Quaternary time. A southeast-flowing stream of probable Pleistocene age may have eroded San Simon Swale; the bottom of the swale is 60 to 70 m below the surrounding high land surface.

The surface lowering at one place in Nash Draw has been estimated at 60 m during the past 600,000 years (a rate of 10 cm/1000 years); salt dissolution and subsidence have been responsible for most of the lowering.[63] Based on this estimate, it seems reasonable to assume that, even if a future climate were to favor increased rates of erosion, no disinterment of waste could take place before several million years.

A drastic change in the rate of erosion could be caused by a significant uplift of the area. There is no indication that the Mescalero plain is presently being uplifted. It is obviously impossible to prove that uplift will not occur in the future; however, the known rates of large-scale vertical movements in midcontinental areas indicate that an uplift of 500 m would require several hundred thousand years.[13,64]

On the basis of these considerations it seems reasonable to conclude that erosion, as a potential mechanism of containment failure for waste buried in southeastern New Mexico at a depth of 600 m, can be neglected."

Corbet, T.F. and Knupp, P.M. 1996 The Role of Regional Groundwater Flow in the Hydrogeology of the Culebra Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico. SAND96-2133. Sandia National Laboratories, Albuquerque, NM.

p. i, para. 1;
1. INTRODUCTION; p. 1, para. 1;
" This report summarizes a study in which numerical simulation is used to enhance conceptual understanding of the hydrogeology of the Culebra Dolomite in the context of groundwater flow on a regional scale in the vicinity of the Waste Isolation Pilot Plant (WIPP). The WIPP is a potential repository for defense-generated transuranic wastes. The Culebra Dolomite is a member of the Permian age Rustler Formation, a sequence of predominantly evaporate deposits that overlie the Salado Formation. The Salado is a thick bedded salt of Permian age that contains the WIPP and provides the primary containment for the repository. The groundwater flow system in the overlying Permian and Triassic deposits forms a secondary barrier to releases from the repository in the even of a breach of the primary containment. Consequently, an important requirement of the performance assessment of the repository is to characterize long-term groundwater flow in the shallow system. We consider the possibility that patterns of groundwater flow in the shallow system change over thousands of years in response to change climate. Although groundwater flow is simulated in all of the strata above the Salado, this report focuses primarily on flow in the Culebra Dolomite because it is thought to be the most likely pathway for lateral migration of radionuclides to the accessible environment."

p. 3, para. 2;
" We developed a new numerical code called SECOFL3D, to perform the simulations. The algorithm implements a rigorous treatment of the free-surface and seepage-face boundary conditions (Bear and Verruijt, 1987; Dagan, 1989; de Marsily, 1986) and is designed to be robust even if extremely large contrasts in hydraulic conductivity are present within the model domain. A moving mesh that adaptively deforms so that its upper surface conforms to the moving water table is used to ensure that the entire computational domain remains saturated.

Lateral boundaries of groundwater basins are sub-vertical flow divides that typically coincide with depressions and highs on the land surface. Flow over a region much larger than the WIPP site (Figure 1-1) was simulated in order to have the model boundary coincide with topographic features that are likely to act as groundwater divides over a range of climatic conditions. A series of steady-state simulations was performed to examine the sensitivity of simulation results to assumed values for hydraulic conductivity and recharge rate. Transient simulations provided insight into how patterns of groundwater flow respond to long-term changes in climate. These simulations covered the time period from late in the Pleistocene (14,000 years ago) to 10,000 years in the future.

The simulations results suggest that patterns of groundwater flow in the Culebra in the

vicinity of the WIPP are influenced by the hydrology of the entire groundwater basin. Flow rates and directions depend on the position of the water table and heterogeneity in hydraulic conductivity at the basin-scale. Groundwater flow changes with time due to interaction among recharge, movement of the water table, and topography of the land surface."

p. 5, para. 2;
" The simulations also provide information about how flow in the Culebra in the vicinity of the WIPP is coupled with flow in adjacent strata. Vertical leakage across the top of the Culebra is directed downward. The amount of vertical leakage into the Culebra cannot be estimated with confidence because the vertical conductivity of the confining units is not well constrained. Vertical leakage may contribute as little as 5% or more than 50% of the total inflow to the portion of the Culebra that lies within the WIPP-site boundary. All of the outflow from this portion of the Culebra is lateral flow. Therefore, contaminants introduced into the Culebra will travel toward the accessible environment along the Culebra rather than by migrating upward or downward into other units."

p. 103, para. 4;
" We performed mass balances over the reference volumes (defined in the introduction to Section 3) of the more conductive layers. This was accomplished by summing the flow across each face of the reference volumes in order to calculate total flow through each reference volume, as well as the proportions of lateral and vertical inflow and outflow from the reference volumes."

p. 105, para. 1;
" Figures such as 3-46, 3-47, and 3-48 mass balances provide a clear overview of the mass balance but are difficult to interpret quantitatively. To complement these figures, we have included tables in Appendix D that summarize the mass balance data at two simulated times: at the present time (zero years) and at 10,000 years into the future. The total inflow to the Dewey Lake/Triassic rocks, Magenta, and Culebra reference volumes at the simulated present time are 5015, 784, and 2100 cubic meters per year (base case in Table D-1). The inflow rates for these units at 10,000 years are somewhat larger: 16738, 1736, and 3354 cubic meters per year (base case in Table D-4). These numbers show that, in this simulation, most of the flow occurs in the Dewey Lake/Triassic rocks and that more flow occurs in the Culebra than the Magenta."

p. 106, para. 1;
" Table D-2 gives the total flow across the upper surface, lower surface, and sides as a percentage of the total flow through the reference volume at zero years simulation time. For the base-case simulation, 42% of the inflow to the Dewey Lake/Triassic reference volume is from groundwater recharge (i.e., 42% of the inflow to the Dewey Lake/Triassic rocks is across the top). Zero percent of the inflow to the Dewey Lake/Triassic is from upward vertical leakage. In fact, an important aspect of all of the transient simulations performed for

this study is that the vertical flow components are directed downward in all layers within the vicinity of the WIPP site. 98% of the inflow to the Magenta reference volume is vertical leakage from the Dewey Lake/Triassic and 30% of the inflow to the Culebra is leakage from the Magenta. All of the outflow from the Culebra reference volume is by lateral flow. Table D-5 provides the same information at 10,000 years."

p. 139, para. 2;
" Within the region of intact strata, the contrast in hydraulic conductivities plays an important role in determining flow patterns. The Dewey Lake and Triassic rocks are more permeable than the anhydrites at the top of the Rustler Formation. Consequently most of the water that recharges the groundwater basin flows only in these rocks above the Rustler. The rest leaks vertically through the upper anhydrites and is available for flow through the rest of the Rustler. Differences in hydraulic head along the base of the Dewey Lake provide the driving force for flow in the Rustler.

Groundwater flow in the Rustler Formation is characterized by very slow vertical leakage through confining units and faster lateral flow in conductive units. Specific discharges (flow rates per unit area) in the Culebra are 2 to 3 orders of magnitude greater than the vertical specific discharges across the top of the Culebra. However, vertical leakage can contribute a significant portion of the total inflow to portions of the Culebra that are extensive enough that the upper surface is very much larger than the area available for lateral flow."

p. 141, para. 4;
" These simulations suggest that, in the vicinity of the WIPP site, vertical flow across the top of the Culebra is directed downward. The amount of vertical leakage into Culebra at this site cannot be estimated with confidence. It contributes a small portion of the total inflow to the Culebra reference volume, perhaps 5% to 10%, if the vertical conductivity of the confining units is 1×10^{-13} m/s or less. However vertical leakage may contribute more than 50% of the total inflow if the conductivity is an order of magnitude larger.

A robust implication of these simulations is that nearly all (greater than 90% in all simulations) outflow from the Culebra reference volume is by lateral flow. Therefore, contaminants introduced into the Culebra will travel toward the accessable environment within the Culebra rather than by leaking upward or downward into other units. This result provides confidence that a flow and transport model that assumes that flow occurs only in the Culebra would include the appropriate release pathways."

Davies, P.B. 1984. "Deep-Seated Dissolution and Subsidence in Bedded Salt Deposits." Ph.D. Thesis. Stanford University, Palo Alto, CA.

Section 2.3.5 Summary, p 175;

" A suite of structure contour maps constructed from available borehole logs confirms the existence of an anomalous, closed, structural depression in the northern portion of the WIPP site. This depression persists through several hundred feet of the middle and upper Salado Formation. The depression is broad and shallow in the upper portion of the section and becomes narrower and deeper in successively lower strata. Isopach maps show that the strongest local variations in bed thickness occur in the lowermost unit and are spatially associated with the structural depression. The salt appears to be anomalously thin in the margin areas.

Physical analyses of salt deformation processes suggest that this structural depression formed as the result of ductile subsidence in response to the localized removal of salt at some lower horizon. Processes capable of removing salt include dissolution of lower Castile salt, dissolution of lower Salado salt, and depletion of Castile salt by gravity driven flow. Deep boreholes in the northern WIPP area and elsewhere in the basin reveal geologic features that are characteristic of each of these processes. Consideration of complex structures in these areas leads to the conclusion that there are potentially significant interrelationships between individual processes and that more than one process may be active in a given area. For example, lower Castile salt dissolution may play a critical role in triggering the gravity foundering process by creating local increase in the deviatoric stress at the quasi-stable Anhydrite II and III density inversions and by causing the influx of a small amount of intergranular saturated brine, thereby decreasing the strength of the salt. Another example of process interrelationships is the potentially important role of lower Castile salt dissolution and gravity foundering in creating vertical and horizontal hydrologic pathways, thereby facilitating lower Salado dissolution.

At the Salado depression in the northern WIPP site, there is insufficient data in the Castile and lower Salado to delineate which processes have been active and what process interrelationships exist. Therefore, either additional subsurface data should be gathered in the lower Salado and Castile, or safety analyses of the WIPP facility should explicitly encompass all possible processes, or both."

Davies, P.B., 1989. Variable-Density Ground-Water Flow and Paleohydrology in the Waste Isolation Pilot Plant (WIPP) Region, Southeastern New Mexico. Open-File Report 88-490. U.S. Geological Survey, Albuquerque, NM. WPO 38854.

ABSTRACT, p 1;

" A series of analyses, including variable-density flow simulations, was used to examine groundwater flow in the vicinity of the Waste Isolation Pilot Plant (WIPP) in the context of the regional flow system. WIPP is an underground repository mined from a thick bedded-salt unit to provide a facility for the disposal of radioactive waste. WIPP is located in southeastern New Mexico. The analyses primarily examined the Culebra Dolomite Member of the Rustler Formation, which is a potential pathway for the transport of radionuclides to the biosphere in the event of a breach of the WIPP repository.

An analysis of the relative magnitude of pressure-related and density-related flow-driving forces indicates that density-related forces are not significant at the WIPP Site and to the west but are significant in areas to the north, northeast, and south of the site. The area to the south is important because it lies along potential transport pathways from the site. In this area, groundwater flow simulations based on equivalent-freshwater head produce very misleading information on predicted flow directions and velocity magnitudes.

A regional-scale, variable-density model of ground-water flow in the Culebra Dolomite Member was developed in which a baseline, approximate steady-state simulation was calibrated to the distribution of equivalent-freshwater heads. The flow field from the baseline simulation, along with long-term brine transport patterns, indicates that flow velocities are relatively fast west of the site and extremely slow east and northeast of the site. In the transition zone between these two extremes, which includes the WIPP Site, velocities are highly variable.

A series of sensitivity simulations was used to analyze boundary effects and vertical flux. These simulations indicate that if the Culebra is as impermeable to the east and northeast of the WIPP Site as geologic conditions indicate, the central and western parts of the region, including the WIPP Site, are fairly well insulated from the eastern and northeastern boundaries and are insensitive to whatever conditions are assumed to be present along these boundaries. A simulation of a 5-meter head increase along the Pecos River boundary indicates that if the Culebra were tightly confined throughout the entire region, approximately 50 percent of any change in river elevation would eventually reach the WIPP Site. Uncertainty in the regional distribution of storage characteristics in the Culebra makes it difficult to accurately predict how long it would take for Pecos-related stresses to propagate through the WIPP region. A series of vertical-flux simulations indicates that as much as 25 percent of total inflow to the Culebra could be entering as vertical flux. These simulations also indicate that if significant volumes of water enter the Culebra vertically, most of the influx must be occurring in the westernmost part of the transition zone adjacent to Nash Draw.

Motivated by recent isotopic and geochemical analyses, a simple cross-sectional model was developed to provide a physically based analysis of the flow system as it may

have drained through time following recharge during a past glacial pluvial. Drainage for 20,000 years was simulated using a variety of hydraulic-conductivity distributions for rock units overlying the Culebra. These simulations indicate that the system as a whole drains very slowly and that it apparently could sustain flow from a purely transient drainage following recharge of the system during the Pleistocene. Although these simulation do not prove that this has been the case, they do show that such long-term transient drainage is physically possible. The simulations also indicate that the observed underpressuring of the Culebra in the vicinity of the WIPP site is most likely the hydrodynamic result of the Culebra having a relatively high hydraulic conductivity and being well connected to its discharge area but poorly connected to sources of recharge."

Driving-Force Analysis of the Model Area of Barr and Others (1983), p 35, para 3;
" South of the WIPP site, density-related driving-force components are as much as an order of magnitude larger than the pressure-related driving-force components (fig. 13). The density-related driving-force components are not only much greater in magnitude, but the angle between the two driving-force components is very large, almost 180 degrees in some areas. Because flow simulation based on equivalent-freshwater head ignore the density-related driving-forces, such simulations will produce large errors in predicted flow direction in this area. Flow directions in this area south of the site are important because this area may include flow paths for potential contaminant transport away from the site."

Hydraulic-conductivity distribution, p 110, para 3;
" No hydraulic conductivity data were available for the Dewey Lake Red Beds, which overlie the Rustler Formation. Mercer (1983) indicated that these fine-grained sandstones and siltstones have relatively low hydraulic conductivity. Therefore, a hydraulic conductivity of 10^{-8}m/s, which falls at the low end of the range of typical values for fine-grained sandstones (Morris and Johnson, 1967, p. D18), was used in the standard simulation.

Deal, D.E., and Case, J.B. 1987. Brine Sampling and Evaluation Program Phase I Report. DOE-WIPP 87-008. Westinghouse Electric Corporation, Carlsbad, NM.

ABSTRACT;

" This interim report presents preliminary data obtained in the course of the WIPP Brine Sampling and Evaluation Program. The investigations focus on the brine present in the near-field environment around the WIPP underground workings that is easily moved under existing pressure gradients. Observations began in 1983 and were expanded in 1984 and 1985. Most of the data reported in this document were acquired in the 600 days after January 1, 1985.

Although the WIPP underground workings are considered 'dry,' small amounts of brine are present, probably on the order of 0.1 to 0.5 percent by weight of the surrounding rocks. This amount of brine is not unexpected in rocks of marine sedimentary origin. Part of that brine can and does migrate into the repository in response to pressure gradients, at essentially isothermal conditions. These small volumes of brine have little effect on the day-to-day operations, but are pervasive throughout the repository and may contribute enough moisture over a period of years to affect resaturation and repressurization after sealing and closure.

The inflows occur as 'weeps' on the exposed surfaces and as very small inflows of brine at various locations, most noticeably in holes drilled outward from the underground workings. Over 1400 underground drill holes, most 15 meters or less in length, exist at WIPP. Gas is usually associated with the brine inflows. Gas bubbles are observed in many of the brine occurrences. Gas is also known to exsolve from solution as the brine is poured from container to container.

Measured brine occurrences have inflow rates that range from less than surface evaporation rates to approximately 0.5 liters per day. Most range between a few tenths and a few hundredths of a liter per day. Individual occurrences vary greatly and some drill holes less than a meter apart have brine inflows that contrast dramatically, making the discussion of 'averages' or 'typical occurrences' difficult or misleading. Most occurrences have initial peak inflow rates that decline to steady rates over the observation period. Some have ceased entirely, and a few have increased inflows.

The largest individual production that was measured during this reporting period produced an aggregate of over 235 liters of brine. It was clearly an unusual and exceptional occurrence, and inflow rates for that occurrence have declined over the observation period.

It is clear from these preliminary data that the brine, gas, and salt creep phenomena are intimately associated. Pressure-driven brine inflows that are not the result of brine migration in a thermal gradient may occur at any time a pressure difference exists, including after sealing and closure of the repository. It is likely that the observed inflows into the repository excavations are dominated by the response to transient pressure gradients resulting from the excavation of the repository itself. A component due to regional hydraulic head cannot be ruled out at this time, but if it exists, it appears to be relatively very small.

Investigations of the occurrence and chemistry of the brines are continuing."

Deal, D.E., Case, J.B., Deshler, R.M., Drez, P.E., Myers, J. and Tyburski, J.R. 1987. Brine Sampling and Evaluation Program Phase II Report. DOE-WIPP-87-010. Westinghouse Electric Corporation, Carlsbad,NM.

INTRODUCTION, p 1;

" The Waste Isolation Pilot Plant (WIPP) project is a Department of Energy (DOE) research and development facility constructed to demonstrate the safe disposal of radioactive wastes derived from the defense activities of the United States. The WIPP Project's mission consists of two parts. The first is to demonstrate the safe handling and disposal of transuranic (TRU) waste in bedded salt. The second is to create a research facility for in situ examination of the technical issues related to the emplacement of defense-related radioactive waste in bedded salt.

The WIPP facility is located approximately 42 kilometers east of Carlsbad, New Mexico, in an area known as Los Medanos (Figure 1-1). The underground portion of the facility is located at a depth of approximately 655 meters in the bedded salt deposits of the Salado Formation, part of an evaporite sequence over 1000 meters thick (Figure 1-2). An extensive program of site characterization and validation has been conducted for the past eleven years (1976-1987). The results of these studies are summarized in the WIPP 'Geological Site Characterization Report' (Powers, et al., 1978), the WIPP 'Safety Analysis Report' (U.S. DOE, 1986), the WIPP 'Preliminary Design Validation Report' (bechtel National, Inc., 1983), the WIPP 'Design Validation Final Report' (Bechtel National, Inc., 1986b), and the WIPP 'Results of Site Validation Experiments' (Black, et al., 1983). Additional site investigations are being conducted as part of an ongoing program to further refine the understanding of the site-specific geology. The hydrogeological activities of the Brine Sampling and Evaluation Program (BSEP), as outlined in the Brine Testing Program Plan (Morse and Hassinger, 1985), are part of these investigations. Phase I of the BSEP activities were reported by Deal and Case (1987).

The purpose of the BSEP is to investigate the origin, hydraulic characteristics, extent, and composition of brine occurrences in the excavations for the WIPP repository in the Salado Formation. Although considered dry workings, brine is observed to weep from exposed surfaces in the repository horizon and seep into drill holes in the underground excavations.

These brine occurrences become visible shortly after excavation or drilling. The more noticeable occurrences that have been observed for more than three years produced brine at the rate of a few tenths or a few hundredths of a liter per day.

Although individual occurrences are small and not particularly noticeable on a day-to-day basis, they are pervasive throughout the repository (Deal and Case, 1987). Over a period of months and years they may contribute enough moisture to merit consideration from the standpoint of long-term repository performance. During present operations, virtually all of the moisture entering the workings from the host rock is evaporated and removed in the air that is circulated by the underground ventilation system. The assessment and understanding of the brine occurrences becomes especially important when considering what

their long-term impacts might be on operations during the demonstration and retrieval period and the rates of resaturation and repressurization of the excavations after closure of the facility.

The data presented in this report are a continuation and update of studies that began in 1983 (Black, et al., 1983; TSC-D'Appolonia, Part II, 1983; and Alcorn, 1983), formalized by Morse and Hassinger,(1985), and previously reported in the Brine Sampling and Evaluation Phase I report (Deal and Case, 1987). Users should consult Deal and Case (1987) for background information, detailed descriptions of the data gathering and analysis procedures, and the cautions that should be exercised when using the data presented herein."

Deal, D.E., Abitz, R.J., Belski, D.S., Case, J.B., Crawley, M.E., Deshler, R.M., Drez, P.E., Givens, C.A., King, R.B., Lauctes, B.A., Myers, J., Niou, S., Peitz, J.M., Roggenthen, W.M., Tyburski, J.R., and Wallace, M.G. 1989. Brine Sampling and Evaluation Program, 1988 Report. DOE-WIPP-89-015. Carlsbad, NM: Westinghouse Electric Corporation.

Executive Summary, p. E-1;

" The data presented in this report are the result of Brine Sampling and Evaluation Program (BSEP) activities at the Waste Isolation Pilot Plant (WIPP) during 1988. These activities, which are a continuation and update of studies that began in 1982 as part of the Site Validation Program, were formalized as the BSEP in 1985 to document and investigate the origins, hydraulic characteristics, extent, and composition of brine occurrences in the Permian Salado Formation, and seepage of that brine into the excavations at the WIPP. Previous BSEP reports (Deal and Case, 1987; Deal and others, 1987) described the results of ongoing activities that monitor brine inflow into boreholes in the facility, moisture content of the Salado Formation, brine geochemistry, and brine weeps and crusts. The information provided in this report updates past work and describes progress made during the calendar year 1988.

During 1988, BSEP activities focused on four major areas to describe and quantify brine activity: (1) monitoring of brine inflow parameters, e.g., measuring brines recovered from holes drilled upward from the underground drifts (upholes), downward from the underground drifts (downholes), and near-horizontal holes; (2) characterizing the brine, e.g., the geochemistry of the brine and the presence of bacteria and their possible interaction with experiments and operations; (3) characterizing formation properties associated with the occurrence of brine, e.g., determining the water content of various geologic units, examining these units in boreholes using a video camera system, and measuring their resistivity (conductivity); and (4) modeling to examine the interaction of salt deformation near the workings and brine seepage through the deforming salt."

Deal, D.E., Abitz, R.J., Belski, D.S., Clark, J.B., Crawley, M.E., and Martin, M.L. 1991a. Brine Sampling and Evaluation Program, 1989 Report. DOE-WIPP-91-009. Carlsbad, NM: Westinghouse Electric Corporation.

INTRODUCTION, p 1-1;

" The Waste Isolation Pilot Plant (WIPP) project is a Department of Energy (DOE) research and development facility established to demonstrate the safe disposal of defense generated radioactive wastes in the United States. The WIPP Project's mission consists of two parts: (1) to demonstrate the safe handling and disposal of transuranic (TRU) waste in bedded salt, and to create a research facility for in situ examination of the technical issues related to the emplacement of defense related radioactive waste in bedded salt.

The WIPP facility is located approximately 42 kilometers east of Carlsbad, New Mexico (Figure 1-1). The underground portion of the facility is located approximately 655 meters below the surface in the Salado Formation, an evaporite sequence over 1000 m thick (Figure 1-3). An extensive program of site characterization and validation has been conducted for the past 13 years (1976-1989). Initial studies are summarized in the WIPP 'Geological Site Characterization Report' (Powers and others, 1989) and the WIPP 'Preliminary Design Validation Report' (Bechtel National, Inc., 1983). Additional site investigations are being conducted as part of an ongoing program to refine the understanding of the site-specific geology. The hydrogeological activities of the Brine Sampling and Evaluation Program (BSEP) are part of these investigations.

The purpose of the BSEP is to investigate the origin, hydraulic characteristics, extent, and composition of brine in the Salado Formation excavations at the WIPP repository horizon. Although the repository horizon is considered dry, brine is observed to weep from exposed surfaces and seep into drillholes placed in the underground excavations. Brine studies began in 1982 as part of the Site Validation Program (Black and others, 1983), and was formalized in 1985 (Morse and Hassinger, 1985). The data presented in this report are an update of studies previously reported (Deal and Case, 1987; Deal and others, 1987; Deal and others, 1989). To facilitate a better understanding of the presented data, readers should consult those previous reports. Detailed descriptions of the data gathering and analytical procedures, and the cautions that should be exercised when using the data presented herein are given in these earlier reports.

Activities in 1989 provide information on the amount of brine that flows into the underground (Section 2.0), the geochemical properties of the brine (Section 3.0), and the hydrologic properties of the zone of macrofractures that develop beneath the excavations as those excavations age (Section 4.0). Other than Section 4.0, this report is an update of the 1988 Brine Sampling and Evaluation Program report (Deal and others, 1989) and further substantiates the observations and conclusions therein.

This report constitutes a permanent quality assurance record and will be retained as such as provided for in the quality assurance sections of the geotechnical Engineering Program plans and procedures."

Deal, D.E., Abitz, R.J., Myers, J., Case, J.B., Martin, M.L., Roggenthen, W.M., and Belski, D.S. 1991b. Brine Sampling and Evaluation Program 1990 Report. DOE-WIPP 91-036. Prepared for U.S. Department of Energy by IT Corporation and Westinghouse Electric Corporation. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

EXECUTIVE SUMMARY, p XV;

" The data presented in this report are the result of Brine Sampling and Evaluation Program (BSEP) activities at the Waste Isolation Pilot Plant (WIPP) during 1990. When excavations began in 1982, small brine seepages (weeps) were observed on the walls. These brine occurrences were initially described as part of the Site Validation Program. Brine studies were formalized in 1985. The BSEP activities document and investigate the origins, hydraulic characteristics, extent, and composition of brine occurrences in the Permian Salado Formation and seepage of that brine into the excavations at the WIPP. The brine chemistry is important because it assists in understanding the origin of the brine and because it may affect possible chemical reactions in the buried waste after sealing the repository. The volume of brine and the hydrologic system that drives the brine seepage also need to be understood to assess the long-term performance of the repository.

After more than eight years of observations (1982-1990), no credible evidence exists to indicate that enough naturally occurring brine will seep into the WIPP excavations to be of practical concern. The detailed observations and analyses summarized herein and in previous BSEP reports confirm the evidence apparent during casual visits to the underground workings--that the excavations are remarkably dry."

4.2.3 Model Input Parameters, p. 4-4, para. 4, second line;

" A determination was made of the moisture content of the Salado salt at the WIPP (Deal and others, 1989) that showed that the facility horizon is about 1.56 percent brine by volume (0.6 percent by weight), which must occupy that much pore space."

5.2 Origin of the Brine, p. 5-3, para. 2, 7th line;

" Estimates of the amount of fluid-inclusion brine range from 0.22 weight percent (Black and others, 1983) to 0.6 weight percent (Stein, 1985) and are clearly a minor portion of the WIPP host rocks."

5.7 Further Investigations, p. 5-13, para 3, first bullet;

" Clay samples have been collected from the WIPP underground and are being subjected to laboratory testing. Preliminary results indicate that the clay is quite wet and may contain 20 percent or more by volume. After quantification, this work will be reported in the BSEP 1991 annual report. ..."

DOE (U.S. Department of Energy), 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026, Vols. 1 and 2, Office of Environmental Restoration and Waste Management, Washington, D.C.

p 1-2, Section 1.2.1 1980 WIPP FEIS

" The 1980 WIPP Final Environmental Impact statement (FEIS) and the associated public review and comment period provided environmental input for the DOE's initial decision to proceed with the WIPP (DOE, 1980). The significance of impacts associated with the various alternatives was assessed. For the selected alternative, a two-phased approach to development was proposed: 1) a site and preliminary design validation (SPDV) program, as discussed in Subsection 8.2.1 of the FEIS, and 2) full construction, as discussed in FEIS Subsection 8.2.2. The durations of key WIPP activities are shown in Figure 1.1.

The 1980 FEIS presented an analysis of the environmental impacts of a number of alternatives for demonstrating the safe disposal of TRU waste. The alternatives considered include:

- Alternative 1. No action. A research and development facility to demonstrate safe disposal of TRU waste would not be developed and post-1970 TRU waste would continue to be retrievably stored.

- Alternative 2. Developing the WIPP at the Los Medanos site in southeastern New Mexico.

- Alternative 3. Disposing of stored TRU waste in the first available repository for high-level radioactive waste.

- Alternative 4. Delaying a decision on the site for a WIPP until at least 1984 to allow for investigation of alternative sites.

Alternative methods and geologic media for TRU waste disposal were also considered but rejected in the FEIS. The alternative methods included burial in deep ocean sediments, emplacement in deep drillholes, transmutation, and ejection into space. The alternative geologic media included igneous, volcanic, and argillaceous rocks.

The DOE's Record of Decision, published January 28, 1981 (46 FR 9162), announced the DOE's selection of Alternative 2: to proceed with the phased development of the WIPP at the Los Medanos site in southeastern New Mexico. . . ."

Volume 1, Section 1.3 The Los Medanos Site, p 1-3, para 5, line 1;

" The site is in the north-central part of the Delaware basin, a region in which evaporation in a shallow sea deposited about 3600 feet of evaporites during the Permian period 280 to 225 million years ago. A repository at this site would be built in nearly pure salt in the Salado Formation, itself almost 2000 feet thick, with a mined disposal level 2150

feet below the surface."

Volume I, Section 7.1.1, Climate, p. 7-3;
" The climate of the region is semiarid, with generally mild temperatures, low precipitation and humidity, and a high evaporation rate. Winds are mostly from the southeast and moderate. In late winter and spring, there are strong west winds and dust storms. During the winter, the weather is often dominated by a high-pressure system situated in the central portion of the Western United States and a low-pressure system located in north-central Mexico. During the summer, the region is affected by a low-pressure system normally situated over Arizona.

Temperatures are moderate throughout the year, although seasonal changes are distinct. Mean annual temperatures in southeastern New Mexico are near 60°F (Eagleman, 1976). In the winter (December through February) nighttime lows average near 23°F and average maximums are in the 50s. The lowest recorded temperature at the nearest class A weather station in Roswell was -29°F, in February 1905. In the summer (June through August), the daytime temperature exceeds 90°F approximately 75% of the time. The highest recorded temperature at Roswell was 110°F, in July 1958.

Precipitation is light and unevenly distributed throughout the year, averaging 11 to 13 inches. Winter is the season of least precipitation, averaging less than 0.6 inch of rainfall per month. Snow averages about 5 inches per year at the site and seldom remains on the ground for more than a day at a time because of the typically above-freezing temperatures in the afternoon. Approximately half the annual precipitation comes from frequent thunderstorms in June through September. Rains are usually brief but occasionally intense when moisture from the Gulf of Mexico spreads over the region."

Volume I, Section 7.1.3, Aquatic Ecology, p. 7-9, para. 4;
" The combination of high salinity, elevated concentrations of heavy metals, and salt-tolerant and marine fauna makes the lower Pecos a unique river system."

Volume 1, Section 7.3.1 Summary, p 7-17, para 7, line 1;
" Analysis of risk from vibratory ground motion at the surface shows that the greatest ground acceleration expected to occur once in 1000 and 10,000 years are less than or equal to 0.06g and 0.1g, respectively. The probabilities of higher values depend mainly on assumptions about the seismic potential of the area near the site."

Volume 1, Section 7.3.2, Regional Geology, p. 7-21, para. 8;
"Physiography and geomorphology

The WIPP site is in the Pecos Valley section of the southern Great Plains physiographic province, a broad highland belt sloping gently eastward from the Rocky Mountains and the Basin and Range province to the Central Lowlands province (Figure 7-10). The Pecos Valley section itself is dominated by the Pecos River Valley, a long north-south trough 5 to 30 miles wide and as much as 1000 feet deep in the north. The valley has

an uneven rock- and alluvium-covered floor with widespread solution-subsidence features, the result of dissolution in the underlying Upper Permian rocks. The terrain varies from plains and lowlands to rugged canyonlands, including such erosional features as scarps, cuestas, terraces, and mesas. The surface slopes gently eastward, reflecting the underlying rock strata. Elevations range from more than 6000 feet in the northwest to about 2000 feet in the south (Powers et al., 1978, pp. 3-3ff).

The Pecos Valley section is bordered on the east by the Llano Estacado, a virtually uneroded plain formed by river action. The Llano Estacado is part of the High Plains section of the Great Plains physiographic province. Few and minor topographic features are present in the High Plains section, formed when more than 500 feet of Tertiary silts, gravels, and sands were laid down in alluvial fans by streams draining the Rocky Mountains. In many areas the nearly flat surface is cemented by a hard caliche layer.

To the west of the Pecos Valley section are the Sacramento and the Guadalupe Mountains, part of the Sacramento section of the Basin and Range province. The Capitan escarpment along the southeastern side of the Guadalupe Mountains marks the boundary between the Basin and Range and the Great Plains provinces. The Sacramento section has large basinal areas and a series of intervening mountain ranges.

The main geomorphic features bearing on the region are the Pecos River drainage system, the Mescalero plain, a karst terrain, and wind-erosion 'blowouts.' The Pecos River system has evolved from the south, cutting headward through the Ogallala sediments and becoming entrenched sometime after the middle Pleistocene. It receives almost all the surface and subsurface drainage of the region; most of its tributaries are intermittent because of the semiarid climate. Most of the ground surface east of the Pecos River Valley lies in the Llano Estacado, a poorly drained eastward-sloping surface covered by gravels, wind-blown sand, and caliche that has developed since early to middle Pleistocene time. The surface locally has a karst terrain containing superficial sinkholes, dolines, and solution-subsidence troughs, from both surface erosion and subsurface dissolution. The site lies near a caliche- and sand-covered drainage divide separating two major and actively developing solution-erosion features: Nash Draw to the west and San Simon Swale to the east."

7.3.6 Seismology, p 7-48;

" The purpose of the seismic studies is to build a basis from which to predict the ground motions that the WIPP repository might be subjected to both in the near and in the distant future. The concern about seismic effects in the near future, during the operational period, pertains mainly to the design requirements for surface and underground structures to withstand levels of ground motion much greater than those expected during this period. The concern about effects occurring over the long term, after the repository has been decommissioned and sealed, pertains more to relative motions (faulting) within the repository and possible effects on the integrity of the salt beds and/or shaft seals.

In this discussion, all intensities are based on the modified Mercalli intensity scale (Wood and Neuman, 1931). Most of the magnitudes were determined by the New Mexico Institute of Mining and Technology or described in the Geological Characterization Report

(Powers et al., 1978, pp. 5-10ff).

Seismic history

Seismic data are presented here in two time frames, before and after the time when seismograph data for the region became available.

The earthquake record in southern New Mexico dates back only to 1923, and seismic instruments have been in place in the State only since 1961. Sanford and Toppozada (1974) have examined various records to determine the seismic history of the area within 180 miles of the site. Their results for the period before 1961 are given in Table 7-3. With the exception of the weak shock in 1926 at Hope, New Mexico, and the shocks in 1936 and 1949 felt at Carlsbad, all known shocks before 1961 occurred to the west and southwest of the site and more than 100 miles away.

Since 1961, instrumental coverage has become comprehensive enough to locate most of the moderately strong earthquakes (local magnitude >3.5) in the region. Instrumentally determined shocks that occurred within 180 miles of the site since 1961 are listed in Table 7-4 and shown in Figure 7-21. Their distribution may be biased by the fact that seismic stations were more numerous and were in operation for longer periods north and west of the site.

Except for the activity southeast of the site, the distribution of epicenters since 1961 differs little from that of shocks before that time. There are two clusters, one associated with the Rio Grande Rift on the Texas-Chihuahua border and another associated with the Central Basin platform in Texas near the southeastern corner of New Mexico. This latter activity was not reported before 1964. It is not clear from the record whether earthquakes were occurring in the Central Basin platform before 1964, although local historical societies and newspapers tend to confirm their absence before that time.

A station operated for 10 months at Fort Stockton, Texas, indicated many small shocks from the Central Basin platform. Activity was observed at the time the station opened on June 21, 1964. Shurbet (1969) suggested that this activity is related to the injection of water underground for oil recovery. The suggestion has merit in that the Central Basin platform is an old structure (Early Permian), with no surface indication of having been rejuvenated, and in that enormous quantities of water have been injected. In one of the oil fields, the Ward-Estes North operated by the Gulf Oil Corporation, the cumulative total of water injected up to 1970 was over 1 billion barrels. Accounting for 42% of the water injected in Ward and Winkler Counties, Texas, the quantity is three times the total injected in all the oil fields of southeastern New Mexico in the same period. The known hydrocarbon resources nearest the site are two gas wells approximately 3 miles to the southwest of the center of the site. Water injection has not been used in this region to stimulate gas production. The nearest oil fields in the Delaware basin, where secondary recovery might be attempted, are 7 miles from the site. Water-injection operations would be prohibited within the site during the period of administrative control. After the closing of the repository, seismicity induced by water injection would not produce enough ground displacement to jeopardize the repository.

The strongest earthquake on record within 180 miles of the site was the Valentine, Texas, earthquake of August 16, 1931 (event 4 in Table 7-3). Coffman and von Hake (1973) estimate it to have been of magnitude 6.4 (modified Mercalli intensity of VIII). The Valentine earthquake was 130 miles southwest of the site. Its modified Mercalli intensity at the site is estimated to have been V; this is believed to be the highest intensity felt at the site in this century.

In 1887, a major earthquake occurred in northeast Sonora, Mexico. Although about 335 miles west-southwest of the site, it is indicative of the size of earthquakes possible in the eastern portion of the Basin and Range province, west of the province containing the site. Sanford and Toppozada (1974) estimate its magnitude to have been 7.8, and Coffman and von Hake (1973) list it as VIII-IX in modified Mercalli intensity. It was felt over an area of 0.5 million square miles (as far as Santa Fe to the north and Mexico City to the south); fault displacements near the epicenter were as large as 26 feet (Aguilera, 1920).

Local observations

From April 1974 to October 1978, 420 events identifiable as local and regional earthquakes (within about 210 miles) were recorded by a station (CLN) 4 miles from the center of the site (see Appendix J). For 159 of the 420 events, the epicenters were identified and magnitudes determined (Table 7-4). Nine tentative locations were also determined. These seismic patterns are similar to those of the preinstrumental data.

Local earthquakes. Any seismic activity at or near the site is of great interest. Three events (July 26, 1972; November 28, 1974; and January 19, 1978) have been instrumentally recorded within 35 miles of the WIPP site. Seismic events become more numerous with distance.

The nearest event to the WIPP site occurred on January 19, 1978, about 10 miles northeast of station CLN. its magnitude was 2.3, and the event does not appear to have been related to human activity.

The other two nearby events (July 26, 1972, and November 28, 1974) had magnitudes of 2.8 and 3.6, respectively, and both were about 25 miles to the northwest. At both times, rockfalls and ground cracking were reported at an active potash mine. To determine whether the two epicenters coincided. They were about 6 miles apart. Thus the two events cannot both have been caused by the mine. Moreover, the earthquake had too much energy to have been caused by the rockfall. In the absence of additional seismic data on these events, seismic risk at the site should be estimated on the assumption that both were natural (Caravella and Sanford, 1977).

Seismic risk

Maps of the position and intensity of recorded earthquakes are useful in evaluating the probability of an earthquake at a given site. To increase their usefulness, the historical data have been supplemented with field geologic data.

Several researchers have divided the United States into zones of earthquake risk. The standard estimate is that of Algermissen (1969). According to this estimate, the site is

located in seismic risk zone 1, where only minor damage to structures is to be expected, corresponding to a modified Mercalli intensity of V to VI. Earlier, Richter (1959) had placed the region within a seismic zone where the probable maximum intensity would be VIII. Sanford and Toppozada (1974) considered the site to be either on the boundary of zones 2 and 3 or within zone 2, depending on whether earthquakes in the Central Basin platform are found to be natural or induced by human activity.

One desires not only an estimate of the largest seismic motions possible at a site but also an estimate of their probability. Such an estimate has been made for the WIPP site, starting with an analysis of the recurrence rates of earthquakes in nearby active areas.

Earthquakes in the Central Basin platform. The Central Basin platform is a structural feature less than 30 miles east of the site, adjacent to the Delaware basin. Instrumental studies have shown the Central Basin platform to be much more active than would be expected from its stable tectonic setting. Primarily for this reason, a seismographic station array was established in Kermit, Texas, late 1975. During the period from November 1975 to July 1977, 407 local events were detected and 135 located with array data.

The Central Basin platform has been active since at least mid-1964. It has been the most active seismic area within 180 miles of the site in the number of events, but not in magnitude of events. The data imply that seismic activity is equally likely to occur anywhere along the Central Basin platform, without any clear relationship to small-scale structural details such as pre-Permian buried faults. Attempts have been made to relate this seismicity to the injection of water for the recovery of oil. Such a relationship has not been unequivocally established, but the lack of evidence for a tectonic origin suggests this correlation.

Sanford et al. (1978) calculated the apparent recurrence rates for earthquakes on the Central Basin platform. The distribution of minor shocks implied a recurrence rate of every 10,000 years for earthquakes of the size of the 1887 Sonoran event. There is no evidence that such earthquakes have occurred (fault scarps 25 miles long would be expected from shallow quakes such as these, with displacements of perhaps 10 feet; they are not found). To explain this discrepancy, three possible explanations have been advanced:

1. Crustal movement has only recently resumed on the Central Basin platform.
2. The structure of the Central Basin platform imposes a limit on the possible magnitude of earthquakes.
3. The minor shocks observed were caused by human activity.

The first explanation may not be absolutely discarded. However, it is extremely unlikely that a structure such as the Central Basin platform, which has exhibited no tectonic movement for about 200 million years, should be tectonically reactivated so recently that no surface manifestations are observed. The calculated recurrence rates previously discussed indicate a large event every 10,000 years; no surficial evidence has been found to confirm such events. The first explanation is not reasonable given the information now available. The third explanation, which seems best supported by the evidence, means that the seismic activity in the Central Basin platform is not natural and should be not be used for assessing tectonic stability over the long term. The second explanation is used for assessing tectonic

stability over the long term. The second explanation is used in the analysis presented here. It is more conservative in that it assumes natural causes (which is probably not the case), but with an upper limit to the magnitude of an earthquake on the Central Basin platform. This assumption would be consistent with natural earthquakes in a region where the geology does not indicate large recent events.

The method of Cornell (1968) was used to estimate seismic risk at the site (Powers et al., 1978, pp.5-32ff). Three source regions suggested by Algermissen and Perkins (1976) were used: the Rio Grande rift, the Central Basin platform, and the remainder of the area within 180 miles of the WIPP site (site source zone). The analysis used Sanford's recurrence relationships (Sanford et al., 1976, 1978). On the basis of the earthquake of 1887, an upper limit of 7.5 was set on the magnitude of earthquakes in the Rio Grande rift.* On the basis of the largest earthquake observed so far (magnitude 3.2) and considering the uncertainties in causative mechanisms, the upper magnitude limit for the Central Basin platform was set at 5 and 6 in separate calculations. The largest earthquake so far observed in the remaining region (the site source zone) was of magnitude 3.6; from this, and from the absence of any indication of Holocene local faulting, the upper magnitude limit for the site region was set at 4.5 and 5 in separate calculations. The depth of earthquakes in the site source zone was assumed to be 3 miles.

The Cornell method expresses seismic risk as the probability per year that a specific acceleration will be reached or exceeded. The probabilities calculated for the WIPP site are shown in Figure 7-22.

Figure 7-22 shows the separate contributions to these totals of each of the three sources regions with each of the assumed upper magnitude limits. The contribution of the Rio Grande rift source zone to the total seismic risk at the site is small at all acceleration levels. Curves A and B and curves C and D indicate the total combined acceleration for the various combinations of upper magnitude limits indicated above.

From Figure 7-22 the accelerations that would be experienced at the site from earthquakes in the three source zones separately are as follows for two levels of probability:

Source zone	Upper limit magnitude	Acceleration g for probability (per year) 10^{-8}	10^{-6}
Rio Grande rift	7.5	0.14	0.09
Central Basin platform	6.0	0.17	0.15
Central Basin platform	5.0	0.07	0.07
Site source zone	5.0	>0.3	0.23
Site source zone	4.5	0.21	0.17

The total seismic risk is controlled by earthquake probabilities in one of these source zones, depending on the acceleration level considered. The relationships are shown below.

	Upper limit magnitude		Controlling zone	
Rio Grande rift	Central Basin platform(CBP)	Site source zone (SSZ)	High acceleration	Low acceleration
7.5	5	4.5	SSZ	SSZ
7.5	6	4.5	SSZ	CBP
7.5	5	5.0	SSZ	SSZ
7.5	6	5.0	SSZ	CBP

Thus assumptions about the seismic properties of the area around and beneath the site (site source zone) are important in estimating seismic accelerations at the WIPP site and the potential for faulting through the repository after its closure. The possibility of faulting at the site of a magnitude that could significantly affect its integrity is extremely low."

7.3.7 Energy and Mineral Resources, page 7-64, para 6;
"Methods used to determine potash reserves at the WIPP site

Two separate studies were conducted for the DOE by the U.S. Bureau of Mines (USBM, 1977) and Agricultural and Industrial Minerals, Inc. (AIM, 1979) to determine what portion of the potash resources at the WIPP site is economic and may be considered to be reserves. Both studies started with the basic grade and thickness data provided by the USGS, and the USBM study was available for use by AIM. However, the two studies used different concepts for the development of the potash reserves and evaluated processing difficulties independently. The AIM approach, which may more nearly resemble the perspective of a potash operator, results in lower reserve estimates. However, because estimates of reserves and the associated economics are subject to uncertainty and because the USBM report gives a higher estimate of reserves, most table presented here will use USBM reserve estimates. The AIM report also estimated potash resources in the Carlsbad district and in the United States to allow comparison with the WIPP-site resources, and their values will be used in these comparisons. It should also be noted that local potash operators question the economic feasibility of mining the WIPP reserves.*

The USBM method of determining to what extent the deposits could be profitably mined and thus considered reserves consisted of designing conceptual models for exploiting the deposits. Models ranged from new mines and refineries to mines that merely send the new ore to existing refineries. Shaft locations were selected to minimize underground development and allow the richest ore beds to be mined first. The latter is important to the quick recovery of invested capital.

Costs were either estimated or, when available, matched to known cost experience at nearby mines. All costs, including construction, were used in discounted cash-flow analysis to determine the market price for refined products guaranteeing a 15% rate of return on

invested capital. Federal, State, and local taxes and royalties were taken into account.

In all, the USBM prepared 12 different conceptual plans (which it has termed mining units) for exploiting the potash deposits in the WIPP site. Of these, eight were fully evaluated and four discarded because of complex problems related to the enrichment of raw ore.

Results of the potash-reserve determination

The full findings of the reserve evaluation have been reported (USBM, 1977; AIM, 1979), and the USBM estimates are summarized in Table 7-8. The eight mining units that were conceived and then costed are listed in the approximate order in which they would rank as potentially minable. Only the 48.46 million tons in mining units B-1 (Figure 7-25) within the site were classified as reserves by the USBM study. This is much less than would be classified as reserves by the USGS. The USGS used the potash grade and thickness parameters of the most efficient producers in the district. These minimum ore standards, excluding all other minability parameters, include all material in the WIPP site with a minimum cutoff grade of 4% K_2O as langbeinite or 10% K_2O as sylvite in a thickness of 4 feet.

The USBM used criteria consistent with industry practice in preparing economic-feasibility studies. In calculating potash-ore reserves, it used a method based on engineering design and economic-analysis procedures, including discounted cash flow, to determine the tonnage of minable potash ore that will yield a 15% rate of return on the total capital investment. Only economically recoverable ore is included in the USBM reserve estimates.

Under the USBM criteria, only mining unit B-1 meets the 1977 market prices current at the time of the study: $42 per ton of muriate, $84 per ton of "sulfate" (K_2SO_4), and $48 per ton of langbeinite. This particular reserve consists of langbeinite, mostly in ore bed 4 in the northern portion of the site. (Restriction of mining within the WIPP site would not render uneconomic the remainder of mining unit B-1 outside the site.)

Unit A-1 does not meet the market-price requirements; however, the market price of muriate has exceeded $52 per ton in the recent past, at which point the A-1 deposit would be considered a marginal, or "nearly economic," deposit. (Average market prices for October 1979 were $58.37 per ton of muriate, $42-44 per ton of langbeinite, and $56.14 per ton of all sulfate products: USGS Conservation Division, Monthly Mining Report, Roswell, New Mexico.) The A-1 deposit consists of sylvite contained in ore bed 10 and located on the west side of the site.

Methods used to determine the hydrocarbon resources at the WIPP site

The New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) conducted hydrocarbon-resource study in southeastern New Mexico under contract to the Oak Ridge National Laboratory (Foster, 1974). The study included an area of 1512 square miles (Figure 7-26). At the time of that study, the proposed repository site was about 5 miles northeast of the current site. The NMBM&MR evaluation included a more detailed study of

a four-township area centered on the old site; the present site is in the southwest quadrant of that area (Figure 7-26).

The resource evaluation was based both on the known reserves of crude oil and natural gas in the region and on the probability of discovering new reservoirs in areas where past unsuccessful wildcat drilling was either too widely spread or too shallow to have allowed discovery. All potentially productive zones were considered in the evaluation; therefore, the findings may be used for determining the total hydrocarbon resources at the site. A fundamental assumption in this study is that the WIPP area has the same potential for containing hydrocarbons as the much larger region in which the study was conducted and for which exploration data are available. Whether such resources actually exist can be satisfactorily established only by drilling at spacings close enough to give a high probability of discovery.

Results of the hydrocarbon-resource evaluation

Table 7-9 summarizes the findings of the NMBM&MR hydrocarbon evaluation as the potential resource of hydrocarbons that probably exist under a square mile (640 acres) with the typical geologic and stratigraphic section of that region. The New Mexico Bureau of Mines and Mineral Resources examined an area of 967,680 acres (1512 square miles). The hydrocarbon resources under the site are then estimated as the proportion of the total in the 29.625 square miles of the site (Table 7-10).

The hydrocarbon-resource quantities given in Table 7-10 are equivalent to potash-resource-quantity estimates in that both relate to the quantity of what is present, and not to its economic value or recoverability. Because the hydrocarbon-resource evaluation relies on statistical probability, it is not as accurate as the potash-resource evaluation. The potash resources were actually drilled and assayed, while the hydrocarbon resources were estimated by projecting historical drilling success into an untested area. Site-selection requirements dictated that the inner zones be free of deep holes (i.e., oil and gas test holes)."

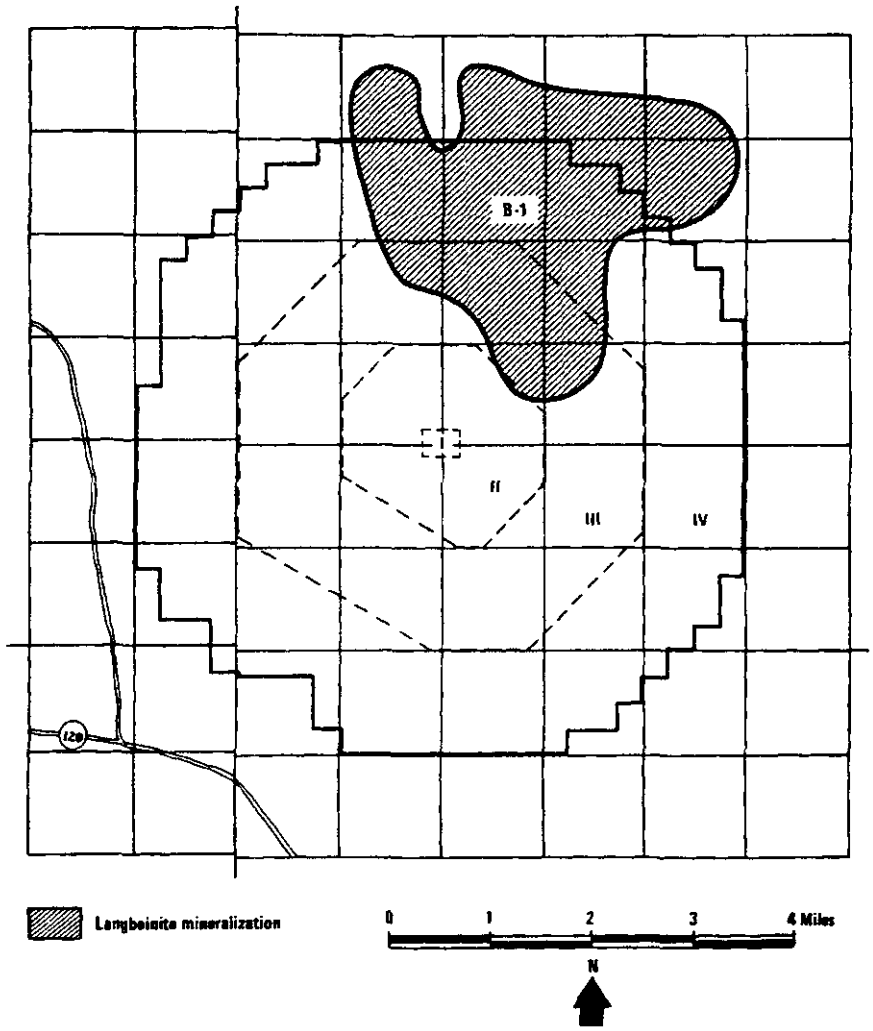

Figure 7-25. Economic langbeinite mineralization in mining unit B-1. (After USBM, 1977).

7.4.1 Surface-Water Hydrology, p 7-79, para 4;
" The maximum recorded flood on the Pecos River near Malaga occurred on August 23, 1966, with a discharge of 120,000 cubic feet per second (cfs) and a stage elevation of about 2938 feet above mean sea level (USGS Station No. 08406500). The minimum surface elevation of the WIPP site is approximately 300 feet above the elevation of this maximum historical flood elevation."

7.4.1 Surface-Water Hydrology, p 7-80, para 2;
" More than 90% of the mean annual precipitation at the site is lost by evapotranspiration. Table 7-15 shows the mean monthly temperature at Artesia, the mean

monthly pan evaporation at Lake Avalon, and the mean monthly rainfall at Carlsbad. On a mean monthly basis, evapotranspiration at the site greatly exceeds the available rainfall; however, intense local thunderstorms may produce runoff and percolation. Water-infiltration rates in the local sand dunes are probably similar to the 1.6-inch-per-hour intake rate of Harkey sandy loam (75% sand) near Carlsbad (Blaney and Hanson, 1965)."

7.4.1 Surface-Water Hydrology, Local surface-water hydrology,p 7-83, para 1;
" The drainage area of the Pecos River at this location is 19,000 square miles (Figure 7-29). A few small creeks and draws are the only westward-flowing tributaries of the Pecos River within 20 miles north or south of the site. (A low-flow investigation has been initiated by the USGS within the Hill Tank Draw drainage area, the most prominent drainage feature near the WIPP site. The drainage area is about 4 square miles, with an average channel slope of 1 to 100, and the drainage is westward into Nash Draw. Two years of observations showed only four flow events. The USGS estimates that the flow rate for these events was under 2 cubic feet per second.) The Black River (drainage area 400 square miles) joins the Pecos from the west about 16 miles southwest of the site. The Delaware River (drainage area 700 square miles) and a number of small creeks and draws also join the Pecos along this reach. The flow in the Pecos River below Fort Sumner is regulated by storage in Lake Sumner, Lake McMillan, Lake Avalon, and several other smaller irrigation dams."

8.7.5 Airborne Effluents, p 8-36, para 3;
"Emissions from fuel combustion
There will be three principal sources of emissions from the combustion of diesel fuel: the emergency-power system, the surface handling equipment, and the underground handling equipment. In addition, an oil-fired drier may be required to dry the salt stored on the surface for backfilling the repository. Table 8-9 shows the calculated annual emissions. The calculations were based on emission factors published by the U.S. Environmental Protection Agency (EPA, 1977) and on the following assumptions: The emergency-power diesel-generator plant, with an installed capacity of about 10,000 horsepower, will be used 1% of the time (88 hours per year). The diesel-powered surface handling equipment (about 3400 horsepower) will be used about 10% of the time during one work shift each day. The underground salt-handling equipment (about 560 horsepower) will be used about 40% of the time during one work shift each day. The salt drier (approximately 30 million Btu per hour, using about 800,000 gallons of fuel per year) will be used during one work shift each day after mining has ceased."

Table 8-9. Estimated Annual Emissions from the Combustion of Diesel Fuel[a]

Pollutant	EPA emission factor (g/hp-hr)	Total (lb/yr)
EMERGENCY POWER PLANT		
Carbon monoxide	3.03	5,870
Hydrocarbons	1.12	2,170
Nitrogen oxides	14.00	27,100
Sulfur dioxide	0.93	1,800
Particulates	1.00	1,940
SURFACE HANDLING EQUIPMENT[b]		
Carbon monoxide	2.62	5,730
Hydrocarbons	0.85	1,860
Nitrogen oxides	14.9	32,600
Sulfur dioxide	0.89	1,950
Particulates	0.78	1,710
UNDERGROUND HANDLING EQUIPMENT[b]		
Carbon monoxide	2.62	3,780
Hydrocarbons	0.85	1,220
Nitrogen oxides	14.9	21,500
Sulfur dioxide	0.89	1,280
Particulates	0.78	1,120
MINED-SALT DRIER[c]		
Carbon monoxide	5.0[d]	4,000
Hydrocarbons	1.0[d]	800
Nitrogen oxides	22.0[d]	17,600
Sulfur dioxide	71.0[d]	56,800
Sulfur trioxide	1.0[d]	800
Particulates	2.0[d]	1,600

[a]Based on factors published by the EPA (1977).
[b]Emission rates based on one 8-hour work shift per day.
[c]Emission rates based on one 8-hour work shift per day after mining has ceased or decommissioning decision has been made.
[d]Units of pounds per 1 thousand gallons of fuel consumed.

9.2.1 Biophysical Environment, p 9-14, para 3;
"Biological resources

Adverse impacts on biological resources are expected to be slight for the following reasons (Appendix H, Section H.5):

1. No proposed natural areas are present on or animals are known to inhabit the site or the vicinity of the site; nor are any critical habitats known to exist on or near the site.

2. No endangered species of plants or animals are known to inhabit the site or the vicinity of the site; nor are any critical habitats known to exist on or near the site.
3. Water requirements for the site are low.
4. The land contains soil types and vegetation associations that are common throughout the region.
5. Access in the form of dirt roads is already available throughout the area; therefore, recreational use of the area is not likely to increase significantly.

Planned mitigation measures (Section 9.6) will prevent unnecessary damage to plants and animals in areas that might be affected by fugitive dust and dispersed salt. The removal of land from rangeland habitats during construction will produce other effects on biological resources; the acreages to removed are listed in Table 9-1.

During the SPDV program and repository construction, a total of 49 and 192 acres, respectively, will be cleared of vegetation from the shinnery oak, senecio, sage-brush, yucca, mesquite, and broom snakeweed vegetation types. All vegetation and wildlife in this area will be removed for the duration of the project. Environmental studies conducted at nearby potash mines indicate that vegetation adjacent to the mined-rock (salt) pile will be reduced or eliminated (Appendix H, Section H.5). It is probable that, in small areas near the pile, enough material will be deposited to cause adverse effects, and some vegetation may be lost. However, a 1978 field examination around a mined-rock pile at the site of Project Gnome, an underground nuclear explosion carried out in 1961 9 miles from the WIPP site, found no identifiable salt-related stress on any of the vegetation in the area with the single exception of a mesquite tree growing on one end of the pile itself (Intera, 1978). There is thus some evidence that the local vegetation may be able to adapt to a more saline environment than it is now experiencing.

In addition to the areas that will be cleared of vegetation, 18 and 710 acres of existing vegetation will be disturbed, respectively, for rights-of-way corridors during the SPDV program and repository construction. For the complete repository, 112 acres of rights-of-way will be covered with roads and railroads (Table 9-1). Creosote bush may invade the roadway and railroad and thrive there, providing cover in these corridors. Much of the land cleared during construction will revert to natural vegetation. Although some of the removed plant species may remain absent from the rights-of-way for years, the impact is considered minor because the removed species are very common in the region.

Impacts on wildlife from construction can be classified as follows:

1. Direct mortality of nonmobile species, such as small and burrowing mammals, ground-nesting birds, reptiles, and insects.
2. Displacement of mobile species (including game species and birds) by the loss of habitat and human intrusion (visibility of people and increased noise levels).
3. Increased competition and stress among species in adjacent areas.
4. Direct loss of species from road kills and poaching.

No unique species or populations have been identified at the site, and the loss of individuals of the species present is not significant to the overall ecology of the site area.

The environmental impact of corridors has been studied by ecologists for a relatively short time, and concepts are still in the formative stages. A number of impacts can be expected from the construction of rights-of-way. Some raptor deaths may be caused by electrocution on utility lines, but the lines will be designed to minimize such occurrences (Bulletin 61-10 of the Rural Electrification Administration). Although some negative effects (increased animal mortality, inhibition of animal movements) should be expected when the roads are built, roadways often have a positive effect on local biota by increasing the diversity of habitats. Corridors provide habitat that may favor the establishment of small-mammal communities differing in composition from surrounding communities. Animals adapted to open areas may appear in the new communities, and transient species may be able to outcompete residents.

Right-of-way construction will frighten and displace the larger and more mobile wildlife inhabitants. This disturbance is attributed not only to habitat removal but also to an increase in the visibility of people and frequent sharp increases in ambient noise levels. The displaced species will migrate to adjacent undisturbed habitats and may temporarily cause an ecological imbalance or stress condition in local adjacent habitats, resulting in a loss of most of the displaced organisms. The highly mobile game species present at the site, the mule deer and the pronghorn, while displaced, are not expected to suffer any significant losses in their local population because the area of disturbance will be small when compared to the normally large ranges of these species. Bird populations, on the other hand, may benefit from right-of-way corridors (Anderson et al., 1977). The increased habitat diversity (the "edge effect") increases the densities of some bird species. Summer residents have sometimes increased in density at the apparent expense of year-round residents."

Table 9-14. Significance of the Resources and Reserves at the WIPP Site.

Deposit	WIPP site	Region	United States	World
RESOURCES[a]				
Sylvite (at lease grade) Quantity, millions tons ore Percentage at WIPP site High grade Low grade	 88.5 54.0 133.2	 4260 2.1	 8500 1.0	 850,000 0.010
Langbeinite (at lease grade) Quantity, millions tons ore Percentage at WIPP site High grade Low grade	 264.2 77.6 351.0	 1140 23 (21.5 as K_2O)	No estimate available	
Crude oil Quantity, million barrels Percentage at WIPP site	 37.50	 1915 2.0	 200,000 0.019	 Not available
Natural gas Quantity, billion cubic feet Percentage at WIPP site	 490	 25,013 2.0	 855,000 0.057	 Not available
Distillate Quantity, million barrels Percentage at WIPP site	 5.72	 293 2.0	Not available	
RESERVES[b]				
Sylvite[c] Quantity, million tons K_2O Percentage at WIPP site	 3.66	 106 3.4	 206 1.8	 11,206 0.033
Langbeinite[d] Quantity, Million tons K_2O Percentage at WIPP site	 0.92[d]	 9.3 10	 9.3 10	 Not available
Crude oil Quantity, million barrels Percentage at WIPP site	 Nil	 471.7 0	 29,486 0	 646,000 0
Natural gas Quantity, billion cubic feet Percentage at WIPP site	 44.62	 3865 1.15	 208,800 0.021	 2,520,000 0.0018
Distillate Quantity, million barrels Percentage at WIPP site	 0.12	 169.1 0.07	 35,500 0.0003	 Not available

[a]Data sources: Hydrocarbons, Foster (1974) for the site and region; potash salts, John et al. (1978) for the site and region; Brobst and Pratt (1973) for U.S. oil and gas and the world resources of sylvite.

[b]Data sources: Hydrocarbons, Keesey (1979) for the site, American Petroleum Institute (1978) for the region, the United States, and the world; potash salts, U.S. Bureau of Mines (USBM, 1977).

[c]The U.S. Bureau of Mines (USBM, 1977) does not consider any sylvite to be commercial today. However, one bed (mining unit A-1) of sylvite was marginal and has been added to the reserve list.

[d]Estimated from the AIM (1979) study. The USBM estimate for the WIPP site is 4.41 million tons K_2O equivalent, but no comparable USBM estimate is available for the entire district.

9.2.3.5 Significance of the Hydrocarbon Resources, p 9-26;

" Table 9-14 puts the hydrocarbon resources into perspective. While the quantities of hydrocarbons that may exist under the site are large, they account for only 2.0% of the crude oil, 2.0% of the natural gas, and 2.0% of the distillate that could exist in the region. (The region is here defined as the area studied by the New Mexico Bureau of Mines and Mineral Resources. That area contains 967,700 acres, or 1512 square miles, versus only 18,960 acres, or 29.625 square miles, for the site.) On a national basis, the expected crude oil at the site accounts for only 0.019% and natural gas for only 0.057% of U.S. resources."

Section 9.7.2.2 Effects of Subsidence, p 9-152, para 1,2, line 3;

" In Nash Draw subsidence on the order of 200 feet are suspected to have created vertical interconnections between water-bearing strata in the Rustler Formation. Hydrologic testing has not yet determined whether this is true, but the possibility remains that to a lesser extent, because of the smaller subsidence, interconnections may also appear over the repository. Water from the Magenta and the Culebra aquifers might then be introduced to the top of the Salado salt. That by itself would have little significance because of the 1200 feet of slat intervening between the top of the salt and the disposal level. At worst, pathways for water intrusion similar to those postulated in scenarios 2 or 4 (Section 9.7.1.3) might be initiated. It has been noted that the radiation doses produced as a consequence of these scenarios are much lower than doses from natural background radiation. Therefore subsidence, even when extrapolated to an extreme, would not significantly affect public health and safety. Furthermore, water has not flowed into the local potash mines in spite of much more severe subsidence than the repository will experience.

Investigations of subsidence continue. A first-order level-line survey line was laid out in 1978 to establish baseline elevations at the site and to monitor subsidence over certain active potash-mining operations. These field observations will help in developing a better understanding of the subsidence processes and in providing data for testing models. Other studies are now investigating the effects of subsidence on the surface, on the rock column and on the aquifers.".

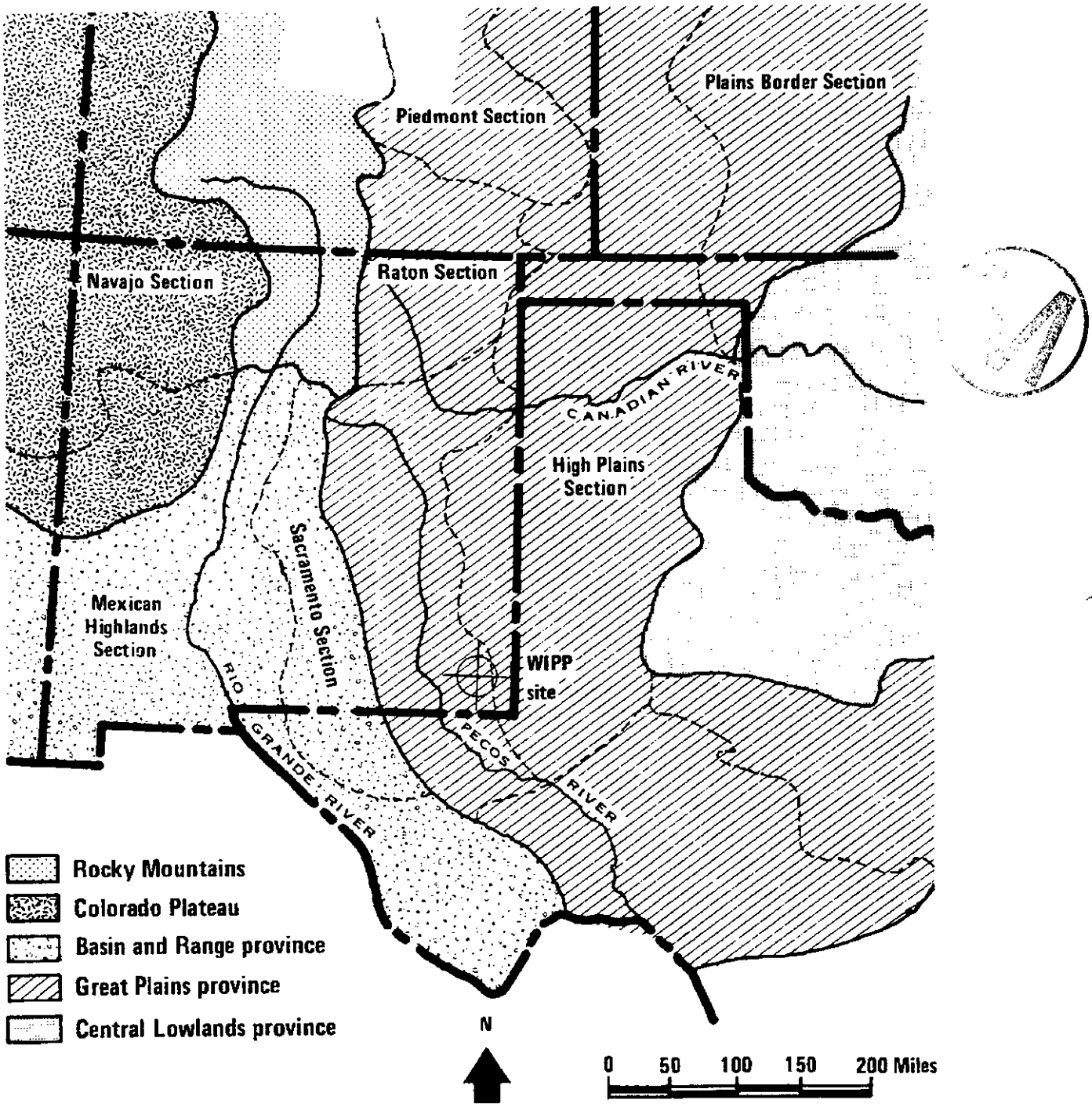

Adapted from Fenneman (1931).

Figure 7-10. Physiographic provinces and sections.

Deal, D.E., Abitz, R.J., Myers, J., Martin, M.L., Milligan, D.J., Sobocinski, R.W., Lipponer, P.P.J., and Belski, D.S. 1993. Brine Sampling and Evaluation Program, 1991 Report. DOE-WIPP-93-026. Carlsbad, NM: Westinghouse Electric Corporation.

Executive Summary, para 2;
" During nine years of observations (1982-1991), evidence has mounted that the amount of brine seeping into the WIPP excavations is limited, local, and only a small fraction of that required to produce hydrogen gas by corroding the metal in the waste drums and waste inventory. The data through 1990 is discussed in detail and summarized by Deal and others (1991). The data presented in this report describes progress made during the calendar year 1991 and focuses on four major areas: (1) quantification of the amount of brine seeping across vertical surfaces in the WIPP excavations (brine weeps); (2) monitoring of brine inflow, e.g., measuring brines recovered from holes drilled downward from the underground drifts (downholes), upward from the underground drifts (upholes), and from subhorizontal holes; (3) further characterization of brine geochemistry; and (4) preliminary quantification of the amount of brine that might be released by squeezing the underconsolidated clays present in the Salado Formation."

Moisture Contents of Clay in the Salado Formation., p. x, Para. 1;
" Clay samples from the WIPP underground were tested in the laboratory to determine how much brine could be squeezed out of them if they were compacted under lithostatic loading. Approximately 25 to 29 percent brine by volume is available. Preliminary calculations indicate that there is enough brine available in the clay within a meter or two of the excavations to account for the observed brine weeps."

4.3.1. Brine Available from Clay Consolidation, p. 4-2, Para. 3;
" The assumption that moisture in the Salado Formation is associated with clays is made for the following reasons. The amount of moisture driven from the WIPP rock samples by heating to 95°C varies directly with the clay content (Deal and others, 1989, Section 4.1). Borehole conductivity studies (Deal and others, 1989, Section 4.2) also show a direct correlation between conductivity, clay content, and moisture, allowing moisture content to be calculated from conductivity. Observations in the WIPP excavations consistently record that patches of moisture often extend downward from the lithologic unites that have the most clay (Deal and others, 1991, Section 2.2.2)."

p. 4-4, Para. 1;
" The volumetric brine content of pure clay can be calculated using the following equation

$$\text{Volumetric Brine Content (\%)} = \frac{\text{Density of Clay}}{\text{Brine Mass (\%)} \times \text{Density of Brine}}$$

(after Hillel, 1980)

where

Brine mass = 12.35 percent
Brine density = 1.22
Range of clay density = 2.5 to 2.9.

The calculated volumetric brine contents of pure Salado clay is shown in Table 4-2, ranging between approximately 25 and 29 percent, with most likely values near 26 or 27 percent."

DOE (U.S. Department of Energy). 1995. Brine Sampling and Evaluation Program, 1992-1993 Report and Summary of BSEP Data Since 1982. DOE-WIPP-94-011, Carlsbad, NM: Westinghouse Electric Corporation.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Domski, P.S., Upton, D.T., and Beauheim, R.L. 1996. Hydraulic Testing Around Room Q: Evaluation of the Effects of Mining on the Hydraulic Properties of Salado Evaporites. SAND96-0435. Sandia National Laboratories, Albuquerque, NM. WPO 37380.

ABSTRACT; p. 1, para. 1;

" Room Q is a 109-m-long cylindrical excavation in the Salado Formation at the Waste Isolation Pilot Plant (WIPP) site. Fifteen boreholes were drilled and instrumented around Room Q so that tests could be conducted to determine the effects of room excavation on the hydraulic properties of the surrounding evaporite rocks. Pressure-buildup and pressure-pulse tests were conducted in all of the boreholes before Room Q was mined. The data sets from only eight of the boreholes are adequate for parameter estimation, and five of those are of poor quality. Constant-pressure flow tests and pressure-buildup tests were conducted after Room Q was mined, producing eleven interpretable data sets, including two of poor quality. Pre-mining transmissivities interpreted from the three good-quality data sets ranged from 1 x 10^{-15} to 5 x $10^{-14}m^2/s$ (permeability-thickness products of 2 x 10^{-22} to 9 x $10^{-21}m^3$) for test intervals ranging in length from 0.85 to 1.37 m. Pre-mining average permeabilities, which can be considered representative of undisturbed, far-field conditions, were 6 x 10^{-20} and 8 x $10^{-20}m^2$ for anhydrite, and 3 x $10^{-22}m^2$ for halite. Post-mining transmissivities interpreted from the good-quality data sets ranged from 1 x 10^{-16} to 3 x $10^{-13}m^2/s$ (permeability-thickness products of 2 x 10^{-23} to 5 x $10^{-20}m^3$). Post-mining average permeabilities for anhydrite ranged from 8 x 10^{-20} to 1 x $10^{-19}m^2$. These values are thought to have been only slightly, if at all, affected by excavation of Room Q. Post-mining average permeabilities for halite ranged from 2 x 10^{-23} to 5 x $10^{-20}m^2$, and are thought to reflect varying degrees of excavation response. Pore pressures decreased by several MPa after mining at all boreholes for which reliable pre- and post-mining comparisons are possible, except for one borehole at which no change was observed. The changes in hydraulic properties and pore pressures that were observed can be attributed to one or a combination of three processes: stress reduction, changes in pore connectivity, and flow towards Room Q. the effects of the three processes cannot be individually quantified with the available data."

Eager, G.P. 1983. Core from the Lower Dewey Lake, Rustler, and Upper Salado Formation, Culberson County, Texas. In Permian Basin Cores, R.L. Shaw and B.J. Pollen, eds., P.B.S.-S.E.P.M. Core Workshop No. 2, pp. 273–283. Permian Basin Section, Society of Economic Paleontologists and Mineralogists, Midland, TX.

INTRODUCTION, p 273;

" Seven hundred and twenty feet of continuous Upper Permian core is displayed by Texasgulf, Inc. The formations cored include the lower portion of the Dewey Lake, the Rustler, and the upper portion of the Salado. This core was obtained by Texasgulf, Inc., as part of a sulphur exploration program. The depth of the core is from 37 feet to 757 feet. It is located in the SE¼, Section 5, PSL, Block 45 (12 miles southwest of Orla) Culberson County, Texas (Fig. 1). Gamma ray and neutron logs are included (Fig. 2) so that the lithology can be compared to the geophysical response. All depths are reported in feet.

The core is presented to give Delaware Basin geologists a 'hands-on' look at the strata that comprise the 'overburden' and troublesome drilling zones through which they must drill to reach the deeper oil-bearing horizons. The Rustler Formation may have reservoir potential."

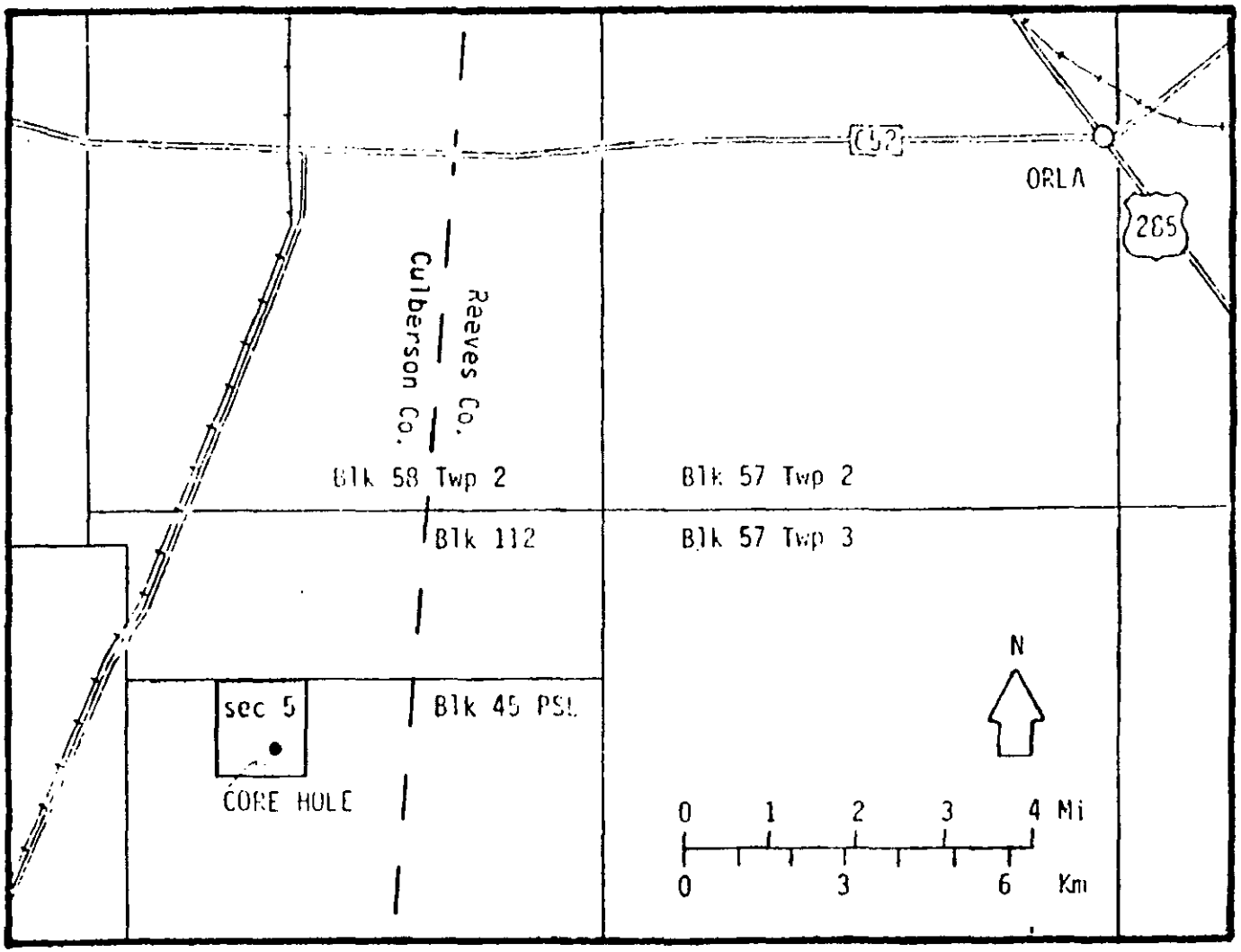

Figure 1.--Map showing the location of the Texasgulf Inc. sulphur core test.

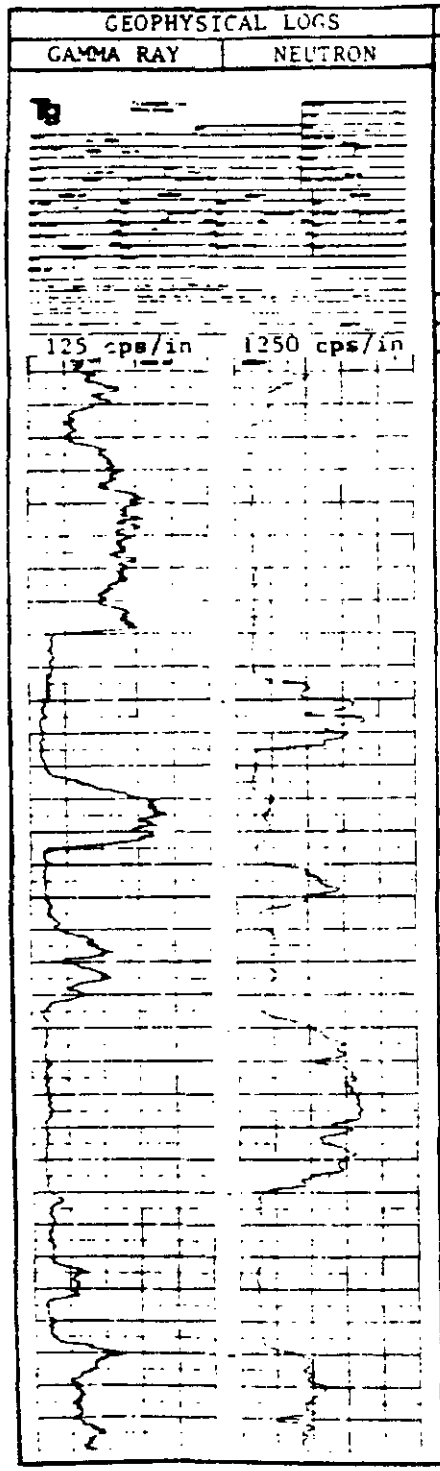

FORMATION ABBREVIATIONS

Pdl	Permian	Dewey Lake Formation
Prf	"	Rustler Fm, Forty-niner Mbr
Prm	"	" " Magenta Mbr
Prt	"	" " Tamarisk Mbr
Prc	"	" " Culebra Mbr
Prl	"	" " Lower gyp-mdst mbr
Prs	"	Rustler Fm, Siltstone mbr
Ps	Permian	Salado Formation

DEPTH FT	DEPTH M	CSNG	FM	DESCRIPTION
0	0	7"	NR	0.0- 37.0 No Record
50		4"	Pdl	37.0- 79.6 Siltstone, muddy
100			Prf	79.6- 94.7 Gypsum 94.7-115.8 Anhydrite 115.8-127.2 Gypsum 127.2-144.3 Mudstone 144.3-150.0 Gypsum 150.0-163.2 Anhydrite 163.2-169.8 Gypsum
150	50	HCQ	Prm	169.8-190.7 Dolomite, gypsiferous
200			Prt	190.7-196.3 Gypsum 196.3-249.5 Anhydrite 249.5-272.5 Gypsum 272.5-281.5 Mudstone with gypsum 281.5-297.3 Gypsum
250				
300			Prc	297.3-330.0 Dolomite
330	100			

Figure 2A.--Geophysical logs of Texasgulf core hole, surface to 330.0 feet.

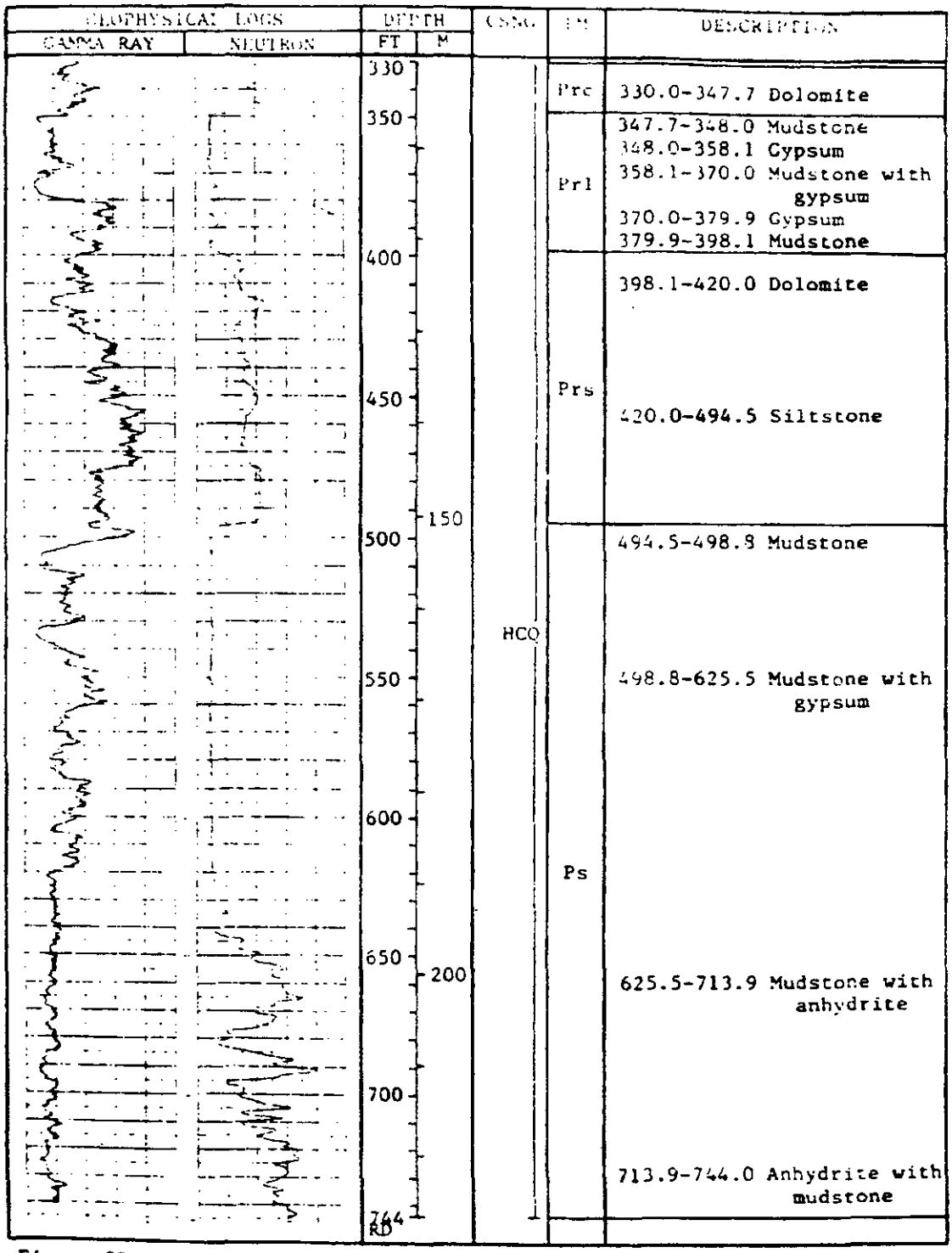

Figure 2B.--Geophysical logs of Texasgulf core hole, 330.0 to 744.0 feet.

Earth Technology Corporation. 1988. Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site. SAND87-7144. Albuquerque, NM: Sandia National Laboratories.

EXECUTIVE SUMMARY, p ii;

The Earth Technology Corporation was contracted by Sandia National Laboratories to perform a time domain electromagnetic (TDEM) survey at the WIPP site for the purpose of mapping the depth of occurrence of brine pockets and layers. The impetus for the geophysical survey was that pressurized brine had been encountered in drill holes in the Castile Formation immediately underlying the bedded salts of the Salado Formation in which the waste storage panels are mined. TDEM is a geophysical technique that determines layering in the subsurface from surface resistivity measurements. Because brine layers and pockets have low resistivities compared to the bedded salts of the host rock, they are good targets for electrical exploration.

Most of the measurements (36 out of 38) were located in a 1.5 by 1 km grid directly over the waste storage panels. Two measurements were made next to drill holes WIPP #12 and DOE #1 to validate the interpretation of the geophysical survey. Also, one drill hole (ERDA #9) at the northern boundary of the survey grid was used for calibration.

The results of the survey can be summarized as follows:

- The geoelectric sections derived from the TDEM measurements compare well with geologic and geophysical data of the three drill holes. At WIPP #12 the occurrence of brine at a depth of about 800m (2600 ft.) is clearly seen in the TDEM data.

- The results of the TDEM survey over the waste storage panels show the first occurrence of brine at depths corresponding to the Castile Formation in portions of the area and to the Bell Canyon Formation in the rest of the area, some 400 to 600 m below the mined depth of the waste storage panels in the Salado formation. There is no evidence in the data for brine pockets in the Salado or other formations over the waste storage panels.

Only one sounding was made near drill hole WIPP #12 for the purpose of calibration. Since the center loop TDEM surveys conducted correlate well with drill holes and other geologic data, it is recommended that the areal extent of the brine pocket encountered at WIPP #12 be mapped by surveying a grid centered on WIPP #12."

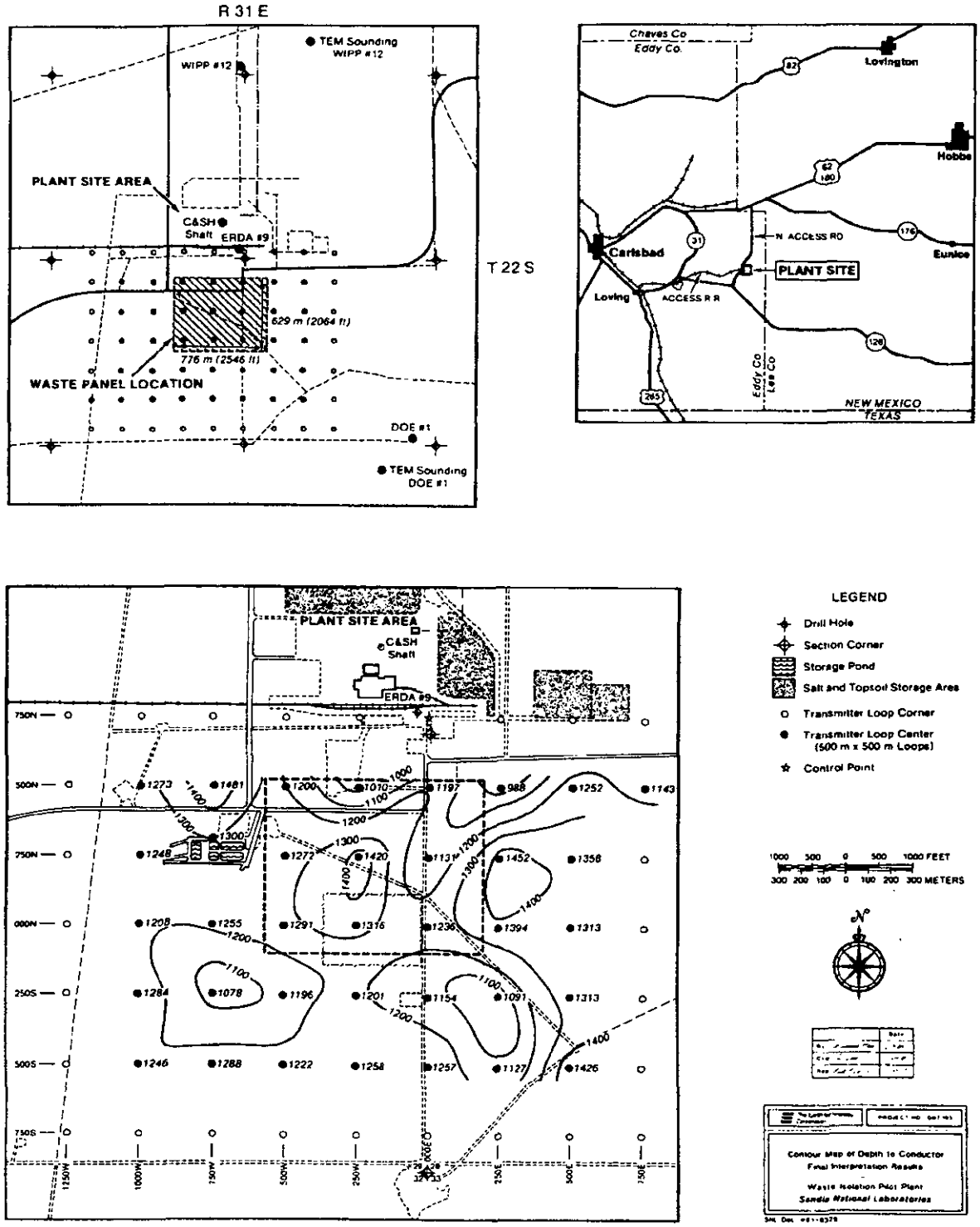

Figure 1-1. TEM Sounding Locations and Waste Panel Location

Elliot Geophysical Company. 1976. A Preliminary Geophysical Study of a Trachyte Dike in Close Proximity to the Proposed Los Medaños Nuclear Waste Disposal Site, Eddy and Lea Counties, New Mexico. Elliot Geophysical Company, Tucson, AZ.

" A long linear magnetic feature that has been geologically interpreted as a dike of Tertiary age has been well known by petroleum and potash explorations for many years. This long linear feature strikes approximately N 50° E across the northwestern part of the Delaware basin in southeastern New Mexico. This structural feature has been intercepted by many petroleum exploratory wells and potash test drill holes and it or related material outcrop in several areas south-southwest of the Carlsbad Caverns.

The trace of this dike is located approximately nine miles northwest of the Los Medaños Nuclear Waste Disposal Site that is currently under investigation. At this distance, the dike itself may possibly present a geologic hazard to the selection of Los Medaños as a viable site for a nuclear waste disposal pilot plant. Further, the dike may be, as is often the case, part of a swarm of en echelon dikes and, therefore, a parallel dike or dikes could exist closer to or beneath the Los Medaños site, and , therefore, a definite geologic hazard to site selection would be present. As a result, it seems pertinent to study this dike in detail in order to ascertain its possible significance, genetic origin, age, and any signs of structural movement in the last several million years. In that this dike is only exposed in one area, a long way from the Los Medanos site, then geologic study by itself cannot adequately define some of the parameters of interest. Fortunately, the dike material has relatively strong magnetic properties and, therefore, the dike can be mapped and studied in part, at least, by geophysical techniques. . . ."

EPA (U.S. Environmental Protection Agency). 1988. "40 CFR Parts 124, 144, 146 and 148 Underground Insertion Control Program: Hazardous Waste Disposal Injection Restrictions; Amendments to Technical Requirements for Class I Hazardous Waste Injection Wells, and Additional Monitoring Requirements Applicable to All Class I Wells." Federal Register, Vol. 53, 28188, July 26, 1988.

p. 210, para. 1;
" ACTION: Final Rule.

SUMMARY: The Environmental Protection Agency (EPA) is today promulgating its approach to implementing the statutorily mandated prohibitions on the underground injection of hazardous waste. This action is being taken in response to amendments to the Resource Conservation And Recovery Act (RCRA) enacted through the Hazardous and Solid Waste Amendments of 1984 (HSWA). In addition, the Agency is promulgating amendments to the existing Underground Injection Control (UIC) Regulations as they pertain to hazardous Waste injection.

Today's notice codifies at 40 CFR Part 148, for those hazardous wastes that are disposed in Class I hazardous waste injection wells, the directly applicable sections of Part 268, the Agency's regulatory framework for implementing the land disposal restrictions (51 FR 40572 et seq. November 7, 1986)."

Section II, p. 237, para. 4;
" Summary of Today's Rulemaking: Response to Comments, Part 148. H. Information To Be Submitted in Support of Petitions--Section 148.21. Several commenters objected to the requirement that, "All waste and environmental sampling, test and analysis data shall be accurate and reproducible and performed in accordance with quality assurance standards." They noted that in many cases, petitions will be based on information gathered during the drilling of the well--information which cannot be reproduced in accordance with procedures specified long after the drilling occurred. These commenters also noted that much of the data relied upon for characterizing the regional geology will be obtained from operations which are conducted by entities other than the petitioner. These commenters believed that the net effect of this requirement would be to prohibit the use of vast amounts of data. The geologic descriptions would therefore be less accurate, they contended.

The Agency agrees. Excluding historical data or information which might have been gathered off-site by methods not consistent with certain prescribed procedures may be counterproductive. The purpose of @@ 148.21 (a) (5) and (6) should be to allow the use of such data, but assure that its limitations are accounted for in a petition review. Accordingly, EPA will require that only measurements pertaining to the waste or that result from testing performed to gather data for the petition demonstration comply with prescribed procedures. The Agency believes, however, that the concerns about the accuracy of geologic data are addressed more appropriately by requiring that the demonstration identify and account for limits on data quality rather than by excluding data from consideration. Again, @ 148.21(b), as revised, requires precisely such consideration. Therefore, the demonstration in @ 148.20

as promulgated, will allow the use of existing data."

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste; Final Rule. Federal Register, Vol. 58, No. 242, pp. 66398-66416, December 20, 1993, Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

PREAMBLE: SUMMARY;

" The U.S. Environmental Protection Agency (EPA) is promulgating amendments to the environmental standards for the disposal of spent nuclear fuel, high-level and transuranic wastes (40 CFR 191.15 and Subpart C).

EPA originally promulgated these standards in 1985 pursuant to the Agency's authorities and responsibilities under the Nuclear Waste Policy Act of 1982, as amended, the Atomic Energy Act of 1954, as amended, and §2(a)(6) of Reorganization Plan No. 3 of 1970 (5 USC app. 1). In 1987, following a legal challenge, the U.S. Court of Appeals for the First Circuit (hereinafter referred to as 'the First Circuit' or ' the court') remanded subpart B of the 1985 standards to the Agency for further consideration. *Natural Resources Defense Council, Inc. v. United States Environmental Protection Agency*, 824 F.2d 1258 (1st Cir. 1987). Recently enacted legislation, (Pub. L. 102-579) known as the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA), however, reinstates the 1985 disposal standards except 'the 3 aspects of §§191.15 and 191.16 of such [standards] that were subject of the remand ordered' by the First Circuit. The WIPP LWA directs EPA to expedite issuance of final disposal standards and specifies that such regulations shall not be applicable to the characterization, licensing, construction, operation, or closure of any site required to be characterized under §113(a) of Public Law 97-425, the Nuclear Waste Policy Act of 1982."

STATUTORY AND REGULATORY BACKGROUND;

" The WIPP Land Withdrawal and Nuclear Waste Policy Acts

As noted above, today's action responds to the directive in section 8 of the WIPP LWA that EPA conduct a rulemaking to issue certain radioactive waste disposal regulations at 40 CFR Part 191, subpart B. The EPA initially promulgated subpart B in 1985 (50 FR 38084 (Sept. 19, 1985)), but those regulations were subsequently vacated in whole as part of a remand order issued by the First Circuit in 1987 (discussed further above and below). See *NRDC v. EPA*, 824 F.2d 1258 (1st Cir. 1987).

Section 8(a)(1) of the WIPP LWA reinstates those portions of subpart B except §§191..15 and 191.16 (which were the bases of remand by the First Circuit). Accordingly, section 8(a)(2)(A) of the WIPP LWA exempts the requirements at 40 CFR 191.15 (individual protection) and 191.16 (ground-water protection) from the statutory reinstatement. Section 8(b)(2) addresses these non-reinstated provisions by directing the EPA promulgate final regulations. Today's action responds to that directive by revising the individual protection requirements in 40 CFR 191.15, discussed above, and by adding new ground-water protection standards as 40 CFR part 191, subpart C (discussed below)."

§191.27. Effective date: p. 66415, col. 3;
"Appendix A to Part 191--Table for Subpart B

9.Appendix B is redesignated as Appendic C to part 191 and the heading is revised as follows:
Appendix C to Part 191--Guidance for Implementation of Subpart B."

50 FR 38088, p. 38088, col. 2;
" Appendix B--Guidance for Implementation of Subpart B

[Note: The supplemental information in this appendix is not an integral part of 40 CFR Part 191. Therefore, the implementing agencies are not bound to follow this guidance. However, it is included because it describes the Agency's assumptions regarding the implementation of Subpart B. This appendix will appear in the Code of Federal Regulations]"

. . .

" Scope of Performance Assessments.

Section 191.13 requires the implementing agencies to evaluate compliance through performance assessments as defined in § 191-12(q). The Agency assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. Furthermore, the performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changes by such omissions."

EPA (U.S. Environmental Protection Agency). 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. Federal Register, Vol. 61, No. 28, pp. 5224-5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C. In NWM Library as KF70.A35.C751. 1996 (Reference).

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992. EFFECTIVE DATE: These regulations are effective April 9, 1996."

p. 5238, col. 2;
" §194.14. Content of compliance certification application.

Any compliance application shall include:

(a) A current description of the natural and engineered features that may affect the performance of the disposal system. The description of the disposal system shall include, at a minimum, the following information:

(1) The location of the disposal system and the controlled area;

(2) A description of the geology, geophysics, hydrogeology, hydrology and geochemistry of the disposal system and its vicinity and how these conditions are expected to change and interact over the regulatory time frame. Such description shall include, at a minimum:

(i) Existing fluids and fluid hydraulic potential, including brine pockets, in and near the disposal system; and

(ii) Existing higher permeability anhydrite interbeds located at or near the horizon of the waste.

(3) The presence and characteristics of potential pathways for transport of waste from the disposal system to the accessible environment including, but not limited to: Existing boreholes, solution features, breccia pipes, and other potentially permeable features, such as interbeds.

(4) The projected geophysical, hydrogeologic, and geochemical conditions of the disposal system due to the presence of waste including, but not limited to, the effects of production of heat or gases from the waste."

Foster, R.W. 1974. Oil and Gas Potential of a Proposed Site for the Disposal of high-Level Radioactive Waste. BNL/SUB-44231/1. Ridge National Laboratory, Oak Ridge, TN. Available fro NTIS. NTIS Accession number: ORNL/SUB-4423-1.

NOTE: Figure 3 from this document is too large to be scanned for this document.

INTRODUCTION, p. 1;

" This study was in part funded by the Atomic Energy Commission under Contract No. AT-(40-1)-4423. Terms of this contract as they involve this particular study, are restated here so that reviewers may be aware of the basic aims of the project.

Project I - Evaluate the Petroleum Potential of the Proposed Radioactive Waste Disposal Site: Initial studies to be completed by February 15, 1973, will involve the development of pertinent information related to the location of a favorable site for coring of the Salado Formation and underlying rocks somewhere within Ts. 22-23 S., [Ts. 21-22 S.] , Rs. 31-32 E.

Evaluation of petroleum potential of the above-mentioned townships will include all rocks from the surface to the Pre-Cambrian [Precambrian] basement with emphasis on the deeper horizons. This study will include all wells in the area, and pertinent structural, lithologic and isopach data for the proposed disposal site. Necessary regional interpretation of these strata will be conducted and will include existing fields, wells, secondary recovery operations, areas of salt water disposal, production data, and pressures. In addition, the 1961 report by Foster and Stipp showing basement configuration in southeastern New Mexico will be revised. . . ."

p 9, para 2;

" Based on isotopic dating, Muehlberger (1964) considered the grouping of the Texas craton too broad and abandoned the use of this term. He introduced Central Basin platform terrane for an area including but not restricted to the structural Central Basin platform. Ages of Precambrian rocks in southeastern New Mexico vary considerably (Wassenburg, et. al., 1962, and Muehlberger, et. al., 1964, 1966, and 1967). The Panhandle Volcanic terrane has an age of approximately 1.14 by, and the Central Basin platform terrane, two distinct ages of 1.17 and 1.35 by. The older rocks are located primarily on the northwestern shelf and are similar in age to the intrusive events of central and northeastern New Mexico. The younger rocks dated from granite and a gneiss suggest an association with the Panhandle Volcanic terrane. The rhyolite to the west of the map area, although not dated, is similar to rhyolite of the Franklin Mountains and possible Pump Station Hills. The Franklin Mountains rhyolite has a maximum age of about 0.97 by (Denison and Hetherington, 1969) somewhat younger than the Panhandle Volcanic terrane.

Ordovician System

Rocks of Cambrian age are not believed to be present in this area. The west-east transgressive overlap of Cambrian/Ordovician sediments onto the Precambrian surface has

been well documented for many years. The Bliss Sandstone in the Franklin Mountains of west Texas, is in part of Cambrian age, but is thought to be entirely Early Ordovician in the Sacramento Mountains of New Mexico. Conglomerate and sandstone at the base of the Ordovician section in the subsurface of southeastern New Mexico are sometimes called Bliss Sandstone, particularly in the western part of the Delaware basin. These rocks probably correlate with the Ordovician part of the Bliss.

Barnes, et.al. (1959) have shown that the Gorman Formation of the Ellenburger Group overlies the Precambrian in the area of the Central Basin platform, and locally is as thin as 100 feet in parts of Lea County. Elsewhere in southeastern New Mexico the older Tanyard formation overlies Precambrian. This indicates a greater relief on the Precambrian surface on parts of the Central Basin platform. Areas suggestive of island chains consisting of Precambrian rocks, in the Early Ordovician seas have been noted in other parts of southern New Mexico and west Texas (Kottlowski, et. al., 1973)."

p. 18;
"

Silurian/Devonian Systems

Rocks of Silurian and Devonian ages in southeastern New Mexico have been rather poorly defined. The standard usage includes the Woodford Shale and an underlying carbonate sequence referred to as Silurian, Devonian, or Siluro/Devonian. Locally rocks presumed to be of Silurian age have been separated into the Fusselman Dolomite and Upper Silurian. The difficulty in separating the carbonate sequence has been discussed by numerous geologists. Gibson (1965) used the term Hunton terrane for the carbonate sequence because of the varied terminology in the Permian basin. McGlasson (1967) suggested that the carbonate rocks in the Delaware basin of New Mexico are restricted to Fusselman and Upper Silurian with rocks of Devonian age found only at the southern end of the Central Basin platform in Lea County. Lacking any justification from the present work for specific formational designations for the carbonate sequence, the common oil-field usage of Siluro/Devonian is followed although modified to the more acceptable Silurian/Devonian. Included, however, is a brief description of the derivation of the Fusselman Formation."

p. 24;
"

Mississippian System

Rocks assigned to the Mississippian in this report include a series of limestone referred to simply as Mississippian limestone, and an overlying shaly interval called the Barnett Shale. This follows the general oil-field usage in southeastern New Mexico. The top and base of the Mississippian limestone can be easily recognized, in most cases, in well samples and from mechanical logs. Where some doubt might exist as to the top and base it becomes only a question of a few tens of feet. Because of this, reported scout tops usually are quite reliable. The contact between the Barnett Shale and overlying Pennsylvanian rocks is less reliable. For this report a distinctive 'kick' on mechanical logs that could be traced throughout the Study area, was used as the base of the Pennsylvanian. From sample studies this kick seems to represent a thin sandstone. For most wells this top for the Barnett

coincides with the consensus of data reported for southeastern New Mexico. Chester is sometimes used for the Barnett and an overlying section of shale and sandstone here included with the Pennsylvanian. Lower Mississippian also is used occasionally for the Mississippian limestone of this report."

p. 25, para. 3;
" At the reference section locality (fig. 9) the Mississippian includes 540 feet of light-yellowish brown limestone, locally containing fairly abundant chert, and minor gray shale. The barnett consists of 80 feet of brown, in part silty shale."

p. 31, para. 2;
" Meyer's classification was not used in this report because most of these terms are not commonly used in the literature of southeastern New Mexico or in completion reports for specific wells. Above the Morrow oil-field usage is Atoka or sometimes Bend, Strawn, Canyon, and Cisco. Only in a few cases are attempts made to differentiate the Cisco and Canyon intervals; these, as in this report, being included in the Wolfcamp. Hills (1963), in contrast to the interpretation of Meyer, indicates Strawn underlying Wolfcamp in the Delaware basin of New Mexico. In well completion reports the top of the Strawn is picked fairly consistently. The Atoka may be picked at the top of the sandstone included here as the Strawn, at the top of the first sandstone in the Atoka of this report, or coinciding with the usage of this report. The Morrow top may be the same as used here or be as high as the uppermost sandstone in the Strawn interval."

p. 35, para. 4;
" Silver and Todd (1969) have reported that the upper part of the Wolfcamp in the northern part of the Delaware basin is characterized by shale and micritic limestone. In general this lithologic description is adequate for the upper part for the Wolfcamp in the Study area of this report. In the reference section (fig. 14) the Wolfcamp consists of interbedded carbonate and shale including considerable dolomite and minor sandstone. To the south, where a much thicker section is present, the lower part consists mostly of shale. The increase in limestone to the north suggests approach to a shelf margin facies."

p. 39, para 2;
" The Bone Springs was originally referred to by Blanchard and Davis (1929) and later defined by King (1942). At the type locality in the Delaware Mountains, West Texas, the unit consists mostly of limestone with a few members of shaly limestone and shale. Two members have been named; Victorio Peak Limestone and overlying Cutoff Shale. These intervals underlie the Brushy Canyon Formation of the Delaware Mountain Group. The Victorio Peak and Cutoff members crop out in the Guadalupe Mountains of New Mexico (Boyd, 1958).

As noted by King (1942) and Silver and Todd (1969) the Bone Spring facies of the Delaware basin is markedly different than in the outcrop sections to the west. A typical

basinal section of the Bone Springs was drilled in the reference well (fig. 16). The interval consists of a thick, partly cherty, limestone at the top, underlain by alternating units of sandstone and limestone. The three very fine-to-fine-grained sandstone intervals are referred to simply as the first, second, and third Bone Spring sands. The lower most 'third sand' is also called the Dean sand. Shale is a minor constituent of the Bone Springs but limestone beds are commonly argillaceous. The lithologic sequence as shown in the reference well is quite uniform throughout the Study area with minor variations in thickness of members. The shelf-margin carbonates, consisting of reefs or banks that limit the areal extent of the Bone Springs basinal facies to the west, north, and east are not present in this area.

The thickest sections of the Bone Springs occur in the western part of the Study area (fig. 17). The interval, in the area of thickest accumulation of sediments ranges from 3,300 to 3,500 feet. At an angle to this north-south depositional axis there is a northeast trending area where 3,000 to 3,300 feet of sediments were deposited. This is an area where a comparatively thin section of Wolfcamp rocks is present although it follows the structural axis of the Delaware basin. The Bell Lake structure remains evident in rather abrupt thinning of the Bone Springs interval onto this pre-Wolfcamp formation high. In the Pilot area the Bone Springs Formation ranges from 2,900 feet to over 3,400 feet in thickness."

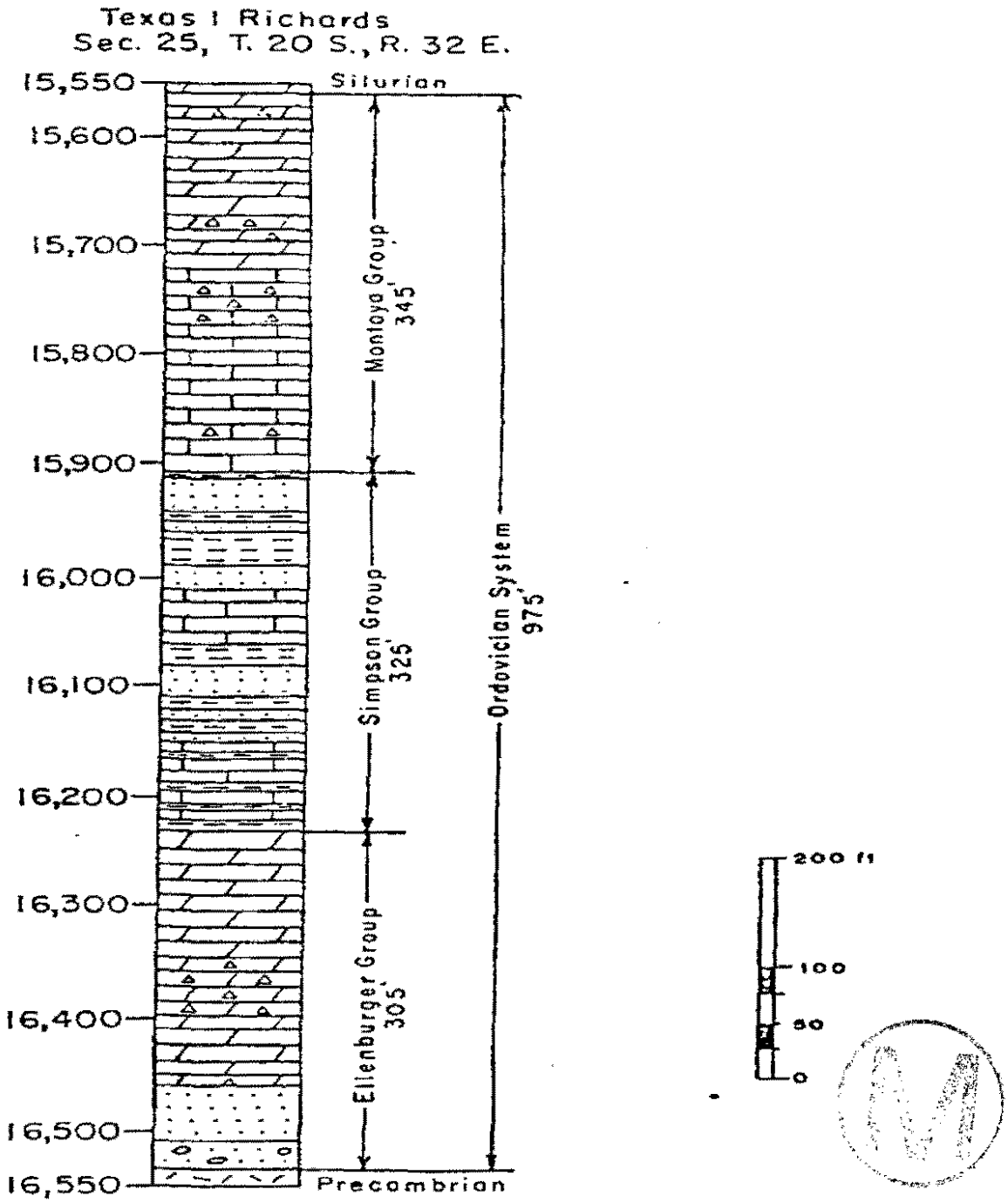

Fig.4 Ordovician reference section

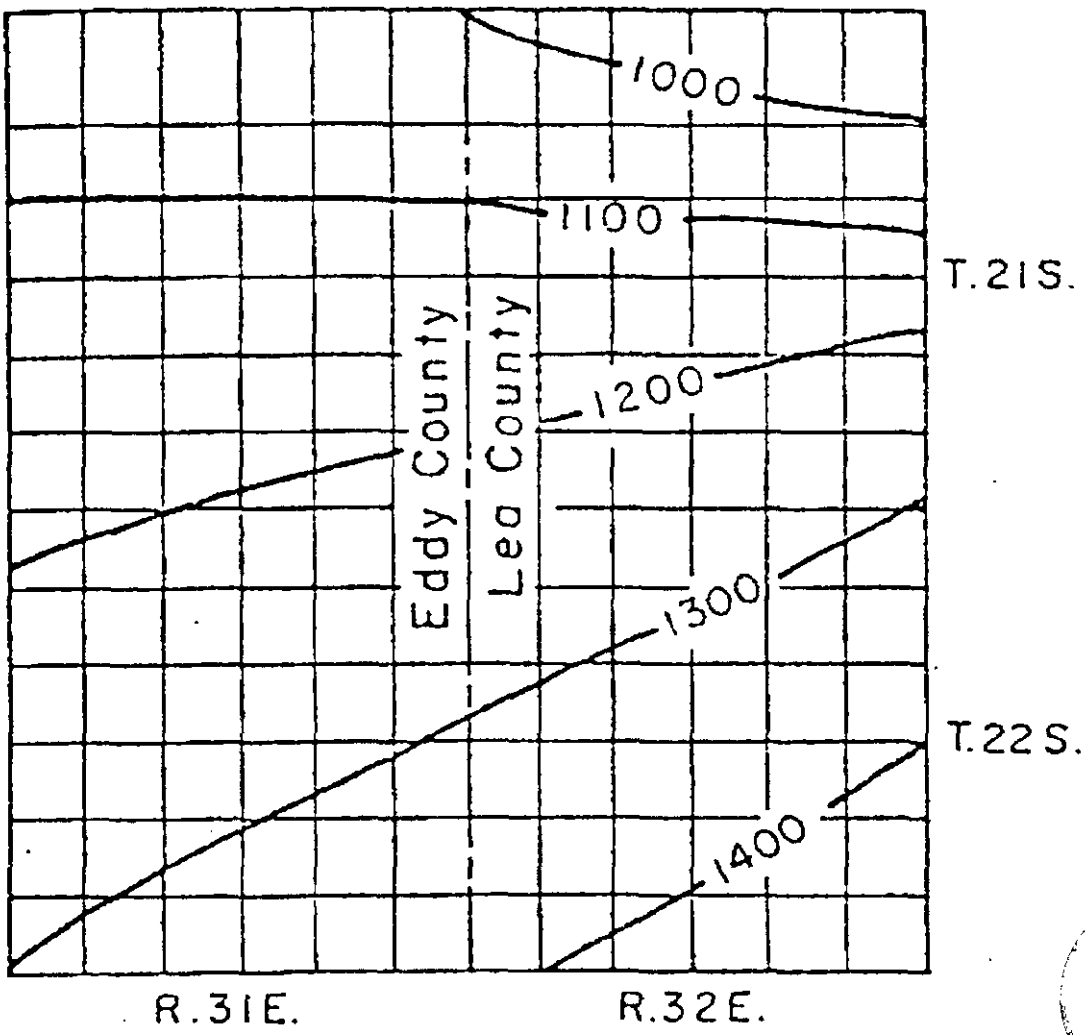

Fig.5 Isopach map: Ordovician

Contour interval: 100 feet

0 2 4 miles

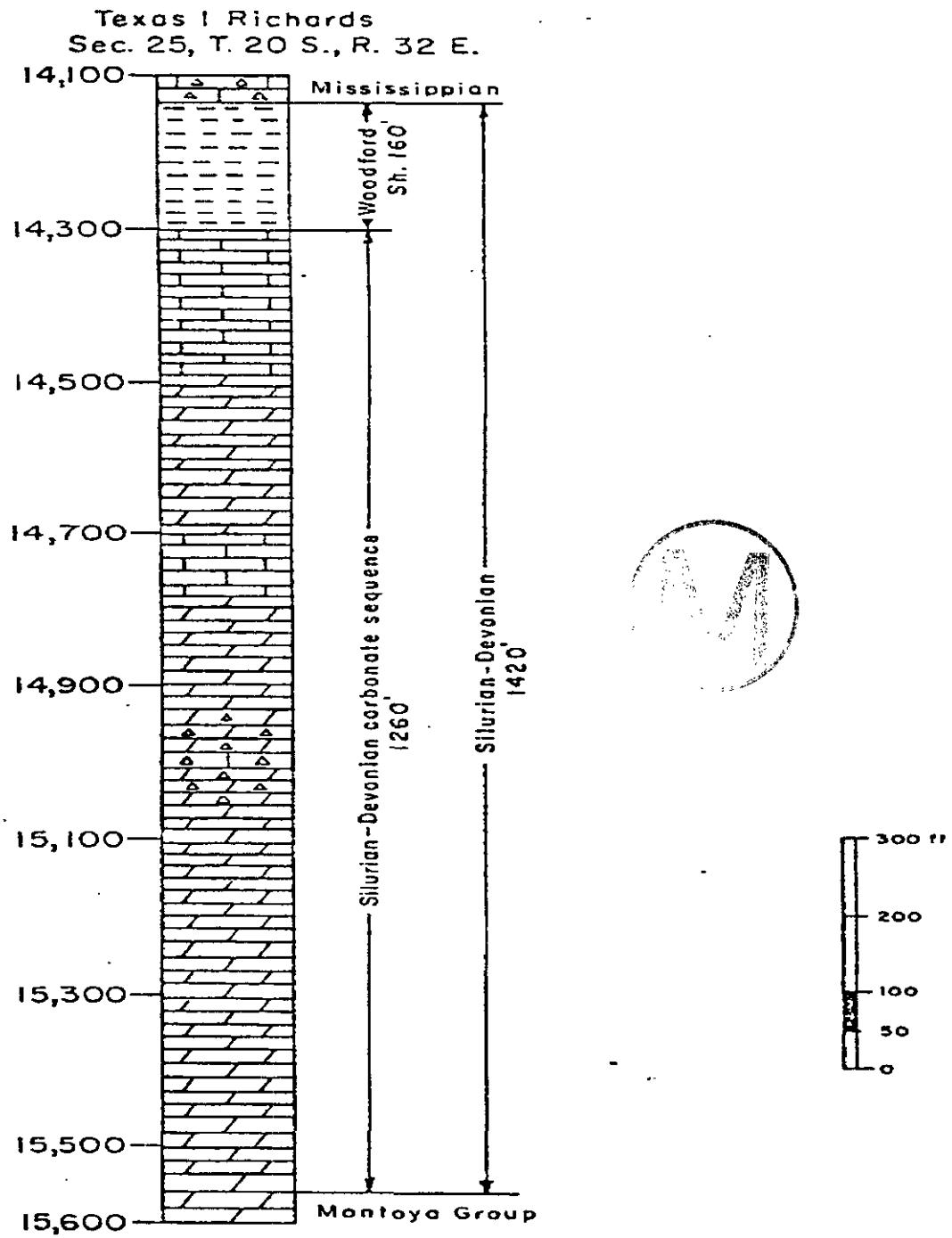

Fig. 6 Silurian / Devonian reference section

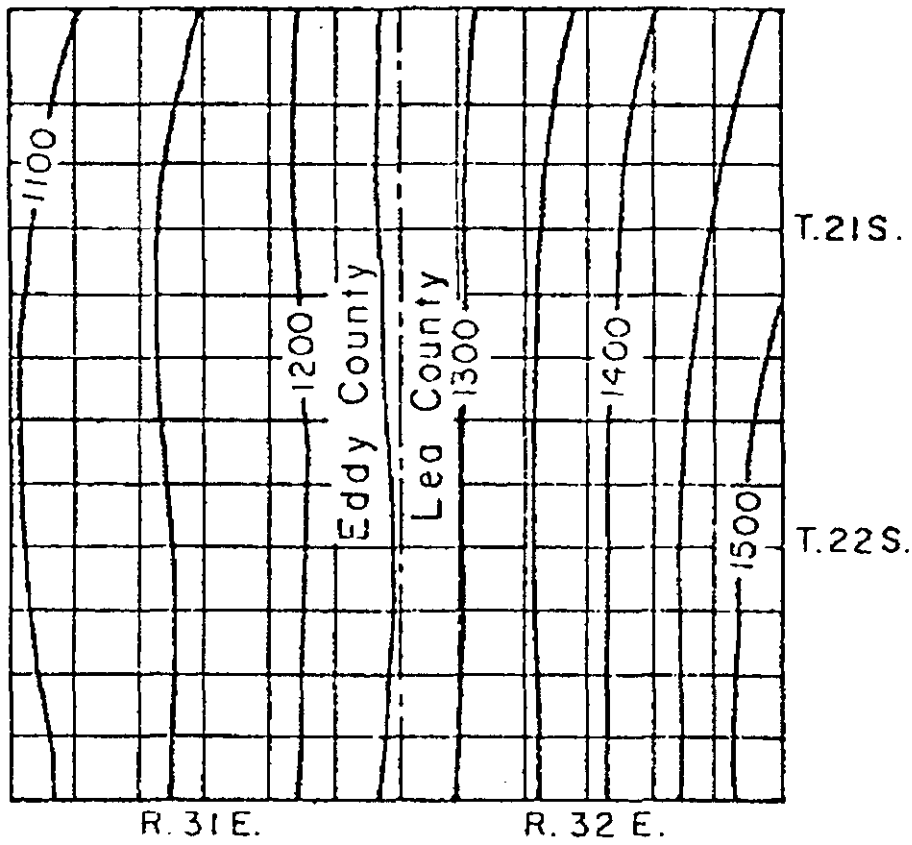

Fig. 7 Isopach map: Silurian / Devonian carbonates
Contour interval: 50 feet

0 2 4 miles

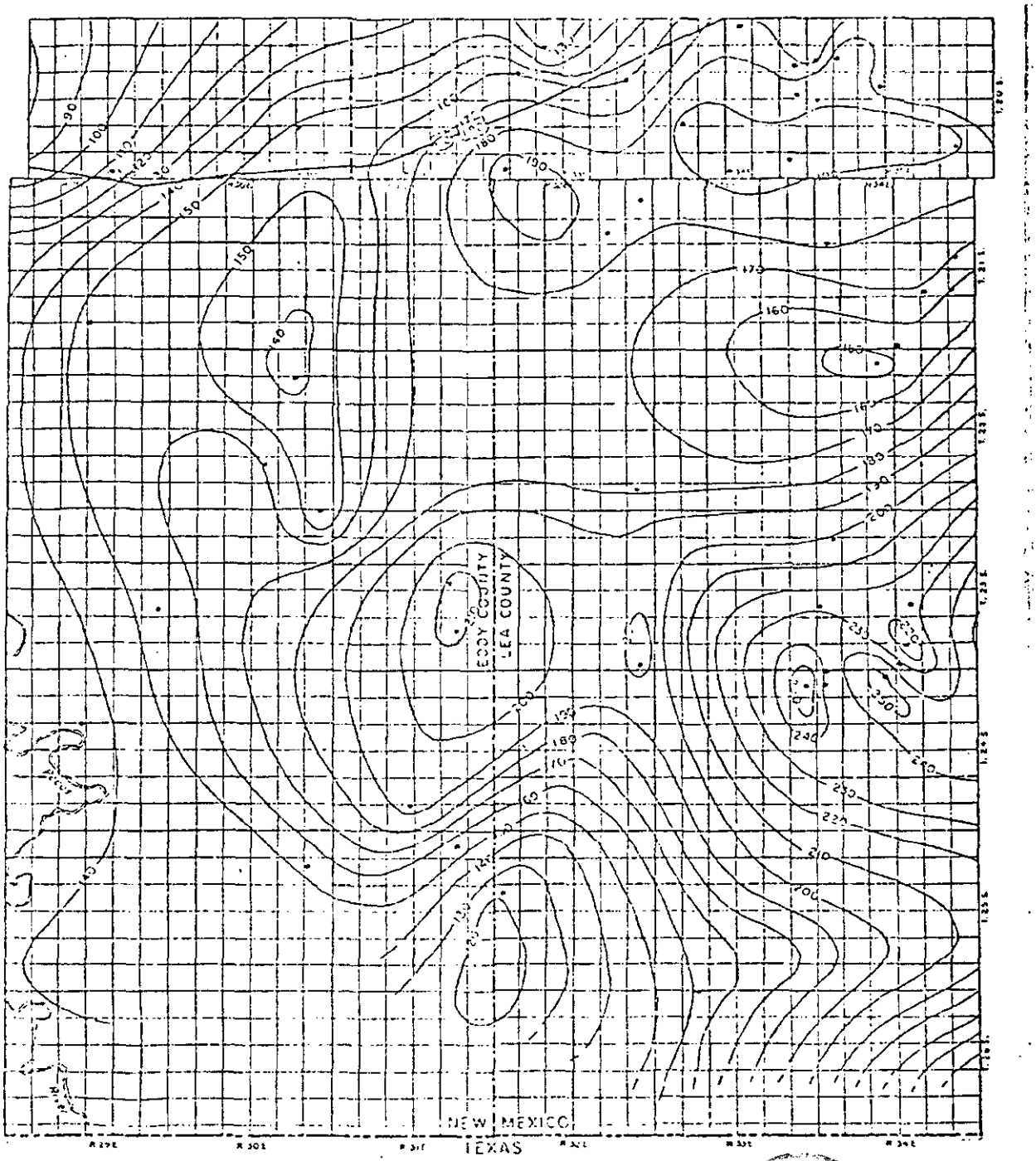

Fig. 8 Isopach map: Woodford Shale
Contour interval: 10 feet
0 5 10 miles

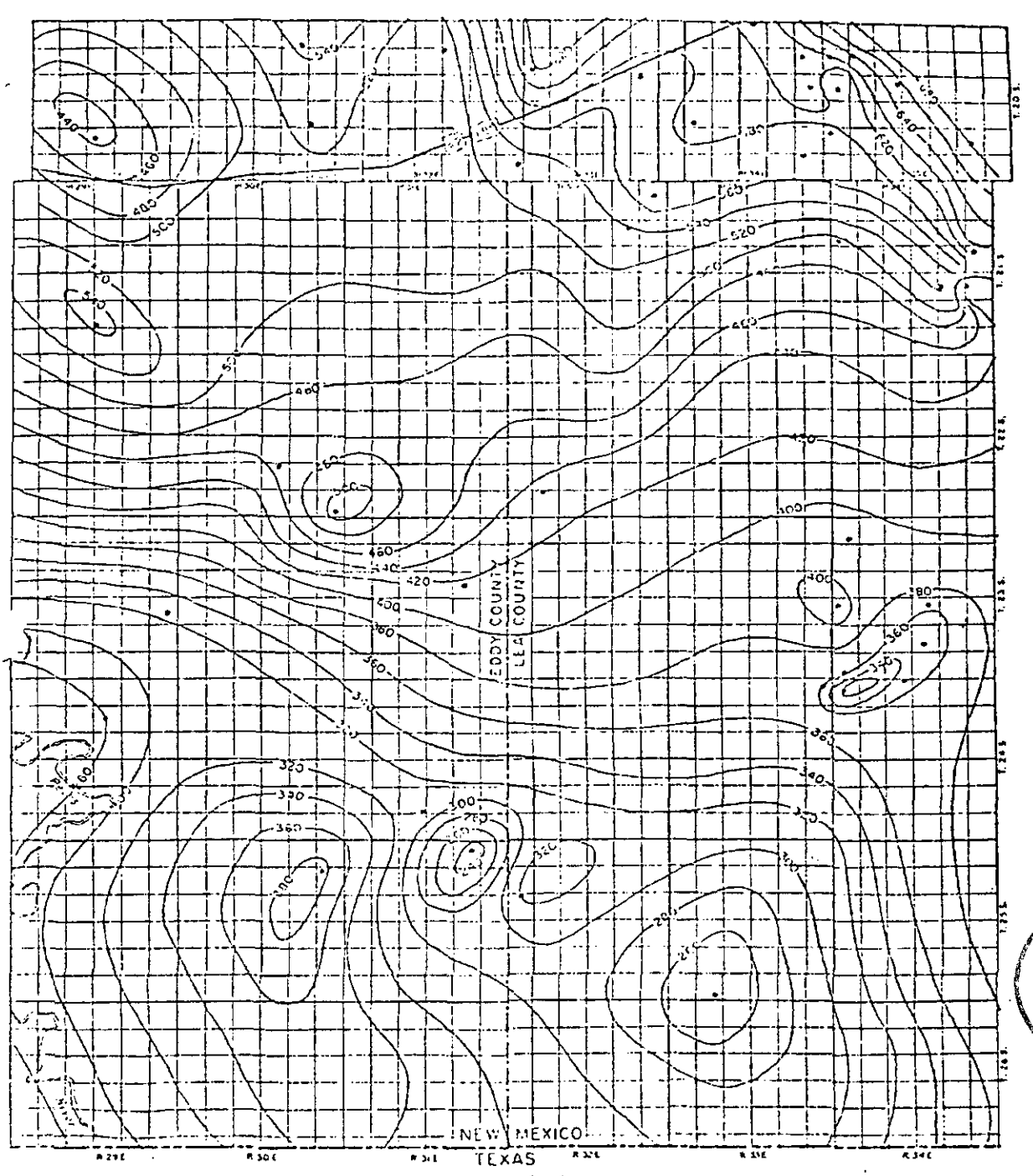

Fig.10 Isopach map: Mississippian carbonates

Contour interval: 200 feet

0 5 10 miles

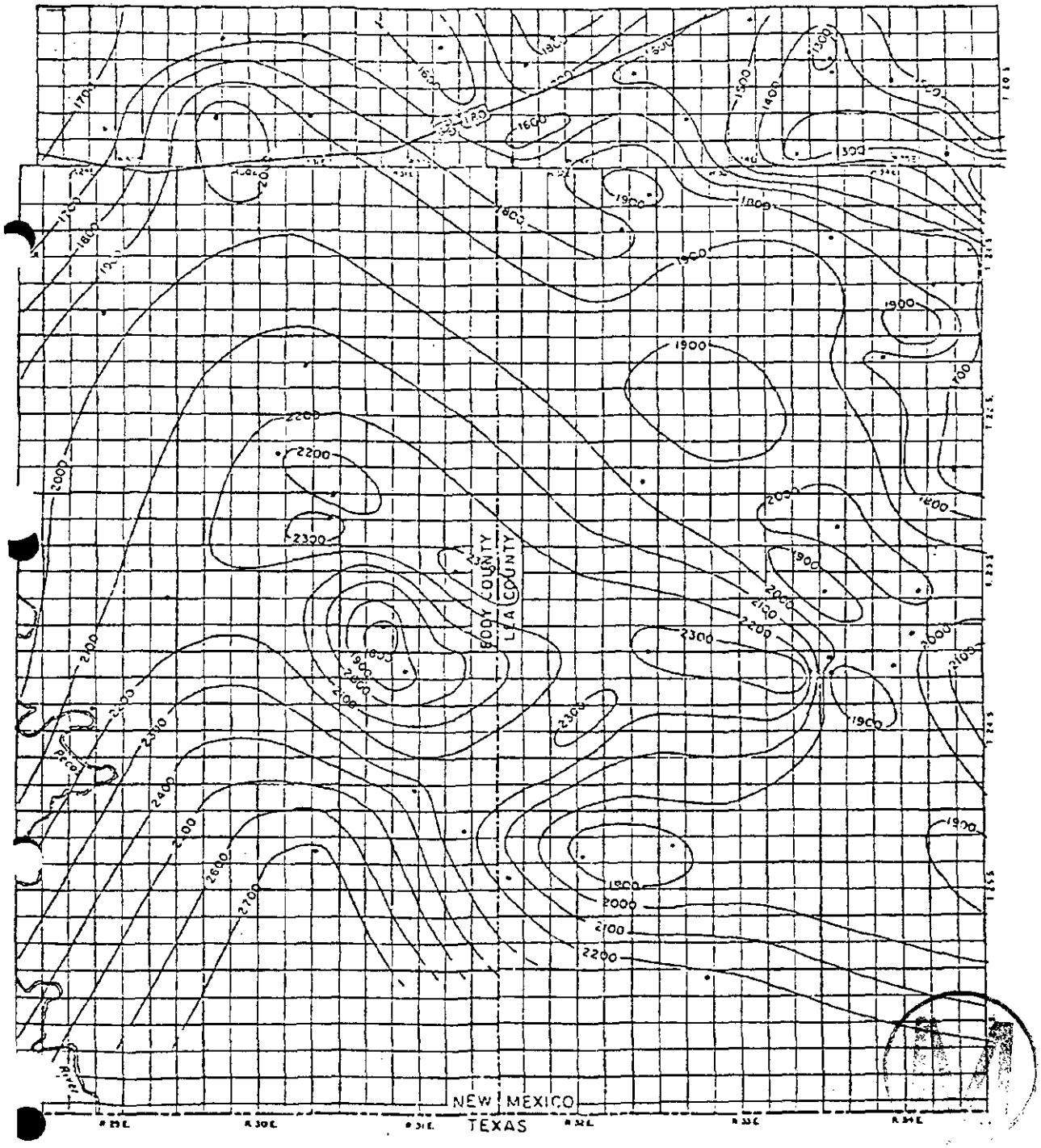

Fig.13 Isopach map: Pennsylvanian

0 Contour interval: 100 feet 10 miles

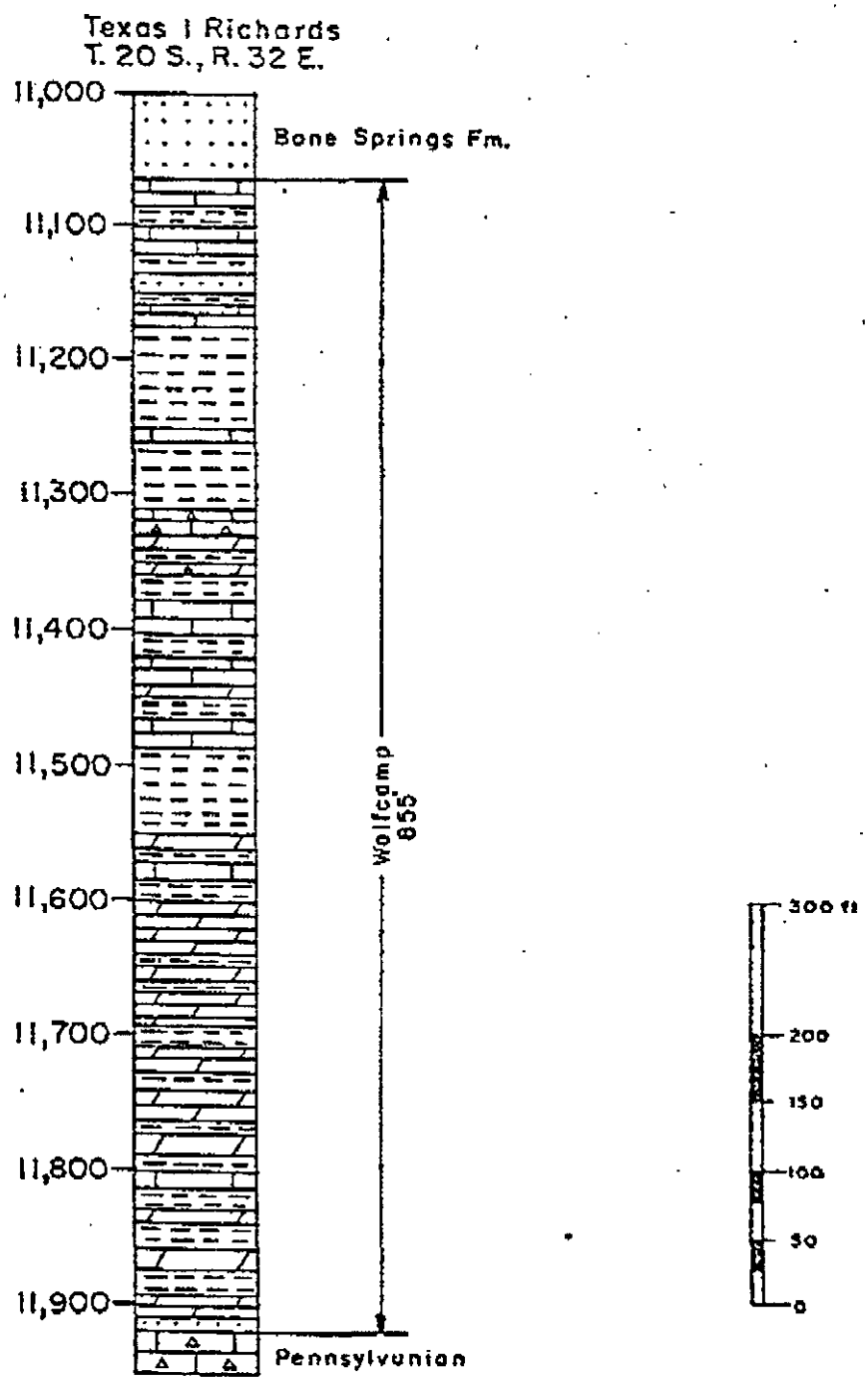

Fig. 14 Wolfcamp reference section

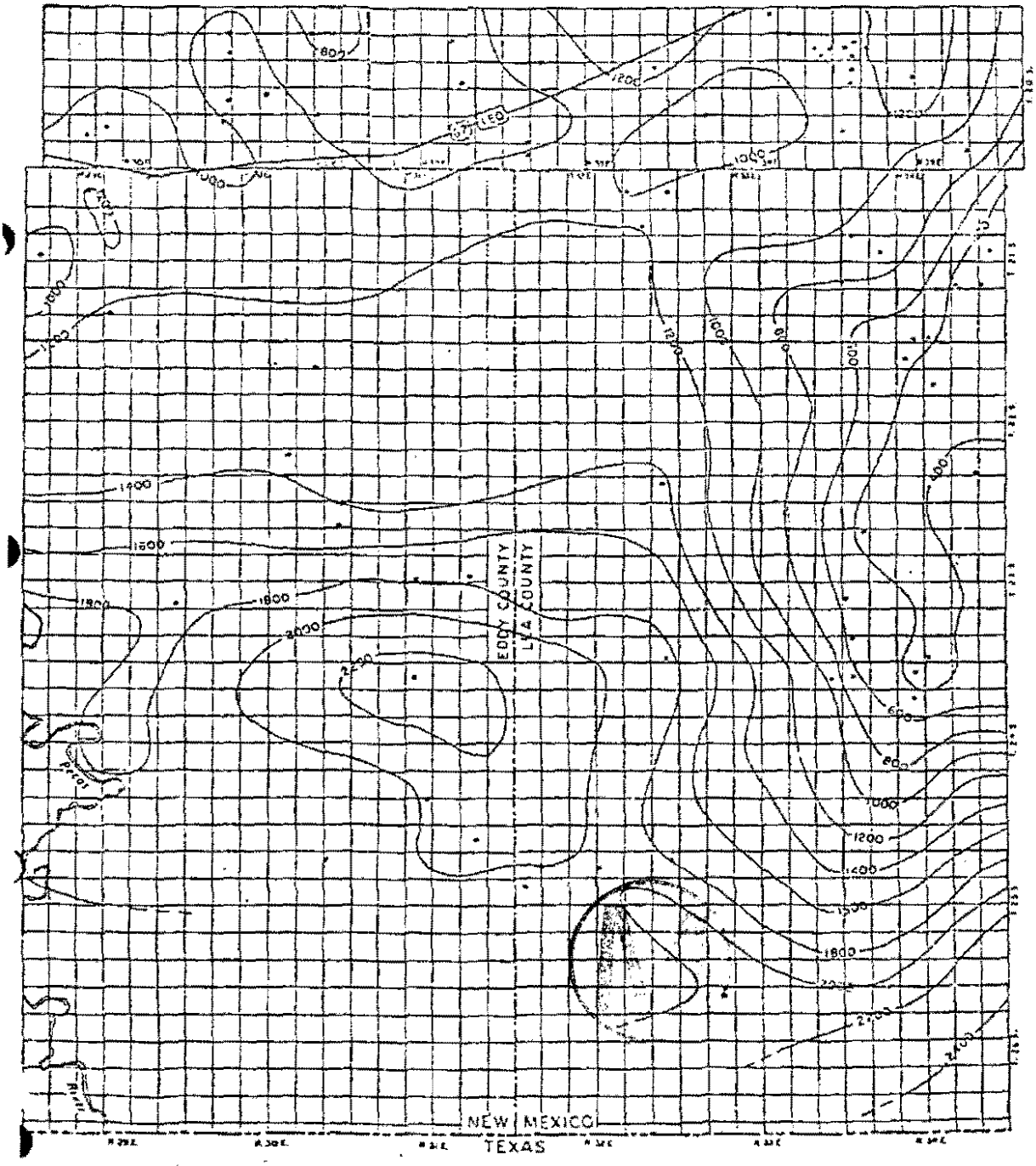

Fig.15 Isopach map: Wolfcamp

Contour interval: 200 feet

0 5 10 miles

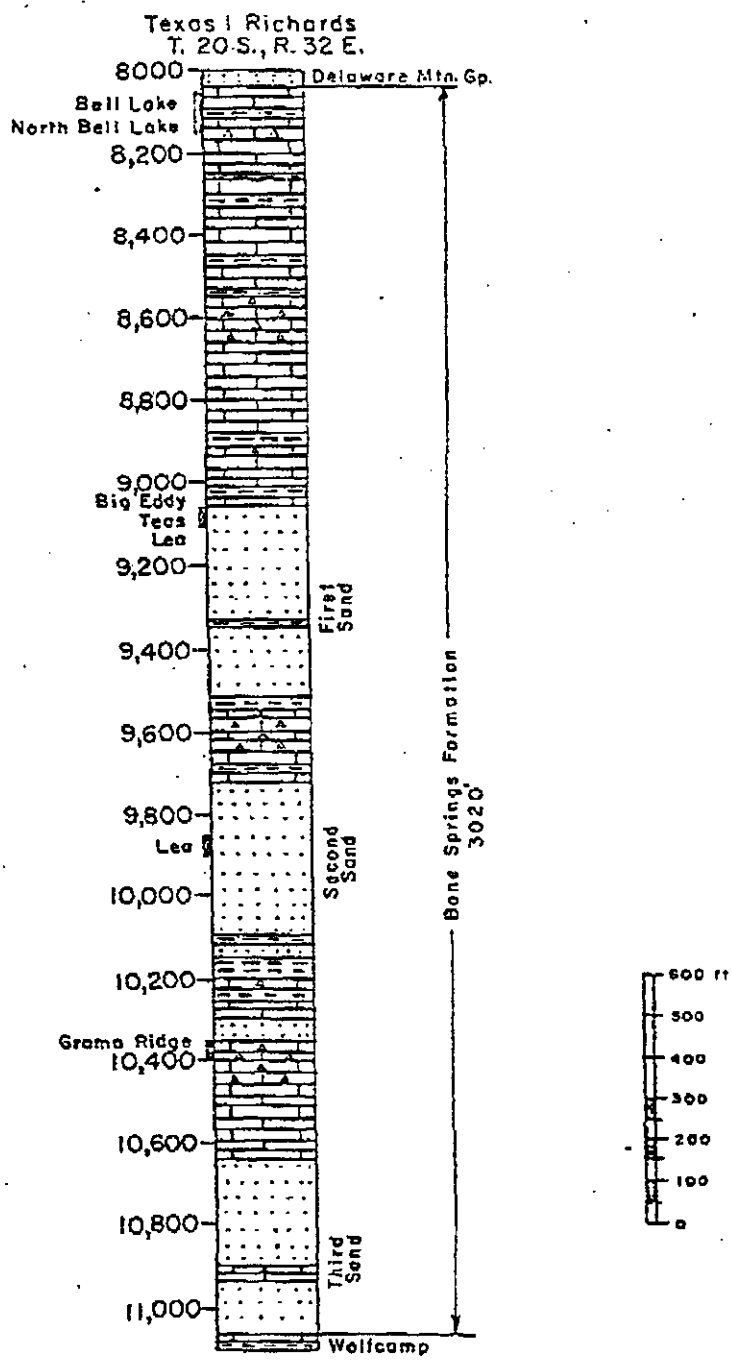

Fig.16 Bone Springs Formation reference section showing stratigraphic position of Study area fields.

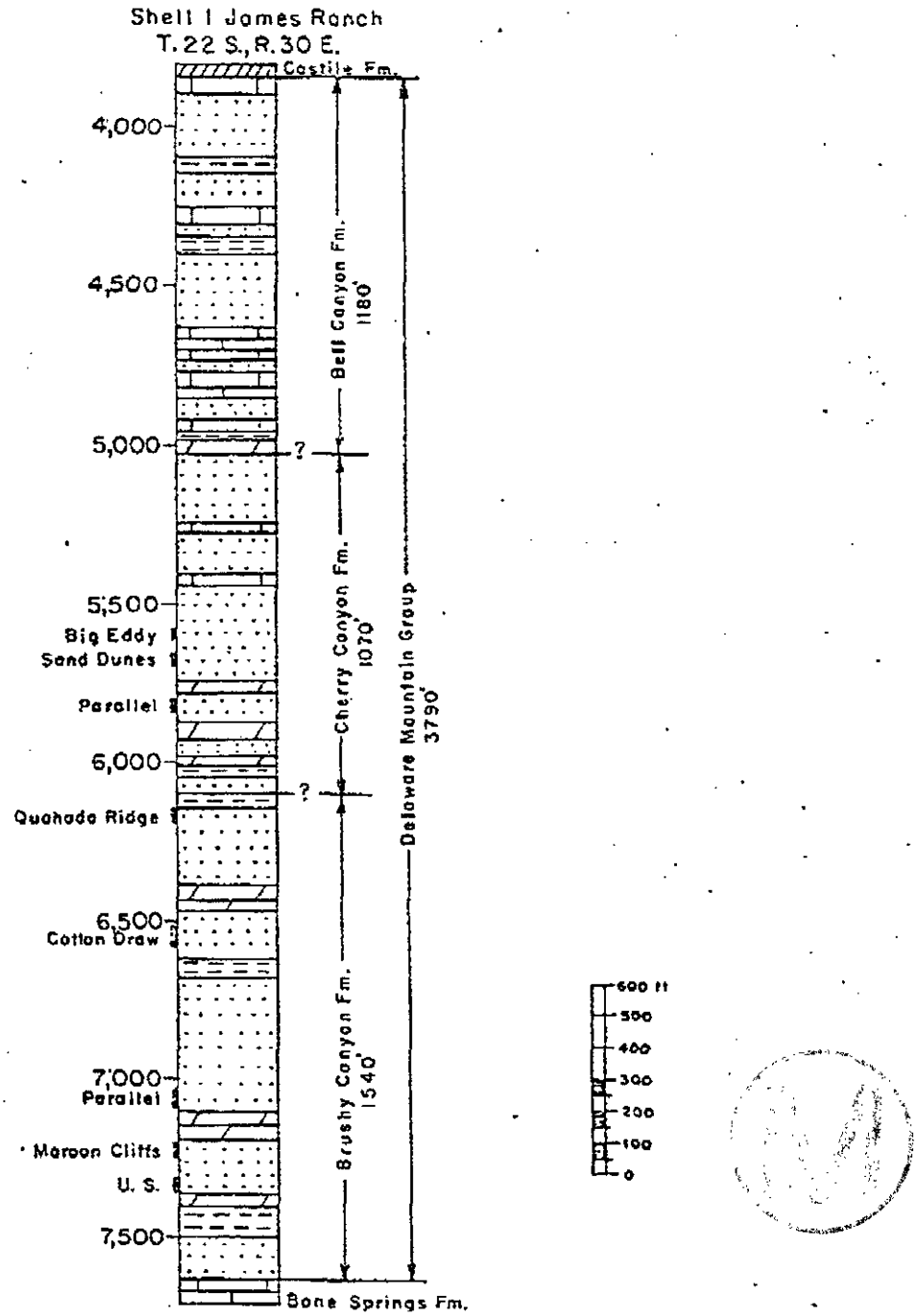

Fig. 18 Delaware Mountain Group reference section showing stratigraphic position of study area fields

Hale, W.E., Hughes, L.S., and Cox, E.R. 1954. Possible Improvement of Quality of Water of the Pecos River by Diversion of Brine at Malaga Bend, Eddy County, NM. Pecos River Commission New Mexico and Texas, in cooperation with United States Department of the Interior, Geological Survey, Water Resources Division, Carlsbad, NM.

ABSTRACT, p B-1;

" About 420 tons of dissolved minerals of which about 370 tons is common salt is added daily to the mineral load of the Pecos River through seeps and springs along a stretch of about 3 miles in the Malaga Bend of the river in T.24 S., R.29 E., which is 17 miles southeast of Carlsbad in southern Eddy County, N.Mex. In this reach, the river gains on the average approximately 2 1/2 cfs, a mixture of water of which about 2 cfs is return from irrigation water applied to nearby lands and about 0.4 cfs (200 gpm) is a concentrated brine. Elimination of the small inflow of concentrated brine would result in substantial improvement in the quality of the water reaching the Red Bluff reservoir, the water from which is used for irrigation in the valley farther downstream in Texas.

Brine, almost saturated with sodium chloride, occurs at shallow depth in the alluvium in the Grandson Spring area on the inside of the Malaga Bend and between Livingston's Ford and the Lower Wading station on the outside and lower end of the Malaga Bend. Elsewhere at shallow depth in the Malaga Bend area, the ground water present is a mixture of brine and water derived from application of water to nearby farm lands. The chloride content of the water in the alluvium increases with depth and, in the lower part of the alluvium, the water is saturated with common salt.

The source of the concentrated brine in the alluvium at Malaga Bend is a brine aquifer that underlies the area at a depth of about 200 feet. The aquifer is developed mostly in gypsum near the base of the Rustler formation and in places directly overlies the thick sequence of impermeable salt and anhydrite beds of the Salado formation. The brine is under sufficient head in the brine aquifer to percolate upward through thin and incompetent beds of gypsum and clay into the overlying beds of sand, clay, and silt and thence into the river. The Malaga Bend area is the only known discharge area for this concentrated brine.

The basal brine aquifer extends northward from the Malaga Bend area in a strip 3 to 5 miles wide into Nash Draw. The known length of the aquifer containing brine is about 25 miles. The principal area of recharge is inferred to be in the vicinity of Bear Grass Draw in T. 18 N., R. 30 E., several miles north of Nash Draw. In the recharge area truncated beds of the Rustler formation are exposed or immediately underlie the alluvium in the area. Some recharge to the brine aquifer occurs at times through sinkholes in the area about 2 miles west of the Malaga Bend. The source of the dissolved salt in the basal brine aquifer is undoubtedly the salt in the underlying Salado formation.

The transmissibility of the brine aquifer obtained from aquifer tests appears to be about 60,000 gallons a day per foot, and on the basis of the width of the aquifer of 5 miles and a gradient of 1.4 feet per mile the aquifer is estimated to be transmitting about 0.6 cfs toward the discharge area in the Malaga Bend. This value is of the same order of magnitude as the rate of discharge (0.4 cfs) calculated on the basis of the observed gain in salt load of

the river in the Malaga Bend area. The latter method of determining the discharge from the aquifer is considered to be more precise.

The alluvium in the Malaga Bend area extends to a depth of 150 feet below the Pecos River in places. It is composed of silt, sand, clay, and some gravel. The transmissibility of the alluvium appears to be small, of the order of 10,000 gallons a day per foot. Pumping of shallow wells constructed in the alluvium and finished only a few feet into the saturated brine would have the most immediate effect in eliminating the brine inflow to the Pecos River. The number of wells required would be large and, unless careful regulation of the discharge were maintained, considerable overlying fresh water would be drawn into the wells, which would diminish the efficiency of the pumping system. Wells finished and open only in the basal part of the alluvium probably could be pumped at rates greater than the shallower wells, and the number of wells required to effectively lower the head of the brine below river level throughout the bend area would be less than that required for a shallow-well system. Again, however, careful observations would need to be maintained and the pumping rate from each well regulated to prevent drawing in of fresher water in the upper part of the alluvium.

Aquifer tests indicate that the basal brine aquifer has a high coefficient of transmissibility and low coefficient of storage. One or two properly located wells in the basal brine aquifer could be pumped at such a rate as to lower the head of the brine below river level over the entire discharge area. There is little likelihood that the fresh water in the overlying alluvium would be drawn into the wells. An initial pumping rate of 600 to 700 gallons a minute from the deeper wells would lower the head of the brine to about river level in a few days. The pumping rate could be lowered in time and eventually could be reduced to approximately 200 gallons a minute, the natural discharge rate from the aquifer. Some additional water may be induced into the basal brine aquifer in the recharge area as a result of lowering of the head on the brine aquifer, but the amount probably would be small. A high initial rate of withdrawal of brine from the basal brine aquifer would induce the brine to move from the alluvium into the basal brine aquifer, hastening the diminution of flow of brine to the river.

Hawley, J.W. 1993. "The Ogallala and Gatuña Formations in the Southeastern New Mexico Region, a Progress Report." In Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society, Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993. D.W. Love et al., eds., pp. 261-269. New Mexico Geological Society, Socorro, NM.

ABSTRACT, p 261;

" The Ogallala Formation in the Southern High Plains section (Great Plains province) of southeastern New Mexico includes alluvial, eolian and playa-lake deposits and pedogenic calcretes of late Miocene and early Pliocene age (about 4-12 Ma). Beneath the Llano Estacado, it forms an almost continuous cover on rocks of Mesozoic age, is locally more than 400 ft (120 m) thick and is a major aquifer. In the Pecos Valley section of the Great Plains and along the Portales Valley through the western Llano Estacado, fine- to coarse-grained clastics of the late Miocene to middle Pleistocene age locally form thick fills (>1000 ft., 300 m) in large solution-subsidence depressions. These features are aligned along segments of the ancestral Pecos and Brazos Valleys and are underlain by evaporites of Late Permian age. Some of these deposits have always been included in the Ogallala Formation, but in the lower Pecos Valley area (Roswell, NM to Pecos, TX), correlative depression and valley fills have been mapped variously as 'older alluvium, quartzose conglomerate, valley-fill alluvial deposits,' and as the Gatuña Formation. Gatuña-Ogallala chronologic and nomenclature problems have not yet been resolved in that area; however, it is clear that an ancestral 'lower' Pecos fluvial system has existed since late Miocene time near the present valley position between the Roswell (artesian) and Delaware Basins. In the sediment source area west of the Great Plains, Ogallala and Gatuña correlatives are discontinuous, commonly thin and only locally aquifers. The oldest deposits include piedmont fan alluvium, pediment veneers and valley and basin fills. They record semiarid climatic conditions, prior epeirogenic uplift and volcanism and ongoing Basin-and-Range tectonism in a broad area extending southward from the Southern Rocky Mountains through the Sacramento section of the Basin and Range province. Significant uplift of mountain fault blocks occurred along the Rio Grande rift margin in the western part of the (sediment) source region. The facies-distribution patterns of both the Ogallala and Gatuña Formations are quite complex west of the Southern High Plains. The oldest units may form basal fills of structural basins, solution-subsidence depressions, or stream valleys, or they may be preserved as piedmont alluvium capping high divides and tablelands, with younger deposits occurring as inset valley fills. Rising western highlands not only contributed runoff and sediment to prominent zones of secondary-carbonate accumulation in paleosols of the High Plains eolian cover indicates increasingly dry and more continental conditions in late Cenozoic time. Episodic deflation of alluvial plains prograding eastward and southeastward from mountain and piedmont source areas also produced eolian sediments that are a significant component of the Ogallala Formation and overlying Plio-Pleistocene deposits of the Llano Estacado area."

CURRENT INTERPRETATIONS OF LATE NEOGENE HISTORY AND

STRATIGRAPHY, p. 264, Col. 2, Para 4;

" Differential uplift and subsidence of Basin-and-Range and Rocky Mountain-Front Range blocks had a major impact on the Ogallala sediment source area, particularly during the late Miocene (O'Neill, 1988; S. Kelley et al., 1992). Uplift and east tilting of crustal blocks that form the major ranges of the southeastern Sacramento Section (Sacramento, Guadalupe, Delaware) has continued through late Quaternary time. Late Quaternary faults are well documented in the Salt and Tularosa Basins west, respectively, of the Guadalupe-Delaware and Sacramento uplifts (V. Kelley, 1971; Goetz, 1980; Seager, 1980; Pray, 1988)."

Hayes, P.T., and Bachman, G.O. 1979. Examination and Reevaluation of Evidence for the Barrera Fault, Guadalupe Mountains, New Mexico. Open-File Report 79-1520. U.S. Geological Survey, Denver, CO.

ABSTRACT, p. 1;

" In southeastern New Mexico a prominent escarpment marks the southeastern boundary of the Guadalupe Mountains and the massive Capitan limestone of Permian age is well exposed along the mountain front. Vincent Kelley (1971, 1972) described faults that he named the Barrera and Carlsbad faults along the escarpment. As part of the earth-science investigations for the Waste Isolation Pilot Plant (WIPP) site, we examined the evidence for those faults in the field and conclude that the faults are nonexistent and that Kelley's conclusions were based on misinterpretation of exposures of fan gravel, jointing and shrub alinement."

Hills, J.M., 1984. Sedimentation, Tectonism, and Hydrocarbon Generation in Delaware Basin, West Texas and Southeastern New Mexico. American Association of Petroleum Geologists Bulletin, Vol. 68.

Introduction;

" The Delaware basin is the western major structural subdivision of the Permian basin of west Texas and southeastern New Mexico (Figure 1). It covers an area of more than 13,000 mi^2 (33,500 km^2) and is filled to a maximum depth of 24,00 ft (7,300 m) by Phanerozoic sedimentary rocks-a volume of about 40,000 mi^3 (170,000 km^3) Figure 2). Its history as a separate structural unit dates from the Early Carboniferous, but an ancestral basin, the Tobosa (Galley, 1958), was in existence from latest Precambrian to middle Paleozoic. The separation of the Tobosa basin into the Delaware basin, Central Basin uplift, and Midland basin was influenced by Proterozoic lines of weakness connected with the development of a north-northwest-trending trough, which may have been an aulacogen on the edge of the North American craton during the Grenvillian orogeny about 1 b.y.B.P. If this was an aulacogen, subsidence must have ceased before the Paleozoic began, inasmuch as Lower Cambrian rocks are not present and Ordovician strata are not overly thickened.

Movement along these zones of weakness was not renewed until the Mississippian and culminated in the formation of a deep Delaware basin in the Early Permian.

The most important aspect of the Phanerozoic history of the Delaware basin is the repeated accumulation of large amounts of organic materials in the deep, poorly ventilated marine basin and the subsequent conversion of these substances to kerogen. After conversion to hydrocarbons, the fluids not only migrated into traps within the basin, but also into reservoirs associated with broad shelves of carbonate rocks surrounding the basin.

The very mild tectonism and increasing sedimentary overburden in the basin contributed to several generations of oil and gas formation. The deposition of thick evaporite beds in the Late Permian helped to seal the traps and preserve the hydrocarbons. Adams (1965) gave an excellent summary of the development of the Delaware basin as known at the time. The present paper attempts to add to the history of this basin and to point our the influence of sedimentation and tectonism on oil and gas generation and accumulation."

Conclusion, p. 266, para 7;

" The Delaware basin originated in the Proterozoic along the edge of the North American craton, perhaps as a result of northward movement of a segment of oceanic crust from a spreading center between North and South American craton. The basin persisted throughout the Paleozoic, first as a portion of the Tobosa basin and then as a separate subbasin of the larger Permian basin underlain by thickened crust.

Throughout its history, the Delaware basin remained unusually stable, with the most notable tectonic activity being a slow eastward tilting along faulted zones on its east side. During the Carboniferous, compressional forces formed several large anticlines in the older Paleozoic rocks of the eastern part of the basin. In later times, the basin was remarkably

free of intense tectonic activity.

The sedimentary filling of the basin shows that through much of the Paleozoic, marine circulation in the basin was slightly restricted. The result was deposition of numerous shales with high organic contents, which became the source beds for large amounts of hydrocarbons."

Hiss, W.L., 1975. "Stratigraphy and Ground-Water Hydrology of the Capitan Aquifer, Southeastern New Mexico and West Texas," PhD dissertation. University of Colorado, Department of Geological Sciences,.Boulder, CO.

Introduction p 1, para 1;

" This study was started during the summer of 1965 by the U.S. Geological Survey in cooperation with the New Mexico State Engineer. The primary objective was to determine the effects on the Capitan aquifer of the withdrawal of fluids from this aquifer and other aquifers in measurable hydraulic communication; and, to assess, qualitatively, the effect, if any, of continued withdrawal of fluid from this aquifer on the flow of the Pecos River at Carlsbad, N. Mex. Secondary objectives included definition of the Capitan and other associated aquifers; and determination of (1) the stratigraphic position and dimensions of the Capitan aquifer; (2) the determination of the hydraulic characteristics of the Capitan aquifer and associated formation of Permian Guadalupian age; (3) the quality of water contained in these aquifers; (4) the stratigraphic and hydrologic relationships between the Capitan aquifers and other formation; and (5) the total amount of fluids of various types produced from the Capitan aquifers and other reservoirs of Permian Guadalupian age.

The Capitan aquifer is defined elsewhere in this report but is comprised chiefly of the Capitan and Goat Seep Limestones and the Carlsbad facies of the Artesia Group. The Capitan aquifer and several stratigraphic units of equivalent age are important sources of ground water for the city of Carlsbad and for irrigation in the Pecos River basin in New Mexico and Texas. In addition to the fresh water produced for domestic, municipal, and agricultural use in New Mexico and the slightly to moderately saline water used of irrigation in Texas, large quantities of saline ground water are being withdrawn from the Capitan aquifer in Lea County, New Mexico, and Winkler and Ward Counties, Texas (Guyton and Associates, 1958; Brackbill and Gaines, 1964; and Table 1). This water, along with additional saline waste water produced with oil, is transported to other areas where it is injected into several formations to repressurize partly depleted reservoirs in a number of oil fields."

Location and extent of the area, p 8;

" The concentration of project activities was more intensive in New Mexico than in Texas. Emphasis was placed on an arcuate strip following the trend of the Capitan aquifer along the north and east margins of the Delaware basin between the Guadalupe Mountains southwest of Carlsbad and the Glass Mountains southwest of Fort Stockton, Tex. (figs. 2 and 3)."

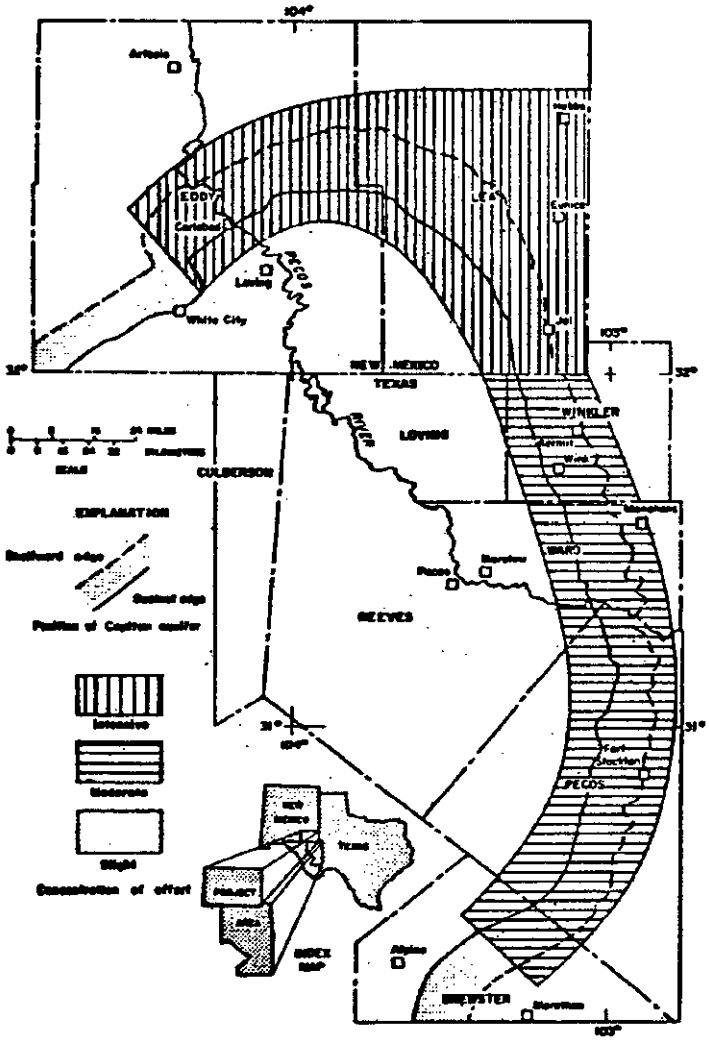

Figure 3.—Map showing concentration of effort within project area.

Structural configuration of the Guadalupian Series, p 114;
" ... Rocks in the Delaware Mountain Group dip gently eastward from the Delaware and Guadalupe Mountains, northeast from the Apache Mountains, and northward from the Glass Mountains, toward the center of basin in eastern Reeves and northern Pecos Counties, Texas, at about the same rate."

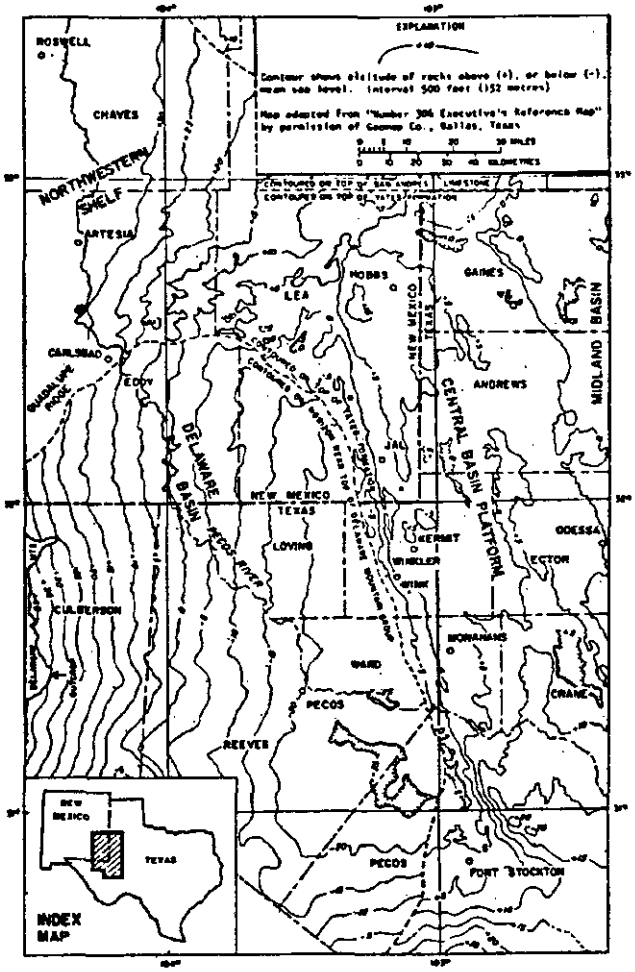

Figure 15.--Map showing structural configuration of the Delaware basin, Northwestern shelf, and Central Basin platform near the top of rocks of Permian Guadalupian age.

Regional hydraulic conductivity, p. 198;

" Meager data of often-questionable reliability, in conjunction with an interpretation of the geohydrological history of the region, suggest that the hydraulic conductivity of the Capitan aquifer along the western margin of the Central Basin platform in Texas and New Mexico ranges from 1 to 25 ft/day (.3 to 7.6 m/day) (table 7). The hydraulic conductivity of the Capitan aquifer probably averages 5.0 ft/day (1.5 m/day) in most of southern Lea County, New Mexico, but appears to increase progressively southward to an estimated 10.0 ft/day (3.0 m/day) near the Pecos-Brewster County boundary in Texas. The hydraulic conductivity of the Capitan aquifer in the Glass Mountains is probably very high because of the numerous small caverns developed in this area (D. J. Sibley, Jr., personal commun.).

An average hydraulic conductivity of 5.0 ft/day (1.5 m/day) also would seem to be reasonable for the Capitan aquifer over a span of approximately 15 miles (14 kilometers) immediately east of the Pecos River valley at Carlsbad. Values of hydraulic conductivity in the Capitan aquifer west of the Pecos River at Carlsbad are apparently larger by as much as several orders of magnitude (Hale, 1945a and 1945b).

Local variations in transmissivity

The transmissivity of the Capitan aquifer in a small area near the boundary between Eddy and Lea Counties, New Mexico, in the vicinity of the deeply incised Laguna submarine canyons appears to be the lowest encountered anywhere within the project area.

A representative transmissivity for this major restriction has not yet been determined. However, the general response to stresses placed on the aquifer by (1) withdrawal of water in the water fields to the east, (2) recharge by floods in the Pecos River valley, and (3) precipitation in the Guadalupe Mountains to the west, suggest that the transmissivity must be at least one and perhaps two orders of magnitude lower than the average transmissivity of the Capitan aquifer.

Values of transmissivity for the Capitan aquifer in the area extending east of the Pecos River at Carlsbad around the northern and eastern margin of the Delaware basin to the Pecos-Brewster County boundary in Texas are estimated to range from approximately 10,000 ft^2/day (900 m^2/day) in the thicker intercanyon nodes to less than 500 ft^2/day (450 m^2/day) in the vicinity of the more deeply incised submarine canyons."

"Conclusions

Permian Guadalupian age strata can be divided into three aquifers. The Capitan aquifer is lithosome that includes the Capitan and Goat Seep Limestones and most or all of the Carlsbad facies of Meissner (1972). Some of the shelf-margin carbonate banks or stratigraphic reefs in the upper of San Andres Limestone are included within the Capitan aquifer whenever they cannot be readily distinguished from the Goat Seep Limestone and Carlsbad facies. Saturated strata yielding significant quantities of water from the San Andres Limestone and the Bernal and Chalk Bluff facies of Meissner (1972) comprise the shelf aquifers. The contact between the Capitan and shelf aquifers is gradational and is difficult to discern with accuracy is some areas. Similarly, saturated strata yielding significant quantities

of water from the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations of the Delaware Mountain Group are referred to as the basin aquifers."

Hiss, W.L. 1976. Structure of the Permian Guadalupian Capitan Aquifer, Southeast New Mexico and West Texas. Resource Map. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

INTRODUCTION;

" The Capitan aquifer of Permian (Guadalupian) age is an important source of the ground water used for municipal, industrial, and agricultural purposes at and in the vicinity of Carlsbad, N. Mex. In addition, water pumped from this aquifer in southern Lea County, New Mexico and Winkler and Ward Counties, Texas, is injected into other subsurface reservoirs by oil companies to increase the recovery of petroleum from partly depleted oil fields (Hiss, 1971; White, 1971). A knowledge of the structural position of the Capitan aquifer in southeastern New Mexico and western Texas will be useful in programs designed either to explore for and develop additional ground-water supplies or to manage this important resource."

Structural position, para. 4;

" The contours showing the structural position of the top of the Capitan aquifer may falsely suggest a series of closed structural highs alternating with plunging synclines. However, when the configurations of the contours of the structural position and the thickness of the Capitan aquifer (Hiss, 1975b) are compared, there is a striking coincidence of features. Apparently, most of the features appearing as structural lows are depressions in the surface of the Capitan aquifer and are due to nondeposition and (or) erosion in surge channels and submarine canyons of Guadalupian age rather than to warping of the Capitan aquifer (Hiss, 1974; 1975a; 1975c)."

Holt, R.M., and Powers, D.W. 1984. Geotechnical Activities in the Waste Handling Shaft Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico. WTSD-TME-038. U.S. Department of Energy, Carlsbad, NM.

ABSTRACT, p. v;

" The Waste handling shaft (waste shaft) at the Waste Isolation Pilot Plant (WIPP) site is an enlargement of the drilled, Site and Preliminary Design Validation (SPDV) ventilation shaft. Geotechnical activities in the waste shaft were designed to confirm the SPDV ventilation shaft mapping results and to provide additional information about identified zones of interest. The activities included identification of instrument locations, geologic inspections of the exposed shaft surface during sinking operations, reconnaissance geologic mapping of the waste shaft sump, and detailed geologic mapping in identified zones of interest. These activities were carried out concurrently with construction.

The results of the geologic inspections in the waste shaft and the reconnaissance geologic mapping in the waste shaft sump correlate well with previous characterizations. However, the detailed 360° geologic mapping performed in several zones of interest did not reveal post-depositional dissolution features, thought to occur at several stratigraphic horizons in the Rustler Formation at the WIPP site. At the waste shaft, zones previously identified as dissolution residues in nearby boreholes contained pronounced primary sedimentary features."

4.2.2.4 Culebra Dolomite Member, p. 4-6, para. 4;

" In the waste shaft, the Culebra occurs in the depth interval from 706.5 feet to 728.5 feet (Figure 9). The upper one-half to two feet of the Culebra is a medium brown, microlaminated to thinly laminated carbonate. This unit averages about 0.8 feet in thickness throughout the circumference of the shaft, but thickens up to two feet in the vicinity of mound-like dome structures. In general, the laminations within the carbonate unit are horizontal to subhorizontal. However, the laminae in the mound structures are often crenulated and dip slightly away from the center. It is likely that this unit is of algal origin. a 1/4 to 1-inch thick bed of cohesive, black claystone underlies the carbonate unit. The remainder of the Culebra primarily consists of brown, finely crystalline dolomite containing both empty and gypsum-filled vugs of varying size."

p. 4-9, para. 1;

" From a depth of about 781.0 feet to a depth of about 844.0 feet, the lower member consists of interbedded siltstone, sandstone, mudstone, and claystone with an abundance of primary sedimentary structures. These sedimentary structures include laminated sediments, cross-laminations, trough cross laminations, and channel lag (Plate 4) containing invertebrate fossil hash. The basal contact with the Salado is sharp, and the rock overlying the contact appears to be undisturbed by dissolution. The average depth to the Rustler/Salado contact in the shaft is about 844.0 feet."

Holt, R.M., and Powers, D.W. 1986. Geotechnical Activities in the Exhaust Shaft. DOE-WIPP-86-008. U.S. Department of Energy, Carlsbad, NM.

INTRODUCTION, p. 1-1;

" The Waste Isolation Pilot Plant (WIPP) project is a Department of Energy (DOE) research-and-development facility constructed to demonstrate the safe disposal of radioactive wastes derived from the defense activities of the United States. The WIPP project's mission consists of two parts. The first is to demonstrate the safe handling and disposal of transuranic (TRU) waste in bedded salt. The second is to create a research facility for in-situ examination of the technical issues related to the emplacement of defense-related radioactive waste in bedded salt.

The WIPP facility is located approximately 26 miles east of Carlsbad, New Mexico in an area known as Los Medanos (Figure 1). The underground portion of the facility is located at a depth of approximately 2,150 feet in the bedded salt deposits of the Salado Formation (Figure 2). An extensive program of site characterization and validation has been conducted for the past nine years (1976-1985). The results of these studies are summarized in the WIPP 'Geological Characterization Report' (Powers et al., 1978), the WIPP 'Safety Analysis Report' (DOE, 1980), the WIPP 'Preliminary Design Validation Report' (Bechtel, 1983), and the WIPP 'Results of Site Validation Experiments' (Black et al., 1983). Additional site investigations are being conducted as part of an ongoing program to further refine the understanding of the site-specific geology. The geotechnical activities conducted in the exhaust shaft are part of this program.

The exhaust shaft will provide a pathway for the release of exhaust air from the facility to the surface. The shaft is an enlargement of a six-foot diameter, upreamed shaft. The finished diameter is 14 feet in the lined portion of the shaft and 15 feet minimum in the unlined portion. Geotechnical activities consisting of reconnaissance geologic mapping, detailed geologic mapping in specific zones of interest, geologic confirmation of instrument locations, and field adjustment and modification of the key and aquifer seal design were performed concurrently with construction from July 16, 1984 to January 18, 1985. This report presents and discusses the findings from the geologic mapping efforts in the exhaust shaft. Also, the construction history of the exhaust shaft is summarized, and several engineering geology characteristics are discussed."

NOTE: The notes applicable to Figures 6, 7, & 8 (Figure 6 - Sh 2 of 11 through 11 of 11; Figure 7 - Sh 2 of 9 through 9 of 9; and Figure 8 - Sh 2 of 6 through 6 of 6) have not been included in this document to reduce document size.

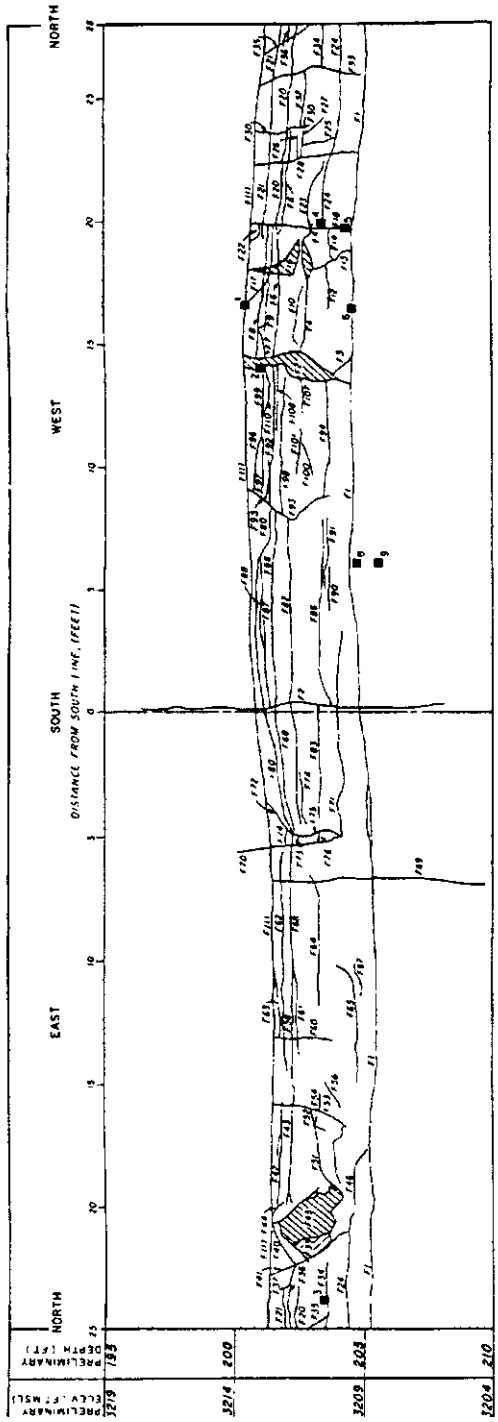

NOTES

1) THIS INTERVAL WAS MAPPED ON 10-3-86.
2) THE LITHOLOGY OF THIS INTERVAL IS DESCRIBED IN FIGURE 6.
3) DEPTHS AND EVALUATIONS ARE RELATED TO THE REFERENCE ELEVATION OF 3409 FEET ABOVE MSL.
4) ONLY FRACTURES THAT WERE DEEMED "MAPPABLE" AT A SCALE OF ONE INCH EQUALS FIVE FEET ARE INCLUDED ON THE MAP.
5) MAPPING EFFORTS WERE CONCENTRATED IN THE DEPTH INTERVAL FROM 195.0 FEET TO 208.0 FEET.

EXPLANATION

F20/ MAPPED FRACTURE #20, SEE FRACTURE NOTES FOR DESCRIPTION

24 SAMPLE LOCATION, EXHAUST SHAFT DETAILED MAPPING SAMPLE #24

MAPPED FRACTURE #29, FRACTURE SURFACE EXPOSED

FIGURE 6 - SHEET 1 OF 11

FRACTURE LOG IN
THE DEWEY LAKE REDBEDS
DEPTH 190.0 THROUGH 205.0 FEET
(EXHAUST SHAFT)

WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

PREPARED FOR
WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

IT CORPORATION

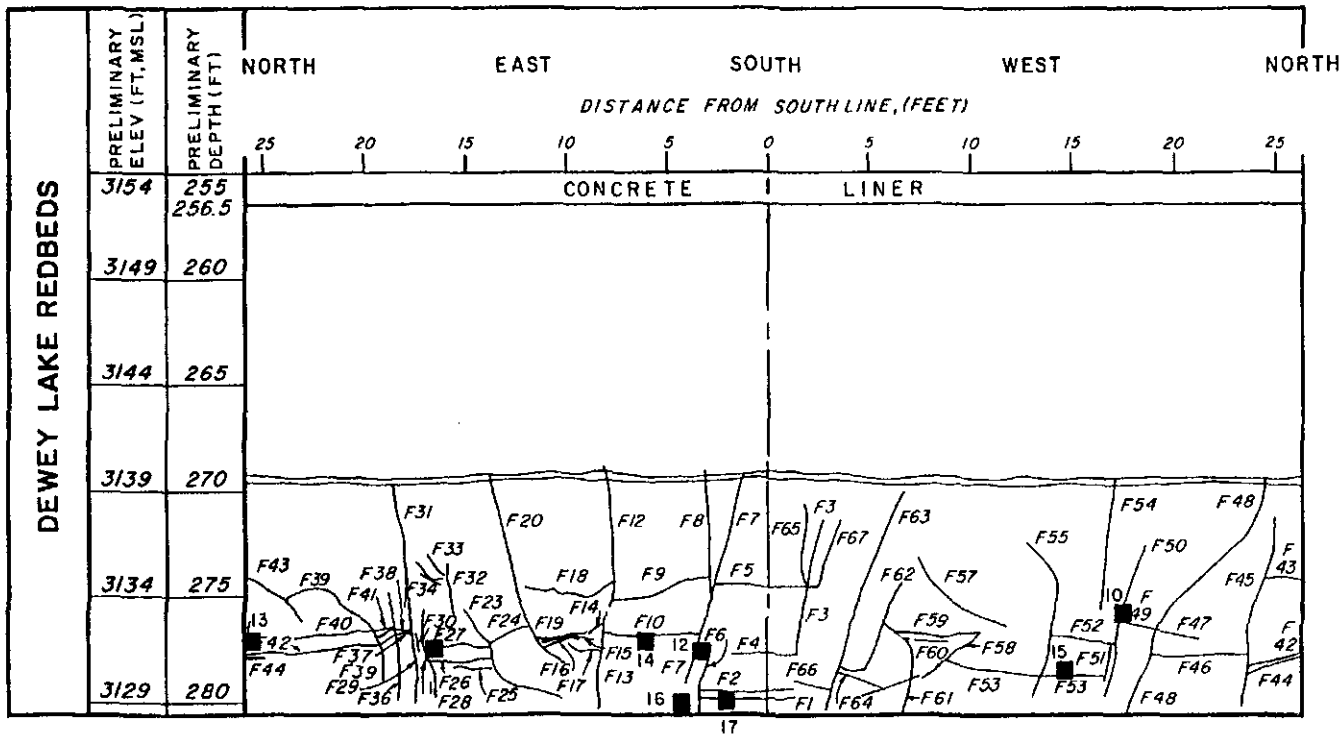

FIGURE 7 - SHEET 1 OF 9

FRACTURE LOG IN THE DEWEY LAKE REDBEDS
DEPTH 256.5 TO 280.5 FEET, EXHAUST SHAFT

WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

PREPARED FOR
WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

IT CORPORATION

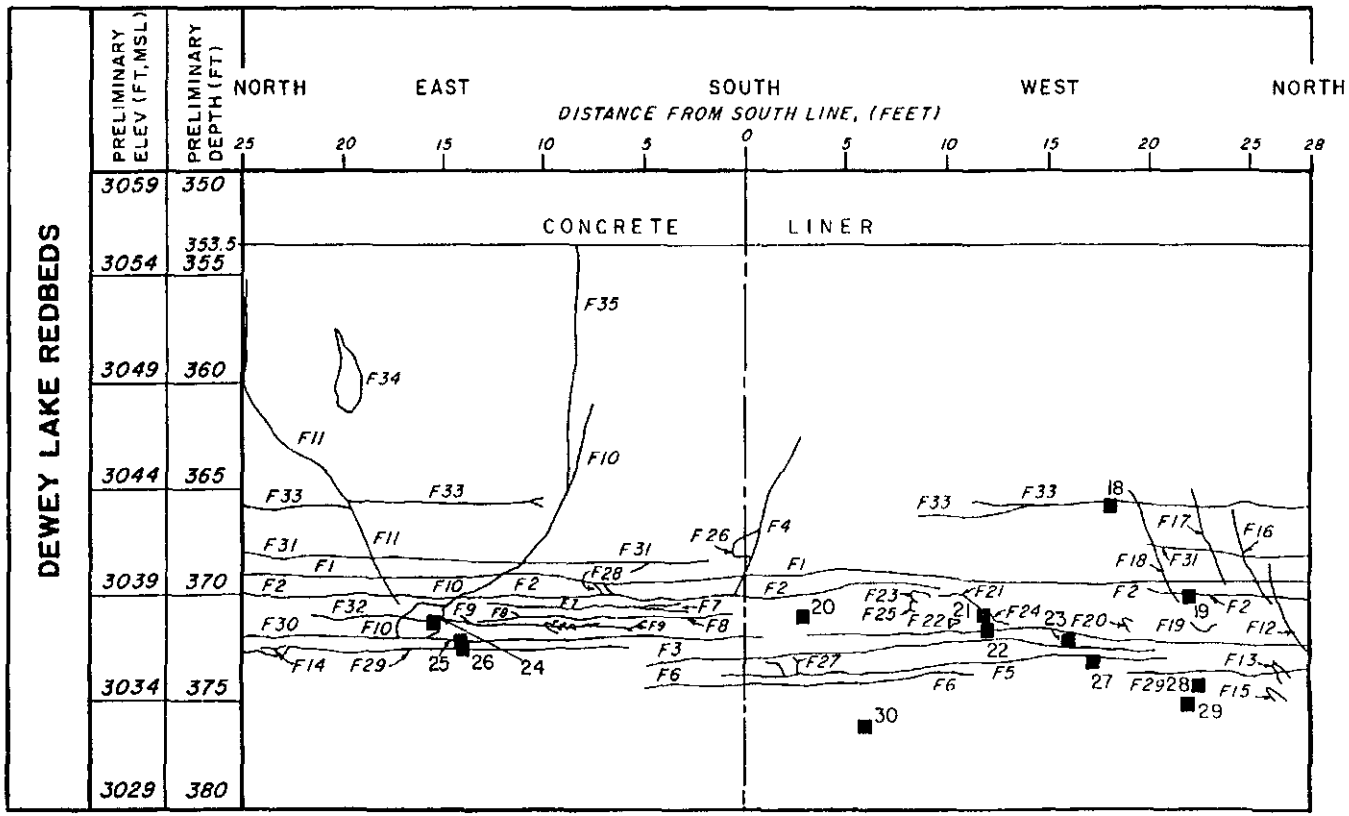

FIGURE 8 - SHEET 1 OF 6

FRACTURE LOG IN THE DEWEY LAKE REDBEDS
DEPTH 353.5 TO 380.0 FEET, EXHAUST SHAFT

WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

PREPARED FOR
WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

IT CORPORATION

Holt, R.M., and Powers, D.W. 1990. Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant. DOE/WIPP 90-051. U.S. Department of Energy, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-1;

" The air intake shaft (AIS) at the Waste Isolation Pilot Plant (WIPP) site was constructed to provide a pathway for fresh air into the underground repository and maintain the desired pressure balances for proper underground ventilation. It was up-reamed to minimize construction-related damage to the rock wall. The upper portion of the shaft was lined with slip-formed concrete, while the lower part of the shaft, from approximately 903 ft below top of concrete at the surface, was unlined. As part of WIPP site characterization activities, the AIS was geologically mapped.

The AIS was geologically mapped during the period from March 11, 1988 to November 14, 1989. The objectives of the geologic mapping were to: 1)provide confirmation and documentation of strata overlying the WIPP facility horizon; 2)provide detailed information of the geologic conditions in strata critical to repository sealing and operations; 3) provide technical basis for field adjustments and modification of key and aquifer seal design, based upon the observed geology; 4) provide geological data for the selection of instrument borehole locations; 5) and characterize the geology at geomechanical instrument locations to assist in data interpretation. All mapping activities were performed from a two deck galloway (work platform) and synchronized with shaft construction activities. The AIS was mapped according to the procedures described in WP 07-503, 'Geologic Mapping of Shafts' (April 25, 1988) (Appendix B).

The entire shaft section including the Mescalero Caliche, Gatuña Formation, Santa Rosa Formation, Dewey Lake Redbeds, Rustler Formation, and Salado Formation to the WIPP facility horizon was geologically described. The shaft construction method, up-reaming, created a nearly ideal surface for geologic description. Small-scale textures usually best seen on slabbed core were easily distinguished on the shaft wall while larger-scale textures not revealed in core were well displayed. Previously undescribed textures were interpreted, and the AIS data were used to further refine depositional and post-depositional models of the units mapped.

The upper part of the Dewey Lake Redbeds displayed features consistent with Schiel's (1988) interpretation of the depositional environments. The geologic mapping data indicated deposition in a fine-grained, ephemeral fluvial system (Schiel, 1988). The lower part of the Dewey Lake, however, was depositionally a continuation of Rustler style sedimentation and accumulated in saline mud flat/mud flat environments. Most gypsum-filled fractures developed incrementally in response to unloading, while some Dewey Lake are syndepositional. Within the Dewey Lake, a cement change between carbonate and, possibly, anhydrite was observed at a depth of 164.5 feet. Perched water tables within the Dewey Lake may rest on this cement change. Above the cement change, the shaft surface was moist and displayed an efflorescent crust consisting of halite. The source of the halitic water is attributed to the muck-piles north and east of the AIS.

The features observed within the Rustler are consistent with those reported by Holt

and Powers (1984, 1986, and 1988). Mudstones within the Rustler created a spalling hazard as several feet of mudstone had spalled out of the units and large slabs to desk-top size had to be scaled from the rib prior to mapping. Liner plate was installed over all Rustler mudstones. The surface of the lower part of the Rustler required extensive washing and scaling prior to mapping as Culebra and construction waters dissolved halite crystals and cements. Extensive vertical fluxing was observed.

The AIS data from the Salado allowed the authors to add considerably to the understanding of the depositional and diagenetic history of the Salado. Unprecendeted halite textural and fabric data was collected, characterized, and interpreted from the Salado. An idealized Salado halite sequence was constructed, and all Salado halite observed within the AIS fits partially or wholly into the idealized sequence. Complete Salado halite sequences consist of four lithofacies, in ascending order: 1) stratified mud-poor halite; 2) 'podular' muddy halite; 3) 'dilated' mud-rich halite; and 4) halitic mudstone. These lithofacies developed in four distinct depositional environments: 1) a mud-poor salt pan; 2) a 'hummocky' salt pan; 3) a mud-rich salt pan; and 4) a saline mud flat.

Salado sulfate interbeds (including Markerbeds) displayed abundant previously undescribed textures and fabrics. Textural data from the AIS provided the basis for further interpretation of these interbeds. Salado sulfate interbeds were deposited in shallow saline lagoon environments following eustatically- or meteorically-driven, basin-wide flooding and freshening events (Lowenstein, 1982, 1983, 1988). Different hydrologic conditions produced three distinct types of sulfate interbeds within the Salado. The sulfate interbeds bounding the repository horizon may be laterally variable due to facies changes within the depositional environment. Geologic evidence of naturally occurring late-stage fluid migration or alteration within the halite of the Salado was not found. Mineralized and fluid-filled fractures occur within some sulfate interbeds within the Salado."

p. 3-3, para. 1;

" At the AIS, the Gatuña is 13 feet thick and consists of very calcareous, very friable, soft sandstone (Figures 4 and 5). The Gatuña is light red and mottled with dark stains. Carbonate occurs as stringers and concretions in probable rhizolithic structures. Clay-sized materials locally appear translocated. Some pebble-sized clasts of sandstone are probably derived from the underlying Santa Rosa Formation. The Gatuña overlies a sharp erosional contact on the Santa Rosa Formation."

p. 3-4, para. 2;

" The Dewey Lake is characterized by its reddish-orange to reddish-brown color and varying sedimentary structure. At the WIPP site (as exposed in the AIS), the Dewey Lake is 476 feet thick and consists of interbedded reddish-brown fine sandstone, siltstone, mudstone and claystone (Figure 5). The Dewey Lake is distinguished from other redbed units by the presence of greenish-gray reduction spots, which are liberally sprinkled throughout the formation, and locally abundant fibrous gypsum-filled fractures. Its upper contact with the Santa Rosa Formation is sharp and erosional (Figure 6). The lower contact of the Dewey

Lake with the Rustler Formation is sharp, with a minor amount of erosional relief (Figure 7 and 8). This contact is locally disconformable, but there is evidence of a regional unconformity (Holt and Powers, 1988)."

3.4.3 Origin and Significance of Gypsum-Filled Fractures, p. 3-8;
" With the exception of the upper portion, the Dewey Lake is characterized by locally abundant gypsum-filled fractures. Most of the fractures are filled with fibrous gypsum, although granular gypsum fracture fillings do occur in the upper portion of the Dewey Lake. In the AIS, gypsum-filled fractures are abundant below 164.5 feet. The fracture filling gypsum is fibrous indicating incremental growth. The fracture pattern and filling morphology is governed by the grain-size of the fractured host material, as discussed below."

3.4.4 Origin of Perched Water Tables in the Dewey Lake, p. 3-10, para. 2;
" At the AIS, the Dewey Lake is cemented with carbonate above 164.5 feet. The coarse-grained units (sandstones and siltstones) are usually moderately hard, though a few are soft. The mudstones and claystones are soft and commonly fissile. Fractures are unfilled or filled with carbonate, and carbonate-filled fractures increase downward. The surface of the AIS wall in the Dewey Lake is moist down to 164.5 feet, and a halitic efflorescence is sometimes present on the shaft wall. ..."

p 3-11, para 2;
" At the WIPP site, meteoric water probably infiltrates through the surface materials (dune sand and construction fill material) to the Mescalero caliche, where it moves downgradient off of the site or evaporites. When the Mescalero caliche and the Pleistocene and Triassic rocks have been disturbed by construction activities, this water can infiltrate along these newly created pathways into the underlying Dewey Lake. The water will infiltrate to the cement change surface and either stop or move down gradient. The impact of this process should be assessed with respect to shaft plugs and seals."

p 3-26, para 3;
" The lower mud-poor section of the sequence is dominated texturally by an overall sense of horizontal to subhorizontal stratification and is named the 'stratified' mud-poor lithofacies (Figure 1, Appendix F). It is subdivided into three zones with small-scale textures. The first zone is dominated by bottom growth halite textures including halite chevron, cornet, and cumulates and clay or sulfate laminae. The second zone shows abundant passive pore-filling halite cements in small dissolution pits and pores. The uppermost zone contains exhibits mostly expansive halite cement textures (displacive halite) mixed with various syndepositional solution textures and fabrics. These textures are consistent with deposition in a mud-poor salt pan.

The 'podular' muddy halite lithofacies is characterized by lenses and pods of fine to medium crystalline halite (Figure 1, Appendix F). Generally, it is more argillaceous then the 'stratified' mud-poor lithofacies. The 'podular' muddy halite lithofacies is subdivided into

two zones which laterally and vertically interfinger: 1) a zone dominated by expansive (displacive) halite cements and 2) a zone with few expansive cements. Few textures reflecting subaqueous deposition are preserved, and continuous strata are very rare. Dissolution pits, pipes, and pores are common. Textures within this lithofacies are similar to 'hummocky' salt pan halite in the Devil's Golf Course in Death Valley, California."

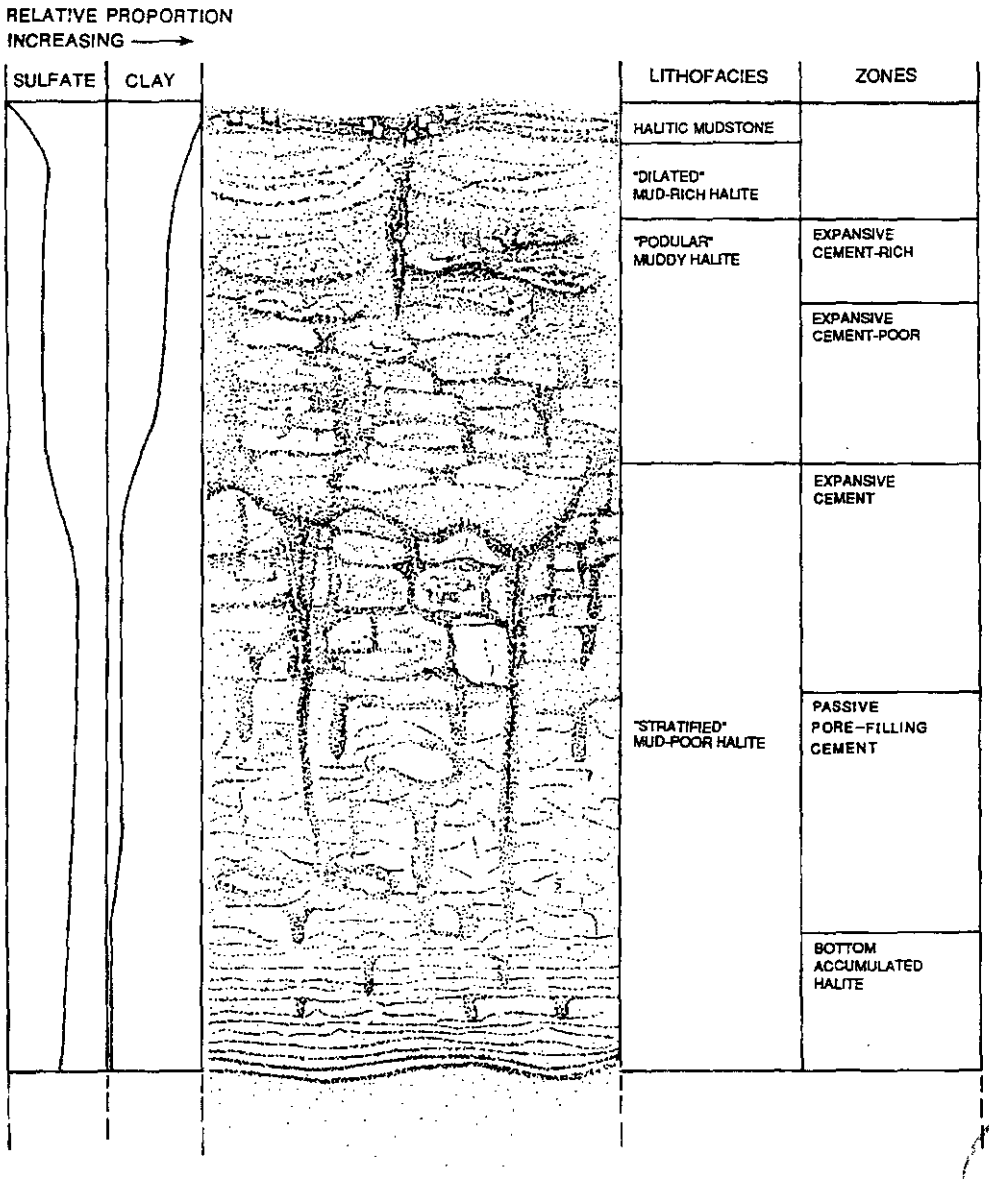

FIGURE 1 IDEALIZED SALADO HALITE SEQUENCE LITHOFACIES AND ZONES.

Appendix F - Figure 1

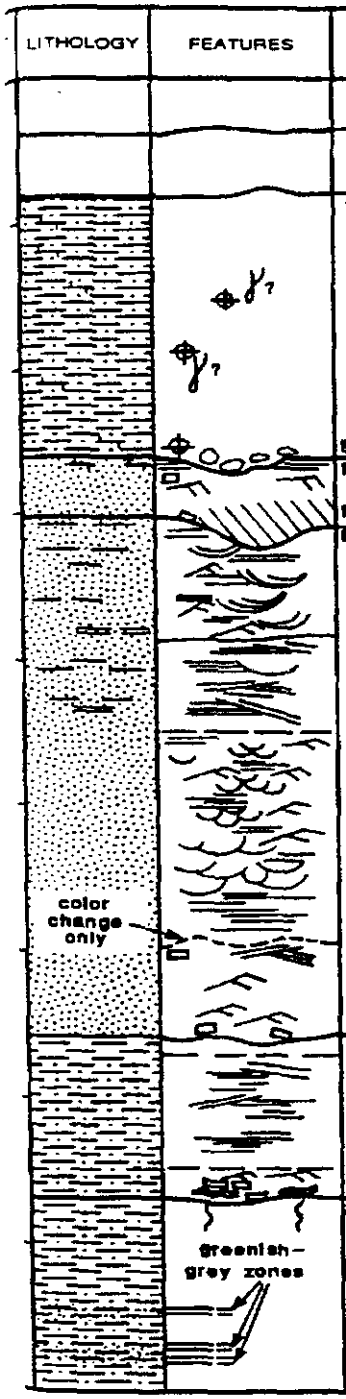

LITHOLOGY	FEATURES	REMARKS
		TOP OF SUBCOLLAR CONCRETE BASE OF SUBCOLLAR CONCRETE
		FILL MATERIAL, DARK REDDISH BROWN, MOTTLED; BECOMES LESS DISTURBED DOWNWARD.
		GATUNA FORMATION - UNDISTURBED. SANDSTONE, LIGHT RED, MOTTLED, VERY CALCAREOUS, SLIGHTLY ARGILLACEOUS. VERY FINE SAND TO SILT-SIZED GRAINS, SUBANGULAR TO ROUNDED. ESTIMATED 80 PERCENT QUARTZ, 5 PERCENT MAFIC GRAINS, 15 PERCENT OTHER. CARBONATE STRINGERS GENERALLY ORIENTED SUBHORIZONTALLY, CARBONATE CONCRETIONS ARE POSSIBLE ROOT CASTS. SOME CLAYS AND ARGILLACEOUS MATERIAL ARE POSSIBLY TRANSLOCATED; POSSIBLE BIOTURBATION. UNIT LOCALLY CONTAINS CLASTS OF MORE CALCAREOUS, HARDER SANDSTONE (POSSIBLY REWORKED CALICHE CLASTS) AND GREENISH-GRAY CLASTS (POSSIBLY SANTA ROSA FM.). SURFACE OF UNIT IS LOCALLY MOIST AND EXHIBITS NaCl-RICH EFFLORESCENT CRUST; UNIT IS VERY FRIABLE, SOFT. BASAL CONTACT SHARP, EROSIONAL (2 FT RELIEF), OVERLAIN WITH COBBLE-SIZE RIPUPS OF UNDERLYING SANDSTONE AND GRANULE-SIZED RIPUPS OF DARK BROWN CLAYSTONE.
	E R R E	SANTA ROSA FORMATION. SANDSTONE, CALCAREOUS, RED; SILT TO FINE SAND-SIZED GRAINS, 80 PERCENT QUARTZ, 5 PERCENT MAFIC, 15 PERCENT OTHER, GRAINS SUBANGULAR TO ROUNDED. TABULAR CROSS-CUTTING BEDS UP TO 2 FT THICK; UPPER SURFACE BOUNDED BY HARD, VERY CALCAREOUS, VERY THIN BEDS AND CLASTS OF SANDSTONE; DARKER BEDS MAY BE CROSS-LAMINATED; LIGHTER INTERBEDS CONTAIN THIN LAMINAE TO LAMINAE OF CALCAREOUS SANDSTONE PARALLEL TO CROSS-CUTTING SURFACES; CALCITE-RICH UNITS CONTAIN RIPUP CLASTS OF DARK RED SILTSTONE, LOCAL COBBLE-SIZE RIPUP CLASTS OF WELL-CEMENTED SANDSTONE. VERY RARE SUBVERTICAL FRACTURES ARE FILLED WITH CALCITE, LOCAL STRINGERS POSSIBLY DEVELOPED ALONG FRACTURES; UNIT IS SOFT TO MEDIUM HARD. BASAL CONTACT SHARP, EROSIONAL RELIEF OF 2 FT.
	R R	SILTY SANDSTONE TO SILTSTONE, DARK REDDISH BROWN (10R3/6), WITH PALE OLIVE (10Y6/2) FROM 30 FT TO BASE; CALCAREOUS; FINE TO MEDIUM AT BASE TO FINE TO VERY FINE SAND GRAINS UPWARD; DOMINANTLY QUARTZ, 1-5 PERCENT MAFIC GRAINS; SOFT TO MODERATELY WELL INDURATED. THINLY LAMINATED TO CROSS-LAMINATED FROM 15-19 FT WITH LOCALLY ABUNDANT TROUGH CROSS-BEDS HAVING TANGENTIAL BOTTOMSETS, TROUGH .1-.3 FT DEEP AND 1 FT WIDE IN A CHANNEL BAR COMPLEX. PLANAR LAMINAE TO LOW ANGLE CROSS-LAMINAE (IN-CHANNEL BARS) FROM 19-22 FT IN SETS <.3 FT HIGH WITH LOCAL ARGILLACEOUS ZONES MARKING TOPS OF SETS. TROUGH CROSS-BEDS FROM 22-28 FT (CHANNEL DEPOSITS) IN SETS .4-.7 FT HIGH, DECREASING IN SIZE UPWARD TO .1-.3 FT SETS INTERBEDDED WITH THIN LAMINAE AND CROSS-LAMINAE. PARALLEL PLANAR, HORIZONTAL TO SUBHORIZONTAL, THIN BEDS TO LAMINAE FROM 28-30 FT, WITH SOME BROAD CROSS-CUTTING SETS (CHANNEL DEPOSITS); UNDULATORY, BUT SHARP, COLOR CHANGE AT ABOUT 30 FT CUTS ACROSS BEDDING; ZONE OF SMALL CLAYSTONE CLASTS (1/4" X 1") AT 30.5 FT; COARSENS DOWNWARD FROM FINE TO MEDIUM SANDSTONE FROM 30.5-33 FT, WITH MINOR SILT AND CLAY. SHARP, EROSIONAL BASE WITH ABOUT 6" RELIEF OVERLAIN BY A FEW REDDISH BROWN CLASTS.
	R R	SILTSTONE, ARGILLACEOUS, SLIGHTLY SANDY, FINING UPWARD TO SILTY CLAYSTONE; PALE OLIVE (10Y6/2) IN BASAL 1.5 FT, INTERBEDDED WITH AND OVERLAIN BY DARK REDDISH BROWN (10R3/6) TO VERY DARK REDDISH BROWN (10R3/3) AT TOP, SMALL, GREENISH REDUCTION SPOTS NEAR GRADATION TO CLAYSTONE; VERY CALCAREOUS. BEDDING UNCLEAR NEAR BASE, INTERBEDDED REDDISH BROWN LAYERS IN GREEN ZONE CONSIST OF CLAYSTONE AND CLAYSTONE CLASTS, SMALL (<.1 FT) RIPPLES NEAR TOP OF GREEN ZONE. ABOVE GREEN ZONE, MAINLY HORIZONTAL TO SUBHORIZONTAL LAMINAE WITH LOW ANGLE CROSS-CUTTING BEDS; SUBUNITS ARE UP TO 1 FT THICK, FINE UPWARD INTERNALLY. CLAYSTONE IS WET AND PROBABLY COLLECTING WATER IN OVERLYING SANDSTONE; VARIABLE SALT EFFLORESCENCE ON SHAFT WALLS; MODERATELY WELL INDURATED IN GREEN ZONE, WELL INDURATED TO SOMEWHAT FISSILE NEAR TOP. SHARP BASAL CONTACT.
		DENEY LAKE FORMATION. CLAYSTONE, SILTY AND SANDY, VERY DARK REDDISH BROWN (10R3/3), WITH GRAYISH GREEN (10GY5/2), SLIGHTLY MORE SANDY BEDS NEAR BASE AND GREEN REDUCTION SPOTS NEAR TOP. SLIGHTLY COARSER ZONES AND INTERBEDS ARE VERY CALCAREOUS, WELL INDURATED, AND USUALLY .1-.3 FT THICK AT .3 TO 1 FT INTERVALS. BASAL PART SHOWS FINING UPWARD CYCLES ABOUT .5-1 FT THICK AND INTERBEDDED SILTSTONE AND CLAYSTONE. VERTICAL TO SUBVERTICAL FRACTURES IN UPPER 1-2 FT ARE

AIR INTAKE SHAFT LITHOLOGIC LOG
SHEET 3 OF 22

FIGURE 5

NOTE: Figure 16 is a photograph and will not scan in properly, therefore it is not included here.

Howard, K.A., Aaron, J.M., Brabb, E.E., Brock, M.R., Gower, H.D., Hunt, S.J., Milton, D.J., Muehlberger, W.R., Nakata, J.K., Plafker, G., Prowell, D.C., Wallace, R.E., and Witkind, I.J. 1971 [reprinted 1991]. Preliminary Map of Young Faults in the United States as a Guide to Possible Fault Activity. Miscellaneous Field Studies Map MF-916, 1:5,000,000. 4 maps on 2 sheets. U.S. Geological Survey, Denver, CO.

RIO GRANDE BASIN AND RANGE, Sheet 2 of 2;
"Rio Grande.--Abundant high-angle normal faulting in the late Cenozoic has formed the Rio Grande trough and adjacent basins and ranges. Evidence for movements in the Quaternary is common. The Rio Grande fault systems blend northward with similar basin-and-range faults that are somewhat masked by the surrounding topography of high Colorado Rocky Mountains."

Hunter, R.L., 1985. A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area. SAND84-2233. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. 3;
" The WIPP water-balance study area defined here comprises ~2000 mi^2 in Eddy and Lea Counties, southeastern New Mexico. Inflows to the study area are precipitation (roughly 1.47 x 10^6 ac-ft/yr), surface water (roughly 1.1 x 10^5 ac-ft/yr), water imported by municipalities and industries (roughly 3 x 10^4 ac-ft/yr), and ground water (volume not estimated). Outflows from the area are evapotranspiration (roughly 1.5 x 10^6 ac-ft/yr), surface water (roughly 1.2 x 10^5 ac-ft/yr), and possibly some ground water. The volume of surface and ground water in storage in Nash Draw has increased since the beginning of potash refining. Regional ground water flow in aquifers above the Salado Formation is from the northeast to the southwest, although this pattern is interrupted by Clayton Basin, Nash Draw, and San Simon Swale. The Pecos River is the only important perennial stream. Most of the area has no integrated surface-water drainage.

The available data suggest that ~1600 mi^2 of the study area are hydrologically separate from Nash Draw and the WIPP site. Ground water north of Highway 180 apparently discharges into Clayton Basin and evaporates. Water in San Simon Swale apparently percolates downward and flows to the southeast. Data are inadequate to create a water budget for the Nash Draw-WIPP site hydrologic system alone, although an attempt to do so can provide guidance for further study."

Table 10, p. 29;
"Minimum and Maximum Annual Ground-water Discharge to the Pecos River

Pairs of Stations	Gain in TDS (tons)	Minimum Discharge (ac-ft)	Maximum Discharge (ac-ft)
4040-4052	--	--	7400
4052-4065	168,300	397.6	6100
4065-4070	99,000	233.9	3100
4070-4075	330,000	779.7	7000

p 32, col. 1, para 4, line 18;
". . . If no ground water evaporates from the southern two-thirds (other than precipitation that falls locally and seeps into the lake through the ground.), and if 12 in. of rain is equivalent to 3 ft of evaporation from the lake (using Mr. Williamson's estimate), then 1.4 ft/acre of ground water evaporates from 660 acres of the lake. This rough calculation results in an estimate of 924 ac-ft/yr of natural ground-water discharge from Laguna Grande de la Sal. Surprise Spring is the largest of the springs discharging into the lake, and therefore its

known discharge provides a check on the estimate of total ground-water discharge from the lake. In 1942, Surprise Spring discharged 120 gpm (194 ac-ft/yr) (National Resources Planning Board 1942, p 69). The estimate of 924 ac-ft/yr total ground-water discharge does not seem unreasonable. No correction for the volume of dissolved solids, which would further reduce the estimate of ground-water discharge, has been made in this report."

Izett, G.A., and Wilcox, R.E. 1982. Map Showing Localities and Inferred Distribution of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds in the Western United States and Southern Canada. Misc. Investigations Map I-1325, scale 1:4,000,000. U.S. Geological Survey.

DISCUSSION;

" During the past 10 years there has been increasing interest among earth scientists for tephrochronological data useful for establishing volcanic ash beds as time-stratigraphic markers. When tephrochronological data are combined with other geological information such as stratigraphic position, faunal age, paleomagnetic direction, and isotopic age, the result is a multipronged analytical device with a combined resolving power far greater than that of any individual geologic technique. Correct identification of an isotopically dated volcanic ash bed can provide critical information to help resolve problems such as (1) the correlation (over long distances) of sedimentary deposits of diverse origins (marine, lacustrine, fluviatile, paludal, glacial, periglacial, and eolian); (2) the determination of the times and rates of fault movements and other types of crustal deformation; (3) the determination of the average rates of deposition of sediments; (4) the evaluation of geologic hazards such as volcanic eruptions and earthquakes; (5) the calibration of paleomagnetic stratigraphies and faunal chronologies; (6) the calibration of experimental dating methods such as uranium-trend dating; (7) the identification of tephra sources; and (8) the evolution of silicic magma bodies and related tephra ejection mechanics, transportation, and deposition. Several upper Cenozoic volcanic ash beds of the western United States have been studied in considerable detail including tephra of Holocene age from Mount St. Helens volcano in Washington (Fryxell, 1965; Mullineaux and others, 1975; Westgate, 1977) in Washington; the Mazama ash bed of Holocene age (Powers and Wilcox, 1964); the Glacier Peak ash bed of latest Pleistocene age (Powers and Wilcox, 1964; Westgate and Evans, 1978); and the Bishop ash bed of middle Pleistocene age (Izett and others, 1970; Borchardt and others, 1972; Merriam and Bischoff, 1975; Sama-Wojcicki and others, 1980). These volcanic ashes are found interbedded in various types of fluvial, colluvial, and lacustrine Holocene and Pleistocene sedimentary deposits scattered from the West Coast of the United States to as far east as central Nebraska. Another set of volcanic ashes, the Pearlette family ash beds, also has been extensively studied and used for long range correlations of the enclosing sediments and their contained fossil materials. These ash beds are the main subject of this report.

By the late 1950's, the Pearlette ash was widely used as an important stratigraphic marker in the Great Plains area, and was thought to be a single bed, marking an instant of time in the geologic record of the middle Pleistocene. Vertebrate and invertebrate paleontologists used it as a datum to stratigraphically relate their fossil collections and stratigraphers used it as a correlation tool to relate sedimentary deposits over large areas of the Great Plains. However, a few geologists and paleontologists questioned the prevalent idea that the Pearlette constituted a single bed. Smith (1940, p. 119), Hibbard (1944, p. 744), and Powers and others (1958) pointed out evidence that conflicted with the established concept of a single Pearlette ash, and Smith (1940), in particular, suggested that the Pearlette

might represent several beds of distinctly different age. Although these and other geologists had suspected that the Pearlette might be a multiple set of ash beds, no one, however, had found stratigraphically superposed beds of Pearlette-like ash beds in the Great Plains. Recently, superposed beds of Pearlette ash of markedly different ages have been found in the type area of the Pearlette ash in central Meade County, Kans., by detailed geologic mapping and stratigraphic studies (G.A. Izett and J.G. Honey, unpublished mapping, 1980).

As a result of detailed mineralogical and chemical studies of the Pearlette ash using newly developed analytical tools (spindle stage study of microphenocrysts, atomic absorption photospectrometric analyses of glass shards, instrumental neutron activation analyses of glass shards, paleomagnetic studies, and electron microprobe analyses of glass shards and microphenocrysts) we determined in the late 1960's that the Pearlette comprised three different but closely related mineralogical-chemical ash varieties. We provisionally designated these ashes as types B, S, and O (Izett and others, 1970; Izett and others, 1971) and correlated them with three, voluminous rhyolite ash-flow tuffs in the Yellowstone National Park area then being mapped by R.L. Christiansen and H. R. Blank of the U.S. Geological Survey. These ash-flow tuffs were named the Huckleberry Ridge, the Mesa Falls, and the Lava Creek Tuffs by Christiansen and Blank (1972). Precise, potassium-argon age determinations of sanidine were made of the three ash-flow tuffs and their associated air-fall units (J.D. Obradovich, written commun., 1979). The K-Ar ages of these units, calculated using current decay constants and $^{40}K/^{39}K$ abundance (Steiger and Jäger, 1977), are as follows: Huckleberry Ridge Tuff 2.02 m.y.; Mesa Falls Tuff, 1.27 m.y.; and Lava Creek Tuff (members A and B), 0.62 m.y. By inference, the ages of the downwind ash beds (Huckleberry Ridge, Mesa Falls, and Lava Creek) equivalents of the K-Ar dated source-area tuffs are also firmly dated--provided that firm mineralogical and chemical correlations are made between the source-area pyroclastic units and their suspected downwind correlative ashes.

. . .

The ash localities shown on the map are numbered sequentially in each State and number keyed to table 1 that gives locality and other information. The localities are listed in alphabetical order, first by State and then by County. In addition to ash beds of the map being classified as either Huckleberry Ridge, Mesa Falls, Lava Creek A, or Lave Creek B ash, certain other ash beds are designated as Pearlette family ash or simply Pleistocene ash. Many of the ash beds on the map can only be designated as Pearlette family because insufficient tephrochronological work has been done to further identify them as belonging to the Huckleberry Ridge, Mesa Falls, or Lava Creek ashes. Many of the localities shown on the map as Pleistocene ash (especially in Oklahoma) may be Pearlette family ashes based on their inferred stratigraphic position, inferred Pleistocene ages, and geographic locations, but no chemical or petrographic information is available for them. Where we have identified an ash as being either Huckleberry Ridge, Mesa Falls, or Lava Creek we have sufficient analytical data available in our files to make the identification with a high probability."

Jarolimek, L., Timmer, M.J., and McKinney, R.F. 1983. Geotechnical Activities in the Exploratory Shaft -- Selection of the Facility Interval, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3178. U.S. Department of Energy, Albuquerque, NM.

Section 1.0 ABSTRACT, p 1-1;

" This report on geotechnical activities in the exploratory shaft was prepared as part of the Site validation Field Program for the U. S. Department of Energy's Waste Isolation Pilot Plant near Carlsbad, New Mexico. The report (1) summarizes basic data on shaft drilling and construction, (2) presents the geologic mapping results which essentially correspond to the conditions predicted from previous investigations, and (3) discusses the optimization process based on the geologic conditions encountered and its results for the (a) adjustment and modification of the shaft key design, (b) selection of the facility interval, and (c) selection of the geotechnical instrument locations."

Section 4.3 STATION ZONE GEOLOGY, P4-6, PARA 4;

" Of particular interest during the mapping was the location and nature of MB 139 and the presence of any clay seams or partings. As shown in Figure 6 and Plates 8 and 10, MB 139 is approximately 2 to 3.4 feet thick and is principally composed of anhydrite with minor amounts of polyhalite that occur in stringers and thin beds, particularly in the upper portion of the bed. The upper contact of MB 139 is undulatory and occurs between the elevations of 1251.7 and 1253.9 feet MSL. This undulatory contact (with an amplitude of 1.6 feet around the shaft) is believed to be the result of syndepositional processes, such as differential compaction of soft sediments and/or growth of 'swallow-tail' gypsum crystals (Plate 10). The absence of displaced stratigraphic contacts implies a nontectonic origin to the undulatory top of MB 139. More detailed discussion on MB 139 is presented in TME 3179 (Jarolimek, et al., 1983)."

Section 6.3 CONFORMANCE OF SELECTED INTERVAL TO CRITERIA, p 6-5;

" Subsequent to the geologic mapping and ensuing discussions, the following observations were made and conclusions reached regarding conformance of the selected facility interval to the selection criteria, as listed in Section 6.1:

Criterion No. 1:

Faults and fractures were not observed in the facility interval and no features known to be due to dissolution were observed."

Jones, C.L., Bowles, C.G., and Bell, K.G. 1960. Experimental Drillhole Logging in Potash Deposits of the Carlsbad District, New Mexico. Open-File Report. U.S. Geological Survey, Denver, CO.

p 6, para 2;
" Polyhalite, which is one of the hydrous minerals, is the most abundant and widespread potassium mineral. It is not economically valuable, but is important in the stratigraphy of the Salado formation. The mineral forms discrete beds, and occurs with anhydrite in other beds. These polyhalite-anhydrite beds are widespread, laterally persistent layers that serve as stratigraphic marker beds. Some of them are recognized by names, such as the Union anhydrite of local usage, and others are recognized by number. Numbering of potassium-bearing beds was introduced by Smith (1938). A modification of his system currently is used by most of the potash companies in the Carlsbad district. The polyhalite-anhydrite marker beds are numbered, and salt beds containing potash deposits are given names, such as the First Ore Zone. The lithologic character and thickness of the polyhalite-anhydrite marker beds, the potassium-bearing ore zones, and the name or number by which each bed or group of beds is recognized are shown on the composite columnar section (fig. 1)."

Figure 1. Generalized columnar section and radioactivity log of potassium-bearing rocks, Carlsbad district, southeastern New Mexico is a drawing too large to include in this document.

Jones, C.L., Cooley, M.E., and Bachman, G.O. 1973. Salt Deposits of Los Medaños Area, Eddy and Lea Counties, New Mexico. Open File Report 4339-7.U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;

" The salt deposits of Los Medaños area, in Eddy and Lea Counties, southeastern New Mexico, are being considered for possible use as a receptacle for radioactive wastes in a pilot-plant repository.

The salt deposits of the area are in three evaporite formations: the Castile, Salado, and Rustler Formations, in ascending order. The three formations are dominantly anhydrite and rock salt; but some gypsum, potassium ores, carbonate rock, and fine-grained clastic rocks are present. They have combined thicknesses of slightly more than 4,000 feet, of which roughly one-half belongs to the Salado. Both the Castile and the Rustler are richer in anhydrite and poorer in rock salt than the Salado, and they provide this salt-rich formation with considerable protection from any fluids which might be present in underlying or overlying rocks.

The Salado Formation contains many thick seams of rock salt at moderate depths below the surface. The rock salt has a substantial cover of well-consolidated rocks, and it is very little deformed structurally.

Certain geological details essential for waste-storage purposes are unknown or poorly known, and additional study involving drilling is required to identify seams of rock salt suitable for storage purposes and to establish critical details of their chemistry, stratigraphy, and structure."

p. 8, Para. 2;

" The Castile Formation underlies Los Medaños area at depths ranging from 1,700 feet near the northwest corner of the area to 3,600 feet near the southeast corner. As developed in this area, the Castile is a very typical basinal evaporite showing great lateral continuity of individual rock units, a well-formed lamination in most units, and a marked paucity of terrigenous debris. In general, the formation is composed of as much as 1,830 feet of anhydrite and rock salt with subordinate limestone, but it is readily separable into three informal members by a salt-rich zone 200-400 feet above the base (fig. 4). The threefold division includes: a lower member composed chiefly of anhydrite, a middle member composed chiefly of rock salt, and an upper member composed chiefly of anhydrite. The three members are discrete, readily distinguished lithologic units throughout the southern and central parts of the area, but northward they merge into a single wedgelike mass of anhydrite that thins rapidly to a narrow tongue at the north edge of Los Medaños area (fig. 3).

The lower member of the Castile Formation is a well-stratified evaporite consisting of laminae of gray anhydrite and brownish-gray limestone in regular, rhythmic alternation. Some beds of laminated dark-gray and brownish-gray limestones, a few inches to several feet thick, are present at wide intervals in the lower and middle parts of the member, and there are a few thicker beds of massive gray anhydrite at long intervals. The member is 200-240

feet thick along the southern border of Los Medaños area, but it thickens northward and reaches a thickness of at least 400 feet before merging with other members of the Castile to form a single unbroken mass of anhydrite in the northern part of the area (fig. 3).

The middle member of the Castile Formation is predominantly rock salt, but it includes some thin to thick beds of interlaminated anhydrite and limestone. The member ranges in thickness from about 560 feet near the southern margin of Los Medaños area to as much as 1,200 feet in deformationally thickened masses in the Culberson & Irwin 1 Murray well (figs. 3 and 4) and elsewhere in the central part of the area. The member terminates northward by grading laterally into, and intertonguing with, anhydrite.

The upper member of the Castile Formation is composed chiefly of anhydrite laminated by calcitic limestone and, to a lesser extent, of massive anhydrite, rock salt, and carbonate rock, including both magnesite and dolomite. The member includes a northwardly thinning tongue of anhydrite that overlaps the Capitan Limestone and Tansill Formation in the northern part of Los Medaños area (fig. 3). The main body of the member is 600-700 feet thick at the south end of the area. It thins rapidly northward and is as little as 170 feet thick in the central part of the area. The northward thinning is attributed to a transition involving a stratigraphic descent in the top of the member as beds of anhydrite give way laterally to rock salt of the Salado Formation (fig. 4). The transition is accomplished partly by direct gradation from anhydrite to rock salt, and partly in pinch out of anhydrite beds between tongues of rock salt.

The contact between the Castile Formation and the overlying Salado Formation is conformable and gradational, but, nevertheless, is generally rather sharply defined as the horizon at which dominant anhydrite below gives way to rock salt."

Figure 3 - Texas L J 1973 - B-B' is roughly North South

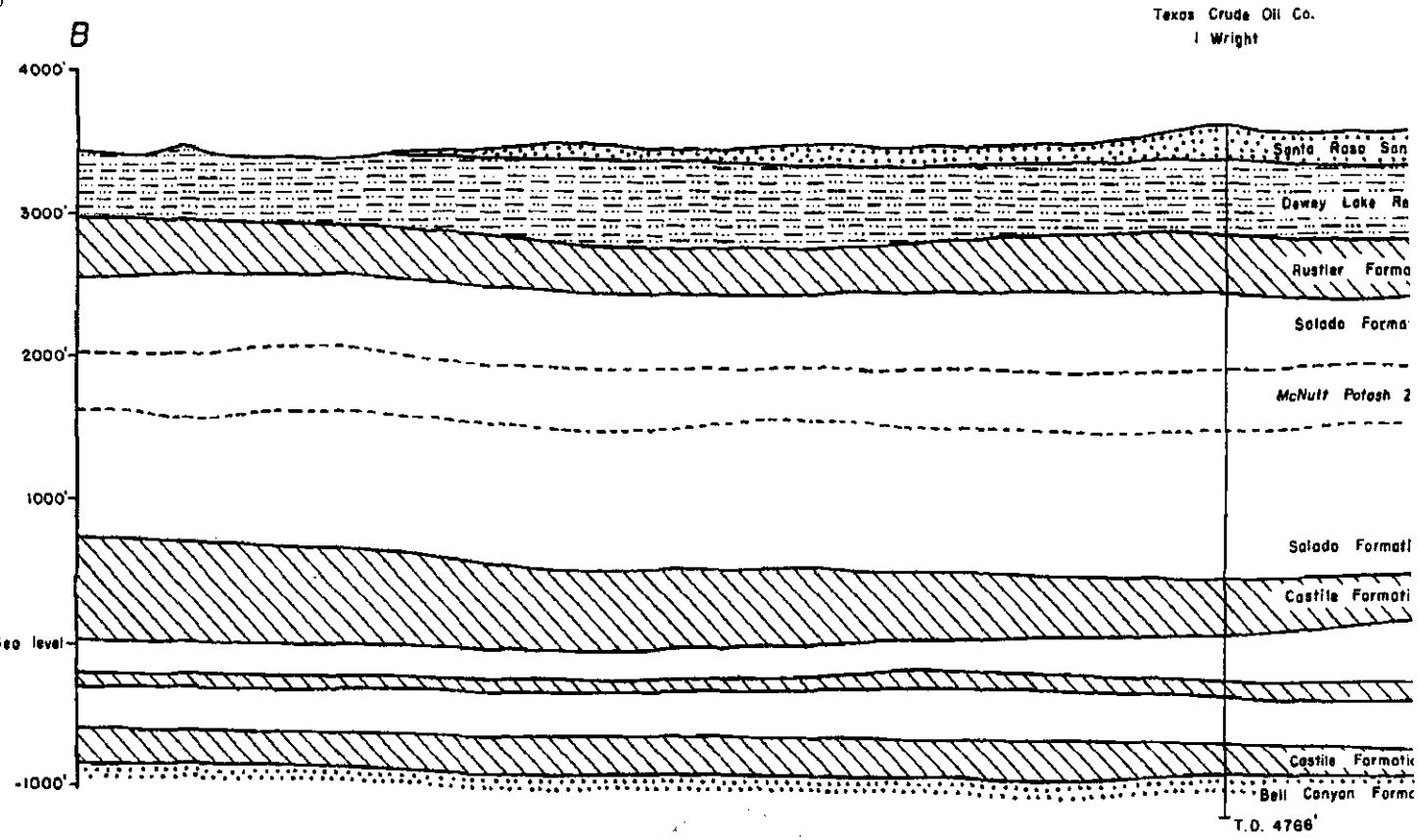

U.S. Geological Survey
OPEN FILE REPORT
This map is preliminary and has not been edited or reviewed for conformity with Geological Survey standards.

GEOLOGIC SECTIONS OF
EDDY AND LEA COU
TRACE OF SECTIONS SHO

Vertical exaggera

FIGURE

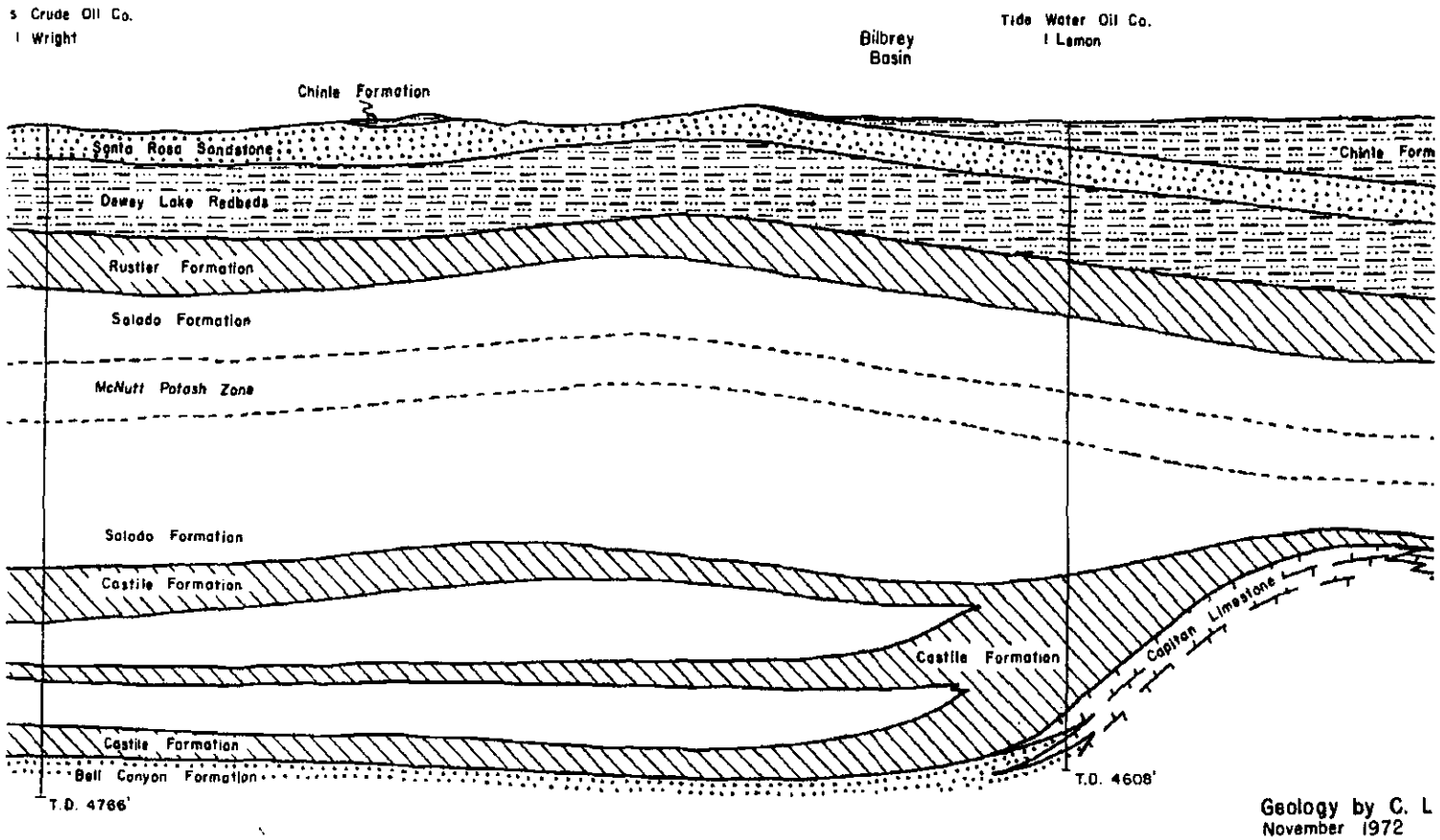

·TIONS OF LOS MEDAÑOS AREA

ND LEA COUNTIES, NEW MEXICO

)F SECTIONS SHOWN ON GEOLOGIC MAP

1 2 3 4 Miles

Vertical exaggeration 5.3X

FIGURE 3

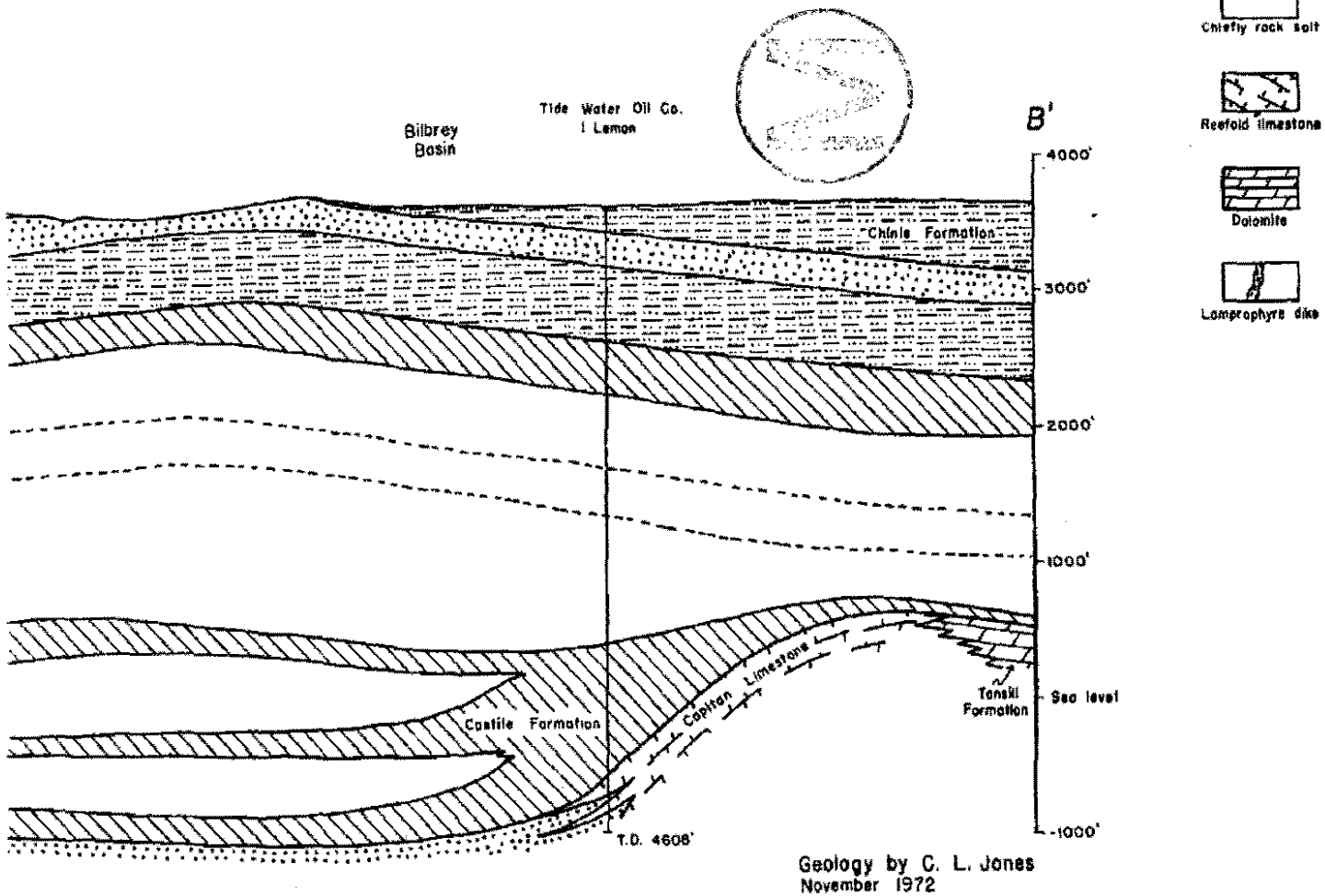

DAÑOS AREA

MEXICO

MAP

Miles

Jones, C.L., 1978. Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico. Open-File Report 78-592. Vols. 1 and 2. U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;
" Twenty-one borings to augment existing information on potash resources at the proposed site for a waste isolation pilot plant in eastern Eddy County, N. Mex., were drilled and logged in an 11-week period, mid-August to November 1976. The basic data developed from the borings are tabulated in the present report. The tabulation includes lithologic and geophysical logs of all the borings, as well as the results of chemical analyses, X-ray determinations, and calculations to establish a modal mineralogical composition of core samples from potash ore zones and mineralized salt beds."

Rustler Formation, p 9;
" Overlying the Salado Formation in all the resource-evaluation borings is the Rustler Formation, which was named by Richardson (1904) for exposures in the Rustler Hills in western Texas about 80 km (50 mi) southwest of the WIPP site. In the borings, the Rustler is 88-140 m (288-460 ft) of anhydrite (locally altered to gypsum), dolomite, and fine-grained clastic rocks. Rock salt is present locally but formerly was more widespread, as indicated by the presence of dissolution debris, convergence of beds, and structural evidence for subsidence. The clastic rocks range in composition from mudstone, through clayey siltstone, to very fine grained sandstone, and include structureless accumulations of unconsolidated clays and silts that are residual dissolution products of clayey and silty rock salt."

Table 9A--Abridged drill-hole history, p. 168;
" DRILLING RECORD: Commenced drilling on September 16, and completed on September 25, 1976, at 547 m (1,796 ft) below land surface.

Drilled with air foam to 225 m (738 ft) below land surface. Driller reported water at 67 m (220 ft) below land surface, making about 95 lpm (25 gpm)."

Jones, C.L. 1981. Geologic Data for Borehole ERDA-6, Eddy County, New Mexico. Open-File Report 81-468. U.S. Geological Survey, Denver, CO.

ABSTRACT, p. 1;
" ERDA-6 is an exploratory test hole drilled in eastern Eddy County, New Mexico, to evaluate a candidate site for a nuclear waste repository that was subsequently rejected on the basis of geologic data. The rocks penetrated include surficial deposits of Quaternary age; the Santa Rosa Sandstone of Triassic age; and the Dewey Lake Red Beds, the Rustler Formation, the Salado Formation, and part of the Castile Formation, all of Permian age. The pre-Quaternary rocks are sharply deformed into an anticline that has a faulted core of salt and anhydrite containing a reservoir of geopressurized brine carrying H_2S, CO_2, and CH_4 in solution. The structure of the rocks and the geopressurized brine are severe geologic impediments to the design, construction, and operation of a nuclear waste repository at the candidate site."

Rock Deformation, p. 18, Para. 2;
" Complex deformation of rock salt and anhydrite at ERDA-6 is documented by the irregular stratigraphic section caused by faulting, the schistosity and shear folds in rock salt, and the breccia and vein-filled fractures in banded anhydrite. These features also provide guides to the identification of the nature, magnitude, and timing of that deformation. Structurally all the rocks at ERDA-6 are higher in elevation than anticipated at the start of drilling, and their elevated position is attributed to the emplacement of Castile salt and anhydrite in the Salado Formation at a height of several hundred feet above their normal stratigraphic level. The emplacement has involved salt movement and accumulation in a swell or mound sufficiently thick at ERDA-6 to uplift in a pronounced arch or anticline at least 2,400 feet of strata ranging from Permian through Triassic in age. The stratigraphic relationship of the Castile and Salado to this anticline indicates episodic salt movement during Permian time, and it is inferred that the movement was due to updip sediment loading before dewatering of Castile salt was completed. Evidence to the upper limit of salt movement is lacking at ERDA-6. Elsewhere, on the ERDA-6 structure, however, the uplift and arching of Triassic rocks by salt movement was completed before deposition of the Ogallala Formation of Pliocene age. The Ogallala along the crest of the structure is flat-lying and undeformed but truncates uplifted and eroded Triassic rocks."

Jones, T.L., Kelley, V.A., Pickens, J.F., Upton, D.T., Beauheim, R.L., and Davies, P.B. 1992. Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site. SAND92-1579. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" Conservative tracer tests have been conducted within the Culebra Dolomite Member of the Rustler Formation at the H-2, H-3, H-4, H-6, and H-11 hydropads for transport scales ranging from approximately 20 to 40 m. Convergent-flow and two-well recirculating tracer tests provide data that is used to quantitatively characterize flow and transport processes. The observed long time period required for initial (detectable) tracer breakthrough (74 to 316 days) in the H-2 and H-4 tracer tests suggest the prevalence of single-porosity, matrix-only transport at these locations. Hydraulic-test responses at these two hydropads also indicate single-porosity, matrix-only conditions. The relatively poor quality of data defining the breakthrough curves from the H-2 and H-4 tracer tests precluded a detailed, quantitative analysis of transport parameter values from these tests. Interpretations of pumping tests and tracer tests at the H-3, H-6, and H-11 hydropads indicated that the Culebra dolomite behaves as a double-porosity (fracture-plus-matrix) medium at these locations. Both the H-3 and H-11 hydropads are located along the offsite transport pathways southeast of the Waste Isolation Pilot Plant waste-panel area. Significant fracture participation in transport is evidenced by rapid initial tracer breakthrough (1 to 21 hrs) on one travel path at each of these hydropads. The H-3, H-6 , and H-11 convergent-flow tracer tests were analyzed using the SWIFT II model with the Culebra fracture/matrix system idealized as three, orthogonal, intersecting fracture sets equally spaced in all three directions. Input values and ranges for the assigned transport parameters (effective thickness, well spacing, pumping rate, free-water diffusion coefficient, longitudinal dispersivity, and matrix porosity) were specified based on field measurements, laboratory measurements on Culebra core, and scientific judgement. Measurement and/or calculated uncertainties were also defined for the assigned parameters. Two approaches were used to model double-porosity transport. The first approach assumed that differences in tracer breakthrough behavior at a single hydropad were caused by differences (heterogeneity) in matrix-block length (fracture spacing) between different travel paths. The second approach assumed that differences in tracer breakthrough behavior were caused by horizontal anisotropy in the flow field. Interpretations based on the heterogeneous-analysis approach yielded matrix-block lengths ranging from 0.11 to 1.23 m and fracture porosities ranging from 5.0×10^{-4} to 1.0×10^{-3}. Interpretations based on the anisotropic-analysis approach yielded matrix-block lengths ranging from 0.15 to 0.48 m, fracture porosities ranging from 1.0×10^{-3} to 3.0×10^{-3}, and anisotropy ratios ranging from 3:1 to 7:1. Sensitivity analyses were conducted to provide insight into the relative impact of varying individual transport parameters and to provide estimates of fitted-parameter uncertainty. These analyses yielded minimum and maximum matrix-block lengths for all hydropads that ranged from 0.02 to 3.22 m. Sensitivity analyses also showed that neither single-porosity, fracture-only transport nor single-porosity, matrix-only transport can

reproduce the observed transport behavior at the H-3, H-6, and H-11 hydropads."

Section 5.1.6 Matrix Porosity, p. 5-23, para. 2;
" Laboratory matrix-porosity determinations have been performed on 79 core samples from the Culebra at 15 borehole or hydropad locations at and surrounding the WIPP site (Table 5-3). Factors affecting core selection for laboratory porosity determinations included availability of core samples and competency of the core samples for analysis. Not all boreholes have core available. In addition, core recovery during drilling was very poor at some locations (e.g., approximately 10 and 40 percent at H-3b2 and H-3b3, respectively)."

Table 5-3 (cont'd). Summary of Porosities Determined Using Boyle's Law Technique on Culebra Core Samples (after Kelley and Saulnier, 1990), p. 5-26;
" . . .

Number of samples	= 79
Average porosity	= 0.153
Standard deviation	= 0.053
Range for all samples	= 0.028-0.303

Range for averaged hydropad or borehole porosities = 0.10-0.25"

Section 5.3 Identification of Independent Parameter Groups, p 5-46;
" The second matrix-parameter group is the characteristic matrix-diffusion time given by:

$$\tau' = \frac{L'^2}{\theta' D'} \qquad (5\text{-}13)$$

where:

τ' = characteristic matrix-diffusion time,

L' = one half of the matrix-block length,

θ' = matrix tortuosity, and

D' = free-water diffusion coefficient.

Physically, the characteristic matrix-diffusion time represents the time required for diffusion to penetrate from the fracture-matrix interface to the center of the matrix block, and for the concentration at that point to reach approximately 68 percent of its value at the fracture-matrix interface."

Keesey, J.J. 1976. Hydrocarbon Evaluation, Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico. SAND71-7033. Vols. I and II. Sipes, Williamson, and Aycock, Midland, TX.

Introduction, Vol 1, p 1, para 2;
" The purpose of this evaluation was to determine the future remaining economically recoverable oil and gas reserves underlying the proposed radioactive waste material storage site, commonly known as the Los Medanos Site. This evaluation is to serve as a guideline to Sandia Laboratories in determining the acceptability of the "site area" and the potential value to the owners of the hydrocarbon rights. It is not, however, intended to be the basis for condemnation proceedings.

p. 4, Para. 1;
" Exhibit No. 2 is a geologic correlation time chart for this portion of the Delaware Basin. Hydrocarbon producing formations are first encountered in the Delaware formation at approximately 4,200 feet. Moving downward, hydrocarbon accumulations have been found in the Cherry Canyon, Brushy Canyon, Bone Springs, Wolfcamp, Strawn, Atoka, Morrow, Devonian and Ellenburger zones. This multi-zone pay development is typical of the Southeastern New Mexico-West Texas area. The shallower Delaware sand formations were developed during the late 1930's with deeper tests to the Morrow and Ellenburger zones generally beginning in the early to mid-1950's."

Summary

The proposed radioactive waste material storage site is located in the northern portion of the Delaware Basin. No hydrocarbon production exists within the current boundaries of the "site area", but oil and gas are being produced from 60 wells in a 38 square-mile area around the site. These wells produce from the Delaware, Bone Springs, Wolfcamp, Strawn, Atoka and Morrow zones at a total rate of about 22,682 MCF of gas and 429 barrels of oil per day. This area is considered to be potentially rich in hydrocarbon reserves and the lack of fuller development and exploration drilling is due primary to low gas prices, lack of sales outlets and/or pipelines and moratoriums on drilling in the potash areas. Proved producing and proved nonproducing reserves are present in two wells in the Los Medanos Field area immediately adjacent to the southwest corner of the "site area". In addition, proved undeveloped, probable and possible reserves exist at six potential drilling locations in the Los Medanos Field. Further, probable and possible reserves were assigned to fifteen other potential drilling locations in the northwest ans south-central portions of the "site area". Total future economically recoverable reserves projected for these wells are 62,253,244 MCF of gas and 409,628 barrels of oil. The future net undiscounted revenue to the oil operators was determined to be $48,410,821. The discounted future net revenue is $21,216,899, discounted at 10 percent per annum. The fair market value for these projected reserves is $12,730,139, assuming a fair market factor of 0.50."

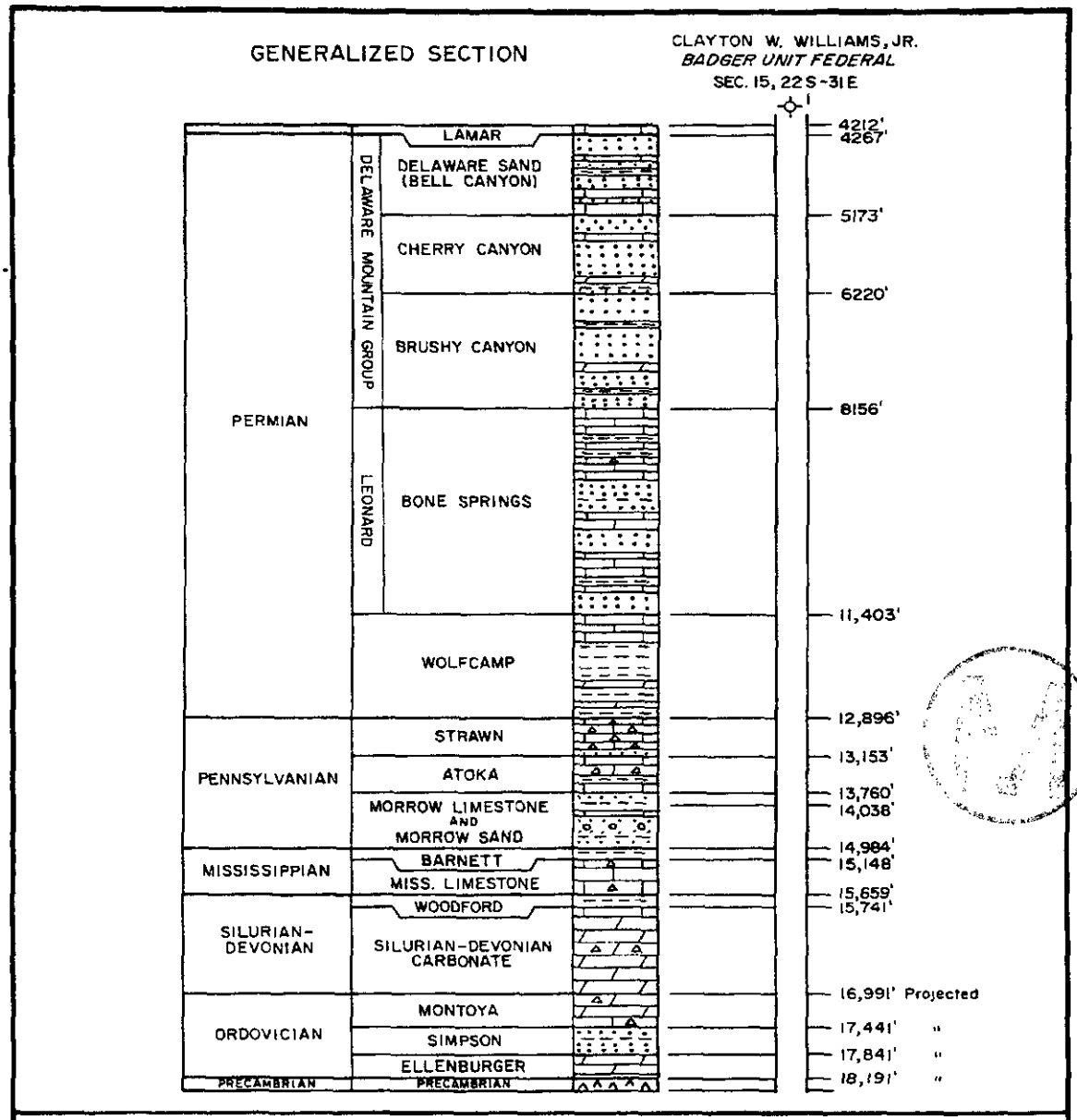

CORRELATION TIME CHART

FIELD DELAWARE BASIN		County EDDY & LEA	State NEW MEXICO
Engineer J. J. K.	Drwn. By H's	Date 9-1-76	File SANDIA
SIPES, WILLIAMSON & AYCOCK, INC.		Ref. No.	EXHIBIT NO. 2

Kelley, V.A., 1971. Geology of the Pecos Country, Southeastern New Mexico. Memoir 24. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p. 1, col. 2, para. 6;
" Two faults, Barrera and Carlsbad, are mapped at the base of the Capitan reef escarpment. Offsets at the surface suggest that the basin side is downthrown, although not of a magnitude equal to that of the escarpment. Most of the relief of the escarpment is due to erosion of the relatively weak basin evaporitic facies. Little or no confirmation of these faults is found in subsurface vertical separations. Strike slip is considered possible, but the nature and origin of the faults are unknown."

BARRERA FAULT, p. 48, col. 2, para. 5;
" The Barrera fault lies along the base of the Capitan reef escarpment and it is traceable in outcrop expression for 18 miles. It is projected as a possible buried feature beneath alluvial outwash 5 to 6 miles to the southwest along the base of the escarpment to about R. 22 E. It is extended also to the northeast for 7 to 8 miles, past the turn of the reef monocline into the Frontier Hills monocline, beneath alluvium and at the southern base of a small hill of Rustler. The fault is expressed at the surface by small scarps and a line of bushes. It is shown strikingly on air photos by a smooth well-defined line (fig. 23)."

CARSLBAD FAULT, p. 50, col. 2, para 1;
" The Carlsbad fault is expressed in outcrop about 2 miles north of the entrance to Dark Canyon for 5 miles northeasterly toward Carlsbad. Where well exposed in sec. 6, T. 23 S., R. 26 E., it strikes N. 56°E. and dips 60°S. Its expression on air photos is sharp and straight (fig. 23). At the surface red mudstone and gypsum of the Salado Formation is clearly dropped against Tansill dolomite which dips south toward the fault at 5 degrees."

Kelley, V.A., and Saulnier, Jr., G.J. 1990. Core Analyses for Selected Samples from the Culebra Dolomite at the Waste Isolation Pilot Plant Site. SAND90-7011. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. i;

" Two groups of core samples from the Culebra Dolomite Member of the Rustler Formation at and near the Waste Isolation Pilot Plant were analyzed to provide estimates of hydrologic parameters for use in flow-and-transport modeling. Whole-core and core-plug samples were analyzed by helium porosimetry, resaturation porosimetry, mercury-intrusion porosimetry, electrical-resistivity techniques, and gas-permeability methods.

Seventy-nine (79) helium-porosity determinations indicated that the distribution of Culebra porosities was skewed toward lower porosity values with an arithmetic mean and standard deviation of 0.153 and 0.053, respectively.

The vertical heterogeneity of porosity was indicated by 21 pairs of helium-porosity determinations where each sample of the pair was separated by approximately 5 cm. The porosity differences between the samples in the pairs varied from 0.050 to 0.093.

Water-resaturation-porosimetry results showed a near 1-to-1 correlation with the results from helium-porosity determinations. In some cases, the resaturation porosities were slightly larger than the helium porosities, possibly due to mineral dissolution by the resaturation fluid (deionized water) or to the experimental reproducibility of the two measuring techniques.

Endpoint mercury pore-volume saturations for 25 samples ranged from 66.7% to 99.9%, with an average endpoint pore-volume saturation of 95.4%. The endpoint pressure was 207 MPa. The median pore-throat radius varied over an order of magnitude from 0.077 μm to 0.588 μm, with an arithmetic average value of 0.315 μm. Eighty-four percent of the pore-throat radii in the samples analyzed were between 0.1 μm and 0.5 μm. The average mercury-intrusion porosity was 0.148, as compared with the helium-porosity average of 0.154.

Seventy-three (73) grain-density measurements indicated a skewed distribution toward larger values of grain density with an arithmetic average of 2.82 g/cm^3 and a standard deviation of 0.19 g/cm^3. The most common value of grain density was 2.83 g/cm^3, which was also the median of the distribution.

Electrical-resistivity measurements of 15 saturated core plugs were used to calculate estimates of formation factor and tortuosity. Formation-factor values were log-normally distributed and values ranged from 12 to 407, with a geometric mean of 58.8. Tortuosity ranged from 0.04 to 0.33, with an arithmetic average of 0.14 and a median of 0.12. The results show a general trend of increasing tortuosity with increasing porosity. The diffusion porosities and diffusion tortuosities determined by Dykhuizen and Casey (1989) agree with the lower range of the values determined by this core-analysis study.

Sixty-six (66) horizontal-permeability measurements ranged from 7.9E-18 m^2 to 3.6E-13 m^2, and the distribution had an arithmetic average of 6.2E-15 m^2, a geometric mean of 4.5E-16 m^2, and a median of 2.7E-16 m^2. Twenty-six (26) vertical-permeability

measurements ranged from 8.4E-18 m^2 to 5.2E-14 m^2, with an arithmetic mean of 5.1E-15 m^2, a geometric mean of 9.0E-16 m^2, and a median of 3.5E-16 m^2. Plots of the $\log_{10}$ of permeability versus porosity indicated a weak correlation between the $\log_{10}$ of permeability and porosity. A plot of $\log_{10}$ of horizontal permeability versus the median pore-throat radii determined for the same samples indicated that the $\log_{10}$ horizontal permeability is directly related to median pore-throat radius."

p 4-10;

" There are several possible explanations for the endpoint mercury saturations being less than 100% for most samples. The most obvious explanation is that all non-saturated pore spaces have radii less than the radius accessible to mercury at 207 MPa. Another possible explanation lies in the sequence of laboratory procedures. K & A Laboratories determined helium porosity before conducting mercury-intrusion porosimetry and then used that porosity to define sample pore volume. Figure 4.4 shows that K & A Laboratories consistently determined a higher helium porosity than Terra Tek when testing the same core-plug samples. If Terra Tek's values were actually more representative of the true porosity, this fact could explain the less than 100% endpoint mercury saturations reported. Alternatively, if large pore spaces were only accessible by extremely small pore radii, it is conceivable that the larger pores could not be accessed by mercury intrusion.

Median pore-throat radii calculated from the cumulative-frequency plots of the results of mercury-intrusion porosimetry range from a low of 0,077 μm to a high of 0.588 μm. The arithmetic mean of the calculated mean pore-throat radii is 0.315 μm. Given the assumptions implicit to mercury-intrusion porosimetry, 50% of the pore-throat radii for the 25 samples are greater than 0.315 μm. The distributions of pore-throat radii for the samples analyzed by K & A Laboratories (Appendix D) indicate that the pore-throat radii are distributed differently between samples. However, most pore radii generally range between 0.05 and 0.6 μm and the median pore radii for all samples have a range of approximately one order of magnitude."

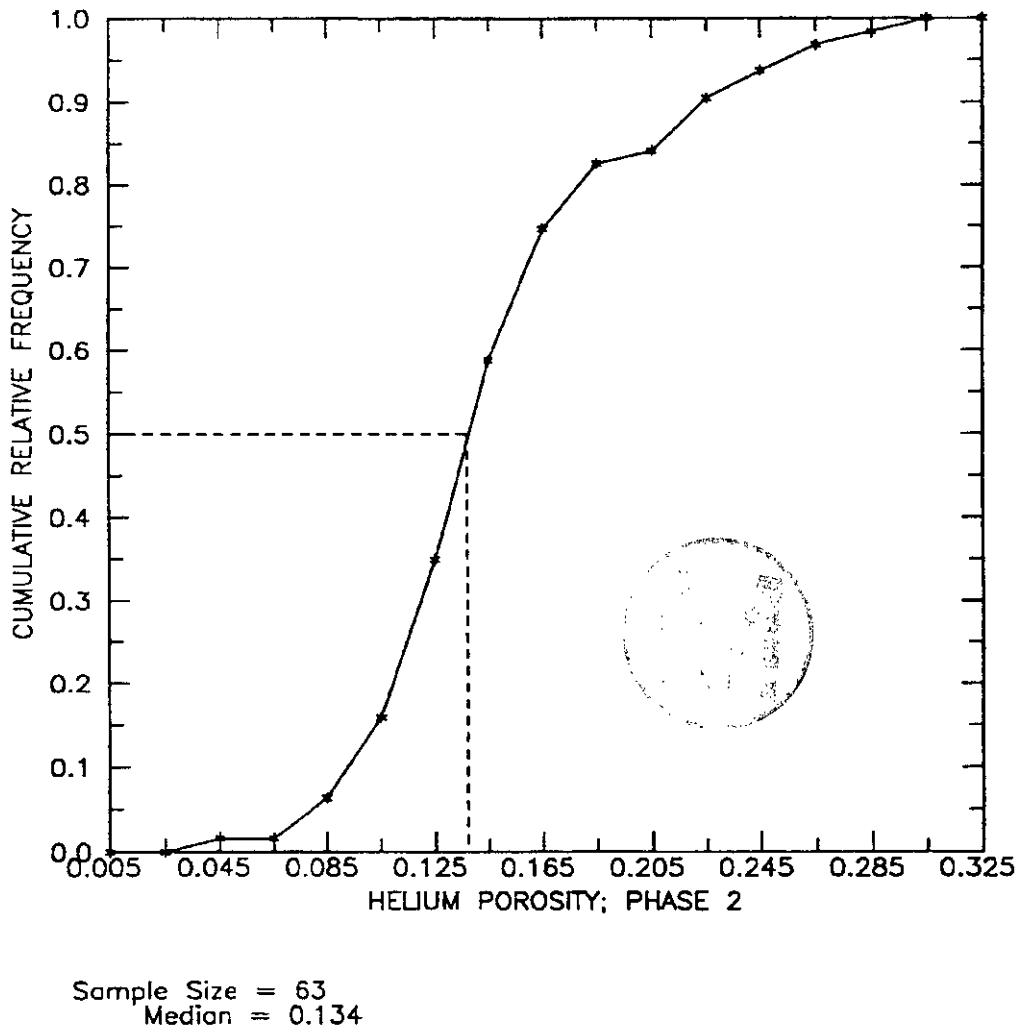

Sample Size = 63
Median = 0.134

Drawn by ABW	Date 12/6/89	Cumulative Relative-Frequency Curve for Phase 2 Helium Porosities
Checked by G.S.	Date 12/6/89	
Revisions	Date	
#105000R019	12/6/89	
INTERA Technologies		Figure 4.7

King, P.B. 1948. Geology of the Southern Guadalupe Mountains, Texas. Professional Paper 215. U.S. Geological Survey, Washington, D.C.

ABSTRACT, P 1;
" This report deals with an area of 425 square miles in the western part of Texas, immediately south of the New Mexico line. The area comprises the south end of the Guadalupe Mountains and the adjacent part of the Delaware Mountains; it includes the highest peaks in the State of Texas. The area is a segment of a large mountain mass that extends 50 miles or more northward and southward. The report describes the geology of the area, that is, the nature of its rocks, tectonics, and surface features, and the evidence that they give as to the evolution of the area through geologic time. Incidental reference is made to the geology of surrounding regions in order to place the area in its environment.
Stratigraphy of Permian Rocks-- . . ."

FEATURES OF EARLY CENOZOIC AGE, p 108, col 1, para 3;
" The Permian rocks now exposed in the Guadalupe Mountains had a broadly warped structure by Cretaceous time. Afterwards, as shown in figure 15, A, and plate 21, they were broken into tilted fault blocks. The close relation of the fault blocks to the present topography suggests that most of the post-Cretaceous disturbance took place in later Cenozoic time, which implies that the region was little deformed during early Cenozoic time."

HISTORY OF GUADALUPE AND DELAWARE MOUNTAINS UPLIFT, p 120, col 2;
" The early phases of the uplift of the Guadalupe and Delaware Mountains are imperfectly recorded in this region. The initial uplift, however, may have taken place at the same time as that farther northwest in the Sacramento section, where deposits, land forms, and tectonic features related to it are well exposed and have been studied by Kirk Bryan and his students.[85] According to Bryan, the initial uplift here took place before the deposition of the Santa Fe formation, and hence were probably of Miocene or early Pliocene age. They thus correspond approximately to the post-volcanic deformation in trans-Pecos Texas.

East and west of the Guadalupe Mountains, deposits of about the same age as the Santa Fe formation were formed as a result of erosion that followed the initial uplifts. To the east they form the cap of the Llano Estacado and are a part of the Ogallala formation. To the west, they probably form the main mass of the thick, unconsolidated deposits of the Salt Basin. The nature of the latter deposits is little known, however, because they are everywhere covered by Quaternary deposits.

In the mountains themselves, some indication of the nature of the initial uplift is given by the present stream patterns in the limestone uplands (fig. 19). Some of the streams seem to be unrelated, and hence antecedent, to the fault blocks that they cross; thus, the stream in McKittrick Canyon crosses from the downthrown to the upthrown side of the Lost Peak fault zone with little or no deflection (pl. 22). Other streams, such as those in the upper courses of Dog and West Dog Canyons, follow depressed fault blocks, and appear to belong to a later generation. In the parts of the mountains where no faulting has taken place, the two

generations of streams cannot be differentiated. It seems plausible, however, that most of them were consequent on the surface of the original uplift, and that in the limestone areas their courses become relatively fixed by incision into the resistant rock.

As indicated by the stream pattern, the initial uplift was a broad arch, not broken by as many faults as at present. The crest of the arch was probably near the present summits of the southern Guadalupe Mountains,for the supposedly consequent streams radiate northeastward, northward, and northwestward from it (fig. 19). The slopes of the arch seem to have been more gentle than the present slopes of the mountains, and its crest may not have stood as high. The incised streams of the limestone areas have distinctive, meandering courses, and join one another at wide angles, forming an open, dendritic pattern, as though they originally flowed down a gentle slope. This pattern, shown in the stippled areas of figure 19, is unlike that shown in the southeast part of figure 19, where the rocks are less resistant, and where the streams could adjust their courses to the steeper gradients of later periods.

Part of the jointing of the rocks of the Guadalupe and Delaware Mountains probably took place during the initial uplift. Fracturing of the rocks near the surface is likely to take place, even under the application of stresses too gentle to produce faults. If the rocks were jointed during the early phases of the uplift, the faults that came into existence later followed the pre-existing fractures.

If it could be proved that the joints normal to tilted beds in the western part of the area were originally formed in a vertical position, and had been rotated along with the beds at the time of block faulting, the suggested conclusion that the joints were older than the faults would be confirmed. It is equally possible, however, that the joints originated in their present attitudes, after the beds had been tilted."

Later Phase, p. 121, col. 2, para. 4;

" Younger movements in the Guadalupe and Delaware Mountains are indicated by the faulting of deposits of probable older Pleistocene age. The movements took place after an extended period of quiescence, for some of the deposits that are now faulted were laid down on a pediment carved from the disturbed Permian rocks.

Movements appear to have taken place only along faults that were already in existence, and to have resulted in displacements in the same direction as during the main phase. The displacements, however, were only about a tenth as great as the older ones, amounting at most to several hundred feet (p. 113). Movement took place along the faults of the Border zone and those immediately west of it, or in a much narrower belt than during the main phase. Faults in the east and west were undisturbed.

No definite evidence is available as to whether or not the faulting of the later phase was accompanied by further uplift of the mountain area. An increase in the relief of the mountains with respect to the floor of the Salt Basin is indicated not only by the displacements on the faults themselves but also by the dissection of the older, probably early Pleistocene deposits, which was caused by the accelerated activity of streams resulting from a change in base level. This dissection, however, may have been caused by a subsidence of

the basin, rather than an uplift of the mountains. The dissection of similar older deposits on the east flank of the mountains by streams draining into the Pecos River may have resulted in part from actual uplift of the mountains, although it is undoubtedly influenced by other factors.

The later phase of the uplift is younger than the deposits of probable early Pleistocene age and older than deposits of Recent and perhaps later Pleistocene age, which are undisturbed by it. It is, therefore, perhaps of later Pleistocene age. No evidence for any still younger movements has been found in the Guadalupe and Delaware Mountains."

EARLY PLEISTOCNE (?) TOPOGRAPHIC FEATURES AND DEPOSITS, p. 144, col. 1, para 3;

" In the Guadalupe Mountains, a period of movement later than the initial (Pliocene?) uplift is suggested by the second generation of consequent streams--those consequent on tilted fault blocks. During this second period of movement, faulting was apparently a dominant feature. The second period of movement was probably a major uplift, comparable to major uplifts farther northwest in the Sacramento section, which are assigned to a post-Santa Fe (late Pliocene or early Pleistocene) age."

Kloska, M.B., Saulnier, Jr., G.J., and Beauheim, R.L. 1995. Culebra Transport Program Test Plan: Hydraulic Characterization of the Culebra Dolomite Member of the Rustler Formation at the H-19 Hydropad on the WIPP Site. On file in the Sandia WIPP Central Files.

1.DESCRIPTION OF THE EXPERIMENT, p. 1;
" The hydraulic testing described in this Test Plan constitutes one component of a Sandia National Laboratories (SNL) program to understand solute transport through the Culebra Dolomite Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP) site. The overall Culebra Transport Program is discussed below, followed by a summary of the specific activities described in this Test Plan and their objectives."

1.1, p. 1, para. 3;
" Evaluation of WIPP's compliance with 40 CFR 191B by the WIPP Performance Assessment Computational Support Department of SNL relies on a model of radionuclide transport through the Culebra. Modeling of transport through the Culebra requires, first, a conceptual model of the mechanisms and processes governing that transport and, second, quantitative estimates of the parameters required for numerical simulation of those processes. The Culebra Transport Program represents the combined efforts of the SNL Geohydrology (6115) and WIPP Chemical and Disposal Room Processes (6748) Departments to provide the conceptual understanding and data necessary to construct a numerical model for Culebra transport.

Field tracer tests are a major component of the Culebra Transport Program. Tracer tests provide data with which to evaluate different processes affecting transport and to estimate transport parameters. Interpretations of previous tracer tests conducted at the WIPP site (Jones et al., 1992) indicated that the Culebra behaves locally as a double-porosity medium in which advective flow occurs through fractures while diffusion of solutes from the fractures to the surrounding rock matrix acts to retard solute transport. Using a double-porosity transport model based on these tracer-test interpretations, the WIPP PA Department (1993) showed that physical retardation arising from matrix diffusion makes the Culebra an effective barrier to release of radionuclides to the accessible environment.

This Test Plan supports the Culebra Transport Program by providing for the hydraulic characterization of the Culebra at a future tracer-test-site, the H-19 hydropad, which has been established southeast of the WIPP surface facilities between the H-3 hydropad and observation well DOE-1 (Figure 1-2; Saulnier and Beauheim, 1995). Figure 1-3 shows the as-built pattern of the test wells at the H-19 hydropad. The activities described in this Test Plan are designed to provide information about the hydrologic connections between the wells at the H-19 hydropad. This information will be used in the design and interpretation of subsequent tracer tests. The activities will involve single- and cross-hole tests of the entire thickness of the Culebra and/or of individual layers within the Culebra. Figures 1-4 and 1-5 show the completions of the H-19 test wells. This Test Plan describes plans, procedures, and specifications for the hydraulic tests to be conducted at the H-19 hydropad. The tracer

testing to be performed at the H-19 hydropad after hydraulic characterization of the Culebra is completed will be described in a separate Test Plan prepared specifically for that activity."

Lambert, S.J., 1983a. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. SAND82-0461. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3;

" Permian evaporites in the Ochoan Castile, Salado, and Rustler Formations in the Delaware Basin of southeastern New Mexico and west Texas have been subjected to various degrees of dissolution (notably of halite and gypsum) through geologic time. Eastward tilting of the Delaware Basin has resulted in the exhumation and erosion of Ochoan rocks in the western part of the basin. Waters in the Capitan, Rustler, Castile, and Bell Canyon Formations have previously been proposed as agents or consequences of evaporite dissolution according to four principle models; solution-and-fill, phreatic dissolution, brine density flow, and stratabound dissolution (along bedding planes). Several geomorphological features of positive and negative relief have previously been cited as indicators of evaporite dissolution. Brine density flow has been used to explain the selective dissolution of certain evaporite horizons during the late Cenozoic. A review of available geological data has revealed that

- Halite deposition was probably not so extensive as formerly believed
- Waters with potential to dissolve evaporites are in the Rustler and Capitan, but not in the Bell Canyon, Salado mine seeps, or the Castile brine reservoirs
- Brine density flow has not been active in removing most of the 'missing' halite, nor are 'point-source' dissolution features likely to have their roots at the Bell Canyon
- Major evaporite dissolution has not been confined to the late Cenozoic, but much of it took place during the Permian, Triassic, Jurassic, and Tertiary periods
- The Bell Canyon Formation has not been a sink for dissolution-derived brine

Stratabound dissolution is an efficient process for the removal of evaporites and is well exemplified in Nash Draw. This process entails downdip migration of meteoric water within beds of competent fractured rock, with upward and downward excursions of the water into adjacent halite-bearing beds. The chief weakness in the stratabound model for dissolution is the as-yet-unidentified sink for dissolution brine. If the stratabound model of dissolution is active in removal of lower Salado halite, the threat of dissolution to the WIPP in the next 250,000 yr is comparable to the threat to the same area posed by the growth of Nash Draw during the past 600,000 yr. The regional geological history showed the past threat to be negligible."

Lambert, S.J. 1983b. "Evaporite Dissolution Relevant to the WIPP Site, Northern Delaware Basin, Southeastern New Mexico," In Scientific Basis for Nuclear Waste Management VI, Materials Research Society Symposium Proceedings, Boston, MA, November 1-4, 1982, SAND82-1416C. D.G. Brookins, ed., pp. 291-298. Elsevier Science Publishing Company, New York, NY.

ABSTRACT, p 291;

" Evaluation of the threat of natural dissolution of host evaporites to the integrity of the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico has taken into consideration (1) the volume of 'missing' rock salt, (2) the occurrence (or not) of characteristic dissolution brines, (3) geomorphic features, some of which are unrelated to dissolution, and (4) the time intervals over which dissolution may have been active. Even under the assumption that all 'missing' halite was originally present and has been removed by dissolution, there is no evidence of active preferential removal of the lower Salado Formation halite by any geologically reasonable process. The geologic record contains evidence of dissolution in the Triassic and Jurassic; to constrain all removal of basinal halite to the late Cenozoic yields an unrealistically high rate of removal. Application to the lower Salado of a strata-bound mechanism known to be active in Nash Draw, a near-surface feature within the Basin, allows a minimum survival time of 2,500,000 years to be predicted for the subsurface facility for storage of radioactive waste at WIPP. This calculation is based on an analysis of all known dissolution features in the Delaware Basin and takes into account the wetter (pluvial) climate during the past 600,000 years."

ORIGINAL AND SURVIVING EVAPORITES, p 292;

" An issue central to the discussion of evaporite dissolution as a threat to WIPP has been the amount of halite which has been removed by dissolution since deposition. Recent descriptions of the Delaware Basin [2,3] have cited the variation in thickness of halite beds in the Castile and Salado Formations as evidence of dissolution. Anderson [2] proposed that the lower Salado Formation has been preferentially dissolved so as to undermine the evaporite section overlying marker bed 136. (Reference [4] describes the marker bed nomenclature.) This conclusion was drawn to account for 'missing' halite beds as inferred from acoustic logs of a number of boreholes. In actual fact, dissolution to account for regionally 'missing' halite is neither inescapable nor in some cases geologically reasonable.

As an example of some possible misinterpretation of 'missing' halite as evidence of dissolution, Figure 1 shows an overlay of Snider's [5] isopach map of Castile Anhydrite I (the lowermost evaporite unit in the Delaware Basin) on Anderson's [6] map of 'deep sinks' in the immediately overlying Halite I. At several locations the local thinnings in Halite I correspond to local thickenings in Anhydrite I. Anhydrite is not known to exhibit the same plastic behavior as halite under comparable overburden conditions, so the local thickenings of anhydrite cannot be attributed to flowage. The total thickness of Anhydrite I plus Halite I throughout the Delaware Basin remains nearly the same, indicating that subsurface variations in Halite I thickness are depositional, not dissolutional, in nature.

There are various hypotheses to account for regionally 'missing' halite in the evaporite section:

Nondeposition. There are several delaware Basin boreholes in which a thinning (or absence) of halite is compensated by an underlying thickening of anhydrite; the local anhydrite substrate stood above the depositional base level for halite, and so precluded halite deposition.

Lateral facies changes. The basin-margin equivalents of halite in the Castile Formation, for example, are anhydrites. These anhydrites preserve their laminations [7], are correlatable throughout the basin and are largely undeformed. IN basinal locations in the Salado and Castile, the relative proportions of halite and anhydrite show considerable variation, whereas the total thickness remains the same [8].

Uniform halite removal. a 1° eastward tilting of the Delaware Basin has resulted in the exposure of progressively older rocks to the west, until at the western margin no evaporites remain. Much of the western basin evaporites consist now only of exposures of gypsum, attesting to the increased access of meteoric waters to the western rocks for dissolving halite and gypsifying anhydrite.

Salt tectonics. Growth of a subsurface structure can result in flowage of salt away from the crest of an antiformal fold [9].

Widespread preferential dissolution of a bed. A preferential 'undermining' type of dissolution has been proposed to account for the truncation of individual halite beds."

THE THREAT OF DISSOLUTION TO WIPP, p. 296, para. 7;

" Any postulated process must leave identifiable dissolution products. If no evidence of active dissolution can be found, or if the proposed mechanisms are not supported by the geological observations, it must be concluded that dissolution is not active. Furthermore, it may not be possible to identify details of the process(es) which caused the dissolution. If so, application of the uniformitarian principle to predictive geology leads us to seek the processes presently active and extrapolate their consequences, based on their past observed effects.

Extensive research has been made for old and active dissolution features. Some 25 WIPP project boreholes, many of which provided core and all of which were geophysically logged, have explored the subsurface geology of breccia pipes, brine reservoirs, depressions, hills, and sites of geophysical anomalies. Except for the breccia pipes, all the holes have terminated in or penetrated stratified, nonchaotic sections of evaporites. The only basinal area found to contain dissolution brines, textures or residues was Nash Draw.

Nash Draw was formed by solution-and-fill [21] and by stratabound dissolution [8] in the last 600,000 years. The age is well established because the Gatuña Formation dissected in Nash Draw contains a remnant of the Pearlette type 'O' ash bed, whose age has been determined by fission-track dating [16]. Whereas solution-and-fill has been active in the removal of the near-surface Rustler gypsum units in Nash Draw, the stratabound model more effectively describes removal of halite in the lower Rustler and upper Salado Formations. The most active subsurface dissolution in Nash Draw is associated with marker bed 103, a 4- to 5-meter-thick anhydrite layer about 15 meters below the top of the Salado Formation."

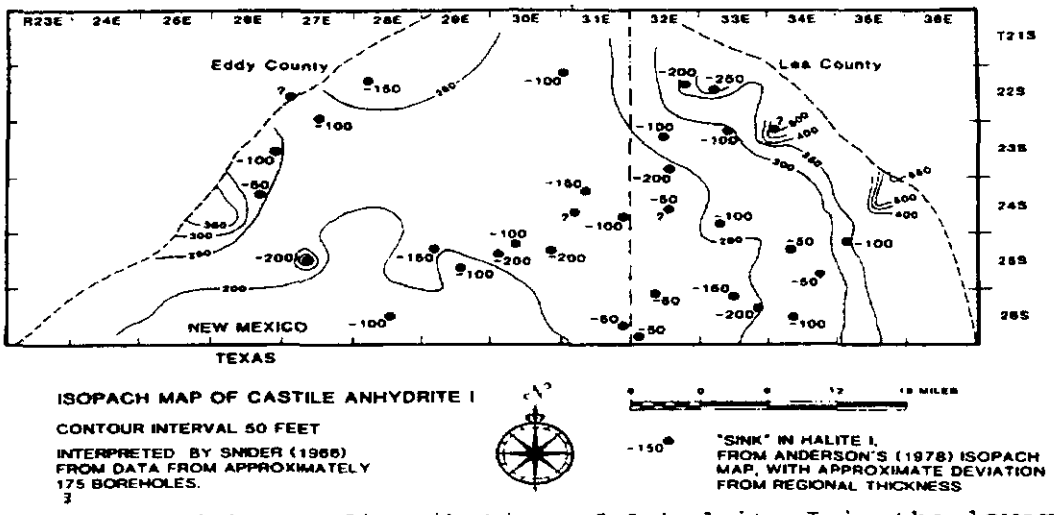

Fig. 1. Thickness distribution of Anhydrite I in the lower Castile Formation [5], superimposed on locations of "sinks" in overlying Halite I [6]. The dashed line marks the depositional edge of the Delaware Basin and the basinward extent of Capitan limestone.

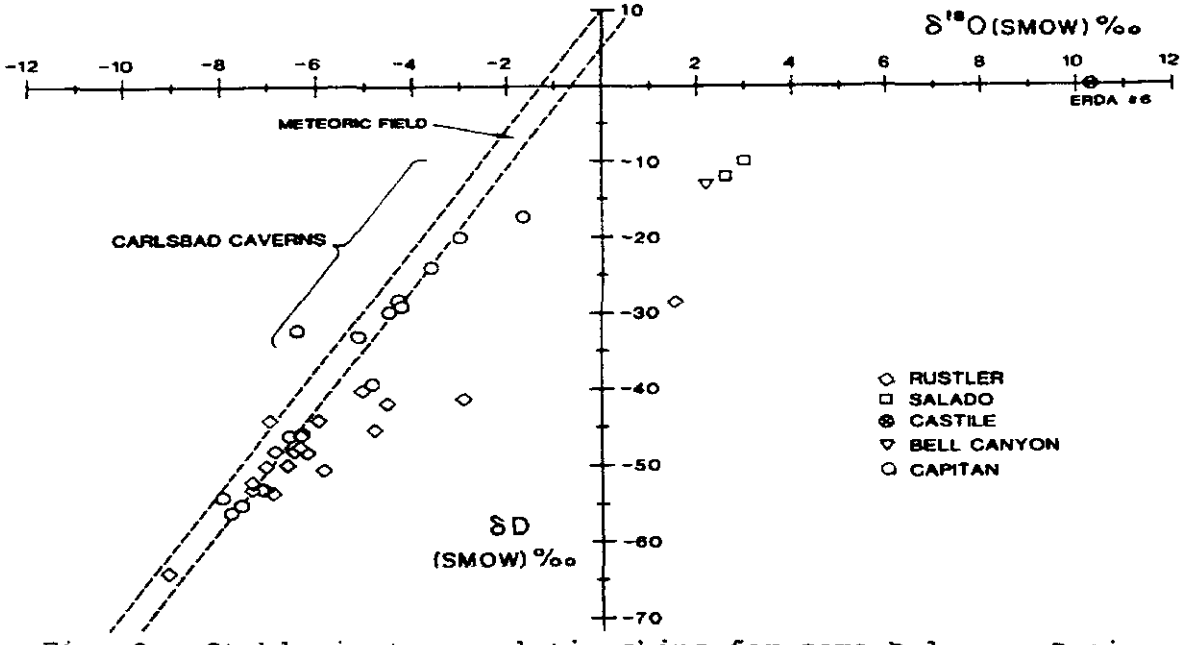

Fig. 2. Stable-isotope relationships for some Delaware Basin groundwaters, δD versus $\delta^{18}O$. "Meteoric field" is delineated after H. Craig, Science 133, 1702 (1961) and S. Epstein et al., Science 168, 1570 (1970).

Lambert, S.J. 1987. Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and other Nuclides to the Groundwater Hydrology of the Rustler Formation, Southeastern New Mexico. SAND86-1054. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. i;

" Radiocarbon, tritium, and ^{36}Cl were measured in groundwaters from the dolomite aquifers of the Rustler Formation in the northern Delaware Basin of southeastern New Mexico to determine the feasibility of using these nuclides in dating the groundwater at and near the Waste Isolation Pilot Plant, a facility for geological disposal of radioactive waste. No measurable ^{36}Cl was found in any of these groundwaters, which derive their dissolved chloride from Permian evaporites. Demonstrably uncontaminated groundwaters contained no significant amounts of tritium (<0.2 TU). Percent modern carbon (PMC) correlates linearly and directly with bicarbonate concentration, indicating mixing of a high-PMC/high-bicarbonate reservoir with a low-PMC/low-bicarbonate reservoir. This relationship, together with the history of development of the wells sampling the groundwaters, indicates contamination by anthropogenic modern carbon rather than simple dilution by dissolving rock carbonate. $\delta^{13}C$ does not linearly correlate with bicarbonate, indicating no single source of contaminant radiocarbon. Values of PMC and $\delta^{13}C$ for groundwaters were used to calculate apparent radiocarbon ages according to an interpretive model that accounts for water/rock interactions in carbonate aquifers. All but six pairs of values gave significant negative ages (-1,000 to -7,000 years). This suggests that in contaminated samples the model over-adjusts (based on $\delta^{13}C$) for radiocarbon loss due to dilution and isotopic exchange with the rock. Four groundwater samples (3 from the Rustler and 1 from the overlying Dewey Lake Red Beds) gave apparent radiocarbon ages $>$ 10,000 a, and their carbon-isotope systematics suggest that their apparent ages are all the result of a single evolutionary trend of rock/water interaction involving carbon isotope exchange, with a probable recharge age of 13,000 a b. p. This time of isolation from the atmosphere, which is unrelated to travel time within the Rustler, is consistent with paleoclimatic evidence of wetter conditions more conducive to recharge in the Late Pleistocene than at present."

TABLE 5, p. 50;
" TABLE 5. RADIOCARBON AGES, MODEL OF EVANS ET AL.[1]

Well	$\delta^{13}C$(%) All Replicates	PMC All Replicates	Apparent Age (radiocarbon years)
Pocket Dewey Lake	-3.8	3.67 (cyl)[2]	14,000
WIPP-25 Magenta	-6.8 -6.4	50.7 (bulk)[3] 49.27 (pptn)[4]	-3,250 -3,490
WIPP-27 Magenta	-7.0 -9.0	69.6 (bulk) 67.76 (pptn)	-5,650 -3,460
H-4B Culebra	-6.7	4.82 (bulk)	16,100
H-5C Culebra	-3.7	18.0 (bulk)	714
H-6C Culebra	-8.4	9.7 (pptn)	12,100
H-9B Culebra	-2.4	2.22 (cyl)	14,900
WIPP-25 Culebra	-7.6 -7.1	59.8 (bulk) 56.6 (pptn)	-3,760 -3,830
WIPP-26 Culebra	-5.9 -5.8	36.2 (bulk) 33.3 (pptn)	-1,560 -1,000
WIPP-27 Culebra	-4.3 -5.1	30.7 (bulk) 30.0 (bulk)	-2,560 -1,120
WIPP-29 Culebra	-5.1	49.76 (bulk)	-5,300
RF-10 Culebra	-5.4	39.7 (cyl)	-3,020
Engle Culebra	-2.8	11.5 (cyl)	2,410
WIPP-26 R/S	-7.1	90.7 (bulk)	-7,730
WIPP-28 R/S	-4.7	48.5 (bulk)	-5,710
WIPP-29 R/S	-4.8	53.4 (bulk)	-6,340

1. $\delta^{13}C_r$ = 5.7%; ε_{13} = 5.2% for dolomite
2. cyl- Water samples collected in 500 mL steel cylinders, whose carbon-isotope compositions were analyzed by accelerator mass spectrometry.
3. bulk- Bulk water samples (in was-sealed polyethylene jerrycans) from which carbon dioxide was liberated by acidification and nitrogen-purging in the laboratory.
4. pptn- carbon dioxide samples obtained by acidification of the barium carbonate precipitate prepared in the field immediately following the collection of the water."

p. 66, para. 4;

" There is a conspicuous dichotomy in carbon-isotope systematics between waters containing less than 10 PMC (four sampling localities having apparent radiocarbon ages of 12,000 to 16,000 years) and those containing more than 10 PMC (12 sampling locations for which one could argue that contamination had taken place during well development). The wide geographic separation (Figure 1) of sampling localities yielding model ages > 10,000 a suggests that water of this apparent age was originally widespread throughout the area near the WIPP site. The mathematical relationships among the data from the contaminated wells suggest that the mechanism generating the observed PMC values has involved nonsystematic modern mixing of three carbon-reservoir endmembers: (1) ancient organic material dissolved in the water at the time of recharge, (2) carbonaceous species dissolved from the host carbonate rock, and (3) modern organic material introduced during water-well development. The last two dominate the more contaminated samples, but such samples probably contain some component of original dissolved carbon dioxide. Consequently it is concluded that the contaminated waters were derived from the original widespread Pleistocene-age waters."

Lambert, S.J., and Carter, J.A. 1987. Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico, I. Principles and Preliminary Results. SAND87-0388. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" Values for uranium concentration ([U]) and $^{234}U/^{238}U$ activity ratio (A.R.), have been determined for groundwaters and host rocks from the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) site in the northern Delaware Basin of southeastern New Mexico. [U] varies from about 0.02 to 40 x 10^{-9} g/g, increasing westward across the WIPP site to Nash Draw, a dissolution valley underlain by outcrops of Rustler Formation evaporites. Large deviations from secular equilibrium (A.R. $\approx$ 1) in the groundwaters increase eastward from about 2 to 3 in Nash Draw to almost 12 in the eastern part of the WIPP site. [U] and A.R. variations cannot be completely explained by simple mixing due to congruent dissolution of uranium from rock (without isotopic fractionation). A.R. values typically increase along the flow path in a reducing environment, and the observed eastward increase in A.R. suggests a relict flow system whose dominant flow direction (eastward) was at high angles to that now observed. A westward decrease in A.R., coupled with a steady increase in [U] indicates not only that there was a change in flow direction since recharge, but that Rustler groundwater is now draining from areas of high potentiometric level and low permeability near the WIPP site, without appreciable recharge. The maximum time required for this westward drainage is about 200,000 a. The minimum time required to achieve the highest observed A.R.s during the earlier episode of eastward flow from recharge in the west is 10,000 to 30,000 a. Radiocarbon and stable-isotope studies of the Rustler Formation near the WIPP indicate that the modern Rustler flow system is not at steady state, recharge being dominated by wetter climatic conditions in the Pleistocene. Uranium-isotope studies are consistent with these results, and further suggest that present flow directions are qualitatively different from those existing at the time of recharge."

Lambert, S.J., and Harvey, D.M. 1987. Stable-Isotope Geochemistry of Groundwaters In the Delaware Basin of Southeastern New Mexico. SAND87-0138. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" $^{18}O/^{16}O$ and D/H ratio measurements have been made on groundwaters sampled from the Rustler Formation (Ochoan, Permian) and related rocks in the northern Delaware Basin of southeastern New Mexico. Most confined Rustler waters at the Waste Isolation Pilot Plant (WIPP) site and to the west in Nash Draw and confined waters from the Capitan limestone constitute one population in $\delta D/\delta^{18}O$ space, while unconfined groundwaters inferred to originate as modern surface recharge to alluvium, sandstones in the Ogallala Formation, the near-surface Rustler in southwestern Nash Draw, and the Capitan vadose zone in the Guadalupe Mountains (Carlsbad caverns) constitute a distinctly different population; the two do not overlap. A likely explanation for this distinction is that meteoric recharge to most of the Rustler and Capitan took place in the geologic past under climatic conditions significantly different from the present. Available tritium and radiocarbon data are consistent with this hypothesis, and the apparent age of confined groundwaters is in excess of 12,000 radiocarbon years, suggesting that recharge took place under wetter conditions in the late Pleistocene. Processes governing recharge in the Delaware basin are significantly different from those in the nearby Roswell Artesian Basin, but may be similar to those previously described for the Albuquerque (New Mexico) and Murray (South Australia) Basins. Rustler water from the WIPP site and east-central Nash Draw is not discharging from springs in southwestern Nash Draw; the discharge there is part of a local shallow groundwater system associated with surficial gypsum karst and discharge from nearby potash refining. Water at the Rustler/Salado contact at the WIPP site is of meteoric origin, but has experienced isotope shift that increases with decreasing permeability, and is part of the same isotopic trend as the ERDA 6 brine occurrence and fluid inclusions from Salado Formation halite core. Radiometric ages of secondary Salado minerals are not consistent with vertical mixing between deep brines and meteoric waters to form the fluid inclusions. Mine seeps and WIPP fluid inclusions have similar isotopic compositions, perhaps related to syndepositional mixing of evaporite brines and rainwaters. Rustler dolomites have not recrystallized in isotopic equilibrium with Rustler water, but much of the gypsum in the Ochoan section has done so. The absence of modern meteoric recharge to the Rustler at and near the WIPP site indicates that the hydrologic system there is not at steady state. Instead, the system is responding to the cessation of local recharge, this cessation occurring some 10,000 to 30,000 years ago."

4.5.3 The Age of Rustler Groundwaters, p 100, para 1;

" Four groundwater (three Rustler and one Dewey Lake) gave significant positive ages, all of which were found to be statistically indistinguishable (in radiocarbon years):
H4, 16,100 a; H9, 14,900 a; H6, 12,100 a (all Culebra); Pocket (Dewey Lake), 14,000 a. Given that these groundwaters could contain traces of contaminant ^{14}C, these were regarded as <u>minimum</u> times of isolation from the atmosphere. If the flow path to the vicinity of the

WIPP site is long, these results represent travel times from the recharge area. If recharge was originally local, these results more likely represent a discrete recharge event of end of a discrete recharge-time interval, probably indicative of wetter climate in the Pleistocene. Other evidence of a wetter Pleistocene climate in southeastern New Mexico has been presented by Van Devender (1980), who determined from packrat middens in Rocky Arroyo east of Carlsbad (Figure 1) that a juniper-oak plant community existed there 10,500 to 10,000 years ago, at an elevation of about 3700 feet, where now desert scrub communities have been stable for the last 4,000 years. Thus, a limited number of the groundwaters interpreted here to be distinct from modern meteoric precipitation, in fact have radiocarbon ages indicative of late Pleistocene recharge."

4.5.4 Summary: Meteoric Recharge of Rustler Groundwaters, p 103, para 4;
" The absence of significant (e.g., >5-10 TU) tritium in groundwaters of the Rustler Formation is another compelling bit of evidence that argues against direct (rapid) recharge to the Rustler. If recharge is taking place, its rate is very slow, in that no tritium has shown up in the 36 years of atmospheric testing of nuclear weapons, or the amount of recharge is miniscule, being diluted by mixing with older groundwater to concentrations indistinguishable from zero. Not even background levels of tritium have been found (10 TU is estimated as the local upper concentration limit for precipitation containing tritium generated by cosmic rays; Gross et al., 1976). If the Rustler receives its water by direct infiltration, either the expected tritium spike has not yet reached the Rustler, or the amount of tritium in this recharge is diluted by mixing with older groundwater to concentrations not significantly different from zero. If the dilution factor is indeed large, one should question whether this minute amount of recharge is to be considered significant."

Lang, W.B. 1939. Salado Formation of the Permian Basin. American Association of Petroleum Geologists Bulletin, Vol. 23, pp. 1569–1572.

SALADO FORMATION OF THE PERMIAN BASIN[1]

WALTER B. LANG[2]
Washington, D.C.

The Delaware basin is a structural depression in western Texas and southeastern New Mexico. This depression was filled and overlain by chemical deposits of late Permian age which are now either partially eroded away west of the Pecos River, or, east of it, masked from view by a covering of younger deposits. Most of the detailed information now at hand concerning these deposits has been obtained from the study of well cuttings and has disclosed that these sediments are divisible into two formations:[3] The lower, or Castile formation, is composed of typically banded anhydrite and calcite and in the northeast half of the basin includes thick beds of clean white halite. The upper, or Salado formation, occupies not only the eastern portion of the Delaware basin but spreads northward and eastward above and beyond the basin rim, which is formed by the Capitan reef. This upper formation, which is absent in most of the western half of the basin, is apparently exposed nowhere at the surface. It is composed essentially of halite with relatively thin beds of anhydrite, polyhalite, reddish sandy shale, and locally other potash-bearing salts. However, in southern Reeves and northwestern Pecos counties, Texas, the halite grades into massive anhydrite. Therefore, a complete section of the Castile and Salado deposits can be found only in the subsurface in the northeastern portion of the Delaware basin. Even here a section may not display all phases and aspects of the deposits. The Castile and Salado formations have also been referred to as the 'Lower Castile' and 'Upper Castile,' respectively.[4]

In 1921, the Pinal Dome Corporation's Means well was drilled in the SE. corner, Sec. 23, Blk. C-26, P.S.L., slightly east of the center of Loving County, Texas, to a depth of 5,208 feet, and approximately in the middle of the northeastern half of the Delaware basin where a complete section of both formations is present. It was, and still is, one of the best sampled and analyzed standard cable-tool wells in the basin. Cuttings were taken every 5-10 feet and potash analyses were made of the salt section to 3,600 feet or through 2,700 feet of salt. In this and other wells drilled about the same time it was observed that showings of polyhalite extended downward in the thick salt sections only part way, but in the shorter sections outside the Delaware basin, underlain by the Carlsbad limestone and correlative deposits, polyhalite was found almost to the base of the salt. In the Means well evident showings of polyhalite are last observed at 2,340 feet. When the writer originally defined the Salado, he arbitrarily selected the figure of 2,350 feet as the base. At this time, only a few widely spaced wells had been drilled and correlation of the various anhydrite beds could not be made with certainty. In the light of additional evidence it is now desirable to redefine the base of the Salado.

This may be accomplished in several ways, four of which are worthy of consideration.

I. One method would be to place the lower boundary of the Salado at the 'base of the salt,' where it overlies the reef limestones and is separated from them by 50-100 feet or more of solid anhydrite; but, if this contact be extended into the basin, it lies at different horizons due to the interfingering of anhydrite with halite. Were it not for the interfingering this method would have merit, in that it is simple and easily applied. The chief point against it is that it is a temporary expedient and would soon fall into disfavor as the minute details of correlation continue to accumulate. In the Means well this contact may be selected at 2,965 feet.

2. The presence of potash in the form of polyhalite is an outstanding feature of the Salado. If the last showings of polyhalite in well cuttings are plotted they form a fairly regular horizon in the reef and back-reef areas but are far less consistent in the basin. For this reason, though the evidence is important, it is not in itself sufficiently reliable for the purpose of selecting boundaries. This lack of consistency is demonstrated in the Means well, for at 2,325-2,340 feet are two analyses showing respectively the presence of 3.10 and 3.31 per cent of K_2O in soluble salts and thus corroborating the visual evidence of polyhalite. These are followed to a depth of 3,600 feet by a succession of analyses, all showing results of less than 1.0 percent of K_2O in soluble salts, though 500 feet or more of the section below 2,340 feet must be equivallent to salts that yield evidence of polyhalite at or near the area of the reef.

3. In like manner the first indication of banded anhydrite or of calcite reveals the presence of the Castile, though these features may not appear at the same horizon in different places because prominent banding or calcite may be lacking in the deposits, or because the observer may be unable to recognize them. In general, the top of the observed banded anhydrites forms a fairly uniform horizon, though in places the actual position of this banding may be far below its hypothetical position. Thus it is not well to place too much reliance on the observed position of the top of the banded anhydrites. The beds of typical, banded anhydrite do not extend beyond the basin but lap against the marginal reef deposits. In the Means well the banded anhydrites appear at about 3,400 feet.

4. If one surface is postulated to pass through the deepest indications of polyhalite and another to include the highest showings of banded anhydrite, a gap of 500-700 feet or more lies between them. Within this gap may be found a third surface that represents the stratigraphic position of the base of the beds that lie disconformably on the top of the reef. The top of the reef is a definite, recognizable, and continuous horizon, marking the top of the Capitan and Carlsbad limestones and the correlative beds of the back-reef. Immediately overlying the limestone is a dense non-banded anhydrite, 50-100 feet thick. The top of this anhydrite is the so-called 'base of the salt' in the reef and back-reef areas. The writer included this anhydrite in the top of the Castile in 1937.[5] Whether the top or bottom of this anhydrite member is chosen to separate the Salado ('Upper Castile' of some authors) from the Castile ('Lower Castile' of some authors) the boundary between the two units would be at a definite, fundamental stratigraphic position. The sedimentary characteristics that are typical of each formation would thus be placed in their proper province.

In redefining the Salado formation, the writer prefers to include the anhydrite as its

basal member, for this anhydrite does not show any of the characteristics of the typical anhydrite beds in the Castile. It is in places magnesitic, dense, non-banded, and contains no calcite. If placed in the Salado it confines the Castile to the Delaware basin and eliminates the awkward situation of having to carry a thin strip of Castile across the reef and back-reef areas for no apparent good reason. Within the Delaware basin the horizon of the top of the anhydrite member is found in most well samples with no greater facility than the base. The base of the Salado formation in the Means well as redefined in this note is placed at a depth of approximately 3,300 feet or at a position equivalent to the base of the anhydrite member on the crest of the capitan reef on the northeastern rim of the Delaware basin.

[1] Printed by permission of the director of the Geological Survey, United States Department of the Interior, Manuscript received, August 31, 1939.

[2] Geologist, United States Geological Survey

[3] W. B. Lang, "Upper Permian Formations of Delaware Basin of Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol 19 (1935), pp. 262-70.

[4] L. D. Cartwright, "Transverse Section of Permian Basin, West Texas and Southeast New Mexico,' *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 979-80.

[5].W. B. Lang, "Permian Formations of the Pecos Valley of New Mexico and Texas,"*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21 (1937), pp. 833-98."

Lang, W.B. 1942. Basal Beds of Salado Formation in Fletcher Potash Core Test near Carlsbad, New Mexico. American Association of Petroleum Geologists Bulletin, Vol. 26.

ABSTRACT, p 63;

" The Fletcher potash core test, drilled east of Carlsbad, New Mexico, penetrated a section of the salt-bearing Salado formation of Permian age, from which no other consecutive cores are available either from potash core tests or the numerous wells drilled for oil. These cores have been studied in detail for the sedimentary and stratigraphic evidence they disclose; a detailed log has been compiled of the section; and some of the minerals of the core have been determined by means of chemical analysis and X-rays. The sequence here described extends from above the Cowden anhydrite member of the Salado formation into the underlying Carlsbad limestone. Two members of the Salado formation, the La Huerta and Fletcher anhydrite members, are here defined. Also evidence for an erosional unconformity between the Fletcher anhydrite member and the Carlsbad limestone as disclosed by the core is presented."

p. 63, Para. 3;

" Although churn-drill samples are not available, it is possible from the driller's log and the core material to classify the rocks into the following formations.

Age	Formation	Internal (Feet)	Thickness (Feet)
Quaternary.....	Surface sand and caliche.....	0- 10	10
Triassic.....	Santa Rosa(?)sandstone.....	10- 65	55
Triassic.....	Pierce Canyon redbeds.....	65- 570	505
Permian.....	Rustler formation(upper part).	570- 660	90
Permian.....	Rustler formation(lower part).	660- 890	230
Permian.....	Salado formation.....	890- 1,380	490
Permian.....	Carlsbad limestone.....	1,380-1,381½	1½

"

FLETCHER ANHYDRITE MEMBER OF THE SALADO, p 75;

" The lowest halite bed of the Salado grades within a foot or two into an uncommonly massive bed of anhydrite, which may range from 50 to 100 feet or more in thickness. In this core test it is 69 feet thick. Because of its stratigraphic importance this unit is here called the Fletcher anhydrite member of the Salado formation, the name being taken from the well in which this core test was made."

LaVenue, A.M., Haug, A., and Kelley, V.A. 1988. Numerical Simulation of Ground-water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site; Second Interim Report. SAND88-7002. Sandia National Laboratories, Albuquerque, NM. WPO 28588.

EXECUTIVE SUMMARY, p ii;

" This hydrologic modeling study has been performed as part of the regional hydrologic characterization of the Waste Isolation Pilot Plant (WIPP) Site in southeastern New Mexico. The study resulted in an estimation of the transmissivity distribution, hydraulic potentials, flow field, and fluid densities in the Culebra Dolomite Member of the Permian Rustler Formation at the WIPP site.

The three-dimensional finite-difference code SWIFT-II . . ."

Section 6.0 CONCLUSIONS, p 6-1, para 2;

" (1) The calibrated transmissivity distribution contains the same general trend over the model area as the observed transmissivities with predominantly lower transmissivities ($<1 \times 10^{-7}$ m^2/s) east of the WIPP-site boundary, intermediate transmissivities in the central part of the model area (1×10^{-6} to 1×10^{-4} m^2/s) and high transmissivities ($>1 \times 10^{-3}$ m^2/s) in the western part of the model area representing Nash Draw. local differences to the general trend are present west of WIPP-30 and WIPP-26 and between H-17 and P-17. The transmissivities in these areas were increased to reduce the differences between the calculated and observed heads below the uncertainties of the observed heads. The high-transmissivity feature between H-17 and P-17 is less transmissive than a similar feature proposed in Haug et al. (1987).

ELEVATION DATA BASE - UPDATED 12-29-87

WELL	GROUND-SURFACE ELEV FT AMSL	GROUND-SURFACE ELEV SOURCE	CULEBRA DEPTH FT BGS T	C	B	CULEBRA ELEVATION M AMSL T	C	B	CUL THICK M
H-1	3397.9	MERCER 83	676	688	699	829.6	826.1	822.6	7.0
H-2A	3377.8	RLB	623	634	645	839.7	836.3	833.0	6.7
H-2B1	3377.6	RLB	624	633	642	839.3	836.6	833.8	5.5
H-2B2	3377.6	REDDY	623	634	645	839.6	836.2	832.9	6.7
H-2C	3377.7	RLB	624	633	642	839.3	836.6	833.8	5.5
H-3B1	3389.4	RLB	670	682	694	828.9	825.2	821.6	7.3
H-3B2	3388.3	S 86-7109	676	688	700	826.7	823.1	819.4	7.3
H-3B3	3387.1	S 86-7109	673	685	696	827.3	823.8	820.3	7.0
H-4A	3332.8	RLB	496	508	520	864.7	861.0	857.3	7.3
H-4B	3332.7	RLB	490	503	516	866.4	862.5	858.5	7.9
H-4C	3332.5	RLB	490	503	516	866.4	862.4	858.5	7.9
H-5A	3505.6	RLB	897	909	920	795.1	791.6	788.1	7.0
H-5B	3505.4	RLB	897	909	920	795.0	791.5	788.0	7.0
H-5C	3505.8	RLB	899	912	924	794.5	790.7	786.9	7.6
H-6A	3347.3	MERCER 83	604	616	627	836.1	832.6	829.1	7.0
H-6B	3347.6	MERCER 83	604	616	627	836.2	832.7	829.2	7.0
H-6C	3347.9	MERCER 83	604	616	627	836.3	832.8	829.3	7.0
H-7B1	3163.6	RLB	237	256	274	892.0	886.4	880.8	11.3
H-7B2	3164.0	CALCULATED	237	256	274	892.1	886.5	880.9	11.3
H-7C	3163.4	RLB	237	256	274	892.0	886.3	880.7	11.3
H-8B	3433.8	S 87-0039	588	601	614	867.4	863.4	859.5	7.9
H-8C	3433.0	MERCER 83	588	601	614	867.2	863.2	859.2	7.9
H-9A	3405.4	RLB	647	662	677	840.8	836.2	831.6	9.1
H-9B	3405.6	MERCER 83	647	662	677	840.8	836.2	831.7	9.1
H-9C	3405.9	MERCER 83	647	662	677	840.9	836.3	831.8	9.1
H-10B	3687.0	MERCER 83	1360	1376	1391	709.3	704.5	699.8	9.4
H-10C	3686.9	MERCER 83	1360	1376	1391	709.2	704.5	699.8	9.4
H-11B1	3412.1	REDDY	730	743	756	817.5	813.5	809.6	7.9
H-11B2	3412.1	REDDY	733	745	757	816.6	812.9	809.3	7.3
H-11B3	3412.1	REDDY	734	747	759	816.3	812.5	808.7	7.6
H-12	3426.0	REDDY	823	837	850	793.4	789.3	785.2	8.2
H-14	3345.6	RLB	545	559	572	853.6	849.5	845.4	8.2
H-15	3480.2	RLB	861	872	883	798.3	795.0	791.6	6.7
H-16	3409.6	REDDY	700	712	724	826.0	822.2	818.4	7.6
H-17	3384.0	REDDY	706	719	731	816.3	812.4	808.5	7.8

Drawn by	Date	Ground-Surface and Culebra Dolomite Elevations for WIPP-Area Boreholes
Checked by	Date	
Revisions	Date	
HD9700R554		
INTERA Technologies		Table B.1

ELEVATION DATA BASE - UPDATED 12-29-87

WELL	GROUND-SURFACE ELEV FT AMSL	GROUND-SURFACE ELEV SOURCE	CULEBRA DEPTH FT BGS T	C	B	CULEBRA ELEVATION M AMSL T	C	B	CUL THICK M
DOE-1	3465.1	REDDY	820	832	843	806.2	802.7	799.2	7.0
DOE-2	3418.4	RLB	824	835	846	790.8	787.4	784.1	6.7
P-1	3345.1	MERCER 83	538	552	565	855.6	851.5	847.4	8.2
P-2	3479.4	MERCER 83	857	870	883	799.3	795.3	791.4	7.9
P-3	3382.7	MERCER 83	642	654	665	835.4	831.9	828.4	7.0
P-4	3443.8	MERCER 83	775	789	802	813.5	809.3	805.2	8.2
P-5	3470.9	MERCER 83	804	816	827	812.9	809.4	805.9	7.0
P-6	3354.1	MERCER 83	537	549	560	858.7	855.1	851.6	7.0
P-7	3332.0	MERCER 83	496	509	522	864.4	860.5	856.5	7.9
P-8	3338.6	MERCER 83	563	576	588	846.0	842.2	838.4	7.6
P-9	3411.5	MERCER 83	734	746	757	816.1	812.6	809.1	7.0
P-10	3509.3	MERCER 83	931	944	957	785.9	781.9	777.9	7.9
P-11	3503.9	MERCER 83	912	925	938	790.0	786.0	782.1	7.9
P-12	3373.6	MERCER 83	633	645	656	835.3	831.8	828.3	7.0
P-13	3345.2	MERCER 83	604	616	627	835.5	832.0	828.5	7.0
P-14	3359.8	REDDY	573	584	595	849.4	846.1	842.7	6.7
P-15	3309.8	RLB	413	424	435	882.9	879.6	876.2	6.7
P-16	3317.9	MERCER 83	500	512	523	858.9	855.4	851.9	7.0
P-17	3335.8	REDDY	558	571	583	846.7	842.9	839.1	7.6
P-18	3477.3	REDDY	912	926	940	781.9	777.6	773.4	8.5
P-19	3545.1	MERCER 83	967	982	997	785.8	781.2	776.7	9.1
P-20	3552.7	MERCER 83	953	966	979	792.4	788.4	784.5	7.9
P-21	3509.0	MERCER 83	899	912	924	795.5	791.7	787.9	7.6
WIPP-11	3426.1	MERCER 83	844	856	867	787.0	783.5	780.0	7.0
WIPP-12	3471.3	REDDY	810	823	835	811.2	807.4	803.5	7.6
WIPP-13	3405.4	RLB	701	713	724	824.3	820.8	817.3	7.0

Drawn by	Date	Ground-Surface and Culebra Dolomite Elevations for WIPP-Area Boreholes
Checked by	Date	
Revisions	Date	
HD9700R554		
INTERA Technologies		Table B.1 (cont.)

ELEVATION DATA BASE - UPDATED 12-29-87

WELL	GROUND-SURFACE ELEV FT AMSL	GROUND-SURFACE ELEV SOURCE	CULEBRA DEPTH FT BGS T	C	B	CULEBRA ELEVATION M AMSL T	C	B	CUL THICK M
WIPP-18	3456.4	RLB	787	798	808	813.6	810.4	807.2	6.4
WIPP-19	3433.1	S 87-0039	756	768	779	816.0	812.5	809.0	7.0
WIPP-21	3417.1	REDDY	729	741	753	819.3	815.7	812.0	7.3
WIPP-22	3425.8	S 87-0039	742	753	764	818.0	814.7	811.3	6.7
WIPP-25	3212.5	RLB	447	460	472	842.9	839.1	835.3	7.6
WIPP-26	3151.7	RLB	186	198	209	904.0	900.4	896.9	7.0
WIPP-27	3177.2	RLB	292	305	318	879.4	875.4	871.5	7.9
WIPP-28	3346.6	RLB	420	433	446	892.0	888.1	884.1	7.9
WIPP-29	2977.0	RLB	12	27	42	903.7	899.1	894.6	9.1
WIPP-30	3427.5	RLB	631	642	653	852.4	849.0	845.7	6.7
ERDA-6	3540.2	MERCER 83	710	723	735	862.6	858.8	855.0	7.6
ERDA-9	3408.8	RLB	704	716	727	824.4	820.9	817.4	7.0
ERDA-10	3371.2	MERCER 83	476	490	504	882.5	878.2	873.9	8.5
CB-1	3327.3	RLB	503	516	529	860.8	856.9	852.9	7.9
ENGLE T	3419.0	S 87-0039	659	670	681	841.2	837.9	834.5	6.7
AEC-7	3654.0	MERCER 83	870	883	896	848.6	844.6	840.6	7.9
AEC-8	3531.5	MERCER 83	833	846	859	822.5	818.5	814.6	7.9
FFG242 *							726.2		
								AVG = THICKNESS	7.7 m

REFERENCES

* - FFG242 DEPTH TO BASE OF CULEBRA VALUE FROM DAVIES (1988)
A THICKNESS OF EIGHT M IS ASSUMED FOR MIDPOINT-VALUE CALCULATION

Drawn by	Date	Ground-Surface and Culebra Dolomite Elevations for WIPP-Area Boreholes
Checked by	Date	
Revisions	Date	
HD9700R554		
INTERA Technologies		Table B.1 (cont.)

Lord, K.J., and Reynolds, W.E., eds. 1985. Archaeological Investigations of Three Sites within the WIPP Core Area. Prepared for the U.S. Army Corps of Engineers (COE), Albuquerque District in NM. Eddy County, NM, Chambers Consultants and Planner, Albuquerque, NM.

ABSTRACT, p i;

" Archaeological investigations of ENM 10222, ENM 10230, and ENM 10418 have produced significant information on one portion of the seasonal round of prehistoric groups which inhabited southeast New Mexico between 1000 B.C. and A.D 1400. The results of intensive surface collections and subsurface testing suggest that a hunter-gatherer subsistence system was in effect for the entire occupational history of the sites. This system developed out of an indigenous Late Archaic population and continued well into the Neoarchaic. During the Neoarchaic period an overlay of Jornada Mogollon traits entered the area, i.e., ceramics and arrow points. The evidence suggests that these additions did not effect the basic adaptive strategy.

ENM 10222 and ENM 10230 represent plant collection and processing localities and probably were satellite sites to more complex limited base camps. ENM 10418 represents one of these limited base camps. Both functional categories represent one subset in a seasonal round of activities. The three sites investigated represent the summer portion of a seasonal round with acorn and mesquite being the primary subsistence focus."

B. Bradley in Lord, K.J., and Reynolds, W.E., eds. 1985. *Archaeological Investigations of Three Sites within the WIPP Core Area.* Prepared for the U.S. Army Corps of Engineers (COE), Albuquerque District in NM. Eddy County, NM, Chambers Consultants and Planner, Albuquerque, NM.

ABSTRACT;

" A cultural resource inventory of a 100 foot wide by 18 mile long corridor (218 acres) for a water pipeline for the Waste Isolation Pilot Plant (WIPP) was completed in June, 1982. This project was undertaken for the U. S. Army Corps of Engineers, Albuquerque District by Complete Archaeological Service Associates of Cortez, Colorado. One small prehistoric site was located adjacent to the proposed right-of-way, but will not be affected by the pipeline installation. An additional four isolated artifact occurrences were recorded within the right-of-way, two of which were collected. Archaeological clearance is recommended for construction of the pipeline."

Lowenstein, T.K. 1987 Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico: Textural, Stratigraphic and Chemical Evidence. EEG-36. New Mexico Health and Environment Department, Santa Fe, New Mexico.

PREFACE, p vii;

" A repository for permanent isolation of defense transuranic wastes is being excavated in southeastern New Mexico, about 40 km 925 miles) east of Carlsbad. The Waste Isolation Pilot Plant (WIPP) repository has been designed for the disposal of waste in the lower part of the Salado (salt) Formation at a depth of 655 meters (2150 ft). The water-bearing zones of the Rustler Formation, which overlies the Salado, are considered to be the main pathway for the transport of radionuclides to the biosphere, if the repository is breached.

The Rustler Formation is 150 meters (490 feet) thick, 6.4 Km (4 miles) east of the center of the WIPP site. The thickness reduces drastically to the west so that it is only 91 meters (300 ft) thick in the western part of the WIPP site. At its thickest location, the Rustler consists of siltstone and anhydrite with two dolomite beds and both clear and clayey halite. Halite is progressively missing from deeper layers from east to west in the Rustler cross-section across the WIPP site. These observations were interpreted by Powers et al (1978), Mercer (1983), Lambert (1983), Chaturvedi and Rehfeldt (1984), Bachman (1984), Snyder (1985), Chaturvedi and Channell (1985) and others as indicating post-burial dissolution of halite and increased gypsification of anhydrite further west. Increased permeability of the water-bearing dolomites from east to west also was thought to result from the increased fracturing as a result of dissolution.

In 1984, Powers and Holt (1984) and Holt and Powers (1984) expressed doubts about the concept of post-burial dissolution of Rustler evaporites, on the basis of detailed mapping in the WIPP Waste Handling Shaft, and stated the following:

> 'Post-depositional dissolution features were not observed in any stratigraphic horizons in the Waste Shaft. In fact, several zones previously identified as dissolution residues in nearby boreholes (e.g. ERDA-9) contain pronounced primary sedimentary features. This is of great significance since dissolution has, historically, been considered as an important process that has greatly modified the Rustler Formation in this area.' (Holt and Powers, 1984)

This statement was based on the first detailed sedimentological study of the Rustler stratigraphy, but only at one location, albeit in situ, in a shaft. It clearly signaled the need for further work on the lateral variations in the stratigraphy of the Rustler Formation across the WIPP site. Since the interpretation by Powers and Holt was based on sedimentary features, the need was for a sedimentological study of the Rustler Formation.

To resolve this issue, the Environmental Evaluation Group (EEG) asked Dr. Tim K. Lowenstein to perform a sedimentological study of the available cores of the Rustler Formation. Dr. Lowenstein is a sedimentologist with special interest in the study of evaporites and has studied the Ochoan evaporites of the delaware Basin (Lowenstein, 1982,

1985). For this study, he performed a detailed sedimentological analysis of the Rustler cores from four wells, viz. DOE-2, W-19, H-11 and H-12. This included visual examination of the cores, preparation and petrographic analyses of 52 thin sections from selected locations of the cores, and x-ray diffraction analyses of 40 samples from selected locations of the cores. In addition, descriptive data on the rock cuttings and geophysical logs of borehole P-18 were used for correlation purposes. This report is a result of these analyses and correlation of sedimentary features between the drill-holes.

This study was confined to a miniscule area (only about 0.05%) of the total extent of the Rustler Formation and therefore cannot be considered to be a study of post-burial alteration of the Rustler Formation as a whole. Within the confines of this area, however, detailed stratigraphic correlations by Dr. Lowenstein based on sedimentary structures and textures indicate overall uniformity of depositional setting. Further, the physical and chemical alteration features, based on crosscutting relations, represent the last processes which have operated on these rocks. Four distinct dissolution zones in the Rustler Formation have been interpreted by Dr. Lowenstein. Although the strata above and below the inferred dissolution zones are chemically and physically altered, they contain abundant sedimentary structures and internal stratigraphy that can easily be matched from well to well. Dr. Lowenstein does not see a contradiction between post depositional dissolution and the survival of sedimentary structures. His interpretation is that the dissolved species produced by solution are removed from the site of reaction and the zones in which the effects of dissolution are now seen were at the periphery of main dissolution activity and therefore may exhibit some alteration as well as primary sedimentary structures."

CULEBRA DOLOMITE MEMBER, p. 19;

" The Culebra Dolomite Member is a tan to gray colored dolostone with minor quartz silt (Fig. 5 and Photos 10 and 11). The rock is predominantly structureless, although vague layering, on a scale of 1-5 cm, is seen in places. Well preserved mm-scale lamination is present at the base of the unit. The top of the Culebra Member, about 30 cm in thickness, is finely laminated and the unit is capped by a brown to black laminate with sub-mm scale, black organic-rich and tan carbonate-rich layers. One common feature of the Culebra Dolomite is the large number of nodular masses and open vugs from a mm to greater than 10 cm in diameter. They are roughly spherical to ellipsoidal in shape and are in sharp contrast with the surrounding dolostone. In core H-12, the vugs are open or filled with (1) a core of anhydrite laths and a rim of gypsum (Photo 10) or (2) gypsum. In the other 3 cores, most of the vugs are open but some are entirely filled with coarse gypsum crystals (Fig. 5)."

CRITERIA FOR RECOGNIZING LATE STAGE ALTERATION, p. 29;

" Features interpreted to have been produced by late-stage alteration have been observed in all four cores of the Rustler Formation in the study area. This alteration has occurred to varying degrees in the top of the Lower Member (A-1 anhydrite and Mudstone I), the Culebra Dolomite Member, the Tamarisk Member (A-2 anhydrite, Mudstone II and A-3 anhydrite), the Magenta Dolomite Member, and the Forty Niner Member (A-4 anhydrite,

Mudstone III and A-5 anhydrite)(see Figs. 4, 5 and 6). The alteration has involved physical processes such as brecciation, slumping, fracturing and faulting and chemical processes such as rehydration of anhydrite to gypsum, gypsum precipitation and dissolution of halite, anhydrite and gypsum.

Two assumptions that have led to the above interpretations are first addressed. . . ."

p. 30, para. 2;

" The second assumption is that sometime after deposition, most, if not all, of the $CaSO_4$ in the Rustler Formation was anhydrite. The abundant pseudomorphs of gypsum, now composed of anhydrite, indicate that an originally gypsum-rich sediment has since been converted to anhydrite. This assumption is backed by evidence from many other ancient evaporites where primary gypsum has been wholly converted to anhydrite upon burial. therefore, the gypsum now present in the Rustler is interpreted to have formed as a rehydration replacement of anhydrite or as a void filling cement, or fracture filling, the three of which are commonly associated. There is abundant evidence indicating that the formation of gypsum as one of the above textures has been the last process that has operated in the Rustler Formation. This evidence includes (1) gypsum-filled fractures that crosscut all other sedimentary features, (2) gypsum crystals with remnants of anhydrite in the cores of nodules and clasts, and gypsum rims around anhydrite nodules (Culebra Dolomite), and (3) gypsum-cemented breccias. Thus, where the gypsum of the Rustler Formation forms anything other than a void-filling, it is interpreted to have undergone the transformation sequence of dehydration of gypsum to anhydrite (upon burial) and rehydration of anhydrite to gypsum (upon exhumation). Such changes should result in the loss of primary sedimentary structures compared to rocks still composed of anhydrite and in general this is true. In such 'gypsified' rocks, the gypsum crystals may crosscut the original gypsum pseudomorph boundaries, which confirms that the gypsum is a later alteration product.

The presence of gypsum in the Rustler Formation therefore serves as a general indicator of late stage alteration (see Figs. 4, 5 and 6). In all zones identified as altered in the study area, gypsum is present. Waters capable of directly precipitating gypsum and rehydrating anhydrite to gypsum on a large scale are not likely to be connate evaporite formation waters, but were probably introduced into the rock at some later time. In the Rustler Formation, the most likely candidate for an introduced 'alien' water is groundwater. The present-day Rustler Formation waters (in the Culebra and Magenta Dolomites) are for the most part 'dilute' and probably meteoric in origin. These waters have not migrated from the evaporite within or below the Rustler Formation. The chemistry of present-day Rustler Formation waters will be further discussed below.

Evidence for late-stage chemical alteration.

The textural features in the Rustler Formation interpreted to have formed during late stage chemical alteration by the introduction of alien waters include (1) precipitation of gypsum as void-filling cement, breccia cement and fracture filling (Figs. 4, 5 and 6 and Photos 8, 9, 11, 15, 19), (2) replacement of anhydrite by gypsum by rehydration (Figs 4, 5 and 6 and Photos 8, 10, 22, 23, 24), (3) precipitation of euhedral gypsum crystals and

gypsum crystal rosettes (Figs. 4, 5 and 6 and Photo 13), (4) dissolution of gypsum and anhydrite (open vugs in Culebra and Magenta Dolomite Members, Photos 10 and 11) and (5) precipitation of calcite (Figs. 4, 5 and 6)."

Lowenstein, T.K. 1988. "Origin of Depositional Cycles in a Permian Saline Giant: the Salado (McNutt Zone) Evaporites of New Mexico and Texas." Geological Society of America Bulletin, Vol. 100, No. 4, pp. 20-21, 592-608.

ABSTRACT, p 592, col 1;
" Two types of metre-scale depositional cycles have been recognized within the McNutt Potash Zone of the Permian Salado evaporites. The cycles record progressive drawdown and concentration of brine in a shallow, marginal marine basin. 'Type I' cycles, made of basal carbonate-siliciclastic mudstone, then anhydrite-polyhalite pseudomorphous after primary gypsum, overlain by halite and capped by muddy halite, are interpreted as marine sea water dominated. They formed by massive spillover of sea water through a connection with the Permian Ocean at high relative sea-level stands (lagoonal mudstone and anhydrite-polyhalite after subaqueous gypsum), followed by relative lowering of sea level and gradual basin restriction (shallow saline-lake and salt-pan halite) and ending with a desiccated basin, isolated from the Permian Ocean (salt-pan halite and saline mudflat muddy halite cycle cap). 'Type II' cycles occur between the Type I cycles and contain halite overlain transitionally by muddy halite. They record a temporal evolution of environments from a shallow saline lake to an ephemeral salt-pan-saline mudflat complex and are interpreted as continental-dominated sequences sourced by meteoric inflow from surrounding land areas that mixed with variable amounts of sea water, either residual or introduced into the Salado basin by seepage.

The vertical stacking of Type I cycles is best explained by periodic invasions of sea water into the Salado basin coincident with eustatic sea-level rises. The continental-dominated Type II cycles formed during intervening periods of eustatic sea-level fall and low stands. The *maximum* time interval between major marine incursions is an average of 10^5 yr."

INTRODUCTION, p 592, col 3, para 2, line 3;
" The Salado Formation is a 'giant' evaporite deposit (150,000 km^2) with potash-bearing intervals."

Lucas, S.G., and Anderson, O.J. 1993a. "Triassic Stratigraphy in Southeastern New Mexico and Southwestern Texas." In Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society, Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993. D.W. Love et al., eds., pp. 231-235. New Mexico Geological Society, Socorro, NM.

ABSTRACT, p 231;

" Upper Triassic strata exposed in southeastern New Mexico and southwestern Texas are assigned to the Santa Rosa, San Pedro Arroyo and Dockum Formations of the Chinle Group. In southeastern New Mexico (Chaves, Eddy and Lea Counties) the Santa Rosa Formation is as much as 25 m thick and is mostly trough-crossbedded extraformational conglomerate and sandstone with minor beds of mudstone or siltstone. It disconformably overlies Upper Permian (Artesia Group or Quartermaster Formation) strata. The San Pedro Arroyo Formation conformably (?) overlies the Santa Rosa Formation and is at least 50 m of variegated smectitic mudstone and minor sandstone/conglomerate. Regional geologic maps have greatly overstated the extent of Upper Triassic exposures in southeastern New Mexico. In southwestern Texas (area from Pecos to Mitchell Counties) the Dockum Formation consists of the basal Camp Spring Member and overlying strata here assigned to a new stratigraphic unit, the Iatan Member. The Camp Springs Member is at least 15 m thick and is dominantly extraformational, siliceous conglomerate. It disconformably overlies the Upper Permian Quartermaster (=Dewey Lake) Formation and is conformably (?) overlain by the Iatan Member, which is 80-100 m thick and characterized by intercalcated, persistent intervals of red smectitic mudstone and trough-crossbedded micaceous sandstone. Fossil vertebrates indicate the Camp Springs and Iatan Members are of late Carnian (Tuvalian) age. Physical stratigraphy and lithology suggest correlation of the Santa Rosa Formation with the Camp Springs Member and the San Pedro Arroyo Formation with the Iatan Member."

Santa Rosa Formation, p 232, col 1;

" We assign the basal sandstones and conglomerates of the Upper Triassic section in southeastern New Mexico to the Santa Rosa Formation, as did Lang (1935) and subsequent workers. The Santa Rosa is as much as 25 m thick and is mostly trough-crossbedded extraformational conglomerate and sandstone with minor beds of mudstone or siltstone. Typical colors are grayish red (10 R 4/2) and pale reddish brown (10 R 5/4) for the sandstones, siltstones and mudstones, whereas conglomerate beds are mostly yellowish gray (5 Y 8/1) to light greenish gray (5G Y 8/1). Sandstones are micaceous subarkoses or litharenites. Conglomerate clasts typically are rip-ups of underlying Permian red beds (Artesia Group or Quartermaster Formation) at the base of the Santa Rosa Formation. Some quartzite clasts (usually in the very coarse to pebbly size range) also are present in basal Santa Rosa conglomerates. Conglomerates higher in the unit contain reworked Triassic siltstone and sandstone clasts.

The base of the Santa Rosa Formation is a disconformity above Permian red beds. Permian strata are finer grained, more texturally and mineralogically mature, gypsiferous,

more evenly bedded and a different color (mostly moderate reddish brown) than the Santa Rosa Formation. Despite these differences, in southeastern New Mexico both Miller (1955) and Vine (1963) incorrectly included uppermost sandstones of the Quartermaster Formation in the Santa Rosa Formation (Schiel, 1988; Lucas and Anderson, this volume).

The top of the Santa Rosa Formation in southeastern New Mexico is visible only at Maroon Cliffs. Here, variegated moderate reddish brown (10 R 4/6) and grayish red purple (5 RP 4/2) mudstone of the San Pedro Arroyo Formation rests directly (conformably ?) on the uppermost conglomerate bed of the Santa Rosa Formation (Fig. 2).

Other than undefinable fragments of petrified wood, bone and coprolites, no fossils have been collected in the Santa Rosa Formation in southeastern New Mexico. Nevertheless, regional correlation suggests this unit is of Late Triassic (late Carnian) age (see below)."

Lucas, S.G., and Anderson, O.J. 1993b. "Stratigraphy of the Permian-Triassic Boundary in Southeastern New Mexico and West Texas." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

TRIASSIC STRATA, p. 222;

" Triassic strata in southeastern New Mexico and west Texas pertain to the Chinle Group of Lucas (1993). In southeastern New Mexico, the basal unit of the Chinle Group is the Santa Rosa Formation, whereas in west Texas it is the Camp Springs Member of the Dockum Formation (Lucas and Anderson, 1992, 1993 and this volume).

In east-central New Mexico, the Santa Rosa Formation consists of, is ascending order, the Tecolitito, Los Esteros and Tres Lagunas Members. The medial, mudstone-dominated Los Esteros Member contains fossil plants and vertebrates that indicate a late Carnian age (Ash, 1988; Hunt and Lucas, 1988). In west Texas (Randall, Scurry and Crosby Counties) the Camp Springs Member of the Dockum Formation produced the phytosaur *Paleorhinus*, indicative of a late Carnian age (Hunt and Lucas, 1991). These fossils thus establish the age of the oldest Triassic strata in southeastern New Mexico and west Texas as Late Triassic (late Carnian). On the Harland et al. (1989) numerical time scale this is about 225 Ma."

Machette, M.N. 1985. "Calcic Soils of the Southwestern United States." In Soils and Quaternary Geology of the Southwestern United States. D.L. Weide and M.L. Faber, eds., Special Paper Vol. 203, pp. 1-21. Geological Society of America, Denver, CO.

ABSTRACT, p 1;

" Calcic soils are commonly developed in Quaternary sediments throughout the arid and semiarid parts of the southwestern United States. In alluvial chronosequences, these soils have regional variations in their content of secondary calcium carbonate ($CaCO_3$) because of (1) the combined effects of the age of the soil, (2) the amount, seasonal distribution, and concentration of Ca^{++} in rainfall, and (3) the $CaCO_3$ content and net influx of airborne dust, silt, and sand. This study shows that the morphology and amount of secondary $CaCO_3$ (cS) are valuable correlation tools that can also be used to date calcic soils.

The structures in calcic soils are clues to their age and . . ."

NOTE: The tables and text on the following pages are taken from p. 5 of the reference.

Calcic soils of the southwestern United States

TABLE 1. STAGES OF CALCIUM CARBONATE MORPHOLOGY OBSERVED IN CALCIC SOILS AND PEDOGENIC CALCRETES DEVELOPED IN NONCALCAREOUS PARENT MATERIALS UNDER ARID AND SEMIARID CLIMATES OF THE AMERICAN SOUTHWEST [Modified from Gile and others (1966, p. 348, Table 1) and Bachman and Machette (1977, p. 40, Tables 2 and 3)]

Stage	Gravel content[1]	Diagnostic morphologic characteristics	$CaCO_3$ distribution	Maximum $CaCO_3$ content[2]
		CALCIC SOILS		
I	High-----	Thin, discontinuous coatings on pebbles, usually on undersides.	Coatings sparse to common	Tr-2
	Low------	A few filaments in soil or faint coatings on ped faces.	Filaments sparse to common	Tr-4
II	High-----	Continuous, thin to thick coatings on tops and undersides of pebbles.	Coatings common, some carbonate in matrix, but matrix still loose.	2-10
	Low------	Nodules, soft, 0.5 cm to 4 cm in diameter	Nodules common, matrix generally noncalcareous to slightly calcareous.	4-20
III	High-----	Massive accumulations between clasts, becomes cemented in advanced form.	Essentially continuous dispersion in matrix (K fabric).	10-25
	Low------	Many coalesced nodules, matrix is firmly to moderately cemented.	----------do----------	20-60
		PEDOGENIC CALCRETES (INDURATED CALCIC SOILS)		
IV	Any------	Thin (<0.2 cm) to moderately thick (1 cm) laminae in upper part of Km horizon. Thin laminae may drape over fractured surfaces	Cemented platy to weak tabular structure and indurated laminae. Km horizon is 0.5-1 m thick.	>25 in high gravel content >60 in low gravel content
V	Any------	Thick laminae (>1 cm) and thin to thick pisolites. Vertical faces and fractures are coated with laminated carbonate (case-hardened surface)	Indurated dense, strong platy to tabular structure. Km horizon is 1-2 m thick.	>50 in high gravel content >75 in low gravel content
VI	Any------	Multiple generations of laminae, breccia, and pisolites; recemented. Many case-hardened surfaces.	Indurated and dense, thick strong tabular structure. Km horizon is commonly >2 m thick.	>75 in all gravel contents

[1]High is more than 50 percent gravel; low is less than 20 percent gravel.
[2]Percent $CaCO_3$ in the <2-mm-fraction of the soil. Tr, trace of carbonate.

"Stage V and VI calcic soils are particularly well preserevd at numerous locations in the Southwest. The most spectacular of these soils are associated with the constructional geomorphic surfaces of the following geologic

$CaCO_3$ stage	Geomorphic surface and probable age	Geologic unit and probable age	Location
V	Upper La Mesa, early Pleistocene	Camp Rice Formation of Strain (1966), middle Pleistocene to Pliocene	Las Cruces, New Mexico
V	Mescalero middle Pleistocene	Gatuna Formation, middle Pleistocene	Southeastern New Mexico
VI	Mormon Mesa, early(?) Pliocene	Muddy Creek Formation, Miocene	Overton, Nevada
VI	Ogallala, late(?) Miocene	Ogallala Formation, Miocene	Eastern New Mexico and western Texas

units:

Madsen, B.M., and Raup, O.B. 1988. Characteristics of the Boundary between the Castile and Salado Formations near the Western Edge of the Delaware Basin, Southeastern New Mexico. New Mexico Geology, Vol. 10, No. 1.

ABSTRACT, p 1, col. 1;

" The contact between the Upper Permian Castile and Salado Formations throughout the Delaware Basin, southeast New Mexico and west Texas, has been difficult to define because of facies changes from the basin center to the western edge. Petrographic studies of core from a Phillips Petroleum Company well, drilled in the western Delaware Basin, indicate that there are major mineralogical and textural differences between the Castile and Salado Formations. The Castile is primarily laminated anhydrite with calcite and dolomite. The Salado Formation is also primarily anhydrite at the location of this core hole, but with abundant layers of magnesite. This magnesite indicates an increase in magnesium enrichment in the basin brines, which later resulted in the deposition of magnesium-rich potash deposits within the Salado Formation elsewhere in the basin. A breccia zone at the top of the Castile Formation shows evidence of massive recrystallization, which indicates a break in sedimentation and possible subaerial erosion. This breccia zone probably represents an unconformity along the western edge of the basin between the Castile and Salado Formations, which has been recognized by other workers."

Summary and conclusions, p 4, col 3, para 4;

" The Castile and Salado Formations in the Delaware Basin represent sediments that were deposited in an evaporite environment of steadily increasing salinity. The boundary between the two formations, in general, represents a change from sulfate, carbonate, and some chloride deposition in the Castile, to deposition of chlorides and magnesium-rich potash minerals in the Salado Formation.

Adams (1944) recognized an unconformity between the Castile and Salado Formations in the northern part of the Delaware Basin. Correlations of acoustical logs and facies studies by Anderson (1978, 1981) support Adams' interpretation. Anderson (1978, p. 17) said that 'there was an episode of non-deposition, angular unconformity, and even salt dissolution in the northern part of the basin following the deposition of the Halite III unit (upper halite) of the Castile Formation.'

The Phillips core hole, on which this study is based, was drilled at the western edge of the Delaware Basin where both the Castile and Salado Formations are now primarily anhydrite with some layers of carbonate. The major difference between the Castile Formation in this core, as compared to core from farther into the basin, is the absence of halite that has been removed by dissolution. The Salado Formation in the core can be distinguished from the underlying Castile Formation on the basis of anhydrite characterized by major inclusions of magnesite. The magnesite in this basin-edge facies indicates an enrichment of magnesium in the basin brines that later resulted in the deposition of magnesium-rich potash deposits within the Salado Formation elsewhere in the basin.

The top of the breccia zone in the Phillips core probably represents the unconformity,

and perhaps the period of subaerial erosion at the top of the Castile that was described by Adams (1944) and Anderson (1978, 1981). This breccia zone in the core represents dissolution of halite that resulted in brecciation and massive recrystallization of the anhydrite at the top of the Castile before deposition of the overlying magnesitic anhydrite of the Salado Formation along the western edge of the basin. Contortion of the magnesite layers, as described from this core hole, probably resulted from slumping and differential compaction of soft sediments that were deposited over the irregular breccia surface at the top of the Castile Formation."

McGowen, J.H., and Groat, C.G. 1971. Van Horn Sandstone, West Texas: An Alluvial Fan Model for Mineral Exploration. Report of Investigations No. 72. Bureau of Economic Geology, Austin, TX.

ABSTRACT;

" The Van Horn Sandstone is an ancient alluvial-fan system with a northern highland source area of rhyolite, granite, metamorphic and sedimentary rocks. Sediment ranging in size from silt to boulders was transported southward through canyons by high-gradient mountain streams. South of the mouths of the canyons, sediment was transported by less confined braided streams.

The fan was deposited on a surface of faulted, folded, and highly dissected Precambrian sedimentary, metamorphic, and intrusive basic igneous rocks. Topography of the subjacent erosional surface was rugged and characterized by deep canyons that controlled the distribution of gravel downfan beyond the termination of high-gradient mountain feeder systems.

Three principle facies of the Van Horn area are, from north to south, (1) proximal, chiefly gravel; (2) mid-fan, alternating gravel and sand; and (3) distal, dominantly coarse and very coarse sand. The proximal facies is 300 to 600 feet thick in the northern outcrop area and consists of lower thick, massive cobble and boulder beds and upper thin to thick, horizontally bedded pebble, cobble, and boulder gravels. It grades southward and vertically into alternating gravel and sand of the mid-fan.

Mid-fan deposits are up to 300 feet thick in the northern outcrop area and about 30 feet thick in the central area where the facies plunge southward into the subsurface. Mid-fan gravels occur as lenses of parallel-bedded depositional units with flat bases and convex upper surfaces and as channel-fill deposits. Sands associated with the mid-fan occur either as broad channel-fill deposits or as lenses deposited in low areas flanking gravel lenses (or bars). Two stratification types, foreset and trough crossbeds, dominate these sands.

The distal facies consists chiefly of coarse and very coarse sand; the mid-fan facies grades southward downfan into distal facies, which also overlies mid-fan deposits throughout the fan. Maximum outcrop thickness of distal facies is about 700 feet. Three distal fan subfacies (main braided stream, braided distributary, and braided interlobe) have been differentiated. Main braided stream deposits occur as foreset and trough crossbeds; relative abundance of each crossbed type is variable. Scale of foresets and trough crossbeds decreases upward in the section and to the south. Braided distributary deposits are characterized by a relatively high content of muddy sand units, well-preserved channel-fill deposits, some ripple cross-laminated sand units, foreset- and trough-crossbedded sands (locally the facies may be dominated by small trough crossbeds), and units displaying soft sediment deformation and injection structures. Braided interlobe deposits consist of thick sand sequences composed almost exclusively of trough crossbeds. Muddy sand is uncommon and trough laminae are accentuated by heavy mineral placers. This subfacies contains the greatest heavy mineral concentration within the Van Horn Sandstone.

Facies relationships, textural trends, succession of sedimentary structures, and dip

direction of crossbeds indicate a southerly sediment transport direction. Depth of flow, slope of the fan surface, stream velocity, and competence decreased southward. Proximal facies developed under confined, rapid flow conditions; surges were common events within the feeder system and within the canyons. Mid-fan deposits were laid down by braided streams; both rapid and tranquil flow conditions are indicated by longitudinal gravel bars and by flanking transverse bars with dunes, respectively. The distal fan was the area of lowest physical energy. Tranquil flow conditions dominated, slope of the surface was extremely low, and sediment remained saturated for relatively lengthy periods following a depositional event.

The Bliss Sandstone (Ordovician) is the oldest sedimentary rock sequence that overlies the Van Horn. In places the contact between Bliss and Van Horn is discordant, but in others the contact is conformable.

Although placer gold has been reported in the Van Horn Sandstone, laboratory analysis of 71 samples revealed no significant amounts. Despite the absence of gold, the concentration of other heavy minerals in the braided interlobe subfacies of the distal-fan facies and the detailed descriptions of the facies relationships should contribute to a prospecting model that will be applicable to similar but ore-bearing alluvial fan systems."

McGuire, R.K. 1976. FORTRAN Computer Program for Seismic Risk Analysis. Open-File Report No. 76-67, pp. 1-68. U.S. Geological Survey.

ABSTRACT, p 1;

" A program for seismic risk analysis is described which combines generality of application, efficiency and accuracy of operation, and the advantage of small storage requirements. The theoretical basis for the program is first reviewed, and the computational algorithms used to apply this theory are described. The information required for running the program is listed. Published attenuation functions describing the variation with earthquake magnitude and distance of expected values for various ground motion parameters are summarized for reference by the program user. Finally, suggestions for use of the program are made, an example problem is described (along with example problem input and output) and the program is listed."

Mercer, J.W., Beauheim, R.L., Snyder, R.P. and Fairer, G.M. 1987. Basic Data Report For Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-0611. Sandia National Laboratories, Albuquerque, NM. WPO 27646.

ABSTRACT;

" Drillhole DOE-2 was drilled to investigate a structural depression marked by the downward displacement of stratigraphic markers in the Salado formation ~2 mi north of the center of the WIPP site. This depression was named informally after the shallow borehole FC-92 in which the structure was described. The presence of the depression was confirmed by drilling. Contrary to several hypotheses, halite layers were thicker in the lower part of the Salado, not thinner as a result of any removal of halite. The upper Castile anhydrite in Drillhole DOE-2 is anomalously thick and is strongly deformed relative to the anhydrite in adjacent drillholes. In contrast, the halite was <8 ft thick and significantly thinner than usually encountered. The lower Castile anhydrite appears to be normal. The depression within the correlated marker beds in the Salado Formation in Drillhole DOE-2 is interpreted as a result of gravity-driven deformation of the underlying Castile Formation.

Several stratigraphic units were hydrologically tested in Drillhole DOE-2. Testing of the unsaturated lower portion of the Dewey Lake Red Beds was unsuccessful because of exceptionally small rates of fluid intake. Drill-stem tests were conducted in five intervals in the Rustler Formation, over the Marker Bed 138-139 interval in the Salado Formation, and over three sandstone members of the Bell Canyon Formation. A pumping test was conducted in the Culebra Dolomite Member of the Rustler Formation. Pressure-pulse tests were conducted over the entire Salado Formation. Fluid samples were collected from the Culebra Dolomite Member and from the Hays Member of the Bell Canyon Formation."

p. 23, Table 3-2. Stratigraphic Summary of Drillhole DOE-2, (condensed from text);

Rock Unit	Depth Interval (feet)
Quaternary	
Holocene	
Dune Sand	0 - 8
Pleistocene	
Mescalero Caliche	8 - 13
Triassic	
Santa Rosa Sandstone	13 - 133.3
Permian	
Dewey Lake Red Beds	133.3 - 639.1
Rustler Formation	639.1 - 960.9
Salado Formation	960.9 - 3082.8
Castile Formation	3082.8 - 4071.4
Delaware Mountain Group	4071.4 - 4248+

p 28, col 2, para 3;
" DOE-2 penetrated the upper part of the Bell Canyon Formation of the Delaware Mountain Group. From the top downward, units penetrated are the Lamar Limestone, the Ramsey sand, the Ford shale, the Olds sand, and the Hays sand. The Lamar Limestone was first described by Lang (1935); the other units are informal units of local usage."

p 312, para 4;

" Lithologic description	Depth interval Feet
Anhydrite, medium-dark-gray (N4), microcrystalline; nodular structure breaks and disrupts most dusky-yellow-brown (10YR-2/2) laminations; few 3-mm-thick laminae, wavy; basal contact sharp, slightly irregular, and horizontal	4045.3 - 4069.7
Dolomite and anhydrite, dusky-yellow-brown (10YR-2/2) and dark-gray (N3), horizontal laminae; oil bleeding from vertical nearly-healed fracture; basal contact sharp	

and horizontal	4069.7 - 4071.4
Shale, grayish-black (N2) to dark-gray (N3), calcareous, basal contact sharp	4071.4 - 4073.8

Limestone, grayish-black (N2), bedded with dark-gray (N3); pelecypod shells as long as 6 mm and corals(?); basal 5.5 ft alternating ..."

Miller, D.N. 1955. Petrology of the Pierce Canyon Formation, Delaware Basin, Texas and New Mexico [Ph.D. Dissertation]. University of Texas, Austin.

ABSTRACT, p. iii;

" The Pierce Canyon formation of the Delaware Basin is a red siltstone sequence about 350 feet thick that overlies the Permian Rustler evaporites and underlies the Upper Triassic Santa Rosa sandstone. It consists of crosslaminated, gypsiferous, slightly sandy and slightly clayey siltstone and ranks as submature to mature arkose or sub-arkose containing 20 to 30 per cent feldspar. Petrographic and textural analyses show that there is little variation in composition or texture either vertically or horizontally. These redbeds typically contain hollow sanidine grains which may prove useful as a stratigraphic marker. Authigenic biotite was detected in a few of the reduction spots.

The Pierce Canyon redbeds were probably derived predominantly from a granitic source in northern Coahuila, Mexico, under the influence of an arid climate, transported by the wind, and deposited in a shallow saline sea in west Texas and southeastern New Mexico.

Comparison with other redbeds shows that the Dewey Lake formation of the Midland Basin, and the Quartermaster formation of the Texas panhandle, have compositions that are essentially identical with that of the Pierce Canyon redbeds.

The Pierce Canyon differs mineralogically from the Yates, Rustler, Tecovas, Santa Rosa, Chinle, and Gatuna formations. If the Pierce Canyon is assigned to the Permian system, then there are eight mineralogic differences to distinguish Permian from Triassic redbeds."

Miller, D.N. 1966. Petrology of Pierce Canyon Redbeds, Delaware Basin, Texas and New Mexico. American Association of Petroleum Geologists Bulletin, Vol. 80.

ABSTRACT, p 283;

" The Pierce Canyon Formation of the Delaware basin is a brick-red siltstone about 150 feet thick that conformably overlies the Permian Rustler Formation and unconformably underlies the Upper Triassic Santa Rosa Sandstone. Field and laboratory data suggest that the Pierce Canyon is a first-cycle sediment derived from a granite source in northern Mexico under the influence of an arid climate, transported by the wind, and deposited in a shallow saline lagoon that covered western Texas and southeastern New Mexico at the close of the Permian.

In addition, surface and subsurface data from the encompassing strata substantiate the opinion that the Dewey Lake Formation of the southern Permian basin and the Quartermaster Formation of the Texas Panhandle and northwestern Oklahoma have essentially identical mineral assemblages and occupy the same stratigraphic position as the Pierce Canyon. Eight distinct mineralogic differences make it possible to distinguish these formations from the redbeds in the overlying Triassic Dockum Group. The name Pierce Canyon probably could be discontinued in favor of the name Dewey Lake."

Muehlberger, W.R., Belcher, R.C., and Goetz, L.K. 1978. Quaternary Faulting in Trans-Pecos Texas. Geology, Vol. 6, No. 6, pp. 337-340.

ABSTRACT, p 337;

" Faults that displace Quaternary units can be observed in scarps in Trans-Pecos Texas and are restricted to two north-trending zones in contrast to late Tertiary faults that cover the region and strike north, northwest, and west. The western zone of Quaternary faults, near El Paso, is usually included as the southern part of the Rio Grande rift. The eastern zone of Quaternary faults extends for 300 km from southern New Mexico along the Salt Basin graben through Van Horn, Texas; its probable extensions and subparallel associates extend southward to Presidio, Texas. This belt of faults is parallel to the Rio Grande rift zone and should be considered a southeast extension of that zone.

These fault zones die out southward into the edge of the Chihuahua tectonic belt, a region underlain by a thick Mesozoic carbonate and clastic section that in turn rests on a thick layer of evaporites. The evaporite zone may mask Cenozoic normal faulting and thus may define a zone of no data rather than a southern limit of basin-and-range or Rio Grande graben tectonics.

All Quaternary and most Tertiary faults trend parallel to pre-existing structures. The map pattern of Quaternary scarps suggest a maximum extension oriented about S80°W; however, first-motion studies of the 1931 Valentine, Texas earthquake show a maximum elongation direction of S50° to 55°W. This difference may be unique to this one earthquake or may be due to the pre-existing lines of weakness that control the location of presently active faults."

DESCRIPTION OF SCARPS IN SALT BASIN GRABEN, p 338, col 2;

" Only two fault scarps in Quaternary alluvium were found in the New Mexico portion of Salt Basin graben, and these are located along the eastern margin of the graben. The northernmost scarp, 50 km above the Texas border, was mapped northwest of the Brokeoff Mountains by Kelley (1971). A second scarp, 10 km south, was mapped in Crow Flat during our study. A cluster of faults, in the vicinity of Bitterwell Mountain, part of which was mapped by P. B. King (1948, 1965), constitutes the main area of scarps on the east side of the graben. Only two other fault scarps on the east side of the graben definitely can be shown to cut the youngest basin fill; one is at the western base of the southernmost Delaware Mountains, the other is located south of the Apache Mountains."

Nicholson, Jr., A., and Clebsch, Jr., A. 1961. Geology and Ground-Water Conditions in Southern Lea County, New Mexico. Ground-Water Report 6. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p 1;

" Southern Lea County is at the southeastern corner of New Mexico. Most of the area is in the Pecos Valley section of the Great Plains physiographic province; it also includes the southern margin of the Llano Estacado. There are no perennial streams and no throughgoing surface drainage.

Rocks of Quaternary, Tertiary, and Triassic age are exposed and contain the principle aquifers. The most important aquifer is the Ogallala formation, which underlies the Llano Estacado and forms outliers south of it. In large parts of southern Lea County, however, the Ogallala has been removed by erosion and in the low-lying areas Quaternary alluvium, derived principally from the Ogallala formation, has been deposited and is the main aquifer. The two aquifers are continuous in the eastern part of the area. Below the Cenozoic rocks are sandstones and shales of the Dockum group of Late Triassic age, from which small quantities of water are obtained. No usable ground water is obtained from rocks older than the Triassic, but highly saline water is produced along with oil from Paleozoic rocks.

In 1954 about 6,000 acre-feet of ground water were used. Most of this quantity was needed for irrigation and for gasoline plants, in about equal amounts. Economic growth from a rapidly developing petroleum industry has brought about a demand for water for industrial and public supplies that is expected to continue. Development of adequate supplies is hindered by restricted occurrence and low transmissibility of the sediments. Because of the low recharge rate, most of the water pumped is being removed from storage.

The chemical quality of the ground water from the principal aquifers is generally fair to good. Production of large quantities of oil-field brine (3,700 acre-feet in 1955) has created a waste-disposal problem of major importance. Most of the brine has been discharged into surface pits. Leakage from the pits has caused contamination of the shallow water in some areas and unless other disposal methods are used, the problem will spread."

p 14, line 9;

" The lowest point within the swale is the San Simon Sink, in sec. 18, T. 23 S., R. 35 E., just west of the eastern escarpment of the swale. The sink is about 100 feet deep from its rim to the bottom and approximately half a square mile in area. Within the sink there is a secondary collapse about 25 to 30 feet deep (see fig. 6). The fill in the sink is mostly calcareous silt and fine sand. Active subsidence is reported to have taken place as recently as 25 to 30 years ago, when large annular fissures developed at the edge of the sink (see fig. 6, 7 and 8). These fissures are still evident and are still as deep as 5 feet in some places. The area immediately adjacent to the sink on the north, south, and west is a grassy plain underlain by sand and silt. Another sink, no longer active, is in sec. 33, T. 21 S., R. 33 E.

The San Simon Swale probably originated as the result of deep-seated collapse. The area may have subsided as a unit. More probably, however, the depression is the result of

the removal of material by deflation and by fluvial erosion into large sinks of which the San Simon Sink may be the only one exposed, the others having been completely filled and hidden by the cover of dune sand."

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site. Vols. 1 to 4.

EXECUTIVE SUMMARY, p E-1;

" The Waste Isolation Pilot Plant (WIPP) land withdrawal area occupies 16 mi^2, on the southeastern edge of the Known Potash Leasing Area (administered by BLM), about 30 miles southeast of Carlsbad, Eddy County, New Mexico. It is four miles on a side and is located in secs. 15 to 22 and 27 to 34 of T22S R31E. This study includes an additional study area about one mile wide surrounding and containing an additional 20 mi^2. The combined study area comprises about 36 mi^2.

The amount and value of natural resources under the WIPP land withdrawal area have not been calculated for more than ten years. This report performs this calculation using current and projected prices, production, geologic data, and conditions. The need for recalculating the volume and value of mineral resources within the boundaries of the WIPP land withdrawal area stems from the discovery of oil and associated natural gas in adjacent lease tracts during the late 1980s and 1990s, and the approach of potash mining.

During the late 1980s and early 1990s oil was discovered in the lower parts of the Delaware Mountain Group (Permian: Cherry Canyon and Brushy Canyon Formations) along the eastern, southern, and western boundaries of the land withdrawal area. In the Delaware Basin as a whole, these formations were not generally recognized as exploratory and development targets until the late 1980s. Prior to that time, they were usually bypassed during drilling with little or no thought that they might contain economically recoverable oil resources. Although these two formations had been penetrated by thousands of wells throughout the Delaware Basin, few attempts were made to adequately test them.

The main reason for bypassing these formations during drilling was a lack of understanding of their production characteristics. Water saturations calculated from analysis of electric logs were often high and did not differentiate oil-productive sandstones from sandstones that would yield mostly water upon completion. However, recent developments in log analysis (Asquith and Thomerson, 1994) have made it possible to differentiate Delaware sandstones with a high percentage of movable hydrocarbons from those with a low percentage of movable hydrocarbons. This type of analysis, in conjunction with the discovery of several commercial oil pools in the Brushy Canyon Formations, set off an oil drilling boom throughout the Delaware Basin that continues to the present. The Delaware play is currently the primary exploration and development play in the Permian Basin and is one of the most active oil plays in the United States. Of special note in the vicinity of WIPP was the discovery and development of commercial oil accumulations in the Brushy Canyon Formation at Cabin Lake; Livingston Ridge, Lost Tank, and Los Medaños pools.

During the last decade or so, potash mining has continued and the mining front is now much closer to the WIPP boundary. Mining by IMC has reached the edge of the additional study area on the southwest side of the WIPP. Future mining may occur mainly there or on the north.

The value of potash (sylvite and langbeinite) and petroleum (oil and gas) were calculated using iterative economic models commencing in 1996 and lasting until 2031 (potash), 2026 (petroleum), and 2038 (natural gas plus associated oil). The potash and petroleum resources produced over this time frame were calculated from estimates based on drill hole data and projections of data and geology as needed. The value calculation used these resource data and projections of historical cost, price, and other economic data.

Potash Reserves

The results of the potash resources and reserve calculation are:

Resources and reserves of the 4th langbeinite ore zone (short tons in millions).

Area, Type of Lease, and Scenario	Tons	Avg % K_2O
Entire study area		
In-place resource (>4% K_2O & actual thickness)	168.7	8.02
BLM Lease Grade reserve (>4% K_2O & 4 ft mining height)	166.5	7.22
Minable reserve (>6.25% K^2O & 6 ft mining height	72.4	7.95
Inside WIPP boundary		
In-place resource (>4% K_2O & actual thickness)	47.0	7.21
BLM Lease Grade reserve (>4% K_2O & 4 ft mining height)	40.5	6.99
Minable reserve (>6.25% K^2O & 6 ft mining height	18.0	7.59
Outside of the WIPP boundary (about one mile)		
In-place resource (>4% K_2O & actual thickness)	121.7	8.33
BLM Lease Grade reserve (>4% K_2O & 4 ft mining height)	126.0	7.30
Minable reserve (>6.25% K^2O & 6 ft mining height	54.4	8.07

Resources and reserves of the 10th sylvite ore zone (short tons in millions).

Area, Type of Lease, and Scenario	Tons	Avg % K_2O
Combined Area		
In-place resource (>10% K_2O & actual thickness)	168.2	14.61
BLM Lease Grade reserve (>10% K_2O & 4 ft mining height)	157.3	14.64
Minable reserve (>12.25% K^2O & 4.5 ft mining height	107.8	15.33
WIPP Area		
In-place resource (>10% K_2O & actual thickness)	53.7	14.26
BLM Lease Grade reserve (>10% K_2O & 4 ft mining height)	52.3	13.99
Minable reserve (>12.25% K^2O & 4.5 ft mining height	30.6	15.00
Additional Area (~1 mile around WIPP)		
In-place resource (>10% K_2O & actual thickness)	114.5	14.77
BLM Lease Grade reserve (>10% K_2O & 4 ft mining height)	105.0	14.96
Minable reserve (>12.25% K^2O & 4.5 ft mining height	77.2	15.46

p. E-4;
"Petroleum Reserves
The Results of the calculation of probable petroleum resources are:

Oil and gas resources (probable)

	Combined Area	WIPP Area	Additional Area
Primary Oil (million bbls)	35.2	12.3	22.9
Secondary Oil (million bbls)	20.2	6.4	13.8
Oil Subtotals (million bbls)	55.4	18.7	36.7
Gas Subtotals (MCF)	354	186	168

NOTE: In addition, there is an unknown but significant amount of possible oil and gas resources beneath the WIPP land withdrawal area and surrounding one-mile-wide additional area."

p. VII-1, *METHOD OF POTASH RESERVE EVALUATION*;
" Evaluation of potash reserves was based solely on subsurface information from 40 core holes previously drilled within and around the WIPP Site. The nearest underground mine operations are currently no closer than one mile from the outer boundary of WIPP. All 40 holes were drilled using brine (containing potassium as well as sodium chloride) to inhibit dissolution of potassium minerals. The results of chemical analyses of the ore-bearing intervals were adjusted to calculate the percentage equivalent as individual natural mineral

species. Only the K_2O percentages as either sylvite or langbeinite were used to compute ore reserves."

p. XI-1, OIL AND GAS RESOURCE ESTIMATES
Ronald F. Broadhead, Fang Luo, and Stephen W. Speer
SUMMARY OF OIL AND GAS RESOURCES;
" Rigorous, quantitative estimates were made of oil, natural gas, and natural gas condensate resources that exist beneath the 16 mi^2 area of the WIPP land withdrawal area and an additional one-mile wide study area around the WIPP site. Calculations were made for resources that are extensions of known, currently producible oil and gas resources thought to extend underneath the WIPP land withdrawal area with reasonable certainty (*probable resources*). Qualitative estimates were also made of oil and gas that may be present in undiscovered pools and fields beneath the WIPP land withdrawal area (*possible resources*). Possible resources were not quantified."

p. XI-2, INTRODUCTION;
" Oil and gas resources are typically divided into several categories (Potential Gas Committee, 1993; Energy Information Administration, 1994; **Figs. 1a, 1b**). For purposes of this report, five categories of resources are referred to: 1)cumulative production; 2) proved reserves; 3) probable resources (extensions of known pools); 4) undiscovered recoverable resources; and 5) unrecoverable resources. *Cumulative production* is the total volume of crude oil, natural gas condensate, and natural gas that have been withdrawn (produced) from a pool or well. *Proved reserves* are an estimated quantity of crude oil, natural gas condensate, or natural gas that analyses of geologic and engineering data demonstrate with reasonable certainty to be recoverable in the future from discovered oil and gas pools. Pools are considered proved that have demonstrated the ability to produce by either actual production or by conclusive formation tests (Potential Gas Committee, 1993), that is by drilling. This report restricts the definition of proved reserves to those producible resources identified as producible by existing wells (whether currently producing or abandoned). *Ultimate recovery* is the sum of cumulative production and proved reserves or probable resources for a pool or individual well.

The remainder of the resource base consists of *potential resources*. These can be summarized as hydrocarbons that can be inferred to exist, but have not yet been proven by drilling to exist. These can be grouped into: 1)*probable resources (extensions of known pools*; 2) *probable resources (new pools)*; 3) *possible resources*; and 4) *speculative resources*. These subdivisions of potential resources are differentiated on the basis of available geologic, geophysical, and engineering data and studies. *Probable resources (extensions)* consist of oil and gas in pools that have been discovered but have not yet been developed by drilling; their presence and distribution can generally be surmised with a high degree of confidence. *Probable resources (new pools)* consist of oil and gas that are surmised to exist in undiscovered pools within existing fields. *Possible resources* are less assured; they are postulated to exist outside of known fields but within productive stratigraphic units in a

productive basin or geologic province. *Speculative resources* are expected to be found in stratigraphic units, basins, or geologic provinces that have not yet been proved productive; estimates of speculative resources are the least assured of all resource estimates. *Unrecoverable resources* are dispersed in such minute accumulations or under such conditions that they can not be extracted with existing or foreseeable technology."

p. XI-11, DELAWARE MOUNTAIN GROUP;
" The Delaware Mountain Group (Guadalupian) is the major oil producing unit near the WIPP site (Fig. 14). It is subdivided into three formations (descending): Bell Canyon, Cherry Canyon, and Brushy Canyon. It was deposited basinward of the Getaway, Goat Seep, and Capitan shelf-margin and reef complexes (Fig. 15). The Delaware Mountain Group consists of sandstone, siltstone, shale, and minor (<5%) limestone, dolostone, and conglomerate (Harms and Williamson, 1988). IN areas adjacent to the WIPP site, production is obtained from the Cherry Canyon and Brushy Canyon Formations with most production coming from the Brushy Canyon.

The Bell Canyon Formation, at a depth of approximately 4500 ft, has been penetrated by most wells in the study area (Fig. 2). Most oil and gas exploratory wells drilled in the WIPP area prior to 1965 reached total depth in the upper or middle part of the Bell Canyon. Objectives were upper Bell Canyon sandstones. . . ."

p. XI-28, para 1;
" . . . stratigraphic traps and stratigraphic trends have not been fully defined and the Bone Spring remains inadequately explored and developed in the area. It is highly likely that numerous significant commercial accumulations of oil and associated gas (possible resources) remain to be found, especially in stratigraphic traps in off-structure areas. The Potash Area, in particular, has been poorly explored because of restrictions on drilling (see Ramey, this report, for a discussion of drilling restrictions in the potash area)."

p. XI-32, ATOKA GROUP;
" The Atoka Group is found within the WIPP site area at depths of 12,700 to more than 13,700 ft. The Atoka is composed of interbedded limestone, sandstone, and shale and generally mimics the Strawn Group in structural configuration. It ranges from 210 ft to more than 270 ft in thickness.

Although prolific production has been established within the nine-township study area from this unit in both limestone and sandstone reservoirs, all of the productive wells found within or adjacent to the WIPP land withdrawal area produce primarily from one narrow and thin (5 to 15+ ft) lenticular sandstone channel deposit. . . . Estimated ultimate recoveries push the per well average to over 8 BCF and 70 KBC. . . ."

p. XI-33, para 2;
" Based on subsurface mapping of this particular reservoir, it appears that there is excellent potential for similar Atoka production within the confines of the WIPP land

withdrawal area. . . ."

NRC (U.S. Nuclear Regulatory Commission). 1973. Design Spectra for Seismic Design of Nuclear Power Plants, Revision 1. Regulatory Guide 1.60, December 1973.

INTRODUCTION, p 1.60-1;
" Criterion 2, 'Design Bases for Protection Against Natural Phenomena,' of Appendix A, 'General Design Criteria for Nuclear Power Plants,' to 10 CFR Part 50, 'Licensing of Production and Utilization Facilities,' requires, in part, that nuclear power plant structures , systems, and components important to safety be designed to withstand the effects of earthquakes. Proposed Appendix A, 'Seismic and Geologic Siting Criteria,' to 10 CFR Part 100, 'Reactor Site Criteria,' would require, in part, that the Safe Shutdown Earthquake (SSE) be defined by response spectra corresponding to the expected maximum ground accelerations. This guide describes a procedure acceptable to the AEC Regulatory staff for defining response spectra for the seismic design of nuclear power plants. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position."

p. 1.60-2, col. 1, para. 3;
" The horizontal and vertical component Design Response Spectra in Figures 1 and 2, respectively, of this guide correspond to a maximum horizontal ground acceleration of 1.0 g. For sites with different acceleration values specified for the design earthquake, the Design Response Spectra should be linearly scaled from Figures 1 and 2 in proportion to the specified maximum horizontal ground acceleration."

Nuttli, O.W. 1973. Design Earthquakes for the Central United States. Miscellaneous Paper S-73-1, pp. 1-45. U.S. Army Waterways Experiment Station, Vicksburg, MS.

SUMMARY, p. ix;

" The earthquake risk problem in the Central United States, taken to be approximately the area east of the Rocky Mountains and west of the Appalachians, is discussed. The seismic history of the area is reviewed and is used to divide the area into various seismic regions.

A design earthquake, defined as the largest earthquake that can be expected to occur within an area, is specified for each of the three seismic regions. Specification of the design earthquake is accomplished by giving ground displacement, particle velocity, and acceleration values in hard rock as a function of distance from the earthquake, for three particular wave frequencies. The results are presented i graphical and tabular form.

A brief discussion of the effects of soil instability is included. The problem is of particular importance in the Mississippi and other major river valleys of the Central United States."

Palmer, A.R. 1983. "The Decade of North American Geology 1983 Geologic Time Scale." Geology, Vol. 11, No. 9, pp. 503-504.

p. 503;
" Preparation of the 27 synthesis volumes of *The Geology of North America* for the Decade of North American Geology (DNAG) is now in progress. In order to encourage uniformity among DNAG authors in the citation of numerical ages for chronostratigraphic units of the geologic time scale, an ad hoc Time Scale Advisory Committee was established by the DNAG Steering Committee in 1982. This advisory committee, consisting of Z.E. Peterman (Chairman) and J. F. Harrison, U.S. Geological Survey; R. I. Armstrong, University of British Columbia; and W. A. Berggren, Woods Hole Oceanographic Institution, was asked to evaluate numerical dating schemes that were either recently published or in press and to provide recommendations for the best numbers to use in preparation of a DNAG time scale. The chart on the opposite side of this page was developed from the recommendations of the Time Scale Advisory Committee."

The figure on the following page is taken from p. 504 of the referenced document.

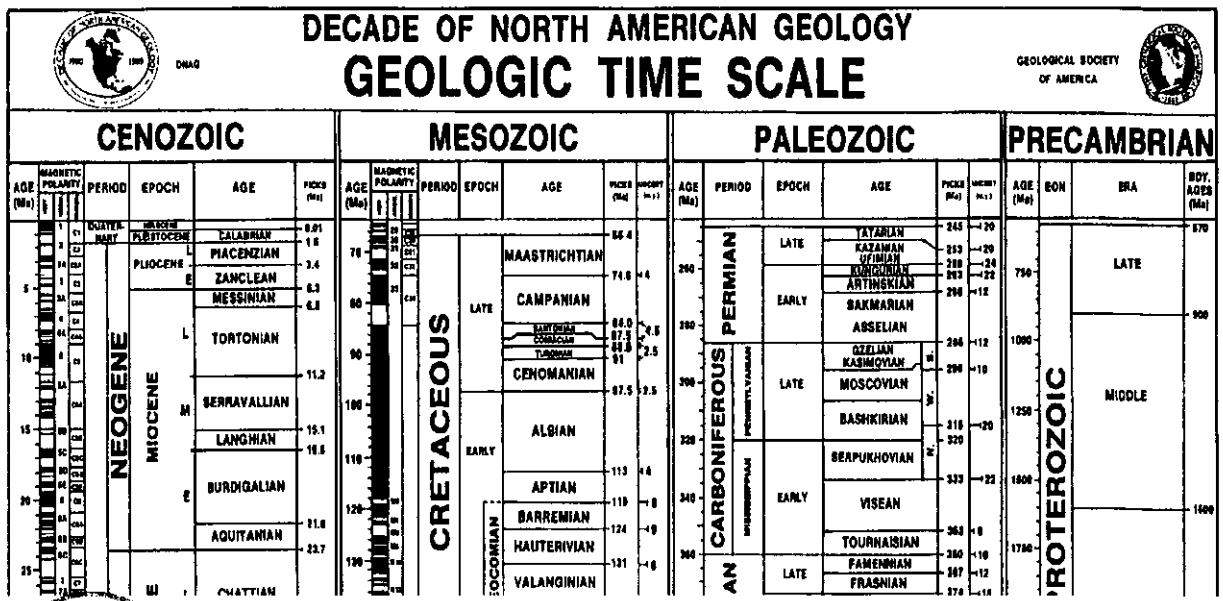
DECADE OF NORTH AMERICAN GEOLOGY
GEOLOGIC TIME SCALE
GEOLOGICAL SOCIETY OF AMERICA
CENOZOIC
MESOZOIC
PALEOZOIC
PRECAMBRIAN
AGE (Ma)
MAGNETIC POLARITY
PERIOD
EPOCH
AGE
PICKS (Ma)
QUATERNARY
NEOGENE
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
CALABRIAN
PIACENZIAN
ZANCLEAN
MESSINIAN
TORTONIAN
SERRAVALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
CRETACEOUS
LATE
EARLY
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
PERMIAN
CARBONIFEROUS
TATARIAN
KAZANIAN
UFIMIAN
KUNGURIAN
ARTINSKIAN
SAKMARIAN
ASSELIAN
GZELIAN
KASHIRIAN
MOSCOVIAN
BASHKIRIAN
SERPUKHOVIAN
VISEAN
TOURNAISIAN
FAMENNIAN
FRASNIAN
PROTEROZOIC
EON
ERA
BDY. AGES (Ma)
LATE
MIDDLE

Piper, A.M. 1973. Subrosion in and about the Four-Township Study Area near Carlsbad, New Mexico. Report to Oak Ridge National Laboratories, Oak Ridge, TN.

SCOPE AND ACKNOWLEDGEMENTS, p. 1;

" This paper concerns one aspect of the feasibility of storing wastes from the nuclear-fired power industry in bedded salt of the Salado formation near Carlsbad, New Mexico. The center of concern is a four-township study area--Ts. 21 and 22 S., Rs. 31 and 32 E.--which has been selected by the Oak Ridge National Laboratory as a candidate locality for a pilot repository. The paper is based wholly on prior investigations by others, and so is no more than an appraisal of information at hand. Figures 1 and 2 (in pocket) illustrate selected features in the vicinity of the study area.

The one aspect here considered is the vulnerability of the candidate area and storage horizon to future subrosion--specifically, to dissolution and removal of common salt and other evaporites by circulating ground water, also to other agents by which thickness, composition, texture, and structure of rock units may be modified in place. Principle among these other agents are: (1) subsidence or collapse of strata overlying a zone of dissolution; (2) volume expansion of anhydrite as it converts to gypsum in the presence of water, such expansion commonly shattering the texture of enclosing strata that are lightly loaded or merely inflating those strata if they are heavily loaded; (3) plastic flow of common salt under unequal load, tending to close voids created by dissolution; and (4) up-doming of strata as underlying anhydrite-bearing beds inflate or as salt flows.

Principles of dissolution are examined in another paper (Piper, 1973). Only the three general requirements are restated here, because they are misunderstood commonly. These are: (1) a continual source of unsaturated water, generally of land origin, either physically above or under a hydraulic head higher than strata of soluble evaporite; (2) an aquifer system passing from the water source to the soluble evaporite, and beyond to (3) a discharge area at the land surface, either local or remote, and either physically lower than, or under hydraulic head below, the particular evaporite zone. . . ."

Piper, A.M. 1974. The Four-Township Study Area near Carlsbad, New Mexico: Vulnerability to Future Subrosion. Report to Oak Ridge National Laboratories, Oak Ridge, TN.

SCOPE AND ACKNOWLEDGEMENTS, p. 1;

" In an earlier paper (Piper, 1973-b) the writer summarized information then available as to the present extent and prospective future progress of subrosion in and about a four-township study area near Carlsbad, New Mexico--specifically, Ts. 21 and 22 S., Rs. 31 and 32 E. This paper extends that summary according to additional information now at hand from recent, and current investigations by others. Both papers concern one aspect of storing wastes from the nuclear-fired power industry in bedded salt of the Salado formation.

The one aspect of concern has been the vulnerability of the four-township study area and the candidate storage horizon to future subrosion. The writer's earlier paper was reasonably definitive in regard to natural vulnerability from the west; the present paper seeks chiefly to assess vulnerability from the north, east, and south.

The writer must acknowledge his great indebtedness to . . ."

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3153. Westinghouse Electric Corporation, Carlsbad, NM.

EXECUTIVE SUMMARY, p 1;

" The Waste Isolation Pilot Plant (WIPP) project is a U. S. Department of Energy (DOE) research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States. This demonstration consists of two parts. First, about six million cubic feet of TRU waste will be emplaced in the thick bedded-salt deposits of the Salado Formation in southeastern New Mexico at a depth of about 2150 feet. Second, the WIPP will provide for research relative to the interactions of defense high-level waste with bedded salt, though all high-level waste will be removed prior to facility decommissioning.

A potential location was selected for the WIPP in the northern Delaware Basin of New Mexico, and three exploratory core holes were drilled (AEC-7, AEC-8, and ERDA-6; Figure 1). While drilling the third such hole (ERDA-6), substantial geologic structural deformation was noted, and brine and gas sufficiently pressurized to flow to the surface were encountered. The unpredictability of the geology led to relocation of the site to its present location in 1974 (Figure 1). Since relocation, an extensive site characterization program has been conducted, and the adequacy of the site has generally been demonstrated.

In 1981, an agreement was signed between the State of New Mexico, the DOE, and others which included several studies intended to address the State's concerns relative to the suitability of the proposed WIPP site. Some of these studies addressed an area of geologic interest north of the proposed site, and pressurized brine reservoirs in the Delaware Basin. The work was begun in October 1981 and included the reopening and testing of ERDA-6, and the deepening and testing of WIPP-12, an exploration borehole which also encountered pressurized brine and gas. This report provides an account of these studies.

These studies and preparation of the brine reservoir report were performed by the WIPP Technical Support Contractor (TSC), primarily by D'Appolonia Consulting Engineers, Inc. (a member of the WIPP-TSC) under subcontract to the Westinghouse Electric Corporation (the TSC prime contractor). Sandia National Laboratories, Albuquerque, N.M., provided critical review of the studies and report; the U. S. Geological Survey also made comments.

The occurrence of pressurized brine reservoirs in the Castile Formation (underlying the Salado Formation) of the Delaware Basin has been documented over the past 40 years by reports of reservoir encounters by hydrocarbon exploration drilling. In general, these reservoirs were known to be contained in fractured anhydrite with associated hydrogen sulfide gas and were thought to be related to antiforms in the Castile.

Various theories were advanced to explain the origin of reservoirs, which include dissolution of evaporites by recent ground waters, dehydration of gypsum to form anhydrite, entrapment of ancient seawater during evaporite deposition, and ancient dissolution and

reprecipitation of evaporite minerals. Should certain of these theories be correct, the suitability of the WIPP site could be in question. Thus, the purpose of this study was to determine the characteristics and origin of these reservoirs and evaluate their potential impact on the integrity and stability of the WIPP site.

Data used in the performance of this study were obtained from drilling and hydrological testing in boreholes ERDA-6" and WIPP-12 and from chemical analyses of samples of reservoir brine and gas collected at these two wells. Information was also obtained from a review of published and unpublished literature on the geology and hydrology of the basin. The principle data reviewed and analyzed in this report are contained in "Data File report - ERDA-6 and WIPP-12 Testing" (D'Appolonia, 1982, 1983)."

SUMMARY OF FINDINGS, p2, col 2, para 2;

" The analyses and interpretations by three disciplines -- geology, hydrology, and chemistry -- have been integrated to form a model of brine reservoir genesis, and to assess the current and future status of brine reservoirs as they relate to the WIPP site. The development of the brine reservoirs began in the Permian Period about 235 million years before present. The Castile evaporites, consisting primarily of anhydrite and halite as shown in Figure 2, were deposited at that time. During the initial chemical sedimentation (or precipitation) period, the solids were poorly consolidated and highly porous. Much or all of this pore space was filled with Permian seawater that had been enriched in dissolved solids, oxygen-18, and probably deuterium by evaporation. As sedimentation in the basin continued, the seawater became trapped as an interstitial fluid between individual grains of anhydrite and halite. As compaction increased, grain boundary accretion of halite probably surrounded some of the pore fluids and gave rise to fluid inclusions in halite crystals. Examination of ratios of major and minor element concentrations in the brines leads to the conclusion that the reservoir brines originated from ancient seawater with no evidence for fluid contribution from present meteoric waters."

p. 4, col. 2, para. 2;

" The ERDA-6 and WIPP-12 brine reservoirs, which are located in fractured anhydrites above thickened halite (Figure 2), may be modeled as fractured heterogeneous systems. The volumes of the ERDA-6 and WIPP-12 brine reservoirs are estimated, within an order of magnitude, to be about 630,000 barrels and 17,000,000 barrels, respectively. The vast majority of brine is stored in low-permeability microfractures, and therefore is not readily released in the event the reservoirs are intercepted. In fact, less than three percent of the reservoir fluids would flow unassisted to the surface if encountered during exploration drilling. About five percent of the overall brine volume in each reservoir is stored in large, open fractures.

SUMMARY OF FINDINGS, p 5, col 1, para 2;

" At present, the Castile brine reservoirs appear to be isolated. There is no evidence to suggest hydraulic or chemical connection between reservoirs, or between reservoirs and other

ground-water systems, either at the present or in the past. The persistence of high and different hydraulic heads in Castile brine reservoirs for at least one million years (the age of the most recent tectonic activity) is the principle hydrologic evidence for their isolation. The four Castile brine reservoirs for which accurate data are available show differences in hydraulic head ranging from 280 to 871 feet of water. Similarly, measured heads in the brine reservoirs are at least 1330 feet higher than heads in aquifers in the subjacent Delaware Mountain Group, and at least 1530 feet higher than heads in the overlying Rustler Formation (Figure 4). Hence, there is no physical mechanism for the brine reservoirs to receive recharge from these underlying and overlying units."

p 5, col 1, para 3;

" As regards chemical mechanisms, the gas and brine chemistries of the two reservoirs are distinctly different from each other and from local ground waters. For example, large differences in the reservoir gas compositions exist between WIPP-12 and ERDA-6. The gas in WIPP-12 is composed mostly of methane and has little or no carbon dioxide. The ERDA-6 reservoir contains substantial quantities of carbon dioxide, and more hydrogen sulfide than WIPP-12. Differences observed in the brine composition include boron, bromide, magnesium, potassium, and lithium concentrations. Connection between reservoirs would eliminate or mitigate these differences, especially with respect to the highly mobile gases. Accordingly, if connected in the past, the current brine (and associated gas) compositions of the two reservoirs would be more similar.

In addition to being isolated, the brines appear to be in chemical equilibrium with their surroundings, and they are stagnant. For example, the brines are chemically saturated with the primary phases of the reservoir host rock (anhydrite and calcite). WIPP-12 brine also appears to be saturated with halite, the principle phase of the confining strata. Furthermore, calculations indicate bulk system equilibrium among solid, liquid, and gas.

In summary, the brine reservoirs appear to be local, isolated features that have reached equilibrium with their environment. Evidence for long-term hydraulic and chemical isolation includes:

- Hydraulic heads that are substantially different from reservoir to reservoir and higher than the heads of local ground waters.
- The containment of gas by the reservoirs.
- Brine and associated gas chemistries that differ from reservoir to reservoir.
- Geographic separation and non-uniform distribution of reservoirs, i.e., extensive drilling has taken place in this area, but only a few wells have intercepted pressurized brines. There is no evidence for a continuous, extensive aquifer in the Castile.
- Bulk chemical equilibrium between the brine, gas, and reservoir rock in the ERDA-6 and WIPP-12 reservoirs."

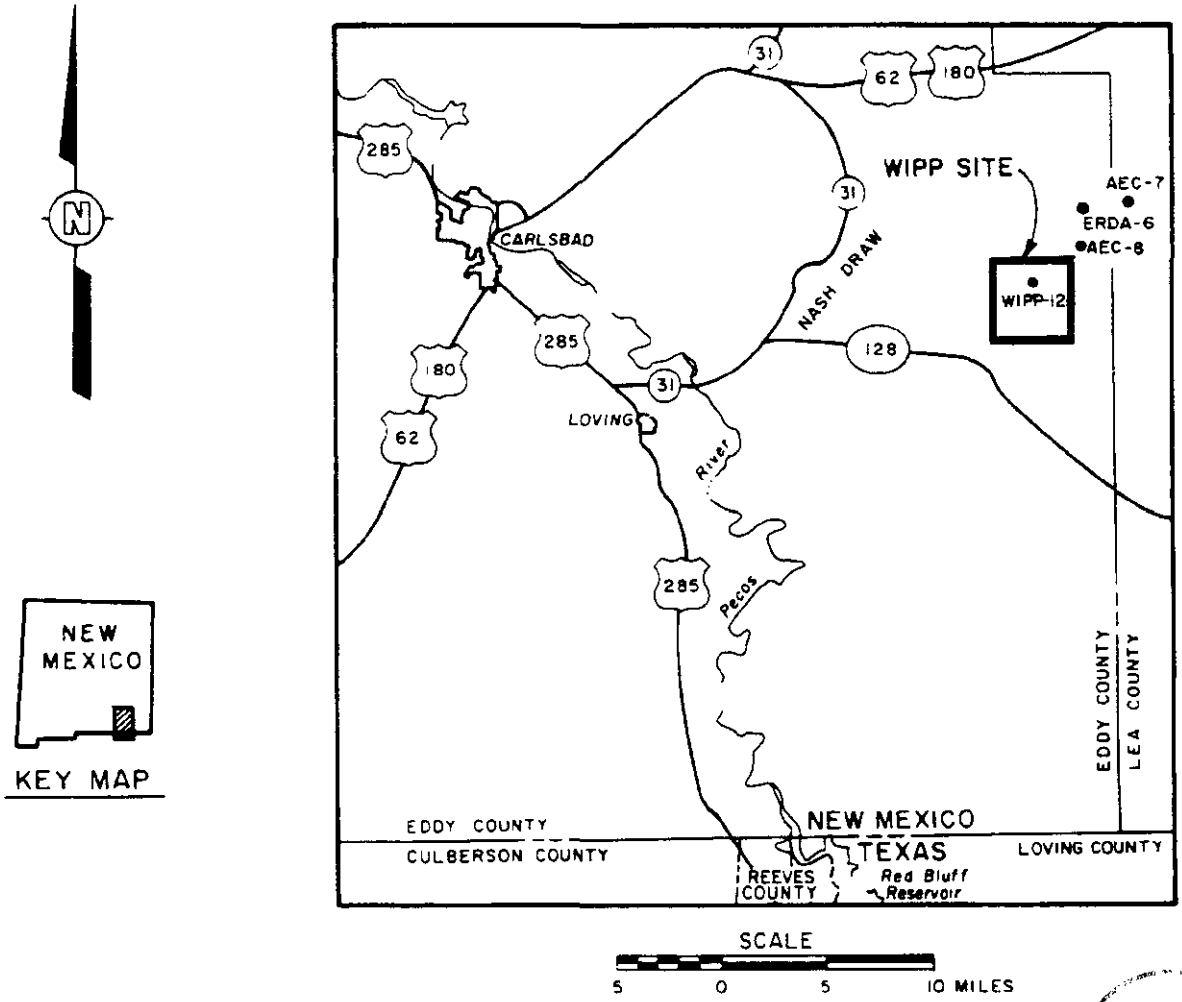

Figure 1 — Location of WIPP Site and Boreholes AEC-7, AEC-8, WIPP-12 and ERDA-6

p. H-45, Reservoir Pressure;

" The maximum pressure measured for the Erda-6 brine reservoir at the wellhead is 604 psig. Extrapolated to a reservoir depth of 2711 feet below ground surface with a fluid pressure gradient of 0.5326 psi/ft of brine, this corresponds to a reservoir pressure of 2048 psig. As shown in Figure H-12, this pressure corresponds to a potentiometric surface at 5551 feet above mean sea level when calculated for the specific gravity of pure water. This is the highest hydraulic head of any ground-water body known in the Delaware Basin.

Following the end of testing in November 1981 and a BOP change in February 1982, the wellhead shut-in pressure at ERDA-6 rose steadily as a result of both reservoir recovery and gas cap formation in the wellbore. A series of apparent gauge-related malfunctions have left the pressure data collected before and after the gas cap release on March 8, 1983 of uncertain validity. The highest pressure measured before the gas cap release was 558 psig on March 5, 1983. Because of a possible fluid leak from a diaphragm assembly attached to the gauge, this value may be too low. The first fully reliable pressure measurement made after the gas cap release was 552 psig on March 19, 1983."

p. H-52, Reservoir Pressure;

" The maximum pressure for the WIPP-12 reservoir at the wellhead is 208 psig. Extrapolated to a reservoir depth of 3017 feet below ground surface with a fluid pressure gradient of 0.5378 psi/ft of brine, this corresponds to a reservoir pressure of 1831 psig. As shown in Figure H-12, this corresponds to a potentiometric surface at 4680 feet above mean sea level calculated for the specific gravity of pure water. Section 3.4.1 contains a detailed discussion of hydraulic heads throughout the Delaware Basin.

Following the end of testing in June 1982, the wellhead shut-in pressure at WIPP-12 rose steadily as a result of both reservoir recovery and gas cap formation in the wellbore. Just prior to releasing the gas cap on March 7, 1983, the wellhead pressure was about 175 psig. On March 7, 1983, approximately 173 ft^3 of gas (at STP) were released from the well (D'Appolonia, 1983). Under the pressure (175.2 psig) and temperature (58°F) conditions then existing in the wellbore, this gas would have occupied a volume of about 14 ft^3, corresponding to maximum gas cap thickness of about 33 feet. Some minor fraction of the gas released probably came from gas exsolution from the brine during the release, however, and is not representative of gas cap volume in the wellbore. From March 8 through at least March 20, 1983, the wellhead pressure at WIPP-12 remained steady at about 162 psig. After more than nine months of recovery, the WIPp-12 reservoir should be near equilibrium. Future increases in wellhead pressure will be predominantly the result of renewed gas cap formation."

Powers, D.W., and Holt, R.M., 1995. Regional Geological Processes Affecting Rustler Hydrogeology. Prepared for U.S. Department of Energy by IT Corporation, Albuquerque, NM.

5.3 History of LOading and Unloading of the Culebra, p. 75, para. 3;
" The loading and unloading history of the Culebra since deposition has been estimated as overburden based on inferences from various local and regional geological trends and data (Figure 33). The history is presented with several alternatives, depending on the inferences that are drawn, ranging from minimal to upper bound estimates. The estimates are made with a reference point and depth to the Culebra at the air intake shaft (AIS) (Holt and Powers, 1991)."

NOTE: Figure 6, Well Control Base Map is included on the following page.

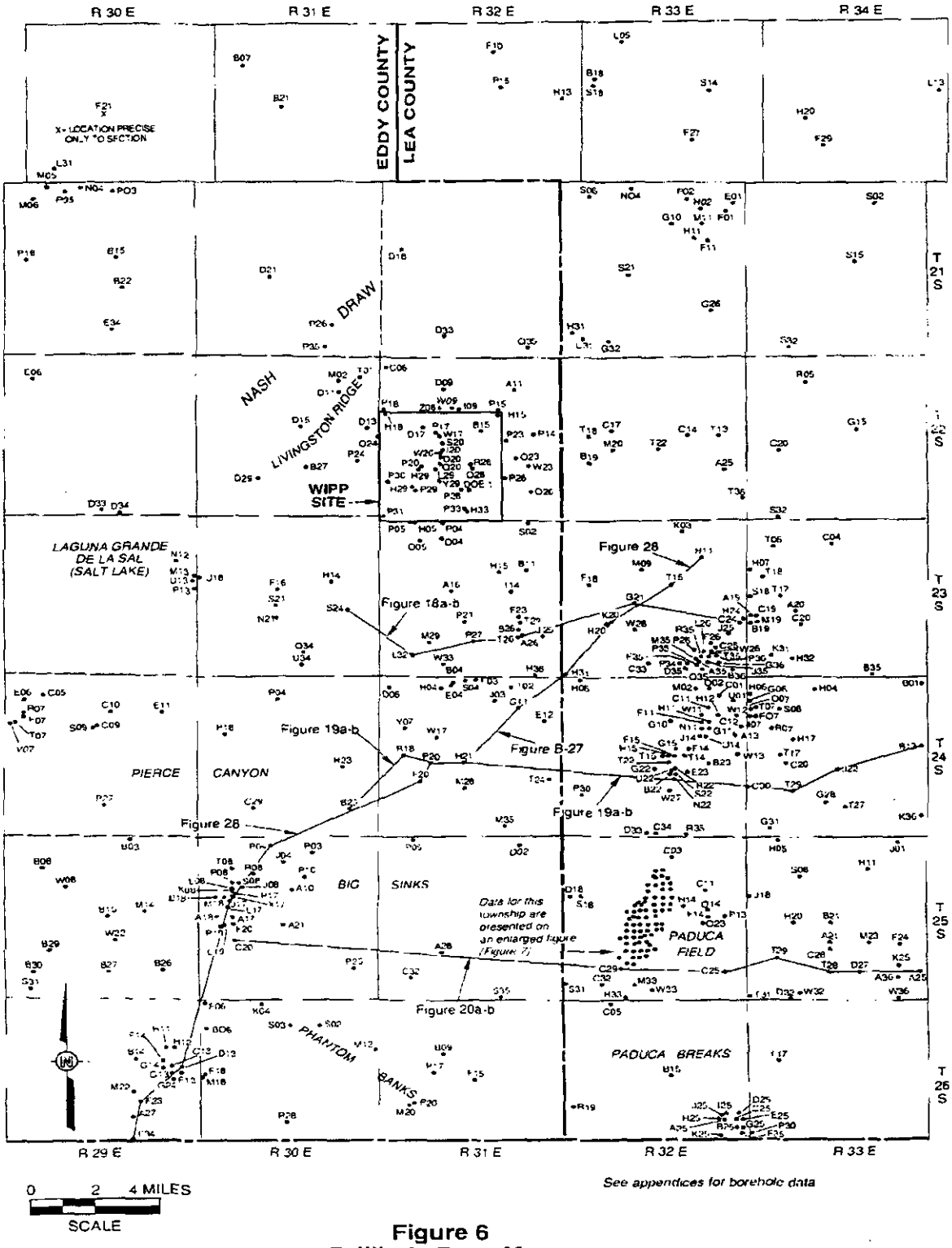

Figure 6
Drillhole Base Map

Powers, D.W., and Holt, R.M. 1993. "The Upper Cenozoic Gatuña Formation of Southeastern New Mexico." In Carlsbad Region, New Mexico and West Texas, New Mexico Geological Society, Forty-Fourth Annual Field Conference, Carlsbad, NM, October 6-9, 1993. D.W. Love et al., eds., pp. 271-282. New Mexico Geological Society, Roswell, NM.

ABSTRACT, p 271;

" The Gatuña Formation of southeastern New Mexico has been studied in the field for two landfill projects and the Waste Isolation Pilot Plant project. Shafts, drilling and field mapping reveal the distribution, thickness and sedimentary features of the unit in an area where it was poorly known or assigned to other units. The Gatuña is at least 300 ft thick in the study area. The formation was deposited in the north and east as clastic beds ranging from conglomerates to laminar claystones. Fining upward cycles are common, though depositional features and facies associations are consistent with braided river/stream environments, not meandering rivers. Laminar and thinly bedded siltstones to claystones were deposited in flood plain to playa environments. Pedogenic features superimposed on many fining upward cycles include soil fractures, slickensides, MnO_2, illuviated clay, bioturbation, probable ped structures and desiccation cracks. The upper Gatuña more consistently includes pedogenic development. Beds of poorly indurated 'orange' sand, consisting of rounded and well-sorted grains, are interpreted as eolian deposits. From southern Nash Draw to Orla, the Gatuña is fine-grained and gypsoferous, including displacive crystals and probable subaqueous deposits. These outcrops represent low energy environments, including playas, which were near local base level. The age of the upper Gatuña is reasonably constrained by the Lava Creek B ash (0.6 Ma) within the Gatuña along Livingston Ridge. The age of basal deposits is poorly or not constrained. An ash within probable Gatuña near Orla, TX, is about 13 Ma based on both radiometric and geochemical data. The Gatuña represents an important piece of the geological history of southeastern New Mexico. Further studies could include efforts to better determine the age of the formation; to obtain paleontological data; and to map Gatuña structural relationships to older and younger beds in detail to determine the timing of and spatial evidence for, dissolution of evaporites and collapse of overlying beds, including the Gatuña."

Further discussion, p. 281, col. 1, para. 3;

" Thick deposits at the eastern part of Pierce Canyon at one time represented a stacked sequence of at least 300 ft prior to slumping and rotation. The base of this section is at an elevation of about 3050 ft. This implies that the pre-rotation top of Gatuña was at an elevation of at least 3350 ft. The top of Gatuña Canyon deposits are at about 3400 ft. as are very tin deposits of Gatuña at the WIPP site. Given the suggestion (Holt and Powers, unpubl. report to U. S. Department of Energy, 1988) that there has been very little, if any, dissolution of underlying halite at the WIPP site, the elevations suggest a general pre-Mescalero high point of Gatuña deposition."

Powers, D.W., Sigda, J.M., and Holt, R.M. 1996. "Probability of Intercepting a Pressurized Brine Reservoir Under the WIPP." Unpublished report, July 10, 1996. Albuquerque, NM: Sandia National Laboratories. (Copy on file in the SWCF.)

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Pratt, H.R., Stephenson, D.E., Zandt, G., Bouchon, M., and Hustrulik, W.A. 1979. Earthquake Damage to Underground Facilities. Proceedings of the 1979 RETC, Vol. 1, AIME, Littleton, CO.

ABSTRACT;

" The potential seismic risk for an underground facility is considered in the evaluation of its location and design. The possible damage resulting from either large-scale displacements or high accelerations should be considered in evaluating potential sites of underground facilities.

Scattered through the available literature are statements to the effect that below a few hundred meters shaking and damage in mines is less than at the surface; however, data for decreased damage underground have not been completely reported or explained. In order to assess the seismic risk for an underground facility, a data base was established and analyzed to evaluate the potential for seismic disturbance.

Substantial damage to underground facilities is usually the result of displacements primarily along pre-existing faults and fractures, or at the surface entrance to these facilities. Evidence of this comes from both earthquakes as a function of depth is important in the evaluation of the hazard to underground facilities. To evaluate potential displacements due to seismic effects of block motions along pre-existing or induced fractures, the displacement fields surrounding two types of faults were investigated.

Analytical models were used to determine relative displacements of shafts and near-surface displacement of large rock masses. Numerical methods were used to determine the displacement fields associated with pure strike-slip and vertical normal faults.

Results are presented as displacements for various fault lengths as a function of depth and distance. This provides input to determine potential displacements in terms of depth and distance for underground facilities, important for assessing potential sites and design parameters."

EXISTING DATA BASE ON EARTHQUAKE DAMAGE, p. 23, para. 4, line 2;

" Observations from 71 tunnels responding to earthquake motions were compared. Dynamic behavior was compared with intensity and magnitude as a function of distance. The studies compared calculated accelerations at the ground surface with tunnel damage and showed that the tunnels are less susceptible to damage than surface structures or facilities. Peak accelerations at the surface of less than 0.2 gravity (g) did not damage the tunnels; between 0.2 and 0.5 g, damage was only minor; and damage was significant only above 0.5 g (Figure 2). [2,3] Most of the damage was located near a portal."

Ramey, D.S., 1985. Chemistry of Rustler Fluids. EEG-31. New Mexico Environmental Evaluation Group, Santa Fe, NM.

EXECUTIVE SUMMARY, p. ii;

" Water chemistry determinations were performed by the U. S. Geological Survey on water samples collected from the three fluid-bearing zones of the Rustler Formation from 20 testholes at and adjacent to the WIPP from 1976 to 1980. Analysis of the data demonstrates that the three fluid-bearing zones are chemically separate from one another at the WIPP site, but progressively merge towards the west into Nash Draw.

The fluids present at the Rustler-Salado contact approach saturation with respect to sodium chloride. Magnesium replaces sodium as the prevalent cation east of the WIPP site; this boundary may represent the approximate limit of salt dissolution in the Rustler Formation.

Three zones (areally) of differing predominant chemical constituents are present in the Culebra Dolomite. Groundwater flow paths cross these zones, changing the Culebra water from a sodium chloride brine to a moderately saline calcium sulfate water. The Culebra waters are undersaturated with respect to halite and have the capacity of dissolving more halite from the Rustler or the Salado formations.

The major ions present in the fluids in the Magenta Dolomite are predominantly sodium and chloride. A few wells have sulfate, rather than chloride as the predominant anion.

Additional work is needed to improve the degree of understanding of the chemical characteristics of the fluids in the Rustler Formation especially with regard to the Culebra Dolomite. More information is needed to understand the chemical changes that occur along proposed groundwater flow paths of the Culebra. It is important that the current groundwater chemistry sampling program obtain representative and replicable groundwater quality data."

Section 6. CONCLUSIONS AND RECOMMENDATIONS, p 41; para 2;

" Three zones of differing predominant chemical constituents are present in the Culebra Dolomite. These zones do not support previously reported directions of water movement and there appears to be an inconsistency between the apparent chemistry and the previously reported flow paths. The Culebra waters are undersaturated with respect to halite and have the capacity of dissolving more halite from the Rustler, or if a connection is produced, from the Salado or repository horizon.

Rawson, D., Boardman, C., and Jaffe-Chazan, N. 1965. The Environment Created by a Nuclear Explosion in Salt. PNE-107F. U.S. Atomic Energy Commission Plowshare Program, Project Gnome, Carlsbad, NM.

ABSTRACT, p 5;

" The Gnome event, a 3.1 $\pm$ 0.5 kiloton nuclear explosion, was conducted at a depth of 361 m in bedded rock salt near Carlsbad, New Mexico. This explosion melted approximately 3.2 x 10^6 kilograms of rock salt and produced a standing cavity with a volume of about 27,200 cubic meters. The cavity has a pronounced bulge at its equator. The development of this asymmetry was controlled by the preshot character of the rock: horizontal weaknesses in the form of bedding planes and clay layers. The molten salt mixed with the condensing radioactive debris and about 11.6 x 10^6 kg of rock from the cavity walls, to form a radioactive 'puddle' of melt and rock breccia at the base of the cavity. This zone is blanketed by about 13.6 x 10^6 kg of rubble that resulted primarily from ceiling collapse, thus shielding the 'puddle' so that when personnel entered the cavity, gamma radiation levels were rarely in excess of 20 mR/hr.

During the dynamic cavity growth period of about 100 msec, radial cracks propagated closely behind the outgoing compressional shock wave. Molten rock had not yet mixed well with vaporized fission products and consequently melt injected into these cracks was not radioactive or slightly so. The maximum observed extent of these fractures, measured from the center of the explosion, is 40 m laterally, 38 m above and 25 m below.

Leakage of radioactive gases through the rock is detectable by the presence of radiation damaged salt. Generally, there was no evidence of leakage beyond 40 m and the maximum observed extent at 65.5 m is thought to be associated with fracturing to a natural cavity.

Close-in stemming failed and cavity gases vented dynamically into the emplacement drift. Back-up stemming confined the dynamic venting but allowed the low pressure release of steam and gaseous fission products. The formation of radial cracks and bedding plan partings, coupled with the emplacement configuration to accommodate a neutron-physics experiment, caused the stemming failure.

Asymmetry of rock displacements, fractures observed, and the permanent surface displacements indicate localized uplift of the rock between the cavity and the ground surface. It is interpreted that this uplift was caused by spall of the upper few hundred feet of rock which momentarily decreased the overburden pressure. The cavity pressure then exceeded overburden pressure and the cavity expanded preferentially upwards.

A zone of increased permeability was defined to extend at least 46 m laterally and 105 m above the point of the explosion. The permeability increase was established by complete circulation loss of the drill fluid and is primarily associated with motions and partings along bedding planes - the major preshot weakness in the rock."

1.1 BACKGROUND, p 8;

" Project Gnome was the first scientific experiment with nuclear explosives designed to

provide information pertaining to the non-military uses of these explosives. A 3.1 ± 0.5 kt nuclear device was detonated at a depth of 361 m underground in bedded salt on December 10, 1961. The test site for Project Gnome was located about 48 km southeast of Carlsbad, New Mexico."

Register, J.K. 1981 Rubidium-Strontium and Related Studies of the Salado Formation, Southeastern New Mexico. SAND81-7072. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. vii;

" The Salado Formation, a member of the Ochoan Series, is a bedded salt deposit found in the Delaware Basin of southeastern New Mexico and west Texas. It is comprised primarily of halite and sylvite with minor amounts of sulfate minerals. Rubidium-strontium age determination of the evaporite minerals in the Salado indicate an age of final equilibration of 214 $\pm$ 15 m.y. This age is fairly consistent with the geologic age of the formation, precluding substantial alkali-alkaline earth migration since deposition. Polyhalite and anhydrite samples from the Salado give $^{87}Sr/^{86}Sr$ values of about .7078, which are consistent with reported values for Permian seawater. The REE and trace element concentrations of the polyhalite and anhydrite samples are very low, reflecting the composition of seawater.

Rubidium-strontium age determinations of the clay minerals extracted from the salt suggest a minimum age of 390 $\pm$ 77 m.y. This age probably represents the minimum age of the provenance of the clay minerals. The REE and trace element concentrations as well as the mineralogy of the clay minerals indicate a detrital origin for the clay minerals with some clay-brine interaction. Clay minerals seem generally depleted in the light REE (relative to NAS) which most likely were replaced by Ca^{2+} and Na^{+} from the evaporitic brines."

Register, J.K., and Brookins, D.G. 1980. "Rb-Sr Isochron Age of Evaporite Minerals from the Salado Formation (Late Permian), Southeastern New Mexico." Isochron/West No. 29, pp. 39-42.

p. 39;

" The bedded evaporites of southeastern New Mexico have been extensively studied in conjunction with potash deposit exploration, and, more recently, for consideration for a Waste Isolation Pilot Plant (WIPP) for radioactive waste disposal. An important facet of the latter study is the chemical and isotopic integrity of the evaporite minerals. Experience elsewhere with evaporite minerals (see discussion in Brookins and others, 1980) suggests post-formational, open-system conditions resulting in anomalously young ages for both halide and sulfate minerals by the K-Ar and Rb-Sr methods. Many of these young dates elsewhere (i.e. Federal Republic of Germany) have been attributed to metamorphic events or, alternatively, to both episodic and/or continuous loss of radiogenic ^{40}Ar and ^{87}Sr by unspecified, though subtle, events. Tremba (1969) and Bodine (1978) have suggested episodic and continuous recrystalization events for the southeastern New Mexico evaporites.

It is the purpose of this report to present our Rb-Sr isochron findings for 41 samples including sylvite-halite rich mixtures, polyhalite-rich samples, and anhydrites. The locations are given in Table 1, the data in Table 2, and the mineralogy in Table 3. Figure 1 shows the isochron. Sample procedures are given in Register (1979). The decay constant of 1.42 x $10^{-11}y^{-1}$ was used, and the York (1969) method for isochron construction was employed."

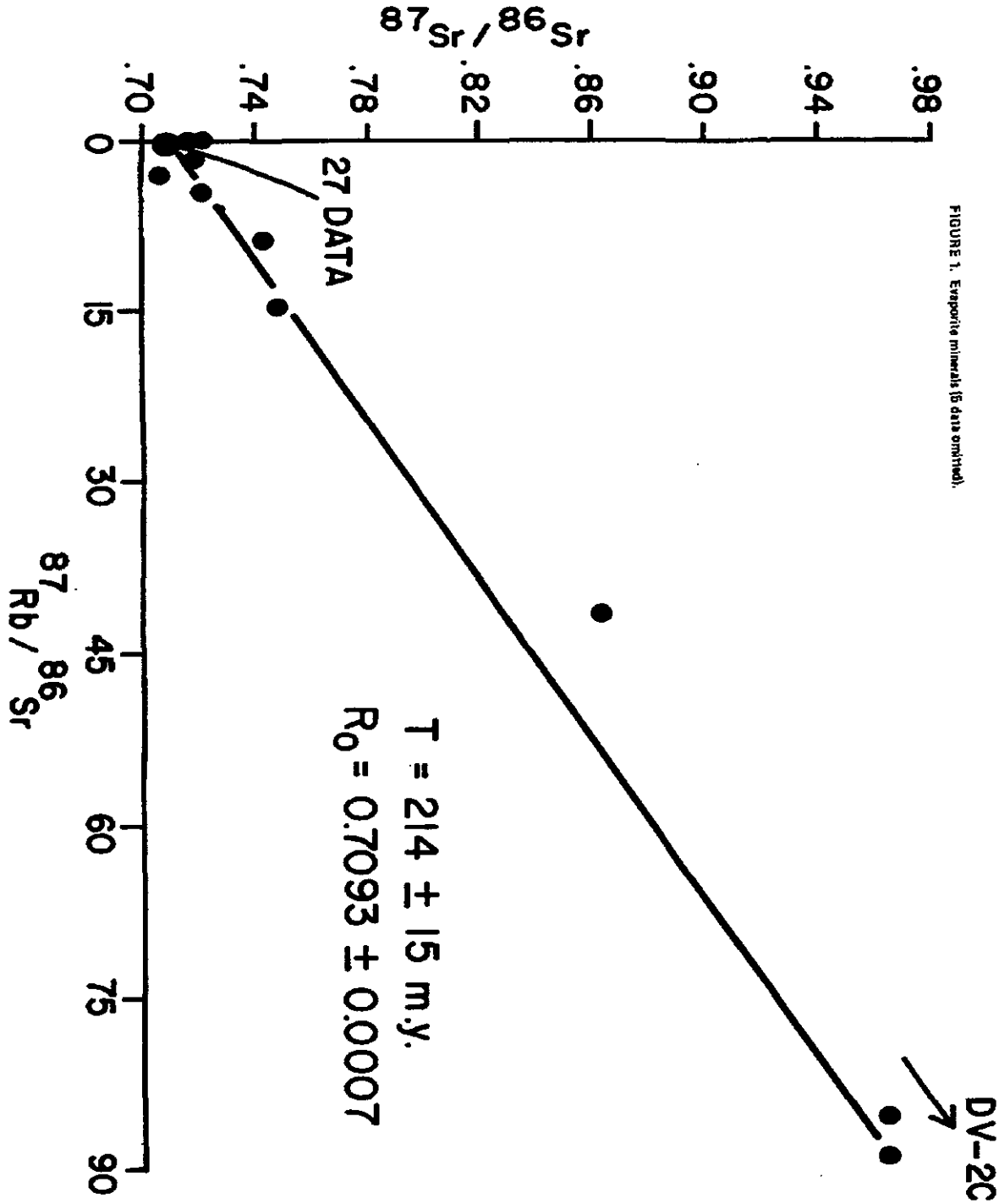

FIGURE 1. Evaporite minerals (6 data omitted).

Reiter, M. Barroll, M.W., and Minier, J. 1991. "An Overview of Heat Flow in Southwestern United States and Northern Chihuahua, Mexico." In Neotectonics of North America, D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 457-466. Geological Society of America, Boulder, CO.

The Rio Grande rift and northern Chihuahua, Mexico, p. 463, col. 1, para. 2;
" In the southern part of the Rio Grande rift there are a few heat-flow measurements and estimates that are intermediate in value (about 70 to 80 mW m_{-2}); most of the data are above the average heat flow (89 mWm_{-2}) for the entire Basin and Range Province (Fig. 7, bottom; see also Plate 1 in Reiter and others, 1986). Between Socorro and Las Cruces there are eight sites where the heat-flow estimates are about 90 to 100 mW m_{-2}. Four of the sites are located in the northern part of the Jornada del Muerto, north of the Jornada Basin. The other four sites are scattered widely. Higher heat-flow estimates (117 to 135 mW m_{-2}) are also made at sites scattered over the region from Socorro to Las Cruces. From these data it is suggested that the regional or background heat flow for the rift area between Socorro and Las Cruces is about 95 mW m_{-2}, a value that closely agrees with the interpretation of previous data by Decker and Smithson (1975). It is also interesting to note that the mean of 15 measurements in extreme southwest New Mexico is 94 $\pm$ 21 mW m_{-2}. Some of the sites with higher heat-flow estimates in the southern Rio Grande rift (117 to 135 mW m_{-2}) are near large normal faults that may act as conduits for hydrothermal circulation to enhance geothermal gradients; but again the actual cause of the elevated geothermal gradients is generally ambiguous . . ."

Richardson, G.B. 1904. "Report of a Reconnaissance of Trans-Pecos Texas, North of the Texas and Pacific Railway." Texas University Bulletin 23. Var Boeckmann-Jones Company, Austin, TX.

p. 43, para 4;
" The Castile gypsum outcrops in a belt between the Delaware Mountains and Rustler Hills, the width of which averages about 15 miles, though at the New Mexico-Texas boundary it is about 30 miles. This gypsum belt begins about 15 miles north of the railroad and extends into New Mexico. Within Texas the gypsum outcrops over 600 square miles. The name of the formation is derived from Castile Spring which is in the midst of the gypsum about 12 miles south of the State boundary."

p. 44, para 2;
" RUSTLER FORMATION.--The Rustler formation consists of a fine-textured white magnesium limestone and less abundant sandstone. The formation occurs in the Rustler Hills, in the dissected southwestern extension of the Rustler Hills between Cottonwood and Hurd's Pass "draws," and in a few isolated areas west of the hills."

Richter, C.F. 1958. Elementary Seismology. W.H. Freeman & Co., San Francisco, CA.

Construction of a Scale--First Form, p. 340;

" Of two earthquakes having the same hypocenter and recorded at the same stations, the larger should write larger seismograms at any one station. If the epicenters differ, the smaller shock may be so much closer to a given station that it writes larger seismograms there. Accordingly, the general procedure is first to determine the epicenter for each shock and then to plot the maximum ground motion at each station as ordinate with the corresponding epicentral distance as abscissa. Of two curves thus plotted for different earthquakes, one will probably be higher than the other, indicating that it represents the larger event.

Calculation of maximum ground motion calls for careful application of the principles given in Chapter 15. For the immediate practical purpose in southern California, considerable simplification was possible. All the stations used were equipped with torsional seismometers designed to have the same constants: $T_0 = 0.8$ second, $V = 2800$, $h = 0.8$. They should have had the same magnification for ground motion of the same character. For this reason, the plots were made using not computed ground motion but trace amplitudes in millimeters and tenths as measured directly on the seismogram; this method materially reduces working time when considering the numerous local earthquakes. Amplitudes were plotted on a logarithmic scale; since the measurements ranged from 0.1 millimeter to 10 to 12 centimeters, this gave a more manageable chart than a linear scale. Moreover, the results could now be stated numerically.

Figure 22-2 shows logarithmic plots for the data of observed earthquakes. The representative curves are roughly parallel to each other and to the dashed curve which is drawn at an arbitrary level. If this parallelism were exact, the difference between the logarithms of amplitudes of any two given shocks would be independent of distance; the amplitudes themselves would be in constant ratio. We could define a quantity M, to be called magnitude given by

$$M = \log A - \log A_0 \qquad (1)$$

where A is the recorded trace amplitude for a given earthquake at a given distance as written by the standard type of instrument, and A_0 is that for a particular earthquake selected as standard. The magnitude is thus a number characteristic of the earthquake and independent of the location of the recording stations.

The term magnitude was selected by analogy with the corresponding usage in astronomy. The scale of star magnitudes is also logarithmic, though on a less simple basis; in a sense it is reversed, since the greater the magnitude the fainter the star.† The earthquake magnitude scale follows the more obvious course of assigning the larger number to the larger earthquake. Logarithmic scales are in use in other fields; examples are the decibel scale in acoustics and the pH scale for hydrogen-ion concentration.

Three arbitrary choices enter into the definition of M: (1) the use of a particular type

of seismometer with specified constants; (2) the use of ordinary logarithms to the base 10; (3) selection of the standard shock whose amplitudes are represented by A_0. This standard shock has also been called the zero shock, since, if $A = A_0$, $M = 0$. This clearly does not mean ' no earthquake'; a small earthquake might conceivably record with amplitudes smaller than those of the standard shock, which would give it a negative magnitude. The zero level was intentionally chosen low enough to make the magnitudes of the smallest recorded earthquake positive.

The zero level A_0 can be fixed by naming its value at a particular distance. This was taken to be one thousandth of a millimeter at a distance of 100 kilometers from the epicenter;"

Robinson, T.W., and Lang, W.B. 1938. "Geology and Ground-Water Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal, New Mexico, with Special Reference to the Salt Content of the River Water." Twelth and Thirteenth Biennial Reports of the State Engineer of New Mexico for the 23rd, 24th, 25th, and 26th Fiscal Years, July 1, 1934 to July 30, 1938, Sate Engineer, Santa Fe, NM. WPO 37942.

INTRODUCTION, p 79;

" At the request and in cooperation with the State Engineer of New Mexico, a study of ground-water conditions in the Pecos River Valley southeast of Carlsbad, Eddy County, New Mexico, has been under way since the spring of 1937. The results of that study are presented in this report. The area involved lies largely in Townships 21, 22, 23 and 24 south, Ranges 26, 27, 28 and 29 east, New Mexico principle meridian. (See plate 1). Intensive work was done chiefly in the vicinity of the Laguna Grande de la Sal and the area lying between it and the Malaga Bend of the Pecos River, about five miles south. The area is crossed by the Pecos River flowing southeastward from Carlsbad. During the growing season, the entire flow of the Pecos River above Carlsbad is normally diverted for irrigation at Lake McMillan and Lake Avalon. During this period the Pecos River from Carlsbad south is fed chiefly by large springs. The largest spring, known as Carlsbad Spring, is located in the river channel just below Lake Avalon. The Black River enters the area from the west and flows eastward to its confluence with the Pecos River northeast of Malaga. It is also spring-fed, deriving most of its water from Blue Spring and Castle Spring, near Black River village. The drainage pattern is well developed on the west, and during rainy periods many normally dry arroyos and draws discharge flood water into the Pecos River. Drainage from the east is by poorly developed draws which carry water to the Pecos only during exceptionally heavy rainfall. A prominent feature east of the river is Laguna Grande de la Sal, which is a shallow salt lake in a playa covering about 3½ square miles.

Carlsbad, the largest town in the area and the county seat of Eddy County, had a population of 3,708 in 1930. However, owing largely to the development of the potash mines located about 20 miles east, the population in 1938 is about double that of 1930. Loving, located about 12 miles south, and Malaga, about 18 miles south of Carlsbad, each had less than 1,000 inhabitants in 1930. Carlsbad is served by the Atchison, Topeka, and Santa Fe Railroad and by main highways leading north to Roswell, New Mexico, southwest to El Paso, Texas, south to Pecos, Texas, and east to Hobbs, New Mexico.

Cotton and hay are raised in the irrigated section along the Pecos River, while cattle, sheep and goat raising predominate in the unirrigated upland areas to the east and west. The principle mineral industry is the mining and refining of potash. A large number of tourists are attracted annually to the famous Carlsbad Caverns, located about 25 miles southwest of Carlsbad, near the highway leading to El Paso, Texas.

A group of farmers who pump water from the river for irrigation report that in recent years the water, because of its salinity, has been injurious to their cotton crop. In September 1932 the U.S. Potash Company began operations, using the Laguna Grande de la Sal as a disposal area for the waste brine from their potash refining operations. The reported

difficulty with salt, shortly after refinery operations began, naturally cast suspicion on the brine in the Laguna Grande. There is no visible outlet from the Laguna Grande, and therefore the problem arose as to whether the lake brine may be percolating underground to the Pecos River.

A study of the chemical character of the water of the Pecos River has been made by C.S. Howard and W.F. White, Jr., and numerous analyses were made of the surface and ground waters in this area (see report on chemical character of Pecos River under 'Quality of Water,' to be found elsewhere in this volume). The ground-water studies by T.W. Robinson were begun on April 13, 1937, and the geologic studies by W.B. Lang on October 15, 1937."

RUSTLER FORMATION, p. 83, para 5;

" The Rustler formation in this area is approximately 500 feet thick. It is divided into two sections: the upper part usually 200 feet thick, consisting of all beds lying above the main limestone to and including the top 30-foot anhydrite or gypsum member; and the lower part, a section that includes the 35-foot dolomitic limestone and everything down to the top of the Salado. The lower section . . ."

Deposits Overlying the Rustler Formation, p. 84;

" Gatuña formation.--The name Gatuña is here given to an assemblage of rocks of various kinds that were laid down in the Pecos Valley in poet-High Plains time and apparently after the completion of the maximum cycle of erosion in this valley. The deposits are of terrestrial origin and with them began the process of refilling the Pecos Valley. The dominant material of which they are composed is fine red sand. However the material is largely of local derivation and therefore the character of the source of the material has had a controlling influence on the composition and color of the resulting deposits. Conglomerates, stream gravels, gypsum and limestone, as well as bedded and unconsolidated sands and silts, comprise this formation. They are gray, purplish, and yellow as well as red. The inclusion of caliche wash has in most places contributed to this formation a slightly paler reddish color than that of the Pierce Canyon redbeds. The name is derived from Gatuña Canyon in northeastern Eddy County, New Mexico. The formation is of Quaternary age."

GENERAL RELATION OF THE GEOLOGY TO THE OCCURRENCE OF BRINE AT THE BASE OF THE RUSTLER FORMATION, p. 86;

" It was observed by the writer more than a decade ago during the investigation for potash, that some of the test wells in the vicinity of T. 21 S., R. 30 E., indicated the presence of a strong sodium chloride brine just above the salt of the Salado halite. Some other test wells that were dry at this zone yielded salt core slightly cellular or cuttings with an uncommon appearance that was interpreted as having been caused by solution. Later, wells drilled farther south in Nash Draw yielded abundant sodium chloride brine in the basal Rustler, but those west of the draw were dry. Thus it seemed likely that the structural conditions that caused the development of Nash Draw might also control the position of a

body of salt water beneath it in the basal Rustler. The investigation has confirmed this assumption."

RUSTLER FORMATION, Character, Extent, and Relations of the Brine Horizon at the Base of Rustler Formation, p. 87;

" The water which occurs in the Rustler formation may be divided into two groups on the stratigraphic position of the water-bearing beds and the quality of the water. These two groups are (1) the water occurring in the brine horizon at the base of the Rustler formation, and (2) the water occurring above the brine horizon.

The brine horizon occurs at or very near the base of the Rustler formation, and as a rule it yields a strong sodium chloride brine. IN some of the oil tests and potash core tests only weak to moderate solutions of sodium chloride were reported. This difference in concentration may be due to the occurrence of weaker brine in the locality of the well, to a dilution of strong brines by fresher water from a higher bed that was not shut out when the well was drilled, or to admixture of water used in drilling. At the seven test wells, described in the appendix, (not included with this report), the material of the brine horizon is composed almost entirely of granular and selenitic gypsum. In some of the wells the bottom of the bed that yields the sodium chloride brine is separated from the salt of the underlying Salado halite by a very few feet of clay and in others it appears to be in contact with the salt. Such close association of the water in this horizon with the salt is obviously favorable for the production of a sodium chloride brine.

The presence of a rather extensive bed yielding a sodium chloride brine at the base of the Rustler formation was not generally recognized until the first test well had been drilled. Previous to the start of the investigation, brine had occasionally been reported in oil tests and potash core tests just above the Salado halite. As the brine was not reported in all wells it was at first believed to occur only locally. However with the drilling of the first test well, 23-29-22C1, by the U. S. Potash Company with a sodium chloride brine reported in two nearby oil tests, 23-29-14N1 (Fogarty No. 1) and 24-29-3F2 (Kerr No. 1) (plate 1), it became evident that there is a continuous horizon yielding a sodium chloride brine east and south of Laguna Grande de la Sal. Subsequent drilling of the other test wells and oil tests, 22-31-30K1 (Texas Welch) (?) and 24-28-28L1 (C. J. Frederick Reed No. 1), has shown that this brine horizon extends over a considerable area. The approximate area underlain by this brine horizon, as it is known at present from all available test wells, oil tests and potash core tests, is outlined o the accompanying map, plate 3. The area shown on the map covers about 122 square miles, but it is approximate only and is subject to revision when more well data are available.

As shown on the map, the area extends as a narrow strip northeast from the vicinity of Willow Lake to Laguna Grande, and then northeast and north to the head of Nash Draw, a distance of approximately 30 miles. It ranges in width from 2 to 8 miles. It is interesting to note that north of Laguna Grande the brine horizon appears to lie within the confines of Nash Draw, suggesting that solution of the Salado halite may have had some influence in the development of this flat valley.

The thickness of the brine horizon based on the six test wells which penetrated to the Salado halite, ranges from 61 feet in well 23-29-28B6 (U. S. P. C. No. 2 Test) to 10½ feet in 22-30-17M1 (U. S. G. S. No. 5 Test), and averages about 36 feet. The seventh test well, 23-29-22C1, (U. S. P. C. No. 1) did not penetrate the Salado halite. The thickness appears to decrease to the north. The average thickness based on all available data of the oil tests, potash core tests and the six test wells, is about 24 feet."

CONCLUSIONS, p 100;

" The discussion in the foregoing pages and the data presented in the appendix lead to the following conclusions: A body of concentrated solution of sodium chloride occurs at the base of the Rustler formation and overlies the extensive deposit of salt known as the Salado halite. This brine horizon extends from some locality north of Laguna Grande de la Sal to the vicinity of the Malaga Bend of the Pecos River. The brine in this horizon is under artesian pressure and has in general a southward hydraulic gradient. Below Fishing Rock, at the Malaga Bend, the artesian pressure is sufficient to raise the brine above the level of the river at normal stages. In the vicinity of the Malaga Bend the confining bed for the brine horizon is thin and incompetent. Salt water is percolating upward from the brine horizon and entering the Pecos River at the Malaga Bend locality.

It is believed that the salt in the brine of the brine horizon is derived chiefly from the underlying deposit of salt in the Salado Halite. The available evidence points to the conclusion that the lake brine does not reach the Malaga Bend through the brine horizon or by any other route."

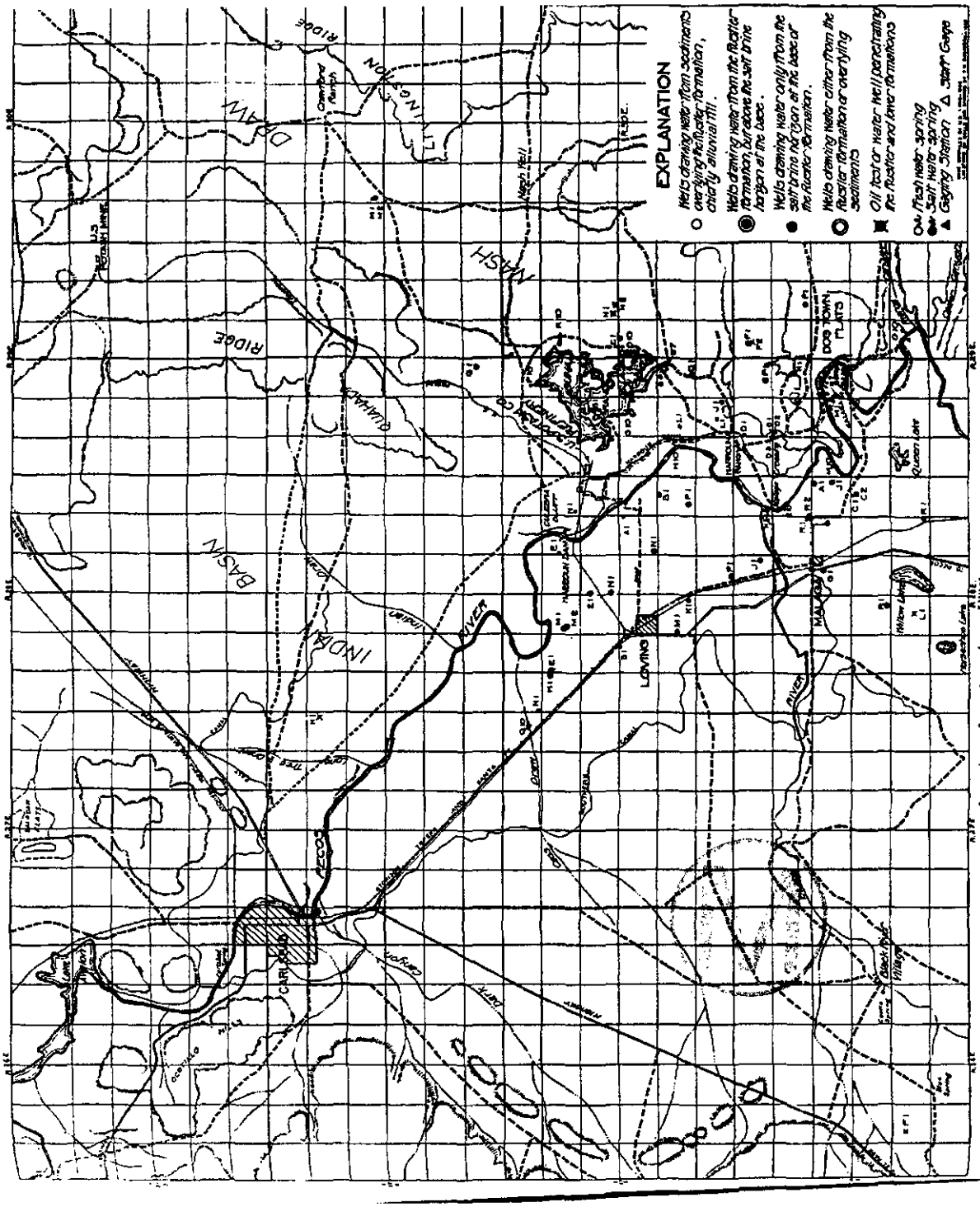
EXPLANATION
Wells drawing water from sediments overlying the Rustler formation, chiefly alluvial fill.
Wells drawing water from the Rustler formation, but above the salt brine horizon at the base.
Wells drawing water only from the salt brine horizon at the base of the Rustler formation.
Wells drawing water either from the Rustler formation or overlying sediments
Oil test or water well penetrating the Rustler and lower formations
Oil, fresh water spring
Salt water spring
Gaging Station
Staff Gage
CARLSBAD
LOVING
MALAGA
DOG TOWN FLATS
PECOS
RIVER
INDIAN
BASIN
WASH
RIDGE
GUADALUPE
EDDY CO.
LEA CO.
Queen Lake
Willow Lake
Red Bluff Reservoir
Grack Ranch
Village
Pecos River Village
Carlsbad Springs
Carlsbad Caverns Nat'l Park
Old Pecos River
Old Texas Road
Old Spanish Trail
Old Stagecoach Road
Old Pecos River Bridge
Old Pecos River Ferry
Old Pecos River Crossing

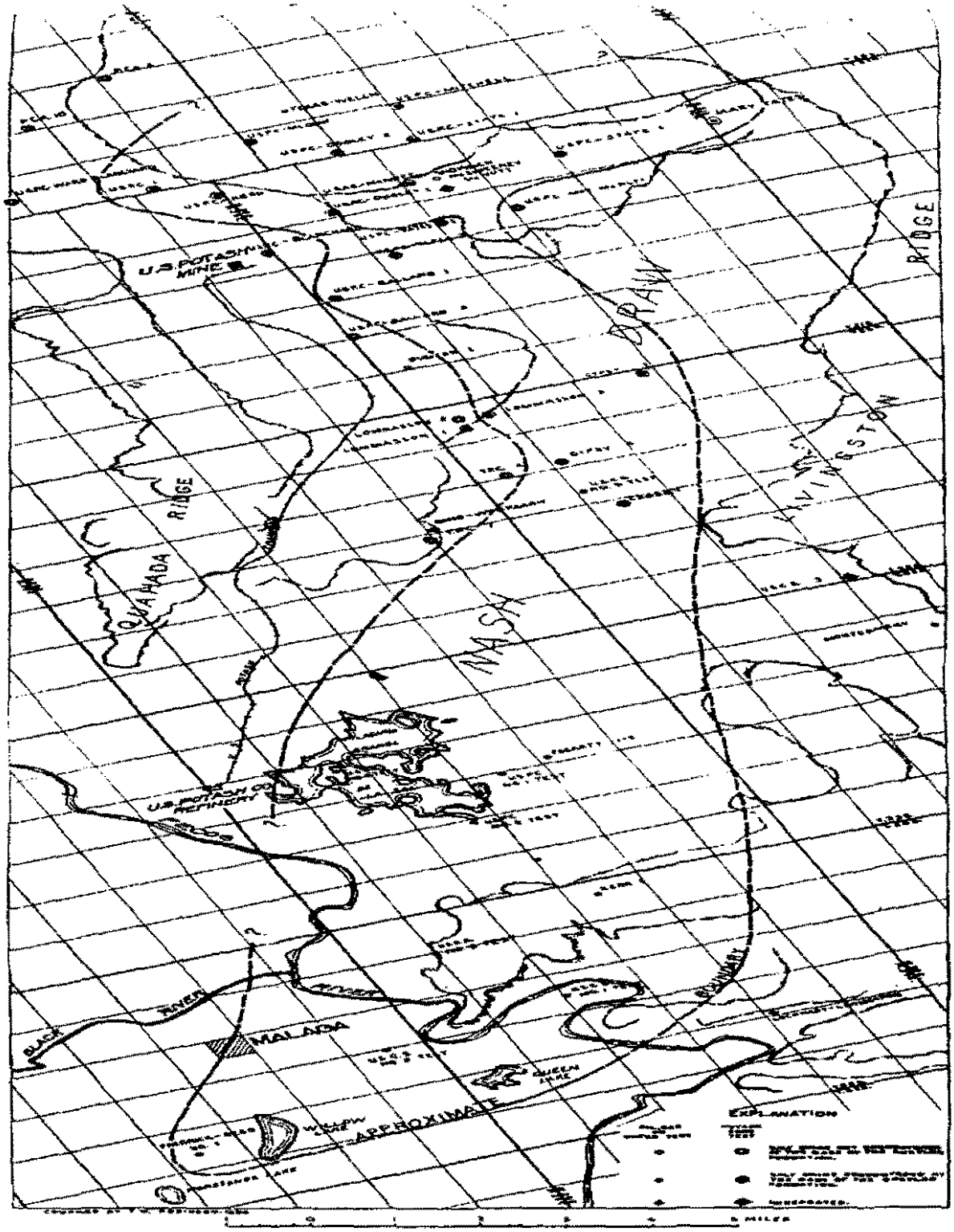

Plate 3. Map showing approximate area underlain by sodium chloride brine at the base of the Rustler formation, in the vicinity of Laguna Grande de la Sal and adjacent area.

Robinson, J.Q., and Powers, D.W. 1987. "A Clastic Deposit within the Lower Castile Formation, Western Delaware Basin, New Mexico." In Geology of the Western Delaware Basin, West Texas and Southeastern New Mexico, D.W. Powers, and W.C. James, eds., El Paso Geological Society Guidebook 18, pp. 69–79. El Paso Geological Society, El Paso, TX.

ABSTRACT, p 69, col 1;

" In the vicinity of CP Hill, about 16 km south-southwest of Whites City, New Mexico, a brecciated sequence in the lower Castile Formation has been examined in detail. Four distinct units associated with the breccia sequence have been defined. Unit A is clast poor, structureless to thinly bedded, and contains kerogen. It occurs only over nodular anhydrite. Unit B is pseudo-bedded, with anhydrite matrix supporting tabular anhydrite clasts. Unit C contains abundant rounded polyclasts and is grain-rich. Unit D is similar to A, but clasts are finer in Unit D. These beds are arranged in vertical sequence and show lateral thinning in an apparent fan shape. The textures, grading, and vertical and lateral relationships suggest this breccia unit was deposited as a subaqueous debris flow."

DISCUSSION, p 77, col 1, para 2;

" Dissolution, as a more general alternative mechanism for the formation of evaporite breccias in the western part of the Delaware Basin, has been proposed by Anderson (1978) and explored in several subsequent publications (Anderson, et al., 1978; Kirkland and Anderson, 1980; Anderson, 1981, 1982). We are providing a depositional model to account for the features along the western margin of the Delaware Basin which have been attributed to dissolution. Nevertheless, the data available prior to this study, for the western margin is principally logs and a few cores, and this is insufficient to exclude a depositional origin for many breccias along the western margin.

The Castile is considered one of the prime examples of deep water evaporite deposits. Among the criteria taken to indicate deep water are (Kendall, 1986):

1. fine laminations of carbonate and sulfate over distance of many kilometers;
2. laminated halite, with finely laminated anhydrite and carbonate; and
3. gravity-displaced evaporites.

The debris flow deposit(s) described here fits into a setting in which the first two criteria appear to have been satisfied, and the presence of the debris flow deposit therefore might be taken as evidence that the third criterion is also satisfied. In this respect, the often repeated assertion that the Castile formed as a deep-water evaporite would seem to be strengthened.

Dean, Davies, and Anderson (1975) discuss nodular anhydrite within the Castile, and conclude that it is not diagnostic as a shallow-water indicator, partly because the Castile is considered a deep-water evaporite. Within the CP Hill area, the lower anhydrite is thicker where additional nodular anhydrite beds are present; depositional changes are consistent with the change in slope. These changes are also consistent with the disappearance of halite, and strongly suggest that halite was not, at least locally, deposited over this slope and to the west. There is a suggestion then that local brine depth or depth of halite-saturated brine was

less than the local change in relief on the Anhydrite-I substrate. Among the pieces of evidence that need to be considered in this discussion is the limited amount of bromine in the Castile (Holser, 1966; Adams, 1969), indicating the brine may not have all resulted from marine water evaporation. We will continue to examine evidence and relative merits of the evidence for the concept of deep-water versus shallow-water deposition of the Castile along the western margin of the Delaware Basin.

The crackle breccias which occur above the main bedded or pseudo-bedded breccia units are consistent with downwarping of a rigid beam (AII). The downwarping is considered due to overburden and loss of partial support from below. Two possible mechanisms for loss of support are dissolution and compaction of the underlying debris flow deposit. A combination of the two are possible as well. We do not yet have specific data favoring or opposing either hypothesis."

CONCLUSIONS, p 78;

" A unit of intraformational clasts within the lower Castile near the western margin of the Delaware Basin exhibits clast rounding, bedding, clast orientation and grading, and a fan-shaped distribution that is generally consistent with a model as a subaqueous debris flow or series of flows. Internal units display common textural features that can be mapped within the fan. This depositional model for this deposit contrasts with a more general model of dissolution of evaporites considered to be the origin of breccia textures in the same stratigraphic interval along the broader western basin margin."

Rogers, A.M., and Malkiel, A. 1979. A Study of Earthquakes in the Permian Basin of Texas-New Mexico. Bulletin of the Seismological Society of America. Vol. 69, pp. 843-865.

ABSTRACT;
" A microearthquake seismograph network has been employed to study earthquakes occurring in the Permian Basin of Texas and New Mexico. The earthquakes are predominantly located on the Central Basin platform, although a few occur in the Delaware Basin. The majority of the earthquakes occur at the depths of sedimentary rocks, and the focal depths are also coincident with the depths at which hydrocarbon production and water-flood (secondary recovery) operations are conducted. Comparison of the historic earthquake activity with water-flood data shows that there was a possible increase in the number of large earthquakes (M >3.0) in the mid-1960s when the number of water-flood projects and their injection pressures increased. The first felt event occurred in 1966. This tentative correlation suggests that the earthquakes are related to hydrocarbon production in this area."

INSTRUMENTATION, p. 847;
" The Kermit seismic network consists of 11 self-contained radio telemetry systems covering an area of 2200 km^2."

APPENDIX, p. 860;
" A list of all known earthquakes on the CBP from December 12, 1975 through June 26, 1977.

Selected Headings	*Explanation*
mag	Duration magnitude.
no	Number of station readings used to locate earthquake.
gap	Largest azimuthal separation between stations in degrees.
dmin	Epicentral distance in km to the nearest station.
ms	Root mean square error of time, in seconds.
erh	Standard error of the epicentral, in km.
erz	Standard error of the focal depth, in km.
q	Solution quality of hypocenter (Lee and Lahr, 1972)."

Rosholt, J.N., and McKinney, C.R. 1980. Uranium Series Disequilibrium Investigations Related to the WIPP Site, New Mexico (USA), Part II. Uranium Trend Dating of Surficial Deposits and Gypsum Spring Deposit Near WIPP Site, New Mexico. Open-File Report 80-879. U.S. Geological Survey, Denver, CO.

INTRODUCTION, p. 1;

" Just how suitable salt beds are for permanent disposal of radioactive wastes has been the subject of extensive studies covering diverse aspects over the past decade. The proposed site of the Waste Isolation Pilot Plant (WIPP) is located in southeastern New Mexico, about 42 km east of Carlsbad, where plans are to construct the storage facility in rock salt beds of the Permian Salado Formation. Detailed surface and subsurface geology at the site and of the surrounding area has been discussed previously (Bachman, 1976; Powers and others, 1978).

A basic concern for waste repositories in salt beds is their high solubility in ground waters. Different kinds of dissolution features are known in most evaporite basins including the Delaware Basin, the region of the proposed WIPP site. Some primary questions that can be posed are: 1. Is there active dissolution of salt at or near the site of WIPP? 2. Is the process of salt dissolution continuous or episodic? 3. If episodic, what is the correlation between time and depth? 4. When did the last salt dissolution cycle occur? 5. What is the rate of dissolution?

Rosholt and others (1966) and Rosholt (1978) demonstrated that a process of isotopic evolution of uranium and thorium occurs in most types of sediments, altered volcanic ashes and deeply buried granites provided that some groundwater is allowed to migrate through the porous zones of these materials during their geologic history. Often the analyses of the isotopes of the ^{238}U-^{234}U-^{230}Th-^{232}Th system yield an estimated age for the time of deposition (uranium-trend age estimate) over the range of the method from 2,000 to about 800,000 years ago (Rosholt, 1978). Accordingly, it was felt that a preliminary study of salt dissolution residue samples near the WIPP site may yield insight into the dissolution processes and/or it may provide a uranium-trend age estimate for the most recent salt dissolution that produced clay residuum and bands of gypsum. The application of uranium trend dating in the investigation of the age of surficial deposits in the area east of Carlsbad, New Mexico, is included in Part II of this report."

Table 5, p. 15;

" Uranium-trend ages of surficial deposits in Nash Draw and Hat Mesa, New Mexico quadrangles.

Deposit	U-trend slope	x-intercept 232Th index	Half period of $P_{(0)}$ (10^3 yr)	Age (10^3 yr)
Berino soil	-0.533	-0.480	140	330±75
Mescalero caliche				
Upper part	-2.34	+.036	590	420±60
Lower part	-.419	+.182	370	570±110
Gypsum spring	-.889	-.196	340	380±60"

Sanford, A.R., Jaksha, L.H., and Cash, D.J. 1991. "Seismicity of the Rio Grande Rift in New Mexico." In Neotectonics of North America. D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 229-244. Geological Society of America, Boulder, CO.

GENERAL FEATURES OF RIO GRANDE RIFT SEISMICITY, p. 230, col. 1, para. 2;

" Starting about 10 years ago, geophysical data began to accumulate that indicated that the RGR boundaries could be extended beyond those proposed by Chapin (1971) in Figure 1. Cordell (1978) summarized geophysical evidence for a broad astenospheric-lithospheric structure centered beneath the chain of grabens shown in Figure 1. Cordell found that the main feature of east-west gravity profiles through New Mexico is a broad negative Bouguer anomaly centered roughly on the axis of the rift. According to Cordell (1978), the anomaly is a consequence of subcrustal structure related to a Rio Grande rift system, which includes a broad uplifted region as well as the obvious grabens and basins usually considered to be RGR. The width of the anomaly appears to be at least 500 km along the New Mexico-Colorado border and broadens progressively to the south. Thus, the gravimetric signature of the rift system, and possibly the structure that produced it, extends beneath the presumably stable Colorado Plateau and Great Plains Provinces, well beyond Chapin's boundaries of the rift shown in Figure 1.

Other geophysical observations support the existence of a broad astenospheric-lithospheric structure beneath the RGR. Davis and others (1984) found a traveltime residual anomaly for teleseismic P-wave arrivals along a profile crossing the RGR. The anomaly has a maximum delay of 1.5 seconds and an east-west extent of approximately 340 km, of which about 60 km underlies the Colorado Plateau and about 70 km underlies the Great Plains.

Shown in Figure 2 is a magnetic map for New Mexico based on the composite magnetic anomaly map of the United States by Taylor and others (1983). The broad north-south-oriented low that appears to be associated with the RGR is one of the strongest and most clearly defined in the conterminous United States. The boundaries for this anomaly are somewhat subjective but clearly fall beneath the Colorado Plateau and the Great Plains and well beyond the maximum boundaries of the RGR in Figure 1.

Gable and Hatton (1983) presented geologic evidence for surface uplift during the past 10 m.y. over a broad region centered on the RGR (Fig, 3). The general character of the uplift extends uninterrupted north through Colorado and south-southeast through west Texas. The east-west extent and generally north-south orientation of the uplift suggests a relation between it and the asthenospheric-lithospheric structures underlying it.

On the basis of geophysical, topographical, and geological information, Eaton (1986) concluded that the Southern Rocky Mountains extend southward through the entire length of New Mexico. Accordingly, the broad geophysical anomalies and surface uplift described above are the signature of the Southern Rocky Mountains, and the RGR is a system of axial grabens along this major north-trending structure."

Saulnier, Jr., G.J., and Avis, J.D. 1988. Interpretation of Hydraulic Tests Conducted in the Waste-Handling Shaft at the Waste Isolation Pilot Plant (WIPP) Site. SAND88-7001. Sandia National Laboratories, Albuquerque, NM. WPO 24164.

ABSTRACT, p ii;
" A series of sub-horizontal boreholes from 8- to 41-feet deep were drilled from four depth levels in the waste-handling shaft at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The waste-handling shaft is one of three shafts built at the WIPP site to provide surface access to the underground waste repository under construction 2150 feet below the ground surface. The boreholes were drilled at the 782- and 805-foot depth levels in a mudstone and a claystone of the unnamed lower member of the Rustler Formation; at the 850-foot depth level in bedded halite in the upper Salado Formation; and at the 1350-foot depth level in halite, anhydrite, and polyhalite of the Salado Formation. Examination of the cores recovered from one borehole at each level indicated no direct evidence of construction-induced fracturing. Pulse-injection tests were conducted in packer-isolated intervals in six of the boreholes to estimate the formation's hydraulic conductivity and apparent formation pressure, and to determine whether or not there was evidence of construction-enhanced permeability up to one shaft diameter from the shaft wall.
The pulse-injection tests . . ."

Section 6.0 SUMMARY AND CONCLUSIONS, 6.1 Test Results, p 6-11, para 2;
" The hydraulic conductivities of the mudstone, claystone, and evaporite beds are low and range from 6.0×10^{-15} to 1.0×10^{-13} m/s."

Schiel, K.A. 1988. "The Dewey Lake Formation: End Stage Deposit of a Peripheral Foreland Basin." Master's thesis. University of Texas at El Paso, El Paso, TX.

ABSTRACT, p iv;

" The red siltstones and fine grained sandstones of the Dewey Lake Formation (Late Permian?) have always been relegated to a rather insignificant role in the geologic history of the Permian Basin. The present study suggests that they are, in fact, an important key to understanding the tectonic evolution of the southwestern United States.

Field work, in southeastern New Mexico, reveals that the Dewey Lake is fluvial in origin. Broad, shallow channels filled with thin horizontal laminations and flanked by laterally thinning wings comprise a large portion of the formation. Floodplain deposits, consisting of interbedded siltstone and silty claystone, are also very common.

The Dewey Lake displays many of the sedimentologic and morphologic characteristics associated with ephemeral fluvial systems. Some of these characteristics are an abundance of horizontal laminations and silty claystone drapes, the existence of interbedded siltstone and silty claystone interpreted to be the distal portion of sheet floods, and the presence of broad channels with laterally thinning wings. The Dewey Lake is, therefore, believed to have been deposited on a very extensive northwest sloping fluvial plain. Movement of sediment across this plain occurred only sporadically, during brief and localized flash floods.

It has previously been theorized that the Dewey Lake was extensively eroded prior to the deposition of the Santa Rosa Formation (Middle to Late Triassic). The results of the present study suggest that the thickness variations in the Dewey Lake are not a reflection of post depositional erosion but syndepositional differences in the subsidence rates of the Central Basin Platform and Delaware Basin. Increased subsidence of the Delaware Basin is reflected by the fact that the base of the Dewey Lake Formation is offset 100 m (300 ft) along the major northwest trending fault zone separating the Delaware Basin and Central Basin Platform. The Delaware Basin, therefore, appears to have been tectonically active throughout the deposition of the Dewey Lake Formation.

If the thickness variations in the Dewey Lake are due to subsidence rather than erosion then the contact between the Dewey Lake and the overlying Santa Rosa Formation is conformable. The Santa Rosa has been dated as Middle to Late Triassic in northeastern New Mexico; if this date is applicable to the Santa Rosa in southeastern New Mexico it dictates that the deposition of the Dewey Lake Formation continued into the Early Triassic.

A major unconformity separates Lower Permian and Cretaceous strata in the Fort Worth, Val Verde and Marfa Basin of Texas. This unconformity, which also exists in northwestern Chihuahua, clearly indicates that a large region of central Texas and northern Mexico was uplifted and eroded during the latest Permian ? and early Mesozoic. The location and timing of this uplift suggests that it was the source of the silt and fine sand comprising the Dewey Lake Formation. A close geographic and temporal relationship between this uplift and Late Triassic rift basins suggests that it originated as a pre-rift bulge.

The very extensive nature of this uplift suggests that the alluvial plain to the north (i.e. the Dewey Lake and Quartermaster Formations) extended significantly beyond the area

of west Texas and eastern New Mexico. The western portion of this plain is theorized to be the redbed facies of the Moenkopi Formation (Early Triassic). Apparent similarities in age, stratigraphic position, lithology and paleoscope all support the concept that the Dewey Lake and Moenkopi Formations are components of a single lithologic unit."

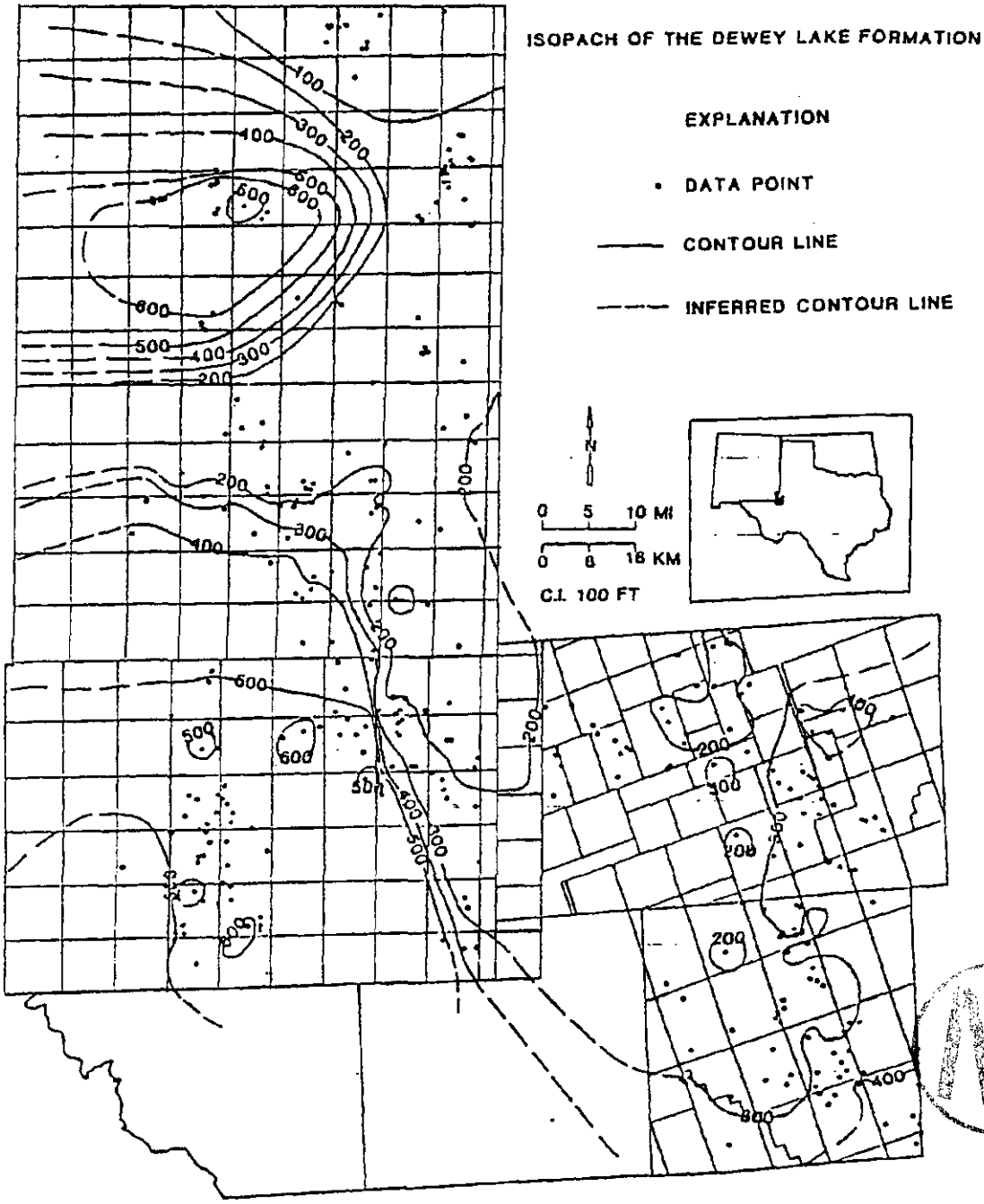

Figure 21 Isopach map of the Dewey Lake Formation.

SUMMARY AND CONCLUSIONS, p 143;

" Broad, winged channels filled with thin, horizontal laminations dominate the Dewey lake Formation. The lateral interfingering and vertical stacking of these channels creates an unusual depositional architecture not seen in either the typical meandering, anastomosing or braided fluvial models. It, however, is not unique. Similar sedimentologic and morphologic characteristics have been noted in other formations and interpreted to represent a fluvial system dominated by ephemeral flood events. The depositional environment of the Dewey Lake is, therefore, envisioned to be a large, arid to semi-arid fluvial plain, which experienced infrequent and localized flash floods. As the flood waters rushed across some portion of the plain they would carve and quickly fill broad, shallow channels. Later floods would erode and fill other channels to create interfingering and stacked architecture now exposed in the Dewey Lake Formation."

Schiel, K.A. 1994. "A New Look at the Age, Depositional Environment and Paleogeographic Setting of the Dewey Lake Formation (Late Permian)." West Texas Geological Society Bulletin, Vol. 33, No. 9, pp. 5-13. WPO 20465.

ABSTRACT, p 5;

" The Dewey Lake Formation (Late Permian?) was studied, using surface and subsurface techniques, to more clearly define its depositional environment and tectonic/paleogeographic setting. The Formation contains numerous wide, shallow channels filled with horizontally laminated siltstone and flanked by laterally thinning 'wings' of micro-cross laminated siltstone. This morphology indicates that the Dewey Lake was deposited in a fluvial plain dominated by localized, ephemeral flows. The 'wings' represent distally thinning, floodplain deposits, formed as the channel filled with sediment and the water overflowed onto the surrounding plain.

The Dewey Lake is generally restricted to the Late Permian; however, the supporting evidence is weak. Lateral thickness variations in the Dewey Lake reflect syndepositional subsidence (i.e, the Delaware Basin was still active), not post-depositional erosion. Ash beds in the lower Quartermaster Formation (lateral equivalent), with ages near the Permo-Triassic boundary, date the initiation of sedimentation, not its duration. These observations suggest that although deposition of Dewey Lake sediments may have begun in the latest Permian, it continued through the Early Triassic.

The silts and fine grained sands comprising the Dewey Lake were derived from an uplift, to the south/southeast, encompassing the Pennsylvanian Ouachita/Marathon thrust belt and fore-deep basins. Triassic uplift of this region is indicated by an erosional unconformity between Late Permian and Cretaceous strata in several fore-deep basins and Triassic conglomerates in the Glass Mountain and Llano Uplift regions interpreted as alluvial fans. Timing and location of this uplift suggest that it may have originated as a pre-rift bulge. Lithologic, stratigraphic, and sedimentologic similarities between the Dewey Lake and Moenkopi Formation suggest that the alluvial plain north of this uplift may have extended throughout the southwestern United States."

p 9;

" Summary of depositional Environment Analysis.

The process of channel carving and filling, during the course of ephemeral flow events, create the unique morphology of the Dewey Lake.

- Runoff from a local shower carves a shallow channel.
- As the channel fills with sediment (Facies 3), water overflows onto the surrounding plain.
- Friction reduces the velocity and climbing cupsate ripples (Facies 4) form along the channel margin (Figure 4A). Further away from the channel the velocity is even lower and less silt is deposited, creating the channel 'wings'.
- As the flow wanes, silty clay drapes the area. This drape thickens away from the channel forming the silty claystone portion of Facies 5.

The abundance of Facies 4 and 5 suggests that many channels were rapidly filled with sediment, which caused overflow onto the surrounding plain. There are, however, several channels in Figure 3 which contain two or more distinct filling episodes. In many cases the initial channel fill consists of the silty claystone of Facies 7. This suggests that some channel forms remained after the cessation of flow. One explanation may be that these 'open' channels were near the origination of flow; hence, there was no 'upstream' sediment to fill the channel.

A few channel orientations,and several sedimentary structure measurements, suggest that flow was to the north/northwest. Therefore, the source area was located to the south/southeast.

The Dewey Lake Formation was deposited in a large, arid fluvial plain subject to ephemeral flood events. The size and location of these flows were dictated by meteorological conditions. Events were probably infrequent and local in nature. Time between flood events in a single locality could easily have been years, or decades. Much of the sediment deposited during any one event was eroded and redeposited down gradient during subsequent channel-carving events (Figure 4B). Preservation of sediment at one locality would ultimately be dictated by the amount of tectonic subsidence between events, and the erosive power of the following event."

Sewards, T., Williams, M.L., and Keil, K. 1991. Mineralogy of the Culebra Dolomite Member of the Rustler Formation. SAND90-7008. Sandia National Laboratories, Albuquerque, NM. WPO 23879.

ABSTRACT, p i, para 4;
" Clay is the second most abundant mineral present and is concentrated along textural features, particularly the surfaces of fractures and vugs, thus making its presence of particular import to the characterization of hydrological transport within the formation. Clay abundances range from less than 1.0% to nearly 60% of the bulk samples.

The clay mineral assemblage includes corrensite (ordered mixed-layer chlorite/smectite), illite, serpentine, and chlorite. Corrensite is the dominant clay mineral, usually constituting about 50% of the clay assemblage;illite is the next most abundant constituent, and serpentine and chlorite are relatively minor components. Because of its high cation exchange capacity (CEC), the presence of corrensite is of particular importance as it can be an effective sorbent of radionuclides."

Section VII. CLAY MINEROLOGY, p VII-1, para 1;
" Clay fraction separates (<2 micron) were obtained from three samples and analyzed by XRD using oriented mounts (Drever, 1973) to both identify the clay mineral present and determine the modes of each clay mineral. XRF analysis was used to determine the bulk composition of the clay separates. AEM was used to study the textural relationships of the clay mineral in one sample, H6B #3."

NOTE:
XRD = X-Ray Diffraction
XRF = X-Ray Fluorescence
AEM = Analytical Electron Microscopy

Siegel, M.D., Lambert, S.J., and Robinson, K.L., eds., 1991. Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico. SAND88-0196. Sandia National Laboratories, Albuquerque, NM. WPO25624.

ABSTRACT, p i;

" Chemical, mineralogical, isotopic, and hydrological studies of the Culebra dolomite member of the Rustler Formation and related rocks are used to delineate hydrochemical facies and form the basis for a conceptual model for post-Pleistocene groundwater flow and chemical evolution. Modern flow within the Culebra in the Waste Isolation Pilot Plant (WIPP) area appears to be largely north-to-south; however, these flow directions under confined conditions are not consistent with the salinity distribution in the region surrounding the WIPP Site. Isotopic, mineralogical, and hydrological data suggest that vertical recharge to the Culebra in the WIPP area and to the immediate east and south has not occurred for several thousand years. Eastward increasing $^{234}U/^{238}U$ activity ratios suggest recharge from a near-surface Pleistocene infiltration zone flowing from the west-northwest and imply a change in flow direction in the last 30,000 to 12,000 years.

Culebra groundwaters are in chemical equilibrium with gypsum and are undersaturated with halite and anhydrite. A partial-equilibrium model for the chemical evolution of the groundwater suggests that Na, Cl, Mg, K, and SO_4 are added to the Culebra by dissolution of evaporite salts in adjacent strata. Equilibrium is maintained with gypsum and calcite, but dolomite supersaturation increases as the salinity of the water increases. Stable-isotope compositions of carbonates are consistent with this model and indicate that no recrystallization of dolomite in equilibrium with the groundwater has occurred. Major and minor element correlations are consistent with several plausible mechanisms of water/rock interaction, including sorption of lithium and boron by clays and dissolution of Mg-rich clays."

EXECUTIVE SUMMARY, p ES-1, para 3;

" An extensive geochemical data base, including analyses of major and minor solutes, redox data, mineralogical studies of intact core samples, and isotopic studies of waters, carbonates, and sulfates, has been assembled for the Rustler Formation and adjacent units in the northern Delaware Basin. These data were evaluated to compare the aqueous geochemistry with host rock mineralogies, to delineate hydrochemical facies in the Culebra member of the Rustler Formation, and to determine the consistency of these facies with groundwater flow patterns derived from site stratigraphy and hydrology. The resulting synthesis of data and current hypotheses concerning the origin, composition, and history of waters in the Culebra member of the Rustler Formation and related units provides a tentative conceptual model for groundwater flow in the Rustler during the last 12,000 to 16,000 years. This model can form part of the basis for assessing the long-term performance of the geological containment system at the WIPP, which is developed in the underlying evaporites of the Salado Formation."

EXECUTIVE SUMMARY, p ES-3, para 3;

" Mineralogical and isotopic studies of sulfates in overlying layers also show that no significant amounts of either solutes or water have permeated vertically downward from the surface to recharge the Culebra. Specifically, much of the anhydrite in the Tamarisk member between the Magenta and Culebra members has not been hydrated to gypsum by recrystallization in the presence of fresh water, D/H ratios in gypsum throughout the Rustler are not consistent with a pervasively large water/rock ratio accompanying such hydration, and comparison of $^{87}Sr/^{86}Sr$ ratios of gypsums and carbonates in Rustler, Dewey Lake, and surface rocks shows that secondary sulfates and carbonates in the Rustler did not form in a hydrological regime that was uniformly interconnected with overlying rocks and the surface. Thus, the available mineralogical, hydrological, and isotopic data indicate no significant vertical connection between the Culebra and overlying strata.

The apparent discrepancy between modern flow direction and solute distribution can be explained by a change in flow direction in the last 30,000, or perhaps 12,000 years. Such a model is consistent with generally eastward-increasing ^{234}"$U/^{238}U$ activity ratios that indicate recharge from a near-surface Pleistocene infiltration zone, flowing from the west-northwest. The model is also consistent with the cessation of recharge in the late Pleistocene, as indicated by the radiocarbon dates. A likely explanation for the less saline waters south of the WIPP Site is that at the time of influx of the present generation of Culebra groundwater from the west-northwest, Rustler halite was absent adjacent to the Culebra in that area, and did not provide a source of NaCl. Thus, the postulated paleoflow direction (from the west-northwest) is consistent with both flow perpendicular to the $^{234}U/^{238}U$ contours and flow parallel to the hydrochemical facies boundary between more saline water in the north and less saline water south of the WIPP."

EXECUTIVE SUMMARY, p ES-5, para 2;

" Isotopic studies of minerals and waters provide some support for this model. Stable-isotope compositions of carbonate minerals indicate that calcite has precipitated in equilibrium with the groundwater now found in the Culebra in some areas, but that dolomite has not extensively recrystallized or exchanged isotopes with meteoric groundwater of any age. There is also isotopic evidence that calcium sulfate has recrystallized (dissolved and reprecipitated) in the presence of Rustler groundwaters.

The results of principle component analysis (PCA) suggest that reactions with clay minerals may exert an observable influence on the water's minor-element chemistry throughout the study area. When the effects of solute addition associated with halite dissolution are factored out prior to the PCA, a Mg-SiO_2-alkalinity association is left that is negatively correlated with a pH-B-Li association. These correlations are consistent with several plausible mechanisms, including uptake of Li by vacant octahedral sites in a clay lattice, sorption of B by surface sites of clays, and dissolution of a reactive amorphous Si-Mg-rich layer in corrensite, the dominant Culebra clay mineral.

Investigations that could further elucidate the hypotheses proposed here include collection and analysis of isotopic and chemical data from additional boreholes, systematic

examination of the mineralogy of samples from highly transmissive zones (containing core rubble rather than intact core), and more rigorous calculations of the extent of mass transfer that could result from precipitation, dissolution, ion exchange, and sorption."

CHAPTER 1: SUMMARY OF HYDROGEOCHEMICAL CONSTRAINTS ON GROUNDWATER FLOW AND EVOLUTION IN THE RUSTLER FORMATION, p 1-1. para 2;

" Isotopic, mineralogical, and hydrological data suggest that vertical recharge to the Culebra in the WIPP area and to the immediate east and south has not occurred for several thousand years. These data are consistent with the view that the apparent discrepancy between modern flow direction and solute distribution can be explained by a change in flow direction during the last 30,000, or perhaps 12,000 years. This model is consistent with generally eastward- increasing $^{234}U/^{238}U$ activity ratios that suggest recharge from a near-surface Pleistocene infiltration zone, flowing from the west-northwest. Culebra groundwater are in chemical equilibrium with gypsum and undersaturated with respect to halite and anhydrite. A partial-equilibrium model for the chemical evolution of the groundwater suggests that Na, Cl, Mg, K, and SO_4 are added to the Culebra by dissolution of evaporite salts in adjacent strata. Equilibrium is maintained with gypsum and calcite, but dolomite supersaturation increases as the salinity of the water increases. Isotopic studies of minerals and waters provide some support for this model. Stable-isotope compositions of carbonates indicate no recrystallization of dolomite in equilibrium with the groundwater now found in the Culebra, but local precipitation of calcite has apparently occurred. There is isotopic as well as mineralogical indication that calcium sulfate has recrystallized (dissolved and reprecipitated) in the presence of Rustler groundwater."

Section 1.4.8 Isotopic Studies of Rustler Waters, p 1-71, para 2;

" By comparison, vadose Capitan waters from the Carlsbad cavern system, groundwater from a water table in alluvium, and near-surface accumulations that homogenize seasonal variations in isotopic composition also have meteoric isotopic signatures, but have isotopic compositions more positive in δD-$\delta^{18}O$ space than confined Rustler and Capitan waters (Lambert and Harvey, 1987). The envelopes of δ-values for these two populations of differing hydrologic character do not overlap (Figure 1-25). The data a Nativ and Smith (1987) reveal that Ogallala groundwaters underlying the high plains to the east, climatically similar to the Delaware Basin, the only groundwaters containing tritium levels indicative of recent (post-1950) meteoric derivation (>10 tritium units [TU] all have δD values >-42% (Figure 1-25), comparable to near-surface unconfined meteoric waters in the Delaware Basin (Figure 1-26). High Plains data for Figure 1-26 are from Nativ and Smith (1987); WIPP data are from Lambert and Harvey (1987) and Lambert (1987). Significantly high tritium concentrations (>10 TU), indicating derivation from a meteoric source since 1950, are restricted largely to groundwaters having δD values more positive than about -42%. Ogallala waters from nearby southeastern New Mexico have δD values between -39 and -41%, corresponding with δD values of modern groundwater recharge in the Texas High Plains.

Hydrogen-isotope characteristics of groundwaters from the nearby climatically similar Delaware Basin (WIPP data) are shown for comparison. The isotopic signatures of confined Rustler and Capitan waters are distinct from that of both Ogallala water with discernable modern input and of vadose Capitan and alluvial water. Thus, it is likely that the isotopic compositions of confined Rustler and Capitan groundwaters in the northern Delaware Basin are not characteristic of groundwaters that would be receiving modern meteoric recharge under the present climatic conditions. . . .

Only four out of 16 well-water occurrences gave internally consistent radiocarbon 'age' calculations based on the internally consistent interpretive model and assumptions of Evans et. al. (1979) for water-bearing carbonate rocks. The model of Evans et. al. takes into account dilution of atmospheric carbon by dissolution of carbonate rock, and carbon isotope exchange between water and host rock. The mean of these four is 14,000 years; 95% confidence limits are $\pm$5,000 years. This is a minimum age estimate. It is not possible to estimate an upper age limit because of the unavoidable possibility of at least small amounts of unmitigable contamination even in these four samples. These tightly clustered ages, given their individual confidence limits, while spread out from north to south across the WIPP Site, do not allow consistent age gradients or travel times to be inferred across the WIPP Site based on differences in radiocarbon ages (Figure 1-27). Ten of the 16 well-water occurrences were completely contaminated due to unmitigable anthropogenic well-bore effects. The remaining two are ambiguous, but all 16 probably represent three-component mixing, including some contamination. The four dated groundwaters (three Culebra and one Dewey Lake) all have stable-isotope compositions belonging to the more negative population inδD-δ^{18}O space (Figure 1-25). Thus, it is inferred that Rustler and Dewey Lake groundwaters in this population have a significant component at least 12,000 radiocarbon years old. All the tritium measurements from the WIPP area, which are associated with the more negative (confined Rustler) isotopic compositions, are $<$3 TU, indicating little or no contribution from the atmosphere since 1950. Figure 1-27 shows tritium and radiocarbon in Rustler and Dewey Lake (DL) or Magenta (MA), measurements in Figure 1-27 (all from Lambert, 1987) apply to water from the Culebra member of the Rustler Formation. The uniformly low ($<$7 TU) tritium concentrations near the WIPP Site indicate no introduction of an atmospheric component since 1950 (cf. Isaacson et. al., 1974). Three Culebra and one Dewey Lake water were amenable to dating by the carbonate-aquifer model of Evans et. al. (1979), giving times of isolation from the atmosphere ranging from 12,000 to 16,000 radiocarbon years. These data indicate long residence times or long travel times from recharge areas, but provide no evidence of either modern vertical infiltration or monotonic age gradients indicating north-to-south flow. Three of these data, from water samples also having δD analyses, are depicted in Figure 1-26."

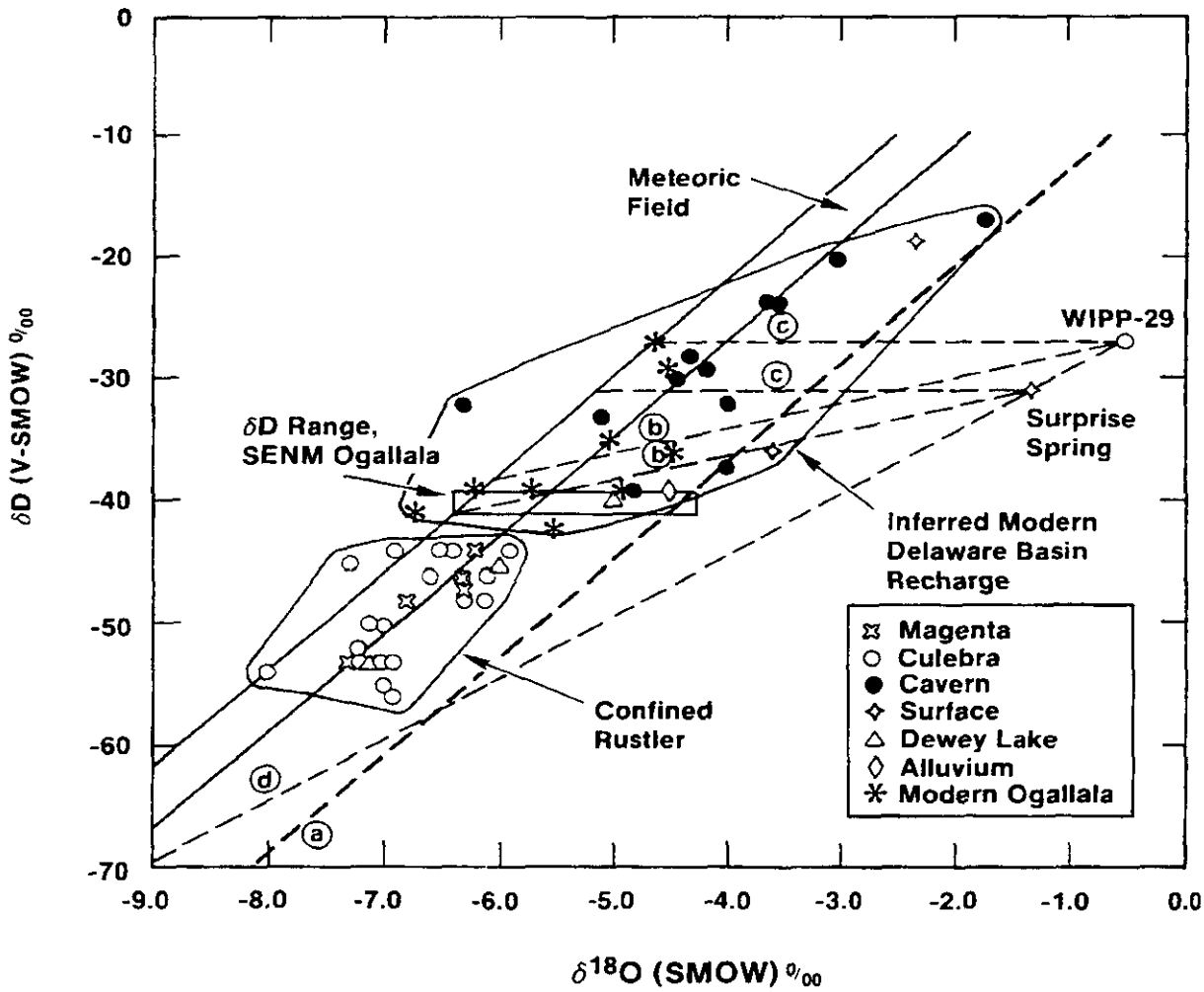

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Figure 1-25. Stable-isotope compositions of groundwaters from the Rustler Formation (Figure 5-1, adapted from Lambert and Harvey, 1987).

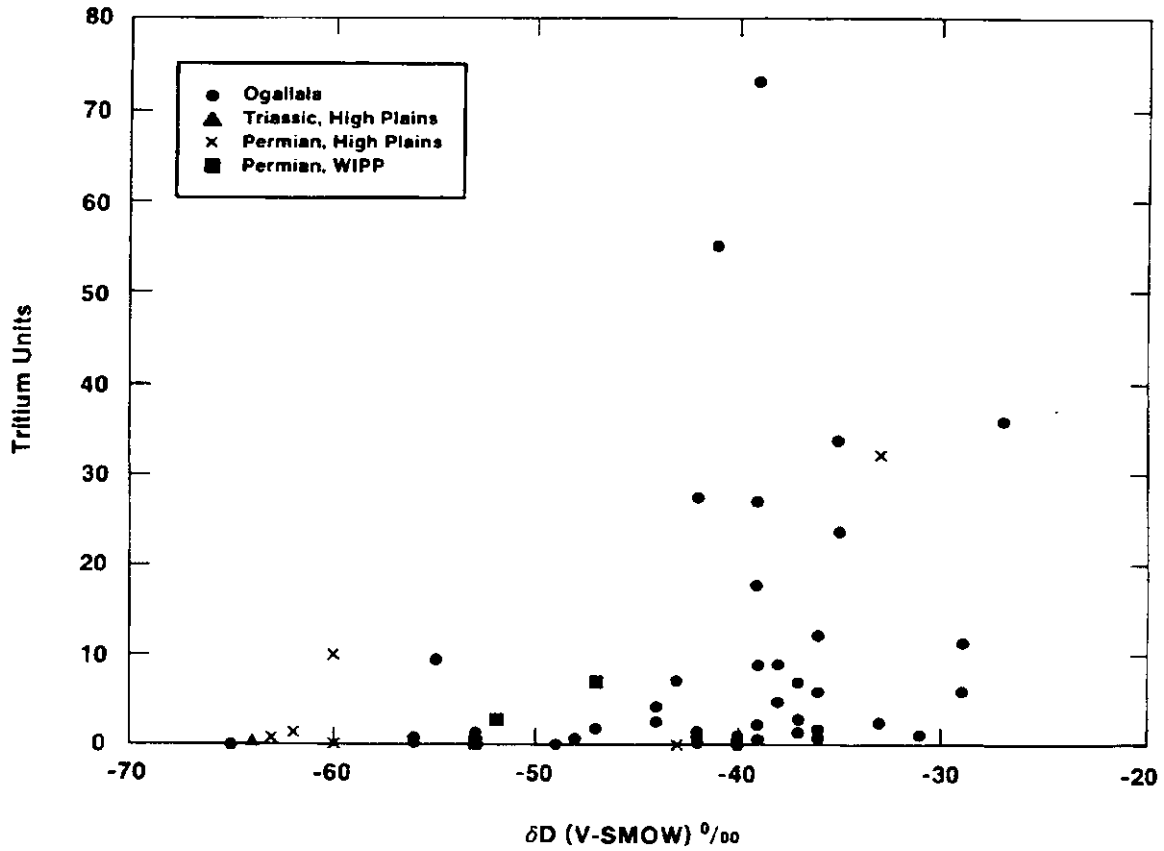

Figure 1-26. Tritium and deuterium concentrations in groundwaters from the Southern High Plains, Texas, and the Delaware Basin, southeastern New Mexico (Figure 5-2, from Lambert and Harvey, 1987).

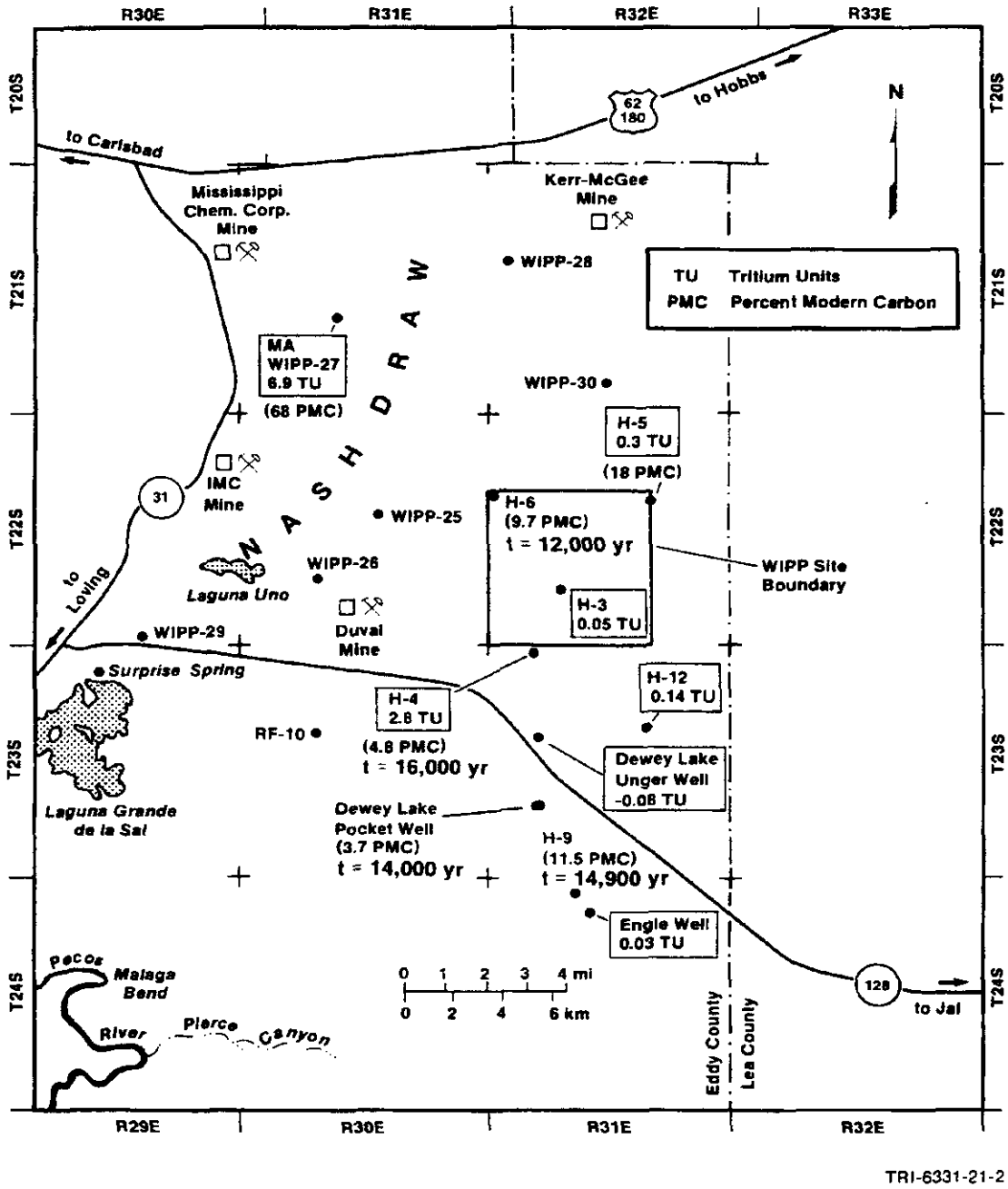

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Figure 1-27. Tritium and radiocarbon in Rustler and Dewey Lake groundwaters (Figure 5-11, adapted from Lambert and Harvey, 1987).

CHAPTER 2, SOLUTE RELATIONSHIPS IN GROUNDWATERS FROM THE CULEBRA DOLOMITE AND RELATED ROCKS IN THE WASTE ISOLATION PILOT PLANT AREA, SOUTHEASTERN NEW MEXICO, ABSTRACT, p 2-1;

" This chapter summarizes solute concentrations in waters of the Culebra member of the Rustler Formation. The solute relationships are used to delineate hydrochemical facies, to compare flow directions suggested by water chemistry with those indicated by modern hydrologic potentials, and to formulate a hypothesis for the chemical evolution of the Culebra groundwaters. Descriptions of waters from the Magenta dolomite, Rustler/Salado contact zone, the Dewey Lake Red Beds, and the Bell Canyon Formation are also included.

Four hydrochemical facies have been delineated in the Culebra. Zone A contains saline (about 3.0 m) NaCl brine and is found in the eastern third of the study area, roughly coincident with the region of low transmissivity and the occurrence of halite in several units of the Rustler Formation. Zone B contains a dilute Ca-SO_4-rich water (I <0.1 m) in the southern part of the study area and is coincident with a zone of high transmissivity where halite is absent from the Rustler. Zone C contains waters of variable composition and ionic strengths (0.3 to 1.6 m); it extends from the central part of the Waste Isolation Pilot Plant (WIPP) Site (four-mile zone), where halite is present in the unnamed member of the Rustler, to the eastern side of Nash Draw where no Rustler halite has been found. Zone D contains WIPP-27 and WIPP-29 and is defined on the basis of anomalously high salinities (3-6 m) and K/Na ratios (0.2), probably related to contamination from potash refining operations in the area."

2.3.2.1 Definition of Hydrochemical Facies in the Culebra Dolomite, p 2-57, para 2;

" Based on the major solute compositions given in table 2-2, four hydrochemical facies have been delineated and are shown in Figure 2-17. Compositions of waters from several other locations (indicated by open circles, open squares, or parentheses around the well name) were not included in the original data set used to define the facies, but their compositions are consistent with the facies boundaries. Compositions of waters in each zone are described in Figure 2-18.

> Zone A (DOE-1, H-5, H-11, H-12, P-17) contains saline (-2 to 3 molal) NaCl brines with Mg/Ca molar ratios of about 1.2 to 2(cf. Figure 2-19). This water is found in the eastern third of the study area; the zone coincides roughly with the region of low transmissivity, although at some wells (e.g., DOE-1 and H-11B3) the transmissivities are greater than 1 ft^2/day. On the western side of the zone, halite in the Rustler has been found only in the lower unnamed member; in the eastern portion of the zone, halite has been observed above and below the Culebra.
>
> Zone B (H-7, H-8, H-9, Engle) contains relatively dilute $CaSO_4$-rich groundwater (ionic strength <0.1 m). This water is found in the southern part of the study area. This zone coincides with a region of high transmissivity; halite is not found in the Rustler in this zone. Chemical data from Bodine et al. (Chapter 4) suggest that

several stock wells (Windmill, Indian, South and Two-Mile) and the Gnome (USGS) wells are also part of this zone.

Zone C contains waters of variable composition with low to moderate ionic strength (0.3 to 1.6 m). These waters occur in the western part of the WIPP Site and the eastern side of Nash Draw. Mg/Ca molar ratios of the fresher waters in this zone (I <1.25 m) range from about 0.3 to about 1.2. This zone coincides with a region of generally high transmissivity (except wells WIPP-30, H-1, H-2, H-4, H-14, and H-16). In the eastern part of this zone, halite is present in the unnamed lower member of the Rustler; on the western side of the zone, halite is not observed in the formation. The most saline (Na-Cl rich) water is found in the eastern edge of the zone, close to borehole locations where halite is observed in the Tamarisk member.

Zone D (WIPP-27, WIPP-29) is defined based on inferred contamination related to potash-refining operations in the area. The Culebra groundwaters from these wells have anomalously high salinities (3-7 m) and K/Na weight ratios (0.2) compared to other wells in the study area (salinities <3 m; K/Na weight ratios 0.01 to 0.09). At WIPP-29, the composition of the Culebra water has changed over the course of a 7-year monitoring period."

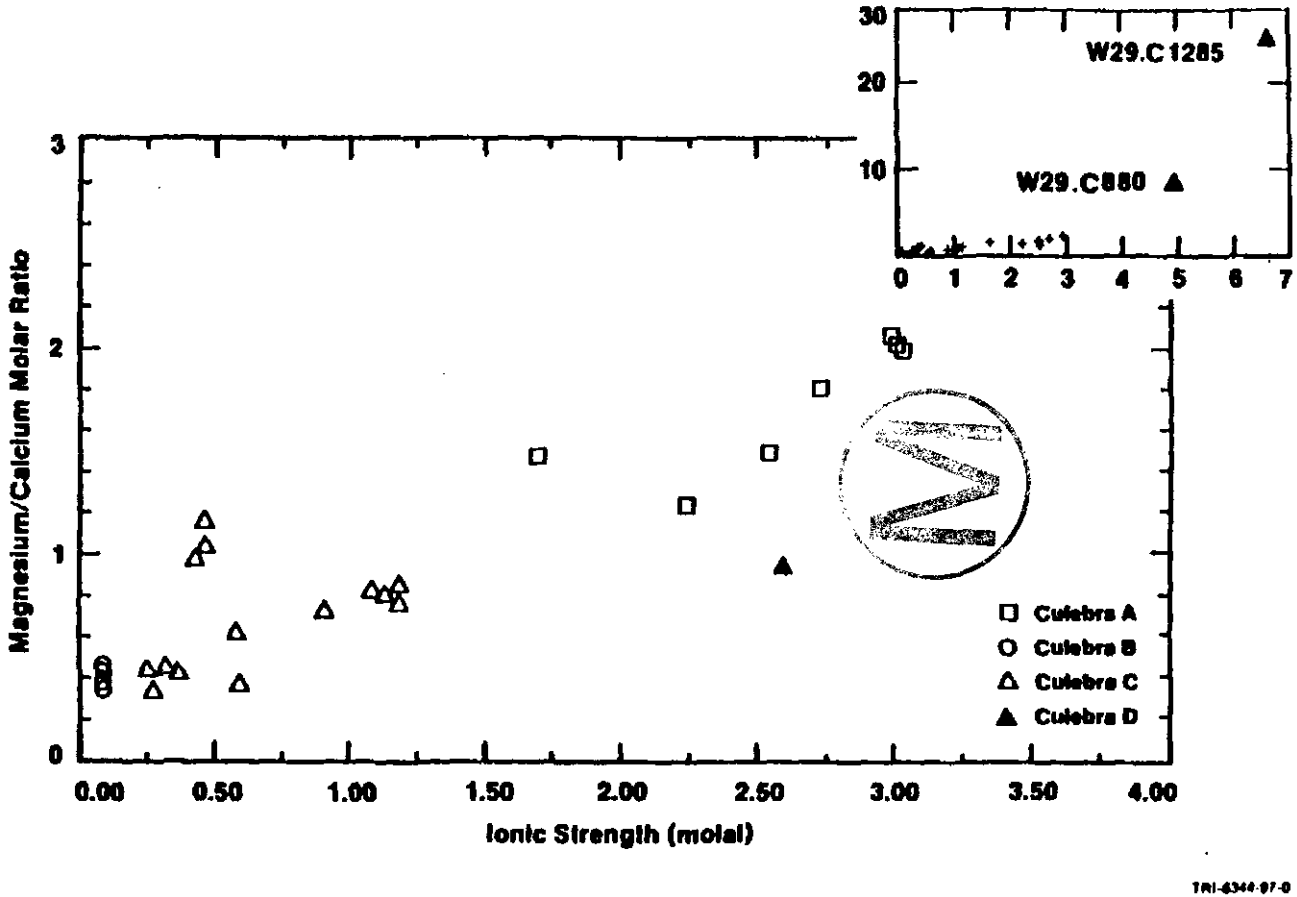

2-19 Relationship between Mg/Ca molar ratios and ionic strengths of Culebra groundwaters.
The Mg/Ca molar ratios were calculated from the UNC Geotech data given in Table 2; ionic strengths are also given in Table 2. Hydrochemical facies is indicated for each sample.

CHAPTER 5: ISOTOPIC CONSTRAINTS ON THE RUSTLER AND DEWEY LAKE GROUNDWATER SYSTEM

Section 5.2.4 Groundwaters Modified by Rock/Water Interactions, p 5-18;

" Confined groundwaters from the Rustler/Salado contact in Nash Draw have meteoric isotopic compositions typical of other Rustler waters. Toward the east, over the WIPP Site, however, the isotopic composition of water from the Rustler/Salado contact shows progressively more positive deviation in δ-value ('isotope shift') from typical Rustler meteoric values (Figure 5-4). Shift-contours roughly parallel the boundaries drawn by Snyder (1985) (dotted line in Figure 5-4) delineating the stratigraphic positions of halite occurrence in the Rustler. The zero-shift contour parallels the scarp defining Nash Draw at Livingston Ridge. The magnitude of the shift is correlative with measured decreases in transmissivity (cf. Mercer, 1983), increasing distance from the eastern dissolution scarp of Nash Draw (cf. Bachman, 1985; 1987), and an increasing amount of halite surviving in the Rustler Formation (cf. Snyder, 1985).

Assuming an eastward-progressing halite-dissolution front, total removal of halite by dissolution in the Rustler has been faster than eastward scarp retreat, development of increased permeability due to subsidence-induced fracturing, and flushing of isotopically shifted water. The isotope shift is attributable to an increasing amount of rock/water interaction accompanying a diminishing water/rock ratio (cf. Clayton et. al., 1966). The precise mechanism of isotope exchange and the reactant solid phase have not been identified, but the potential effect of anhydrite hydration to gypsum or the contribution of a relatively large reservoir of exchangeable water of crystallization in existing gypsum relative to a smaller amount of groundwater should not be overlooked."

p. 5-54, para. 2;

" The Sr_{DL} data show a very wide range in Sr isotopic composition. This reflects the role of denitral Sr brought into the Delaware Basin during sedimentation and also reflects later exchange with waters. The surface caliche and gypsite spring deposits (Sr_{CL}) yield high $^{87}Sr/^{86}Sr$ values consistent with prediction based on mixed provenance for these occurrences. Note that the Pleistocene gypsite spring deposit (Bachman, 1981) contains high $^{87}Sr/^{86}Sr$ material more closely associated with a large component of shallow derivation, similar to the Dewey Lake veins, and is not the result of direct remobilization of the Rustler sulfates at depth. In turn, gypsum veining in the Dewey Lake Red Beds cannot be derived directly and solely from partial dissolution of Rustler sulfates, without the admixture of an apparently surficial component having a significantly higher $^{87}Sr/^{86}Sr$ ratio than the Rustler sulfates."

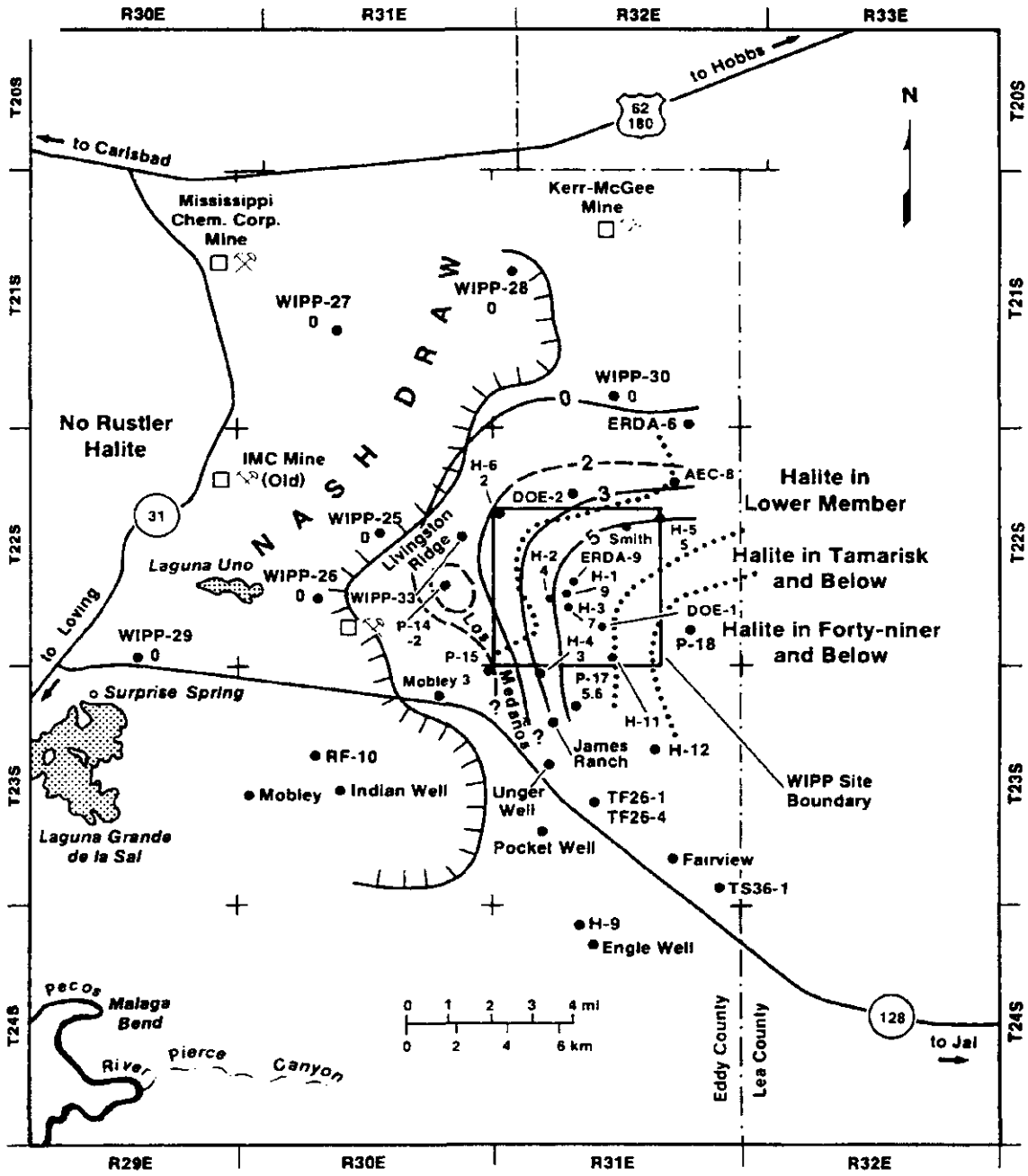

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Figure 5-4. Contour map of oxygen-isotope shift in confined groundwaters at the Rustler/Salado contact, relative to -7‰ (from Lambert and Harvey [1987]).

5.6.4 Inferred Influences of Meteoric Water, p 5-65;

" The reproducibility of δD measurements on gypsums, together with the reproducibility of the water yield of the rock samples (Table 5-3), indicates little if any post-coring exchange of hydrogen isotopes in the water of crystallization of gypsum under conditions of sample storage and laboratory analysis. The analyses were carried out over a period of time during which the temperature and relative humidity were undergoing radical day-to-day changes in the laboratory, accompanying a change in the configuration in the building ventilation system (from summer to winter). The reproducibility of replicate measurements suggests a minimal influence of ambient laboratory conditions on the gypsum D/H ratios. Thus, the D/H ratios in gypsum are taken to represent the in situ isotopic compositions and are assumed to have been determined by the last episode of recrystallization of gypsum in the presence of a given water and a given water/rock ratio.

The gypsum/water fractionation factor (Equation A) was used together with the ranges of δD values of the two different populations of water samples (confined Rustler-type versus less confined shallow-type) to calculate the expected δD values of recrystallized gypsum under varying water/rock ratios. Since the former population of waters (Rustler-type) ranges in δD value between -44 and -58‰ (Section 5.2.3), a very small water/rock ratio would yield a range of -64 to -78‰. These ranges are depicted in Figure 5-19. Similarly, the latter population of waters (shallow-type) range in δD between -17 and -41‰, yielding this same range for gypsums expected to have formed in the presence of this water, gives a small water/rock ratio. A large water/rock ratio would yield the range -37 to -61‰. These ranges are depicted in Figure 5-20.

Taken together, Figures 5-19 and 5-20 show that the δD values of the Rustler gypsum and Dewey Lake selenite vein material at AEC-8 and gypsum from the WIPP-33 Forty-niner and WIPP-34 Magenta are consistent with recrystallization in the presence of a water that isotopically resembles typical Rustler meteoric water, inferred to be late Pleistocene or older (Figure 5-20). However, they are not consistent with recrystallization in the presence of shallow-type water inferred to be modern (Figure 5-20). Also, the WIPP-19 sample cannot be easily generated from Rustler-type water alone, regardless of water/rock ratio. Note that if 0.985 instead of 0.980 is used for the α-value in Equation 1, these constraints apply to one of the WIPP-34 Forty-niner data points also. If the Rustler-type waters more depleted in deuterium are at least as old as late Pleistocene (Section 5.3.5.3), and no waters of similar isotopic composition have entered the subsurface since, then the time of recrystallization also is at least that old, since such groundwaters are not characteristic of modern recharge (Section 5.2.3). These constraints preclude both total preservation of these gypsums as primary seawater precipitates and their recrystallization in response to infiltration typified by local modern meteoric isotopic compositions. Whereas Rustler dolomites generally have not recrystallized in isotopic equilibrium with Rustler water (except at WIPP-33; see Figure 5-6), much of the gypsum in the Ochoan section has done so."

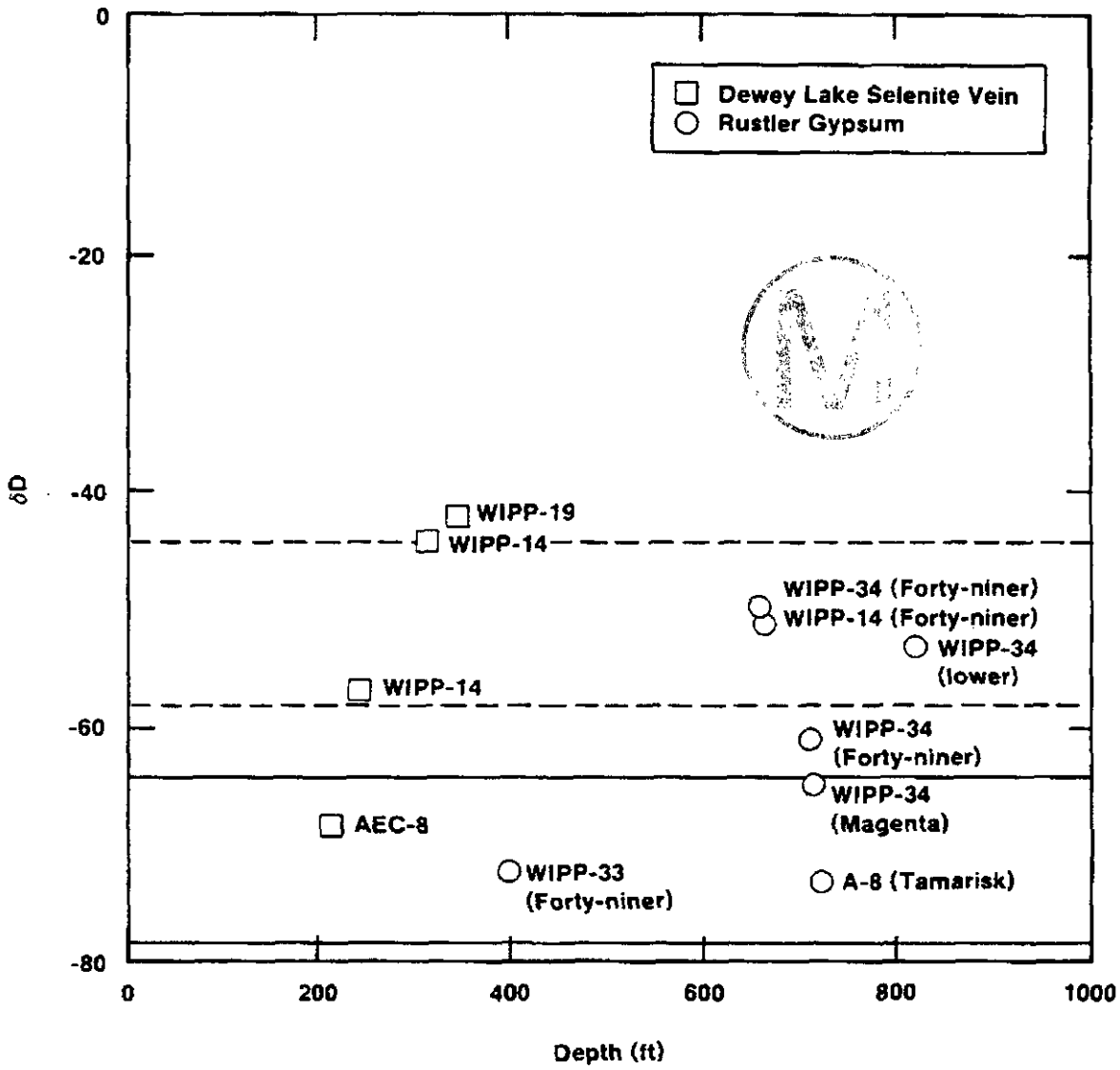

Figure 5-19. δD values of the water of crystallization in gypsums as a function of depth.

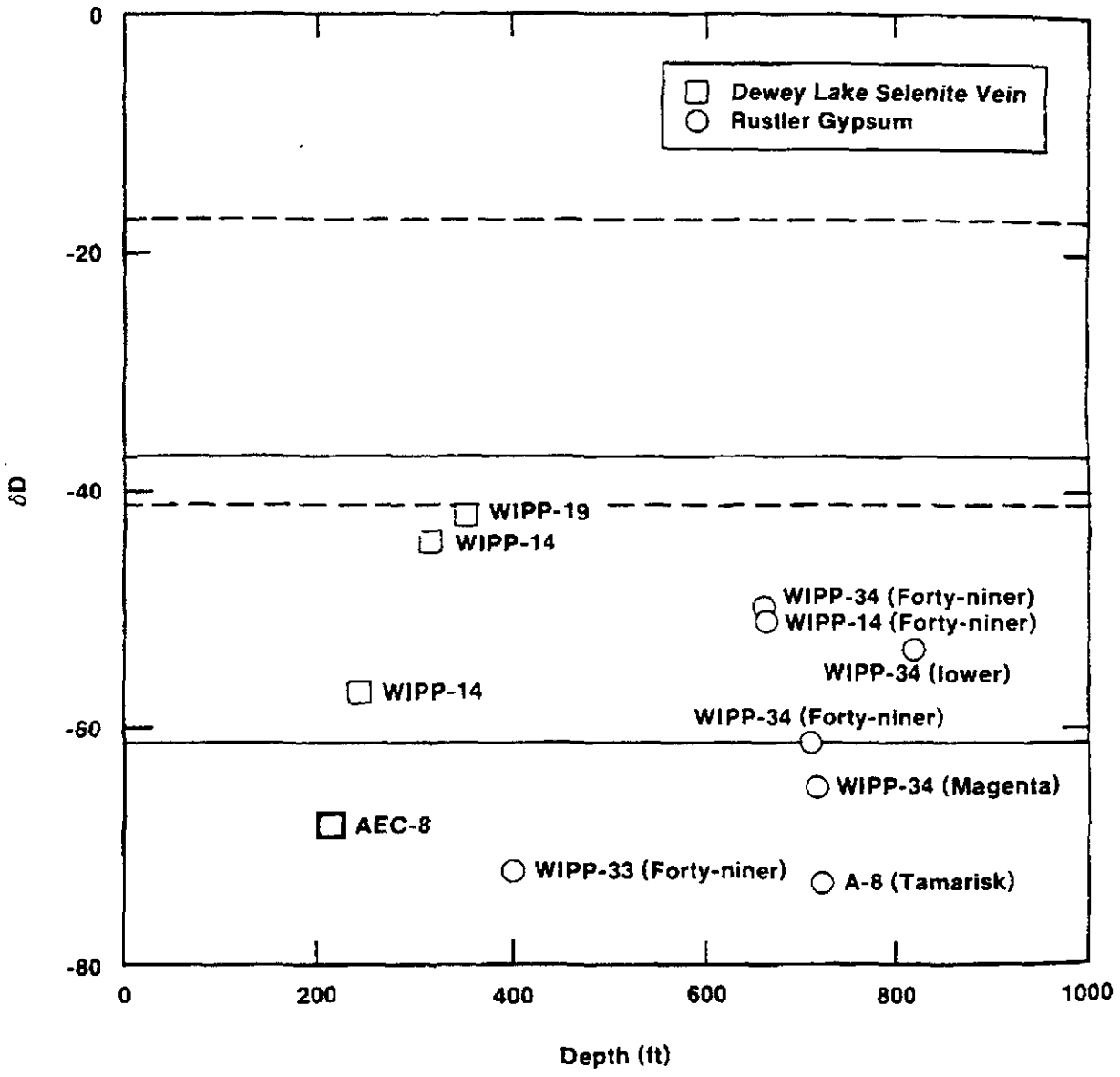

Figure 5-20. δD values of the water of crystallization in gypsums as a function of depth.

Snider, H.I. 1966. "Stratigraphy and Associated Tectonics of the Upper Permian Castile-Salado-Rustler Evaporite Complex, Delaware Basin, West Texas and Southeast New Mexico." Ph.D. dissertation. University of New Mexico, Albuquerque, NM.

ABSTRACT, P 1;

" The Delaware basin of west Texas and southeast New Mexico is roughly pear-shaped with a northwest-southeast length of about 140 miles and a width of 100 miles in the northwest tapering to 60 miles in the southeast--an area of about 10,000 square miles. In late Permian time the basin was essentially encircled by a carbonate depositional environment or reef zone.

The Upper Permian evaporite complex within the Delaware basin consists of Castile, Salado, and Rustler Formations. The Castile Formation contains laminated calcareous anhydrite, halite, and limestone. The Castile Formation was subdivided into seven units: Anhydrite I, Halite I, Anhydrite II, Halite II, Anhydrite III, Anhydrite IV, and Anhydrite V. The lowest four units can be traced over two-thirds of the basin. The upper three units can only be differentiated in the eastern part of the basin. The Salado Formation consists of halite and anhydrite with minor clastics, magnesite, and potassium minerals in the north and east parts of the basin. In the south and west parts of the basin, the Salado consists mainly of anhydrite dolomite, and clastics. The Rustler Formation contains anhydrite, dolomite, clastics, and halite.

The distribution of halite may reflect tectonism during Castile time. Little to no halite is found on the intrabasin shelf, while thick halite beds are found in the Ochoa trough. Halite units of the Castile Formation may have overlapped to the south due to differential subsidence or 'tilting' southward of the Ochoa trough. A reversal of this tilting occurred in Salado time.

Evidence of local movement in Castile units is abundant. Four models are analyzed to account for salt structures found: 1. salt movement contemporaneous with deposition--'down building'; 2. post-depositional halite piercement; 3. post-depositional lateral movement of upper halite over lower halite stock, dome, or anticline; and 4. gravity flow of upper halite over a lower halite structure--'anticline on anticline.' Tectonic 'triggering' is suggested as the major cause of Castile halite movement. Regional movement resulting in structures similar to 'salt pillows' or 'salt stocks' is believed to have occurred in the northeast part of the Delaware basin in Lea County, New Mexico."

p. 39;

" The thickness of the Castile Formation ranges from 1,250 feet in the western part of the Delaware basin to more than 2,000 feet in the east-central part and in the extreme northeastern part of the Delaware basin (Fig. 14, in pocket). A net footage map of halite in the Castile Formation (Fig. 15, in pocket) shows the range of thickness from no halite in the western, southern, and southeastern parts of the Delaware basin to more than 650 feet in east-central and northeastern parts. A net footage map of non-halite strata, primarily laminated anhydrite (Fig. 16, in pocket) shows a range of thickness from 1,000 to 1,500 feet

over most of the basin. Thicknesses of non-halite greater than 1,500 feet are generally found along the basin margin to the east and to the south."

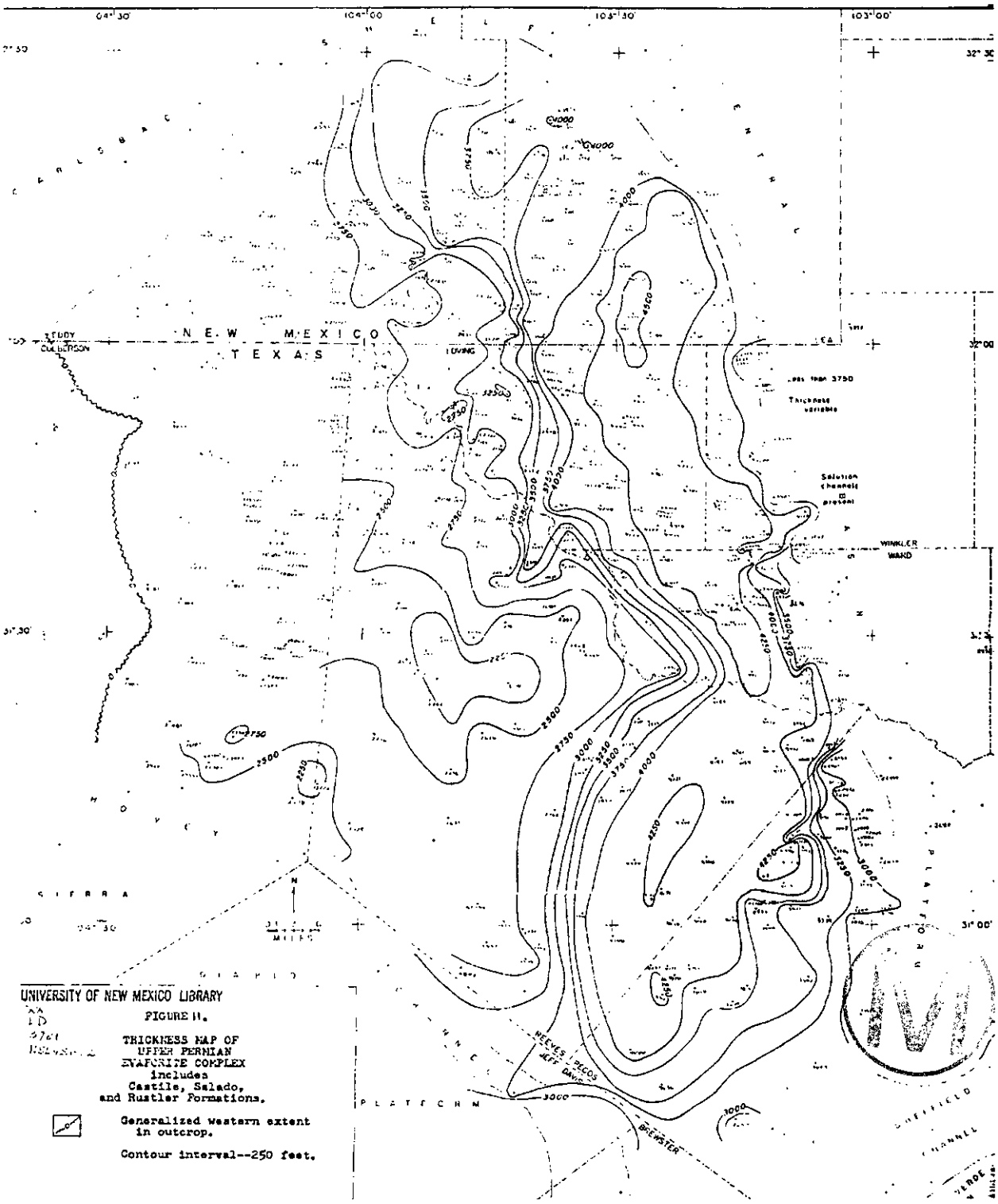
N E W M E X I C O
T E X A S
EDDY
CULBERSON
LOVING
WINKLER
WARD
Thickness variable
Solution channels present
S I E R R A
P L A T E C H M
HEMPHILL
SHEFFIELD CHANNEL
HEMPHILL
HEMVES
PECOS
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FIGURE 11.
THICKNESS MAP OF UPPER PERMIAN EVAPORITE COMPLEX includes Castile, Salado, and Rustler Formations.
Generalized western extent in outcrop.
Contour interval--250 feet.

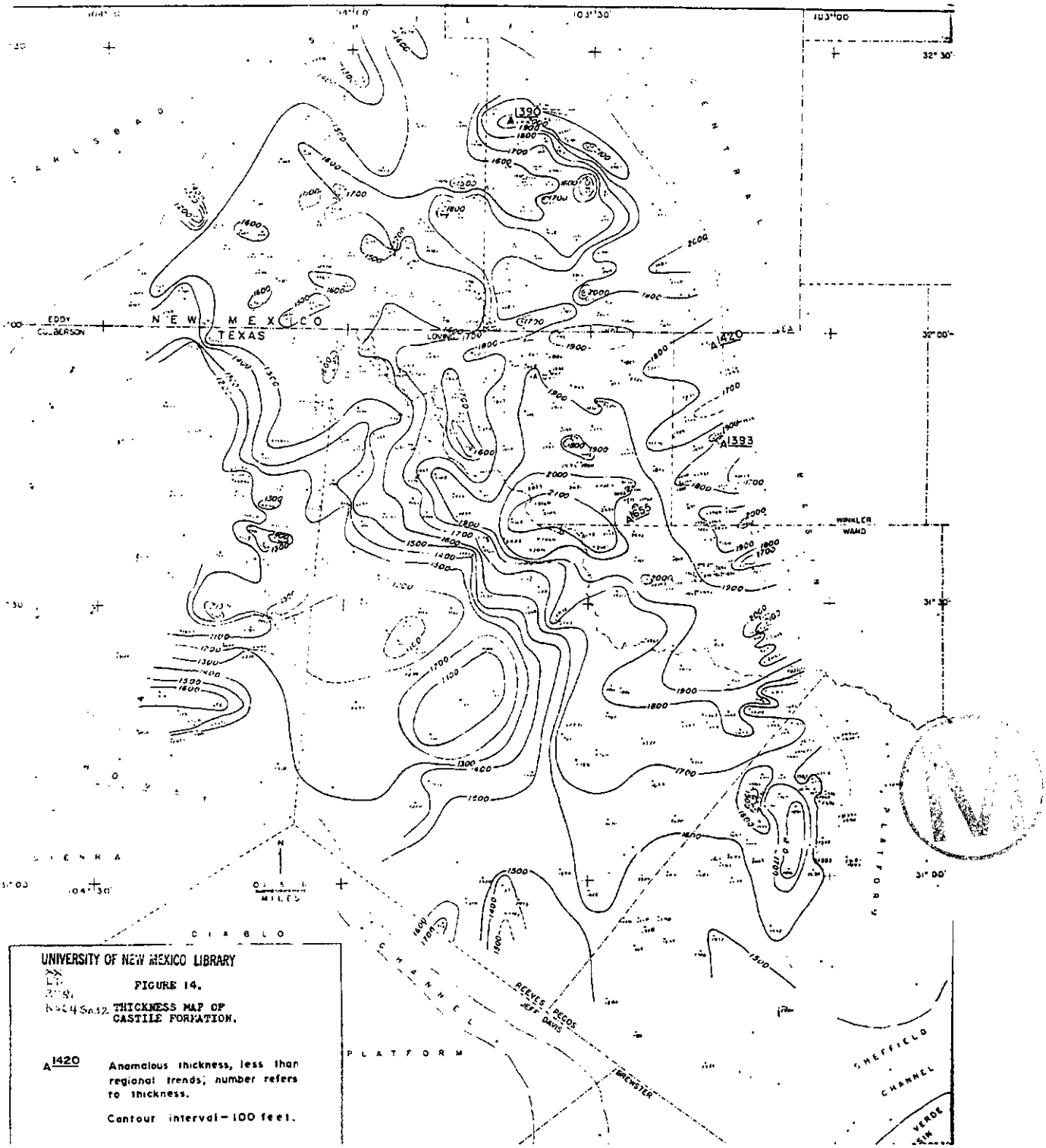

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FIGURE 14.

THICKNESS MAP OF CASTILE FORMATION.

A1420 Anomalous thickness, less than regional trends; number refers to thickness.

Contour interval = 100 feet.

Snyder, R.P., 1985. Dissolution of Halite and Gypsum, and Hydration of Anydrite to Gypsum, Rustler Formation, in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico. Open-File Report 85-229. U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;
" Data from selected drill holes spaced at intervals of 1.5 to 15 km (5,000 to 50,000 ft) in southeastern New Mexico demonstrate a progressive removal of halite by dissolution, hydration of anhydrite to gypsum, and removal of gypsum by dissolution in the Permian Rustler Formation. Thickness of the Rustler decreases as halite is removed, but increases after complete removal due to the hydration of anhydrite to gypsum."

Introduction, p 1, para 2;
" The U.S. Department of Energy (DOE) has selected a site in southeastern New Mexico for the development of a Waste Isolation Pilot Plant (WIPP). The site (fig. 1), 40 km (25 mi) east of Carlsbad, is to be used as a test area for the underground storage of military radioactive waste in bedded salt (halite). Evaporites, mostly halite and anhydrite, constitute the major rock types at the WIPP site to a depth of about 1,280 m (4,200 ft).

Circulating ground water has removed halite, and thus has caused concern about the integrity of the stored waste. The Rustler Formation of Permian age is the uppermost unit at the site that contain evaporites. In addition to halite and anhydrite, the formation also contains two dolomite beds that are known aquifers.

More than 70 holes (Mercer, 1983, p. 7) have been drilled on or near the WIPP site to study the structure, stratigraphy, lithology, and hydrology of the area. The data for this study are from five of these holes plus one hole drilled for the U.S. Bureau of Land Management (BLM) southwest of the site. Lithologic descriptions of the units penetrated were obtained from cores and cuttings supplemented by interpretation of geophysical logs.

STRATIGRAPHY AND LITHOLOGY OF THE RUSTLER FORMATION, p 3, para 7:
" The Culebra Dolomite Member, a 6 to 9.1 m (20 to 30 ft) thick finely crystalline vuggy dolomite overlies the unnamed lower member. The vugs are diagnostic of the Culebra, and may have been formed by gas bubbles during or shortly after deposition (Vine, 1963, B-14). The vugs in some drill holes contain halite or gypsum. The Culebra is one of two known aquifers in the Rustler Formation near the WIPP site. Mercer (1983, p. 60) suggests that direction of ground-water movement in the fractured Culebra Dolomite is affected by directional differences in hydraulic conductivity (anisotropy), and that the regional direction of flow may show little or no relationship to localized direction of flow. The contours on the potentiometric-surface map (Mercer, 1983, fig. 17) show a southward flow trend in the vicinity of the WIPP site.

p 6, para 4, line 1;
" In drill hole W-21, about 3,505 m (11,500 ft) west of P-10, each of the three halite/anhydrite bearing members show evidence of dissolution and hydration. About half the

halite is the unnamed lower member has been removed, and the anhydrite beds are partly converted to gypsum. The halite in the Tamarisk and Forty-niner Members has been completely removed, leaving only silt and clay residue; and much of the anhydrite has been altered to gypsum. The polyhalite bed, represented in drill holes P-10 and P-18, is missing from the Tamarisk member in this hole. Thickening of anhydrite beds as they alter to gypsum is apparent in the Tamarisk and Forty-niner Members (fig. 2). Vine (1963) described a massive siltstone in Forty-niner Member outcrops found west of Livingston Ridge. Jones and others (1960) identified this siltstone as dissolution residue."

p. 8, para. 4;
" An isopach map of the Rustler Formation (fig. 4) shows a general pattern of dissolution of halite and hydration of anhydrite. On the east and progressively westward for about 3.2 km (2 mi) the formation thins. In this area only halite is being removed, generally from the Forty-niner Member. Figure 4 divides the WIPP area into four zones; from east to west they are: (1) no halite dissolved from Rustler Formation, (2) halite dissolved from Forty-niner Member, (3) halite dissolved from Tamarisk Member, and (4) halite dissolved from lower unnamed member. In the first two of these zones the Rustler Formation thins progressively westward, but in the third and fourth zones the formation thins and thickens depending on how much anhydrite has altered to gypsum."

CONCLUSIONS, p. 10;

As one progresses westward across the WIPP site there is both a progressive dissolution of halite and a gradual hydration of anhydrite to gypsum. Seemingly, halite from the uppermost member, the Forty-niner, is removed first, followed by removal of halite from the middle Tamarisk Member, and then finally from the unnamed lower member. The intervening dolomite member are not directly affected by these processes, but as halite is removed from below each of them, the dolomites settle and fracture and transmit ground water more readily. At some stage in the removal of halite, possibly when the dissolution reaches a point where the anhydrites settle and crack allowing ground water to flow through them, the anhydrites begin hydrating to gypsum. This process tends to thicken the formation even though halite is being removed. The mutual interaction between these two processes results in an erratic thickening and thinning of the Rustler Formation as seen on the isopach map (fig. 4).

The increase in transmissivity in the Magenta and Culebra Dolomite Members seems to 'feed upon itself;' fracturing increases as more halite is removed and more anhydrite alters to gypsum, more ground water moves through these aquifers removing more halite and altering more anhydrite. Eventually all the gypsum formed is also removed by dissolution. . . ."

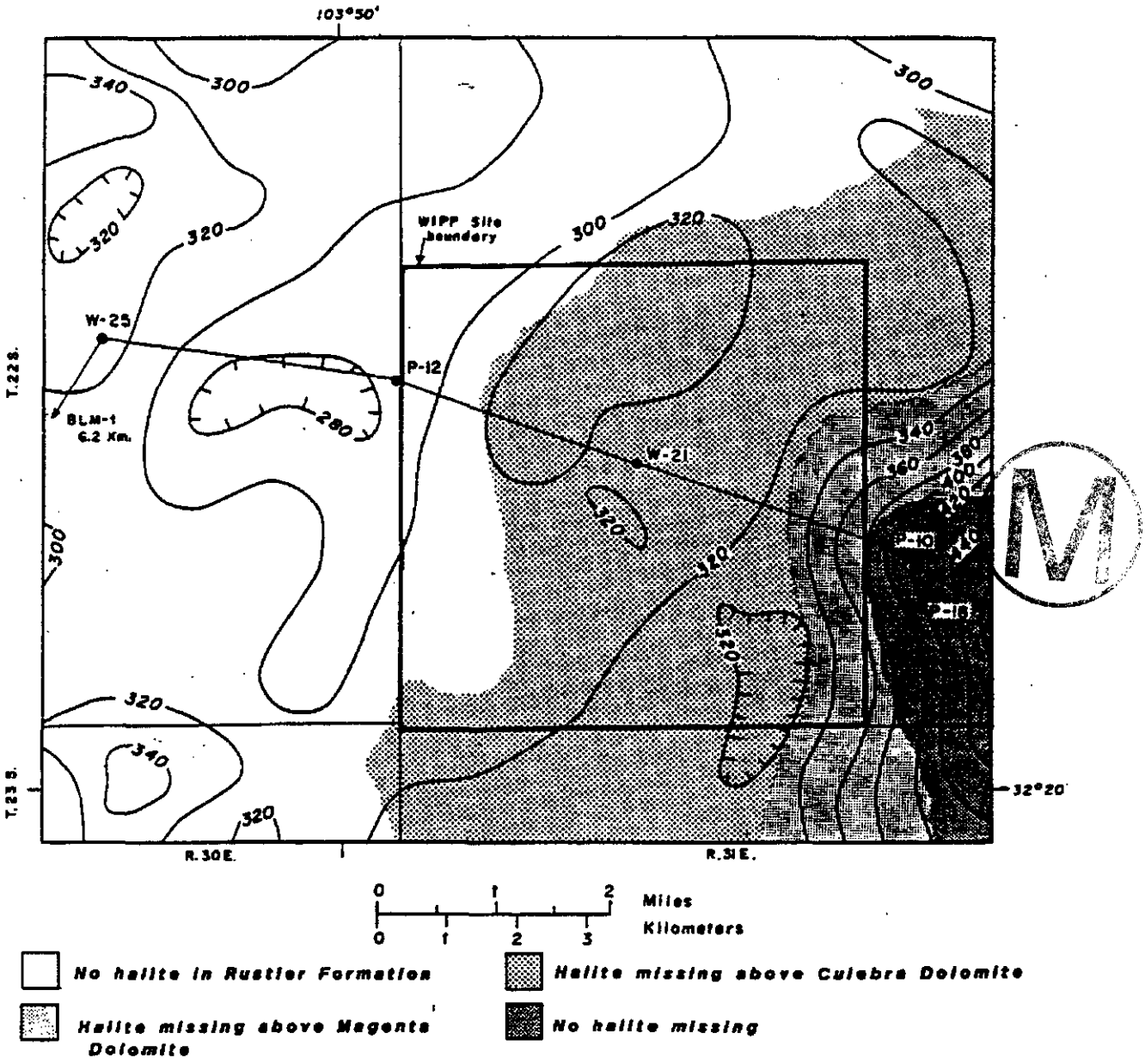

Figure 4.--Isopach map of the Rustler Formation in the vicinity of the WIPP site showing dissolution zones. (Hachures indicate closed lows.)

Snyder, R.P., Gard, Jr., L.M., and Mercer, J.W. 1982. Evaluation of Breccia Pipes In Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, With Section on Drill-Stem Tests. Open-File Report 82-968. U.S. Geological Survey, Denver, CO.

INTRODUCTION, p. 1;

" The Waste Isolation Pilot Plant (WIPP) site is located about 40 km (25 mi) east of Carlsbad, N. Mex. (fig. 1). The site geography has been described in detail by Powers and others (1978) and U.S. Department of Energy (1980, 1981). Site selection was based principally on the existence of a thick section of Permian evaporites, mainly halite. The purpose of establishing this site is to demonstrate whether or not an evaporite environment is acceptable for the disposal of trans-uranic waste generated by the Nation's defense programs.

The primary concern regarding safe disposal of nuclear waste is to isolate the waste from the biosphere until it is no longer a danger to mankind. One of the most probable methods of accidental release of radiation from nuclear waste isolated in a geologic medium is leaching and transport of the waste by moving ground water. It is therefore of primary importance to identify any potential channelways that might allow water to enter a repository site located on bedded salt of the Salado Formation of southeastern New Mexico. The presence of the thick Permian (225 m.y.) rocks attests to the fact that major dissolution of the halite by unsaturated ground water has not occurred at the WIPP site.

Focus of Current Study

This report describes several dissolution features in the Delaware Basin and elsewhere that have been referred to as breccia pipes. Breccia pipes (also called breccia chimneys) as they occur in evaporites are vertical cylindrical pipes or chimneys that may or may not involve more than one geologic formation. The chimneys are filled with downward-displaced brecciated rock. In this context, the rock is brecciated by having collapsed into a void at depth that was probably created by ground-water solution and removal of deep-lying evaporite or carbonate rocks in an underlying aquifer system (Anderson and Kirkland, 1980; Bachman, 1980). Such features have been described in evaporite deposits in many areas of the world.

The current study was done for the U.S. Department of Energy (DOE) in response to a suggestion that because breccia pipes are thought to be the result of deep dissolution, they may represent channelways for future ingress of ground water, and that they should be considered in risk assessment programs for the evaluation of proposed waste repositories in bedded evaporite rocks. To this end, features referred to as breccia pipes in southeastern New Mexico have been assessed in relation to the integrity of the WIPP site. Reports by Anderson (1978), Bachman (1980), and Vine (1960) described dissolution and karst features in the Pecos region of southeastern New Mexico and discussed the origin and history of breccia pipes. The present report is intended to supplement these studies and provide detail that was not available to them at the time their reports were written.

Using the data from exploratory work, answers may be found to the following

questions concerning breccia pipes:

1. Do breccia pipes penetrate through the evaporite section?
2. What is the physical description of a pipe?
3. How are they formed?
4. How deep do they go?
5. When are they formed, and are they forming at present?
6. Are they permeable?
7. Where are they formed, can they form at the WIPP site?
8. Do they represent a threat to the WIPP site?"

Possible Effect on WIPP Site, p 65;

" Numerous domes and sinks dot the landscape in the Delaware Basin. Some of these features can be shown to be remnants of near-surface dissolution or surface erosion; others are from dissolution and cavity formation in the Capitan Limestone. Known locations where deep dissolution occurs and forms structures called breccia pipes are limited to areas over the buried Capitan reef, no closer than 16 km (10 mi) to the WIPP site. The four known occurrences are Hills A, B, C, and the Wills-Weaver site.

Collapse of these structures, at least to the surface, occurred sometime before 400,000-500,000 years ago.

Locales on and around the WIPP site that were investigated for evidence of pipe formation, with none being found, include the sites of drill holes WIPP 13, WIPP 32, WIPP 33, and WIPP 34. Numerous surface features were mapped and found to be near-surface erosion and dissolution features.

No examples of breccia pipes that could lead to breaching of a repository at the WIPP site have been found to date and are not likely because the Capitan Limestone is not present beneath the site."

Stensrud, W.A., 1995. Culebra Transport Program Test Plan: Hydraulic Tests at Wells WQSP-1, WQSP-2, WQSP-3, WQSP-4, WQSP-5, WQSP-6, and WQSP-6a at the Waste Isolation Pilot Plant (WIPP) Site. On file in the Sandia WIPP Central Files.

1.1 Summary, p. 1;

" This Test Plan describes the purpose, objectives, design, equipment, and methodologies for hydraulic tests to be performed by Sandia National Laboratories (SNL) in seven Water Quality Sampling Program (WQSP) wells at the Waste Isolation Pilot Plant (WIPP) site located in southeastern New Mexico (Figure 1-1). The wells were drilled by the Waste Isolation Division (WID) of Westinghouse Electric Corporation during September and October 1994 to provide locations for long-term water-quality monitoring. The locations of the WQSP wells are shown on Figure 1-2."

Thompson, G.A., and Zoback, M.L. 1979. Regional Geophysics of the Colorado Plateau. Technophysics, Vol. 61, Nos. 1-3, pp. 149-181.

ABSTRACT, p. 149, Para. 2;
" The Colorado Plateau (CP) is a relatively coherent block surrounded on three sides by the extensional black faulted regime of the Basin and Range Province (BRP) and the Rio Grande Rift (RGR). The CP appears to be part of an inter-related system including the Sierra Nevada, BRP, and the RGR which has undergone major uplift and extension during the last 20 m.y. The final elevation in any area probably depends upon which processes dominate there.

In most geophysical properties the CP is intermediate between the BRP/RGR and the stable platform of the southern Great Plains. However, many BRP/RGR geophysical characteristics appear to extend well inward of the classical Plateau physiographic boundary. Geologically these 50-100 km wide zones of transition are marked by normal faulting and late Tertiary and Quaternary volcanism. The interior of the Plateau is characterized by a 40 km-thick crust, a P_n velocity of about 7.85 km/sec, and an average heat flow of 1.5-1.6 HFU. Available data on the modern stress field in the Plateau interior indicate high horizontal stresses and a stress field oriented differently from that in the surrounding BRP/RGR, inconsistent with the theory that the plateau is merely an inherited, more coherent subplate subjected to the same stresses as it's surroundings."

Seismic refraction data, p. 152, Para. 2;
" A major and surprising result emerged from seismic refraction experiments beginning with the work of Tatel and Tuve (1995). Compared to stable regions the crust in the elevated, tectonically active region from the Rocky Mountains to the Sierra Nevada Range is abnormally thin, and upper mantle velocities are anomalously low. Within this region, the crust of the CP is thicker than that of the BRP and RGR, which have been subjected to extentional tectonism; however, the changes in thickness do not everywhere correspond with province boundaries. Currently available refraction data are not adequate to define all the major variations within provinces, especially within CP.

Our profile line (Fig. 2) crosses or passes near only three reversed refraction lines. On the figure we have indicated published sources of data and whether the lines were reversed or unreversed; also measurements projected from off the profile are so indicated. Major conclusions from the data of Fig. 2 are: (1) crustal thickness beneath the CP, about 40 km (measured from sea level), is intermediate between that of the BRP, about 30 km, and southern Great Plains, about 50 km; (2) upper mantle (P_n) velocities are 7.8-7.9 km/sec across most of the BRP, CP, and RGR, in marked contrast to 8.2 km/sec beneath the southern Great Plains; (3) the P_n velocity is lowest, about 7.4 km/sec, in the eastern BRP and through a transition zone of the CP to the limits of normal faults that shred the western edge of the CP; and (4) average upper crustal velocity is significantly greater beneath the CP (6.2-6.4 km/sec) than beneath the BRP and RGR (5.9-6.1 km/sec)."

UNM (University of New Mexico). 1984. A Handbook of Rare and Endemic Plants of New Mexico. New Mexico Native Plants Protection Advisory Committee, eds. University of New Mexico Press, Albuquerque, NM.

PREFACE, p xiii;

" The New Mexico Native Plant Protection Advisory Committee is an *ad hoc* group of professionals in the field of botany, representing the academic community, land managers, and private industry. The committee has served informally at the discretion of the governor, under the direction of the secretary of natural resources of New Mexico since 1977. The New Mexico Natural Heritage Program serves as secretary for the committee.

Although the committee has provided the U.S. Fish and Wildlife Service and the New Mexico Natural Heritage Program with information and advice regarding the status of our rarer plant species, this is the first major work produced as a committee effort.

In compiling data for this book, the committee has attempted to provide a single source of information on rare and endemic plants useful both to land managers and to the general public. Plants covered either are principally found in New Mexico or require special management attention. All plants nominated for protection under the Endangered Species Act are included, regardless of their relative abundance."

U.S. Congress, 1992. Waste Isolation Pilot Plant Land Withdrawal Act. Public Law 102-579, October, 1992. 102nd Congress, Washington, D.C.

"An Act
To withdraw land for the Waste Isolation Pilot Plant, and for other purposes.
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,"

SEC.3.LAND WITHDRAWAL AND RESERVATION FOR WIPP.;
" (a)LAND WITHDRAWAL, JURISDICTION, AND RESERVATION.--

(1)LAND WITHDRAWAL.--Subject to valid existing rights, and except as otherwise provided in this Act, the lands described in subsection (c) are withdrawn from all forms of entry, appropriation, and disposal under the public land laws, including without limitation the mineral leasing laws, the geothermal leasing laws, the material sale laws (except as provided in section 4(b)(4) of this Act), and the mining laws.

(2)JURISDICTION.--Except as otherwise provided in this Act, jurisdiction over the Withdrawal is transferred from the Secretary of the Interior to the Secretary.

(3)RESERVATION.--Such lands are reserved for the use of the Secretary for the construction, experimentation, operation, repair and maintenance, disposal, shutdown, monitoring, decommissioning, and other authorized activities associated with the purposes of WIPP as set forth in section 213 of the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Pub.L. 96-164; 93 Stat. 1259, 1265), and this Act.

(b) REVOCATION OF PUBLIC LAND ORDERS.--Public Land Order 6403 of June 29, 1983, as modified by Public Land Order 6826 of January 28, 1991, and any memoranda of understanding accompanying such land orders, are revoked.

(c)LAND DESCRIPTION.--

(1)BOUNDARIES.--The boundaries depicted on the map issued by the Bureau of Land Management of the Department of the Interior, entitled 'WIPP Withdrawal Site Map,' dated October 9, 1990, and on file with the Bureau of Land Management, New Mexico State Office, are established as the boundaries of the Withdrawal.

(2)LEGAL DESCRIPTION AND MAP.--Within 30 days after the date of the enactment of this Act, the Secretary of the Interior shall--

(A) publish in the Federal register a notice containing a legal description of the Withdrawal; and

(B) file copies of the map described in paragraph (1) and the legal description of the Withdrawal with the Congress, the Secretary, the Governor of the State, and the Archivist of the United States."

U.S. Department of Commerce. 1980. Census of Population, General Population Characteristics of New Mexico. Bureau of the Census.

ABSTRACT;
" This report is a one page profile for specific single geographic areas giving detailed information of race, sex, age, households, and some housing characteristics. Geographic levels include the nation, states, SMSA'a, counties, and named places with 2,500 or more population. The report profile was developed to serve the information needs of the Employment and Training Administration; however, it can be used to satisfy other Population and Housing data requirements. This report series was prepared from data contained in Summary Tape File 1. This is one of five Summary Tape Files the Census Bureau plans to make available from the 1980 Census. A separate report is available for each state and the District of Columbia. Write to NTIS for price list and order form."

Intorduction, Abstract, p. iv;
" This report is a one-page profile of selected data from Summary Tape File 1 (STF1) of the 1980 Census of Population and Housing for various government units and census desugnated areas. STF1 summarizes only complete-count (100-percent) data items, i.e., responses to questions that were in the short form distributed to the entire United States population. Data items include age, sex, race, Hispanic origin, marital status, household type and household relationship. Housing items include information on occupancy status, tenure, vacancy rate, contract rent, value, number of condominiums, and plumbing facilities."

Introduction, Geographic coverage, p. iv;
" Areas covered by report 1A include:
- The United States
- State or State equivalent
- Standard Metropolitan Statistical Area (SMSA)
- County or County equivalent
- Places with population of 2,500 or more
- Comprehensive Employment and Training Act (CETA) Prime Sponsor Areas"

Report 1A: Population Characteristics, Table: Population and Housing Characteristics, Eddy County, p. 9;
" Population by Race, including Hispanics 47,855"

Report 1A: Population Characteristics, Table: Population and Housing Characteristics, Lea County, p. 14;
" Population by Race, including Hispanics 55,993"

U.S. Department of Commerce. 1990. Census of Population, General Population Characteristics of New Mexico. Bureau of the Census.

INTRODUCTION; p. 1-1, para. 2;
" Data from the 1990 census are presented in several different report series. These series are published under the following three subject titles:

1. 1990 Census of Population (1990 CP)

2. 1990 Census of Housing (1990 CH)

3. 1990 Census of Population and Housing (1990 CPH)

The types of data and the geographic areas shown in reports differ from one series to another. In most series, there is one report for each State, the District of Columbia, Puerto Rico, and the Virgin Islands of the United States (Virgin Islands), plus a United States summary report. Some series include reports for American Indian and Alaska Native areas, metropolitan areas, and urbanized areas. See appendix F for detailed information about the various report series; additional 1990 census data products such as computer tapes, microfiche, and laser disks; other related materials; and sources of assistance

The data from the 1990 census were derived from a limited number of basic questions asked of the entire population and about every housing unit (referred to as the 100-percent question), and from additional questions asked of a sample of the population and housing units (referred to as the sample questions). Two primary versions of questionnaires were used: a short form containing only the 100-percent questions and a long form containing both the 100-percent questions and the additional sample questions. Appendix E presents facsimiles of the questionnaire pages and the respondent instructions used to collect the data included in this report. Appendix F lists the subjects that are covered by the 100-percent and sample components of the 1990 census.

Legal provision for this census, which was conducted as of April 1, 1990, was made in the Act of Congress of August 31, 1954 (amended August 1957, December 1975, and October 1976), which is codified in Title 13, United States Code."

Table 1; Summary of General Characteristics of Persons: 1990; p. 1;
"

COUNTY	All Persons
. . .	
Eddy County	48,605 . . .
Lea County	55,765 . . ."

Vine, J.D., 1963. "Surface Geology of the Nash Draw Quadrangle, Eddy County, New Mexico." U.S. Geological Survey Bulletin 1141-B, U.S. Government Printing Office, Washington, D.C. WPO 29558.

ABSTRACT, p B1;

" Outycropping rocks and surficial deposits of the Nash Draw quadrangle were mapped to provide geologic information for the U.S. Atomic Energy Commission's Plowshare program. The quadrangle is near the north margin of the Delaware basin and about 15 miles east of Carlsbad, N. Mex. The region is sparsely inhabited and has an arid climate.

As much as 4,000 feet of salt and anhydrite of Permian age is present below the surface, but does not crop out in normal thickness in this area or elsewhere because of their high solubility. These rocks have been divided into the Castile formation below and the Salado formation above. Rocks exposed at the surface overlie these soluble rocks and include the Rustler formation of Late Permian age, the Pierce Canyon redbeds of Permian or Triassic age, the Santa Rosa sandstone of Late Triassic age, and the Gatuna formation, caliche, and a variety of unconsolidated deposits of late Cenozoic age.

The Rustler formation of Late Permian age is subdivided into four easily distinguishable members, excluding about 120 feet of the lower part, which is not exposed at the surface in this area. The oldest member exposed is the Culebra dolomite member, about 30 feet thick, identified only in erratically distributed outcrops in collapse areas. The Culebra consists of microcrystalline gray dolomite or dolomitic limestone characterized by numerous spherical cavities 1 to 10 mm in diameter. It is conformably overlain by the Tamarisk member, named herein for exposures directly east of Tamarisk Flat. It consists of about 115 feet of massive gypsum at the surface, changing to anhydrite in the subsurface, and a bed, 5 feet thick, of siltstone near the base. Surficial deformation caused by hydration and solution are characteristic of all the outcrops. The Tamarisk member is conformably overlain by the Magenta member, about 20 feet thick and consisting of alternating wavy laminae of pale-red dolomite and pale yellowish-green anhydrite or gypsum. The top member of the Rustler formation conformably overlies the Magenta and is here named the Forty-niner member after Forty-niner Ridge, where it crops out. In surface exposures it consists of about 40 to 65 feet of broken and slumped massive gypsum and a bed of siltstone in the lower part. The siltstone beds in the Tamarisk and Forty-niner members probably represent the insoluble residue of salt beds reported from the subsurface to the east."

Overlying the Rustler formation with apparent conformity are the Pierce Canyon redbeds of Permian or Triassic age. These rocks consist of about 200 to 250 feet of laminated or minutely cross-laminated moderate reddish-brown siltstone. The contact between the Pierce Canyon redbeds and the overlying Santa Rosa sandstone is a disconformity, at least locally.

The Santa Rosa sandstone of Late Triassic age consists of pale-red sandstone and conglomerate lenses crossbedded in sets 3 to 15 feet thick separated locally by moderate reddish-brown siltstone and claystone. Only the lower 50 to 70 feet of Santa Rosa was recognized in the area.

The Gatuna formation of Pleistocene (?) age unconformably overlies all older rocks. In much of the area it consists of 3 to 5 feet of moderate reddish-orange sandstone, siltstone, and conglomerate. Locally, in karst depressions, the Gatuna attains a thickness of at least 100 feet. In some areas the lithology closely resembles the Pierce Canyon redbeds or the Santa Rosa sandstone.

Caliche forms a resistant layer at the ground surface, 5 to 10 feet thick, that protects older rocks from erosion in many areas. The caliche consists of calcareous material with a variable amount of imbedded sand grains, pebbles, and rock fragments. Caliche mounds and broken flexure ridges, 10 to 15 feet high, have formed narrow zones 50 to several hundred feet long.

Quaternary alluvium has been deposited along the sides of depressions. It is overlain by playa lake deposits, which are in turn overlain by conspicuous sand dunes as much as 100 feet high.

The regional structure is relatively simple and consists of a dip of a few feet per mile to the east and southeast.

Normally flat-lying strata are tilted, warped, and locally distorted at the surface by hydration and solution of the evaporite rocks in the subsurface. Nash Draw, a depression 4 to 6 miles wide and about 18 miles long, has resulted from the solution of salt in the Rustler and Salado formations and collapse of the overlying relatively insoluble rocks. Topography and surface structure conform in some areas with the configuration of the underlying solution surface at the top of the massive salt in the Salado formation; however, locally there is an inverse correspondence. Many circular karst features 1/10 to 1/2 mile in diameter are in the area. Some of these features are structural domes, but they contain a core of tilted or brecciated rock. These karst features result from the formation and collapse of sinkholes, differential solution at the top of the massive salt, and hydration of the anhydrite beds."

p B14, para 2, line 4;

" Overlying the lower part is the Culebra dolomite member, consisting of about 30 feet of uniformly fine textured microcrystalline gray dolomite or dolomitic limestone. Adams (1944, p 1614) credits W. B. Lang with naming the Culebra for Culebra Bluff on the east side of the Pecos River, about 4 miles northeast of Loving. The rock is characterized by numerous small nearly spherical cavities that range from about 1 to 10 mm in diameter. These cavities are present both in surface exposures of the Culebra and in core taken from the AEC drill hole 1 and therefore are presumed to be either a primary or a diagenetic phenomenon and not related to surface weathering. Some of the cavities are partly filled with secondary gypsum or calcite, but most are open. There seems to be little or no tendency for the cavities to be connected, as might be expected if they were formed by solution in a homogeneous rock. These features suggest that they were formed by the solution of a highly soluble mineral aggregate or by the inclusion of a gas or liquid at the time the sediment was soft. Locally, the Culebra is finely oolitic, and the individual oolites are less than 0.5 mm in diameter.

Exposures of the Culebra dolomite member are in the southern part of the Nash Draw

quadrangle, east of Salt Lake where the rocks are locally deformed by solution collapse, which has caused the outcrop pattern to be irregular. The Culebra outcrops are brecciated locally. For this reason the Culebra was not seen in normal stratigraphic sequence with the underlying and overlying rocks in the Nash Draw quadrangle.

Overlying the Culebra dolomite member is the Tamarisk member of the Rustler formation. The Tamarisk consists of about 115 feet of massive gypsum in exposures but is chiefly anhydrite and locally gypsum in the subsurface, except for a bed 5 feet thick, of siltstone about 20 feet above the base. The siltstone is thought to represent the insoluble residue from a halite bed in the subsurface (Jones and others, 1960, fig. 1). This member forms a broad expanse of barren outcrop 2 to 3 miles wide and about 7 miles long east of Tamarisk Flat, from which the name is here taken."

SANTA ROSA SANDSTONE OF TRIASSIC AGE, p B25, para 3;

" The Santa Rosa sandstone disconformably overlies the Pierce Canyon redbeds. Only the lower 50 to 70 feet of the Santa Rosa sandstone is present in the northern and northeastern part of the Nash Draw quadrangle and therefore the total thickness of the formation could not be determined. In general, the Santa Rosa consists of large-scale trough-type crossbedded pale-red sandstone and conglomerate lenses, 3 to 15 feet thick, separated by thin partings of moderate reddish-brown siltstone and silty claystone (fig. 12). The conglomerate lenses contain both silty dolomite pebbles and chert or quartz pebbles. The sandstone is characteristically poorly sorted. The formation differs from the underlying Pierce Canyon redbeds by being coarser grained, less well sorted, and by having beds that are thicker and more lenticular."

GATUNA FORMATION OF PLEISTOCENE (?) AGE, p B27, para 6;

" The Gatuna formation unconformably overlies the Permian and Triassic rocks in the quadrangle, except where it has been removed by erosion. In most of the area the Gatuna formation is only about 3 to 5 feet thick and is directly overlain by Recent caliche that is more resistant than the Gatuna and masks the underlying rocks. Therefore, except where the Gatuna is thick or forms a broad enough exposure to map separately, it is shown together with the caliche on the geologic map (pl. 1). In general, the Gatuna formation consists of moderate reddish-orange friable sandstone, siltstone, and conglomerate, but locally includes gypsum, gray shale, and claystone. The Gatuna is as much as 100 feet thick locally."

GEOMORPHOLOGY, p. B38, para. 2, line 5;

" At least locally, the rocks exposed along the margins of Nash Draw exhibit dips in toward the center of the topographic depression, contrary to a structural picture consistent with an anticline (fig. 11). The structure of the marker beds within the Salado formation as revealed by well records indicates a gentle homoclinal structure (pl. 1). The anomalous dips seen in surface exposures are interpreted to represent surficial deformation later than the tectonic structures as a result of collapse into the Nash Draw depression. Nash Draw is, therefore, thought to be an undrained physiographic depression superimposed over a gentle

homoclinal structure. The depression probably resulted from regional differential solution of beds in the upper part of the Salado formation. Nash Draw is separated by a gentle divide area from a large depression to the north called Clayton Basin.These depressions are probably similar in origin to the solution-subsidence troughs of the Gypsum Plain in southern Eddy County, N. Mex., and adjacent parts of Texas, described by Olive (1957). However, the solution-subsidence troughs of Olive are more regular in outline, smaller, and are formed in the Castile formation.

In the northern part of Nash Draw, bedrock is largely covered by a mantle of windblown sand, dunes, caliche, and alluvium. In the central and southern part of Nash Draw however, the Rustler formation is highly deformed in outcrops. The deformation is thought to be due primarily to large-scale collapse of the Rustler formation as a result of solution within the anhydrite, gypsum, and halite beds of the Rustler, and at the top of the Salado formation. Evidence for solution within the Rustler can be found almost everywhere that it is exposed. Sinkholes of all sizes abound in the Rustler formation, ranging from small cavernous joints that trap unwary livestock to large shallow depressions, partly filled with alluvial or playa deposits but commonly with identifiable sinks within the depressed area (fig. 13). Where dips in the Rustler can be determined, they are generally in the direction of the larger depressions. In plan, these depressions range from small circular features a few tens or hundreds of feet across to large irregular, or arcuate, features more than a mile across. Many of the larger depressions, including the basin that holds Salt Lake, are probably formed by the coalescing of smaller ones. Some of the depressions tend to line up. These may indicate the probable location of subterranean cavernous water courses."

p. B40;

" Areas of rock deformation that are circular or semicircular in plan and range from a few hundred to a few thousand feet in diameter are a common form of solution or karst feature in this area. Sedimentary strata including caliche are well exposed on the flanks of some of these features and dip away from the center giving them the appearance of structural domes. Generally, such domes contain a core of brecciated or randomly rotated rack that has been displaced downward with respect to the flanking rock. Typically the brecciated rock in the core is overlain by a greater thickness of the Gatuna formation than is present in the adjacent areas. The core of brecciated rock and Gatuna overlain by an unknown arch of caliche on several of these features, which suggests that the brecciation predates the deposition and doming of the caliche. The breccia probably formed as a result of collapse into a sinkhole. Examples of several well-exposed domes directly north of the Nash Draw quadrangle have been described in a separate report (Vine, 1960)."

Weart, W.D., 1983. Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability. SAND83-0450. Albuquerque, NM: Sandia National Laboratories.

p. 9, col. 2, para. 3;
" The WIPP site investigations have been guided by an established set of site selection criteria.[2] These criteria, and the factors that address the criteria, are listed in this section. The criteria are broad statements of desired conditions and must be addressed in practice by identifying and quantifying pertinent site factors. When this has been done, a judgment can be made on how well the criteria are satisfied. The basic criteria listed below are from the WIPP GCR;[2] more specific site evaluation factors are from the Site Validation Program document.[5]

p. 10;
"

Listing of Site Criteria and Qualification Factors

Site Criteria

Geologic Criterion--The geology of the site will be such that the repository will not be breached by natural phenomena while the waste poses a significant hazard to man. The geology must also permit safe operation of the WIPP.

Hydrology Criterion--The hydrology of the site must provide high confidence that natural dissolution will not breach the site while the waste poses a significant hazard to man. Accidental penetrations should not result in undue hazards to mankind.

Tectonic Stability Criterion--Natural tectonic processes must not result in a breach of the site while the wastes represent a significant hazard to man and should not require extreme precautions during the operational period of the repository.

Physical-Chemical Compatibility--The repository medium must not interact with the waste in ways which create unacceptable operational or long-term hazards.

Economic/Social Compatibility Criterion--The site must be operable at reasonable economic cost and should not create unacceptable impact on natural or the biological/sociological environment.

The specific site qualification factors which must be examined in order to assess how well these criteria are fulfilled are listed as follows.

Site Qualification Factors (Criteria)[5]

1.0 Topography

The site must:

1.1 Permit access for transportation.

1.2 Possess relief low enough to avoid significant differences in lithostatic stress at waste disposal level.

1.3 Preclude inundation from surface floods.

2.0 Depth

The waste disposal horizon must be:

2.1 Deep enough to remain below the influence of surficial phenomena (infiltration

of surface waters, erosion/denudation).

2.2 Within the depth where lithostatic stresses will not produce excessive rock deformation rates.

3.0 Thickness of Host Rock

The thickness of waste disposal host rock must be sufficient to:

3.1 Provide a thermal and mechanical buffer zone above and below the facility.

4.0 Lateral Extent

The lateral extent of the waste disposal host rock must be sufficient to:

4.1 Provide the required lateral continuity and distance from the disposal facility to structural or erosional breaches or dissolution boundaries.

5.0 Lithology

The lithology of the waste disposal host rock must:

5.1 Be relatively low in brine content with respect to any horizon selected for heat-producing waste experiments.

5.2 Be relatively pure mineralogically to reduce the chemical interaction which must be considered.

6.0 Stratigraphy

6.1 The individual beds of rock in the disposal zone must be continuous enough to permit location of the facility at essentially one stratigraphic horizon.

6.2 The location and characteristics of interbedded materials, such as clay, must not preclude construction of stable excavations nor provide transport pathways which would significantly reduce the containment capacity of the waste disposal rock.

7.0 Structure

7.1 The site shall be free of active or capable faults.

7.2 The dips of strata at the disposal level shall not exceed the acceptable grade for excavations unless the stratigraphy/lithology allow construction of the disposal facility in beds either side of the selected horizon.

8.0 Dissolution

8.1 The disposal horizon must be free and remain free from dissolution for at least 10,000 years, based upon rates of dissolution determined from an assessment of previous rate of dissolution.

9.0 Subsidence

9.1 Subsidence caused by dissolution or mining should be avoided if it adversely affects the waste facility.

10.0 Surface Water

10.1 The site must be free of flooding hazard which could affect unplugged penetrations to the waste facility.

11.0 Groundwater

11.1 Facility and related shafts must not adversely affect existing aquifers which are, or could be, sources of water supply for humans or animals.

11.2 The underground facility must be able to be isolated from waterbearing strata

and must not, itself, be located in a water-bearing stratum (stratum which will yield water to a drillhole under the influence of gravity alone).

11.3 The hydraulic conductivity of the facility stratum must be sufficiently low (10^{-6} cm/sec or less) to prevent flow of water through that stratum from any source which could develop after facility construction.

11.4 Calculated hydrologic transport of radionuclides through the waste disposal facility and overlying strata must be slow enough that a significant hazard to humans would not exist even if the disposal stratum were breached.

12.0 Tectonic Stability

12.1 The magnitude of maximum historical seismic events must demonstrate a low seismic risk to the site.

12.2 Major faults and pronounced linear structural trends should be avoided.

12.3 Major flow structures (anticline) should be avoided or evaluated for presence of brine.

12.4 Diapirism will be avoided for WIPP siting.

12.5 Areas of active regional uplift or subsidence should be avoided.

12.6 Areas of active or recent volcanism or igneous intrusion should be avoided.

12.7 Areas of high geothermal gradient should be avoided.

13.0 Physical-Chemical Compatibility

13.1 The disposal stratum should not contain more than 3% water content.

13.2 Beds of unusual composition and/or containing minerals with bound water should not occur within 20 feet of the waste horizon.

13.3 The mineralogy of the disposal horizon rock must not be chemically reactive with the waste or waste packages in a way that will reduce the effectiveness of the rock as a barrier to nuclide transport.

13.4 Radiation effects must not compromise the effectiveness of the disposal horizon rock as an enclosing medium.

14.0 Natural Resources

14.1 The site should be located so that losses of natural resources are reduced to acceptable levels, which shall be determined by the value of the resources and alternative sources of those commodities.

15.0 Man-Made Penetrations

15.1 Boreholes or shafts which penetrate through the disposal level to underlying aquifers should be at least 1 mile from the facility.

16.0 Transportation

16.1 Transportation routes should be capable of satisfying transport needs to the site with ready development. Transportation routes should avoid population centers as much as possible.

17.0 Accessibility

17.1 The site should be readily accessible for transportation and utilities.

18.0 Land Acquisition

18.1 The site should be located on federal land to the greatest extent possible.

19.0 Population Density

19.1 The site should be located in a low population area.

20.0 Ecological Effects

20.1 The site should not contain ecological conditions, the disruption of which is irreversible or uncontrollable due to construction or operation of the facilities.

20.2 Archaeological and historical features of significance should be preserved.

21.0 Sociological Impacts

21.1 Construction and operation of the facility at the selected site should not create unmanageable impacts on local governmental, educational, or social institutions.

Before discussing the WIPP site in relation to these criteria, a few comments are in order.

- First, very few of the qualification factors, by and of themselves, disqualify a site. The reason is that assurance of waste isolation relies on the synergy of many factors; one (or a few) unsatisfied factor can often be adequately compensated for by other favorable factors. Only an unsatisfied factor that clearly leads to failure of isolation or that is in opposition to DOE policy would result in *a priori* site rejection. For the same reason it is usually inappropriate to establish quantitative limits for the site factors. These factors may be considered as favorable or unfavorable, or as sufficient but perhaps not necessary for site acceptability.
- Second, these factors were prepared at a time when the WIPP mission considered the possibility of HLW disposal and therefore had to include the aspects important to long-term irradiation and to high-temperature effects. These factors, while they will be addressed (and identified), do not apply to TRU waste isolation.
- Finally, these factors were developed and are worded to apply to sites in the bedded salt of the Delaware Basin. Without omitting any of the generic guideline aspects, they are specific to the WIPP geologic and geographic environment. WIPP siting factors should not be applied to other locations and to other geologic settings. The recently published DOE Draft Siting Guidelines,[47] which apply only to siting of commercial HLW repositories, have been examined; the WIPP siting factors are consistent with these guidelines in scope and intent."

p. 27, col. 1, para 5;

"**Conclusions Regarding Site Suitability**

The preceding discussion has considered all of the site qualification factors that have been identified for the WIPP. Most of these factors are clearly satisfied by the WIPP site and engender little debate. Some of the factors and their associated aspects are more contentious and have required extensive investigation and study to allow reasoned technical judgments. In the opinion of the Sandia WIPP geotechnical staff, well-supported judgments

can now be made on all the relevant issues.

It is important to realize that an attempt to understand complex geological processes may not result in absolute proof of any one hypothesis. A hypothesis may be ruled out if observed data clearly refute it, but more often a hypothesis is adopted because it best explains the observations and presents fewer conflicts with the evidence. Also, it is often virtually impossible to prove a negative hypothesis with respect to some of these geologic issues. For example, it is not practicably possible to *prove* that a large area in the basin does not contain an incipient breccia pipe or a brine reservoir; the argument is always that they may be just too small for geophysics to detect; or they may have been missed by the latest exploratory hole. The best, most meaningful approach to ruling out negative features is to establish a preferred hypothesis for their origin and then to show that the area in question does not possess the requisite characteristics to satisfy the hypothesis. Likewise, hypotheses may sometimes be ruled out if they require conditions that can be shown not to exist. Occasionally one may be left with two or more hypotheses, and a professional judgment is the only way of arriving at a preferred position. For this reason, opinions may sometimes differ among technically competent scientists. For the same reason, the various state and federal technical review groups have been important in providing an independent, unbiased judgment on the various hypotheses that are offered to explain the observations.

It is the judgment of Sandia National Laboratories that the WIPP site fulfills the intent of all the site qualification factors. Sandia recommends, without reservation, the use of the Los Medaños site for the WIPP."

Westinghouse Electric Corporation. 1991A. Waste Isolation Pilot Plant Groundwater Monitoring Program Plan and Procedures Manual. WP02-1. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

FOREWORD, p xi;

" This document is the controlling document for the Waste Isolation Pilot Plant (WIPP) Groundwater Monitoring Program (GMP). The GMP is being conducted as part of the WIPP Operational Environmental Monitoring Program (OEMP), by the Environmental Monitoring (EM) section of the Regulatory and Environmental Programs (REP) department.

This document is a quality assurance project plan (QAPjP) applying to WID environmental data operations (EDOs). As such, its purpose is to define the applicability of the WID quality management system, as described in WP 13-1, to the specific technical activities described within the scope of this plan. Implementation of this plan shall be in accordance with, and subject to the requirements of the quality assurance requirements as prescribed in WP 13-1. Independent assessment of the effectiveness of the activities described in this plan shall be scheduled and performed by the WID Q&RA Department."

Westinghouse Electric Corporation. 1991B. Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1990. DOE/WIPP 91-008. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

PREFACE;

" This is the seventh Annual Site Environmental Report for the U.S. department of Energy, Waste Isolation Pilot Plant (WIPP). The most significant addition to the 1990 report is the inclusion of the Annual Water Quality Data Report which addresses groundwater surveillance at the WIPP. The Water Quality Report was previously issued as a separate document. The combination of these two reports allows readers to have all environmental monitoring information consolidated together for an easy reference. . . ."

Westinghouse Electric Corporation. 1992. Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1991. DOE/WIPP 92-007, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

Section 1.3.1 Airborne Particulate and Effluent Monitoring; p 1-4;

" Sampling airborne aerosol particulates was initiated in 1985 and is an important subprogram of the OEMP. The Final Safety Analysis Report (FSAR) (DOE, 1990) identifies the atmosphere pathway as the only credible release pathway resulting in a potential dose to the public. Continuous particulate aerosol samplers operate at eight locations, three within 1000 meters of the facility boundary, four at local ranches and communities, and one at a sample control site.

The continuous aerosol samplers presently being utilized maintain a regulated flow rate of approximately 950 milliliters per second (two cubic feet per minute) of air through a 47-millimeter 1.9 inch) fiber filter for particulate collection. Particulate filters were collected weekly at all locations in 1991. The collected filters were counted at the Environmental Counting Laboratory at the WIPP, where the gross alpha and gross beta activities of each filter were calculated yielding weekly and quarterly averages for each location. Table 5-1 of Chapter 5 of this document lists the quarterly alpha and beta concentrations for each sampling location."

CHAPTER 6 ENVIRONMENTAL NONRADIOLOGICAL PROGRAM INFORMATION, p 6-1;

" This program is described in the OEMP (DOE/WIPP 88-025) for the WIPP. This plan defines the scope and extent of the WIPP effluent and environmental monitoring programs and quality assurance and quality control programs during the operational life of the facility. Nonradiological Environmental Surveillance (NES) is conducted by the Environmental Monitoring Section of the Environment, Safety, and Health department. This program was preceded by the WIPP Biology Program (1975-1982), which combined scientific and technical expertise from six universities to develop an extensive baseline of information describing the major components of the Los Medanos ecosystem prior to the initiation of WIPP construction activities. The principle functions of the NES are:

- To detect and quantify the impacts of construction and operational activities at the WIPP on the surrounding ecosystem
- To continue the development of the ecological data base for the Los Medanos Area which was initiated by the WIPP Biology Program
- To investigate unusual or unexpected elements in the ecological data bases
- To provide environmental data that are important to the mission of the WIPP project, but which have not or will not be acquired by other programs

This section of the ASER presents and discusses data collected between January 1, 1991, and December 31, 1991, as part of the NES of the OEMP. Ecological monitoring at the WIPP includes five subprograms (1) meteorological monitoring, (2) air quality monitoring, (3) water quality monitoring, (4) wildlife population monitoring, and (5) surface

disturbance monitoring through the analysis of aerial photographs. The salt impact studies include three subprograms: soil chemistry, soil microbial activity, and vegetation. The results of the environmental monitoring activities and discussions of significant findings are presented in this report.

Unless otherwise noted, all methods used in data collection are those described in the first Ecological Monitoring Program semiannual report (DOE/WIPP 86-002) with the modifications described in subsequent ASER reports (Fisher et. al., 1985; Fisher, 1987; Fisher, 1988; Jones et al., 1989, 1990). . . ."

Westinghouse Electric Corporation. 1993. Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1992. DOE/WIPP 93-017, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

Introduction, para 2;
" This report provides a comprehensive description of environmental activities at the WIPP during CY 92. These activities are described in the Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant (i.e. DOE/WIPP 88-025). This plan defines the scope and extent of the WIPP effluent and Environmental Monitoring Programs during the pre-operational life of the site."

Westinghouse Electric Corporation. 1994. Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1993. DOE/WIPP 94-2003. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

INTRODUCTION, 1.1 BACKGROUND, p 1-2, para 2;

" A significant development during the construction phase was the promulgation of environmental standards for the management and disposal of TRU wastes by the U. S. Environmental Protection Agency (EPA) (EPA, 1985). In addition, the EPA ruled that facilities that manage radioactive mixed waste are subject to the regulations implementing the Resource Conservation and Recovery Act (RCRA)(U.S. Congress, 1976).

In October 1992, through the WIPP Land Withdrawal Act (LWA), Public Law 102-579 (U.S. Congress, 1992), Congress transferred jurisdiction of the land from the U.S. Bureau of Land Management to the DOE and reserved the land for the use of the DOE for the WIPP Program. The LWA also provided additional authorization to continue the activities initiated by Public Law 96-164. The LWA requirements (Sec. 6) focus on the test phase and the criteria for certification of compliance with the long-term disposal regulations developed by EPA (Sec. 8). While the Test Phase will not be conducted, many requirements such as the development of certification criteria by the EPA, and other requirements necessary to begin disposal are still applicable. For example, the LWA also requires periodic recertification and verification of continuing compliance with applicable regulations during disposal operations.

The LWA and its provisions are as central to regulatory compliance as are the regulations themselves in that the LWA mandates certain schedules, reviews, approvals and limitations. As a result, an updated flexible regulatory compliance strategy that more fully integrates WIPP Project elements and ensures the sufficiency of information to document compliance is needed. This flexible compliance strategy is also necessary to ensure that the WIPP can accommodate the changing TRU waste inventory resulting from increased decommissioning and decontamination of facilities, environmental restoration activities, the dismantlement of weapons, and newly generated TRU waste that will result from treatment of low level wastes. . . ."

1.2 PURPOSE, p 1-4;

" The primary purpose of this document is to provide a strategy by which the WIPP will demonstrate its ability to perform as a deep geologic repository. To achieve this, the document will: (1) communicate to WIPP Project participants, regulatory agencies, and other stakeholders, the DOE's understanding of the regulations related to long-term repository performance; and (2) provide the most efficient strategy that a) integrates WIPP Project elements, b) ensures the sufficiency of information, and c) provides flexibility for changes in the TRU waste generation system to facilitate disposal of defense-generated TRU wastes.

In addition, this document forms a focal point between the DOE and its various external regulators as well as other stakeholders for the purpose of arriving at compliance decisions that consider all relevant input.

- As a compliance strategy that integrates WIPP Project elements, it will enhance mutual understanding between the DOE, its contractors, and its stakeholders resulting in a cost effective and environmentally sound disposal decision.
- As a flexible strategy to accommodate changes in the TRU waste system, it will assure that WIPP's stakeholder's interest are represented in the decision-making process that affects the future of the TRU waste system.
- As a compliance strategy that ensures sufficiency of information, it will foster discussions between DOE, its contractors, and its stakeholders regarding the data used to support a technically sound disposal decision."

Westinghouse Electric Corporation. 1995 Waste Isolation Pilot Plant Site Environmental Report for Calendar Year 1994. DOE/WIPP 95-Draft-2094. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

PREFACE, p. xvi;

" This is the eleventh Annual Site Environmental Report (ASER), documenting the progress of environmental programs at the U.S. Department of Energy (DOE) Waste Isolation Pilot Plant (WIPP).

Although the cancellation of the Test Phase, during 1993, was a significant change in work scope for the WIPP< there are still numerous environmental monitoring and reporting activities that must be performed as a routing part of daily operations. These activities, and the WIPP's ability to demonstrate compliance with both state and federal environmental compliance requirements, are documented in this report.

This report is a compilation and summarization of environmental data collected at the WIPP site during the calendar year 1994. Should a reader of this report desire to obtain copies of the raw data used to generate this document, please write the U.S. Department of Energy, Manager of the Environment, Safety and Health Department, at P.O. Box 3090, Carlsbad, NM, 88221."

Wolfe, H.G. et al., eds. 1977. An Environmental Baseline Study of the Los Medanos Waste Isolation Pilot Plant (WIPP) Project Area of New Mexico: A Progress Report. SAND77-7017. Sandia National Laboratories, Albuquerque, NM.

INTRODUCTION, p 11;

" Sandia Laboratories, Albuquerque, New Mexico, has been conducting exploratory drilling operations for a Waste Isolation Pilot Program (WIPP) in southeastern New Mexico for a year. (See Fig. 1-1 and 1-2.)

Prior to the establishment of such a program, Sandia Laboratories initiated an environmental study to serve as a baseline for evaluation of the impact of their future activities in the Los Medaños area. Much of this area has been influenced by human activities over a long period; consequently, the baseline data does not reflect pristine conditions but rather the present, relatively disturbed condition of the environment. This study thus presents a description of the present level of human impact.

Sandia contracted for this study with the New Mexico Environmental Institute (NMEI). This progress report presents the preliminary results of the study conducted from August 1975 to April 1976 by NMEI."

Wood, B.J., Snow, R.E., Cosler, D.J., and Haji-Djafari, S. 1982. Delaware Mountain Group (DMG) Hydrology -- Salt Removal Potential, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3166. U.S. Department of Energy, Albuquerque, NM.

INTRODUCTION AND SUMMARY, p. 1;

" This report provides an account of studies performed to evaluate the potential for salt dissolution in the Castile Formation, removal of dissolved salt by fluids in the Bell Canyon aquifer within the Delaware Mountain Group (DMG), and the potential impact of this process on the long-term integrity of the Waste Isolation Pilot Plant (WIPP) facility.

The results of this study provide responses to the stipulated agreement of July 1, 1981 with the U.S. Department of Energy (DOE) and the state of New Mexico regarding the DMG hydrologic investigation. This study was performed and this report prepared by D'Appolonia Consulting Engineers, Inc. (D'Appolonia), under Subcontract S9-CJR-45451 with Westinghouse Electric Corporation, Advanced Energy Systems Division, under Contract DE-AC04-78-ET05346 with the DOE. The Westinghouse team is serving as the Technical Support Contractors (TSC) to the DOE for the WIPP project. ..."

Section 5.3 Implication of Dissolution on the Underground WIPP Facility, p 100, para 2, line 11;

" As indicated above and discussed in detail in Section 5.1, the average dissolution rate may be anticipated to result in a cavity at the Halite I horizon throughout the Delaware Basin of less than 10 centimeters in 10,000 years, provided mechanisms such as creep do eliminate or retard development. The underground WIPP facility is more than 400 meters above the Halite I horizon. Based on the physical phenomena associated with development, support, and stabilization of a solution cavity, a dissolution zone of 10 centimeters cannot be anticipated to have an effect on the site integrity."

Zoback, M.L., and Zoback, M.D. 1980. "State of Stress in the Conterminous United States." Journal of Geophysical Research, Vol. 85, No. B11, pp. 6113-6156.

Southern Great Plains, p. 6134, col. 2, para. 3;

" The southern Great Plains area is characterized by a very uniform state of stress in which the least principal horizontal stress direction to NNE-SSW. The data come from two primary sources: (1) alinement of post-5 m.y. volcanic feeders in the Raton-Clayton volcanic field of northern New Mexico and (2) fracture orientations obtained from hydraulically fractured wells in the Permian basin of western Texas [*Zemanek et al.,* 1970]. An earthquake focal mechanism and in situ stress measurements in eastern Colorado show consistent orientations. Despite the similar least principal horizontal stress orientations in the southern Great Plains and in the plateau interior, the probable extensional regime (as inferred from earthquake focal mechanisms and basaltic volcanism) distinguishes the southern Great Plains from the Colorado Plateau interior and Midcontinent provinces which are dominated by compressional stress regimes. The least principal horizontal stress directions to the southern Great Plains province are generally oblique to those in the Midcontinent stress province; however, in west-central Texas the data suggest a counter-clockwise rotation of the stress field from west to east to directions more consonant with midcontinent stress orientations (Plates 1 and 2). The easternmost site of this group of data (TX-15) is a normal fault focal mechanism, suggesting that the boundary with the compression-dominated Midcontinent stress province must lie further to the east.

Two important characteristics of the stress field in the southern Great Plains province are (1) its uniformity ($\sim \pm 15°$, which is within the range of estimated accuracy of the different stress indicators) over a region with a north-south extent of at least 1100 km and (2) an abrupt transition in stress orientation in relation to the Rio Grande rift that occurs locally over a lateral distance of <50 km. this $\sim 90°$ change in least principal horizontal stress orientation along the Rio Grande rift-Great Plains boundary corresponds to a decrease in heat flow and a crustal and lithospheric thickening under the Great Plains in relation to the Rio Grande rift [*Thompson and Zoback,* 1979]. IN addition, seismic reflection profiling across the Rio Grande rift's eastern boundary [*Brown et al.*, 1979] has revealed a high-angle, narrow, linear zone defined by a lack of coherent reflections which extends from near the surface to the base of the crust. Physically, this sharp boundary may mark a zone of lateral 'decoupling' within the crust facilitating the abrupt change in stress orientation."

Zoback, M.L., Zoback, M.D., Adams, J., Bell, S., Suter, M., Suarez, G., Estabrook, C., and Magee, M. 1991. Stress Map of North America. Continent Scale Map CSM-5, Scale 1:5,000,000. Geological Society of America, Boulder, CO.

EXPLANATION, sheet 1 of 4;

" This map plots modern maximum horizontal stress (SHmax) orientations for North America inferred from a variety of geophysical and geologic data. These data are described and discussed in the companion DNAG Neotectonics of North America volume (Slemmons, D. B., and others, 1990). A brief description of the various stress indicators is given in the Legend to the right and further details can be found in Zoback and Zoback (1990) and Zoback and others (1990). The center symbol of the oriented lines on the map indicates the type of stress indicator and the length of the lines is scaled proportional to quality as described in the table below. Only A-C quality data are shown on the map, D quality data are retained in the database but are not generally considered to be reliable stress indicators (Zoback and Zoback, 1990; Zoback and others, 1990). Color is used to describe stress regime or style of faulting in terms of relative stress magnitudes (see Legend); SHmax=maximum horizontal stress direction, Sv=vertical stress, and SHmin=minimum horizontal stress direction.

The data are plotted on the DNAG base prepared by the U. S. Geological Survey (Transverse Mercator projection, 1:5,000,000, central meridian 100 deg. W). Continental topography is represented by contours of average topography (250 m contour interval) and was computed using the global digital topography data set (Report MGG-2, National Geophysical Data Center, NOAA, Boulder, CO 80303-3328. The 1° topography data were interpolated and resampled on a 50 km x 50 km grid and were then smoothed using an upward continuation filter (to 15 km) commonly used for potential field data. Bathymetric contours are in corrected meters (Carter's Echo-sounding correction, 3rd ed., 1980). and were derived from U.S. Navy gridded bathymetric data base 'DBDB-5' (5' X 5' grid, 1984) by Peter W. Sloss, National Geophysical Data Center.

All data shown on this map have been released as part of the Geophysics of North America data set available on CD-ROM from the National Geophysical Data Center (NGDC), Boulder, CO 80303-3328. An updated and more detailed release of the data is scheduled in early 1991 by NGDC (World Stress Map Dataset).

The data on the map come from a variety of sources. Individuals responsible for data compilation are listed by region together with references to publications describing the data of the region: . . ."

Zoback, M.D., and Zoback, M.L. 1991. "Tectonic Stress Field of North America and Relative Plate Motions." In Neotectonics of North America, D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 339-366. Geological Society of America, Boulder, CO.

STRESS PROVINCES OF NORTH AMERICA, p. 349, col. 1, para. 2;
" In this section we discuss the individual stress provinces shown in Figure 4 and summarized in Table 2.

p. 350;
"

TABLE 2. STRESS PROVINCES OF NORTH AMERICA

	Stress Regime	Principal Stress Direction Maximum	Minimum	Remarks
PLATE-INTERIOR PROVINCES				
Midplate	SS/TF*	ENE	NNW/Vertical	Encompasses most of intraplate North America east of the U.S. Cordillera including the western Atlantic basin. Earthquake focal plane mechanisms in southeastern Canada are predominantly thrust and those in the United States are predominantly strike-slip. Excellent correlation between direction of maximum horizontal stress with absolute plate-motion direction as well as the direction of ridge push from the Mid-Atlantic ridge.
Gulf Coast	NF	Vertical	SSE	Extensive gulfward extension and growth faulting within Coastal Plain sediments. State of stress in the underlaying basement is not known.
Cordilleran Extension	NF/SS	Vertical	WNW *(WSW-WNW)*+	Broad region of variable magnitude extension including the Basin and Range, Rio Grande rift, Northern Rocky Mountain, and Snake River Plain regions of western United States. Extent into Canada and Mexico is uncertain. Correlative with zone of high heat flow, elevation, and thin crust. Pronounced strike-slip deformation (with constant S_{hmin} direction) along western boundary of province (Walker Lane). Predominant S_{hmin} direction within the province is WNW but direction varies between WSW and WNW.
Colorado Plateau/ Southern Great Plains	NF	Vertical	NNE	Unique extension direction, thicker thicker crust, and very low rate of crustal deformation distinguishes the Colorado plateau and Southern Great Plains from the surrounding Cordilleran extension province.

* NF = normal faulting; SS = strike-slip faulting; TF = thrust faulting
+ Directions in italics refer to range of stress directions observed throughout a province."
NOTE: This is not a complete representation of TABLE 2.

p. 349, col. 1, Caption for Figure 4;
" Figure 4. Generalized stress map of North America. Interpretive stress provinces shown in the figure are summarized in Table 2 and discussed in detail in the text. As explained in legend, inward-pointed arrows indicate directions of maximum horizontal compression in areas of reverse and strike-slip faulting and thinner, outward-pointed arrows indicate the direction of least horizontal compression in areas of normal faulting and strike-slip faulting. Single, large shaded arrows indicate direction of absolute plate motion."

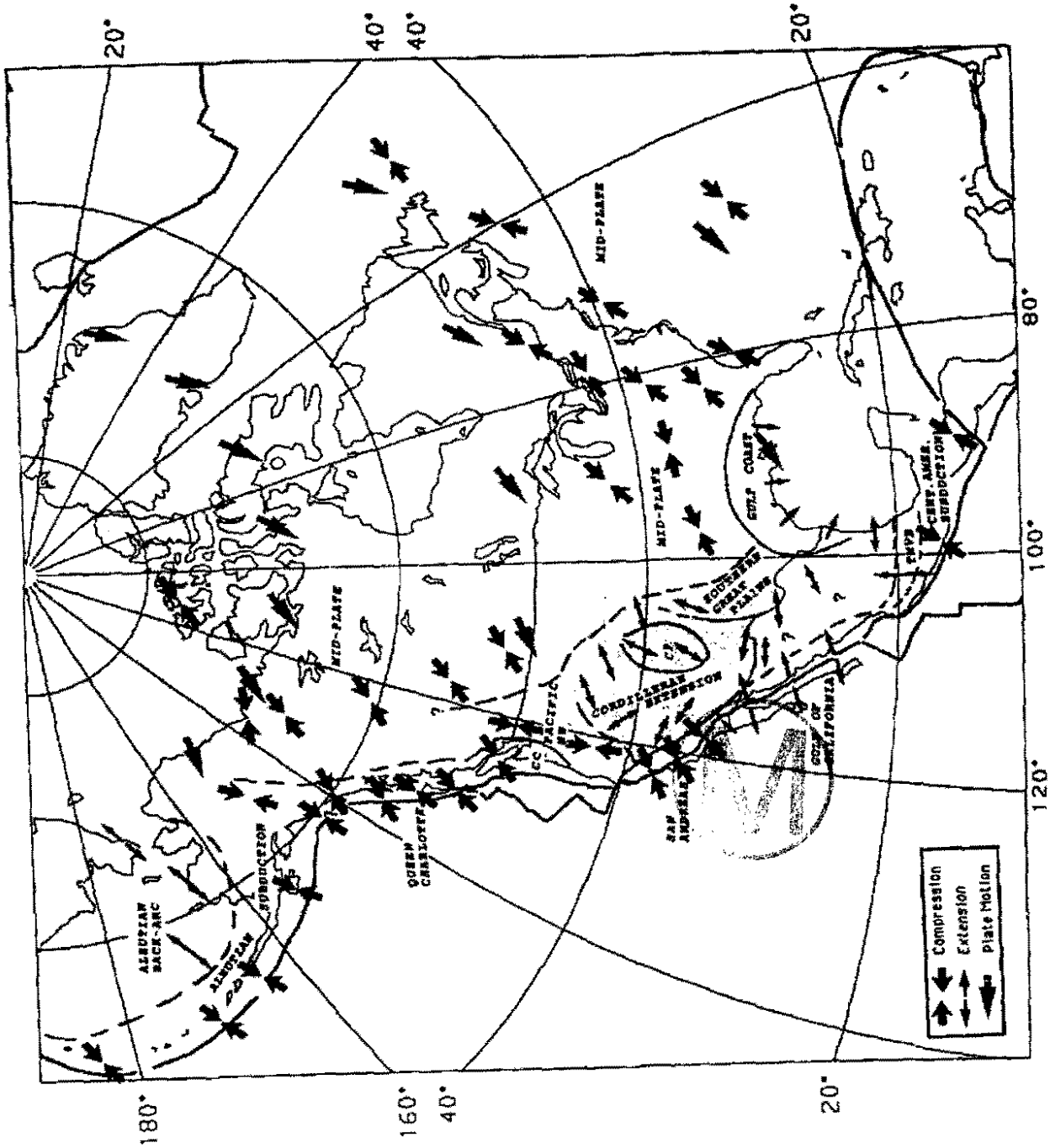
20°
40°
40°
20°
80°
100°
120°
20°
40°
160°
180°
MID-PLATE
MID-PLATE
MID-PLATE
GULF COAST
CENT. AMER. SUBDUCTION
PAPS
SOUTHERN GREAT PLAINS
CONDILLERAN EXTENSION
CC
PACIFIC
SAN ANDREAS
GULF OF CALIFORNIA
QUEEN CHARLOTTE
SUBDUCTION
ALEUTIAN BACK-ARC
ALEUTIAN
Compression
Extension
Plate Motion

p. 353, col. 1, para. 3;

" **Cordilleran extension province.** This stress province coincides generally with the broad thermally elevated region of the western United States (e.g., Eaton, 1979) and extends southward into northern Mexico. It incorporates the classic Basin and Range subprovince of extensive north-south-trending range-bounding normal faults, as well as the regions surrounding the Colorado Plateau : the Rio Grande Rift, and the middle Rocky Mountains and Denver Basin regions (Fig. 4). All these areas are characterized by extensional tectonics with a S_{hmin} orientation varying between west-northwest to east-northeast. Although seismicity occurs throughout the region (Engdahl and Rinehart, this volume), the rate of tectonic activity in southern parts of this province (northern Mexico, Arizona, New Mexico) and northeastern parts (middle Rocky Mountains and Denver Basin) it is considerably less than the part of the province coincident with the'Great Basin' of Nevada and Utah. As the state of stress, deformation and tectonics of much of the Cordilleran extension province have been recently discussed in detail (Zoback, 1989; Zoback and Zoback, 1989), we only briefly summarize key points in here.

Distinct subprovinces of uniform S_{hmin} orientation can be defined within the Cordilleran Extension province: (1) the northern Basin and Range and Rio Grande rift regions are characterized by a west-northwest S_{hmin}, (2) in southern Arizona, New Mexico, and northern Mexico, Quaternary faulting patterns indicate that the S_{hmin} direction is approximately east-west (Muehlberger and others, 1978), and (3) north of the Snake River Plain and in the Denver Basin and middle Rocky Mountain region (Colorado and Wyoming) the S_{hmin} orientation averages about east-northeast."

p. 353, col. 2, para. 3;

" **Colorado Plateau and Southern Great Plains Provinces.** As illustrated in Figures 2 and 4, these two regions are unique within the western United States Cordillera in showing generally north-northeast, rather than approximately east-west extension. The Colorado Plateau, a relatively stable tectonic block throughout much of Phanerozoic time, is surrounded by active west-northwest extension on both its western and eastern border. Deformation within the Colorado Plateau interior is dominated by small-magnitude normal faulting earthquakes (Wong and Humphrey, 1989). Similarly, the southern Great Plains stress province, which is defined largely on the basis of trends of Quaternary basaltic volcanic vent alignments, is bordered on its western side by the west-northwest extension in the Rio Grande rift. It is difficult to define the northeastern boundary of the Southern Great Plains Province using currently available data. However, the extensional state of stress in this province is markedly different than the compression observed in the Mid-plate province. Southeast of this province a change in extension direction occurs as southeastward (gulfward) extension is observed in the Gulf Coast province."

BIBLIOGRAPHY DOCUMENTS

AIM (Agricultural and Industrial Minerals, Inc.). 1979. Resource Study for the [WIPP], Eddy County, NM. AIM, Inc., San Carlos, CA.

INTRODUCTION, p 1;

" A. Purpose of Study

This study has been prepared under terms of Contract No. EW-78-C-04-4233 dated March 8, 1978 and is submitted in fulfillment of that contract. The purpose is to define and evaluate the potash resources and reserves of the Waste Isolation Pilot Plant (WIPP) site area located in Eddy County, New Mexico, Township 22 South Range 30 and 31 East. Said site comprises approximately 18,960 acres. An additional purpose of the study is to determine the impact on the industry and the market supply if the WIPP area is withdrawn from mining. A third purpose is valuation of leaseholders' interests and the State of New Mexico interest as lessor of certain tracts.

B. Site Division and Ownerships

The Department of Energy has divided the site into four generally concentric zones numbered I, II, III and IV. Within the site are four tracts of Federal and State leased lands numbered 301, 302, 303 and 304, the outlines of which are not related to the zones. Map No. 254-8, Page 67, shows the outline of each leased tract and each zone. Table I-1, Page 4, lists Lessees, Lessors, acreage by tract, acreage by zone and percentage relationships of Federal and State lands to the total WIPP site acreage.

C. Division of Resources and Reserves

These have been divided as follows:

1. By ore zones.
2. By WIPP Zones I, II, III and IV.
3. By leaseholder interest.
4. By State of New Mexico interests.

D. Acknowledgements

AIM, Inc. expresses its sincere appreciation to personnel of the following government agencies and companies for their cooperation, supplying data and for judgements which were most helpful in the development of this report. . . .

E. Assumptions and Conclusions

The conclusions reached herein are based on available data from both government and company core hole information. No new drilling was undertaken. Since the core holes are generally on one mile spacing, (a wide spacing) geologic interpretations have been made to arrive at such factors as grades, mineralogy, thickness, tonnage, etc., contained in given areas.

Since no samples exist that represent the true average of any given ore zone or area, selected samples of various cores were used to perform the metallurgical tests. These cores represent a broad range of grades and containments. The data from metallurgical tests were applied to the calculated grades and containments of a given area to determine if marketable products can be produced. Recoveries were also made on the basis of experience in the potash industry. Cut-off grades and thicknesses were established from experience combined

with discussions held with the Carlsbad mining companies. 4.5 feet minimum mining thickness was established as the lower limit even though difficult to sustain.".

Anderson, R.Y., 1982. "Deformation-Dissolution Potential of Bedded Salt, Waste Isolation Pilot Plant Site, Delaware Basin, New Mexico." In Scientific Basis for Nuclear Waste Management, Materials Research Society Proceedings, V. W. Lutze, ed., Vol. 11. Elsevier Science Publishing Co., New York.

INTRODUCTION, p. 449;

" Deep-seated collapse and brecciation is a feature common to bedded salt in a number of evaporite basins. The origin of these features is poorly understood. The relatively young geologic age of uplift and exposure of evaporites in the Delaware Basin, and a still-active hydrologic system, provides a unique opportunity to examine the pathways of water movement related to collapse features and salt dissolution. In addition, salt deformation structures are closely associated with brine, dissolution, and collapse. This report briefly discusses evidence for deep-seated dissolution, considers the relationship between deformation, dissolution, and brine, and examines the potential for dissolution at the WIPP (Waste Isolation Pilot Plant) site with respect to stages in the deformation-dissolution process.

The Delaware Basin, which contains the Upper Permian Castile and Salado evaporites, was uplifted, faulted on the western margin (Fig. 1A), and tilted 19m/km to the east-northeast during the latter part of the Cenozoic, probably 4-6 my ago. This event exposed the tilted limestone (reef) and sandstone aquifers beneath the overlying anhydrite and salt beds (Table 1). Meteoric waters entered the exposed aquifers in the uplifted western and southern margins of the basin. The aquifers became charged and pressurized, with the pressure surface high within the evaporites; almost at the surface. Salt has been removed from beneath and within the evaporite body, apparently by means not related to ordinary near-surface groundwater flow. This report considers how this may have happened."

Anderson, R.Y. 1993. "The Castile as a 'Nonmarine' Evaporite." In Geology of the Carlsbad Region, New Mexico and Texas, D.W. Love et al., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

p 12, col 2;

" After King (1947) showed that the low proportion of halite to anhydrite in the Castile evaporite could be explained by the reflux of brine from the Delaware Basin, the Castile became the classical example of a marine, 'deep water' evaporite. Anderson and Dean (in press) have reexamined the distribution of evaporites units, as well as geochemical evidence and they suggest that reflux is not the only way to explain the compositional and stratigraphic relationships of the Castile. According to the alternate explanation, the brine was not a residual of sea water flowing directly into the basin. Rather, it is suggested that chloride recharge was from ground water seeping into the basin from the south, especially during lowstands (Fig. 1.12a), with the brine derived from a partly marine source or from previously deposited evaporites. In this model, the Delaware Basin was a hydrologically closed basin with water level subject to extreme highstands (Fig. 1.12b) and lowstands, a type of response similar to that observed in existing closed basins in western North America.

Support for a closed-basin model can be found in the record of climatic variability that is preserved in the Castile. For example, millennial oscillations in climate and lake level are strongly expressed in the closed hydrologic basins in western North America during the late Pleistocene. Millennial cycles also are dominant in the Castile and determine the incidence and duration of halite accumulation (lowstands). Cycles of precession and eccentricity also are well defined in the Castile and in the record of the ocean and cryosphere over the past million years. The occurrence of climate cycles recognized in the Pleistocene and Holocene does not address the question of marine recharge for the Castile. However, strong expression of the same climatic periodicities within the Castile is consistent with a closed-basin hydrologic setting and meteoric recharge.

More direct evidence for meteoric recharge can be seen in the depletion of ^{18}O in limestone beds along the western margin of the basin (Magaritz et al., 1983) and in rapid, synchronous changes in the seasonal rate of accumulation of calcium sulfate (freshening events) that resulted in beds of laminated limestone. Such events can be traced from the western margin to the center of the basin, suggesting that a significant volume of meteoric recharge entered the basin from the west during those times when water level was at or near a highstand (Fig. 1.12b). Other evidence for meteoric contributions can be found in the low bromine concentrations in halite, which give the Castile an affinity with other nonmarine evaporites. Ground-water recharge of ions derived from preexisting evaporites provides an alternate mechanism to account for the low ratio of halite to sulfate.

. . ."

Anderson, R.Y., Dean, W.E., Kirkland, Jr., D.W., and Snider, H. I. 1972. Permian Castile Varved Evaporite Sequence, West Texas and New Mexico. Geological Society of America Bulletin, Vol. 83, No. 1, pp. 59–85.

ABSTRACT; p 59, col 1;

" Laminations in the Upper Permian evaporite sequence in the Delaware Basin appear in the preevaporite phase of the uppermost Bell Canyon Formation as alternation of siltstone and organic layers. The laminations then change character and composition upward to organically laminated claystone, organically laminated calcite, the calcite-laminated anhydrite typical of the Castile Formation, and finally to the anhydrite-laminated halite of the Castile and Salado.

Laminae are correlative for distances up to 111 km (70.2 mi) and probably throughout most of the basin. Each laminae is synchronous, and each couplet of two laminated components is interpreted as representing an annual layer of sedimentation--a varve.

The thickness of each couplet in the 260,000-varve sequence (a total thickness of 447.2 m, (1465 ft) has been measured individually and recorded and provides the basis for subdividing and correlating major stratigraphic units within the basin. The uppermost 9.2 m (30.3 ft) of the Bell Canyon Formation contains about 50,850 varve couplets; the Basal Limestone Member of the Castile about 600; the lowermost anhydrite member of the Castile (Anhydrite I) contains 38,397; Halite I, 1,063;Anhydrite II, ??,414; Halite II, 1,758; Anhydrite III, 46,592; Halite III, 17,879; and Anhydrite IV, 54,187. The part of the Salado collected (126.6 m) contains 35,422 varve couplets. The Bell Canyon-Castile sequence in the cores studies is apparently continuous, with no recognizable unconformities.

The dominant petrologic oscillation in the Castile and Salado, other than the laminations, is a change from thinner undisturbed anhydrite laminae to thicker anhydrite laminae that generally show a secondary or penecontemporaneous nodular character, with about 1,000 to 3,000 units between major oscillations or nodular beds. These nodular zones are correlative throughout the area of study and underly halite when it is present. The halite layers alternate with anhydrite laminae, are generally recrystallized, and have an average thickness of about 3 cm. The halite beds were once west of their present occurrence in the basin but were dissolved, leaving beds of anhydrite breccia. The onset and cessation of halite deposition in the basin was nearly synchronous.

The Anhydrite I and II Members thicken gradually across the basin from west to east, whereas the Halite I, II, and III Members are thickest in the eastern and northeastern part of the basin and thicken from southeast to northwest. This distribution and the synchroneity indicate a departure from the classical model of evaporite zonation."

Anderson, R.Y., and Kirkland, D.W. 1980. Dissolution of Salt Deposits by Brine Density Flow. Geology, Vol. 8, No. 2, pp. 66–69.

ABSTRACT, P 66;

" The origin of collapse structures and breccias that vertically penetrate or occur within impermeable evaporites has never really been understood. The density of the brine that develops as salt deposits are dissolved can generate continuous gravitational brine movement. If the source of the dissolving water is artesian, or continuous, a flow cycle is developed in which the salt itself supplies the density gradient that becomes the vehicle of its own dissolution. The Delaware Basin in western Texas and southeastern New Mexico provides a particularly good example of how brine density flow can produce dissolution chambers that collapse to form breccias. The potential for dissolution by brine flow is an inherent property of partly exhumed evaporites and may constitute a risk factor in the storage of radioactive waste in evaporite deposits."

Anderson, R.Y., and Powers, D.W. 1978. "Salt Anticlines in the Castile-Salado Evaporite Sequence, Northern Delaware Basin, New Mexico." In Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas, G.S. Austin, ed., Circular 159, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p 79, col 1, para 1;

" A number of structures have been encountered within the body of the Castile-Salado evaporites that can reasonably be interpreted as salt anticlines. One such structure, associated with brine, H_2S, and dissolution effects, was found during exploratory coring for the proposed nuclear waste disposal site near Carlsbad, New Mexico. Correlation of stratigraphic units in the recovered core with cores and logs from nearby boreholes shows that the middle anhydrite unit (A-II) of the Castile Formation, which attains dips of as much as 70°, has been displaced vertically by as much as 950 ft (290 m). Extension fractures in the A-II unit suggest that it has been stretched over a pod of exceptionally thick salt of the lower halite unit (H-I) of the Castile Formation that moved into the axis of the anticlinal structure. Exceptionally thick and thin units of lower salt (H-I) occur in other nearby boreholes in a zone of deformation marginal to the reef. Suspected salt anticlines also occur at scattered localities in the northern part of the Delaware Basin. The association of extension fracturing to microfolding in the middle anhydrite unit (A-II) suggests that salt deformation accompanied or followed Cenozoic uplift and tilting of the basin."

Bachman, G.O. 1973. Surficial Features and Late Cenozoic History in Southeastern New Mexico. Open-File Report 4339-8. U.S. Geological Survey, Reston, VA.

ABSTRACT, p. 1;

" Since deposition of the Ogallala Formation during Pliocene time, southeastern New Mexico has been subjected to erosion, solution, subsidence, and widespread eolian activity. These processes have combined to influence the formation and morphology of major drainage systems. Aligned drainage patterns resulted from solution of caliche localized by longitudinal sand dunes. San Simon Swale appears to have formed by processes of erosion and solution-subsidence of Permian evaporites, and was formerly an important tributary to the Pecos River. The combination of processes that formed San Simon Swale was similar to the combination of erosion and coalescing sinks that formed the lower Pecos Valley in southern New Mexico.

Bachman, G.O., 1985. Assessment of Near-Surface Dissolution at and near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico. SAND84-7178. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. 3;

" The area at and near the WIPP site was examined for evidence of karst development on the geomorphic surface encompassing the site. Certain surficial depressions of initial concern were identified as blowouts in sand dune fields (shallow features unrelated to karstification). An ancient stream system active more than 500,000 years ago contained more water than any system since. During that time (Gatuña, Middle Pleistocene), many karst features such as Clayton Basin and Nash Draw began to form in the region. Halite was probably dissolved from parts of the Rustler Formation at that time. Dissolution of halite and gypsum from intervals encountered in Borehole WIPP-33 west of the WIPP site occurred during later Pleistocene time (i.e., <450,000 yr ago). However, there is no evidence of active near-surface dissolution within a belt to the east of WIPP-33 in the vicinity of the WIPP shaft."

Bachman, G.O., and Johnson, R.B. 1973. Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico. Open File Report 4339-4. U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;

" The Permian salt basin in the Western Interior of the United States is defined as that region comprising a series of sedimentary basins in which halite and associated salts accumulated during Permian time. The region includes the western part of Kansas, Oklahoma, and Texas, and eastern parts of Colorado and New Mexico.

Following a long period of general tectonic stability throughout the region during most of early Paleozoic time, there was much tectonic activity in the area of the Permian salt basin during Late Pennsylvanian and early Permian time just before bedded salt was deposited. The Early Permian tectonism was followed by stabilization of the basins in which the salt was deposited. These salt basins were neither contemporaneous nor continuous throughout the region so that many salt beds are also discontinuous. In general, beds in the northern part of the basin (Kansas and northern Oklahoma) are older, and the salt is progressively younger towards the south.

Since Permian time, the Permian salt basin has been relatively stable tectonically. Regionally, the area of the salt basin has been tilted and warped, has undergone periods of erosion, and has been subject to a major incursion of the sea; but deep-seated faults or igneous intrusions that postdate Permian salt are rare. In areas of the salt basin where salt is near the surface, such as southern New Mexico and central Kansas, there are no indications of younger deep-seated faulting and only a few isolated igneous intrusives of post-Permian age.

On the other hand, subsidence or collapse of the land surface resulting from dissolution has been commonplace in the Permian salt basin. Some dissolution of salt deposits has probably been taking place ever since deposition of the salt more than 230 million years ago. Nevertheless, the subsurface dissolution fronts of the thick bedded-salt deposits of the Permian basin have retreated at a very slow average rate during that 230 million years.

The preservation of bedded salt from subsurface dissolution depends chiefly on the isolation of the salt from moving groundwater that is not completely saturated with salt. Karst topography is a major criterion for recognizing areas where subsurface dissolution has been active in the past; therefore, the age of the karst development is needed to provide the most accurate
estimate of the dissolution rate. The Ogallala Formation of Pliocene age is probably the most widespread deposit in the Permian salt basin that can be used as a point of reference for dating the development of recent topography. It is estimated that salt has been dissolved laterally in the vicinity of Carlsbad, New Mexico, at an average rate of about 6-8 miles per million years.

Estimates of future rates of salt dissolution and the resulting lateral retreat of the underground dissolution front can be projected with reasonable confidence for southeastern

New Mexico of the assumption that the climatic changes there in the past 4 million years are representative of climatic changes that may be expected in the near future of geologic time.

Large amounts of salt are carried by present-day rivers in the Permian salt basin; some of the salt is derived from subsurface salt beds, but dissolution is relatively slow. Ground-water movement through the Permian salt basin is also relatively slow."

Bachman, G.O., and Machette, M.N. 1977. Calcic Soils and Calcretes in the Southwestern United States. Open-File Report 77-794. U.S. Geological Survey.

ABSTRACT, p 1:

" Secondary calcium carbonate of diverse origins, 'caliche' of many authors, is widespread in the southwestern United States. 'Caliche' includes various carbonates such as calcic soils and products of ground-water cementation. The term 'caliche' is generally avoided in this report in favor of such terms as calcrete, calcic soils, and pervasively cemented deposits.

Criteria for the recognition of various types of calcrete of diverse origins include field relations and laboratory data. Calcic soils provide a comprehensive set of characteristics that aid in their recognition in the field. These characteristics include a distinctive morphology that is zoned horizontally and can frequently be traced over tens of hundreds of square kilometers.

The major process in the formation of pedogenic calcrete and calic soils is the leaching of calcium carbonate from upper soil horizons by downward percolating soil solutions and reprecipitation of the carbonate in illuvial horizons near the base of the soil profile. The formation of pedogenic calcrete involves many factors including climate, source of carbonate, and tectonic stability of the geomorphic surface on which the calcrete is deposited. Most of the carbonate in pedogenic calcrete is probably derived from windblown sand, dust, and rain.

Calcic soils and pedogenic calcretes follow a six-stage sequence of morphologic development and is based on a classification devised by Gile, Peterson, and Grossman in 1966. The six morphologic stages of carbonate deposition in soils are related to the relative age of the soil and are as follows:

I. The first or youngest stage includes filamentous or fault coatings of carbonate on detrital grains.

II. The second stage includes pebble coatings which are continuous; firm carbonate nodules are few to common.

III. The third stage includes coalesced nodules which occur in a friable or disseminated carbonate matrix.

IV. The fourth stage includes platy, firmly cemented matrix which engulfs nodules; horizon is plugged to downward moving solutions.

V. The fifth stage includes soils which are platy to tabular, dense, strongly cemented. A well-developed laminar layer occurs on the upper surface.

VI. The sixth and most advanced stage is massive, multilaminar, and strongly cemented calcrete with abundant pisoliths, the upper surface of which may be brecciated. Pisoliths may indicate many generations of brecciation and reformation.

In general calcic soils include stages I through III and are friable to moderately indurated; whereas pedogenic calcretes include stages IV through VI and are dense and strongly indurated. In a single pedon the morphologic stage of carbonate deposition

decreases downward in the profile. The stage of development may be used in local regions for correlation and determination of relative ages of soils and geomorphic surfaces.

Some structures observed in pedogenic calcretes may be present in other types of calcrete but the horizontal zonation typical of deposits of soil processes is absent. Laminar structure in particular is not restricted to pedogenic deposits and is common in many varieties of calcrete.

Very little chemical change occurs in the noncalcareous nonclayey fractions of calcretes with age; but clay minerals within calcretes undergo a complex history of authigenesis. There is a depletion of magnesium in the calcareous portion and an enrichment of magnesium in the clayey portion of a calcrete with age. In keeping with this relationship, montmorillonite, or mixed layer montmorillinite-illite, is common in younger calcretes; whereas the high magnesium-silicate clays, sepiolite and palygorskite, are common in older calcretes. This indicates that the magnesium depleted from the carbonate is redistributed authigenically in clay minerals.

The mobility of carbonate introduces many problems in attempts to date calcretes directly. Although the relative ages of soils within a province may be determined by quantitative studies, the absolute age can at present be made only by cross reference to other datable deposits such as lava flows, pumice, ash falls, and fossil-bearing beds. Rates of calcium carbonate accumulation vary from 0.22 to 0.51 $g/cm^2/kyr$ for New Mexico. These rates exceed those of many other areas in the southwestern United States. The amount of pedogenic carbonate in a soil as well as its morphology can be used to correlate both Quaternary alluvial deposits and geomorphic surfaces. Additionally, calcic soils and pedogenic calcrete are useful in analyzing recurrent fault histories.

In many areas where climatic conditions and carbonate sources are amenable to the formation of calcic soils, relict pedogenic calcretes are not preserved. In these regions examined during this study, the absence of such calcretes is the result of tectonic instability and rates of erosion and deposition too rapid for the time required to deposit the calcrete."

Balazs, E.I., 1978 [undated]. Report on First-Order Leveling Survey for Sandia Laboratories Waste Isolation Pilot Plant (WIPP) Project.Report to Sandia National Laboratories, Albuquerque, NM. National Geodetic Survey, Rockville, MD.

ABSTRACT

" The National Geodetic Survey (NGS) of the National Ocean Survey (NOS) completed 516 km of first-order, class I leveling in New Mexico and Texas in the fall of 1977.

The survey was accomplished in two parts: Part one was the releveling of a 202 km segment of the existing first-order line, from Carlsbad, New Mexico, to 43 miles N. of Sierra Blanca, Texas (L-24244). The purpose of this releveling was to study vertical movement of the bench marks along the line. In part two, three new level lines were established in the San Simon area (L-24247) with a total length of 314 km. The purpose of the new levelings was to establish elevations for bench marks set in the area designated as a waste disposal site. Periodic releveling of these lines will provide information about vertical movement in the area associated with waste disposal. For location of the level lines, see Figure 1.

In addition to the list of adjusted elevations and bench mark descriptions for the above mentioned lines, corresponding lists of the observed elevations (Phase 1) are included. Those elevations can be used for crustal movement studies. Tabulations of differences of observed elevations for different epochs are enclosed. IN order to be consistent, we always subtracted the elevation of the common bench mark of the base line from the corresponding elevation of the other epoch. The computer generated profiles are also enclosed. These profiles show the apparent movement of the bench marks for each time period relative to a bench mark at the beginning of the profile, which was assumed to be stable.

The profile for the entire project which is the combined, smoothed result of the individual profiles, indicates an apparent regional subsidence of approximately 1 dm at Carlsbad relative to BM L 181 at 41 miles SW of Pine Springs, Texas. Alternatively, it might be concluded, based on the available information of the profiles, that the Carlsbad area is stable and there is uplift at the area 41 miles SW of Pine Springs, Texas. The extent of the . . ."

Balazs, E.I., 1982. Vertical Movement in the Los Medaños and Nash Draw Areas, New Mexico, as Indicated by 1977 and 1981 Leveling Surveys. NOAA Technical Memorandum NOS NGS 37, National Geodetic Survey, Rockville, MD.

ABSTRACT, p 1;

" Free-adjusted heights of two survey epochs were compared for the Los Medanos and Nash Draw areas. The changes in heights of common bench marks were tabulated and plotted. The apparent movement for the area documented in this report is relative to bench mark 1 BOR, set in a bridge in Carlsbad, N. Mex. A total of 122 of the 147 common bench marks indicates consistent subsidence averaging approximately 18 mm between 1977 and 1981 (4.6 mm/yr). At two bench marks, located over potash mines in the area, the subsidence is much larger."

Barker, J.M., and Austin, G.S. 1993. "Economic Geology of the Carlsbad Potash District, New Mexico, in Carlsbad Region, New Mexico and West Texas." In Geology of the Carlsbad Region, New Mexico and Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 283-291. New Mexico Geological Society, Socorro, NM.

ABSTRACT, p 283;

" New Mexico produced 83% of domestic potash and 27% of domestic consumption in 1992. Fertilizer was used 95% of U. S. production; 5% was used in chemicals. The potash industry of New Mexico produces sylvite (KCl), langbeinite ($K_2SO_4 \bullet 2Mg(SO_4)_2$) and artificial K_2SO_4. Sylvite grade in New Mexico decreased from 20-25% K_2O in the 1950s to about 14% today. The average grade of langbeinite (first produced in 1940) remains 8-10% K_2O. Reserves in the Known Potash Leasing Area (KPLA) will sustain production for 25 to 35 years and represent 57% of domestic reserves. Potash horizons extend far outside the KPLA, but none are economic. Commercial potash occurs in the middle or McNutt Member of the Salado Formation (Upper Permian Ochoan Stage). The potash distribution in the Salado is asymmetrical, suggesting a reflux model related to a bar-restricted marine embayment with dense brine underflow toward the bar. The dominantly seawater brine was magnesium-rich, producing primary carnallite or polyhalite, later recycled into the modern complex salt assemblage. The 400-ft-thick McNutt Member dips about 1° east and contains 11 of 12 potential ore zones in the Salado. Potash zones are 3-10 ft thick and contain minable sylvite and/or langbeinite, together with halite and accessory minerals. The zones are consistent laterally, but are locally interrupted by barren halite (salt horses) formed later by undersaturated migrating fluids. Room-and-pillar mining, with pulled pillars, recovers >90% of the potash from depths ranging from 885 to 1400 ft by continuous-mining coal equipment or drilling and blasting. Beneficiation is by various separation, flotation, crystallization, leaching and heavy-media circuits optimized for each ore. The mineralogy and proportion of clay minerals, up to 7% of the ore, influence optimum milling procedures and ore grade cutoff. Agriculture, petroleum and nuclear waste disposal affect production of potash from southeastern New Mexico. Agricultural demand for fertilizer is a complex interaction between weather and climate, advances in crop genetics, soil science, farming practices, GNP of importing nations, farm income, population growth, efficient distribution systems, freight rates and backhauls, substitutes, taxes and tariffs. Petroleum companies compete for petroleum under potash and the Waste Isolation Pilot Plant (WIPP) led to withdrawal of potash reserves."

Barrows, L.J. and Fett, J.D. 1985. A High-Precision Gravity Survey in the Delaware Basin of Southeastern New Mexico. Geophysics, Vol. 50, No. 5, pp. 825-833.

ABSTRACT, p 825;

" Since 1974, the Department of Energy has been studying bedded salt deposits in southeastern New Mexico as a possible location for disposing of defense-generated transuranic and low-level radioactive wastes. The program known as the Waste Isolation Pilot Plant , includes intensive geologic characterization of about 40 km^2 and construction of an underground test facility. The gravity survey reported is part of the site geologic characterization.

The gravity survey was conducted to delineate structural features near and at the proposed site. However, during the survey the gravity field was found to be dominated by effects of lateral density variations within relatively flat-lying strata. Particularly distinctive is a pattern of elongate negative anomalies about one-half mGal in amplitude. Boreholes in the anomalies encountered normal stratigraphy and no unusual geologic structures. However, borehole densilogs showed lower acoustic velocities that are measured outside of the anomalies. The low densities adequately account for the observed gravity anomalies.

The regional stratigraphy contains water-soluble minerals (halite, polyhalite, anhydrite-gypsum, carbonates). Much of this material has dissolved and the region has been identified as a karstland. At the site, dissolution is slowly affecting the Rustler formation overlying the main salt-bearing units. The low rock densities, associated with the negative gravity anomalies, are interpreted as due to alteration in the vicinity of solution conduits within the Rustler formation. This interpretation is supported by (1) partial coincidence between the negative gravity anomalies and closed topographic depressions (alluvial dolines); (2) greater anhydrite-to-gypsum conversion detected in boreholes within the anomalies; and (3) solution conduits encountered in one of the boreholes."

Beauheim, R.L., 1986. Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-1364. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3;

" Eleven different zones were tested in Well DOE-2 in five phases of testing between 1984 and 1986. Testing techniques included a constant-head, borehole-infiltration test, drill-stem tests, slug tests, pressure-pulse tests, and multiwell pumping tests. Four of the zones tested--the lower Dewey Lake Red Beds, the Tamarisk Member of the Rustler Formation, the lower unnamed member of the Rustler Formation and the Rustler/Salado contact, and the entire Salado Formation--had permeabilities too low to measure with the equipment and test techniques used. The other zones had permeabilities ranging over six orders of magnitude. No saturated strata were encountered above the Rustler Formation, although parts of the middle Dewey Lake Red Beds appear to have appreciable permeability.

In the Rustler Formation, the Culebra Dolomite Member is the most permeable unit, having a transmissivity of ~ 90 ft^2/day. The Culebra behaves hydraulically as a double-porosity system, with the major permeability provided by fractures and the major storage provided by matrix porosity. The Culebra at DOE-2 is well connected hydraulically to the Culebra at Wells H-6b and WIPP-13 to the west, probably by interconnected fractures. Response times between these wells are very short (<1 day/10,000 ft). The Culebra does not appear to be as fractured to the south at Wells WIPP-12 and 18, or to the east at Well H-5b, as indicated by delayed, low-magnitude (or nonexistent) responses to DOE-2 pumping, and by low permeabilities interpreted from other tests conducted at those wells. The other Rustler members at DOE-2, which are not known to be fractured and do not display hydraulic responses typical . . ."

Beauheim, R.L., and Holt, R.M. 1990. "Hydrogeology of the WIPP Site." In Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, Geological Society of America 1990 Annual Meeting Field Trip #14 Guidebook, pp. 131-179. Dallas Geological Society, Dallas, TX.

Introduction, p 2, col. 1;
" The field trip provides an on site introduction to the geology and hydrology of the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The mission of the WIPP is to dispose of transuranic (TRU) waste generated since 1970 by the U. S. defense programs. After 18 years of study and the publication of hundreds of documents, these studies remain unknown to many geologists. Although many of the studies are unique, they lack recognition. This field trip and guidebook begin to redress this imbalance."

Beauheim, R.L., Roberts, R.M., Dale, T.F., Fort, M.D., and Stensrud, W.A. 1993. Hydraulic Testing of Salado Formation Evaporites at the Waste Isolation Pilot Plant Site: Second Interpretive Report. SAND92-0533. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" Pressure-pulse, constant-pressure flow, and pressure-buildup tests have been performed in bedded evaporites of the Salado Formation at the Waste Isolation Pilot Plant (WIPP) site to evaluate the hydraulic properties controlling brine flow through the Salado. Transmissivities ranging from about 7 x 10^{-15} to 5 x $10^{-13}m^2/s$ have been interpreted from six sequences of tests conducted on five stratigraphic intervals within 15 m of the WIPP underground excavations. The corresponding vertically averaged hydraulic conductivities of the intervals range from about 1.1 x 10^{-14} to 2 x 10^{-12} m/s (permeabilities of 2 x 10^{-21} to 3 x $10^{-19}m^2$). Storativities of the tested intervals range from about 1 x 10^{-8} to 2 x 10^{-6}, and values of specific storage range from 9 x 10^{-8} to 1 x $10^{-5}m^{-1}$. Pore pressures in eight stratigraphic intervals range from about 2.5 to 12.5 MPa, and appear to be affected by stress relief around the excavations. Anhydrite interbeds appear to be one or more orders of magnitude more permeable than the surrounding halite, primarily because of subhorizontal bedding-plane fractures present in the anhydrites. Interpretations of the tests revealed no apparent hydrologic boundaries within the radii of influence of the tests, which were calculated to range from about 2 to 20 m from the test holes. An assumption of Darcy flow through the evaporites is thought to be a reasonable interpretive approach because Darcy-flow models are able to replicate the flow and pressure behavior observed during entire testing sequences involving different types of tests performed with different hydraulic gradients."

Bertram-Howery, S.G., and Hunter, R.L. 1989. Plans for Evaluation of the Waste Isolation Pilot Plant Compliance with EPA Standards for Radioactive Waste Management and Disposal. SAND88-2871. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. i;

" The Department of Energy (DOE) is actively pursuing the disposal of transuranic (TRU) waste in a geologic environment at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. The WIPP Project will assess compliance with the Environmental Protection Agency's Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR Part 191). The Standard is divided into two subparts. Subpart A limits annual radiation doses to members of the public from waste management and storage operations at disposal facilities, and Subpart B limits cumulative releases of radioactive materials for 10,000 years, radiation doses to members of the public for 1000 years, and radioactive contamination of certain sources of ground water for 1000 years, as a result of disposal of wastes. The WIPP Project will assess compliance with Subpart A primarily by means of an extensive monitoring program. The Project will assess compliance with Subpart B primarily using performance-assessment techniques developed for the evaluation of the performance of high-level-waste repositories. Compliance with the Assurance Requirements and the Ground Water Protection Requirements will be assessed using other techniques. The WIPP Project will be the first to evaluate the compliance of a mined geologic repository with the EPA Standard. Although Subpart B of the Standard was remanded to EPA by the United States Court of Appeals for the First Circuit, this paper discusses the Standard as first promulgated. Compliance plans for the WIPP will be revised as necessary in response to any changes in the Standard."

Blaney, H.F., and Hanson, E.G. 1965. Consumptive Use and Water Requirements in New Mexico. Technical Report 32. New Mexico State Engineer's Office.

ABSTRACT, p 1;

" Many factors influence the amount of water that is consumed by plants. The more important natural influences are climate, water supply, soil, and topography. The climatic factors believed to have the greatest influence on consumptive use are precipitation, temperature, solar radiation, humidity, wind movement, and growing season. Irrigation practices also influence the amount of water consumed as do the kinds of crops grown, their stage of growth, plant species, and many other factors.

This report includes results of experimental studies in New Mexico, Arizona, and other western states. An empirical formula has been developed from these results and from data compiled in the Pecos River Joint Investigation of 1939-41 (9)* which show the relationship between temperature, length of growing season, monthly percent of annual daytime hours, and consumptive use of water. From this relationship, consumptive use of water by crops and natural vegetation can be readily estimated for any area where the basic climatological data are available. Irrigation requirements may be estimated from consumptive use.

Briefly, the procedure was developed by correlating measured consumptive-use data with monthly temperature, monthly percentages of annual daytime hours, quantity and occurrence of precipitation, and length of growing or irrigation season. The coefficients thus developed allow for the computation of consumptive use of each crop if only monthly temperature, latitude, and growing period of the crop are known, since monthly percentages of annual daytime hours are available for latitudes in New Mexico. Seasonal consumptive use can be computed from the Blaney-Criddle (B-C) formula $U = KF$; where U = consumptive use of water in inches, K = empirical seasonal use coefficient, and F = sum of monthly use factors (f) for the season. The monthly use factor (f) is the product of mean monthly temperature (t) and monthly (p) percent of annual daytime hours (4). The equation for monthly or short-period use is $u = kf$.

The seasonal coefficient for each crop appears to be approximately constant for most areas where irrigation is in practice. However, the coefficients do not appear to be constant for consecutive short periods of time throughout the growing season. For short periods, the higher the temperature, the larger the coefficient (k) appears to be. However, temperature is not the only factor affecting consumptive-use relationships. Each crop has its own particular growth and water-use pattern. Thus, for short periods of time, use coefficients vary, largely depending upon temperature and stage of growth.

The net amount of irrigation water required to satisfy consumptive use during any period of time is determined by subtracting the effective precipitation and other available water from the total requirement for the period. This net requirement of irrigation water, divided by the irrigation efficiency, is the overall water requirement to satisfy the needs of the crop. If efficiency measurements are not available they can be estimated by taking into account irrigation practices, soil characteristics, topography, skill of the irrigator, degree of

land preparation, and availability and cost of water supplies. Irrigation efficiency may be measured in the field, but such measurements are expensive to make and -- as an alternative approach -- they are often estimated by making allowances for certain wastes such as ditch seepage, deep percolation, and surface runoff. The diversion requirement is the net consumptive irrigation requirement corrected for conveyance and application losses."

Blackwell, D.D., Steele, J.L., and Carter, L.S. 1991. "Heat-Flow Patterns of the North American Continent; A Discussion of the Geothermal Map of North America." In Neotectonics of North America, D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 423-436. Geological Society of America, Boulder, CO.

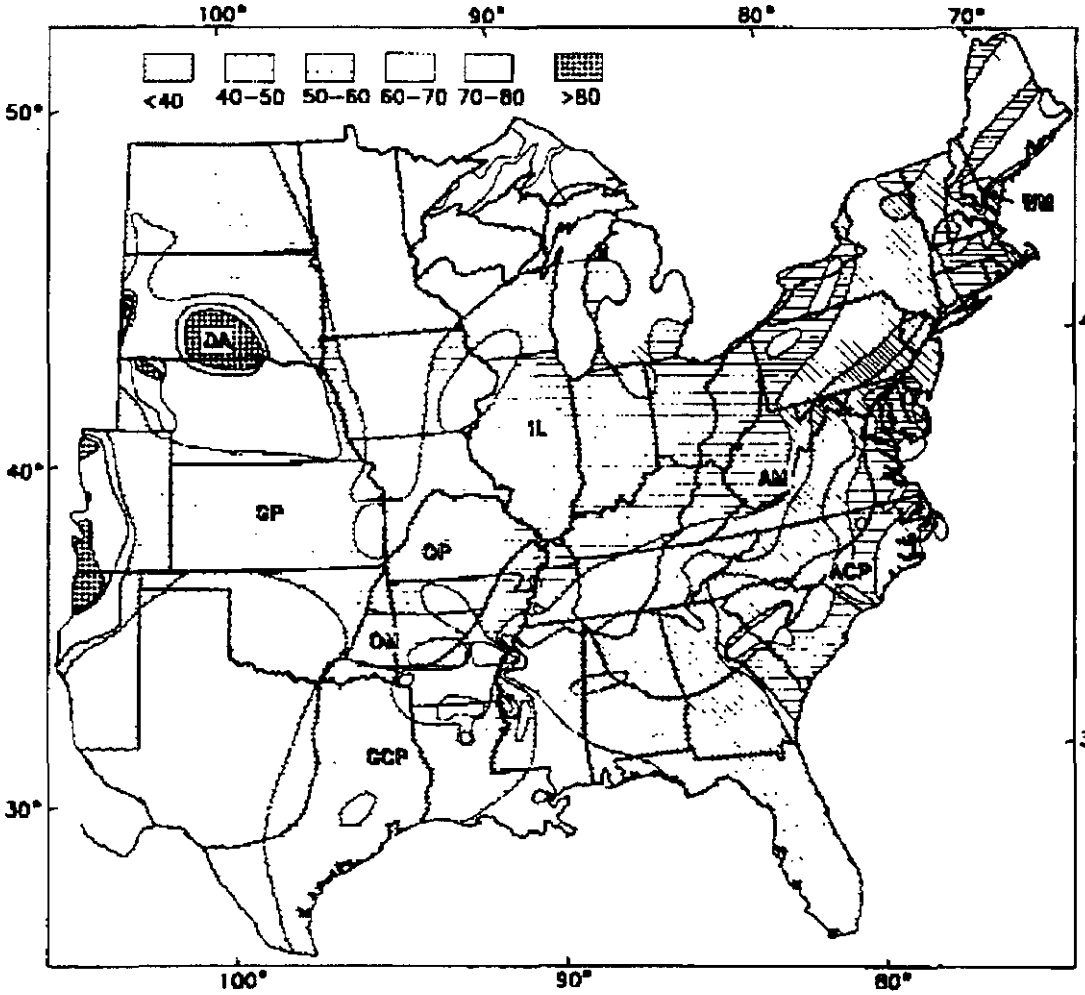

Figure 2. Heat-flow map for the eastern United States. The contours are from the DNAG *Geothermal Map of North America* and are shown at 10-mWm^{-2} intervals. Each band of heat flow is shown by a different pattern. Abbreviations are explained in the text.

Bodine, M.W., Jr., 1978. "Clay-Mineral Assemblages from Drill Core of Ochoan Evaporites, Eddy County, New Mexico," Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas, Circular 159, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p. 21;

" The ERDA-9 drill hole, Eddy County, New Mexico, was cored for 1,987 ft, from 230 ft below the top of the Salado Formation through the upper 41 ft of the Castile Formation. Clay minerals in 47 insoluble residues include corrensite, random to partially ordered clinochlore-saponite mixed-layer clays, illite, clinochlore, saponite, a tentatively identified talc-saponite mixed-layer clay, serpentine, and talc. Serpentine is restricted to the Castile and lowermost Salado Formations; (?)talc-saponite is confined to some polyhalite beds in and overlying the McNutt potash zone. The salztons (thin argillaceous seams) consist of corrensite, illite, and clinochlore, while the adjacent evaporite strata often contain abundant to random mixed-layer clinochlore-saponite, mixed-layer (?)talc-saponite, or saponite. Chemical compositions of the residues have high Mg-Al atom ratios reflecting abundance of the trioctahedral clays. Mineralogy and chemistry of the assemblages strongly indicate that severe alteration and Mg-enrichment of normal clay detritus occurred in the evaporite environment through brine-sediment interaction. It is further suggested that the relatively immature clays--saponite, mixed-layer (?)talc-saponite, and randomly interstratified clinochlore-saponite--formed later through recrystallization of preexisting trioctahedral clays in response to transient pore fluids; the salztons, impermeable to such fluids, developed a more mature clay assemblage in a static pore fluid environment. The serpentine-saponite residues with their high Mg-Al and Si-Al atom ratios in Castile and lowermost Salado evaporites are indicative of a silica-rich detrital source; the more aluminous clay assemblages with decreased Mg-Al and Si-Al atom ratios in the overlying evaporite strata suggest a substantially more argillaceous detrital source."

Borns, D.J. and Shaffer, S.E. 1985. Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin. SAND83-1798. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3;

" Although well logs provide the most complete record of stratigraphy and structure in the northern Delaware Basin, regional interpretations of these logs generate problems of ambiguous lithologic signatures and one-hole anomalies. Interpretation must therefore be based on log-to-log correlation rather than on inferrences from single logs. In this report, logs from 276 wells were used to make stratigraphic picks of Ochoan horizons (the Rustler, Salado, and Castile Formations) in the New Mexico portion of the Delaware Basin. Current log correlation suggests that: (1) the Castile is characterized by lateral thickening and thinning; (2) some Castile thinnings are of Permian age; (3) irregular topography in the Guadalupian Bell Canyon Formation may produce apparent structures in the overlying Ochoan units; and (4) extensive dissolution of the Salado is not apparent in the area of the Waste Isolation Pilot Plant (WIPP) site."

Borns, D.J., and Stormont, J.C. 1987. Delineation of the Disturbed Rock Zone around Excavations in Salt, Waste Isolation Pilot Plant (WIPP), SE New Mexico; Abstracts with Programs. 1987 Annual Meeting and Exposition of the Geological Society of America, Vol. 19, No. 7. Geological Society of America, Phoenix, AZ.

ABSTRACT, p 353;
" At the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico, the Disturbed Rock Zone (DRZ, the zone of rock in which the mechanical and hydrologic properties have changed in response to excavation) has been characterized with visual observations, geophysical methods, and gas-flow measurements. The visual observations, geophysics, and gas-flow tests have defined a DRZ at the WIPP extending laterally throughout the excavation and varying in depth from 1 to 5 m. Desaturation and microfracturing has occurred to some degree within the zone. The dilation that results from the microfracturing in the DRZ provides a component of the observed closure."

Brinster, K.F., 1991. Preliminary Geohydrologic Conceptual Model of the Los Medaños Region Near the Waste Isolation Pilot Plant for the Purpose of Performance Assessment. SAND89-7147 and addendum. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;
" This report describes a geohydrologic conceptual model of the northern Delaware Basin to be used in modeling three dimensional, regional ground-water flow for assessing the performance of the Waste Isolation Pilot Plant (WIPP) in the Los Medaños region near Carlsbad, New Mexico. Geochemical and hydrological evidence indicates that flow is transient in the Rustler Formation and the Capitan aquifer in response to changing geologic, hydrologic, and climatic conditions. Before the Pleistocene, ground-water flow in the Rustler Formation was generally eastward, but uneven tilting of the Delaware Basin lowered the regional base level and formed fractures in the evaporitic sequence of rocks approximately parallel to the basin axis. Dissolution along the fractures, coupled with erosion, formed Nash Draw. Also, the drop in base level resulted in an increase in the carrying power of the Pecos River, which began incising the capitan aquifer near Carlsbad, New Mexico. Erosion and downcutting released hydraulic pressure that caused a reversal in Rustler ground-water flow direction near the WIPP. Flow in the Rustler west of the WIPP is toward Nash Draw and eventually toward Malaga Bend; flow south of the WIPP is toward Malaga bend."

Brokaw, A.L., Jones, C.L., Cooley, M.E., and Hays, W.H. 1972. Geology and Hydrology of the Carlsbad Potash Area, Eddy and Lea Counties, New Mexico, Open File Report 4339-1, U.S. Geological Survey, Denver, CO.

ABSTRACT;

" The potash mines of southeastern New Mexico are in a sparsely populated area 15-30 miles east of Carlsbad. Topographic relief is low, surface drainage poor, and collapse features common. The climate is semiarid.

Sedimentary rocks attain thicknesses of more than 20,000 feet and range in age from Ordovician to Quaternary. The area includes the northern end of the Delaware basin and the largely buried Capitan Reef. The basin contains as much as 13,000 feet of Permian strata. The oldest exposed rocks are of Late Permian age, but drilling has provided much data on the buried older rocks. The principle structures are broad gentle features related to late Paleozoic sedimentation: the northern Delaware basin, a shelf north and west of the basin, and a central basin platform to the east. These structures were tilted eastward before Pliocene time, have been inactive since, and now show a general eastward dip of less than 2°.

The salt deposits are in the Late Permian Ochoan Series composed of a thick salt-bearing evaporite lower part (Castile, Salado, and Rustler Formations) and a thin non-salt-bearing upper part (Dewey Redbeds).

The Castile Formation consists largely of interlaminated gray anhydrite and brownish-gray limestone, but includes much rock salt. It is about 1,500-1,600 feet thick along the southern edge of the potash area; it thins northward to about 1,000 feet near the margin of the Delaware basin and tongues out in the southernmost parts of the northwest shelf. All the salt is concentrated in a thick middle member which lies 200-300 ft above the base of the formation.

The Salado Formation, the main salt-bearing unit of the potash area, ranges in thickness from about 1,900 feet in the south to about 1,000 feet in the north. The formation is characterized by thick persistent units of rock salt alternating with thinner units of anhydrite and polyhalite. Thin seams of claystone underlie the anhydrite and polyhalite unit, and there are a few beds of sandstone and siltstone at large intervals. The Salado Formation is divided into three informal units: a lower and an upper salt member, generally free of sylvite and other potassium and magnesium evaporite minerals, and the McNutt potash zone, generally rich in these minerals.

The Rustler Formation mostly anhydrite and rock salt, thins from 300 to 400 feet in the southern part of the area to about 200-250 feet in the northern part. Some dolomite is present in the upper and lower parts of the formation, and thin to thick units of sandstone and shale are interbedded at long to short intervals.

The Dewey Lake Redbeds at the top of the Ochoan Series consist of reddish-brown siltstone and fine-grained sandstone. The formation is 250-550 feet thick in the potash area.

Three main hydrologic units control the ground-water hydrology of the Carlsbad potash mining area: the Pecos River, the water-bearing strata overlying the Salado

Formation, and the Capitan Limestone and other water-bearing strata underlying the Salado. The distribution and development of large dissolution features, particularly in the Nash Draw and Clayton Basin areas, exert a major effect on the occurrence and movement of the ground water. The Pecos River receives nearly all of the ground-water outflow from the area. Most of that outflow reaches the Pecos near Malaga Bend.

The main water-yielding units overlying the Salado Formation are the basal solution breccia zone and the Culebra Dolomite Member of the Rustler Formation, the Santa Rosa Sandstone, and the alluvium. The basal solution breccia zone is the hydrologic unit most significant in the solution of halite from the upper part of the Salado Formation. The easternmost extent of evaporite solution in the potash mining area is roughly at the common boundary between Ranges 30 and 31 E. The formations above the Salado Formation seem to be connected hydrologically and can be considered a single multiple aquifer system. Solution activity and associated collapse, subsidence, and fracturing have increased the overall permeability of the rocks and the interformational movement of water in the aquifer system.

Ground water in the formations above the Salado moves generally southward and southwestward across the potash mining area toward the Pecos River. Although the total amount of ground water discharging to the Pecos River is not known, it has been estimated that 200 gals per minute enter the river from the basal solution breccia zone.

The potentiometric and water-table contours outline a series of ground-water ridges and troughs imposed on the regional southward to southwestward pattern of ground-water movement. A large southwestward-plunging ground-water trough extends from Malaga Bend northeastward roughly through Nash Draw to beyond the mining area in the vicinity of Laguna Plata. Another much smaller trough is east and southeast of the Project Gnome site.

The Salado Formation has an intergranular porosity and permeability that ranges from low to virtually none. Locally, fractures and solution openings impart a spotty formational permeability. In the potash mining area, the Salado Formation is dry except for water in the leached zone at the top of the formation and small pockets of water or water and gas encountered ocassionally during mining.

The Cambrian to Permian sedimentary rocks underlying the Salado Formation contain water of brine composition and are under high artesian pressure. These rocks are not exposed in the potash mining area but lie deeply buried throughout much of southeastern New Mexico and western Texas. In the potash mining area the elevations of the potentiometric surfaces of different zones of these rocks range from a few feet to a few hundred feet above or below the land surface."

Brookins, D.G. 1980. Polyhalite K-Ar Radiometric Ages from Aoutheastern New Mexico. In Isochron/West pp. 29-31.

p. 29, col. 1;
" This paper lists four new radiometric K-Ar age determinations for polyhalites from southeastern New Mexico. These data are compared with seven published ages by Brookins and others (1980). The new (nos. 1-4) samples were chosen because they were mixed with halite and sylvite, although the exact halide content could not be determined from x-ray diffratometry. Nor can it be stated with certainty that other halides and-or other evaporite minerals are present or not. The detailed geology, mineralogy, chemistry and precise sample locations are given in SAND (1978). Earlier studies of langbeinite and langbeinite-sylvite mixtures have been reported in this journal by Schilling (1973), and will not be repeated here except to note that a distinct lowering of K-Ar ages with increasing sylvite content was noted. The purpose of this note is to see if similar effects are noted for polyhalites. The K-Ar analyses and age calculations were carried out by Geochron Laboratories, Inc., Cambridge, Mass."

Brookins, D.G. and Lambert, S.J. 1987. Radiometric Dating of Ochoan (Permian) Evaporites, WIPP site, Delaware Basin, New Mexico, USA. Materials Research Society, ed., Vol. 84, pp. 771-780.

ABSTRACT, p. 771;

" We have attempted radiometric dating of halide-sulfate salts and clay minerals from the Delaware Basin, New Mexico, USA, as part of geochemical study of the stability of the evaporite sequence at the WIPP (Waste Isolation Pilot Plant--a US DOE facility) site. We undertook this dating to determine: (1) primary age of evaporite genesis or time(s) of recrystallization, (2) if previously undated evaporite minerals (leonite, polyhalite, kieserite) give useful data, and (3) if the detrital clay minerals have been radiometrically reset at any time following their incorporation into the evaporite medium. We have shown earlier that polyhalites can indeed be successfully dated by the K-Ar method, and once corrections are applied for admixed halide minerals, dates of 210-230 Ma for the Delaware Basin are obtained. Rb-Sr isochrons from early stage sylvites-polyhalites-anhydrites yield 220 $\pm$ 10 Ma, even when some sylvites yield lower K-Ar dates due to loss of $^{40}Ar^{*}$. K-Ar dates on leonites and kieserites are also low due to $^{40}Ar^{*}$ loss, but their Rb-Sr dates are higher. Detrital clay minerals from the Delaware Basin collectively yield a highly scattered isochron (390 $\pm$ 77 Ma), but samples from a local area, such as the WIPP Site, give a much better age of 428 $\pm$ 7 Ma. These dates show that the interaction between the clay minerals and the evaporitic brines was insufficient to reset the clay minerals Rb-Sr systematics. In a related study, we note that a dike emplaced in the evaporite at 34 Ma had only very limited effect on the intruded rocks; contact phenomena were all within 2 m of the dike. All of our geochemical (radio-metric and trace element) studies of the WIPP site argue for preservation of the isotopic and chemical integrity of the major minerals for the past 200 Ma."

Brookins, D.G., Lambert, S.J., and Ward, D.B. 1990. Authigenic Clay Minerals in the Rustler Formation, WIPP Site Area, New Mexico. SAND89-1405. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i, para 2;

" We have investigated the Rb-Sr systematics of clay minerals from the Culebra Member and elsewhere in the Rustler Formation. By separating the less than 0.125 μm size material we are able to deal with presumed true authigenic clay minerals. The authigenic fraction is especially sensitive to chemical and isotopic exchange with waters, and an episodic exposure to a large amount of water will reset the clay minerals to such a time. Our data yield 259 $\pm$ 22 Ma Rb-Sr isochron, which is consistent with the Late Permian age of the Rustler Formation. This age demonstrates that age-determining cations in these clay minerals have preserved their isotopic and chemical integrity since the Late Permian."

Brookins, D.G., Register, J.K., and Krueger, H. 1980. Potassium-Argon Dating of Polyhalite in Southeast New Mexico. Geochimica et Cosmoshimica Acta, Vol. 44, pp. 635-637.

ABSTRACT, p 635;

" Polyhalite $K_2Ca_2Mg(SO_4)_4 \bullet 2H_2O$, is an important mineral in many evaporites. Although its use for K-Ar dating has never been investigated, our results indicate that it is a very useful mineral for dating events ranging from the time of potash mineralization to any younger events which may have affected the evaporite. Five K-Ar dates on pure polyhalite, including two from included material and from beds distorted by the formation of a rubble chimney, yield dates between 198 and 216 Myp, in good agreement with Rb-Sr dates and the diagenetic age of the potash deposits from the same rocks. Two polyhalites mixed with sylvite gave lower dates (154 and 174 Myr) which is to be expected because of radiogenic ^{40}K loss from the sylvite phase. One polyhalite, formed after the intrusion of a 31 Myr lamphrophyre dike, yielded 21 Myr. Collectively our results indicate that pure polyhalite is satisfactory for K-Ar dating and may provide critical age information in studies of the geologic history of the evaporite sequences."

Cauffman, T.L., LaVenue, A.M., and McCord, J.P. 1990. Ground-Water Flow Modeling of the Culebra Dolomite. Volume II: Data Base. SAND89-7068/2. Sandia National Laboratories, Albuquerque, NM.

PREFACE, p ii;

" The objective of this report is to present and discuss the hydrogeologic data base for the Culebra dolomite at the WIPP site. The data base includes:

- coordinates of the WIPP-area boreholes,
- Culebra elevations,
- Culebra transmissivities.
- Culebra storativities,
- Culebra formation-fluid densities,
- borehole fluid-density histories for the WIPP-site boreholes,
- estimates of the uncertainty in the borehole-fluid densities and the uncertainty in the related equivalent-freshwater heads,
- transient freshwater heads,
- estimates of an undisturbed freshwater head, and the uncertainty in this value for the WIPP-site boreholes, and
- shaft construction, grouting, and inflow histories.

This report documents the hydrogeologic data base subsequently used in a study which modeled ground-water flow in the Culebra dolomite. The modeling study is given in a companion report 'Ground-Water Flow Modeling of the culebra Dolomite: Volume I - Model Calibration', SAND89-7068/1, by A.M. LaVenue, T.L. Cauffman, and J.F. Pickens."

Chapman, J.B., 1986. Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area. EEG-35. DOE/AL/10752-35. Environmental Evaluation Group, Santa Fe, NM.

EXECUTIVE SUMMARY, p iv;

" The first geologic repository for nuclear waste in the United States, the Waste Isolation Pilot Plant (WIPP), is being excavated at a depth of 2150 ft below ground surface in the Salado Formation in southeastern New Mexico. If a breach of the repository occurs, the water-bearing zones of the Rustler Formation, overlying the Salado, are considered to be the most likely pathways for the transport of radionuclides to the biosphere. A thorough characterization of the hydrology of the Rustler Formation is crucial to the evaluation of the consequences of a breach of the WIPP repository.

The Department of Energy is currently conducting studies of the Rustler Formation (many at the request of the State of New Mexico) that should significantly improve knowledge about the radionuclide contaminant transport ability of the Rustler. One recently completed study examined stable isotope data from Rustler groundwater and concluded that Rustler groundwater in the vicinity of the WIPP Site is not receiving significant modern meteoric recharge (Lambert, 1986). In addition, Lambert (1986) concludes that the stable isotope data reveal an hydraulic isolation of two possible discharge areas (well WIPP-29 and Surprise Spring) from the Rustler Formation elsewhere in Nash Draw and near the site. The conclusion of Lambert's (1986) stable isotope study allow longer residence time of water in the Rustler Formation and reduce the calculated consequences of a breach of the WIPP repository.

The present study compiles stable isotope data from throughout southeastern New Mexico and compares them to data from the WIPP area. The stable isotopic compositions of most samples of groundwater from the Rustler Formation are similar to the composition of other, verifiable young, groundwater in the area. Though the stable-isotope data cannot indicate ages for water in the various aquifers, neither do the data show any distinction between most Rustler groundwater and verifiable young groundwater.

A small number of samples, primarily from the Rustler/Salado contact east of Nash Draw, have isotopic compositions that are not characteristic of recently recharged meteoric water. These waters' enrichment in heavy isotopes may be due to mixing with deeper groundwater (supported by the stable isotopic composition of Salado fluid inclusions and Castile brine) or to exchange between the groundwater and hydrous minerals.

A comparison of the heavy isotope enrichment observed in evaporating waters and the composition of the water at WIPP-29 and Surprise Spring shows that the isotopic composition of these Nash Draw waters could be derived by evaporating Rustler groundwater. Based on stable isotopes, both WIPP-29 and Surprise Spring could be discharge areas for Rustler groundwater moving from elsewhere in Nash Draw and the east.

The enrichment in heavy isotopes found in water from pools in Carlsbad Caverns was used by Lambert (1986) as evidence that the relatively depleted Rustler water was recharged during a past, more pluvial, time. However, the uniqueness of the isotopic composition of

water in the Caverns' pools suggest that rather than representing the composition of recent recharge, the heavy isotopes are enriched by evaporation and equilibrium isotope exchange in the humid cave environment. Recharge in the extreme karst environment near the cavern may also favor isotopically heavy precipitation."

Chapman, J.B., 1988. Chemical and Radiochemical Characteristics of Groundwater in the Culebra Dolomite, Southeastern NM. EEG-39. Environmental Evaluation Group, Santa Fe, NM.

EXECUTIVE SUMMARY, p. iii;

" The nation's first geologic repository for radioactive waste is being excavated in southeastern New Mexico at the Waste Isolation Pilot Plant (WIPP). It is located in the northern part of the Delaware Basin, within the bedded halite of the Salado Formation. Post-closure radioactive release scenarios from WIPP often involve hydrologic transport of radionuclides through the overlying Rustler Formation, in the Culebra Dolomite Member. The Environmental Evaluation Group (EEG) has conducted an investigation of the chemistry of Culebra groundwater with several objectives. Major ion analyses provide geochemical data that can be used to help determine groundwater flow paths and reactions that occur along those flow paths. Radiochemical data establish a baseline of existing radionuclides in area groundwater prior to the arrival of waste at WIPP. Both stable and radioactive constituents provide information that can be used to help predict the behavior of the Culebra as a radionuclide transport pathway.

Salinities in Culebra groundwater generally increase from west to east, with a large decrease in the area south of NM Highway 128. The linear correlation between total dissolved solids and Cl, and the almost one-to-one molar correlation between Cl and Na, are strong evidence that the salinity increase is due to halite dissolution. The increase in K and Mg concentrations eastward across the WIPP site corresponds to an increase in Cl, probably due to the dissolution of evaporite minerals coexisting with the halite. There is no obvious reason to relate the high K and Mg concentrations to low aquifer transmissivity and long residence times (as concluded by Mercer, 1983).

Two chemical facies exist in Culebra groundwater, and one of these can be further subdivided. A Na-Cl type water dominates over most of the sampled area with a Ca-SO_4 type occurring in the southern to southwestern area. The Na-Cl water can be subdivided into a low Ca area to the east and a higher Ca area to the west.

As groundwater moves from north to south across the area, the Total Dissolved Solids (TDS) decrease by an order of magnitude and the major hydrochemical facies change from Na-Cl to Ca-SO_4. The only plausible mechanism to effect this change is the influx of a large quantity of low TDS water. The possibility of recharge in the southern area is enhanced by the presence of solution and fill features such as the gypsum caves in the Forty-Niner Member of the Rustler near the Gnome site. These features could behave as conduits supplying fresher water to deeper Rustler units.

Exclusive of the low-salinity southern area, most wells located on the same general flow path have similar ion ratios. A few anomalies, especially in the area around wells H-1, H-2, and H-3 could be due to leakage of more saline water into the Culebra from underlying units. Abnormally high pressures in the Salado could provide a driving force for fluid movement upward. The possibility of such leakage is also indicated by the oxygen and hydrogen isotopic compositions that indicate mixing through the Rustler, Salado, and Castile

formations."

Chaturvedi, L., ed. 1987. The Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler Formation as it Relates to the WIPP Project. EEG-34, DOE/AL/10752-34. Environmental Evaluation Group, Santa Fe, NM.

INTRODUCTION, p. 1;

" A workshop on 'The Rustler Formation at the WIPP Site' was organized by the Environmental Evaluation Group on March 7, 1985. The workshop was held at a time when a new series of studies on the Rustler Formation was starting. It provided the scientists from Sandia National Laboratories, the U.S. Geological Survey, IT Corporation, the Department of Energy and the Environmental Evaluation Group, an opportunity to exchange and discuss the up-to-date information on the geological and hydrological characteristics of the Rustler Formation. The papers and the summaries that follow reflect the status of knowledge at the time of the workshop (March, 1985). The decision to publish the proceedings was not made until after all the papers were received by the end of 1986.

Eight papers were presented at the workshop and much of the time was spent in discussing the relevance and significance of results obtained thus far and the need for further work. Following is a brief description of each of the papers presented and a summary of the discussions."

Chugg, J.C., Anderson, G.W., Kink, D.L., and Jones, L.H. 1952. Soil Survey of Eddy Area, New Mexico. U.S. Department of Agriculture.

" Major fieldwork for this soil survey was done in the period 1960-]965. Soil names and descriptions were approved in 1966. Unless otherwise indicated, statements in this publication refer to conditions in the Area in 1965. This survey was made cooperatively by the Soil Conservation Service and the New Mexico Agricultural Experiment Station. It is part of the technical assistance furnished to the Carlsbad, Central Valley, and Penasco Soil and Water Conservation Districts.

Either enlarged or reduced copies of the soil map in this publication can be made by commercial photographers, or they can be purchased on individual order from the Cartographic Division, Soil Conservation Service, USDA, Washington, D.C. 20250.

HOW TO USE THIS SOIL SURVEY

THIS SOIL SURVEY contains information that can be applied in managing farms and ranches; in selecting sites for roads, ponds, buildings, and other structures; and in judging the suitability of tracts of land for agriculture, industry, and recreation.

Locating Soils

All the soils of the Eddy Area are shown on the detailed map at the back of this publication. This map consists of many sheets made from aerial photographs. Each sheet is numbered to correspond with a number on the Index to Map Sheets.

On each sheet of the detailed map, soil areas are outlined and are identified by symbols. All areas marked with the same symbol are the same kind of soil. The soil symbol is inside the area if there is enough room; otherwise, it is outside and a pointer shows where the symbol belongs.

Finding and Using Information

The "Guide to Mapping Units,, can be used to find information. This guide lists all the soils of the Area in alphabetic order by map symbol and gives the capability classification of each. It also shows the page where each soil is described and the page for the capability unit and range site in which the soil has been placed. The first part of the guide lists the soils mapped at low intensity; the second part lists the soils mapped at high intensity.

Individual colored maps showing the relative suitability or degree of limitation of soils for many specific purposes can be developed by using the soil map and the information in the text. Translucent material can be used as an overlay over the soil map and colored to show soils that have the same limitation or suitability. For example, soils that have a slight limitation for a given use can be colored green, those with a moderate limitation can be colored yellow, and those with a severe limitation can be colored red.

. . ."

Cornell, C.A. 1968. Engineering Seismic Risk Analysis. Seismological Society of America Bulletin. Vol. 58, pp. 1583-1606.

ABSTRACT, p 1583;

" This paper introduces a method for the evaluation of the seismic risk at the site of an engineering project. The results are in terms of a ground motion parameter (such as peak acceleration) versus average return period. The method incorporates the influence of all potential sources of earthquakes and the average activity rates assigned to them. Arbitrary geographical relationships between the site and potential point, line, or areal sources can be modeled with computational ease. In the range of interest, the derived distributions of maximum annual ground motions are in the form of Type I or Type II extreme value distributions, if the more commonly assumed magnitude distribution and attenuation laws are used."

Cornell, C.A. 1971. "Probabilistic Analysis of Damage to Structures Under Seismic Load." In Dynamic Waves in Civil Engineering, D.A. Howell, I.P. Haigh, and C. Taylor, eds., pp. 473-488.

p. 473;

" Balanced engineering design in the face of uncertain loadings requires an assessment of the risks of various levels of damage associated with alternative designs. The appropriate analysis involves stochastic models of the occurrences in time, the sizes, and the induced damages of loading events. This paper is a compilation of recent work in such risk analysis. The emphasis will be on aseismic structural design, although the application of certain of the methodology to such problems as wind, storm, hurricane, tornado, and sea waves will be evident.

Much of the work to be reported has been done by the author or under his supervision at M.I.T., but several other investigators have also been interested in this and related topics recently. With the limited space available in this summary paper thorough referencing will be left to the reports mentioned in the body of the paper [1,2,3,4,5,6]. Nonetheless, the work of Luis Esteva of the University of Mexico[7,8,9] (whom the author visited in 1966 and who visited M.I.T. in 1969), and the efforts of the author's coworker Erik H. Vanmarcke should be given special mention. Many of the pieces of this paper are due in large part to them. The author would like, too, to acknowledge the support of the M.I.T. Interamerican Program and the National Science Foundation (Grant GK-5141).

To assess the seismic risk at a building site one must anticipate the number, locations, and magnitudes of future earthquakes in a region surrounding his site. This study must be coupled with some means of predicting the motions at the site of a given event at a given location, and some means of predicting the damage to the structure when such motions are experienced. The first portion of this paper will focus on seismicity, that is, on the ground motions themselves; the latter portion will discuss structural analysis, that is, measures of damage for given ground motion parameters, plus the coupling of the probabilistic analysis of the seismicity and the structural analyses."

Cornell, C.A., and Merz, H.A. 1975. Seismic Risk Analysis of Boston. Journal of the Structural Engineering American Society of Civil Engineering, Vol. 10, pp. 2027-2043.

ABSTRACT, p. iii;

" The paper presents an analysis of the annual risk that a firm-ground Boston building site might experience any particular level of seismic ground motion intensity, as expressed in Modified Mercalli Intensity, peak ground acceleration, or design response spectrum. The emphasis is upon providing the input for such an analysis in a real case and upon studying the sensitivity of the results to various important parameters."

Cornell, C.A., and Vanmarke, E.H., 1969. "The Major Influences on Seismic Risk." In Fourth World Conference on Earthquake Engineering, Vol. I, pp. 69-83. Santiago, Chile.

SYNOPSIS, p. A-1;

" A new, analytical method of seismic risk analysis is used to study the sensitivity of the peak ground acceleration values associated with prescribed design return periods to the assumptions which must be made when analyzing a site. The predominant influences on risk are thereby demonstrated quantitatively. It is shown that typically the more frequent, but smaller earthquakes contribute more to the risk than larger, more broadly destructive earthquakes. The importance of collecting instrumental data to provide more accurate attenuation laws for near-focus conditions (even for smaller earthquakes) is emphasized when the major influences on seismic risk are appreciated."

Crandall, K.H. 1929. Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas. American Association of Petroleum Geologists Bulletin, Vol. 13.

ABSTRACT, p 927;

" The relationships of the Permian formations exposed in the Guadalupe, Delaware, and Apache mountains and immediately east have for some time been the subject of much dispute. These are greatly clarified by the classification of the Capitan and Apache limestones as reef formations built of the flanks of a large, subsiding basin. This basin was formed principally after the deposition of the lower Delaware limestone and then was partly filled with Delaware sand. The reefs were built during the deposition of the upper part of the Delaware sandstones. The Carlsbad limestones are considered the lagoonal facies of the reef series.

After being restricted from open marine conditions, the basin was filled with the products of an evaporating sea, the Castile gypsum and a distinct salt series.

No attempt is made to subdivide Darton's Chupadera in other parts of New Mexico."

Crawford, J.E., and Wallace, C.S. 1993. "Geology and Mineralization of the Culberson Sulfur Deposit." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 301–316. New Mexico Geological Society, Socorro, NM.

ABSTRACT, p 301;

" The Culberson sulfur deposit occurs as a replacement of Upper Permian evaporites (Salado and Castile Formations) by sulfur-bearing carbonates in the west-central Delaware basin. Structures from two major periods of tectonic activity control the location of sulfur mineralization. Pre-mineralization faults developed in response to Laramide compressional tectonics in the Late Cretaceous to early Tertiary, as indicated by breccia clast assemblages filling paleokarst features along the faults. Basin and Range extensional tectonics uplifted the western Delaware basin beginning in the middle to latest Miocene, resulting in a change in basin hydrodynamics conducive to bioepigenesis. Age of mineralization may be less than 5 Ma, based on mineralization cross-cutting karst-related deposits thought to be of Ogallala (middle-late Miocene) age. Crude oil analysis and correlation of anionic ground water constituents indicate the Guadalupian Cherry Canyon Formation is a probable source for hydrocarbons and oxygenated waters necessary for bioepigenetic sulfur deposition at Culberson. Sulfur occurs as microcrystalline dissemination in replacement limestone and as crystalline vug fillings associated with epigenetic barite, celestite and isotopically light carbonate minerals."

Crawley, M.E. 1988. Hydrostatic Pressure and Fluid-Density Distribution of the Culebra Dolomite Member of the Rustler Formation Near the Waste Isolation Pilot Plant, Southeastern New Mexico. DOE/WIPP 88-030. U.S. Department of Energy, Carlsbad, NM.

INTRODUCTION, p. 1-1;

" This report presents data collected during the three field periods of Pressure - Density Survey program for the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico. The location of the WIPP Site is shown in Figure 1. The WIPP project is operated by the United States Department of Energy (DOE) for the purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes generated by the defense activities of the United States Government. This report presents data collected from 33 individual wells (Table 1A) located in the vicinity of the WIPP Site (Figure 2). Specific information concerning well completions, surveyed elevations, and other data is given in Table 1B.

The Pressure - Density Survey program (Crawley, 1987[a]) was developed to provide ground-water density and pressure information needed to analyze the ground-water hydrology of the Culebra Member of the Rustler Formation. Because the Culebra is a dipping geologic unit containing highly variable density water, formation pressures and accurately defined formation water densities must be used to determine ground-water flow directions (Jorgensen et al., 1982). Past investigations have calculated or estimated formation pressures using measured water levels from wells and single water-density values derived from the literature or estimated for various points across the project area. Estimated formation pressures are often in considerable error relative to actual measured pressures. The Pressure - Density Survey program has attempted to measure directly the pressures at the formation level, and to define the density profile of the fluids in the well bores standing above the depth of the formation in each well."

Dalrymple, G.B., and Lanphere, M.A. 1969. Potassium-Argon Dating. W.H. Freeman and Company.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Davies, P.B. 1984. Deep-Seated Dissolution and Subsidence in Bedded Salt Deposits [Ph.D. Thesis]. Stanford University, Palo Alto, CA.

Section 2.3.5 Summary, p 175;

" A suite of structure contour maps constructed from available borehole logs confirms the existence of an anomalous, closed, structural depression in the northern portion of the WIPP site. This depression persists through several hundred feet of the middle and upper Salado Formation. The depression is broad and shallow in the upper portion of the section and becomes narrower and deeper in successively lower strata. Isopach maps show that the strongest local variations in bed thickness occur in the lowermost unit and are spatially associated with the structural depression. The salt appears to be anomalously thin in the margin areas.

Physical analyses of salt deformation processes suggest that this structural depression formed as the result of ductile subsidence in response to the localized removal of salt at some lower horizon. Processes capable of removing salt include dissolution of lower Castile salt, dissolution of lower Salado salt, and depletion of Castile salt by gravity driven flow. Deep boreholes in the northern WIPP area and elsewhere in the basin reveal geologic features that are characteristic of each of these processes. Consideration of complex structures in these areas leads to the conclusion that there are potentially significant interrelationships between individual processes and that more than one process may be active in a given area. For example, lower Castile salt dissolution may play a critical role in triggering the gravity foundering process by creating local increase in the deviatoric stress at the quasi-stable Anhydrite II and III density inversions and by causing the influx of a small amount of intergranular saturated brine, thereby decreasing the strength of the salt. Another example of process interrelationships is the potentially important role of lower Castile salt dissolution and gravity foundering in creating vertical and horizontal hydrologic pathways, thereby facilitating lower Salado dissolution.

At the Salado depression in the northern WIPP site, there is insufficient data in the Castile and lower Salado to delineate which processes have been active and what process interrelationships exist. Therefore, either additional subsurface data should be gathered in the lower Salado and Castile, or safety analyses of the WIPP facility should explicitly encompass all possible processes, or both."

DOE (U.S. Department of Energy). 1989. Draft Supplement Environmental Impact Statement Waste Isolation Pilot Plant. DOE/EIS-0026-DS. U.S. Department of Energy, Washington, D.C.

ABSTRACT, p iii;

" IN 1980, the DOE published the Final Environmental Impact Statement (FEIS) for the WIPP. This FEIS analyzed and compared the environmental impacts of various alternatives for demonstrating the safe disposal of transuranic (TRU) radioactive wastes resulting from DOE national defense related activities. Based on the environmental analyses in the FEIS, the DOE published a Record of decision in 1981 to proceed with the phased development of the WIPP in southeastern New Mexico as authorized by the Congress in Public Law 96-164.

Since publication of the FEIS, new geological and hydrological information has led to changes in the understanding of the hydrogeological characteristics of the WIPP site as they relate to the long-term performance of the underground waste repository. In addition, there have been changes in the information and assumptions used to analyze the environmental impacts in the FEIS. These changes include: 1) analyses of certain additional DOE generator and/or storage sites as potential contributors to the WIPP waste inventory, 2) changes in the composition of the TRU waste inventory, 3) consideration of the hazardous chemical constituents in TRU wastes, 4) modification and refinement of the system for the transportation of TRU wastes to the WIPP, and 5) addition of the Test Phase.

The purpose of this SEIS is to update the environmental record established in 1980 by evaluating the environmental impacts associated with new information, new circumstances, and proposal modifications. This SEIS evaluates and compares the proposed action and two alternatives for demonstrating the safe disposal of TRU wastes:

The proposed action is to operate the WIPP under a 'Test Phase' for approximately five years during which time certain tests and operational demonstration would be carried out. The tests would be conducted to reduce uncertainties associated with the prediction of natural processes that might affect long-term performance of the underground waste repository. Results of these tests would be used to assess the ability of the WIPP to meet applicable federal standards for the long-term protection of the public and the environment. The operational demonstrations would be conducted to show the ability of the TRU waste management system to certify, package, transport, and emplace TRU wastes in the WIPP safely and efficiently. Upon completion of the Test Phase, the DOE would determine, based on a performance assessment, whether the WIPP would comply with U.S. Environmental Protection Agency (EPA) standards for the long-term disposal of TRU wastes (i.e., 40 CFR Part 191, Subpart B). If there is a determination of compliance, the WIPP would enter a permanent disposal phase of approximately 20 years to demonstrate the safe disposal of TRU wastes. After completion of waste emplacement, the surface facilities would be decommissioned, and the WIPP underground facilities would serve as a permanent radioactive waste repository.

The first alternative, no action, is similar to the no action alternative discussed in the 1980 FEIS. Under this alternative, TRU wastes would continue to be stored at the various

generator and storage sites, while the WIPP facility would be decommissioned and potentially put to other uses.

The second alternative to the proposed action is to delay emplacement of TRU wastes in the WIPP underground until a determination has been made of compliance with EPA standards for TRU waste disposal (i.e., 40 CFR Part 191, Subpart B). The DOE has determined that bin-scale tests could be conducted outside the WIPP underground facilities in a specially designed aboveground facility. This alternative has many implications including delays in both the operational demonstrations and room-scale tests, and the lack of room-scale test data for the compliance demonstration, a temporary mothballing of the WIPP facilities. This is true in any case. The specialized facility for aboveground bin-scale tests could be constructed at any one of several DOE sites. In order to analyze the environmental impacts of this alternative in the SEIS, the DOE has evaluated the Idaho National Engineering Laboratory in Idaho as a representative site for the aboveground bin-scale tests."

DOE (U.S. Department of Energy). 1983. Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing. WTSD-TME-020. United States Department of Energy, Albuquerque, NM.

Section 1.0 ABSTRACT, p 1-1;

" Borehole Cabin Baby-1 was originally drilled to a depth of 4159.0 feet below kelly bushing (8.0 feet above ground surface) in 1974 and 1975 as a 'wildcat' hydrocarbon exploratory well. Control of the borehole was given to the U. S. Department of Energy (DOE) after it was found to be a 'dry hole'. Cabin Baby-1 was reentered, deepened, and hydrologically tested in August and September, 1983. The well is located in Section 5, T23S, R31E, just outside the limit of WIPP Zone III, approximately 2.5 miles south of the WIPP exploratory shaft.

The deepening and testing of Cabin Baby-1 was undertaken for several reasons:

- To provide data on the hydrologic properties, including hydrostatic head potential of selected permeable zones in the Bell Canyon Formation.
- To provide representative fluid samples from selected permeable zones in the Bell Canyon Formation for determination of fluid composition and density.
- To define further the stratigraphy of the upper Bell Canyon Formation at the Cabin Baby-1 location.

The borehole was deepened from the previous total depth to a new depth of 4298.6 feet below kelly bushing by continuous coring. Field operations related to deepening and logging of the borehole began August 12, 1983 and were completed August 30, 1983. Hydrologic testing activities began August 30, 1983 and were completed September 29, 1983. Drill-stem tests were conducted in four zones in the Bell Canyon Formation, and one test of the Salado Formation was performed. Fluid samples were collected from the Hays and Olds sandstones of the Bell Canyon Formation."

DOE (U.S. Department of Energy), 1990. Final Supplement, Environmental Impact Statement, Waste Isolation Pilot Plant. DOE/EIS-0026-FS. Office of Environmental Restoration and Waste Management, Washington, D.C.

Volume 1, Section 1.3 PURPOSE AND NEED FOR SUPPLEMENT TO FEIS, p 1-4;

" Since the publication of the FEIS in October 1980 and the subsequent Record of Decision to proceed with the phased construction and operation of the WIPP, new geologic and hydrologic information has led to changes in the understanding of the hydrogeologic characteristics of the area as they relate to the long-term performance of the WIPP. In addition, several changes have occurred in the Proposed Action and in the information and assumptions used to calculated the impacts reported in the FEIS. These include changes in the composition of the waste inventory, the transportation of waste to the WIPP, modification of the Test Phase, and the management of TRU mixed waste with hazardous chemical constituents.

This SEIS evaluates the environmental consequences of the Proposed Action as modified since 1980 in light of new information and assumptions. Modifications to the Proposed Action since 1980 that are examined in this SEIS are as follows: . . .

The new data and information and the resulting interpretations principally address the geologic and hydrologic systems at the WIPP site. They include:

- Determination of a locally lower permeability in the Salado Formation, the geologic formation in which the WIPP underground facilities are located (Subsection 4.3.2).
- Determination of a potentially higher moisture content in the Salado Formation and consequent brine inflow (Subsection 4.3.2).
- Discovery of a higher transmissivity zone in the Rustler Formation in the southeastern portion of the WIPP site (Subsection 4.3.3).
- New data leading to a conclusion that 'salt creep' (convergence) in the repository occurs faster than previously believed (Subsection 4.3.2).
- Pressurized brines within the Castile Formation which are assumed to be present beneath a portion of the WIPP waste emplacement panels (Subsection 4.3.4.2).
- Discovery of fractures in SPDV rooms (Subsection 4.3.2.4)."

DOE (U.S. Department of Energy), 1993. Waste Isolation Pilot Plant Land Management Plan. DOE/WIPP 93-004. U.S. Department of Energy, Carlsbad Area Office Carlsbad, NM.

Section 1.2 Management Goal, p 1-5;

" The goal of this land management plan is to manage the surface of the withdrawal area under the traditional public land use concept of multiple use and to minimize, to the extent possible, land use restrictions. It is not the intent of the DOE to manage the surface of the withdrawal area as a WIPP exclusive-use area. The subsurface of the withdrawal area is restricted to exclusive use by the WIPP, except for two 320-acre tracts of land within the withdrawal area that are leased for oil and gas development below 6000 feet (Federal Oil and Gas Leases No. NMNM 02953 and No. NMNM 02953C). This restriction is needed to protect the long-term integrity of the WIPP repository. In addition, it is clearly the intent of DOE that during repository operations, facility safety and security shall be maintained."

DOE (U.S. Department of Energy), 1994. Format and Content Guide for Title 40 CFR 191 and Title 40 CFR 268.6 Compliance Reports. DOE/CAO-94-2004. Carlsbad, NM.

INTRODUCTION, p 1;

" This Format and Content Guide was followed in preparing the WIPP Compliance Status Report submitted in March 1994 and will be used for the compliance documents scheduled for submittal in the Spring of 1995. The Compliance Status Report was issued to stakeholders in March 1994 and describes the status of associated activities on compliance with the requirements in Title 40 CFR 268.6 and Title 40 CFR 191. The Compliance Status Report focuses on 1) the information required for a demonstration of compliance, 2) preliminary results, 3) the areas of the WIPP program that are either not currently mature enough, or do not provide adequate margin for a demonstration of compliance, and 4) the areas of the WIPP program that will be focused upon to provide the remaining necessary information for use in the 1995 compliance demonstration reports. The Compliance Status report is not intended to constitute a statement of compliance or a demonstration of compliance. It is intended to report the status of progress made to date in project efforts to achieve the required level of data/information necessary for the required compliance demonstrations. Comments on the Compliance Status Report from stakeholders will likely result in a modified Format and Content Guide, as will the promulgation of the EPA's Compliance Criteria for WIPP (40 CFR 194)."

DOE (U.S. Department of Energy), 1994. Waste Isolation Pilot Plant 1994 Environmental Monitoring Plan. DOE/WIPP 94-024. U.S. department of Energy, Carlsbad, NM.

Section 1.0 INTRODUCTION, p 1-1;

" U.S. Department of Energy (DOE) Order 5400.1, General Environmental Protection Program Requirements (DOE, 1990a), requires each DOE facility to prepare an Environmental Monitoring Plan (EMP). This document is prepared for the Waste Isolation Pilot Plant (WIPP) in accordance with the guidance contained in DOE Order 5400.1 (DOE, 1990a); DOE Order 5400.5, Radiation Protection of the Public and Environment (DOE, 1990b); and the Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance (DOE/EH-0173T, 1991). The WIPP project is operated by Westinghouse Electric Corporation, Waste Isolation Division (WID), for the DOE.

This plan defines the extent and scope of the WIPP effluent and environmental monitoring programs during the facility's preoperational and operational life. This document also discusses the WIPP's quality assurance/quality control programs.

This plan provides a comprehensive description of environmental activities at WIPP including:

- A summary of environmental programs including the status of environmental permits and monitoring activities (Section 1.0);
- A description of the WIPP project and its mission (Section 2.0);
- A description of the local environment including demographics (Section 3.0);
- An overview of the methodology used to assess radiological consequences to the public including brief discussions of potential exposure pathways, routine and accidental releases, and their consequences (Section 4.0);
- A summary of preoperational environmental monitoring and assessment activities (Section 5.0); and
- Responses to the requirements described in the Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance (DOE/EH-0173T).

This document extensively references DOE Orders and other federal and state regulations affecting effluent and environmental monitoring programs at the site. WIPP procedure manuals, which implement the requirements of this program plan, are also referenced.

. . ."

DOE (U.S. Department of Energy) and state of New Mexico. 1981. Consultation and Cooperation Agreement. Appendix A to the Stipulated Agreement Resolving Civil Action, 81-0363JB, state of New Mexico vs. United States Department of Energy, United States District Court, Albuquerque, NM.

STIPULATED AGREEMENT, p. 1;

" Whereas, the plaintiff, State of New Mexico, ex rel. Jeff Bingaman, Attorney General, has brought this action to address four major concerns of the State of New Mexico; and,

Whereas, these concerns include: (1) that the final decision point for commencing construction of a permanent WIPP repository and its operation should not be reached until all interested parties including the State of New Mexico know the results of actual site and design validation tests and the SPDV program in general; and (2) that the State of New Mexico be given the opportunity to have a final resolution of all essential and integral off-site state government concerns involving health, safety, and public welfare issues prior to a final decision to commence construction of permanent WIPP facilities; and (3) that the State of New mexico be entitled to a binding and enforceable consultation and cooperation agreement that does not waive any right by the State to judicial review of any federal agency action with respect to the WIPP project; and (4) the concern that the withdrawal provisions of the Federal Land Policy and Management Act be complied with, including public hearings to be held before a decision is made to withdraw federal lands from the public domain for the WIPP project; and . . ."

Doser, D.I., Baker, M.R., Luo, M., Marroquin, P., Ballesteros, L., Kingwell, J., Diaz, H.L., and Kaip, G. Undated. The Not So Simple Relationship between Seismicity and Oil Production in the Permian Basin, West Texas. Department of Geological Sciences, University of Texas at El Paso, El Paso, Texas.

ABSTRACT, p 481;

" We have relocated seismicity occurring in the Permian Basin of west Texas between 1975 and 1979 using three-dimensional velocity models constructed from well log information and compared the locations to detailed geological and geophysical models of specific oil fields. The seismicity appears to be related to a variety of causes including migration of naturally occurring overpressured fluids, tectonic activity, reservoir production, and enhanced recovery operations. Many earthquakes may represent a combination of these effects. Although the Permian Basin is the site of numerous oil and gas fields, only a limited number of fields appears to be associated with seismicity. We find that there are similarities in the structural setting in the fields associated with seismicity. Furthermore, fields within the Delaware Basin that are associated with seismicity are located in regions of high vertical and lateral fluid pressure gradients related to an overpressured zone with the Delaware Basin."

Dunham, R.J. 1972. Capitan Reef, New Mexico and Texas: Facts and Questions to Aid Interpretation and Group Discussion. Publication 72-14, pp. 297. Permian Basin Section, Society of Economic Paleontologists and Mineralogists.

PREFACE; p i;

" This book was originally prepared in September, 1962, for geologists working for one particular oil company. In offering it to others at this time I feel the need to explain. The research behind the book and the writing itself were financed by Shell Development Company, with the aim of sharpening the conceptual tools Shell Oil Company used in searching for new hydrocarbons in carbonate reservoir rocks, and in wisely and profitably producing the new reserves and those already found. When Shell's purpose had been served, the book was released to me. The officers of the Permian Basin section of the Society of Economic Paleontologists and Mineralogists at that time, Shell management, and I decided that the book in practically its original edition can still be helpful despite the 1962-vintage words. We see the help going mostly to graduate school and other university groups but also to those geologists who lack contact with the equivalent of Shell's large-scale research effort or are in need of a refresher in carbonates.

The style is out of the ordinary . . ."

EPA (U.S. Environmental Protection Agency), 1990. "Background Document for the U.S. Environmental Protection Agency's Proposed Decision on the No Migration Variance for U.S. Department of Energy's Waste Isolation Pilot Plant," U.S. Environmental Protection Agency, Washington, D.C.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

EPA (U.S. Environmental Protection Agency), 1990. Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant. Federal Register, Volume 55, No. 220, p. 47700, November 14, 1990. Office of Solid Waste and Emergency Response, Washington D.C.

"**Summary**:In response to a petition from the Department of Energy (DOE), the Environmental Protection Agency (EPA) is today making a determination of no migration for placement of hazardous waste at DOE's Waste Isolation Pilot Plant (WIPP), located near Carlsbad, New Mexico. Today's determination imposes several conditions on such placement and is for a maximum of ten years. As a result of this determination, DOE may place a limited amount of untreated hazardous waste subject to the land disposal restrictions of the resource Conservation and Recovery Act (RCRA) in the WIPP for the purposes of testing and experimentation."

"**I. Background**

A. RCRA Land Disposal Restrictions

The Hazardous and Solid Waste Amendments (HSWA) of 1984, which amend the Resource Conservation and Recovery Act (RCRA), imposed substantial new requirements on the land disposal of hazardous waste. In particular, the amendments prohibit the continued land disposal of hazardous wastes, unless either (1) the wastes meet treatment standards specified by the EPA, or (2) the Administrator determines that the prohibition is not required in order to protect human health and the environment. This latter determination must be based on a demonstration by the owner/operator of the facility receiving the waste 'that there will be no migration of hazardous constituents from the disposal unit or injection zone as long as the wastes remain hazardous.' (RCRA sections 3004(d)(1), (e)(1), and (g)(5).) The Department of Energy (DOE) has chosen to comply with the land disposal restrictions for certain transuranic (TRU) wastes to be shipped for testing and experimentation at its Waste Isolation Pilot Plant (WIPP) by pursuing the second option. Today's notice approves, with conditions, DOE's petition for the WIPP site."

EPA (U.S. Environmental Protection Agency), 1992. "No-Migration" Variances to the Hazardous Waste Land Disposal Prohibitions: A Guidance Manual for Petitioners [Draft], EPA530-R-92-023, Office of Solid Waste, Washington, D.C.

Introduction, p ii;

" This draft guidance manual is intended to assist hazardous waste management facility owners and operators who may be considering petitioning the U. S. Environmental Protection Agency (EPA) for a variance from land disposal prohibitions at specific sites for specific wastes. The guidance manual also provides the EPA interpretation and suggested procedures to implement the regulatory standards and procedures set out in 40 CFR 268.6. Readers should note that this guidance document is only a draft, and will be updated consistent with the final 'No Migration' rule, scheduled for publication in January 1993. Thus, this draft guidance manual is not itself binding on the Agency, the regulated community, or the public. EPA will fully consider alternative approaches raised by the applicant or other interested parties to the extent consistent with existing regulations at 40 CFR 268.6, the Resource Conservation and Recovery Act, and other EPA regulations. This manual also contains descriptions of additional requirements for 'no migration' petitions in the Land Disposal Restrictions First Third Rule promulgated on August 17, 1988 (53 FR 31138). The manual specifically does not address the requirements for 'no migration' petitions for waste disposal in deep injection wells. Requirements for deep well injection specifically pertain to the unique technological and hydrological conditions associated with injection. The reader should refer to the Underground Injection Control Rule promulgated on July 26, 1988 (53 FR 28118) for a complete discussion of how the Agency applies the 'no migration' standards in deep injection wells.

This manual is not a comprehensive review of 'no migration' variances, and will not provide the answers to all petitioners' questions; however, it does address the required scope of credible petitions. The EPA is strongly encouraging petitioners to meet with the Agency before preparing petitions to determine the scope and level of detail that will be required in individual petitions."

Esteva, L. and Rosenblueth, E. 1964. Espectros de Temblores a Distancias Moderas y Grandes. Bol. Soc. Mex. Ing. Sism, Vol. 2, pp. 1-18.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Evernden, J.F. 1967. Magnitude Determination at Regional and Near-Regional Distances in the United States. Seismological Society of America Bulletin, Vol. 57, pp. 591-639.

ABSTRACT, p 591;

" This report deals with the problems of variation P_n amplitudes in the regional and near-regional distance ranges (200-2100 kilometers). The data used were recorded by Long Range Seismic Measurement vans of the VELA Seismological Center as a result of earthquakes throughout the United States and numerous nuclear and chemical explosions in the same region.

It is shown that the pattern of P_n amplitudes versus Δ in Western United States and Eastern United States are markedly different and that these differences are related to different velocity structures in the two regions. These differences extend to at least 150 kilometers depth.

Neither the Western United States nor Eastern United States amplitude patterns conform even approximately to that predicted or suggested by Gutenberg and Richter in the 1000-2000 kilometer range. The predicted zone of low-amplitude signals in that distance range does not exist and overestimation of magnitude by as much as 1.5 magnitude units is frequently done because of failure to properly understand the patterns of radiation.

By proper calibration of the Western United States by use of numerous events, it is now possible to make consistent estimates of magnitude at all distance ranges for most explosions and earthquakes. Obtaining consistent estimates of amplitude as a function of distance for a particular event requires a knowledge of the energy distribution between the several refracted phases used between 200 and 2500 kilometers distance. Data on hand show that the energy portion function is reasonably uniform throughout the regions investigated but that locally it may vary radically, resulting in a ten-fold change in relative excitation of two refracted phases.

Patterns of energy radiation and decay are probably approximately determinable from knowledge of velocity structure and vice versa. Both are best determinable from explosion data where origin time and focus are accurately known."

Ewing, T.E. 1993. "Erosional Margins and Patterns of Subsidence in the Late Paleozoic West Texas Basin and Adjoining Basins of West Texas and New Mexico," New Mexico Geological Society Guidebook, 44th Field Conference, Carlsbad Region New Mexico and West Texas, D.W. Love et al., eds., pp. 155-166.

ABSTRACT, p. 155;

" The West Texas Basin is a complex late Paleozoic basin on the unstable craton. It is a composite of Early Pennsylvanian and Early Permian deformation and Early Pennsylvanian through late Permian subsidence. The postdeformational bowl of subsidence of the West Texas Basin is broadly similar to the subsidence of true intracratonic basins, such as the Michigan and Williston Basins. Unlike these basins, however, the present boundaries of the West Texas Basin do not follow or preserve the original limits of subsidence. The southern, western and to a lesser degree the eastern margins have been altered by pre-Albian uplift and erosion, assisted by Laramide and Tertiary uplift on the western margin. Only the northern margin is preserved, although it is complicated by the neighboring Anadarko Basin. The Pennsylvanian and Permian subsidence continued to the south and west of the preserved basin and probably connected with the Orogrande and Pedregosa Basins. This larger 'Permian Basin' contains both the Central Basin axis and the Diablo-Pedernal axis as intrabasin tectonic belts. The post-Permian erosion was probably due to a combination of uplift on the flanks of the Triassic-Jurassic rift complex, which resulted in the opening of the Gulf of Mexico, and uplift on the flanks of the Early Cretaceous Bisbee-Chihuahua Trough. Reconnaissance subsidence analysis of the West Texas Basin discloses a complex pattern of subsidence rates through the Permian. The most rapid tectonic subsidence took place in the Wolfcampian of the southern Delaware Basin, between the Marathon thrust sheets and the Fort Stockton uplift. Flexural subsidence is probably responsible. Post-Wolfcampian (postdeformational) subsidence of unknown origin continued to be centered in the north-south Delaware Basin trough, but extended north and east over a broad area of the Central Basin axis, the MIdland Basin and the Northwest shelf to form the 'Permian Basin.'"

Ferrall, C.C., and Gibbons, J.F. 1980. Core Study of Rustler Formation over the WIPP Site. SAND79-7110. Sandia National Laboratories, Albuquerque, NM.

INTRODUCTION, p. 1;

" This core study deals with the nature of the Rustler Formation at the Waste Isolation Pilot Project (WIPP) site in support of evaluating the influence that the Rustler will have on the effective isolation of wastes potentially disposed in the underlying formation.

The Rustler Formation is the uppermost evaporite formation of the Ochoan age rocks of the Permian Basin in southeastern New Mexico and western Texas. In the region of the WIPP site, the Rustler rocks make up a laterally continuous formation that occurs between the Salado Formation and the existing topographic surface. It is the Salado Formation into which the proposed waste repository is to be placed.

The core study described in this report was conducted in order to provide parameters for the thermomechanical modeling of the behavior of the Rustler Formation in response to heating. The aim of the core study has been to characterize the various members and units of the Rustler Formation in terms of physical properties, distribution, internal discontinuities, and boundary effects. The principle features treated here are results of the original deposition, diagenetic changes which the rocks have undergone, and the strain history of the rocks since deposition. Special attention has been paid to the extent to which the formation is fractured and the nature of fractures so that some estimate can be made of the potential for these discontinuities to be the locus of further strain.

The emphasis of this core study has been a megascopic observation of the rocks. For this purpose . . ."

Foster, R.W. 1974. Oil and Gas Potential of a Proposed Site for the Disposal of High-Level Radioactive Waste. Open-File Report, Contract No. AF(40-1)-4423. Oak Ridge National Laboratory, Oak Ridge, TN.

INTRODUCTION, p. 1;

" This study was in part funded by the Atomic Energy Commission under Contract No. AT-(40-1)-4423. Terms of this contract as they involve this particular study, are restated here so that reviewers may be aware of the basic aims of the project.

Project I - Evaluate the Petroleum Potential of the Proposed Radioactive Waste Disposal Site: Initial studies to be completed by February 15, 1973, will involve the development of pertinent information related to the location of a favorable site for coring of the Salado Formation and underlying rocks somewhere within Ts. 22-23 S., [Ts. 21-22 S.] , Rs. 31-32 E.

Evaluation of petroleum potential of the above-mentioned townships will include all rocks from the surface to the Pre-Cambrian [Precambrian] basement with emphasis on the deeper horizons. This study will include all wells in the area, and pertinent structural, lithologic and isopach data for the proposed disposal site. Necessary regional interpretation of these strata will be conducted and will include existing fields, wells, secondary recovery operations, areas of salt water disposal, production data, and pressures. In addition, the 1961 report by Foster and Stipp showing basement configuration in southeastern New Mexico will be revised. . . ."

Freeze, R.A., and Witherspoon, P.A. 1967. "Theoretical Analyses of Regional Groundwater Flow: 2. Effect of Water-Table Configuration and Subsurface Permeability Variation," Water Resources Research. Vol. 3, No. 2, pp. 623-634.

ABSTRACT, p 623;

" Details of steady-state flow in regional groundwater basins can be investigated using digital computer solutions of appropriately designed mathematical models. The factors that must be considered are: (1) ratio of depth to lateral extent of the basin; (2) water-table configuration; and (3) stratigraphy and resulting subsurface variations in permeability. The results of this study provide a theoretical basis for the following properties of regional flow systems: (10 groundwater discharge will tend to be concentrated in major valleys; (2) recharge areas are invariably larger than discharge areas; (3) in hummocky terrain, numerous sub-basins are superposed on the regional system; (4) buried aquifers tend to concentrate flow toward the principle discharge area, have a limiting effect on sub-basins, and need not outcrop to produce artesian flow conditions; (5) stratigraphic discontinuities can lead to distributions of recharge and discharge areas that are difficult to anticipate and that are largely independent of the water-table configuration."

FWS (U.S. Fish and Wildlife Services). 1989. Letter from John C. Peterson, Field Supervisor, Albuquerque, NM, to Jack B. Tillman, Project Manager, U.S. DOE-Carlsbad, May 25, 1989.

Cover Letter;
"Dear Mr. Tillman:

This responds to your letter dated May 19, 1989 requesting an update of the 1979 consultation regarding the affects of the Waste Isolation Pilot Plant (WIPP) on species Federally listed or proposed to be listed as threatened or endangered. Your geographic area is T22S, R31E, Sections 15-22 and 27-34 of eastern Eddy County, New Mexico.

We have reviewed the 1979 list of species occurring in the project area and find there are none that should be added at this time. However, the black-footed ferret should be removed. The current list should then include the American peregrine falcon, bald eagle, Pecos gambusia and Lee's pincussion cactus.

We suggest you contact the New Mexico Department of Game and Fish and the New Mexico Energy, Minerals and Natural Resources Department for information concerning fish, wildlife and plants of State concern.

If we can be of further assistance, please call Jerry Burton at (505) 883-7877 or FTS 474-7877.

Sincerely yours,
John C. Peterson
Field Supervisor"

Galley, J.E. 1958. "Oil and Geology in the Permian Basin of Texas and New Mexico." In Habitat of Oil—A Symposium, L. G. Weeks, ed.

ABSTRACT, p 395;

" Pre-Mississippian strata in the Permian Basin area consist chiefly of carbonate deposits of Ordovician, Silurian, and Devonian age which were produced in a marine environment probably characterized by clear, shallow seas covering a broad southward-sloping shelf. Oil accumulated in reservoirs in the carbonates, and in sandstone units of Cambrian and middle Ordovician age, the possible external sources being marine shale associated with the sandstone, a shale formation overlying the highest carbonate, and Pennsylvanian and Permian strata which lie unconformably on the older beds, as well as lower Paleozoic strata in a clastic basin south of the carbonate shelf. Mississippian strata are chiefly shale and limestone, containing probable source beds but generally poor reservoir strata.

Near the end of Mississippian time the tectonic environment changed from one of broad structures of gentle relief on a flat cratonic platform to an almost closed basin surrounded by mountain areas of high relief, the greatest of which was the Ouachita-Marathon complex.

Pennsylvanian strata, consisting of interbedded and intergrading marine shale, sandstone and limestone, reflect the changed environment. Oil, which the author believes to be indigenous to the system, accumulated in structural, stratigraphic, and porosity traps in Pennsylvanian reservoirs.

The Permian Period was characterized by deep but areally restricted marine basins of clastic deposition, stagnant at depth and surrounded by shoal platforms on which thick masses of carbonates accumulated and shallow lagoons extended to the shorelines. Burial of earlier strata by evaporites and red beds brought the period to a close. The principle sites of oil generation probably were in the basins; reservoirs include basinal sandstone and platform carbonate and sandstone rocks. The Guadalupe Series, which is stratigraphically the youngest and highest important producing unit and was therefore among the first to be exploited, contained more than half of all the oil which to date has been found in the Permian Basin."

Garber, R.A., Grover, G.A., and Harris, P.M. 1989. "Geology of the Capitan Shelf Margin—Subsurface Data from the Northern Delaware Basin." In Subsurface and Outcrop Examination of the Capitan Shelf Margin, Northern Delaware Basin, P.M. Harris and G.A Grover, eds., Core Workshop No. 13, p. 3-269. Society of Economic Paleontologists and Mineralogists (SEPM).

ABSTRACT, p 3;

" Facies relations determined from outcrop studies have been used in conjunction with subsurface data to better understand the geologic evolution, depositional facies, and diagenesis of the Capitan shelf margin. These studies have centered on a 2400 ft (731 m) portion of the 4800 ft (1463 m) continuous core from the Gulf PDB-04 research well that is located in Eddy County, New Mexico, at the northern end of the Delaware Basin.

The evolution of the Capitan shelf and margin was examined after (a) the establishment of time lines for shelf-to-basin correlations in the Late Guadalupian and (b) the confirmation of the stratigraphic units penetrated in the PDB-04 well. Subsurface and outcrop data revealed that the evolution of the 25 m.y. duration Capitan shelf margin occurred in two major growth phases: a 1.5 m.y. duration phase during Seven Rivers time when over 80% of the total progradation, over half of the aggradation, deposition of thick carbonate debris units on the slope and basin margin, and influx of over 60% of the total siliciclastics of the Bell Canyon Formation occurred. A subsequent, 1.0 m.y. growth phase during Yates and Tansill time is dominated by aggradation, steepening of the margin, and corresponds with abundant clastic deposition on the shelf. Maximum progradation of up to 12 miles (19 km) occurred along the northern rim of the basin, where progradation rates in excess of 7500 μm/year are measured.

Detailed shelf-to-basin correlations have revealed that three major processes were responsible for the profound progradation and differentiation of Capitan growth into two major phases: (a) fluctuations of sea level, (b) maximum emplacement of allochthonous carbonate debris along the basin margin during Seven Rivers time, and (c) that abundant siliciclastics bypassed the actively prograding shelf margin and were an important foundation for the progradation. . . ."

Griswold, G.B., 1977. Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, New Mexico. SAND77-0946. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. 3;

" Bedded-salt deposits of the Salado Formation have been selected for evaluation for a proposed Waste Isolation Pilot Plant (WIPP) to be located in Eddy County, NM, ~26 mi east of Carlsbad. Site selection and evaluation studies that included geologic mapping, geophysical surveys, drilling, and resource appraisal were conducted over and under the prospective location. The lower portion of the Salado meets essential criteria for waste isolation. Beds chosen for waste storage lie 2074-2730 ft below the surface. High-purity salt exists at these depths, and the geologic structure revealed by geophysical surveys indicates that these beds are essentially flat. Additional geophysical surveys are now under way. The initial interpretation of the new data indicates that more structure may exist in the salt beds in the northern portion of the site area. Full evaluation of potentially commercial deposits of potash and natural gas within the WIPP site will be reported by separate studies, as will be the hydrologic details of the region."

Guilinger, J.R. 1993. "The Geology and Development of the Phillips Ranch Sulfur Deposit." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 21-23. New Mexico Geological Society, Socorro, NM.

p 21;

" IN April 1990, Addwest Minerals acquired the Phillips Ranch sulfur property. The deposit is hosted in the lower portion of the Permian Castile anhydrite at a depth of 1400 to 1800 ft below the surface. In July 1990, Addwest successfully completed a drilling program designed to test the grade and continuity of previous favorable results that Texasgulf, Inc. and Pennzoil Sulphur reported in their drilling programs.

The drilling of a regional gravity low . . ."

Gutenberg, B. and Richter, C.F. 1942. Earthquakes Magnitude, Intensity, Energy and Accelerations. Seismological Society of America Bulletin. Vol. 32. pp. 163-191.

p 163;
" The MAGNITUDE of an earthquake was originally defined by the junior author (Richter, 1935), for shocks in southern California, as the logarithm of the maximum trace amplitude expressed in thousandths of a millimeter with which the standard short-period torsion seismometer (free period 0.8 sec., static magnification 2800, damping nearly critical) would register that earthquake at an epicentral distance of 100 kilometers. Gutenberg and Richter (1936) extended the scale to apply to earthquakes occurring elsewhere and recorded on other types of instruments.

Application of the scale involves tables of the logarithm of the maximum trace amplitude for a shock of magnitude zero as a function of epicentral distance. These tables, given in the papers referred to, conveniently represented by a nomogram (fig. 1) designed by Mr. John M. Nordquist, who has drafted all the figures. The magnitude can then be found for shocks of 'normal' depth (about 20 km.). For slightly different depths a correction can be determined by the methods of the present paper. For shocks deeper than about 40 km. no reliable method for assigning magnitudes has been developed.

The magnitude scale has been applied with success to the local earthquakes of New Zealand, where standard torsion seismometers are in operation (Hayes, 1941); its extended form has been used by Ramanathan and Mukherji (1938) and by Mukherjee and Rangaswami (1941).

The purpose of the present paper is primarily to develop and investigate the relation of the magnitude, thus defined, to the energy released in an earthquake; also the relation of intensity on the Modified Mercalli Scale of 1931 to instrumentally determined acceleration. The connection of both magnitude and intensity with other physical elements of an earthquake is also investigated, largely with the help of the empirical equation (eq. 20, below) connecting magnitude with acceleration at the epicenter. The effect of focal depth on all the quantities is discussed."

Harding, S.T., Carver, D., Henrisey, R.F., Dart, R.L., and Langer, C.J. 1978. The Scurry County, Texas, Earthquake Series of 1977-1978: Induced Seismicity? Earthquake Notes, Vol. 49, No. 3.

p. 14;

" Three recent earthquakes (M_L 4.0 on 7 June 1977, M_L 3.5 on 28 November 1977, and M_L 4.75-5.0 on 16 June 1978) were located by the National Earthquake Information Service near Snyder, Texas, in an area where no previous seismic activity had been reported. Eight aftershocks in the magnitude range M_L 1.0-3.0 and a range of focal depth from 1 to 5 km were recorded by a 10-station portable seismograph net whose installation began within a day following the 16 June 1978 earthquake. The aftershocks occurred at the north end of the Scurry Oil Field in Scurry, Kent, and Borden Counties, about 140 km northeast of Midland. Parts of that oil field were undergoing large-scale water flooding, with well-head pressures between 144.8 and 220.6 bars at the time of the recent earthquakes.

The historical lack of seismic activity for this region, coupled with the epicentral locations falling within the oil field and the presence of high-pressure water flooding, suggest the possibility that the earthquakes and aftershocks were induced by the oil-field activities."

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G., and Smith, D.G. 1989. A Geologic Time Scale 1989. Cambridge Earth Science Series. Cambridge University Press.

"This book (GTS 89) is the planned successor to *A Geologic Time Scale* by W. B. Harland, A.V. Cox, P. G. Llewellyn, C. A. G. Pickton, A. G. Smith and R. Walters published in 1982 (GTS 82). It adopts the same style and employs and develops similar methods, but it has been entirely reworked. The state of the art in 1989 is thus presented, but the data assembled provide a source of reference which will serve for some years.

The work develops and assesses a new calibration of the geologic time scale employing a new database (amended to 1988). The new scale is summarized on the book covers and on a wall chart to be published separately. The work has been coordinated in detail throughout; nevertheless each chapter can stand on its own.

Chapter 1 sets out the principles and summarizes the results.

Chapter 2 treats the chronometric scale which is defined numerically and applies mainly for Precambrian time.

Chapter 3 treats the chronostratic scale which is defined in rock. Both Chapters 2 and 3 summarize progress made towards international agreement concerning definition, nomenclature and classification.

Chapter 4 explains the principles on which the database of isotopic determinations has been refined by tests both stratigraphic and geomechanical. Many of the GTS 82 age determinations have been rejected; the database now includes Cenozoic data; about 700 determinations are listed.

Chapter 5 calibrates the chronostratic scale, applying and developing the chronogram method to the data. This enables a time scale to be generated automatically and so allows comparison of the effects of the inclusion and exclusion of different classes of data.

Chapter 6 updates the magnetostratigraphic scale which in turn enables some refinement of the resulting time scale.

Chapter 7. Natural events are distinguished from the artifactual time scales and some global events are plotted linearly against the new time scale. This material has been adopted to the wall chart.

Appendices: (1) reproduces a list of the origins of stage and other names; (2) gives a system of stratigraphic abbreviations; (3) treats isotopic dating methods; (4) plots 125 chronograms; (5) plots the definitive magnetostratigraphic time scale; and (6) introduces the wall chart.

The list of nearly 100 cited and other references amounts to a selected bibliography. There are both general and stratigraphic indexes.

The whole work results in a time scale for 1989. By showing its mode of construction the reader can assess how the scale may be modified as more critical data become available. The estimated uncertainty in the time scale values adopted is significantly less than in previously published estimates."

Harms, J.C., and Williamson, C.R. 1988. Deep-Water Density Current Deposits of Delaware Mountain Group (Permian), Delaware Basin, Texas and New Mexico. American Association of Petroleum Geologists Bulletin, Vol. 72.

ABSTRACT, p. 299;

" The Guadalpian Delaware Mountain Group is a 1000-1600-m (3281-5250-ft) thick section of siltstone and sandstone deposited in a deep-water density-stratified basin surrounded by carbonate banks or reefs and broad shallow evaporite-clastic shelves. The most prevalent style of basinal deposition was suspension settling of silt. Laminated siltstone beds are laterally extensive and cover basin-floor topographic irregularities and flat-floor channels as much as 30 m (99 ft) deep and 1 km or more wide. Channels can be observed in outcrop at the basin margin and can be inferred from closely spaced wells in the basin. The channels are straight to slightly sinuous, trend at high angles to the basin margin, and extend at least 70 km (43 mi) into the basin. Sandstone beds, confined to channels, form numerous stratigraphic traps. Hydrocarbon sealing beds are provided by laminated organic siltstone, which laterally can form the erosional margin where channels are cut into siltstone beds. Thick beds of very fine-grained sandstones fill the channels. These sandstones contain abundant large and small-scale traction-current-produced stratification. These sandy channel deposits generally lack texturally graded sedimentation units and show no regular vertical sequence of stratification types or bed thickness.

Outcrop and subsurface evidence indicates Delaware Mountain Group sediments were deposited by saline density currents. Dense saline water originated on evaporitic shelves and spilled across the carbonate rim, down steep marginal slopes, and into the basin. Basinal waters were density stratified. Denser flows moved along the basin floor cutting channels or depositing sand in existing channels; less-dense flows moved along density interfaces in the water column and carried silt-size material far into the basin where it settled to the floor as thin alternating layers of detrital silt and organic debris. Little proximal to distal change occurred in the size or nature of the channels. Exploration predictions based on submarine fan models formed by turbidity currents would anticipate very different proximal-distal changes in sandstone geometry and facies."

Haug, A., Kelley, V.A., LaVenue, A.M., and Pickens, J.F. 1987. Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report. SAND86-7167. Sandia National Laboratories, Albuquerque, NM.

INTRODUCTION, p. 1-1;

" The modeling studies of ground-water flow in the Culebra Dolomite Member of the Rustler Formation reported here have been performed as part of the regional hydrologic characterization studies for the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico (Figure 1.1). The site characterization studies are being conducted in accordance with the Consultation and Cooperation Agreement between the U.S. Department of Energy and the State of New Mexico as part of the evaluation of the suitability of bedded salt of the Salado Formation for isolation of defense transuranic waste. The regional hydrologic characterization studies are being conducted by Sandia National Laboratories on behalf of the Department of Energy.

Hawley, J.W. 1993. "The Ogallala and Gatuña Formations in the Southeastern New Mexico Region, a Progress Report." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

ABSTRACT, p 261;

" The Ogallala Formation in the Southern High Plains section (Great Plains province) of southeastern New Mexico includes alluvial, eolian and playa-lake deposits and pedogenic calcretes of late Miocene and early Pliocene age (about 4-12 Ma). Beneath the Llano Estacado, it forms an almost continuous cover on rocks of Mesozoic age, is locally more than 400 ft (120 m) thick and is a major aquifer. In the Pecos Valley section of the Great Plains and along the Portales Valley through the western Llano Estacado, fine- to coarse-grained clastics of the late Miocene to middle Pleistocene age locally form thick fills (> 1000 ft., 300 m) in large solution-subsidence depressions. These features are aligned along segments of the ancestral Pecos and Brazos Valleys and are underlain by evaporites of Late Permian age. Some of these deposits have always been included in the Ogallala Formation, but in the lower Pecos Valley area (Roswell, NM to Pecos, TX), correlative depression and valley fills have been mapped variously as 'older alluvium, quartzose conglomerate, valley-fill alluvial deposits,' and as the Gatuña Formation. Gatuña-Ogallala chronologic and nomenclature problems have not yet been resolved in that area; however, it is clear that an ancestral 'lower' Pecos fluvial system has existed since late Miocene time near the present valley position between the Roswell (artesian) and Delaware Basins. In the sediment source area west of the Great Plains, Ogallala and Gatuña correlatives are discontinuous, commonly thin and only locally aquifers. The oldest deposits include piedmont fan alluvium, pediment veneers and valley and basin fills. They record semiarid climatic conditions, prior epeirogenic uplift and volcanism and ongoing Basin-and-Range tectonism in a broad area extending southward from the Southern Rocky Mountains through the Sacramento section of the Basin and Range province. Significant uplift of mountain fault blocks occurred along the Rio Grande rift margin in the western part of the (sediment) source region. The facies-distribution patterns of both the Ogallala and Gatuña Formations are quite complex west of the Southern High Plains. The oldest units may form basal fills of structural basins, solution-subsidence depressions, or stream valleys, or they may be preserved as piedmont alluvium capping high divides and tablelands, with younger deposits occurring as inset valley fills. Rising western highlands not only contributed runoff and sediment to prominent zones of secondary-carbonate accumulation in paleosols of the High Plains eolian cover indicates increasingly dry and more continental conditions in late Cenozoic time. Episodic deflation of alluvial plains prograding eastward and southeastward from mountain and piedmont source areas also produced eolian sediments that are a significant component of the Ogallala Formation and overlying Plio-Pleistocene deposits of the Llano Estacado area."

Hendrickson, G.E., and Jones, R.S. 1952. Geology and Ground-Water Resources of Eddy County, New Mexico. Ground-Water Report, Vol. 3, p. 169. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT;

" Eddy County is physiographically diverse. It includes the Guadalupe Mountains in the southwest, the foothills of the Sacramento Mountains in the northwest, two areas of alluvial terraces bordering the Pecos River on the west, the Mescalero pediment east of the Pecos, and a small area of the High Plains in the northeast corner of the county.

Ground water supplies all public and domestic requirements, most of the stock water, and much of the irrigation water in the county. Some ground water is used for potash refining. The greatest use of ground water is for irrigation. The uses for public supply, industrial supply, and stock and domestic supplies follow in that order.

Ground water occurs in limestone, sandstone, siltstone, and gypsum of Permian and Triassic age, and in sand, silt, gravel, and conglomerate of Tertiary and Quaternary age.

In the Guadalupe Mountains water occurs mostly in limestone, but also in sandstone and siltstone, of Permian age, and in sand and gravel of Quaternary age. Ground water is used for stock and domestic supply, and a little for garden and orchard irrigation. The chief ground-water problem in this area is to find water at moderate depth. The quality and quantity of water are generally satisfactory for all uses. Windmills pump water from depths as great as 900 feet, and dry holes have been drilled to depths of more than 1,000 feet. The most favorable locations for wells are in or near arroyos where recharge is concentrated and water may be perched at the base of the arroyo gravels.

In the Carlsbad area, ground water occurs in the Carlsbad limestone, in the gypsiferous Castile and Rustler formations, and in the alluvium. Ground water is used chiefly for public supply, irrigation, and potash refining. Ground water is available in sufficient quantities for all present uses and is generally of fairly good quality in the Carlsbad limestone, although impotable water is found locally. The water in the overlying Castile and Rustler formations and in the alluvium is impotable in most places. The quality of water pumped from the Carlsbad limestone by the Carlsbad city wells had a wide annual range, but the chloride content of the water pumped showed a general increase from 1943 to 1950. If this increase continues the city of Carlsbad may be obliged to obtain its water from some other source. In the irrigation district south of Carlsbad, ground water is pumped from the alluvium primarily to supplement the surface supply of water for irrigation, except west of the main canal where some land having no surface-water rights is irrigated by ground water. Water levels in wells have declined several feet in places west of the main canal in recent years, but east of the canal water levels have declined little or not at all.

In the lower parts of the Roswell basin, the chief use of ground water is for irrigation. Water is obtained from shallow water-table wells in the alluvium, and from deep artesian wells in the San Andres formation and the lower part of the overlying Chalk Bluff formation. As all water rights are fully developed, the chief problem is to prevent wastage or overuse of water. Water levels in the artesian and especially in the water-table aquifers

have, over a period of years, shown a marked decline. West of the irrigated area depths to water increase to more than 800 feet at the county line. The chief use of ground water west of the irrigated area is for stock and domestic supplies, and the problem is to find water at comparatively shallow depths.

In the area between the Guadalupe Mountains and the Pecos River and generally south of latitude 32°15', ground water is used chiefly for stock and domestic supplies. Water from Rattlesnake Springs is used for the public supply at the Carlsbad caverns, and water from Blue and Geyser Springs is used for irrigation. Water is obtained from the alluvium, from the Castile formation, and possibly from the Rustler formation. Water from the alluvium near the mountains is generally of good quality, but farther east, as the water moves through gypsiferous rocks, the sulfate content increases and the water is locally unfit for domestic use. The depth to water in most wells is less than 100 feet, and the quantity of water available is generally sufficient for stock and domestic supplies.

East of the Pecos River ground water is used for stock and domestic supplies and for potash refining. Water is obtained from the limestone, gypsum, and redbeds of the Chalk Bluff formation and the Rustler formation and from the sandstone of the Dockum group. The chief ground-water problem is to find water of good quality, as the quantity available is generally sufficient and depths to water are not great. Water of fair quality is obtained from wells in the Chalk Bluff formation, which extends northward from Lake Avalon to and beyond the county line in a belt 6 to 10 miles wide bordering the Pecos River on the east, and also from some wells in the Dockum group near the east boundary of the county. Water of poor quality is obtained from most of the wells in Clayton Basin and Nash Draw and just east of the Pecos River from Malaga Bend southward to and beyond the county line. In the small area of the High Plains in the northeast corner of the county a few stock wells provide water of good quality."

Hern, J.L., Powers, D.W., and Barrows, L.J. 1979. Seismic Reflection Data Report Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND79-0264. Vols. 1 and 2. Sandia National Laboratories. Albuquerque, NM.

Section 1.0 ABSTRACT;

" This report describes three seismic reflection (Vibroseis) surveys conducted from 1976 through 1978 by Sandia laboratories to support investigations for the Waste Isolation Pilot Plant (WIPP). Volume I describes the purpose, field parameters, and data processing parameters. Volume II contains uninterrupted processed lines and shotpoint maps. Data interpretations will be the subject of the subsequent reports.

The data collected during these three surveys total 77 line miles; 72 line miles of this are on or very near the WIPP site. The first of the surveys (1976 SAN) covered 25 line miles and was conducted similarly to previous petroleum industry surveys in the area/ 1976 SAN supplemented existing petroleum industry data. The two subsequent surveys (1977 X and 1978 Y) used shorter geophone spacings (110'), higher signal frequencies (up to 100 Hz), and higher data sampling rates (2 ms.) to better define the shallow zone (less than 4000') of primary interest. 1977 X contained 47 line miles on or near the center of the WIPP site. These data show increasing discrimination of shallow reflectors as data collection parameters were modified. Data tables of recording and processing parameters are included.

A fourth Vibroseis survey was conducted at the WIPP site in 1978 by Grant Geophysical Company for Bechtel; the data are not in final form and are not included. Petroleum industry data and an inconclusive weight-drop survey, conducted in 1976, are also not included in this report."

Hicks, P.A. 1981. Mitigative Collection and Testing of Five Archaeological Sites on the Waste Isolation Pilot Project near Carlsbad, New Mexico for Westinghouse, Inc. Agency for Conservation Archaeology, Eastern New Mexico University, Portales, NM.

ABSTRACT, p 1;

" On September 19 & 20, 1981, the Agency for Conservation Archaeology (ACA), Eastern New Mexico University, conducted work at five archaeological sites in order to mitigate the effects of the construction and operation of the Waste Isolation Pilot Project (WIPP) near Carlsbad, New Mexico. The five sites, ENM 10206, ENM 10207, ENM 10209, ENM 10211, and ENM 10212, are all located in close proximity to the southern access road, or ancillary travel routes, placing them in situations of high to moderate impact from increased hydrocarbon pollution from vehicles and illicit collecting and digging activities. Mitigation of these archaeological sites consisted of the point proveniencing of all exposed artifacts and cultural features; the collection of all artifacts, exclusive of burned stone; and the excavation of several test pits to discern if cultural materials extended below the surface. The results of these mitigation procedures are herein reported."

Hicks, P.A. 1981. Mitigation of Four Archaeological Sites on the Waste Isolation Pilot Project near Carlsbad, New Mexico for Westinghouse, Inc. Agency for Conservation Archeology, Eastern New Mexico University, Portales, NM.

ABSTRACT, p 1;

" In January and August of 1981, the Agency for Conservation Archaeology (ACA), Eastern New Mexico University, conducted work at four archaeological sites in order to mitigate the effects of the construction and operation of the Waste Isolation Pilot Project (WIPP) near Carlsbad, New Mexico. The four sites, ENM 10201, ENM 10233, ENM 10237 and ENM 10241, all lie within 40 meters of the proposed location of the SPDV facilities. Mitigation of these archaeological sites consisted of the point proveniencing of all exposed artifacts and cultural features; the collection of all artifacts, exclusive of burned stone; and the excavation of several test pits to discern if cultural materials extended below the surface. The results of these mitigation procedures are herein reported."

Hills, J.M., and Kottlowski, F.E. 1983. Southwest/Southwest Mid-Continent Region. Correlation Chart Series. American Association of Petroleum Geologists.

EDITOR'S NOTE;

" The COSUNA Correlation Charts are intended to show stratigraphic columns which provide fairly complete coverage of the geology of the United States. In most cases, these columns are generalizations of the geology of an area and do not represent single surface or subsurface locations. The locations of the columns on the index map are intended to show the areas in which the stratigraphy is uniform enough to be shown in a single column. Since the columns are generalized they often show a range of thicknesses for each of the units and their dominant lithology within the map area.

Because the COSUNA Charts are correlation charts and not cross-sections their vertical scale is time, not thickness. Due to this difference, a number of features which may be shown on cross-sections cannot be shown on correlation charts.

The positional relationships of units separated by angular unconformities are not necessarily shown properly in each of the columns. Tilted contact lines show a time transgressive relationship the geographic directionality of which is not necessarily implied by the tilt of the line in the column. Units involved in faulting and especially those involved in thrust sheets are shown at a time at which they were deposited, not in the position into which they were thrust.

Igneous intrusives are shown at the time that they were intruded, not necessarily in the strata in which they intrude. Questioned contacts were placed for convenience in the vertical position near where they are most likely to occur. The amount of question in their positioning may vary from contact to contact.

Detailed information regarding the contacts, lithology, paleontology, references, and other significant information on each of the units on this chart is available by accessing the computerized COSU data file on the Petroleum Data System of the University of Oklahoma, Norman, Oklahoma."

Holt, R.M. 1993. Sedimentary Textures, Structures, and Lithofacies in the Salado Formation: A Guide for Recognition, Classification, and Interpretation. DOE/WIPP 93-056. U.S. Department of Energy, Carlsbad, NM.

1.0 INTRODUCTION, p 1-1;

" Evaporite rocks are difficult for most geologists to describe well, because geologists receive very little formal training in the study of evaporites. Although a variety of sedimentary textures and features are present, they are often difficult to recognize and describe. As a result, evaporite descriptions usually contain only mineralogical and crystal size data. Because the geologist's level of experience and background varies, consistent descriptions suitable for multiple uses, such as site characterization, are rarely produced.

At the Waste Isolation Pilot Plant (WIPP) site, the evaporites of the Salado Formation are described from cores and underground exposures as part of general site characterization activities. These activities are performed to document the strata surrounding the underground excavations. The geologic data collected during these activities, however, have potentially many uses besides simple documentation. For example, the data may be used for assessing variability within the formation as relevant to problems of hydrologic, mechanical, geochemical, or gas-flow anisotropy. The data should provide the basis for a second round of more task-specific data collection, if needed. In addition, high-quality detailed data may be essential for the resolution of yet undefined future problems, when data collection may be limited by logistics. The data collected during site characterization activities must be as complete and consistent as possible to meet these various needs, and investigators must be aware of their responsibility to collect those data.

This report is designed to fill the gap left in most geologist's experience by providing the information needed to completely and consistently describe and interpret the rocks of the Salado Formation in the vicinity of the WIPP. The rocks within the Salado Formation display a wide variety of uncommon sedimentary textures and structures. Investigators will become familiar with the types of sedimentary features present within the Salado, the processes which generated those features, the occurrence and distribution of those features in relation to Salado lithofacies, and current depositional models of Salado lithofacies. In addition, methods of describing and classifying evaporite rocks in underground exposures and cores will be presented.

A sedimentological approach to the study of evaporites is being employed by an increasing number of investigators (e.g., Holser, 1966; Kinsman, 1969; Shearman, 1970; Arthurton, 1973; Garrison et al., 1978; Arakel, 1980; Handford, 1981; Kushnir, 1981; Handford, 1982; Lowenstein, 1982, 1987, 1988; Southgate, 1982; Warren, 1982; Hovorka, 1983a, 1983b; Sonnefeld and Hudec, 1985; Lowenstein and Hardie, 1985; Fracasso and Hovorka, 1986; Casas and Lowenstein, 1989; Holt and Powers, 1990) and is emphasized here. Because modern evaporites often provide excellent analogues for depositional and early diagenetic features and textural and mineralogical facies distribution in ancient evaporites, recent studies of the Salado (e.g., Lowenstein, 1982, 1983, 1988; Jarolimek et al., 1983; Borns, 1985; and Holt and Powers, 1990) have relied extensively on modern

analogues. In the following discussion, most descriptions and interpretations of Salado textures, sedimentary structures, and lithofacies are supported by descriptions of modern analogues.

This report is subdivided into four parts: first, the general geology of the Salado is presented (Chapter 2.0) to provide background for investigators. Second, typical Salado sedimentary structures and fabrics within sulfate, halite, and mudrocks are described and interpreted (Chapter 3.0). Third, Salado halite, sulfate, and mudrock lithofacies are discussed (Chapter 4.0). Finally, rock classification systems and descriptive procedures for halite, sulfate, and mudrocks are outlined (Chapter 5.0). The information contained within this report is derived largely from the evaporite literature, including work performed by WIPP investigators and unpublished work by the author."

Holt, R.M., and Powers, D.W. 1986. Geotechnical Activities in the Exhaust Shaft. DOE-WIPP-86-008. U.S. Department of Energy, Carlsbad, NM.

INTRODUCTION, p. 1-1;

" The Waste Isolation Pilot Plant (WIPP) project is a Department of Energy (DOE) research-and-development facility constructed to demonstrate the safe disposal of radioactive wastes derived from the defense activities of the United States. The WIPP project's mission consists of two parts. The first is to demonstrate the safe handling and disposal of transuranic (TRU) waste in bedded salt. The second is to create a research facility for in-situ examination of the technical issues related to the emplacement of defense-related radioactive waste in bedded salt.

The WIPP facility is located approximately 26 miles east of Carlsbad, New Mexico in an area known as Los Medanos (Figure 1). The underground portion of the facility is located at a depth of approximately 2,150 feet in the bedded salt deposits of the Salado Formation (Figure 2). An extensive program of site characterization and validation has been conducted for the past nine years (1976-1985). The results of these studies are summarized in the WIPP 'Geological Characterization Report' (Powers et al., 1978), the WIPP 'Safety Analysis Report' (DOE, 1980), the WIPP 'Preliminary Design Validation Report' (Bechtel, 1983), and the WIPP 'Results of Site Validation Experiments' (Black et al., 1983). Additional site investigations are being conducted as part of an ongoing program to further refine the understanding of the site-specific geology. The geotechnical activities conducted in the exhaust shaft are part of this program.

The exhaust shaft will provide a pathway for the release of exhaust air from the facility to the surface. The shaft is an enlargement of a six-foot diameter, upreamed shaft. The finished diameter is 14 feet in the lined portion of the shaft and 15 feet minimum in the unlined portion. Geotechnical activities consisting of reconnaissance geologic mapping, detailed geologic mapping in specific zones of interest, geologic confirmation of instrument locations, and field adjustment and modification of the key and aquifer seal design were performed concurrently with construction from July 16, 1984 to January 18, 1985. This report presents and discusses the findings from the geologic mapping efforts in the exhaust shaft. Also, the construction history of the exhaust shaft is summarized, and several engineering geology characteristics are discussed."

Holt, R.M., and Powers, D.W. 1990. "Halite Sequences within the Late Permian Salado Formation in the Vicinity of the Waste Isolation Pilot Plant." In Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico, D. Powers et al., eds., Field Trip #14. Geological Society of America, Dallas, TX.

INTRODUCTION, p. 45;

" A sedimentological approach has been used increasingly in the study of ancient halite rocks. As studies of ancient halites have been largely limited to data collected from core and, occasionally, limited underground exposures, most modern and experimental halite analogues have been examined for textures and features which may be identifiable from core or thin-section (Shearman, 1970; Arthurton, 1973; Handford, 1982; Southgate, 1982; Sonnenfeld and Hudec, 1983; Lowenstein and Hardie, 1985; Casas and Lowenstein, 1989). Numerous investigators (e.g., Garrison and others, 1978; Handford, 1981; Hovorka, 1983a, 1983b; Fracasso and Hovorka, 1986; Lowenstein, 1982, 1987, 1988) have used this approach to refine our understanding of the depositional systems of ancient halite rocks. Large-scale surface textures from modern halite deposits have been described by several investigators (e.g., Hunt and Washburn, 1960; Christiansen, 1963; Hunt and others, 1966; Cooke and Smalley, 1968). Except for a few studies of large-scale halite textures from underground exposures (e.g., Tucker, 1981; Powers and Hassinger, 1985), these fabrics have not commonly been studied in ancient halite deposits because they are not often recognized in samples of limited size, and their ability to survive beyond the time of deposition is considered questionable.

Exposures of the Late Permian Salado Formation in a shaft at the Waste Isolation Pilot Plant (WIPP) site showed abundant, previously unreported, large and small halite textures. Many of the large textures are similar to features that occur at the devil's Golf Course in Death Valley, California (Holt and Powerrs, in prep.). We were able to recognize, describe, and interpret numerous previously unrecognized halite textures and fabrics and to place these features into their stratigraphic context. To further refine the depositional model of Salado halite, we have constructed an 'idealized' Salado halite sequence of lithofacies based upon shaft mapping data, interpreted the fabrics observed within Salado halite sequences based upon their relationship to paleo-water table position, and interpreted the depositional environments of the lithofacies within our idealized sequence. . . ."

Holt, R.M., and Powers, D.W. 1993. "Summary of Delaware Basin End-Stage Deposits." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 90–92. New Mexico Geological Society, Socorro, NM.

p 90;
" The Salado, Rustler and Dewey Lake Formations record the end-stage depositional history of the Delaware Basin. After the Delaware Basin became isolated from marine environments at the beginning of the Ochoan Epoch, a unique series of depositional environments produced one of the thickest, uninterrupted records of deposition in the world. As the deep evaporitic lagoons that deposited the Castile Formation became hydrologically isolated from marine waters, solutes and sediments were derived from terrigenous sources outside the basin and Salado salt pan and related environments developed. Salado sediments completely filled the basin and extended over the Central Basin Platform and the Northwest Shelf. Both minor eustatic fluctuations and intermittent meteoric events inundated the basin, producing shallow saline lagoons, that deposited sulfate and ultimately evaporated to halite saturation. During Salado and Rustler time, a cyclical pattern of flooding by desiccation to evaporitic conditions, subaerial exposure and syndepositional alteration produced a series of characteristic environments and lithofacies. This pattern was broken by Middle Dewey Lake time as low-energy fluvial environments dominated sedimentation.

The following discussion summarizes our understanding of the sedimentology and depositional history of the Salado, Rustler and Dewey Lake Formations. . . ."

Howard, K.A., Aaron, J.M., Brabb, E.E., Brock, M.R., Gower, H.D., Hunt, S.J., Milton, D.J., Muehlberger, W.R., Nakata, J.K., Plafker, G., Prowell, D.C., Wallace, R.E., and Witkind, I.J. 1971 [reprinted 1991]. Preliminary Map of Young Faults in the United States as a Guide to Possible Fault Activity: Miscellaneous Field Studies Map MF-916, 1:5,000,000. 2 sheets. U.S. Geological Survey.

RIO GRANDE BASIN AND RANGE, Sheet 2 of 2;
"Rio Grande.--Abundant high-angle normal faulting in the late Cenozoic has formed the Rio Grande trough and adjacent basins and ranges. Evidence for movements in the Quaternary is common. The Rio Grande fault systems blend northward with similar basin-and-range faults that are somewhat masked by the surrounding topography of high Colorado Rocky Mountains."

Hubbert, M.K, 1940. "The Theory of Ground-Water Motion," The Journal of Geology, Vol. 48, no. 8, pt. 1, pp. 785-944.

ABSTRACT, p. 785, Para. 1;

" The existing analytical treatments of ground-water flow have mostly been founded upon the erroneous conception, borrowed from the theory of the flow of the ideal frictionless fluids of classical hydrodynamics, that ground-water motion is derivable from a velocity potential. This conception is in conformity with the principle of the conservation of matter but not with that of the conservation of energy. In the present paper it is shown that a more exceptionless analytical theory results if a potential whose value at a given point is defined to be equal to the work required to transform a unit mass of fluid from an arbitrary standard state to the state at the point in question is employed. Denoting this function by ϕ, it is shown that the differential equation of fluid flow in an isotropic medium is given by $q = -\sigma$ grad ϕ, where q is the flow vector whose magnitude is equal to the volume of fluid crossing a unit of area normal to the flow direction in unit time, and σ a specific conductivity parameter depending upon both the properties of the fluid and the medium. This is an expression of Darcy's law and is physically, as well as mathematically, analogous to Ohm's law in electricity and leads to the same deductions in analogous situations.

It is shown that $\sigma = kp/\eta$, where k is the permeability parameter depending upon the geometrical properties of the medium only and p and η are the density and viscosity, respectively, of the fluid.

The remainder of the paper is devoted to deducting the consequences of Darcy's law as just expressed, with particular regard for the practical problems of ground-water hydrology."

Jarolimek, L., Timmer, M.J., and McKinney, R.F. 1983. Geotechnical Activities in the Exploratory Shaft -- Selection of the Facility Interval, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3178, U.S. Department of Energy, Albuquerque, NM.

Section 1.0 ABSTRACT, p 1-1;

" This report on geotechnical activities in the exploratory shaft was prepared as part of the Site validation Field Program for the U. S. Department of Energy's Waste Isolation Pilot Plant near Carlsbad, New Mexico. The report (1) summarizes basic data on shaft drilling and construction, (2) presents the geologic mapping results which essentially correspond to the conditions predicted from previous investigations, and (3) discusses the optimization process based on the geologic conditions encountered and its results for the (a) adjustment and modification of the shaft key design, (b) selection of the facility interval, and (c) selection of the geotechnical instrument locations."

Jarolimek, L., Timmer, M.J., and Powers, D.W. 1983. Correlation of Drillhole and Shaft Logs, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3179. U.S. Department of Energy, Albuquerque, NM.

ABSTRACT, p. 1-1;

" This report on stratigraphic correlations from drillhole and shaft data along a generally north-south section across the potential extent of underground excavations of the Waste Isolation Pilot Plant (WIPP) facility was prepared as part of the *Site Validation Field Program Plan*. The results provide (1) input for the report entitled *'Results of Site validation Experiments*,' (2) input for other WIPP-related investigations, including the Design Validation Program, and (3) a framework for further underground activities at WIPP.

In general, this correlation study confirmed previous findings, including:

- A relatively high consistency of thickness and lateral continuity of all beds within the Salado Formation, especially in the host rock interval strata;
- Gentle, generally south and southeastward dips/slopes of the host rock interval strata;
- Close correspondence between stratigraphic data obtained from the present underground excavations and data derived from the previous investigative drill holes and shafts; and
- Depositional origin of the undulations on the top of Marker Bed (MB) 139 and relatively small variation in its thickness (1.2 to 4.1 ft)."

John, C.B., Cheeseman, R.J., Lorenz, J.C., and Millgate, M.L. 1978. Potash Ore Reserves in The Proposed [WIPP] Plant Area. Open-File Report for Eddy County, Southeastern, NM. U.S. Geological Survey.

ABSTRACTp. i;

" The proposed Waste Isolation Pilot Plant (WIPP) area includes about 18,960 acres in Tps. 22 and 23 S., Rs. 30 and 31., New Mexico Principle Meridian, Eddy County, southeastern New Mexico. It is located within the Carlsbad Mining District about 25 miles east of Carlsbad.

The WIPP area is immediately south of the Capitan Limestone subcrop, which formed the northern margin of the Delaware Basin in Permian time. During Late Permian (Ochoan) time, gypsum, anhydrite, and halite were deposited in the seas of the Delaware Basin to form the Castile Formation. These deposits have a maximum thickness of about 2,000 feet and grade upward into the more argillaceous beds of the Salado Formation. The Salado Formation contains abundant sulfate minerals, notably anhydrite and polyhalite. The potash ore minerals, langbeinite and sylvite, occur in the upper part of the Salado Formation in the McNutt potash zone, a local name applied to a potassium-rich zone.

Structurally, the WIPP area is situated within a broad syncline (mapped on top of the Salado) plunging gently to the southeast. Drill holes and surface geology analyses indicate no faulting in the area; and the only structural anomalies found are a local high and a small depression located in the southwest corner and north-central part of the WIPP area, respectively.

The minimum US Geological Survey standards for leasable potash ore are 4 feet of 10 percent K_2O as sylvite, 4 feet of 4 percent K_2O as langbeinite, or 4 feet of equivalent mixed ore as defined by a minimum of three data points in any one ore zone. Seven ore zones -- the 10th, 9th, 8th, 5th, 4th, 3d, and 2d -- maintain at least this thickness and grade in parts of the WIPP area. The WIPP area overlies an estimated 353.3 million tons (U.S. Geological Survey lease grade) of measured and indicated sylvite and langbeinite potash ore reserves. Approximately two-thirds of this ore occurs in intervals in the 10th and 4th ore zones; the rest is distributed among the five other ore zones."

Johnson, K.S. 1978. "Stratigraphy and Mineral Resources of Guadalupian and Ochoan Rocks in the Texas Panhandle and Western Oklahoma." In Geology and Mineral Deposits of Ochoan Rocks in Delaware Basin and Adjacent Areas, G.S. Austin, ed., Circular 159, pp. 57-62. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p 57;

" Permian strata of Guadalupian and Ochoan age in the Texas Panhandle and western Oklahoma comprise a thick sequence of evaporites and red-bed shales and sandstones deposited north and northeast of the platform bounding the Midland Basin. These strata are 400 to 600 ft thick in much of the area, but they reach 2,000 to 3,000 ft in the major depositional basins. The study area embraces the Palo Duro, Anadarko, and Dalhart Basins and the Matador, Wichita-Amarillo, Cimarron, and Bravo uplifts. Lithostratigraphic studies enable correlation of the fossiliferous sequence of west Texas and southeast New Mexico with the sparingly fossiliferous red beds and evaporites of the Texas Panhandle and western Oklahoma. The early Guadalupian San Andres Formation of the Palo Duro Basin is correlative with the San Angelo (Duncan), Flowerpot, Blaine, and Dog Creek Formations of the El Reno Group farther north and east. The late Guadalupian Artesia Group of the Palo Duro Basin is equivalent to the Whitehorse Group and part of the overlying Cloud Chief Formation of the Anadarko Basin. Ochoan strata in the western and central parts of the Palo Duro Basin include the Salado, Rustler, and Dewey Lake Formations. The Salado salts pinch out northward within the basin, whereas the upper part of the Rustler extends northward and is correlative with the Alibates Bed. The Dewey Lake is believed equivalent to the Doxey Shale of western Oklahoma. The youngest Ochoan unit is the Elk City Sandstone, which apparently is limited to the axis of the Anadarko Basin. Mineral resources that have been developed include salt, gypsum, copper, uranium, petroleum, dolomite, sandstone, shale, and flint. Other minerals present in small quantities include potash and celestite."

Jones, C.L. 1954. The Occurrence and Distribution of Potassium Minerals in Southeastern New Mexico. Guidebook to Southeastern New Mexico. New Mexico Geographical Society, Albuquerque, NM.

p 107;

" The closing epoch in Permian time is especially known for the extensive evaporite deposits that fill the Delaware basin and extend across the Capitan reef zone for considerable distances over the shelf area. This epoch is represented by the strata of the Ochoa series, which includes the following formations:

Dewey Lake redbeds
Rustler formation
Salado formation
Castile formation

Extensive deposits of halite and anhydrite occur in each of the formations except the Dewey Lake, which does not contain evaporite deposits and which is composed entirely of red sandstone, siltstone, and minor amounts of shale. The Dewey Lake red beds form the protective cover that serves to retard the dissolution and removal of the soluble salts comprising the evaporite deposits of earlier formations of the Ochoa series.

Extensive evaporite deposits are found . . ."

Jones, C.L., 1978. Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico. Open-File Report 78-592. Vols. 1 and 2. U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;
" Twenty-one borings to augment existing information on potash resources at the proposed site for a waste isolation pilot plant in eastern Eddy County, N. Mex., were drilled and logged in an 11-week period, mid-August to November 1976. The basic data developed from the borings are tabulated in the present report. The tabulation includes lithologic and geophysical logs of all the borings, as well as the results of chemical analyses, X-ray determinations, and calculations to establish a modal mineralogical composition of core samples from potash ore zones and mineralized salt beds."

Jones, C.L. 1981. Geologic Data for Borehole ERDA-9, Eddy County, New Mexico. Open-File Report 81-469. U.S. Geological Survey, Denver, CO.

ABSTRACT, p. 1;

" Borehole ERDA-9 is an exploratory well drilled in eastern Eddy County, New Mexico to evaluate and test salt beds for disposal of nuclear wastes. The drilling was done between April 28 and June 4, 1976.

Lithologic and stratigraphic details of the geologic section in ERDA-9 are described herein. The section includes: (1) the Mescalero caliche and the Gatuna Formation of Pleistocene age, (2) the Santa Rosa Sandstone of Triassic age, and (3) the Dewey Lake Red Beds, the Rustler Formation, the Salado Formation, and part of the Castile Formation, all of Permian age."

Keesey, J.J. 1976. Hydrocarbon Evaluation, Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico. Vols. I and II. Sipes, Williamson, and Aycock, Midland, TX.

Introduction, Vol 1, p 1, para 2;
" The purpose of this evaluation was to determine the future remaining economically recoverable oil and gas reserves underlying the proposed radioactive waste material storage site, commonly known as the Los Medanos Site. This evaluation is to serve as a guideline to Sandia Laboratories in determining the acceptability of the "site area" and the potential value to the owners of the hydrocarbon rights. It is not, however, intended to be the basis for condemnation proceedings.

Keesey, J.J., 1977. Hydrocarbon Evaluation, Waste Isolation Pilot Plant Site Area To State and Federal Royalty Interests. Eddy County, NM.

"Gentlemen:

Subject: Hydrocarbon Evaluation, Waste Isolation Pilot Plant Site Area To State and Federal Royalty Interest, Eddy County, New Mexico

In accordance with Mr. George Griswold's request, we have prepared an evaluation to determine the future net revenue and fair market value to the royalty interests held by the State of New Mexico and the United States of America (Federal Government) in the Waste Isolation Pilot Plant (WIPP) site area. The potential values to the State of New Mexico and the Federal Government are from oil and gas production projected to be recovered from twenty potential locations within the boundaries of the WIPP site area. The results of our evaluation can be summarized as follows:

Effective Date: April 1, 1977

	State of New Mexico	Federal Government	Total
Net Reserves Remaining to Evaluated Interest			
BBL	65,470	112,753	178,223
MCF	7,608,000	36,529,000	44,137,000
Future Net Revenue to Evaluated Interest, $			
Undiscounted	1,763,091	7,633,865	9,416,956
Discounted at six percent	1,182,691	5,804,989	6,987,682
Hydrocarbon Fair Market Value, $	751,861	2,949,329	3,701,190
Acreage Value, $	135,000	91,200	226,200
Total Fair Market Value, $	886,861	3,040,529	3,927,390

The bases for the subject evaluation are two earlier reports prepared by Sipes, Williamson & Aycock, Inc. for Sandia Laboratories and the United States Energy Research and Development Administration (ERDA). The first of these reports was entitled, 'Hydrocarbon Evaluation, Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico,' dated September 1, 1976. This report was prepared for Sandia Laboratories and was the basis for establishing the potential hydrocarbon reserves underlying the WIPP site area. The second report was entitled, 'Appraisal Report, Waste Isolation Pilot Plant Site, Eddy County, New Mexico' dated June 17, 1977, and was prepared for ERDA. The second report included the same ultimate forecasts as the first report, but contained updated cash flow projections to account for (1) changes in gas prices; (2) reimbursement for severance taxes; (3) forecasted changes in drilling times due to Bass

Enterprises Production Company's announced plans for drilling; (4) changes in discounting effects due to the later effective date; and (5) drilling costs to allow for directionally drilling under the known potash area. These two reports should be referred to for detailed information regarding reserve determination, pricing, drilling times, etc.

The subject report contains the same production and cash flow projections as were contained in the June 17, 1977 appraisal report for ERDA. This report, however, depicts only the income from royalty interests owned by the State of New Mexico and the Federal Government. For purposes of this report, it was assumed that the State of New Mexico and the Federal Government owned twelve and one-half percent (12.5%) royalty interest in their respective tracts. All capital costs and operating expenses were deleted as the State or Federal Government would not be responsible for such items. In addition, production taxes and ad valorem taxes were set at zero. Another change that was made for these runs was that the primary discount factor employed was six percent per annum whereas a ten percent primary discount factor was used for the referenced June 17, 1977 report. The six percent discount factor was used in accordance with Mr. George Griswold's instructions and was based on the premise that the State of New Mexico and the Federal Government could borrow money at a lower interest rate than the leasehold operators. For comparative purposes, secondary discount factors of eight, ten, twelve and fifteen percent per annum were calculated and are shown as a total figure in the lower right-hand corner of each printout.

Table No. 1 is a summary table depicting the wells forecasted, reserve category, assigned reserves and future net revenue to the State and Federal Government from their royalty interest holdings. ..."

Kelley, V.A., and Pickens, J.F. 1986. Interpretation of the Convergent-Flow Tracer Tests Conducted in the Culebra Dolomite at the H-3 and H-4 Hydropads at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-7161. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. ii;

" Tracer tests utilizing conservative organic tracers have been conducted in the Culebra Dolomite Member of the Rustler Formation at the locations of the H-2, H-3, H-4, and H-6 hydropads. The objective of this report is to present a quantitative evaluation of the physical solute-transport parameters of the Culebra dolomite at the H-3 and H-4 hydropad locations from interpretation of the tracer-test data. The tracer-test configurations consisted of a pumping well and two tracer-addition wells arranged in approximate equilateral triangles with 30-m sides. The transport of organic tracers from the tracer-addition wells to the pumping wells was analyzed using the finite-difference model SWIFT II, which is capable of simulating single- and double-porosity flow and transport.

The interpretive approach for analyzing the tracer-breakthrough curves at the pumping well first consisted of estimating the appropriate governing processes using the information base for each specific hydropad. For the H-3 hydropad, the test data indicated that a double-porosity interpretation approach was the most appropriate. In this conceptualization, the fractures represented the principle transport medium and the matrix provided the bulk of the solute-storage capability. The simulation model accounted for advective-dispersive transport in the fractures and diffusive transport in the matrix. Calibration of the tracer-breakthrough curves included conducting a parameter sensitivity analysis on longitudinal dispersivity, tortuosity, matrix porosity, fracture porosity, effective matrix block size, pumping rate, initial tracer-input distribution, and distance between pumping and tracer-addition wells. Calibration of the tracer-breakthrough curves for the H-3 tracer test resulted in longitudinal dispersivities from 5 to 10% of the flow path (well-separation distance), a fracture porosity of 1.9×10^{-3}, and effective matrix block sizes of 0.25 to 2.1 m.

There is uncertainty in the assumed or calibrated values for tortuosity, fracture porosity, matrix porosity, and matrix block size which were used to describe solute transport in the Culebra at the H-3 hydropad. Reduction in this uncertainty would require additional laboratory and field testing (e.g., additional drilling and coring, additional matrix porosity determinations on core, diffusion experiments, and additional on-site tracer testing). The results obtained from the conservative-tracer test suggest that fracture flow and matrix diffusion dominate solute transport in the Culebra at the H-3 hydropad. Further, the parameters derived to fit the tracer-breakthrough curves are thought to be consistent with the physical conceptualization of the Culebra at the H-3 hydropad.

The interpretation of the H-4 hydropad tracer test has not provided quantitative estimates of the physical solute-transport parameters for the Culebra. Qualitatively, the observed tracer-breakthrough curves could be simulated by representing the Culebra with a layered system of higher- and lower-permeability units. In this system, transport would be dominated by the higher-permeability zones with diffusive interaction with the lower-permeability zones. No evidence was obtained to indicate that transport of the tracers had

occurred through fractures; however, considering the fractured nature of the Culebra at the H-3 and H-6 hydropads and other locations at the WIPP site, the existence of fractures in the Culebra at the H-4 hydropad should still be considered a possibility. However, if present, these fractures do not appear to have had a significant effect on solute transport on paths examined in the H-4 tracer test."

Kenney, J.W., Downes, P.S., Gray, D.H., and Ballard, S.C. 1995. Radionuclide Baseline in Soil Near Project Gnome and the Waste Isolation Pilot Plant. EEG-58. Environmental Evaluation Group, Albuquerque, NM.

EXECUTIVE SUMMARY, p. x;

" The Gnome site is the location of a 1961 underground nuclear detonation in the Atomic Energy Commission (AEC) Plowshare program that vented radioactive contamination to the atmosphere. The resulting ground contamination was cleaned up in 1968-1969 and again in 1977 as weathering affected some shallow burial. Subsequent environmental surveys revealed slightly elevated ^{137}Cs levels, but no transuranic contamination.

The Waste Isolation Pilot Plant (WIPP) is approximately 8.8 km (5.5 mi) northeast of the Gnome site, and the Gnome site is within the preoperational radiological surveillance area for the WIPP. The Environmental Evaluation Group (EEG) conducts a WIPP preoperational radiological surveillance program, and the EEG initiated field surveys at Gnome in 1994.

The EEG used a combination of traditional and state-of-the-art radiological survey techniques. In addition, soil samples were collected for analysis in the newly established EEG radiochemistry laboratory, and the EEG results were compared to commercial laboratory analyses. New methods for contamination surveys, sample screening and telemetry were evaluated and found to be more sensitive and efficient than historical methods.

Localized and surface contamination was identified, and soil samples were taken from selected areas and control locations outside the Gnome site. Radiochemical analyses by EEG and a commercial laboratory indicated elevated levels of ^{238}Pu, $^{239+240}Pu$, and ^{241}Am at Gnome. The radioactivity was heterogeneously distributed within the samples which is consistent with contamination from atmospheric nuclear weapons testing. Samples outside the Gnome area did not indicate transuranic contamination.

The EEG radiochemical analyses, limited to surface soil samples, show the presence of transuranic contamination at the Gnome site. Although there is measurable transuranic contamination at Gnome, the levels do not appear to present any immediate health and safety concerns. Additional work is needed to determine if contamination is ta greater soil depths, and if further remedial action is needed."

King, P.B. 1948. Geology of the Southern Guadalupe Mountains, Texas. Professional Paper 215. U.S. Geological Survey, Washington, D.C.

ABSTRACT, P 1;

" This report deals with an area of 425 square miles in the western part of Texas, immediately south of the New Mexico line. The area comprises the south end of the Guadalupe Mountains and the adjacent part of the Delaware Mountains; it includes the highest peaks in the State of Texas. The area is a segment of a large mountain mass that extends 50 miles or more northward and southward. The report describes the geology of the area, that is, the nature of its rocks, tectonics, and surface features, and the evidence that they give as to the evolution of the area through geologic time. Incidental reference is made to the geology of surrounding regions in order to place the area in its environment.

Stratigraphy of Permian Rocks-- . . ."

King, R.H. 1947. Sedimentation in Permian Castile Sea. American Association of Petroleum Geologists Bulletin, Vol. 31, pp. 470–477.

ABSTRACT, p 470:

" The Permian Castile formation is a favorable starting point for a study of precipitated marine sediments because of its relatively simple stratigraphy. It is 1,300 to 2,000 feet thick and consists principally of 'banded' or laminated anhydrite, but it contains some salt and other materials. It was deposited within the deep steep-walled Delaware Basin of western Texas and southeastern New Mexico. Throughout Castile time communication with the open sea was maintained through a restricted channel near the southwest corner of the basin. Paucity of detrital material indicates that the deposit consists almost exclusively of marine evaporites.

It is suggested that the water within the basin consisted of a body of brine lying below average wave base and a less dense surface layer lying above average wave base. Some of the dense brine continuously returned to the open sea; otherwise the volume of halite deposited would have been about 30 times as great as the volume of anhydrite instead of somewhat less than the volume of anhydrite. The barrier must therefore have been incomplete. Either the top lay partly below wave base or the barrier was permeable. This theory of reflux is presented as a modification of Ochsenius' bar theory.

The calcium sulphate presumably was deposited as anhydrite rather than as gypsum because of the salinity of the brine. The banding is ascribed to seasonal variation in temperature. The average net rate of evaporation in Castile time is calculated as 114 inches a year."

Klemmick, G.F. 1993. "Geology of the Pokorny Sulfur Deposit, Culberson County, Texas." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 18–19. New Mexico Geological Society, Socorro, NM.

p 18;
" The Pokorny sulfur deposit is located in the northwest corner of the Delaware Basin, in the Rustler Springs sulfur district of west Texas (Fig. 1.20), approximately 35 mi south of Carlsbad, New Mexico, in northeast Culberson County, Texas (Fig. 1.21). To date, 57 sulfur test wells have been drilled by Addwest Minerals delineating a resource of greater than one million long tons (lt) of native sulfur.

The Pokorny sulfur deposit was inadvertently discovered . . ."

Kunkler, J.L. 1980. Evaluation of the Malaga Bend Salinity Alleviation Project. Open-File Report 80-1111. U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;

" In an effort to reduce the flow of brine springs in the Malaga Bend reach of the Pecos River in southeastern New Mexico, brine was pumped from an aquifer underlying the Malaga Bend reach to a local depression known as Anderson Lake. The attempt to improve the quality of river water with this experiment was not successful because brine leakage from Anderson Lake to the nearby Pecos River through permeable subsurface rocks was greater than the previous natural spring inflow.

Brine leakage from Anderson Lake from July 22, 1963, through September 30, 1968, was estimated by evaporation-pan, salt-accumulation, and dissolved-constituent methods. The leakage values given by these three methods are in good agreement with each other and indicate that between the dates given, leakage from the lake was about 2,300 acre-feet, compared with a brine inflow to the lake of about 3,690 acre-feet. Other data indicate that pumping from the brine aquifer greatly reduced the natural inflow from brine springs to the Malaga Bend reach.

The rate of brine leakage from Anderson Lake is probably greater than might be expected from other brine lakes in the area because the cavities in the bottom of the lake are in hydrologic connection with the Pecos River. This connection is shown by a relation between the salinity of the Pecos River and the reservoir stage of Anderson Lake."

Lambert, S.J., and Carter, J.A. 1984. "Uranium-Isotope Disequilibrium in Brine Reservoirs of the Castile Formation." In Principles and Methods, Northern Delaware Basin, Southeastern New Mexico. SAND83-0144. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3;

" We evaluated uranium isotope activity ratios with respect to models for the origin of the brines in two brine reservoirs in the Castile Formation (ERDA No. 6 and WIPP No. 12). In Castile anhydrite, a completely closed water system that was continuously leaching Th-recoil-produced ^{234}U from freshly exposed surfaces of fractured host rock would give rise to uranium 234/238 isotope activity ratio (α) values significantly higher than observed values. Therefore, the brine occurrences are not the result of continuous deformation. Similarly, a model assuming movement of intergranular Permian seawater into fractures was found inconsistent with observed uranium isotope systematics. The observed α-values (95% confidence limits) of ERDA No. 6 (1.34 to 1.58) and WIPP No. 12 (1.74 to 2.54), used in conjunction with an inferred initial α_0 higher than observed values, allows calculation of reasonable finite minimum ages, involving no preferential leaching of ^{234}U in the host rock. If the brine occurrences are inferred to have been connected at one time with a more extensive nearby hydrologic system, the Capitan limestone (α_0 = 5.1), calculated minimum ages of isolation from that system are 700 000 to 880 000 yr for ERDA No. 6 and 360 000 to 610 000 yr for WIPP No. 12. These ranges in ages are the 95% confidence limits based on experimental determination of α-values. The ages thus derived may reflect an episode of structural deformation in the Pleistocene that allowed water to enter the resulting fractures."

Lang, W.B. 1935. Upper Permian Formation of Delaware Basin of Texas and New Mexico. American Association of Petroleum Geologists Bulletin, Vol. 19, pp. 262-276.

ABSTRACT, p 262;
" The purpose of this paper is to define and name the formations of the Delaware basin of Texas and New Mexico above the Delaware Mountain formation, that future discussions of the stratigraphy of the area may be facilitated. Something of the relationships and characteristics of these formations are given. The question of the age of the Bissett formation is also discussed."

Lang, W.B. 1947. "Occurrence of Comanche Rocks in Black River Valley, New Mexico." American Association of Petroleum Geologists Bulletin, Vol. 31, pp. 1472-1478.

ABSTRACT, p. 1472;

" The discovery of Comanche fossils in Black River Valley provides a means for more accurately defining the position of the Comanche shoreline in southeastern New Mexico. An explanation is offered for the anomalous occurrence of these fossils and one which may help to clarify previous misconceptions of the geology of the area. A brief reference is made to related early geologic explorations in the region.

In the valley of Black River, near the center of the east side of the NW. ¼ of Sec. 31, T. 25 S., R. 25 E., Eddy County, New Mexico, and about 200 feet southeast of the highway (U.S. 62, State 180) is a patch of loose gravel and rock débris resting on a top soil of gypsite. This débris, which is likely to be overlooked by anyone not purposely in search of it, was turned up by the Army in 1943 when grading a new road, and it was found by a party of Superior Oil Company geologists on a field trip in 1944.[3] This material is of interest because it is geologically anomalous to the area. Here and for miles around, the Castile formation of Permian age, where not covered by a remnant of Rustler dolomite, the Quaternary Gatuña formation, or more recent valley deposits, is exposed at the surface.

Scattered about within a circle approximately 200 feet in diameter are fragments of sandstone and limestone. Many of the fragments are fossiliferous. Though the fossils are abundant they are limited in variety, as becomes apparent when the ground is carefully combed for every variant form. R. W. Imlay examined a collection made here and listed the following forms.

Anorthopygus s. sp	*Opis? sp.*
Gryphaea corrugata (Say)	*Protocardia texana (Conrad)*
Neithea texana (Roemer)	

Imlay states

Gryphaea corrugata Say ranges through the Duck Creek and Kiamichi. The new species of the echinoid genus *Anorthopygus* has been identified by C. W. Cooke, who notes that it has been found in the Duck Creek and Fort Worth. Furthermore, the rock matrix resembles the Duck Creek limestone.

These identifications place the horizon of the strata from which the fragments were derived at the base of the Washita group of the Comanche series. The Kiamichi formation, which was formerly placed at the base of the Washita group, is now placed by the United States Geological Survey at the top of the underlying Fredericksburg group of the Comanche series."

Lappin, A.R., Hunter, R.L., Garber, D.P., Davies, P.B., Beauheim, R.L., Borns, D.J., Brush, L.H., Butcher, B.M., Cauffman, T., Chu, M.S.Y., Gomez, L.S., Guzowski, R.V., Iuzzolino, H.J., Kelley, V., Lambert, S.J., Marietta, M.G., Mercer, J.W., Nowak, E.J., Pickens, J., Rechard, R.P., Reeves, M., Robinson, K.L., and Siegel, M.D., eds., 1989. Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico: March 1989. SAND89-0462. Sandia National Laboratories, Albuquerque, NM.

EXECUTIVE SUMMARY, p iii;

" This report summarizes the current understanding of the expected long-term behavior of the Waste Isolation Pilot Plant (WIPP) repository and estimates long-term radionuclide doses in a series of six analyses investigating both undisturbed repository performance (Case I) and performance in response to a relatively high-consequence human Intrusion (Case II). It is the result of an intensive effort over a short time. The U. S. Department of Energy (DOE) decided to have Sandia National Laboratories prepare this report as a result of a meeting held January 5, 1989. The conceptual model of the expected long-term behavior of the WIPP repository used in this report was formulated in early to mid January 1989, drawing on information and understanding developed over the past decade. Numerical modeling of ground-water flow, radionuclide transport, and doses to humans began January 20, 1989 and was completed March 20, 1989.

The report has several objectives:

1. To briefly summarize Sandia's current technical understanding of the major components of long-term performance of the WIPP repository. The following areas are specifically addressed:

. . . .

f. radionuclide-transport mechanisms and properties of the Culebra Dolomite, the major pathway for ground-water transport of radionuclides from the WIPP to the biosphere.

. . . .

4. To describe, document, and interpret six sets of calculations estimating the potential health effects to individuals resulting from emplacement of CH-TRU wastes in the WIPP, hydrologic saturation of the repository as a result of either natural processes or human intrusion, direct and indirect exposure during and after drilling (where appropriate), and ground-water transport of radionuclides to a hypothetical stock well south of the WIPP site.

The calculations presented here investigate radionuclide transport and resulting health effects both during undisturbed performance of the WIPP repository and in response to a relatively high-consequence human intrusion into the repository. The human intrusion considered is drilling that results in a long-term interconnection of the repository, an underlying brine reservoir in the Castile Fm., and the overlying Culebra Dolomite. The Culebra Dolomite provides a relatively permeable pathway for ground-water transport of radionuclides to the hypothetical stock well."

LaVenue, A.M., Cauffman, T.L., and Pickens, J.F. 1990. Ground-Water Flow Modeling of the Culebra Dolomite. Volume I: Model Calibration. SAND89-7068/1. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. i;

" This hydrogeologic modeling study has been performed as part of the regional hydrologic characterization of the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The study has produced an estimation of the transmissivity and Darcy-velocity distributions in the Culebra Dolomite Member of the Permian Rustler Formation at the WIPP site. The results of this study are intended to support Sandia National Laboratories performance-assessment calculations.

The three-dimensional finite-difference code SWIFT II was employed for the numerical modeling, using a variable-fluid-density and single-porosity formulation. The spatial scale of the model, 21.3 km by 30.6 km, was chosen to allow simulation of regional-scale pumping tests conducted at the H-3 and H-11 hydropads and the WIPP-13 borehole, which are located south, southeast, and northwest, respectively, of the center of the WIPP site. The modeled area includes and extends beyond the controlled area defined by the WIPP-site boundaries.

The work performed in this study consisted of modeling the hydrogeology of the Culebra in two stages: steady-state modeling to develop the best estimate of the undisturbed head distribution (i.e., of the hydraulic conditions before excavation of the WIPP shafts, which began in 1981) and superimposed transient modeling of local hydrologic responses to excavation of the four WIPP shafts at the center of the WIPP site, as well as to various well tests. The transient modeling used the calculated steady-state freshwater heads as initial conditions.

The steady-state calibrated transmissivity field contains transmissivities that vary over seven orders of magnitude increasing westward toward Nash Draw. The most significant feature of the transmissivity field is a high-transmissivity zone in the vicinity of wells H-17, P-17, and H-11. Modeled transmissivities within this zone are approximately 5×10^{-5} m^2/sec. The location of and transmissivities within the zone are similar to those proposed in a previous interim modeling report.

After calibration of the steady-state model, the major drilling and testing activities at the WIPP shafts and well locations were incorporated into the model. The transient simulation of the major hydraulic stresses in the Culebra dolomite extended from January 1, 1981 to June 16, 1989. Calibration of the model to the transient events required additional changes to the steady-state calibrated transmissivity field in order to reduce the differences between the calculated and observed transient heads. The major difference between the transient calibrated transmissivity field and the steady-state calibrated transmissivity field is the extension of the higher transmissivity zone near H-11 northward toward H-15.

The travel times for non-sorbing particles released within the steady-state flow field, using the transient calibrated model, were computed from selected locations within the model to the southern model (down-gradient) boundary. The predicted travel time from a release

point within the Culebra that is coincident with the centroid of the waste panels to the southern WIPP-site boundary is 1.4 x 10^4 years. Calculations were performed to assess the sensitivity of the above travel time to the grid-block transmissivities and the pressure assigned to the model boundaries."

Section 7.0 CONCLUSIONS, p 7-1, para 4;

- The model-calculated ground-water-flow directions are predominantly south to southwest. The largest volume of ground water enters the model area through the northern portion of the western model boundary and enters the high- transmissivity area along the western part of the model representing Nash Draw. A significant portion of the ground water within the WIPP-site boundaries passes through the high-transmissivity zone south of H-15 and exits the southern boundary of the model area near H-9. The model-calculated flow directions support conclusions from previous modeling and isotopic studies that the ground-water chemistry is not at steady state with respect to ground-water flow."

LaVenue, A.M., Haug, A., and Kelley, V.A. 1988. Numerical Simulation of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Second Interim Report. SAND88-7002. Sandia National Laboratories, Albuquerque, NM.

EXECUTIVE SUMMARY, p ii;

" This hydrologic modeling study has been performed as part of the regional hydrologic characterization of the Waste Isolation Pilot Plant (WIPP) Site in southeastern New Mexico. The study resulted in an estimation of the transmissivity distribution, hydraulic potentials, flow field, and fluid densities in the Culebra Dolomite Member of the Permian Rustler Formation at the WIPP site.

The three-dimensional finite-difference code SWIFT-II . . ."

Lee, W.T. 1925. "Erosion by Solution and Fill." In Contributions to Geography in the United States: USGS Bulletin, 760-C.

INTRODUCTION, p 107;

" In a region where the rocks are honeycombed surface material may find its way into subterranean cavities on a large scale. In southeastern New Mexico the formation of caverns by the solution of certain kinds of rocks and the transfer of surface material to these caverns have been carried on so extensively that these processes may be considered the chief causes of the formation of a broad valley.

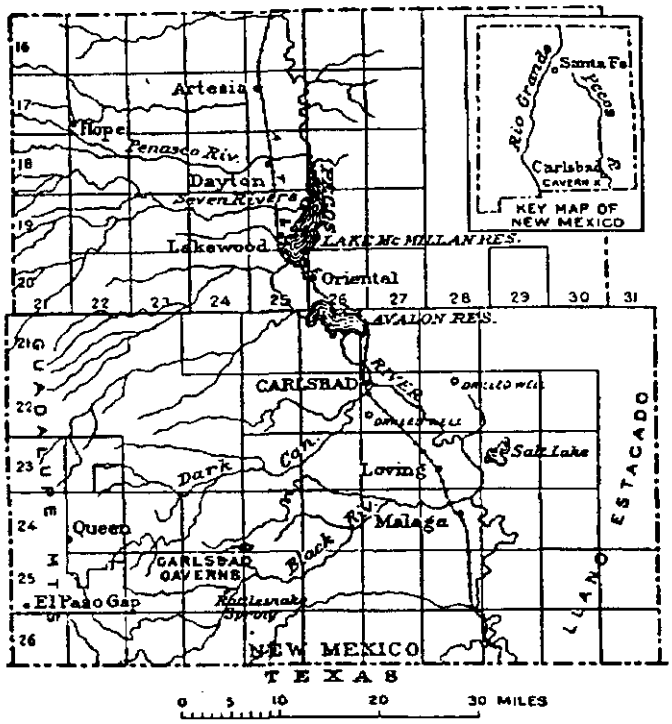

FIGURE 12.—Map of Eddy County, N. Mex.

Pecos Valley lies between the Guadalupe Mountains on the west, which rise to altitudes of nearly 10,000 feet and the Llano Estacado on the east. (See fig. 12) It is the broad, shallow depression through which Pecos River flows, but it is not wholly a valley of erosion in the sense in which the term erosion is generally used.

Streams from the mountains to the west reach the river and erode their channels in the ordinary way. Pecos River also carries much sand and silt and functions in many ways as a normal stream. But no tributary streams were found east of the Pecos in Eddy County, and

over a wide area not even the dry bed of a temporary stream was seen."

Leslie, A., Kendall, A., and Harwood, G. 1993. "The Castile Formation: A Continuing Paradox." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook. New Mexico Geological Society, Socorro, NM.

p 13;

" The Upper Permian (Ochoan) Castile Formation consists of laminated couplets of anhydrite and calcite/organic material, interbedded with massive to poorly laminated halite (Anderson, et al., 1972). The Castile Formation ranges in thickness from under 300 m in the west of the basin where halite has been removed to over 600 m in the east. The Castile Formation was deposited in an embayment of the Permian Basin (the Delaware Basin) during a period of restricted circulation with marine waters, causing a rapid increase in salinity and consequent precipitation of evaporite minerals. The laminates display a number of cyclicities on different scales, which have been related to orbital forcing by Anderson (1982).

At the base of the Ochoan . . ."

Long, G.J., and Associates, Inc. 1976. Interpretation of Geophysical Data, Los Medaños and Vicinity, Lea and Eddy Counties, New Mexico. Report to Sandia National Laboratories.

INTRODUCTION, p. 1;

" The geophysical studies discussed herein comprise a portion of a comprehensive evaluation of a proposed nuclear Waste Isolation Pilot Plant site. The area of investigation is located in the northern portion of the Delaware Basin, Eddy and Lea Counties, New Mexico in the Los Medanos vicinity approximately 25 miles east southeast of the town of Carlsbad. This evaluation is being performed by and under the direction of Sandia Laboratories, and Energy Research and Development Administration (ERDA) facility. The acquisition and interpretation of geophysical data can be applied to the identification of potential geological hazards and the evaluation of the economic impact which could be anticipated as the result of a site withdrawal. The objective of these investigations is to gather information which can be used to select a site having maximum geological stability and structural integrity, especially as to long term isolation from ground water invasion and minimal hydrocarbon/mineral potential.

Subsurface salt dissolution cavities, breccia pipes, shallow (late) faulting, igneous activity and adjoining systems constitute some of the major hazards to a WIPP site. The delineation of subsurface structure at established producing formations provides the primary basis for an economic evaluation of potentially undeveloped hydrocarbon reserves. Geophysical data of the type which oil companies acquire as a part of hydrocarbon exploration programs have been used as a basis for the interpretation and evaluation discussed herein."

Lowenstein, T.K. 1987 Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico. EEG-36. New Mexico Health and Environment Department, Santa Fe, New Mexico.

PREFACE, p vii;

" A repository for permanent isolation of defense transuranic wastes is being excavated in southeastern New Mexico, about 40 km 925 miles) east of Carlsbad. The Waste Isolation Pilot Plant (WIPP) repository has been designed for the disposal of waste in the lower part of the Salado (salt) Formation at a depth of 655 meters (2150 ft). The water-bearing zones of the Rustler Formation, which overlies the Salado, are considered to be the main pathway for the transport of radionuclides to the biosphere, if the repository is breached.

The Rustler Formation is 150 meters (490 feet) thick, 6.4 Km (4 miles) east of the center of the WIPP site. The thickness reduces drastically to the west so that it is only 91 meters (300 ft) thick in the western part of the WIPP site. At its thickest location, the Rustler consists of siltstone and anhydrite with two dolomite beds and both clear and clayey halite. Halite is progressively missing from deeper layers from east to west in the Rustler cross-section across the WIPP site. These observations were interpreted by Powers et al (1978), Mercer (1983), Lambert (1983), Chaturvedi and Rehfeldt (1984), Bachman (1984), Snyder (1985), Chaturvedi and Channell (1985) and others as indicating post-burial dissolution of halite and increased gypsification of anhydrite further west. Increased permeability of the water-bearing dolomites from east to west also was thought to result from the increased fracturing as a result of dissolution.

In 1984, Powers and Holt (1984) and Holt and Powers (1984) expressed doubts about the concept of post-burial dissolution of Rustler evaporites, on the basis of detailed mapping in the WIPP Waste Handling Shaft, and stated the following:

> 'Post-depositional dissolution features were not observed in any stratigraphic horizons in the Waste Shaft. In fact, several zones previously identified as dissolution residues in nearby boreholes (e.g. ERDA-9) contain pronounced primary sedimentary features. This is of great significance since dissolution has, historically, been considered as an important process that has greatly modified the Rustler Formation in this area.' (Holt and Powers, 1984)

This statement was based on the first detailed sedimentological study of the Rustler stratigraphy, but only at one location, albeit in situ, in a shaft. It clearly signaled the need for further work on the lateral variations in the stratigraphy of the Rustler Formation across the WIPP site. Since the interpretation by Powers and Holt was based on sedimentary features, the need was for a sedimentological study of the Rustler Formation.

To resolve this issue, the Environmental Evaluation Group (EEG) asked Dr. Tim K. Lowenstein to perform a sedimentological study of the available cores of the Rustler Formation. Dr. Lowenstein is a sedimentologist with special interest in the study of evaporites and has studied the Ochoan evaporites of the delaware Basin (Lowenstein, 1982,

1985). For this study, he performed a detailed sedimentological analysis of the Rustler cores from four wells, viz. DOE-2, W-19, H-11 and H-12. This included visual examination of the cores, preparation and petrographic analyses of 52 thin sections from selected locations of the cores, and x-ray diffraction analyses of 40 samples from selected locations of the cores. In addition, descriptive data on the rock cuttings and geophysical logs of borehole P-18 were used for correlation purposes. This report is a result of these analyses and correlation of sedimentary features between the drill-holes.

This study was confined to a miniscule area (only about 0.05%) of the total extent of the Rustler Formation and therefore cannot be considered to be a study of post-burial alteration of the Rustler Formation as a whole. Within the confines of this area, however, detailed stratigraphic correlations by Dr. Lowenstein based on sedimentary structures and textures indicate overall uniformity of depositional setting. Further, the physical and chemical alteration features, based on crosscutting relations, represent the last processes which have operated on these rocks. Four distinct dissolution zones in the Rustler Formation have been interpreted by Dr. Lowenstein. Although the strata above and below the inferred dissolution zones are chemically and physically altered, they contain abundant sedimentary structures and internal stratigraphy that can easily be matched from well to well. Dr. Lowenstein does not see a contradiction between post depositional dissolution and the survival of sedimentary structures. His interpretation is that the dissolved species produced by solution are removed from the site of reaction and the zones in which the effects of dissolution are now seen were at the periphery of main dissolution activity and therefore may exhibit some alteration as well as primary sedimentary structures."

Lowenstein, T.K. 1988. Origin of Depositional Cycles in a Permian "Saline Giant": the Salado (McNutt Zone) Evaporites of New Mexico and Texas. Geological Society of America Bulletin, Vol. 100, No. 4, pp. 592-608.

ABSTRACT, p 592, col 1;

" Two types of metre-scale depositional cycles have been recognized within the McNutt Potash Zone of the Permian Salado evaporites. The cycles record progressive drawdown and concentration of brine in a shallow, marginal marine basin. 'Type I' cycles, made of basal carbonate-siliciclastic mudstone, then anhydrite-polyhalite pseudomorphous after primary gypsum, overlain by halite and capped by muddy halite, are interpreted as marine sea water dominated. They formed by massive spillover of sea water through a connection with the Permian Ocean at high relative sea-level stands (lagoonal mudstone and anhydrite-polyhalite after subaqueous gypsum), followed by relative lowering of sea level and gradual basin restriction (shallow saline-lake and salt-pan halite) and ending with a desiccated basin, isolated from the Permian Ocean (salt-pan halite and saline mudflat muddy halite cycle cap). 'Type II' cycles occur between the Type I cycles and contain halite overlain transitionally by muddy halite. They record a temporal evolution of environments from a shallow saline lake to an ephemeral salt-pan-saline mudflat complex and are interpreted as continental-dominated sequences sourced by meteoric inflow from surrounding land areas that mixed with variable amounts of sea water, either residual or introduced into the Salado basin by seepage.

The vertical stacking of Type I cycles is best explained by periodic invasions of sea water into the Salado basin coincident with eustatic sea-level rises. The continental-dominated Type II cycles formed during intervening periods of eustatic sea-level fall and low stands. The *maximum* time interval between major marine incursions is an average of 10^5 yr."

Lucas, S.G., and Anderson, O.J. 1993. "Triassic Stratigraphy in Southeastern New Mexico and Southwestern Texas." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, New Mexico Geological Society, Socorro, NM.

ABSTRACT, p 231;

" Upper Triassic strata exposed in southeastern New Mexico and southwestern Texas are assigned to the Santa Rosa, San Pedro Arroyo and Dockum Formations of the Chinle Group. In southeastern New Mexico (Chaves, Eddy and Lea Counties) the Santa Rosa Formation is as much as 25 m thick and is mostly trough-crossbedded extraformational conglomerate and sandstone with minor beds of mudstone or siltstone. It disconformably overlies Upper Permian (Artesia Group or Quartermaster Formation) strata. The San Pedro Arroyo Formation conformably (?) overlies the Santa Rosa Formation and is at least 50 m of variegated smectitic mudstone and minor sandstone/conglomerate. Regional geologic maps have greatly overstated the extent of Upper Triassic exposures in southeastern New Mexico. In southwestern Texas (area from Pecos to Mitchell Counties) the Dockum Formation consists of the basal Camp Spring Member and overlying strata here assigned to a new stratigraphic unit, the Iatan Member. The Camp Springs Member is at least 15 m thick and is dominantly extraformational, siliceous conglomerate. It disconformably overlies the Upper Permian Quartermaster (=Dewey Lake) Formation and is conformably (?) overlain by the Iatan Member, which is 80-100 m thick and characterized by intercalcated, persistent intervals of red smectitic mudstone and trough-crossbedded micaceous sandstone. Fossil vertebrates indicate the Camp Springs and Iatan Members are of late Carnian (Tuvalian) age. Physical stratigraphy and lithology suggest correlation of the Santa Rosa Formation with the Camp Springs Member and the San Pedro Arroyo Formation with the Iatan Member."

Santa Rosa Formation, p 232, col 1;

" We assign the basal sandstones and conglomerates of the Upper Triassic section in southeastern New Mexico to the Santa Rosa Formation, as did Lang (1935) and subsequent workers. The Santa Rosa is as much as 25 m thick and is mostly trough-crossbedded extraformational conglomerate and sandstone with minor beds of mudstone or siltstone. Typical colors are grayish red (10 R 4/2) and pale reddish brown (10 R 5/4) for the sandstones, siltstones and mudstones, whereas conglomerate beds are mostly yellowish gray (5 Y 8/1) to light greenish gray (5G Y 8/1). Sandstones are micaceous subarkoses or litharenites. Conglomerate clasts typically are rip-ups of underlying Permian red beds (Artesia Group or Quartermaster Formation) at the base of the Santa Rosa Formation. Some quartzite clasts (usually in the very coarse to pebbly size range) also are present in basal Santa Rosa conglomerates. Conglomerates higher in the unit contain reworked Triassic siltstone and sandstone clasts.

The base of the Santa Rosa Formation is a disconformity above Permian red beds. Permian strata are finer grained, more texturally and mineralogically mature, gypsiferous, more evenly bedded and a different color (mostly moderate reddish brown) than the Santa

Rosa Formation. Despite these differences, in southeastern New Mexico both Miller (1955) and Vine (1963) incorrectly included uppermost sandstones of the Quartermaster Formation in the Santa Rosa Formation (Schiel, 1988; Lucas and Anderson, this volume).

The top of the Santa Rosa Formation in southeastern New Mexico is visible only at Maroon Cliffs. Here, variegated moderate reddish brown (10 R 4/6) and grayish red purple (5 RP 4/2) mudstone of the San Pedro Arroyo Formation rests directly (conformably ?) on the uppermost conglomerate bed of the Santa Rosa Formation (Fig. 2).

Other than undefinable fragments of petrified wood, bone and coprolites, no fossils have been collected in the Santa Rosa Formation in southeastern New Mexico. Nevertheless, regional correlation suggests this unit is of Late Triassic (late Carnian) age (see below)."

Machette, M.N. 1985. "Calcic Soils of the Southwestern United States." In Soils and Quaternary Geology of the Southwestern United States. D.L. Weide, and M.L. Faber, eds., Special Paper Vol. 203,pp. 1-21. Geological Society of America, Denver, CO.

ABSTRACT, p 1;

" Calcic soils are commonly developed in Quaternary sediments throughout the arid and semiarid parts of the southwestern United States. In alluvial chronosequences, these soils have regional variations in their content of secondary calcium carbonate ($CaCO_3$) because of (1) the combined effects of the age of the soil, (2) the amount, seasonal distribution, and concentration of Ca^{++} in rainfall, and (3) the $CaCO_3$ content and net influx of airborne dust, silt, and sand. This study shows that the morphology and amount of secondary $CaCO_3$ (cS) are valuable correlation tools that can also be used to date calcic soils.

The structures in calcic soils are clues to their age and . . ."

MacLennan, R.B., and Schermer, S.C.. 1979. An Archaeological Survey for the Waste Isolation Pilot Project: Access Roads and Railroad Right-of-Way. Agency for Conservation Archaeology Report 79-23. Eastern New Mexico University, Portales, NM.

ABSTRACT, p i;

" An archaeological reconnaissance of three access rights-of-way for the Waste Isolation Pilot Project in the Los Medanos area of Eddy County, New Mexico was accomplished between February 22 and February 24, 1979. The project involved 15.75 miles of 200 ft wide corridor, an area of 506.66 acres. The surveyed corridors were generally situated in dune covered areas east of Nash Draw, with only the railroad access descending into the Draw.

This survey encountered two sites and 12 isolated artifacts. The sites, ENM 10418 and ENM 10419, were located on the floor of Nash Draw and on a low bench above the floor of Nash Draw respectively. ENM 10418 appears to be a campsite, with possible Jornado Mogollon affiliations. ENM 10419 consists of four small hearths without artifactual associations; it may be a task locus, of recent origin, used in branding cattle. It is recommended that mitigations be conducted for both sites before further WIPP actions proceed in the railroad access right-of-way."

Maley, V.C., and Huffington, R.M. 1953. Cenozoic Fill and Evaporate Solution in the Delaware Basin, Texas and New Mexico. Geological Society of America Bulletin, Vol. 64.

NOTE: Text "bolded" was not legible in the copy of the document available to Long-Term Regulatory Compliance and is the typist's interpretation of the text.

ABSTRACT, p 539;

" The Delaware Basin, containing thick deposits of late Permian salt and anhydrite, is one of the major **geologic** subdivisions of the Permian Basin of West Texas and southeastern New Mexico. At least three **successive** accumulations of Cenozoic fill, with a maximum thickness of approximately 1900 feet, are present **in the** basin. Localization of these major fill deposits is attributed to evaporite solution, particularly of salts. **Subsequent** slump of the Permian Rustler formation, which immediately overlies the evaporite beds, makes **it difficult** to distinguish true tectonic structures in this formation.

Mariah Associates, Inc. 1987. Report of Class II Survey and Testing of Cultural Resources at the WIPP Site at Carlsbad, NM. Prepared for the U.S. Corps of Engineers, Albuquerque District in NM.

ABSTRACT;
" In September of 1985, the Army Corps of Engineers, Albuquerque District, contracted Mariah Associates, Inc. to conduct a Class II cultural resource survey of approximately 3,100 acres in WIPP Zones III, IV, and V in Eddy County, New Mexico. A total of 40 archaeological sites was located; 11 were subsequently tested. Sites included probable PaleoIndian, Archaic, Mogollon, and Protohistoric camps. Seventy-five isolated artifacts were recorded. Ancillary studies included archaeological and historical interviews and archival research.

Site-specific recommendations concerning eligibility to the National Register of Historic Places are made and recommendations for future work in the project area are advanced."

McTigue, D.F., 1993. Permeability and Hydraulic Diffusivity of Waste Isolation Pilot Plant Repository Salt Inferred from Small-Scale Brine Inflow Experiments. SAND92-1911. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" Brine seepage to 17 boreholes in salt at the Waste Isolation Pilot Plant (WIPP) facility horizon has been monitored for several years. A simple model for one-dimensional, radial, darcy flow due to relaxation of ambient pore-water pressure is applied to analyze the field data. Fits of the model response to the data yield estimates of two parameters that characterize the magnitude of the flow and the time scale over which it evolves. With further assumptions, these parameters are related to the permeability and the hydraulic diffusivity of the salt. For those data that are consistent with the model prediction, estimated permeabilities are typically 10^{-22} to 10^{-21} m^2. The relatively small range of inferred permeabilities reflects the observation that the measured seepage fluxes are fairly consistent from hole to hole, of the order of 10^{-10} m/s. Estimated diffusivities are typically 10^{-10} to 10^{-8} m^2/s. The greater scatter in inferred hydraulic diffusivities is due to the difficulty of matching the idealized model history to the observed evolution of the flows. The data obtained from several of the monitored holes are not consistent with the simple model adopted here; material properties could not be inferred in these cases."

Mercer, J.W. 1987. Compilation of Hydrologic Data From Drilling the Salado and Castile Formations Near the Waste Isolation Pilot Plant (WIPP) Site in Southeastern New Mexico. SAND86-0954. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3-4;

" This report compiles and evaluates data from tests performed on the Salado and Castile Formations during site characterization, exclusive of the 'brine reservoirs' in the Castile. It also examines if regional data are consistent with the experience of fluid encounters in the mined facility--especially whether significant volumes of fluid might be involved in the Salado pressure buildups in the same way as small volumes were in the studies in the mined facility at the Waste Isolation Pilot Plant (WIPP). Preliminary analyses of recently completed data from reentry and testing in WIPP-12 and testing of the Salado in DOE-2 are also included. Results of this study indicate that probably no overall interpretive model can be applied to the Salado and Castile Formations. That is, no definitive or unique explanation exists for the brine and/or gas occurrences or pressure buildups or their distribution in the borehole. Because of certain basic problems of well testing from the surface in low-permeability rock and because of the apparent low permeabilities, we do not recommend continued hydrologic testing conducted from the surface and penetrating the halites and anhydrites of concern at the WIPP. However, testing of the halite and marker beds at or near the WIPP mining horizon is practicable and should be carried out with the most sensitive instrumentation developed for that purpose."

Mercer, J.W., Beauheim, R.L., Snyder, R.P., and Fairer, G.M. 1987. Basic Data Report For Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-0611. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" Drillhole DOE-2 was drilled to investigate a structural depression marked by the downward displacement of stratigraphic markers in the Salado formation ~2 mi north of the center of the WIPP site. This depression was named informally after the shallow borehole FC-92 in which the structure was described. The presence of the depression was confirmed by drilling. Contrary to several hypotheses, halite layers were thicker in the lower part of the Salado, not thinner as a result of any removal of halite. The upper Castile anhydrite in Drillhole DOE-2 is anomalously thick and is strongly deformed relative to the anhydrite in adjacent drillholes. In contrast, the halite was <8 ft thick and significantly thinner than usually encountered. The lower Castile anhydrite appears to be normal. The depression within the correlated marker beds in the Salado Formation in Drillhole DOE-2 is interpreted as a result of gravity-driven deformation of the underlying Castile Formation.

Several stratigraphic units were hydrologically tested in Drillhole DOE-2. Testing of the unsaturated lower portion of the Dewey Lake Red Beds was unsuccessful because of exceptionally small rates of fluid intake. Drill-stem tests were conducted in five intervals in the Rustler Formation, over the Marker Bed 138-139 interval in the Salado Formation, and over three sandstone members of the Bell Canyon Formation. A pumping test was conducted in the Culebra Dolomite Member of the Rustler Formation. Pressure-pulse tests were conducted over the entire Salado Formation. Fluid samples were collected from the Culebra Dolomite Member and from the Hays Member of the Bell Canyon Formation."

Mercer, J.W. and Orr, B.R. 1977. Review and Analysis of Hydrogeologic Condition Near the Site of a Potential Nuclear-Waste Repository, Eddy and Lea Counties, New Mexico. USGS Open-File Report 77-123. U.S. Geological Survey, Albuquerque, NM.

ABSTRACT, p. 7;

" This interim report reviews and summarizes the hydrogeology of rocks associated with the Permian salt beds (Castile and Salado Formations) of Los Medaños area in southeastern New Mexico. The information will be considered, together with other factors, in the preparation of an analysis of the impact of a potential nuclear-waste repository on the environment.

Most of the geologic units in and adjacent to the Permian salt deposits are characterized by low permeabilities and highly mineralized water. Sandstone of the Delaware Mountain Group which underlies the salt, has an average hydraulic conductivity of 0.16 ft/d and an average porosity of 15.65 percent. Flow is north-northeastward toward the margin of the Capitan Limestone, at velocities ranging from 0.0005 to 0.0008 ft/d.

The Capitan Limestone, a relatively high yielding limestone-reef aquifer adjacent to the study area, has been reported to have transmissivity values ranging from 500 ft^2/d to 10,000 ft^2/d and an average hydraulic conductivity of about 5 ft/d. Water movement west of the Pecos River is northeastward in the reef, with discharge at Carlsbad Springs. East of the Pecos River, water moves at very low rates and the direction of movement is uncertain.

The Castile and Salado Formations, which might be used to contain the nuclear waste, have a few isolated pockets of brine and gas, but generally transmit little or no ground water.

An evaporite residuum near the top of the Salado Formation was developed in localities where ground water has dissolved the upper Permian evaporites. Brine in the residuum moves southward along Nash Draw and discharges about 200 gal/min into the Pecos River at Malaga Bend. The transmissivity of the residuum is 8,000 ft^2/d and the flow rate is 0.2 ft/d.

The Rustler Formation overlies the Salado. The major water-bearing beds in the Rustler Formation are the Culebra Dolomite Member and Magenta Member, which in places are capable of yielding up to 700 gal/min. Values of transmissivity in the formation range from near 0 to 500 ft^2/d. The porosity and permeability in the dolomite is attributed to fracturing and to solution activity. Ground-water movement is south-southwestward toward the Pecos River.

Water in the Dewey Lake Red Beds, which overlie the Rustler Formation, occurs in sand lenses. Movement of water in the formation is restricted by low permeabilities.

The Santa Rosa Sandstone, overlying the Dewey Lake Red Beds, also has a low permeability. The porosity is about 10 percent and the rate of flow is 0.3 ft/d south-southwest toward the Pecos River.

Data on the occurrence of water in the Chinle Formation is sparse; however, its lithology indicates it would be a poor aquifer.

Other potential aquifers adjacent to the proposed repository area include the Ogallala Formation, Gatuna Formation, and alluvial deposits. Most water in the Ogallala moves to

the southeast but some moves westward, recharging the Santa Rosa Sandstone aquifer. The Gatuña Formation contains water in sand and gravel lenses. Ground-water movement in the alluvium is in the approximate direction of surface flow of the Pecos River. An average value of transmissivity for the alluvium is 13,600 ft^2/d, and flow-velocity estimates are generally less than 1 ft/d."

Mercer, J.W., and Orr, B.R. 1979. Interim Data Report on Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico. Water Resources Investigations 79-98. U.S. Geological Survey, Albuquerque, NM.

ABSTRACT, p. 1;

" Data were collected during hydrologic investigations at the Waste Isolation Pilot Plant site in southeast New Mexico through September 1977. These data will be considered as part of a site characterization study evaluating the feasibility of nuclear-waste storage within bedded salt of the Salado Formation of Permian age.

Liquids in the rocks overlying the Salado Formation are found at the contact between the Permian-Rustler and Salado Formations, and in the Culebra and Magenta Dolomite Members of the Rustler Formation.

Calculations of hydraulic gradient and direction of flow of water moving along the Rustler-Salado contact have been hindered because heads are stabilizing very slowly. Preliminary calculations of transmissivity range from 10^{-1} feet squared per day on the western margin of the site to 10^{-4} feet squared per day on the eastern margin. Liquids from the Rustler-Salado contact contain from 311,000 to 325,800 milligrams per liter total dissolved solids. Liquid chemistry suggests long residence times and extensive liquid-rock interaction, increasing with decreasing permeability.

Liquids in the Culebra Dolomite Member move southeast at gradients ranging from 7 to 120 feet per mile. Preliminary transmissivity calculations range from 140 feet squared per day on the western margin to 10^{-4} feet squared per day to the east. Total dissolved solids range from 23,721 milligrams per liter along the western margin of the site to 118,292 milligrams per liter to the east. Liquid chemistry within the Culebra varies from well to well probably as a function of fracture distribution.

Liquids in the Magenta Dolomite Member move southwest at a gradient of about 50 feet per mile. Preliminary transmissivity estimates range from less than 1 foot squared per day to 40 feet squared per day. Total dissolved solids range from 10,347 milligrams per liter to 29,683 milligrams per liter.

The extremely low vertical hydraulic conductivity within the Rustler Formation restricts liquid migration between the Magenta and Culebra Dolomite Members, and between the Culebra and the Rustler-Salado contact. Heads are highest in the Magenta and lowest at the Rustler-Salado contact.

Liquid levels in wells tapping the Permian Bell Canyon Formation near the site are lower than levels in wells tapping the Rustler Formation. Liquids from the Bell Canyon Formation contain 189,000 milligrams per liter total dissolved solids. Liquid density and chemistry indicate long residence times and extensive liquid-rock interaction."

Merz, H.A., and Cornell, C.A. 1973. Seismic Risk Analysis Based on a Quadratic Magnitude-Frequency Law. Seismological Society of America Bulletin. Vol. 63, pp. 1999-2006.

ABSTRACT, p 1999;

" The quadratic log frequency versus magnitude relationship is introduced into analytical engineering seismic risk analysis. The analytical risk relationships remain in closed form, and risk analysis remains easily amenable to computer implementation. The availability of both a quadratic relationship and a truncation point or upper bound on the magnitude (or epicentral intensity) permits relatively detailed representation of the large magnitude-low frequency region of the distribution. This region has an important influence on high intensity-low risk site conditions, which are of frequent engineering interest. At lower site intensities, the influence of the quadratic versus a linear form is apparently not significant."

Meyer, R.F. 1966. Geology of Pennsylvania and Wolfcampian Rocks in Southeast New Mexico. Memoir 17. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT;

" The area of this study includes about 38,700 square miles in southeast New Mexico that lie within the Great Plains physiographic province on the east and the Basin and Range province on the west. Pennsylvanian and Wolfcampian rocks are discontinuously exposed in the mountain ranges on the west and in boreholes elsewhere.

Major positive elements of the area during Pennsylvanian and Wolfcampian time included the Pedernal uplift, which extended in a north-south direction through the center of the area, and the Central Basin platform, the northwest corner of which lay in the southeast part of the area. Minor positive features included the domical Roosevelt uplift in the northeast, the Oscura and Joyita uplifts in the northwest, and the Diablo platform in the southwest. Major negative elements were the Permian basin on the east and the Orogrande basin on the west. Subprovinces of the Permian basin were the Northwest shelf and the Delaware basin, which included the Salt Flat embayment. Subprovinces of the Orogrande basin were the Robledo and Sacramento shelves. The Orogrande basin merged northward with the extreme south end of the Estancia basin, and in like manner the Permian basin joined the Tucumcari basin.

. . ."

Mitchell, B.J. 1973. Radiation and Attenuation of Rayleigh Waves from the Southeastern Missouri Earthquake of October 21, 1965. Journal of Geophysical Research. Vol. 78, pp. 886-889.

p 886;
" The southeastern Missouri earthquake of October 21, 1965, generated fundamental mode and higher-mode surface waves that were widely recorded throughout North America. Amplitude radiation patterns for the fundamental and first higher Rayleigh modes were determined and compared with patterns computed for various fault plane solutions. The favored solution is that of a fault 4 km deep, oriented N70°E, dipping 50°S, and having a slip vector oriented 85° downward from the horizontal on the fault face. A least squares fitting process was devised to determine the source spectrum and the values for the Rayleigh wave attenuation coefficient at each period. The fundamental mode attenuation coefficient is slightly greater than 0.001 km^{-1} at a period of 4 sec, decreases rapidly to 0.0002 km^{-1} or less at periods between 17 and 25 sec, and increases slowly to about 0.00017 km^{-1} at 50 sec. The first higher mode attenuation coefficients parallel and are slightly lower than those of the fundamental mode at periods between 4 and 10 sec. The source spectrum peaks between 5 and 9 sec and appears to attain a lower dc level at periods of greater than 20 sec. The similarity in the shapes and the orientations of the short-period radiation patterns and the area of perceptibility for this earthquake suggests that the size of the 'felt area' of an earthquake is related to the nature of the radiation and the attenuation of short-period Rayleigh waves. This observation and the lower short-period Rayleigh wave attenuation coefficient values observed in the eastern United States in comparison with those observed in the western United States indicate that the larger areas of perceptibility of eastern United States earthquakes occur because short-period Rayleigh waves are transmitted more efficiently in that region."

NAS-NRC (National Academy of Sciences-National Research Council), 1957. The Disposal of Radioactive Waste on Land. Publication 519. National Academy of Sciences, Washington, D.C.

ABSTRACT p 1, para. 2;
" Disposal in cavities mined in salt beds and salt domes is suggested as the possibility promising the most practical immediate solution of the problem."

Neill, R.H., Channell, J.K., Chaturvedi, L., Little, M.S., Rehfeldt, K., and Spiegler, P. 1983. Evaluation of the Suitability of the WIPP Site. EEG-23. Environmental Evaluation Group, Santa Fe, NM.

EXECUTIVE SUMMARY, p. ii;

" The determination of the suitability of the site for WIPP is only the first major phase in the evaluation of the radiological impact of the repository on the public health and safety. The Environmental Evaluation Group (EEG) will continue to independently review the design of the facility, the operational procedures (including safety criteria and quality assurance), the criteria for packaging and shipment of the waste, the plans, procedures and results of the WIPP experiments, emergency preparedness, adherence to EPA and pertinent NRC regulations, and other important features of the project.

EEG has concluded from existing evidence that the Los Medanos site for the WIPP project has been characterized in sufficient detail to warrant confidence in the validation of the site for the permanent emplacement of approximately 6 million cubic feet of defense transuranic waste. This conclusion is based on the assumption that the maximum surface dose rate for the unshielded remote-handled transuranic waste (RH-TRU) canisters will be 100 rem per hour with a maximum radionuclide concentration of 23 curies per liter as indicated in Table E-3 of the Final Environmental Impact Statement for WIPP. The Site and Preliminary Design Validation (SPDV) program, through the drilling of two shafts to the selected repository level at 2160 feet below the surface and excavation of about 9000 feet of tunnels, has confirmed the interpretations made about the subsurface geological conditions at the site.

For an assessment of the potential radiation effects of the nuclear waste repository on the public health and safety, it is necessary to understand the regional geological and hydrological setting. A large amount of work has been done to understand these conditions and to address several specific issues which have arisen as a result of such studies. However, in an assessment effort of this magnitude, it is almost inevitable that some questions remain unanswered at a given time in the decision-making process. EEG has identified work which still needs to be done at the Los Medanos site in order to improve confidence in the worst case scenario models of possible breaches of the repository. Also, it is anticipated that some of the additional information will be necessary to assure compliance with the EPA standard when it is promulgated."

Newell, N.D., et al. 1953. The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico—A Study in Paleoecology. W.H. Freeman and Co., San Francisco.

Summary, p xiii;

" This is an attempt to determine the environmental conditions under which the celebrated Permian reefs and associate deposits of the southern Guadalupe Mountains were formed. Conclusions are based mainly on original studies of stratigraphy, petrology, primary structures, and paleontology.

Three geologic provinces in the area are characterized by unlike, but stratigraphically equivalent, rocks and fossils: (1) the Delaware Basin, containing drab-to-black limestones and quartz sandstones; (2) the rim of the basin, occupied by organic reefs and banks of light-colored, massive limestone and dolomite; and (3) a shelf area covered by light colored, thin-bedded dolomite, sandstone, and evaporites.

The organic reefs . . ."

Nicholson, Jr., A., and Clebsch, Jr., A. 1961. Geology and Ground-Water Conditions in Southern Lea County, New Mexico. Ground-Water Report 6. State Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p 1;

" Southern Lea County is at the southeastern corner of New Mexico. Most of the area is in the Pecos Valley section of the Great Plains physiographic province; it also includes the southern margin of the Llano Estacado. There are no perennial streams and no throughgoing surface drainage.

Rocks of Quaternary, Tertiary, and Triassic age are exposed and contain the principle aquifers. The most important aquifer is the Ogallala formation, which underlies the Llano Estacado and forms outliers south of it. In large parts of southern Lea County, however, the Ogallala has been removed by erosion and in the low-lying areas Quaternary alluvium, derived principally from the Ogallala formation, has been deposited and is the main aquifer. The two aquifers are continuous in the eastern part of the area. Below the Cenozoic rocks are sandstones and shales of the Dockum group of Late Triassic age, from which small quantities of water are obtained. No usable ground water is obtained from rocks older than the Triassic, but highly saline water is produced along with oil from Paleozoic rocks.

In 1954 about 6,000 acre-feet of ground water were used. Most of this quantity was needed for irrigation and for gasoline plants, in about equal amounts. Economic growth from a rapidly developing petroleum industry has brought about a demand for water for industrial and public supplies that is expected to continue. Development of adequate supplies is hindered by restricted occurrence and low transmissibility of the sediments. Because of the low recharge rate, most of the water pumped is being removed from storage.

The chemical quality of the ground water from the principal aquifers is generally fair to good. Production of large quantities of oil-field brine (3,700 acre-feet in 1955) has created a waste-disposal problem of major importance. Most of the brine has been discharged into surface pits. Leakage from the pits has caused contamination of the shallow water in some areas and unless other disposal methods are used, the problem will spread."

Nielson, J. 1977. An Archaeological Reconnaissance of a Proposed Site for the Waste Isolation Pilot Plant (WIPP). Sandia National Laboratories, Albuquerque, NM.

INTRODUCTION, p 11;

" An archaeological survey was recently completed by the Agency of Conservation Archaeology (ACA), Eastern New Mexico University, in the Los Medaños area southeast of Carlsbad, New Mexico, on lands administered by the Bureau of Land Management. The area surveyed includes an area 4 square miles in size, plus several rights-of-way emanating from the core area. This locality will be impacted by the construction of a nuclear waste disposal facility by Sandia Laboratories.

The survey was initiated at the request of, and under contract with, Sandia Laboratories and was administered by Dr. Melvin Merritt, Dr. George Griswold, Mr. Joe Magruder, and Mr. Earl Cunningham, of Sandia Laboratories, and Dr. J. Loring Haskell, Operations Director and Principle Investigator, Agency of Conservation Archaeology. Antiquity permit 76-NM-003.

The fieldwork was accomplished between June 14 and July 8, 1976, by Jeffrey Nielsen, Winston Hurst, Miles Linnaberry, and Charles Nelson of the Agency of Conservation Archaeology."

NRC (U.S. Nuclear Regulatory Commission). 1974. Guidance on the License Application, Siting, Design, and Plant Protection for an Independent Spent Fuel Storage Installation. Regulatory Guide 3.24, December, 1974.

A. INTRODUCTION;

" An 'independent spent fuel storage installation' (ISFSI) is a self-contained installation for storing spent fuel. It has its own support services and operates independently of any other facility; i.e., it is not a part of either a nuclear power plant or a fuel reprocessing plant. Such an installation is visualized as being capable of storing 1000 tons or more of spent light-water reactor fuel.

Licensed spent fuel storage installations historically have been integrated parts of either fuel reprocessing plants or nuclear power plants. Such plants have been licensed under 10 CFR Parts 30, 40, and 70 in addition to 10 CFR Part 50.

An ISFSI, independent and separate from either a nuclear power plant or a fuel reprocessing plant, would be licensed under Parts 30, 40, and 70. An applicant for a license for an ISFSI meeting the requirements for a Part 70 license would automatically satisfy the requirements for a Part 30 and 40 license. Therefore, a license application for an ISFSI would be reviewed under the requirements of 10 CFR Part 70.

'Licensing and Regulatory Policy and Procedures for Environmental Protection.' 10 CFR Part 51, sets forth the Atomic Energy Commission's policy and procedures for preparing and processing environmental impact statements and related documents pursuant to section 102(2)(C) of the National Environmental Policy Act of 1969 (83 Stat. 852). Certain limitations on the Commission's authority and responsibility pursuant to the NEPA are imposed by the Federal Water Pollution Control Act amendments of 1972 (86 Stat. 816). These limitations are addressed in an Interim Policy Statement published in the Federal register on January 29, 1973 (38 FR 2679).

Regulatory Guide 4.2, 'Preparation of Environmental reports for Nuclear Power Plants,' is generally applicable as a guide for the preparation of an environmental report for an ISFSI. Subjects that are pertinent only to nuclear power plants are obviously not applicable, however, and subjects that are important to an ISFSI, such as spent fuel transportation, should be emphasized.

This guide discusses the license application, site evaluation, design, and plant protection of an ISFSI. It describes the measures acceptable to the Regulatory staff for meeting the requirements of 10 CFR Part 70. In addition, it identifies the information needed by the staff in its evaluation of an ISFSI application."

c. Seismology - Design Earthquake, p. 3.24-6, col. 2, para 2;

" (3) Definition of Design Earthquake

The ISFSI 'design earthquake' is an earthquake event that has a reasonably high probability of occurrence based on studies of historic seismicity and structural geology.

(4) Determination of the Design Earthquake

In evaluating historic seismicity and regional structural geology, the historic

earthquakes identified from the above investigations should be associated with tectonic structures to the extent practical.

If historic earthquake data indicate a high incidence of earthquakes along only a particular portion of a tectonic structure, the probability of similar earthquakes in the future should be assumed uniformly throughout the same segment of the tectonic structure. (Where geologic evidence indicates that the structure is a major, continuous, through-going structure with significant displacement, a more conservative assumption may be appropriate.) These earthquakes should be used in determining the maximum vibratory motion at the site that could be caused by an earthquake related to the tectonic structure.

Correlation of tectonic structure and historic seismicity may not be possible because (a) there is insufficient data or (b) seismicity appears uniform over a network of tectonic structures or cannot be correlated with specific structures. If so, the seismicity should be identified with the tectonic province in which it is reported.

(5) Selection of a Design Earthquake

In view of the limited consequences of seismic events in excess of those used as the basis for seismic design, it appears appropriate that the design earthquake developed from the above information should be such as to have a predicted recurrence interval of about once in a thousand years."

Nuttli, O.W. 1973. The Mississippi Valley Earthquakes of 1811 and 1812--Intensities, Ground Motion and Magnitudes. Seismological Society of America Bulletin. Vol. 63, pp. 227-248.

ABSTRACT, p 227;

" Contemporary newspaper accounts of the 1811-1812 Mississippi Valley earthquakes sequence are used to construct a generalized isoseismal map of the first three principle shocks of the sequence, that of December 16, 1811. The map is characterized by an unusually large felt area, with MM intensities of V as far away as the southeast Atlantic coastal area.

By correlating the isoseismal map with that of recent earthquakes for which ground motion data are available, the body-wave magnitude of the December 16, 1811 earthquake is estimated to be 7.2. The other principle shocks, on January 23, 1812 and February 7, 1812, had estimated m_b values of 7.1 and 7.4, respectively. The total energy released by the principle shocks and their larger-magnitude aftershocks is estimated to be equivalent to that of an $m_b = 7.5$ (or $M_g = 8.0$) earthquake.

The anomalously large areas of damage and of perceptibility of the principle shock result from both the surficial geological conditions of the Mississippi Valley and the relatively low attenuation of surface-wave energy in eastern North America.

Estimates of the vertical component of ground motion, for an earthquake of $m_b = 7.2$ occurring in eastern North America, are given. These include values for particle velocity, displacement, and acceleration at frequencies of about 3, 1 and 0.3 Hz."

Nuttli, O.W. 1973. Seismic Wave Attenuation and Magnitude Relations for Eastern North America. Journal Geophysical Research, Vol. 78, pp. 876-885.

ABSTRACT, p 876;

" Observational data on the attenuation of short-period Rayleigh waves in North America east of the Rocky Mountains yield the following average values for the coefficient of anelastic attenuation: $\gamma=0.07$ deg^{-1} for 1-sec-period waves and $\gamma=0.10$ deg^{-1} for waves with a maximum particle velocity in the period range 3-12 sec. By way of comparison, the amplitude data that form the basis of Richter's empirical local magnitude scale for southern California gives $\gamma=0.60$ deg^{-1}. Differences in γ values are sufficient to explain the observation that earthquakes in the eastern United States have a radius of perceptibility as much as 10 times larger than that of earthquakes of the same magnitude in the western United States. Theoretical curves of log A/T versus log Δ are nor linear. Thus magnitude formulas of the type $M = B + C (\log \Delta) + \log A/T$ are valid only over a limited range of distance, for which the curve can be approximated by a straight line. Formulas of this kind, which give m_σ and M_s from short-period Rayleigh waves, are proposed for eastern North America."

Olive, W.W. 1957. Solution-Subsidence Troughs, Castile Formation of Gypsum Plain, Texas and New Mexico. Geological Society of America Bulletin, Vol. 68.

ABSTRACT, p 351;

" Solution-subsidence troughs are straight narrow depressions ranging in width from a few hundred feet to 1 mile, and in length from about half a mile to 10 miles. The troughs are formed by subsidence of near-surface earth blocks to fill voids dissolved by underground waters moving along subjacent drainage channels parallel to the troughs. Numerous solution-subsidence troughs are developed in the Castile Formation (upper Permian) of the Gypsum Plain in west Texas and southeastern New Mexico where they characteristically have broad relatively flat bottoms, which occupy about two-thirds of the width of the trough. The bottoms are bounded by gentle slopes rising 15-20 feet to narrow straight divides, which stand 2 or 3 feet above the general level of the Gypsum Plain. The troughs trend roughly parallel to the direction of the regional dip, about 1°-2° eastward. Displacement and local folding in strata of the Castile Formation in and near the troughs are not reflected in the Lamar limestone member of the Bell Canyon Formation (lower Permian), which conformably underlies the Castile. The trends of the underground channels are interpreted as the result of solution along eastward-trending joints parallel to the regional dip. Most of the water that causes the solution is believed to be derived by artesian flow from the mountainous area west of the Gypsum Plain."

Orphal, D.L., and Lahoud, J.A. 1974. Prediction of Peak Ground Motion from Earthquakes. Seismological Society of America Bulletin, Vol. 64, pp. 1563-1574.

ABSTRACT, p 1563;

" A statistical analysis shows that the peak horizontal accelerations recorded from the San Fernando earthquake of February 1971 attenuate with focal distance as $R^{-1.39}$. This attenuation rate is nearly identical to that reported for peak accelerations from underground nuclear explosions. Assuming that the derived attenuation is independent of source parameters and using data from a number of other California earthquakes, the scaling of peak horizontal acceleration with magnitude was determined statistically. Assuming that the attenuation of peak velocity and displacement with distance is identical for earthquakes and underground nuclear explosions, the scaling of earthquake peak velocity and displacement with magnitude was also determined. The equations resulting from these analyses are: $a = 6.6 \times 10^{-2}\ 10^{0.40M}R^{-1.39}$, $v = 7.26 \times 10^{-1}\ 10^{0.52M}R^{-1.34}$ and $d = 4.71 \times 10^{-2}\ 10^{0.57M}R^{-1.18}$, where a, v, and d are maximum acceleration (g), velocity (in centimeters per second) and displacement (in centimeters), respectively. M is the local magnitude, and R is the focal distance (in kilometers). In this analysis, no attempt was made to account for effects of recording site geology."

Palmer, A.R. 1983. The Decade of North American Geology 1983 Geologic Time Scale. Geology, Vol. 11, pp. 503-504.

p. 503;
" Preparation of the 27 synthesis volumes of *The Geology of North America* for the Decade of North American Geology (DNAG) is now in progress. In order to encourage uniformity among DNAG authors in the citation of numerical ages for chronostratigraphic units of the geologic time scale, an ad hoc Time Scale Advisory Committee was established by the DNAG Steering Committee in 1982. This advisory committee, consisting of Z.E. Peterman (Chairman) and J. F. Harrison, U.S. Geological Survey; R. I. Armstrong, University of British Columbia; and W. A. Berggren, Woods Hole Oceanographic Institution, was asked to evaluate numerical dating schemes that were either recently published or in press and to provide recommendations for the best numbers to use in preparation of a DNAG time scale. The chart on the opposite side of this page was developed from the recommendations of the Time Scale Advisory Committee."

Powers, D.W. 1995. Tracing Early Breccia Pipe Studies, Waste Isolation Pilot Plant, Southeastern New Mexico: A Study of the Documentation Available and Decision-Making during the Early Years of WIPP. SAND94-0991. Sandia National Laboratories, Albuquerque, New Mexico.

ABSTRACT, p. i;

" Breccia pipes in southeastern New Mexico are local dissolution-collapse features that formed over the Capitan reef more than 500,000 years ago. During early site studies for the Waste Isolation Pilot Plant (WIPP), the threat to isolation by these features was undetermined. Geophysical techniques, drilling, and field mapping were used beginning in 1976 to study breccia pipes. None were found at the WIPP site, and they are considered unlikely to be a significant threat even if undetected.

WIPP documents related to breccia pipe studies were assembled, inspected, and analyzed, partly to present a history of these studies. The main objective is to assess how well the record reflects the purposes, results, and conclusions of the studies from concept to decision-making. The main record source was the Sandia WIPP Central File (SWCF). Documents reviewed ranged from generally available reports (e.g., SAND reports) to individual memoranda and contracting papers.

The history of WIPP breccia pipe studies is relatively clear. After a potash company mined into breccia during 1975, Sandia and U.S. Geological Survey (USGS) personnel began investigating the threat to WIPP. By 1982, a USGS summary report inferred that breccia pipes are restricted to the Capitan reef, which does not underlie the WIPP site. DOE 2 was later drilled at an alleged dissolution feature. Castile Formation salt was deformed, not dissolved; no further breccia pipe studies have been undertaken.

Available records clearly reveal the efforts to investigate breccia pipes. Early records (about 1975 to 1977) are very limited, however, about details of objectives and plans predating any investigation. Drilling programs from about 1977 were covered by a broadly standardized statement of work, field operations plan, drilling history, and basic data report. Generally standardized procedures for peer, management, and quality assurance review were developed during this time. Agencies such as the USGS conducted projects according to internal standards. Records of detailed actions for individual programs may not be available, though a variety of such records were found in the SWCF. A complete written record cannot be reconstructed. With persistence, a professional geologist can follow individual programs, relate data to objectives (even if implied), and determine how conclusions were used in decision-making."

Powers, D.W., and Holt, R.M. 1993. "The Upper Cenozoic Gatuña Formation of Southeastern New Mexico." In Geology of the Carlsbad Region, New Mexico and West Texas, D.W. Love et al., eds., Forty-Fourth Annual Field Conference Guidebook, pp. 271–282. New Mexico Geological Society, Socorro, NM.

ABSTRACT, p 271;

" The Gatuña Formation of southeastern New Mexico has been studied in the field for two landfill projects and the Waste Isolation Pilot Plant project. Shafts, drilling and field mapping reveal the distribution, thickness and sedimentary features of the unit in an area where it was poorly known or assigned to other units. The Gatuña is at least 300 ft thick in the study area. The formation was deposited in the north and east as clastic beds ranging from conglomerates to laminar claystones. Fining upward cycles are common, though depositional features and facies associations are consistent with braided river/stream environments, not meandering rivers. Laminar and thinly bedded siltstones to claystones were deposited in flood plain to playa environments. Pedogenic features superimposed on many fining upward cycles include soil fractures, slickensides, MnO_2, illuviated clay, bioturbation, probable ped structures and desiccation cracks. The upper Gatuña more consistently includes pedogenic development. Beds of poorly indurated 'orange' sand, consisting of rounded and well-sorted grains, are interpreted as eolian deposits. From southern Nash Draw to Orla, the Gatuña is fine-grained and gypsoferous, including displacive crystals and probable subaqueous deposits. These outcrops represent low energy environments, including playas, which were near local base level. The age of the upper Gatuña is reasonably constrained by the Lava Creek B ash (0.6 Ma) within the Gatuña along Livingston Ridge. The age of basal deposits is poorly or not constrained. An ash within probable Gatuña near Orla, TX, is about 13 Ma based on both radiometric and geochemical data. The Gatuña represents an important piece of the geological history of southeastern New Mexico. Further studies could include efforts to better determine the age of the formation; to obtain paleontological data; and to map Gatuña structural relationships to older and younger beds in detail to determine the timing of and spatial evidence for, dissolution of evaporites and collapse of overlying beds, including the Gatuña."

Powers, D.W., and Holt, R.M., 1995. "Regional Geological Processes Affecting Rustler Hydrogeology," Westinghouse Electric Corp, Carlsbad, NM.

NOTE: Figure 6 is on the following page of this document.

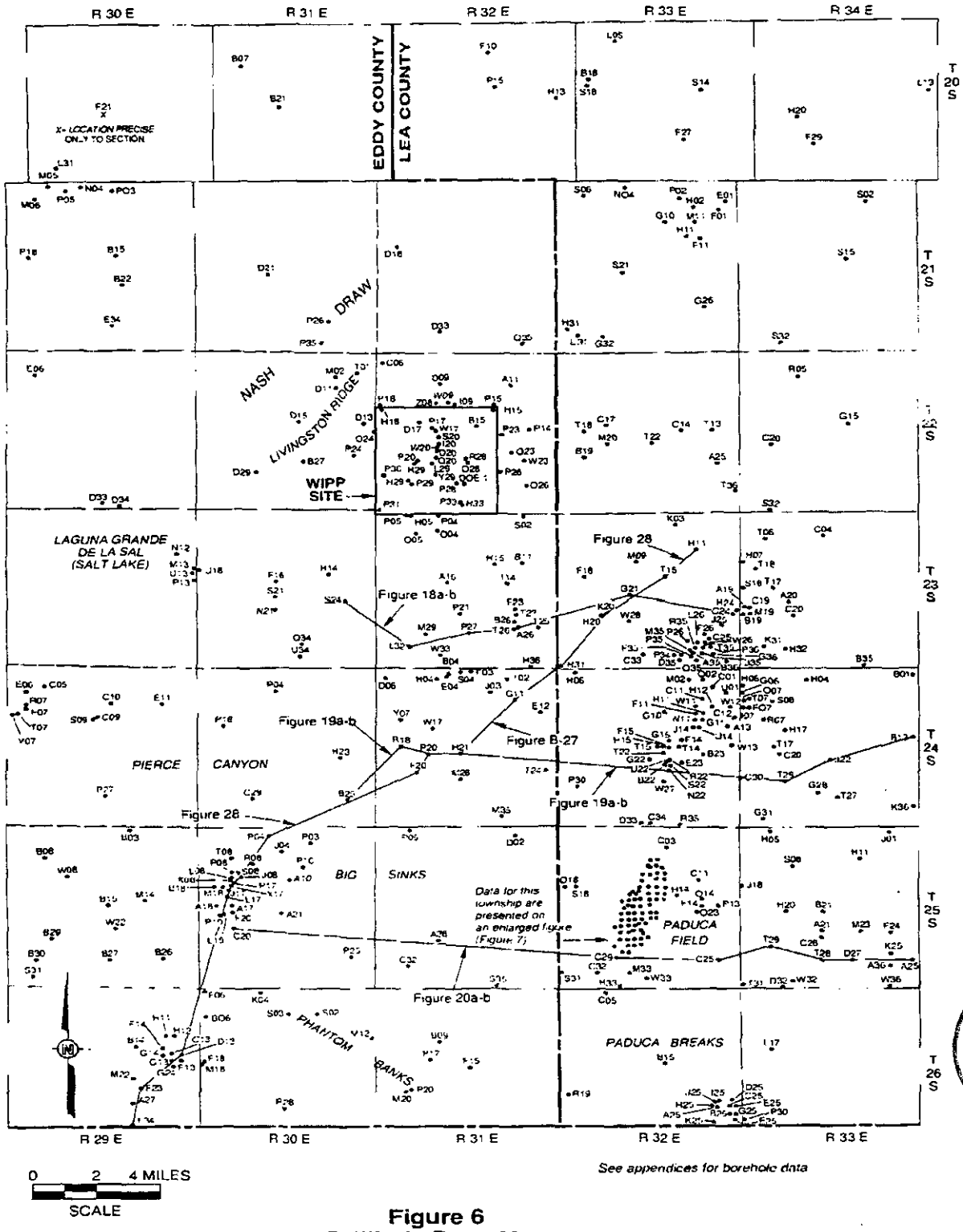

Figure 6
Drillhole Base Map

Powers, D.W., and LeMone, D.V. 1987. A Summary of Ochoan Stratigraphy, Western Delaware Basin. Guidebook 18, pp. 63-68. El Paso Geological Society.

ABSTRACT, p 63, col 1;
" Four formations comprise the Ochoan Series of the northern Delaware Basin. They are, in ascending order, the Castile, Salado, Rustler, and Dewey Lake formations. Boundaries within the series all appear to be transitional, though the uppermost boundary is an erosional unconformity. The faunal evidence for age is very limited, and the regional and broader correlations are for the most part problematical."

Powers, D.W., and Martin, M.L. 1993. A Select Bibliography with Abstracts of Reports Related to Waste Isolation Pilot Plant (WIPP) Geotechnical Studies (1972–1990). SAND92-7277. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" This select bibliography contains 941 entries. Each bibliographic entry contains the citation of a report, conference paper, or journal article containing geotechnical information about the Waste Isolation Pilot Plant (WIPP). The entries cover the period from 1972, when investigations began for a WIPP Site in southeastern New mexico, through December 1990.

Each entry is followed by an abstract. If an abstract or suitable summary existed, it has been included; 316 abstracts were written for other documents. For some entries, an annotation has been provided to clarify the abstract, comment on the setting and significance of the document, or guide the reader to related reports. An index of key words/phrases is included for all entries."

Powers, D.W. and Holt, R.M. 1990. Sedimentology of the Rustler Formation Near the Waste Isolation Pilot Plant (WIPP) Site. pp. 77-106. GSA Field Trip #14. Geological Society of America 1990 Annual Meeting. October 29-November 1, 1990. Dallas, TX.

Section Regional Relationships, p 100, col 1, para 7;
" About 600 geophysical logs (natural gamma and acoustic) of the Rustler Formation were interpreted to understand the regional relationship between various units (Holt and Powers, 1988; Powers and Holt, in prep.). Geophysical logs near the site were carefully compared to lithofacies described from cores and shafts, easily relating many subdivisions. Several extended cross-sections were drafted to show lateral relationships in some detail (Holt and Powers, 1988). Structure contour and isopach maps for different units were drafted and compared. . . ."

Register, J.K., and Brookins, D.G. 1980. Rb-Sr Isochron Age of Evaporite Minerals from the Salado Formation (Late Permian), Southeastern New Mexico. Isochron/West, 29, pp. 39-42.

p. 39;

" The bedded evaporites of southeastern New Mexico have been extensively studied in conjunction with potash deposit exploration, and, more recently, for consideration for a Waste Isolation Pilot Plant (WIPP) for radioactive waste disposal. An important facet of the latter study is the chemical and isotopic integrity of the evaporite minerals. Experience elsewhere with evaporite minerals (see discussion in Brookins and others, 1980) suggests post-formational, open-system conditions resulting in anomalously young ages for both halide and sulfate minerals by the K-Ar and Rb-Sr methods. Many of these young dates elsewhere (i.e. Federal Republic of Germany) have been attributed to metamorphic events or, alternatively, to both episodic and/or continuous loss of radiogenic ^{40}Ar and ^{87}Sr by unspecified, though subtle, events. Tremba (1969) and Bodine (1978) have suggested episodic and continuous recrystalization events for the southeastern New Mexico evaporites.

It is the purpose of this report to present our Rb-Sr isochron findings for 41 samples including sylvite-halite rich mixtures, polyhalite-rich samples, and anhydrites. The locations are given in Table 1, the data in Table 2, and the mineralogy in Table 3. Figure 1 shows the isochron. Sample procedures are given in Register (1979). The decay constant of 1.42 x $10^{-11}y^{-1}$ was used, and the York (1969) method for isochron construction was employed."

Reilinger, R., Brown, L., and Powers, D. 1980. New Evidence for Tectonic Uplift in the Diablo Plateau Region, West Texas. Geophysical Research Letters, Vol. 7, No. 3.

ABSTRACT, p. 181;

" Recent releveling measurements conducted by the National Geodetic Survey in West Texas and southeastern New Mexico indicate uplift of the Diablo Plateau-Salt Basin region relative to benchmarks to the northeast in the Great Plains. These new measurements confirm and enhance the previously reported interpretations of releveling data in this area. Total relative uplift measured between 1934 and 1977 reaches 19 $\pm$ 3 cm. Combining this new information with leveling data from 1934, 1943, and 1958 along this same route indicates that: (1) the uplifted area extends 120 km in the east-west direction (there is presently no control on any north-south component of tilting), with maximum relative uplift occurring approximately 12 km west of the boundary between the Diablo Plateau and Salt Basin graben; and (2) on the time scale between measurements ($\sim$20 yrs.), uplift appears to be occurring more or less continuously, although not at a constant rate. The progressive deformation indicated by the releveling measurements, the large magnitude relative to possible leveling errors, and the spatial dimensions of the uplift rule out systematic errors or near-surface effects (water table variations, sediment compaction, etc.) as an explanation and favor a tectonic origin. Intracrustal magmatic activity of some form of preseismic deformation (dilitancy, fault creep at depth, etc.) appear to be the most reasonable explanations in view of presently available geologic and geophysical information.

The pattern of uparching is perturbed at the Salt Basin graben, indicating 4.2 $\pm$ 0.3 cm of subsidence relative to its margins between 1958 and 1977. This subsidence could be related to the regional tectonic uparching, although near-surface, non-tectonic effects cannot be excluded."

Reiter, M. Barroll, M.W., and Minier, J. 1991. "An Overview of Heat Flow in Southwestern United States and Northern Chihuahua, Mexico." In Neotectonics of North America, D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 457-466. Geological Society of America, Boulder, CO.

The Rio Grande rift and northern Chihuahua, Mexico, p. 463, col. 1, para. 2;
" In the southern part of the Rio Grande rift there are a few heat-flow measurements and estimates that are intermediate in value (about 70 to 80 mW m_{-2}); most of the data are above the average heat flow (89 mWm_{-2}) for the entire Basin and Range Province (Fig. 7, bottom; see also Plate 1 in Reiter and others, 1986). Between Socorro and Las Cruces there are eight sites where the heat-flow estimates are about 90 to 100 mW m_{-2}. Four of the sites are located in the northern part of the Jornada del Muerto, north of the Jornada Basin. The other four sites are scattered widely. Higher heat-flow estimates (117 to 135 mW m_{-2}) are also made at sites scattered over the region from Socorro to Las Cruces. From these data it is suggested that the regional or background heat flow for the rift area between Socorro and Las Cruces is about 95 mW m_{-2}, a value that closely agrees with the interpretation of previous data by Decker and Smithson (1975). It is also interesting to note that the mean of 15 measurements in extreme southwest New Mexico is 94 $\pm$ 21 mW m_{-2}. Some of the sites with higher heat-flow estimates in the southern Rio Grande rift (117 to 135 mW m_{-2}) are near large normal faults that may act as conduits for hydrothermal circulation to enhance geothermal gradients; but again the actual cause of the elevated geothermal gradients is generally ambiguous . . ."

Richey, S.F. 1989. Geologic and Hydrologic Data for the Rustler Formation Near the Waste Isolation Pilot Plant, Southeastern New Mexico. Open-File Report 89-32. U.S. Geological Survey, Albuquerque, NM.

ABSTRACT, P 1;

" The U. S. Geological Survey is investigating the geohydrology in the vicinity of the Waste Isolation Pilot Plant in southeastern New Mexico. Data presented in this report were compiled in support of a regional ground-water flow model. The data include water-level measurements obtained from the U. S. Geological Survey's Ground-Water Site-Inventory and OMNIANA data bases and stratigraphic information interpreted from commercial geophysical logs."

DATA PRESENTED, p. 3;

" Data presented in the water-level table (table 1) include well identifier and name, well location, water-bearing unit, land-surface altitude, total well depth, date of water-level measurement, and water level. These data were obtained from two U.S. Geological Survey data bases. The Ground-Water Site-Inventory data base (GWSI) is a national data base for storing site and water-level data. OMNIANA is an older data base used by the Survey for the same purpose; the data currently are being transferred to GWSI. Accuracy of land-surface altitude in GWSI and OMNIANA is unknown because they generally were obtained by locating the wells on topographic maps of various scales.

Data presented in the stratigraphic information table (table 2) include well identifier and name, well location, land-surface altitude at the well, total well depth, and stratigraphic depths to top, which were interpreted from commercial geophysical logs by C.L. Jones and R.P. Snyder of the Survey's Geologic Division. Well name, location, datum altitude, and total well depth usually were obtained from the log headers, and their accuracies are dependent on the drilling and logging companies. Occasionally the datum on a log was missing or ambiguous, in which case the land-surface altitude was obtained from a 1:24,000-scale Survey topographic map. A correction for kelly bushing was added when necessary."

Robinson, T.W., and Lang, W.B. 1938. Geology and Ground-Water Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal, New Mexico, With Special Reference to the Salt Content of the River Water. Twelfth and Thirteenth Biennial Reports of the State Engineer Engineer of New Mexico for the 23rd, 24th, 25th, and 26th Fiscal Years, July 1, 1934 to July 30, 1938. State Engineer, Santa Fe, NM.

INTRODUCTION, p 79;

" At the request and in cooperation with the State Engineer of New Mexico, a study of ground-water conditions in the Pecos River Valley southeast of Carlsbad, Eddy County, New Mexico, has been under way since the spring of 1937. The results of that study are presented in this report. The area involved lies largely in Townships 21, 22, 23 and 24 south, Ranges 26, 27, 28 and 29 east, New Mexico principle meridian. (See plate 1). Intensive work was done chiefly in the vicinity of the Laguna Grande de la Sal and the area lying between it and the Malaga Bend of the Pecos River, about five miles south. The area is crossed by the Pecos River flowing southeastward from Carlsbad. During the growing season, the entire flow of the Pecos River above Carlsbad is normally diverted for irrigation at Lake McMillan and Lake Avalon. During this period the Pecos River from Carlsbad south is fed chiefly by large springs. The largest spring, known as Carlsbad Spring, is located in the river channel just below Lake Avalon. The Black River enters the area from the west and flows eastward to its confluence with the Pecos River northeast of Malaga. It is also spring-fed, deriving most of its water from Blue Spring and Castle Spring, near Black River village. The drainage pattern is well developed on the west, and during rainy periods many normally dry arroyos and draws discharge flood water into the Pecos River. Drainage from the east is by poorly developed draws which carry water to the Pecos only during exceptionally heavy rainfall. A prominent feature east of the river is Laguna Grande de la Sal, which is a shallow salt lake in a playa covering about 3½ square miles.

Carlsbad, the largest town in the area and the county seat of Eddy County, had a population of 3,708 in 1930. However, owing largely to the development of the potash mines located about 20 miles east, the population in 1938 is about double that of 1930. Loving, located about 12 miles south, and Malaga, about 18 miles south of Carlsbad, each had less than 1,000 inhabitants in 1930. Carlsbad is served by the Atchison, Topeka, and Santa Fe Railroad and by main highways leading north to Roswell, New Mexico, southwest to El Paso, Texas, south to Pecos, Texas, and east to Hobbs, New Mexico.

Cotton and hay are raised in the irrigated section along the Pecos River, while cattle, sheep and goat raising predominate in the unirrigated upland areas to the east and west. The principle mineral industry is the mining and refining of potash. A large number of tourists are attracted annually to the famous Carlsbad Caverns, located about 25 miles southwest of Carlsbad, near the highway leading to El Paso, Texas.

A group of farmers who pump water from the river for irrigation report that in recent years the water, because of its salinity, has been injurious to their cotton crop. In September 1932 the U.S. Potash Company began operations, using the Laguna Grande de la Sal as a disposal area for the waste brine from their potash refining operations. The reported

difficulty with salt, shortly after refinery operations began, naturally cast suspicion on the brine in the Laguna Grande. There is no visible outlet from the Laguna Grande, and therefore the problem arose as to whether the lake brine may be percolating underground to the Pecos River.

A study of the chemical character of the water of the Pecos River has been made by C.S. Howard and W.F. White, Jr., and numerous analyses were made of the surface and ground waters in this area (see report on chemical character of Pecos River under 'Quality of Water,' to be found elsewhere in this volume). The ground-water studies by T.W. Robinson were begun on April 13, 1937, and the geologic studies by W.B. Lang on October 15, 1937."

Salvador, A. 1985. Chronostratigraphic and Geochronometric Scales in Colorado SUNA Stratigraphic Correlation Charts of the United States. American Association of Petroleum Geologists Bulletin, Vol. 69.

INTRODUCTION, p 181, col 1;

" During 1976, the American Association of Petroleum Geologists undertook the ambitious task of preparing a new set of stratigraphic correlation charts for the United States. The project named 'Correlation of Stratigraphic Units of North America,' or COSUNA for short, was as needed as it was ambitious. The last comprehensive set of stratigraphic correlation charts had been published by the Geological Society of America between 1942 and 1960. The charts were in urgent need of revision.

Otis E. Childs accepted the post of project director, and a Steering Committee was created that included representatives from the American Association of Petroleum Geologists, Association of American State Geologists, U.S. Geological Society, American Association of Stratigraphic Palynologists, North American Commission on Stratigraphic Nomenclature, JOIDES Planning Committee, Geological Society of America, and Society of Economic Paleontologists and Mineralogists. Grant Steele served as chairman of the Steering Committee for the entire life of the project. To advise the project director on technical matters, a Stratigraphic Technical Committee also was established.

The United States was divided into appropriate geologic provinces, and . . ."

Sandia National Laboratories. 1992. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 3: Model Parameters. SAND92-0700/3. Sandia National Laboratories, Albuquerque, NM.

Volume 3
Section 1.3.2 Construction of Distributions, p 1-15;
" The steps below describe the procedure developed by the PA Department to construct probability distributions (CDFs) for the uncertain parameters in consequence and probability models (Figure 1.3-1)(modified from Tierney, 1990).
STEP 1 Determine whether site-specific data for the parameter in question exist, i.e., find a set of site-specific sample values for the parameter. Data and information are usually either documented in a formal report or are described in an internal memorandum (see Appendix A). If data sets exist, go to Step 3; if no data sets are found, go to Step 2.
STEP 2 Request that the investigator supply a specific shape (e.g., normal, lognormal) and associated numerical parameters for the distribution of the parameter. If the investigator assigns a specific shape and numerical values for the distribution's parameters, go to Step 5; if the investigator cannot assign a specific shape and appropriate parameters, go to Step 4. In responding to this request, the investigator may use his or her knowledge of global data to form an answer. Distributions supplied by investigators may be documented by a memorandum (see Appendix A).
STEP 3 Determine the size of the combined data sets. If the number of values in the combined data set is > 3, use the combined data to construct a piecewise-linear cumulative distribution function or, alternatively, a discreet cumulative distribution function, and then go to Step 5. If the number of variables in the combined data set is ≤ 3, go to Step 4.
STEP 4 Request that the investigator provide subjective estimates of (a) the range of the variable (i.e., the minimum and maximum values taken by the variable with at least 99% confidence and preferably 100% confidence) and (b) if possible, one of the following (in decreasing order of preference): (1) percentile points for the distribution of the variable (e.g., the 25th, 50th [median], and 75th percentiles), (2) the mean value and standard deviation of the distribution, or (3) the mean value. Again, in responding to this request, the investigator may use his or her knowledge of global data to form an answer and may document that answer in a memorandum (see Appendix A). Then, using the maximum entropy formulation (MEF), construct one of the following distributions depending upon the kind of subjective estimate that has been provided (Tierney, 1990; Harr, 1987):

- Uniform probability distribution function (PDF) over the range of the variable,
- Piecewise-linear cdf based on the subjective percentiles,
- Exponential pdf (truncated) based on the subjective range and mean value,
- Normal pdf based on subjective mean value and standard deviation.

Then go to Step 5.
STEP 5 End of procedure; distribution is assigned. Computational considerations and limitations on the data itself may require later modification to some distributions. Some of these limitations are discussed in the next section."

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1982. Basic Data Report for Drillhole WIPP 12 (Waste Isolation Pilot Plant—WIPP). SAND82-2336. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

ABSTRACT, p 1;

" WIPP 12 is a borehole drilled in eastern Eddy County, New Mexico, to investigate the stratigraphy, structure and lithology in the WIPP area. WIPP 12 was drilled in section 17, T22S,R31E, between November 9 and December 7, 1978. The hole was drilled to a depth of 2785.8 ft. It encountered from top to bottom, 16.2 ft of sand, 3 ft of Mescalero Caliche and 9.6 ft of the Gatuna Formation, all of Quaternary age; 138.2 ft of the Triassic Santa Rosa Formation, 483 ft of the Dewey Lake Red Beds, 326 ft of the Rustler Formation, 1771.5 ft of the Salado Formation, and 48.3 ft of the Castile Formation, all of Permian age. Cores or cuttings were obtained for the entire hole. A suite of geophysical logs, including neutron gamma and density curves, was run to the full depth of WIPP 12. The borehole demonstrated that the elevation of the top of the Castile is about 160' above the same horizon in ERDA 9.

The WIPP is a demonstration facility for the disposal of transuranic (TRU) waste from defense programs. The WIPP will also provide a research facility to investigate the interactions between bedded salt and high level wastes."

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1982. Basic Data Report for Drillhole WIPP 14 (Waste Isolation Pilot Plant—WIPP). SAND82-1783. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 1;

" Borehole WIPP 14 is an exploratory well drilled in eastern Eddy County, New Mexico, in section 9, T22S,R31E. The borehole was drilled to a depth of 1000.0 ft measured from ground level. It penetrates, from top to bottom, 15.4 ft of Quaternary sands, 125.6 ft of the Triassic Santa Rosa Sandstone, and in the Permian strata, 497.7 ft of the Dewey Lake Red Beds, 312.9 ft of the Rustler Formation and 48.4 ft of the Upper Salado Formation. Seven hundred feet of the well were cored, at consecutive and nonconsecutive 10-ft intervals to a depth of 925.5 ft. Cuttings were collected where core was not taken. Density, gamma ray neutron and caliper logs were run the full depth of the hole.

The WIPP is a demonstration facility for the disposal of transuranic (TRU) waste from defense programs. The WIPP will also provide a research facility to investigate the interactions between bedded salt and high level wastes."

Sandia National Laboratories and D'Appolonia Consulting Engineers. 1983. Basic Data Report for Drillhole ERDA 10 (Waste Isolation Pilot Plant—WIPP). SAND79-0271. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 1;

" Borehole ERDA 10 was drilled to obtain information on possible dissolution of halite within the Castile Formation and on the hydrologic characteristics of the fluid-bearing zones in the Bell Canyon Formation. The borehole is located in Section 14, T22S,R30E in southern Eddy County, New Mexico. ERDA 10 was drilled to a depth of 4431.5 feet. Cores from the Castile were taken to obtain direct information which was supplemented by geophysical logging. Based on preliminary analysis of the data, the ERDA 10 stratigraphic section is interpreted as a sequence of sandstones, siltstones, claystones, and evaporites normal for the area. No evidence of dissolution of significant amounts of halite was observed."

Sandia National Laboratories and UNM (University of New Mexico). 1981. Basic Data Report for Drillhole WIPP 15 (Waste Isolation Pilot Plant - WIPP). SAND79-0274. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 1;

" WIPP 15 is a borehole drilled in March, 1978, in section 18, T.23S., R. 35E. of south-central Lea County. The purpose of WIPP 15 was to examine fill in San Simon Sink in order to extract climatic information and to attempt to date the collapse of the sink. The borehole was cored to total depth (810.5 feet) and encountered, from top to bottom, Quaternary calcareous clay, marl and sand, and claystones and siltstones of the Triassic Santa Rosa Formation (?). Neutron and gamma ray geophysical logs were run to measure density and radioactivity.

The sink has about 547 feet of Quaternary fill indicating subsidence and deposition. Diatomaceous beds exposed on the sink margin yielded samples date by ^{14}C at 20,570 $\pm$ 540 years BP and greater than 32,000 years BP; these beds are believed stratigraphically equivalent to diatomaceous beds at 153-266 feet depth in the core. Aquatic fauna and flora from the upper 98 feet of core indicate a pluvial period (probably Tahokan) followed by an arid or very arid time before the present climate was established.

Aquifer pump tests performed in the Quaternary sands and clays show transmissivities to be as high as 600 feet squared per day. As the water quality was good, the borehole was released to the lessee as a potential water well."

Sandia National Laboratories and USGS (U.S. Geological Survey). 1979. Basic Data Report for Drillhole WIPP 13 (Waste Isolation Pilot Plant - WIPP). SAND79-0273. Sandia National Laboratories, Albuquerque, NM.

Section 1.0 ABSTRACT, p 1;

" The borehole WIPP-13 was drilled in the SW 1/4 section 17, T22S, R31E of eastern Eddy County during July and August, 1978, to investigate the nature of a resistivity anomaly. The stratigraphic section was normal, consisting of 13 feet of Quaternary deposits (including artificial fill for drill pad), 53 feet of the Triassic Santa Rosa Sandstone, 451 feet of Dewey Lake Red Beds, 269 feet of the Rustler Formation, and 179 feet of the upper member of the Salado Formation. Consecutive cores were taken from 570 to 595, 656 to 729, and 827 to 878 feet. Cuttings were collected at 10-foot intervals throughout the rest of the hole. Geophysical logs were run to aid in interpretation of the stratigraphy.

The WIPP is to demonstrate (through limited operations) disposal technology for transuranic (TRU) defense wastes. Eventual conversion of the facility to a repository for TRU defense wastes is anticipated. The WIPP will also provide research facilities for interactions between high-level waste and salt."

Sandia National Laboratories and USGS (U.S. Geological Survey). 1980. Basic Data Report for Drillhole WIPP 18 (Waste Isolation Pilot Plant—WIPP). SAND79-0275. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" WIPP 18 is an exploratory borehole whose objective is to determine the nature of the near-surface formations after seismic information indicated a possible fault. The borehole is located in section 20, T.22S., R.31E., in eastern Eddy County, New Mexico and was drilled between March 14 and 30, 1978. The hole was drilled to a depth of 1060 feet and encountered, from top to bottom, surficial Holocene deposits (5', including artificial fill for drill pad), the Mescalero caliche (4'), the Santa Rosa Sandstone (129'), the Dewey Lake Red Beds (475'), the Rustler Formation (315'), and the upper portion of the Salado Formation (132'). Cuttings were collected at 10-foot intervals. A suite of geophysical logs was run to measure acoustic velocities, density, and radioactivity. On the basis of comparison with other geologic sections drilled in the area, the WIPP 18 section is a normal stratigraphic sequence and it does not show structural disruption.

The WIPP is to demonstrate (through limited operations) disposal technology for transuranic defense wastes. The WIPP will also provide facilities to research interactions between high-level waste and salt."

Sandia National Laboratories and USGS (U.S. Geological Survey). 1980. Basic Data Report for Drillhole WIPP 32 (Waste Isolation Pilot Plant - WIPP). SAND80-1102. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 4;

" WIPP 32 is an exploratory borehole drilled to examine the subsurface at a small topographic high in Nash Draw. The borehole is located in east-central Eddy County, New Mexico, in NE 1/4 SE 1/4 Sec. 33, T.22S., R.29E. and was drilled in August, 1979. The hole was drilled to a depth of 390 feet, and encountered, from top to bottom, the Rustler Formation, (166') and the upper Salado Formation (224'). Core was taken from 4 to 353 feet. Geophysical logs were run the full length of the hole to measure formation properties.

The WIPP is to demonstrate (through limited operations) disposal technology for transuranic defense wastes. The WIPP will also provide facilities to research interactions between high-level waste and salt."

Sandia National Laboratories and USGS (U.S. Geological Survey). 1981. Basic Data Report for Drillhole WIPP 33 (Waste Isolation Pilot Plant—WIPP). SAND80-2011. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 1;

" WIPP 33 is an exploratory borehole to investigate the nature of unusually thick fill material in the northwest portion of the WIPP site; a breccia pipe was considered a possibe, (sic) though unlikely, cause of the fill. The borehole is located in Section 13, T22S, R30E, in east central Eddy County, New Mexico and was drilled during July, 1979. The hole was drilled to a depth of 840 feet, and encountered, from top to bottom, surficial Holocene deposits (44' including artificial fill for drill pad), the Dewey Lake Red Beds (357'), the Rustler Formation (276') and the upper portion of the Salado Formation (163'). Selected intervals were cored, and cuttings were taken for examination by geologists. Geophysical logs were taken the full length of the borehole to measure radioactivity, resistivity and density. The stratigraphic profile was found to be normal, and no breccia was observed."

Sandia National Laboratories and USGS (U.S. Geological Survey). 1982. Basic Data Report for Drillhole WIPP 11 (Waste Isolation Pilot Plant—WIPP). SAND79-0272. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 1;

" Seismic reflection data from petroleum industry sources showed anomalous reflectors in the Castile Formation over a small area about 3 miles north of the center of the Waste Isolation Pilot Plant (WIPP) site. Additional corroborative seismic reflection data were collected as part of WIPP investigations, and WIPP 11 was drilled to investigate the anomaly. WIPP 11 was drilled near the northwest corner of Section 9, T.22.S., R.31E. it penetrated, in descending order, sand dune deposits and the Gatuna Formation (29'), Santa Rosa Sandstone (132'), Dewey Lake Red Beds (502'), Rustler Formation (288'), Salado Formation (1379'), and most of the Castile Formation 1240'). Beds within the lower part of the Salado, and the upper anhydrite of the Castile, are thinner than normal; these beds are displaced upward structurally by the upper Castile halite which is highly thickened (about 968'). The lowest halite is thin (51') and the basal anhydrite was not completely penetrated. Subsequent seismic and borehole data has shown WIPP 11 to be in a structural complex now identified as the 'disturbed zone.'

The WIPP is a demonstration facility for the disposal of transuranic (TRU) waste from defense programs. The WIPP will also provide a research facility to investigate the interactions between bedded salt and high level waste, though there are no plans at this time to dispose of high level waste or spent fuel at WIPP."

Sanford, A., Sandford, S., Wallace, T., Barrows, L., Sheldon, J., Ward, R., Johansen, S., and Merritt, L. 1980. Seismicity in the Area of the Waste Isolation Pilot Plant (WIPP). Report by the New Mexico Institute of Mining and Technology to Sandia National Laboratories. SAND80-7096. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 1;

" The Rio Grande rift zone is the most probable area of New Mexico to have substantial seismic activity. The principal data used in establishing the seismicity of this region were: (1) reports of strong earthquakes before 1960, (2) instrumental studies of moderate shocks ($M_L > 2.7$) after 1960, (3) analyses of microearthquakes ($M_L < 2.7$) recorded at Albuquerque, Socorro, and Las Cruces, and (4) analysis of fault scarps offsetting the Quaternary geomorphic surfaces in the Socorro area.

Historical reports indicate a moderately high seismic risk in a zone from Albuquerque to Socorro. In this region, particularly near Socorro, the largest shock in a 100-year period is likely to be magnitude 6. Instrumental data on earthquakes ($M > 2.7$) since 1960 show that activity is highest near Socorro and Las Cruces. However, estimated seismic risk from these data is low, with a maximum magnitude shock of about 5 each 100 years over the entire extent of the rift zone. Analyses of microearthquakes ($M_L < 2.7$) also lead to low estimates of seismic risk in the rift zone, e.g. a maximum magnitude shock of 4.6 in the Socorro-Bernardo region each 100 years.

Historical reports, spanning a century, are probably more reliable indicators of seismic risk than the relatively short-term instrumental data spanning only about a decade. The historical data indicate probability of a magnitude 6 earthquake each 100 years. Both categories of data indicate seismic risk is not uniform and is greatest in the following regions: (1) Socorro-Bernardo, (2) Albuquerque-Belen, and (3)El Paso-Las Cruces.

In the region of highest seismic risk, Socorro-Bernardo, little direct correlation exists between the distribution of microearthquakes and faults. Analyses of data for faults offsetting recent geomorphic surfaces indicates seismic activity has been occurring in the Socorro-Bernardo region for thousands of years. Estimates of seismicity based on the fault scarps cover a fairly wide range because of the uncertainty in the age of the scarps. However, the most reasonable estimates for the age yield seismicity values comparable to those calculated from earthquake data."

Sanford, A.R., and Toppozada, T.R. 1974. Seismicity of Proposed Radioactive Waste Isolation Disposal Site in Southeastern New Mexico. New Mexico Bureau of Mines and Mineral Resources, Circular 143, pp. 1-15.

ABSTRACT, p. iv;

" Seismicity was determined for the area within a 300-km radius from the proposed nuclear waste disposal site in southeastern New Mexico. The primary data used to establish seismic risk were: reports of felt shocks prior to 1961; instrumental epicenters and magnitudes from 1961 through 1972; and lengths, displacements, and ages of fault scarps cutting Quaternary geomorphic surfaces. The principle results of this study were: 1) earthquakes exceeding local magnitude 3.5 have not occurred within 40 km of the site in the past 12 years; probably not in the past 50 years, 2) on the average of once every 50,000 years major earthquakes (magnitude 7.8) are possible within 115 km of the site, but these events will produce accelerations of only about 0.07 g at the site; and 3) some evidence indicates that earthquakes located on the Central Basin Platform, 80 to 100 km southeast of the site, could be related to water injection for secondary recovery of oil."

Sanford, A.R., Toppozada, T.R., Ward, R.M., and Wallace, T.C. 1976. The Seismicity of New Mexico 1962 through 1972. Geological Society of America Abstracts with Programs, Vol. 8, p. 625.

ABSTRACT, p. 626;

" Epicenters and magnitudes have been determined for 183 earthquakes that occurred within or bordering New Mexico from January 1, 1962 through 1972. The crustal model used for earthquake locations consisted of a 42 km thick layer with a velocity of 6.15 km/sec overlying a semi-infinite layer with a velocity of 8.10 km/sec. Because of the small number of seismograph stations, Pg arrivals beyond the crossover distance were used in the location procedure, a computer adaptation of the arc method. Locations obtained are believed to be better than ± 15 km in nearly all cases.

The majority of seismic activity appears to follow two broad belts. One belt extends southwestward from the northeast corner of New Mexico across the Rio Grande valley to the vicinity of Grants and then southward to the Silver City area. This diffuse zone of epicenters may be associated with Late Cenozoic volcanics. The other belt of seismicity follows the Rio Grande valley which has been an active rift structure since Miocene time. Shocks with $M_L \geq 3.4$ have also occurred in the High Plains and the Colorado Plateau.

Recurrence rates have been calculated for regions of 697,000, 311,000, 125,000, and 49,000 sq. km centered on stations located at Socorro and Albuquerque. The maximum Magnitude earthquakes/100 years/100,000 sq. km for the four areas are 5.1, 4.7, 4.7, and 5.1 respectively. These levels of seismic activity are less than 1/100 of that observed in Southern California."

Sanford, A.R., Jaksha, L.H., and Cash, D.J. 1991. "Seismicity of the Rio Grande Rift in New Mexico." In Neotectonics of North America. D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 229-244.

GENERAL FEATURES OF RIO GRANDE RIFT SEISMICITY, p. 230, col. 1, para. 2;

" Starting about 10 years ago, geophysical data began to accumulate that indicated that the RGR boundaries could be extended beyond those proposed by Chapin (1971) in Figure 1. Cordell (1978) summarized geophysical evidence for a broad astenospheric-lithospheric structure centered beneath the chain of grabens shown in Figure 1. Cordell found that the main feature of east-west gravity profiles through New Mexico is a broad negative Bouguer anomaly centered roughly on the axis of the rift. According to Cordell (1978), the anomaly is a consequence of subcrustal structure related to a Rio Grande rift system, which includes a broad uplifted region as well as the obvious grabens and basins usually considered to be RGR. The width of the anomaly appears to be at least 500 km along the New Mexico-Colorado border and broadens progressively to the south. Thus, the gravimetric signature of the rift system, and possibly the structure that produced it, extends beneath the presumably stable Colorado Plateau and Great Plains Provinces, well beyond Chapin's boundaries of the rift shown in Figure 1.

Other geophysical observations support the existence of a broad astenospheric-lithospheric structure beneath the RGR. Davis and others (1984) found a traveltime residual anomaly for teleseismic P-wave arrivals along a profile crossing the RGR. The anomaly has a maximum delay of 1.5 seconds and an east-west extent of approximately 340 km, of which about 60 km underlies the Colorado Plateau and about 70 km underlies the Great Plains.

Shown in Figure 2 is a magnetic map for New Mexico based on the composite magnetic anomaly map of the United States by Taylor and others (1983). The broad north-south-oriented low that appears to be associated with the RGR is one of the strongest and most clearly defined in the conterminous United States. The boundaries for this anomaly are somewhat subjective but clearly fall beneath the Colorado Plateau and the Great Plains and well beyond the maximum boundaries of the RGR in Figure 1.

Gable and Hatton (1983) presented geologic evidence for surface uplift during the past 10 m.y. over a broad region centered on the RGR (Fig, 3). The general character of the uplift extends uninterrupted north through Colorado and south-southeast through west Texas. The east-west extent and generally north-south orientation of the uplift suggests a relation between it and the asthenospheric-lithospheric structures underlying it.

On the basis of geophysical, topographical, and geological information, Eaton (1986) concluded that the Southern Rocky Mountains extend southward through the entire length of New Mexico. Accordingly, the broad geophysical anomalies and surface uplift described above are the signature of the Southern Rocky Mountains, and the RGR is a system of axial grabens along this major north-trending structure."

Saulnier, Jr., G.J., and Avis, J.D. 1988. Interpretation of Hydraulic Tests Conducted in the Waste-Handling Shaft at the Waste Isolation Pilot Plant (WIPP) Site. SAND88-7001. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p ii;

" A series of sub-horizontal boreholes from 8- to 41-feet deep were drilled from four depth levels in the waste-handling shaft at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The waste-handling shaft is one of three shafts built at the WIPP site to provide surface access to the underground waste repository under construction 2150 feet below the ground surface. The boreholes were drilled at the 782- and 805-foot depth levels in a mudstone and a claystone of the unnamed lower member of the Rustler Formation; at the 850-foot depth level in bedded halite in the upper Salado Formation; and at the 1350-foot depth level in halite, anhydrite, and polyhalite of the Salado Formation. Examination of the cores recovered from one borehole at each level indicated no direct evidence of construction-induced fracturing. Pulse-injection tests were conducted in packer-isolated intervals in six of the boreholes to estimate the formation's hydraulic conductivity and apparent formation pressure, and to determine whether or not there was evidence of construction-enhanced permeability up to one shaft diameter from the shaft wall.

The pulse-injection tests . . ."

Saulnier, Jr., G.J., Domski, P.S., Palmer, J.B., Roberts, R.M., and Stensrud, W.A. 1991. WIPP Salado Hydrology Program Data Report #1. SAND90-7000. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" WIPP Salado Hydrology Program Data Report #1 presents hydrologic data collected during permeability tests of the Salado Formation performed from August 1988 through December 1989. Analysis and interpretation of the test data are presented in a separate report. The report presents the results of the drilling and testing of six boreholes drilled from the WIPP underground facility 655 m below ground surface in the Salado Formation. Permeability tests were conducted using multipacker test tools with inflatable packers to isolate borehole intervals to allow formation pore-pressure buildup and subsequent pulse-withdrawal tests. Test data include pressures and temperatures in brine-filled, packer-isolated test intervals and borehole-closure and axial test-tool-movement measurements. The test boreholes are 4.0-inch (10.2-cm) in diameter, and were cored in halite and associated anhydrite interbeds and clay seams. The boreholes are oriented vertically downward, angled downward, and horizontal. The boreholes were drilled and cored using compressed air to remove drill cuttings. Three boreholes were drilled in Room C2:C2H01, C2H02, and C2H03. Borehole C2H01 was initially drilled to a depth of 5.68m below the floor of Room C2 and later deepened to 8.97 m to include Marker Bed 139 in the test interval. Borehole C2H02 was drilled to a depth of 10.86 m (7.68 m vertical projection from the floor of Room C2) at a 45° downward angle from the junction of the west wall and floor of Room C2. Marker bed 139 was included in the test interval in borehole C2H02. Borehole C2H03 was drilled horizontally into the west wall of Room C2. Vertically downward boreholes were drilled from the floor in the North 1420 drift (borehole N4P50); the South 1300 drift (borehole S0P01); and in Room 7, Waste Panel 1 in the waste-storage area (borehole S1P71).

Permeability tests were performed after installing multipacker test tools in test boreholes, inflating the packers, and allowing pressures to build up in the isolated intervals. Pulse-withdrawal tests were performed after buildup pressures approached the apparent formation pore pressure. Pulse injections were sometimes performed to increase the fluid pressures in isolated intervals.

Compliance tests were conducted in lengths of steel and stainless-steel casings to evaluate the mechanical performance of the multipacker test tools. The stainless-steel compliance-test chamber was installed with externally mounted thermocouples in a downward-angled borehole in Experimental Room 4. Compliance tests included leak tests and simulated pulse-injection and pulse-withdrawal sequences."

Schaller, W.T., and Henderson, E.P. 1932. Mineralogy of Drill Cores from the Potash Field of New Mexico and Texas. U.S. Geological Survey Bulletin, Vol. 833.

SUMMARY, p VII;

" The potash field of southeastern New Mexico and adjacent parts of Texas is confined to the southern part of the Permian salt basin, covering about 40,000 square miles. The potash and associated minerals lie in a body of Permian halite, whose top is at least several hundred feet below the present surface.

The material described in this report was obtained from drill cores and well cuttings. All the specimens illustrated are parts of the drill cores that were shipped to Washington for examination and chemical analysis of their potash content.

The minerals identified . . ."

Schermer, S.C. 1980. A Report on the Archaeological Site Locations in the WIPP Core Area with Mitigation Recommendations for Bechtel National, Inc. Report 80-176. Agency for Conservation Archaeology, Eastern New Mexico University, Portales, NM.

INTRODUCTION, p 1;

" During the week of January 7, 1980, ACA conducted a project designed to relocate, accurately, 28 sites originally recorded by ACA crews during the summer of 1976. The project was conducted at the request of Bechtel National, Inc. and was administered by Mr. David Gieffer for Bechtel and Scott Schermer, Assistant Director, Agency for Conservation Archaeology. The project archaeologists, Miles Linnabery and Rodrick MacLennan, were able to relocate all but one site, which had apparently been obliterated by the construction of a caliche road. The archaeologists noted that the surface configuration of several sites had been changed by the movement of sand due to wind action.

METHODOLOGY

This project was designed to relocate previously recorded sites extant in the core area of the WIPP project, define their current surface configuration and condition, and accurately locate site center. . . ."

Schiel, K.A. 1988. The Dewey Lake Formation: End Stage Deposit of a Peripheral Foreland Basin [M.S. thesis]. University of Texas at El Paso, El Paso, TX.

ABSTRACT, p iv;

" The red siltstones and fine grained sandstones of the Dewey Lake Formation (Late Permian?) have always been relegated to a rather insignificant role in the geologic history of the Permian Basin. The present study suggests that they are, in fact, an important key to understanding the tectonic evolution of the southwestern United States.

Field work, in southeastern New Mexico, reveals that the Dewey Lake is fluvial in origin. Broad, shallow channels filled with thin horizontal laminations and flanked by laterally thinning wings comprise a large portion of the formation. Floodplain deposits, consisting of interbedded siltstone and silty claystone, are also very common.

The Dewey Lake displays many of the sedimentologic and morphologic characteristics associated with ephemeral fluvial systems. Some of these characteristics are an abundance of horizontal laminations and silty claystone drapes, the existence of interbedded siltstone and silty claystone interpreted to be the distal portion of sheet floods, and the presence of broad channels with laterally thinning wings. The Dewey Lake is, therefore, believed to have been deposited on a very extensive northwest sloping fluvial plain. Movement of sediment across this plain occurred only sporadically, during brief and localized flash floods.

It has previously been theorized that the Dewey Lake was extensively eroded prior to the deposition of the Santa Rosa Formation (Middle to Late Triassic). The results of the present study suggest that the thickness variations in the Dewey Lake are not a reflection of post depositional erosion but syndepositional differences in the subsidence rates of the Central Basin Platform and Delaware Basin. Increased subsidence of the Delaware Basin is reflected by the fact that the base of the Dewey Lake Formation is offset 100 m (300 ft) along the major northwest trending fault zone separating the Delaware Basin and Central Basin Platform. The Delaware Basin, therefore, appears to have been tectonically active throughout the deposition of the Dewey Lake Formation.

If the thickness variations in the Dewey Lake are due to subsidence rather than erosion then the contact between the Dewey Lake and the overlying Santa Rosa Formation is conformable. The Santa Rosa has been dated as Middle to Late Triassic in northeastern New Mexico; if this date is applicable to the Santa Rosa in southeastern New Mexico it dictates that the deposition of the Dewey Lake Formation continued into the Early Triassic.

A major unconformity separates Lower Permian and Cretaceous strata in the Fort Worth, Val Verde and Marfa Basin of Texas. This unconformity, which also exists in northwestern Chihuahua, clearly indicates that a large region of central Texas and northern Mexico was uplifted and eroded during the latest Permian ? and early Mesozoic. The location and timing of this uplift suggests that it was the source of the silt and fine sand comprising the Dewey Lake Formation. A close geographic and temporal relationship between this uplift and Late Triassic rift basins suggests that it originated as a pre-rift bulge.

The very extensive nature of this uplift suggests that the alluvial plain to the north (i.e. the Dewey Lake and Quartermaster Formations) extended significantly beyond the area

of west Texas and eastern New Mexico. The western portion of this plain is theorized to be the redbed facies of the Moenkopi Formation (Early Triassic). Apparent similarities in age, stratigraphic position, lithology and paleoscope all support the concept that the Dewey Lake and Moenkopi Formations are components of a single lithologic unit."

Schiel, K.A. 1994. A New Look at the Age, Depositional Environment and Paleogeographic Setting of the Dewey Lake Formation (Late Permian). West Texas Geological Society Bulletin, Vol. 33, No. 9, pp. 5-13.

ABSTRACT, p 5;

" The Dewey Lake Formation (Late Permian?) was studied, using surface and subsurface techniques, to more clearly define its depositional environment and tectonic/paleogeographic setting. The Formation contains numerous wide, shallow channels filled with horizontally laminated siltstone and flanked by laterally thinning 'wings' of micro-cross laminated siltstone. This morphology indicates that the Dewey Lake was deposited in a fluvial plain dominated by localized, ephemeral flows. The 'wings' represent distally thinning, floodplain deposits, formed as the channel filled with sediment and the water overflowed onto the surrounding plain.

The Dewey Lake is generally restricted to the Late Permian; however, the supporting evidence is weak. Lateral thickness variations in the Dewey Lake reflect syndepositional subsidence (i.e, the Delaware Basin was still active), not post-depositional erosion. Ash beds in the lower Quartermaster Formation (lateral equivalent), with ages near the Permo-Triassic boundary, date the initiation of sedimentation, not its duration. These observations suggest that although deposition of Dewey Lake sediments may have begun in the latest Permian, it continued through the Early Triassic.

The silts and fine grained sands comprising the Dewey Lake were derived from an uplift, to the south/southeast, encompassing the Pennsylvanian Ouachita/Marathon thrust belt and fore-deep basins. Triassic uplift of this region is indicated by an erosional unconformity between Late Permian and Cretaceous strata in several fore-deep basins and Triassic conglomerates in the Glass Mountain and Llano Uplift regions interpreted as alluvial fans. Timing and location of this uplift suggest that it may have originated as a pre-rift bulge. Lithologic, stratigraphic, and sedimentologic similarities between the Dewey Lake and Moenkopi Formation suggest that the alluvial plain north of this uplift may have extended throughout the southwestern United States."

Seed, H.B., Idriss, I.M., and Kiefer, R.W. 1976. Characteristics of Rock Motions during Earthquakes. Report No. 68-5. Earthquake Engineering Research Center.

INTRODUCTION, p 1;

" The behavior of soil deposits during earthquakes can often be assessed with the aid of appropriate analyses of their response to the motions developed in underlying rock formations. Methods of analysis based on this approach have been proposed for evaluating the characteristics of ground surface motions (13,21,24,26,28,29,30,37,38),[4] the liquification potential of sand deposits (34) and the stability of slopes of earth banks (18,19,32,35) and embankments (1,6,7,11,33,36). The relatively good agreement between analytical results and observed field performance in a number of cases (22,34,36,37) has indicated that such analyses are often capable of providing a satisfactory guide to appropriate design conditions.

In order to make an analysis of the response of any soil deposit, it is first necessary to determine:

(1) The surface topography, the underlying rock configuration and any irregularities in the boundaries between soil layers,

(2) The types of soil comprising the deposit and the characteristics determining their response under dynamic loading conditions, and . . ."

Schnabel, P.B., and Seed, H.B. 1973. Accelerations in Rock for Earthquakes in the Western United States. Seismological Society of America Bulletin, Vol. 63, pp. 501-516.

ABSTRACT, p 501;

" Maximum accelerations recorded on rock sites during earthquakes in the western part of the United States are summarized, and attenuation curves showing the decrease in maximum acceleration with increasing distance from the zone of energy release are developed for different magnitude earthquakes. Changes in acceleration level and predominant periods of rock motions with distance are also analyzed. The significance of maximum acceleration level as an indicator of intensity of ground shaking is discussed."

Sewards, T., Glenn, R., and Keil, K. 1991. Mineralogy of the Rustler Formation in the WIPP-19 Core. SAND87-7036. Sandia National Laboratories, Albuquerque, NM.

IX. SUMMARY AND CONCLUSIONS, p IX-1;

" We have reported here the species, quantities, distribution, and compositions of the minerals of the Rustler Formation as seen in the WIPP-19 borehole, one of the boreholes closest to the WIPP facility that was completely cored through the Rustler section. The major components, as determined by x-ray diffraction are halite, anhydrite, gypsum, dolomite, magnesite, quartz, and clay. Minor components include calcite, pyrite, feldspar, and phyllosilicates of metamorphic origin (muscovite, biotite, and chlorite). Clay minerals, identified by XRD, include illite, serpentine, chlorite, and mixed-layer chlorite/smectite (including corrensite).

Quartz and clay, with some halite and anhydrite, dominate the lower member; the Culebra and Magenta units are primarily dolomite with some quartz and clay, while the Forty-niner Member consists of quartz, clay, and sulfates (anhydrite and gypsum).

Halite occurs in four textural styles: bedded, recrystallized halite; displacive halite; as a cement in mud/siltstones; and as a fracture filling, and is largely restricted to the lower member. Anhydrite occurs primarily as a massive, crudely banded nodular structure, although there is often evidence of partial alteration to gypsum. Gypsum also is usually massive, in a crudely banded form. The massive areas consist of fine-grained irregular crystals ('patchy' gypsum); these areas are separated by veins of 'fibrous' gypsum, usually parallel to bedding. Fibrous gypsum vein filling in other lithologies is very common. Dolomite is unfossiliferous, laminated, and very fine-grained; it contains numerous vugs and fractures: these are usually lined with clay, gypsum, and powdery dolomite. Magnesite, a relatively minor component, occurs as microcrystalline nodules and as euhedral elongated platy crystals included in halite. Quartz and clay always occur together with minor amounts of feldspar and detrital phyllosilicate grains. Calcite is restricted to a thin bed above the Culebra Dolomite in the samples studied.

Halite, anhydrite, and gypsum have nearly ideal compositions, whereas dolomite has a nonideal ratio of calcium to magnesium, plus a significant amount of iron; similarly, magnesite contains some iron.

In general, this study should be considered a detailed analysis of the Rustler section mineralogy. It is unlikely that any other minerals are present in any great quantity elsewhere in the Rustler Formation. Abundances of individual minerals, however, may vary considerably in other areas of the formation."

Shah, H.C., Mortgat, C.P., Kiremidjian, A., and Zsutty, T.C. 1975. A Study of Seismic Risk for Nicaragua. Report 11. Department of Civil Engineering, Stanford University, Palo Alto, CA.

ABSTRACT, (from Report Documentation page);
" The geological setting for the country in general and the Managua area in particular is described. The data base for past seismic events was extensively studied. Limitations of the data and approximations are discussed. Seismic recurrence for ten line sources and three area sources was developed. Based on the assumption of the Poisson occurrence of seismic events, probabilities of exceeding different magnitude levels as functions of time for different regions were derived. Using Esteva's attenuation relationship, isoacceleration maps for the country were constructed. Eleven cities in Nicaragua were considered in this mapping process. Cumulative distribution functions of peak ground accelerations for 20 and 50 years were established. This is shown to be one way of presenting seismic risk for Nicaragua. Based on isoacceleration maps, the Acceleration Zone Graphs (AZG) were developed for the eleven cities. A method for determining load levels for consistent risk for the whole country is discussed and suggested. It is proposed that charts such as AZG be used for seismic zoning of Nicaragua. Ground acceleration values from AZG were employed to set the level of the design spectra for structural damage prevention and condemnation control. A design methodology is proposed based on ultimate strength and loads resulting from the above inelastic design spectra."

Shumard, G.G. 1858. "Observations on the Geological Formation of the Country between the Rio Pecos and the Rio Grande, in New Mexico, Near the Line of the 32nd Parallel, Being an Abstract of Portion of the Geological Report of the Expedition Under Capt. John Pope, Corps of Topographical Engineers, U.S. Army, in the Year 1855." In St. Louis Academy of Sciences Transactions, Vol. 1.

p 273;

" The Expedition remained, for several months, encamped on the Rio Pecos, near the mouth of Delaware Creek, and a favorable opportunity was thus afforded for examining minutely the geological structure of that vicinity. The Llano Estacado was to be seen from our camp, stretching for an indefinite distance eastward, in the form of an elevated and gently undulating plateau, thinly covered with short grass, and presenting, generally, but little variety of surface. It is abruptly terminated, on the west, by the Pecos River, which flows, in a tortuous course, with an average width of about eighty feet, amid low hills and bluffs of conglomerate and limestone. Beyond the Pecos, the country assumes a more broken and hilly appearance, and, at the distance of sixty miles, rise the lofty summits of the Guadalupe Mountains, of which the highest points had been observed long before we arrived at the mouth of Delaware Creek.

The following is a section taken near the mouth of Delaware Creek:

1. Quaternary Conglomerate, composed of limestone from the Guadalupe Mountains	70 feet.
2. Upper Cretaceous limestone	100* "
3. Lower Cretaceous marls and sandstone (as far as bored)	800 "
Total thickness	1000 feet.

The rocks of this vicinity, save the limestone . . . "

Siegel, M.D., Lambert, S.J., and Robinson, K.L. eds., 1991. Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico. SAND88-0196. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" Chemical, mineralogical, isotopic, and hydrological studies of the Culebra dolomite member of the Rustler Formation and related rocks are used to delineate hydrochemical facies and form the basis for a conceptual model for post-Pleistocene groundwater flow and chemical evolution. Modern flow within the Culebra in the Waste Isolation Pilot Plant (WIPP) area appears to be largely north-to-south; however, these flow directions under confined conditions are not consistent with the salinity distribution in the region surrounding the WIPP Site. Isotopic, mineralogical, and hydrological data suggest that vertical recharge to the Culebra in the WIPP area and to the immediate east and south has not occurred for several thousand years. Eastward increasing $^{234}U/^{238}U$ activity ratios suggest recharge from a near-surface Pleistocene infiltration zone flowing from the west-northwest and imply a change in flow direction in the last 30,000 to 12,000 years.

Culebra groundwaters are in chemical equilibrium with gypsum and are undersaturated with halite and anhydrite. A partial-equilibrium model for the chemical evolution of the groundwater suggests that Na, Cl, Mg, K, and SO_4 are added to the Culebra by dissolution of evaporite salts in adjacent strata. Equilibrium is maintained with gypsum and calcite, but dolomite supersaturation increases as the salinity of the water increases. Stable-isotope compositions of carbonates are consistent with this model and indicate that no recrystallization of dolomite in equilibrium with the groundwater has occurred. Major and minor element correlations are consistent with several plausible mechanisms of water/rock interaction, including sorption of lithium and boron by clays and dissolution of Mg-rich clays."

Siemers, W.T., Hawley, J.W., Rautman, C., and Austin, G. 1978. Evaluation of the Mineral Potential (Excluding Hydrocarbons, Potash, and Water) of the Waste Isolation Pilot Plant Site, Eddy County, New Mexico. Open-File Report 87. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT;

" The mineral potential of a proposed WIPP site, located 40 km east of Carlsbad, Eddy County, New Mexico, has been evaluated on the basis of information obtained from onsite field studies, the examination of records provided by Sandia Laboratories, and pertinent literature. The site is located near the northern edge of the Delaware Basin; the upper part of the stratigraphic section is comprised of marine and continental redbeds underlain by marine Ochoan evaporites.

Available data indicate that the only WIPP site-related commodities that may have any economic potential are (1) caliche, (2) salt, (3) gypsum, (4) lithium-bearing brines, (5) sulfur, and (6) uranium. A more detailed study however, indicates that for one or more of several reasons including (1) commodity abundance, (2) commodity accessibility, (3) low demand for the commodity, and (4) adequate supplies of the commodity elsewhere, these six commodities are uneconomic at present and for the foreseeable future."

Snider, H.I. 1966. Stratigraphy and Associated Tectonics of the Upper Permian Castile-Salado-Rustler Evaporite Complex, Delaware Basin, West Texas and Southeast New Mexico [Ph.D. dissertation]. University of New Mexico, Albuquerque.

ABSTRACT, P 1;

" The Delaware basin of west Texas and southeast New Mexico is roughly pear-shaped with a northwest-southeast length of about 140 miles and a width of 100 miles in the northwest tapering to 60 miles in the southeast--an area of about 10,000 square miles. In late Permian time the basin was essentially encircled by a carbonate depositional environment or reef zone.

The Upper Permian evaporite complex within the Delaware basin consists of Castile, Salado, and Rustler Formations. The Castile Formation contains laminated calcareous anhydrite, halite, and limestone. The Castile Formation was subdivided into seven units: Anhydrite I, Halite I, Anhydrite II, Halite II, Anhydrite III, Anhydrite IV, and Anhydrite V. The lowest four units can be traced over two-thirds of the basin. The upper three units can only be differentiated in the eastern part of the basin. The Salado Formation consists of halite and anhydrite with minor clastics, magnesite, and potassium minerals in the north and east parts of the basin. In the south and west parts of the basin, the Salado consists mainly of anhydrite dolomite, and clastics. The Rustler Formation contains anhydrite, dolomite, clastics, and halite.

. . .

The distribution of halite may reflect tectonism during Castile time. Little to no halite is found on the intrabasin shelf, while thick halite beds are found in the Ochoa trough. Halite units of the Castile Formation may have overlapped to the south due to differential subsidence or 'tilting' southward of the Ochoa trough. A reversal of this tilting occurred in Salado time.

Evidence of local movement in Castile units is abundant. Four models are analyzed to account for salt structures found: 1. salt movement contemporaneous with deposition--'down building'; 2. post-depositional halite piercement; 3. post-depositional lateral movement of upper halite over lower halite stock, dome, or anticline; and 4. gravity flow of upper halite over a lower halite structure--'anticline on anticline.' Tectonic 'triggering' is suggested as the major cause of Castile halite movement. Regional movement resulting in structures similar to 'salt pillows' or 'salt stocks' is believed to have occurred in the northeast part of the Delaware basin in Lea County, New Mexico."

Snyder, R.P., 1985. Dissolution of Halite and Gypsum, and Hydration of Anydrite to Gypsum, Rustler Formation, in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico. Open-File Report 85-229. U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;
" Data from selected drill holes spaced at intervals of 1.5 to 15 km (5,000 to 50,000 ft) in southeastern New Mexico demonstrate a progressive removal of halite by dissolution, hydration of anhydrite to gypsum, and removal of gypsum by dissolution in the Permian Rustler Formation. Thickness of the Rustler decreases as halite is removed, but increases after complete removal due to the hydration of anhydrite to gypsum."

Snyder, R.P., and Gard, Jr., L.M. 1982. Evaluation of Breccia Pipes in Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, with Section on Drill-Stem Tests. Open-File Report 82-968. U.S. Geological Survey, Denver, CO.

INTRODUCTION, p. 1;

" The Waste Isolation Pilot Plant (WIPP) site is located about 40 km (25 mi) east of Carlsbad, N. Mex. (fig. 1). The site geography has been described in detail by Powers and others (1978) and U.S. Department of Energy (1980, 1981). Site selection was based principally on the existence of a thick section of Permian evaporites, mainly halite. The purpose of establishing this site is to demonstrate whether or not an evaporite environment is acceptable for the disposal of trans-uranic waste generated by the Nation's defense programs.

The primary concern regarding safe disposal of nuclear waste is to isolate the waste from the biosphere until it is no longer a danger to mankind. One of the most probable methods of accidental release of radiation from nuclear waste isolated in a geologic medium is leaching and transport of the waste by moving ground water. It is therefore of primary importance to identify any potential channelways that might allow water to enter a repository site located on bedded salt of the Salado Formation of southeastern New Mexico. The presence of the thick Permian (225 m.y.) rocks attests to the fact that major dissolution of the halite by unsaturated ground water has not occurred at the WIPP site.

Focus of Current Study

This report describes several dissolution features in the Delaware Basin and elsewhere that have been referred to as breccia pipes. Breccia pipes (also called breccia chimneys) as they occur in evaporites are vertical cylindrical pipes or chimneys that may or may not involve more than one geologic formation. The chimneys are filled with downward-displaced brecciated rock. In this context, the rock is brecciated by having collapsed into a void at depth that was probably created by ground-water solution and removal of deep-lying evaporite or carbonate rocks in an underlying aquifer system (Anderson and Kirkland, 1980; Bachman, 1980). Such features have been described in evaporite deposits in many areas of the world.

The current study was done for the U.S. Department of Energy (DOE) in response to a suggestion that because breccia pipes are thought to be the result of deep dissolution, they may represent channelways for future ingress of ground water, and that they should be considered in risk assessment programs for the evaluation of proposed waste repositories in bedded evaporite rocks. To this end, features referred to as breccia pipes in southeastern New Mexico have been assessed in relation to the integrity of the WIPP site. Reports by Anderson (1978), Bachman (1980), and Vine (1960) described dissolution and karst features in the Pecos region of southeastern New Mexico and discussed the origin and history of breccia pipes. The present report is intended to supplement these studies and provide detail that was not available to them at the time their reports were written.

Using the data from exploratory work, answers may be found to the following questions concerning breccia pipes:

1. Do breccia pipes penetrate through the evaporite section?
2. What is the physical description of a pipe?
3. How are they formed?
4. How deep do they go?
5. When are they formed, and are they forming at present?
6. Are they permeable?
7. Where are they formed, can they form at the WIPP site?
8. Do they represent a threat to the WIPP site?"

Stensrud, W.A., Dale, T.F., Domski, P.S., Palmer, J.B., Roberts, R.M., Fort, M.D., and Saulnier, Jr., G.J. 1992. Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2. SAND92-7072. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;
" WIPP Salado Hydrology Program Data Report #2 presents hydrologic data collected during permeability testing of the Salado Formation performed from August 1989 through July 1992. The report presents the results of the drilling and testing of six boreholes drilled from the WIPP underground facility 655 m below ground surface in the Salado Formation. Permeability tests were conducted using multipacker test tools with inflatable packers to isolate borehole intervals to allow formation pore-pressure buildup and subsequent pressure-pulse and constant-pressure-withdrawal tests. The tests performed in boreholes L4P51, L4P52, SCP01, S1P71, S1P72, and S1P73 involved Marker Beds 138 and 139, anhydrites 'a,' 'b,' and 'c,' clays B, D, E, G, H, J, and K, and several halitic strata. Test data include pressure and temperature from the brine-filled, packer-isolated test intervals, fluid and gas production during constant-pressure-withdrawal tests, and borehole-closure and axial test-tool-movement measurements. The boreholes were drilled and/or cored to nominal 10.2-cm diameters using compressed air to remove drill cuttings. Compliance tests were conducted in lengths of steel and stainless-steel casing to evaluate the mechanical performance of the multipacker test tools. Compliance tests included leak tests and pulse-injection and pulse-withdrawal sequences. Following permeability testing, fluid pressures were monitored in packer-isolated sections of test boreholes C2H01, C2H02, SCP01, S1P71, S1P72, DPD01, DPD02, and DPD03."

Thompson, G.A., and Zoback, M.L. 1979. Regional Geophysics of the Colorado Plateau. Technophysics, Vol. 61, Nos. 1-3, pp. 149-181.

ABSTRACT, p. 149, Para. 2;

" The Colorado Plateau (CP) is a relatively coherent block surrounded on three sides by the extensional black faulted regime of the Basin and Range Province (BRP) and the Rio Grande Rift (RGR). The CP appears to be part of an inter-related system including the Sierra Nevada, BRP, and the RGR which has undergone major uplift and extension during the last 20 m.y. The final elevation in any area probably depends upon which processes dominate there.

In most geophysical properties the CP is intermediate between the BRP/RGR and the stable platform of the southern Great Plains. However, many BRP/RGR geophysical characteristics appear to extend well inward of the classical Plateau physiographic boundary. Geologically these 50-100 km wide zones of transition are marked by normal faulting and late Tertiary and Quaternary volcanism. The interior of the Plateau is characterized by a 40 km-thick crust, a P_n velocity of about 7.85 km/sec, and an average heat flow of 1.5-1.6 HFU. Available data on the modern stress field in the Plateau interior indicate high horizontal stresses and a stress field oriented differently from that in the surrounding BRP/RGR, inconsistent with the theory that the plateau is merely an inherited, more coherent subplate subjected to the same stresses as it's surroundings."

Tóth, J., 1963. "A Theoretical Analysis of Groundwater Flow in Small Drainage Basins," Journal of Geophysical Research, Vol. 68, no. 16, pp. 4795-4812.

ABSTRACT, p 4795;

" Theoretically, three types of flow systems may occur in a small basin: local, intermediate, and regional. The local systems are separated by subvertical boundaries, and the systems of different order are separated by subhorizontal boundaries. The higher the topographic relief, the greater is the importance of the local systems. The flow lines of large unconfined flow system do not cross major topographic features. Stagnant bodies of groundwater occur at points where flow systems meet or branch. Recharge and discharge areas alternate; thus only part of the basin will contribute to the baseflow of its main stream. Motion of groundwater is sluggish or nil under extended flat areas, with little chance of the water being freshened. Water level fluctuations decrease with depth, and only a small percentage of the total volume of the groundwater in the basin participates in the hydrologic cycle."

Urry, W. D. 1936. Post-Keweenawan Timescale. Exhibit 2, pp. 35–40. National Research Council, Report Committee on Measurement of Geologic Time 1935–36.

REPORT OF THE COMMITTEE ON THE MEASUREMENT
OF GEOLOGIC TIME
May 2, 1936
(Appendix K of Annual Report of
the Division with Exhibits 1-13)
(Reissued July, 1952-1953)

p. 35;
" The progress of the principle application of the helium method during the past year to the setting up of a Post-Keweenawan time scale by selecting material from authenticated horizons is summed up in the accompanying chart, which constitute the basis of a paper presented by Wm. D. Urry at the December Meeting of the Geological Society of America. Due acknowledgement to the contributors of the material will be made in the manuscript now in preparation."

p. 40;
"

Low Results

Five results are low. For three of these, plausible explanations are forthcoming and possibly for the fourth. The fifth low result is not yet explained.

		Millions of years
1).	Sill or dike basaltic intrusion into Permian Salts. Carlsbad, N.M. Churn drill 1/2 to 1 mm pieces.	30 ± 1.5 "

USBM (U.S. Bureau of Mines). 1977. Valuation of Potash Occurrences within the [WIPP] Site in Southeastern New Mexico. Prepared for the U.S. Energy Research and Development Administration.

ABSTRACT, p. 1;

" Current production costs and market conditions in the potash industry of the Carlsbad area were studied to determine the potential values of the potash mineral resource that would be lost or foregone if the Waste Isolation Pilot Plant (WIPP) facility is constructed on the proposed site in that area. The purpose of the WIPP project is to investigate the possibility of developing a nuclear waste disposal plant in the salt formations at the site. Analyses were made of all potash deposits determined to be in the site. Mining and processing under the most favorable recovery systems were considered. Value determinations were based upon estimated operating and capital costs of current mine-mill operations in the Carlsbad area. This study was made for the Energy Research and Development Administration (ERDA) by members of the Federal Bureau of Mines Minerals Availability System staff."

Vail, P.R., Mitchum, Jr., R.M., Thompson, III, S., 1977. "Seismic Stratigraphy and Global Changes of Sea Level, Part 4: Global Cycles of Relative Changes of Sea Level," In Seismic Stratigraphy-Applications to Hydrocarbon Exploration, C.E. Payton ed., AAPG Memoir 26, pp. 83-97, American Association of Petroleum Geologists.

Abstract; p. 83, para. 2, col.1;

" Cycles of relative change of sea level on a global scale are evident throughout Phanerozoic time. The evidence is based on the facts that many regional cycles determined on different continental margins are simultaneous, and that the relative magnitudes of the changes generally are similar. Because global cycles are records of geotectonic, glacial, and other large-scale processes, they reflect major events of Phanerozoic history.

A global cycle of relative change of sea level is an interval of geologic time during which a relative rise and fall of mean sea level takes place on a global scale. A global cycle may be determined from a modal average of correlative regional cycles derived from seismic stratigraphic studies.

On a global cycle curve for Phanerozoic time, three major orders of cycles are superimposed on the sea-level curve. Cycles of first, second, and third order have durations of 200 to 300 million, 10 to 80 million, and 1 to 10 million years, respe4ctively. Two cycles of the first order, over 14 of the second order, and approximately 80 of the third order are present in the Phanerozoic, not counting late Paleozoic cyclothems. Third-order cycles for the pre-Jurassic and Cretaceous are not shown. Sea-level changes from Cambrian through Early Triassic are not as well documented globally as are those from Late Triassic through Holocene.

Relative changes of sea level from Late Triassic to the present are reasonably well documented with respect to the ages, durations, and relative amplitudes of the second-and third-order cycles, but the amplitudes of the eustatic changes of sea level are only approximations. Our best estimate is that sea level reached a high point near the end of the Campanian (Late Cretaceous) about 350 m above present sea level, and had low points during the Early Jurassic, middle Oligocene, and late Miocene about 150, 250, and 200 m, respectively, below present sea level.

Interregional unconformities are related to cycles of global highstands and lowstands of sea level, as are facies and general patterns of distribution of many depositional sequences. Geotectonic and glacial phenomena are the most likely causes of the sea-level cycles.

Major applications of the global cycle cart include (1) improved stratigraphic and structural analyses within a basin, (2) estimation of the geologic age of strata prior to drilling, and (3) development of a global system of geochronology."

Vine, J.D., 1963. Surface Geology of the Nash Draw Quadrangle, Eddy County, New Mexico. U.S. Geological Survey Bulletin 1141-B.
ABSTRACT, p B1;

" Outycropping rocks and surficial deposits of the Nash Draw quadrangle were mapped to provide geologic information for the U.S. Atomic Energy Commission's Plowshare program. The quadrangle is near the north margin of the Delaware basin and about 15 miles east of Carlsbad, N. Mex. The region is sparsely inhabited and has an arid climate.

As much as 4,000 feet of salt and anhydrite of Permian age is present below the surface, but does not crop out in normal thickness in this area or elsewhere because of their high solubility. These rocks have been divided into the Castile formation below and the Salado formation above. Rocks exposed at the surface overlie these soluble rocks and include the Rustler formation of Late Permian age, the Pierce Canyon redbeds of Permian or Triassic age, the Santa Rosa sandstone of Late Triassic age, and the Gatuna formation, caliche, and a variety of unconsolidated deposits of late Cenozoic age.

The Rustler formation of Late Permian age is subdivided into four easily distinguishable members, excluding about 120 feet of the lower part, which is not exposed at the surface in this area. The oldest member exposed is the Culebra dolomite member, about 30 feet thick, identified only in erratically distributed outcrops in collapse areas. The Culebra consists of microcrystalline gray dolomite or dolomitic limestone characterized by numerous spherical cavities 1 to 10 mm in diameter. It is conformably overlain by the Tamarisk member, named herein for exposures directly east of Tamarisk Flat. It consists of about 115 feet of massive gypsum at the surface, changing to anhydrite in the subsurface, and a bed, 5 feet thick, of siltstone near the base. Surficial deformation caused by hydration and solution are characteristic of all the outcrops. The Tamarisk member is conformably overlain by the Magenta member, about 20 feet thick and consisting of alternating wavy laminae of pale-red dolomite and pale yellowish-green anhydrite or gypsum. The top member of the Rustler formation conformably overlies the Magenta and is here named the Forty-niner member after Forty-niner Ridge, where it crops out. In surface exposures it consists of about 40 to 65 feet of broken and slumped massive gypsum and a bed of siltstone in the lower part. The siltstone beds in the Tamarisk and Forty-niner members probably represent the insoluble residue of salt beds reported from the subsurface to the east."

Overlying the Rustler formation with apparent conformity are the Pierce Canyon redbeds of Permian or Triassic age. These rocks consist of about 200 to 250 feet of laminated or minutely cross-laminated moderate reddish-brown siltstone. The contact between the Pierce Canyon redbeds and the overlying Santa Rosa sandstone is a disconformity, at least locally.

The Santa Rosa sandstone of Late Triassic age consists of pale-red sandstone and conglomerate lenses crossbedded in sets 3 to 15 feet thick separated locally by moderate reddish-brown siltstone and claystone. Only the lower 50 to 70 feet of Santa Rosa was recognized in the area.

The Gatuna formation of Pleistocene (?) age unconformably overlies all older rocks. In much of the area it consists of 3 to 5 feet of moderate reddish-orange sandstone, siltstone,

and conglomerate. Locally, in karst depressions, the Gatuna attains a thickness of at least 100 feet. In some areas the lithology closely resembles the Pierce Canyon redbeds or the Santa Rosa sandstone.

Caliche forms a resistant layer at the ground surface, 5 to 10 feet thick, that protects older rocks from erosion in many areas. The caliche consists of calcareous material with a variable amount of imbedded sand grains, pebbles, and rock fragments. Caliche mounds and broken flexure ridges, 10 to 15 feet high, have formed narrow zones 50 to several hundred feet long.

Quaternary alluvium has been deposited along the sides of depressions. It is overlain by playa lake deposits, which are in turn overlain by conspicuous sand dunes as much as 100 feet high.

The regional structure is relatively simple and consists of a dip of a few feet per mile to the east and southeast.

Normally flat-lying strata are tilted, warped, and locally distorted at the surface by hydration and solution of the evaporite rocks in the subsurface. Nash Draw, a depression 4 to 6 miles wide and about 18 miles long, has resulted from the solution of salt in the Rustler and Salado formations and collapse of the overlying relatively insoluble rocks. Topography and surface structure conform in some areas with the configuration of the underlying solution surface at the top of the massive salt in the Salado formation; however, locally there is an inverse correspondence. Many circular karst features 1/10 to 1/2 mile in diameter are in the area. Some of these features are structural domes, but they contain a core of tilted or brecciated rock. These karst features result from the formation and collapse of sinkholes, differential solution at the top of the massive salt, and hydration of the anhydrite beds."

Von Hake, C., and Cloud, W.K. 1968. United States Earthquakes 1966. Coast and Geodetic Survey. U.S. Department of Commerce, Washington, D.C.

INTRODUCTION, p. 1;

" This publication, issued by the National Earthquake Information Center of the Coast and Geodetic Survey, is a summary of earthquake activity in the United States and regions under its jurisdiction for the calendar year 1966. The sources of non-instrumental information used in the compilation include the U. S. Weather Bureau whose observers prepare periodic reports on local seismic activity; telegraphic information collected by the Science Service, Washington, D.C.; bulletins of the Seismological Society of America; special reports of various institutions; newspaper clippings; and reports from interested individuals. Instrumental data used in locating earthquakes are obtained from the seismological observatories listed on page 85, and from other cooperating seismological stations located throughout the United States.

The Coast and Geodetic Survey endeavors to coordinate efforts in collecting all types of earthquake information with the special objective of correlating instrumental earthquake locations with noninstrumental reports received from the epicentral areas. This is achieved through intensive regional investigations in various states by local organizations, and by the Coast and Geodetic Survey. This information is used to map the seismic areas of the country, thereby promoting public safety through a better understanding of earthquake phenomena. Since the success of the general information service depends largely on the cooperation of local officials and citizens, all are urged to complete and return earthquake questionnaire forms."

Westinghouse Electric Corporation 1990. WIPP Final Safety Analysis Report. WP02-9. Rev. 0. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

PREFACE

"**Background**

This Final Safety Analysis Report (FSAR) has been prepared for the Waste Isolation Pilot Plant (WIPP) in order to satisfy the commitments made in the Working Agreement for Consultation and Cooperation(Article III, Section C and Article IV, Section K, known as the Working Agreement) between the State of New Mexico and the U.S. department of energy (DOE) and the requirements of Order DOE 5481.1B,Safety Analysis and Review System.

The objectives of the Safety Analysis Preparation and Review process, as specified in Order DOE 5481.1B, ensure that:

1. Potential hazards are systematically identified;

2. Potential consequences are analyzed;

3. Reasonable measures to eliminate, control or mitigate the hazards have been taken, including, where applicable, compliance with commitments made in environmental assessments and impact statements;

4. There is documented management authorization of the DOE operation based upon an objective assessment of the safety analysis.

Specific hazards that are analyzed include credible natural hazards such as flood, weather (tornado, wind, etc.) and earthquake; and credible man made hazards such as fire, explosion, radiation, and mining hazards. Mitigating measures include facility design and construction, operational controls, and administrative limits.

This FSAR represents a statement and commitment by the DOE that the WIPP facility can be operated safely and at minimum risk, if operated in accordance with this FSAR. Consequently, this FSAR has been prepared to document that a systematic analysis of the potential hazards associated with operating the WIPP facility has been performed (objective 1 of Order DOE 5481.1B); that potential consequences have been analyzed (objective 2 of Order DOE 5481.1B); and that reasonable measures have been taken to eliminate, control, or mitigate the hazards (objective 3 of Order DOE 5481.1B). In addition, this FSAR documents the implementation of commitments made in the environmental impact statement regarding the mitigation of adverse impacts to the environment (objective 3 of Order DOE 5481.1B)."

Zoback, M.L., and Zoback, M.D. 1980. State of Stress in the Conterminous United States. Journal of Geophysical Research, Vol. 85, No. B11, pp. 6113-6156.

Southern Great Plains, p. 6134, col. 2, para. 3;

" The southern Great Plains area is characterized by a very uniform state of stress in which the least principal horizontal stress direction to NNE-SSW. The data come from two primary sources: (1) alinement of post-5 m.y. volcanic feeders in the Raton-Clayton volcanic field of northern New Mexico and (2) fracture orientations obtained from hydraulically fractured wells in the Permian basin of western Texas [*Zemanek et al.*, 1970]. An earthquake focal mechanism and in situ stress measurements in eastern Colorado show consistent orientations. Despite the similar least principal horizontal stress orientations in the southern Great Plains and in the plateau interior, the probable extensional regime (as inferred from earthquake focal mechanisms and basaltic volcanism) distinguishes the southern Great Plains from the Colorado Plateau interior and Midcontinent provinces which are dominated by compressional stress regimes. The least principal horizontal stress directions to the southern Great Plains province are generally oblique to those in the Midcontinent stress province; however, in west-central Texas the data suggest a counter-clockwise rotation of the stress field from west to east to directions more consonant with midcontinent stress orientations (Plates 1 and 2). The easternmost site of this group of data (TX-15) is a normal fault focal mechanism, suggesting that the boundary with the compression-dominated Midcontinent stress province must lie further to the east.

Two important characteristics of the stress field in the southern Great Plains province are (1) its uniformity ($\sim \pm 15°$, which is within the range of estimated accuracy of the different stress indicators) over a region with a north-south extent of at least 1100 km and (2) an abrupt transition in stress orientation in relation to the Rio Grande rift that occurs locally over a lateral distance of <50 km. this $\sim 90°$ change in least principal horizontal stress orientation along the Rio Grande rift-Great Plains boundary corresponds to a decrease in heat flow and a crustal and lithospheric thickening under the Great Plains in relation to the Rio Grande rift [*Thompson and Zoback,* 1979]. IN addition, seismic reflection profiling across the Rio Grande rift's eastern boundary [*Brown et al.*, 1979] has revealed a high-angle, narrow, linear zone defined by a lack of coherent reflections which extends from near the surface to the base of the crust. Physically, this sharp boundary may mark a zone of lateral 'decoupling' within the crust facilitating the abrupt change in stress orientation."

Zoback, M.D., and Zoback, M.L. 1991. "Tectonic Stress Field of North America and Relative Plate Motions." In Neotectonics of North America, D.B. Slemmons, E.R. Engdahl, M.D. Zoback, and D.D. Blackwell, eds., pp. 339-366. Geological Society of America, Boulder, CO.

STRESS PROVINCES OF NORTH AMERICA, p. 349, col. 1, para. 2;
" In this section we discuss the individual stress provinces shown in Figure 4 and summarized in Table 2.

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ASME (American Society of Mechanical Engineers). 1989. Quality Assurance Program Requirements for Nuclear Facilities. ASME NQA-1-1989. September 15, 1989. The American Society of Mechanical Engineers, New York, NY.

INTRODUCTION, 1 PURPOSE, p 1;
" This Standard sets forth requirements for the establishment and execution of quality assurance programs for the siting, design, construction, operation, and decommissioning of nuclear facilities. Nonmandatory guidance is provided in the Appendices."

Christensen, C.L., and Peterson, E.W. 1981. "Field-Test Programs of Borehole Plugs in Southeastern New Mexico." In The Technology of High-Level Nuclear Waste Disposal Advantages in the Science and Engineering of the Management of High-Level Nuclear Wastes, P.L. Hofmann and J.J. Breslin, eds., SAND79-1634C, DOE/TIC-4621, Vol. 1, pp. 354-369. Technical Information Center of the U.S. Department of Energy, Oak Ridge, TN.

FOREWORD, p 1;
" This paper provides an update on the Sandia Borehole Plugging Program (BHP) as reported at the October 1979 National Waste Terminal Storage (NWTS) Information Meeting, sponsored by ONWI, and included in ONWI 62. As reported in that paper, the Sandia BHP is specifically designed to support plugging activities for the proposed Waste Isolation Pilot Plant (WIPP) being considered by the U. S. Department of Energy (DOE) for the storage of defense non-heat producing transuranic (TRU) waste. This program will also provide generic information on bedded-salt formations to ONWI for inclusion in the NWTS commercial nuclear-waste repository programs. The goal of the Sandia BHP is to provide the plugging technology that will be required at the decommissioning and final closure of the WIPP facility.

At the time of the 1979 meeting, . . ."

p. 3, para 2;
" Field-testing experience with cementitious materials indicates that emplacement techniques used within the oil-field cementing industry will be adequate for repository plugging operations. Any modifications that may be required are expected to involve only minor changes; no new technology will be required."

Section VIII. SUMMARY AND CONCLUSIONS, p 25;
" The Bell Canyon Test (BCT) was conducted to evaluate candidate grout plugging mixes and plug emplacement techniques, and to asses plug performance under in-situ cured conditions. Grout plugging procedures are routinely performed in standard oil-field operations; however, quantitative measurements of plug performance are rarely obtained. the BCT was an attempt to quantify the state-of-the-art.

The experiment was performed in a 20-cm (8-inch) diameter wellbore that intercepted a natural aquifer having a shut-in pressure of 12.4 MPa (1800 psi) and a production capability of 38,000 liter/day (10^4 gals/day). This aquifer was located below a thick anhydrite bed (in the Castile Formation) near the site of the proposed Waste Isolation Pilot Plant (WIPP) in SENM. A 2-m (6-ft) grout plug was emplaced above the aquifer between 1368 m and 1370 m (4495 ft). By unloading the wellbore fluids from above the plug, the full 12.4 MPa pressure differential could be applied to the plug for flow testing.

Following the coring operation to deepen the wellbore, extensive logging, conditioning, and testing was conducted over a three-month period prior to plug emplacement. After plug emplacement on September 26, 1979, six test periods at forty-day intervals were scheduled to evaluate plug performance. Following the first four periods, the

plug was extended as additional 4 m (12 feet). However, tests on this extension have not been completed.

Brine-mixed grout was initially identified as the prime candidate for the plug. Laboratory samples (prepared to evaluate grout/rock interface performance), however, indicated permeability at the interface that was higher than either the grout or rock values taken separately (10-200 μdarcy vs 0.1-1 μdarcy). This leakage was attributed to a poor seal at the interface possibly caused by a salt residue formed during grout hydration. Hence an alternate fresh water mix was selected for the BCT plug. Routine tests (compressive strength, push-out strength, etc.) did not reflect this variation between the brine and fresh water mixes.

The plug performance was assessed using three basic techniques: fluid build-up tests (FBU), shut-in tests, and tracer transit-time tests; all testing was conducted through an "umbrella" packer emplaced 3-4 m above the plug to create a test chamber. The fluid build-up tests exhibited leakage in the tubing and packer plumbing as high as or higher than the leakage around the plug, leading to complications in the analysis. The shut-in tests and the tracer transit times worked satisfactorily.

The field data, taken together with laboratory data, suggest, that the predominant flow into the test region occurs through the cement plug/borehole interface region, with smaller contributions to total flow occurring through the wellbore damage zone, the plug core, and the surrounding undisturbed anhydrite bed.

The 2.0-m-long by 20-cm-diameter grout plug limits flow from the high-pressure (12.4 MPa) Bell Canyon aquifer to 0.6 liter/day (0.2 gal/day), a reduction factor of about 10^5. Tracer flow studies are consistent with a flow channel having a maximum width not greater than about $2x10^{-5}$cm, in which the maximum flow velocity is approximately 1.2 m/day. This suggests that predominant flow is not through a finite number of fractures, but through a region whose microstructure approximates a porous medium. If the flow path cross-sectional area is assumed to be equal to that of the wellbore, the corresponding permeability and connected porosity would be 50 microdarcies and 1.5%, respectively. Plug performance remained consistent throughout the relatively short 4-month test period.

If the measured data are attributed to flow through a formation disturbed zone surrounding the umbrella packer(positioned approximately 4 m above the cement grout plug), then the kA value of this disturbed zone is nearly one order of magnitude less than that through the plug+formation system. If the medium surrounding the cement grout plug is similar, the predominant flow must occur through the plug or plug/wellbore interface. It is of interest to note that if the cross-sectional area of the wellbore damage region surrounding the umbrella packer is assumed equal to that of the wellbore, it must have a permeability on the order of 10 microdarcies.

Experience from conducting the BCT and analysis of the test data have allowed the following conclusions to be drawn:

While an industrial capability exists in the form of downhole passive pressure recorders or a limited system for uphole monitoring of downhole conditions, these both have serious drawbacks in field testing. The passive systems have limited resolution capability

and require recovery of the sensing system, thus terminating the test sequence. The active system, while having adequate resolution (0.1 psi), was not readily compatible with the packers that were initially used. By suitable field modifications, both systems were successfully used; however, with minor improvements, these systems could be made even more effective.

Cement-emplacement technology is generally adequate to satisfy repository plugging requirements; however, plug compatibility with the host rock must be carefully assessed for each repository site. generally accepted laboratory cement-testing techniques need to be supplemented by flow characteristics and geochemical stability.

The BCT indicated that grouts can be effective in sealing boreholes, if proper care is exercised in matching physical properties of the local rock with grout mixtures. Further, the reduction in fluid flow provided by even limited length plugs is far in excess of that required by bounding safety assessments for the WIPP.

Future plans for the next and succeeding years include continued testing of the BCT, removal of selected core sections from a three-year-old plug emplaced during the initial WIPP site evaluation program in the Potash Core test (PCT) and the establishment of a Surface Wellbore Test Bank (SWTB) for the emplacement and subsequent removal at nominal 2-, 5-, 10-, 15-, 30-year increments of in-situ cured plugs for long-term analysis. Other field tests that will address multi-component, multi-barrier plugs, in-situ diagnostic techniques in large diameter plugs leading to shaft sealing experience, and in-situ determination of formation parameters are now in the planning stage."

DOE (U.S. Department of Energy), 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant. DOE/EIS-0026, Vol. 1 and 2. U.S. Department of Energy, Washington, D.C.

Alternative 2: The authorized WIPP facility, p. 1-5;

" The authorized WIPP facility would consist of both surface and underground facilities, including a waste-handling building, an underground-personnel building to support underground construction, an administration building, four shafts to the underground area, underground openings at a single level for waste disposal and for experiments, and various support structures. There would be a storage pile for mined rock (primarily salt), an evaporation pond for runoff from the mined-rock pile, a sewage-treatment plant, a disposal area for construction spoils, and a landfill for sanitary wastes. The construction of the facility would take 4.5 years, and the plant would be designed for an operating life of about 25 years. The facility would be operational in 1987.

The development of the WIPP would occur in two distinct phases: (1) site and preliminary-design validation (SPDV), in which two deep shafts and an underground experimental area would be constructed; and (2) full construction in which the required surface and underground facilities and the remaining shafts would be built. . . .

Over its 25-year operating life, the WIPP could receive about 6.2 million cubic feet of contact-handled TRU waste and as much as 250,000 cubic feet of remotely handled TRU waste. This would account for all of the TRU waste currently held in interim storage in Idaho, two-thirds of that expected to be generated at all DOE facilities between now and 1990, and all of that expected to be produced from 1990 through 2003. In addition, the WIPP could receive about 150 cubic feet of high-level waste for experiments."

2.1.1 Decisions for Which This Environmental Impact Statement Provides Environmental Input, p. 2-2;

" This environmental impact statement (EIS), prepared in accordance with the requirements of the National Environmental Policy Act (NEPA) of 1969, provides environmental information for the following decisions:

1. What should be the strategy for the long-term management of the TRU waste stored at INEL?
2. Should the TRU waste stored at the INEL be disposed of in the first available HLW repository or in a repository for TRU waste only, such as the authorized WIPP facility?
3. Should the WIPP facility at the Los Medanos site be constructed and operated?
4. If the WIPP facility is not to be constructed at the Los Medanos site, should the site be retained to preserve the option of characterizing it as a potential site for a combined TRU-HLW repository?

If the answer to the fourth question is yes, additional NEPA documentation will be prepared prior to decisions on the qualification of the Los Medanos site as a candidate for an HLW repository. The qualification of other sites, site selection, and repository construction

and operation will also require NEPA documentation (DOE, 1980a)."

2.1.2 Contents of This Environmental Impact Statement, p. 2-3, para. 6;
" Structure

This document consists of two parts. The first part consists of chapters 2 through 4. It begins with a description of the national program for the management of radioactive waste and the WIPP project (Chapter 2). Chapter 3 formulates four alternative plans for the disposal of the TRU waste now stored at the INEL. Chapter 4 analyses the environmental impacts of these four alternatives.

The second part of this document presents the environmental impacts of the authorized alternative. It describes the waste to be received at the WIPP (Chapter 5); the methods and the environmental impacts of transporting the waste (Chapter 6); the environment of the Los Medanos site in southeastern New Mexico (Chapter 7); and the design of the facility (Chapter 8). These data are the basis for a detailed analysis of the environmental impacts induced by its construction and operation (Chapter 9). Because the WIPP is designed to keep the waste isolated far into the future, Chapter 9 discusses environmental impacts both in the short term, during the operating life of the repository, and in the long term, for hundreds of thousands of years into the future."

DOE (U.S. Department of Energy), 1990a. Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant. DOE/EIS-0026-FS. U.S. Department of Energy, Office of Environmental Restoration and Waste Management, Washington, D.C. Available from NTIS as DE90005774.

Section 3.1.1 Changes to the Proposed Action and New Information or Circumstances, p 3-2;
" This subsection describes specific proposed changes not covered in the 1980 FEIS, and new circumstances and information that have developed since 1980. These changes have been factored into the impact analyses in this final SEIS.

○ Clarifying that the WIPP may eventually include permanent emplacement of post-1970 TRU waste from the 10 DOE generator facilities listed in Table 3.1. According to the 1981 Record of Decision, the WIPP was to initially dispose of waste in retrievable storage at the Idaho National Engineering Laboratory. After this waste was emplaced at the WIPP, the WIPP would then be available to dispose of TRU waste from ". . . other defense waste generating facilities, . . ." which were not specified by name.

The 1980 FEIS focused on the total inventory of 6.2 million cubic feet of CH TRU waste and 250,000 cubic feet of RH TRU waste expected to be received at the WIPP over its 25-year operating life. In 1980 this amount included all of the CH and RH waste in retrievable storage at the Idaho National Engineering Laboratory, two-thirds of the estimated waste to be generated at all DOE facilities between 1980 and 1990, and all TRU waste to be generated at all facilities between 1990 and 2003.

The DOE still proposes that the phased development of the WIPP proceed for the permanent emplacement of 6.2 million cubic feet of CH and 250,000 cubic feet of RH waste. This SEIS clarifies that the waste may eventually come directly from the 10 DOE generator facilities listed in Table 3.1. By analyzing the impacts of transportation and emplacement of post-1970 waste from all 10 DOE generator facilities, this SEIS updates the FEIS analyses of the environmental impacts of transporting to and emplacing in the WIPP only post-1970 TRU waste from Idaho National Engineering Laboratory and Rocky Flats Plant."

p. 3-4;
" Changes in volume of the TRU waste inventory. In 1980, it was contemplated that approximately 6.2 million ft^3 of CH and 250,000 ft^3 of RH TRU waste would be available for disposal at the WIPP. The WIPP as designed would be able to accommodate this volume of TRU waste. Recent estimates indicate that approximately 5.6 million ft^3 of CH TRU and 95,000 ft^3 of RH TRU waste are in retrievable storage at 6 generator/storage facilities or would be newly generated at these facilities and by an additional 4 facilities through the year 2013, the projected operating life of the WIPP (Tables 3.1 and 3.2). This lesser volume is currently estimated because of an improvement in recordkeeping and inventory sampling, a change in the definition of TRU waste (Appendix B), changes to the WIPP Waste Acceptance Criteria (WAC) (Subsection 2.3 and Appendix A), and expected facility process modifications that would result in waste minimization and volume reduction (e.g., Rocky Flats Plant supercompacter).

This SEIS, however, assesses the impacts of the WIPP using the volume limits of 6.2 million ft^3 of CH TRU and 250,000 ft^3 of RH TRU waste to set an upper limit on the potential impacts of filling the WIPP repository to its design capacity. The WIPP design capacity is sufficient to encompass TRU waste generated from new or planned defense-related facilities through the year 2013 (e.g., Special Isotope Separation Facility and the proposed Modular High Temperature Gas Cooled Reactor at the Idaho National Engineering Laboratory). Thus, the impacts associated with transporting, receiving, and permanently emplacing waste from all 10 facilities is conservatively "bounded" by the SEIS analysis."

DOE (U.S. Department of Energy), 1990b. Final Safety Analysis Report. WP02-9, Rev. 0. May 1990. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

PREFACE

"**Background**

This Final Safety Analysis Report (FSAR) has been prepared for the Waste Isolation Pilot Plant (WIPP) in order to satisfy the commitments made in the Working Agreement for Consultation and Cooperation(Article III, Section C and Article IV, Section K, known as the Working Agreement) between the State of New Mexico and the U.S. department of energy (DOE) and the requirements of Order DOE 5481.1B,Safety Analysis and Review System.

The objectives of the Safety Analysis Preparation and Review process, as specified in Order DOE 5481.1B, ensure that:

1. Potential hazards are systematically identified;

2. Potential consequences are analyzed;

3. Reasonable measures to eliminate, control or mitigate the hazards have been taken, including, where applicable, compliance with commitments made in environmental assessments and impact statements;

4. There is documented management authorization of the DOE operation based upon an objective assessment of the safety analysis.

Specific hazards that are analyzed include credible natural hazards such as flood, weather (tornado, wind, etc.) and earthquake; and credible man made hazards such as fire, explosion, radiation, and mining hazards. Mitigating measures include facility design and construction, operational controls, and administrative limits.

This FSAR represents a statement and commitment by the DOE that the WIPP facility can be operated safely and at minimum risk, if operated in accordance with this FSAR. Consequently, this FSAR has been prepared to document that a systematic analysis of the potential hazards associated with operating the WIPP facility has been performed (objective 1 of Order DOE 5481.1B); that potential consequences have been analyzed (objective 2 of Order DOE 5481.1B); and that reasonable measures have been taken to eliminate, control, or mitigate the hazards (objective 3 of Order DOE 5481.1B). In addition, this FSAR documents the implementation of commitments made in the environmental impact statement regarding the mitigation of adverse impacts to the environment (objective 3 of Order DOE 5481.1B)."

Section 1.1 INTRODUCTION; p 1.1-1. para 3;
" In addition, this FSAR has been prepared in accordance with Article III of the 1981 Consultation and Cooperation Agreement (C&C Agreement) between the DOE and the State of New Mexico and, as such, represents the most comprehensive document concerning the WIPP facility both in general terms and specifically as related to public health and safety."

Section 1A.1.1.1 Earthquakes, p 1A.1-2;
" Seismic risk analysis has defined a conservative DBE for the WIPP facility with a maximum ground acceleration of 3.2 in/s^2 (0.1g) horizontally and vertically, with 10 maximum stress cycles, and based on a 1000-year recurrence interval. This maximum acceleration is used in analysis and design of surface confinement facilities and equipment. Response spectrum analysis was contacted using structural mode shapes and frequencies for two principal horizontal directions, and modal responses (shear, moments,stresses, deflection, accelerations) were combined to assess the contribution to loading from seismic sources.
Seismic overturning moment was used to compute foundation reactions and account for vertical earthquake effects. . . . "

DOE (U.S. Department of Energy). 1995. Safety Analysis Report. DOE/WIPP-95-2065, Rev. 0, November 30, 1995. Carlsbad Area Office, Carlsbad, NM.

Facility Background and Mission, p. 1-4;

" The United States Department of Energy (DOE) was authorized by Public Law 96-164[1] to provide a research and development facility for demonstrating the safe permanent disposal of transuranic (TRU) wastes from national defense activities and programs of the United States exempted from regulations by the U.S. Nuclear Regulatory Commission (NRC). The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico near Carlsbad, was constructed to determine the efficacy of an underground repository for disposal of TRU wastes.

In accordance with the 1981 and 1990 Records of Decision (ROD),[2,3] the development of the WIPP was to proceed with a phased approach. Development of the WIPP began with a siting phase, during which several sites were evaluated and the present site selected based on extensive geotechnical research, supplemented by testing.

The site and preliminary design validation (SPDV) followed the siting phase, during which two shafts were constructed, an underground testing area was excavated, and various geologic, hydrologic, and other geotechnical features were investigated. The construction phase followed the SPDV phase during which surface structures for receiving waste were built and underground excavations were completed for waste emplacement. . . ."

p. 1-5, para 1;

" This Safety Analysis Report (SAR) documents the safety analyses that develop and evaluate the adequacy of the WIPP CH TRU safety bases necessary to ensure the safety of workers, the public, and the environment from the hazards posed by WIPP waste handling and emplacement operations during the disposal phase and hazards associated with the decommissioning and decontamination phase.

The analyses of the hazards associated with the long-term (10,000 year) disposal of TRU and TRU mixed waste, and demonstration of compliance with the requirements of 40 CFR 191, Subpart B[4] and 40 CFR 268.6[6] will be addresses in detail in the WIPP Final Certification Application scheduled for submittal in October 1996 (40 CFR 191) and the No-Migration Variance Petition (40 CFR 268.6) scheduled for submittal in June 1996. Section 5.4, Long-Term Waste Isolation Assessment summarizes the current status of the assessment. Section 5.4 will be updated upon completion of the long-term assessment demonstration (currently scheduled for the FY-97 Annual Update)."

2.5 Meteorology, 2.5.1 Recent Climatic Conditions, p. 2-51;

" Current climatic conditions are provided to allow for the assessment of impacts of these factors on the disposal unit and the site. The WIPP facility does not rely on climatic conditions to control waste migration; however, meteorological information is used in the evaluation of the air pathway during operation of the facility."

2.5 Meteorology, 2.5.1.2 Regional Meteorological Conditions for Design and Operating Bases, 2.5.1.2.1 Heavy Precipitation, p. 2-51;

" The maximum 24-hour rainfall at Roswell was 5.65 inches in November 1901.[2] The maximum 24-hour snowfall in Roswell was 15.3 inches in December 1960. The greatest snowfall during a 1-month period was 23.3 inches in February 1905.[3]."

3.2.4 Water Level (Surface Flood) Design, p. 3-17;

" Flood elevations for the Pecos River and the vicinity of the WIPP facility are described in Chapter 2. The WIPP facility nominal grade elevation is more than 400 ft above the probable maximum flood (PMF) level of the Pecos River, and the WIPP facility is separated from the river by about 14 mi of gradually rising land. Since there are no perennial or intermittent streams near the WIPP facility that have the potential for sustained flooding of the site, neither buoyancy nor static water forces due to flood elevations shall be considered in the WIPP facility design.

3.2.4.1 Phenomena Considered in Design Load Calculations

Phenomena such as flood currents or wind-induced waves shall not apply because the grades for the WIPP facility structures are more than 400 ft above the PMF level on the Pecos River, and none of the local drainage ways has the potential for sustained flooding of the WIPP facility.

3.2.4.2 Flood Force Application

As stated above, the WIPP facility structures are above the PMF level and are not subjected to flood loadings.

3.2.4.3 Flood Protection

Protection against the PMF level on the Pecos River shall not be required for WIPP facility SSCs. Protection from flooding, caused by locally intense precipitation, is described in Chapter 2.

An accidental rupture of the fire water tanks may result in a local flood around the tanks, and provisions shall be made so that any liquid released does not cause a flood of sufficient depth to endanger equipment or systems. Static and dynamic fluid pressures resulting from a tank rupture shall be considered in the design of structures where applicable. Water storage tanks shall be located outside of buildings so that water released from them does not flood Design Class II SSCs, and floor drainage systems shall accommodate any water from other small tanks or piping systems within the buildings."

DOI (Department of the Interior). 1995a. 43 CFR Part 3160, Onshore Oil and Gas Operations, Federal and Indian Oil and Gas Leases Drilling Operations. Subpart 3162, Requirements for Operating Rights, Owners and Operators. Subpart 3162.3-4, Well Abandonment. 43 CFR Chapter 2. October 9, 1995. 53 Federal Register 22 847, June 17, 1988. Bureau of Land Management, Washington, D.C.

3162.3-4 Well abandonment:

" (a) The operator shall promptly plug and abandon, in accordance with a plan first approved in writing or prescribed by the authorized officer, each newly completed or recompleted well in which oil or gas is not encountered in paying quantities or which, after being completed as a producing well, is demonstrated to the satisfaction of the authorized officer to be no longer capable of producing oil or gas in paying quantities, unless the authorized officer shall approve the use of the well as a service well for injection to recover additional oil or gas or for subsurface disposal of produced water. In the case of a newly drilled or recompleted well, the approval to abandon may be written or oral with written confirmation.

(b) Completion of a well as plugged and abandoned may also include conditioning the well as water supply source for lease operations or for use by the surface owner or appropriate Government Agency, when authorized by the authorized officer. All costs over and above the normal plugging and abandonment expense will be paid by the party accepting the water well.

(c) No well may be temporarily abandoned for more than 30 days without the prior approval of the authorized officer. The authorized officer may authorize a delay in the permanent abandonment of a well for a period of 12 months. When justified by the operator, the authorized officer may authorize additional delays, no one of which may exceed an additional 12 months. Upon the removal of drilling or producing equipment from the site of a well which is to be permanently abandoned, the surface of the lands disturbed in connection with the conduct of operations shall be reclaimed in accordance with a plan first approved or prescribed by the authorized officer."

DOI (Department of the Interior). 1995b. 43 CFR Part 3593, Boreholes and Samples. Subpart 3593.1, Core and Testhole Cores, Samples, Cuttings. 43 CFR Chapter 2, October 9, 1995. 53 Federal Register 22 847, June 17, 1988. Bureau of Land Management, Washington, D.C.

3593.1, Core and test hole cores, samples, cuttings:

" (a) The operator/lessee shall submit promptly to the authorized officer a signed copy of records of all core or test holes made on the lands covered by the lease, license or permit. The records shall be a form that will allow the position and direction of the holes to be located on a map. The records shall include a log of all strata penetrated and conditions encountered, such as water, gas or unusual conditions. Copies of analysis of all samples shall be transmitted to the authorized officer as soon as obtained or as requested by the authorized officer. The operator/lessee shall furnish the authorized officer a detailed lithologic log of each drill hole and all other in-hole surveys or other logs produced. The core from test holes shall be retained by the operator/lessee for 1 year or such other period as may be directed by the authorized officer, and shall be available for inspection by the authorized officer. The authorized officer may cut such cores and receive samples as appropriate. Upon the request of the authorized officer, the operator/lessee shall furnish samples of strata, drill cuttings, and mill products.

(b) Surface drill holes for development or holes for prospecting shall be abandoned to the satisfaction of the authorized officer by cementing and/or casing or by other methods approved in advance by the authorized officer and in a manner to protect the surface and not endanger any present or future underground operation or any deposit of oil, gas, other mineral substances or aquifer.

(c) Logs and analyses of development holes shall not be required unless specifically requested by the authorized officer. Drill holes may be converted to surveillance wells for the purpose of determining the effect of subsequent operations upon the quantity, quality of pressure of ground water or mine gases. Such conversion may be required by the authorized officer or requested by the operator/lessee and approved by the authorized officer. Prior to the termination of the lease, license or permit term, all surveillance wells shall be reclaimed unless the surface owner assumes responsibility for reclamation of such surveillance wells. The transfer of liability for reclamation shall be approved in writing by the authorized officer.

(d) When drilling on lands with potential for encountering high pressure oil, gas or geothermal formations, drilling equipment shall be equipped with blowout control devices acceptable to the authorized officer."

EPA (U.S. Environmental Protection Agency), 1993. 40 CFR Part 191 Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. Federal Register, Volume 58, No. 242, pp. 66398-66416, December 20, 1993, Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

PREAMBLE: SUMMARY;

" The U.S. Environmental Protection Agency (EPA) is promulgating amendments to the environmental standards for the disposal of spent nuclear fuel, high-level and transuranic wastes (40 CFR 191.15 and Subpart C).

EPA originally promulgated these standards in 1985 pursuant to the Agency's authorities and responsibilities under the Nuclear Waste Policy Act of 1982, as amended, the Atomic Energy Act of 1954, as amended, and §2(a)(6) of Reorganization Plan No. 3 of 1970 (5 USC app. 1). In 1987, following a legal challenge, the U.S. Court of Appeals for the First Circuit (hereinafter referred to as 'the First Circuit' or ' the court') remanded subpart B of the 1985 standards to the Agency for further consideration. *Natural Resources Defense Council, Inc. v. United States Environmental Protection Agency*, 824 F.2d 1258 (1st Cir. 1987). Recently enacted legislation, (Pub. L. 102-579) known as the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA), however, reinstates the 1985 disposal standards except 'the 3 aspects of §§191.15 and 191.16 of such [standards] that were subject of the remand ordered' by the First Circuit. The WIPP LWA directs EPA to expedite issuance of final disposal standards and specifies that such regulations shall not be applicable to the characterization, licensing, construction, operation, or closure of any site required to be characterized under §113(a) of Public Law 97-425, the Nuclear Waste Policy Act of 1982.

Today's action represents the Agency's response to this legislation and to the issues raised by the court pertaining to individual and ground-water protection requirements. After considering the relevant comments received on the February 10, 1993 proposed rulemaking, the Agency has taken this final action in the form of amendments to parts 191 of title 40 of the Code of Federal Regulations. In so doing, EPA has not revised any of the regulations reinstated by the WIPP LWA.

DATES: These amendments will become effective on January 19, 1994. These amendments will be promulgated for purposes of judicial review at 1 p.m. eastern standard time on December 20, 1993."

50 FR 38085, col 2;

" §191.12 Definitions.

Unless otherwise indicated in this Subpart, all terms shall have the same meaning as in Subpart A of this Part.

(a) "Disposal system" means any combination of engineered and natural barriers that isolate spent nuclear fuel or radioactive waste after disposal.

50 FR 38086, col. 2;

" §191.14 Assurance requirements.

To provide the confidence needed for long-term compliance with the requirements of 191.13, disposal of spent nuclear fuel or high-level or transuranic waste shall be conducted in accordance with the following provisions, except that these provisions do not apply to facilities regulated by the Commission (see 10 CFR Part 60 for comparable provisions applicable to facilities regulated by the Commission):"

. . .

" (b) Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring."

. . .

(d) Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included."

EPA (U.S. Environmental Protection Agency), 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. Federal Register, Vol. 61, No. 28, pp. 5224-5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C. In NWM Library as KF70.A35.C751 1996 (Reference).

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992. EFFECTIVE DATE: These regulations are effective April 9, 1996."

§194.14 Content of compliance certification application, p. 5238, col. 2;
" Any compliance application shall include:

. . .

(b) A description of the design of the disposal system including:

(1) Information on materials of construction including, but not limited to: Geologic media, structural materials, engineered barriers, general arrangement, and approximate dimensions; and

(2) Computer codes and standards that have been applied to the design and construction of the disposal system."

State of New Mexico, Oil Conservation Division, Energy, Mineral, and Natural Resources Department. 1988. Order R-111-P, Potash Areas of Eddy and Lea Counties, NM. Case 9316, Revision to Order R-111-P, April 21, 1988. Santa Fe, NM.

F. PLUGGING AND ABANDONMENT OF WELLS;

" (1) All wells heretofore and hereafter drilled within the Potash Area shall be plugged in a manner and in accordance with the general rules or field rules established by the Division that will provide a solid cement plug through the salt section and any water-bearing horizon and prevent liquids or gases from entering the hole above or below the salt section.

(2) The fluid used to mix the cement shall be saturated with the salts common to the salt section penetrated and with suitable proportions but not more than three (3) percent of calcium chloride by weight of cement being considered the desired mixture whenever possible."

State of New Mexico, Oil Conservation Division, Energy, Minerals, and Natural Resources Department. 1991. Rule 202, Plugging and Permanent Abandonment, March 1, 1991. Santa Fe, NM.

RULE 202. - PLUGGING AND PERMANENT ABANDONMENT:

" A. NOTICE OF PLUGGING

(1) Notice of intention to plug must be filed with the Division on Form C-103, Sundry Notices and Reports on Wells, by the operator prior to the commencement of plugging operations, which notice must provide all of the information required by Rule 1103 including operator and well identification and proposed procedures for plugging said well, and in addition the operator shall provide a well-bore diagram showing the proposed plugging procedure. Twenty-four hours notice shall be given prior to commencing any plugging operations. In the case of a newly drilled dry hole, the operator may obtain verbal approval from the appropriate District Supervisor or his representative of the method of plugging and time operations are to begin. Written notice in accordance with this rule shall be filed with the Division ten (10) days after such verbal approval has been given.

B. PLUGGING

(1) Before any well is abandoned, it shall be plugged in a manner which will permanently confine all oil, gas and water in the separate strata in which they are originally found. This may be accomplished by using mud-laden fluid, cement and plugs singly or in combination as approved by the Division on the notice of intention to plug.

(2) The operator shall mark the exact location of plugged and abandoned wells with a steel marker not less than four inches (4") in diameter set in cement and extending at least four feet (4') above mean ground level. The operator name, lease name and well number and location, including unit letter, section, township and range, shall be welded, stamped or otherwise permanently engraved into the metal of the marker.

(3) As soon as practical but no later than one year after completion of plugging operations, the operator shall:

(a) fill all pits;
(b) level the location;
(c) remove deadmen and all other junk; and
(d) take such other measures as are necessary or required by the Division to restore the location to a safe and clean condition.

(4) Upon completion of plugging and clean up restoration operations as required, the operator shall contact the appropriate district office to arrange for an inspection of the well and location.

C. Reports

(1) The operator shall file Form C-105, Well Completion or Recompletion Report and Log as provided in Rule 1105.

(2) Within thirty (30) days after completing all required restoration work, the operator shall file with the Division, in TRIPLICATE, a record of the work done on Form C-103 as provided in Rule 1103.

(3) The Division shall not approve the record of plugging or release any bonds until all necessary reports have been file and the location has been inspected and approved by the Division."

State of New Mexico, State Engineer's Office. 1995. Article 4, Well Drillers' Licensing-Construction, Repair, and Plugging of Wells: Articles 4-14, Shallow Wells Construction Repair Plugging, and 4-20.2, Abandonment-Plugging. Santa Fe, NM.

Article 4-14, Shallow Wells-Construction-Repair-Plugging:
" The State Engineer has not adopted any general specifications for the construction, repair, or plugging of non-artesian or shallow wells. Any specific requirements and provisions made by the State Engineer shall be set forth in the permit. Application for Permit to Repair is required for all repair work, cleaning, scaling, deepening, modification of casing, or other work requiring the use of a well rig. Any specific requirements or conditions governing the repair will be set out in the approval of the permit. If plugging is required (Article 2-13), shallow wells shall be plugged by filling to the ground surface or, if the casing is not to be removed, by welding a steel plate or cap to the casing."

Article 4-20.2, Abandonment-Plugging:
" In the event that the test or exploratory well is to be abandoned, the State Engineer shall be notified. Such well shall be plugged in accordance with Article 4-19.1 so that the fluids will be permanently confined to the specific strata in which they were originally encountered."

U.S. Congress, 1992. Waste Isolation Pilot Plant Land Withdrawal Act, Public Law 102-579, October 1992, 102nd Congress, Washington, D.C.

An Act
To withdraw land for the Waste Isolation Pilot Plant, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

"SEC.7.DISPOSAL OPERATIONS.

(a)TRANSURANIC WASTE LIMITATIONS.--

(1) REM LIMITS FOR REMOTE-HANDLED TRANSURANIC WASTE.--

(A) 1,000 REMS PER HOUR.--No transuranic waste received at WIPP may have a surface dose rate in excess of 1,000 rems per hour.

(B) 100 REMS PER HOUR.--No more than 5 percent by volume of the remote-handled transuranic waste received at WIPP may have a surface dose rate in excess of 100 rems per hour.

(2) CURIE LIMITS FOR REMOTE-HANDLED TRANSURANIC WASTE.--

(A) CURIES PER LITER.--Remote-handled transuranic waste received at WIPP shall not exceed 23 curies per liter maximum activity level (averaged over the volume of the canister).

(B) TOTAL CURIES.--The total curies of the remote-handled transuranic waste received at WIPP shall not exceed 5,100,000 curies.

(3) CAPACITY OF WIPP.--The total capacity of WIPP by volume is 6.2 million cubic feet of transuranic waste."

BIBLIOGRAPHY DOCUMENTS

Beauheim, R.L., Saulnier, Jr., G.J., and Avis, J.D. 1991. Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report. SAND90-0083. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" Pressure-pulse tests have been performed in bedded evaporites of the Salado Formation at the Waste Isolation Pilot Plant (WIPP) site to evaluate the hydraulic properties controlling brine flow through the Salado. Hydraulic conductivities ranging from about 10^{-14} to 10^{-11} m/s (permeabilities of about 10^{-21} to 10^{-18} m^2) have been interpreted from nine tests conducted on five stratigraphic intervals within eleven meters of the WIPP underground excavations. Tests of a pure halite layer showed no measurable permeability. Pore pressures in the stratigraphic intervals range from about 0.5 to 93. MPa. An anhydrite interbed (Marker Bed 139) appears to be one or more orders of magnitude more permeable than the surrounding halite. Hydraulic conductivities appear to increase, and pore pressures decrease, with increasing proximity to the excavations. These effects are particularly evident within two or three meters of the excavations. Two tests indicated the presence of apparent zero-flow boundaries about two to three meters from the boreholes. The other tests revealed no apparent boundaries within the radii of influence of the tests, which were calculated to range from about four to thirty-five meters from the test holes. The data are sufficient to determine if brine flow through evaporites results from Darcy-like flow driven by pressure gradients within naturally interconnected porosity or from shear deformation around excavations connecting previously isolated pores, thereby providing pathways for fluids at or near lithostatic pressure to be driven towards the low-pressure excavations. Future testing will be performed at greater distances from the excavations to evaluate hydraulic properties and processes beyond the range of excavation effects.

Bechtel National. 1986. Quarterly Geotechnical Field Data Report. DOE/WIPP-221. U.S. Department of Energy, Carlsbad, NM.

FOREWORD, p iii;

" The purpose of the Quarterly Geotechnical Field Data Reports is to meet the U.S. Department of Energy intent to provide geotechnical and related information from WIPP underground activities to interested persons or groups in a timely manner. This Quarterly Geotechnical Field Data Report (GFDR) presents information obtained from the geotechnical studies at the WIPP site underground facilities from April 1 through June 30, 1985, as well as all previous data collected from the geomechanical instruments. During this period, the geotechnical activities at the site included maintaining and repairing instruments and monitoring previously installed geomechanical instruments in shafts, underground drifts, and test rooms. The data presented in this GFDR reflect the update of continuing measurements and monitoring. Also continuing and included in this report are preliminary geotechnical and structural analyses and interpretations of the data.

The GFDR is organized into two principle parts. The first part, Geotechnical Field Data, . . ."

Borns, D.J., 1985. Marker Bed 139: A Study of Drillcore from a Systematic Array. SAND85-0023. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3;

" In southeastern New Mexico, Marker Bed 139 (referred to in this report as MB139) is one of 45 numbered siliceous or sulfatic units within the Salado Formation of the northern Delaware Basin. MB139 is divided into five zones. Zones I and V are the upper and lower contact zones, respectively. Zone II is a syndepositionally deformed subunit of polyhalitic anhydrite. Zone III is mixed anhydrite and polyhalitic anhydrite, a distinctive pale-green and pink, with subhorizontal fractures. Zone IV consists of interlayered halite and anhydrite without the overprint of polyhalite.

This sequence was transitional between submarine and subaerial. The anhydritic units of MB139 formed in salt-pan or mudflat environments or both. Undulations observed along the upper contact of MB139 are interpreted to result from traction deposits or from reworking of the upper portion of the marker bed during the transition from anhydrite to halite deposition. Zones II and III exhibit soft-sediment deformation and later traces of dewatering; e.g., formation of stylolites. Such deformation is not observed in the halite above MB139 or in Zone V and the halite units below MB139.

A distinctive set of subhorizontal fractures occurs in MB139 in mid-Zone III and, to some extent, in Zone IV. These fractures are partially infilled with halite and polyhalite. Brine occurrences at the mined facility horizon at the Waste Isolation Pilot Plant may be related to these fractures. The fractures formed either in response to stress cycles that were functions of sedimentation and erosion, or in response to deformation in the underlying Castile Formation. The subhorizontal orientation, dominant in the sampling to date, is more consistent with the interplay between stress and sedimentation cycles."

Borns, D.J., and Stormont, J.C. 1988. An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone. SAND87-1375. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" For nuclear waste repositories with both long operational periods (50 yr) and long performance assessment periods (10 000 yr), the Disturbed Rock Zone (the zone of rock in which the mechanical and hydrologic properties have changed in response to excavation; abbreviated as DRZ) is important to both operational (e.g., slab or fracture failure of the excavation) and long term performance (e.g., seal system performance and fluid transport). At the Waste Isolation Pilot Plant (WIPP), the DRZ has been characterized with three approaches: visual observation; geophysical methods; and permeability measurements. Visual observations in drillholes indicate that fluids and fractures are common in the host rock of the underground facility. Geophysical studies have utilized radar, electromagnetic (EM), and direct current (DC) electromagnetic methods. Radar has been useful, but the penetration is limited by the water content and the bedded nature of the host rock. The EM method was able to detect a fourfold increase in resistivity from 1 to 5 m into the rock. This trend reflects a fourfold increase in the moisture content from near the excavation (0.5 to 1% by weight) to 5 m into the host rock (2 to 3% by weight). The DC method has been able to detect zones of moisture around the excavation. Numerous gas permeability measurements indicate that beyond 2 m from an excavation halite and interbeds (anhydrite and clay) allow very low gas flow (calculated permeabilities < 1 microdarcy for gas flow tests and < 0.01 microdarcy for brine-based permeability tests). Within 2 m of the excavation, very high flow rates (10^4 SCCM) were measured. All three approaches have defined a DRZ at the WIPP extending laterally throughout the excavation and varying in depth from 1 to 5 m, according to the size and age of the opening."

Borns, D.J., and Stormont, J.C. 1989. The Delineation of the Disturbed Rock Zone Surrounding Excavations in Salt. Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Proceedings of the 30th US Symposium on Rock Mechanics, June 19-22, 1989, A.W. Khair, ed., SAND88-2230c, pp. 353-360, A.A. Balkema, Brookfield, VT.

ABSTRACT, p 353;
" At the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico, the Disturbed Rock Zone (DRZ, the zone of rock in which the mechanical and hydrologic properties have changed in response to excavation) has been characterized with visual observations, geophysical methods, and gas-flow measurements. The visual observations, geophysics, and gas-flow tests have defined a DRZ at the WIPP extending laterally throughout the excavation and varying in depth from 1 to 5 m. Desaturation and microfracturing has occurred to some degree within the zone. The dilation that results from the microfracturing in the DRZ provides a component of the observed closure."

Chan, K.S., Bodner, S.R., Fossum, A.F., and Munson, D.E. 1992. A Constitutive Model for Inelastic Flow and Damage Evolution in Solids Under Triaxial Compression. Mechanics of Materials, SAND92-0546J, Vol. 14, No. 1, pp. 1-14.

ABSTRACT, p 1;

" A constitutive model for describing time-dependent, pressure-sensitive inelastic flow and damage evolution in crystalline solids under non-hydrostatic compression has been developed on the basis that the relevant damage and dislocation flow processes both contribute to the overall inelastic strain rate. A damage-based kinetic equation is first formulated using the work-conjugate approach and the continuum damage concept. That relation is then added to the dislocation-based kinetic equation of a multi-mechanism deformation (M-D) model to obtain the macroscopic inelastic strain rate. The proposed kinetic relation for the overall inelastic strain rate is shown to be derivable from a flow potential. The kinetic equation indicates plastic dilitancy under triaxial compression when the damage term is activated, and leads to plastic incompressibility when inelastic straining is primarily provided by dislocation flow mechanisms. The dependence of creep rate and plastic dilitancy on confining pressure shown by model calculations for rock salt is in accord with experimental observations."

COE (U.S. Army Corps of Engineers). 1985. Federal Engineering Operating Procedures for Construction of the Waste Isolation Pilot Plant.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

DOE (U.S. Department of Energy) 1986. Waste Isolation Pilot Plant Design Validation Final Report. DOE/WIPP 86-010. U.S. Department of Energy, Carlsbad, NM.

EXECUTIVE SUMMARY, INTRODUCTION, p 1;

" The Waste Isolation Pilot Plant (WIPP) is being developed by the U. S. Department of Energy (DOE) as a research and development facility to demonstrate the safe disposal of radioactive waste from U. S. defense programs. The facility is located in southeastern New Mexico, about 25 miles east of the city of Carlsbad. Underground development is at a depth of about 2,150 feet in thick deposits of bedded salt. The facility operation will include in situ experiments addressing technical issues for defense waste programs and storage of defense related contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste.

In 1979, the DOE established a Site and Preliminary Design Validation (SPDV) Program to provide additional confidence in the siting and design of the WIPP facility. On July 1, 1981, the DOE entered into an agreement with the State of New Mexico whereby the DOE would perform certain work to validate the reference design of the WIPP underground openings. The results of the site validation portion of the program are presented in the report titled Results of Site Validation Experiments, Volumes I and II, TME document 3177, dated March 1983. The results of the preliminary design validation portion of the program are presented in the report Waste Isolation Pilot Plant Preliminary Design Validation Report, dated March 30, 1983.

Design validation of the WIPP is defined as the process by which the reference design of the underground openings is confirmed by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. The design validation process consists of an assessment of the condition and behavior of shafts, drifts and a full-sized, four-room test panel excavated during the SPDV Program and full WIPP construction. Based on this assessment of these excavations, and on predictions of their future behavior, any modifications to the design criteria, design bases or design configurations required to achieve a validated reference design will be developed. In addition, the validated reference design may be modified in the future as still more data and experience are gained during a 5-year demonstration period (period during which all waste must be retrievable) and permanent storage operations.

The WIPP Preliminary Design Validation Report was an interim report prepared as part of the overall validation of the WIPP underground opening reference design. The WIPP Design Validation Final Report contains additional information gathered after completion of the SPDV Program. This information has been analyzed and evaluated to complete the design validation process for the WIPP.

Four types of information were gathered for the WIPP Design Validation Final Report:

(1) observations of the behavior of the underground openings;
(2) descriptions of the geologic conditions encountered during underground construction;
(3) descriptions of core samples from instrumentation and other holes in the roof

and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

The design validation process provides for the collection, analysis and evaluation of in situ data. This process is designed to permit determination of the need to modify elements of the underground opening reference design so that construction and operation of the full facility can proceed in a timely, safe, environmentally acceptable and cost effective manner. Observation and instrumentation data have been collected and evaluated for each of the underground design elements. Tables I through VI at the end of this summary present the evaluation results for the design criteria, design bases and design configurations of the shafts and horizontal openings. . . ."

DOE (U.S. Department of Energy). 1988. Geotechnical Field Data Report and Analysis Report. DOE/WIPP 87-017. U.S. Department of Energy, Carlsbad, NM.

FOREWORD AND ACKNOWLEDGEMENTS;

" The Geotechnical Field Data and Analysis Report (GFDAR) is prepared to provide a timely assessment of the geotechnical status of the Waste Isolation Pilot Plant (WIPP). During the period of shaft sinking and construction of the principle underground access and experimental areas, reporting was on a quarterly basis. Because geotechnical responses of existing underground facilities have slowed to nearly steady-state and excavation of the waste storage panels will take place more slowly and over an extended period, reporting in the coming years will be on an annual cycle. Data collected before June 30 of the year of the report will be presented and analyzed. This report presents and analyzes all data collected between July 31, 1986, and June 30, 1987.

The two-volume format of the GFDAR was selected to meet the needs of several audiences. Volume I focuses on the performance of the various underground facilities including the three shafts, shaft stations, access drifts, test rooms, and waste storage areas. It provides a direct evaluation of the geotechnical aspects of performance in the context of the relevant design criteria. In addition, it provides, where possible, projections of the future performance of these facilities. The results of stratigraphic mapping and the occurrence of gas and brine are also documented. The depth and breadth of analysis for the different underground facilities varies according to the types and quantities of data that are available, and the complexity of the recorded geotechnical responses. The anticipated audience of this volume is primarily Project and external personnel who are interested in engineering aspects of facility performance.

Volume II constitutes the principle documentation and presentation of data and techniques used to acquire the data, the performance history of the instrumentation, and the complete set of data from each of the underground facilities. In addition, it presents the results of geologic logging, stratigraphic mapping, and mapping and evaluation of excavation-induced fractures. This volume has as its anticipated audience those Project personnel who need to perform data analyses beyond those provided in Volume I, and external personnel who may choose to perform other analyses and evaluations for their own purposes. Data tapes will be made available at nominal cost upon request to the U. S. Department of Energy (DOE) . . ."

DOE (U.S. Department of Energy). 1995. "Waste Isolation Pilot Plant Seal System Design Report," DOE/WIPP-95-3117. Carlsbad, NM.

ABSTRACT, p. iii;

" This report documents the Waste Isolation Pilot Plant shaft sealing system design. The seals are designed to limit the release of radionuclides and hazardous constituents from an underground nuclear waste repository in salt. Design concepts documents in this report will form the basis for no-migration variance petition modeling. In addition, these concepts are the basis for detailed sealing system design development and evaluations that will be completed in 1996 in support of the planned Compliance Certification Application. The report describes the geologic and hydrologic setting for the seals, presents qualitative and quantitative design guidance, describes the design, documents the sealing materials and their properties, and discusses evaluations of sealing system performance. The design uses a variety of common materials that have very low permeability, demonstrated technologies for construction processes, multiple components to perform each intended function, and the entire length of the shafts to effect a seal system that will meet the performance requirements. For the permanent or long-term seal that resists both gas and brine flow, more than 500 ft of highly compacted crushed salt is used in series with more than 400 ft of clay barriers. The design retards gas flow in the short term using a combination or a rigid concrete barrier (enhanced by an asphalt waterstop) and a compacted clay barrier approximately 100 ft high. Short-term brine flow down the shaft is limited by a clay barrier within the overlying formation and by a combination of more than 500 ft of asphalt, clay, and concrete barriers within the salt."

DOE (U.S. Department of Energy). 1995. Conceptual Design for Operational Phase Panel Closure Systems. DOE/WIPP-95-2057, U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-i;

" The Waste Isolation Pilot Plant (WIPP), a U.S. Department of Energy (DOE) research facility located near Carlsbad, New Mexico, was established to demonstrate the safe disposal of defense-generated transuranic (TRU) waste. The WIPP repository is approximately 2,150 feet (ft) (655 meters [m]) below the surface in bedded salt. The WIPP facility includes a northern experimental area, a shaft-pillar area, and a waste-disposal area. The waste disposal area is comprised of panels, each of which consists of seven rooms and two access panel entries (Figure ES-1).

Following completion of waste emplacement in each panel, ventilation will be established in the next panel to be used and the panel containing the waste will be closed. The DOE will seek approval for 'partial closure' of each of the panels as they are sequentially filled with waste on a panel-by-panel basis. Partial closure is the process of rendering a part of the underground repository inactive and closed according to the approved facility closure plans.

The plan covers administrative procedures deemed necessary by the U. S. Environmental Protection Agency (EPA) to provide assurance that individual panel closures are being achieved according to the New Mexico Administrative Code (NMAC) Resource Conservation and Recovery Act (RCRA) permit and as a condition of this permit. The partial closure plan will address requirements for future monitoring that are deemed necessary for the post closure period.

A review of existing literature on panel closure systems including the applicable design criteria for closure systems during the anticipated operational life of the facility of 35 years, was conducted. The literature review included panel barrier concepts and field testing as developed by the ONWI high-level waste program, the SNL WIPP Repository Sealing Program, and other panel barrier concepts. This information was reviewed because of it's application to showing compliance to quantitative flow standards during underground operations. The results of the literature review were presented to summarize previous panel barrier designs, and their application to WIPP. In addition, information on the disturbed rock zone (DRZ) (extent and permeability enhancement), potential fracturing of the Anhydrite MB139, and interface zone properties directly relevant to developing a conceptual design for panel closure systems is presented.

This report considers engineering designs such that the migration mass flow rate of hazardous constituents at the WIPP point of compliance will not exceed the environmental migration mass flow rate limit established for specific volatile organic compounds (VOCs) during the operational period. The performance criteria considers the point of compliance for the release of VOCs as the 16-section land withdrawal boundary. . . ."

ERDA (Energy Research and Development Administration). 1976. Management Guideline and Project Executive Assistance, Construction Management Plan.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Fernandez, J.A., Hinkebein, T.E., and Case, J.B. 1989. Selected Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain. SAND85-0598, Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. 3;

" This report presents a number of analyses to determine whether the construction of two shafts associated with the exploratory shaft facility can significantly influence the long-term isolation capabilities of a high-level nuclear waste repository at Yucca Mountain, on and adjacent to the Nevada Test Site. Both shafts are planned to be located predominantly in fractured, welded tuff within the unsaturated zone. The calculational effort, using analytical solutions, focuses primarily on the potential influence of the shaft liner and the zone of increased rock damage around the shaft (termed in this paper the modified permeability zone, MPZ). Two mechanisms are considered in determining whether the MPZ can significantly enhance radionuclide releases. These mechanisms include water flow entering the exploratory shafts from both realistic and improbable scenarios and airflow exiting the shaft as a result of convective and barometric forces. The influence of the liner on the performance of the repository is determined by evaluating the potential chemical interaction between ground water and the concrete liner and the subsequent potential for precipitates to deposit within the MPZ and the shaft fill. It is concluded from these calculations and the current knowledge of the hydrology of the unsaturated zone at Yucca Mountain that the presence of the shafts and the associated MPZ and shaft liner do not significantly impact the long-term isolation capability of the repository. This conclusion is reached because both exploratory shafts will be collared in bedrock above and laterally away from the flood channel. This location makes it unlikely that significant amounts of water will enter the shaft even if a probable maximum flood occurs. Additionally, airflow out of the shaft can be controlled effectively by emplacement of shaft fill, and deposition of solids from the interaction of the shaft liner with the ground water is a localized phenomenon and should not significantly decrease the drainage capability of the rock at the base of the shaft. This report also (1) describes methods to remove the liner, to restore the MPZ, to emplace a seal, and to restore the exploratory shaft pad area in the event that future analyses suggest that further reduction of shaft inflow is necessary and (2) evaluates the impact on the sorption of the Calico Hills zeolites if the decision is made to sink the shaft into the Calico Hills unit."

Griswold, G.B., 1977. Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM. SAND77-0946. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p. 3;

" Bedded-salt deposits of the Salado Formation have been selected for evaluation for a proposed Waste Isolation Pilot Plant (WIPP) to be located in Eddy County, NM, ~26 mi east of Carlsbad. Site selection and evaluation studies that included geologic mapping, geophysical surveys, drilling, and resource appraisal were conducted over and under the prospective location. The lower portion of the Salado meets essential criteria for waste isolation. Beds chosen for waste storage lie 2074-2730 ft below the surface. High-purity salt exists at these depths, and the geologic structure revealed by geophysical surveys indicates that these beds are essentially flat. Additional geophysical surveys are now under way. The initial interpretation of the new data indicates that more structure may exist in the salt beds in the northern portion of the site area. Full evaluation of potentially commercial deposits of potash and natural gas within the WIPP site will be reported by separate studies, as will be the hydrologic details of the region."

Nowak, E.J., and McTigue, D.F. 1987. Interim Results of Brine Transport Studies in the Waste Isolation Pilot Plant. SAND87-0880. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" It is important to have quantitative predictions of brine movement in a radioactive waste repository for performance assessment and for seal design evaluations. Experiments to quantify brine transport to boreholes in multi-heater, full scale tests simulating high level waste repository environments have been under way in the bedded salt of the Waste Isolation Pilot Plant (WIPP) since April, 1985. Water vapor released to the test boreholes has been collected in flowing nitrogen and weighed periodically. Before heating, water was collected during several days from four test boreholes at rates in the range of 5 to 15 g/day. This result highlights the need for an isothermal model for brine movement in the WIPP host rock salt. After heating began, the water collection rates rose to a peak, decreased, and then remained nearly constant for several hundred days. Subsequently, trends to decreasing rates have been observed. Cumulative quantities of water were 4.3 kg at 441 days from each of two boreholes in Room A1 (with a 470 W heater in each borehole) and 36 to 38 kg at 600 days from each of the two boreholes in Room B (with a 1500 W heater in each borehole). After the early transients, approximately 8 g/day/borehole were collected in Room A1, and 50 to 80 g/day/borehole were collected in Room B. These are much larger brine inflow rates than were observed during heated brine migration tests in the domal salt of the Asse mine in the Federal Republic of Germany. Results from in situ brine transport tests in domal salt are not necessarily applicable to bedded salt.

A preliminary analysis of the results was begun with a highly idealized fluid flow model for porous media. Our water collection data for unheated boreholes agreed reasonably well with the brine inflows that were calculated with this model. Agreement was attained using permeability and porosity values that are generally consistent with measured WIPP host rock properties. It was also shown that the WIPP experiments are well within the transient stage of this model. However, the temperature dependence of viscosity, when used in this model, is inadequate to account for the large water collection rates in the heated boreholes. Further model development and additional experiments are needed to understand brine movement in the WIPP, with and without sources of heat. Parametric studies of time, scale, and salt composition are needed. Measurements of pore pressure at intervals within a few meters of WIPP excavations were shown by the model analyses to be important for testing mechanistic hypotheses concerning brine transport. WIPP hydrologic and disturbed zone characterization studies can also contribute to our mechanistic understanding of brine transport to WIPP excavations."

ORNL (Oak Ridge National Laboratory). 1973. Site Selection Factors for the Embedded Salt Pilot Plant. ORNL-TM-4219. Oak Ridge National Laboratory, Oak Ridge, TN.

ABSTRACT, p 1;

" Because of the nature of radioactive waste disposal in geologic formations, the selection of suitable sites is a unique exercise totally different from that for any other type of facility. This compilation of the various factors which must be taken into consideration was assembled as an aid in the selection and confirmation of a site for the Bedded Salt Pilot Plant. As might be expected, most of these factors are related to geologic characteristics, which are discussed under the headings of: (1) stratigraphy, (2) structure, (3) hydrology, and (4) mineral resources. Other factors concerned with geography and facility design and operation are also included."

Pfeifle, T.W. and Brodsky, N.S. 1991. Swelling Pressure Water Uptake and Permeability of 70/30 Crushed Salt Bentonite. SAND91-7070. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" Two experiments were conducted on specimens consisting of 70 percent by dry weight crushed salt and 30 percent by dry weight bentonite. The experiments included fifteen tests and were designed to measure the swell pressures induced by the introduction of saturated Brine A, a high Magnesium-content brine, and to measure permeability. Specimens of three dry densities were used: 1,600 $kg \bullet m^{-3}$, 1,800 $kg \bullet m^{-3}$, and 2,100 $kg \bullet m^{-3}$. Experiments were conducted in an oedometer which is a stiff pressure vessel designed to maintain specimens at constant volume. Ten durations ranged from 3 to 112 days.

When specimens were put into contact with brine, their swelling was inhibited by the oedometer, and the pressures that were required to restrict swelling were recorded. The mean peak pressures increased with density and were 0.5 MPa, 1.1 MPa, and 6.5 MPa for densities of 1,600 $kg \bullet m^{-3}$, 1,800 $kg \bullet m^{-3}$, and 2,100 $kg \bullet m^{-3}$, respectively. For tests at 1,600 $kg \bullet m^{-3}$ and 1,800 $kg \bullet m^{-3}$, the pressures peaked and then decayed to residual values. These residual values also increased with density and had mean values of 0.15 MPa and 0.37 MPa for densities of 1,600 $kg \bullet m^{-3}$ and 1,800 $kg \bullet m^{-3}$, respectively. The pressure never decayed for test at 2,100 $kg \bullet m^{-3}$ even though one test ran for 112 days.

Permeability measurements were made on specimens with densities of 1,600 $kg \bullet m^{-3}$ and 1,800 $kg \bullet m^{-3}$ using the constant hydraulic head, steady-state flow method. Flow was never established for the 2,100 $kg \bullet m^{-3}$ specimens. Including recent data, permeability changed approximately two orders of magnitude (from $1 \times 10^{-15} m^2$ to $1 \times 10^{-17} m^2$) as density increased from 1,600 $kg \bullet m^{-3}$ to 1,950 $kg \bullet m^{-3}$. Moisture content and distribution measurements were made on all specimens post-test. On the average, all specimens reached saturation; however, moisture content distributions were nonuniform in many specimens."

Sandia National Laboratories. 1992. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 3: Model Parameters. SAND92-0700/3, Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM.

Volume 1: ABSTRACT, p i;

" Before disposing of transuranic wastes in the Waste Isolation Pilot Plant (WIPP), the United States Department of energy (DOE) must evaluate compliance with applicable long-term regulations of the United States Environmental Protection Agency (EPA). Sandia National Laboratories is conducting iterative performance assessments of the WIPP for the DOE to provide interim guidance while preparing for final compliance evaluations.

This volume contains an overview of WIPP performance assessment and a preliminary comparison with the long-term requirements of the *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR 191, Subpart B)*. Detailed information about the technical basis for the preliminary comparison is contained in Volume 2. The reference data base and values for input parameters used in the modeling system are contained in Volume 3. Uncertainty and sensitivity analyses related to 40 CFR 191B are contained in Volume 4. Volume 5 contains uncertainty and sensitivity analyses of gas and brine migration for undisturbed performance. Finally, guidance derived from the entire 1992 performance assessment is presented in Volume 6.

Results of the 1992 performance assessment are preliminary, and are not suitable for final comparison with 40 CFR 191, Subpart B. Portions of the modeling system and the data base remain incomplete, and the level of confidence in the performance estimates is not sufficient for a defensible compliance evaluation. Results are, however, suitable for providing guidance to the WIPP Project.

All results are conditional on the models and data used, and are presented for preliminary comparison to the Containment Requirements of 40 CFR 191, Subpart B as mean complimentary cumulative distribution functions (CCDFs) displaying estimated probabilistic releases of radionuclides to the accessible environment. Results compare three conceptual models for radionuclide transport in the Culebra Dolomite Member of the Rustler Formation and two approaches to estimating the probability of inadvertent human intrusion into the WIPP by exploratory drilling. The representation for disposal-system performance believed to be most realistic includes intrusion probabilities based on expert-panel judgement and dual-porosity transport with chemical retardation. For intrusions occurring 1000 years after decommissioning, the mean CCDF for this representation lies more than one order of magnitude below the EPA limits. Using the same approach to intrusion probabilities used in the 1991 performance assessment (i.e., not taking expert judgement into account and basing the probability model on the maximum intrusion probability indicated in Appendix B of 40 CFR 191, Subpart B) significantly increases the probability of releases, regardless of the model used for subsurface transport. Assuming the higher intrusion probabilities and dual-porosity transport without chemical retardation, the mean CCDF is approximately one order of magnitude below the EPA limits. For the higher intrusion probabilities and single-

porosity, fracture-only transport, the mean CCDF is less than one order of magnitude below the EPA limits."

Stormont, J.C., Howard, C.L., and Daemen, J.J.K. 1991. In Situ Measurements of Rock Salt Permeability Changes Due to a Nearby Excavation. SAND90-3134. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;
" The Small-Scale Mine-By was an in situ experiment to measure changes in brine and gas permeability of rock salt as a result of nearby excavation. A series of small-volume pressurize brine- and gas-filled test intervals were established 8 m beneath the floor of Room L1 in the WIPP underground. The test intervals were isolated in the bottom of the 4.8-cm diameter monitoring boreholes with inflatable rubber packers, and are initially pressurized to about 2 MPa.. Both brine- and gas-filled test intervals were located 1.25, 1.5, 2, 3, and 4 r from the center of a planned large-diameter hole, where r is the radius of the large-diameter hole. Prior to the drilling of the large-diameter borehole, the responses of both the brine- and gas-filled test intervals were consistent with the formation modeled as a very low permeability, low porosity porous medium with a significant pore (brine) pressure and no measurable gas permeability. The drilling of the mine-by borehole created a zone of dilated, partially saturated rock out to about 1.5 r. The formation pressure increases from near zero at 1.5 r to the pre-excavation value at 4 r. Injection tests reveal a gradient of brine permeabilities from 5 x 10^{-18} m^2 at 1.25 r to about the pre-excavation value ($10^{-21}m^2$) by 3 r. Gas-injection tests reveal measurable gas permeability is limited to within 1.5 r."

Stormont, J.C., Peterson, E.W., and Lagus, P.L. 1987. Summary and Observations about WIPP Facility Horizon Flow Measurements through 1986. SAND87-0176. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" Numerous gas flow measurements have been made at the Waste Isolation Pilot Plant (WIPP) facility horizon from 1984 through 1986. Almost all tests have been constant-pressure or pressure-decay tests from single boreholes drilled in the underground excavations. Results indicate that beyond about 2 m from an excavation, both halite and interbeds (anhydrite and clay layers) allowed very low gas flows, and calculated permeabilities are below 1 microdarcy. In regions within 2 m of an excavation, very high flow rates were measured in the interbeds immediately above and below an excavation when the test hole was drilled from near the center of the excavation. The halite also permits substantially greater gas flow within about 1 m of the excavations. Limited tracer measurements reveal that flow paths in both the halite and interbeds in the near field region are significantly larger than those in the presumed undisturbed condition. The gas flow measurements are consistent with the development of a (perhaps partially-saturated) dilitant zone (increased porosity) around the excavations. Considerable uncertainty is associated with permeabilities calculated from these flow measurements, due to unknowns of rock saturation, entry pressure effects, flow homogeneity, etc.

Observations based on these gas flow measurements will aid in understanding the behavior and response of rocks surrounding the WIPP Facility excavations. The implications of these measurements for seal design are useful, particularly in assessing the degree of seal bypass to expect in adjacent rock. Results suggest that seal be emplaced as soon as possible after excavation and in as narrow drifts as possible to minimize potential bypass. These data are also useful in separate studies of brine influx and gas generation/dissipation. Future measurements will focus on the development and extent of the disturbed zone, and on obtaining data which will make conversion of flow data to intrinsic permeabilities more defensible."

Stormont, J.C. 1991. "Gas Flow Measurements as Index Tests for the Disturbed Rock Zone," Memorandum to Distribution, Sandia National Laboratories, Albuquerque, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Stormont, J.C., 1988. Preliminary Seal Design Evaluation for the Waste Isolation Pilot Plant. SAND87-3083. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT

" This report presents a preliminary evaluation of design concepts for the eventual sealing of the shafts, drifts, and boreholes at the Waste Isolation Pilot Plant Facility. The purpose of the seal systems is to limit the flow of water into, through, and out of the repository. . . ."

Westinghouse Electric Corporation. 1995. Conceptual Design for Operational Phase Panel Closure System. DOE/WIPP-Draft-2057. Closure and Post Closure Plans. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-i;

" The Waste Isolation Pilot Plant (WIPP), a U.S. Department of Energy (DOE) research facility located near Carlsbad, New Mexico, was established to demonstrate the safe disposal of defense-generated transuranic (TRU) waste. The WIPP repository is approximately 2,150 feet (ft) (655 meters [m]) below the surface in bedded salt. The WIPP facility includes a northern experimental area, a shaft-pillar area, and a waste-disposal area. The waste disposal area is comprised of panels, each of which consists of seven rooms and two access panel entries (Figure ES-1).

Following completion of waste emplacement in each panel, ventilation will be established in the next panel to be used and the panel containing the waste will be closed. The DOE will seek approval for 'partial closure' of each of the panels as they are sequentially filled with waste on a panel-by-panel basis. Partial closure is the process of rendering a part of the underground repository inactive and closed according to the approved facility closure plans.

The plan covers administrative procedures deemed necessary by the U. S. Environmental Protection Agency (EPA) to provide assurance that individual panel closures are being achieved according to the New Mexico Administrative Code (NMAC) Resource Conservation and Recovery Act (RCRA) permit and as a condition of this permit. The partial closure plan will address requirements for future monitoring that are deemed necessary for the post closure period.

A review of existing literature on panel closure systems including the applicable design criteria for closure systems during the anticipated operational life of the facility of 35 years, was conducted. The literature review included panel barrier concepts and field testing as developed by the ONWI high-level waste program, the SNL WIPP Repository Sealing Program, and other panel barrier concepts. This information was reviewed because of it's application to showing compliance to quantitative flow standards during underground operations. The results of the literature review were presented to summarize previous panel barrier designs, and their application to WIPP. In addition, information on the disturbed rock zone (DRZ) (extent and permeability enhancement), potential fracturing of the Anhydrite MB139, and interface zone properties directly relevant to developing a conceptual design for panel closure systems is presented.

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Croff, A.B. 1980. A User's Manual for the ORIGEN2 Code. ORNL/TM-7175, Oak Ridge National Laboratory, July 1980.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

DOE (U.S. Department of Energy). 1988. Radioactive Waste Management, Order 5820.2A, Washington, D.C.

1. PURPOSE, p. 1;
" To establish policies, guidelines, and minimum requirements by which the Department of Energy (DOE) manages its radioactive and mixed waste and contaminated facilities."

Attachment 2, Page 1, #6;
" Contact-Handled Transuranic Waste. Packaged transuranic waste whose external surface dose rate does not exceed 200 mrem per hour."

Page 4, #31;
" Remote-Handled Transuranic Waste. Packaged transuranic waste whose external surface dose rate exceeds 200 mrem per hour. Test specimens of fissionable material irradiated for research and development purposes only and not for the production of power or plutonium may be classified as remote-handled transuranic waste."

DOE (U.S. Department of Energy). 1995a. Performance Demonstration Program Plan for Nondestructive Assay for the TRU Waste Characterization Program, Appendix A, Determining the Number of Containers to Visually Examine Using the Hypergeometric Distribution. DOE/CAO-94-1045, Revision 0, March 1995. Carlsbad, NM.

INTRODUCTION, General, p. 1;

" The Performance Demonstration Program (PDP) for Nondestructive Assay (NDA) will consist of a series of tests conducted on a regular frequency to evaluate the capability for nondestructive assay of transuranic (TRU) waste throughout the Department of Energy (DOE) complex. Each test is termed a PDP cycle. These evaluation cycles will provide an objective measure of the reliability of measurements performed with TRU waste characterization systems.

Measurement facility performance will be demonstrated by the successful analysis of blind audit samples according to the criteria set by this Program Plan. Intercomparison between measurement groups of the DOE complex will be achieved by comparing the results of measurements on similar or identical blind samples reported by the different measurement facilities. Blind audit samples (hereinafter referred to as PDP samples) will be used as an independent means to assess the performance of measurement groups regarding compliance with the established Quality Assurance Objectives (QAOs). As defined for this program, a PDP sample consists of a 55-gallon standard drum emplaced with standards and fabricated matrix inserts. These PDP sample components, once manufactured, will be secured and stored at each participating measurement facility under secure conditions to protect them from loss, tampering, or accidental damage."

INTRODUCTION, Purpose, p. 1;

" The Performance Demonstration Programs (PDPs) are designed to help ensure compliance with the QAOs identified in the TRU Waste Characterization Quality Assurance Program Plan (QAPP) for the Waste Isolation Pilot Plant (WIPP)(DOE,1994). The PDPs are intended for use by the Carlsbad Area Office)CAO) as part of the assessment and approval process for the measurement facilities supplying services for the characterization of WIPP TRU waste. . . ."

DOE (U.S. Department of Energy). 1995b. Transuranic Waste Characterization Quality Assurance Program Plan. DOE/CAO-94-1010, Revision 0, April 30, 1995. Carlsbad, NM.

1.0 PROGRAM MANAGEMENT, p 1;

" This Quality Assurance Program Plan (QAPP) identifies the quality of data necessary, and techniques designed to attain and ensure the required quality, to meet the specific Data Quality Objectives (DQOs) associated with the Department of Energy (DOE) Waste Isolation Pilot Plant (WIPP) Transuranic (TRU) Waste Characterization Program (the Program). Waste characterization data will be collected to support regulatory compliance programs associated with the WIPP facility. These regulatory compliance programs include an assessment and certification of the WIPP repository performance, the preparation of permit applications and a variance petition, and an evaluation of existing TRU waste transportation restrictions. Although this QAPP specifies waste testing, sampling, and analytical methods, it also allows for the introduction, consideration, and development of innovative techniques for TRU waste characterization. Prior to implementation of new waste characterization techniques for use in Program activities, the proposed techniques must be submitted to the Carlsbad Area Office (CAO) for review and approval. This QAPP will be reviewed annually, and revised as necessary, to incorporate lessons learned during waste characterization activities.

The CAO *Quality Assurance Program Description* (QAPD) [DOE 1994b] is the quality management document which identifies federal, state, and industry quality requirements applicable to the CAO quality assurance (QA) program. The QAPD establishes the minimum requirements for the development of QA programs by WIPP program and National TRU Program participants. Requirements contained in the QAPD are based on the QA requirements and criteria contained in 10 CFR Part 830, 'Nuclear Safety Management,' and other programmatic requirements. The QAPD also is consistent with applicable Environmental Protection Agency (EPA) QA requirements. This QAPP addresses the applicable requirements outlined in the QAPD, as appropriate.

This QAPP follows the guidelines recommended by EPA in QA/R-5, *EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations* (EPA 1994a). This QAPP satisfies all applicable requirements of 10 CFR § 830.120, which governs the conduct of the DOE management and operating (M&O) contractors and other persons at DOE nuclear facilities. Because DOE facilities are managing nuclear materials contained in TRU waste, all applicable quality elements in the American Society of Mechanical Engineers (ASME), *Quality Assurance Program Requirements for Nuclear Facilities* (ASME NQA-1) (ASME 1994) are addressed.

This QAPP addresses all of the basic requirements, and their supplements, of ASME NQA-1. However, nothing in this document relieves any Program participant from the responsibility of complying with any existing requirement. All exceptions to the basic requirements of NQA-1 such as applicable federal, state, and local regulation; DOE Orders; permits and interagency agreements; or any site-specific controls on operations, shall be documented in quality assurance project plans (QAPjPs) (Section 1.2.2) which must be prepared by each participating DOE generator/storage site (site). The CAO manager shall be notified

immediately of any conflicts between this QAPP and any existing requirements.

Because the American National Standards Institute/ American Society for Quality Control (ANSI/ASQC) E4-1993, *Quality Systems Requirements for Environmental Programs* (ANSI/ASQC 1993), incorporates the QA requirements of applicable EPA, DOE, and ASME documents, the requirements stated in the ANSI/ASQC E4-1993 document were considered in developing this QAPP. A cross reference of the content of this QAPP; the EPA QA/R-5 elements; the analogous CAO QAPD and 10 CFR § 830.120 criteria; and ASME NQA-1 basic requirements is provided in Table 1-1."

DEFINITIONS;

" NEWLY GENERATED WASTE - Waste that is generated after the development and implementation of a TRU waste characterization program that meets the requirements outlined in this QAPP."

" RETRIEVABLY STORED WASTE - Waste that has been generated before the development and implementation of a TRU waste characterization program that meets the requirements outlined in this QAPP."

APPENDIX A, Determining the Number of Containers to Visually Examine Using the Hypergeometric Distribution, p. 1, para. 1:

" For the hypergeometric approach to determining the number of containers to be visually examined, the acceptable level of uncertainty in the estimate of the proportion miscertified (along with the information on the previous percentage miscertified) determines the number of containers that must be examined. The rationale and details of this methodology are discussed below.

In a population of size N, there are M miscertified containers, so the true proportions of the miscertified containers in the population is $M/N=p_{true}$. Since p_{true} (or M) is not known, we wish to estimate it by randomly sampling some of the containers. If in a sample of n containers, x are found to be miscertified, the sample estimate of the true population proportion p_{true} is

$$\hat{p} = \frac{x}{n} \qquad \text{(A-1)}$$

This value is only an estimate, and such has some uncertainty associated with it. This uncertainty is quantified by calculating the upper one-sided (1-α) percent confidence limit for p, call it p_{ucl}. This confidence limit gives the largest value the true proportion could take on and still have a "reasonable" chance (e.g., an α=.10 probability) of producing x miscertified containers in a sample of n out of N. This upper confidence limit is calculated as

$$p_{UCL} = M_{UCL}/N \tag{A-2}$$

Where M_{ucl} is the largest value of M such that the probability of observing x or fewer miscertified containers in a sample of size n is less than or equal to α. That is, it is the largest value of M such that the following inequality is true

$$\sum_{k=0}^{x} \frac{\binom{M}{k}\binom{N-M}{n-k}}{\binom{N}{n}} \leq \alpha. \tag{A-3}$$

Where each term in parentheses has the usual combinatorial interpretation. For example

$$\binom{M}{k} = \frac{M!}{k!\ (M-k)\ !} \tag{A-4}$$

Each term in the sum in Equation (A-3) is the hypergeometric probability of observing k miscertified containers in a sample of size n from a population of size N in which there are M miscertified containers (and hence the population proportion of miscertified containers is $p=M/N$). The value M_{ucl} is obtained by substituting different values for M into Equation (A-3) until the largest value satisfying the inequality is found.

Note that in Equation (A-3), the upper confidence limit is dependent on x, the number of miscertifications observed in the sample, as well as on n, the sample size. So, to obtain the required sample size, the values of x that are likely to be seen also need to be considered. Sample size is thus determined by setting a desired upper confidence limit value and then manipulating x and n in Equation (A-3). The detailed steps are given in the following algorithm, along with an example application to clarify the steps involved:"

DOE (U.S. Department of Energy), 1995c. Transuranic Waste Characterization Sampling and Analysis Methods Manual. DOE/WIPP-91-043, Revision 1, April 1996. Carlsbad, NM.

Procedure 310.2, PHYSICAL WASTE FORM CHARACTERIZATION USING VISUAL EXAMINATION, p. 310.2-1;

" 1.0 Scope and Application

1.1 This procedure for the visual examination of the contents of a waste container is designed to provide data on the type and amount of material in each of the waste containers included in the TRU Waste Characterization Program (the Program). This procedure is used as a quality control check for "Physical Waste Form Characterization Using Radiography" (Procedure 310.1 of this Methods Manual). IN addition, sites may choose to perform visual examination of waste packages instead of radiography. Therefore, this procedure may be used either to confirm the matrix parameter category and waste material parameter weights as determined by radiography, or to determine the matrix parameter category and waste material parameters for waste that has not undergone radiography. This procedure must be implemented with a site-specific standard operating procedure (SOP). SOPs must include all of the elements found in this procedure.

The waste material parameters of interest for performance assessment are listed in Table 1. The estimated or measured weight of waste within these waste material parameters are determined using this procedure.

1.2 If used to verify the results of radiography, the results of visual examination will be included in the testing batch data reports for radiography. For the purposes of the TRU Waste Characterization Program, waste containers are to be characterized by radiography in testing batches. A testing batch is defined as suite of waste containers undergoing radiography suing the same equipment. A testing batch can be up to 20 waste containers or the number of waste containers that can be examined in one day without regard to waste matrix. If used in place of radiography, the results of visual examination will be in a separate visual examination report. In this case, waste containers are also visually examined in testing batches."

DOE (U.S. Department of Energy). 1995d. Waste Isolation Pilot Plant Safety Analysis Report. DOE/WIPP-95-2065, Revision 0, November 1995. Carlsbad, NM.

Facility Background and Mission, p. 1-4;

" The United States Department of Energy (DOE) was authorized by Public Law 96-164[1] to provide a research and development facility for demonstrating the safe permanent disposal of transuranic (TRU) wastes from national defense activities and programs of the United States exempted from regulations by the U.S. Nuclear Regulatory Commission (NRC). The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico near Carlsbad, was constructed to determine the efficacy of an underground repository for disposal of TRU wastes.

In accordance with the 1981 and 1990 Records of Decision (ROD),[2,3] the development of the WIPP was to proceed with a phased approach. Development of the WIPP began with a siting phase, during which several sites were evaluated and the present site selected based on extensive geotechnical research, supplemented by testing.

The site and preliminary design validation (SPDV) followed the siting phase, during which two shafts were constructed, an underground testing area was excavated, and various geologic, hydrologic, and other geotechnical features were investigated. The construction phase followed the SPDV phase during which surface structures for receiving waste were built and underground excavations were completed for waste emplacement. . . ."

p. 1-5, para 1;

" This Safety Analysis Report (SAR) documents the safety analyses that develop and evaluate the adequacy of the WIPP CH TRU safety bases necessary to ensure the safety of workers, the public, and the environment from the hazards posed by WIPP waste handling and emplacement operations during the disposal phase and hazards associated with the decommissioning and decontamination phase.

The analyses of the hazards associated with the long-term (10,000 year) disposal of TRU and TRU mixed waste, and demonstration of compliance with the requirements of 40 CFR 191, Subpart B[4] and 40 CFR 268.6[6] will be addresses in detail in the WIPP Final Certification Application scheduled for submittal in October 1996 (40 CFR 191) and the No-Migration Variance Petition (40 CFR 268.6) scheduled for submittal in June 1996. Section 5.4, Long-Term Waste Isolation Assessment summarizes the current status of the assessment. Section 5.4 will be updated upon completion of the long-term assessment demonstration (currently scheduled for the FY-97 Annual Update)."

ATTACHMENT 1, DOE/WIPP-95-2125, Rev. 0, *Technical Safety Requirements*, p. 5-6, Section 5.8.12 Waste Characteristics;

" A Waste Characterization Program shall ensure that only wastes that are compatible with the design, operation and long-term performance of the WIPP facility are shipped to WIPP and that any exceptions are weighed against all applicable baseline douments prior to their authorization for shipment.

Procedures shall be established, implemented, and maintained to ensure that the following

WIPP WAC[3] requirements apply to all WASTE that is to be shipped to the WIPP are implemented:

- The WASTE accepted for placement in the WIPP facility must conform with the WIPP WAC[3] unless an exception to the WAC has been approved as a result of examination in relation to the SAR.[2] Specific criteria used in the development of the safety analysis are as follows:
  - Waste Containers
    1. Containers shall be noncombustible and meet DOT Type A packaging requirements.
    2. Limit acceptable containers to 55-gallon drums and standard waste boxes (SWBs).
  - Liquids
    1. Only residual liquids; as a guideline, residual liquid in well-drained internal containers to be restricted to approximately 1 volume % of the internal container; aggregate amount of residual liquid < 1 volume % of external container.
  - Pyrophoric Materials
    1. No non-radionuclide pyrophorics permitted. Radionuclides in pyrophoric form are limited to <1% by weight in each waste package."

DOE (U.S. Department of Energy). 1995e. WWIS Software Quality Assurance Plan. CAO-95-1108, Version 0, May 1995, Carlsbad, NM.

1. INTRODUCTION, 1.1 Purpose, p. 1;
" The purpose of this Software Quality Assurance Plan (SQAP) is to identify and define the standards and methodologies required to ensure conformance to accepted quality standards during the development and maintenance of the WIPP Waste Information System (WWIS). In addition, the standards and methodologies provide adequate confidence that the products conform to established technical requirements. This document will be developed in the concept phase to be used throughout the WWIS software life cycle as depicted in Figure 1."

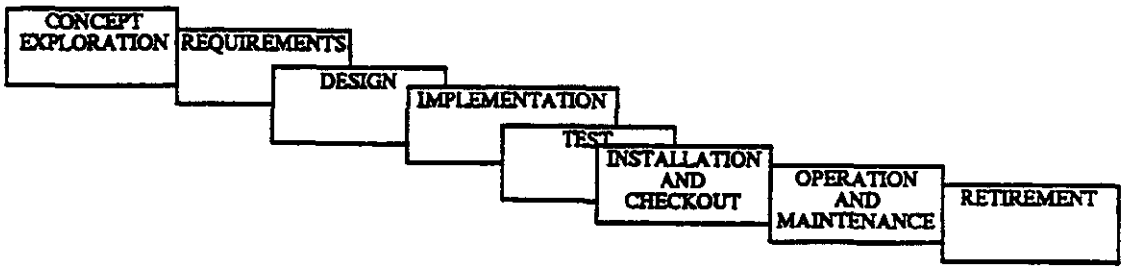

Figure 1 Software Life Cycle

DOE (U.S. Department of Energy). 1995f. DOE Waste Treatability Group Guidance. DOE/LLW-217, Revision 0, January 1995. Washington, D.C.

p. 5-1, para. 1;
"5. MATRIX PARAMETER This section presents the matrix parameter categories (MPCs) and definitions. This parameter is common to treatability group assignments for all four primary, and associated secondary, waste types. The MPC describes the overall, composite physical/chemical form (i.e., matrix) of the waste. The matrix can affect all facets of management.

5.1 OVERVIEW OF MATRIX CATEGORIES
Figure B-1 of Appendix B provides a foldout chart depicting all of the MPCs currently defined in this guidance. Figures 5-1 through 5-7 of this section highlight different portions of the foldout chart to facilitate discussion of the MPC definitions. As indicated in Figure B-1 and Figures 5-1 through 5-7, each MPC is identified by a title and a single-character alpha or five-character alphanumeric code. Furthermore, each is designated as being either a "summary," "specific-detailed," or "unknown/other-detailed" MPC.

The array of MPCs is arranged in a logical hierarchy beginning with four broad, summary categories and one associated unknown/other-detailed category. The summary categories are Liquids (S), Solids (S), Specific Waste Forms (X), and Final Waste Forms (Z), while the unknown/other-detailed category is Unknown/Other matrix (U9999). Each of the initial four summary MPCs is followed by levels of successively more definitive, or waste form specific, categories. The first successive level includes the MPCs for which the last non-zero digit in the numeric portion of their codes is in the 1000s. These are referred to as the "Level 1000" MPCs. Each of the Level 1000 MPCs that is a summary category is, in turn, followed by yet more definitive Level 100 MPCs. This logic continues until reaching a final level that consists of only detailed MPCs. The associated MPCs at any given level include one unknown/other-detailed category. Inherent within the logical hierarchy of the complete array is the ability to perform aggregates by rolling the more definitive MPCs up to their associated, less definitive summary MPCs (i.e., Level 1⇒ Level 10⇒ Level 100⇒ Level 1000).

Definitions for the MPCs are provided in Sections 5.3 through 5.7. Defining the MPCs, particularly for the Solids (S) categories, required the establishment of physical/chemical form "concentration" criteria. As indicated in the opening remarks of Section 5, the MPC is intended to describe the overall, composite matrix of the waste. Containerized, solid waste often does not consist of a single physical/chemical form. This is perhaps most true for debris. This waste frequently contains multiple debris materials that are organic (e.g., plastic, rags) and inorganic (e.g., metal, glass, ceramic materials). Because of this, definitions for the Debris (S5000s) and other more definitive Solids (S) MPCs include criteria specifying how much of the physical/chemical form described by the category must be contained in the waste for assignment to the category. For example, the specific-detailed Organic Debris (S5100s) and Inorganic

Debris (S5300s) categories specify that for a waste to be categorized as such, it must contain 80% or more of the subject debris materials. These physical/chemical form concentration criteria are volume based. In the interest of performing technical waste management studies, it might be preferred that these criteria be mass based. However, more often than not, the available waste information more readily supports MPC assignment per these volume-based criteria.

5.2 MATRIX CATEGORY SELECTION GUIDELINES

Matrix category selection essentially involves a process of successive evaluations whereby the characteristic information on the waste matrix is compared with the definitions of the appropriate summary and specific-detailed MPCs. As implied in Figures B-1 and 5-1, the process begins with evaluating the waste per the criteria of the initial Liquids (L), Solids (S), Specific Waste Forms (X), and Final Waste Forms (Z) summary MPCs. If the waste is insufficiently characterized to enable this evaluation or does not meet the criteria specified for any of the four summary categories, it is assigned to the Unknown/Other Matrix (U9999) detailed category. If the waste is determined to meet the criteria for one of the initial summary categories, the evaluation process proceeds to the more definitive Level 1000 MPCs associated with that initial summary level category. For example, if the waste was determined to be a liquid, it would be evaluated per the criteria of the Aqueous Liquids/Slurries (L1000) and Organic Liquids (L2000) summary categories.

Repetition of the evaluation process per the criteria of the summary and specific-detailed categories, as applicable, in the successively more definitive levels (i.e., Level 1000 ⇒ Level 100 ⇒ Level 10 ⇒ Level 1) leads to eventual selection of the MPC. The appropriate MPC is selected when on of the following situations arises:

- A level is reached where the waste meets the criteria of a specific-detailed category. In this situation, that specific-detailed category is selected.
- A level is reached where either (a) it cannot be determined whether the waste meets the criteria for any of the summary or specific-detailed categories, or (b) the waste does not meet the criteria for nay of the summary or specific-detailed categories. The former case would typically arise because of a lack of characteristic information on the waste. The latter case would arise if the waste is of a physical/chemical form not within the criteria specified for the summary or specific-detailed categories. In either case, the associated unknown/other-detailed category is selected.

Actual selection of the MPCs is not as laborious as might be impled by the above discussion. While the process of successive evaluations is inherently part of MPC selection, once a user is familiar with the categories and definitions, selecting the appropriate MPC is relatively straightforward, depending on the availability and quality of documentation on the matrix characteristics of the waste.

The two key guidelines implicit in the above discussion are that (a) the MPC should be selected from the most definitive, or lowest, applicable category level that can be supported by available characteristic data on the waste matrix, and (b) waste should not be assigned the summary MPCs. The time and effort involved to assign the MPCs, or any of the treatability group parameter, is primarily expended in evaluating the available, applicable data on the waste. Once the data are reviewed and the MPCs are assigned, aggregation to less definitive, upper-level summary categories is easily performed given the logic in the MPC codes. However, separation to more definitive, lower-level categories would require revisiting the available data on the waste and reassigning the MPC. Aggregates to the summary categories can be misconstrued if waste is actually assigned to those MPCs.

Sections 5.3 through 5.6 present the definitions for the four initial summary MPCs and their associated, more definitive categories. Section 5.7 presents the definition for the Unknown/Other Matrix (U9999) MPC.

5.3 DEFINITIONS-LIQUIDS AND ASSOCIATED CATEGORIES

The initial Liquids (L) summary category addresses wastes that are liquids, including slurries. Slurries are defined as liquids with a total suspended/settled solids (TSS) content of $\geq 1\%$ and $\leq 30\%$. Waste with a TSS content $> 30\%$ is defined as sludges (see Section 5.4). Only liquids and slurries packaged in bulk, free form (e.g., drum, tank) are included in this category. Liquids and slurries packaged as lab packs are assigned to other MPCs (see Section 5.5).

As shown in Figure 5-2, liquids are initially evaluated per the criteria of the Aqueous Liquids/Slurries (L1000) and Organic Liquids (L2000) summary categories. Liquids that are insufficiently characterized to enable this evaluation are assigned to the Unknown/Other Liquid (L9000) detailed category.

5.3.1 L1000 AQUEOUS LIQUIDS/SLURRIES

This summary category includes liquids and slurries containing less than 1% total organic carbon (TOC). This waste is further evaluated per the criteria of the Wastewaters (L1100) and Aqueous Slurries (L1200) summary categories.

L1100 Wastewaters

This summary category includes aqueous liquids and slurries that meet the EPA LDR criteria for wastewaters ($< 1\%$ TSS). The appropriate detailed MPCs for this waste are selected from the following categories.

L1110 Acidic Wastewaters

This specific-detailed category includes wastewaters with a pH $\leq$ 2.0.

L1120 Basic Wastewaters

This specific-detailed category includes wastewaters with a pH $\geq$ 12.5. Basic

wastewaters that contain cyanides at or above applicable LDR treatment standard levels are assigned to category L1140.

L1130 Neutral Wastewaters
This specific-detailed category includes wastewaters with 2.0 < pH < 12.5. Neutral wastewaters that contain cyanides at or above applicable LDR treatment standard level are assigned to category L1140.

L1140 Cyanide Wastewaters
This specific-detailed category includes wastewaters containing cyanides at or above applicable LDR treatment standard levels, regardless of the pH.

L1190 Unknown/Other Wastewaters
This unknown/other-detailed category includes waste that is consistent with the definition for the Wastewaters (L1100) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the L1110 through L1140 specific-detailed categories, or
- Does not meet the criteria for assignment into one of the L1110 through L1140 specific-detailed categories.

5.3.2 L2000 ORGANIC LIQUIDS

This summary category includes liquids and slurries containing $\geq$1% TOC. As shown in Figure 5-2, this waste is further evaluated per the criteria of the Aqueous/Organic Liquids (L2100) and Pure Organic Liquids (L2200) summary categories. Organic liquids that are insufficiently characterized to enable this evaluation are assigned to the Unknown/Other Organic Liquid (L2900) detailed category.

L2100 Aqueous/Organic Liquids
This summary category includes mixtures, both miscible and immiscible, of aqueous and organic liquids. The appropriate detailed MPCs for this waste are selected from the following categories.

L2110 Aqueous/Halogenated Organic Liquids
This specific-detailed category includes aqueous and organic liquids that contain at least 1,000 ppm halogenated organic compounds (HOC).

L2120 Aqueous/Nonhalogenated Organic Liquids
This specific-detailed category includes aqueous and organic liquids that contain less than 1,000 ppm HOC.

L2190 Unknown/Other Aqueous and Organic Liquids
This unknown/other-detailed category includes waste that is consistent with the

definition for the Aqueous/Organic Liquids (L2100) summary category, but it is not known whether the HOC content is less than, equal to, or greater than 1,000 ppm.

L2200 Pure Organic Liquids
This summary category includes liquids that are essentially purely organic. The appropriate detailed MPCs for this waste are selected from the following categories.

L2210 Halogenated Pure Organic Liquids
This specific-detailed category includes pure organic liquids that contain at least 1,000 ppm HOC.

L2220 Nonhalogenated Pure Organic Liquids
This specific-detailed category includes pure organic liquids that contain less than 1,000 ppm HOC.

L2290 Unknown/Other Pure Organic Liquids
This unknown/other-detailed category includes waste that is consistent with the definition for the Pure Organic Liquids (L2000) summary category, but it is not known whether the HOC content is less than, equal to, or greater than 1,000 ppm.

L2290 Unknown/Other Organic Liquids
This unknown/other-detailed category includes waste that is consistent with the definition of the Organic Liquids (L2000) summary category, but insufficient information is available to enable evaluation per the criteria of the Aqueous/Organic Liquids (L2100) and Pure Organic Liquids (L2200) summary categories.

5.3.3 L9000 UNKNOWN/OTHER LIQUIDS

This unknown/other-detailed category includes waste that is consistent with the definition for the Liquids (L) summary category, but insufficient information is available to enable evaluation per the criteria of the Aqueous Liquid/Slurry (L1000) and Organic Liquid (L2000) summary categories.

5.4 DEFINITIONS-SOLIDS AND ASSOCIATED CATEGORIES

The initial Solids (S) summary category addresses waste with physically solid matrices, including sludges. Sludges are defined as having a TSS > 30%. Certain waste with physically solid matrices are excluded from this category. These include solids that meet the criteria for assignment to the Specific (X) and Final (Z) Waste Forms summary categories (see Sections 5.5 and 5.6).

As shown in Figure 5-3, solids are initially evaluated per the criteria of the Homogeneous Solids

(S3000), Soil/Gravel (S4000), and Debris (S5000) summary categories. Solids that are insufficiently characterized to enable this evaluation, or that do not meet the criteria specified for nay of these summary categories are assigned the Unknown/Other Solids (S9000) detailed category.

5.4.1 S3000 HOMOGENEOUS SOLIDS

Homogeneous solids are defined in this guidance as solid waste materials, excluding soil/gravel (see Section 5.4.2), that do not meet the EPA LDR criteria for classification as debris. Homogeneous solids may include water or other residual or absorbed liquids. Examples of homogenous solids are sludges and particulate-type materials.

This summary category includes waste that is at least 50% by volume homogeneous solids. The balance of the matrix may be other solid physical/chemical forms. For example, a drum of waste from a spill cleanup may contain particulate absorbents and debris (e.g., rags, paper). The drum would be assigned to the appropriate homogeneous solids category provided the particulate absorbents, including any absorbed liquids, account for at least 50% of the waste volume. [If the wast volume were 50% or more debris, then the drum would be assigned to the appropriate debris category (see Section 5.4.3)].

As shown in Figure 5-4, this waste is further evaluated per the criteria of the Inorganic Homogeneous Solids (S3100) and Organic Homogeneous Solids (S3200) summary categories. Homogeneous solids that are insufficiently characterized to enable this evaluation or that do not meet the criteria specified for either of these summary categories are assigned the Unknown/Other Homogeneous Solids (S3900) detailed category.

S3100 Inorganic Homogeneous Solids

Homogeneous solids with sufficient inorganic solids content such that a minimum of approximately 20% by weight would remain as residue (i.e., ash or solids) following incineration are defined in this guidance as inorganic. This summary category includes waste that is at least 50% by volume inorganic homogeneous solids.

As shown in Figure 5-4, this waste is further evaluated per the criteria of the Inorganic Particulates (S3110), Inorganic Sludges (S3120), Paint Waste (S3130), and Salt Waste (S3140) summary MPCs, and the Solidified Homogeneous Solids (S3150) and Inorganic Chemicals (S3160) specific-detailed MPCs. Inorganic homogeneous solids that are insufficiently characterized to enable this evaluation or that do not meet the criteria specified for any of these categories are assigned the Unknown/Other Inorganic Homogeneous Solid (S3190) detailed category.

S3110 Inorganic Particulates

This summary category includes waste that is at least 50% by volume inorganic particulates, including any residual or absorbed liquids. Typical examples of inorganic

particulates are incinerator ash, dust, sandblasting residue, vermiculite, and ion-exchange media. The appropriate detailed MPCs for this waste are selected from the following categories.

S3111 Ash
This specific-detailed category includes waste that is primarily (i.e., $\geq$50% by volume bottom or fly ash resulting from incineration.

S3112 Sandblasting Media
This specific-detailed category includes waste that is primarily (i.e., $\geq$50% by volume) unused or spent surface cleaning or decontamination particulate material. Typical examples of surface cleaning or decontamination particulate materials are coarse sand and glass beads.

S3113 Inorganic Particulate Absorbents
This specific-detailed category includes waste that is primarily (i.e., $\geq$50% by volume) inorganic particulate absorbent materials, including absorbed aqueous liquids, if present. Typical examples of inorganic particulate absorbent materials are clay, vermiculite, and diatomaceous earth.

S3114 Absorbed Organic Liquids
This specific-detailed category includes waste that is primarily (i.e., $\geq$50% by volume) inorganic particulate absorbent materials with absorbed organic liquids. Typical examples of inorganic particulate absorbent materials are clay, vermiculite, and diatomaceous earth.

S3115 Ion-Exchange Media
This specific-detailed category includes waste that is primarily (i.e., $\geq$50% by volume) unused or spent inorganic ion-exchange resins.

S3116 Metal Chips/Turnings
This specific-detailed category includes waste that is primarily (i.e., $\geq$50% by volume) metal chips, turnings, fines, and powders, including any machining coolants, oils, etc. This category would not be selected for certain metal chips or turnings waste. This includes waste meeting the criteria for classification as Debris (S5000), Beryllium Dust (X7300), or Reactive Metals (X7500) (see Sections 5.4.3 and 5.5.2). Also, if the metals exist as oxides or hydroxides, the Metal Oxides/Hydroxides (S3144) category should be selected.

S3117 Glass/Ceramic Materials
This specific-detailed category includes waste tat is primarily (i.e., $\geq$50% by volume) glass or ceramic material too small to qualify as debris (i.e., $\leq$60-mm

particle size). Examples of this waste may be broken glassware, crushed light tubes, and ceramic packing material, such as raschig rings. (If the waste is glass beads used as the media for sandblasting, it should be assigned to S3112 as a more descriptive matrix category.)

S3118 Activated Carbon
This specific-detailed category includes waste that is primarily (i.e., $\geq$50% by volume) spent or unused activated carbon, including any residual liquids. The activated carbon may be in powdered (typically 50 to 100 μm) or granular (typically 0.1 to 1 mm) form.

S3119 Unknown/Other Inorganic Particulates
This unknown/other-detailed category includes waste that is consistent with the definition for the Inorganic Particulates (S3110) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the S3111 through S3118 specific-detailed categories, or
- Does not meet the criteria for assignment into one of the S3111 through S3118 specific-detailed categories.

S3120 Inorganic Sludges
This summary category includes waste that is at least 50% by volume inorganic sludges, including water content. As previously mentioned, sludges are defined as having a TSS >30%. The inorganic sludge may be mixed with stabilization agents, such as cement, provided the mixture has not properly cured to form a solidified monolith (see category S3150). The inorganic sludge may also be mixed with inorganic particulate absorbent materials. The appropriate detailed MPCs for this waste are selected from the following categories.

S3121 Wastewater Treatment Sludges
This specific-detailed category includes waste that is at least 50% by volume secondary sludge, or filtercase from wastewater treatment processes or heavy metal sludges resulting from recovery processes, excluding high-level waste (S3125).

S3122 Pond Sludges
This specific-detailed category includes waste that is at least 50% by volume inorganic sludge generated from the remediation of surface impoundments, such as evaporation or sedimentation basins.

S3123 Off-Gas Treatment Sludges
This specific-detailed category includes waste that is at least 50% by volume inorganic sludge generated from wet off-gas treatment systems.

S3124 Plating Waste Sludges
This specific-detailed category includes waste that is at least 50% by volume inorganic sludge generated from plating operations.

S3125 Reprocessing Sludges
This specific-detailed category includes waste that is at least 50% by volume inorganic sludge generated from nuclear fuel reprocessing operations.

S3129 Unknown/Other Inorganic Sludges
This unknown/other-detailed category includes waste that is consistent with the definition for the Inorganic Sludges (S3120) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the S3121 through
- Does not meet the criteria for assignment into one of the S3121 through S3125 specific-detailed categories.

S3130 Paint Wastes
This summary category includes waste that is at least 50% by volume new, used, or removed paint. This includes such paint waste packaged in a lab pack configuration (see Section 5.5.1). The appropriate detailed MPCs for this waste are selected from the following categories.

S3131 Paint Chips/Solids
This specific-detailed category includes waste that is at least 50% by volume solid, or unpourable, paint. Examples of waste that might be included in this category are dried paint chips or containers filled with dried paint. this category does not include waste that is 50% by volume, or more, paint-related solids, such as empty paint cans, depressurized spray paint cans, or other painting equipment (brushes, rollers, etc.). The appropriate debris category (see Section 5.4.3) would be selected for this waste. Pressurized spray paint cans are categorized as Compressed Gases/Aerosols (X7700) (see Section 5.5.2).

S3132 Paint Sludges
This specific-detailed category includes waste that is at least 50% by volume paint sludge. An example of waste that might be included in this category is opened or unopened cans of heavy, viscous paint. Paints cut sufficiently with thinners (i.e., TSS $<<30\%$) would be more correctly considered liquids and categorized appropriately depending on whether packaged in bulk or lab packed (see Sections 5.3 or 5.5.1).

S3139 Unknown/Other Paint Waste
This unknown/other-detailed category includes waste that is consistent with the

definition for the Paint Waste (S3130) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into either of the S3131 or S3132 specific-detailed categories, or
- Does not meet the criteria for assignment into either of the S3131 or S3132 specific-detailed categories.

S3140 Salt Waste

This summary category includes waste that is at least 50% by volume salts, including interstitial liquids, if present. The appropriate detailed MPCs for this waste are selected from the following categories.

S3141 Chloride Salts

This specific-detailed category includes waste that is at least 50% by volume salts and contains more than trace (i.e., > 1,000 ppm) levels of chlorides or other halogens.

S3142 Sulfate Salts

This specific-detailed category includes waste that is at least 50% by volume salts and contains more than trace (i.e., >1,000 ppm) levels of sulfur compounds.

S3143 Nitrate Salts

This specific-detailed category includes waste that is at least 50% by volume salts. The salts are predominantly (i.e., >50% by volume of salt) nitrates.

S3144 Metal Oxides/Hydroxides

This specific-detailed category includes waste that is at least 50% by volume metal oxides or hydroxides. Metal oxides resulting from roasting or other treatment processes are included in this category. Solid materials generated from the calcination of liquids, such as high-level waste calcine at the Idaho National Engineering Laboratory, are also included in this category. An example of metal hydroxides included in this category is dry chemical reagents such as sodium hydroxide. Metal hydroxide precipitation sludges should not be assigned to this category; these should be assigned to the appropriate Inorganic Sludges (S3120s) category.

S3149 Unknown/Other Salt Waste

This unknown/other-detailed category includes waste that is consistent with the definition for the Salt Waste (S3140) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the S3141 through S3144 specific-detailed categories, or
- Does not meet the criteria for assignment into one of the S3141 through S3144 specific-detailed categories.

S3150 Solidified Homogeneous Solids
This specific-detailed category includes waste that is at least 50% by volume solidified forms that require further treatment before disposal. An example might be a particulate or sludge waste that has been immobilized with cement and cured into a solidified form, but that does not meet LDR treatment standards, if applicable, or other relevant disposal criteria.

S3160 Inorganic Chemicals
This specific-detailed category includes waste that is at least 50% by volume discarded inorganic solid chemicals that do not meet the criteria for assignment into a more prescriptive Inorganic Homogeneous Solids category. The inorganic chemicals may be particulate- or granular-type materials, or monolithic-type chunks.

Only inorganic chemicals packaged in bulk, free form (e.g., drum, tank) are included in this category. Inorganic chemicals packaged as lab packs, or that are in temporary storage and will be packaged as lab packs before transfer to long-term storage or treatment, are assigned to other MPCs (see Section 5.5.1). Inorganic chemicals that meet the criteria for assignment into a more prescriptive Inorganic Homogeneous Solids category should be categorized as such. (For example, bulk sodium chloride should be assigned to category S3141).
S3190 Unknown/Other Inorganic Homogeneous Solids

This unknown/other-detailed category includes waste that is consistent with the definition for the Inorganic Homogeneous Solids (s3100) summary category, but:

- Is insufficiently characterized to enable evaluation per the criteria of the S3110 through S3140 summary categories and the S3150 and S3160 specific-detailed categories, or
- Does not meet the criteria specified for any of the S3110 through S3140 summary categories or the S3150 specific-detailed categories.

S3200 Organic Homogeneous Solids
Homogeneous solids with a base structure that is primarily organic such that a maximum of approximately 20% by weight would remain as residue (i.e., ash or solids) following incineration are defined in this guidance as organic. This summary category includes waste that is at least 50% by volume organic homogeneous solids.

As shown in Figure 5-4, this waste is further evaluated per the criteria of the Organic Particulates (S3210) and Organic Sludges (S3220) summary MPCs, and the Organic Chemicals (S3230) specific-detailed MPC. Organic homogeneous solids that are insufficiently characterized to enable this evaluation or that do not meet the criteria specified for any of these categories are assigned the Unknown/Other Organic

Homogeneous Solid (S3290) detailed category.

S3210 Organic Particulates
This summary category includes waste that is at least 50% by volume organic particulates, including any residual or absorbed liquids. Examples of organic particulates are certain resins used in wastewater treatment and particulate organic absorbent materials. The appropriate detailed MPCs for this waste are selected from the following categories.

S3211 Organic Resins
This specific-detailed category includes waste that is primarily (e.g., $\geq$50% by volume) spent or unused organic based resins used in wastewater treatment or other applications. An example of waste that might be included in this category is organic ion-exchange resins.

S3212 Organic Absorbents
This specific-detailed category includes waste that is primarily (e.g., $\geq$50% by volume) organic particulate absorbent materials, including any absorbed aqueous or organic liquids. Examples of organic particulate absorbents are sawdust and ground corn cobs.

S3219 Unknown/Other Organic Particulates
This unknown/other-detailed category includes waste that is consistent with the definition for the Organic Particulates (S3210) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into either of the S3211 or S3212 specific-detailed categories, or
- Does not meet the criteria for assignment into either of the S3211 or S3212 specific-detailed categories.

S3220 Organic Sludges
This summary category includes waste that is at least 50% by volume organic sludges, including liquids, if present. Examples of waste included in this category are biological sludges and heavy, unpourable organic materials, such as tars or greases. The appropriate detailed MPCs for this waste are selected from the following categories.

S3221 Biological Sludges
This specific-detailed category includes waste that is at least 50% by volume biological materials generated in treating wastewater from animals or people, or other biological materials that cannot be classified as debris.

S3222 Halogenated Organic Sludges
This specific-detailed category includes waste that is at least 50% by volume

organic sludges that contain at least 1,000 ppm HOC.

S3223 Nonhalogenated Organic Sludges
This specific-detailed category includes waste that is at least 50% by volume organic sludges that contain less than 1,000 ppm HOC.

S3229 Unknown/Other Organic Sludges
This unknown/other-detailed category includes waste that is consistent with the definition for the Organic Sludges (S3220) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the S3221 through S3223 specific-detailed categories, or
- Does not meet the criteria for assignment into one of the S3221 through S3223 specific-detailed categories.

S3230 Organic Chemicals
this specific-detailed category includes waste that is at least 50% by volume discarded organic solid chemicals that do not meet the criteria for assignment into a more prescriptive Organic Homogeneous Solids category. The organic chemicals may be particulate- or granular-type materials, or monolithic-type chunks.

Only organic chemicals packaged in bulk, free form (e.g., drum, tank) are included in this category. Organic chemicals packaged as lab packs, or that are in temporary storage and will be packaged as lab packs before transfer to long-term storage or treatment, are assigned to other MPCs (see Section 5.5.1).

S3290 Unknown/Other Organic Homogeneous Solids
This unknown/other-detailed category includes waste that is consistent with the definition for the Organic Homogeneous Solids (S3200) summary category, but:

- Is insufficiently characterized to enable evaluation per the criteria of the S3210 and S3220 summary categories and the S3230 specific-detailed category, or
- Does not meet the criteria specified for any of the S3210 and S3220 summary categories or the S3230 specific-detailed category.

S3900 Unknown/Other Homogeneous Solids
This unknown/other-detailed category includes waste that is consistent with the definition for the Homogeneous Solids (S3000) summary category, but:

- Is insufficiently characterized to enable evaluation per the criteria of the Inorganic Homogeneous Solids (S3100) and Organic Homogeneous (S3200) summary categories, or
- Does not meet the criteria specified for either of the Inorganic Homogeneous

Solids (S3100) or Organic Homogeneous Solids (S3200) summary categories.

5.4.2 S4000 SOIL/GRAVEL

This summary category includes waste estimated to be 50% by volume soil, including sand and silt, or rock and gravel that does not meet the EPA LDR criteria for classification as debris. As shown in Figure 5-3, the appropriate MPCs for this waste are selected from the following detailed categories.

S4100 Soil

This specific-detailed category includes waste estimated to be greater than 95% by volume soil, including sand, silt, and rock and gravel, with rock and gravel volumes totalling less than 50% of the matrix.

S4200 Soil/Debris

This specific-detailed category includes waste estimated to be at least 50%, but no greater than 95%, by volume soil, sand, silt, or rock and gravel, with rock and gravel volumes totalling less than 50% of the matrix and the balance of the matrix being debris.

S4300 Rock/Gravel

This specific-detailed category includes waste estimated to be at least 50% by volume rock and gravel that do not meet the EPA LDR criteria for classification as debris. The balance of the matrix may be soil, including sand and silt, debris, or other solids.

S4900 Unknown/Other Soil/Gravel

This unknown/other-detailed category includes waste that is consistent with the definition for the Soil/Gravel (S4000) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the S4100 through S4300 specific-detailed categories, or
- Does not meet the criteria for assignment into one of the S4100 through S4300 specific-detailed categories.

5.4.3 S5000 DEBRIS WASTE

This summary category includes waste that is at least 50% by volume materials that meet the EPA LDR criteria for classification as debris. These criteria are as follows:

"Debris means solid material exceeding a 60 mm particle size that is intended for disposal and that is: 1) a manufactured object, or 2) plant or animal matter, or 3) natural geologic material. However, the following materials are not debris: 1) any material for which a specific treatment standard is provided in Subpart D, Part 268, 2) process residuals such as smelter slag and residues from the treatment of waste, wastewater,

sludges, or air emission residues; and 3) intact containers of hazardous waste that are not ruptured and that retain at least 75% of their original volume. A mixture of debris that has not been treated to the standards provided by §268.45 and other material is subject to regulation as debris if the mixture is comprised primarily of debris, by volume, based on visual inspection."[40 CFR §268.2(g)]

While specifically written to address EPA regulated hazardous debris, these criteria, particularly particle size, are equally applicable to nonhazardous waste.

This summary category includes waste that is at least 50% by volume materials that meet the above criteria. The balance of the matrix may be other physical or chemical waste forms. For example, the drum of spill cleanup waste discussed in the definition for Homogeneous Solids (S3000) (see Section 5.4.1) would be assigned to the appropriate debris category, provided the debris materials account for at least 50% of the bulk matrix volume.

As shown in Figure 5-5, this waste is further evaluated per the criteria of the Inorganic Debris (S5100), Organic Debris S95300), and Heterogeneous Debris (S5400) summary categories. Debris that is insufficiently characterized to enable this evaluation is assigned the Unknown/Other Debris (S5900) detailed category.

S5100 Inorganic Debris
This summary category includes waste that is estimated to be 80% by volume, or more, inorganic debris materials. Examples of inorganic debris materials include scrap metal, concrete, brick, and glass.

As shown in Figure 5-5, this waste is further evaluated per the criteria of the Metal Debris (S5110) and Inorganic Nonmetal Debris (S5120) summary categories. Inorganic debris that is insufficiently characterized to enable this evaluation, or that does not meet the criteria specified for either of these summary categories is assigned to the Unknown/Other Inorganic Debris (S5190) detailed category.

S5110 Metal Debris
This summary category includes waste that is estimated to be 80% by volume, or more, metal debris materials. The appropriate detailed MPCs for this waste are selected from the following categories.

S5111 Metal Debris without Pb or Cd
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, metal debris and does not contain any bulk, separable or bonded, lead or cadmium as part of the matrix.

S5112 Metal Debris with Pb

This specific-detailed category includes waste that is estimated to be 80% by volume, or more, metal debris and contains bulk, separable or bonded, lead as part of the matrix. Examples of waste that might be included in this category are glovebox parts with lead clad in stainless steel or scrap metal that includes some lead bricks. This category does not include waste that meets the criteria for categorization as elemental lead (i.e., $\geq$50% by volume elemental lead) or lead acid batteries (see Section 5.5).

S5113 Metal Debris with Cd
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, metal debris and contains bulk, separable or bonded, cadmium as part of the matrix. This category does not include waste that meets the criteria for categorization as elemental cadmium (i.e., $\geq$50% by volume elemental cadmium) or cadmium batteries (see Section 5.5).

S5119 Unknown/Other Metal Debris
This unknown/other-detailed category includes waste that is consistent with the definition for the Metal Debris (S5110)summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the S5111 through S5113 specific-detailed categories, or
- Contains both lead and cadmium, separable or bonded, as part of the bulk matrix.

S5120 Inorganic Nonmetal Debris
This summary category includes waste that is estimated to be 80% by volume, or more, inorganic nonmetal debris. The appropriate detailed MPCs for this waste are selected from the following categories.

S5121 Concrete Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, concrete debris. An example of waste that might be included in this category is concrete chunks and blocks from decontamination and decommissioning activities. This category does not include waste solidified with cement or other stabilization agents (see Sections 5.4.1 and 5.6.1).

S5122 Glass Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, glass debris. Examples of waste that might be included in this category are leaded glass windows, bottles, or lightbulbs.

S5123 Ceramic/Brick Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, ceramic or brick debris materials. Examples of waste that might be included in this category are bricks, ceramic crucibles, and ceramic refractories.

S5124 Rock Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, rock or gravel materials provided the particle size meets the EPA LDR criteria for classification as debris.

S5125 Asbestos Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, asbestos or asbestos-based debris materials. Examples of waste that might be included in this category are asbestos-containing gloves, firehoses, aprons, flooring tiles, pipe insulation, boiler jackets, and laboratory tabletops.

S5126 Graphite Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, graphite-based debris materials. Examples of waste that might be included in this category are crucibles, graphite components, and pure graphite.

S5129 Unknown/Other Inorganic Nonmetal Debris
This unknown/other-detailed category includes debris that is consistent with the definition for the Inorganic Nonmetal Debris (S5120) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the S5121 through S5126 specific-detailed categories, or
- Does not meet the criteria for assignment into one of the S5121 through S5126 specific-detailed categories.

S5190 Unknown/Other Inorganic Debris
This unknown/other-detailed category includes waste that is consistent with the definition for the Inorganic Debris (S5100) summary category, but:

- Is insufficiently characterized to enable evaluation per the criteria of the Metal Debris (S5110) and Inorganic Debris (S5100) summary categories, or
- Does not meet the criteria specified for either of the Metal Debris (S5110) or Inorganic Nonmetal Debris (S5120) summary categories.

S5300 Organic Debris
this summary category includes waste that is estimated to be 80% by volume, or more, organic debris materials. Examples of organic debris are materials constructed of plastic, rubber, wood, paper, cloth, and biological materials.

As shown in Figure 5-5, this waste is further evaluated per the criteria of the Plastic/Rubber Debris (S5310) summary category and the Wood Debris (S5320), Paper/Cloth Debris (S5330), and Biological Debris (S5340) specific-detailed categories. Organic debris that is insufficiently characterized to enable this evaluation, or that does not meet the criteria specified for any of these categories is assigned the Unknown/Other Organic Debris (S5390) detailed category.

S5310 Plastic/Rubber Debris
This summary category includes waste that is estimated to be 80% by volume, or more, plastic or rubber debris materials. Examples of plastic and rubber debris materials are plastic or rubber sheeting, containers, gloves, gaskets, and components of benelex or plexiglass. The appropriate detailed MPCs for this waste are selected from the following categories.

S5311 Leaded Gloves/Aprons
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, rubber debris materials that contain a high fraction of lead or lead compounds. Examples of waste that might be included in this category are leaded glovebox gloves or aprons.

S5312 Halogenated Plastic Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, plastic or rubber debris materials that contain halogenated plastics, such as PVC, as part of the matrix.

S5313 Nonhalogenated Plastic Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, plastic or rubber debris materials, excluding leaded gloves and aprons, that do not contain halogenated plastics as part of the matrix.

S5319 Unknown/Other Plastic/Rubber Debris
This unknown/other-detailed category includes waste that is consistent with the definition for the Plastic/Rubber Debris(S5310) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the S5311 through S5313 specific-detailed categories,

or

- Does not meet the criteria for assignment into one of the S5311 through S5313 specific-detailed categories.

S5320 Wood Debris
This specific-detailed category includes debris that is estimated to be 80% by volume, or more, wood or wood products other paper. Examples of waste that might be included in this category are structural timbers, boxes, or pallets.

S5330 Paper/Cloth Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, paper or cloth debris materials. Examples of waste that might be included in this category are protective clothing, rags, or wipes. Rags and wipes may contain some absorbed organic or aqueous liquids.

S5340 Biological Debris
This specific-detailed category includes waste that is estimated to be 80% by volume, or more, biological debris materials, including any chemical agents such as lime or formaldehyde. Examples of waste that might be included in this category are biological samples and animal carcasses.

S5390 Unknown/Other Organic Debris
This unknown/other-detailed category includes waste that is consistent with the definition for the Organic Debris (S5300) summary category, but:

- Is insufficiently characterized to enable evaluation per the criteria of the S5310 summary category and the S5320 through S5340 specific-detailed categories, or

- Does not meet the criteria specified for the S5310 summary category or any of the S5320 through S5340 specific-detailed categories.

S5400 Heterogeneous Debris
This summary category includes waste that is at least 50% by volume debris materials that do not meet the criteria for assignment as either an Inorganic Debris (S5100) or Organic Debris (S5300). An example is waste that is essentially entirely debris, but is not dominant (i.e., estimated to be 80% by volume or more) in either inorganic or organic debris materials. Another examples is waste that is at least 50% by volume debris materials, with the balance being soil or homogeneous solids. The appropriate detailed MPCs for this waste are selected from the following categories.

S5410 Composite Filter Debris
This specific-detailed category includes debris that is estimated to be 50% by

volume, or more, high-efficiency particulate air filters (HEPA) or other filters constructed of more than one material type (e.g., metal, inorganic nonmetal, and organic materials). Filters constructed of a single material type are assigned into the appropriate inorganic, organic, or heterogeneous debris category depending on the composition of the entire waste matrix.

S5420 Predominantly Inorganic Debris
This specific-detailed category includes waste that is estimated to contain at least 50%, but less than 80%, by volume inorganic debris materials. The balance of the matrix may be organic debris materials, soil, or homogeneous solids.

S5440 Predominantly Organic Debris
This specific-detailed category includes waste that is estimated to contain at least 50%, but less than 80%, by volume organic debris materials. the balance of the matrix may be inorganic debris materials (i.e., metal, inorganic nonmetal), soil, or homogeneous solids.

S5450 Asphalt Debris
This specific-detailed category includes debris that is estimated to be 50% by volume, or more, asphalt or other bituminous materials. Examples of waste that might be included in this category are asphalt materials from roadways, shingles, bituminous cement, or other materials containing both tar and gravel.

S5460 Electronic Equipment
This specific-detailed category includes waste that is estimated to be 50% by volume, or more, electronic equipment constructed of more than one material type (e.g., metal, inorganic nonmetal, and organic materials). Examples may include circuit boards, electronic laboratory equipments, computer and ancillary equipment, process controllers, etc. Electronic equipment constructed of a single material type is assigned into the appropriate inorganic, organic, or heterogeneous debris category depending on the composition of the entire waste matrix.

S5490 Unknown/Other Heterogeneous Debris
This unknown/other-detailed category includes waste that is consistent with the definition for the Heterogeneous Debris (S5400) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into any of the S5410, S5420, S5440, S5450, or S5460 specific-detailed categories, or
- Does not meet the criteria for assignment into any of the S5410, S5420, S5440, S5450, or S5460 specific-detailed categories.

S5900 Unknown/Other Debris

This unknown/other-detailed category includes waste that is consistent with the definition for the Debris (S5000) summary MPC, but insufficiently characterized to enable evaluation per the criteria of the Inorganic Debris (S5100), Organic Debris (S5300), and Heterogeneous Debris (S5400) summary categories (i.e., insufficient data exist to estimate whether the waste is 80% by volume, or more, inorganic or organic debris materials).

5.4.4 S9000 UNKNOWN/OTHER SOLIDS

This unknown/other-detailed category includes waste that is consistent with the definition for the Solids (S) summary category, but:

- Is insufficiently characterized to enable evaluation per the criteria of the Homogeneous Solids (S3000), Soil/Gravel (S4000), and Debris (S5000) summary categories, or
- Does not meet the criteria for any of the Homogeneous Solids (S3000), Soil/Gravel (S4000), or Debris (S5000) summary categories.

5.5 DEFINITION-SPECIFIC WASTE FORMS AND ASSOCIATED CATEGORIES

The initial Specific Waste Forms (X) summary category addresses waste that is of certain specific forms. these forms include waste with matrices that are liquids, solids, or combinations of both. As shown in Figure 5-6, specific waste forms are initially evaluated per the criteria of the Lab Packs (X6000) and Special Waste (X7000) summary categories.

5.5.1 X6000 LAB PACKS

Per this guidance, a lab pack configuration is defined as two or more waste containers packaged within a larger outer container. Typically, the inner containers are surrounded by absorbent materials; however, this is not an absolute criterion. If present, the absorbents can be homogeneous solids or debris materials. Examples may include rags, vermiculite, diatomaceous earth, and paper wipes.

This summary category includes waste that either (a) is packaged as a lab pack upon generation, or (b) will be packaged as a lab pack before transfer to long-term storage or treatment. The reason for inclusion of the second item is that many sites maintain inventories of small waste volumes (e.g., excessed or expired chemicals) in temporary storage. Often, this waste is lab packed before transfer for long-term storage or treatment.

This category does not include lab packs of elemental liquid mercury (see Section 5.5.2) or paint waste (see Section 5.4.1). In addition, waste packaged in a lab pack configuration that is considered overpacked is excluded. A typical example of an overpack is a single 55-gallon drum of waste that is placed in a 85-gallon drum because of deterioration of the 55-gallon container. This waste should be assigned the appropriate category based on the waste within the inner, overpacked container(s). The appropriate detailed MPCs for lab packs are selected from the following categories.

X6100 Organic Lab Packs
This specific-detailed category includes lab packs for which the inner waste packages contain only organic liquids. this category does not include organic scintillation fluids in containers (i.e., vials) that are packaged in a lab pack configuration.

X6200 Aqueous Lab Packs
This specific-detailed category includes lab packs for which the inner waste packages contain only aqueous liquids. This category does not include aqueous scintillation fluids in containers (i.e., vials) that are packaged in a lab pack configuration.

X6300 Solid Lab Packs
This specific-detailed category includes scintillation fluids in containers (i.e., vials) that are packaged in a lab pack configuration.

X6900 Unknown/Other Lab Packs
This unknown/other-detailed category includes waste that is consistent with the definition for the Lab Packs (X6000) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the X6100 through X6400 specific-detailed categories, or
- Does not meet the criteria for assignment into one of the X6100 through X6400 specific-detailed categories.

5.5.2 X7000 SPECIAL WASTE
In general, this summary category includes waste that (a) is inherently hazardous (i.e., the bulk material itself is RCRA hazardous), often with specific LDR treatment technology requirements, or (b) presents unique treatment concerns. As shown in Figure 5-6, this waste is further evaluated per the criteria of the tal Hazardous Metals (X7200), Batteries (X7400), and Reactive Metals (X7500) summary categories, and the Elemental Mercury (X7100), Beryllium Dusty (X7300), Explosives/Propellants (X7600), and Compressed Gases/Aerosols (X7700) specific-detailed categories. Special waste that does not meet the criteria specified for any of these categories is assigned to the Unknown/Other Special Waste (X7900) detailed category.

X7100 Elemental Mercury
This specific-detailed category includes waste that is bulk, pourable liquid mercury. The liquid mercury may be packaged in a lab pack configuration. Manometers, or other equipment, that contain small residual amounts of mercury should be assigned to the appropriate debris category (see Section 5.4.3).

X7200 Elemental Hazardous Metals
This summary category includes waste that contains at least 50% by volume solid, bulk elemental hazardous metals that meet the EPA size criteria for classification as debris. Waste that contains at least 50% by volume solid, bulk elemental hazardous metals that

do not meet the EPA size criteria for classification as debris are assigned into the Metal Chips/Turnings (S3116) category. Also, beryllium dust is excluded from this category (X7300).

This waste is further evaluated per the criteria of the Elemental Lead (X7210) summary MPC and the Elemental Cadmium (X7220) specific-detailed MPC. Elemental hazardous metals that do not meet the criteria specified for either of these two categories are assigned to the Unknown/Other Elemental Hazardous Metals (X7290) detailed category.

X7210 Elemental Lead
This summary category includes waste that contains at least 50% by volume bulk elemental lead. Examples of waste in this category are lead bricks, sheets, and pipes. The appropriate detailed MPCs for this waste are selected from the following categories.

X7211 Nonactivated Lead
This specific-detailed category includes waste meeting the above criteria for categorization as elemental lead in which the elemental lead shapes are only surface contaminated with radionuclides.

X7212 Activated Lead
This specific-detailed category includes waste meeting the above criteria for categorization as elemental lead in which the elemental lead shapes are activated.

X7219 Unknown/Other tal Lead
This unknown/other-detailed category includes waste that is consistent with the definition of the Elemental Lead (X7210) summary category, but it is not known whether the lead is activated or nonactivated. This category also indicated elemental lead that is not radioactive.

X7220 Elemental Cadmium
This specific-detailed category includes waste that contains at least 50% by volume bulk elemental cadmium. Examples of waste in this category are cadmium bricks, sheets, and pipes.

X7290 Unknown/Other Elemental Hazardous Metals
This unknown/other-detailed category includes waste that contains at least 50% by volume solid, bulk elemental hazardous metals, other than lead or cadmium, that meet the EPA size criteria for classification as debris. This category also includes waste that is at least 50% by volume a mixture of two or more bulk elemental hazardous metals that meet the EPA size criteria for classification as debris.

X7300 Beryllium Dust

This specific-detailed category includes beryllium waste that is subject to the metal recovery treatment standard as specified in the Third Third LDR rule (55 *FR* 22545). Waste contaminated with beryllium but not subject to the metal recovery treatment standard should be assigned to the appropriate category based on the bulk matrix compositions.

X7400 Batteries
This summary category includes waste consisting of batteries. The batteries may be packaged with absorbent materials (e.g., particulates, rags). The appropriate detailed MPCs for this waste are selected from the following categories.

X7410 Lead Acid Batteries
This specific-detailed category addresses battery waste as defined for the X7400 summary category in which only drained or undrained lead acid batteries are included.

X7420 Cadmium Batteries
This specific-detailed category addresses battery waste as defined for the X7400 summary category in which only cadmium batteries are included.

X7430 Mercury Batteries
This specific-detailed category addresses battery waste as defined for the X7400 summary category in which only mercury batteries are included.

X7490 Unknown/Other Batteries
This unknown/other-detailed category includes waste that is consistent with the definition for the Batteries (X7400) summary category, but:

- Is insufficiently characterized to enable more definitive assignment into one of the X7410 through X7430 specific-detailed categories, or
- Does not meet the criteria for assignment into any one of the X7410 through X7430 specific-detailed categories.

X7500 Reactive Metals
This summary category includes reactive metals waste. In this guidance, reactive metals are defined as waste meeting the criteria for classification as water reactive or ignitable reactive per the Third Third LDR rule (55 *FR* 22545 and 22553). Typically, this waste is sodium metal or sodium metal alloys, but can also include particulate fines of aluminum, uranium, zirconium, or other pyrophoric materials. The waste may be mixed with stabilizing materials. The appropriate detailed MPCs for this waste are selected from the following categories.

X7510 Bulk Reactive Metals

This specific-detailed category includes waste that is essentially bulk reactive metals and meets the criteria for classification as water reactive per the Third Third LDR rule. Typically, this waste is sodium metal or sodium metal alloys.

X7520 Reactive Metal Contaminated Components
This specific-detailed category includes piping, pumps, and other retired equipment waste that is considered water reactive per the Third Third LDR rule because of reactive metal contamination. The bulk of the material is not reactive metals, but the reactive metals require treatment before disposal.

X7530 Pyrophoric Fines
This specific-detailed category includes waste that is essentially bulk materials that meet the criteria for classification as ignitable reactive per the Third Third LDR rule. Examples are fines of aluminum, uranium, zirconium, or other pyrophoric materials. The waste may be mixed with stabilizing materials.

X7590 Unknown/Other Reactive Metals
This unknown/other-detailed category includes reactive metal waste with characteristics that are not consistent with the definitions for the X7510 through X7530 specific-detailed MPCs.

X7600 Explosives/Propellants
This specific-detailed category includes waste consisting of substances that undergo rapid chemical transformations that produce large amounts of gases and heat. The gases rapidly expand at velocities exceeding the speed of sound (due to the heat of reaction), which creates a shock wave and explosion. Waste that meets this definition should be identified here regardless of the specific physical form. Liquid nitroglycerine, for instance, should be categorized as an explosive and not as an organic liquid. Similarly, TNT would be categorized as explosive rather than as a homogeneous solid.

X7700 Compressed Gases/Aerosols
This specific-detailed category includes waste consisting of pressurized gas cylinders, including aerosols. Waste consisting of depressurized gas cylinders or aerosol cans would not be assigned to this category. This waste would be assigned to the appropriate debris category (see Section 5.4.3).

X7900 Unknown/Other Special Waste
This unknown/other-detailed category which includes waste that is consistent with the definition for the Special Waste (X7000) summary category, but inconsistent with the definitions for the X7200, X7400, and X7500 summary categories and the X7100, X7300, X7600, and X7700 specific-detailed categories.

5.6 DEFINITIONS-FINAL WASTE FORMS AND ASSOCIATED CATEGORIES

The initial Final Waste Forms (Z) summary category addresses waste that is in final form and meets applicable disposal criteria, including applicable LDR and PCB treatment standards. The final waste form categories currently defined in this guidance are shown in Figure 5-7. These categories are primarily intended for assignment to final waste forms resulting from the treatment of hazardous or mixed waste. Typically, preparing radioactive or sanitary waste for disposal does not require the rigorous treatments that produce these final waste forms. In other words, the final disposable forms of these primary waste types may be one of the previously defined solid MPCs (see Section 5.4). However, if applicable, the final waste form MPCs may be applied to waste other than that resulting from treatment of hazardous or mixed waste.

As shown in Figure 5-7, final waste forms are initially evaluated per the criteria of the Immobilized Forms (Z1000) and Decontaminated Solids (Z2000) summary categories. Final waste forms that do not meet the criteria specified for either of these summary categories are assigned to the Other Final Forms (Z9000) detailed category.

5.6.1 Z1000 IMMOBILIZED FORMS

This summary category includes waste forms that are immobilized. Immobilized final forms are further evaluated per the criteria of the Microencapsulated Forms (Z1100) and Macroencapsulated Forms (Z1200) categories. As defined in this guidance, the key distinction between microencapsulation and macroencapsulation is the matrix characteristic of the waste before immobilization. In general, immobilized forms resulting from the treatment of liquids and slurries, or solids with relatively small particle sizes (e.g., not meeting the EPA particle size criteria for classification as debris) are considered microencapsulated. Immobilized forms resulting from the treatment of solids with large particle sizes (e.g., debris) are considered macroencapsulated. This represents a deviation from more stringent definitions of microencapsulation used by the EPA and others.

Z1100 Microencapsulated Forms

This summary category includes waste that has been immobilized via microencapsulation. The appropriate detailed MPCs for this waste are selected from the following categories.

Z1110 Cement Forms

This specific-detailed category includes waste that has been immobilized with grout or other cement-type binders.

Z1120 Vitrified Forms

This specific-detailed category includes waste that has been immobilized via vitrification.

Z1130 Polymer Forms
This specific-detailed category includes waste that has been microencapsulated with organic binders.

Z1140 Amalgamated Forms
This specific-detailed category includes waste that has been immobilized via amalgamation.

Z1150 Crystalline Forms
This specific-detailed category includes waste that has been immobilized via methods that produce a crystalline final waste form. Example methods are microwave solidification and the Synrock process.

Z1190 Other Microencapsulated Forms
This unknown/other-detailed category includes microencapsulated forms other than those addressed by the Z1110 through Z1150 specific-detailed categories.

Z1200 Macroencapsulated Forms
This specific-detailed category includes waste that has been immobilized via macroencapsulation.

5.6.2 Z2000 DECONTAMINATED SOLIDS
This summary category includes waste that has been decontaminated and is ready for disposal or recycling. The appropriate detailed MPCs for this waste are selected from the following categories.

Z2100 Decontaminated Metal
This specific-detailed category includes metal waste that has been decontaminated and is read for disposal or recycling.

Z2900 Other Decontaminated Solids
This unknown/other-detailed category includes waste, other than metal materials, that has been decontaminated and is ready for disposal or recycling.

5.6.3 Z9000 OTHER FINAL FORMS
This unknown/other-detailed category includes final waste forms other than immobilized forms and decontaminated solids.

5.7 DEFINITION-UNKNOWN/OTHER MATRIX (U9999) CATEGORY
This category includes waste for which insufficient characterization is known to enable

evaluation per the criteria of the initial Liquids (L), Solids (S), Specific Waste Form (X), and Final Waste Form (Z) summary categories, or waste that does not meet the criteria specified for nay of those categories."

Figure 5-1. Matrix Parameter Categories - Initial Categories

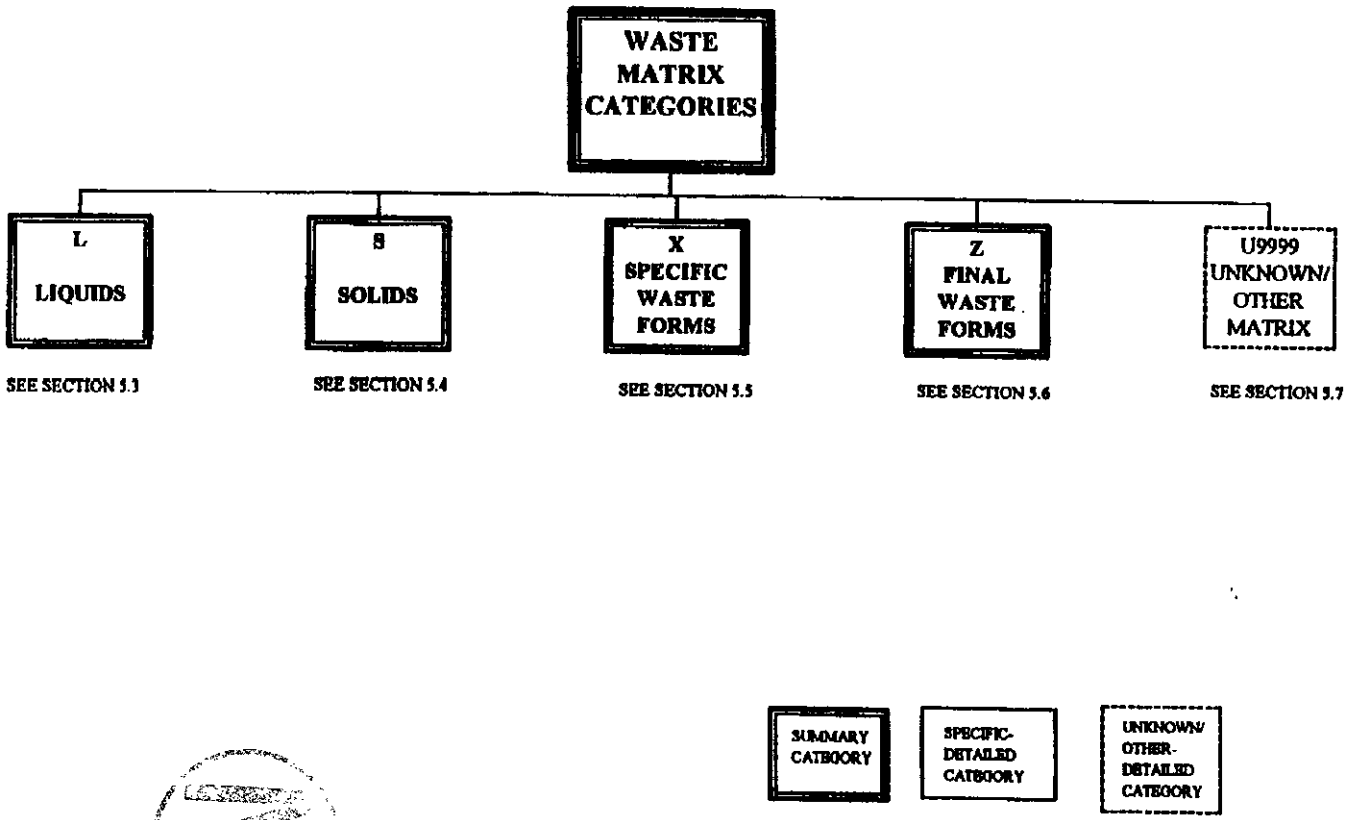

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Figure 5-2. Matrix Parameter Categories- Liquids

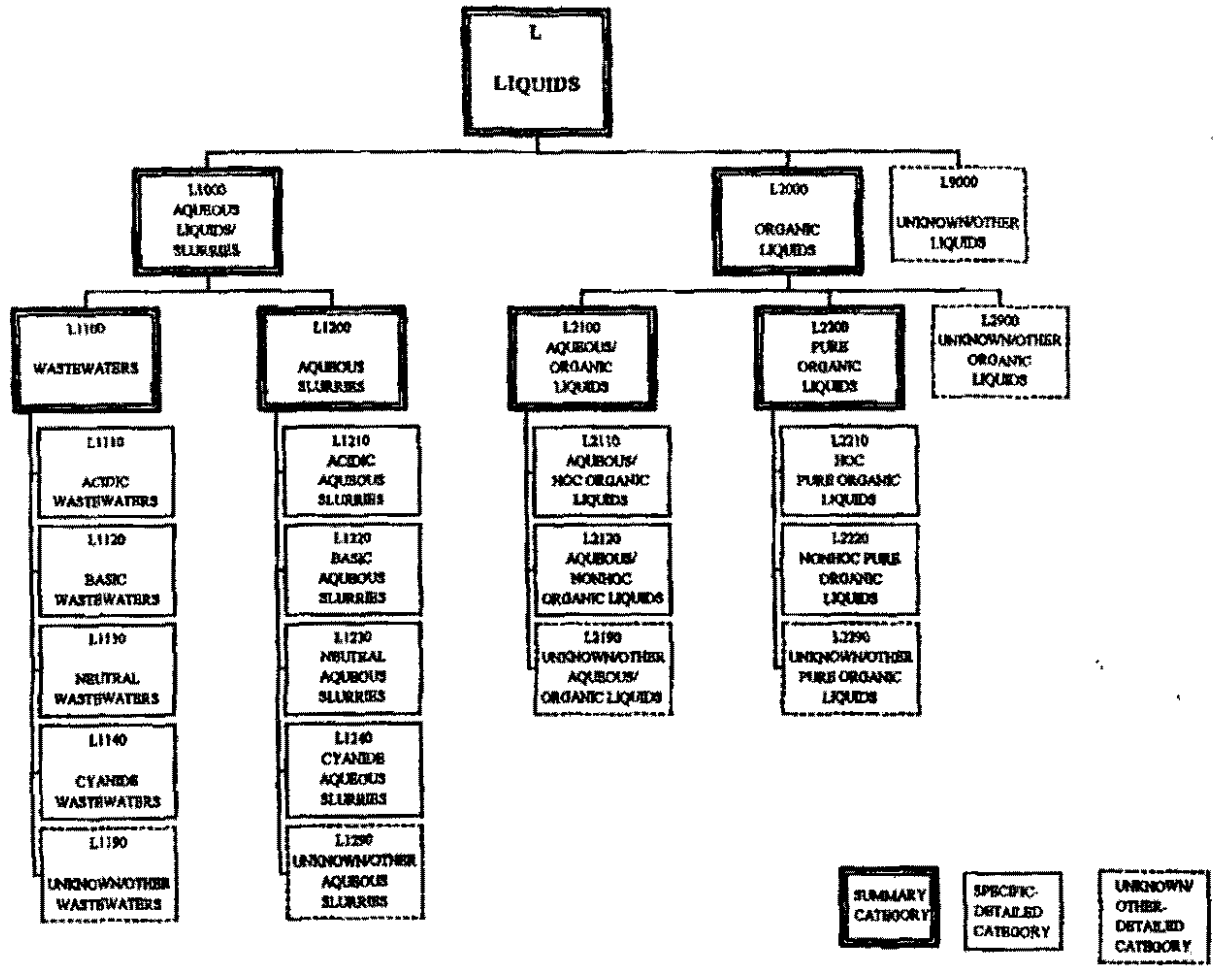

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Figure 5-3. Matrix Parameter Categories - Solids

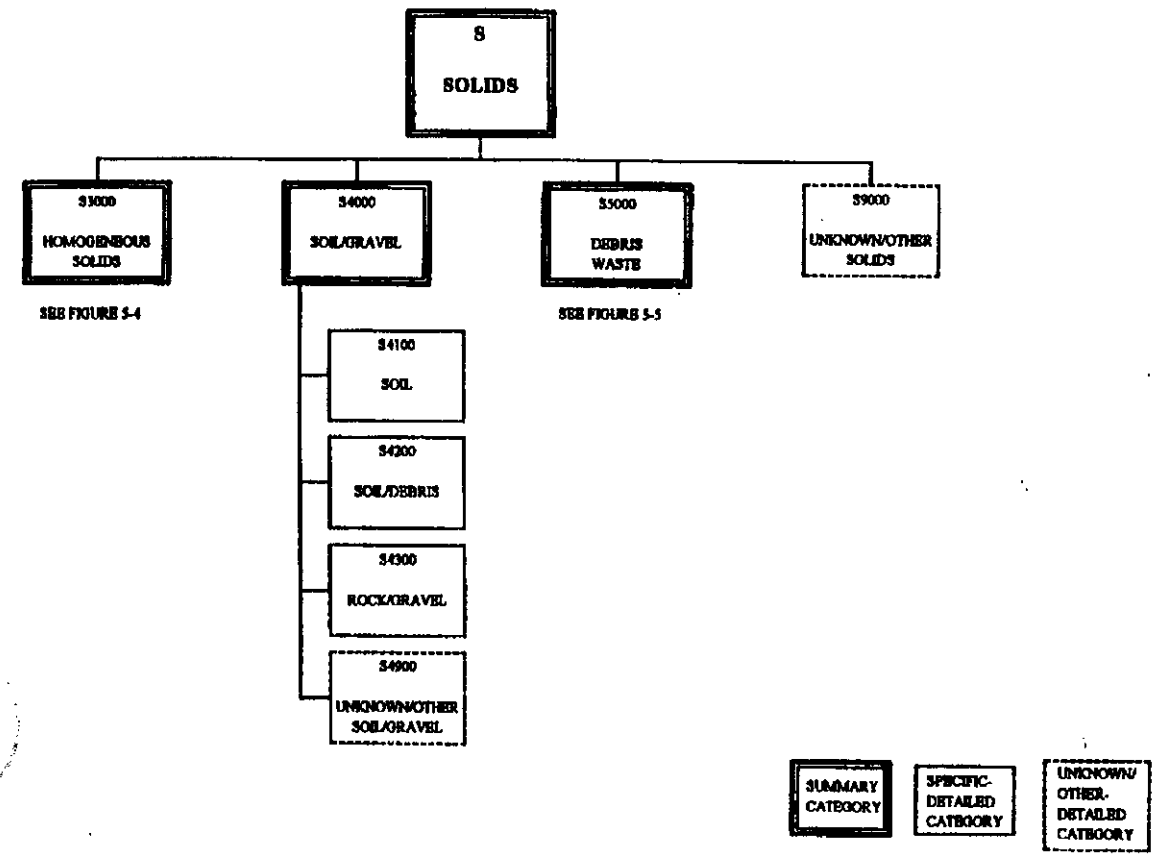

DOE Waste Treatability Group Guidance - January 1995

Figure 5-4. Matrix Parameter Categories - Homogeneous Solids

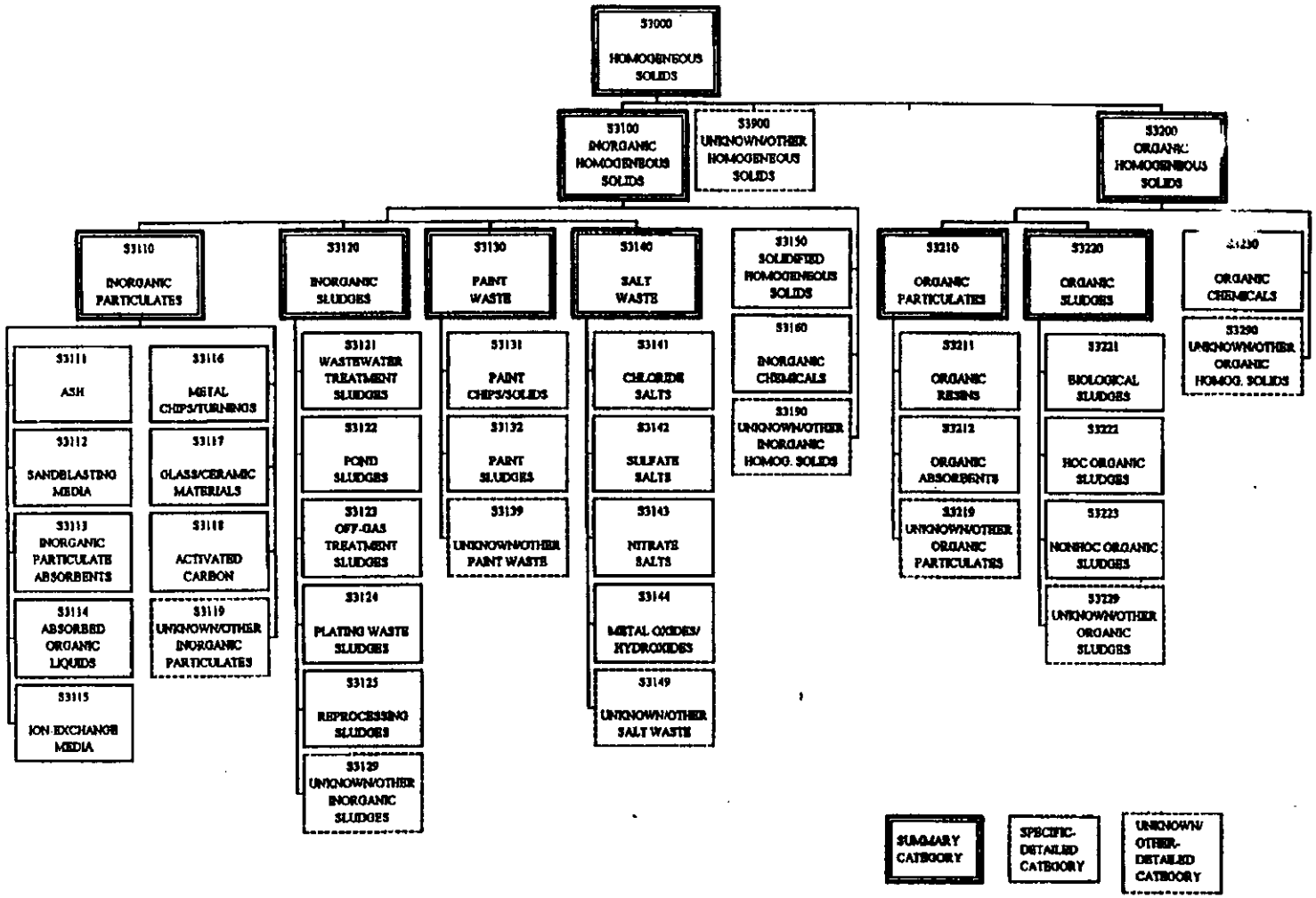

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Figure 5-5. Matrix Parameter Categories - Debris

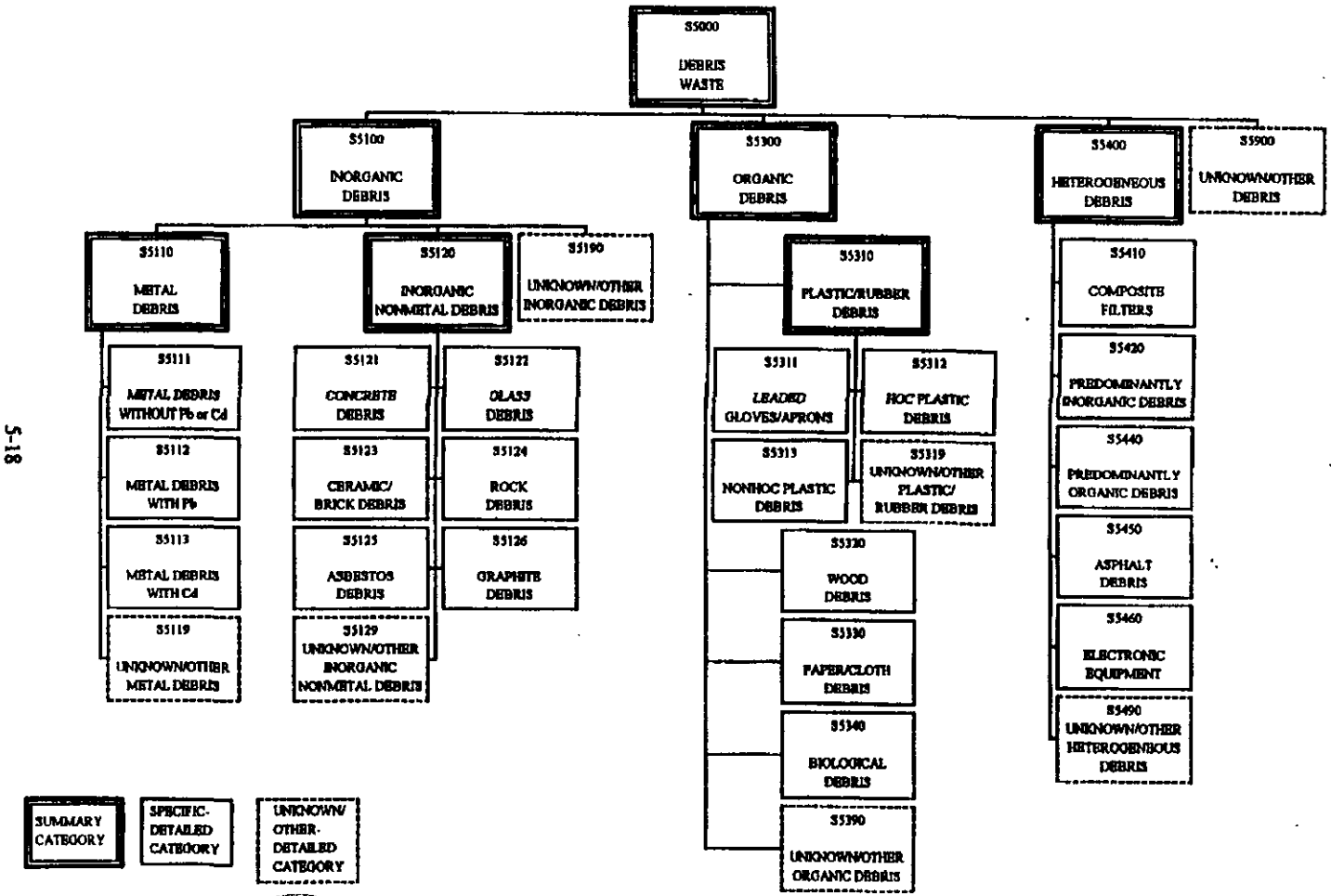

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Figure 5-6. Matrix Parameter Categories - Specific Waste Forms

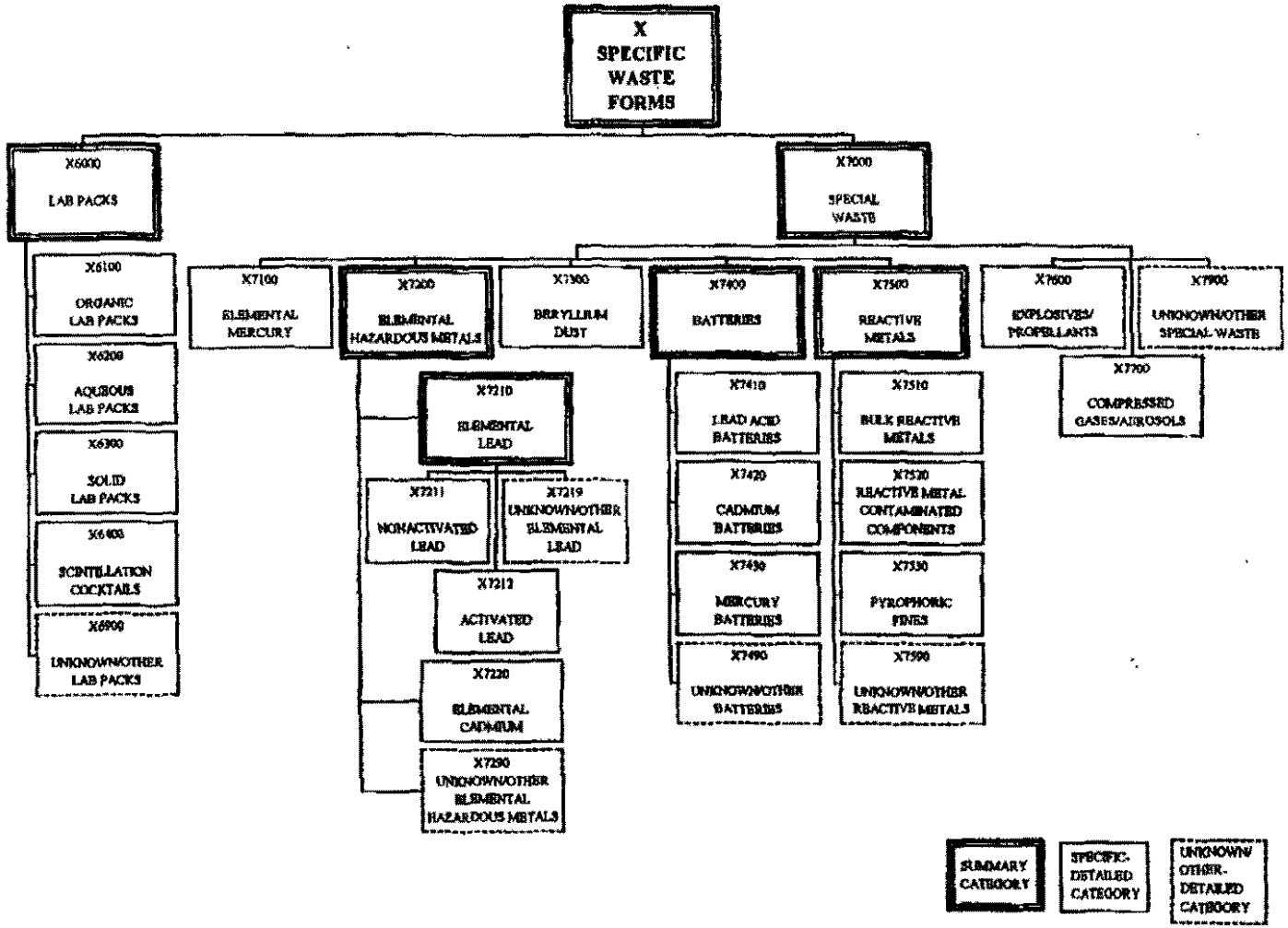

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Figure 5-7. Matrix Parameter Categories - Final Waste Forms

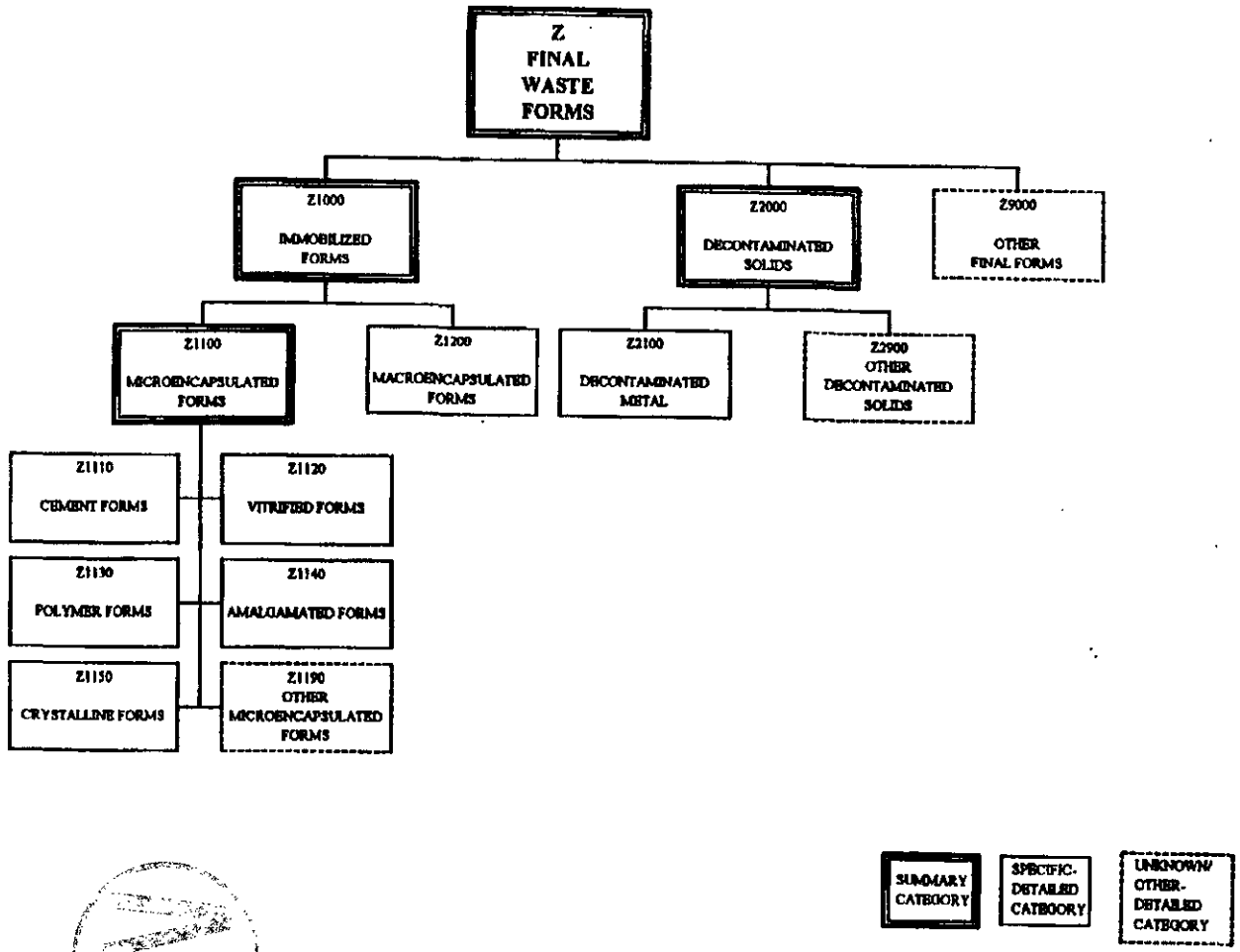

DOE Waste Treatability Group Guidance - January 1995

DOE (U.S. Department of Energy). 1996a. Waste Acceptance Criteria for the Waste Isolation Pilot Plant. DOE/WIPP-96-069, Revision 5, April 1996. Carlsbad, NM.

INTRODUCTION, p. 1-1;

" The Waste Isolation Pilot Plant (WIPP) Waste Acceptance Criteria (WAC), DOE/WIPP-069, was initially developed by a U.S. Department of Energy (DOE) Steering Committee to provide performance requirements to ensure public health and safety as well as the safe handling of transuranic (TRU) waste at the WIPP. This revision of the WAC reflects the organizational restructuring of the DOE and the change from test phase requirements to disposal requirements. This revision incorporates the most current environmental compliance requirements from the Resource Conservation and Recovery Act (RCRA) Permit Application (Reference 1), the draft No-Migration Variance Petition (NMVP) (Reference 2) and the 40 CFR 191 Draft Compliance Certification Application (DCCA) Reference 3), along with the most up-to-date technical and regulatory requirements for transportation and operational safety. This Revision 5 of the WAC supercedes Revision 4 (Reference 11). TRU Waste Generator/Storage Sites (Sites) participating in the National Transuranic Program (NTP) must certify their TRU waste to the criteria and requirements defined in this WAC prior to transport to, and disposal in the WIPP. The characterization of TRU waste must be in accordance with the TRU Waste Characterization Quality Assurance Program Plan (Reference 4).

This WAC document applies to both contact-handled (CH) and remote-handled (RH) TRU waste forms for disposal in the WIPP. The criteria (parameters for waste acceptance) and the requirements (conditions or limits which must be met for each criterion) are presented in Section 3. Known criteria and requirements necessary for certification of CH-TRU wastes have been defined; however only preliminary characterization and transportation-related waste packaging requirements for RH-TRU waste have been identified. The WAC does not address specific local, State or Federal regulations affecting the handling or shipping of TRU mixed waste at Generator/Storage sites (e.g., State EPA Hazardous Waste Codes, DOE marking on containers, etc.). Requirements have not yet been finalized for the RH-TRU 72-B Cask but are included to provide technical guidance to Sites. Specific RH-TRU waste transportation requirements will be included after Nuclear Regulatory Commission (NRC) approval of the RH-TRU 72-B Cask Safety Analysis Report for Packaging (SARP) and issuance of a Certificate of Compliance (C of C). The WAC is a controlled document. Revised pages will be supplied to all holders of controlled copies."

3.8.3 CANISTER/CASK CONTACT DOSE RATES; 3.8.3.1 WIPP Operations and Safety Requirements, p. 3-39;

" The RH-TRU canister limit is based upon the total RH-TRU waste volume at the WIPP, not upon the Site's number of RH-TRU canisters. No more than 5 percent of the RH canisters received at the WIPP are allowed to have dose rates of > 100 rem/hr. Prior approval by the WIPP is required before RH-TRU canisters having dose rates > 100 rem/hr but ≤ 1000 rem/hr may be shipped to the WIPP. All RH-TRU canisters shall have a maximum contact dose rate at any point no greater than 1000 rem/hr. Neutron contributions are limited to 270 mrem/hr.

Neutron contributions of gretare than 20 mrem/hr to the total canister dose rate shall be reported in the data package."

DOE (U.S. Department of Energy). 1996b. WIPP Waste Information System Software Design Description, CAO-96-1111, Revision 0, September 1996. Carlsbad, NM.

1. INTRODUCTION, 1.1 Purpose, p. 1;

" The Waste Isolation Pilot Plant Waste Information System (WWIS) Software Design Description (SDD) is the primary medium for communicating software design information about the system's application software. The SDD is a translation of requirements into a description of software structure, components, interfaces, and data necessary for implementation. This document will be used by the development team as the blueprint for implementation in conjunction with the *WWIS Software Requirements Specification*,[1] which defines design requirements. This document will be developed in the design phase and used throughout the WWIS software life cycle as depicted in Figure 1.

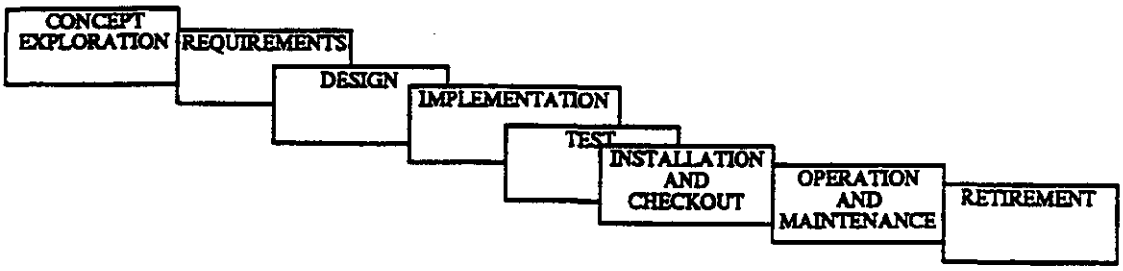

Figure 1 Software Life Cycle

DOE (U.S. Department of Energy). and State of New Mexico. 1981. Consultation and Cooperation Agreement. Appendix A to the Stipulated Agreement Resolving Civil Action, 81-0363JB, State of New Mexico vs. United States Department of Energy, United States District Court, Albuquerque, NM.

STIPULATED AGREEMENT, p. 1;

" Whereas, the plaintiff, State of New Mexico, ex rel. Jeff Bingaman, Attorney General, has brought this action to address four major concerns of the State of New Mexico; and,

Whereas, these concerns include: (1) that the final decision point for commencing construction of a permanent WIPP repository and its operation should not be reached until all interested parties including the State of New Mexico know the results of actual site and design validation tests and the SPDV program in general; and (2) that the State of New Mexico be given the opportunity to have a final resolution of all essential and integral off-site state government concerns involving health, safety, and public welfare issues prior to a final decision to commence construction of permanent WIPP facilities; and (3) that the State of New mexico be entitled to a binding and enforceable consultation and cooperation agreement that does not waive any right by the State to judicial review of any federal agency action with respect to the WIPP project; and (4) the concern that the withdrawal provisions of the Federal Land Policy and Management Act be complied with, including public hearings to be held before a decision is made to withdraw federal lands from the public domain for the WIPP project; and"

p. 2, para. 6;

" NOW, THEREFORE, the parties hereby stipulate and agree as follows:

1. Simultaneous with the entry of the Stipulated Agreement, the United States Department of Energy and the State of New Mexico shall execute a consultation and cooperation agreement which shall provide for the timely exchange of information about the WIPP project and procedures for them to follow to attempt to resolve conflicts between them relating to the public health, safety or welfare of the citizens of the State should any such conflicts arise during the course of that project. This consultation and cooperation agreement shall be a binding, enforceable agreement between the Department of Energy and the State of New Mexico and shall expressly provide that it does not constitute a waiver by the State of any right it may have to judicial review of federal agency actions with respect to the WIPP project. The consultation and cooperation agreement is attached to and incorporated herein as Appendix A hereto."

First Modification to the July 1, 1981 "Agreement for Consultation and Cooperation" on WIPP by the State of New Mexico and U. S. Department of Energy; Modifications to Agreement for Consultation and Cooperation; 1. Modify Article VI - WIPP MIssion by revising existing paragraphs B. and C.; , p 3, line 13;

" The analyses in the WIPP FEIS use the upper limit of 100 rem per hour as the maximum surface dose rate for a canister of remote handled transuranic (RH-TRU) waste and an expected maximum activity level of 23 curies per liter for the waste. The Record of

decision dated January 22, 1981 also limited the total volume of RH-TRU to be shipped to WIPP to 250,000 cubic feet."

U.S. Congress. 1992a. Federal Faciltiy Compliance Act. Public Law 102-386.

" An Act

To amend the Solid Waste Disposal Act to clarify provisions concerning the application of certain requirements and sanctions to Federal facilities.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

TITLE I-FEDERAL FACILITY
COMPLIANCE ACT

SEC.101.SHORT TITLE.

This title may be cited as the "Federal Facility Compliance Act of 1992"."

SEC.105.MIXED WASTE INVENTORY REPORTS AND PLAN.

" (b) DEFINITION.-Section 1004 of the Solid Waste Disposal Act (42 U.S.C. 6902) is amended by adding at the end the following new paragraph:

"(41) The term 'mixed waste' means waste that contains both hazardous waste and source, special nuclear, or by- product material subject to the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.)."."

U.S. Congress, 1992b. Waste Isolation Pilot Plant Land Withdrawal Act, Public Law 102-579, October 1992. 102nd Congress, Washington, D.C.

"An Act
To withdraw land for the Waste Isolation Pilot Plant, and for other purposes.
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,"

"SEC.7.DISPOSAL OPERATIONS.
(a)TRANSURANIC WASTE LIMITATIONS.--
(1) REM LIMITS FOR REMOTE-HANDLED TRANSURANIC WASTE.--
(A) 1,000 REMS PER HOUR.--No transuranic waste received at WIPP may have a surface dose rate in excess of 1,000 rems per hour.
(B) 100 REMS PER HOUR.--No more than 5 percent by volume of the remote-handled transuranic waste received at WIPP may have a surface dose rate in excess of 100 rems per hour.
(2) CURIE LIMITS FOR REMOTE-HANDLED TRANSURANIC WASTE.--
(A) CURIES PER LITER.--Remote-handled transuranic waste received at WIPP shall not exceed 23 curies per liter maximum activity level (averaged over the volume of the canister).
(B) TOTAL CURIES.--The total curies of the remote-handled transuranic waste received at WIPP shall not exceed 5,100,000 curies."
(3) CAPACITY OF WIPP.--The total capacity of WIPP by volume is 6.2 million cubic feet of transuranic waste."

BIBLIOGRAPHY DOCUMENTS

ASME (American Society of Mechanical Engineers), 1989a. Quality Assurance Program Requirements for Nuclear Facilities. ASME NQA-1-1989.

INTRODUCTION, 1 PURPOSE, p 1;
" This Standard sets forth requirements for the establishment and execution of quality assurance programs for the siting, design, construction, operation, and decommissioning of nuclear facilities. Nonmandatory guidance is provided in the Appendices."

ASME (American Society of Mechanical Engineers), 1989b. Quality Assurance Requirements for Nuclear Facility Applications. ASME NQA-2a-1990 Addenda, Part 2.7, to ASME NQA2-2-1989 edition.

Part 2.7 Quality Assurance Requirements of Computer Software for Nuclear Facility Applications, 1 GENERAL, p 58.3;

" Part 2.7 provides requirements for the development, procurement, maintenance, and use of computer software, as applied to the design, construction, operation, modification, repair, and maintenance of nuclear facilities. It supplements the requirements of ASME NQA-1 and shall be used in conjunction with applicable Basic and Supplementary Sections of ASME NQA-1 when and to the extent specified by the organization invoking this Part."

ASME (American Society of Mechanical Engineers). 1989c. Quality Assurance Program Requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories. ASME NQA-3-1989, excluding Sections 2.1(b), 2.1(c), and 17.1.

FOREWORD, p iii;

" Early in 1975, the American National Standards Institute (ANSI) assigned overall responsibility for coordination among technical societies, development, and maintenance of nuclear power quality assurance standards to the American Society of Mechanical Engineers (ASME). The ASME Committee on Nuclear Quality Assurance was constituted on October 3, 1975, and began operating under the ASME Procedures for Nuclear projects. The ASME Committee on Nuclear Quality Assurance currently operates under the ASME Operating Procedures and Practices for Nuclear Codes and Standards Development Committees. This committee prepared ANSI/ASME NQA-1, Quality Assurance Program requirements for Nuclear facilities and ANSI/ASME NQA-2, Quality Assurance Requirements for Nuclear facility Applications. The need for a document like ASME NQA-3 was established after extensive studies by the ASME Nuclear Quality Assurance Subcommittee on Nuclear Waste Management, and after contractors and government agencies experienced difficulty in implementing NQA-1 as the Quality Assurance Program standard on the unique type of work involved in a high-level nuclear waste management program.

In 1984, the NQA Subcommittee on Nuclear Waste management was assigned responsibility for developing a Quality Assurance Program standard appropriate to site characterization of high-level nuclear waste repositories. This Subcommittee prepared ASME NQA-3, Quality Assurance Program requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories.

NQA-3 is to be used in conjunction with NQA-1 to set forth Quality Assurance Program requirements and nonmandatory guidance for the collection of scientific and technical information for site characterization of high-level nuclear waste repositories. It contains an Introduction, Basic Requirements, and Supplements. In addition, nonmandatory guidance is provided in the appendices, which do not set forth requirements. The requirements of NQA-1 and NQA-3 are intended to meet and clarify the criteria of 10CFR50, Appendix B and 10CFR60, Subpart G (Repository Quality Assurance Requirements) for high-level nuclear waste repositories.

The arrangements of the basic and supplementary requirements of these standards permit judicious application of the entire documents or only portions of the documents. The extent to which these documents should be applied, either wholly or in part, will depend upon the nature and scope of the work to be performed and the relative importance of the items being produced or services being provided. The extent of application is to be determined by the organization imposing this document. For example, it may only involve the Basic Requirements, or the Basic Requirements in combination with Supplements and Nonmandatory Appendices. These documents may be modified, as appropriate, or they may be applied in their entirety. These documents are written to allow application to any

structure, system, component, or activity that is essential to the satisfactory completion of site characterization of high-level nuclear waste repositories. . . ."

EPA (U.S. Environmental Protection Agency), 1993. Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, 40 CFR Part 191, Final Rule. 58 FR 66398.

PREAMBLE: SUMMARY;

" The U.S. Environmental Protection Agency (EPA) is promulgating amendments to the environmental standards for the disposal of spent nuclear fuel, high-level and transuranic wastes (40 CFR 191.15 and Subpart C).

EPA originally promulgated these standards in 1985 pursuant to the Agency's authorities and responsibilities under the Nuclear Waste Policy Act of 1982, as amended, the Atomic Energy Act of 1954, as amended, and §2(a)(6) of Reorganization Plan No. 3 of 1970 (5 USC app. 1). In 1987, following a legal challenge, the U.S. Court of Appeals for the First Circuit (hereinafter referred to as 'the First Circuit' or ' the court') remanded subpart B of the 1985 standards to the Agency for further consideration. *Natural Resources Defense Council, Inc. v. United States Environmental Protection Agency*, 824 F.2d 1258 (1st Cir. 1987). Recently enacted legislation, (Pub. L. 102-579) known as the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA), however, reinstates the 1985 disposal standards except 'the 3 aspects of §§191.15 and 191.16 of such [standards] that were subject of the remand ordered' by the First Circuit. The WIPP LWA directs EPA to expedite issuance of final disposal standards and specifies that such regulations shall not be applicable to the characterization, licensing, construction, operation, or closure of any site required to be characterized under §113(a) of Public Law 97-425, the Nuclear Waste Policy Act of 1982.

Today's action represents the Agency's response to this legislation and to the issues raised by the court pertaining to individual and ground-water protection requirements. After considering the relevant comments received on the February 10, 1993 proposed rulemaking, the Agency has taken this final action in the form of amendments to parts 191 of title 40 of the Code of Federal Regulations. In so doing, EPA has not revised any of the regulations reinstated by the WIPP LWA.

DATES: These amendments will become effective on January 19, 1994. These amendments will be promulgated for purposes of judicial review at 1 p.m. eastern standard time on December 20, 1993."

EPA (U.S. Environmental Protection Agency), 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, Final Rule. Federal Register, Vol. 58, No. 242, pp. 66398-66416, December 20, 1993, Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

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EPA (U.S. Environmental Protection Agency). 1994. Waste Analysis at Facilities that Generate, Treat, Store, and Dispose of Hazardous Waste: A Guidance Manual. EPA 530-R-94-024. Washington, D.C.

MEMORANDUM, Transmittal of Waste Analysis Plan Guidance Manual (OSWER Directive Number 9938.4-03);

" Attached is the revised waste analysis guidance manual. The manual will provide guidance to the regulated community, permit writers and enforcement officials in establishing the criteria to properly evaluate and prepare RCRA waste analysis plans (WAP).

The guidance manual updates the Agency's 1984 manual and incorporates the many changes to the hazardous waste regulations including the Land Disposal Restrictions (LDR). The manual is divided into the following four parts;

- **Part One** - provides guidance on determining individual waste analysis responsibilities and how to meet these responsibilities.
- **Part Two** - provides facility-specific procedures for conducting waste analysis and developing a waste analysis plan. Some important components include:
  - Content and organization of a WAP
  - Waste analysis parameters
  - Sampling procedures
  - Laboratory testing and analytical methods
  - Waste re-evaluation frequencies.
- **Part Three** - provides a checklist to ensure that all relevant waste analysis responsibilities at individual facilities have been addressed.
- **Part Four** - provides facility-specific (i.e., generator, disposal, and on and off-site treatment facilities) model WAPs. These should be used as guides when developing site-specific WAPs.

. . ."

1.5 How Can You Meet The Waste Analysis Requirements For Your Facility?, p. 1-11;

" You can meet general and specific waste analysis requirements using several methods or combinations of methods. Wherever feasible, the preferred method to meet the waste analysis requirements is to conduct *sampling and laboratory analysis* because it is more accurate and defensible than other options. (The procedures and equipment for both obtaining and analyzing samples are discussed in Part Two of this manual, and are described in Appendices I and II of 40 CFR Part 261.)

However, generators and TSDFs also can meet waste analysis requirements by applying *acceptable knowledge*. Acceptable knowledge can be used to meet all or part of the waste analysis requirements.

Acceptable knowledge can be broadly defined to include:

- "**Process knowledge**," whereby detailed information on the wastes is obtained from existing published or documented waste analysis data or studies conducted on hazardous wastes generated by processes similar to that which generated the waste.

As mentioned previously, EPA lists (i.e., F, K, P, and U lists) certain hazardous wastes in 40 CFR Part 261. The K-listed wastes, for example, contain wastes generated from specified sources. Examples of K-listed wastes include:

- K001 -- Bottom sediment sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or pentachlorophenol.
- K062 - Spent pickle liquor generated by steel finishing operations of facilities within the iron and steel industry.

K-listed wastes, therefore, are identified by comparing the specific process that generated the waste to those processes listed in 40 CFR §261.32 (rather than conducting a chemical/physical analysis of the waste). Similarly, any waste described in the F, P, or U list has already been designated as hazardous by EPA. Therefore, with many listed wastes the application of acceptable knowledge is appropriate because the physical/chemical makeup of the waste is generally well known and consistent from facility to facility.

- **Waste analysis data** obtained from facilities which send wastes off site for treatment, storage, or disposal (e.g., generators).
- **The facility's records of analysis performed before the effective date of RCRA regulations**. While seemingly attractive because of the potential savings associated with using existing information (such as published data), the facility must ensure that this information is current and accurate."

EPA (U.S. Environmental Protection Agency), 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. Federal Register, Vol. 61, No. 28, pp. 5224-5245, February 9, 1996. Office of Air and Radiation, Washington, D.C. In NWM Library as KF70.135.C751 1996 (Reference).

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992. EFFECTIVE DATE: These regulations are effective April 9, 1996."

p. 5238, col. 2;
" §194.14. Content of compliance certification application

. . .

(b) A description of the design of the disposal system including:

(1) Information on materials of construction including, but not limited to: Geologic media, structural materials, engineered barriers, general arrangement, and approximate dimensions, and

(2) Computer codes and standards that have been applied to the design and construction of the disposal system."

p. 5240, col. 2;
" §194.24 Waste characterization.

(a) Any compliance application shall describe the chemical, radiological and physical composition of all existing waste proposed for disposal in the disposal system. To the extent practicable, any compliance application shall also describe the chemical, radiological and physical composition of to-be-generated waste proposed for disposal in the disposal system. These descriptions shall include a list of waste components and their approximate quantities in the waste. This list may be derived from process knowledge, current non-destructive examination/assay, or other information and methods.

p. 5243, Assurance Requirements, col. 3;
" §194.44 Engineered barriers.

(a) Disposal systems shall incorporate engineered barrier(s) designed to prevent or

substantially delay movement of water or radionuclides toward the accessible environment."

EPA (U.S. Environmental Protection Agency). 1996. Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations, 40 CFR Part 194, final rule. 61 FR 5224.

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992. EFFECTIVE DATE: These regulations are effective April 9, 1996."

p. 5240, col. 2;
" §194.24 Waste characterization.
(a) Any compliance application shall describe the chemical, radiological and physical composition of all existing waste proposed for disposal in the disposal system. To the extent practicable, any compliance application shall also describe the chemical, radiological and physical composition of to-be-generated waste proposed for disposal in the disposal system. These descriptions shall include a list of waste components and their approximate quantities in the waste. This list may be derived from process knowledge, current non-destructive examination/assay, or other information and methods."

NMAC (New Mexico Administrative Code). 20 NMAC 4.1 Subpart V, §264.13. and Subpart VIII, §268.35(d).

NOTE: This document utilizes the appropriate portions of 40 CFR §264.13 and 40 CFR §268.35(d).

RCRA 1976. Resource, Conservation, and Recovery Act of 1976. Public Law 94-580, 90 Stat. 2795.

"An Act
To provide technical and financial assistance for the development of management plans and facilities for the recovery of energy and other resources from discarded materials and for the safe disposal of discarded materials, and to regulate the management of hazardous waste.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SHORT TITLE

Section 1. This Act may be cited as the 'Resource Conservation and Recovery Act of 1976'."

42 USC 6902. OBJECTIVES;
"Sec. 1003. The objectives of this Act are to promote the protection of health and the environment and to conserve valuable material and energy resources by--

"(1) providing technical and financial assistance to State and local governments and interstate agencies for the development of solid waste management plans (including resource recovery and resource conservation systems) which will promote improved solid waste management techniques (including more effective organizational arrangements), new and improved methods of collection, separation, and recovery of solid waste, and the environmentally safe disposal of nonrecoverable residues;

"(2) providing training grants in occupations involving the design, operation, and maintenance of solid waste disposal systems;

"(3) prohibiting future open dumping on the land and requiring the conversion of existing open dumps to facilities which do not pose a danger to the environment or to health;

"(4) regulating the treatment, storage, transportation, and disposal of hazardous wastes which have adverse effects on health and the environment;

"(5) providing for the promulgation of guidelines for solid waste collection, transport, separation, recovery, and disposal practices and systems;

"(6) promoting a national research and development program for improved solid waste management and resource conservation techniques, more effective organizational arrangements, and new and improved methods of collection, separation, and recovery, and recycling of solid wastes and environmentally safe disposal of nonrecoverable residues;

"(7) promoting the demonstration, construction, and application of solid waste management, resource recovery, and resource conservation systems which preserve and enhance the quality of air, water, and land resources; and

"(8) establishing a cooperative effort among the Federal, State, and local governments and private enterprise in order to recover valuable materials and energy from solid waste."

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ASME (American Society of Mechanical Engineers)., 1989a. Quality Assurance Program Requirements for Nuclear Facilities. ASME NQA-1-1989, September 15, 1989. The American Society of Mechanical Engineers, New York, NY.

INTRODUCTION, 1 PURPOSE, p 1;

" This Standard sets forth requirements for the establishment and execution of quality assurance programs for the siting, design, construction, operation, and decommissioning of nuclear facilities. Nonmandatory guidance is provided in the Appendices."

ASME (American Society of Mechanical Engineers), 1989b. "Part 2.7 Quality Assurance Requirements of Computer Software for Nuclear Facility Applications," Quality Assurance Requirements for Nuclear Facility Applications. ASME NQA-2a-1990, Part 2.7. May 31, 1990. ASME, New York, NY.

Part 2.7 Quality Assurance Requirements of Computer Software for Nuclear Facility Applications, 1 GENERAL, p 58.3;

" Part 2.7 provides requirements for the development, procurement, maintenance, and use of computer software, as applied to the design, construction, operation, modification, repair, and maintenance of nuclear facilities. It supplements the requirements of ASME NQA-1 and shall be used in conjunction with applicable Basic and Supplementary Sections of ASME NQA-1 when and to the extent specified by the organization invoking this Part."

ASME (American Society of Mechanical Engineers). 1989c. Quality Assurance Program Requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories. ASME NQA-3-1989. March 23, 1990. American Society of Mechanical Engineers, New York, NY.

FOREWORD, p iii;

" Early in 1975, the American National Standards Institute (ANSI) assigned overall responsibility for coordination among technical societies, development, and maintenance of nuclear power quality assurance standards to the American Society of Mechanical Engineers (ASME). The ASME Committee on Nuclear Quality Assurance was constituted on October 3, 1975, and began operating under the ASME Procedures for Nuclear projects. The ASME Committee on Nuclear Quality Assurance currently operates under the ASME Operating Procedures and Practices for Nuclear Codes and Standards Development Committees. This committee prepared ANSI/ASME NQA-1, Quality Assurance Program requirements for Nuclear facilities and ANSI/ASME NQA-2, Quality Assurance Requirements for Nuclear facility Applications. The need for a document like ASME NQA-3 was established after extensive studies by the ASME Nuclear Quality Assurance Subcommittee on Nuclear Waste Management, and after contractors and government agencies experienced difficulty in implementing NQA-1 as the Quality Assurance Program standard on the unique type of work involved in a high-level nuclear waste management program.

In 1984, the NQA Subcommittee on Nuclear Waste management was assigned responsibility for developing a Quality Assurance Program standard appropriate to site characterization of high-level nuclear waste repositories. This Subcommittee prepared ASME NQA-3, Quality Assurance Program requirements for the Collection of Scientific and Technical Information for Site Characterization of High-Level Nuclear Waste Repositories.

NQA-3 is to be used in conjunction with NQA-1 to set forth Quality Assurance Program requirements and nonmandatory guidance for the collection of scientific and technical information for site characterization of high-level nuclear waste repositories. It contains an Introduction, Basic Requirements, and Supplements. In addition, nonmandatory guidance is provided in the appendices, which do not set forth requirements. The requirements of NQA-1 and NQA-3 are intended to meet and clarify the criteria of 10CFR50, Appendix B and 10CFR60, Subpart G (Repository Quality Assurance Requirements) for high-level nuclear waste repositories.

The arrangements of the basic and supplementary requirements of these standards permit judicious application of the entire documents or only portions of the documents. The extent to which these documents should be applied, either wholly or in part, will depend upon the nature and scope of the work to be performed and the relative importance of the items being produced or services being provided. The extent of application is to be determined by the organization imposing this document. For example, it may only involve the Basic Requirements, or the Basic Requirements in combination with Supplements and Nonmandatory Appendices. These documents may be modified, as appropriate, or they may be applied in their entirety. These documents are written to allow application to any structure, system, component, or activity that

is essential to the satisfactory completion of site characterization of high-level nuclear waste repositories. . . ."

EPA (U.S. Environmental Protection Agency). 1993. 40 CFR Part 191 Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule. Federal Register, Vol. 58, No. 242, pp. 66398-66416, December 20, 1993, Office of Radiation and Indoor Air, Washington, D.C. WPO 39133.

PREAMBLE: SUMMARY;

" The U.S. Environmental Protection Agency (EPA) is promulgating amendments to the environmental standards for the disposal of spent nuclear fuel, high-level and transuranic wastes (40 CFR 191.15 and Subpart C).

EPA originally promulgated these standards in 1985 pursuant to the Agency's authorities and responsibilities under the Nuclear Waste Policy Act of 1982, as amended, the Atomic Energy Act of 1954, as amended, and §2(a)(6) of Reorganization Plan No. 3 of 1970 (5 USC app. 1). In 1987, following a legal challenge, the U.S. Court of Appeals for the First Circuit (hereinafter referred to as 'the First Circuit' or ' the court') remanded subpart B of the 1985 standards to the Agency for further consideration. *Natural Resources Defense Council, Inc. v. United States Environmental Protection Agency*, 824 F.2d 1258 (1st Cir. 1987). Recently enacted legislation, (Pub. L. 102-579) known as the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA), however, reinstates the 1985 disposal standards except 'the 3 aspects of §§191.15 and 191.16 of such [standards] that were subject of the remand ordered' by the First Circuit. The WIPP LWA directs EPA to expedite issuance of final disposal standards and specifies that such regulations shall not be applicable to the characterization, licensing, construction, operation, or closure of any site required to be characterized under §113(a) of Public Law 97-425, the Nuclear Waste Policy Act of 1982.

Today's action represents the Agency's response to this legislation and to the issues raised by the court pertaining to individual and ground-water protection requirements. After considering the relevant comments received on the February 10, 1993 proposed rulemaking, the Agency has taken this final action in the form of amendments to parts 191 of title 40 of the Code of Federal Regulations. In so doing, EPA has not revised any of the regulations reinstated by the WIPP LWA.

DATES: These amendments will become effective on January 19, 1994. These amendments will be promulgated for purposes of judicial review at 1 p.m. eastern standard time on December 20, 1993."

STATUTORY AND REGULATORY BACKGROUND;

" The WIPP Land Withdrawal and Nuclear Waste Policy Acts

As noted above, today's action responds to the directive in section 8 of the WIPP LWA that EPA conduct a rulemaking to issue certain radioactive waste disposal regulations at 40 CFR Part 191, subpart B. The EPA initially promulgated subpart B in 1985 (50 FR 38084 (Sept. 19, 1985)), but those regulations were subsequently vacated in whole as part of a remand order issued by the First Circuit in 1987 (discussed further above and below). See *NRDC v. EPA*, 824 F.2d 1258 (1st Cir. 1987).

Section 8(a)(1) of the WIPP LWA reinstates those portions of subpart B except §§191..15 and 191.16 (which were the bases of remand by the First Circuit). Accordingly, section 8(a)(2)(A) of the WIPP LWA exempts the requirements at 40 CFR 191.15 (individual protection) and 191.16 (ground-water protection) from the statutory reinstatement. Section 8(b)(2) addresses these non-reinstated provisions by directing the EPA promulgate final regulations. Today's action responds to that directive by revising the individual protection requirements in 40 CFR 191.15, discussed above, and by adding new ground-water protection standards as 40 CFR part 191, subpart C (discussed below)."

Federal register, Vol. 58 No. 242, p 66398, dated December 20,1993

"191.15 Individual protection requirements.

(a) Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts).

(b) Annual committed effective doses shall be calculated in accordance with appendix B of this part.

(c) Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved.

(d) Compliance with the provisions in this section does not negate the necessity to comply with any other applicable Federal regulations or requirements.

(e) The standards in this section shall be effective on January 19, 1994."

"Subpart C-Environmental Standards for Ground-Water Protection

. . .191.23 General provisions.

(a) Determination of compliance with this subpart shall be based upon underground sources of drinking water which have been identified on the date the implementing agency determines compliance with subpart C of this part.

191.24 Disposal standards.

(a) Disposal systems.

(1) General. Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that 10,000 years of undisturbed performance after disposal shall not cause the levels of radioactivity in any underground source of drinking water, in the accessible environment, to exceed the limits specified in 40 CFR part 141 as they exist on January 19, 1994.

(2) Disposal systems above or within a formation which within one-quarter (1/4) mile

contains an underground source of drinking water. [Reserved]

(b) Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved. . . ."

§191.27. Effective date: p. 66415, col. 3;
"Appendix A to Part 191--Table for Subpart B

9.Appendix B is redesignated as Appendic C to part 191 and the heading is revised as follows:
Appendix C to Part 191--Guidance for Implementation of Subpart B."

50 FR 38088, p. 38088, col. 2;
" Appendix B--Guidance for Implementation of Subpart B

[Note: The supplemental information in this appendix is not an integral part of 40 CFR Part 191. Therefore, the implementing agencies are not bound to follow this guidance. However, it is included because it describes the Agency's assumptions regarding the implementation of Subpart B. This appendix will appear in the Code of Federal Regulations]"

. . .

" Scope of Performance Assessments.

Section 191.13 requires the implementing agencies to evaluate compliance through performance assessments as defined in § 191-12(q). The Agency assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. Furthermore, the performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changes by such omissions."

EPA (U.S. Environmental Protection Agency). 1996. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule. Federal Register, Vol. 61, No. 28, pp. 5224-5245, February 9, 1996. Office of Air and Radiation, Washington, D.C. In NWM Library as KF70.A35.C751 1996 (Reference).

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992.
EFFECTIVE DATE: These regulations are effective April 9, 1996."

p. 5238, col. 2;
" §194.14. Content of compliance certification application.

Any compliance application shall include:

(a) A current description of the natural and engineered features that may affect the performance of the disposal system. The description of the disposal system shall include, at a minimum, the following information:

(1) The location of the disposal system and the controlled area;

(2) A description of the geology, geophysics, hydrogeology, hydrology and geochemistry of the disposal system and its vicinity and how these conditions are expected to change and interact over the regulatory time frame. Such description shall include, at a minimum:

(i) Existing fluids and fluid hydraulic potential, including brine pockets, in and near the disposal system; and

(ii) Existing higher permeability anhydrite interbeds located at or near the horizon of the waste.

(3) The presence and characteristics of potential pathways for transport of waste from the disposal system to the accessible environment including, but not limited to: Existing boreholes, solution features, breccia pipes, and other potentially permeable features, such as interbeds.

(4) The projected geophysical, hydrogeologic, and geochemical conditions of the disposal system due to the presence of waste including, but not limited to, the effects of production of heat or gases from the waste."

p. 5240, col. 2;
" §194.24 Waste characterization.

(a) Any compliance application shall describe the chemical, radiological and physical composition of all existing waste proposed for disposal in the disposal system. To the extent practicable, any compliance application shall also describe the chemical, radiological and physical composition of to-be-generated waste proposed for disposal in the disposal system. These descriptions shall include a list of waste components and their approximate quantities in the waste. This list may be derived from process knowledge, current non-destructive examination/assay, or other information and methods."

p. 5243, Assurance Requirements, col. 3;
" §194.44 Engineered barriers.

(a) Disposal systems shall incorporate engineered barrier(s) designed to prevent or substantially delay movement of water or radionuclides toward the accessible environment."

NRC (U.S. Nuclear Regulatory Commission). 1988. Qualification of Existing Data for High-Level Nuclear Waste Repositories. NUREG-1298, February 1988.

ABSTRACT, p iii;

" This document provides guidance on methods of qualifying data not initially collected under a 10 CFR Part 60, Subpart G quality assurance (QA) program. The license applicant for a geologic repository must demonstrate that the applicable health, safety, and environmental regulations in 10 CFR Part 60 have been met. Confidence in the data used to support the license application is obtained through a QA program.

Some data which have not been initially generated under a 10 CFR Part 60, Subpart G QA program may be needed to support a license application to construct and operate a geologic repository. This document provides guidance on the use and qualification of data not initially collected under a Subpart G, QA program."

BIBLIOGRAPHY DOCUMENTS

NRC (U.S. Nuclear Regulatory Commission). 1988a. Peer Review for High-Level Nuclear Waste Repositories. NUREG-1297. February 1988.

ABSTRACT, p iii;

" This document provides guidance on the use of the peer review process in the high-level nuclear waste repository program. The applicant must demonstrate in the license application that the applicable health, safety, and environmental regulations in 10 CFR Part 60 have been met. Confidence in the data used to support the license application is obtained through a quality assurance (QA) program as described in 10 CFR Part 60, Subpart G.

Peer reviews may be used as part of the QA actions necessary to provide adequate confidence in the work being reviewed. Because of several unique conditions inherent in the geologic repository program, expert judgement will need to be utilized in assessing the adequacy of work. Peer reviews are a mechanism by which these judgements may be made.

This document provides guidance on areas where a peer review is appropriate, the acceptability of peers, and the conduct and documentation of a peer review."

Knight, J.P. 1989. Memorandum. " Waste Isolation Pilot Plant Safety Evaluation Report," on EH-30 Safety Evaluation Report (SER) for the Waste Isolation Pilot Plant (WIPP) plus attachment.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

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Andersson, J., Ed. 1989. The Joint SKI/SKB Scenario Development Project. SKB Technical Report 89-35, Authors: J. Andersson, T. Carlsson, T. Eng, F. Kautsky, E. Söderman, and S. Wingefors. Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden.

ABSTRACT; p. 1, para. 1;

" The Swedish Nuclear Power Inspectorate (SKI) and the Swedish Nuclear Waste Management Co. (SKB) have carried through a joint scenario development exercise of a hypothetical repository for spent nuclear fuel and high level waste based on the KBS-3 concept as disposal method.

The starting point of the scenario development strategy has been the "Sandia Methodology", but the actual implementation of the steps in this method has required new strategy development. The work started with a relatively large internationally composed group meeting, which identified an extensive list (approximately 150 items) of features, events and processes (FEPs) that might influence the long term performance of a repository. All these FEPs and a memo-text containing a description of the FEP as well as its possible causes and consequences have been entered into a computer database.

The next step in the development was to remove from the list approximately 30 FEPs of low probability or negligible consequence. In a following step a large number of the FEPs on the original list were assigned to the "PROCESS SYSTEM". The PROCESS SYSTEM comprises the complete set of "deterministic" chemical and physical processes that might influence the release from the repository to the biosphere. A scenario is defined by a set of external conditions which will influence the processes in the PROCESS SYSTEM.

Approximately 50 FEPs were left representing external conditions. These remaining FEPs have been grouped (lumped) into a few (10) primary FEPs of external conditions. The remaining FEPs could all be combined to form scenarios, but it is concluded that it is not meaningful to discuss combinations without first analyzing the consequence and probability of the individual conditions.

An important aspect of the work is that the developed strategy includes a framework for the documentation of the complete chain of scenario development. Such a transparent documentation makes possible an extensive review and updating of the set of scenarios. A reviewing process, open to very broad groups in the society, is probably the best means of assuring reasonable completeness and of building up a general consensus on what are the critical issues for the safe disposal of radioactive waste.

In conclusion, the strategy developed within the project appear to be a feasible approach to scenario development, but it must be stressed that the present project is a first stage and that the complete analysis must be reiterated several times."

Barr, G.E., Miller, W.B., and Gonzalez, D.D. 1983. Interim Report on the Modeling of the Regional Hydraulics of the Rustler Formation. SAND83-0391. Sandia National Laboratories, Albuquerque, NM, pp. 26-27. WPO 27557.

ABSTRACT, pp 3-4;

" The finite-element code ISOQUAD was used to simulate the head distribution within the two major water-bearing units of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP), the Magenta and Culebra dolomites. The derived surfaces correlate well with those generated manually by the US Geological Survey (USGS) and Sandia National Laboratories (SNL). Calculated migration of a continuously injected contaminant from an assumed smeared point source at the center of the site was observed in terms of concentration relative to the initial input. Migration rates of specific concentration fronts decreased with increasing time. The average rate of movement of the 10^{-3} relative concentration contour was less than 10 m/yr for the first 800 yr in the Culebra Dolomite. By 800 yr, the migration of this concentration front has essentially ceased. In the case of the Magenta Dolomite, the average rate of movement of the 10^{-3} relative concentration contour was 0.44 m/yr for the first 676 yr of continuous contaminant injection; the contaminant plume in the Magenta shows little movement thereafter. For reasons of scale, the plume calculation overestimates the actual rate of movement of contaminants. Particle velocities for selected streamlines, more characteristic of contaminant movement, are calculated in Appendix B for comparison with the results of the FEIS. These particle velocities indicate groundwater travel times of ~130 000 yr from the center of the WIPP site to a distance of 12.9 km (8 mi).

The validity of the porous-medium approximation of the Rustler aquifers was examined by the evaluation of the drawdown portion of aquifer pump tests. Drawdown curves were successfully duplicated as a function of hydraulic conductivity, storativity, and well radius. Estimation of the effective radius examined in each well test indicates that there are no significant fluid-bearing fractures of channels within 60 m of tested wells. Because of variable test duration and in situ hydraulic properties, effective radii tested range from 37 to 1500 m (see Appendix A)."

Magenta Unit; p. 26, col. 2;

" The data for the Magenta for the 16 mi x 16 mi region modeled consist of water level measurements, slug tests, and pumptests at 10 different locations. The wells measured were H-1, H-2, H-3, H-4, H-5, H-6, H-9, H-10, W-25 and W-27. In addition there are two holes, W-26 and W-28, where the Magenta did not yield water to a well. At W-29 the Magenta Unit is not present due to erosion. The Magenta Unit is similar in character to the Culebra and is discussed by Gonzalez (1983a). This unit was not tested for anisotropy and so is presumed for the purposes here to be isotropic, although transport is so slight that this presumption is essentially irrelevant. Values for the hydraulic conductivity are assigned as shown in Figure 15, except for W-26 and W-28, which were dry and were given an extremely small value of conductivity. The initial head distribution calculated with a reflecting boundary and fixed well head values is shown in Figure 16. The corresponding

self-consistent head distribution or potentionmetric surface derived in these calculations is shown in Figure 17, and the corresponding derived values for the hydraulic conductivity are listed in Table 2. The head potential exhibits the steepest gradients in the vicinity of Nash Draw, to the west of the site. The repository site is indicated by the 8-sided figure (Figure 16). The smaller square inside this figure is a cutout used for a plume calculation in the manner of that discussed for the Culebra with the same concentration input. The cutout is a 2.4 x 2.4 km (1.5 x 1.5 mi) block with 289, 150 x 150 m (492 x 492 ft) elements. A plume is assumed to have formed around a central continuous source of cantaminant. The initial plume is shown in Figure 18. The extent of the plume 676 yr later is shown in Figure 19, amounting to less than 300 m (1000 ft) growth in that period (0.44 m/yr). There is so little movement in this long period, and much of that movement appears to be numerical dispersion, that it seems pointless to transfer the plume to subsequent cutouts as was done for the Culebra. To check this conclusion, we assigned to the large-size problem, 25,8 x 25.8 km (16 x 16 mi), so that the plume clearly overlapped the region of highest gradients. The results were similar; in effect, no movement on the 1610 x 1610 m (1 x 1 mi)grid scale of the calculations. This calculation is not shown. Unless the well data change substantially, or new data are added, it seems inappropriate to examine the Magenta Unit further."

Beauheim, R.L., 1987. Interpretations of Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987. SAND87-0039. Sandia National Laboratories, Albuquerque, NM, pp. 110-118. WPO 27679.

ABSTRACT, p 3, para 1;

" Both single-well and multiple-well hydraulic tests have been performed in wells at and near the WIPP site as part of the site hydrogeologic-characterization program. The single-well tests conducted from 1983 to 1987 in 23 wells are the subject of this report. The stratigraphic horizons tested include the upper Castile Formation; the Salado Formation; the unnamed, Culebra, Tamarisk, Magenta, and Forty-niner Members of the Rustler Formation; The Dewey Lake Red Beds; and Cenozoic alluvium. Tests were also performed to assess the integrity of a borehole plug isolating a pressurized brine reservoir in the Anhydrite III unit of the Castile Formation. The types of tests performed included drillstem tests (DST's), rising-head slug tests, falling-head slug tests, pulse tests, and pumping tests."

The Castile and Solado testing was performed at well WIPP-12 to try to define the source of high pressures measured at the WIPP-12 wellhead between 1980 and 1985. The test of the plug above the Castile brine reservoir indicated that the plug may transmit pressure, but if so, the apparent surface pressure from the underlying brine reservoir is significantly lower than the pressure measured at the wellhead. The remainder of the upper Castile did not show a pressure response differentiable from that of the plug. All attempts at testing the Salado in WIPP-12 using a straddle-packer DST tool failed because of an inability to locate good packer seats. Four attempts to test large sections of the Salado using a single-packer DST tool and a bridge plug were successful. All zones tested showed pressure buildups, but none showed a clear trend to positive surface pressures. The result of the WIPP-12 testing indicate that the source of the observed high pressures is within the Salado Formation rather than within the upper Castile Formation and that this source must have a very low flow capacity and can only create high pressures in a well shut in over a period of days to weeks.

DST's performed on the lower siltstone portion of the unnamed lower member of the Rustler Formation at H-16 indicated a transmissivity for the siltstone of about 2.4 x 10^{-4} ft^2/day. The formation pressure of the siltstone is higher than that of the overlying Culebra at H-16 (compensated for the elevation difference), indicating the potential for vertical leakage upward into the Culebra. However, the top of the tested interval is separated from the Culebra by over 50 ft of claystone, halite, and gypsum.

The Culebra Dolomite Member of the Rustler Formation was tested in 22 wells. In 12 of these wells (H-4c, H-12, WIPP-12, WIPP-18, WIPP-19, WIPP-21, WIPP-22, WIPP-30 P-15, P-17, ERDA-9, and Cabin Baby-1), falling-head slug tests were performed in H-1, and only a rising-head slug test was performed in P-18. DSTs were performed in conjunction with rising-head slug tests in wells H-14, H-15, H-16, H-17, and H-18. At all of these wells except H-18, the indicated transmissivities were 1 ft^2/day or less and single-porosity models fit the data well. At H-18, the Culebra has a transmissivity of about 2 ft^2/day. The apparent single-porosity behavior of the Culebra at H-18 may be due to the small spatial scale of the

tests rather than to the intrinsic nature of the Culebra at that location. Pumping tests were performed in the other 3 Culebra wells. The Culebra appears to behave hydraulically like a double-porosity medium at wells H-8b and DOE-1, where transmissivities are 8.2 and 11 ft^2/day, respectively. The Culebra transmissivity is highest, 43 ft^2/day, at the Engle well. No double-porosity behavior was apparent in the Engle drawdown data, but the observed single-porosity behavior may be related more to wellbore and near-wellbore conditions than to the true nature of the Culebra at that location.

The claystone portion of the Tamarisk Member of the Rustler Formation was tested in wells H-14 and H-16. At H-14, the pressure in the claystone failed to stabilize in three days of shut-in testing, leading to the conclusion that the transmissivity of the claystone is too low to measure in test performed on the time scale of days. Similar behavior at H-16 led to the abandonment of testing at that location as well.

The Magenta Dolomite Member of the Rustler Formation was tested in wells H-14 and H-16. At H-14, examination of the pressure response during DSTs revealed that the Magenta had taken on a significant overpressure skin during drilling and Tamarisk-testing activities. Overpressure-skin effects were less pronounced during the drillstem and rising-head slug tests performed on the Magenta at H-16. The transmissivity of the Magenta at H-14 is about 5.5. x 10^{-3} ft^2/day, while at H-16 it is about 2.7 x 10^{-2} ft^2/day. The static formation pressures calculated for the Magenta at H-14 and H-16 are higher than those of the other Rustler members.

The Forty-niner Member of the Rustler Formation was tested in wells H-14 and H-16. Two portions of the Forty-niner were tested at H-14: the medial claystone and the upper anhydrite. DST's and a rising-head slug test were performed on the claystone, indicating a transmissivity of about 7 x 10^{-2} ft^2/day. A buildup test of the forty-niner anhydrite revealed a transmissivity too low to measure on a time scale of days. a pulse test, DST's, and a rising-head slug test of the Forty-niner clay at H-16 indicated a transmissivity of about 5.3 x 10^{-3} ft^2/day. Formation pressures estimated for the Forty-niner at H-14 and H-16 are lower than those calculated for the Magenta (compensated for the elevation differences), indicating that water cannot be moving downwards from the Forty-niner to the Magenta at these locations. . . ."

Section 5.2.1 Unnamed Lower Member., p 50, col 1, para 4;

" The unnamed lower member of the Rustler was tested only at H-16. This testing had two objectives: 1)to determine the transmissivity of the unit; and 2) to determine the hydraulic head of the unit. The transmissivity is a parameter needed to calculate potential leakage rates from the unnamed lower member into the WIPP shafts. The hydraulic head is also needed for leakage calculations, as well as to evaluate directions of potential vertical movement of groundwaters within the Rustler Formation. . . ."

p 50, col 2, para 4;

" The simulation in Figure 5-12 is of a single-porosity medium with a transmissivity of 2.7 x 10^{-4} ft^2/day (Table 5-2). Assuming a porosity of 30%, a total-system compressibility of

1.0×10^{-5} psi^{-1}, and a fluid viscosity of 1.0 cp, the skin factor for the well in this simulation is -0.4, indicating a very slightly stimulated well. The dimensionless Horner plot of the FBU (Figure 5-13) shows an excellent fit of the simulation to the data, and indicates that the static formation pressure is about 213 psia.

The SLF lasted about 29 minutes, and was followed by a 50-hr SBU. The log-log plot of the SBU data (Figure 5-14) shows behavior similar to that seen in the FBU plot (Figure 5-12). The single-porosity simulation shown, however, uses a transmissivity of 2.2 x 10^{-4}ft^2/day, and a skin factor of 0.2 (Table 5-2). These values imply a slightly less permeable formation and a slightly more damaged well than were indicated by the FBU analysis."

$$\frac{2.7 \times 10^{-4}\text{ft}^2}{\text{day}} \times \frac{12^2\text{in}^2}{\text{ft}^2} \times \frac{\text{m}^2}{39.3^2\text{in}^2} \times \frac{\text{day}}{24\text{ hour}} \times \frac{\text{hour}}{3600\text{ sec.}} = \frac{2.9 \times 10^{-10}\text{m}^2}{\text{second}}$$

$$\frac{2.2 \times 10^{-4}\text{ft}^2}{\text{day}} \times \frac{12^2\text{in}^2}{\text{ft}^2} \times \frac{\text{m}^2}{39.3^2\text{in}^2} \times \frac{\text{day}}{24\text{ hour}} \times \frac{\text{hour}}{3600\text{ sec.}} = \frac{2.4 \times 10^{-10}\text{m}^2}{\text{second}}$$

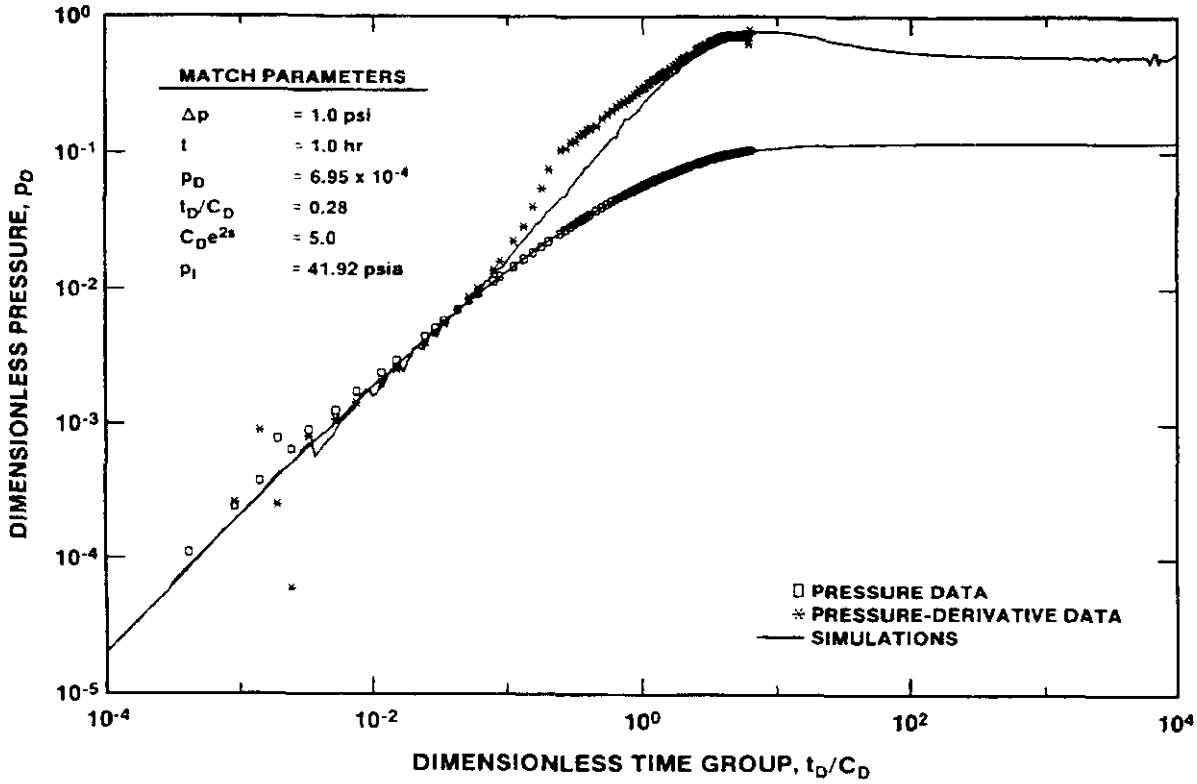

Figure 5-12. H-16/Unnamed Lower Member Siltstone First Buildup Log-Log Plot with INTERPRET Simulation

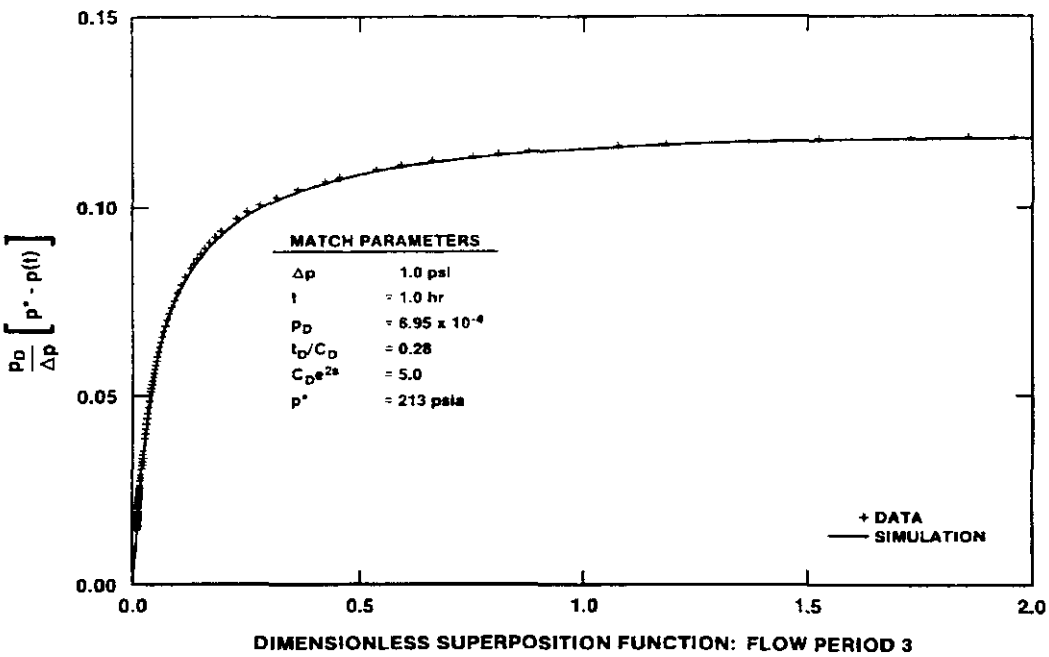

Figure 5-13. H-16/Unnamed Lower Member Siltstone First Buildup Dimensionless Horner Plot with INTERPRET Simulation

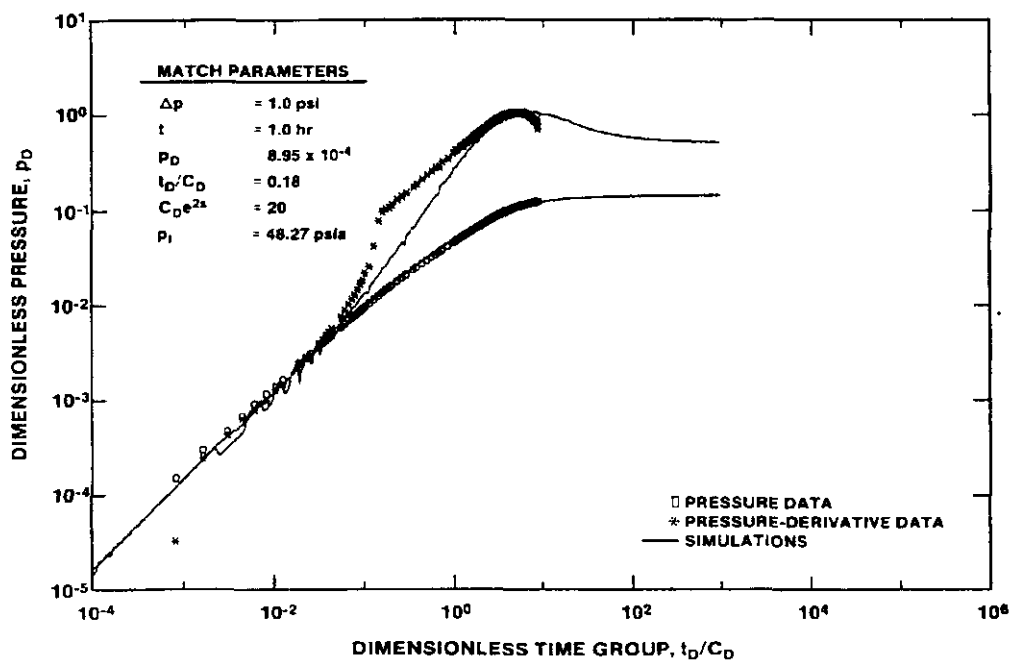

Figure 5-14. H-16/Unnamed Lower Member Siltstone Second Buildup Log-Log Plot with INTERPRET Simulation

TABLE 5-2
SUMMARY OF NON-CULEBRA SINGLE-WELL TEST RESULTS

WELL	ZONE NAME	ZONE DEPTH INTERVAL (ft)	DEPTH INTERVAL TESTED (ft)*	TEST TYPE	TRANSMISSIVITY (ft^2/day)	SKIN FACTOR
H-16	Unnamed lower member siltstone	778-842	739-851	DST/FBU	2.7×10^{-4}	-0.4
				DST/SBU	2.2×10^{-4}	0.2
H-14	Magenta	424-448	420-448	DST/FBU	5.6×10^{-3}	0.5
				DST/SBU	5.6×10^{-3}	0.4
				DST/TBU	5.3×10^{-3}	0.3
H-16	Magenta	590-616	589-621	DST/FBU	2.8×10^{-2}	-0.4
				DST/SBU	2.8×10^{-2}	-0.8
				slug	2.4×10^{-2}	–
H-14	Forty-niner claystone	390-405	381-409	DST/FBU	7.1×10^{-2}	3.2
				DST/SBU	6.9×10^{-2}	3.3
				slug	3.0×10^{-2}	–
H-16	Forty-niner clay	563-574	560-581	pulse	2.2×10^{-4}	–
				DST/FBU	5.3×10^{-3}	0.7
				DST/SBU	5.6×10^{-3}	0.6
				slug	5.0×10^{-3}	–
Carper	Cenozoic alluvium	263-386	263-386	pumping	55	–

*Actual intervals open to the wells.

p. 73;
"Conclusions: The Culebra is 26.5 ft thick at H-14. The transmissivity of the upper 5.8 ft is 0.10 ft^2/day, while that of the entire unit is 0.30 ft^2/day. Hence, the average hydraulic conductivity of the upper 5.8 ft of the Culebra appears to be about 1.8 times greater than that of the lower 20.7 ft. This difference does not represent a great degree of heterogeneity."

Section 5.2.3 Tamarisk Member, p. 108, col. 1, para 2;
" The Tamarisk Member of the Rustler Formation was tested in wells H-14 and H-16. The purposes of the Tamarisk testing were to: 1) define the hydraulic head of the unit; and 2) measure the transmissivity of the unit. Information on the hydraulic head of the Tamarisk is needed to evaluate potential direction of vertical movement of groundwater between the Rustler members. The transmissivity of the Tamarisk is a parameter needed for vertical cross-sectional or three-dimensional modeling of groundwater flow in the Rustler. The claystone/mudstone/siltstone portion of the Tamarisk (referred to hereafter simply as the claystone) is believed to be more permeable than the anhydrite/gypsum sections, and therefore easier to test. Consequently, tests were attempted only on the claystone portion of the Tamarisk at H-14 and H-16.
5.2.3.1 H-14.

At H-14, the Tamarisk claystone extends from about 517 to 525 ft deep (Figure 3-6). The initial test was performed over an interval from the base of a packer at a depth of 494.5 ft to the then-bottom of the hole 533 ft deep. Thus, the test interval included the 8-ft thickness of claystone, and 30.5 ft of overlying and underlying anhydrite and gypsum. Descriptions of the test instrumentation and the test data are contained in Stensrud et al. (1987).

Testing began on October 7, 1986, by setting the packer, swabbing the tubing to decrease the pressure in the test interval, and closing the shut-in tool to isolate the test interval and allow the test-interval pressure to recover and equilibrate at the existing static formation pressure. The pressure response observed during the testing is shown in Figure 5-82. After being shut in for nearly 37 hr, the fluid pressure in the Tamarisk claystone test interval had still not stabilized, but was rising at an ever-decreasing rate. The pressure in the wellbore above the packer, in contrast, was dropping as fluid was apparently entering the exposed Magenta and Forty-niner Members. Because the Tamarisk pressure had not stabilized, and did not appear likely to stabilize for several days or weeks, no drillstem tests were performed.

To verify that the observed response during the shut-in period was representative of the Tamarisk claystone and not caused by a tool malfunction, the packer was deflated and the DST tool was reset 8 ft deeper in the hole on October 9, 1986. After swabbing and shutting in the new test interval, a pressure buildup similar to that observed at the previous depth was measured for 4.5 hr (Figure 5-82). At this point, we concluded that the permeability of the Tamarisk at H-14 is too low to allow testing on the time scale of a few days, and abandoned the effort.

No conclusions about the static formation pressure of the Tamarisk can be drawn

from the observed pressure buildups, because we have no way of evaluating the role played by the overpressure skin that was probably created during drilling. Subsequent testing of the Magenta and Forty-niner Members, discussed below, revealed fluid-pressure buildups to be significantly affected by overpressure skins.

5.2.3.2 H-16

At H-16, the Tamarisk claystone extends from 677.5 to 690.1 ft deep (Figure 3-8). The interval tested extended from 674.5 to 697.9 ft, the bottom of the hole at that time, thus including 10.8 ft of overlying and underlying gypsum. Descriptions of the test instrumentation and the test data are presented in Stensrud et al. (1988).

Testing was performed on August 5, 1987. After the packer was set, the tubing was swabbed and the shut-in tool was opened to relieve the pressure that had been exerted on the formation by the column of drilling fluid in the well. The test interval was then shut in to allow the wellbore and formation pressures to equilibrate. Figure 5-83 shows the slow pressure rise that resulted over the next 10 hr. This pressure recovery was very similar to that observed for the Tamarisk claystone at H-14 (Figure 5-82). Based on the similarity to the H-14 response and the conclusion that the Tamarisk could not be tested on the time scale of a few days at H-14, the testing effort at H-16 was abandoned.

This decision was borne out by subsequent pressure measurements made by the transducer installed at the Tamarisk horizon as part of the 5-packer installation in H-16 (Figure 3-8). From August 31, 1987, 4 days after the 5-packer installation was completed, until December 15, 1987, the pressure in the Tamarisk interval declined from 204 psig to 169 psig (Stensrud et al., 1988 and in preparation), with complete stabilization apparently several months in the future. The Tamarisk transducer in the 5-packer system is mounted at a depth of 647.1 ft. IN a borehole containing brine with a specific gravity of 1.2, the pressure at the midpoint of the Tamarisk claystone 684 ft deep is about 19 psi higher than that measured by the transducer. Hence, the most that can be said at present is that the static formation pressure of the Tamarisk is less than 188 psig. The very slow pressure stabilization of the Tamarisk claystone likely indicates that its transmissivity is one or more orders of magnitude lower than that of the least-transmissive unit successfully tested in H-16, the unnamed lower member siltstone ($2 \times 10^{-4} ft^2/day$; Table 5-2)."

Section 5.2.4 Magenta Dolomite Member, p. 110, col. 1, para. 2;

" The Magenta dolomite was tested in wells H-14 and H-16. The objectives of the Magenta testing were to obtain quantitative information on the hydraulic head and transmissivity of the unit."

Section 5.2.4.1 H-14, p 111, col 1, para 2, line 3;

" The simulation is representative of a single-porosity medium with a transmissivity of 5.6×10^{-3} ft^2/day (Table 5-2). Assuming a porosity of 20%, a total-system compressibility of $1.0 \times 10^{-5} psi^{-1}$, and a fluid viscosity of 1.0 cp, the skin factor of this simulation is about 0.5 indicating a well with very little wellbore damage. The simulation does not fit the observed early-time data very well, but it does fit the middle- and late-time pressure data adequately."

Section 5.2.4.2 H-16, page 115, col 2, para 2, line 3;

" The simulation is representative of a single-porosity medium with a transmissivity of 2.8 x $10^{-2}ft^2$/day (Table 5-2). Assuming a porosity of 20%, a total system compressibility of 1.0 x $10^{-5}psi^{-1}$, and a fluid viscosity of 1.0 cp, the skin factor for this simulation is -0.4, indicating a very slightly stimulated well. The pressure derivative shows oscillations similar, although with much lower amplitudes, to those observed in the H-14 Magenta SBU and TBU data (Figures 5-87 and 89)."

Section 5.2.5 Forty-niner Member, p. 119;

" The Forty-niner Member of the Rustler Formation was tested in wells H-14 and H-16. The objectives of the testing were to obtain hydraulic-head and transmissivity estimates. The hydraulic-head measurements are particularly important in helping to determine whether or not water from the Dewey Lake Red Beds, and by extension from the surface, can be recharging the Magenta and Culebra dolomites at the WIPP site. The transmissivity estimates allow an evaluation of the ability of the Forty-niner to provide water to the WIPP shafts, as well as providing data for cross-sectional or three-dimensional modeling of groundwater flow in the Rustler.

5.2.5.1 H-14.

Two sets of Forty-niner tests were performed at H-14, tests of the medial claystone/mudstone/siltstone unit (hereafter referred to simply as claystone) and tests of the upper anhydrite unit. The claystone tests were to provide data on the hydraulic head and transmissivity of the most permeable section of the Forty-niner. The anhydrite tests were intended to verify the assumptions that the Rustler anhydrites are much less permeable than the claystones, and that they cannot be tested on the time scale of days.

Forty-niner Claystone:

At H-14, the claystone portion of the Forty-niner lies between 390 and 405 ft deep (Figure 3-6). The claystone was tested in a DST straddle interval extending from 381.0 to 409.5 ft deep. Thus, about 13.5 ft of Forty-niner anhydrite and gypsum were included in the test interval. Descriptions of the test instrumentation and the test data are contained in Stensrud et al. (1987).

The Forty-niner claystone was tested on October 13 and 14, 1986. Testing consisted of two flow periods, two buildup periods, and a rising-head slug test (Figure 5-95). The FFL lasted about 18 minutes, and was followed by a 92-minute FBU. The SFL lasted about 32 minutes, and was followed by a SBU almost 16 hr long. To obtain equivalent constant-rate flow periods, each of the flow periods was divided into two shorter periods. The FFL was divided into two periods with flow rates of 0.028 and 0.021 gpm, and the SFL was divided into periods with flow rates of 0.022 and 0.017 gpm (Table 5-1). The slug test lasted slightly over 6 hr, by which time about 57% of the induced pressure differential had dissipated.

Overpressure skin effects were apparent during the Forty-niner claystone testing, just as they were during all other testing at H-14. The fluid pressure reached a maximum of 67.9 psia during the initial equilibration period, was essentially constant at 66.8 psia at the

end of the FBU, and peaked at 66.2 psia during the SBU (Figure 5-95). The superposition of pressure-skin effects manifested in the Magenta test data (see Section 5.2.4.1) was not apparent, however, in the Forty-niner claystone test data.

Figure 5-96 shows a log-log plot of the Forty-niner claystone FBU data with an INTERPRET-generated simulation. The late-time pressure derivative shows the decline indicative of overpressure skin. The simulation is representative of a single-porosity medium with a transmissivity of 7.1 x 10^{-2} ft^2/day (Table 5-2). Assuming a porosity of 30%, a total-system compressibility of 1.0 x 10^{-5} psi^{-1}, and a fluid viscosity of 1.0 cp, the skin factor for this simulation is about 3.2, indicating a damaged well.

The dimensionless Horner plot of the FBU data is shown in Figure 5-97. The simulation matches the observed data very well until late time, when the data deviate towards a static pressure lower than the 67.8 psia specified for the simulation. This discrepancy between the observed data and the simulation is entirely consistent with the effects of an overpressure skin.

The log-log plot of the SBU data is shown in Figure 5-98. Overpressure-skin effects are once again evident in the late-time pressure derivative. The simulation shown was generated by INTERPRET using a single-porosity model and a transmissivity of 6.9 x $10^{-2}$$ft^2$/day (Table 5-2). With the assumed parameter values listed above, the skin factor for this simulation is about 3.3, comparable to the value obtained from the FBU analysis.

A log-log early-time plot of the rising-head slug-test data is shown in Figure 5-99, along with the best-fit type curve. The fit is quite good until near the end, when the observed data oscillate for an unknown reason. The type-curve fit shown provides a transmissivity estimate of 3.0 x $10^{-2}$$ft^2$/day (Table 5-2), which is slightly less than half of the values provided by the FBU and SBU analyses. A slightly different type-curve fit might have been indicated had the late-time data been better behaved.

The static formation pressure for the Forty-niner claystone is difficult to estimate because of the overpressure-skin effects present during the buildup tests, and because of the nonideal behavior during the latter portion of the slug test. The static formation pressure must be less than the final pressure measured at the end of the SBU, 65.5 psia. The slug-test analysis relied on a static formation pressure estimate of 62 psia, although a reasonably good fit was also obtained using an estimate of 65 psia. Considering that the transducer during these tests was set 362.9 ft deep, that the transducer measured an atmospheric pressure of 12 psia before testing began, and that the borehole contained brine with a specific gravity of 1.2, 65 psia corresponds to a static formation pressure of 71 psig at the midpoint of the claystone 398 ft deep. This value is reliably a maximum.

Forty-niner Anhydrite.

The upper anhydrite and gypsum unit of the Forty-niner Member lies 359.5 to 390 ft deep at H-14 (Figure 3-6). The unit is roughly 75% anhydrite and 25% gypsum, based on interpretation of a neutron log. The unit was tested in a DST straddle interval extending from 356.0 to 384.5 ft deep. Thus, the bottom 3.5 ft of the Dewey Lake Red Beds and the Dewey Lake/Rustler contact were included in the test interval. Descriptions of the test instrumentation and the test data are contained in Stensrud et al. (1987).

The Forty-niner anhydrite was tested from October 14 to 15, 1986. Because the anhydrite was expected to have too low a permeability to allow quantitative testing the few days available for testing, no pressure-equilibration period preceded the testing. Instead, as soon as the packers were set, the tubing was swabbed with the shut-in tool open, and the test interval was left open to the tubing for about 16 minutes for a flow period (Figure 5-100). Very little fluid entered the tubing at this time. The test interval was then shut in for about 16.5 hr. The pressure increased by about 1 psi over the first 1.5 hr of the buildup, and by another psi over the last 1.5 hr. At that time, the testing was terminated. The Forty-niner anhydrite was judged to have a permeability much lower than that of the claystone, and quantitative testing of the anhydrite appeared to require weeks to months of effort."

Section 5.3 Dewey Lake Red Beds, p 128, col 1, para 2;
" Little testing of the Dewey Lake Red Beds near the WIPP site has ever been attempted, primarily because of the lack of evidence of continuous zones of saturation (Mercer, 1983). The Dewey Lake Red Beds are permeable, however, as evidenced by losses of circulation fluid during drilling of holes such as DOE-2 and H-3d, and therefore the unit remains of interest when considering groundwater-transport pathways in the event of a breach of the WIPP facility. Beauheim (1986) reported on unsuccessful attempts to test the lower Dewey Lake at DOE-2. The only other Dewey Lake testing attempted on behalf of the WIPP project was performed at well H-14. No information was obtained during the drilling of H-14 pertaining to the presence or absence of a water table in the Dewey Lake at that location. Nevertheless, limited testing of the lower portion of the Dewey Lake Red Beds was planned based on the supposition that either a water table did exist in the lower Dewey Lake, or sufficient water would have infiltrated into the Dewey Lake during drilling and Rustler testing to allow at least qualitative testing. . . ."

Section 6. DISCUSSION OF RUSTLER FLOW SYSTEM, p. 131;
" The single-well testing discussed in this report has provided significant information on the transmissivities and hydraulic-head relations of the five Rustler members. IN particular, our knowledge of the distribution of transmissivity within the Culebra dolomite has increased considerably. Section 6.1 attempts to explain the distribution of Culebra transmissivity in the context of geologic models of halite deposition and dissolution within the Rustler. Section 6.2 discusses the hydraulic-head relations among the Rustler members, and their implications regarding recharge to the Rustler Formation."

Section 6.1 Culebra Transmissivity, p. 131;
" Mercer (1983) reported values for Culebra transmissivity at 20 locations. The testing described in this report has provided values for Culebra transmissivity at 15 new locations, and new estimates at 7 locations for which values had previously been reported. Combined with other recent work performed at DOE-2 (Beauheim, 1986), H-3 (Beauheim, 1987a), H-11 (Saulnier, 1987), and WIPP-13 (Beauheim, 1987b), the WIPP project has tested 38 locations and the transmissivity values at each provided by this report or those referenced

above.

Figure 6-2 shows the areas around the WIPP site where halite is present in the non-dolomite Rustler members, as indicated by Snyder (1985 and personal communication) and Powers (personal communication). According to Snyder, halite was originally deposited in the unnamed lower, Tamarisk, and Forty-niner Members of the Rustler over the entire area covered by Figure 6-2. The present-day absence of halite from these members reflects the eastward progression of a dissolution front. This dissolution front apparently affects the uppermost Rustler halite, that in the Forty-niner, first, and works progressively downsection to the upper Salado Formation. Thus, the eastward extent of the Forty-niner dissolution front is greater than that of the Tamarisk dissolution front, which is in turn greater than the eastward extent of the dissolution front in the unnamed lower member (Figure 6-2). Dissolution of the upper Salado follows dissolution of halite from the unnamed lower member of the Rustler. Lagging behind the dissolution front in each member is a second front where anhydrite is being hydrated to gypsum. In Snyder's view, as halite is removed beneath the Rustler dolomites, the dolomites subside and fracture. Similar subsidence and fracturing may affect the anhydrites, allowing more groundwater flow through them which may effect their hydration to gypsum. Note that the areas shown on Figure 6-2 indicate that only some halite is present in the appropriate members, not that the full thicknesses originally deposited are present. For example, Snyder (1985) states that only about half of the halite originally present in the unnamed lower member at WIPP-21 is there today.

Alternatively, Holt and Powers (1988) believe that the different amounts of halite seen in the Rustler members at the WIPP site more likely represent original depositional differences and/or syndepositional dissolution that later progressive dissolution. They relate fracturing to stress relief caused by unloading of the Rustler, citing a preponderance of horizontal (as opposed to vertical) fractures within the Rustler as evidence. According to their hypothesis, fracturing would be expected to become less pronounced eastward as the depth of burial of the Rustler increases. Holt and Powers (1988) also do not believe that all of the gypsum present in the Rustler is related to the hydration of anhydrite, but that it is instead primary, pointing to the preservation of primary sedimentary structures as evidence. Hold and Powers do find evidence for late-stage dissolution of halite from the upper Salado in Nash Draw, however, and relate disruption of the overlying Rustler to this dissolution.

As can be seen on Figure 6-2, the highest values of Culebra transmissivity are found in areas in or close to Nash Draw where no halite is present in the Rustler. At DOE-2 and WIPP-13, which are very close to the boundary west of which no halite is present in the unnamed lower member, the transmissivity of the Culebra is also relatively high. Relatively high transmissivities are also found, however, ate DOE-1 and H-11, where little or no halite is missing beneath the Culebra. WIPP-30, on the other hand, lies in an area of no Rustler halite, and yet the transmissivity of the Culebra is low at that location. Neither Snyder's (1985) nor Holt and Powers' (1988) model of halite deposition and dissolution can adequately explain the entire transmissivity distribution observed around the WIPP site.

If the absence of halite in the unnamed lower member is caused by dissolution and if this dissolution causes fracturing of the Culebra as Snyder (1985) suggests, then the high

transmissivities shown in the area of no halite on Figure 6-2 would be expected. Further, the high transmissivities at DOE-2 and WIPP-13 could be explained as the result of partial dissolution of halite from the unnamed lower member. The lower transmissivity at WIPP-30, however, cannot be explained by this hypothesis, nor can the low transmissivities at H-14 and P-15, which are closer to the no-halite boundary than is H-18. The relatively high transmissivities at DOE-1 and H-11 also cannot be related to dissolution of underlying halite.

Holt and Powers' (1988) model could predict the high transmissivities in Nash Draw by relating them to dissolution of the upper Salado. Their model further states that no Rustler halite was deposited and no dissolution of the Salado has occurred at WIPP-30, thus explaining the low Culebra transmissivity at that location. If their argument that fracturing is related to unloading is correct, then a correlation between the present-day depth of burial of the Culebra and the transmissivity of the Culebra might be expected to exist. Preliminary evaluation by Holt (personal communication) indicates that some correlation between depth of burial and Culebra transmissivity is evident, but that the correlation is not perfect. For example, despite the fact that the Culebra is approximately 200 ft shallower at WIPP-30 than at DOE-2, the Culebra transmissivity is over two orders of magnitude lower at WIPP-30 than at DOE-2. Other, as yet undefined, factors may be as important as depth of burial in controlling the transmissivity of the Culebra. The Holt and Powers (1988) model also fails to explain the relatively high transmissivities at DOE-1 and H-11.

Clearly, neither of the geologic models cited above provides a complete understanding of the distribution of transmissivity within the Culebra. The two models need not be considered completely mutually exclusive, however, and as discussed above, elements of both models provide reasonable explanations of <u>some</u> features observed in the Culebra. Nondeposition (or syndepositional dissolution) of halite may have been more widespread than believed by Snyder (1985), and late-stage dissolution may have occurred more than is believed by Holt and Powers (1988). The most significant problem area is in the vicinity of DOE-1 and H-11, where relatively high transmissivities would not be expected based on either model.

One additional observation that can be made from consideration of Figure 6-2 is that all measurements of Culebra transmissivity greater than 1 ft^2/day coincide with areas having no halite in the Tamarisk. The simple dissolution of Tamarisk halite would not seem likely to affect the transmissivity of the Culebra. The lack of high Culebra transmissivity <u>everywhere</u> that halite has been removed from the Tamarisk further argues against a direct relationship between Culebra transmissivity and Tamarisk halite. Nevertheless, absence of Tamarisk halite appears to be a necessary, but not sufficient, condition for high Culebra transmissivity. *Perhaps the removal of Tamarisk halite makes possible a second process that* directly affects the transmissivity of the Culebra."

p. 137, col. 2, line 7;

" ... Attempts to collect representative data on the formation pressure of the Tamarisk have failed to date, but recent data from DOE-2, H-14, and H-16 support Mercer's observation of downward hydraulic gradients from the Magenta to the Culebra at the WIPP

site. Together these observations imply that the Culebra, the most transmissive member of the Rustler, acts as a drain on the overlying and underlying Rustler"

p 138, col 2, para 1;
" The unnamed lower member of the Rustler Formation was tested only in well H-16, where DST's were performed on the lower siltstone portion of the unit. The transmissivity of the siltstone is about 2.4 x $10^{-4}ft^2$/day (Table 5-2). . . ."

p 138, col 2, para 3;
" The claystone portion of the Tamarisk member of the Rustler Formation was tested in wells H-14 and H-16. At H-14, the pressure in the claystone failed to stabilize in three days of shut-in testing, leading to the conclusion that the transmissivity of the claystone is too low to measure in tests performed on the time scale of days. Similar behavior at H-16 led to the abandonment of testing at that location as well."

Section 7. SUMMARY AND CONCLUSIONS, p 139, col 1, para 3;
" The Forty-niner Member of the Rustler Formation was also tested in wells H-14 and H-16. Two portions of the Forty-niner were tested in H-14: the medial claystone and the upper anhydrite. DST's and a rising-head slug test were performed on the claystone. The transmissivity of the claystone is about 7 x $10^{-2}ft^2$/day (table 5-2). A prolonged buildup test performed on the Forty-niner anhydrite revealed a transmissivity too low to measure on a time scale of days. A pulse test, DST's, and a rising-head plug test were performed on the Forty-niner clay at H-16, indicating the clay has a transmissivity of about 5 x $10^{-3}ft^2$/day (Table 5-2). Formation pressures estimated for the Forty-niner at H-14 and H-16 are lower than those calculated for the Magenta (compensated for the elevation differences), indicating that water cannot be moving downwards from the Forty-niner to the Magenta at these locations."

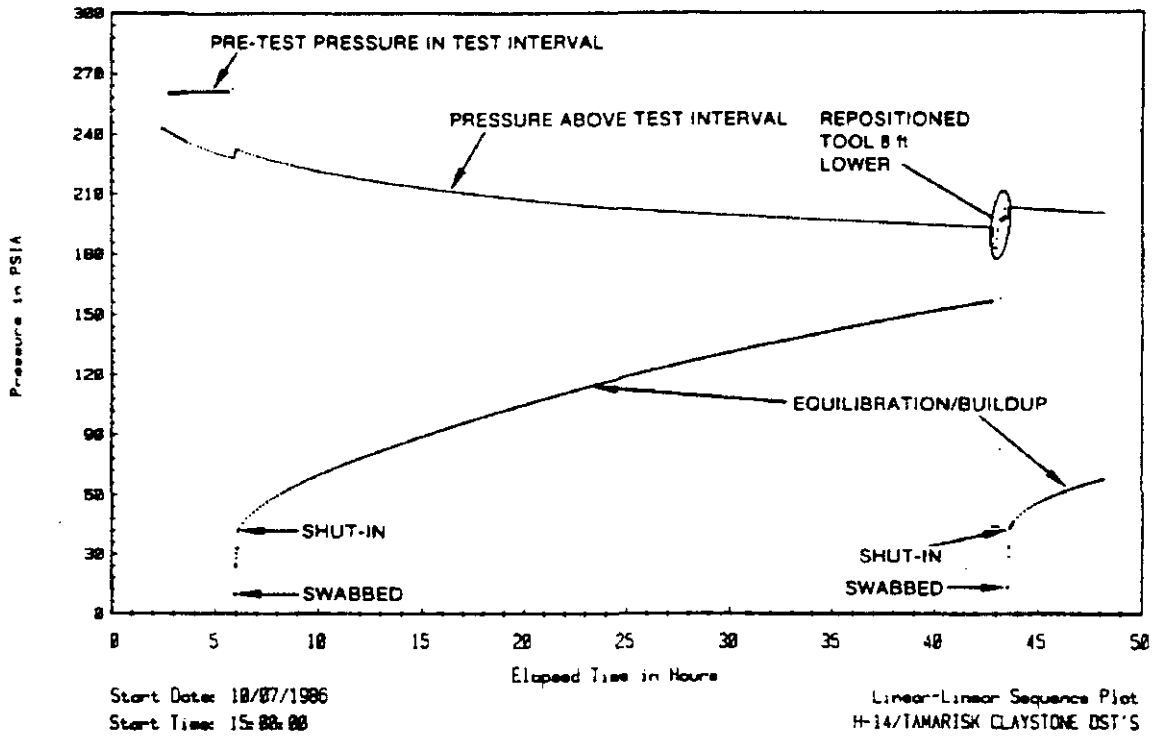

Figure 5-82. H-14/Tamarisk Claystone Shut-In Test Linear-Linear Sequence Plot

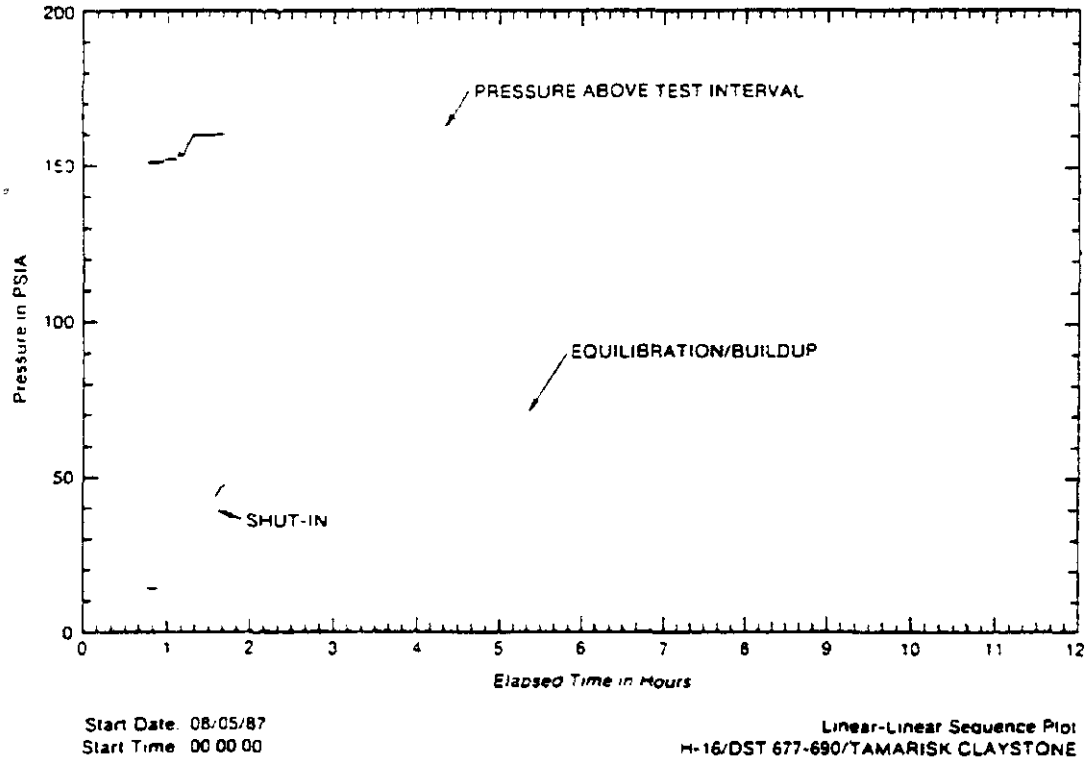

Figure 5-83. H-16/Tamarisk Claystone Shut-In Test Linear-Linear Sequence Plot

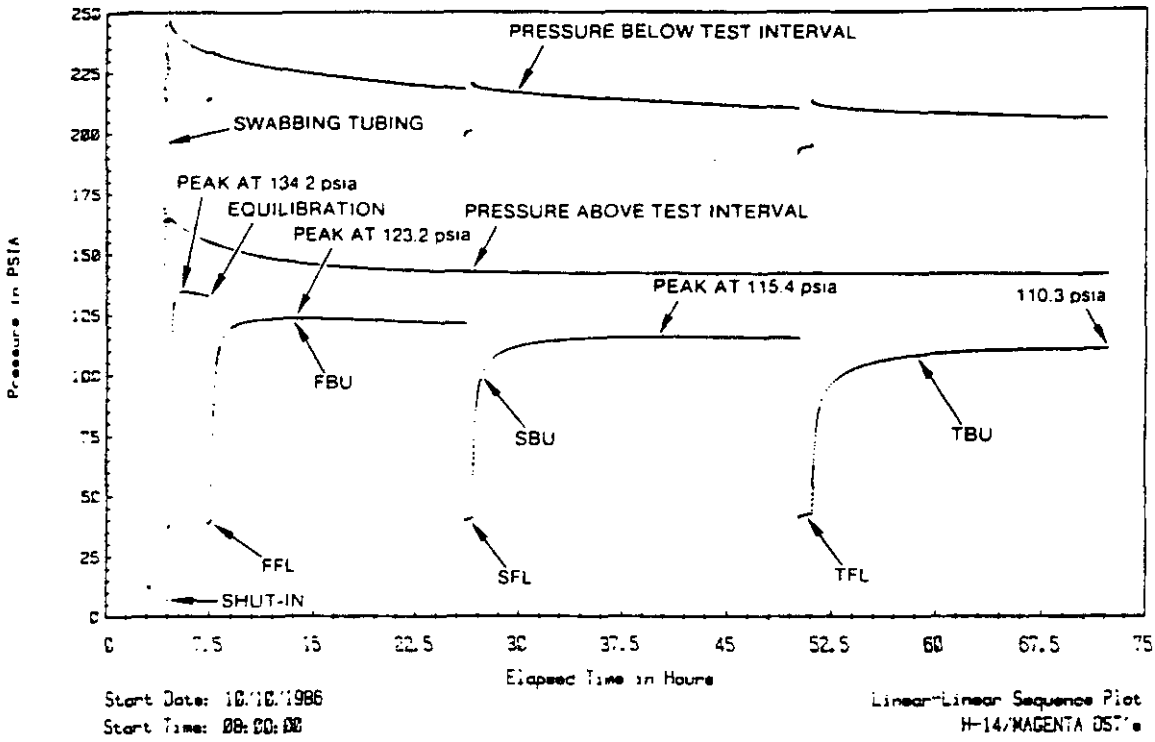

Figure 5-84. H-14/Tamarisk Claystone Shut-In Linear-Linear Sequence Plot

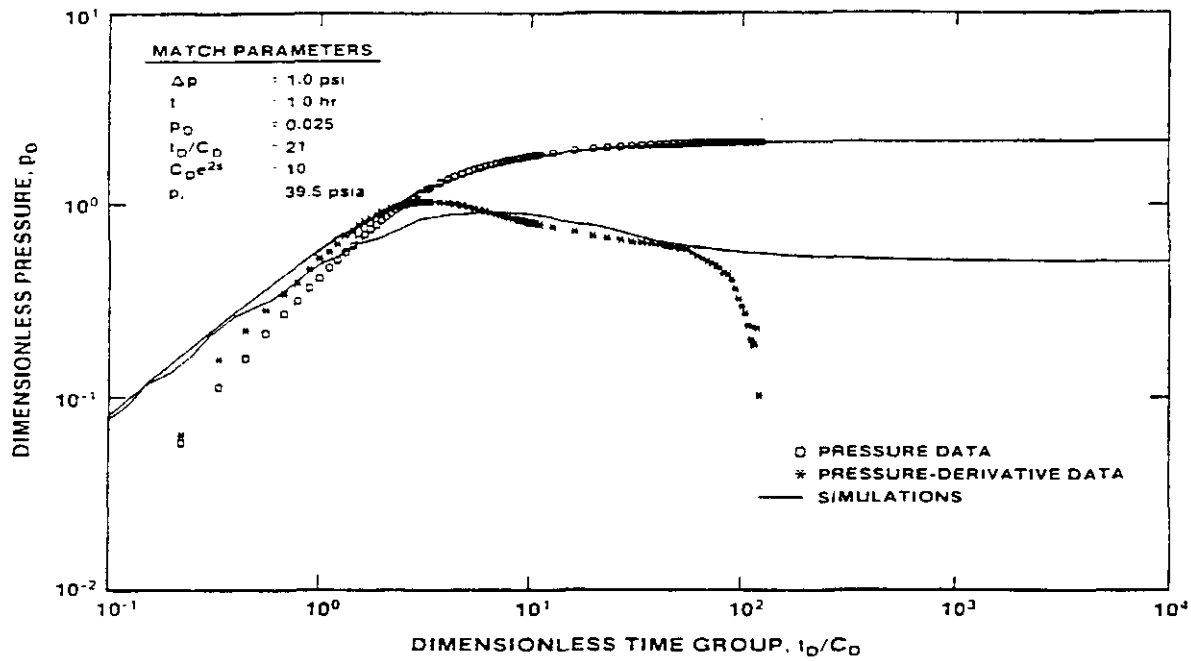

Figure 5-85. H-14/Magenta First Buildup Log-Log Plot with INTERPRET Simulation

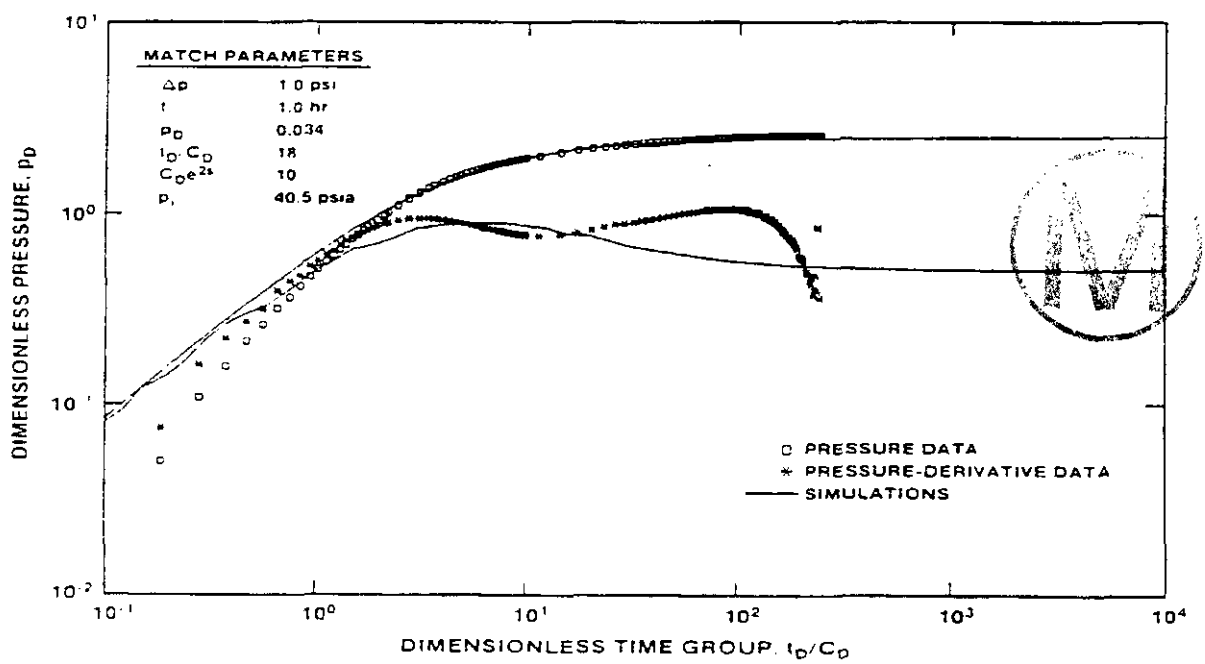

Figure 5-86. H-14/Magenta Second Buildup Log-Log Plot with INTERPRET Simulation

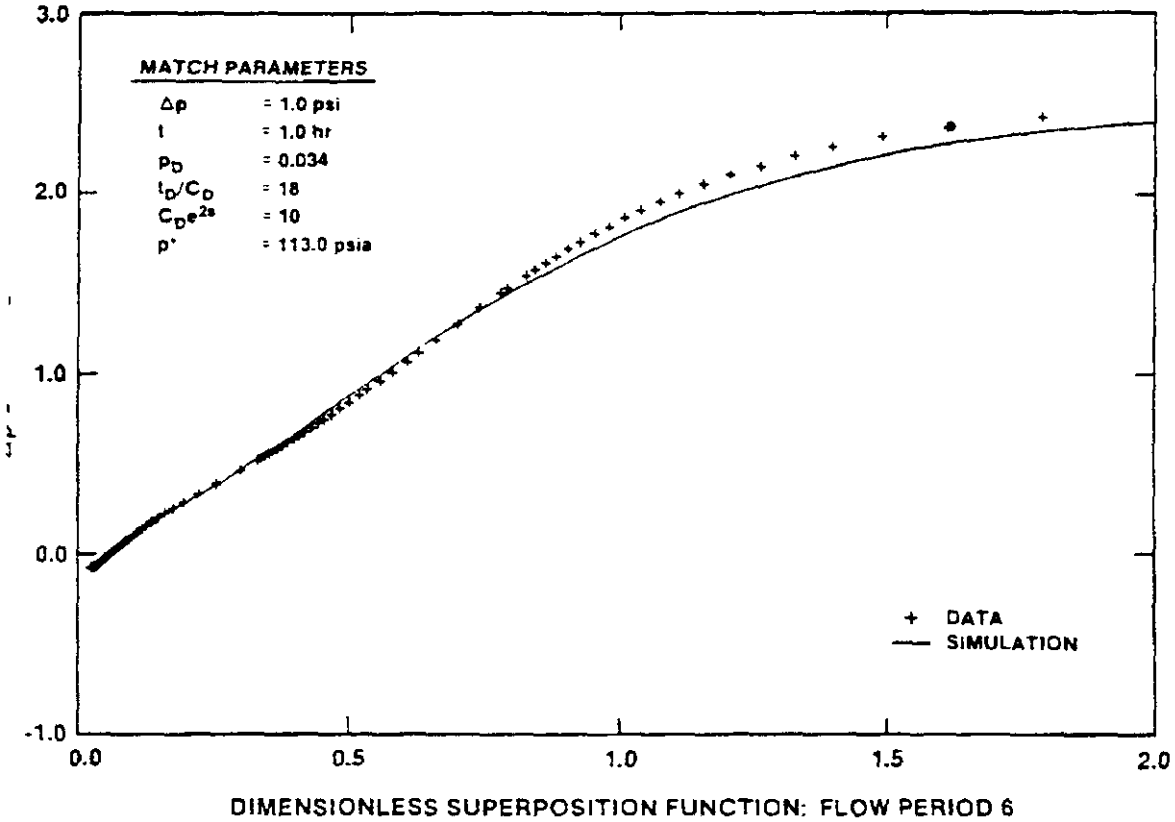

ıre 5-87. H-14/Magenta Second Buildup Dimensionless Horner Plot with INTERPRET Simulation

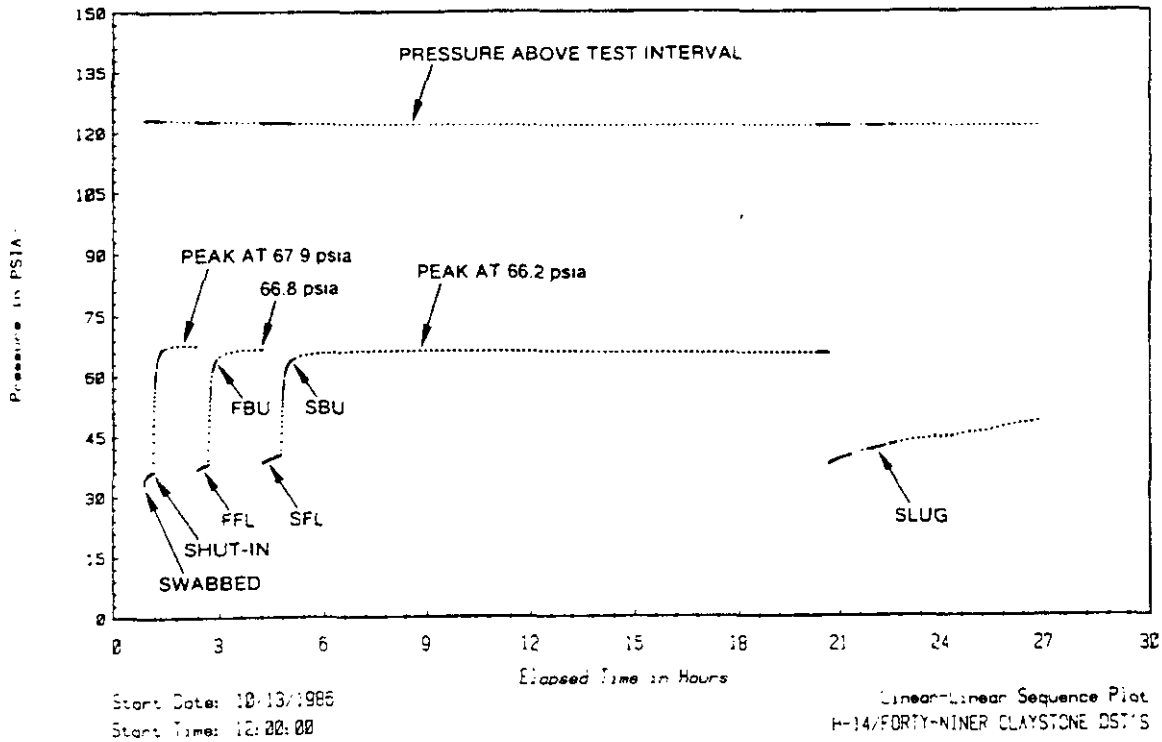

Figure 5-95. H-14/Forty-Niner Claystone Drillstem and Slug Testing Linear-Linear Sequence Plot

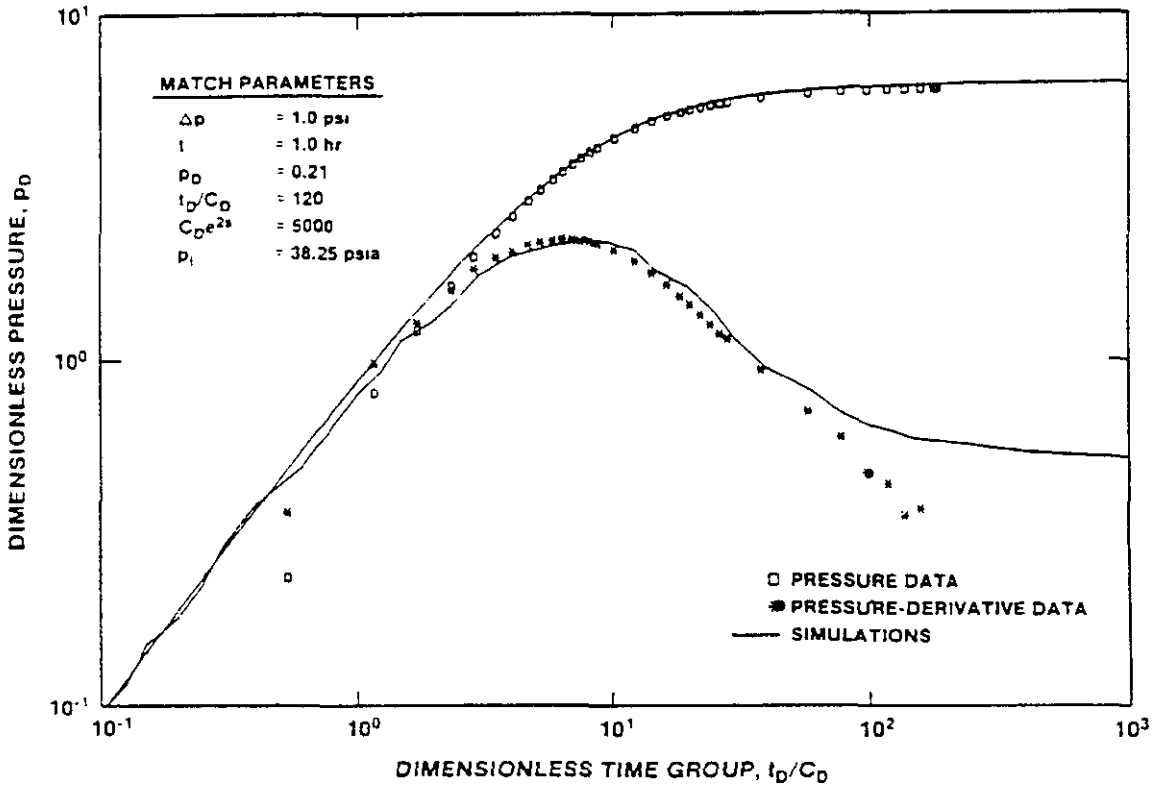

Figure 5-96. H-14/Forty-Niner Claystone First Buildup Log-Log Plot with INTERPRET Simulation

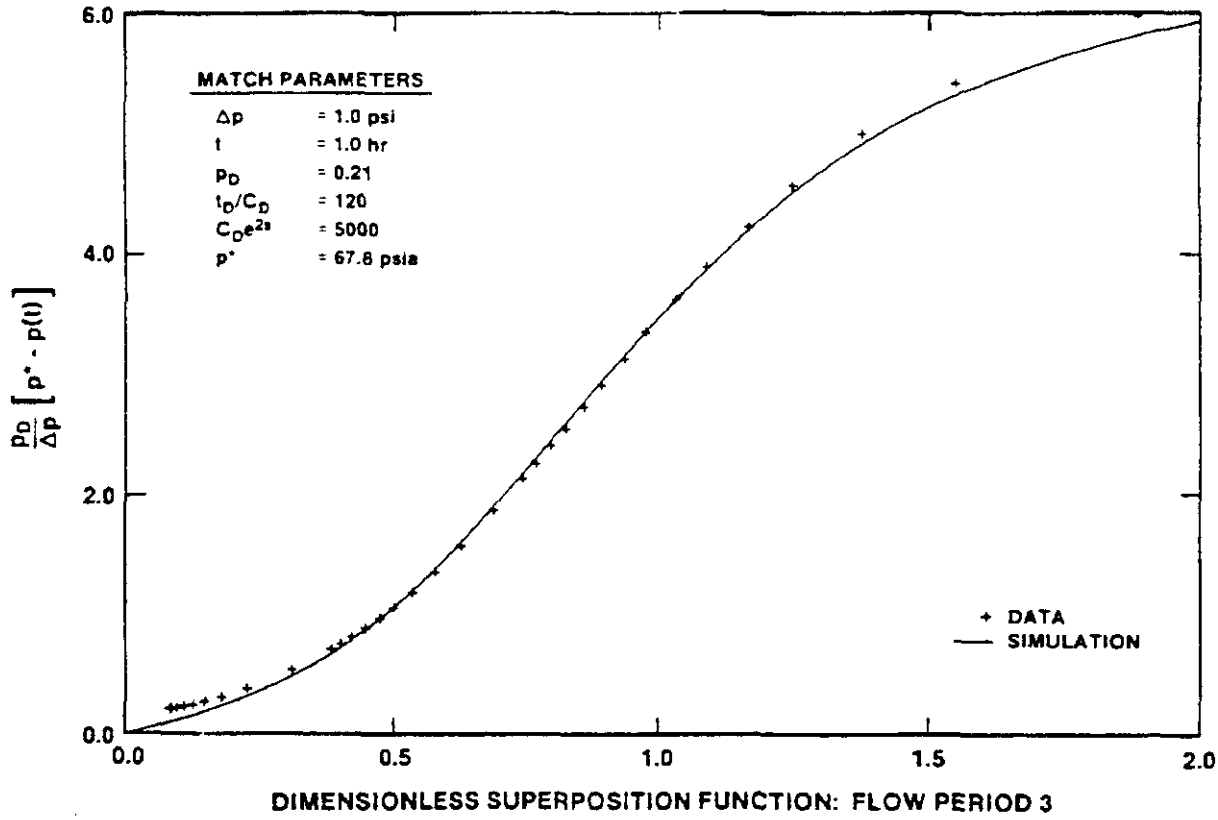
MATCH PARAMETERS
Δp = 1.0 psi
t = 1.0 hr
pD = 0.21
tD/CD = 120
CDe2s = 5000
p* = 67.8 psia
+ DATA
— SIMULATION
6.0
4.0
2.0
0.0
0.0
0.5
1.0
1.5
2.0
pD/Δp [p* - p(t)]
DIMENSIONLESS SUPERPOSITION FUNCTION: FLOW PERIOD 3

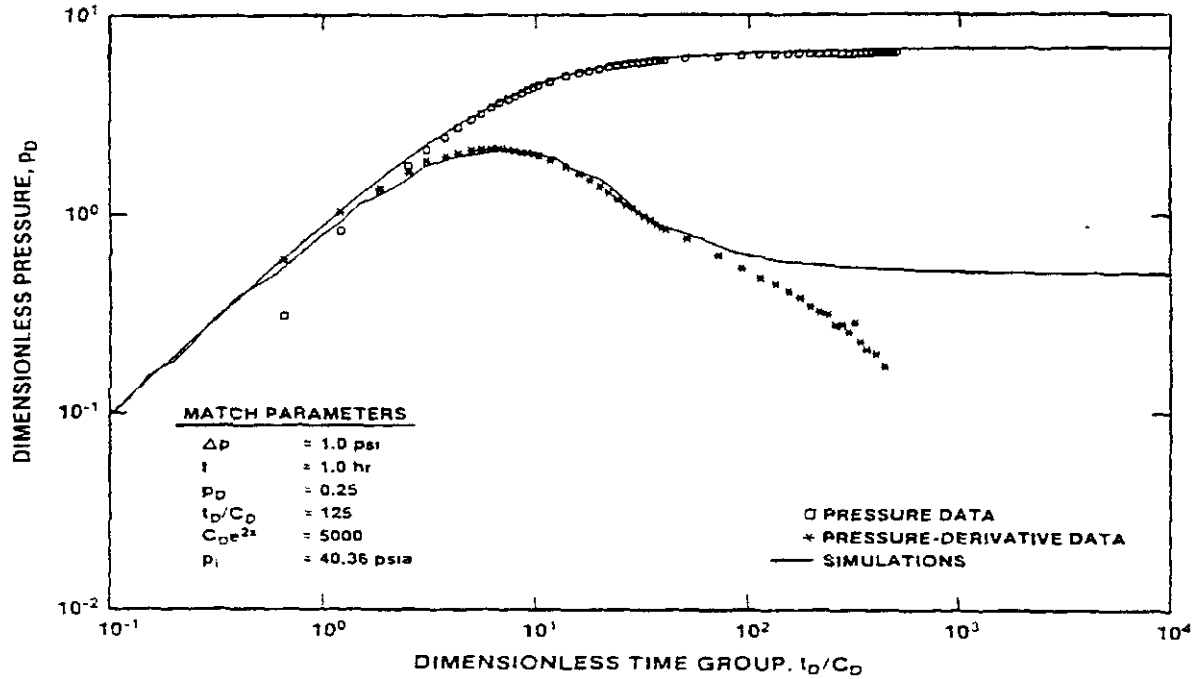

Figure 5-98. H-14/Forty-Niner Claystone Second Buildup Log-Log Plot with INTERPRET Simulation

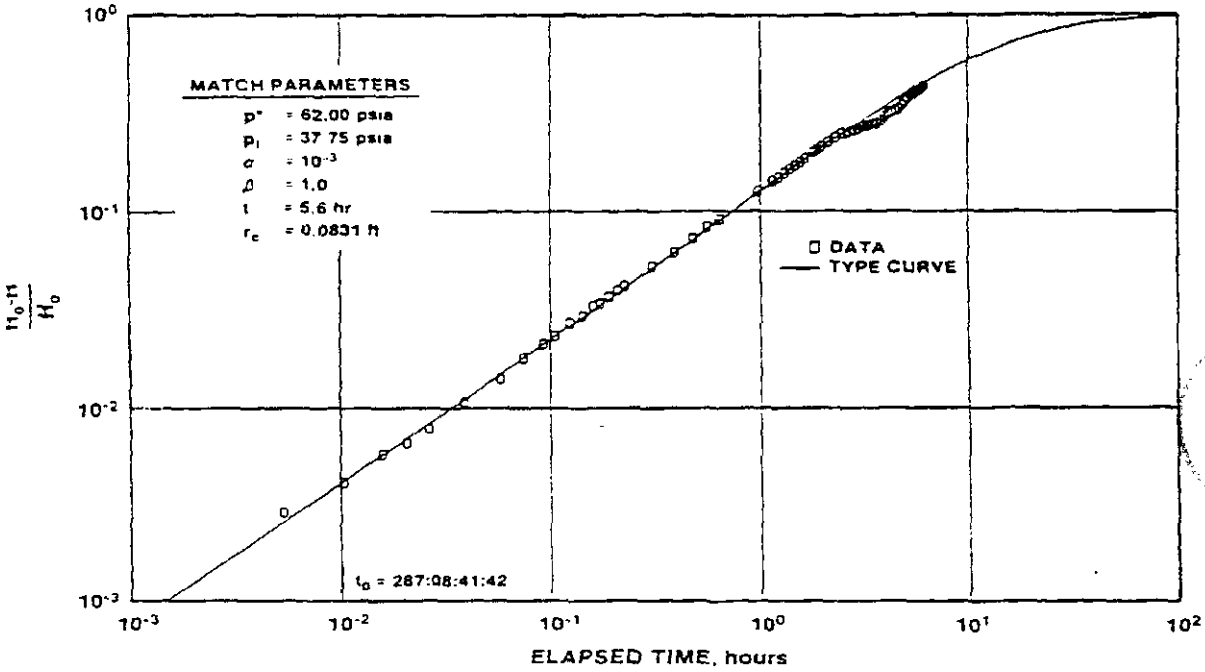

Figure 5-99. H-14/Forty-Niner Claystone Early-Time Slug-Test Plot

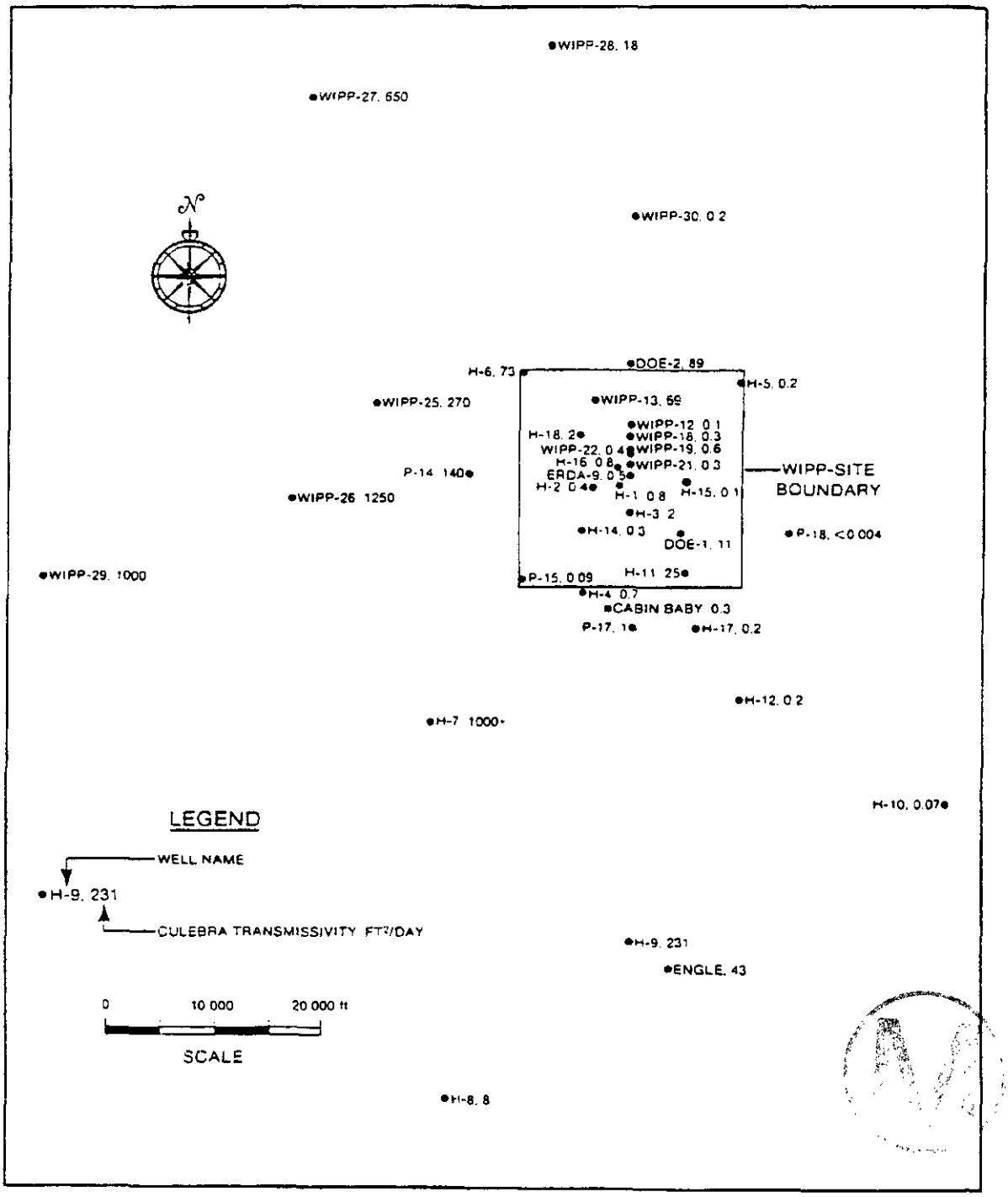

Figure 6-1. Culebra Wells Tested by the WIPP Project

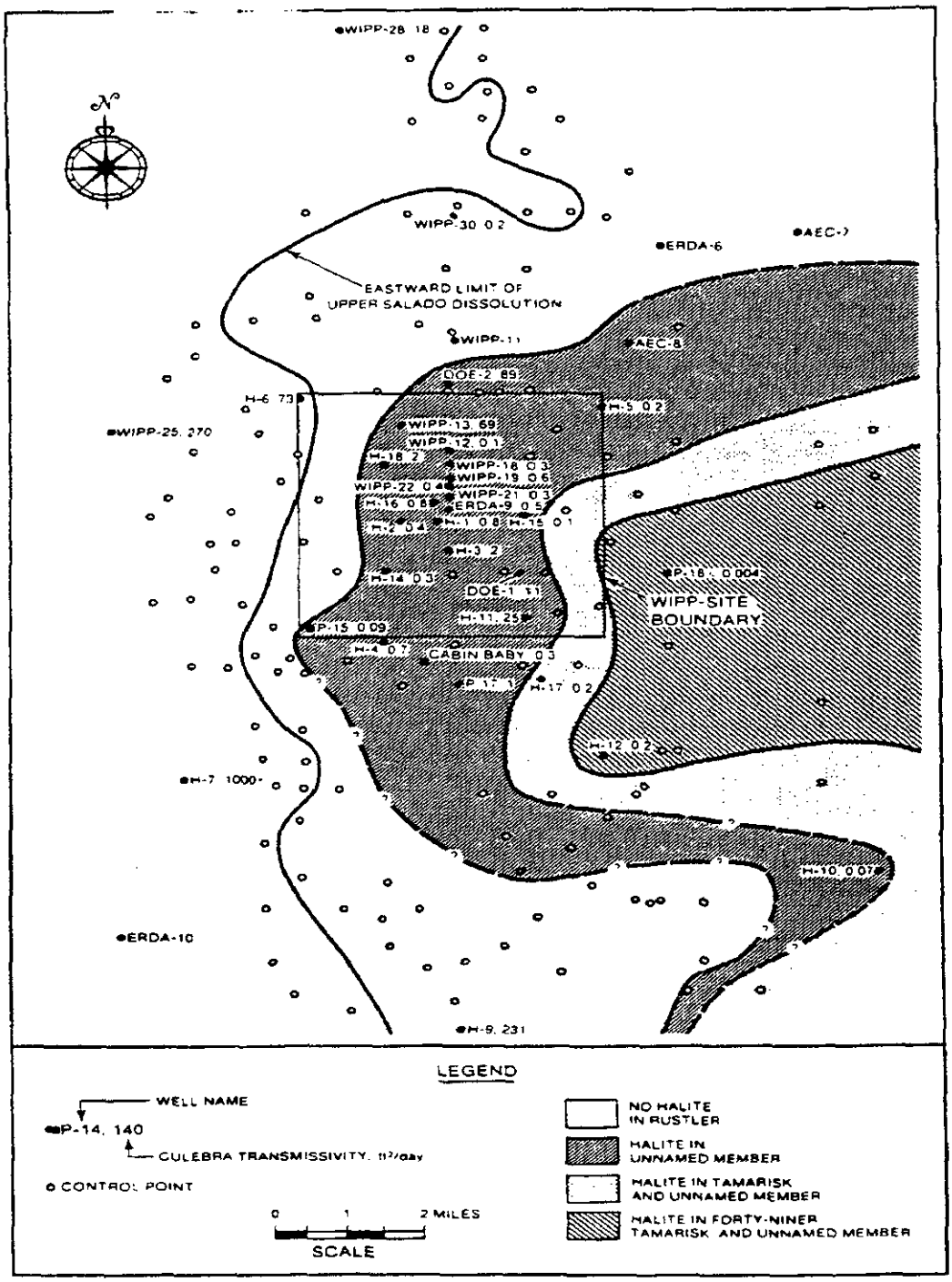

Figure 6-2. Distribution of Rustler Halite and Culebra Transmissivity Around the WIPP Site.

Beauheim, R.L., Wawersik, W.R., and Roberts, R.M. 1993. "Coupled Permeability and Hydrofracture Tests to Assess the Waste-Containment Properties of Fractured Anhydrite." Journal of Rock Mechanics. Vol. 30, No. 7, pp. 1159-1163.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Butcher, B.M. 1996. Memo to M.S. Tierney, RE: QAP 9-1 Documentation of the Initial Waste Water Content for the CCA, January 29, 1996. WPO 30925.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Butcher, B.M., Thompson, T.W., VanBuskirk, R.G., and Patti, N.C. 1991. Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste. SAND90-1206. Sandia National Laboratories, Albuquerque, NM. WPO 23968.

ABSTRACT, p i;

" The investigation described in this report acquired experimental information about how materials simulating transuranic (TRU) waste compact under axial compressive stress, and used these data to define a model for use in the Waste Isolation Pilot Plant (WIPP) disposal room analyses. The first step was to determine compaction curves for various simulant materials characteristic of TRU waste. Stress-volume compaction curves for various combinations of these materials were then derived to represent the combustible, metallic, and sludge waste categories. Prediction of compaction response in this manner is considered essential for the WIPP program because of the difficulties inherent in working with real (radioactive) waste.

Next, full-sized 55-gallon drums of simulated combustible, metallic, and sludge waste were axially compacted. These results provided data that can be directly applied to room consolidation and data for comparison with the predictions obtained in Part I of the investigation. Good agreement was obtained between prediction and test results.

Finally, compaction curves, which represent the combustible, metallic, and sludge waste categories, were determined, and a curve for the averaged waste inventory of the entire repository was derived. The results for axial compaction of combustible and metallic waste were found to be consistent with the assumptions used to estimate the final mechanical state of a typical disposal room, initially made as supporting information for the Draft Supplemental Environmental Impact Statement for WIPP."

Section 3.0 DRUM COMPACTION MEASUREMENTS, 3.1 Objectives, p 49;

" The objective of the second part of the testing program was to acquire collapse data for drums filled with different materials. These full-scale loading tests were conducted on single drums of waste by crushing them along their axis of symmetry with no restriction on lateral expansion. Loading continued until an axial stress of 13.8 MPa was exceeded. DOT-17C, 55-gallon drums with standard 90 mil polyethylene liners were used in all tests.

An empty drum was tested first for baseline information and to check out the mechanical systems and quality-assurance procedures. Next, a total of 10 waste-filled drums representing of combustible, metallic, and sludge waste were compacted. No lateral restraint was placed on the drums during the tests. Data acquired during compaction usually consisted of the force exerted on the top of the drum and its height.

A special feature of the tests incorporated both photographic and VCR coverage at prescribed time intervals to determine approximate drum volumes. Collapse was expected to be nonuniform, but only the sludge drums showed evidence of extensive bulging. Both the combustible and metallic waste drums were observed to compact uniformly with little indication of lateral deformation. Bulging was probably slight because tensile hoop stresses within the walls of the drums were sufficient to restrict any lateral movement of the waste."

Section 3.3.2 RING FORMATION IN THE DRUMS DURING COLLAPSE, p 52, para 2;
" The last information needed for drum collapse predictions was the way that the drums collapse during the tests. Cross-sections of the drums showed that they collapsed uniformly and independently of the drum contents, at least during the early parts of the tests, and formed crushed rings around the waste.[1] Because the drum appeared to crush straight down, without significant change in diameter, the assumption was made for data reduction purposes that a constant cross-section could be assumed in calculating drum densities.

To test this assumption, two test were performed by filling the voids in the filled waste drum with water before compaction. During the crush down, the water was allowed to move through tubing to another drum where the volume was measured to define the height versus volume of the waste relationship. These tests indicated that throughout most (about 2/3) of the crush down, the constant cross-section assumption was reasonable. For about the first half of the crush down, the cross-section was less than original, suggesting that the drum folded inward. Later, the volume reduction was less than assumed, showing that the drum was starting to bulge outward as compaction continued. The tendency of the curve of water-out versus drum height to reach a limit suggested that water would have eventually stopped coming out of the drum. This point was never reached in our tests; leaks either in the seal or the lid of the drum required an end to the water-collection portion of the test.

In contrast to the tests on simulated combustible and metallic waste, ring formation was not obvious during collapse of the sludge drums because both their total amount of collapse and the compressibility of the material was less. Compaction of the waste caused the drums to bulge outward slightly at the center, stretching the steel drums circumferentially and eventually causing them to break open at the seam, at which point some of the material near the seam would extrude from the drum and the tops of the drums would tilt downward towards the seam opening. However, the assumption was made, in reducing the sludge drum collapse data, that the drum crushed straight down without change in diameter. Therefore, the reduced data is truly representative of the early portions of the tests when bulging was minimal. The stress required to cause additional collapse rose so rapidly during the latter part of the test, however, that the constant cross-section assumption was probably adequate as a first approximation during the later portions of the tests."

4.0 REPOSITORY COMPACTIBILITY, p 65,

[1]Buckling patterns appearing along 'rolls' (strengthening hoops) in the drum were sinusoidal in shape, with five full sine waves at each roll. The sine wave pattern stayed stationary but grew in amplitude as the drum collapsed. After the pattern 'matured,' at a first ridge (generally the center of the drum), a second sinusoidal pattern would start at a second location on the drum (usually the bottom of the drum). The sine wave would contain five full waves as before, and the wave pattern would be a simple vertical translation from the wave pattern developed before. The third wave pattern would form like the second, at still another location on the drum.

4.1 Method of Analysis;

" A composite compaction curve for the entire repository will be defined in this section. This calculation proceeds in the same manner as for the composite compaction curves (Section 2.3.4), but what should be a simple procedure becomes more uncertain when the data for the inventory of CH-TRU waste from the most current references are examined. The basic problem is that the inventory data from DOE/RW-0006, Rev 4, (1988), and Drez and James-Lipponer (1989), summarized in Table 4-1, are difficult to correlate. The first source reports only volume data, whereas the second source quotes only weight data and is incomplete.

4.2 Repository Inventory

4.2.1 METALS INVENTORY

Definition of how much waste will eventually be stored in the repository (Table 4-1) started with metal waste. Metal and glass waste, according to Drez and James-Lipponer (1989), is composed of 2% by weight tantalum, 68% iron and steel, 17% lead (an upper bound), 4% Copper, and 9% aluminum. Using the theoretical solid densities listed in Table 2-2, and assuming that: (1) the weight assigned to leaded gloves in Drez's inventory was assumed to be entirely due to the lead, and (2) waste in the form of paint cans was were added to the total weight of iron and steel waste, although the paint cans probably are filled with stabilized sludge, this mixture is estimated to have a theoretical solid density of 7110 kg/m^3.

The total amount of steel waste reported by Drez also requires some adjustment because sometimes the weights of the containers were included in the totals for metallic waste given by INEL and the Los Alamos National Laboratory (LANL), and sometimes they were not separated out. Although Drez did not attempt to adjust his summary of results for this inconsistency, it was required for estimation of repository-wide averages, and was accomplished by estimating the volumes of INEL and LANL waste, finding the number of equivalent 55-gallon drums the volumes represented, and using this information to estimate the total weight of the containers. This procedure is a poor substitute for actual information, but it represents the best estimate that is possible at present. Thus, the estimates in this report that depend upon the separation of the total weight of the metal containers from the total weights of the waste categories must be redone as soon as more definitive information becomes available.

TABLE 4-1. TRU WASTE INVENTORY ANALYSIS

	Weight kg	Volume m^3	Volume Fraction[1]	Weight of Container steel, kg	Weight of Plastic liners & bags, kg	Weight of Wood containers	Total Weight kg	Weight Fraction
Metals	7,330,000							
Glass	1,120,000							
Metal/Glass	8,450,000	54,000	.40	4,400,000	744,000	596,000	14,190,000	.28
Combustibles	8,590,000	55,400	.41	4,510,000	763,000	611,000	14,480,000	.28
Sludge	20,300,000[2]	25,400	.19	2,090,000	353,000	283,000	23,030,000	.44
Steel Containers	11,000,000							
Polyethylene Liners	1,550,000							
PVC liners, bags	310,000							
Wood/Fiberboard	1,490,000							
	51,700,000	134,800	1.00	11,000,000	1,860,000	1,490,000	51,700,000	1.00

1. Values of the volume fraction were computed assuming the volume of the "other" category of waste to be proportionally distributed among the three major categories of waste.

2. Estimated value.

In the absence of any better information, the total weight of the INEL and LANL containers was estimated to be 7,350,000 kg, reducing the total weight of steel waste from the value of 9,170,000 kg quoted by Drez to 1,820,000 kg. The weight of iron in the Drez inventory remained unchanged at 2,620,000 kg. The total weight of metals in the inventory was 7,330,000 kg, and the weight of glass was estimated to be 1,120,000 kg.

A comparison of the new metallic waste inventory values by Drez with previous estimates by Clements and Kudera (1985) is also of interest. Clements and Kudera's study determined that the metals inventory was 4% tantalum, 64% steel, 7% lead, and 25% other metals such as aluminum and copper, by weight, with an average solid density of 6650 kg/m^3. The principal difference between the two compilations is that there is a greater amount of lead, and less aluminum and copper in the Drez inventory.

4.2.2 COMBUSTIBLES INVENTORY

For combustible waste, Drez reported that the total weight of cellulosics was 4,350,000 kg, the weight of plastics was 4,180,000 kg, and other combustibles were present in the amount of 60,500 kg. In the absence of additional information, we will assume that the cellulosics

are composed of about 60% wood and paper and 40% cloth (Butcher, 1989), with a solid density of 1100 kg/m^3 estimated from the densities quoted in Table 2-2. The category of "other" combustibles" was assumed to be 50% cellulosics and 50% plastics, and a solid density of 1200 kg/m^3 was assumed for plastics.

4.2.3 SLUDGE INVENTORY

The total weight of the sludges in the waste was not available at the time this report was prepared, nor was information available for estimating its solid density. Therefore, the weights of the sludge drum contents, estimated by Butcher (1989), from Clements and Kudera's (1985) data, were used to define the total weight of the sludge. These values were 170 kg for uncemented inorganic sludge, with an estimated solid density of 1330 kg/m^3 and 188 kg with an estimated solid density of 1480 kg/m^3 for uncemented organic sludge. For comparison, the mixture of water, quartz sand, and Portland cement for the tests used to simulate sludge in this investigation was estimated to have a no-void density of 2200 kg/m^3. The sand-cement mixture was relatively unsaturated, however, and addition of water could have easily reduced its no-void density to the order of the densities computed for the Clements and Kudera results.

For an estimate of the total weight of sludges, the assumption was made that an average drum of sludge weighs approximately 180 kg. To obtain the number of equivalent drums of sludge-like material, the volumes of adsorbed liquids and sludges, concreted or cemented sludges, and dirt, gravel or asphalt categories, listed in Table 4-1, were added together. This sum, 23,700 m^3 was divided by 0.21 m^3, the volume of an average 55-gallon drum, and the result multiplied by 180 kg to arrive at 20,300,000 kg for the total weight of sludge.

4.2.4 CONTAINER MATERIALS

The total weights of the steel in the containers, the plastic liners, and the wood/plywood boxes were determined by Drez to be 11,000,000 kg of steel containers, 1,550,000 kg of polyethylene rigid liners, 1,490,000 kg of fiberboard liners or wood/plywood boxes, and 310,000 kg of PVC liners and bags.

4.2.5 INVENTORY DISCREPANCIES

Discrepancies in the inventory data are best illustrated by using the weights and volumes given in Table 4-1 (257,000 equivalent drums assumed), and assuming a drum volume of 0.21 m^3, to determine that the weight of an average drum of metal and glass combustible waste is 55.2 kg. Of this amount, the drum itself weighs about 29 kg, with the remaining 26 kg, or approximately 60 lb the weight of the contents. The computed value of 26 kg appears far too low, when compared with the average weight of the contents of INEL metallic waste drums of 64.5 kg (142 lb), estimated by Butcher (1989), even when the additional weight of

a liner (approximately 8 kg) is added to the weight of the waste. The computed value for the contents of combustible waste drums, using the data in Table 4-1, would also be 26 kg, versus 40 kg from the INEL survey. There is also no information from Drez's study for determining the average weight of sludge in a typical 55-gallon drum.

The differences in the weights of single drums of metallic waste obtained, computed from the results in Table 4-1 suggest that either the estimated volumes are too large by a factor of 2 or the weights are too small by a factor of 2 in Table 4-1. Attempts to reconcile such inconsistency are likely to be even more difficult in the future as waste volumes are constantly being revised downward because of greater utilization of pre- or supercompaction without being specific about how the weight of the waste will change.

Other methods of estimating the inventory of nonradioactive materials in the waste have been explored (Appendix A), because the inventory data is not consistent. The conclusion of this study is that the best current estimate is that 0.28 by weight of the inventory will be metallic waste, that the weight fraction of combustible waste will be 0.28, and the weight fraction of sludges will be 0.44. The initial porosity of the waste in the repository will be 0.79, its average theoretical solid density will be 2000 kg/m^3, and the average initial density will be 426 kg/m^3.

4.3 Repository Curves for Axial Drum Compaction

For axial compaction, the average compaction curve for the repository is estimated using the predicted compaction curves for the three major types of waste. These curves differ slightly from the experimental drum collapse curves and include the corrections for creep. The method of estimation was as follows: (1) For a given value of the compaction stress, the density of each category of waste was obtained; (2) the assumption was made that the weight fraction of combustible waste was 0.28, the weight fraction of metallic waste was 0.28, and the weight fraction of sludge was 0.44 (c.f. Table 4-1 and Appendix A). Using the simple mixture rule (Sections 2.3.2 and 2.3.4), the average compacted density and the average solid density of the waste in the repository were then estimated in a similar manner, assuming average solid densities of 3440 kg/m^3 for metallic waste,l 1310 kg/m^3 for combustibles, and 2370 kg/m^3 for sludges (cf. Appendix I). (3) The porosity was then computed from quantity $(1 - \rho/\rho s)$, where ρ is the compacted density at the given stress, and ρs is the solid density. Results are given in Figure 4-1. The initial density of the waste, derived in Appendix A, is 426 kg/m^3, corresponding to a porosity of 0.787[2].

The following extrapolations of the density curves for combustible and metallic waste were used to extend the respective curves in Figure 4-1 beyond lithostatic pressure (14.8 MPa):

Combustibles: $\sigma = 0.392 \exp(0.001876\ \rho)$, $\sigma > 13.8$ MPa.

Metallic: $\sigma = 0.00867\ \rho - 13.55,$ $\sigma > 13.8$ MPa.

Sludge: $\sigma = 0.0379\ \rho - 61.0,$ $\sigma > 13.8$ MPa.

While curve fitting of the data below these stress limits with simple functions did not provide a sufficient correlation to warrant their use for the individual components of waste, the average curve for the repository is approximately represented by:

$\sigma = 31.6772 - 118.511\eta + 161.808\eta 2 - 79.227\eta 3,\ \ \sigma < 13.8$ MPa,

where σ is the stress in MPa and η is the porosity. The results, shown in Figure 4-1 and Table 3-2, indicate that the average drum would collapse to a minimum porosity of about 0.186.

1. For combustible waste, we assume 0.08 weight fraction metal with a solid density of 7110 kg/m^3, 0.52 plastics with a solid density of 1200 kg/m^3, 0.32 cellulosics with a solid density of 1100 kg/m^3, and 0.08 sorbents with a grain density of 3000 kg/m^3. For metal waste, we assume a composition (waste + drums) of 0.75 weight fraction metal, 0.18 weight fraction plastics, 0.02 weight fraction cellulosics, and 0.05 weight fraction sorbents (Portland cement). For sludge, we assume 0.134 weight fraction metals, 0.048 plastics, 0.058 sorbents, and 0.76 sludges. The sludge is assumed to have a solid density of 2200 kg/m^3

2. Although the quality of the data does not warrant it, three significant figures are retained here to assure compatibility with an empirical fit of the repository consolidation curve defined below.

Finally, it is useful to compare the results for axial compaction of combustible and metallic waste in Table 3-2 with the assumptions for the final mechanical state of a typical disposal room made for analyses supporting the Draft Supplemental Environmental Impact Statement (DSEIS) (Lappin et al., 1989). The DSEIS assumptions were made prior to the availability of any test data. In the DSEIS analyses, the assumption was made that combustible waste would compact to a porosity of 0.1 or less. The results of this investigation predict a final porosity of 0.137 at 14.8 MPa (Table 3-2)

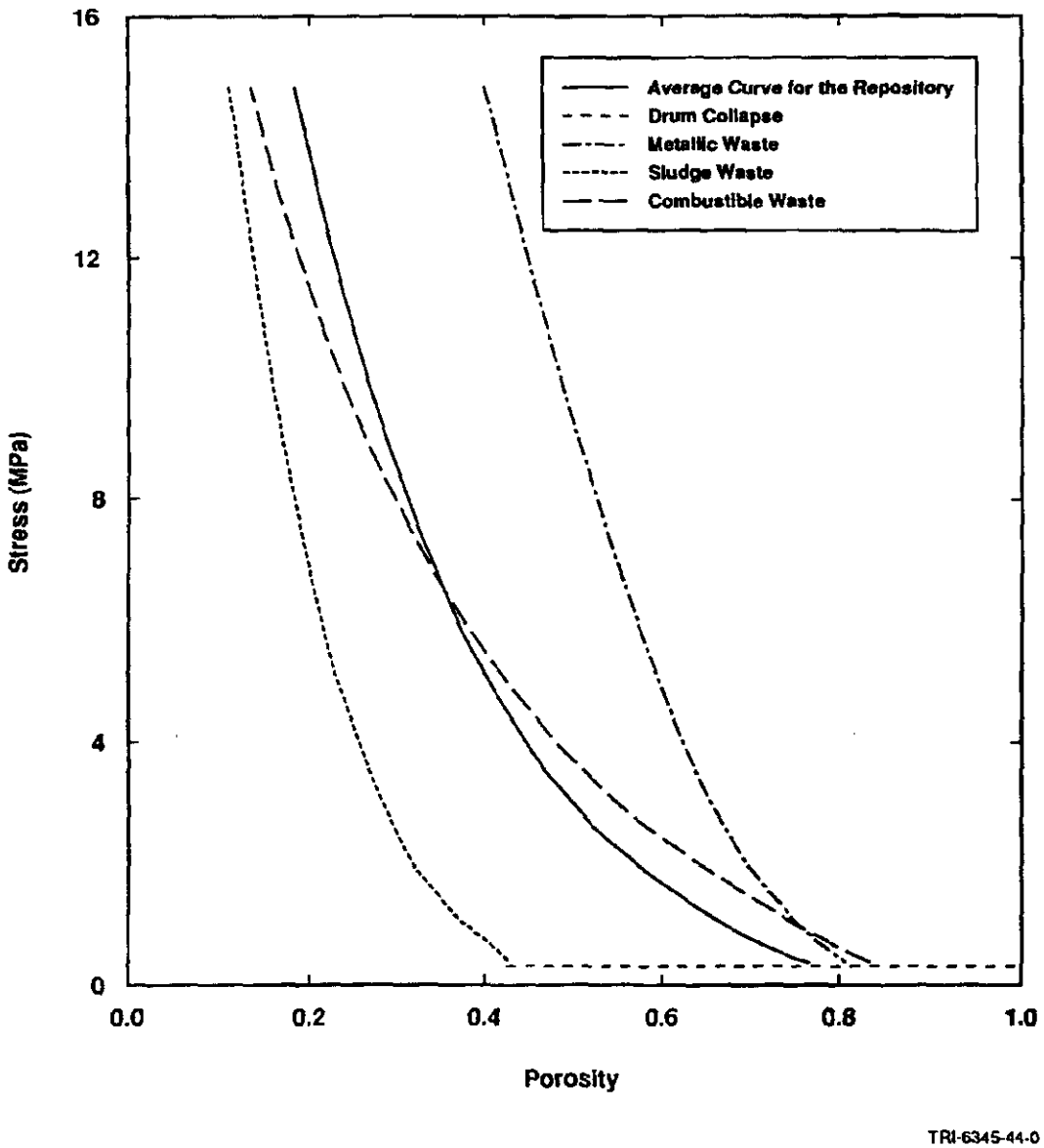

Figure 4-1. A comparison between the predicted compaction curve for all the waste in the WIPP repository and the recommended compaction curves for combustible, metallic, and simulated sludge wastes.

For metallic waste, a porosity of 0.4 was assumed for the DSEIS analyses. The results of this investigation suggest that metallic waste will compact to the DSEIS porosity estimate of 0.4. For sludge, a porosity of 0.1 was assumed for the DSEIS, and the results of this investigation suggest that sludge waste will compact to 0.113 porosity. However, the assumptions of this last porosity were similar to the DSEIS assumptions; therefore, little difference should be expected between the two values.

4.4 Repository Curves for Lateral Compaction of the Waste

4.4.1 THE INFLUENCE OF SHEAR STRESS ON COMPACTION

All of the information up to this point in the report has been concerned with the axial stress that must be applied to achieve a given state of compaction. The axial stress is defined as the stress along the axis of symmetry of a drum. The axial representations were necessary because the simulated wastes were too heterogeneous to permit direct measurement of lateral stresses during testing and because of the impossibility of making such measurements during drum collapse. Limiting results to a one-dimensional description, was justified, therefore, because either the waste was contained in a rigid die and could not expand, or that little lateral expansion of the drums occurred during collapse. Shear stresses within the waste during drum collapse were believed to be small, because otherwise the outward lateral stresses exerted by the wastes against the walls of the drums would have exceeded the yield stress of the drums, expanding them outward during the tests. The exception was that the shear stresses in the simulated sludge material were sufficient to burst the drums.

Nevertheless, although the assumption that shear stresses could be ignored was convenient for data representation, the magnitude of shear stress that when exceeded will produce plastic deformation is one of the parameters that must be specified for a general mechanical description of the waste. Further, since measurement of shear stresses did not appear feasible, the alternative that was selected was to use computational means to determine how sensitive the results of closure analysis would be to various assumptions about the deviatoric (shear) behavior of the waste.

To illustrate the approach further, assume that a cylinder of waste with a yield stress Y is loaded axisymetrically, under stresses σ_z, $\sigma_r = \sigma_\theta$, with $\sigma_z > \sigma_r$ the axial stress, and that it is plastically deforming. For this state of stress, the mean stress, p, that is considered to have the same magnitude as the hydrostatic pressure, is:

$$p = (\sigma_z + 2*\sigma_r)/3$$

and the yield point is the difference between the axial and lateral stress:

Yield point $Y = \sigma_z - \sigma_r$.

Therefore:

$$\sigma_z = p + 2/3 \star Y,$$

$$\sigma_r = p - Y/3,$$

and the extremes of possible experimental drum response are:

1) If $\sigma_r = 0$; then $p = Y/3 = \sigma_z/3$; $Y = \sigma_z$,

2) If $\sigma_r = \sigma_z$; then $p = \sigma_z$; $Y = 0$."

4.4.2 CLOSURE OF A ROOM ENTIRELY FILLED WITH WASTE AND SALT/BENTONITE BACKFILL

This reasoning must now be implemented in a full-fledged numerical closure calculation. The room configuration selected for the calculations was approximately the same as the design configuration of a typical disposal room with the exceptions that a 0.61 m (2 ft) air gap at the top of the room was omitted, since its presence occasionally caused numerical stability problems. This omission is not likely to influence the results greatly because it simply implies that contact of the waste with the surrounding salt begins immediately, rather than after the short time predicted for closure of the 0.61 m (2 ft) gap. Gap closure is estimated to occur within less than ten years. Another major assumption was that the room was symmetric with regard to both its vertical center line and its horizontal center line (Figure 4-2). The calculation has the vertical symmetry plane common to these problems, but use of a horizontal symmetry plane differs from past investigations. The assumption of horizontal symmetry greatly reduces computer run time, and it is a close enough approximation of the actual configuration to justify its use.

The calculations were estimates of the closure of a room filled with TRU waste and salt/bentonite backfill, using the finite-element, finite strain code SANCHO (Stone et al., 1985). Salt/bentonite backfill was selected because closure times predicted for its consolidation are longer than those for pure crushed salt backfill; therefore, variations caused by different assumptions about the shear stress in the waste would be more apparent.

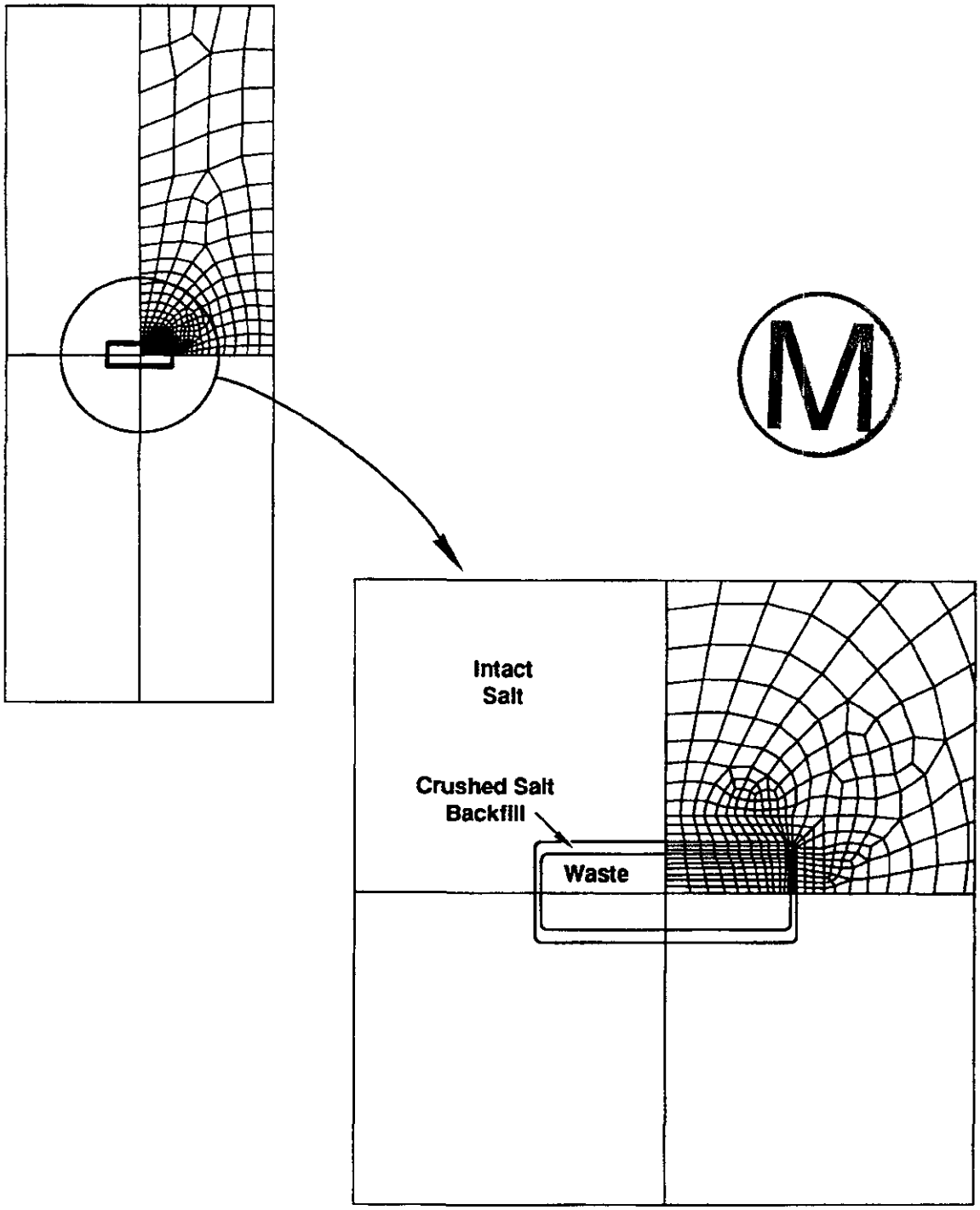

TRI-6346-114-2

Figure 4-2. Plane strain-finite element model of a TRU storage room.

Two compaction models were considered: (1) a model based on the assumption that the confining stress during laboratory compaction tests on the various waste types was zero ($\sigma r = 0$), and (2) a model based on the assumption that the confining stress in the compaction tests was equal to the applied stress ($\sigma r = \sigma z$). These assumptions represent the bounds of waste response as reflected by the magnitudes of the shear stresses that might be generated during consolidation. Assumption (1) represents a material that can support large shearing stresses, and assumption (2) represents a more fluid-like response, with essential no shear stresses developing during consolidation.

The results of the calculations, in Figure 4-3, show little difference between the closure history computed using a maximum possible value for the shear stress in the waste and the history for fluid-like response (the shear stress in this calculation was simply made very small) (Weatherby, personal communication 1991). Void fraction is plotted in this figure because, being equivalent to porosity (as discussed further in Footnote 2) it is the parameter most closely related to the permeability of the room contents. The conclusion from these results is that the closure histories are not very sensitive to the exact value of shear stress selected for the waste; therefore, a precise definition of this parameter is not needed. This observation also supports the original hypothesis of this investigation that a one-dimensional description would prove beneficial in describing waste compaction.

4.4.3 LATERAL COMPACTION OF DRUMS

In reality, lateral compaction curves for the waste are expected to lie somewhere between the limits of $Y = \sigma z$, and $Y = 0$, defined in Section 4.4.1. Further, in the sense that (1) axial drum compaction also does not appear to be sensitive to the details of how the drums collapse; and (2) lateral drum collapse is expected to exhibit even less buckling than axial collapse, the exact way that the drums collapse laterally is expected to have little effect on compaction of the waste. Some secondary effects will exist at the ends of the drums because of buckling of the lids, but the creation of collapse rings, such as those observed in the axial drum collapse tests, are considered unlikely. In the absence of information about the magnitude of the shear stresses within the waste, but with the likelihood that they will be small, the recommendation is made that shear stresses be neglected.

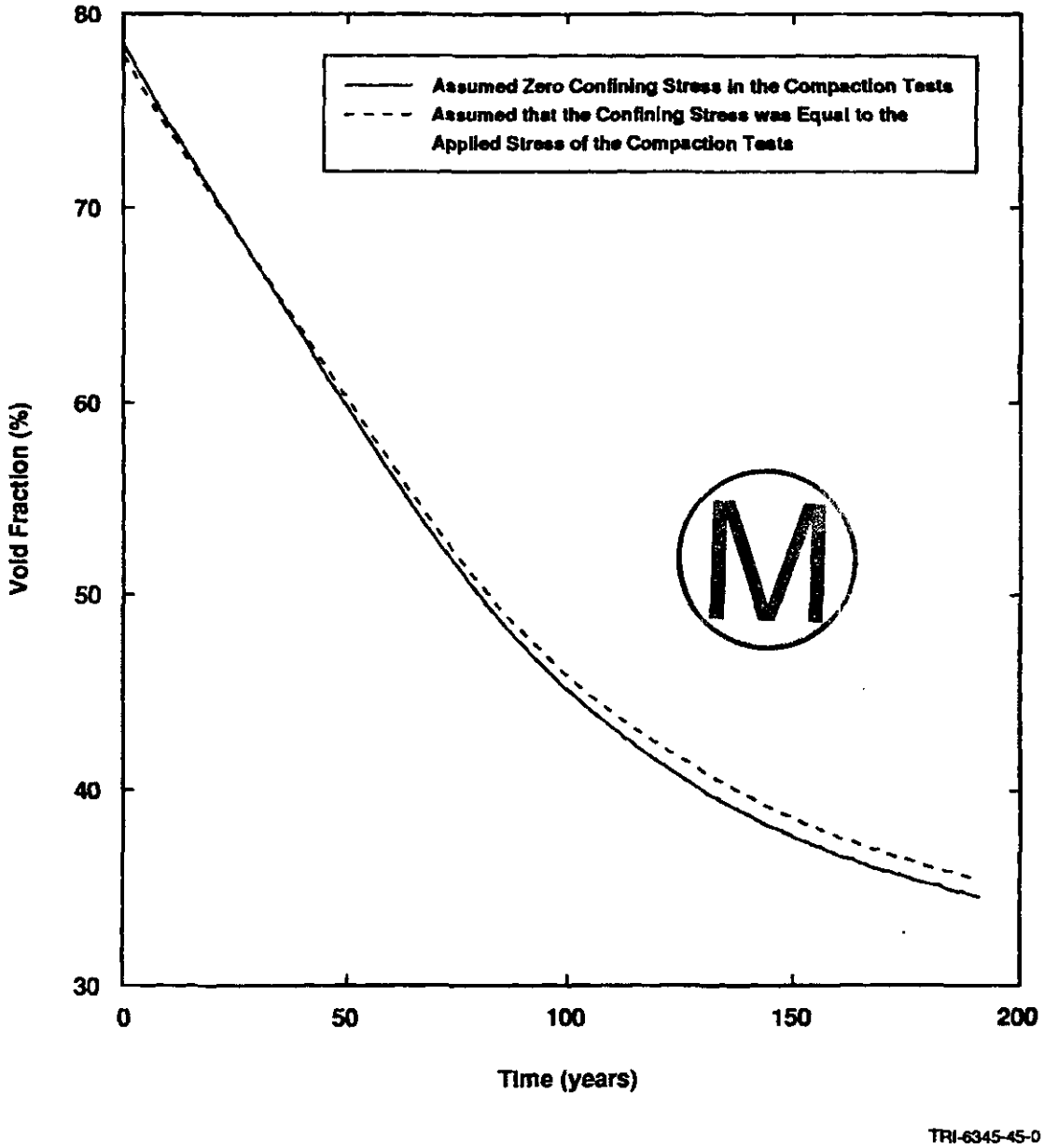

Figure 4-3. Predicted average void fraction-time history for waste in a room filled with TRU waste and 70% salt/30% bentonite backfill.

The reader is cautioned, however, that predictions of how drums collapse laterally within the repository are not nearly as straight forward as for axial collapse. In the axial collapse mode, lateral expansion of the drums is minimal and little or no intrusion into spaces between drums occurs. On the other hand, lateral collapse of the drums is likely to involve considerable alteration of their shapes, depending upon where they are located within the room, and the extent of this shape change will depend upon the nature of the material between them. However, refinement of models to account for this type of detail during consolidation would cause changes in how the waste initially consolidates, but probably not have much effect on the final end point (at lithostatic pressure). Such analyses are presently beyond the capabilities of numerical closure analyses, and it is not clear whether such detail, even if it could be incorporated in the codes, would have much additional impact on performance assessment.

Christian-Frear, G.L., and Webb, S.W. 1996. The Effect of Explicit Representation of the Stratigraphy on Brine and Gas Flow at the Waste Isolation Pilot Plant. SAND94-3173. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" Stratigraphic units of the Salado Formation at the Waste Isolation Pilot Plant (WIPP) disposal room horizon includes various layers of halite, polyhalitic halite, argillaceous halite, clay, and anhydrite. Current models, including those used in the WIPP Performance Assessment calculations, employ a "composite stratigraphy" approach in modeling. This study was initiated to evaluate the impact that an explicit representation of detailed stratigraphy around the repository may have on fluid flow compared to the simplified "composite stratigraphy" models currently employed. Sensitivity of model results to intrinsic permeability anisotropy, interbed fracturing, two-phase characteristic curves, and gas-generation rates were studied. The results of this study indicate that explicit representation of the stratigraphy maintains higher pressures and does not allow as much fluid to leave the disposal room as compared to the "composite stratigraphy" approach. However, the differences are relatively small. Gas migration distances are also different between the two approaches. However, for the two cases in which explicit layering results were considerably different than the composite model (anisotropic and vapor-limited), the gas-migration distances for both models were negligible. For the cases in which gas migration distances were considerable, van Genuchten/Parker and interbed fracture, the differences between the two models were fairly significant. Overall, this study suggests that explicit representation of the stratigraphy in the WIPP PA models is not required for the parameter variations modeled if "global quantities" (e.g., disposal room pressures, net brine and gas flux into and out of disposal rooms) are the only concern."

Corbet, T.F. and Knupp, P.M. 1996 The Role of Regional Groundwater Flow in the Hydrogeology of the Culebra Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico. SAND96-2133. Albuquerque, NM: Sandia National Laboratories.

p. i, para. 1;
1. INTRODUCTION; p. 1, para. 1;
" This report summarizes a study in which numerical simulation is used to enhance conceptual understanding of the hydrogeology of the Culebra Dolomite in the context of groundwater flow on a regional scale in the vicinity of the Waste Isolation Pilot Plant (WIPP). The WIPP is a potential repository for defense-generated transuranic wastes. The Culebra Dolomite is a member of the Permian age Rustler Formation, a sequence of predominantly evaporate deposits that overlie the Salado Formation. The Salado is a thick bedded salt of Permian age that contains the WIPP and provides the primary containment for the repository. The groundwater flow system in the overlying Permian and Triassic deposits forms a secondary barrier to releases from the repository in the even of a breach of the primary containment. Consequently, an important requirement of the performance assessment of the repository is to characterize long-term groundwater flow in the shallow system. We consider the possibility that patterns of groundwater flow in the shallow system change over thousands of years in response to change climate. Although groundwater flow is simulated in all of the strata above the Salado, this report focuses primarily on flow in the Culebra Dolomite because it is thought to be the most likely pathway for lateral migration of radionuclides to the accessible environment."

p. 3, para. 2;
" We developed a new numerical code called SECOFL3D, to perform the simulations. The algorithm implements a rigorous treatment of the free-surface and seepage-face boundary conditions (Bear and Verruijt, 1987; Dagan, 1989; de Marsily, 1986) and is designed to be robust even if extremely large contrasts in hydraulic conductivity are present within the model domain. A moving mesh that adaptively deforms so that its upper surface conforms to the moving water table is used to ensure that the entire computational domain remains saturated.

Lateral boundaries of groundwater basins are sub-vertical flow divides that typically coincide with depressions and highs on the land surface. Flow over a region much larger than the WIPP site (Figure 1-1) was simulated in order to have the model boundary coincide with topographic features that are likely to act as groundwater divides over a range of climatic conditions. A series of steady-state simulations was performed to examine the sensitivity of simulation results to assumed values for hydraulic conductivity and recharge rate. Transient simulations provided insight into how patterns of groundwater flow respond to long-term changes in climate. These simulations covered the time period from late in the Pleistocene (14,000 years ago) to 10,000 years in the future.

The simulations results suggest that patterns of groundwater flow in the Culebra in the

vicinity of the WIPP are influenced by the hydrology of the entire groundwater basin. Flow rates and directions depend on the position of the water table and heterogeneity in hydraulic conductivity at the basin-scale. Groundwater flow changes with time due to interaction among recharge, movement of the water table, and topography of the land surface."

p. 5, para. 2;
" The simulations also provide information about how flow in the Culebra in the vicinity of the WIPP is coupled with flow in adjacent strata. Vertical leakage across the top of the Culebra is directed downward. The amount of vertical leakage into the Culebra cannot be estimated with confidence because the vertical conductivity of the confining units is not well constrained. Vertical leakage may contribute as little as 5% or more than 50% of the total inflow to the portion of the Culebra that lies within the WIPP-site boundary. All of the outflow from this portion of the Culebra is lateral flow. Therefore, contaminants introduced into the Culebra will travel toward the accessible environment along the Culebra rather than by migrating upward or downward into other units."

p. 103, para. 4;
" We performed mass balances over the reference volumes (defined in the introduction to Section 3) of the more conductive layers. This was accomplished by summing the flow across each face of the reference volumes in order to calculate total flow through each reference volume, as well as the proportions of lateral and vertical inflow and outflow from the reference volumes."

p. 105, para. 1;
" Figures such as 3-46, 3-47, and 3-48 mass balances provide a clear overview of the mass balance but are difficult to interpret quantitatively. To complement these figures, we have included tables in Appendix D that summarize the mass balance data at two simulated times: at the present time (zero years) and at 10,000 years into the future. The total inflow to the Dewey Lake/Triassic rocks, Magenta, and Culebra reference volumes at the simulated present time are 5015, 784, and 2100 cubic meters per year (base case in Table D-1). The inflow rates for these units at 10,000 years are somewhat larger: 16738, 1736, and 3354 cubic meters per year (base case in Table D-4). These numbers show that, in this simulation, most of the flow occurs in the Dewey Lake/Triassic rocks and that more flow occurs in the Culebra than the Magenta."

p. 106, para. 1;
" Table D-2 gives the total flow across the upper surface, lower surface, and sides as a percentage of the total flow through the reference volume at zero years simulation time. For the base-case simulation, 42% of the inflow to the Dewey Lake/Triassic reference volume is from groundwater recharge (i.e., 42% of the inflow to the Dewey Lake/Triassic rocks is across the top). Zero percent of the inflow to the Dewey Lake/Triassic is from upward vertical leakage. In fact, an important aspect of all of the transient simulations performed for

this study is that the vertical flow components are directed downward in all layers within the vicinity of the WIPP site. 98% of the inflow to the Magenta reference volume is vertical leakage from the Dewey Lake/Triassic and 30% of the inflow to the Culebra is leakage from the Magenta. All of the outflow from the Culebra reference volume is by lateral flow. Table D-5 provides the same information at 10,000 years."

p. 139, para. 2;
" Within the region of intact strata, the contrast in hydraulic conductivities plays an important role in determining flow patterns. The Dewey Lake and Triassic rocks are more permeable than the anhydrites at the top of the Rustler Formation. Consequently most of the water that recharges the groundwater basin flows only in these rocks above the Rustler. The rest leaks vertically through the upper anhydrites and is available for flow through the rest of the Rustler. Differences in hydraulic head along the base of the Dewey Lake provide the driving force for flow in the Rustler.

Groundwater flow in the Rustler Formation is characterized by very slow vertical leakage through confining units and faster lateral flow in conductive units. Specific discharges (flow rates per unit area) in the Culebra are 2 to 3 orders of magnitude greater than the vertical specific discharges across the top of the Culebra. However, vertical leakage can contribute a significant portion of the total inflow to portions of the Culebra that are extensive enough that the upper surface is very much larger than the area available for lateral flow."

p. 141, para. 4;
" These simulations suggest that, in the vicinity of the WIPP site, vertical flow across the top of the Culebra is directed downward. The amount of vertical leakage into Culebra at this site cannot be estimated with confidence. It contributes a small portion of the total inflow to the Culebra reference volume, perhaps 5% to 10%, if the vertical conductivity of the confining units is 1×10^{-13} m/s or less. However vertical leakage may contribute more than 50% of the total inflow if the conductivity is an order of magnitude larger.

A robust implication of these simulations is that nearly all (greater than 90% in all simulations) outflow from the Culebra reference volume is by lateral flow. Therefore, contaminants introduced into the Culebra will travel toward the accessable environment within the Culebra rather than by leaking upward or downward into other units. This result provides confidence that a flow and transport model that assumes that flow occurs only in the Culebra would include the appropriate release pathways."

Cranwell, R.M., Guzowski, R.V., Campbell, J.E., and Ortiz, N.R. 1990. Risk Methodology for Geologic Disposal of Radioactive Waste, Scenario Selection Procedure. NUREG/CR-1667, SAND80-1429, Sandia National Laboratories, Albuquerque, NM. WPO 26750.

ABSTRACT, p iii;
" This report contains the description of a procedure for identifying and screening those events, features and processes, both natural and human induced, felt to be important to the isolation of radioactive wastes in deep geologic formations. In this report, the term 'scenario' is used to represent a sequence of these events, features and processes. The scenario selection and screening procedure discussed in this report is demonstrated by applying it to the analysis of a hypothetical waste disposal site containing a bedded salt formation as the host medium for the underground facility (repository). A final set of 12 scenarios is selected for this hypothetical site. Detailed risk calculations will be performed on these 12 scenarios in a later report."

PROCEDURE FOR SCENARIO SELECTION, P. 5;
"2.1 Identification of Events and Processes

The first step in any scenario selection procedure should be the identification of a comprehensive set of events and processes, both natural and human-induced, believed to be important to the disruption of the isolation of radioactive waste at the site being considered. This identification would generally be accomplished through discussions among persons knowledgeable in the areas of earth science and waste-management analyses. The use of knowledgeable and experienced individuals helps ensure that potentially important scenarios are not overlooked. For the demonstration of the Performance Assessment Methodology, a panel of knowledgeable earth scientists was convened for the purpose of identifying those events and processes considered to be important to the disruption of the isolation of radioactive waste in bedded salt (see Section 3.3, Table 2).

2.2 Classification of Events and Processes

The classification of events and processes provides a logical aid to help ensure that important scenarios will not be overlooked. The initial list of phenomena (see Table 2) was classified into the categories of natural, human-induced, and waste- and repository-induced. This classification was based on the origin and physical characteristics of these phenomena. A procedure for further classification is presented below. In addition to addressing the question of completeness, this classification also provides the organization needed to begin developing and analyzing scenarios.

Events and processes will also be classified based upon the manner by which they influence the disposal system consisting of the repository and the surrounding geology. Those

phenomena in the near vicinity of the repository, whose major effect is to influence the release and movement of radionuclides from the waste packages and engineered barrier system to a nearby aquifer or directly to the land surface, will be referred to as release phenomena. Similarly, those phenomena in the far field whose major effect is to influence the transport of radionuclides in ground water will be referred to as transport phenomena.

The distinction between those events and processes included as release phenomena and those included as transport phenomena is not always obvious. For example, faulting may be classified as either a release or transport phenomenon, depending on the proximity to the site. If the fault should pass through or very near the repository, its primary effect would be to influence the release and movement of radionuclides from the repository to a nearby aquifer. In this case, the fault would be classified as a release phenomenon. On the other hand, if the fault should occur at some distance away from the repository so that its primary effect is to influence the transport of radionuclides in ground water, then it would be classified as a transport phenomenon. Regardless of its classification, a given event or process may influence both radionuclide release and transport, depending on its effect on the site hydrology. Despite the seemingly arbitrary division of phenomena into release and transport categories, the reasons for this division become more apparent when the one considers the complex thermal, mechanical, geochemical and hydraulic analyses that may be required for near-field (release) phenomena analysis compared to the more straightforward flow and transport analyses required for far-field (transport) phenomena analysis.

While only two classification schemes are used in this example, additional classifications are helpful in developing a comprehensive list of phenomena.

2.3 Screening of Events and Processes

Many of the events and processes from the initial list considered for a potential disposal site can be eliminated based on firm and well-defined screening criteria. A screening of these events and processes is not only desirable but also essential if one considers the thousands of scenarios that could be defined by taking specific combinations of these phenomena.

Initial screening criteria should consist of the following:

1. Physical reasonableness of the events and processes being considered.

2. Probability of significant release of radionuclides from these events and processes.

3. Potential consequences associated with the occurrence of these events and processes.

Physical Reasonableness. Events and processes whose occurrence is impossible due to the physical and chemical characteristics of the waste and characteristics of the engineered

facility or geologic site can be eliminated by this screening criterion. Some examples of phenomena that could be eliminated based on the test of physical reasonableness are

- A nuclear explosion in an underground facility designed to prevent criticality.
- Formation of dissolution cavities in crystalline rock.
- Tsunamis for a repository far removed from coastal regions.

Clearly, the elimination of phenomena due to this criterion would be largely site specific. Therefore, this step in the screening process should be repeated for each repository site.

Probability. Events and processes with very "small" probability can generally be rejected. The specification of "small" should be the responsibility of the regulator or the applicant and should be consistent with the appropriate regulations. Once a value has been selected, judgmental decisions will undoubtedly still have to be made as many probabilities associated with various phenomena will have large uncertainties. The value selected in the demonstration analysis of this report was 10-8/yr .

In several safety studies, numerical probability criteria have been used to reject scenarios. For example, WASH-1400 [U.S. Nuclear Regulatory Commission, 1975] uses a limit of 10^{-9}/yr to reject accident sequences. Other references [Griesmeyer and Okrent, 1981] suggest larger numbers (e.g., 10^{-7}/yr). The U.S. Environmental Protection Agency (EPA) [U.S. Environmental Protection Agency, 1985] suggests that categories of events and processes with probability of occurrence smaller than 10^{-8}/yr can be ignored.

Consequence. As used in this report, "consequence" can have different interpretations, depending upon the stage of the screening process. For example, in the earlier stages of the screening process, "consequence" generally refers to the effects that a certain event or process might have on the natural properties of the site (e.g., hydraulic head distribution). Thus, only flow and possibly thermomechanical analyses are needed at this point. In the screening of scenarios, "consequence" generally refers to the amount of radionuclides being discharged to the environment and the health effects associated with these discharges. Thus, radionuclide transport and health effects calculations are needed at this point. The reason for this breakdown is that in the early stages of the screening process, detailed transport and health effects calculations should be avoided because of the higher computer and man-power costs associated with these efforts. The total scenarios should be reduced to a reasonable number before undertaking detailed risk calculations.

At any rate, screening based on consequence can occur in several ways. For example, events and processes having similar consequences (e.g., effects on hydraulic head) could conceivably be grouped together provided the probabilities of these phenomena are

appropriately combined. Also, events and processes with insignificant consequences (e.g., no apparent effect on hydraulic head) could be eliminated. However, before eliminating phenomena based on insignificant consequences, their potential maximum consequence should be considered.

2.4 Scenario Construction

The next step in the scenario selection procedure involves the formation or development of scenarios by taking meaningful combinations of those phenomena remaining after the screening process. Recall that at this point, the events and processes have been classified as to "release" and "transport" phenomena as discussed in Section 2.2. The development of scenarios by taking combinations of the various release and transport phenomena is illustrated by a simple example.

Consider the simple case of two release phenomena (Rl, R2) and three transport phenomena (Tl, T2, T3). The possible scenarios that can be created by taking combinations of these phenomena are shown in Figure 2. There are 25 - 32 possible combinations in this example. The use of a logic diagram as illustrated in Figure 2 ensures that all possible combinations are identified. The base case scenario represents the initial conceptualization of the disposal system including the repository and emplaced waste. All components of the engineered-barrier system are assumed to perform as designed. The other scenarios are perturbations to these basic conditions.

This organizational method is preferable to the classical event-tree, fault-tree techniques frequently used in the analysis o£ engineered systems. This statement is made for the following reasons.

1. Many of the so-called "events" associated with geologic environments do not represent immediate or abrupt changes in the system but rather slow, continuous changes over hundreds to thousands of years (e.g., dissolution cavities in bedded-salt formations, shaft or borehole seal degradation, etc.). Hence their occurrence cannot be represented by a simple "yes" or "no" statement

2. Feedback loops frequently appear in the investigation of the processes that could affect the release of radionuclides from the underground facility. Event trees and fault trees do not adequately incorporate interactions between various factors influencing radionuclide movement.

3. For a given set of conditions, many of the processes are basically deterministic. Thus, the question of when and if a certain "barrier" will be breached is answered when a given set of conditions is specified. The real question is, what conditions exist?

4. Event trees and fault trees force artificial divisions in the representation of processes. The important question is how the entire system behaves.

Other studies [Burkholder, 1981; Koplik et al., 1982] have also concluded that event and fault trees are not useful for analyzing geologic processes or their interactions. They recommend the use of simulation techniques with models to describe the evolution over time of a set of variables representing the scenarios. The latter method is used in this study as described in the next chapter.

2.5 Screening of Scenarios

The next step in the scenario selection procedure would be to screen the scenarios developed from taking combinations of the various release and transport phenomena. An initial screening of these scenarios is based on physical reasonableness, probability, and consequence.

Physical Reasonableness. The most readily applicable of these screening criteria is physical reasonableness. Certain combinations of events and processes are incompatible. For example, consider a basaltic dike that intrudes through the repository. The effects of such an intrusion primarily would be on the release of radionuclides. A dike that behaved as a barrier to flow could be designated as Rl. If a fracture or rubble zone occurred as a result of the intrusion, a high-conductivity zone could be formed that would enhance ground-water flow. For this example, the presence of a high-conductivity zone is designated R2. The presence of the dike must be considered as either R1 or R2. The combination Rl R2 requires the dike to have incompatible properties. As a result, all scenarios (e.g., Figure 2) that include both R1 and R2 could be dropped from consideration on the basis that the components are not a physically reasonable combination.

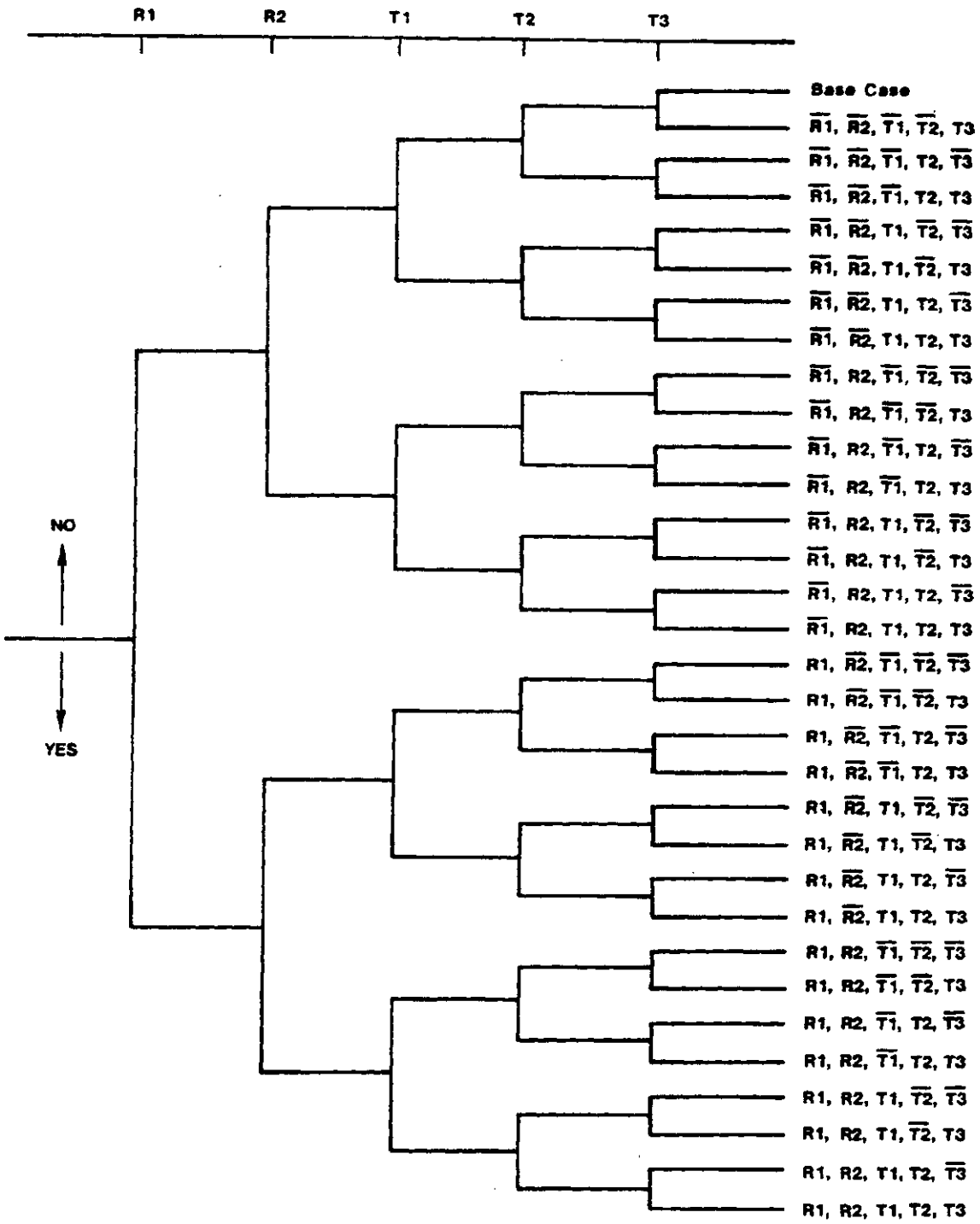

Figure 2. Potential Combinations of Two Release and Three Transport Phenomena

Probability. Assuming probabilities have been assigned to the various release and transport phenomena (components) comprising a scenario, a probability of that scenario can be arrived at by simply multiplying the probabilities of each of the components (assuming, of course, independence among the components). If the components of a scenario are not independent, then conditional probabilities can be used to arrive at the probability of the scenario. If this probability falls below the agreedupon cutoff (e.g., 10^{-8}/yr), and one is relatively confident in the probability estimates for each component comprising the scenario, then this scenario could be eliminated from any further consideration.

Consequences. Scenarios can also be screened on the basis of consequence. Here, consequence generally refers to either radionuclide discharges to the environment or the health effects resulting from these discharges. Thus, radionuclide transport and health effects calculations are needed. If, in performing transport calculations for a scenario, no discharges are observed for the period of time used in the analysis, no additional consideration of the scenario is necessary. However, if discharges occur, the scenario must be retained for inclusion in regulatory compliance assessments, such as those specified in the containment requirements, 40 CFR 191.13 [U.S. Environmental Protection Agency, 1985].

A final screening of the scenarios remaining at this point can be accomplished using combined probability and consequence arguments, namely risk. However, unless regulations for disposal are risk-based, the use of risk in screening scenarios is generally not applicable.

TABLE; p. 26, tbl. 2;
"

Table 2.

Potentially Disruptive Events and Processes

Natural Events and Process

Celestial Bodies

Meteorite Impacts

Surficial Events and Process

Erosion/Sedimentation

Pluvial Periods

Sea Level Variations

Hurricanes

Seiches

Tsunamis

Regional Subsidence or Uplift
(also applies to subsurface

Glaciation

Landslides

Subsurface Events and Processes
Seismic Activity
Volcanic Activity
Magmatic Activity
Formation of Dissolution Cavities
Formation of Interconnected Fracture Systems
Faulting

Human-Included Events and Processes

Inadvertent Intrusions
Explosions
Drilling
Mining
Waste Disposal (Injection Wells)
Withdrawal Wells

Hydrologic Stresses
Irrigation
Damming of Rivers

Waste-and Repository-Induced Events and Processes

Subsidence and Caving
Shaft and Borehole Seal Degradation
Thermally-Induced Stress/Fracturing in Host Rock
Excavation-Induced stress/Fracturing in Host Site"

Dale, T. and L.D. Hurtado. 1996. "WIPP Air-Intake Shaft Disturbed-Rock Zone Study," 4th International Conference on the Mechanical Behavior of Salt, Montreal, Quebec, June 17-18, 1996. SAND96-1327C. Albuquerque, NM: Sandia National Laboratories.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Davies, P.B., 1991. Evaluation of the Role of Threshold Pressure in Controlling Flow of Waste-Generated Gas into Bedded Salt at the Waste Isolation Pilot Plant. SAND90-3246. Sandia National Laboratories, Albuquerque, NM, pp. 17-19. WPO 26169.

ABSTRACT:

" Anoxic corrosion and microbial degradation of contact-handled transuranic waste may produce sufficient quantities of gas over a long time period to generate high pressure in the disposal rooms at the Waste Isolation Pilot Plant (WIPP) repository. Dissipation of pressure by outward gas flow will be inhibited by the low permeability of the surrounding rock and by capillary forces that resist gas penetration into this water-saturated rock. Threshold pressure is the gas pressure required to overcome capillary resistance to initial gas penetration and to the development of interconnected gas pathways that would allow outward gas flow. The primary objectives of this study are to estimate the magnitude of threshold pressure in the bedded salt that surrounds the WIPP repository and to evaluate the role this parameter plays in controlling the outward flow of waste-generated gas. Estimates of threshold pressure have been made based on an empirical correlation of threshold pressure with intrinsic permeability from other low-permeability rock types and on a capillary tube model. These two approaches yield generally consistent estimates, suggesting that threshold pressure in relatively pure halite is 20 to 50 MPa, or larger; threshold pressure in impure halite is 5 to 25 MPa; and threshold pressure in more permeable nonhalite interbeds is 2 to 1/2 MPa, or less. Because of the compounding effect of low threshold pressure and relatively high permeability, the nonhalite interbeds are likely to be the dominant pathways for flow of waste-generated gas away from a pressurized repository. Near the repository, a number of processes occur that may significantly reduce threshold pressure. Local fracturing and pore dilation in response to excavation-related stresses creates larger pore apertures. Desaturation occurs as a result of drying, dilation, and/or exsolution of gas that is dissolved in Salado brine under natural conditions. All of these processes contribute to the development of a zone surrounding the repository that contains pore space that is readily accessible to waste-generated gas due to significantly decreased threshold pressures. The threshold pressure estimates and analyses presented in this report are based primarily on threshold pressure information from low-permeability, nonsalt rock types and must be confirmed with direct, laboratory, and/or in situ measurements specific to the Salado Formation at the WIPP repository. In particular, such measurements should be directed toward the nonhalite interbeds and impure halite."

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Section 4.1 Empirical Correlations, p. 17;

" Correlations of threshold pressure with intrinsic permeability have been presented in the soils literature for unconsolidated materials (Stakman, 1968) and in the petroleum literature for consolidated rock (Thomas et al., 1968; Ibrahim et al., 1970). The physical rationale behind this approach is that both threshold pressure and intrinsic permeability are strongly related to pore size and pore interconnections in some fashion. As noted in the previous discussion of the capillary tube model, over the broad spectrum of geologic environments, intrinsic permeability ranges over 13 orders of magnitude (Table 2) and is the dominant factor controlling threshold pressure. The parameter with the second largest range (2-1/2 orders of magnitude) is porosity. Empirical correlations for threshold pressure that incorporate both intrinsic permeability and porosity have also been tested, but show no significant improvement in fit over correlations that use only intrinsic permeability (Ibrahim, 1970).

A detailed literature review has yielded threshold pressure and intrinsic permeability data for a broad range of lithologies with permeabilities ranging from approximately 1×10^{-9} to 1×10^{-22} m^2 (1000 darcies to 0.1 nanodarcy). Most data at the lower end of this range come from measurements on caprock lithologies associated with underground gas storage research. Data at the high end of this range are primarily from unconsolidated soils and

artificial porous media. Figure 5 is a plot of the threshold pressure versus intrinsic permeability, grouped by lithology. This plot contains only data from research laboratory measurements carried out under carefully controlled conditions. Data from commercial laboratories were not included because of the frequent absence of lithologic information and uncertainty in the range of quality control in the measurements. Data from Cosby et al. (1984) for unconsolidated materials have been presented as a separate curve because these data represent mean values from a large number of samples in groups of different textural classifications rather than individual sample points.

The empirical correlations presented in Figure 5 and summarized in Table 3 reveal a distinct similarity in threshold-pressure versus intrinsic-permeability relationships for the consolidated lithologies, which include sandstone, shale, carbonate, and anhydrite. These data have been fit with a power curve of the form:

$$y = ax^b \tag{7}$$

The best fit power curves for these lithologies are quite similar, with exponents ranging from -0.34 to -0.37 and coefficients ranging from 3×10^{-7} to 9×10^{-7}. On the other hand, the curves for the high permeability lithologies (unconsolidated soils and artificial porous media) are different, with the exponents ranging from -0.46 to -0.71 and coefficients ranging from 3×10^{-8} to 3×10^{-12}. The exponents for the best fit power curves for all lithologies are generally similar to the theoretical -0.50 exponent indicated by the capillary tube model (Equation 5). The Stakman (1968) data for sorted sand are characterized by a close fit ($\mathbf{R^2}$ is equal to 0.97) and by an exponent (-0.46) that is quite similar to the theoretical -0.50 value. Exponents for the consolidated lithologies are all close to-0.35, suggesting that factors other than intrinsic permeability may exert secondary influence on the correlation for consolidated materials."

Dotson, L.J. 1996. Non-Salado Initial Pressure. Sandia National Laboratories, NM. WPO 30713.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Earth Technology Corporation, 1988. Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site. SAND87-7144. Albuquerque, NM, Sandia National Laboratories.

EXECUTIVE SUMMARY, p ii;

The Earth Technology Corporation was contracted by Sandia National Laboratories to perform a time domain electromagnetic (TDEM) survey at the WIPP site for the purpose of mapping the depth of occurrence of brine pockets and layers. The impetus for the geophysical survey was that pressurized brine had been encountered in drill holes in the Castile Formation immediately underlying the bedded salts of the Salado Formation in which the waste storage panels are mined. TDEM is a geophysical technique that determines layering in the subsurface from surface resistivity measurements. Because brine layers and pockets have low resistivities compared to the bedded salts of the host rock, they are good targets for electrical exploration.

Most of the measurements (36 out of 38) were located in a 1.5 by 1 km grid directly over the waste storage panels. Two measurements were made next to drill holes WIPP #12 and DOE #1 to validate the interpretation of the geophysical survey. Also, one drill hole (ERDA #9) at the northern boundary of the survey grid was used for calibration.

The results of the survey can be summarized as follows:

- The geoelectric sections derived from the TDEM measurements compare well with geologic and geophysical data of the three drill holes. At WIPP #12 the occurrence of brine at a depth of about 800m (2600 ft.) is clearly seen in the TDEM data.

- The results of the TDEM survey over the waste storage panels show the first occurrence of brine at depths corresponding to the Castile Formation in portions of the area and to the Bell Canyon Formation in the rest of the area, some 400 to 600 m below the mined depth of the waste storage panels in the Salado formation. There is no evidence in the data for brine pockets in the Salado or other formations over the waste storage panels.

Only one sounding was made near drill hole WIPP #12 for the purpose of calibration. Since the center loop TDEM surveys conducted correlate well with drill holes and other geologic data, it is recommended that the areal extent of the brine pocket encountered at WIPP #12 be mapped by surveying a grid centered on WIPP #12."

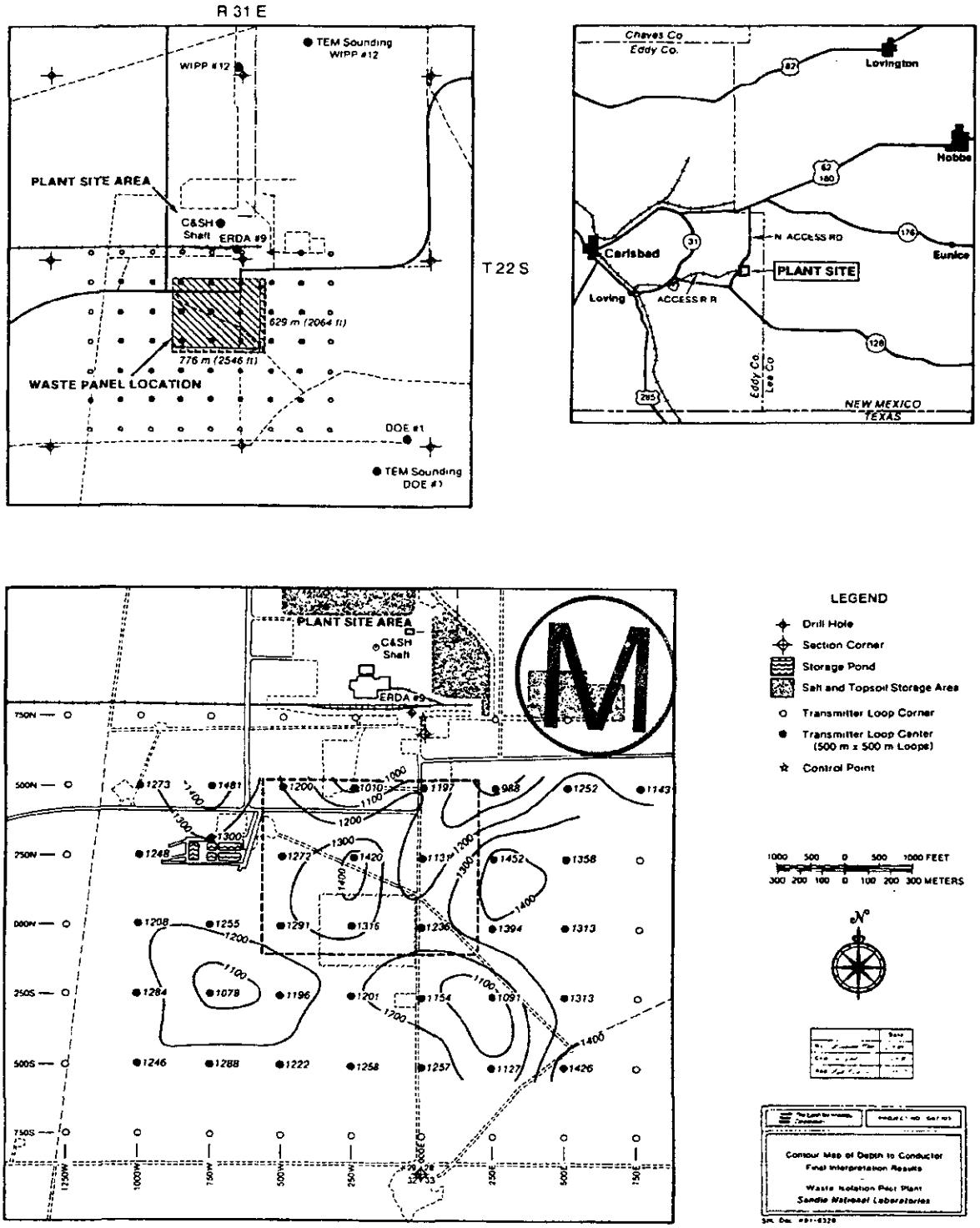

Figure 1-1. TEM Sounding Locations and Waste Panel Location

EPA (U.S. Environmental Protection Agency), 1985. "40 CFR Part 191: Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule." Federal Register, Vol. 50, No. 182, pp.38066-38089, September 19, 1985. Office of Radiation and Air, Washington, D.C. WPO 39132.

SUMMARY, p. 38066, col. 1;

" The Environmental Protection Agency (EPA) is promulgating generally applicable environmental standards for the management and disposal of spent nuclear fuel and high-level and transuranic wastes. The standards apply to management and disposal of such materials generated by activities regulated by the Nuclear Regulatory Commission (NRC) and to disposal of similar materials generated by atomic energy defense activities under the jurisdiction of the Department of Energy (DOE). These standards have been developed pursuant to the Agency's authorities and responsibilities under the Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act of 1982.

Subpart A of these standards limits the radiation exposure of members of the public from the management and storage of spent fuel or high-level or transuranic wastes prior to disposal at waste management and disposal facilities regulated by the NRC. Subpart A also limits the radiation exposures to members of the public from waste emplacement and storage operations at DOE disposal facilities that are not regulated by the NRC.

Subpart B establishes several different types of requirements for disposal of these materials. The primary standards for disposal are long-term containment requirements that limit projected releases of radioactivity to the accessible environment for 10,000 years after disposal. These release limits should insure that risks to future generations from disposal of these wastes will be no greater than the risks that would have existed if the uranium ore used to create the wastes had not been mined to begin with. A set of six qualitative assurance requirements is an equally important element of Subpart B designed to provide adequate confidence that all containment requirements will be met. The third set of requirements are limitations on exposures to individual members of the public for 1,000 years after disposal. Finally, a set of ground water protection requirements limits radionuclide concentrations for 1,000 years after disposal in water withdrawn from most Class I ground waters to the concentrations allowed by the Agency's interim drinking water standards (unless concentrations in the Class I ground waters already exceed limits in 40 CFR Part 141, in which case this set of requirements would limit the increases in the radionuclide concentrations to those specified in 40 CFR Part 141). Subpart B also contains informational guidance for implementation of the disposal standards to clarify the Agency's intended application of these standards, which address a time frame without precedent in environmental regulations. Although disposal of these materials in mined geologic repositories has received the most attention, the disposal standards apply to disposal by any method, except disposal directly into the oceans or ocean sediments.

This notice describes the final rule that the Agency developed after considering the public comments received on the proposed rule published on December 29, 1982, and the

recommendations of a technical review conducted by the Agency's Science Advisory Board (SAB). The major comments received on the proposed standards are summarized together with the Agency's responses to them. Detailed responses to all the comments received are discussed in the Response to Comments Document prepared for this final rule.
DATE: These standards shall be promulgated for purposes of judicial review at 1:00 p.m. eastern time on October 3, 1985. These standards shall become effective on November 18, 1985."

50 FR 38087, col. 2;
"Appendix A--Table for Subpart B . . .
Application of Table 1

Note 1:Units of Waste. The Release Limits in Table 1 apply to the amount of wastes in any one of the following:

(a) An amount of spent nuclear fuel containing 1,000 metric tons of heavy metal [MTHM] exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal [MWd/MTHM] and 40,000 MWd/MTHM;

(b) The high-level radioactive wastes generated from reprocessing each 1,000 MTHM exposed to a burnup between 25,000 MWd/MTHM and 40,000 MWd/MTHM;

(c) Each 100,000,000 curies of gamma or beta-emitting radionuclides with half-lives greater than 20 years but less than 100 years (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with Part B of the definition of high-level waste in NWPA);

(d) Each 1,000,000 curies of other radionuclides (i.e., gamma or beta-emitters with half-lives greater than 100 years or any alpha-emitters with half-lives greater than 20 years) (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in NWPA); or

(e) An amount of transuranic (TRU) wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years."

EPA (U.S. Environmental Protection Agency), 1993. "40 CFR Part 191: Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule." Federal Register, Vol. 48, No. 242, pp. 66398-66416, December 20, 1993. Office of Radiation and Air, Washington, D.C. WPO 39133.

PREAMBLE: SUMMARY;

" The U.S. Environmental Protection Agency (EPA) is promulgating amendments to the environmental standards for the disposal of spent nuclear fuel, high-level and transuranic wastes (40 CFR 191.15 and Subpart C).

EPA originally promulgated these standards in 1985 pursuant to the Agency's authorities and responsibilities under the Nuclear Waste Policy Act of 1982, as amended, the Atomic Energy Act of 1954, as amended, and §2(a)(6) of Reorganization Plan No. 3 of 1970 (5 USC app. 1). In 1987, following a legal challenge, the U.S. Court of Appeals for the First Circuit (hereinafter referred to as 'the First Circuit' or ' the court') remanded subpart B of the 1985 standards to the Agency for further consideration. *Natural Resources Defense Council, Inc. v. United States Environmental Protection Agency*, 824 F.2d 1258 (1st Cir. 1987). Recently enacted legislation, (Pub. L. 102-579) known as the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA), however, reinstates the 1985 disposal standards except 'the 3 aspects of §§191.15 and 191.16 of such [standards] that were subject of the remand ordered' by the First Circuit. The WIPP LWA directs EPA to expedite issuance of final disposal standards and specifies that such regulations shall not be applicable to the characterization, licensing, construction, operation, or closure of any site required to be characterized under §113(a) of Public Law 97-425, the Nuclear Waste Policy Act of 1982.

Today's action represents the Agency's response to this legislation and to the issues raised by the court pertaining to individual and ground-water protection requirements. After considering the relevant comments received on the February 10, 1993 proposed rulemaking, the Agency has taken this final action in the form of amendments to parts 191 of title 40 of the Code of Federal Regulations. In so doing, EPA has not revised any of the regulations reinstated by the WIPP LWA.

DATES: These amendments will become effective on January 19, 1994. These amendments will be promulgated for purposes of judicial review at 1 p.m. eastern standard time on December 20, 1993."

STATUTORY AND REGULATORY BACKGROUND;

" The WIPP Land Withdrawal and Nuclear Waste Policy Acts

As noted above, today's action responds to the directive in section 8 of the WIPP LWA that EPA conduct a rulemaking to issue certain radioactive waste disposal regulations at 40 CFR Part 191, subpart B. The EPA initially promulgated subpart B in 1985 (50 FR 38084 (Sept. 19, 1985)), but those regulations were subsequently vacated in whole as part of a remand order issued by the First Circuit in 1987 (discussed further above and below). See *NRDC v. EPA*, 824 F.2d 1258 (1st Cir. 1987).

Section 8(a)(1) of the WIPP LWA reinstates those portions of subpart B except §§191..15 and 191.16 (which were the bases of remand by the First Circuit). Accordingly, section 8(a)(2)(A) of the WIPP LWA exempts the requirements at 40 CFR 191.15 (individual protection) and 191.16 (ground-water protection) from the statutory reinstatement. Section 8(b)(2) addresses these non-reinstated provisions by directing the EPA promulgate final regulations. Today's action responds to that directive by revising the individual protection requirements in 40 CFR 191.15, discussed above, and by adding new ground-water protection standards as 40 CFR part 191, subpart C (discussed below)."
Federal register, Vol. 58 No. 242, p 66398, dated December 20,1993
"191.15 Individual protection requirements.

(a) Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts).

(b) Annual committed effective doses shall be calculated in accordance with appendix B of this part.

(c) Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved.

(d) Compliance with the provisions in this section does not negate the necessity to comply with any other applicable Federal regulations or requirements.

(e) The standards in this section shall be effective on January 19, 1994."

"Subpart C-Environmental Standards for Ground-Water Protection
. . .191.23 General provisions.

(a) Determination of compliance with this subpart shall be based upon underground sources of drinking water which have been identified on the date the implementing agency determines compliance with subpart C of this part.

191.24 Disposal standards.

(a) Disposal systems.

(1) General. Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that 10,000 years of undisturbed performance after disposal shall not cause the levels of radioactivity in any underground source of drinking water, in the accessible environment, to exceed the limits specified in 40 CFR part 141 as they exist on January 19, 1994.

(2) Disposal systems above or within a formation which within one-quarter (1/4) mile contains an underground source of drinking water. [Reserved]

(b) Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved. . . ."

§191.27. Effective date: p. 66415, col. 3;
"Appendix A to Part 191--Table for Subpart B

9.Appendix B is redesignated as Appendic C to part 191 and the heading is revised as follows:
Appendix C to Part 191--Guidance for Implementation of Subpart B."

50 FR 38088, p. 38088, col. 2;
" Appendix B--Guidance for Implementation of Subpart B

[Note: The supplemental information in this appendix is not an integral part of 40 CFR Part 191. Therefore, the implementing agencies are not bound to follow this guidance. However, it is included because it describes the Agency's assumptions regarding the implementation of Subpart B. This appendix will appear in the Code of Federal Regulations]"

. . .

" Scope of Performance Assessments.

Section 191.13 requires the implementing agencies to evaluate compliance through performance assessments as defined in § 191-12(q). The Agency assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. Furthermore, the performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changes by such omissions."

EPA (U.S. Environmental Protection Agency), 1996a. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule." Federal Register, Vol. 61, No. 28, pp. 5224-5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C. In NWM Library as KF70.A35.C751 1996 (Reference).

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992. EFFECTIVE DATE: These regulations are effective April 9, 1996."

p. 5238, col. 2;
" §194.14. Content of compliance certification application.

Any compliance application shall include:

(a) A current description of the natural and engineered features that may affect the performance of the disposal system. The description of the disposal system shall include, at a minimum, the following information:

(1) The location of the disposal system and the controlled area;

(2) A description of the geology, geophysics, hydrogeology, hydrology and geochemistry of the disposal system and its vicinity and how these conditions are expected to change and interact over the regulatory time frame. Such description shall include, at a minimum:

(i) Existing fluids and fluid hydraulic potential, including brine pockets, in and near the disposal system; and

(ii) Existing higher permeability anhydrite interbeds located at or near the horizon of the waste.

(3) The presence and characteristics of potential pathways for transport of waste from the disposal system to the accessible environment including, but not limited to: Existing boreholes, solution features, breccia pipes, and other potentially permeable features, such as interbeds.

(4) The projected geophysical, hydrogeologic, and geochemical conditions of the disposal system due to the presence of waste including, but not limited to, the effects of production of heat or gases from the waste."

p. 5240, col. 2;
" §194.24 Waste characterization.

(a) Any compliance application shall describe the chemical, radiological and physical composition of all existing waste proposed for disposal in the disposal system. To the extent practicable, any compliance application shall also describe the chemical, radiological and physical composition of to-be-generated waste proposed for disposal in the disposal system. These descriptions shall include a list of waste components and their approximate quantities in the waste. This list may be derived from process knowledge, current non-destructive examination/assay, or other information and methods."

p. 5243, Assurance Requirements, col. 3;
" §194.44 Engineered barriers.

(a) Disposal systems shall incorporate engineered barrier(s) designed to prevent or substantially delay movement of water or radionuclides toward the accessible environment."

EPA (U.S. Environmental Protection Agency), 1996b. Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Background Information Document for 40 CFR Part 194. EPA 402-R-96-002. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

1. Introduction; p. 1-1, para. 1;

" The Environmental Protection Agency's (EPA) regulation, 40 CFR part 194, sets forth criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste, found at 40 CFR part 191 subparts B and C. If the Administrator of EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use 40 CFR part 194 to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. The final preamble and regulation to 40 CFR part 194, as they appear in the Federal Register, take precedence over any descriptions or interpretations of the final rule that appear in this document.

This document provides much of the necessary background information and technical analyses which the Agency used during the development of 40 CFR part 194. The document explicates fourteen issues considered by EPA in establishing the individual criteria contained in 40 CFR part 194."

p. 8-41, para. 1;

" In 40 CFR part 194, EPA decided that the statistical portion of the determination of compliance with 40 CFR part 191 will be based on the sample mean. The LHS sample sizes should be demonstrated operationally (approximately 300 when 50 variable are considered) to improve (reduce the size of) the confidence interval for the estimated mean. The underlying principle is to show convergence of the mean."

9 Consideration of Human Intrusion

9.4 Intrusion by Mining

9.4.3.2 Other Relevent Studies; p. 9-36, para. 5;

" IT Corporation summarized subsidence observations made at potash mines in southeastern New Mexico (ITC94). Observed angles of draw, measured from vertical edge of the mine workings to the point where surface subsidence ceased, varied from 25 to 58 degrees."

Geologic Column; p. 9-46, para. 4;

" The geologic column used in the analysis was adapted from the ERDA 9 borehole

near the center of the WIPP site (POW78). Table 9-5 gives the depth, formation, and thickness of the different strata represented in the finite element model."

Table 9-5. Strata Depth and Thickness; p. 9-47, tbl. 9-5;"

Formation	Depth (ft)	Thickness (ft)
1. Dewey Lake	0	550
2. Rustler	550	58
3. Magenta	608	24
4. Rustler	632	82
5. Culebra	714	26
6. Rustler	740	120
7. Upper Salado	860	507
8. McNutt	1,367	176
9. Potash Seam	1,543	10
10. McNutt	1,553	188
11. Lower Salado	1,741	333
12. Storage Zone	2,074	104
13. Lower Salado	2,178	442
14. Storage Zone	2,620	110
15. Lower Salado	2,730	106
16. Castile	2,836	1,664[11]"

Freeze, G.A., Larson, K.W., and Davies, P.B. 1995. A Summary of Methods for Approximating Salt Creep and Disposal Room Closure in Numerical Models of Multiphase Flow. SAND94-0251. Sandia National Laboratories, Albuquerque, NM. WPO 29557.

ABSTRACT;

" Eight alternative methods for approximating salt creep and disposal room closure in a multiphase flow model of the Waste Isolation Pilot Plant (WIPP) were implemented and evaluated; three fixed-room geometries (initial, intermediate, fully consolidated); three porosity functions (moles-time-porosity surface, moles-time-porosity lines, pressure-time-porosity lines); and two fluid-phase-salt methods (boundary backstress, capillary backstress). The pressure-time-porosity line interpolation (pressure lines) method is used in current WIPP Performance Assessment calculations. The room closure approximation methods were calibrated against a series of room closure simulations performed by Stone (1995a) using a creep closure code, SANCHO.

The fixed-room geometries did not incorporate a direct coupling between room void volume and room pressure. The two porosity function methods that utilize moles of gas as an independent parameter for closure coupling were unable to account for the presence of brine in the room and, therefore, could not capture the dynamic relationship between room pressure, brine volume in the room, and room expansion. The capillary backstress method was unable to accurately simulate conditions of re-closure of the room followed room expansion. Only two methods were found to be accurate and robust enough to approximate the effects of room closure under most conditions, the boundary backstress method and pressure-time-porosity line interpolation.

The boundary backstress method is thought to be a more reliable indicator of system behavior due to a theoretical basis for modeling salt deformation as a viscous process. It is a complex method and a detailed calibration process is required. The pressure lines method is thought to be less reliable because the results were skewed towards SANCHO results in simulations where the sequence of gas generation was significantly different from the SANCHO gas-generation rate histories used for closure calibration. This limitation in the pressure lines method is most pronounced at higher gas-generation rates (> 0.8 moles per drum per year) and is relatively insignificant at lower gas-generation rates (≤ 0.4 moles per drum per year). Due to its relative simplicity, the pressure lines method is easier to implement in multiphase flow codes and simulations have a shorter execution time (10 to 20 times faster than boundary backstress). The pressure lines method is suggested for continued use in WIPP Performance Assessment calculations as long as simulated gas-generation rate histories are low or are not significantly different from the SANCHO-simulated rates."

Goodwin, B.W., Stephens, M.E., Davison, C.C., Johnson, L.H., and Zach, R. 1994. Scenario Analysis for the Postclosure Assessment of the Canadian Concept for Nuclear Fuel Waste Disposal. AECL-10969, COG-94-247. Whiteshell Laboratories, Pinawa, Manitoba, Canada.

ABSTRACT; p. 1, para. 1;

" AECL Research has developed and evaluated a concept for disposal of Canada's nuclear fuel waste involving deep underground disposal of the waste in intrusive igneous rock of the Canadian Shield. The postclosure assessment of this concept focusses on the effects on human health and the environment due to potential contaminant releases into the biosphere after the disposal vault is closed. Both radiotoxic and chemically toxic contaminants are considered.

One of the steps in the postclosure assessment process is scenario analysis. Scenario analysis identifies factors that could affect the performance of the disposal system and groups these factors into scenarios that require detailed quantitative evaluation.

This report documents a systematic procedure for scenario analysis that was developed for the postclosure assessment and then applied to the study of a hypothetical disposal system. The application leads to a comprehensive list of factors and a set of scenarios that require further quantitative study. The application also identifies a number of other factors and potential scenarios that would not contribute significantly to environmental and safety impacts for the hypothetical disposal system."

Hodgkinson, D.P. and Sumerling, T.J., 1989. "A Review of Approaches to Scenario Analysis for Repository Safety Assessment." In Proceedings of the IAEA/CEC/NEA (OECD) Symposium on Safety Assessment of Radioactive Waste Repositories (Paris, 1989). OECD/NEA, Paris, France. pp. 333-350.

ABSTRACT; p. 333, para. 1;
" This paper surveys approaches to scenario analysis for repository safety assessment which have been under scrutiny by the NEA Scenarios Working Group. Scenario analysis blends information on site and waste characteristics, established understanding of processes, and subjective views of appropriately experienced scientists and others. It is important to follow systematic procedures and to document each step carefully so that it is amenable to scrutiny. There is a wide agreement about the general approach that should be taken to the identification, classification and screening of phenomena that need to be considered. Three general approaches have been identified to the difficult problem of combining these phenomena into scenarios, and consideration has been given to their ranges of applicability."

p. 348, para. 1;
"APPENDIX
EXAMPLE COMPILATION OF EVENTS, FEATURES AND PROCESSES FOR A DEEP REPOSITORY IN HARD ROCK"

Holt, R.M., and Powers, D.W. 1984. Geotechnical Activities in the Waste Handling Shaft Waste Isolation Pilot Plant (WIPP) Project Southeastern New Mexico. WTSD-TME-038. U.S. Department of Energy, Carlsbad, NM.

ABSTRACT, p. v;

" The Waste handling shaft (waste shaft) at the Waste Isolation Pilot Plant (WIPP) site is an enlargement of the drilled, Site and Preliminary Design Validation (SPDV) ventilation shaft. Geotechnical activities in the waste shaft were designed to confirm the SPDV ventilation shaft mapping results and to provide additional information about identified zones of interest. The activities included identification of instrument locations, geologic inspections of the exposed shaft surface during sinking operations, reconnaissance geologic mapping of the waste shaft sump, and detailed geologic mapping in identified zones of interest. These activities were carried out concurrently with construction.

The results of the geologic inspections in the waste shaft and the reconnaissance geologic mapping in the waste shaft sump correlate well with previous characterizations. However, the detailed 360° geologic mapping performed in several zones of interest did not reveal post-depositional dissolution features, thought to occur at several stratigraphic horizons in the Rustler Formation at the WIPP site. At the waste shaft, zones previously identified as dissolution residues in nearby boreholes contained pronounced primary sedimentary features."

4.2.2.4 Culebra Dolomite Member, p. 4-6, para. 4;

" In the waste shaft, the Culebra occurs in the depth interval from 706.5 feet to 728.5 feet (Figure 9). The upper one-half to two feet of the Culebra is a medium brown, microlaminated to thinly laminated carbonate. This unit averages about 0.8 feet in thickness throughout the circumference of the shaft, but thickens up to two feet in the vicinity of mound-like dome structures. In general, the laminations within the carbonate unit are horizontal to subhorizontal. However, the laminae in the mound structures are often crenulated and dip slightly away from the center. It is likely that this unit is of algal origin. a 1/4 to 1-inch thick bed of cohesive, black claystone underlies the carbonate unit. The remainder of the Culebra primarily consists of brown, finely crystalline dolomite containing both empty and gypsum-filled vugs of varying size."

p. 4-9, para. 1;

" From a depth of about 781.0 feet to a depth of about 844.0 feet, the lower member consists of interbedded siltstone, sandstone, mudstone, and claystone with an abundance of primary sedimentary structures. These sedimentary structures include laminated sediments, cross-laminations, trough cross laminations, and channel lag (Plate 4) containing invertebrate fossil hash. The basal contact with the Salado is sharp, and the rock overlying the contact appears to be undisturbed by dissolution. The average depth to the Rustler/Salado contact in the shaft is about 844.0 feet."

Holt, R.M., and Powers, D.W. 1986. Geotechnical Activities in the Exhaust Shaft. DOE/WIPP-86-008. U.S. Department of Energy, Carlsbad, NM.

INTRODUCTION, p. 1-1;

" The Waste Isolation Pilot Plant (WIPP) project is a Department of Energy (DOE) research-and-development facility constructed to demonstrate the safe disposal of radioactive wastes derived from the defense activities of the United States. The WIPP project's mission consists of two parts. The first is to demonstrate the safe handling and disposal of transuranic (TRU) waste in bedded salt. The second is to create a research facility for in-situ examination of the technical issues related to the emplacement of defense-related radioactive waste in bedded salt.

The WIPP facility is located approximately 26 miles east of Carlsbad, New Mexico in an area known as Los Medanos (Figure 1). The underground portion of the facility is located at a depth of approximately 2,150 feet in the bedded salt deposits of the Salado Formation (Figure 2). An extensive program of site characterization and validation has been conducted for the past nine years (1976-1985). The results of these studies are summarized in the WIPP 'Geological Characterization Report' (Powers et al., 1978), the WIPP 'Safety Analysis Report' (DOE, 1980), the WIPP 'Preliminary Design Validation Report' (Bechtel, 1983), and the WIPP 'Results of Site Validation Experiments' (Black et al., 1983). Additional site investigations are being conducted as part of an ongoing program to further refine the understanding of the site-specific geology. The geotechnical activities conducted in the exhaust shaft are part of this program.

The exhaust shaft will provide a pathway for the release of exhaust air from the facility to the surface. The shaft is an enlargement of a six-foot diameter, upreamed shaft. The finished diameter is 14 feet in the lined portion of the shaft and 15 feet minimum in the unlined portion. Geotechnical activities consisting of reconnaissance geologic mapping, detailed geologic mapping in specific zones of interest, geologic confirmation of instrument locations, and field adjustment and modification of the key and aquifer seal design were performed concurrently with construction from July 16, 1984 to January 18, 1985. This report presents and discusses the findings from the geologic mapping efforts in the exhaust shaft. Also, the construction history of the exhaust shaft is summarized, and several engineering geology characteristics are discussed."

NOTE: The notes applicable to Figures 6, 7, & 8 (Figure 6 - Sh 2 of 11 through 11 of 11; Figure 7 - Sh 2 of 9 through 9 of 9; and Figure 8 - Sh 2 of 6 through 6 of 6) have not been included in this document to reduce document size.

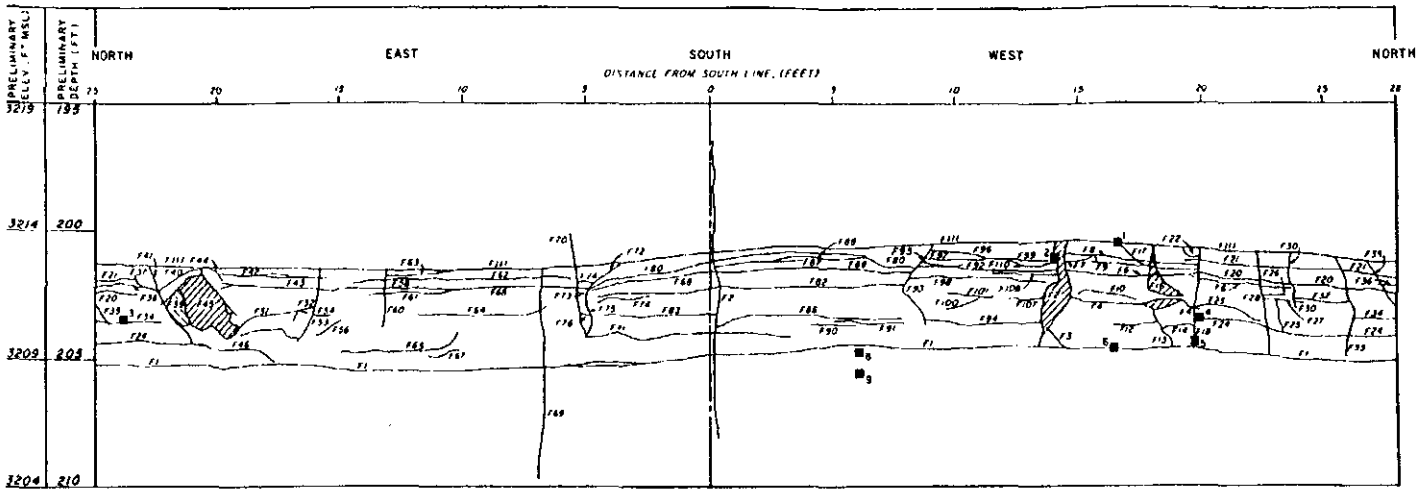

NOTES

1) THIS INTERVAL WAS MAPPED ON 10-3-84.
2) THE LITHOLOGY OF THIS INTERVAL IS DESCRIBED IN FIGURE 4.
3) DEPTHS AND EVALUATIONS ARE RELATED TO THE REFERENCE ELEVATION OF 3409 FEET ABOVE MSL.
4) ONLY FRACTURES THAT WERE DEEMED "MAPABLE" AT A SCALE OF ONE INCH EQUALS FIVE FEET ARE INCLUDED ON THE MAP.
5) MAPPING EFFORTS WERE CONCENTRATED IN THE DEPTH INTERVAL FROM 195.0 FEET TO 200.0 FEET.

EXPLANATION

F20 MAPPED FRACTURE #20, SEE FRACTURE NOTES FOR DESCRIPTION

24 SAMPLE LOCATION. EXHAUST SHAFT DETAILED MAPPING SAMPLE #24

MAPPED FRACTURE #29, FRACTURE SURFACE EXPOSED

FIGURE 6 - SHEET 1 OF 11

FRACTURE LOG IN
THE DENEY LAKE REDBEDS
DEPTH 190.0 THROUGH 205.0 FEET
EXHAUST SHAFT

WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

PREPARED FOR
WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

IT CORPORATION

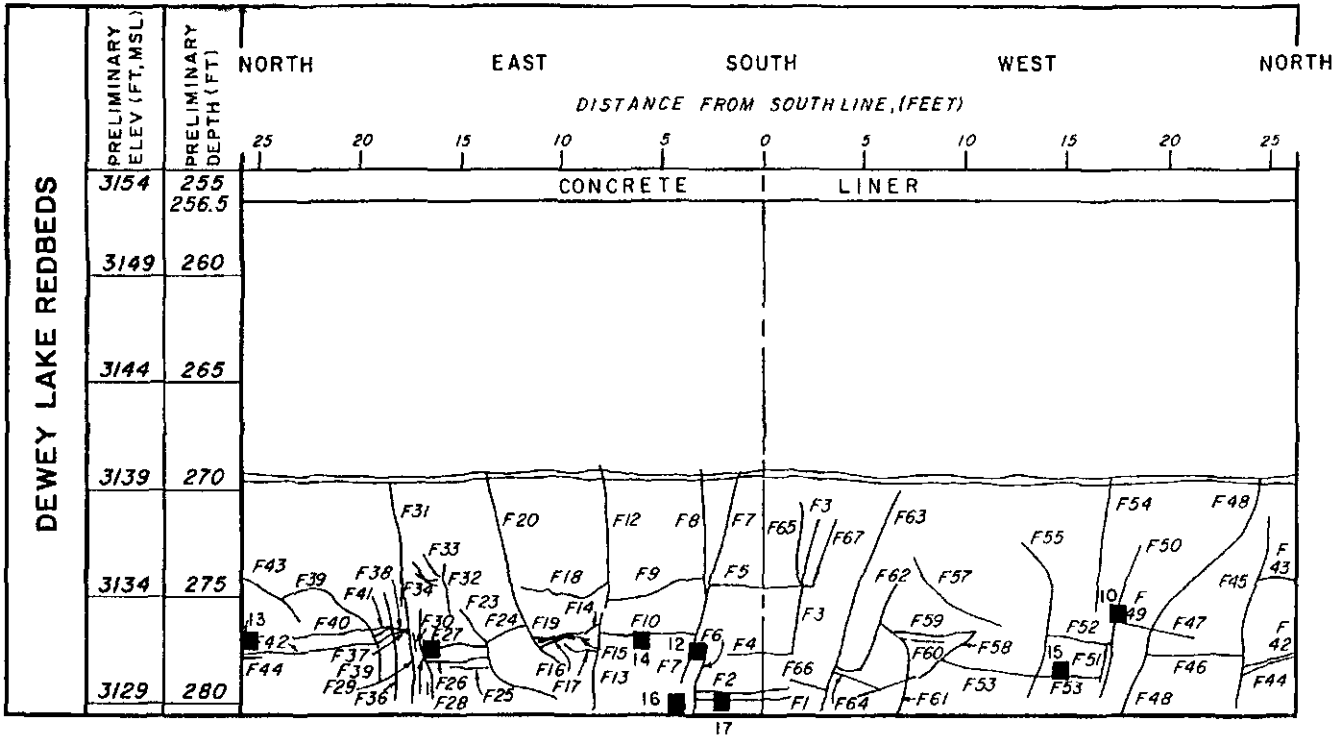

FIGURE 7 - SHEET 1 OF 9

FRACTURE LOG IN THE DEWEY LAKE REDBEDS
DEPTH 256.5 TO 280.5 FEET, EXHAUST SHAFT

WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

PREPARED FOR
WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

IT CORPORATION

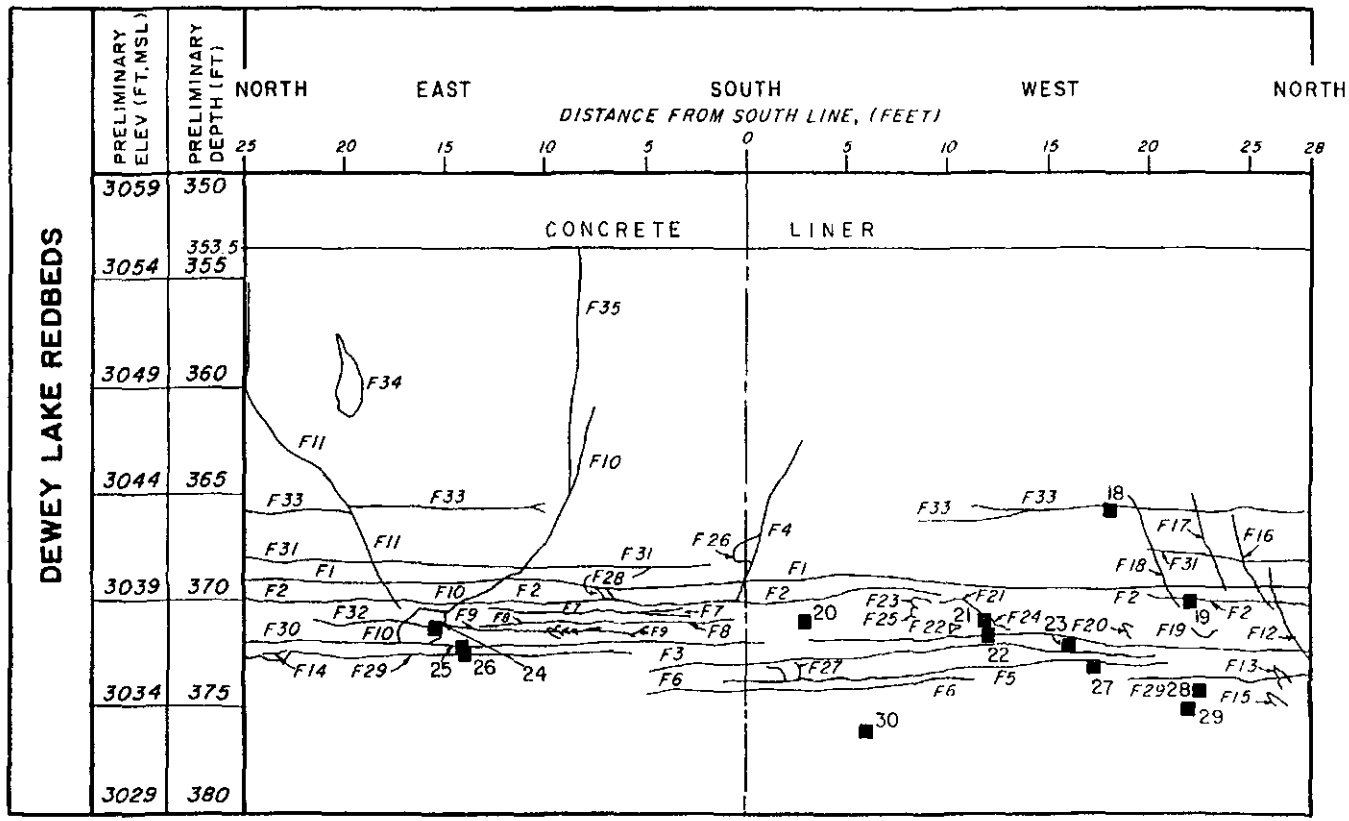

FIGURE 8 - SHEET 1 OF 6

FRACTURE LOG IN THE DEWEY LAKE REDBEDS
DEPTH 353.5 TO 380.0 FEET, EXHAUST SHAFT

WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

PREPARED FOR
WESTINGHOUSE ELECTRIC CORPORATION
CARLSBAD, NEW MEXICO

IT CORPORATION

Holt, R.M., and D.W. Powers, 1990. Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant. DOE/WIPP 90-051. Westinghouse Electric Corporation, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-1;

" The air intake shaft (AIS) at the Waste Isolation Pilot Plant (WIPP) site was constructed to provide a pathway for fresh air into the underground repository and maintain the desired pressure balances for proper underground ventilation. It was up-reamed to minimize construction-related damage to the rock wall. The upper portion of the shaft was lined with slip-formed concrete, while the lower part of the shaft, from approximately 903 ft below top of concrete at the surface, was unlined. As part of WIPP site characterization activities, the AIS was geologically mapped.

The AIS was geologically mapped during the period from March 11, 1988 to November 14, 1989. The objectives of the geologic mapping were to: 1)provide confirmation and documentation of strata overlying the WIPP facility horizon; 2)provide detailed information of the geologic conditions in strata critical to repository sealing and operations; 3) provide technical basis for field adjustments and modification of key and aquifer seal design, based upon the observed geology; 4) provide geological data for the selection of instrument borehole locations; 5) and characterize the geology at geomechanical instrument locations to assist in data interpretation. All mapping activities were performed from a two deck galloway (work platform) and synchronized with shaft construction activities. The AIS was mapped according to the procedures described in WP 07-503, 'Geologic Mapping of Shafts' (April 25, 1988) (Appendix B).

The entire shaft section including the Mescalero Caliche, Gatuña Formation, Santa Rosa Formation, Dewey Lake Redbeds, Rustler Formation, and Salado Formation to the WIPP facility horizon was geologically described. The shaft construction method, up-reaming, created a nearly ideal surface for geologic description. Small-scale textures usually best seen on slabbed core were easily distinguished on the shaft wall while larger-scale textures not revealed in core were well displayed. Previously undescribed textures were interpreted, and the AIS data were used to further refine depositional and post-depositional models of the units mapped.

The upper part of the Dewey Lake Redbeds displayed features consistent with Schiel's (1988) interpretation of the depositional environments. The geologic mapping data indicated deposition in a fine-grained, ephemeral fluvial system (Schiel, 1988). The lower part of the Dewey Lake, however, was depositionally a continuation of Rustler style sedimentation and accumulated in saline mud flat/mud flat environments. Most gypsum-filled fractures developed incrementally in response to unloading, while some Dewey Lake are syndepositional. Within the Dewey Lake, a cement change between carbonate and, possibly, anhydrite was observed at a depth of 164.5 feet. Perched water tables within the Dewey Lake may rest on this cement change. Above the cement change, the shaft surface was moist and displayed an efflorescent crust consisting of halite. The source of the halitic water is attributed to the muck-piles north and east of the AIS.

The features observed within the Rustler are consistent with those reported by Holt and Powers (1984, 1986, and 1988). Mudstones within the Rustler created a spalling hazard as several feet of mudstone had spalled out of the units and large slabs to desk-top size had to be scaled from the rib prior to mapping. Liner plate was installed over all Rustler mudstones. The surface of the lower part of the Rustler required extensive washing and scaling prior to mapping as Culebra and construction waters dissolved halite crystals and cements. Extensive vertical fluxing was observed.

The AIS data from the Salado allowed the authors to add considerably to the understanding of the depositional and diagenetic history of the Salado. Unprecendeted halite textural and fabric data was collected, characterized, and interpreted from the Salado. An idealized Salado halite sequence was constructed, and all Salado halite observed within the AIS fits partially or wholly into the idealized sequence. Complete Salado halite sequences consist of four lithofacies, in ascending order: 1) stratified mud-poor halite; 2) 'podular' muddy halite; 3) 'dilated' mud-rich halite; and 4) halitic mudstone. These lithofacies developed in four distinct depositional environments: 1) a mud-poor salt pan; 2) a 'hummocky' salt pan; 3) a mud-rich salt pan; and 4) a saline mud flat.

Salado sulfate interbeds (including Markerbeds) displayed abundant previously undescribed textures and fabrics. Textural data from the AIS provided the basis for further interpretation of these interbeds. Salado sulfate interbeds were deposited in shallow saline lagoon environments following eustatically- or meteorically-driven, basin-wide flooding and freshening events (Lowenstein, 1982, 1983, 1988). Different hydrologic conditions produced three distinct types of sulfate interbeds within the Salado. The sulfate interbeds bounding the repository horizon may be laterally variable due to facies changes within the depositional environment. Geologic evidence of naturally occurring late-stage fluid migration or alteration within the halite of the Salado was not found. Mineralized and fluid-filled fractures occur within some sulfate interbeds within the Salado."

p. 3-3, para. 1;

" At the AIS, the Gatuña is 13 feet thick and consists of very calcareous, very friable, soft sandstone (Figures 4 and 5). The Gatuña is light red and mottled with dark stains. Carbonate occurs as stringers and concretions in probable rhizolithic structures. Clay-sized materials locally appear translocated. Some pebble-sized clasts of sandstone are probably derived from the underlying Santa Rosa Formation. The Gatuña overlies a sharp erosional contact on the Santa Rosa Formation."

p. 3-4, para. 2;

" The Dewey Lake is characterized by its reddish-orange to reddish-brown color and varying sedimentary structure. At the WIPP site (as exposed in the AIS), the Dewey Lake is 476 feet thick and consists of interbedded reddish-brown fine sandstone, siltstone, mudstone and claystone (Figure 5). The Dewey Lake is distinguished from other redbed units by the presence of greenish-gray reduction spots, which are liberally sprinkled throughout the formation, and locally abundant fibrous gypsum-filled fractures. Its upper contact with the

Santa Rosa Formation is sharp and erosional (Figure 6). The lower contact of the Dewey Lake with the Rustler Formation is sharp, with a minor amount of erosional relief (Figure 7 and 8). This contact is locally disconformable, but there is evidence of a regional unconformity (Holt and Powers, 1988)."

3.4.3 Origin and Significance of Gypsum-Filled Fractures, p. 3-8;
" With the exception of the upper portion, the Dewey Lake is characterized by locally abundant gypsum-filled fractures. Most of the fractures are filled with fibrous gypsum, although granular gypsum fracture fillings do occur in the upper portion of the Dewey Lake. In the AIS, gypsum-filled fractures are abundant below 164.5 feet. The fracture filling gypsum is fibrous indicating incremental growth. The fracture pattern and filling morphology is governed by the grain-size of the fractured host material, as discussed below."

3.4.4 Origin of Perched Water Tables in the Dewey Lake, p. 3-10, para. 2;
" At the AIS, the Dewey Lake is cemented with carbonate above 164.5 feet. The coarse-grained units (sandstones and siltstones) are usually moderately hard, though a few are soft. The mudstones and claystones are soft and commonly fissile. Fractures are unfilled or filled with carbonate, and carbonate-filled fractures increase downward. The surface of the AIS wall in the Dewey Lake is moist down to 164.5 feet, and a halitic efflorescence is sometimes present on the shaft wall. ..."

p 3-11, para 2;
" At the WIPP site, meteoric water probably infiltrates through the surface materials (dune sand and construction fill material) to the Mescalero caliche, where it moves downgradient off of the site or evaporites. When the Mescalero caliche and the Pleistocene and Triassic rocks have been disturbed by construction activities, this water can infiltrate along these newly created pathways into the underlying Dewey Lake. The water will infiltrate to the cement change surface and either stop or move down gradient. The impact of this process should be assessed with respect to shaft plugs and seals."

p 3-26, para 3;
" The lower mud-poor section of the sequence is dominated texturally by an overall sense of horizontal to subhorizontal stratification and is named the 'stratified' mud-poor lithofacies (Figure 1, Appendix F). It is subdivided into three zones with small-scale textures. The first zone is dominated by bottom growth halite textures including halite chevron, cornet, and cumulates and clay or sulfate laminae. The second zone shows abundant passive pore-filling halite cements in small dissolution pits and pores. The uppermost zone contains exhibits mostly expansive halite cement textures (displacive halite) mixed with various syndepositional solution textures and fabrics. These textures are consistent with deposition in a mud-poor salt pan.

The 'podular' muddy halite lithofacies is characterized by lenses and pods of fine to medium crystalline halite (Figure 1, Appendix F). Generally, it is more argillaceous then the

'stratified' mud-poor lithofacies. The 'podular' muddy halite lithofacies is subdivided into two zones which laterally and vertically interfinger: 1) a zone dominated by expansive (displacive) halite cements and 2) a zone with few expansive cements. Few textures reflecting subaqueous deposition are preserved, and continuous strata are very rare. Dissolution pits, pipes, and pores are common. Textures within this lithofacies are similar to 'hummocky' salt pan halite in the Devil's Golf Course in Death Valley, California."

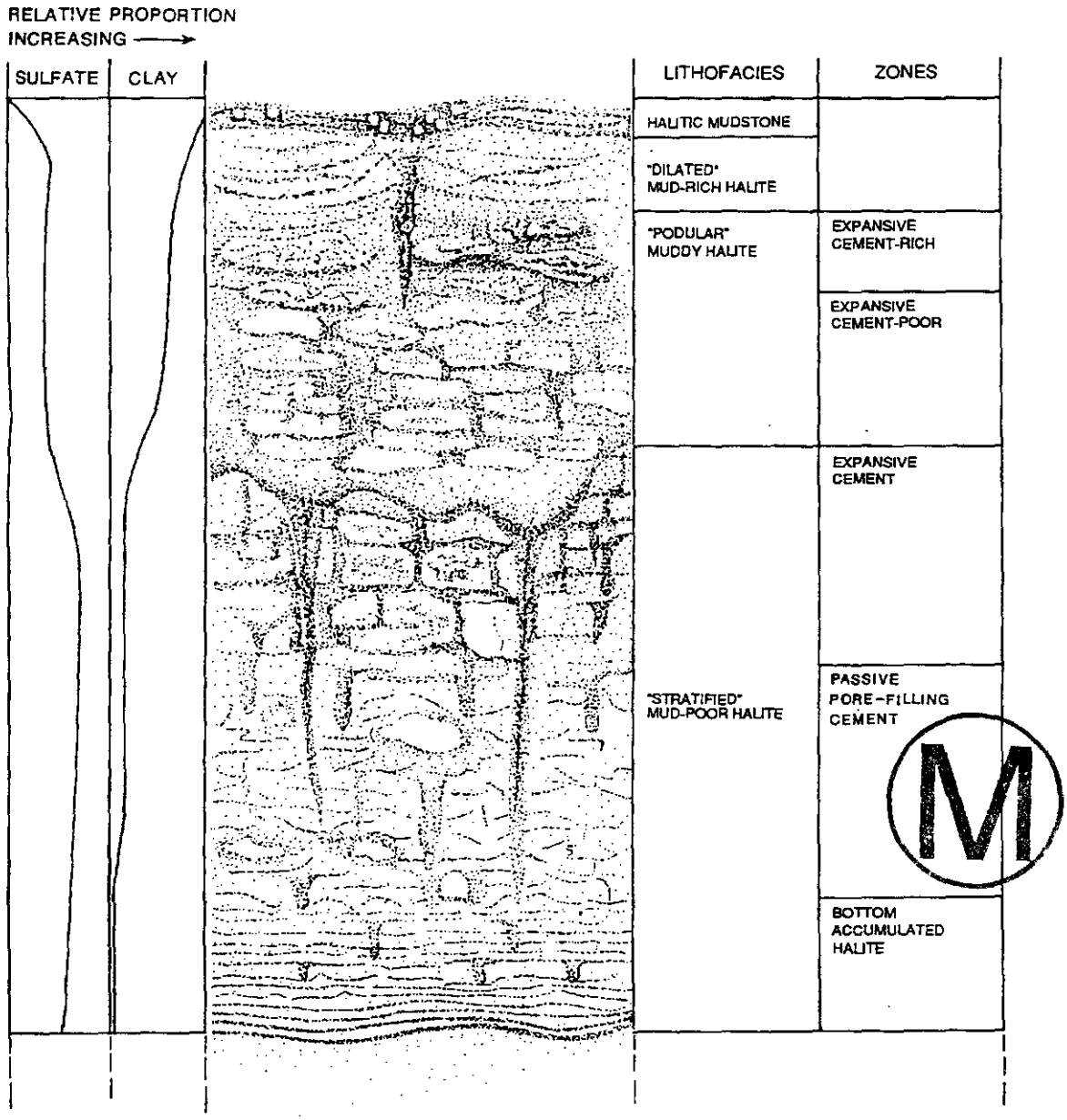

FIGURE 1 IDEALIZED SALADO HALITE SEQUENCE LITHOFACIES AND ZONES.

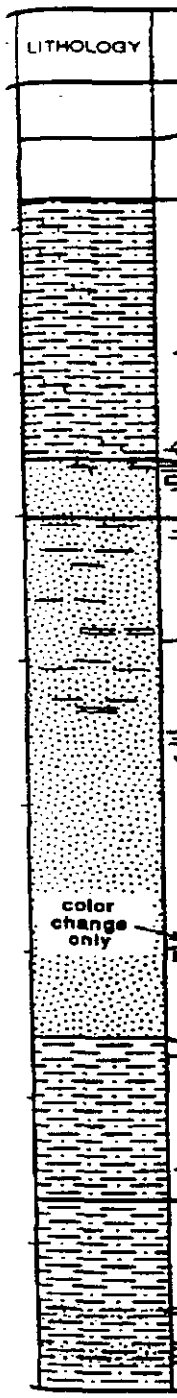

LITHOLOGY	FEATURES	REMARKS
		TOP OF SUBCOLLAR CONCRETE BASE OF SUBCOLLAR CONCRETE
		FILL MATERIAL, DARK REDDISH BROWN, MOTTLED: BECOMES LESS DISTURBED DOWNWARD.
		GATUNA FORMATION - UNDISTURBED. SANDSTONE, LIGHT RED, MOTTLED, VERY CALCAREOUS, SLIGHTLY ARGILLACEOUS. VERY FINE SAND TO SILT-SIZED GRAINS, SUBANGULAR TO ROUNDED. ESTIMATED 80 PERCENT QUARTZ, 5 PERCENT MAFIC GRAINS, 15 PERCENT OTHER, CARBONATE STRINGERS GENERALLY ORIENTED SUBHORIZONTALLY, CARBONATE CONCRETIONS ARE POSSIBLE ROOT CASTS. SOME CLAYS AND ARGILLACEOUS MATERIAL ARE POSSIBLY TRANS-LOCATED; POSSIBLE BIOTURBATION. UNIT LOCALLY CONTAINS CLASTS OF MORE CALCAREOUS, HARDER SANDSTONE (POSSIBLY REWORKED CALICHE CLASTS) AND GREENISH-GRAY CLASTS (POSSIBLY SANTA ROSA FM.). SURFACE OF UNIT IS LOCALLY MOIST AND EXHIBITS NaCl-RICH EFFLORESCENT CRUST; UNIT IS VERY FRIABLE, SOFT. BASAL CONTACT SHARP, EROSIONAL (2 FT RELIEF), OVERLAIN WITH COBBLE-SIZE RIPUPS OF UNDERLYING SANDSTONE AND GRANULE-SIZED RIPUPS OF DARK BROWN CLAYSTONE.
	E R R E	SANTA ROSA FORMATION. SANDSTONE, CALCAREOUS, RED: SILT TO FINE SAND-SIZED GRAINS, 80 PERCENT QUARTZ, 5 PERCENT MAFIC, 15 PERCENT OTHER, GRAINS SUBANGULAR TO ROUNDED. TABULAR CROSS-CUTTING BEDS UP TO 2 FT THICK: UPPER SURFACE BOUNDED BY HARD, VERY CALCAREOUS, VERY THIN BEDS AND CLASTS OF SANDSTONE; DARKER BEDS MAY BE CROSS-LAMINATED; LIGHTER INTERBEDS CONTAIN THIN LAMINAE TO LAMINAE OF CALCAREOUS SANDSTONE PARALLEL TO CROSS-CUTTING SURFACES: CALCITE-RICH UNITS CONTAIN RIPUP CLASTS OF DARK RED SILTSTONE, LOCAL COBBLE-SIZE RIPUP CLASTS OF WELL-CEMENTED SANDSTONE. VERY RARE SUBVERTICAL FRACTURES ARE FILLED WITH CALCITE, LOCAL STRINGERS POSSIBLY DEVELOPED ALONG FRACTURES: UNIT IS SOFT TO MEDIUM HARD. BASAL CONTACT SHARP, EROSIONAL RELIEF OF 2 FT.
	R R	SILTY SANDSTONE TO SILTSTONE, DARK REDDISH BROWN (10R3/6), WITH PALE OLIVE (10Y6/2) FROM 30 FT TO BASE; CALCAREOUS; FINE TO MEDIUM AT BASE TO FINE TO VERY FINE SAND GRAINS UPWARD; DOMINANTLY QUARTZ, 1-5 PERCENT MAFIC GRAINS; SOFT TO MODERATELY WELL INDURATED. THINLY LAMINATED TO CROSS-LAMINATED FROM 15-19 FT WITH LOCALLY ABUNDANT TROUGH CROSS-BEDS HAVING TANGENTIAL BOTTOMSETS, TROUGH .1-.3 FT DEEP AND 1 FT WIDE IN A CHANNEL BAR COMPLEX. PLANAR LAMINAE TO LOW ANGLE CROSS-LAMINAE (IN-CHANNEL BARS) FROM 19-22 FT IN SETS <.3 FT HIGH WITH LOCAL ARGILLACEOUS ZONES MARKING TOPS OF SETS. TROUGH CROSS-BEDS FROM 22-28 FT (CHANNEL DEPOSITS) IN SETS .4-.7 FT HIGH, DECREASING IN SIZE UPWARD TO .1-.3 FT SETS INTERBEDDED WITH THIN LAMINAE AND CROSS-LAMINAE. PARALLEL PLANAR, HORI-ZONTAL TO SUBHORIZONTAL, THIN BEDS TO LAMINAE FROM 28-30 FT, WITH SOME BROAD CROSS-CUTTING SETS (CHANNEL DEPOSITS); UNDULATORY, BUT SHARP, COLOR CHANGE AT ABOUT 30 FT CUTS ACROSS BEDDING; ZONE OF SMALL CLAYSTONE CLASTS (1/4" X 1") AT 30.5 FT; COARSENS DOWNWARD FROM FINE TO MEDIUM SANDSTONE FROM 30.5-33 FT, WITH MINOR SILT AND CLAY. SHARP, EROSIONAL BASE WITH ABOUT 6" RELIEF OVERLAIN BY A FEW REDDISH BROWN CLASTS.
	R R	SILTSTONE, ARGILLACEOUS, SLIGHTLY SANDY, FINING UPWARD TO SILTY CLAYSTONE: PALE OLIVE (10Y6/2) IN BASAL 1.5 FT, INTERBEDDED WITH AND OVERLAIN BY DARK REDDISH BROWN (10R3/6) TO VERY DARK REDDISH BROWN (10R3/3) AT TOP, SMALL, GREENISH REDUCTION SPOTS NEAR GRADATION TO CLAYSTONE: VERY CALCAREOUS. BEDDING UNCLEAR NEAR BASE, INTERBEDDED REDDISH BROWN LAYERS IN GREEN ZONE CONSIST OF CLAYSTONE AND CLAYSTONE CLASTS, SMALL (<.1 FT) RIPPLES NEAR TOP OF GREEN ZONE. ABOVE GREEN ZONE, MAINLY HORIZONTAL TO SUBHORIZONTAL LAMINAE WITH LOW ANGLE CROSS-CUTTING BEDS; SUBUNITS ARE UP TO 1 FT THICK, FINE UPWARD INTERNALLY. CLAYSTONE IS WET AND PROBABLY COLLECTING WATER IN OVERLYING SANDSTONE; VARIABLE SALT EFFLORESCENCE ON SHAFT WALLS; MODERATELY WELL INDURATED IN GREEN ZONE, WELL INDURATED TO SOMEWHAT FISSILE NEAR TOP. SHARP BASAL CONTACT.
		DEWEY LAKE FORMATION. CLAYSTONE, SILTY AND SANDY, VERY DARK REDDISH BROWN (10R3/3), WITH GRAYISH GREEN (10GY5/2), SLIGHTLY MORE SANDY BEDS NEAR BASE AND GREEN REDUCTION SPOTS NEAR TOP. SLIGHTLY COARSER ZONES AND INTERBEDS ARE VERY CALCAREOUS, WELL INDURATED, AND USUALLY .1-.3 FT THICK AT .3 TO 1 FT INTERVALS. BASAL PART SHOWS FINING UPWARD CYCLES ABOUT .5-1 FT THICK AND INTERBEDDED SILTSTONE AND CLAYSTONE. VERTICAL TO SUBVERTICAL FRACTURES IN UPPER 1-2 FT ARE

AIR INTAKE SHAFT LITHOLOGIC LOG
SHEET 3 OF 22

FIGURE 5

NOTE: Figure 16 is a photograph and will not scan in properly, therefore it is not included here.

IAEA (International Atomic Energy Agency). 1981. Safety Assessment for the Underground Disposal of Radioactive Wastes. IAEA Safety Series No. 56, Vienna, Austria.

1. INTRODUCTION; p. 1, para. 1;

" Nuclear energy is playing a continuing and increasing role in electricity generation in many countries. Therefore, these countries are faced with adopting appropriate systems for the management and disposal of the radioactive wastes. These wastes vary greatly in physical/chemical form and isotopic content. While various concepts have been proposed and are being studied, it is generally agreed that disposal underground, with the wastes appropriately immobilized, is an adequate way of providing the necessary protection for humans and the environment.

Underground disposal means the emplacement of radioactive waste materials in the terrestrial subsurface without the intention of retrieval. Accordingly, underground disposal concepts can range from shallow ground burial to emplacement in very deep bore-holes. Most effort is currently focused upon mined repositories in deep (e.g. up to 1000 meters). Continental geologic formations, and this emphasis is reflected in the present document.

Safety assessments are necessary to estimate the expected performance of a system considered for underground disposal of radioactive wastes and to compare it with acceptability criteria, both for the operational and post-operational phases; they are useful also to identify the potential significance of possible improvements of the system. They are important in every phase in system development; system selection; site confirmation; repository design, construction, operation, shutdown and sealing; and licensing processes relevant to these phases. Thus, safety assessments are a tool to predict the probable consequences of creating a waste repository, to compare the consequences with acceptability criteria (as defined in the Glossary), and to present the results for judgement by the appropriate bodies.

Safety assessments proceed from generic to site-specific studies. Generic assessments can be useful for making programmatic decisions regarding the choice of a disposal concept and the appropriate use of available resources. Generic assessments may also be helpful in gaining recognition of the feasibility of a disposal concept. Site-specific assessments are necessary for decisions affecting siting, design, and licensing for construction, operation, shutdown and sealing of a repository.

Safety assessments are performed by:

(a) working backward from acceptability criteria to working forward from the characteristics of systems to determine and compare their expected performance with acceptability criteria.

(b) working forward from the characteristics of systems to determine and compare their expected performance with acceptability criteria.

These two approaches are complementary and used in an iterative process. During this process the effects of potential improvements of the overall system of natural barriers

and man-made provisions can also be evaluated relative to an 'as low as reasonably achievable' solution for the future consequences of the underground waste disposal, taking present-day economic and social factors into account.

Performance of such safety assessments requires an interdisciplinary team of specialists to cover the many technical aspects, working throughout all phases of repository planning, designing and licensing activities.

The purposes of this document are to introduce:

(a) overall safety assessment approaches that can be useful during all phases of disposal system development, including both generic and site-specific studies;

(b) general methods that can be applied within that overall approach.

Subsequent documents to be published by the IAEA will describe specific safety assessments and present further details on the methodologies used and the status of this rapidly developing technology."

Iman, R.L. 1982. "Statistical Methods for Including Uncertainties Associated with the Geologic Isolation of Radioactive Waste Which Allow for a Comparison with Licensing Criteria," *Proceedings of the Symposium on Uncertainties Associated with the Regulation of the Geologic Disposal of High Level Radioactive Waste*, Gatlinsburg, Tennessee, March 9-13, 1981, ed. D.C. Kocher. NUREG/CP-0022, CONF810372, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 145-157. Available from NTIS. Order#: DE82008883.

ABSTRACT, p. 145;

" A project funded at Sandia National Laboratories by the Nuclear Regulatory Commission has as its charter to develop a methodology for evaluating applications for nuclear waste repositories. Since the Sandia methodology has the capability of expressing the output variable (for example integrated discharge rates) as a distribution, this report illustrates how to put uncertainty bounds on the output distribution. Additionally this approach permits a comparison against licensing criteria. The licensing criteria used in this paper while hypothetical in nature did involve guidance from experts."

Iman, R.L., and Conover, W.J. 1982. A Distribution-Free Approach to Inducing Rank Correlation Among Input Variables. Communications in Statistics: Simulation and Computation, Vol. B11, No. 3, pp. 311-334.

ABSTRACT, p 311;
" A method for inducing a desired rank correlation matrix on a multivariate input random variable for use in a simulation study is introduced in this paper. This method is simple to use, is distribution free, preserves the exact form of the marginal distributions on the input variables, and may be used with any type of sampling scheme for which correlation of input variables is a meaningful concept. A Monte Carlo study provides an estimate of the bias and variability associated with the method. Input variables used in a model for study of geologic disposal of radioactive waste provide an example of the usefulness of this procedure. A textbook example shows how the output may be affected by the method presented in this paper."

Kaplan, S., and Garrick, B.J. 1981. On the Quantitative Definition of Risk. Risk Analysis, Vol. 1, No. 1, pp. 11-27.

INTRODUCTION, p 11, col 1;

" As readers of this journal are well aware, we are not able in life to avoid risk but only to choose between risks. Rational decision-making requires, therefore, a clear and quantitative way of expressing risk so that it can be properly weighed, along with all other costs and benefits, in the decision process.

The purpose of this paper is to provide some suggestions and contributions toward a uniform conceptual/linguistic framework for quantifying and making precise the notation of risk. The concepts and definitions we shall present in this connection have shown themselves to be sturdy and serviceable in practical application to a wide variety of risk situations. They have demonstrated in the courtroom and elsewhere the ability to improve communication and greatly diminish the confusion and controversy that often swirls around public decision making involving risk. We hope therefore with this paper to widen the understanding and adoption of this framework, and to that end adopt a leisurely and tutorial place.

We begin in the next section with a short discussion of several qualitative aspects of the notion of risk. We then proceed to a first-pass or first-level quantitative definition. Since the notion of 'probability' is fundamentally intertwined with the definition of risk, the next section addresses the precise meaning adopted in this paper for the term 'probability.' In particular, at this point, we carefully draw a distinction between 'probability' and 'frequency.' Then, using this distinction, we return to the idea of risk, and give a 'second-level' definition (of risk which generalizes the first-level definition) and is large enough and flexible enough to include at least all the aspects and subtleties of risk that have been encountered in the authors' experience."

3. QUANTITATIVE DEFINITION OF RISK (FIRST LEVEL), p 12, col 2,

3.1 "Set of Triples Idea";

" In analyzing risk we are attempting to envision how the future will turn out if we undertake a certain course of action (or inaction). Fundamentally, therefore, a risk analysis consists of an answer to the following three questions:

(i) What can happen? (i.e., What can go wrong?)

(ii) How likely is it that that will happen?

(iii) If it does happen, what are the consequences?

Table I. Scenario List

Scenario	Likelihood	Consequence
S_1	p_1	x_1
S_2	p_2	x_2
.	.	.
.	.	.
.	.	.
S_N	p_N	x_N

To answer these questions we would make a list of outcomes or 'scenarios' as suggested in Table I. The *i*th line in Table I can be thought of as a triplet:

$$(s_i, p_i, x_i)$$

where s_i is a scenario identification or description;
p_i is the probability of that scenario; and
x_i is the consequence or evaluation measure of that scenario, i.e., the measure of damage.

If this table contains all the scenarios we can think of, we can then say that it (the table) is the answer to the question and therefore is the risk. More formally, using braces { }, to denote 'set off' we can say that the risk, *R*, 'is' the set of triplets:

$$R = \{(s_i, p_i, x_i)\}, \quad i=1,2,\ldots,N.$$

This definition of risk as a set of triplets is our first-level definition. We shall refine and enlarge it later.[3] For now let us show how to give a pictorial representation of risk.

[3]Having defined risk as a set of triplets, we may now, in line with section 2.2, define hazard as a set of doublets thus $H=\{(s_i,x_i)\}$."

5.2. Inclusion of Uncertainty, p 20, col 1;

" Now since we have not yet actually done the thought experiment of the previous section, we have uncertainty about what its outcome would be. The degree of uncertainty depends upon our total state of knowledge as of right now; upon all the evidence, data, and experience with similar courses of action in the past. We seek therefore to express this uncertainty using, naturally, the language of probability.

Since the thing we are uncertain about is a curve, $\Phi(x)$, we express the uncertainty by embedding this curve in a space of curves and erecting a probability distribution over this space.

Pictorially, this is represented by a diagram of the form of Fig. 7. This figure is what we call a risk curve in probability of frequency format. It consists of a family of curves $\Phi_p(x)$, with the parameter being the cumulative probability. To use this diagram we

would, for example, enter with a specific x value and choose say the curve $P=0.90$. The ordinate of this curve $\Phi_{0.90}(x)$ is then the 90th percentile frequency of x. That is to say, we are 90% confident that the frequency with which damage level x or greater occurs, is not larger than $\Phi_{0.90}(x)$.

Figure 7 is the pictorial form of our level 2 definition of risk. It is of interest to express this definition also in terms of the set of triplets idea.

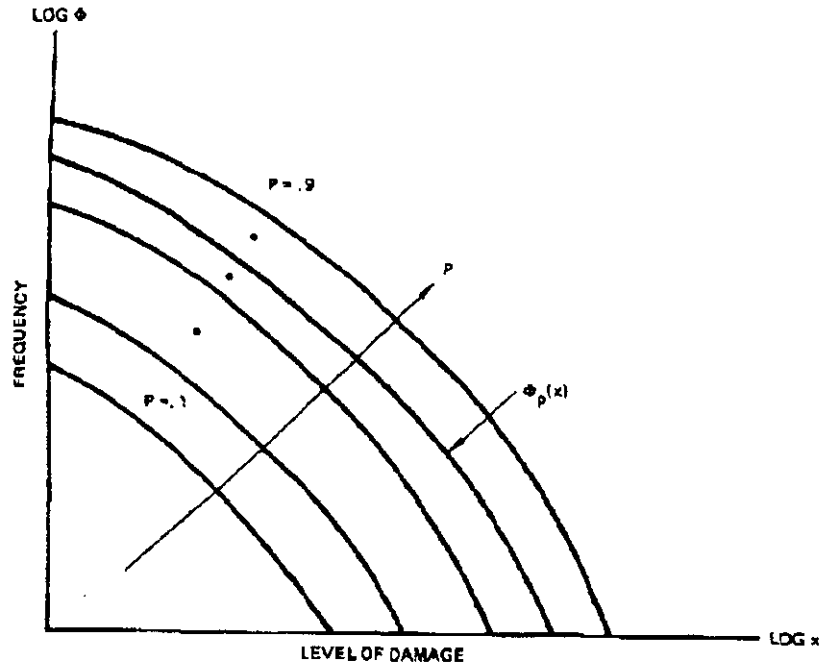

Fig. 7. Risk curve in probability of frequency format.

Lappin, A.R., Hunter, R.L., Garber, D.P., Davies, P.B., Beauheim, R.L., Borns, D.J., Brush, L.H., Butcher, B.M., Cauffman, T., Chu, M.S.Y., Gomez, L.S., Guzowski, R.V., Iuzzolino, H.J., Kelley, V., Lambert, S.J., Marietta, M.G., Mercer, J.W., Nowak, E.J., Pickens, J., Rechard, R.P., Reeves, M., Robinson, K.L., and Siegel, M.D., eds., 1989. Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico: March 1989. SAND89-0462. Sandia National Laboratories, Albuquerque, NM. WPO 24125.

EXECUTIVE SUMMARY, p iii;

" This report summarizes the current understanding of the expected long-term behavior of the Waste Isolation Pilot Plant (WIPP) repository and estimates long-term radionuclide doses in a series of six analyses investigating both undisturbed repository performance (Case I) and performance in response to a relatively high-consequence human Intrusion (Case II). It is the result of an intensive effort over a short time. The U. S. Department of Energy (DOE) decided to have Sandia National Laboratories prepare this report as a result of a meeting held January 5, 1989. The conceptual model of the expected long-term behavior of the WIPP repository used in this report was formulated in early to mid January 1989, drawing on information and understanding developed over the past decade. Numerical modeling of ground-water flow, radionuclide transport, and doses to humans began January 20, 1989 and was completed March 20, 1989.

The report has several objectives:

1. To briefly summarize Sandia's current technical understanding of the major components of long-term performance of the WIPP repository. The following areas are specifically addressed:

. . . .

f. radionuclide-transport mechanisms and properties of the Culebra Dolomite, the major pathway for ground-water transport of radionuclides from the WIPP to the biosphere.

. . . .

4. To describe, document, and interpret six sets of calculations estimating the potential health effects to individuals resulting from emplacement of CH-TRU wastes in the WIPP, hydrologic saturation of the repository as a result of either natural processes or human intrusion, direct and indirect exposure during and after drilling (where appropriate), and ground-water transport of radionuclides to a hypothetical stock well south of the WIPP site.

The calculations presented here investigate radionuclide transport and resulting health effects both during undisturbed performance of the WIPP repository and in response to a relatively high-consequence human intrusion into the repository. The human intrusion considered is drilling that results in a long-term interconnection of the repository, an underlying brine reservoir in the Castile Fm., and the overlying Culebra Dolomite. The Culebra Dolomite provides a relatively permeable pathway for ground-water transport of radionuclides to the hypothetical stock well."

E.1.5.1 Use of a Stream Tube to Calculate Transport, p. E-15;

" To calculate transport, the numerical model assumes that the steady-state flow field and brine-density distribution of LaVenue et al. (1988) is disturbed significantly by the release. To justify this approach, particle travel times in the Culebra Dolomite from the release point to the stock-well location have been calculated for three flow fields, corresponding to steady-state, Case IIA, and Case IIB/IIC/IID conditions. By definition, particle travel times are calculated using the Darcy velocities and a selected porosity. The process of dispersion, matrix diffusion, and sorption are not included. The calculated particle travel times assumed fracture-dominated transport to assess the maximum transport impact of the transient brine-reservoir perturbations to the undisturbed Culebra flow field. The particle travel time for the undisturbed, steady-state flow simulation differs by about 2% from the Case IIA particle travel time and about 7% from the CASE IIB, IIC, and IID travel times. Thus, a release from the breach borehole to the Culebra Dolomite will form a plume, the centerline of which will coincide with the transport pathway illustrated in Figure E-2. The numerical model calculates transport along this centerline using a stream tube. Constructed as described in Appendix B of Reeves et al. (1987), the stream tube yields the same spatial variations in velocity along the transport pathway as the flow model of LaVenue et al. (1988).

Figure E-3 represents an idealized contaminant plume formed as the result of point-source injection at constant rate Q into a unidirectional flow field, which has Darcy velocity u_o and aquifer thickness b. The stream-tube concept, based on undisturbed flow, can be considered with the disturbed flow field (Figure E-3). The latter describes a release of brine-reservoir fluids to the Culebra Dolomite, focusing on the streamlines near the borehole. These streamlines diverge from the point of release an, at a distance, become parallel to the direction of natural ground-water flow.

The streamlines of the injected fluids form a plume of contaminated water of width 2w from flow divide to flow divide, as illustrated in Figure E-3 and defined by the relation

$$2w = Q/bu_o \tag{E-27}$$

Asymptotically, the flux within the plume equals that of the natural ground-water u_o. The distance s that separates the points of release and stagnation is defined by the relation

$$s = Q/2\pi bu_o \tag{E-28}$$

This distance also provides a measure of the spatial extent of the region in which fluid velocities differ significantly from u_o. The maximum rate of fluid release Q_{max} calculated for the borehole and the natural ground-water velocity u_o calculated by LaVenue et al. (1988) at the point of release (i.e., the borehole) yield stagnation-point distances (Table E-3) for Cases IIA, IIB, IIC, and IID. A comparison of the 7.8 to 69.6-m range of stagnation-point distance at 75 years with the 4840-m distance from the point of release to the stock well indicates that the region of disturbed velocities is small relative to the overall scale for solute

transport, thus supporting the assumption of a negligibly disturbed steady-state flow field."

Luker, R.S., Thompson, T.W., and Butcher, B.M. 1991. "Compaction and Permeability of Simulated Waste." In Rock Mechanics as a Multidisciplinary Science: Proceedings of the 32nd U.S. Symposium, University of Oklahoma, Norman, OK, July 10-12, 1991. J.C. Roegiers, ed.. SAND90-2368C, pp. 694-702. A. A. Balkema, Brookfield, VT. WPO 38847.

ABSTRACT;

" This paper focuses on the mechanical and hydraulic properties of simulated contact handled transuranic radioactive waste that are associated with the Waste Isolation Pilot Plant (WIPP). In particular, the mechanical behavior of the simulated (nonradioactive) waste and its permeability after substantial time dependent compaction are being measured to give input data for modeling contaminated brine flow in a geologic repository stratum.

A number of deformation and permeability tests have been performed on materials comprising this waste. A variety of material mixtures were used, including cloth, wood, metals (various geometries), plastics, and minerals (various grain size distributions). Prior to the permeability tests, specimens were loaded under a constant stress (2000 psi) from 1 to 50 days and allowed to achieve a stable density state. Specimens, four inches in diameter with various lengths, were loaded axially via a piston and confined radially by the pressure vessel cylinder wall. Axial deformation was measured for production of stress-density and density-time curves. Subsequent to the deformation stage, which was terminated after evidence of density stabilization, brine was passed through the specimen for permeability measurements.

Deformation and permeability measurements of the simulated waste material are presented. Permeability values ranged through several orders of magnitude."

1. 0 INTRODUCTION

.1 Project Overview

The Waste Isolation Pilot Project (WIPP) facility, near Carlsbad, New Mexico, is currently being evaluated for the purpose of storing contact handled and remotely handled transuranic radioactive waste.

Characterization of the mechanical and hydrological properties of the waste is important for predicting the repository behavior with time. More specifically, the potential for migration of groundwater through the storage areas and the dispersal of radioactive materials must be established. The radioactive waste to be stored in the WIPP facility consists of a variety of materials, including metals, combustibles (plastics and fibers) and "sludge". A large portion of these materials will be contained In 55 gallon drums and stored in rooms that will be backfilled. Because most of the materials initially have high porosities, they will be highly permeable. However over time the drums may be expected to collapse due to volume decreases in the rooms because of creep closure. Under these conditions the waste will compact leading to a reduction in porosity and permeability (Butcher 1989).

This paper summarizes the results of a series of experiments performed to investigate the time dependent compaction and permeability of simulated waste materials. The experiments were limited to ambient laboratory conditions. Permeability measurements were only performed on compacted specimens. Procedures, equipment, and data from these studies are presented and the results are discussed.

2 0 PROGRAM PLANNING

Butcher (1989) identified five major waste components: plastics, fibers (cellulosics: paper, cloth, wood, etc.) sorbents, metals, and sludge. The results from earlier 55-gallon drum testing (Butcher et al., in preparation) together with information on the anticipated waste inventories, were used to select mixtures of some of the waste components for the tests discussed here. Certain additional materials were also tested. These included granular limonite and magnetite, which were chosen to represent metal materials after decomposition, a mixture of granular
magnetite and steel, representing an intermediate corrosion state, and a mixture of shredded metal and crushed salt, which is being considered as an engineered alternative to untreated wastes. These mixtures are described by their respective weight percentages in Table 2 1.

Table 2 1 Specimen Summary

MATERIAL NUMBER	MATERIAL DESCRIPTION
1	39% Intact and sectioned bottles, 42% PVC Conduit, 19% Surgeons Gloves
2	40% Rags, 60% Pine wood cubes (1" dimension)
3	60% 1" dimension steel, 40% crushed salt
4	45% Material 1, 37% Material 2, 9% 1" dimension metals, 9% Dry Portland Cement
5	Magnetite granules (coarse, well graded)
6	Limonite granules (coarse, well graded)
7	50% Magnetite particles, 50% 1" dimension steel
8	80% crushed salt, 20% shredded metals

3.O EXPERIMENTATION

Two uniaxial strain compaction and brine permeability tests were run on each of the materials in an oedometer to a maximum axial stress os approximately 2000 psi, the estimated lithostatic pressure at the repository horizon.

Because the mechanical and hydrological properties of the simulated contact handled transuranic waste were thought to be variable through a broad range, a laboratory measurement system had to be assembled that accommodated acceptable precision and accuracy at extreme levels of strain and permeability. System reliability was another concern due to the lengthy nature of most tests (weeks to months), specimen transience (i.e., destructive testing), corrosive properties of the saturating brine, and rigid quality assurance requirements.

To alleviate some of these concerns, a redundancy in data collection was assured by incorporating several transducers into the measurement system. For example, three pressure transducers and two flowmeters were put in the permeability flow circuit; thermocouples were placed in the fluid reservoir enclosure and on the pressure vessels. In this manner, back-ups were available in case the primary transducer failed, and additionally, a larger range of measurement was realized by using two or more transducers with different ranges, without sacrificing significant precision or accuracy.

3.1 Specimen Preparation

All specimens were assembled according to weight percent specifications, photographed, and mixed together in the pressure vessel. A 'random' yet well mixed blend was attempted for most of the specimens (e.g., particulate matter and small components), while other specimens were packed in specific configurations due to the specimen component size and composition (e.g., metal blocks and particulate matter). After specimen insertion brine was introduced into the pressure vessel chamber to saturate the specimen. The brine consisted of a prototypical chemistry, designed to simulate in situ water chemistry after several thousand years of waste emplacement.

3.2 Compaction System

Apparatus for these tests consisted of an oedometer (pressure vessel) used as the sample holder, a load control system for maintaining constant axial stress, a flow control system for permeability testing, and instrumentation to monitor loads, deformations, and brine flow.

Samples were contained in a 4" ID, 6" OD steel pressure vessel fitted with an integral axial piston to provide axial stress (Figure 3.1). The axial piston assembly attached to the bottom of the sample holder, and extended to the hydraulic pressure system through a standard dog-bone strain gaged load cell. Both the top end-piece and the bottom piston were pierced to allow flow of brine through the sample; mesh screens were used at either end of the sample to allow brine flow without extrusion of any sample material.

Hydraulic pressure to the axial position system was provided by a gas control system consisting of an a gas/hydraulic bladder accumulator backed by a nitrogen bottle. Both the accumulator and the nitrogen bottle were in an insulated enclosure, with temperature

controlled at 24 to 26 °C. Load on the sample was monitored using a strain-gaged load cell, with backup provided by a pressure transducer in the hydraulic pressure line.

Axial deformation was monitored with a 4" stroke LVDT attached to the lower loading piston. Temperature of the vessel during the tests was monitored using a thermocouple.

Load was applied to the axial piston by pressurizing the bladder accumulator to the required gas pressure, then slowly opening the valve to the piston assembly until the required hydraulic pressure and axial load were achieved. Axial load, line pressure, temperature, and sample deformation were monitored during specimen loading. On achieving full load the gas and hydraulic fluid pressure were maintained for the duration of the test while monitoring compaction. In the longer term tests load was held constant until a density/time slope of approximately 10^{-5} gm/cm^3/hr was obtained, or until the specified test duration was reached. Final density/time slopes ranged from 1.2x 10^{-8} to 3.9x10^{-4} kg/m3/hr. The duration of the tests varied from 1 to 59 days.

3.3 Permeability System

Brine permeability was determined at the end of the constant stress compaction portion of the tests. Brine flow was initiated by pressurizing an accumulator using a nitrogen bottle and controlled via a metering valve. Flow rate and pressure drop were monitored, and upstream pressure adjusted until a constant flow was established within the range of the flow meter and pressure transducer. In several tests different flow rates were used. Good agreement was obtained between the two flow measuring devices. Pressure difference between the upstream and downstream sides was monitored using one of three available upstream pressure transducers, with ranges of 25, 100 and 1000 psi.

3.4 Data Acquisition System

All instrumentation outputs were monitored using an IBM compatible 8086 computer with an internal clock, and a 16-bit analog-to-digital converter. Data were stored on hard disc, and backed up periodically onto a floppy disc.

Prior to testing, all instrumentation, including the load cells, LVDTs, pressure transducers, and flowmeters, were calibrated. Additional system calibrations were performed on the permeability measurements system, including a flow rate-pressure calibration for the flow lines.

Data were acquired at different frequencies during the tests. During the initial portion of the compaction test when specimen loading was relatively rapid, the automated DAS acquired data every 20 seconds the decremented the rate to a minimum of one scan every hour during the latter stages of compaction, a total of four scanning rates were used through each test.

3.5 Equipment Limitations

The equipment had limitations imposed by the resolution of the instruments, which determined the lower bound of measurable permeability, and by the friction in the lines which imposed an effective upper bound on the permeabilities. The flowmeter has a resolution of 0.0036 cc/s, based on the resolution of the voltmeter and the calibration constant for the instrument. The accuracy of the LVDT float system, including electronic

noise, is +/- 0.005 liters: this translates to an accuracy of the order of 0.083 cc/s over a 60 second reading, or 0.0083 cc/s over 600 seconds.

A practical upper limit for permeability is reached when the pressure drop through the specimen is not significantly different than the pressure drop through the tubing. This is true because, as the pressure drop becomes dominated by the tubing, the correction for tubing flow resistance (some delta pressure value) involves the subtraction of two similar values and approaches zero. The upper limit is seen as an increase in uncertainty as the conductivity of the sample approaches that of the tubing, the actual limit depending on the relative values of these specimen conductivities and their individual uncertainties. Related to tubing (flow) friction was an upstream filter to remove particulates from the brine; early in the test series this filter was positioned downstream of the pressure transducers. Since this added additional line pressure loss, the filter was moved upstream of the pressure transducers for later tests of high permeability materials.

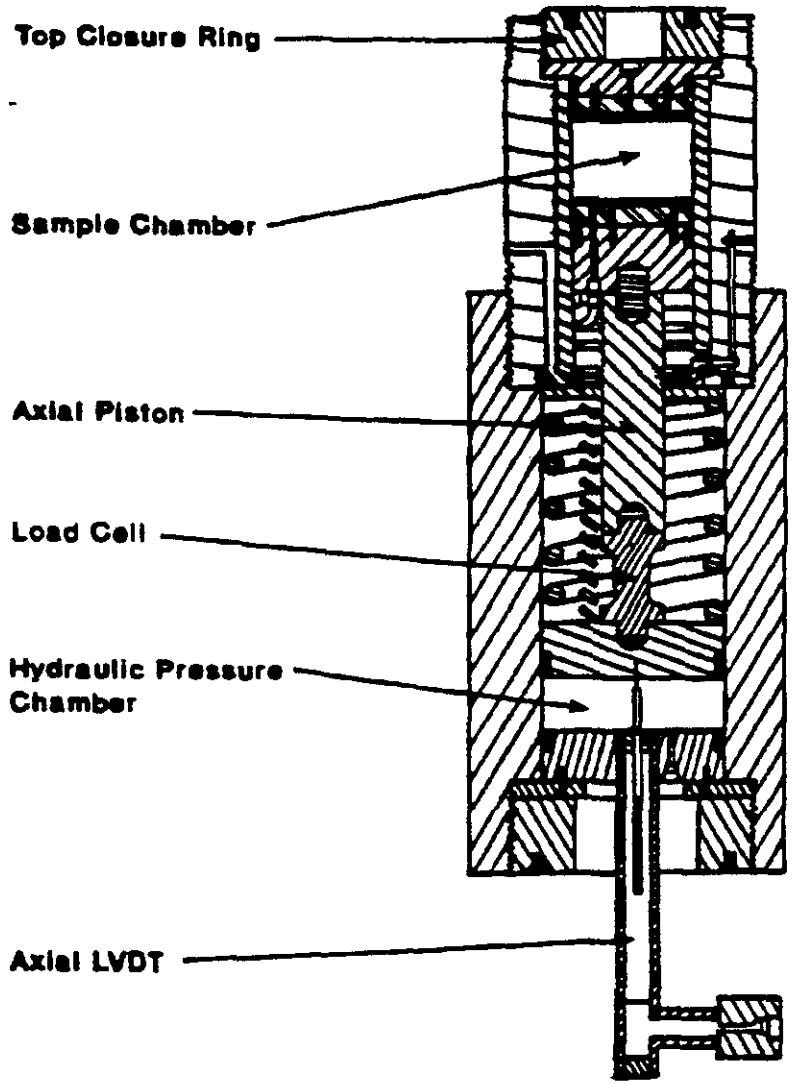

Figure 3.1: The oedometer setup for compaction and permeability testing.

4 0 RESULTS

4 1 Time Dependent Compaction Results

The compaction results for the various tests are presented in Table 4.1. Stress/density and density/time plots are given for the two plastics specimens that exhibited the most extreme changes in density values (Figures 4.1 and 4.2). Data in the tables are presented in terms of the densities and porosities of the materials at various times during the tests.

The compaction curves for the earlier tests show a periodic variation in density. This is not temperature related but is a function of the early load control system. In the earliest tests the bladder accumulator used for pressure control was isolated from the back up nitrogen bottle. Due to the small volume of fluid in the system early compaction and small system leaks, reductions occurred in hydraulic pressure which were adjusted manually on a daily basis and are seen as density fluctuations in the plots. Despite these periodic variations the overall curves follow a regular trend and can be smoothed to give needed time dependent compaction parameters such as those discussed by Butcher (1989). In later tests the control system was modified to give continuous back up to the nitrogen bottles. Smoother time dependent compaction curves were observed with this system. In some of the compaction curves especially for the magnetite and limonite irregular curves are seen. This is believed to be a true effect
which is exaggerated in the plots because of the small density changes involved.

4.2 Permeability Results

Permeability results are given in Table 4.1. Typical data acquired by the automated DAS for permeability testing are shown in Figures 4.3 and 4.4. Brine permeabilities were determined on all examples at the end of the time dependent compaction phase by flowing brine through the samples and recording flow rate and pressure.

Slopes of the permeability calibration curves (flow rate versus pressure drop exemplified in Figure 4.4) designated here as K_1 were used to correct the measured permeabilities. The correction is applied by treating the lines (K_1) and sample (K_s,) as two elements in series so that:

TABLE 4.1

MATERIAL DESCRIPTION	SPECIMEN TYPE #	TEST #	TEST DURATION (hours)	Initial DENSITIES (kg/m³)	Final DENSITIES (kg/m³)	Initial POROSITY[2] (%)	Final POROSITY[2] (%)	DENSITY/ TIME SLOPE (kg/m³/hr)[3]	PERMEABILITY (mD)
Wood/Rags	2	1	243	184.3	933.8	83.3	15.4	3.2×10^{-6}	17
	2	6	330	200.6	808.0	81.8	26.7	5.4×10^{-8}	>71
Plastics	1	2	325	290.3	1042.0	71.0	-4.2	1.4×10^{-8}	No Flow
	1	11	643	309.7	970.7	69.0	2.9	1.2×10^{-8}	99
SPEC. 1, 2, metals, cement	4	3	430	343.1	1092.0	71.6	9.6	3.6×10^{-7}	63
	4	10	973	378.3	979.4	77.1	4.1	3.3×10^{-8}	45
Steel cubes/ crushed salt	3	5	383	1181.0	2003.0	69.0	47.4	6.8×10^{-8}	27
Magnetite granules	5	7	26	2429.0	3134.0	53.3	39.7	3.5×10^{-7}	109
	5	12	24	2540.0	3121.0	51.2	40.0	3.9×10^{-6}	1096
Limonite granules	6	8	28	1454.0	2046.0	46.1	24.2	6.8×10^{-8}	93
	6	13	24	1430.0	1996.0	47.0	26.1	3.1×10^{-8}	1136
Magnetite gran./ steel cubes	7	9	24	1883.0	2696.0	69.9	56.9	7.2×10^{-7}	88
	7	14	24	1808.0	2728.0	71.1	56.4	2.0×10^{-7}	8
Shredded metal/ crushed salt	8	15	1414	1168.0	1917.0	53.4	23.4	1.6×10^{-8}	100-5000[2]
	8	16	1414	1165.0	2260.0	53.5	9.8	1.6×10^{-8}	151

NOTES: [1] Porosities were calculated using assumed values for solid densities. Uncertainties in these assumed values result in large uncertainties at low calculated porosity, leading to calculated small (or negative) values.
[2] A range of permeability values indicates that steady-state conditions were poorly defined during the test.
[3] Taken from latter (time) stage of density/time curve.

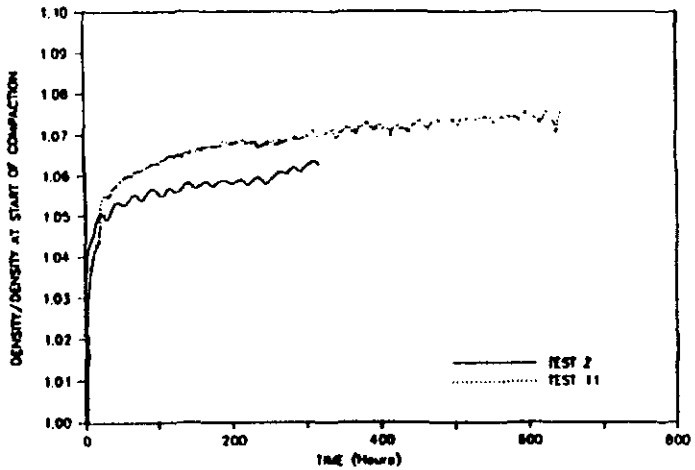

Figure 4.1. Change in density with time of simulated plastics waste at a constant stress of 2000 psi.

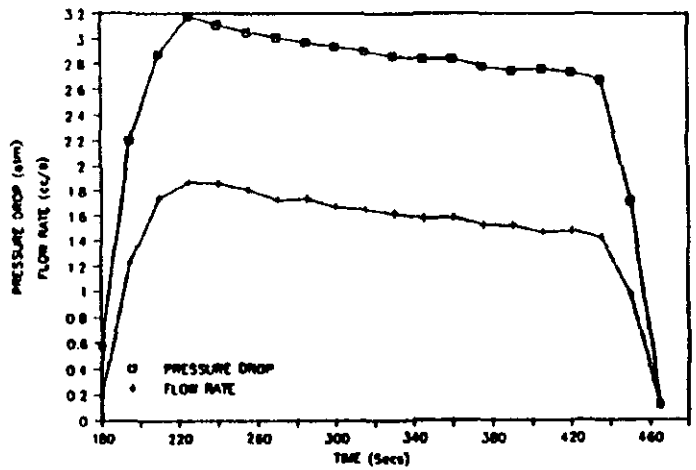

Figure 4.3. Permeability test history for simulated plastics waste.

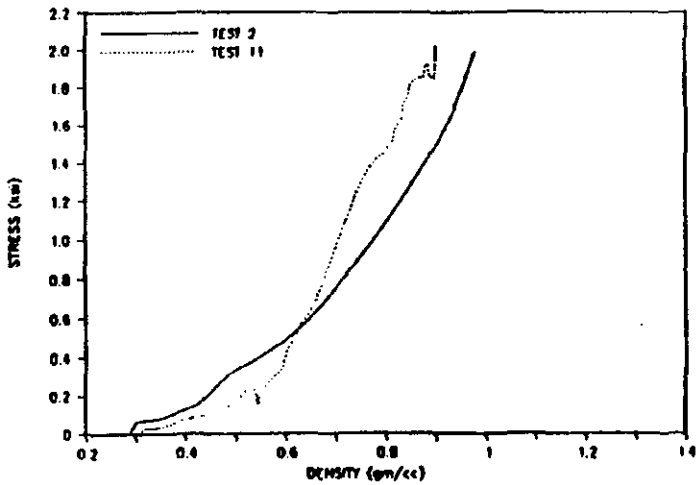

Figure 4.2. Change in density with applied axial stress of simulated plastics waste

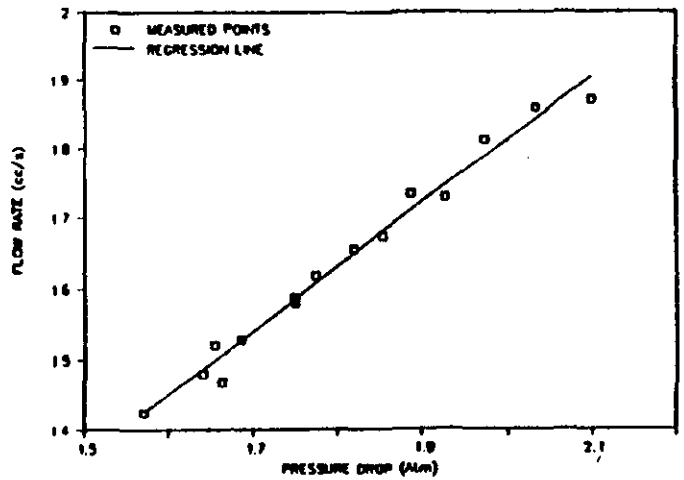

Figure 4.4. Flow rate – pressure drop relationship for simulated plastics waste.

(1) $1/K_s = 1/K' - 1/K_1$,

where K' is the slope of the Q (flow rate) vs dP (pressure difference) plot. Sample permeability k_s, is then calculated from Darcy's Law:

(2) $k_s = (Q/dP).v.L_sA_s$, and

(3) $k_s = K_s.v.L_s/A_s$,

where
A_s is the sample area (internal area of the sample holder) = 81.073 cm^2
L_s is the sample length (determined from the original sample height and the axial deformation determined during the load up and time dependent compaction tests)
v is the viscosity of brine (assumed to be 1.2 cp at 25 °C).

Permeabilities for the various tests have in general been calculated from the slopes of the pressure difference (dP) - flow rate (Q) curves, this method having the advantages of allowing a check on the linearity of the results and of removing the effects of small offsets in the pressure or flowrate data. In one test, magnetite and steel cubes, the flow rate was too small for this method to be used. Here an average of the flow rate/pressure drop (Q/dP) values over the stable portion of the test was used to determine permeabilities. In another test, shredded metal and crushed salt, the permeability of the sample varied by large amounts during the flow test, and point by point permeabilities were calculated.

5.0 CONCLUSIONS

A series of uniaxial strain time dependent compaction and brine permeability tests was performed on materials simulating wastes to be stored at the WIPP site. Some of the materials were designed to simulate the long term corrosion products of metal waste and steel drums. One specimen was made up of crushed salt mixed with shredded metals to simulate an alternate form of metallic waste.

All of the materials tested show increasing density and decreasing porosity when loaded in an oedometer to an axial stress of 2000 psi. All of the materials showed some time dependent compaction under constant stress. Final porosities were low for the plastics (less than 5%) but remained quite high for the limonlte and magnetite samples (25%to 57%). Final time dependent compaction density/time slopes of the order of 10^{-6} to 10^{-8} $kg/m^3/s$ were reached in 24 to 1400 hours.

Brine permeabilities determined at the end of the compaction stage while still under an axial stress of 2000 psi, varied with materials and were quite variable between different samples of the same materials. Most of the waste materials had permeabilities of the order of 10 to 100 millidarcies. Granular magnetite and limonite had permeabilities of the order of 100 to 1000 millidarcies, while the values for crushed salt and metals varied from less than 100 to over 1000 millidarcies. It should be noted that the various granular materials had large grain sizes to intentionally represent worst case scenarios with respect to permeability.

REFERENCES

Butcher, B. M., 1989 "Waste Isolation Pilot Plant Simulated Waste Compositions and Mechanical Properties," Sandia National Laboratories, SAND89-0372.

Butcher, B. M., Thompson, T. W., van Buskirk, R. and N. C. Patti (in preparation) "Mechanical Compaction of WIPP Simulated Waste," Sandia National Laboratories.

Thompson, T. W., von Buskirk, R. and N. C. Patti, 1989. "~Material Compaction and Drum Collapse Test Results," Report by Science Applications International Corporation for Sandia National Laboratories."

Mercer, J.W., and Orr, B.R. 1979. Interim Data Report on Geohydrology of the Proposed Waste Isolation Pilot Plant Site, Southeast New Mexico. Water Resources Investigations 79-98. U.S. Geological Survey, Albuquerque, NM.

ABSTRACT, p. 1;

" Data were collected during hydrologic investigations at the Waste Isolation Pilot Plant site in southeast New Mexico through September 1977. These data will be considered as part of a site characterization study evaluating the feasibility of nuclear-waste storage within bedded salt of the Salado Formation of Permian age.

Liquids in the rocks overlying the Salado Formation are found at the contact between the Permian-Rustler and Salado Formations, and in the Culebra and Magenta Dolomite Members of the Rustler Formation.

Calculations of hydraulic gradient and direction of flow of water moving along the Rustler-Salado contact have been hindered because heads are stabilizing very slowly. Preliminary calculations of transmissivity range from 10^{-1} feet squared per day on the western margin of the site to 10^{-4} feet squared per day on the eastern margin. Liquids from the Rustler-Salado contact contain from 311,000 to 325,800 milligrams per liter total dissolved solids. Liquid chemistry suggests long residence times and extensive liquid-rock interaction, increasing with decreasing permeability.

Liquids in the Culebra Dolomite Member move southeast at gradients ranging from 7 to 120 feet per mile. Preliminary transmissivity calculations range from 140 feet squared per day on the western margin to 10^{-4} feet squared per day to the east. Total dissolved solids range from 23,721 milligrams per liter along the western margin of the site to 118,292 milligrams per liter to the east. Liquid chemistry within the Culebra varies from well to well probably as a function of fracture distribution.

Liquids in the Magenta Dolomite Member move southwest at a gradient of about 50 feet per mile. Preliminary transmissivity estimates range from less than 1 foot squared per day to 40 feet squared per day. Total dissolved solids range from 10,347 milligrams per liter to 29,683 milligrams per liter.

The extremely low vertical hydraulic conductivity within the Rustler Formation restricts liquid migration between the Magenta and Culebra Dolomite Members, and between the Culebra and the Rustler-Salado contact. Heads are highest in the Magenta and lowest at the Rustler-Salado contact.

Liquid levels in wells tapping the Permian Bell Canyon Formation near the site are lower than levels in wells tapping the Rustler Formation. Liquids from the Bell Canyon Formation contain 189,000 milligrams per liter total dissolved solids. Liquid density and chemistry indicate long residence times and extensive liquid-rock interaction."

Shallow-zone hydrology, p. 173, para. 2;

" Hydrologic tests of liquid-bearing zones in the Rustler Formation indicate that heads decrease with depth; consequently, potential liquid movement would be downward in rocks above the salt. The degree to which ground water can move toward the Salado, however, is

controlled by the very low vertical hydraulic conductivity of the Rustler.

Minor solution of salt has occurred along the western margin of the site at the top of the Salado Formation. SOlution of salt in the Rustler ranges from complete removal in the west to little or no removal in the east.

High concentrations of dissolved solids, particularly sodium chloride, occur in liquids above the salt, and chemical composition of these liquids is dependent upon extensive interaction with the evaporite host rocks resulting from long residence times.

Rustler-Salado contact.--Brines are found along the Rustler-Salado contact, but extremely low yields require long-term testing to establish reliable heads. Preliminary values of transmissivity of the Rustler-Salado contact range from $10^{-1}ft^2$/day in P-14 to $10^{-4}ft^2$/day in P-18. Water from the Rustler-Salado contact contains from 31,000 mg/L to 327,000 mg/L dissolved solids. Sodium Chloride ranges from 266,000 mg/L to 300,000 mg/L.

Culebra Dolomite Member of the Rustler Formation.--Head distribution determined for the Culebra Dolomite Member indicates liquid movement to the southeast beneath the site. Gradients range from 7 to 120 ft/mi and vary as a function of hydraulic conductivity.

Salt dissolution in the Rustler and Salado Formations, with accompanying subsidence of the Rustler, causes an increase in fracture porosity of the Culebra and contributes to variabilities in transmissivities.

Preliminary values of transmissivity for the Culebra range from 140 ft^2/day in P-14 on the flanks of Nash Draw, to $10^{-1}ft^2$/day in H-1 near the site center, to 10^{-4} ft^2/day in P-18 to the east. Culebra liquids range from 8,890 mg/L to 118,000 mg/L dissolved solids. Sodium chloride ranges from 4,900 mg/L to 89,200 mg/L.

Magenta Dolomite Member of the Rustler Formation.--Head distribution within the Magenta Dolomite Member has only been determined in three holes (H-1, H-2a, and H-3) and suggests fluid movement to the southwest. The hydraulic gradient in the vicinity of these three holes is 50 ft/mi.

Preliminary values of transmissivity for the Magenta range from 2 ft^2/day in H-3 to less than 1 ft^2/day in H-1. Magenta liquids range from 10,300 mg/L to 29,700 mg/L dissolved solids. Sodium chloride ranges from 6,800 mg/L to 24,300 mg/L."

Miller, W.M., and Chapman, N.A., Ed., 1992. Identification of Relevant Processes, System Concept Group Report, UKDOE/HMIP Report TR-ZI-11, London, England.

Summary; p. iii, para. 1;
" The System Concept Group (SCG) consisted of a group of eight experts in various aspects of deep disposal of radioactive wastes and was conceived as a means of providing a preliminary but comprehensive overview of processes and factors which could be important in the post-closure safety assessment of the proposed repository at Sellafield. Part of the Dry Run 3 exercise involved the elicitation of a list of processes relevant to the Harwell site considered in Dry Run 3. For the current assessment it was considered appropriate to use the Dry Run 3 Process List as the starting point for the SCG.

In general the Dry Run 3 Process List was found to be comprehensive and a few additional processes were added. A number of processes were removed or substituted where they were obviously specific to the Harwell site environment. In addition the list was restructured to take into account, (a) the necessary re-ordering of the biosphere component processes which were generally thought to be far too complex, given the inherent uncertainties in the earlier parts of the release chain (near and far-fields), and (b) to brine to prominence the following processes which the SCG felt were critical to the behaviour of a repository at the Sellafield site.

- Stability of the repository-The backfill used in the ILW vaults is seen as having no structural function. There will be no backfill in the LLW vaults and, possibly, no backfill above the ILW concrete cells. Vault roof stability, therefore, becomes and issue. Progressive collapse of the roof onto the degrading wastes and upwards migration of the collapse-damage rock is anticipated producing an extensive zone of increased porosity and permeability in the host rock.

- ILW near-field chemical environment-The long-term maintenance of low-flow, stable flux, highly alkaline, reducing conditions in the ILW vaults are central to the Nirex disposal concept and safety case. Consequently, this aspect requires close scrutiny to determine that chemical homogeneity will develop rapidly, persist and behave as predicted.

- Hydrology at repository depth-Groundwater fluxes at depth will require careful evaluation given the proximity of the repository to the Ravenglass sub-basin and other features. It must be determined whether the system can be evaluated exclusively in terms of steady-state topographically related head differences, or if other driving forces need to be taken into consideration.

- Groundwater flow and radionuclide transport modeling-It is likely that models used to date to represent groundwater flow and radionuclide transport are based on overly simplistic assumptions and do not adequately characterize the

system. Alternative concepts should be considered to model planar and fracture flow.

- Consequences of glaciation-It is likely that climatic cycling will continue for the whole period covered in the quantitative assessment and that significant climate changes will be apparent within 5,000 years from present. Evidence exists to suggest that there is potential for deep incision to occur as a consequence of glaciation and that the effect on deep groundwater flows may be signifcant."

NAGRA, 1985. Nuclear Waste Management in Switzerland: Feasibility Studies and Safety Analyses (Project Gewahr, 1985). NAGRA Project Report NGB 85-09 (English Summary), Wettingen, Switzerland.

SUMMARY; p. v, para. 1;
" The validity of the operational licences of the existing Swiss nuclear power plants (NPP) Beznau I and II, Mühlberg, GÖsgen and Leibstadt after 31st December 1985 is, because of official requirements, dependent on the demonstration of permanent, safe management and final disposal of radioactive waste. Accordingly, the NPP companies have been required to prepare a so-called "guarantee project" (Project Gewähr) and to present this to the Swiss Federal Government (Bundesrat) for review.

The appropriate investigations and research have been carried out by Nagra (National Cooperative for the Storage of Radioactive Waste). The 1985 Project Gewähr is described in an eight volume report NGB 85-01 to 85-08 and individual research projects are documented in separate NTB-series reference reports.

The main tasks of Project Gewähr 1985, as determined by official requirements, can be defined by three points:

- Sufficiently detailed projects based on present-day knowledge and technology must illustrate the technical feasibility of repository construction in Switzerland.

- By means of safety analyses it must be shown quantitatively that final disposal of all categories of radioactive waste is currently feasible without exposing the population to unreasonable radiation risks (demonstration of long-term safety).

- The data used in the safety analyses must be derived from appropriate investigations in Switzerland or abroad or must, in some other way, correspond to the present technical and scientific state of knowledge. The data include geological, hydrogeological and material-specific parameters and also a quantitative description of the behaviour of radionuclides in the geo-and biosphere as determined by their physical and chemical properties."

p. 4-13;
" Table 4-1 gives a list of processes and events for a type C repository location in the geological formations of northern Switzerland which can potentially have an effect on the repository system."

OECD Nuclear Energy Agency. 1992. Systematic Approaches to Scenario Development. Organisation for Economic Co-Operation and Development, Paris, France. NWM Library, NNA.920610.0027.

ABSTRACT, p. 4;

" This report describes and discusses the current approaches to the identification and selection of scenarios for the safety assessment of radioactive waste disposal systems. The scenario development process blends information on site and waste characteristics, and the understanding of various processes at work within the disposal system, with the judgement of appropriately experienced scientists and others. In this process, it is important to follow systematic procedures and to carefully document each step so that it is amenable to scrutiny. There is wide agreement on the general approach that should be taken for the identification, classification, and screening of phenomena that need to be considered. Several approaches have been identified to meet the challenge of combining these phenomena into scenarios, and consideration has been given to their range of applicability. Although several different approaches can be applied to form scenarios, experience to date indicates that the scenarios selected for detailed assessment will be very similar.

The approach adopted in a particular case will be determined by a range of factors, including the purpose of the assessment, regulatory requirements, available resources, experience, and confidence in the methods used. Scenario development is an interactive and iterative process within the overall safety assessment procedure. Different approaches to scenario development may be used at different stages of a safety assessment programme depending on the level of information and resources available and the immediate goal, e.g., direction of site investigation, determining research priorities. However, for safety assessments in support of licensing applications, a consistent ans systematic scenario development procedure must be followed, which should fulfill the need to be both transparent and to provide a high level of confidence that all important safety aspects of the disposal system will be covered by the assessment."

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. Brine Reservoirs in the Castile Formation Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME-3153, Vols. 1 and 2. Westinghouse Electric Corp., Carlsbad, NM.

EXECUTIVE SUMMARY, p 1;

" The Waste Isolation Pilot Plant (WIPP) project is a U. S. Department of Energy (DOE) research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States. This demonstration consists of two parts. First, about six million cubic feet of TRU waste will be emplaced in the thick bedded-salt deposits of the Salado Formation in southeastern New Mexico at a depth of about 2150 feet. Second, the WIPP will provide for research relative to the interactions of defense high-level waste with bedded salt, though all high-level waste will be removed prior to facility decommissioning.

A potential location was selected for the WIPP in the northern Delaware Basin of New Mexico, and three exploratory core holes were drilled (AEC-7, AEC-8, and ERDA-6; Figure 1). While drilling the third such hole (ERDA-6), substantial geologic structural deformation was noted, and brine and gas sufficiently pressurized to flow to the surface were encountered. The unpredictability of the geology led to relocation of the site to its present location in 1974 (Figure 1). Since relocation, an extensive site characterization program has been conducted, and the adequacy of the site has generally been demonstrated.

In 1981, an agreement was signed between the State of New Mexico, the DOE, and others which included several studies intended to address the State's concerns relative to the suitability of the proposed WIPP site. Some of these studies addressed an area of geologic interest north of the proposed site, and pressurized brine reservoirs in the Delaware Basin. The work was begun in October 1981 and included the reopening and testing of ERDA-6, and the deepening and testing of WIPP-12, an exploration borehole which also encountered pressurized brine and gas. This report provides an account of these studies.

These studies and preparation of the brine reservoir report were performed by the WIPP Technical Support Contractor (TSC), primarily by D'Appolonia Consulting Engineers, Inc. (a member of the WIPP-TSC) under subcontract to the Westinghouse Electric Corporation (the TSC prime contractor). Sandia National Laboratories, Albuquerque, N.M., provided critical review of the studies and report; the U. S. Geological Survey also made comments.

The occurrence of pressurized brine reservoirs in the Castile Formation (underlying the Salado Formation) of the Delaware Basin has been documented over the past 40 years by reports of reservoir encounters by hydrocarbon exploration drilling. In general, these reservoirs were known to be contained in fractured anhydrite with associated hydrogen sulfide gas and were thought to be related to antiforms in the Castile.

Various theories were advanced to explain the origin of reservoirs, which include dissolution of evaporites by recent ground waters, dehydration of gypsum to form anhydrite, entrapment of ancient seawater during evaporite deposition, and ancient dissolution and

reprecipitation of evaporite minerals. Should certain of these theories be correct, the suitability of the WIPP site could be in question. Thus, the purpose of this study was to determine the characteristics and origin of these reservoirs and evaluate their potential impact on the integrity and stability of the WIPP site.

Data used in the performance of this study were obtained from drilling and hydrological testing in boreholes ERDA-6" and WIPP-12 and from chemical analyses of samples of reservoir brine and gas collected at these two wells. Information was also obtained from a review of published and unpublished literature on the geology and hydrology of the basin. The principle data reviewed and analyzed in this report are contained in "Data File report - ERDA-6 and WIPP-12 Testing" (D'Appolonia, 1982, 1983)."

SUMMARY OF FINDINGS, p2, col 2, para 2;

" The analyses and interpretations by three disciplines -- geology, hydrology, and chemistry -- have been integrated to form a model of brine reservoir genesis, and to assess the current and future status of brine reservoirs as they relate to the WIPP site. The development of the brine reservoirs began in the Permian Period about 235 million years before present. The Castile evaporites, consisting primarily of anhydrite and halite as shown in Figure 2, were deposited at that time. During the initial chemical sedimentation (or precipitation) period, the solids were poorly consolidated and highly porous. Much or all of this pore space was filled with Permian seawater that had been enriched in dissolved solids, oxygen-18, and probably deuterium by evaporation. As sedimentation in the basin continued, the seawater became trapped as an interstitial fluid between individual grains of anhydrite and halite. As compaction increased, grain boundary accretion of halite probably surrounded some of the pore fluids and gave rise to fluid inclusions in halite crystals. Examination of ratios of major and minor element concentrations in the brines leads to the conclusion that the reservoir brines originated from ancient seawater with no evidence for fluid contribution from present meteoric waters."

p. 4, col. 2, para. 2;

" The ERDA-6 and WIPP-12 brine reservoirs, which are located in fractured anhydrites above thickened halite (Figure 2), may be modeled as fractured heterogeneous systems. The volumes of the ERDA-6 and WIPP-12 brine reservoirs are estimated, within an order of magnitude, to be about 630,000 barrels and 17,000,000 barrels, respectively. The vast majority of brine is stored in low-permeability microfractures, and therefore is not readily released in the event the reservoirs are intercepted. In fact, less than three percent of the reservoir fluids would flow unassisted to the surface if encountered during exploration drilling. About five percent of the overall brine volume in each reservoir is stored in large, open fractures.

SUMMARY OF FINDINGS, p 5, col 1, para 2;

" At present, the Castile brine reservoirs appear to be isolated. There is no evidence to suggest hydraulic or chemical connection between reservoirs, or between reservoirs and other

ground-water systems, either at the present or in the past. The persistence of high and different hydraulic heads in Castile brine reservoirs for at least one million years (the age of the most recent tectonic activity) is the principle hydrologic evidence for their isolation. The four Castile brine reservoirs for which accurate data are available show differences in hydraulic head ranging from 280 to 871 feet of water. Similarly, measured heads in the brine reservoirs are at least 1330 feet higher than heads in aquifers in the subjacent Delaware Mountain Group, and at least 1530 feet higher than heads in the overlying Rustler Formation (Figure 4). Hence, there is no physical mechanism for the brine reservoirs to receive recharge from these underlying and overlying units."

p 5, col 1, para 3;

" As regards chemical mechanisms, the gas and brine chemistries of the two reservoirs are distinctly different from each other and from local ground waters. For example, large differences in the reservoir gas compositions exist between WIPP-12 and ERDA-6. The gas in WIPP-12 is composed mostly of methane and has little or no carbon dioxide. The ERDA-6 reservoir contains substantial quantities of carbon dioxide, and more hydrogen sulfide than WIPP-12. Differences observed in the brine composition include boron, bromide, magnesium, potassium, and lithium concentrations. Connection between reservoirs would eliminate or mitigate these differences, especially with respect to the highly mobile gases. Accordingly, if connected in the past, the current brine (and associated gas) compositions of the two reservoirs would be more similar.

In addition to being isolated, the brines appear to be in chemical equilibrium with their surroundings, and they are stagnant. For example, the brines are chemically saturated with the primary phases of the reservoir host rock (anhydrite and calcite). WIPP-12 brine also appears to be saturated with halite, the principle phase of the confining strata. Furthermore, calculations indicate bulk system equilibrium among solid, liquid, and gas.

In summary, the brine reservoirs appear to be local, isolated features that have reached equilibrium with their environment. Evidence for long-term hydraulic and chemical isolation includes:

- Hydraulic heads that are substantially different from reservoir to reservoir and higher than the heads of local ground waters.
- The containment of gas by the reservoirs.
- Brine and associated gas chemistries that differ from reservoir to reservoir.
- Geographic separation and non-uniform distribution of reservoirs, i.e., extensive drilling has taken place in this area, but only a few wells have intercepted pressurized brines. There is no evidence for a continuous, extensive aquifer in the Castile.
- Bulk chemical equilibrium between the brine, gas, and reservoir rock in the ERDA-6 and WIPP-12 reservoirs."

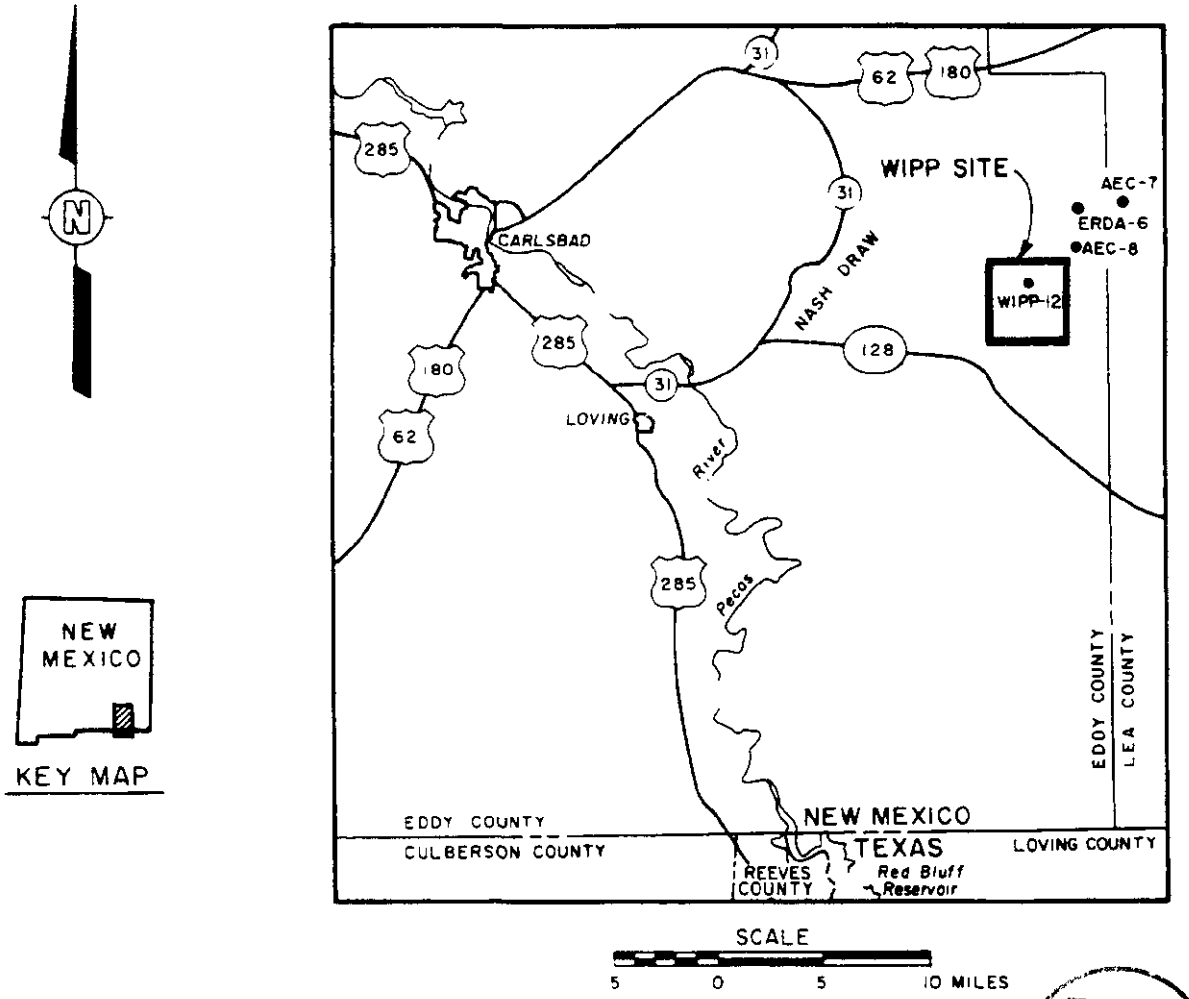

Figure 1 — Location of WIPP Site and Boreholes AEC-7, AEC-8, WIPP-12 and ERDA-6

1.0 INTRODUCTION AND SUMMARY, p. G-1, para. 3;

" At WIPP-12 the Castile Formation is comprised of five members (in ascending order): Anhydrite I, Halite I, Anhydrite II, Halite II, and Anhydrite III. Halite I is somewhat thicker than the typical section in the basin. The anhydrite rock is microcrystalline and dense, with thin bedding laminae made up of carbonates, organic material, and clays. Fractures are present in Anhydrite III, Anhydrite II, and an anhydrite stringer within Halite II, which dip between 70° and vertical. The fracture at 3016 feet depth produced brine. No fractures were detected in the halite members. At ERDA-6, the Anhydrite III member is apparently missing, based on previous geologic interpretation (Jones, 1981a). High-angle fractures are located in Anhydrite II which contain pressurized brine. Information on other brine occurrences was analyzed and compared with WIPP-12 and ERDA-6 data to determine any basic patterns. Brine occurrences are associated with a belt of deformation in the Castile that parallels the Capitan reef subcrop and underlies the WIPP site. The brines appear to be located in the uppermost Castile anhydrite unit present at each location. At WIPP-12, Anhydrite III produced brine; at ERDA-6 the brine is thought to be located in Anhydrite II. Brine occurrences are associated in every known case with anticlinal structures of varying size within the belt of deformation."

p. G-33, para. 5;

" The acoustic log, which measures compressional wave travel time through the rock, uses a correlation between the wave velocity and elastic rock properties to estimate the bulk modules of the rock (Dresser Atlas, 1981b). The computed values of bulk modules range from 8 to 11 x 10^6 psi. Laboratory compression tests on anhydrite from other WIPP locations indicate similar results (Teufel, 1981; Pfiefle and Senseny, 1981). This value is representative of the bulk modules of relatively intact, unfractured rock, because the laboratory tests are performed on unbroken rock and the acoustic logging tool measures velocities over a relatively short distance with few if any fractures included."

p. H-45, Reservoir Pressure;

" The maximum pressure measured for the Erda-6 brine reservoir at the wellhead is 604 psig. Extrapolated to a reservoir depth of 2711 feet below ground surface with a fluid pressure gradient of 0.5326 psi/ft of brine, this corresponds to a reservoir pressure of 2048 psig. As shown in Figure H-12, this pressure corresponds to a potentiometric surface at 5551 feet above mean sea level when calculated for the specific gravity of pure water. This is the highest hydraulic head of any ground-water body known in the Delaware Basin.

Following the end of testing in November 1981 and a BOP change in February 1982, the wellhead shut-in pressure at ERDA-6 rose steadily as a result of both reservoir recovery and gas cap formation in the wellbore. A series of apparent gauge-related malfunctions have left the pressure data collected before and after the gas cap release on March 8, 1983 of uncertain validity. The highest pressure measured before the gas cap release was 558 psig on March 5, 1983. Because of a possible fluid leak from a diaphragm assembly attached to the gauge, this value may be too low. The first fully reliable pressure measurement made

after the gas cap release was 552 psig on March 19, 1983."

p. H-52, Reservoir Pressure;

" The maximum pressure for the WIPP-12 reservoir at the wellhead is 208 psig. Extrapolated to a reservoir depth of 3017 feet below ground surface with a fluid pressure gradient of 0.5378 psi/ft of brine, this corresponds to a reservoir pressure of 1831 psig. As shown in Figure H-12, this corresponds to a potentiometric surface at 4680 feet above mean sea level calculated for the specific gravity of pure water. Section 3.4.1 contains a detailed discussion of hydraulic heads throughout the Delaware Basin.

Following the end of testing in June 1982, the wellhead shut-in pressure at WIPP-12 rose steadily as a result of both reservoir recovery and gas cap formation in the wellbore. Just prior to releasing the gas cap on March 7, 1983, the wellhead pressure was about 175 psig. On March 7, 1983, approximately 173 ft^3 of gas (at STP) were released from the well (D'Appolonia, 1983). Under the pressure (175.2 psig) and temperature (58°F) conditions then existing in the wellbore, this gas would have occupied a volume of about 14 ft^3, corresponding to maximum gas cap thickness of about 33 feet. Some minor fraction of the gas released probably came from gas exsolution from the brine during the release, however, and is not representative of gas cap volume in the wellbore. From March 8 through at least March 20, 1983, the wellhead pressure at WIPP-12 remained steady at about 162 psig. After more than nine months of recovery, the WIPp-12 reservoir should be near equilibrium. Future increases in wellhead pressure will be predominantly the result of renewed gas cap formation."

Sandia National Laboratories. 1991. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 1: Methodology and Results. SAND91-0893/1. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM. wpo 26404.

ABSTRACT, p i;

" Before disposing of transuranic wastes at the Waste Isolation Pilot Plant (WIPP), the United States Department of Energy must have a reasonable expectation that the WIPP will comply with the quantitative requirements of Subpart B of the United States Environmental Protection Agency's (EPA) Standard, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*. Sandia National Laboratories, through iterative performance assessments of the WIPP disposal system, is conducting an evaluation of the long-term performance of the WIPP that includes analyses for the Containment Requirements and the Individual Protection Requirements of Subpart B of the Standard. Recognizing that unequivocal proof of compliance with the Standard is not possible because of the substantial uncertainties in predicting future human actions or natural events, the EPA expects compliance to be determined on the basis of specified quantitative analyses and informed, qualitative judgment. Performance assessments of the WIPP will provide as detailed and thorough a basis as practical for the quantitative aspects of that decision.

The 1991 preliminary performance assessment is a snapshot of a system that will continue to evolve until a final compliance evaluation can be made. Results of the 1991 iteration of performance assessment are preliminary and are not suitable for final compliance evaluations because portions of the modeling system and data base are incomplete, conceptual model uncertainties are not fully included, final scenario probabilities remain to be determined, and the level of confidence in the results remains to be established. In addition, the final version of the EPA Standard, parts of which were remanded to the EPA in 1987 for further consideration, has not been promulgated. Results of the 1991 preliminary performance assessment do not indicate potential violations of Subpart B of the Standard and support the conclusion based on previous analyses, including the 1990 preliminary performance assessment, that reasonable confidence exists that compliance with Subpart B of the Standard can be achieved."

Volume 1, Section 3. PERFORMANCE-ASSESSMENT OVERVIEW, p 3-1;

" The design and implementation of a performance assessment is greatly facilitated by a clear conceptual model for the performance assessment itself. The purpose of this chapter is to present such a model and then to indicate how the individual parts of the WIPP performance assessment fit into this model. The WIPP performance assessment is, in effect, a risk assessment, for nuclear power plants and other complex systems is also appropriate for the WIPP performance assessment."

Volume 1, Section 3.1.3 CHARACTERIZATION OF UNCERTAINTY IN RISK, p 3-8;

" If the inputs to a performance assessment as represented by the vector **x** in Equation 3-3 are uncertain, then so are the results of the assessment. Characterization of the uncertainty in the results of a performance assessment requires characterization of the uncertainty in **x**. Once the uncertainty in **x** has been characterized, then Monte Carlo techniques can be used to characterize the uncertainty in the risk results.

The outcome of characterizing the uncertainty in **x** is a sequence of probability distributions

$$D_1, D_2, \ldots, D_{nV}, \tag{3-5}$$

where D_j is the distribution developed for the variable x_j, $j=1,2 \ldots, nV$, contained in **x**. The definition of these distributions may also be accompanied by the specification of correlations and various restrictions that further define the possible relations among the x_j. These distributions and other restrictions probabilistically characterize where the appropriate input to use in the performance assessment might fall, given that the analysis is structured so that only one value can be used for each variable under consideration. In most cases, each D_j will be a subjective distribution that is developed from available information through a suitable review process and serves to assemble information from many sources into a form appropriate for use in an integrated analysis. However, it is possible that the D_j may be obtained by classical statistical techniques for some variables.

Once the distributions in Equation 3-5 have been developed, Monte Carlo techniques can be used to determine the uncertainty in $R(\mathbf{x})$ from the uncertainty in **x**. First, a sample

$$x_k = [x_{k1}, x_{k2}, \ldots, x_{k,nV}], k=1,\ldots,nK \tag{3-6}$$

is generated according to the specified distributions and restrictions, where nK is the size of the sample. Performance-assessment calculations are then performed for each sample element $\mathbf{x}_k$, which yields a sequence of risk results of the form

$$R(x_k) = \{(S_i(x_k), cS_i(x_k), i-1,\ldots,nS(x_k)\}, \tag{3-7}$$

for $k=1, \ldots, nK$. Each set $R(\mathbf{x}_k)$ is the result of one complete performance assessment performed with a set of inputs (i.e., $\mathbf{x}_k$) that the review process producing the distributions in Equation 3-5 concluded was possible. Further, associated with each risk result $R(\mathbf{x}_k)$ in Equation 3-7 is a probability or weight[1] that can be used in making probabilistic statements about the distribution of $R(\mathbf{x})$.

In most performance assessments, CCDFs are the results of greatest interest. For a particular consequence result, a CCDF will be produced for each set $R(\mathbf{x}_k)$ of results shown

in Equation 3-5. This yields a distribution of CCDFs of the form shown in Figure 3-4.

Although Figure 3-4 provides a complete summary of the distribution of CCDFs obtained for a particular consequence result by propagating the sample shown in Figure 3-6 through a performance assessment, the figure is hard to read. A less crowded summary can be obtained by plotting the mean value and selected percentile values of the exceedence probabilities shown on the ordinate for each consequence value on the abscissa. For example, the mean plus the 5th, 50th (i.e., median), and 95th percentile values might be used. The mean and percentile values can be obtained from the exceedance probabilities associated with the individual consequence values and the weight or 'probabilities' associated with the individual sample elements.[1] The determination of the mean and percentile values for cS = 1 is illustrated in Figure 3-5. If the mean and percentile values associated with individual consequence values are connected, a summary plot of the form shown in Figure 3-6 is obtained. Due to their construction, the percentile bounds for the distribution of $R(\mathbf{x})$, which is a distribution of functions. However, the mean curve is an estimate for the expected value of this distribution of functions. . . ."

Volume 1, Section 3.2 Definition of Scenarios, p 3-32;

" As indicated in Equation 3-1, the outcome of a performance assessment for WIPP can be represented by a set of ordered triples. The first element of each triple, denoted S_i, is a set of similar occurrences or, equivalently, a scenario. As a result, an important part of the WIPP performance assessment is the development of scenarios.

Volume 1, p 4-64, line 15 thru p 4-66, line 34

" Radionuclide migration depends on the degree of saturation within the repository. Gas pressure resulting from microbial activity and corrosion may prevent brine inflow and desaturate the nearby Solado Formation, MB139, and anhydrite layers A and B. These conditions, in addition to the consumption of water by anoxic corrosion and possibly microbial activity, also would result in a decrease in the amount of water in the waste and backfill and a lower potential for radionuclide transport.

Two pathways for groundwater flow and radionuclide transport dominate the disposal system (Figure 4-6). In the first path, brine and radionuclides enter MB139, either through fractures in salt or directly as a result of rooms and drifts intersecting the marker bed during construction or room closure. Following repository decommissioning, waste-generated gas will begin to pressurize the waste panels (Weatherby et. al., 1989). Brine will drain by gravity to the lower half of the panels. Gas will saturate the DRZ above the panel and open flow paths to anhydrite layers A and B above the panel. MB139 beneath the panel will remain brine saturated, but gas will open flow paths into the MB139 beyond the panels. The more-mobile gas phase will flow outward over the less-mobile brine phase. After gas generation ceases, pressure and phase distribution will gradually equilibrate throughout the entire region. Gas will continue to expand outward, but brine flow reverses, flowing inward primarily along the lower portions of anhydrite layers A and B and MB139. Gas saturation near the waste panels will diminish. The anhydrite layers above the waste panels will be a

major flow path for gas. In contrast, brine will inhibit gas inflow in the MB139 beneath the waste panels.

Because material in the upper shaft is expected to be poorly consolidated, the hydraulic pressure at the junction of the upper and lower parts of the shaft seals is assumed to approximate the pressure head of the Culebra Dolomite member. As a result, the pressure gradient resulting from waste-generated gas (approximately 15 MPa+) and hydrostatic pressure at the Culebra (1 MPa) tends to force radionuclide-bearing brine from MB139 beneath the panel through the seal in the marker bed, along the fractures in MB139 to the base of the shaft. Concurrently, gas flows through the upper portion of the drifts and the anhydrite layers A and B to the shaft. Gas saturation in the shaft seals will inhibit brine migration up the shaft to the Culebra Dolomite Member. Brine and radionuclides will eventually reach the Culebra and Migrate downgradient to the accessible environment.

Relative motion during salt creep and gas generation prevents MB139 from returning to its original position, and the salt-creep-induced fractures do not completely close. Flow is through MB139 instead of through the overlaying access drift because of the substantially higher hydraulic conductivity in MB139. Flow in MB139 is to the north through the seal rather than to the south down the pre-excavation hydraulic gradient within MB139, because the pressure drop to the north is greater after excavation, and the flow to the south would be impeded by extremely low permeability of the intact marker bed. Therefore, the horizontal path directly through MB139 to the accessible environment is not included for this assessment, but this path is considered for other analyses (see Volume 2 of this report).

The other dominant path is assumed to be from the repository vertically through the intact Solado Formation toward the Culebra Dolomite Member (Figure 4-6) (Lappin et. al., 1989). This path has the largest pressure decline over the shortest distance of any path. In addition, large potential exists for radionuclides to leave the repository along this path because of the large horizontal cross-sectional area of the waste-bearing rooms and drifts in the repository.

The methodology can determine pathways to individuals and calculate doses to humans if a release pathway is added. The pathway used in an earlier analysis (Lappin et. al., 1989) is described in the next section. Because undisturbed performance releases no radionuclides in 1,000 years, these calculations are not necessary for this scenario (Marietta et. al., 1989)"

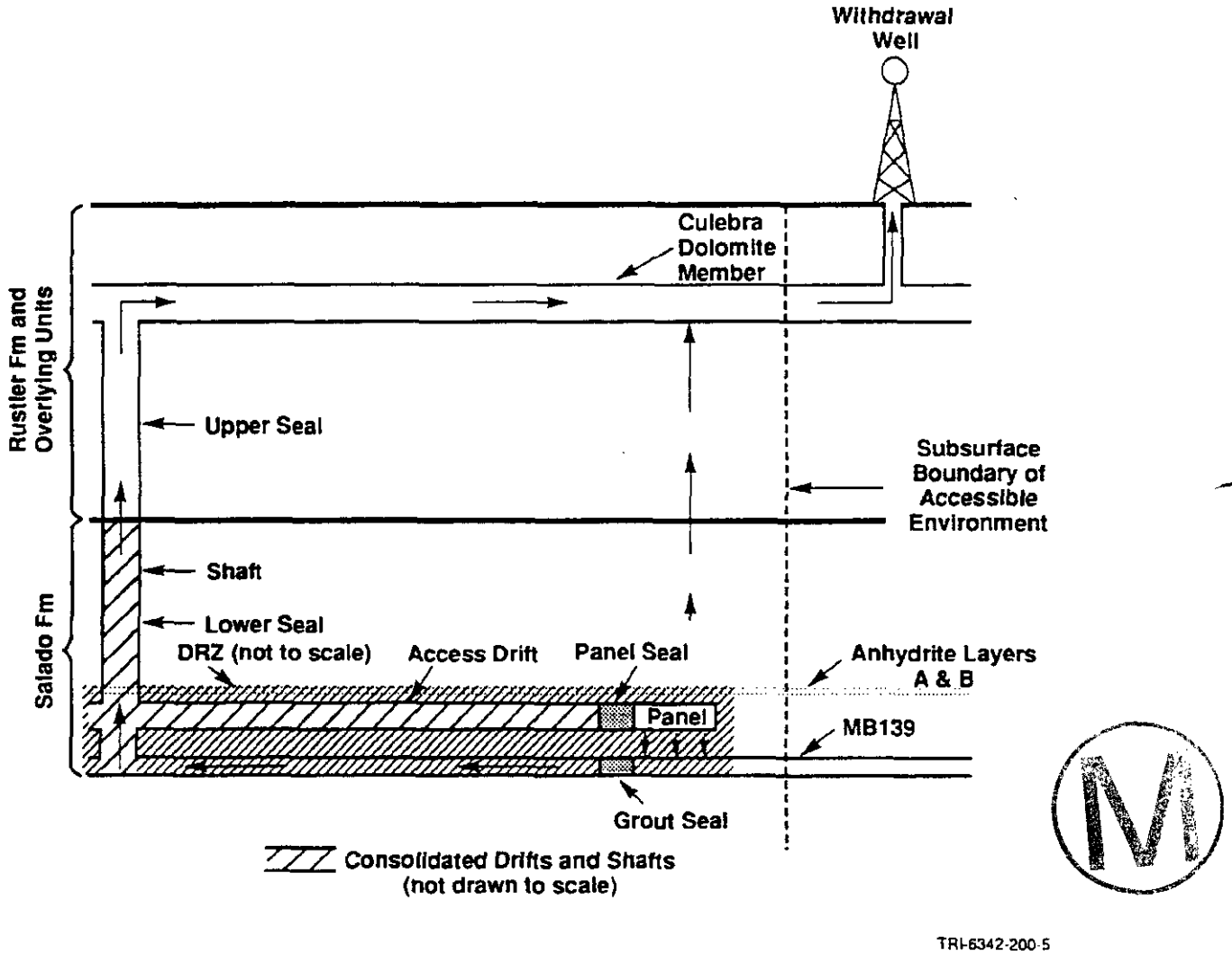

Figure 4-6. Conceptual Model Used in Simulating Undisturbed Performance.

Volume 1, p 5-47, lines 3 through 5:
"5.2 The Engineered Barrier System
5.2.2 Repository and Seal Design . . .
Seals in the lower portion of the shafts must provide a long-term, low-permeability barrier that will prevent Salado Formation brine from migrating up the shaft."

Volume 2, Section 3. CONSTRUCTION OF COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTIONS, p 3-1;
" Sandia National Laboratories is conducting an ongoing performance assessment for the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico (Bertram-Howery and Hunter, 1989; Lappin et. al., 1989). At present, a performance assessment is performed each year to summarize what is known about the WIPP and to provide guidance for future work (Marietta et. al., 1989; Bertram-Howery et. al., 1990). It is anticipated that these iterative performance assessments will continue until the WIPP is either licensed for the disposal of transuranic wastes or found to be unsuitable for such disposal.

The results of greatest interest obtained in these performance assessments is a complimentary cumulative distribution function (CCDF) that is used for comparison with the U. S. Environmental Protection Agency (EPA) release limits for radioactive waste disposal (U.S.EPA, 1985). As discussed in the preceding chapter (Chapter 2 of this volume), the EPA standard requires that the normalized releases to the accessible environment be expressed as a single CCDF and that this CCDF fall under certain specified bounds. At present, drilling intrusions are believed to be the most severe potential disruptions that need be considered at the WIPP (Guzowski, 1990 and 1991). Thus, the construction of this CCDF for the WIPP is based on summary scenarios that result from drilling intrusions.

This presentation will describe how a CCDF can be constructed for comparison against the EPA release limits when the disruptions to the waste disposal site under consideration result from drilling intrusions. For the results presented here, the drilling intrusions are assumed to follow a Poisson process (i.e., occur randomly in time and space)(Cox and Lewis, 1966; Haight, 1967; Cox and Isham, 1980) with a fixed rate constant. However, the described approach would work with any probability model for drilling intrusions.

With regard to the risk representation

$$\mathbb{R}=\{(S_i,pS_i,cS_i),i=1,\ldots,nS\} \qquad (3-1)$$

described in the preceding chapter and elsewhere (Kaplan and Garrick, 1981; Helton et. al., 1991). S_i is a set of similar time histories defined on the basis of drilling intrusions, pS_i is the probability for S_i, and **cS***i* contains the EPA normalized release for S_i. The S_i appearing in (3-1) are obtained by discretizing a suitable sample space. For comparisons with the EPA release limits, this sample space is

$S=\{x:x$ a single 10,000-year time history beginning at decommissioning of the facility under consideration$\}$. (3-2)

In what follows, an approach will be described for defining the S_i, assigning probabilities pS_i, and consequences $\mathbf{c}S_i$, to these S_i, and then constructing the resultant CCDF."

Volume 2, Section 5.2.3 SPATIAL AND TEMPORAL GRIDS, p 5-22;

" The geometry used in the two-phase disturbed conditions modeling is similar to that used in the undisturbed calculations. It represent as axisymmetric approximation to an equivalent panel. Cylindrical geometry was necessary for two reasons. First, the actual geometry of the WIPP repository is too complex for PA modeling; a mesh having all the detail of the repository, or even of a single panel, would be prohibitively large and would require more computation time than is available for a single year's PA calculation. Second, BRAGFLO is currently a two-dimensional model; cylindrical geometry allows the most important aspects of flow over a large areal extent to be simulated in only two dimensions. Specifically, the convergence of flow radially toward a point sink can be modeled more accurately in cylindrical geometry than in rectangular geometry. This is important because on a large scale the flow radial toward the intrusion borehole, which is located along the axis of symmetry. Even within a panel, because of the relatively high permeability of the waste, flow will be essentially radial, though constrained by the pillars to be more rectilinear. For flow into a panel from the far field, the most important features of a panel are its perimeter, both the length and the distance of the perimeter from the center where an intrusion well is assumed located, and the enclosed volume. How these parameters are averaged into a cylinder is somewhat arbitrary, and compromises are necessary.

In modeling a panel for PA purposes, the panel is treated as a cylinder having the same enclosed floor area as an actual panel, including the area occupied by the pillars. This results in a cylinder having a radius of 96.78 m. To account for the inclusion of pillars, which have a very low porosity, the porosity of the panel is adjusted from the final porosity of the waste alone. The initial brine saturation is also adjusted for the presence of pillars that are fully saturated with brine. These calculations are discussed in Section 3.4.8 of Volume 3.

The region modeled includes the cylindrical equivalent panel and the surrounding Salado formation with anhydrite layers above and below (see Figure 4-1). The borehole is coincident with the axis of symmetry. The region extends upward to the top of the Culebra, downward to the bottom of the Castile brine reservoir, and outward approximately 22.3 km. By including the Castile and Culebra, the major sources and sinks for brine flow to and from the repository are represented in a single model. The far-field boundary is intended to be far enough away to justify the use of a no-flow boundary, which is required in BRAGFLO, without the boundary effecting the behavior of the repository. While a further removed boundary might be desirable for greater accuracy with this model, the formations being modeled actually extend only about 10 km north of the repository (see Figure 1.5-2, Volume 3). Anhydrite layers a and b immediately above the repository have been consolidated into a

single layer with a thickness equal to the combined thicknesses of a and b and located at the elevation of layer b, the one closer to the repository. The panel thickness was varied, depending on the final porosity of the waste, which in turn depends on the composition of the waste and the total gas generation potential. The procedure for calculating the panel height and porosity, and the assumptions used, are described in Section 3.4.8 of Volume 3. The DRZ extends vertically upward through the anhydrite layer and downward through MB139. Beyond the outer radius of the panel, both the anhydrite layers and the Salado are intact. The center of the intrusion borehole is located at the axis of symmetry."

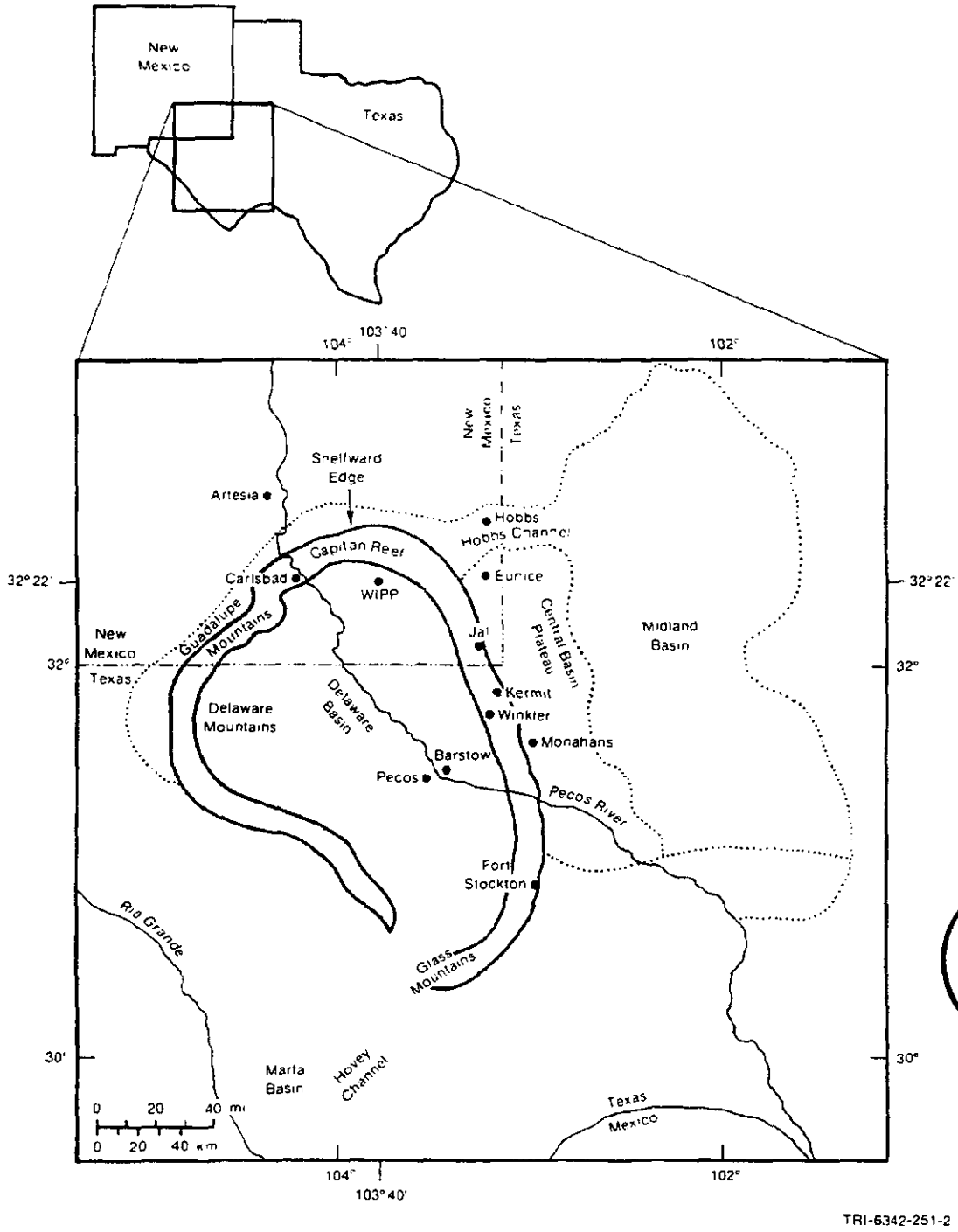

Figure 1.5-2. Location of the WIPP in the Delaware Basin (modified from Richey et al., 1985 and Lappin, 1988, Figure 1.4).

Volume 2, Section 6.2 Generation of Transmissivity Fields by Geostatics, p 6-5;

" Previous WIPP Performance Assessments used a simple zonal approach for including uncertainty in the transmissivity (*T*) field within the Culebra Dolomite Member of the Rustler Formation. The zonal method divides the regional and local computational domains into geographic regions; 8, 13, and 15 regions have been used for different analyses reported in Marietta et. al. (1989) and Bertram-Howery et. al. (1990). In each region, a distribution was constructed using transmissivity measurements from available wells. This empirical distribution was sampled and one constant value used for the transmissivity in each zone. Each zone was sampled independently, so a single simulation used 8 (or 13 or 15) transmissivity values to represent the regional *T* field. Some simulations used distributions constructed from pilot point values (LaVenue et. al., 1990) at locations assigned during calibration in addition to actual measurements at well locations.

This approach can be improved in two ways:

- The reason for varying transmissivity over geographic zones is to include spatial variability in the *T* field. Correlations exist in the *T* field over distances greater than five kilometers; however, assuming that the 8 (or 13 or 15) zones are independent during sampling is only a first approximation. Spatial dependence should be included over the whole model domain.
- The *T* fields generated by the simple zonal approach directly used transmissivity measurements whereas other information was included indirectly through pilot point values. Many other data are available, and it would be better to incorporate these data directly, e.g. hydraulic head measurements and geologic information.

Several methods have been proposed in the scientific literature to resolve these two issues. Most suggestions have relied on geostatistical techniques combined with inverse methods (de Marsily, 1986; Yeh, 1986). To obtain fast guidance on development of a package for WIPP PA to use in the final compliance assessment, a Geostatistical eXpert Group (GXG) was convened. The GXG was asked to provide advice given the modeling work completed, calibrated transmissivity field, data collected, and the above two objectives listed for improvement of the earlier zonal approach. The group's recommendations were organized into three categories:

- Proposing methods for generating conditional random fields to be used in the present assessment.
- Proposing methods for including conceptual model uncertainty.
- Proposing methods for including geological information.

These recommendations are summarized in the following discussion. . . ."

Volume 2, Section 6.4.2.2 Changing Climate Models, p 6-35;

" The climate model was planned to utilize the user-modifiable climate factor routines to input a modified sinusoidal variability of flux, including an LHS-sampled, uniformly distributed factor. This climatic variability was entered as a boundary recharge along 15 kilometers of the north and west regional boundaries. Difficulties arose from trying to apply

a single average flux value along the entire recharge boundary. The variability of sampled transmissivities changed this property by six orders of magnitude along this boundary, requiring a similar range of head values. This required us to look at other ways to incorporate climatic change in the model. For preliminary analysis a steady-state simulation with heads along the same recharge boundary set to the land surface elevation was used to represent the effects on climatic change.

Section 6.4.2.3 Climate Factors and Climatic Variability Calculations; p 6-35;
" For the 1991 preliminary comparison, climate variability was modeled by varying head along the recharge boundary. The amplitude of the climate function was bounded between present values and the land surface elevation, multiplied by a uniformly sampled value, ClimtIdx, ranging from zero to one. The user-modifiable climate function routine was utilized to model an equation with three peaks in ten thousand years (see Volume 3). This does not match the data base definition of five peaks in ten thousand years because it was written before the data base was defined. However, the integrated effect will be the same and the historical data show three minor climate peaks in the last ten thousand years. This model with its peaks occurring at exactly four thousand year intervals is not intended to predict the exact climatic change but only to model its effect."

Volume 2, Section 6.5.2 LOCAL TRANSPORT MODELING OF STAFF2D, p 6-47;
" The local transport modeling was performed with the STAFF2D finite element program. STAFF2D calculates either Darcy fluid flow or radionuclide transport. The flow fields used in the transport calculations were also calculated with STAFF2D as discussed above. Transport was calculated using the dual-porosity conceptual model. The flow and transport are assumed to take place in the fractures with a solute exchange between the fractures and matrix controlled by a one-diminsional diffusion equation. Single porosity fracture transport was calculated using a fracture field derived from the specific discharge by scaling the fracture porosity. Dual porosity transport used the fracture flow field but included diffusion into the matrix. Transport was also calculated using single-porosity fracture transport with no diffusion into the matrix."

Volume 3, Section 1.3.4 Elicitation of distributions from Experts, 1-20;
" This section discusses formal elicitation of probability distributions for model parameters that are uncertain and are considered significant in the performance assessment (e.g., estimate of radionuclide concentration in the disposal region [Trauth et. al., 1991]). Formal elicitation is also being used in the performance assessment of the WIPP to hypothesize about possible futures of society and the effects of appropriate markers to warn future societies about the WIPP; these elicitation efforts are discussed elsewhere (Hora et. al., 1991).

In all aspects of data gathering, professional judgement (i.e., opinion) must bridge the gaps in knowledge that invariably exist in scientific explanations. For example, the selection of methods to collect data (characterizing a site), interpretation of data, development of

conceptual models, and selection of model parameters all require professional judgement by the investigator. This volume summarizes these judgements.

When data are lacking, either because of the complexity of the processes or the time and resources it would take to collect data or when data have a major impact on the performance assessment, a formal elicitation of expert judgement is pursued. The procedure has the following advantages. First, formal elicitation offers a structured procedure for gathering opinion. Second, it encourages diversity in opinions and thus guards against understating the uncertainty. Finally, it promotes clear and thorough documentation of how the results were achieved (Hora and Iman, 1989).

The judgements that result from formal elicitation are a snapshot of the current state of knowledge. As new observations are made, the state of knowledge is refined. Even though the compilation of information through formal elicitation is often enlightening and helps to prevent bias, it does not create information. An important aspect of elicitation, which occurs either during or following the procedure, is to examine how new data collected may improve understanding."

Section 3.4.7 Permeability, p 3-130;

Parameter:	**Permeability (k), combustibles**
Median:	1.7×10^{-14}
Range:	2×10^{-15}
	2×10^{-13}
Units:	m^2
Distribution:	Cumulative
Source(s)	Butcher, B. M., T. W. Thompson, R. G. Van Buskirk, and N. C. Patti. 1991. *Mechanical Compaction of WIPP Simulated Waste.* SAND90-1206. Albuquerque, NM: Sandia National Laboratories

Parameter:	**Permeability (k), metals/glass**
Median:	5×10^{-13}
Range:	4×10^{-14}
	1.2×10^{-12}
Units:	m^2
Distribution:	Cumulative
Source(s)	Butcher, B. M., T. W. Thompson, R. G. Van Buskirk, and N. C. Patti. 1991. *Mechanical Compaction of WIPP Simulated Waste.* SAND90-1206. Albuquerque, NM: Sandia National Laboratories

Parameter:	**Permeability (k), sludge**
Median:	1.2×10^{-16}
Range:	1.1×10^{-17}
	1.7×10^{-16}
Units:	m^2
Distribution:	Cumulative
Source(s)	Butcher, B. M., T. W. Thompson, R. G. Van Buskirk, and N. C. Patti. 1991. *Mechanical Compaction of WIPP Simulated Waste.* SAND90-1206. Albuquerque, NM: Sandia National Laboratories

Mean Permeability of Drum, p 3-131, para 3;

" For computational ease, the PA Division assumed that the permeabilities of each component were uniformly distributed from the minimum to the maximum values given above in evaluating the permeability of an average drum. Consequently,, the distribution of local permeability (i.e., the effective permeability of a collapsed drum) was the weighted sum of uniform distributions, the weights being percent by volume of each component."

(Swift, P.N., 1991. Appendix A: Volume 3)

Introduction, p A-110;

" Ideally, it could be possible to describe variability in recharge within a single conceptual model for flow in the Culebra using a single parameter--future recharge as a function of present recharge. I recommend, however, separating recharge into two component functions: variability in mean annual precipitation and variability in the amount of precipitation that reaches our Culebra model domain as recharge. This distinction allows examining model sensitivity to climatic change independently of the uncertainty in the physical recharge process. The distinction is meaningful because we can assess climatic variability relatively confidently, whereas uncertainty about the recharge process is high. Sampling on separate parameters will permit us to perform sensitivity analyses (to be reported by Swift et. al., [in prep.], separately from the 1991 *Preliminary Comparison*) on both climate variability and the assumed recharge function.

This memo defines climate and recharge functions and the associated parameters to be sampled. The memo does not address conceptual model uncertainty about the location or amount of present recharge to the model domain, or about the location of the future recharge. These model uncertainties will be addressed in 1992 or later, as results become available from the geostatistics project addressing uncertainty in the Culebra flow model. The assumption is made here that future model recharge will be expressed as a function of nominal present flux into a calibrated steady-state flow model.

For the 1991 PA calculations, there appears to be little need to sample on a distribution of climate parameter values. As explained below, we can select 'best estimate' values for climate variability for the full-system simulations, and wait for the separate sensitivity analysis report to examine the impact of the assumptions. This does not mean that

the 1991 calculations will not include climate variability. Climate variability will be incorporated, and the results will reflect the knowledge that some future climates will be wetter than that of the present. The function and values I am recommending will give us an 'average' future precipitation roughly 1.3 times present, with peaks of just over 2 times present.

I do recommend sampling on the recharge function parameter. As defined here, this parameter is a simple multiplier that is applied to the nominal increase in precipitation, yielding the change in model recharge. The multiplier represents uncertainty in numerous parameters, including (i) the location and extent of the surface recharge area, (ii) groundwater flow between the surface recharge area and the boundary of the model domain, and (iii) the relationship between precipitation and infiltration in the surface recharge area, which in turn is dependent on factors such as vegetation, temperature, local topography, and soil characteristics. There is no particular reason to assume a 1-to-1 correlation between increases in precipitation and increases in model recharge, and limited evidence for water-table conditions in semi-arid climates suggests that increases in precipitation may result in substantially larger increases in infiltration. I recommend that we incorporate recharge uncertainty in the 1991 calculations by sampling a uniformly distributed recharge parameter (defined below) over a range that permits the relationship between mean annual precipitation and model recharge to vary between 1-to-1 and 10-to-1. This would mean that with precipitation at a maximum of 2x present, model recharge could range from 2x to 20x present. Both the range and the distribution are preliminary, and should be adjusted as new data or interpretations warrant."

Volume 4, ABSTRACT, p i;

" The most appropriate conceptual model for performance assessment at the Waste Isolation Pilot Plant (WIPP) is believed to include gas generation due to corrosion and microbial action in the repository and a dual-porosity (matrix and fracture porosity) representation for solute transport in the Culebra Dolomite Member of the Rustler Formation. Under these assumptions, complementary cumulative distribution functions (CCDFs) summarizing radionuclide releases to the accessible environment due to both cuttings removal and groundwater transport fall substantially below the release limits promulgated by the Environmental Protection Agency (EPA). This is the case even when the current estimates of the uncertainty in analysis inputs are incorporated into the performance assessment. The best-estimate performance-assessment results are dominated by cuttings removal. The releases to the accessible environment due to groundwater transport make very small contributions of CCDFs that must be considered in comparisons with the EPA release limits is dominated by the variable LAMBDA (rate constant in Poisson model for drilling intrusions). The variability in releases to the accessible environment due to individual drilling intrusions is dominated by DBDIAM (drill bit diameter). Most of the imprecisely known variables considered in the 1991 WIPP performance assessment relate to radionuclide releases to the accessible environment due to groundwater transport. For a single borehole (i.e., an E2-type scenario), whether or not a release from the repository to the Culebra even

occurs is controlled by the variable SALPERM (Salado permeability), with no releases for small values (i.e., $<5 \times 10^{-21} m^2$) of this variable. When SALPERM is small, the repository never fills with brine and so there is no flow up an intruding borehole that can transport radionuclides to the Culebra. Further, releases that do reach the Culebra for larger values of SALPERM are small and usually do not reach the accessible environment. A potentially important scenario for the WIPP involves two or more boreholes through the same waste panel, of which at least one penetrates a pressurized brine pocket and at least one does not (i.e., an E1E2-type scenario). For these scenarios, the uncertainty in release to the Culebra is dominated by the variables BHPERM (borehole permeability), BPPRES (brine pocket pressure), and the solubilities for the individual elements (i.e., Am, Np, Pu, Th, U) in the projected radionuclide inventory for the WIPP. Once a release reaches the Culebra, the matrix distribution coefficients for the individual elements are important, with releases to the Culebra often failing to reach the accessible environment over the 10,000-yr period specified in the EPA regulations. To provide additional perspective, the following variants of the 1991 WIPP performance assessment have also been considered: (1) no gas generation in the repository and a dual-porosity transport model in the Culebra; (2) gas generation in the repository and a single-porosity (fracture porosity) transport model in the Culebra; (3) no gas generation in the repository and a single-porosity transport model in the Culebra; (4) gas generation in the repository and a dual-porosity transport model in the Culebra without chemical retardation; and (5) gas generation in the repository, a dual-porosity transport model in the Culebra, and extremes of climatic variation. All of these variations relate to groundwater transport and thus do not affect releases due to cuttings removal, which were found to dominate the results of the 1991 WIPP performance assessment. However, these variations do have the potential to increase the importance of releases due to groundwater transport relative to releases due to cuttings removal."

Volume 4, 2.1 Conceptual Model, p 2-3, para 4;

" Once the distributions in Eq. 2.1-4 have been developed, Monte Carlo techniques can be used to determine the uncertainty in $R(\mathbf{x})$ that results from the uncertainty in $\mathbf{x}$. First, a sample

$$x_k = [x_{k1}, x_{k2}, ..., x_{k,nV}],\ k=1, ..., nK, \qquad (2.1\text{-}5)$$

is generated according to the specified distributions and restrictions, where nK is the size of the sample. The performance assessment is then performed for each sample element $\mathbf{x}_k$, which yields a sequence of risk results of the form

$$R(x_k) = [S_i(x_k), pS_i(x_k), cS_i(x_k)],\ i=1, ..., nS(x_k) \qquad (2.1\text{-}6)$$

for $k = 1, \ldots, nK$. Each set $R(\mathbf{x}_k)$ is the result of one complete performance assessment performed with a set of inputs (i.e., $\mathbf{x}_k$) that the review process producing the distributions in Eq. 2.1-4 concluded was possible. Further, associated with each risk result $R(\mathbf{x}_k)$ in Eq. 2.1-6 is a probability or weight that can be used in making probabilistic statements about the distribution of $R(\mathbf{x})$. When randon or Latin hypercube sampling is used, this weight is the reciprocal of the sample size (i.e., 1/nK)."

Volume 4, Section 3. UNCERTAIN VARIABLES, p 3-7, para 4;
" In addition to the variation between the cases shown in Table 3-2, the sampling-based approach to the treatment of subjective uncertainty also produces uncertainty and sensitivity results for the individual cases. In the following two chapters, box plots and distributions of CCDFs will be used to display the effect of subjective uncertainty on the cases listed in Table 3-2, and the impact of individual variables will be investigated with sensitivity analysis techniques based on scatterplots, regression analysis and partial correlation analysis. Scatterplots will also be used to compare results obtained with the different analysis cases listed in Table 3-2."

Sandia National Laboratories. 1992-1993. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. SAND92-0700, Vols. 1-5. Sandia National Laboratories, WIPP Performance Assessment Division, Albuquerque, NM. Vol. 1-WPO 20762, Vol. 2-WPO 20805, Vol. 3-WPO 23529, Vol. 4-WPO 20958, Vol. 5-WPO 20929.

Volume 1:
ABSTRACT, p i;

" Before disposing of transuranic wastes in the Waste Isolation Pilot Plant (WIPP), the United States Department of energy (DOE) must evaluate compliance with applicable long-term regulations of the United States Environmental Protection Agency (EPA). Sandia National Laboratories is conducting iterative performance assessments of the WIPP for the DOE to provide interim guidance while preparing for final compliance evaluations.

This volume contains an overview of WIPP performance assessment and a preliminary comparison with the long-term requirements of the *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR 191, Subpart B)*. Detailed information about the technical basis for the preliminary comparison is contained in Volume 2. The reference data base and values for input parameters used in the modeling system are contained in Volume 3. Uncertainty and sensitivity analyses related to 40 CFR 191B are contained in Volume 4. Volume 5 contains uncertainty and sensitivity analyses of gas and brine migration for undisturbed performance. Finally, guidance derived from the entire 1992 performance assessment is presented in Volume 6.

Results of the 1992 performance assessment are preliminary, and are not suitable for final comparison with 40 CFR 191, Subpart B. Portions of the modeling system and the data base remain incomplete, and the level of confidence in the performance estimates is not sufficient for a defensible compliance evaluation. Results are, however, suitable for providing guidance to the WIPP Project.

All results are conditional on the models and data used, and are presented for preliminary comparison to the Containment Requirements of 40 CFR 191, Subpart B as mean complimentary cumulative distribution functions (CCDFs) displaying estimated probabilistic releases of radionuclides to the accessible environment. Results compare three conceptual models for radionuclide transport in the Culebra Dolomite Member of the Rustler Formation and two approaches to estimating the probability of inadvertent human intrusion into the WIPP by exploratory drilling. The representation for disposal-system performance believed to be most realistic includes intrusion probabilities based on expert-panel judgement and dual-porosity transport with chemical retardation. For intrusions occurring 1000 years after decommissioning, the mean CCDF for this representation lies more than one order of magnitude below the EPA limits. Using the same approach to intrusion probabilities used in the 1991 performance assessment (i.e., not taking expert judgement into account and basing the probability model on the maximum intrusion probability indicated in Appendix B of 40 CFR 191, Subpart B) significantly increases the probability of releases, regardless of the model used for subsurface transport. Assuming the higher intrusion probabilities and dual-

porosity transport without chemical retardation, the mean CCDF is approximately one order of magnitude below the EPA limits. For the higher intrusion probabilities and single-porosity, fracture-only transport, the mean CCDF is less than one order of magnitude below the EPA limits."

4. PERFORMANCE-ASSESSMENT METHODOLOGY; p. 4-1, para. 1;

" This chapter contains a brief and simplified overview of the methodology used in WIPP performance assessment. A more complete discussion is presented in Volume 2 of this report and in references cited therein.

The WIPP performance assessment represents risk as a triplet consisting of the answers to the following three questions (Kaplan and Garrick, 1981):

(1) What can happen? (scenarios)

(2) How likely are things to happen? (probabilities of scenarios)

(3) What are the consequences of these things (scenarios) happening?

The first question is answered by a systematic scenario construction procedure that results in a set of comprehensive and mutually exclusive scenarios for consequence analysis (Guzowski, 1990; Cranwell et al., 1990; NEA, 1992b). Answering the second question requires that probability estimates be made for the scenarios retained for analysis. A formal elicitation procedure using expert panels has been recommended by other programs (Hora and Iman, 1989; Andersson et al., 1989; Stephens and Goodwin, 1989; Bonano et al., 1990) and employed by WIPP performance assessment. Answering the third question requires a modeling system to estimate consequences, expressed in terms of the performance measures of interest. The WIPP performance assessment uses a Monte Carlo technique to examine uncertainty in performance estimates and to perform sensitivity analyses that provide guidance to the Project.

The WIPP performance assessment is iterative, and answers to each of these three questions will be reexamined as the Project moves toward a final regulatory compliance evaluation. Thus, the set of scenarios selected for consequence analysis may change as new information dictates (although the scenarios examined in 1992 are essentially unchanged from 1991). Scenario probabilities have changed as expert judgement is incorporated, and the modeling system continues to change as new models and data become available."

State of New Mexico, Oil Conservation Division, Energy, Minerals, and Natural Resources Department. 1988. "Application of the Oil Conservation Division Upon It's Own Motion to Revise Order R-111. As Amended. Pertaining to the Potash Areas of Eddy and Lea Counties, New Mexico." Case 9316, Revision to Order R-111-P, April 21, 1988. Santa Fe, NM. On file in the NWM Library as KFN2581.

F. PLUGGING AND ABANDONMENT OF WELLS;

" (1) All wells heretofore and hereafter drilled within the Potash Area shall be plugged in a manner and in accordance with the general rules or field rules established by the Division that will provide a solid cement plug through the salt section and any water-bearing horizon and prevent liquids or gases from entering the hole above or below the salt section.

(2) The fluid used to mix the cement shall be saturated with the salts common to the salt section penetrated and with suitable proportions but not more than three (3) percent of calcium chloride by weight of cement being considered the desired mixture whenever possible."

Stenhouse, M.J., Chapman, N.A., and Sumerling, T.J. 1993. SITE-94 Scenario Development FEP Audit List Preparation: Methodology and Presentation. SKI Technical Report 93:27. Swedish Nuclear Power Inspectorate, Stockholm. Available from NTIS as DE 94621513.

PREFACE;

" This report concerns a study which is part of the SKI performance assessment project SITE-94. SITE-94 is a performance assessment of a hypothetical repository at a real site. The main objective of the project is to determine how site specific data should be assimilated into the performance assessment process and to evaluate how uncertainties inherent in site characterization will influence performance assessment results. Other important elements of SITE-94 are the development of a practical and defensible methodology for defining, constructing and analyzing scenarios, the development of approaches for treatment of uncertainties, evaluation of canister integrity, and the development and application of an appropriate Quality Assurance plan for Performance Assessments."

Thorne, M.C. 1992. Dry Run 3 - A Trial Assessment of Underground Disposal of Radioactive Wastes Based on Probabilistic Risk Analysis - Volume 8: Uncertainty and Bias Audit. United Kingdom Department of Environment Report DOE/HMIP/RR/92.040, London, England.

Preface to Volume 8, p. ii, para. 3;
" This volume-Uncertainty and Bias Audit-describes a possible procedure for carrying out a post-closure radiological safety assessment incorporating an audit of uncertainties and biases. This procedure has not been applied in Dry Run 3 since the methodology was under development in parallel with Dry Run 3. However, Dry Run 3 has provided a convenient opportunity to test certain aspects of the methodology. In particular:

- an Expert Group has been utilised to advise on factors/phenomena that should be included in a comprehensive assessment and to determine priorities for modelling;

- scoping calculations have been carried out to provide illustrative results, which have been used to demonstrate the potential biases inherent in the trial assessment;

- expert judgements have been used to assess the status of Dry Run 3 relative to a minimal assessment, as defined below.

Following a brief introduction (Chapter 1), Chapter 2 of the report summarises the over-all procedure for a post-closure radiological assessment incorporating an uncertainty and bias audit which was developed prior to the start of Dry Run 3. This procedure relies to a significant extent on the use of expert judgements. Such judgements have to be elicited in an appropriately structured manner, so that the judgements made, their bases, and their applications in the assessment, can be suitably documented. The use of expert judgements in the quantification of uncertainty, by the elicitation of parameter value distribution, is the subject of Volume 4. Expert judgement in relation to factors/phenomena that should be included in an assessment is the topic of Chapter 3 of this volume. This includes discussion of a formal procedure selecting the expert group (often the least well-documented part of the process), a description of the various phases of work involved in deriving groups of factors/phenomena for modelling, and assignment of levels of confidence in the results that would be obtained from assessments of different degrees of complexity.

Overall, it proved possible for the expert group to define a minimal assessment that they estimated would not exhibit gross bias because of excluded factors/phenomena. Small deletions from this minimal assessment could be tolerated with only a limited to moderate (less than a factor of 10) estimated effect on peak individual risks. More extensive deletions resulted in the expert group judging that too much of substance had been deleted and that the degree of bias would be unquantifiable without modeling studies, which effectively

corresponds to reintroducing the factors/phenomena into the assessment.

The material included in Chapter 3 provides a justification for the various modelling studies described in Chapter 4. These include both scoping calculations and deterministic calculations related to the pra studies undertaken as part of the main Dry Run 3 exercise and reported in Volume 6. In this section, reference is also made to the component model investigations reported in Volume 5.

The deliberations of the expert group, and the various calculations undertaken, lead to a variety of results. The individual results are summarised in Chapter 5, where approaches to their presentation and aggregation are explored, in so far as the limited material available allows.

Chapter 6 provides a discussion of the work undertaken. In particular, the Dry Run 3 experienced is used to estimate resource requirements for those parts of the uncertainty and bias component of a comprehensive post-closure radiological assessment of a site, which have been exercised. Limitations and deficiencies of the methodology are also discussed and areas requiring further development are highlighted."

Van Pelt, R.S. 1995. "Permeability Estimates of MGFT08 and MGFT09." SNL Technical Memorandum to M.K. Knowles. Contained in SWCF Record Package, "Small-Scale Seals Performance Test: Series A Post-Mortem," WPO 39631.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Vaughn, P., Bean, J., Garner, J., Lord, M., MacKinnon, R., McArthur, D., Schreiber, J., and Shinta, A. 1995. FEPs Screening Analysis DR2, DR3, DR6, DR7, and S6. Record Package submitted to SWCF-A:1.1.6.3:PA:QA:TSK:DR2, DR3, DR6, DR7, and S6. Sandia National Laboratories, Albuquerque, NM. WPO 38152.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wallace, M.G., Beauheim, R., Stockman, C., Martell, M.A., Brinster, K., Wilmot, R., and Corbet, T. 1995. FEPs Screening Analysis, NS-1: Dewey Lake Data Collection and Compilation. Record Package submitted to SWCF-A:1.1.6.3:PA:QA:TSK:NS1. Sandia National Laboratories, Albuquerque, NM WPO 30650.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wang, Y., and Brush, L.H. January 26, 1996. "Estimates of Gas Generation Parameters for the Long-Term WIPP Performance Assessment." WPO 31943.

Introduction, p. 1, para. 1;
" Steel corrosion and organic-material biodegradation have been identified as major gas-generation processes in the WIPP repository (Brush, 1995). Gas production will affect room closure and chemistry (Butcher, 1990; Brush, 1990). This memorandum provides the current estimates of gas-generation parameters for the long-term WIPP performance assessment. The parameters provided here include the rates of gas generation under inundated and humid conditions, the stoichiometric factors of gas generation reactions, and the probability of the occurence of organic material biodegradation (Table 1). To satisfy the quality assurance (QA) requirement (QAP 9-5), we summarize all hand calculations for estimating these parameters in Appendices I and II.

Biodegradation of Organic Materials

Cellulosics, plastics, and rubbers have been identified as the major organic materials to be emplaced in the WIPP repository (DOE/CAO, 1996) and could be degraded by microbes in 10,000 years. Cellulosics has been demonstrated experimentally to be the most biodegradable among these materials (Franci et al., 1995). The occurrence of significant microbial gas generation in the repository will depend on: (1) whether microbes capable of consuming the emplaced organic materials will be present and active; (2) whether sufficient electron acceptors will be present and available; (3) whether enough nutrients will be present and available. Considering uncertainties in evaluation of these factors and also in order to bracket all possible effect of gas generation on the WIPP performance assessment, we assign a 50% probabability to the occurance of significant microbial gas generation.

●Microbial Reactions

Microorganism will consume cellulosics mainly via the following reaction pathways in the repository (Brush, 1995):

$$C_6H_{10}O_5 + 4.8\ H^+ + 4.8\ NO_3^- \rightarrow 7.4\ H_2O + 6\ CO_2 + 2.4\ N_2 \quad (1)$$
$$C_6H_{10}O_5 + 6\ H^+ + 3\ SO_4^{2-} \rightarrow 5\ H_2O + 6\ CO_2 + 3\ H_2S \quad (2)$$
$$C_6H_{10}O_5 \rightarrow 3\ CH_4 + 3\ CO_2. \quad (3)$$

We assume that Reactions 1 to 3 will proceed sequentially according to the energy yield of each reaction. Here we ignore the reaction pathways of aerobic respiration, Mn(IV) and Fe(III) dissimilatory reduction, since the quantities of O_2, Mn(IV) and Fe(III) initially present in the repository will be negligible relative to the other electron acceptors. In Reactions 1 to 3, biomass accumulation is also taken into account. This is because significant biomass accumulation seems unlikely in the WIPP repository and the accumulated

biomass, if any, will be recycled by microbes after all biodegradable cellulosics is consumed.

In addition to Reaction (3), methanogenesis may proceed via:

$$4\ H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O. \qquad (4)$$

However, this reaction will be ignored in our calculations, because (1) no experimental data are availabe to evaluate the rate of this reaction and (2) the net effect of this reaction is to reduce the total gas generation and the amount of CO_2 in the repository and, therefore, it is conservative to ignore this reaction in respect of repository pressurization and actinide solubility."

Anoxic Steel Corrosion, p. 4, para. 2;
" According to current waste inventory estimates, a large amount of steels will be emplaced in the WIPP repository (DOE/CAO, 1996). Those steels will be capable of reacting with the repository brine to form H_2 gas. Both thermodynamic calculations and experimental observations indicate that the H_2 gas can be generated to pressures exceeding the lithostatic pressure at the WIPP horizon, if enough brine enters the repository (Brush, 1990; Telander & Westerman, 1993, 1995). Since the repository will become anoxic shortly after waste emplacement and sealing, we here focus only on anoxic steel corrosion."

Stoichiometric Factors in the Average-Stoichiometry Model, p. 6, para. 3;
" In the Average-Stoichiometry Model, which is currently implemented in BRAGFLO, microbial gas generation is represented by the overall reaction:

$$\frac{1}{6}\ C_6\ H_{10}\ O_5 + unknown \rightarrow y\ gas + unknown \qquad (10)$$

and H_2 production due to steel corrosion is described by:

$$Fe + \frac{4+2x}{3}\ H_2O \rightarrow \frac{4-x}{3}\ H_2 + x\ Fe(OH)_2 + \frac{1-x}{3}\ Fe_3O_4. \qquad (11)$$

The stoichiometric factors x and y in Reaction 10 and 11 are estimated as follows.

- Average-Stoichiometric FactorY in Microbial Reaction

The stoichiometric factor y depends on the extent of the progress of each individual reaction pathway (Reactions 1 through 3). It can be estimated based on the inventory estimates of the transuranic waste to be emplaced in the Waste Isolation Pilot Plant

(DOE/CAO, 1996; Drez, 1996).

First, we estimate the maximum quantities (in moles) of cellulosics and steels that will be potentially consumed in 10,000 years:

$$M'_{cel} = \min\left\{\frac{6000M_{cel}}{162},\ 10000R'_C M_{cel}\right\} \tag{12}$$

$$M'_{Fe} = \min\left\{\frac{1000M_{Fe}}{56},\ 1410R_{c,i}A\right\} \tag{13}$$

with

$$R'_c = \max\left\{R_{m,i},\ R_{m,h}\right\} \tag{14}$$

where M_{cel} and M_{Fe} are the quantities (in kg) of cellulosics and steels initially present in the repository; $R_{c,i}$ is the inundated steel-corrosion rate (μu/year); $R_{m,i}$ and $R_{m,h}$ are the sampled rates of cellulosics biodegradation under inundated and humid conditions respectively (mole/kg/year). In Equation (13), we use the factor of 0.141 mole/μm/m^2 to convert steel-corrosion-rate unit from μm/year to mole/m^2/year (Telander and Westerman, 1995). Here, we assume that cellulosics biodegradation and steel corrosion both follow zero order reaction kinetics. Next, we calculate the average stoichiometric factor y by distributing M'_{cel} into individual biodegradation pathways. Consider two extreme cases, corresponding to the maximum and minimum values of y: (1) no reaction of microbially produced CO_2 and H_2S with steel and steel-corrosion products.

If no CO_2 or H_2S is consumed by reactions with steel and steel-corrosion products, we would expect the maximum quantity of microbial gas production in the repository and therefore the maximum value for y. We assume that Reactions 1 to 3 will proceed sequentially. The maximum value of y can be estimated by averaging the gas-yields for all reaction pathways:

$$y_{max} = \frac{\frac{8.4M_{NO3}}{4.8} + \frac{9M_{SO4}}{3} + \left(M'_{cel} - \frac{6M_{NO3}}{4.8} - \frac{6M_{SO4}}{3}\right)}{M'_{cel}} \tag{15}$$

where M_{NO3} and M_{SO4} are the quantities of NO_3^- and SO_4^{2-}(in moles) initially present in the repository.

If CO_2 or H_2S reacts with steel and steel-corrosion products, we expect that a significant quantity or, perhaps, all of these microbially produced gases would be consumed, thus forming $FeCO_3$ and FeS. This would result in the minimum value of y. The total gas consumed by those reactions (G) is:

$$G = \min\left\{\frac{6M_{NO3}}{4.8} + \frac{9M_{SO4}}{3} + \frac{3}{6}\left(M'_{cel} - \frac{6M_{NO3}}{4.8} - \frac{6M_{SO4}}{3}\right), M'_{Fe}\right\} \tag{16}$$

The minimum value of y can then be estimated by:

$$y_{min} = \frac{\frac{8.4M_{NO3}}{4.8} + \frac{9M_{SO4}}{3} + \left(M'_{cel} - \frac{6M_{NO3}}{4.8} - \frac{6M_{SO4}}{3}\right) - G}{M'_{cel}} = y_{max} - \frac{G}{M'_{cel}} \tag{17}$$

For each BRAGFLO simulation, y will be uniformly sampled over $[y_{min}, y_{max}]$:

$$y = y_{min} + \beta(y_{max} - y_{min}) \tag{18}$$

with $0 \leq \beta \leq 1.0$. The calculational scheme proposed here automatically correlates y with waste inventory estimates as well as with reaction rates.

The above calculational scheme does not take into account the SO_4^{2-} that will be brought into repository by brine inflow. Based the previous BRAGFLO simulations for undisturbed cases, the total volume of the brine entering the repository in 10000 years is unlikely to be larger than 2.2×10^7 liters, the value corresponding to the case with unrealistically low gas generation and therefore the worst repository flooding. With a typical SO_4^{2-} concentration of 200mM in WIPP brines (Brush, 1990), we estimate that the amount of SO_4^{2-} brought into the repository by brine inflow would be less than 0.4×10^7 moles. This amount of SO_4^{2-} will increase the fraction of sulfate reduction pathway in total cellulosics

biodegradation only by less than 1%. Therefore, neglecting the sulfate brought by brine inflow would introduce an error of no more than a few percents in y values.

- Average-Stoichiometric FactorX in Steel Corrosion Reaction

While magnetite (Fe_3O_4) has been observed to form on steel as a corrosion product in low-Mg anoxic brines at elevated temperatures (Telander & Westerman, 1995) and in oxic brine (Haberman & Frydrych, 1988), there is no evidence that it will form at WIPP repository temperatures. If Fe_3O_4 were to form, it would be expected that H_2 would be produced (on a molar basis) in excess of Fe consumed. But, the anoxic corrosion experiments did not show the production of H_2 in excess of Fe reacted. Therefore, we set the stoichiometric factor x to 1.0 in Reaction 11."

BIBLIOGRAPHY DOCUMENTS

Adams, J.E. 1944. Upper Permian Ochoa Series of the Delaware Basin, West Texas and Southeastern New Mexico. American Association of Petroleum Geologists Bulletin, Vol. 28, No. 11, pp. 1596–1625. WPO 37940.

ABSTRACT, p 1596;

" The Ochoa series includes the uppermost Permian deposits of the southwestern United States. Most of the rocks included in the series are poorly exposed unfossiliferous evaporites. The well known subsurface section in and around the Delaware basin is described and illustrated by cross sections. A short chapter discusses theories on the origin and distribution of the characteristic evaporites."

Anderson, R.Y., 1978. Deep Dissolution of Salt, Northern Delaware Basin, New Mexico. Sandia National Laboratories, Albuquerque, NM. WPO 29527 - WPO 29530.

Abstract, p v:

" Deep-seated dissolution in the Delaware basin has developed in association with the Capitan (reef) and the underlying Bell Canyon (Delaware) aquifers and at a more permeable horizon between the Castile and Salado formations. The uplift, erosion, and exposure of the reef in the Guadalupe and Glass mountains has channeled meteoric waters through the reef aquifer. These waters gained access to the salt through fractures around the reef margin, and dissolved overlying and superjacent salt by means of brine density flow. This type of deep dissolution moved into the salt beds laterally at a horizon of increased permeability between the Castile and Salado formations and dissolved a wedge that undercut the overlying evaporites. The deep-seated dissolution also produced a number of large-scale collapse structures along the basin margin and along the western edge of salt. This wedge-like effect, combined with surface dissolution, has removed 50 percent of the original salt from the basin and removed 70 percent of the original salt at the lower Salado horizon.

The water in the aquifers, by gaining access to overlying chambers though fractures, have also dissolved smaller scale localized chambers in overlying salt beds that subsequently collapse to form breccia pipes, deep-seated sinks, and other collapse structures. These features have been exhumed to different stratigraphic levels in the tilted and eroded basin, resulting in surface expression as limestone buttes (Castiles), collapsed outliers, domal structures with collapsed centers (breccia pipes), and deep-seated sinks. Many of the deep-seated sinks are associated with salt anticlines which probably formed as a result of differential stress from unloading related to dissolution. Localized collapse, as well as regional dissolution, is an ongoing process.

The W.I.P.P. site lies in a corner of the Delaware basin that has been relatively protected from regional but not localized effects of deep dissolution. Deep seated, wedge-like dissolution, however, has progressed from north to south in the basin and salt in the northern part of the Delaware basin will eventually be dissolved at the lower Salado horizons before overlying salt has been removed from the basin by processes of near-surface dissolution (suberosion)."

Anderson, R.Y., and Kirkland, D.W. 1980. Dissolution of Salt Deposits by Brine Density Flow. Geology, Vol. 8, No. 2, pp. 66-69.

ABSTRACT, P 66;

" The origin of collapse structures and breccias that vertically penetrate or occur within impermeable evaporites has never really been understood. The density of the brine that develops as salt deposits are dissolved can generate continuous gravitational brine movement. If the source of the dissolving water is artesian, or continuous, a flow cycle is developed in which the salt itself supplies the density gradient that becomes the vehicle of its own dissolution. The Delaware Basin in western Texas and southeastern New Mexico provides a particularly good example of how brine density flow can produce dissolution chambers that collapse to form breccias. The potential for dissolution by brine flow is an inherent property of partly exhumed evaporites and may constitute a risk factor in the storage of radioactive waste in evaporite deposits."

Anderson, R.Y., Dean, W.E., Kirkland, D.W., and Snider, H. I. 1972. Permian Castile Varved Evaporite Sequence, West Texas and New Mexico. Geological Society of America Bulletin, Vol. 83, No. 1, pp. 59-85.

ABSTRACT; p 59, col 1;

" Laminations in the Upper Permian evaporite sequence in the Delaware Basin appear in the preevaporite phase of the uppermost Bell Canyon Formation as alternation of siltstone and organic layers. The laminations then change character and composition upward to organically laminated claystone, organically laminated calcite, the calcite-laminated anhydrite typical of the Castile Formation, and finally to the anhydrite-laminated halite of the Castile and Salado.

Laminae are correlative for distances up to 111 km (70.2 mi) and probably throughout most of the basin. Each laminae is synchronous, and each couplet of two laminated components is interpreted as representing an annual layer of sedimentation--a varve.

The thickness of each couplet in the 260,000-varve sequence (a total thickness of 447.2 m, (1465 ft) has been measured individually and recorded and provides the basis for subdividing and correlating major stratigraphic units within the basin. The uppermost 9.2 m (30.3 ft) of the Bell Canyon Formation contains about 50,850 varve couplets; the Basal Limestone Member of the Castile about 600; the lowermost anhydrite member of the Castile (Anhydrite I) contains 38,397; Halite I, 1,063;Anhydrite II, ??,414; Halite II, 1,758; Anhydrite III, 46,592; Halite III, 17,879; and Anhydrite IV, 54,187. The part of the Salado collected (126.6 m) contains 35,422 varve couplets. The Bell Canyon-Castile sequence in the cores studies is apparently continuous, with no recognizable unconformities.

The dominant petrologic oscillation in the Castile and Salado, other than the laminations, is a change from thinner undisturbed anhydrite laminae to thicker anhydrite laminae that generally show a secondary or penecontemporaneous nodular character, with about 1,000 to 3,000 units between major oscillations or nodular beds. These nodular zones are correlative throughout the area of study and underly halite when it is present. The halite layers alternate with anhydrite laminae, are generally recrystallized, and have an average thickness of about 3 cm. The halite beds were once west of their present occurrence in the basin but were dissolved, leaving beds of anhydrite breccia. The onset and cessation of halite deposition in the basin was nearly synchronous.

The Anhydrite I and II Members thicken gradually across the basin from west to east, whereas the Halite I, II, and III Members are thickest in the eastern and northeastern part of the basin and thicken from southeast to northwest. This distribution and the synchroneity *indicate a departure from the classical model of evaporite zonation.*"

Argüello, J.G., Molecke, M.A., and Beraun, R., 1989. "3D Thermal Stress Analysis of WIPP T RH TRU Experiments." Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Proceedings of the 30th U.S. Rock Mechanics Symposium, West Virginia University, Morgantown, WV, June 19-22, 1989, A.W. Khair, Ed. SAND88-2734C, pp. 681-688. A. A. Balkema, Brookfield, VT. WPO 25724.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Bachman, G.O. 1973. Surficial Features and Late Cenozoic History in Southeastern New Mexico. Open-File Report 4339-8. U.S. Geological Survey, Reston, VA.

ABSTRACT, p. 1;

" Since deposition of the Ogallala Formation during Pliocene time, southeastern New Mexico has been subjected to erosion, solution, subsidence, and widespread eolian activity. These processes have combined to influence the formation and morphology of major drainage systems. Aligned drainage patterns resulted from solution of caliche localized by longitudinal sand dunes. San Simon Swale appears to have formed by processes of erosion and solution-subsidence of Permian evaporites, and was formerly an important tributary to the Pecos River. The combination of processes that formed San Simon Swale was similar to the combination of erosion and coalescing sinks that formed the lower Pecos Valley in southern New Mexico.

Bachman, G.O. 1974. Geologic Processes and Cenozoic History Related to Salt Dissolution in Southeastern New Mexico. Open-File Report 74-194, U.S. Geological Survey, Denver, CO.

ABSTRACT, P 1;

" Salt of Permian age in the subsurface of an area near The Divide, east of Carlsbad, N. Mex., is being considered for a nuclear waste repository. The geologic history of the region indicates that dissolution of salt has occurred in the past during at least three distinct epochs: (1) after Triassic but before middle Pleistocene time; (2) during middle Pleistocene; and (3) during late Pleistocene. Thus, destructive geologic processes have been intermittent through more than 100 million years.

Nash Draw, near The Divide, formed during late Pleistocene time by the coalescing of collapse sinks. The rate of its subsidence is estimated to have been about 10 cm (0.33 ft) per thousand years. The immediate area of the Divide adjacent to Nash Draw has not undergone stress by geologic processes during Pleistocene time and there are no present indications that this geologic environment will change drastically within the period of concern for the repository."

Bachman, G.O., 1976. Cenozoic Deposits of Southeastern New Mexico and an Outline of the History of Evaporite Dissolution. Journal of Research, Vol. 4, No. 2, pp. 135-149. US Geological Survey, Denver, CO.

ABSTRACT, p 135;

" Sedimentary records of Cenozoic history in Southeastern New Mexico begin with the Ogallala Formation , Miocene and Pliocene age. Later records include the Gatuna Formation of early or middle Pleistocene age, Mescalero caliche, an informal term, of middle Pleistocene age, and fluvial deposits of late Pleistocene age but there are many gaps in some record. The modern landscape is the result of erosion and deposition in climates that have ranged from semihumid to semiarid as well as dissolution of soluble rocks in Permian Formations in the subsurface. This dissolution may have been as early as Jurassic time and has continued intermittently to the present.

Bachman, G.O., 1980. Regional Geology and Cenozoic History of Pecos Region, Southeastern New Mexico. Open-File Report 80-1099. U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;

" This report summarizes the Cenozoic history of the Pecos drainage in the Delaware basin, southeastern New Mexico, and incorporates an outline of the dissolution and karst development in Permian evaporites in the region.

Evaporites include anhydrite, gypsum, halite and related minerals. They are included in the Castile, Salado and Rustler Formations of Late Permian (ochoan) age. These formations have been transgressed by strata of the Dockum Group of Late Triassic age and unnamed formations of early Cretaceous age.

Complex karst features include collapse sinks, karst mounds (new term), karst domes (new term) and caves. Karst mounds are erosional remnants of regional breccia. Karst domes are structural features which have formed on a very irregular dissolution surface. They are analogous to towers, kegelkarst or mogotes in tropical regions except that karst domes are almost buried by their own dissolution residue.

Breccia chimneys are collapse sinks which have formed over the Capitan aquifer system. They appear to be the result of unsaturated water rising under a strong hydraulic head through fractures and dissolving upward into the evaporite sequence.

Breccia chimneys, karst mounds and karst domes studied during this work were formed during middle Pleistocene time.

Dissolution has been an active process in the Delaware basin at least since Triassic time and it is impractical to attempt to calculate a rate of dissolution for the basin. Earlier estimates of the rate of dissolution are considered to be conservative. Subsurface evidence does not suggest that deep dissolution is presently an active process in the Castile Formation beneath the thick beds of Salado salt.

Pleistocene glaciation in the northern and central United States was probably accompanied by 'pluvial' periods in southeastern New Mexico. Pluvials are characterized by less extreme temperatures, less evaporation and more effective moisture than at present."

Bachman, G.O. 1981. Geology of Nash Draw, Eddy County, New Mexico. Open-File Report 81-31. U.S. Geological Survey, Denver, CO.

ABSTRACT, p. 1;

" Nash Draw is a partially closed depression about 29 km (17 mi) east of Carlsbad, Eddy County, New Mexico. It has been mapped geologically in conjunction with detailed studies to evaluate the proposed nuclear Waste Isolation Pilot Plant (WIPP). Maps at scales of 1:24,000 accompany this report.

The stratigraphic section exposed in Nash Draw includes the Rustler Formation and Dewey Lake Red Beds of Late Permian (Ochoan) age, the Dockum Group of Late Triassic age, and the Pleistocene Gatuna Formation. Other deposits of Middle to late Quaternary age include the Mescalero caliche, spring deposits, and windblown sand.

Dissolution of evaporites has been a major process in the formation of Nash Draw. Nash Draw formed before, and during, Gatuna time about 600,000 years ago. Near-surface dissolution of gypsum in the Rustler Formation is presently active and is responsible for numerous collapse sinks and related karst features."

Bachman, G.O., 1984. Regional Geology of Ochoan Evaporites, Northern Part of Delaware Basin. Circular 184, pp. 1-22. New Mexico Bureau of Mines and Mineral Resources Socorro, NM.

ABSTRACT, p 5;

" The Ochoan Series (Permian) in the northern part of the Delaware Basin, southeastern New Mexico, includes in ascending order the Castile, Salado, and Rustler Formations, and the Dewey Lake Red Beds. The Castile and Salado Formations comprise a sequence of evaporites which include anhydrite, gypsum, halite, and associated potash salts. The Rustler Formation contains some halite and minor amounts of potash minerals. These evaporites were deposited within the basin formed by the Capitan barrier reef, as well as across the reef. The evaporites, as well as the Capitan reef, are all subject to dissolution with resulting karst features analogous to those formed in limestone regions.

An Ancestral Pecos River was the major drainage system in the western part of the Delaware Basin, New Mexico, during the Cenozoic time. That ancient river system was responsible for the formation of an extensive karst terrain along the east side of the present Pecos River in New Mexico and southward into Texas. During late Cenozoic time extensive dissolution occurred in the Salado Formation within the karst area as a result of the ground-water regime. The dissolution front was perched on the upper anhydrite member of the Castile Formation.

On the eastern side of the Delaware Basin in New Mexico, a large collapse sink--San Simon sink--overlies the Capitan reef which is a prominent aquifer system in that area. So-called 'breccia pipes' are ancient sinks which collapsed into the caverns in the reef on the northern margin of the basin. These have since been partially exhumed. The San Simon sink is presumed to be a modern analog of these breccia pipes."

Bachman, G.O., 1985. Assessment of Near-Surface Dissolution at and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico. SAND84-7178. Sandia National Laboratories, Albuquerque, NM. WPO 24609.

ABSTRACT, p. 3;

" The area at and near the WIPP site was examined for evidence of karst development on the geomorphic surface encompassing the site. Certain surficial depressions of initial concern were identified as blowouts in sand dune fields (shallow features unrelated to karstification). An ancient stream system active more than 500,000 years ago contained more water than any system since. During that time (Gatuña, Middle Pleistocene), many karst features such as Clayton Basin and Nash Draw began to form in the region. Halite was probably dissolved from parts of the Rustler Formation at that time. Dissolution of halite and gypsum from intervals encountered in Borehole WIPP-33 west of the WIPP site occurred during later Pleistocene time (i.e., <450,000 yr ago). However, there is no evidence of active near-surface dissolution within a belt to the east of WIPP-33 in the vicinity of the WIPP shaft."

Bachman, G.O., 1987. Karst in Evaporites in Southeastern New Mexico. SAND86-7078. Sandia National Laboratories, Albuquerque, NM. WPO 24006.

ABSTRACT;
" Permian evaporites in southeastern New Mexico include gypsum, anhydrite, and salt, which are subject to both blanket and local, selective dissolution. Dissolution has produced many hundreds of individual karst features including collapse sinks, karst valleys, blind valleys, karst plains, caves, and breccia pipes. Dissolution began within some formations during Permian time and has been intermittent but continual ever since. Karst features other than blanket deposits of breccia are not preserved from the early episodes of dissolution, but some karst features preserved today--such as breccia pipes--are remnants of karst activity that was active at least as early as mid-Pleistocene time. Rainfall was much more abundant during Late Pleistocene time, and many features visible today may have been formed then. The drainage history of the Pecos River is related to extensive karstification of the Pecos Valley during mid-Pleistocene time. Large-scale stream piracy and dissolution of salt in the subsurface resulted in major shifts and excavations in the channel. In spite of intensive groundwater studies that have been carried out in the region, major problems in groundwater in near-surface evaporite karst remain to be solved. Among these are determination of recharge areas and time of recharge."

Bachman, G.O., Johnson, R.B., and Swenson, F.A. 1973. Stability of Salt in the Permian Salt Basin of Kansas, Oklahoma, Texas, and New Mexico, Open-File Report 4339-4. U.S. Geological Survey, Denver, CO.

ABSTRACT, p 1;

" The Permian salt basin in the Western Interior of the United States is defined as that region comprising a series of sedimentary basins in which halite and associated salts accumulated during Permian time. The region includes the western part of Kansas, Oklahoma, and Texas, and eastern parts of Colorado and New Mexico.

Following a long period of general tectonic stability throughout the region during most of early Paleozoic time, there was much tectonic activity in the area of the Permian salt basin during Late Pennsylvanian and early Permian time just before bedded salt was deposited. The Early Permian tectonism was followed by stabilization of the basins in which the salt was deposited. These salt basins were neither contemporaneous nor continuous throughout the region so that many salt beds are also discontinuous. In general, beds in the northern part of the basin (Kansas and northern Oklahoma) are older, and the salt is progressively younger towards the south.

Since Permian time, the Permian salt basin has been relatively stable tectonically. Regionally, the area of the salt basin has been tilted and warped, has undergone periods of erosion, and has been subject to a major incursion of the sea; but deep-seated faults or igneous intrusions that postdate Permian salt are rare. In areas of the salt basin where salt is near the surface, such as southern New Mexico and central Kansas, there are no indications of younger deep-seated faulting and only a few isolated igneous intrusives of post-Permian age.

On the other hand, subsidence or collapse of the land surface resulting from dissolution has been commonplace in the Permian salt basin. Some dissolution of salt deposits has probably been taking place ever since deposition of the salt more than 230 million years ago. Nevertheless, the subsurface dissolution fronts of the thick bedded-salt deposits of the Permian basin have retreated at a very slow average rate during that 230 million years.

The preservation of bedded salt from subsurface dissolution depends chiefly on the isolation of the salt from moving groundwater that is not completely saturated with salt. Karst topography is a major criterion for recognizing areas where subsurface dissolution has been active in the past; therefore, the age of the karst development is needed to provide the most accurate estimate of the dissolution rate. The Ogallala Formation of Pliocene age is probably the most widespread deposit in the Permian salt basin that can be used as a point of reference for dating the development of recent topography. It is estimated that salt has been dissolved laterally in the vicinity of Carlsbad, New Mexico, at an average rate of about 6-8 miles per million years.

Estimates of future rates of salt dissolution and the resulting lateral retreat of the underground dissolution front can be projected with reasonable confidence for southeastern

New Mexico of the assumption that the climatic changes there in the past 4 million years are representative of climatic changes that may be expected in the near future of geologic time.

Large amounts of salt are carried by present-day rivers in the Permian salt basin; some of the salt is derived from subsurface salt beds, but dissolution is relatively slow. Ground-water movement through the Permian salt basin is also relatively slow."

Baes, C.F., and Mesmer, R.E. 1976. The Hydrolysis of Cations. John Wiley & Sons, New York, NY.

1. Introduction, p 1;

" The word *hydrolysis* is applied to chemical reactions in which a substance is split or decomposed by water. In organic chemistry, the products of the reaction are usually molecular, being formed by combination with H and OH groups, as in hydrolysis of an ester to an alcohol and a carboxylic acid. In inorganic chemistry, the word most often has been applied to solutions of salts and the reactions by which they are converted to new ionic species or to precipitates--oxides, hydroxides, or basic salts. The hydrolysis of salts can involve either the cation, the anion, or both. We shall be concerned primarily with the hydrolysis of cations to form soluble hydroxide or oxide complexes and, to a lesser extent, with the formation of hydroxide and oxide precipitates."

Barker, D.S. 1977. Northern Trans-Pecos Magmatic Province: Introduction and Comparison with the Kenya Rift. Geological Society of America Bulletin. Vol. 88, no. 10, pp. 1421-1427.

ABSTRACT, p 1421, col 1;

" The Trans-Pecos magmatic province of West Texas and southern New Mexico is a more eroded analogue of the Kenya (Gregory) rift in East Africa. Trans-Pecos alkalic-rocks are similar to the basalt-phonolite-trachyte-rhyolite assemblage from fissure and multicenter eruptions, and from some central volcanoes, in the Kenya rift. In both provinces, quartz-normative and nepheline-normative mafic rocks occur, providing likely parents for the entire observed range of silica saturation. Thus, no special mechanism is needed for deriving silica-undersaturated and silica-oversaturated rocks from one another, because both groups evolved independently. The Kenya rocks tend to be more mafic and, at the silicic end of their compositonal range, more peralkalic than the Trans-Pecos rocks.

Similarities in tectonic style, extent and duration of magnetism, and igneous rock compositions in the two provinces suggest that the alkalic rocks in both regions were generated by differentiation from quartz- and nepheline-normative parents in the upper parts of elongate mafic or ultramafic intrusions, probably diapiric welts that caused doming and normal faulting."

Bear, J. 1988. Dynamics of Fluids in Porous Media. Dover Publications, Inc., New York, NY. NNA. 911127.0046.

PREFACE, p xvii;

" This book is an attempt to present, in an ordered manner, the theory of dynamics (actually, also of statics) of fluids in porous media, as applicable to many disciplines of science and engineering. For some years I have taught courses on flow through porous media, and have treated this subject as a part of other courses, such as ground water hydrology, while at the Technion--Israel Institute of Technology, at M.I.T., while I spent my sabbatical leave (1966-7), and at several other institutions. I have felt the lack of a suitable textbook on this subject. Ideally, such a text should start from first principles of fluid mechanics and mechanics of continua, should show the passage from the microscopic to the macroscopic level of treatment, should emphasize the special features of porous media, establish the macroscopic theory and then show how it is applied to cases of practical interest.

It is rather surprising that in spite of its performance in many fields of practical interest, such as petroleum engineering, ground water hydrology, agricultural engineering and soil mechanics, so small number of treatises is available on fluids in porous media. This circumstance is even more surprising in view of the vast amount of literature published on the subject in a number of scientific and engineering journals. Although dynamics of fluids in porous media could become an interesting interdisciplinary course serving several departments, I believe that the relatively small number of courses offered by universities on the subject is due in part to lack of a suitable textbook. To overcome this lack I prepared notes for my own classes, which I present here in the form of a book, hoping that it will serve others in a similar situation.

The book is designed primarily for advanced undergraduate students and for graduates in fields such as ground water hydrology, soil mechanics, soil physics, drainage and irrigation engineering, sanitary engineering, petroleum engineering and chemical engineering, where flow through porous media plays a fundamental role. The book, I hope, will also serve the needs of scientists and engineers already active in these fields, who require a sound theoretical basis for their work. The emphasis in this book is on understanding the microscopic phenomena occurring in porous media and on their macroscopic description. The reader is led to grasp the meanings of the various parameters and coefficients appearing in the macroscopic descriptions of problems of flow through porous media, and their actual determination, as well as the limitations and approximations inherent in their description. In each case, the objective is to achieve a clear formulation of the flow problem considered and a complete mathematical statement of it in terms of partial differential equations and a set of initial and boundary conditions. Once a flow problem is stated properly in mathematical terms, three methods of solution are possible in principle: analytic solution, numerical solution aided by high speed digital computers and solution by means of laboratory models and analogs. All three tools are described in this book. Typical examples of analytic solutions are scattered throughout the book, but no attempt is made to present a collection of

a large number of solved problems. The principles of the numerical method of solution are presented, and a detailed description is given of laboratory models and analogs, their scaling and applications.

Mathematics is employed extensively and the reader is expected to have a good background in advanced engineering mathematics, including such subjects as vector analysis, Cartesian tensor analysis, partial differential equations and elements of the theory of functions.

Obviously, a single book, even of this size, cannot include everything related to the subject treated. Although we consider porous media in general, the discussion is limited to media with relatively large pores, thus excluding clays and media with micropores or colloidal-size particles. Similarly, chemical and electrochemical surface phenomena are excluded. The discussion is restricted to Newtonian fluids.

With these objectives and limitations in mind, the book starts with examples of two important porous media: the ground water aquifer and the oil reservoir. An attempt is made to define porous media, and the continuum approach is introduced as a tool for treating phenomena in porous media. This requires the definition of a 'representative elementary volume' based on the definition of porosity. Chapter 2 includes a summary of some important fluid and porous media properties. In chapter 3, the concepts of pressure and piezometric head are introduced. Chapter 4 starts with the definition of velocities and fluxes in a fluid continuum. Then the equations of conservation of mass, momentum and energy in a fluid continuum are presented, and using a porous medium conceptual model these equations are averaged to obtain the basic equations that describe flow through porous media: the equations of volume and mass conservation , including the equation of mass conservation of a species in solution (also called the equation of hydrodynamic dispersion), and the motion equation for the general case of an anisotropic medium and inhomogeneous fluid. Although the basic equations of motion and of mass conservation are developed from first principles in chapter 4, chapters 5 and 6 return to these topics, discussing them from a different point of view, perhaps more suitable for the reader who is less versed in fluid mechanics. Chapter 5 presents the equations of motion, starting from its original one-dimensional form (as suggested by Darcy on the basis of experiments), and extending it to three-dimensional flow, compressible fluids and anisotropic media. This chapter also contains a review of theoretical derivations of Darcy's law. My objectives in presenting this and similar reviews is to indicate research methods, such as the use of conceptual and statistical models. A section on the motion equation at high Reynolds numbers is also included.

In chapter 6, the control volume approach is introduced as a general tool for developing mass conservation equations. Special attention is devoted to deformable media. Also included in this chapter is the stream function and its relationship to the piezometric head. Once the continuity or mass conservation equations have been established, the next natural step is to consider the initial and boundary conditions. These are discussed in detail in chapter 7. Special attention is given to the phreatic surface boundary condition and to its description in the hodograph plane. The second part of this chapter contains a discussion on various analytic and numerical solution techniques.

Upon reaching this point, the reader should be able to state a problem of flow through porous media in terms of an appropriate partial differential equation and a set of initial and boundary conditions. He should also know the major methods of solution (analog solutions are discussed in chapter 11).

Chapter 8 deals with the problem of flow in unconfined aquifers. This is a problem often encountered in ground water hydrology and in drainage. The Dupuit assumptions are explained and employed to derive the continuity equations for unconfined flow. The hodograph method, as a tool for solving two-dimensional, steady phreatic flow problems, is discussed in detail with many examples. Several linearization techniques and solutions of the nonlinear equation of unconfined flow are also presented in this chapter.

In chapter 9 the discussion, hitherto confined to single-phase flow, is extended to polyphase flow in porous media, a topic of special interest in petroleum engineering. Starting from the fundamental concepts of saturation, capillary pressure and relative permeability, the motion and continuity equations are established. The case of unsaturated flow as treated by soil physicists is presented as a special case of flow of immiscible fluids, where one of the fluids--the air--is stationary and at constant pressure. Special cases of interest, dealing with infiltration into soils, are considered in more detail. A new concept is introduced: that of an abrupt interface as an approximation replacing the actual transition zone that occurs between two fluids, whether miscible or immiscible. A detailed discussion is presented on the coastal interface, of great interest to ground water hydrologists.

Chapter 10 deals with hydrodynamic dispersion. Again, although the fundamental equation is developed from first principles in chapter 4, a review of several other theories leading to this equation is presented. Special attention is given to the coefficient of dispersion and its relationship to matrix and flow characteristics. A section on heat and mass transfer completes the discussion on hydrodynamic dispersion.

Chapter 11 presents the use of models and analogs, both as research tools and as tools for solving boundary value problems. Following the presentation of a general method for deriving analog scales, a detailed description is given of the sand box model, the electric analogs of various types, the Hele-Shaw analogs and the membrane analog. Recommendations for application are indicated in each case.

In brief, this is the subject matter I have chosen to cover in this book. I have made an effort to present the information in such a way as to require a minimum of supplementary material, except for those who wish to dig more deeply into the subject. A large number of problems and exercises is included in this book.

I should like to express my appreciation to the many individuals who, through their comments and criticism, have contributed to the completion of this book. Special thanks . . .

I realize that an attempt to represent a systematic account of a theory, such as I have made here, is bound to have defects. I will accept with gratitude all readers' suggestions directed toward the improvement of this book."

Bear, J., and Verruijt, A. 1987. Modeling Groundwater Flow and Pollution. D. Reidel Publishing Company, Boston, MA. NNA. 900212.0003.

PREFACE, p. xi;

" Groundwater constitutes an important component of many water resource systems, supplying water for domestic use, for industry, and for agriculture. Management of a groundwater system, an aquifer, or a system of aquifers, means making such decisions as to the total quantity of water to be withdrawn annually, the location of wells for pumping and for artificial recharge and their rates, and control conditions at aquifer boundaries. Not less important are decisions related to groundwater quality. IN fact, the quantity and quality problems cannot be separated. In many parts of the world, with the increased withdrawal of groundwater, often beyond permissible limits, the quality of groundwater has been continuously deteriorating, causing much concern to both suppliers and users. In recent years, in addition to general groundwater quality aspects, public attention has been focused on groundwater contamination by hazardous industrial wastes, by leachate from landfills, by oil spills, and by agricultural activities such as the use of fertilizers, pesticides, and herbicides, and by radioactive waste in repositories located in deep geologic formations, to mention some of the most acute contamination sources.

In all these cases, management means making decisions to achieve goals without violating specified constraints. In order to enable the planner, or the decision maker, to compare alternative modes of action and to ensure that the constraints are not violated, a tool is needed that will provide information about the response of the system (the aquifer) to various alternatives. Good management requires the ability to forecast the aquifer's response to planned operations, such as pumping and recharging. The response may take the form of changes in water levels, changes in water quality, or land subsidence. Any planning of mitigation, clean-up operations, or control measures, once contamination has been detected in the saturated or unsaturated zones, requires the prediction of the path and the fate of the contaminants in response to the planned activities. Any monitoring or observation network must be based on the anticipated behavior of the system.

The necessary information about the response of a system is . . ."

Bear, J., Tsang, C.F., and de Marsily, G. 1993. Flow and Contaminant Transport in Fractured Rock. Academic Press, Inc., San Diego, CA.

PREFACE, p xi;

" The question of how to deal with fractured rock domains has always been on the agenda of geohydrologists. Are Darcy's law and the theory of flow through porous media applicable to fractured rock aquifers, at least when the flow is assumed to be in the laminar flow range? And is the continuum approach applicable? The subject has always been investigated by reservoir engineers, this time in connection with multiphase flow, because many important petroleum reservoirs are in fractured rock formations. Of special interest are reservoirs composed of fractured porous rocks, in which the blocks surrounded by the network of fractures are porous. The permeability of such blocks is often rather low; but the porosity, and hence the storage capacity for fluids, is very high. This 'double porosity' model for fractured porous rock domains was first introduced in the field of reservoir engineering.

In the past two or three decades, fractured rock domains have received increasing attention not only in reservoir engineering and hydrology but also in connection with geological isolation of radioactive waste. Locations in both the saturated and unsaturated zones have been under consideration. Such repositories are sources of heat and potential sources of ground water contamination. Thus, in addition to the transport of mass of fluid phases in single or multiphase flow, the issues of heat transport and mass transport of components have to be addressed.

A large number of articles on these subjects exist in the scientific and professional literature of a number of disciplines, including geology, hydrology, reservoir engineering, and environmental engineering. We feel that the time is ripe to put together the main ideas and methodologies found in the literature on flow and tracer transport in fractured rock domains, in the form of an edited book written by experts from various disciplines, for the benefit of researchers and practitioners. We have decided not to excessively edit or unify the chapters. This has the advantage that each chapter is relatively self-contained and can be studied independently of the others. Also, the reader may find it interesting to sample the varying styles of different authors in different disciplines.

The editors hope that the book will serve its purposes: to present the state of the art on flow and tracer transport in fractured rock domains as viewed by scientists working in different disciplines, to encourage practical field engineers and scientists to use the various methods suggested in this book, and to stimulate researchers to further advance the state of the art of this fruitful research area."

Beauheim, R.L., 1986. Hydraulic-Test Interpretations for Well DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-1364. Sandia National Laboratories, Albuquerque, NM. WPO 27656.

ABSTRACT, p 3;

" Eleven different zones were tested in Well DOE-2 in five phases of testing between 1984 and 1986. Testing techniques included a constant-head, borehole-infiltration test, drill-stem tests, slug tests, pressure-pulse tests, and multiwell pumping tests. Four of the zones tested--the lower Dewey Lake Red Beds, the Tamarisk Member of the Rustler Formation, the lower unnamed member of the Rustler Formation and the Rustler/Salado contact, and the entire Salado Formation--had permeabilities too low to measure with the equipment and test techniques used. The other zones had permeabilities ranging over six orders of magnitude. No saturated strata were encountered above the Rustler Formation, although parts of the middle Dewey Lake Red Beds appear to have appreciable permeability.

In the Rustler Formation, the Culebra Dolomite Member is the most permeable unit, having a transmissivity of ~ 90 ft^2/day. The Culebra behaves hydraulically as a double-porosity system, with the major permeability provided by fractures and the major storage provided by matrix porosity. The Culebra at DOE-2 is well connected hydraulically to the Culebra at Wells H-6b and WIPP-13 to the west, probably by interconnected fractures. Response times between these wells are very short (<1 day/10,000 ft). The Culebra does not appear to be as fractured to the south at Wells WIPP-12 and 18, or to the east at Well H-5b, as indicated by delayed, low-magnitude (or nonexistent) responses to DOE-2 pumping, and by low permeabilities interpreted from other tests conducted at those wells. The other Rustler members at DOE-2, which are not known to be fractured and do not display hydraulic responses typical . . ."

Beauheim, R.L., 1987. Interpretation of the WIPP-13 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site. SAND87-2456. Sandia National Laboratories, Albuquerque, NM. WPO 28512.

ABSTRACT, p 3;

" A large-scale pumping test of the Culebra Dolomite Member of the Rustler Formation was performed in early 1987 at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. This test (the WIPP-13 or northern) multipad test, complemented the H-3 (or southern) multipad test (conducted in late 1985 and early 1986) by creating a hydraulic stress that could be measured over the northern portion of the WIPP site. The test consisted of pumping well WIPP-13 at a rate of 30 gpm for 36 days and monitoring drawdown and recovery responses in 17 observation wells and one WIPP shaft. Responses were observed in 14 of these wells, including one well 20 550 ft from WIPP-13 and in the WIPP exhaust shaft. Several of these wells had also responded during the H-3 multipad test.

Individual well tests at locations around the WIPP site have demonstrated that the Culebra is a heterogeneous, water-bearing unit. The responses measured at observation wells to pumping tests in heterogeneous systems cannot be rigorously interpreted using standard analytical (as opposed to numerical) techniques developed for tests in homogeneous, porous media. Application of analytical techniques to data from heterogeneous media results in evaluations of average hydraulic properties between pumping and observation wells that are nonunique in the sense that they are representative only of the responses observed when a hydraulic stress is imposed at a certain location. These 'apparent' hydraulic properties do, however, provide a qualitative understanding of the nature and distribution of both hydraulic properties and heterogeneities or boundaries within the tested area.

The interpretations of the responses at the pumping and observation wells are consistent with the following conceptualization: The Culebra is a fractured, double-porosity system around WIPP-12, H-6, and DOE-2, with relatively high transmissivity ($\sim$70 ft^2/day) and relatively low storativity (5×10^{-6} to 8×10^{-6}). This system appears to extend further to the north toward WIPP-30, although WIPP-30 itself lies in a lower transmissivity zone. The apparent transmissivity between WIPP-13 and observation wells toward the center of the WIPP site to the south and east, where fracturing in the Culebra decreases, decreases to 16 to 28 ft^2/day, and apparent storativity increases to 3.6×10^{-5} to 5.5×10^{-5}. To the west toward Nash Draw, the apparent transmissivity increases to 265 to 650 ft^2/day, reflecting increased fracturing in that direction, while the apparent storativity increases to 5.2×10^{-5} to 6.4×10^{-5}.

The analyses of the responses measured at observation wells to the WIPP-13 multipad pumping test provide a qualitative conceptualization of three distinct domains within a heterogeneous portion of the Culebra north of the center of the WIPP site. This conceptualization is being refined by using numerical-modeling techniques to simulate the WIPP-13 multipad test and other tests at the WIPP site in an attempt to define the distribution of hydraulic properties that will reproduce the responses observed."

Beauheim, R.L. 1987. Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-2311. Sandia National Laboratories, Albuquerque, NM. WPO 28468.

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ABSTRACT;

" Two pumping tests were conducted in the Culebra Dolomite Member of the Rustler Formation at the H-3 hydropad at the Waste Isolation Pilot Plant (WIPP) site. The first test was in 1984, with well H-3b3 pumped for 14 days at an average rate of 4 gpm. The second test, the H-3 multipad test, was in late 1985 and early 1986, with well H-3b2 pumped for 62 days at an average rate of 4.8 gpm. Both tests provided information on the hydraulic properties of the Culebra at the H-3 hydropad. The second test provided information on average Culebra hydraulic properties on a much larger scale; responses were observed up to 8000 ft from the pumping well.

The interpretation of these tests had three principle objectives. The first was to determine the most appropriate conceptualization of the nature of the Culebra flow system around the H-3 hydropad. The pumping well responses during the H-3 tests appear to be those of wells completed in a double-porosity medium with unrestricted interporosity flow. In such a system, fractures provide the bulk of the permeability, while matrix pores provide the majority of the storage capacity. The importance of fracture flow is indicated by the speed with which the observation wells on the H-3 hydropad respond to pumping and the nearly identical behaviors of these wells and the pumping well. The similarity between pumping- and observation-well behavior on the H-3 hydropad is so pronounced that the responses of all three wells on the hydropad can be interpreted only by using pumping-well analytical techniques, not observation-well analytical techniques. H-3b1 and H-3b3, in particular, appear to be very well connected by fractures.

The second objective was to quantify the hydraulic properties of the Culebra in the vicinity of the H-3 hydropad. The total-system (fractures plus matrix) transmissivity of the Culebra derived from the first test is 2.9 ft^2/day; that from the second test is 1.7 ft^2/day. The lower value derived from the second test probably represents lower transmissivity (lower fracture connectivity) at H-3b2 than at H-3b3, and/or lower average transmissivity of the volume of Culebra stressed in the multipad test as opposed to the smaller volume stressed in the first test. The fracture-to-total-system storativity ratios derived from the various analyses range from 0.03 to 0.25, indicating a relatively high degree of storage within the fractures. The highest storativity ratios were consistently found at H-3b1. Wellbore skin values are highly negative, indicating direct wellbore connection with fractures.

The third objective was to quantify the average hydraulic properties of the Culebra between the H-3 hydropad and more-distant observations wells. Meeting this objective . . ."

Beauheim, R.L., and Holt, R.M. 1990. "Hydrogeology of the WIPP Site." Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico. Field Trip #14 Guidebook, Geological Society of America 1990 Annual Meeting, Dallas, TX, October 19-November 1, 1990. pp. 131-179. D.W. Powers, R.M. Holt, R.L. Beauheim, and N. Rempe, leaders. SAND90-2035J. Dallas Geological Society, Dallas, TX. WPO 29377.

Introduction, p 2, col. 1;
" The field trip provides an on site introduction to the geology and hydrology of the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The mission of the WIPP is to dispose of transuranic (TRU) waste generated since 1970 by the U. S. defense programs. After 18 years of study and the publication of hundreds of documents, these studies remain unknown to many geologists. Although many of the studies are unique, they lack recognition. This field trip and guidebook begin to redress this imbalance."

Beauheim, R.L., Hassinger, B.W. and Klaiber, J.A. 1983. Basic Data Report for Borehole Cabin Baby-1 Deepening and Hydrologic Testing, WTSD-TME-020, Albuquerque, NM, U.S. DOE.

Section 1.0 ABSTRACT, p 1-1;

" Borehole Cabin Baby-1 was originally drilled to a depth of 4159.0 feet below kelly bushing (8.0 feet above ground surface) in 1974 and 1975 as a 'wildcat' hydrocarbon exploratory well. Control of the borehole was given to the U. S. Department of Energy (DOE) after it was found to be a 'dry hole'. Cabin Baby-1 was reentered, deepened, and hydrologically tested in August and September, 1983. The well is located in Section 5, T23S, R31E, just outside the limit of WIPP Zone III, approximately 2.5 miles south of the WIPP exploratory shaft.

The deepening and testing of Cabin Baby-1 was undertaken for several reasons:

- To provide data on the hydrologic properties, including hydrostatic head potential of selected permeable zones in the Bell Canyon Formation.
- To provide representative fluid samples from selected permeable zones in the Bell Canyon Formation for determination of fluid composition and density.
- To define further the stratigraphy of the upper Bell Canyon Formation at the Cabin Baby-1 location.

The borehole was deepened from the previous total depth to a new depth of 4298.6 feet below kelly bushing by continuous coring. Field operations related to deepening and logging of the borehole began August 12, 1983 and were completed August 30, 1983. Hydrologic testing activities began August 30, 1983 and were completed September 29, 1983. Drill-stem tests were conducted in four zones in the Bell Canyon Formation, and one test of the Salado Formation was performed. Fluid samples were collected from the Hays and Olds sandstones of the Bell Canyon Formation."

Beauheim, R.L., Dale, T.F., and Pickens, J.F. 1991. Interpretations of Single-Well Hydraulic Tests of the Rustler Formation Conducted in the Vicinity of the Waste Isolation Pilot Plant (WIPP) Site, 1988-1989. SAND89-0869. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p i;

" In 1988 and 1989, hydraulic tests were conducted in seven wells to provide data on the transmissivities of four members of the Rustler Formation. These data will be used in modeling of groundwater flow through the Rustler Formation. Pressure-pulse, slug, and pumping tests were performed. The pressure-pulse and slug tests were simulated using the computer code GTFM to obtain estimates of transmissivity and the radius of influence of the testing. The pressure-pulse tests proved difficult to interpret because no measurements of test-zone compressibility were made. Slug tests at two of the wells were also interpreted using type curves based on an analytical solution for slug tests. The type-curve results differed by 35 percent or less from the transmissivities determined using GTFM. The pumping test was interpreted using the computer code Interpret/2. The slug-test interpretations provided estimates of transmissivity as follows: 2.1×10^{-4} to 3.0×10^{-4} ft^2/day for the siltstone within the unnamed lower member of the Rustler at well H-16; 0.16 to 0.20 ft^2/day and 1.9 to 2.5 ft^2/day for the Culebra dolomite at wells AEC-7 and D-268, respectively; 2.1×10^{-3} to 2.7×10^{-3} ft^2/day and 0.14 to 0.18 ft^2/day for the Magenta dolomite at wells H-2b1 and H-3b1, respectively; and 3.5×10^{-3} to 4.5×10^{-3} ft^2/day for the Forty-niner claystone at well H-3d. The calculated radii of influence of the tests ranged from about 50 to 300 ft. Interpretations of the pumping test of the Culebra dolomite at well H-18 are ambiguous in that the test responses are equally representative of a single-porosity medium having a transmissivity of 2.0 ft^2/day and a no-flow boundary 58 ft from H-18, and of a double-porosity medium with a transmissivity of 1.0 ft^2/day and no apparent boundaries."

Beauheim, R.L., Saulnier, Jr., G.J., and Avis, J.D. 1991. Interpretation of Brine-Permeability Tests of the Salado Formation at the Waste Isolation Pilot Plant Site: First Interim Report, SAND90-0083, Albuquerque, NM, Sandia National Laboratories.

ABSTRACT, p i;

" Pressure-pulse tests have been performed in bedded evaporites of the Salado Formation at the Waste Isolation Pilot Plant (WIPP) site to evaluate the hydraulic properties controlling brine flow through the Salado. Hydraulic conductivities ranging from about 10^{-14} to 10^{-11} m/s (permeabilities of about 10^{-21} to 10^{-18} m^2) have been interpreted from nine tests conducted on five stratigraphic intervals within eleven meters of the WIPP underground excavations. Tests of a pure halite layer showed no measurable permeability. Pore pressures in the stratigraphic intervals range from about 0.5 to 9.3 MPa. An anhydrite interbed (Marker Bed 139) appears to be one or more orders of magnitude more permeable than the surrounding halite. Hydraulic conductivities appear to increase, and pore pressures decrease, with increasing proximity to the excavations. These effects are particularly evident within two or three meters of the excavations. Two tests indicated the presence of apparent zero-flow boundaries about two to three meters from the boreholes. The other tests revealed no apparent boundaries within the radii of influence of the tests, which were calculated to range from about four to thirty-five meters from the test holes. The data are sufficient to determine if brine flow through evaporites results from Darcy-like flow driven by pressure gradients within naturally interconnected porosity or from shear deformation around excavations connecting previously isolated pores, thereby providing pathways for fluids at or near lithostatic pressure to be driven towards the low-pressure excavations. Future testing will be performed at greater distances from the excavations to evaluate hydraulic properties and processes beyond the range of excavation effects.

Bechtel National. 1986. Quarterly Geotechnical Field Data Report. DOE/WIPP-221. U.S. Department of Energy, Carlsbad, NM.

FOREWORD, p iii;

" The purpose of the Quarterly Geotechnical Field Data Reports is to meet the U.S. Department of Energy intent to provide geotechnical and related information from WIPP underground activities to interested persons or groups in a timely manner. This Quarterly Geotechnical Field Data Report (GFDR) presents information obtained from the geotechnical studies at the WIPP site underground facilities from April 1 through June 30, 1985, as well as all previous data collected from the geomechanical instruments. During this period, the geotechnical activities at the site included maintaining and repairing instruments and monitoring previously installed geomechanical instruments in shafts, underground drifts, and test rooms. The data presented in this GFDR reflect the update of continuing measurements and monitoring. Also continuing and included in this report are preliminary geotechnical and structural analyses and interpretations of the data.

The GFDR is organized into two principle parts. The first part, Geotechnical Field Data, . . ."

Bell, J.T., Coleman, C.F., Costanzo, D.A., and Biggers, R.E. 1973. "Plutonium polymerization--III. The nitrate precipitation of Pu(IV) polymer." Journal of Inorganic and Nuclear Chemistry. Vol. 35: 629-632.

ABSTRACT, p 629;

" The precipitation of aged Pu(IV) polymer by HNO_3, $LiNO_3$, $Al(NO_3)_3$ and $NaNO_3$ has been observed. With the exception of $LiNO_3$, the precipitation of 0●00678M Pu(IV) polymer was independent of the source of NO_2^-m and the maximum amount of precipitated polymer occurred at 1●O NO_2^-. Further addition of NO_2^- redissolved the polymer. The nitrate precipitation of Pu(IV) polymer has been analyzed according to the solubility product principle and has been found to closely resemble a solubility product mechanism."

Bell, J.T., Costanzo, D.A. and Biggers, R.E. 1973. "Plutonium polymerization--II. Kinetics of the plutonium polymerization." Journal of Inorganic and Nuclear Chemistry. Vol. 35: 623-628.

ABSTRACT, p 623;

" Experimental data for the distribution of Pu(III), Pu(IV), Pu(V), Pu(VI) and Pu(IV) polymer have been used to calculate the rates of polymerization of Pu(IV). The rate of formation of Pu(IV) polymer is proportional to the first power of the Pu(IV) concentration and to the inverse square of the acidity as long as the solution contains a detectable amount of Pu(IV). When the concentration of Pu(IV) is not detectable, the rate of polymerization is proportional to the product of the square roots of the Pu(V) and (III) concentrations. When the concentrations of both the Pu(IV) and (III) are not detectable, the rate of polymerization is proportional to the product of the squares of the Pu(V) and the acid concentrations and to the inverse first power of the Pu(VI) concentration."

Bellin, A., Salandin, P., and Rinaldo, A. 1992. Simulation of Dispersion in Heterogeneous Porous Formations: Statistics, First-Order Theories, Convergence of Computations. Water Resources Research, Vol. No. 9, pp. 2211-2228.

ABSTRACT, p. 2211;

" This paper discusses the results of numerical analysis of dispersion of passive solutes in two-dimensional heterogeneous porous formations. Statistics of flow and transport variables, the accuracy and the role of approximations implicit in existing first-order theories, and the convergence of computational results are investigated. The results suggest that quite different rates of convergence with Monte Carlo runs hold for different spatial moments and that over 1000 realizations are required to stabilize second moments even for relatively mild heterogeneity ($\sigma_Y^2 < 1.6$). This has implications for the extent of the spatial domain for single-realization numerical studies of the same type. A comparison of the variance of plumes with the results of linear theories ($0.05 < \sigma_Y^2 < 1.6$) shows an unexpectedly broad validity field for the theoretical solution obtained from a suitable linearization of flow and transport. Reformulation of the same problem linearizing in turn the flow or the transport equation shows opposite deviations from the linear theory. The interesting consequence is that the errors induced by linearizations in the flow or the transport equations have different signs, and their effects on the moments of dispersing plumes are compensating, thereby yielding consistent formulations. Unexpected features of the statistics of probability distributions of longitudinal and transverse velocities and travel times are also computed and discussed."

Berger, A. 1988. "Milankovitch Theory and Climate," Reviews of Geophysics. Vol. 26, no. 4, 624-657.

ABSTRACT, p 624, col 1;

" Among the longest astrophysical and astronomical cycles that might influence climate (and even among all forcing mechanisms external to the climatic system itself), only those involving variations in the elements of the Earth's orbit have been found to be significantly related to the long-term climatic data deduced from the geological record. The aim of the astronomical theory of paleoclimates, a particular version of which being due to Milankovitch, is to study this relationship between insolation and climate at the global scale. It comprises four different parts: the orbital elements, the insolation, the climate model, and the geological data. In the nineteenth century, Croll and Pilgrim stressed the importance of severe winters as a cause of ice ages. Later, mainly during the first half of the twentieth century, Köppen, Spitaler, and Milankovitch regarded mild winters and cool summers as favoring glaciation. After Köppen and Wagener related the Milankovitch new radiation curve to Penck and Brückner's subdivision of the Quaternary, there was a long-lasting debate on whether or not such changes in the insolation can explain the Quaternary glacial-interglacial cycles. In the 1970s, with the improvements in dating, in acquiring, and in interpreting the geological data, with the advent of computers, and with the development of astronomical and climate models, the Milankovitch theory revived. Over the last 5 years it overcame most of the geological, astronomical, and climatological difficulties. The accuracy of the long-term variations of the astronomical elements and of the insolation values and the stability of their spectra have been analyzed by comparing seven different astronomical solutions and four different time spans (0-0.8 million years before present (Myr B.P.), 0.8-1.6 Myr B.P., 1.6-2.4 Myr B.P., and 2.4-3.2 Myr B.P.). For accuracy in the time domain, improvements are necessary for periods earlier than 2 Myr B.P. As for the stability of the frequencies, the fundamental periods (around 40, 23, and 19 kyr) do not deteriorate with time over the last 5 Myr, but their relative importance for insolation and each astronomical parameter is a function of the period considered. Spectral analysis of paleoclimatic records has provided substantial evidence that, at least near the obliquity and precession frequencies, a considerable fraction of the climatic variance is driven in some way by insolation changes forced by changes in the Earth's orbit. Not only are the fundamental astronomical and climatic frequencies alike, but also the climatic series are phase-locked and strongly coherent with orbital variations. Provided that monthly insolation (i.e., a detailed seasonal cycle) is considered for the different latitudes, their long-term deviations can be as large as 13% of the long-term average, and sometimes considerable changes between extreme values can occur in less than 10,000 years. Models of different categories of complexity, from conceptual ones to three-dimensional atmospheric general circulation models and two-dimensional time-dependent models of the whole climate system, have now been astronomically forced in order to test the physical reality of the astronomical theory. The output of most recent modeling efforts compares favorably with data of the past 400,000 years. Accordingly, the model predictions for the next 100,000 years are used as a basis for

forecasting how climate would evolve when forced by orbital variations in the absence of anthropogenic disturbance. The long-term cooling trend which began some 6,000 years ago will continue for the next 5,000 years; this first temperature minimum will be followed by an amelioration at around 15 kyr A.P. (after present), by a cold interval centered at 23 kyr A.P., and by a major glaciation at around 60 kyr A.P."

Bertram-Howery, S.G., and R. L. Hunter, eds. 1989. Preliminary Plan for Disposal-System Characterization and Long-term Performance Evaluation of the Waste Isolation Pilot Plant. SAND89-0178. Albuquerque, NM: Sandia National Laboritories.

ABSTRACT;
" The U. S. Department of Energy is planning to dispose of transuranic wastes at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Sandia National Laboratories is responsible for evaluating the compliance of the WIPP with the Environmental Protection Agency's Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR 191, Subpart B). This plan has been developed to present the issues that will be addressed before compliance can be evaluated. These issues examine the procedural requirements for evaluating compliance, which follow from the procedural nature of the Standard, and the technical requirements for further characterizing the behavior of the disposal system, including uncertainties, to support the compliance assessment. The plan briefly describes the activities that will be conducted prior to 1993 by Sandia to characterize the WIPP disposal system's behavior and predict its performance."

Bertram-Howery, S.G., M.G. Marietta, R.P. Rechard, P.N. Swift, D.R. Anderson, B.L. Baker, J.E. Bean, Jr., W. Beyeler, K.F. Brinster, R.V. Guzowski, J.C. Helton, R.D. McCurley, D.K. Rudeen, J.D. Schreiber, and P. Vaughn, 1990. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990, SAND90-2347, Albuquerque, NM, Sandia National Laboratories.

ABSTRACT, p i;

" The Waste Isolation Pilot Plant (WIPP) is planned as the first mined geologic repository for transuranic (TRU) wastes generated by defense programs of the United States Department of Energy (DOE). Before disposing of waste at the WIPP, the DOE must evaluate compliance with the United States Environmental Protection Agency's (EPA) Standard, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 1919, U. S. EPA, 1985). Sandia National Laboratories (SNL) is evaluating long-term performance against criteria in Subpart B of the Standard. 'Performance assessment' as used in this report includes analyses for the Containment Requirements (§ 191.13(a)) and the Individual Protection Requirements (§ 191.15). Because proving predictions about future human actions or natural events is not possible, the EPA expects compliance to be determined on the basis of specified quantitative analyses and informed, qualitative judgment. The goal of the WIPP performance-assessment team at SNL is to provide as detailed and thorough a basis as practical for the quantitative aspect of that decision.

This report summarizes SNL's late-1990 understanding of the WIPP Project's ability to evaluate compliance with Subpart B. This preliminary assessment cannot be defensibly compared to the requirements of the Standard to interpret whether the WIPP disposal system complies with Subpart B. Defensibility of the compliance evaluation ultimately will be determined primarily by qualitative judgment regarding 'reasonable expectations of compliance,' assuming that concept is retained by the EPA in promulgating the vacated Subpart B. Other considerations such as completeness and adequacy of the numerical simulations will also be factors in determining defensibility. Performance assessment must determine the events that can occur, the likelihood of these events, and the consequences of these events. The impacts of uncertainties must be characterized and displayed; however, no single summary measure can adequately display all the information produced in a performance assessment. Adequate documentation is an essential part of a performance assessment.

In lieu of results suitable for comparison with the Standard, this report presents results of sensitivity analyses that address specific uncertainties in the modeling system. All results are preliminary, and are conditional on assumed conceptual models and parameter value distributions. The results show the degree to which some uncertainties in the conceptual models that describe aspects of disposal-system behavior may affect predicted performance. The results also demonstrate the methodology used to assess performance. The reported complementary cumulative distribution functions (CCDF's) are statistical means of families of CCDFs. The modeling system is sensitive to changes in scenario probabilities,

and reductions in the probability of intrusion significantly reduce predicted probabilistic cumulative releases. Comparison of clay-lined-fracture and dual-porosity transport models for the dominant water-bearing unit above the repository indicate a significant increase in radionuclide retardation and a consequent reduction in predicted releases with the dual-porosity model. Simulations of a variable number of intrusions show that, for the selected probability model, multiple intrusions do not increase the largest cumulative releases. Simulations of a hypothetical waste modification suggest that for modifications to be effective, waste permeability must be reduced more than four orders of magnitude below the estimated unmodified value to restrict brine flow to an intruding borehole. Simulations of gas generation and the effects gas will have on brine flow and radionuclide transport are not sufficiently advanced to be incorporated in this year's CCDF curves, but preliminary results of one-dimensional simulations are included. Preliminary analyses for the Individual Protection Requirements suggest that no releases will occur; therefore, dose predictions are not likely to be required.

Although disposal-system characterization work has been underway for about 15 years, and much is known about the WIPP, all work necessary to support the performance assessment has not been completed. Most work currently in progress to support the performance assessment is not advanced enough to support a defensible comparison to the Standard because many important modules are in preliminary or intermediate stages of understanding or readiness. The compliance assessment system can be used for sensitivity and uncertainty analyses, and is adequate for preliminary performance studies."

Bird, R.B., Stewart, W.E., and Lightfoot, E.N. 1960. Transport Phenomena. Wiley & Sons, New York, NY. NNA. 900919.0195.

Chapter 16, p 513;
"§16.5 THEORIES OF ORDINARY DIFFUSION IN LIQUIDS

In the absence of rigorous theory for diffusion in liquids, there are two rough theories that have been useful in making order of magnitude of calculations: the *hydrodynamical theory* and *Eyring theory*. (We have already given some results of the theories of Eyring and co-workers in connection with the calculation of viscosity and thermal conductivity of liquids.)

The *hydrodynamical theory* takes as its starting point the Nernst-Einstein equation,[1] which states that the diffusivity of a single particle or solute molecule of A through a stationary medium B is

$$D_{AB}=\kappa T\frac{u_A}{F_A} \tag{16.5-1}$$

in which u_A/FA is the 'mobility' of the particle A (that is, the steady-state velocity attained by the particle under the action of a unit force). A relation between force and velocity for a rigid sphere moving in 'creeping flow' (that is, $\mathrm{Re} \ll 1$) may be obtained from hydrodynamics. If the possibility of 'slip' at the sphere-fluid interface is taken into account, then[2]

$$F_A=6\pi\mu_B u_A R_A\left(\frac{2\mu_B+R_A\beta_{AB}}{3\mu_B+R_A\beta_{AB}}\right) \tag{16.5-2}$$

in which μ_B is the viscosity of the pure solvent, $\mathbf{R}_A$ is the radius of the diffusing particle, and β_{AB} is the *coefficient of sliding friction*. It has been pointed out[3] that there are two limiting cases of interest:

a. If there is no tendency for the fluid to slip at the surface of the diffusing particle ($\beta_{AB} = \infty$), then Eq. 16.5-2 becomes Stoke's law. (See §2.6).

$$F_A=6\pi\mu_B u_A R_A \tag{16.5-3}$$

and substitution into Eq. 16.5-1 gives

$$\frac{D_{AB}\mu_B}{\kappa T} = \frac{1}{6\pi R_A} \tag{16.5-4}$$

which is usually called the *Stokes-Einstein equation*. Equation 16.5-4 has been shown to be fairly good for describing the diffusion of *large spherical particles* or *large spherical molecules*, under which conditions the solvent appears to the diffusing species as a continuum.[4]

b. If there is no tendency for the fluid to stick at the surface of the diffusing particle ($\beta_{AB} = 0$), Eq 16.5-2 becomes

$$F_A = 4\pi\mu_B u_A R_A \tag{16.5-5}$$

and substitution into Eq. 16.5-1 gives

$$\frac{D_{AB}\mu_B}{\kappa T} = \frac{1}{4\pi R_A} \tag{16.5-6}$$

If the molecules are all alike (that is, *self-diffusion*) and if they can be assumed to be arranged in a cubic lattice with all molecules just touching, the $2R_A$ may be set equal to $(\tilde{V}_A/\tilde{N})^{1/2}$ and

$$\frac{D_{AA}\mu_A}{\kappa T} = \frac{1}{2\pi}\left(\frac{\tilde{N}}{\tilde{V}_A}\right)^{1/2} \tag{16.5-7}$$

It has been shown[5] that Eq. 16.5-7 predicts the self-diffusion data for a number of liquids within about ± 12 per cent; that comparison includes polar substances, associated substances, liquid metals, and molten sulfur.

It is thus seen that the simple hydrodynamical approach gives expressions for the diffusion coefficient for spherical molecules in dilute solution and also for the coefficient of self-diffusion. The theory further predicts that there should be a variation of D_{AB} with the size of the diffusing species. The hydrodynamical theory suggests that the shape of the

diffusing species may well be important, since the friction factor increases by a factor of about 2 as the length-to-width ratio of a body goes from 1 to 10.

[1]F. Daniels and R. A. Alberty, Physical Chemistry, Wiley, New York (1955), p. 650. See also Eq. 18.4-14a.
[2]H. Lamb, Hydrodynamics, Dover, New York, §337.
[3]R. Fürth, in Handbuch der physikalischen und technischen Mechanik, Barth, Leipzig (1931), Vol. 7, p. 635.
[4]W. Sutherland, Phil. Mag., **9**, 781-785 (1905).
[5]J.C.M. Li and P. Chang, J. Chem. Phys., **23**, 518-520 (1955)."

Borns, D.J., 1985. Marker Bed 139: A Study of Drillcore From A Systematic Array, SAND85-0023, Sandia National Laboratories, Albuquerque, NM.

ABSTRACT, p 3;

" In southeastern New Mexico, Marker Bed 139 (referred to in this report as MB139) is one of 45 numbered siliceous or sulfatic units within the Salado Formation of the northern Delaware Basin. MB139 is divided into five zones. Zones I and V are the upper and lower contact zones, respectively. Zone II is a syndepositionally deformed subunit of polyhalitic anhydrite. Zone III is mixed anhydrite and polyhalitic anhydrite, a distinctive pale-green and pink, with subhorizontal fractures. Zone IV consists of interlayered halite and anhydrite without the overprint of polyhalite.

This sequence was transitional between submarine and subaerial. The anhydritic units of MB139 formed in salt-pan or mudflat environments or both. Undulations observed along the upper contact of MB139 are interpreted to result from traction deposits or from reworking of the upper portion of the marker bed during the transition from anhydrite to halite deposition. Zones II and III exhibit soft-sediment deformation and later traces of dewatering; e.g., formation of stylolites. Such deformation is not observed in the halite above MB139 or in Zone V and the halite units below MB139.

A distinctive set of subhorizontal fractures occurs in MB139 in mid-Zone III and, to some extent, in Zone IV. These fractures are partially infilled with halite and polyhalite. Brine occurrences at the mined facility horizon at the Waste Isolation Pilot Plant may be related to these fractures. The fractures formed either in response to stress cycles that were functions of sedimentation and erosion, or in response to deformation in the underlying Castile Formation. The subhorizontal orientation, dominant in the sampling to date, is more consistent with the interplay between stress and sedimentation cycles."

Borns, D.J. and S.E. Shaffer. 1985. Regional Well-Log Correlation in the New Mexico Portion of the Delaware Basin. SAND83-1798. Sandia National Laboratories, Albuquerque, NM. WPO 24511.

ABSTRACT, p 3;

" Although well logs provide the most complete record of stratigraphy and structure in the northern Delaware Basin, regional interpretations of these logs generate problems of ambiguous lithologic signatures and one-hole anomalies. Interpretation must therefore be based on log-to-log correlation rather than on inferrences from single logs. In this report, logs from 276 wells were used to make stratigraphic picks of Ochoan horizons (the Rustler, Salado, and Castile Formations) in the New Mexico portion of the Delaware Basin. Current log correlation suggests that: (1) the Castile is characterized by lateral thickening and thinning; (2) some Castile thinnings are of Permian age; (3) irregular topography in the Guadalupian Bell Canyon Formation may produce apparent structures in the overlying Ochoan units; and (4) extensive dissolution of the Salado is not apparent in the area of the Waste Isolation Pilot Plant (WIPP) site."

Borns, D.J., and Stormont, J.C. 1988. An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone, SAND87-1375, Sandia National Laboratories, Albuquerque, NM. WPO 24694.

ABSTRACT, p i;

" For nuclear waste repositories with both long operational periods (50 yr) and long performance assessment periods (10 000 yr), the Disturbed Rock Zone (the zone of rock in which the mechanical and hydrologic properties have changed in response to excavation; abbreviated as DRZ) is important to both operational (e.g., slab or fracture failure of the excavation) and long term performance (e.g., seal system performance and fluid transport). At the Waste Isolation Pilot Plant (WIPP), the DRZ has been characterized with three approaches: visual observation; geophysical methods; and permeability measurements. Visual observations in drillholes indicate that fluids and fractures are common in the host rock of the underground facility. Geophysical studies have utilized radar, electromagnetic (EM), and direct current (DC) electromagnetic methods. Radar has been useful, but the penetration is limited by the water content and the bedded nature of the host rock. The EM method was able to detect a fourfold increase in resistivity from 1 to 5 m into the rock. This trend reflects a fourfold increase in the moisture content from near the excavation (0.5 to 1% by weight) to 5 m into the host rock (2 to 3% by weight). The DC method has been able to detect zones of moisture around the excavation. Numerous gas permeability measurements indicate that beyond 2 m from an excavation halite and interbeds (anhydrite and clay) allow very low gas flow (calculated permeabilities < 1 microdarcy for gas flow tests and < 0.01 microdarcy for brine-based permeability tests). Within 2 m of the excavation, very high flow rates (10^4 SCCM) were measured. All three approaches have defined a DRZ at the WIPP extending laterally throughout the excavation and varying in depth from 1 to 5 m, according to the size and age of the opening."

Borns, D.J., and Stormont, J.C. 1989. "The Delineation of the Disturbed Rock Zone Surrounding Excavations in Salt," Rock Mechanics as a Guide for Efficient Utilization of Natural Resources, Proceedings of the 30th U.S. Symposium, Morgantown, WV, June 19-22, 1989, A.W. Khair, ed., pp. 353-360. SAND88-2230C. A.A. Balkema, Brookfield, VT. WPO 29974.

ABSTRACT, p 353;

" At the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico, the Disturbed Rock Zone (DRZ, the zone of rock in which the mechanical and hydrologic properties have changed in response to excavation) has been characterized with visual observations, geophysical methods, and gas-flow measurements. The visual observations, geophysics, and gas-flow tests have defined a DRZ at the WIPP extending laterally throughout the excavation and varying in depth from 1 to 5 m. Desaturation and microfracturing has occurred to some degree within the zone. The dilation that results from the microfracturing in the DRZ provides a component of the observed closure."

Borns, D.J., Pfeifer, M.C., Andersen, H.T., and Skokan, C.K. 1990. "Electrical Methods to Delineate Fluid Flow In Situ in Bedded Salt." In Society of Exploration Geophysicists Workshop on Permeability, Fluid Pressure and Pressure Seals in the Crust, Denver, CO, August 5-8, 1990. SAND90-1685A. Sandia National Laboratories, Albuquerque, NM. WPO 28590.

" Seepage into excavations and the observation of brine infilling boreholes suggest that brine flows at a depth of 650 m in the bedded salts at the Waste Isolation Pilot Plant near Carlsbad, NM. Due to the very low permeability ($\leq 10^{-19} m^2/sec$) and the deformation around excavations and boreholes, traditional borehole hydrologic methods are problematic. Since there are large contrasts in resistivity between salt, unsaturated fractures and the brine that fills pores, geophysical methods, especially electrical, provide alternate techniques to characterize flow systems in bedded salt.

At the WIPP site, we have conducted charged-body (mise-a-la-mase), modified direct current (DC), and permanent DC-Resistivity array surveys. Each method shows that the geoelectric structure varies markedly in the seemingly homogeneous salt. Our assumption is that these differences mirror variations in the hydrologic flow system. The modified DC-Method and mise-a-la-mase methods suggest that the electrical structure and the fluid flow reflect a network of fractures in an anhydrite interbed. These fractures form in response to burial/denudation cycles and stress redistribution around underground excavations. Such fractures can remain propped for extended periods. The presence of stiff inclusions, such the anhydrite interbeds, are important in the development flow systems and localized reservoirs.

Spontaneous potential surveys using the DC-Resistivity array show different current flow in each distinct interbed (approx. 1 m thick) that the underground excavation intersects. We map these units based on clay (generally $\simeq 5\%$) and secondary mineral content. We believe that the spontaneous potential reflects electrokinetic (pore fluid motion) currents and not chemoelectric currents. The different spontaneous potentials may indicate that fluid flow is highly stratified. This stratification may reflect the effects of intergranular impurities such as clays, polyhalite, and hematite. The DC-Resistivity arrays show that the excavation induced flow system rapidly dominates the natural flow system. The growth of a disturbed rock zone in part by dilitancy around the excavation affects fluid flow within a depth of several meters. Resistivity increases in some interbeds and decreases in other interbeds reflecting changes in saturation and permeability adjacent to the excavation."

Bredehoeft, J.D., Riley, F.S., and Roeloffs, E.A. 1987 Earthquakes and Groundwater. Earthquakes and Volcanoes, Vol 19, no. 4, pp. 138-146.

Dynamic Response, p 139;

" Certain seismic waves, especially Rayleigh waves, cause a volume change in the rock. A volume change in an aquifer produces a pressure change in the fluid. A Rayleigh wave produces a fluctuating fluid pressure in an aquifer, or fluid reservoir rock. The fluid level in an open observation well will try to go up and down in an attempt to balance pressure fluctuations in the aquifer. The dynamics of the oscillation in the well involve further complications.

As frequencies approach those of the Rayleigh waves (period from 8 to 30 seconds) the open water well behaves as a simple harmonic oscillator. In elementary physics the classic simple harmonic oscillator is a spring with a suspended mass. When disturbed, the mass will tend to oscillate up and down with the motion gradually decaying away. Some water wells behave in a similar manner. An experiment was performed in the Florida well in which the water level fluctuated 17 feet during the Alaskan earthquake. What is interesting is the free oscillation. The forcing , which was near the natural frequency of the well, built the oscillation; the oscillation then died away following the forcing.

If you remember back to freshman physics, you may recall that simple harmonic oscillators could be overdamped or underdamped. When disturbed, underdamped ones oscillate; overdamped ones do not oscillate but simply return with an exponential motion to their original resting place. Hilton Cooper and some colleagues at the USGS in the mid-60's developed the theory for the water well as a simple harmonic oscillator. The mass is provided by the height of the water column in the well; the damping depends on the ease with which water can move in and out of the well. In a highly permeable aquifer, water moves readily in and out of the well; if the permeability is sufficiently high, the well behaves as an underdamped oscillator. If the permeability is low, water can not move in and out of the well readily; the well is overdamped and the oscillation at the well is smaller than the pressure-head fluctuation in the aquifer. In particularly 'tight' (less permeable) formations, the well may not respond at all to seismic-pressure fluctuations in the aquifer.

The Florida well, which fluctuated so dramatically during the Alaskan earthquake, was excited by a Rayleigh wave-pressure change very close to the natural resonant frequency of the well. A 'sympathetic' response occurred; because of the inertia of the fluid column, the actual fluctuation of the water well was larger than the pressure-head change in the aquifer."

Static Response, p 141;

" The static response of a well to an earthquake is much less complicated than the dynamic response. The simplest geophysical model of an earthquake is a displacement along a finite rupture plane in an elastic material.

Using this simple elastic conceptual model, a dislocation along a finite rupture in an elastic space requires that the elastic material strain accommodate the displacement along the

rupture plane. Frank Press showed, following the Alaskan earthquake, that the simple model predicted measurable strains to large distances, perhaps to several thousand kilometers or more, for great earthquakes. The size of larger earthquakes is more or less correlated with the length of the fault which ruptures during the earthquake. The measurable strain field also depends upon the size of the rupture plane."

Brush, L.H., and Anderson, D.R. 1989. "Appendix E: Estimates of Gas Production Rates, Potentials, and Periods, and Dissolved Radionuclide Concentrations for the WIPP Supplemental Environmental Impact Statment." In Performance Assessment Methodology Demonstration: Methodology development for Evaluating Compliance With EPA 40 CFR Part 191, Subpart B, for the Waste Isolation Pilot Plant. M.G. Marietta, S.G. Bertram-Howery, D.R. Anderson, K.F. Brinster, R.V. Guzowski, H. Iuzzolino, and R.P. Rechard, eds. SAND89-2027. Sandia National Laboratories, Albuquerque, NM. pp. E-1 through E-14. In Appendix E of WPO 25952.

ABSTRACT;

" This report describes a demonstration of the performance assessment methodology for the Waste Isolation Pilot Plant (WIPP) to be used in assessing compliance with the Environmental Protection Agency's Standard, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 191, Subpart B). This demonstration incorporates development and screening of potentially disruptive scenarios. A preliminary analysis of the WIPP disposal system's response to human intrusion scenarios produces preliminary complementary cumulative distribution functions (CCDFs) similar to those that will ultimately be used to assess the compliance of the WIPP with the Containment Requirements of the Standard. Preliminary estimates of scenario probabilities are used to construct two demonstration CCDFs. The conceptual model of the disposal system consists of geologic,, hydrologic, and disposal system subsystems along with the physical and chemical processes associated with these subsystems. Parameter values defining the systems contain uncertainties and modeling approximations of such a disposal system contributes to those uncertainties. The WIPP compliance assessment methodology consists of a system of techniques and computer codes that estimate releases of radionuclides from the disposal system, incorporating analysis of the parameter uncertainties in the estimates. Demonstration CCDFs are presented, but are not yet credible enough to judge the probability of compliance of the WIPP with the EPA Standard. One CCDF, based primarily on conservative reference data and conservative conceptual models, exceeds EPA limits, and another CCDF that represents effects of possible engineered alternatives does not exceed EPA limits."

Buddemeier, R.W., and Hunt, J.R. 1988. "Transport of Colloidal Contaminants in Groundwater: Radionuclide Migration at the Nevada Test Site," Applied Geochemistry. Vol. 3, no. 5, 535-548.

ABSTRACT, p 535;

" Large-volume groundwater samples were collected at the Nevada Test Site from within a nuclear detonation cavity and from approximately 300 m outside the cavity. The samples were filtered and ultrafiltered, and the filtrates and various particle size fractions were analyzed for chemical composition and radionuclide activity. In samples from both locations, approximately 100% of the transition element (Mn,Co) and lanthanide (Ce,Eu) radionuclides were associated with colloids. Their presence outside the cavity indicates transport in the colloidal form. Distribution coefficients calculated for Ru, Sb, and Cs nuclides from both field sample locations indicate equilibrium partitioning on the 0.05-0.003 μm colloids. Calculation of transport efficiencies relative to colloid mass concentrations and dissolved neutral or anionic nuclides indicates that both the cations and the radiolabelled colloids appear to experience capture by or exchange with immobile aquifer surfaces."

Burton, P.L., Adams, J.W., and Engwall, C. 1993. "History of the Washington Ranch, Eddy County, New Mexico." In Carlsbad Region, New Mexico and West Texas. D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.W. Austin, and J. M. Barker, eds., Forty-Fourth Annual Conference, October 6-9, 1993, pp 65-67. New Mexico Geological Society, Roswell, NM.

p 66, col 1, para 1;

" By today's standards, W. E. Washington, aka, Bill Washington, aka 'Uncle Bill' would be called 'a colorful character.' He *was* an unusual individual. With his intermarriage into the Chickasaw tribe, he was able to start what would become a small empire. The father of his bride was a wealthy man in his own right in Mississippi until he was forced into exile and marched over the terrible Trail of Tears to Indian Territory (now Oklahoma).

By marriage to May Ellen, Bill was . . ."

Cauffman, T.L., LaVenue, A.M., and McCord, J.P. 1990. Ground-Water Flow Modeling of the Culebra Dolomite. Volume II: Data Base, SAND89-7068/2, Sandia National Laboratories, Albuquerque, NM. WPO 10551.

PREFACE, p ii;

" The objective of this report is to present and discuss the hydrogeologic data base for the Culebra dolomite at the WIPP site. The data base includes:

- coordinates of the WIPP-area boreholes,
- Culebra elevations,
- Culebra transmissivities.
- Culebra storativities,
- Culebra formation-fluid densities,
- borehole fluid-density histories for the WIPP-site boreholes,
- estimates of the uncertainty in the borehole-fluid densities and the uncertainty in the related equivalent-freshwater heads,
- transient freshwater heads,
- estimates of an undisturbed freshwater head, and the uncertainty in this value for the WIPP-site boreholes, and
- shaft construction, grouting, and inflow histories.

This report documents the hydrogeologic data base subsequently used in a study which modeled ground-water flow in the Culebra dolomite. The modeling study is given in a companion report 'Ground-Water Flow Modeling of the culebra Dolomite: Volume I - Model Calibration', SAND89-7068/1, by A.M. LaVenue, T.L. Cauffman, and J.F. Pickens."

Chapman, J.B., 1986. Stable Isotopes in Southeastern New Mexico Groundwater: Implications for Dating Recharge in the WIPP Area, EEG-35, DOE/AL/10752-35. Environmental Evaluation Group, Santa Fe, NM.

EXECUTIVE SUMMARY, p iv;

" The first geologic repository for nuclear waste in the United States, the Waste Isolation Pilot Plant (WIPP), is being excavated at a depth of 2150 ft below ground surface in the Salado Formation in southeastern New Mexico. If a breach of the repository occurs, the water-bearing zones of the Rustler Formation, overlying the Salado, are considered to be the most likely pathways for the transport of radionuclides to the biosphere. A thorough characterization of the hydrology of the Rustler Formation is crucial to the evaluation of the consequences of a breach of the WIPP repository.

The Department of Energy is currently conducting studies of the Rustler Formation (many at the request of the State of New Mexico) that should significantly improve knowledge about the radionuclide contaminant transport ability of the Rustler. One recently completed study examined stable isotope data from Rustler groundwater and concluded that Rustler groundwater in the vicinity of the WIPP Site is not receiving significant modern meteoric recharge (Lambert, 1986). In addition, Lambert (1986) concludes that the stable isotope data reveal an hydraulic isolation of two possible discharge areas (well WIPP-29 and Surprise Spring) from the Rustler Formation elsewhere in Nash Draw and near the site. The conclusion of Lambert's (1986) stable isotope study allow longer residence time of water in the Rustler Formation and reduce the calculated consequences of a breach of the WIPP repository.

The present study compiles stable isotope data from throughout southeastern New Mexico and compares them to data from the WIPP area. The stable isotopic compositions of most samples of groundwater from the Rustler Formation are similar to the composition of other, verifiable young, groundwater in the area. Though the stable-isotope data cannot indicate ages for water in the various aquifers, neither do the data show any distinction between most Rustler groundwater and verifiable young groundwater.

A small number of samples, primarily from the Rustler/Salado contact east of Nash Draw, have isotopic compositions that are not characteristic of recently recharged meteoric water. These waters' enrichment in heavy isotopes may be due to mixing with deeper groundwater (supported by the stable isotopic composition of Salado fluid inclusions and Castile brine) or to exchange between the groundwater and hydrous minerals.

A comparison of the heavy isotope enrichment observed in evaporating waters and the composition of the water at WIPP-29 and Surprise Spring shows that the isotopic composition of these Nash Draw waters could be derived by evaporating Rustler groundwater. Based on stable isotopes, both WIPP-29 and Surprise Spring could be discharge areas for Rustler groundwater moving from elsewhere in Nash Draw and the east.

The enrichment in heavy isotopes found in water from pools in Carlsbad Caverns was used by Lambert (1986) as evidence that the relatively depleted Rustler water was recharged during a past, more pluvial, time. However, the uniqueness of the isotopic composition of

water in the Caverns' pools suggest that rather than representing the composition of recent recharge, the heavy isotopes are enriched by evaporation and equilibrium isotope exchange in the humid cave environment. Recharge in the extreme karst environment near the cavern may also favor isotopically heavy precipitation."

Chappell, J., and Shackelton, N.J. 1986. "Oxygen Isotopes and Sea Level," Nature. Vol. 324, No. 6093, 137-140.

p 137, para 1;
" From the time that detailed oxygen isotope records derived from foraminifera living in the constant-temperature environment of the abyssal ocean became available, there has been a discrepancy between the ice volume record that these records imply, and that derived from the altitude of dated coral terraces around the world. Here, we re-examine the data and conclude that the temperatures of the abyssal ocean has been an actively varying component of the climate system."

Chaturvedi, L. 1993. "WIPP-Related Geological Issues." In Carlsbad Region, New Mexico and West Texas. D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.S. Austin, and J. M. Barker, eds., Forty-Fourth Annual Field Conference, October 6-9, 1993, pp 331-338. New Mexico Geological Society, Roswell, NM.

ABSTRACT, p 331;

" The Waste Isolation Pilot Plant (WIPP) is a proposed repository for disposal of defense transuranic (TRU) radioactive waste. Located in southeastern New Mexico, 25 mi (40 km) east of Carlsbad, the repository has been excavated in the Salado Formation bedded salt at a depth of 2150 ft (655 m) below the surface. The concept of geologic isolation of radioactive waste, with the half-life of the radionuclides measured in tens of thousands of years, is to primarily rely on the geologic barriers to keep the radionuclides from leaking to the biosphere. Several geologic features and processes have been identified during the site characterization of the WIPP site that could impact the performance of the repository for the 10,000 year regulatory period. These include salt dissolution, breccia chimneys, brine reservoirs, Salado Formation hydrology, hydrology of the overlying Rustler Formation water-bearing units, disturbed rock behavior and natural resources. These geologic factors are being considered in the analysis of breach scenarios from the WIPP repository for the next 10,000 year period."

Choppin, G.R. 1988. "Humics and Radionuclide Migration." Radiochimica Acta. Vol 44/45: 23-28.

ABSTRACT, p. 23;

" Humic materials occur throughout the ecosphere in soils and waters, even in deep anoxic underground systems. The spectrum of molecular weights, the nature of the carbon skeleton and the types, positions and relative numbers of functional groups vary widely, in part depending on the origin and age of the humic material. Acid-base titration, C-13 CP/MAS solid-state nuclear magnetic resonance and ultrafiltration serve to define major operational characteristics of these materials. Humic materials sorb to surfaces and particulate matter in waters and can form colloids themselves. The structures and other general properties of humic substances are discussed briefly.

Of importance in the migration of radionuclides in geological media is the strong complexing and redox interactions of humic materials to metal ions. The polyelectrolyte nature of humic molecules leads to very strong complexing which increases in strength with the increasing degree of ionization of the carboxylate groups. In addition, metal ions can be reduced to lower states; e.g., Pu(VI) to Pu(IV). Some unique problems are encountered in measuring the metal binding and/or redox by humic materials. However, such data is important as humic material can have significant effects on metal ion speciation and behavior in geologic systems even at 0.1 ppm levels. Measurements of actinide-humate interactions and their possible consequences on actinide migration are reviewed. "

Chugg, J.C., Anderson, G.W., King, D.L., and Jones, L.H. 1952. Soil Survey of Eddy Area, New Mexico. U.S. Department of Agriculture, Washington, D.C.

"Major fieldwork for this soil survey was done in the period 1960-]965. Soil names and descriptions were approved in 1966. Unless otherwise indicated, statements in this publication refer to conditions in the Area in 1965. This survey was made cooperatively by the Soil Conservation Service and the New Mexico Agricultural Experiment Station. It is part of the technical assistance furnished to the Carlsbad, Central Valley, and Penasco Soil and Water Conservation Districts.

Either enlarged or reduced copies of the soil map in this publication can be made by commercial photographers, or they can be purchased on individual order from the Cartographic Division, Soil Conservation Service, USDA, Washington, D.C. 20250."

Coats, K.H. 1989. "Implicit Compositional Simulation of Single-Porosity and Dual-Porosity Reservoirs." In Proceedings, Tenth SPE Symposium on Reservoir Simulation, Houston, TX. February 6-8, 1989. SPE 18427, pp. 239-275. Society of Petroleum Engineers, Richardson, TX.

ABSTRACT, p 239;
" This paper describes an implicit numerical model for compositional simulation of single-porosity and dual-porosity oil or gas condensate reservoirs. A 3-component equation-of-state compositional approach is proposed as a desirable alternative to extended black oil modeling, requiring little more computing time than the latter. The approach is illustrated for an actual near-critical volatile oil reservoir. A simple method for reducing implicit formulation time truncation error is described and illustrated. A new bottomhole constraint function is described for better preservation of production well target rates in compositional models. A new matrix-fracture transfer formulation including matrix-fracture diffusion is presented for the dual-porosity description; its accuracy is examined in connection with several test problems where correct results are available from single-porosity simulation. Results are discussed for a 3D 600-block simulation of a highly fractured near-critical volatile oil reservoir."

Cooper, J.B., and Glanzman, V.M. 1971. Geohydrology of Project Gnome Site, Eddy County, New Mexico. United States Geological Survey Professional Paper 712-A. U.S. Geological Survey, Washington, D.C.

ABSTRACT, p A1;

" On December 10, 1961, a nuclear device was detonated 1,200 feet underground in the massive salt of the Salado Formation in southeastern Eddy County, N. Mex. In support of the public safety program of the U. S. Atomic Energy Commission, the water regimen of about 1,200 square miles, mostly east of the Pecos River and within 15 miles of the project site, was investigated before, at the time of, and after the explosion. Preliminary investigations determined that about 70 wells were in use in the area around the Project Gnome site. The wells range in depth from a few tens of feet to nearly 800 feet and tap water in rocks of Permian, Triassic, Tertiary, and Quaternary ages. Most ground water in the area is saline; however, it is a valuable resource utilized for stock water. Seven test holes drilled at the project site penetrated similar sequences of rocks overlying the massive salt.

All aquifers in the Project Gnome area lie above the massive salt of the Salado Formation. The only water at the project site is contained in the Culebra Dolomite Member of the Rustler Formation, a confined aquifer about 30 feet thick. The aquifer is about 500 feet beneath the surface and about 200 feet above the top of the salt. The potentiometric surface for the confined water is 75 feet above the top of the aquifer and slopes 0.2 to 1.0 foot per mile westward. Fluctuations of water levels observed in wells are small. Data from a pumping test on the aquifer at the Project Gnome site indicate that 100 gallons per minute could be pumped continuously from a well for as long as 1 year without lowering pumping levels below the top of the aquifer. Pressure changes in the aquifer due to the release of water through drill holes and removal by bailing were easily detected by a recording gage.

Water levels in four observation wells at the site were being recorded at the time of the nuclear explosion. The estimated maximum rise of water level immediately following the explosion was about 4 feet at a distance of 2,000 feet from ground zero. About 3,200 feet from ground zero, the water level rose about 2.2 feet, then gradually returned to normal level within a period of about 11 hours. Water in the four test holes returned to preexplosion levels 2 days after the explosion.

Continued observations of water level in those holes and three additional observation wells indicated no anomalous water-level fluctuations after the nuclear explosion, suggesting that the aquifer probably was not significantly ruptured by the explosion."

Corbet, T.F., and Wallace, M.G. 1993. "Post-Pleistocene Patterns of Shallow Groundwater Flow in the Delaware Basin, Southeastern New Mexico and West Texas," In Carlsbad Region, New Mexico and West Texas, D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.S. Austin, and J.M. Barker, eds. Forty-Fourth Annual Field Conference, October 6-9, 1993, SAND93-1318J, pp. 321-351. New Mexico Geological Society, Roswell, NM. WPO 28643.

ABSTRACT, p 321;

" We used a numerical model to evaluate factors potentially affecting ground water flow in the Rustler and Dewey Lake Formations within a northern portion of the Delaware basin. The model, which is based on the concept of the ground water basin, suggests that flow patterns respond significantly to changes in climate. We include the effects of climate change in the model by varying the amount of moisture that infiltrates to the saturated zone. Calculated hydraulic heads in confined units, such as the Culebra Dolomite Member of the Rustler formation, change by as much as tens of meters in response to long-term changes in the infiltration rate. Results support the concept that patterns of ground water flow in confined units are strongly influenced by the relief of the overlying water table. A substantial portion of the water flowing in the confined units is derived from slow vertical leakage through underlying and overlying aquitards. Flow rates and directions at depth can apparently be affected by changes of only a few tenths of a millimeter per year in the rate of infiltration to the saturated zone. During the simulated period of time, reversals in the direction of vertical flow through the aquitards occur over extensive areas of the model domain. There is great uncertainty in many of the parameters used in our calculations. We do not, therefore, claim that these results are quantitatively correct. Instead, these results improve our intuitive understanding of regional ground water flow in the shallow portion of the Delaware Basin."

Cranwell, R.M., Campbell, J.E., Helton, J.C., Iman, R.L., Longsine, D.E., Ortiz, N.R., Runkle, G.E., and Shortencarier, M.J. 1987. Risk Methodology for Geologic Disposal of Radioactive Waste: Final Report. NUREG/CR-2452, SAND81-2573. Sandia National Laboratories, Albuquerque, NM. WPO 28296.

ABSTRACT, p 5;

" This report contains the description of a risk assessment methodology developed for the US Nuclear Regulatory Commission for use in assessing the risk from the disposal of radioactive wastes in deep geologic formations. This methodology consists of (1) techniques for selecting and screening scenarios, (2) models for use in simulating the physical processes and estimating the consequences associated with the occurrence of these scenarios, (3) probabilistic and statistical techniques for use in risk estimates and sensitivity and uncertainty analyses, and (4) a procedure for utilizing these models and techniques to assess compliance with regulatory standards. The use of this methodology is demonstrated in this report by applying it in the analysis of a hypothetical disposal site containing a bedded-salt formation as the host medium for the waste."

Davies, P.B. 1983 "Assessing the Potential for Deep-Seated Salt Dissolution and the Subsidence at the Waste Isolation Pilot Plant (WIPP)." In State of New Mexico Environmental Evaluation Group Conference, WIPP Site Suitability for Radioactive Waste Disposal, Carlsbad, NM, May 12-13, 1983. (Copy on file at the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM as WPO 29533.)

INTRODUCTION, p 1;

" The following discussion of technical questions concerning deep-seated salt dissolution and the Waste Isolation Pilot Plant (WIPP) has been prepared for the Environmental Evaluation Group conference on "WIPP Site Suitability for Radioactive Waste Disposal" (May 12-13, 1983, Carlsbad, New Mexico). The discussion focuses on recently released WIPP studies of the geologic and hydrologic evidence for and against the occurrence of deep-seated salt dissolution within the Delaware Basin (as opposed to dissolution associated with the Capitan Reef around the margin of the basin) (Figures 1-1 and 1-2). This paper assumes that the reader has a working knowledge of the geology and hydrology of the Delaware Basin, as well as familiarity with the WIPP project.

The central question of concern is whether or not deep-seated salt dissolution and the associated development of breccia chimneys (breccia pipes) or other subsidence structures pose a significant threat to the long term integrity of the WIPP repository. This question can be broken down into the following geotechnical problems:

- Are the hydrogeologic conditions at WIPP capable of producing deep-seated salt dissolution?
- If deep-seated salt dissolution occurs, what type of subsidence would be produced, and how would this subsidence affect the hydrologic integrity of the repository? . . ."

Davies, P.B., 1989. Variable-Density Ground-Water Flow and Paleohydrology in the Waste Isolation Pilot Plant (WIPP) Region, Southeastern New Mexico, Open-File Report 88-490. U.S. Geological Survey. Albuquerque, NM. WPO 38854.

ABSTRACT, p 1;

" A series of analyses, including variable-density flow simulations, was used to examine groundwater flow in the vicinity of the Waste Isolation Pilot Plant (WIPP) in the context of the regional flow system. WIPP is an underground repository mined from a thick bedded-salt unit to provide a facility for the disposal of radioactive waste. WIPP is located in southeastern New Mexico. The analyses primarily examined the Culebra Dolomite Member of the Rustler Formation, which is a potential pathway for the transport of radionuclides to the biosphere in the event of a breach of the WIPP repository.

An analysis of the relative magnitude of pressure-related and density-related flow-driving forces indicates that density-related forces are not significant at the WIPP Site and to the west but are significant in areas to the north, northeast, and south of the site. The area to the south is important because it lies along potential transport pathways from the site. In this area, groundwater flow simulations based on equivalent-freshwater head produce very misleading information on predicted flow directions and velocity magnitudes.

A regional-scale, variable-density model of ground-water flow in the Culebra Dolomite Member was developed in which a baseline, approximate steady-state simulation was calibrated to the distribution of equivalent-freshwater heads. The flow field from the baseline simulation, along with long-term brine transport patterns, indicates that flow velocities are relatively fast west of the site and extremely slow east and northeast of the site. In the transition zone between these two extremes, which includes the WIPP Site, velocities are highly variable.

A series of sensitivity simulations was used to analyze boundary effects and vertical flux. These simulations indicate that if the Culebra is as impermeable to the east and northeast of the WIPP Site as geologic conditions indicate, the central and western parts of the region, including the WIPP Site, are fairly well insulated from the eastern and northeastern boundaries and are insensitive to whatever conditions are assumed to be present along these boundaries. A simulation of a 5-meter head increase along the Pecos River boundary indicates that if the Culebra were tightly confined throughout the entire region, approximately 50 percent of any change in river elevation would eventually reach the WIPP Site. Uncertainty in the regional distribution of storage characteristics in the Culebra makes it difficult to accurately predict how long it would take for Pecos-related stresses to propagate through the WIPP region. A series of vertical-flux simulations indicates that as much as 25 percent of total inflow to the Culebra could be entering as vertical flux. These simulations also indicate that if significant volumes of water enter the Culebra vertically, most of the influx must be occurring in the westernmost part of the transition zone adjacent to Nash Draw.

Motivated by recent isotopic and geochemical analyses, a simple cross-sectional model was developed to provide a physically based analysis of the flow system as it may

have drained through time following recharge during a past glacial pluvial. Drainage for 20,000 years was simulated using a variety of hydraulic-conductivity distributions for rock units overlying the Culebra. These simulations indicate that the system as a whole drains very slowly and that it apparently could sustain flow from a purely transient drainage following recharge of the system during the Pleistocene. Although these simulation do not prove that this has been the case, they do show that such long-term transient drainage is physically possible. The simulations also indicate that the observed underpressuring of the Culebra in the vicinity of the WIPP site is most likely the hydrodynamic result of the Culebra having a relatively high hydraulic conductivity and being well connected to its discharge area but poorly connected to sources of recharge."

Dearlove, J.P.L., Longworth, G., Ivanovich, M., Kim, J.I., Delakowit, B. and Zeh, P. 1990. "Organic Colloid Transport of Radionuclides at Gorleben, West Germany." In Proceedings of the Symposium on Waste Management, Tucson, AZ, February 25-March 1, 1990. R.G. Post, ed., Vol. 2, pp. 565-569. University of Arizona, Tucson, AZ.

ABSTRACT, p 565;

" A study has been carried out on the Gorleben glacial sand/silt aquifer system, West Germany, to determine both the nature and actinide loading of the organic colloids present at the site and their transport characteristics. Six boreholes were sampled and two distinct groundwaters were identified, an organic-rich groundwater containing humic colloids and a saline groundwater which appears to contain mainly fulvic acid. A mixed organic-rich/saline groundwater has also been identified. There is unequivocal evidence for the association of uranium and thorium isotopes with the humic colloids in the organic-rich groundwaters. The values of the $^{234}U/^{238}U$ activity ratio for the colloid fraction in all the boreholes sampled are different from the corresponding values for the solution phase. Uranium isotopes in the colloid fraction are therefore not in chemical equilibrium with those in solution. Other elements strongly bound to the humic colloids in the organic-rich groundwaters include lanthanides and trivalent/tetravalent metals such as Fe, Mn and Ti. Divalent alkaline earths and monovalent metals are less strongly bound."

Doctor, P.G. Liebtrau, A.M., Eslinger, P.W., Reimus, P.W., Elwood, D.M., Strenge, D.L., Engel, D.W., Tanner, J.E., and Freshley, M.D. 1992. An Example Postclosure Risk Assessment Using the Potential Yucca Mountain Site. PNL-8081. Pacific Northwest Laboratory, Richland, WA. NNA. 930414.0031.

PREFACE, p iii;

" The risk analysis described in this document was performed for the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste management (OCRWM) over a 2-year time period ending in June 1988. The objective of Pacific Northwest Laboratory's (PNL) task was to demonstrate an integrated, though preliminary, modeling approach for estimating the postclosure risk associated with a geologic repository for the disposal of high-level nuclear waste. The modeling study used published characterization data for the proposed candidate site at Yucca Mountain, Nevada, along with existing models and computer codes available at that time. Some of the site data and conceptual models reported in the Site Characterization Plan published in december 1988, however, were not yet available at the time that PNL conducted the modeling studies.

The final report describing PNL's study was subsequently reviewed by OCRWM and its contractors, with the comment period extending to August 1989. At that time, DOE decided, based on the reviewer's concerns, not to proceed with comment resolution and publication of the document. Even though PNL's study was conducted as a demonstration of performance assessment methodology, reviewers were concerned that the results would be perceived as an actual risk assessment for the Yucca Mountain site at a time when most detailed site characterization studies had not even been initiated.

In April 1991, OCRWM requested PNL to continue publication of the document, after addressing the review comments, but without performing significant new calculations. This report provides not only a citable reference for work completed in 1988, but documentation for some of the early performance assessment studies that contribute to OCRWM's eventual approach to the risk analyses needed for the license application. New Models have been developed, more site data have been collected, and new risk calculations have been initiated since this work was completed. The results contained here should be interpreted as only a demonstration of an initial stage of study for determining the risk of the proposed repository, rather than a definitive statement of risk based on comprehensive models and the most recent data."

DOE (U.S. Department of Energy), 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026, Vols. 1 and 2, U.S. Department of Energy, Washington, D.C. WPO 38835, WPO 38838 - WPO 38839.

p 1-2, Section 1.2.1 1980 WIPP FEIS

" The 1980 WIPP Final Environmental Impact statement (FEIS) and the associated public review and comment period provided environmental input for the DOE's initial decision to proceed with the WIPP (DOE, 1980). The significance of impacts associated with the various alternatives was assessed. For the selected alternative, a two-phased approach to development was proposed: 1) a site and preliminary design validation (SPDV) program, as discussed in Subsection 8.2.1 of the FEIS, and 2) full construction, as discussed in FEIS Subsection 8.2.2. The durations of key WIPP activities are shown in Figure 1.1.

The 1980 FEIS presented an analysis of the environmental impacts of a number of alternatives for demonstrating the safe disposal of TRU waste. The alternatives considered include:

- Alternative 1. No action. A research and development facility to demonstrate safe disposal of TRU waste would not be developed and post-1970 TRU waste would continue to be retrievably stored.

- Alternative 2. Developing the WIPP at the Los Medanos site in southeastern New Mexico.

- Alternative 3. Disposing of stored TRU waste in the first available repository for high-level radioactive waste.

- Alternative 4. Delaying a decision on the site for a WIPP until at least 1984 to allow for investigation of alternative sites.

Alternative methods and geologic media for TRU waste disposal were also considered but rejected in the FEIS. The alternative methods included burial in deep ocean sediments, emplacement in deep drillholes, transmutation, and ejection into space. The alternative geologic media included igneous, volcanic, and argillaceous rocks.

The DOE's Record of Decision, published January 28, 1981 (46 FR 9162), announced the DOE's selection of Alternative 2: to proceed with the phased development of the WIPP at the Los Medanos site in southeastern New Mexico. . . ."

DOE (U.S. Department of Energy), 1990. Final Safety Analysis Report. WP02-9, Rev. 0, May 1990. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

PREFACE

"**Background**

This Final Safety Analysis Report (FSAR) has been prepared for the Waste Isolation Pilot Plant (WIPP) in order to satisfy the commitments made in the Working Agreement for Consultation and Cooperation(Article III, Section C and Article IV, Section K, known as the Working Agreement) between the State of New Mexico and the U.S. department of energy (DOE) and the requirements of Order DOE 5481.1B,Safety Analysis and Review System.

The objectives of the Safety Analysis Preparation and Review process, as specified in Order DOE 5481.1B, ensure that:

1. Potential hazards are systematically identified;

2. Potential consequences are analyzed;

3. Reasonable measures to eliminate, control or mitigate the hazards have been taken, including, where applicable, compliance with commitments made in environmental assessments and impact statements;

4. There is documented management authorization of the DOE operation based upon an objective assessment of the safety analysis.

Specific hazards that are analyzed include credible natural hazards such as flood, weather (tornado, wind, etc.) and earthquake; and credible man made hazards such as fire, explosion, radiation, and mining hazards. Mitigating measures include facility design and construction, operational controls, and administrative limits.

This FSAR represents a statement and commitment by the DOE that the WIPP facility can be operated safely and at minimum risk, if operated in accordance with this FSAR. Consequently, this FSAR has been prepared to document that a systematic analysis of the potential hazards associated with operating the WIPP facility has been performed (objective 1 of Order DOE 5481.1B); that potential consequences have been analyzed (objective 2 of Order DOE 5481.1B); and that reasonable measures have been taken to eliminate, control, or mitigate the hazards (objective 3 of Order DOE 5481.1B). In addition, this FSAR documents the implementation of commitments made in the environmental impact statement regarding the mitigation of adverse impacts to the environment (objective 3 of Order DOE 5481.1B)."

DOE (U.S. Department of Energy). 1990. WIPP Test Phase Plan: Performance Assessment. DOE/WIPP-89-011, Rev. 0. U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-1;

" The U. S. Department of Energy (DOE) is responsible for managing the disposition of transuranic (TRU) waste resulting from nuclear weapons production activities of the United States. These wastes are currently stored nationwide at several of the DOE's waste generating/storage sites. The goal is to eliminate interim waste storage and achieve environmentally and institutionally acceptable permanent disposal of these TRU wastes, much of which is mixed waste, that is, waste that is also contaminated with hazardous substances. The Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico is being considered as a disposal facility for these TRU wastes.

The mission of WIPP as established by Congress in 1979 (Public Law 96-164) is to provide '...a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States exempted from regulation by the Nuclear Regulatory Commission.' The fundamental responsibility of WIPP's mission, to demonstrate safe disposal of TRU wastes, is being fulfilled in a phased stepwise approach, leading up to the decision whether to designate WIPP a disposal facility. With the Construction Phase nearing completion, WIPP is ready to initiate the next major phase in its development, the Test Phase. The Test Phase period is proposed to collect additional technical data to improve confidence in the prediction of the long-term performance of the repository as required by the applicable environmental regulations (40 CFR 191 and 268). . . ."

DOE (U.S. Department of Energy), 1991. Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force, DOE/WIPP 91-007, Rev. 0, Vols. 1 and 2. Waste Isolation Pilot Plant, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-i;

" The Engineered Alternatives Task Force (EATF) was established by the United States Department of Energy (DOE) WIPP Project Office (WPO) in September, 1989 (Hunt, A., 1990), to evaluate the relative effectiveness and feasibility of implementation of selected design enhancements (referred to as 'engineered alternatives') for the Waste Isolation Pilot Plant (WIPP). These enhancements consist of modifications of existing waste forms and/or the WIPP facility, and other design variations such as passive marker systems. The purpose of this report is to summarize the methodologies and results of evaluation of the effectiveness of selected engineered alternatives relative to the existing repository design, and to discuss the feasibility of implementing these alternatives with respect to availability of technology, cost, schedule, and regulatory concerns.

Preliminary analyses of the long-term performance of the WIPP disposal system performed by Sandia National Laboratories (SNL) (referred to as 'performance assessment') have identified two potential problems in demonstrating compliance with the applicable regulation 40 CFR Part 191 (EPA, 1985) that governs the disposal of transuranic radioactive waste. The first potential problem relates to gas generation. Lappin et al. (1989) discuss the possibility that up to 1,500 moles of gas can be generated per drum (or drum equivalent) of waste from anoxic corrosion, microbial degradation, and radiolysis, at rates that may be as high as 2.55 moles/drum/year. Although processes exist to dissipate excess gas pressure, these processes are currently believed to be slow relative to the current estimates of gas generation rates, resulting in gas pressures in storage rooms that may temporarily exceed lithostatic pressure. The consequences of exceeding lithostatic pressure are currently being evaluated by SNL (Lappin et al., 1989). Unless these evaluations demonstrate that either excess pressures will not occur, or that excess pressures will not degrade the performance of the disposal system, some type of waste form or facility modification may be required to either eliminate gas generation or reduce the rate of gas generation. For example, if the organics in the waste are incinerated and vitrified, then microbial gas generation can be eliminated.

A second potential problem in demonstrating compliance with 40 CFR Part 191 relates to the consequences predicted from future inadvertent human intrusion events. Preliminary evaluations of compliance with the containment requirement of 40 CFR Part 191 performed by SNL suggest that some of the current waste forms (under current interpretations of human intrusion provisions) may eventually be found to be unacceptable for disposal at the WIPP (Marietta et al., 1989). This may be due to uncertainties in key performance parameters of the waste forms. Key parameters that control the release of radionuclides during human intrusion scenarios are permeability of the waste storage rooms, radionuclide solubilities, and the availability of brine. Permeability of the storage rooms can

be effectively reduced by the use of a grout backfill and/or shredding and cementation of the waste. Solubilities can be reduced by the use of grout backfill or the addition of lime to raise the pH of any brine that may come in contact with the waste."

DOE (U.S. Department of Energy), 1991. Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Revision 7, Oak Ridge National Laboratory, Oak Ridge, TN. HQX. 910711.0004.

ABSTRACT; P 1;

" The Integrated Data Base (IDB) Program has compiled current data on inventories and characteristics of commercial spent fuel and both commercial and U. S. government-owned radioactive wastes through December 31,1990. These data are based on the most reliable information available from government sources, the open literature, technical reports, and direct contacts. The current projections of future waste and spent fuel to be generated generally through the year 2020 and characteristics of these materials are also presented. The information forecasted is consistent with the latest U.S. Department of Energy/Energy Information Administration (DOE/EIA) projections of U.S. commercial nuclear power growth and the expected DOE-related and private industrial and institutional (I/I) activities.

The radioactive materials considered, on a chapter-by-chapter basis, are spent fuel, high-level waste, transuranic waste, low-level waste, commercial uranium mill tailings, environmental restoration wastes, commercial reactor and fuel cycle facility decommissioning wastes, and mixed (hazardous and radioactive) low-level waste. For most of these categories, current and projected inventories are given through the year 2020, and the radioactivity and thermal power are calculated based on reported or estimated isotopic compositions. In addition, characteristics and current inventories are reported for miscellaneous radioactive materials that may require geologic disposal."

DOE (U.S. Department of Energy). 1994. Compliance Status Report for the Waste Isolation Pilot Plant. DOE/WIPP 94-019, Rev. 0. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

1.0 Introduction, p 1-1;

" The U.S. Department of Energy (DOE) is responsible for the disposition of transuranic (TRU) waste generated through national defense-related activities. Approximately 53,700 m^2 of these wastes have been generated and are currently stored at government defense installations across the country. The Waste Isolation Pilot Plant (WIPP), located in southeastern New mexico, has been sited and constructed to meet the criteria established by the scientific and regulatory community for the safe, long-term disposal of TRU and TRU-mixed wastes. This Compliance Status Report (CSR) provides an assessment of the progress of the WIPP Program toward compliance with long-term disposal regulations, set forth in Title 40 CFR 191 (EPA, 1993a), Subparts B and C, and Title 40 CFR §268.6 (EPA, 1993b), in order to focus on-going and future experimental and engineering activities. The CSR attempts to identify issues associated with the performance of the WIPP as a long-term repository and to focus on the resolution of these issues. This report will serve as a tool to focus project resources on the areas necessary to ensure complete, accurate, and timely submittal of the compliance application. This document is not intended to constitute a statement of compliance or a demonstration of compliance."

DOE (U.S. Department of Energy). 1994. Experimental Program Plan for the Waste Isolation Pilot Plant. DOE/WIPP 94-008, Rev. 0. U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-2, para 3;

" This Plan describes DOE plans for demonstrating compliance with both long- and short-term regulations that apply to the WIPP. For the demonstrations of compliance for the long-term as required by 40 CFR Part 191 and 40 CFR 268.6, the DOE will use performance assessment to predict the behavior of the WIPP over thousands of years. Performance assessment is an analytical process that begins by using available information to characterize the waste and the disposal system. This assessment evaluates the natural barriers provided by the host rock and the surrounding formations and the design of the repository and the engineered barriers. The assessment identifies the processes (i.e., phenomena that might develop slowly, over long periods of time) and events that might affect the system. It examines the effects of these processes and events on the performance of the overall system. Release estimates of radionuclides and hazardous chemical constituents can then be developed, considering associated uncertainties, and sensitivity analyses can be performed to determine which characteristics of the disposal system or which processes or events exert the greatest effect on system performance.

DOE (U.S. Department of Energy) 1994. U.S. Department of Energy Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report, DOE/CAO-94-1005, Rev. 1, Vols. 1-2. WIPP Technical Assistance Contractor for U.S. Department of Energy, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-1;

" The Waste Isolation Pilot Plant (WIPP) Transuranic Waste Baseline Inventory Report (WTWBIR) establishes a methodology for grouping wastes of similar physical and chemical properties, from across the U.S. Department of Energy (DOE) transuranic (TRU) waste system, into a series of 'waste profiles' that can be used as the basis for waste form discussions with regulatory agencies.

The WIPP baseline inventory is estimated using waste streams identified in the recent information released in the Mixed Waste Inventory Report (MWIR), supplemented by information from the Nonradionuclide Inventory Database (NID) and the 1993 Integrated Data Base (IDB). Each waste stream is defined in a waste stream profile and has been assigned a waste matrix code (WMC) by a DOE TRU waste generator/storage site. Waste stream profiles with WMCs that have similar physical and chemical properties can be combined into a waste matrix code group (WMCG), which is then documented in a site-specific waste profile for each TRU waste generator/storage site that contains waste streams in that particular WMCG.

Based on methodology presented here in the WTWBIR, a maximum of 11 site-specific waste profiles have been identified for contact-handled (CH) TRU waste and a maximum of 11 have been identified for remote-handled (RH) TRU waste. Based on analyses of existing inventories, no site has more than 10 site-specific CH-TRU waste profiles, nor more than 5 site-specific RH-TRU waste profiles. Each of these site-specific waste profiles have unique WMCG criteria and they are developed, if appropriate, for each of the TRU waste generator/storage sites. A particular site-specific waste profile, with a specific WMCG, can be combined with other site-specific waste profiles having identical WMCGs from the TRU waste generator/storage sites to derive a WIPP waste profile. Therefore, a maximum of 11 WIPP waste profiles for CH-TRU waste and a maximum of 6 WIPP waste profiles for RH-TRU waste have been identified that describe the different TRU wastes across the DOE system.

The anticipated inventory of TRU waste is defined as the sum of retrievably stored waste plus currently projected TRU waste volumes. The anticipated inventory is not sufficient to fill the allowed capacity of WIPP (calculated: 6.2×10^6 ft^3 [$\sim 1.76 \times 10^5$ m#]), and scaling has been developed as a means of examining the impacts of the full repository. Additionally, there is a high uncertainty in and a current lack of data on wastes produced from decontamination and decommissioning (D&D) and environmental restoration (ER) activities. Therefore, the anticipated inventory has been 'scaled' to the WIPP capacity. The scaling of the inventory in future revisions of the WTWBIR will be derived from the best available data and assumptions.

An example of five waste streams at two sites (Idaho National Engineering Laboratory and Rocky Flats Plant) has been used to illustrate the waste profile methodology.

Preliminary total WIPP inventory volumes for the 11 CH-TRU and 6 RH-TRU WIPP waste profiles are provided; final volumes will be provided in Revision 1 of this document after the DOE TRU waste generator/storage sites have reviewed the data and after quality checks of the data have been completed.

Using the same waste profile methodology, the WTWBIR also estimates the WIPP disposal inventory (anticipated inventory that has been scaled to WIPP design capacity) in terms of 10 waste material parameters and packaging materials that have been identified as inputs needed for the system prioritization (SP) and performance assessment (PA) calculations. The 10 waste material parameters and packaging materials are waste constituents that occur in TRU waste and are input parameters for one or more SP and PA models or are required to adequately describe the waste form. These parameters may change as a result of SP and PA efforts.

The 10 waste material parameters and packaging materials that are identified and included in the WTWBIR are:

- Inorganics
  - Iron-based metals/alloys
  - Aluminum-based metals/alloys
  - Other metals
  - Other inorganic materials
- Organics
  - Cellulosics
  - Rubber
  - Plastics
- Solidified Materials
  - Inorganic matrix
  - Organic matrix
- Soils
- Packaging Materials
  - Steel
  - Plastic or lead

The waste material parameter information is reported in kilograms per cubic meters (kg/m^3) and estimates of the uncertainty in the waste material parameters have been calculated, based on data derived from the NID (i.e., average, minimum, and maximum estimates of waste material parameters on a per-waste-stream basis). The maximum values for waste material parameters in the waste stream, site-specific, and WIPP waste profiles are expressed on a weight/volume basis. However, the occurrence of more than one waste material parameter at the maximum value within a waste stream is highly unlikely. During SP and PA calculations, the sampling statistics must be controlled so that several waste material parameters do not get sampled all at their maximum value (weight/volume), lest the maximum weight/volume is exceeded. A five-waste-stream/two-site example is used to illustrate the methodology for estimating quantities of waste material parameters. The preliminary total WIPP inventory for the waste material parameters is provided and should

be used in any SP and PA calculations until Rev. 1 of the WTWBIR is published, pending completion of quality checks of the data used. The nonradionuclide and radionuclide inventory presented in this report replaces any previously used information in SP and PA calculations.

Although the initial purpose of this report is to provide data to be included in the Sandia National Laboratories/New Mexico SP and PA processes, all data are presented and explained in such a way that they can be adapted as needed for other applications. The WTWBIR, Revision 0, is presented in two parts: Book 1 contains this Executive Summary through Chapter 7, References; Book 2 contains Appendix A, Glossary, through Appendix M, MWIR Code Designations and Descriptions."

Dowding, C.H., and Rozen, A. 1978. Damage to Rock Tunnels for Earthquake Shaking. Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, Vol. 104, No. GT2, pp. 175-191.

INTRODUCTION, p. 175;

" Observations of rock tunnel response to earthquake motions is compared with calculated peak ground motions for 71 cases to determine damage modes. Damage, ranging from cracking to closure, is recorded in 42 of the observations. These tunnels, located in California, Alaska, and Japan, served as railway and water links and were 10 ft-20 ft (3 m-6 m) in diameter. This comparison of peak motion with observed damage can serve as a framework both for development of analytical models and for estimation of expected losses resulting from earthquake shaking failure of tunnels in rock. This is the first such correlation besides a consulting report by Cooke (2).

The potential damage to tunnels from earthquakes is a factor to be considered in the siting of any subsurface project whose failure would result in severance of life-line supply. This paper focuses upon the evaluation of rock tunnel damage caused by shaking, but treats damage from other causes. There are three reasons for the more restricted focus: (1) Damage from other sources, such as ground failure or displacement from fault movement, is location specific, and potential damage may be minimized through careful siting; (2) shaking can result from movement of a number of faults (i.e., is not location specific) and therefore potentially affects long lengths of tunnel; and (3) it is useful for project planning to compare damage to tunnels with that to above-ground structures ate the same intensity of shaking."

Eager, G.P. 1983. Core from the Lower Dewey Lake, Rustler, and Upper Salado Formation, Culberson County, Texas. Permian Basin Cores. R.L. Shaw and B.J. Pollan, eds. P.B.S.-S.E.P.M. Core Workshop No. 2, pp. 273–283. Permian Basin Section, Society of Economic Paleontologists and Mineralogists, Midland, TX.

INTRODUCTION, p 273;

" Seven hundred and twenty feet of continuous Upper Permian core is displayed by Texasgulf, Inc. The formations cored include the lower portion of the Dewey Lake, the Rustler, and the upper portion of the Salado. This core was obtained by Texasgulf, Inc., as part of a sulphur exploration program. The depth of the core is from 37 feet to 757 feet. It is located in the SE¼, Section 5, PSL, Block 45 (12 miles southwest of Orla) Culberson County, Texas (Fig. 1). Gamma ray and neutron logs are included (Fig. 2) so that the lithology can be compared to the geophysical response. All depths are reported in feet.

The core is presented to give Delaware Basin geologists a 'hands-on' look at the strata that comprise the 'overburden' and troublesome drilling zones through which they must drill to reach the deeper oil-bearing horizons. The Rustler Formation may have reservoir potential."

EPA (U.S. Environmental Protection Agency), 1996. Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations Final Rule. Response to Commments Document for 40 CFR Part 194. EPA 402-R-96-001. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Francis, A.J., and Gillow, J.B. 1994. Effects of Microbial Processes on Gas Generation Under Expected Waste Isolation Pilot Plant Repository Conditions. SAND93-7036. Sandia National Laboratories, Albuquerque, NM. WPO 26555.

ABSTRACT, p i;
" Microbial processes involved in gas generation from degradation of the organic constituents of transuranic waste under conditions expected at the Waste Isolation Pilot Plant (WIPP) repository are being investigated at Brookhaven National Laboratory. These laboratory studies are part of the Sandia National Laboratories - WIPP Gas Generation Program. Gas generation due to microbial degradation of representative cellulosic waste was investigated in short-term (< 6 months) and long-term (> 6 months) experiments by incubating representative paper (filter paper, paper towels, and tissue) in WIPP brine under initially aerobic (air) and anaerobic (nitrogen) conditions. Samples from the WIPP surficial environment and underground workings harbor gas-producing halophilic microorganisms, the activities of which were studied in short-term experiments. The microorganisms metabolized a variety of organic compounds including cellulose under aerobic, anaerobic, and denitrifying conditions. In long-term experiments, the effects of added nutrients (trace amounts of ammonium nitrate, phosphate, and yeast extract), nutrients plus excess nitrate, and no nutrients on gas production from cellulose degradation were investigated. Results to date (up to 200 days of incubation) show that: (i) gas production was not detected in abiotic control samples; (ii) cellulose incubated without nutrients showed limited but sustained gas production; (iii) the addition of nutrients enhanced the biodegradation of cellulose as evidenced by an increase in the production of total gas, carbon dioxide, and nitrous oxide; (iv) in the presence of excess nitrate, gas production was the highest and nitrous oxide accumulated to varying amounts; (v) the addition of bentonite increased the background carbon-dioxide concentration and stimulated microbial activity specifically in aerobic samples; and (vi) in addition to total gas and carbon dioxide production, cellulose degradation in nutrient-amended samples was evidenced by the gradual bleaching of brown paper towel, the formation of gas bubbles, the formation of paper pulp, and the appearance of a red color at the bottom of the sample bottles, indicating the growth of halophilic microorganisms. Estimates of the total gas production on the basis of initial results ranged from 0.001 to 0.039 mL g^{-1} cellulose day^{-1}."

Freeland, M.H. 1982, "Basic Data Report for Borehole DOE-1, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico," TME 3159, U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM.

ABSTRACT, p 1-1;

" Borehole DOE-1 is one of several exploratory boreholes drilled at the Waste Isolation Pilot Plant (WIPP) site for the purpose of gathering stratigraphic, hydrologic and structural data. DOE-1 is located in Section 28, T22S, R31E in Eddy County, New Mexico. Within the WIPP site proper, DOE-1 is located in Zone III about 1.25 miles to the southeast of the exploratory shaft location.

This project was undertaken for several reasons:

- To investigate the presence of an anticlinal structure in the Castile Formation indicated by seismic reflection surveys in the area.
- To gather data on the stratigraphy, structure and lithology of the rocks which comprise the facility horizon in an area immediately southeast of the facility itself.
- To test for the presence of gas or fluids in the rocks associated with the anticlinal structure, if present, or in the flat-lying rocks.
- To determine the nature of the Castile Formation near the site, but outside the 'disturbed zone'.

Field operations were initiated July 12, 1982 and completed July 30, 1982. The borehole was drilled to a depth of 4065.3 feet below kelly bushing, with approximately 420 feet of that interval cored. Where no core was taken, cutting samples were collected and described at ten-foot intervals, largely for stratigraphic control and estimation of coring points.

Data collected and observations made during drilling indicate that the lithology, stratigraphy and structure penetrated in DOE-1 are similar to that observed elsewhere in the WIPP vicinity. No brine or gas was noted, either by sensors at the wellhead or in trace amounts in the mud. Cored sections showed no structural disruption in the halite and anhydrite units of the Castile, other than minor, commonly observed folding and tilting of laminae in the anhydrites.

This Basic Data Report includes lithologic and geophysical information collected during the field operations. With minor exceptions, no analytical interpretive work was performed on the data for inclusion in this report. Slight adjustments were made on drilling depths to achieve correlation with the geophysical logs and some lithologic assumptions were made for a few sample intervals where unrepresentative cuttings samples resulted from inadequate brine saturation."

Freeze, R.A., and Cherry, J.A. 1979. Groundwater.Prentice-Hall, Englewood Cliffs, NJ. NNA. 870406.0444.

PREFACE, p xv;

" We perceive a trend in the study and practice of groundwater hydrology. We see a science that is emerging from its geological roots and its early hydraulic applications into a full-fledged environmental science. We see a science that is becoming more interdisciplinary in nature and of greater importance in the affairs of man.

This book is our response to these perceived trends. We have tried to provide a text that is suited to the study of groundwater during this period of emergence. We have made a conscious attempt to integrate geology and hydrology, physics and chemistry, and science and engineering to a greater degree than has been done in the past.

This book is designed for use as a text in introductory groundwater courses of the type normally taught in the junior or senior year of undergraduate geology, geological engineering, or civil engineering curricula. It has considerably more material than can be covered in a course of one-semester duration. Our intention is to provide a broad coverage of groundwater topics in a manner that will enable course instructors to use selected chapters or chapter segments as a framework for a semester-length treatment. The remaining material can serve as a basis for a follow-up undergraduate course with more specialization or as source material for an introductory course at the graduate level. We recognize that the interdisciplinary approach may create some difficulties for students grounded only in the earth sciences, but we are convinced that the benefits of the approach far outweigh the cost of the additional effort that is required.

The study of groundwater at the introductory level . . ."

Galson, D.A., Hicks, T.W., Wilmot, R.W., and Swift, P.N. 1995. Systems Prioritization Method--Iteration 2 Baseline Position Paper: Scenario Development for Long-Term Performance Assessments of the WIPP. Sandia National Laboratories, Albuquerque, NM. WPO 28726

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Gonzales, M.M. 1989. Compilation and Comparison of Test-Hole Location Surveys in the Vicinity of the Waste Isolation Pilot Plant Site. SAND88-1065. Sandia National Laboratories, Albuquerque, NM. WPO 24121.

ABSTRACT;
" Between 1976 and 1988, many surveys were performed related to the Waste Isolation Pilot Plant and its geologic and hydrologic test holes, which are part of the hydrogeologic-characterization program. Among these surveys were two First-Order, Class I vertical surveys, a satellite survey, and a number of township-range surveys. An overview of the basic function, history, and methodology of each survey type is provided in this report along with a review and comparison of the two major test-hole surveys. Elevation and location data for 96 test holes and 4 shafts are also included. The comparison of the satellite survey to the township-range surveys showed that the latter have the following advantages: their data are more complete; their elevation data are more accurate; and their techniques can be used for surveying new wells, keeping the data set consistent. Therefore, the final township-range surveys were selected as the best source of elevation and location data to use in the WIPP hydrology program."

Griswold, G.B., 1977. Site Selection and Evaluation Studies of the Waste Isolation Pilot Plant (WIPP), Los Medaños, Eddy County, NM. SAND77-0946. Sandia National Laboratories, Albuquerque, NM. WPO 28125.

ABSTRACT, p. 3;

" Bedded-salt deposits of the Salado Formation have been selected for evaluation for a proposed Waste Isolation Pilot Plant (WIPP) to be located in Eddy County, NM, ~26 mi east of Carlsbad. Site selection and evaluation studies that included geologic mapping, geophysical surveys, drilling, and resource appraisal were conducted over and under the prospective location. The lower portion of the Salado meets essential criteria for waste isolation. Beds chosen for waste storage lie 2074-2730 ft below the surface. High-purity salt exists at these depths, and the geologic structure revealed by geophysical surveys indicates that these beds are essentially flat. Additional geophysical surveys are now under way. The initial interpretation of the new data indicates that more structure may exist in the salt beds in the northern portion of the site area. Full evaluation of potentially commercial deposits of potash and natural gas within the WIPP site will be reported by separate studies, as will be the hydrologic details of the region."

Hays, J.D., Imbrie, J. and Shackleton, N.J. 1976. Variations in the Earth's Orbit: Pacemaker of the Ice Ages," Science. Vol. 194, No. 4270, pp. 1121-1132. HQS.880517.2140.

p 1121, col 1;

" For more than a century the cause of fluctuations in the Pleistocene ice sheets has remained an intriguing and unsolved scientific mystery. Interest in this problem has generated a number of possible explanations (1,2). One group of theories invokes factors external to the climate system, including variations in the output of the sun, or the amount of solar energy reaching the earth caused by changing concentrations of interstellar dust (3); the seasonal and latitudinal distribution of incoming radiation caused by changes in the earth's orbital geometry (4); the volcanic dust content of the atmosphere (5); and the earth's magnetic field (6). Other theories are based on internal elements of the system believed to have response times sufficiently long to yield fluctuations in the range 10^4 to 10^6 years. Such features include the growth and decay of ice sheets (7); the surging of the Antarctic ice sheet (8); the ice cover of the Arctic ocean (9); the distribution of carbon dioxide between atmosphere and ocean (10); and the deep circulation of the ocean (11). Additionally, it has been argued that as an almost intransitive system, climate could alternate between different states on an appropriate time scale without the intervention of any external stimulus or internal time constant (12).

Among these ideas, only the orbital hypothesis has been formulated so as to predict the frequencies of major Pleistocene glacial fluctuations. Thus it is the only explanation that can be tested geologically by determining what these frequencies are. Our main purpose here is to make such a test. . . ."

Helton, J.C., Garner, J.W., McCurley, R.D., and Rudeen, D.K. 1991. Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant. SAND90-7103. Sandia National Laboratories, Albuquerque, NM. WPO 23803.

ABSTRACT, p i;

" The purposes of this report are to (1) review available techniques for the performance of uncertainty and sensitivity analyses for computer models, (2) discuss the approach to uncertainty and sensitivity analysis selected for use in performance assessment for the Waste Isolation Pilot Plant (WIPP), (3) present the results of uncertainty and sensitivity analyses performed in support of the 1990 preliminary performance assessment for the WIPP, and (4) discuss the U. S. Environmental Protection Agency (EPA) release limits to the accessible environment (40 CFR 191) in the context of a formal; representation for risk. The following approaches to uncertainty and sensitivity analysis are reviewed: differential analysis, Monte carlo analysis, response surface methodology, and Fourier amplitude sensitivity test. Of these approaches, Monte Carlo analysis is felt to be the most widely applicable to the problems that arise in performance assessment for radioactive waste disposal. Monte Carlo analysis is based on performing multiple model evaluations with probabilistically selected model input, and then using the results of these evaluations to determine both the uncertainty in model predictions and the independent variables that give rise to this uncertainty. A Monte Carlo analysis involves five steps: (1) selection of a range and distribution for each independent variable, (2) generation of a sample from the ranges and distributions assigned to then independent variables, (3) evaluation of the model for each element of the sample, (4) assessment of the uncertainty in model predictions through the use of estimated means, variances and distribution functions, and (5) determination of the sensitivity of model predictions to model input on the basis of scatterplots, regression analysis and correlation analysis. The preceding steps are discussed and then applied in uncertainty/sensitivity analyses for scenarios involving drilling intrusions that arose in the 1990 preliminary performance assessment for the WIPP. These analyses used Latin hypercube sampling to select model input and made extensive use of stepwise regression analysis with rank-transformed data to assess the impact of individual variables on model predictions. Releases to the accessible environment due to groundwater transport were dominated by solubility limit and retardation; releases to the surface environment due to the removal of cuttings from boreholes were dominated by borehole cross-sectional area, time of intrusion, and number of boreholes. Overall, the releases were small, usually much smaller than the EPA release limits for the WIPP. Calculation of the EPA release limits involves a Monte carlo calculation of the complementary cumulative distribution function (CCDF). The calculation of this CCDF is discussed and shown to fit into a formal representation for risk based on scenarios, scenario probabilities, and scenario consequences. The relationship between the Monte carlo procedures used in the WIPP performance assessment and this formal representation for risk are developed."

Helton, J.C., Garner, J.W., Rechard, R.P., Rudeen, D.K., and Swift, P.N. 1992 Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 4: Uncertainty and Sensitivity Analysis Results. SAND91-0893/4, Sandia National Laboratories, Albuquerque, New Mexico, WPO 26423.

Volume 4, ABSTRACT, p i;

" The most appropriate conceptual model for performance assessment at the Waste Isolation Pilot Plant (WIPP) is believed to include gas generation due to corrosion and microbial action in the repository and a dual-porosity (matrix and fracture porosity) representation for solute transport in the Culebra Dolomite Member of the Rustler Formation. Under these assumptions, complementary cumulative distribution functions (CCDFs) summarizing radionuclide releases to the accessible environment due to both cuttings removal and groundwater transport fall substantially below the release limits promulgated by the Environmental Protection Agency (EPA). This is the case even when the current estimates of the uncertainty in analysis inputs are incorporated into the performance assessment. The best-estimate performance-assessment results are dominated by cuttings removal. The releases to the accessible environment due to groundwater transport make very small contributions of CCDFs that must be considered in comparisons with the EPA release limits is dominated by the variable LAMBDA (rate constant in Poisson model for drilling intrusions). The variability in releases to the accessible environment due to individual drilling intrusions is dominated by DBDIAM (drill bit diameter). Most of the imprecisely known variables considered in the 1991 WIPP performance assessment relate to radionuclide releases to the accessible environment due to groundwater transport. For a single borehole (i.e., an E2-type scenario), whether or not a release from the repository to the Culebra even occurs is controlled by the variable SALPERM (Salado permeability), with no releases for small values (i.e., $<5 \times 10^{-21} m^2$) of this variable. When SALPERM is small, the repository never fills with brine and so there is no flow up an intruding borehole that can transport radionuclides to the Culebra. Further, releases that do reach the Culebra for larger values of SALPERM are small and usually do not reach the accessible environment. A potentially important scenario for the WIPP involves two or more boreholes through the same waste panel, of which at least one penetrates a pressurized brine pocket and at least one does not (i.e., an E1E2-type scenario). For these scenarios, the uncertainty in release to the Culebra is dominated by the variables BHPERM (borehole permeability), BPPRES (brine pocket pressure), and the solubilities for the individual elements (i.e., Am, Np, Pu, Th, U) in the projected radionuclide inventory for the WIPP. Once a release reaches the Culebra, the matrix distribution coefficients for the individual elements are important, with releases to the Culebra often failing to reach the accessible environment over the 10,000-yr period specified in the EPA regulations. To provide additional perspective, the following variants of the 1991 WIPP performance assessment have also been considered: (1) no gas generation in the repository and a dual-porosity transport model in the Culebra; (2) gas generation in the repository and a single-porosity (fracture porosity) transport model in the Culebra; (3) no gas generation in the repository and a single-porosity transport model in the Culebra; (4) gas

generation in the repository and a dual-porosity transport model in the Culebra without chemical retardation; and (5) gas generation in the repository, a dual-porosity transport model in the Culebra, and extremes of climatic variation. All of these variations relate to groundwater transport and thus do not affect releases due to cuttings removal, which were found to dominate the results of the 1991 WIPP performance assessment. However, these variations do have the potential to increase the importance of releases due to groundwater transport relative to releases due to cuttings removal."

Helton, J.C., Marietta, M.G., and Rechard, R.P. 1993. Conceptual Structure of Performance Assessments Conducted for the Waste Isolation Pilot Plant. SAND92-2285. Sandia National Laboratories, Albuquerque, NM. WPO 27834.

ABSTRACT, p i;
" The Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico is being developed by the U. S. Department of Energy as a disposal facility for transuranic waste. In support of this project, Sandia National Laboratories is conducting an ongoing performance assessment (PA) for the WIPP. The ordered triple representation for risk proposed by Kaplan and Garrick is used to provide a clear conceptual structure for this PA. This presentation describes how the preceding representation provides a basis in the WIPP PA for (1) the definition of scenarios and the calculation of scenario probabilities and consequences, (2) the separation of subjective and stochastic uncertainties, (3) the construction of the complementary cumulative distribution functions required in comparisons with the U. S. Environmental Protection Agency's standard for the geologic disposal of radioactive waste (i.e., 40 CFR Part 191, Subpart B), and (4) the performance of uncertainty and sensitivity studies. Results obtained in a preliminary PA for the WIPP completed in December of 1991 are used for illustration.

Hiemenz, P.C., 1986. Principles of Colloid and Surface Chemistry. 2nd ed. Marcel Dekker, Inc., New York, NY.

PREFACE TO THE SECOND EDITION, p iii;

" In the preface to the first edition, I stated that this is 'primarily a textbook, written with student backgrounds, needs, and objectives in mind.' This continues to be true of the second edition, and many of the revisions I have made are attempts to make the book even more useful than its predecessor to student readers. In addition, colloid and surface science continue to flourish. In preparing the second edition I have also attempted to 'open up' the coverage to include some of the newer topics from an ever-broadening field.

A number of differences between the first and second editions can be cited which are readily traceable to either one or both of the foregoing considerations.

Two new chapters have been added which explore--via micelles and related structures and metal surfaces under ultra-high vacuum--both 'wet' and 'dry' facets of colloids and surfaces. Although neither of these areas is new, both are experiencing an upsurge of activity as new instrumentation is developed and new applications are found.

A number of chapters have been overhauled so thoroughly that they bear only minor resemblence to their counterparts in the first edition. The thermodynamics of polymer solutions is introduced in connection with osmometry and the drainage and spatial extension of polymer coils is discussed in connection with viscosity. The treatment of contact angle is expanded so that it is presented on a more equal footing with surface tension in the presentation of liquid surfaces. Steric stabilization as a protyective mechanism against flocculation is discussed along with the classical DLVO theory.

Solved problems have been scattered throughout the text. I am convinced that students must work problems to gain mastery of the topics we discuss. Including examples helps bridge the gap between the textbook presentation of theory and student labors over the analysis and mechanics of problem solving.

SI units have been used fairly consistently throughout the book. Since the problems. . . ."

Hill, A.C., and Thomas, G.W. 1985. "A New Approach for Simulating Complex Fractured Reservoirs." In Proceedings, Eighth SPE Sympsium on Reservoir Simulation, Dallas, TX, February 10-13, 1985, L.C. Young, ed. SPE 13537. pp. 429-440. Society of Petroleum Engineers of AIME, Richardson, TX.

ABSTRACT, p 429;

" This paper treats a dual porosity and dual permeability system in which two grids - one each for the fractures and matrix occupy the same volume. We employ 5 pseudo components in the formulation which extends the capability beyond normal black-oil applications. The formulation also permits inert gas injection (i.e. nonhydrocarbon - N_2, CO_2, etc.) which can diffuse into the liquid phases. Moreover, the oil properties can be optionally treated as functions of pressure and API gravity.

We briefly review the mathematical description of the system. We also describe a memory management scheme whereby one can study large reservoir problems (in excess of 20,000 cells) on computers offering modest core capability. Finally, we present example applications for an isolated fracture system, the effect of cyclic water injection, and the effect of variable API gravity."

Hills, J.M., and Kottlowski, F.E. 1983. Southwest/Southwest Mid-Continent Region: Correlation of Stratigraphic Units of North America (COSUNA) Project. Correlation Chart Series 1983. AAPG Bookstore, Tulsa, OK.

EDITOR'S NOTE;

" The COSUNA Correlation Charts are intended to show stratigraphic columns which provide fairly complete coverage of the geology of the United States. In most cases, these columns are generalizations of the geology of an area and do not represent single surface or subsurface locations. The locations of the columns on the index map are intended to show the areas in which the stratigraphy is uniform enough to be shown in a single column. Since the columns are generalized they often show a range of thicknesses for each of the units and their dominant lithology within the map area.

Because the COSUNA Charts are correlation charts and not cross-sections their vertical scale is time, not thickness. Due to this difference, a number of features which may be shown on cross-sections cannot be shown on correlation charts.

The positional relationships of units separated by angular unconformities are not necessarily shown properly in each of the columns. Tilted contact lines show a time transgressive relationship the geographic directionality of which is not necessarily implied by the tilt of the line in the column. Units involved in faulting and especially those involved in thrust sheets are shown at a time at which they were deposited, not in the position into which they were thrust.

Igneous intrusives are shown at the time that they were intruded, not necessarily in the strata in which they intrude. Questioned contacts were placed for convenience in the vertical position near where they are most likely to occur. The amount of question in their positioning may vary from contact to contact.

Detailed information regarding the contacts, lithology, paleontology, references, and other significant information on each of the units on this chart is available by accessing the computerized COSU data file on the Petroleum Data System of the University of Oklahoma, Norman, Oklahoma."

Holcomb, D.J. 1988. "Cross-Hole Measurements of Velocity and Attenuation to Detect a Disturbed Zone in Salt at the Waste Isolation Pilot Plant." In Key Questions in Rock Mechanics: Proceedings of the 29th U.S. Symposium, University of Minnesota, Minneapolis, MN, June 13-15, 1988, P.A. Cundall, R.L. Sterling, and A.M. Starfield, eds. SAND87-3016C, pp. 633-640. A.A. Balkema, Brookfield, VT. WPO 29992.

ABSTRACT, p. 633;

" Cross-hole ultrasonic measurements were made at the Waste Isolation Pilot Plant (near Carlsbad, New Mexico) to delineate the disturbed zone around drifts and rooms. Using compressional mode waves it was found that there was a small decrease in velocity and a large increase in attenuation immediately after the test room was mined. Disturbances extended at least 3 metres from a room with a width of 5.5 metres. The results are interpreted as resulting from the introduction of about 0.5% crack-like, pore space."

Hora, S.C. 1992. Appendix A: Probabilities of Human Intrusion into the WIPP, Methodology for the 1992 Preliminary Comparison. In Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Volume 3: Model Parameters. SAND92-0700/3, Sandia National Laboratories, Albuquerque, NM. In Appendix A of WPO 23529, pp. A-69 through A-99.

(vol 3)Page A-71, line 6;
" . . .The second group, after considering the findings of the first group, studied how markers might be used to warn future societies about the presence and danger of the buried waste. Both groups provided probabilities and probability distributions for critical aspects of the human intrusion problem."

(vol 3)Page A-71, para 4;
"The Markers Group
A second group of thirteen experts was organized into two teams to study markers for the WIPP site. These markers are to serve as warnings to future societies about the presence of nuclear waste. Such warnings, hopefully, will deter inadvertent intrusions. Each team was asked to consider the findings of the futures teams, to suggest design characteristics for a marker system, and to assess the efficacy of such a system of markers. The ability of a marker system to deter intrusions rests on the survival of the marker system over an extended period of time, and the ability of potential intruders to detect the markers and to understand the message that they carry. The markers team members where (sic) asked to provide probabilities for several events. The first of these is the event that a marker and its message(s) remain intact at various times in the future. Second, for several types of intrusion, the team members were asked to provide probabilities that, given the marker and its messages are intact, the potential intruders are able to understand the message and thus become forewarned of the inherent dangers of intrusion. These assessments were made under various assumptions about the state of technology in the future."

Hora, S.C., von Winterfeldt, D., and Trauth, K.M. 1991. Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant. SAND90-3063. Sandia National Laboratories, Albuquerque, NM. WPO 26161.

ABSTRACT, p i;
" Four expert-judgement teams have developed analyses delineating possible future societies in the next 10,000 years in the vicinity of the Waste Isolation Pilot Plant (WIPP). Expert-judgement analysis was used to address the question of future societies because neither experimentation, observation, nor modeling can resolve such uncertainties. Each of the four, four-member teams, comprised of individuals with expertise in the physical, social, or political sciences, developed detailed qualitative assessments of possible future societies. These assessments include detailed discussions of the underlying physical and societal factors that would influence society and the likely modes of human-intrusion at the WIPP, as well as the probabilities of intrusion. Technological development, population growth, economic development, conservation of information, persistence of government control, and mitigation of danger from nuclear waste were the factors the teams believed to be most important. Likely modes of human-intrusion were categorized as excavation, disposal/storage, tunneling, drilling, and offsite activities. Each team also developed quantitative assessments by providing probabilities of various alternative futures, of inadvertent human intrusion, and in some cases, of particular modes of intrusion. The information created throughout this study will be used in conjunction with other types of information, including experimental data, calculations from physical principles and computer models, and perhaps other judgements, as input to a 'performance assessment.' The more qualitative results of this study will be used as input to another expert panel considering markers to deter inadvertent human intrusion at the WIPP."

Houghton, J.T., Jenkins, G.J., and Ephraums, J.J. 1990. Climate Change: The IPCC Scientific Assessment. Cambridge University Press, New York, NY.

ABSTRACT;
" This is the final Report of Working Group 1 of the Intergovernmental Panel on Climate Change, which is sponsored jointly by the World Meteorological Organization and the United Nations Environment Programme. This report considers the scientific assessment of climate change. Several hundred working scientists from 25 countries have participated in the preparation and review of the scientific data. The result is the most authoritative and strongly supported statement on climate change that has ever been made by the international scientific community. The issues confronted with full rigour include: global warming, greenhouse gases, the greenhouse effect, sea level changes, forcing of climate, and the history of the Earth's changing climate. The information presented here is of the highest quality. It will inform the necessary scientific, political and economic debates and negotiations that can be expected in the immediate future. Appropriate strategies in response to the issue of climate change can now be firmly based on the scientific foundation that the Report provides. The Report is, therefore, an essential reference for all who are concerned with climate change and its consequences."

Howard, C.L., Jensen, A.L., Jones, R.L., and Peterson, T.P. 1993. Room Q Data Report: Test Borehole Data From April 1989 Through November 1991. SAND92-1172. Sandia National Laboratories, Albuquerque, NM. WPO 23548.

ABSTRACT;
" Pore-pressure and fluid-flow tests were performed in 15 boreholes drilled into the bedded evaporites of the Salado Formation from within the Waste Isolation Pilot Plant (WIPP). The tests measured fluid flow and pore pressure within the Salado. The boreholes were drilled into the previously undisturbed host rock around a proposed cylindrical test room, Room Q, located on the west side of the facility about 655 m below ground surface. The boreholes were about 23 m deep and ranged over 27.5 m of stratigraphy. They were completed and instrumented before excavation of Room Q. Tests were conducted in isolated zones at the end of each borehole. Three groups of 5 isolated zones extend above, below, and to the north of Room Q at increasing distances from the room axis. Measurements recorded before, during, and after the mining of the circular test room provided data about borehole closure, pressure, temperature, and brine seepage into the isolated zones. The effects of the circular excavation were recorded. This data report presents the data collected from the borehole test zones between April 25, 1989 and November 25, 1991. The report also describes test development, test equipment, and borehole drilling operations."

Hunter, R.L., 1985. A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area. SAND84-2233. Sandia National Laboratories, Albuquerque, NM. WPO 27628.

ABSTRACT, p. 3;

" The WIPP water-balance study area defined here comprises ~2000 mi^2 in Eddy and Lea Counties, southeastern New Mexico. Inflows to the study area are precipitation (roughly 1.47×10^6 ac-ft/yr), surface water (roughly 1.1×10^5 ac-ft/yr), water imported by municipalities and industries (roughly 3×10^4 ac-ft/yr), and ground water (volume not estimated). Outflows from the area are evapotranspiration (roughly 1.5×10^6 ac-ft/yr), surface water (roughly 1.2×10^5 ac-ft/yr), and possibly some ground water. The volume of surface and ground water in storage in Nash Draw has increased since the beginning of potash refining. Regional ground water flow in aquifers above the Salado Formation is from the northeast to the southwest, although this pattern is interrupted by Clayton Basin, Nash Draw, and San Simon Swale. The Pecos River is the only important perennial stream. Most of the area has no integrated surface-water drainage.

The available data suggest that ~1600 mi^2 of the study area are hydrologically separate from Nash Draw and the WIPP site. Ground water north of Highway 180 apparently discharges into Clayton Basin and evaporates. Water in San Simon Swale apparently percolates downward and flows to the southeast. Data are inadequate to create a water budget for the Nash Draw-WIPP site hydrologic system alone, although an attempt to do so can provide guidance for further study."

Hunter, R.L., Cranwell, R.M., and Chu, M.S.Y. 1986. Assessing Compliance with the EPA High-Level Waste Standard: An Overview. SAND86-0121, NUREG/CR-4510. Sandia National Laboratories, Albuquerque, NM. WPO 28435.

ABSTRACT, p iii;

" The US Environmental Protection Agency has set a standard for the performance of geologic repositories for the disposal of high-level radioactive waste. The standard is divided into several sections, including a section on containment requirements. The containment requirement is probabilistic, in that it allows certain small amounts of radioactive waste to be released at high probabilities and larger amounts to be released at lower probabilities. The US Nuclear Regulatory Commission is responsible for implementing the standard. Implementation of the standard will probably involve development and screening of scenarios, assignment of probabilities to the scenarios, determination of consequences of the scenarios, and analysis of uncertainties.

Scenario development consists of first, identifying events and processes that could initiate waste releases or affect waste transport, and second, combining the events and processes in physically reasonable ways. Scenarios can be screened on the basis of low probabilities or consequences. Consequences of scenarios are estimated using a series of models that simulate the movement of radionuclides out of the waste package and underground facility and the transport of the radionuclides by ground water or other means to the accessible environment. Sensitivity and uncertainty analysis examines the sources and effects of uncertainties on the calculations. This document uses a simple example to illustrate techniques for the implementation of the standard."

IAEA (International Atomic Energy Agency). 1989. Evaluating the Reliability of Predictions Made Using Environmental Transfer Models. Safety Series Report No. 100. International Atomic Energy Agency, Vienna.

FOREWORD;

" The development and application of mathematical models for predicting the consequences of releases of radionuclides into the environment from normal operations in the nuclear fuel cycle and hypothetical accident conditions has increased dramatically in the last two decades. Along with this development has come the recognition that it is not enough to have results presented as single value estimates of radiation dose or of environmental concentrations of radionuclides. Models are only approximations to real environmental systems and therefore there will always be some uncertainty associated with predictions obtained from their use. A model prediction without some estimate of the associated uncertainty is of little value to decision makers.

This Safety Practice publication has been prepared to provide guidance on the available methods for evaluating the reliability of environmental transfer model predictions. It provides a practical introduction to the subject and particular emphasis has been given to worked examples in the text, It is intended to supplement existing IAEA publications on environmental assessment methodology.

Although the book addresses the subject of environmental dose assessment, the methods described in it are of general application and are equally useful in other areas where modelling techniques are applied.

The text of this publication was produced through a series of consultants meetings and one Advisory Group Meeting. The IAEA wishes to acknowledge . . ."

Imbrie, J. 1985. "A Theoretical Framework for the Pleistocene Ice Ages," Journal of the Geological Society. Vol. 142, 417-432.

SUMMARY, p 417;

" This paper reviews 150 years of progress towards understanding the succession of Pleistocene ice ages. Emphasis is placed on the process of explaining *forced variations* in climate which occur in the *Milankovitch band* (periods from 10000 to 400000 years), where astronomical forcing functions are clearly identified and where the amplitudes of climatic change are large. An hierarchy of explanatory models is employed, including a statistical model that uses gain and phase terms to parameterize the climatic response to orbital forcing in several narrow frequency bands. This type of model accounts for a substantial fraction of the observed temporal variations of $\delta^{18}O$ over the past 800000 years. Experiments using the model suggest that a change in the system response occurred about 400000 years ago. The problem of explaining climatic variations in other frequency bands is broadly reviewed. In the *decadal band* (10-400 years), there is good evidence of volcanic forcing, solar forcing, and tidal forcing, but much of the observed pattern is presumed to reflect *free variations*. In the *millenium band* (400 to 10000 years), significant climatic changes occur at periods ranging from 1000 to 3000 years. Their cause remains a challenging problem. Over the *tectonic band* (more than 400000 years), volcanic fluxes, continental elevation, and continental position are the most likely forcing functions of the observed climatic changes."

Imbrie, J. and Imbrie, J.Z. 1980. "Modeling the Climatic Response to Orbital Variations," Science. Vol. 207, no. 4434, 943-953.

SUMMARY, p 943;

" According to the astronomical theory of climate, variations in the earth's orbit are the fundamental cause of the succession of Pleistocene ice ages. This article summarizes how the theory has evolved since the pioneer studies of James Croll and Milutin Milankovitch, reviews recent evidence that supports the theory, and argues that a major opportunity is at hand to investigate the physical mechanisms by which the climate system responds to orbital forcing. After a survey of the kinds of models that have been applied to this problem, a strategy is suggested for building simple, physically motivated models, and a time-dependent model is developed that simulates the history of planetary glaciation for the past 500,000 years. Ignoring anthropogenic and other possible sources of variation acting at frequencies higher than one cycle per 19,000 years, this model predicts that the long-term cooling trend which began some 6000 years ago will continue for the next 23,000 years."

Imbrei J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., and Shackleton, J.J. 1984. "The Orbital Theory of Pleistocene Climate: Support from a Revised Chronology of the Marine ^{18}O Record," in Milankovitch and Climate, Understanding the Response to Astronomical Forcing, Proceedings of the NATO Advanced Research Workshop on Milankovitch and Climate, Palisades, NY, November 30-December 4, 1982, A. Berger, J. Imbrie, J. Hays, G. Kukla, and B. Saltzman, eds. Pt. 1, pp. 269-305. D. Reidel, Boston, MA.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Imbrie, J., McIntyre, A., and Mix, A. 1989. "Oceanic Response to Orbital Forcing in the Late Quaternary: Observational and Experimental Strategies," Climate and Geo-sciences. Eds. A. Berger, S. Schneider, and J.C. Duplessy. 121-164. Kluwer, Boston, MA.

ABSTRACT, p 121;

" Observations on deep-sea cores demonstrate that late Pleistocene climate is determined by three broad-band cycles centered near periods of 23 ky, 41 ky, and 100 ky. These cycles permeate the global system, and include changes in the atmosphere, cryosphere, surface ocean, and deep ocean. The periods of these climatic cycles match orbital cycles of precession, obliquity, and eccentricity; and each orbit-climate pair is significantly correlated (coherent). These observations may be explained in different ways. We review various models and conclude that the climatic styles can be explained as an interaction between orbitally forced and internally driven oscillations of the climate system. Depending on the cycle and model, the external forcing may influence climate either as part of a driving mechanism which determines both the amplitude and phase of the cycle, or as a pacing mechanism which sets the phase of an internal oscillation. Our goal is to search climatic data for clues about the mechanisms which operate within the climate system on orbital time scales. Our strategy is patterned after previous investigations which partition the climatic record into cyclic components, record the phase of system responses in each cycle, and examine these phase sequences for clues about the chain of causal mechanisms.

We review the stratigraphic, chronologic, and statistical methods adopted to achieve these objectives, and then apply the strategy to two sets of data: (1) time series with local implications about conditions at the sea surface at 17 sites ranging from 54°N in the Atlantic to 44°S in the Indian Ocean (faunal estimates of sea-surface temperature, SST); and (20 time series with global implications about ice volume and ocean chemistry ($\delta^{18}O$, $\Delta\delta^{13}C$, and Cd/Ca). The spatial pattern of SST response in each cycle is documented by mapping its amplitude and phase. Each cycle has a characteristic pattern, but all cycles show an early response near 40°S. Information drawn from both data sets is then combined to form a preliminary phase portrait of the entire system. In each cycle, responses occur over a wide range of phases centered on the point of minimum ice, and include indicators which lead and those which lag ice volume. Each cycle is characterized by the same three leading indicators: Cd/Ca, $\Delta\delta^{13}C$, and SST at ~40°S (with the addition of equatorial SST at 23 ky). Lagging indicators include North Atlantic SST at 23 ky.

Data on SST and $\delta^{18}O$ phases are used to test simple models of radiation forcing in the 23 ky and 41 ky bands, and limited to explaining the observations of $\delta^{18}O$, and SST near 50°N and 40°S. The simplest model that fits our data assumes that summer radiation forces the system in the Northern Hemisphere, and that the response at high latitudes is transmitted rapidly to the Southern Hemisphere by modulation of the North Atlantic sources of deep water. In the 100 ky band we assume that the phase of an internally generated cycle is set by the amplitude of the 23 ky radiation cycle.

We conclude that the strategy developed here can guide the acquisition of new data, serve as a framework for synthesizing information on different parts of the climate system,

and stimulate interactions between data and models. Opportunities now exist for comparing the predicted sequence of system response with the observed sequence."

Izett, G.A., and Wilcox, R.E. 1982. Map Showing Localities and Inferred Distribution of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds in the Western United States and Southern Canada. Misc. Investigations Map I-1325, scale 1:4,000,000. U.S. Geological Survey.

DISCUSSION;

" During the past 10 years there has been increasing interest among earth scientists for tephrochronological data useful for establishing volcanic ash beds as time-stratigraphic markers. When tephrochronological data are combined with other geological information such as stratigraphic position, faunal age, paleomagnetic direction, and isotopic age, the result is a multipronged analytical device with a combined resolving power far greater than that of any individual geologic technique. Correct identification of an isotopically dated volcanic ash bed can provide critical information to help resolve problems such as (1) the correlation (over long distances) of sedimentary deposits of diverse origins (marine, lacustrine, fluviatile, paludal, glacial, periglacial, and eolian); (2) the determination of the times and rates of fault movements and other types of crustal deformation; (3) the determination of the average rates of deposition of sediments; (4) the evaluation of geologic hazards such as volcanic eruptions and earthquakes; (5) the calibration of paleomagnetic stratigraphies and faunal chronologies; (6) the calibration of experimental dating methods such as uranium-trend dating; (7) the identification of tephra sources; and (8) the evolution of silicic magma bodies and related tephra ejection mechanics, transportation, and deposition. Several upper Cenozoic volcanic ash beds of the western United States have been studied in considerable detail including tephra of Holocene age from Mount St. Helens volcano in Washington (Fryxell, 1965; Mullineaux and others, 1975; Westgate, 1977) in Washington; the Mazama ash bed of Holocene age (Powers and Wilcox, 1964); the Glacier Peak ash bed of latest Pleistocene age (Powers and Wilcox, 1964; Westgate and Evans, 1978); and the Bishop ash bed of middle Pleistocene age (Izett and others, 1970; Borchardt and others, 1972; Merriam and Bischoff, 1975; Sama-Wojcicki and others, 1980). These volcanic ashes are found interbedded in various types of fluvial, colluvial, and lacustrine Holocene and Pleistocene sedimentary deposits scattered from the West Coast of the United States to as far east as central Nebraska. Another set of volcanic ashes, the Pearlette family ash beds, also has been extensively studied and used for long range correlations of the enclosing sediments and their contained fossil materials. These ash beds are the main subject of this report.

The Pliocene and Pleistocene boundary . . ."

Jones, C.L., 1978. Test Drilling for Potash Resources: Waste Isolation Pilot Plant Site, Eddy County, New Mexico, Open-File Report 78-592, Vols. 1 and 2. U.S. Geological Survey Denver, CO.

ABSTRACT, p 1;
" Twenty-one borings to augment existing information on potash resources at the proposed site for a waste isolation pilot plant in eastern Eddy County, N. Mex., were drilled and logged in an 11-week period, mid-August to November 1976. The basic data developed from the borings are tabulated in the present report. The tabulation includes lithologic and geophysical logs of all the borings, as well as the results of chemical analyses, X-ray determinations, and calculations to establish a modal mineralogical composition of core samples from potash ore zones and mineralized salt beds."

Jones, T.L., Kelley, V.A., Pickens, J.F., Upton, D.T., Beauheim, R.L., and Davies, P.B. 1992. Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site. SAND92-1579. Sandia National Laboratories, Albuquerque, NM. WPO 23504.

ABSTRACT, p i;

" Conservative tracer tests have been conducted within the Culebra Dolomite Member of the Rustler Formation at the H-2, H-3, H-4, H-6, and H-11 hydropads for transport scales ranging from approximately 20 to 40 m. Convergent-flow and two-well recirculating tracer tests provide data that is used to quantitatively characterize flow and transport processes. The observed long time period required for initial (detectable) tracer breakthrough (74 to 316 days) in the H-2 and H-4 tracer tests suggest the prevalence of single-porosity, matrix-only transport at these locations. Hydraulic-test responses at these two hydropads also indicate single-porosity, matrix-only conditions. The relatively poor quality of data defining the breakthrough curves from the H-2 and H-4 tracer tests precluded a detailed, quantitative analysis of transport parameter values from these tests. Interpretations of pumping tests and tracer tests at the H-3, H-6, and H-11 hydropads indicated that the Culebra dolomite behaves as a double-porosity (fracture-plus-matrix) medium at these locations. Both the H-3 and H-11 hydropads are located along the offsite transport pathways southeast of the Waste Isolation Pilot Plant waste-panel area. Significant fracture participation in transport is evidenced by rapid initial tracer breakthrough (1 to 21 hrs) on one travel path at each of these hydropads. The H-3, H-6 , and H-11 convergent-flow tracer tests were analyzed using the SWIFT II model with the Culebra fracture/matrix system idealized as three, orthogonal, intersecting fracture sets equally spaced in all three directions. Input values and ranges for the assigned transport parameters (effective thickness, well spacing, pumping rate, free-water diffusion coefficient, longitudinal dispersivity, and matrix porosity) were specified based on field measurements, laboratory measurements on Culebra core, and scientific judgement. Measurement and/or calculated uncertainties were also defined for the assigned parameters. Two approaches were used to model double-porosity transport. The first approach assumed that differences in tracer breakthrough behavior at a single hydropad were caused by differences (heterogeneity) in matrix-block length (fracture spacing) between different travel paths. The second approach assumed that differences in tracer breakthrough behavior were caused by horizontal anisotropy in the flow field. Interpretations based on the heterogeneous-analysis approach yielded matrix-block lengths ranging from 0.11 to 1.23 m and fracture porosities ranging from 5.0×10^{-4} to 1.0×10^{-3}. Interpretations based on the anisotropic-analysis approach yielded matrix-block lengths ranging from 0.15 to 0.48 m, fracture porosities ranging from 1.0×10^{-3} to 3.0×10^{-3}, and anisotropy ratios ranging from 3:1 to 7:1. Sensitivity analyses were conducted to provide insight into the relative impact of varying individual transport parameters and to provide estimates of fitted-parameter uncertainty. These analyses yielded minimum and maximum matrix-block lengths for all hydropads that ranged from 0.02 to 3.22 m. Sensitivity analyses also showed that neither single-porosity, fracture-only transport nor single-porosity, matrix-only transport can

reproduce the observed transport behavior at the H-3, H-6, and H-11 hydropads."

Jung, Y., Ibrahim, A., and Borns, D.J. 1991. Mapping Fracture Zones in Salt; High Resolution Cross-Gallery Seismic Tomography, Geophysics: The Leading Edge of Exploration, Vol. 10, No. 4, pp. 37-39.

ABSTRACT p 37;

" The purpose of this article is to demonstrate the feasibility of high-resolution seismic tomography to identify fracture zones in salt at the Waste Isolation Pilot Plant (WIPP) located approximately 23 miles east of Carlsbad, New Mexico. The WIPP was established by the Department of Energy as an experimental facility to study the feasibility of using salt as a repository for transuranic nuclear wastes. The underground excavations, lying 2100 ft below the surface, were completed in the Salado formation (primarily a halite sequence of Permian age). The underground facility is composed of rooms and passageways developed within salt. Salt pillars separate the rooms and support the mine roof. Usually they have three faces forming walls for rooms and hallways. The fourth face does not exist because of the presence of unmined salt in the back of the pillar. Brine occurrences, which have been observed in excavations and drilling, are thought to be related to either sedimentary-related brine inclusions in the salt itself, or fractures in the marker beds created as a result of stress adjustments caused by the excavations.

Understanding the process of fracture development at the WIPP site is essential in predicting future changes in formation brine movement. Because a major groundwater unit in this area (the Rustler formation) exists above the salt sequence, the presence of fractures in the salt is of major interest in relation to the solubility of the salt as a safe disposal medium for radioactive waste. Fractures may create a hydrologic connection between the water-bearing unit and the underlying disposal area through shafts and boreholes. Another problem at the WIPP site is the development of a disturbed rock zone (DRZ) around underground excavations in the salt. The development of fractures and resultant dehydration of the pore fluid mark the growth of the DRZ. There is a concern that fracturing within the pillars will occur at a high enough rate to create unsafe conditions underground and reduce the planned operational lifetime of the project.

This study aims at developing high-resolution techniques to map fracture zones in salt. Preliminary studies suggest that fracture zones are identifiable through their linear lower seismic velocity pattern. As a means of mapping the seismic velocity in the salt pillar, several seismic techniques are under study. This paper focuses on the seismic tomographic study. To monitor changes in fracture patterns with time, the tomographic study should be done at time intervals on the same pillar. However, this is a lengthy process. Instead, two salt pillars excavated at different times were chosen for this study."

Kazemi, H., Merrill, Jr., L.S., Porterfield, K.L., and Zeman, P.R. 1976. Numerical Simulation of Water-Oil Flow in Naturally Fractured Reservoirs, Society of Petroleum Engineers Journal, Vol. 16, No. 6, pp. 317-326.

ABSTRACT, p 317;

" A three-dimensional, multiple-well, numerical simulator for simulating single- or two-phase flow of water and oil is developed for fractured reservoirs. The simulator equations are two-phase flow extensions of the single-phase flow equations derived by Warren and Root.[1] The simulator accounts for relative fluid mobilities, gravity force, imbibition, and variation in reservoir properties. The simulator handles uniformly and nonuniformly distributed fractures and/or no fractures at all. The simulator can be used to simulate the water-oil displacement process and in the transient testing of fractured reservoirs.

The simulator was used on the conceptual models of two naturally fractured reservoirs: a quadrant of a five-spot reservoir and a five-well dipping reservoir with water drive. These results show the significance of imbibition in recovering oil from the reservoir rock in reservoirs with an interconnected fracture network."

Kelley, V.A., and Saulnier, Jr., G.J. 1990. Core Analyses for Selected Samples from the Culebra Dolomite at the Waste Isolation Pilot Plant. SAND90-7011. Sandia National Laboratories, Albuquerque, NM. pp. 4-10. WPO 28629.

ABSTRACT, p. i;

" Two groups of core samples from the Culebra Dolomite Member of the Rustler Formation at and near the Waste Isolation Pilot Plant were analyzed to provide estimates of hydrologic parameters for use in flow-and-transport modeling. Whole-core and core-plug samples were analyzed by helium porosimetry, resaturation porosimetry, mercury-intrusion porosimetry, electrical-resistivity techniques, and gas-permeability methods.

Seventy-nine (79) helium-porosity determinations indicated that the distribution of Culebra porosities was skewed toward lower porosity values with an arithmetic mean and standard deviation of 0.153 and 0.053, respectively.

The vertical heterogeneity of porosity was indicated by 21 pairs of helium-porosity determinations where each sample of the pair was separated by approximately 5 cm. The porosity differences between the samples in the pairs varied from 0.050 to 0.093.

Water-resaturation-porosimetry results showed a near 1-to-1 correlation with the results from helium-porosity determinations. In some cases, the resaturation porosities were slightly larger than the helium porosities, possibly due to mineral dissolution by the resaturation fluid (deionized water) or to the experimental reproducibility of the two measuring techniques.

Endpoint mercury pore-volume saturations for 25 samples ranged from 66.7% to 99.9%, with an average endpoint pore-volume saturation of 95.4%. The endpoint pressure was 207 MPa. The median pore-throat radius varied over an order of magnitude from 0.077 μm to 0.588 μm, with an arithmetic average value of 0.315 μm. Eighty-four percent of the pore-throat radii in the samples analyzed were between 0.1 μm and 0.5 μm. The average mercury-intrusion porosity was 0.148, as compared with the helium-porosity average of 0.154.

Seventy-three (73) grain-density measurements indicated a skewed distribution toward larger values of grain density with an arithmetic average of 2.82 g/cm^3 and a standard deviation of 0.19 g/cm^3. The most common value of grain density was 2.83 g/cm^3, which was also the median of the distribution.

Electrical-resistivity measurements of 15 saturated core plugs were used to calculate estimates of formation factor and tortuosity. Formation-factor values were log-normally distributed and values ranged from 12 to 407, with a geometric mean of 58.8. Tortuosity ranged from 0.04 to 0.33, with an arithmetic average of 0.14 and a median of 0.12. The results show a general trend of increasing tortuosity with increasing porosity. The diffusion porosities and diffusion tortuosities determined by Dykhuizen and Casey (1989) agree with the lower range of the values determined by this core-analysis study.

Sixty-six (66) horizontal-permeability measurements ranged from 7.9E-18 m^2 to 3.6E-13 m^2, and the distribution had an arithmetic average of 6.2E-15 m^2, a geometric mean of 4.5E-16 m^2, and a median of 2.7E-16 m^2. Twenty-six (26) vertical-permeability

measurements ranged from 8.4E-18 m^2 to 5.2E-14 m^2, with an arithmetic mean of 5.1E-15 m^2, a geometric mean of 9.0E-16 m^2, and a median of 3.5E-16 m^2. Plots of the $\log_{10}$ of permeability versus porosity indicated a weak correlation between the $\log_{10}$ of permeability and porosity. A plot of $\log_{10}$ of horizontal permeability versus the median pore-throat radii determined for the same samples indicated that the $\log_{10}$ horizontal permeability is directly related to median pore-throat radius."

Kim, J.I. 1991. "Actinide Colloid Generation in Groundwater," Radiochimica Acta. Vol. 52/53, Pt. 1, pp. 71-81.

ABSTRACT;
" The progress made in the investigation of actinide colloid generation in groundwaters is summarized and discussed with particular examples relevant to an understanding of the migration behavior of actinides in natural aquifer systems. The first part deals with the characterization of colloids: groundwater colloids, actinide real-colloids and actinide pseudocolloids. The second part concentrates on the generation processes and migration behavior of actinide pseudocolloids, which are discussed with some notable experimental examples. Importance is stressed more on the chemical aspects of the actinide colloid generation in groundwater. This work is a contribution to the CEC project MIRAGE II, particularly, to research area: complexation and colloids."

Lambert, S.J., 1983. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. SAND82-0461. Sandia National Laboratories, Albuquerque, NM. WPO 27520.

ABSTRACT, p 3;

" Permian evaporites in the Ochoan Castile, Salado, and Rustler Formations in the Delaware Basin of southeastern New Mexico and west Texas have been subjected to various degrees of dissolution (notably of halite and gypsum) through geologic time. Eastward tilting of the Delaware Basin has resulted in the exhumation and erosion of Ochoan rocks in the western part of the basin. Waters in the Capitan, Rustler, Castile, and Bell Canyon Formations have previously been proposed as agents or consequences of evaporite dissolution according to four principle models; solution-and-fill, phreatic dissolution, brine density flow, and stratabound dissolution (along bedding planes). Several geomorphological features of positive and negative relief have previously been cited as indicators of evaporite dissolution. Brine density flow has been used to explain the selective dissolution of certain evaporite horizons during the late Cenozoic. A review of available geological data has revealed that

- Halite deposition was probably not so extensive as formerly believed
- Waters with potential to dissolve evaporites are in the Rustler and Capitan, but not in the Bell Canyon, Salado mine seeps, or the Castile brine reservoirs
- Brine density flow has not been active in removing most of the 'missing' halite, nor are 'point-source' dissolution features likely to have their roots at the Bell Canyon
- Major evaporite dissolution has not been confined to the late Cenozoic, but much of it took place during the Permian, Triassic, Jurassic, and Tertiary periods
- The Bell Canyon Formation has not been a sink for dissolution-derived brine

Stratabound dissolution is an efficient process for the removal of evaporites and is well exemplified in Nash Draw. This process entails downdip migration of meteoric water within beds of competent fractured rock, with upward and downward excursions of the water into adjacent halite-bearing beds. The chief weakness in the stratabound model for dissolution is the as-yet-unidentified sink for dissolution brine. If the stratabound model of dissolution is active in removal of lower Salado halite, the threat of dissolution to the WIPP in the next 250,000 yr is comparable to the threat to the same area posed by the growth of Nash Draw during the past 600,000 yr. The regional geological history showed the past threat to be negligible."

Lambert, S.J. 1987. "Stable-Isotope Studies of groundwaters in Southeastern New Mexico," In *The Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler Formation as it relates to the WIPP Project*. Ed. L. Chaturvedi. SAND85-1978C, EEG-34, pp. 36-57. Environmental Evaluation Group, Santa Fe, NM. WPO 28418.

ABSTRACT, p 36;

" Oxygen-18/16 and deuterium/hydrogen ratio measurements have been made on groundwaters sampled according to specific field criteria applied during pump tests of the Rustler Formation (the uppermost Permian evaporite unit) in Nash Draw, a solution-subsidence valley west of the WIPP site in the northern Delaware Basin of southeastern New Mexico. Comparison of these data with similar measurements on other groundwaters from the northern Delaware Basin indicates two nonoverlapping populations of meteoric groundwaters in delta-O-18/ delta-D space. Most of the Rustler waters in Nash Draw and at the WIPP site and older waters from the eastern two-thirds of the Capitan Limestone constitute one population, while unconfined groundwaters originating as observable modern surface recharge to alluvium, the near-surface Rustler in southwestern Nash Draw, and the Capitan in the Guadalupe Mountains (Carlsbad Caverns) constitute the other. The isotopic distinction suggests that Rustler groundwater in most of Nash Draw and at the WIPP site is not receiving significant modern meteoric recharge. A likely explanation for this distinction is that meteoric recharge to most of the Rustler and Capitan took place in the geologic past under climatic conditions significantly different from the present."

Lenhardt, W.A. 1988. "Damage Studies at a Deep Level African Gold Mine." In Rockbursts & Seismicity In Mines, Proceedings of the Second International Symposium, Minneapolis, MN, June 8-10, 1988, C. Fairhurst, ed., 1990, pp. 391-393. A.A. Balkema, Brookfield, VT

ABSTRACT, p. 391;

" The effect of seismic event magnitude on damage at Western Deep Levels Limited, a deep level gold mine in South Africa, is evaluated. Relationships between length of face affected, number of panel shifts lost and seismic event magnitude were determined. Theoretical studies and observations elsewhere lend confidence to the validity of the results. Some insight was gained into the spread of truly damaging events across the seismic event magnitude spectrum. It is believed that the results will allow improved assessment of seismic related lossess (sic), thus facilitating the cost-benefit evaluation of regional support type, depth and other factors."

Lieser, K.H., Gleitsmann, B., and Steinkopff, T. 1986. "Sorption of Trace Elements or Radionuclides in Natural Systems Containing Groundwater and Sediments," Radiochimica Acta. Vol. 40, no. 1, 33-37.

ABSTRACT, p. 33;

" A general formula for the sorption ratio that is observed experimentally in natural systems is presented taking into account three kinds of processes: sorption at the outer surface of the solid particles, sorption in porous particles and one-directional processes such as precipitation or coprecipitation. These various processes as well as the mechanisms and the kinetics of sorption are discussed.

The sorption of radioactive Cs^+, Sr^{2+} and Ce^{3+} is studied in two selected natural sediment/groundwater systems, one of low and one of high salinity, under various conditions. Cs^+ ions are mainly sorbed in clay minerals that are suspended in the groundwater with relatively high sorption ratios, Sr^{2+} ions are mainly sorbed on the sediments with relatively low sorption ratios, and Ce^{3+} is mainly found in form of colloids or in suspended particles or in coprecipitates. Coprecipitation leads to very high sorption ratios for Ce^{3+}. The behavior of Cs^+, Sr^{2+} and Ce^{3+} is typical for all elements with similar properties."

Lieser, K.H., Gleitsmann, B., Peschke, S., and Steinkopff, T. 1986. Colloid Formation and Sorption of Radionuclides in Natural Systems. Radiochimica Acta, Vol. 40, No. 1, pp. 39-47.

ABSTRACT, p39;
" Natural systems comprising sediments and groundwaters of low and of high salinity are investigated with respect to the formation and the influence of coarsely dispersed particles and finely dispersed particles (colloids). Equations are derived for the sorption equilibria in such systems and it is shown that the efficiencies of mutual separation of coarsely dispersed particles, finely dispersed particles and sediments (efficiencies of filtering) strongly influence the sorption ratios that are observed.

In groundwater without sediments the formation of colloids of radioactive Ce^{3+} is demonstrated, whereas Cs^{+} and Sr^{2+} do not form colloids under these conditions, as expected.

The amount of elements and of colloids given off by the sediments into the groundwaters are measured for the samples of low and of high salinity and the influence of agitation is shown. Sorption ratios of radioactive Cs^{+}, Sr^{2+}, and Ce^{3+} are investigated as function of the ratio of the groundwater volume to the mass of the sediment without filtration, after filtration through 0.45 μm filters and after ultrafiltration. The results are discussed on the basis of the equations derived. It is shown that Cs^{+} ions are sorbed mainly on the clay particles and that the larger amount of these clay particles has grain sizes greater than 0.45 μm under the experimental conditions of smooth shaking. Sr^{2+} ions are mainly sorbed on the sediments with a relatively low sorption ratio. Ce^{3+} ions form colloids (''Eigenkolloide'') that are retained by ultrafiltration."

Lieser, K.H., Ament, A., Hill, R., Singh, R.N., Stingl, U. and Thybusch, B.. 1990. Colloids in Groundwater and Their Influence on Migration of Trace Elements and Radionuclides. Radiochimica Acta, Vol. 49, No. 2, pp.83-100.

ABSTRACT, p 83;

" A survey on colloid and radiocolloid formation in groundwaters is given. Three groundwaters are analyzed after standing at rest for several months and after equilibration with the corresponding sediments. The partition of radioactive Cs, Sr, Pb, Ac and Th on the coarse particle fraction (>0.45 μm), the fine particle fraction (0.002 to 0.45 μm) and the molecular fraction (<0.002 μm) in these groundwaters is investigated. Thereafter the groundwaters are passed through columns filled with the corresponding sediments from the same sites as the groundwaters at a linear flow rate of about 10 cm per day and the relative concentrations as well as the partition of the radionuclides on the three fractions in the effluent groundwaters are measured.

Strong retention of Cs, Pb, Ac and Th and to a smaller extent Sr in the columns is observed which is mainly due to sorption by ion exchange (Cs, Sr) or hydrolytic adsorption (Pb, Ac, Th) on the sediments as well as on the coarse and fine particles in the groundwaters. These particles serve as carriers. Comparison of column and batch experiments show that size filtration of coarse particles is very important with respect to retention."

Litvak, B.L. 1986. "Simulation and Characterization of Naturally Fractured Reservoirs." In Reservoir Characterization Technical Conference, Dallas, TX, April 29-May 1, 1985, L.W. Lake and H.B. Carroll, Jr., eds. pp. 561-584. Academic Press, Orlando, FL.

ABSTRACT, p 561;
" A three-dimensional, three-phase numerical simulator with rigorous treatment of matrix/fracture flow is developed for modeling naturally fractured reservoirs. A new method was developed in the simulator for description of capillary pressure and gravity forces in the matrix/fracture media. The simulator is designed for the solution of field reservoir problems. At the same time it considers physical processes in a single matrix block surrounded by fractures. A significant effect of different treatment of capillary and gravity forces in fractured reservoirs is demonstrated in an example problem."

Lowenstein, T.K. 1987 Post Burial Alteration of the Permian Rustler Formation Evaporites, WIPP Site, New Mexico: Textural, Stratigraphic and Chemical Evidence. EEG-36, DOE/AL/10752-36, Environmental Evaluatio Group, Santa Fe, NM.

PREFACE, p vii;

" A repository for permanent isolation of defense transuranic wastes is being excavated in southeastern New Mexico, about 40 km 925 miles) east of Carlsbad. The Waste Isolation Pilot Plant (WIPP) repository has been designed for the disposal of waste in the lower part of the Salado (salt) Formation at a depth of 655 meters (2150 ft). The water-bearing zones of the Rustler Formation, which overlies the Salado, are considered to be the main pathway for the transport of radionuclides to the biosphere, if the repository is breached.

The Rustler Formation is 150 meters (490 feet) thick, 6.4 Km (4 miles) east of the center of the WIPP site. The thickness reduces drastically to the west so that it is only 91 meters (300 ft) thick in the western part of the WIPP site. At its thickest location, the Rustler consists of siltstone and anhydrite with two dolomite beds and both clear and clayey halite. Halite is progressively missing from deeper layers from east to west in the Rustler cross-section across the WIPP site. These observations were interpreted by Powers et al (1978), Mercer (1983), Lambert (1983), Chaturvedi and Rehfeldt (1984), Bachman (1984), Snyder (1985), Chaturvedi and Channell (1985) and others as indicating post-burial dissolution of halite and increased gypsification of anhydrite further west. Increased permeability of the water-bearing dolomites from east to west also was thought to result from the increased fracturing as a result of dissolution.

In 1984, Powers and Holt (1984) and Holt and Powers (1984) expressed doubts about the concept of post-burial dissolution of Rustler evaporites, on the basis of detailed mapping in the WIPP Waste Handling Shaft, and stated the following:

> 'Post-depositional dissolution features were not observed in any stratigraphic horizons in the Waste Shaft. In fact, several zones previously identified as dissolution residues in nearby boreholes (e.g. ERDA-9) contain pronounced primary sedimentary features. This is of great significance since dissolution has, historically, been considered as an important process that has greatly modified the Rustler Formation in this area.' (Holt and Powers, 1984)

This statement was based on the first detailed sedimentological study of the Rustler stratigraphy, but only at one location, albeit in situ, in a shaft. It clearly signaled the need for further work on the lateral variations in the stratigraphy of the Rustler Formation across the WIPP site. Since the interpretation by Powers and Holt was based on sedimentary features, the need was for a sedimentological study of the Rustler Formation.

To resolve this issue, the Environmental Evaluation Group (EEG) asked Dr. Tim K. Lowenstein to perform a sedimentological study of the available cores of the Rustler Formation. Dr. Lowenstein is a sedimentologist with special interest in the study of evaporites and has studied the Ochoan evaporites of the delaware Basin (Lowenstein, 1982,

1985). For this study, he performed a detailed sedimentological analysis of the Rustler cores from four wells, viz. DOE-2, W-19, H-11 and H-12. This included visual examination of the cores, preparation and petrographic analyses of 52 thin sections from selected locations of the cores, and x-ray diffraction analyses of 40 samples from selected locations of the cores. In addition, descriptive data on the rock cuttings and geophysical logs of borehole P-18 were used for correlation purposes. This report is a result of these analyses and correlation of sedimentary features between the drill-holes.

This study was confined to a miniscule area (only about 0.05%) of the total extent of the Rustler Formation and therefore cannot be considered to be a study of post-burial alteration of the Rustler Formation as a whole. Within the confines of this area, however, detailed stratigraphic correlations by Dr. Lowenstein based on sedimentary structures and textures indicate overall uniformity of depositional setting. Further, the physical and chemical alteration features, based on crosscutting relations, represent the last processes which have operated on these rocks. Four distinct dissolution zones in the Rustler Formation have been interpreted by Dr. Lowenstein. Although the strata above and below the inferred dissolution zones are chemically and physically altered, they contain abundant sedimentary structures and internal stratigraphy that can easily be matched from well to well. Dr. Lowenstein does not see a contradiction between post depositional dissolution and the survival of sedimentary structures. His interpretation is that the dissolved species produced by solution are removed from the site of reaction and the zones in which the effects of dissolution are now seen were at the periphery of main dissolution activity and therefore may exhibit some alteration as well as primary sedimentary structures."

Lowenstein, T.K. 1988. Origin of Depositional Cycles in a Permian "Saline Giant": The Salado (McNutt Zone) Evaporites of New Mexico and Texas. Geological Society of America Bulletin, Vol. 100, No. 4, pp. 592–608.

ABSTRACT, p 592, col 1;

" Two types of metre-scale depositional cycles have been recognized within the McNutt Potash Zone of the Permian Salado evaporites. The cycles record progressive drawdown and concentration of brine in a shallow, marginal marine basin. 'Type I' cycles, made of basal carbonate-siliciclastic mudstone, then anhydrite-polyhalite pseudomorphous after primary gypsum, overlain by halite and capped by muddy halite, are interpreted as marine sea water dominated. They formed by massive spillover of sea water through a connection with the Permian Ocean at high relative sea-level stands (lagoonal mudstone and anhydrite-polyhalite after subaqueous gypsum), followed by relative lowering of sea level and gradual basin restriction (shallow saline-lake and salt-pan halite) and ending with a desiccated basin, isolated from the Permian Ocean (salt-pan halite and saline mudflat muddy halite cycle cap). 'Type II' cycles occur between the Type I cycles and contain halite overlain transitionally by muddy halite. They record a temporal evolution of environments from a shallow saline lake to an ephemeral salt-pan-saline mudflat complex and are interpreted as continental-dominated sequences sourced by meteoric inflow from surrounding land areas that mixed with variable amounts of sea water, either residual or introduced into the Salado basin by seepage.

The vertical stacking of Type I cycles is best explained by periodic invasions of sea water into the Salado basin coincident with eustatic sea-level rises. The continental-dominated Type II cycles formed during intervening periods of eustatic sea-level fall and low stands. The *maximum* time interval between major marine incursions is an average of 10^5 yr."

Lyklema, J. 1978. Surface Chemistry of Colloids in Connection with Stability. The Scientific Basis of Flocculation. K.J. Ives, Ed.,pp. 3-36. Sijthoff and Noordhoff: Dordrecht.

ABSTRACT, p. 3;

" A review is given of the fundamental features of the interfacial electrochemistry of colloid particles, emphasizing its role in colloid stability. The discussion includes a description of double layers in the presence of simple electrolytes and with polymers.

Lyon, M.L. 1989 Annual Water Quality Data Report for the Waste Isolation Pilot Plant. DOE/WIPP 89-001. Westinghouse Electric Corporation, Carlsbad, NM.

1.1 SAMPLING PROGRAM SCOPE, p 1-5;

" The WIPP Water Quality Sampling Program (WQSP) was initiated in January 1985. The program's goals are to collect reproducible and representative ground-water samples from water-bearing zones in the WIPP vicinity. The Waste Isolation Pilot Plant Water Quality Sampling Manual WP 7-2, Revision 1 (October 1987) was the governing document for the program in 1988. This manual details the WQSP wells to be sampled and lists the types of analyses required for the program. Procedures detailing sample collection techniques and methods for field analyses accompany WP 7-2 are located in the Waste Isolation Pilot Plant Geotechnical and Geosciences Procedure Manual.

The water quality analytical data obtained by the WQSP directly support four major programs at the WIPP. These programs include site characterization, performance assessment (compliance with 40 CFR 191), the Radiological Baseline Program, and the Ecological Monitoring Program. Additionally, the State of New Mexico Environmental Evaluation Group is provided with water samples from each sampling location for independent analysis. Each of these programs requires a unique set of analyses and data, but overlap of analytical needs does occur. The particular set of water sample analyses supporting a given program are defined by that program and not by the WQSP. A brief description of each program is given below to illustrate the role of the WQSP at the WIPP."

Machette, M.N. 1985. "Calcic Soils of the Southwestern United States." In Soils and Quaternary Geology of the Southwestern United States. D.L. Weide and M.L. Faber, eds., Special Paper Vol. 203, pp. 1-21. Geological Society of America, Denver, CO.

ABSTRACT, p 1;

" Calcic soils are commonly developed in Quaternary sediments throughout the arid and semiarid parts of the southwestern United States. In alluvial chronosequences, these soils have regional variations in their content of secondary calcium carbonate ($CaCO_3$) because of (1) the combined effects of the age of the soil, (2) the amount, seasonal distribution, and concentration of Ca^{++} in rainfall, and (3) the $CaCO_3$ content and net influx of airborne dust, silt, and sand. This study shows that the morphology and amount of secondary $CaCO_3$ (cS) are valuable correlation tools that can also be used to date calcic soils.

The structures in calcic soils are clues to their age and . . ."

Maiti, T.C., Smith, M.R., and Laul, J.C. 1989. Colloid Formation Study of U, Th, Ra, Pb, Po, Sr, Rb, and Cs in Briny (High Ionic Strength) Groundwaters: Analog Study for Waste Disposal. Nuclear Technology. Vol. 84, No. 1, pp. 82-87.

ABSTRACT, p. 82;
" Colloid formation of uranium, thorium, radium, lead, polonium, strontium, rubidium, and cesium in briny (high ionic strength) groundwaters is studied to predict their capability as vectors for transporting radionuclides. This knowledge is essential in developing models to infer the transport of radionuclides from the source region to the surrounding environment. Except polonium, based on the experimental results, colloid formation of uranium, thorium, radium, lead, strontium, rubidium, and cesium is unlikely in brines with compositions similar to the synthetic Palo Duro Basin brine. This observation of no colloid formation is explained by electrokinetic theory and inorganic solution chemistry."

Mansure, A. and Reiter, M. 1977. An Accurate Equilibrium Temperature Log in AEC No. 8, A Drill Test in the Vicinity of the Proposed Carlsbad Disposal Site. Open File Report 80. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM. WPO 21200.

" On February 24, 1977 an accurate, equilibrium log was run in drill test AEC #8, which is in the vicinity of the Carlsbad disposal site. The log was run from 50 feet to 4810 feet. Temperature data were taken at varying depth intervals with the sonde continuously moving. At 50 ft, 1000 ft, 2000 ft, 3000 ft, 4000 ft, 4500 ft, and 4810 ft the sonde was stopped to examine tool response and wellbore stability. The sonde is a thermistor device which is connected to Mueller bridge electronics at the surface. The measurements are believed to be accurate to ± .03°F. Data are printed out in this report and shown graphically.

From the graph it is evident that there are three distinct gradient zones. They are approximately : 1) 50 ft to 1035 ft, 2) 1056 ft to 4247 ft, and 3) 4306 ft to 4810 ft. The temperature gradients in these zones are respectively: 1) .85°F/100 ft, 2) .43°F/100 ft, and 3) .91°F/100 ft.

Sandia lab supplied thermal conductivity data (taken by Russel U. Acton, Sandia Lab tech. doc. in prep.) applicable to the middle gradient zone. The apparent average of these values is 5.5 W/M-°K or 13.7 mcal/cm-sec-°C. The product of the temperature gradient and the thermal conductivity mean in the middle zone yields an estimate of the geothermal heat flux at AEC #8; this is 1.07 μcal/cm^2-sec."

Marietta, M.G., Bertram-Howery, S.G., Anderson, D.R., Brinster, K.F., Guzowski, R.V., Iuzzolino, H., and Rechard, R.P. 1989. Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance With EPA 40 CFR Part 191, Subpart B, for the Waste Isolation Pilot Plant. SAND89-2027. Sandia National Laboratories, Albuquerque, NM. WPO 25952.

ABSTRACT;

" This report describes a demonstration of the performance assessment methodology for the Waste Isolation Pilot Plant (WIPP) to be used in assessing compliance with the Environmental Protection Agency's Standard, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 191, Subpart B). This demonstration incorporates development and screening of potentially disruptive scenarios. A preliminary analysis of the WIPP disposal system's response to human intrusion scenarios produces preliminary complementary cumulative distribution functions (CCDFs) similar to those that will ultimately be used to assess the compliance of the WIPP with the Containment Requirements of the Standard. Preliminary estimates of scenario probabilities are used to construct two demonstration CCDFs. The conceptual model of the disposal system consists of geologic,, hydrologic, and disposal system subsystems along with the physical and chemical processes associated with these subsystems. Parameter values defining the systems contain uncertainties and modeling approximations of such a disposal system contributes to those uncertainties. The WIPP compliance assessment methodology consists of a system of techniques and computer codes that estimate releases of radionuclides from the disposal system, incorporating analysis of the parameter uncertainties in the estimates. Demonstration CCDFs are presented, but are not yet credible enough to judge the probability of compliance of the WIPP with the EPA Standard. One CCDF, based primarily on conservative reference data and conservative conceptual models, exceeds EPA limits, and another CCDF that represents effects of possible engineered alternatives does not exceed EPA limits."

McGrath E.J., and Irving, D.C. 1975. Techniques for Efficient Monte Carlo Simulation. Volume III. Variance Reduction. ORNL-RSIC-38, Vol. 3. Oak Ridge National Laboratory, Oak Ridge, TN.

ABSTRACT, p v;

" Many Monte Carlo simulation problems lend themselves readily to the application of variance reduction techniques. These techniques can result in great improvements in simulation efficiency. This document describes the basic concepts of various reduction (Part I), and a methodology for application of variance reduction techniques is presented in Part II. Appendices include the basic analytical expressions for application of variance reduction schemes as well as an abstracted bibliography.

The techniques considered here include importance sampling, Russian roulette and splitting, systematic sampling, stratified sampling, expected values, statistical estimation, correlated sampling, history reanalysis, control variates, antithetic variates, regression, sequential sampling, adjoint formulation, transformations, orthonormal and conditional Monte Carlo. Emphasis has been placed on presentation of the material for application by the general user. This has been accomplished by presenting a step by step procedure for selection and application of the appropriate technique(s) for a given problem."

McGrath E.J., and Irving, D.C. 1975. Techniques for Effecient Monte Carlo Simulation. Volume II. Random Number Generation for Selected Probability Distributions. ORNL-RSIC-38 Vol. 2. Oak Ridge National Laboratory, Oak Ridge, TN.

ABSTRACT, p v;

" Algorithms for efficient generation of random numbers from various probability distributions are presented, in both a flowchart form and as a sample Fortran subroutine. Twenty-two different distributions, including all commonly encountered discrete and continuous functions, the Weibull, Johnson, and Pearson families of empirical distributions, and histogram distributions, are covered. The general techniques to apply in deriving a random number selection scheme for an arbitrary distribution are discussed. A machine-independent subroutine for generating uniform random numbers is also described."

McGrath E.J., Basin, S.L., Burton, R.W., Irving, D.C., and Jaquette, S.C. 1975. Techniques for Efficient Monte Carlo Simulation. Volume I. Selecting Probability Distributions. ORNL-RSIC-38 Vol. 1. Oak Ridge National Laboratory, Oak Ridge, TN.

ABSTRACT, p vii;

" This document is the first of three volumes which present techniques and methods for developing efficient Monte Carlo simulations: Each volume presents techniques for reducing computational effort in one of the following areas: Vol. I - Selecting Probability Distributions, Vol II - Random Number Generation For Selected Probability Distributions, and Vol. III - Variance Reduction.

This volume provides a straightforward approach and associated techniques for selecting the most appropriate probability distributions for use in Monte Carlo simulations. Part I, BASIC CONSIDERATIONS, presents the underlying concepts and principles for selecting probability distributions. Part II, SELECTION OF DISTRIBUTIONS, gives the mathematical models representing stochastic processes and presents step-by-step procedures for identification and selection of the appropriate probability distributions based upon the degree of knowledge and available data for the random variable under study."

McKay, M.D., Beckman, R.J., and Conover, W.J. 1979. A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code. Technometrics, Vol. 21, No. 2, pp. 239-245.

p 239;

" Two types of sampling plans are examined as alternatives to simple random sampling in Monte Carlo studies. These plans are shown to be improvements over simple random sampling with respect to variance for a class of estimators which includes the sample mean and the empirical distribution function."

Mercer, J.W., and Snyder, R.P. 1990. Basic Data Report for Drillholes at the H-11 Complex (Waste Isolation Pilot Plant--WIPP). SAND89-0200. Sandia National Laboratories, Albuquerque, NM. WPO 27705.

ABSTRACT, p iii;

" Drillholes H-11b1, H-11b2, and H-11b3 were drilled from August to December 1983 for site characterization and hydrologic studies of the Culebra Dolomite Member of the Upper Permian Rustler Formation at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. In October 1984, the three wells were subjected to a series of pumping tests designed to develop the wells, provide information on hydraulic communication between the wells, provide hydraulic properties information, and to obtain water samples for quality of water measurements. Based on these tests, it was determined that this location would provide an excellent pad to conduct a convergent-flow non-sorbing tracer test in the Culebra dolomite. In 1988, a fourth hole (H-11b4) was drilled at this complex to provide a tracer-injection hole for the H-11 convergent-flow tracer test and to provide an additional point at which the hydraulic response of the Culebra H-11 multipad pumping test could be monitored.

The geologic units penetrated in H-11b1 are surficial deposits (0-12.5 feet) of Holocene age, the Dockum Group (undifferentiated) (12.5-63 feet) of Upper Triassic age, the Dewey Lake Redbeds (63-558 feet) and the Rustler Formation (558-785+ feet) of Upper Permian age. There was evidence of Rustler halite in the core at 763 feet, which was 7 feet into the unnamed lower member).

The geologic units penetrated in H-11b2 are surficial deposits (0-11 feet) of Holocene age, the Dockum Group (undifferentiated) (11-62 feet) of Triassic age, the Dewey Lake Redbeds (62-560 feet) and the Rustler Formation (560-776+ feet) of Permian age. There was evidence of Rustler halite in place in the core at 764 feet, which was 7 feet into the unnamed lower member).

The geologic units penetrated in H-11b3 are surficial deposits (0-11 feet) of Holocene age, the Dockum Group (undifferentiated) (11-59.5 feet) of Upper Triassic age, the Dewey Lake Redbeds (59.5-560.2 feet) and the Rustler Formation (560.2-788.7+ feet) of Permian age. There was evidence of Rustler halite in the core at 777.7 feet, which was 17.7 feet into the unnamed lower member).

The geologic units penetrated in H-11b4 are surficial deposits (0-11 feet) of Holocene age, the Dockum Group (undifferentiated) (11-60 feet) of Upper Triassic age, the Dewey Lake Redbeds (60-554 feet) and the Rustler Formation (564-765.3+ feet) of Upper Permian age. There was no evidence of Rustler halite in the core to 765.3 feet, which was 19.2 feet into the unnamed lower member).

A suite of geophysical logs was run on the drillholes and was used to identify different lithologies and aided in interpretation of the hydraulic tests."

Mercer, J.W., Beauheim, R.L., Snyder, R.P., and Fairer, G.M. 1987. Basic Data Report For Drilling and Hydrologic Testing of Drillhole DOE-2 at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-0611. Sandia National Laboratories, Albuquerque, NM.

ABSTRACT;

" Drillhole DOE-2 was drilled to investigate a structural depression marked by the downward displacement of stratigraphic markers in the Salado formation ~2 mi north of the center of the WIPP site. This depression was named informally after the shallow borehole FC-92 in which the structure was described. The presence of the depression was confirmed by drilling. Contrary to several hypotheses, halite layers were thicker in the lower part of the Salado, not thinner as a result of any removal of halite. The upper Castile anhydrite in Drillhole DOE-2 is anomalously thick and is strongly deformed relative to the anhydrite in adjacent drillholes. In contrast, the halite was <8 ft thick and significantly thinner than usually encountered. The lower Castile anhydrite appears to be normal. The depression within the correlated marker beds in the Salado Formation in Drillhole DOE-2 is interpreted as a result of gravity-driven deformation of the underlying Castile Formation.

Several stratigraphic units were hydrologically tested in Drillhole DOE-2. Testing of the unsaturated lower portion of the Dewey Lake Red Beds was unsuccessful because of exceptionally small rates of fluid intake. Drill-stem tests were conducted in five intervals in the Rustler Formation, over the Marker Bed 138-139 interval in the Salado Formation, and over three sandstone members of the Bell Canyon Formation. A pumping test was conducted in the Culebra Dolomite Member of the Rustler Formation. Pressure-pulse tests were conducted over the entire Salado Formation. Fluid samples were collected from the Culebra Dolomite Member and from the Hays Member of the Bell Canyon Formation."

Mitchell, J.F.B. 1989. The "Greenhouse" Effect and Climate Change. Reviews of Geophysics. Vol. 27, No. 1, pp. 115-139.

ABSTRACT, p. 115;

" The presence of radioactively active gases in the Earth's atmosphere (water vapor, carbon dioxide, and ozone) raises its global mean surface temperature by 30 K, making our planet habitable by life as we know it. There has been an increase in carbon dioxide and other trace gases since the Industrial revolution, largely as a result of man's activities, increasing the radiative heating of the troposphere and surface by about 2 W m^{-2}. This heating is likely to be enhanced by resulting changes in water vapor, snow and sea ice, and cloud. The associated equilibrium temperature rise is estimated to be between 1 and 2 K, there being uncertainties in the strength of climate feedbacks, particularly those due to cloud. The large thermal inertia of the oceans will slow the rate of warming, so that the expected temperature rise will be smaller than the equilibrium rise. This increases the uncertainty in the expected warming to date, with estimates ranging from less than 0.5 K to over 1 K. The observed increase of 0.5 K since 1900 is consistent with the lower range of these estimates, but the variability in the observed record is such that one cannot necessarily conclude that the observed temperature change is due to increases in trace gases. The prediction of changes in temperature over the next 50 years depends on assumptions concerning future changes in trace gas concentrations, the sensitivity of climate, and the effective thermal inertia of the oceans. On the basis of our current understanding a further warming of at least 1 K seems likely. Numerical models of climate indicate that the changes will not be uniform, nor will they be confined to temperature. The simulated warming is largest in high latitudes in winter and smallest over sea ice in summer, with little seasonal variation in the tropics. Annual mean precipitation and runoff increase in high latitudes, and most simulations indicate a drier land surface in northern mid-latitudes in summer. The agreement between different models is much better for temperature than for changes in the hydrological cycle. Priorities for future research include developing an improved representation of cloud in numerical models, obtaining a better understanding of vertical mixing in the deep ocean, and determining the inherent variability of the ocean-atmosphere system. Progress in these areas should enable detection of a man-made'greenhouse' warming within the next two decades.

Molecke, M.A., Argüello, J.G., and Beraún, R. 1993. Waste Isolation Pilot Plant Simulated RH-TRU Waste Experiments: Data and Interpretation Report. SAND88-1314. Sandia National Laboratories, Albuquerque, NM. WPO 24906.

ABSTRACT, p. i;

" The simulated, i.e., nonradioactive remote-handled transuranic waste (RH TRU) experiments being conducted underground in the Waste Isolation Pilot Plant (WIPP) were emplaced in mid-1986 and have been in heated test operation since 9/23/86. These experiments involved the in situ, waste package performance testing of eight full-size, reference RH TRU containers emplaced in horizontal, unlined test holes in the rock salt ribs (walls) of WIPP Room T. All of the test containers have internal electrical heaters; four of the test emplacements were filled with bentonite and silica sand backfill materials. We designed test conditions to be 'near-reference' with respect to anticipated thermal outputs of RH TRU canisters and their geometrical spacing or layout in WIPP repository rooms, with RH TRU waste reference conditions current as of the start date of this test program. We also conducted some thermal overtest evaluations. This paper provides a: detailed test overview; comprehensive data update for the first 5 years of test operations; summary of experiment observations; initial data interpretations; and, several recommendations for future RH TRU waste emplacements in the WIPP. Details included are: current test status; experimental objectives -- how these tests support WIPP TRU waste acceptance, performance assessment studies, underground operations, and the overall WIPP mission; and, in situ performance evaluations of RH TRU waste package materials plus design details and options. We provide instrument data and results for in situ waste container and borehole temperatures, pressures exerted on test containers through the backfill materials, and vertical and horizontal borehole-closure measurements and rates. The effects of heat on borehole closure, fracturing, and near-field materials (metals, backfills, rock salt, and intruding brine) interactions were closely monitored and are summarized, as are assorted test observations. Predictive 3-dimensional thermal and structural modeling studies of borehole and room closures and temperature fields were also performed. Computed and measured borehole closure results indicate greater closure occurs near the middle- and back-end of the holes than at the (open) rib-end. Computed vertical closure results provide an upper bound estimate on borehole closure that is 1.5 - 2.5 times larger than the measured in situ values, but are in qualitative agreement. Based on our current data, results, observations, and interpretations, RH TRU waste packages, materials, and emplacement geometry in unlined salt boreholes appear to be quite adequate and safe for repository-phase isolation at WIPP. There should be no restrictions on RH TRU waste acceptance at WIPP due to observed waste package behavior."

Muehlberger, W.R., Belcher, R.C., and Goetz, L.K. 1978. Quaternary Faulting on Trans-Pecos Texas. Geology, Vol. 6, No. 6, pp. 337-340.

ABSTRACT, p 337;

" Faults that displace Quaternary units can be observed in scarps in Trans-Pecos Texas and are restricted to two north-trending zones in contrast to late Tertiary faults that cover the region and strike north, northwest, and west. The western zone of Quaternary faults, near El Paso, is usually included as the southern part of the Rio Grande rift. The eastern zone of Quaternary faults extends for 300 km from southern New Mexico along the Salt Basin graben through Van Horn, Texas; its probable extensions and subparallel associates extend southward to Presidio, Texas. This belt of faults is parallel to the Rio Grande rift zone and should be considered a southeast extension of that zone.

These fault zones die out southward into the edge of the Chihuahua tectonic belt, a region underlain by a thick Mesozoic carbonate and clastic section that in turn rests on a thick layer of evaporites. The evaporite zone may mask Cenozoic normal faulting and thus may define a zone of no data rather than a southern limit of basin-and-range or Rio Grande graben tectonics.

All Quaternary and most Tertiary faults trend parallel to pre-existing structures. The map pattern of Quaternary scarps suggest a maximum extension oriented about S80°W; however, first-motion studies of the 1931 Valentine, Texas earthquake show a maximum elongation direction of S50° to 55°W. This difference may be unique to this one earthquake or may be due to the pre-existing lines of weakness that control the location of presently active faults."

Myers, J., Derz, P., and James. 1991. "Chapter 6: The Redox State and the Occurrence and Influence of Organics in the Culebra." In Hydrogeochemical Studies of the Rustler Formation and Related Rocks in the Waste Isolation Pilot Plant Area, Southeastern New Mexico, M.D. Siegel, S.J. Lambert, and K.L. Robinson, eds. SAND88-0196. Sandia National Laboratories, Albuquerque, NM. In WPO 25624 (Chapter 6) pp. 6-1 through 6-35.

ABSTRACT, p i;

" Chemical, mineralogical, isotopic, and hydrological studies of the Culebra dolomite member of the Rustler Formation and related rocks are used to delineate hydrochemical facies and form the basis for a conceptual model for post-Pleistocene groundwater flow and chemical evolution. Modern flow within the Culebra in the Waste Isolation Pilot Plant (WIPP) area appears to be largely north-to-south; however, these flow directions under confined conditions are not consistent with the salinity distribution in the region surrounding the WIPP Site. Isotopic, mineralogical, and hydrological data suggest that vertical recharge to the Culebra in the WIPP area and to the immediate east and south has not occurred for several thousand years. Eastward increasing $^{234}U/^{238}U$ activity ratios suggest recharge from a near-surface Pleistocene infiltration zone flowing from the west-northwest and imply a change in flow direction in the last 30,000 to 12,000 years.

Culebra groundwaters are in chemical equilibrium with gypsum and are undersaturated with halite and anhydrite. A partial-equilibrium model for the chemical evolution of the groundwater suggests that Na, Cl, Mg, K, and SO_4 are added to the Culebra by dissolution of evaporite salts in adjacent strata. Equilibrium is maintained with gypsum and calcite, but dolomite supersaturation increases as the salinity of the water increases. Stable-isotope compositions of carbonates are consistent with this model and indicate that no recrystallization of dolomite in equilibrium with the groundwater has occurred. Major and minor element correlations are consistent with several plausible mechanisms of water/rock interaction, including sorption of lithium and boron by clays and dissolution of Mg-rich clays."

Nicholson, Jr., A., and Clebsch, Jr., A. 1961. Geology and Ground-Water Conditions in Southern Lea County, New Mexico. Ground-Water Report 6. State Bureau of Mines and Mineral Resources, Socorro, NM.

ABSTRACT, p 1;

" Southern Lea County is at the southeastern corner of New Mexico. Most of the area is in the Pecos Valley section of the Great Plains physiographic province; it also includes the southern margin of the Llano Estacado. There are no perennial streams and no throughgoing surface drainage.

Rocks of Quaternary, Tertiary, and Triassic age are exposed and contain the principle aquifers. The most important aquifer is the Ogallala formation, which underlies the Llano Estacado and forms outliers south of it. In large parts of southern Lea County, however, the Ogallala has been removed by erosion and in the low-lying areas Quaternary alluvium, derived principally from the Ogallala formation, has been deposited and is the main aquifer. The two aquifers are continuous in the eastern part of the area. Below the Cenozoic rocks are sandstones and shales of the Dockum group of Late Triassic age, from which small quantities of water are obtained. No usable ground water is obtained from rocks older than the Triassic, but highly saline water is produced along with oil from Paleozoic rocks.

In 1954 about 6,000 acre-feet of ground water were used. Most of this quantity was needed for irrigation and for gasoline plants, in about equal amounts. Economic growth from a rapidly developing petroleum industry has brought about a demand for water for industrial and public supplies that is expected to continue. Development of adequate supplies is hindered by restricted occurrence and low transmissibility of the sediments. Because of the low recharge rate, most of the water pumped is being removed from storage.

The chemical quality of the ground water from the principal aquifers is generally fair to good. Production of large quantities of oil-field brine (3,700 acre-feet in 1955) has created a waste-disposal problem of major importance. Most of the brine has been discharged into surface pits. Leakage from the pits has caused contamination of the shallow water in some areas and unless other disposal methods are used, the problem will spread."

Nowak, E.J., Tillerson, J.R., and Torres, T.M. 1990. Initial Reference Seal System Design: Waste Isolation Pilot Plant. SAND90-0355. Sandia National Laboratories, Albuquerque, NM. WPO 23981.

ABSTRACT, p i;

" Waste Isolation Pilot Plant (WIPP) sealing program results are embodied in the initial seal system strategy and reference design. The design provides a common basis for calculations and analyses so that results can be compared directly. The sealing strategy combines both long- and short-term seal components. Crushed salt, consolidated by creep closure of the excavations, is the principle long-term barrier to fluid flow. Short-term seal components are used until creep consolidation is sufficient. Concretes developed specifically for WIPP seals and a swelling clay material that exhibits low permeability to WIPP groundwater and brine have been chosen for the short-term components. A body of evidence exists showing the stability of these materials for the length of time they are required to function. Reference designs are described and drawings are shown for each of the principle multi-component seals. Confidence in the sealing strategy and the reference designs resulted from a combination of laboratory tests, numerical modeling, and in situ demonstrations. The sealing strategy, materials, and designs for the WIPP repository are consistent with the concepts and designs proposed previously for other national and international waste management programs. Past accomplishments and planned activities in the sealing program will produce a detailed conceptual design for the seal system and a seal system performance model. Additional design, analysis, laboratory testing, and in situ testing are needed to assure the performance of the seal system."

OECD Nuclear Energy Agency. 1995. Future Human Actions at Disposal Sites: A Report of the NEA Working Group on Assessment of Future Human Actions at Radioactive Waste Disposal Sites. Organisation for Economic Co-Operation and Development, Paris, France.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Parry, G.W. 1988. On the Meaning of Probability in Probabilistic Safety Assessment. Reliability Engineering and System Safety. Vol. 23, No. 4, pp. 309-314.

ABSTRACT, p. 309;
" The paper addresses the meaning of the term probability as it is used in Probabilistic Safety Assessment (PSA). The use of two different interpretations of probability, the classical interpretation to describe random physical processes, and the subjectivist interpretation to represent uncertainty, is discussed within the context of the PSA framework. Possible sources of confusion, largely resulting from a lack of clear definition of the scope and meaning of the analysis, are identified."

Paté-Cornell, M.E. 1986. Probability and Uncertainty in Nuclear Safety Decisions. Nuclear Engineering and Design. Vol. 93, No. 2-3, pp. 319-327.

ABSTRACT, p. 319;

" In this paper, we examine some problems posed by the use of probabilities in Nuclear Safety decisions. We discuss some of the theoretical difficulties due to the collective nature of regulatory decisions, and, in particular, the calibration and the aggregation of risk information (e.g., experts opinions). We argue that, if one chooses numerical safety goals as a regulatory basis, one can reduce the constraints to an individual safety goal and a cost-benefit criterion. We show the relevance of risk uncertainties in this kind of regulatory framework. We conclude that, whereas expected values of future failure frequencies are adequate to show compliance with economic constraints, the use of a fractile (e.g., 95%) to be specified by the regulatory agency is justified to treat hazard uncertainties for the individual safety goal."

Pfeifer, M.C., Borns, D.J., Skokan, C.K., Andersen, H.T., and Starett, J.M. 1989. "Geophysical Methods to Monitor the Development of the Disturbed Rock Zone Around Underground Excavations in Bedded Salt." In Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, Golden, CO, March 13-16, 1989. SAND89-7055A. Vol. 2, pp. 400-411. WPO 29630.

SUMMARY, p. 400;

" A zone of disturbed rock develops around underground excavations. The manner and rate of degradation has direct implications on the intended long-term use of the excavations. The rate and manner of deformation is dependant on the time after interval since removal supporting room or tunnel material.

Several geophysical methods can be employed to monitor and characterize the zone of deformation as there is a change in the physical rock properties. Electrical methods have been used to monitor the change in moisture content and the development of voids in the excavation floor. Acoustic methods have been successfully used to both test the mechanical integrity of the pillars between excavations and the zone immediately around the underground opening."

Powers, D.W. and Holt, R.M. 1990. "Sedimentology of the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) Site." Geological and Hydrological Studies of Evaporites in the Northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico. Field Trip #14 Guidebook, Geological Society of America 1990 Annual Meeting, October 29-November 1, 1990. pp. 79-106. Dallas Geological Society, Dallas, TX.

Section Regional Relationships, p 100, col 1, para 7;
" About 600 geophysical logs (natural gamma and acoustic) of the Rustler Formation were interpreted to understand the regional relationship between various units (Holt and Powers, 1988; Powers and Holt, in prep.). Geophysical logs near the site were carefully compared to lithofacies described from cores and shafts, easily relating many subdivisions. Several extended cross-sections were drafted to show lateral relationships in some detail (Holt and Powers, 1988). Structure contour and isopach maps for different units were drafted and compared. . . ."

Powers, D.W., and Holt, R.M. 1993. "The Upper Cenozoic Gatuña Formation of Southeastern New Mexico." In Carlsbad Region, New Mexico and West Texas, D.W. Love, J.W. Hawley, B.S. Kues, J.W. Adams, G.S. Austin, and J.M. Barker, eds., Forty-Fourth Annual Field Conference, October 6-9, 1993, pp. 271-282. New Mexico Geological Society, Socorro, NM.

ABSTRACT, p 271;

" The Gatuña Formation of southeastern New Mexico has been studied in the field for two landfill projects and the Waste Isolation Pilot Plant project. Shafts, drilling and field mapping reveal the distribution, thickness and sedimentary features of the unit in an area where it was poorly known or assigned to other units. The Gatuña is at least 300 ft thick in the study area. The formation was deposited in the north and east as clastic beds ranging from conglomerates to laminar claystones. Fining upward cycles are common, though depositional features and facies associations are consistent with braided river/stream environments, not meandering rivers. Laminar and thinly bedded siltstones to claystones were deposited in flood plain to playa environments. Pedogenic features superimposed on many fining upward cycles include soil fractures, slickensides, MnO_2, illuviated clay, bioturbation, probable ped structures and desiccation cracks. The upper Gatuña more consistently includes pedogenic development. Beds of poorly indurated 'orange' sand, consisting of rounded and well-sorted grains, are interpreted as eolian deposits. From southern Nash Draw to Orla, the Gatuña is fine-grained and gypsoferous, including displacive crystals and probable subaqueous deposits. These outcrops represent low energy environments, including playas, which were near local base level. The age of the upper Gatuña is reasonably constrained by the Lava Creek B ash (0.6 Ma) within the Gatuña along Livingston Ridge. The age of basal deposits is poorly or not constrained. An ash within probable Gatuña near Orla, TX, is about 13 Ma based on both radiometric and geochemical data. The Gatuña represents an important piece of the geological history of southeastern New Mexico. Further studies could include efforts to better determine the age of the formation; to obtain paleontological data; and to map Gatuña structural relationships to older and younger beds in detail to determine the timing of and spatial evidence for, dissolution of evaporites and collapse of overlying beds, including the Gatuña."

Rechard, R.P., 1989. Review and Discussion of Code Linkage and Data Flow in Nuclear Waste Compliance Assessments. SAND87-2833. Sandia National Laboratories, Albuquerque, NM. WPO 25675.

ABSTRACT;
" This report presents a review and discussion of data flow in a compliance assessment for high-level and transuranic waste, primarily the Containment Requirement of the Environmental Protection Agency (EPA) regulations, 40 CFR 191, *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.* Two major points concerning data flow are presented. First, assuring the quality of a compliance assessment requires that the flow of data and linkage of computer codes be well defined and precisely controlled during execution. Second, the need to analyze many different scenarios using different computer codes requires a flexible data linkage. The manner of linking codes to simultaneously provide quality assurance and flexibility is emphasized, rather than specific computer codes used. Thus, this report is not a user's guide, but a description of how a compliance assessment system was implemented in accordance with EPA regulatory guidance. Although the methods described are general, all examples pertain to the Waste Isolation Pilot Plant (WIPP) project, which prompted development of the concepts."

Rechard, R.P., ed, 1992. User's Reference Manual for CAMCON: Compliance Assessment Methodology Controller Version 3.0. SAND90-1983. Sandia National Laboratories, Albuquerque, NM. WPO 25628.

Section 2. CAMCON General Description, 2.1 Purpose, p 2-1;

" A performance assessment (PA) for a nuclear waste repository such as WIPP can be viewed as a complex process (or composite function) that provides a prediction of performance. Within the complex process, the CAMCON system (Rechard, 1991a) has two important functions. First, the CAMCON system provides the analyst with flexibility (specifically, a variety of software tools and flexibility in use) necessary to investigate various events and phenomena (combined into scenarios), perform simulations, and present the predicted results. (For 40 CFR 191, the results are presented as a complementary cumulative distribution function [CCDF] and compared with probabilistically-based limits [see Appendix A for more information].) Second, the CAMCON system directory structure and several of its procedures and utility programs assist in implementing quality assurance (QA) procedures (Rechard et. al., 1991). For example, CAMCON serves as a software management system providing configuration control, FORTRAN libraries of commonly used subroutines, and on-line documentation for each code. In other words, the CAMCON system allows the analyst flexibility in building various software into an analysis system while providing assurance the analysis system is properly built and executed."

Richey, S.F. 1987. Water-level Data from Wells in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico. Open-File Report 87-120. United States Geological Survey, Albuquerque, NM.

ABSTRACT, p 1;

" The U. S. Geological Survey monitored water levels in wells in the vicinity of the Waste Isolation Pilot Plant in southeastern New Mexico during 1977 to 1985. Water-level data are presented, as are brief descriptions of measurement methods used."

Robinson, J.Q., and Powers, D.W. 1987. "A Clastic Deposit Within the Lower Castile Formation, Western Delaware Basin, New Mexico." In Geology of the Western Delaware Basin, West Texas and Southeastern New Mexico. D.W. Powers and W.C. James, eds. El Paso Geological Society Guidebook 18, pp. 69-79. El Paso Geological Society, El Paso, TX. WPO 37942.

ABSTRACT, p 69, col 1;

" In the vicinity of CP Hill, about 16 km south-southwest of Whites City, New Mexico, a brecciated sequence in the lower Castile Formation has been examined in detail. Four distinct units associated with the breccia sequence have been defined. Unit A is clast poor, structureless to thinly bedded, and contains kerogen. It occurs only over nodular anhydrite. Unit B is pseudo-bedded, with anhydrite matrix supporting tabular anhydrite clasts. Unit C contains abundant rounded polyclasts and is grain-rich. Unit D is similar to A, but clasts are finer in Unit D. These beds are arranged in vertical sequence and show lateral thinning in an apparent fan shape. The textures, grading, and vertical and lateral relationships suggest this breccia unit was deposited as a subaqueous debris flow."

Robinson, T.W., and Lang, W.B. 1938. Geology and Ground-Water Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal, New Mexico, with Special Reference to the Salt Content of the River Water. Twelth and Thirteenth Biennial Reports of the State Engineer of New Mexico for the 23rd, 24th, 25th, and 26th Fiscal Years, July 1, 1935 to July 30, 1938. State Engineer, Santa Fe, NM. WPO 37942.

INTRODUCTION, p 79;

" At the request and in cooperation with the State Engineer of New Mexico, a study of ground-water conditions in the Pecos River Valley southeast of Carlsbad, Eddy County, New Mexico, has been under way since the spring of 1937. The results of that study are presented in this report. The area involved lies largely in Townships 21, 22, 23 and 24 south, Ranges 26, 27, 28 and 29 east, New Mexico principle meridian. (See plate 1). Intensive work was done chiefly in the vicinity of the Laguna Grande de la Sal and the area lying between it and the Malaga Bend of the Pecos River, about five miles south. The area is crossed by the Pecos River flowing southeastward from Carlsbad. During the growing season, the entire flow of the Pecos River above Carlsbad is normally diverted for irrigation at Lake McMillan and Lake Avalon. During this period the Pecos River from Carlsbad south is fed chiefly by large springs. The largest spring, known as Carlsbad Spring, is located in the river channel just below Lake Avalon. The Black River enters the area from the west and flows eastward to its confluence with the Pecos River northeast of Malaga. It is also spring-fed, deriving most of its water from Blue Spring and Castle Spring, near Black River village. The drainage pattern is well developed on the west, and during rainy periods many normally dry arroyos and draws discharge flood water into the Pecos River. Drainage from the east is by poorly developed draws which carry water to the Pecos only during exceptionally heavy rainfall. A prominent feature east of the river is Laguna Grande de la Sal, which is a shallow salt lake in a playa covering about 3½ square miles.

Carlsbad, the largest town in the area and the county seat of Eddy County, had a population of 3,708 in 1930. However, owing largely to the development of the potash mines located about 20 miles east, the population in 1938 is about double that of 1930. Loving, located about 12 miles south, and Malaga, about 18 miles south of Carlsbad, each had less than 1,000 inhabitants in 1930. Carlsbad is served by the Atchison, Topeka, and Santa Fe Railroad and by main highways leading north to Roswell, New Mexico, southwest to El Paso, Texas, south to Pecos, Texas, and east to Hobbs, New Mexico.

Cotton and hay are raised in the irrigated section along the Pecos River, while cattle, sheep and goat raising predominate in the unirrigated upland areas to the east and west. The principle mineral industry is the mining and refining of potash. A large number of tourists are attracted annually to the famous Carlsbad Caverns, located about 25 miles southwest of Carlsbad, near the highway leading to El Paso, Texas.

A group of farmers who pump water from the river for irrigation report that in recent years the water, because of its salinity, has been injurious to their cotton crop. In September 1932 the U.S. Potash Company began operations, using the Laguna Grande de la Sal as a disposal area for the waste brine from their potash refining operations. The reported

difficulty with salt, shortly after refinery operations began, naturally cast suspicion on the brine in the Laguna Grande. There is no visible outlet from the Laguna Grande, and therefore the problem arose as to whether the lake brine may be percolating underground to the Pecos River.

A study of the chemical character of the water of the Pecos River has been made by C.S. Howard and W.F. White, Jr., and numerous analyses were made of the surface and ground waters in this area (see report on chemical character of Pecos River under 'Quality of Water,' to be found elsewhere in this volume). The ground-water studies by T.W. Robinson were begun on April 13, 1937, and the geologic studies by W.B. Lang on October 15, 1937."

Rosholt, J.N., and McKinney, C.R. 1980. Uranium Series Disequilibrium Investigations Related to the WIPP Site, New Mexico (USA). Part II Uranium Trend Dating of Surficial Deposits and Gypsum Spring Deposit Near WIPP Site, New Mexico. Open-File Report 80-879. U.S. Geological Survey, Denver, CO.

INTRODUCTION, p. 1;

" Just how suitable salt beds are for permanent disposal of radioactive wastes has been the subject of extensive studies covering diverse aspects over the past decade. The proposed site of the Waste Isolation Pilot Plant (WIPP) is located in southeastern New Mexico, about 42 km east of Carlsbad, where plans are to construct the storage facility in rock salt beds of the Permian Salado Formation. Detailed surface and subsurface geology at the site and of the surrounding area has been discussed previously (Bachman, 1976; Powers and others, 1978).

A basic concern for waste repositories in salt beds is their high solubility in ground waters. Different kinds of dissolution features are known in most evaporite basins including the Delaware Basin, the region of the proposed WIPP site. Some primary questions that can be posed are: 1. Is there active dissolution of salt at or near the site of WIPP? 2. Is the process of salt dissolution continuous or episodic? 3. If episodic, what is the correlation between time and depth? 4. When did the last salt dissolution cycle occur? 5. What is the rate of dissolution?

Rosholt and others (1966) and Rosholt (1978) demonstrated that a process of isotopic evolution of uranium and thorium occurs in most types of sediments, altered volcanic ashes and deeply buried granites provided that some groundwater is allowed to migrate through the porous zones of these materials during their geologic history. Often the analyses of the isotopes of the ^{238}U-^{234}U-^{230}Th-^{232}Th system yield an estimated age for the time of deposition (uranium-trend age estimate) over the range of the method from 2,000 to about 800,000 years ago (Rosholt, 1978). Accordingly, it was felt that a preliminary study of salt dissolution residue samples near the WIPP site may yield insight into the dissolution processes and/or it may provide a uranium-trend age estimate for the most recent salt dissolution that produced clay residuum and bands of gypsum. The application of uranium trend dating in the investigation of the age of surficial deposits in the area east of Carlsbad, New Mexico, is included in Part II of this report."

Sandia National Laboratories. 1992. Long-Term Gas and Brine Migration at the Waste Isolation Pilot Plant, Preliminary Sensitivity Analyses for Post-Closure 40 CFR 268 (RCRA), May 1992. SAND92-1933. Sandia National Laboratories, WIPP Performance Assessment Department, Albuquerque, NM. WPO 23513.

ABSTRACT;

" This report describes preliminary probabilistic sensitivity analyses of long-term gas and brine migration at the Waste Isolation Pilot Plant (WIPP). Because gas and brine are potential transport media for organic compounds and heavy metals, understanding two-phase flow in the repository and the surrounding Salado Formation is essential to evaluating long-term compliance with 40 CFR 268.6, which is the portion of the Land Disposal Restrictions of the Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act that states the conditions for disposal of specified hazardous wastes. Calculations described here are designed to provide guidance to the WIPP Project by identifying important parameters and helping to recognize processes not yet modeled that may affect compliance. Based on these analyses, performance is sensitive to shaft-seal permeabilities, parameters affecting gas generation, and the conceptual model used for the disturbed rock zone surrounding the excavation. Brine migration is less likely to affect compliance with 40 CFR 268.6 than gas migration. However, results are preliminary, and additional iterations of uncertainty and sensitivity analyses will be required to provide the confidence needed for a defensible compliance evaluation. Specifically, subsequent analyses will explicitly include effects of salt creep and, when conceptual and computational models are available, pressure-dependent fracturing of anhydrite marker beds."

Saulnier, G.J., Jr., 1987. Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-11 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site. SAND87-7124. Sandia National Laboratories, Albuquerque, NM. WPO 28520.

ABSTRACT, p ii;

" The Culebra Dolomite Member of the Permian Rustler Formation was hydrologically evaluated in a series of pumping tests conducted at the H-11 hydropad at the Waste Isolation Pilot Plant (WIPP) site in 1984 and 1985. The H-11 hydropad was constructed in 1983 and consists of three wells, H-11b1, H-11b2, and H-11b3, each completed open-hole to the Culebra dolomite. At H-11, the Culebra dolomite is a 25-ft thick argillaceous dolomite with 0.1- to 0.5-foot thick layers with a high density of vugs. The vugs range in size from 0.1 to 0.5 inches in diameter; most are 0.1 to 0.2 inches in diameter. The thin vuggy layers alternate with thicker, more competent layers which have few vugs, but which do contain high-angle fractures. Some of the vugs and fractures are gypsum-filled.

The three pumping tests performed in 1984 consisted of 12- to 21-hour pumping periods at each of the three wells, while using the other two wells at the hydropad as observation wells. The 1985 pumping test was conducted at H-11b3 with H-11b1 and H-11b2 as observation wells. The 1985 test was a 32-day multirate test with four pumping and recovery periods. The 1984 tests were conducted by lowering a submersible pump and pressure transducers in the boreholes. The 1985 test added a downhole packer with feed-through assembly designed to isolate the test interval and reduce or minimize the effect of wellbore storage. The data from all tests were recorded and stored on floppy disks.

The pumping tests at the H-11 hydropad were analyzed with the INTERPRET reservoir-analysis software developed by Scientific Software-Intercomp. The analysis of the test data from both test periods indicates that at H-11, the Culebra dolomite behaves as a multilayered, double-porosity reservoir with slab-type geometry. The INTERPRET analysis of the H-11 pumping tests provided estimates of the double-porosity parameters omega and lambda. Omega is defined as the ratio of the storage capacity of the secondary-porosity system of the producing formation, usually considered to be fractures, to the storage capacity of the combined primary- and secondary-porosity systems.

The range of values calculated for the double-porosity parameter omega in the observation wells was 0.30 to 0.43 for the 1984 tests and 0.07 for the 1985 test. The lower value for 1985 is probably due to the fact that the Culebra in all wells for this testing period was packer-isolated. The omega values for the type curves used to analyze the 1985 H-11 test suggest that the primary-porosity part of this double-porosity reservoir provides 93% of the storage capacity of the formation. The double-porosity parameters lambda (also called the interporosity flow parameter) describes the ability of fluid to flow from the primary-porosity system to the secondary-porosity system (e.g., from matrix to fractures). The definition includes the ratio of the permeability of the primary-porosity system to the permeability of the secondary-porosity system. The average lambda value for the H-11 tests was 3.0×10^{-6}, with and effective range of 3.73×10^{-7} to 1.25×10^{-6}. Analysis of the lambda values determined for the H-11 test data indicates a permeability contrast between the

primary- and secondary-porosity systems of about 1.0×10^{-6} with a characteristic slab-block dimension of 1 to 2 feet.

Using INTERPRET, the average transmissivity of the Culebra was calculated to be 23.2 ft^2/day for the 1984 tests, 26.2 ft^2/day for the 1985 test, and 24.0 ft^2/day using the results of all the tests. The storativity of the Culebra, as determined from the pumping tests, is between 2.9×10^{-3} and 4.5×10^{-4}. The skin factors calculated from the pumping-well data range from -3.3 to -4.6, indicating that these wells behave as stimulated wells. The 1985 test at H-11b3 had both the highest transmissivity and the most negative skin factor, possibly implying that H-11b3 had undergone development during and after its 1984 test.

The results of the 1984 series of tests were also analyzed to determine the degree of anisotropy at the H-11 hydropad. The storage coefficient was estimated to be 6.3×10^{-4}. The average maximum transmissivity vector was 31.1 ft^2/day oriented 5.8° north of east and the average minimum transmissivity vector was 19.3 ft^2/day oriented 5.8° west of north. The ratio of the maximum to the minimum transmissivity vectors was calculated to be 1.6, indicating a low degree of anisotropy at H-11, although the degree of anisotropy may be dependent on fracture orientation and locations of the wells."

Saulnier, Jr., G.J., Domski, P.S., Palmer, J.B., Roberts, R.M., and Stensrud, W.A. 1991. WIPP Salado Hydrology Program Data Report #1. SAND90-7000. Sandia National Laboratories, Albuquerque, NM. WPO 25746.

ABSTRACT;

" WIPP Salado Hydrology Program Data Report #1 presents hydrologic data collected during permeability tests of the Salado Formation performed from August 1988 through December 1989. Analysis and interpretation of the test data are presented in a separate report. The report presents the results of the drilling and testing of six boreholes drilled from the WIPP underground facility 655 m below ground surface in the Salado Formation. Permeability tests were conducted using multipacker test tools with inflatable packers to isolate borehole intervals to allow formation pore-pressure buildup and subsequent pulse-withdrawal tests. Test data include pressures and temperatures in brine-filled, packer-isolated test intervals and borehole-closure and axial test-tool-movement measurements. The test boreholes are 4.0-inch (10.2-cm) in diameter, and were cored in halite and associated anhydrite interbeds and clay seams. The boreholes are oriented vertically downward, angled downward, and horizontal. The boreholes were drilled and cored using compressed air to remove drill cuttings. Three boreholes were drilled in Room C2:C2H01, C2H02, and C2H03. Borehole C2H01 was initially drilled to a depth of 5.68m below the floor of Room C2 and later deepened to 8.97 m to include Marker Bed 139 in the test interval. Borehole C2H02 was drilled to a depth of 10.86 m (7.68 m vertical projection from the floor of Room C2) at a 45° downward angle from the junction of the west wall and floor of Room C2. Marker bed 139 was included in the test interval in borehole C2H02. Borehole C2H03 was drilled horizontally into the west wall of Room C2. Vertically downward boreholes were drilled from the floor in the North 1420 drift (borehole N4P50); the South 1300 drift (borehole S0P01); and in Room 7, Waste Panel 1 in the waste-storage area (borehole S1P71).

Permeability tests were performed after installing multipacker test tools in test boreholes, inflating the packers, and allowing pressures to build up in the isolated intervals. Pulse-withdrawal tests were performed after buildup pressures approached the apparent formation pore pressure. Pulse injections were sometimes performed to increase the fluid pressures in isolated intervals.

Compliance tests were conducted in lengths of steel and stainless-steel casings to evaluate the mechanical performance of the multipacker test tools. The stainless-steel compliance-test chamber was installed with externally mounted thermocouples in a downward-angled borehole in Experimental Room 4. Compliance tests included leak tests and simulated pulse-injection and pulse-withdrawal sequences."

Schiel, K.A. 1988. The Dewey Lake Formation: End Stage Deposit of a Peripheral Foreland Basin [M.S. thesis]. University of Texas at El Paso, El Paso, TX.

ABSTRACT, p iv;

" The red siltstones and fine grained sandstones of the Dewey Lake Formation (Late Permian?) have always been relegated to a rather insignificant role in the geologic history of the Permian Basin. The present study suggests that they are, in fact, an important key to understanding the tectonic evolution of the southwestern United States.

Field work, in southeastern New Mexico, reveals that the Dewey Lake is fluvial in origin. Broad, shallow channels filled with thin horizontal laminations and flanked by laterally thinning wings comprise a large portion of the formation. Floodplain deposits, consisting of interbedded siltstone and silty claystone, are also very common.

The Dewey Lake displays many of the sedimentologic and morphologic characteristics associated with ephemeral fluvial systems. Some of these characteristics are an abundance of horizontal laminations and silty claystone drapes, the existence of interbedded siltstone and silty claystone interpreted to be the distal portion of sheet floods, and the presence of broad channels with laterally thinning wings. The Dewey Lake is, therefore, believed to have been deposited on a very extensive northwest sloping fluvial plain. Movement of sediment across this plain occurred only sporadically, during brief and localized flash floods.

It has previously been theorized that the Dewey Lake was extensively eroded prior to the deposition of the Santa Rosa Formation (Middle to Late Triassic). The results of the present study suggest that the thickness variations in the Dewey Lake are not a reflection of post depositional erosion but syndepositional differences in the subsidence rates of the Central Basin Platform and Delaware Basin. Increased subsidence of the Delaware Basin is reflected by the fact that the base of the Dewey Lake Formation is offset 100 m (300 ft) along the major northwest trending fault zone separating the Delaware Basin and Central Basin Platform. The Delaware Basin, therefore, appears to have been tectonically active throughout the deposition of the Dewey Lake Formation.

If the thickness variations in the Dewey Lake are due to subsidence rather than erosion then the contact between the Dewey Lake and the overlying Santa Rosa Formation is conformable. The Santa Rosa has been dated as Middle to Late Triassic in northeastern New Mexico; if this date is applicable to the Santa Rosa in southeastern New Mexico it dictates that the deposition of the Dewey Lake Formation continued into the Early Triassic.

A major unconformity separates Lower Permian and Cretaceous strata in the Fort Worth, Val Verde and Marfa Basin of Texas. This unconformity, which also exists in northwestern Chihuahua, clearly indicates that a large region of central Texas and northern Mexico was uplifted and eroded during the latest Permian ? and early Mesozoic. The location and timing of this uplift suggests that it was the source of the silt and fine sand comprising the Dewey Lake Formation. A close geographic and temporal relationship between this uplift and Late Triassic rift basins suggests that it originated as a pre-rift bulge.

The very extensive nature of this uplift suggests that the alluvial plain to the north (i.e. the Dewey Lake and Quartermaster Formations) extended significantly beyond the area

of west Texas and eastern New Mexico. The western portion of this plain is theorized to be the redbed facies of the Moenkopi Formation (Early Triassic). Apparent similarities in age, stratigraphic position, lithology and paleoscope all support the concept that the Dewey Lake and Moenkopi Formations are components of a single lithologic unit."

Schlesinger, M.E., and Mitchell, J.F.B. 1987. Climate Model Simulations of the Equilibrium Climatic Response to Increased Carbon Dioxide. Reviews of Geophysics. Vol. 25, No. 4, pp. 760-798.

ABSTRACT, p. 760;

" The first assessments of the potential climatic effects of increased CO_2 were performed using simplified climate models, namely, energy balance models (EBMs) and radiative-convective models (RCMs). A wide range of surface temperature warming has been obtained by surface EBMs as a result of the inherent difficulty of these models in specifying the behavior of the climate system away from the energy balance level. RCMs have given estimates of ΔT_a for a CO_2 doubling that range from 0.48° to 4.2°C. This response can be characterized by $\Delta T_R = \Delta R_T G_0/(1-f)$, where ΔR_T is the radiative forcing at the tropopause due to the CO_2 doubling (~ 4 W m^{-2}), G_0 is the gain of the climate system without feedbacks (~ 0.3°C/(W m^{-2})), and f is the feedback. The feedback processes in RCMs include water vapor feedback (f is 0.3 to 0.4), moist adiabatic lapse rate feedback (f is -0.25 to -0.4), cloud altitude feedback (f is 0.15 to 0.30), cloud cover feedback (f is unknown), cloud optical depth feedback (f is 0 to -1.32), and surface albedo feedback (f is 0.14 to 0.19). However, these feedbacks can be predicted credibly only by physically based models that include the essential dynamics and thermodynamics of the feedback processes. Such physically based models are the general circulation models (GCMs). The earliest GCM simulations of CO_2-induced climate change were performed without the annual insolation cycle. These 'annual mean' simulations gave for a CO_2 doubling a global mean surface air temperature warming of 1.3° to 3.9°C, an increase in the global mean precipitation rate of 2.7 to 7.8%, and an indication of a soil moisture drying in the middle latitudes. The first GCM simulation of the seasonal variation of CO_2-induced climate change was performed for a CO_2 quadrupling and obtained annual global mean surface temperature and precipitation changes of 4.1°C and 6.7%, respectively. Substantial seasonal differences in the CO_2-induced climate changes were found, especially in polar latitudes where the warming was maximum in winter and in the middle latitudes of the northern hemisphere where a soil moisture desiccation was found in summer. Recently, three CO_2-doubling experiments have been performed with GCMs that include the annual insolation cycle. These seasonal simulations give an annual global mean warming of 3.5° to 4.2°C and precipitation increases of 7.1 to 11%. These changes are approximately twice as large as those implied for a CO_2 doubling by the earliest seasonal simulation, apparently as a result of a positive cloud feedback. The geographical distributions of the CO_2-induced warming obtained by the recent simulations agree qualitatively but not quantitatively. Furthermore, the precipitation and soil moisture changes do not agree quantitatively and even show qualitative differences. In particular, the summertime soil moisture drying in middle-latitudes is simulated by only one of the CGMs. In order to improve the state of the art in simulating the equilibrium climatic change induced by increased CO_2 concentrations, it is recommended first that the contemporary GCM simulations be analyzed to determine the feedback processes responsible for their differences and second that the parameterization of these processes in the GCMs be

validated against highly detailed models and observations."

Sewards, T., Glenn, R., and Keil, K. 1991. Mineralogy of the Rustler Formation in the WIPP-19 Core. SAND87-7036. Sandia National Laboratories, Albuquerque, NM. WPO 24140

ABSTRACT, p i;

" The mineralogy of the Rustler Formation is a critical element in many of the radionuclide release models for the Waste Isolation Pilot Plant (WIPP), and it is necessary to know the abundances of the various minerals present, their compositions, their textures and locations with respect to water-bearing features, and their interrelationships. Clay mineralogy in particular is of vital importance because of the ability of clay minerals to sorb contaminant cations. Furthermore, the minerals present in the different units of the Rustler Formation are possible sources for solutes present in waters taken from various boreholes in the vicinity of the WIPP site.

This report characterizes the mineralogy of the Rustler Formation as represented in core from borehole WIPP-19. The major components, as determined by x-ray diffraction (XRD), are halite, anhydrite, gypsum, dolomite, magnesite, quartz, and clay. Minor components include calcite, pyrite, feldspar and phyllosilicates of metamorphic origin (muscovite, biotite, and chlorite). Clay minerals, identified by XRD, include illite, serpentine, chlorite, and mixed-layer chlorite/smectite (including corrensite).

Quartz and clay, with some halite and anhydrite, dominate the lower member; the Culebra and Magenta units are primarily dolomite with some quartz and clay, while the Forty-niner Member consists of quartz, clay, and sulfates (anhydrite and gypsum).

Halite occurs in four textural styles: bedded, recrystallized halite; displacive halite; as a cement in mud/siltstones; and as a fracture filling, and is largely restricted to the lower member. Anhydrite occurs primarily as a massive, crudely banded nodular structure, although there is often evidence of partial alteration to gypsum. Gypsum also is usually massive, in a crudely banded form. The massive areas consist of fine-grained irregular crystals ('patchy' gypsum); these areas are separated by veins of 'fibrous' gypsum, usually parallel to bedding. Fibrous gypsum vein filling in other lithologies is very common. Dolomite is unfossiliferous, laminated, and very fine-grained; it contains numerous vugs and fractures these are usually lined with clay, gypsum, and powdery dolomite. Magnesite, a relatively minor component, occurs as microcrystalline nodules and as euhedral elongated platy crystals included in halite. Quartz and clay always occur together with minor amounts of feldspar and detrital phyllosilicate grains. Calcite is restricted to a thin bed above the Culebra Dolomite in the samples studied.

In general, this study should be considered a detailed analysis of the Rustler section mineralogy. It is unlikely that any other minerals are present elsewhere in the Rustler Formation in any great quantity. Abundances of individual minerals may vary considerably in other areas of the formation."

Shinta, A.A., and Kazemi, H. 1993. "Tracer Transport in Characterization of Dual-Porosity Reservoirs." In Reservoir Engineering Proceedings, SPE Annual Technical Conference and Exhibition, Houston, TX, October 3-6, 1993. SPE 26636, pp. 285-299. Society of Petroleum Engineers, Richardson, TX.

ABSTRACT, p 285;

" A single-porosity model (SPM) for the tracer response analysis in fractured reservoirs is developed in this paper. This new technique is useful in characterizing fractures in terms of flow anisotropy and quantifying fractures properties such as porosity and permeability. Specifically, tracer response has good resolution and, therefore, its analysis can determine the orientation and conductivity of high permeability fractured systems in the reservoir. This information is highly desirable in improved oil recovery planning and management. The simulator used here is five-point, nine-point finite-difference, two-dimension and two-phase (oil and water) model. In addition to SPM, the simulator conducts a single block simulation (SBS) and conventional dual-porosity calculations. Several options to eliminate or minimize grid orientation effect (GOE) in fractured and unfractured reservoirs are included. These nine-point options appropriately account for the permeability tensor and flow channeling. The SPM is used successfully to characterize an anisotropic confined five-spot pattern in an actual field test."

Silva, M. 1994. Implications of the Presence of Petroleum Resources on the Inetgrity of the WIPP. EEG-55, DOE/AL/58309-55. Environmental Evaluation Group, Albuquerque, NM. WPO 9607.

EXECUTIVE SUMMARY;

" The Waste Isolation Pilot Plant (WIPP) is a facility of the U.S. Department of Energy (DOE), designed and constructed for the permanent disposal of transuranic (TRU) defense waste. The WIPP is surrounded by reserves of potash, crude oil, and natural gas. These are attractive targets for exploratory drilling which could disrupt the integrity of the transuranic waste repository. To proceed with disposal, the U.S. Environmental Protection Agency (EPA) Administrator must certify that the probabilities and fraction of the repository's release of radionuclides to the biosphere over the next 10,000 years will be less than those allowed by the EPA standards (U.S. EPA, 1993). The performance assessment calculations published to date have identified future drilling for oil and gas reserves as an event that may disrupt the repository and may release radionuclides in excess of the standards (SNL, 1992, vol. 1, Section 4.1.2). Therefore, the probability of inadvertent human intrusion into the repository by drilling and its impact on the integrity of the repository must be carefully assessed.

While the DOE funded a number of studies and reviews on the possibility of oil and gas reserves in the vicinity of the WIPP, the recent production of crude oil in the WIPP vicinity indicates that the 1974 study by Foster was correct. However, the DOE decided to rely on the reports which indicated or strongly suggested that crude oil was not considered economically recoverable.

The 1974 New Mexico Bureau of Mines and Mineral Resources (Foster, 1974) estimated crude oil reserves would range from 550,000 to 1,200,000 barrels per section in the vicinity of the WIPP Site. The Environmental Evaluation Group (Neill et al., 1983, p. 98) agreed with the Geologic Characterization Report (Powers et al., 1978) and commented that "since Foster's study used a regional statistical approach, there may be considerably more or less than the average quantity of hydrocarbons if the site were actually drilled. " But the Environmental Evaluation Group also concluded that "it is possible that significant reserves of oil also exist within the site." The New Mexico Energy and Minerals Department (NMEMD, 1984) Task Force on natural resources relied on Foster's (1974) estimates of petroleum reserves.

However, four other studies and several reviews commissioned and used by the DOE stated or suggested that there were little or no economically recoverable crude oil reserves in the immediate vicinity of the WIPP. These include the studies of Netherland et al. (1974) and Keesey (1976, 1977, 1979) and the reviews of Griswold (1977), Powers et al. (1978), the DOE WIPP Final Environmental Impact Statement (U.S. DOE, 1980), Brausch et al. (1982), Weart (1983), and Weart et al. (1991).

The Department of Energy acknowledged that the statistical study of the New Mexico Bureau of Mines and Mineral Resources indicated the presence of crude oil, but the DOE decided that later studies had discounted the existence of economically attractive quantities at

the site. (McGough, 1983a, p. 4). With respect to the impact of secondary recovery methods on the integrity of the repository, Brausch et al (1982) did not evaluate such production methods because they argued that there was a minimal amount of crude oil likely to exist within the WIPP Site. The report of Brausch et al. (1982) served as the basis for the major decision to relinquish control of a one mile buffer zone (Weart, 1983; McGough, 1983b) initially intended to provide DOE control of natural resource production methods (U.S. DOE, 1980). Less than ten years later, the WIPP area was confirmed by the oil and gas industry to be "extremely high in oil and gas reserves...." (Nibert, 1992).

The DOE position of minimal or no crude oil reserves persists in guiding assumptions on other major issues including demonstration of compliance with EPA disposal standards. For example, participants in two expert elicitation exercises conducted by Sandia National Laboratories (SNL) were asked to provide information with which to estimate oil and gas drilling rates in the WIPP vicinity over the next 10,000 years (Hora, 1992). Participants in the first elicitation were asked to identify the activities of future societies that would disrupt the integrity of the repository and to assign probabilities to events such as exploratory drilling.

Participants in the second elicitation were asked to design a marker that would discourage human intrusion and to evaluate the effectiveness of the markers they recommended. However, the participants in both exercises were provided outdated and incorrect information on the two issues that were most important to their discussions -- the actual drilling intensity and the crude oil reserves in the immediate vicinity of the WIPP Site. The effective drilling intensities, inferred from the elicitations, were consistently and substantially less than the EPA recommended maximum value of 30 boreholes per km2 over 10,000 years (Hora, 1992).

The WIPP Project's experience indicates that allowing credit for institutional control in the performance assessment calculations may be difficult to justify. Experts from each of the four teams in the future societies elicitation exercise expressed reservations about the ability of the project to maintain active control for even a very short period of time (Hora et al., 1991). Two active oil and gas leases within the WIPP Site Boundary and a producing gas well were overlooked in several important DOE documents (Silva and Channell, 1992). Records indicate that DOE and the Department of Interior's Bureau of Land Management (DOI/BLM) did not implement required review, comment, and approval procedures in twenty-two of the twenty-five (88%) drilling applications filed during the first two years a Memorandum of Understanding was in effect and while the WIPP facility was in a state of full readiness to receive waste. The DOE review of the interface with the BLM failed to detect the problem. There is no plan nor commitment by DOE to active institutional control. The DOE intends to negotiate the extent of active institutional control with the State of New Mexico just prior to decommissioning of the facility or approximately 30 years after having taken full credit for active institutional control in the performance assessment calculations. Some components of passive institutional control, such as government ownership of the site, public records, and markers, failed to communicate the existence and location of oil and gas wells, a salt water disposal well, and a pipeline crossover in the WIPP area to WIPP project

employees.

The WIPP facility will be subjected to the actual exploration, production, and abandonment practices of the petroleum industry on adjacent properties. The potential problems due to secondary recovery have not yet been addressed because the project assumed that there were minimal crude oil reserves. Primary production of crude oil immediately adjacent to the WIPP is underway. The feasibility of secondary recovery or tertiary recovery for adjacent oil fields needs to be investigated. Of particular concern is the potential migration of injected water from adjacent properties through the Salado Formation (Ramey, 1976; Bailey, 1990, LaVenue, 1991; Hartman, 1993).

The leakage of existing and future oil, gas, and salt water injection wells appears to have a potential impact on the regional hydrology. In addition to faulty cement emplacement, leakage can result from rapid corrosion of well casings in the highly corrosive saline environment (LaVenue, 1991). There are several salt water disposal wells operating in the vicinity of the WIPP Site.

The performance assessment effort needs to address the problems associated with inadequate borehole sealing and abandonment practices on Bureau of Land Management properties (U.S. DOI, 1989, U.S. DOI, 1990, Baier, 1990). ~The Bureau of Land Management's (BLM) existing guidelines on well completions, workovers and abandonments have never been formalized and published" (U.S. DOI, 1991, p. 20568). The potential impact of abandoned wells on the regional hydrology and on the performance of the repository has yet to be determined."

Slezak, S., and Lappin, A. 1990. "Potential for and Possible Impacts of Generation of Flammable and/or Detonable Gas Mixtures during the WIPP Transportation, Test, and Operational Phases," In Memorandum to D. Mercer and C., Fredrickson, January 5, 1990. Sandia National Laboratories, Albuquerque, NM. WPO 21224.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Snyder, R.P., Gard, Jr., L.M., and Mercer, J.W. 1982. Evaluation of Breccia Pipes In Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site. Open-File Report 82-968. U.S. Geological Survey, Denver, CO.

INTRODUCTION, p. 1;

" The Waste Isolation Pilot Plant (WIPP) site is located about 40 km (25 mi) east of Carlsbad, N. Mex. (fig. 1). The site geography has been described in detail by Powers and others (1978) and U.S. Department of Energy (1980, 1981). Site selection was based principally on the existence of a thick section of Permian evaporites, mainly halite. The purpose of establishing this site is to demonstrate whether or not an evaporite environment is acceptable for the disposal of trans-uranic waste generated by the Nation's defense programs.

The primary concern regarding safe disposal of nuclear waste is to isolate the waste from the biosphere until it is no longer a danger to mankind. One of the most probable methods of accidental release of radiation from nuclear waste isolated in a geologic medium is leaching and transport of the waste by moving ground water. It is therefore of primary importance to identify any potential channelways that might allow water to enter a repository site located on bedded salt of the Salado Formation of southeastern New Mexico. The presence of the thick Permian (225 m.y.) rocks attests to the fact that major dissolution of the halite by unsaturated ground water has not occurred at the WIPP site.

Focus of Current Study

This report describes several dissolution features in the Delaware Basin and elsewhere that have been referred to as breccia pipes. Breccia pipes (also called breccia chimneys) as they occur in evaporites are vertical cylindrical pipes or chimneys that may or may not involve more than one geologic formation. The chimneys are filled with downward-displaced brecciated rock. In this context, the rock is brecciated by having collapsed into a void at depth that was probably created by ground-water solution and removal of deep-lying evaporite or carbonate rocks in an underlying aquifer system (Anderson and Kirkland, 1980; Bachman, 1980). Such features have been described in evaporite deposits in many areas of the world.

The current study was done for the U.S. Department of Energy (DOE) in response to a suggestion that because breccia pipes are thought to be the result of deep dissolution, they may represent channelways for future ingress of ground water, and that they should be considered in risk assessment programs for the evaluation of proposed waste repositories in bedded evaporite rocks. To this end, features referred to as breccia pipes in southeastern New Mexico have been assessed in relation to the integrity of the WIPP site. Reports by Anderson (1978), Bachman (1980), and Vine (1960) described dissolution and karst features in the Pecos region of southeastern New Mexico and discussed the origin and history of breccia pipes. The present report is intended to supplement these studies and provide detail that was not available to them at the time their reports were written.

Using the data from exploratory work, answers may be found to the following questions concerning breccia pipes:

1. Do breccia pipes penetrate through the evaporite section?
2. What is the physical description of a pipe?
3. How are they formed?
4. How deep do they go?
5. When are they formed, and are they forming at present?
6. Are they permeable?
7. Where are they formed, can they form at the WIPP site?
8. Do they represent a threat to the WIPP site?"

Stensrud, W.A., Bame, M.A., Lantz, K.D., Caufmann T.L., Palmer, J.B., and Saulnier, Jr., G.J. 1988. WIPP Hydrology Program, Waste Isolation Pilot Plant, Southeastern New Mexico, Hydrologic Data Report #6. SAND87-7166. Sandia National Laboratories, Albuquerque, NM. WPO 29674.

Foreword, p xxvii;

" Hydrologic Data Report #6, the sixth of a series of basic data reports, contains data from hydrologic testing and water-level measurements conducted at the Waste Isolation Pilot Plant (WIPP) site over the period May through October 1987. The purpose of these reports is to disseminate basic hydrologic data to interested parties in a timely manner, often before data interpretation has been performed. Performance of the field investigations was carried out by or under the direction of Sandia National Laboratories, Albuquerque, New Mexico. This report includes recent hydrologic data collected by INTERA Technologies, Inc. of Austin, Texas.

Hydrologic Data Report #6 contains descriptions of: permeability tests conducted from July to August 1987 in six sub-horizontal boreholes drilled from the waste-handling shaft (Part A); well development and slug testing conducted at wells H-1, H-12, and P-15 (Part B); a pumping test performed from July to September 1987 in conjunction with water-quality sampling at the H-2 hydropad (Part C); and drill-stem, slug, and pulse testing conducted by Sandia at wells H-16, H-17, and H-18 (Part D). Part E has been produced by INTERA from water-level and fluid-pressure data collected by INTERA and Sandia from May to October 1987.

The report is organized into five parts with sub-sections internally numbered without letter designations. The pages in each part are numbered consecutively with the letter prefixes A through E. The table of contents should be consulted for overall organizational details and content. For ease of reading, all Figures and Tables are grouped together at the end of the corresponding part, prior to the Appendixes."

Stensrud, W.A., Dale, T.F., Domski, P.S., Palmer, J.B., Roberts, R.M., Fort, M.D., and Saulnier, Jr., G.J. 1992. Waste Isolation Pilot Plant Salado Hydrology Program Data Report #2. SAND92-7072. Sandia National Laboratories, Albuquerque, NM. WPO 26432.

ABSTRACT;
" WIPP Salado Hydrology Program Data Report #2 presents hydrologic data collected during permeability testing of the Salado Formation performed from August 1989 through July 1992. The report presents the results of the drilling and testing of six boreholes drilled from the WIPP underground facility 655 m below ground surface in the Salado Formation. Permeability tests were conducted using multipacker test tools with inflatable packers to isolate borehole intervals to allow formation pore-pressure buildup and subsequent pressure-pulse and constant-pressure-withdrawal tests. The tests performed in boreholes L4P51, L4P52, SCP01, S1P71, S1P72, and S1P73 involved Marker Beds 138 and 139, anhydrites 'a,' 'b,' and 'c,' clays B, D, E, G, H, J, and K, and several halitic strata. Test data include pressure and temperature from the brine-filled, packer-isolated test intervals, fluid and gas production during constant-pressure-withdrawal tests, and borehole-closure and axial test-tool-movement measurements. The boreholes were drilled and/or cored to nominal 10.2-cm diameters using compressed air to remove drill cuttings. Compliance tests were conducted in lengths of steel and stainless-steel casing to evaluate the mechanical performance of the multipacker test tools. Compliance tests included leak tests and pulse-injection and pulse-withdrawal sequences. Following permeability testing, fluid pressures were monitored in packer-isolated sections of test boreholes C2H01, C2H02, SCP01, S1P71, S1P72, DPD01, DPD02, and DPD03."

Stone, C.M., Krieg, R.D., and Beisinger, Z.E. 1985. SANCHO, A Finite Element Computer Program for the Quasistatic, Large Deformation, Inelastic Response of Two-Dimensional Solids. SAND84-2618. Sandia National Laboratories, Albuquerque, NM. WPO 24658.

ABSTRACT, p 3;

" SANCHO is a finite element computer program designed to compute the quasistatic, large deformation, inelastic response of planar or axisymmetric solids. Finite strain constitutive theories for plasticity, volumetric plasticity, and metallic creep behavior are included. A constant bulk strain, bilinear displacement isoparametric finite element is employed for the spatial discretization. The solution strategy used to generate the sequence of equilibrium solutions is a self-adaptive dynamic relaxation scheme which is based on explicit central difference pseudo-time integration and artificial damping. A master-slave algorithm for sliding interfaces is also implemented. A theoretical development of the appropriate governing equations and a description of the numerical algorithms are presented along with a user's guide which includes several sample problems and their solution."

Stormont, J.C. 1990. Discontinuous Behavior Near Excavations in a Bedded Salt Formation. International Journal of Mining and Geological Engineering, SAND89-2403J, Vol. 8, No. 1, pp. 35-56. WPO 29472.

Behavior of overlying strata, page 4, para 1, Line 1;
" Limited tracer gas measurements indicate the flow paths are larger in the vertical direction than the horizontal direction in the center of the drift."

Behavior of underlying strata, p 5, para 10, line 4;
" Tracer gas measurements made in various size drifts have shown that the 1 m thick layer of salt has larger vertical than horizontal flow paths (equivalent aperatures), and that the dimension of these flow paths increase an order of magnitude from about 2E-5 m to 2E-4 m as the drift span increases from 6.6 m to 11 m (Borns and Stormont, 1988)."

Stormont, J.C., Peterson, E.W., and Lagus, P.L. 1987. Summary and Observations About WIPP Facility Horizon Flow Measurements Through 1986. SAND87-0176. Sandia National Laboratories, Albuquerque, NM. WPO 27053.

ABSTRACT;

" Numerous gas flow measurements have been made at the Waste Isolation Pilot Plant (WIPP) facility horizon from 1984 through 1986. Almost all tests have been constant-pressure or pressure-decay tests from single boreholes drilled in the underground excavations. Results indicate that beyond about 2 m from an excavation, both halite and interbeds (anhydrite and clay layers) allowed very low gas flows, and calculated permeabilities are below 1 microdarcy. In regions within 2 m of an excavation, very high flow rates were measured in the interbeds immediately above and below an excavation when the test hole was drilled from near the center of the excavation. The halite also permits substantially greater gas flow within about 1 m of the excavations. Limited tracer measurements reveal that flow paths in both the halite and interbeds in the near field region are significantly larger than those in the presumed undisturbed condition. The gas flow measurements are consistent with the development of a (perhaps partially-saturated) dilitant zone (increased porosity) around the excavations. Considerable uncertainty is associated with permeabilities calculated from these flow measurements, due to unknowns of rock saturation, entry pressure effects, flow homogeneity, etc.

Observations based on these gas flow measurements will aid in understanding the behavior and response of rocks surrounding the WIPP Facility excavations. The implications of these measurements for seal design are useful, particularly in assessing the degree of seal bypass to expect in adjacent rock. Results suggest that seal be emplaced as soon as possible after excavation and in as narrow drifts as possible to minimize potential bypass. These data are also useful in separate studies of brine influx and gas generation/dissipation. Future measurements will focus on the development and extent of the disturbed zone, and on obtaining data which will make conversion of flow data to intrinsic permeabilities more defensible."

Stormont, J.C., Howard, C.L., and Daemen, J.J.K. 1991. In Situ Measurements of Rock Salt Permeability Changes due to a Nearby Excavation. SAND90-3134. Sandia National Laboratories, Albuquerque, NM. WPO 26166.

ABSTRACT;

" The Small-Scale Mine-By was an in situ experiment to measure changes in brine and gas permeability of rock salt as a result of nearby excavation. A series of small-volume pressurize brine- and gas-filled test intervals were established 8 m beneath the floor of Room L1 in the WIPP underground. The test intervals were isolated in the bottom of the 4.8-cm diameter monitoring boreholes with inflatable rubber packers, and are initially pressurized to about 2 MPa.. Both brine- and gas-filled test intervals were located 1.25, 1.5, 2, 3, and 4 r from the center of a planned large-diameter hole, where r is the radius of the large-diameter hole. Prior to the drilling of the large-diameter borehole, the responses of both the brine- and gas-filled test intervals were consistent with the formation modeled as a very low permeability, low porosity porous medium with a significant pore (brine) pressure and no measurable gas permeability. The drilling of the mine-by borehole created a zone of dilated, partially saturated rock out to about 1.5 r. The formation pressure increases from near zero at 1.5 r to the pre-excavation value at 4 r. Injection tests reveal a gradient of brine permeabilities from 5 x 10^{-18} m^2 at 1.25 r to about the pre-excavation value ($10^{-21}m^2$) by 3 r. Gas-injection tests reveal measurable gas permeability is limited to within 1.5 r."

Telander, M.R., and Westerman, R.E. 1993. Hydrogen Generation by Metal Corrosion in Simulated Waste Isolation Pilot Plant Environments: Progress Report for the Period November 1989 through December 1992. SAND92-7347. Sandia National Laboratories, Albuquerque, NM. pp. 6-14 to 6-27. WPO 23456.

ABSTRACT, p i;

" The corrosion and gas-generation characteristics of three material types: low-carbon steel (the current waste packaging material for the Waste Isolation Pilot Plant), Cu-base materials, and Ti-base materials were determined in both the liquid and vapor phase of Brine A, a brine representative of an intergrannular Salado Formation brine. Test environments included anoxic brine and anoxic brine with overpressures of CO_2, H_2S, and H_2. Low-carbon steel reacted at a slow, measurable rate with anoxic brine, liberating H_2 on an equimolar basis with Fe reacted. Presence of CO_2 caused the initial reaction to proceed more rapidly, but CO_2-induced passivation stopped the reaction if the CO_2 were present in sufficient quantities. Low-carbon steel immersed in brine with H_2S showed no reaction, apparently because of passivation of the steel by formation of a protective iron sulfide reaction product. Cu- and Ti-base materials showed essentially no corrosion when exposed to brine and overpressures of N_2, CO_2, and H_2S except for the rapid and complete reaction between Cu-base materials and H_2S. No significant reaction took place on any material in any environment in the vapor-phase exposures."

Thorne, B.J, and Rudeen, D.K. 1980. Regional Effects of TRU Repository Heat. SAND80-7161. Sandia National Laboratories, Albuquerque, NM. WPO 10281.

INTRODUCTION, p 1;

" A modification of a calculation reported in reference 1 was used to estimate the impact of heat from a 730,000 m^2 (180 acre) 0.69 W/m^2 (2.8 kW/acre) RH TRU repository at the WIPP site. The original calculation, reported in SAI-FR-145, was designed to estimate the effect of a 81,000 m^2 (20 acre) 7.4 kW/m^2 (30 kW/acre) spent fuel repository. This calculation is on much too coarse a scale to accurately predict details of the response. However, estimates obtained by this method are accurate enough to determine whether or not heat effects are large enough to justify more finely zoned calculations.

COMPUTATIONAL SETUP

All materials models, boundary conditions, initial conditions and computing techniques were identical to those described in Reference 1. ...

[1]D.E. Maxwell, K.K. Wahi, B. Dial, The Thermomechanical Response of WIPP Repositories, Science Applications, Inc., SAI-FR-145, Sandia National Laboratories, SAND 79-7111, May 1980."

Tierney, M.S. 1993. "PA Methodology Overview." In Initial Performance Assessment of the Disposal of Spent Nuclear Fuel and High-Level Waste Stored at Idaho National Engineering Laboratory. Volume 1: Methodology and Results. R.P. Rechard, ed. SAND93-2330/1. Sandia National Laboratories, Albuquerque, NM. 3-1 through 3-28. Chapter 3 of WPO 26694.

3.1 Introduction; p 3-1;

" The U. S. Environmental Protection Agency (EPA's) guidance and intentions concerning the nature and purpose of performance assessment (see Chapter 2) suggests that PA is ideally a *stochastic simulation* (Section 3.2.4) of possible long-term behaviors of a real system with a computer-implemented mathematical model of that system. In this respect performance assessment is similar to other large-scale simulations (e.g., the *Reactor Safety Study*[Rasmussen, 1975]) that have been used by federal agencies in the past to explore policy options and develop regulations. Performance assessments of systems for the disposal of radioactive and toxic wastes may nevertheless differ from most simulations with 'regulatory models' (Morgan et al., 1990, p. 292) in two significant and related ways: the way results of a performance assessment are to be used; and the nature of the real system that is being simulated.

In contrast with past simulations with federally sponsored models, PA results are ultimately used to test compliance of a real system with an existing environmental standard, not merely to gain insight into the behavior of the system with the purpose of discovering a rational basis for new standards. Furthermore, a quantitative treatment of uncertainty in PA calculations is not merely good analytical practice but is mandated by the explicitly probabilistic statement of the Standard in which all results are to be combined in an 'overall probability distribution' whenever practicable. As will be seen later, such a quantitative treatment of uncertainty forces the development of two categories of models of the same system; the usual, deterministic phenomenological models (called 'consequence' models in PA; Section 3.2.1), and probability models (Section 3.2.3) that can provide quantitative estimates of the degree of uncertainty associated with parameters that specify the possible configuration of the consequence models.

The problems arising from direct use of PA results in testing compliance and a mandated quantitative treatment of uncertainty are compounded by the nature of the focal system in PA: geological waste-disposal systems are built up largely from natural components (as opposed, for example, to the man-made components of a nuclear reactor), the physical and chemical characteristics of which are usually inhomogeneous and distributed in space and time. There is little published work on effecient methods for conducting sensitivity and uncertainty analyses of such distributed- parameter systems; objective methods for the assignment of the parametric uncertainty associated with such systems are also lacking. Indeed, in building methodologies for PA, investigators have in the past drawn heavily upon ideas and analytical techniques developed primarily for the study of 'lumped parameter' systems and have largely ignored the special needs of PA that arise from the problems mentioned above.

With the hope that a firm understanding of the structure of a PA will help in meeting PA's special needs, this overview offers a description of current PA methodologies in terms and concepts taken from the broader context in which they are imbedded, i.e., the general theory of stochastic simulation, as it is applied to the study of natural systems that may change or 'fail' over long periods of time. To minimize misunderstanding among investigators with diverse backgrounds, terminology developed for PA will be maintained throughout the overview, but PA terms will be matched with their mathematical counterparts whenever possible. Discussion of each topic proceeds from generalities to specifics, and from theory to practical applications. The structure of a PA is summarized in Section 3.2, where emphasis is upon the correspondence of PA concepts such as consequence models, probability models, and performance measures, with concepts from the general theory of stochastic simulation. Section 3.3 is a technical treatment of certain topics of special interest to PA practitioners; in particular, the confusing topic of 'scenarios' is treated. Applications and examples are taken from the initial performance assessment described in this report and from an assessment of the performance of the Waste Isolation Pilot Plant (WIPP), a research and development facility located in southeastern New Mexico for the purpose of demonstrating safe disposal of defense-generated transuranic wastes (WIPP PA Division, 1991a, 1991b; WIPP PA Department, 1992b).

Tiller, C.L., and O'Melia, C.R. 1993. "Natural Organic Matter and Colloidal Stability. Models and Measurements." In Colloids in the Aquatic Environment. Colloids and Surfaces A: Physiochemical and Engineering Aspects, T.F. Tadros and J. Gregory, eds., pp. 89-102. Elsevier Applied Science, London.

ABSTRACT, p 89;

" Laboratory and field observations by several investigators indicate that natural organic matter (NOM) affects and probably controls the colloidal stability of particles in aquatic systems. The enhanced stability of particles in aquatic systems containing NOM is a consistent observation without a clear cause. In this work, the potential importance of the macromolecular nature of NOM was investigated using model systems. A mathematical model for the adsorption of linear, flexible polyelectrolytes was used to examine the effects of molecular weight, pH, and ionic strength on the conformations of these surrogates for NOM at interfaces in natural waters. Laboratory experiments involving submicron hematite particles, two anionic polyelectrolytes, and an aquatic NOM were used to examine the effects of solution composition on colloidal stability. Together, the results of the mathematical simulations and the laboratory experiments indicate that electrostatic effects dominate particle-particle interactions, but that the macromolecular nature of NOM can have direct influence under certain conditions. At low ionic strength, anionic polyelectrolytes affect the coagulation of positively charged particles by altering net surface charge in a way similar to specifically adsorbing, multivalent, monomeric anions. At high ionic strength (I»0.1), the conformational characteristics of adsorbed polyelectrolytics at the solid/water interface directly affect coagulation by expanding the effective distance of electrostatic repulsion between approaching particles, as well as by altering net surface charge. Non-electrostatic steric repulsion plays little or no role in the stabilization of hematite particles by the organic macromolecules used in this work. Calcium acts to destabilize hematite particles in the presence of the organic macromolecules, perhaps through a combination of special chemical and charge effects."

Tipping, E. 1993. "Modeling Ion Binding by Humic Acids." In Colloids in the Aquatic Environment. Colloids and Surfaces A: Physiochemical and Engineering Aspects, T.F. Tadros and J. Gregory, eds., pp. 117-131. Elsevier Applied Science, London.

ABSTRACT, p 117;

" Humic ion-binding Model V is a discrete site/electrostatic model of ion binding by humic matter that describes competition amongst interacting species (protons and metal species) and the effects on binding of ionic strength. Six adjustable parameters are required to describe proton binding. These are n_A (equivalent acid groups per gram), pK_A and pK_B (midrange intrinsic proton disassociation constants), ΔpK_A and ΔpK_B (ranges of pK values), and *P* (empirical constant for electrostatics). For each metal species, two further parameters are required; these are intrinsic equilibrium constants for metal-proton exchanges (pK_{MHA} and pK_{MHB}). Both monodentate and bidentate binding sites for metal species are included, and binding for non-specific accumulation of counterions is taken into account. In this study, Model V parameter values are derived from published results for humic acids (acid base titrations and binding studies with 15 metals). It is found that an approximate relationship between pK_{MHA} and pK_{MHB} can be derived, which eliminates an adjustable parameter and allows useful rationalization of the different data sets. Electrostatic effects with humic acids are greater than those with fulvic acids, and the two types of humic material also differ in the affinities of their discrete binding sites for protons and metal ions."

Tóth, L.M., Friedman, H.A., and Osborne, M.M. 1981. Polymerization of Pu(IV) in Aqueous Nitric Acid Solutions. Journal of Inorganic and Nuclear Chemistry, Vol. 43, No. 11, pp. 2929-2934.

ABSTRACT, p 2929;

" The polymerization of Pu(IV) in aqueous nitric acid solutions has been studied spectrophotometrically both to determine the effects of large $UO_2(NO_3)_2$ concentrations on the polymerization rates and, more generally, to review the influence of other major parameters on the polymer reaction. Typically, experiments have been performed at 50°C and at 0.05M Pu in aqueous solutions of HNO_3 at concentrations ranging from 0.07 to 0.4M. An induction period usually precedes the polymer growth stage, during which time it is believed that primary hydrolysis products form and begin to aggregate. Uranyl nitrate retards the polymerization reaction by approximately 35% despite the counteracting influence of the nitrate ions associated with this solute. The rate of polymer formation at 50°C has been shown to be third order in Pu(IV) concentration."

Van der Lee, J., de Marsily, G. and Ledoux, E. 1993. "Are Colloids Important for Transport Rate Assessment of Radionuclides? A Microscopic Modeling Approach," In High Level Radioactive Waste Management, Proceedings of the Fourth Annual International Conference, Las Vegas, NV, April 26-30, 1993, pp. 646-652. American Society of Civil Engineers. New York, NY.

ABSTRACT, p 646;
" Understanding the transport phenomena of radionuclides migrating through weakly-permeable rock forms an essential part of far-field safety assessment studies. Colloidal matter can be important in view of the solubility of radioactive waste, and as a potential rapid carrier of the radionuclides in far-field migration. When estimating the influence of colloids on the fate of radionuclides, a key aspect is the understanding of the interaction mechanisms of the phases involved, i.e. aqueous, solute and colloidal phase and the solid medium, because they define the retardation and hence the arrival time of the pollutant in the human environment.

The present study is an attempt to quantify interaction phenomena according to a microscopic modeling approach, based on a combination of chemical and electro-physical considerations. In order to define the state of the surface of colloids and medium, a model based upon the surface complexation theory was developed. Migration from the inner pore-space towards the surface is governed by diffusion, gravitation and, very close to the surface, electrostatic forces. Colloidal fixation is electrochemically as well as physically bounded by a maximum adsorption capacity and it is expected that electrostatical surface properties change when the surface becomes progressively saturated by colloids. Therefore, the model includes surface reactions with parameters depending on the maximum concentration at the surface.

The result is a microscopic model which includes chemical speciation, electrochemical characteristics of the medium and colloids, pH, ionic strength and surface boundary-layer phenomena. The model can be used for predictive purposes in laboratory experiments, using simple hydrogeological geometries and organic colloids. Effects of radionuclide concentration (e.g. Am(III)), pH and surface potential are quantified.

Van Sambeek, L.L., Luo, D.D., Lin, M.S., Ostrowski, W., and Oyenuga, D. 1993. Seal Design Alternatives Study. SAND92-7340. Sandia National Laboratories, Albuquerque, NM. WPO 23445.

ABSTRACT;

" This report presents the results from a study of various sealing alternatives for the WIPP sealing system. Overall, the sealing system has the purpose of reducing to the extent possible the potential for fluids (either gas or liquid) from entering or leaving the repository. The sealing system is divided into three subsystems: drifts and panel seals within the repository horizon, shaft seals in each of the four shafts, and borehole seals.

Alternatives to the baseline configuration for the WIPP seal system design included evaluating different geometries and schedules for seal component installations and the use of different materials for seal components. Order-of-magnitude costs for the various alternatives were prepared as part of the study. Firm recommendations are not presented, but the advantages and disadvantages of the alternatives are discussed. Technical information deficiencies are identified and studies are outlined which can provide required information."

Vesely, W.E., and Rasmuson, D.M. 1984. Uncertainties in Nuclear Probabilistic Risk Analyses. Risk Analysis, Vol. 4, No. 4, pp. 313-322.

p 313;
" There are many uncertainties in a probabilistic risk analysis (PRA). We identify the different types of uncertainties and describe their implications. We then summarize the uncertainty analyses which have been performed in current PRAs and characterize results which have been obtained. We draw conclusions regarding interpretations of uncertainties, areas having largest uncertainties, and needs which exist in uncertainty analysis. We finally characterize the robustness of various utilizations of PRA results."

Vilks, P. 1994. The Role of Colloids and Suspended Particles in Radionuclide Transport in the Canadian Concept for Nuclear Fuel Waste Disposal. AECL-10280. Whiteshell Laboratories, Atomic Energy of Canada, Ltd., Pinawa, Manitoba. Yucca Mt #. MOL.19950202.0067.

ABSTRACT;

" AECL Research is developing a concept for the permanent disposal of nuclear fuel waste in a deep engineered vault in plutonic rock of the Canadian Shield and is preparing an Environmental Impact Statement (EIS) to document its case for the acceptability of the disposal concept. This report, one in a series of supporting documents for the EIS, addresses the role of particles in radionuclide transport. It summarizes our studies of natural particles in groundwater and presents the arguments used to justify the omission of particle-facilitated transport in the geosphere model that is based on the Whiteshell Research Area (WRA) and used in the postclosure assessment study case.

Because radionuclides formed in the vault will not be able to migrate through the clay buffer, radiocolloid formation in the geosphere will be determined by the sorption of radionuclides onto particles in groundwater. These particles consist of typical fracture-lining minerals, such as clays, micas and quartz; precipitated particles such as colloidal silica and Fe-Si oxyhydroxides; and organic particles. In groundwater from the WRA, the average concentrations of colloids and suspended particles are 0.34 and 1.4 mg/L respectively. Particle-facilitated transport is not included in the geosphere model because the concentrations of particles in groundwater from the WRA are too low to have significant impact on radionuclide transport."

Vine, J.D., 1963. Surface Geology of the Nash Draw Quadrangle, Eddy County, New Mexico. U.S. Geological Survey Bulletin, 1141-B. WPO 39558.

ABSTRACT, p B1;

" Outycropping rocks and surficial deposits of the Nash Draw quadrangle were mapped to provide geologic information for the U.S. Atomic Energy Commission's Plowshare program. The quadrangle is near the north margin of the Delaware basin and about 15 miles east of Carlsbad, N. Mex. The region is sparsely inhabited and has an arid climate.

As much as 4,000 feet of salt and anhydrite of Permian age is present below the surface, but does not crop out in normal thickness in this area or elsewhere because of their high solubility. These rocks have been divided into the Castile formation below and the Salado formation above. Rocks exposed at the surface overlie these soluble rocks and include the Rustler formation of Late Permian age, the Pierce Canyon redbeds of Permian or Triassic age, the Santa Rosa sandstone of Late Triassic age, and the Gatuna formation, caliche, and a variety of unconsolidated deposits of late Cenozoic age.

The Rustler formation of Late Permian age is subdivided into four easily distinguishable members, excluding about 120 feet of the lower part, which is not exposed at the surface in this area. The oldest member exposed is the Culebra dolomite member, about 30 feet thick, identified only in erratically distributed outcrops in collapse areas. The Culebra consists of microcrystalline gray dolomite or dolomitic limestone characterized by numerous spherical cavities 1 to 10 mm in diameter. It is conformably overlain by the Tamarisk member, named herein for exposures directly east of Tamarisk Flat. It consists of about 115 feet of massive gypsum at the surface, changing to anhydrite in the subsurface, and a bed, 5 feet thick, of siltstone near the base. Surficial deformation caused by hydration and solution are characteristic of all the outcrops. The Tamarisk member is conformably overlain by the Magenta member, about 20 feet thick and consisting of alternating wavy laminae of pale-red dolomite and pale yellowish-green anhydrite or gypsum. The top member of the Rustler formation conformably overlies the Magenta and is here named the Forty-niner member after Forty-niner Ridge, where it crops out. In surface exposures it consists of about 40 to 65 feet of broken and slumped massive gypsum and a bed of siltstone in the lower part. The siltstone beds in the Tamarisk and Forty-niner members probably represent the insoluble residue of salt beds reported from the subsurface to the east."

Overlying the Rustler formation with apparent conformity are the Pierce Canyon redbeds of Permian or Triassic age. These rocks consist of about 200 to 250 feet of laminated or minutely cross-laminated moderate reddish-brown siltstone. The contact between the Pierce Canyon redbeds and the overlying Santa Rosa sandstone is a disconformity, at least locally.

The Santa Rosa sandstone of Late Triassic age consists of pale-red sandstone and conglomerate lenses crossbedded in sets 3 to 15 feet thick separated locally by moderate reddish-brown siltstone and claystone. Only the lower 50 to 70 feet of Santa Rosa was recognized in the area.

The Gatuna formation of Pleistocene (?) age unconformably overlies all older rocks.

In much of the area it consists of 3 to 5 feet of moderate reddish-orange sandstone, siltstone, and conglomerate. Locally, in karst depressions, the Gatuna attains a thickness of at least 100 feet. In some areas the lithology closely resembles the Pierce Canyon redbeds or the Santa Rosa sandstone.

Caliche forms a resistant layer at the ground surface, 5 to 10 feet thick, that protects older rocks from erosion in many areas. The caliche consists of calcareous material with a variable amount of imbedded sand grains, pebbles, and rock fragments. Caliche mounds and broken flexure ridges, 10 to 15 feet high, have formed narrow zones 50 to several hundred feet long.

Quaternary alluvium has been deposited along the sides of depressions. It is overlain by playa lake deposits, which are in turn overlain by conspicuous sand dunes as much as 100 feet high.

The regional structure is relatively simple and consists of a dip of a few feet per mile to the east and southeast.

Normally flat-lying strata are tilted, warped, and locally distorted at the surface by hydration and solution of the evaporite rocks in the subsurface. Nash Draw, a depression 4 to 6 miles wide and about 18 miles long, has resulted from the solution of salt in the Rustler and Salado formations and collapse of the overlying relatively insoluble rocks. Topography and surface structure conform in some areas with the configuration of the underlying solution surface at the top of the massive salt in the Salado formation; however, locally there is an inverse correspondence. Many circular karst features 1/10 to 1/2 mile in diameter are in the area. Some of these features are structural domes, but they contain a core of tilted or brecciated rock. These karst features result from the formation and collapse of sinkholes, differential solution at the top of the massive salt, and hydration of the anhydrite beds."

Vlassopoulos, D., Wood, S.A., and Mucci, A. 1990. Gold Speciation in Natural Waters: II. The Importance of Organic Complexing--Experiments with Some Simple Model Ligands. Geochimica et Cosmochimica Acta, Vol. 54, No. 6, pp. 1575-1586.

NOTE:portions of the following text were not clear on the document that they were copied from and have been interpreted for content by the typist.

ABSTRACT, P 1575;

" The solubility of Au has been measured at 25°C in aqueous solutions in the presence of various organic ligands (acetate, benzoate, oxalate, phthalate, salicylate, and thiosalicylate). These ligands were chosen as sample analogs of humic acid moieties in order to model the complexation of AU by humic and fulvic acids in natural waters. With the first five ligands (ΣL = 0.1 M), solubilities were generally below 25 μg/l, whereas in the thiosalicylate solutions (ΣL = 0.45 M), a maximum Au concentration of 680 mg/l was measured. Acetate and benzoate complexes are too weak to detect by the solubility method. Oxalate appears to have a reducing effect on Au in solution, and both oxalate and phthalate complexes of Au(I) may be coordinatively unfavorable. It was only possible to identify one salicylate complex ($log\ \beta_2 = 17.5 \pm 0.5$) and two thiosalicylate species ($log\ \beta_1 = 29.9 \pm 0.3$ and $log\ \beta_2 = 31.7 \pm 0.3$). In addition, stability constants for a number of O-, N-, and S-donor complexes of Au(I) were estimated from linear free energy relationships with Cu(I), Ag(I), and Hg(II).

General trends in stability constants of Au-organic complexes with various donor atoms are $S \gg N \geq 0$. Calculations based on a simple model of a fulvic acid suggest that Au is almost exclusively bound to S-donor sites under reducing conditions, but $AuOH(H_2O)^6$ and complexing by organic O-donors are more important in oxidizing environments."

Wallner, M. 1981. "Critical Examination of Conditions for Ductile Fracture in Rock Salt." In Proceedings of the Workshop on Near-Field Phenomena in Geologic Repositories for Radioactive Waste, Seattle, WA, August 31-September 3, 1981, pp. 243-253. Organisation for Economic Co-Operation and Development, Paris, France.

ABSTRACT, p. 243;

" Rock salt because of its ductility in general prevents the presence of open cracks. This favorable property is derived from the capability of the material to reduce deviatoric stresses by means of creep deformations. Ductile fracture of halite under in situ stress conditions therefore is only possible under certain circumstance. The condition to initiate and propogate fractures in a salt formation on one hand and the fracture healing process on the other are discussed.

An extensive experimental programme was performed to ascertain the fracture strength of rock salt. A summary of results from these tests are given and a proposed criterion for creep fracture in compression is explained."

Warrick, R. and Oerlemans, J. 1990. "Sea Level Rise." In Climate Change: The IPCC Scientific Assessment, J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds., pp. 257-281. Intergovernmental Panel on Climate Change, Sweden.

Section 9.5 **HOW MIGHT SEA LEVEL CHANGE IN THE FUTURE?**, p. 278, col. 1;
" Various estimates of future sea level rise are noted in Table 9.9. Such estimates are very difficult to compare because different time periods are chosen, and because assumptions regarding future greenhouse gas concentrations, changes in climate, response times, etc., are either different or not clearly stated. In general, most of the studies in Table 9.9 foresee a sea level rise of somewhere between 10cm and 30 cm over the next four decades. This represents a rate of rise that is significantly faster than that experienced, on average, over the last 100 years."

Washington, W.M., and Meehl, G.A. 1984. Seasonal Cycle Experiment on the Climate Sensitivity Due to Doubling of CO_2 with an Atmospheric General Circulation Model Coupled to a Simple Mixed-Layer Ocean Model. Journal of Geophysical Research, Vol. 89, No. D6, pp. 9475-9503.

ABSTRACT, p. 9475;

" A simple slab ocean of 50 m depth, which allows for seasonal ocean heat storage but no ocean heat transport, is coupled to a global special general circulation model with global domain, realistic geography, and computed clouds. Globally averaged, the annual mean surface air temperature increase computed over the last 3 years of an integration with a full annual cycle for 2 x CO_2 compared to the control for 1 x CO_2 is 3.5°C. Zonal mean air temperature differences indicate stratospheric cooling and tropospheric warming as seen in other CO_2 modeling studies. Greatest increases of surface air temperature in the 2 x CO_2 case, compared to the control, occur the sea ice margins. Retreat of sea ice in the 2 x CO_2 case is associated with changes in the positions of the cloud maxima. Ice-free areas of ocean in the 2 x CO_2 case, which are ice covered in the 1 x CO_2 case, store relatively more heat during the summer season. Warmer surface air temperatures then occur in areas that are much colder in the control case because of the lack of the insulating effect of the sea ice, especially in winter. Increases of zonal mean precipitation are evident at most latitudes as a result of increases of available moisture evaporated from the warmer oceans. In the tropics this is associated with a strengthening of the mean meridional circulation and with intensification of the upper level zonal-component winds in the subtropics. Warming near the surface associated with the retreat of the ice line in the 2 x CO_2 case slackens the meridional temperature gradient and results in weaker upper level zonal-component winds in the mid-latitudes. Three-year seasonal means of soil moisture show decreases in tropical and subtropical continental areas and increases at high latitudes, but at mid-latitudes the change depends on the season. An analysis of the statistical significance of the geographical distribution of 7-year seasonal means of surface air temperature and soil moisture differences is given for the 2 x CO_2 case compared to the control. Areas of significant differences correspond to similar regions of large differences seen in the 3-year seasonal means. Certain regions experience summer drying seen in other studies, but zonal mean soil moisture differences show increases of soil moisture at mid and high latitudes of the northern hemisphere year-round, with a relative minimum of increase in late summer. These differences are attributed to large increases of soil moisture in late spring that persist into summer and cause a positive feedback with precipitation and low clouds. This inhibits continental warming and limits summer drying seen in the zonal mean as a result of the doubling of CO_2. A comparison of the present experiment with the previous swamp model experiment is consistent with other studies in that the extent of sea ice in the control case critically influences the climatic response to increased CO_2 such that more extensive sea ice is associated with a larger response. The seasonal cycle along with ocean heat storage in the mixed layer model are shown to be important in producing a more realistic simulation of the present climate than does the swamp experiment and, presumably, a more credible response

to increased CO_2. However, in the context of recent studies the overextensive sea ice in the present mixed layer model suggests that the inclusion of ocean heat transport from a fully computed ocean model and a resulting sea ice distribution closer to the observed would possibly produce less of a response to increased CO_2."

Weatherby, J.R., Brown, W.T., and Butcher, B.M. 1991. "The Closure of WIPP Disposal Rooms Filled with Various Waste and Backfill Combinations." In Rock Mechanics as a Multidisciplinary Science, Proceedings of the 32nd U.S. Symposium, University of Oklahoma, Norman, OK, July 10-12, 1991, J.C. Roegiers, ed. SAND90-2399C, pp. 919-928. A.A. Balkema, Brookfield, VT. WPO 28617.

ABSTRACT p. 1;

" Two-dimensional finite element analyses were used to investigate the closure of WIPP disposal rooms filled with backfill and rooms filled with a combination of waste and backfill. Two different backfill materials were considered. The analyses provide estimates of the porosity in the disposal room as a function of time. These results have been used to help evaluate the suitability of the backfill materials for use in the repository."

Westinghouse Electric Corporation. 1994. Backfill Engineering Analysis Report, Waste Isolation Pilot Plant. Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM. WPO 37909.

Executive Summary, Scope, p i;

" The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico 26 miles east of Carlsbad, is a facility designed for the permanent disposal of transuranic waste generated at U. S. Department of Energy (DOE) facilities across the United States. The primary purpose of this report is to determine if there is a geomechanical need or advantage to backfilling the WIPP underground. The concept of backfilling the WIPP underground is usually associated with the final sealing of the repository. Since WIPP was designed to be a permanent waste disposal facility, sealing is a part of the decommissioning process, which can include backfilling some or all of the underground workings. The main focus of this report is on the various proposed geomechanical uses for backfill in the WIPP underground: operational and long-term performance uses are also discussed briefly. (Information on the validity of each backfill use is presented, when available.) The primary geomechanical effect explored in this report is subsidence, which could affect the stability of the facilities at the surface and in the shafts and could potentially disturb the Culebra Dolomite or other water-bearing units of the Rustler Formation above the WIPP underground facility."

Wilson, C.A., and Mitchell, J.F.B. 1987. A Doubled CO_2 Climate Sensitivity Experiment with a Global Climate Model Including a Simple Ocean. Journal of Geophysical Rsearch, Vol. 92, No. D11, pp. 13,315-13,343.

ABSTRACT, p 13,315;

" The sensitivity of a global climate to increased atmospheric CO_2 concentrations is presented, assessed, and compared with earlier studies. The ocean is represented by a 50-m slab in which the heat convergence due to oceanic dynamics is prescribed, producing an accurate simulation of sea surface temperatures, sea-ice extents, and associated features in the control simulation. Changes in surface temperature are qualitatively similar to those found in earlier studies using models with similar or lower horizontal resolution, although the global warming is slightly larger. The simulated changes in hydrology agree broadly with those in studies made with higher horizontal resolution and prescribed changes in sea surface temperatures and include a drying over the northern mid-latitude continents. Many of the discrepancies in the responses of different models can be traced to differences in the simulations of present-day climate. The choice of convective parametrization appears to influence the sensitivity of the simulated response in the tropics."

Wolery, T.J. 1992. EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, Users guide, and Related Documentation (Version 7.0). UCRL-MA-110662 PT 3. Lawrence Livermore National Laboratory, Livermore, CA.

ABSTRACT; p. 1, para. 1;

" EQ3NR is an aqueous solution speciation-solubility modeling code. it is part of the EQ3/6 software package for geochemical modeling. It computes the thermodynamic state of an aqueous solution by determining the distribution of chemical species, including simple ions, ion pairs, and complexes, using standard state thermodynamic data and various equations which describe the thermodynamic activity coefficients of these species. The input to the code describes the aqueous solution in terms of analytical data, including total (analytical) concentrations of dissolved components and such other parameters as the *pH, pHCl, Eh, pe,* and oxygen fugacity. The input may also include a desired electrical balancing adjustment and various constraints which impose equilibrium with specified pure minerals, solid solution end-member components (of specified mole fractions), and gases (of specified fugacities). The code evaluates the degree of disequilibrium in terms of the saturation index ($Sl = 1og\ Q/K$) and the thermodynamic affinity ($A = -2.303\ RT\ log\ Q/K$) for various reaction, such as mineral dissolution or oxidation-reduction in the aqueous solution itself. Individual values of *Eh, pe,* oxygen fugacity, and *Ah* (redox affinity) are computed for aqueous redox couples. Equilibrium fugacities are computed for gas species. The code is highly flexible in dealing with various parameters as either model inputs or outputs. The user can specify modification or substitution of equilibrium constants at run time by using options on the input file. The output consists of an output file and a pickup file, which can be used to initialize an EQ6 reaction path calculation. The chief numerical method employed is a hybrid Newton-Raphson technique. This is supported by a set of algorithms which create and optimize starting values. EQ3NR reads a secondary unformatted data file (data1) that is created from a primary formatted data file (data0) by EQPT, the EQ3/6 data file preprocessor. There is currently a set of five data (data0) files. Three of these may be used with either the Davies equation or the B-dot equation to describe the activity coefficients of the aqueous species. Their use is restricted to modeling dilute solutions. The other two of these use Pitzer's equations and are suitable for modeling solutions to high concentrations, though with fewer chemical components. The temperature range of the thermodynamic data on the data files varies from 25°C only to 0-300°C. EQ3NR may be used by itself or to initialize a a (sic) reaction path calculation by EQ6, its companion code in the EQ3/6 package. EQ3NR and the other codes in the EQ3/6 package are written in FORTRAN 77 and have been developed to run under the UNIX operating system on computers ranging from workstations to supercomputers."

Wolery, T.J., and Daveler, S.A., 1992. EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems; Theoretical Manual, User's Guide and Related Documentation (Version 7.0). UCRL-MA-110662-Pt.4. Lawrence Livermore National Laboratory, Livermore, CA.

ABSTRACT; p. 1, para. 1;

" EQ6 is a FORTRAN computer program in the EQ3/6 software package (Wolery, 1979). It calculates reaction paths (chemical evolution) in reacting water-rock waste systems. Specification in aqueous solution is an integral part of these calculations. EQ6 computes models of titration processes (including fluid mixing), irreversible reaction in closed systems, irreversible reaction in some simple kinds of open systems, and heating or cooling processes, as well as solve "single-point" thermodynamic equilibrium calculations. Chemical evolution is driven by a set of irreversible reactions (i.e., reactions out of equilibrium) and/or changes in temperature and/or pressure. These irreversible reactions usually represent the dissolution or precipitation of minerals or other solids. The code computes the appearance and disappearance of phases in solubility equilibrium with the water. It finds the identities of these phases automatically. The user may specify which potential phases are allowed to form and which are not. There is an option to fix the fugacities of specified gas species, simulating contact with a large external reservoir. Rate laws for irreversible reactions may be either relative rates or actual rates. If any actual rates are used, the calculation has a time frame. Several forms for actual rate laws are programmed into the code. EQ6 is presently able to model both mineral dissolution and growth kinetics. The user can specify modification or substitution of equilibrium constants at run time by using option on the input file. The output consists of an output file, a tab file (tables of output parameters), and a pickup file, which allows a restart capability. The chief numerical method employed for equilibrium calculations is a hybrid Newton-Raphson technique. This is supported by a set of algorithms which create and optimize starting values. When actual rate laws are used, EQ6 integrates them using a finite-difference based ordinary differential equation (ODE) solver. EQ6 reads a secondary unformatted data file (data1) that is created from a primary formatted data file (data0) by EQPT, the EQ3/6 data file preprocessor. There is currently a set of five data (data0) files. Three of these may be used with either the Davies equation or the B-dot equation to describe the activity coefficients, and their use is restricted to modeling dilute solution. The other two of these use Pitzer's equations and are suitable for modeling solution to high concentrations, though with fewer chemical components. The temperature range of the thermodynamic data on the data files varies from 25°C only to 0-300°C. The companion code EQ3NR must be used to initialize a a (sic) reaction path calculation by EQ6. EQ6 and the other codes in the EQ3/6 package are written in FORTRAN 77 and have been developed to run under the UNIX operating system on computers ranging from workstations to supercomputers."

Wood, B.J., Snow, R.E., Cosler, D.J., and Haji-Djafari, S. 1982. Delaware Mountain Group (DMG) Hydrology -- Salt Removal Potential, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3166. U.S. Department of Energy, Albuquerque, NM.

INTRODUCTION AND SUMMARY, p. 1;

" This report provides an account of studies performed to evaluate the potential for salt dissolution in the Castile Formation, removal of dissolved salt by fluids in the Bell Canyon aquifer within the Delaware Mountain Group (DMG), and the potential impact of this process on the long-term integrity of the Waste Isolation Pilot Plant (WIPP) facility.

The results of this study provide responses to the stipulated agreement of July 1, 1981 with the U.S. Department of Energy (DOE) and the state of New Mexico regarding the DMG hydrologic investigation. This study was performed and this report prepared by D'Appolonia Consulting Engineers, Inc. (D'Appolonia), under Subcontract S9-CJR-45451 with Westinghouse Electric Corporation, Advanced Energy Systems Division, under Contract DE-AC04-78-ET05346 with the DOE. The Westinghouse team is serving as the Technical Support Contractors (TSC) to the DOE for the WIPP project. ..."

Zoback, M.D., and Zoback, M.L. State of Stress and Interplate Earthquakes in the United States. Science, Vol. 213, No. 4203, pp. 96-104.

SUMMARY, p 96, col 1;
" Recently compiled data on the state of stress have been used to define stress provinces in the conterminous United States in which the orientation and relative magnitude of the horizontal principle stresses are fairly uniform. The observed patterns of stress constrain mechanisms for generating interplate lithospheric stresses. Coupled with new information on geologic structure and tectonism in seismically active areas of the Midcontinent and East, these data help to define some characteristics common to these areas and to identify key questions regarding why certain faults seem to be seismically active."

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Bellus, P.A., and Eckerman, J. 1994. Airborne or Spaceborne Surveillance Radar Detection of WIPP Site. Westinghouse Electric Corporation, 10950, Minnetonka, MN.

2. Radar Reflectors, p. 1;

" A radar retroreflector fabricated from intersecting plates of metal provides a high radar cross section. The trihedral formed by the right-angle placement of adjacent plates gives a high reflection coefficient independent of angle. These devices have been used for many radar enhancement applications. Figure 1 shows such a device, sold under the trade name RADARK, for use as a boat radar signature enhancement navigational aid.

If the reflector is sized for 100MHz, the wavelength is 3 meters and the dimension of the trihedral facet should be 3 wavelengths on a side, for a length of 9 meters. Since there is a facet on either side of the center plane, the overall size of the reflector is 18 meters across. To get the maximum reflectivity, the accuracy of the right angle (the deviation of the surface of the plate from the plane) and the flatness of metal plates must be controlled to much less than a wavelength. Of course, the degree of control in absolute terms depends on wavelength, making for tighter tolerances as frequency increases. By providing a gradient of accuracy in towards the center, a smaller portion of the center could provide a high RCS for a high frequency radar, with more of the reflector area contributing to the RCS for lower frequency radar. Further, since the stresses on the plates increase with increasing distance from the center, as does the area of the plates, precision is easier to come by at the center, where it is most needed, at lower cost.

Will this corner reflector provide a sufficient signal? Consider the radar backscatter coefficient of a trihedral reflector. The peak RCS per unit area of trihedral reflector (dBsm/sm) is given by:

$$10\log(4\pi\ A/\lambda^2)$$

where A is the area of the reflector and λ is the wavelength of the radar.

For a triangular corner that is half a square 9 meters by 9 meters the area is 40 m^2. For 100 MHz radar λ is 3 meters, thus the RCS per unit area is:

$$10\log(4\pi\ (40)/3^2))=17\text{dBsm/sm}$$

Consider that the radar cross section of terrain at relatively oblique incidence is on the order of -15 dBsm/sm for many terrain types over a variety of frequencies and polarizations, a target with a backscatter coefficient of +17 dBsm/sm will be highly visible.

For L-band radars (1000 MHz, λ=0.3 m), the wavelength is 1/10th as large as for 100 MHz, so the trihedral sides can be 1/10 as large. The triangular corner is half of a square 0.9 x 0.9 m or 0.4 square meters. Thus the RCS per unit area is:

$$10\log(4\pi\ (0.4)/0.3^2))=17\text{dBsm/sm}$$

If the larger 9 m x 9 m target had the tolerances and surface finish required for the higher L-band frequency, its RCS per unit area would be:

$10\log(4\pi\ (40)/0.3^2))=37\text{dBsm/sm}$

while the smaller 0.9 m x 0.9 m target at 100 MHz will have an RCS per unit area of only:

$10\log(4\pi\ (0.4)/3^2))=2.5\text{dBsm/sm}$

Thus the larger target will be adequate at 100 MHz and 1 GHz, but the smaller target, while adequate at 1 GHz, will be clutter limited at 100 MHz, especially if buried under lossy material."

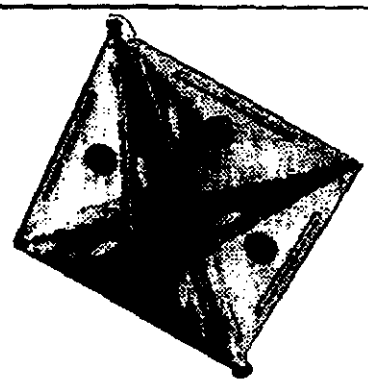

Figure 1 - RADARK Radar Reflector

DOE (U.S. Department of Energy), 1980. Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026, Volumes 1 and 2, Department of Energy Office of Environmental Restoration and Waste Management, Washington, D.C.

p 1-2, Section 1.2.1 1980 WIPP FEIS

" The 1980 WIPP Final Environmental Impact statement (FEIS) and the associated public review and comment period provided environmental input for the DOE's initial decision to proceed with the WIPP (DOE, 1980). The significance of impacts associated with the various alternatives was assessed. For the selected alternative, a two-phased approach to development was proposed: 1) a site and preliminary design validation (SPDV) program, as discussed in Subsection 8.2.1 of the FEIS, and 2) full construction, as discussed in FEIS Subsection 8.2.2. The durations of key WIPP activities are shown in Figure 1.1.

The 1980 FEIS presented an analysis of the environmental impacts of a number of alternatives for demonstrating the safe disposal of TRU waste. The alternatives considered include:

- Alternative 1. No action. A research and development facility to demonstrate safe disposal of TRU waste would not be developed and post-1970 TRU waste would continue to be retrievably stored.

- Alternative 2. Developing the WIPP at the Los Medanos site in southeastern New Mexico.

- Alternative 3. Disposing of stored TRU waste in the first available repository for high-level radioactive waste.

- Alternative 4. Delaying a decision on the site for a WIPP until at least 1984 to allow for investigation of alternative sites.

Alternative methods and geologic media for TRU waste disposal were also considered but rejected in the FEIS. The alternative methods included burial in deep ocean sediments, emplacement in deep drillholes, transmutation, and ejection into space. The alternative geologic media included igneous, volcanic, and argillaceous rocks.

The DOE's Record of Decision, published January 28, 1981 (46 FR 9162), announced the DOE's selection of Alternative 2: to proceed with the phased development of the WIPP at the Los Medanos site in southeastern New Mexico. . . ."

7.3.7 Energy and Mineral Resources, page 7-64, para 6;
"<u>Methods used to determine potash reserves at the WIPP site</u>

Two separate studies were conducted for the DOE by the U.S. Bureau of Mines (USBM, 1977) and Agricultural and Industrial Minerals, Inc. (AIM, 1979) to determine what

portion of the potash resources at the WIPP site is economic and may be considered to be reserves. Both studies started with the basic grade and thickness data provided by the USGS, and the USBM study was available for use by AIM. However, the two studies used different concepts for the development of the potash reserves and evaluated processing difficulties independently. The AIM approach, which may more nearly resemble the perspective of a potash operator, results in lower reserve estimates. However, because estimates of reserves and the associated economics are subject to uncertainty and because the USBM report gives a higher estimate of reserves, most table presented here will use USBM reserve estimates. The AIM report also estimated potash resources in the Carlsbad district and in the United States to allow comparison with the WIPP-site resources, and their values will be used in these comparisons. It should also be noted that local potash operators question the economic feasibility of mining the WIPP reserves.*

The USBM method of determining to what extent the deposits could be profitably mined and thus considered reserves consisted of designing conceptual models for exploiting the deposits. Models ranged from new mines and refineries to mines that merely send the new ore to existing refineries. Shaft locations were selected to minimize underground development and allow the richest ore beds to be mined first. The latter is important to the quick recovery of invested capital.

Costs were either estimated or, when available, matched to known cost experience at nearby mines. All costs, including construction, were used in discounted cash-flow analysis to determine the market price for refined products guaranteeing a 15% rate of return on invested capital. Federal, State, and local taxes and royalties were taken into account.

In all, the USBM prepared 12 different conceptual plans (which it has termed mining units) for exploiting the potash deposits in the WIPP site. Of these, eight were fully evaluated and four discarded because of complex problems related to the enrichment of raw ore.

Results of the potash-reserve determination

The full findings of the reserve evaluation have been reported (USBM, 1977; AIM, 1979), and the USBM estimates are summarized in Table 7-8. The eight mining units that were conceived and then costed are listed in the approximate order in which they would rank as potentially minable. Only the 48.46 million tons in mining units B-1 (Figure 7-25) within the site were classified as reserves by the USBM study. This is much less than would be classified as reserves by the USGS. The USGS used the potash grade and thickness parameters of the most efficient producers in the district. These minimum ore standards, excluding all other minability parameters, include all material in the WIPP site with a minimum cutoff grade of 4% K_2O as langbeinite or 10% K_2O as sylvite in a thickness of 4 feet.

The USBM used criteria consistent with industry practice in preparing economic-feasibility studies. In calculating potash-ore reserves, it used a method based on engineering design and economic-analysis procedures, including discounted cash flow, to determine the

tonnage of minable potash ore that will yield a 15% rate of return on the total capital investment. Only economically recoverable ore is included in the USBM reserve estimates.

Under the USBM criteria, only mining unit B-1 meets the 1977 market prices current at the time of the study: $42 per ton of muriate, $84 per ton of "sulfate" (K_2SO_4), and $48 per ton of langbeinite. This particular reserve consists of langbeinite, mostly in ore bed 4 in the northern portion of the site. (Restriction of mining within the WIPP site would not render uneconomic the remainder of mining unit B-1 outside the site.)

Unit A-1 does not meet the market-price requirements; however, the market price of muriate has exceeded $52 per ton in the recent past, at which point the A-1 deposit would be considered a marginal, or "nearly economic," deposit. (Average market prices for October 1979 were $58.37 per ton of muriate, $42-44 per ton of langbeinite, and $56.14 per ton of all sulfate products: USGS Conservation Division, Monthly Mining Report, Roswell, New Mexico.) The A-1 deposit consists of sylvite contained in ore bed 10 and located on the west side of the site.

Methods used to determine the hydrocarbon resources at the WIPP site

The New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) conducted hydrocarbon-resource study in southeastern New Mexico under contract to the Oak Ridge National Laboratory (Foster, 1974). The study included an area of 1512 square miles (Figure 7-26). At the time of that study, the proposed repository site was about 5 miles northeast of the current site. The NMBM&MR evaluation included a more detailed study of a four-township area centered on the old site; the present site is in the southwest quadrant of that area (Figure 7-26).

The resource evaluation was based both on the known reserves of crude oil and natural gas in the region and on the probability of discovering new reservoirs in areas where past unsuccessful wildcat drilling was either too widely spread or too shallow to have allowed discovery. All potentially productive zones were considered in the evaluation; therefore, the findings may be used for determining the total hydrocarbon resources at the site. A fundamental assumption in this study is that the WIPP area has the same potential for containing hydrocarbons as the much larger region in which the study was conducted and for which exploration data are available. Whether such resources actually exist can be satisfactorily established only by drilling at spacings close enough to give a high probability of discovery.

Results of the hydrocarbon-resource evaluation

Table 7-9 summarizes the findings of the NMBM&MR hydrocarbon evaluation as the potential resource of hydrocarbons that probably exist under a square mile (640 acres) with the typical geologic and stratigraphic section of that region. The New Mexico Bureau of Mines and Mineral Resources examined an area of 967,680 acres (1512 square miles). The hydrocarbon resources under the site are then estimated as the proportion of the total in the 29.625 square miles of the site (Table 7-10).

The hydrocarbon-resource quantities given in Table 7-10 are equivalent to potash-

resource-quantity estimates in that both relate to the quantity of what is present, and not to its economic value or recoverability. Because the hydrocarbon-resource evaluation relies on statistical probability, it is not as accurate as the potash-resource evaluation. The potash resources were actually drilled and assayed, while the hydrocarbon resources were estimated by projecting historical drilling success into an untested area. Site-selection requirements dictated that the inner zones be free of deep holes (i.e., oil and gas test holes)."

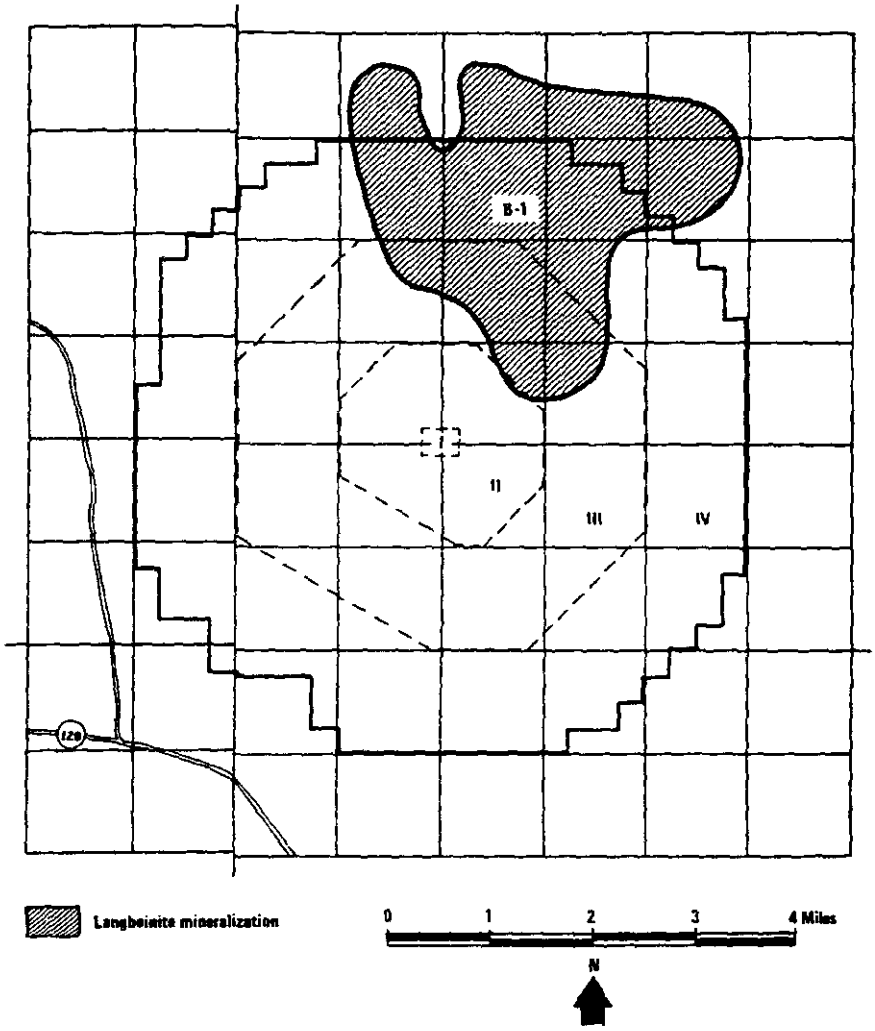

Figure 7-25. Economic langbeinite mineralization in mining unit B-1. (After USBM, 1977).

DOE (U.S. Department of Energy), 1990. Final Safety Analysis Report; Waste Isolation Pilot Plant, WP02-9, Revision 0, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, New Mexico.

PREFACE

"**Background**

This Final Safety Analysis Report (FSAR) has been prepared for the Waste Isolation Pilot Plant (WIPP) in order to satisfy the commitments made in the Working Agreement for Consultation and Cooperation(Article III, Section C and Article IV, Section K, known as the Working Agreement) between the State of New Mexico and the U.S. department of energy (DOE) and the requirements of Order DOE 5481.1B,Safety Analysis and Review System.

The objectives of the Safety Analysis Preparation and Review process, as specified in Order DOE 5481.1B, ensure that:

1. Potential hazards are systematically identified;

2. Potential consequences are analyzed;

3. Reasonable measures to eliminate, control or mitigate the hazards have been taken, including, where applicable, compliance with commitments made in environmental assessments and impact statements;

4. There is documented management authorization of the DOE operation based upon an objective assessment of the safety analysis.

Specific hazards that are analyzed include credible natural hazards such as flood, weather (tornado, wind, etc.) and earthquake; and credible man made hazards such as fire, explosion, radiation, and mining hazards. Mitigating measures include facility design and construction, operational controls, and administrative limits.

This FSAR represents a statement and commitment by the DOE that the WIPP facility can be operated safely and at minimum risk, if operated in accordance with this FSAR. Consequently, this FSAR has been prepared to document that a systematic analysis of the potential hazards associated with operating the WIPP facility has been performed (objective 1 of Order DOE 5481.1B); that potential consequences have been analyzed (objective 2 of Order DOE 5481.1B); and that reasonable measures have been taken to eliminate, control, or mitigate the hazards (objective 3 of Order DOE 5481.1B). In addition, this FSAR documents the implementation of commitments made in the environmental impact statement regarding the mitigation of adverse impacts to the environment (objective 3 of Order DOE 5481.1B)."

Section 1.1 INTRODUCTION; p 1.1-1. para 3;

" In addition, this FSAR has been prepared in accordance with Article III of the 1981 Consultation and Cooperation Agreement (C&C Agreement) between the DOE and the State of New Mexico and, as such, represents the most comprehensive document concerning the WIPP facility both in general terms and specifically as related to public health and safety."

Section 1A.1.1.1 Earthquakes, p 1A.1-2;
" Seismic risk analysis has defined a conservative DBE for the WIPP facility with a maximum ground acceleration of 3.2 in/s^2 (0.1g) horizontally and vertically, with 10 maximum stress cycles, and based on a 1000-year recurrence interval. This maximum acceleration is used in analysis and design of surface confinement facilities and equipment. Response spectrum analysis was contacted using structural mode shapes and frequencies for two principal horizontal directions, and modal responses (shear, moments,stresses, deflection, accelerations) were combined to assess the contribution to loading from seismic sources. Seismic overturning moment was used to compute foundation reactions and account for vertical earthquake effects. . . . "

Section 2.2.1 INDUSTRIAL AND COMMERCIAL FACILITIES, p 2.2-1, line 4;
" There are three potash mines and two chemical processing plants (adjacent to the mines) between five and 10 miles of the WIPP facility."

Section **5.1 CH TRU WASTE HANDLING SYSTEM**, para 3;
" The average CH TRU waste throughput is shown in Table 5.1-2. This table is based on handling only drums. This assumption produces an upper bound for the WIPP facility on handling processes. The design basis throughput for CH TRU is 500,000 ft^3 per year at 250 days per year. The anticipated average throughput is 250,000 ft^3 per year."

Section **3.1.3.1 RH TRU Waste Quantities and Storage**, Paragraph 2;
" The RH TRU waste design throughput capacity is two canisters per shift or a maximum of 250 canisters per year (7500 ft^3 per year)."

throughput 7500 ft^3 per year
facility design life x 25 years
187,500 ft^3

25 year throughput 187,500 ft^3
design capacity ÷250,000 ft^3
0.79 or 79 percent of design capacity

Table 5.1-2

AVERAGE CH TRU WASTE VEHICLE, CONTAINER, AND DRUM THROUGHPUT

Vehicle	No. of TRUPACT II's Per Vehicle	Vehicles per day	TRUPACT II per day	Drums* per day	Vehicles per year	Volume per year ft³
Truck Trailer	3	3.2	9.7	136	810	250,000

*Assumes 14 drums/TRUPACT II

Introduction

" The DOE's plan for monitoring VOCs emitted from the WIPP during the test phase is described in this document.

The monitoring program is designed to demonstrate that there will be no migration of hazardous chemicals from the WIPP in concentrations exceeding health-based criteria. The monitoring plan included an overview of the WIPP test program, a description of waste sources, the monitoring design, and justification of the design. The plan also includes a description of sampling and analysis procedures, QA objectives, and reporting activities.

Possible migration pathways from the unit, both during the active life of the facility and through the postclosure phase."

Section 6.1.7.2.1 Migration Pathways, p 6.1-34;

"Hazardous chemicals available for release are predominantly volatile organic gases. The only pathway of concern for exposure and risk from such releases is airborne diffusion and inhalation. The highest air concentration at the WIPP Site boundary was approximately four orders of magnitude below the minimum detection limit using EPA standard methods (EPA, 1984). Due to the low air concentrations, the relative insolubility of these chemicals and their tendency to break down in the atmosphere, ingestion exposure from scavenging and deposition of contaminated particles is considered very minor and without significant risks. This pathway is not evaluated. There is little probability that liquids will be released, as only residual liquids are allowed in the waste, and potential pathways for liquids released in groundwater or surface water are nonexistent."

Summary

" The results of the experiments conducted during the test phase will be used, in part, to refine the monitoring programs that will be established for the planned operational phase, during which full-scale waste emplacement activities will occur. Environmental monitoring currently anticipated during both the operational and postclosure phase is described in Volume 1 of the petition (DOE, 1990a)."

Section 2.6.4.5.3 Regional Warping, p 2.6-24;

" In 1977 the DOE commissioned the National Geodetic Survey to put in a first order

line across the WIPP facility area. This line extends from Carlsbad to San Simon Sink. It runs through both Nash Draw and the WIPP facility. In 1981, this line was resurveyed and showed subsidence in the WIPP facility at less than 0.04 in. [106]"

DOE (U.S. Department of Energy), 1991. Draft Report: Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force, DOE/WIPP 91-007, Rev. 0, Westinghouse Electric Corporation, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-i;

" The Engineered Alternatives Task Force (EATF) was established by the United States Department of Energy (DOE) WIPP Project Office (WPO) in September, 1989 (Hunt, A., 1990), to evaluate the relative effectiveness and feasibility of implementation of selected design enhancements (referred to as 'engineered alternatives') for the Waste Isolation Pilot Plant (WIPP). These enhancements consist of modifications of existing waste forms and/or the WIPP facility, and other design variations such as passive marker systems. The purpose of this report is to summarize the methodologies and results of evaluation of the effectiveness of selected engineered alternatives relative to the existing repository design, and to discuss the feasibility of implementing these alternatives with respect to availability of technology, cost, schedule, and regulatory concerns.

Preliminary analyses of the long-term performance of the WIPP disposal system performed by Sandia National Laboratories (SNL) (referred to as 'performance assessment') have identified two potential problems in demonstrating compliance with the applicable regulation 40 CFR Part 191 (EPA, 1985) that governs the disposal of transuranic radioactive waste. The first potential problem relates to gas generation. Lappin et al. (1989) discuss the possibility that up to 1,500 moles of gas can be generated per drum (or drum equivalent) of waste from anoxic corrosion, microbial degradation, and radiolysis, at rates that may be as high as 2.55 moles/drum/year. Although processes exist to dissipate excess gas pressure, these processes are currently believed to be slow relative to the current estimates of gas generation rates, resulting in gas pressures in storage rooms that may temporarily exceed lithostatic pressure. The consequences of exceeding lithostatic pressure are currently being evaluated by SNL (Lappin et al., 1989). Unless these evaluations demonstrate that either excess pressures will not occur, or that excess pressures will not degrade the performance of the disposal system, some type of waste form or facility modification may be required to either eliminate gas generation or reduce the rate of gas generation. For example, if the organics in the waste are incinerated and vitrified, then microbial gas generation can be eliminated.

A second potential problem in demonstrating compliance with 40 CFR Part 191 relates to the consequences predicted from future inadvertent human intrusion events. Preliminary evaluations of compliance with the containment requirement of 40 CFR Part 191 performed by SNL suggest that some of the current waste forms (under current interpretations of human intrusion provisions) may eventually be found to be unacceptable for disposal at the WIPP (Marietta et al., 1989). This may be due to uncertainties in key performance parameters of the waste forms. Key parameters that control the release of radionuclides during human intrusion scenarios are permeability of the waste storage rooms, radionuclide solubilities, and the availability of brine. Permeability of the storage rooms can

be effectively reduced by the use of a grout backfill and/or shredding and cementation of the waste. Solubilities can be reduced by the use of grout backfill or the addition of lime to raise the pH of any brine that may come in contact with the waste."

Section 1.0 INTRODUCTION, p 1-1;
" The Engineered Alternatives Task Force (EATF) was formed by the Department of Energy (DOE) WIPP Project Office (WPO) to evaluate the feasibility and relative effectiveness of selected enhancements to the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico (Hunt, A. 1990). These enhancements (referred to as engineered alternatives) include modifications to existing waste forms and/or the WIPP facility, and other design variations such as passive marker systems. Recommendations of the EATF will be forwarded by DOE to Sandia National Laboratories (SNL) for input into their experimental and Performance Assessment (PA) programs, as appropriate. Subsequent sections of this report describe the methodology used by the EATF to evaluate the relative effectiveness, the results of this evaluation, and the feasibility of implementing various engineered alternatives. An overview of the WIPP project in reference to the EATF effort, and the framework of the EATF, are described in this section."

Section **7.0 FEASIBILITY OF IMPLEMENTING BACKFILL ALTERNATIVES**,
7.1 STATUS OF DEVELOPMENT, p 7-1;
" Three backfill modification alternatives have been recommended for inclusion in the WIPP Experimental Program (DOE, 1990b):

- Salt with Brine Absorbent - Addition of an absorbent, such as bentonite, introduces brine absorbing capability to reduce the potential for brine penetration into the waste. . . ."

7.1.1 Salt with Brine Absorbent, p 7-2;
" Mining of the WIPP facility produces bulk salt, which is stored above ground at the WIPP site. Granulation of this salt to a consistency required for efficient emplacement and the addition of a brine sorbent such as bentonite clay will not require a research and development program. Bentonite is expected to possess the beneficial characteristics of radionuclide sorption, and brine sorption (Butcher, 1990b)."

DOE (U.S. Department of Energy), 1994. Permanent Marker Conceptual Design Report, Draft. Rev 2, November 1994. U.S. Department of Energy, Carlsbad, New Mexico.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

EPA (U.S. Environmental Protection Agency), 1985. "40 CFR 191:Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste; Final Rule." Federal Register, Volume 50, No. 182, pp.38066-38089, September 19, 1985, Office of Radiation and Air, Washington, D.C. WPO 39132.

SUMMARY, p. 38066, col. 1;

" The Environmental Protection Agency (EPA) is promulgating generally applicable environmental standards for the management and disposal of spent nuclear fuel and high-level and transuranic wastes. The standards apply to management and disposal of such materials generated by activities regulated by the Nuclear Regulatory Commission (NRC) and to disposal of similar materials generated by atomic energy defense activities under the jurisdiction of the Department of Energy (DOE). These standards have been developed pursuant to the Agency's authorities and responsibilities under the Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act of 1982.

Subpart A of these standards limits the radiation exposure of members of the public from the management and storage of spent fuel or high-level or transuranic wastes prior to disposal at waste management and disposal facilities regulated by the NRC. Subpart A also limits the radiation exposures to members of the public from waste emplacement and storage operations at DOE disposal facilities that are not regulated by the NRC.

Subpart B establishes several different types of requirements for disposal of these materials. The primary standards for disposal are long-term containment requirements that limit projected releases of radioactivity to the accessible environment for 10,000 years after disposal. These release limits should insure that risks to future generations from disposal of these wastes will be no greater than the risks that would have existed if the uranium ore used to create the wastes had not been mined to begin with. A set of six qualitative assurance requirements is an equally important element of Subpart B designed to provide adequate confidence that all containment requirements will be met. The third set of requirements are limitations on exposures to individual members of the public for 1,000 years after disposal. Finally, a set of ground water protection requirements limits radionuclide concentrations for 1,000 years after disposal in water withdrawn from most Class I ground waters to the concentrations allowed by the Agency's interim drinking water standards (unless concentrations in the Class I ground waters already exceed limits in 40 CFR Part 141, in which case this set of requirements would limit the increases in the radionuclide concentrations to those specified in 40 CFR Part 141). Subpart B also contains informational guidance for implementation of the disposal standards to clarify the Agency's intended application of these standards, which address a time frame without precedent in environmental regulations. Although disposal of these materials in mined geologic repositories has received the most attention, the disposal standards apply to disposal by any method, except disposal directly into the oceans or ocean sediments.

This notice describes the final rule that the Agency developed after considering the

public comments received on the proposed rule published on December 29, 1982, and the recommendations of a technical review conducted by the Agency's Science Advisory Board (SAB). The major comments received on the proposed standards are summarized together with the Agency's responses to them. Detailed responses to all the comments received are discussed in the Response to Comments Document prepared for this final rule.
DATE: These standards shall be promulgated for purposes of judicial review at 1:00 p.m. eastern time on October 3, 1985. These standards shall become effective on November 18, 1985."

Long-Term Monitoring; p. 38081, col. 2;
" The proposed rule addressed active institutional controls over a disposal site only in a negative sense-to prohibit reliance upon them for more than a few hundred years after disposal. The Agency's intent was to be sure that long-term protection of the environment did not depend upon positive actions by future generations. Almost all commenters agreed with this intent, although many suggested a shorter period of reliance was appropriate (see the preceding discussion under "Approach Towards Institutional Controls").

However, several commenters (including most of the States) also urged addition of a requirement for long-term monitoring of a repository after disposal. This view did not deny the need to select and design disposal systems without depending upon active controls in the future. However, it broadened this perspective by arguing that a disposal system so designed should still be monitored for a long time after disposal to guard against unexpected failures.

The Agency had not considered this viewpoint in developing the proposed rule. Accordingly, further information on this idea was sought during the "second round" of public comment, and the Agency surveyed the capabilities and expectations of long-term monitoring approaches. Evaluating this information led the Agency to several conclusions:

(1) Perhaps most importantly, the techniques used for monitoring after disposal must not jeopardize the long-term isolation capabilities of the disposal system. Furthermore, plans to conduct monitoring after disposal should never become an excuse to relax the care with which systems to isolate these wastes must be selected, designed, constructed, and operated.

(2) Monitoring for radionuclide releases to the accessible environment is not likely to be productive. Even a poorly performing geologic repository is very unlikely to allow measurable releases to the accessible environment for several hundreds of years of more, particularly in view of the engineered controls needed to comply with 10 CFR Part 60. A monitoring system based only on detecting radionuclide releases-a system which would almost certainly not be detecting anything for several times the history of the United States-is not likely to be maintained for long enough to be of much use.

(3) Within the above constraints, however, there are likely to be monitoring approaches which may, in a relatively short time, significantly improve confidence that a repository is performing as intended. Two examples are of particular interest. One involves the concept of monitoring ground water sources at a variety of distances for benign tracers intentionally released to the ground water in the repository; this approach can evaluate the delay involved in ground water movement from the repository to the environment and can

serve to validate expectations of the performance expected from the system's natural barriers. Another concept involves monitoring the small uplift of the land surface over the repository in order to validate predictions of the system's thermal behavior. Both of these approaches can be carried out without enhancing pathways for the wastes to escape from the repository.

Based on these conclusions and the public comments on this question, the Agency has included a provision for long-term monitoring after disposal in the assurance requirements of the final rule: "Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring." This new provision is consistent with the overall intent of the assurance requirements: To take prudent and cautious steps necessary to minimize the risks posed by the inherent uncertainties in expectations of the future. Beyond this broad mandate, however, the Agency has not specified the details of a monitoring program. That is properly left to the implementing agencies. Furthermore, the precise objectives of an appropriate monitoring program probably should not be spelled out until much more information is gathered about the characteristics and expected behavior of specific sites and designs.

Ability To Recover Wastes After Disposal

The proposed rule included an assurance requirement that recovery of these wastes be feasible for "a reasonable period of time" after disposal. The agency specifically sought comment on whether this was a desirable provision, since it would rule out certain disposal concepts, such as deep-well injection of liquid wastes. The comments received were split about evenly between those who thought the provision should be retained and those who thought it was detrimental to the overall rule. Many of those who opposed the requirement argued that it would encourage designing a geologic repository to make retrieving waste relatively easy-which might compromise the isolation capabilities of the repository or which might encourage recovery of the waste to make use of some intrinsic value it might retain (the potential energy content of spent nuclear fuel, for example).

The intent of this provision was not to make recovery of waste easy or cheap, but merely possible in case some future discovery or insight made is clear that the wastes needed to be relocated. EPA reiterates the statement in the preamble to the proposal that any current concept for a mined geologic repository meets this requirement without any additional procedures or design features. For example, there is no intent to require that a repository shaft be kept open to allow future recovery. To meet this assurance requirement, it only need be technologically feasible (assuming current technology levels) to be able to mine the sealed repository and recover the waste-albeit at substantial cost and occupational risk. The Commission's requirements for multiple engineered barriers within a repository (10 CFR Part 60) adequately address any concerns about the feasibility of recovering wastes from a repository.

Therefore, this provision should not have any effect upon plans for mined geologic repositories. Rather, it is intended to call into question any other disposal concept that might

not be so reversible-because the Agency believes that future generations should have options to correct any mistakes that this generation might unintentionally make. Almost all of the commenters agreed with the validity of the objective. Accordingly, the Agency has decided to retain this assurance requirement in the final rule as proposed."

EPA (U.S. Environmental Protection Agency). 1988. Test Methods for Evaluating Solid Waste. Volume 1A through 1C and Volume 2. Field Manual Physical Chemical Methods (3rd Edition). Report EPA/SW-846, September 1988, National Technical Information Service, Springfield, VA.

ABSTRACT, p i;

" The manual provides test procedures which may be used to evaluate those properties of a solid waste which determine whether the waste is a hazardous waste within the definition of Section 3001 of the Resource Conservation and Recovery Act (PL 94-580). These methods are approved for obtaining data to satisfy the requirement of 40 CFR Part 261, Identification and Listing of Hazardous Waste. Volume IA deals with quality control, selection of appropriate test methods, and analytical methods for metallic species. Volume IB consists of methods for organic analytes. Volume IC includes a variety of test methods for miscellaneous analytes and properties for use in evaluating the waste characteristics. Volume II deals with sample acquisition and includes quality control, sampling plan design and implementation, and field sampling methods."

EPA (U.S. Environmental Protection Agency), 1996a. 40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Final Rule, Federal Register, Vol. 61, No. 28, pp. 5224-5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C.

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992. EFFECTIVE DATE: These regulations are effective April 9, 1996."

p. 5238, col. 2;
" §194.14. Content of compliance certification application.

Any compliance application shall include:

(a) A current description of the natural and engineered features that may affect the performance of the disposal system. The description of the disposal system shall include, at a minimum, the following information:

(1) The location of the disposal system and the controlled area;

(2) A description of the geology, geophysics, hydrogeology, hydrology and geochemistry of the disposal system and its vicinity and how these conditions are expected to change and interact over the regulatory time frame. Such description shall include, at a minimum:

(i) Existing fluids and fluid hydraulic potential, including brine pockets, in and near the disposal system; and

(ii) Existing higher permeability anhydrite interbeds located at or near the horizon of the waste.

(3) The presence and characteristics of potential pathways for transport of waste from the disposal system to the accessible environment including, but not limited to: Existing boreholes, solution features, breccia pipes, and other potentially permeable features, such as interbeds.

(4) The projected geophysical, hydrogeologic, and geochemical conditions of the disposal system due to the presence of waste including, but not limited to, the effects of production of heat or gases from the waste."

p. 5240, col. 2;

" §194.24 Waste characterization.

(a) Any compliance application shall describe the chemical, radiological and physical composition of all existing waste proposed for disposal in the disposal system. To the extent practicable, any compliance application shall also describe the chemical, radiological and physical composition of to-be-generated waste proposed for disposal in the disposal system. These descriptions shall include a list of waste components and their approximate quantities in the waste. This list may be derived from process knowledge, current non-destructive examination/assay, or other information and methods."

p. 5243, Assurance Requirements, col. 3;

" §194.44 Engineered barriers.

(a) Disposal systems shall incorporate engineered barrier(s) designed to prevent or substantially delay movement of water or radionuclides toward the accessible environment."

EPA (U.S. Environmental Protection Agency) 1996b. Compliance Application Guidance for 40 CFR 194, EPA 402-R-95-014, March 29, 1996. Washington, D.C. WPO 39159.

INTRODUCTION, p. 1;

" The Compliance Application Guidance (CAG) is a companion to the final rule published at 61 FR 5224, February 9, 1996, 'Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's (WIPP) Compliance With the 40 CFR Part 191 Disposal Regulations' (to be codified at 40 CFR Part 194).

The CAG summarizes and explains the February 9, 1996 final rule. The United States Environmental Protection Agency (EPA) developed this guidance to assist the United States Department of Energy (DOE) with the preparation of any Compliance Certification Application (CCA) for the WIPP and, in turn, to assist in EPA's review of the CCA for completeness and generally to enhance the readability and accessibility of the CCA for EPA and public scrutiny. It is EPA's intent that this guidance will facilitate the understanding that DOE and the public have of the specific information that is expected to be included in a *complete* application for certification of compliance. Examples used for clarification purposes in this guidance should not be considered exhaustive or definitive, since they are provided merely to facilitate DOE's understanding of the types of information EPA is expecting. . . ."

p. 2, para. 2;

" The CAG summarizes and explains EPA's expectations of the format and content of the CCA, based on the February 9, 1996 final rule (hereafter referred to as '40 CFR Part 194'). The technical and legal requirements pertaining to the CCA are addressed by 40 CFR Parts 191 and 194. The CAG's format follows that of 40 CFR Part 194, restating the rule language in *italics*, followed by the specific guidance for that section in standard type. Only those portions of 40 CFR Part 194 (and, by reference, applicable portions of 40 CFR Part 191) for which DOE is required to submit specific information to EPA, are addressed. Portions of 40 CFR Part 194 which are applicable only to EPA, such as Subpart D, were excluded from this guidance.

The information DOE presents in any compliance application must conform to the requirements of 40 CFR Part 194."

Hora, S.C., D. von Winterfeldt, and K.M. Trauth, 1991. Expert Judgment on Inadvertent Human Intrusion into the Waste Isolation Pilot Plant, SAND90-3063, Albuquerque, NM, Sandia National Laboratories.

ABSTRACT, p i;
" Four expert-judgement teams have developed analyses delineating possible future societies in the next 10,000 years in the vicinity of the Waste Isolation Pilot Plant (WIPP). Expert-judgement analysis was used to address the question of future societies because neither experimentation, observation, nor modeling can resolve such uncertainties. Each of the four, four-member teams, comprised of individuals with expertise in the physical, social, or political sciences, developed detailed qualitative assessments of possible future societies. These assessments include detailed discussions of the underlying physical and societal factors that would influence society and the likely modes of human-intrusion at the WIPP, as well as the probabilities of intrusion. Technological development, population growth, economic development, conservation of information, persistence of government control, and mitigation of danger from nuclear waste were the factors the teams believed to be most important. Likely modes of human-intrusion were categorized as excavation, disposal/storage, tunneling, drilling, and offsite activities. Each team also developed quantitative assessments by providing probabilities of various alternative futures, of inadvertent human intrusion, and in some cases, of particular modes of intrusion. The information created throughout this study will be used in conjunction with other types of information, including experimental data, calculations from physical principles and computer models, and perhaps other judgements, as input to a 'performance assessment.' The more qualitative results of this study will be used as input to another expert panel considering markers to deter inadvertent human intrusion at the WIPP."

Murphy, John N. and H.F. Parkinson. 1978. "Underground Mine Communications," Proceedings of the IEEE, Vol. 66, No. 1, pp. 26-50.

Seismic Trapped Miner Signaling:, p. 42, col. 1, para. 2;

" In the seismic system, the trapped miner signals on the mine floor with a timber or sledge hammer, and multiple geophone arrays on the surface can detect signals in the majority of areas in overburden less than 150 m deep. Various signal-processing techniques enhance the signal-to-noise ratio; the predominant noise sources during a rescue operation are surface-generated noises from moving equipment, people walking, and power lines. A variety of processing schemes have been tried [77]; the computation of the location of the trapped miner by using the differences in the arrival time of the signals at various geophone arrays has been quite successful when the leading edge of the miner-generated pulses is of adequate clarity to accurately obtain arrival times. A seismic location system has the advantage that the miners do not have any special equipment and need only to be trained in how and when to signal. The disadvantage is that discontinuities in the overburden can significantly affect rescue signal propagation relative to both detection and computation of location of the signal. Additionally, in a rescue and recovery operation, the time required to deploy and relocate, if necessary, a massive geophone array may hamper the progress desired. However, until a suitable alternative is available, the seismic scheme does provide the miner with an additional degree of protection. The Mining Enforcement and Safety Administration (MESA) does maintain a seismic rescue system as part of its Mine Emergency Operations group [78]. Additional work is nearing completion in terms of optimizing the hardware.

The advantages and disadvantages of the seismic approach have been identified above. Also in the work described above, the propagation of VF signals through the overburden has been thoroughly analyzed. The advantages of an electromagnetic scheme for the detection and location of trapped miners are that it would not require the time-consuming deployment of geophone arrays--in fact, the site could be scanned by helicopter--and that the propagation of a VF signal through the overburden would not be so susceptible to typical overburden anomalies as is the seismic approach. The disadvantage is that a piece of special equipment (a transmitter) is required underground. Considerable efforts have been directed toward development of suitable hardware and evaluation of same in operating mines [79]. The present configurations consist of a transmitter [80] with dimensions 6.25 X 3.2 X 1.5 cm, which, when connected to an external loop of wire 25 m long, generates a peak magnetic moment of 1000 A • m^2. The transmitter and the antenna have been packaged two ways, on the left as an attachment to the top of the cap-lamp battery, and on the right as a self-contained unit to be worn on the miner's belt.

A recent modification to the system has been to incorporate an inductive voice receiver into the transmitting package so that, via a longwire or loop antenna on the surface, voice messages can be sent to the miner; he responds via code with his beacon transmitter. To support there transmitters, surface equipment has been developed--a receiver for handheld or helicopter-borne use."

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site. Vol. I, Ch. I-III, December 22, 1994.

EXECUTIVE SUMMARY, p E-1;

" The Waste Isolation Pilot Plant (WIPP) land withdrawal area occupies 16 mi^2, on the southeastern edge of the Known Potash Leasing Area (administered by BLM), about 30 miles southeast of Carlsbad, Eddy County, New Mexico. It is four miles on a side and is located in secs. 15 to 22 and 27 to 34 of T22S R31E. This study includes an additional study area about one mile wide surrounding and containing an additional 20 mi^2. The combined study area comprises about 36 mi^2.

The amount and value of natural resources under the WIPP land withdrawal area have not been calculated for more than ten years. This report performs this calculation using current and projected prices, production, geologic data, and conditions. The need for recalculating the volume and value of mineral resources within the boundaries of the WIPP land withdrawal area stems from the discovery of oil and associated natural gas in adjacent lease tracts during the late 1980s and 1990s, and the approach of potash mining.

During the late 1980s and early 1990s oil was discovered in the lower parts of the Delaware Mountain Group (Permian: Cherry Canyon and Brushy Canyon Formations) along the eastern, southern, and western boundaries of the land withdrawal area. In the Delaware Basin as a whole, these formations were not generally recognized as exploratory and development targets until the late 1980s. Prior to that time, they were usually bypassed during drilling with little or no thought that they might contain economically recoverable oil resources. Although these two formations had been penetrated by thousands of wells throughout the Delaware Basin, few attempts were made to adequately test them.

The main reason for bypassing these formations during drilling was a lack of understanding of their production characteristics. Water saturations calculated from analysis of electric logs were often high and did not differentiate oil-productive sandstones from sandstones that would yield mostly water upon completion. However, recent developments in log analysis (Asquith and Thomerson, 1994) have made it possible to differentiate Delaware sandstones with a high percentage of movable hydrocarbons from those with a low percentage of movable hydrocarbons. This type of analysis, in conjunction with the discovery of several commercial oil pools in the Brushy Canyon Formations, set off an oil drilling boom throughout the Delaware Basin that continues to the present. The Delaware play is currently the primary exploration and development play in the Permian Basin and is one of the most active oil plays in the United States. Of special note in the vicinity of WIPP was the discovery and development of commercial oil accumulations in the Brushy Canyon Formation at Cabin Lake; Livingston Ridge, Lost Tank, and Los Medaños pools.

During the last decade or so, potash mining has continued and the mining front is now much closer to the WIPP boundary. Mining by IMC has reached the edge of the additional study area on the southwest side of the WIPP. Future mining may occur mainly there or on the north.

The value of potash (sylvite and langbeinite) and petroleum (oil and gas) were calculated using iterative economic models commencing in 1996 and lasting until 2031 (potash), 2026 (petroleum), and 2038 (natural gas plus associated oil). The potash and petroleum resources produced over this time frame were calculated from estimates based on drill hole data and projections of data and geology as needed. The value calculation used these resource data and projections of historical cost, price, and other economic data.

Potash Reserves

The results of the potash resources and reserve calculation are:

Resources and reserves of the 4th langbeinite ore zone (short tons in millions).

Area, Type of Lease, and Scenario	Tons	Avg % K_2O
Entire study area		
In-place resource (>4% K_2O & actual thickness)	168.7	8.02
BLM Lease Grade reserve (>4% K_2O & 4 ft mining height)	166.5	7.22
Minable reserve (>6.25% K^2O & 6 ft mining height	72.4	7.95
Inside WIPP boundary		
In-place resource (>4% K_2O & actual thickness)	47.0	7.21
BLM Lease Grade reserve (>4% K_2O & 4 ft mining height)	40.5	6.99
Minable reserve (>6.25% K^2O & 6 ft mining height	18.0	7.59
Outside of the WIPP boundary (about one mile)		
In-place resource (>4% K_2O & actual thickness)	121.7	8.33
BLM Lease Grade reserve (>4% K_2O & 4 ft mining height)	126.0	7.30
Minable reserve (>6.25% K^2O & 6 ft mining height	54.4	8.07

Resources and reserves of the 10th sylvite ore zone (short tons in millions).

Area, Type of Lease, and Scenario	Tons	Avg % K_2O
Combined Area		
In-place resource (>10% K_2O & actual thickness)	168.2	14.61
BLM Lease Grade reserve (>10% K_2O & 4 ft mining height)	157.3	14.64
Minable reserve (>12.25% K^2O & 4.5 ft mining height	107.8	15.33
WIPP Area		
In-place resource (>10% K_2O & actual thickness)	53.7	14.26
BLM Lease Grade reserve (>10% K_2O & 4 ft mining height)	52.3	13.99
Minable reserve (>12.25% K^2O & 4.5 ft mining height	30.6	15.00
Additional Area (-1 mile around WIPP)		
In-place resource (>10% K_2O & actual thickness)	114.5	14.77
BLM Lease Grade reserve (>10% K_2O & 4 ft mining height)	105.0	14.96
Minable reserve (>12.25% K^2O & 4.5 ft mining height	77.2	15.46

p. E-4;
"Petroleum Reserves

The Results of the calculation of probable petroleum resources are:

Oil and gas resources (probable)

	Combined Area	WIPP Area	Additional Area
Primary Oil (million bbls)	35.2	12.3	22.9
Secondary Oil (million bbls)	20.2	6.4	13.8
Oil Subtotals (million bbls)	55.4	18.7	36.7
Gas Subtotals (MCF)	354	186	168

NOTE: In addition, there is an unknown but significant amount of possible oil and gas resources beneath the WIPP land withdrawal area and surrounding one-mile-wide additional area."

p. VII-1, METHOD OF POTASH RESERVE EVALUATION;
" Evaluation of potash reserves was based solely on subsurface information from 40 core holes previously drilled within and around the WIPP Site. The nearest underground mine operations are currently no closer than one mile from the outer boundary of WIPP. All 40 holes were drilled using brine (containing potassium as well as sodium chloride) to inhibit dissolution of potassium minerals. The results of chemical analyses of the ore-bearing intervals were adjusted to calculate the percentage equivalent as individual natural mineral species. Only the K_2O percentages as either sylvite or langbeinite were used to compute ore reserves."

p. XI-1, OIL AND GAS RESOURCE ESTIMATES
Ronald F. Broadhead, Fang Luo, and Stephen W. Speer
SUMMARY OF OIL AND GAS RESOURCES;
" Rigorous, quantitative estimates were made of oil, natural gas, and natural gas

condensate resources that exist beneath the 16 mi^2 area of the WIPP land withdrawal area and an additional one-mile wide study area around the WIPP site. Calculations were made for resources that are extensions of known, currently producible oil and gas resources thought to extend underneath the WIPP land withdrawal area with reasonable certainty (*probable resources*). Qualitative estimates were also made of oil and gas that may be present in undiscovered pools and fields beneath the WIPP land withdrawal area (*possible resources*). Possible resources were not quantified."

p. XI-2, INTRODUCTION;

" Oil and gas resources are typically divided into several categories (Potential Gas Committee, 1993; Energy Information Administration, 1994; **Figs. 1a, 1b**). For purposes of this report, five categories of resources are referred to: 1)cumulative production; 2) proved reserves; 3) probable resources (extensions of known pools); 4) undiscovered recoverable resources; and 5) unrecoverable resources. *Cumulative production* is the total volume of crude oil, natural gas condensate, and natural gas that have been withdrawn (produced) from a pool or well. *Proved reserves* are an estimated quantity of crude oil, natural gas condensate, or natural gas that analyses of geologic and engineering data demonstrate with reasonable certainty to be recoverable in the future from discovered oil and gas pools. Pools are considered proved that have demonstrated the ability to produce by either actual production or by conclusive formation tests (Potential Gas Committee, 1993), that is by drilling. This report restricts the definition of proved reserves to those producible resources identified as producible by existing wells (whether currently producing or abandoned). *Ultimate recovery* is the sum of cumulative production and proved reserves or probable resources for a pool or individual well.

The remainder of the resource base consists of *potential resources*. These can be summarized as hydrocarbons that can be inferred to exist, but have not yet been proven by drilling to exist. These can be grouped into: 1)*probable resources (extensions of known pools*; 2) *probable resources (new pools)*; 3) *possible resources*; and 4) *speculative resources*. These subdivisions of potential resources are differentiated on the basis of available geologic, geophysical, and engineering data and studies. *Probable resources (extensions)* consist of oil and gas in pools that have been discovered but have not yet been developed by drilling; their presence and distribution can generally be surmised with a high degree of confidence. *Probable resources (new pools)* consist of oil and gas that are surmised to exist in undiscovered pools within existing fields. *Possible resources* are less assured; they are postulated to exist outside of known fields but within productive stratigraphic units in a productive basin or geologic province. *Speculative resources* are expected to be found in stratigraphic units, basins, or geologic provinces that have not yet been proved productive; estimates of speculative resources are the least assured of all resource estimates. *Unrecoverable resources* are dispersed in such minute accumulations or under such conditions that they can not be extracted with existing or foreseeable technology."

p. XI-11, DELAWARE MOUNTAIN GROUP;

" The Delaware Mountain Group (Guadalupian) is the major oil producing unit near the WIPP site (Fig. 14). It is subdivided into three formations (descending): Bell Canyon, Cherry Canyon, and Brushy Canyon. It was deposited basinward of the Getaway, Goat Seep, and Capitan shelf-margin and reef complexes (Fig. 15). The Delaware Mountain Group consists of sandstone, siltstone, shale, and minor (<5%) limestone, dolostone, and conglomerate (Harms and Williamson, 1988). IN areas adjacent to the WIPP site, production is obtained from the Cherry Canyon and Brushy Canyon Formations with most production coming from the Brushy Canyon.

The Bell Canyon Formation, at a depth of approximately 4500 ft, has been penetrated by most wells in the study area (Fig. 2). Most oil and gas exploratory wells drilled in the WIPP area prior to 1965 reached total depth in the upper or middle part of the Bell Canyon. Objectives were upper Bell Canyon sandstones. . . ."

p. XI-28, para 1;
" . . . stratigraphic traps and stratigraphic trends have not been fully defined and the Bone Spring remains inadequately explored and developed in the area. It is highly likely that numerous significant commercial accumulations of oil and associated gas (possible resources) remain to be found, especially in stratigraphic traps in off-structure areas. The Potash Area, in particular, has been poorly explored because of restrictions on drilling (see Ramey, this report, for a discussion of drilling restrictions in the potash area)."

p. XI-32, ATOKA GROUP;
" The Atoka Group is found within the WIPP site area at depths of 12,700 to more than 13,700 ft. The Atoka is composed of interbedded limestone, sandstone, and shale and generally mimics the Strawn Group in structural configuration. It ranges from 210 ft to more than 270 ft in thickness.

Although prolific production has been established within the nine-township study area from this unit in both limestone and sandstone reservoirs, all of the productive wells found within or adjacent to the WIPP land withdrawal area produce primarily from one narrow and thin (5 to 15+ ft) lenticular sandstone channel deposit. . . . Estimated ultimate recoveries push the per well average to over 8 BCF and 70 KBC. . . ."

p. XI-33, para 2;
" Based on subsurface mapping of this particular reservoir, it appears that there is excellent potential for similar Atoka production within the confines of the WIPP land withdrawal area. . . ."

Powell, J.A. 1976. *An Electromagnetic System for Detecting and Locating Trapped Miners*, U.S. Bureau of Mines Report of Investigations, RI 8159, U.S.B.M, Pittsburgh, PA.

ABSTRACT, p. 1;

" The theory of electromagnetic fields indicates such fields could be used to detect and locate trapped miners. To be useful, the hardware of the system must meet a number of requirements, including small size, intrinsic safety, and rugged construction. Such hardware has been built, and the system has been tested by the Bureau of Mines and its contractors. These tests indicate that the electromagnetic method provides a practical means to locate miners in emergencies."

Trauth, K.M., S.C. Hora, and R.V. Guzowski, 1993. Expert Judgment on Markers to Deter Inadvertent Human Intrusion into the Waste Isolation Pilot Plant, SAND92-1382, Albuquerque, NM, Sandia National Laboratories. WPO 23389.

ABSTRACT, p i, para 2;
" The expert panel identified the basic principles to guide current and future marker development efforts: (1) the site must be marked, (2) message(s) must be truthful and informative, (3) multiple components within a marker system, (4) multiple means of communication (e.g., language, pictographs, scientific diagrams), (5) multiple levels of complexity within individual messages on individual marker system elements, (6) use of materials with little recycle value, and (7) international effort to maintain knowledge of the locations and contents of nuclear waste repositories. The efficacy of the markers in deterring inadvertent human intrusion was estimated to decrease with time, with the probability function varying with the mode of intrusion (who is intruding and for what purpose) and the level of technological development of the society. The development of a permanent, passive marker system capable of surviving and remaining interpretable for 10,000 years will require further study prior to implementation."

APPENDIX F, 3.4.2.1 *Linguistic Demography of the WIPP Site*, p. F-44;
" The language in daily use by the majority of the residents of Eddy County (in which both WIPP and the city of Carlsbad are located) is English. The county has a sizable Hispanic population (although not as large as in other parts of New Mexico) with Spanish spoken by a minority of residents, most of whom are bilingual in English. The Mexican border, however, is only 150 miles away, and parts of west texas and New Mexico in which Spanish predominates are even closer. All projections agree that the percentage of Spanish speakers in this area will increase steadily in the foreseeable future.

Eddy County is less than 1% Indian and does not contain a community of speakers of an Indian language. There is a Mescalero Apache reservation about 120 miles to the northwest, with about 1,800 speakers out of a population of 2,000. There is no actively used written language, however, and even the spoken language is severely threatened, as children are not learning it or are learning it imperfectly. The huge Navajo reservation occupies the opposite corner of the state from WIPP site and extends into northeast Arizona. The Navajo language has 130,000 speakers out of a population of 170,000, many of whom live in Albuquerque and other towns outside the reservation. The written language is in the healthiest condition of any indigenous to North America; newspapers and books are published in it. Given current trends, Navajo should last well into the next century; as only about a third of the children are becoming fluent speakers, however, it too must be considered threatened.

3.4.2.2 *The Choice of Languages*

Which languages should the messages be in? English and Spanish are obvious choices, by virtue of their being spoken in the area of WIPP and also being two of the most widely spoken languages in the world. Our feeling is that if the scholars of future millennia cannot

read current English or Spanish, they won't be able to read any language of today. However, because there are good reasons to mark every radioactive waste site in the world identically, more languages should be represented. Those of the United Nations are obvious choices: Arabic, Chinese, French, and Russian, in addition to English and Spanish.

Markers in countries where none of the above is the local language (say, Japan) will also have to be marked in that language. This means that (assuming that at least some markers will have all languages represented) there will have to be space on the markers for a seventh language. We suggest that the seventh language on the WIPP site markers be Navajo. While the immediate area contains few if any Navajo speakers, marking in Navajo grants recognition to the fact that Native American peoples predominated in the area for many thousands of years. Also, Mescalero Apache, which is spoken relatively close to WIPP, is very closely related to Navajo.

It will be important to consult with the Navajos themselves to ensure that they feel that including a message in their language is appropriate. After all, they may see it as a patronizing attempt to appease them as one more desecration of what was once Indian land is carried out. That Native peoples might not have an automatic revulsion at the idea of marking the WIPP site in an indigenous language, however, is suggested by the fact that the President of the Mescalero Apache Tribal Council, Wendell Chino, has recently received a Department of Energy grant to investigate the possibility of storing radioactive waste on their reservation.

There exists today a number of artificially constructed 'international' languages, the most notable of which is Esperanto. Millions of people in dozens of countries have had some connection with this language, but the number of effective speakers is under 50,000. Study and use of Esperanto has had its ups and downs. It peaked between the two world wars, and was especially popular in the smaller European countries. Its effective death knell was sounded when the U.S. and the Soviet Union joined forces to prevent it from becoming a working language of the United Nations. We see no prospect of a widespread adoption of Esperanto, and do not recommend it as a language of the markers."

BIBLIOGRAPHY DOCUMENTS

DOE (U.S. Department of Energy). 1990. *Radionuclide Emission Data Package for the Waste Isolation Pilot Plant*. U.S. Department of Energy, Carlsbad, NM.

SUMMARY, p 5-1;

" The EPA has established regulations (40 CFR 61, Subpart H) limiting airborne radionuclide emissions from DOE facilities to releases that would not cause any member of the public to receive, in any year, an effective dose equivalent equal to or exceeding 10 mrem/yr. The total dose to a member of the public at maximum risk from projected annual radioactive releases from the WIPP facility during the Test Phase is established to be 0.00257 mrem/yr. This value represents 0.025 percent of the EPA airborne radionuclide emission standard. Increased chances of contracting a fatal cancer for this individual at maximum risk are less than 1 in 70,000,000 (1.43×10^{-08})."

DOE (U.S. Department of Energy), 1992. Statistical Summary of the Radiological Baseline Program for the Waste Isolation Pilot Plant, DOE/WIPP 92-037, U.S. Department of Energy, Carlsbad, NM.

Section 1.0 Introduction, p 1-1;
" The Waste Isolation Pilot Plant (WIPP) is a U. S. Department of Energy (DOE) research and development project to demonstrate the safe disposal of waste materials contaminated with transuranic (TRU) radionuclides from defense programs. From 1986 through 1989, the WIPP Radiological Baseline Program (RBP) was dedicated to characterizing the radiological environment in the vicinity of WIPP prior to the start of waste handling operations. The preoperational data collected during the RBP, along with operational data collected at control locations, will serve as a basis for evaluating the results of the WIPP Operational Environmental Monitoring Program (OEMP). This report presents statistical summaries of the RBP data bases in a form that will facilitate their use in the OEMP."

DOE (U.S. Department of Energy), 1993. Waste Isolation Pilot Plant Land Management Plan, DOE/WIPP 93-004, U.S. Department of Energy, Carlsbad Area Office, Carlsbad, NM.

Section 1.2 Management Goal, p 1-5;

" The goal of this land management plan is to manage the surface of the withdrawal area under the traditional public land use concept of multiple use and to minimize, to the extent possible, land use restrictions. It is not the intent of the DOE to manage the surface of the withdrawal area as a WIPP exclusive-use area. The subsurface of the withdrawal area is restricted to exclusive use by the WIPP, except for two 320-acre tracts of land within the withdrawal area that are leased for oil and gas development below 6000 feet (Federal Oil and Gas Leases No. NMNM 02953 and No. NMNM 02953C). This restriction is needed to protect the long-term integrity of the WIPP repository. In addition, it is clearly the intent of DOE that during repository operations, facility safety and security shall be maintained."

DOE (U.S. Department of Energy). 1994. WIPP Active Access Controls After Disposal Design Concept Description (Draft). Revision 1, December 1994. U.S. Department of Energy, Carlsbad, NM.

SCOPE, p 2;

" The design description addresses a means of controlling access to the site of the repository's surface footprint (the repository area projected to the surface). It is anticipated that active control of access to the site will be exercised by the DOE or other federal government entity for at least 100 years. Control of access will preclude the inadvertent intrusion into the disposed waste by deep well drilling or mining of natural resources. The report also describes a process for scheduling activities required to meet the needs of the Long Term Monitoring of the repository performance. Many of these activities will be initiated during the disposal phase to establish data bases and are planned to continue beyond the time after removal of the site structures and return of the site to as near its original configuration as possible. Permanent Marker testing and Long Term Monitoring requirements will impact return of the site to its original condition."

U.S. Congress, 1992. Waste Isolation Pilot Plant Land Withdrawal Act, Public Law 102-579.

"An Act
To withdraw land for the Waste Isolation Pilot Plant, and for other purposes.
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,"

SEC 2 (20) defines TRANSURANIC WASTE as follows: "The term 'transuranic waste' means waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years, except for--

(A)high-level radioactive waste;

(B) waste that the Secretary has determined, with the concurrence of the Administrator, does not need the degree of isolation required by the disposal regulations; or

(C) waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with part 61 of title 10, Code of Federal Regulations."

SEC.3.LAND WITHDRAWAL AND RESERVATION FOR WIPP.;

" (a)LAND WITHDRAWAL, JURISDICTION, AND RESERVATION.--

(1)LAND WITHDRAWAL.--Subject to valid existing rights, and except as otherwise provided in this Act, the lands described in subsection (c) are withdrawn from all forms of entry, appropriation, and disposal under the public land laws, including without limitation the mineral leasing laws, the geothermal leasing laws, the material sale laws (except as provided in section 4(b)(4) of this Act), and the mining laws.

(2)JURISDICTION.--Except as otherwise provided in this Act, jurisdiction over the Withdrawal is transferred from the Secretary of the Interior to the Secretary.

(3)RESERVATION.--Such lands are reserved for the use of the Secretary for the construction, experimentation, operation, repair and maintenance, disposal, shutdown, monitoring, decommissioning, and other authorized activities associated with the purposes of WIPP as set forth in section 213 of the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Pub.L. 96-164; 93 Stat. 1259, 1265), and this Act.

(b) REVOCATION OF PUBLIC LAND ORDERS.--Public Land Order 6403 of June 29, 1983, as modified by Public Land Order 6826 of January 28, 1991, and any memoranda of understanding accompanying such land orders, are revoked.

(c)LAND DESCRIPTION.--

(1)BOUNDARIES.--The boundaries depicted on the map issued by the Bureau of Land Management of the Department of the Interior, entitled 'WIPP Withdrawal Site Map,' dated October 9, 1990, and on file with the Bureau of Land Management, New Mexico State Office, are established as the boundaries of the Withdrawal.

(2)LEGAL DESCRIPTION AND MAP.--Within 30 days after the date of the

enactment of this Act, the Secretary of the Interior shall--

(A) publish in the Federal register a notice containing a legal description of the Withdrawal; and

(B) file copies of the map described in paragraph (1) and the legal description of the Withdrawal with the Congress, the Secretary, the Governor of the State, and the Archivist of the United States.

(d)TECHNICAL CORRECTIONS.--The map and legal description referred to in subsection (c) shall have the same force and effect as if they were included in this Act. The Secretary of the Interior may correct clerical and typographical errors in the map and legal description.

(e)WATER RIGHTS.--This Act does not establish, nor may any provision be construed to establish, a reservation to the United States with respect to any water or water rights. Nothing in this Act shall affect any water rights acquired by the United States prior to the date of enactment of this Act. The United States may apply for and obtain water rights for purposes associated with this Act only in accordance with the substantive and procedural requirements of the laws of the State."

"SEC.7.DISPOSAL OPERATIONS.

(a)TRANSURANIC WASTE LIMITATIONS.--

(1) REM LIMITS FOR REMOTE-HANDLED TRANSURANIC WASTE.--

(A) 1,000 REMS PER HOUR.--No transuranic waste received at WIPP may have a surface dose rate in excess of 1,000 rems per hour.

(B) 100 REMS PER HOUR.--No more than 5 percent by volume of the remote-handled transuranic waste received at WIPP may have a surface dose rate in excess of 100 rems per hour.

(2) CURIE LIMITS FOR REMOTE-HANDLED TRANSURANIC WASTE.--

(A) CURIES PER LITER.--Remote-handled transuranic waste received at WIPP shall not exceed 23 curies per liter maximum activity level (averaged over the volume of the canister).

(B) TOTAL CURIES.--The total curies of the remote-handled transuranic waste received at WIPP shall not exceed 5,100,000 curies."

(3) CAPACITY OF WIPP.--The total capacity of WIPP by volume is 6.2 million cubic feet of transuranic waste."

SEC. 8. ENVIRONMENTAL PROTECTION AGENCY DISPOSAL REGULATIONS.

(a) REINSTATEMENT.--

(1) IN GENERAL.--Except as provided in paragraph (2), the disposal regulations issued by the Administrator on September 19, 1985, and contained in subpart B of part 191 of title 40, Code of federal regulations, shall be in effect.

(2) EXCEPTIONS.--Paragraph (1) shall not apply to--

(A) the 3 aspects of sections 191.15 and 191.16 of such regulations that were the subject of the remand ordered in Natural Resources Defense Council, Inc. v. United States Environmental Protection Agency, 824 F.2d 1258(1st Cir., 1987); and

(B) the characterization, licensing, construction, operation, or closure of any site required to be characterized under section 113(a) of Public Law 97-425."

(d) DISPOSAL REGULATIONS.--

(A) IN GENERAL.--The Secretary shall comply at WIPP with the final disposal regulations. Within 7 years of the date of first receipt of transuranic waste at WIPP, the Secretary shall submit to the Administrator an application for certificatio of compliance with such regulations.

(B) CERTIFICATION BY ADMINISTRATOR.--Within 1 year of receipt of the application under subparagraph (A), the Administrator shall certify, by rule pursuant to section 553 of title 5, United Staes Code, whether the WIPP facility will comply with the final disposal regulations, and sections 556 and 557 of such title shall not apply.

(C) JUDICIAL REVIEW.--Judicial review of the certification of the Administrator under subparagraph (B) shall not be restricted by the provisions of section 221 c. of the Atomic Energy Act of 1954 (42 U.S.C. 2271(c)).

(D) LIMITATION.--Any certification of the Administrator under subparagraph (B) may only be made after the application is submitted to the Administrator under subparagraph (A)."

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EPA (U.S. Environmental Protection Agency), 1993. Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste, Federal Register, Vol. 58, No. 242, pp. 66398-66416, December 20, 1993, (58FR 66398), Environmental Protection Agency Office of Radiation and Indoor Air, Washington, D.C. WPO 39133

PREAMBLE: SUMMARY;

" The U.S. Environmental Protection Agency (EPA) is promulgating amendments to the environmental standards for the disposal of spent nuclear fuel, high-level and transuranic wastes (40 CFR 191.15 and Subpart C).

EPA originally promulgated these standards in 1985 pursuant to the Agency's authorities and responsibilities under the Nuclear Waste Policy Act of 1982, as amended, the Atomic Energy Act of 1954, as amended, and §2(a)(6) of Reorganization Plan No. 3 of 1970 (5 USC app. 1). In 1987, following a legal challenge, the U.S. Court of Appeals for the First Circuit (hereinafter referred to as 'the First Circuit' or ' the court') remanded subpart B of the 1985 standards to the Agency for further consideration. *Natural Resources Defense Council, Inc. v. United States Environmental Protection Agency*, 824 F.2d 1258 (1st Cir. 1987). Recently enacted legislation, (Pub. L. 102-579) known as the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA), however, reinstates the 1985 disposal standards except 'the 3 aspects of §§191.15 and 191.16 of such [standards] that were subject of the remand ordered' by the First Circuit. The WIPP LWA directs EPA to expedite issuance of final disposal standards and specifies that such regulations shall not be applicable to the characterization, licensing, construction, operation, or closure of any site required to be characterized under §113(a) of Public Law 97-425, the Nuclear Waste Policy Act of 1982.

Today's action represents the Agency's response to this legislation and to the issues raised by the court pertaining to individual and ground-water protection requirements. After considering the relevant comments received on the February 10, 1993 proposed rulemaking, the Agency has taken this final action in the form of amendments to parts 191 of title 40 of the Code of Federal Regulations. In so doing, EPA has not revised any of the regulations reinstated by the WIPP LWA.

DATES: These amendments will become effective on January 19, 1994. These amendments will be promulgated for purposes of judicial review at 1 p.m. eastern standard time on December 20, 1993."

STATUTORY AND REGULATORY BACKGROUND;

" The WIPP Land Withdrawal and Nuclear Waste Policy Acts

As noted above, today's action responds to the directive in section 8 of the WIPP LWA that EPA conduct a rulemaking to issue certain radioactive waste disposal regulations at 40 CFR Part 191, subpart B. The EPA initially promulgated subpart B in 1985 (50 FR 38084 (Sept. 19, 1985)), but those regulations were subsequently vacated in whole as part of a remand order issued by the First Circuit in 1987 (discussed further above and below). See *NRDC v. EPA*, 824 F.2d 1258 (1st Cir. 1987).

Section 8(a)(1) of the WIPP LWA reinstates those portions of subpart B except §§191..15 and 191.16 (which were the bases of remand by the First Circuit). Accordingly, section 8(a)(2)(A) of the WIPP LWA exempts the requirements at 40 CFR 191.15 (individual protection) and 191.16 (ground-water protection) from the statutory reinstatement. Section 8(b)(2) addresses these non-reinstated provisions by directing the EPA promulgate final regulations. Today's action responds to that directive by revising the individual protection requirements in 40 CFR 191.15, discussed above, and by adding new ground-water protection standards as 40 CFR part 191, subpart C (discussed below)."

Federal register, Vol. 58 No. 242, p 66398, dated December 20,1993

"191.15 Individual protection requirements.

(a) Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts).

(b) Annual committed effective doses shall be calculated in accordance with appendix B of this part.

(c) Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved.

(d) Compliance with the provisions in this section does not negate the necessity to comply with any other applicable Federal regulations or requirements.

(e) The standards in this section shall be effective on January 19, 1994."

"Subpart C-Environmental Standards for Ground-Water Protection

. . .191.23 General provisions.

(a) Determination of compliance with this subpart shall be based upon underground sources of drinking water which have been identified on the date the implementing agency determines compliance with subpart C of this part.

191.24 Disposal standards.

(a) Disposal systems.

(1) General. Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that 10,000 years of undisturbed performance after disposal shall not cause the levels of radioactivity in any underground source of drinking water, in the accessible environment, to exceed the limits specified in 40 CFR part 141 as they exist on January 19, 1994.

(2) Disposal systems above or within a formation which within one-quarter (1/4) mile

contains an underground source of drinking water. [Reserved]

(b) Compliance assessments need not provide complete assurance that the requirements of paragraph (a) of this section will be met. Because of the long time period involved and the nature of the processes and events of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with paragraph (a) of this section will be achieved. . . ."

§191.27. Effective date: p. 66415, col. 3;
"Appendix A to Part 191--Table for Subpart B

9.Appendix B is redesignated as Appendic C to part 191 and the heading is revised as follows:
Appendix C to Part 191--Guidance for Implementation of Subpart B."

EPA (U.S. Environmental Protection Agency), 1996. 40 CFR Part 194: Criteria for the Certification and Recertification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations. Final Rule. Federal Register, Vol. 61, pp. 5224-5245, February 9, 1996. Office of Radiation and Indoor Air, Washington, D.C. In NWM Library as KF70.A35.C757 1996 (Reference).

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992.
EFFECTIVE DATE: These regulations are effective April 9, 1996."

p. 5238, col. 2;
" §194.14. Content of compliance certification application.

Any compliance application shall include:

(a) A current description of the natural and engineered features that may affect the performance of the disposal system. The description of the disposal system shall include, at a minimum, the following information:

(1) The location of the disposal system and the controlled area;

(2) A description of the geology, geophysics, hydrogeology, hydrology and geochemistry of the disposal system and its vicinity and how these conditions are expected to change and interact over the regulatory time frame. Such description shall include, at a minimum:

(i) Existing fluids and fluid hydraulic potential, including brine pockets, in and near the disposal system; and

(ii) Existing higher permeability anhydrite interbeds located at or near the horizon of the waste.

(3) The presence and characteristics of potential pathways for transport of waste from the disposal system to the accessible environment including, but not limited to: Existing boreholes, solution features, breccia pipes, and other potentially permeable features, such as interbeds.

(4) The projected geophysical, hydrogeologic, and geochemical conditions of the disposal system due to the presence of waste including, but not limited to, the effects of production of heat or gases from the waste."

p. 5240, col. 2;
" §194.24 Waste characterization.

(a) Any compliance application shall describe the chemical, radiological and physical composition of all existing waste proposed for disposal in the disposal system. To the extent practicable, any compliance application shall also describe the chemical, radiological and physical composition of to-be-generated waste proposed for disposal in the disposal system. These descriptions shall include a list of waste components and their approximate quantities in the waste. This list may be derived from process knowledge, current non-destructive examination/assay, or other information and methods."

p. 5243, Assurance Requirements, col. 3;
" §194.44 Engineered barriers.

(a) Disposal systems shall incorporate engineered barrier(s) designed to prevent or substantially delay movement of water or radionuclides toward the accessible environment."

BIBLIOGRAPHY DOCUMENTS

U.S. Department of Energy (DOE), 1988, Internal Dose-Rate Conversion Factors for Calculation of Dose to the Public, DOE/EH-0071, DOE Office of Environmental Guidance and Compliance, Washington, D.C.

ABSTRACT; p. iii, para. 1;
" This publication contains 50-year committed dose equivalent factors, in tabular form. The document is intended to be used as the primary reference by the U. S. Department of Energy (DOE) and its contractors for calculating radiation dose equivalents for members of the public, resulting from ingestion or inhalation of radioactive materials. Its application is intended specifically for such materials released to the environment during routine DOE operations, except in those instances where compliance with 40 CFR 61 (National Emission Standards for Hazardous Air Pollutants) requires otherwise. However, the calculated values may be equally applicable to unusual releases or to occupational exposures. The use of these committed dose equivalent tables should ensure that doses to members of the public from internal exposures are calculated in a consistent manner at all DOE facilities.

These tables are to be used with the revised DOE radiation standards for members of the public, which was adopted by the DOE on August 5, 1985, and incorporated in the DOE Order entitled "Radiation Protection of the Public and the Environment." Those standards are based on the system of radiation risk assessment described in Publication 26 et seq. of the International Commission on Radiological Protection (ICRP).

The series of ICRP publications starting with Publication 26 provides the technical base used in calculating the committed dose equivalent factors in these tables. The factors are expressed in committed dose equivalent per unit intake of radioactive materials. For radionuclides with a long effective half-life in the body, the committed dose equivalent may be received over a period of years following the intake; for radionuclides with short effective half-lives, the entire dose equivalent may be received in the year following intake. Accompanying the tables is a discussion that explains how the committed dose equivalent values were derived and how they are to be used. Consistent with ICRP recommendations, the tables incorporate:

- the 50-year committed dose equivalent for specific organs, and

- the effective dose equivalent, corresponding to an equivalent risk of health effects from uniform irradiation of the whole body, using the weighting factors given in ICRP Publication 26."

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Aldrich Chemical Company. 1994. Aldrich Catalog Handbook of Fine Chemicals, 1994-1995. Milwaukee, WI: Aldrich Chemical Co.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Al-Hussaini, M. 1981. "Tensile Properties of Compacted Soils," Laboratory Shear Strength of Soil, Eds. R.N. Yong and F.C. Townsend, ASTM Special Technical Publication No. 740 American Society for Testing and Materials, Philadelphie, PA. pp. 207-225.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Altman, W.D., Donnelly, J.P., and Kennedy, J.E. 1988. Peer Review for High-Level Nuclear Waste Repositories Generic Technical Position. NUREG-1297, Division of High-Level Nuclear Waste Management, Office of Nuclear Material Safety and Safeguards. U.S. Nuclear Regulatory Commission, Washington, D.C.

ABSTRACT, p iii;

" This document provides guidance on the use of the peer review process in the high-level nuclear waste repository program. The applicant must demonstrate in the license application that the applicable health, safety, and environmental regulations in 10 CFR Part 60 have been met. Confidence in the data used to support the license application is obtained through a quality assurance (QA) program as described in 10 CFR Part 60, Subpart G.

Peer reviews may be used as part of the QA actions necessary to provide adequate confidence in the work being reviewed. Because of several unique conditions inherent in the geologic repository program, expert judgement will need to be utilized in assessing the adequacy of work. Peer reviews are a mechanism by which these judgements may be made.

This document provides guidance on areas where a peer review is appropriate, the acceptability of peers, and the conduct and documentation of a peer review."

Anderson, R., Vaughn,P.L., Stoelzel, D., and O'Brien, D. 1996. "Justification of Brine Pocket Volume Uncertainty." Memorandum to Margaret Chu, July 22, 1996. Sandia National Laboratories, Albuquerque, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Bachman, G.O., 1985. Assessment of Near-Surface Dissolution At and Near the Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico, SAND84-7178, Sandia National Laboratories, Albuquerque, NM. WPO 24609.

ABSTRACT, p. 3;

" The area at and near the WIPP site was examined for evidence of karst development on the geomorphic surface encompassing the site. Certain surficial depressions of initial concern were identified as blowouts in sand dune fields (shallow features unrelated to karstification). An ancient stream system active more than 500,000 years ago contained more water than any system since. During that time (Gatuña, Middle Pleistocene), many karst features such as Clayton Basin and Nash Draw began to form in the region. Halite was probably dissolved from parts of the Rustler Formation at that time. Dissolution of halite and gypsum from intervals encountered in Borehole WIPP-33 west of the WIPP site occurred during later Pleistocene time (i.e., <450,000 yr ago). However, there is no evidence of active near-surface dissolution within a belt to the east of WIPP-33 in the vicinity of the WIPP shaft."

Bachman, G.O., 1987. Karst in Evaporites in Southeastern New Mexico, SAND86-7078, Sandia National Laboratories, Albuquerque, NM. WPO 24006.

ABSTRACT;
" Permian evaporites in southeastern New Mexico include gypsum, anhydrite, and salt, which are subject to both blanket and local, selective dissolution. Dissolution has produced many hundreds of individual karst features including collapse sinks, karst valleys, blind valleys, karst plains, caves, and breccia pipes. Dissolution began within some formations during Permian time and has been intermittent but continual ever since. Karst features other than blanket deposits of breccia are not preserved from the early episodes of dissolution, but some karst features preserved today--such as breccia pipes--are remnants of karst activity that was active at least as early as mid-Pleistocene time. Rainfall was much more abundant during Late Pleistocene time, and many features visible today may have been formed then. The drainage history of the Pecos River is related to extensive karstification of the Pecos Valley during mid-Pleistocene time. Large-scale stream piracy and dissolution of salt in the subsurface resulted in major shifts and excavations in the channel. In spite of intensive groundwater studies that have been carried out in the region, major problems in groundwater in near-surface evaporite karst remain to be solved. Among these are determination of recharge areas and time of recharge."

Bates, R.L., and Jackson, J.A., eds. 1987. Glossary of Geology, 3rd ed. American Geological Institute, Alexandria, VA.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Beauheim, R.L. 1987a. Analysis of Pumping Tests of the Culebra Dolomite Conducted at the H-3 Hydropad at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-2311. Sandia National Laboratories, Albuquerque, NM. WPO 28468.

ABSTRACT;

" Two pumping tests were conducted in the Culebra Dolomite Member of the Rustler Formation at the H-3 hydropad at the Waste Isolation Pilot Plant (WIPP) site. The first test was in 1984, with well H-3b3 pumped for 14 days at an average rate of 4 gpm. The second test, the H-3 multipad test, was in late 1985 and early 1986, with well H-3b2 pumped for 62 days at an average rate of 4.8 gpm. Both tests provided information on the hydraulic properties of the Culebra at the H-3 hydropad. The second test provided information on average Culebra hydraulic properties on a much larger scale; responses were observed up to 8000 ft from the pumping well.

The interpretation of these tests had three principle objectives. The first was to determine the most appropriate conceptualization of the nature of the Culebra flow system around the H-3 hydropad. The pumping well responses during the H-3 tests appear to be those of wells completed in a double-porosity medium with unrestricted interporosity flow. In such a system, fractures provide the bulk of the permeability, while matrix pores provide the majority of the storage capacity. The importance of fracture flow is indicated by the speed with which the observation wells on the H-3 hydropad respond to pumping and the nearly identical behaviors of these wells and the pumping well. The similarity between pumping- and observation-well behavior on the H-3 hydropad is so pronounced that the responses of all three wells on the hydropad can be interpreted only by using pumping-well analytical techniques, not observation-well analytical techniques. H-3b1 and H-3b3, in particular, appear to be very well connected by fractures.

The second objective was to quantify the hydraulic properties of the Culebra in the vicinity of the H-3 hydropad. The total-system (fractures plus matrix) transmissivity of the Culebra derived from the first test is 2.9 ft^2/day; that from the second test is 1.7 ft^2/day. The lower value derived from the second test probably represents lower transmissivity (lower fracture connectivity) at H-3b2 than at H-3b3, and/or lower average transmissivity of the volume of Culebra stressed in the multipad test as opposed to the smaller volume stressed in the first test. The fracture-to-total-system storativity ratios derived from the various analyses range from 0.03 to 0.25, indicating a relatively high degree of storage within the fractures. The highest storativity ratios were consistently found at H-3b1. Wellbore skin values are highly negative, indicating direct wellbore connection with fractures.

The third objective was to quantify the average hydraulic properties of the Culebra between the H-3 hydropad and more-distant observations wells. Meeting this objective . . ."

Pg. 100 Table A-3

Table A-3. Water Levels and Pressures in Observation Well DOE-1 During the 1984 H-3 Pumping Test

Day	Hr	Min	Elapsed Time (hr)	Depth to Water (ft)	Pressure* (psi)	Comments
101	16	32	-305.970	499.18	47.69	
108	14	10	-140.330	499.21	47.67	
110	8	55	-97.583	499.31	47.63	
110	14	5	-92.417	499.08	47.74	
110	15	44	-90.767	499.21	47.67	
111	12	45	-69.750	499.18	47.69	
114	8	45	-1.750	499.74	47.42	
114	12	7	1.617	499.61	47.48	PUMP ON AT H-3B3
115	9	42	23.200	499.61	47.48	114:10:30
117	13	46	75.267	499.41	47.58	
118	13	40	99.167	500.00	47.30	
121	13	17	170.783	500.75	46.95	
122	13	20	194.833	500.85	46.90	
123	11	52	217.367	501.05	46.80	
124	9	24	238.900	501.35	46.66	
125	10	6	263.600	501.51	46.59	
128	13	48	339.300	502.46	46.14	

*Pressure = (600 ft - Depth to Water) x 0.473 psi/ft

Beauheim, R.L., 1987b. Interpretations of Single-Well Hydraulic Tests Conducted At and Near the Waste Isolation Pilot Plant (WIPP) Site, 1983-1987, SAND87-0039, Sandia National Laboratories, Albuquerque, NM. WPO 27679.

1. INTRODUCTION; p. 17, col. 1, para. 1;

" This report presents the results of single-well hydraulic tests performed in 23 wells in the vicinity of the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico (Figure 1-1) between 1983 and 1987.

Most of the tests discussed in this report were performed in the Culebra Dolomite Member of the Rustler Formation. The Culebra was tested at wells H-1, H-4c, H-8b, H-12, H-14, H-15, H-16, H-17, H-18, WIPP-12, WIPP-18, WIPP-19, WIPP-21, WIPP-22, WIPP-30, P-15, P-17, P-18, ERDA-9, Cabin Baby-1, DOE-1, and Engle. The Forty-niner, Magenta, and Tamarisk Members of the Rustler were tested in H-14 and H-16. The unnamed lower member of the Rustler Formation was tested in H-16. The Dewey Lake Red Beds were tested in H-14. Alluvium of Cenozoic age was tested in the Carper Well. The Castile and Salado Formations were tested in WIPP-12. With the exception of additional testing performed at DOE-2 that has been previously reported by Beauheim (1986), this report discusses all single-well testing initiated by Sandia and its subcontractors at the WIPP site from 1983 through 1987."

p. 100, col. 1, para. 1;

" Two type-curve matches are shown with the test data on Figure 5-71. The early-time data were best fit by a type curve characteristic of damaged (i.e., having a positive skin) wells, whereas the late-time data were best fit by a type curve characteristic of undamaged (i.e., having a neutral or no skin) wells. The two type-curve matches also provide contrasting transmissivity estimates. The transmissivity derived from the early-time match is about 4 x 10-3 ft^2/day, while that from the late-time match is about 7 x 10-5 ft^2/day (Table 5-3). These observations indicate that the P-18 wellbore may be poorly connected hydraulically to a small portion of the culebra having a higher transmissivity than more-distant portions. The contrast between the transmissivity of the Culebra and that of the well "skin" may decrease as the transmissivity of the Culebra decreases with distance from P-18, resulting in the neutral skin shown by the late-time data. The fact that the slope of the data on Figure 5-71 changes abruptly as opposed to smoothly appears to indicate that the change in transmissivity is discrete rather than gradational. Drilling of the borehole may have caused minor fracturing of the formation around the hole, which may have led to a slightly enhanced transmissivity in the immediate vicinity of the hole. Casing, cementing, and perforation may have resulted in a poor connection between the wellbore and the surrounding formation, resulting in the positive skin observed.

Given the peculiarities in the response to the P-18 slug test and the uncertainties as to their cause, the transmissivity of the Culebra at P-18 remains poorly defined. The estimate provided by the early-time type-curve match does not appear to be valid beyond the immediate vicinity (a few feet?) of the well. The transmissivity estimate provided by the

late-time type-curve match may not be quantitatively reliable because the time match between the data and the type curve, which defines the transmissivity, would probably be greater, thus indicating a lower transmissivity, if the hydraulic response of the Culebra had been more consistent (i.e., homogeneous). In summary, the transmissivity estimate from the early-time data, 4 x 10-3 ft^2/day, is probably unrealistically high, but is reliably a maximum value. The estimate from the late-time data, 7 x 10-5 ft^2/day, is probably more representative of the Culebra in the vicinity of P-18, but cannot be interpreted as a minimum value."

Beauheim, R.L. 1989. Interpretation of H-11b4 Hydraulic Tests and the H-11 Multipad Pumping Test of the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site. SAND89-0536. Sandia National Laboratories, Albuquerque, NM. WPO 24154.

ABSTRACT, p. 3;

" Drillstem tests, slug tests, a small-scale pumping test, and a large-scale pumping test of the Culebra Dolomite Member of the Rustler Formation were performed in 1988 at the H-11 hydropad at the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico. The drillstem, slug, and small-scale pumping tests were conducted in well H-11b4 to evaluate well and aquifer properties in preparation for a tracer test. The large-scale pumping test, known as the H-11 multipad test, was performed by pumping well H-11b1 in the southern part of the WIPP site at a rate of six gpm for 63 days and monitoring drawdown and recovery responses in three other wells on the H-11 hydropad and at 11 observation wells within a three-mile radius. Responses were observed in 10 of these distant wells. The H-11 multipad pumping test complemented the H-3 and WIPP-13 multipad pumping tests conducted in the central and northern portions of the WIPP site in late 1985 and early 1987, respectively.

Individual well tests at various locations around the WIPP site have demonstrated that the Culebra is a laterally heterogeneous water-bearing unit. The responses measured at observation wells to pumping tests in heterogeneous systems cannot be rigorously interpreted using standard analytical (as opposed to numerical) techniques developed for tests in homogeneous results in evaluations of average hydraulic properties between pumping and observation wells that are nonunique in the sense that they are representative only of the responses observed when a hydraulic stress is imposed at a certain location. These 'apparent' hydraulic properties do, however, provide a qualitative understanding of the nature and distribution of both hydraulic properties and heterogeneities or hydraulic boundaries with the tested area.

The interpretations of the responses at the test and observation wells provided the following information: The Culebra is a fractured, double-porosity system at H-11 with a transmissivity between 27 and 43 ft^2/day and a storativity between 3.4 x 10^{-5} and 1.5 x 10^{-4}. Drawdown during the multipad test appeared to be largely concentrated to the north and south of H-11; wells to the east and west showed relatively low-magnitude responses. The rapid and high-magnitude responses observed at DOE-1, H-3b2, and H-15 during the multipad test are believed to reflect the presence of a fracture network extending to the north from H-11. Numerical simulations indicate that the fracture network extends south of H-11. but no wells are currently situated within it.

Double-porosity hydraulic behavior was observed at DOE-1 during the multipad test, and at both DOE-1 and H-3b2 during other pumping tests performed at those locations. The fractures appear to continue past DOE-1 to the north toward H-15, although H-15 itself lies in a lower transmissivity, apparently single-porosity zone. Apparent transmissivities in the region north of H-11 range from 7.1 to 9.0 ft^2/day and apparent storativities range from 2.4 x 10^{-6} to 8.4 x 10^{-6}. Apparent transmissivities between H-11 and observation wells to the

west, southwest, and southeast, where fracturing in the Culebra decreases and single-porosity hydraulic behavior is observed, range from 6.0 to 21.0 ft^2/day and apparent storativities range from 1.8×10^{-5} to 6.5×10^{-5}. Interpretation of the responses to the multipad test observed at the western and southern wells was complicated by an anomalous and widespread rise in water levels of unknown origin.

Thus, the analyses of the responses measured at observation wells to the H-11 multipad pumping test are consistent with a conceptualization of two distinct domains within a heterogeneous portion of the Culebra south of the center of the WIPP site: a fractured region having low storativity extending to the north and south from H-11, and a relatively unfractured region west, southwest, and southeast of H-11 having higher storativity. This conceptualization is being refined using numerical-modeling techniques to simulate the H-11 multipad test and other tests at the WIPP site, in an attempt to define a distribution of hydraulic properties that will reproduce the response observed."

Bechtel National, Inc. 1979-1980. Waste Isolation Pilot Plant Title I Design Report, Bechtel National Inc., San Francisco, CA. (This 32 volume set in on file in the Nuclear Waste Management Library, Sandia National Laboratories, Albuquerque, NM as UN00597.)

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Berglund, J.W., and Lenke, L.R. 1995. "One Dimensional Experiments of Gas Induced Spall." NMERI 1995/3. prepared for Sandia National Laboratories. New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, NM, WPO 27589.

ABSTRACT, p. ii, para. 1;

" An investigation of 1-dimensional outgassing from cohesive granular media and resultant induced spall are described in this report. An experimental laboratory program was developed to model sudden outgassing and resultant spall from a waste repository breached by a rotary drilling bit. A simple 1-dimensional geometry was employed in order to obtain a better understanding of the phenomenology of transient gas flow from porous media at an unsupported free boundary. The experimental results suggest that, in addition to the permeability and porosity of the porous media, the tensile strength of the cohesive granular media dictates the spall resistance of such materials. Based on the knowledge gained from this geometry, a simple bounding model is proposed for predicting the volume of waste released in the event of inadvertent intrusion by a drilling operation."

2.1 Material Selection, p. 4, para. 2;

" Butcher (1994) has proposed a model for estimating the properties of released waste. His model is based on the premise that a precise definition of the end states of the biological and chemical waste degradation processes in the WIPP repository are difficult, if not impossible, to define. One extreme of the model is that microbiological degradation may reduce all the cellulosics to a small amount of inert residue, while corrosion processes may alter all ferrous materials to a high-strength oxide. Butcher suggests that such a material would be highly resistant to erosion. At the other extreme, the combination of cellulosics degradation and metal corrosion could produce a mixture of low shear strength with little resistance to erosion. One would surmise that similar arguments would apply to the response of these materials to transient out gassing and resultant spall, i.e., materials with a high resistance to spall and those having virtually no resistance to spall.

Butcher states that there is no known method to replicate these long-term chemical processes in the laboratory and produce such complex waste mixtures. Instead, the selection of well chosen surrogate materials which are representative of various decomposition and corrosion states is proposed. At the low shear strength extreme, a clay material is used to represent the soft, perhaps "soapy," amorphous substances that may be typical of some stages of microbial degradation. Clay is also considered to represent the "slimy" hydrated or unhydrated iron hydroxide ($Fe(OH)_2$) corrosion products. Quartz sand is proposed to represent the other extreme of corrosion products, namely, those with higher shear strength. This sand is believed to be a good surrogate for end products such as iron oxide (Fe_3O_4) because it is relatively incompressible and its chemical composition is less important that particle size and shape and resultant mechanical properties of relatively inert end products.

In summary, samples of sand and clay were used in this experimental program as waste surrogates for partially corroded and decomposed waste mixtures. A kaolin clay and select silica sand gradation were chosen as waste surrogate materials."

2.3.3.1 Direct Tension Tests, p. 13, para. 4;

" The sample geometry employed for most conventional tensile testing is one with a high length to width aspect ratio. Such geometry is not practical for low strength soil samples. It was decided to keep the geometry similar to that of conventional soil strength tests with a sample length twice that of the diameter. The cylinders used for permeability lend themselves nicely to preparing samples 2 inch (50 mm) in diameter by 4 inch (100 mm) in length. Samples were prepared by compacting lifts to the specified density using a Harvard compaction tamper (Wilson, 1970). Early tests were conducted using prismatic cylindrical endcaps. Because of stress concentrations at the soil-endcap interfaces, failure invariably occurred at this point.

Because of the non-uniform stress field in the cylindrical samples, efforts were then made to develop a "dog-bone" shape sample. Such a sample is shown in Figure 2-7 along with a section view of the mold used for sample preparation. This sample, 2 inch diameter by 4 inch long (50 mm by 100 mm), tapers uniformly from the 2 inch diameter at a distance of 0.25 inch (6.4 mm) from each end to a diameter of 1.6 inch (40.6 mm) at the center. This sample geometry was used in all subsequent tensile tests. The sample is prepared in a split mold having the same shape as the sample of Figure 2-7. The upper half of the sample is compacted first. A cylindrical plug 1.6 inch (40.6 mm) in diameter and 2 inch (51 mm) long is placed at the bottom of the sample mold. The top of the sample is then compacted in three lifts (labeled 1, 2, and 3 in Figure 2-7). The plug is then removed and the sample is inverted with compaction of the remaining three lifts. Upon completion of compaction, the split sample mold is removed leaving an intact tensile specimen.

FIGURE 2-7 NOT INCLUDED IN TEXT

The prepared tensile specimen is secured to two aluminum end caps (2 inch (50 mm) diameter) using a gap-filling slow-set cyanoacrylate adhesive, i.e., "super glue." It was found that a drill press works rather nicely for aligning the end caps with the specimen and provides a means of lightly clamping the specimen while the adhesive sets. Once the end caps are properly aligned and clamped in place, a super glue accelerator is sprayed at the specimen endcap interface which cures the super glue almost instantaneously.

The end caps each have spherical bearings placed on their center lines. These bearings assure that the specimen will maintain a vertical alignment during the actual test resulting in a uniform tensile field within the sample. The complete test setup is shown in Figure 2-8. A bolt passes through the top spherical bearing which is clamped in the chuck of the drill press. A similar bolt with a small diameter cable through a small hole on center line is placed in the lower bearing. Attached to this cable is a light weight pail (paint can). Once the sample is in this configuration, lead shot is slowly poured in the pail via a long funnel. When the sum weight of the lead shot, pail, bottom end cap and lower half of the failed sample causes failure the test is complete. This weight is then determined and is used

to calculate the tensile strength based on the actual area corresponding to the failure plane.

2.3.3.2 Indirect Tension Tests, p. 15, para. 2;
" An additional verification of the tensile properties of the waste surrogate was made by testing a cylindrical sample indirect tension. This test, also known as a diametrical tension test, produces a fairly uniform tensile stress along the vertical axis of the sample."

p. 17, para. 1;
" Figure 2-10 compares results from both direct and indirect tensile tests of 15% clay-sand blends prepared at a dry density of 107 pcf (1715 kg/m^3) and moisture content of 7.5%."

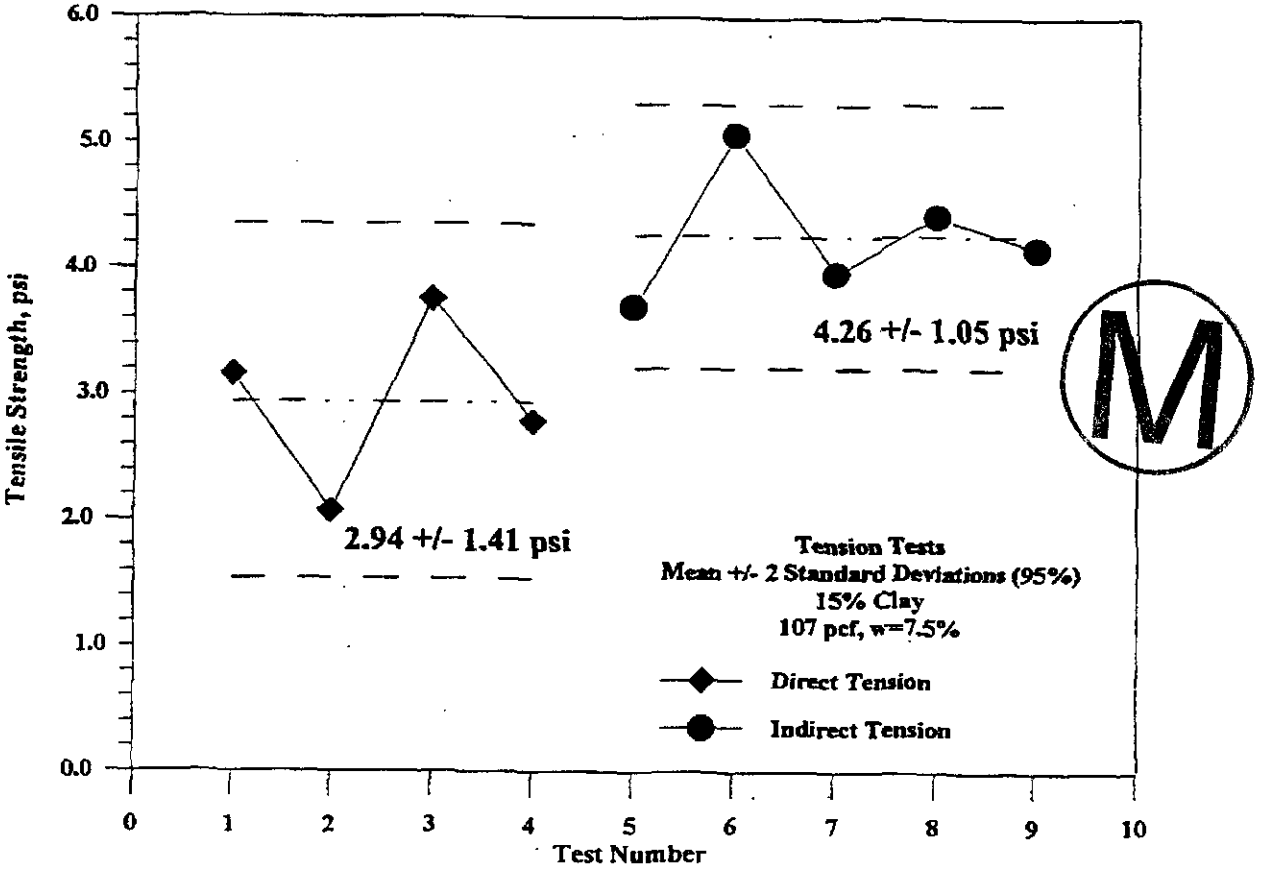

Figure 2- 10. Tension Test Results.

Bertram-Howery, S.G., and Hunter, R.L., eds. 1989. Preliminary Plan for Disposal-System Characterization and Long-term Performance Evaluation of the Waste Isolation Pilot Plant. SAND89-0178. Sandia National Laboritories, Albuquerque, NM. WPO 24103.

ABSTRACT;
" The U. S. Department of Energy is planning to dispose of transuranic wastes at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Sandia National Laboratories is responsible for evaluating the compliance of the WIPP with the Environmental Protection Agency's Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR 191, Subpart B). This plan has been developed to present the issues that will be addressed before compliance can be evaluated. These issues examine the procedural requirements for evaluating compliance, which follow from the procedural nature of the Standard, and the technical requirements for further characterizing the behavior of the disposal system, including uncertainties, to support the compliance assessment. The plan briefly describes the activities that will be conducted prior to 1993 by Sandia to characterize the WIPP disposal system's behavior and predict its performance."

Bertram-Howery, S.G., and Swift, P.N., 1990. Status Report: Potential for Long-Term Isolation by the Waste Isolation Pilot Plant Disposal System. SAND90-0616. Sandia National Laboratories, Albuquerque, NM. WPO 23865.

ABSTRACT, p. 1, para. 1;

" This report summarizes the early-1990 status of the WIPP performance-assessment work to evaluate compliance with EPA regulation 40 CFR Part 191, Subpart B, which sets environmental standards for radioactive waste disposal (Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes). The report reviews the qualitative and quantitative requirements for compliance, and identifies issues where unknowns complicate evaluating compliance. It discusses in relatively non-technical terms the approaches to resolving those issues, and concludes that compliance is achievable. The report is not an evaluation of compliance: available data are insufficient to make evaluations; and 40 CFR Part 191 has not been reissued following remand.

Work to date indicates a high degree of confidence that, as currently designed, the WIPP will comply with the Individual Protection Requirements of Subpart B, applicable to the undisturbed performance of the Repository. Compliance with the Ground Water Protection Requirements of Subpart B does not apply to the WIPP: no "special source of ground water," as defined in Subpart B, exists at the repository.

Compliance with the Containment Requirements of Subpart B appears uncertain for present design only in the event of inadvertent human intrusion into the repository prior to 10,000 years after decommissioning. Preliminary calculations show excessive radionuclide releases possibly could occur following intrusion given a coincidence of unfavorable conditions. The DOE is investigating two options to assure compliance. One reduces the probability of future intrusion through a passive marker system. The second redesigns the repository to achieve compliance by lessening the removal of radionuclides following intrusion. Numerous modifications that could assure compliance are technically feasible: testing will verify effectiveness, and modifications will be made if performance assessments indicate they will be needed. Benefits of modifications must be balanced against questions of safety, cost, regulatory constraints, and public acceptance. The DOE is confident compliance with the Containment Requirements can be achieved through these options."

Bethke, C.M., 1994. "The Geochemist's Workbench - Version 2.0 - A User's Guide to Rxn, Act2, Tact, React, Gtplot." Unpublished code. University of Illinois at Champaign-Urbana, Hydrogeology Program, Urbana, IL.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Borns, D.J., 1985. Marker Bed 139: A Study of Drillcore from a Systematic Array, SAND85-0023, Sandia National Laboratories, Albuquerque, NM. WPO 24529.

ABSTRACT, p 3;

" In southeastern New Mexico, Marker Bed 139 (referred to in this report as MB139) is one of 45 numbered siliceous or sulfatic units within the Salado Formation of the northern Delaware Basin. MB139 is divided into five zones. Zones I and V are the upper and lower contact zones, respectively. Zone II is a syndepositionally deformed subunit of polyhalitic anhydrite. Zone III is mixed anhydrite and polyhalitic anhydrite, a distinctive pale-green and pink, with subhorizontal fractures. Zone IV consists of interlayered halite and anhydrite without the overprint of polyhalite.

This sequence was transitional between submarine and subaerial. The anhydritic units of MB139 formed in salt-pan or mudflat environments or both. Undulations observed along the upper contact of MB139 are interpreted to result from traction deposits or from reworking of the upper portion of the marker bed during the transition from anhydrite to halite deposition. Zones II and III exhibit soft-sediment deformation and later traces of dewatering; e.g., formation of stylolites. Such deformation is not observed in the halite above MB139 or in Zone V and the halite units below MB139.

A distinctive set of subhorizontal fractures occurs in MB139 in mid-Zone III and, to some extent, in Zone IV. These fractures are partially infilled with halite and polyhalite. Brine occurrences at the mined facility horizon at the Waste Isolation Pilot Plant may be related to these fractures. The fractures formed either in response to stress cycles that were functions of sedimentation and erosion, or in response to deformation in the underlying Castile Formation. The subhorizontal orientation, dominant in the sampling to date, is more consistent with the interplay between stress and sedimentation cycles."

Borns, D.J. 1987. *Rates of Evaporite Deformation: The Role of Pressure Solution.* SAND85-1599. Sandia National Laboratories, Albuquerque, NM. WPO 27640.

Rates of Evaporite Deformation: The Role of Pressure Solution, p. 1;
" Evaporite sequences have been intensely studies for hazardous waste disposal and hydrocarbon development and storage. Rates of deformation are important in evaluating the long-term performance of different evaporites. Reported naturally occurring strain rates ($\dot{\xi}$) are: $5 \times 10^{-11}\ s^{-1}$ for a salt glacier; 10^{-11} for mine closure; 3×10^{-14}, 10^{-15}, and 10^{-16} for salt domes; 3×10^{-16} for bedded salt. Rates are controlled by temperature, differential stress, and active mechanism of deformation for each specific type of evaporite and setting.

Strain rates are estimated through in-situ measurements and the integration of geometric strain analysis and stratigraphic arguments for the time required for the observed deformation to occur. An inherent problem in such calculations is the large extrapolation of rates through time. Another approach for rate estimation is to calculate ξ directly, using the constitutive models for different deformation mechanisms that may be dominant. Specific mechanisms can be determined from petrofabric study, as at the WIPP site, SE New Mexico, where textures indicating that pressure solution was active are observed. Calculations based on experimental data are limited by the relatively poor data on diffusion in intergranular fluids. A variety of grain boundary diffusion models have been used. Some models (e.g., cubic approximation of the grain shape) leave gradients undefined at the grain edge.

Fore gravity-driven deformation near the WIPP site, geometric-stratigraphic integration predicts a $\dot{\xi}$ of $10^{-14}\ s^{-1}$ to $10^{-16}\ s^{-1}$ are predicted using models for dislocation creep and pressure solution. The rates using two approaches, geometric-stratigraphic and constitutive, are basically in agreement. These rates for the gravity-driven flow structures near WIPP reflect lower temperatures and stresses than salt domes. At the temperatures and stresses estimated for the WIPP flow structures, pressure solution is probably the dominant mechanism, rather than dislocation creep. It remains to be determined where in the transition from transient to steady-state response to an underground excavation in rock-salt pressure solution becomes a major mechanism."

Brausch, L.M., Kuhn, A.K. and Register, J.K. 1982. Natural Resources Study, Waste Isolation Pilot Plant (WIPP) Project, Southeastern, New Mexico. TME 3156, U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM. WPO 39094.

1.1.1 Description of the WIPP Site; p. 2, para. 2;

" The land area presently being considered for the WIPP project is about 18, 960 acres, an area approximately six miles in diameter, of which nearly 17,000 acres will be used to provide buffer zones around the underground facility. The site is divided into four control zones as follows (Figure 2):

- Control Zone I at the site center will contain nearly all of the surface facilities and occupy about 100 acres.
- Control Zone II, an area of about 1,800 acres, overlies the area of maximum potential underground development.
- Control Zone III occupies an area of about 6,200 acres. This zone provides a one-mile buffer strip around the area of maximum potential underground development.
- Control Zone IV, a second one-mile-wide buffer zone, contains an area of about 11,000 acres."

5.0 SUMMARY AND CONCLUSIONS; p. 64, para. 1;

" Studies have been conducted to evaluate the potential effects of developing the mineral and energy resources underlying or accessible from within (and outside of) Control Zone IV at the WIPP site. These assessments serve as input to the DOE decision-making process and reevaluation regarding the interim policy for resource recovery at the WIPP site. During the study, it was assumed that resource recovery was not allowed in Control Zones I, II, and III.

The methodology used in developing this evaluation can be summarized as follows:

- Determine the extraction technologies/activities that are applicable to the potash and hydrocarbon resources present at the WIPP site.
- Evaluate the type, extent, and degree of disturbance of the rock strata in the vicinity of the WIPP facility induced by these extraction activities.
- Assess whether such disturbance would affect the radiation dose consequences previously reported in the WIPP SAR long-term waste isolation assessment.

The conclusion of this study is that activities related to potash and hydrocarbon resource extraction and solution mining from within (and outside of) Control Zone IV, using currently available and applicable technology, will not compromise the integrity of the WIPP waste emplacement facility and increase the likelihood of a breaching event."

Brodsky, N.S. 1994. Hydrostatic and Shear Consolidation Tests With Permeability Measurements on Waste Isolation Pilot Plant Crushed Salt. SAND93-7058. Sandia National Laboratories, Albuquerque, NM. WPO 10087.

Pg. 66 Para. 1

" **ABSTRACT.** Sandia National Laboratories (SNL) has been pursuing a laboratory program designed to quantify its consolidation properties and permeability. Experimental results presented in this report complement existing studies and work in progress conducted by SNL. The experiments described in this report were designed to 1) measure permeabilities of consolidated specimens of crushed salt, 2) determine the influence of brine saturation on consolidation under hydrostatic loads, and 3) measure the effects of small applied shear stresses on consolidation properties."

Pg. 67 Para. 4

" To obtain the highest permeabilities (and therefore the worst case scenario from the standpoint of repository performance), the data were replotted in Figure 5-20 using only the initial slopes for tests in which flow rates slowed substantially."

Brush, L.H., 1990. Test Plan for Laboratory and Modeling Studies of Repository and Radionuclide Chemistry for the Waste Isolation Pilot Plant. SAND90-0266, Sandia National Laboratories, Albuquerque, NM. WPO 26015.

1.10.1 Temperature; p. 8, para. 2;

" The WIPP repository horizon is 655 m below the surface. The temperature of the Salado Fm. at this depth, beyond the annular volume affected by ventilation of the mine, is 28°C (Munson et al., 1987).

The CH TRU waste to be emplaced in drums and boxes in WIPP disposal rooms will produce essentially no heat.

The RH TRU waste to be emplaced in canisters in the ribs will produce some heat, but will probably not increase the temperature within WIPP disposal rooms significantly."

In lieu of modeling studies of the thermal response of the contents of WIPP disposal rooms to RH TRU waste, Brush specified a temperature of 30°C for the laboratory and modeling studies described herein. Most investigators are carrying out their experiments at this temperature. However, in some cases they conduct experiments at 25°C or at ambient laboratory temperatures."

2.3.1.3 PRELIMINARY DEFINITION OF A STANDARD SALADO-FM. BRINE COMPOSITION; p. 17, para. 5;

" Molecke (1990a) is planning bin-scale tests with CH TRU waste. The volume of brine required for these tests is too large to collect from the WIPP underground workings. Brush therefore defined a preliminary, standard composition for brine from the Salado Fm. and is developing a formulation for this brine (a description of this formulation will appear elsewhere). The composition of this or any other "average" Salado-Fm. brine depends on the data used to compute its composition and how those data are weighted. Because he cannot yet explain the chemical variations described in 2.3.1.1, these choices are arbitrary. The composition of this Salado-Fm. brine is subject to revision as he quantifies the causes of these chemical variations."

2.3.2 Castile-Fm. Brines; p. 21, para. 2;

" Popielak et al. (1983) investigated the occurrence of brine reservoirs in the Castile Fm. in the vicinity of the WIPP site and analyzed numerous samples of these brines from three drillholes. Because the WIPP project has not studies the chemistry of these fluids since the investigation of Popielak et al. (1983), Brush will use the results of their chemical analyses to define a standard Castile-Fm. brine for studies of repository and radionuclide chemistry."

2.3.3 Fluids from Overlying Formation; p. 23, para. 1;

" Two groups are studying the chemistry of fluids from the Rustler Fm. and the Rustler/Salado contact zone in the vicinity of the WIPP site. For results from the Water Quality Sampling Program, see: Uhland and Randall, 1986; Uhland, Randall, and Carrasco,

1987; Randall, Crawley, and Lyon, 1988. See Robinson (1988) and Lappin et al. (1989) for results from SNL. These groups participate in an interlaboratory comparison study comparable to that under way for analyses of brines from the Salado Fm. (2.4.3).

Brush is evaluating these previously published results to select chemical analyses of fluids that could seep down the shafts, along the drifts, and around or through the seals to WIPP disposal rooms. Brush is currently using five of these fluids (Table 2.4) for his study of reactions between fluids from overlying formations and Salado-Fm. brines and minerals (2.4.6)."

2.4 DESCRIPTIONS OF LABORATORY, MODELING, AND FIELD STUDIES; p. 23, para. 4;

" The objectives of these studies are to: (1) quantify the causes of chemical variations in brines from the Salado Fm. (2.4.1); (2) quantify any spatial or stratigraphic variations in Salado-Fm. brines (2.4.2); (3) quantify the variations caused by differences in the analytical techniques used by the three laboratories analyzing Salado-Fm. brines (2.4.3); (4) quantify the effects of sampling artifacts described in 2.3.1.1 on variations in Salado-Fm. brines (2.4.4); (5) simulate reactions between fluids from the Castile Fm. or overlying formations, and Salado-Fm. brines and minerals (2.4.5 and 2.4.6)."

p. 67, para. 3;

" Studies reviewed by Spinks and Woods (1976) imply that the range of α particles in plastics is generally a few tens of microns. This is less than their range in air (a few centimeters) and similar to their range in aqueous solutions. These estimates all assume energies of a few MeV for α particles. The altered zone will actually extend beyond 10 μm due to secondary electrons and γ rays generated by interactions between the α particles and the polymer matrix. The thickness of the plastics used in the studies described in 5.5.1 is probably greater than the range of α particles in these materials. Irradiation damage will fall off sharply as a function of depth; therefore, the plastics will be inhomogeneously irradiated. Because a relatively small volume of the samples may be affected, it may be difficult to detect microbial activity even if irradiation actually increases the biodegradability of these plastics. The limited range of α particles in plastics might also limit the extent to which radiolysis increases their biodegradability in WIPP disposal rooms."

7.4 ESTIMATES OF LIGAND CONCENTRATIONS IN WIPP BRINES; p. 87, para. 3;

" Estimates of the likely concentrations of organic and inorganic ligands in any brine present in WIPP disposal rooms are necessary to design realistic laboratory speciation and solubility studies, as well as other laboratory studies of radionuclide chemistry. Brush and Anderson (1988b) estimated the concentrations of the organic ligands citrate, EDTA, oxine, and TTA in three quantities of brine that could eventually resaturate WIPP disposal rooms for Choppin's (1988a) estimates of radionuclide solubilities (7.1 and Table 7.1).

Subsequently, Drez and James-Lipponer (1989) revised previous estimates of the quantities of citrate and oxine in the WIPP inventory and made new estimates for eight

additional organic and inorganic ligands not considered previously. The estimates of the quantities of EDTA and TTA in the WIPP inventory that Brush and Anderson (1988b) used (7.1) are still the best estimates available. Furthermore, Brush revised his estimates of the quantities of brine that could eventually resaturate WIPP disposal rooms.

During the Preparation of their preliminary inventory of the nonradioactive constituents of the CH TRU waste to be emplaced in the WIPP, Drez and James-Lipponer (1989) identified numerous, additional organic compounds (Table 7.2) that might form complexes with Pu, Am, Th, and U in any brine present in WIPP disposal rooms and increase their solubilities. Based on his review of this list, Choppin (1988b) concluded that if present at high enough concentrations, ten of the 60 compounds listed in Table 7.2 could increase radionuclide solubilities. These ten compounds are soluble in aqueous solutions, at least under some conditions. They are acetamide, acetic acid, ammonium thiocyanate, ascorbic acid, citric acid, di(20ethylhexyl)-phosphoric acid (DHP), α-hydroxy isobutyric acid, lactic acid, oxalic acid, and 1,10-phenanthroline. Choppin (1988b) also concluded that dihexyl-n, n-diethylcarbamoyl methyl phosphonate (DHDECMP), TBP, and TOPO could also increase radionuclide solubilities, but only in organic solvents. Unlike the ten compounds listed above, DHDECMP, TBP and TOPO are insoluble in aqueous solution under any condition."

Brush, L.H., 1995. "Systems Prioritization Method - Iteration 2 Baseline Position Paper: Gas Generation in the Waste Isolation Pilot Plant." Sandia National Laboratories, Albuquerque, NM. WPO 28740.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Budavari, S., O'Neil, M.J., Smith, A., and Heckelman, P.E. eds. 1989. The Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals. 11th ed. Merck & Co., Rathway, New Jersey.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Budescu, D.V., and Wallsten, T.S. 1987. "Subjective Estimation of Precise and Vague Uncertainties," Judgmental Forecasting. eds. G. Wright and P. Ayton. John Wiley & Sons, Chichester, New York. p. 63. WPO 39635.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Butcher, B.M. 1994. "A Model for Cuttings Release Waste Properties." Memorandum, January 6, 1994. Sandia National Laboratories, Albuquerque, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Butcher, B.M., Thompson, T.W., VanBuskirk, R.G., and Patti, N.C. 1991. Mechanical Compaction of Waste Isolation Pilot Plant Simulated Waste. SAND90-1206. Sandia National Laboratories, Albuquerque, NM. WPO 23968.

1.0 INTRODUCTION; p. 1, para. 1;

" A fundamental issue in evaluating performance of the Waste Isolation Pilot Plant (WIPP) facility near Carlsbad, NM, is the migration of fluids through the storage areas and the potential for dispersing radioactive materials in the event of human intrusion. The radioactive wastes to be stores in the WIPP consist of a variety of materials, including metals, combustibles (plastics and fibers), and "sludge." Unprocessed waste will be contained in 55-gallon drums (DOT-17C) or other containers such as standard waste boxes.

Most of the waste materials will initially have high porosities (or void volumes) and hence will be highly permeable if the waste remains unprocessed. However, over time the drums may be expected to collapse due to the closure of the rooms and the consequent loading of the containers. Under these conditions the contained materials will compact and cause a reduction in porosity and permeability (Butcher, 1989). These changes need to be defined as a function of time to evaluate the performance of the repository. For example, estimation of the change in density of the waste with time is required to predict what the final density of the waste will be and how soon states approaching this condition will occur. Information about the compaction characteristics of the waste must be obtained to make these predictions.

This report summarizes the results of a series of experiments and analyses performed to investigate the compaction of the waste materials and the collapse of waste filled drums.[1] Two phases of testing have been performed:

Part I: Determined the stress-density consolidation curves of various mixtures of solid materials to provide a preliminary characterization of this behavior and to select a suitable description for the waste.

Part II: Determined the collapse behavior of actual drums filled with a variety of materials."

Bynum, R.V., 1996. Memo to M.S. Tierney and C. Stockman. "Update of Uncertainty Range and Distribution for Actinide Solubilities to be Used in CCA NUTS Calculation." WPO 38535.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

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Callahan, G.D. 1993. "Further Discussion of the TRU Waste Model," A Summary of the Models Used for the Mechanical Response of Disposal Rooms in the Waste Isolation Pilot Plant with Regard to Compliance with 40 CFR 191, Subpart B. SAND92-0427. B.M. Butcher and F.T. Mendenhall. Sandia National Laboratories, Albuquerque, NM. pp. A-27 through A-30. In Appendix A of WPO 23356.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Chaturvedi, L., ed. 1987. The Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler Formation as it Relates to the WIPP Project. EEG-34. Environmental Evaluation Group, Santa Fe, NM.

INTRODUCTION, p. 1;

" A workshop on 'The Rustler Formation at the WIPP Site' was organized by the Environmental Evaluation Group on March 7, 1985. The workshop was held at a time when a new series of studies on the Rustler Formation was starting. It provided the scientists from Sandia National Laboratories, the U.S. Geological Survey, IT Corporation, the Department of Energy and the Environmental Evaluation Group, an opportunity to exchange and discuss the up-to-date information on the geological and hydrological characteristics of the Rustler Formation. The papers and the summaries that follow reflect the status of knowledge at the time of the workshop (March, 1985). The decision to publish the proceedings was not made until after all the papers were received by the end of 1986.

Eight papers were presented at the workshop and much of the time was spent in discussing the relevance and significance of results obtained thus far and the need for further work. Following is a brief description of each of the papers presented and a summary of the discussions."

Christ, C.L., and Hostetler, P.B. 1970. "Studies in the System $MgO-SiO_2-CO_2-H_2O$.II. Activity-Product Constant of Magnesite." American Journel of Science. Vol 268, no. 4, pp. 439-453.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

DOE (U.S. Department of Energy), 1979. Draft Environmental Impact Statement Waste Isolation Pilot Plant DOE/EIS-0026-D. U.S. Department of Energy, Washington, D.C.

Foreword; p. iii, para. 1;

" In furtherance of its responsibilities to develop and implement methods for the safe and environmentally acceptable management of radioactive wastes, the U. S. Department of Energy (DOE) is considering five major decisions:

1. Whether to pursue the construction of the proposed Waste Isolation Pilot Plant (WIPP), a mined repository for the disposal of transuranic wastes, with an initial period of retrievable emplacement
2. Whether the WIPP should include an intermediate-scale facility in which up to 1000 assemblies of spent fuel from commercial electricity-generating reactors would be disposed of, with an initial period of retrievable emplacement
3. Whether the WIPP should include a research-and-development facility in which experiments with all types of nuclear waste, including high-level waste, can be performed
4. What the timing and location of the WIPP should be
5. Whether to commit land now for a potential repository site in Eddy County, New Mexico

Pursuant to its responsibilities under the National Environmental Policy Act of 1969 (42 U. S. C. 4321 et seq.), the DOE has prepared this document as environmental input for the foregoing decisions. It also may be used as input for subsequent decisions by the DOE and other Federal agencies with respect to the site of the proposed facility."

p. iv, para. 2;

" This document is concerned only with decisions concerning a transuranic-waste repository, an intermediate-scale facility, and associated experiments. To provide a sufficient basis for these decisions, it also analyzes the radiological consequences of waste transportation and processing. Nevertheless, it is not intended to provide an environmental analysis to support decision on actual routes or methods for transporting material to the repository or to support decision on the construction of facilities for processing waste destined for the repository. The environmental implications of these decisions will be addressed in subsequent documents.

This environmental impact statement is arranged in the following manner: Chapter 1 is an overall summary of the analysis contained in the document. Chapters 2 through 4 set forth the policy objectives of the national waste management program and analyze the full spectrum of reasonable alternatives for meeting these objectives, including the WIPP. Chapter 5 presents the interim waste-acceptance criteria and waste-form alternatives for the WIPP. Chapters 6 through 13 provide a detailed description and environmental analysis of the WIPP repository and its proposed site. Chapter 14 describes the interactions that have taken place with Federal, State, and local authorities and with the general public in connection with the repository. The appendices contain data and discussions in support of

the material in the text."

DOE (U.S. Department of Energy), 1980a. Final Environmental Impact Statement, Waste Isolation Pilot Plant, DOE-EIS-0026, U.S. Department of Energy, Assistant Secretary for Defense Programs, Washington, D.C. WPO 38835, WPO 38838 - WPO 38839.

p 1-2, Section 1.2.1 1980 WIPP FEIS

" The 1980 WIPP Final Environmental Impact statement (FEIS) and the associated public review and comment period provided environmental input for the DOE's initial decision to proceed with the WIPP (DOE, 1980). The significance of impacts associated with the various alternatives was assessed. For the selected alternative, a two-phased approach to development was proposed: 1) a site and preliminary design validation (SPDV) program, as discussed in Subsection 8.2.1 of the FEIS, and 2) full construction, as discussed in FEIS Subsection 8.2.2. The durations of key WIPP activities are shown in Figure 1.1.

The 1980 FEIS presented an analysis of the environmental impacts of a number of alternatives for demonstrating the safe disposal of TRU waste. The alternatives considered include:

- Alternative 1. No action. A research and development facility to demonstrate safe disposal of TRU waste would not be developed and post-1970 TRU waste would continue to be retrievably stored.

- Alternative 2. Developing the WIPP at the Los Medanos site in southeastern New Mexico.

- Alternative 3. Disposing of stored TRU waste in the first available repository for high-level radioactive waste.

- Alternative 4. Delaying a decision on the site for a WIPP until at least 1984 to allow for investigation of alternative sites.

Alternative methods and geologic media for TRU waste disposal were also considered but rejected in the FEIS. The alternative methods included burial in deep ocean sediments, emplacement in deep drillholes, transmutation, and ejection into space. The alternative geologic media included igneous, volcanic, and argillaceous rocks.

The DOE's Record of Decision, published January 28, 1981 (46 FR 9162), announced the DOE's selection of Alternative 2: to proceed with the phased development of the WIPP at the Los Medanos site in southeastern New Mexico. . . ."

DOE (U.S. Department of Energy), 1980b. WIPP SAR: Waste Isolation Pilot Plant Safety Analysis Report, U.S. Department of Energy, Washington, D.C.

INTRODUCTION, p. 1.1-1;

" This Safety Analysis Report (SAR) has been prepared by the U.S. department of Energy (DOE) to support construction and operation of the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico. The WIPP facility is designed to receive, inspect, emplace, and store unclassified defense-generated transuranic wastes in a retrievable fashion in an underground salt medium and to conduct studies and perform experiments in salt with high-level wastes. Upon the successful completion of these studies and experiments, WIPP is designed to serve as a permanent facility.

The first chapter of this report provides a summary of the location and major design features of WIPP. Chapters 2 through 5 describe the site characteristics, design criteria, and design bases used in the design of the plant and plant operations. Chapter 6 discusses radiation protection; Chapters 7 and 8 present an accident analysis of the plant and an assessment of the long-term waste isolation at WIPP. The conduct of operations and operating controls and limits are discussed in Chapters 9 and 10. The quality assurance programs are described in Chapter 11."

DOE (U.S. Department of Energy). 1989. Draft Supplement Environmental Impact Statement, Waste Isolation Pilot Plant. DOE/EIS-0026-DS, U.S. Department of Energy, Washington, D.C.

ABSTRACT, p iii;

" IN 1980, the DOE published the Final Environmental Impact Statement (FEIS) for the WIPP. This FEIS analyzed and compared the environmental impacts of various alternatives for demonstrating the safe disposal of transuranic (TRU) radioactive wastes resulting from DOE national defense related activities. Based on the environmental analyses in the FEIS, the DOE published a Record of decision in 1981 to proceed with the phased development of the WIPP in southeastern New Mexico as authorized by the Congress in Public Law 96-164.

Since publication of the FEIS, new geological and hydrological information has led to changes in the understanding of the hydrogeological characteristics of the WIPP site as they relate to the long-term performance of the underground waste repository. In addition, there have been changes in the information and assumptions used to analyze the environmental impacts in the FEIS. These changes include: 1) analyses of certain additional DOE generator and/or storage sites as potential contributors to the WIPP waste inventory, 2) changes in the composition of the TRU waste inventory, 3) consideration of the hazardous chemical constituents in TRU wastes, 4) modification and refinement of the system for the transportation of TRU wastes to the WIPP, and 5) addition of the Test Phase.

The purpose of this SEIS is to update the environmental record established in 1980 by evaluating the environmental impacts associated with new information, new circumstances, and proposal modifications. This SEIS evaluates and compares the proposed action and two alternatives for demonstrating the safe disposal of TRU wastes:

The proposed action is to operate the WIPP under a 'Test Phase' for approximately five years during which time certain tests and operational demonstration would be carried out. The tests would be conducted to reduce uncertainties associated with the prediction of natural processes that might affect long-term performance of the underground waste repository. Results of these tests would be used to assess the ability of the WIPP to meet applicable federal standards for the long-term protection of the public and the environment. The operational demonstrations would be conducted to show the ability of the TRU waste management system to certify, package, transport, and emplace TRU wastes in the WIPP safely and efficiently. Upon completion of the Test Phase, the DOE would determine, based on a performance assessment, whether the WIPP would comply with U.S. Environmental Protection Agency (EPA) standards for the long-term disposal of TRU wastes (i.e., 40 CFR Part 191, Subpart B). If there is a determination of compliance, the WIPP would enter a permanent disposal phase of approximately 20 years to demonstrate the safe disposal of TRU wastes. After completion of waste emplacement, the surface facilities would be decommissioned, and the WIPP underground facilities would serve as a permanent radioactive waste repository.

The first alternative, no action, is similar to the no action alternative discussed in the 1980 FEIS. Under this alternative, TRU wastes would continue to be stored at the various

generator and storage sites, while the WIPP facility would be decommissioned and potentially put to other uses.

The second alternative to the proposed action is to delay emplacement of TRU wastes in the WIPP underground until a determination has been made of compliance with EPA standards for TRU waste disposal (i.e., 40 CFR Part 191, Subpart B). The DOE has determined that bin-scale tests could be conducted outside the WIPP underground facilities in a specially designed aboveground facility. This alternative has many implications including delays in both the operational demonstrations and room-scale tests, and the lack of room-scale test data for the compliance demonstration, a temporary mothballing of the WIPP facilities. This is true in any case. The specialized facility for aboveground bin-scale tests could be constructed at any one of several DOE sites. In order to analyze the environmental impacts of this alternative in the SEIS, the DOE has evaluated the Idaho National Engineering Laboratory in Idaho as a representative site for the aboveground bin-scale tests."

DOE (U.S. Department of Energy), 1991. Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives: Final Report of the Engineered Alternatives Task Force, DOE/WIPP 91-007, Revision 0, Waste Isolation Pilot Plant, Carlsbad, NM.

EXECUTIVE SUMMARY, p ES-i;

" The Engineered Alternatives Task Force (EATF) was established by the United States Department of Energy (DOE) WIPP Project Office (WPO) in September, 1989 (Hunt, A., 1990), to evaluate the relative effectiveness and feasibility of implementation of selected design enhancements (referred to as 'engineered alternatives') for the Waste Isolation Pilot Plant (WIPP). These enhancements consist of modifications of existing waste forms and/or the WIPP facility, and other design variations such as passive marker systems. The purpose of this report is to summarize the methodologies and results of evaluation of the effectiveness of selected engineered alternatives relative to the existing repository design, and to discuss the feasibility of implementing these alternatives with respect to availability of technology, cost, schedule, and regulatory concerns.

Preliminary analyses of the long-term performance of the WIPP disposal system performed by Sandia National Laboratories (SNL) (referred to as 'performance assessment') have identified two potential problems in demonstrating compliance with the applicable regulation 40 CFR Part 191 (EPA, 1985) that governs the disposal of transuranic radioactive waste. The first potential problem relates to gas generation. Lappin et al. (1989) discuss the possibility that up to 1,500 moles of gas can be generated per drum (or drum equivalent) of waste from anoxic corrosion, microbial degradation, and radiolysis, at rates that may be as high as 2.55 moles/drum/year. Although processes exist to dissipate excess gas pressure, these processes are currently believed to be slow relative to the current estimates of gas generation rates, resulting in gas pressures in storage rooms that may temporarily exceed lithostatic pressure. The consequences of exceeding lithostatic pressure are currently being evaluated by SNL (Lappin et al., 1989). Unless these evaluations demonstrate that either excess pressures will not occur, or that excess pressures will not degrade the performance of the disposal system, some type of waste form or facility modification may be required to either eliminate gas generation or reduce the rate of gas generation. For example, if the organics in the waste are incinerated and vitrified, then microbial gas generation can be eliminated.

A second potential problem in demonstrating compliance with 40 CFR Part 191 relates to the consequences predicted from future inadvertent human intrusion events. Preliminary evaluations of compliance with the containment requirement of 40 CFR Part 191 performed by SNL suggest that some of the current waste forms (under current interpretations of human intrusion provisions) may eventually be found to be unacceptable for disposal at the WIPP (Marietta et al., 1989). This may be due to uncertainties in key performance parameters of the waste forms. Key parameters that control the release of radionuclides during human intrusion scenarios are permeability of the waste storage rooms, radionuclide solubilities, and the availability of brine. Permeability of the storage rooms can

be effectively reduced by the use of a grout backfill and/or shredding and cementation of the waste. Solubilities can be reduced by the use of grout backfill or the addition of lime to raise the pH of any brine that may come in contact with the waste."

DOE (U.S. Department of Energy). 1995c. Waste Isolation Pilot Plant Safety Analysis Report. DOE/WIPP-95-2065, Rev. 0, Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM. NTIS Order # DE9006847.

5.4 Long-Term Waste Isolation Assessment; p. 5-71, para. 1;

" Applicable regulations require the DOE to assess the capability of the WIPP repository to isolate TRU & TRU mixed wastes for a 10,000-year period (40 CFR 191[1], 40 CFR 268.6[2]). The DOE is required to demonstrate, through this long-term assessment, that the repository can reasonably be expected to contain the wastes such that established quantitative release limits for both radionuclides and hazardous constituents are not exceeded for the 10,000-year performance period. The DOE's Performance Assessment (PA) is a probabilistic risk assessment tool designed to evaluate the long-term performance of the repository.

The PA process requires three (3) general types of information. These include: 1) those future events and processes that could occur, 2) the relative probabilities that such events and processes will occur, and 3) the consequences of such events and processes, should they occur.

Once a comprehensive set of such Features, Events and Processes (FEPs) are identified, a screening process is initiated. FEPs that are specifically excluded by regulation, are determined physically not reasonable, are of low probability, or are of low consequence are screened from the PA analysis. All FEPs that remain are treated in the PA through either incorporation in the modeling system or through modeling assumptions.

Consequence analyses are conducted using the applicable quantitative measures of performance from the driving regulations. The results are used to develop probabilistic distributions of calculated releases. These distributions will be used to display results in the form of a Complimentary Cumulative Distribution Function (CCDF). This CCDF will allow direct measure of calculated performance to the applicable release limits.

Uncertainty and sensitivity analyses will be conducted as appropriate. These efforts will differ in that the compliance assessment for hazardous chemicals will be deterministic in nature. Uncertainty analysis for this assessment will consist of a qualitative pre-modeling process where reasonable, discreet values are estimated for parametric input in instances where variables are imprecisely known. The compliance assessment for radionuclides is probabilistic in that imprecisely known variables are expressed in terms of ranges for parametric input and are randomly sampled across the range during the modeling process. The uncertainty analyses will be performed as a post-modeling process and will be both qualitative and quantitative.

Sensitivity analysis will identify those portions of the disposal system that drive the largest change in calculated result with their variation. Results of sensitivity analysis will be important for such activities as developing long-term monitoring concepts and other qualitative assurances, which will complement the expected performance of the natural disposal system.

Applicable regulatory agencies will determine the DOE's compliance with the

regulations. The PA analysis will be presented in the Compliance Certification Application (40 CFR 191[1]) and the No-Migration Variance Petition (40 CFR 268.6[2])."

DOE (U.S. Department of Energy). 1995d. Waste Isolation Pilot Plant Seal System Design Report, DOE/WIPP-95-3117. Waste Isolation Pilot Plant, Carlsbad, NM. WPO 29062.

ABSTRACT, p. iii;

" This report documents the Waste Isolation Pilot Plant shaft sealing system design. The seals are designed to limit the release of radionuclides and hazardous constituents from an underground nuclear waste repository in salt. Design concepts documents in this report will form the basis for no-migration variance petition modeling. In addition, these concepts are the basis for detailed sealing system design development and evaluations that will be completed in 1996 in support of the planned Compliance Certification Application. The report describes the geologic and hydrologic setting for the seals, presents qualitative and quantitative design guidance, describes the design, documents the sealing materials and their properties, and discusses evaluations of sealing system performance. The design uses a variety of common materials that have very low permeability, demonstrated technologies for construction processes, multiple components to perform each intended function, and the entire length of the shafts to effect a seal system that will meet the performance requirements. For the permanent or long-term seal that resists both gas and brine flow, more than 500 ft of highly compacted crushed salt is used in series with more than 400 ft of clay barriers. The design retards gas flow in the short term using a combination or a rigid concrete barrier (enhanced by an asphalt waterstop) and a compacted clay barrier approximately 100 ft high. Short-term brine flow down the shaft is limited by a clay barrier within the overlying formation and by a combination of more than 500 ft of asphalt, clay, and concrete barriers within the salt."

6.0 CONCLUSIONS, p. 53;

" The WIPP shaft sealing system design documented in this report is an effective implementable design concept. The design concepts were developed through an interactive process involving technical specialists in the design and construction of underground facilities, materials behavior, rock mechanics analysis, and fluid flow analysis. The design uses (1) a variety of common materials that have very low permeability, (2) demonstrated technologies for construction processes, (3) multiple components to perform each intended function, and (4) the entire length of the shafts to effect a sealing system. In addition, the design incorporates recent developments related to:

- successful demonstrations of compactions technology for salt compaction;
- Attainment of high densities and accompanying low permeabilities in consolidating crushed salt;
- Development of a constitutive model for crushed salt consolidation;
- Design guidance that better quantify performance goals for, and the importance of, seal permeability;
- design guidance on functional requirements for seal components;
- development of improved capabilities for simulating WIPP salt creep behavior and potential DRZ development and healing;

- successful retesting ($\sim$10 years after emplacement) of WIPP small-scale concrete seal performance, which shows permeability $\sim 10^{-20} m^2$; and
- additional information from WIPP studies, international studies, and construction experience related to the very low permeabilities of salt-saturated concrete, asphalt, and clay.

The designers have provided a shaft sealing system that is an effective barrier to brine and gas flow. For the permanent or long-term seal that resists both gas and brine flow, robustness is achieved by providing more than 500 ft of a highly-compacted crushed salt barrier in series with more than 400 ft of clay barriers. The design retards gas flow in the short-term using a redundant combination of a rigid concrete barrier (enhanced by an asphalt waterstop included as an additional DRZ barrier) and a compacted clay barrier approximately 100 ft in length. Finally, short-term brine flow down the shaft is limited by a clay barrier within the Rustler Formation and by a combined length of mare than 500 ft of asphalt, clay, and concrete barriers within the Salado Formation. These design concepts form the basis for No-Migration Variance Petition modeling, initiation of the detailed design development, and evaluations that will be completed in 1996 for incorporation, as appropriate, into the Compliance Certification Application."

DOE (U.S. Department of Energy). 1996a. CAO Management Plan, Peer Review. CAO-96-1187, Carlsbad Area Office, Carlsbad, NM.

Introduction, p.1;
" This Peer Review Management Plan (PRMP) describes the management processes which the U. S. Department of Energy (DOE), Carlsbad Area Office (CAO) will use to control the planning, implementation, and documentation of peer reviews (PR) to be conducted by the CAO-Office of Regulatory Compliance (ORC), as prescribed in 40 CFR Part 194, and as deemed necessary by the ORC to meet the criteria described in this rule. These PRs include conceptual models, waste characterization sensitivity analyses [as prescribed in 40 CFR Part 194 section 27(a)(1&2)], qualification of existing data [as prescribed in 40 CFR Part 194 section 22(b)], and confirmation of the Passive Institutional Controls (PICs) analyses and design document (40 CFR Part 194 section 43)."

Purpose, p. 1;
" The purpose of this PRMP is to identify and initiate activities necessary to determine if (Rev. 1) data and other WIPP-related information not obtained in accordance with an appropriate quality assurance program are qualified to be used to demonstrate compliance with 40 CFR Part 191 and 40 CFR Part 194 (Rev. 1). The requirement for conducting PRs is specified in the CAO Quality Assurance Program Description (QAPD). The purpose of the PRs conducted by ORC is to meet the requirements of 40 CFR Part 194 section 27(a)(1) and (2), to qualify existing unqualified data [as prescribed in section 22(b)], and to confirm the results of the Passive Institutional Controls design analyses and report according to 40 CFR Part 194 section 43.

A PR is a documented, critical review performed by peers who are independent of the work being reviewed. The peers' independence from the work being reviewed means that the peer: a) was not involved as a participant, supervisor, technical reviewer or advisor in the work being reviewed; and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed."

DOE (U.S. Department of Energy). 1996b. "CAO Team Procedure." TP 10.5, Rev. 0, Carlsbad Area Office, Carlsbad, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

DOE (U.S. Department of Energy). 1996d. Waste Isolation Pilot Plant Disposal Phase Supplemental Environmental Impact Statement: Implementation Plan. DOE/EIS-OO26-S-2-IP, REV. O, United States Department of Energy, Carlsbad Area Office, Carlsbad, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

DOI (U.S. Department of the Interior), Bureau of Mines. 1976. Mineral Facts and Problems, 1975 Edition. U.S. Bureau of Mines Bulletin 667 (BUMINES-B-667). Bureau of Mines, Washington, D.C. Abvailable from NTIS as PB-266 089/2.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Drez. P. 1991. "Preliminary Nonradionuclide Inventory of CH-TRU Waste," Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. Volume 3: Reference Data. WIPP Performance Assessment Division, Eds. R.P. Rechard, A.C. Peterson, J.D. Schreiber, H.J. Iuzzolino, M.S. Tierney, and J.S. Sandha. SAND91-0893/3. Sandia National Laboratories, Albuquerque, NM. pp. A-43 through A-53. In Appendix A of WPO 26015.

Preliminary Nonradionuclide Inventory of CH-TRU Waste; p. A-45, para. 1;

" May 9. 1989

Dear Dr. Brush:

Attached is a preliminary report on the status of the Nonradionuclide Inventory Database and detailed tabulations of waste materials as requested in the last amendment to the IT Sandia Support contract. I am sorry for the slight delay in completing the report, but the CH-TRU generator/storage sites were late in their responses and the process of tabulating the appropriate data proved to be a difficult task. Part of the difficulty has to do with the slight variations in the way the sites report data.

Listed below is the information contained in this package:

- Report entitled: "Preliminary Nonradionuclide Inventory for CH-TRU Waste." The report includes a description of how the data was collected from the CH-TRU waste generator/storage sites, a description of the database used to compile the data, and examples of how the calculations were made including any limitations (Item 7 in Statement of Work).
- Table 3-5 in the report summarizes the total quantity of combustible materials in the waste, including cellulosics, plastics and other combustibles (Item 3 in Statement of Work).

  Although only total cellulosics were requested, data on plastics and other combustibles were also tabulated, anticipating their eventual need to support the Performance Assessment program.
- Table 3-5 in the report estimates the quantity of various types of cellulosic materials in the total cellulosic inventory (Item 4 in Statement of Work).

  A breakdown of the various types of plastic and rubber materials has also been provided in Table 3-5. <u>Caution is advised in the interpretation of the plastics in the tables, since two sites choose to report the weight of plastic bagging and rigid liners as part of the waste totals</u>.
- Table 3-6 in the report estimates the total quantity of metals in the CH-TRU waste and also provides a breakdown of the various types of metals in the waste (Item 5 in Statement of Work).

  <u>Caution is advised in the interpretation of this table, since two sites choose to report the amount of metal in the waste packaging as part of the waste contents in this table</u>. I have no way of separating out the weight of the waste cannister from the database at this time.

  In an attempt to provide a complete inventory (including waste packaging), Table 3-8

provides a preliminary estimate of the amount of plastic and other internal packaging in addition to an estimate of the metal included in the waste. Variations in the method of packaging from site to site have been accounted for in the tabulation of the data.

- Table 3-7 in the report estimates the total quantity of nitrates and total inorganic carbon (TIC) in the waste (Items 2 and 6 in Statement of Work). Graphite or charcoal is not considered part of this summary, only inorganic carbonate.
- Printouts for each generator/storage site that represent complete data dumps of the Nonradionuclide Inventory Database (Item 7 of Statement of Work).
- Floppy disks containing all the dBASE files for the database. An explanation of the files is provided in Appendix 2.0 of the report (Item 7 of Statement of Work)."

Dunham C.W., 1966, The Theory and Practice of Reinforced Concrete. 4th ed. McGraw-Hill, New York, p 36.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Earth Technology Corporation. 1988. Final Report for Time Domain Electromagnetic (TDEM) Surveys at the WIPP Site, SAND87-7144, The Earth Technology Corporation, Golden, CO; Sandia National Laboratories, Albuquerque, NM. WPO 25668.

EXECUTIVE SUMMARY, p ii;

The Earth Technology Corporation was contracted by Sandia National Laboratories to perform a time domain electromagnetic (TDEM) survey at the WIPP site for the purpose of mapping the depth of occurrence of brine pockets and layers. The impetus for the geophysical survey was that pressurized brine had been encountered in drill holes in the Castile Formation immediately underlying the bedded salts of the Salado Formation in which the waste storage panels are mined. TDEM is a geophysical technique that determines layering in the subsurface from surface resistivity measurements. Because brine layers and pockets have low resistivities compared to the bedded salts of the host rock, they are good targets for electrical exploration.

Most of the measurements (36 out of 38) were located in a 1.5 by 1 km grid directly over the waste storage panels. Two measurements were made next to drill holes WIPP #12 and DOE #1 to validate the interpretation of the geophysical survey. Also, one drill hole (ERDA #9) at the northern boundary of the survey grid was used for calibration.

The results of the survey can be summarized as follows:

- The geoelectric sections derived from the TDEM measurements compare well with geologic and geophysical data of the three drill holes. At WIPP #12 the occurrence of brine at a depth of about 800m (2600 ft.) is clearly seen in the TDEM data.

- The results of the TDEM survey over the waste storage panels show the first occurrence of brine at depths corresponding to the Castile Formation in portions of the area and to the Bell Canyon Formation in the rest of the area, some 400 to 600 m below the mined depth of the waste storage panels in the Salado formation. There is no evidence in the data for brine pockets in the Salado or other formations over the waste storage panels.

Only one sounding was made near drill hole WIPP #12 for the purpose of calibration. Since the center loop TDEM surveys conducted correlate well with drill holes and other geologic data, it is recommended that the areal extent of the brine pocket encountered at WIPP #12 be mapped by surveying a grid centered on WIPP #12."

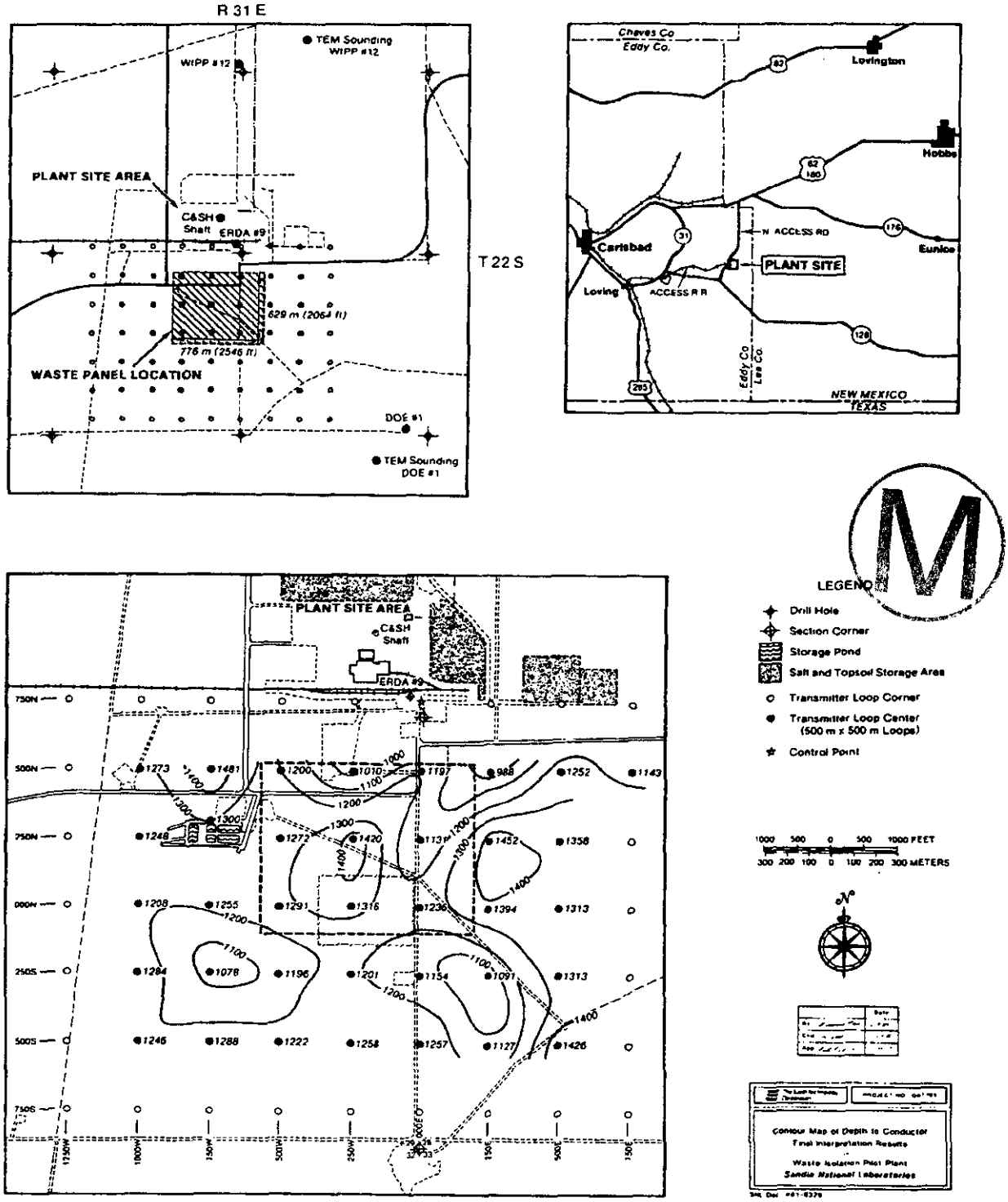

Figure 1-1. TEM Sounding Locations and Waste Panel Location

EPA (U.S. Environmental Protection Agency), 1985. "40 CFR Part 191: Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," Federal Register, Volume 50, no. 182, pp. 38066-38089. WPO 39132.

SUMMARY, p. 38066, col. 1;

" The Environmental Protection Agency (EPA) is promulgating generally applicable environmental standards for the management and disposal of spent nuclear fuel and high-level and transuranic wastes. The standards apply to management and disposal of such materials generated by activities regulated by the Nuclear Regulatory Commission (NRC) and to disposal of similar materials generated by atomic energy defense activities under the jurisdiction of the Department of Energy (DOE). These standards have been developed pursuant to the Agency's authorities and responsibilities under the Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act of 1982.

Subpart A of these standards limits the radiation exposure of members of the public from the management and storage of spent fuel or high-level or transuranic wastes prior to disposal at waste management and disposal facilities regulated by the NRC. Subpart A also limits the radiation exposures to members of the public from waste emplacement and storage operations at DOE disposal facilities that are not regulated by the NRC.

Subpart B establishes several different types of requirements for disposal of these materials. The primary standards for disposal are long-term containment requirements that limit projected releases of radioactivity to the accessible environment for 10,000 years after disposal. These release limits should insure that risks to future generations from disposal of these wastes will be no greater than the risks that would have existed if the uranium ore used to create the wastes had not been mined to begin with. A set of six qualitative assurance requirements is an equally important element of Subpart B designed to provide adequate confidence that all containment requirements will be met. The third set of requirements are limitations on exposures to individual members of the public for 1,000 years after disposal. Finally, a set of ground water protection requirements limits radionuclide concentrations for 1,000 years after disposal in water withdrawn from most Class I ground waters to the concentrations allowed by the Agency's interim drinking water standards (unless concentrations in the Class I ground waters already exceed limits in 40 CFR Part 141, in which case this set of requirements would limit the increases in the radionuclide concentrations to those specified in 40 CFR Part 141). Subpart B also contains informational guidance for implementation of the disposal standards to clarify the Agency's intended application of these standards, which address a time frame without precedent in environmental regulations. Although disposal of these materials in mined geologic repositories has received the most attention, the disposal standards apply to disposal by any method, except disposal directly into the oceans or ocean sediments.

This notice describes the final rule that the Agency developed after considering the public comments received on the proposed rule published on December 29, 1982, and the

recommendations of a technical review conducted by the Agency's Science Advisory Board (SAB). The major comments received on the proposed standards are summarized together with the Agency's responses to them. Detailed responses to all the comments received are discussed in the Response to Comments Document prepared for this final rule.
DATE: These standards shall be promulgated for purposes of judicial review at 1:00 p.m. eastern time on October 3, 1985. These standards shall become effective on November 18, 1985."

EPA (U.S. Environmental Protection Agency), 1993. "40 CFR Part 191: Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; Final Rule," Federal Register, Vol. 58, no. 242, pp. 66398-66416. WPO 39133.

PREAMBLE: SUMMARY;

" The U.S. Environmental Protection Agency (EPA) is promulgating amendments to the environmental standards for the disposal of spent nuclear fuel, high-level and transuranic wastes (40 CFR 191.15 and Subpart C).

EPA originally promulgated these standards in 1985 pursuant to the Agency's authorities and responsibilities under the Nuclear Waste Policy Act of 1982, as amended, the Atomic Energy Act of 1954, as amended, and §2(a)(6) of Reorganization Plan No. 3 of 1970 (5 USC app. 1). In 1987, following a legal challenge, the U.S. Court of Appeals for the First Circuit (hereinafter referred to as 'the First Circuit' or ' the court') remanded subpart B of the 1985 standards to the Agency for further consideration. *Natural Resources Defense Council, Inc. v. United States Environmental Protection Agency*, 824 F.2d 1258 (1st Cir. 1987). Recently enacted legislation, (Pub. L. 102-579) known as the Waste Isolation Pilot Plant Land Withdrawal Act (WIPP LWA), however, reinstates the 1985 disposal standards except 'the 3 aspects of §§191.15 and 191.16 of such [standards] that were subject of the remand ordered' by the First Circuit. The WIPP LWA directs EPA to expedite issuance of final disposal standards and specifies that such regulations shall not be applicable to the characterization, licensing, construction, operation, or closure of any site required to be characterized under §113(a) of Public Law 97-425, the Nuclear Waste Policy Act of 1982.

Today's action represents the Agency's response to this legislation and to the issues raised by the court pertaining to individual and ground-water protection requirements. After considering the relevant comments received on the February 10, 1993 proposed rulemaking, the Agency has taken this final action in the form of amendments to parts 191 of title 40 of the Code of Federal Regulations. In so doing, EPA has not revised any of the regulations reinstated by the WIPP LWA.

DATES: These amendments will become effective on January 19, 1994. These amendments will be promulgated for purposes of judicial review at 1 p.m. eastern standard time on December 20, 1993."

EPA (U.S. Environmental Protection Agency), 1996a. "40 CFR Part 194: Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations; Final Rule," Federal Register, Vol. 61, no. 28, pp. 5224-5245.

SUMMARY, p. 5224, col. 1;
" The Environmental Protection Agency (EPA) is promulgating criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste. If the Administrator of the EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use this final rule to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. This rulemaking was mandated by the WIPP Land Withdrawal Act of 1992. EFFECTIVE DATE: These regulations are effective April 9, 1996."

§194.27 Peer review; p. 5241, col. 3, para. 10;
" (a) Any compliance application shall include documentation of peer review that has been conducted, in a manner required by this section, for:

(1) Conceptual models selected and developed by the Department;

(2) Waste characterization analyses as required in §194.24(b)/ and

(3) Engineered barrier evaluation as required in §194.44.

(b) Peer review processes required in paragraph (a) of this section, and conducted subsequent to the promulgation of this part, shall be conducted in a manner that is compatible with NUREG-1297, "Peer Review for High-Level Nuclear Waste Repositories," published February 1988. (Incorporation by reference as specified in §194.5.)

(c) Any compliance application shall:

(1) Include information that demonstrates that peer review processes required in paragraph (a) of this section, and conducted prior to the implementation of the promulgation of this part, were conducted in accordance with an alternate process substantially equivalent in effect to NUREG-1297 and approved by the Administrator or the Administrator's authorized representative; and

(2) Document any peer review processes conducted in addition to those required pursuant to paragraph (a) of this section. Such documentation shall include formal requests, from the Department to outside review groups or individuals, to review or comment on any information used to support compliance applications, and the responses from such groups or individuals."

EPA (U.S. Environmental Protection Agency), 1996b. Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations: Background Information Document for 40 CFR Part 194. EPA 402-R-96-002. U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

1. Introduction; p. 1-1, para. 1;

" The Environmental Protection Agency's (EPA) regulation, 40 CFR part 194, sets forth criteria for determining if the Waste Isolation Pilot Plant (WIPP) will comply with EPA's environmental radiation protection standards for the disposal of radioactive waste, found at 40 CFR part 191 subparts B and C. If the Administrator of EPA determines that the WIPP will comply with the standards for disposal, then the Administrator will issue to the Secretary of Energy a certification of compliance which will allow the emplacement of transuranic waste in the WIPP to begin, provided that all other statutory requirements have been met. If a certification is issued, EPA will also use 40 CFR part 194 to determine if the WIPP has remained in compliance with EPA's environmental radiation protection standards, once every five years after the initial receipt of waste for disposal at the WIPP. The final preamble and regulation to 40 CFR part 194, as they appear in the Federal Register, take precedence over any descriptions or interpretations of the final rule that appear in this document.

This document provides much of the necessary background information and technical analyses which the Agency used during the development of 40 CFR part 194. The document explicates fourteen issues considered by EPA in establishing the individual criteria contained in 40 CFR part 194."

7.1.1 Background

The 40 CFR part 194 compliance criteria for the WIPP provide the following requirements for peer review, at §194.27 of the final rule:

(a) Any compliance application shall include documentation of peer review that has been conducted for, in a manner required by this section, for:
(1) Conceptual models selected and developed by the Department;
(2) Waste characterization analysis as required in §194.24(b); and
(3) Engineered barrier evaluation as required in §194.44.

(b) Peer review processes required in paragraph (a) of this section, and conducted subsequent to the promulgation of this part, shall be conducted in a manner that is compatible with NUREG-1297 "Peer Review for High-Level Nuclear Waste Repositories."

(c) Any compliance application shall:
(1) Include information that demonstrates that peer review process required in paragraph (a), and conducted prior to the implementation of the promulgation of this part, were conducted in accordance with an alternate process substantially equivalent in effect to NUREG-1297 and approved by the

Administrator or the Administrator's authorized representative; and

(2) Document any peer review processes conducted in addition to those required pursuant to paragraph (a) of this section. Such documentation shall include formal requests, from the Department to outside review groups or individuals, to review or comment on any information used to support compliance applications, and the responses from such groups or individuals.

The EPA must be satisfied that peer review processes at the WIPP are sufficient to assess the scientific premises properly on which the performance assessments are based."

EPA (U.S. Environmental Protection Agency) 1996c. Compliance Application Guidance for 40 CFR Part 194. EPA 402-R-95-014. United States Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C. WPO 39159.

p. 60, para. 7;

" (c) *The Administrator may allow the Department to assume passive institutional control credit, in the form of reduced likelihood of human intrusion, if the Department demonstrates in the compliance application that such credit is justified because the passive institutional controls are expected to endure and be understood by potential intruders for the time period approved by the Administrator. Such credit, or a smaller credit as determined by the Administrator, cannot be used for more than several hundred years and may decrease over time. In no case, however, shall passive institutional controls be assumed to eliminate the likelihood of human intrusion entirely.*

EPA may allow up to approximately 700 years of credit for passive institutional controls in performance assessments. If DOE proposes a credit, EPA expects that DOE's implementation plan for such controls will clearly articulate why credit is warranted for the proposed time frame. For example, if DOE assumes credit for as long as 700 years after disposal, the information provided in the compliance application relative to PICs is expected to support that assumption. Under no circumstance may passive controls be assumed to eliminate human intrusion entirely.

If DOE assumes credit for passive controls, EPA expects any compliance application to identify:

- the estimated effectiveness of passive controls over time, in terms of reducing the likelihood of potential human intrusion; for example, a graphic representation illustrating how credit will diminish over time;
- the methodology employed to estimate the effectiveness of passive controls; and
- justification for the proposed credit, based on how well the controls are expected to endure and be understood.

If any credit is assumed for passive controls, credit should begin at the time of disposal (i.e., when the shafts of the disposal system are backfilled and sealed), although some of the credit may not be needed in light of credit for active institutional controls.

EPA will make its determination regarding credit for passive controls based on the two aspects of PICs identified in §194.43(c): that they are expected to endure for the proposed period, and that they are expected to be understood by potential intruders for the proposed period. EPA expects that DOE's justification of the proposed credit will clearly address these two aspects. The first aspect, the period of time for which the markers "are expected to endure," is likely to require a deterministic analysis, based on scientific data, that takes into account assumptions like those outlined in the CAG for §194.43(a)(1).

The second aspect, the period of time for which the markers will "be understood by potential intruders," is likely to require qualitative analysis and discussion. EPA expects that DOE will establish a framework of assumptions for PICs that is a prudent extrapolation of the future state assumptions established in §194.25. For example, §194.25 may allow DOE

to assume, for the purpose of developing the performance assessment models, that particular governmental regulations will remain in force. Such an assumption would be inappropriate, however, in the justification of credit for PICs. Instead, DOE may choose to assume that while some form of governmental regulation exists, the exact form and content of any regulation cannot be identified with certainty. In other words, DOE may not a priori rely on the future states assumption in this context. Rather, DOE must demonstrate--based on the particular measures at issue and documented, reasoned justification--why any assumptions made in these circumstances are sound.

EPA believes that there are certain societal 'common denominators,' such as the existence of some form of government and some level or regulatory control over the exploration for and some level of regulatory control over the exploration for and development of resources, that could be considered in the discussion of the PICs. These common denominators are patterns of human behavior that may be detected throughout history and around the world. The degree to which the PICs implemented at the WIPP rely on common denominators will determine the degree to which the PICs are effective at being understood by potential intruders in the future. Other examples of common denominators (but by no means a comprehensive list) are: the ability of pictures to convey meaning, the curiosity of humans, the expectation that some people will avoid, ignore or be ignorant of government controls, the use of the written word to transmit information and concepts, and story-telling or the generational 'passing down' of history.

Explicit application of future state assumptions to passive controls--i.e., the assumption that all present-day societal and demographic factors will remain constant--will not be considered by EPA to justify adequately the design of PICs or the estimation of credit."

Felmy, A.R., and Weare, J.H. 1986. "The Prediction of Borate Mineral Equilibria in Natural Waters: Application to Searles Lake, California," Geochimica et Cosmochimica Acta. Vol. 50, no. 12, pp. 2771-2783. WPO 30421.

ABSTRACT, p. 2771;

" The chemical equilibrium model of HARVIE et al, (1984) has been extended to include borate species. The model is based upon the semi-empirical equations of PITZER (1973) and is valid to high ionic strength (≈ 14 m) and high borate concentration. Excellent agreement with the existing emf, isopiestic, and solubility data in the system (Na-K-Ca-Mg-H-Cl-SO_4-CO_2-$B(OH)_4$-H_2O) is obtained. Calculated mineral solubilities are in general within 10% of their experimental values, even at high ionic strengths.

The model was applied to the multicomponent, high ionic strength (≈ 10) and high borate concentration ($B_T \sim 0.5$m) Searles Lake evaporite deposit. Utilizing the chemical composition of the interstitial brine, the model predicts equilibrium between the brine and only those minerals which are known to be in contact with the brine. These calculations clearly demonstrate the applicability of the model to high ionic strength, high borate concentration natural waters.

The model was also utilized to calculate the mineral sequences which should result from evaporation of the major source of water for Searles Lake, the Owens River. The geochemical conditions necessary for the formation of the most recent mud and saline units are examined. The final results indicate that the mineral sequences found in the most recent saline unit in Searles Lake can be produced by evaporation of a water close in composition to present Owens River water, provided primary dolomite formation is delayed and back reaction between the Parting Mud and the Upper Salt is inhibited."

Finley, R.E. 1996. "Tensile Strength of Consolidated Crushed Salt," Memorandum to D.R. Anderson and M.S.Y. Chu, May 3, 1996. Sandia National Laboratories, Albuquerque, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Friend, D.G., and Huber, M.L.. 1994. "Thermophysical Property Standard Reference Data from NIST," International Journal of Thermophysics. Vol. 15, no. 6, pp. 1279-1288.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Gonzalez, D.D. 1983. Groundwater Flow in the Rustler Formation, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico (SENM): Interim Report. SAND82-1012. Sandia National Laboratories, Albuquerque, NM. WPO 27528.

ABSTRACT, p. 2;

" The Culebra Dolomite of the Rustler Formation is the dominant aquifer near the WIPP. If this artesian aquifer became contaminated as a result of the most probable release scenario, radionuclides could be transported to the biosphere through the groundwater. Five sites have been selected for intensive geohydrologic investigations to determine the hydraulic parameters needed to describe the flow and solute transport characteristics of the Culebra Dolomite. Tracer tests at two locations have determined an effective porosity of 0.7% in the principle direction of flow northwest of the proposed facility and near Nash Draw, and 18% at a site 1-1/4 miles southwest; dispersivity was 100 and 17 ft, respectively. Anisotropy has been evaluated at three locations where the ratio of the principle to minor transmissivity tensor has been found to range from 2.1:1 to 2.7:1, despite a variation of three orders of magnitude in transmissivity. The principle transmissivity component is about northwest by southeast for those locations. Aquifer head potentials for the Culebra Dolomite indicate that flow patterns are southeast over most of the designated WIPP area, based on the anisotropy at three locations and potentials in fresh-water equivalant (sic) head throughout."

Graf, D.L., Eardley, A.J., and Shimp, S.F. 1961. "A Preliminary Report on Magnesium Carbonate Formation in Glacial Lake Bonneville," Journal of Geology. Vol. 69, no. 2, pp. 219-223.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Hansen, F.D. 1996. "Review Plan: Shaft Seal System Design for the Waste Isolation Pilot Plant." Sandia National Laboratories, Albuquerque, NM. Attachment in WPO 36546.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Hansen, F.D. and Ahrens, E.H. 1996. "Large-Scale Dynamic Compaction of Natural Salt," 4th International Conference on the Mechanical Behavior of Salt, Montreal, Canada, June 17-18, 1996. SAND96-0792C. Sandia National Laboratories, Albuquerque, NM. WPO 39544.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Harvie, C.E., Møller, N., and Weare, J.H. 1980. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-SO_4-H_2O System from Zero to High Concentration at 25°C, Geochemica et Cosmochimica Acta., Vol. 44, no. 7, pp. 981-999. WPO 30423.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Harvie, C.E., N. Møller, and J.H. Weare. 1984. "The Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O System to High Ionic Strengths at 25°C," Geochimica et Cosmochimica Acta. Vol. 48, no. 4, pp. 723-751. WPO 30422.

ABSTRACT, p 723;

" The mineral solubility model of HARVIE and WEARE (1980) is extended to the eight component system, Na-K-Mg-Ca-H-Cl-SO_4-OH-HCO_3-CO_3-CO_2-H_2O to high concentrations. The model is based on the semi-empirical equations of PITZER (1973) and co-workers for the thermodynamics of aqueous electrolyte solutions. The model is parameterized using many of the available isoplastic, electromotive force, and solubility data available for many of the subsystems. The predictive abilities of the model are demonstrated by comparison to experimental data in systems more complex than those used in parameterization. The essential features of a chemical model for aqueous electrolyte solutions and the relationship between pH and the equilibrium properties of a solution are discussed."

Haug, A., Kelley, V.A., LaVenue, A.M., and Pickens, J.F. 1987. Modeling of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant (WIPP) Site: Interim Report, SAND86-7167, Sandia National Laboratories, Albuquerque, NM. WPO 28486.

INTRODUCTION, p. 1-1;

" The modeling studies of ground-water flow in the Culebra Dolomite Member of the Rustler Formation reported here have been performed as part of the regional hydrologic characterization studies for the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico (Figure 1.1). The site characterization studies are being conducted in accordance with the Consultation and Cooperation Agreement between the U.S. Department of Energy and the State of New Mexico as part of the evaluation of the suitability of bedded salt of the Salado Formation for isolation of defense transuranic waste. The regional hydrologic characterization studies are being conducted by Sandia National Laboratories on behalf of the Department of Energy."

Holcomb, D.J., and Shields, M. 1987. Hydrostatic Creep Consolidation of Crushed Salt with Added Water. SAND87-1990. Sandia National Laboratories, Albuquerque, NM. WPO 26778.

Background, p 6;

" A facility for the disposal of radioactive waste has been constructed near Carlsbad, New Mexico in bedded salt of the Salado formation. Beginning in 1988, the Waste Isolation Pilot Plant (WIPP) is scheduled to accept waste generated by defense programs. In order to show the long-term safety of the facility; it is necessary to demonstrate that the system of sealing the rooms and drifts will be effective for times on the order of 10,000 years. Only one sealing material can be guaranteed to be compatible with the unmined salt for that length of time: salt. If it could be shown that the mined salt could be reemplaced ("backfilled") and reconsolidated by the creep closure of the drifts and rooms to a sufficiently low permeability in a reasonable time, then the security of the seals would be assured. For this reason, a program to determine the long-term mechanical and hydrological properties of the crushed salt under various conditions has been carried out. A number of studies have been done on the consolidation of granulated salt. Studies were carried out by Stinebaugh[1] and Holcomb and Hannum[2] on the rapid (quasistatic) compression of granulated salt, where pressure up to 20 MPa were applied and removed over the span of about ten minutes. Results for quasistatic compression indicated that even at a pressure of 20 MPa, crushed salt would not consolidate to a fractional density of more than about .8, where fractional density is defined as the actual density divided by the intact density. At this density, permeability is in the darcy range ($10^{-12}m^2$) [3] as compared to 50 nanodarcies for the intact, healed salt [4].

Clearly, is reconsolidated salt is to play any role in sealing, the permeability must be reduced to near that of the formation. Because salt is known to creep relatively rapidly it was expected that consolidation would also be a time-dependent process. One of the earliest studies of the time-dependent consolidation of granulated salt is that of Shor, Baes and Canonico [5]. Using pure salt with grain sizes in the range of 100 micrometers they investigated the effects of various pore fluids, from air to saturated brine, on the consolidation rate under uniaxial strain conditions. From this work they developed a model which included a strong third-power dependence on the particle size. By extrapolation, they predicted that in NaCl brine, particle sizes of 1 centimetre would require about 30,000 years to consolidate to a point where permeability was in the microdarcy range. If the salt particle size was reduced to 1 millimetre, then the time would scale to about 30 years. As might be expected, the consolidation rates were much higher for salt grains in brine than for salt grains in air. A suprising result was that if dodecane, an organic solvent which is insoluble in water, was used as a pore fluid, then consolidation rates were actually higher than that of the brine-saturated sample, but only if the salt was not carefully dried. When dried salt was used, the consolidation rates were less than when air was used as the pore fluid. This is the first indication that even trace amounts of water are sufficient to greatly accelerate the consolidation process of salt.

Several studies have been done on . . ."

Holt, R.M., and Powers, D.W. 1984. Geotechnical Activities in the Waste Handling Shaft, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. WTSD-TME-038. U.S. Department of Energy, Waste Isolation Pilot Plant, Carlsbad, NM.

ABSTRACT, p. v;

" The Waste handling shaft (waste shaft) at the Waste Isolation Pilot Plant (WIPP) site is an enlargement of the drilled, Site and Preliminary Design Validation (SPDV) ventilation shaft. Geotechnical activities in the waste shaft were designed to confirm the SPDV ventilation shaft mapping results and to provide additional information about identified zones of interest. The activities included identification of instrument locations, geologic inspections of the exposed shaft surface during sinking operations, reconnaissance geologic mapping of the waste shaft sump, and detailed geologic mapping in identified zones of interest. These activities were carried out concurrently with construction.

The results of the geologic inspections in the waste shaft and the reconnaissance geologic mapping in the waste shaft sump correlate well with previous characterizations. However, the detailed 360° geologic mapping performed in several zones of interest did not reveal post-depositional dissolution features, thought to occur at several stratigraphic horizons in the Rustler Formation at the WIPP site. At the waste shaft, zones previously identified as dissolution residues in nearby boreholes contained pronounced primary sedimentary features."

1.0 INTRODUCTION; p. 27, para. 1;

" The Permian Rustler Formation was recently examined in detail in two shafts at the WIPP site: the waste handling shaft (waste shaft) and the exhaust shaft. The examination of the Rustler in the shafts has provided unique data previously unavailable from any other source. Fresh exposures of the Rustler in the shafts exhibited abundant primary sedimentary structures. Though some evidence of these features has been reported in outcrop and core descriptions, the abundance of primary sedimentary structures observed in the shafts is unequaled in previously described sections. These data are reported here in their stratigraphic context as an initial basis for evaluation of depositional environments of the Rustler and reevaluating the role of dissolution in the formation of the Rustler."

Holt, R., and Powers, D. 1987. "Rustler Formation in the Waste Handling and Exhaust Shafts, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico," The Rustler Formation at the WIPP Site, Report of a Workshop on the Geology and Hydrology of the Rustler Formation as it Relates to the WIPP Project. EEG-34. Environmental Evaluation Group, Santa Fe, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Hunter, R.L., 1985. A Regional Water Balance for the Waste Isolation Pilot Plant (WIPP) Site and Surrounding Area. SAND84-2233, Sandia National Laboratories, Albuquerque, NM. WPO 27628.

ABSTRACT, p. 3;

" The WIPP water-balance study area defined here comprises ~2000 mi^2 in Eddy and Lea Counties, southeastern New Mexico. Inflows to the study area are precipitation (roughly 1.47 x 10^6 ac-ft/yr), surface water (roughly 1.1 x 10^5 ac-ft/yr), water imported by municipalities and industries (roughly 3 x 10^4 ac-ft/yr), and ground water (volume not estimated). Outflows from the area are evapotranspiration (roughly 1.5 x 10^6 ac-ft/yr), surface water (roughly 1.2 x 10^5 ac-ft/yr), and possibly some ground water. The volume of surface and ground water in storage in Nash Draw has increased since the beginning of potash refining. Regional ground water flow in aquifers above the Salado Formation is from the northeast to the southwest, although this pattern is interrupted by Clayton Basin, Nash Draw, and San Simon Swale. The Pecos River is the only important perennial stream. Most of the area has no integrated surface-water drainage.

The available data suggest that ~1600 mi^2 of the study area are hydrologically separate from Nash Draw and the WIPP site. Ground water north of Highway 180 apparently discharges into Clayton Basin and evaporates. Water in San Simon Swale apparently percolates downward and flows to the southeast. Data are inadequate to create a water budget for the Nash Draw-WIPP site hydrologic system alone, although an attempt to do so can provide guidance for further study."

Jaeger, J.C. and Cook, N.G.W. 1979. Fundamentals of Rock Mechanics, 2nd ed. Chapman and Hall, London; Halsted Press, New York, NY.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Jones, T.L., Kelley, V.A., Pickens, J.F., Upton, D.T., Beauheim, R.L., and Davies, P.B. 1992. Integration of Interpretation Results of Tracer Tests Performed in the Culebra Dolomite at the Waste Isolation Pilot Plant Site. SAND92-1579. Sandia National Laboratories, Albuquerque, NM. WPO 23504.

ABSTRACT, p i;

" Conservative tracer tests have been conducted within the Culebra Dolomite Member of the Rustler Formation at the H-2, H-3, H-4, H-6, and H-11 hydropads for transport scales ranging from approximately 20 to 40 m. Convergent-flow and two-well recirculating tracer tests provide data that is used to quantitatively characterize flow and transport processes. The observed long time period required for initial (detectable) tracer breakthrough (74 to 316 days) in the H-2 and H-4 tracer tests suggest the prevalence of single-porosity, matrix-only transport at these locations. Hydraulic-test responses at these two hydropads also indicate single-porosity, matrix-only conditions. The relatively poor quality of data defining the breakthrough curves from the H-2 and H-4 tracer tests precluded a detailed, quantitative analysis of transport parameter values from these tests. Interpretations of pumping tests and tracer tests at the H-3, H-6, and H-11 hydropads indicated that the Culebra dolomite behaves as a double-porosity (fracture-plus-matrix) medium at these locations. Both the H-3 and H-11 hydropads are located along the offsite transport pathways southeast of the Waste Isolation Pilot Plant waste-panel area. Significant fracture participation in transport is evidenced by rapid initial tracer breakthrough (1 to 21 hrs) on one travel path at each of these hydropads. The H-3, H-6 , and H-11 convergent-flow tracer tests were analyzed using the SWIFT II model with the Culebra fracture/matrix system idealized as three, orthogonal, intersecting fracture sets equally spaced in all three directions. Input values and ranges for the assigned transport parameters (effective thickness, well spacing, pumping rate, free-water diffusion coefficient, longitudinal dispersivity, and matrix porosity) were specified based on field measurements, laboratory measurements on Culebra core, and scientific judgement. Measurement and/or calculated uncertainties were also defined for the assigned parameters. Two approaches were used to model double-porosity transport. The first approach assumed that differences in tracer breakthrough behavior at a single hydropad were caused by differences (heterogeneity) in matrix-block length (fracture spacing) between different travel paths. The second approach assumed that differences in tracer breakthrough behavior were caused by horizontal anisotropy in the flow field. Interpretations based on the heterogeneous-analysis approach yielded matrix-block lengths ranging from 0.11 to 1.23 m and fracture porosities ranging from 5.0×10^{-4} to 1.0×10^{-3}. Interpretations based on the anisotropic-analysis approach yielded matrix-block lengths ranging from 0.15 to 0.48 m, fracture porosities ranging from 1.0×10^{-3} to 3.0×10^{-3}, and anisotropy ratios ranging from 3:1 to 7:1. Sensitivity analyses were conducted to provide insight into the relative impact of varying individual transport parameters and to provide estimates of fitted-parameter uncertainty. These analyses yielded minimum and maximum matrix-block lengths for all hydropads that ranged from 0.02 to 3.22 m. Sensitivity analyses also showed that neither single-porosity, fracture-only transport nor single-porosity, matrix-only transport can

reproduce the observed transport behavior at the H-3, H-6, and H-11 hydropads."

Kelley, V.A., and Pickens, J.F. 1986. Interpretation of the Convergent-Flow Tracer Tests Conducted in the Culebra Dolomite at the H-3 and H-4 Hydropads at the Waste Isolation Pilot Plant (WIPP) Site. SAND86-7161. Sandia National Laboratories, Albuquerque, NM. WPO 27674.

ABSTRACT, p. ii;

" Tracer tests utilizing conservative organic tracers have been conducted in the Culebra Dolomite Member of the Rustler Formation at the locations of the H-2, H-3, H-4, and H-6 hydropads. The objective of this report is to present a quantitative evaluation of the physical solute-transport parameters of the Culebra dolomite at the H-3 and H-4 hydropad locations from interpretation of the tracer-test data. The tracer-test configurations consisted of a pumping well and two tracer-addition wells arranged in approximate equilateral triangles with 30-m sides. The transport of organic tracers from the tracer-addition wells to the pumping wells was analyzed using the finite-difference model SWIFT II, which is capable of simulating single- and double-porosity flow and transport.

The interpretive approach for analyzing the tracer-breakthrough curves at the pumping well first consisted of estimating the appropriate governing processes using the information base for each specific hydropad. For the H-3 hydropad, the test data indicated that a double-porosity interpretation approach was the most appropriate. In this conceptualization, the fractures represented the principle transport medium and the matrix provided the bulk of the solute-storage capability. The simulation model accounted for advective-dispersive transport in the fractures and diffusive transport in the matrix. Calibration of the tracer-breakthrough curves included conducting a parameter sensitivity analysis on longitudinal dispersivity, tortuosity, matrix porosity, fracture porosity, effective matrix block size, pumping rate, initial tracer-input distribution, and distance between pumping and tracer-addition wells. Calibration of the tracer-breakthrough curves for the H-3 tracer test resulted in longitudinal dispersivities from 5 to 10% of the flow path (well-separation distance), a fracture porosity of 1.9×10^{-3}, and effective matrix block sizes of 0.25 to 2.1 m.

There is uncertainty in the assumed or calibrated values for tortuosity, fracture porosity, matrix porosity, and matrix block size which were used to describe solute transport in the Culebra at the H-3 hydropad. Reduction in this uncertainty would require additional laboratory and field testing (e.g., additional drilling and coring, additional matrix porosity determinations on core, diffusion experiments, and additional on-site tracer testing). The results obtained from the conservative-tracer test suggest that fracture flow and matrix diffusion dominate solute transport in the Culebra at the H-3 hydropad. Further, the parameters derived to fit the tracer-breakthrough curves are thought to be consistent with the physical conceptualization of the Culebra at the H-3 hydropad.

The interpretation of the H-4 hydropad tracer test has not provided quantitative estimates of the physical solute-transport parameters for the Culebra. Qualitatively, the observed tracer-breakthrough curves could be simulated by representing the Culebra with a layered system of higher- and lower-permeability units. In this system, transport would be dominated by the higher-permeability zones with diffusive interaction with the lower-

permeability zones. No evidence was obtained to indicate that transport of the tracers had occurred through fractures; however, considering the fractured nature of the Culebra at the H-3 and H-6 hydropads and other locations at the WIPP site, the existence of fractures in the Culebra at the H-4 hydropad should still be considered a possibility. However, if present, these fractures do not appear to have had a significant effect on solute transport on paths examined in the H-4 tracer test."

Labreche, D.A., Callahan, G.D., DeVries, K.L., and Osnes, J.D. 1993. Comparison of Two Geomechanical Analysis Codes for WIPP Disposal Room Modeling: Sancho and Spectrom-12. Topical Report RSI-0461, Albuquerque, NM; RE/SPEC Inc., Rapid City, SD. WPO 36821.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Lambert, S.J., 1983. Dissolution of Evaporites in and Around the Delaware Basin, Southeastern New Mexico and West Texas. SAND82-0461. Sandia National Laboratories, Albuquerque, NM. WPO 27520.

ABSTRACT, p 3;

" Permian evaporites in the Ochoan Castile, Salado, and Rustler Formations in the Delaware Basin of southeastern New Mexico and west Texas have been subjected to various degrees of dissolution (notably of halite and gypsum) through geologic time. Eastward tilting of the Delaware Basin has resulted in the exhumation and erosion of Ochoan rocks in the western part of the basin. Waters in the Capitan, Rustler, Castile, and Bell Canyon Formations have previously been proposed as agents or consequences of evaporite dissolution according to four principle models; solution-and-fill, phreatic dissolution, brine density flow, and stratabound dissolution (along bedding planes). Several geomorphological features of positive and negative relief have previously been cited as indicators of evaporite dissolution. Brine density flow has been used to explain the selective dissolution of certain evaporite horizons during the late Cenozoic. A review of available geological data has revealed that

- Halite deposition was probably not so extensive as formerly believed
- Waters with potential to dissolve evaporites are in the Rustler and Capitan, but not in the Bell Canyon, Salado mine seeps, or the Castile brine reservoirs
- Brine density flow has not been active in removing most of the 'missing' halite, nor are 'point-source' dissolution features likely to have their roots at the Bell Canyon
- Major evaporite dissolution has not been confined to the late Cenozoic, but much of it took place during the Permian, Triassic, Jurassic, and Tertiary periods
- The Bell Canyon Formation has not been a sink for dissolution-derived brine

Stratabound dissolution is an efficient process for the removal of evaporites and is well exemplified in Nash Draw. This process entails downdip migration of meteoric water within beds of competent fractured rock, with upward and downward excursions of the water into adjacent halite-bearing beds. The chief weakness in the stratabound model for dissolution is the as-yet-unidentified sink for dissolution brine. If the stratabound model of dissolution is active in removal of lower Salado halite, the threat of dissolution to the WIPP in the next 250,000 yr is comparable to the threat to the same area posed by the growth of Nash Draw during the past 600,000 yr. The regional geological history showed the past threat to be negligible."

Lambert, S.J. 1987. Feasibility Study: Applicability of Geochronologic Methods Involving Radiocarbon and Other Nuclides to the Groundwater Hydrology of the Rustler Formation, Southeastern New Mexico. SAND86-1054. Sandia National Laboratories, Albuquerque, NM. WPO 24475.

ABSTRACT, p. i;

" Radiocarbon, tritium, and ^{36}Cl were measured in groundwaters from the dolomite aquifers of the Rustler Formation in the northern Delaware Basin of southeastern New Mexico to determine the feasibility of using these nuclides in dating the groundwater at and near the Waste Isolation Pilot Plant, a facility for geological disposal of radioactive waste. No measurable ^{36}Cl was found in any of these groundwaters, which derive their dissolved chloride from Permian evaporites. Demonstrably uncontaminated groundwaters contained no significant amounts of tritium (<0.2 TU). Percent modern carbon (PMC) correlates linearly and directly with bicarbonate concentration, indicating mixing of a high-PMC/high-bicarbonate reservoir with a low-PMC/low-bicarbonate reservoir. This relationship, together with the history of development of the wells sampling the groundwaters, indicates contamination by anthropogenic modern carbon rather than simple dilution by dissolving rock carbonate. $\delta^{13}C$ does not linearly correlate with bicarbonate, indicating no single source of contaminant radiocarbon. Values of PMC and $\delta^{13}C$ for groundwaters were used to calculate apparent radiocarbon ages according to an interpretive model that accounts for water/rock interactions in carbonate aquifers. All but six pairs of values gave significant negative ages (-1,000 to -7,000 years). This suggests that in contaminated samples the model over-adjusts (based on $\delta^{13}C$) for radiocarbon loss due to dilution and isotopic exchange with the rock. Four groundwater samples (3 from the Rustler and 1 from the overlying Dewey Lake Red Beds) gave apparent radiocarbon ages $>$ 10,000 a, and their carbon-isotope systematics suggest that their apparent ages are all the result of a single evolutionary trend of rock/water interaction involving carbon isotope exchange, with a probable recharge age of 13,000 a b. p. This time of isolation from the atmosphere, which is unrelated to travel time within the Rustler, is consistent with paleoclimatic evidence of wetter conditions more conducive to recharge in the Late Pleistocene than at present."

Lambert, S.J., and Carter, J.A. 1984. Uranium-Isotope Disequilibrium in Brine Reservoirs of the Castile Formation, Northern Delaware Basin, Southeastern New Mexico. I: Principles and Methods. SAND83-0144. Sandia National Laboratories, Albuquerque, NM. WPO 28341.

ABSTRACT, p 3;

" We evaluated uranium isotope activity ratios with respect to models for the origin of the brines in two brine reservoirs in the Castile Formation (ERDA No. 6 and WIPP No. 12). In Castile anhydrite, a completely closed water system that was continuously leaching Th-recoil-produced ^{234}U from freshly exposed surfaces of fractured host rock would give rise to uranium 234/238 isotope activity ratio (α) values significantly higher than observed values. Therefore, the brine occurrences are not the result of continuous deformation. Similarly, a model assuming movement of intergranular Permian seawater into fractures was found inconsistent with observed uranium isotope systematics. The observed α-values (95% confidence limits) of ERDA No. 6 (1.34 to 1.58) and WIPP No. 12 (1.74 to 2.54), used in conjunction with an inferred initial α_0 higher than observed values, allows calculation of reasonable finite minimum ages, involving no preferential leaching of ^{234}U in the host rock. If the brine occurrences are inferred to have been connected at one time with a more extensive nearby hydrologic system, the Capitan limestone (α_0 = 5.1), calculated minimum ages of isolation from that system are 700 000 to 880 000 yr for ERDA No. 6 and 360 000 to 610 000 yr for WIPP No. 12. These ranges in ages are the 95% confidence limits based on experimental determination of α-values. The ages thus derived may reflect an episode of structural deformation in the Pleistocene that allowed water to enter the resulting fractures."

Lambert, S.J., and Carter, J.A. 1987. Uranium-Isotope Systematics in Groundwaters of the Rustler Formation, Northern Delaware Basin, Southeastern New Mexico, I: Principles and Preliminary Results. SAND87-0388. Sandia National Laboratories, Albuquerque, NM. WPO 24453.

ABSTRACT, p i;

" Values for uranium concentration ([U]) and $^{234}U/^{238}U$ activity ratio (A.R.), have been determined for groundwaters and host rocks from the Rustler Formation near the Waste Isolation Pilot Plant (WIPP) site in the northern Delaware Basin of southeastern New Mexico. [U] varies from about 0.02 to 40 x 10^{-9} g/g, increasing westward across the WIPP site to Nash Draw, a dissolution valley underlain by outcrops of Rustler Formation evaporites. Large deviations from secular equilibrium (A.R. $\approx$ 1) in the groundwaters increase eastward from about 2 to 3 in Nash Draw to almost 12 in the eastern part of the WIPP site. [U] and A.R. variations cannot be completely explained by simple mixing due to congruent dissolution of uranium from rock (without isotopic fractionation). A.R. values typically increase along the flow path in a reducing environment, and the observed eastward increase in A.R. suggests a relict flow system whose dominant flow direction (eastward) was at high angles to that now observed. A westward decrease in A.R., coupled with a steady increase in [U] indicates not only that there was a change in flow direction since recharge, but that Rustler groundwater is now draining from areas of high potentiometric level and low permeability near the WIPP site, without appreciable recharge. The maximum time required for this westward drainage is about 200,000 a. The minimum time required to achieve the highest observed A.R.s during the earlier episode of eastward flow from recharge in the west is 10,000 to 30,000 a. Radiocarbon and stable-isotope studies of the Rustler Formation near the WIPP indicate that the modern Rustler flow system is not at steady state, recharge being dominated by wetter climatic conditions in the Pleistocene. Uranium-isotope studies are consistent with these results, and further suggest that present flow directions are qualitatively different from those existing at the time of recharge."

Lambert, S.J., and Harvey, D.M. 1987. Stable-Isotope Geochemistry of Groundwaters In the Delaware Basin of Southeastern New Mexico. SAND87-0138. Sandia National Laboratories, Albuquerque, NM. WPO 24150.

ABSTRACT, p i;

" $^{18}O/^{16}O$ and D/H ratio measurements have been made on groundwaters sampled from the Rustler Formation (Ochoan, Permian) and related rocks in the northern Delaware Basin of southeastern New Mexico. Most confined Rustler waters at the Waste Isolation Pilot Plant (WIPP) site and to the west in Nash Draw and confined waters from the Capitan limestone constitute one population in $\delta D/\delta^{18}O$ space, while unconfined groundwaters inferred to originate as modern surface recharge to alluvium, sandstones in the Ogallala Formation, the near-surface Rustler in southwestern Nash Draw, and the Capitan vadose zone in the Guadalupe Mountains (Carlsbad caverns) constitute a distinctly different population; the two do not overlap. A likely explanation for this distinction is that meteoric recharge to most of the Rustler and Capitan took place in the geologic past under climatic conditions significantly different from the present. Available tritium and radiocarbon data are consistent with this hypothesis, and the apparent age of confined groundwaters is in excess of 12,000 radiocarbon years, suggesting that recharge took place under wetter conditions in the late Pleistocene. Processes governing recharge in the Delaware basin are significantly different from those in the nearby Roswell Artesian Basin, but may be similar to those previously described for the Albuquerque (New Mexico) and Murray (South Australia) Basins. Rustler water from the WIPP site and east-central Nash Draw is not discharging from springs in southwestern Nash Draw; the discharge there is part of a local shallow groundwater system associated with surficial gypsum karst and discharge from nearby potash refining. Water at the Rustler/Salado contact at the WIPP site is of meteoric origin, but has experienced isotope shift that increases with decreasing permeability, and is part of the same isotopic trend as the ERDA 6 brine occurrence and fluid inclusions from Salado Formation halite core. Radiometric ages of secondary Salado minerals are not consistent with vertical mixing between deep brines and meteoric waters to form the fluid inclusions. Mine seeps and WIPP fluid inclusions have similar isotopic compositions, perhaps related to syndepositional mixing of evaporite brines and rainwaters. Rustler dolomites have not recrystallized in isotopic equilibrium with Rustler water, but much of the gypsum in the Ochoan section has done so. The absence of modern meteoric recharge to the Rustler at and near the WIPP site indicates that the hydrologic system there is not at steady state. Instead, the system is responding to the cessation of local recharge, this cessation occurring some 10,000 to 30,000 years ago."

Lappin, A.R., 1988. Summary of Site-Characterization Studies Conducted From 1983 Through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico. SAND 88-0157. Sandia National Laboratories, Albuquerque, NM. WPO 24945.

" SUMMARY

The Waste Isolation Pilot Plant (WIPP), which is designed for receipt, handling, storage, and permanent isolation of defense-generated transuranic wastes, is being excavated at a depth of approximately 655 m in bedded halites of the Permian Solado Formation of southeastern New mexico. Site-characterization activities at the present WIPP site began in 1976. Full construction of the facility began in 1983, after completion of "Site and Preliminary Design validation" (SPDV) activities and reporting. Site-characterization activities since 1983 have had the objectives of updating or refining the overall conceptual model of the geologic, hydrologic, and structural behavior of the WIPP site and providing data adequate for use in WIPP performance assessment.

This report has four main objectives:

1. Summarize the results of WIPP site-characterization studies carried out since the spring of 1983 as a result of specific agreements between the U. S., Department of Energy and the state of new mexico.

2. Summarize the results and status of site-characterization and facility-characterization studies carried out since 1983, but not specifically included in mandated agreements.

3. Compile the results of WIPP site-characterization studies into an internally consistent conceptual model for the geologic, hydrologic, geochemical, and structural behavior of the WIPP site. This model includes some consideration of the effects of the WIPP facility and shafts on the local characteristics of the Solado and Rustler Formations.

4. Discuss the present limitations and/or uncertainties in the conceptual geologic model of the WIPP site and facility."

Lappin, A.R., Hunter, R.L., Garber, D.P., and Davies, P.B. eds. 1989. Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP), Southeastern New Mexico; March 1989. SAND89-0462. Sandia National Laboratories, Albuquerque, NM. WPO 24125.

EXECUTIVE SUMMARY, p iii;

" This report summarizes the current understanding of the expected long-term behavior of the Waste Isolation Pilot Plant (WIPP) repository and estimates long-term radionuclide doses in a series of six analyses investigating both undisturbed repository performance (Case I) and performance in response to a relatively high-consequence human Intrusion (Case II). It is the result of an intensive effort over a short time. The U. S. Department of Energy (DOE) decided to have Sandia National Laboratories prepare this report as a result of a meeting held January 5, 1989. The conceptual model of the expected long-term behavior of the WIPP repository used in this report was formulated in early to mid January 1989, drawing on information and understanding developed over the past decade. Numerical modeling of ground-water flow, radionuclide transport, and doses to humans began January 20, 1989 and was completed March 20, 1989.

The report has several objectives:

1. To briefly summarize Sandia's current technical understanding of the major components of long-term performance of the WIPP repository. The following areas are specifically addressed:

. . . .

f. radionuclide-transport mechanisms and properties of the Culebra Dolomite, the major pathway for ground-water transport of radionuclides from the WIPP to the biosphere.

. . . .

4. To describe, document, and interpret six sets of calculations estimating the potential health effects to individuals resulting from emplacement of CH-TRU wastes in the WIPP, hydrologic saturation of the repository as a result of either natural processes or human intrusion, direct and indirect exposure during and after drilling (where appropriate), and ground-water transport of radionuclides to a hypothetical stock well south of the WIPP site.

The calculations presented here investigate radionuclide transport and resulting health effects both during undisturbed performance of the WIPP repository and in response to a relatively high-consequence human intrusion into the repository. The human intrusion considered is drilling that results in a long-term interconnection of the repository, an underlying brine reservoir in the Castile Fm., and the overlying Culebra Dolomite. The Culebra Dolomite provides a relatively permeable pathway for ground-water transport of radionuclides to the hypothetical stock well."

LaVenue, A.M., Haug, A., and Kelley, V.A. 1988. Numerical Simulation of Ground-Water Flow in the Culebra Dolomite at the Waste Isolation Pilot Plant WIPP Site: Second Interim Report. SAND88-7002. Sandia National Laboratories, Albuquerque, NM. WPO 28558.

EXECUTIVE SUMMARY, p ii;

" This hydrologic modeling study has been performed as part of the regional hydrologic characterization of the Waste Isolation Pilot Plant (WIPP) Site in southeastern New Mexico. The study resulted in an estimation of the transmissivity distribution, hydraulic potentials, flow field, and fluid densities in the Culebra Dolomite Member of the Permian Rustler Formation at the WIPP site.

The three-dimensional finite-difference code SWIFT-II . . ."

Lenke, L.R., Berglund, J.W., and Cole, R.A. 1996. "Blowout Experiments Using Fine Grained Silica Sands in an Axisymmetric Geometry." NMERI 1996/7/32250. New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, NM.

1. INTRODUCTION; p. 1, para. 1;

" The Waste Isolation Pilot Plant (WIPP) located in southern New Mexico is the first planned, mined geologic repository for transuranic wastes generated by U. S. defense programs. WIPP is currently being evaluated to assess compliance with the requirements of EPA 40 CFR 191 Subpart B (US EPA, 1985). Briefly, this requirement, promulgated by the Environmental Protection Agency, limits the amount of radioactive material that can be released to the accessible environment over a 10000 year regulatory period.

This report addresses an experimental laboratory program developed to model sudden solids release during outgassing and resultant blowout from a waste repository breached by a rotary drilling bit. An axisymmetric geometry was employed. These experiments were conducted on uniform sized, cohesionless silica sands in a partially saturated condition. Pressures within the experimental model were monitored and release volumes as a function of these pressures were measured.

The release volumes were compared with a mathematical model developed by the authors which is described in a subsequent section of this report. This model assumes that the sole source of strength within the partially saturated granular media is caused by capillary surface tension between particles. The transport mechanism for subsequent mass removal is based on the terminal velocity of individual particles.

1.1 Background

Of the possible pathways for release to the accessible environment during the 10000 year regulatory period, one of the most important is that caused by the inadvertent penetration of a waste storage room by an exploratory drillbit. Assuming that current, standard drilling practices for gas and oil are used, solid radioactive waste can be released to the ground surface by three mechanisms; namely, cuttings, cavings and spallings. The last mechanism includes the borehole spall caused by the flow of waste generated gas to the borehole and resultant blowout to the ground surface. The volume associated with such a blowout is difficult to assess.

The waste in its unmodified form will consist of a mixture of contaminated organic (e.g., cloth, wood, rubber, plastics) and inorganic (e.g., metal, glass) materials and sludges. After placement in the mined (salt) repository the waste will be compressed by the creep closure of the surrounding salt and in addition may become exposed to brine. The exposure of the metallic waste to brine is expected to cause corrosion of the metals and as a byproduct will generate hydrogen gas (H_2). Additional gas will be generated by the biodegradation of the organics in the waste inventory. The gas volumes generated by corrosion and biodegradation are expected to rise continuously for 400 to 600 years until they reach and possibly exceed the lithostatic overburden stress which at the repository horizon is estimated to be 14.8 MPa. If a waste room is penetrated by a drillbit when the pressure is high, the gas will escape to the lower pressure borehole, and may initiate spalling of the borehole wall

and blowout to the ground surface. The waste will then be transported to the ground surface in the drilling mud and/or in the flowing gas.

Cuttings, cavings, and spallings have been identified as potentially important direct release processes affecting the long term compliance requirements of 40 CFR 191. The computational model for cuttings and cavings is complete and except for values of the effective shear resistance to erosion the data are adequate. No experimental data for waste shear resistance to erosion are available and, consequently, values typical for sea bed erosion have been used for performance assessment computations. These values are probably conservative and generate releases greater than for partially decomposed unmodified waste."

2. MATHEMATICAL MODEL; p. 4, para. 1;

" The CUTTING_S User's Manual (1995). discusses the physical processes that are assumed to influence the quantity of waste brought to the ground surface as the result of the inadvertent penetration of the repository by an exploratory drill bit. The range of activity of these release processes based on waste permeability and pore pressure are depicted graphically in Figure 2-1. Above a repository gas pressure of 8 MPa waste is forced toward the lower pressure borehole (spalling) and some of the waste i s transported to the surface. In this section of the report a mathematical model is developed that addresses the solid waste release caused only by blowout as depicted in Figure 2-1.

The results from steady state flow experiments conducted on a partially saturated granular media (glass spheres) in an axisymmetric cylindrical geometry indicate that a porous pattern of channels is formed adjacent to the "borehole" (Lenke and Berglund, 1995). As a consequence of these experiments, the following conceptual model is developed which more closely corresponds to the physical processes observed in the experiments. The basis of this conceptual model is described in the remainder of this section."

Marietta, M.G., Bertram-Howery, S.G., Anderson, D.R., Brinster, K.F., Guzowski, R.V., Iuzzolino, H., and Rechard, R.P. 1989. Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance With EPA 40 CFR Part 191, Subpart B, for the Waste Isolation Pilot Plant. SAND89-2027. Sandia National Laboratories, Albuquerque, NM. WPO 25952.

ABSTRACT;
" This report describes a demonstration of the performance assessment methodology for the Waste Isolation Pilot Plant (WIPP) to be used in assessing compliance with the Environmental Protection Agency's Standard, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 191, Subpart B). This demonstration incorporates development and screening of potentially disruptive scenarios. A preliminary analysis of the WIPP disposal system's response to human intrusion scenarios produces preliminary complementary cumulative distribution functions (CCDFs) similar to those that will ultimately be used to assess the compliance of the WIPP with the Containment Requirements of the Standard. Preliminary estimates of scenario probabilities are used to construct two demonstration CCDFs. The conceptual model of the disposal system consists of geologic,, hydrologic, and disposal system subsystems along with the physical and chemical processes associated with these subsystems. Parameter values defining the systems contain uncertainties and modeling approximations of such a disposal system contributes to those uncertainties. The WIPP compliance assessment methodology consists of a system of techniques and computer codes that estimate releases of radionuclides from the disposal system, incorporating analysis of the parameter uncertainties in the estimates. Demonstration CCDFs are presented, but are not yet credible enough to judge the probability of compliance of the WIPP with the EPA Standard. One CCDF, based primarily on conservative reference data and conservative conceptual models, exceeds EPA limits, and another CCDF that represents effects of possible engineered alternatives does not exceed EPA limits."

Martell, A.E., and Smith, R.M., 1977. Critical Stability Constants. Vol. 3: Other Organic Ligands. Plenum Publishing Corp, New York, NY.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Matalucci, R.V. 1982. Simulated-Waste Experiments Planned for the Waste Isolation Pilot Plant (WIPP). SAND82-0547. Sandia National Laboratories, Albuquerque, NM. WPO 24689..

ABSTRACT, p. 3-4;

" The US Department of Energy manages an R&D Program to provide a technical basis for systems design and safety and environmental assessments for future repositories of radioactive wastes resulting from US defense activities. The Waste Isolation Pilot Plant (WIPP) is southeast New Mexico is being developed within that Program as an R&D facility to demonstrate the safe disposal of such wastes in bedded salt. The Simulated-Waste Experiments (SWEs) refer to the in situ tests (without radioactivity) in the WIPP R&D Program that address the technical issues of isolating radioactive wastes in bedded salt. The SWEs include tests that concern the program areas of repository development and interactions of the waste package with the host rock. Data obtained from these tests will be used in evaluating performance assessment models and in developing a technical basis for future repository design and operations."

Mavor, M.J., and Logan, T.L. 1994. "Recent Advances in Coal Gas-Well Openhole Well Completion Technology," JPT, Journal of Petroleum Technology, Vol. 46, no. 7, pp. 587-593.

Summary, p. 587, col 1;
" This paper reviews the current applications of openhole techniques in the San Juan basin. Examples of recent advances and details for the use of the technology are documented in many of the references. The range of reservoir properties required for successful implementation of the technology is included. Hypotheses proposed to explain the success of the openhole wells are presented. The paper concludes with a discussion on future advances required to improve current completion procedures and the potential applicability of the process to other reservoir rock types."

Molecke, M.A., 1979. Gas Generation from Transuranic Waste Degradation: Data Summary and Interpretation. SAND79-1245. Sandia National Laboratories, Albuquerque, NM. WPO 26715.

1.0 INTRODUCTION, p 1, para 1;
" The generation of gases from the degradation of existing and potential forms of defense-related transuranic wastes has been the subject of extensive experimental investigations (1,2,3,4,5,6) over the past two to four years."

p. 1, para. 2;
" This paper summarizes and provides interpretation of all applicable waste degradation-gas generation data. This is an updated and significantly expanded review of an interim assessment document presented in January, 1979 (7). For completeness, data presented earlier (7) will be included along with the significant body of new data gathered in the last six months. This review and assessment has been compiled to assist the Department of Energy Waste Acceptance Criteria Steering Committee (WACSC) on their deliberations of acceptable TRU waste forms, whether existing in temporary storage or in laboratory development, for safe isolation in the WIPP.

This comprehensive review includes data and gas generation rates from several common TRU waste forms, various degradation mechanisms, synergism between mechanisms, resultant gas compositions, methods for reducing gas production rates, and comparisons between generation modes. Many of the experimental investigations to be described are still in progress; some of the data are preliminary and may be subsequently refined."

NIST (National Institute of Science and Technology). 1996. NIST Standard Reference Materials Catalog, 1995-1996. Standards Reference Materials Program, National Insititute of Standards and Technology, Washington, D.C.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Novak, C.F. 1995. "The Waste Isolation Pilot Plant (WIPP) Actinide Source Term: Test Plan for the Conceptual Model and the Dissolved Concentration Submodel." SAND95-1895 (September 21, 1995 revision). Sandia National Laboratories, Albuquerque, NM. WPO 27860.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Novak, C.F., Moore, R.C., and Vann Bynum, R. 1996. "Prediction of Dissolved Concentrations for $^{+}$III, $^{+}$IV, $^{+}$V, and $^{+}$VI Actinides in Salado and Castile Brine." Memorandum. Sandia National Laboratories, Albuquerque, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Papenguth, H.W., and Behl, Y.K. 1996. Test Plan for Evaluation of Colloid-Facilitated Actinide Transport at the Waste Isolation Pilot Plant. TP 96-01. Sandia National Laboratories, Albuquerque, NM. WPO 31337.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Perry, R.H., and Clinton, C.H. 1973. Chemical Engineers" Handbook, 5th ed. McGraw-Hill Book Company, New York, NY.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Peterson, M.N.A., and von der Borch, C.C., and Bien, G.S. 1966. "Growth of Dolomite Crystals," Amercan Journal of Science. Vol. 264, no. 4, pp. 257-272.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Pfeifle, T.W., Hansen, F.D., and Knowles, M.K. 1996. "Salt-Saturated Concrete Strength and Permeability," 4th Materials Engineering Conference, ASCE Materials Engineering Division, Washington, DC, November 11-18, 1996. Sandia National Laboratories, Albuquerque, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Pitzer, K.S. 1991. "Ion Interaction Approach: Theory and Data." Activity Cooefficients in Electrolyte Solutions. 2nd ed. Ed. K.S. Pitzer. CRC Press, Boca Raton, FL. pp. 75-154.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Popielak, R.S., Beauheim, R.L., Black, S.R., Coons, W.E., Ellingson, C.T., and Olsen, R.L. 1983. Brine Reservoirs in the Castile Formation, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, TME 3153, U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM. (Available from NTIS as DE86004341/XAB.)

EXECUTIVE SUMMARY, p 1;

" The Waste Isolation Pilot Plant (WIPP) project is a U. S. Department of Energy (DOE) research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States. This demonstration consists of two parts. First, about six million cubic feet of TRU waste will be emplaced in the thick bedded-salt deposits of the Salado Formation in southeastern New Mexico at a depth of about 2150 feet. Second, the WIPP will provide for research relative to the interactions of defense high-level waste with bedded salt, though all high-level waste will be removed prior to facility decommissioning.

A potential location was selected for the WIPP in the northern Delaware Basin of New Mexico, and three exploratory core holes were drilled (AEC-7, AEC-8, and ERDA-6; Figure 1). While drilling the third such hole (ERDA-6), substantial geologic structural deformation was noted, and brine and gas sufficiently pressurized to flow to the surface were encountered. The unpredictability of the geology led to relocation of the site to its present location in 1974 (Figure 1). Since relocation, an extensive site characterization program has been conducted, and the adequacy of the site has generally been demonstrated.

In 1981, an agreement was signed between the State of New Mexico, the DOE, and others which included several studies intended to address the State's concerns relative to the suitability of the proposed WIPP site. Some of these studies addressed an area of geologic interest north of the proposed site, and pressurized brine reservoirs in the Delaware Basin. The work was begun in October 1981 and included the reopening and testing of ERDA-6, and the deepening and testing of WIPP-12, an exploration borehole which also encountered pressurized brine and gas. This report provides an account of these studies.

These studies and preparation of the brine reservoir report were performed by the WIPP Technical Support Contractor (TSC), primarily by D'Appolonia Consulting Engineers, Inc. (a member of the WIPP-TSC) under subcontract to the Westinghouse Electric Corporation (the TSC prime contractor). Sandia National Laboratories, Albuquerque, N.M., provided critical review of the studies and report; the U. S. Geological Survey also made comments.

The occurrence of pressurized brine reservoirs in the Castile Formation (underlying the Salado Formation) of the Delaware Basin has been documented over the past 40 years by reports of reservoir encounters by hydrocarbon exploration drilling. In general, these reservoirs were known to be contained in fractured anhydrite with associated hydrogen sulfide gas and were thought to be related to antiforms in the Castile.

Various theories were advanced to explain the origin of reservoirs, which include dissolution of evaporites by recent ground waters, dehydration of gypsum to form anhydrite, entrapment of ancient seawater during evaporite deposition, and ancient dissolution and

reprecipitation of evaporite minerals. Should certain of these theories be correct, the suitability of the WIPP site could be in question. Thus, the purpose of this study was to determine the characteristics and origin of these reservoirs and evaluate their potential impact on the integrity and stability of the WIPP site.

Data used in the performance of this study were obtained from drilling and hydrological testing in boreholes ERDA-6" and WIPP-12 and from chemical analyses of samples of reservoir brine and gas collected at these two wells. Information was also obtained from a review of published and unpublished literature on the geology and hydrology of the basin. The principle data reviewed and analyzed in this report are contained in "Data File report - ERDA-6 and WIPP-12 Testing" (D'Appolonia, 1982, 1983)."

Quality Assurance Department. 1995. "Verification of Design Adequacy." Waste Isolation Pilot Plant Quality Assurance Procedure QAP 3-2, Revision 1 (July 31, 1995). Sandia National Laboratories, Albuquerque, NM. Filed in records package WPO 37178.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Reeves, M., Kelley, V.A., and Pickens, J.F. 1987. Regional Double-Porosity Solute Transport in the Culebra Dolomite: An Analysis of Parameter Sensitivity and Importance at the Wste Isolation Pilot Plant (WIPP) Site. SAND87-7105. Sandia National Laboratories, Albuquerque, NM. WPO 25714.

ABSTRACT, p. ii;

" A high-transmissivity fracture-controlled path is assumed, for modeling purposes, to provide the means for transport of infinitely long-lived radionuclides through the Culebra dolomite to the accessible environment at the Waste Isolation Pilot Plant (WIPP) site, following a breach which does not disturb the existing head potentials within the unit. Both matrix diffusion and sorption retard the transport. Parameter ranges and base-case values depict the uncertain properties of the Culebra while simulations with SWIFT II exhibit the corresponding ranges in travel time, the performance measure adopted for this report. Consistent with the paucity of the double-porosity data base, model assumptions are kept simple and parameter ranges relatively large. Thus, computed travel times may be unrealistic and should not be quoted apart from the model assumptions. Computed parameter sensitivities and estimated parameter importance, however, should provide valuable guidance to the current site-characterization program at the WIPP site. The report demonstrates the importance of the rate of fluid flow within the fractures and the relative capacity of the rock matrix for the retention of radioactive contaminants. It also demonstrates the relative unimportance of some of the matrix kinetic parameters which relate to the matrix-diffusion time. The report underscores the importance of hydraulic and tracer tests, particularly in the southeast sector of the WIPP site. Such tests would further confirm the flow and transport conceptualization, determine the extent of site heterogeneity, and reduce uncertainty in the transport properties."

Sax, N.I., and Lewis, R.J. 1987. Hawley's Condensed Chemical Dictionary, 11th ed. Van Nostrand Reinhold, New York, NY.

INTRODUCTION, P. ix;

" The first edition of the Condensed Chemical Dictionary appeared in 1919, when the chemical industry in the United States was entering a huge expansion program as a result of World War I. The urgent need for such a reference book became apparent to Francis M. Turner, President of the Chemical Catalog Company, predecessor of the Reinhold Publishing Corporation. Under his supervision a succession of Editors developed and expanded the Condensed Chemical Dictionary to meet the growing needs of the chemical industries. Since his death this development has continued, with the result that the work has achieved worldwide recognition in its field.

The Condensed Chemical Dictionary is a unique publication. It is not a dictionary in the usual sense of a compilation of brief definitions, but rather a compendium of technical data and descriptive information covering many thousand chemicals and chemical phenomena, organized in such a way as to meet the needs of those who have only minutes to devote to any given substance or topic.

Three distinct types of information are presented: (1) descriptions of chemicals, raw materials, processes and equipment; (2) expanded definitions of chemical entities, phenomena, and terminology; and (3) description or identification of a wide range of trademarked products used in the chemical industries. Supplementing these are listings of accepted chemical abbreviations used in the literature, short biographies of chemists of historic importance, and descriptions or notations of the nature and location of many American technical societies and trade associations. In special cases editorial notes have been supplied where it was felt necessary to clarify or amplify a definition or description. A few entries written by specialists are acknowledged by use of the author's name.

In a work of this nature, selection of topics for inclusion can hardly fail to be influenced by current interests and developing concerns within the topic area. The growing importance to chemists, and to the general public as well, of environmental and health hazards, which came to the forefront so quickly in the 1960s was reflected in the Eighth Edition, which greatly increased its coverage of this aspect of chemistry. After that, the magnitude of the energy problem became uppermost in the thinking of a broad spectrum of engineers, chemists, and physicists, since it has certainly become one of the most important technical problems confronting this country. Both the Ninth and Tenth Editions, while retaining emphasis on environmental considerations, were expanded in the area of energy and its sources, as far as permitted by available information. The effort in the eleventh edition has been to provide condensed, authoritative, factually oriented statements and descriptions, and to resist prognostications as to the future potential of any particular energy source. At the same time, continuing attention has been devoted to common hazards, such as flammable and explosive materials, poisons, pesticides, carcinogens, corrosive agents, radioactive wastes, etc., in line with the increasing public concern over these matters.

In connection with certain classifications of substances, particularly pesticides and

carcinogens, which have occasioned the most controversy, the statement "Use may be restricted" indicates that a state or local regulation may exist even though the product has not been officially banned, or that a definitive ruling on its use is pending. When a product has been banned outright, the statement "Use has been prohibited" is used. A number of disputed cases have arisen in recent years; though some have been definitely settled, others are still being evaluated or are in the process of litigation, for example, saccharin.

In such a work as this, in view of the many materials in various stages of evaluative testing, court procedures, appeals, hearings, etc., it is impossible to keep abreast of every development. The user should check the current status of any questionable products before making decisions that involve them (see also paragraph on Hazards, below)."

Sayles, F.L., and Fyfe, W.S. 1973. "The Crystallization of Magnesite from Aqueous Solution," Geochimica et Cosmochimica Acta. Vol 37, no. 1, pp 87-99.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Snyder, R.P., Gard, L.M., Jr., and Mercer, J.W. 1982. Evaluation of Breccia Pipes In Southeastern New Mexico and Their Relation to the Waste Isolation Pilot Plant (WIPP) Site, With Section on Drill-Stem Tests, WIPP-31. Open-File Report 82-968, U.S. Geological Survey for the U.S. Department of Energy, Albuquerque Operations Office, Denver, CO.

INTRODUCTION, p. 1;

" The Waste Isolation Pilot Plant (WIPP) site is located about 40 km (25 mi) east of Carlsbad, N. Mex. (fig. 1). The site geography has been described in detail by Powers and others (1978) and U.S. Department of Energy (1980, 1981). Site selection was based principally on the existence of a thick section of Permian evaporites, mainly halite. The purpose of establishing this site is to demonstrate whether or not an evaporite environment is acceptable for the disposal of trans-uranic waste generated by the Nation's defense programs.

The primary concern regarding safe disposal of nuclear waste is to isolate the waste from the biosphere until it is no longer a danger to mankind. One of the most probable methods of accidental release of radiation from nuclear waste isolated in a geologic medium is leaching and transport of the waste by moving ground water. It is therefore of primary importance to identify any potential channelways that might allow water to enter a repository site located on bedded salt of the Salado Formation of southeastern New Mexico. The presence of the thick Permian (225 m.y.) rocks attests to the fact that major dissolution of the halite by unsaturated ground water has not occurred at the WIPP site.

Focus of Current Study

This report describes several dissolution features in the Delaware Basin and elsewhere that have been referred to as breccia pipes. Breccia pipes (also called breccia chimneys) as they occur in evaporites are vertical cylindrical pipes or chimneys that may or may not involve more than one geologic formation. The chimneys are filled with downward-displaced brecciated rock. In this context, the rock is brecciated by having collapsed into a void at depth that was probably created by ground-water solution and removal of deep-lying evaporite or carbonate rocks in an underlying aquifer system (Anderson and Kirkland, 1980; Bachman, 1980). Such features have been described in evaporite deposits in many areas of the world.

The current study was done for the U.S. Department of Energy (DOE) in response to a suggestion that because breccia pipes are thought to be the result of deep dissolution, they may represent channelways for future ingress of ground water, and that they should be considered in risk assessment programs for the evaluation of proposed waste repositories in bedded evaporite rocks. To this end, features referred to as breccia pipes in southeastern New Mexico have been assessed in relation to the integrity of the WIPP site. Reports by Anderson (1978), Bachman (1980), and Vine (1960) described dissolution and karst features in the Pecos region of southeastern New Mexico and discussed the origin and history of breccia pipes. The present report is intended to supplement these studies and provide detail that was not available to them at the time their reports were written.

Using the data from exploratory work, answers may be found to the following

questions concerning breccia pipes:

1. Do breccia pipes penetrate through the evaporite section?
2. What is the physical description of a pipe?
3. How are they formed?
4. How deep do they go?
5. When are they formed, and are they forming at present?
6. Are they permeable?
7. Where are they formed, can they form at the WIPP site?
8. Do they represent a threat to the WIPP site?"

Stein, C.L. 1985. Mineralogy in the Waste Isolation Pilot Plant (WIPP) Facility Stratigraphic Horizon. SAND85-0321. Sandia National Laboratories, Albuquerque, NM. WPO 27631.

ABSTRACT; p. 3, para. 1;

" Forty-six samples were selected for this study from two cores, one extending 50 ft up through the roof of the WIPP facility and the other penetrating 50 ft below the facility floor. These samples, selected from approximately every other foot of core length, represent the major lithologies present in the immediate vicinity of the WIPP facility horizon: "clean" halite, polyhalitic halite, argillaceous halite, and mixed polyhalitic-argillaceous halite. Samples were analyzed for not NaCl mineralogy by determining weight percents of water- and EDTA-insoluble residues, which were then identified by x-ray diffraction. In general, WIPP halite contains at most 5 wt% non-NaCl residue. The major mineral constituents are quartz, magnesite, anhydrite, gypsum, polyhalite, and clays. Results of this study confirm that, in previous descriptions of WIPP core, trace mineral quantities have been visually overestimated by approximately an order of magnitude."

Streeter, V.L. 1958. Fluid Mechanics. 2nd ed. McGraw-Hill. New York, NY.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Stühenberg, D., and Zhang, C. 1995. "Results of Experiments on the Compaction and Permeability Behavior of Crushed Salt," Fifth International Conference on Radioactive Waste Management and Environmental Remediation -- ICEM '95: Proceedings. Volume 1:Cross-Cutting Issues and Management of High-Level Waste and Environmental Remediation, Berlin, Germany, September 3-9, 1995. Eds. S. Slate and F. Feizollahi. American Society of Mechanical Engineers, New York, NY. p. 797-801. ISBN: 0-7918-1219-7.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Thompson, T.W., Coons, W.E., Krumhansl, J.L., and Hansen, F.D. 1996. "Inadvertent Intrusion Borehole Permeability. Final Report." Filed as an attachment to WPO 39622, WPO 39624 and WPO 39626

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Vaughn, P.L. 1996. "Impacts of Using Only H_2 on Repository Flow and Pressure." May 21, 1996. Sandia National Laboratories, Albuquerque, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Von der Borch, C. 1965. "The Distribution and Preliminary Geochemistry of Modern Carbonate Sediments of the Coorong Area, South Australia," Geochimica et Cosmochemica Acta, vol. 29, pp. 781-799.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wang Y., 1996a, "Define Chemical Conditions for FMT Actinide Solubility Calculations." Memorandum to Malcolm Siegel, May 18, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 37038.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wang, Y. 1996b. "Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment." Memorandum to R.V. Bynum and L.H. Brush, July 19, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 39871.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wang, Y., and L.H. Brush. 1996a. "Estimates of Gas-Generation Parameters for the Long-Term WIPP Performance Assessment." Memorandum to M.S. Tierney, January 26, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 31943.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wang, Y., and L.H. Brush. 1996b. "Modify the Stoichiometric Factor y in BRAGFLO to Inlcude the Effect MgO Added to WIPP Repository as Backfill." Memorandum to M.S. Tierney, February 23, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 32286.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Watkins, D. 1996. "Estimate of Cement Content in TRU Solidified Waste Forms Scheduled for Disposal in WIPP," Memorandum to Les Shephard, April 4, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 37064.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wawersik, W.R., and Stone, C.M 1989. "A Charcertization of Pressure Records in Inelastic Rock Demonstrated by Hydraulic Fracturing Measurements in Salt," International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts. Vol. 26, no. 6, pp. 613-627. (This document was also released as SAND87-2569J, which is filed in the SWCF as WPO 24523.)

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Weatherby, J.R., Brown, W.T., and Butcher, B.M. 1991. "The Closure of WIPP Disposal Rooms Filled with Various Waste and Backfill Combinations," Rock Mechanics as a Multidisciplinary Science, Proceedings of the 32nd U.S. Symposium on Rock Mechanics, Norman, OK, July 10-12, 1991. Ed. J-C. Roegiers. A.A. Balkema, Brookfield, VT. pp. 919-928. (This document was also released as SAND90-2399C, which is filed in the SWCF as WPO 28617.)

ABSTRACT p. 1;
" Two-dimensional finite element analyses were used to investigate the closure of WIPP disposal rooms filled with backfill and rooms filled with a combination of waste and backfill. Two different backfill materials were considered. The analyses provide estimates of the porosity in the disposal room as a function of time. These results have been used to help evaluate the suitability of the backfill materials for use in the repository."

p 4, para 4;
" The stress-strain behavior of the waste was represented by a volumetric plasticity model with a piecewise linear function defining the relationship between the mean stress p and the volumetric strain e_v. Compaction experiments on simulated waste were used to develop this relationship. Table 2 lists the ordered pairs that define the piecewise linear relationship between p and e_v in the two analyses that include waste."

Table 2: Assumed relationship between the mean stress and the volume strain for the CH-TRU waste.

Mean Stress, p (MPa)	Volume Strain, e_v ($\log(\rho/\rho_0)$)
0.028	0.032
0.733	0.741
1.133	0.898
1.667	1.029
2.800	1.180
10.17	1.536

Weiner, R.F. 1996. "Dissolved Ligand Concentrations." Memorandum to C.F. Novak, March 27, 1996. Sandia National Laboratories, Albuquerque, NM. WPO 36163.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

WIPP PA (Performance Assessment). 1991-1992. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1991. SAND91-0893. Sandia National Laboratories, Albuquerque, NM. Vols. 1-4.

ABSTRACT, p i;

" Before disposing of transuranic wastes at the Waste Isolation Pilot Plant (WIPP), the United States Department of Energy must have a reasonable expectation that the WIPP will comply with the quantitative requirements of Subpart B of the United States Environmental Protection Agency's (EPA) Standard, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*. Sandia National Laboratories, through iterative performance assessments of the WIPP disposal system, is conducting an evaluation of the long-term performance of the WIPP that includes analyses for the Containment Requirements and the Individual Protection Requirements of Subpart B of the Standard. Recognizing that unequivocal proof of compliance with the Standard is not possible because of the substantial uncertainties in predicting future human actions or natural events, the EPA expects compliance to be determined on the basis of specified quantitative analyses and informed, qualitative judgment. Performance assessments of the WIPP will provide as detailed and thorough a basis as practical for the quantitative aspects of that decision.

PREFACE; p. vii, para. 1;

" The Waste Isolation Pilot Plant (WIPP) is planned as the first mined geologic repository for transuranic (TRU) wastes generated by defense programs of the United States Department of Energy (DOE). Assessing compliance with the long-term performance criteria of Subpart B of the United States Environmental Protection Agency's (EPA) Standard, Environmental Radiation Protection Standards for the Management and Disposal of Spend Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (40 CFR Part 191), is a cornerstone for the DOE's successful implementation of a TRU-waste disposal system.

This report (the 1991 Preliminary Comparison) is a preliminary version of the planned document, Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plane (the Comparison). The 1991 Preliminary Comparison is the second in a series of annual "Performance Analysis and DOE Documentation" reports shown in the timing for performance assessment in the 1991 DOE report Strategy for the Waste Isolation Pilot Plant Test Phase (DOE/EM/48063-2). The Test Phase schedule and projected budget may change; if so, the schedule for the performance-assessment reports will also change. Where data and models are available, the text is a preview of the final report scheduled for 1996 (DOE/EM/48063-2). This report is a preview of the final Comparison only to the extent that the Standard, when repromulgated, is the same as the vacated 1985 Standard. This report treats the vacated Subpart B of the Standard as if it were still effective, because the DOE and the State of New Mexico have agreed that compliance evaluation will continue on that basis until a new Subpart B is promulgated. The approach to the Standard and the resultant methodology reported here do not reflect the EPA's efforts to develop a new Subpart B.

The 1991 Preliminary Comparison is based on last year's reports: the Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990 (SAND90-2347), Data Used in Preliminary Performance Assessment of the Waste Isolation Pilot Plant (1990) (SAND89-2408), and Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant (SAND90-7103). The 1991 Preliminary Comparison consists of four volumes. Volumes 2 (Probability and Consequence Modeling) and 3 (Reference Data) will be published in December 1991 with this volume (Methodology and Results). Volume 4 (Uncertainty and Sensitivity Analyses) will be published in March 1992.

Performance assessment is a dynamic process that relies on iterative simulations using techniques developed and data collected as work progresses. Neither the data base nor the models are fixed at this stage, and all aspects of the compliance-assessment system are subject to review as new information becomes available. Much of the modeling system described in this report will not change as the work progresses. Some of it will change, however, as problems are resolved and new models and data are incorporated into the system for use in subsequent simulations.

Vertical change bars in the right margins of Volume 1 of the 1991 Preliminary Comparison indicate changes from the text published in the single-volume 1990 Preliminary Comparison. Chapters 3 through 7 and Chapters 10 and 11 of the 1991 report, however, have been substantially revised or rewritten since the 1990 version and do not contain change bars. Chapters 3, 4, and 5 have been revised to reflect additions to the methodology and data used in evaluating the WIPP. Chapters 6 and 7 contain the results of the 1991 preliminary performance-assessment calculations. Chapters 10 and 11 discuss the 1991 results and summarize the status of the work to be completed to develop an adequate basis for evaluating compliance with Subpart B of the Standard.

Volumes 2, 3, and 4 do not contain change bars. Volume 2 is a compilation of essentially new material or material that was presented in a briefer form in 1990. Volume 3 is based on Data Used in Preliminary Performance Assessment of the Waste Isolation Pilot Plant (1990), SAND89-2408, but contains numerous additions and refinements to the reference data base. Volume 4 reports the results of the uncertainty and sensitivity analyses for the 1991 calculations. Sensitivity analyses identify aspects of the modeling system that have the greatest potential to affect performance, thereby helping guide ongoing research. Because new data or new interpretations of existing data may change the conceptual models and/or the ranges and distributions of parameters throughout the life of the WIPP Project, sensitivity analyses are also iterative. Volume 4 is substantially revised and rewritten compared to the previous year's report, Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant, SAND90-7103."

APPENDIX B: RESPONSE TO REVIEW COMMENTS; p. b-3, para. 1;

" Comments in this appendix relate to SAND90-2347, Preliminary Comparison with CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990. Responses relate to SAND91-0893, the 1991 version of SAND90-2347."

WIPP PA (Performance Assessment) 1992-1993. Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992. SAND92-0700. Sandia National Laboratories, Albuquerque, NM. Vols. 1-5.

1. INTRODUCTION; p. 1-1, para. 1;

" The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is a research and development project of the United States Department of Energy (DOE). The WIPP is authorized by Congress (Public Law 96-164, 1979) and is designed as a full-scale, mined geologic repository to demonstrate the safe management, storage, and disposal of transuranic (TRU) radioactive wastes generated by DOE defense programs since 1970. In addition to TRU radionuclides, the wastes may contain hazardous (nonradioactive) constituents. Before permanently disposing of radioactive wastes in the WIPP, the DOE must evaluate the repository based on various regulatory criteria for disposal of all the waste components, and the United States Environmental Protection Agency (EPA) must certify that compliance has been satisfactorily demonstrated.

Performance assessments will form the basis for evaluations of compliance with applicable long-term regulations of the EPA, including regulations pertaining to both radioactive and hazardous wastes (see Section 1.2 for a discussion of applicable regulations). This volume provides an overview of WIPP performance assessment and summarizes the December 1992 preliminary comparison with 40 CFR Part 191, Subpart B, which contains the long-term requirements of the Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (US EPA, 1985). Results presented here are preliminary and are not suitable for final comparison with 40 CFR 191, Subpart B. Portions of the modeling system remain incomplete, and the level of confidence in the performance estimates is not sufficient for a defensible compliance evaluation. Results are suitable for providing interim guidance to the WIPP Project as it prepares for a final compliance evaluation.

Several DOE documents explain the relationship between long-term regulatory information needs and the experimental programs that will fill those needs. The WIPP Test Phase Plan (US DOE, 1990a, currently in revision) contains descriptions of experimental programs related to disposal room and drift systems (see also Section 2.4 of this volume and Volumes 2 and 3 of this report), TRU-waste experiments, sealing systems and rock mechanics, hydrology of the transport within the host rock for the WIPP, and flow and transport in rock layers surrounding the WIPP. For each experimental program, the document describes the relevant information needs identified by performance assessments (defined in Section 3.3.1 of this volume) and indicates how the program has been designed to fill those needs.

The technical needs for laboratory and field experiments involving TRU and TRU-mixed waste and simulated waste have been assessed (US DOE, 1992a). These tests are designed to provide information on two topics identified as important for evaluating regulatory compliance: generation of gas from degradation of TRU wastes (defined in Section 2.5.1 of this volume), and the concentration of radionuclides and hazardous

constituents within disposal-room brine, both as dissolved species and as colloids.

Extensive laboratory and field studies conducted during the Site Characterization Phase for the WIPP have provided information used to date in performance assessments of the WIPP. References for these studies and discussion of how their results are used in performance assessments are provided in WIPP Test Phase Activities in Support of Critical Performance Assessment (40 CFR 191 B) Information Needs (US DOE, 1992b), which is a document prepared by the DOE for the National Academy of Sciences (NAS) WIPP Panel (referred to in Section 1.1.1 of this volume), and in other reports (Tyler et al., 1988; Lappin et al., 1989; US DOE, 1990a).

This report documents the third in a series of preliminary analyses of predicted long-term performance of the WIPP that Sandia National Laboratories (SNL) conducts for the DOE. Preparation for preliminary performance assessments began with the December 1989 Draft Forecast of the Final Report for the Comparison to 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant (Bertram-Howery et al., 1989 and Performance Assessment Methodology Demonstration: Methodology Development for Evaluating Compliance with EPA 40 CFR 191, Subpart B, for the Waste Isolation Pilot Plant (Marietta et al., 1989). The 1990 report (Bertram-Howery et al., 1990) and two supporting volumes (Rechard et al., 1990a; Helton et al., 1991) presented preliminary results of evaluation that addressed only the long-term performance criteria for disposal specified in the radioactive-waste disposal standards (40 CFR 191, Subpart B, US EPA, 1985; see Chapter 3 and Appendix A of this volume). The 1991 version of the report (WIPP PA Division, 1991a, b, c; Helton et al., 1992) presented preliminary evaluations for comparison with the regulatory requirements of 40 CFR 191, Subpart B. A preliminary safety assessment that evaluates possible long-term consequences to the public health as a result of radioactive waste emplaced in the WIPP is currently being prepared.

This 1992 report updates the preliminary results of the analyses included in the 1991 version of the report. Where data and models are available, the report presents preliminary results that preview a final report. With respect to the disposal of radioactive wastes, this 1992 report is a valid preview only to the extent that 40 CFR 191, Subpart B, which was promulgated by the EPA in 1985 and remanded by a U. S. Appeals Court in 1987 (NRDC v. US EPA, 1987), is the same as the vacated 1985 version. This report treats the vacated portion of 40 CFR 191 as if it were still effective because the DOE and the State of New Mexico have agreed that compliance planning will continue on that basis until a new Subpart B is promulgated (US DOE and State of New Mexico, 1981, as modified)."

APPENDIX B; p. b-3, para. 1;

" As stated in the Waste Isolation Pilot Plant Land Withdrawal Act (Public Law 102-579, 1992), performance assessment (PA) analyses shall be provided every two years "to the State [of New Mexico], the [EPA], the National Academy of Sciences, and the EEG [Environmental Evaluation Group] for their review and comment."

The inclusion of this appendix in the 1992 Preliminary Performance Assessment marks the third year that the Sandia National Laboratories' (SNL) PA Department has

published the complete text of formal comments received from these groups together with responses indicating how comments will be addressed in future PA iterations (Bertram-Howery et al., 1990; WIPP PA Division, 1991a). In previous years this appendix has included comments from the New Mexico Environment Department (1990, 1991), the EPA Office of Radiation Programs (1990), and the EEG (1990, 1991). Comments have been received in 1992 only from the EEG. These comments pertain to the 1991 preliminary PA, as published in the first four volumes of SAND91-0893 (WIPP PA Division, 1991a, b, c; Helton et al., 1992)."

Wolery, T.J. 1992. EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0). UCRL-MA-110662 Pt. 3. Lawrence Livermore National Laboratory, Livermore, CA.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wolery, T.J., and Daveler, S.A., 1992. EQ6, A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems; Theoretical Manual, User's Guide and Related Documentation (Version 7.0), UCRL-MA-110662, Pt. 4. Lawrence Livermore National Laboratory, Livermore, CA.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Wood, B.J., Snow, R.E., Cosler, D.J., and Haji-Djafari, S. 1982. Delaware Mountain Group (DMG) Hydrology -- Salt Removal Potential, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3166, U.S. Department of Energy, Waste Isolation Pilot Plant, Albuquerque, NM.

INTRODUCTION AND SUMMARY, p. 1;

" This report provides an account of studies performed to evaluate the potential for salt dissolution in the Castile Formation, removal of dissolved salt by fluids in the Bell Canyon aquifer within the Delaware Mountain Group (DMG), and the potential impact of this process on the long-term integrity of the Waste Isolation Pilot Plant (WIPP) facility.

The results of this study provide responses to the stipulated agreement of July 1, 1981 with the U.S. Department of Energy (DOE) and the state of New Mexico regarding the DMG hydrologic investigation. This study was performed and this report prepared by D'Appolonia Consulting Engineers, Inc. (D'Appolonia), under Subcontract S9-CJR-45451 with Westinghouse Electric Corporation, Advanced Energy Systems Division, under Contract DE-AC04-78-ET05346 with the DOE. The Westinghouse team is serving as the Technical Support Contractors (TSC) to the DOE for the WIPP project.

This report is divided into the following six chapters:

- Introduction and Summary (1.0)
- Site Conditions (2.0)
- Salt Dissolution Features and Mechanisms (3.0)
- Evaluation of Dissolution Mechanisms in the Delaware Basin (4.0)
- Assessment of Salt Dissolution (5.0)
- Conclusions (6.0)

and supplementary appendices:

- Review of Numerical Simulation Techniques and Basic Governing Equations of Flow and Mass Transport (Appendix A)
- Sensitivity Analysis of Salt Dissolution and Transport Parameters (Appendix B)"

BIBLIOGRAPHY DOCUMENTS

Brush, L.H., 1995. Systems Prioritization Method - Iteration 2 Baseline Position Paper: Gas Generation in the Waste Isolation Pilot Plant. Sandia National Laboratories, Albuquerque, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Bertram-Howery, S.G., Marietta, M.G., Rechard, R.P., Swift, P.N., Anderson, D.R., Baker, B.L., Bean, J.E., Jr., Beyeler, W., Brinster, K.F., Guzowski, R.V., Helton, J.C., McCurley, R.D., Rudeen, D.K., Schreiber, J.D., and Vaughn, P. 1990. Preliminary Comparison with 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant, December 1990. SAND90-2347. Sandia National Laboratories, Albuquerque, NM. WPO 27796.

ABSTRACT, p i;

" The Waste Isolation Pilot Plant (WIPP) is planned as the first mined geologic repository for transuranic (TRU) wastes generated by defense programs of the United States Department of Energy (DOE). Before disposing of waste at the WIPP, the DOE must evaluate compliance with the United States Environmental Protection Agency's (EPA) Standard, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 1919, U. S. EPA, 1985). Sandia National Laboratories (SNL) is evaluating long-term performance against criteria in Subpart B of the Standard. 'Performance assessment' as used in this report includes analyses for the Containment Requirements (§ 191.13(a)) and the Individual Protection Requirements (§ 191.15). Because proving predictions about future human actions or natural events is not possible, the EPA expects compliance to be determined on the basis of specified quantitative analyses and informed, qualitative judgment. The goal of the WIPP performance-assessment team at SNL is to provide as detailed and thorough a basis as practical for the quantitative aspect of that decision.

This report summarizes SNL's late-1990 understanding of the WIPP Project's ability to evaluate compliance with Subpart B. This preliminary assessment cannot be defensibly compared to the requirements of the Standard to interpret whether the WIPP disposal system complies with Subpart B. Defensibility of the compliance evaluation ultimately will be determined primarily by qualitative judgment regarding 'reasonable expectations of compliance,' assuming that concept is retained by the EPA in promulgating the vacated Subpart B. Other considerations such as completeness and adequacy of the numerical simulations will also be factors in determining defensibility. Performance assessment must determine the events that can occur, the likelihood of these events, and the consequences of these events. The impacts of uncertainties must be characterized and displayed; however, no single summary measure can adequately display all the information produced in a performance assessment. Adequate documentation is an essential part of a performance assessment.

In lieu of results suitable for comparison with the Standard, this report presents results of sensitivity analyses that address specific uncertainties in the modeling system. All results are preliminary, and are conditional on assumed conceptual models and parameter value distributions. The results show the degree to which some uncertainties in the conceptual models that describe aspects of disposal-system behavior may affect predicted performance. The results also demonstrate the methodology used to assess performance. The reported complementary cumulative distribution functions (CCDF's) are statistical means of families of CCDFs. The modeling system is sensitive to changes in scenario probabilities,

and reductions in the probability of intrusion significantly reduce predicted probabilistic cumulative releases. Comparison of clay-lined-fracture and dual-porosity transport models for the dominant water-bearing unit above the repository indicate a significant increase in radionuclide retardation and a consequent reduction in predicted releases with the dual-porosity model. Simulations of a variable number of intrusions show that, for the selected probability model, multiple intrusions do not increase the largest cumulative releases. Simulations of a hypothetical waste modification suggest that for modifications to be effective, waste permeability must be reduced more than four orders of magnitude below the estimated unmodified value to restrict brine flow to an intruding borehole. Simulations of gas generation and the effects gas will have on brine flow and radionuclide transport are not sufficiently advanced to be incorporated in this year's CCDF curves, but preliminary results of one-dimensional simulations are included. Preliminary analyses for the Individual Protection Requirements suggest that no releases will occur; therefore, dose predictions are not likely to be required.

Although disposal-system characterization work has been underway for about 15 years, and much is known about the WIPP, all work necessary to support the performance assessment has not been completed. Most work currently in progress to support the performance assessment is not advanced enough to support a defensible comparison to the Standard because many important modules are in preliminary or intermediate stages of understanding or readiness. The compliance assessment system can be used for sensitivity and uncertainty analyses, and is adequate for preliminary performance studies."

DOE (U.S. Department of Energy), 1980. Waste Isolation Pilot Plant Safety Analysis Report, Washington, D.C.

Volume 1, Section, 2.4.2.2 Flood Design Consideration, p 2.4.8, para 1;
" The local drainage pattern (western slope) is such that surface runoff from areas north, south, and west of the surface facilities drains westward into the Pecos River without affecting the structures at the site. However, surface runoff generated by intense precipitation over local catchments immediately east of the surface facilities can pass through the site. Storm water runoff from areas around the surface facilities, including that on the east, are diverted by a system of peripheral interceptor drains. The site drainage system is designed so that storm runoff due to the probable maximum precipitation on the contributing drainage areas does not flood the plant. The floors of the waste handling building and other surface facilities are 0.5 feet above the grade elevation. The grade elevations of the roads, tracks, and surface facilities are designed so that storm water will drain off site under the most severe conditions (probable maximum precipitation; PMP)."

Volume 1, Section 2.4.2.3 Effects of Local Intense Precipitation, p 2.4-9, para 2, line 7;
" The WIPP is about 14 miles from the Pecos River. The general ground elevation in the vicinity of the surface facilities is about 500 feet above the riverbed and over 400 feet above the flood plain. AS discussed in sub-section 2.4.3.5 and 2.4.4, a probable maximum flood (PMF) or floods induced by potential dam failure on the Pecos River or its tributaries cannot raise the water level 500 feet to endanger the WIPP site. Therefore, as far as the potential for flooding from the Pecos River is concerned, the site is categorized as a "dry site." Since the distance between the Pecos River and the site is large and the permeability of the material separating the two is low, the response of groundwater at the site to changes in the surface level of the Pecos River is extremely slow. Therefore, it is concluded that groundwater elevation at the site are not affected by floods in the Pecos River."

Volume 1, Section 2.4.3.2 Precipitation Losses, p 2.4-11, line 20;
" The potential evaporation is much greater than the average annual precipitation of about 12 inches. In the southeastern valley, annual evaporation from a Class A pan is of the order of 110 inches. During the ward months, May through October, evaporation in the southeast portion of the state where the site is located, is about 73 inches. The monthly evaporation in the Pecos River basin is at the maximum in June and at the minimum during the months of December and January. The average annual Class A pan evaporation at Alamogordo, Avalon and Red Bluff is 109.06, 112.98 and 111.37 inches, respectively."

DOE (U.S. Department of Energy), 1990. Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant, DOE/EIS-0026-FS, U.S. Department of Energy, Office of Environmental Restoration and Waste Management, Washington, D.C. Vols. 1-13.

Volume 1, Section 1.3 PURPOSE AND NEED FOR SUPPLEMENT TO FEIS, p 1-4;

" Since the publication of the FEIS in October 1980 and the subsequent Record of Decision to proceed with the phased construction and operation of the WIPP, new geologic and hydrologic information has led to changes in the understanding of the hydrogeologic characteristics of the area as they relate to the long-term performance of the WIPP. In addition, several changes have occurred in the Proposed Action and in the information and assumptions used to calculated the impacts reported in the FEIS. These include changes in the composition of the waste inventory, the transportation of waste to the WIPP, modification of the Test Phase, and the management of TRU mixed waste with hazardous chemical constituents.

This SEIS evaluates the environmental consequences of the Proposed Action as modified since 1980 in light of new information and assumptions. Modifications to the Proposed Action since 1980 that are examined in this SEIS are as follows: . . .

The new data and information and the resulting interpretations principally address the geologic and hydrologic systems at the WIPP site. They include:

- Determination of a locally lower permeability in the Salado Formation, the geologic formation in which the WIPP underground facilities are located (Subsection 4.3.2).
- Determination of a potentially higher moisture content in the Salado Formation and consequent brine inflow (Subsection 4.3.2).
- Discovery of a higher transmissivity zone in the Rustler Formation in the southeastern portion of the WIPP site (Subsection 4.3.3).
- New data leading to a conclusion that 'salt creep' (convergence) in the repository occurs faster than previously believed (Subsection 4.3.2).
- Pressurized brines within the Castile Formation which are assumed to be present beneath a portion of the WIPP waste emplacement panels (Subsection 4.3.4.2).
- Discovery of fractures in SPDV rooms (Subsection 4.3.2.4)."

DOE (U.S. Department of Energy) 1991. Resource Conservation and Recovery Act Part B Permit Application, February 1991, DOE/WIPP91-005, Prepared for the Department of Energy by Westinghouse Electric Corporation, Waste Isolation Division, Carlsbad, NM.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Martell, A.E., and R.M. Smith. 1982. Critical Stability Constants, Volume 5: Other Organic Ligands, Plenum Press, New York, NY.

NOTE: The above listed document was not available for inclusion in the Reference Expansion as of the printing date. Page changes will be provided as the above document becomes available for inclusion.

Mavor, M.J., and T.L. Logan. 1994. Recent Advances in Coal Gas-Well Openhole Well Completion Technology. JPT, July 1994. pp. 587-593.

Summary, p. 587, col 1;
" This paper reviews the current applications of openhole techniques in the San Juan basin. Examples of recent advances and details for the use of the technology are documented in many of the references. The range of reservoir properties required for successful implementation of the technology is included. Hypotheses proposed to explain the success of the openhole wells are presented. The paper concludes with a discussion on future advances required to improve current completion procedures and the potential applicability of the process to other reservoir rock types."

NMBMMR (New Mexico Bureau of Mines and Mineral Resources). 1995. Final Report Evaluation of Mineral Resources at the Waste Isolation Pilot Plant (WIPP) Site. March 31, 1995. New Mexico Bureau of Mines and Mineral Resources for Westinghouse Electric Corporation, Socorro, NM. WPO 39149 - WPO 39150.

EXECUTIVE SUMMARY, p E-1;

" The Waste Isolation Pilot Plant (WIPP) land withdrawal area occupies 16 mi^2, on the southeastern edge of the Known Potash Leasing Area (administered by BLM), about 30 miles southeast of Carlsbad, Eddy County, New Mexico. It is four miles on a side and is located in secs. 15 to 22 and 27 to 34 of T22S R31E. This study includes an additional study area about one mile wide surrounding and containing an additional 20 mi^2. The combined study area comprises about 36 mi^2.

The amount and value of natural resources under the WIPP land withdrawal area have not been calculated for more than ten years. This report performs this calculation using current and projected prices, production, geologic data, and conditions. The need for recalculating the volume and value of mineral resources within the boundaries of the WIPP land withdrawal area stems from the discovery of oil and associated natural gas in adjacent lease tracts during the late 1980s and 1990s, and the approach of potash mining.

During the late 1980s and early 1990s oil was discovered in the lower parts of the Delaware Mountain Group (Permian: Cherry Canyon and Brushy Canyon Formations) along the eastern, southern, and western boundaries of the land withdrawal area. In the Delaware Basin as a whole, these formations were not generally recognized as exploratory and development targets until the late 1980s. Prior to that time, they were usually bypassed during drilling with little or no thought that they might contain economically recoverable oil resources. Although these two formations had been penetrated by thousands of wells throughout the Delaware Basin, few attempts were made to adequately test them.

The main reason for bypassing these formations during drilling was a lack of understanding of their production characteristics. Water saturations calculated from analysis of electric logs were often high and did not differentiate oil-productive sandstones from sandstones that would yield mostly water upon completion. However, recent developments in log analysis (Asquith and Thomerson, 1994) have made it possible to differentiate Delaware sandstones with a high percentage of movable hydrocarbons from those with a low percentage of movable hydrocarbons. This type of analysis, in conjunction with the discovery of several commercial oil pools in the Brushy Canyon Formations, set off an oil drilling boom throughout the Delaware Basin that continues to the present. The Delaware play is currently the primary exploration and development play in the Permian Basin and is one of the most active oil plays in the United States. Of special note in the vicinity of WIPP was the discovery and development of commercial oil accumulations in the Brushy Canyon Formation at Cabin Lake; Livingston Ridge, Lost Tank, and Los Medaños pools.

During the last decade or so, potash mining has continued and the mining front is now much closer to the WIPP boundary. Mining by IMC has reached the edge of the additional study area on the southwest side of the WIPP. Future mining may occur mainly

there or on the north.

The value of potash (sylvite and langbeinite) and petroleum (oil and gas) were calculated using iterative economic models commencing in 1996 and lasting until 2031 (potash), 2026 (petroleum), and 2038 (natural gas plus associated oil). The potash and petroleum resources produced over this time frame were calculated from estimates based on drill hole data and projections of data and geology as needed. The value calculation used these resource data and projections of historical cost, price, and other economic data.

Quality Assurance Department. 1995. Verification of Design Adequacy. Quality Assurance Procedure (QAP)3-2. Rev. 1, Sandia National Laboratories, Albuquerque, NM.

1.0 Purpose, p. 3;
" The purpose of this procedure is to establish methods for verifying the adequacy of design(s) developed by Sandia National Laboratories (SNL) personnel or its contractors in support of the Waste Isolation Pilot Plant (WIPP) Project. This procedure also establishes the minimum criteria for implementing a verification method and the documentation of the method and results."

Wang, Y. 1996b. Evaluation of the Thermal Effect of Exothermal Chemical Reactions for WIPP Performance Assessment. Unpublished memorandum to R.V. Bynum and L.H. Brush, July 19, 1996. Sandia National Laboratories, Albuquerque, NM.

p.1, para. 1;

" To support your response to peer reviewer's comments, in this memo I will evaluate possible temperature increases caused by exothermal chemical reactions in the repository. The thermal effect of MgO hydration, which was evaluated previously, will be re-evaluated, based on current BRAGFLO calculations.

Assumptions:

The following exothermal chemical reactions are considered:

$$MgO + H_2O \rightarrow Mg(OH)_2 \quad (1)$$
$$Mg(OH)_2 + CO_2 \rightarrow MgCO_3 \quad (2)$$
$$Fe + H_2O \rightarrow Fe(OH)_2 + H_2 \quad (3)$$
$$C_6H_{10}O_5 + H_2O \rightarrow 3CH_4 + 3CO_2 \quad (4)$$
$$Al + 3H_2O \rightarrow Al(OH)_3 + 1.5H_2 \quad (5)$$

Considering that the vertical dimension of the repository (_1 m, B. M. Butcher, personal comm.) will be much less than the horizontal extension after room closure, we assume that the heat released from the reactions will be dissipated away mainly from the ceiling and ground of the repository and the heat loss from the side walls is negligible. We also assume that all reactions will take place uniformly in a reaction region of interest. We here restrict the reaction region in a single waste panel, for the following reason: Some of the above reactions may be limited by brine inflow. BRAGFLO simulations have shown that, in the human intrusion cases, the rate of brine inflow into a borehole-penetrated waste panel will be significantly higher than that into the rest of the repository. Choosing a panel rather than the whole repository as a reaction region will make heat generation rate per unit of volume higher and the heat dissipating surface area smaller in our calculations, and therefore it is conservative. However, this choice will not affect the calculations for the reactions that are not limited by brine inflow, as you will see below."

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